BESIII粲物理进展

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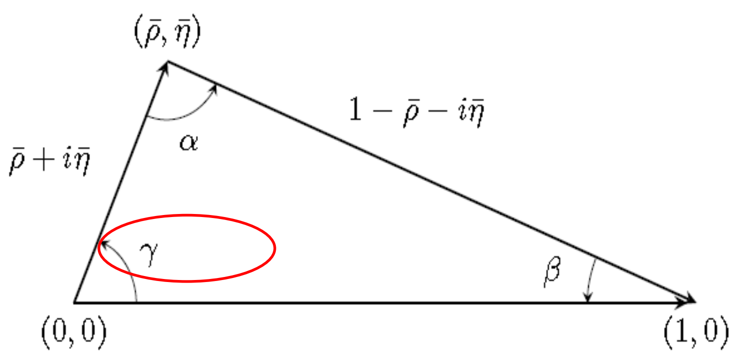
2018年BESIII粲物理研讨会，辽宁科技大学，
辽宁省鞍山市，2018年8月3日

粲物理实验主要目标

- **(Semi-)leptonic $D_{(s)}$ decays**
  1. $f_{D(s)+}$, $f^{K(\pi)}_{+}(0)$: better calibrate LQCD
  2. $|V_{cs(d)}|$: better test on CKM matrix unitarity
  3. LFU test and search of rare SL decays

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \boldsymbol{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **Hadronic $D_{(s)}$ decays**
  1. $D^0\bar{D}^0$ mixing parameters and CPV
  2. Strong phase difference in D^0 decays: Constrain γ/ϕ_3 measurement in B decays
  3. SU(3) symmetry and break effect



- **Absolute BFs of Λ_c^+ decays**

  No absolute BF measurements of Λ_c^+ using near threshold data before BESIII

主要内容

- Charm samples at BESIII
- (Semi-)leptonic $D_{(s)}$ decays
- Hadronic $D_{(s)}$ decays
- Λ_c^+ decays
- Summary

近十年来的粲物理实验

Experiment	Machine	C.M	Lumin.	N(D)	efficiency	advantage/disadvantage
CLEO	CESR (e^+e^-)	3.77 GeV	0.8 fb^{-1}	2.9×10^6 $2.3 \times 10^6 (D^\pm)$	$\sim$10-30%	☺ extremely clean enviroment ☺ pure D-beam, almost no bkg ☺ quantum coherence ☹ no CM boost, no T-dep analyses
		4.17 GeV	0.6 fb^{-1}	0.6×10^6		
BESIII	BEPC-II (e^+e^-)	3.77 GeV	2.92 fb^{-1}	10.5×10^6 8.4×10^6 $D^{0(+)}$		
		4.18 GeV	3 fb^{-1}	3×10^6 D_s^+		
				★	★★★	
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	1.3×10^9	$\sim$5-10%	☺ clear event environment ☺ high trigger efficiency ☺ high-efficiency detection of neutrals ☺ many high-statistics control samples ☺ time-dependent analysis ☹ smaller cross-section than pp colliders
BaBar	PEP-II (e^+e^-)	10.58 GeV	0.5 ab^{-1}	6.5×10^8		
				★★	★★	
CDF	Tevatron ($p\bar{p}$)	1.96 TeV	9.6 fb^{-1}	1.3×10^{11}	<0.5%	☺ large production cross-section ☺ large boost: excellent time resolution ☹ dedicated trigger required ☹ hard to do neutrals and neutrinos
LHCb	LHC (pp)	7 TeV 8 TeV	1.0 fb^{-1} 2.0 fb^{-1}	5.0×10^{12}		
				★★★	★	

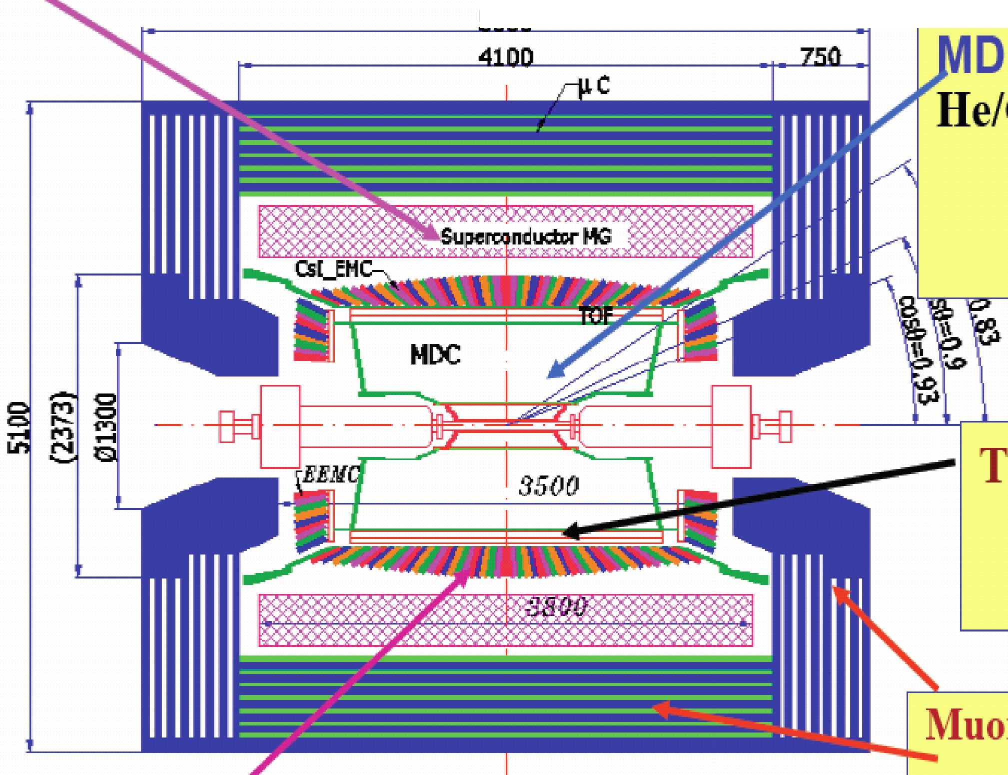
BEPCII加速器

Beam energy: 1.0-2.3 GeV
Optimum energy: 1.89 GeV
Designed luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$
Data taken from: 2009
Achieved luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$

BESIII探测器

Nucl. Instr. Meth. A614, 345 (2010)

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
$\sigma z = 0.6\ cm/\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

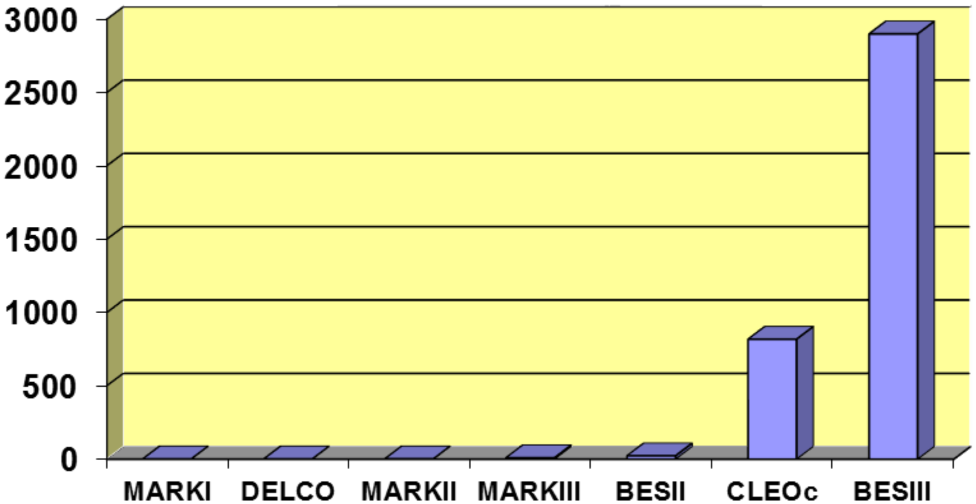
2015年ETOF升级改造后，分辨好于60 ps

BESIII $D^{0(+)}$, D_s^+和Λ_c^+ 样本

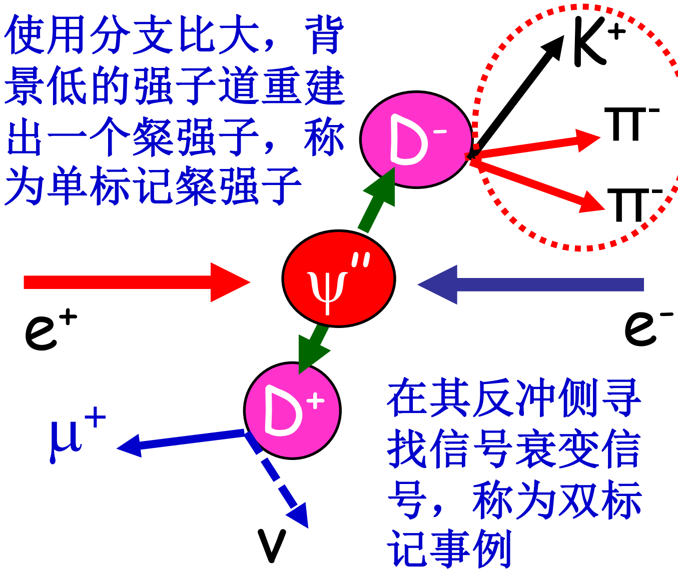
➢ $D^{0(+)}$样本@ψ(3770)

2010-2011

3.773 GeV



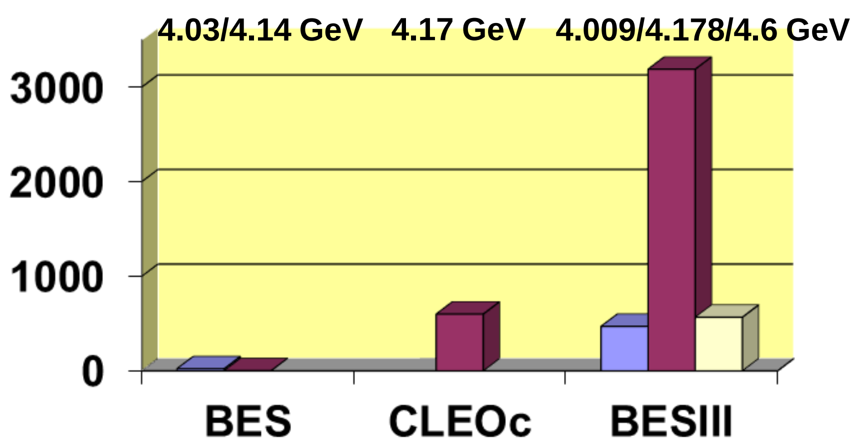
使用分支比大，背景低的强子道重建出一个粲强子，称为单标记粲强子



在其反冲侧寻找信号衰变信号，称为双标记事例

➢ $D_s^+/D_s^+/\Lambda_c^+$样本

2011/2016/2014



联合单、双标记粲强子，测定绝对分支比，研究动力学机制

$$N_{\rm ST}^{i} = 2 \times N_{D\bar{D}} \times B_{\rm ST}^{i} \times \varepsilon_{\rm ST}^{i}$$

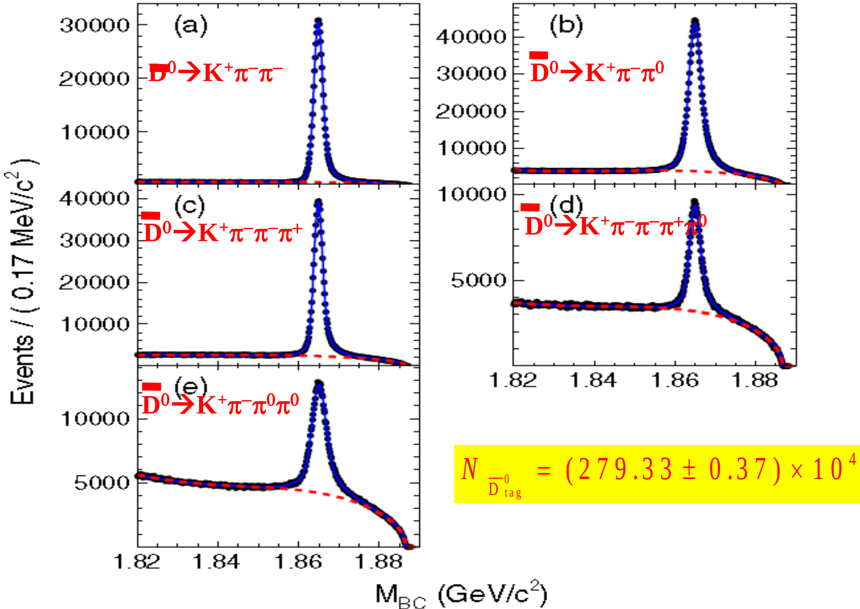
$$N_{\rm DT}^{i} = 2 \times N_{D\bar{D}} \times B_{\rm ST}^{i} \times B_{\rm sig} \times \varepsilon_{\rm ST\,vs.sig}^{i}$$

$$B_{\rm sig} = \frac{N_{\rm DT}^{\rm tot}}{N_{\rm ST}^{\rm tot} \times \bar{\varepsilon}_{\rm sig}}$$

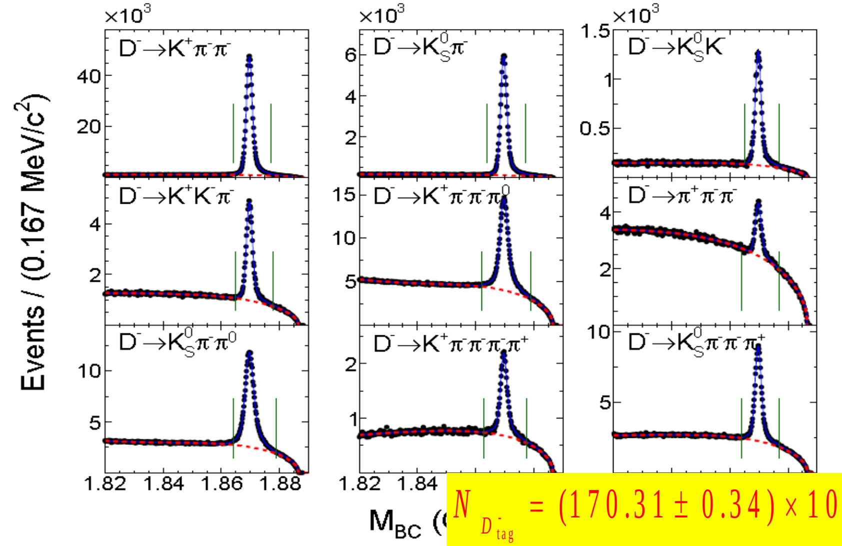
$$\bar{\varepsilon}_{\rm sig} = \sum_{i=1}^{N} (N_{\rm ST}^{i} \times \varepsilon_{\rm ST\,vs.sig}^{i} / \varepsilon_{\rm ST}^{i}) / \sum_{i=1}^{N} N_{\rm ST}^{i}$$

单标记粲强子样本

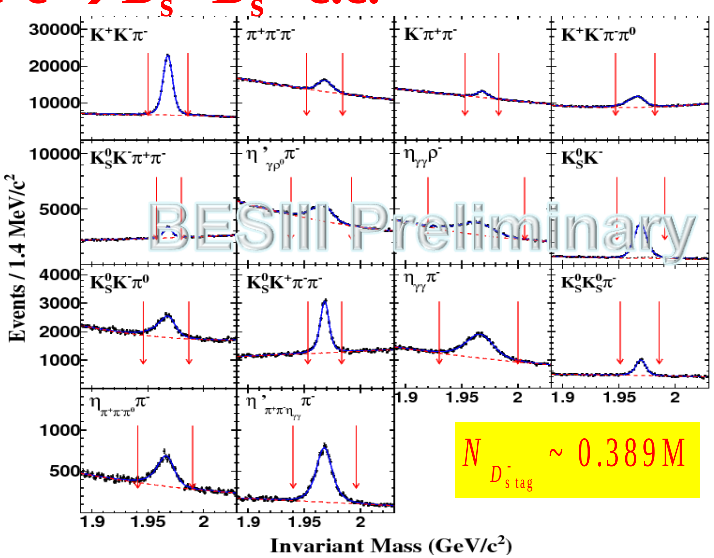
$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$



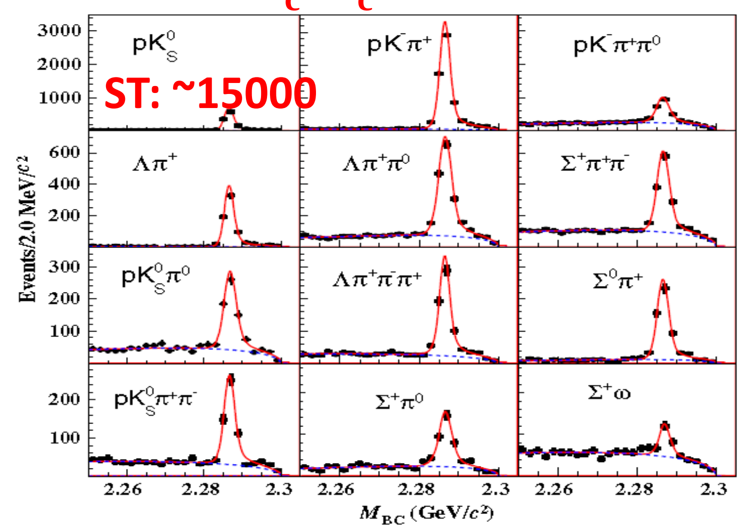
$e^+e^- \to \psi(3770) \to D^+D^-$



$e^+e^- \to D_s^{*+}D_s^- + c.c.$



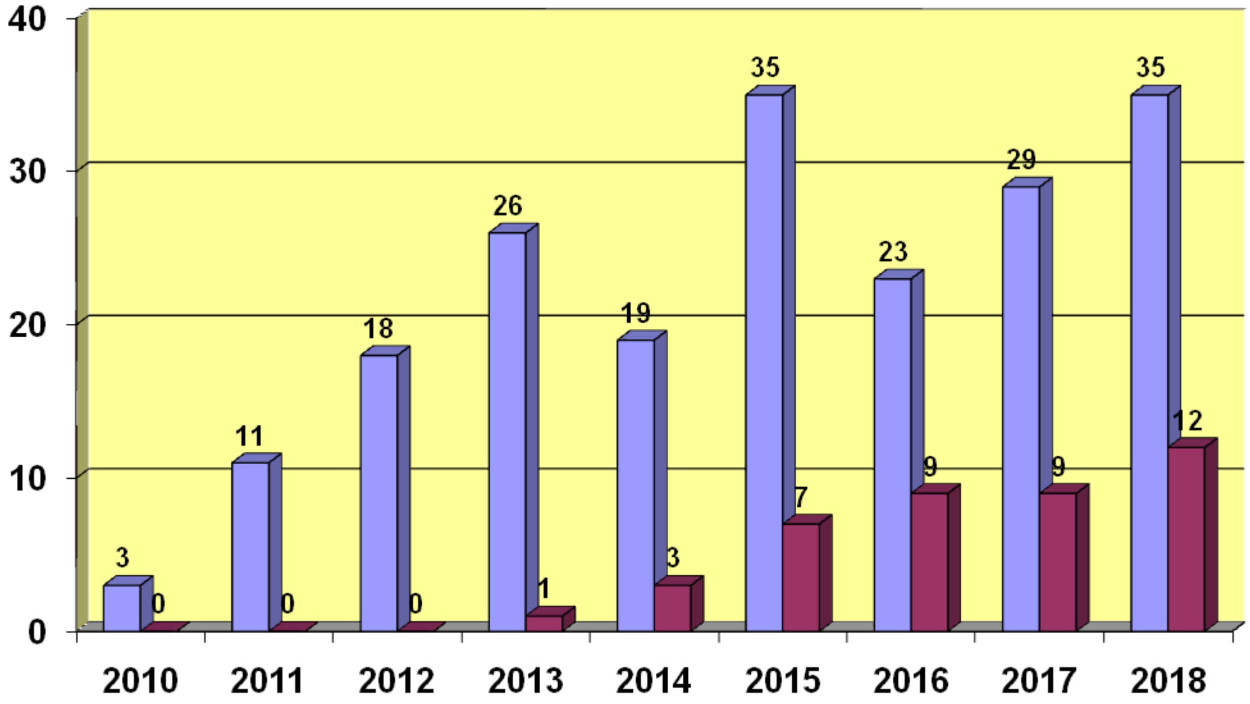
$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^- + c.c.$



BESIII粲物理研究进展概况

- 4年来，粲物理文章数量、质量大幅提高：4→41篇；其中PRL文章0→9篇。
- 全组开展粲物理分析的学生从约12人增加到目前的约30人。

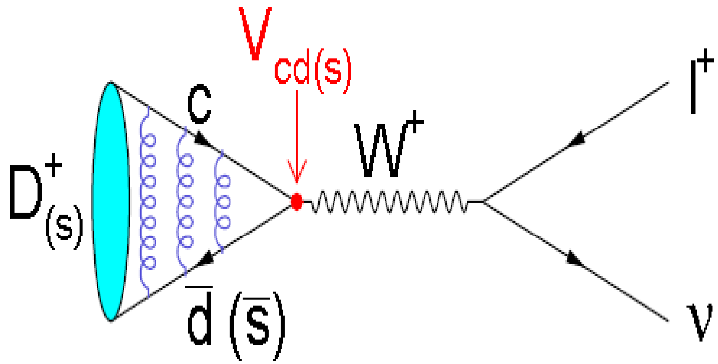
稳中向好

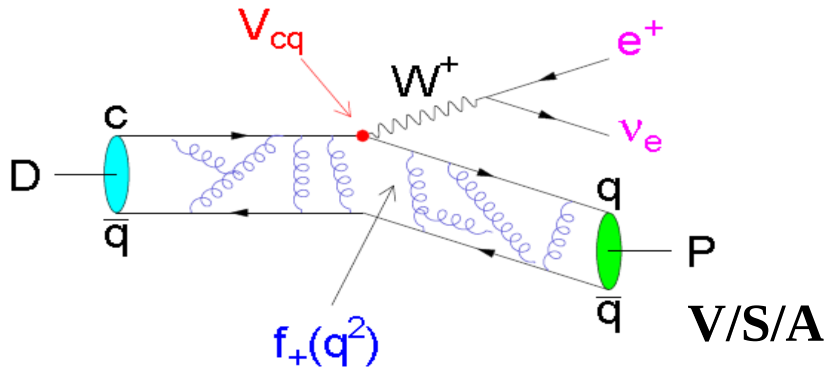


$D_{(s)}$轻子和半轻衰变

- l^+v
- P(赝标介子)l^+v → Some selected topics
- V(矢量介子)l^+v
- S(标量介子)l^+v
- Rare SL decays

$D_{(s)}$纯轻和半轻衰变：标准模型精密检验

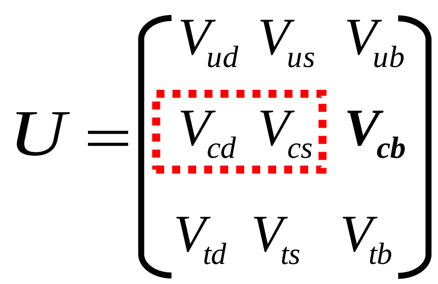




$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m_{D^+_{(s)}}^2}\right)^2$$

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

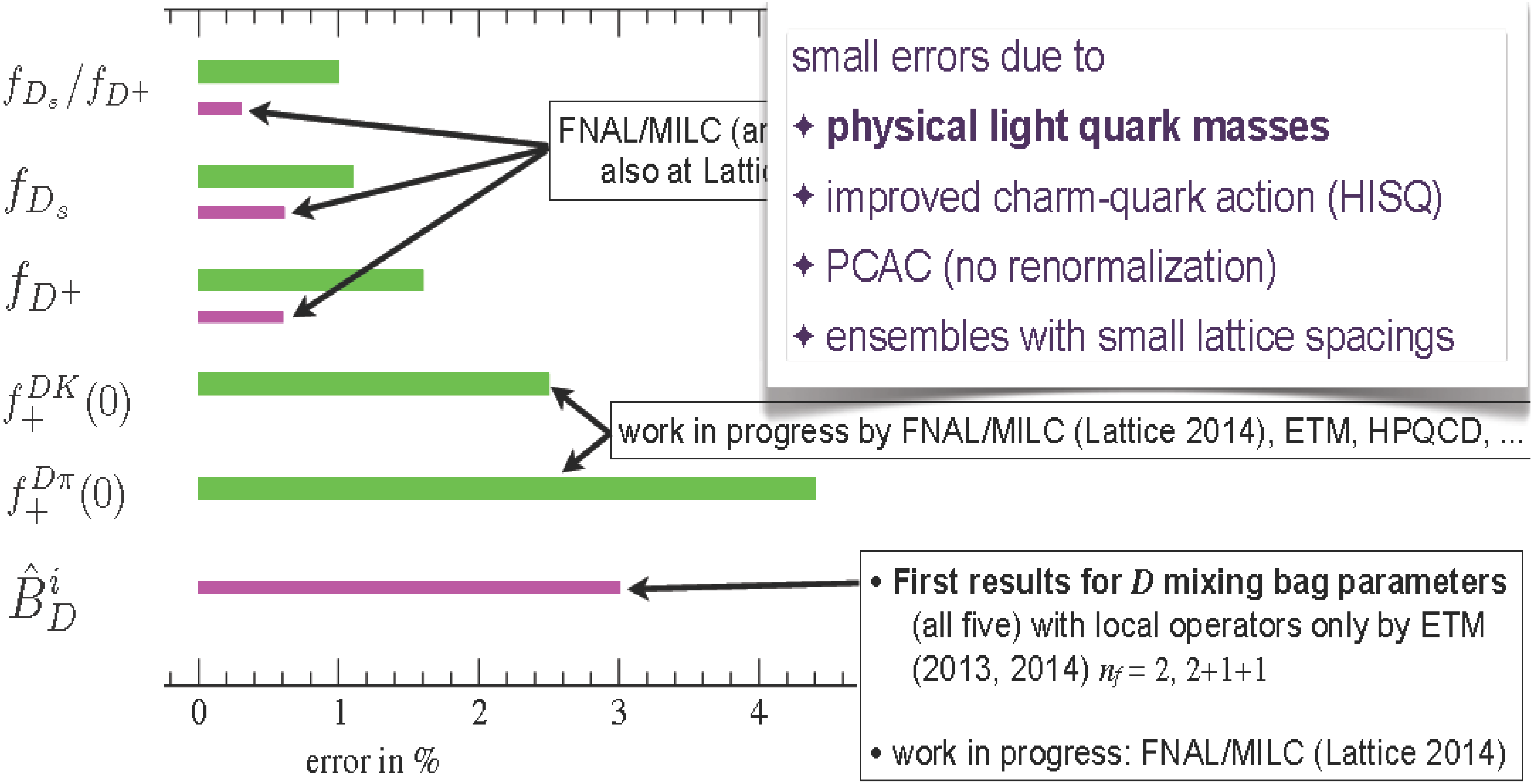
- 测定$|V_{cs}|$、$|V_{cd}|$，检验CKM矩阵的幺正性
- 测定D衰变常数、半轻形状因子，检验理论计算
- 寻找含标量介子(S)、轴矢量介子(A)半轻衰变
- 轻子味道普适性(LFU)检验……



格点QCD计算取得重要进展

Taking from Aida X. El-Khadra's talk at Beauty2014

errors (in %) comparison: **FLAG-2 averages** vs. **new results**



review by C. Bouchard @ Lattice 2014

最高精度的f_{D^+}/首次使用$D^+\to\mu^+\nu$测定$|V_{cd}|$

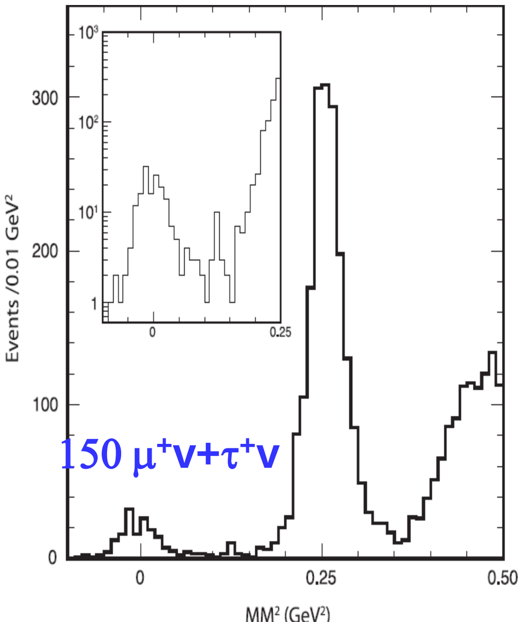
818 pb^{-1} at $\psi(3770)$
(2004–2008)

2.93 fb^{-1} data@ 3.773 GeV

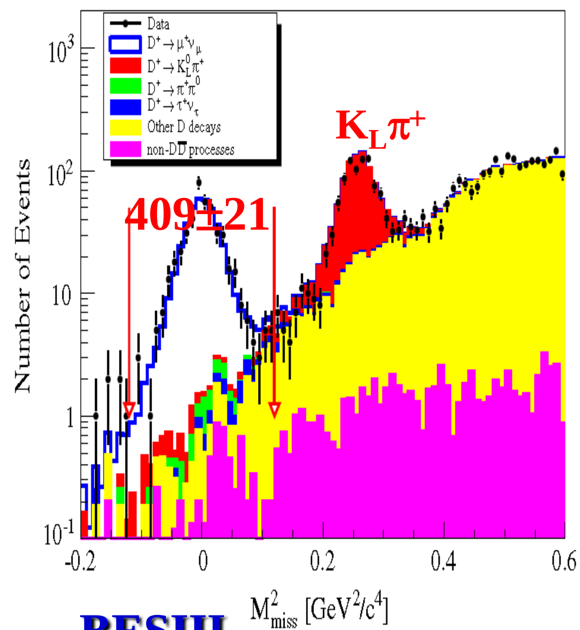
BESIII获得世界上单次测量精度最高的f_{D+}和$|V_{cd}|$

PRD78(2008)052003

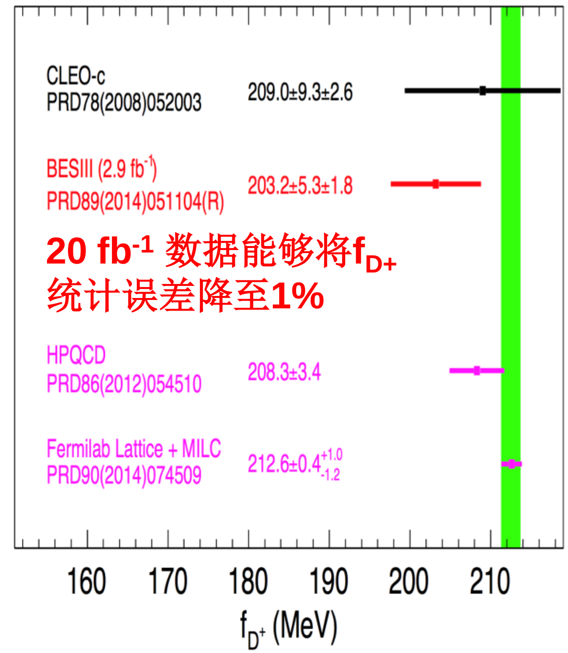
PRD89(2014)051104(RC)



CLEO



BESIII



$B_{D^+\to\mu^+\nu}=(3.82\pm0.32\pm0.09)\times10^{-4}$

$f_{D+}=205.8\pm7.5\pm2.5$ MeV

$B_{D^+\to\mu^+\nu}=(3.71\pm0.19\pm0.06)\times10^{-4}$

$f_{D+}=(203.2\pm5.3\pm1.8)$ MeV

$|V_{cd}|=0.2210\pm0.0058\pm0.0047$

D轻子测量方案改变了此前$|V_{cd}|$测量由中微子散射、D半轻方案主导的局面，随即被PDG采纳，使得$|V_{cd}|$世界平均值误差从4.8%降至1.8%

f_{D+}, f_{Ds+}和f_{D+}:f_{Ds+}比较(2014)

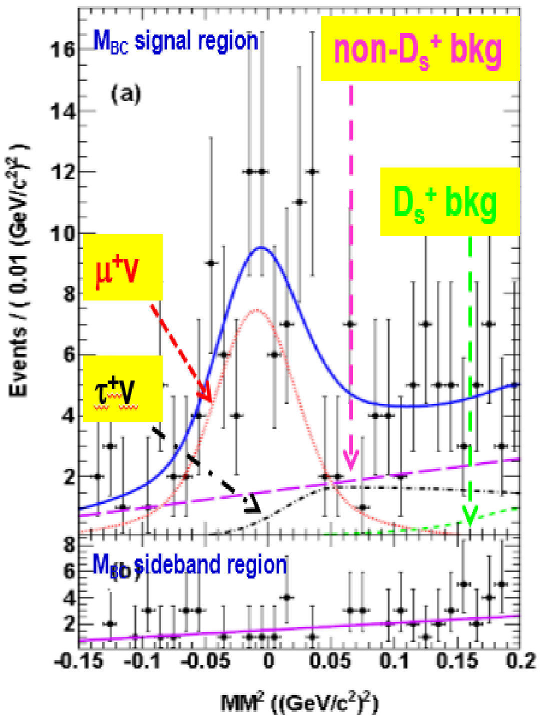
	Experiments	Femilab Lattice+MILC (2014)		HPQCD (2012)	
	Averaged	Expected	Δ	Expected	Δ
f_{D+}(MeV)	203.9±4.7	$212.6\pm0.4^{+1.0}_{-1.2}$	1.8σ	208.3±3.4	0.8σ
f_{Ds+}(MeV)	256.9±4.4	$249.0\pm0.3^{+1.1}_{-1.5}$	1.7σ	246.0±3.6	1.4σ
f_{D+}:f_{Ds+}	1.260±0.036	$1.1712\pm0.0010^{+0.0029}_{-0.0032}$	2.5σ	1.187±0.013	1.9σ

- 实验精度远小于理论精度(f_{D+}, f_{Ds+}, f_{D+}:f_{Ds}达0.5%,0.5%,0.3%)
- 实验与理论预期f_{D+}, f_{Ds+}, f_{D+}:f_{Ds+}偏离约2σ
- 期待实验上更精确的结果

$D_s^+ \to l^+ v \to$ 单次最高精度的$f_{Ds}|V_{cs}|$

0.48 fb^{-1} data@4.01 GeV

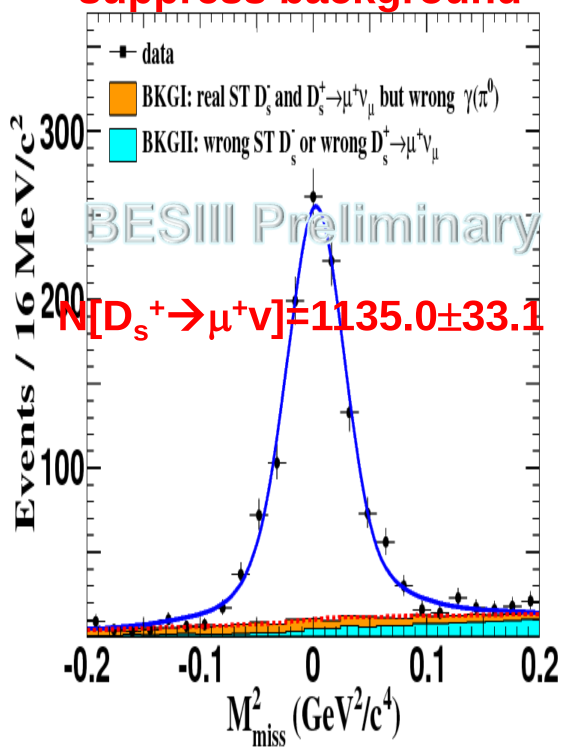
PRD94(2016)072004



f_{Ds+}=(241.0±16.3±6.6) MeV

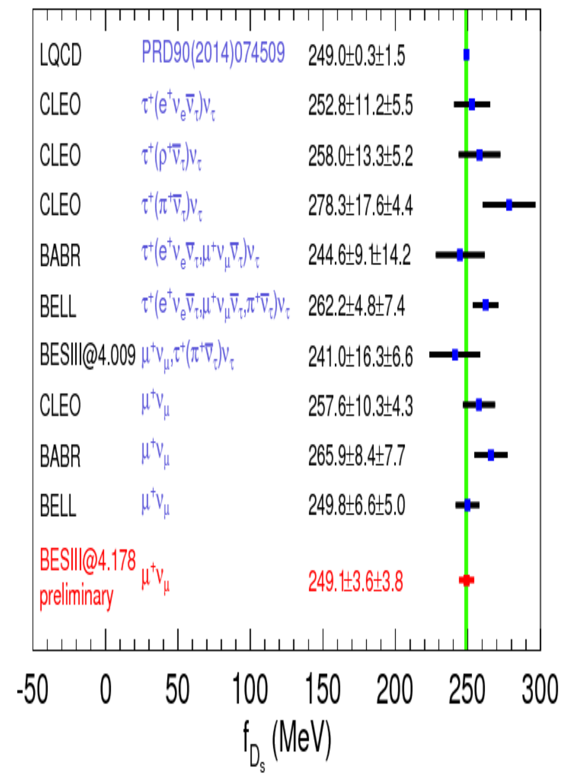
3.19 fb^{-1} data@4.178 GeV

Use μ counter to suppress background



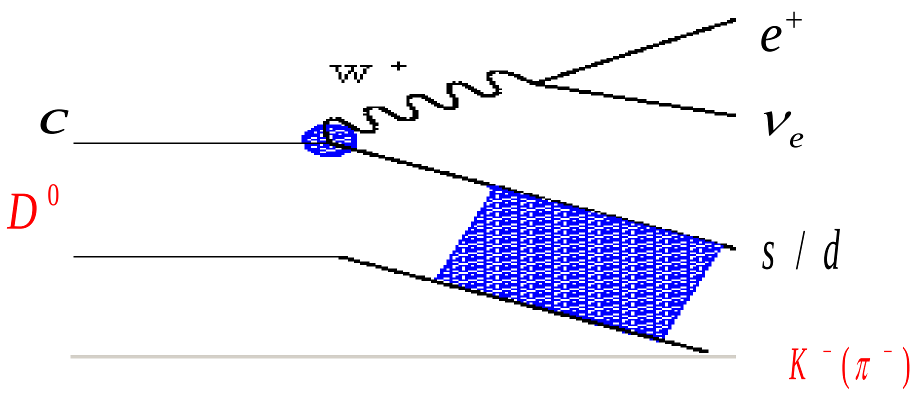
$f_{Ds}|V_{cs}|$=242.5±3.5±3.7 MeV

BESIII获得世界上单次测量精度最高的f_{Ds+}和$|V_{cs}|$



BESIII f_{Ds+}精度达2%，联合$\tau^+ v$研究，能够降至1.5%水平

分析$D^0 \to K(\pi)^- e^+ \nu$提取$f^{K(\pi)}_+(0)|V_{cs(d)}|$



$$\frac{\Delta\Gamma(D^0 \to K/\pi^- e^+ \upsilon_e)}{dq^2} = X \frac{G_F^2 |V_{cs(d)}|^2}{24\pi^3} p^3 |f_+^2(q^2)|^2$$

– **Single pole form**

$$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M^2_{\mathrm{pole}}}}$$

– **Modified pole model**

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M^2_{\mathrm{pole}}})(1 - \alpha\frac{q^2}{M^2_{\mathrm{pole}}})}$$

– **ISGW2 model**

$$f_+(q^2) = f_+(q^2_{\mathrm{max}}) \left(1 + \frac{r^2_{\mathrm{ISGW2}}}{12}(q^2_{\mathrm{max}} - q^2)\right)^{-2}$$

– **Series expansion model**

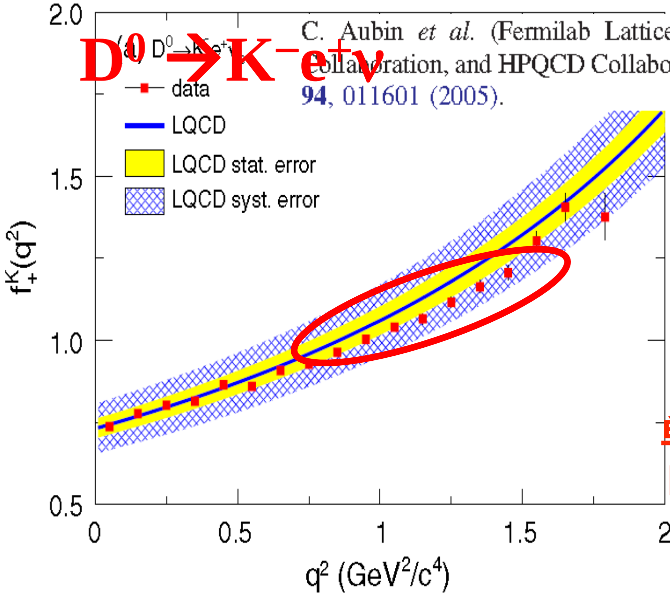
$$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

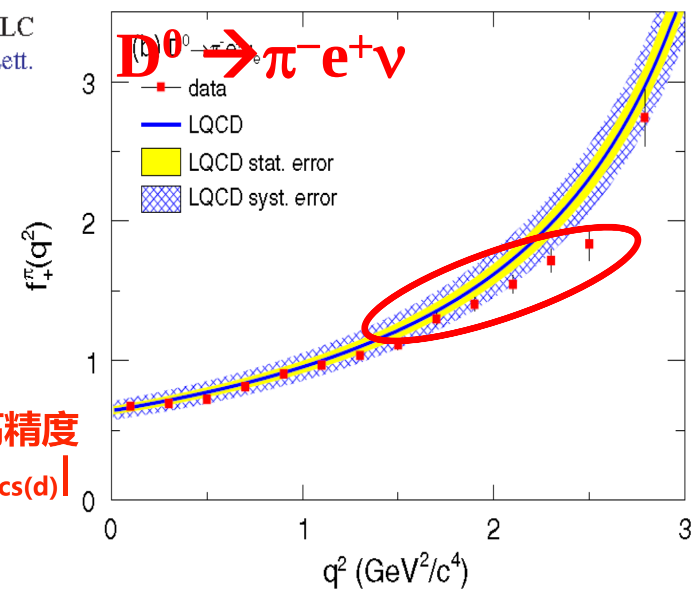
Recently improved LQCD calculations on $f_+^{D \to K(\pi)}(0)$ [2.4(4.4)%] provide good chance to precisely measure the CKM matrix element $|V_{cs(d)}|$, which are important for the unitarity test of the CKM matrix and search for NP beyond the SM

检验LQCD计算的$f^{K(\pi)}_+(q^2)$

PRD92(2015)072012

C. Aubin *et al.* (Fermilab Lattice Collaboration, MILC Collaboration, and HPQCD Collaboration), Phys. Rev. Lett. **94**, 011601 (2005).





单次测量最高精度的$f^{K(\pi)}_+(0)|V_{cs(d)}|$

J. Zhang and C.X. Yue, arXiv:1805.00700v1 [hep-ph]

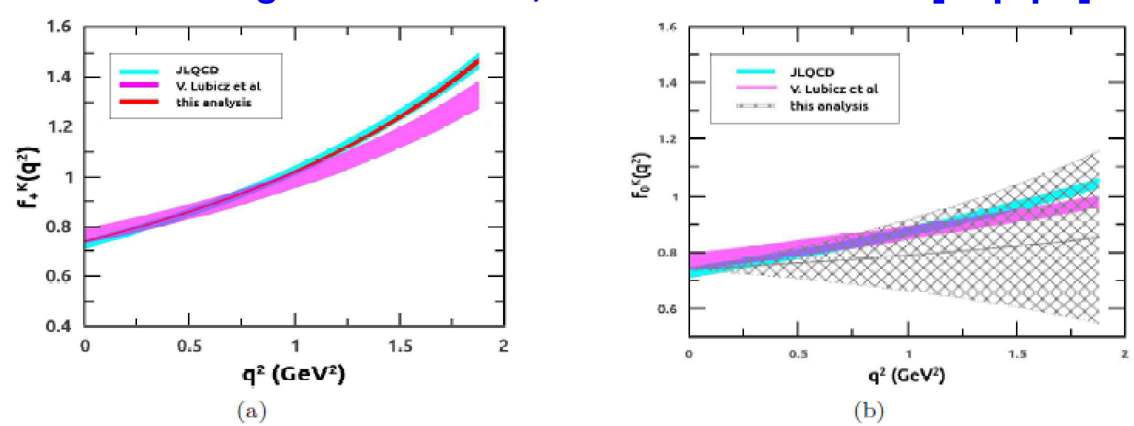
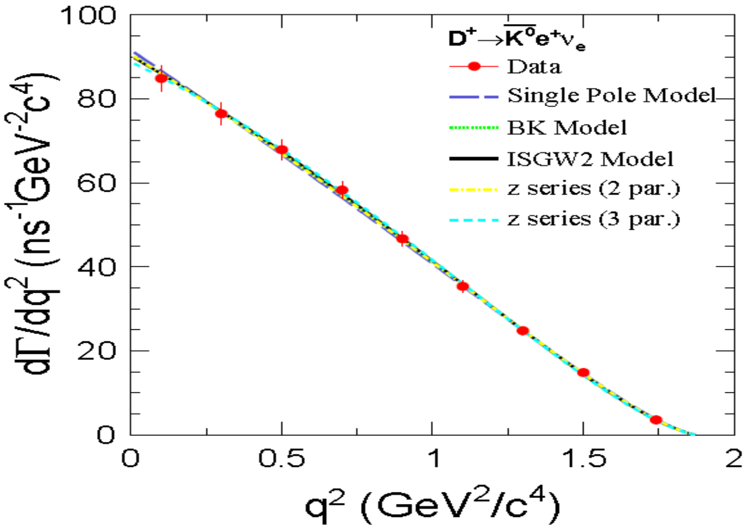
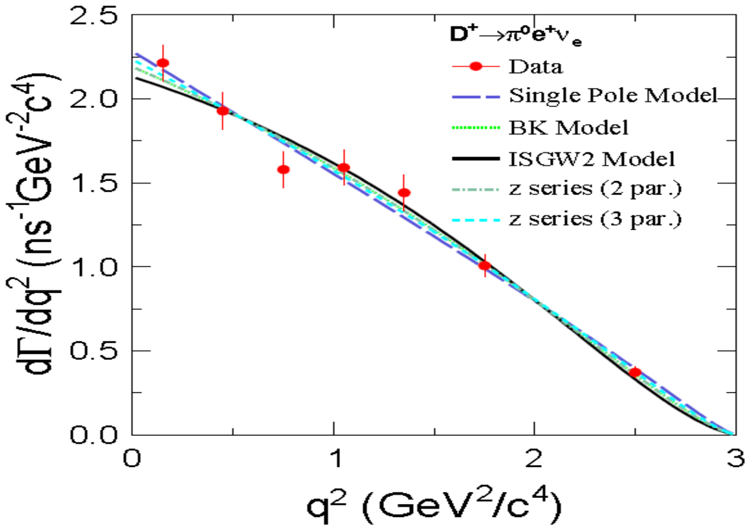


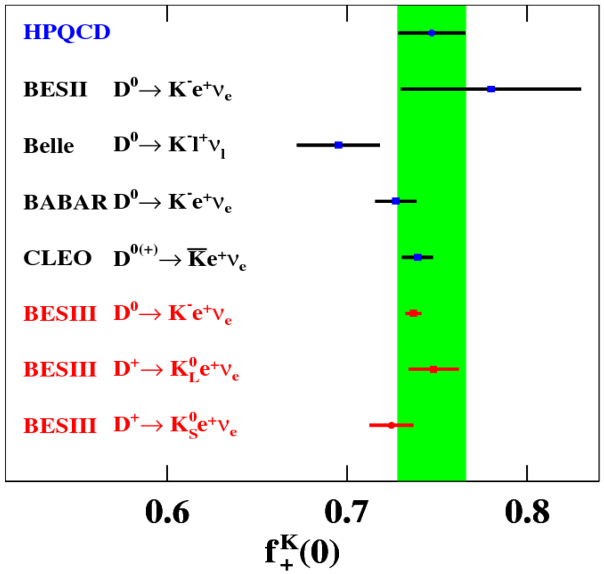
Figure 7: Comparisons of the result of fit to experimental measurements and lattice calculations for $f_+^K(q^2)$ (a) and $f_0^K(q^2)$ (b).

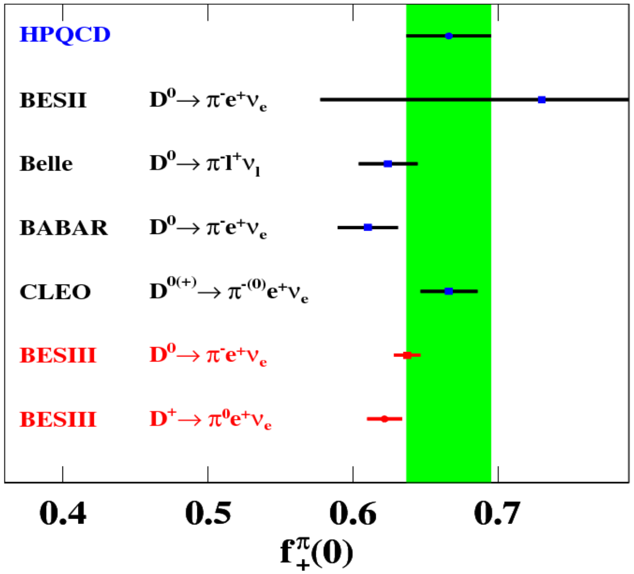
分析$D^+ \to \bar{K}^0(\pi^0)e^+\nu$提取$f^{K(\pi)}_+(0)|V_{cs(d)}|$

PRD96(2017)012002



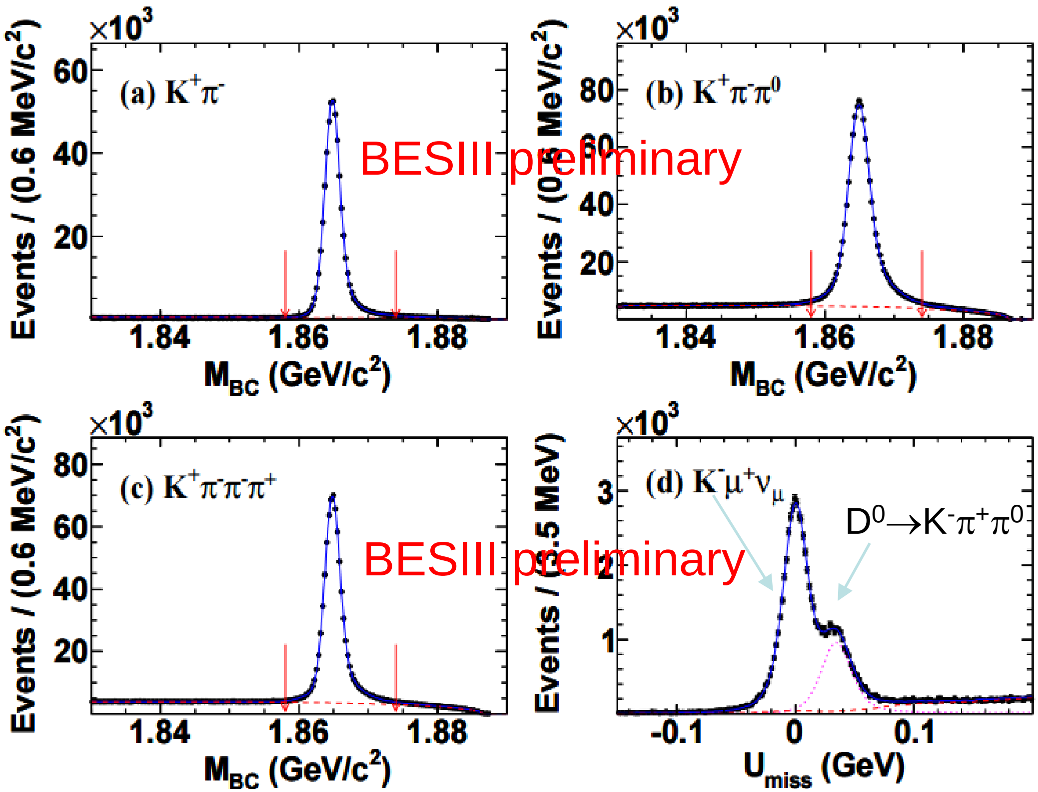


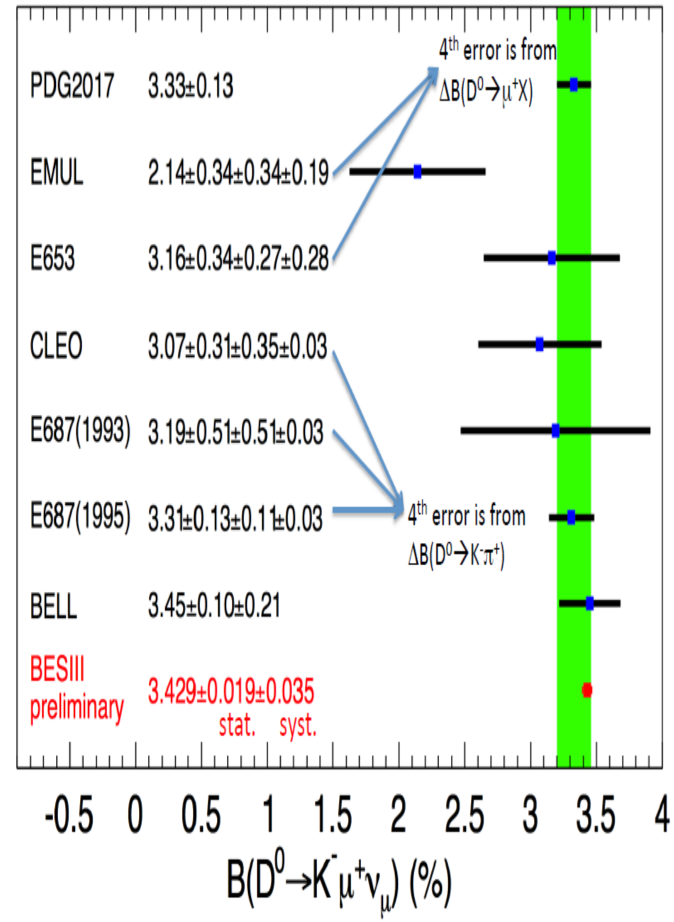




BESIII获得世界上单次测量精度最高的形状因子$f^{D\to K(\pi)}_+(0)$，精度好于1%

$D^0 \to K^- \mu^+ \nu$分支比的精密测量





Total ST yield: $(234\pm2)\times10^4$

DT yield: 47100 ± 259

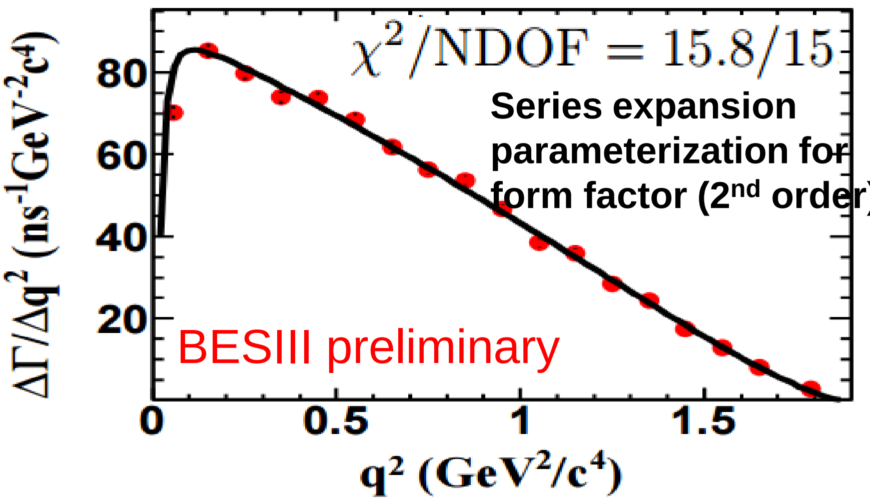
$D^0 \to K^-\mu^+\nu$衰变的精密动力学研究

Differential partial widths

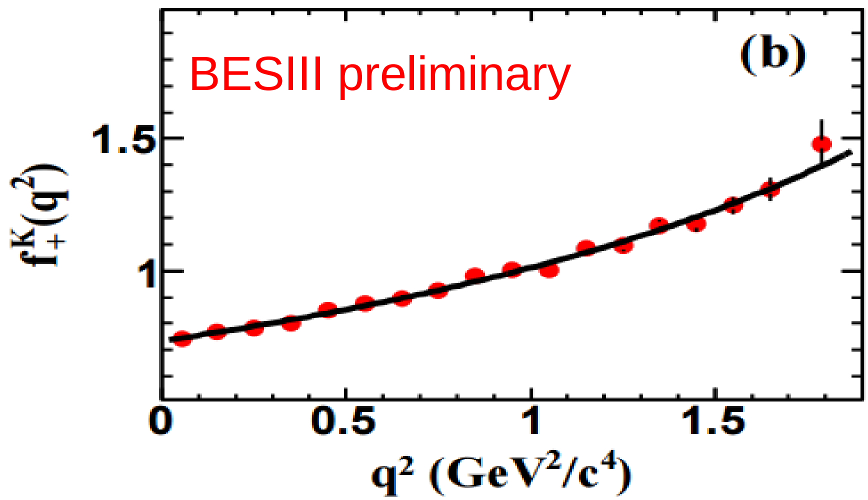
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cs}|^2}{8\pi^3 m_D}|\vec{p}_K||f_+^K(q^2)|^2(\frac{W_0 - E_K}{F_0})^2$$
$$\times [\frac{1}{3}m_D|\vec{p}_K|^2 + \frac{m_\ell^2}{8m_D}(m_D^2 + m_K^2 + 2m_D E_K)$$
$$+ \frac{1}{3}m_\ell^2\frac{|\vec{p}_K|^2}{F_0} + \frac{1}{4}m_\ell^2\frac{m_D^2 - m_K^2}{m_D}\mathrm{Re}(\frac{f_-^K(q^2)}{f_+^K(q^2)})$$
$$+ \frac{1}{4}m_\ell^2 F_0|\frac{f_-^K(q^2)}{f_+^K(q^2)}|^2]$$

Assumed to be independent of q^2 following FOCUS's treatment (PLB607(2005)233)

$$q = p_\mu + p_\nu$$
$$W_0 = (m_D^2 + m_K^2 - m_\ell^2)/2m_D$$
$$F_0 = W_0 - E_K + m_\ell^2/2m_D$$



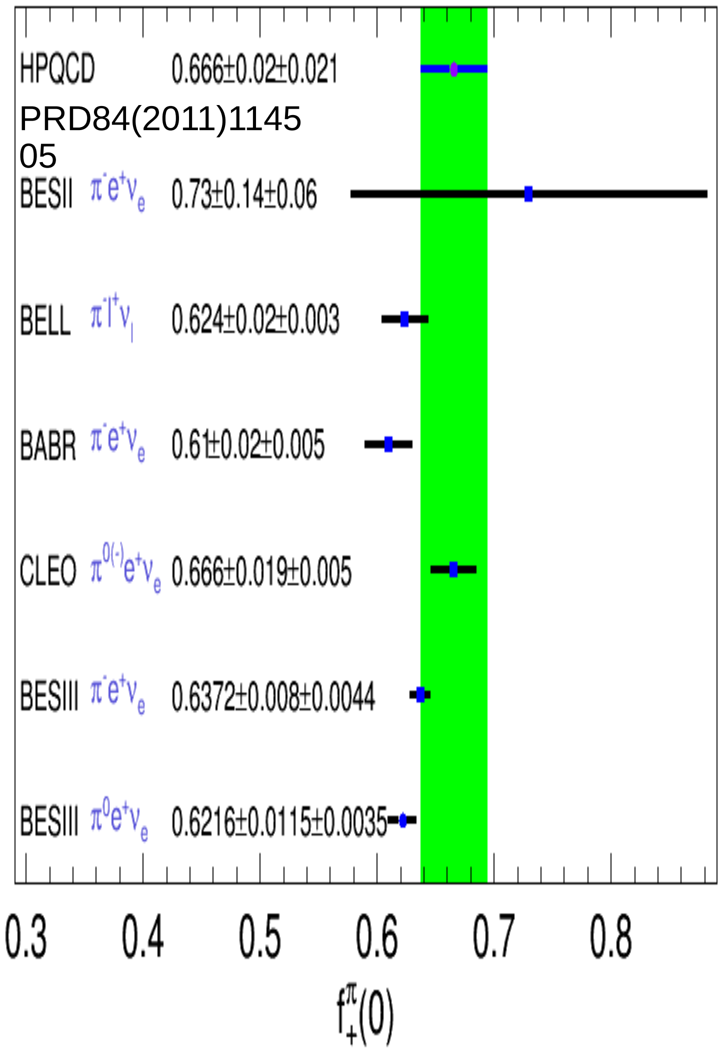
Series expansion parameterization for form factor (2nd order):

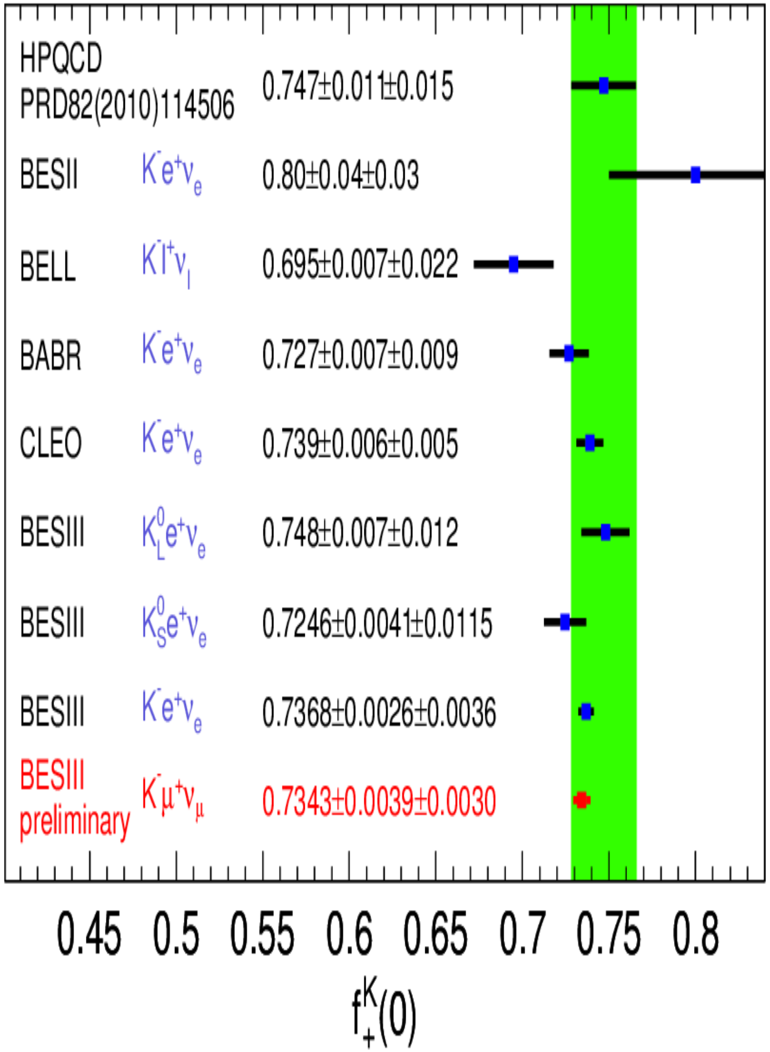


$$f_+^K(0)|V_{cs}| = 0.7148 \pm 0.0038_{\mathrm{stat.}} \pm 0.0029_{\mathrm{syst.}}$$
$$r_1 = -1.94 \pm 0.21_{\mathrm{stat.}} \pm 0.07_{\mathrm{syst.}}$$

$$f_-^K/f_+^K = -0.7 \pm 0.9_{\mathrm{stat.}} \pm 0.1_{\mathrm{syst.}}$$

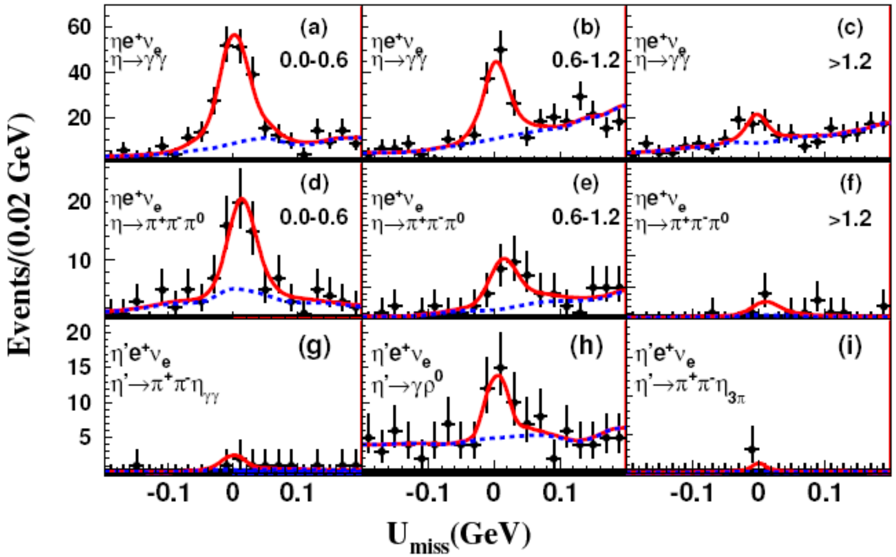
形状因子$f_+^{K(\pi)}(0)$的实验和理论比较

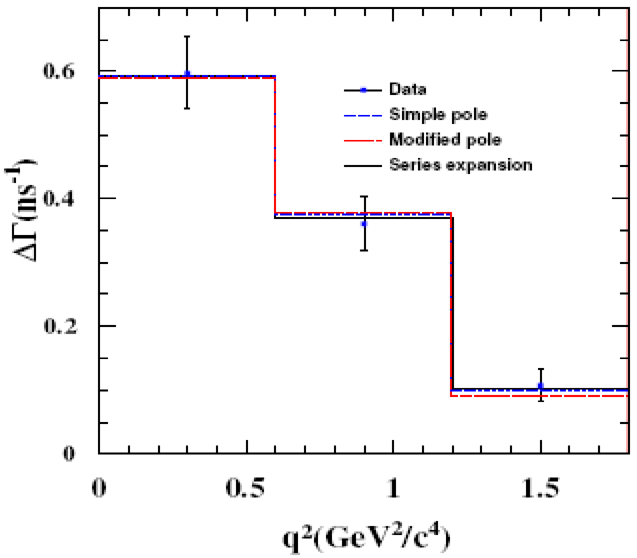




$D^+ \to \eta^{(\prime)} e^+ \nu$分支比和动力学研究

PRD97(2018)092009





Fit parameters	Simple pole	Modified pole	Series expansion
$f_+(0)\|V_{cd}\|$ $(\times 10^{-2})$	$8.15 \pm 0.45 \pm 0.18$	$8.24 \pm 0.51 \pm 0.22$	$7.86 \pm 0.64 \pm 0.21$
Shape parameter	$1.73 \pm 0.17 \pm 0.03$	$0.50 \pm 0.54 \pm 0.08$	$-7.33 \pm 1.69 \pm 0.40$
ρ	0.80	−0.85	0.90
χ^2/ndf	$0.1/(3-2)$	$0.3/(3-2)$	$0.5/(3-2)$

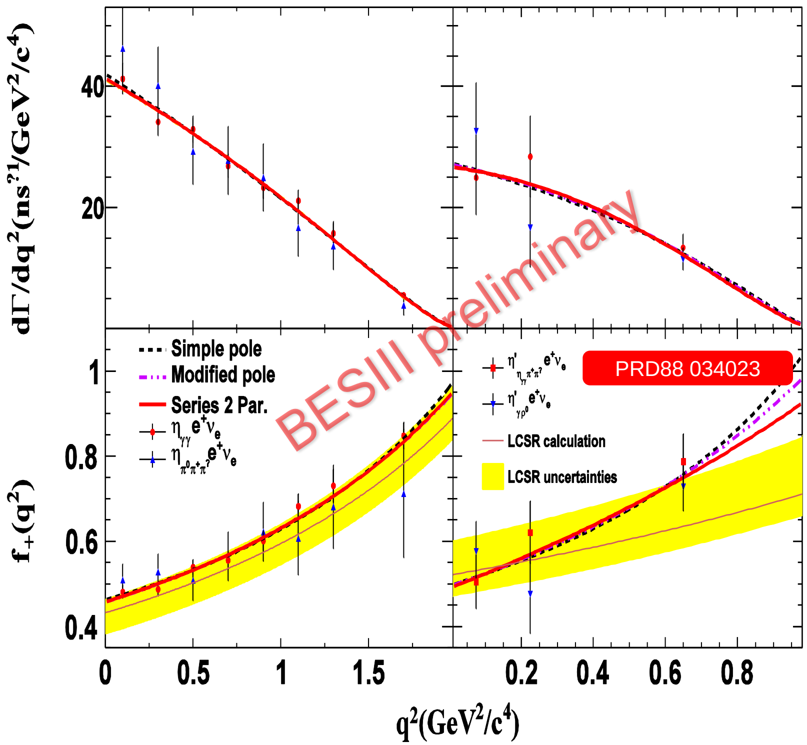
- $\langle\eta| = \cos\phi_P \langle\eta_q| - \sin\phi_P \langle\eta_s|$,
- $\langle\eta'| = \cos\phi_G(\sin\phi_P \langle\eta_q| + \cos\phi_P \langle\eta_s|) + \sin\phi_G \langle gg|$;
- $\frac{\Gamma(D^+\to\eta'\ell^+\nu_\ell)}{\Gamma(D^+\to\eta\ell^+\nu_\ell)} = \tilde{R}_D \tan^2\phi_P$,

$\mathcal{B}_{\eta e^+\nu_e} = (10.74 \pm 0.81 \pm 0.51) \times 10^{-4}$
$\mathcal{B}_{\eta' e^+\nu_e} = (1.91 \pm 0.51 \pm 0.13) \times 10^{-4}$
$\phi_P = (40 \pm 3 \pm 3)^\circ (\phi_G{=}0)$

该方法需要输入外部参数

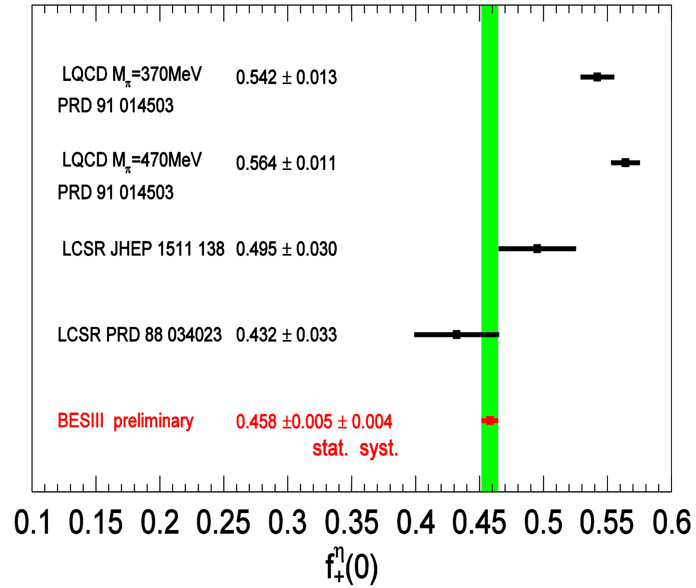
$D_s \to \eta^{(\prime)} e^+ \nu$形状因子的首次测量

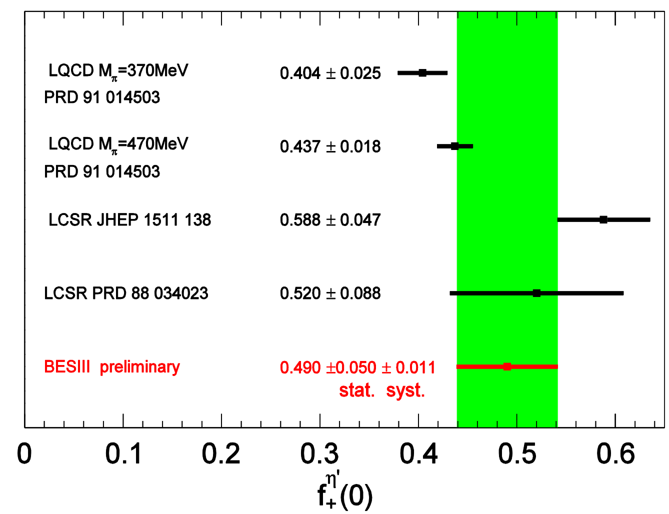
Fits to partial decay rates



Case	Simple pole			Modified pole			Series 2 Par.		
	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	M_{pole}	χ^2/NDOF	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	α	χ^2/NDOF	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	r_1	χ^2/NDOF
$\eta e^+ \nu_e$	0.450(5)(3)	3.77(8)(5)	12.2/14	0.445(5)(3)	0.30(4)(3)	11.4/14	0.446(5)(4)	−2.2(2)(1)	11.5/14
$\eta' e^+ \nu_e$	0.494(45)(10)	1.88(54)(5)	1.8/4	0.481(44)(10)	1.62(91)(11)	1.8/4	0.477(49)(11)	−13.1(76)(11)	1.9/4

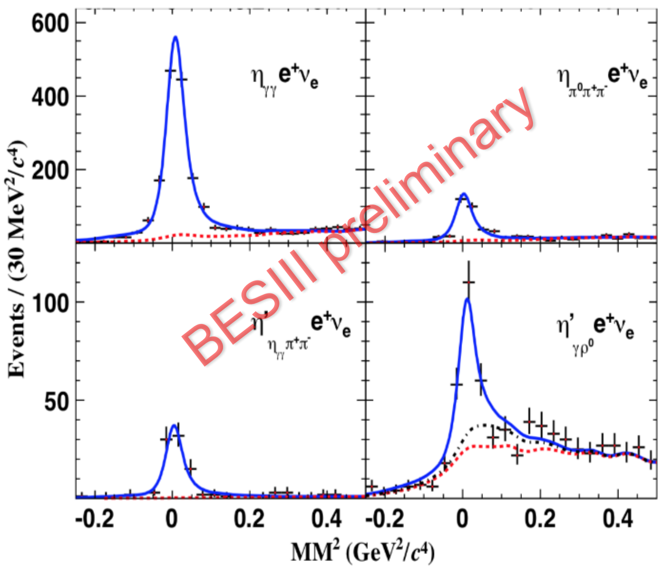
Comparisons of form factors



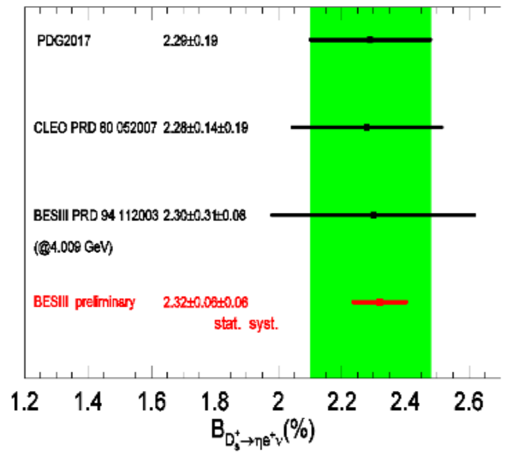


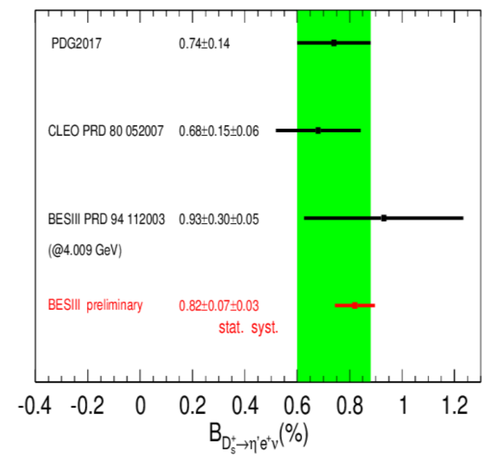
$D_s \rightarrow \eta^{(\prime)} e^+ \nu$分支比和η–η′混合角

MM² fits



Comparisons of branching fractions



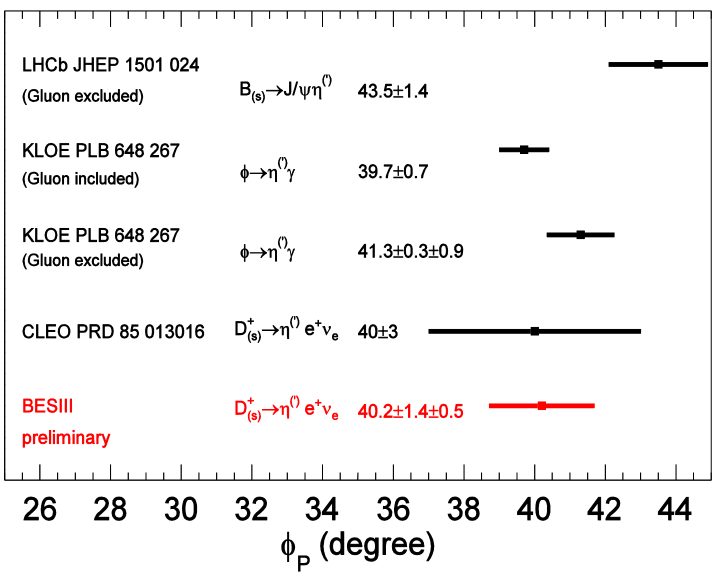


Decay	$\eta^{(\prime)}$ decay	$\epsilon_{\gamma(\pi^0)\mathrm{SL}}$ (%)	$N_{\mathrm{DT}}^{\mathrm{tot}}$	$\mathcal{B}_{\mathrm{SL}}$ (%)
$\eta e^+\nu_e$	$\gamma\gamma$	41.11±0.27	1834±47	2.32±0.06±0.06
	$\pi^0\pi^+\pi^-$	16.06±0.31		
$\eta' e^+\nu_e$	$\eta\pi^+\pi^-$	14.07±0.10	261±22	0.82±0.07±0.03
	$\gamma\rho^0$	18.98±0.10		

Combining the branching fractions measured in this work and B$[D^+\to\eta e^+\nu_e]=(10.74\pm0.81\pm0.51)\times10^{-4}$, B$[D^+\to\eta' e^+\nu_e]=(1.91\pm0.51\pm0.13)\times10^{-4}$ (BESIII arxiv: 1803.05570) into below equation, we obtain

η-η' mixing angle

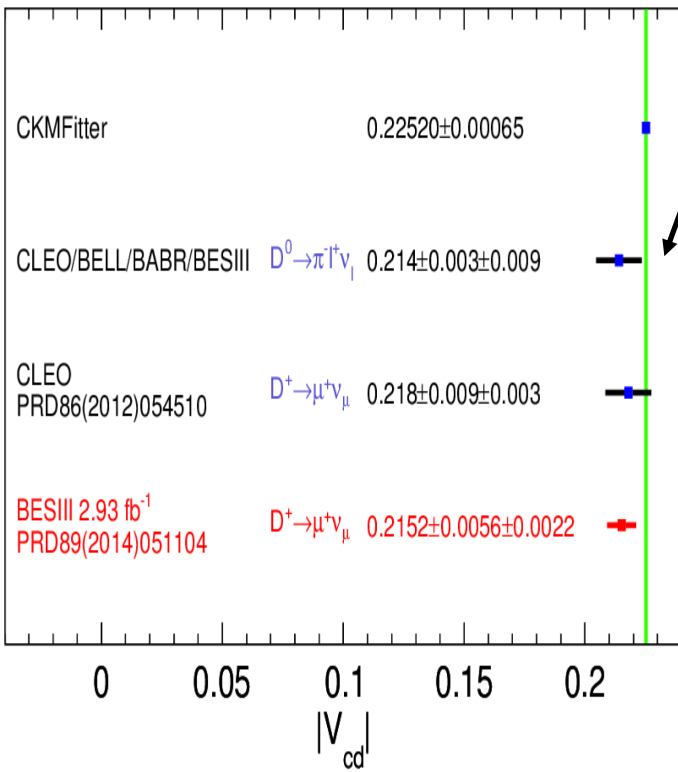
$$\frac{\Gamma(D_s^+\to\eta' e^+\nu)/\Gamma(D_s^+\to\eta e^+\nu)}{\Gamma(D^+\to\eta' e^+\nu)/\Gamma(D^+\to\eta e^+\nu)} \simeq \cot^4\phi_P$$



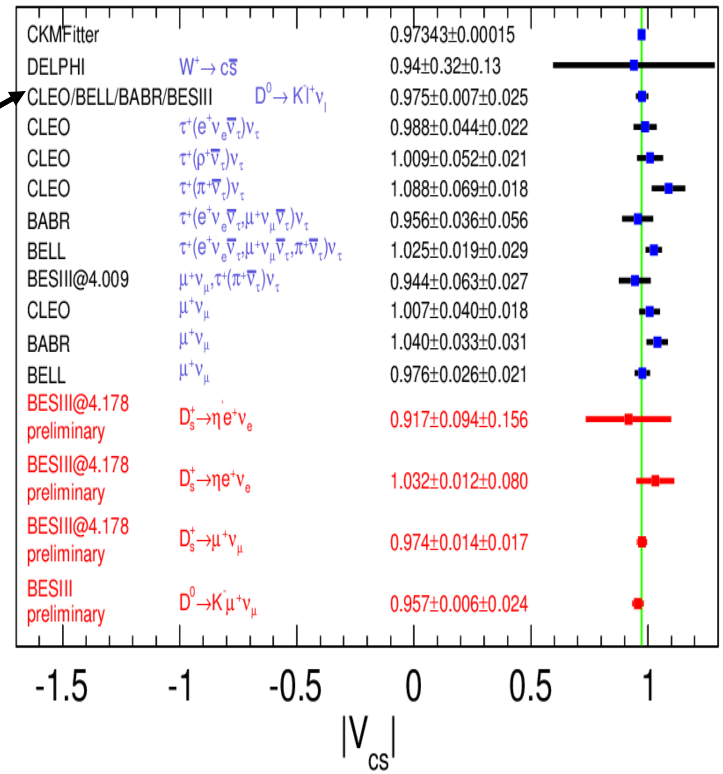
BESIII获得最高精度的$|V_{cs(d)}|$

- **Method 1** $f_{D(s)}|V_{cd(s)}|$ $|V_{cd(s)}|$
- **Method 2** $f^{D\to K(\pi)}_{+}(0)|V_{cs(d)}|$ $|V_{cs(d)}|$
- **Method 3** $f^{D(s)\to\eta}_{+}(0)|V_{cd(s)}|$ $|V_{cd(s)}|$ ← **Limited by both statistics and LQCD input**

For measurements, the first error is the combined stat. and syst. errors, the second is LQCD uncertainty



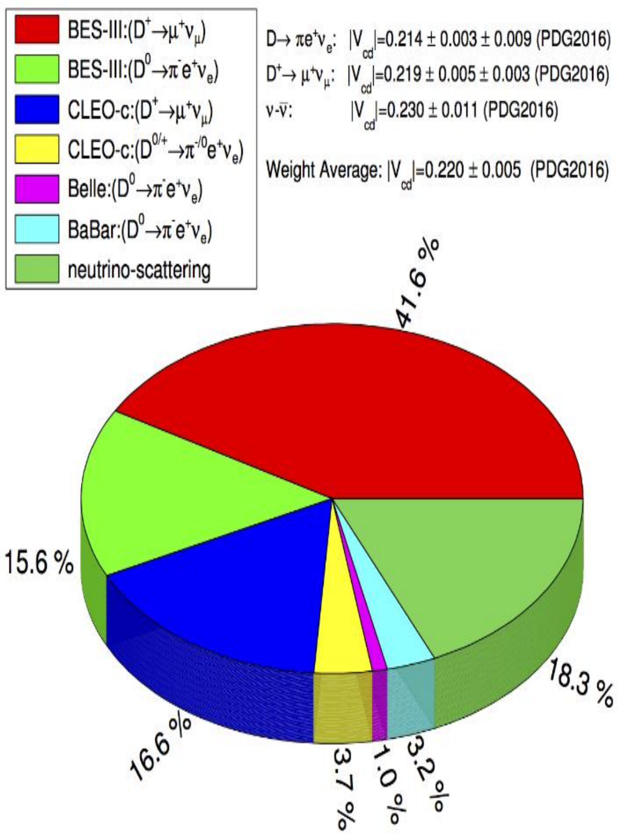
PDG



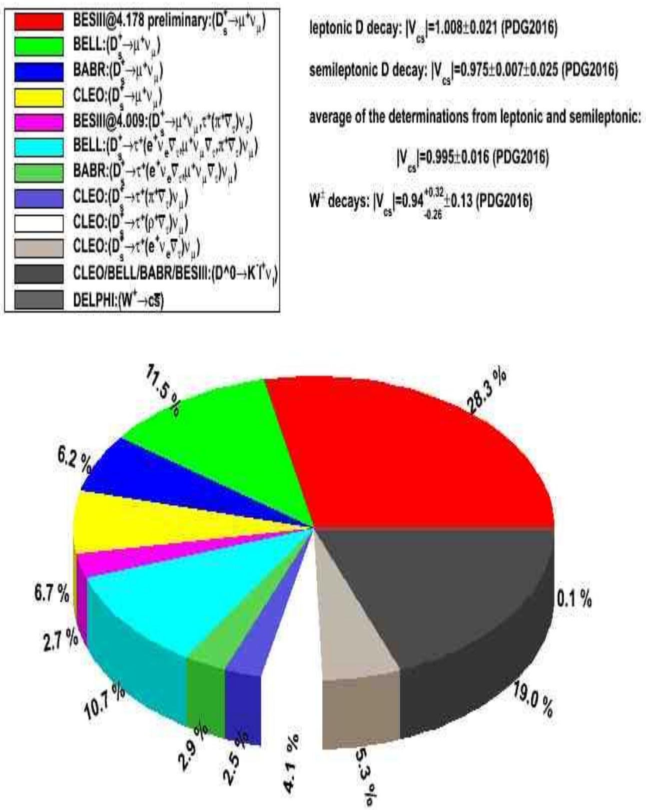
半轻方法受$f_+^{K(\pi)}(0)$格点计算精度限制 **[2.4(4.4)%]**

各实验测量对$|V_{cs(d)}|$的权重

BESIII $|V_{cd}|$权重>50%



BESIII $D_s^+ \to \mu^+ \nu$对$|V_{cs}|$贡献的权重为28%



BESIII $D_s^+ \to \tau^+ \nu$研究完成后，对$|V_{cs}|$贡献的权重有望达到50%左右

CKM矩阵的测量状态[2001→2018]

$\Delta V_{ud}/V_{ud} = 0.1\%$

0.02%

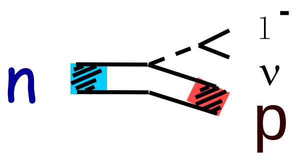
$\Delta V_{us}/V_{us} = 1\%$

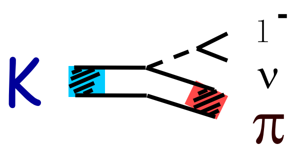
0.4%

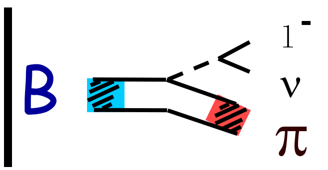
$\Delta V_{ub}/V_{ub} = 25\%$

12%

1







$e^{i\gamma}$

$\Delta V_{cd}/V_{cd} = 7\%$

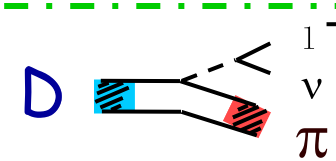
2.3%

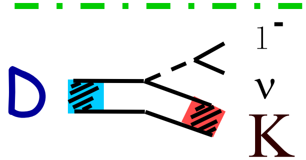
$\Delta V_{cs}/V_{cs} = 16\%$

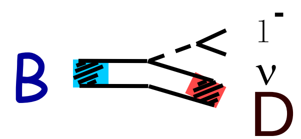
1.7%

$\Delta V_{cb}/V_{cb} = 5\%$

3.1%







联合$D^+ \rightarrow l^+ v$

联合$D_s^+ \rightarrow l^+ v$

BESIII纯轻结果主导

BESIII纯轻结果有望在未来两年主导

$\Delta V_{td}/V_{td} = 36\%$

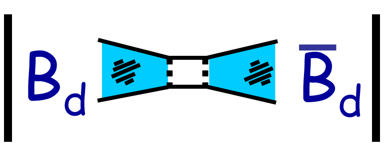
7.3%

$\Delta V_{ts}/V_{ts} = 39\%$

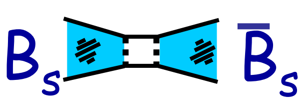
6.8%

$\Delta V_{tb}/V_{tb} = 29\%$

3.1%

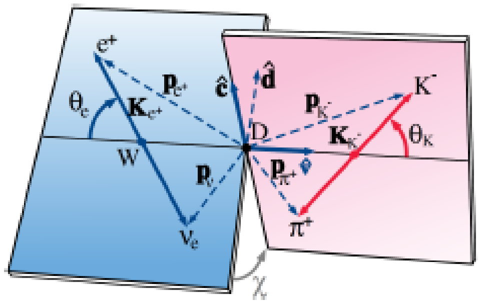


$e^{i\beta}$



1

D→Ve⁺ν形状因子研究



- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\hat{D}\cdot \mathbf{K}_{K^-}}{|\mathbf{K}_{K^-}|}$
- $\cos(\chi) = \hat{c}\cdot\hat{d}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\hat{D}\cdot \mathbf{K}_{e^+}}{|\mathbf{K}_{e^+}|}$
- $\sin(\chi) = (\hat{c}\times\hat{D})\cdot\hat{d}$

Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2|V_{cs}|^2}{(4\pi)^6 m_D^2} X\beta\mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi) dm^2 dq^2 d\cos(\theta_K) d\cos(\theta_e) d\chi$$

- $X = p_{K\pi} m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the D rest frame
- $\beta = 2p^*/m$, p^* is the breakup momentum of the $K\pi$ system in its rest frame
- $\mathcal{I}$ can be expressed in terms of helicity amplitudes $H_{0,\pm}$:

  $H_0(q^2) = \frac{1}{2m_q}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D+m}A_2(q^2)\right]$

  $H_\pm(q^2) = (m_D + m)A_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D+m}V(q^2)$
- Vector form factor: $V(q^2) = \frac{V(0)}{1-q^2/m_V^2}$; or: FF ratio $r_V = V(0)/A_1(0)$
- Axial-vector form factor: $A_1(q^2) = \frac{A_1(0)}{1-q^2/m_A^2}$, $A_2(q^2) = \frac{A_2(0)}{1-q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

Determine FFs in D→Ve⁺ν and understand nature of resonance V

$D^+ \to K^-\pi^+e^+\nu$振幅分析

PRD94(2016)032001

- **Fractions with >5σ significance**

$$f(D^+ \to (K^-\pi^+)_{K^{*0}(892)}\, e^+\nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$

$$f(D^+ \to (K^-\pi^+)_{S-wave}\, e^+\nu_e) = (6.05 \pm 0.22 \pm 0.18)\%$$

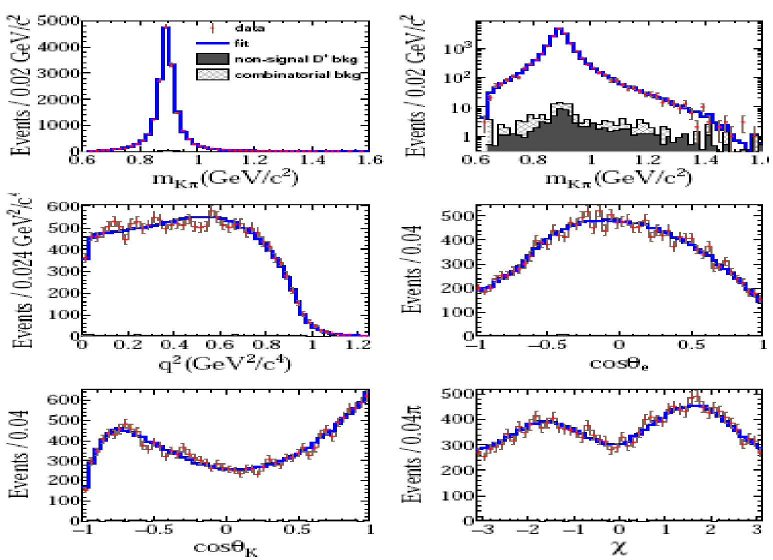
- **Properties of different Kπ (non-) resonant amplitudes**

$$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$$

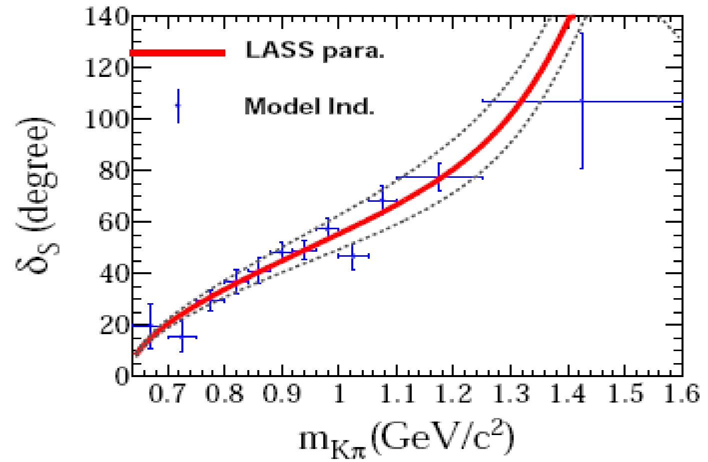
$$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$$

$$r_{BW} = (3.07 \pm 0.26 \pm 0.11)\ (\mathrm{GeV}/c)^{-1}$$

- **q^2 dependent form factors in $D^+ \to \bar{K}^{*0}(892)e^+\nu$**



Model independent S-wave phase measurement



$$V(q^2) = \frac{V(0)}{1-q^2/m_V^2}, \quad A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1-q^2/m_A^2}$$

$M_{V/A}$ is expected to $M_{D^*(1-/+)}$

$$m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)\ \mathrm{GeV}/c^2$$

$$m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)\ \mathrm{GeV}/c^2$$

$$A_1(0) = 0.573 \pm 0.011 \pm 0.020$$

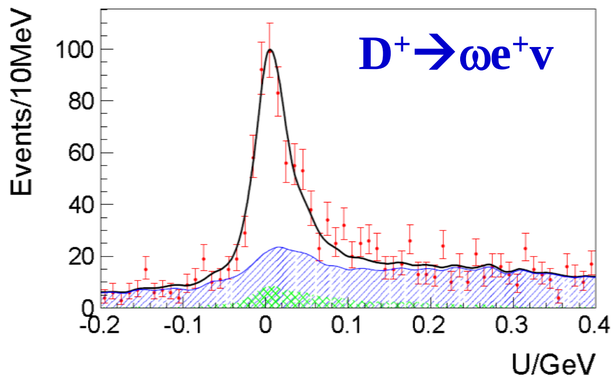
$$r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007$$

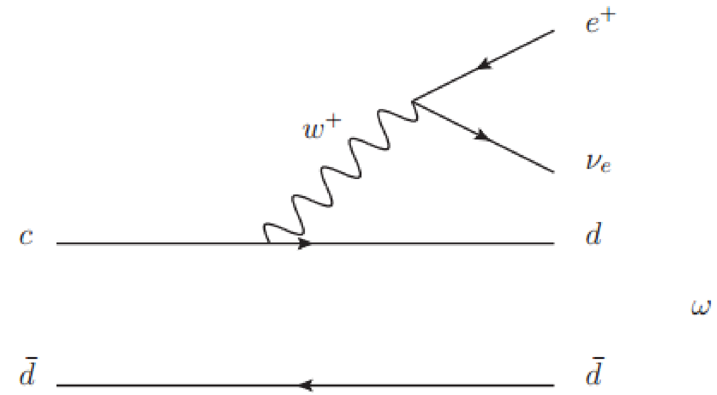
$$r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$$

Model independent form factors

$D^+ \rightarrow \omega e^+ v$振幅分析研究

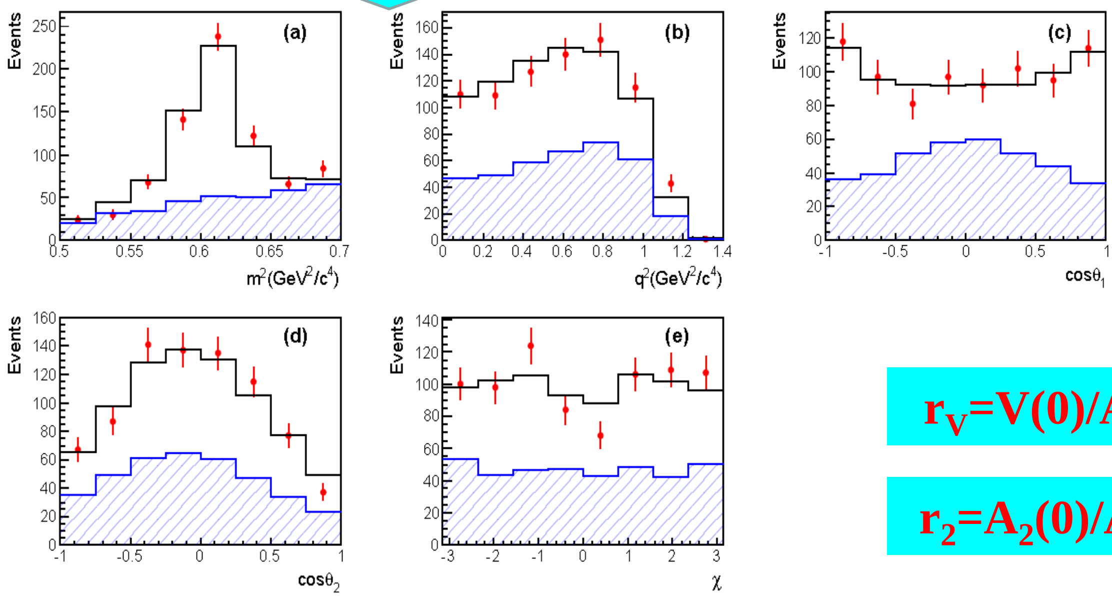
PRD92(2015)071101(RC)





$B[D^+ \rightarrow \omega e^+ v] = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$

Better precision or sensitivity

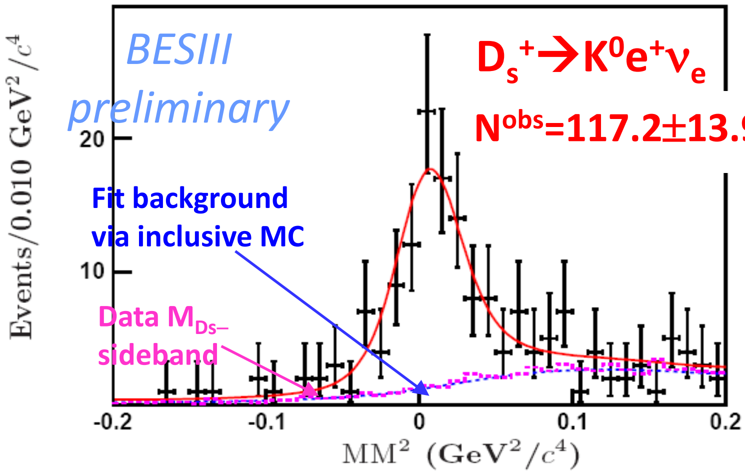


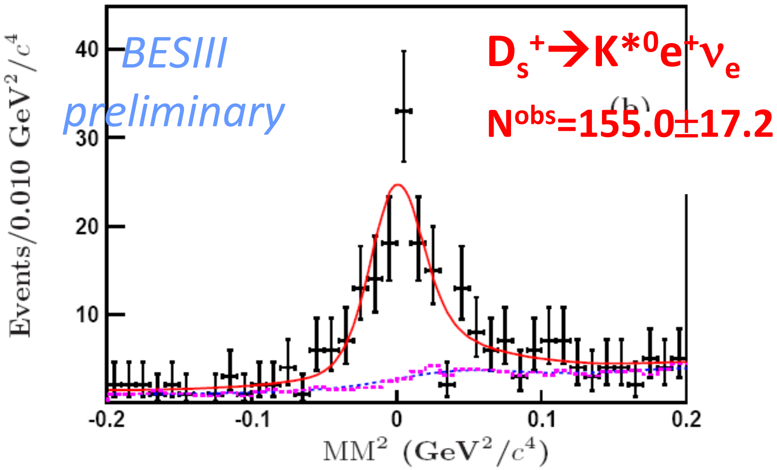
Amplitude analysis of $D^+ \rightarrow \omega e^+ v$ is performed for the first time

$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$

$D_s^+ \to K^{(*)0} e^+ \nu$形状因子的首次测量



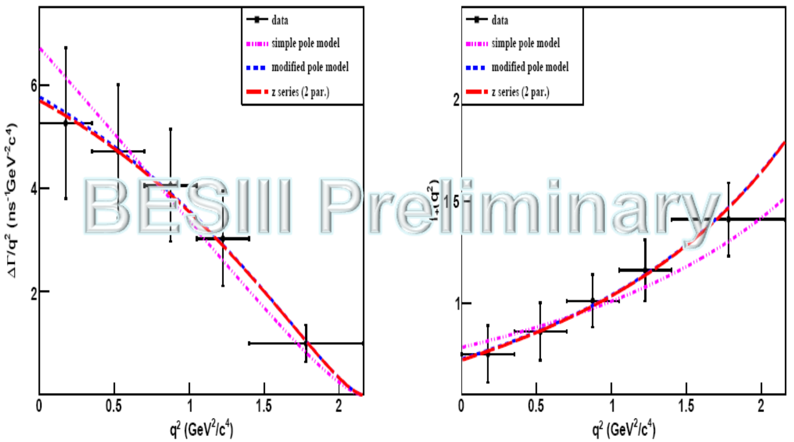


$B[D_s^+ \to K^0 e^+ \nu_e] = (3.25 \pm 0.38_{stat} \pm 0.14_{syst}) \times 10^{-3}$

$(3.9 \pm 0.9) \times 10^{-3}$ [PDG17]

$B[D_s^+ \to K^{*0} e^+ \nu_e] = (2.38 \pm 0.26_{stat} \pm 0.12_{syst}) \times 10^{-3}$

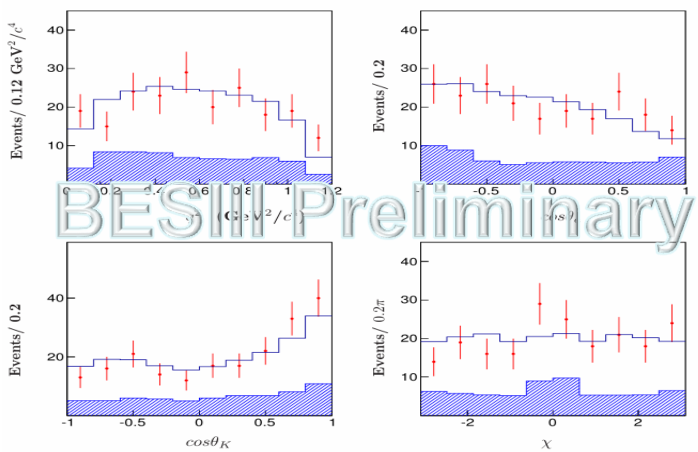
$(1.8 \pm 0.4) \times 10^{-3}$ [PDG17]



Model	Parameter	Value	$f_+(0)$
Simple pole	$f_+(0)\|V_{cd}\|$	$0.175 \pm 0.010 \pm 0.001$	$0.778 \pm 0.044 \pm 0.004$
Modified pole model	$f_+(0)\|V_{cd}\|$	$0.163 \pm 0.017 \pm 0.003$	$0.725 \pm 0.076 \pm 0.013$
	α	$0.45 \pm 0.44 \pm 0.02$	
Series two parameters	$f_+(0)\|V_{cd}\|$	$0.162 \pm 0.019 \pm 0.003$	$0.720 \pm 0.084 \pm 0.013$
	r_1	$-2.94 \pm 2.32 \pm 0.14$	

Taking $|V^{CKMfitter}_{cd}|$ as input

Four dimensional un-binned likelihood fit is performed. K* paramters are fixed



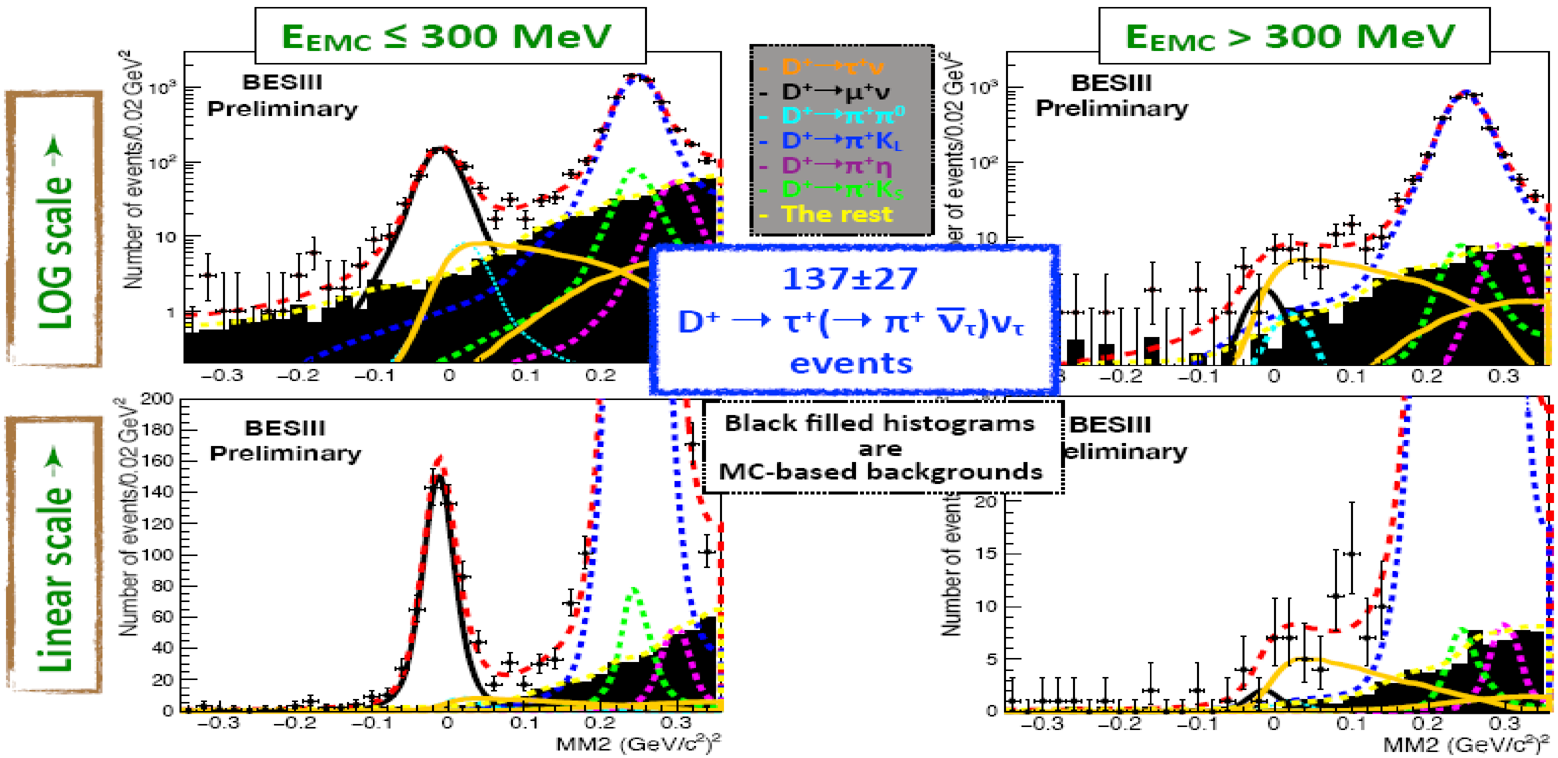
$r_V = 1.67 \pm 0.34 \pm 0.16$

$r_2 = 0.77 \pm 0.28 \pm 0.07$

首次测量$D^+\to\tau^+\nu$和LFU检验

11

Fitting to DATA



4σ

$$B[D^+\to\tau^+\nu]=(1.20\pm0.24_{stat.})\times10^{-3}$$

$$R \equiv \frac{\Gamma(D^+\to\tau^+\nu)}{\Gamma(D^+\to\mu^+\nu)} = \frac{m_{\tau^+}^2\left(1-\frac{m_{\tau^+}^2}{M_{D^+}^2}\right)^2}{m_{\mu^+}^2\left(1-\frac{m_{\mu^+}^2}{M_{D^+}^2}\right)^2}$$

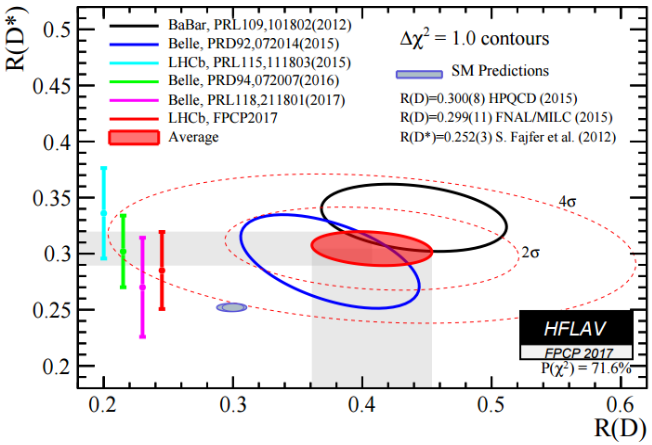
SM prediction: 2.66

BESIII: 3.21±0.64

$D^{0(+)} \to \pi l^+ \nu$分支比测量和LFU检验

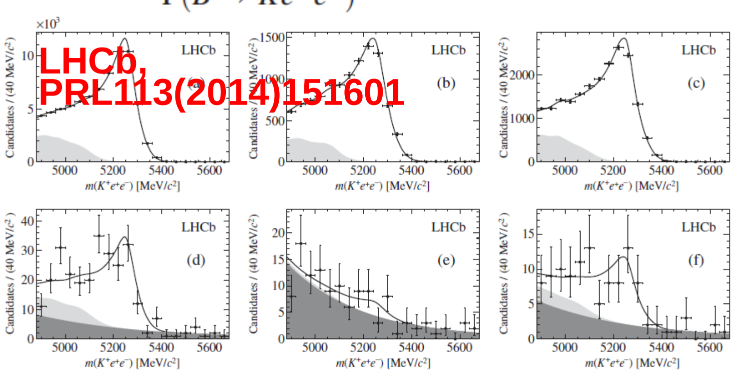
Evidence of violation of LFU at 4σ in

$$R(D^{(*)}) = \frac{B(B \to D^{(*)}\tau\nu)}{B(B \to D^{(*)}l\nu)}$$



Evidence at 2.6σ in FCNC decays $B^+ \to K^+\mu^+\mu^-/K^+e^+e^-$

$$R_K = \frac{\Gamma(\bar{B} \to \bar{K}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

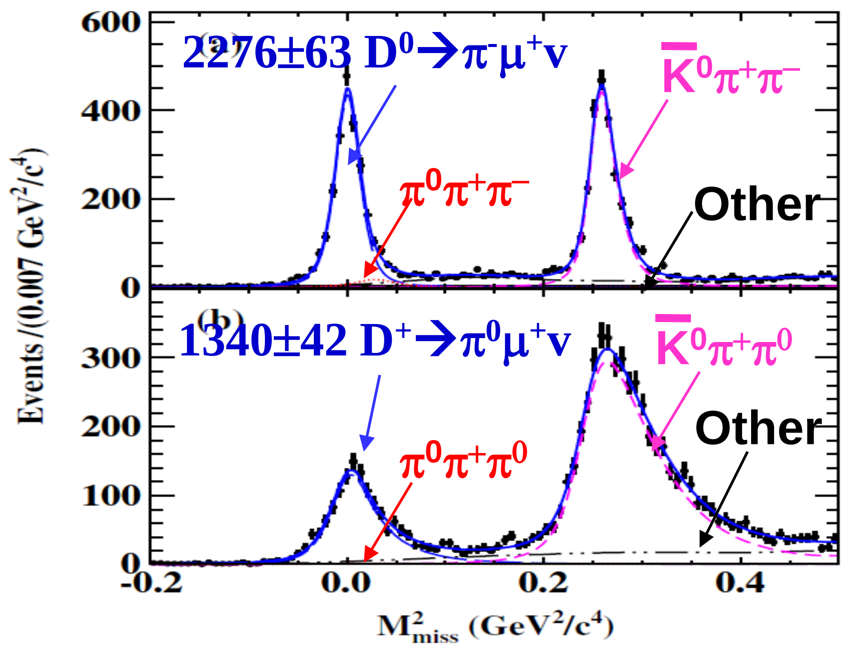


$$R_{LU}^{0(+)} = \frac{B(D^{0(+)} \to \pi^{-(0)}\mu^+\nu)}{B(D^{0(+)} \to \pi^{-(0)}e^+\nu)} \sim 0.985(2)$$

B^PDG16: $R_{LU}^0 = 0.82 \pm 0.08 \quad (\sim 2.1\sigma)$

$B(D^0 \to \pi^-\mu^+\nu) = (0.237 \pm 0.024)\%$

arXiv:1802.05492, submitted to PRL



$B[D^0 \to \pi^-\mu^+\nu] = (0.267 \pm 0.007 \pm 0.007)\%$

$B[D^+ \to \pi^0\mu^+\nu] = (0.342 \pm 0.011 \pm 0.010)\%$

$$\mathcal{R}_{LU}^0 = 0.905 \pm 0.027_{stat.} \pm 0.023_{syst.}$$

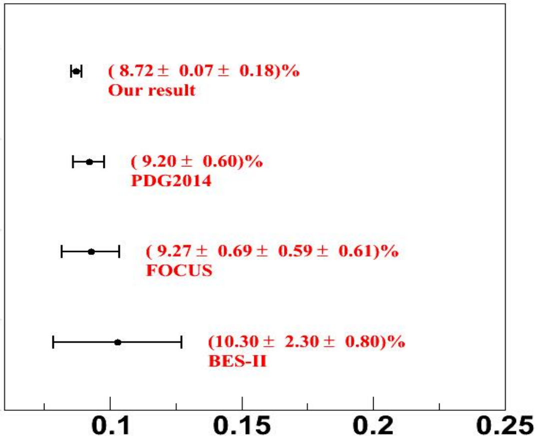
$$\mathcal{R}_{LU}^+ = 0.942 \pm 0.037_{stat.} \pm 0.027_{syst.}$$

D→K̄l⁺v分支比或分宽度和LFU检验

EPJC76(2016)369

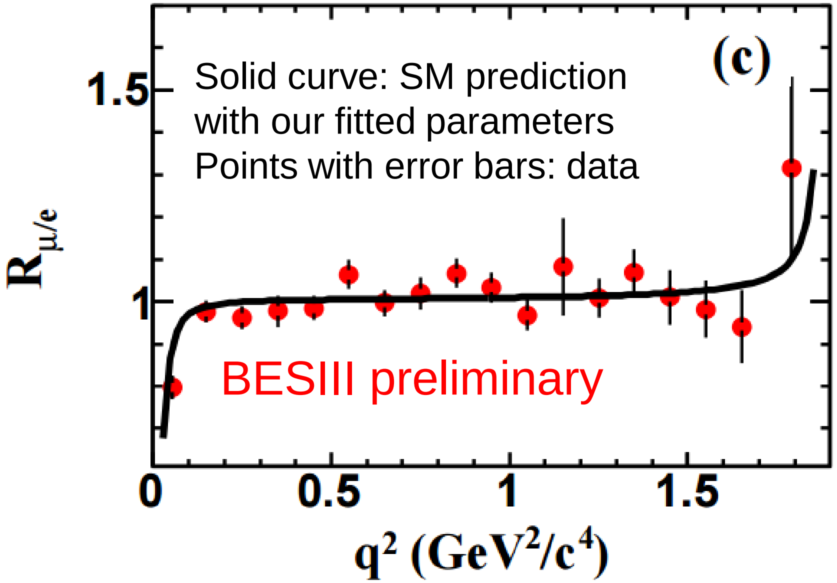
$$\frac{\Gamma[D^+ \to \overline{K}^0 \mu^+ \nu]}{\Gamma[D^+ \to \overline{K}^0 e^+ \nu]} = 0.988 \pm 0.033$$

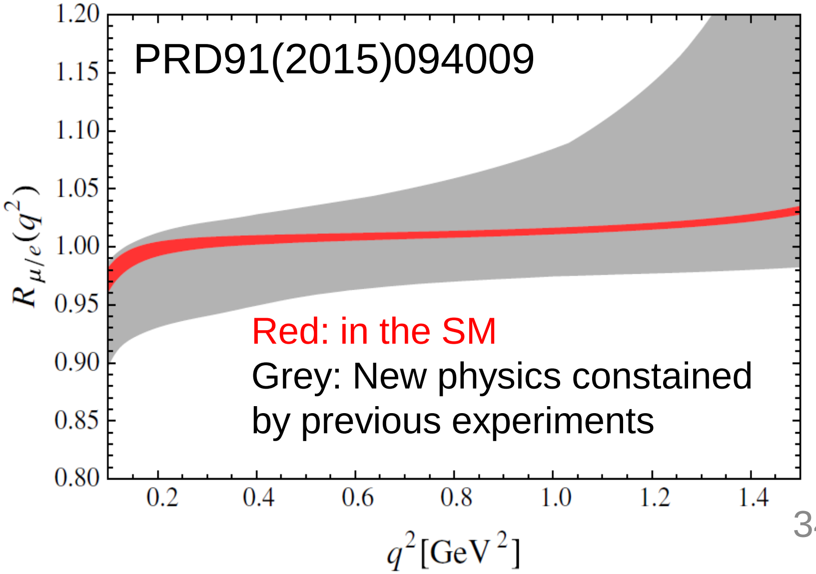
Consistent with theory prediction 0.97 within error



BESIII preliminary

$$R_{\mu/e} = \frac{\Gamma(D^0 \to K^- \mu^+ \nu_\mu)}{\Gamma(D^0 \to K^- e^+ \nu_e)} = 0.978 \pm 0.007_{stat.} \pm 0.012_{syst.}$$





$D^+ \to S e^+ \nu$半轻衰变的首次观测

- Explore the nontrivial internal structure of light mesons, traditional $q\bar{q}$ states, tetra quark system.

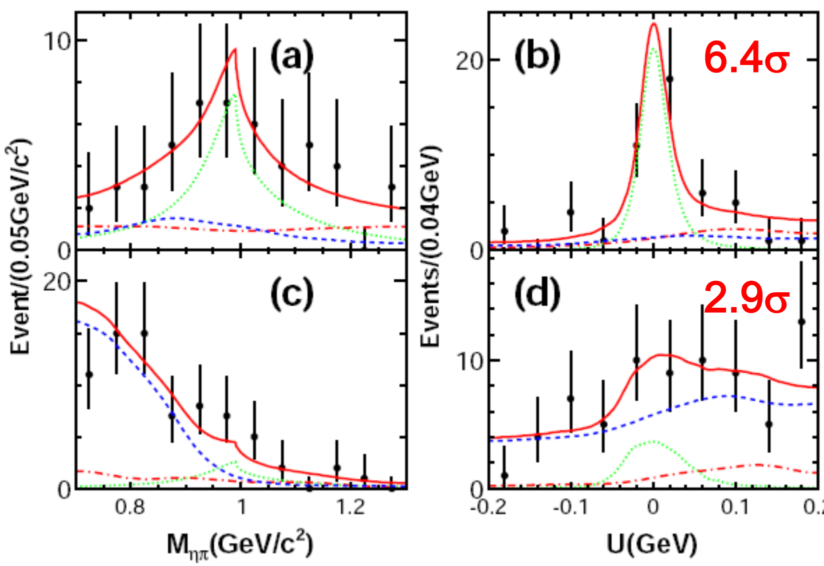
- With chiral unitarity approach in the coupled channels, BF is predicted to be order of $5(6)\times10^{-5}$ for $D^{0(+)}$ decays

- Improve understanding of classification of light scalar mesons

$$R \equiv \frac{B(D^+\to f_0 l^+ \nu)+B(D^+\to \sigma l^+ \nu)}{B(D^+\to a_0 l^+ \nu)}$$

R=1(3) if traditional $q\bar{q}$ (tetra quark) system

arXiv:1803.02166, accepted by PRL

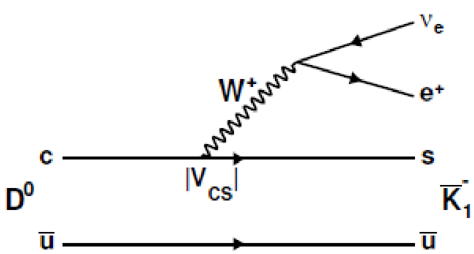


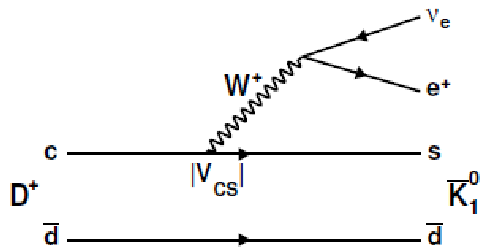
$$\mathcal{B}(D^+ \to a_0(980)^0 e^+\nu_e) \times \mathcal{B}(a_0(980)^0 \to \eta\pi^0)$$
$$= (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}, \quad < 3.0 \times 10^{-4} \text{ at the } 90\% \text{ C.L.}$$

$$\mathcal{B}(D^0 \to a_0(980)^- e^+\nu_e) \times \mathcal{B}(a_0(980)^- \to \eta\pi^-)$$
$$= (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$$

$$\frac{\Gamma(D^0 \to a_0(980)^- e^+\nu_e)}{\Gamma(D^+ \to a_0(980)^0 e^+\nu_e)} = 2.03 \pm 0.95 \pm 0.06$$

D→Ae⁺v半轻衰变的寻找





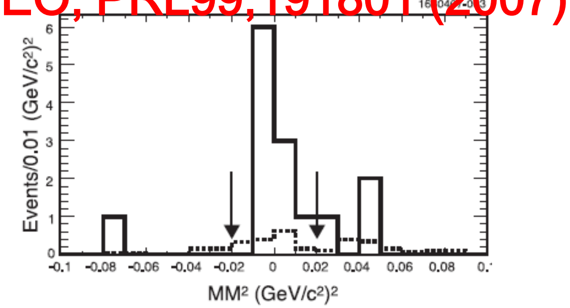
$D^+ \to \bar{K}^0_1(1270)e^+v$是CF衰变

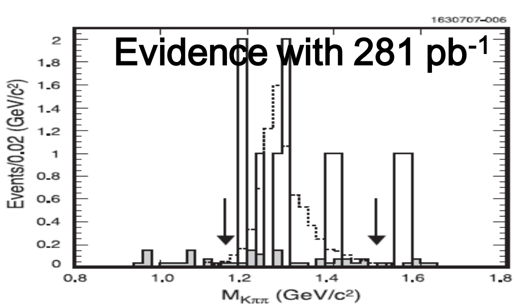
$D_s \to \bar{K}^0_1(1270)e^+v$是CS衰变

它们应大约满足20倍的关系

PRD52,2783(1995)预期:
其占$c \to sl^+v$总宽度的2%。
D^0~0.12%，D^+~0.34%

CLEO, PRL99,191801 (2007)





$$\mathcal{B}(D^0 \to K_1^-(1270)e^+\nu_e) = [7.6^{+4.1}_{-3.0}(\text{stat}) \pm 0.6(\text{syst}) \pm 0.7] \times 10^{-4}$$

EPJC77, 587(2017)

Table 1 Branching fractions of D and D_s decays to $(P, V, S, A)e^+\nu_e$. Units are shown in parentheses. PDG average values are taken from Ref. [30], while data are not yet available for the S and A modes. When the error bar is comparable to the central value, instead we show the minimum and maximum values in the brackets

Channel	$D \to \pi$	$D \to \bar{K}$	$D \to \eta$	$D \to \eta'$	$D_s \to K$	$D_s \to \eta$	$D_s \to \eta'$
Theory (10^{-2})	0.41 ± 0.03	10.32 ± 0.93	0.12 ± 0.01	0.018 ± 0.002	0.27 ± 0.02	2.26 ± 0.21	0.89 ± 0.09
PDG (10^{-2})	0.41 ± 0.02	8.82 ± 0.13	0.11 ± 0.01	0.022 ± 0.005	0.39 ± 0.09	2.29 ± 0.19	0.74 ± 0.14
Channel	$D \to \rho$	$D \to \omega$	$D \to \bar{K}^*$	$D_s \to K^*$	$D_s \to \phi$		
Theory (10^{-2})	0.23 ± 0.02	0.21 ± 0.02	7.5 ± 0.7	0.19 ± 0.02	3.1 ± 0.3		
PDG (10^{-2})	$0.22^{+0.02}_{-0.03}$	0.17 ± 0.01	5.40 ± 0.10	0.18 ± 0.04	2.39 ± 0.23		
Channel	$D \to a_0(1450)$	$D \to f_0(1500)$	$D \to f_0(1710)$	$D \to K_0^*(1450)$	$D_s \to K_0^*(1450)$	$D_s \to f_0(1500)$	$D_s \to f_0(1710)$
Theory (10^{-5})	0.54 ± 0.05	0.11 ± 0.02	$(4.7 \pm 0.8) \cdot 10^{-4}$	29 ± 3	2.7 ± 0.2	15 ± 3	0.034 ± 0.006
Channel	$D \to f_1(1285)$	$D \to f_1(1420)$	$D \to b_1(1235)$	$D \to h_1(1170)$	$D \to h_1(1380)$	$D_s \to h_1(1170)$	$D_s \to h_1(1380)$
Theory (10^{-5})	3.7 ± 0.8	{0.02, 0.14}	7.4 ± 0.7	14 ± 1.5	{0, 0.02}	{0, 19.7}	64 ± 7
Channel	$D \to K_1(1270)$	$D \to K_1(1400)$	$D_s \to K_1(1270)$	$D_s \to K_1(1400)$	$D_s \to f_1(1285)$	$D_s \to f_1(1420)$	
Theory (10^{-5})	17 ± 2	{0.03, 0.10}	320 ± 32	{1.0, 2.6}	{6.0, 36}	25 ± 5	

EPJC77, 863(2017)

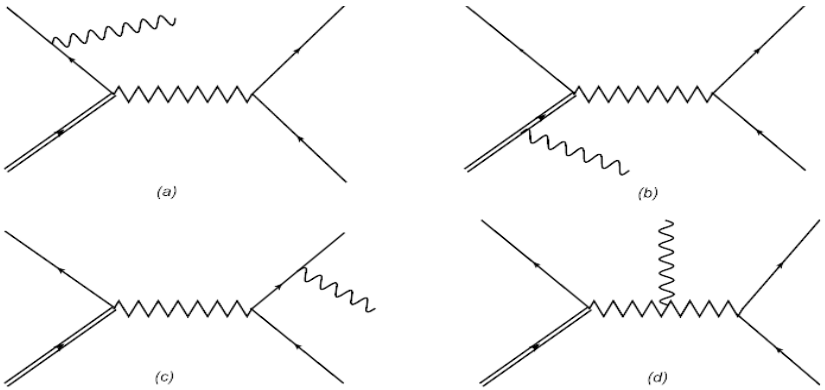
Table 1

Channel	$D \to K_1(1270)$	$D \to K_1(1400)$	$D_s \to K_1(1270)$	$D_s \to K_1(1400)$
Theory (10^{-5})	320 ∓ 40	{0.5, 2.0}	17 ∓ 2	{0.05, 0.14}

BESIII将首次观测到$D^{0(+)} \to Ae^+v$衰变，相关工作正在开展

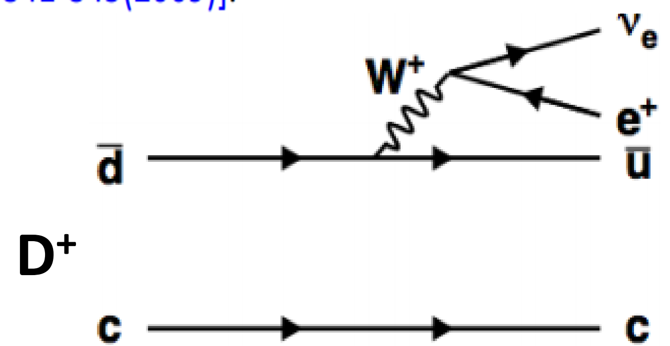
D介子稀有半轻衰变的寻找

Various theory models predict BFs in 10^{-6}–10^{-4}

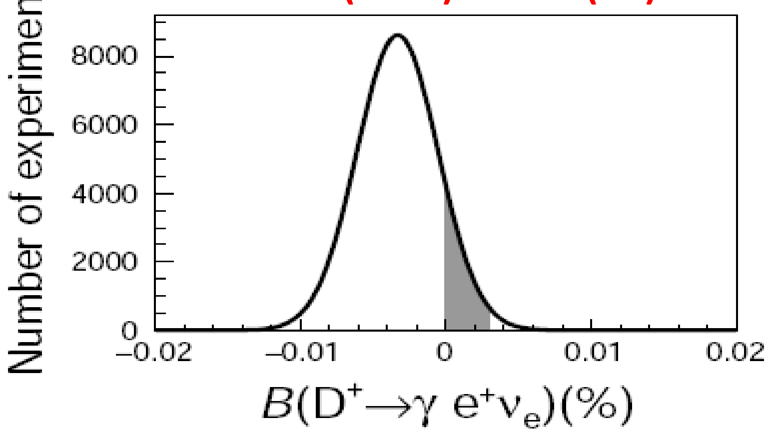


Tree level amplitudes

Applying the SU(3) symmetry for the light quarks, this rare decay branching fraction can be predicted by theoretical calculation and its theoretical value is 2.78×10^{-13} [EPJC, 59:841-845(2009)].

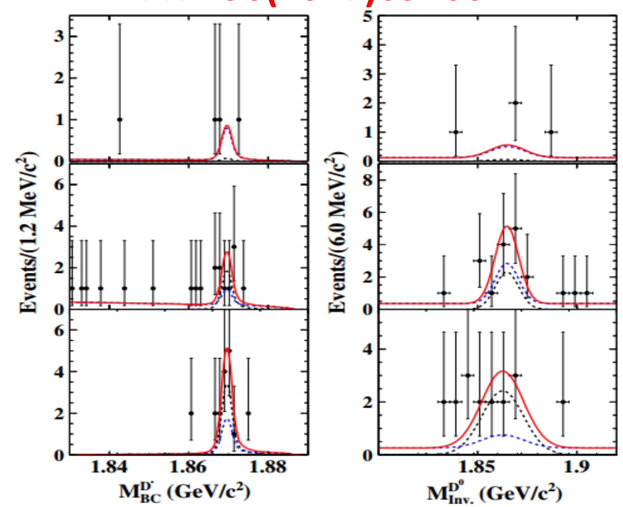


PRD 95(2017)071102(RC)



$B[D^+\to\gamma e^+\nu]|_{E\gamma>10\ MeV}<3.0\times10^{-4}$ @90%C.L.

PRD 96(2017)092002



$B[D^+\to D^0e^+\nu]<1\times10^{-4}$ @90%C.L.

$D_{(s)}$强子衰变

- $D^0\bar{D}^0$ mixing parameters
- Strong phase difference
- SU(3) symmetry and break effect

BESIII测得$D^0\bar{D}^0$混合参数y_{CP}

- **BESIII, 3 fb^{-1} at 3.773 GeV**

PLB744(2015)339

For D decay to CP eigenstates:

$$R_{CP\pm} \propto |A_{CP\pm}|^2(1 \mp y_{CP})$$

$$y_{CP} = \frac{1}{2}[y\cos\phi(|\frac{q}{p}| + |\frac{p}{q}|) - x\sin\phi(|\frac{q}{p}| - |\frac{p}{q}|)]$$

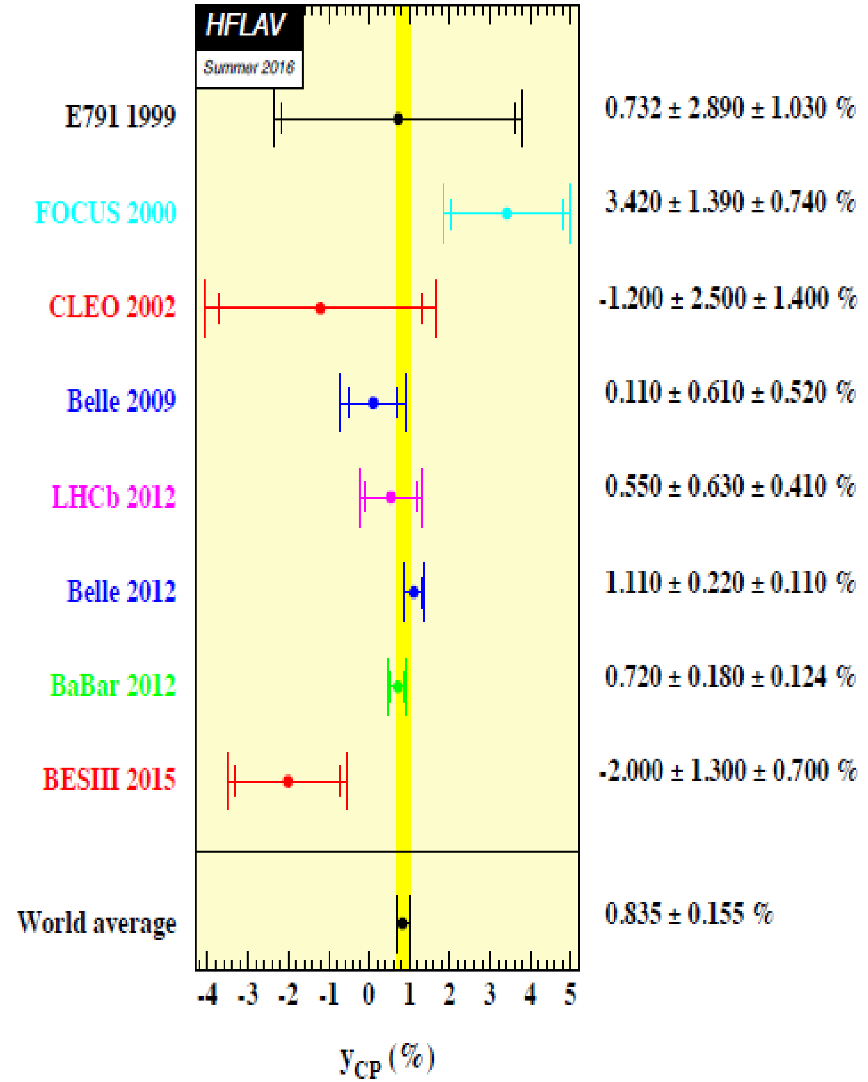
For CP tagged semileptonic D decays:

$$R_{l,CP\pm} \propto |A_l|^2|A_{CP\pm}|^2$$

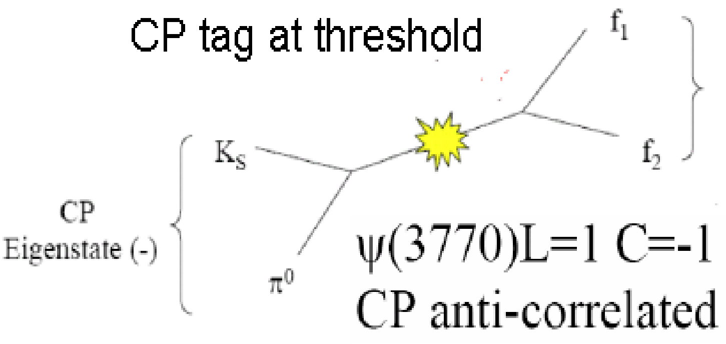
$$y_{CP} \approx \frac{1}{4}(\frac{R_{l;CP+}R_{CP-}}{R_{l;CP-}R_{CP+}} - \frac{R_{l;CP-}R_{CP+}}{R_{l;CP+}R_{CP-}})$$

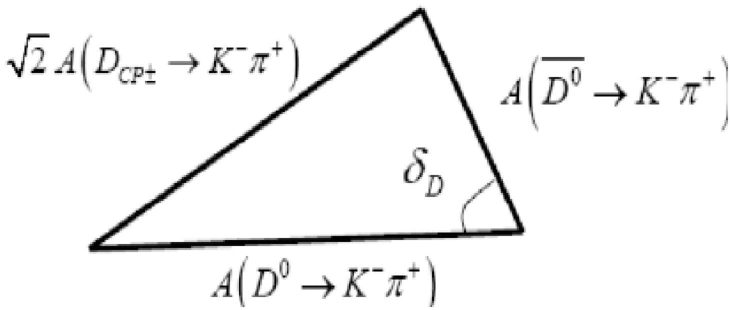
Type	Modes
CP^+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$
CP^-	$K^0_S\pi^0$, $K^0_S\omega$, $K^0_S\eta$
$l^\pm$	$Ke\nu$, $K\mu\nu$

y_{CP}=(-2.0±1.3±0.7)%



BESIII测得$D^0\bar{D}^0$混合参数$\delta_{K\pi}$





$$\mathcal{A}_{CP\to K\pi} = \frac{\mathcal{B}_{D_2\to K^-\pi^+} - \mathcal{B}_{D_1\to K^-\pi^+}}{\mathcal{B}_{D_2\to K^-\pi^+} + \mathcal{B}_{D_1\to K^-\pi^+}}.$$

$$2r\boxed{\cos\delta_{K\pi}} + y = (1+R_{\rm WS})\cdot\mathcal{A}_{CP\to K\pi},$$

$$|D_1\rangle \equiv \frac{|D^0\rangle + |\overline{D}^0\rangle}{\sqrt{2}} \quad |D_2\rangle \equiv \frac{|D^0\rangle - |\overline{D}^0\rangle}{\sqrt{2}}.$$

Type	Mode
Flavored	$K^-\pi^+, K^+\pi^-$
$CP+$	$K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0$
$CP-$	$K_S^0\pi^0, K_S^0\eta, K_S^0\omega$

$\delta_{K\pi}$ is related to mixing parameters x and y from x' and y'

目前最精确结果

$A^{K\pi}_{CP}$=(12.7±1.3±0.7)×10^{-2}

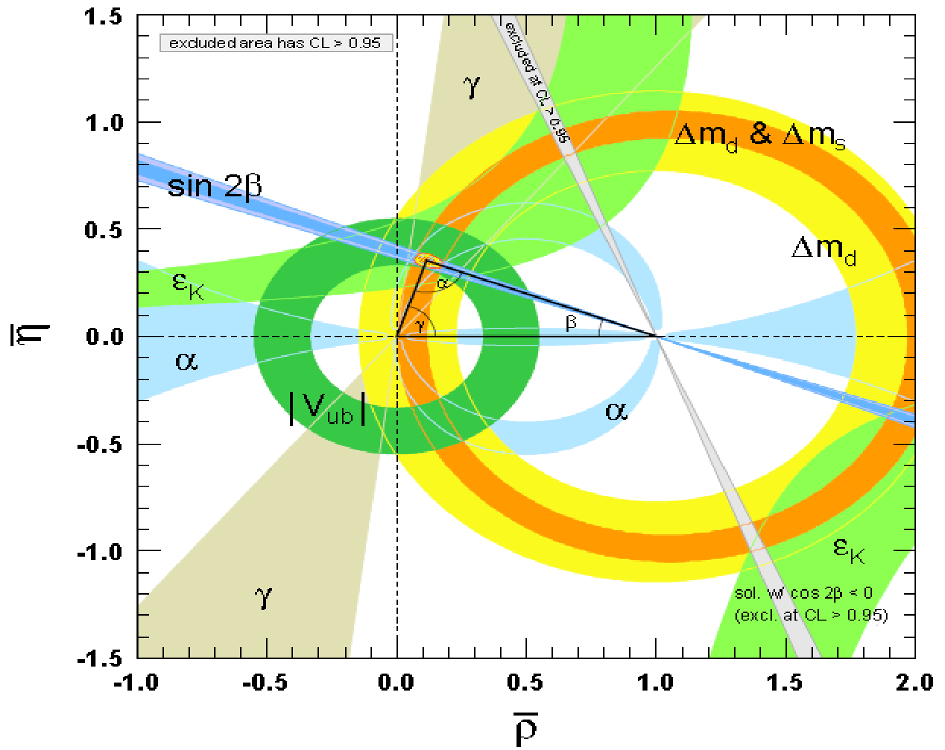
$\cos\delta_{K\pi}$=1.02±0.11±0.06±0.01

PLB734(2014)227

D^0衰变强相差: 约束γ/ϕ_3的理想桥梁

Direct measurement

$$\alpha/\phi_2 = \left(85.4^{+4.0}_{-3.9}\right)^\circ$$
$$\beta/\phi_1 = \left(21.38^{+0.79}_{-0.77}\right)^\circ$$
$$\gamma/\phi_3 = \left(68^{+8.0}_{-8.5}\right)^\circ$$

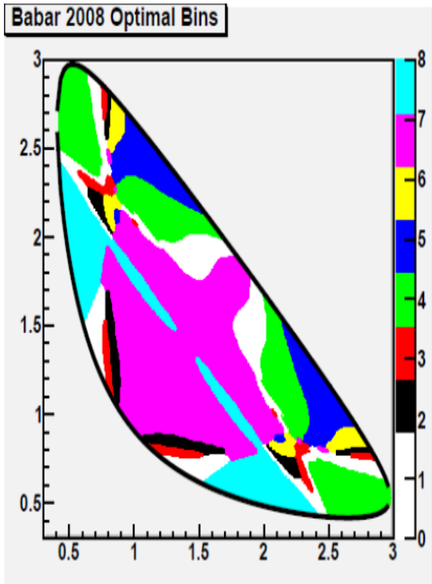


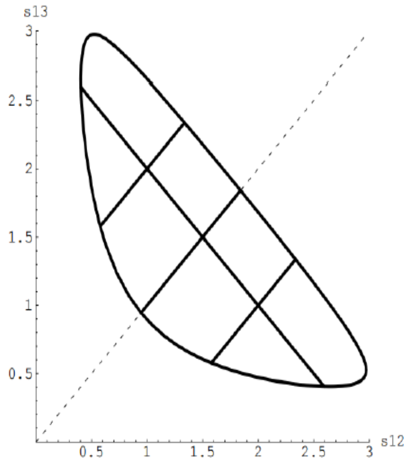
γ is the worst measured angle, mostly due to systematic error

Significant deviation from UT will imply NP beyond SM

- **Quantum correlated $D^0\bar{D}^0$ decays in $\psi(3770)$**
  - **CP asymmetry in mixing and decays**
  - **Interference → strong phase parameters → Constrain γ/ϕ_3, which is important for CKM UT**

$D^0 \to K_S\pi^+\pi^-$衰变强相差研究





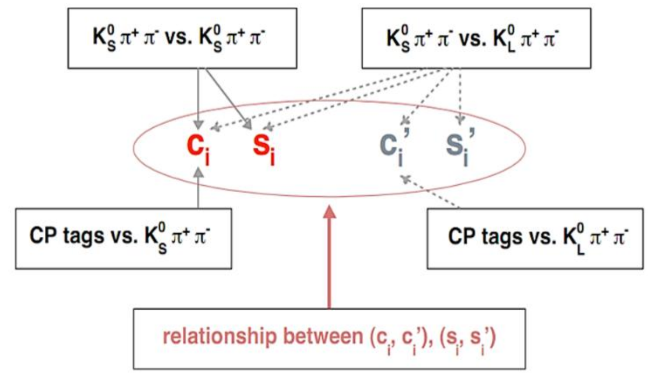
Mirrored binning over x=y makes it so c_i=c_{-i} and s_i =-s_{-i}

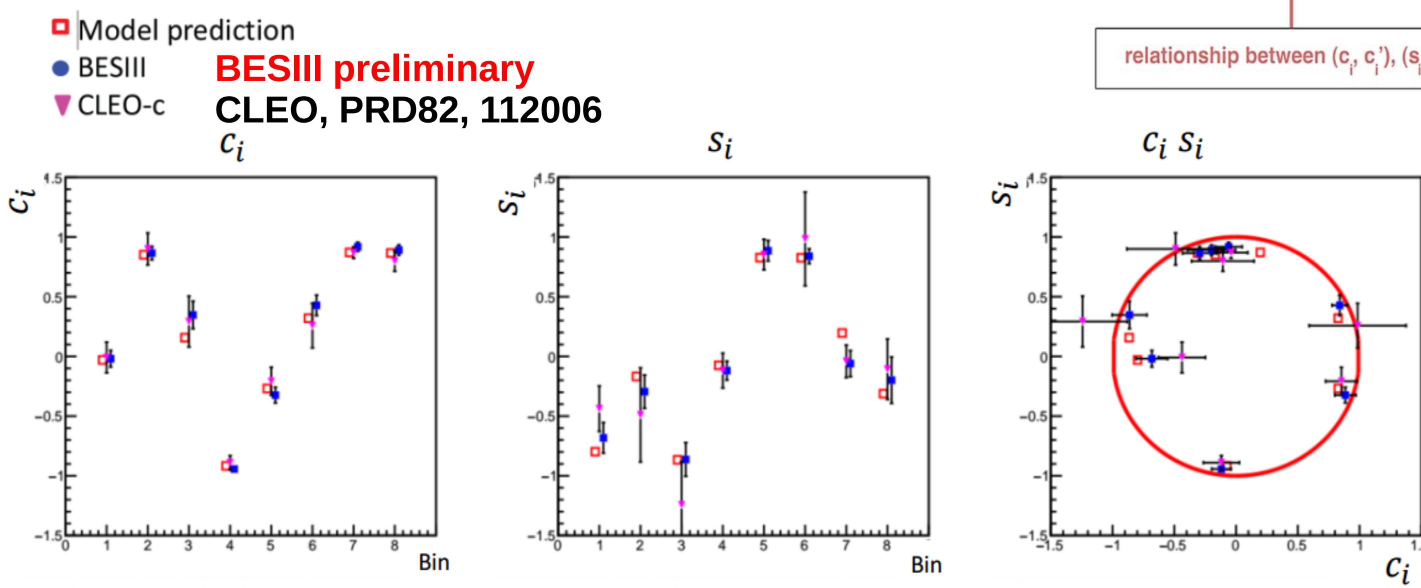
- T_i : Bin yield measured in flavor decays
- r_B : color suppression factor~0.1
- δ_B : strong phase of B decay
- c_i, s_i : weighted average of $\cos(\Delta\delta_D)$ and $\sin(\Delta\delta_D)$ respectively

  where $\Delta\delta_D$ is the difference between phase of D^0 and $\bar{D}^0$

Measured at B-Factories

Through $D^0 \to K_S\pi^+\pi^-$ analysis





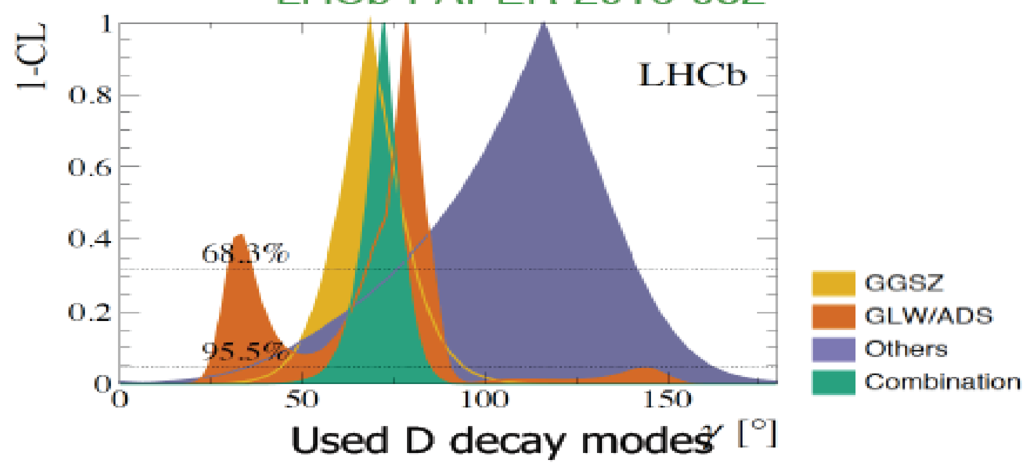
D^0衰变强相差对γ/ϕ_3的约束及前景

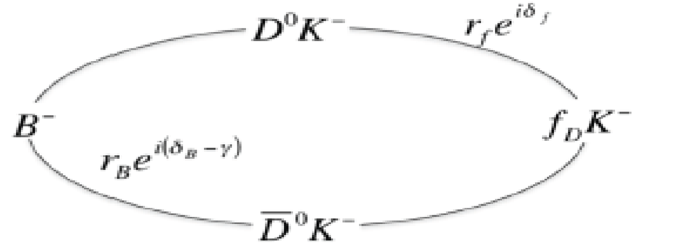
taken from Liming Zhang's talk at FPCPV2016

γ combination at LHCb

Determine γ from CPV measurements

LHCb-PAPER-2016-032





$\gamma = (72.2^{+6.8}_{-7.3})^\circ$ syst. included

BaBar: $\gamma = (70\pm18)^\circ$

Belle: $\gamma = (73^{+13}{}_{-15})^\circ$

Used D decay modes

GLW: $D\to K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0$

ADS: $D\to \pi^-K^+$

quasi-ADS $D\to \pi^-K^+\pi^+\pi^-$, $\pi^-K^+\pi^0$

quasi-GLW $D\to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$

GGSZ $D\to K_S\pi^+\pi^-$, $K_SK^+K^-$

GLS $D\to K_SK^-\pi^+$, $K_S\pi^-K^+$

Prospects

Sample	$\sigma_{stat}(\gamma)^\circ$
Run 1	8
Run 2	4
Upgrade	~ 1
Future upgrade	<0.5

- **Current one syst. ~2° from CLEO strong phase measurements**
- **15-20 fb^{-1} ψ(3770) data from BESIII are desired to avoid syst. limitation for upgrade scenario**

More 15 fb^{-1} ψ(3770) data@BESIII will avoid syst. limitation for γ/ϕ_3 measurement

SU(3)对称性及破坏效应

- Ratio of branching fractions of D to KK and pi pi

$$R = \frac{Br(D^0 \to K^+K^-)}{Br(D^0 \to \pi^+\pi^-)} \approx 2.8$$

  - R=1 in the SU(3) flavour symmetry limit

- Branching fraction of $\mathcal{B}(D^0 \to K^0\overline{K}^0) = (0.320 \pm 0.038) \times 10^{-3}$

  vanishes in the SU(3) limit

- DDbar mixing parameters

$$x, y \sim \sin^2\theta_C \times [SU(3)\ \text{breaking}]^2$$

  - Non-zero mixing parameters indicate large SU(3) breaking effect

两体D衰变分支比的理论计算

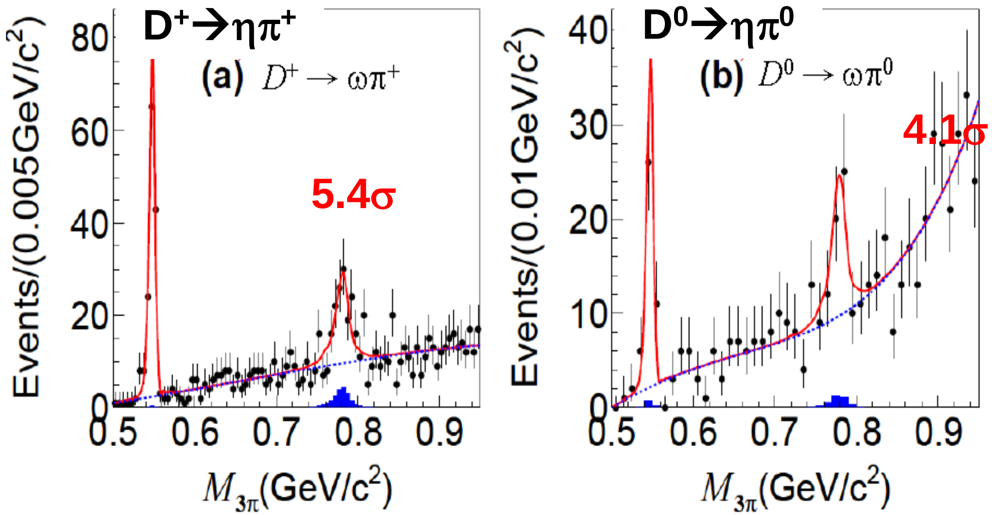
Modes	Amplitudes	Br(FSI)	Br(diagrammatic)	Br(pole)	Br(FAT)	Br(FAT[mix])	Br(exp)
$D^0 \to \pi^+\rho^-$	$T_V, (E_P)$	6.5	3.92 ± 0.46	3.5 ± 0.6	4.74	4.66	4.96 ± 0.24
$D^0 \to \pi^0\rho^0$	$C_P, C_V, (E_P, E_V)$	1.7	2.96 ± 0.98	1.4 ± 0.6	3.55	3.83	3.72 ± 0.22
$D^0 \to \pi^0\omega$	$C_P, C_V, (E_P, E_V)$	0.08	0.10 ± 0.18	0.08 ± 0.02	0.85	0.18	< 0.26
$D^0 \to \pi^0\phi$	C_P	1.1	1.22 ± 0.08	1.0 ± 0.3	1.11	1.11	1.31 ± 0.10
$D^0 \to \pi^-\rho^+$	$T_P, (E_V)$	8.2	8.34 ± 1.69	10.2 ± 1.5	10.2	10.0	9.8 ± 0.4
$D^0 \to K^+K^{*-}$	$T_V, (E_P)$	2.8	1.99 ± 0.24	1.6 ± 0.3	1.72	1.73	1.56 ± 0.12
$D^0 \to K^0\overline{K}^{*0}$	E_P, E_V	0.99	0.29 ± 0.22	0.16 ± 0.05	1.1	1.1	< 1
$D^0 \to \overline{K}^0K^{*0}$	E_P, E_V	0.99	0.29 ± 0.22	0.16 ± 0.05	1.1	1.1	< 0.56
$D^0 \to K^-K^{*+}$	$T_P, (E_V)$	4.5	4.25 ± 0.86	4.7 ± 0.8	4.37	4.37	4.38 ± 0.21
$D^0 \to \eta\rho^0$	$C_P, C_V, (E_P, E_V)$	0.24	1.11 ± 0.86	0.05 ± 0.01	0.54	0.45	
$D^0 \to \eta\omega$	$C_P, C_V, (E_P, E_V)$	1.9	3.08 ± 1.42	1.2 ± 0.3	2.4	2.0	
$D^0 \to \eta\phi$	$C_P, (E_P, E_V)$	0.57	0.31 ± 0.10	0.23 ± 0.06	0.19	0.18	0.14 ± 0.05
$D^0 \to \eta'\rho^0$	$C_P, C_V, (E_P, E_V)$	0.10	0.14 ± 0.02	0.08 ± 0.02	0.21	0.27	
$D^0 \to \eta'\omega$	$C_P, C_V, (E_P, E_V)$	0.001	0.07 ± 0.02	0.0001 ± 0.0001	0.04	0.02	
$D^+ \to \pi^+\rho^0$	$T_V, C_P, (A_P, A_V)$	1.7		0.8 ± 0.7	0.42	0.58	0.81 ± 0.15
$D^+ \to \pi^+\omega$	$T_V, C_P, (A_P, A_V)$	0.35		0.3 ± 0.3	0.95	0.80	< 0.34
$D^+ \to \pi^+\phi$	C_P	5.9	6.21 ± 0.43	5.1 ± 1.4	5.65	5.65	$5.42^{+0.22}_{-0.24}$
$D^+ \to \pi^0\rho^+$	$T_P, C_V, (A_P, A_V)$	3.7		3.5 ± 1.6	2.7	2.5	
$D^+ \to K^+\overline{K}^{*0}$	$T_V, (A_V)$	2.5		4.1 ± 1.0	3.61	3.60	$3.675^{+0.14}_{-0.21}$
$D^+ \to \overline{K}^0K^{*+}$	$T_P, (A_P)$	1.70		12.4 ± 2.4	11	11	32 ± 14
$D^+ \to \eta\rho^+$	$T_P, C_V, (A_P, A_V)$	0.002		0.4 ± 0.4	0.7	2.2	< 15
$D^+ \to \eta'\rho^+$	$T_P, C_V, (A_P, A_V)$	1.3		0.8 ± 0.1	0.7	0.8	
$D_s^+ \to \pi^+K^{*0}$	$T_V, (A_V)$	3.3		1.5 ± 0.7	2.52	2.35	2.25 ± 0.39
$D_s^+ \to \pi^0K^{*+}$	$C_V, (A_V)$	0.29		0.1 ± 0.1	0.8	1.0	
$D_s^+ \to K^+\rho^0$	$C_P, (A_P)$	2.4		1.0 ± 0.6	1.9	2.5	2.7 ± 0.5
$D_s^+ \to K^+\omega$	$C_P, (A_P)$	0.72		1.8 ± 0.7	0.6	0.07	< 2.4
$D_s^+ \to K^+\phi$	$T_V, C_P, (A_V)$	0.15		0.3 ± 0.3	0.166	0.166	0.184 ± 0.045
$D_s^+ \to K^0\rho^+$	$T_P, (A_P)$	19.5		7.5 ± 2.1	9.1	9.6	
$D_s^+ \to \eta K^{*+}$	$T_P, C_V, (A_P, A_V)$	0.24		1.0 ± 0.4	0.2	0.2	
$D_s^+ \to \eta' K^{*+}$	$T_P, C_V, (A_P, A_V)$	0.24		0.6 ± 0.2	0.2	0.2	

[Qin, Li, Lu, FSY, PRD2014]

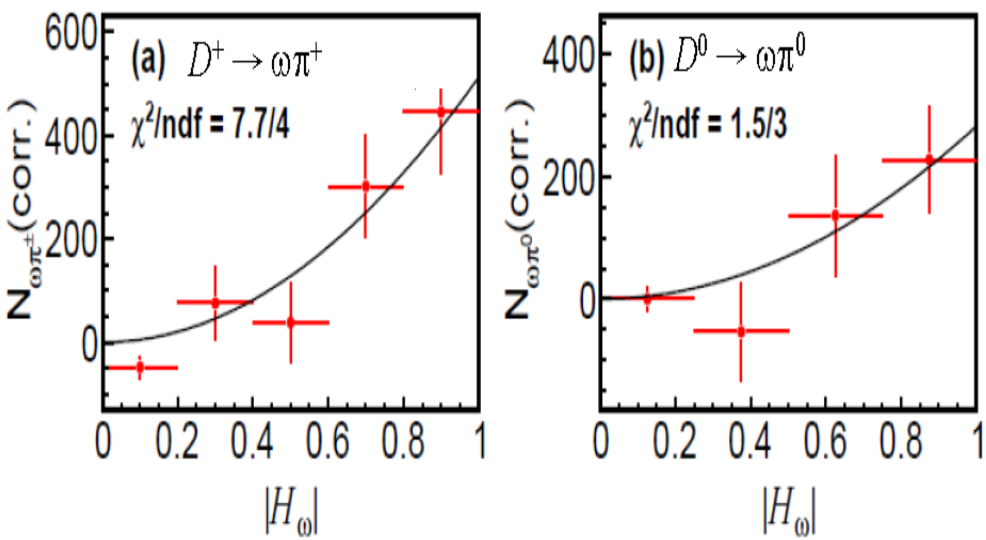
D→VP衰变ωπ的首次观测

Double tag method

PRL116(2016)082001



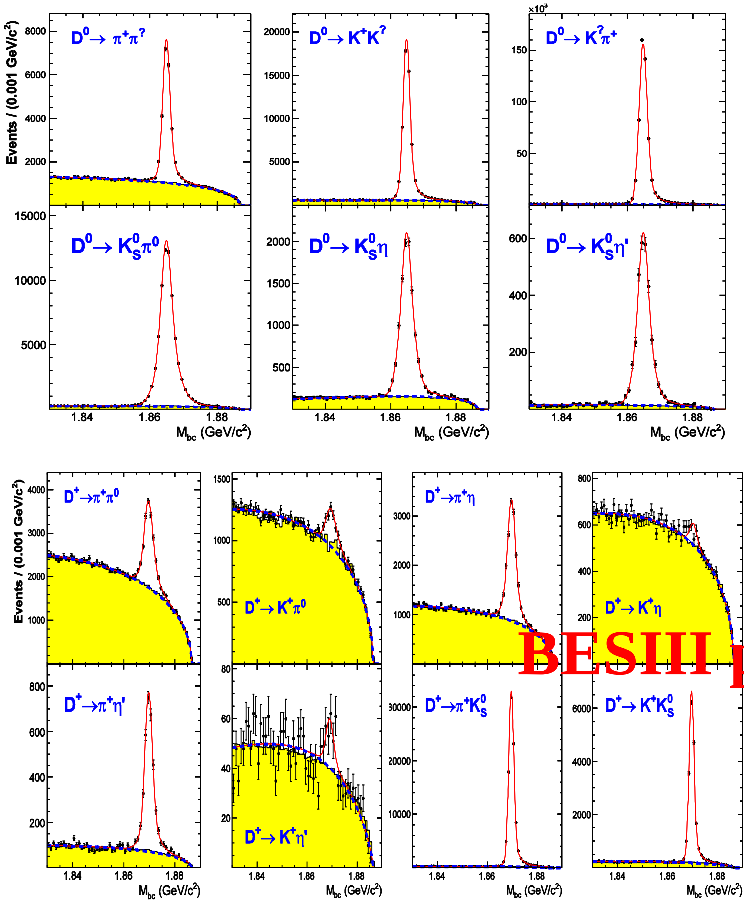
Decay mode	This work	Previous measurements
$D^+ \to \omega\pi^+$	$(2.74 \pm 0.58 \pm 0.17) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.
$D^0 \to \omega\pi^0$	$(1.05 \pm 0.41 \pm 0.09) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.
$D^+ \to \eta\pi^+$	$(3.13 \pm 0.22 \pm 0.19) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.67 \pm 0.10 \pm 0.05) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$



Studies of singly cabibbo-suppressed decays is limited by data set and background

Benefit the understanding of SU(3) symmetry breaking and CP violation, improve theory calculation

$D^{0(+)} \to PP$分支比的改进测量



$$\mathcal{B} = \frac{N_{net}^{signal}}{2 \cdot N_{D^0\bar{D}^0(D^+D^-)} \cdot \varepsilon}, \quad N_{D^0\bar{D}^0} = (10{,}621 \pm 29_{(stat)}) \times 10^3, \; N_{D^+D^-} = (8{,}296 \pm 31_{(stat)}) \times 10^3$$

quoted from Derrick's talk given at APS2014

The $\mathcal{B}(D^0 \to K^-\pi^+)$ has been corrected by the PDG value of $\mathcal{B}(D^0 \to K^+\pi^-)$.

For $D^0 \to K_S^0\eta$, $D^+ \to \pi^0\pi^+$, $D^+ \to \eta\pi^+$, $D^+ \to \eta'\pi^+$, $D^+ \to K_S^0\pi^+$ and $D^+ \to K_S^0K^+$, it shows better precision than the present values.

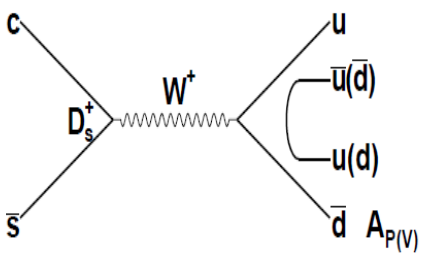
- The study of the hadronic decays of charmed *D* mesons is of great significance in the study of the strong and weak interactions in *D* decays.
- The analysis on $D \to PP$ modes will provide materials for the study of SU(3) breaking effect[1] . And the observation of CP violation in D decay is commonly believed to be indications of new physics.
- $D^0 \to K^-\pi^+$ is an important normalization mode.
- Most of the D decays have been studied by CLEO in 2010[2] , other measurements come from Belle[3] , BaBar[4] and CDF[5] , etc.
- Some of the branching fractions (BFs) are not well established. With the 2.93 fb^{-1} data taken at 3.773 GeV within BESIII , the results will help to improve these measurements.

Mode	N_{signal}^{net}	ε (%)	$\mathcal{B}\pm$(stat)$\pm$(sys)	$\mathcal{B}_{PDG}$
$\pi^+\pi^-$	21105 ± 249	66.03 ± 0.25	$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$	$(1.421 \pm 0.025) \times 10^{-3}$
K^+K^-	5543[illegible] ± 273	62.82 ± 0.32	$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$	$(4.01 \pm 0.07) \times 10^{-3}$
$K^-\pi^+$	537745 ± 767	64.98 ± 0.09	$(3.896 \pm 0.006 \pm 0.073)$ %	(3.93 ± 0.04) %
$K_S^0\pi^0$	66539 ± 302	38.06 ± 0.17	$(1.236 \pm 0.006 \pm 0.032)$ %	(1.20 ± 0.04) %
$K_S^0\eta$	9532 ± 126	31.96 ± 0.14	$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$	$(4.85 \pm 0.30) \times 10^{-3}$
$K_S^0\eta'$	3007 ± 61	12.66 ± 0.08	$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$	$(9.5 \pm 0.5) \times 10^{-3}$
$\pi^0\pi^+$	10108 ± 267	48.98 ± 0.34	$(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$	$(1.24 \pm 0.06) \times 10^{-3}$
π^0K^+	1834 ± 168	51.52 ± 0.42	$(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$	$(1.89 \pm 0.25) \times 10^{-4}$
$\eta\pi^+$	11636 ± 215	46.96 ± 0.25	$(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$	$(3.66 \pm 0.22) \times 10^{-3}$
ηK^+	439 ± 72	48.21 ± 0.31	$(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$	$(1.12 \pm 0.18) \times 10^{-4}$
$\eta'\pi^+$	3088 ± 83	21.49 ± 0.18	$(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$	$(4.84 \pm 0.31) \times 10^{-3}$
$\eta'K^+$	87 ± 25	22.39 ± 0.22	$(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$	$(1.83 \pm 0.23) \times 10^{-4}$
$K_S^0\pi^+$	93884 ± 352	51.38 ± 0.18	$(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$	$(1.53 \pm 0.06) \times 10^{-2}$
$K_S^0K^+$	17704 ± 151	48.45 ± 0.14	$(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$	$(2.95 \pm 0.15) \times 10^{-3}$

BESIII preliminary

D_s^+介子纯湮灭衰变和重子衰变的首次观测

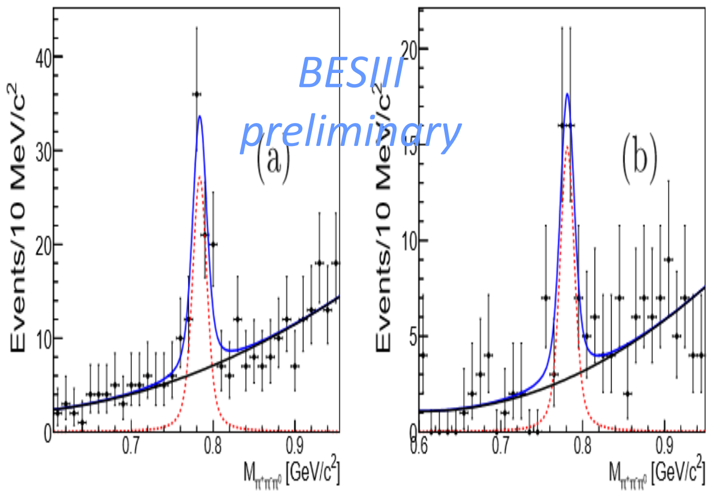
首次确认纯湮灭衰变$D_s^+ \to \omega\pi^+$
并首次测定$D_s^+ \to \omega K^+$



Under the model-independent approach:

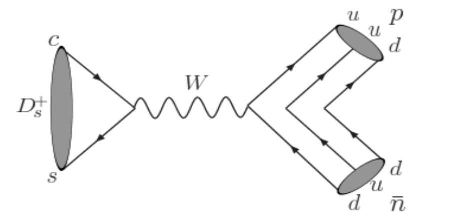
$$A(D_s^+ \to \omega\pi^+) = \frac{1}{\sqrt{2}}(A_P + A_V)$$

$(A_{P,V}$: P, V contain $\bar{q}'$ of $q\bar{q}'$ configuration)

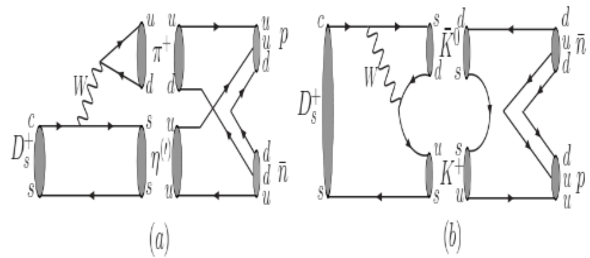


Signal mode	Branching fraction (10^{-3})
$D_s^+ \to \omega\pi^+$	$1.85 \pm 0.30(stat.) \pm 0.19(sys.)$
$D_s^+ \to \omega K^+$	$1.13 \pm 0.24(stat.) \pm 0.14(sys.)$

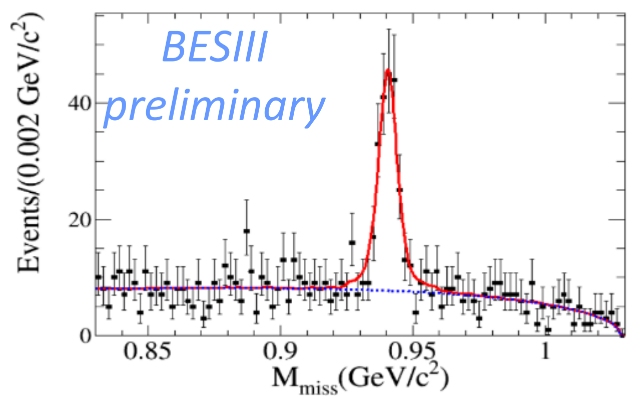
首次确认重子衰变$D_s^+ \to p\bar{n}$



(a) Short-distance effects



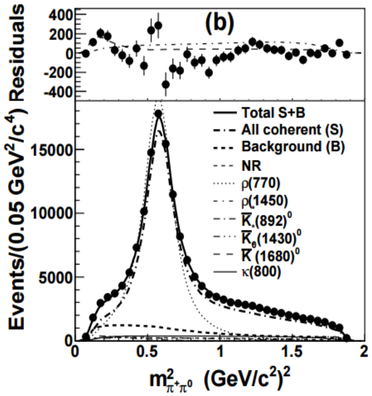
(b) Long-distance effects



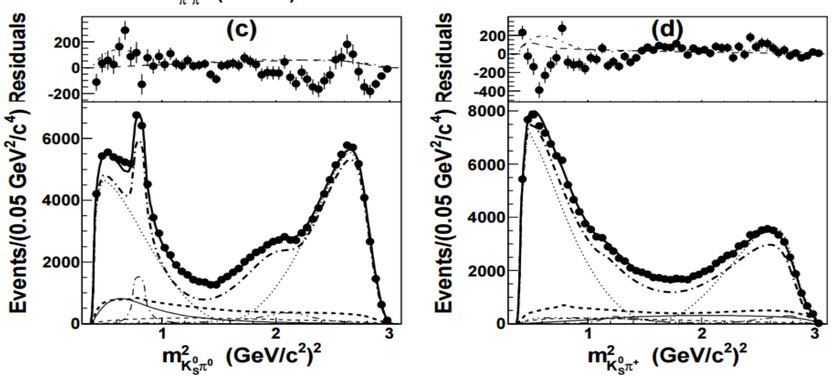
$$\mathcal{B}_{D_s^+ \to p\bar{n}} = (1.22 \pm 0.10) \times 10^{-3}$$

多体D衰变振幅分析:VP/VV/SP/...两体衰变

$D^+ \rightarrow K_S\pi^+\pi^0$



PRD89(2014)052001



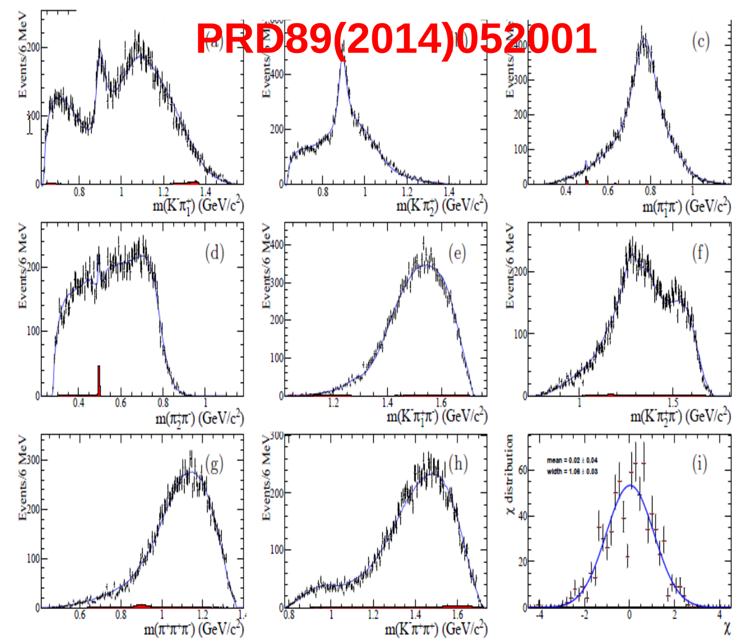
Mode	Partial Branching Fraction (%)
$D^+ \to K^0_S\pi^+\pi^0$ Non Resonant	$0.32{\pm}0.05{\pm}0.25^{+0.28}_{-0.25}$
$D^+ \to \rho^+ K^0_S, \rho^+ \to \pi^+\pi^0$	$5.83{\pm}0.16{\pm}0.30^{+0.45}_{-0.15}$
$D^+ \to \rho(1450)^+ K^0_S, \rho(1450)^+ \to \pi^+\pi^0$	$0.15{\pm}0.02{\pm}0.09^{+0.07}_{-0.11}$
$D^+ \to \overline{K}^*(892)^0\pi^+, \overline{K}^*(892)^0 \to K^0_S\pi^0$	$0.250 \pm 0.012 \pm 0.015^{+0.025}_{-0.024}$
$D^+ \to \overline{K}^*_0(1430)^0\pi^+, \overline{K}^*_0(1430)^0 \to K^0_S\pi^0$	$0.26 \pm 0.04 \pm 0.05 \pm 0.06$
$D^+ \to \overline{K}^*(1680)^0\pi^+, \overline{K}^*(1680)^0 \to K^0_S\pi^0$	$0.09 \pm 0.01 \pm 0.05^{+0.04}_{-0.08}$
$D^+ \to \overline{\kappa}^0\pi^+, \overline{\kappa}^0 \to K^0_S\pi^0$	$0.54 \pm 0.09 \pm 0.28^{+0.36}_{-0.19}$
$NR{+}\overline{\kappa}^0\pi^+$	$1.30{\pm}0.12{\pm}0.12^{+0.12}_{-0.30}$
$K^0_S\pi^0$ S-wave	$1.21{\pm}0.10{\pm}0.16^{+0.19}_{-0.27}$

$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$

Help to determine the absolute BF, strong phase, benefit γ/φ₃

Previous analyses only from MarkIII and E691

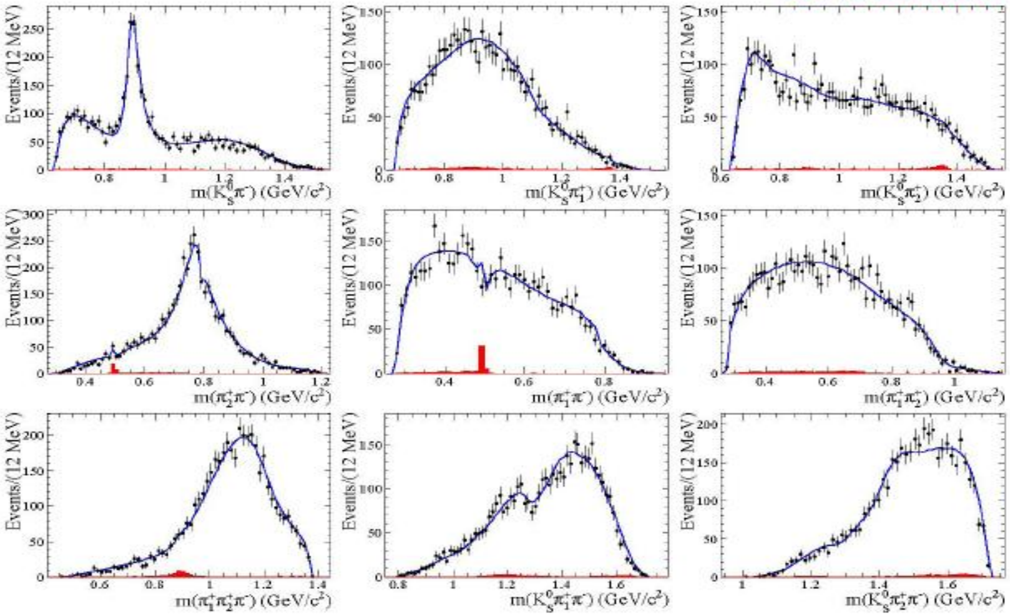
PRD89(2014)052001



Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{*0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{*0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.04 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.20 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.04 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

$D^+ \to K_S\pi^+\pi^+\pi^-$振幅分析

BESIII Preliminary



BESIII Preliminary

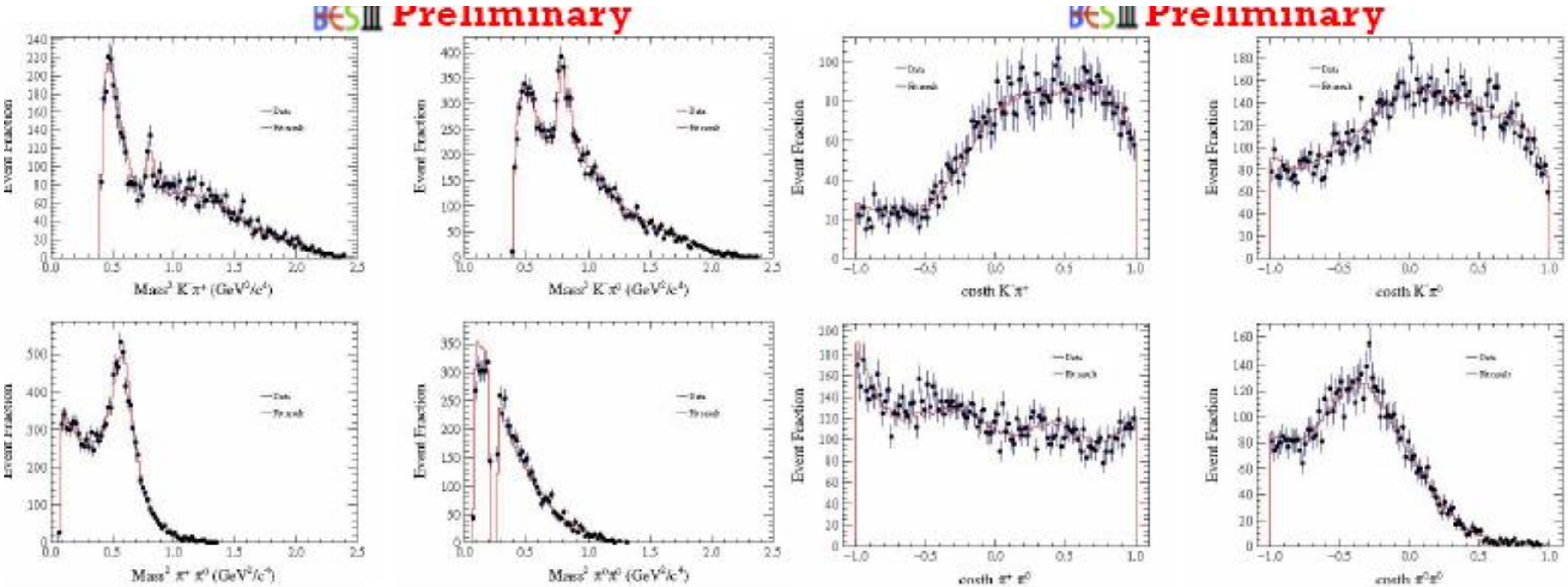
Component	Branching fraction (%)
$D^+ \to K_S^0 a_1(1260)^+(\rho^0\pi^+)$	$1.684 \pm 0.059 \pm 0.131 \pm 0.062$
$D^+ \to K_S^0 a_1(1260)^+(f_0(500)\pi^+)$	$0.149 \pm 0.018 \pm 0.021 \pm 0.006$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+)\pi^+$	$1.105 \pm 0.045 \pm 0.048 \pm 0.041$
$D^+ \to \bar{K}_1(1270)^0(K_S^0\rho^0)\pi^+$	$0.107 \pm 0.012 \pm 0.006 \pm 0.004$
$D^+ \to \bar{K}(1460)^0(K_S^0\rho^0)\pi^+$	$0.042 \pm 0.012 \pm 0.009 \pm 0.002$
$D^+ \to K_S^0\pi^+\rho^0$	$0.131 \pm 0.015 \pm 0.015 \pm 0.005$
$D^+ \to K^{*-}\pi^+\pi^+$	$0.413 \pm 0.036 \pm 0.059 \pm 0.015$
$D^+ \to K_S^0\pi^+\pi^+\pi^-$	$0.220 \pm 0.015 \pm 0.024 \pm 0.008$

Stat. uncertainty from FF

Sys. uncertainty from FF

uncertainties related to $B(D^+ \to K_S^0\pi^+\pi^+\pi^-)$ in PDG

$D^+ \rightarrow K^-\pi^+\pi^0\pi^0$振幅分析



BESIII Preliminary

Amplitude	ϕ	Fit fraction
$D^+ \to K_S^0 a_1(1260)^+, a_1(1260)^+ \to \rho^0\pi^+[S]$	0.000(fixed)	$0.567 \pm 0.020 \pm 0.044$
$D^+ \to K_S^0 a_1(1260)^+, a_1(1260)^+ \to f_0(500)\pi^+$	$-2.023 \pm 0.068 \pm 0.113$	$0.050 \pm 0.006 \pm 0.007$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[S]$	$-2.714 \pm 0.038 \pm 0.051$	$0.380 \pm 0.013 \pm 0.014$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[D]$	$3.431 \pm 0.137 \pm 0.117$	$0.015 \pm 0.004 \pm 0.005$
$D^+ \to \bar{K}_1(1270)^0\pi^+, \bar{K}_1(1270)^0 \to K_S^0\rho^0[S]$	$-0.418 \pm 0.070 \pm 0.087$	$0.036 \pm 0.004 \pm 0.002$
$D^+ \to \bar{K}(1460)^0\pi^+, \bar{K}(1460)^0 \to K_S^0\rho^0$	$-1.850 \pm 0.120 \pm 0.223$	$0.014 \pm 0.004 \pm 0.003$
$D^+ \to (K_S^0\rho^0)_A[D]\pi^+$	$2.328 \pm 0.097 \pm 0.068$	$0.011 \pm 0.003 \pm 0.002$
$D^+ \to K_S^0(\rho^0\pi^+)_P$	$1.656 \pm 0.083 \pm 0.056$	$0.031 \pm 0.004 \pm 0.010$
$D^+ \to (K^{*-}\pi^+)_A[S]\pi^+$	$1.962 \pm 0.047 \pm 0.073$	$0.132 \pm 0.011 \pm 0.011$
$D^+ \to (K^{*-}\pi^+)_A[D]\pi^+$	$0.989 \pm 0.158 \pm 0.229$	$0.013 \pm 0.004 \pm 0.004$
$D^+ \to (K_S^0(\pi^+\pi^-)_S)_A\pi^+$	$-2.935 \pm 0.060 \pm 0.125$	$0.051 \pm 0.004 \pm 0.003$
$D^+ \to ((K_S^0\pi^-)_S\pi^+)_P\pi^+$	$1.864 \pm 0.069 \pm 0.288$	$0.022 \pm 0.003 \pm 0.003$

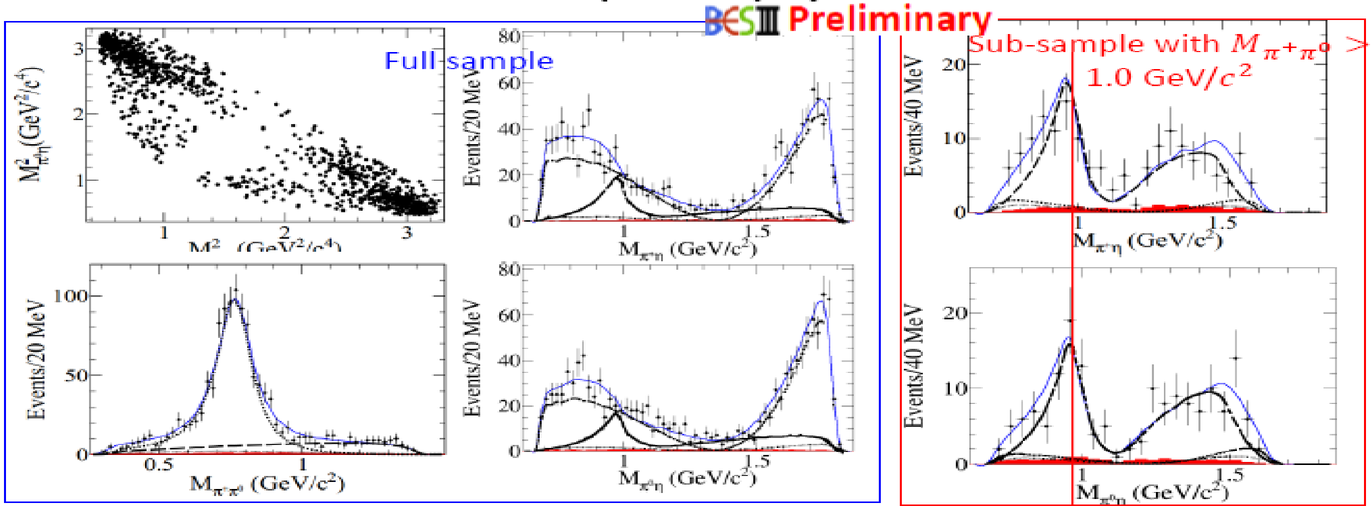
First measurement!

$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.98 \pm 0.13(\text{stat}) \pm 0.40(\text{syst}))\%$$

BESIII Preliminary

$D_s^+ \to \eta\pi^+\pi^0$振幅分析

Dalitz plot and projections



Dots with error bar: data; solid: total fit; dashed: $D_s^+ \to \rho^+\eta$; dotted: $D_s^+ \to (\pi^+\pi^0)_V\eta$; long dashed: $D_s^+ \to a_0(980)\pi$.

Obvious peaks for two $a_0(980)$ mesons!

The significances, phases, and FFs for intermediate processes.

Amplitude	Significance (σ)	Phase BESIII Preliminary	FF
$D_s^+ \to \rho^+\eta$	> 20	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \to (\pi^+\pi^0)_V\eta$	5.7	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.026$
$D_s^+ \to a_0(980)\pi$	16.2	$2.794 \pm 0.087 \pm 0.041$	$0.232 \pm 0.023 \pm 0.034$

The amplitude analysis agrees with the isospin conserved expectation ($A(D_s^+ \to$

$$BF(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28_{stat.} \pm 0.41_{sys.})\%$$ BESIII Preliminary

$$BF(n) = BF(D_s^+ \to \pi^+\pi^0\eta)FF(n)$$

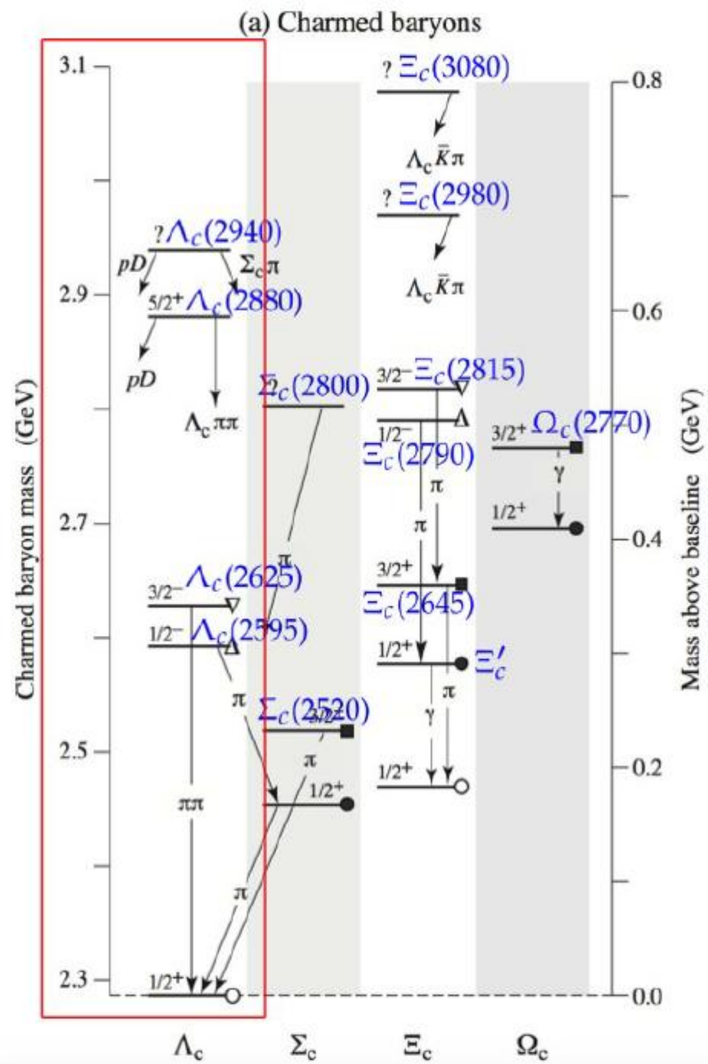
Branching fraction	This measurement (%)	PDG value (%)
$BF(D_s^+ \to \rho^+\eta)$	$7.44 \pm 0.48_{stat.} \pm 0.44_{sys.}$	8.9 ± 0.9
$BF(D_s^+ \to a_0(980)\pi)$ *	$2.20 \pm 0.22_{stat.} \pm 0.34_{sys.}$	-
$BF(D_s^+ \to a_0(980)^+\pi^0)$ * $BF(D_s^+ \to a_0(980)^0\pi^+)$ *	$1.46 \pm 0.15_{stat.} \pm 0.22_{sys.}$	-

BESIII Preliminary

*Here, $a_0(980) \to \pi\eta$.

粲重子Λ_c^+衰变

2014年前粲重子研究



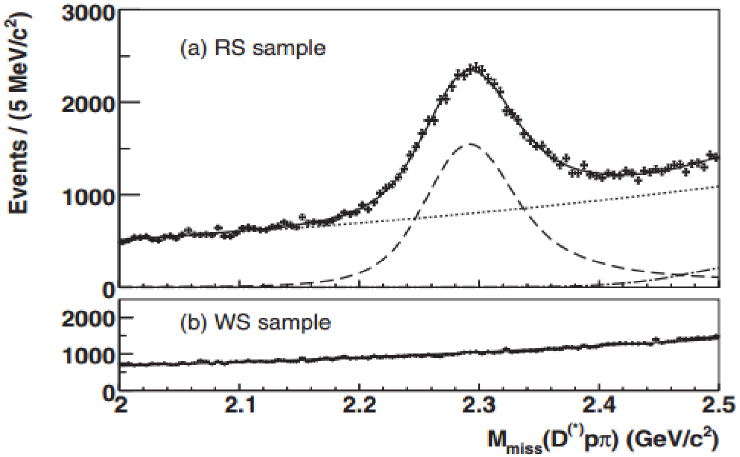
- Λ_c^+ was observed in 1979
- **All decays of Λ_c^+ were measured with high energy data and relative to $pK^-\pi^+$, which suffers an error of 25%. No absolute measurement using threshold Λ_c^+ data**
- **Only about 60% decays are known**

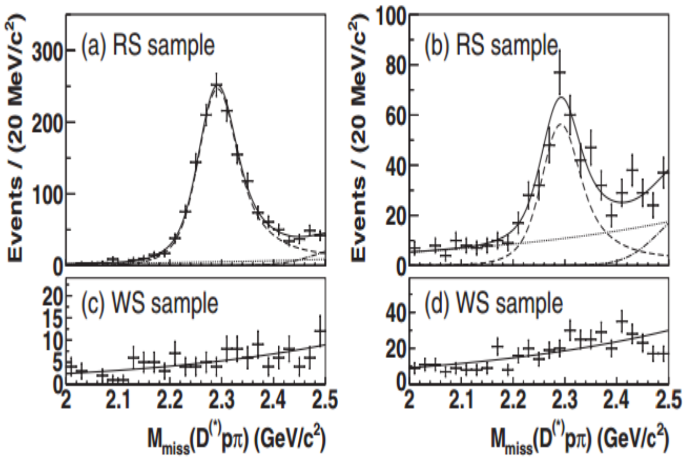
Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states				
$p\overline{K}^0$		(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a]	(5.0 ± 1.3) %		823
$p\overline{K}^*(892)^0$	[b]	(1.6 ± 0.5) %		685
$\Delta(1232)^{++}K^-$		(8.6 ± 3.0) $\times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b]	(1.8 ± 0.6) %		627
$pK^-\pi^+$ nonresonant		(2.8 ± 0.8) %		823
$p\overline{K}^0\pi^0$		(3.3 ± 1.0) %		823
$p\overline{K}^0\eta$		(1.2 ± 0.4) %		568

Systematic studies of Λ_c^+, search for new decays, absolute BF measurements are important to explore Λ_c^+ decay mechanisms

$\Lambda_c^+ \rightarrow$强子衰变绝对分支比的改进测量

BELLE, PRL113(2014)042002

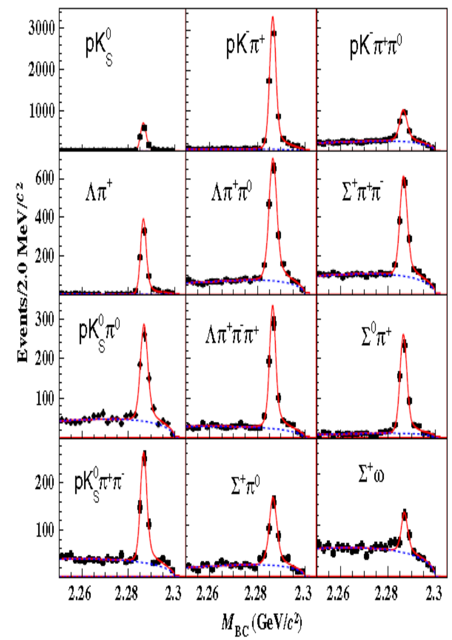


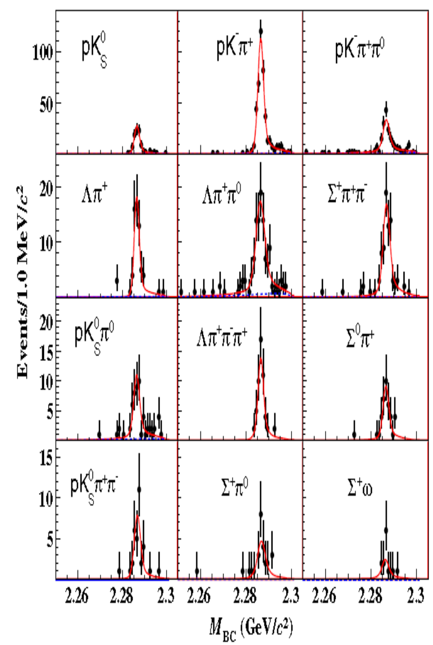


$B[\Lambda_c^+ \rightarrow pK^-\pi^+]=(6.84\pm0.24^{+0.21}_{-0.27})\%$

BESIII, PRL116(2016)052001

ST: ~15000 **DT: ~1000**

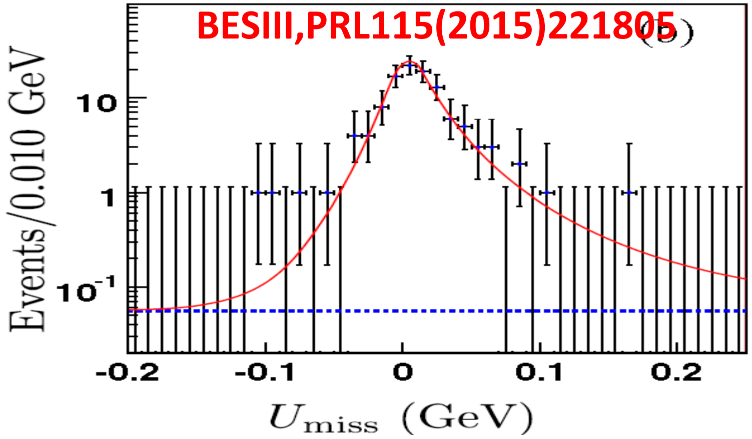




Mode	This work (%)	PDG (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0

Much better precision

首次测定半轻衰变$\Lambda_c^+ \to \Lambda l^+ \nu$的绝对分支比

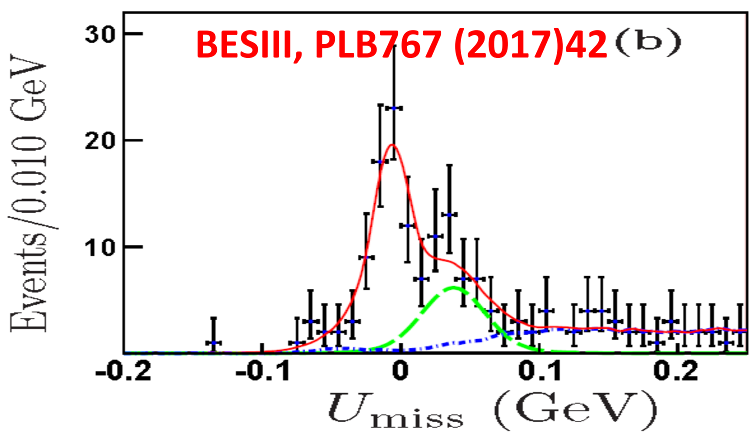


$B[\Lambda_c^+ \to \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$

3 fb^{-1} data help to explore FF studies

Calibrate theoretical calculations:
(1.4-9.2)%

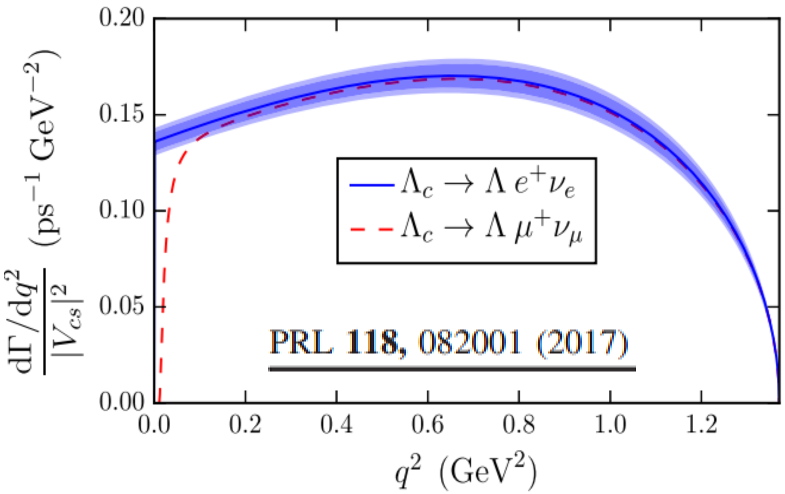
Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$



$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

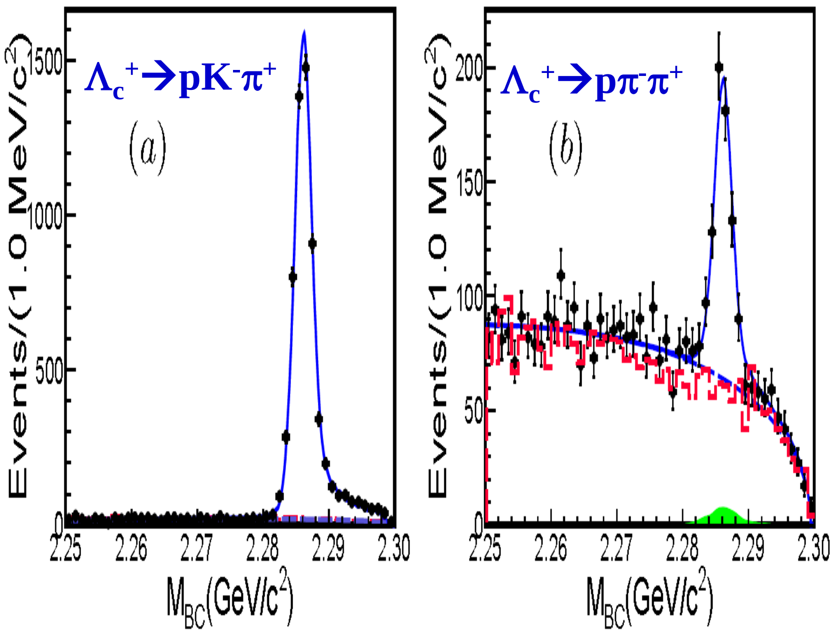
$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

促进LQCD对形状因子的计算

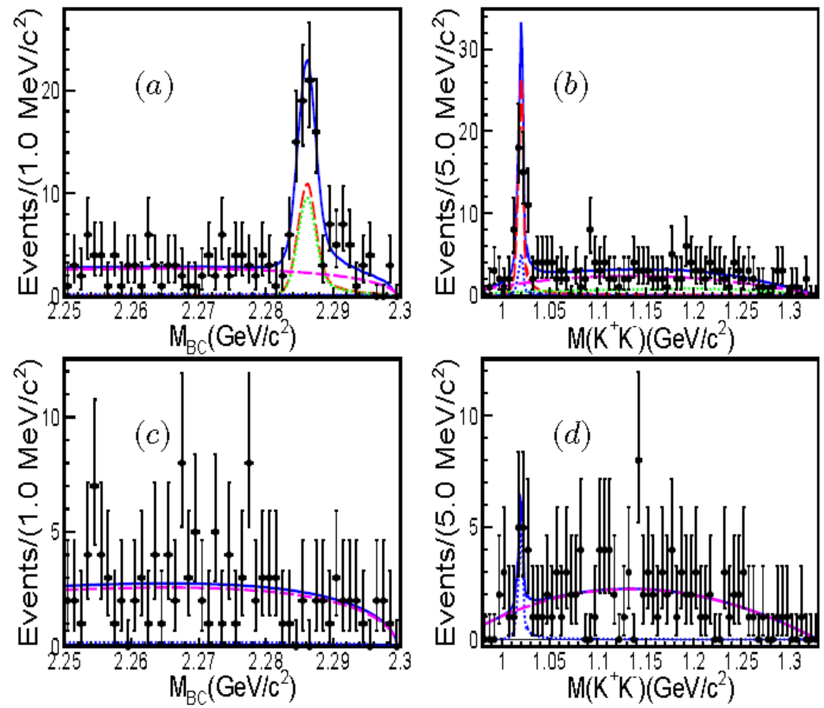


改进测定$\Lambda_c^+ \to pK^+K^-/p\pi^+\pi^-$绝对分支比

BESIII,PRL117(2016)232002



$\Lambda_c^+ \to pK^-K^+$

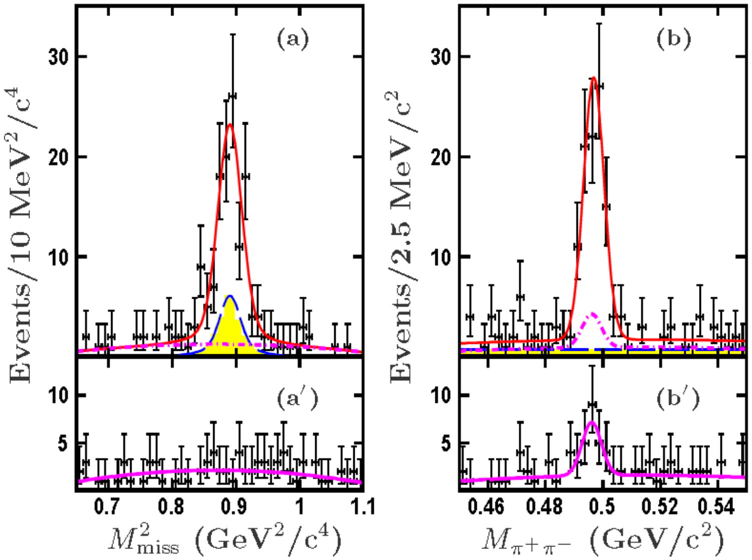


These help to distinguish predictions from different theoretical models and understand contributions from factorizable effects

Decay modes	$\mathcal{B}_{\rm mode}/\mathcal{B}_{\rm ref.}$	$\mathcal{B}_{\rm mode}$	$\mathcal{B}$(PDG)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

首次观测到含中子衰变$\Lambda_c^+ \to nK_S\pi^+$

BESIII,PRL118(2017)112001



$B[\Lambda_c^+ \to nK_S\pi^+]=(1.82\pm0.23\pm0.11)\%$

$\Gamma[\Lambda_c^+ \to n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \to pK^-\pi^+]=0.62\pm0.09$

$\Gamma[\Lambda_c^+ \to n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \to p\bar{K}^0\pi^+]=0.97\pm0.16$

First measurement of BF of Λ_c^+ decay containing neutron

$$\cos\delta = -0.24 \pm 0.08$$

$$|I^{(1)}|/|I^{(0)}| \quad 1.14 \pm 0.11$$

Help to understand SU(3) and isospin symmetry and determine strong phase

Cai-Dian Lv et al, PRD93(2016)056008

$$\cos\delta = \frac{\mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(pK^-\pi^+)}{2\sqrt{\mathcal{B}(p\bar{K}^0\pi^0)(\mathcal{B}(pK^-\pi^+) + \mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(p\bar{K}^0\pi^0))}}$$

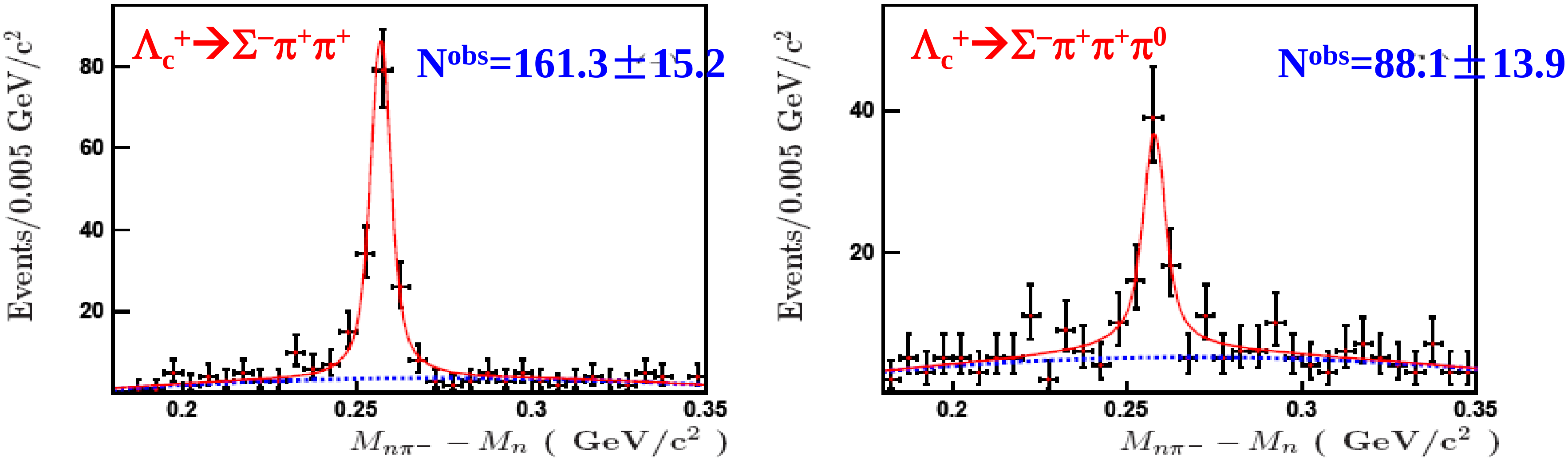
$$R_p = \frac{\mathcal{B}(\Lambda_c \to p\bar{K}^0\pi^0)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}, \qquad R_n = \frac{\mathcal{B}(\Lambda_c \to n\bar{K}^0\pi^+)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}$$

involving a neutron. Under the isospin symmetry, its amplitude is related to those of the most favored proton modes $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to p\bar{K}^0\pi^0$ as $\mathcal{A}(n\bar{K}^0\pi^+) + \mathcal{A}(pK^-\pi^+) + \sqrt{2}\mathcal{A}(p\bar{K}^0\pi^0) = 0$. Hence, precise measure-

[2,3]. In the three-body Λ_c^+ decay to $N\bar{K}\pi$, the total decay amplitudes can be decomposed into two isospin amplitudes of the $N\bar{K}$ system as isosinglet ($I^{(0)}$) and isospin-one ($I^{(1)}$). In the factorization limit, the color-allowed tree diagram, in which the π^+ is emitted and the $N\bar{K}$ is an isosinglet, dominates $I^{(0)}$, and $I^{(1)}$ is expected to be small compared to $I^{(0)}$ as it can only proceed through the color-suppressed tree diagrams. Though the factorization scheme is spoiled in

首次测定$\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+ \pi^0$

BESIII, PLB772(2017)388



Preliminary results :

$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+] = (1.81 \pm 0.17 \pm 0.09)\%$

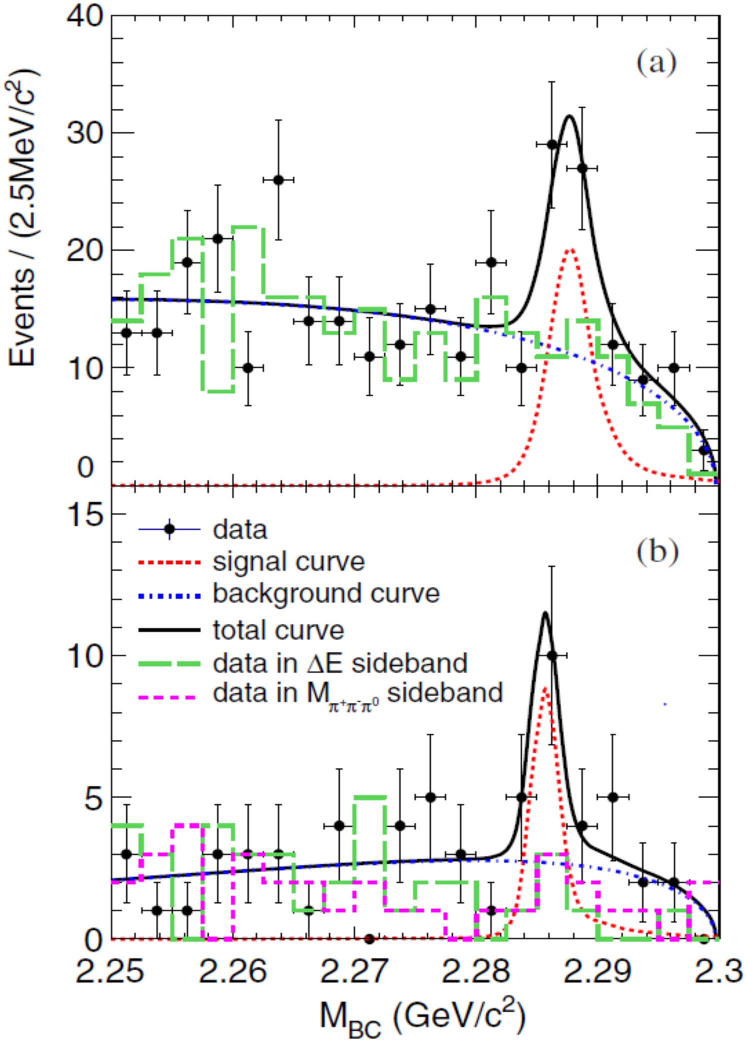
$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+ \pi^0] = (2.11 \pm 0.33 \pm 0.14)\%$ **[First observation]**

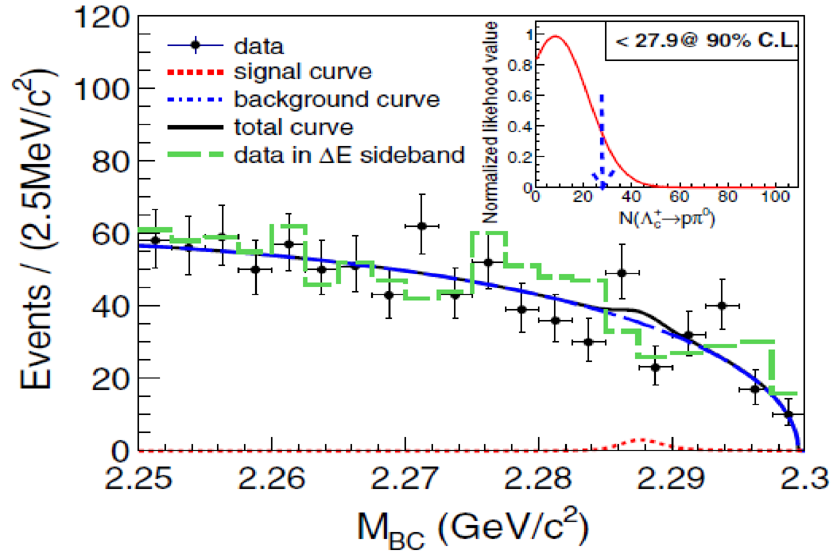
The previous one is consistent with and more precise than the PDG value of $[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+] = (2.3 \pm 0.4)\%$.

首次测定$\Lambda_c^+ \to p\eta$并寻找$\Lambda_c^+ \to p\pi^0$

BESIII, PRD95(2017)111102(RC)

4.2σ





$B[\Lambda_c^+ \to p\pi^0] < 2.7\times10^{-4}$ 90%CL

	$\Lambda_c^+ \to p\eta$	$\Lambda_c^+ \to p\pi^0$	$\frac{\mathcal{B}_{\Lambda_c^+\to p\pi^0}}{\mathcal{B}_{\Lambda_c^+\to p\eta}}$
BESIII	1.24 ± 0.29	<0.27	<0.24
Sharma *et al.* [3]	0.2[a](1.7[b])	0.2	1.0[a](0.1[b])
Uppal *et al.* [4]	0.3	0.1–0.2	0.3–0.7
S. L. Chen *et al.* [12]	...	0.11–0.36[c]	...
Cai-Dian Lü *et al.* [13]	...	0.45	...

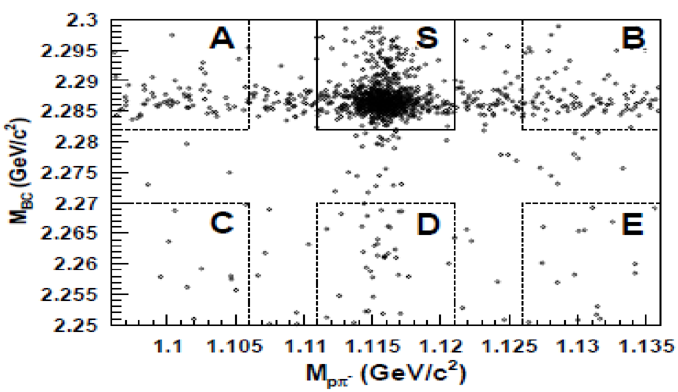
[a]Assumed to have a positive sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.
[b]Assumed to have a negative sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.
[c]Calculated relying on different values of parameters b and α.

$B[\Lambda_c^+ \to p\eta] = (1.24\pm0.28\pm0.10)\times10^{-3}$

Λ_c^+研究最新进展

- $\Lambda_c^+ \to \Lambda X$分支比

arXiv:1803.05706, acceppted by PRL



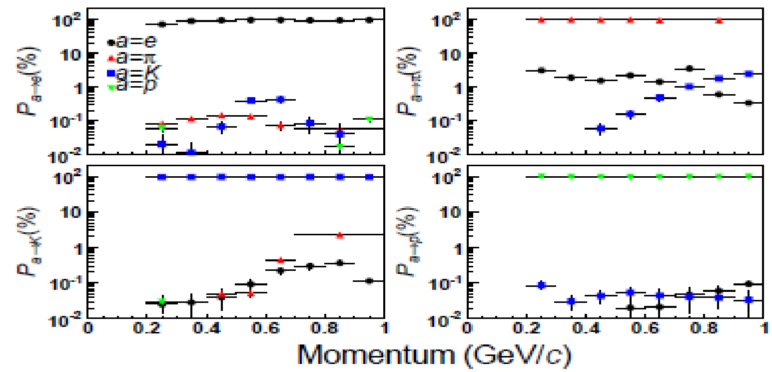
p (GeV/c)	$N^{sig}_{-,j}$ $\lvert\cos\theta\rvert$ [0.00, 0.20)	[0.20, 0.40)	[0.40, 0.65)	[0.65, 1.00)
[0.0, 0.3)	$5.3^{+5.1}_{-3.8}$	$11.4^{+5.5}_{-4.2}$	$9.1^{+5.5}_{-4.2}$	$6.3^{+5.4}_{-4.0}$
[0.3, 0.5)	$59.8^{+9.9}_{-8.6}$	$41.6^{+8.9}_{-7.7}$	$71.9^{+10.7}_{-9.5}$	$33.1^{+8.7}_{-7.4}$
[0.5, 0.7)	$86.7^{+10.9}_{-9.7}$	$72.5^{+10.0}_{-8.8}$	$74.8^{+10.1}_{-9.0}$	$53.9^{+9.1}_{-7.9}$
[0.7, 0.9)	$40.4^{+7.8}_{-6.6}$	$28.3^{+6.8}_{-5.6}$	$44.0^{+8.1}_{-6.9}$	$38.4^{+7.9}_{-6.7}$
[0.9, 1.1)	$6.9^{+4.3}_{-3.0}$	$12.4^{+5.0}_{-3.7}$	$8.3^{+4.2}_{-2.9}$	$5.5^{+3.9}_{-2.6}$
p (GeV/c)	ε^{sig}_j (%) $\lvert\cos\theta\rvert$ [0.00, 0.20)	[0.20, 0.40)	[0.40, 0.65)	[0.65, 1.00)
[0.0, 0.3)	8.28 ± 0.38	8.22 ± 0.37	8.01 ± 0.31	4.45 ± 0.21
[0.3, 0.5)	29.03 ± 0.37	28.28 ± 0.37	26.56 ± 0.33	14.98 ± 0.21
[0.5, 0.7)	35.43 ± 0.32	35.00 ± 0.33	33.25 ± 0.32	20.15 ± 0.25
[0.7, 0.9)	39.68 ± 0.47	39.27 ± 0.50	36.56 ± 0.50	23.80 ± 0.51
[0.9, 1.1)	40.82 ± 0.14	40.21 ± 0.14	37.76 ± 0.12	29.97 ± 0.11

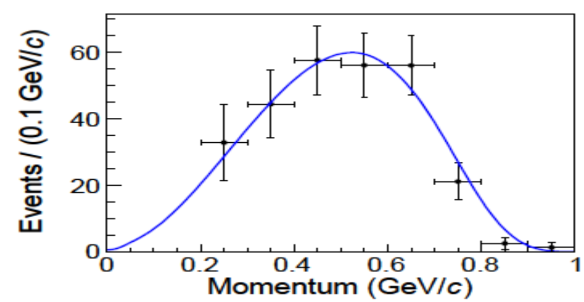
$$\mathcal{B}(\Lambda_c^+ \to \Lambda + X) = (38.2^{+2.8}_{-2.2} \pm 0.8)\%.$$

$(24.5\pm2.1)\%$ in PDG $\qquad \mathcal{A}_{CP} = (2.1^{+7.0}_{-6.6}\pm1.4)\%.$

- $\Lambda_c^+ \to X e \nu_e$分支比

arXiv:1805.09060, submitted to PRL



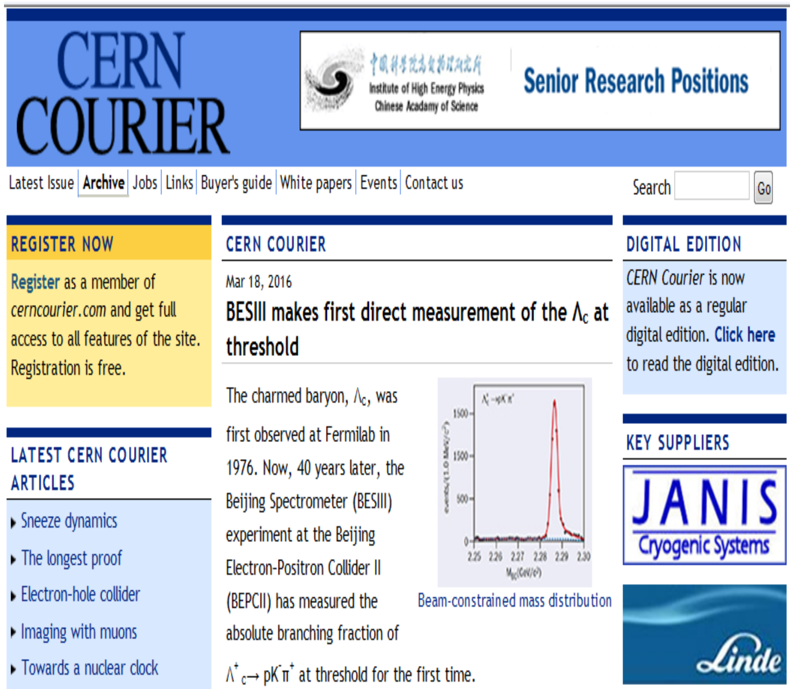


$$\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = (3.95 \pm 0.34 \pm 0.09)\%$$

$$\frac{\Gamma(\Lambda_c^+ \to X e^+ \nu_e)}{\Gamma(D \to X e^+ \nu_e)} \quad 1.26 \pm 0.12$$

Larger threshold Λ_c^+ data at BESIII

国际粲重子Λ_c^+衰变实验研究的里程碑：BESIII开辟使用近阈数据绝对测量Λ_c^+衰变的新领域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Mar 18, 2016

BESIII makes first direct measurement of the Λ_c at threshold

The charmed baryon, Λ_c, was first observed at Fermilab in 1976. Now, 40 years later, the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider II (BEPCII) has measured the absolute branching fraction of $\Lambda^+_c \to pK^-\pi^+$ at threshold for the first time.

Beam-constrained mass distribution

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KEY SUPPLIERS

JANIS Cryogenic Systems

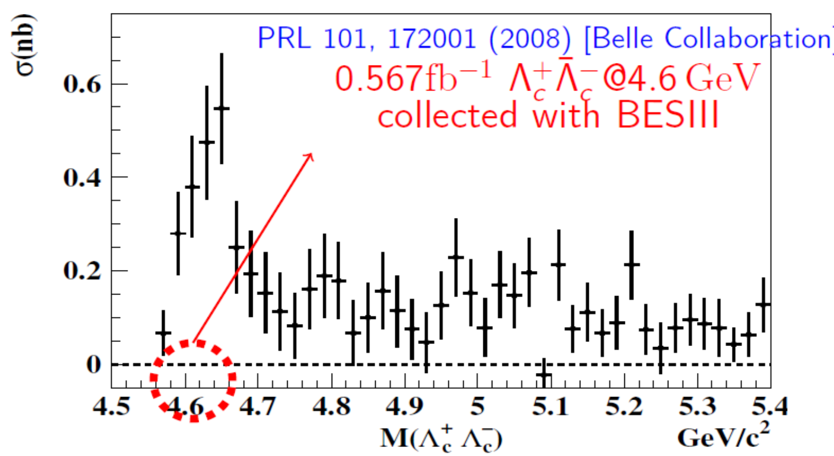
Linde

一个月左右数据已发表10篇物理文章，其中6篇PRL

与PDG14比，Λ_c^+衰变测量精度普遍改进3-5倍。但与粲介子的测量精度(1-2%)水平比，统计误差仍是制约因素

	Golden hadronic mode	δB/B	Golden SL mode	δB/B
D^0	$B(K\pi)=(3.88\pm0.05)\%$	1.3%	$B(Kev)=(3.55\pm0.05)\%$	1.4%
D^+	$B(K\pi\pi)=(9.13\pm0.19)\%$	2.1%	$B(K^0ev)=(8.83\pm0.22)\%$	2.5%
D_s	$B(KKpi)=(5.39\pm0.21)\%$	3.9%	$B(\phi ev)=(2.49\pm0.14)\%$	5.6%
Λ_c	$B(pK\pi)=(5.0\pm1.3)\%$(PDG2014) $=(6.8\pm0.36)\%$ (BELLE) $=(5.84\pm0.35)\%$ (BESIII) $=(6.46\pm0.24)\%$ (HFAG)	26% 5.3% 6.0% 3.7%	$B(\Lambda ev)=(2.1\pm0.6)\%$(PDG2014) $=(3.63\pm0.43)\%$ (BESIII) $=(3.18\pm0.32)\%$ (HFAG)	29% 12% 10%

更高能量4.65 GeV，更大近阈Λ_c^+样本，进一步系统研究Λ_c^+，寻找40%未知衰变(半轻、含中子和光子衰变)...



See H. Atamacan at ICHEP
and Belle II Physics Book appearing soon

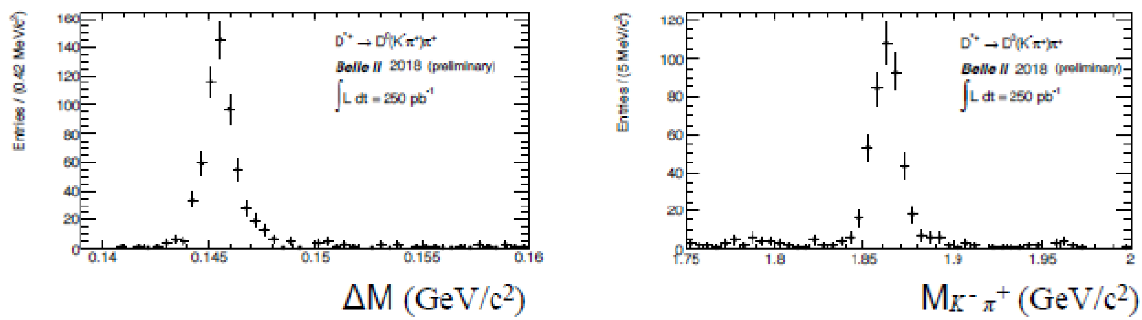
Epilogue: Belle II

Flavour not just a *B* factory

@$\sqrt{s} = 10.58$ GeV: $\sigma(c\bar{c})$ =1.18$\sigma(B\bar{B})$

All the attributes of *B* physics experiment – hermeticity, PID, vertexing, low momentum track and photon reconstruction – good for charm!

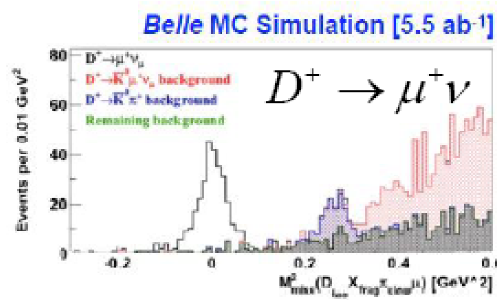
$D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+$



light mesons $(K, \pi, \ldots)$

$$e^+e^- \to c\bar{c} \to D_{tag} X_{frag} D_{sig}$$

$(D^{(*)0}, D^{(*)+}, D_s^{(*)+}, \Lambda_c^+)$ signal



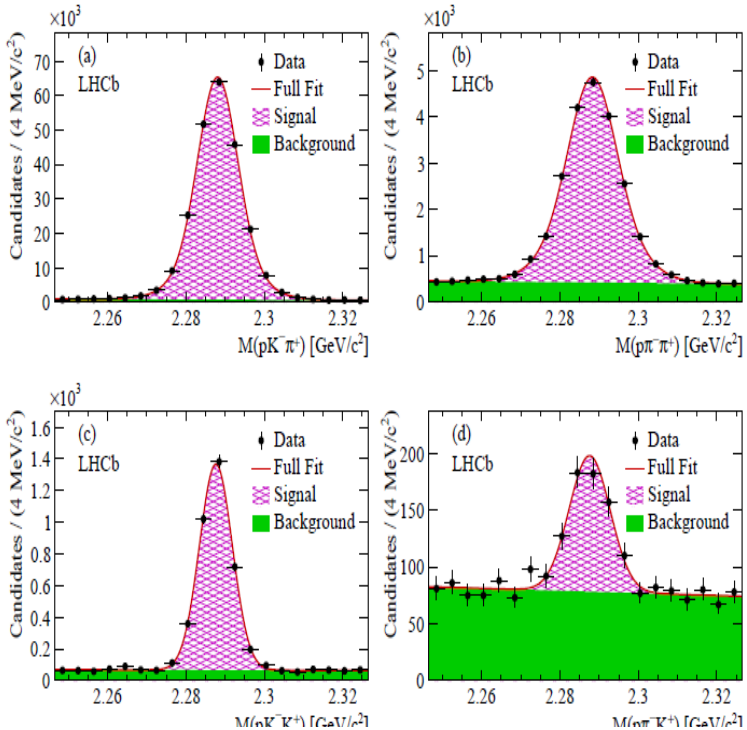
Tag	Millions of events in 50 ab^{-1}	Current BESIII
D^0	38	2.8
D^+	3.5	1.7
D_s^+	5.2	0.4

LHCb国际竟争 [举例]

LHCb, JHEP 1803 (2018) 043

1 fb^{-1} data @ 7 TeV

$\Lambda_b^0 \to \Lambda_c^+(phh')\mu^-\overline{\nu}_\mu$ selection

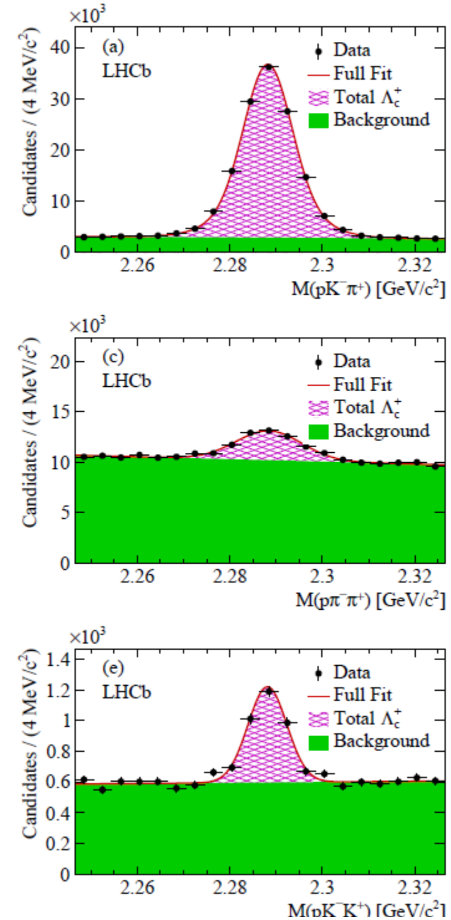


$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (7.44 \pm 0.08 \pm 0.18)\,\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to pK^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (1.70 \pm 0.03 \pm 0.03)\,\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (0.165 \pm 0.015 \pm 0.005)\,\%,$$

Prompt $\Lambda_c^+ \to phh'$ selection



$$\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+) = (4.72 \pm 0.05 \pm 0.11 \pm 0.25) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \to pK^-K^+) = (1.08 \pm 0.02 \pm 0.02 \pm 0.06) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \to p\pi^-K^+) = (1.04 \pm 0.09 \pm 0.03 \pm 0.05) \times 10^{-4},$$

BESIII粲物理研究总结

- $D^{0(+)}$研究取得一些重要物理成果

  --D^+衰变常数f_{D+}

  --形状因子$f^{D\to K(\pi)}_+(q^2)$

  --CKM矩阵元$|V_{cs(d)}|$

  --$D^0\bar{D}^0$混合参数y_{CP}, $\delta_{K\pi}$

  --$D^0\to K_S\pi^+\pi^-$强相差初步结果

  →精密检验格点QCD计算和CKM矩阵幺正性、探讨$D^0\bar{D}^0$混合、约束γ/ϕ_3测量

- Λ_c^+衰变的系统研究结束了其发现近40年来无近阈数据绝对测量的历史

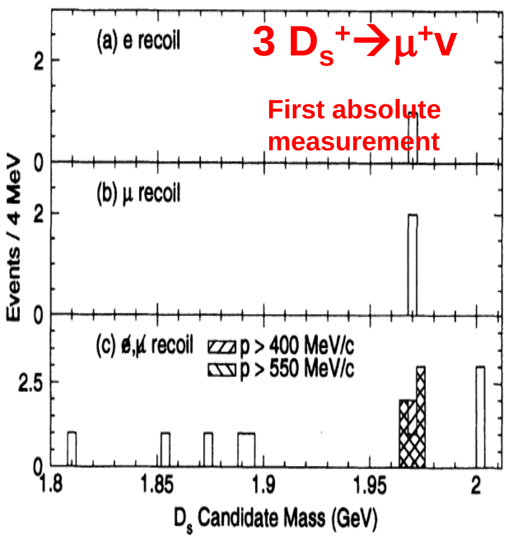
- 2016年，在4.178 GeV采集了3.2 fb^{-1} D_s^+数据。已取得D_s^+衰变常数f_{Ds+}、CKM矩阵元$|V_{cs}|$等初步结果

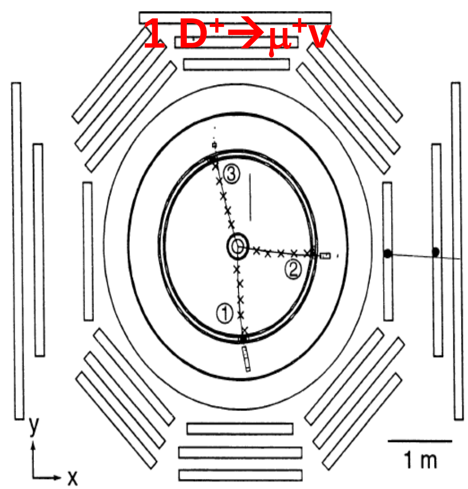
- 更多物理结果将在未来1–2年完成

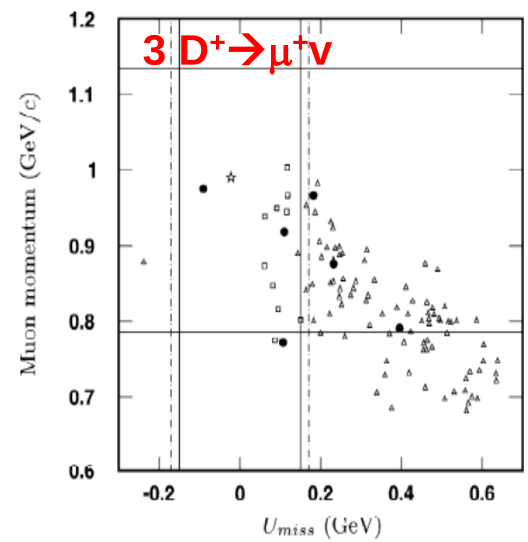
谢谢！

BESI/II上$D_{(s)}^+ \to l^+ \nu$的寻找

22.3 pb^{-1} at 4.03 GeV	22.3 pb^{-1} at 4.03 GeV	33 pb^{-1} around $\psi(3770)$
PRL74(1995)4599	PLB429(1998)188	PLB610(2005)183







$f_{D_s^+} = (430^{+150+40}_{-130-40})$ MeV

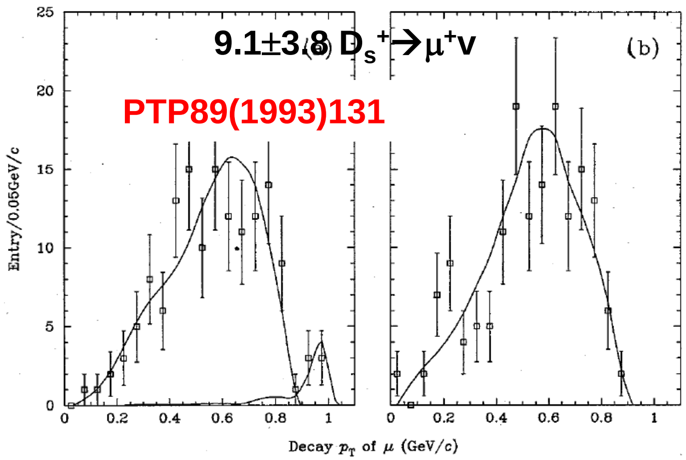
$f_{D^+} = (300^{+180+80}_{-150-40})$ MeV

$f_{D^+} = (371^{+129}_{-119} \pm 25)$ MeV

BESI | **BESI** | **BESII**

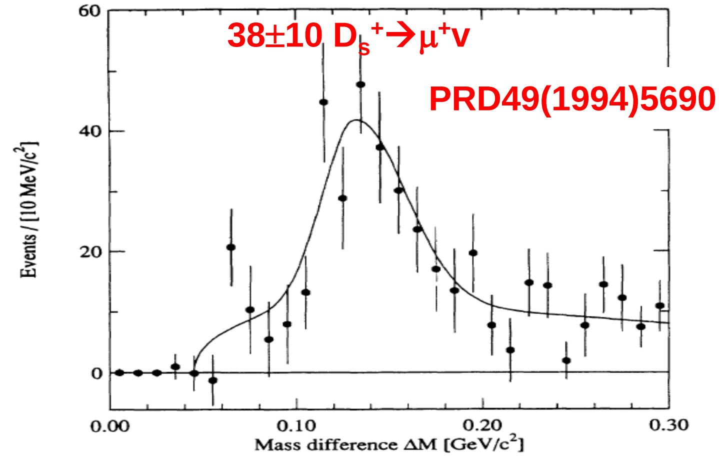
早期关于f_{Ds+}的测量

- **WA75, Fixed target experiment**



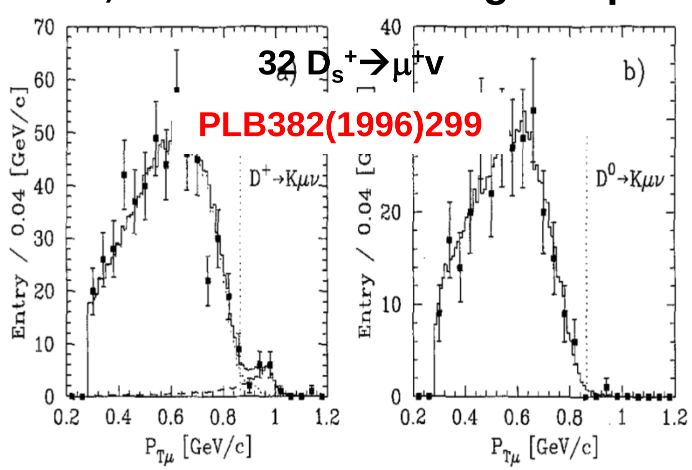
f_{Ds+}=232±45±20±48 MeV

- **CLEOII, 2.13 fb^{-1} at 10.6 GeV**



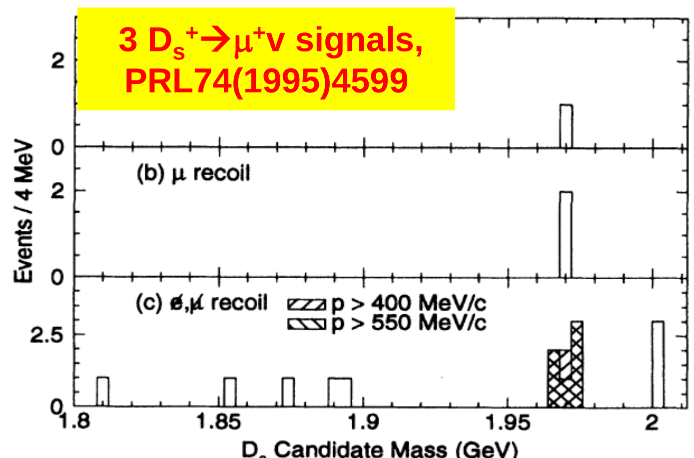
f_{Ds+}=344±37±52±42 MeV

- **E653, Fermilab fixed target experiment**



f_{Ds+}=194±35±20±14 MeV

- **BESI, 22.3 pb^{-1} at 4.03 GeV**

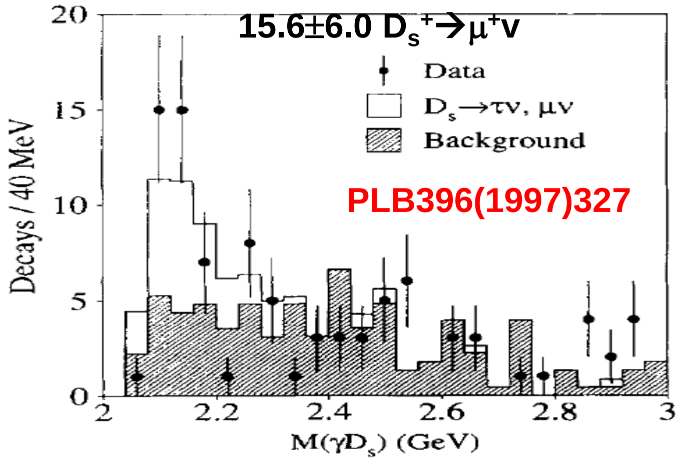


$$f_{D_s^+} = (430^{+150+40}_{-130-40})\ \text{MeV}$$

First absolute measurement

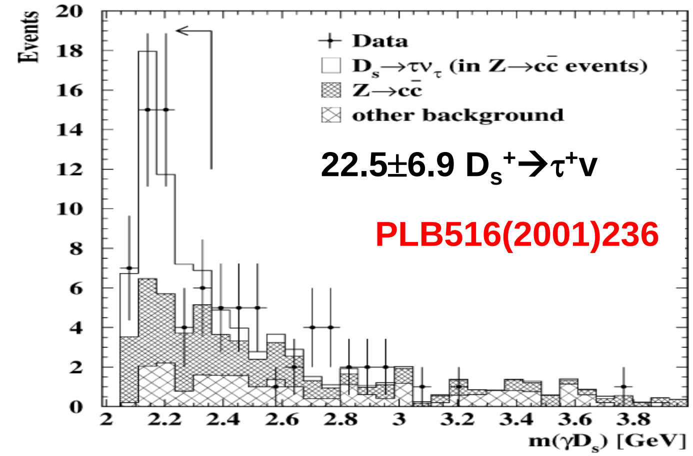
早期关于f_{D_s+}的测量

- L3, $Z \to q\bar{q}$, 49.6 pb^{-1} at 91.2 GeV



f_{Ds+}=309±58±33±38 MeV

- OPAL, 3.9×10^6 $e^+e^- \to q\bar{q}$



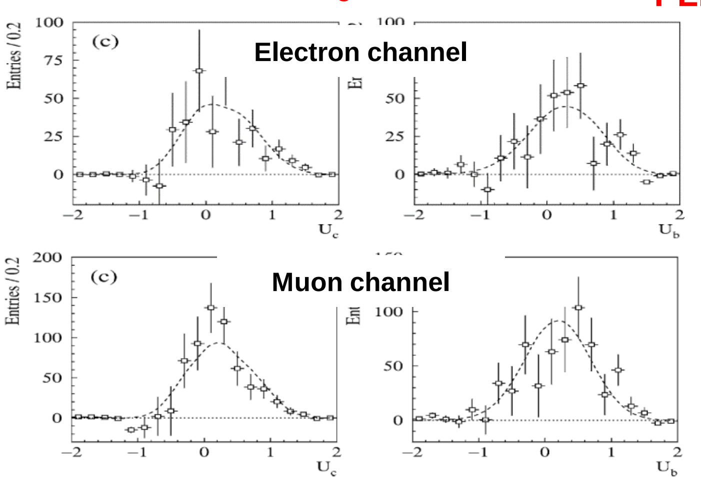
f_{Ds+}=286±44±41 MeV

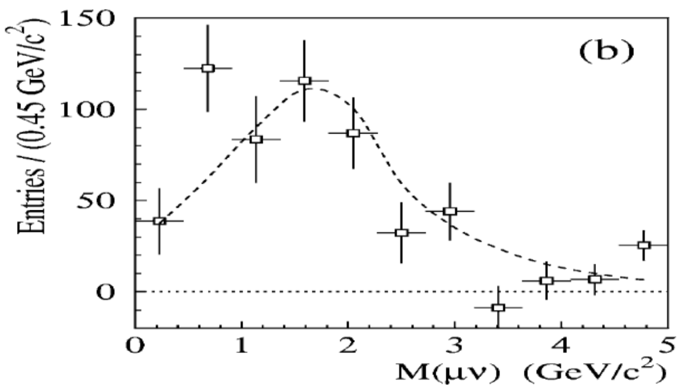
- ALPHA, 3.97×10^6 Z hadronic decay

306±62 $D_s^+ \to \tau^+ v$

PLB528(2002)1

575±84 $D_s^+ \to \mu^+ v$





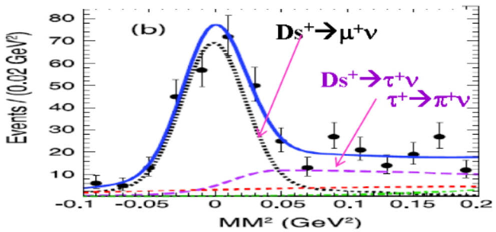
f_{Ds+}=285±19±40 MeV

已有$D_s^+ \to l^+\nu$实验测量

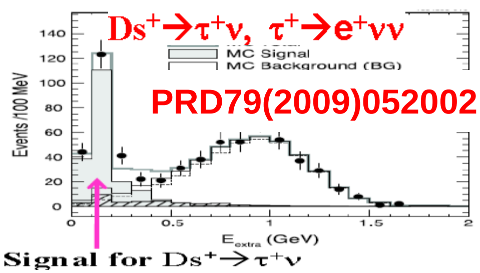
In the past 30 years, $D_s^+ \to l^+\nu$ has been studied by WA75, CLEOII, E653, BESI, L3, OPAL, ALPHA, CLEO-c, BELLE, Babar

- $D_s^{*+}D_s^-$, 600 pb^{-1} @ 4.17 GeV [697 $l^+\nu$]

PRD79(2009)052001



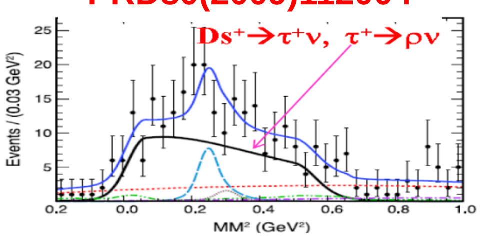
f_{Ds+}=263.3±8.2±1.9 MeV



PRD79(2009)052002

f_{Ds+}=252.2±11.1±5.2 MeV

PRD80(2009)112004

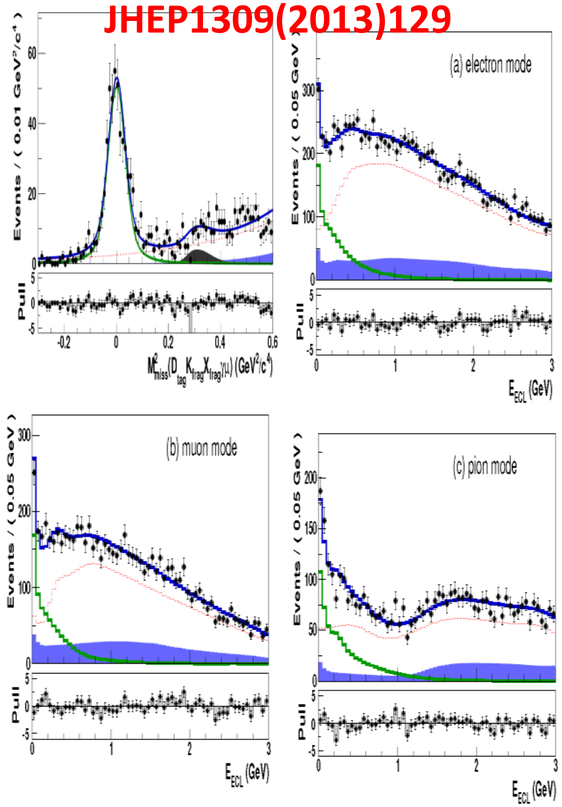


f_{Ds+}=257.8±13.3±5.2 MeV

- Belle, 913 fb^{-1} at 10.58 GeV [2698 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

JHEP1309(2013)129

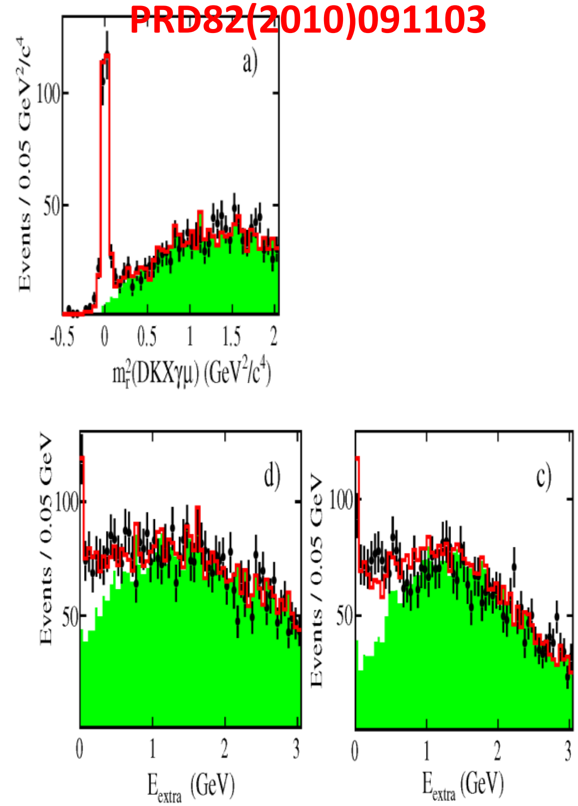


f_{Ds+}=255.5±4.2±5.1 MeV

- Babar, 521 fb^{-1} at 10.58 GeV [1023 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

PRD82(2010)091103



f_{Ds+}=258.6±6.4±7.5 MeV

$D^+ \to K^0_L e^+ \nu$分支比的首次测量

PRD92(2015)112008

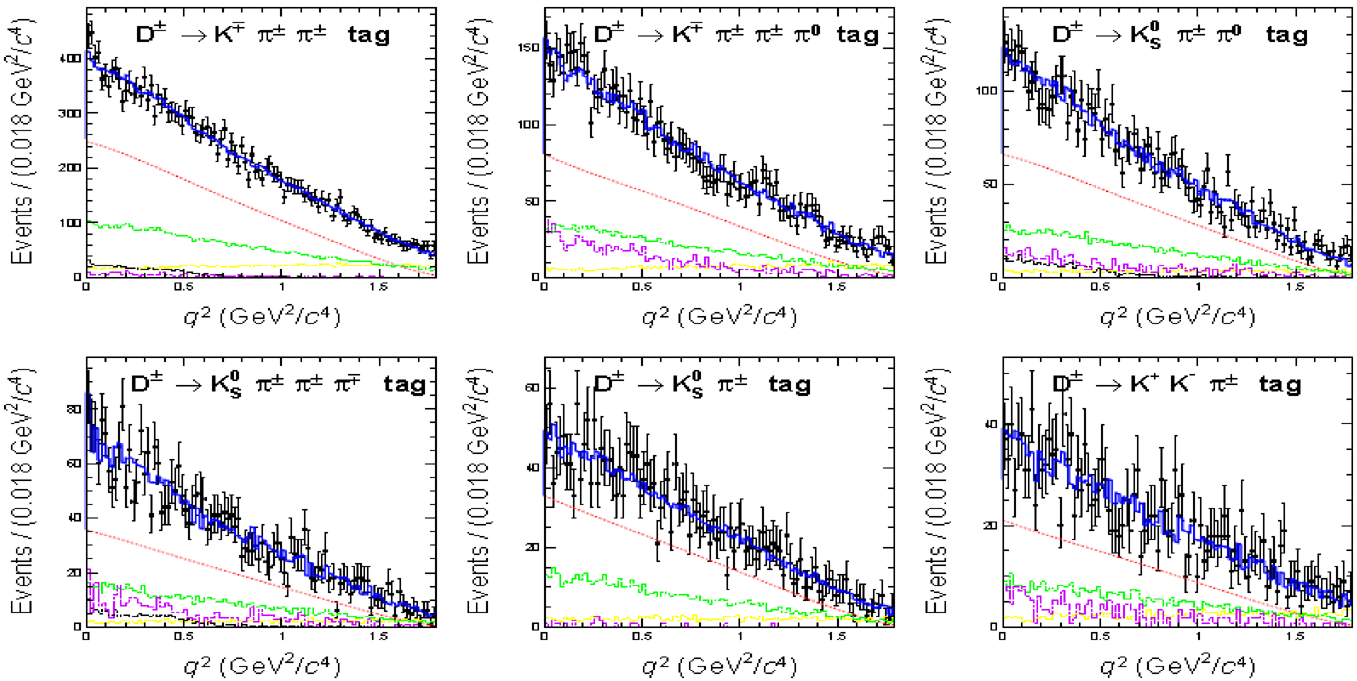
- **Regardless of long flight distance, K^0_L interact with EMC and deposit part of energy, thus giving position information**
- **After reconstructing all other particles, K^0_L can be inferred with position information and constrain $U_{miss} \to 0$**

$B(D^+ \to K^0_L e^+ \nu) = (4.482 \pm 0.027 \pm 0.103)\%$

$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K^0_L e^+ \nu_e) - \mathcal{B}(D^- \to K^0_L e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K^0_L e^+ \nu_e) + \mathcal{B}(D^- \to K^0_L e^- \bar{\nu}_e)}$$

$A_{CP}^{D^+ \to K_L e^+ \nu} = (-0.6 \pm 0.6 \pm 1.5)\%$

Simultaneous fit to event density $I(q^2)$ with 2-par. series Form Factor



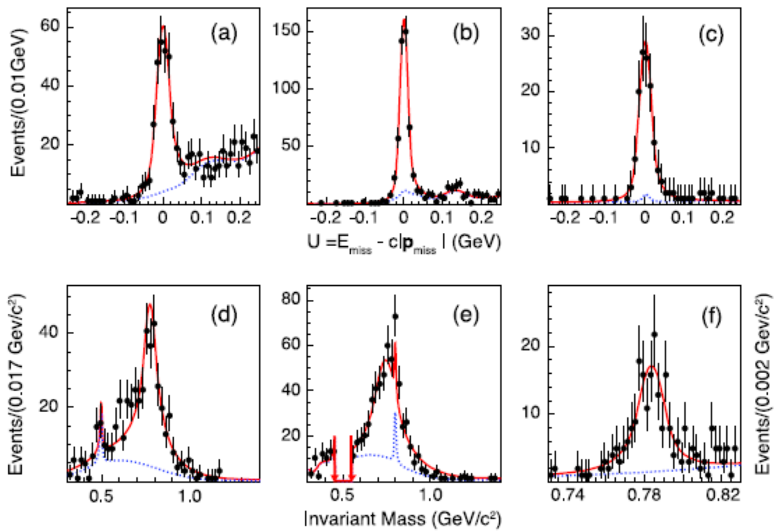
$D^+ \to K^0_L e^+ \nu$ is measured for the first time

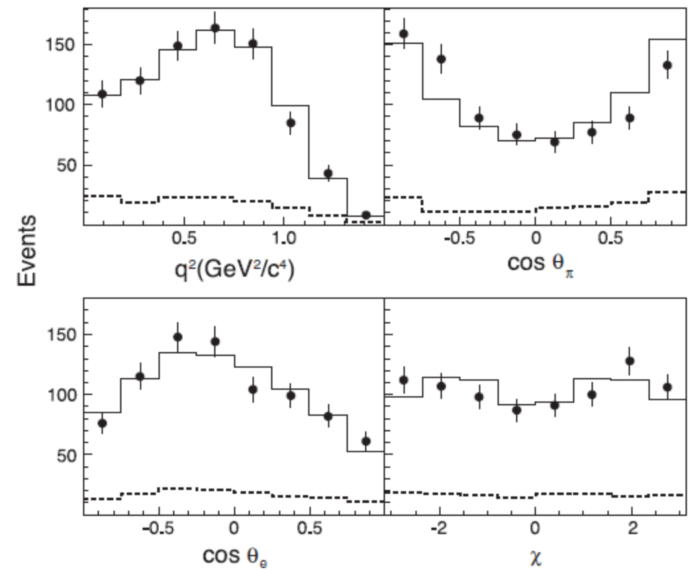
$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

$r_1 = a_1/a_0 = -1.91 \pm 0.33 \pm 0.24$

$D^{+(0)}\to\rho^{0(-)}e^+\nu$振幅分析研究

CLEO, PRL110,131802 (2008)





Decay Mode	ϵ (%)	$N_{\rm tag,SL}$	$\mathcal{B}_{\rm SL}$	$\mathcal{B}_{\rm SL}$ (prev)	$\mathcal{B}_{\rm SL}$ (QCD SR)	$\mathcal{B}_{\rm SL}$(ISGW2)	$\mathcal{B}_{\rm SL}$(FK)
$D^0\to\rho^-e^+\nu_e$	26.03 ± 0.02	304.6 ± 20.9	$1.77\pm0.12\pm0.10$	$1.94\pm0.39\pm0.13$	0.5 ± 0.1	1.0	2.0
$D^+\to\rho^0e^+\nu_e$	42.84 ± 0.03	447.4 ± 24.5	$2.17\pm0.12^{+0.12}_{-0.22}$	$2.1\pm0.4\pm0.1$	$\cdots$	1.3	2.5
$D^+\to\omega e^+\nu_e$	14.67 ± 0.03	128.5 ± 12.6	$1.82\pm0.18\pm0.07$	$1.6^{+0.7}_{-0.6}\pm0.1$	$\cdots$	1.3	2.5

$$\frac{\Gamma(D^0\to\rho^-e^+\nu_e)}{2\Gamma(D^+\to\rho^0e^+\nu_e)}=1.03\pm0.09^{+0.08}_{-0.02}$$

BESIII相关工作正在开展

$r_V=V(0)/A_1(0)=1.48\pm0.15\pm0.05$

$r_2=A_2(0)/A_1(0)=0.83\pm0.11\pm0.04$

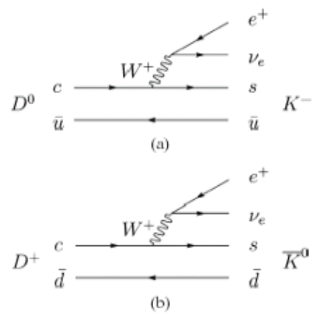
粲介子半轻衰变中同位旋是否守恒？

The 'long-standing puzzle' of whether the Isospin conservation holds in the exclusive semileptonic D decays

半轻子衰变的研究

$$D^0 \to K^- e^+ \nu,\quad D^+ \to \overline{K}^0 e^+ \nu$$

Motivation



Isospin conservation implies

$$\Gamma(D^0 \to K^- e^+ \nu_e)/\Gamma(D^+ \to \overline{K}^0 e^+ \nu_e) = 1$$

$$\Gamma(D^0 \to K^- e^+ \nu_e)/\Gamma(D^+ \to \overline{K}^0 e^+ \nu_e) = 1.4 \pm 0.2$$

	BES	MARK III	PDG02
$\dfrac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \overline{K}^0 e^+ \nu_e)}$	1.08±0.22±0.07	1.44±0.62	1.4±0.2

Obtained based on the branching fractions quoted from PDG02

Moriond EW04 (2004 年 3 月)
ICHEP'04

BES-II 实验结果支持"D介子半轻子衰变过程中同位旋守恒"。解决了粲介子物理领域内过去二十年中存在的一个"Puzzle"。

Paper published in PLB 608 (2005) 24

PLB644 (2007) 20

μ道联合电子道

Measurement of the ratio of the partial widths

	BES	MARK III	PDG02
$\dfrac{\Gamma(D^0 \to K^- l^+ \nu_e)}{\Gamma(D^+ \to \overline{K}^0 l^+ \nu_e)}$	$1.00 \pm 0.17 \pm 0.06$	1.44 ± 0.62	1.4 ± 0.2

Obtained based on the branching fractions quoted from PDG02

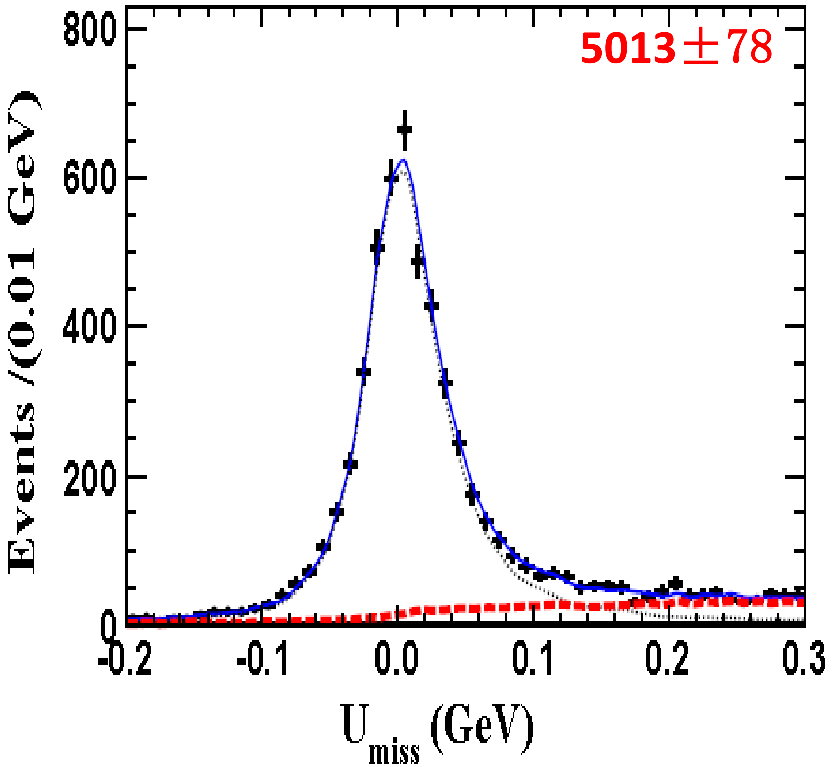
BES-II 实验结果支持"D介子半轻子衰变过程中同位旋守恒"。Solved the long-standing puzzle in D decays！ I. Shipsey, ICHEP'04 23

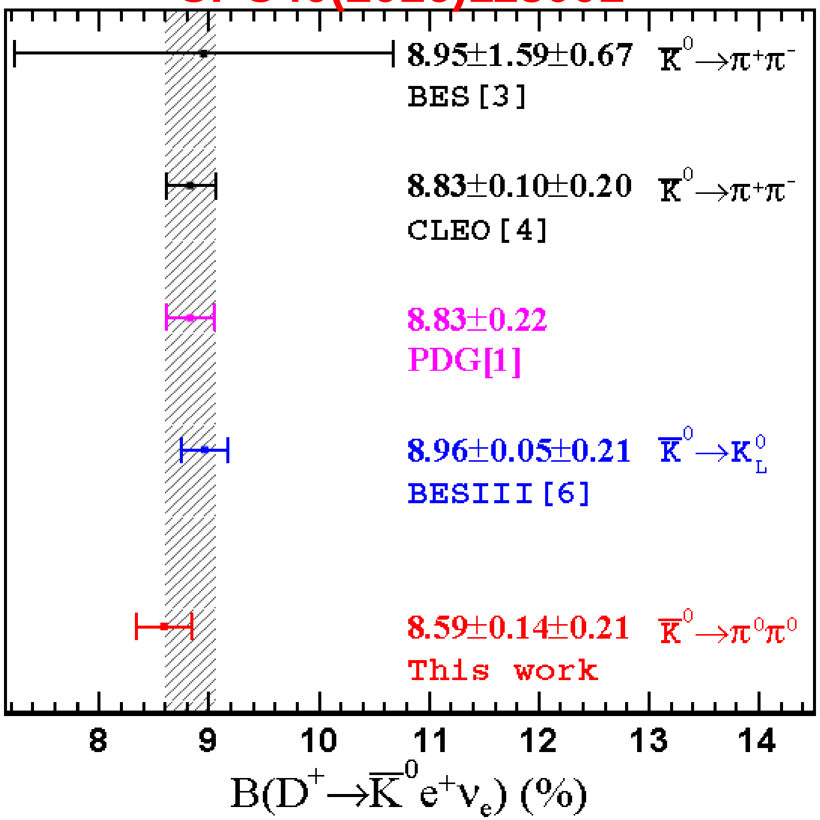
CLEO-c confirmed the BES-II result

$$\frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \overline{K}^0 e^+ \nu_e)} = 1.00 \pm 0.05 \pm 0.04$$

首次使用$\bar{K}^0 \to \pi^0\pi^0$测量$D^+ \to \bar{K}^0 e^+ \nu$分支比

CPC40(2016)113001





Taking τ_{D+}, τ_{D0}, $B[D^0 \to K^- e^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

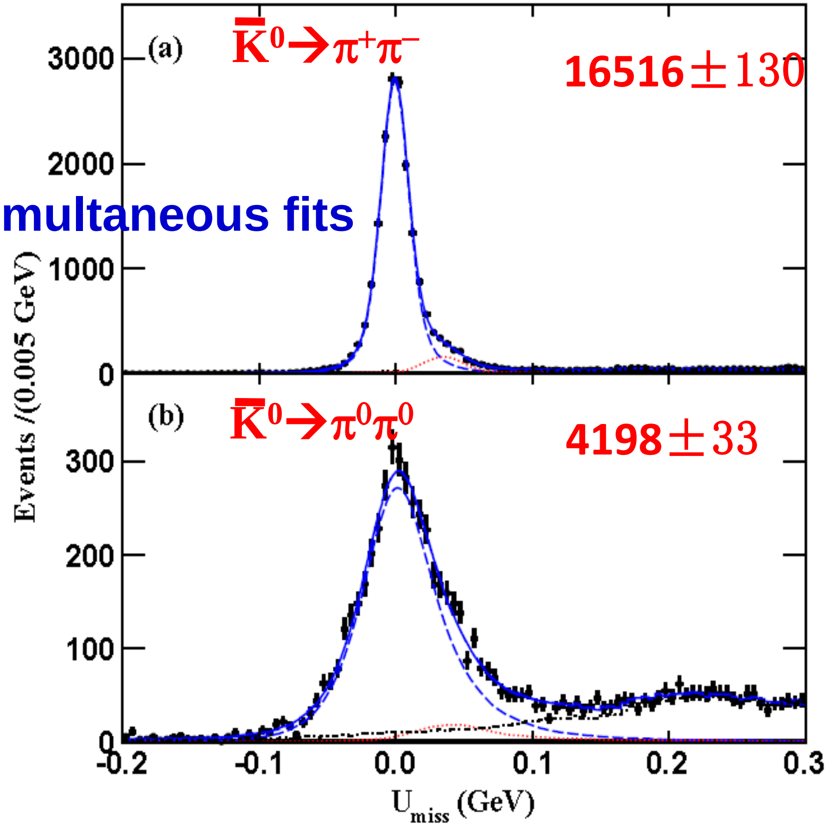
$$\frac{\Gamma[D^0 \to K^- e^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.969 \pm 0.025$$

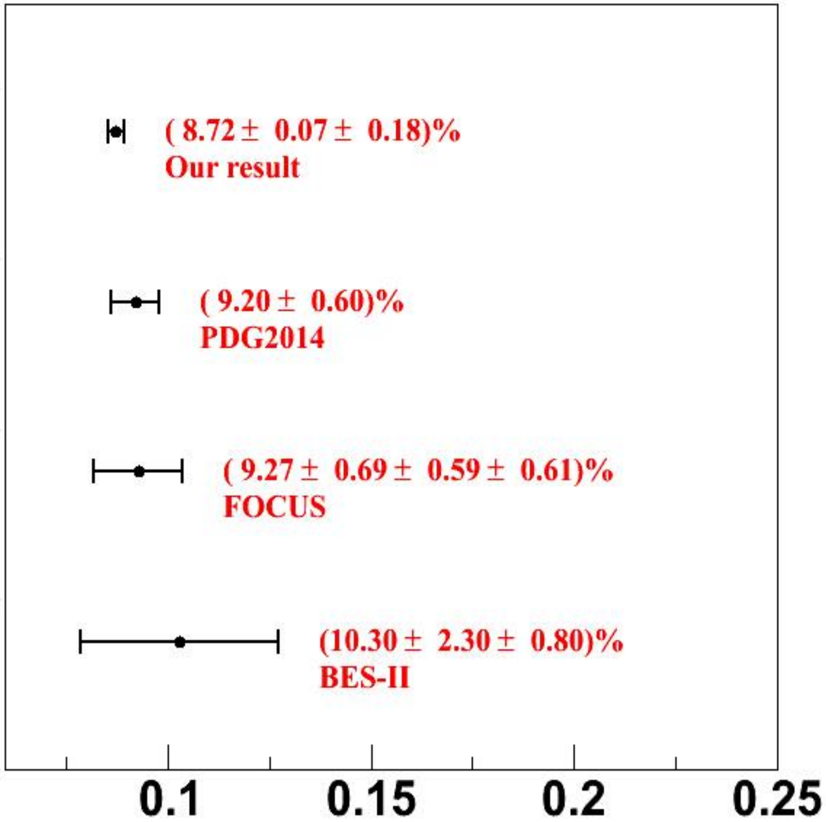
Agrees with isospin conservation within 1.2σ

$D^+ \to \bar{K}^0 \mu^+ \nu$分支比的改进测量

EPJC76(2016)369

Simultaneous fits





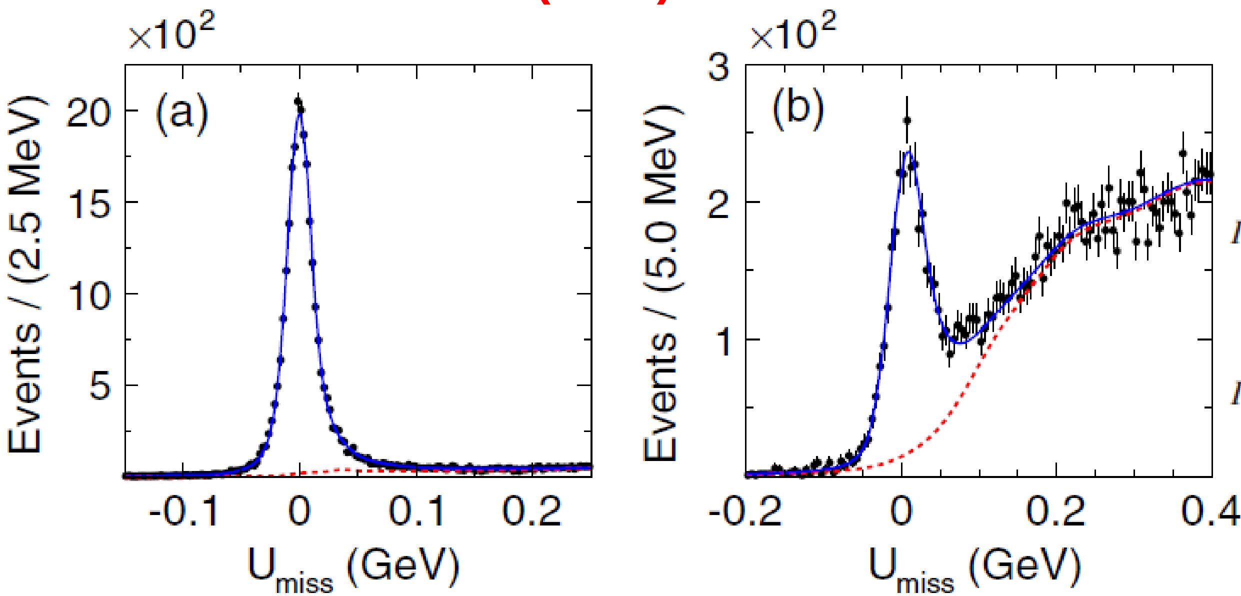
Taking $B[D^0 \to K^- \mu^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

$$\frac{\Gamma[D^0 \to K^- \mu^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 \mu^+ \nu]} = 0.963 \pm 0.044$$

Support isospin conservation in these two decays within errors

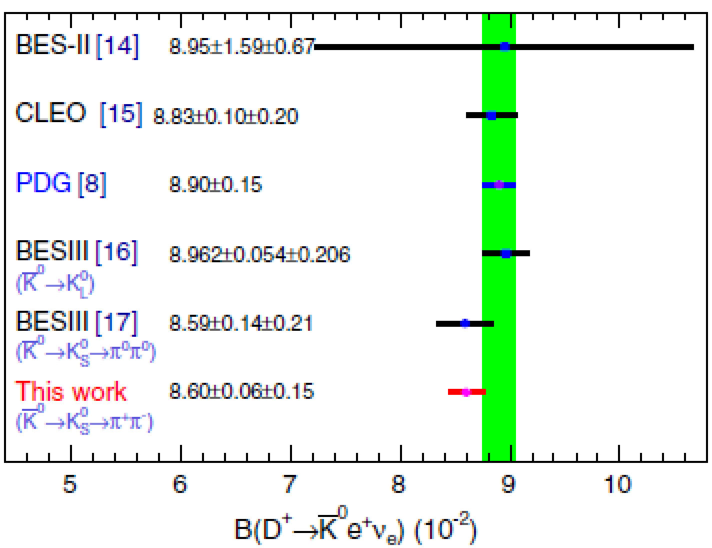
检验同位旋是否守恒

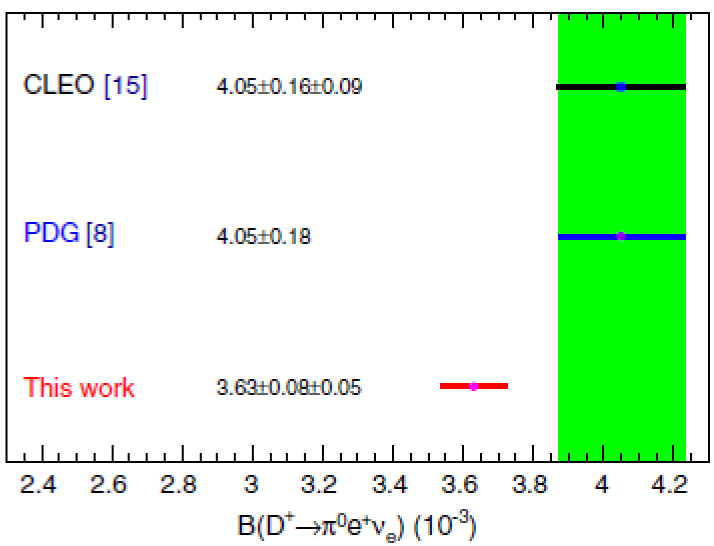
PRD96(2017)012002



$$I_K \equiv \frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu_e)} = 1.03 \pm 0.01 \pm 0.02$$

$$I_\pi \equiv \frac{\Gamma(D^0 \to \pi^- e^+ \nu_e)}{2\Gamma(D^+ \to \pi^0 e^+ \nu_e)} = 1.03 \pm 0.03 \pm 0.02$$

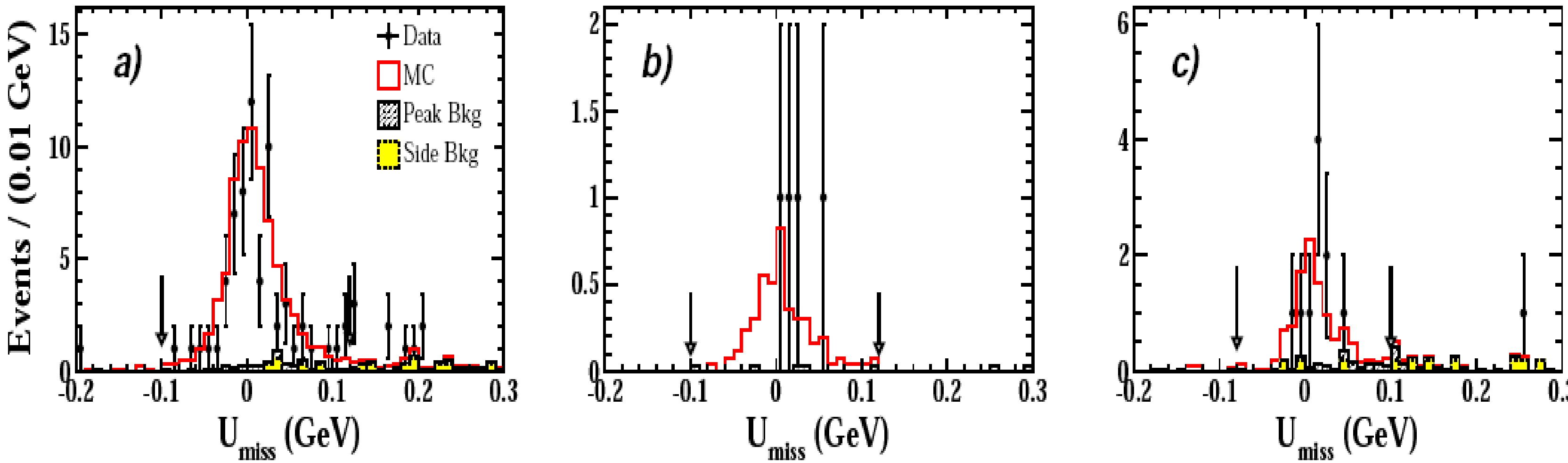




$D_s^+ \to \eta^{(\prime)} e^+ \nu$分支比测量

- Benefit the understanding of the source of difference of inclusive decay rates of $D^{0(+)}$ and D_s^+
- Complementary information to understand η–η' mixing

482 pb^{-1} data@4.009 GeV, PRD94(2016)112003

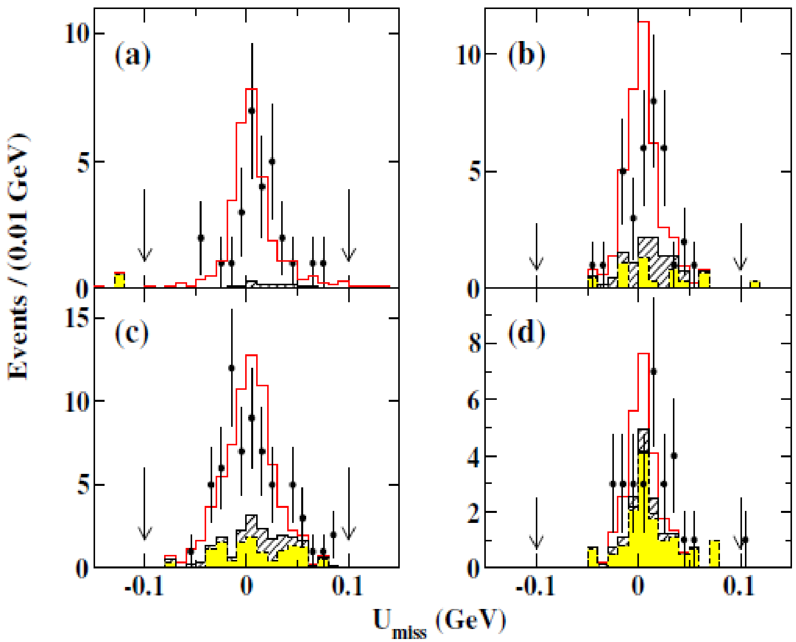


	BESIII	CLEOII 95	CLEOc09	CLEOc15	PDG [4]
$B(D_s^+ \to \eta e^+ \nu_e)[\%]$	$2.30 \pm 0.31 \pm 0.08$	—	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.20$	2.67 ± 0.29
$B(D_s^+ \to \eta' e^+ \nu_e)[\%]$	$0.93 \pm 0.30 \pm 0.05$	—	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$	0.99 ± 0.23
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	—	—	—

$D_s^+ \to \phi\mu^+\nu$, $\eta^{(\prime)}\mu^+\nu$分支比的首次测量

PRD97(2018)012006

482 pb^{-1} data@4.009 GeV



- BFs of semi-muonic D_s^+ decays are measured for the first time
- Benefit testing of lepton flavor universality and measuring the η–η' mixing angle

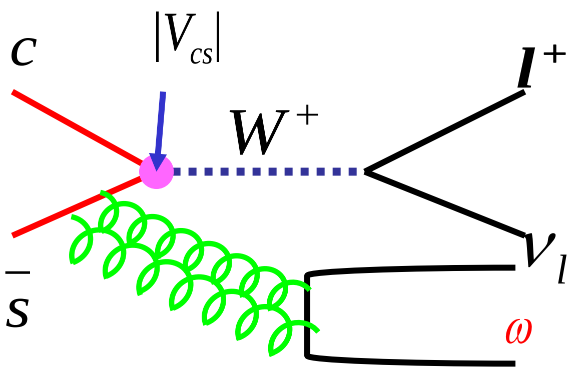
$$\frac{\Gamma[D_s^+ \to \phi\mu^+\nu]}{\Gamma[D_s^+ \to \phi e^+\nu]} = 0.86 \pm 0.29$$

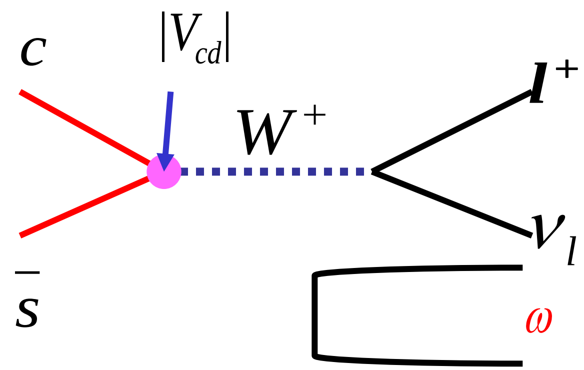
$$\frac{\Gamma[D_s^+ \to \eta\mu^+\nu]}{\Gamma[D_s^+ \to \eta e^+\nu]} = 1.05 \pm 0.24$$

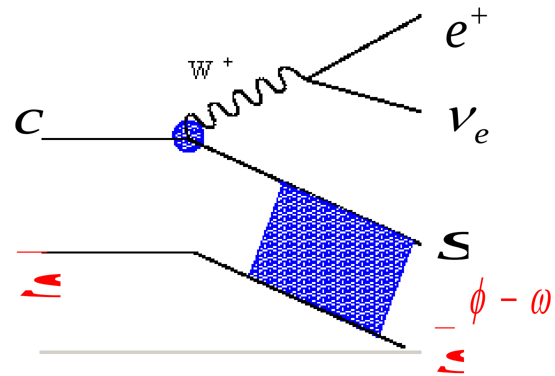
$$\frac{\Gamma[D_s^+ \to \eta'\mu^+\nu]}{\Gamma[D_s^+ \to \eta' e^+\nu]} = 1.14 \pm 0.68$$

μ^+ mode	$\mathcal{B}_{\rm BESIII}$ (%)	$\mathcal{B}_{\rm PDG}$ (%)	e^+ mode	$\mathcal{B}_{\rm BESIII}$ (%)	$\mathcal{B}_{\rm PDG}$ (%)
$D_s^+ \to \phi\mu^+\nu_\mu$	$1.94 \pm 0.53 \pm 0.09$	···	$D_s^+ \to \phi e^+\nu_e$	$2.26 \pm 0.45 \pm 0.09$	2.39 ± 0.23
$D_s^+ \to \eta\mu^+\nu_\mu$	$2.42 \pm 0.46 \pm 0.11$	···	$D_s^+ \to \eta e^+\nu_e$	$2.30 \pm 0.31 \pm 0.08$ [8]	2.28 ± 0.24
$D_s^+ \to \eta'\mu^+\nu_\mu$	$1.06 \pm 0.54 \pm 0.07$	···	$D_s^+ \to \eta' e^+\nu_e$	$0.93 \pm 0.30 \pm 0.05$ [8]	0.68 ± 0.16

$D_s^+ \to \omega e^+ \nu$的寻找







$$\begin{pmatrix} \omega \\ \phi \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} \omega^I \\ \phi^I \end{pmatrix}$$

D_s^+四夸克态图象

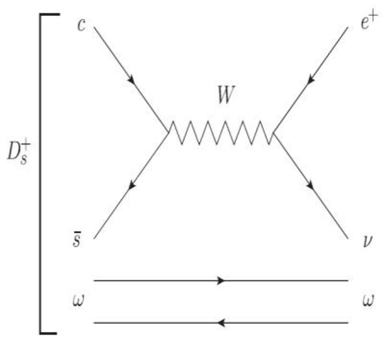
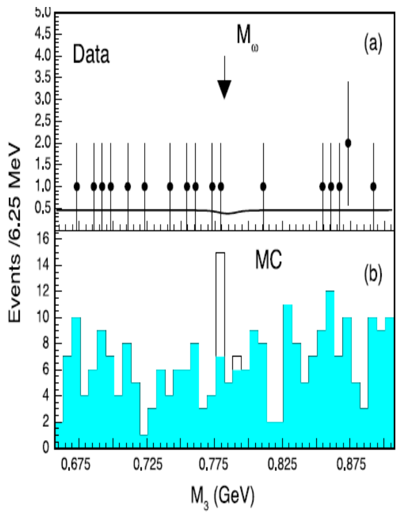
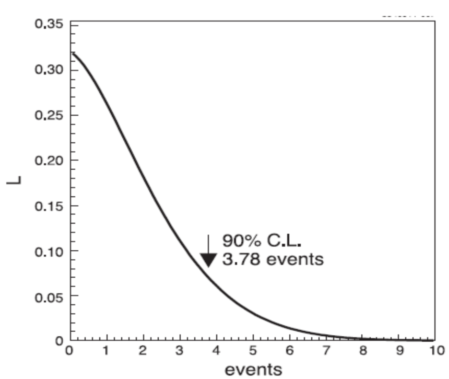


FIG. 1. Feynman diagram representing the four-quark semi-leptonic decay $D_s^+ \to \omega e^+ \nu$.

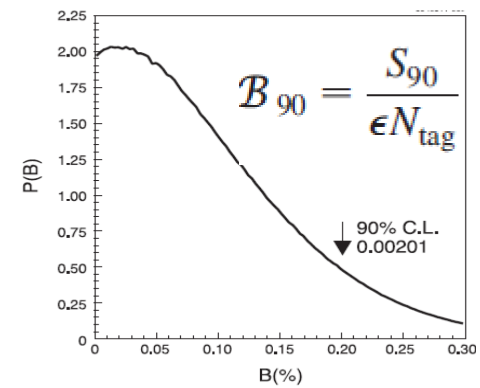
CLEO, PRD84, 012005





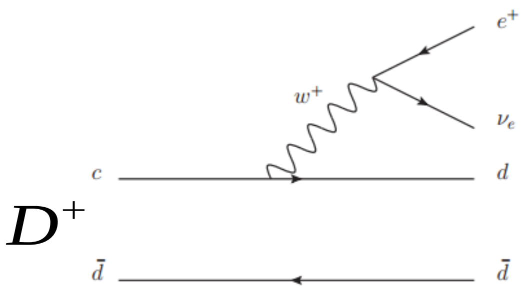
PRD79,074006: < 2×10^{-4}

$$R = (4.1\text{–}8.2)(\delta/3.34^\circ)^2 \times 10^{-3}$$



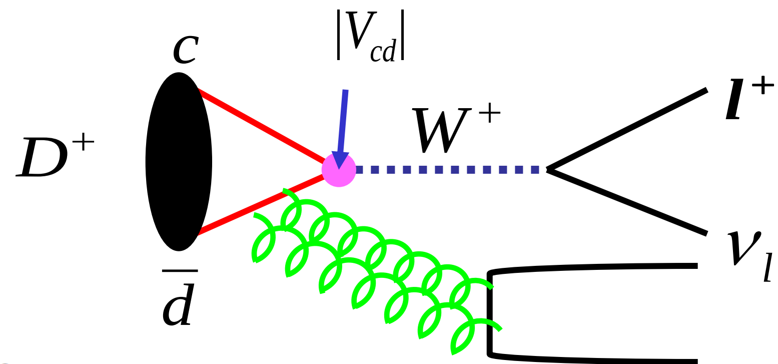
Search@BESIII is ongoing

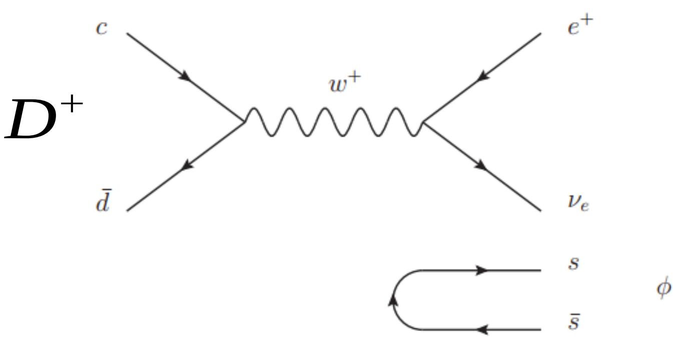
D⁺→φe⁺ν的寻找



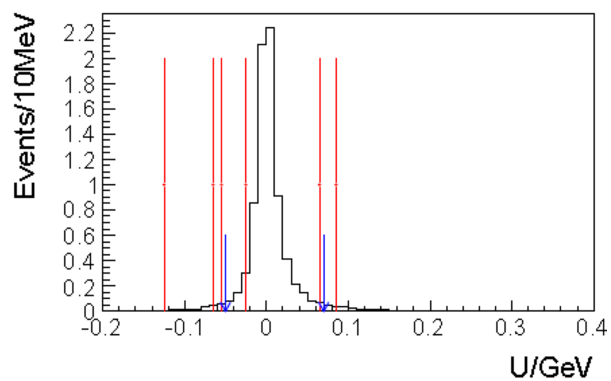
$\omega \longrightarrow \phi$

$$\begin{pmatrix}\omega\\ \phi\end{pmatrix} = \begin{pmatrix}\cos\delta & \sin\delta\\ -\sin\delta & \cos\delta\end{pmatrix}\begin{pmatrix}\omega^I\\ \phi^I\end{pmatrix}$$





PRD92(2016)071101(RC)



B[D⁺→φe⁺ν]<1.3×10⁻⁵ at 90% C.L.

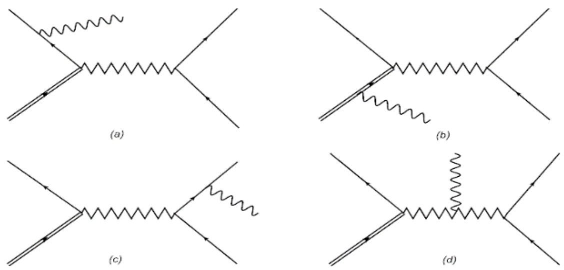
$D_{(s)}^+$介子辐射半轻衰变

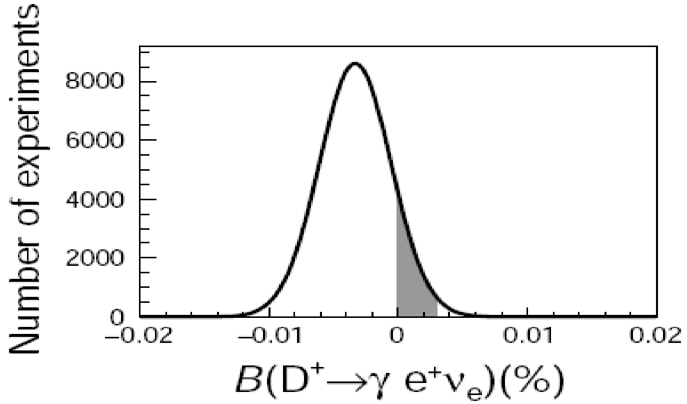
- no helicity suppression in contrast to pure leptonic decay, and simpler non-perturbative QCD calculation without final-state hadron

models	pQCD[1]	light front quark[2] & NR constituent quark model[3]	VMD[4]	factorization[5]
$\mathcal{B}_{theo.}$	10^{-4}	10^{-6}	10^{-5}(enhanced by LD)	10^{-5}

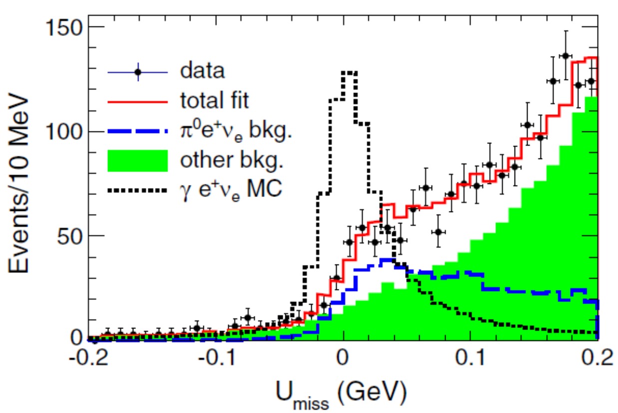
[1][PRD 51, 111 (1995)] [2]MPLA 15, 2087 (2000); [3]PLB 562, 75 (2003);
[4]MPLA 27, 1250120 (2012);[5]Nucl. Phys. B 889, 778 (2014); 914, 301 (2017)

Tree level amplitudes





PRD95(2017)071102(RC)



$B[D^+\rightarrow\gamma e^+\nu]|_{E\gamma>10\ MeV}<3.0\times10^{-4}$ @90%C.L.

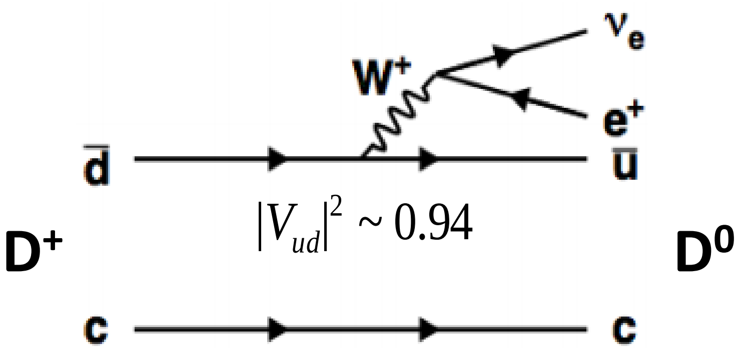
Search for $D_s^+\rightarrow\gamma e^+\nu$ @BESIII is ongoing

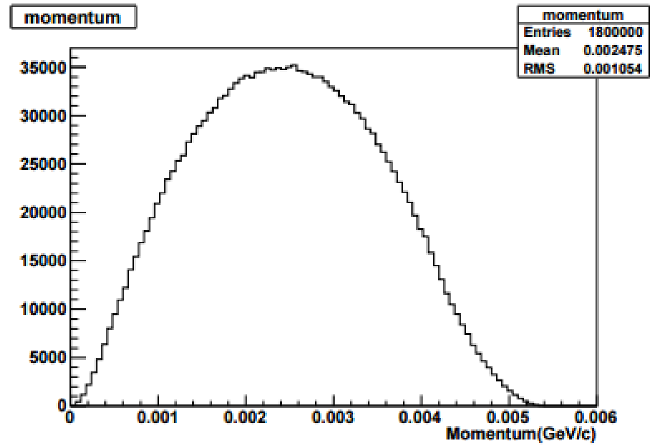
$D_{(s)}^{+}$→$D^0e^+\nu$的寻找

与其他半轻衰变c→d/sl⁺v不同

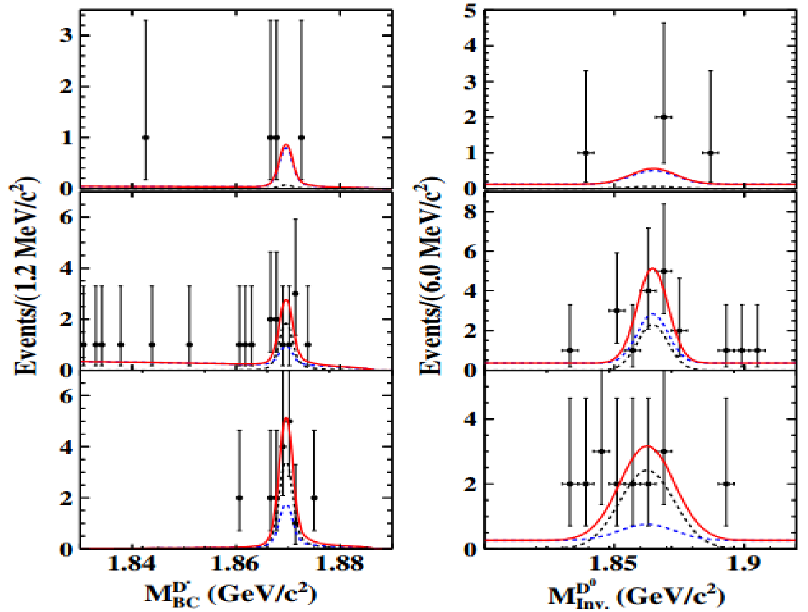
此衰变通过d/s→ul⁺v

Applying the SU(3) symmetry for the light quarks, this rare decay branching fraction can be predicted by theoretical calculation and its theoretical value is 2.78×10^{-13} [EPJC, 59:841-845(2009)].





PRD96(2017)092002



$B[D^+ \to D^0 e^+\nu] < 1\times10^{-4}$ @90%C.L.

$D^0\bar{D}^0$混合和CP破坏

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \overline{K^0},\ B_d^0 \Leftrightarrow \overline{B_d^0},\ B_s^0 \Leftrightarrow \overline{B_s^0},\ D^0 \Leftrightarrow \overline{D^0}$$

- Flavor eigenstate $(|D^0\rangle, |\overline{D^0}\rangle) \neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$)

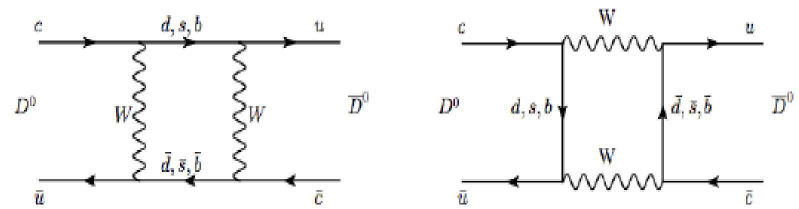
$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D^0}\rangle \text{ (CPT: } p^2+q^2=1)$$

- Mixing parameters definition:

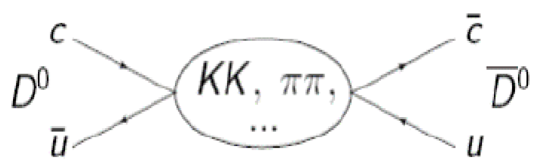
$$\mathbf{x} \equiv \frac{M_1 - M_2}{\Gamma}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \quad \Gamma \equiv \frac{\Gamma_1 + \Gamma_2}{2}$$

- under phase convention $CP|D^0\rangle = |\overline{D^0}\rangle$, $CP|\overline{D^0}\rangle = |D^0\rangle$,
- with CP conservation ($q = p = 1/\sqrt{2}$): $|D_{1,2}\rangle = |D_{+,-}\rangle$ (CP eigenstates)

- Unique: only the up-type meson for mixing
- Standard Model predicts: $\sim \mathcal{O}(1\%)$



(1) short distance (< 0.1% by CKM and GIM)



(2) long distance (∼ 1%)

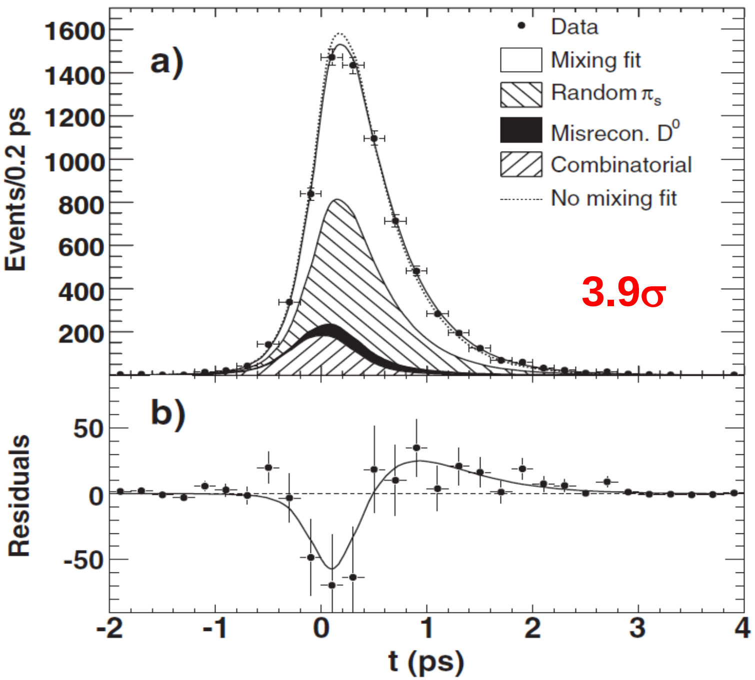
- Precise measurement of x, y: effectively limit New Physics(NP) modes;
- search for NP, eg: $|x| \gg |y|$

$D^0\bar{D}^0$混合的迹象

- **Babar, 384 fb^{-1}@10.58 GeV**

PRL98(2007)211802

$$\frac{T_{WS}(t)}{e^{-\Gamma t}} \propto R_D + \sqrt{R_D}y'\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2$$



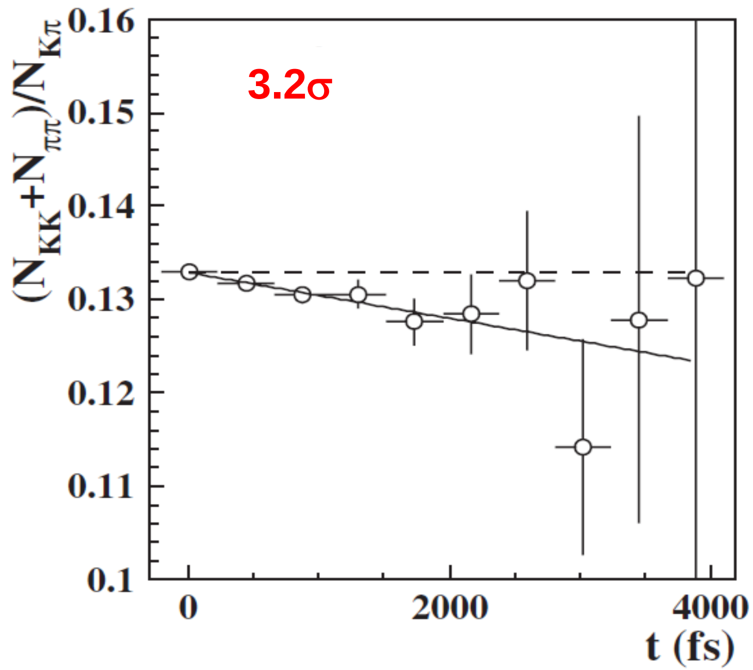
R_D=(0.303±0.016(stat)±0.010(syst))%
x'^2=(-0.22±0.30(stat)±0.21(syst))×10^{-3}
y'=(9.7±4.4(stat)±3.1(syst))×10^{-3}
(x'^2, y') with correlation -0.95

- **BELLE, 540 fb^{-1}@10.58 GeV**

PRL98(2007)211803

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1,$$

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$



$$A_\Gamma = [0.01 \pm 0.30(\text{stat}) \pm 0.15(\text{syst})]\%.$$

$$y_{CP} = [1.31 \pm 0.32(\text{stat}) \pm 0.25(\text{syst})]\%.$$

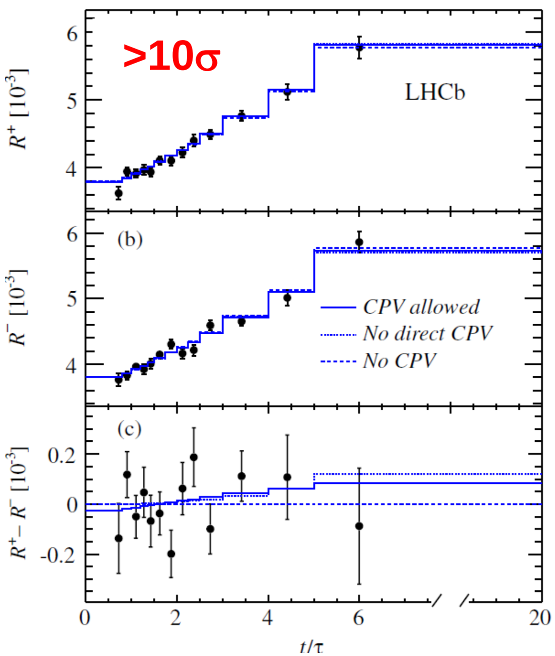
$D^0\bar{D}^0$混合的确认

- **LHCb, 3 fb^{-1} $p\bar{p}$ at 7/8 TeV**

PRL110(2013)101802 (1fb^{-1})

PRL111(2013)251801

$$R(t) \approx R_D + \sqrt{R_D}y'\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$



$$x'^2 = (5.5 \pm 4.9) \times 10^{-5},$$

$$y' = (4.8 \pm 1.0) \times 10^{-3}$$

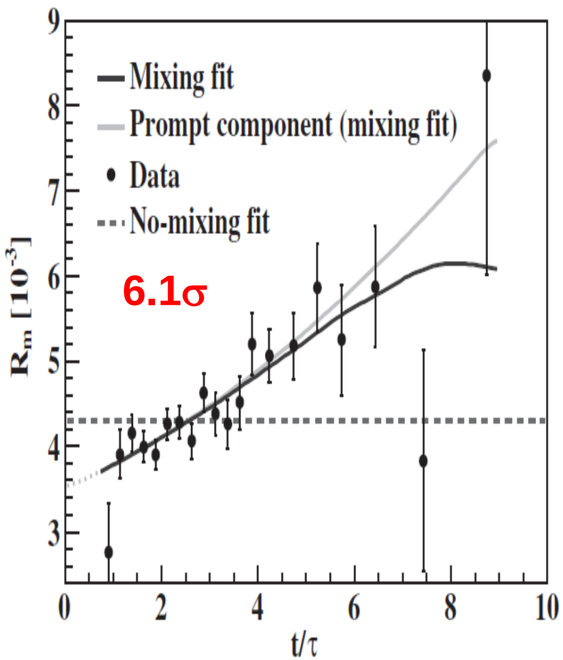
$$R_D = (3.568 \pm 0.066) \times 10^{-3}$$

- **CDFII, 9.6 fb^{-1} $p\bar{p}$ at 1.96 TeV**

PRL100(2008)121802(1.5 fb^{-1})

PRL111(2013)231802

$$R(t/\tau) = R_D + \sqrt{R_D}y'(t/\tau) + \frac{x'^2 + y'^2}{4}(t/\tau)^2.$$



$$x'^2 = (0.08 \pm 0.18) \times 10^{-3},$$

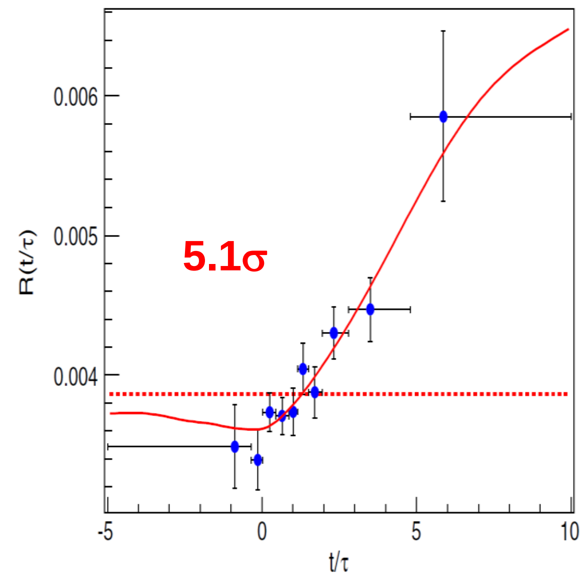
$$y' = (4.3 \pm 4.3) \times 10^{-3},$$

$$R_D = (3.51 \pm 0.35) \times 10^{-3}$$

- **Belle, 976 fb^{-1} at 10.58 GeV**

PRL112(2014)111801

$$R(\tilde{t}/\tau) = \frac{\Gamma_{WS}(\tilde{t}/\tau)}{\Gamma_{RS}(\tilde{t}/\tau)} \approx R_D + \sqrt{R_D}y'\frac{\tilde{t}}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{\tilde{t}}{\tau}\right)^2$$



$$x'^2 = (0.09 \pm 0.22) \times 10^{-3}$$

$$y' = (4.6 \pm 3.4) \times 10^{-3}$$

$$R_D = (3.53 \pm 0.13) \times 10^{-3}$$

$D^0\bar{D}^0$混合和CP破坏参数

Decay Mode	Observables	Relationship
$D^0 \to K^+K^-/\pi^+\pi^-$	y_{CP} A_Γ	$2y_{CP} = (\lvert q/p\rvert + \lvert p/q\rvert)\, y\cos\phi -$ $(\lvert q/p\rvert - \lvert p/q\rvert)\, x\sin\phi$ $2A_\Gamma = (\lvert q/p\rvert - \lvert p/q\rvert)\, y\cos\phi -$ $(\lvert q/p\rvert + \lvert p/q\rvert)\, x\sin\phi$
$D^0 \to K^0_S\,\pi^+\pi^-$	x y $\lvert q/p\rvert$ ϕ	
$D^0 \to K^+\ell^-\nu$	R_M	$R_M = (x^2+y^2)/2$
$D^0 \to K^+\pi^-\pi^0$ (Dalitz plot analysis)	x'' y''	$x'' = x\cos\delta_{K\pi\pi} + y\sin\delta_{K\pi\pi}$ $y'' = y\cos\delta_{K\pi\pi} - x\sin\delta_{K\pi\pi}$
"Double-tagged" branching fractions measured in $\psi(3770)\to DD$ decays	R_M y R_D $\sqrt{R_D}\cos\delta$	$R_M = (x^2+y^2)/2$
$D^0 \to K^+\pi^-$	$x'^2,\ y'$ $x'^{2+},\ x'^{2-}$ $y'^+,\ y'^-$	$x' = x\cos\delta + y\sin\delta$ $y' = y\cos\delta - x\sin\delta$ $A_M \equiv (\lvert q/p\rvert^4 - 1)/(\lvert q/p\rvert^4 + 1)$ $x'^{\pm} = [(1\pm A_M)/(1\mp A_M)]^{1/4} \times$ $(x'\cos\phi \pm y'\sin\phi)$ $y'^{\pm} = [(1\pm A_M)/(1\mp A_M)]^{1/4} \times$ $(y'\cos\phi \mp x'\sin\phi)$
$D^0 \to K^+\pi^-/K^-\pi^+$ (time-integrated)	$\frac{\Gamma(D^0\to K^+\pi^-) + \Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+) + \Gamma(\overline{D}^0\to K^+\pi^-)}$ $\frac{\Gamma(D^0\to K^+\pi^-) - \Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-) + \Gamma(\overline{D}^0\to K^-\pi^+)}$	R_D A_D
$D^0 \to K^+K^-/\pi^+\pi^-$ (time-integrated)	$\frac{\Gamma(D^0\to K^+K^-) - \Gamma(\overline{D}^0\to K^+K^-)}{\Gamma(D^0\to K^+K^-) + \Gamma(\overline{D}^0\to K^+K^-)}$ $\frac{\Gamma(D^0\to \pi^+\pi^-) - \Gamma(\overline{D}^0\to \pi^+\pi^-)}{\Gamma(D^0\to \pi^+\pi^-) + \Gamma(\overline{D}^0\to \pi^+\pi^-)}$	$A_K + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\rm indirect}\quad (A_{CP}^{\rm indirect} \approx -A_\Gamma)$ $A_\pi + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\rm indirect}\quad (A_{CP}^{\rm indirect} \approx -A_\Gamma)$

混合参数:x,y

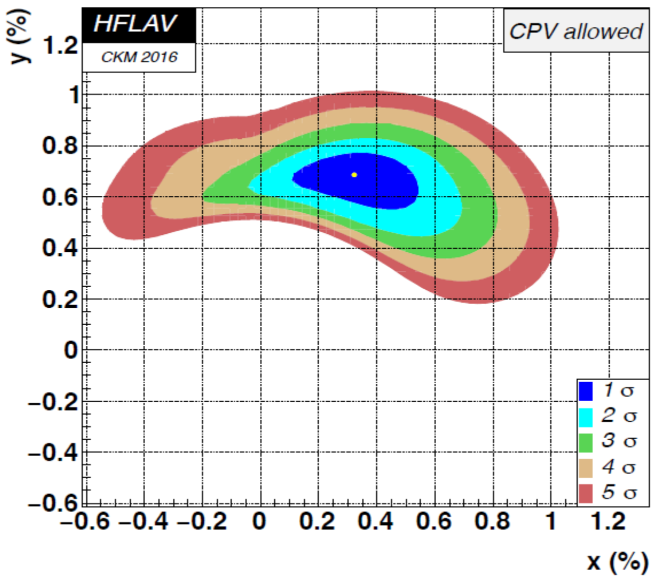
间接CPV参数:|q/p|,ϕ

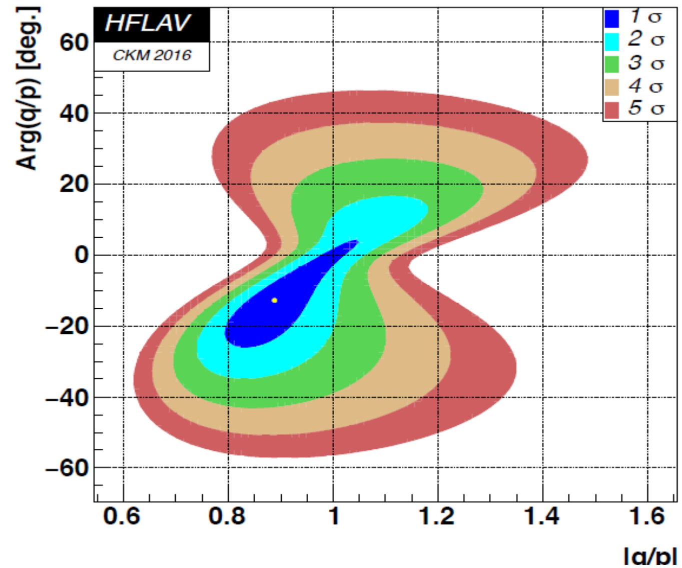
直接CPV参数:A_D,A_K,A_π

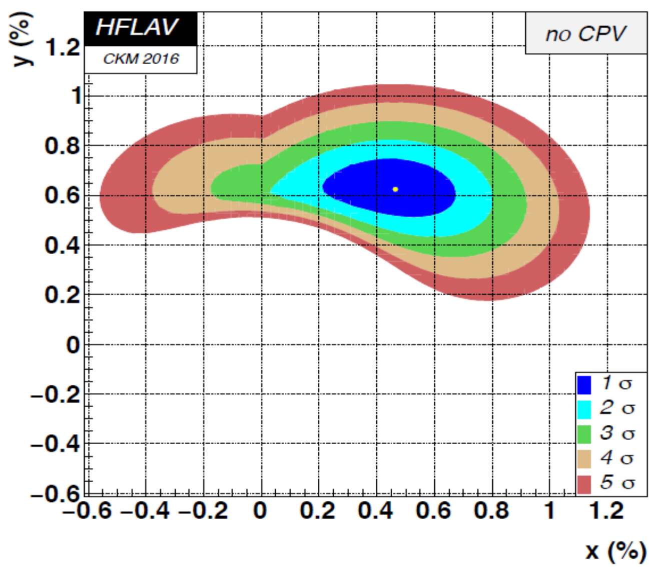
R_D

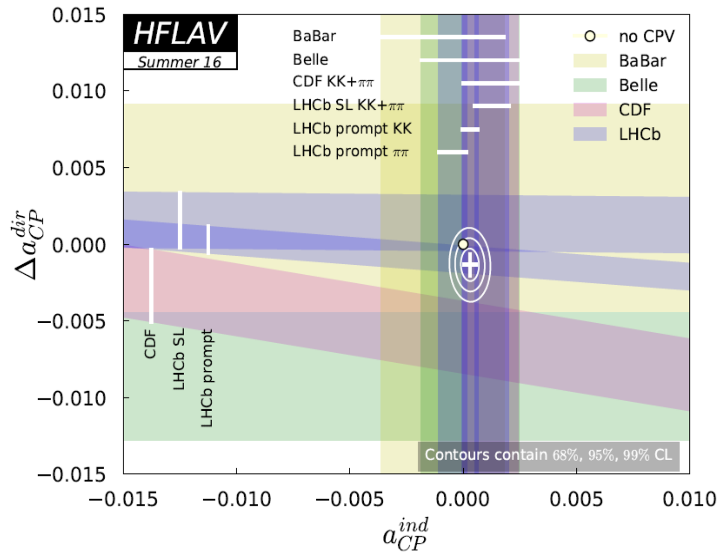
强相差参数:$\delta_{K\pi}$, $\delta_{K\pi\pi0}$

$D^0\bar{D}^0$混合和CP破坏主要参数平均









$D^0\bar{D}^0$ mixing is observed, no direct CPV is found