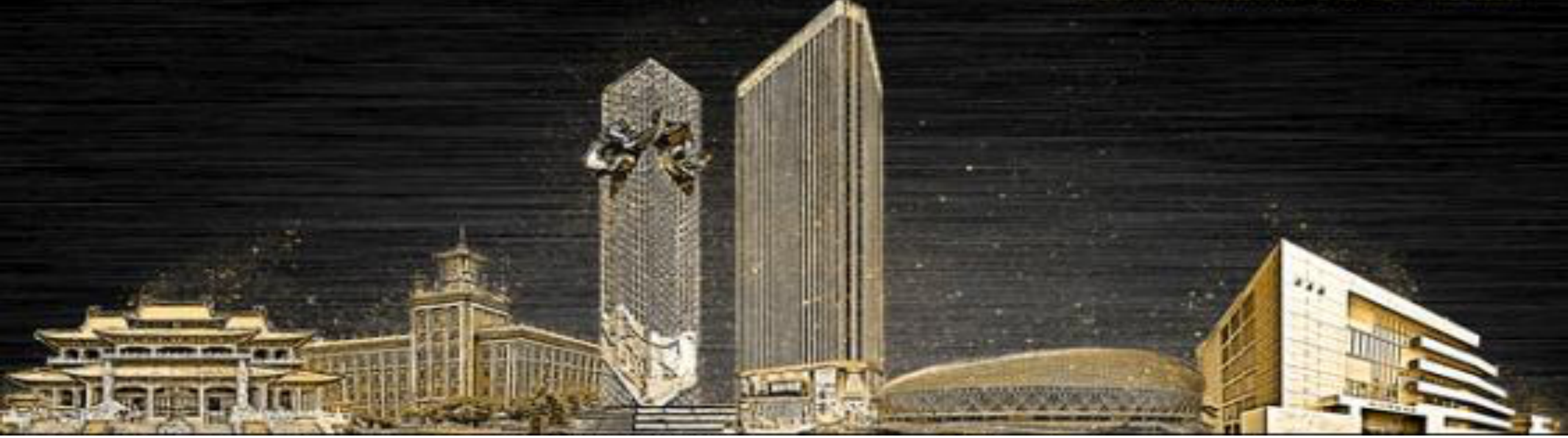


New Physics Searches at BESIII

王大勇
北京大学物理学院

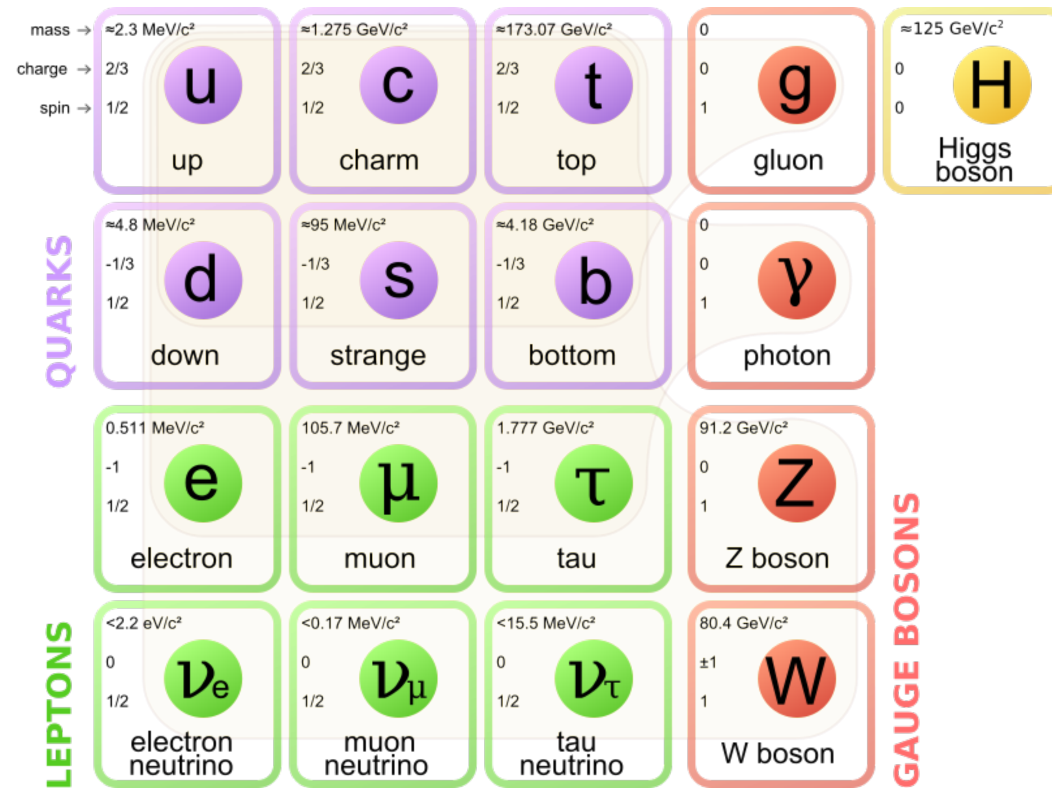
BESIII 粲物理研讨会， 鞍山 2018/8/1

寻找超出标准模型新物理

当代粒子物理学前沿的重大问题

- 暗物质
- 中微子质量
- 物质-反物质不对称
- …… ……

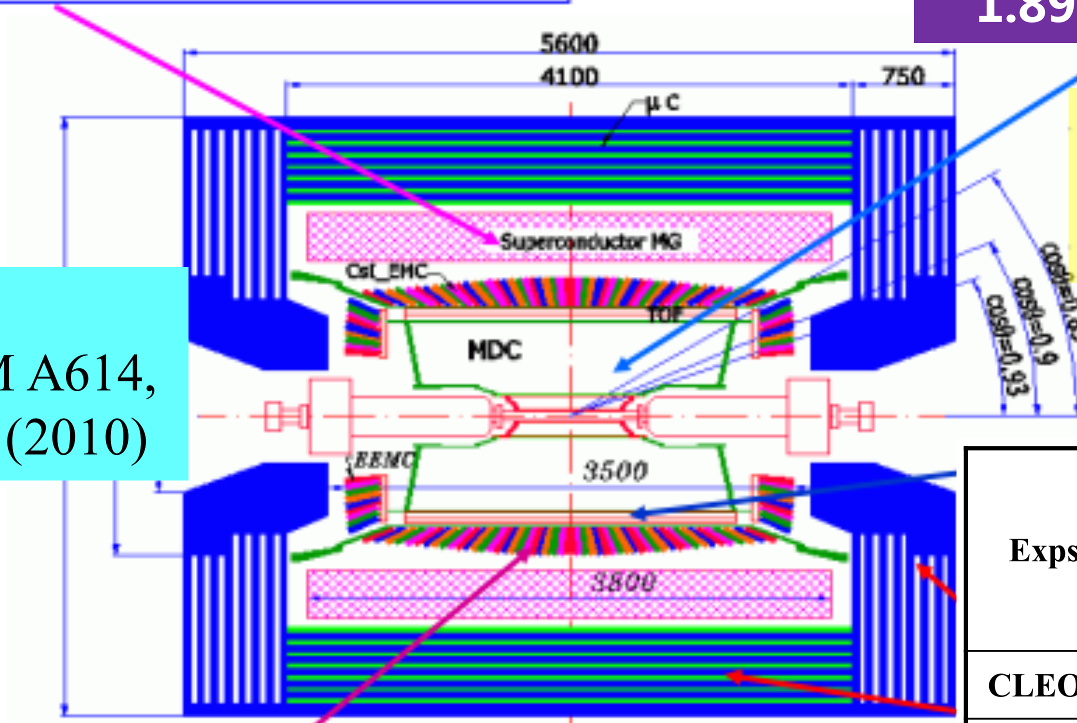
高亮度前沿发挥愈来愈重要的作用



粒子物理标准模型

BESIII@BEPCII

Magnet: 1 T Super conducting



peak lumi of 1x10^{33} cm^{-2}s^{-1} at 1.89GeV reached in April 2016

~ 1.3B +4.6B J/ψ ~ 100×BESII
~ 0.5 B $\psi(3686)$ ~ 24×CLEO-c
~ 2.9/fb $\psi(3770)$ ~ 3.5×CLEO-c

Data sets for results in this talk

Ref:
NIM A614, 345 (2010)

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO-c	110 μm	5%	2.2-2.4 %
BaBar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

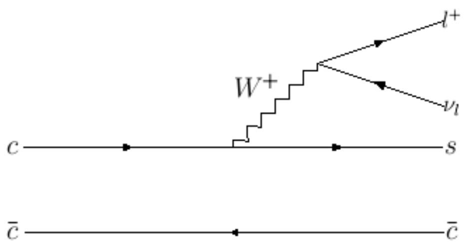
high lumi, large datasets, hermetic detector with good performance and clean environment at BESIII are helpful for probing BSM physics

competitive in channels with low energy electron/photons, neutrons, pi0's

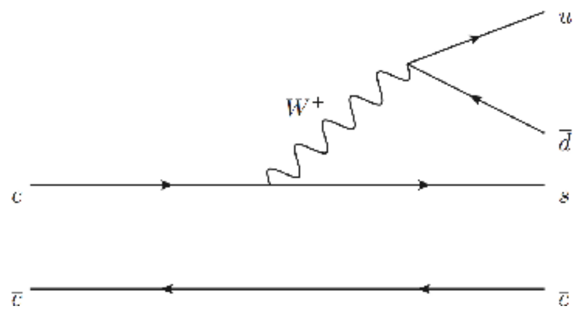
Selected topics from BESIII

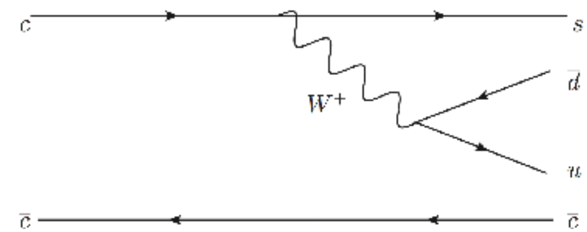
- the processes that are allowed in the SM (but rare)
  - Charmonia weak decays
  - Charm meson radiative decays
- processes that are not allowed in the SM at tree level
  - FCNC processes
- processes that are not allowed/existent in the SM
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - C-violation EM processes and C and CP violation decays
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays
- More on charm rare decays

J/ψ weak decays



$J/\psi \to D_s^{(*)-} e^+ \nu_e$

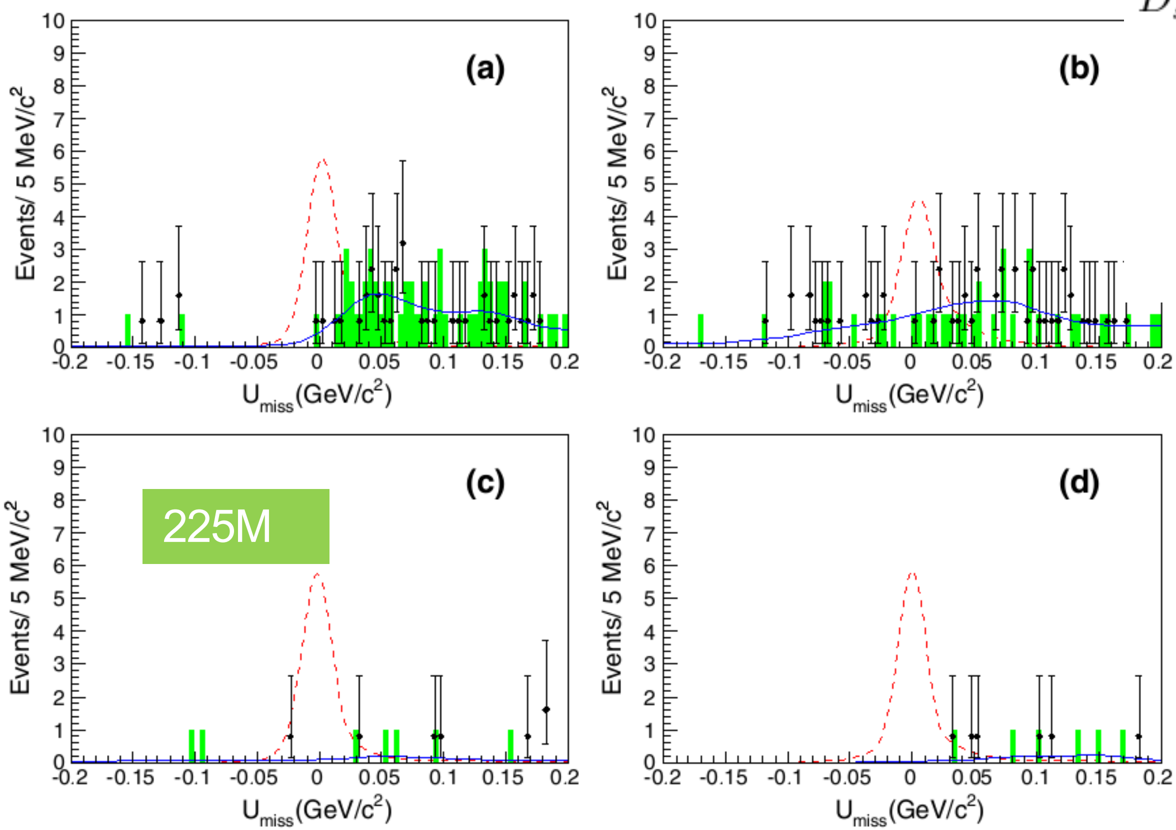




$J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

- Hadronic, electromagnetic, and radiative decays of the J/ψ have been widely studied, weak decays seldom searched before, especially for purely hadronic processes.
- Kinematically, the J/ψ cannot decay to a pair of charmed D mesons, but can decay to a single D meson.
- The weak decay of charmonium are rare decays. Searches for weak decays of charmonium to single D or D_s mesons provide tests of standard model (SM) theory and serve as a probe of new physics.

J/ψ weak decays: semileptonic



D_s^- mesons are reconstructed by:

- $D_s^- \to K^+K^-\pi^-$
- $D_s^- \to K^+K^-\pi^-\pi^0$ & $\pi^0 \to \gamma\gamma$
- $D_s^- \to K_s^0K^-$ & $K_s^0 \to \pi^+\pi^-$
- $D_s^- \to K_s^0K^-\pi^+\pi^-$ & $K_s^0 \to \pi^+\pi^-$

$$D_s^{*-} \to D_s^-\gamma$$

$$\mathcal{B}(J/\psi \to D_s^- e^+\nu_e + \text{c.c.}) < 1.3 \times 10^{-6}$$

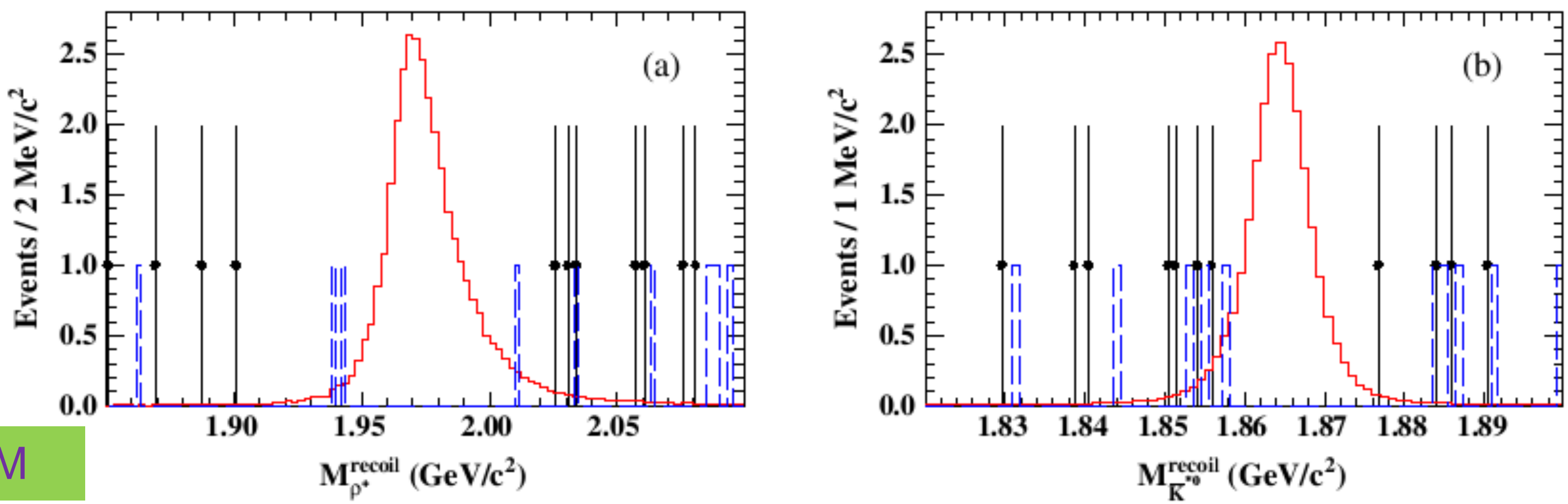
$$\mathcal{B}(J/\psi \to D_s^{*-} e^+\nu_e + \text{c.c.}) < 1.8 \times 10^{-6}$$

PHYSICAL REVIEW D90,112014 (2014)

J/ψ weak decays: hadronic

- $J/\psi \to D_s^- \rho^+$
- $\rho^- \to \pi^+ \pi^0$
- $D_s^+ \to \phi e^- \overline{\nu}_e$
- $\phi \to K^+ K^-$

- $J/\psi \to \overline{D}^0 \overline{K}^{*0}$
- $\overline{K}^{*0} \to K^- \pi^+$
- $\overline{D}^0 \to K^+ e^- \overline{\nu}_e$



225M

$$\mathcal{B}(J/\psi \to D_s^- \rho^+) < 1.3 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \bar{D}^0 \bar{K}^{*0} + \text{c.c.}) < 2.5 \times 10^{-6}$$

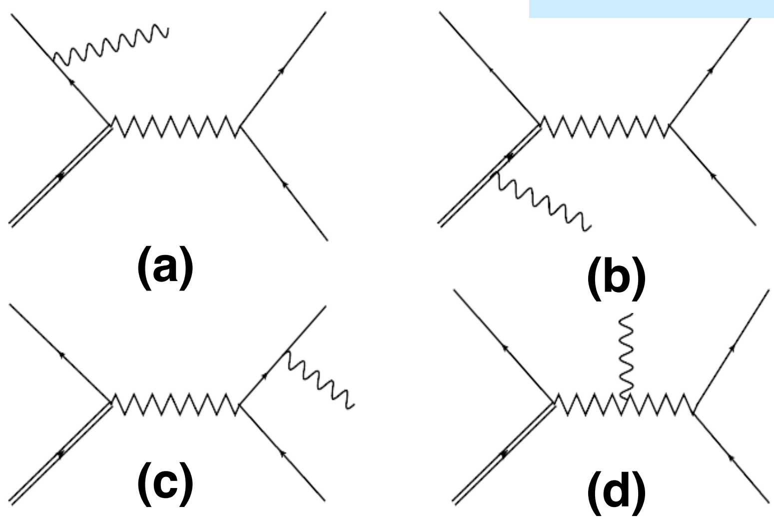
Searches with other states, Dpi, Deta Drho etc are in progress
参见杨友华报告

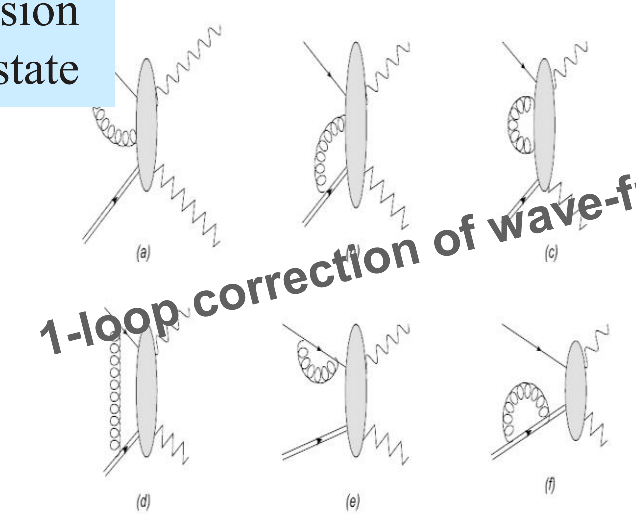
PHYSICAL REVIEW D89,071101(R) (2014)

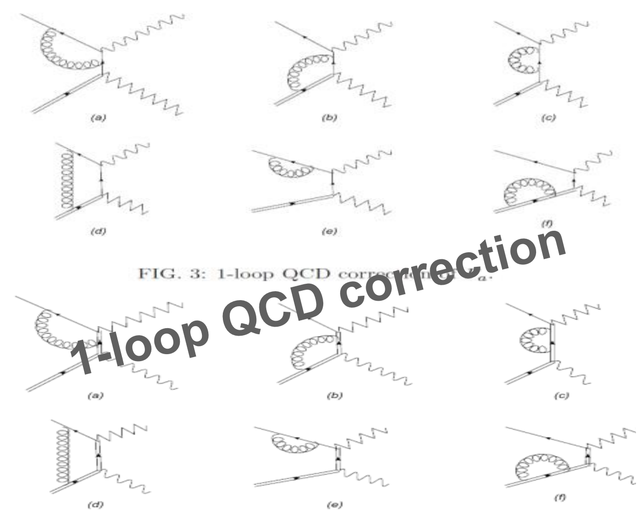
radiative decay $D^+ \to \gamma e^+ \nu_e$

- **Tree level**

No helicity suppression
No hadron in final state

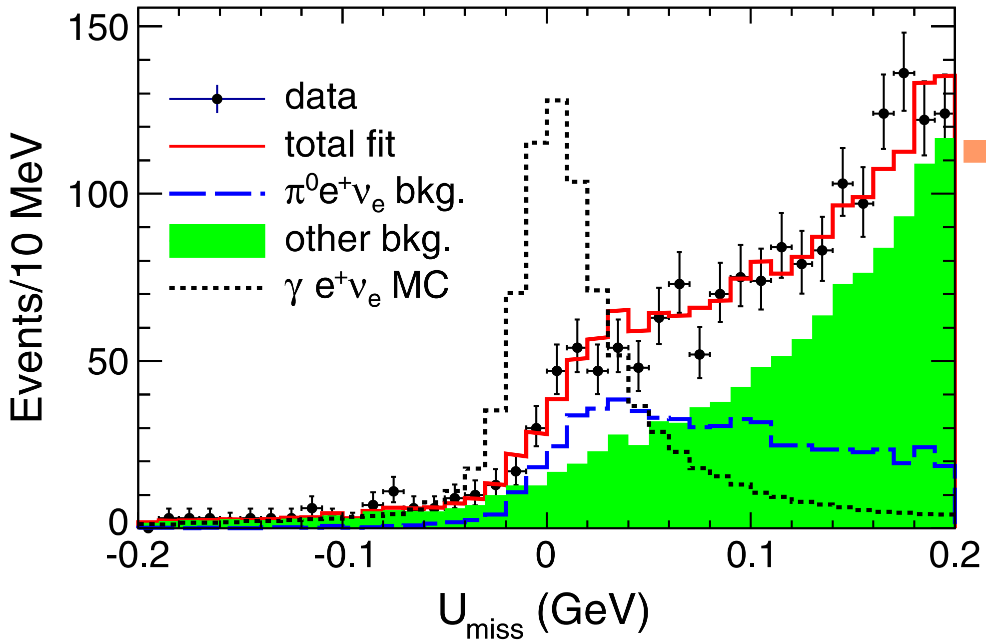






- **Figs. (a) and (b) are Structure-Dependent (SD) radiative decays,**
- **fig. (c) is the Internal Bremsstrahlung (IB) radiative decay.**
- **(d) Suppressed by a factor of $1/M_w^2$, thus can be neglected.**

$D^+ \to \gamma e^+ \nu_e$ search at BESIII



- Double Tag analysis with $2.9 fb^{-1}$ @3.773GeV
- pio e v background normalization with dedicate DT analysis

$$N_{\pi^0}^{\exp} = \frac{N_{\rm DT}^{\pi^0}}{\sum_i \frac{N_{\rm ST}^i}{\varepsilon_{\rm ST}^i}\varepsilon_{{\rm DT},\pi^0}^i} \sum_i \frac{N_{\rm ST}^i}{\varepsilon_{\rm ST}^i}\varepsilon_{{\rm DT},\pi^0}^{i,\gamma},$$

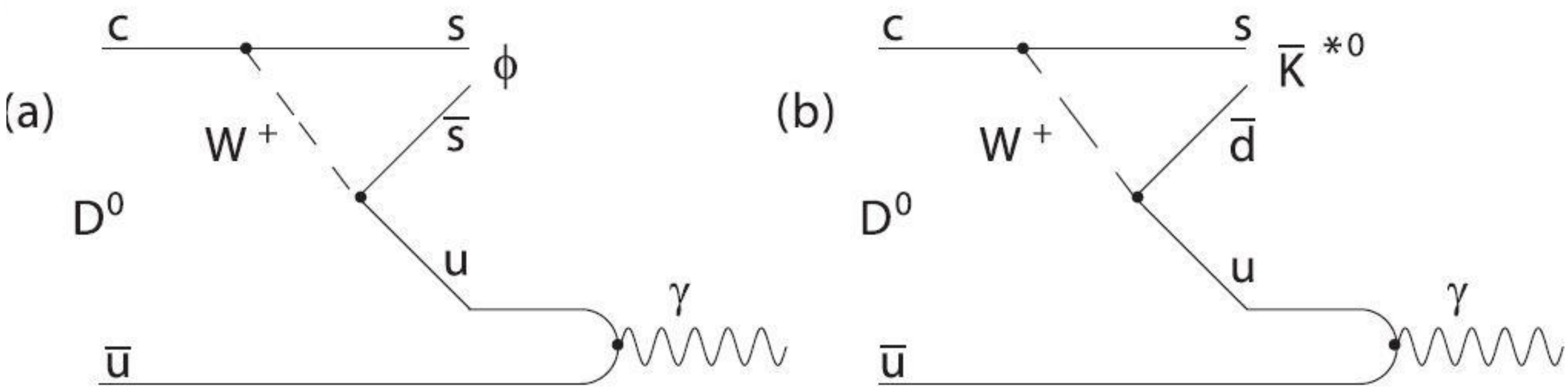
$$\mathcal{B}(D^+ \to \gamma e^+ \nu_e) < 3.0 \times 10^{-5}.$$

With E_γ>10MeV

Source	Relative uncertainty (%)
Signal MC model	3.5
e^+ tracking	0.5
e^+ PID	0.5
γ reconstruction	1.0
Lateral moment	4.4
$\pi^0 e^+ \nu_e$ backgrounds	2.7[a]

PHYSICAL REVIEW D 95, 071102(R) (2017)

Search for $D^0 \to \gamma \overline{K}^{*0}(\phi)$



- Belle Collaboration (2004)
  - $B(D^0 \to \phi\gamma) = \left[2.60^{+0.70}_{-0.61}(stat)^{+0.15}_{-0.17}(syst)\right] \times 10^{-5}$

- BABAR Collaboration (2008)
  - $B(D^0 \to \phi\gamma) = (2.78 \pm 0.30 \pm 0.27) \times 10^{-5}$
  - $B(D^0 \to \overline{K}^{*0}\gamma) = (3.28 \pm 0.20 \pm 0.27) \times 10^{-4}$

- Belle Collaboration (2017)
  - $B(D^0 \to \phi\gamma) = (2.76 \pm 0.19 \pm 0.10) \times 10^{-5}$
  - $B(D^0 \to \overline{K}^{*0}\gamma) = (4.66 \pm 0.21 \pm 0.21) \times 10^{-4}$

- BESIII work in progress
- With present data set, gamma K* could be within reach
- Difficult for phi, due to phi pi0 and phi KL backgrounds

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- More on charm rare decays

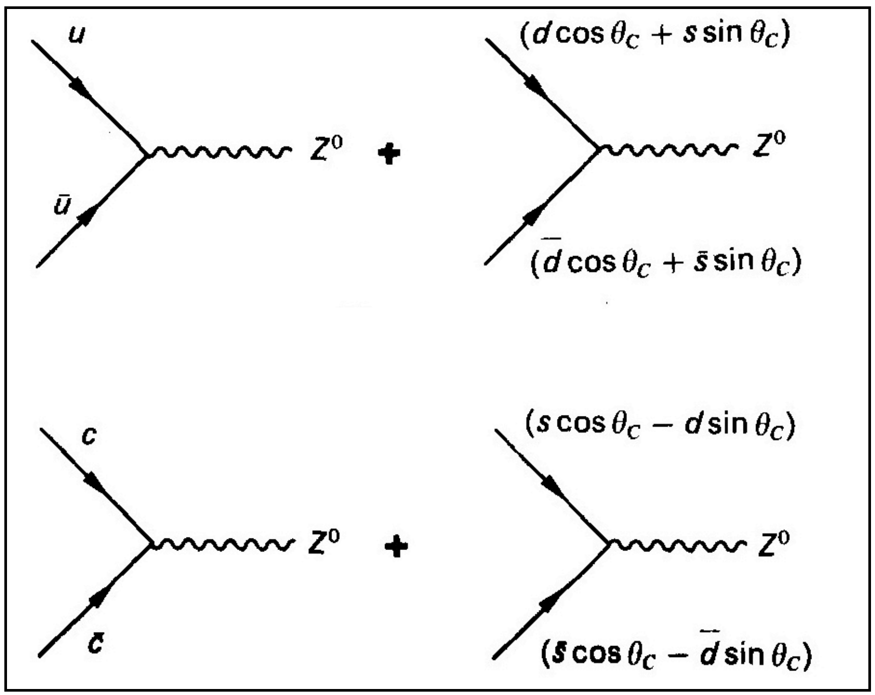
FCNC is suppressed in SM

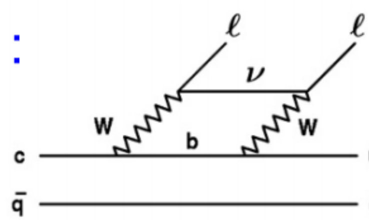
PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

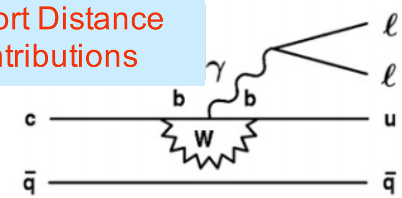
S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

BESIII can probe c→ ull, esp c→ uee
Stronger diagram cancellation than down-types



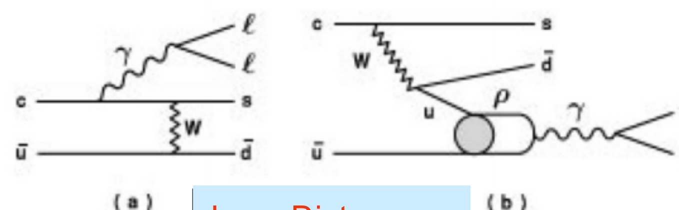


Short Distance contributions



$$\mathcal{L}_{eff}^{SD} = \frac{G_F}{\sqrt{2}} V_{cb}^* V_{ub} \sum_{i=7,9,10} C_i Q_i,$$

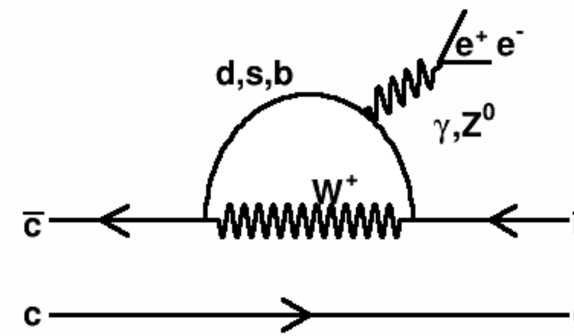
Sensitive to new physics



Long Distance contributions

D → hee

Search for the rare decays J/ψ→ $D^0e^+e^- + c.c.$ and ψ(3686)→ $D^0e^+e^- + c.c.$



dataset: 1310M J/ ψ and 448M ψ(3686)

With D decay modes:

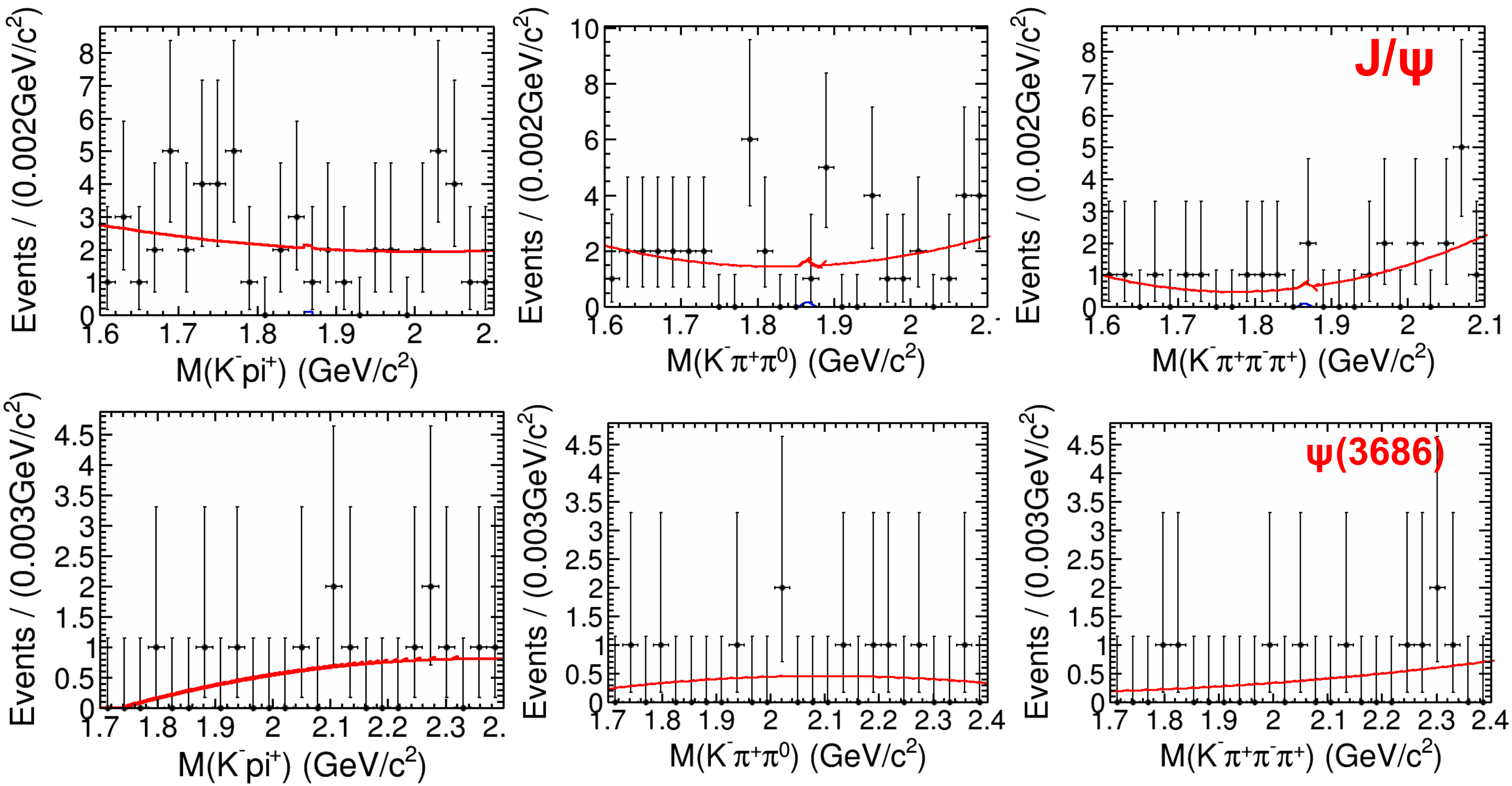
$$D^0 \to K^-\pi^+$$

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

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

Published at Phys. Rev. D96,111101(2017) (RC)

Fitting of D^0 mass spectra



Simultaneous fit for three decay channels.

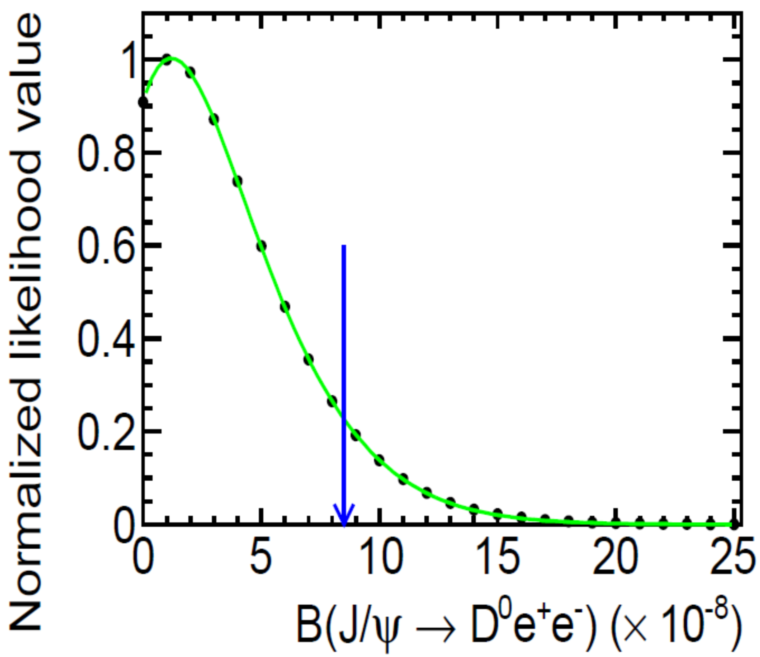
Systematic Uncertainties

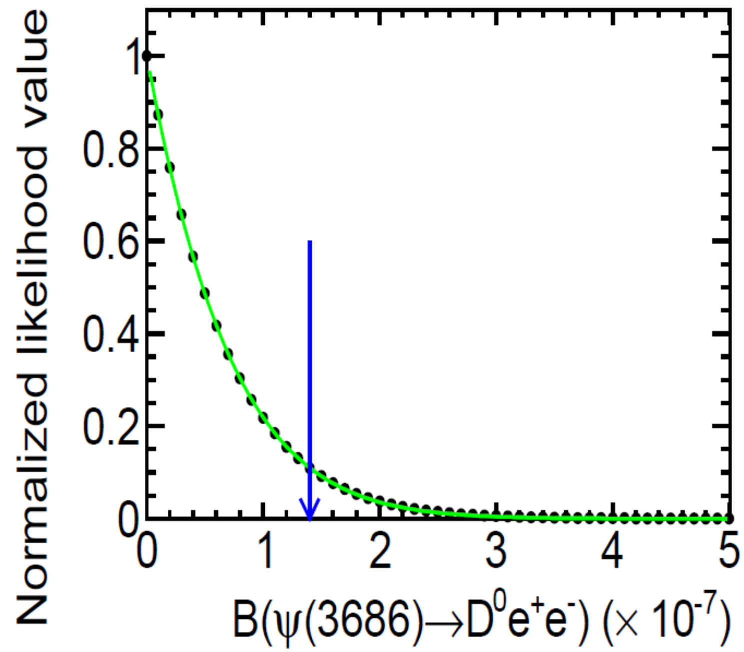
	$D^0 \to K^-\pi^+$		$D^0 \to K^-\pi^+\pi^0$		$D^0 \to K^-\pi^+\pi^+\pi^-$	
	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$
Tracking*	4.0	4.0	4.0	4.0	6.0	6.0
PID*	6.0	6.0	6.0	6.0	8.0	8.0
γ detection	···	···	1.2	1.2	···	···
Kinematic fit	1.7	1.6	1.1	1.8	2.2	2.0
Veto γ conversion*	1.7	1.7	1.7	1.7	1.7	1.7
Veto $K_S \to \pi^0\pi^0$	···	···	0.6	···	···	
Veto $K_S \to \pi^+\pi^-$	···	···	···	···	2.1	2.2
Veto $J/\psi \to e^+e^-$	···	0.1	···	···		···
Branching fraction	1.3	1.3	3.6	3.6	2.6	2.6
ψ total number*	0.55	0.62	0.55	0.62	0.55	0.62
Others	1.0	1.0	1.0	1.0	1.0	1.0
Total	7.8	7.8	8.5	8.7	11.0	10.9

The Upper Limits on BRs

combining three D decay channels

Phys. Rev. D96,111101(2017) (RC)



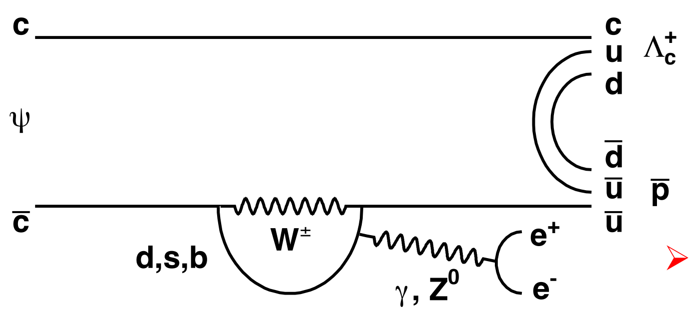


Considering the systematic uncertainty, at 90%C.L.

$J/\psi \to D^0e^+e^- + c.c.$ $< 8.5\times 10^{-8}$ more stringent by 2 orders in magnitude compared to the previous results Phys. Lett. B 639, 418 (2006).

$\psi(3686) \to D^0e^+e^- + c.c.$ $< 1.4 \times 10^{-7}$ set for the first time

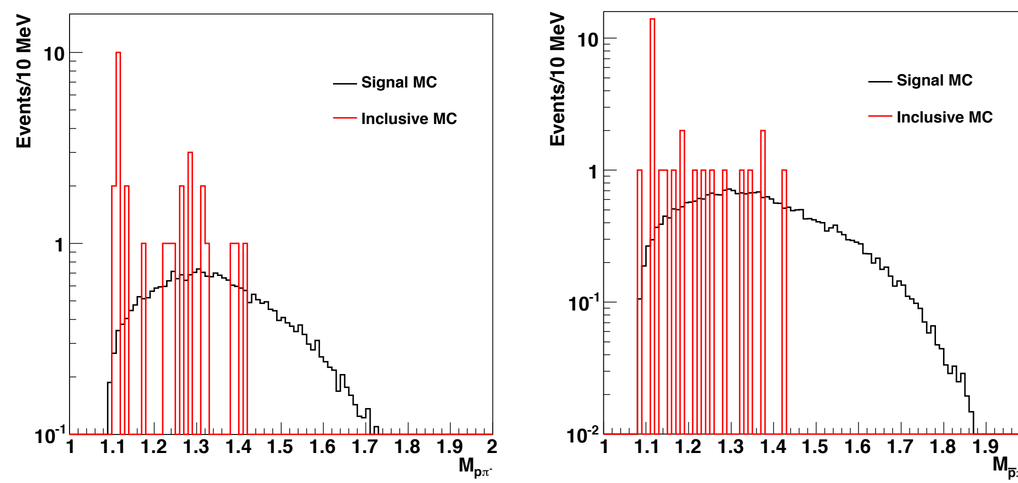
Search $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^- + \text{c.c.}$



New physics models predict the BR could reach ~10^{-6}

Phys. Rev. D 60, 014011(1999);
Nucl. Phys. 25, 461 (2001);

- 29 simulated events remain after 4C kinematic fit, from inclusive $\psi(3686)$ MC sample of 506 M events.
- Most of the background contain Λ or $\bar{\Lambda}$ particle.



- To further remove the background,
  - $M(\bar{p}\pi^+)$>1.13 GeV and $M(p\pi^-)$> 1.13 GeV

Event selection

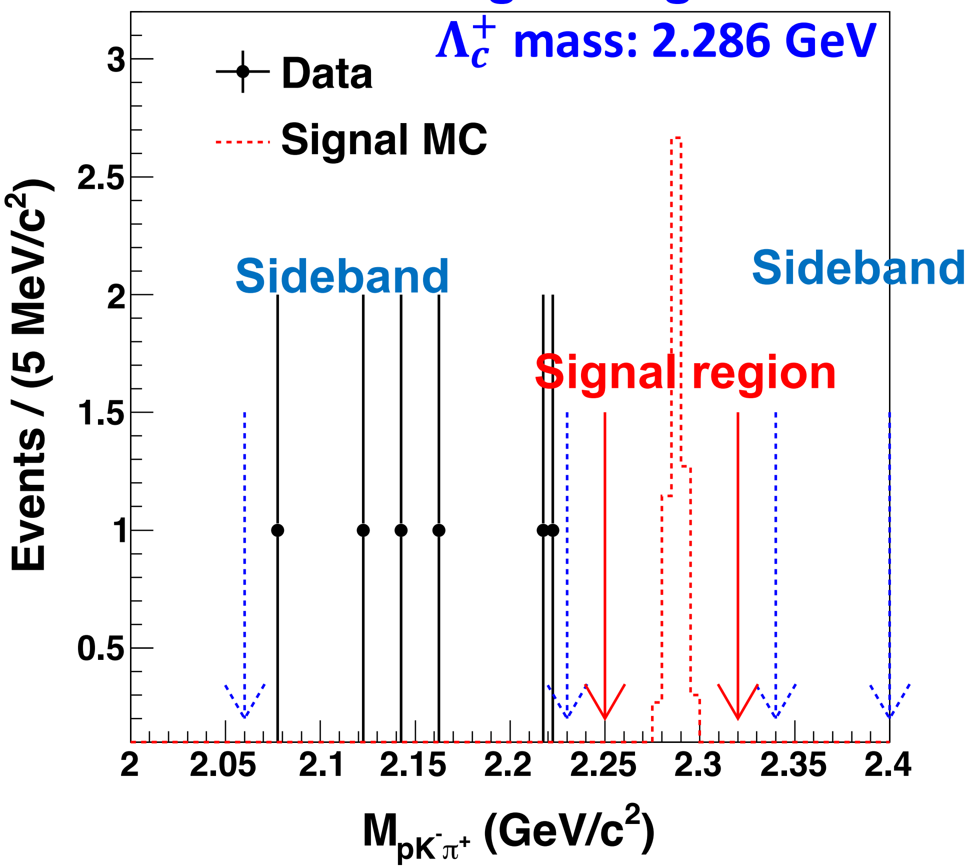
- $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^- + \text{c.c.}$
  - $\Lambda_c^+ \to p K^- \pi^+$
- Final state
  - $p \bar{p} K^- \pi^+ (K^+ \pi^-) e^+ e^-$

- At least 3 positive and 3 negative charged tracks are required with zero net charge
- partID, vertexFit, 4CFit
- Define 2.25≤ $m(\Lambda_c^+)$ ≤2.32 GeV as signal region (>99%)

The continuum background in the $\psi(3686)$ data is negligible.

$\psi(3686) \to \Lambda_c^+ \bar{p} e^+ e^-$ search result

Signal region: 2.25-2.32 GeV.



Phys. Rev. D 97, 091102(RC)(2018)

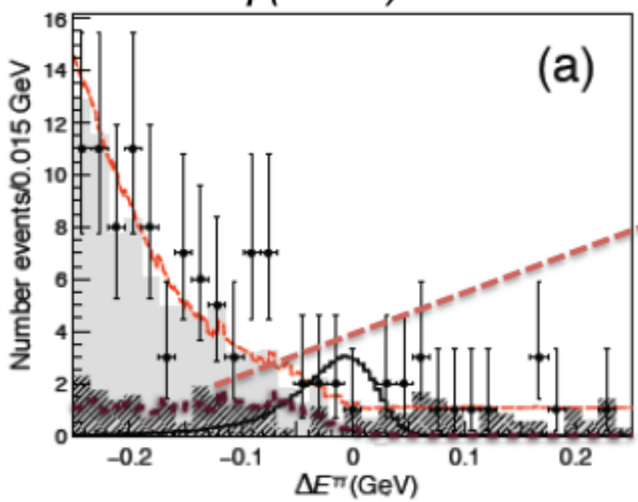
- **No signal is found.**
- **the 90% C.L. upper limit (Nup=47.3) is obtained taking into account the efficiency and systematic uncertainties.**

Nucl. Instrum. Methods A 551 (2005) 493– 503.

- **The BF upper limit @90% C.L. is determined to be 1.7×10^{-6} with systematic uncertainties taken into account.**

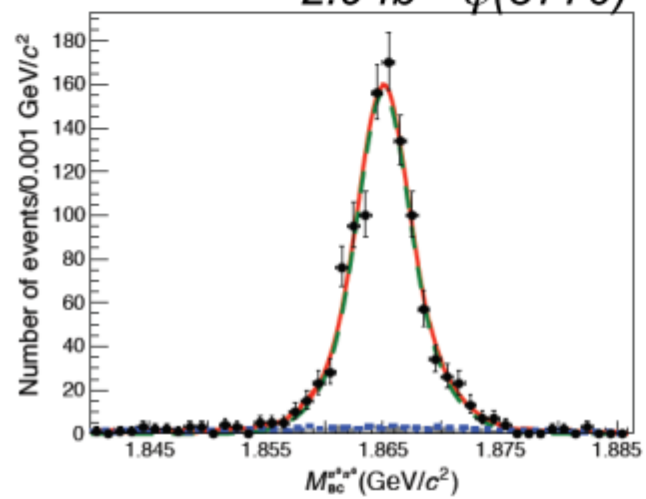
Search for D⁰->γγ: Results

2.9 fb^{-1} $\psi(3770)$

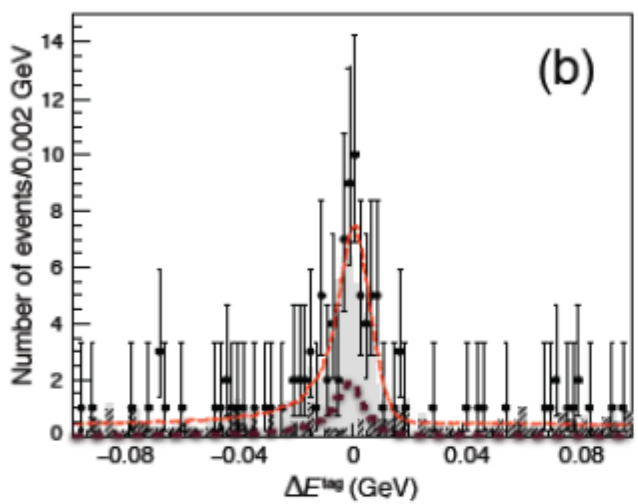


Major background $D^0 \to \pi^0\pi^0$ is determined in data with similar double-tag method.

2.9 fb^{-1} $\psi(3770)$



$B(D^0 \to \pi^0\pi^0) = (8.24 \pm 0.21 \pm 0.30) \times 10^{-4}$



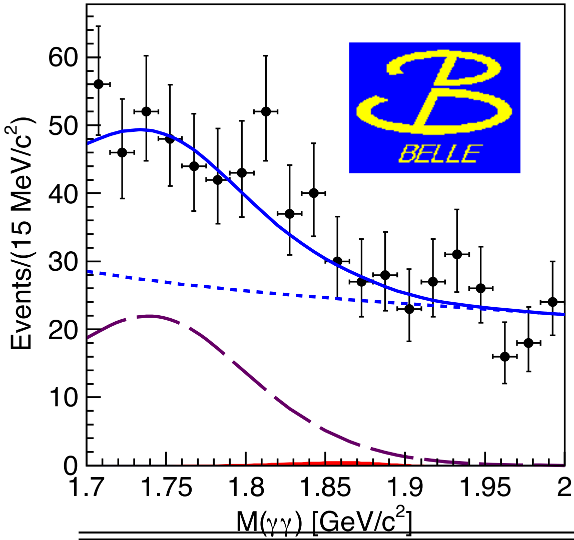
2-D fit to ΔE in both tag side and γγ sides to determine $D^0 \to \gamma\gamma$ yield.

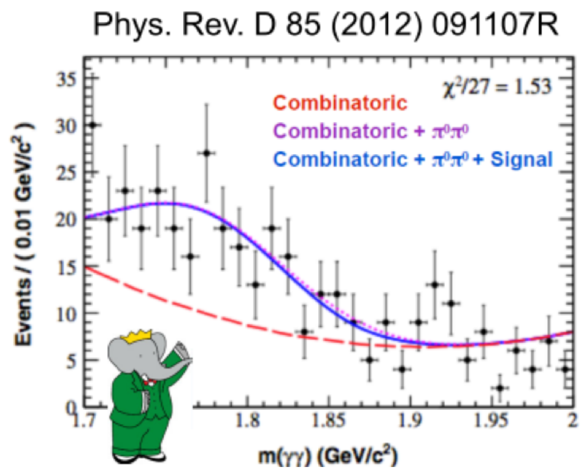
$$B(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$

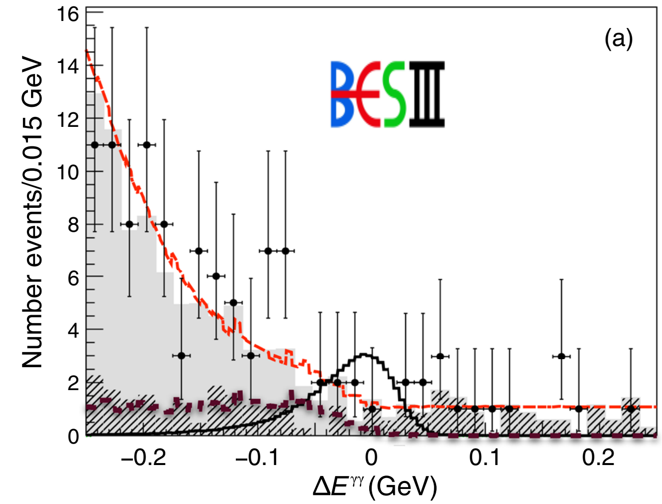
PRD91, 112015 (2015)

Comparison and prospects

PhysRevD(2016).93.051102







Source	Contribution
Cut variation	$\pm 6.8\%$
PDF shape	$^{+4.0}_{-2.4}$ events
Photon detection	$\pm 4.4\%$
K_S^0 reconstruction	$\pm 0.7\%$
π^0 identification	$\pm 4.0\%$
$\mathcal{B}(D^0 \to K_S^0\pi^0)$	$\pm 3.3\%$

Uncertainties independent of fitting procedure	
Source	Relative uncertainty (%)
Photon reconstruction	2.0
$M_{\rm BC}^{\gamma\gamma}$ requirement	3.1
ST D^0 yields	1.0
Total	3.8

- BESIII has the least background contamination
- and very good control of systematics
- Could still be competitive with the final DDbar sample

Detailed projection study is needed to check what is the critical points for DDbar sample size

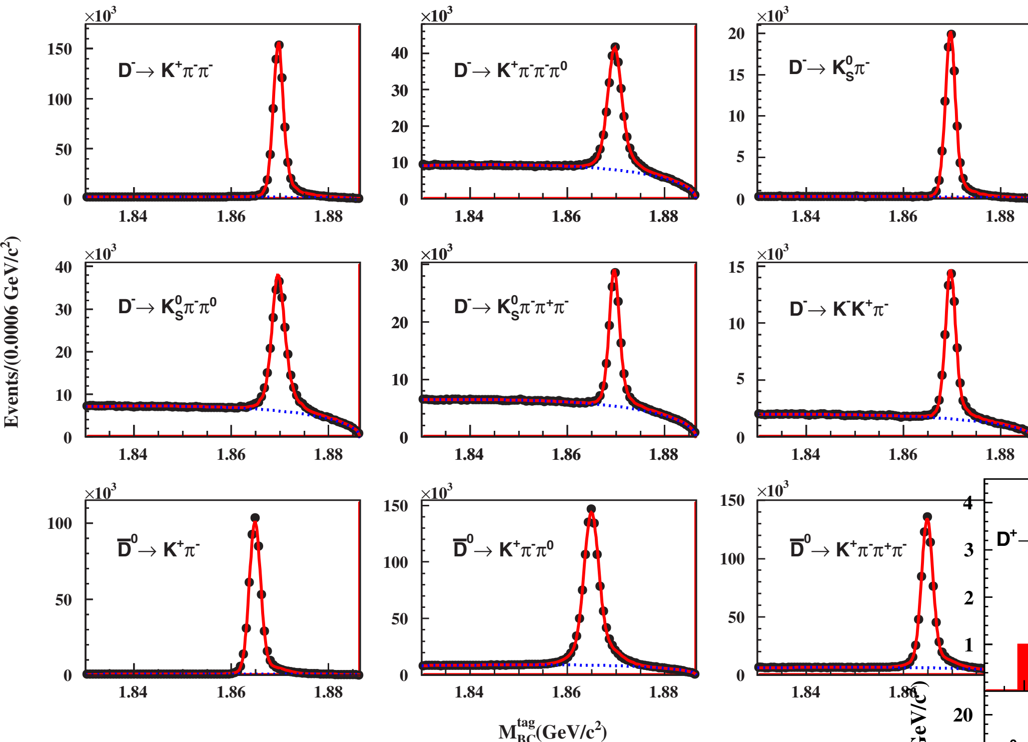
D->h(h')ee: previous results

Decay	Upper limit	Experiment	Year	Ref.
$D^0 \to \pi^0 e^+ e^-$	45.0	CLEO	1996	[14]
$D^0 \to \eta e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \omega e^+ e^-$	180.0	CLEO	1996	[14]
$D^0 \to \overline{K}^0 e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \rho e^+ e^-$	124.0	E791	2001	[15]
$D^0 \to \phi e^+ e^-$	59.0	E791	2001	[15]
$D^0 \to \overline{K}^{*0} e^+ e^-$	47.0	E791	2001	[15]
$D^0 \to \pi^+ \pi^- e^+ e^-$	370.0	E791	2001	[15]
$D^0 \to K^+ K^- e^+ e^-$	315.0	E791	2001	[15]
$D^0 \to K^- \pi^+ e^+ e^-$	385.0	E791	2001	[15]
$D^+ \to \pi^+ e^+ e^-$	1.1	BaBar	2011	[16]
$D^+ \to K^+ e^+ e^-$	1.0	BaBar	2011	[16]
$D^+ \to \pi^+ \pi^0 e^+ e^-$				
$D^+ \to \pi^+ K^0_S e^+ e^-$				
$D^+ \to K^+ \pi^0 e^+ e^-$				
$D^+ \to K^+ \overline{K}^0 e^+ e^-$				

In unit of 10^{-6}

- Previous D^0 limits are in the level of $10^{-5} \sim 10^{-4}$
- D^+ limits are better, but only few three-body decays
- LHCb observed some four-body decays of $D^0 \to hh\mu^+\mu^-$ at 10^{-7} level
- BESIII could probe all of the above e+e- modes

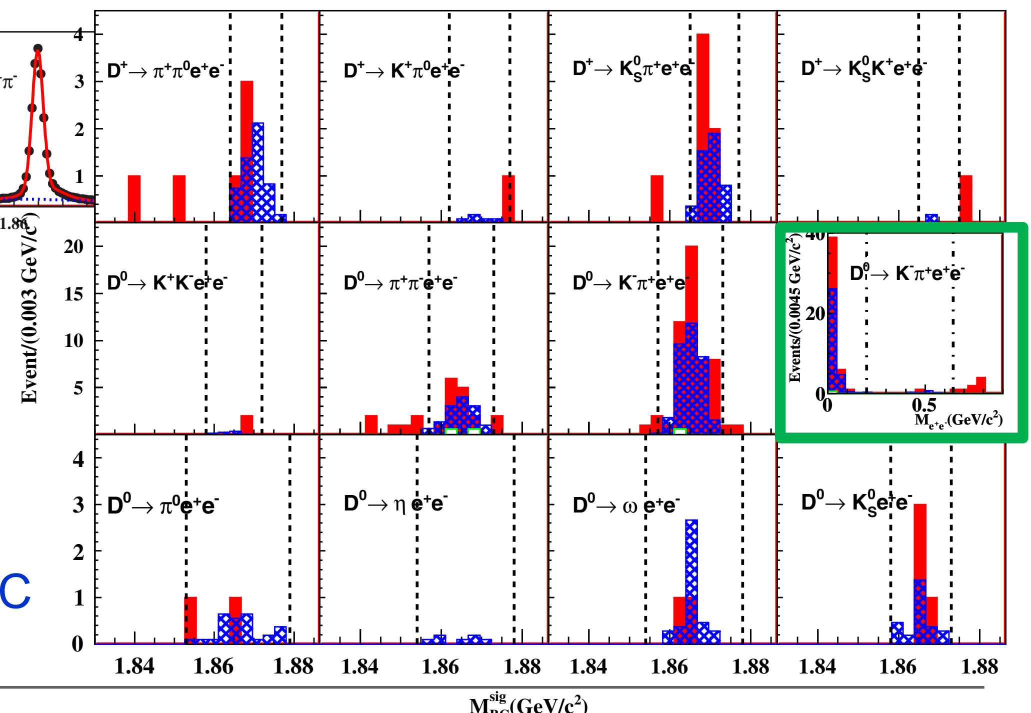
Double tag(DT) analysis



DT: Fully make use of DD pair production at threshold

- Event is very clean, bkg low
- High tagging efficiency
- Many systematic uncertainties can be cancelled
- Could measure absolute BFs

Blind analysis based on Monte Carlo (MC) simulations to validate the analysis strategy,



Data
Inclusive MC
sideband

$D \to h(h')ee$: BESIII results

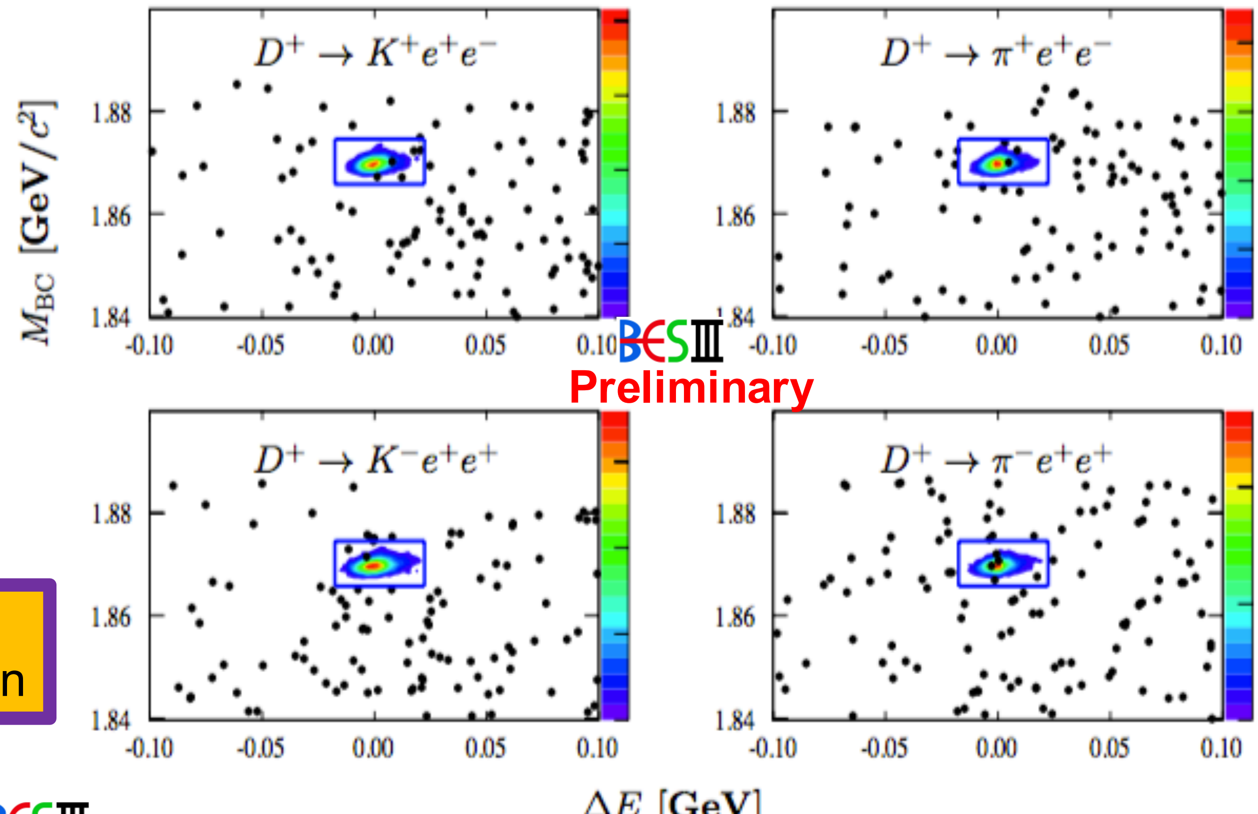
Signal decays	$\mathcal{B}$ ($\times 10^{-5}$)	PDG [9] ($\times 10^{-5}$)
$D^+ \to \pi^+\pi^0 e^+e^-$	<1.4	$\cdots$
$D^+ \to K^+\pi^0 e^+e^-$	<1.5	$\cdots$
$D^+ \to K_S^0\pi^+ e^+e^-$	<2.6	$\cdots$
$D^+ \to K_S^0 K^+ e^+e^-$	<1.1	$\cdots$
$D^0 \to K^-K^+ e^+e^-$	<1.1	<31.5
$D^0 \to \pi^+\pi^- e^+e^-$	<0.7	<37.3
$D^0 \to K^-\pi^+ e^+e^{-\dagger}$	<4.1	<38.5
$D^0 \to \pi^0 e^+e^-$	<0.4	<4.5
$D^0 \to \eta e^+e^-$	<0.3	<11
$D^0 \to \omega e^+e^-$	<0.6	<18
$D^0 \to K_S^0 e^+e^-$	<1.2	<11
† in $M_{e^+e^-}$ regions:		
$[0.00, 0.20)$ GeV/c^2	<3.0 ($1.5^{+1.0}_{-0.9}$)	$\cdots$
$[0.20, 0.65)$ GeV/c^2	<0.7	$\cdots$
$[0.65, 0.90)$ GeV/c^2	<1.9 ($1.0^{+0.5}_{-0.4}$)	$\cdots$

- With double tag technique at threshold, both D^0 and D^+ FCNC are studied.
- UL for D^+ 4-track events are provided for 1st time
- other FCNC upper limits are greatly improved
- divide the M(ee) distribution into 3 regions for Kpiee to help separate LD effect

Phys. Rev. D 97, 072015 (2018)

Babar claimed observation of $D^0 \to K^-\pi^+e^+e^-$ in ICHEP2018, consistent with BESIII limit

$D^+ \to h^+e^+e^-$ and $D^+ \to h^-e^+e^+$



Need to publish soon

BESIII Preliminary

	$N_{\rm inside}^{\rm data}$	$N_{\rm outside}^{\rm data}$	$f_{\rm scale}$	ϵ [%]	$\Delta_{\rm sys}$ [%]	s_{90}	$\mathcal{B}[\times 10^{-6}]$
$D^+ \to K^+e^+e^-$	5	69	0.08 ± 0.01	22.53	5.4	19.4	< 1.2
$D^+ \to K^-e^+e^+$	3	55	0.08 ± 0.01	24.08	6.1	10.2	< 0.6
$D^+ \to \pi^+e^+e^-$	3	65	0.09 ± 0.02	25.72	5.9	4.2	< 0.3
$D^+ \to \pi^-e^+e^+$	5	68	0.06 ± 0.02	28.08	6.8	20.5	< 1.2

Search for $D^0 \to \pi^0 \nu\bar{\nu}$:

- EM dynamics is absent
- LD contributions are much suppressed
- Much clean to probe FCNC transitions in charm
- Could be complementary to results from B mesons
  - Belle B → $h^{(*)}$ νν: Phys. Rev. Lett. 99, 221802 (2007).
  - BaBar B^0 →γνν: Phys. Rev. Lett. 93, 091802 (2004).

Decay mode	Experimental limit	$Br_{S.D.}$	$Br_{L.D.}$
$D^+ \to X_u^+ e^+ e^-$		2×10^{-8}	
$D^+ \to \pi^+ e^+ e^-$	$<4.5\times10^{-5}$		2×10^{-6}
$D^+ \to \pi^+ \mu^+ \mu^-$	$<1.5\times10^{-5}$		1.9×10^{-6}
$D^+ \to \rho^+ e^+ e^-$	$<1.0\times10^{-4}$		4.5×10^{-6}
$D^0 \to X_u^0 e^+ e^-$		0.8×10^{-8}	
$D^0 \to \pi^0 e^+ e^-$	$<6.6\times10^{-5}$		0.8×10^{-6}
$D^0 \to \rho^0 e^+ e^-$	$<5.8\times10^{-4}$		1.8×10^{-6}
$D^0 \to \rho^0 \mu^+ \mu^-$	$<2.3\times10^{-4}$		1.8×10^{-6}
$D^+ \to X_u^+ \nu\bar{\nu}$		1.2×10^{-15}	
$D^+ \to \pi^+ \nu\bar{\nu}$			5×10^{-16}
$D^0 \to \bar{K}^0 \nu\bar{\nu}$			2.4×10^{-16}
$D_s \to \pi^+ \nu\bar{\nu}$			8×10^{-15}

Pure neutral final state with missing momenta.
Unique for BESIII,
Work ongoing

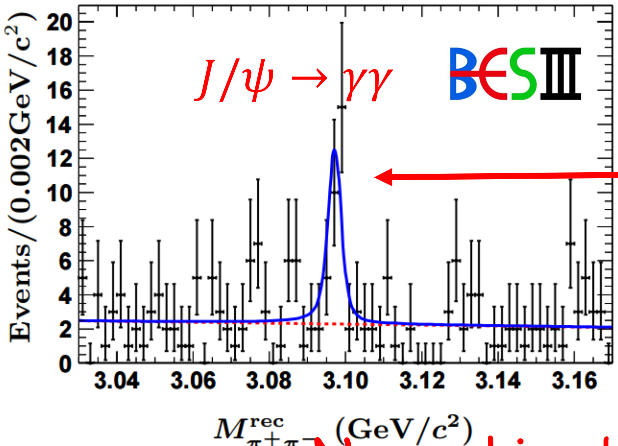
Phys. Rev. D 66 014009

Selected topics from BESIII

- the processes that are allowed in the SM (but rare)
  - Charmonia weak decays
  - Charm meson radiative decays
- processes that are not allowed in the SM at tree level
  - FCNC processes
- processes that are not allowed/existent in the SM
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - C-violation EM processes and C and CP violation decays
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays
- More on charm rare decays

Search for C-violation EM processes

PRD **90**,092002(2014)

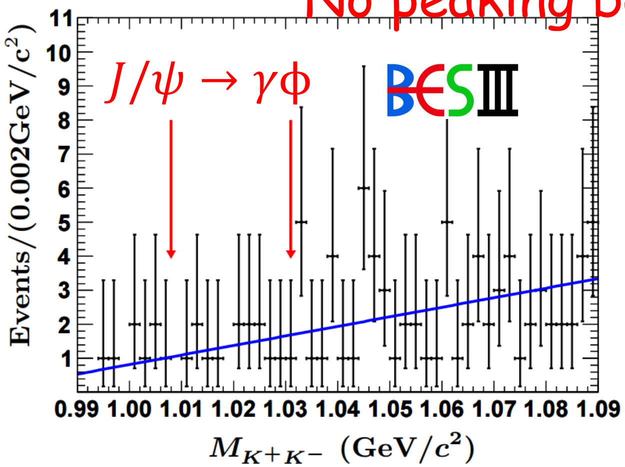


Peaking background

Background channel	Expected counts (N^{bkg})
$J/\psi \to \gamma\pi^0, \pi^0 \to 2\gamma$	18.5 ± 1.9
$J/\psi \to \gamma\eta, \eta \to 2\gamma$	24.6 ± 1.6
$J/\psi \to \gamma\eta_c, \eta_c \to 2\gamma$	1.3 ± 0.3
$J/\psi \to 3\gamma$	0.9 ± 0.3
Total	45.3 ± 2.5

$$\mathcal{B}(J/\psi \to f) < \frac{N^{up}_{sig}}{N^{tot}_{\psi(3686)} \times \epsilon \times \mathcal{B}_i \times (1-\Delta_{sys})}$$

No peaking background



B($J/\psi \to \gamma\gamma$) < 5×10^{-6} CLEO: PRL 101, 101801 (2008)

B($J/\psi \to \gamma\gamma$) < 2.7×10^{-7}

- Improve a magnitude for $J/\psi \to \gamma\gamma$

B($J/\psi \to \gamma\phi$) < 1.4×10^{-6}

- Unique report for $J/\psi \to \gamma\phi$

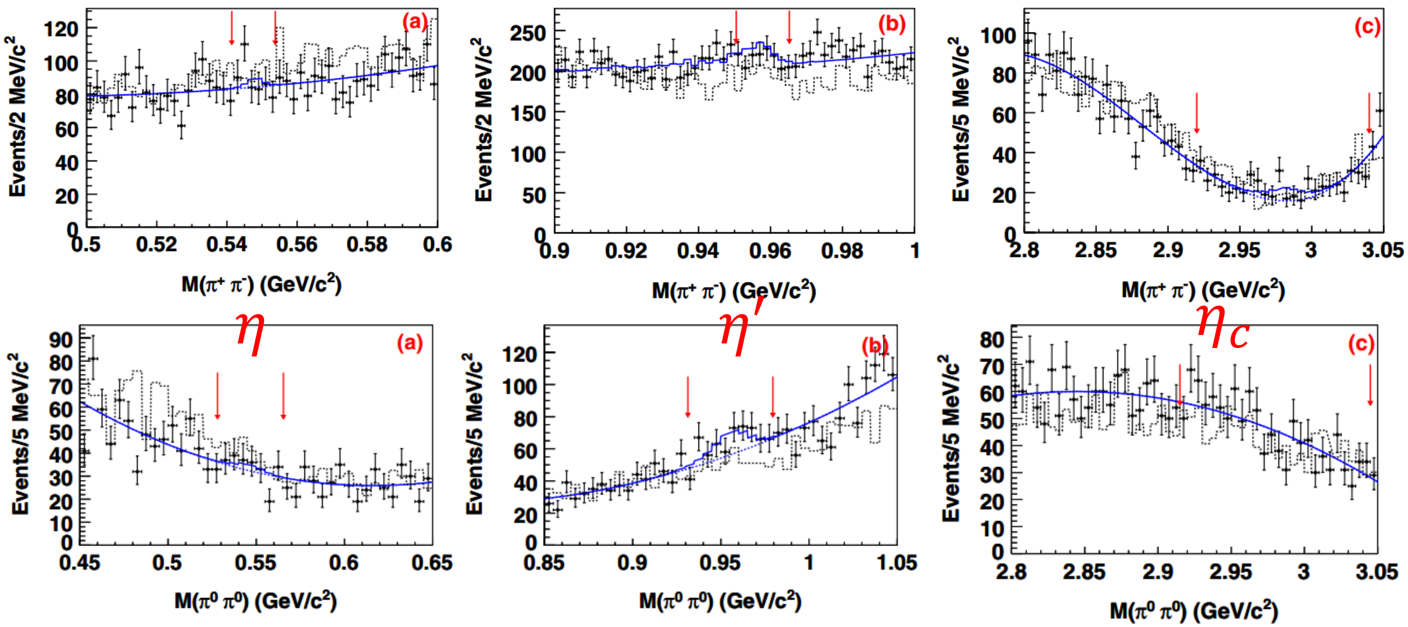
CP and P violating pseudoscalar decays

- SM predicted BR: $\sim 10^{-27}$ (weak interaction only)
- BR can be enhanced to $10^{-17} \sim 10^{-15}$ by introducing a CP violation term in QCD lagrangian or allowing a CP violation in the extended Higgs sector .
  - 225M J/ψ data: $J/\psi \to \gamma P$, $P \to \pi\pi$

PRD **84**,032006(2011)

$\pi^+\pi^-$

$\pi^0\pi^0$



Process	$N_{\rm sig}^{\rm UP}$	ε (%)	$\sigma_{\rm sys}$ (%)	S	$\mathcal{B}^{\rm UP}$
$\eta \to \pi^+\pi^-$	48	54.28	7.3	0.8σ	3.9×10^{-4}
$\eta' \to \pi^+\pi^-$	32	53.81	8.6	0.1σ	5.5×10^{-5}
$\eta_c \to \pi^+\pi^-$	92	25.27	27	1.5σ	1.3×10^{-4}
$\eta \to \pi^0\pi^0$	36	23.75	8.6	0.6σ	6.9×10^{-4}
$\eta' \to \pi^0\pi^0$	110	23.18	8.5	2.6σ	4.5×10^{-4}
$\eta_c \to \pi^0\pi^0$	40	35.70	28	0.1σ	4.2×10^{-5}

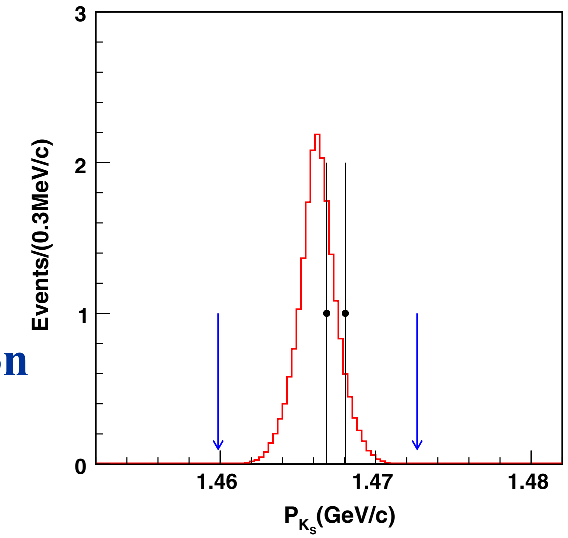
(90%CL)

- η' and η_c results are the world best , provide experimental limits for theoretical study.

Search for $J/\psi \to K_S K_S$
testing EPR and K^0 oscillation model

- **Search for $J/\psi \to K_S K_S$**
  - CP and Bose-Einstein statistics violating process
  - EPR: $\sim 10^{-8}$ level
  - K^0 oscillation model: 10^{-9}
  - Compared MARKIII and BESII, the upper limit is improved by 10^2 and reaches the order of EPR expectation

$N_{\rm obs}$	2
$N_{\rm bkg}$	2.4
N^{UL}	4.7
$\epsilon_{\rm MC}$ (%)	25.7
$\mathcal{B}(J/\psi \to K_S K_S)$ (95% C.L.)	$< 1.4 \times 10^{-8}$

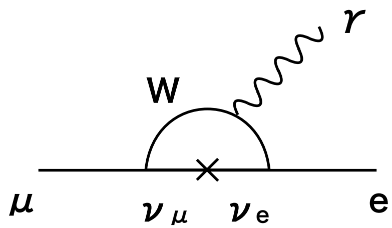


arXiv: 1710.05738
PRD 96, 112001 (2017)

- **Measurement of $\mathcal{B}(J/\psi \to K_S K_L)$**
  - $\mathcal{B}(J/\psi \to K_S K_L) = (1.91 \pm 0.01(stat.) \pm 0.05(syst.)) \times 10^{-4}$.
  - the precision is improved from 19%(PDG) to 2.6%, while the central value consistent.

Search for Charge flavor lepton violation(cFLV) process

Considering neutrino mixing, extended νSM

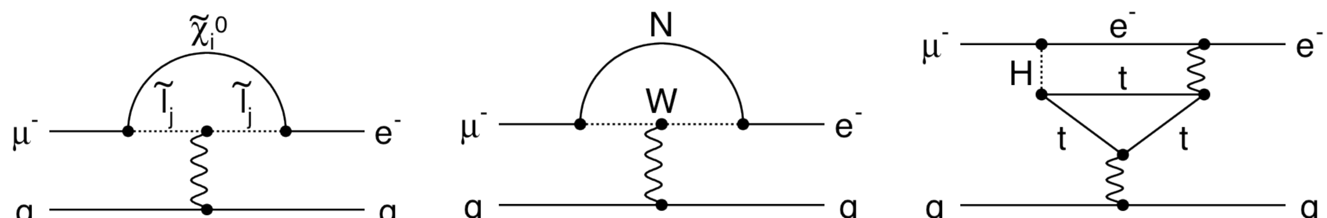


$$\mathcal{M} \propto \sum_j U_{ej} U^*_{\mu j} \frac{m_j^2}{M_W^2}$$

$$\sim \mathcal{O}(10^{-54})$$

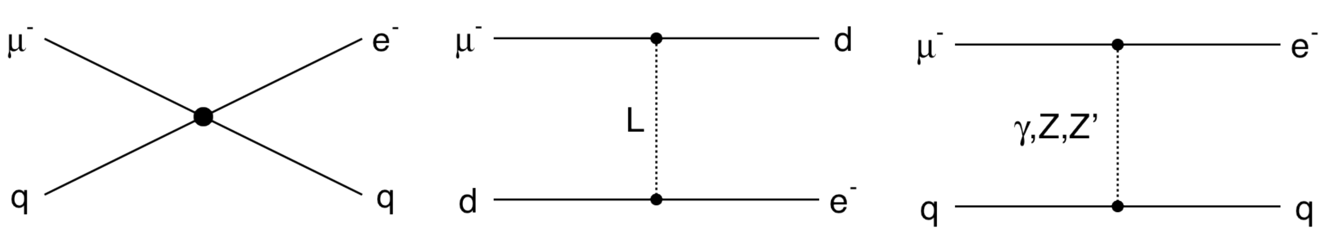
Possible CLFV from NP models

Loops



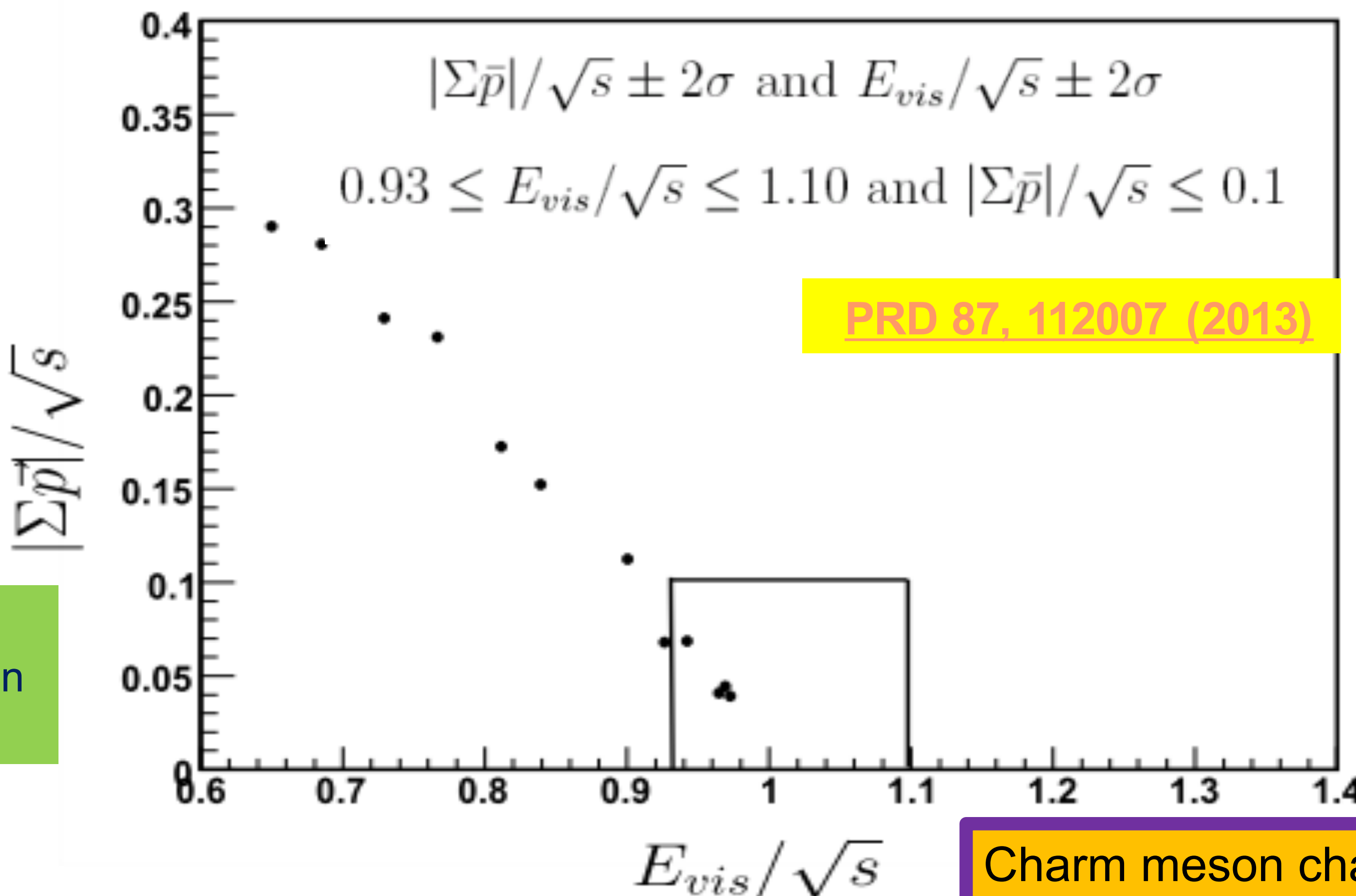
Supersymmetry | Heavy Neutrinos | Extended higgs models

Contact Terms



Compositeness | Leptoquarks | New Heavy Bosons / Anomalous Couplings

J/ψ → eμ: Unblinded Data and Results



PRD 87, 112007 (2013)

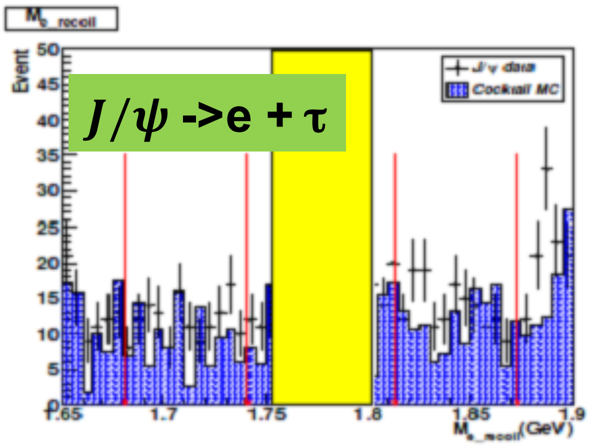
Among 225M J/ψ, 4 events in the signal box

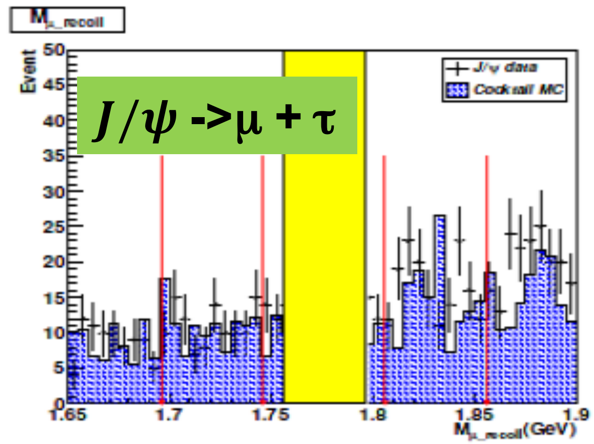
$$\mathcal{B}(J/\psi \to e\mu) < 1.6 \times 10^{-7} \text{ (90\% C.L.)}$$

Charm meson channels are also possible, to be investigated

cFLV searches in J/ψ: Prospects

$$\mathcal{A}(V \to \ell_1\bar{\ell}_2) = \bar{u}(p_1,s_1)\left[A_V^{\ell_1\ell_2}\gamma_\mu + B_V^{\ell_1\ell_2}\gamma_\mu\gamma_5 + \frac{C_V^{\ell_1\ell_2}}{m_V}(p_2-p_1)_\mu + \frac{iD_V^{\ell_1\ell_2}}{m_V}(p_2-p_1)_\mu\gamma_5\right] v(p_2,s_2)\ \epsilon^\mu(p)$$





$J/\psi \to e(\mu)\,\tau$
$J/\psi \to e\,\mu$
$J/\psi \to \gamma\, e(\mu)\,\tau$
$\psi(2s) \to \gamma\, e(\mu)\,\tau$

Expected to *improve the UL by* $\sim 10^2$

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
Current UL	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
BESIII projected(CC)	3.0×10^{-8}	4.5×10^{-8}	1.0×10^{-8}
BESIII projected(MVA/ML)	1.5×10^{-8}	2.5×10^{-8}	6.0×10^{-9}

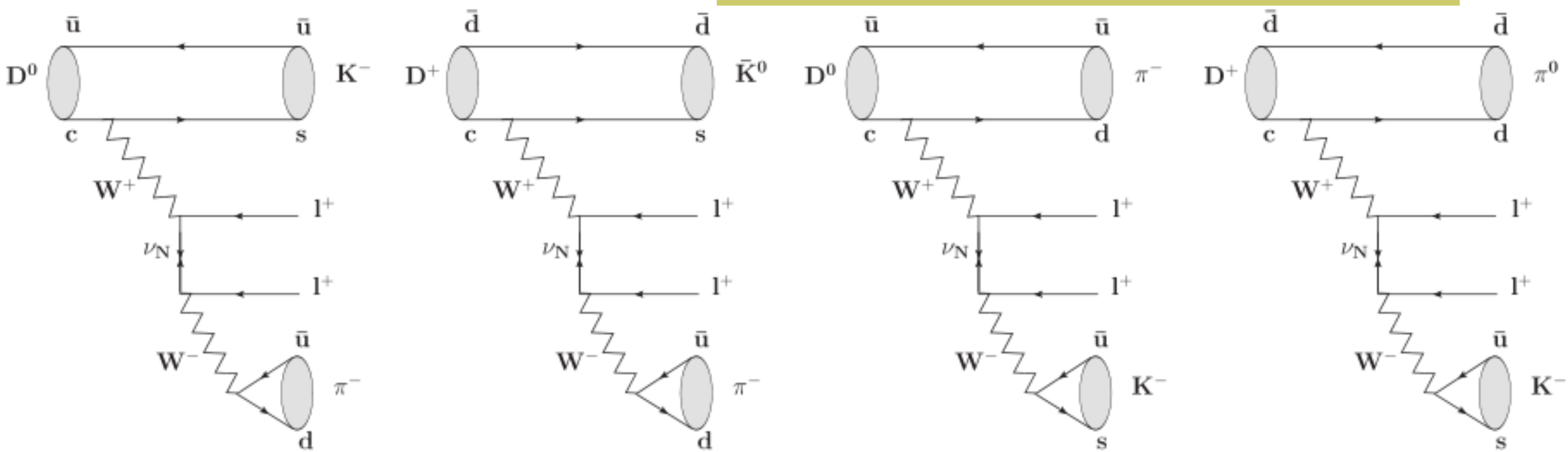
Wilson coeff (GeV^{-2})	Leptons $\ell_1\ell_2$	Constraints Current	Constraints Projected
$\lvert C_{VL}^{cc\ell_1\ell_2}/\Lambda^2\rvert$	$\mu\tau$	5.5×10^{-5}	$[5.0,7.1]\times10^{-6}$
	$e\tau$	1.1×10^{-4}	$[6.5,8.7]\times10^{-6}$
	$e\mu$	1.0×10^{-5}	$[2.8,3.7]\times10^{-6}$

Phys. Rev. D **87**, 112007 (2013).

efficiencies ~30-35%

Search for LNV: D→Kπe⁺e⁺

H.R. Dong et al Chin, Phys. C **39** 013101 (2015).

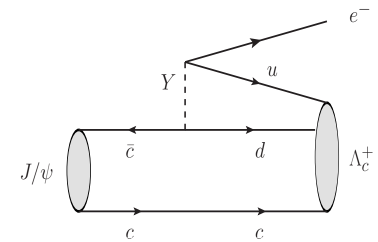


(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

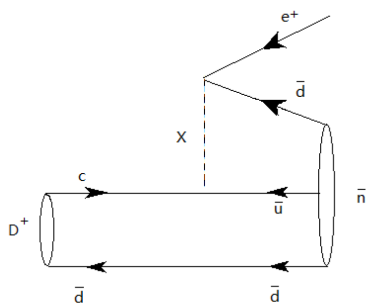
- **Lepton number violating(LNV) process (ΔL =2)**
  - **possibly due to a single Majorana neutrino exchange**
- **The best BR limit around 10^{-4} ~10^{-5} level by E791[PRL 86, 3969(2001)].**
- **BESIII could improve them to ~10^{-6}**
- **Further constrain mass-dependent D→K$e^+\nu_N$(πe^+) decay**
  - **constrain mixing matrix element $|V_{eN}|^2$**
- **Work in progress, the results to be published**

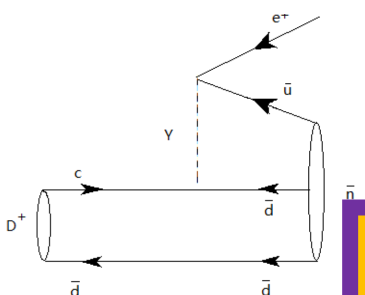
Search for BNV process

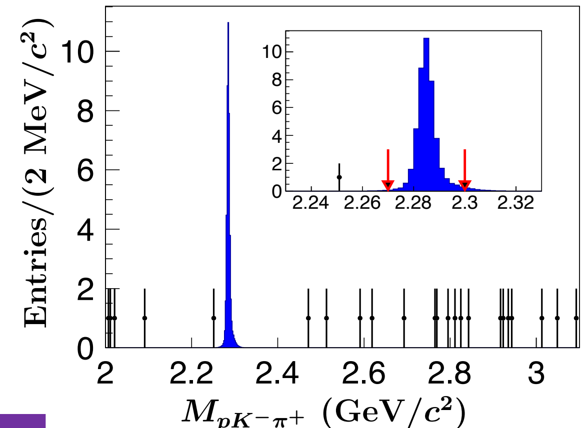
- The first of **"Sakharov conditions"**: "there must be BNV process"
- Many theory could have BNV, such as Georgi – Glashow GUT model, there are X and Y bosons with charges 4/3 and 1/3, which couples quarks and leptons and thus BNV and LNV

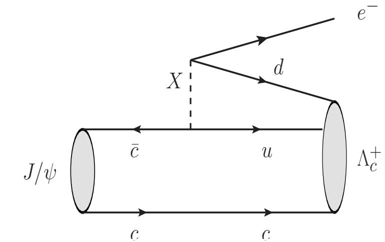


Phys.Rev.Lett. 32 (1974) 438-441









$\Delta B=1,\ \Delta(B-L)=0$

arxiv: 1803.04789
Submitted to PRL

$B(J/\psi \rightarrow \Lambda_c^+ e^-) < 6.9 \times 10^{-8}$

expected UL with $10^{10} J/\psi$: 10^{-9}

粲介子相关寻找
$D^+ \to \bar{\Lambda}(\bar{\Sigma}) e^+$
$D_s \to \Lambda\, e$
$D^+ \to \bar{n}\, e^+$
$D^0 \to \bar{p}\, e^+$
will benefit from the final charm dataset

light Higgs search:Motivation

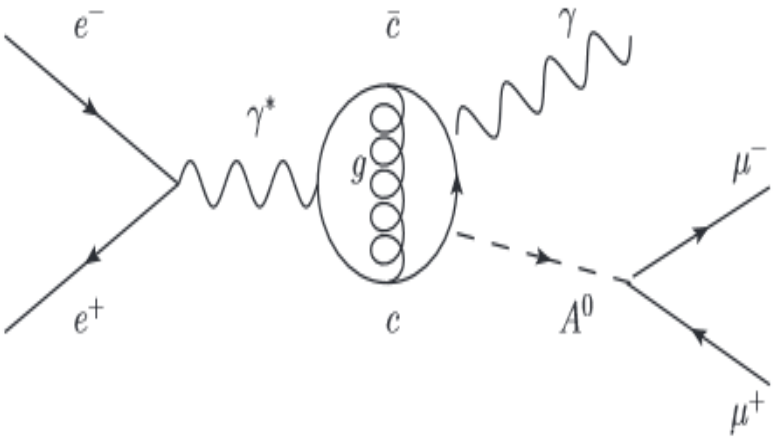
- Coupling of fermions and the CP-odd Higgs A^0 in the NMSSM:

$$L_{\mathrm{int}}^{f\bar{f}} = -\cos\theta_A \tan\beta \frac{m_f}{v} A^0 \bar{d}(i\gamma_5)d,$$

d = d, s, **b**, e, μ, τ

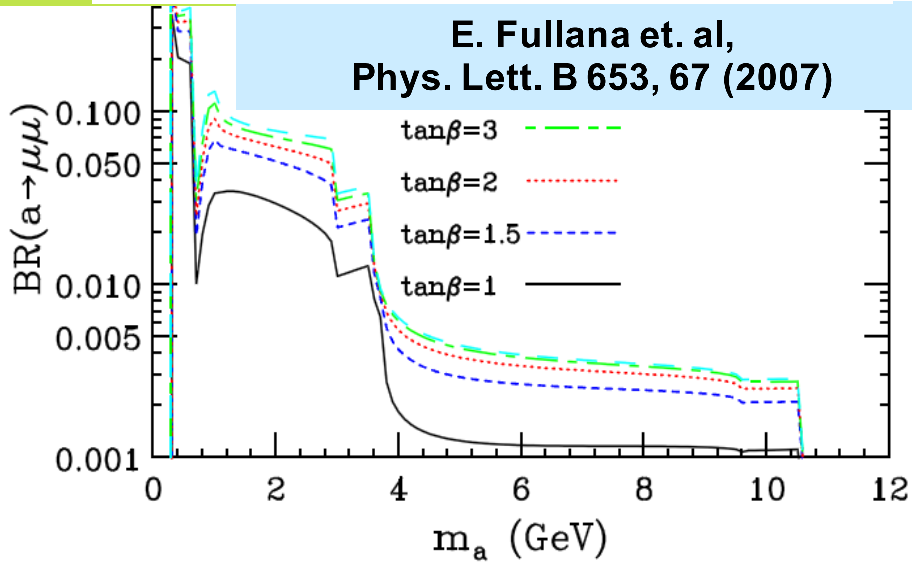
$$L_{\mathrm{int}}^{f\bar{f}} = -\cos\theta_A \cot\beta \frac{m_f}{v} A^0 \bar{u}(i\gamma_5)u,$$

u = u, **c**, t, ν_e, ν_μ, ν_τ



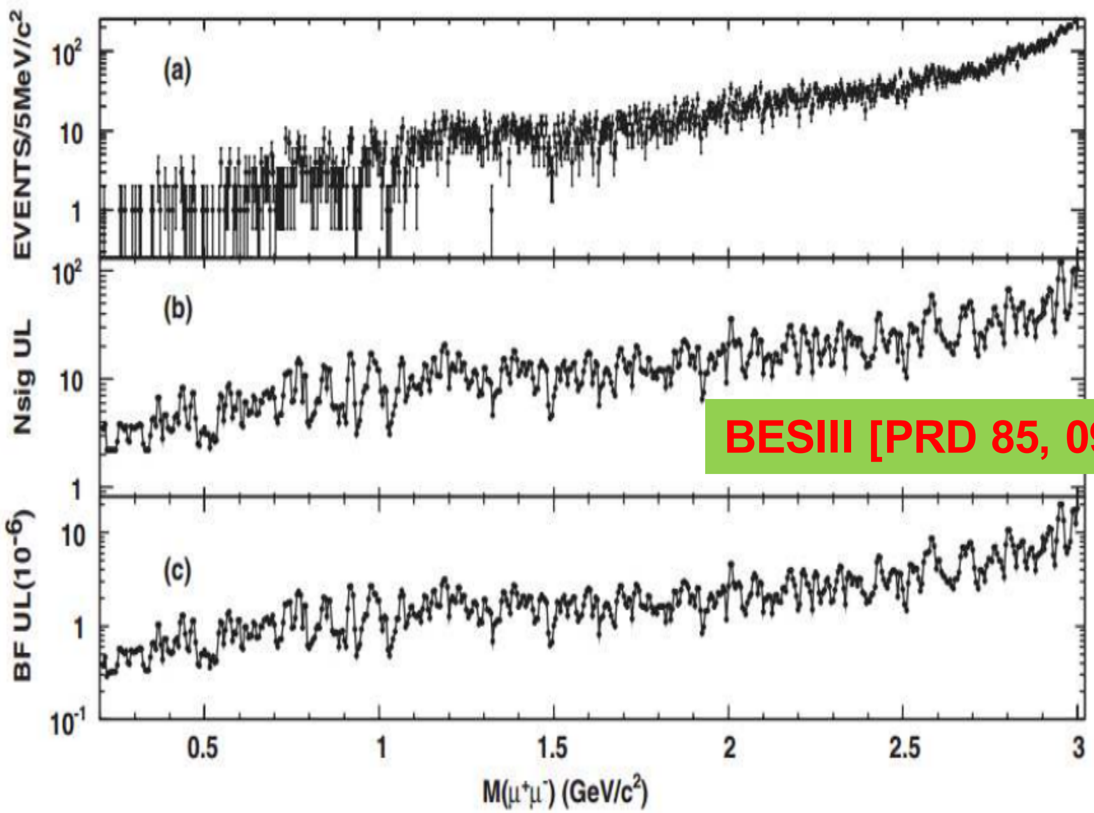
$$\tan\beta = \frac{v_u}{v_d}$$

E. Fullana et. al,
Phys. Lett. B 653, 67 (2007)



Results with ψ' data in published in 2012

ψ'->pipi J/ψ, $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$



BESIII [PRD 85, 092012 (2012)]

Coupling of c-quark to the A^0:

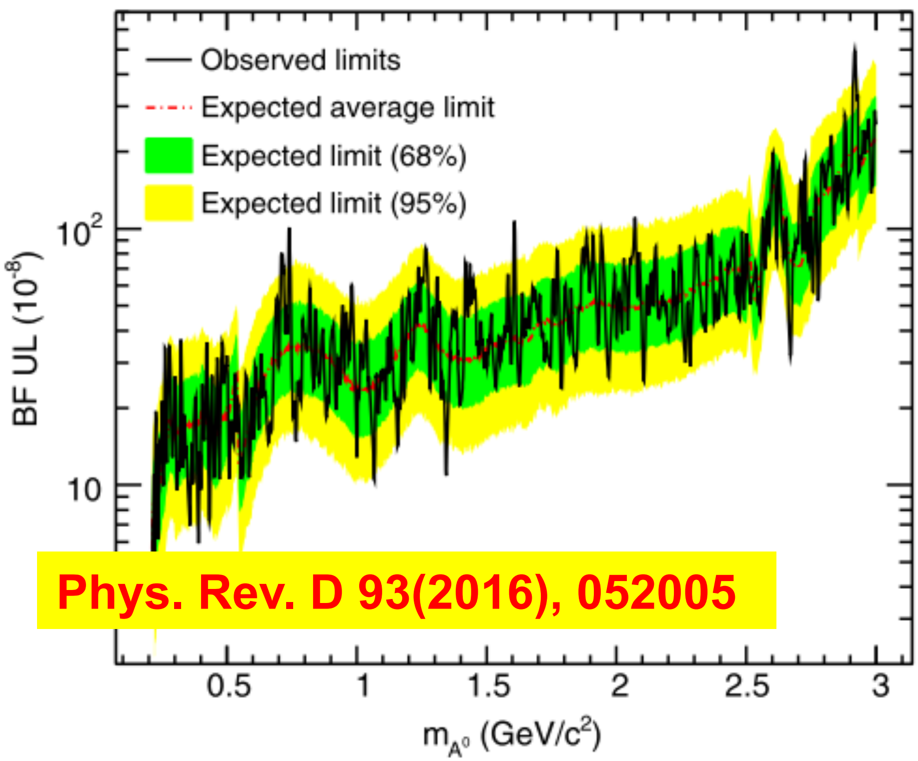
Expected BF: 10^{-7} -10^{-9}

[PRD 76, 051105 (2007)]

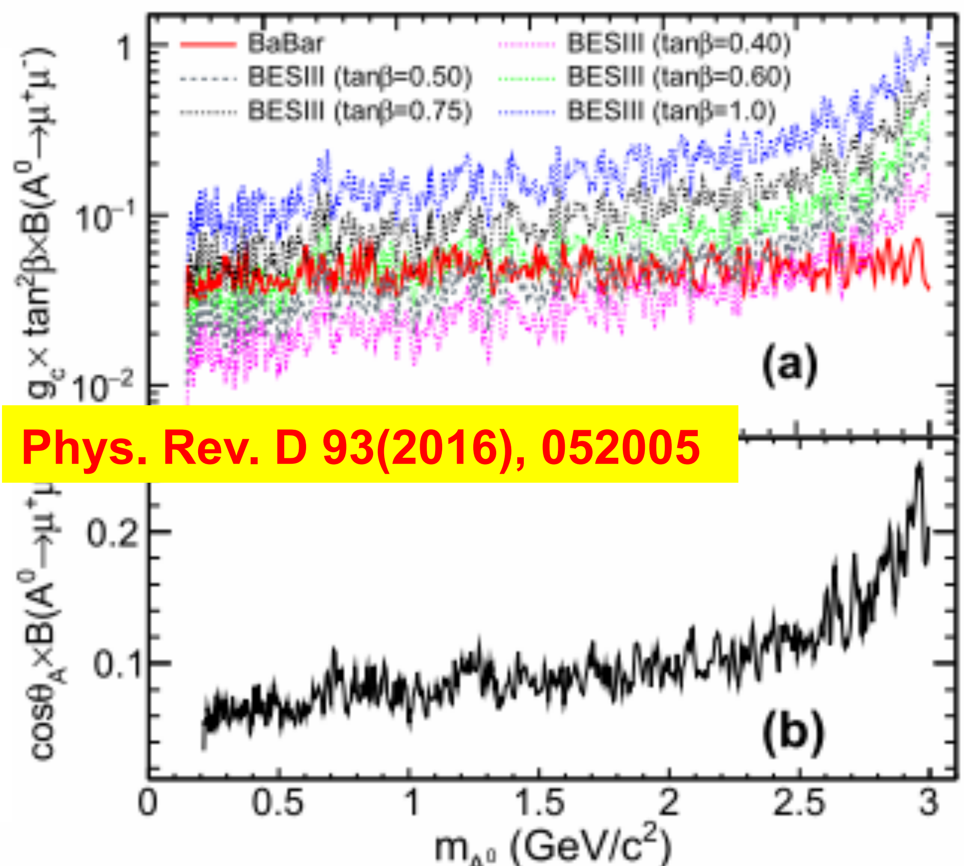
106M psi' data

BESIII exclusion limit ranges from 4×10^{-7} - 2.1×10^{-5} depending on A^0 mass points.

New BESIII Results(225M J/ψ)



Phys. Rev. D 93(2016), 052005



Phys. Rev. D 93(2016), 052005

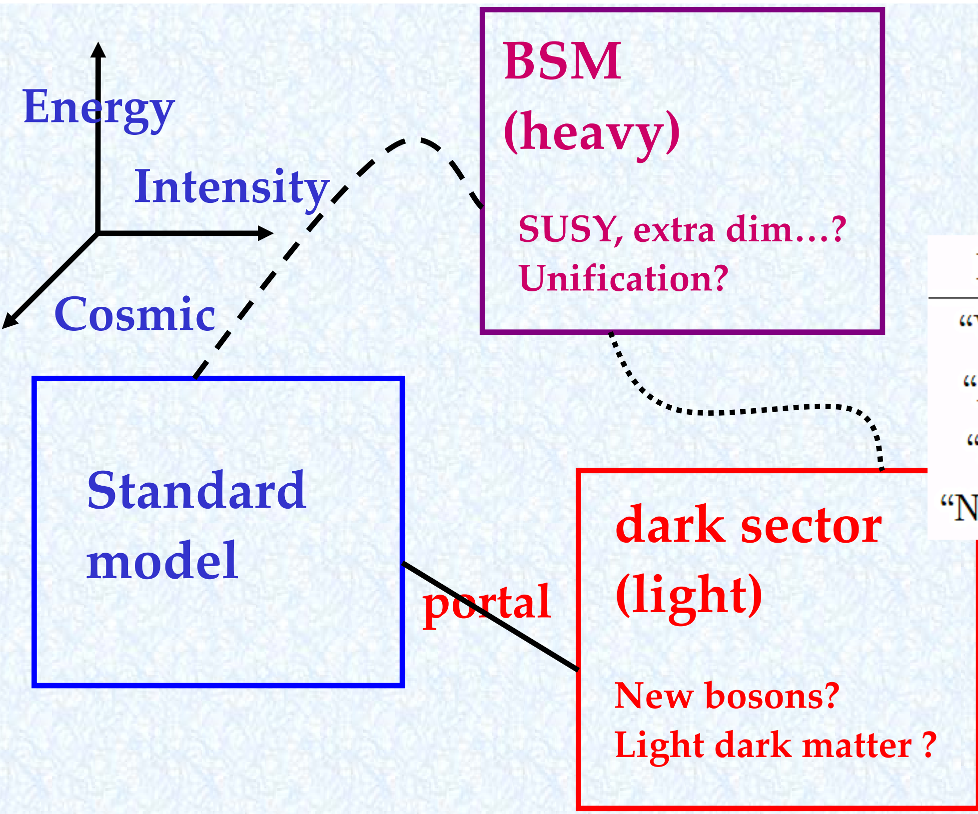
PRD 87, 031102 (R) (2013) (BaBar experiment)

The new limits are five times below our previous results (2012, Psip)

BESIII [PRD 85, 092012 (2012)]

BESIII vs. BaBar measurements comparison and combination, A0 is mostly singlet

Dark sector and portal



It is also referred as to heavy photon, hidden photon, A’, γ’ or U boson in the literature

Portal	Particles	Operator(s)
“Vector”	Dark photons	$-\frac{\epsilon}{2\cos\theta_W}B_{\mu\nu}F'^{\mu\nu}$
“Axion”	Pseudoscalars	$\frac{a}{f_a}F_{\mu\nu}\widetilde{F}^{\mu\nu}$, $\frac{a}{f_a}G_{i\mu\nu}\widetilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
“Higgs”	Dark scalars	$(\mu S+\lambda S^2)H^\dagger H$
“Neutrino”	Sterile neutrinos	$y_N LHN$

Dark Sectors 2016 Workshop: Community Report

Jim Alexander (VDP Convener),[1] Marco Battaglieri (DMA Convener),[2] Bertrand Echenard (RDS Convener),[3] Rouven Essig (Organizer),[4,*] Matthew Graham (Organizer),[5,†] Eder Izaguirre (DMA Convener),[6] John Jaros (Organizer),[5,‡] Gordan Krnjaic (DMA Convener),[7] Jeremy Mardon (DD Convener),[8] David Morrissey (RDS Convener),[9] Tim Nelson (Organizer),[5,§] Maxim Perelstein (VDP Convener),[1] Matt Pyle (DD Convener),[10] Adam Ritz (DMA Convener),[11] Philip Schuster (Organizer),[5,6,¶] Brian Shuve (RDS Convener),[5] Natalia Toro (Organizer),[5,6,**] Richard G Van De Water (DMA Convener),[12] … [15] David

arxiv: 1608.08632

The Jefferson Lab's Free-Electron Laser is a low-cost option in the bid to discover dark-se

PARTICLE PHYSICS

Physicists hunt for dark forces

NATURE 2012.4

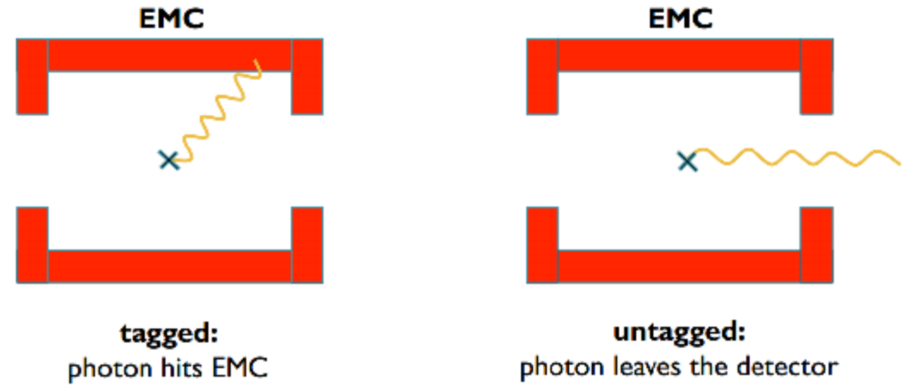
Dark photon search with ISR

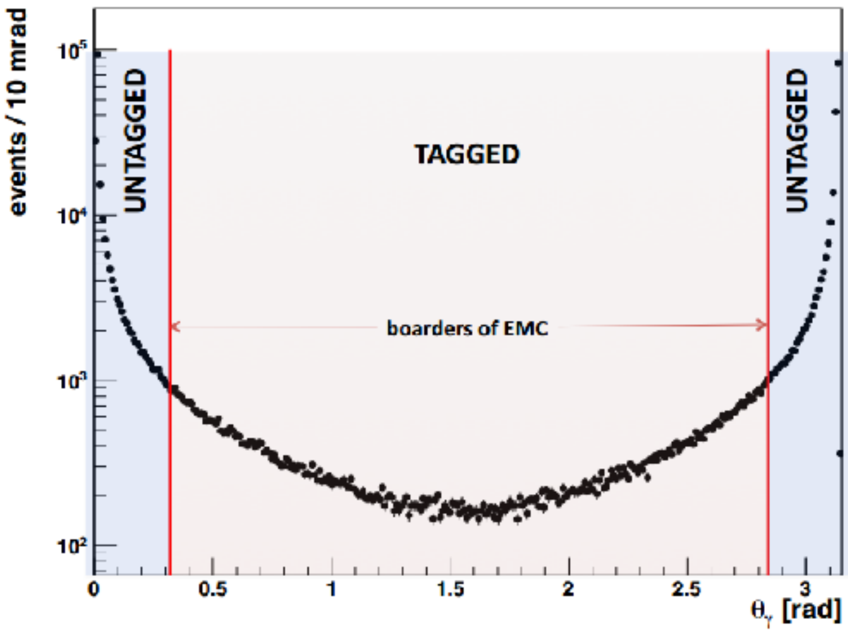
Search for narrow structure on top of the continuum QED background $e^+ e^- \to \gamma_{ISR} l^+ l^-$

➢ Use an untagged photon method to perform this analysis.

Event selection: $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ and $e^+e^- \to e^+e^-\gamma_{ISR}$

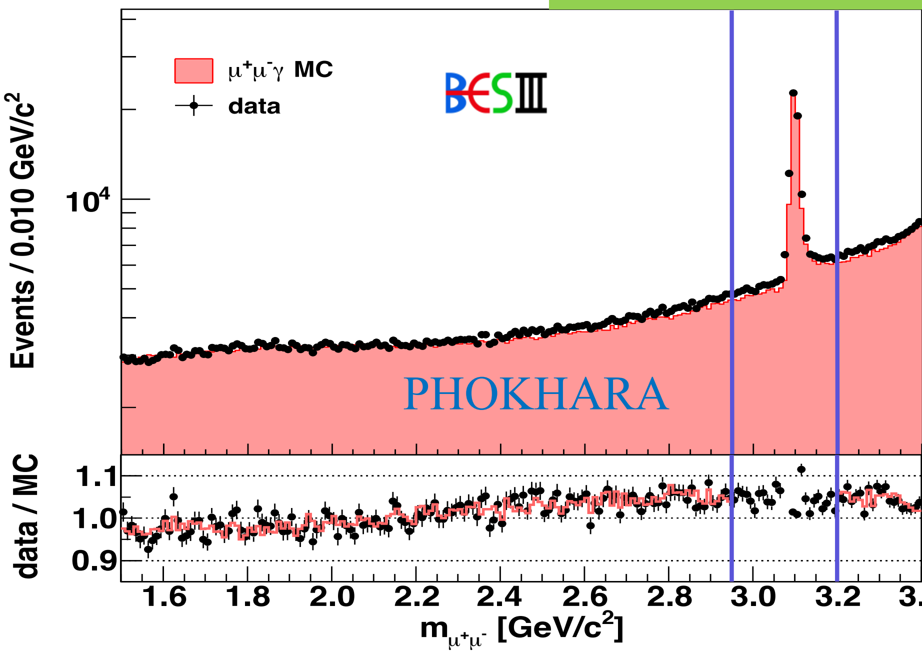
distance to interaction point	R_{xy} < 1.0 cm R_z < 10.0 cm
acceptance	0.4 rad < θ < π – 0.4 rad
to supress background	PID
# charged tracks	= 2
total charge	= 0
# photons	= 0 (untagged analysis)
missing photon angle	< 0.1 rad or > π – 0.1 rad
1C kinematic fit	χ^2_{1C} < 20

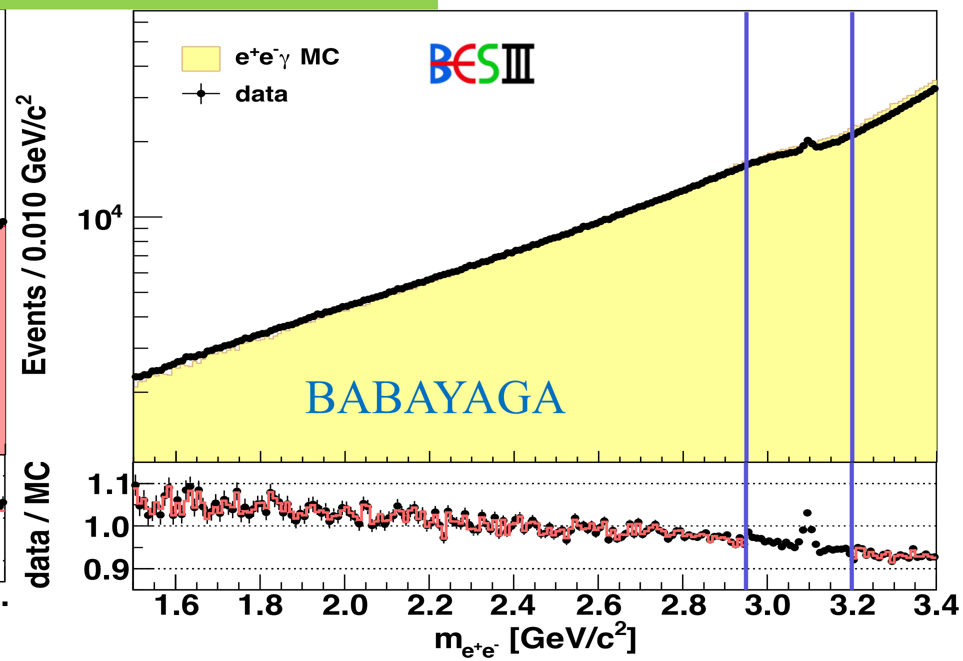




Mass spectrum of mumu and ee

$2.9\,fb^{-1}$ psi(3773) dataset(2010+2011)





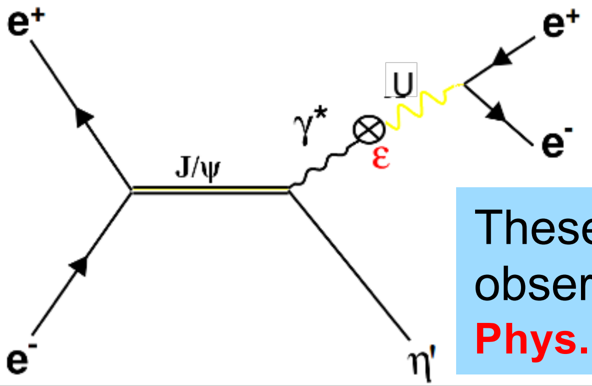
Cover mass region: 1.5 GeV/c 2 ~ 3.4 GeV/c

- <1.5 GeV/c 2 : $\pi^+\pi^-$ background dominates
- >3.4 GeV/c 2 : hadronic qq-bar process

arXiv:1705.04265, Phy. Lett. B 774, 252(2017)

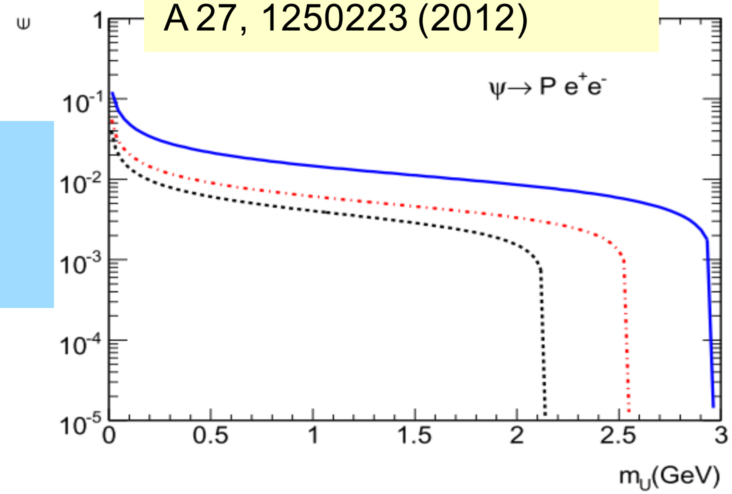
$$\frac{\sigma_i(e^+e^- \to \gamma' \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{\sigma_i(e^+e^- \to \gamma^* \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})} = \frac{N_i^{\rm up}(e^+e^- \to \gamma' \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{N_i^{\rm B}(e^+e^- \to \gamma^* \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})} \cdot \frac{1}{\epsilon} = \frac{3\pi \cdot \varepsilon^2 \cdot m_{\gamma'}}{2N_f^{l^+l^-} \alpha \cdot \delta_m^{l^+l^-}}$$

DP search through meson decays



These processes were first observed by BESIII
Phys. Rev. D 89, 092008 (2014)

J Fu et al., Mod. Phys. Lett. A 27, 1250223 (2012)



- $(1310.6 \pm 7.0) \times 10^6\ J/\psi$ data sample
  - $J/\psi \to \gamma' \eta' \to e^+ e^- \eta'$
    - $\eta' \to \gamma \pi^+ \pi^- /\ \eta \pi^+ \pi^-$
    - η' window [0.93, 0.98] GeV/c^2
  - $J/\psi \to \gamma' \eta \to e^+ e^- \eta$
    - $\eta \to \gamma\gamma\ /\ \pi^0 \pi^+ \pi^-$
    - η window [0.52, 0.57] GeV/c^2

With 1.3 billion J/ψ data, it is a good opportunity to search for the dark photon through decays $J/\psi \to \eta^{(\prime)} \gamma', \gamma' \to e^+ e^-$ at BESIII.

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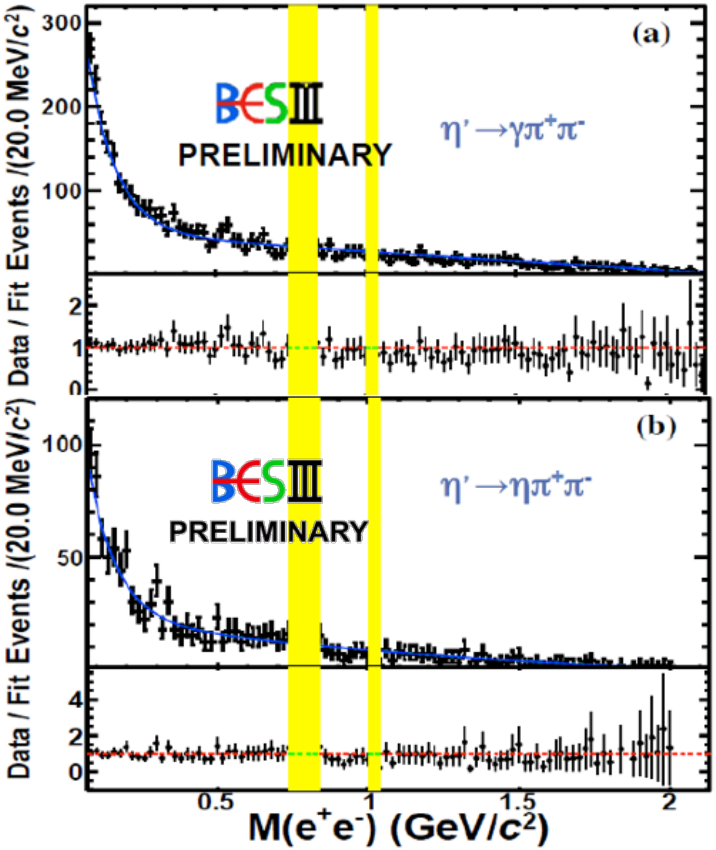
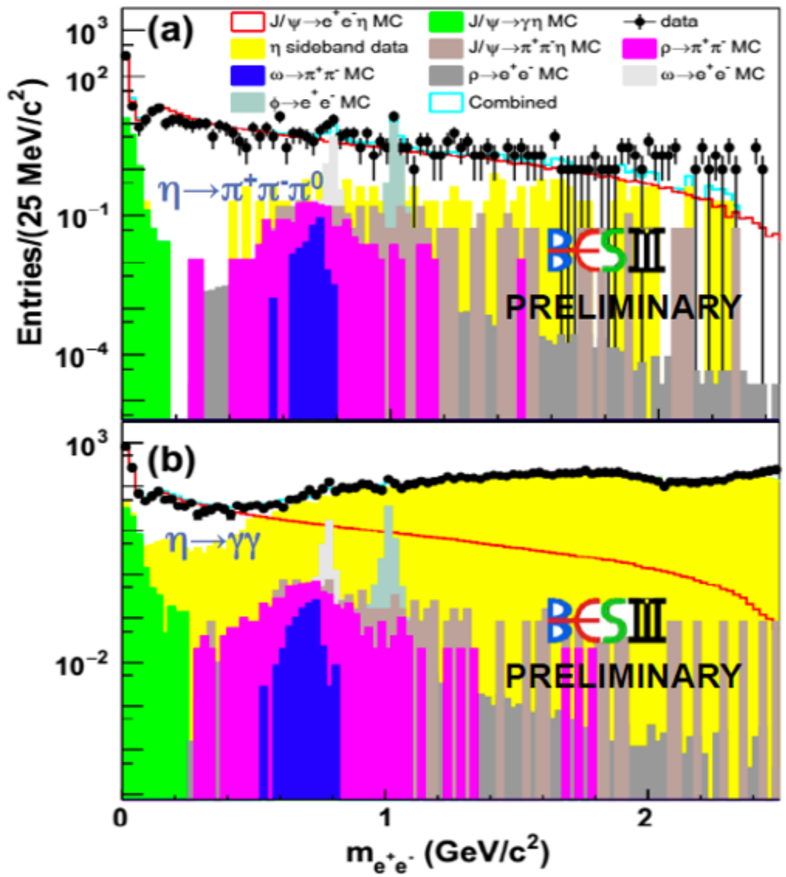
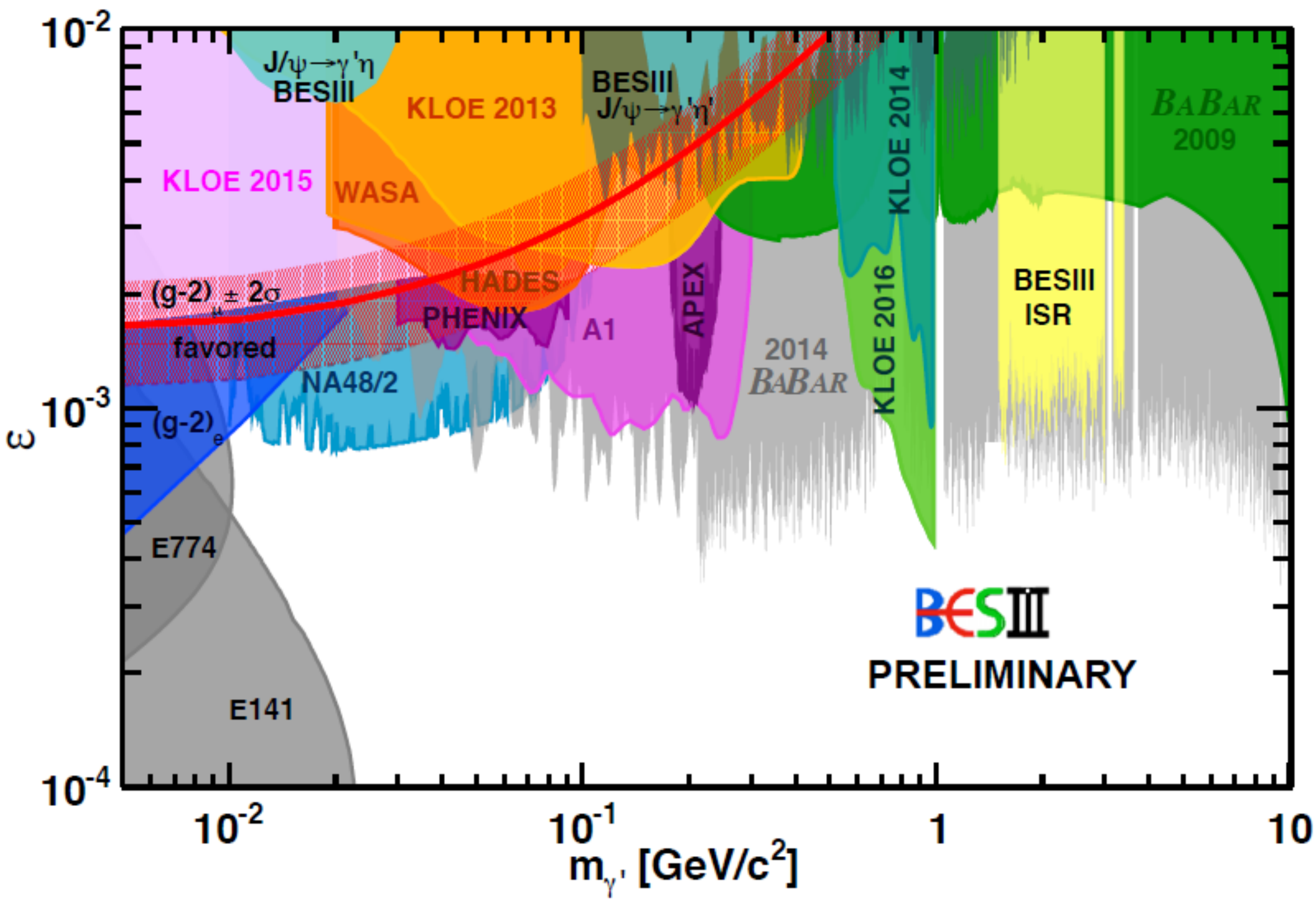
Mass spectrum of e^+e^-





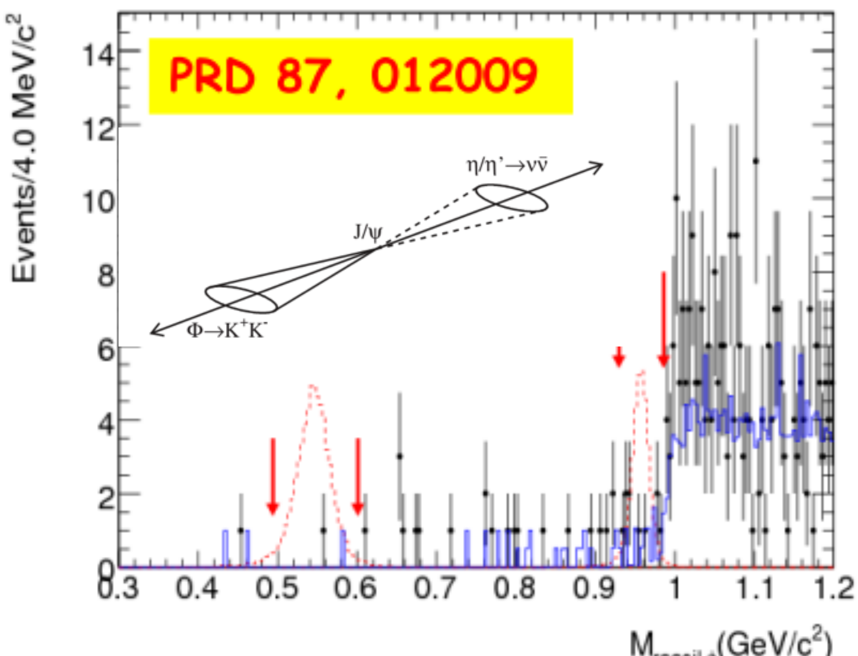
- $0.1 \sim 2.1$ / $0.01 \sim 2.4$ GeV/c^2
- Signal: Two crystal-ball function
- Exclude ρ/ω and ϕ mass region
- No unexpected peaking structure observed
- Background: $c_1 m + c_2 m^2 + e^{c_3 m}$ / 2nd polynomial or $c_1 m + c_2 m^2 + e^{c_3 m}$

BESIII Constraints on DP



Search for η /η' invisible decays

- η/η' decay play special role in low energy scale QCD theory.
- Invisible and radiative decays offer a window for new physics beyond the SM.
- The observation of the invisible final states provide information for light dark matter states χ, spin-0 axions, and light spin-1 U bosons.
- Huge J/ψ sample, large branching fraction of $J/\psi\to(\gamma/\phi)\eta/\eta'$ and narrow intermediate meson widths provide clean, large η/η' sample.



$Br(\eta'\to invisible)/Br(\eta'\to\gamma\gamma)<2.39\times10^{-2}$
$Br(\eta\to invisible)/Br(\eta\to\gamma\gamma)<2.58\times10^{-4}$

$Br(\eta'\to invisible)<5.21\times10^{-4}$@90%C.L.
$Br(\eta\to invisible)<1.01\times10^{-4}$@90%C.L.
Improved PDG Values

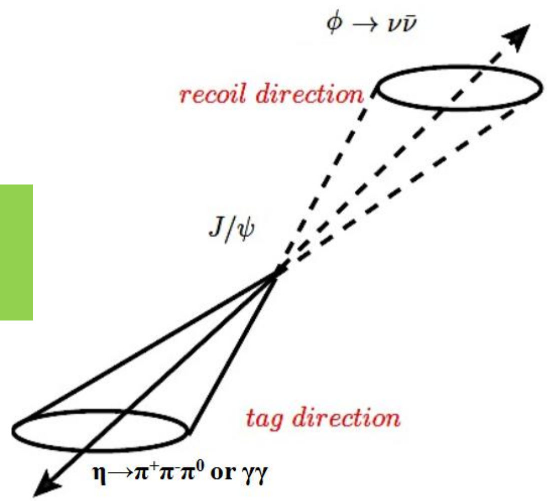
PDG : $Br(\eta'\to invisible)<9\times10^{-4}$@90%C.L
$Br(\eta\to invisible)<6\times10^{-4}$@90%C.L.

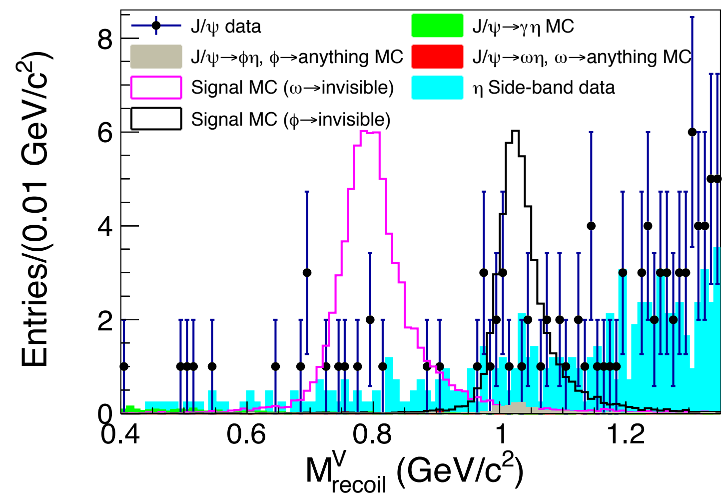
Theory : $Br(\eta'\to\chi\chi)\sim8.1\times10^{-7}$
$Br(\eta\to\chi\chi)\sim7.4\times10^{-5}$
B. McElrath, PRD 72, 103508 (2005)

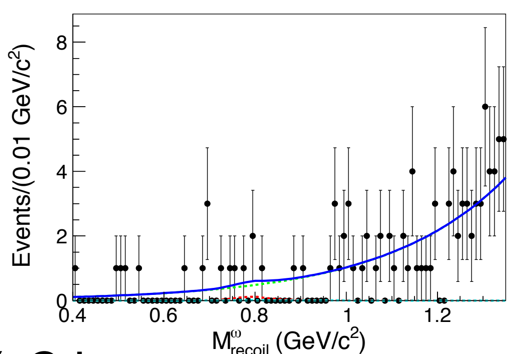
Omega and phi invisible decay

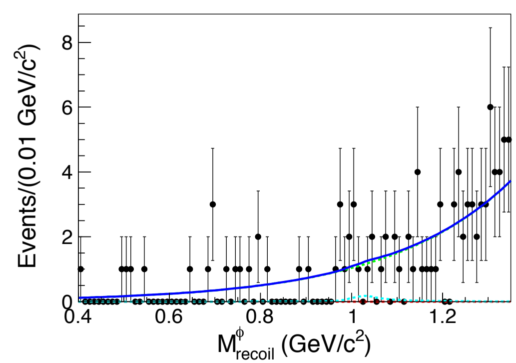
The first search of invisible decays of light vector mesons

arxiv:1805.05613
Accepted by PRD









Upper limits set at 90% C.L.

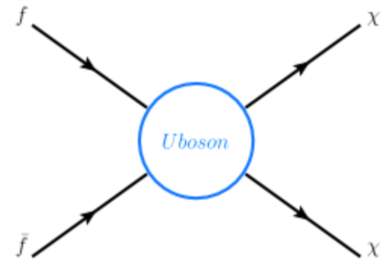
$$\frac{\mathcal{B}(\omega\to\text{invisible})}{\mathcal{B}(\omega\to\pi^+\pi^-\pi^0)} < 8.1\times10^{-5} \qquad \frac{\mathcal{B}(\phi\to\text{invisible})}{\mathcal{B}(\phi\to K^+K^-)} < 3.4\times10^{-4}$$

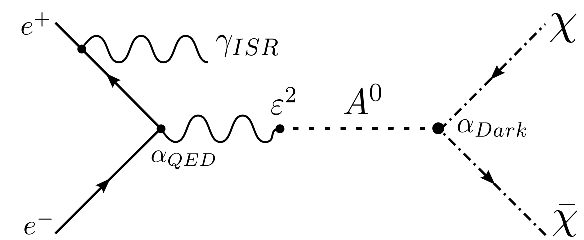
$$\mathcal{B}(\omega \to \text{invisible}) < 7.3\times10^{-5} \qquad \mathcal{B}(\phi\to\text{invisible}) < 1.7\times10^{-4},$$

More dark sector related analyses

- **Meson invisible decays**
  - Jpsi -> inv
  - Jpsi -> gamma+inv
  - chic -> inv
- **DP search channels**
  - Invisible DP in ISR process: competitive, but facing Belle-II
  - LUV dark scalar search with e+e->mu+ mu- Z'
  - Resonance searches in other ee channels
  - Associated Uh' production
  - … and more

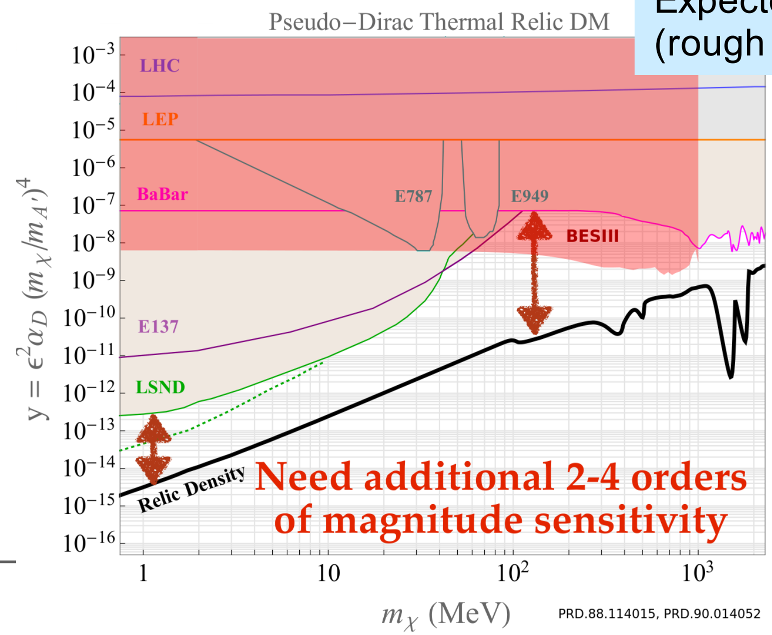
Charm meson channels are also possible, to be investigated





$\sigma_{nonISR} \sim \alpha_{QED}\epsilon^2\alpha_{Dark}\frac{m_\chi^2}{m_{A^0}^2}$

Expected sensitivity (rough estimation)



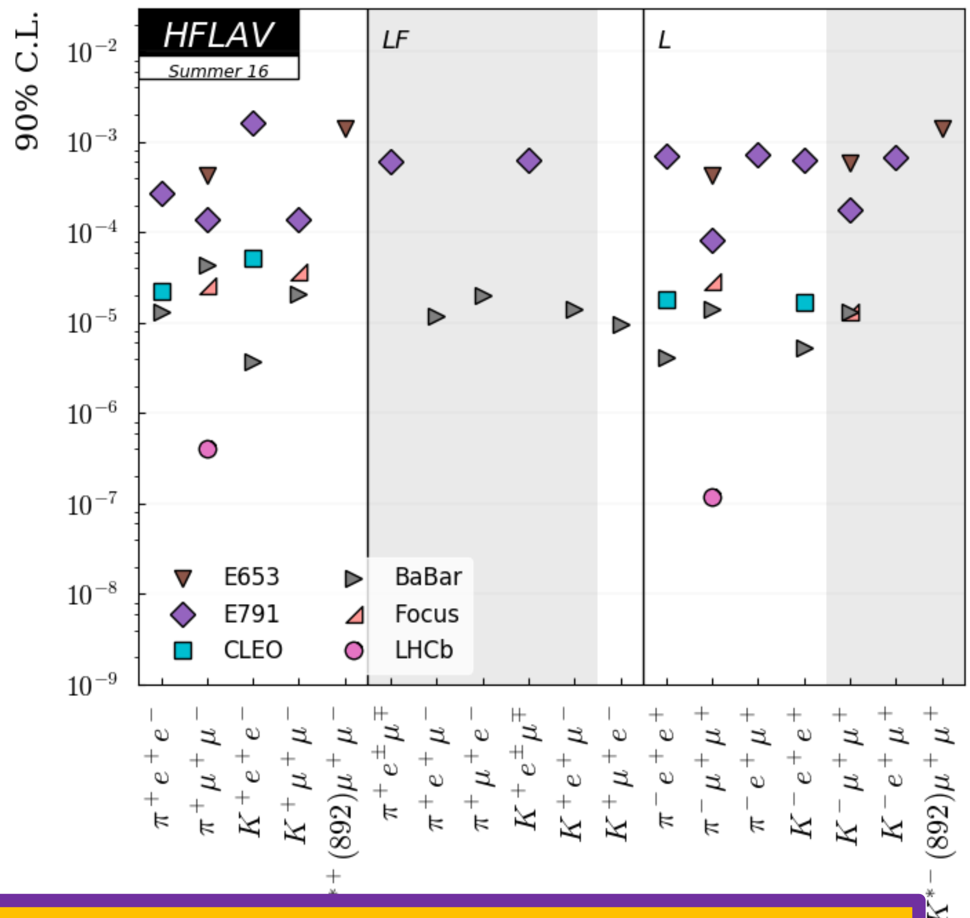
More on charm rare decays(I)

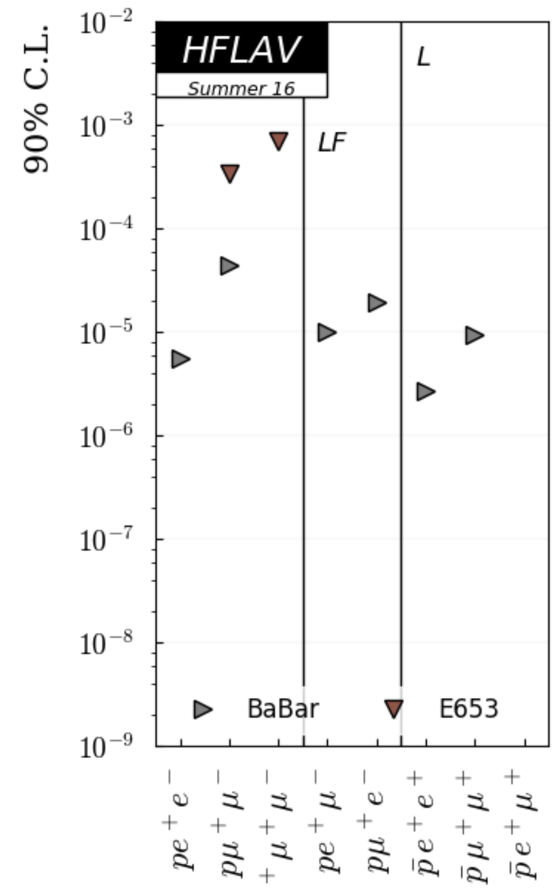
- Measurements of D → V P (e.g.D → ωπ) and the form factors in D → V (D → ω) are needed as input for new physics analyses in resonant semi-leptonic decays D → PV → Pl+l– and radiative decays D → V γ decays, respectively. 已经发表，但精度还需要改进
- The complex structure of D → h(h')l+l– gives rise to various beneficial observables, also with resonances, to search for new physics in rare charm decays. For e, BESIII has set the best limits (complementary to LHCb for μ, but orders of magnitude weaker limits) and permits a test of lepton-flavor-universality. Rare Λc → pe^+e^- will play an important role in this context.

More on charm rare decays(II)

- Rare radiative decays $D \to V\gamma$ probe new physics in dipole operators (best limits by Belle (II)). The photon polarization of right/left- handed currents can be measured in $\Lambda_c \to p\gamma$, polarized Λ_c are required .This decay is presently not measured; its branching ratio is expected to be $O(10^{-5})$.
- Lepton-flavor-violating decays and decays into di-neutrinos are currently clean probes of the SM. $D \to \pi\nu\bar{\nu}$ to be measured. $D^0 \to \tau^{\pm}e^{\mp}$ is also not measured, but this decay is suppressed by a small phase space. 中性道已经在分析，带点道也可以尝试

Rare D_s and Λ_c Decays





BESIII could probe FCNC with e+e-, and LFV with heμ in both Ds and Λ_c

Special for BESIII: weak radiative decay

$\Lambda_c^+ \to \gamma\Sigma^+$

Reach of rare charm decays

SM predictions

Experimental reaches

10^{-1}			
10^{-2}	Cabibbo favored		
10^{-3}	Singly Cabibbo suppressed		
10^{-4}	Doubly Cabibbo suppressed		CLEO-c
10^{-5}			
10^{-6}	Radiative decays	$D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$	BESIII
10^{-7}		$D^+ \to K^{*+}\gamma / \rho^+\gamma \quad D_S^+ \to K^{*+}\gamma / \rho^+\gamma$	BESIII final/B factory
10^{-8}	Long distance: Vector meson Dominance	$D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$	LHCb
10^{-9}			Super-B
10^{-10}			Super-τ-charm
10^{-11}	Short distance FCNC	$D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$	
10^{-12}		$D^0 \to \mu^+\mu^-$	
10^{-13}		$D^0 \to e^+e^-$	
10^{-14}			
10^{-15}		$D \to (h)\mu^+e^-$	
	Forbidden decays: LNV, LFV, BNV	$D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$	

BESIII is more competitive in channels with low energy electron/photons, neutrons, pi0's

BESIII未来物理白皮书

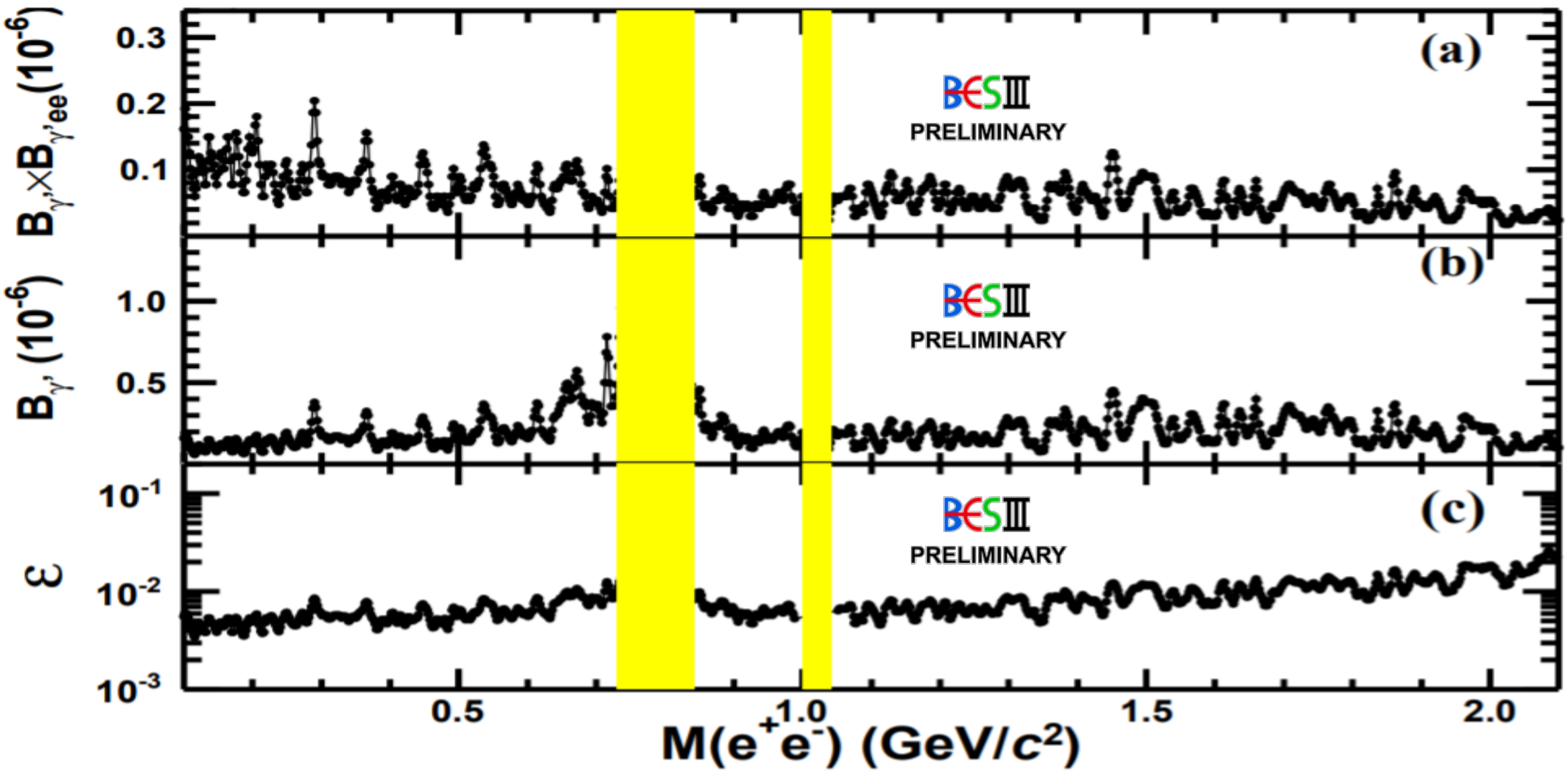
- 未来BESIII取数计划的重要依据
- 对HIEPA物理预研究也有重要启发
- 计划与合作组年会进行内部审议，和外部评估
- 预期发布文档到arxiv
- 新物理部分目录如下（草稿）

It will define the future physics program of BESIII experiment

Summary

- **BESIII has performed wide range of searches to probe new physics BSM.**
  - Charmonia weak decays
  - Charm meson radiative decays
  - FCNC processes
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - C-violation EM processes and C and CP violation decays
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays
- **BESIII has great potential with unique (and increasing) datasets and analysis techniques:**
  - More to come, stay tuned!
  - More ideas/collaborations are welcome!

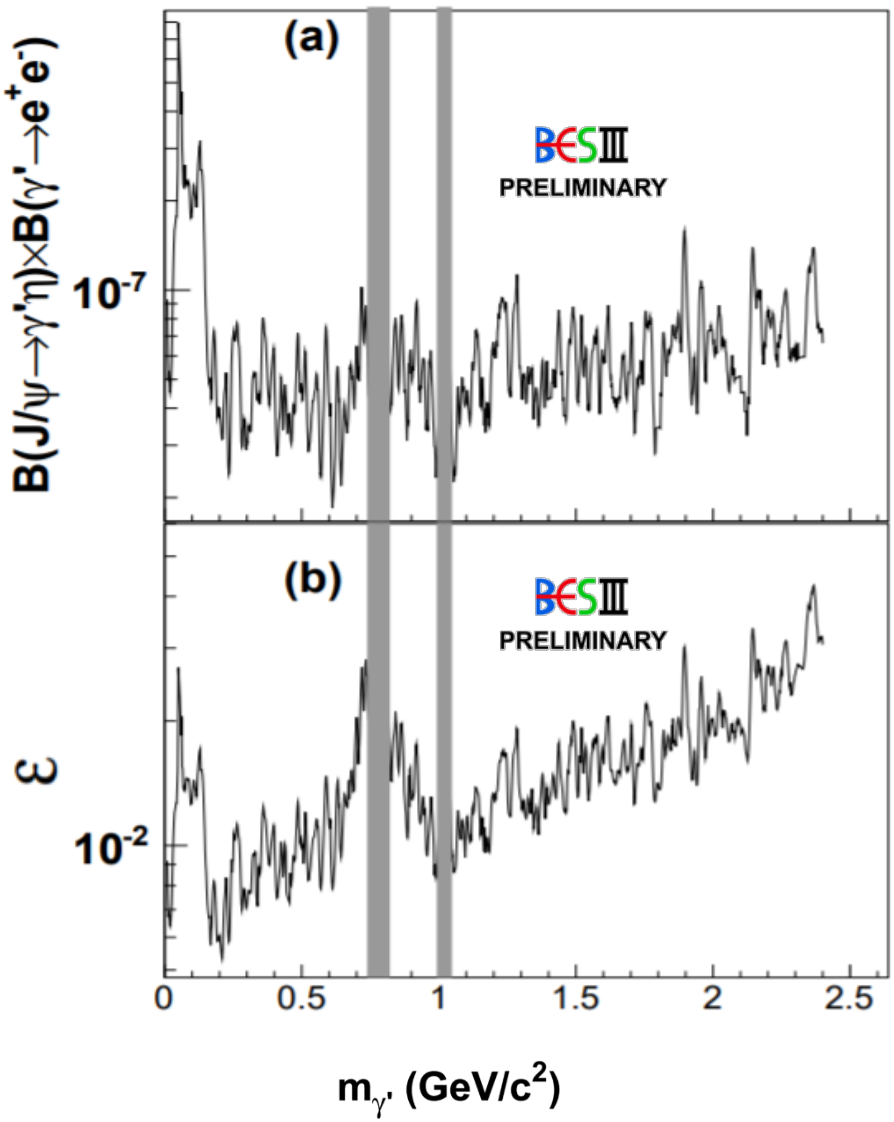
Combined results of $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \eta\pi^+\pi^-$



(a) $B(J/\psi \to \gamma'\eta') \times B(\gamma' \to e^+e^-)$: $< 1.8 \times 10^{-8} \sim 2.0 \times 10^{-7}$

(b) $B(J/\psi \to \gamma'\eta')$: $< 6.0 \times 10^{-8} \sim 7.8 \times 10^{-7}$

(c) ε : $< 3.4 \times 10^{-3} \sim 2.6 \times 10^{-2}$



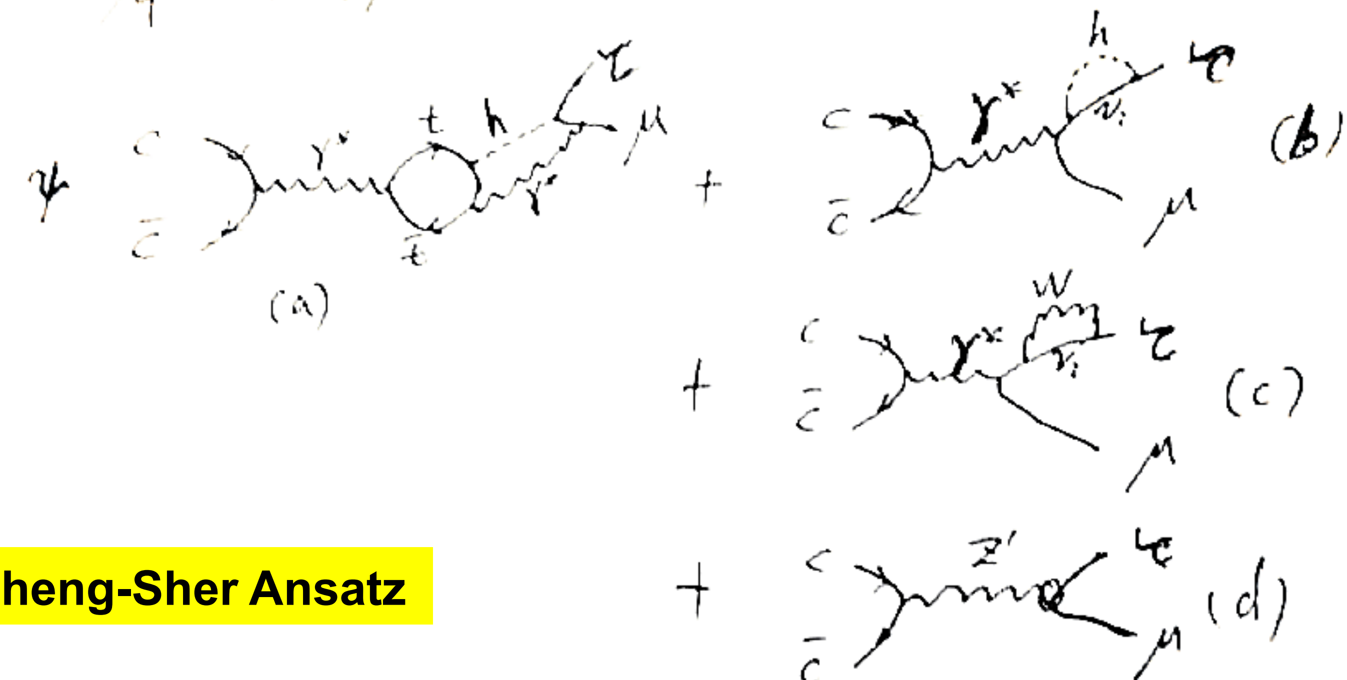
Combined results of $\eta \to \gamma\gamma$ and $\eta \to \pi^0 \pi^+\pi^-$

(a) $B(J/\psi \to \gamma'\eta) \times B(\gamma' \to e^+e^-)$: $< 1.9 \times 10^{-8} \sim 9.1 \times 10^{-7}$

(b) ε : $< 10^{-3} \sim 10^{-2}$

Possible Enhancements in Jpsi decays

$J/\psi \to \tau\mu$.



$\Psi \to \tau\mu$

Inspired by Cheng-Sher Ansatz

$J/\psi \to \gamma\tau\mu$.

$\Psi \to \gamma\tau\mu$