# Study of $D_s^+ \to \tau^+ \nu_\tau$

## via $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$

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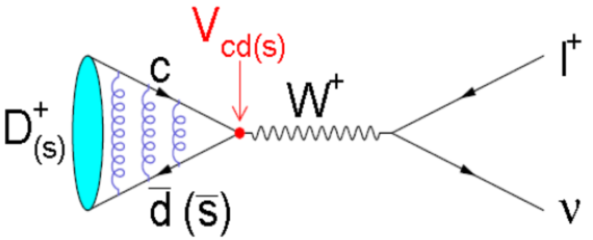
# Motivation

1. Since there is no strong interaction in the $l^+ \nu_l$ final states, the pure-leptoinc $D_s^+ \to l^+ \nu_l$ decays are the very clean channels to probe the hidden strong interaction between the initial quark and anti-quark, which is reflected in the decay constant $f_{D_s^+}$.
    - Precisely measure $f_{D_s^+}$ → precisely test lattice QCD.

2. The decay rate of $D_s^+ \to l^+ \nu_l$ is:




$$\Gamma(D_s^+ \to l^+\nu_l) = \frac{G_F^2}{8\pi} f_{D_s^+}^2 m_l^2 m_{D_s^+} \left(1 - \frac{m_l^2}{m_{D_s^+}^2}\right)^2 |V_{cs}|^2$$

to test the Lepton universality (the standard model prediction):

$$R \equiv \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = \frac{m_{\tau^+}^2 \left(1 - \frac{m_{\tau^+}^2}{m_{D_s^+}^2}\right)^2}{m_{\mu^+}^2 \left(1 - \frac{m_{\mu^+}^2}{m_{D_s^+}^2}\right)^2} = 9.74 \pm 0.01$$

If there exists the obviously deviation from 9.74 from experimental measurements, perhaps there will be some new physics beyond the standard model.

Low statistics, statistic uncertainty dominants

Higher background sources, systematic uncertainty dominants

**Experimental measurements**

| Collaboration | Energy | Integrated Luminosity | $B(D_s^+ \to \tau^+ \nu_\tau)(\%)$ | $f_{D_s^+}$ (MeV) | Decay mode |
|---|---|---|---|---|---|
| CLEO[1] | Near 4.170 GeV | $602\ \mathrm{pb}^{-1}$ | $5.30 \pm 0.47 \pm 0.22$ | $246.1 \pm 10.9 \pm 5.4$ | $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$ |
| CLEO[2] | | | $6.42 \pm 0.81 \pm 0.18$ | $271.4 \pm 16.8 \pm 5.2$ | $\tau^+ \to \pi^+ \bar{\nu}_\tau$ |
| CLEO[3] | | | $5.52 \pm 0.57 \pm 0.21$ | $250.4 \pm 12.3 \pm 5.7$ | $\tau^+ \to \rho^+ \bar{\nu}_\tau, \rho \to \pi^+ \pi^0$ |
| BABAR[4] | 10.58 GeV | $521\ \mathrm{fb}^{-1}$ | $4.96 \pm 0.37 \pm 0.57$ | $259.9 \pm 6.6 \pm 7.6$ | $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$; $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$ |
| BELLE[5] | Near $\Upsilon(4S)$, at $\Upsilon(5S)$ reaonance | $913\ \mathrm{fb}^{-1}$ | $5.70 \pm 0.21^{+0.31}_{-0.30}$ | $255.5 \pm 4.2 \pm 5.1$ | $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$; $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$; $\tau^+ \to \pi^+ \bar{\nu}_\tau$ |
| BESIII[6] | 4.009 GeV | $482\ \mathrm{pb}^{-1}$ | $4.83 \pm 0.65 \pm 0.26$ | $241.0 \pm 16.3 \pm 6.5$ | $\tau^+ \to \pi^+ \bar{\nu}_\tau$ |
| PDG(2017) | | | $5.48 \pm 0.23$ | | |
| BESIII | 4.178 GeV | $3.19\ \mathrm{fb}^{-1}$ (~ 5x of CLEO) | High statistics and low background sources→ precisely measured | | $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$; $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$ |

| **Mode** | **Branching fraction(%)** |
|---|---|
| $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$ | $17.82 \pm 0.04$ |
| $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$ | $17.39 \pm 0.04$ |
| $\tau^+ \to \pi^+ \bar{\nu}_\tau$ | $10.82 \pm 0.05$ |
| $\tau^+ \to \pi^+ \pi^0 \bar{\nu}_\tau$ | $25.49 \pm 0.09$ |


[1] P. U. E. Onyisi, et al. (CLEO Collaboration), Phys. Rev. D 79, 052002(2009);
[2] J. P. Alexander, et al. (CLEO Collaboration), Phys. Rev. D 79, 052001 (2009);
[3] P. Naik, et al. (CLEO Collaboration), Phys. Rev. D80, 112004(2009);
[4] P. del Amo Sanchez, et al. (BABAR Collaboration), Phys. Rev. D 82, 091103(R) (2010).
[5] A. Zupanc, et al.(BELLE Collaboration), JHEP 1309 (2013) 139.
[6] M. Ablikim, et al. (BESIII Collaboration), Phys. Rev. D94, 072004 (2016).

# Data sets

Boss version: 703 for MC sample(10x) and data ($1.45 fb^{-1}$)

Method: double tag

Channel: $e^+ e^- \to D_s^{*+} D_s^-$,

Tag mode: $D_s^- \to$ $K_S K^-$,

$K^+K^-\pi^-$,

$K^+K^- \pi^-\pi^0$,

$K_S K^- \pi^-\pi^+$,

$K_S K^+\pi^-\pi^-$,

$\pi^-\eta$, $\eta \to\gamma\gamma$

$\pi^-\pi^0\eta$, $\eta \to\gamma\gamma$

$\pi^-\eta'$, $\eta'\to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$

$\pi^-\eta'$, $\eta'\to \gamma\rho^0$, $\rho\to \pi^+\pi^-$

Signal mode： $D_s^+ \to \tau^+ \nu_\tau$ , $\tau^+ \to e^+\nu_e \bar{\nu}_\tau$

The charge conjugated channels are also implied.

Data: 2016.1.9 ~2016.3.25, ~1.45 $fb^{-1}$ (the luminosity of full data is 3.189 $fb^{-1}$ [1]) .

Cocktail MC: to analyze background, and obtain the single tag and double tag efficiency;

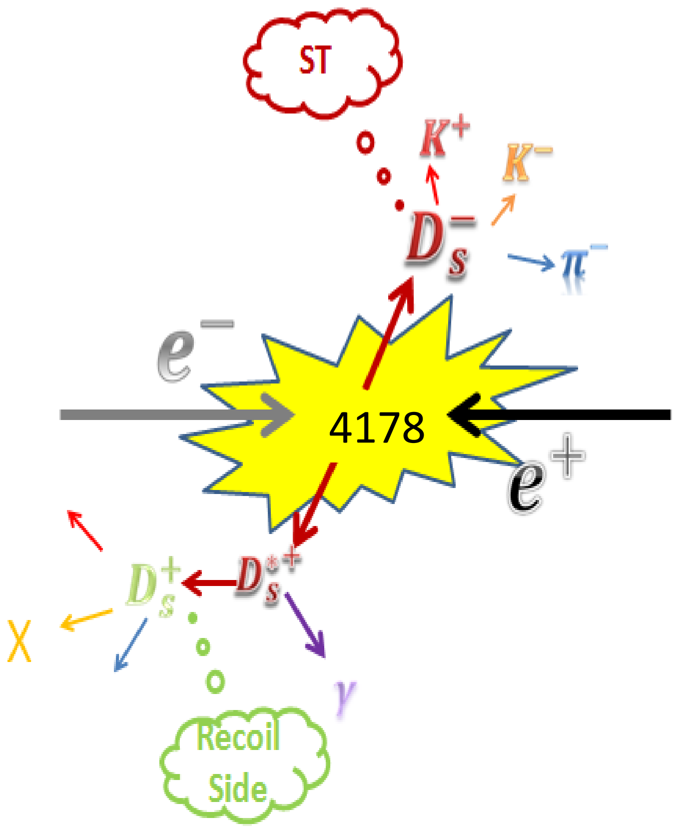
10x of data : open charm, $q\bar{q}$, di-τ, di-μ, γγ, γ J/ψ, γψ(3686), γψ(3770).

0.4x of data: Bhabha events;

| Component | cross setion (pb) | Events (× $10^6$) |
|---|---|---|
| $D^0\bar{D}^0$ | 179 | 0.5719 |
| $D^+D^-$ | 197 | 0.6294 |
| $D^{*0}\bar{D}^0$ | 1211 | 3.8691 |
| $D^{*+}D^-$ | 1296 | 4.1407 |
| $D^{*0}\bar{D}^{*0}$ | 2173 | 6.9427 |
| $D^{*+}D^{*-}$ | 2145 | 6.8533 |
| $D_s^+D_s^-$ | 7 | 0.0225 |
| $D_s^{*+}D_s^-$ | 961 | 3.0700 |
| $DD^*\pi^+$ | 383 | 1.2237 |
| $DD^*\pi^0$ | 192 | 0.6134 |
| $DD\pi^+$ | 50 | 0.1508 |
| $DD\pi^0$ | 25 | 0.0799 |
| Component | cross setion (nb) | Events (× $10^6$) |
| $q\bar{q}$ | 13.8 | 44.0910 |
| $\gamma J/\psi$ | 0.40 | 1.2780 |
| $\gamma\psi(3686)$ | 0.42 | 1.3419 |
| $\gamma\psi(3770)$ | 0.06 | 0.1917 |
| $\tau\tau$ | 3.45 | 11.0228 |
| $\mu\mu$ | 5.24 | 16.7418 |
| $ee$ | 423.99 | 13.5465(0.01×) |
| $\gamma\gamma$ | 1.7 | 5.4315 |

[1]. http://docbes3.ihep.ac.cn/DocDB/0006/000603/004.

# Analysis method




Not reconstruct $\gamma/\pi^0$ from $D_s$* decays.

$N_{tag} = 2\, N_{D_s\, D_s}\, B_{tag}\, \epsilon_{tag}$ ;

$N_{sig} = 2\, N_{D_s\, D_s}\, B_{tag}\, B_{\tau^+ \to e^+ \nu_e \bar{\nu}_\tau} \epsilon_{tag,sig}$

$N_{D_s D_s}$: the number of total $D_s D_s$ pairs events;
$B_{tag}$ : the branching fraction of $D_s^- \to a\ tag$ mode;

For a given tag mode:

$$B_{sig} = \frac{N_{sig}\, \epsilon_{tag}}{N_{tag}\, \epsilon_{tag,sig}\, B_{\tau^+ \to e^+ \nu_e \bar{\nu}_\tau}}$$

$B_{sig}$: the branching fraction of $D_s^+ \to \tau^+ \nu_\tau$ ;

$N_{tag}$: ST yield;
$\epsilon_{tag}$: ST efficiency;
} Obtained from Single tag analysis

$N_{sig}$: DT yield;
$\epsilon_{tag,sig}$: DT efficiency;
} Obtained from Double tag analysis

# Single tag

# Event selections

- Good charged track
  - From $K_S$: |dz|<20cm and cos $\theta$ <0.93
  - Others: |dr|<1 cm , |dz|<10cm and cos $\theta$ <0.93

- PID(Particle ID) (dE/dx and TOFCorr):
  - For pion except from $K_S$ : prob($\pi$) >0, prob($\pi$) > prob(K)
  - For kaon : prob(K) >0, prob(K) > prob($\pi$)

- Good photon
  - Barrel EMC: ($\cos\theta$<0.8)
    - $E_\gamma$>25MeV
  - Endcap EMC: (0.86<$\cos\theta$<0.92)
    - $E_\gamma$>50MeV
  - TDC: [0, 14] (/50ns)
  - $\theta_{\gamma\text{ - charged}}$ >10 $^o$(without this cut for photons from $\pi^0$ and $\eta$)

- Ks candidates
  - Using VeeVertexAlg package
  - Vertex/second vertex fit: $\chi^2$<100
  - $M(\pi^+\pi^-)$: [0.487,0.511] GeV/$c^2$
  - L/$\sigma$ > 2(without this cut for $K_SK^-$)

- $\pi^0$ / $\eta$ candidates
  - Using Pi0EtatoGGRecAlg package
  - $M(\gamma\gamma)$ : [0.115,0.150] GeV/$c^2$ for $\pi^0$, [0.50,0.57] GeV/$c^2$ for $\eta$.
  - $\chi^2_{1c}<200$, Candidates with both daughter photons from end cap region are rejected.
  - Momentum of $\pi^0$ : $p(\pi^0)$ >0.1 GeV/c.

- $\rho^0$ candidates: $M(\pi^+\pi^-)$ >0.5 GeV/$c^2$
- $\eta'$ candidates: $M(\pi^+\pi^-\eta)$ : [0.946, 0.97] GeV/$c^2$
  $M(\gamma\rho^0)$: [0.94, 0.976] GeV/$c^2$

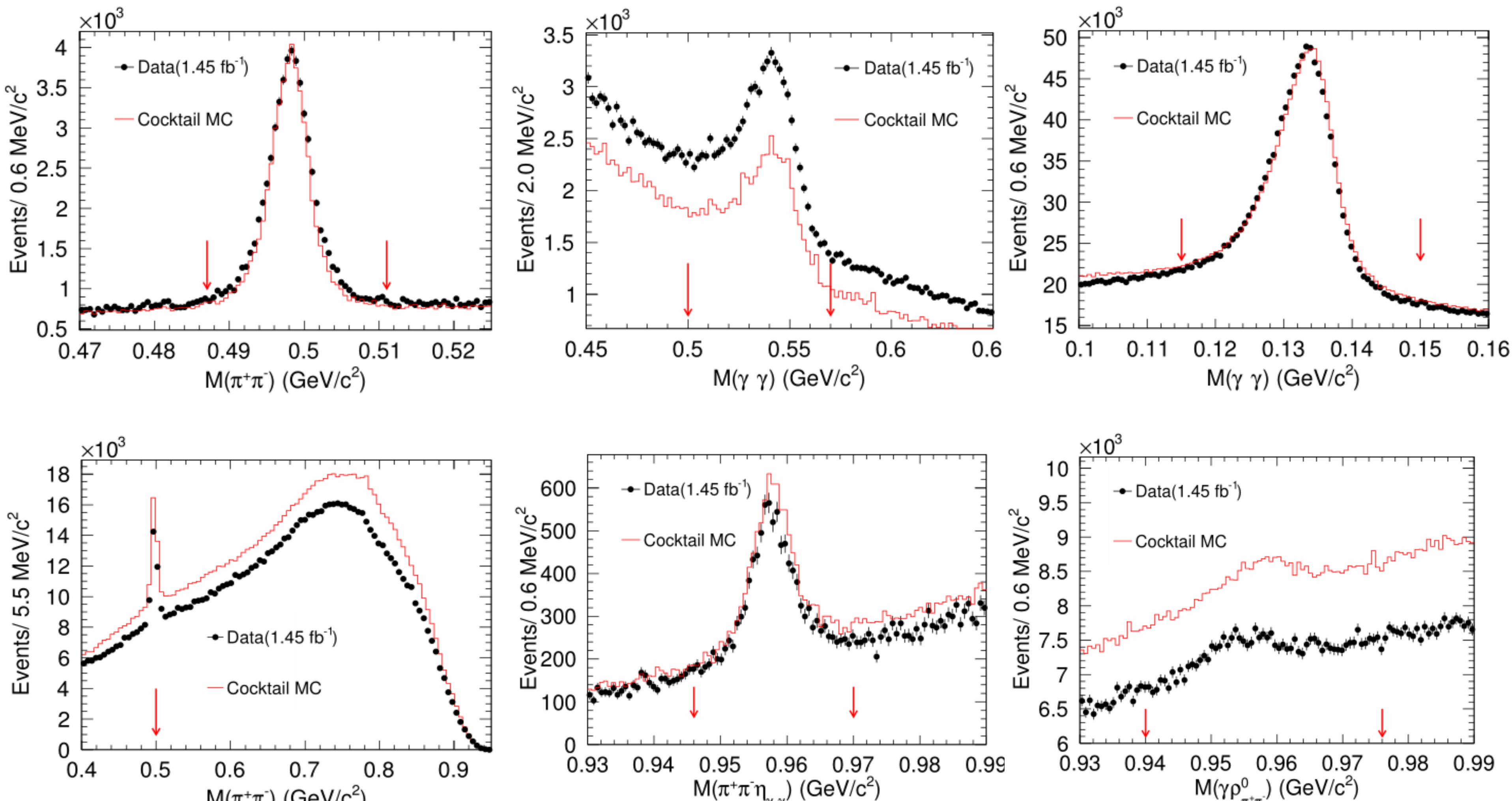
- Momenta of Charged pions: > 0.1GeV/c
- Momentum of $\gamma$ from $\eta'\rightarrow\gamma\rho^0$: > 0.1GeV/c.

- The sum of ratios for all charged tracks (n) from tag side for a given tag mode is less than 2.0 (0.9 for n==1) to suppress Bhabha events:

$$\mathcal{S} = \sum_{j=1}^{n} R = \sum_{j=1}^{n} \frac{prob(e)}{prob(\pi) + prob(K) + prob(e)}$$

# The distribution of invariant mass

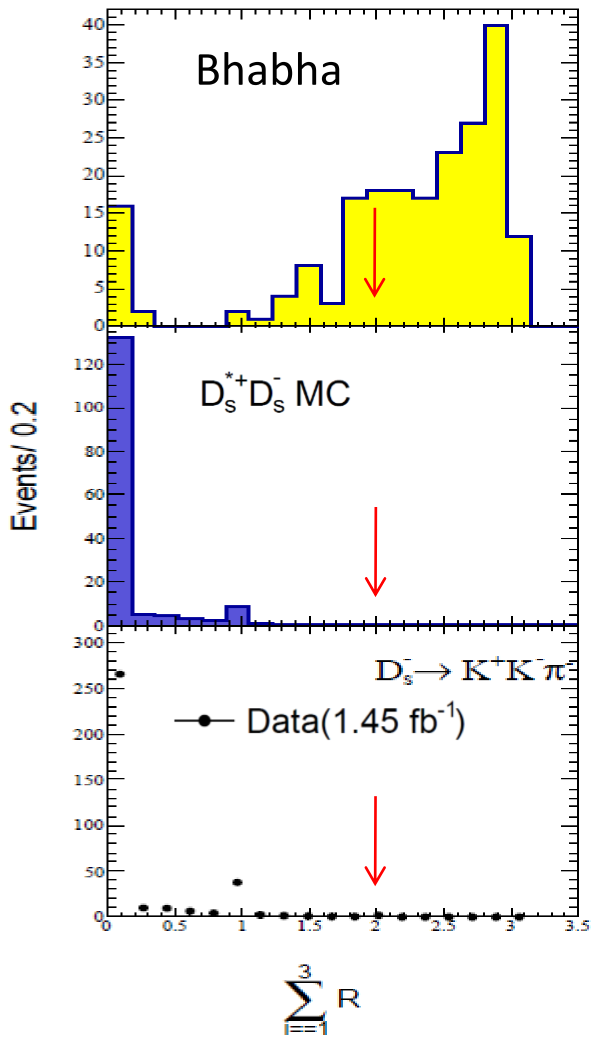
Scaled to the luminosity of 1.45 $fb^{-1}$

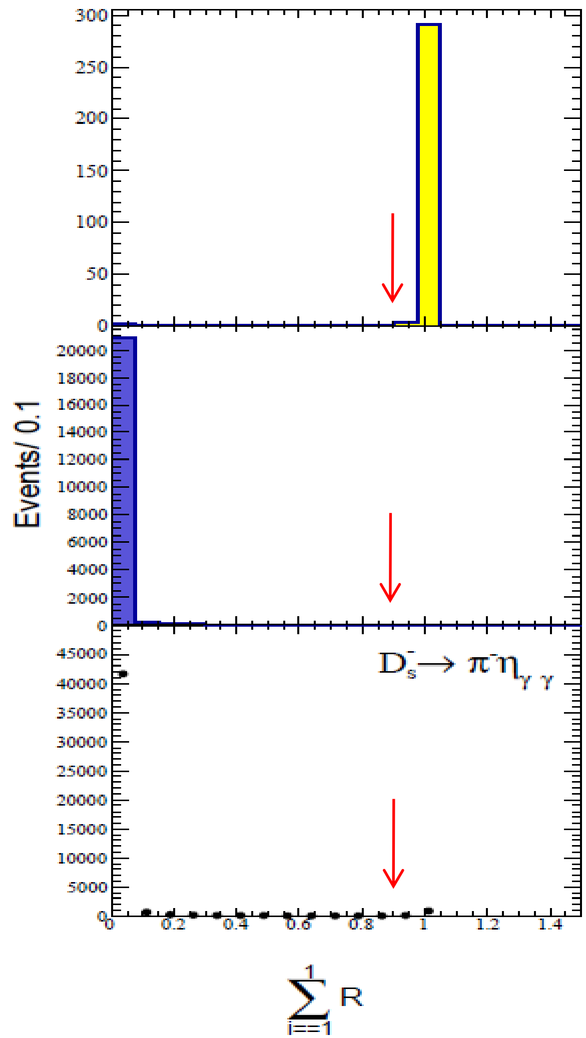


# The distribution of sum of ratios

Scaled to the luminosity of 0.4 times of data

$$\mathcal{S} = \sum_{j=1}^{n} R = \sum_{j=1}^{n} \frac{prob(e)}{prob(\pi) + prob(K) + prob(e)} < 2.0\ (n > 1)\ \text{or}\ 0.9\ (n == 1)$$

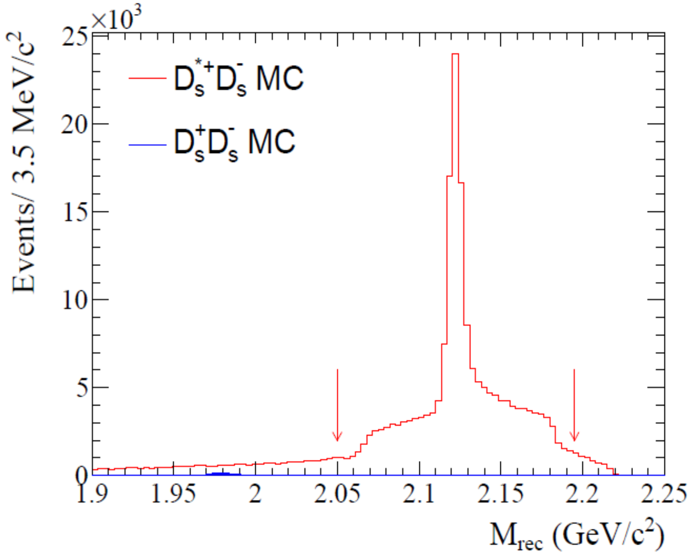


- Recoiling mass of tag-Ds: [2.05,2.195]GeV/c$^2$,

$$M_{rec}^2 c^4 = \left(E_{cm} - \sqrt{\left|\vec{p}_{D_s^-}\right|^2 c^2 + m_{D_s^-}^2 c^4}\right)^2 - \left|-\vec{p}_{D_s^-}\right|^2 c^2$$

- Select all tag-Ds candidates per event. (minimize the tag bias)



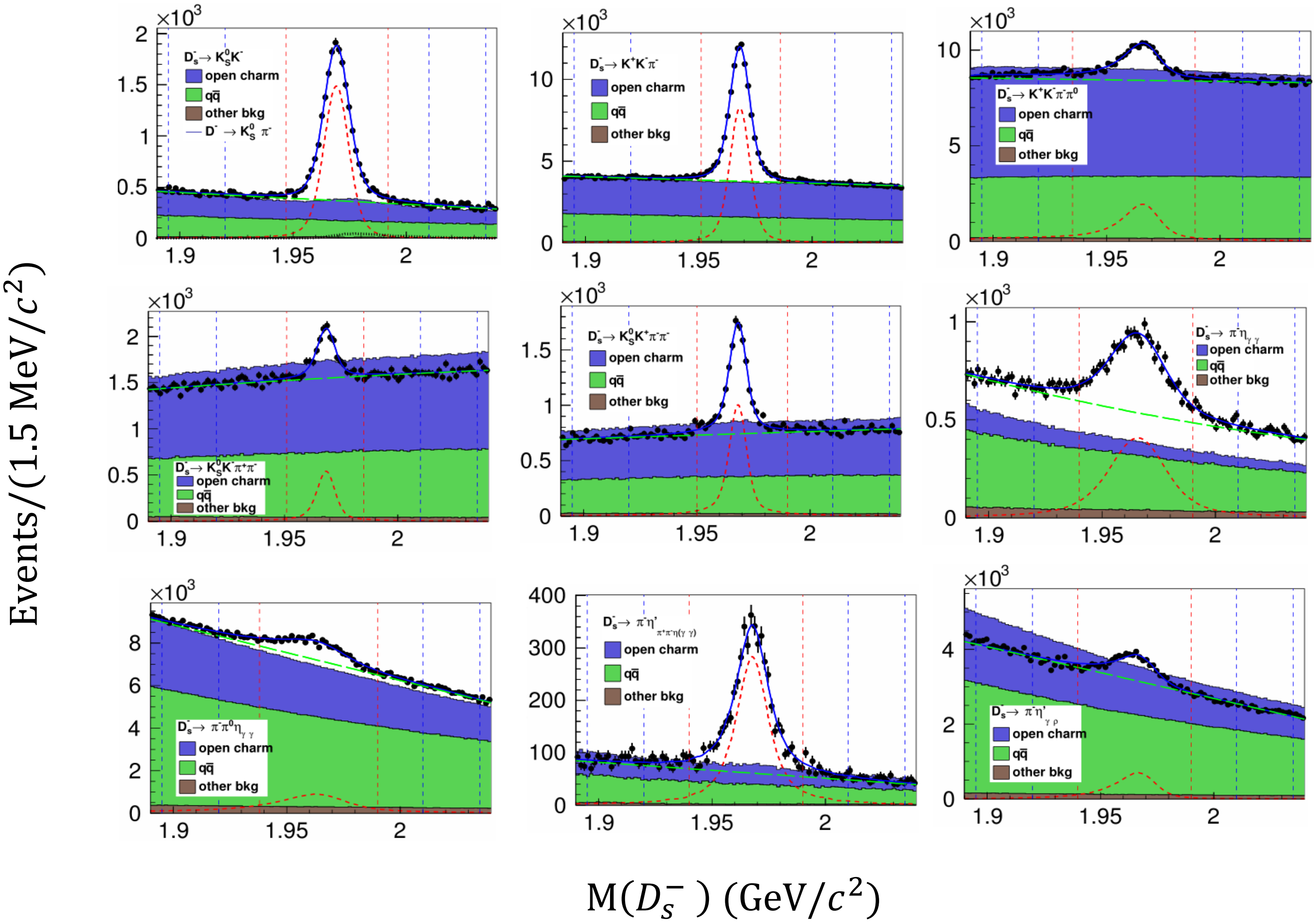

Peak: due to the primary $D_s$ ;
Broad flat: due to the secondary $D_s$ from $D_s^*$ decays.

# The distribution of $M(D_s^-)$

Fit = MC shape⊗Gaussian + 1st /2nd Chebychev

Dotted with error bar is from data of 1.45 fb$^{-1}$.

Cocktail MC samples are normalized to the luminosity of 1.45 fb$^{-1}$



# The efficiency and yield of single tag

ST efficiency is obtained by fitting $M(D_s^-)$ from cocktail MC sample(10x).

$M(D_s^-)$ signal region is about $3\sigma$(we use a double Gaussian plus 2nd order Chebychev to fit $M(D_s^-)$ to obtain the sigma).

ST efficiency (%)    ST yield

| Mode | $M(D_s^-)$ Signal region | $M(D_s^-)$ Sidenband region | $\epsilon_{ST}$ | $N_{yield}^{ST}$ |
|---|---|---|---|---|
| $D_s^- \to K_S^0 K^-$ | [1.947,1.992] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $34.88 \pm 0.08$ | $14640 \pm 196$ |
| $D_s^- \to K^+ K^- \pi^-$ | [1.951,1.986] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $42.77 \pm 0.05$ | $65578 \pm 392$ |
| $D_s^- \to K^+ K^- \pi^- \pi^0$ | [1.935,1.989] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $18.49 \pm 0.08$ | $32083 \pm 763$ |
| $D_s^- \to K_S^0 K^- \pi^+ \pi^-$ | [1.951,1.985] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $15.26 \pm 0.13$ | $4140 \pm 233$ |
| $D_s^- \to K_S^0 K^+ \pi^- \pi^-$ | [1.950,1.990] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $16.17 \pm 0.07$ | $7618 \pm 156$ |
| $D_s^- \to \pi^- \eta_{\gamma\gamma}$ | [1.940,1.990] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $17.69 \pm 0.10$ | $8365 \pm 335$ |
| $D_s^- \to \pi^- \pi^0 \eta_{\gamma\gamma}$ | [1.938,1.990] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $9.37 \pm 0.09$ | $23235 \pm 1244$ |
| $D_s^- \to \pi^- \eta'_{\pi^+\pi^-\eta(\gamma\gamma)}$ | [1.940,1.990] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $3.87 \pm 0.02$ | $3815 \pm 81$ |
| $D_s^- \to \pi^- \eta'_{\gamma\rho^0}$ | [1.940,1.990] | $[1.895, 1.92] \Vert [2.01, 2.035]$ | $11.45 \pm 0.09$ | $10938 \pm 362$ |

When counting the number of generated events for single tag efficiency, we don't care sub-particles ($K_S$, $\pi^0$, $\eta$, $\eta'$) decays.

# Double tag

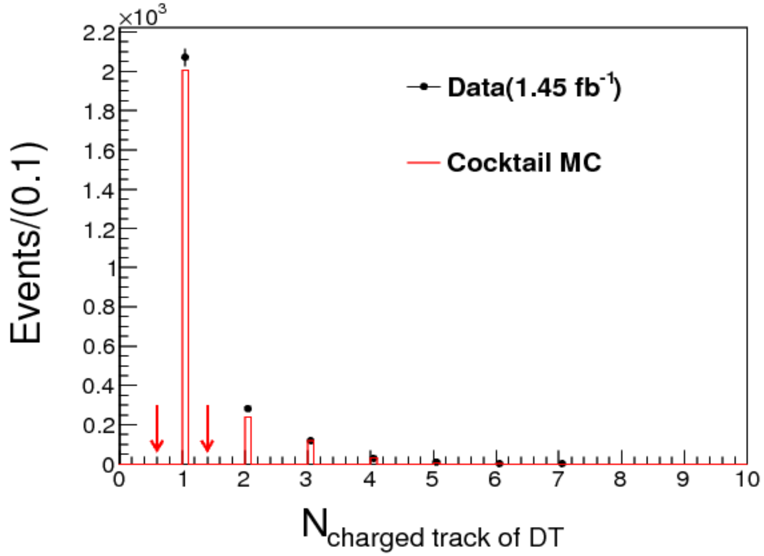
# Event selection

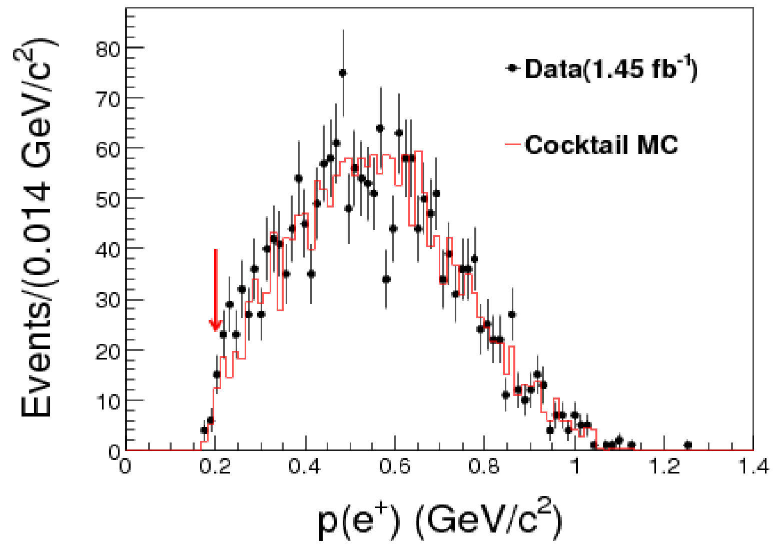
1. Only one charged track with the opposite charge of $D_s^-$, which satisfies:
   |dr|<1 cm , |dz|<10cm and cos $\theta$ <0.93

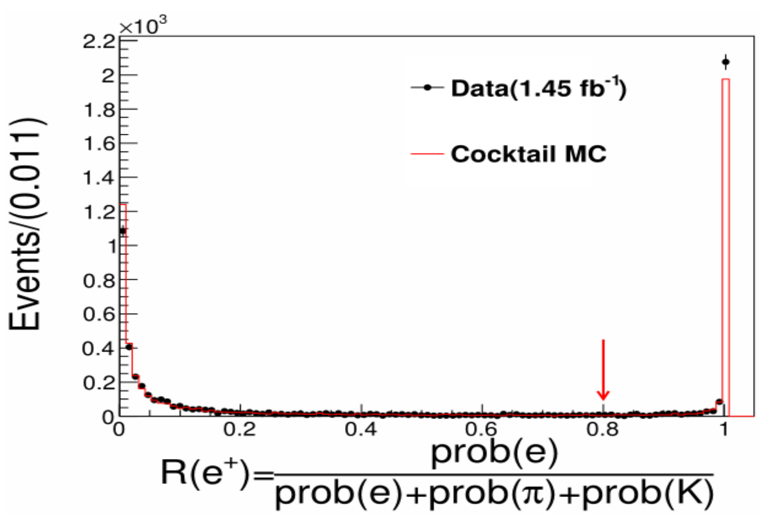
2. PID(dE/dx, TOFCorr and EMC)
   - $prob(e) > 0.001$;
   - $\frac{prob(e)}{prob(e)+prob(\pi)+prob(K)} > 0.8$
   - $\frac{E}{p}(e) > 0.8$
3. The momentum of electron: $p(e) > 0.2\ \mathrm{GeV}/c$ ;
4. Not reconstruct $\gamma/\pi^0$ from $D_s^*$ decay

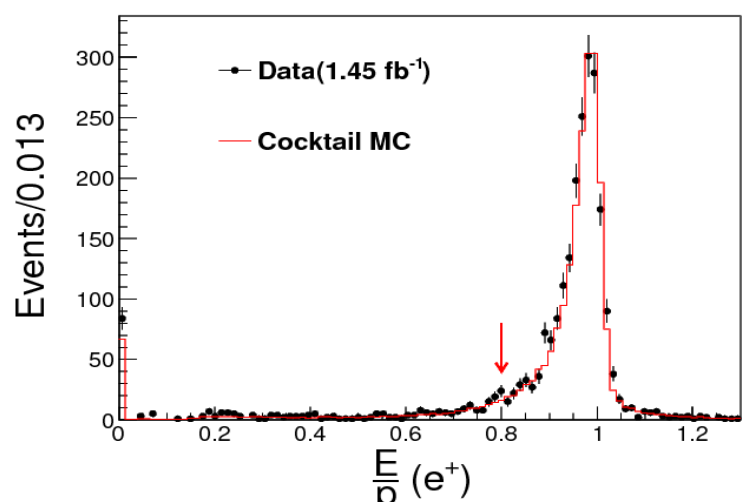
# The distributions of some DT requirements

Scaled to the luminosity of 1.45 $fb^{-1}$



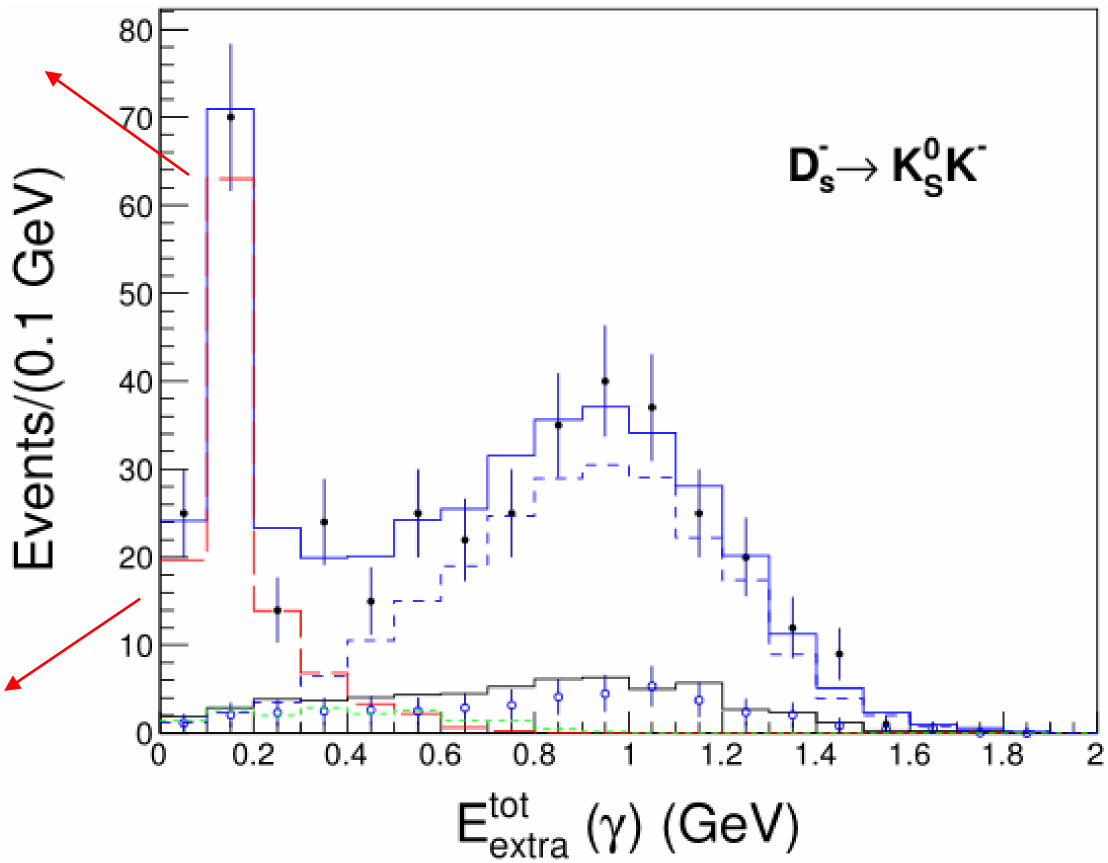
# The definition of $E_{extra}^{tot}(\gamma)$

$E_{extra}^{tot}(\gamma) = \sum_i E_i^{\gamma}$ :
the total energy of all good showers in EMC, except for those used in tag side.

To obtain the DT efficiency and DT yield

signal region: [0.0,0.4] GeV
sideband region: [0.6,2.0] GeV

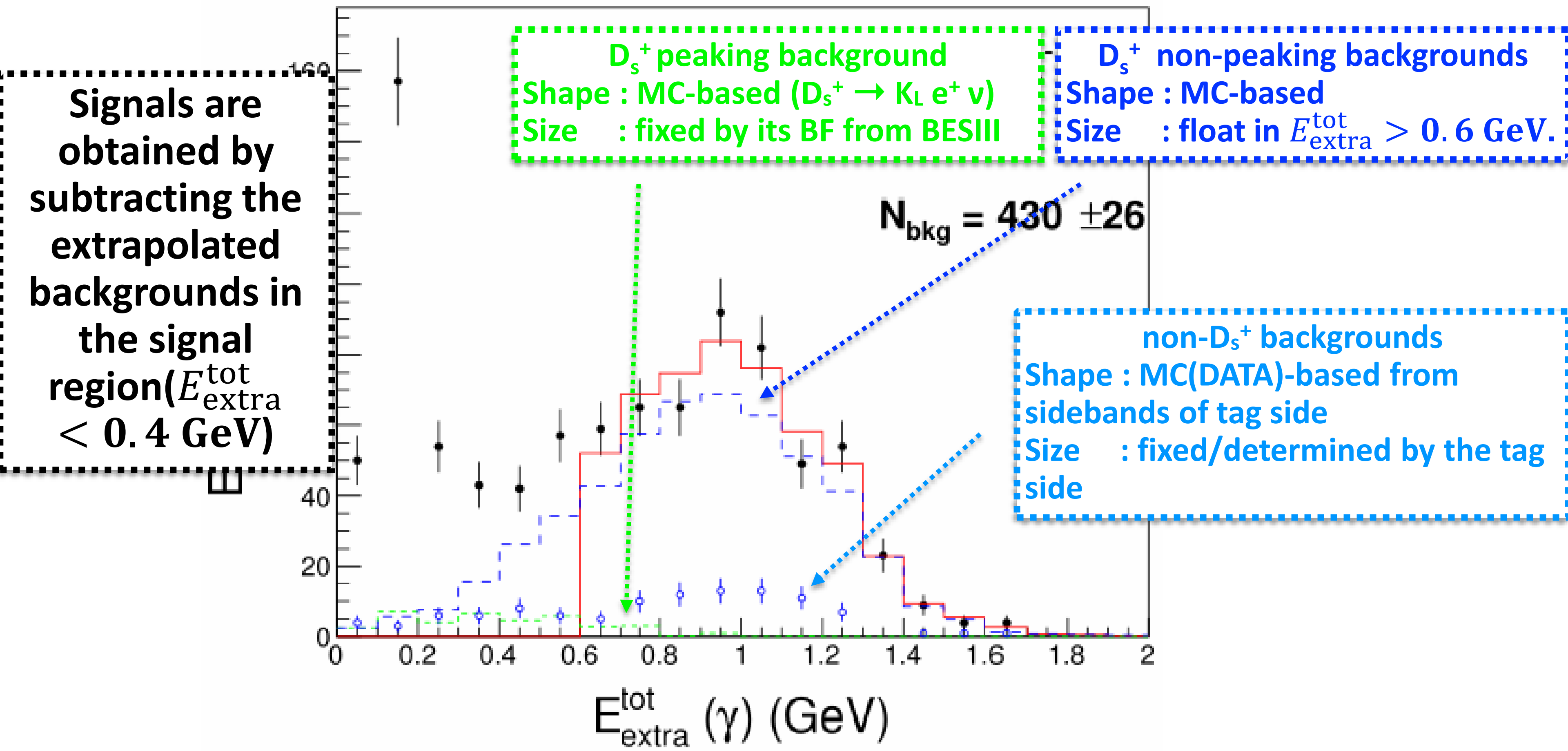
Peak: $\gamma/\pi^0$ from $D_s^* \to \gamma(\pi^0)D_s$




Near 0: some events when the photon from $D_s^*$ decay escapes detection

# Fitting method

Example (case of tagged $D_s^- \to K_S K^-$ from cocktail MC in round11)



# The efficiency of double tag

Using the same fitting method, fit $E_{\text{extra}}^{\text{tot}}(\gamma)$ from cocktail MC sample (10x), to obtain the efficiency of double tag.

DT efficiency

| Mode | $N_{ST}^{obs}$ | $N_{ST}^{gen}$ | $\epsilon_{ST}(\%)$ | $N_{DT}^{obs}$ | $N_{DT}^{gen}$ | $\epsilon_{DT}(\%)$ |
|---|---|---|---|---|---|---|
| $D_s^- \to K_S^0 K^-$ | $327175 \pm 787$ | 938106 | $34.88 \pm 0.08$ | $2359 \pm 56$ | 9240 | $25.52 \pm 0.60$ |
| $D_s^- \to K^+ K^- \pi^-$ | $1432970 \pm 1658$ | 3350775 | $42.77 \pm 0.05$ | $9203 \pm 117$ | 33006 | $27.88 \pm 0.36$ |
| $D_s^- \to K^+ K^- \pi^- \pi^0$ | $683768 \pm 3003$ | 3697582 | $18.49 \pm 0.08$ | $3440 \pm 89$ | 36422 | $9.45 \pm 0.24$ |
| $D_s^- \to K_S^0 K^- \pi^+ \pi^-$ | $89827 \pm 773$ | 588551 | $15.26 \pm 0.13$ | $524 \pm 34$ | 5797 | $9.03 \pm 0.58$ |
| $D_s^- \to K_S^0 K^+ \pi^- \pi^-$ | $166381 \pm 679$ | 1028658 | $16.17 \pm 0.07$ | $1024 \pm 40$ | 10132 | $10.10 \pm 0.40$ |
| $D_s^- \to \pi^- \eta_{\gamma\gamma}$ | $184789 \pm 1054$ | 1044711 | $17.69 \pm 0.10$ | $1439 \pm 45$ | 10291 | $13.98 \pm 0.43$ |
| $D_s^- \to \pi^- \pi^0 \eta_{\gamma\gamma}$ | $527751 \pm 4920$ | 5632459 | $9.37 \pm 0.09$ | $3772 \pm 85$ | 55480 | $6.80 \pm 0.15$ |
| $D_s^- \to \pi^- \eta'_{\pi^+\pi^-\eta(\gamma\gamma)}$ | $92529 \pm 458$ | 2391609 | $3.87 \pm 0.02$ | $630 \pm 29$ | 23558 | $2.67 \pm 0.12$ |
| $D_s^- \to \pi^- \eta'_{\gamma\rho^0}$ | $273726 \pm 2139$ | 2391609 | $11.45 \pm 0.09$ | $2005 \pm 63$ | 23558 | $8.51 \pm 0.27$ |

When counting the number of generated events, we don't care what sub-particles ($K_S$, $\pi^0$, $\eta$, $\eta'$) decays.

# Input / Output check

Using the same fitting method discussed above, to fit the distribution of $E_{\mathrm{extra}}^{\mathrm{tot}}(\gamma)$ from cocktail MC sample in round11, round12, round13, round14 and round15, respectively.

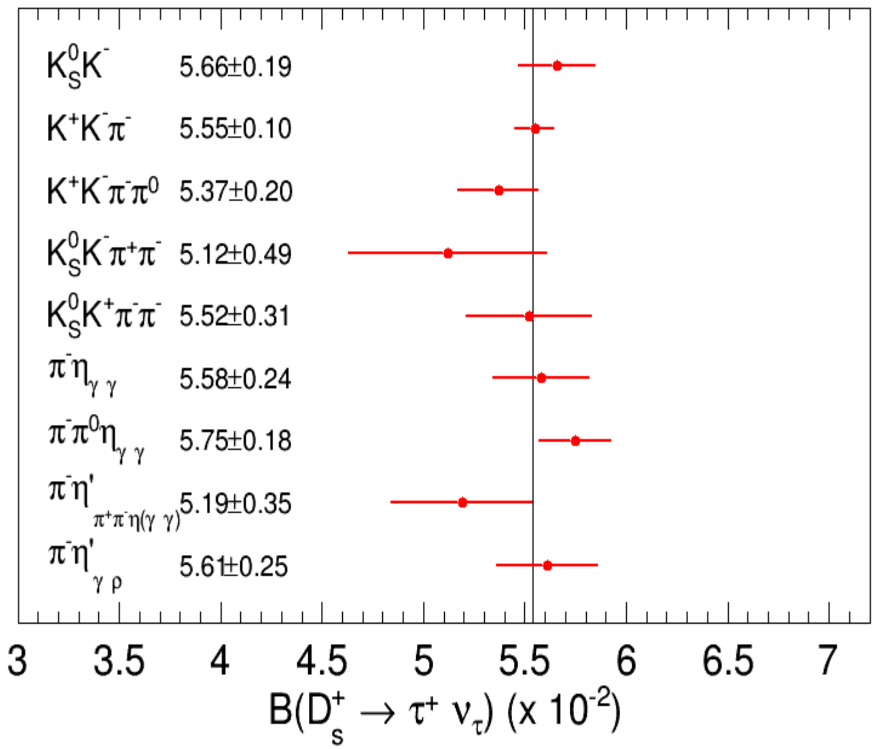
Check the Input / Output results in two different ways:

1. For a given tag mode, weighted by the error of the branching fraction from each round sample, to obtain the average branching fraction of signal side.
2. In each round sample, weighted by the error of the branching error from each tag mode, to obtain the average branching fraction of signal side.

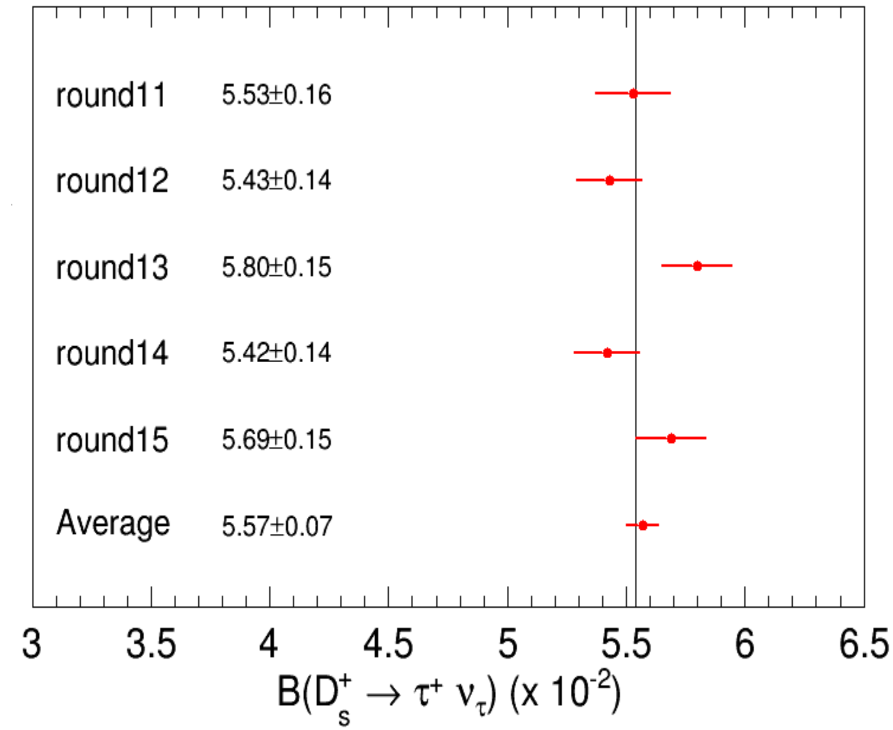
# Result of Input / Output check

Input value: 5.54%

The average results for each tag mode after combining the results of 5 rounds

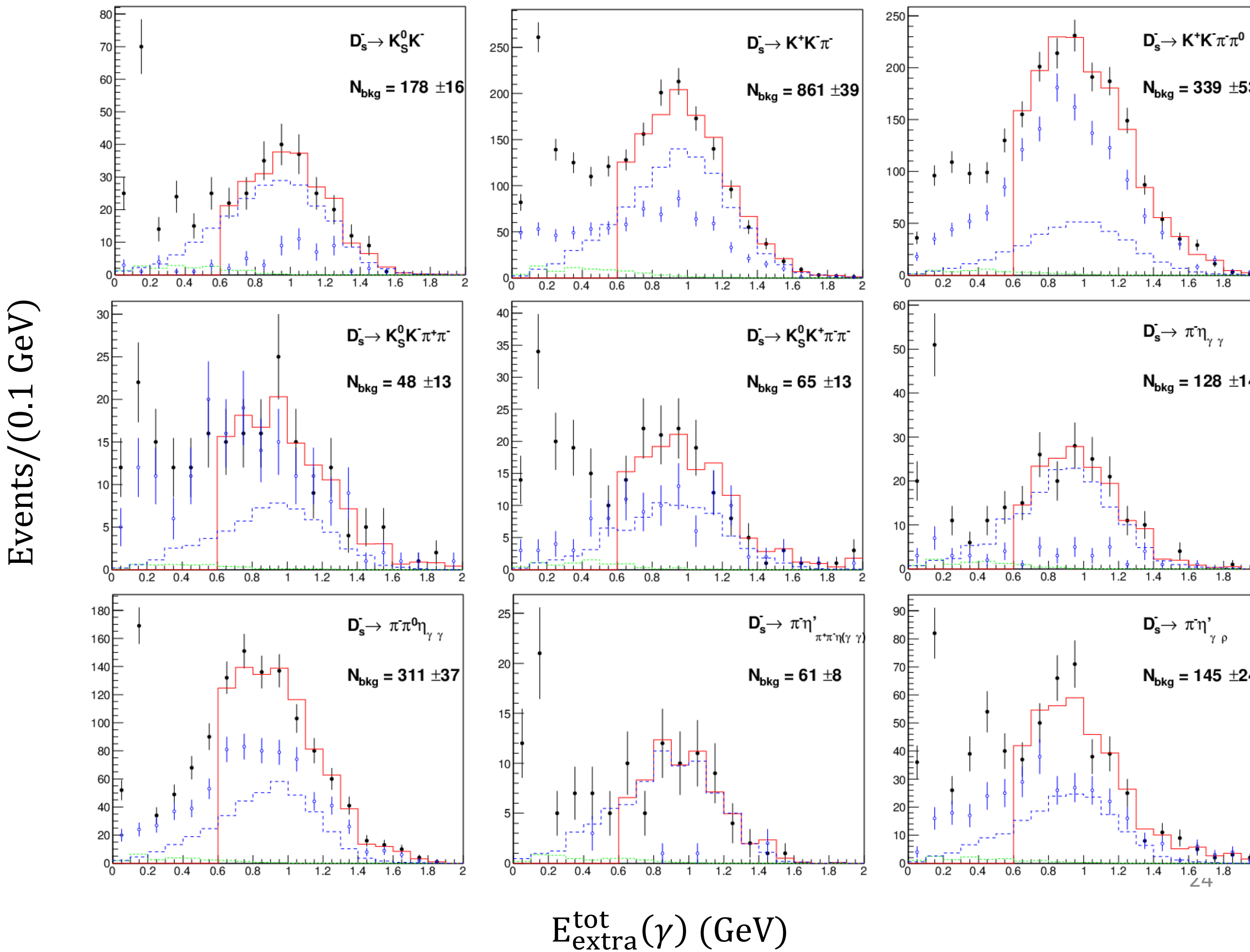



The average results for each round after combining the results of 9 tag modes.

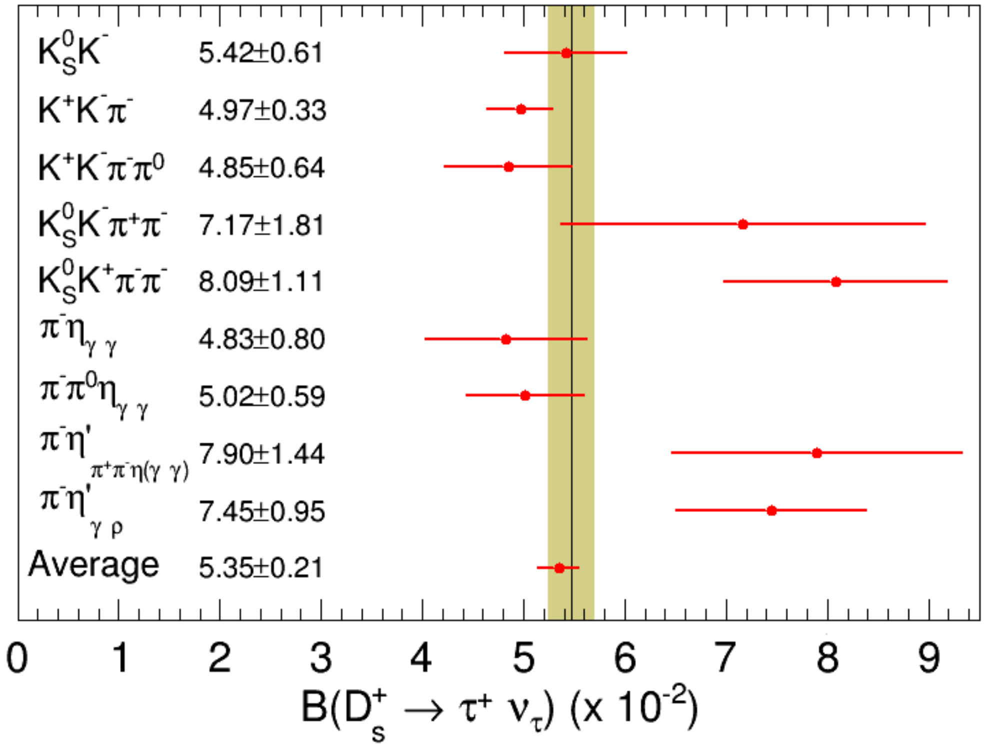



The output result is consistent with the input one within uncertainties

# Fitting result from data of 1.45 $fb^{-1}$



# Result from data of 1.45 fb$^{-1}$




| Experimental measurement | | | |
|---|---|---|---|
| Collaboration | $B(D_s^+ \to \tau^+\nu_\tau)(\%)$ | $f_{D_s^+}$(MeV) | Mode |
| CLEO | $5.30 \pm 0.47 \pm 0.22$ | $246.1 \pm 10.9 \pm 5.4$ | $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$ |
| CLEO | $6.42 \pm 0.81 \pm 0.18$ | $271.4 \pm 16.8 \pm 5.2$ | $\tau^+ \to \pi^+\bar{\nu}_\tau$ |
| CLEO | $5.52 \pm 0.57 \pm 0.21$ | $250.4 \pm 12.3 \pm 5.7$ | $\tau^+ \to \rho^+\bar{\nu}_\tau, \rho^+ \to \pi^+\pi^0(\gamma\gamma)$ |
| BABAR | $4.96 \pm 0.37 \pm 0.57$ | $259.9 \pm 6.6 \pm 7.6$ | $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$, or $\mu^+\nu_\mu\bar{\nu}_\tau$ |
| BELL | $5.70 \pm 0.21^{+0.31}_{-0.30}$ | $255.5 \pm 4.2 \pm 5.1$ | $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$, or $\mu^+\nu_\mu\bar{\nu}_\tau$, or $\pi^+\bar{\nu}_\tau$ |
| BESIII | $4.83 \pm 0.65 \pm 0.26$ | $241.0 \pm 16.3 \pm 6.5$ | $\tau^+ \to \pi^+\bar{\nu}_\tau$ |
| PDG | $5.48 \pm 0.23$ | | |

# Systematic uncertainty

| **Sources** | |
|---|---|
| Fitting tag $M(D_s^+)$ | Fitting range; Signal shape; Bkg shape; Bin size |
| Tag bias | |
| Tracking efficiency of $e^+$ | Radiative Bhabha sample: $e^+e^- \to \gamma e^+e^-$ |
| PID efficiency of $e^+$ | |
| Extra tracks | Double hadronic tag sample: $D_s^- \to 9$ tag modes, with $D_s^+ \to K_S^0 K^+, K^+K^-\pi^+$ |
| Non-$D_s^+$ bkg | |
| $D_s^+$ non-peaking bkg | |
| $D_s^+ \to K_L^0\, e^+\, \nu_e$ bkg | Control sample: $D^0 \to K_L^0\, \pi^+\pi^-$ |
| Cited $B(\tau^+ \to e^+\, \nu_e\bar{\nu}_\tau)$ | 0.2 % |
| FSR | |
| Total | |

# Summary and next to do

1. Based on double tag method, we perform the analysis $D_s^+ \to \tau^+\nu_\tau, \tau^+ \to e^+\nu_e\bar{\nu}_\tau$ with 9 tag modes ;
2. Using the cocktail MC sample in round11, round12, round13, round14 and round15, two different ways are used to check the input/output results:
   a. For a given tag mode, average the results of 5 round samples;
   b. For a given round sample, average the results of 9 tag modes.
   and the output results are consistent with the input value within uncertainties.
3. With the data sample of 1.45 $fb^{-1}$, the branching fraction of $D_s^+ \to \tau^+\nu_\tau$ is measured to be $(5.35 \pm 0.21_{stat})\%$, which is consistent with PDG $(5.48 \pm 0.23)\%$.

Next to do:

1. Finish systematic uncertainties;
2. Finish memo.

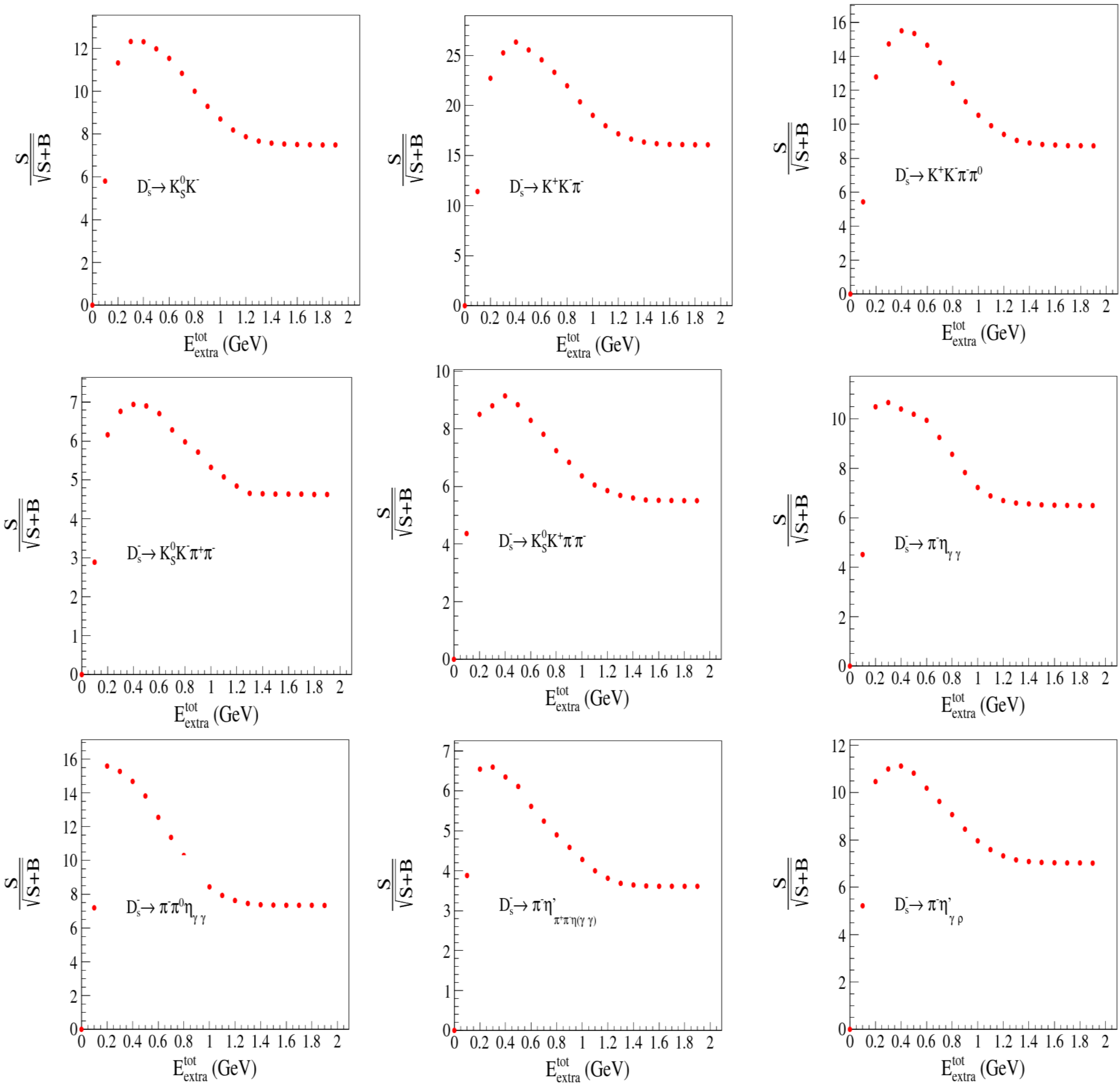
Thanks for your attention!

# Back up

The optimal signal region in $E_{\text{extra}}$ for DT yield extraction is predicted from a MC simulation study. Choosing $E_{\text{extra}}$ less than 400 MeV maximizes the signal significance. Note that with our chosen requirement of $E_{\text{extra}} < 400$ MeV, we are including $D_s^+ \to \tau^+ \nu_\tau \gamma$ as signal. However, this is expected to be very small, as the kinetic energy of the $\tau^+$ in the $D_s^+$ rest frame is only 9.3 MeV and it cannot radiate much.

Ds* Ds MC sample

The optimization of $E^{tot}_{extra}(\gamma)$



# Fitting method

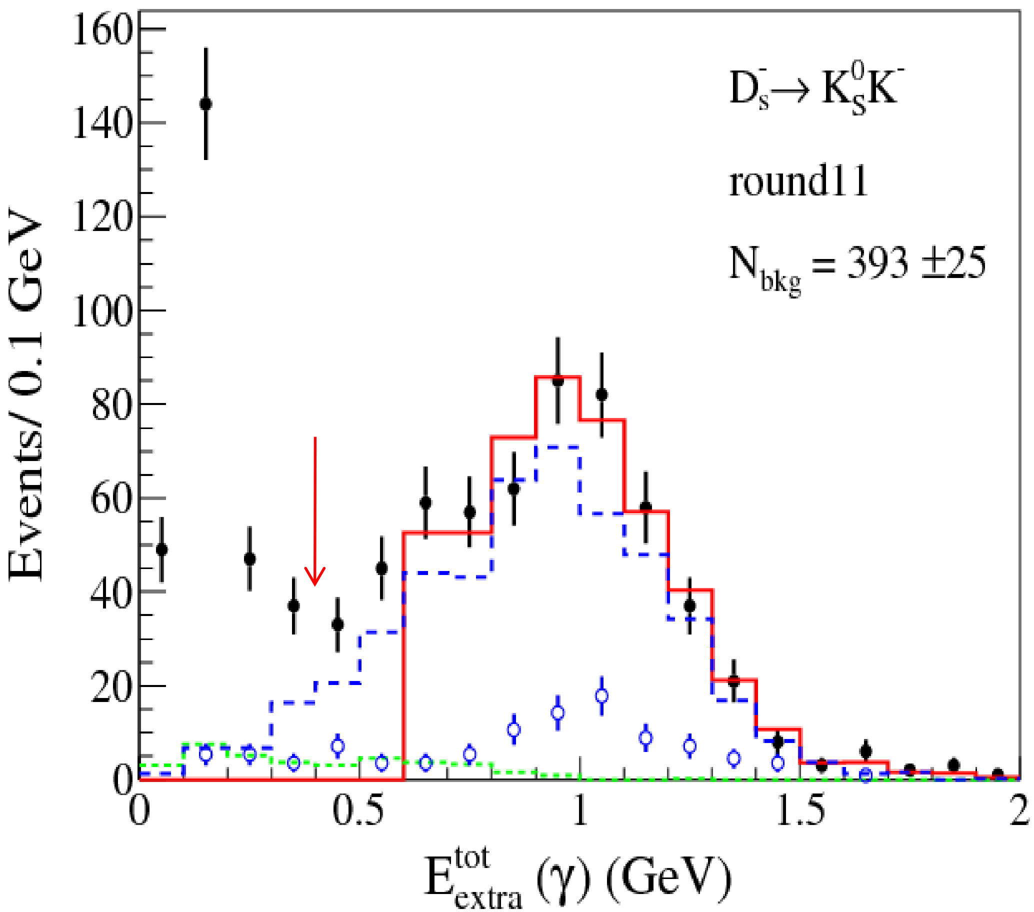
For example: the distribution of $E^{tot}_{extra}(\gamma)$ from cocktail MC sample in round11:

a. Fit the high side of $E^{tot}_{extra}(\gamma)$;

b. And then count the number of signal events in $E^{tot}_{extra}(\gamma)$ signal region by:

$$N_{sig} = N^{t}_{sig} - N_{D_s^+ \to K_L^0 e^+ \nu_e} - f_1 N_{tagside} - f_2 N_{D_s^+ bkg}$$

$f_1$ and $f_2$ are the scaled factor for tag sideband background events and $D_s^+$ background




Dotted with error bar:
from cocktail MC sample in round11;

Red:
fit result of high side of $E^{tot}_{extra}(\gamma)$.

Circle(non-$D_s^+$ bkg):
from tag $M(D_s^-)$ sideband events.

Short-dashed Green($D_s^+$ peaking bkg):
$D_s^+ \to K_L e^+ \nu_e$ matched histogram extracted from $D_s^* D_s$ MC sample in the first 5 rounds: round01 ~ round05, and the number of events is the average value from round 01 to round15.

Dashed Blue($D_s^+$ non-peaking bkg):
the histogram from $D_s^* D_s$ MC sample in the first 5 rounds that excludes signal and $D_s^+ \to K_L e^+ \nu$, float the number of events.

# Summary of the systematic uncertainty

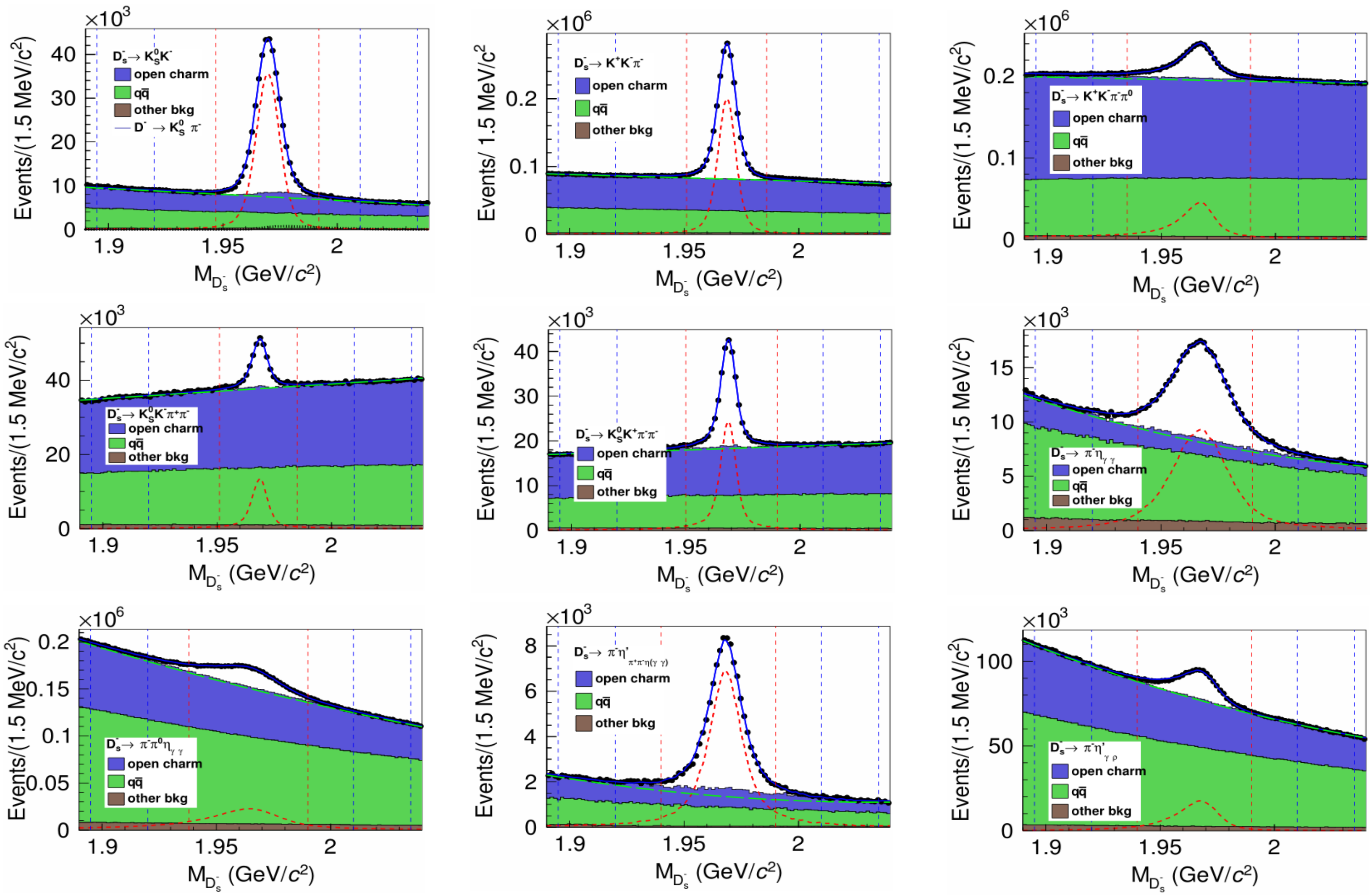
In this analysis, the statistical uncertainty with full data sample is about 2.9%. Perhaps the systematical uncertainty will be comparable with statistical uncertainty.

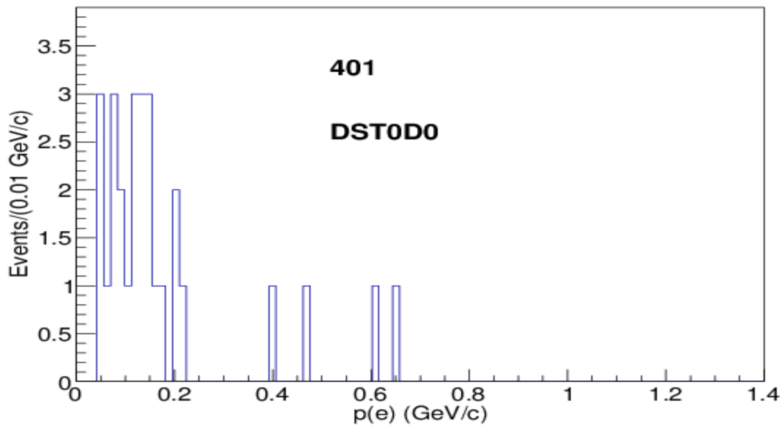
| Sources | Effect on $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau)$ (%) | Status |
|---|---|---|
| Fitting M($D_s^-$) | 0.85 | $\surd$ |
| Tag bias | 1.04 | $\surd$ |
| Extra track | 1.0 | $\surd$ |
| Tracking | 0.28 | $\surd$ |
| PID | 0.40 | $\surd$ |
| Non electron | 0.1 | to be done |
| non-$D_s^+$ bkg | | to be done |
| $D_s^+$ non-peaking bkg | 1.38 | $\surd$ |
| $D_s^+ \to K_L^0 e^+ \nu_e$ bkg | 1.26 | to be done |
| Cited $\mathcal{B}(\tau^+ \to e^+ \nu_e \bar{\nu}_\tau)$ | 0.2 | $\surd$ |
| FSR | 0.15 | $\surd$ |
| Total | 2.6 | |

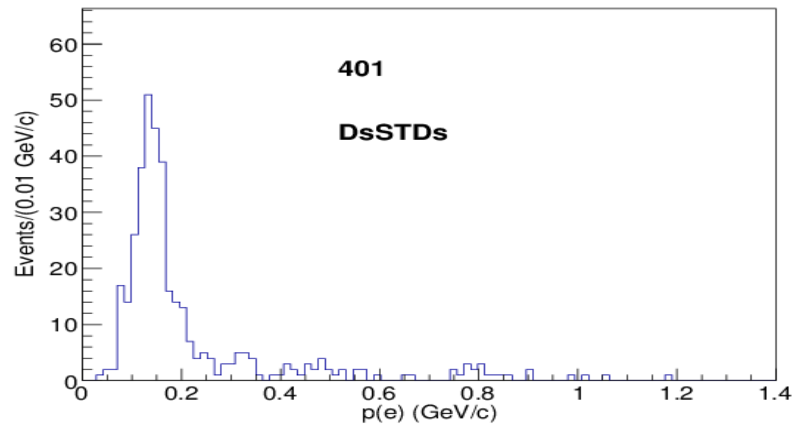
# The distribution of $M(D_s^-)$

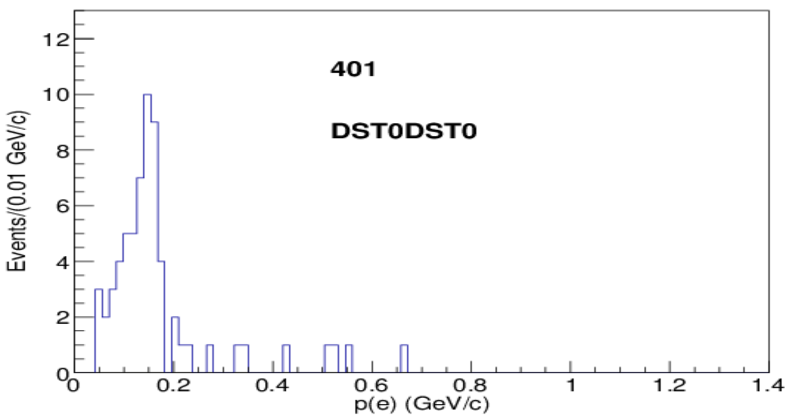
Fit = MC matched shape + 1st /2nd Chebychev

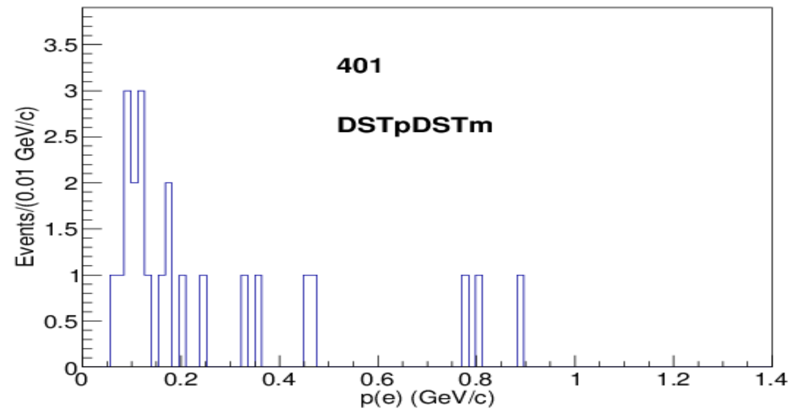
Dotted with error bar is from cocktail MC with ten times of data.

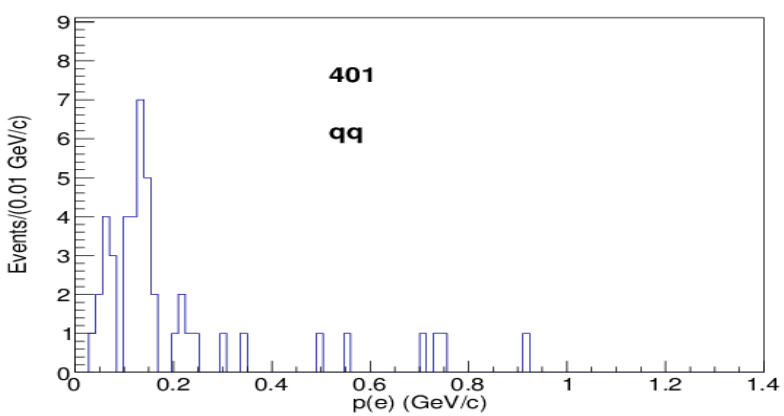




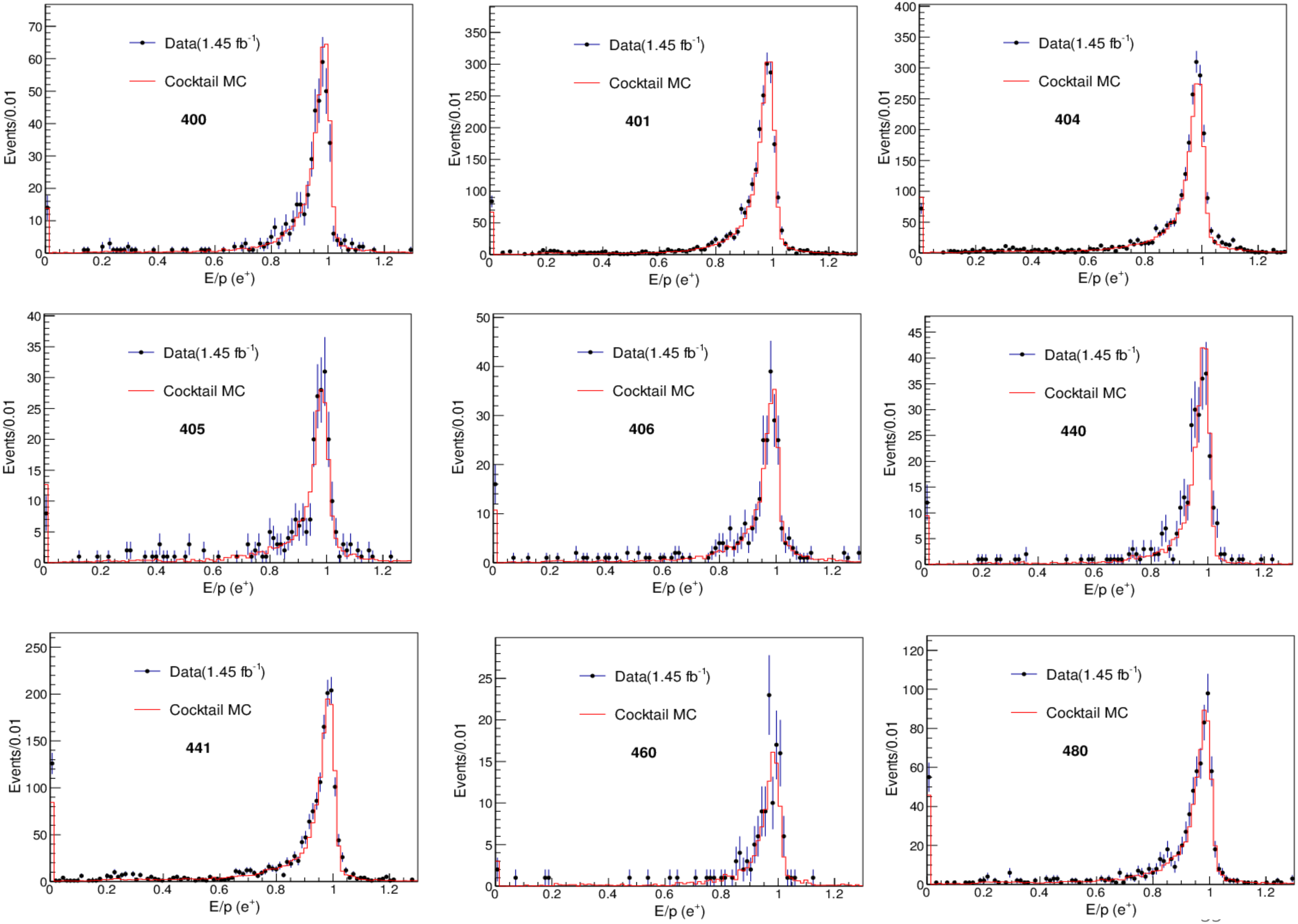




With $E/p < 0.0001$

1x cocktail MC


Data(1.45 fb$^{-1}$)
Cocktail MC
400
401
404
405
406
440
441
460
480
Events/0.01
E/p (e$^{+}$)