$Study\ of\quad D_S^+ \to \tau^+ \nu_\tau$

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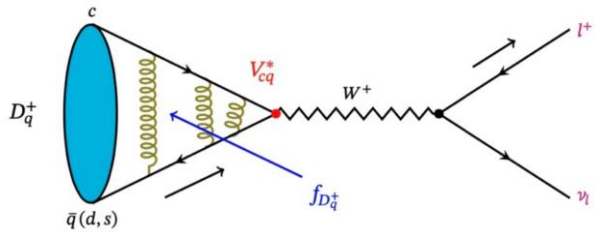
Outline

Motivation



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

- Measurement of the bf of $D_S^+ \to l^+\nu_l$ is important to determine $f_{D_S^+}$ to validate the calculation in LQCD,and better $|V_{cs}|$ to test the unitarity of the CKM matrix.
- Test on lepton flavor universality in charm sector.
- Further measurements of leptonic D_S decays are still high desirable.

Motivation

PDG: (5.32±0.11)%

Experiment	Mode	$\mathcal{B}$ (%)
CLEO-c [4]	$D_s^+ \to \tau^+(e^+\nu_e\bar{\nu}_\tau)\nu$	$5.30 \pm 0.47 \pm 0.22$
CLEO-c [5]	$D_s^+ \to \tau^+(\pi^+\bar{\nu})\nu$	$6.42 \pm 0.81 \pm 0.18$
CLEO-c [6]	$D_s^+ \to \tau^+(\rho^+\bar{\nu})\nu$	$5.52 \pm 0.57 \pm 0.21$
Belle [7]	$D_s^+ \to \tau^+\nu$	$5.70 \pm 0.21^{+0.31}_{-0.30}$
Babar [8]	$D_s^+ \to \tau^+\nu$	$5.00 \pm 0.35 \pm 0.49$
BESIII [9]	$D_s^+ \to \tau^+(\pi^+\pi^0\bar{\nu})\nu$	$5.29 \pm 0.25 \pm 0.20$
BESIII [10]	$D_s^+ \to \tau^+(e^+\nu_e\bar{\nu}_\tau)\nu$	$5.27 \pm 0.10 \pm 0.12$
BESIII [11]	$D_s^+ \to \tau^+(\pi^+\bar{\nu})\nu$	$5.21 \pm 0.25 \pm 0.17$
BESIII [12]	$D_s^+ \to \tau^+(\pi^+\bar{\nu})\nu$	$4.83 \pm 0.65 \pm 0.26$

[4] P. U. E. Onyisi et al., CLEO Collaboration, Phys. Rev. D **79** (2009) 052002.

[5] J. P. Alexander et al., CLEO Collaboration, Phys. Rev. D **79** (2009) 052001.

[6] P. Naik et al., CLEO Collaboration, Phys. Rev. D **80** (2009) 112004.

[7] A. Zupanc et al., Belle Collaboration, Journal of High Energy Physics **09** (2013) 139.

[8] P. del Amo Sanchez et al., Babar Collaboration, Phys. Rev. D **82** (2010) 091103.

[9] M. Ablikim et al., BESIII Collaboration, Phys. Rev. D **104** (2021) 032001.

[10] M. Ablikim et al., BESIII Collaboration, Phys. Rev. Lett. **127** (2021) 171801.

[11] M. Ablikim et al., BESIII Collaboration, Phys. Rev. D **104** (2021) 052009.

[12] M. Ablikim et al., BESIII Collaboration, Phys. Rev. D **94** (2016) 072004.

$$D_S^+ \to \tau^+\nu_\tau$$

$$\tau^+ \to e^+\nu_e\bar{\nu}_\tau \qquad \tau^+ \to \pi^+\bar{\nu}_\tau$$

$$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau \qquad \tau^+ \to \rho^+_{\pi^+\pi^0}\bar{\nu}_\tau$$

MC samples

BOSS version : 7.0.3

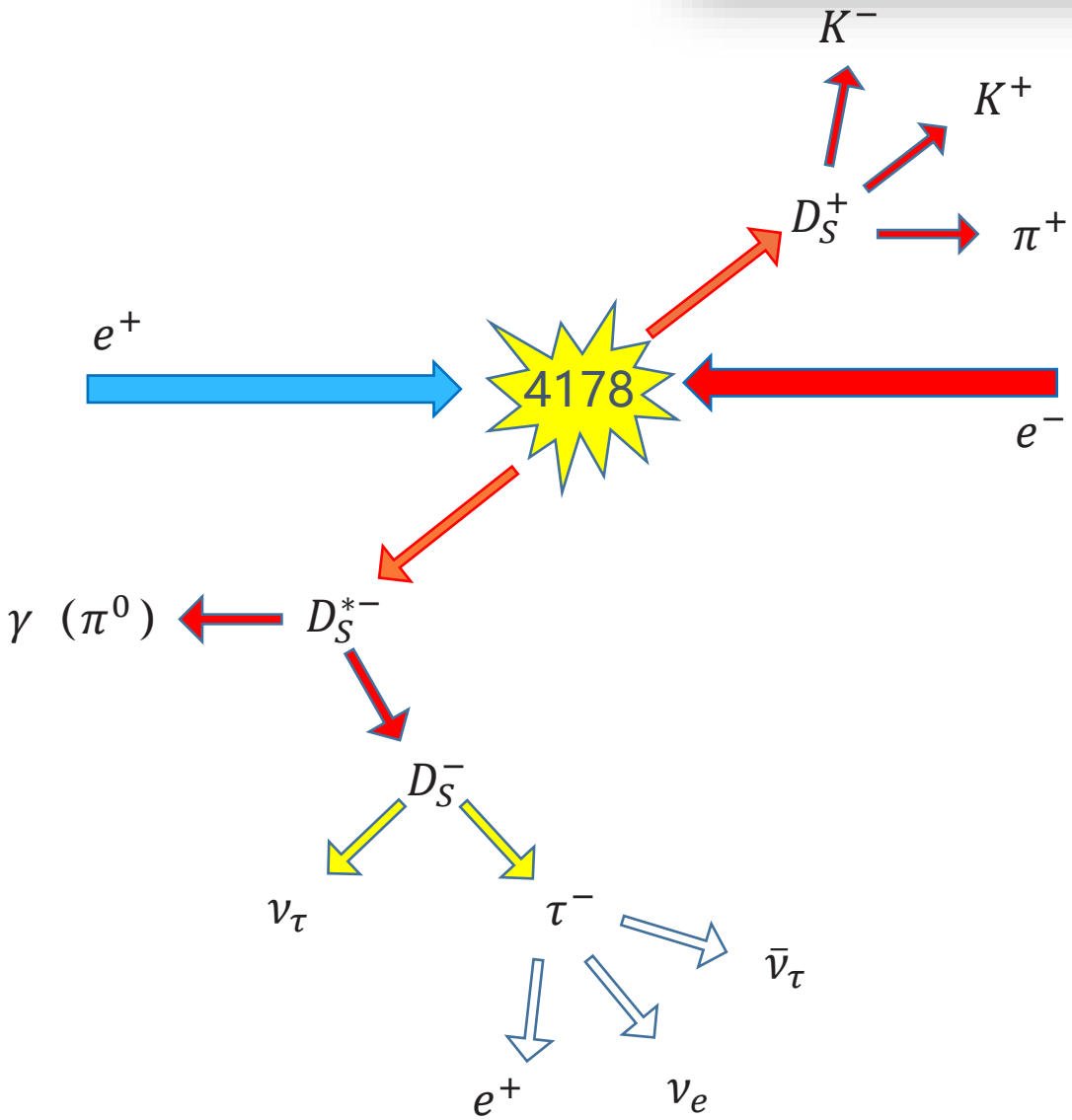
MC samples.(10x)

Component	directory	4180
D^0D^0	D0D0	179
D^+D^-	DpDm	197
$D^{*0}D^0$	DST0D0	1211
$D^{*+}D^-$	DSTpDm	1296
$D^{*0}D^{*0}$	DST0DST0	2173
$D^{*+}D^{*-}$	DSTpDSTm	2145
$D_s^+D_s^-$	DsDs.newLS[2]	37.7
$D_s^{*+}D_s^-$	DsSTDs.newLS[3]	961
$D_s^{*+}D_s^{*-}$	DsSTDsST	
$DD^*\pi^+$	DDSTPIp	383
$DD^*\pi^0$	DDSTPI0	192
$DD\pi^+$	DDPIp	50
$DD\pi^0$	DDPI0	25
$q\bar{q}$	qq	13.8
$\gamma J/\psi$	RR1S	0.40
$\gamma\psi(2S)$	RR2S	0.42
$\gamma\psi(3770)$	RR3770	0.06
$\tau\tau$	tt	3.45
$\mu\mu$	mm	5.24
ee	ee[5]	424.81
ee	eeNLO[6]	416.10
$\gamma\gamma$	TwoGam	1.7
HCT	HCT	0.10178

Signal MC.

Decay mode	Generator
$D_S^+ \to \tau^+\nu_\tau$	SLN
$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	PHOTOS TAULNUNU
$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$	PHOTOS TAULNUNU
$\tau^+ \to \pi^+\bar{\nu}_\tau$	TAUSCALARNU
$\tau^+ \to \rho^+_{\pi^+\pi^0}\bar{\nu}_\tau$	TAUHADNU -0.108 0.775 0.149 1.364 0.400

Analytic Strategy



$$\mathcal{B}_{\rm sig}^{\alpha} = \frac{N_{\rm sig_{com}}^{\rm obs,\ \alpha} / \epsilon_{\rm tag,sig_{com}}^{\alpha}}{\mathcal{B}_{\tau^+\to e^+\nu_e\bar{\nu}_\tau} \sum_i N_{\rm tag}^{\rm obs,\ \alpha,\ i} / \epsilon_{\rm tag}^{\alpha,\ i}}.$$

$$N_{\rm tag}^{\rm obs,\ \alpha,\ i} = 2N_{D_s^*D_s}\mathcal{B}_{\rm tag}^{\alpha,\ i}\epsilon_{\rm tag}^{\alpha,\ i};$$

$$N_{\rm sig}^{\rm obs,\ \alpha,\ i} = 2N_{D_s^*D_s}\mathcal{B}_{\rm tag}^{\alpha,\ i}\mathcal{B}_{\rm sig}^{\alpha,\ i}\mathcal{B}_{\tau^+\to e^+\nu_e\bar{\nu}_\tau}\epsilon_{\rm tag,\ sig}^{\alpha,\ i}.$$

Good charged tracks

- |Vz| < 10 cm
- |Vxy| < 1 cm
- |cosθ| < 0.93

Good photon

- Barrel E ≥ 25MeV，Endcap E ≥50 MeV
- θγ−charged >10 °
- 0 ≤ TDC ≤ 14 (x50ns)

PID

- K：prob(K) > 0, prob(K) > prob(π)
- π：prob(π) > 0, prob(π) > prob(K)

K_S^0

- M K_S^0 ($\pi^+\pi^-$) ∈ (0.487，0.511)GeV/c^2
- χ^2_{vtx}< 100
- |Vz| < 20 cm , |cosθ| < 0.93

π^0 / η

- π^0 : Mπ^0 ($\gamma\gamma$) ∈ (0.115, 0.150)GeV/c ^{2}
  p(π^0) > 0.1 GeV/c^2
- η : Mη ($\gamma\gamma$)∈ (0.50,0.57) GeV/c ^{2}
- χ^2_{1c} < 200

$\rho^{-(0)}$, η'

- $\rho^{-(0)}$: M $\rho^{-(0)}$($\pi^{0(+)}\pi^-$) ∈ (0.57, 0.97) GeV/c^2
- η': Mη'($\gamma\rho^0$)∈ (0.94, 0.976)GeV/ c^2
  Mη'($\pi^+\pi^-\eta$) ∈ (0.946, 0.97)GeV/ c^2

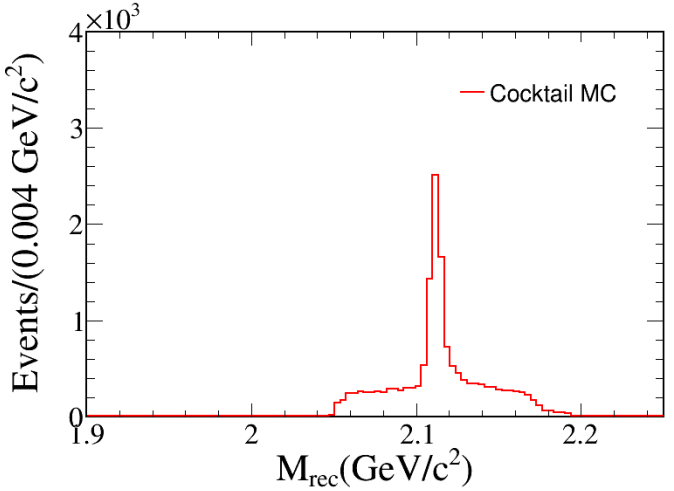
Further requirements

- p($\pi^{\pm}$)> 0.1 GeV/c
- p(γ)from $\eta' \to \gamma\rho^0$: p(γ) > 0.1 GeV/c

$D_S^{\pm}$

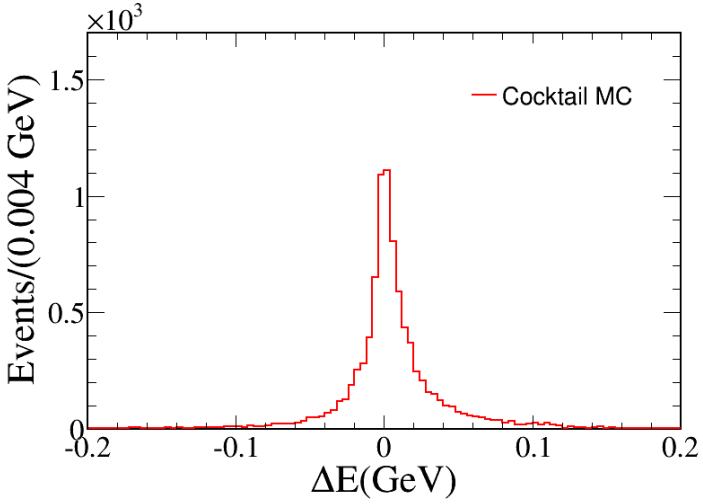
$$M_{\rm rec}^2c^4 = (E_{\rm cms} - \sqrt{|\vec{p}_{D_s^-}|^2c^2 + m_{D_s^-}^2c^4})^2 - |-\vec{p}_{D_s^-}|^2c^2$$

- minimum $|M_{\rm rec} - m(D_s^*)|$
- $M_{\rm rec} \in (2.05, 2.195)\ {\rm GeV}/c^2$

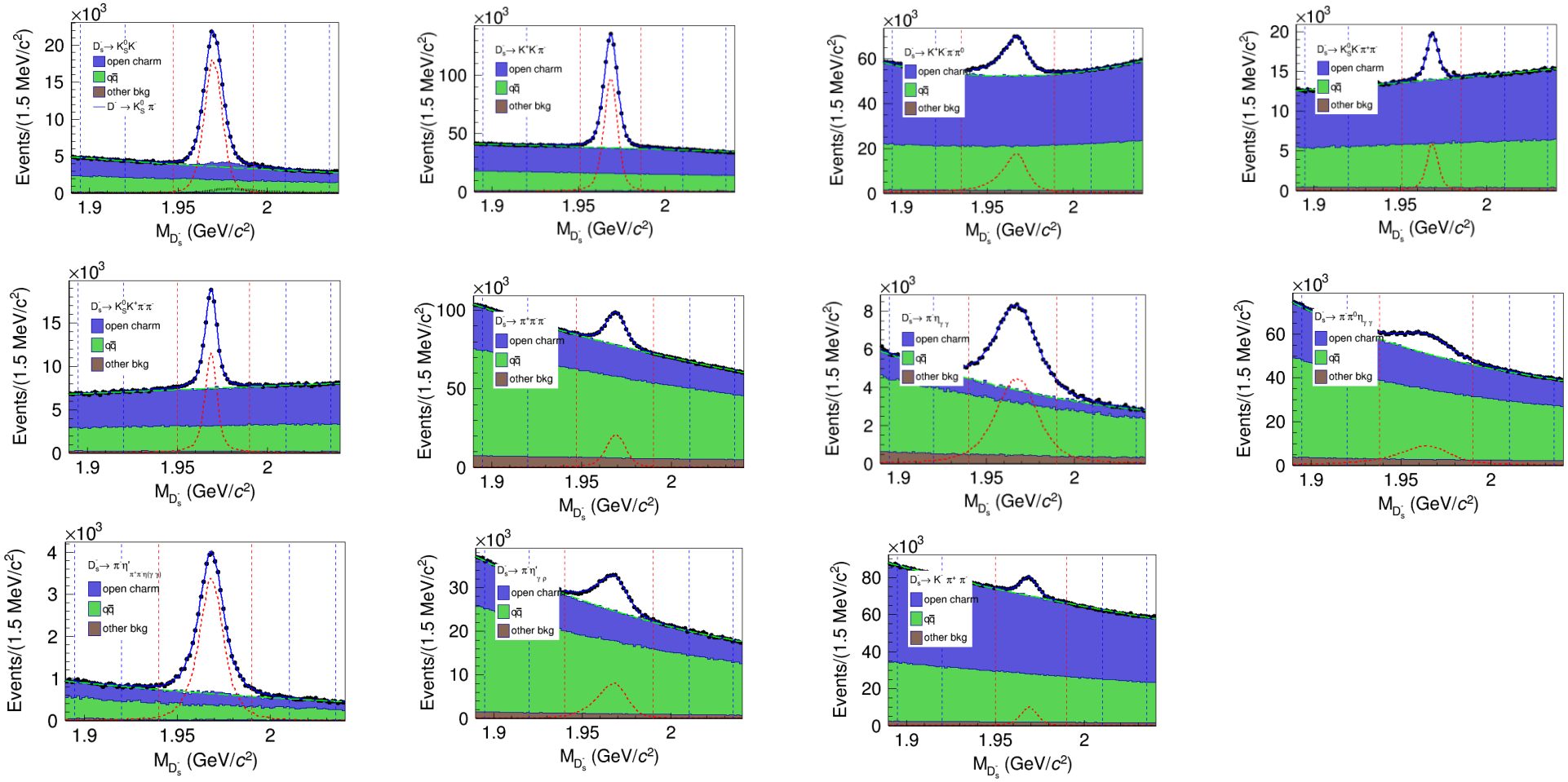


γ / π^0 from D_S^{*-}

$$\Delta E = E_{\rm cm} - E_{\rm tag} - E_{\rm miss} - E_{\gamma/\pi^0},$$
$$E_{\rm tag} = \sqrt{|\vec{p}_{\rm tag}|^2 + M_{D_s^-}^2},$$
$$E_{\rm miss} = \sqrt{|\vec{p}_{\rm miss}|^2 + M_{D_s^+}^2},$$
$$\vec{p}_{\rm miss} = -\vec{p}_{\rm tag} - \vec{p}_{\gamma(\pi^0)}$$



Event Selection



- Bkg:1st to 3rd Chebychev function
- Sig: signal shape extracted from MC truth matched sample

ST yields and efficiencies

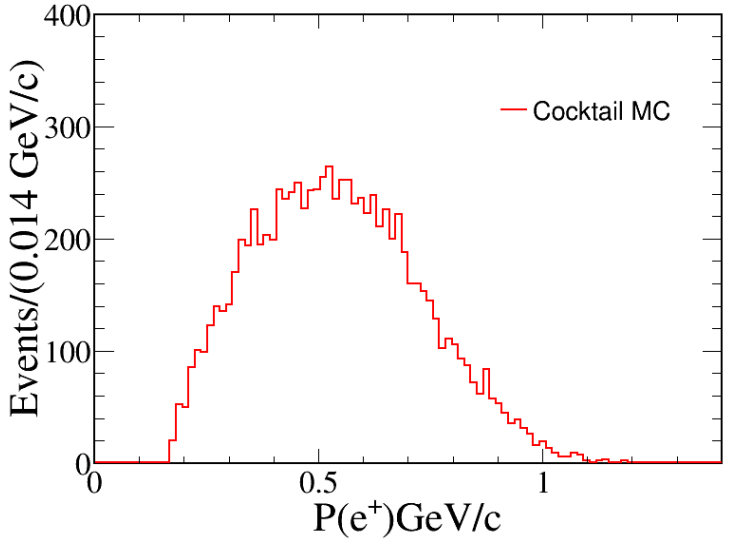
$\epsilon_{tag}^{\alpha} = N_{ST}^{obs} / N_{ST}^{gen}$

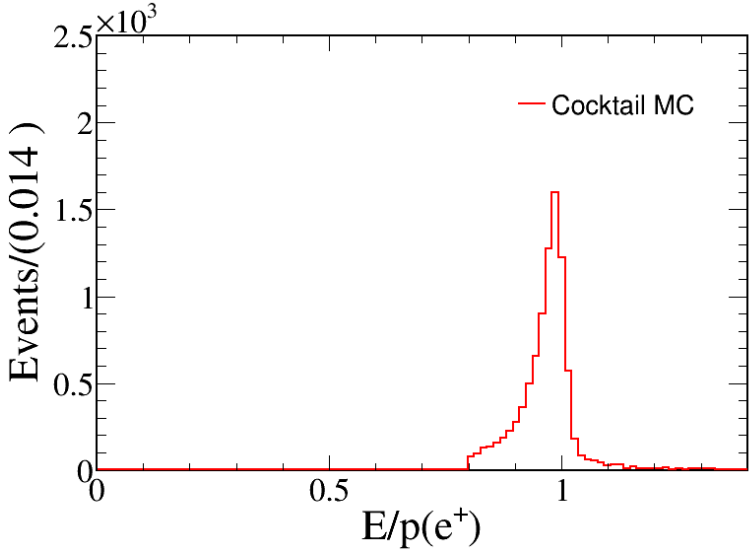
Mode	$M_{D_s^-}$ Signal region	$M_{D_s^-}$ Sideband region
$D_s^- \to K_S^0 K^-$	[1.947,1.992]	
$D_s^- \to K^+ K^- \pi^-$	[1.951,1.986]	
$D_s^- \to K^+ K^- \pi^- \pi^0$	[1.935,1.989]	
$D_s^- \to K_S^0 K^- \pi^+ \pi^-$	[1.951,1.985]	
$D_s^- \to K_S^0 K^+ \pi^- \pi^-$	[1.950,1.990]	
$D_s^- \to \pi^+ \pi^- \pi^-$	[1.947,1.990]	[1.895, 1.92] || [2.01, 2.035]
$D_s^- \to \pi^- \eta_{\gamma\gamma}$	[1.940,1.990]	
$D_s^- \to \pi^- \pi^0 \eta_{\gamma\gamma}$	[1.938,1.990]	
$D_s^- \to \pi^- \eta'_{\pi^+\pi^-\eta(\gamma\gamma)}$	[1.940,1.990]	
$D_s^- \to \pi^- \eta'_{\gamma\rho^0}$	[1.940,1.990]	
$D_s^- \to K^- \pi^+ \pi^-$	[1.950,1.990]	

Mode	ϵ_{tag}^{4180}
$D_S^- \to K_S^0 K^-$	34.27±0.12
$D_S^- \to K^+ K^- \pi^-$	41.65±0.07
$D_S^- \to K^+ K^- \pi^- \pi^0$	13.37±0.09
$D_S^- \to K_S^0 K^- \pi^+ \pi^-$	12.92±0.17
$D_S^- \to K_S^0 K^+ \pi^+ \pi^-$	14.37±0.08
$D_S^- \to \pi^- \eta$	55.61±0.39
$D_S^- \to \pi^+ \pi^- \pi^-$	17.16±0.13
$D_S^- \to \pi^- \pi^0 \eta$	7.13±0.05
$D_S^- \to \pi^- \eta'_{\pi^+\pi^-\eta}$	3.40±0.02
$D_S^- \to \pi^- \eta'_{\gamma\rho^0}$	9.91±0.09
$D_S^- \to K^- \pi^+ \pi^-$	48.77±0.69

Selection criteria for $D_S^+ \to \tau^+\nu_\tau$, $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

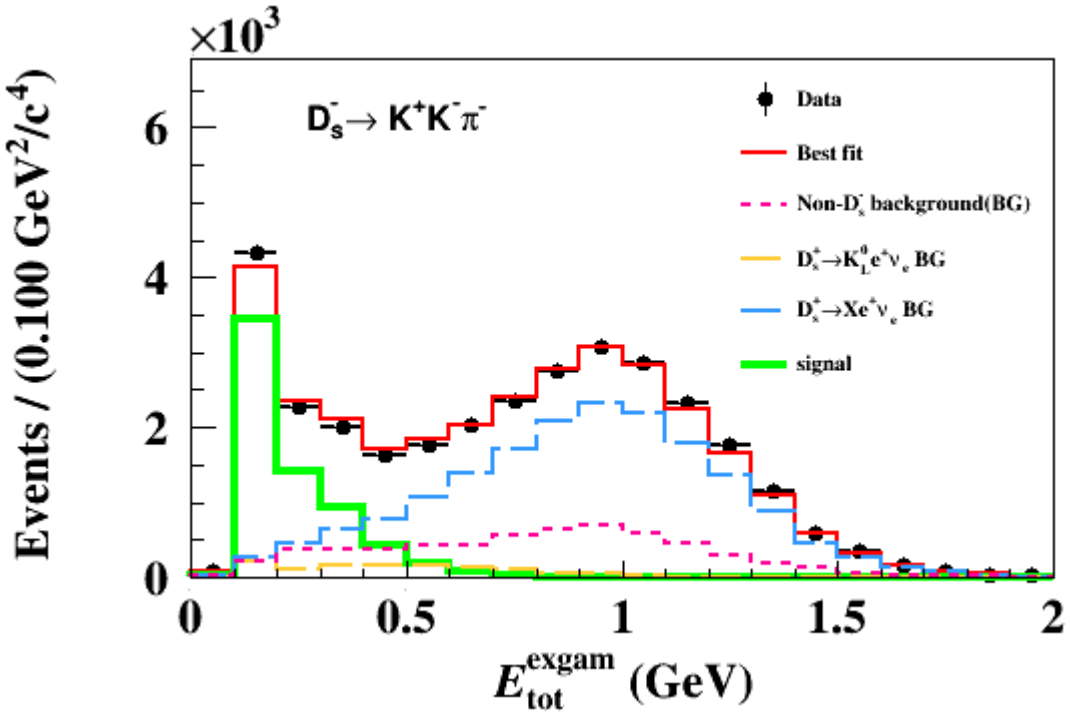
- Only one charged track
- $P(e) > 0.001$;
- $\mathrm{R}(e^+) = \frac{P(e)}{P(e)+P(\pi)+P(K)} > 0.8$;
- the deposited energy in EMC over the momentum for positron: $\frac{E}{p}(e^+) > 0.8$.
- the momentum of positron: $p(e^+) > 0.2$ GeV/c.





Fitting result (cocktail MC 10x)

BF : 5.42±0.083 %

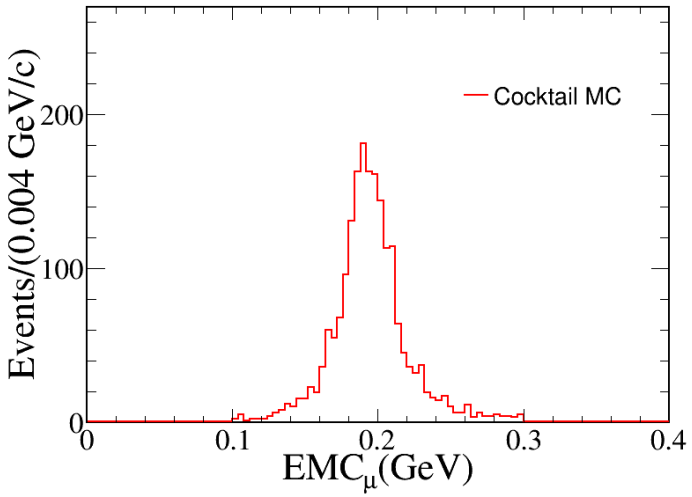


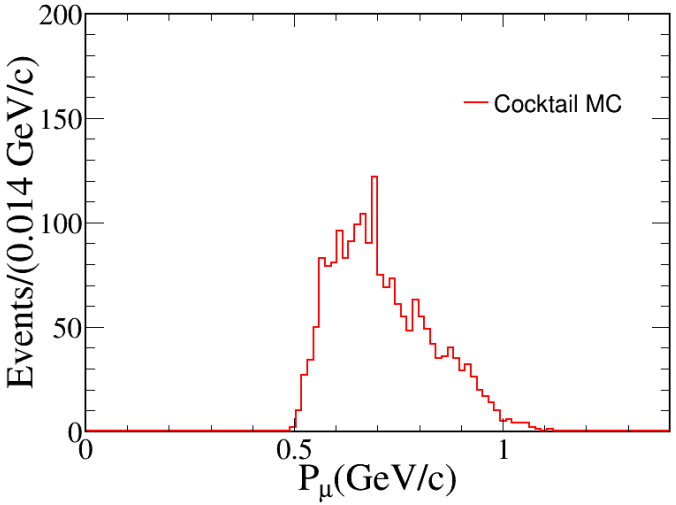
- Signal : the shape extracted from D_S^{*+} D_S^- MC truth matched event.
- $\mathrm{non}D_S^+$ bkg : the shape is extracted from the corresponding MDs sideband region, the size is fixed according to the corresponding MDs sideband scale factor from cocktail MC.
- $D_S^- \to K_L^0 e^- \nu_e$: the shape is extracted the D_S^{*+} D_S^- MC truth matched events, the size is fixed.
- $D_S^- \to X e^- \nu_e$: the shape is extracted from MC ,the size is the float.

Selection criteria for $D_S^+ \to \tau^+\nu_\tau$, $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$

- Only one charged track
- P(μ) > 0.001 , P(μ) > P(K) , P(μ) > P(e)
- The deposited energy in EMC ∈ (0.1, 0.3)GeV
- cosθ , momentum , depth

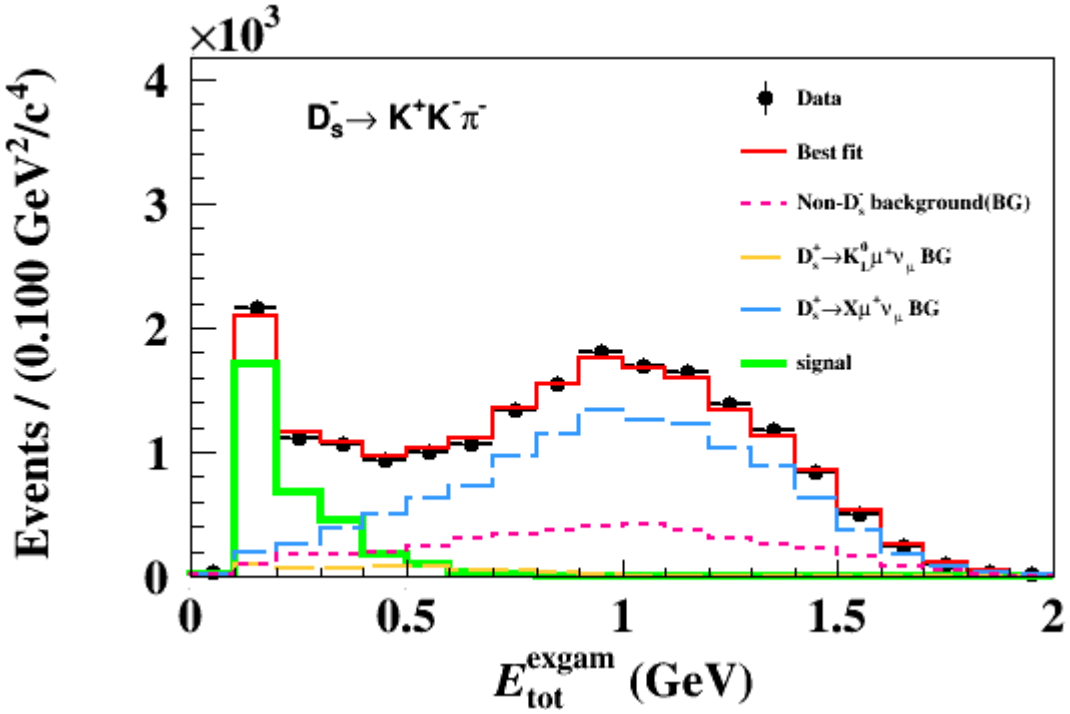
$\lvert\cos\theta\rvert$	momentum (GeV/c)	depth (cm)
(0.0,0.2)	$0.50 < p < 0.61$	> 3.0
	$0.61 < p < 0.75$	$> 100.0 \times p - 58.0$
	$0.75 < p < 0.88$	> 17.0
	$0.88 < p < 1.04$	$> 100.0 \times p - 71.0$
	$1.04 < p < 1.20$	> 33.0
(0.2,0.4)	$0.50 < p < 0.64$	> 3.0
	$0.64 < p < 0.78$	$> 100.0 \times p - 61.0$
	$0.78 < p < 0.91$	> 17.0
	$0.91 < p < 1.07$	$> 100.0 \times p - 74.0$
	$1.07 < p < 1.20$	> 33.0
(0.4,0.6)	$0.50 < p < 0.67$	> 3.0
	$0.67 < p < 0.81$	$> 100.0 \times p - 64.0$
	$0.81 < p < 0.94$	> 17.0
	$0.94 < p < 1.10$	$> 100.0 \times p - 77.0$
	$1.10 < p < 1.20$	> 33.0
(0.6,0.8)		> 9.0
(0.8,0.93)		> 9.0





Fitting result(cocktail MC 10x)

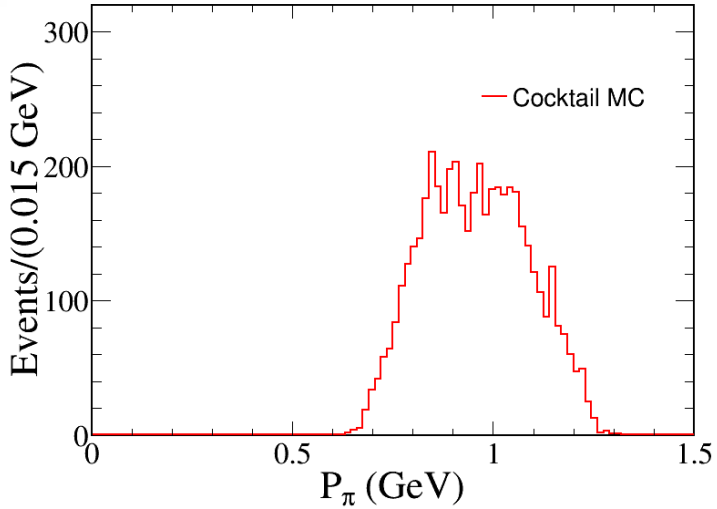
BF : 5.66±0.127 %

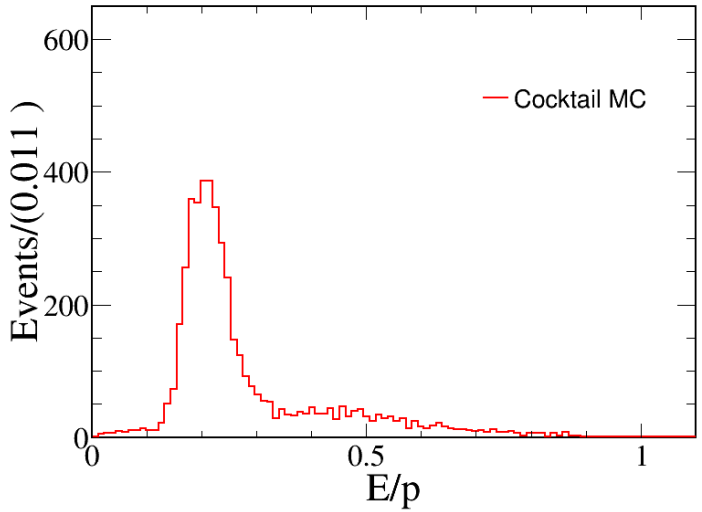


- Signal : the shape extracted from D_S^{*+} D_S^- MC truth matched event.
- $\mathrm{non}D_S^+$ bkg : the shape is extracted from the corresponding MDs sideband region, the size is fixed according to the corresponding MDs sideband scale factor from cocktail MC.
- $D_S^- \to K_L^0 \mu^- \nu_\mu$: the shape is extracted the D_S^{*+} D_S^- MC truth matched events, the size is fixed.
- $D_S^- \to X \mu^- \nu_\mu$: the shape is extracted from MC , the size is the float.

Selection criteria for $D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$

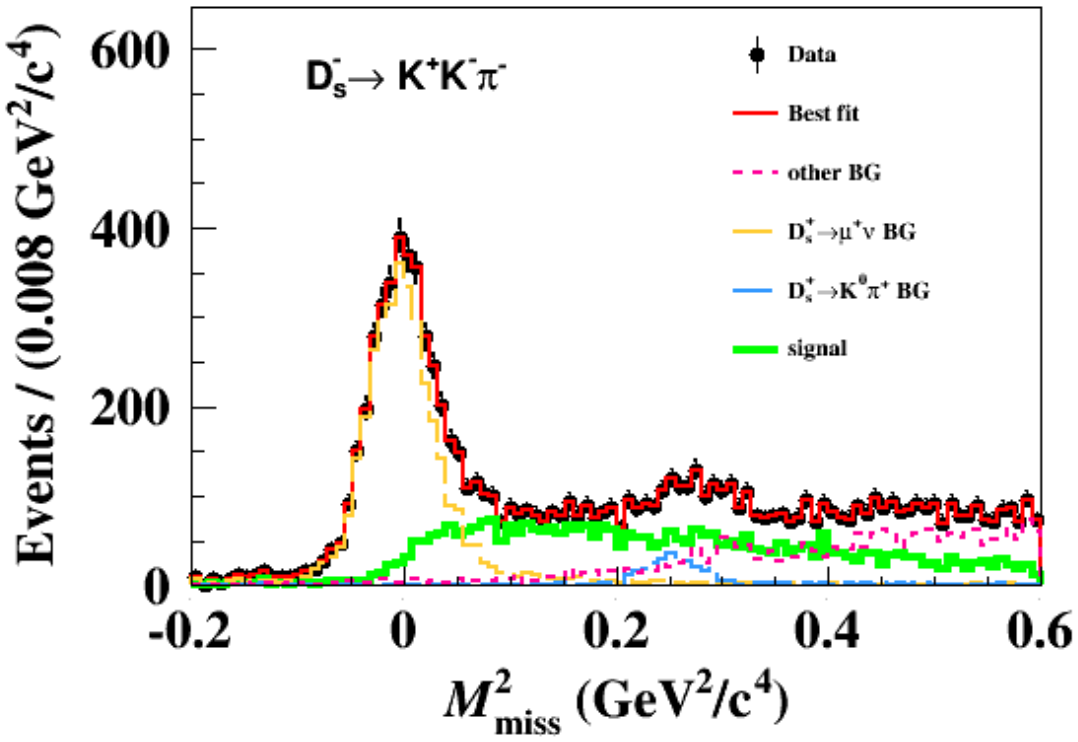
- No extra charged tracks.
- No extra π^0.
- $-0.2 < M^2_{\text{miss}} < 0.6\ \text{GeV}^2/c^4$
- The ratio of the energy deposited in the EMC over the MDC momentum of the charged track is less than 0.9.
- The absolute value of the cosine of the polar angle of $\vec{p}_{\text{miss}}$ in the center-of-mass system of initial e^+e^- is less than 0.9.
- The maximum energy of extra photons is less than 0.3 GeV.





Fitting result(cocktail MC 10x)

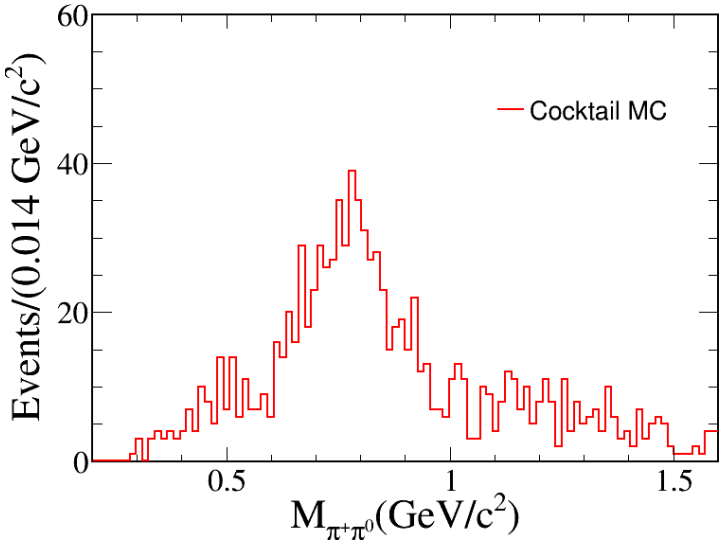
BF : 5.98±0.20 %

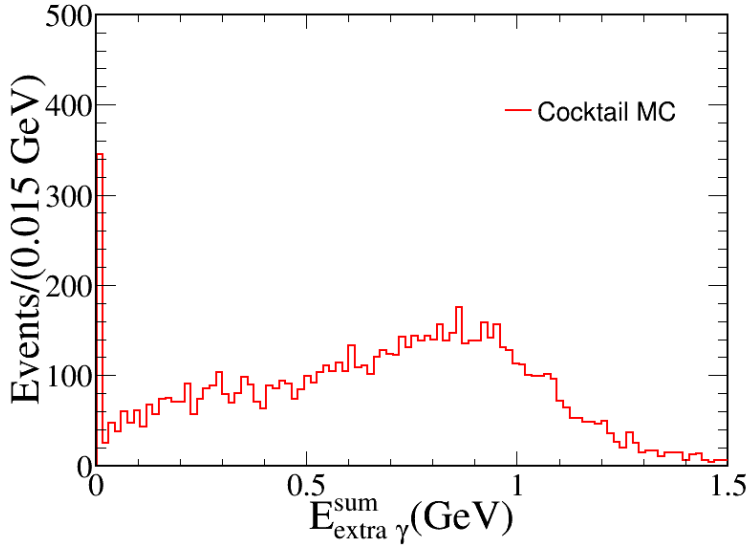


- Signal : the shape extracted from D_S^{*+} D_S^- MC truth matched events.
- $D_S^- \to \mu^- \nu_\mu$: the shape is extracted from inclusive MC truth matched events , the size is float.
- $D_S^- \to K^0\pi^-$: the shape is extracted from inclusive MC truth matched events , the size is float.
- Other bkg : the shape is extracted from MC , the size is the float.

Selection criteria for $D_S^+ \to \tau^+\nu_\tau$, $\tau^+ \to \rho^+_{\pi^+\pi^0}\bar{\nu}_\tau$

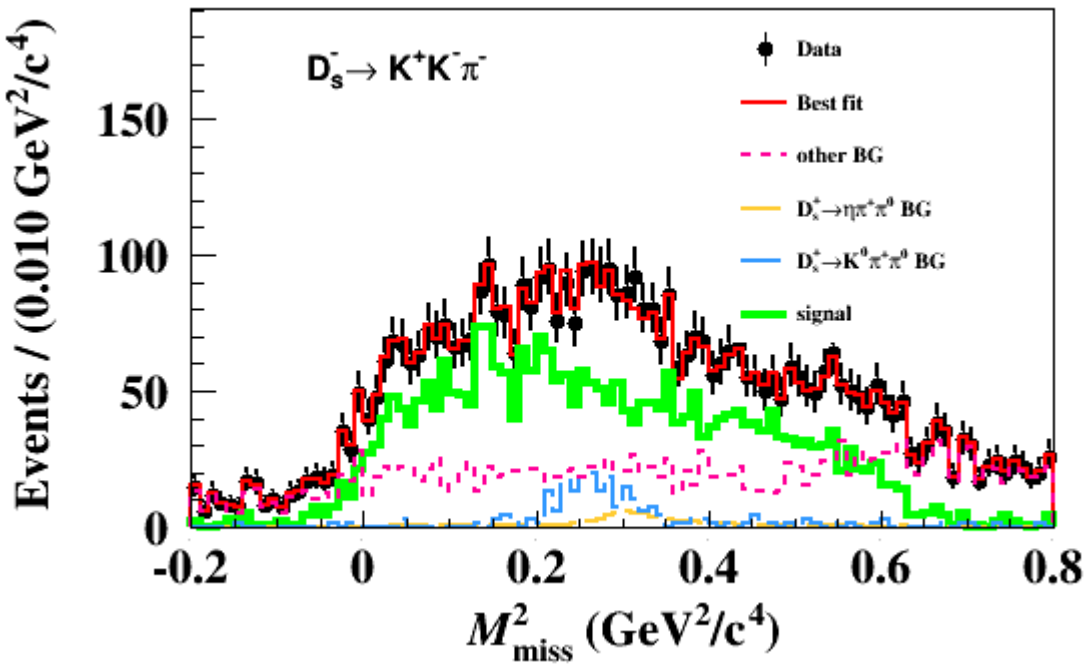
- Only one good charged track
- At least 2 good photos to form a π^0
- $|M_{\pi^+\pi^0} - M_{\rho^+}| < 0.2\ \mathrm{GeV}/c^2$
- $E^{sum}_{extra} < 0.1$ GeV





Fitting result(cocktail MC 10x)

BF : 5.85±0.21 %

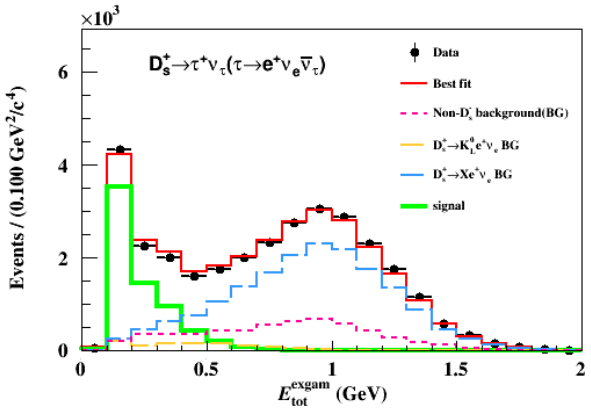


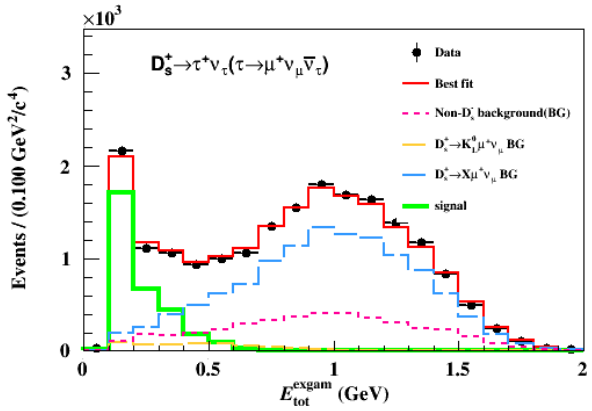
- Signal : the shape extracted from D_S^{*+} D_S^- MC truth matched events.
- $D_S^- \to \eta\pi^-\pi^0$: the shape is extracted from signal MC , the size is fixed.
- $D_S^- \to K^0\pi^-\pi^0$: the shape is extracted from inclusive MC truth matched events , the size is float.
- Other bkg : the shape is extracted from MC , the size is the float.

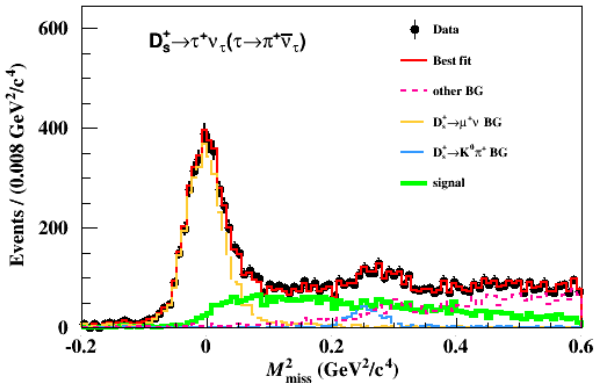
Signal efficiencies(%)

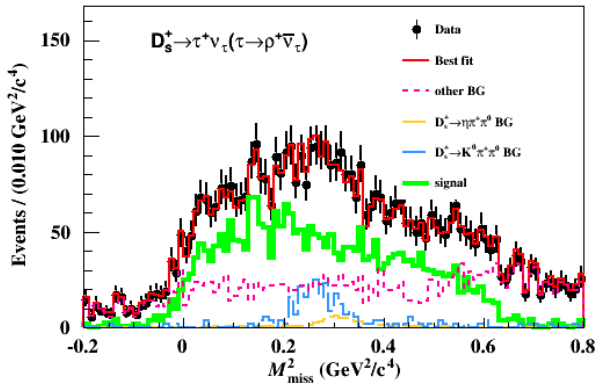
Mode	$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$	$\tau^+ \to \pi^+\bar{\nu}_\tau$	$\tau^+ \to \rho^+_{\pi^+\pi^0}\bar{\nu}_\tau$
$D_S^- \to K_S^0 K^-$	26.20	12.30		
$D_S^- \to K^+K^-\pi^-$	20.58	9.57	15.72	5.48
$D_S^- \to K^+K^-\pi^-\pi^0$	8.18	3.87		
$D_S^- \to K_S^0 K^-\pi^+\pi^-$	9.74	4.57		
$D_S^- \to K_S^0 K^+\pi^+\pi^-$	10.95	5.10		
$D_S^- \to \pi^+\pi^-\pi^-$	28.39	13.41		
$D_S^- \to \pi^-\eta$	24.29	11.38		
$D_S^- \to \pi^-\pi^0\eta$	11.65	5.56		
$D_S^- \to \pi^-\eta'_{\pi^+\pi^-\eta}$	10.71	5.06		
$D_S^- \to \pi^-\eta'_{\gamma\rho^0}$	12.72	9.10		
$D_S^- \to K^-\pi^+\pi^-$	27.01	12.70		

Simultaneous fits









- Use the common bf to simultaneous fit 4 channel , other conditions remain unchanged.

Preliminary result : 5.54±0.063%

Summary

- We obtain the BF to be (5.54±0.063%)
- The simultaneous fit result accords with separate fit.

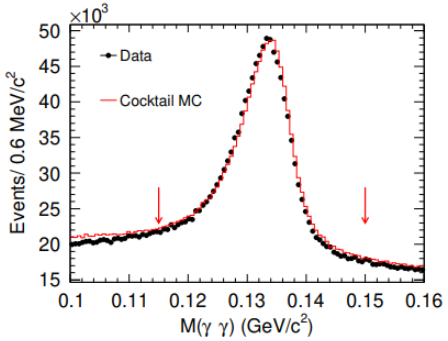
Next to do

- Finish all MC between 4128-4226 and data.
- To do uncertainty studies.

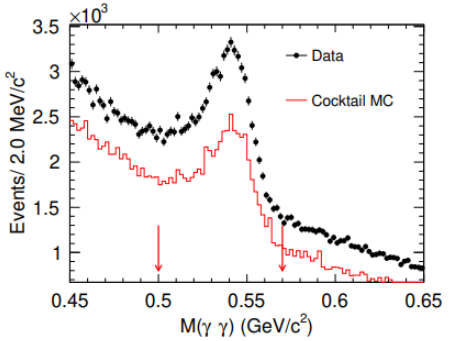
Thank you for your attention!

Back up

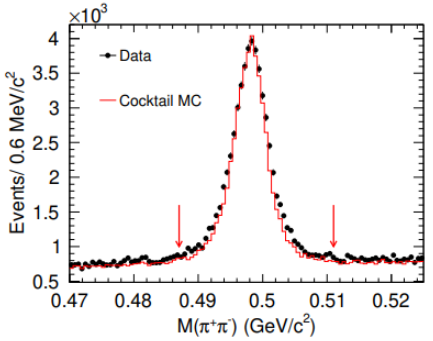
The invariant mass distributions



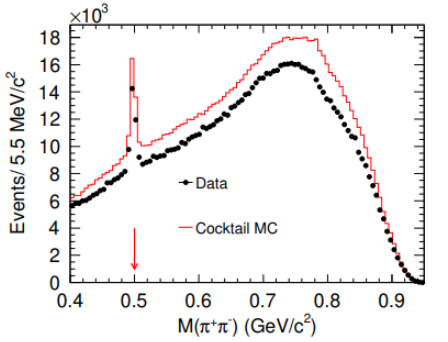
(a) $\pi^0 \to \gamma\gamma$ from $D_s^- \to K^+K^-\pi^-\pi^0$



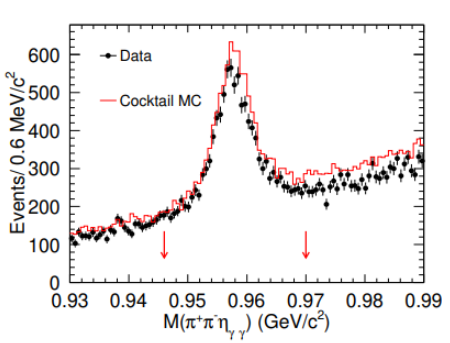
(b) $\eta \to \gamma\gamma$ from $D_s^- \to \pi^-\eta_{\gamma\gamma}$



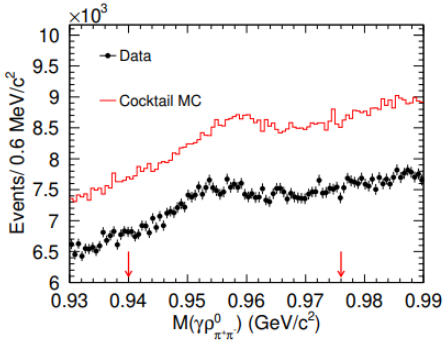
(c) $K_S^0 \to \pi^+\pi^-$ from $D_s^- \to K_S^0K^-$



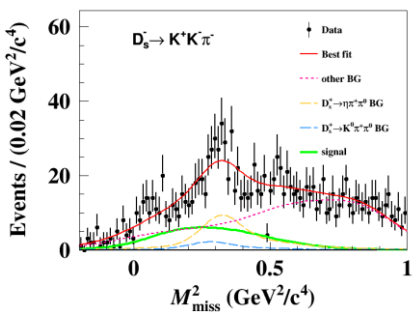
(d) $\rho^0 \to \pi^+\pi^-$ from $D_s^- \to \pi^-\eta'_{\gamma\rho^0}$

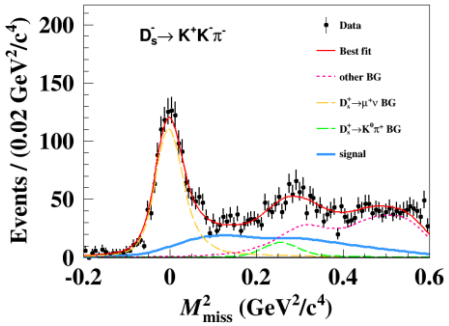


(e) $\eta' \to \pi^+\pi^-\eta$ from $D_s^- \to \pi^-\eta'_{\pi^+\pi^-\eta(\gamma\gamma)}$



(f) $\eta' \to \gamma\rho^0$ from $D_s^- \to \pi^-\eta'_{\gamma\rho^0}$





$$M^2_{\text{miss}} = (E_{\text{cm}} - E_{\text{tag}} - E_{\gamma\pi^0} - E_{D_s^+})^2 - (-\vec{p}_{\text{tag}} - \vec{p}_{\gamma\pi^0} - \vec{p}_{D_s^+})^2$$