BESIII上$D^*_{(s)}$衰变研究和展望

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中国科学技术大学 2023.4.9

Outline

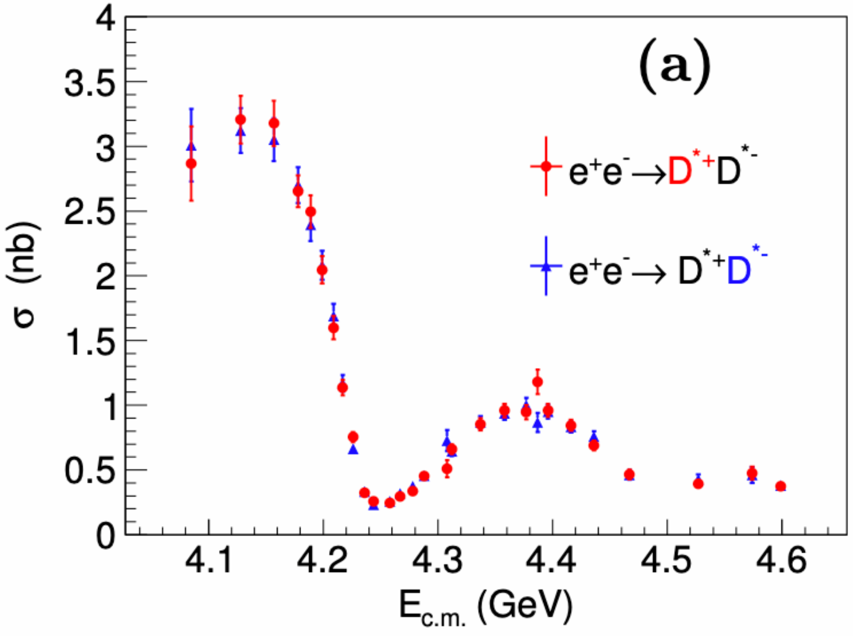
- Introduction
- Recent results of $D^*_{(s)}$ decays
- Summary
- Prospects for the future

Introduction

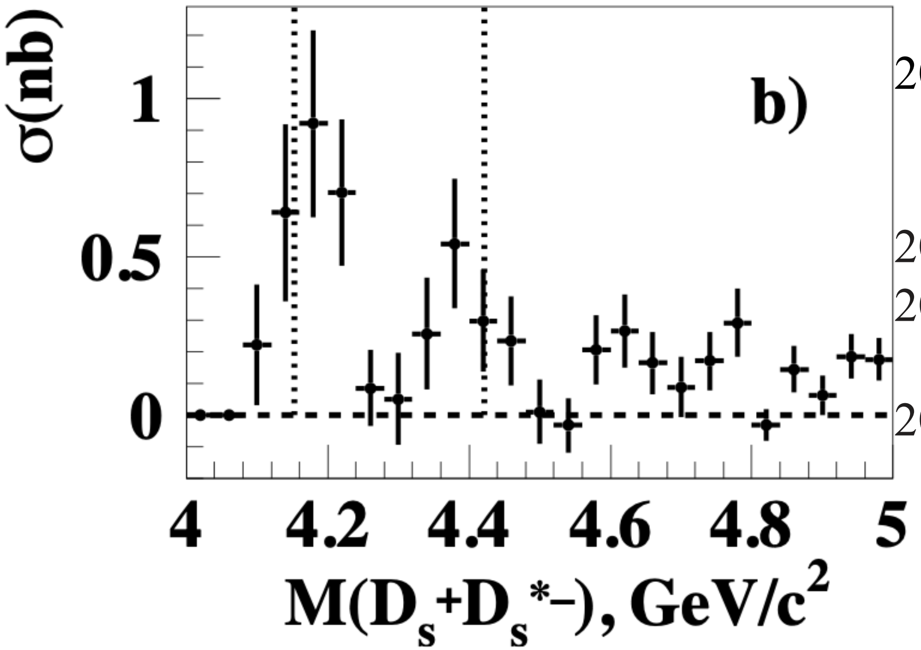
- Over the years, BESIII precisely measure the ground-state $D_{(s)}$ meson and test the standard model (SM).
- Meanwhile, BESIII can also study the $D^*_{(s)}$ physics, which has the largest near threshold data sample and clean enough.
- The theoretical studies are relatively slow and no experimental study of their weak decays has been reported so far.

Total 7.33fb^{-1} data sample can be used to $D^*_{(s)}$ study.

BESIII JHEP05(2022)155



(Belle), PRD 83, 011101(2011)



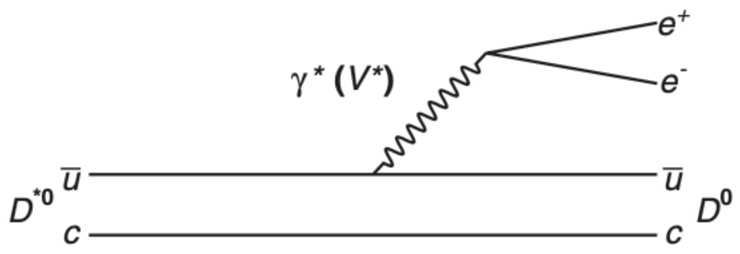
2013: 1.09 fb^{-1} @4.23GeV
0.83 fb^{-1} @ 4.26GeV
0.54fb^{-1} @4.36GeV
2016: 3.20fb^{-1} @4.178GeV
2017: 7×0.5fb^{-1}XYZ scan @4.19-4.27GeV
2019: 8×0.5 fb^{-1}XYZ scan @4.13,4.16,4.29-4.44GeV

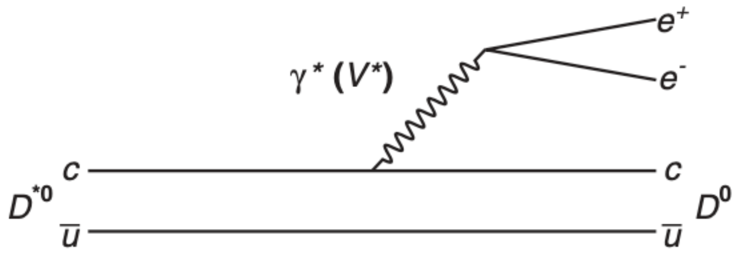
Electromagnetic Dalitz decay $D^{*0} \to D^0 e^+e^-$

- A virtual photon converted to an e^+e^-pair have been observed in several light mesons ($\omega \to \pi^0 e^+e^-$).
- Such decay in electromagnetic decays of mesons containing charm quarks, only D_s^{*+} has been reported by CLEO($D_s^{*+} \to D_s{}^+ e^+ e^-$). The result can be used to compare with the vector dominance model (VDM).
- VDM model expectation $R_{ee} = \frac{\mathcal{B}(D_s^{*+} \to D_s^+ e^+ e^-)}{\mathcal{B}(D_s^{*+} \to D_s^+ \gamma)} = 0.65\%$,

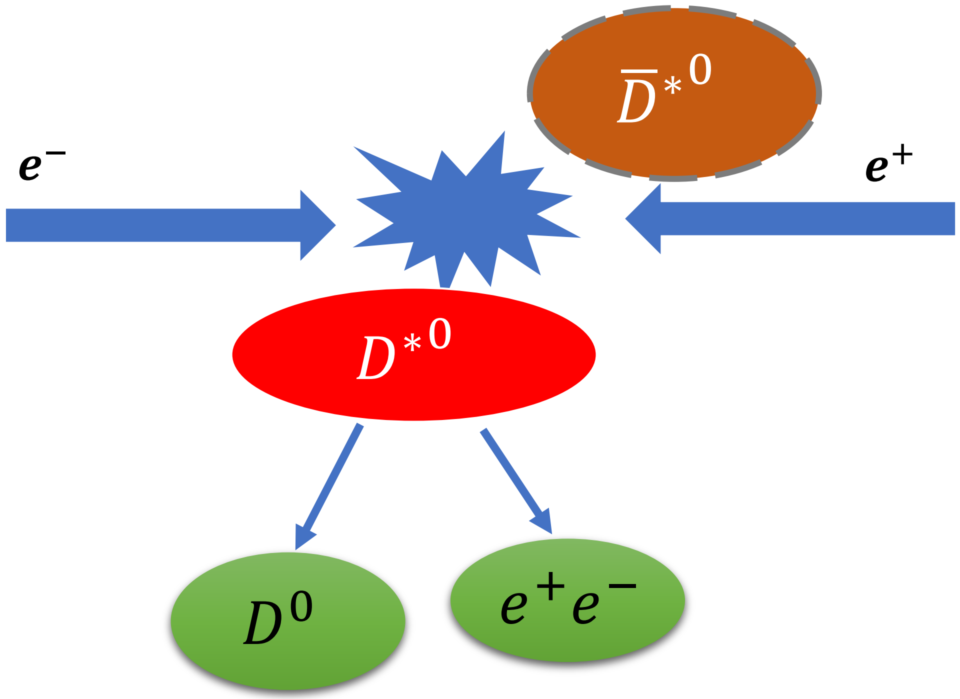
result of CLEO R_{ee} =$[0.72^{+0.15}_{-0.13}(\text{stat}) \pm 0.10(\text{syst})]\%$.

- There is no experimental result for the corresponding EM Dalitz decays of D^{*0} and D^{*+} have not been reported.





Electromagnetic Dalitz decay $D^{*0} \to D^0 e^+ e^-$

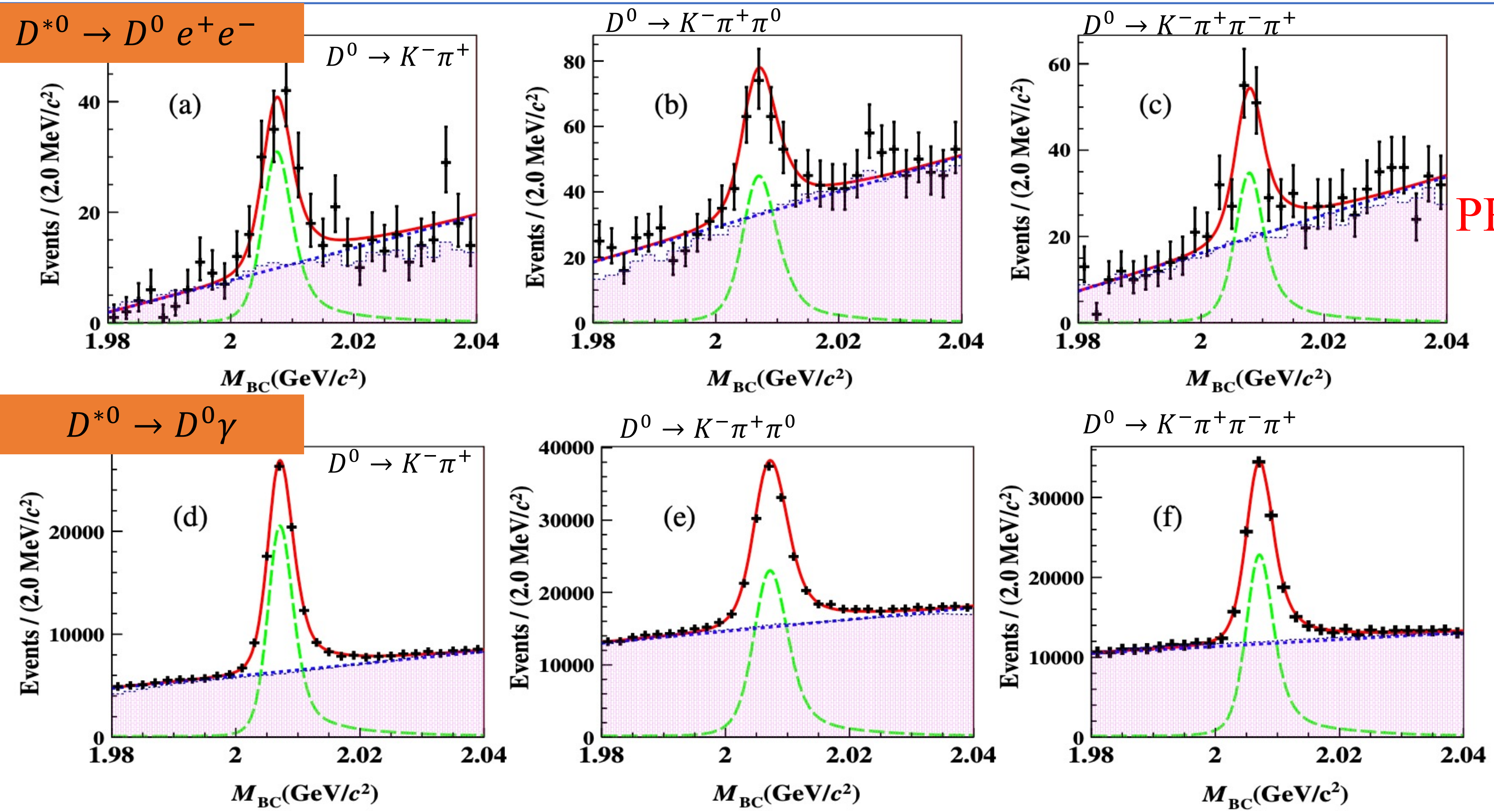


- $e^+e^- \to D^{*0}\bar{D}^{*0}$
- Data sample: 3.19fb^{-1} @4.178 GeV
- Single tag reconstruction method
  - Signal channel : $D^{*0} \to D^0 e^+e^-$
  - Reference channel: $D^{*0} \to D^0\gamma$
- D^0 tag mode:
  - $D^0 \to K^-\pi^+$
  - $D^0 \to K^-\pi^+\pi^0$
  - $D^0 \to K^-\pi^+\pi^-\pi^+$

- $N_{\text{sig}} = 2\, N_{D^{*0}\bar{D}^{*0}}\mathcal{B}(D^{*0} \to D^0e^+e^-)\mathcal{B}_{\text{int}}\varepsilon_{\text{sig}}$
- $N_{\text{ref}} = 2\, N_{D^{*0}\bar{D}^{*0}}\mathcal{B}(D^{*0} \to D^0\gamma)\mathcal{B}_{\text{int}}\varepsilon_{\text{ref}}$
- $M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{D^{*0}}|^2}$

$$R_{ee} = \frac{\mathcal{B}(D^{*0} \to D^0e^+e^-)}{\mathcal{B}(D^{*0} \to D^0\gamma)} = \frac{N_{\text{sig}}\varepsilon_{\text{ref}}}{N_{\text{ref}}\varepsilon_{\text{sig}}}$$

Electromagnetic Dalitz decay $D^{*0} \to D^0 e^+e^-$



First observation
PRD 104, 112012 (2021)

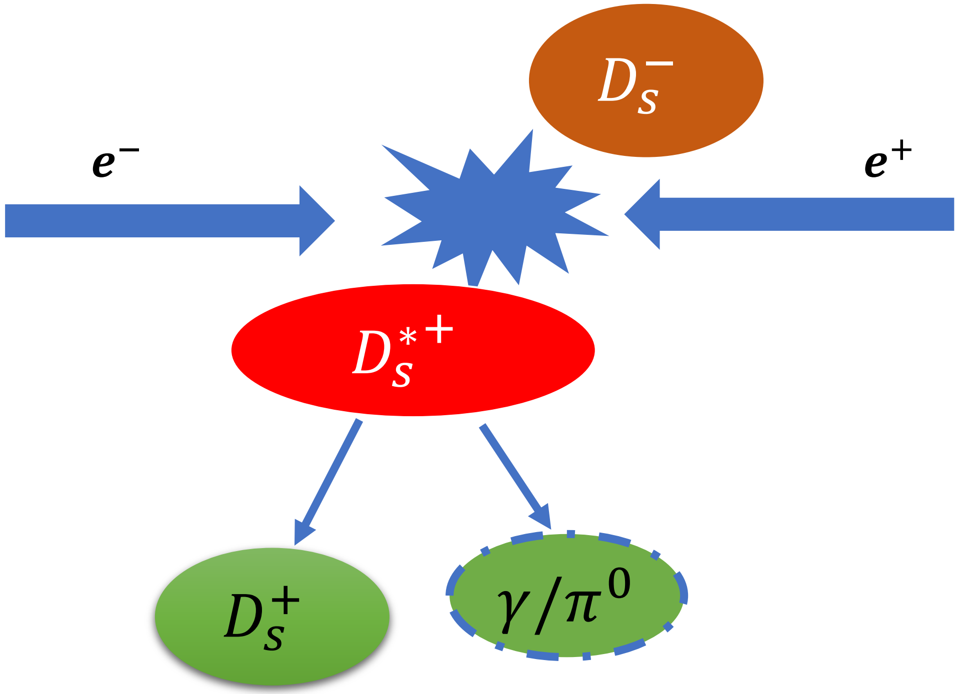
- Experiment measurement : $R_{ee} = \frac{\mathcal{B}(D^{*0}\to D^0e^+e^-)}{\mathcal{B}(D^{*0}\to D^0\gamma)} = (11.08 \pm 0.76 \pm 0.49)\times 10^{-3}$
- VDM model expectation: $R_{ee} = 0.67\%$, deviates 3.5σ with experiment result.
- Using the world average $\mathcal{B}(D^{*0} \to D^0\gamma)$, determine $\mathcal{B}(D^{*0} \to D^0e^+e^-)$= $(3.91 \pm 0.27 \pm 0.17 \pm 0.10)\times 10^{-3}$

$D_s^{*+} \to D_s^+\pi^0$ relative to $D_s^{*+} \to D_s^+\gamma$

- Due to the quark SU(2) flavor-breaking effects, the D_s^{*+} decays are dominated by the radiative process $D_s^{*+} \to D_s^+\gamma$ and the isospin-violating hadronic process $D_s^{*+} \to D_s^+\pi^0$
- The improved measurements of these branching fractions offer precise input for accurate measurements of D_s^+ decays via $D_s^{*+}D_s^+$, especially for precision measurements of the D_s^+ decay constant and the CKM matrix element $|V_{cs}|$.

	$\Gamma[\mathcal{B}]_{D_s^* \to D_s^+\gamma}$	$\Gamma[\mathcal{B}]_{D_s^* \to D_s^+\pi^0}$	$\mathcal{B}_{D_s^{*+} \to D_s^+\pi^0}/\mathcal{B}_{D_s^{*+} \to D_s^+\gamma}$
CM [14]	3.53 [$(92.7 \pm 0.7)\%$]	$0.277^{+0.028}_{-0.026}$ [$(7.3 \pm 0.7)\%$]	$(7.9 \pm 0.8)\%$
χPT [2][a]	4.5	...	...
χPT [3]	...	...	$8 \times 10^{-5}/\mathcal{B}(D^{*+} \to D^+\gamma)$
χPT [4]	0.32 ± 0.30	...	...
χPT [5]	...	$0.0081^{+0.0030}_{-0.0026}$	...
LFQM [6][b]	0.18 ± 0.01	...	...
RQM [7][c]	$0.321^{+0.009}_{-0.008}$	...	...
QCDSR [8]	0.25 ± 0.08	...	...
QCDSR [9]	0.59 ± 0.15	...	...
NJLM [10]	0.09	...	...
LQCD [11]	0.066 ± 0.026	...	...
NRQM [12]	0.21	...	...
NRQM [13][d]	0.40	...	...

$D_s^{*+} \to D_s^+ \pi^0$ relative to $D_s^{*+} \to D_s^+ \gamma$



- $e^+e^- \to D_s^{*+}D_s^-$, $D_s^{*+} \to D_s^+\gamma, D_s^+\pi^0$
- Data sample: 7.33fb^{-1} @4.128-4.226 GeV
- Reconstruct D_s^+, D_s^- , missing γ/π^0
- D_s^+, D_s^- tag mode:
  - $D_s^+ \to K^+K^-\pi^+$ vs $D_s^- \to K^+K^-\pi^-$
  - $D_s^+ \to K^+K^-\pi^+$ vs $D_s^- \to K_S^0K^-$
  - $D_s^+ \to K_S^0K^+$ vs $D_s^- \to K_S^0K^-$

$$f_\gamma = \frac{\mathcal{B}(D_s^{*+} \to D_s^+\gamma)}{\mathcal{B}(D_s^{*+} \to D_s^+\gamma) + \mathcal{B}(D_s^{*+} \to D_s^+\pi^0)}$$

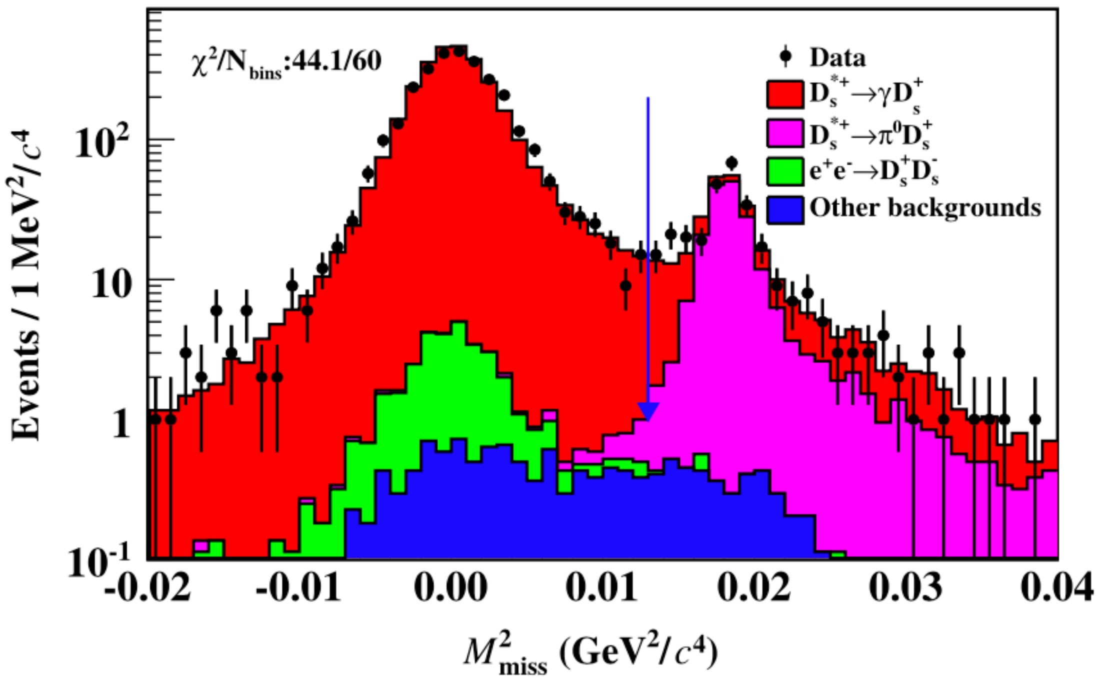
- $M_{\rm rec} = \sqrt{(E_{cm} - \sqrt{|p_{tag}|^2 + m_{D_s}^2})^2 - |\vec{p}_{tag}|^2}$

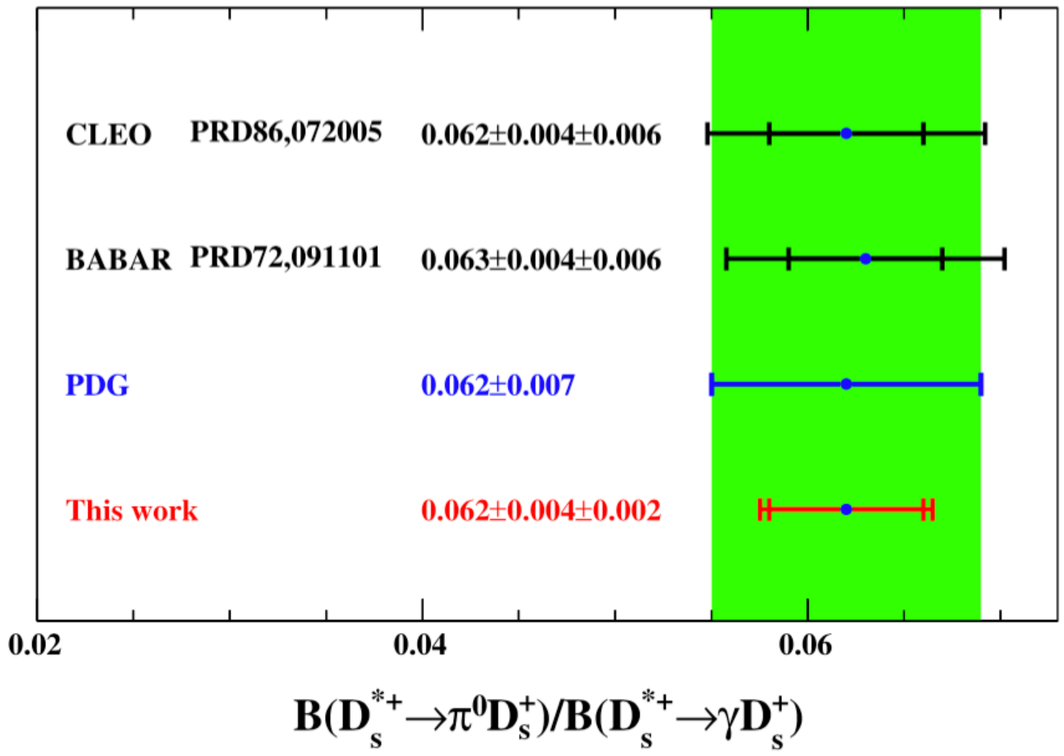
$$\begin{pmatrix} N_\gamma^{\rm obs} - N_\gamma^{\rm bkg} \\ N_{\pi^0}^{\rm obs} - N_{\pi^0}^{\rm bkg} \end{pmatrix} = \begin{pmatrix} \epsilon_{\gamma\gamma} & \epsilon_{\pi^0\gamma} \\ \epsilon_{\gamma\pi^0} & \epsilon_{\pi^0\pi^0} \end{pmatrix} \begin{pmatrix} N_\gamma^{\rm prod} \\ N_{\pi^0}^{\rm prod} \end{pmatrix}$$

- $M_{miss}^2 = (E_{cm} - E_{D_s^+} - E_{D_s^-})^2 - |-\vec{p}_{D_s^+} - \vec{p}_{D_s^-}|^2$

$D_s^{*+} \to D_s^+\pi^0$ relative to $D_s^{*+} \to D_s^+\gamma$

PRD 107, 032011 (2023)





$$\frac{\mathcal{B}(D_s^{*+} \to D_s^+\pi^0)}{\mathcal{B}(D_s^{*+} \to D_s^+\gamma)} = (6.16 \pm 0.43 \pm 0.18)\%$$

$\mathcal{B}(D_s^{*+} \to D_s^+\gamma)$=(93.57±0.38±0.22)% $\mathcal{B}(D_s^{*+} \to D_s^+\pi^0)$=(5.76 ±0.38±0.16)%

- Our measurement is consistent with the previous results but with better precision.

$D^*_{(s)}$ spin parity measurement

- There is no decisive experimental results of spin and parity have been reported for the ground 1S states $D^*_{(s)}$ since the discovery.
- In PDG, the status of J^P for D^{*0} and D^{*+} are assigned to be 1^- while they need to be confirmed experimentally.
- Although the quark model works well for the mass spectroscopy and spin-parity assignment, experimental confirmation is essential for testing the quark model.
- Comparing with LHCb experiment, BESIII has clear $D_s^{*+}D_s^-$ data sample and can detect the photon.

CHARMED, STRANGE MESONS
($C = S = \pm1$)
$D_s^+ = c\,\bar{s}$, $D_s^- = \bar{c}\,s$, similarly for D_s^*'s

$\boldsymbol{D_s^{*\pm}}$ $I(J^P) = 0(?^?)$

J^P is natural, width and decay modes consistent with 1^-.

CHARMED MESONS
($C = \pm1$)
$D^+ = c\,\bar{d}$, $D^0 = c\,\bar{u}$, $\bar{D}^0 = \bar{c}\,u$, $D^- = \bar{c}\,d$, similarly for D^*'s

$\boldsymbol{D^*}(2007)^0$ $I(J^P) = 1/2(1^-)$ *I, J, P* need confirmation.

J consistent with 1, value 0 ruled out (NGUYEN 1977).

CHARMED MESONS
($C = \pm1$)
$D^+ = c\,\bar{d}$, $D^0 = c\,\bar{u}$, $\bar{D}^0 = \bar{c}\,u$, $D^- = \bar{c}\,d$, similarly for D^*'s

$\boldsymbol{D^*}(2010)^\pm$ $I(J^P) = 1/2(1^-)$ *I, J, P* need confirmation.

$D^*_{(s)}$ spin parity measurement

- Data sample: 3.19fb^{-1} @4.178 GeV
- Decay chains: $e^+e^- \to D_s^{*+}D_s^-, D_s^{*+} \to \gamma D_s^+, D_s^+ \to K_S K^+$

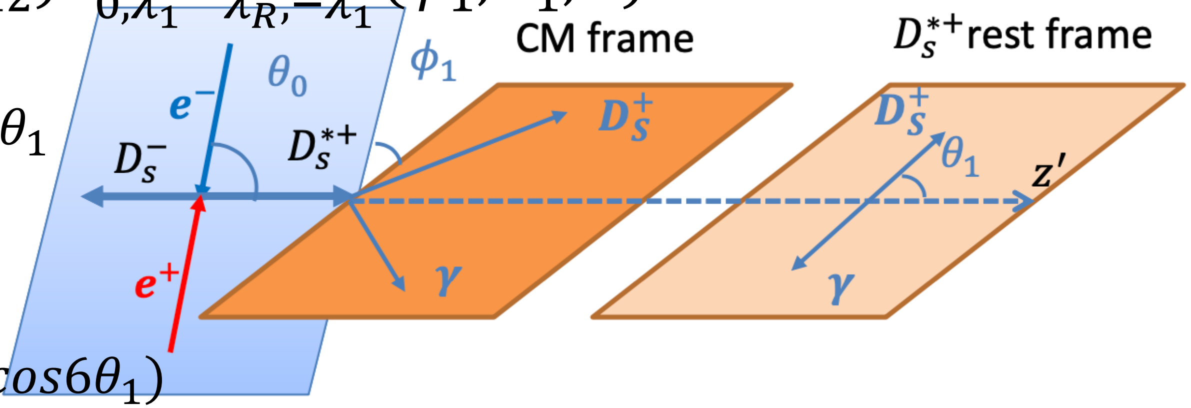
  $e^+e^- \to D^{*0}\bar{D}^0, D^{*0} \to \pi^0 D^0, D^0 \to K^-\pi^+$ and $\pi^0 \to \gamma\gamma$

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

Partial reconstruction of γ and D_s^+ and recoil side missing D_s^-
(similar technique for D^{*0} and D^{*+})

- The joint amplitude of process $e^+e^- \to \gamma^* \to D_s^{*+}(\lambda_R)D_s^-, D_s^{*+} \to \gamma(\lambda_1)D_s^+$ shown as

$$A(m,\lambda_1,\vec{\omega}) = \sum_{\lambda_R} F_{\lambda_R,0} D^{1*}_{m,\lambda_R}(\phi_0,\theta_0,0) BW(m_{12}) F^J_{0,\lambda_1} D^{J*}_{\lambda_R,-\lambda_1}(\phi_1,\theta_1,0)$$

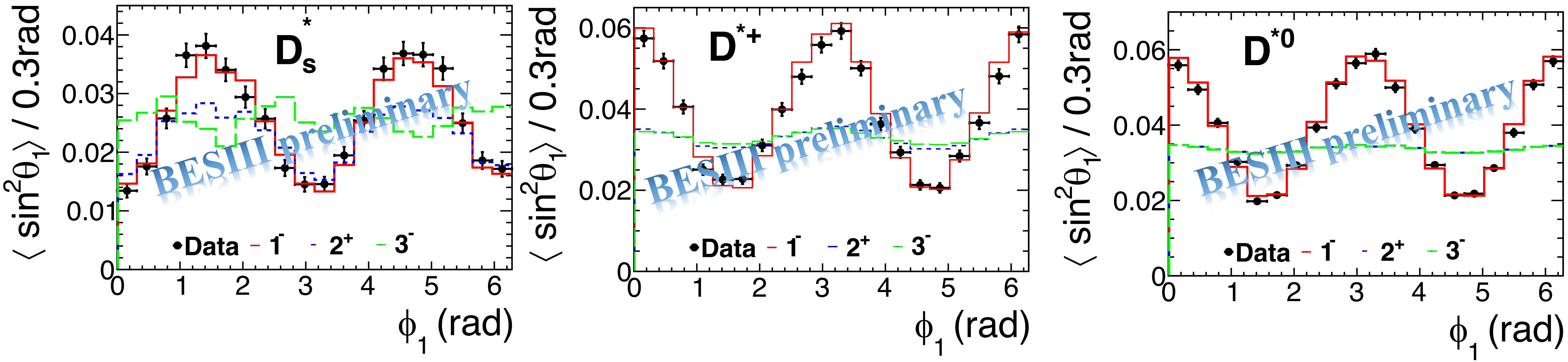


$$\mathcal{W}^{(1^-)} \propto (3+\cos 2\theta_0)(3+\cos 2\theta_1) - 4\cos 2\phi_1 \sin^2\theta_0 \sin^2\theta_1$$

$$\mathcal{W}^{(2^+)} \propto (3+\cos 2\theta_0)(2+\cos 2\theta_1+\cos 4\theta_1) - 4(1+2\cos 2\theta_1)\cos 2\phi_1 \sin^2\theta_0 \sin^2\theta_1$$

$$\mathcal{W}^{(3^-)} \propto (3+\cos 2\theta_0)(398+271\cos 2\theta_1+130\cos 4\theta_1+255\cos 6\theta_1) - 8(163+380\cos 2\theta_1+225\cos 4\theta_1)\cos 2\phi_1 \sin^2\theta_0 \sin^2\theta_1$$

$D_{(s)}^{*}$ spin parity measurement



- $\langle \sin^2 \theta_1 \rangle$ vs ϕ_1 illustrate the different behaviors.
- Data obviously favor the 1^- assignment over $2^+$and 3^-.
- The significance is greater than 10σ.

Summary

- Based on the data sample from 4.128-4.226 GeV, BESIII have studied $D^{*}_{(s)}$ decays.
  - $e^{+}e^{-} \rightarrow D^{*0}\overline{D}^{*0}$, first observation $D^{*0} \rightarrow D^{0}\, e^{+}e^{-}$
  - $e^{+}e^{-} \rightarrow D_{s}^{*+}D_{s}^{-}$, precisely measurement $D_{s}^{*+} \rightarrow D_{s}^{+}\gamma, D_{s}^{+}\pi^{0}$
  - The first experiment measurement $D^{*}_{(s)}$ spin parity, in high significance.

➢ Prospects for the future

In the near future, BESIII will collect 3fb^{-1} @ 4.178 GeV, nearly 10 fb^{-1} data could be used to $D^*_{(s)}$ study.

➢ further improved the precision

- $D_s^{*+} \to D_s{}^+ e^+ e^-$, 10 times larger than CLEOc

➢ Pure leptonic study

- $D_s^{*+} \to e^+ \nu_e$ BAM-561

Full Lattice QCD (PRL 112, 212002) and other theoretical calculations give the $\mathcal{B}(D_s^{*+} \to e^+ \nu_e)$ up to 10^{-5} , is potential to measurement.

- $D^{*+} \to e^+ \nu_e$, $D^{*+} \to \mu^+ \nu_\mu$ BAM-448

the branching fractions of D^{*+} weak decays are at the $10^{-10} - 10^{-5}$, any observation of the leptonic D^{*+} decays at a rate above the SM prediction would be a potential hint of new physics. But now is challenging to present statistic.