Charmonium Spectroscopy at BESIII

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Istituto Nazionale di Fisica Nucleare

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Outline

- BESIII Experiment
- Preamble… Why Charmonia?
- Study of Charmonium Features
- Investigating the Light Sector
- Hexaquarks in the Midst
- Charming Cross-Sections
- Summary

DISCLAIMER

This presentation is not an encyclopaedic review of all the charmonium analyses at BESIII

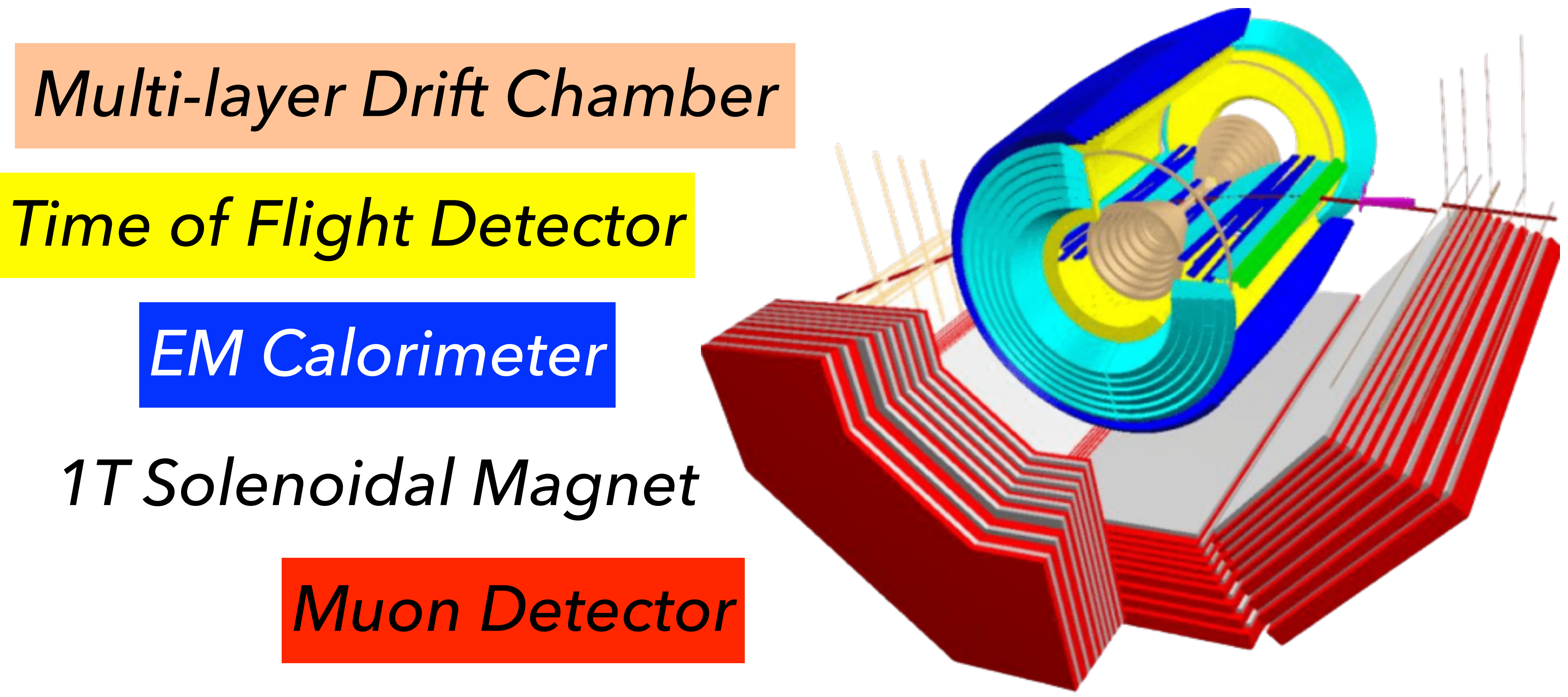
BESIII Experiment

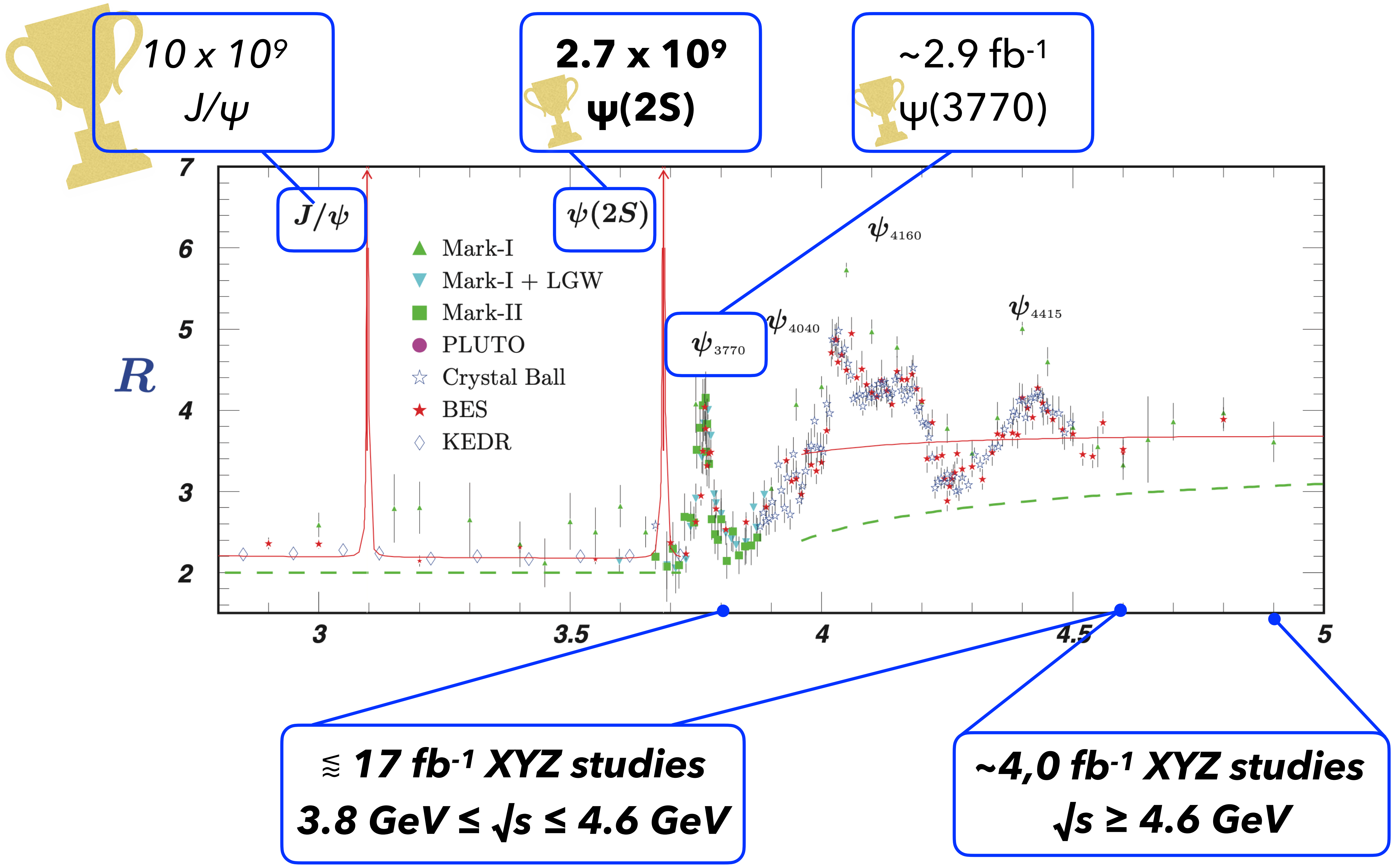
BESIII (BEijing Spectrometer III) is an experiment located at the BEPCII (Beijing Electron Positron Collider II) at IHEP (Institute of High Energy Physics)

Being **BEPCII** an **e^+e^- collider**, BESIII can profit from **direct production** of **vector states** ($J^{PC} = 1^{--}$)

The **statistics of the ψ(nS)** decays allows to probe and study with **high precision** also the **non-vector** states

BESIII has also **unique opportunities** with datasets **above 3.8 GeV**





τ-charm factory 2.0 GeV ≤ $\sqrt{s}$ ≤ 4.9 GeV

with an instantaneous luminosity of 10^{33} $cm^{-2}s^{-1}$ @ $\sqrt{s}$ = 3.77 GeV

Why Charmonia…?

Charmonium resonances are located in the transition region of perturbative and non-perturbative QCD

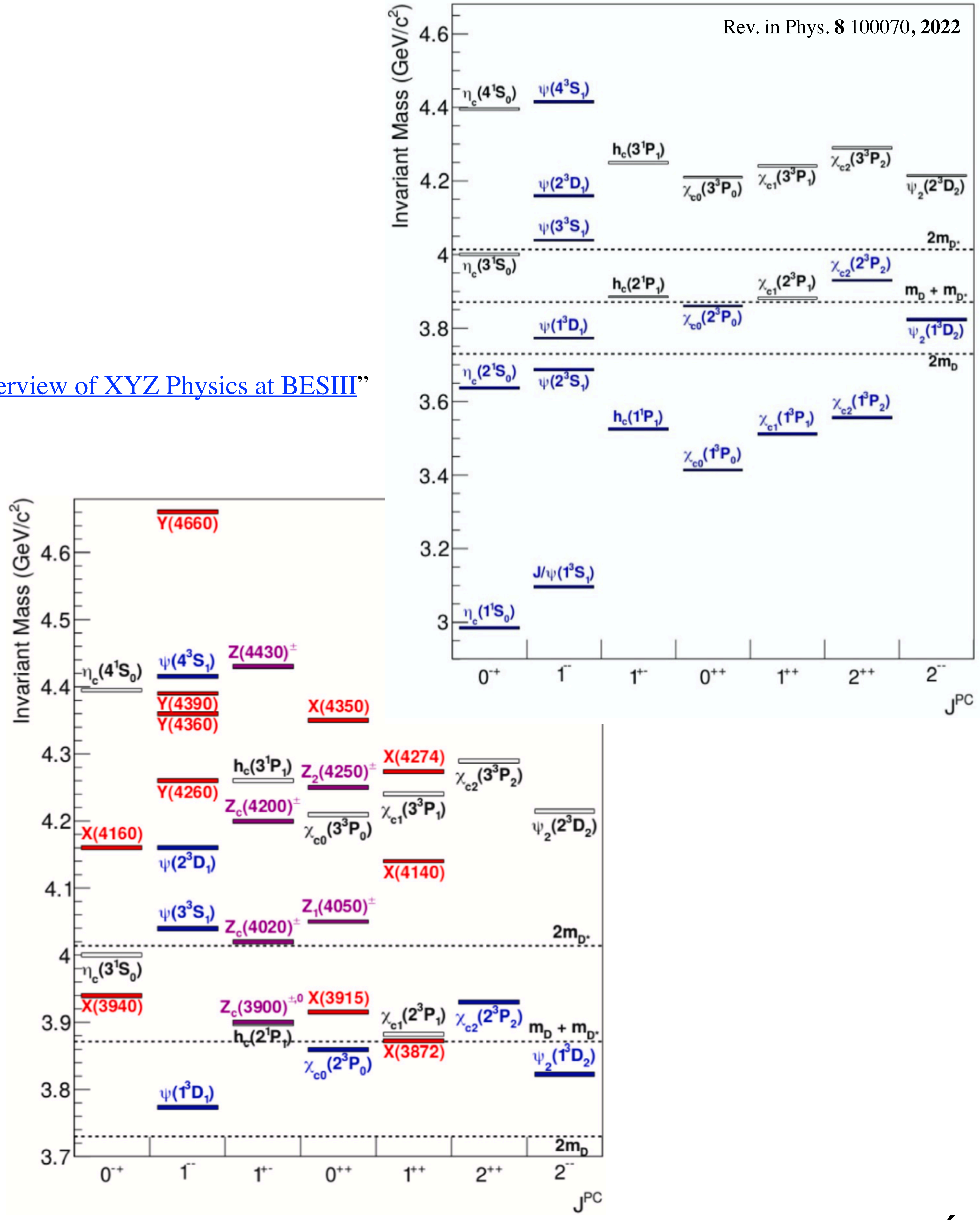
Non-vector and above-threshold states are partly unknown

Vector states can be used either to reach non-1^{--} ones or as a way to test pQCD predictions (e.g., 12% rule, $\mathcal{A}$(EM - strong), …)

Gateway to the XYZ exotic states[I]

Another way to probe the SM (via weak decays)

[I] R. Mitchell, "Overview of XYZ Physics at BESIII"



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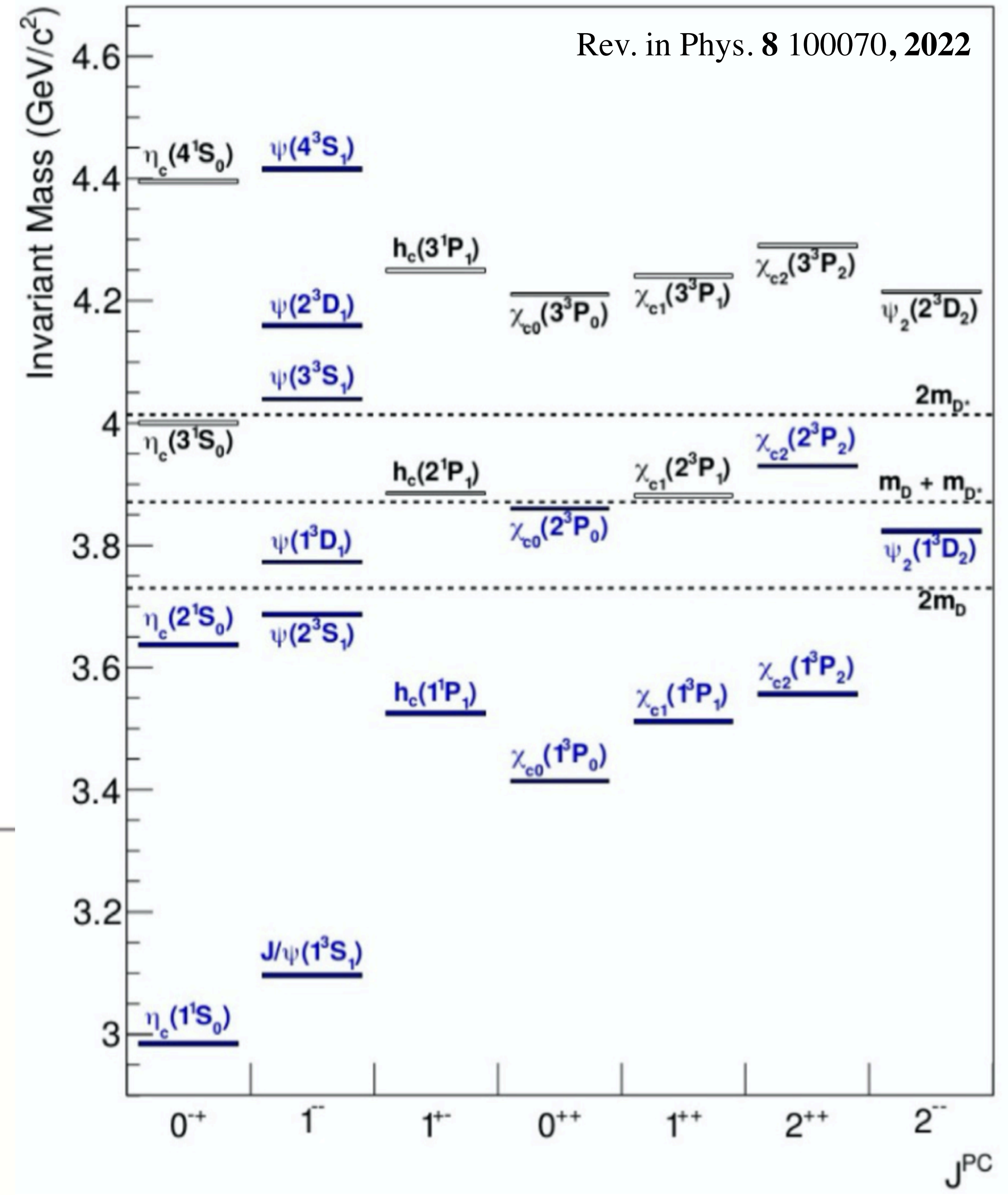
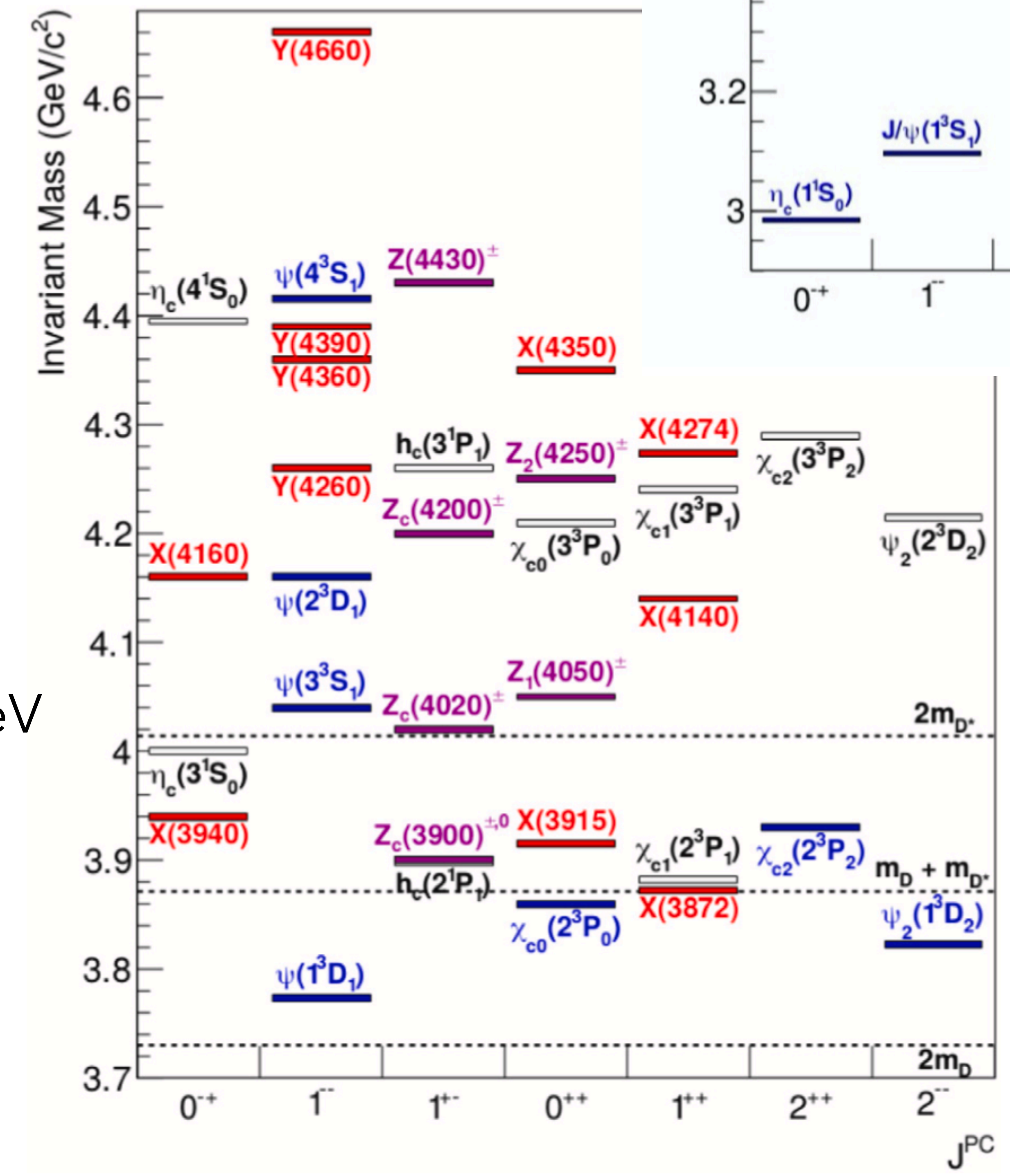




BESIII can perform such studies, but we will focus on what BESIII can provide to expand the knowledge on the charmonium spectrum itself:

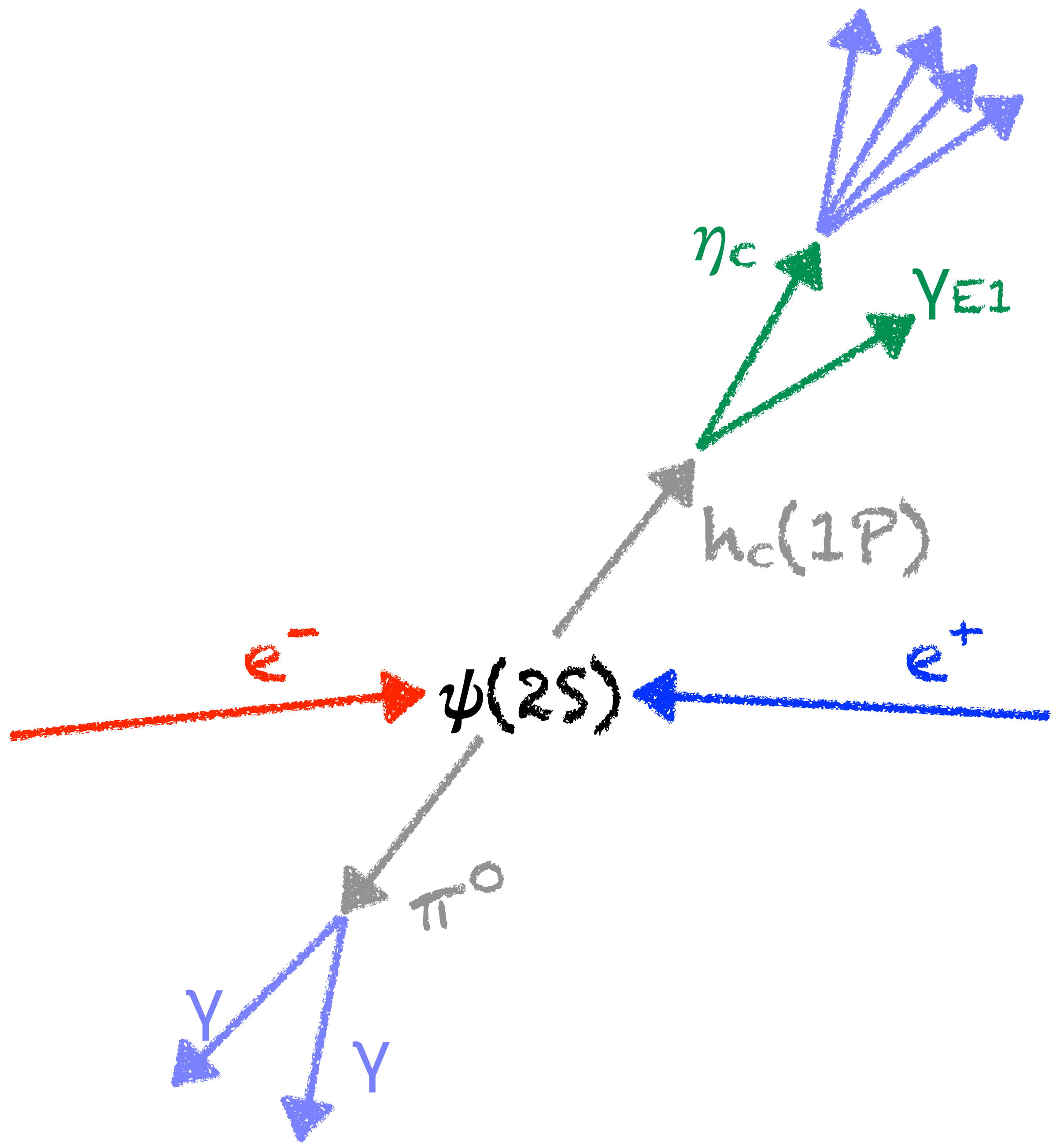
1. Study of the $h_c(1P)$ meson via $\psi(2S) \to \pi^0 h_c$ decays at BESIII
2. Observation of Resonance Structures in $e^+e^- \to \pi^+\pi^-\psi_2(3823)$ and Mass Measurement of $\psi_2(3823)$
3. *Observation of of* $e^+e^- \to \pi^0\pi^0\psi_2(3823)$
4. Study of the $e^+e^- \to \pi^+\pi^-\omega$ process at center-of-mass energies between 4.0 and 4.6 GeV
5. Observation of $e^+e^- \to pp\bar{p}\bar{n}\pi$ + c.c.
6. Measurement of $e^+e^- \to \pi^+\pi^- D^+ D^-$ cross sections at center-of-mass energies from 4.190 to 4.946 GeV
7. Observation of Three Charmoniumlike States with $J = 1^{--}$ in $e^+e^- \to D^{*0}D^{*-}\pi^+$
8. Precise measurement of the $e^+e^- \to D_s^{*+}D_s^{*-}$ cross sections at center-of-mass energies from threshold to 4.95 GeV

Study of the $h_c(1\,^1P_1)$ meson via $\psi(2S) \rightarrow \pi^0 h_c$ decays at BESIII

PRD **106**, 072007 (2022)

Using 448 million $\psi(2S)$ events

Search for the **E1 $h_c \rightarrow \gamma\eta_c$ transition** through the $\psi(2S) \rightarrow \pi^0 h_c$ decay to **determine h_c(1P) features and** the **relative $\mathcal{B}$**



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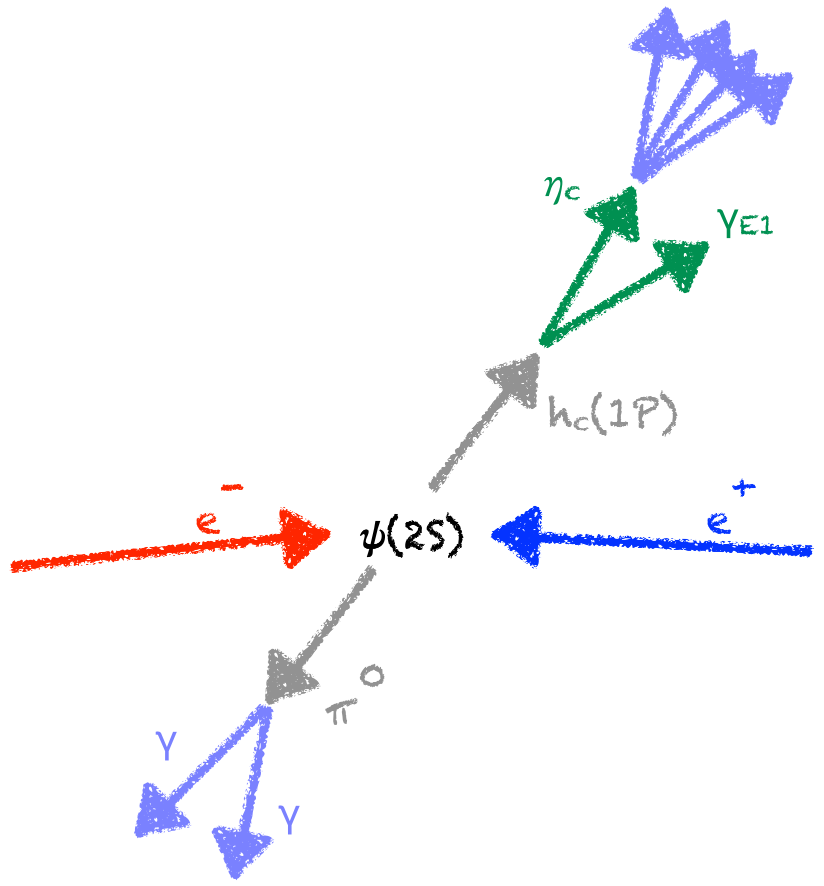

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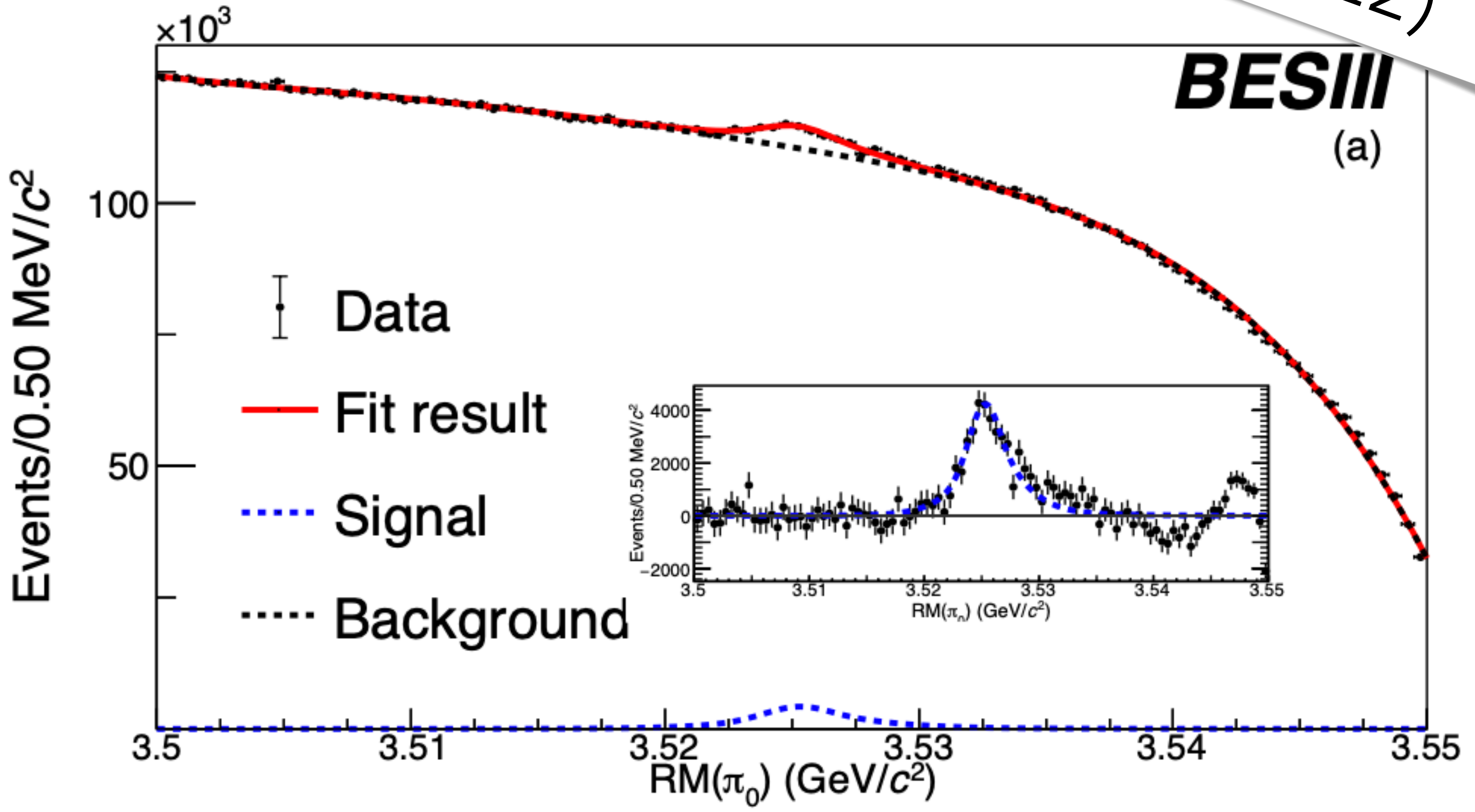

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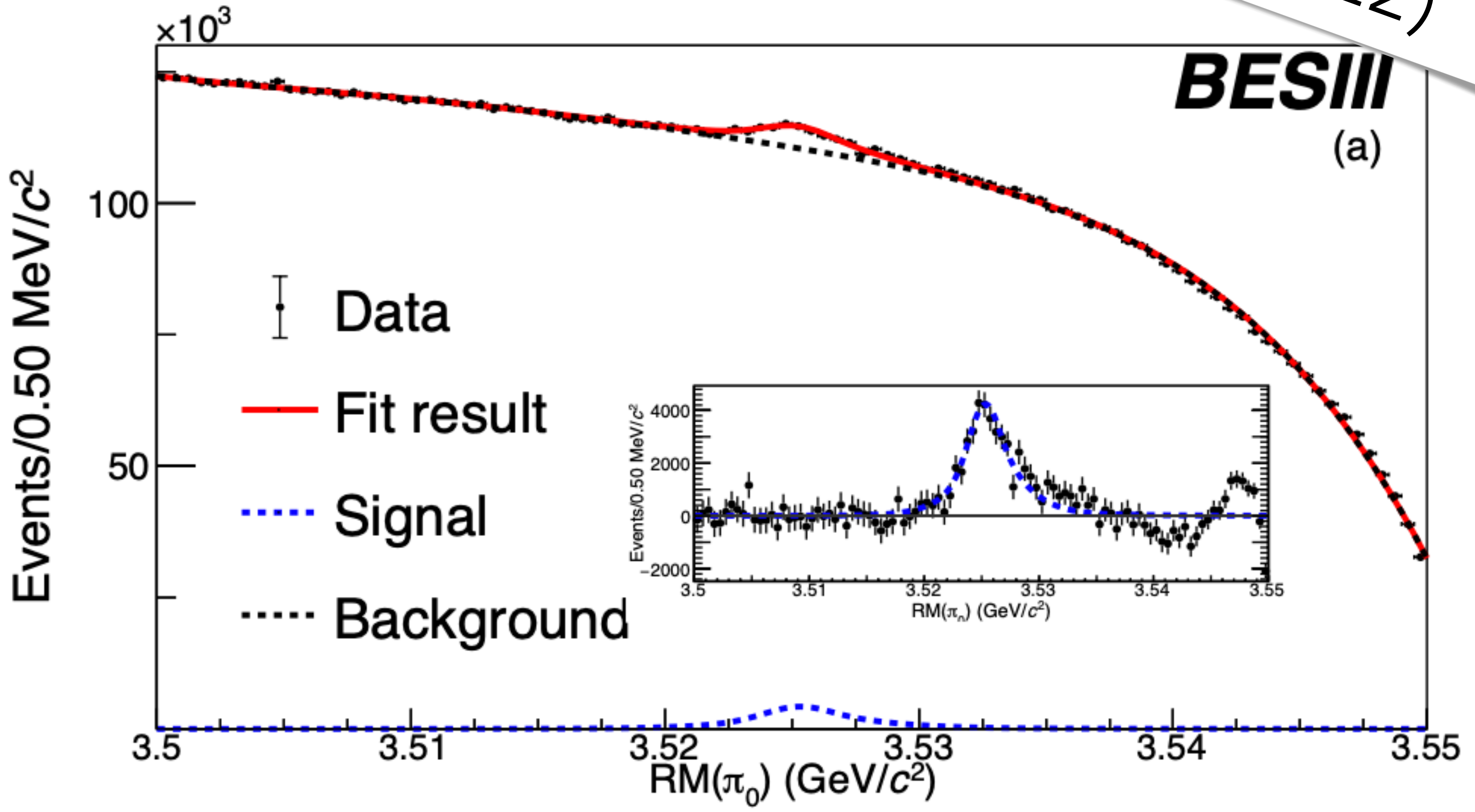
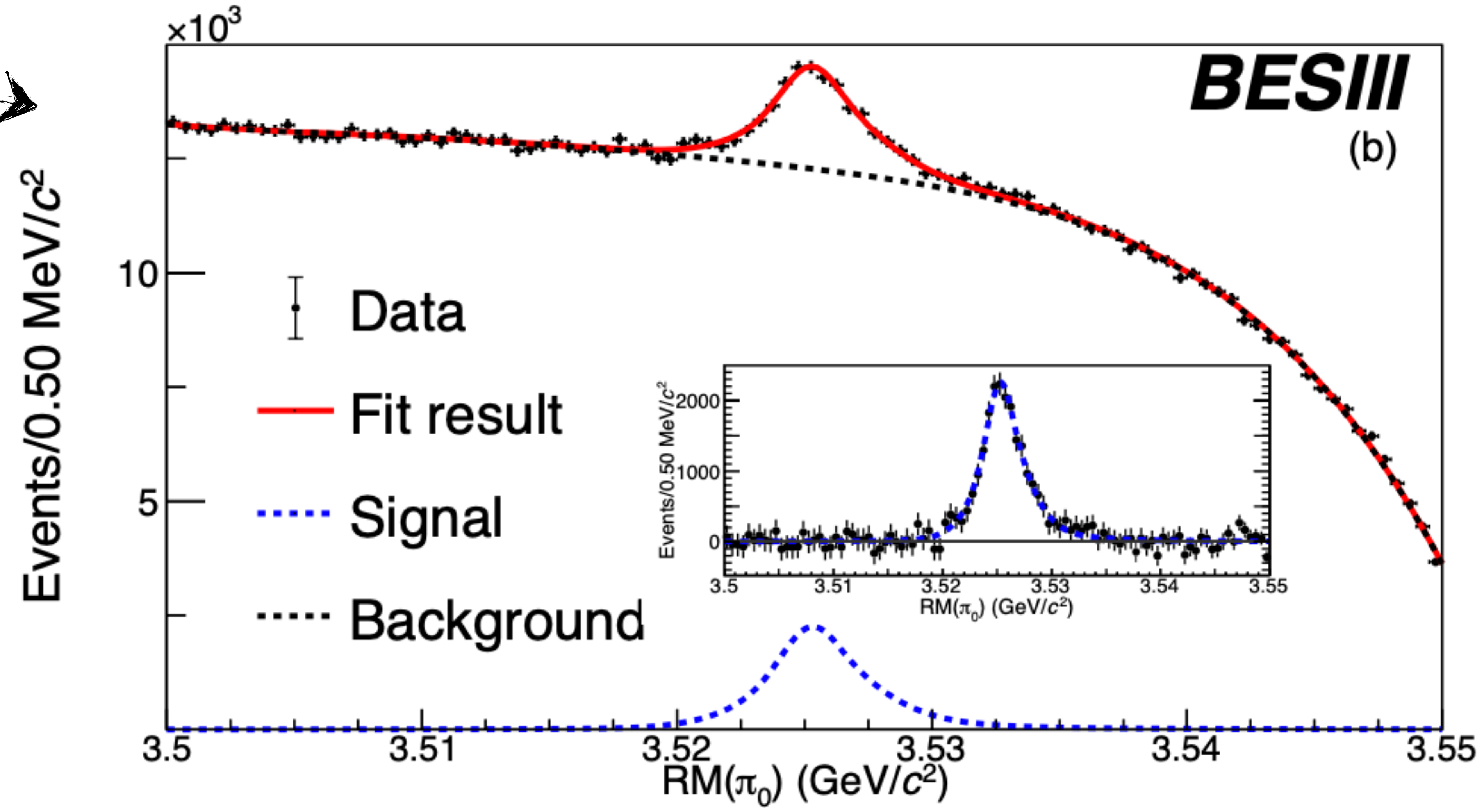
either allowing the h_c to decay inclusively
or tagging the γ_{E1} of the $h_c \to \gamma\eta_c$ transition





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PRD **106**, 072007 (2022)

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$N_{\text{Tag}}(h_c)$	23118^{+1500}_{-1398}	...

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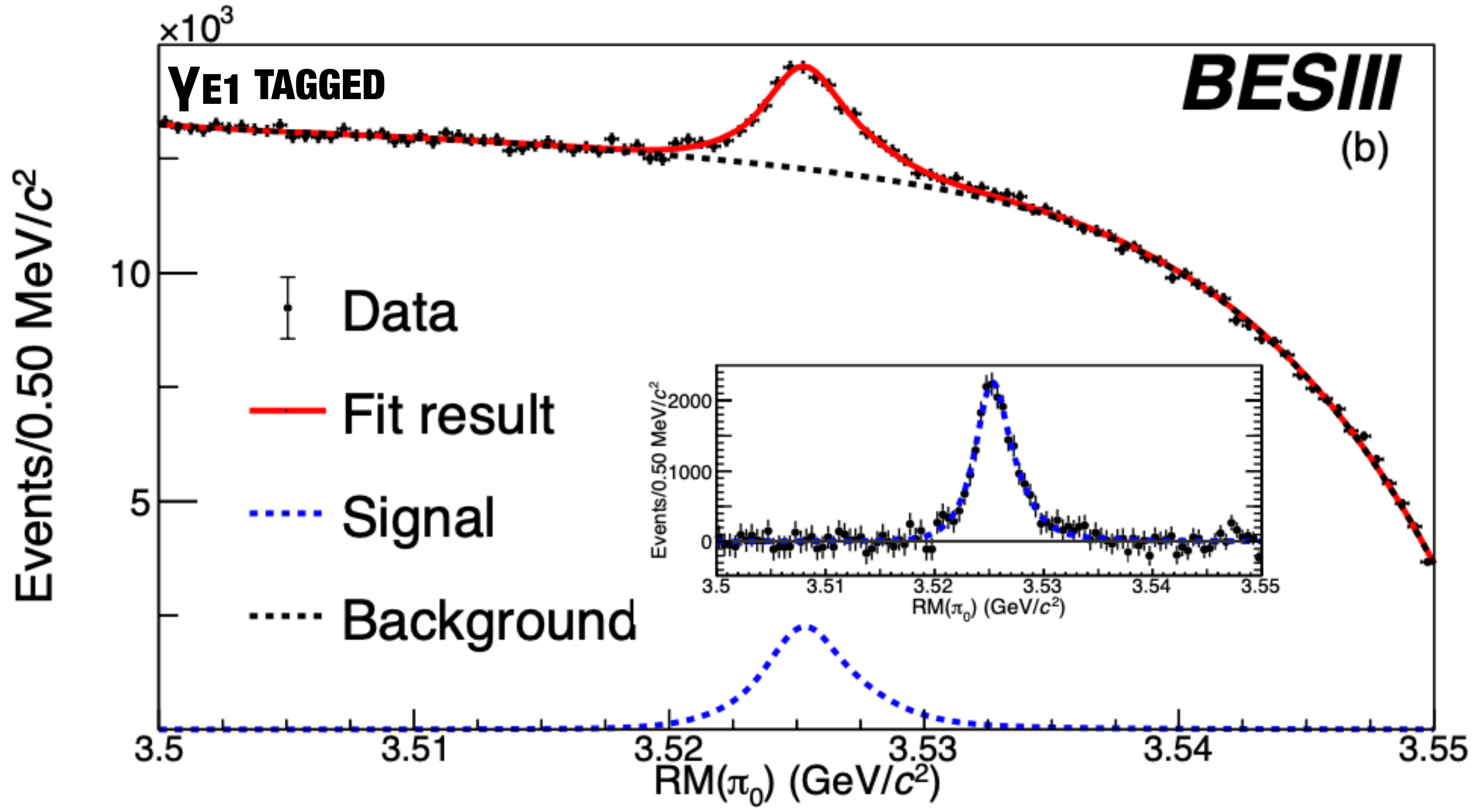
Being the S/B more favourable, the **tagged data set** is used to estimate the **h_c mass** and **width**, which is the **2nd estimate ever** of this parameter



[1] Phys. Rev. Lett. **104**, 132002

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$\mathcal{B}_{\text{Inc}} \times \mathcal{B}_{\text{Tag}}$ (10^{-4})	$4.22^{+0.27}_{-0.26} \pm 0.19$	4.58 ± 0.64 (BESIII [2]) 4.16 ± 0.48 (CLEO [3])

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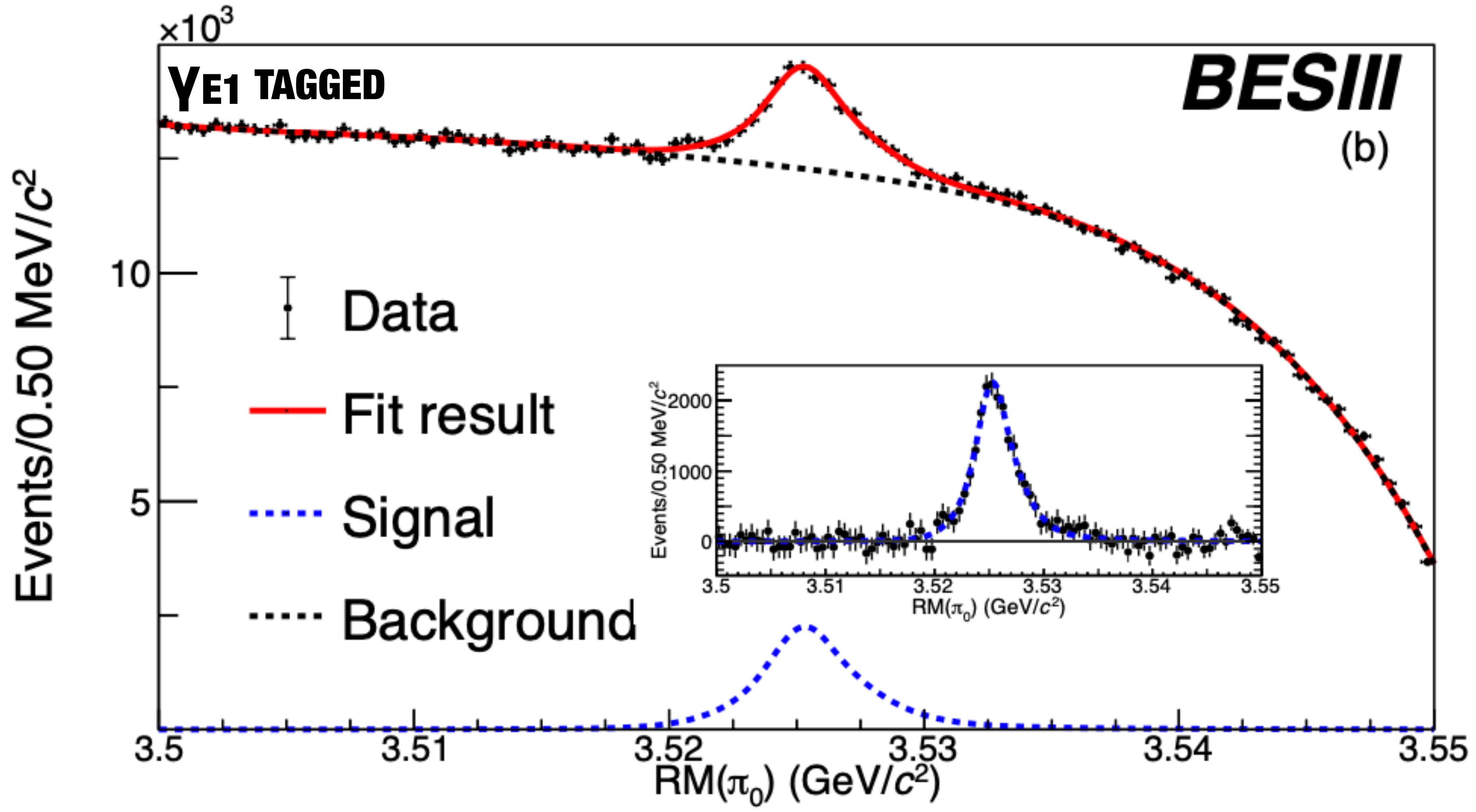
$$\mathcal{B}_{\text{Inc}}(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_{\text{Tag}}(h_c \to \gamma\eta_c) = \frac{N_{\text{Tag}}}{\epsilon_{\text{Tag}} \times N(\psi(2S)) \times \mathcal{B}(\pi^0 \to \gamma\gamma)}$$



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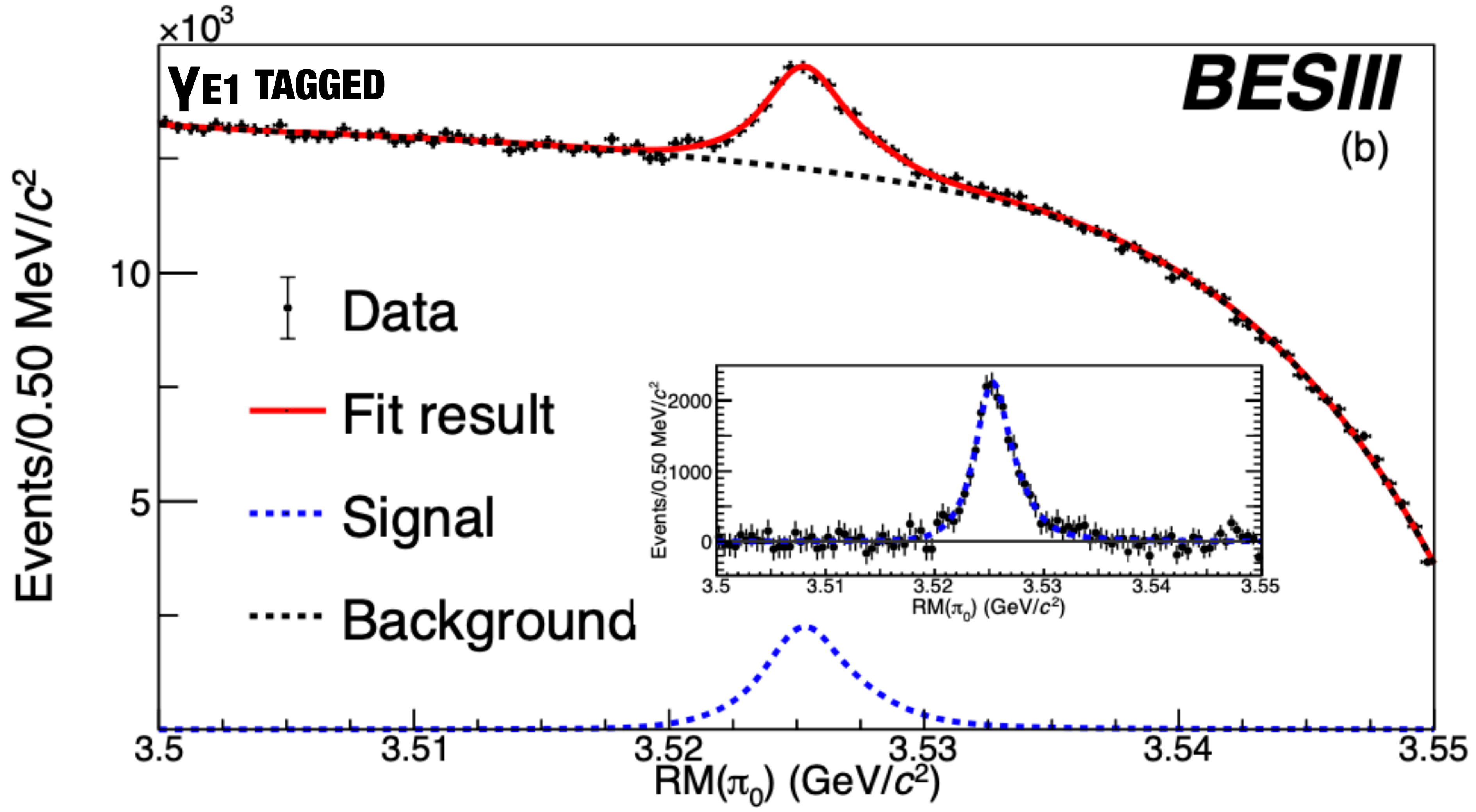
$N_{\rm Inc}(h_c)$	46187 ± 2123	...
$\mathcal{B}_{\rm Inc}$ (10^{-4})	$7.32 \pm 0.34 \pm 0.41$	$8.40 \pm 1.30 \pm 1.00$ (BESIII [2]) $9.00 \pm 1.5 \pm 1.3$ (CLEO [4])
$\mathcal{B}_{\rm Tag}$ (%)	$57.66^{+3.62}_{-3.50} \pm 0.58$	$53 \pm 7 \pm 8$ (BESIII [2]) $48 \pm 6 \pm 7$ (CLEO [3])

Most precise single estimates



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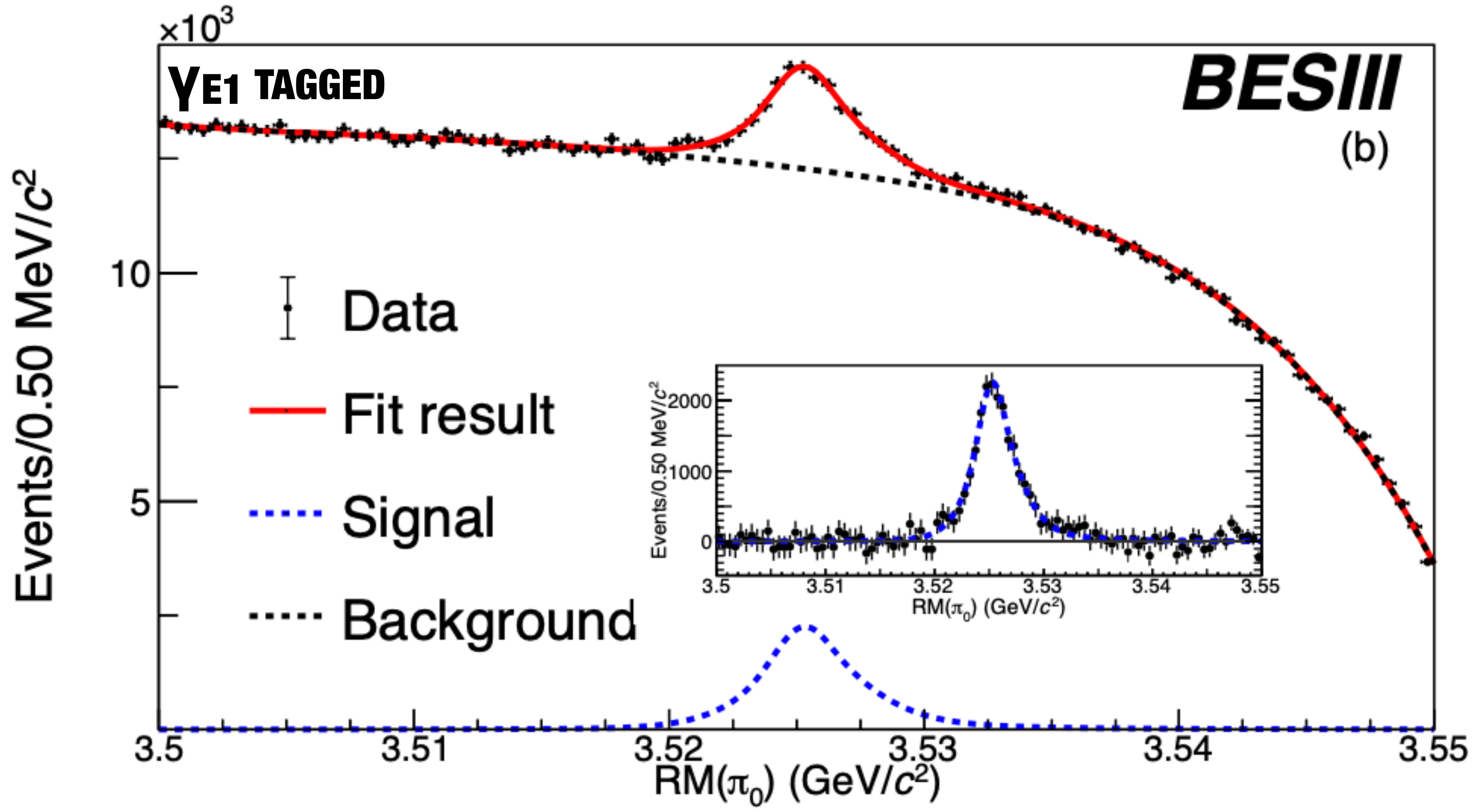
With respect to the **center-of-gravity mass** (M(c.o.g.)) of the three $\boldsymbol{\chi_{cJ}(1^3P_J)}$ states

$$M(\text{c.o.g.}) = \frac{M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2})}{9}$$

no mass splitting ($\Delta_{\rm hyp} = 0.03 \pm 0.06 \pm 0.15$ MeV/c^2) is observed **as** predicted by potential model **calculations**[5,6]



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[5] Ann. Rev. Nucl. Part. Sci. **37**, 325 (1987)
[6] Phys. Rev. D **96**, 056015

Ys and ψs

Phys. Rev. Lett. **129**, 102003 (2023)

Using 20 energy points @$\sqrt{s}$ = **[4.230, 4.700] GeV** for a $\mathcal{L}_{int}$ = 11.3 fb^{-1}

Study of the **$\sigma(e^+e^- \to \pi^+\pi^-\psi_2(3823))$**, (employing a partial) reconstruction technique: $\pi^+\pi^-$, (γ)γ & J/ψ ($\to \ell^+\ell^-$)

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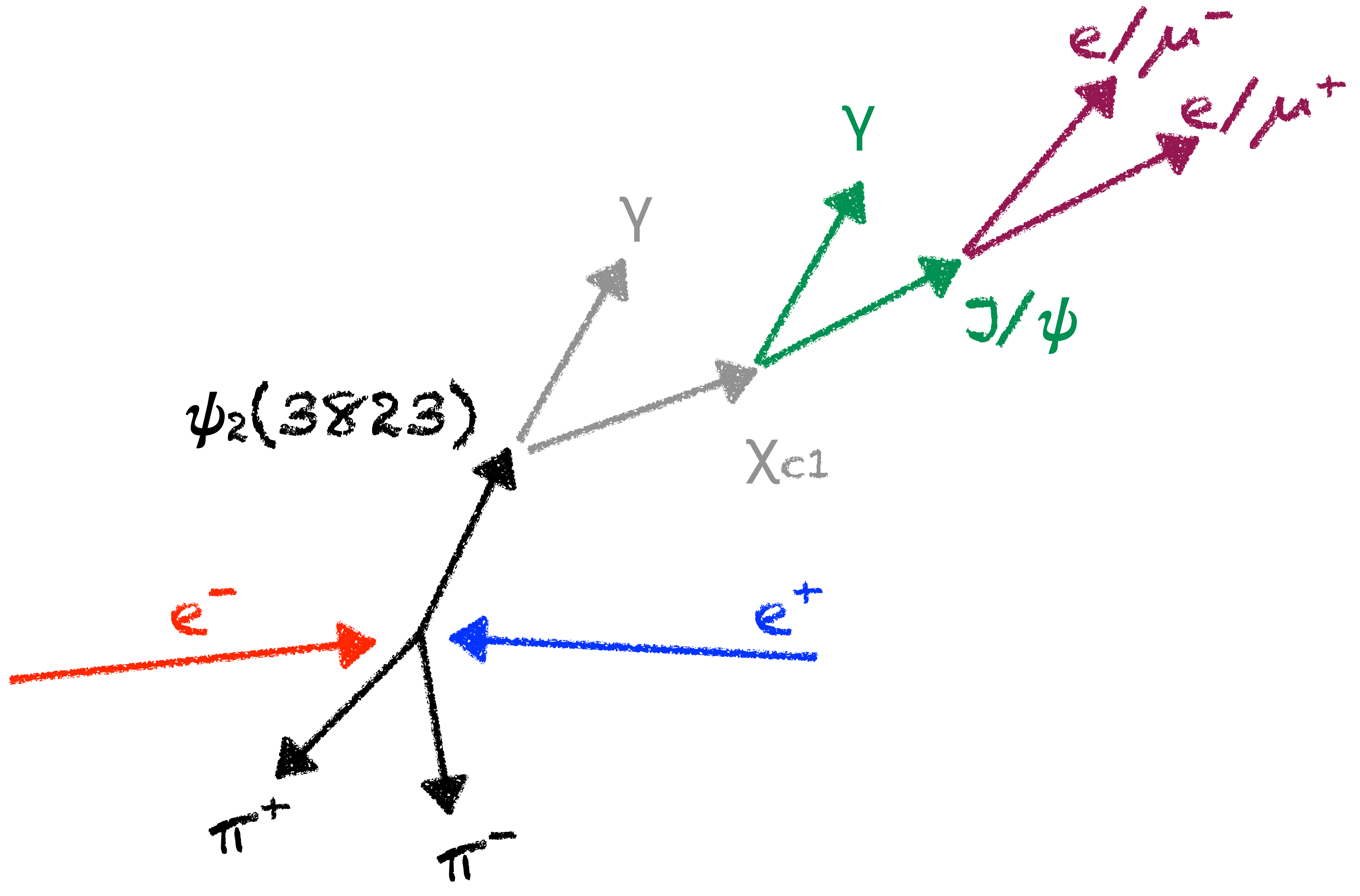

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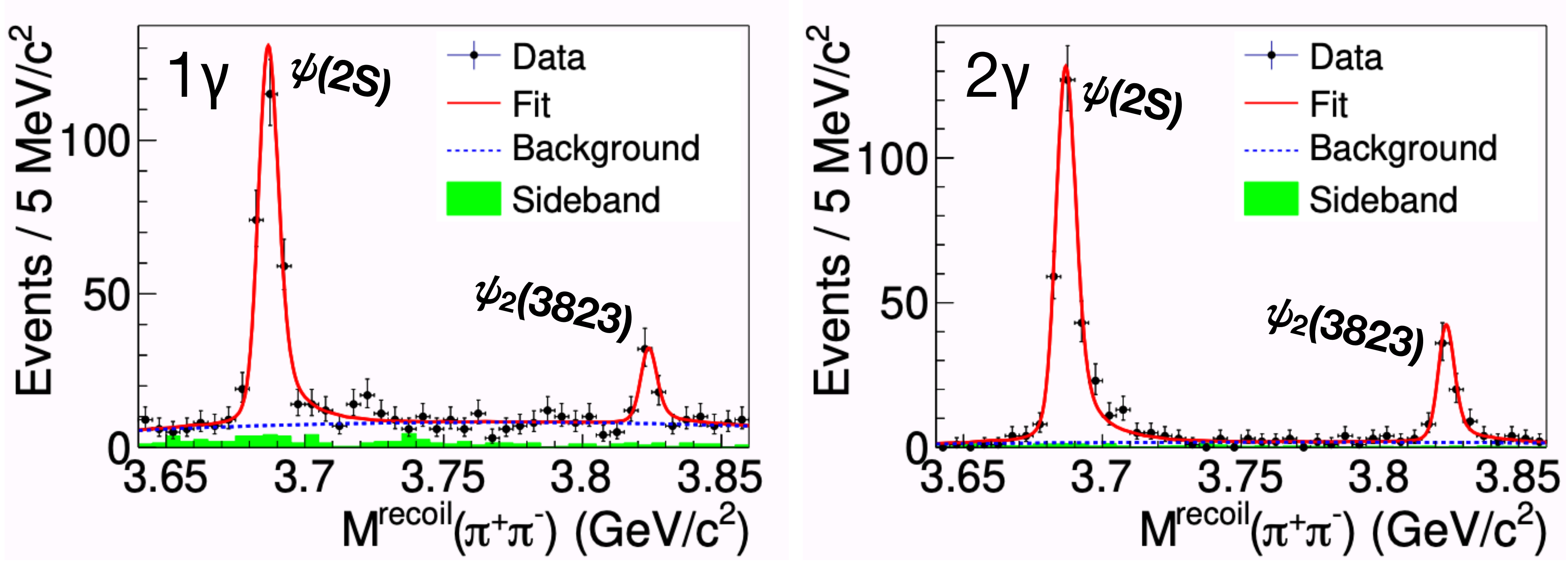

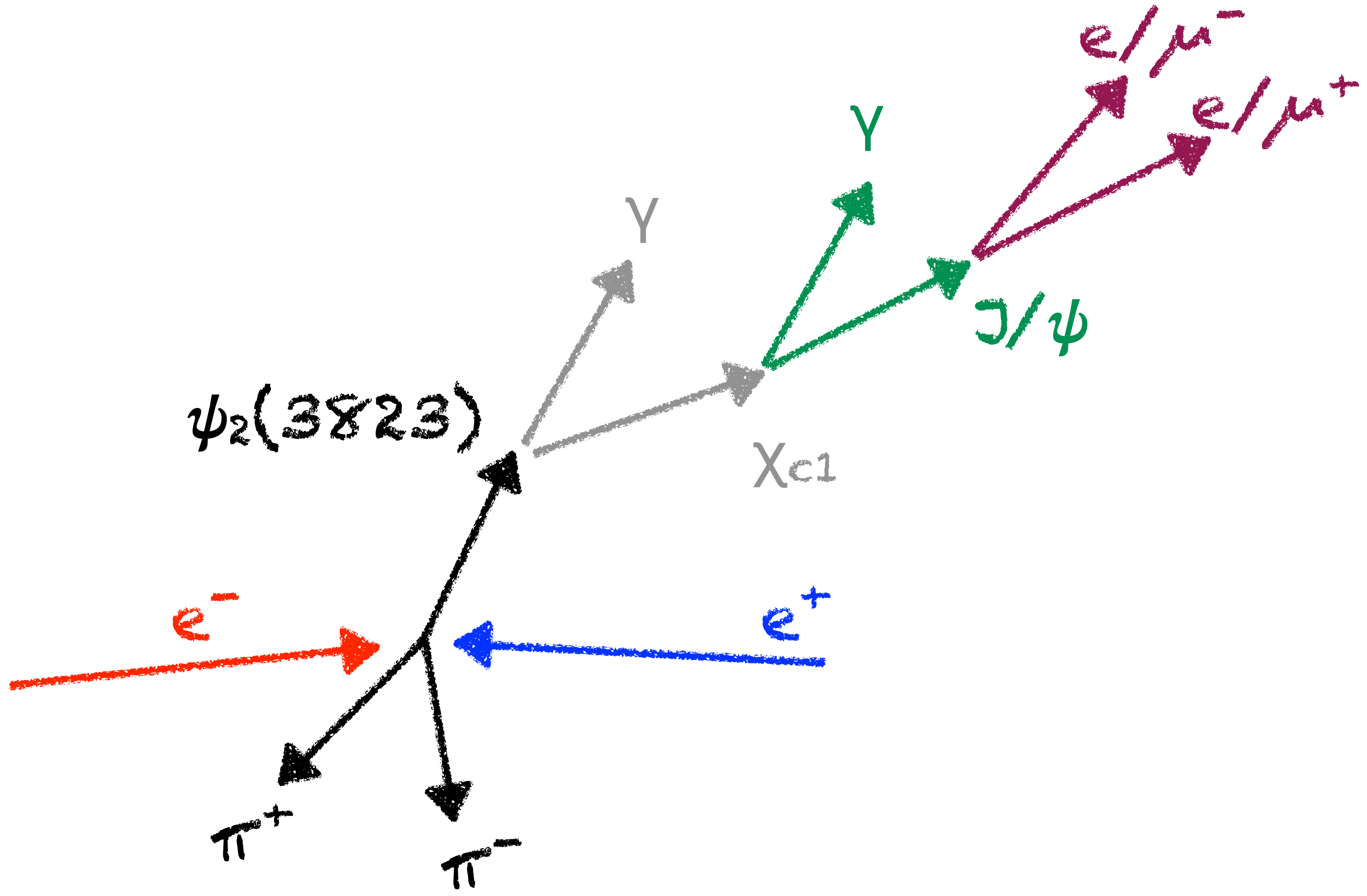

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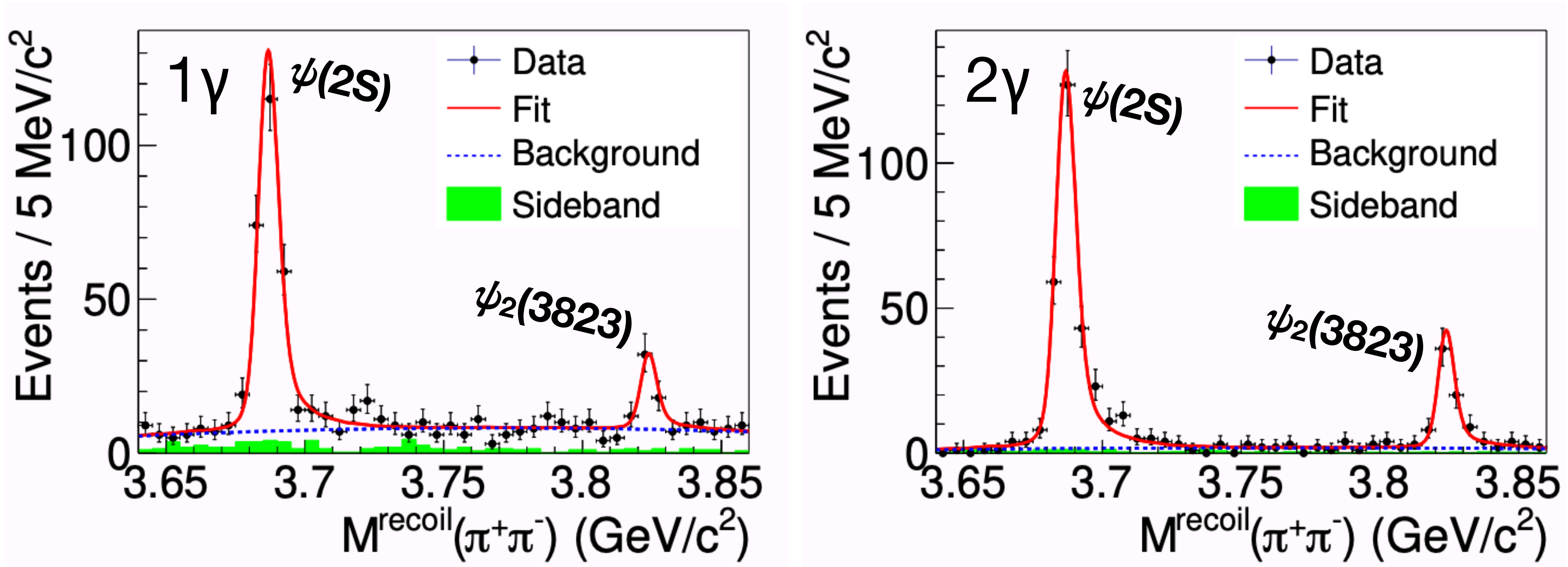

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- 3823.12 ± 0.43 ± 0.13 MeV/c^2
  Most precise estimate up to date
- $\Gamma_{\psi_2(3823)}$ < 2.9 MeV
  Most stringent upper limit

In accordance with the predictions for the charmonium $\psi_2(1^3D_2)$ state[7]

[7] Phys. Rev. D. **72**, 054026

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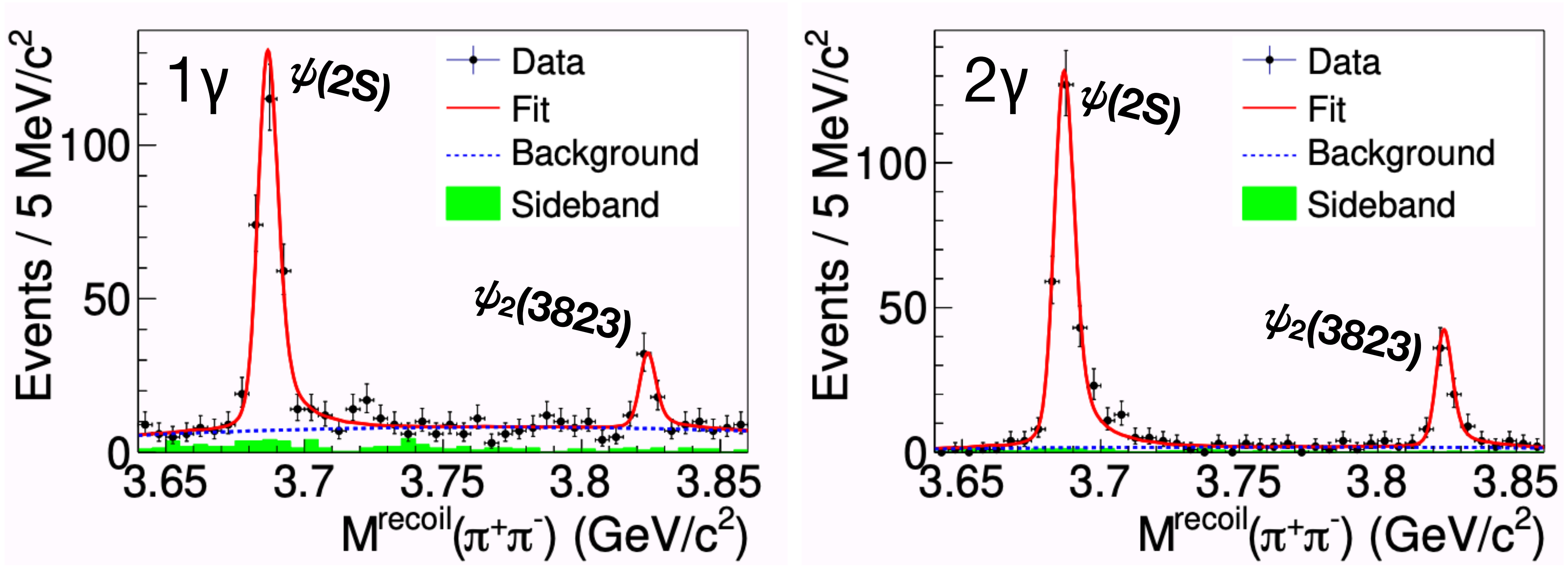

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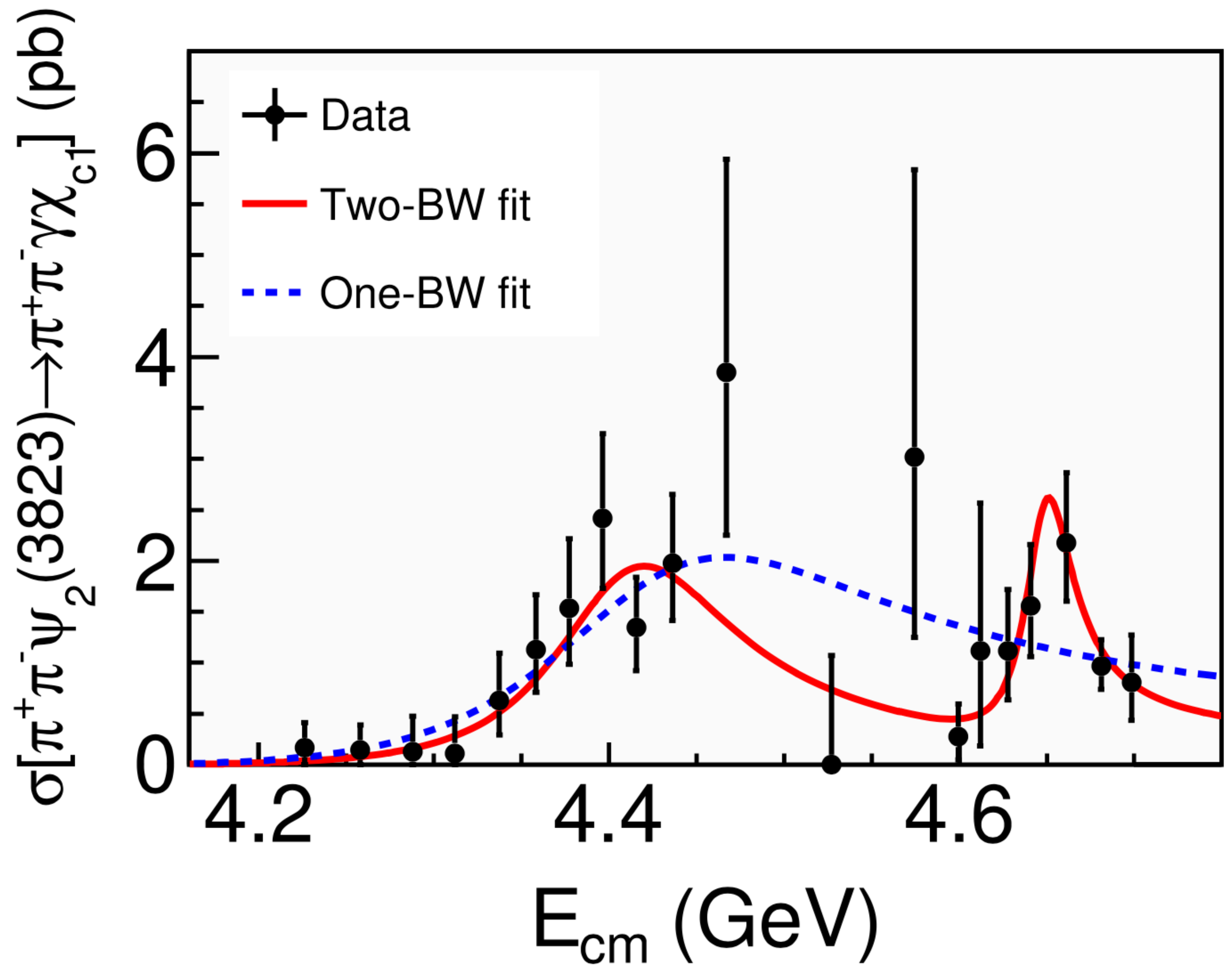
In the σ($e^+e^- \to \pi^+\pi^-\psi_2$(3823)), found structures corresponding to the Y(4360) and Y(4660)

Parameters	Solution I	Solution II
$M[R_1]$	$4406.9 \pm 17.2 \pm 4.5$	
$\Gamma_{tot}[R_1]$	$128.1 \pm 37.2 \pm 2.3$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_1}\mathcal{B}_2$	$0.36 \pm 0.10 \pm 0.03$	$0.30 \pm 0.09 \pm 0.03$
$M[R_2]$	$4647.9 \pm 8.6 \pm 0.8$	
$\Gamma_{tot}[R_2]$	$33.1 \pm 18.6 \pm 4.1$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_2}\mathcal{B}_2$	$0.24 \pm 0.07 \pm 0.02$	$0.06 \pm 0.03 \pm 0.01$
ϕ	$267.1 \pm 16.2 \pm 3.2$	$-324.8 \pm 43.0 \pm 5.7$

The observation of the **Y(4660) in this channel challenges** the f_0(980)ψ(2S) **hadron molecule** interpretation[7] and the extended **baryonium** picture[8]



[7] Phys. Lett. B **665**, 26 (2008)
[8] J. Phys. G **35**, 075008 (2008)

Ys and ψs

Though Neutrals This Time

JHEP **02**, (2023) 171

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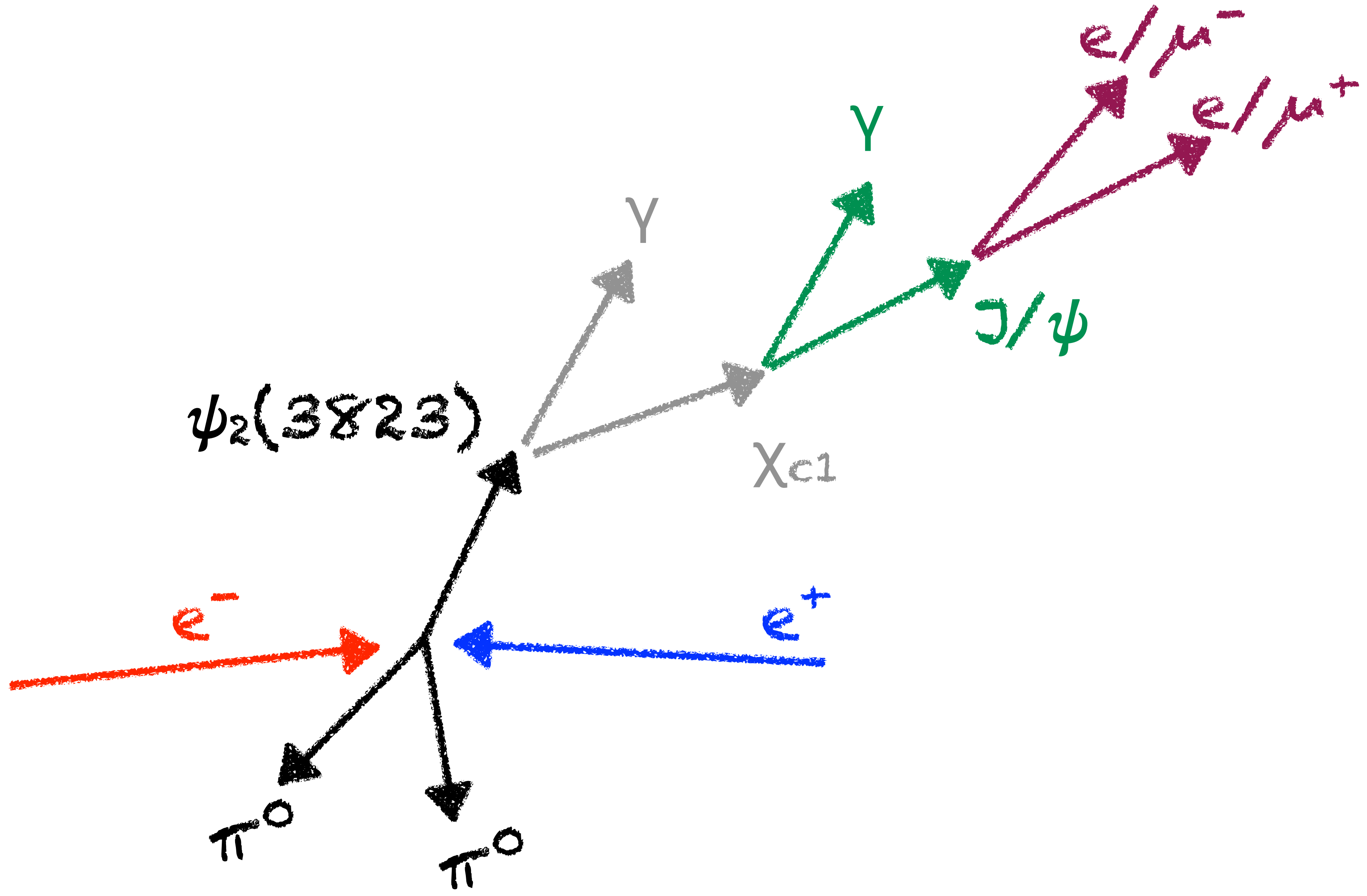

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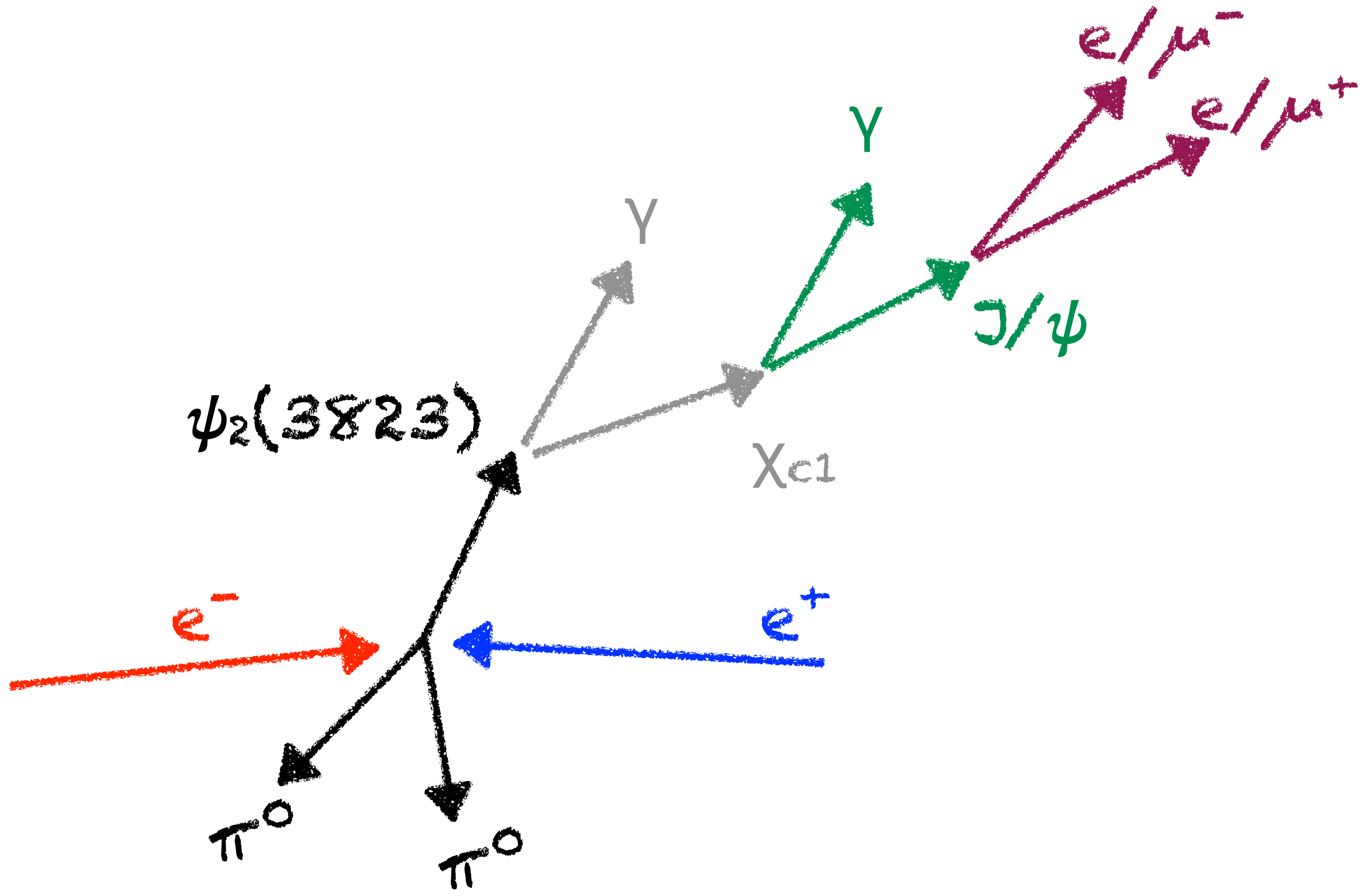

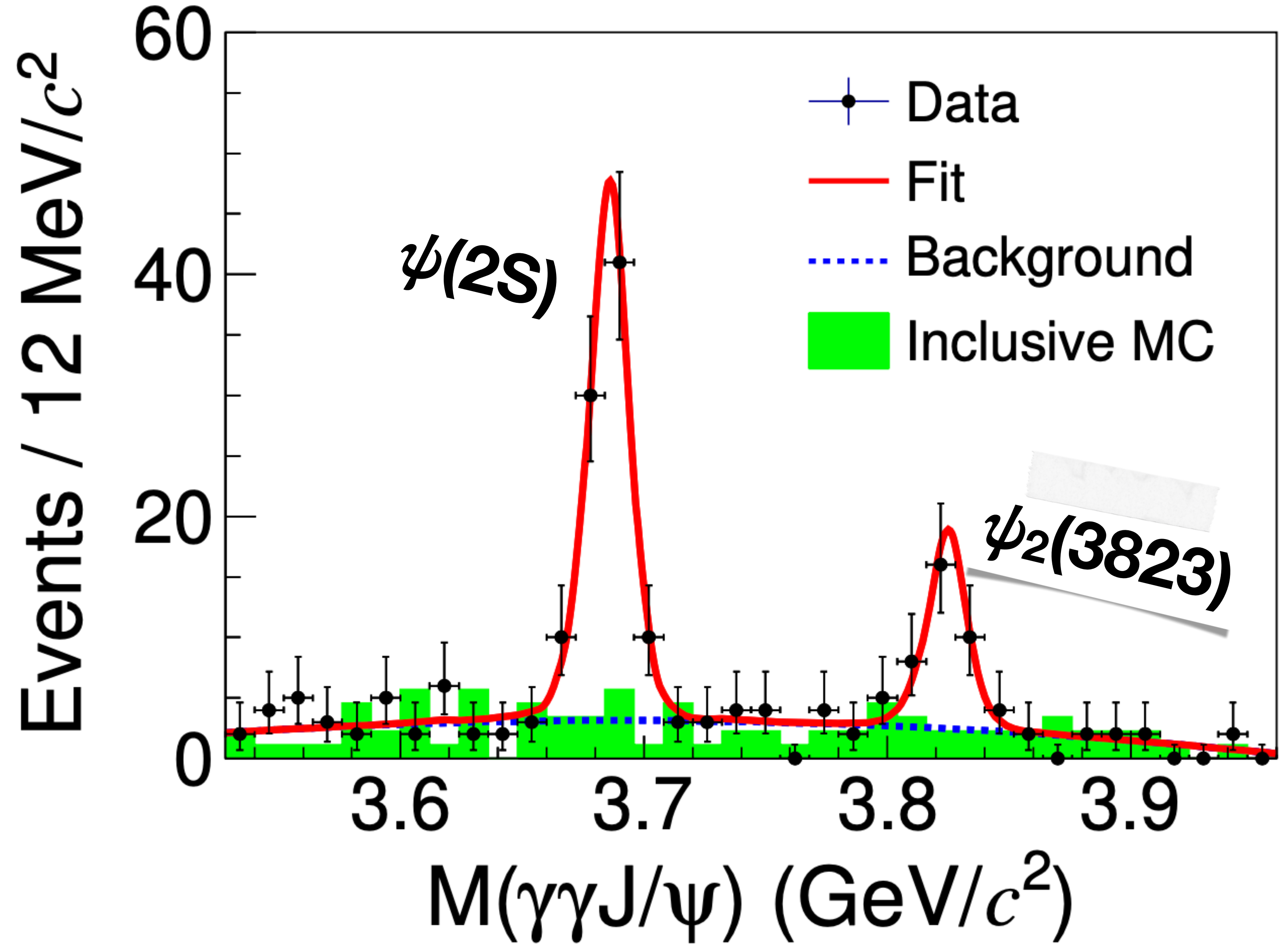

Ys and ψs

Though Neutrals This Time

Using 20 energy points @$\sqrt{s}$ **= [4.230, 4.700] GeV** for a $\mathcal{L}_{int}$ = 11.3 fb^{-1}

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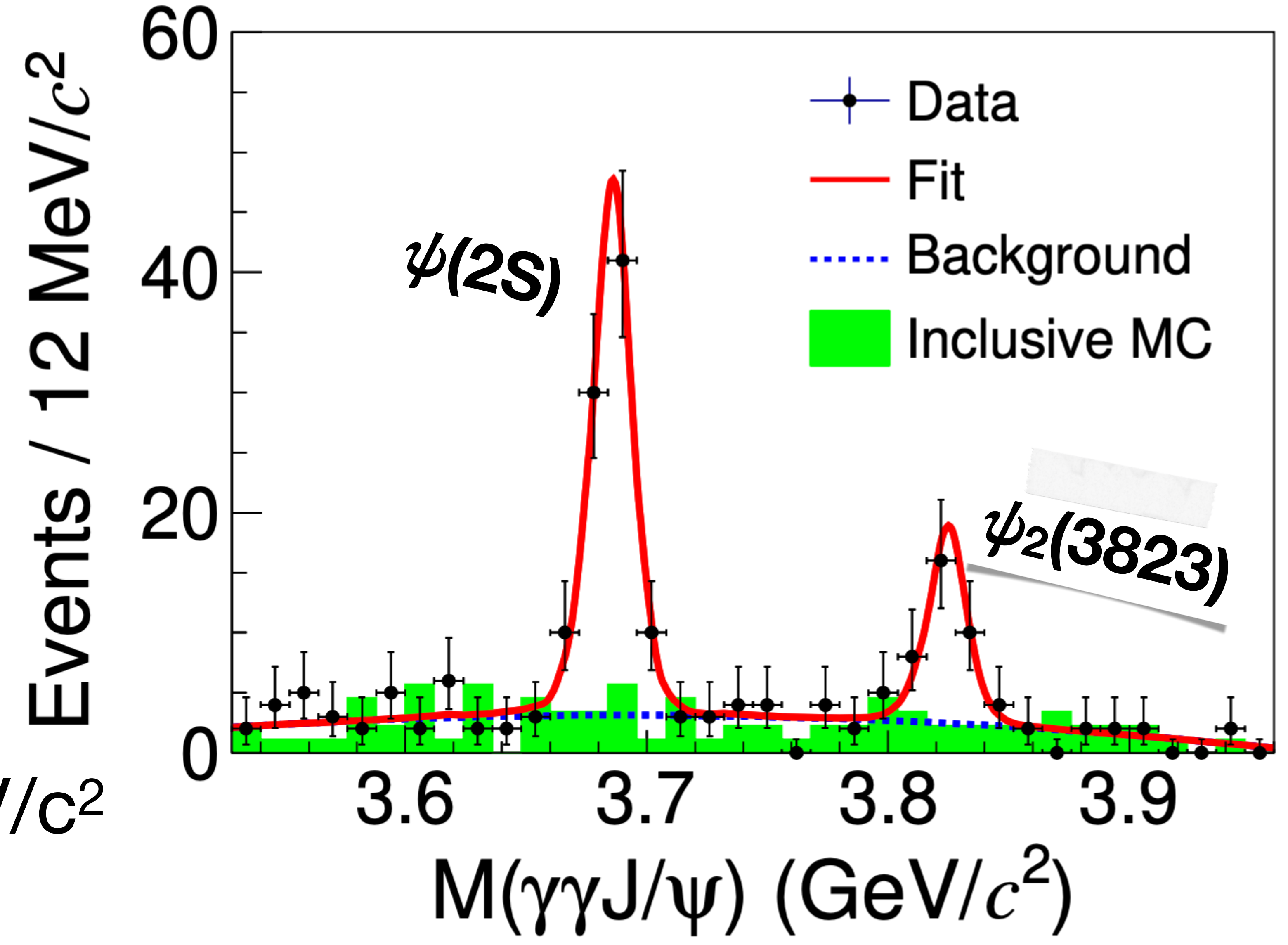
Fit to $M(\gamma\gamma J/\psi)$ to estimate $\psi_2(3823)$ mass and $N^{\pi\pi\psi}_{obs}$

3824.3 ± 2.4 ± 0.9 MeV/c^2

$\Gamma_{\psi_2(3823)}$ < 18.8 MeV

JHEP **02**, (2023) 171



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JHEP **02**, (2023) 171

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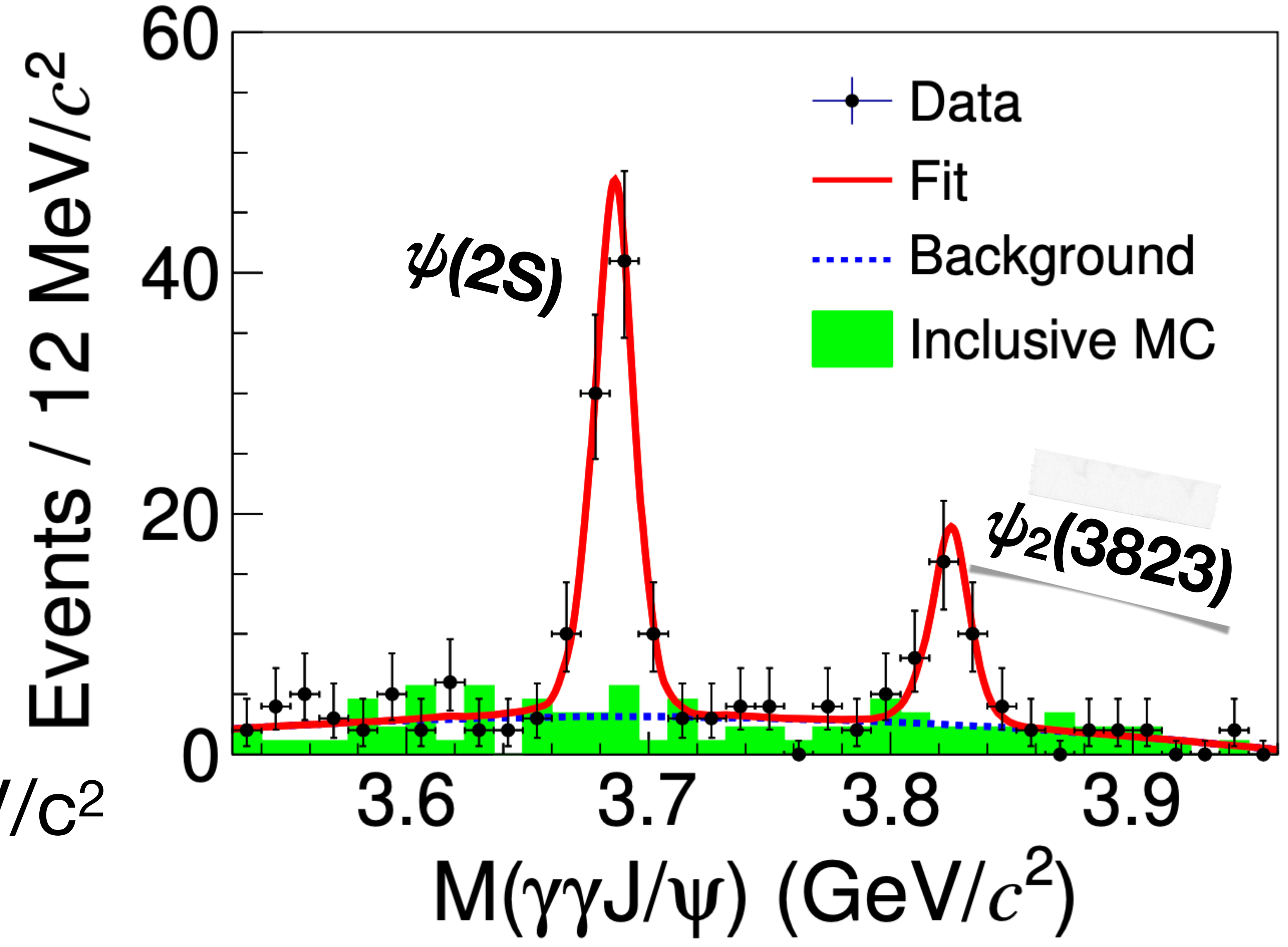

Due to the limited statistics, a cross-section scan cannot be performed with enough significance…

$$\mathcal{R} = \frac{\sigma^{Avg\ Born}_{\pi^0\pi^0\psi_2}}{\sigma^{Avg\ Born}_{\pi^+\pi^-\psi_2}} = \frac{N_{\pi^0\pi^0\psi_2}(\sum_i \mathcal{L}_i(1+\delta)_i\epsilon_i)_{\pi^+\pi^-\psi_2}}{N_{\pi^+\pi^-\psi_2}(\sum_i \mathcal{L}_i(1+\delta)_i\epsilon_i)_{\pi^0\pi^0\psi_2}} \cdot \frac{1}{\mathcal{B}^2(\pi^0\rightarrow\gamma\gamma)}$$

Ys and ψs

Though Neutrals This Time

JHEP **02**, (2023) 171

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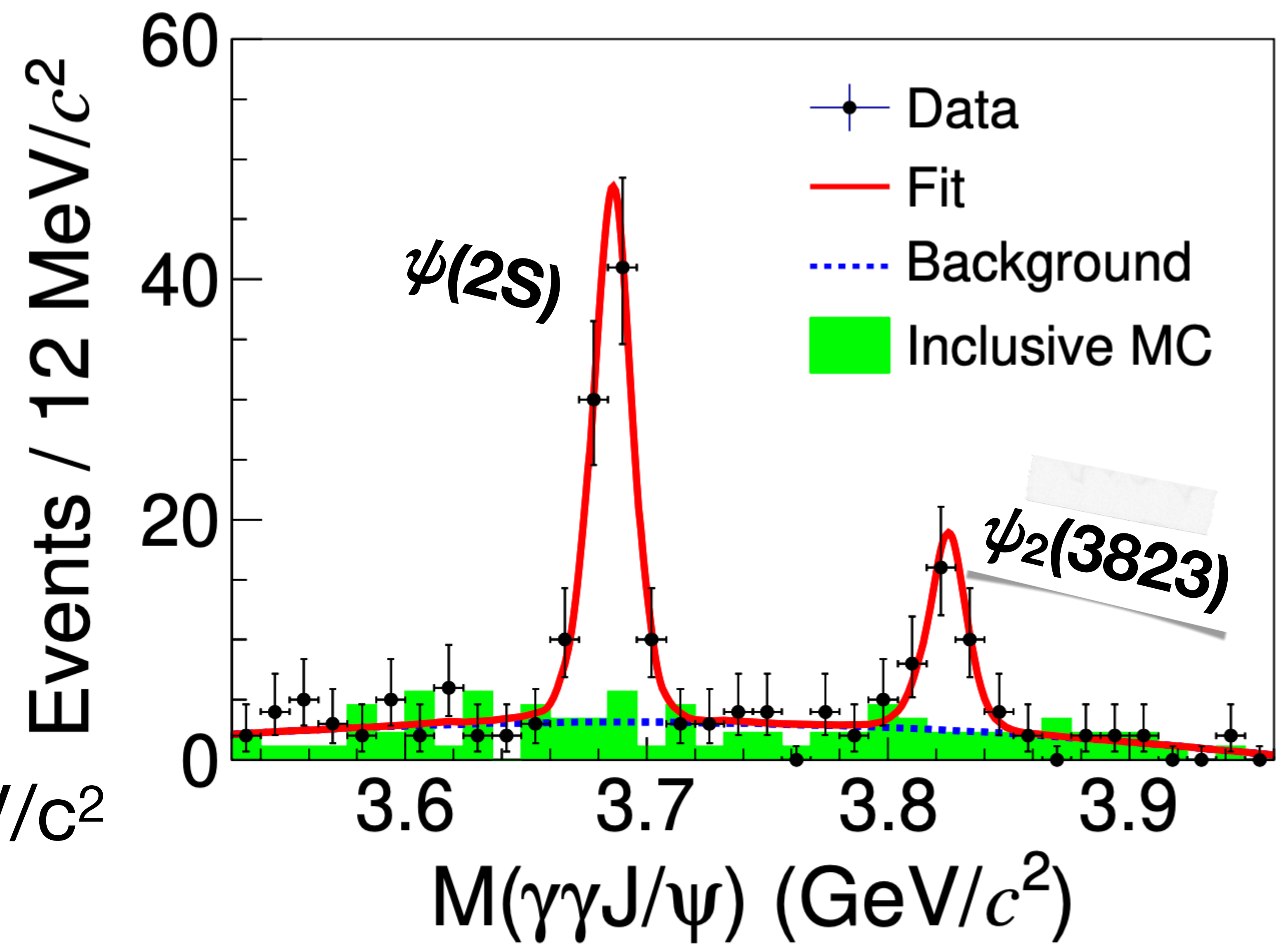
Fit to M(γγJ/ψ) to estimate $\psi_2(3823)$ mass and $N^{\pi\pi\psi}_{obs}$



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Consistent with isospin symmetry

$\psi_2(3823)$ - $\psi_2(1^3D_2)$

The $\pi^+\pi^-$ system in $e^+e^- \to \pi^+\pi^-\psi_2(3823)$ process is expected to be dominated by S-wave

Since $\rho^0 \to \pi^0\pi^0$ is forbidden, the observation of $e^+e^- \to \pi^0\pi^0\psi_2(3823)$ corroborates the S-wave ($f_0(500) \to \pi^0\pi^0$) expectation

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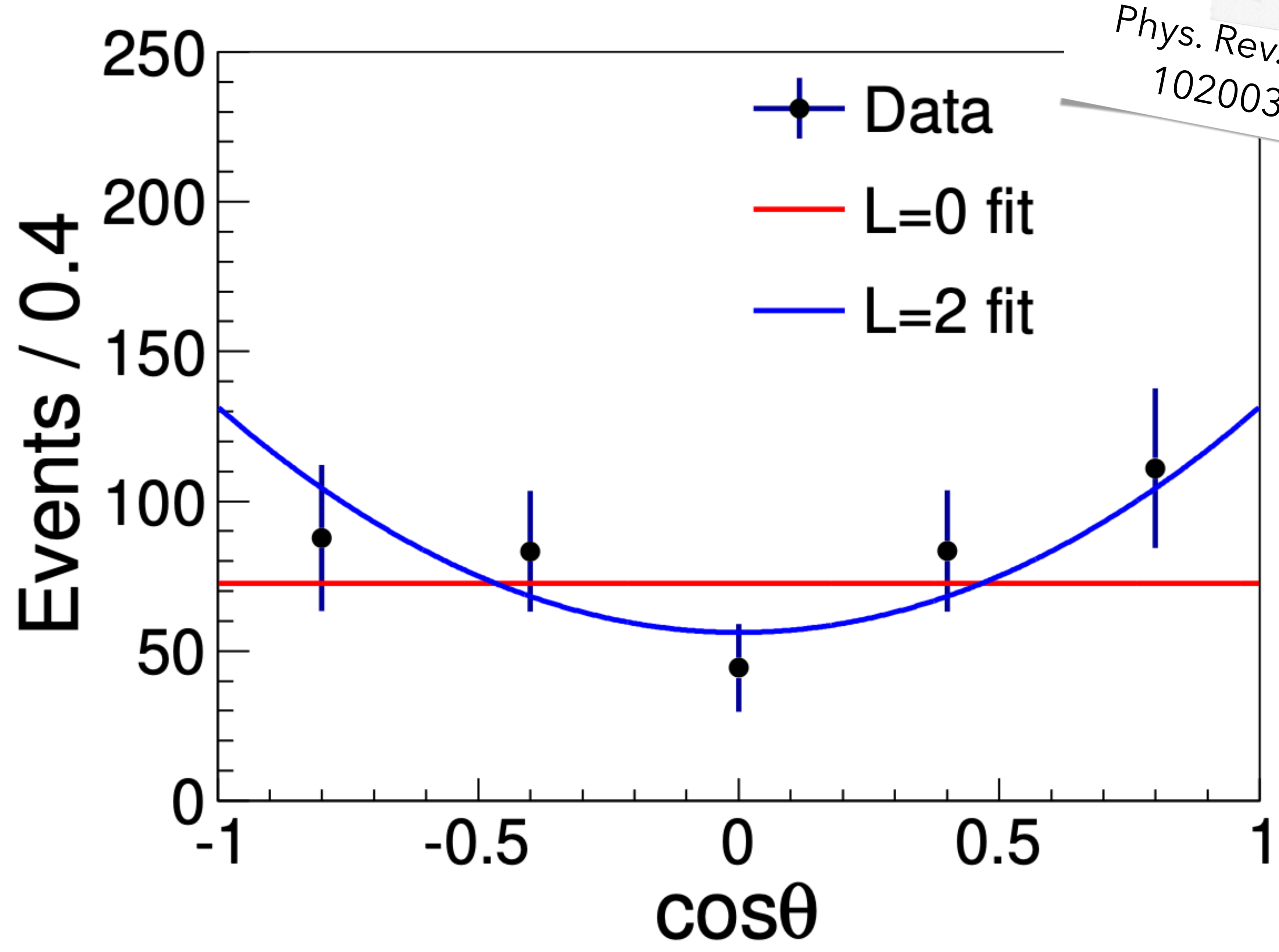
If this was true and $\psi_2(3823)$ was a $\psi_2(1^3D_2)$ state, the relative orbital angular momentum should be 2

Phys. Rev. Lett. **129**, 102003 (2023)



This, together with mass estimations and width upper limits **supports** the **$J^{PC} = 2^{--}$ assignment** and the **hypothesis** that the ***$\psi_2(3823)$* is** a **$\psi_2(1^3D_2)$ state**

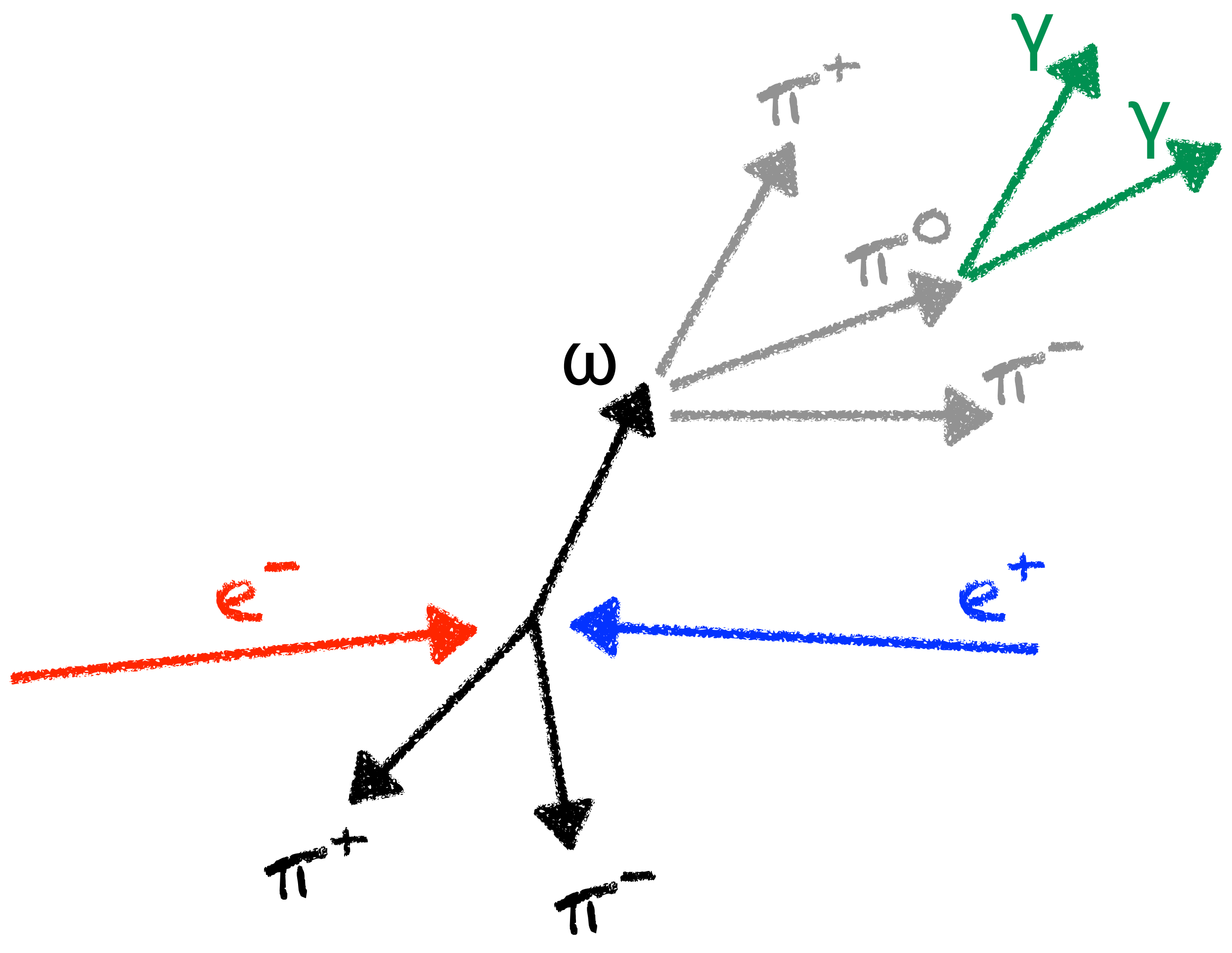
Looking at the Light Sector

arXiv:2303.0971
Submitted to JHEP

Using 24 energy points @$\sqrt{s}$ = **[4.0, 4.6] GeV** for a $\mathcal{L}_{int}$ = 15.6 fb^{-1}

Study of the **$\sigma(e^+e^- \to \pi^+\pi^-\omega)$** and all the possible **$\pi^+\pi^-$** intermediate resonance states via Partial Wave Analysis

Fit to $M(\pi^+\pi^-\pi^0)$ to estimate σ^{Born}, and investigation of the $M(\pi^+\pi^-)$ and $M(\pi\omega)$ to extract intermediate states and their cross-sections



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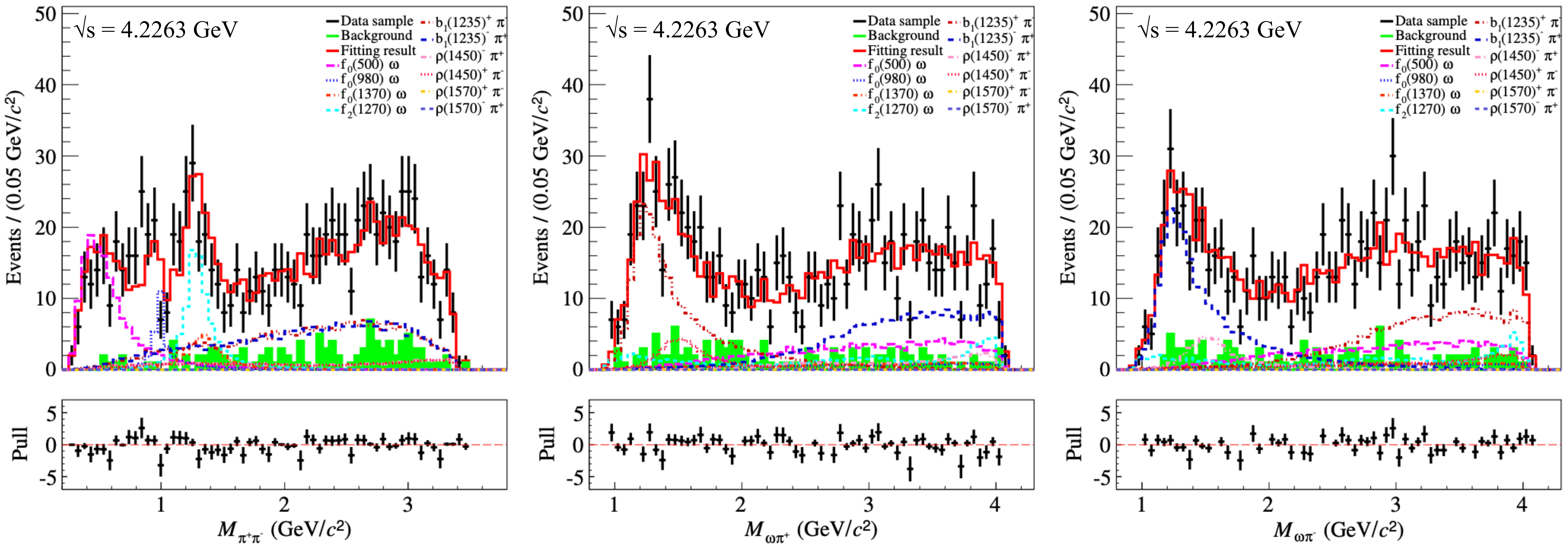
In the PWA the total **amplitude** of the $e^+e^- \rightarrow$ **$\pi^+\pi^-\omega$ process** is parameterised as a sum of sequential quasi-two-body processes

$f_0(500)$ and $b_1(1235)^{\pm}$ mesons contributions are the most significant ones



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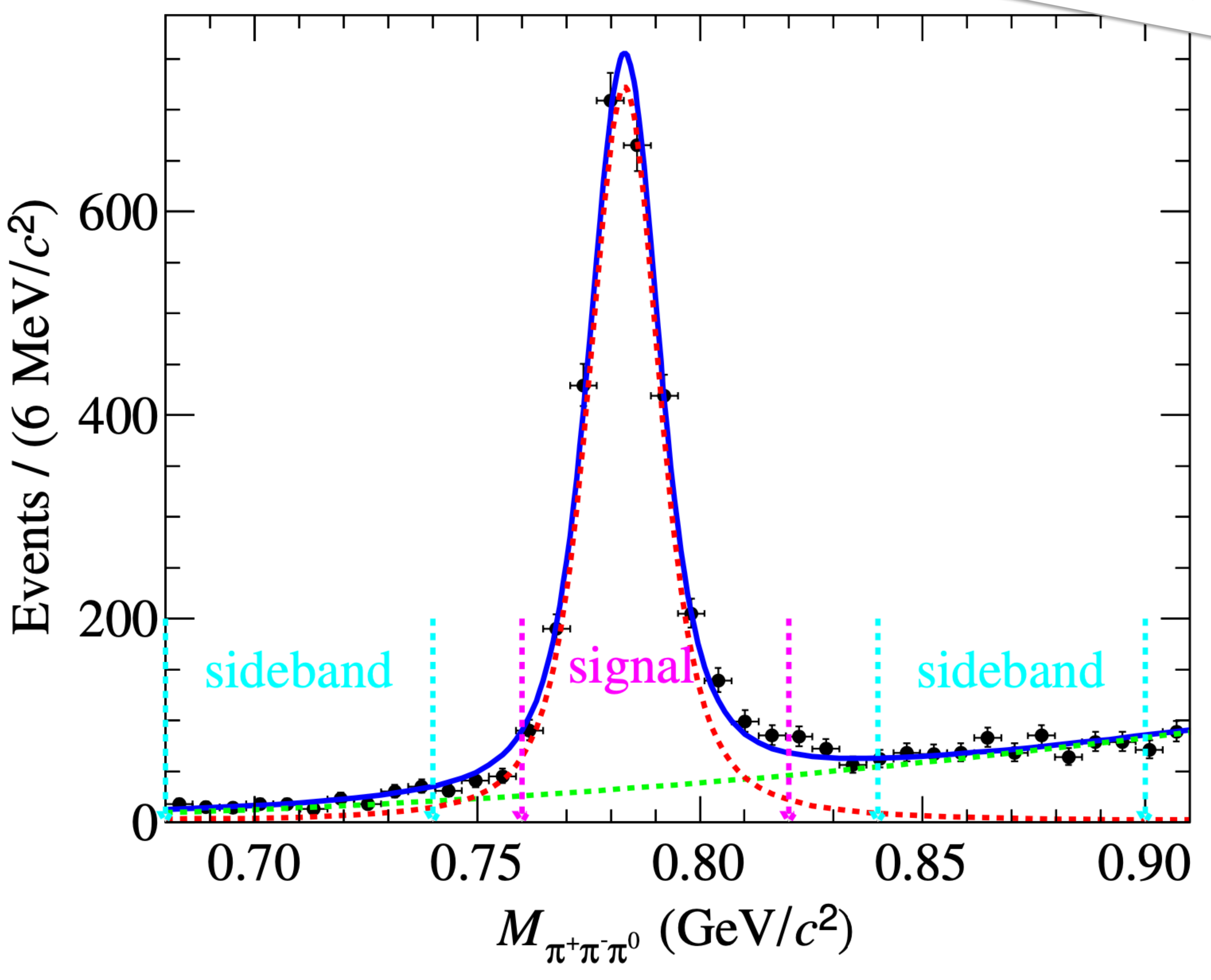

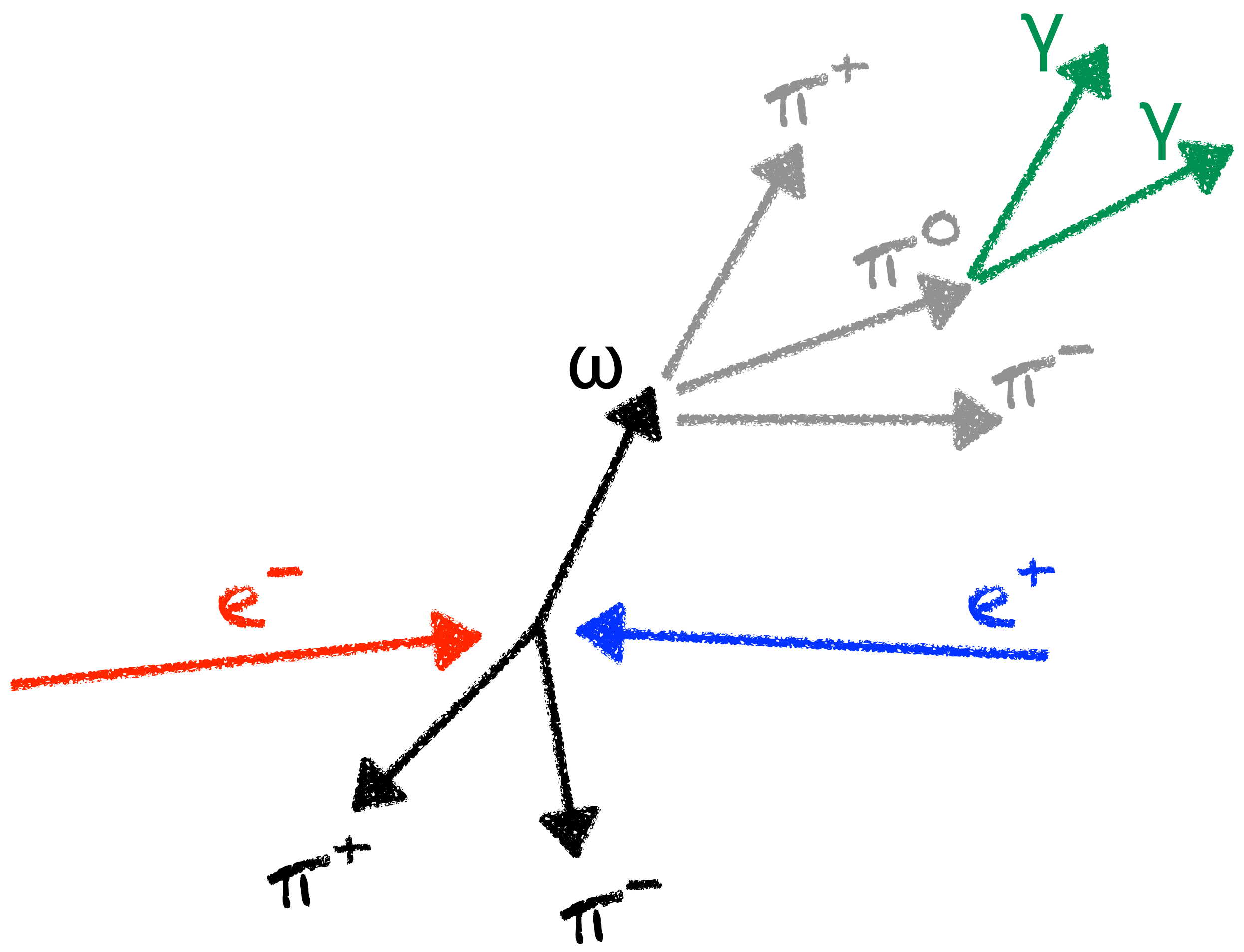

$$\sigma^{Born} = \frac{N_{\pi^+\pi^-\omega}}{\mathcal{L}\cdot(1+\delta)\cdot\epsilon\cdot\frac{1}{|1-\Pi|^2}}\cdot\frac{1}{\mathcal{B}(\omega\to\pi^+\pi^-\pi^0)\cdot\mathcal{B}(\pi^0\to\gamma\gamma)}$$

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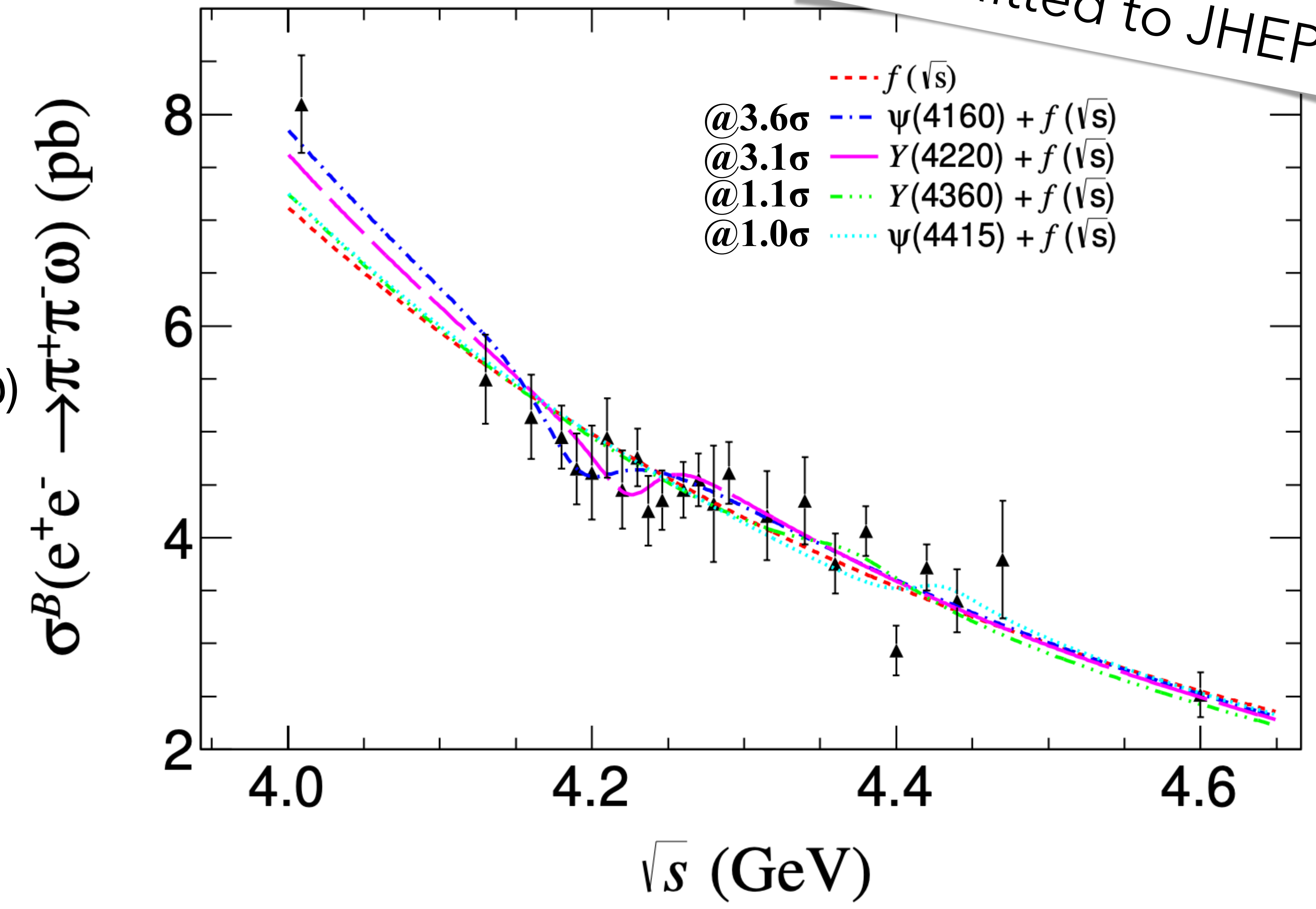
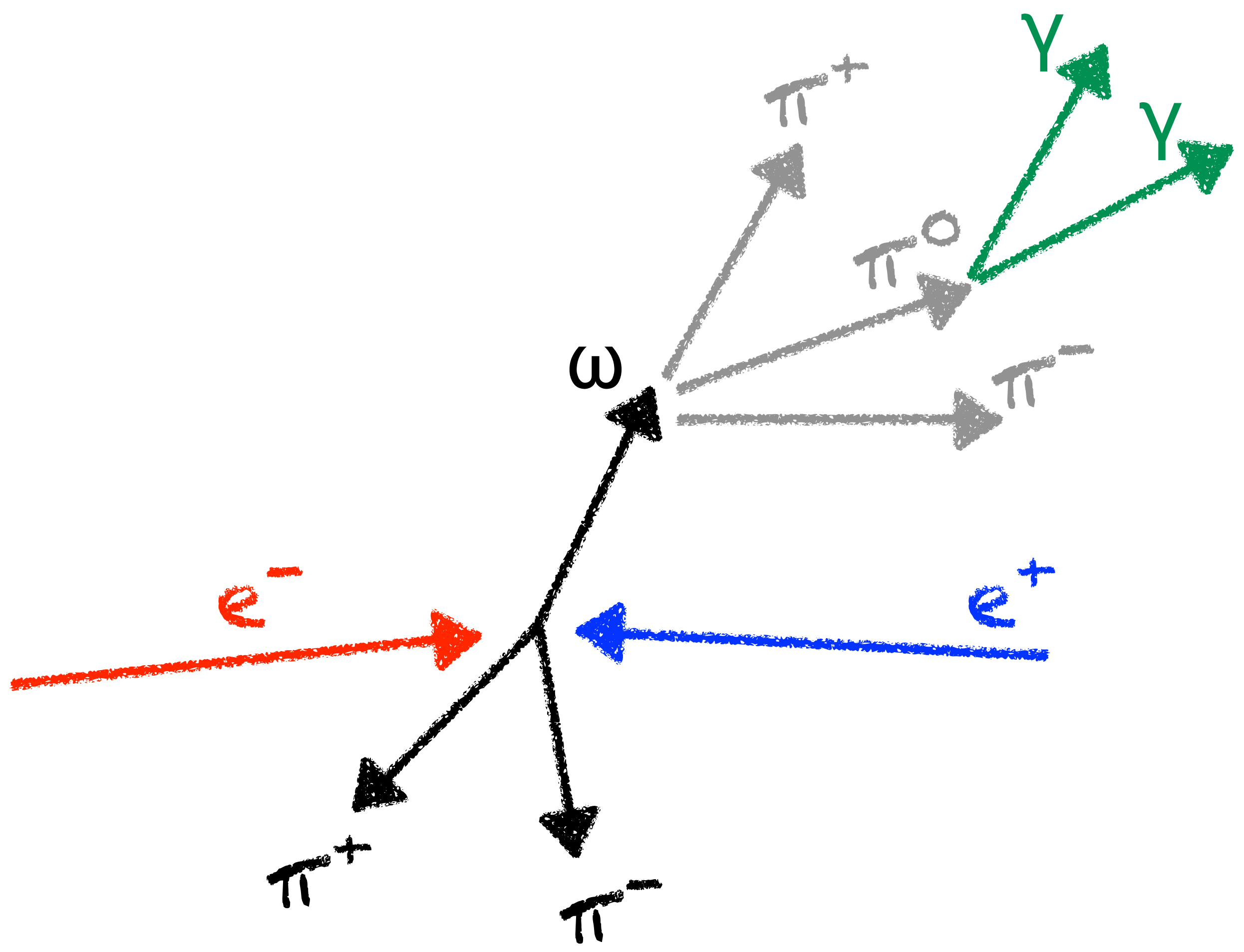




$$\sigma^{Born} = \frac{N_{\pi^+\pi^-\omega}}{\mathcal{L}\cdot(1+\delta)\cdot\epsilon\cdot\frac{1}{|1-\Pi|^2}} \cdot \frac{1}{\mathcal{B}(\omega\to\pi^+\pi^-\pi^0)\cdot\mathcal{B}(\pi^0\to\gamma\gamma)}$$

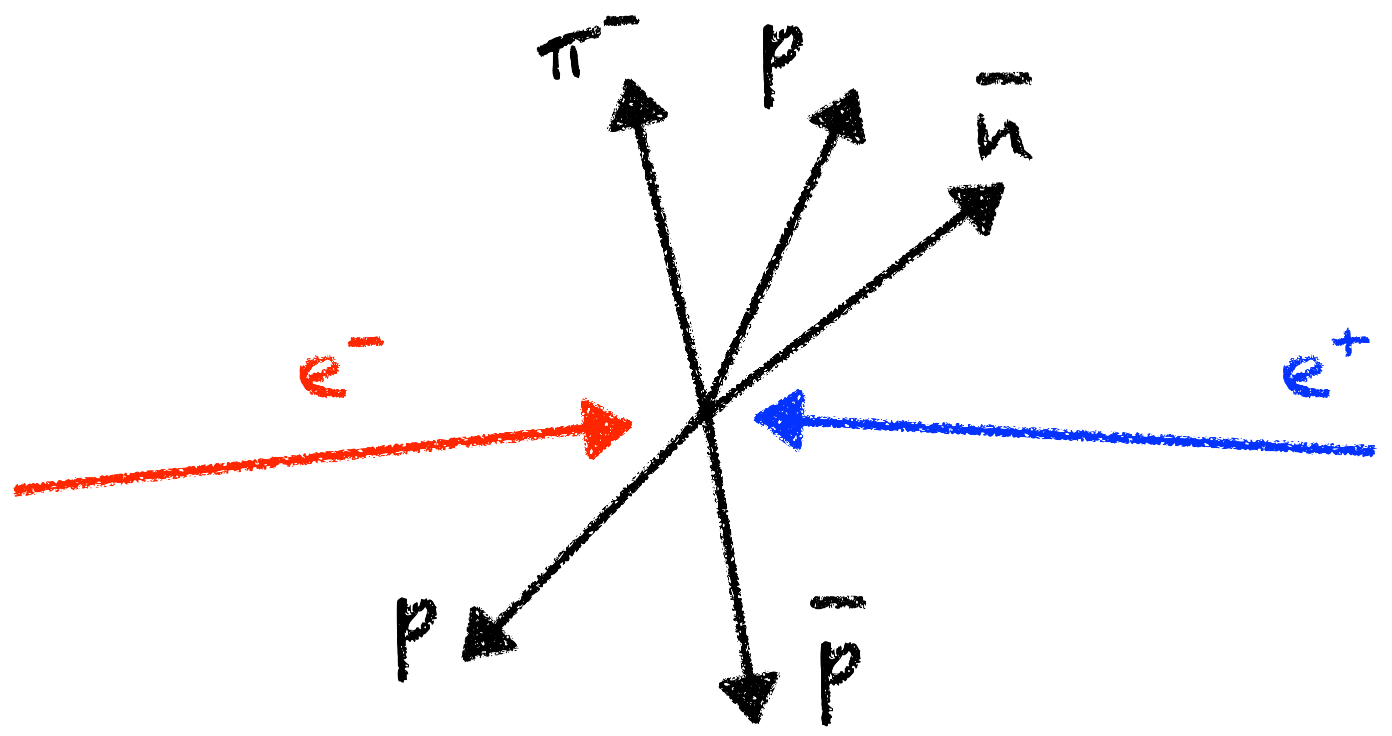
Hexaquarks in the Midst[II]

Chinese Phys. C **47** 043001

Using 29 energy points @$\sqrt{s}$ = **[4.16, 4.70] GeV** for a $\mathcal{L}_{int}$ = 18.8 fb^{-1}

Study of the $\sigma(e^+e^- \rightarrow pp\bar{p}\bar{n}\pi^- + c.c.)$, and search for exotic states in the $\bar{p}\bar{n}$ and $pp\pi^-$ invariant mass distributions

Fit to $M^{recoil}(pp\bar{p}\pi^-)$ to estimate σ^{Born}



[II] B. Zheng, "Search for hexaquark or di-baryon state at BESIII"

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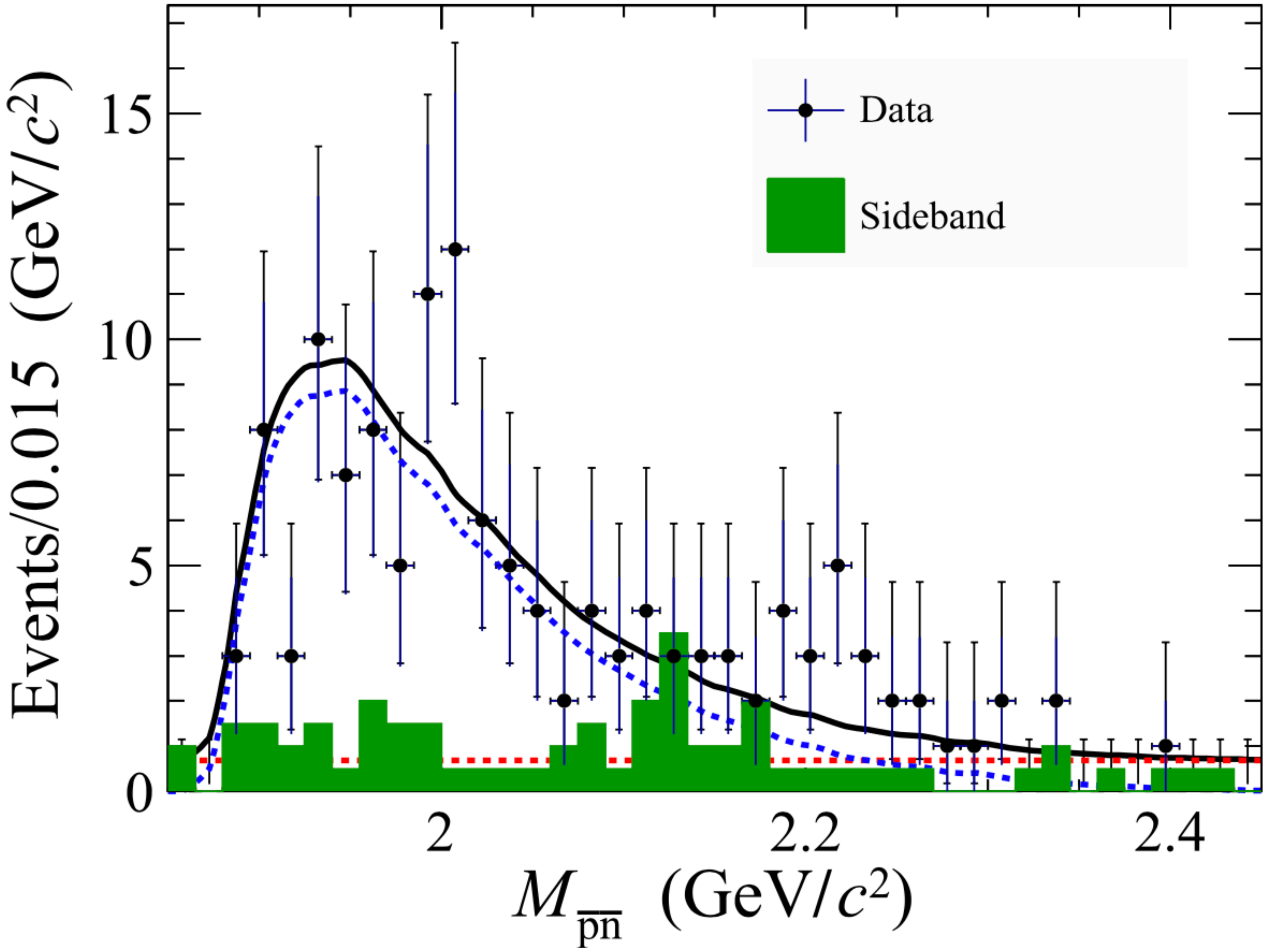
Invariant mass spectra are consistent with phase space distributions, hence that no hexaquark or di-baryon state is observed



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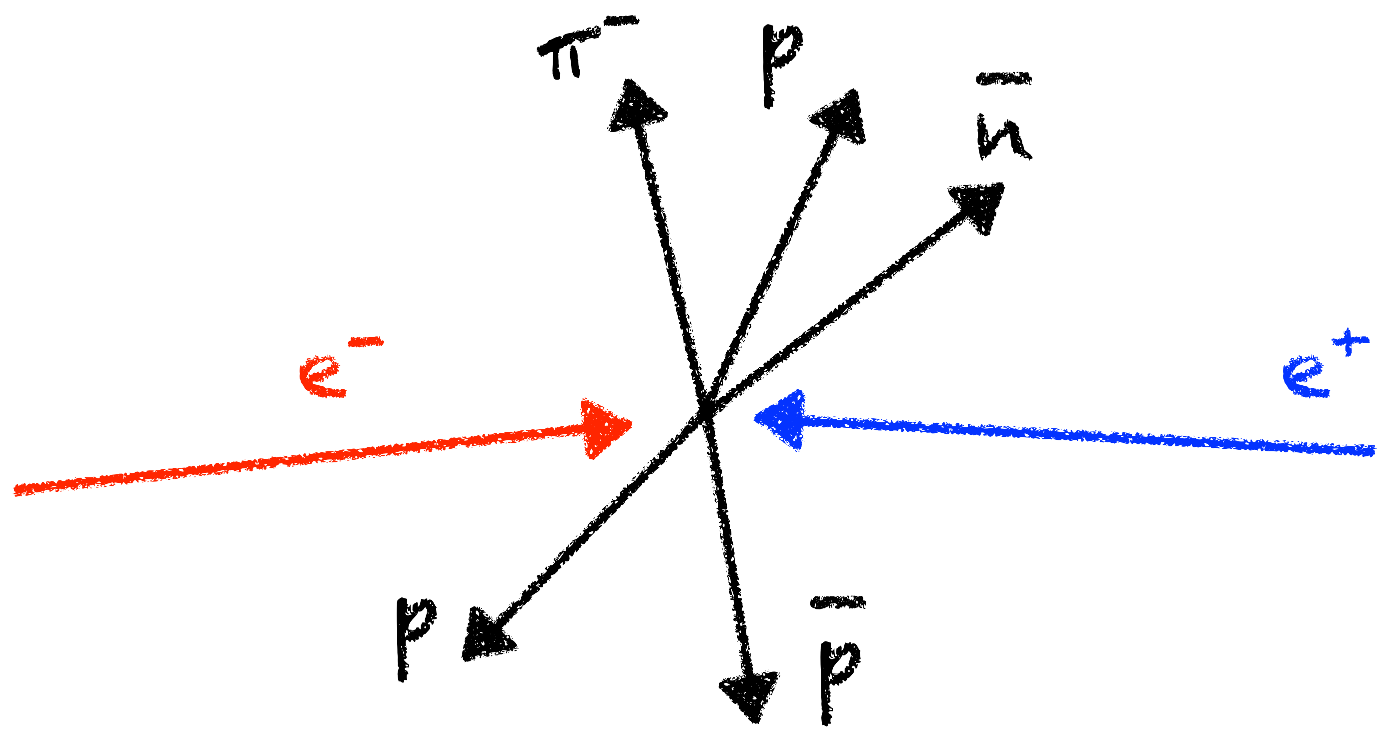

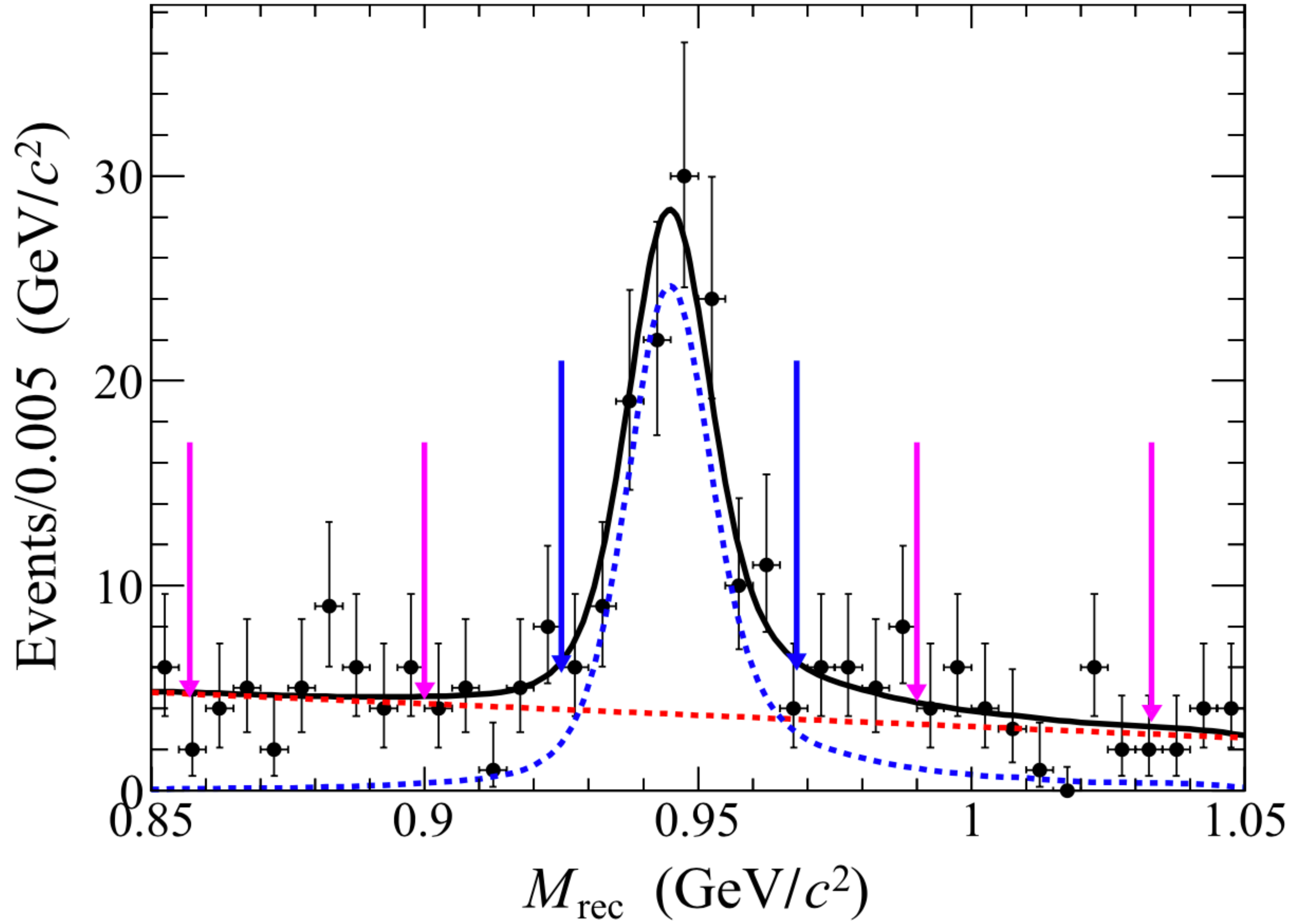

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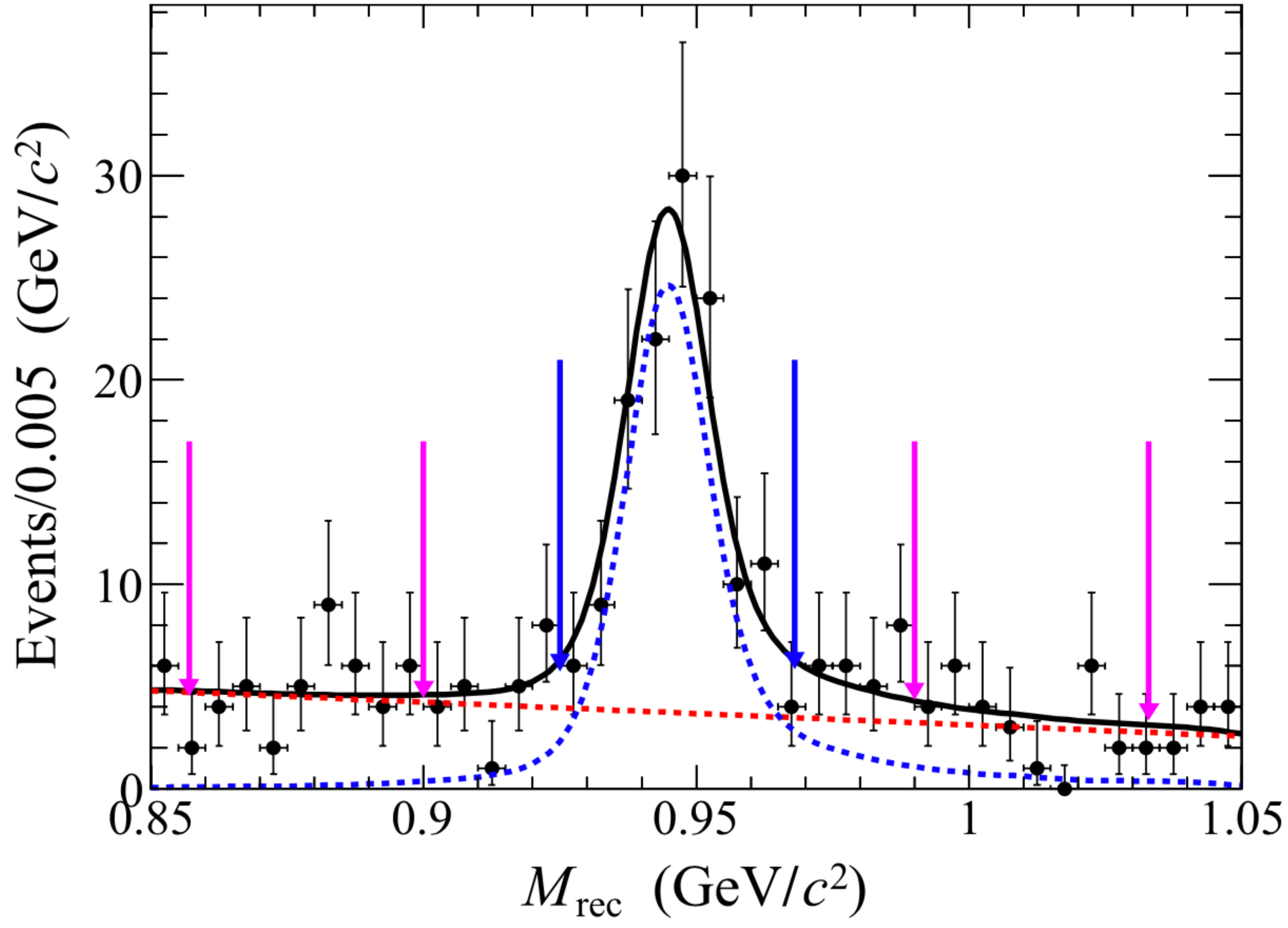
Due to the **limited statistics**, the cross-section is measured in **three energy bins** (4.160, 4.380), (4.400, 4.600), and (4.610, 4.700) GeV

For each bin, the average Born cross-section is

$$< \sigma^{Born} >= \frac{N^{Sig}}{\sum_i \epsilon_i \mathcal{L}_i} \cdot \frac{|1-\Pi^2|}{(1+\delta)}$$



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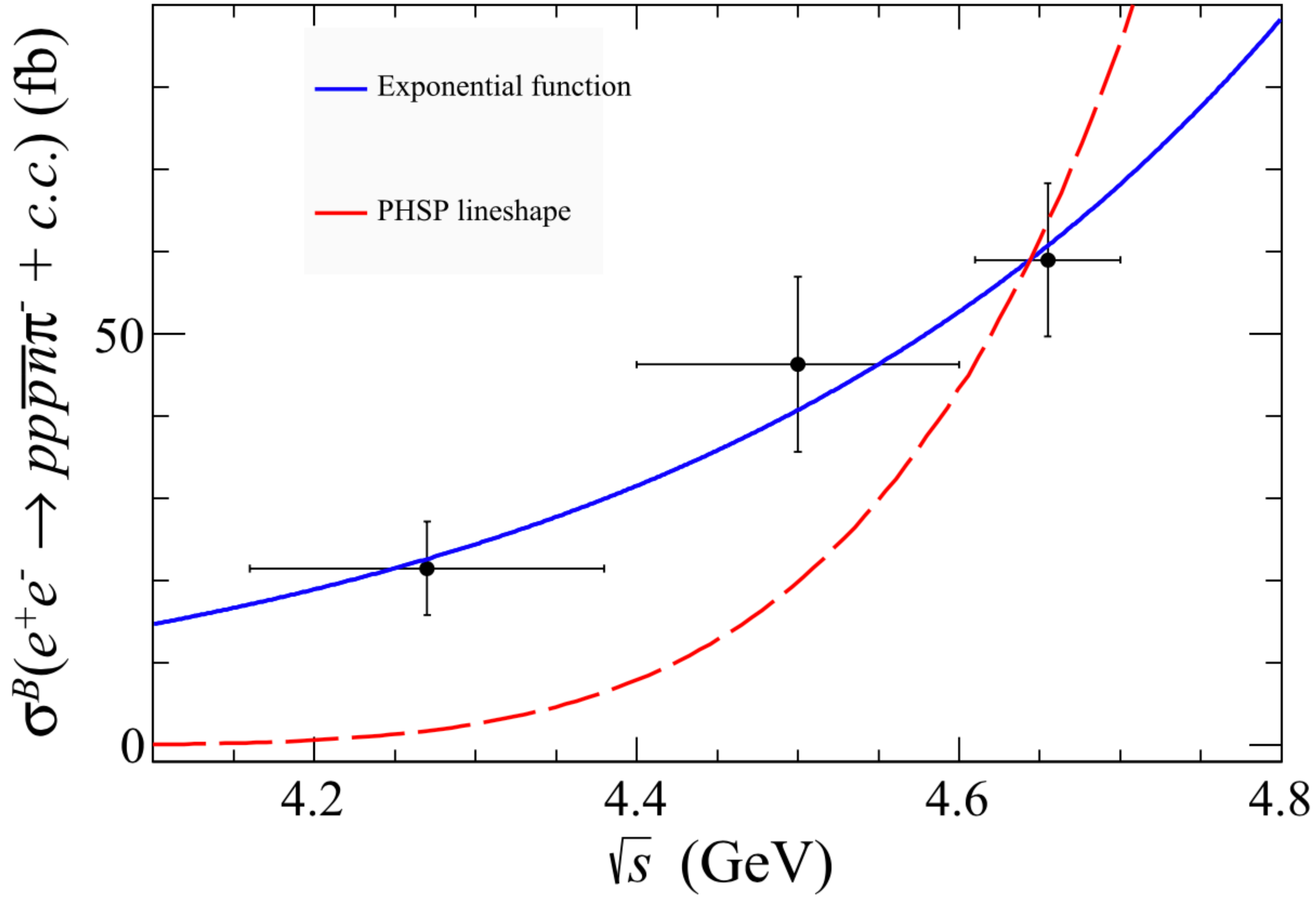


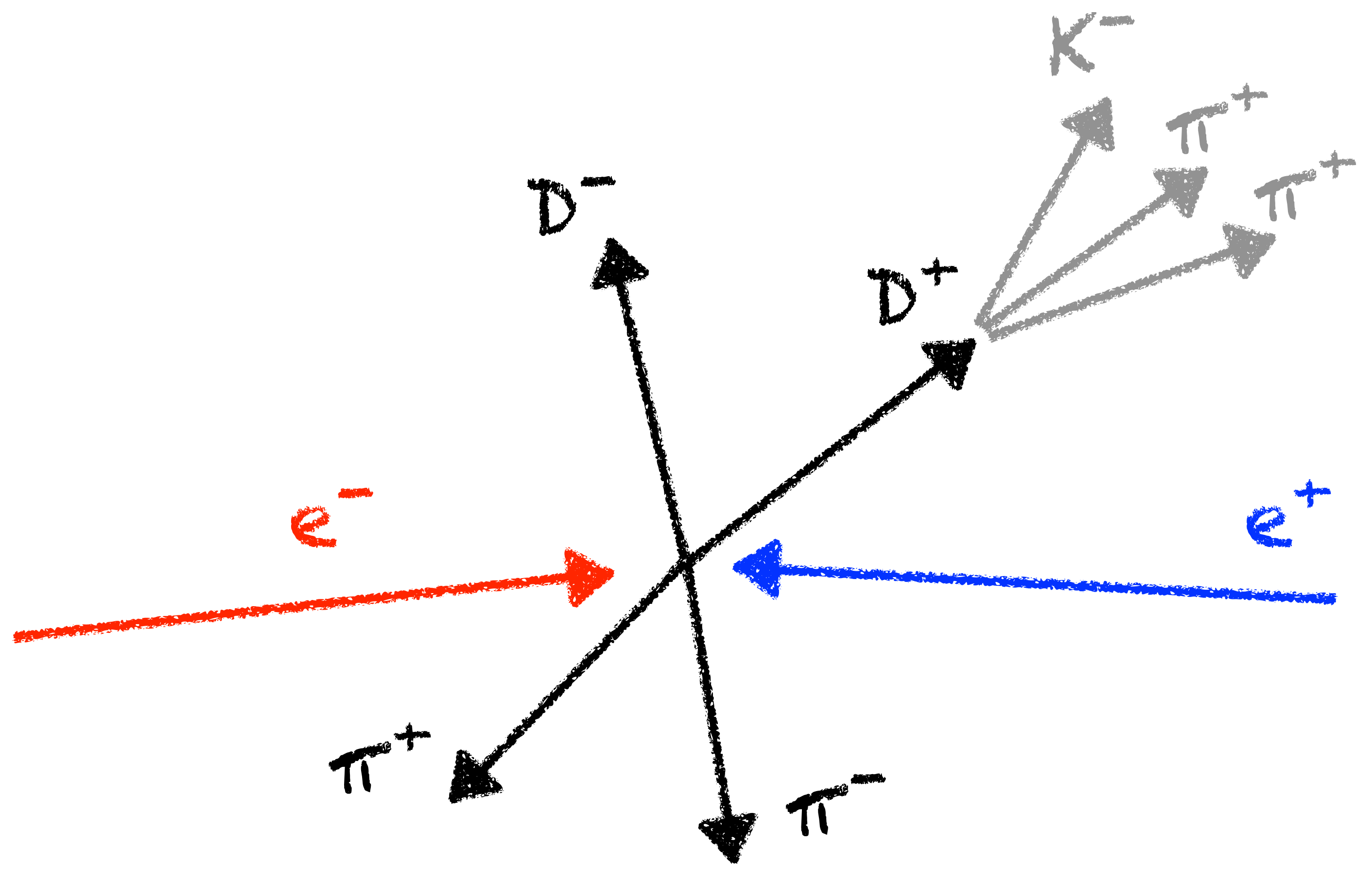
Charming Cross-Sections

PRD **106**, 072012 (2022)

Using 20 energy points @$\sqrt{s}$ = **[4.190, 4.946] GeV**

Study of the **$\sigma(e^+e^- \to \pi^+\pi^-D^+D^-)$**, reconstructing only the D^+ ($\to K^-\pi^+\pi^+$)

Fit to $M^{recoil}(D^+\pi^+\pi^-)$ to estimate σ^{Born}



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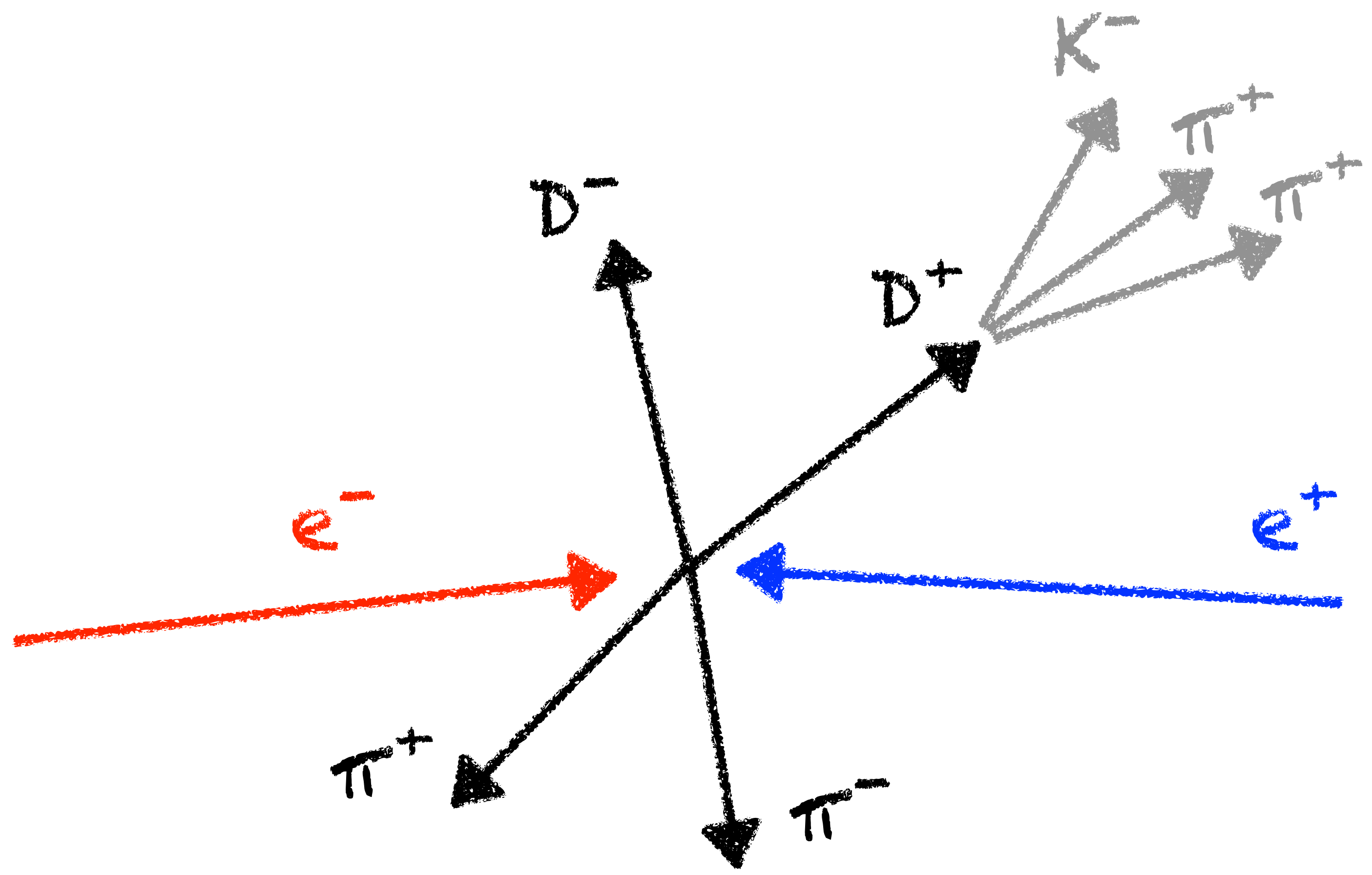

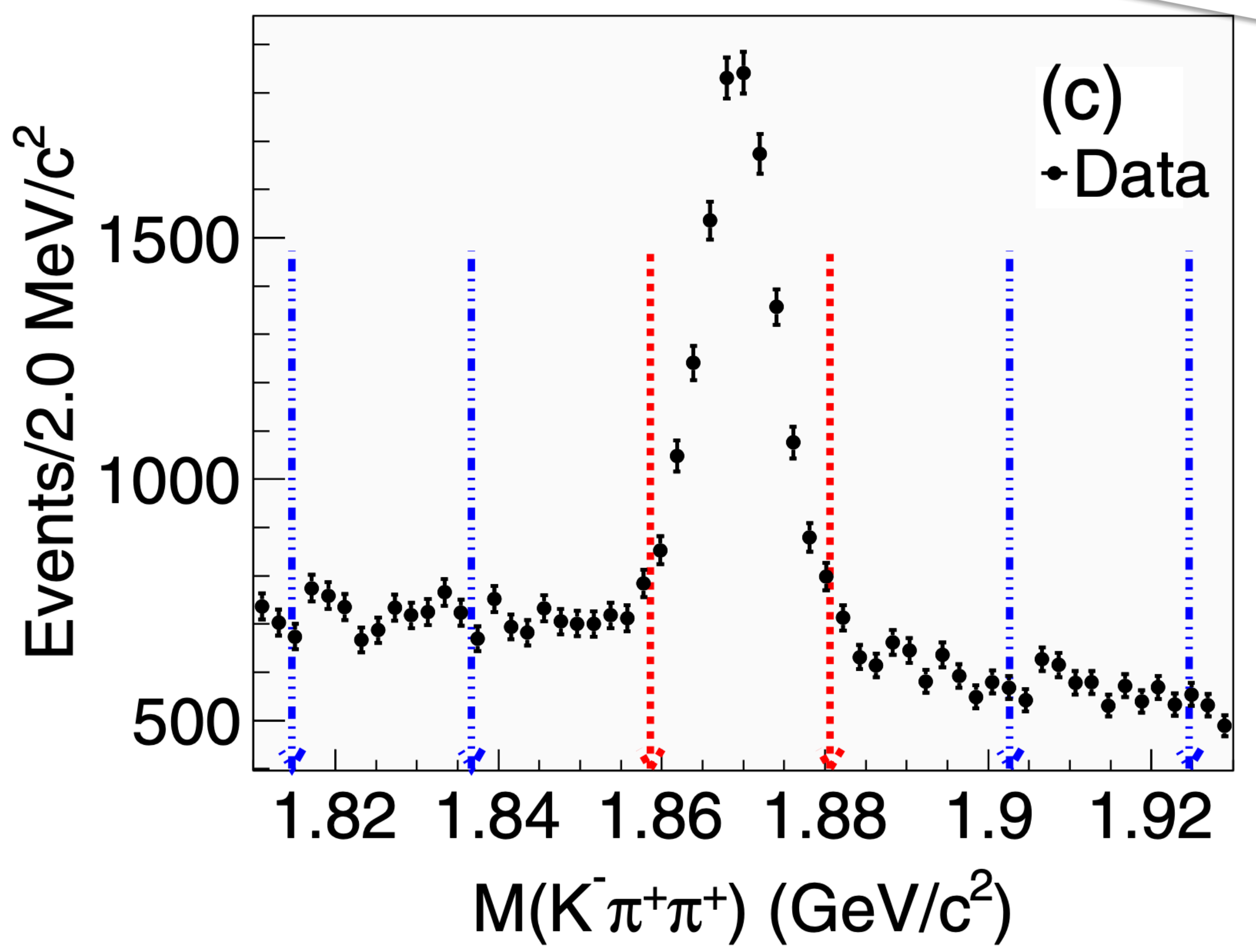

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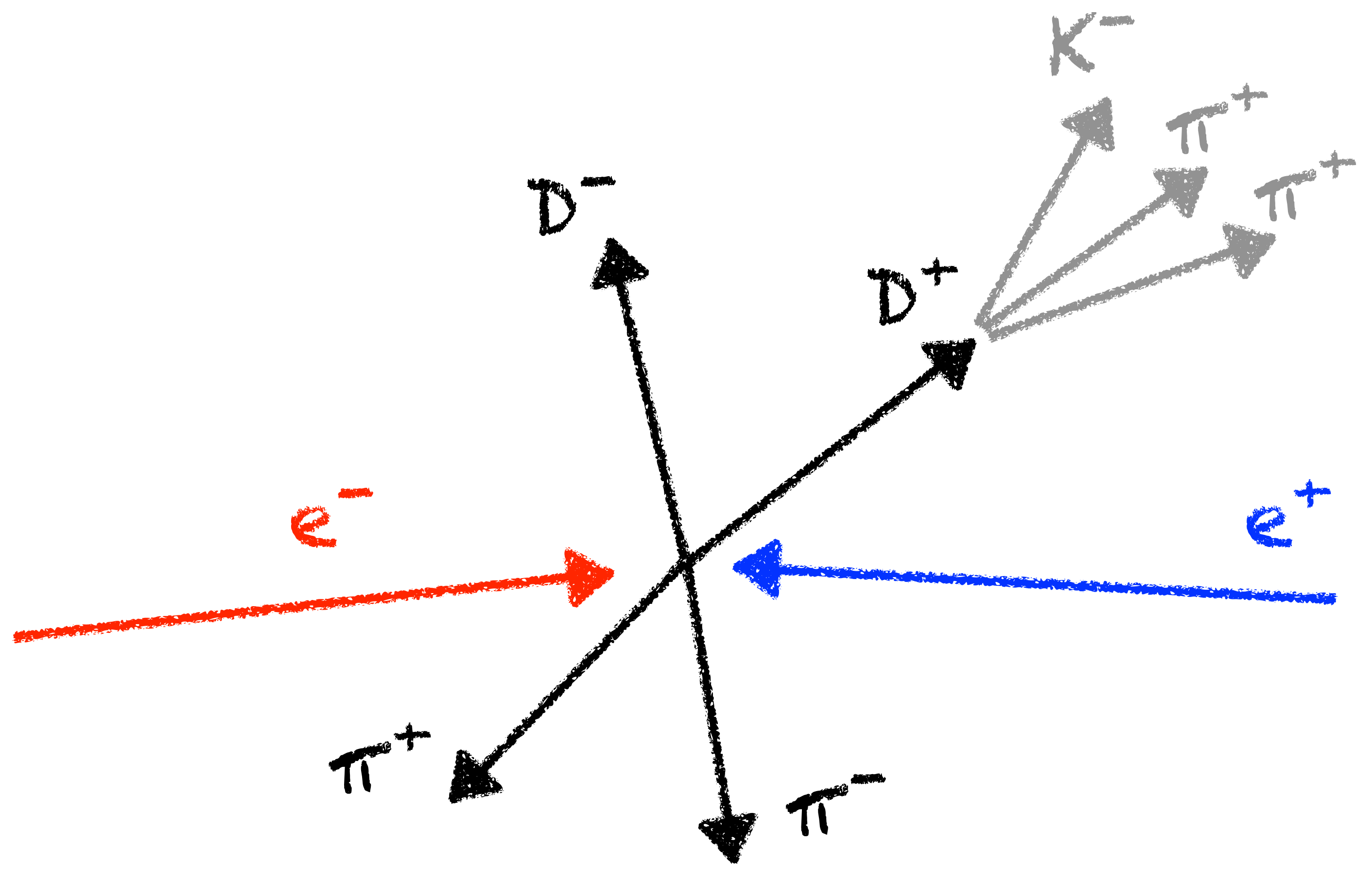

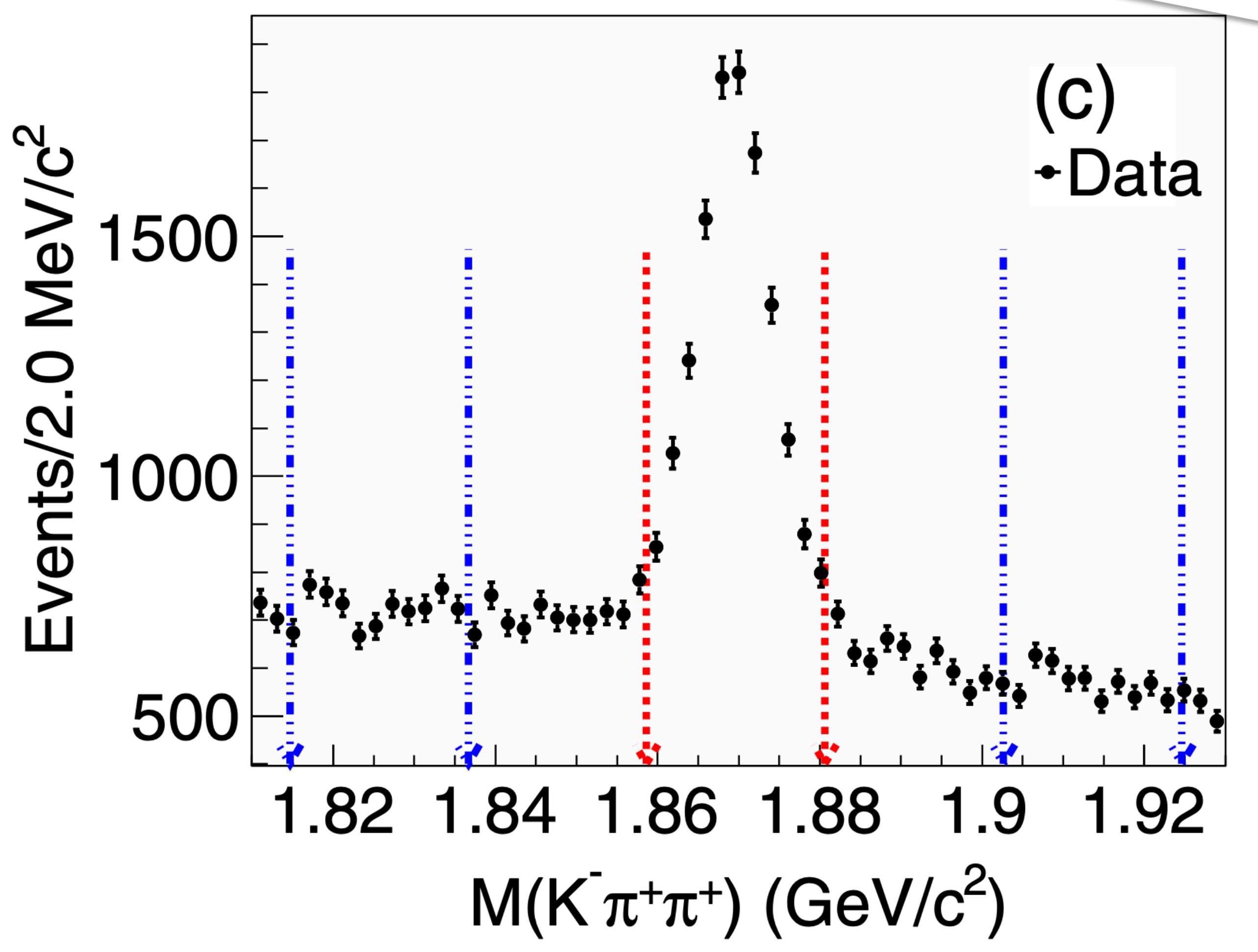

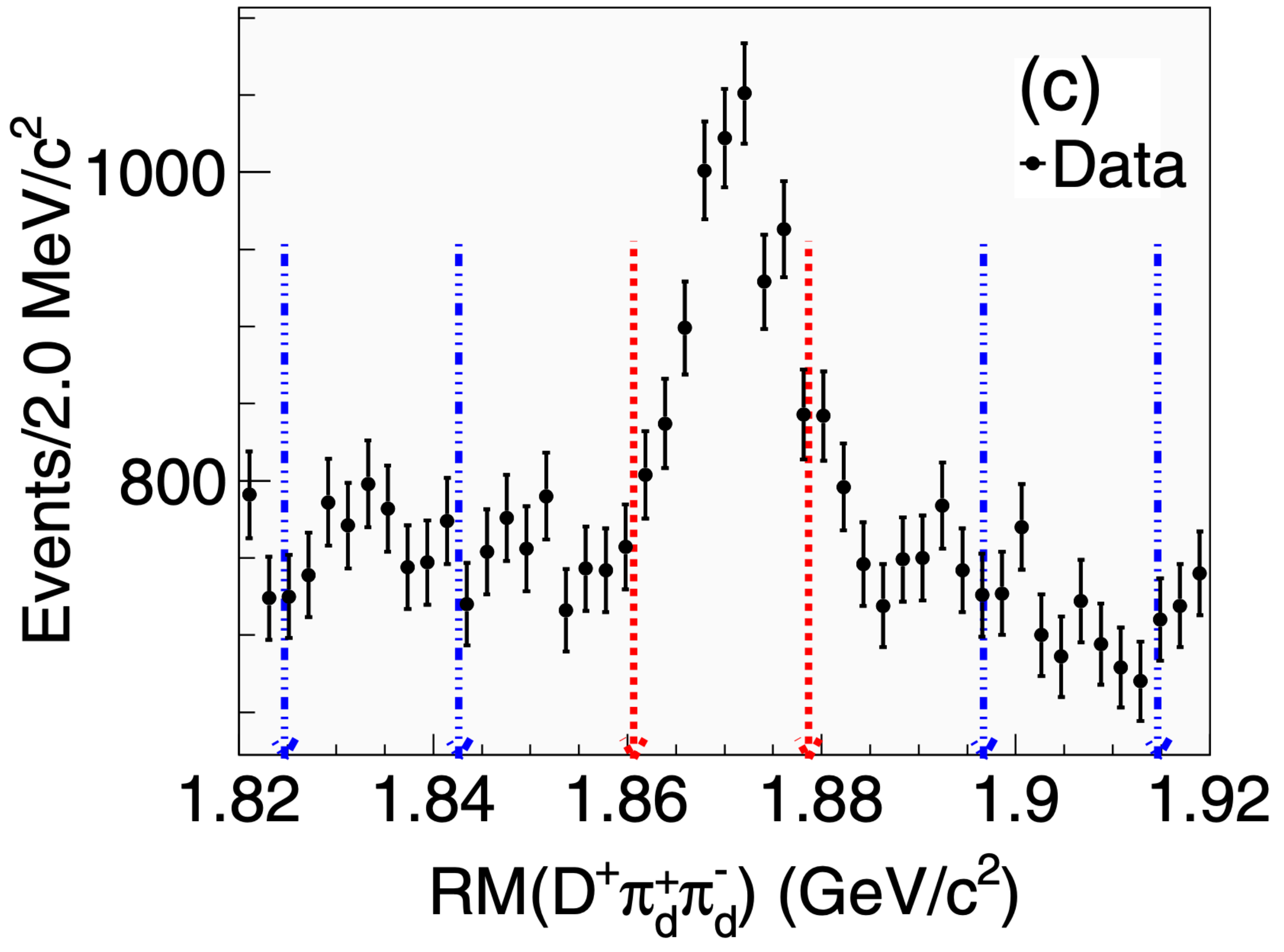

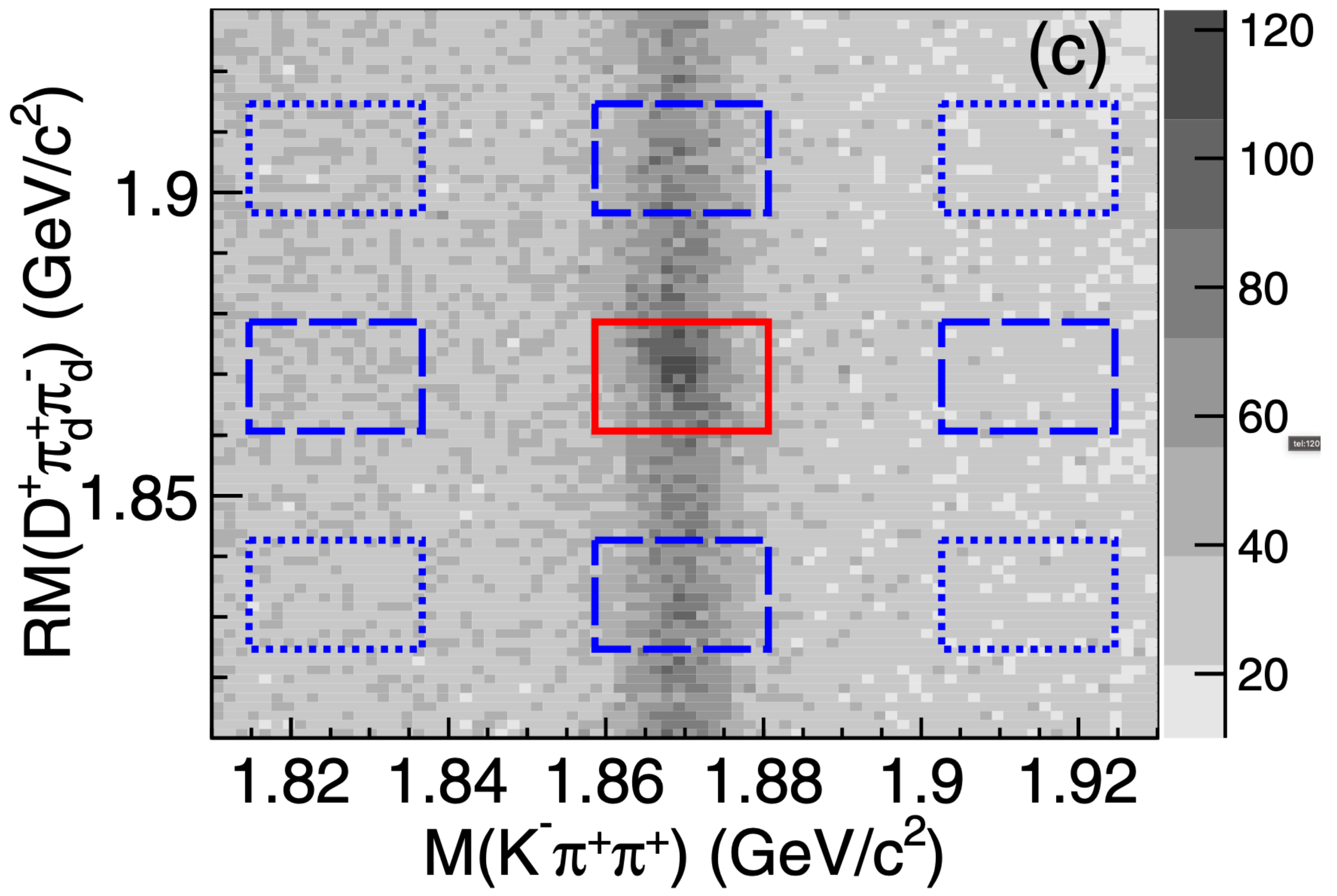

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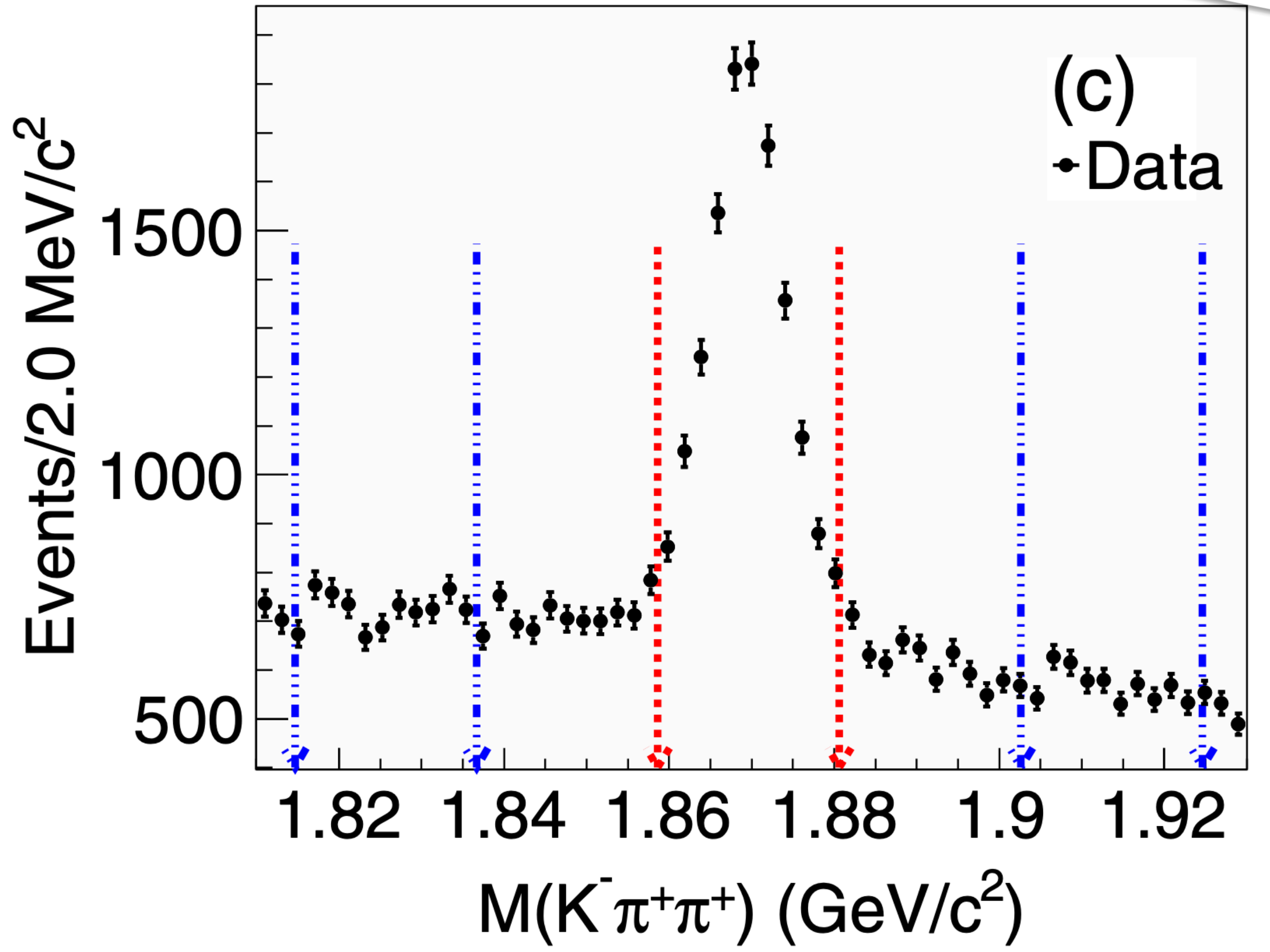
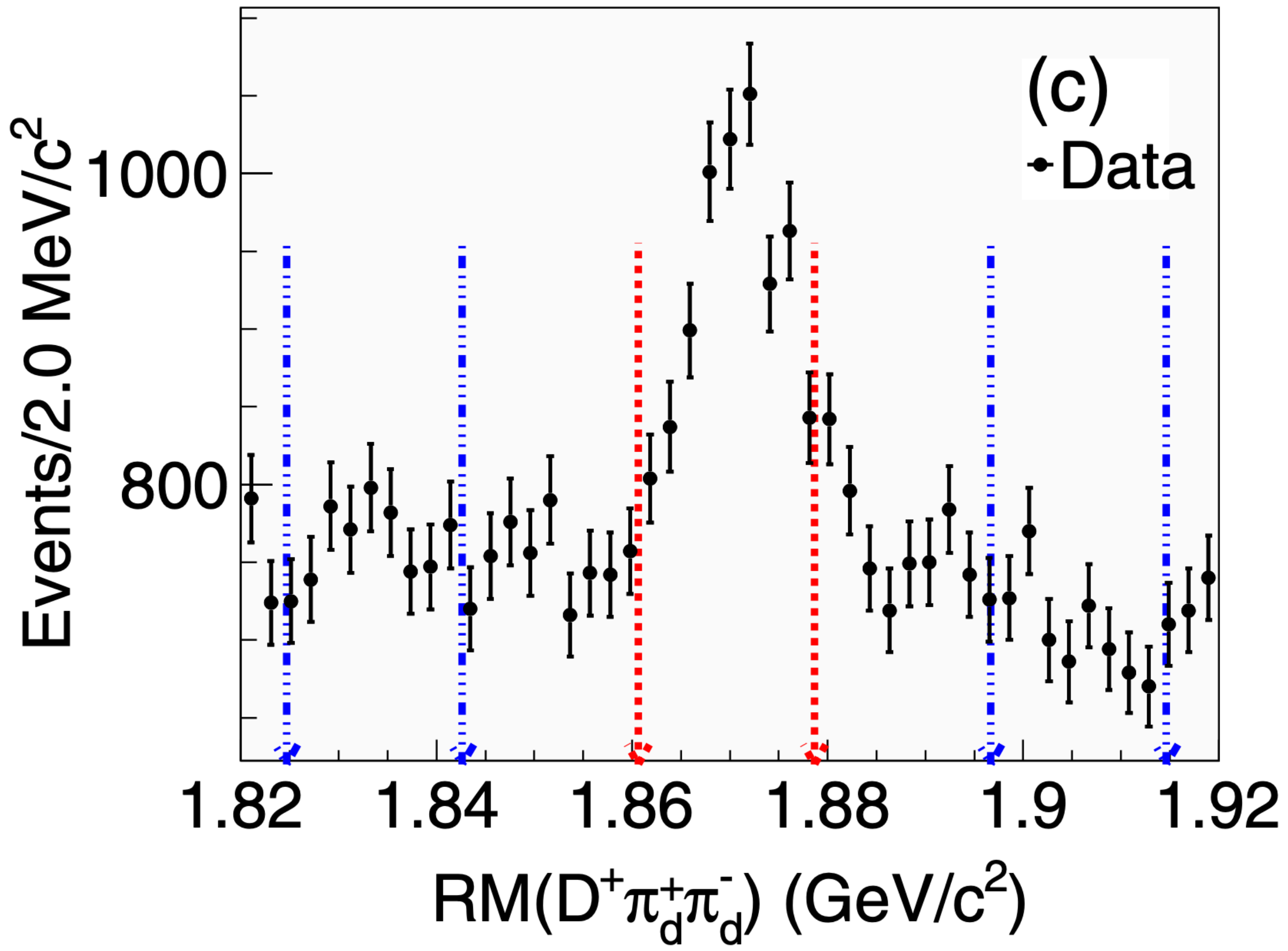
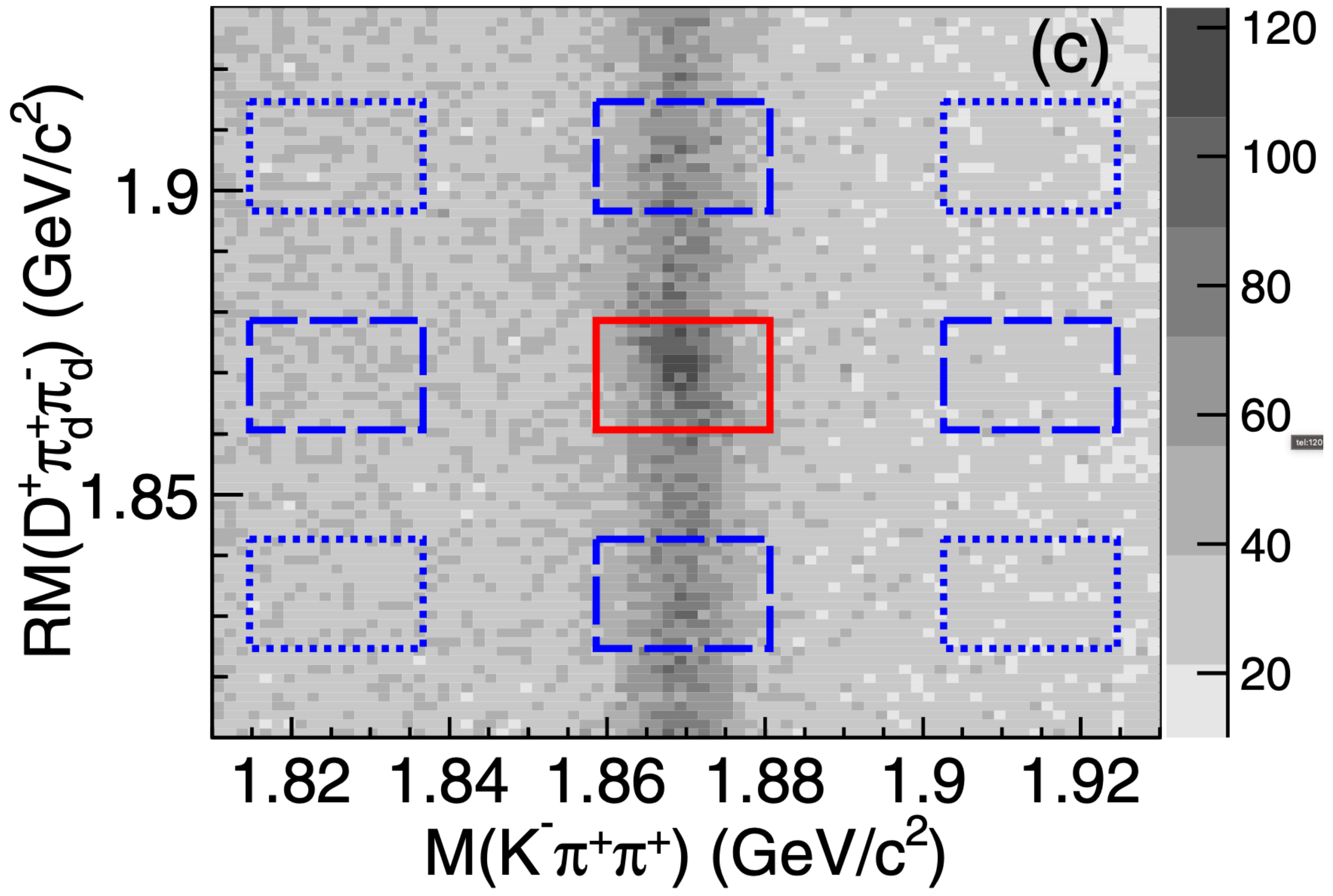
$$\sigma^{Born} = \frac{N^{Sig} - N^{Sideband}/2}{2f(\sum_i \omega_i \epsilon_i(1+\delta)_i)\frac{1}{|1-\Pi^2|}\mathcal{L}\mathcal{B}(D^+ \to K^+\pi^-\pi^-)}$$

Efficiency correction factor to account for any MC/data mismatch

Fraction and selection efficiency of $D_1(2420)^+ \to D^+\pi^+\pi^-$, $\psi(3770) \to D^+D^-$, and PHSP subprocesses







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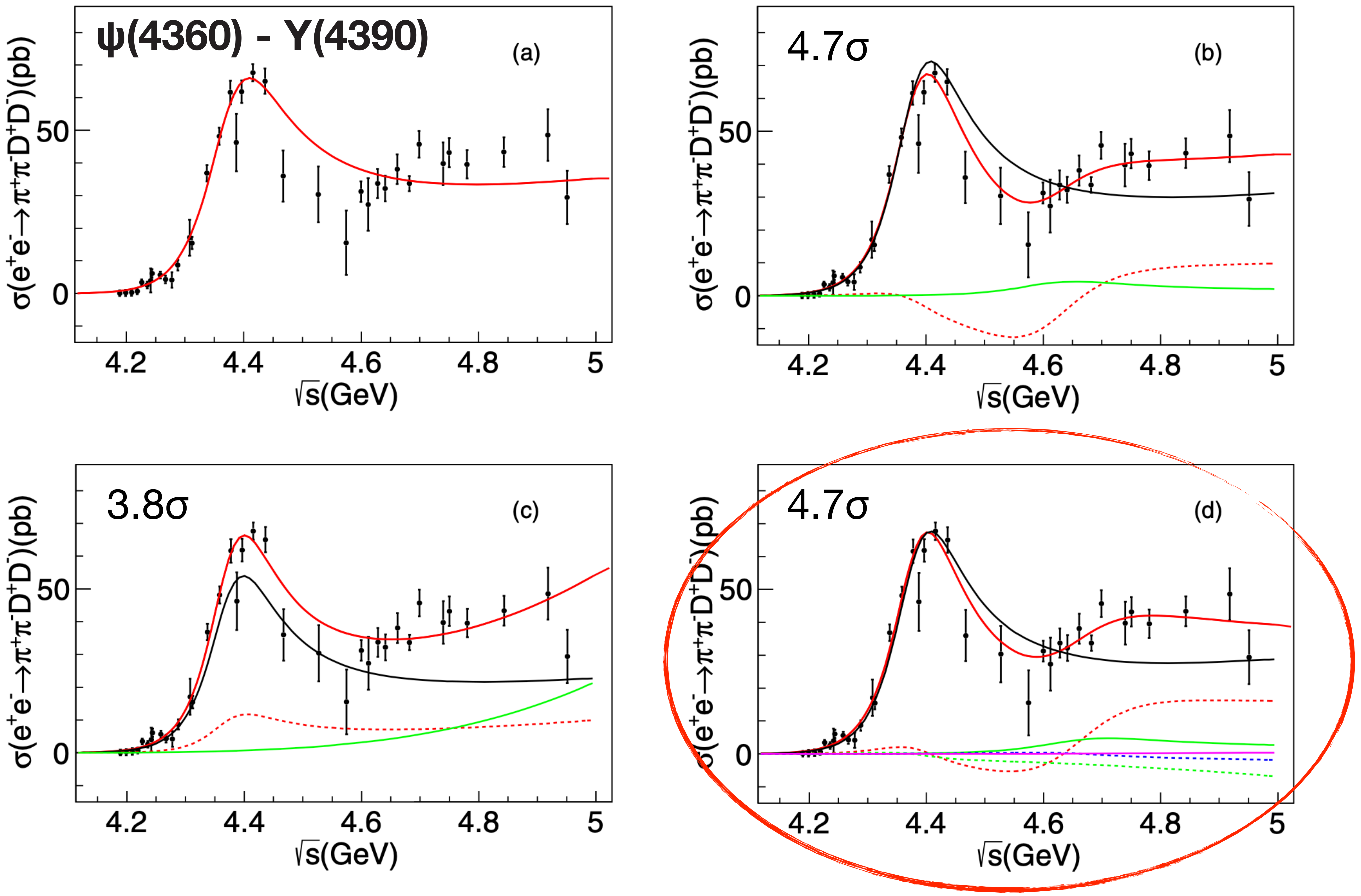
$\boldsymbol{\sigma}^{Born}$ is fitted following 4 hypothesis…

(a) One resonance

(b) Coherent sum of two resonances

(c) Coherent sum of a resonance and a PHSP term

(d) Coherent sum of two resonances and a PHSP term



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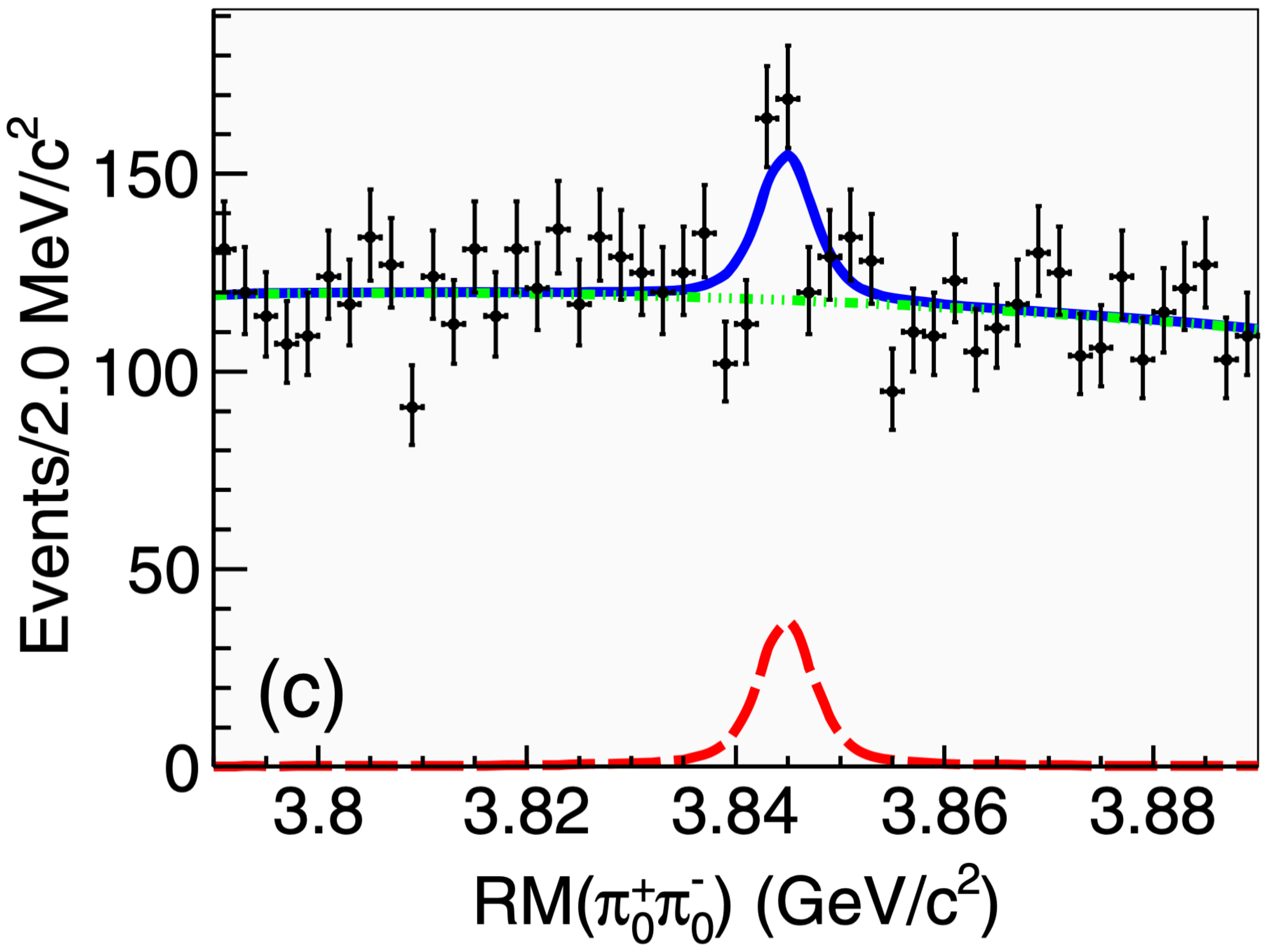
BONUS!
Evidence for the $\psi_3(1^3D_3)$ candidate in the $X(3842) \to D^+D^-$ process

Unlike its spin-partners ($\psi(3770)$ and $\psi_2(3823)$), the X(3842) production does not peak @$\sqrt{s}$ < 4.4 GeV



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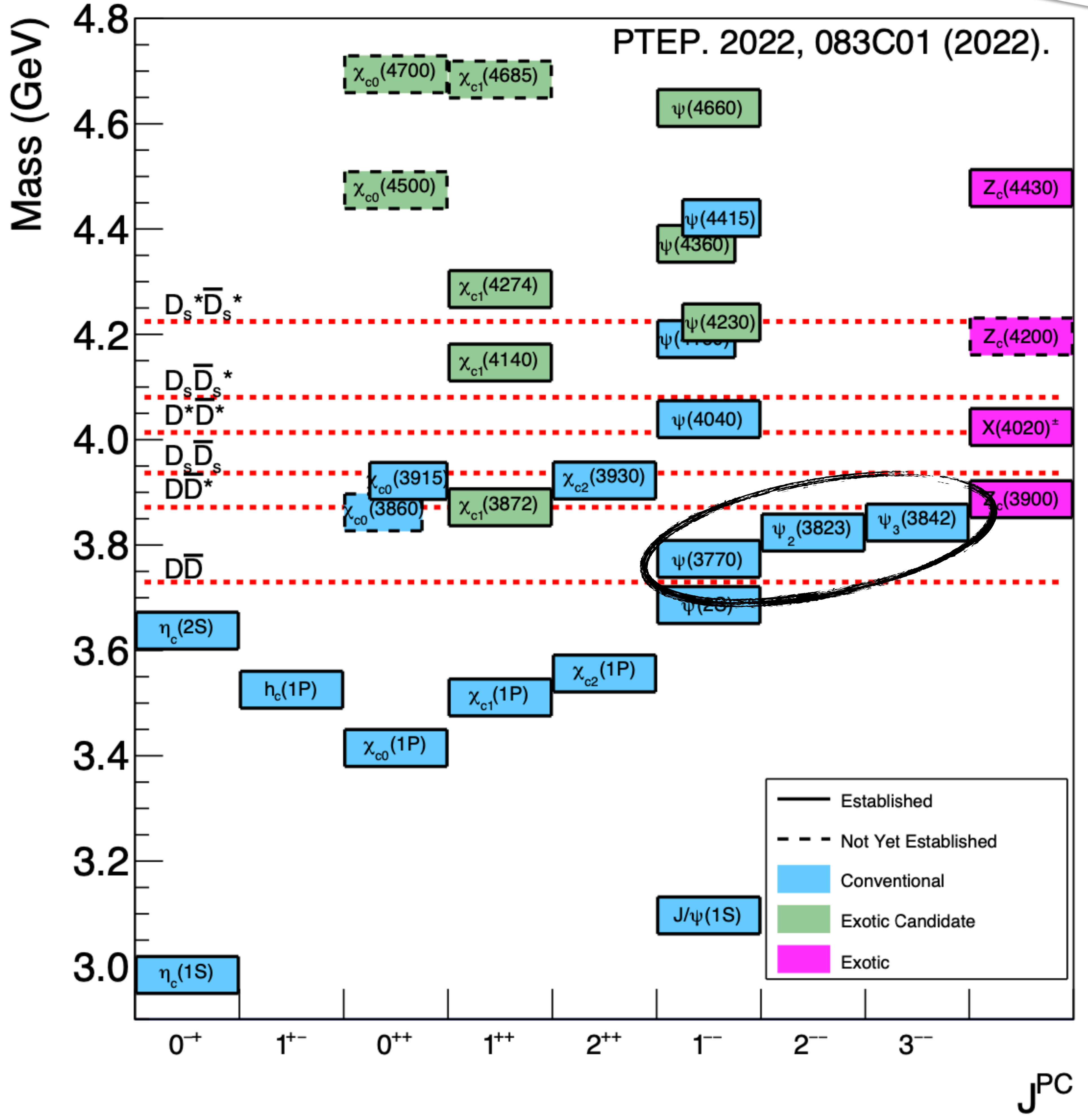


Charming Cross-Sections

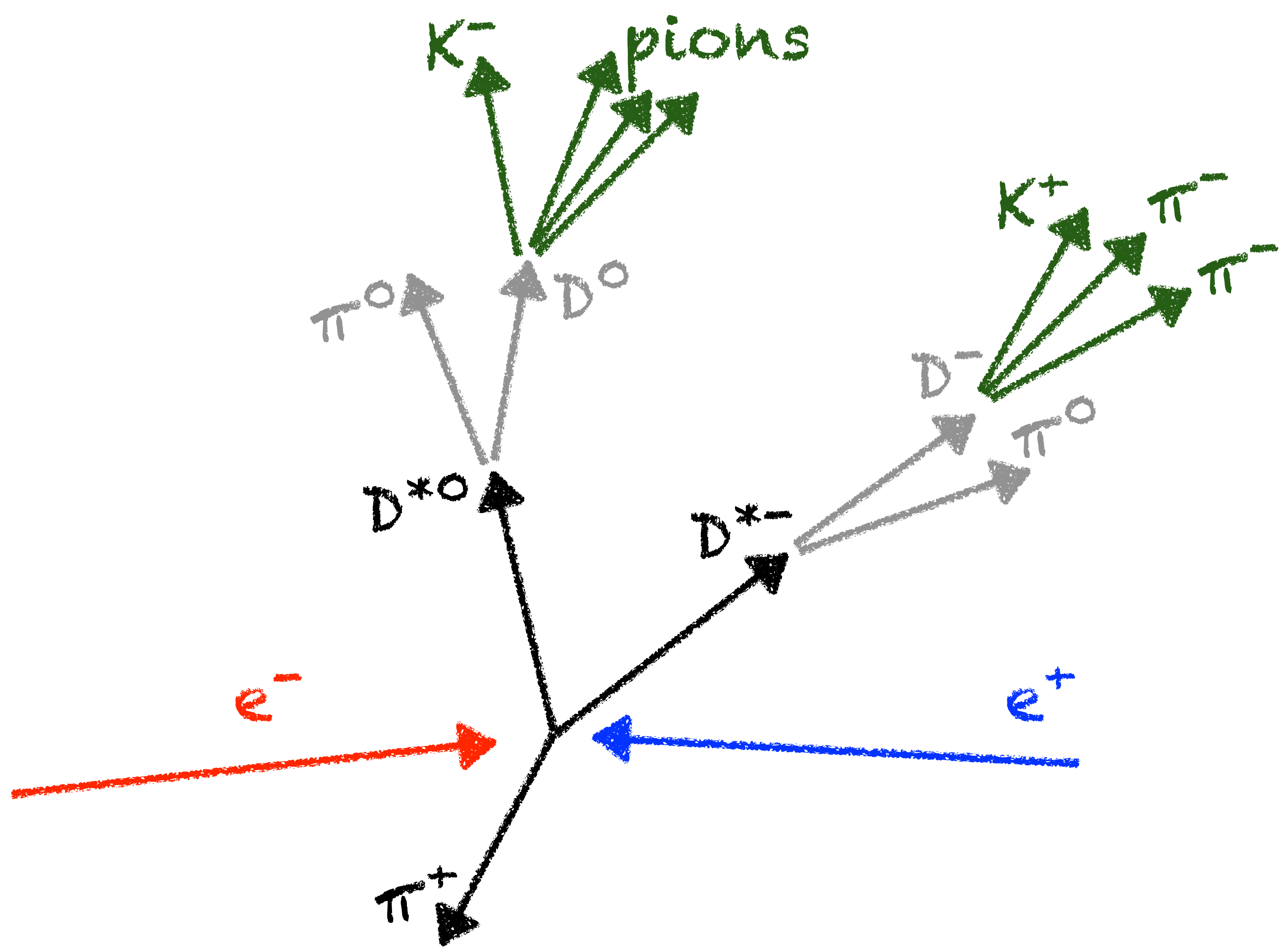
Excited Ones!

Phys. Rev. Lett. **130**, 121901 (2023)

Using 20 energy points @$\sqrt{s}$ = **[4.19, 4.95] GeV** for a $\mathcal{L}_{int}$ = 17.9 fb^{-1}

Study of the **$\sigma(e^+e^- \to \pi^+ D^{*0} D^{*-})$**, either the **$D^{*0}$** ($\to D^0\pi^0$) or **$D^{*-}$** ($\to D^-\pi^0$) the are reconstructed

Simultaneous fit to $M^{recoil}(D^0\pi^+\pi^0)$ and $M^{recoil}(D^-\pi^+\pi^0)$ to estimate σ^{Born}



Charming Cross-Sections

Excited Ones!

Phys. Rev. Lett. **130**, 121901 (2023)

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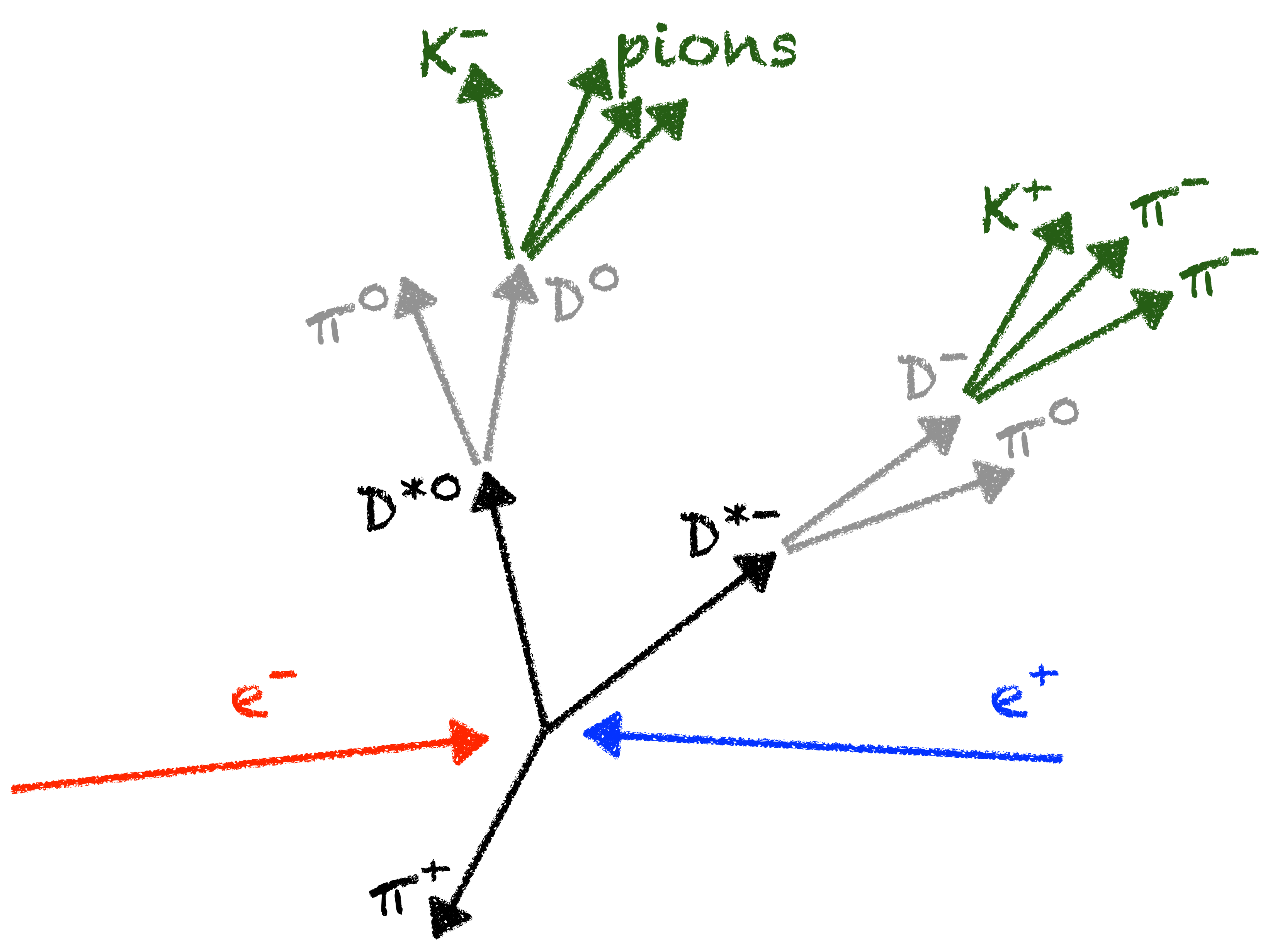
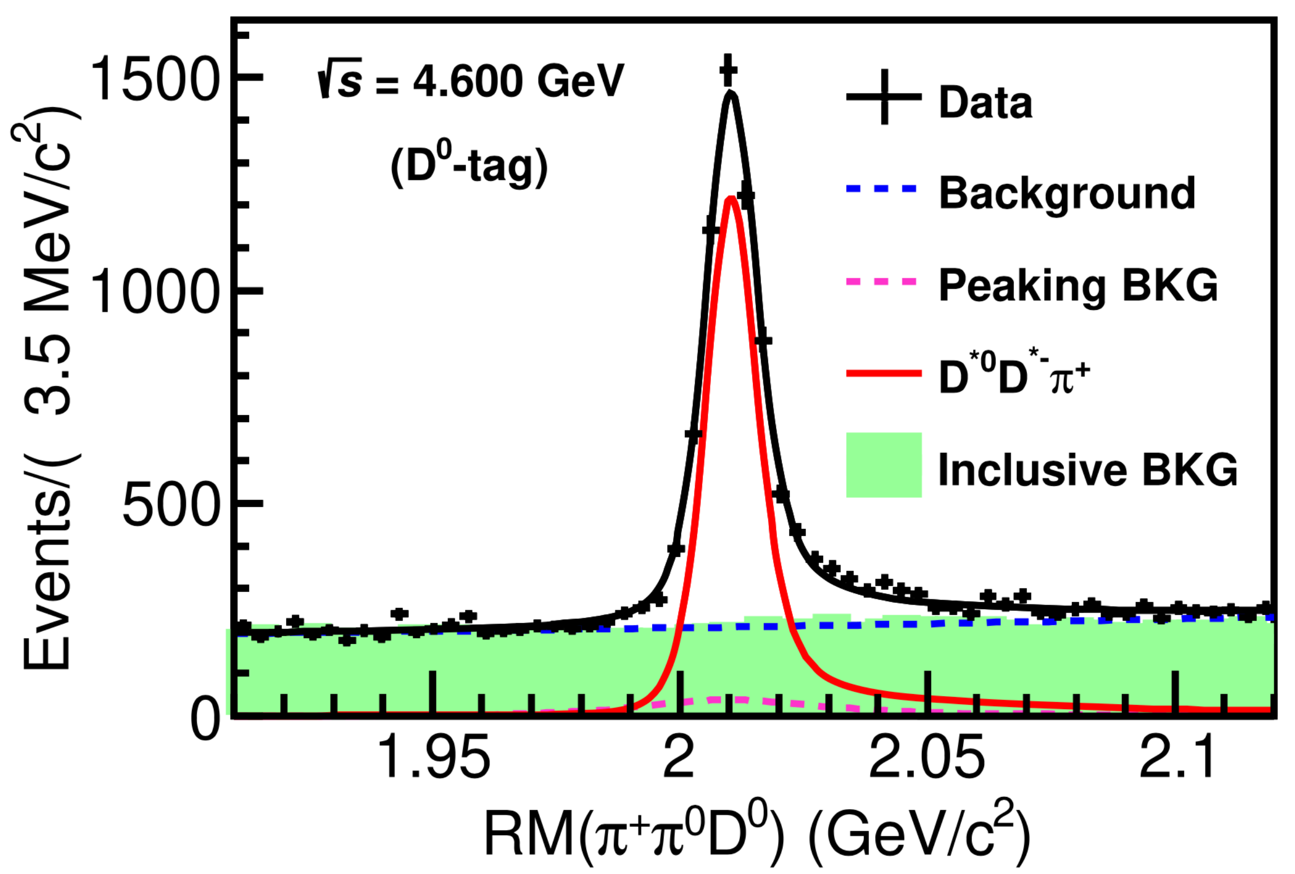
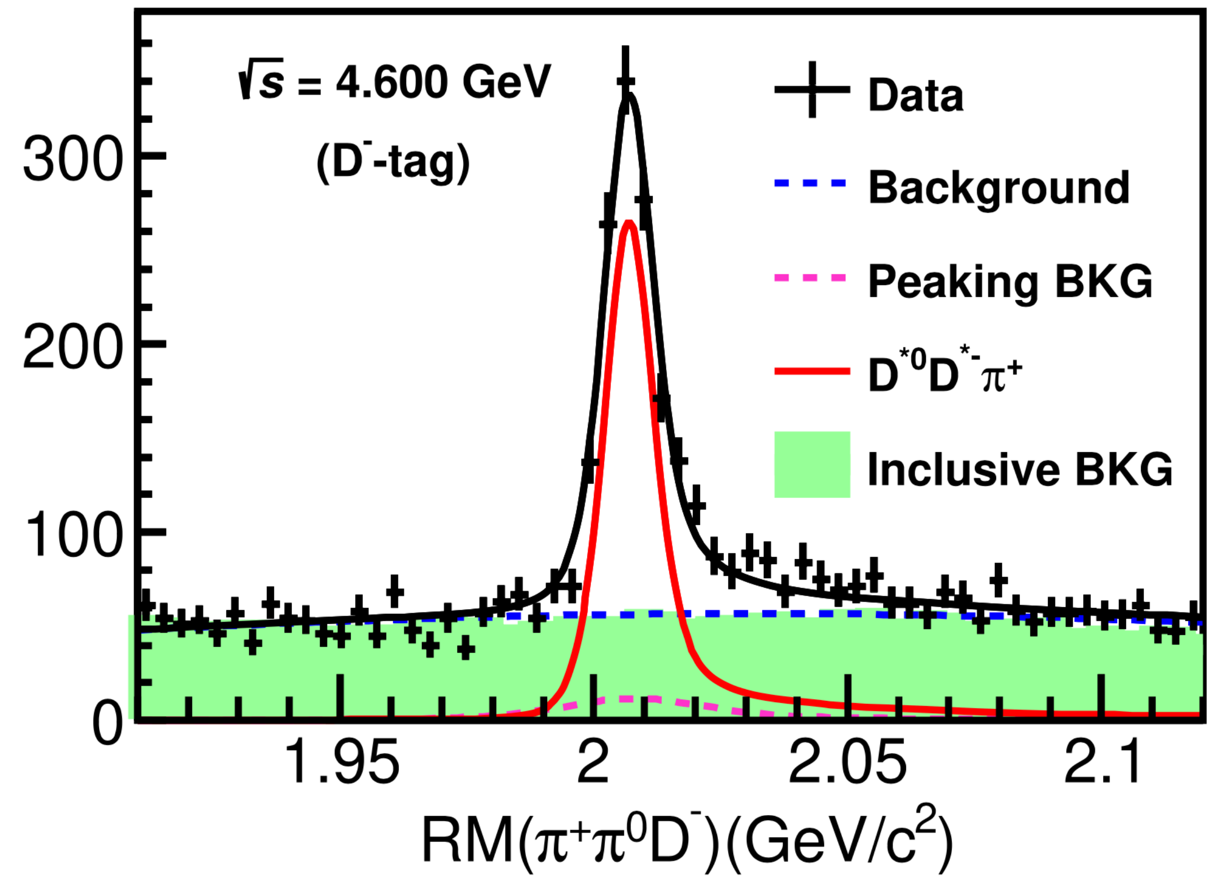
Study of the $\boldsymbol{\sigma(e^+e^- \rightarrow \pi^+ D^{*0} D^{*-})}$, either the $\mathbf{D^{*0}}$ ($\rightarrow D^0\pi^0$) or $\mathbf{D^{*-}}$ ($\rightarrow D^-\pi^0$) the are reconstructed

Simultaneous fit to $M^{recoil}(\pi^+D^0\pi^0)$ and $M^{recoil}(\pi^+D^-\pi^0)$ to estimate $\boldsymbol{\sigma}^{Born}$







Charming Cross-Sections

Excited Ones!

Phys. Rev. Lett. **130**, 121901 (2023)

Using 86 energy points @$\sqrt{s}$ = **[4.19, 4.95] GeV** for a $\mathcal{L}_{int}$ = 17.9 fb^{-1}

Study of the **$\sigma(e^+e^- \to \pi^+ D^{*0} D^{*-})$**, either the **$D^{*0}$** ($\to D^0\pi^0$) or **$D^{*-}$** ($\to D^-\pi^0$) the are reconstructed

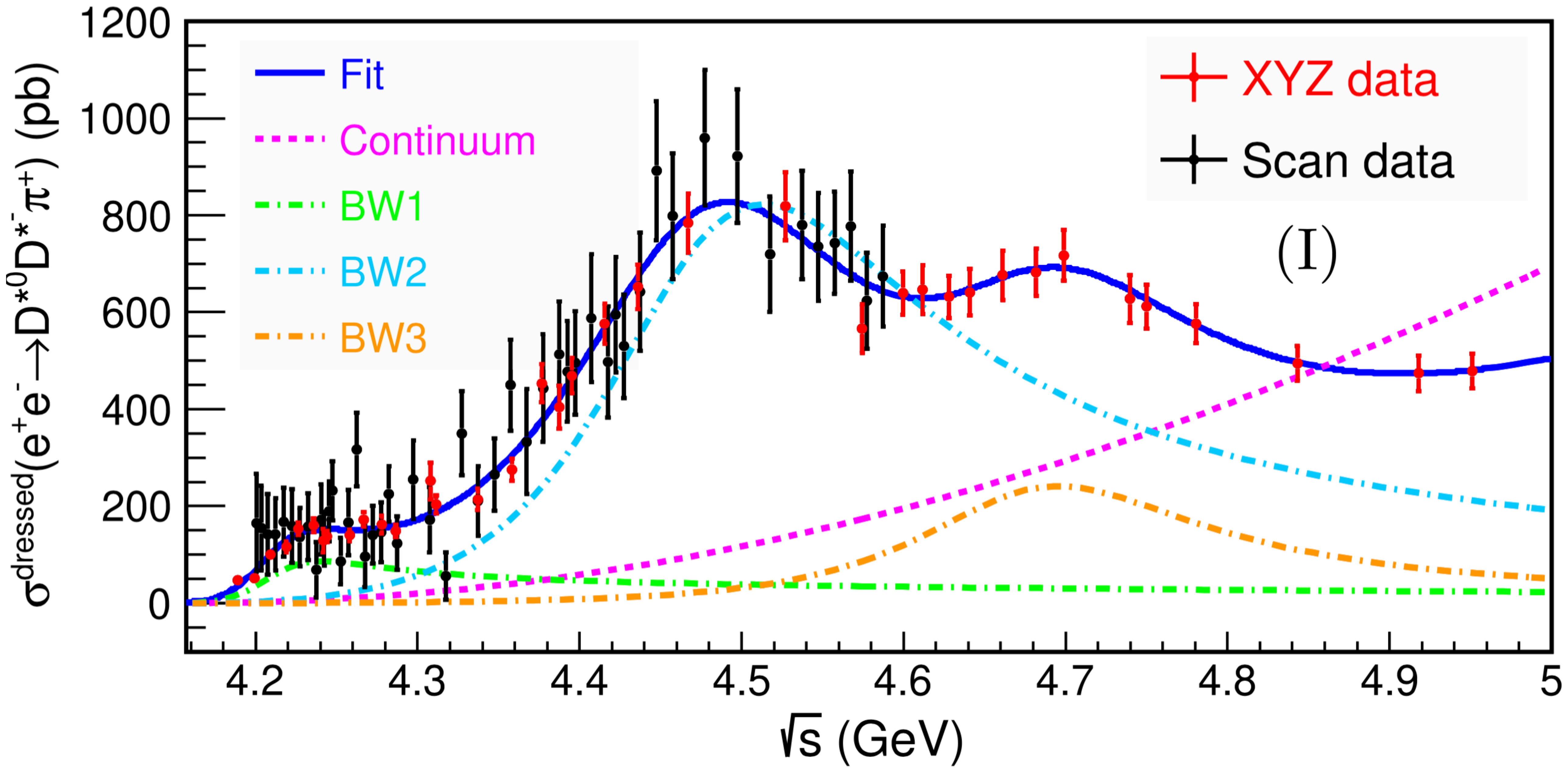
Simultaneous fit to $M^{recoil}(\pi^+ D^0 \pi^0)$ and $M^{recoil}(\pi^+ D^- \pi^0)$ to estimate **$\sigma^{Dressed}$**

$\sigma^{Dressed}$ is fitted with a coherent sum of three resonances and a PHSP term…

1) Y(4230), its electronic width measurement disfavours hybrid interpretation[9]

2) Y(4500), the $\mathcal{B}(\psi \to \pi^+ D^{*0} D^{*-}) > \mathcal{B}(\psi \to K^+K^- J/\psi)$ is inconsistent with a hidden-strangeness tetraquark[10]

3) Y(4660), first time in open-charm meson states



[9] Chinese Phys. C **40** 081002

[10] Phys. Rev. D **73**, 094510 (2006)

Charming Cross-Sections

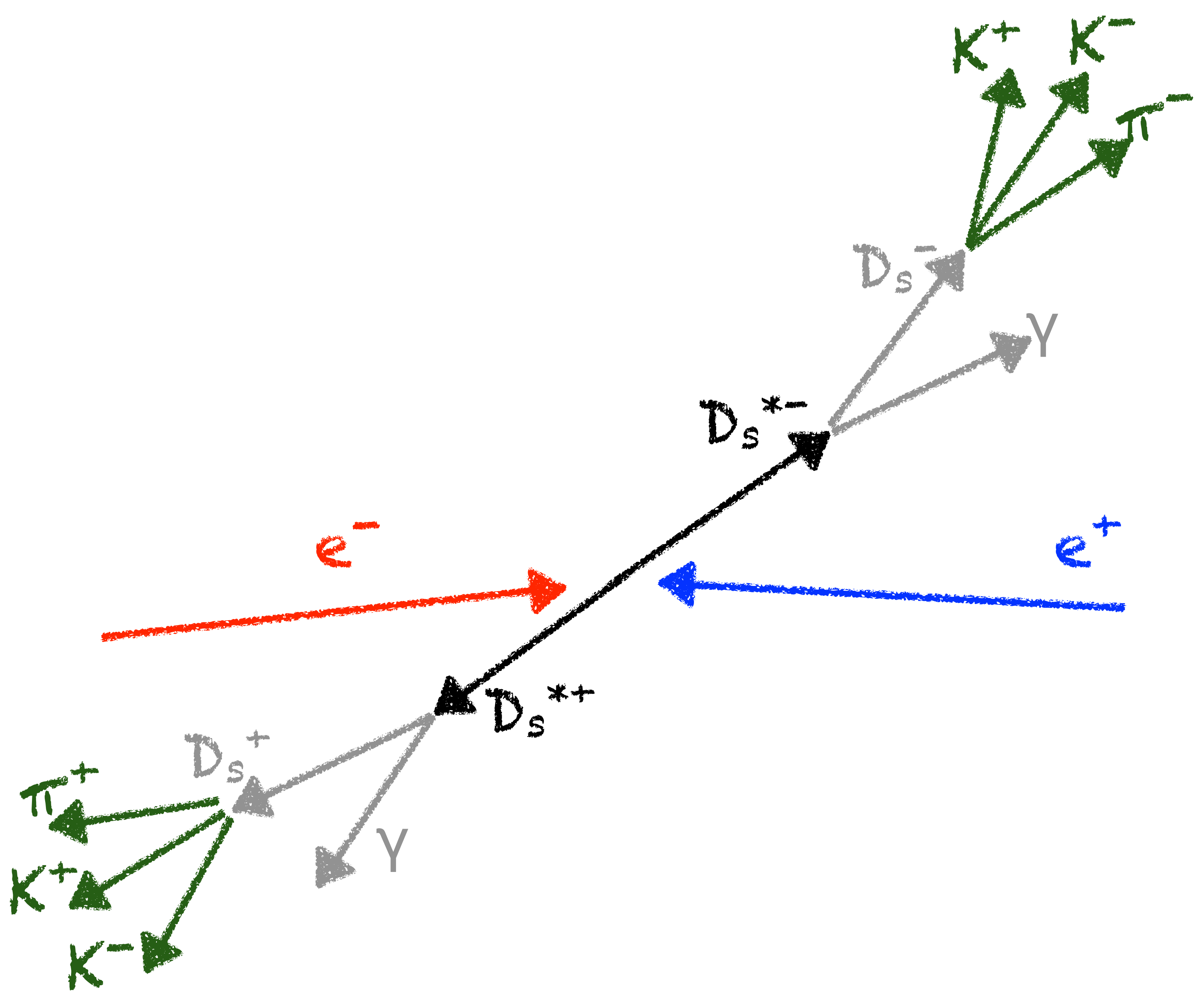
Strange!

arXiv:2305.10789
Submitted to PRL

Using 20 energy points @$\sqrt{s}$ = **[4.23, 4.95] GeV**

Study of the $\boldsymbol{\sigma}(e^+e^- \to \mathbf{D_s^{*+}D_s^{*-}})$ semi-inclusively, either the $\mathbf{D_s^{*+}}$ ($\to \gamma K^+K^-\pi^+$) or $\mathbf{D_s^{*-}}$($\to \gamma K^+K^-\pi^-$) are reconstructed

Fit to M($\gamma K^+K^-\pi$) to estimate $\boldsymbol{\sigma}^{Born}$



Charming Cross-Sections

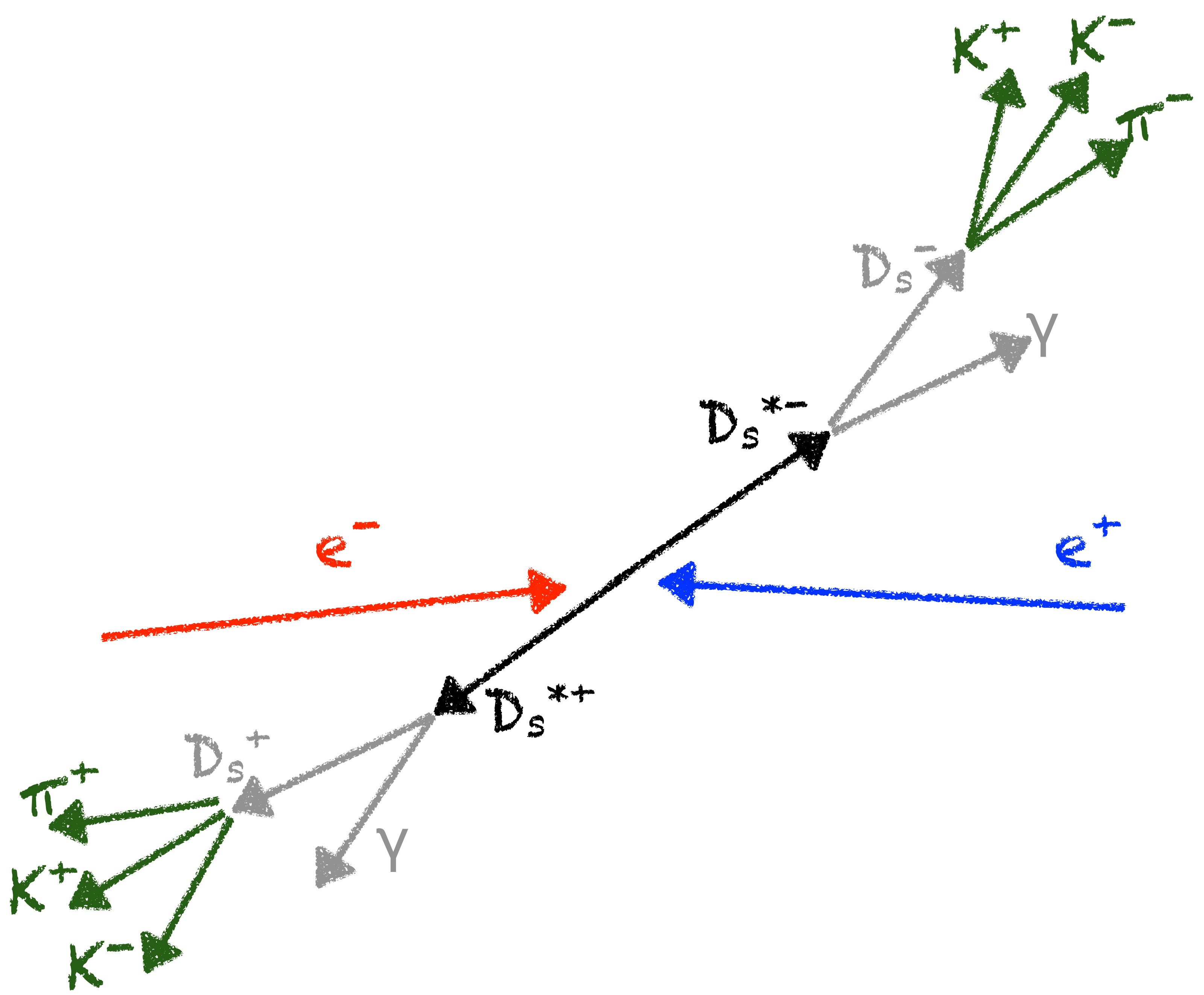
Strange!

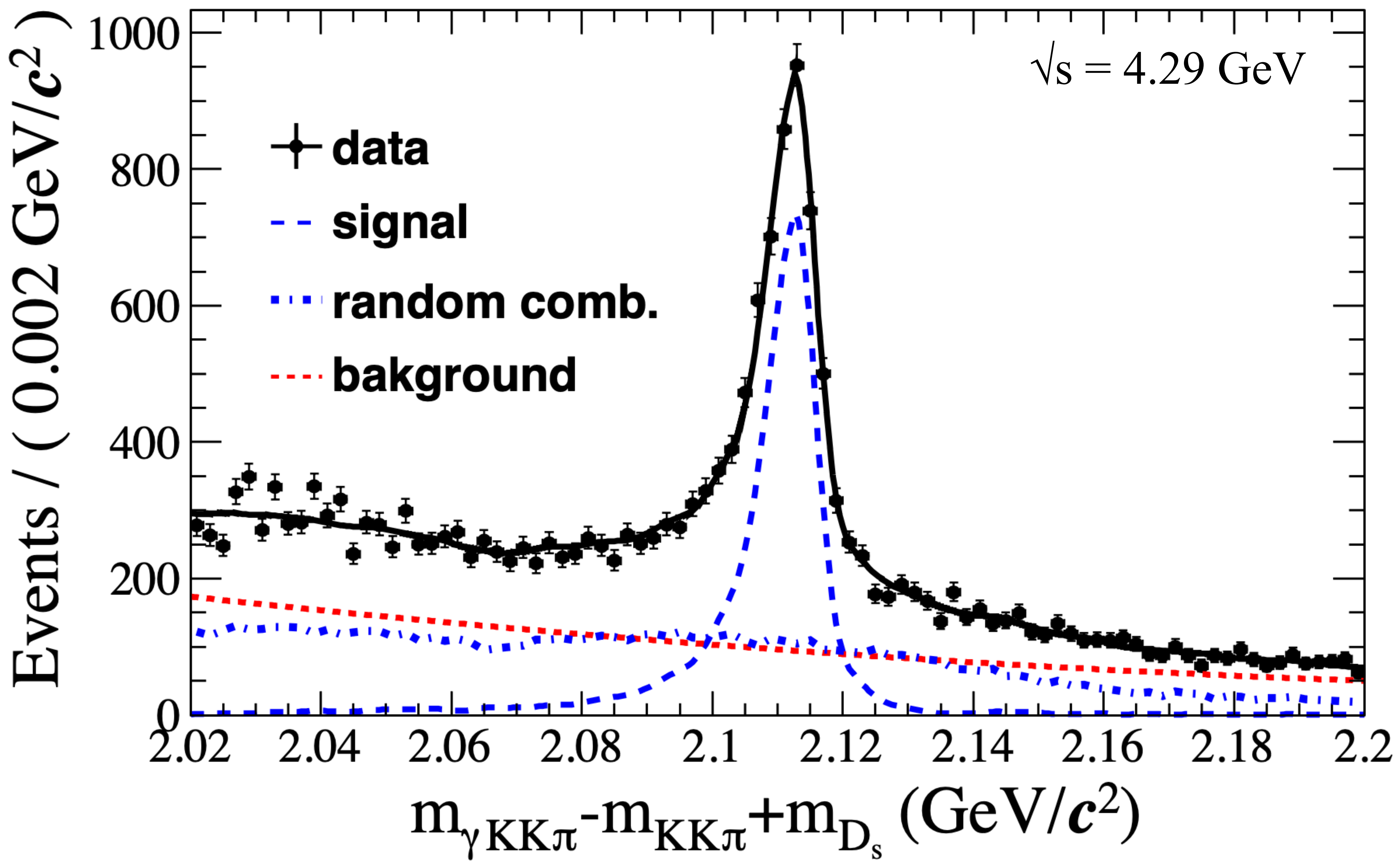
arXiv:2305.10789
Submitted to PRL

Using 20 energy points @$\sqrt{s}$ = **[4.23, 4.95] GeV**

Study of the $\boldsymbol{\sigma}(e^+e^- \to D_s^{*+}D_s^{*-})$ semi-inclusively, either the D_s^{*+} ($\to \gamma K^+K^-\pi^+$) or D_s^{*-}($\to \gamma K^+K^-\pi^-$) are reconstructed

Fit to M($\gamma K^+K^-\pi$) to estimate $\boldsymbol{\sigma}^{Born}$





Charming Cross-Sections

Strange!

arXiv:2305.10789
Submitted to PRL

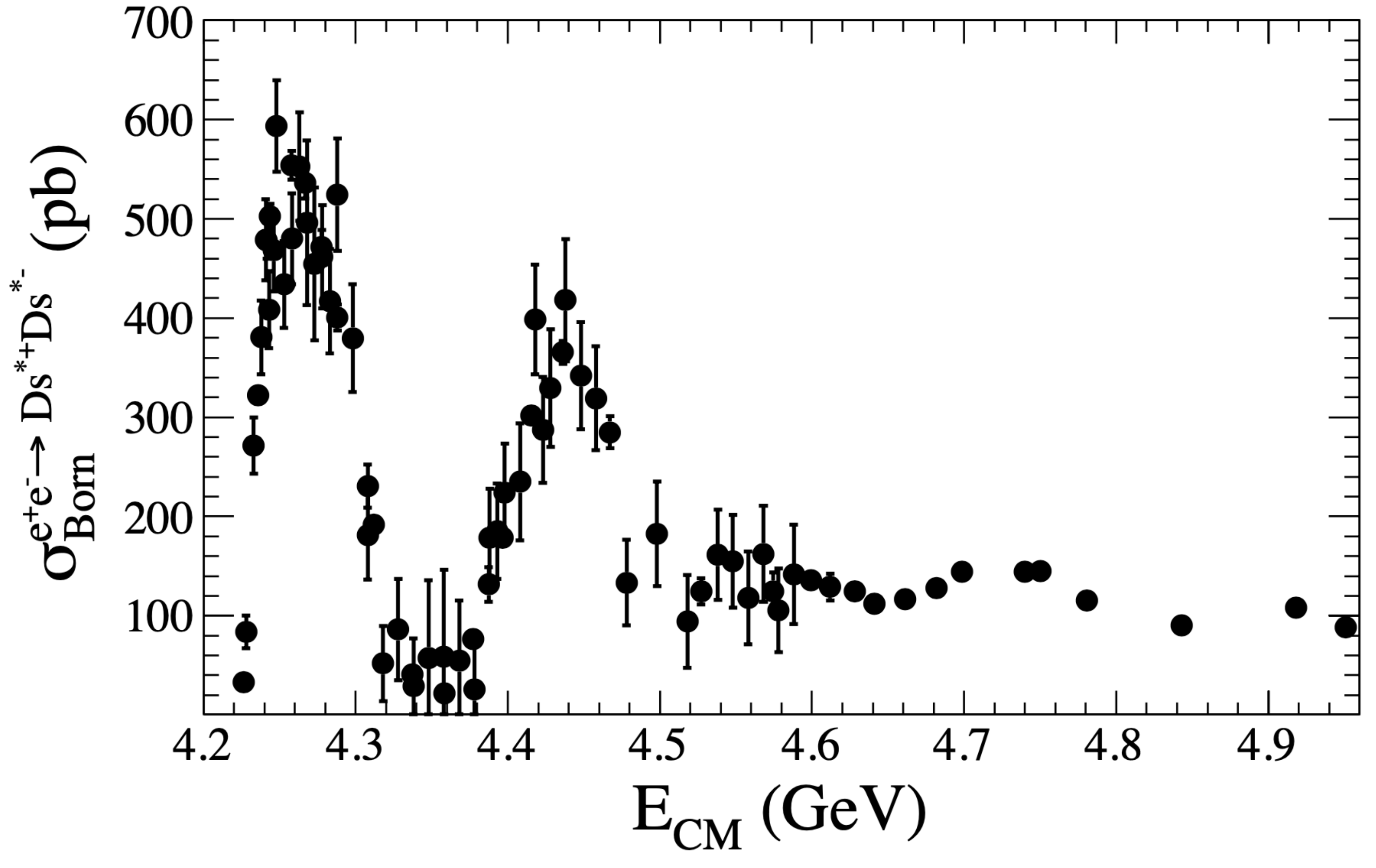
Using 20 energy points @$\sqrt{s}$ = **[4.23, 4.95] GeV**

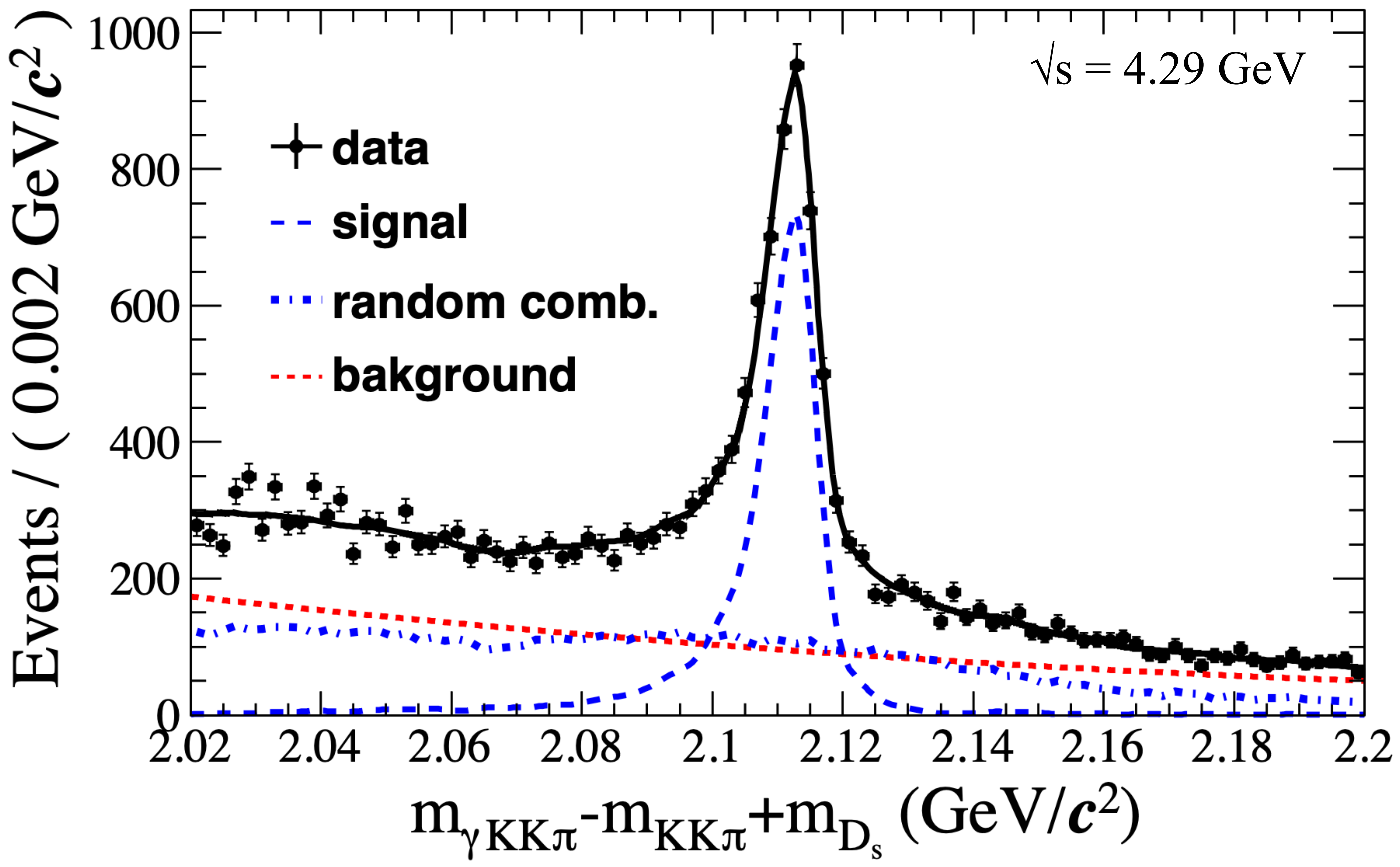
Study of the **$\sigma(e^+e^- \to D_s^{*+}D_s^{*-})$** semi-inclusively, either the **D_s^{*+}** ($\to \gamma K^+K^-\pi^+$) or **D_s^{*-}**($\to \gamma K^+K^-\pi^-$) are reconstructed

Fit to $M(\gamma K^+K^-\pi)$ to estimate **σ^{Born}**

Peaking bkg

$$\sigma^{Born} = \frac{N_{D_s^*} - N_{D_s D_s^*}}{\mathcal{L}\epsilon(1+\delta)\frac{1}{|1-\Pi^2|}2\mathcal{B}(D_s \to K^+K^-\pi)}$$





Charming Cross-Sections

Strange!

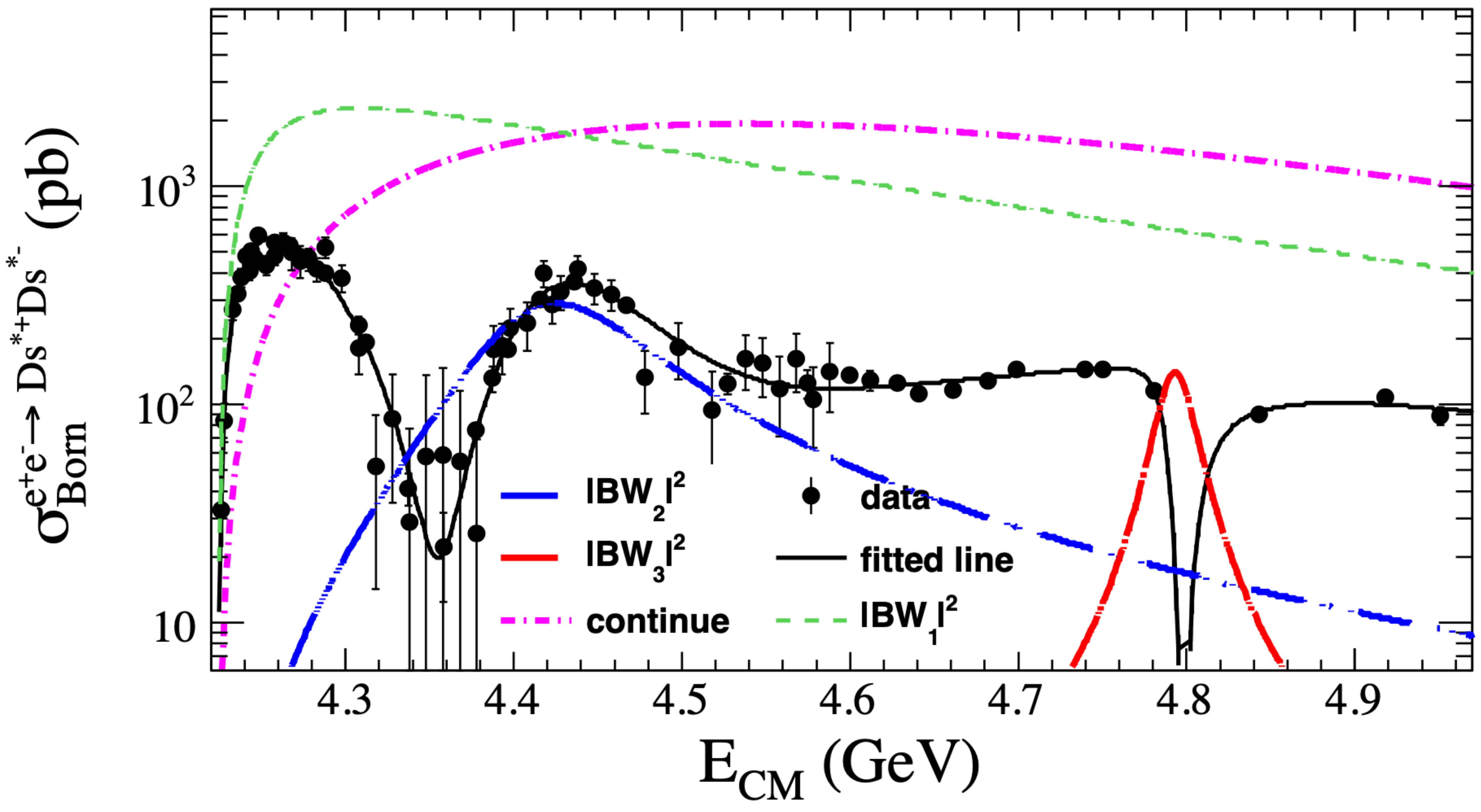
arXiv:2305.10789
Submitted to PRL

Using 20 energy points @$\sqrt{s}$ **= [4.23, 4.95] GeV**

Study of the $\boldsymbol{\sigma}(e^+e^- \rightarrow D_s^{*+}D_s^{*-})$ semi-inclusively, either the D_s^{*+} ($\rightarrow \gamma K^+K^-\pi^+$) or D_s^{*-}($\rightarrow \gamma K^+K^-\pi^-$) are reconstructed

Fit to $M(\gamma K^+K^-\pi)$ to estimate $\boldsymbol{\sigma}^{Born}$

	Mass (MeV/c^2)	Width (MeV)
#1 Res	4186.5±9.0±30	55±17±53
#2 Res	4414.5±3.2±6.0	122.6±7.0±8.2
#3 Res	4793.3±7.5±9.3	27.1±7.0±34



1. Consistent with the $\psi(4160)$ (also with the Y(4230) considering the systematic), a candidate for the $\psi(2^3D_1)$
2. Possibly the $\psi(4415)$ state, a $\psi(4^3S_1)$ candidate
3. Y(4793), a new 1^{--} state…?

Summary

BESIII started taking data in '08, and since then it has been **exploring and shedding light** on the **charmonium spectrum**

The **largest datasets** of **$c\bar{c}$ vector** states collected by BESIII provide the power to **investigate** not only rare vector decays but also to **study** the **h_c(1P)**, χ_{cJ}(1P), and η_c(2S) states and their decays

Also **datasets above** the **DD threshold** can shed new light on charmonium decays and hint at possible **connections** between **XYZ states and** conventional **charmonia**

Thanks to its **tuneable centre-of-mass energy** in the charmonium range and **leptonic beams**, **BESIII** can be **competitive** even with smaller datasets

Finally, **new data sets** are currently being taken and analysed

~$2.7x10^9$ @$\psi(2S)$

~$20 fb^{-1}$@$\psi(3770)$

Hence, exciting times wait ahead…

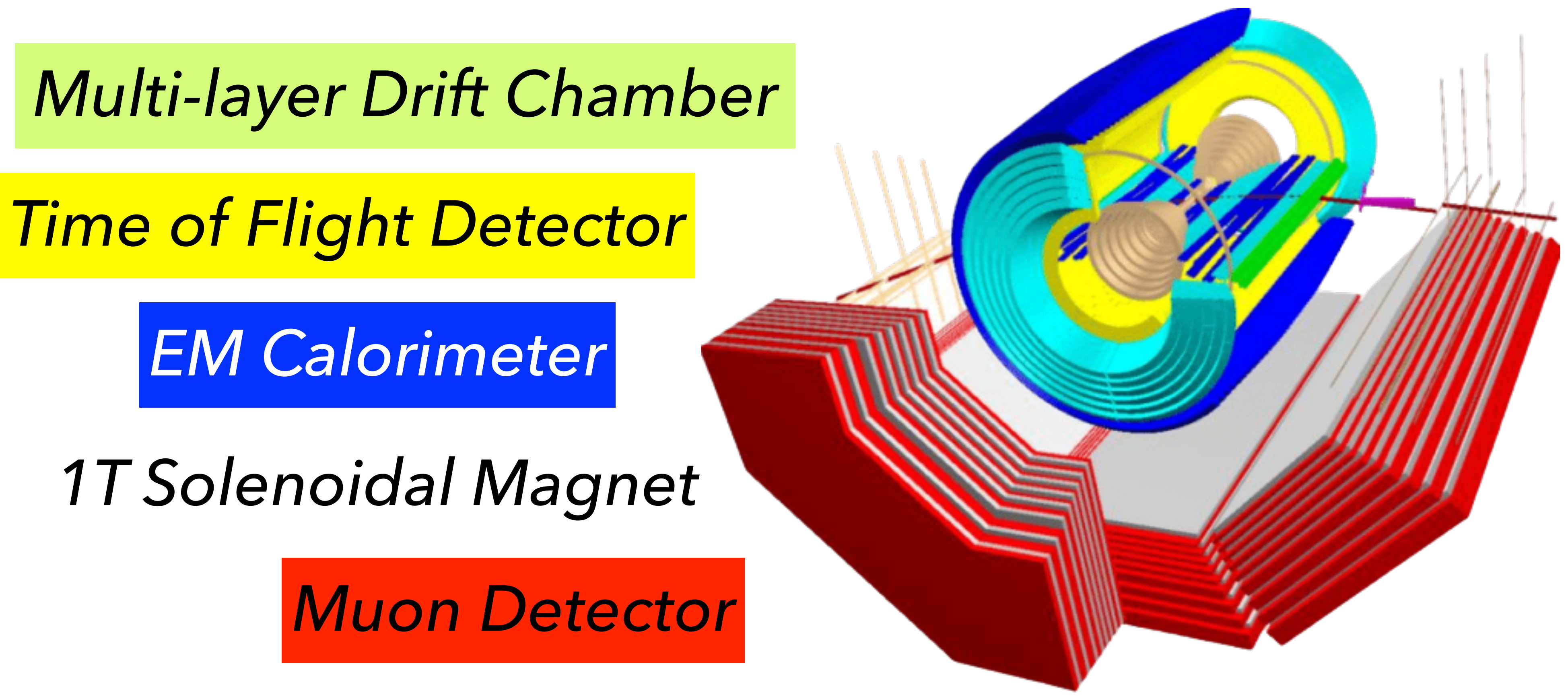
Thank you for the attention!

Backup Slides

BESIII Collaboration

BESIII Experiment

BESIII (BEijing Spectrometer III) is an experiment located at the BEPCII (Beijing Electron Positron Collider II) at IHEP (Institute of High Energy Physics)



τ-charm factory 2.0 GeV ≤ $\sqrt{s}$ ≤ 4.9 GeV

with a 10^{33} $cm^{-2}s^{-1}$ designed luminosity

@ $\sqrt{s}$ = 3.77 GeV

MDC		
Single wire $\sigma_{r\phi}$ (1 GeV)	130	μm
σ_z (1 GeV)	~2	mm
σ_p/p (1 GeV)	0.5	%
$\sigma_{dE/dx}$ (1 GeV)	6	%

EMC		
σ_E/E (1 GeV)	2.5	%
Position resolution (1 GeV)	0.6	cm

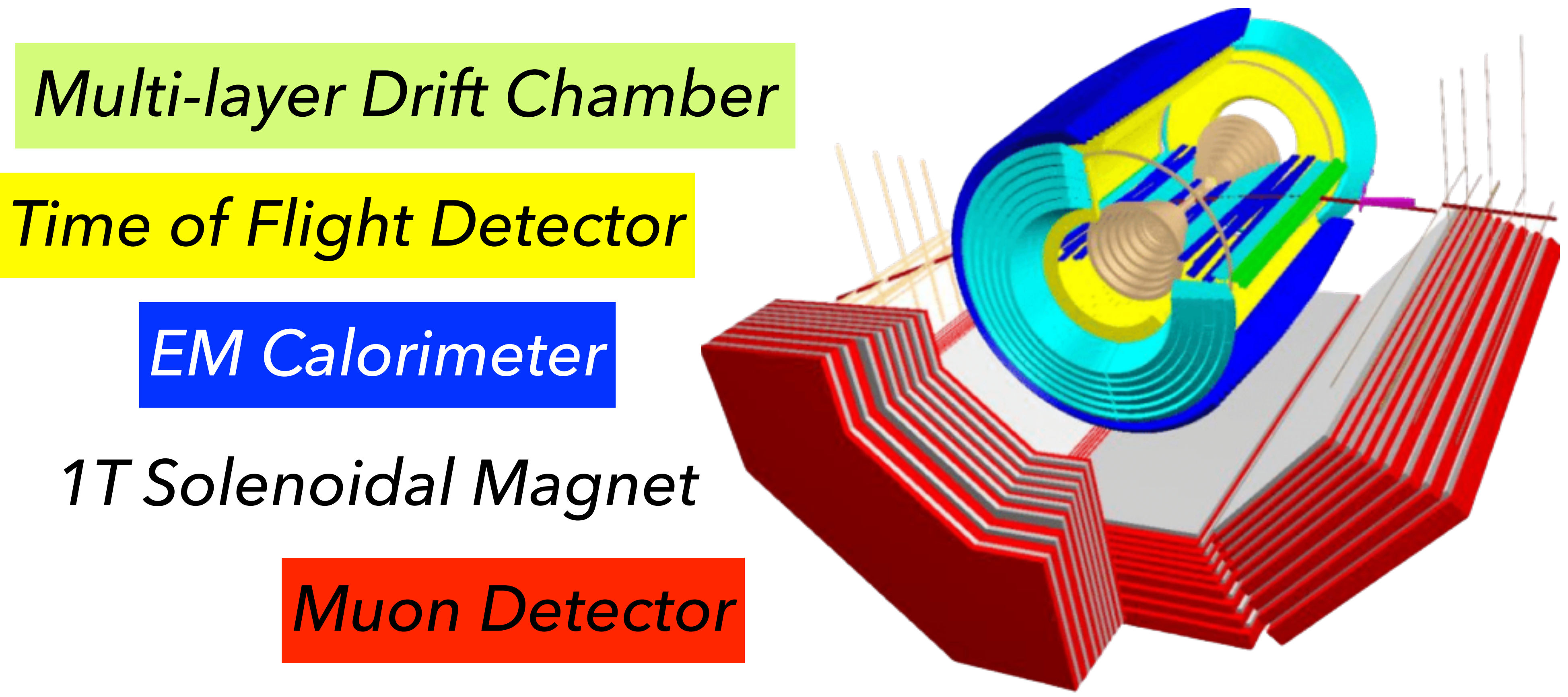
TOF		
σ_T		
Barrel (1 GeV/c muons)	100	ps
End cap (0.8 GeV/c pions)	65	ps

Muon Identifier		
No. of layers (barrel/end cap)	9/8	
Cut-off momentum	0.4	GeV/c

Solenoid field	1.0	T
$\Delta\Omega/4\pi$	93	%

BESIII Experiment

BESIII (BEijing Spectrometer III) is an experiment located at the BEPCII (Beijing Electron Positron Collider II) at IHEP (Institute of High Energy Physics)



τ-charm factory $2.0 \text{ GeV} \leq \sqrt{s} \leq 4.9 \text{ GeV}$

with a $10^{33}\ \text{cm}^{-2}\text{s}^{-1}$ designed luminosity

@ $\sqrt{s} = 3.77$ GeV

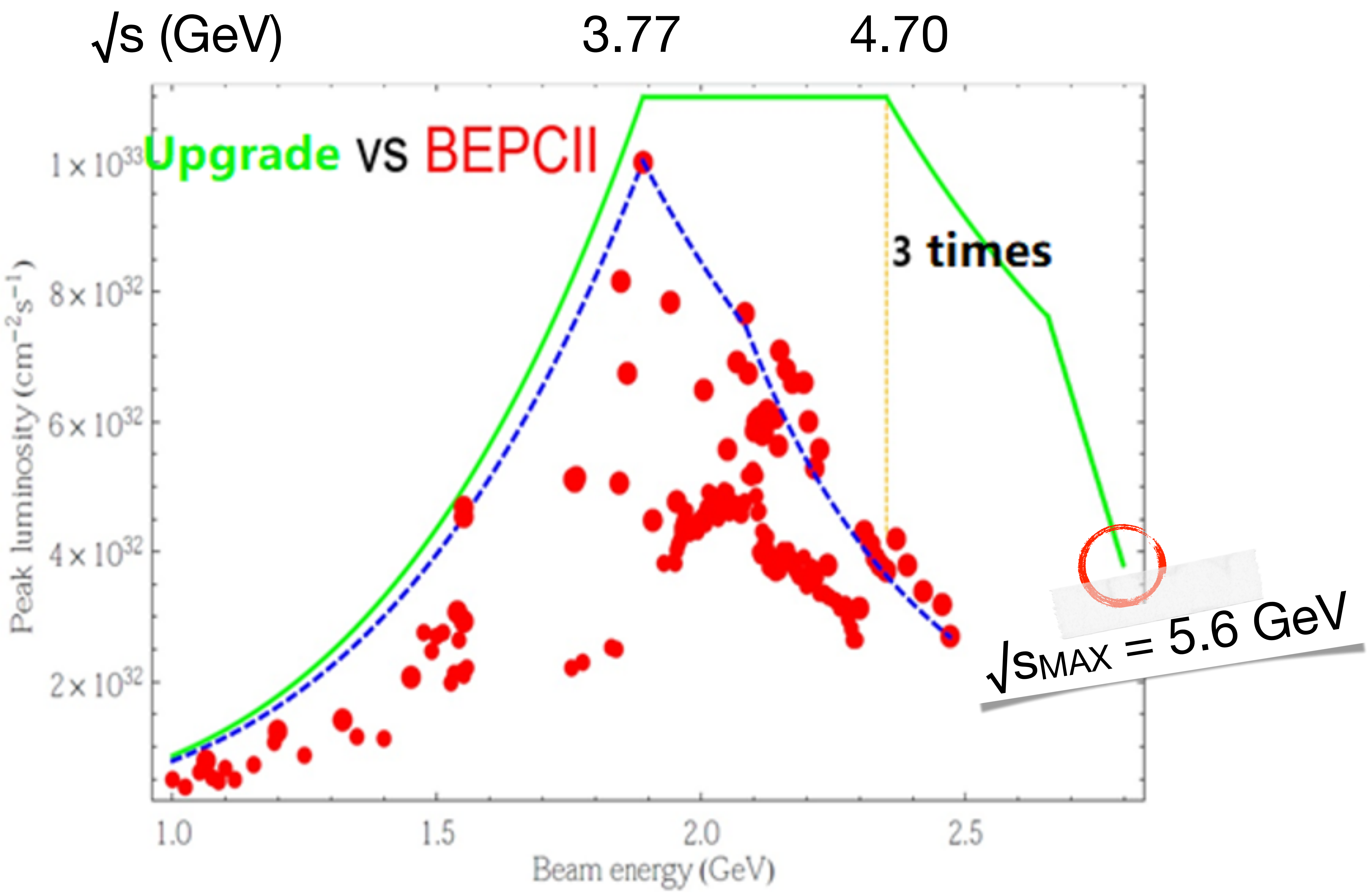
Data sets

2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
$10 \times 50\ \text{pb}^{-1}$ scan 3.81 — 4.42 GeV
2014: 1029 pb^{-1} at 4.42 GeV
110 pb^{-1} at 4.47 GeV
110 pb^{-1} at 4.53 GeV
48 pb^{-1} at 4.575 GeV
567 pb^{-1} at 4.6 GeV
0.8 fb^{-1} R-scan 3.85 — 4.59 GeV
2015: R-scan 2 — 3 GeV + 2.175 GeV
2016: ~3fb^{-1} at 4.18 GeV (for D_s)
2017: $7 \times 500\ \text{pb}^{-1}$ scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
$8 \times 500\ \text{pb}^{-1}$ scan 4.13, 4.16, 4.29 — 4.44 GeV
2020: 3.8 fb^{-1} scan 4.61 - 4.7 GeV
2021: 2 fb^{-1} scan 4.74 - 4.946 GeV
3.0B (total) $\psi(2S)$

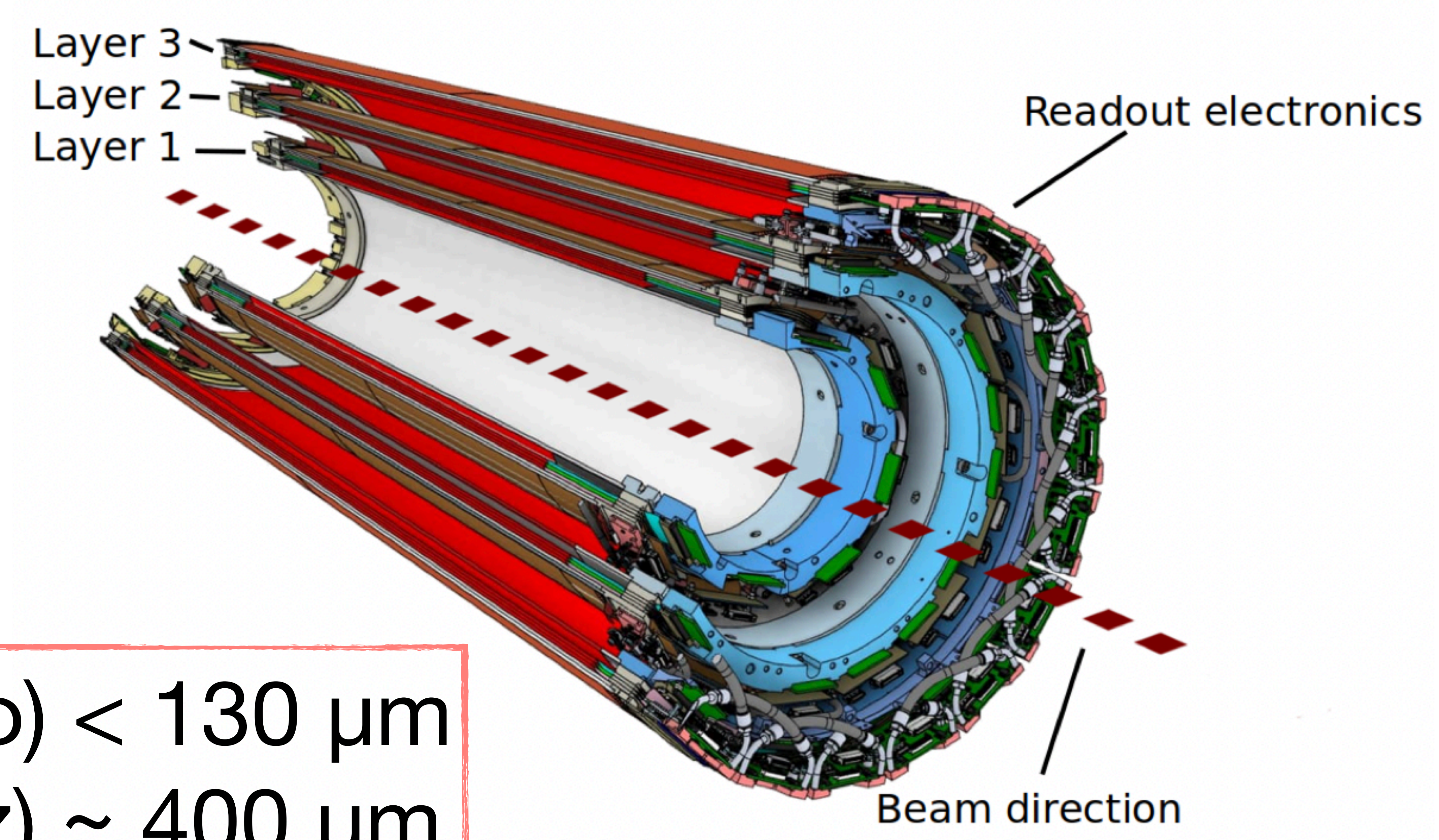
Upgrading the BESIII Experiment

Born Cross-sections

Energy & Luminosity



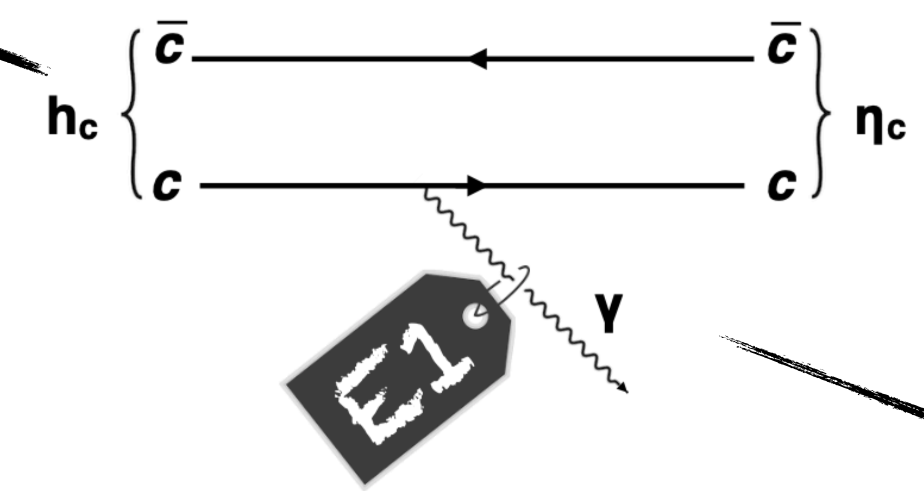
CGEM-IT



$\delta(\phi) < 130\ \mu m$
$\delta(z) \sim 400\ \mu m$

Back to the Origins… Rediscovering the $h_c(1^1P_1)$

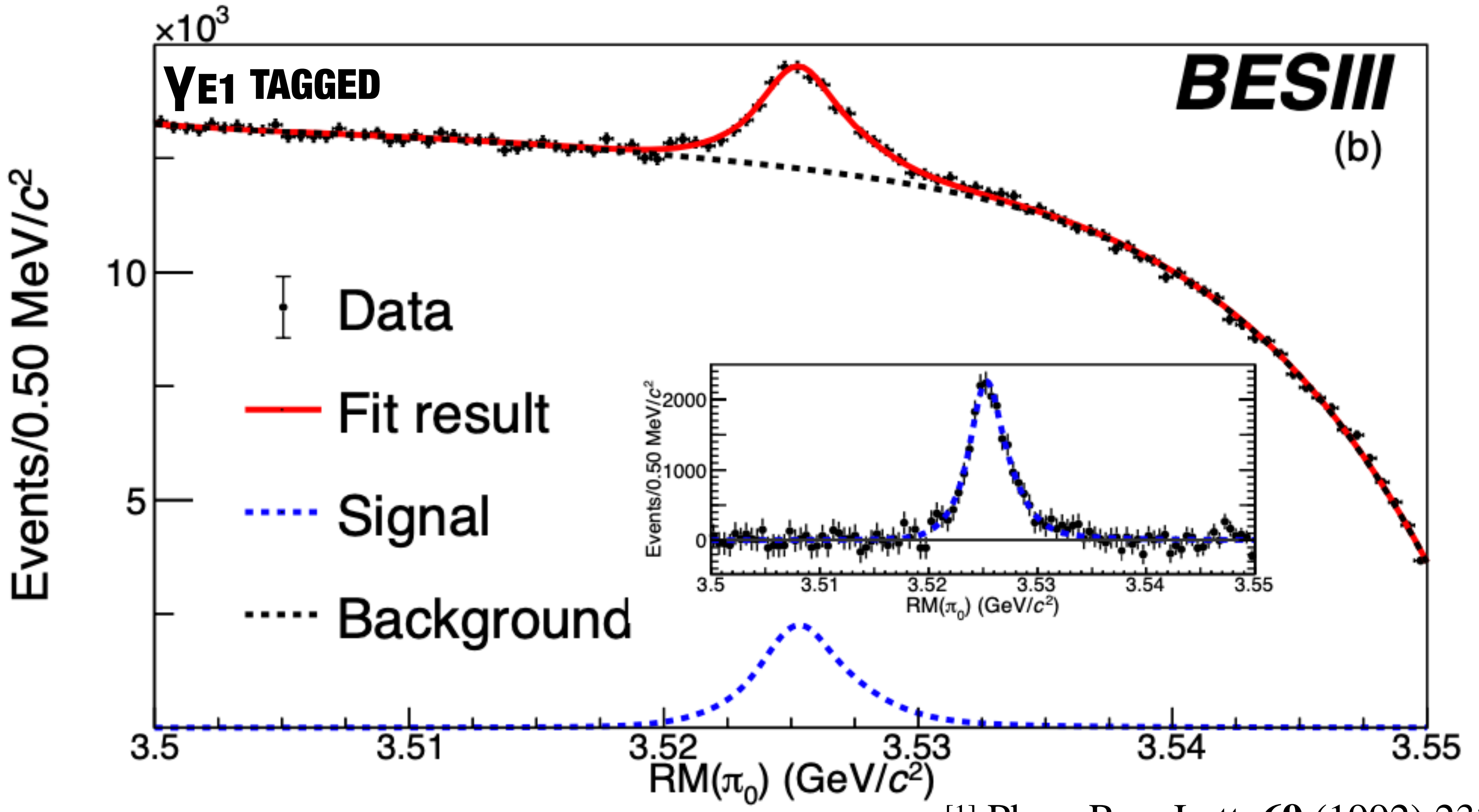
Using 448 million $\psi(2S)$ events



PRD **106**, 072007 (2022)

Variable	Value	PDG
$M(h_c)$ (MeV/c^2)	$3525.32 \pm 0.06 \pm 0.15$	3525.38 ± 0.11
$\Gamma(h_c)$ (MeV)	$0.78\ ^{+0.27}_{-0.24} \pm 0.12$	0.7 ± 0.4
$N_{\mathrm{Tag}}(h_c)$	$23118\ ^{+1500}_{-1398}$	—
$\mathcal{B}_{\mathrm{Inc}} \times \mathcal{B}_{\mathrm{Tag}}$ (10^{-4})	$4.17\ ^{+0.27}_{-0.25} \pm 0.19$	4.58 ± 0.64 (BESIII [11]) 4.16 ± 0.48 (CLEO [23])
$N_{\mathrm{Inc}}(h_c)$	46187 ± 2123	—
$\mathcal{B}_{\mathrm{Inc}}$ (10^{-4})	$7.23 \pm 0.33 \pm 0.38$	8.60 ± 1.30
$\mathcal{B}_{\mathrm{Tag}}$ (%)	$57.66^{+3.62}_{-3.50} \pm 0.58$	50 ± 9

Wrt the **center-of-gravity mass** of the three $\chi_{cJ}(1^3P_J)$ states, **no mass splitting** is observed with this measurement **as** predicted by potential model **calculations**[3]



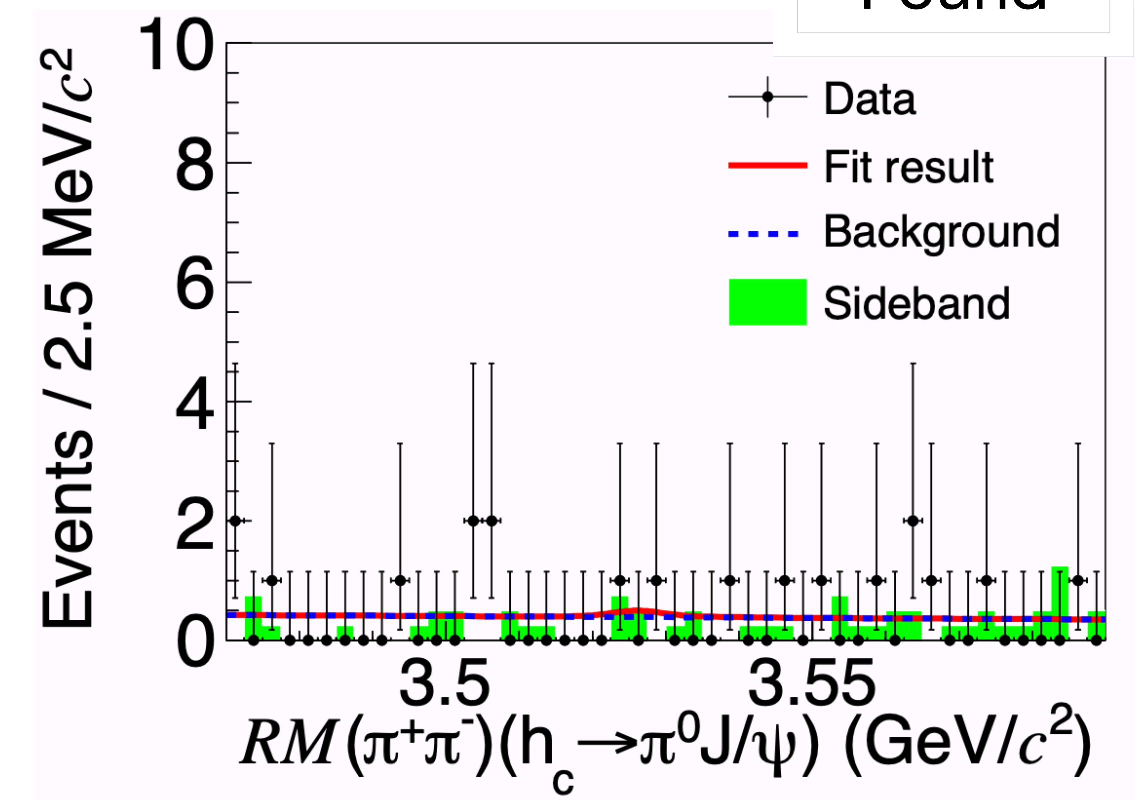
JHEP **2022**, 3 (2022)

$e^+e^- \to \pi^+\pi^- h_c$ with $\mathcal{L}_{int}$ = 11.3 fb^{-1}

$h_c \to \pi^0 J/\psi$ @$\sqrt{s}$ = [4.189, 4.437] GeV

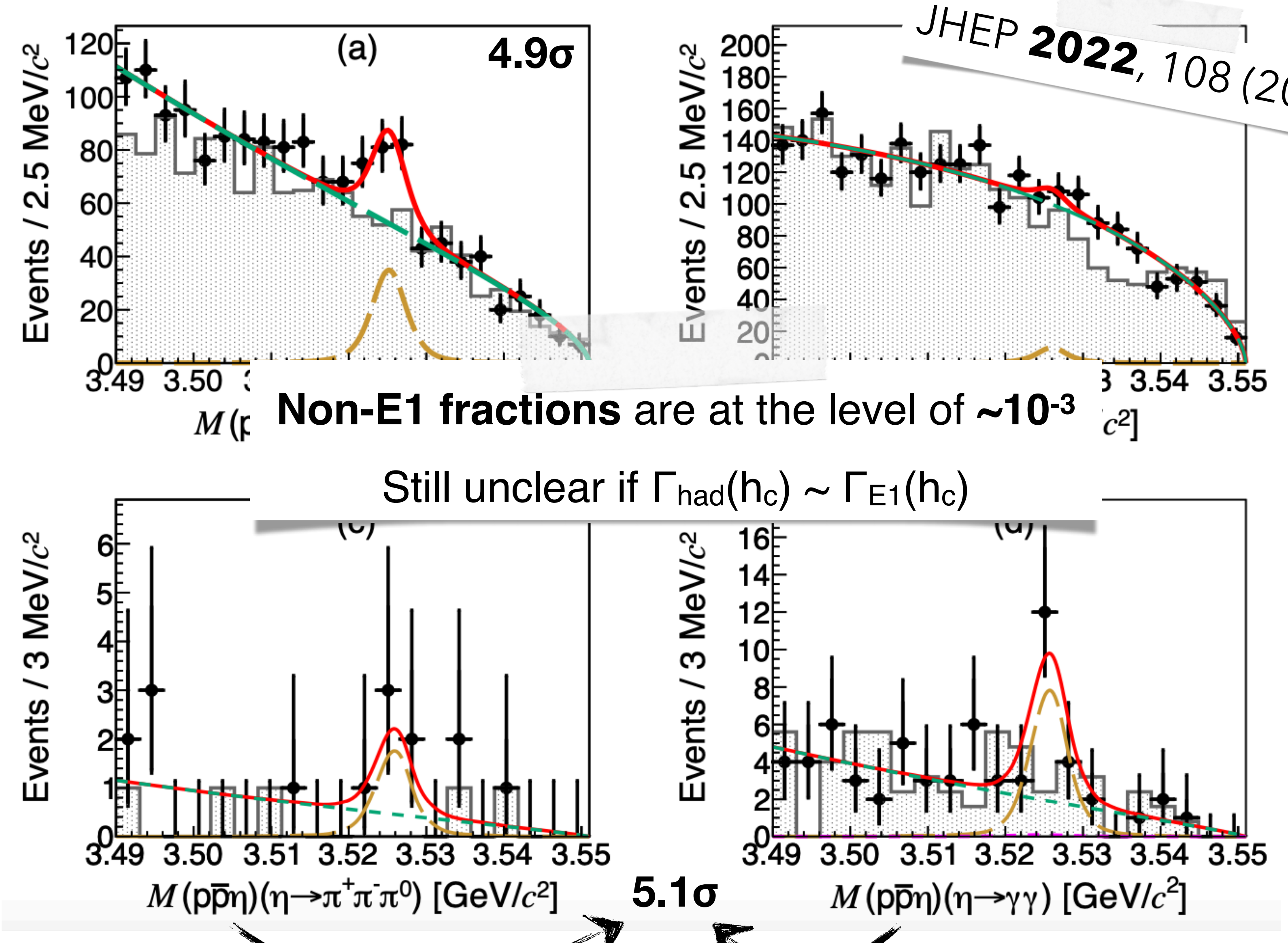
Tensions with E760[1]
Agreement with E835[2]

No Signal Found



Non-E1 decays

JHEP **2022**, 108 (2022)



Non-E1 fractions are at the level of **~10^{-3}**

Still unclear if $\Gamma_{had}(h_c) \sim \Gamma_{E1}(h_c)$

[1] Phys. Rev. Lett. **69** (1992) 2337
[2] Phys. Rev. D **72** (2005) 032001
[3] Ann. Rev. Nucl. Part. Sci. **37**, 325 (1987)