Spectroscopy at BESIII

A Selected XYZ Review

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on behalf of the BESIII Collaboration

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Outline

- BESIII Experiment
- Preamble… The XYZ Exotic States
- The X(3872) Structure
- The Y(4230) Resonance
- The Z_{cs} Tetraquarks
- Summary

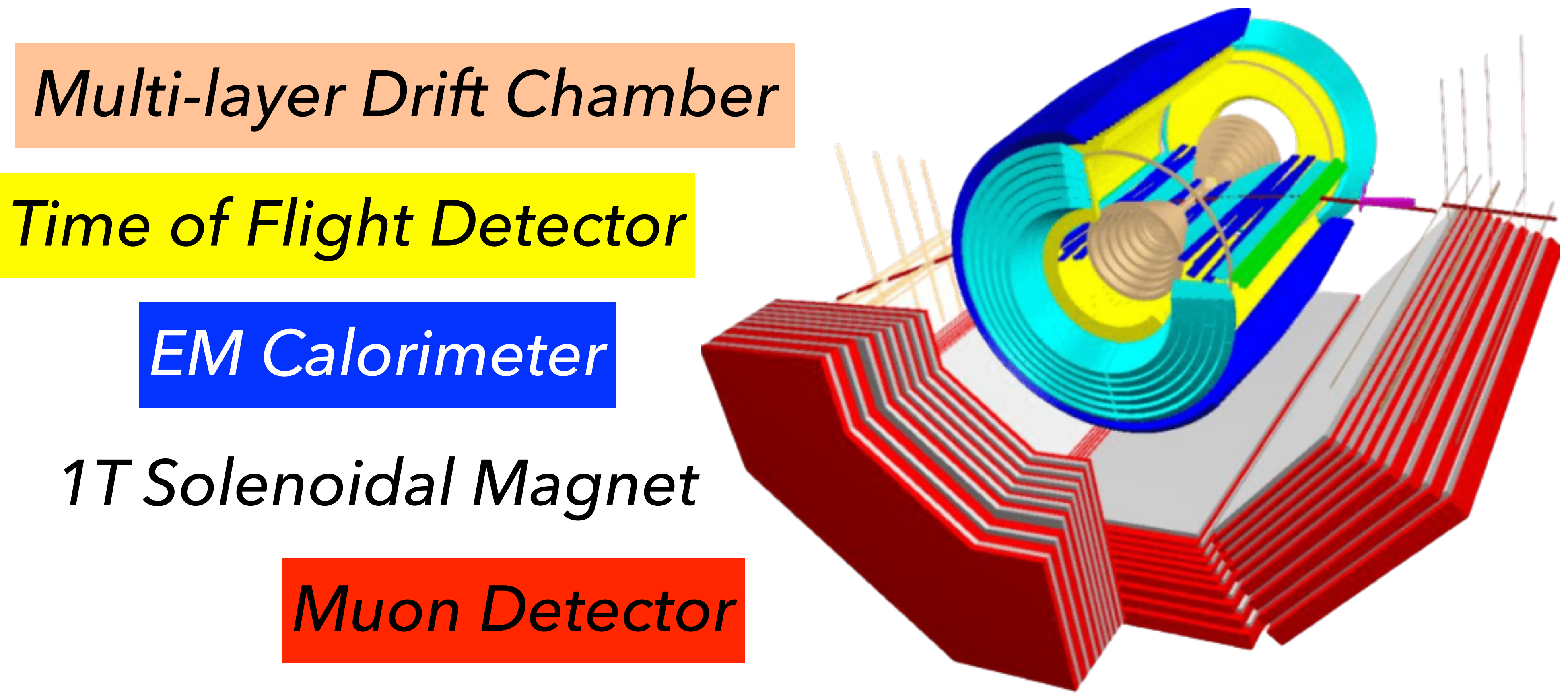
BESIII Experiment

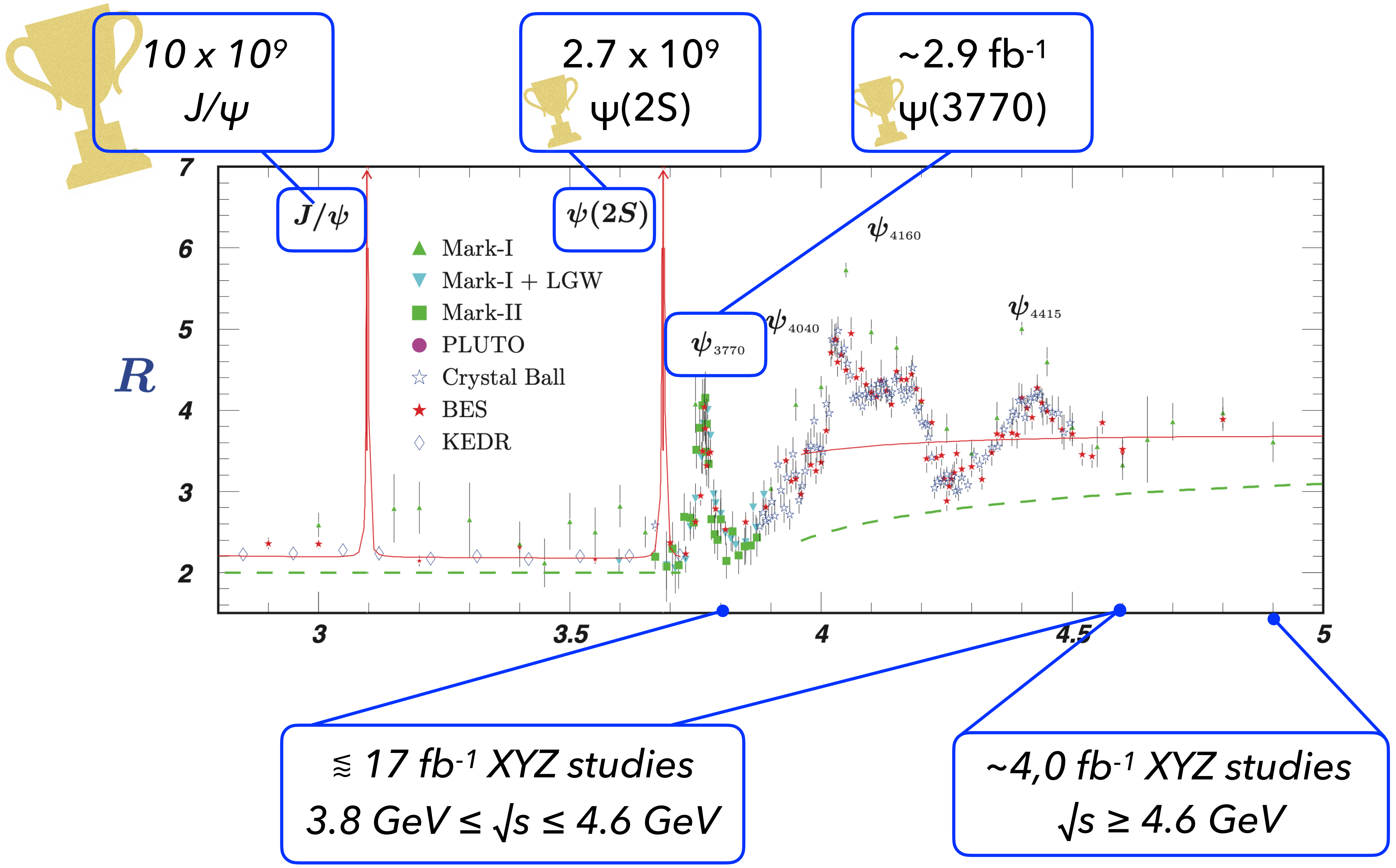
BESIII (BEijing Spectrometer III) is an experiment located at the BEPCII (Beijing Electron Positron Collider II) at IHEP (Institute of High Energy Physics)

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

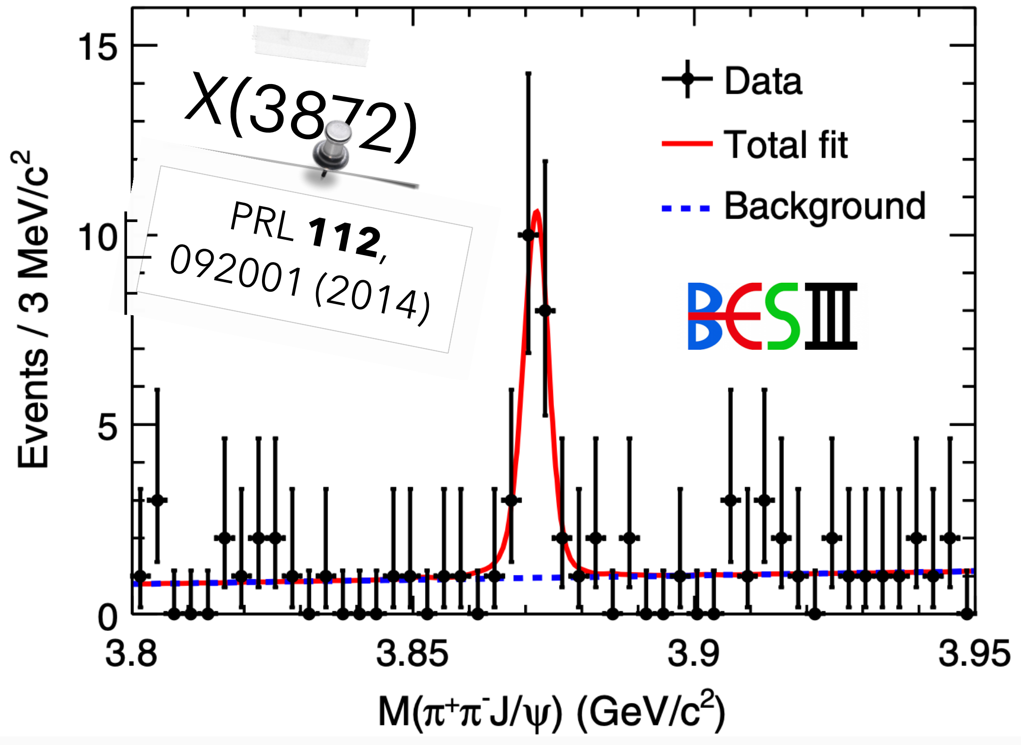
with an instantaneous luminosity of 10^{33} $cm^{-2}s^{-1}$ @ $\sqrt{s}$ = 3.77 GeV

Charmonium-like XYZ States

$c\bar{c}$ spectrum features **supernumerary states**

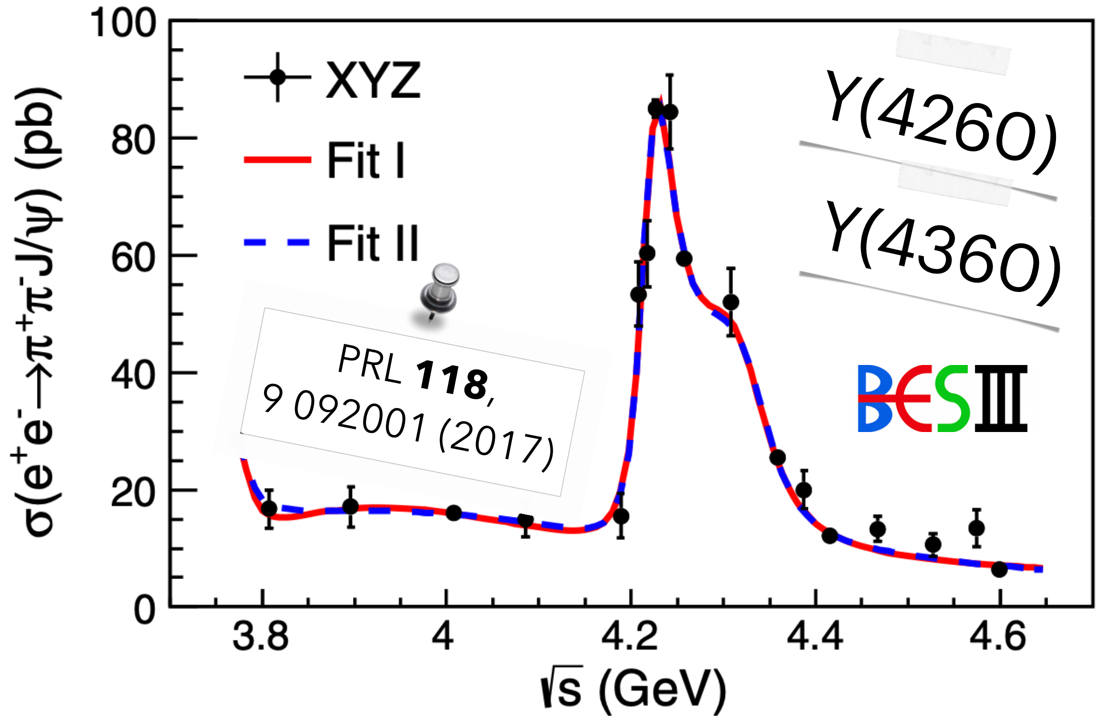
Exotic states **don't fit** potential model **predictions**, show strong **couplings to hidden charm** states, and exhibit a **non-zero charge**

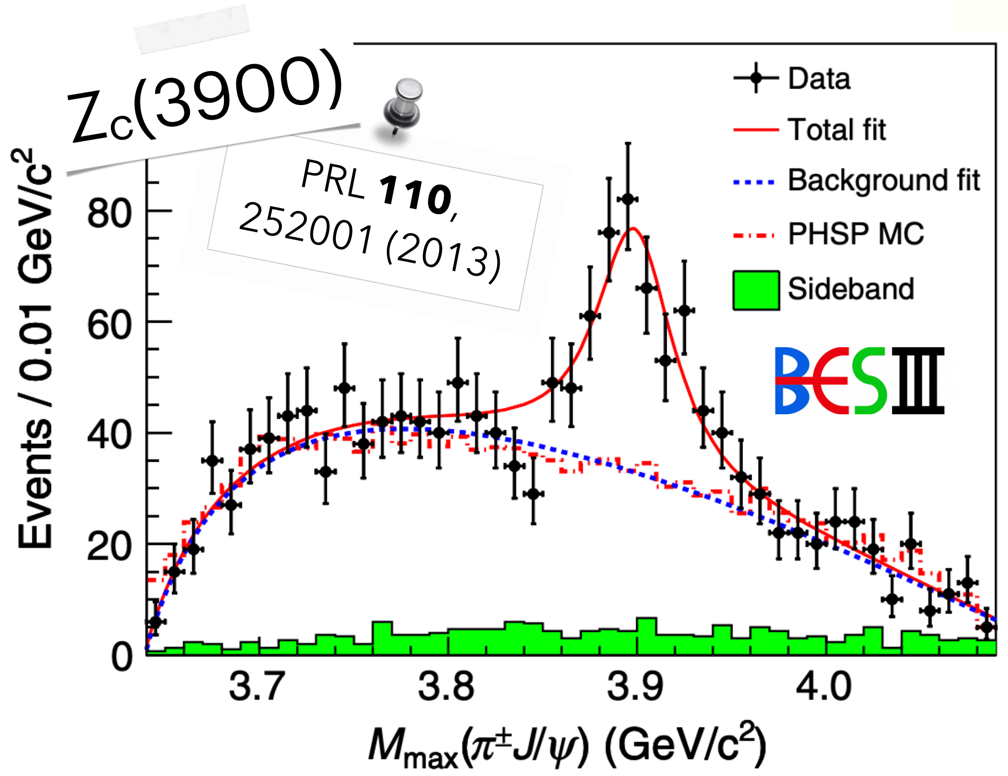
The **nature** of these exotic states is **not** yet **clear**



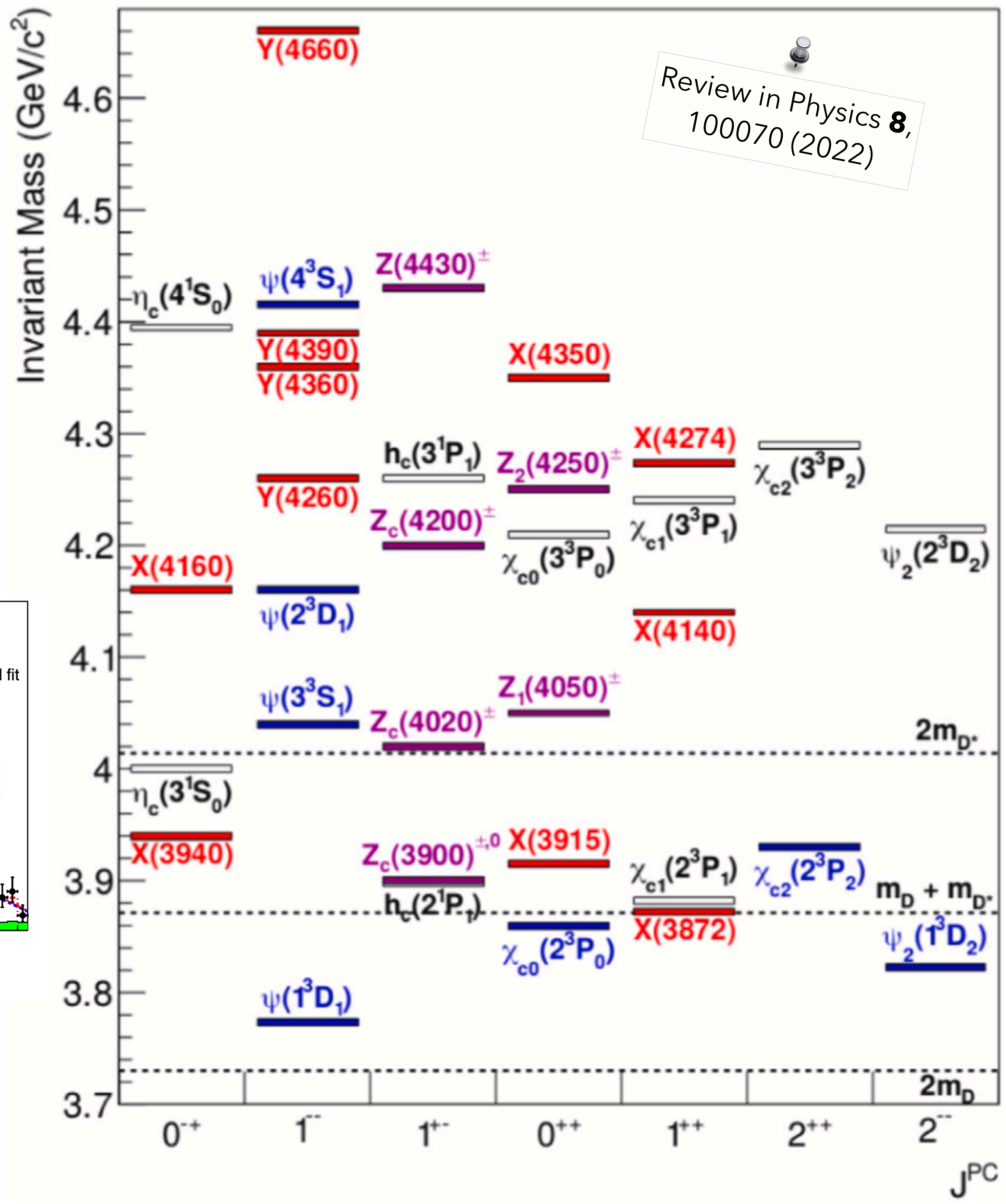
X: **Neither *Y* nor *Z***

Y: **Vector resonances**





Z: **Charged structures**



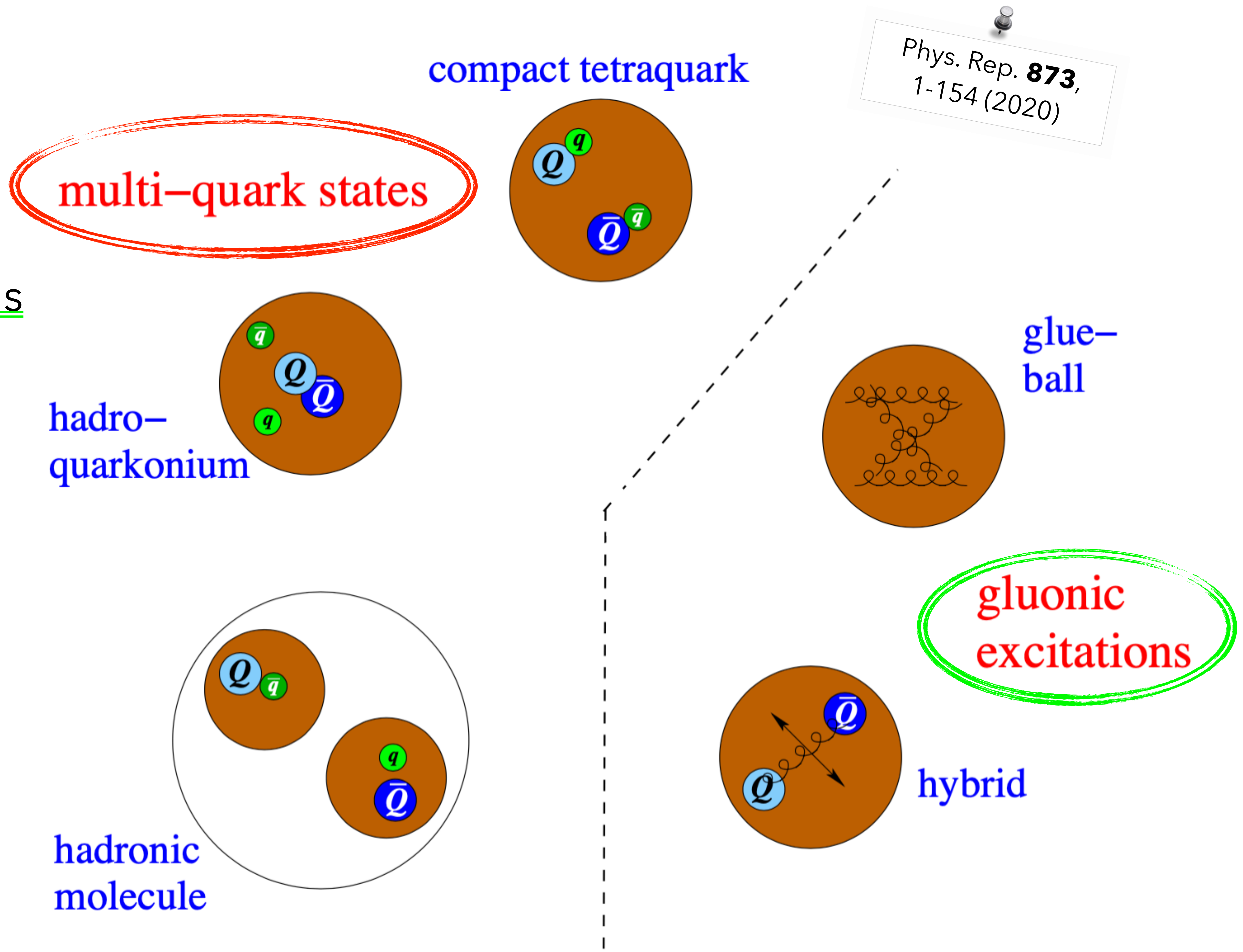
Exotic States

Assuming a novel physical origin, **exotic hadrons** can be grouped into **two families following their valence content** with respect to the standard meson-baryon picture:

* they might contain additional (or only) valence gluons
* they can be multi-quark states

Some are **close to open-flavour thresholds**, which might induce kinematic **enhancements**[1, 2]

They **could** emerge as **interference effects** of various standard quarkonia



[1] Phys. Lett. B **598**, 8-14 (2004)
[2] Int. J. Mod. Phys. E **25**, 07 1642010 (2016)

X(3872)/χ_{c1}(3872)

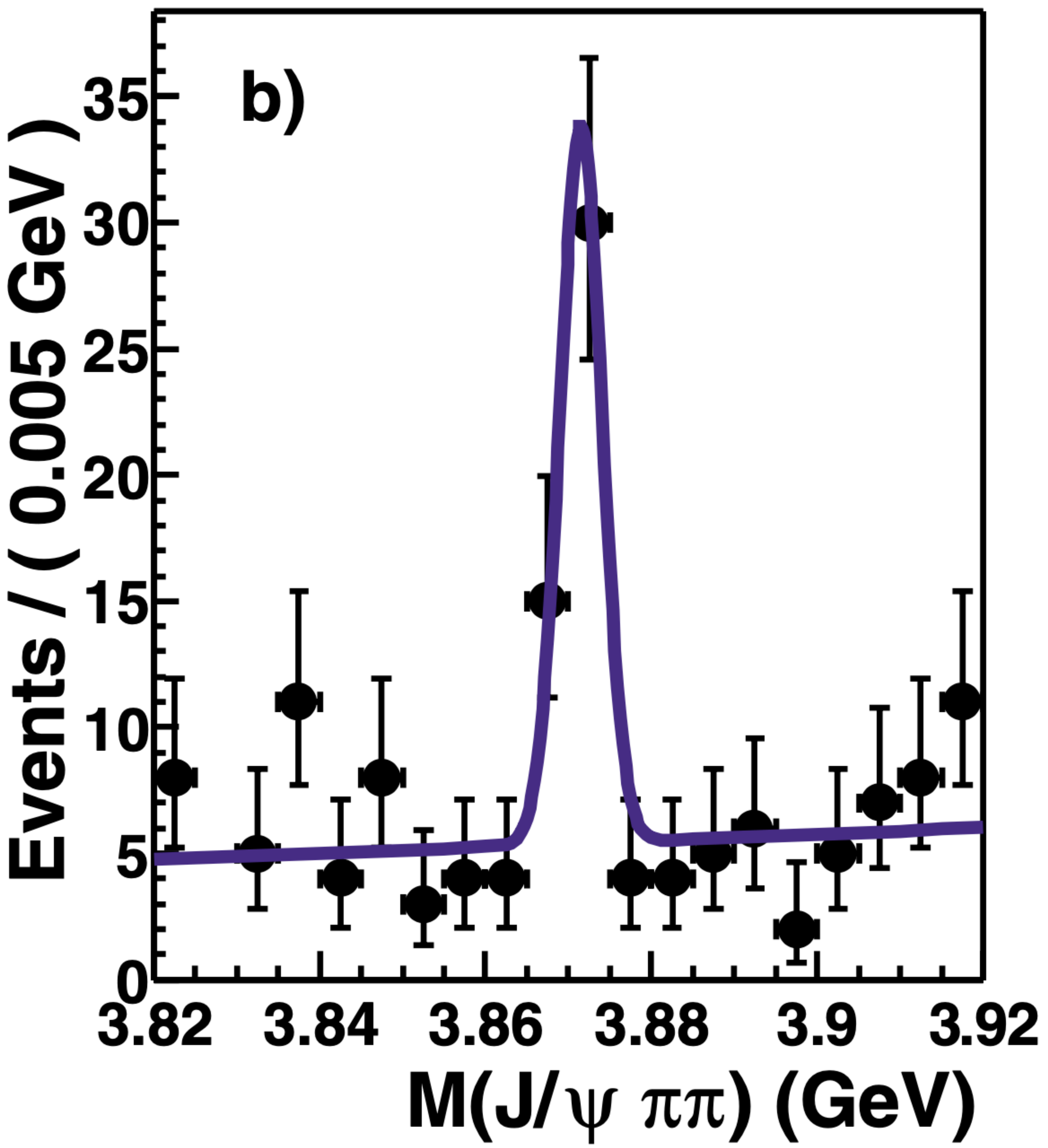
The **mass** lies **near** the **$D^0\bar{D}^{0*}$ threshold** ($M_{X(3872)} - E_{Threshold} \lesssim \delta$), suggesting a possible molecular nature

The **loosely bound molecular nature** can explain the relatively **small width** (~1 MeV/c^2)[3]

Though, the relatively **large branching fraction** for the radiative transition **to hidden charm mesons** suggests an **admixture** of a conventional charmonium and a $D^0\bar{D}^{0*}$ molecule

BESIII is at the forefront of the X(3872) studies, thanks to its direct production mode(s) and clean leptonic environment

The BESIII collaboration found, in 2014[4], evidence for the Y(4230) → γX(3872) decay



[3] Phys. Lett. B **590**, 209–215 (2004)
[4] Phys. Rev. Lett. E **112**, 092001 (2014)

The New $\omega X(3872)$ Production Mode

Using 9 energy points @$\sqrt{s}$ = **[4.661 4.951] GeV**

Study of the $\sigma^{Born}(e^+e^- \to \omega\pi^+\pi^- J/\psi)$

Fit to $M(\pi^+\pi^- J/\psi)$ to estimate the X(3872) mass and its production cross-section

If the **X(3872) contains** a component of the spin-triplet state χ_{c1}**(2P)**, the **process** $e^+e^- \to \omega X(3872)$ should **exist**, as BESIII observed the $e^+e^- \to \omega\chi_{cJ}(1P)$ transitions[5]

Phys. Rev. Lett. **130**, 151904 (2023)

[5] Phys. Rev. Lett. **114**, 092003 (2015)

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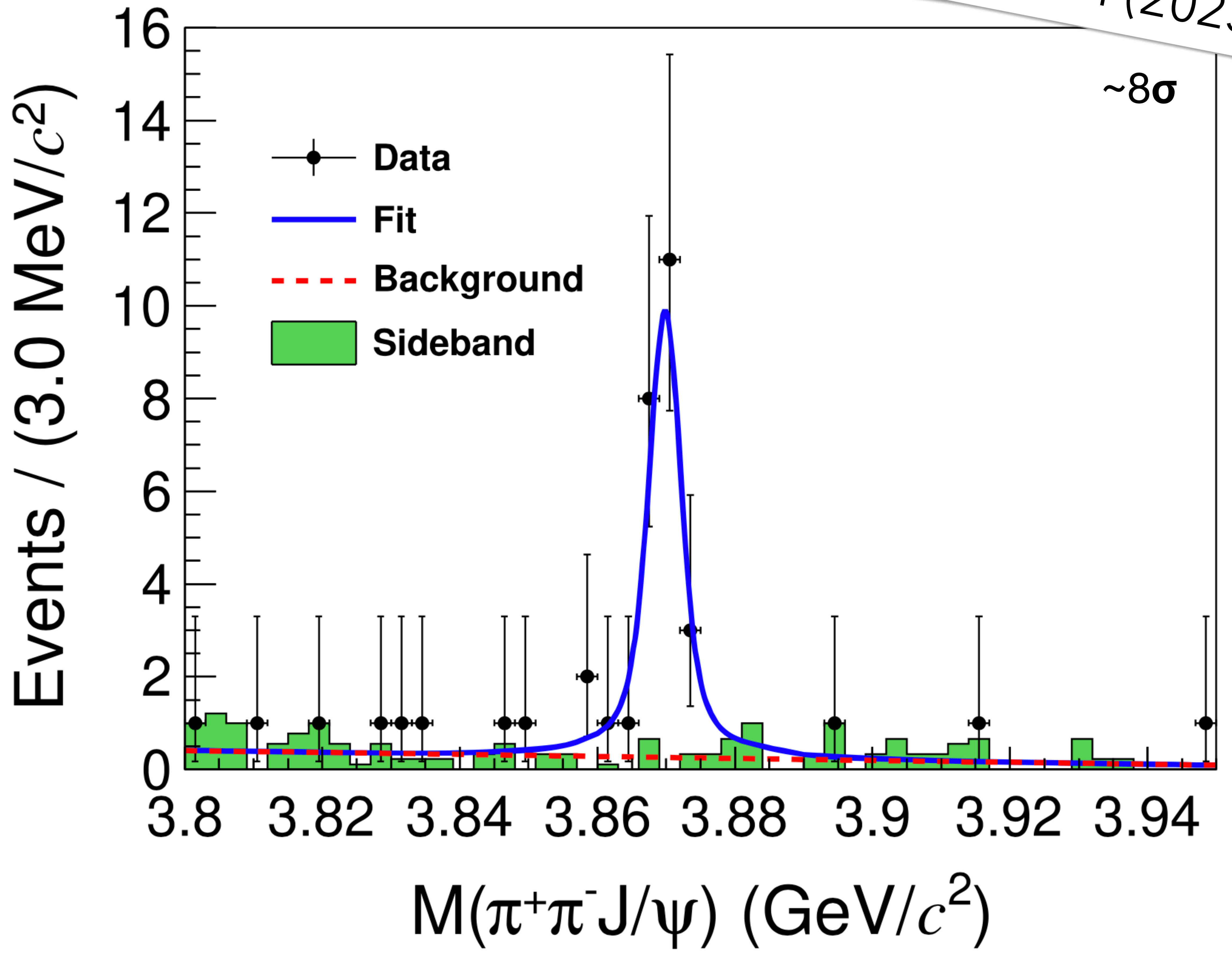

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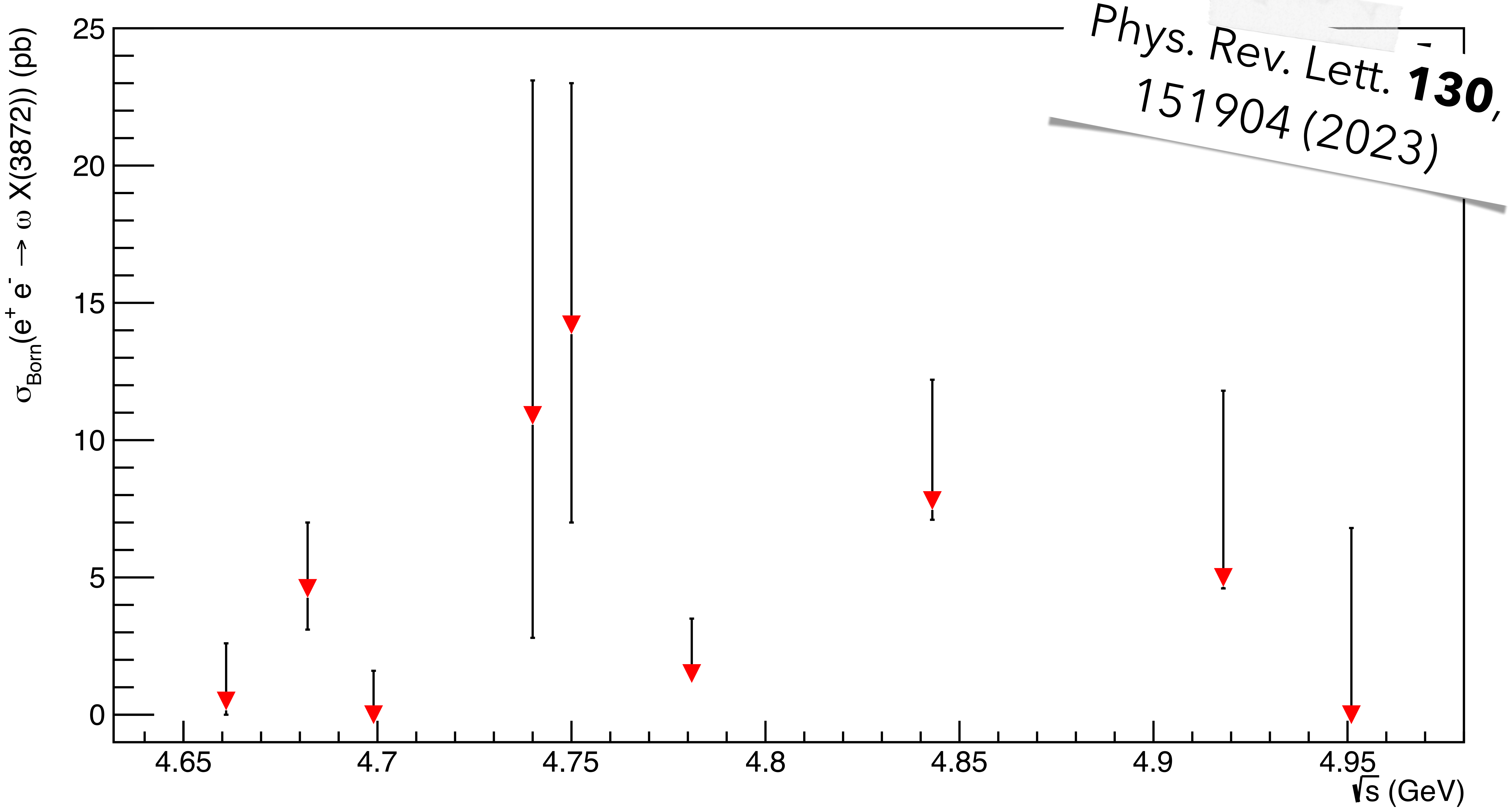

The **line-shape** suggests that the ***ωX(3872)*** production mode may derive from some **nontrivial structures** decays

[5] Phys. Rev. Lett. **114**, 092003 (2015)

X(3872) to Light Hadrons

arXiv:**2308.13980v1**
Submitted to PRL

Using 16 energy points @**√s = [4.13, 4.34] GeV**

Search for the e^+e^-→ **γX(3872) → γπ⁺π⁻η** process

Assuming a **loosely bound molecular** state, the X(3872) size would be relatively large and the **charm quarks** would be **far away** from each other[6], hence, the **light hadron decays** should be **suppressed**

[6] Rev. Mod. Phys. **90**, 015004 (2018)

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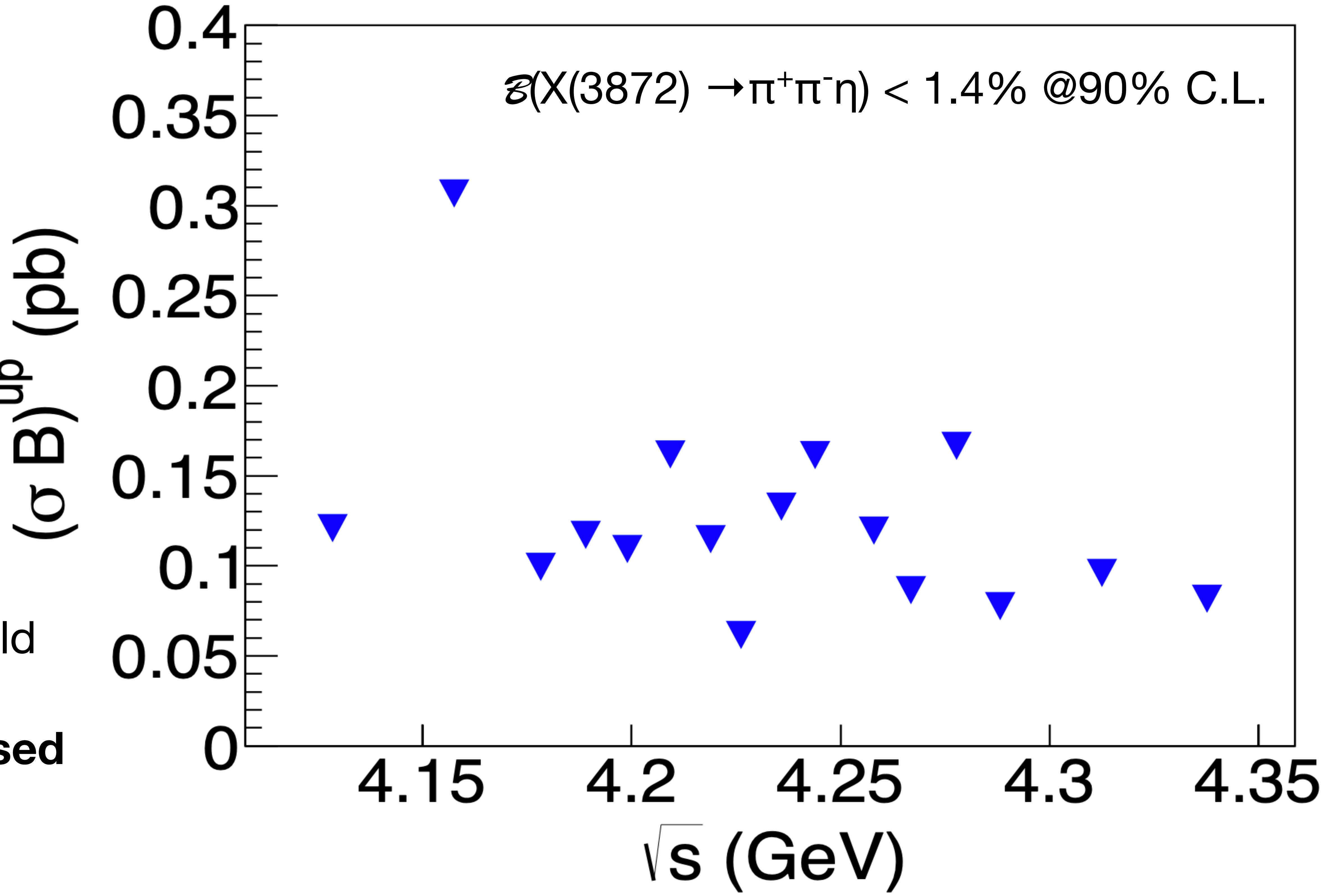
Search for the $e^+e^- \to$ **$\gamma X(3872) \to \gamma\pi^+\pi^-\eta$** process

Fit to M(**$\pi^+\pi^-\eta$**) to estimate the upper limits to the [$\sigma(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^-\eta)$] product



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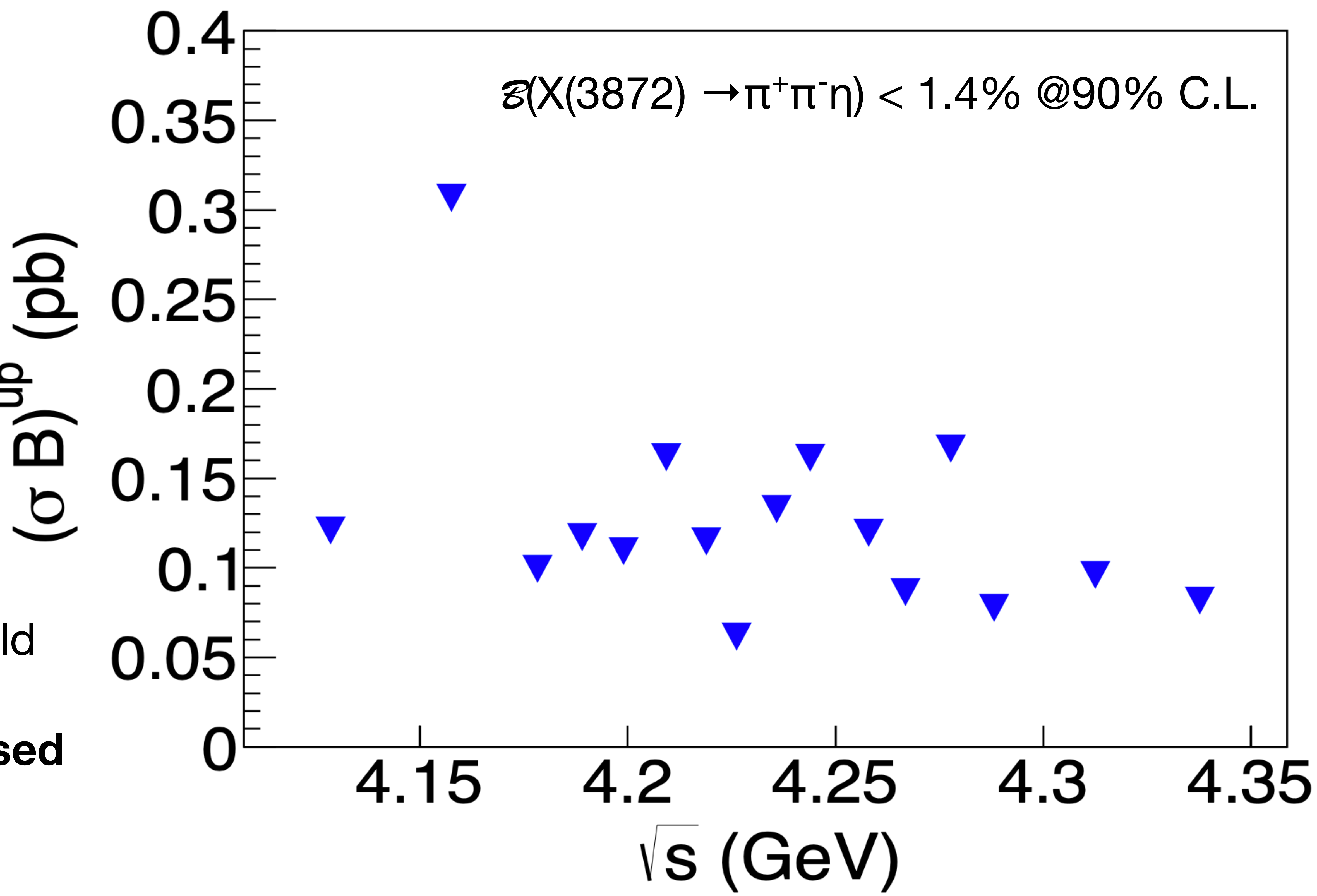

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Ref. [7] estimates a light hadron decay width in the range of [10 - 100] keV corresponding to $\mathcal{B}$ ~ [1 - 10] %

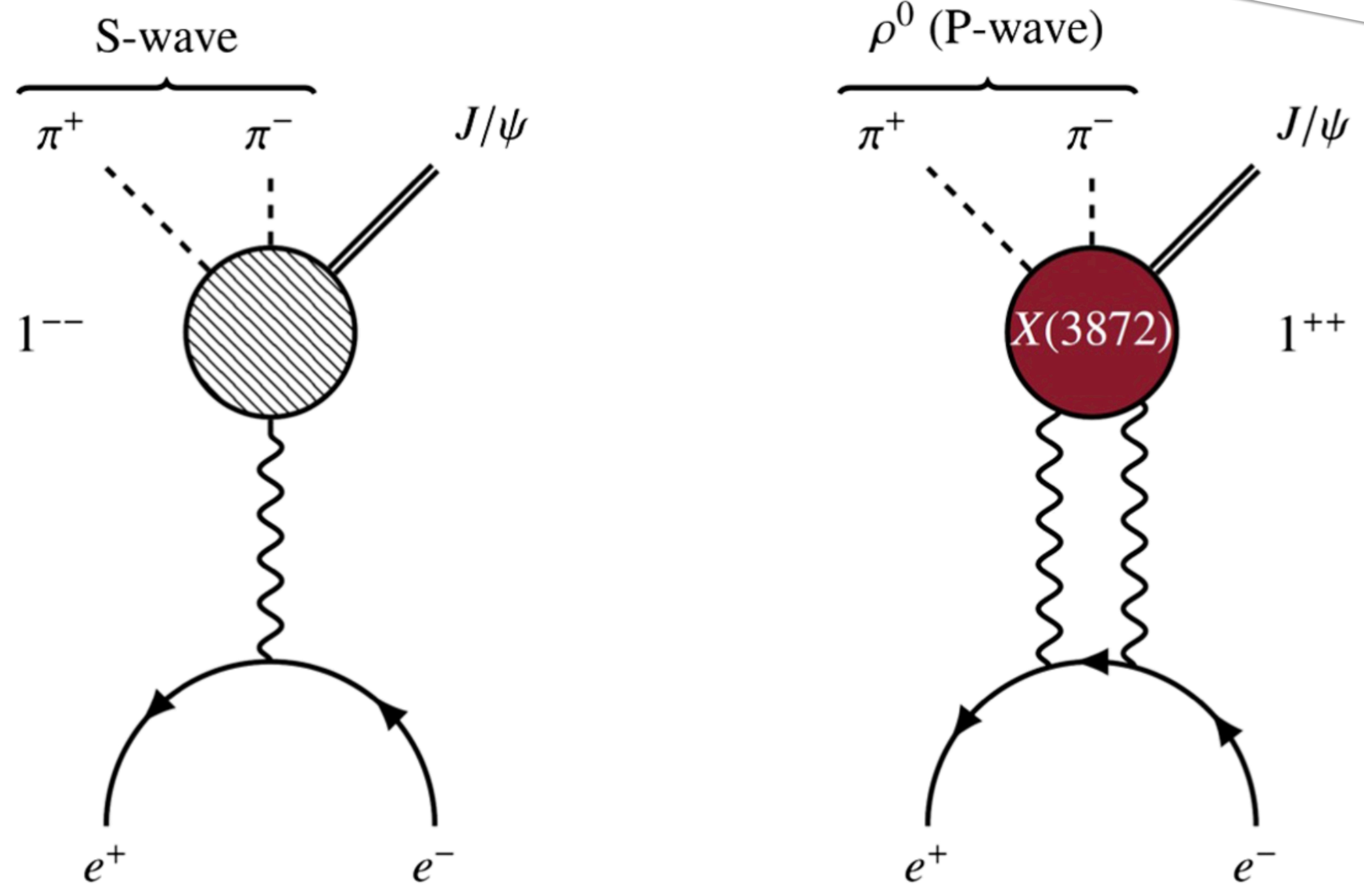
[6] Rev. Mod. Phys. **90**, 015004 (2018)
[7] Phys. Rev. D **106**, 074015 (2022)

Search for X(3872) Direct Production

Phys. Rev. D **107**, 032007 (2023)

Using 4 energy points **around the X(3872) mass**

Search for the $e^+e^- \to$ **X(3872) → $\pi^+\pi^-$J/ψ** process



The **Belle** collaboration found **evidence of** the **X(3872) in** the $e^+e^- \to e^+e^-\pi^+\pi^-J/\psi$ **two-photon interactions** process[8]

The **BESIII** collaboration has **observed** the **direct production of** the **χ_{c1}(1P)** charmonium state[9]

[8] Phys. Rev. Lett. **126**, 122001 (2021)
[9] Phys. Rev. Lett. **129**, 122001 (2022)

Search for X(3872) Direct Production

Using 4 energy points **around the X(3872) mass**

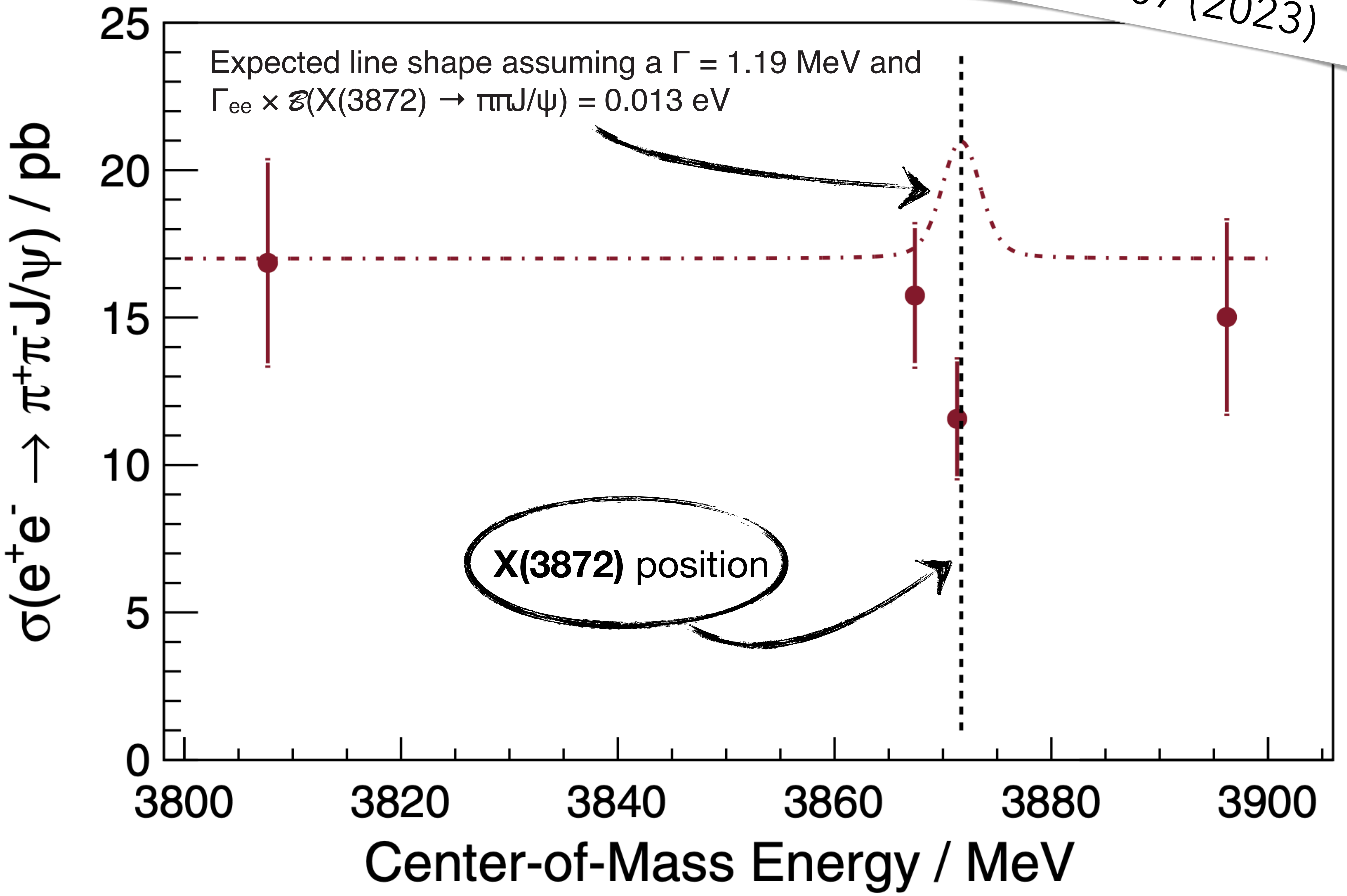
Search for the $e^+e^- \to$ **X(3872) → $\pi^+\pi^-J/\psi$** process

Fit to M($\pi^+\pi^-J/\psi$) to estimate the upper limits to the direct production

The **U.L.** on $\Gamma_{ee} \times \mathcal{B}(X(3872) \to \pi^+\pi^-J/\psi)$ is 7.5×10^{-3} eV **@90% C.L.** (17 times tighter than the previous one!), with **$\Gamma_{ee} < 0.32$ eV**

Ref. [10] reports **$\Gamma_{ee} \gtrsim 0.03$ eV** and a lower bound of $\Gamma_{ee} \times \mathcal{B}(X(3872) \to \pi^+\pi^-J/\psi) \gtrsim 0.96 \times 10^{-3}$ eV, **using VMD** and making **no structure assumptions**

Phys. Rev. D **107**, 032007 (2023)



[10] Phys. Lett. B **736**, 221–225 (2014)

Search for a Scalar Partner of the X(3872)

Phys. Rev. D **108**, 052012 (2023)

Using the data sample of the ψ**(3770)**

The X(3700), a lighter scalar parter of the **X(3872), is searched via the $\gamma\pi^+\pi^- J/\psi$ and $\gamma\eta\eta'$** processes

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Phys. Rev. D **108**, 052012 (2023)

Using the data sample of the **ψ(3770)**

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Before 2010 **hints** of the existence **of X(3700)**[11, 12], a bump in the $D\bar{D}$ spectrum **by Belle**[13] and enhancement above the $D\bar{D}$ threshold was both seen **by BABAR**[14] in the reaction $\gamma\gamma \to D\bar{D}$

[11] Eur. Phys. J. A **36**, 189 (2008)
[12] Eur. Phys. J. A **57**, 38 (2021)
[13] Phys. Rev. Lett. **100**, 202001 (2008)
[14] Phys. Rev. D **81**, 092003 (2010)

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Under **molecular assumptions**[15], the **main decay** of the **X(3700) is to ηη'**, with

$[\mathcal{B}(\psi(3770) \to \gamma X(3700)) \times \mathcal{B}(X(3700) \to \eta\eta')] \sim 1.08\times10^{-5}$

[11] Eur. Phys. J. A **36**, 189 (2008)
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[15] Eur. Phys. J. A **49**, 52 (2013)

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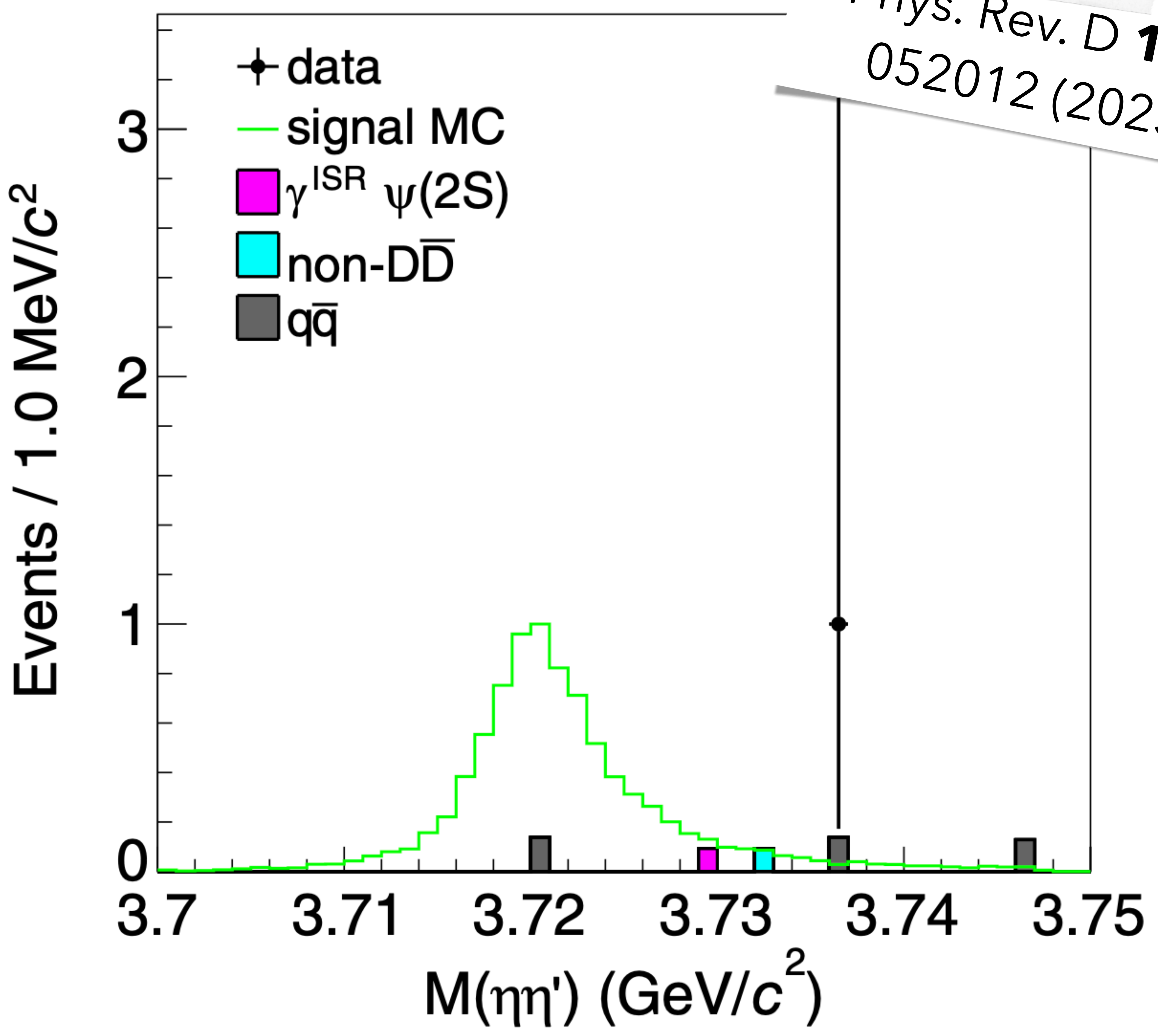
[$\mathcal{B}$(ψ(3770) → γX(3700)) x $\mathcal{B}$(X(3700)→ηη')] ~ 1.08×10^{-5}

The U.L. for $\mathcal{B}$(ψ(3770) → γX(3700)) x $\mathcal{B}$(X(3700)→ηη') are [0.9 - 1.9] × 10^{-5}

Also no significant signals to $\pi^+\pi^-$**J/ψ** are found
The U.L. are calculated to be from [0.9 - 3.4] ×10^{-5}



Phys. Rev. D **108**, 052012 (2023)

[15] Eur. Phys. J. A **49**, 52 (2013)

A coupled-channel analysis of the X(3872) line-shape with BESIII data

arXiv:**2309.01502v1**
Submitted to PRL

Using 11 energy points @√**s = [4.178, 4.278] GeV**

Study of the **X(3872)** production **line-shape**

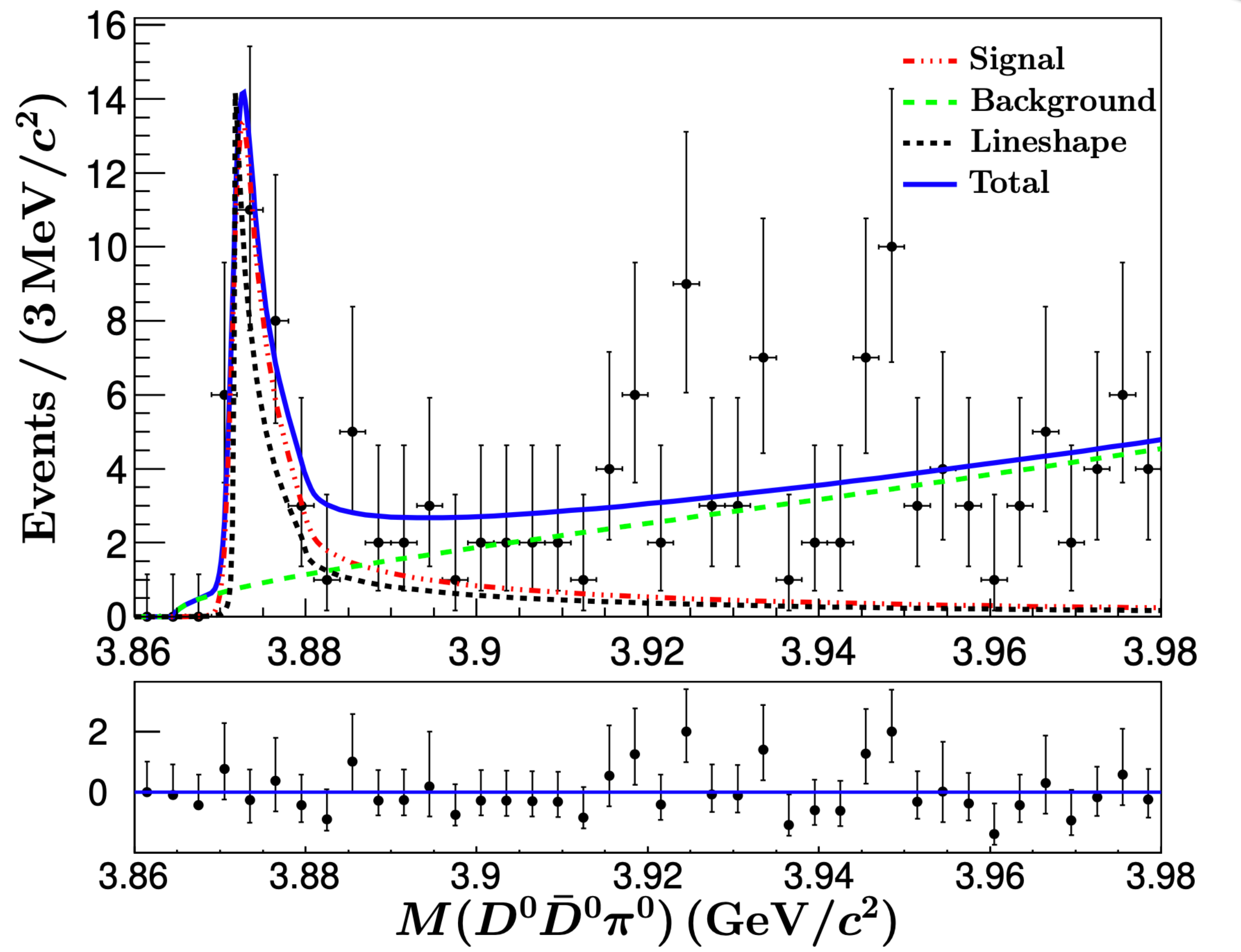
Simultaneous fit to the invariant masses of the two X(3872) decay channels ($D^0\bar{D}^0\pi^0$ e $\pi^+\pi^- J/\psi$)

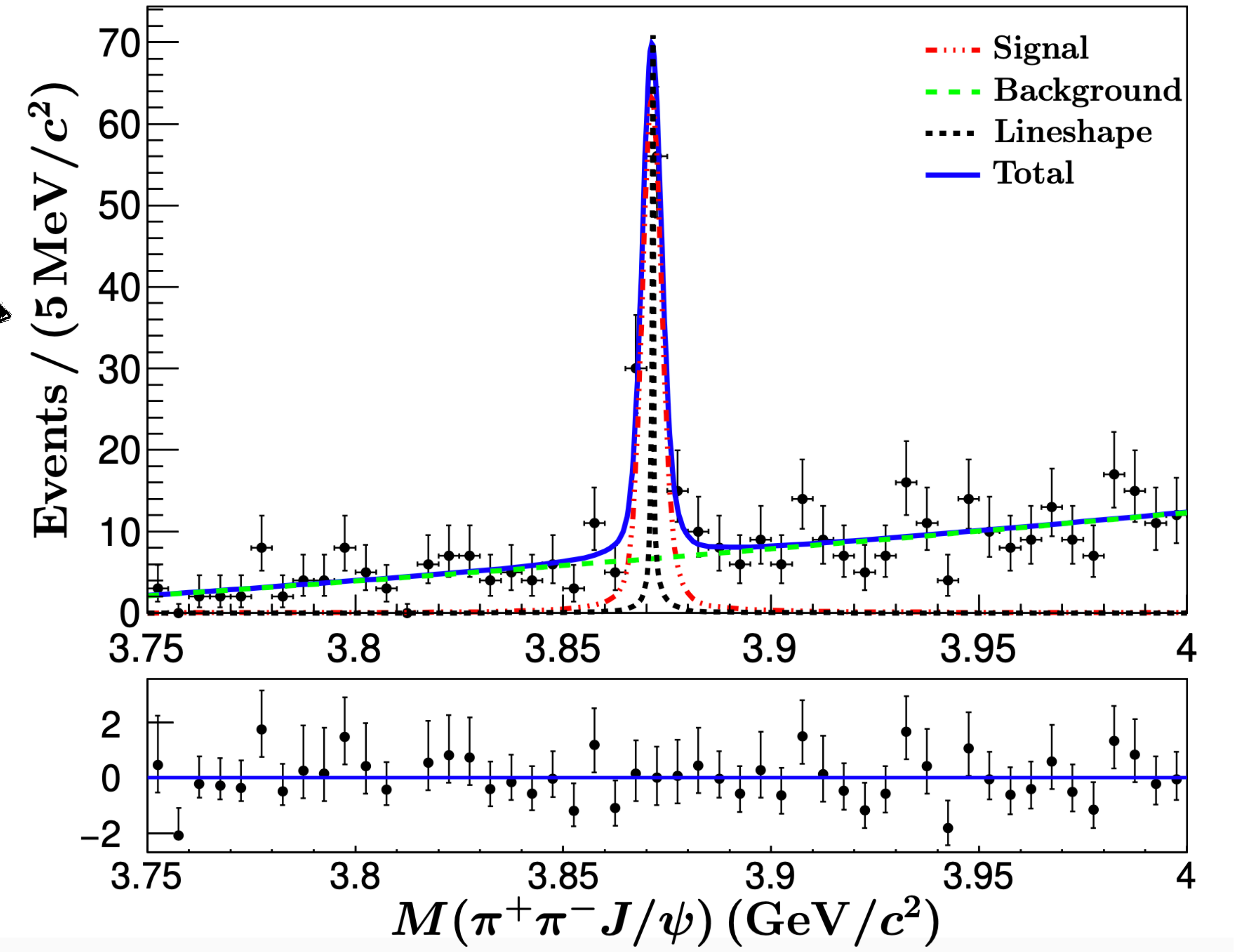
Signal parametrisation is from Ref. [16]

$$\frac{d\mathrm{Br}(D^0\bar{D}^0\pi^0)}{dE} = \mathcal{B}\frac{\mathrm{Br}(D^{*0}\to D^0\pi^0)\times g\times k_{\mathrm{eff}}(E)}{|D(E)|^2}$$

$$\frac{d\mathrm{Br}(\pi^+\pi^- J/\psi)}{dE} = \mathcal{B}\frac{\Gamma_{\pi^+\pi^- J/\psi}}{|D(E)|^2}$$

$$D(E) = E - E_X + \tfrac{1}{2}g\left[(\kappa_{\mathrm{eff}}(E) + ik_{\mathrm{eff}}(E)) + (\kappa^c_{\mathrm{eff}}(E) + ik^c_{\mathrm{eff}}(E))\right] + \tfrac{i}{2}\Gamma_0$$





[16] Phys. Rev. D 81, 094028 (2010)

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$\mathcal{B}$ → Encapsulates X(3872) production terms

g → X(3872) - $D^*\bar{D}$ effective coupling constant

$\kappa_{\mathrm{eff}} + ik_{\mathrm{eff}}$, $\kappa^c_{\mathrm{eff}} + ik^c_{\mathrm{eff}}$ → Self-energy term, i.e., parametrisation of the coupling to the $D^*\bar{D}$ channels

Γ_0 → Amplitude of all decay channels, but $D^*\bar{D}$

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$$\left(-\sqrt{-2\left(E - E_R + \frac{i\Gamma_{D^{*0}}}{2}\right)} + \text{cost}\right)$$

Self-energy term, i.e., parametrisation of the coupling to the $D^*\bar{D}$ channels

Amplitude of all decay channels, but $D^*\bar{D}$

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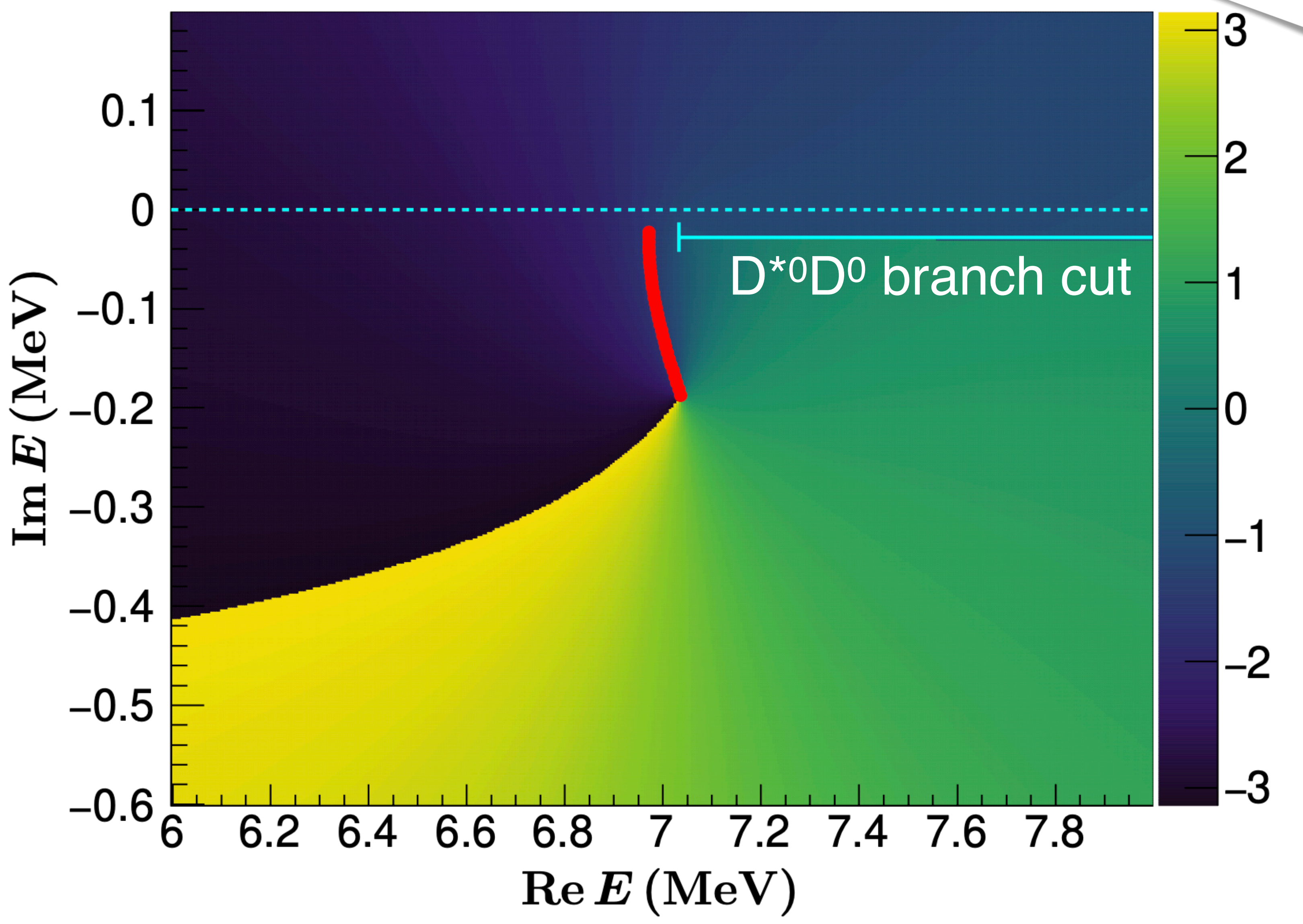
The $D^*\bar{D}$ term of the parametrisation identifies two Riemann sheets

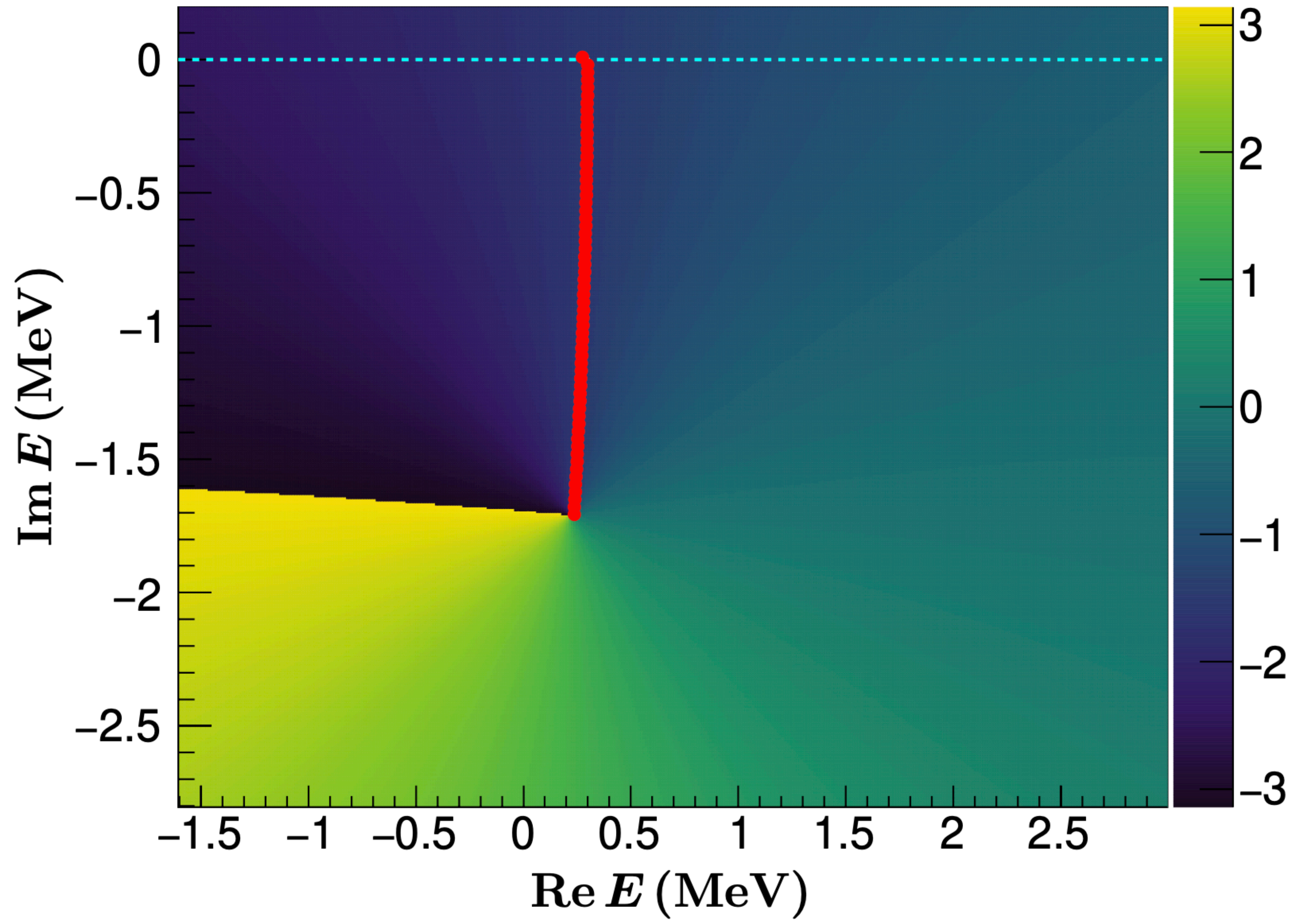
$$\mathrm{I}: \quad -g\sqrt{-2\left(E-E_R+\frac{i\Gamma_{D^{*0}}}{2}\right)}+i\Gamma_0$$

$$\mathrm{II}: \quad +g\sqrt{-2\left(E-E_R+\frac{i\Gamma_{D^{*0}}}{2}\right)}+i\Gamma_0$$

"***Switching off***" Γ_0, all the decay channels, but the $D^*\bar{D}$, disappear, showing that the E_I pole is the nearest to the $D^{*0}\bar{D}^0$ threshold

$$E_I = (7.04 \pm 0.15^{+0.07}_{-0.08}) + i(-0.19 \pm 0.08^{+0.14}_{-0.19})\ \mathrm{MeV}$$





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$$D(k) = \frac{1}{a} - ik + \frac{r_e}{2}k^2 + \mathcal{O}(k^3)$$

$$a = -\frac{2(1-Z)}{(2-Z)}\frac{1}{\gamma} + \mathcal{O}(\beta^{-1})$$

$$r_e = -\frac{Z}{1-Z}\frac{1}{\gamma} + \mathcal{O}(\beta^{-1})$$

BONUS

Effective Range Expansion parameters are also estimated (a and r_e found to be negative) and a **Z = 0.18**$^{+0.20}_{-0.23}$ is found (with big uncertainties!), suggesting a **similar compositeness to the deuteron**

"This is qualitatively different from a bona fide loosely bound molecule, for which Z = 0 and r_0 > 0"

PHYS. REV. D **105**, L031503 (2022)

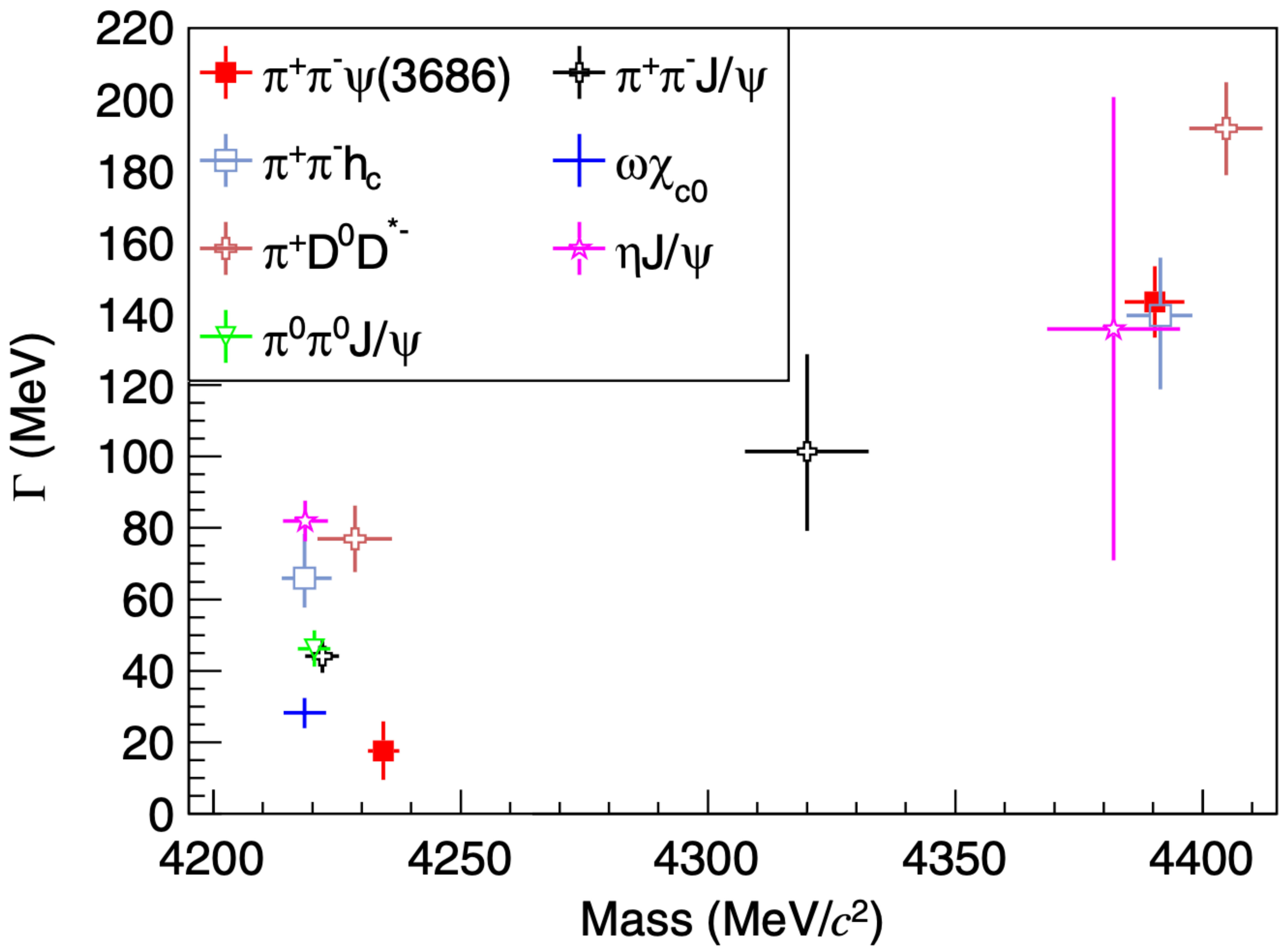
Y(4230)

Y states rose up showing **unexpected features**, interpreted as states, in **exclusive e^+e^- cross-sections**

Observed by the **BaBar** collaboration[17], **BESIII** allowed to **disentangle** two resonant structure around 4.23 GeV/c² and 4.32 GeV/c²

Looking at the inclusive cross-section the Y(4230) shows a dip around 4.26 GeV, suggesting a non-standard $c\bar{c}$ structure

BESIII discovered many of its decay channels and observed the transition to the X(3872)[4] and the Z_c(3900)[18] states suggesting a possible common nature



[17] Phys. Rev. Lett. **95**, 142001 (2015)
[4] Phys. Rev. Lett. E **112**, 092001 (2014)
[18] Phys. Rev. D **102**, 012009 (2020)

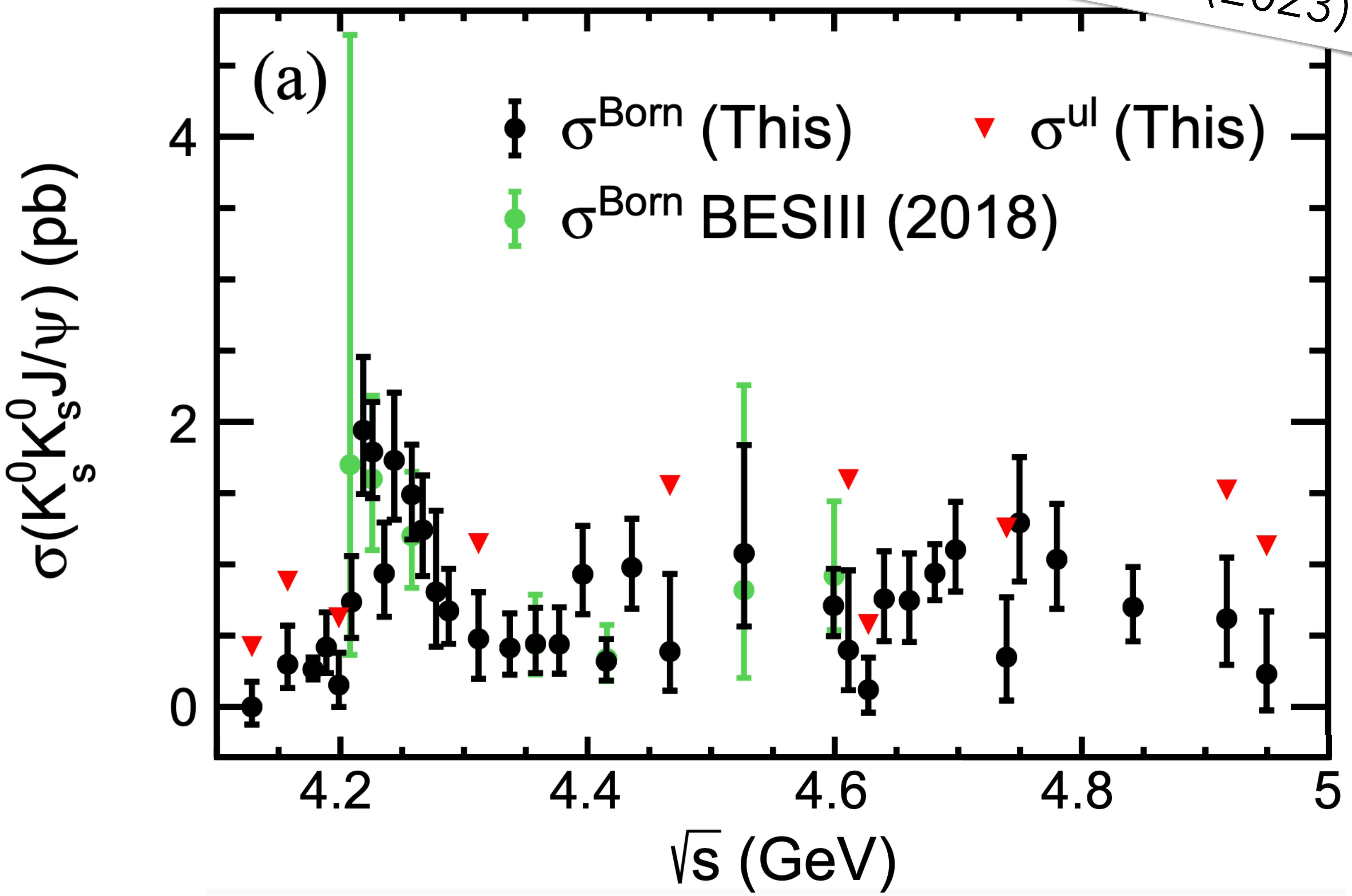
The Y(4230) → $K^0_S K^0_S J/\psi$ Cross-sections

Using 36 energy points @$\sqrt{s}$ = **[4.128, 4.951] GeV**

Study of the $\boldsymbol{\sigma^{Born}}(e^+e^- \to$ **$K^0_S K^0_S J/\psi$),** already measured by the Belle collaboration[19], but only U.L. were provided

Fit to M(**J/ψ**) to estimate the Born cross-section

Phys. Rev. D **107**, 092005 (2023)



[19] Phys. Rev. D **89**, 072015 (2014)

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Fit to M(**J/ψ**) to estimate the Born cross-section

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

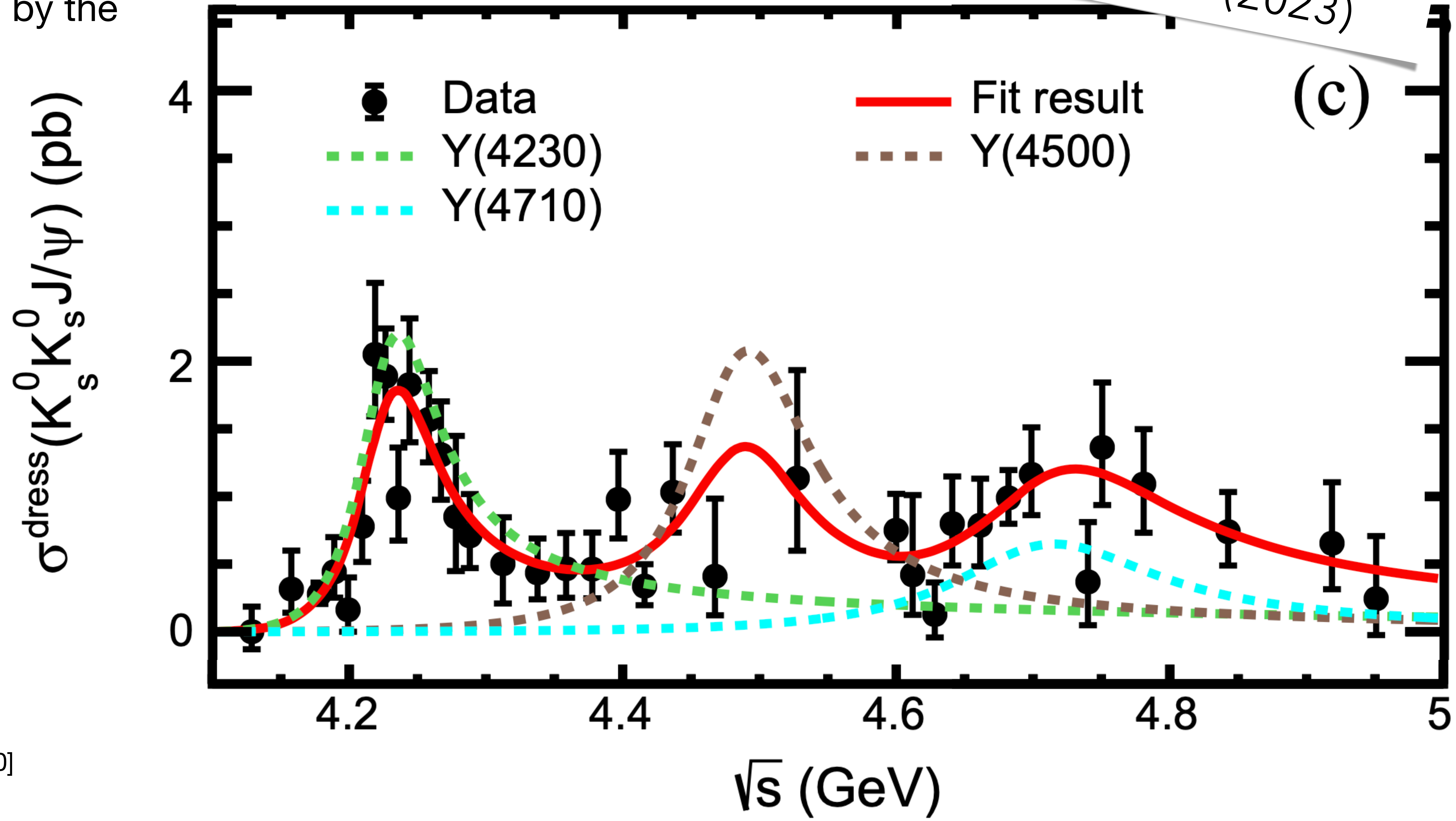
1) Y(4230), observed clearly (~26σ significance) for the first time

2) Y(4500), already seen in the $e^+e^- \to$ **K^+K^-J/ψ** process [this resonance has little influence over the total fit]

3) Y(4710), parameters are 1σ away from those of the Y(4660), a possible candidate for the ψ**(5S)**[20]

Phys. Rev. D **107**, 092005 (2023)

$$\sigma^{\text{dress}} \equiv |BW_1 + BW_2 e^{i\phi_2} + BW_3 e^{i\phi_3}|^2$$



[19] Phys. Rev. D **89**, 072015 (2014)
[20] Phys. Rev. D **98**, 016010 (2018)

More Exclusive Cross-sections

The J/ψ → φ switcheroo

Phys. Rev. D **108**, 032004 (2023)

Using 33 energy points @**$\sqrt{s}$ = [3.773, 4.701] GeV**

Study of the **σ^{Born}($e^+e^-\to K^0_S K^0_S \phi$) and σ^{Born}($e^+e^-\to K^+K^-\phi$)**

Fit to M(**ϕ**) to estimate the Born cross-section

In Ref. [21], the **Y(4230)** is interpreted as a **compact tetraquark** $cs\bar{c}\bar{s}$, which would lead to **decays into final states containing $s\bar{s}$**. This is supported by the evidence of the $Z_c(3900)$ in the process $e^+e^- \to Y(4230) \to \pi^+\pi^- J/\psi$[22]

[21] Phys. Rev. D **72**, 031502 (2005)
[22] Phys. Rev. Lett. **119**, 072001 (2017)

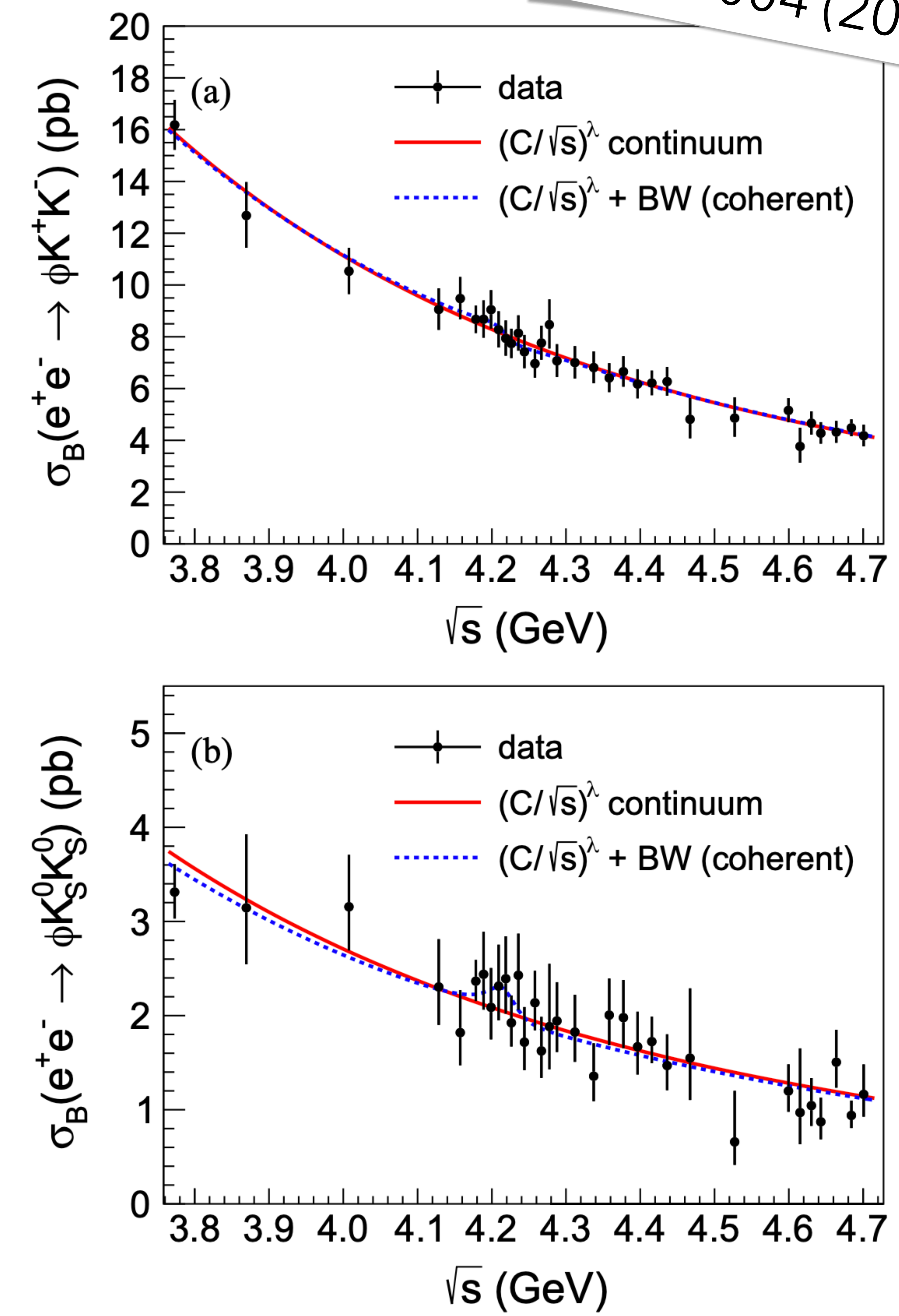
More Exclusive Cross-sections
The $J/\psi \rightarrow \phi$ switcheroo

Phys. Rev. D **108**, 032004 (2023)

Using 33 energy points @$\sqrt{s}$ **= [3.773, 4.701] GeV**

Study of the $\boldsymbol{\sigma^{Born}}$**(**$e^+e^- \rightarrow$ **$K^0_S K^0_S \phi$) and** $\boldsymbol{\sigma^{Born}}$**(**$e^+e^- \rightarrow$ **$K^+K^-\phi$)**

Fit to M(**ϕ**) to estimate the Born cross-section



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No evidence for a resonant contribution is found, suggesting the **Y(4230) prefers to preserve** its **charm** content

[21] Phys. Rev. D **72**, 031502 (2005)
[22] Phys. Rev. Lett. **119**, 072001 (2017)

The Y(4230) → η J/ψ Cross-section

arXiv:**2310.03361v1**
Submitted to PRD

Using 44 energy points @**$\sqrt{s}$ = [3.808, 4.951] GeV**

Study of the **σ^{Born}(e^+e^-→ ηJ/ψ)**

Search for the ψ(3770) → η J/ψ decay, and **study of the $\sigma^{Dressed}$(e^+e^- → η J/ψ) line-shape @$\sqrt{s}$ = [3.773, 4.600] GeV**

Assuming the Y(4230) is a **conventional ψ(4S)**, the expected $\mathcal{B}$(ψ(4S) → ηJ/ψ) is ~ 1.9×10^{-3} [23]

Assuming a **hadronic molecular state**, Refs. [24] predicts $\mathcal{B}$(Y(4230) → ηJ/ψ) to be [2.52×10^{-6}, 13.92×10^{-4}]

[23] Phys. Rev. D **91**, 094023 (2015)
[24] Phys. Rev. D **88**, 094008 (2013)

The Y(4230) → ηJ/ψ Cross-section

Using 44 energy points @$\sqrt{s}$ = **[3.808, 4.951] GeV**

Study of the $\boldsymbol{\sigma^{Born}(e^+e^- \to \eta J/\psi)}$

Search for the ψ(3770) → η J/ψ decay, and **study of the $\boldsymbol{\sigma^{Dressed}(e^+e^- \to \eta J/\psi)}$ line-shape @$\sqrt{s}$ = [3.773, 4.600] GeV**

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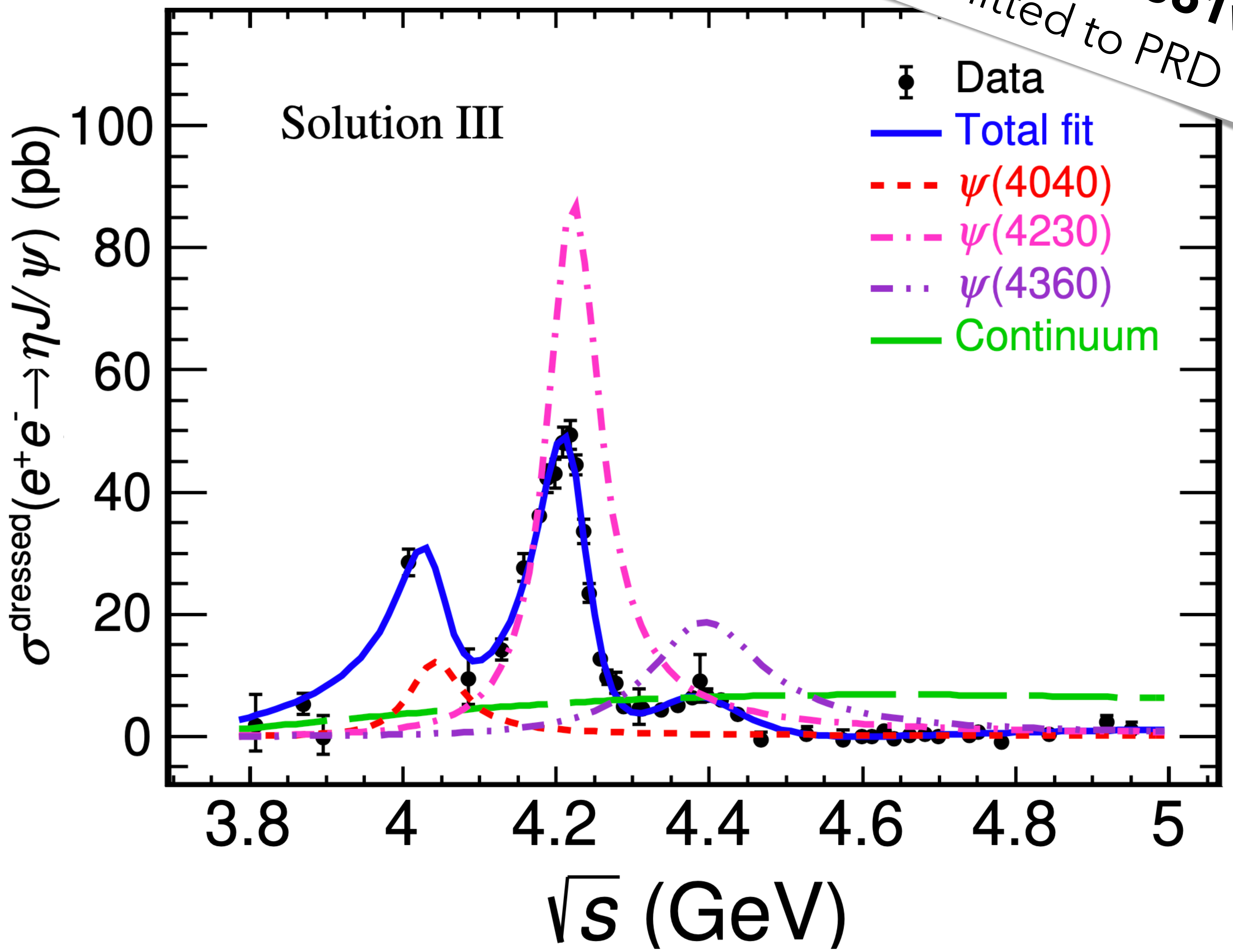
$\mathcal{B}$(Y(4230) → ηJ/ψ) is estimated to be in the range of

(6.06 ± 0.76 ± 0.17) × 10^{-3} to (18.89 ± 1.75 ± 0.90) × 10^{-3}

arXiv:**2310.03361v1**
Submitted to PRD



[23] Phys. Rev. D **91**, 094023 (2015)
[24] Phys. Rev. D **88**, 094008 (2013)

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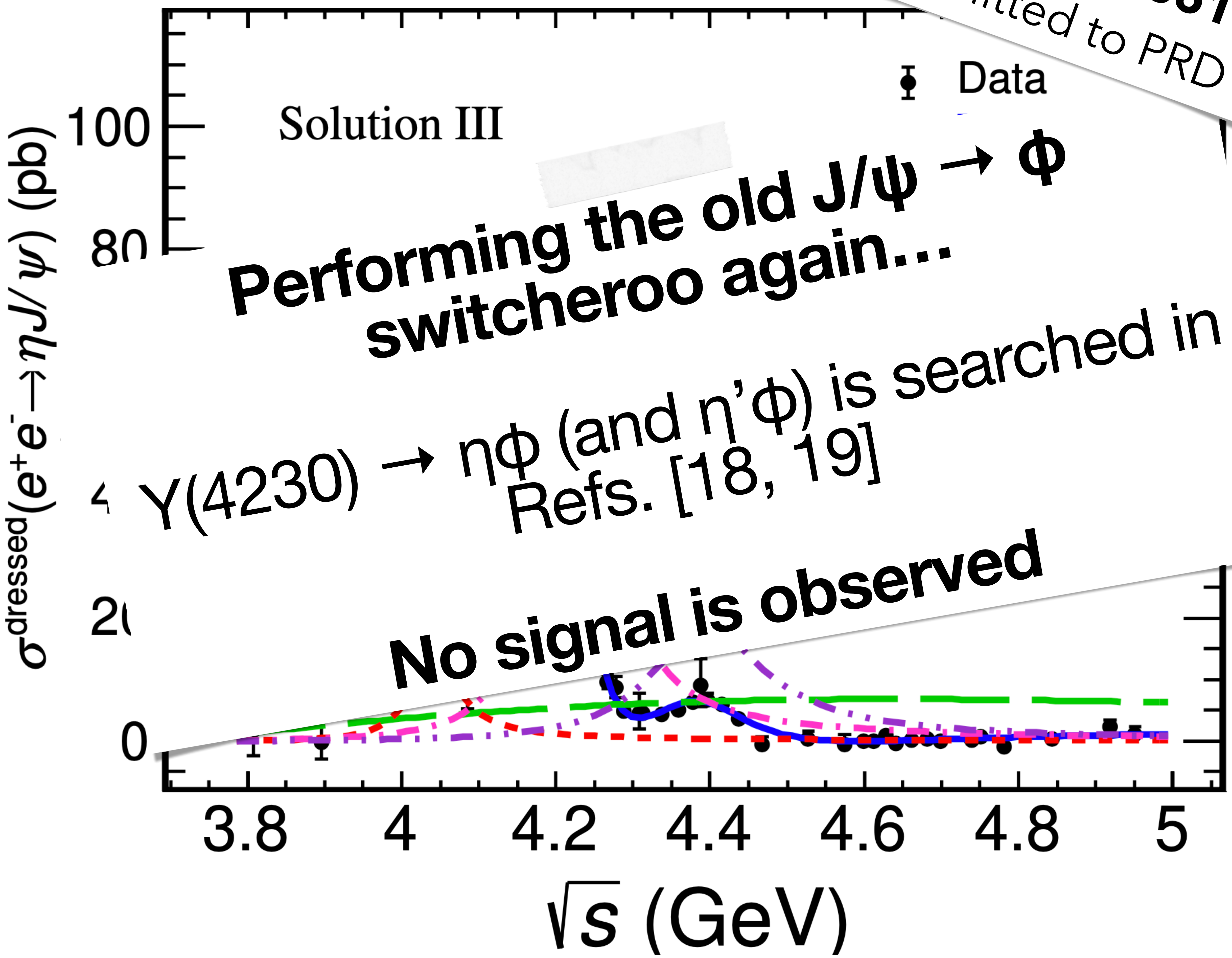


Performing the old J/ψ → ϕ switcheroo again…

Y(4230) → ηϕ (and η'ϕ) is searched in Refs. [18, 19]

No signal is observed

[23] Phys. Rev. D **91**, 094023 (2015)
[24] Phys. Rev. D **88**, 094008 (2013)

Charming Excited Cross-Sections

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

Using 86 energy points @$\sqrt{s}$ = **[4.19, 4.95] GeV**

Study of the $\boldsymbol{\sigma(e^+e^- \to \pi^+ D^{*0} D^{*-})}$

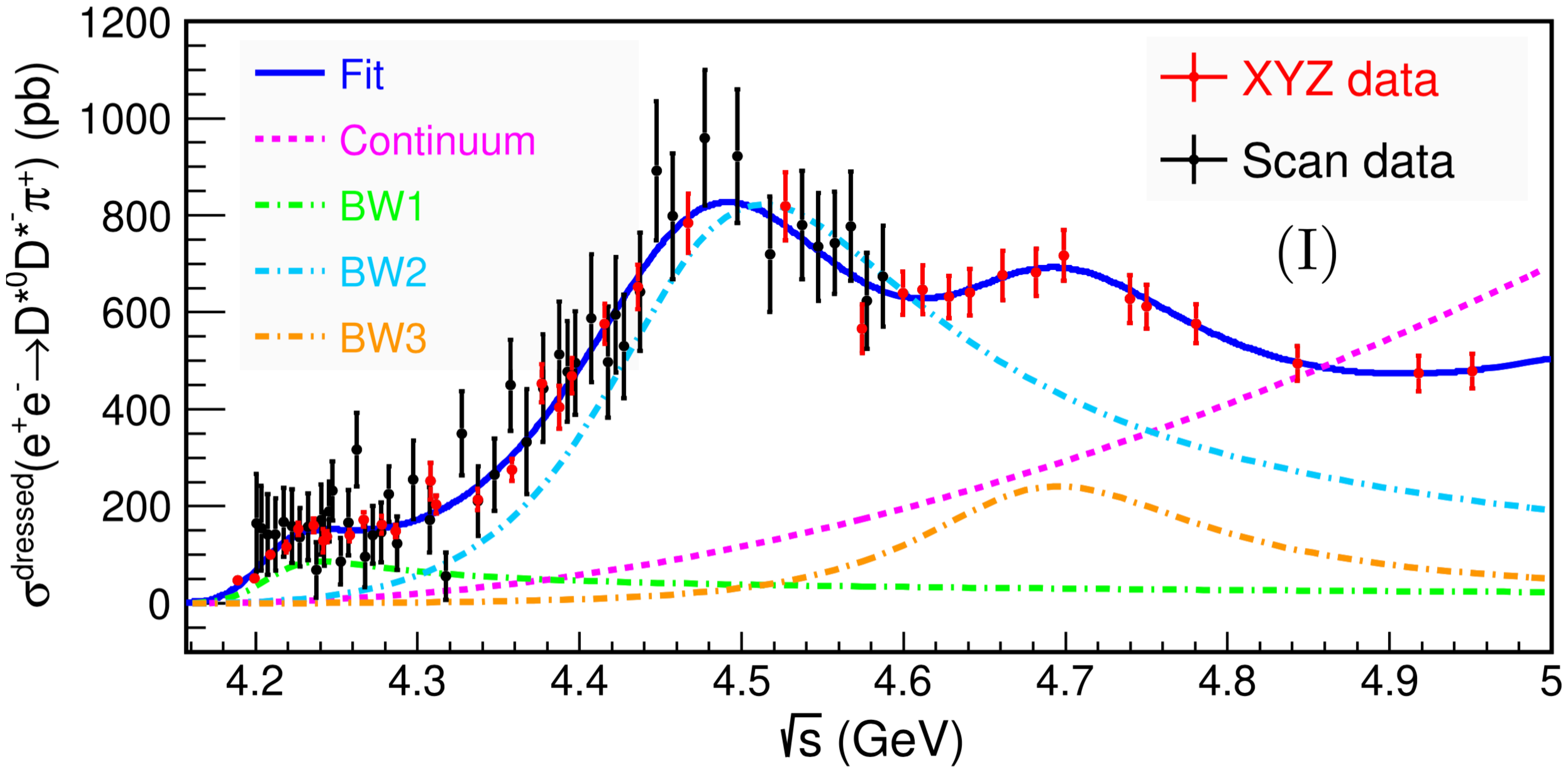
Simultaneous fit to $M^{recoil}(\pi^+ D^0 \pi^0)$ and $M^{recoil}(\pi^+ D^- \pi^0)$ to estimate $\boldsymbol{\sigma}^{Dressed}$

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

1) **Y(4230)**, its **electronic width** measurement **(~40 eV) disfavours hybrid interpretation** under lattice QCD calculation[25]

2) Y(4500), the $\mathcal{B}(\psi \to \boldsymbol{\pi^+ D^{*0} D^{*-}}) > \mathcal{B}(\psi \to K^+K^- J/\psi)$ is inconsistent with a hidden-strangeness tetraquark[26]

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



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

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

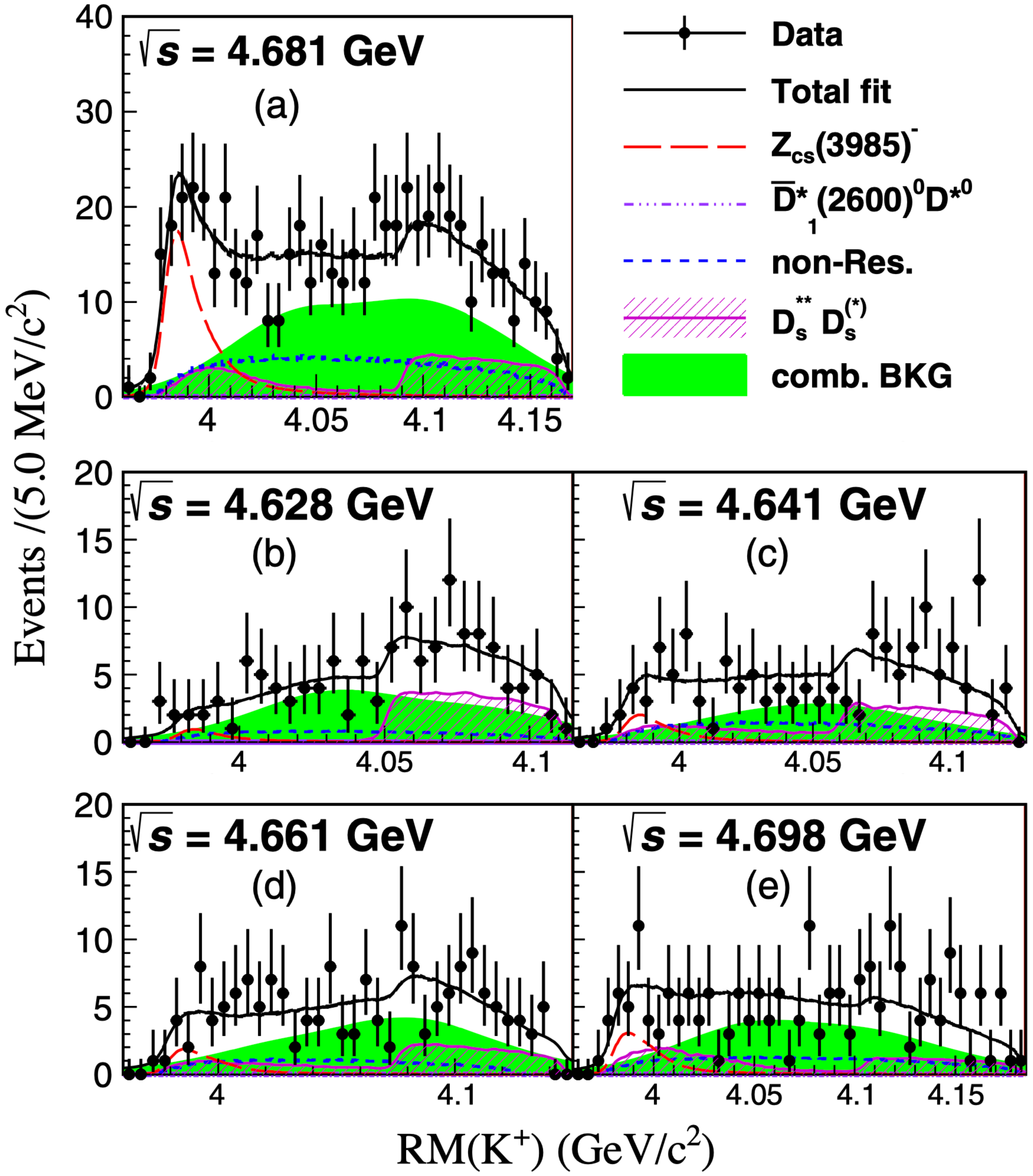
The "New" Z_{cs} States

Charged structures seem to hint at a completely **exotic nature**, as they require a minimum quark content of at least four

As these features present themselves **near $D(*)_{(s)}D(*)_{(s)}$ thresholds**, they might be as well threshold cusps

In 2021, **BESIII** found the **first isospin-1/2 charged state with** obvious **open-strange content**, the $Z_{cs}(3985)$[27]

Then, the LHCb collaboration reported[28] the $Z_{CS}(4000)$ candidate in the K^+J/ψ final state, the mass of which is consistent with the $Z_{CS}(3985)$, but with a width 10 times bigger



[27] Phys. Rev. Lett. **126**, 102001 (2021)
[28] Phys. Rev. Lett. **127**, 082001 (2021)

The Spin Partner $Z_{cs}(3985)^0$

Phys. Rev. Lett. **129**, 112003 (2022)

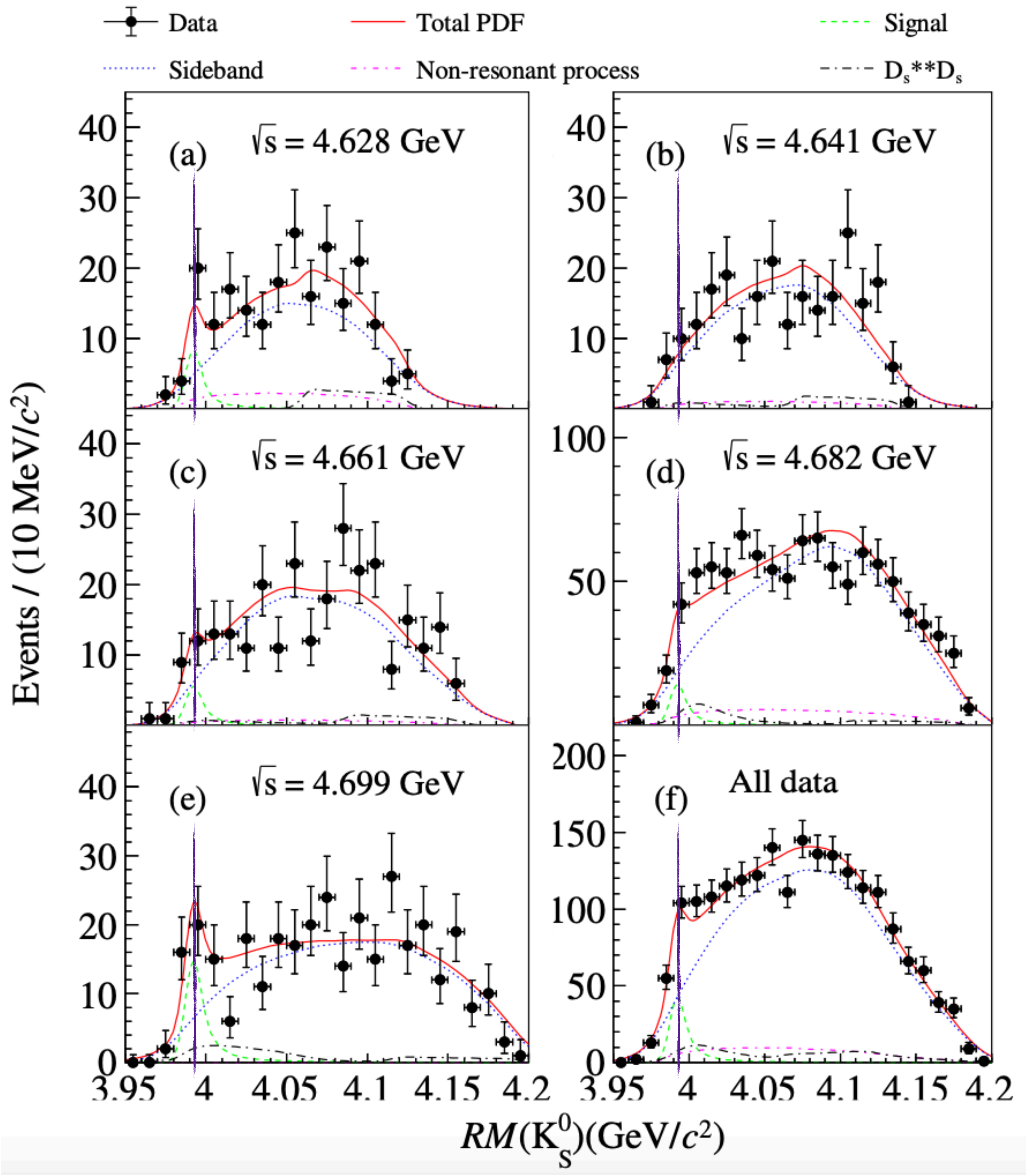
Using 5 data sets @$\sqrt{s}$ = [4.628, 4.699] GeV

In K_S^0 recoil-mass spectrum, evidence in $e^+e^- \rightarrow K_S^0(D_s^- D^{*+} + D_s^{*-} D^+)$ of a near-threshold structure @4.6σ

Coupling to $D_s^- D^{*+}$ and $D_s^{*-} D^+$ suggests $c\bar{c}s\bar{d}$

m(Z_{cs}^0) > m(Z_{cs}^+), which is **consistent with predictions**[29] in either a molecular or compact tetraquark framework

	Mass (MeV/c^2)	Width (MeV)
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$



[29] Nucl. Phys. B **968**, 115450 (2021)

σ^Born x $\mathcal{B}$ is found to be **consistent with** the **charged partner**

It is concluded that **Z_{cs}^0** is the **isospin** partner of **Z_{cs}^+**

$\sqrt{s}$ (MeV)	$\sigma^{Born} \times \mathcal{B}$ (pb) $\bar{K}^0 Z_{cs}(3985)^0$	$K^- Z_{cs}(3985)^+$
4628	$4.4^{+2.6}_{-2.2} \pm 2.0$	$0.8^{+1.2}_{-0.8} \pm 0.6$
4641	$0.0^{+1.6}_{-0.0} \pm 0.2$	$1.6^{+1.2}_{-1.1} \pm 1.3$
4661	$2.8^{+1.8}_{-1.6} \pm 0.6$	$1.6^{+1.3}_{-1.1} \pm 0.8$
4682	$2.2^{+1.2}_{-1.0} \pm 0.8$	$4.4^{+0.9}_{-0.8} \pm 1.4$
4699	$7.0^{+2.2}_{-2.0} \pm 1.8$	$2.4^{+1.1}_{-1.0} \pm 1.2$

$Z_{cs}(3985)$ vs $Z_{cs}(4000)$

arXiv:**2308.15362v1**
Submitted to PRL

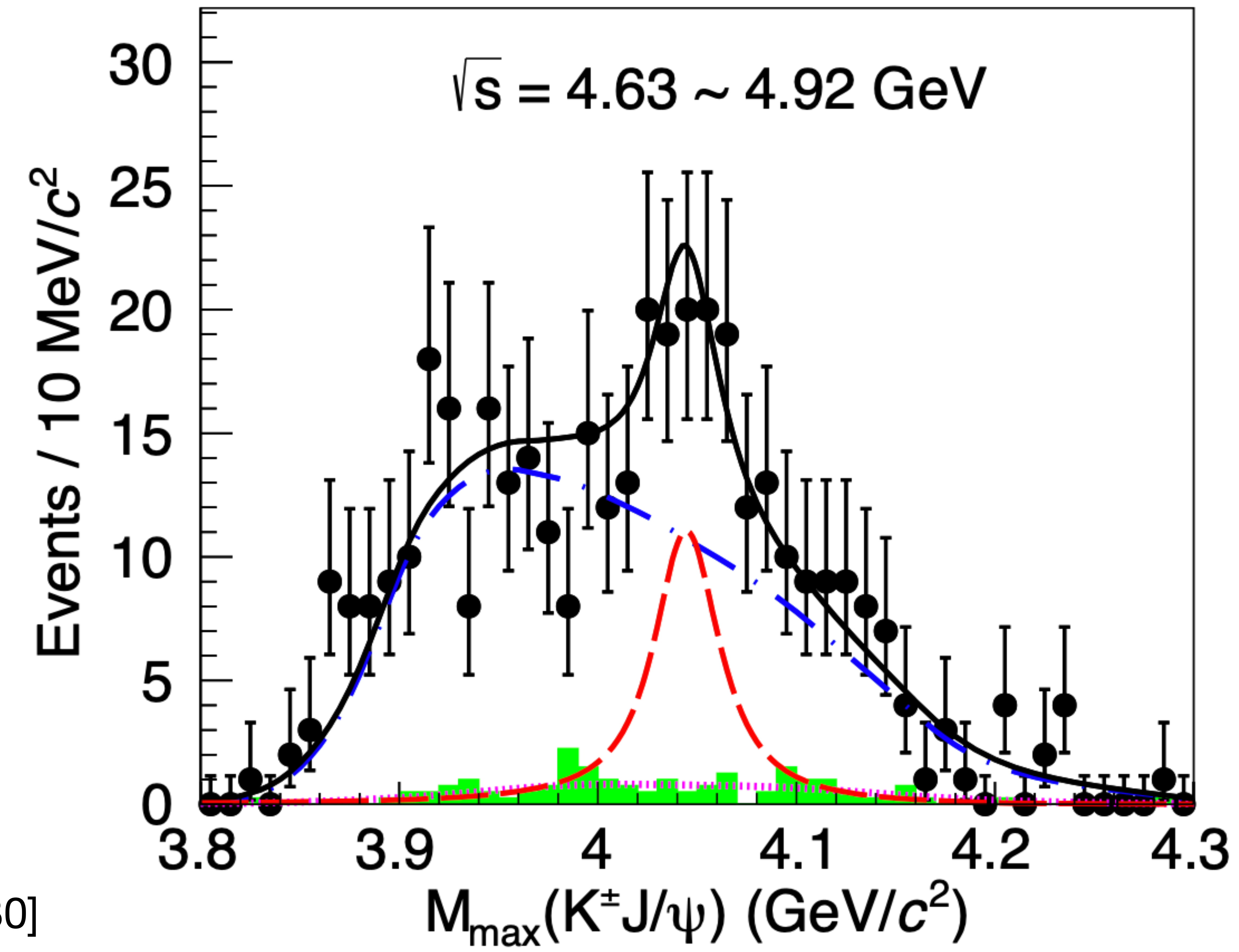
Using 12 energy points @√s = **[4.61, 4.95] GeV**

Study of the **σ^{Born}(e^+e^-→ K^+K^-J/ψ),** and investigate the KJ/ψ invariant mass

No significant Z_{cs} is found (~2.3**σ**)

σ(ee → KZ_{cs}(3985)) × B(Z_{cs}(3985) → K**J/ψ**) ~ O(1) pb, while
σ(ee → KZ_{cs}(4000)) × B(Z_{cs}(4000) → K**J/ψ**) ~ O(3) pb

$$R_B \equiv \frac{\mathcal{B}(Z_{cs}(3985)^+ \to K^+ J/\psi)}{\mathcal{B}(Z_{cs}(3985)^+ \to (\bar{D}^0 D_s^{*+} + \bar{D}^{*0} D_s^+))} < 0.03$$



The **suppression of the Z_{cs}(3985) → KJ/ψ** decay disfavours Ref. [30] under the molecular state assumption, **supporting** the fact that **Z_{cs}(3985) and Z_{cs}(4000)** are **two different states**[31]

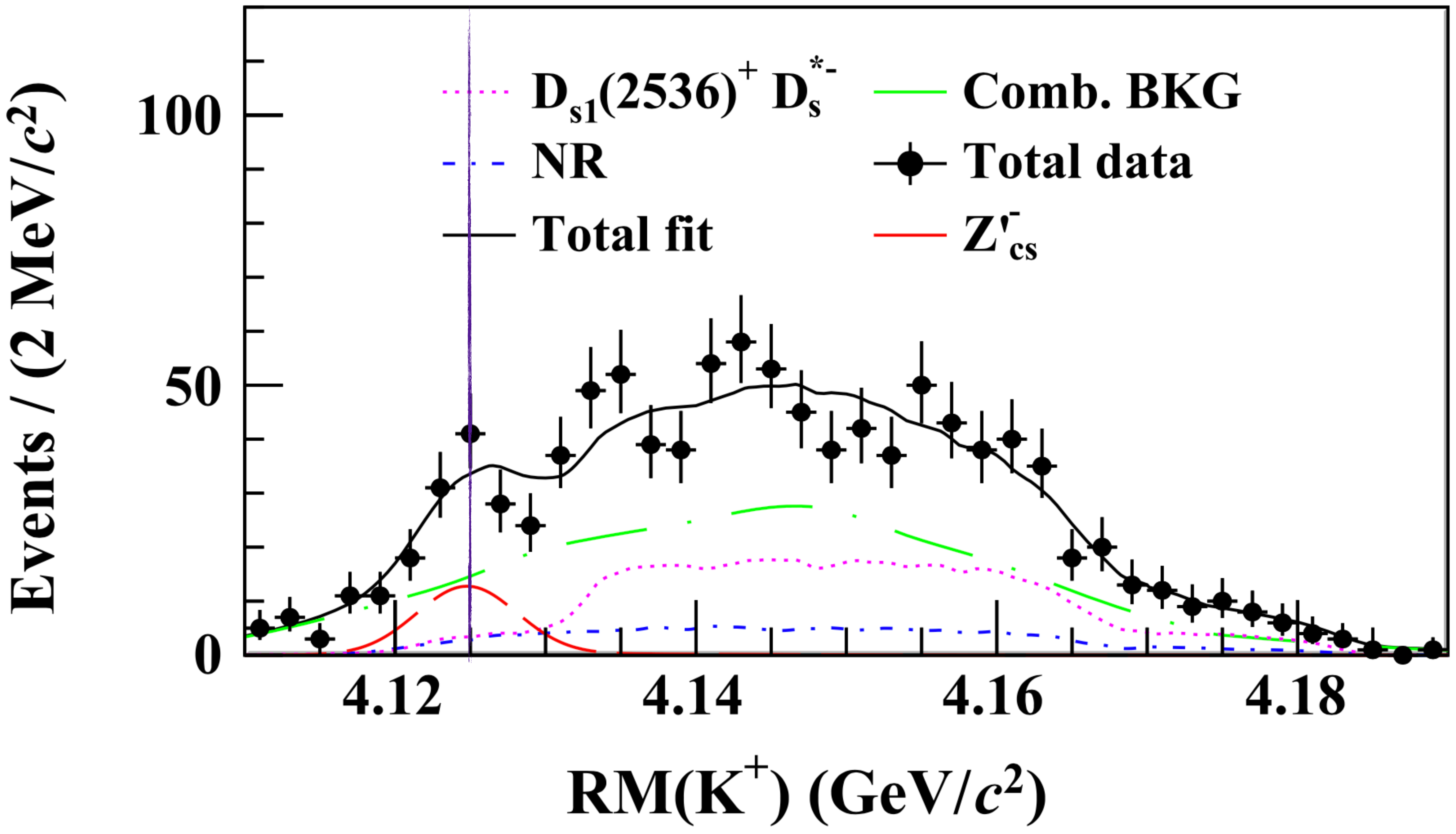
[30] Phys. Rev. D **88**, 096014 (2013)
[31] Sci. Bull. **66**, 2065-2071 (2021)

An Heavier Partner, the Z'$_{cs}$

Chinese Physics C **47**, 3 033001 (2023)

Using 3 energy points @$\sqrt{s}$ = **[4.61, 4.70] GeV**

Study of the **σ^{Born}($e^+e^- \to K^+(D^*_s{}^- D^0)$ + c.c.)**



Z'_{cs} state is expected to decay abundantly to D^*_sD with masses ranging from 4120 to 4200 MeV/c^2 following different models

E.g., Ref. [32] predicts a 4124 MeV/c^2 mass under a D^*_sD molecular hypothesis

No significant Z'$_{cs}$ (2.1σ) after systematic uncertainties, the statistical local significance is 4.1σ

$M_{Z'_{cs}}$ = (4123.5 ± 0.7 ± 4.7) MeV/c^2

[32] Phys. Rev. D **103**, L021501 (2021)

Summary

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

Datasets above the **$D\bar{D}$ threshold** can shed new light on charmonium decays and hint at possible **connections** between **XYZ states and** conventional **charmonia**

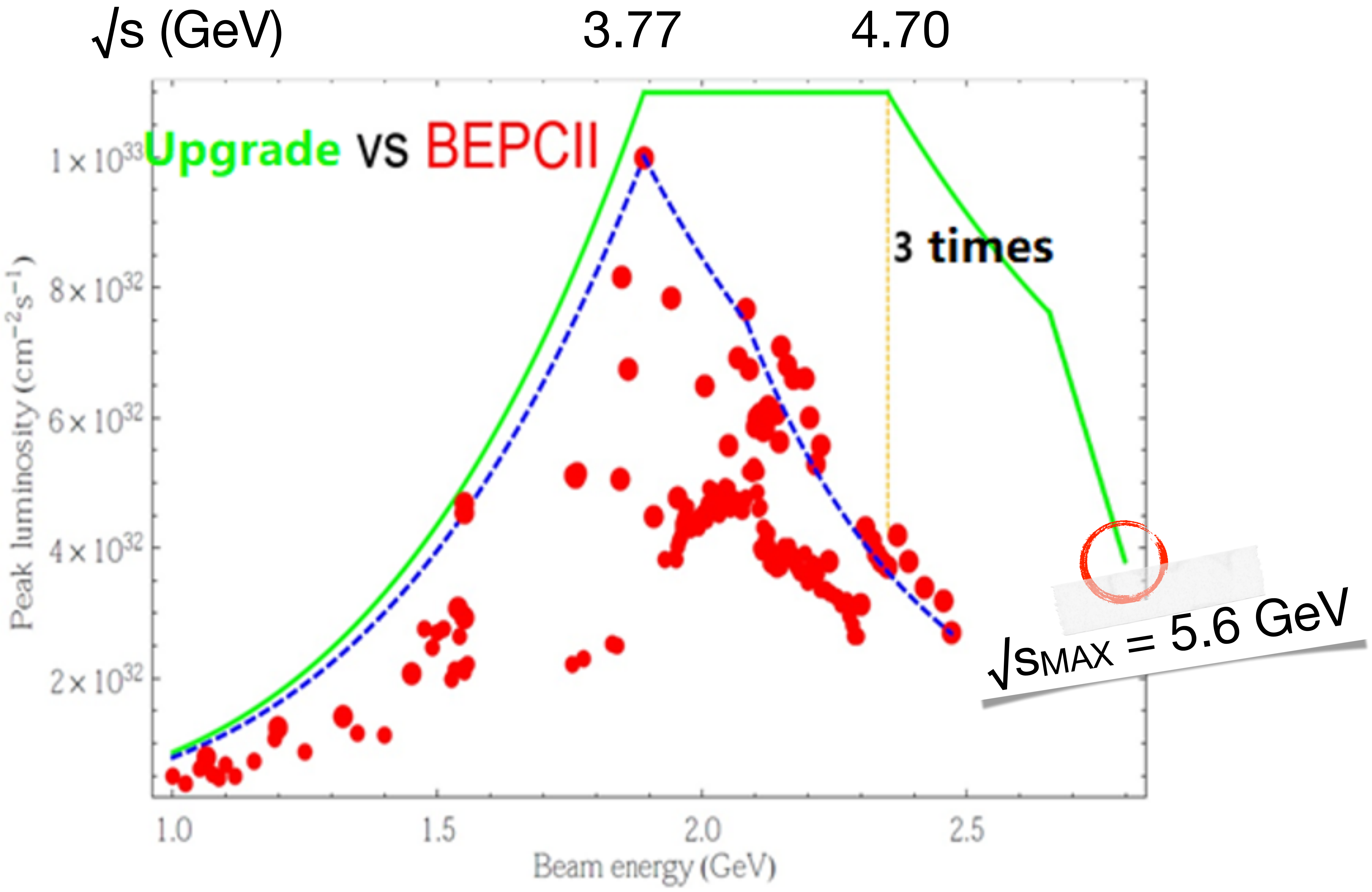
Thanks to its **tuneable centre-of-mass energy** in the charmonium range and **leptonic beams**, **BESIII** can be **competitive** even with smaller datasets

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

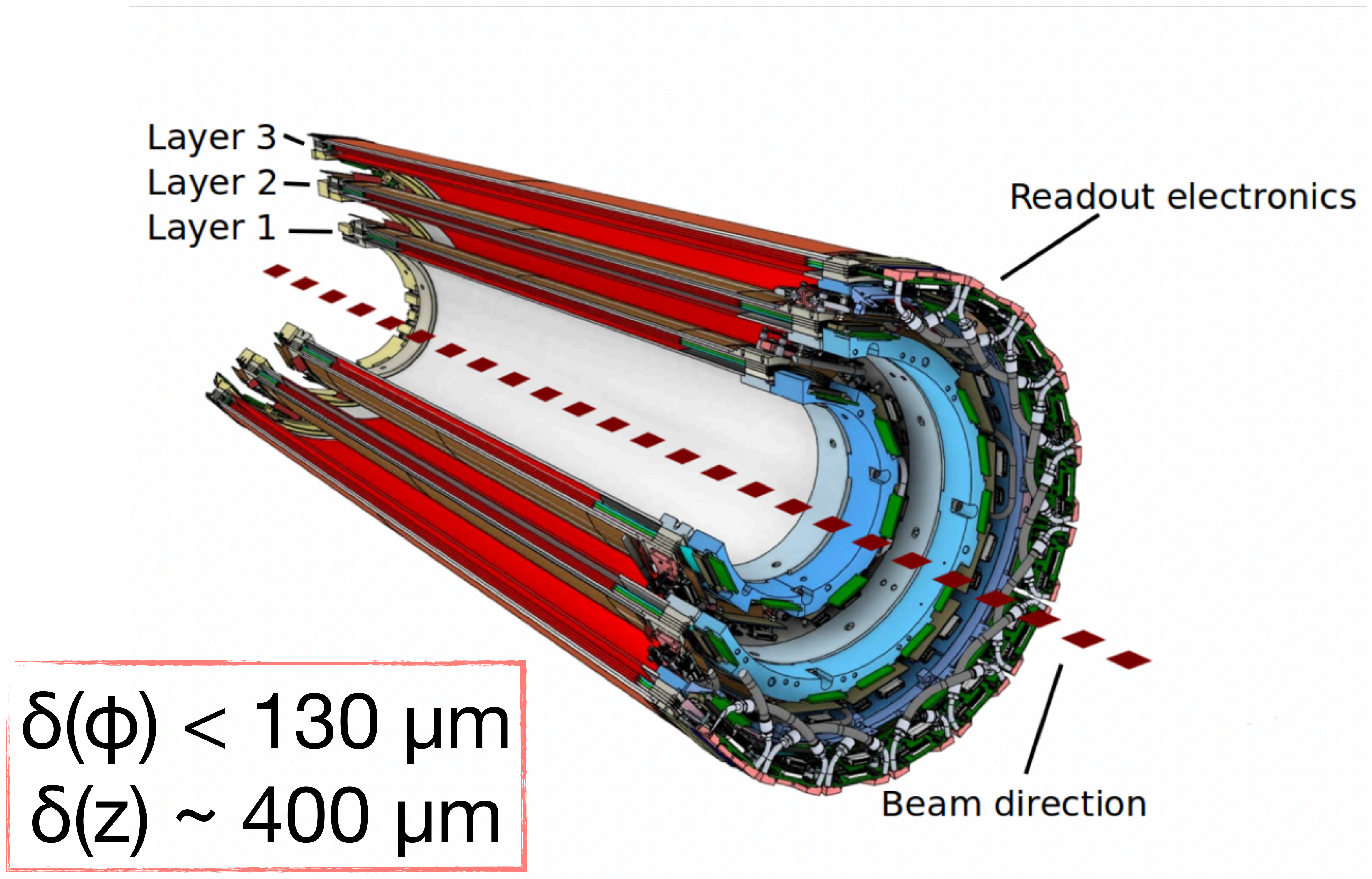
With the expected inner tracker and accelerator upgrades, exciting times wait ahead…

Upgrading the BESIII Experiment

Energy & Luminosity



CGEM-IT



With the expected inner tracker and accelerator upgrades, exciting times wait ahead…

Horizon Europe
THE NEXT EU RESEARCH & INNOVATION PROGRAMME (2021 – 2027)
European Commission

Thank you for the attention!

We acknowledge the support of the BESIIICGEM Project (645664) - H2020-MSCA-RISE-2014
We acknowledge the support of the FEST Project (872901) - H2020-MSCA-RISE-2019

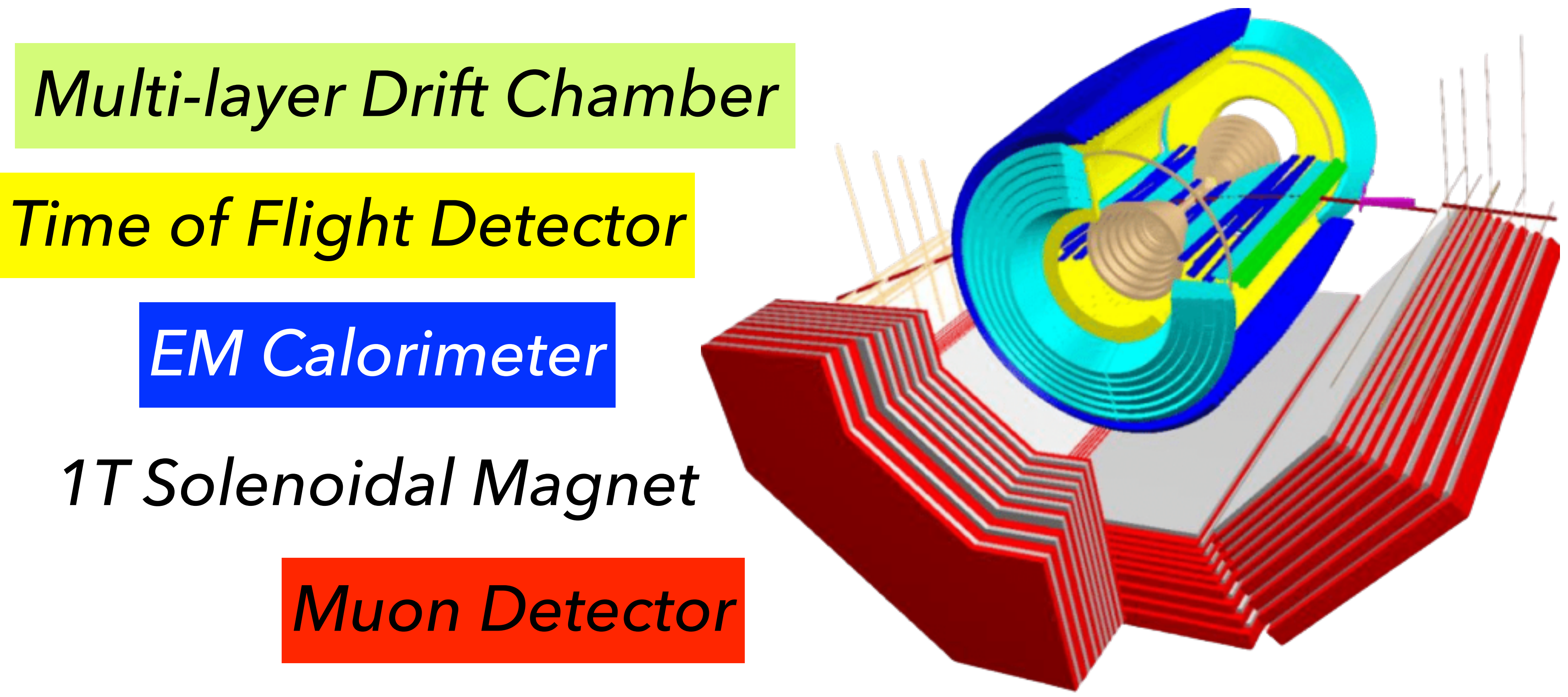
Backup Slides

BESIII Collaboration

~500 members
From 82 institutions in 17 countries

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

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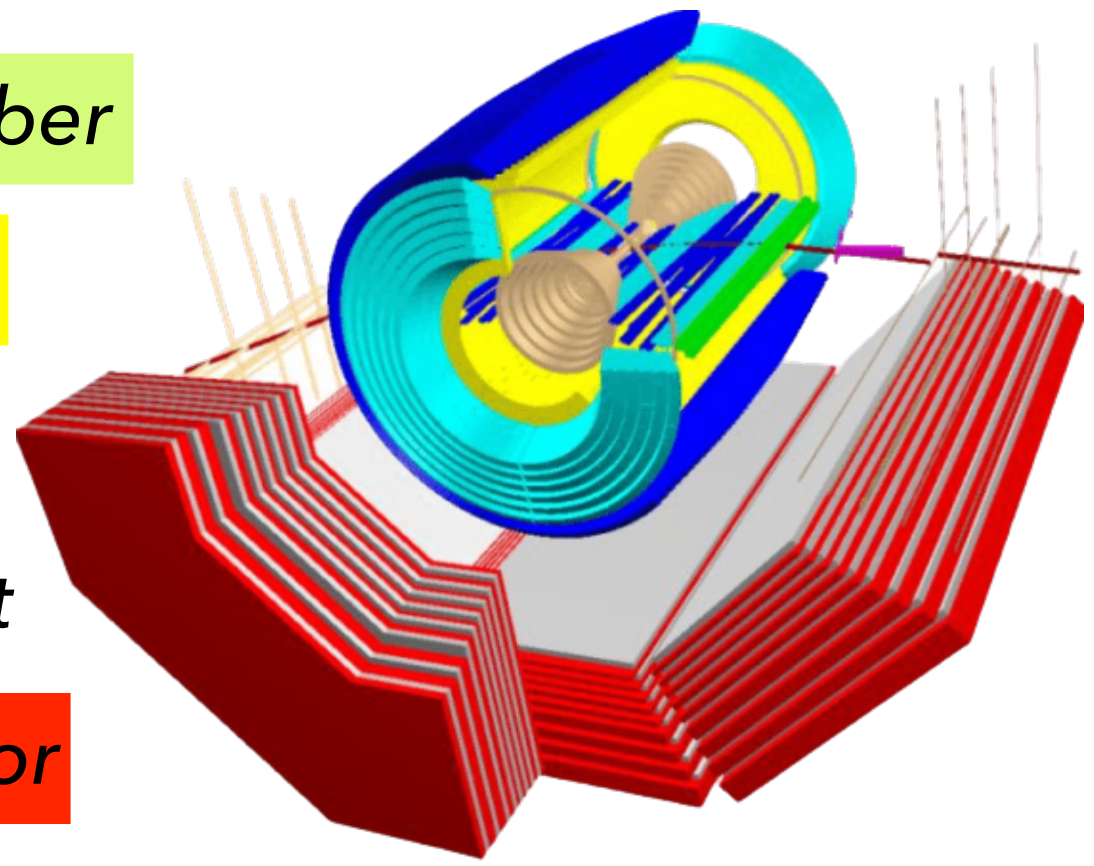


τ-charm factory 2.0 GeV ≤ $\sqrt{s}$ ≤ 4.9 GeV

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

@ $\sqrt{s}$ = 3.77 GeV

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
10×50 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: 7×500 pb^{-1} scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
8×500 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) $\psi(2S)$

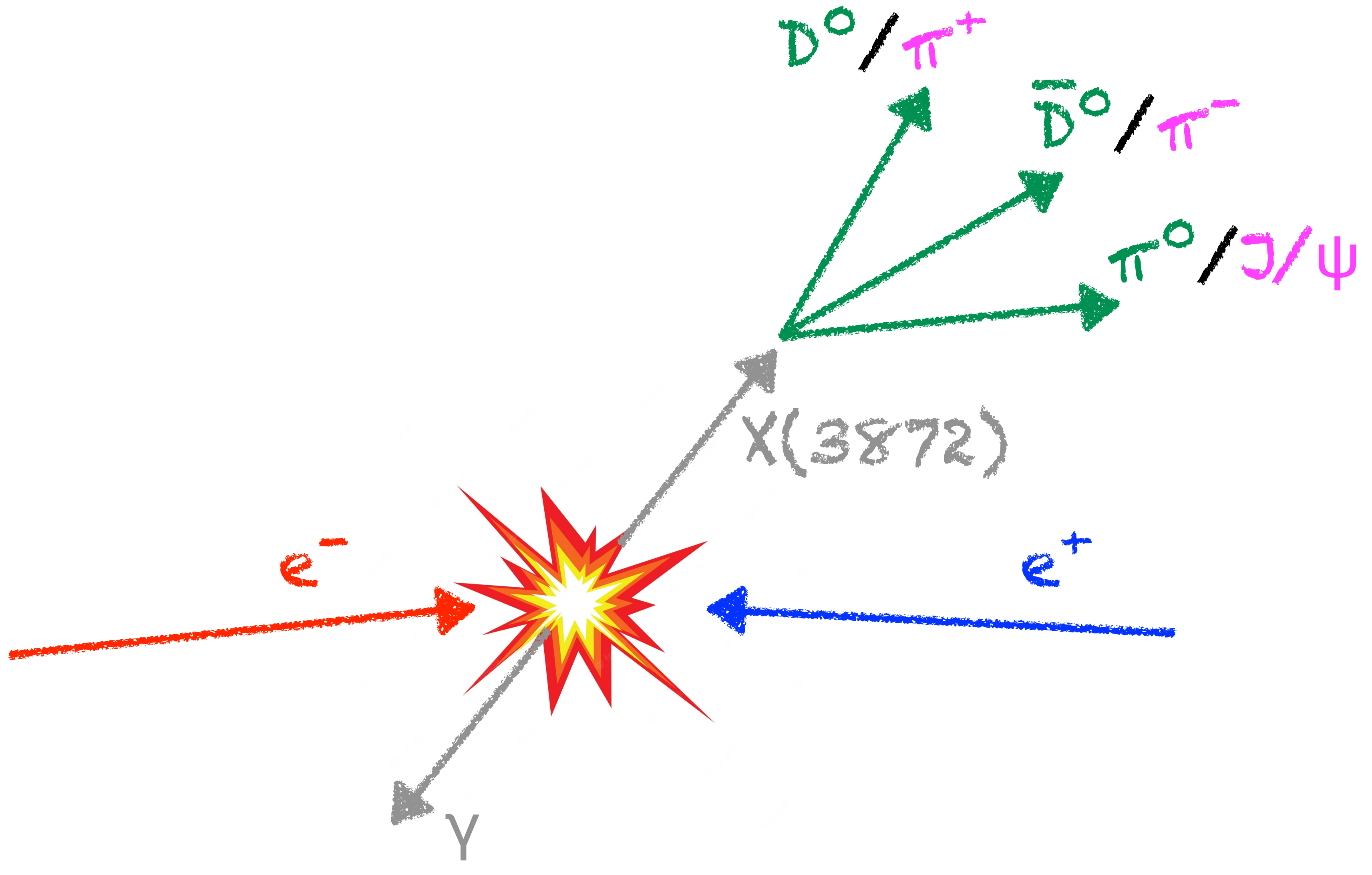
A coupled-channel analysis of the X(3872) line-shape with BESIII data

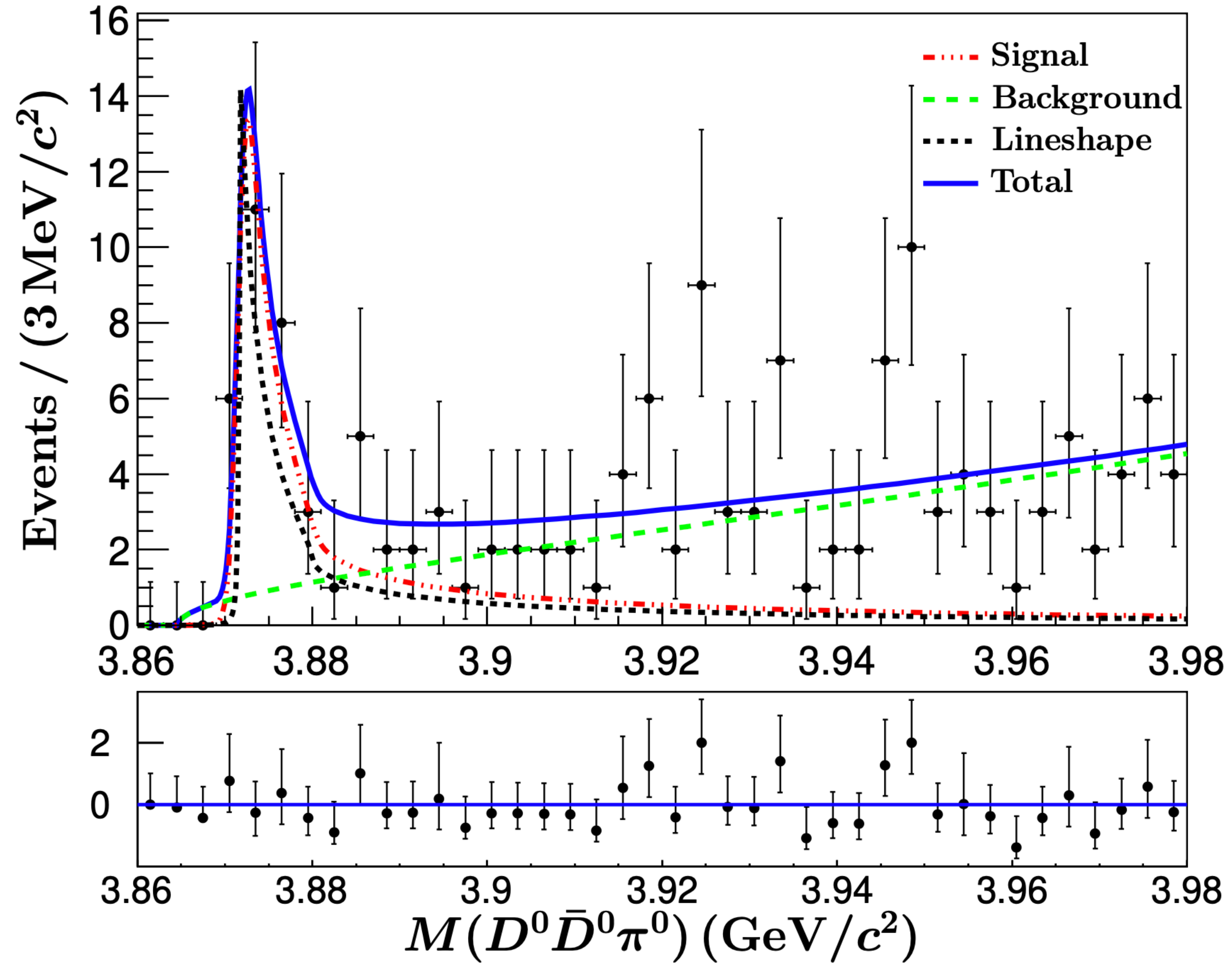
arXiv:**2309.01502v1**
Submitted to PRL

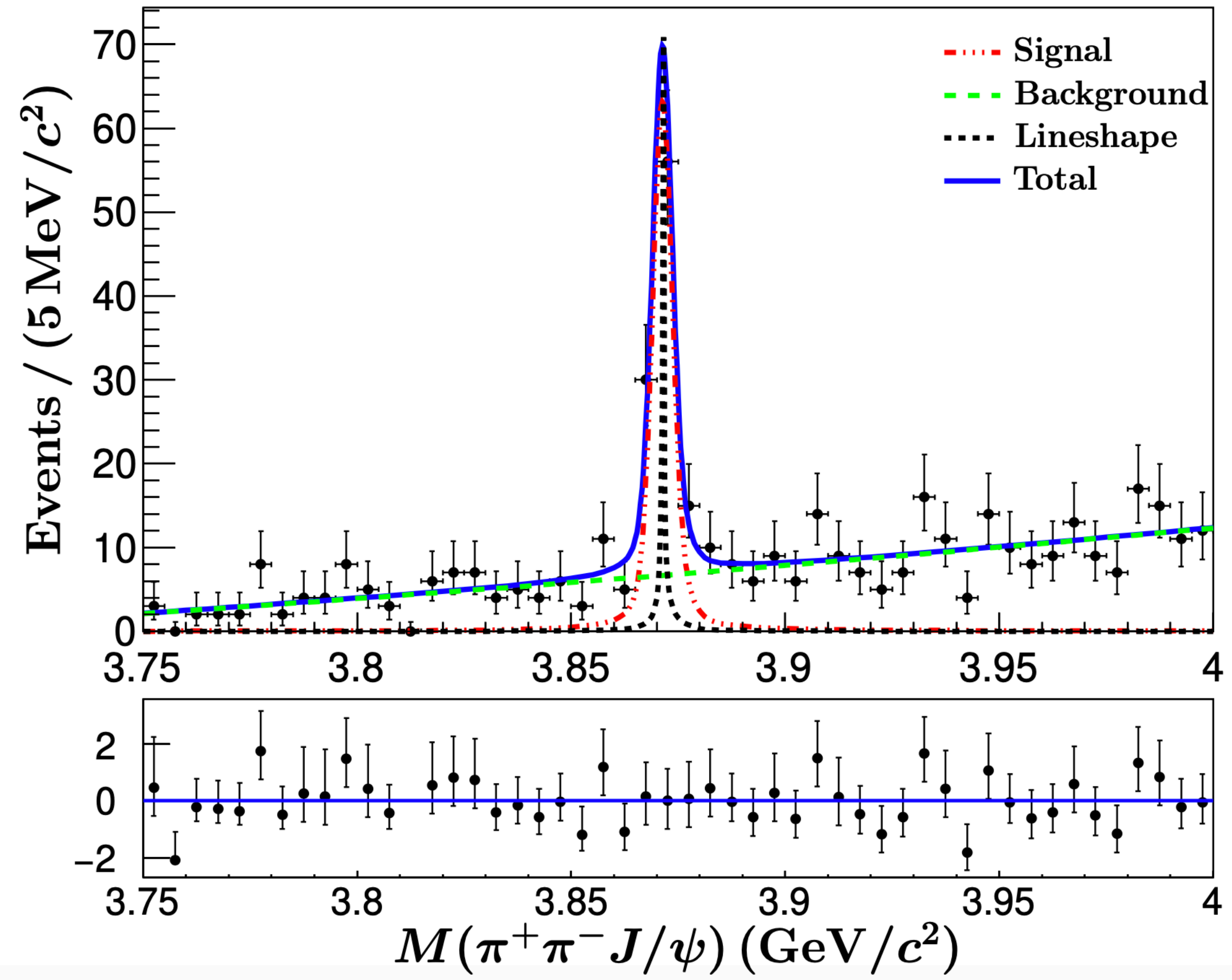
Using 11 energy points @√**s = [4.178, 4.278] GeV**

Study of the **X(3872)** production **line-shape**

Simultaneous fit to the invariant masses of the two X(3872) decay channels ($D^0\bar{D}^0\pi^0$ e $\pi^+\pi^- J/\psi$)







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Study of the **X(3872)** production **line-shape**

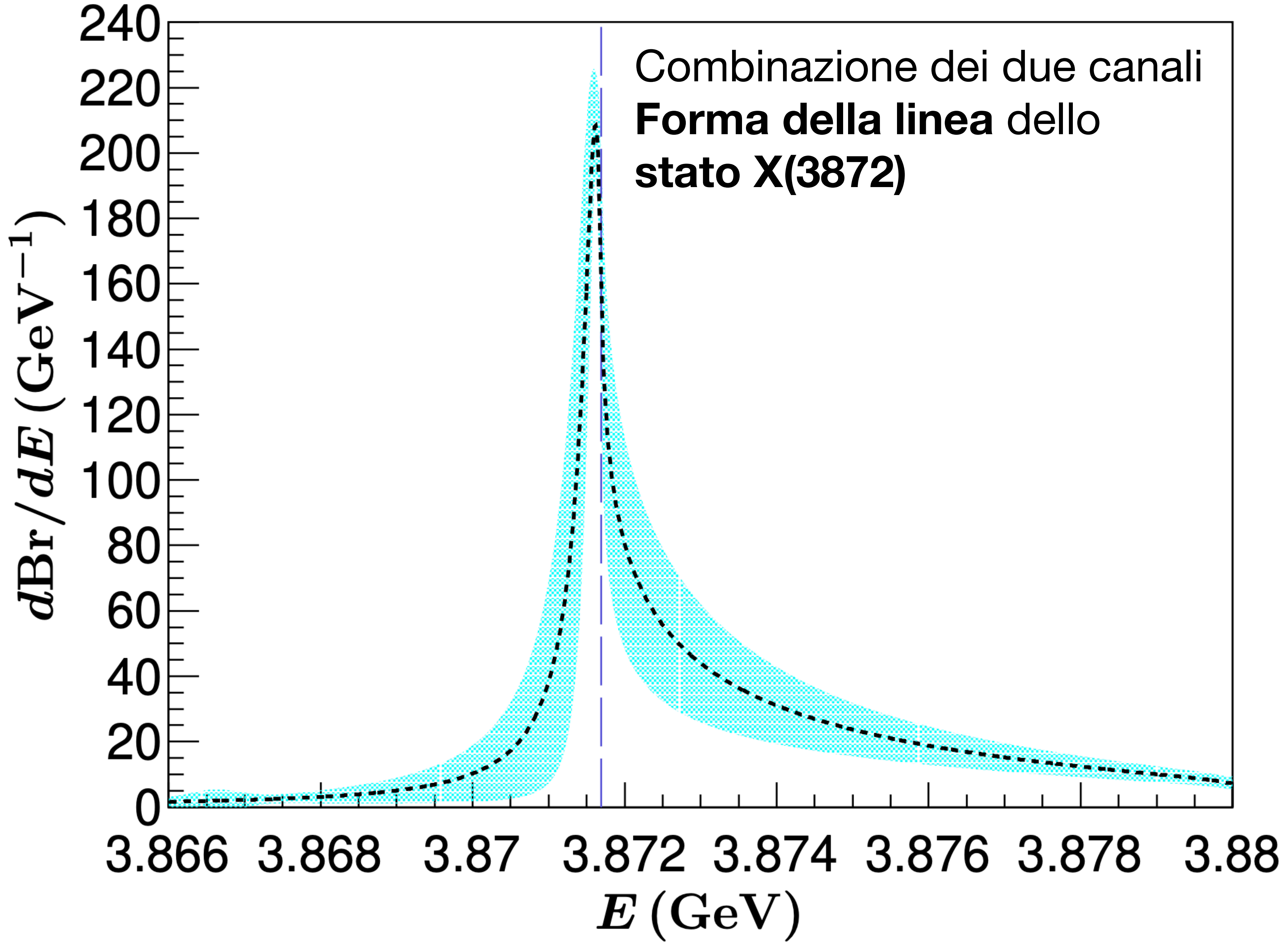
Simultaneous fit to the invariant masses of the two X(3872) decay channels ($D^0\bar{D}^0\pi^0$ e $\pi^+\pi^- J/\psi$)

Signal parametrisation is from Ref. [16]

$$\frac{d\mathrm{Br}(D^0\bar{D}^0\pi^0)}{dE} = \mathcal{B}\frac{\mathrm{Br}(D^{*0}\to D^0\pi^0)\times g\times k_{\mathrm{eff}}(E)}{|D(E)|^2}$$

$$\frac{d\mathrm{Br}(\pi^+\pi^- J/\psi)}{dE} = \mathcal{B}\frac{\Gamma_{\pi^+\pi^- J/\psi}}{|D(E)|^2}$$

$$D(E) = E - E_X + \tfrac{1}{2}g\left[(\kappa_{\mathrm{eff}}(E) + ik_{\mathrm{eff}}(E)) + (\kappa^c_{\mathrm{eff}}(E) + ik^c_{\mathrm{eff}}(E))\right] + \tfrac{i}{2}\Gamma_0$$



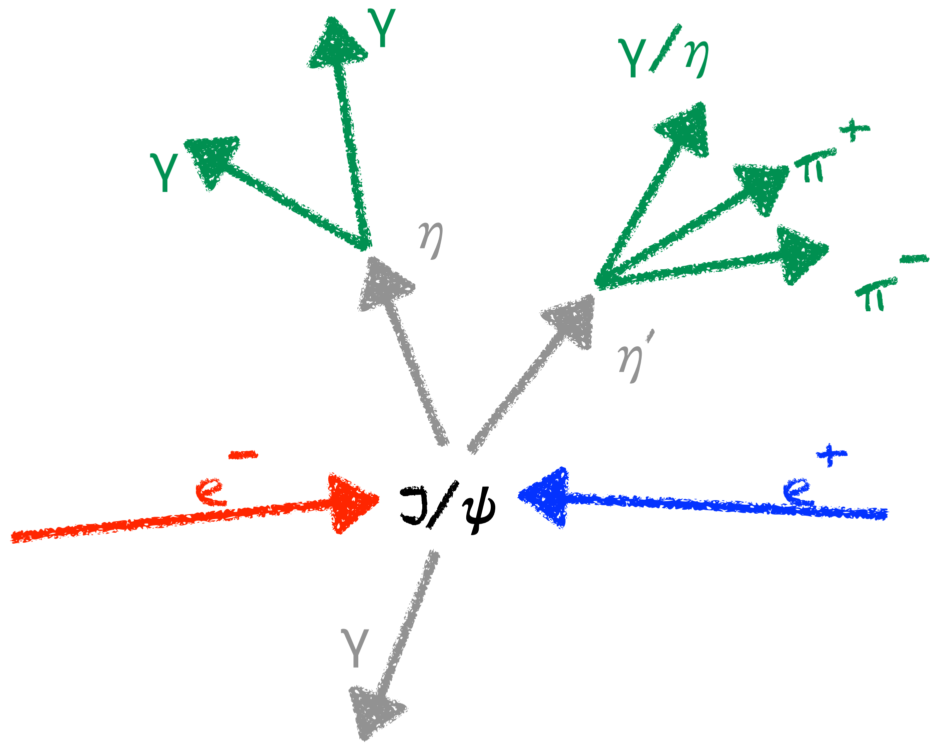
Parametri Liberi	g	Γ_0 (MeV)	M_X (MeV)
Risultato del Fit	0.16 ± 0.10	2.67 ± 1.77	3871.63 ± 0.13
Incertezza sist.	$+1.12 \quad -0.11$	$+8.01 \quad -0.82$	$+0.06 \quad -0.05$

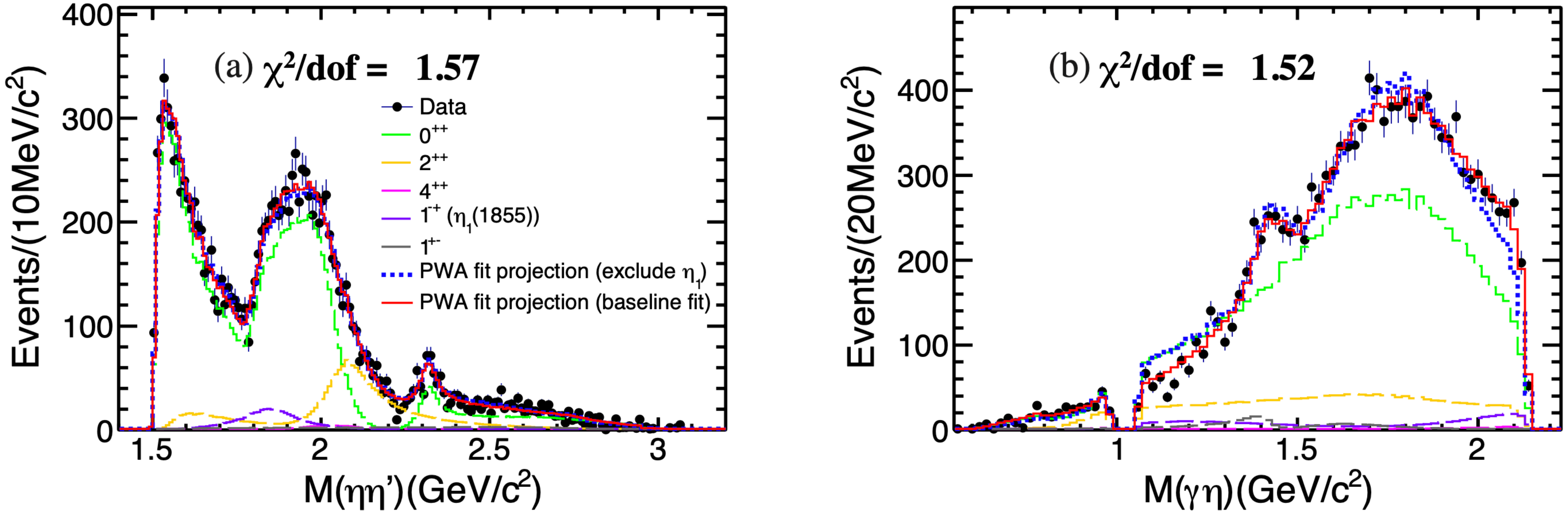
[16] Phys. Rev. D 81, 094028 (2010)

Partial wave analysis of $J/\psi \to \gamma\eta\eta'$

Phys. Rev. D **106**, 072012 (2022)

Phys. Rev. D **107**, 079901 (Erratum)



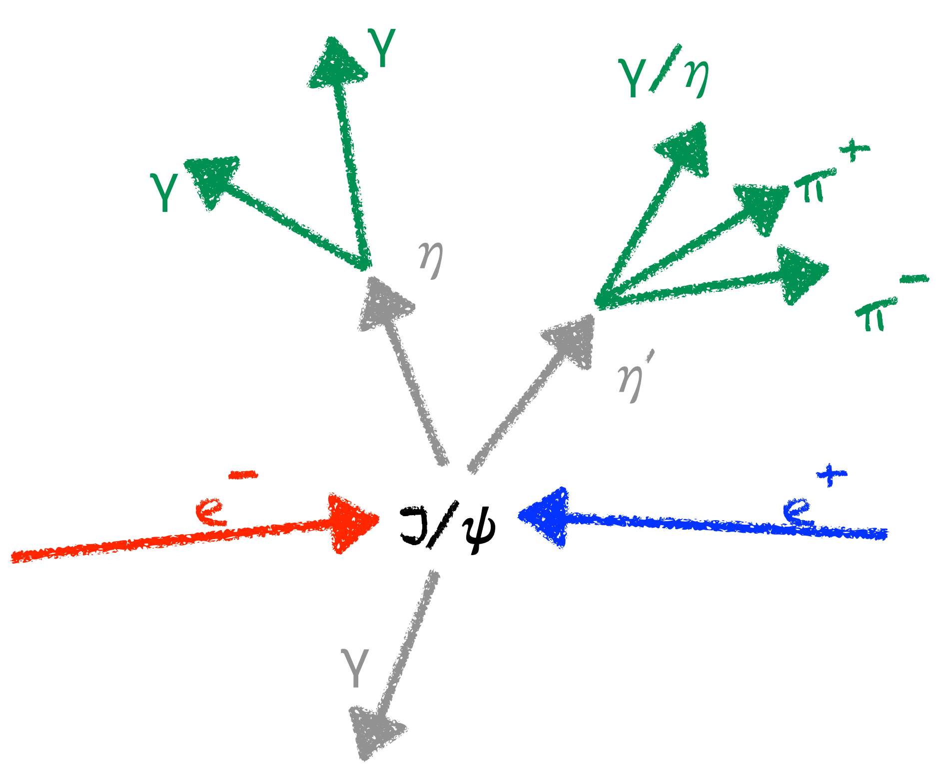


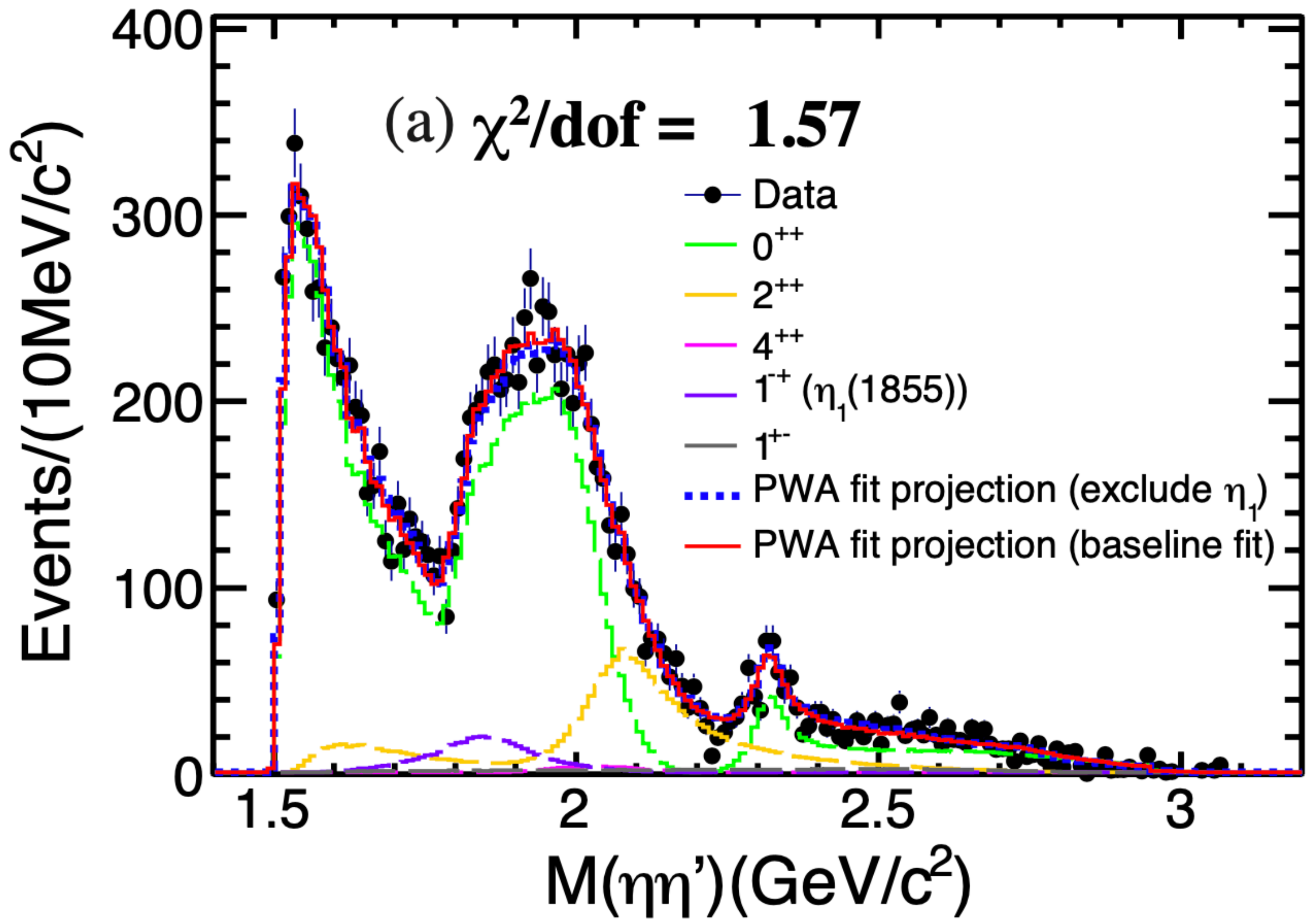
Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	$M_{\rm PDG}$ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV)	B.F. ($\times 10^{-5}$)	Sig.
	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg 30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	1992	442	$2.28\pm0.12^{+0.29}_{-0.20}$	24.6σ
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(2330)$	$2312\pm7^{+7}_{-3}$	$65\pm10^{+3}_{-12}$	2314	144	$0.10\pm0.02^{+0.01}_{-0.02}$	13.2σ
	$\eta_1(1855)$	$1855\pm9^{+6}_{-1}$	$188\pm18^{+3}_{-8}$	-	-	$0.27\pm0.04^{+0.02}_{-0.04}$	21.4σ
	$f_2(1565)$	1542	122	1542	122	$0.32\pm0.05^{+0.12}_{-0.02}$	8.7σ
	$f_2(2010)$	$2062\pm6^{+10}_{-7}$	$165\pm17^{+10}_{-5}$	2011	202	$0.71\pm0.06^{+0.10}_{-0.06}$	13.4σ
	$f_4(2050)$	2018	237	2018	237	$0.06\pm0.01^{+0.03}_{-0.01}$	4.6σ
	0^{++} PHSP	-	-	-	-	$1.44\pm0.15^{+0.10}_{-0.20}$	15.7σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	$0.08\pm0.01^{+0.01}_{-0.02}$	10.2σ
	$h_1(1595)$	1584	384	1584	384	$0.16\pm0.02^{+0.03}_{-0.01}$	9.9σ

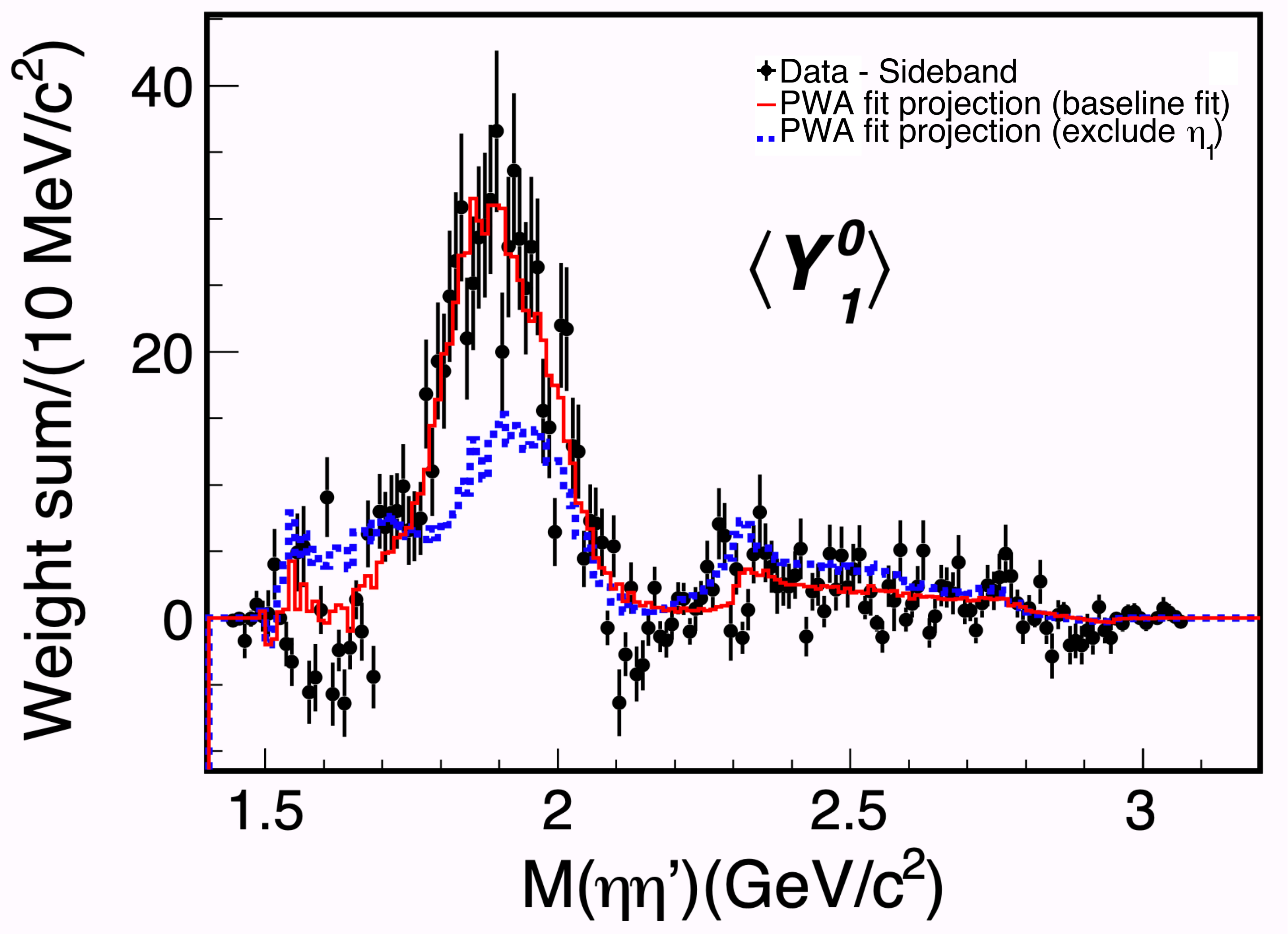
Partial wave analysis of $J/\psi \to \gamma\eta\eta'$

Phys. Rev. D **106**, 072012 (2022)

Phys. Rev. D **107**, 079901 (Erratum)







Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	$M_{\rm PDG}$ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg 30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	1992	442	$2.28\pm0.12^{+0.29}_{-0.20}$	24.6σ
	$f_0(2330)$	$2312\pm7^{+7}_{-3}$	$65\pm10^{+3}_{-12}$	2314	144	$0.10\pm0.02^{+0.01}_{-0.02}$	13.2σ
	$\eta_1(1855)$	$1855\pm9^{+6}_{-1}$	$188\pm18^{+3}_{-8}$	-	-	$0.27\pm0.04^{+0.02}_{-0.04}$	21.4σ
	$f_2(1565)$	1542	122	1542	122	$0.32\pm0.05^{+0.12}_{-0.02}$	8.7σ
	$f_2(2010)$	$2062\pm6^{+10}_{-7}$	$165\pm17^{+10}_{-5}$	2011	202	$0.71\pm0.06^{+0.10}_{-0.06}$	13.4σ
	$f_4(2050)$	2018	237	2018	237	$0.06\pm0.01^{+0.03}_{-0.01}$	4.6σ
	0^{++} PHSP	-	-	-	-	$1.44\pm0.15^{+0.10}_{-0.20}$	15.7σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	$0.08\pm0.01^{+0.01}_{-0.02}$	10.2σ
	$h_1(1595)$	1584	384	1584	384	$0.16\pm0.02^{+0.03}_{-0.01}$	9.9σ

Uno stato **esotico isoscalare** $J^{PC} = 1^{-+}$, i cui parametri sono **consistenti** con i **calcoli LQCD** per lo stato ibrido 1^{-+} hybrid

[III] Phys. Rev. D **88**, 094505 (2013)