Overview of most recent BESIII results

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on behalf of the BESIII Collaboration

Dipartimento
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QCD@Work
June 2022

Istituto Nazionale di Fisica Nucleare

Outline:

- BESIII Experiment
- Charmonium (-like) States
- Light Hadrons
- Charm Mesons for QCD
- Baryon Studies
- Summary

DISCLAIMER 1

This presentation is not an encyclopaedic review of all the physics that one could do at BESIII

DISCLAIMER 2

The presented topics are the ones I personally selected among many interesting possibilities

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**

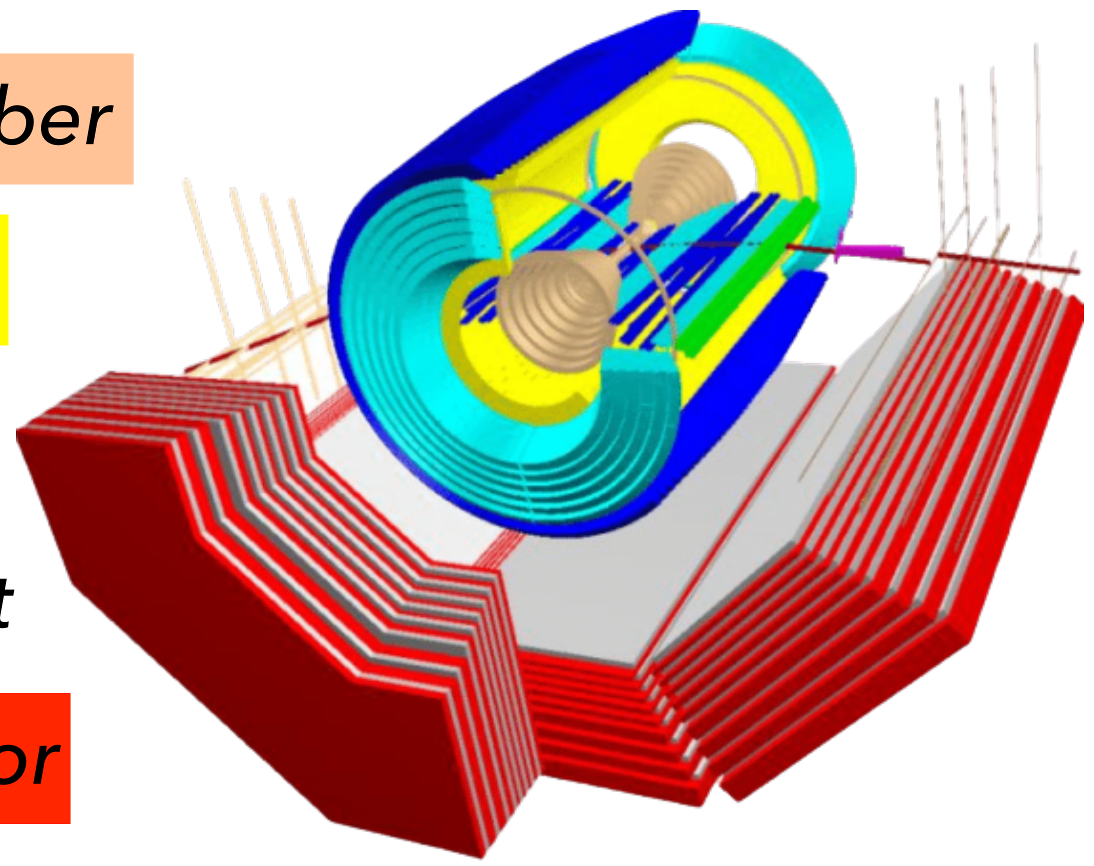
Multi-layer Drift Chamber

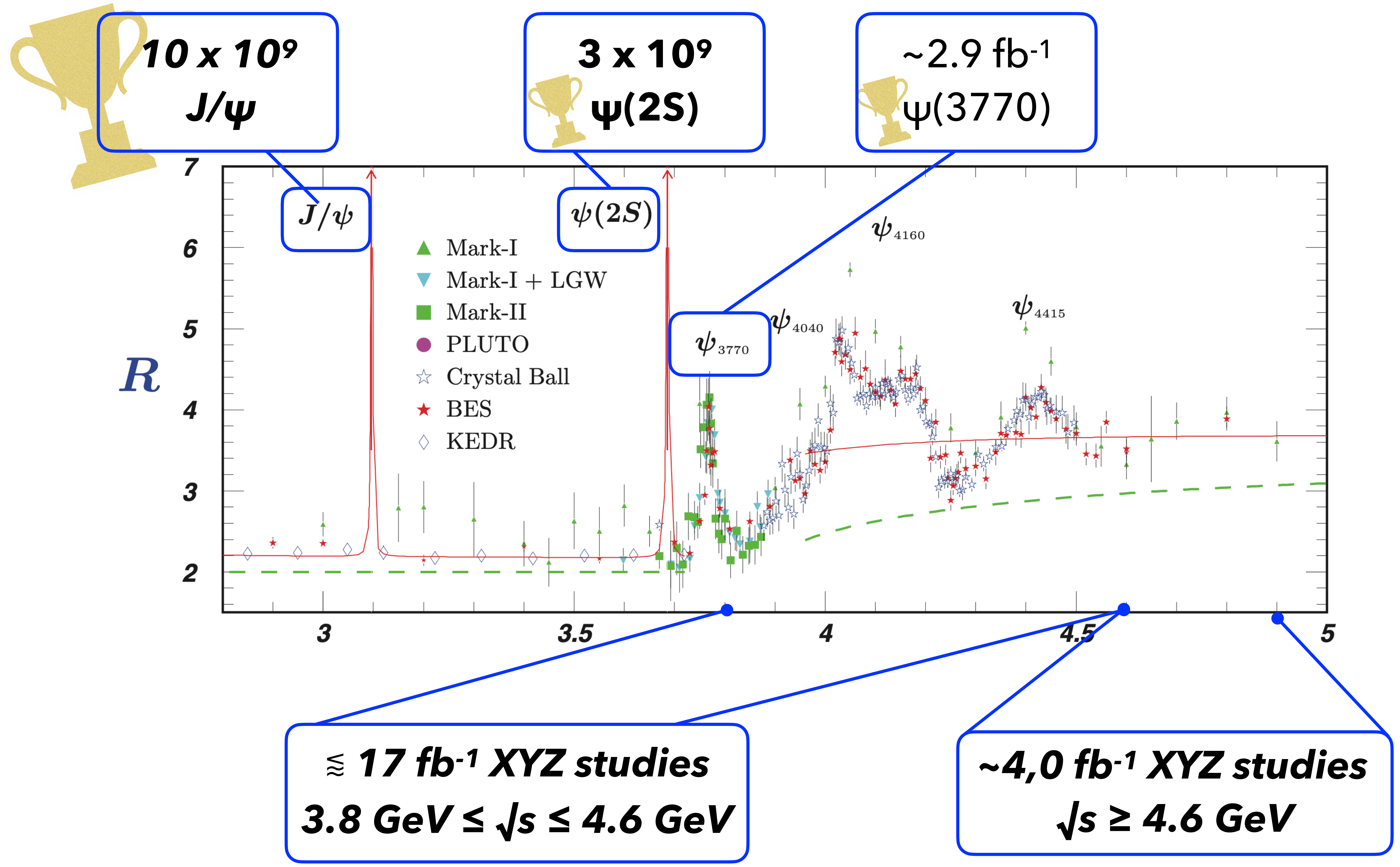
Time of Flight Detector

EM Calorimeter

1T Solenoidal Magnet

Muon Detector





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

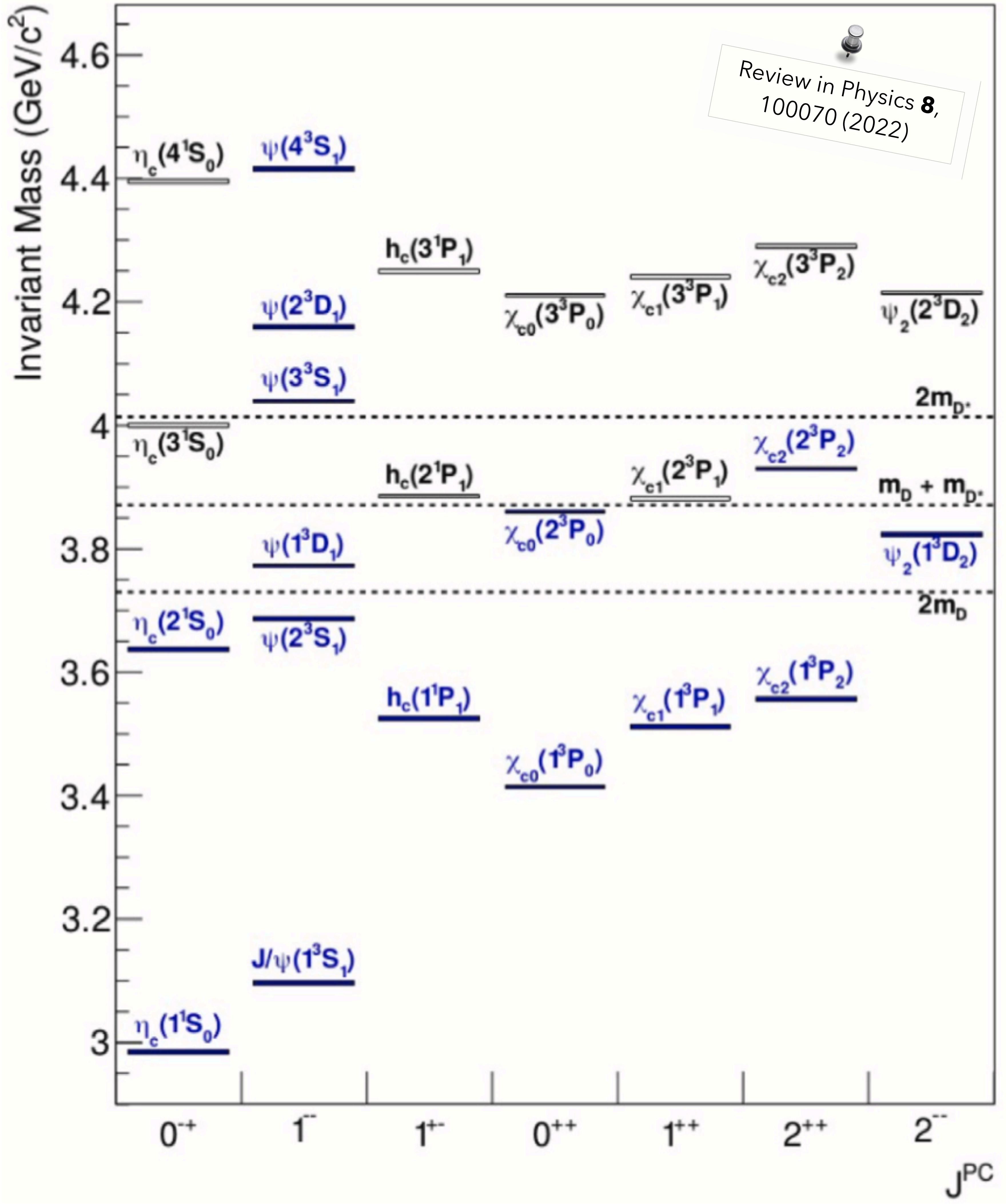
Charmonium (-like) States

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

Despite **conventional charmonia fit** fairly well potential model **predictions**, **non-vector** states are still **not** entirely **known**

$c\bar{c}$ spectrum features **supernumerary (XYZ) states**, (1) **not fitting** potential model **predictions**, (2) showing strong couplings to hidden charm states, and (3) can exhibit a non-zero charge

The **nature** of these exotic states is **not** yet **clear** (*hybrids*, *mesonic molecules*, *tetraquarks*…)



Review in Physics **8**, 100070 (2022)

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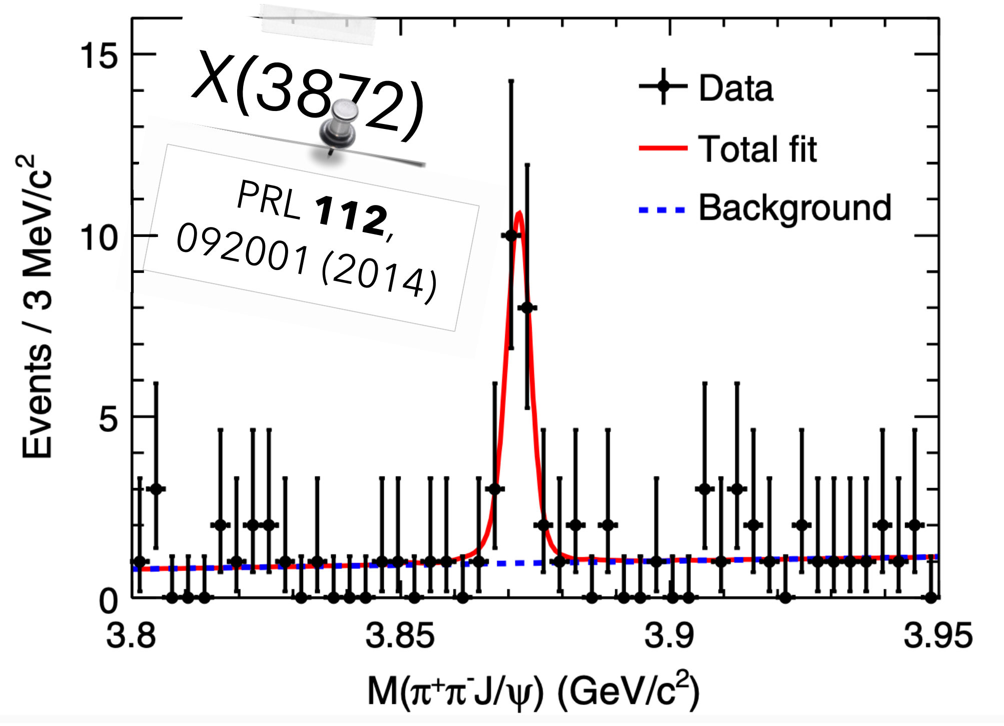
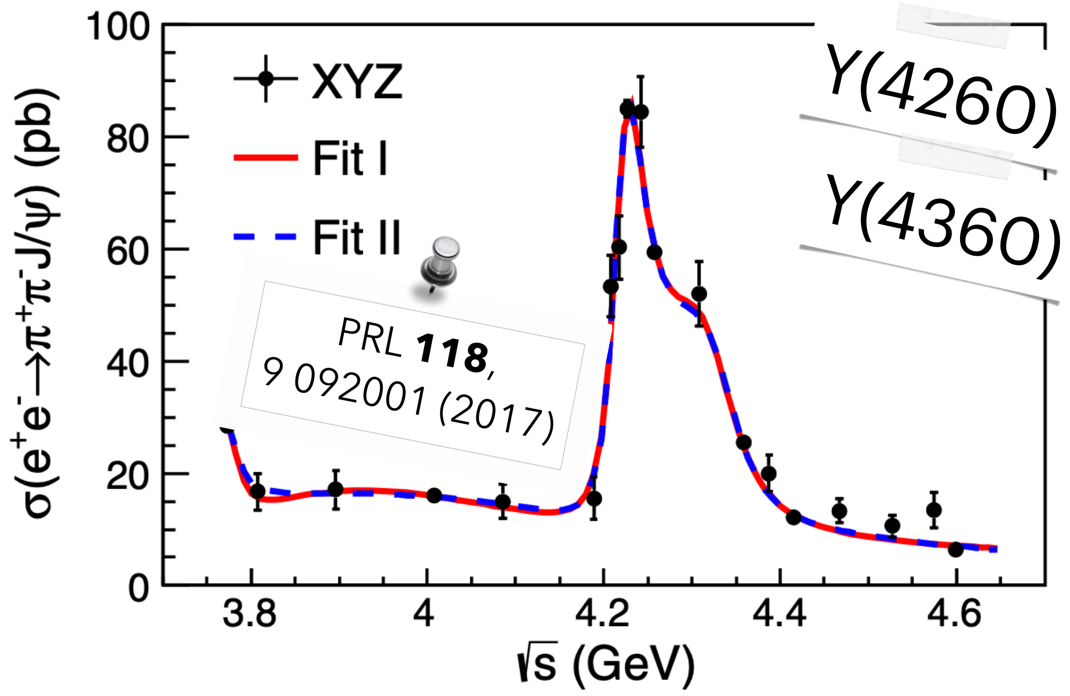
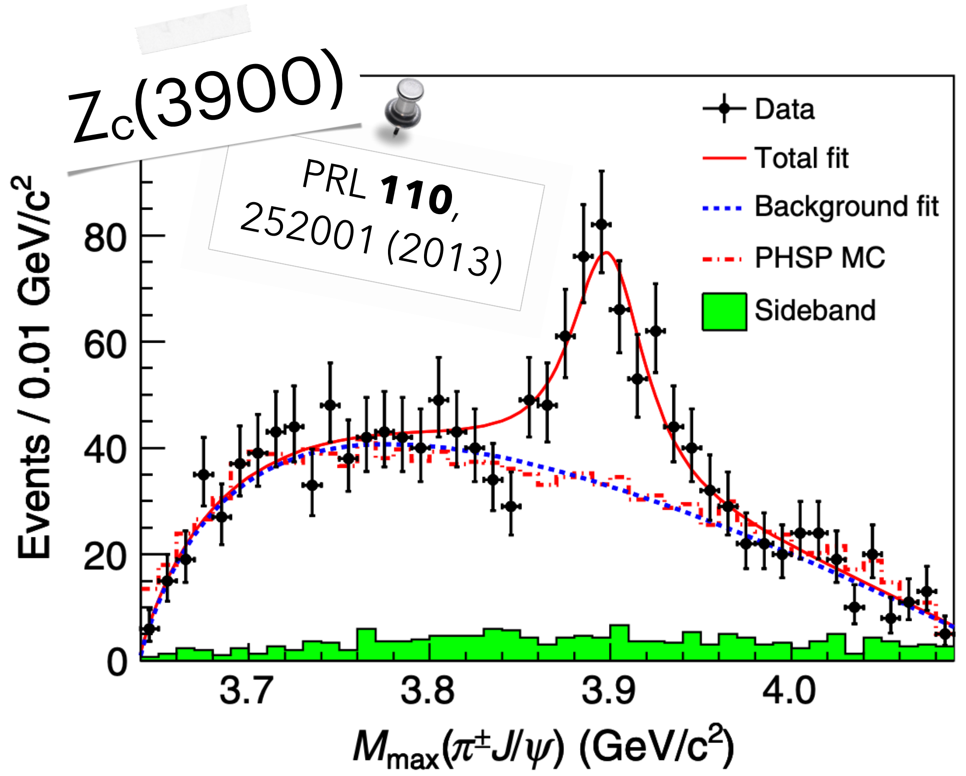
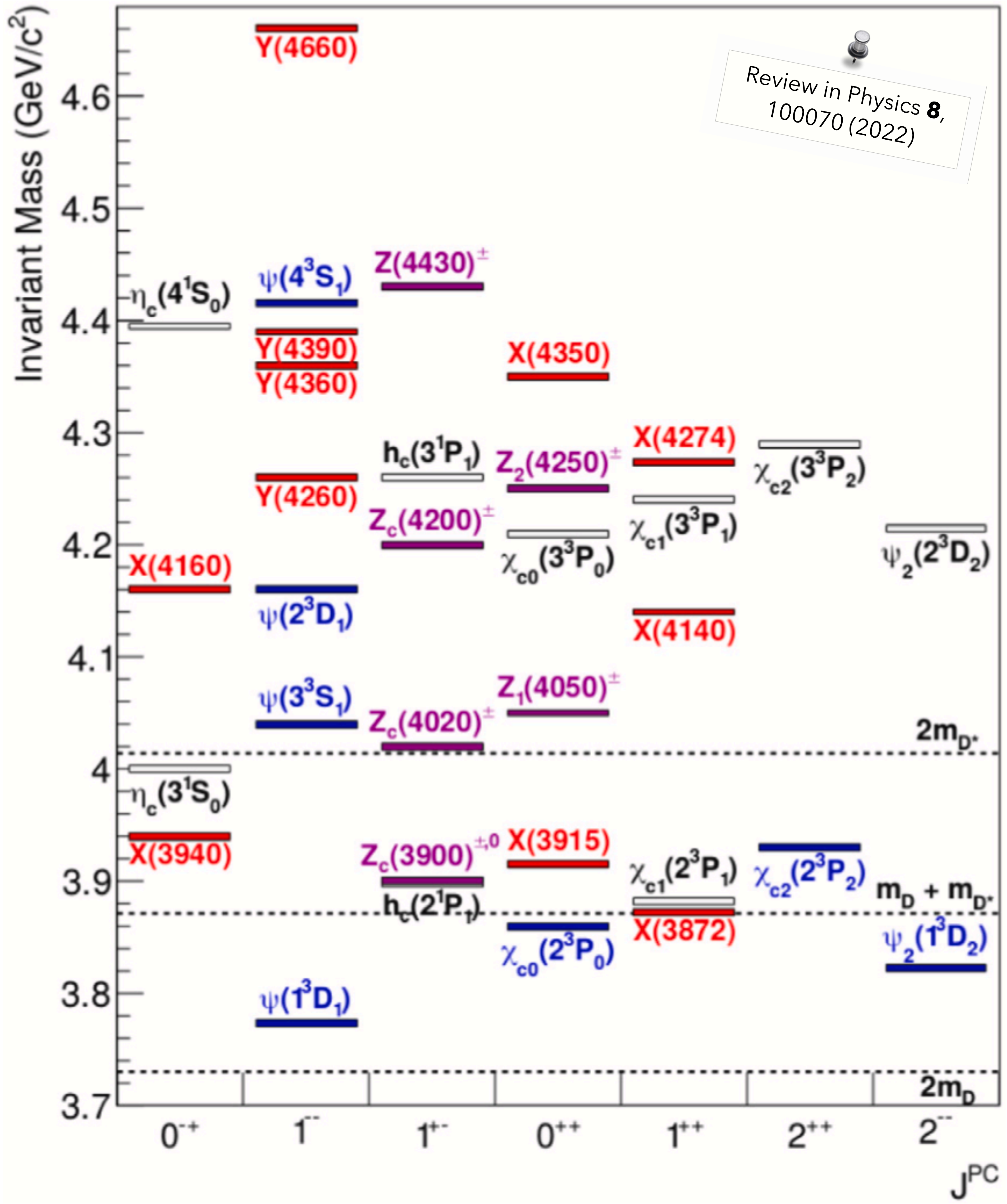








The Latest Addition… $Z_{cs}(3985)^0$

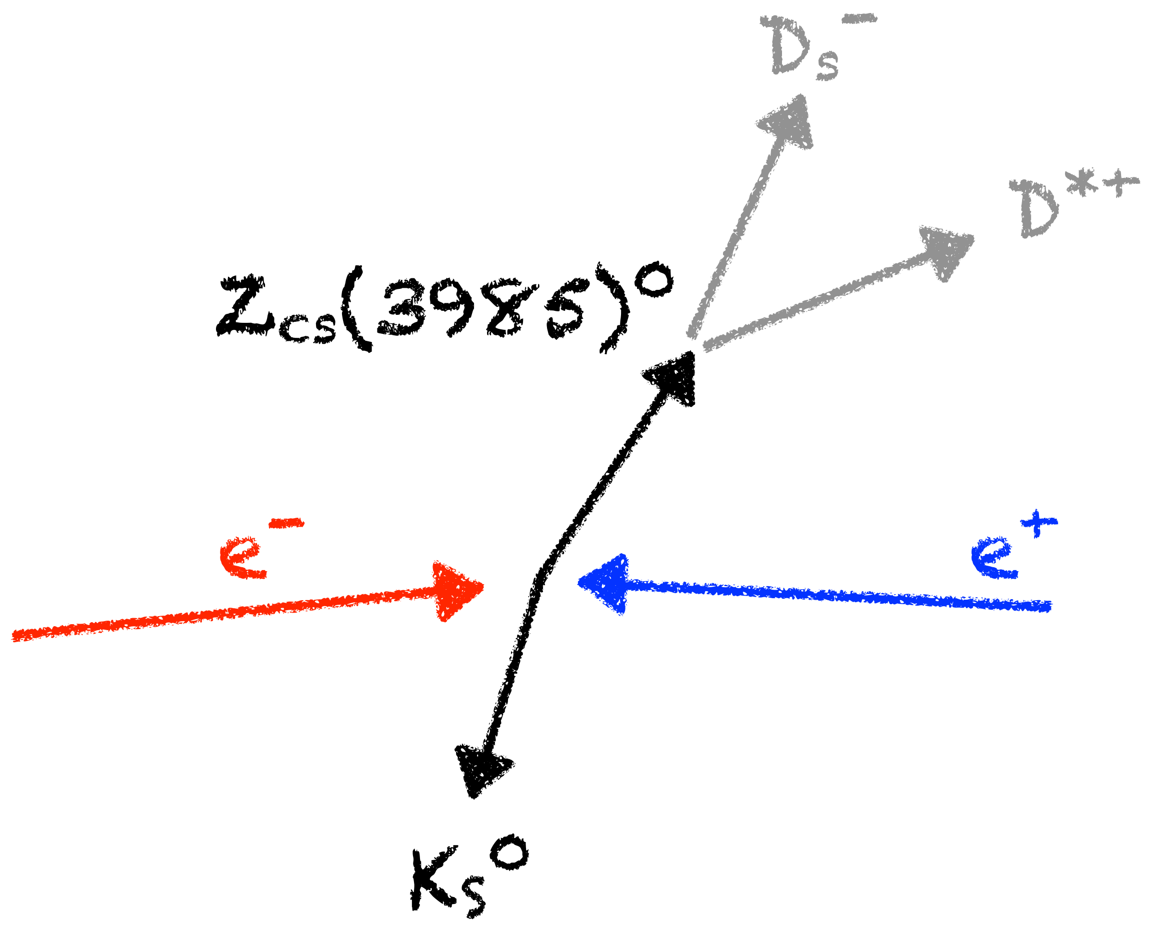
arXiv:2204.13703
Submitted to PRL

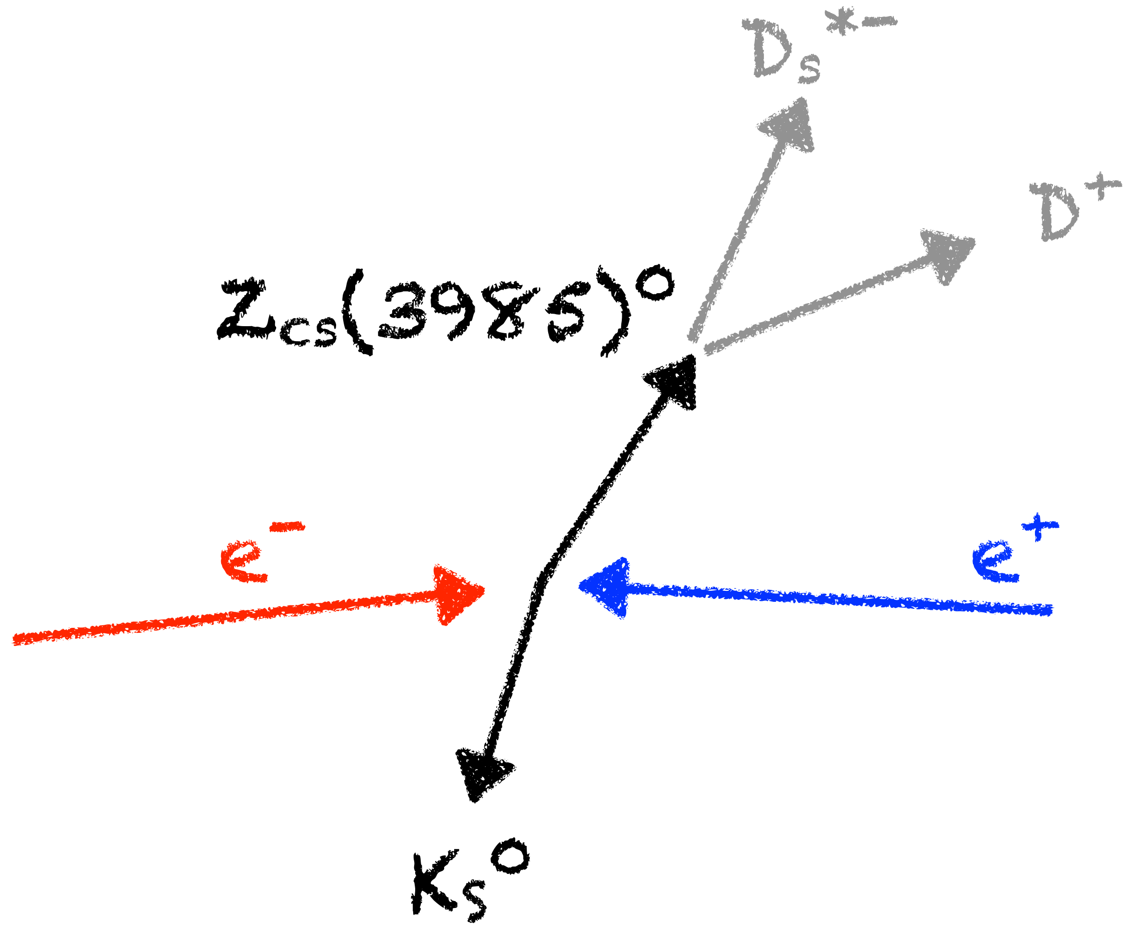
Using 5 data sets for a $\mathcal{L}_{int}$ = 3.8 fb^{-1} @$\sqrt{s}$ = [4.628, 4.699] GeV

Employing a partial reconstruction technique: K_S^0 & D_s^-/D^+

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

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





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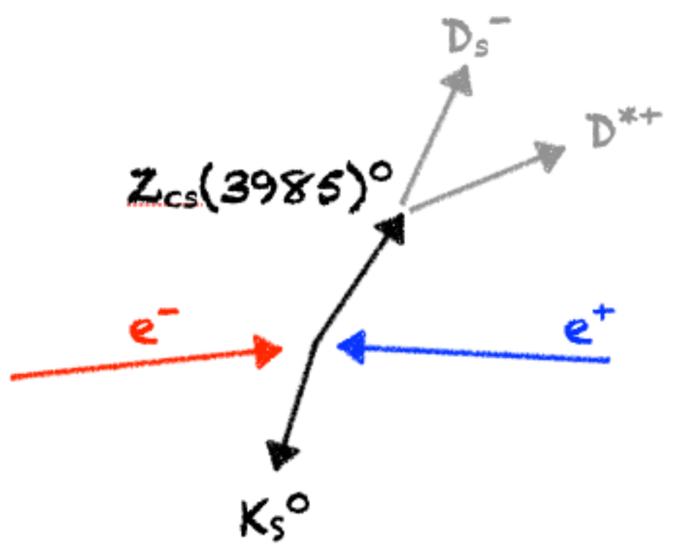

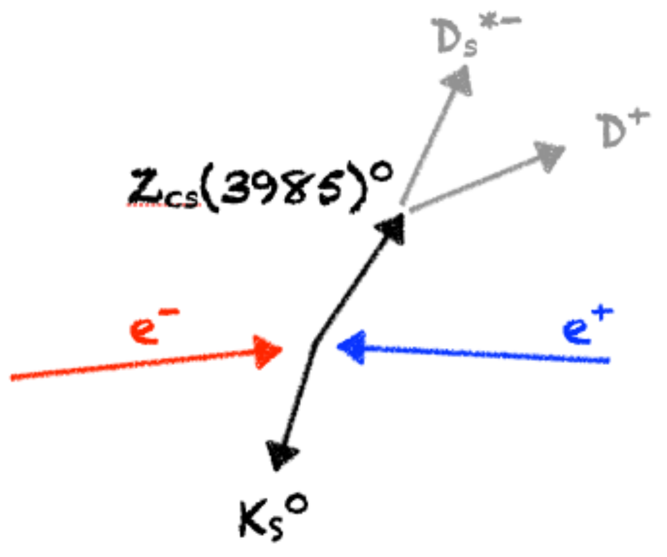

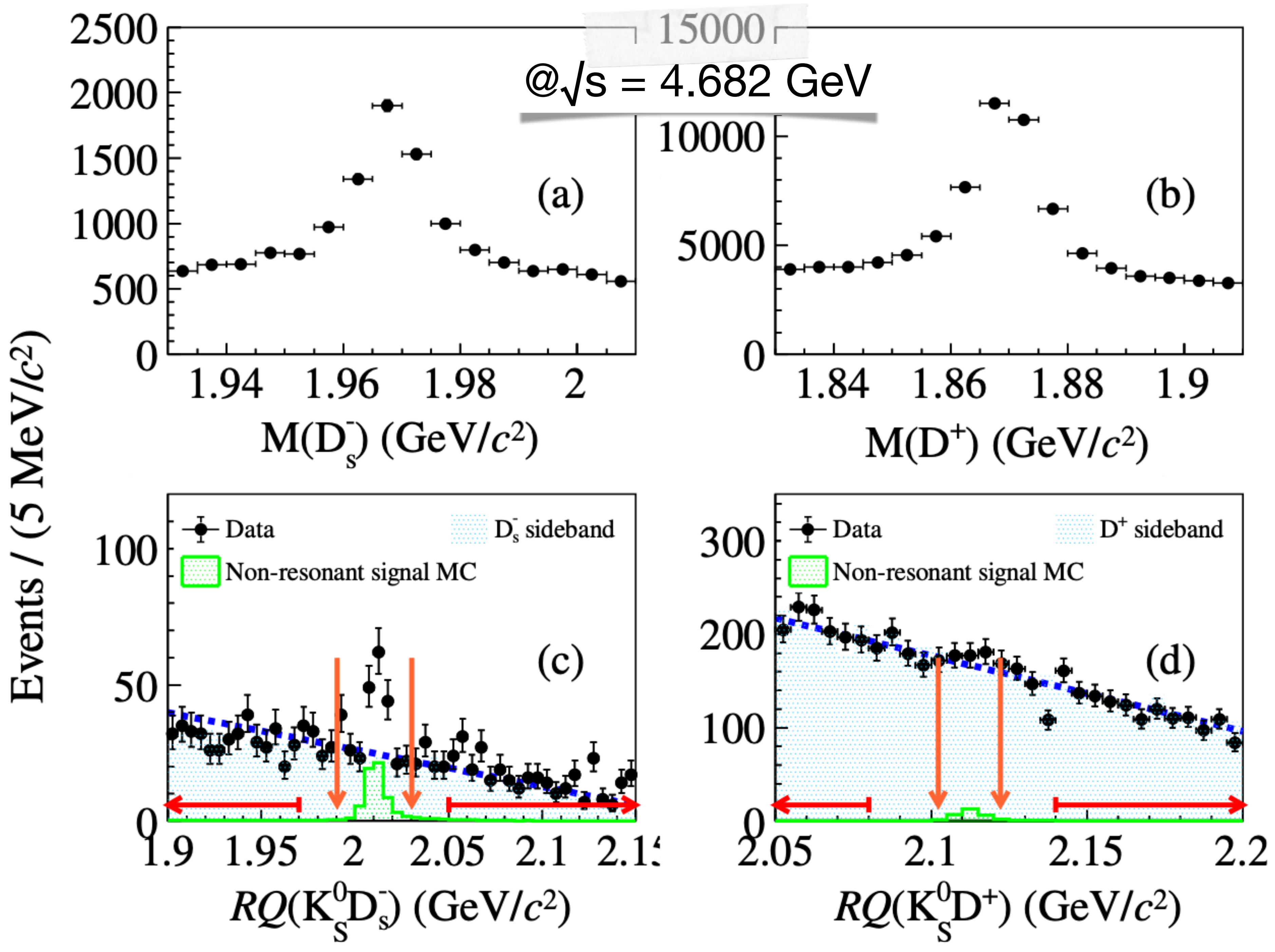

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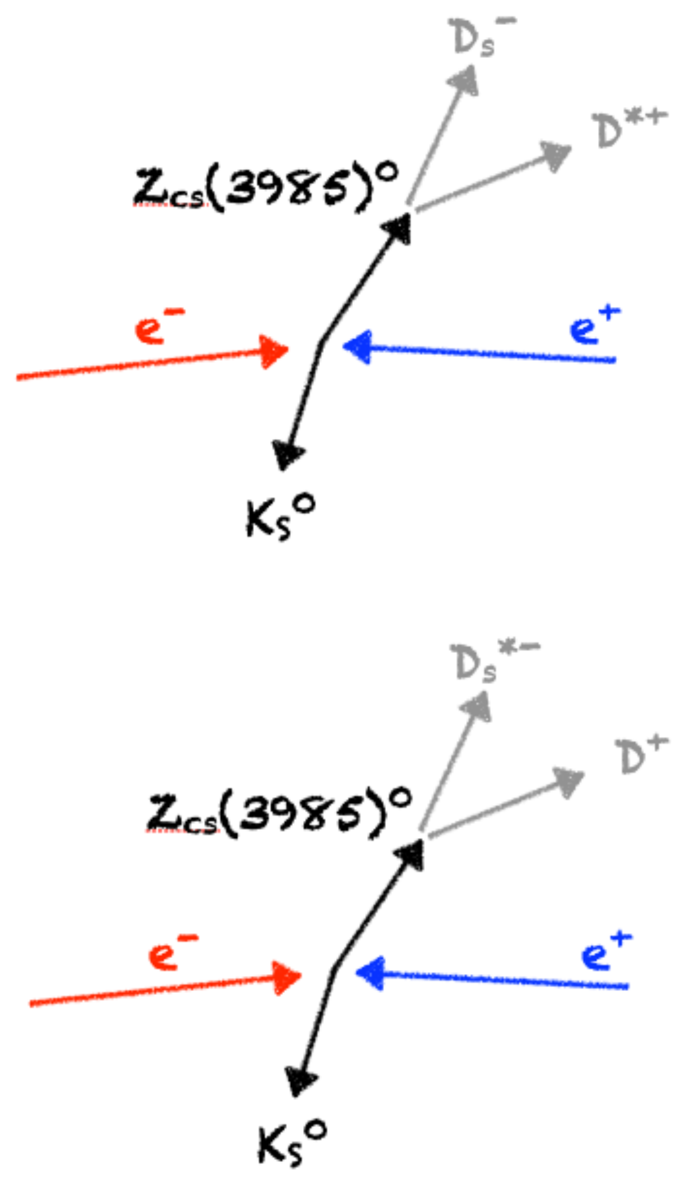

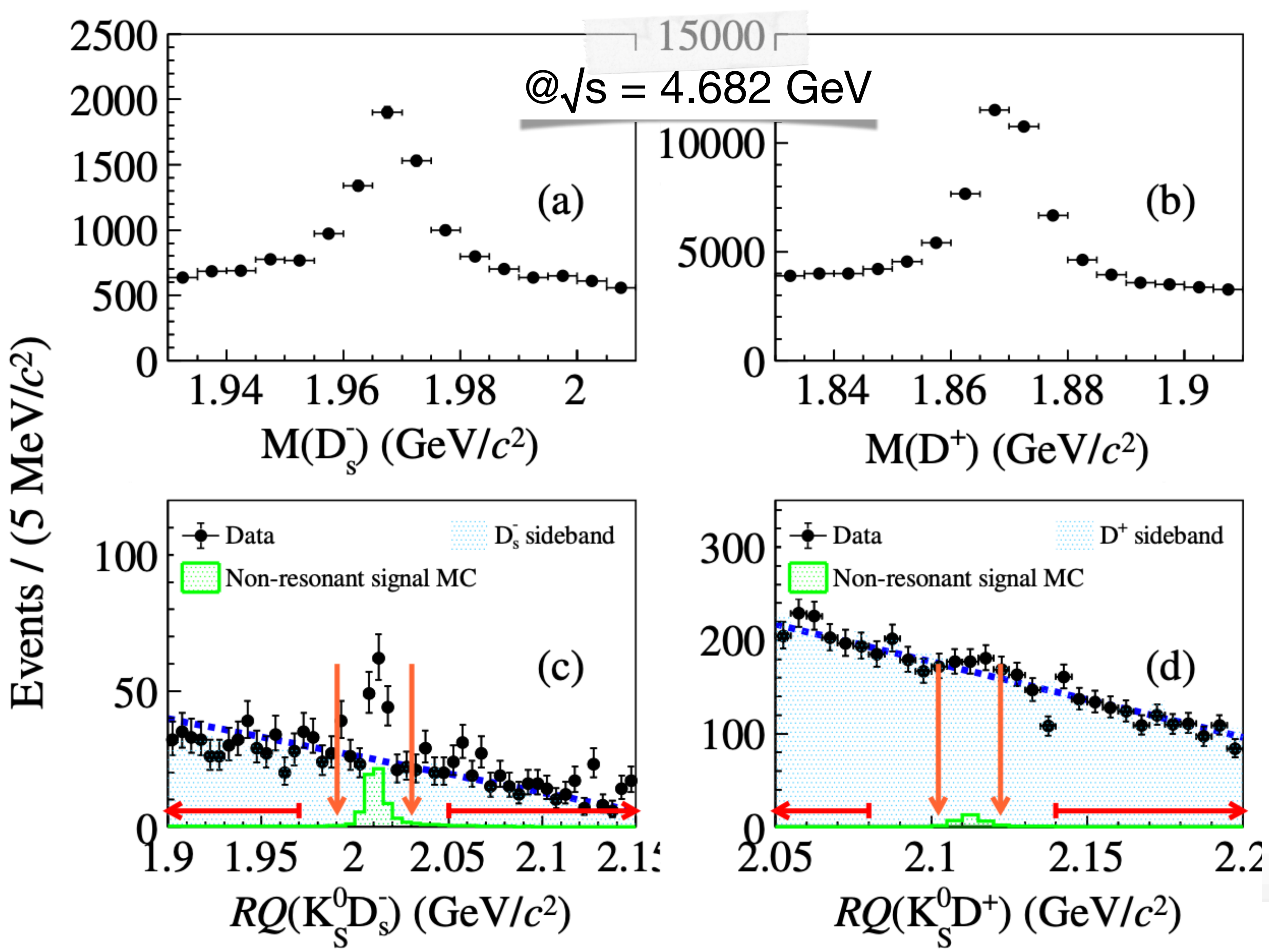

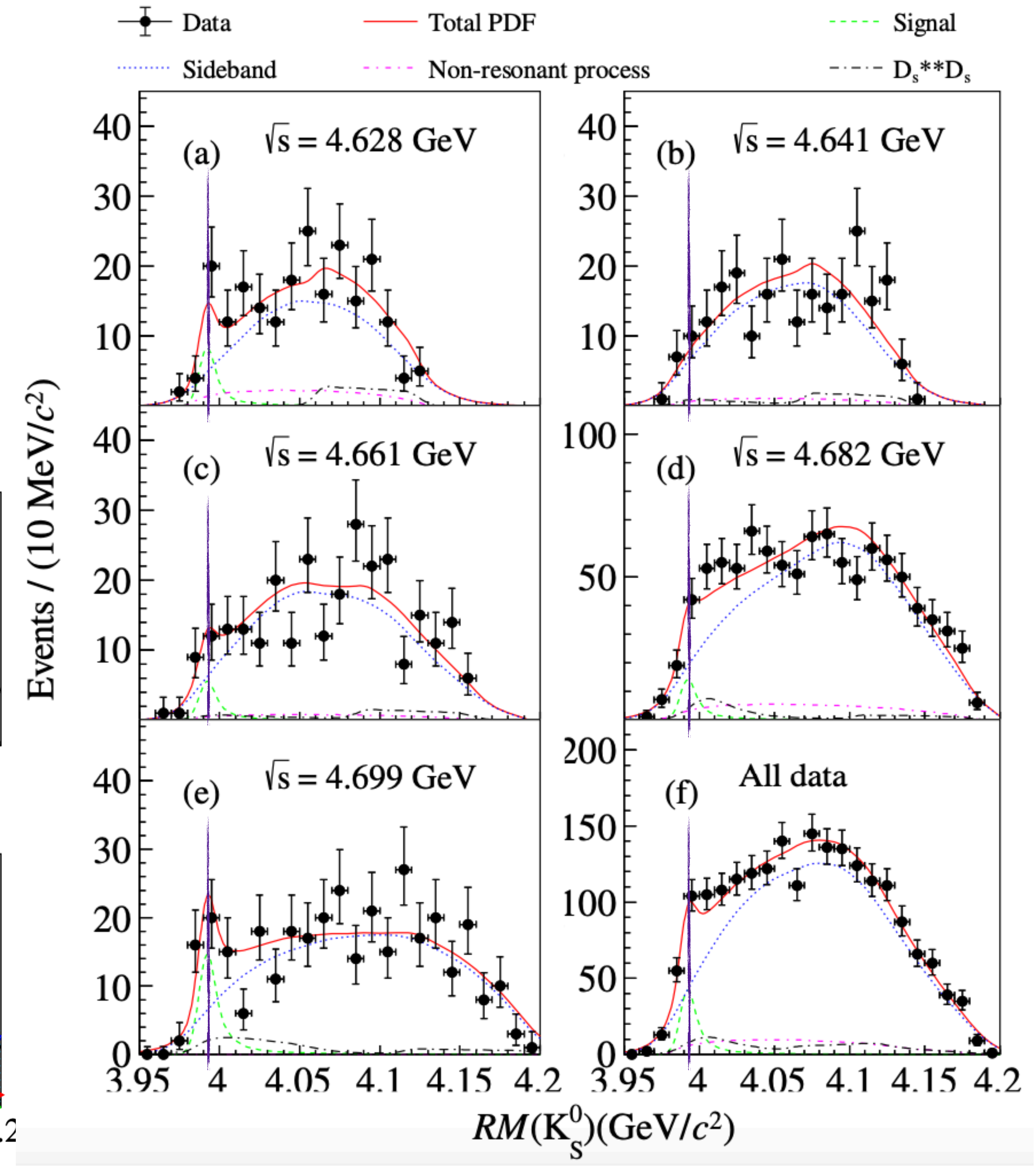

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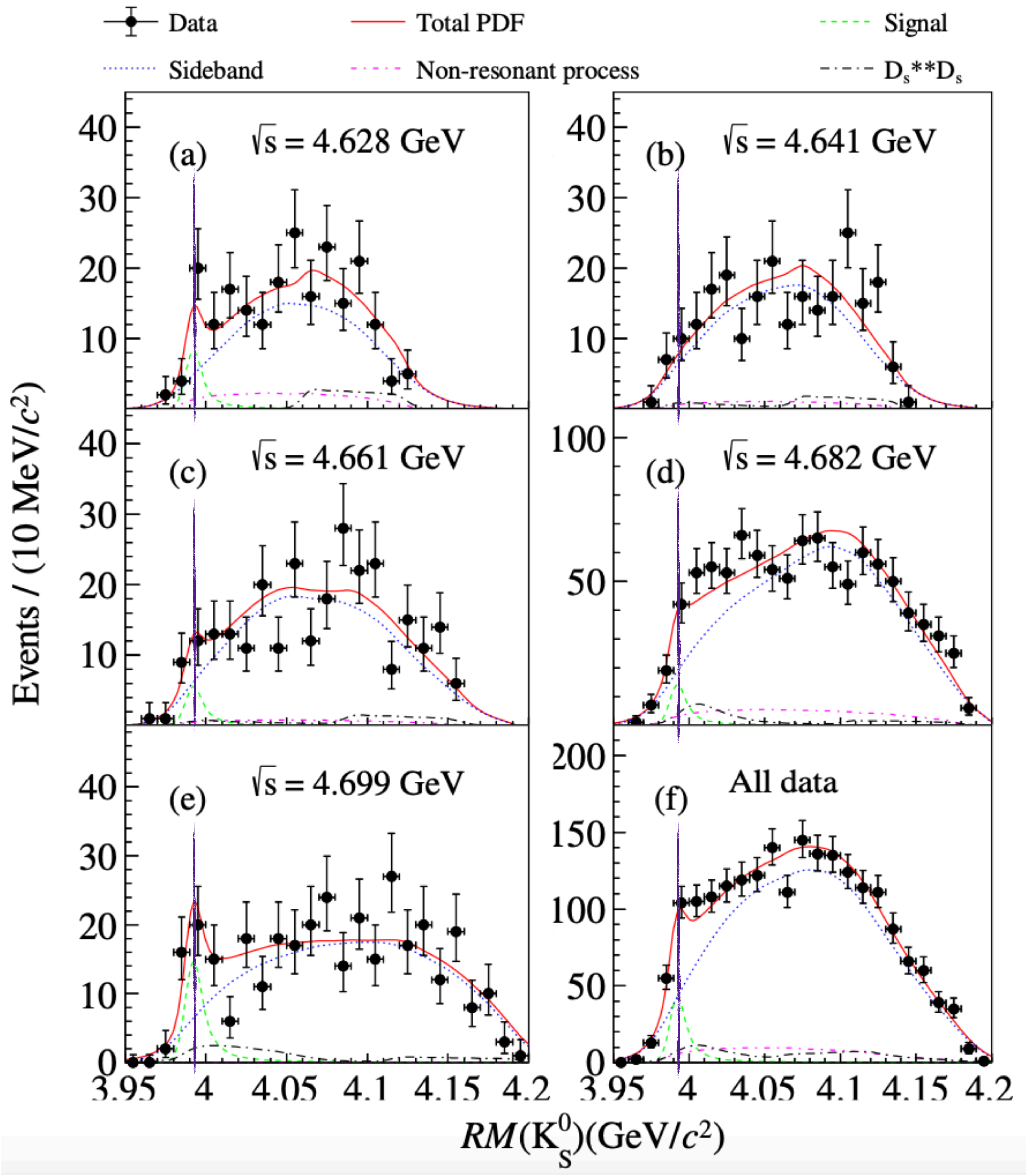
Coupling to $D_s^- D^{*+}$ and $D_s^{*-} D^+$ suggests $c\bar{c}s\bar{d}$

m(Z_{cs}^0) > m(Z_{cs}^+), which is **consistent with predictions**[1]

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



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

$\sqrt{s}$ (MeV)	$\sigma^{Born} \times \mathcal{B}$ (pb) $\bar{K}^0 Z_{cs}(3985)^0$	$\sigma^{Born} \times \mathcal{B}$ (pb) $K^- Z_{cs}(3985)^+$
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	$7.0^{+2.2}_{-2.0} \pm 1.8$	$2.4^{+1.1}_{-1.0} \pm 1.2$

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

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

Y and ψ States

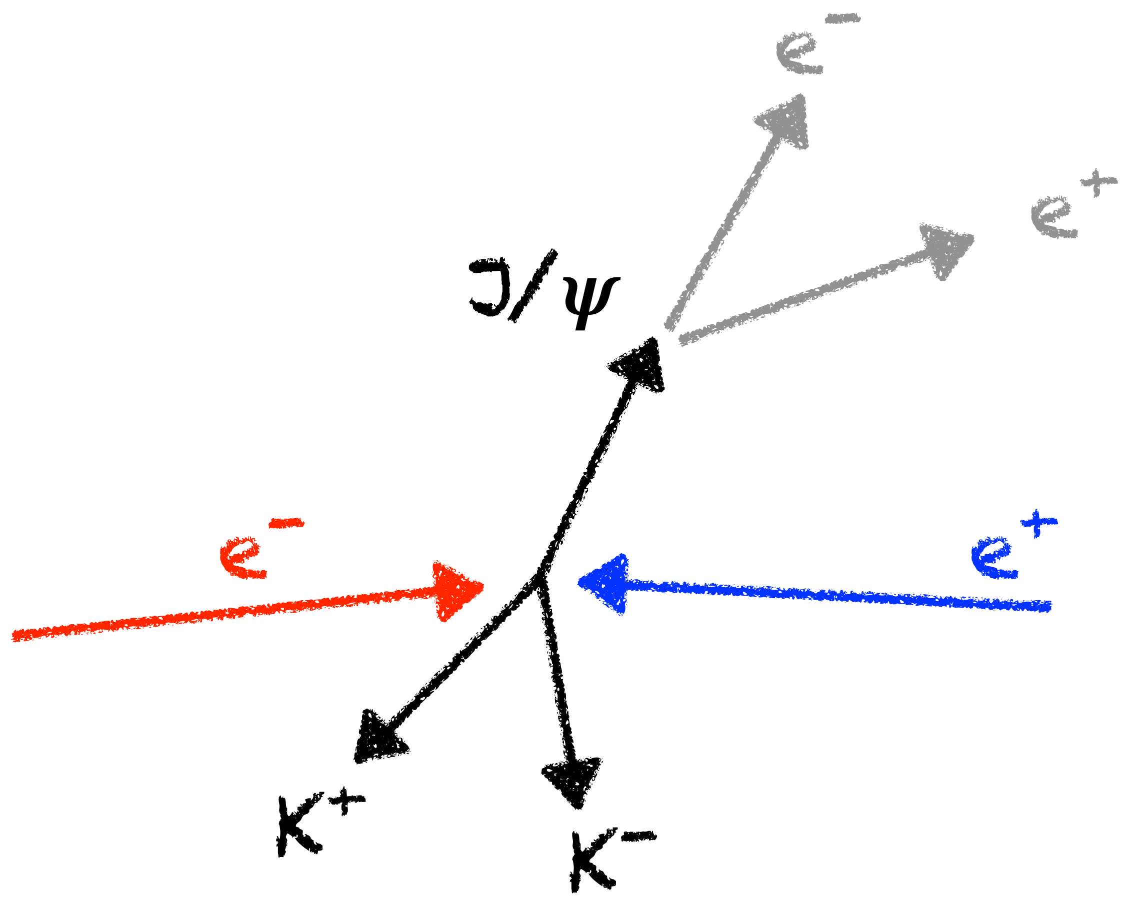
arXiv:2204.07800
Submitted to PRL

Using 28 energy points @$\sqrt{s}$ = **[4.127, 4.600] GeV** for a $\mathcal{L}_{int}$ = 15.6 fb^{-1}

Study of the **$\sigma(e^+e^- \rightarrow K^+K^-J/\psi)$** line-shape, employing a partial reconstruction technique: K & J/ψ ($\rightarrow \ell^+\ell^-$)

KK distributions, with $N^{KKJ/\psi}_{obs} > 55$, are then fitted to extrapolate signal yields

Yields for energy points with $N^{KKJ/\psi}_{obs} < 55$ are estimated via linear interpolation



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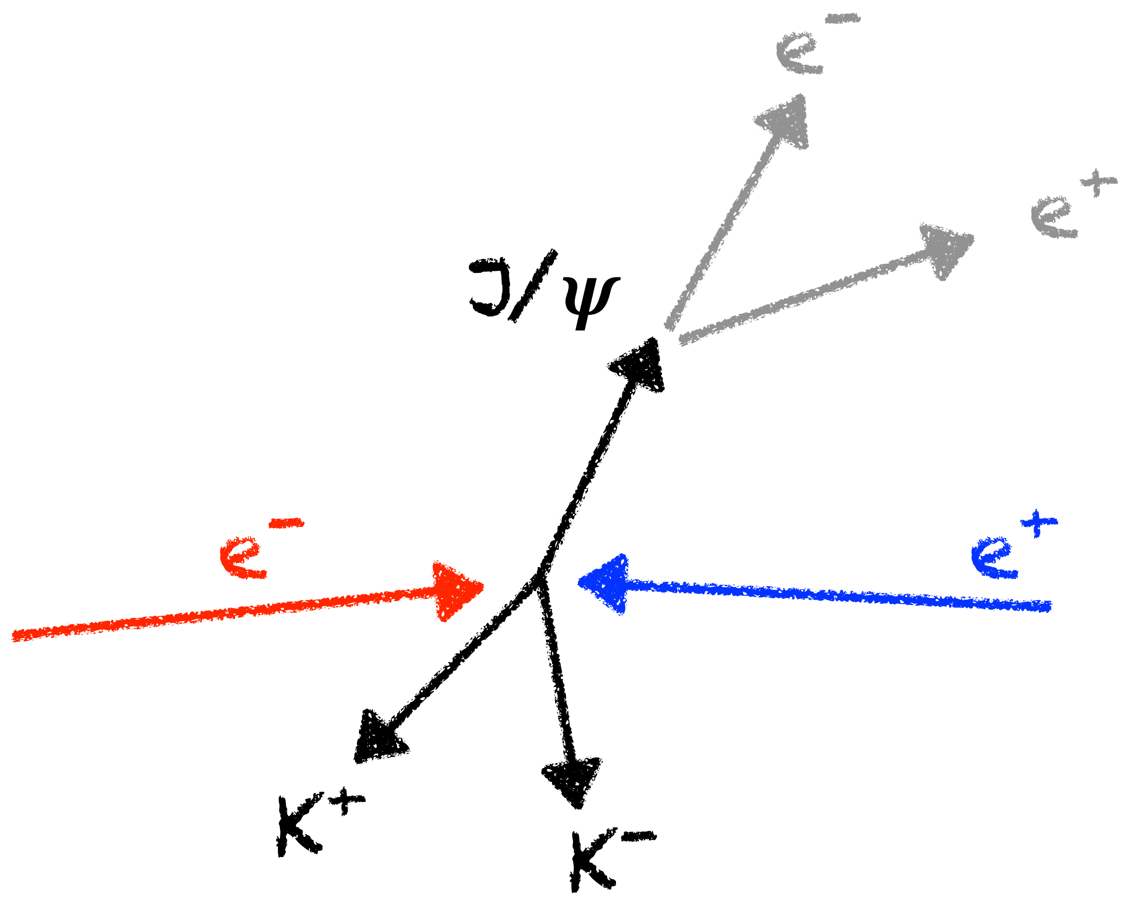

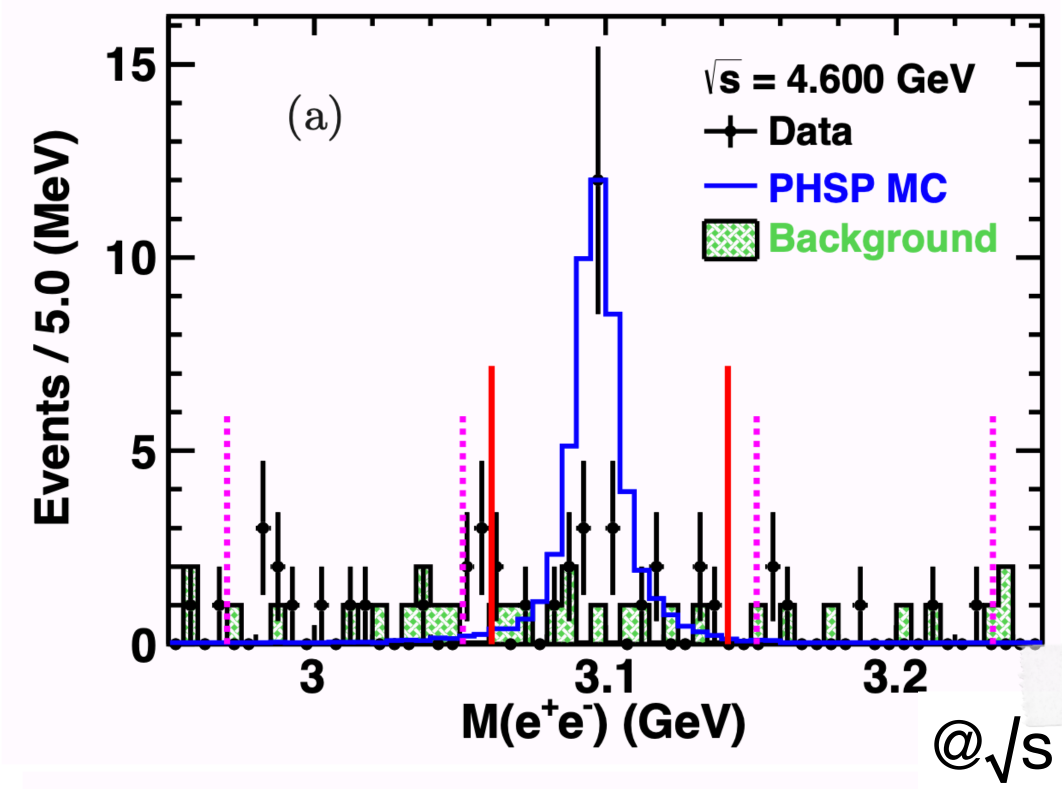

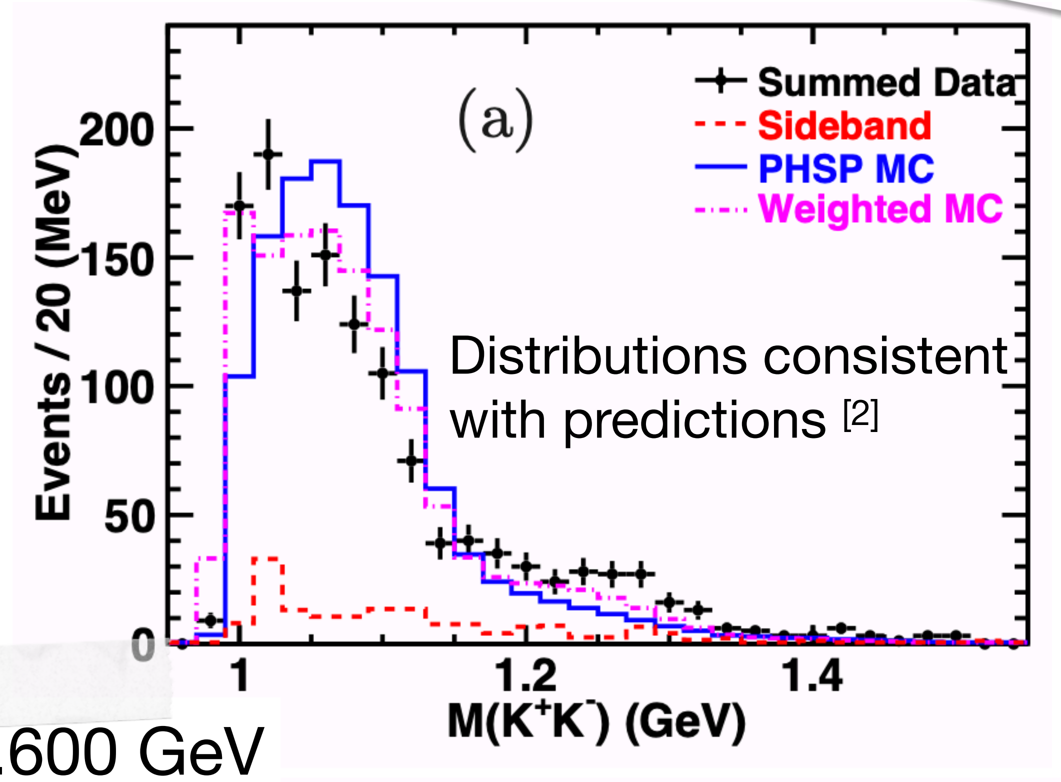

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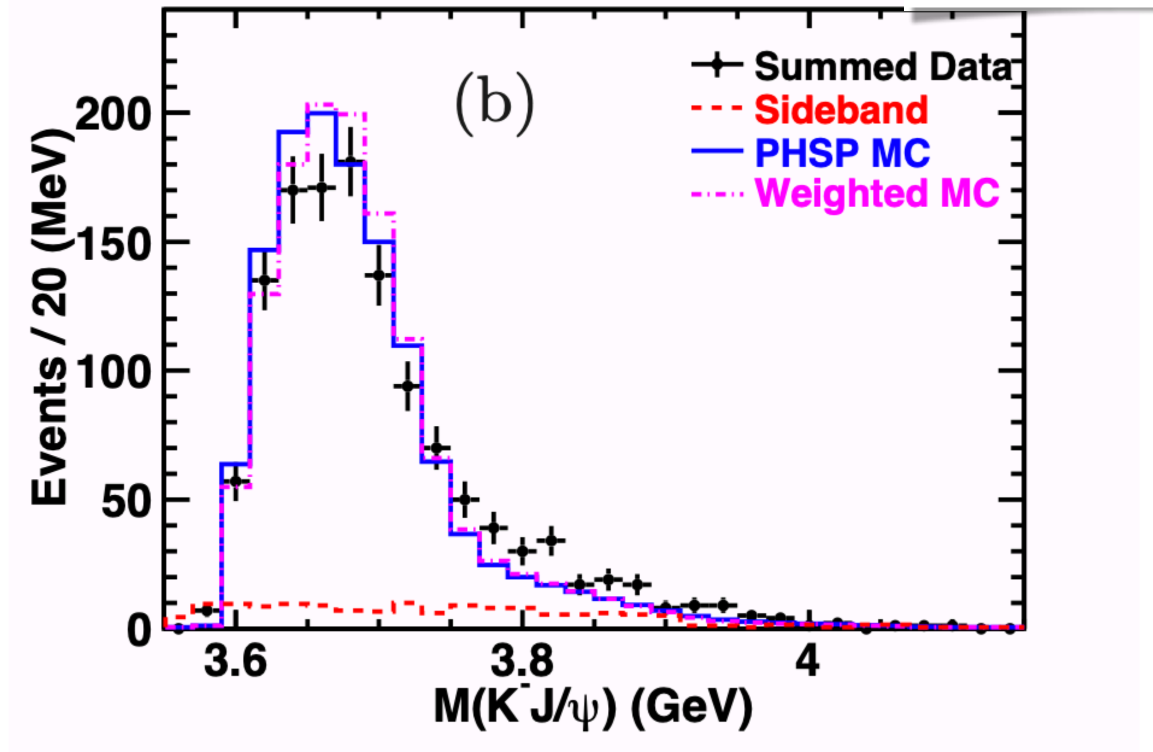

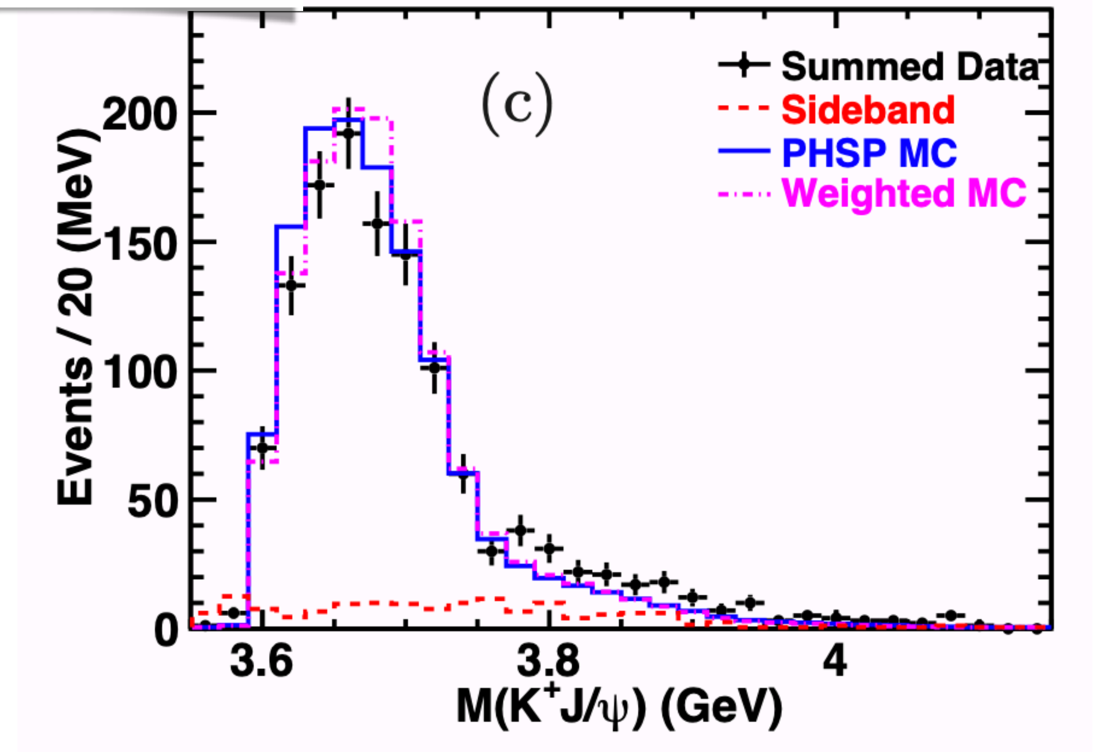

[2] Phys. Rev. D **102**, 016019 (2020)

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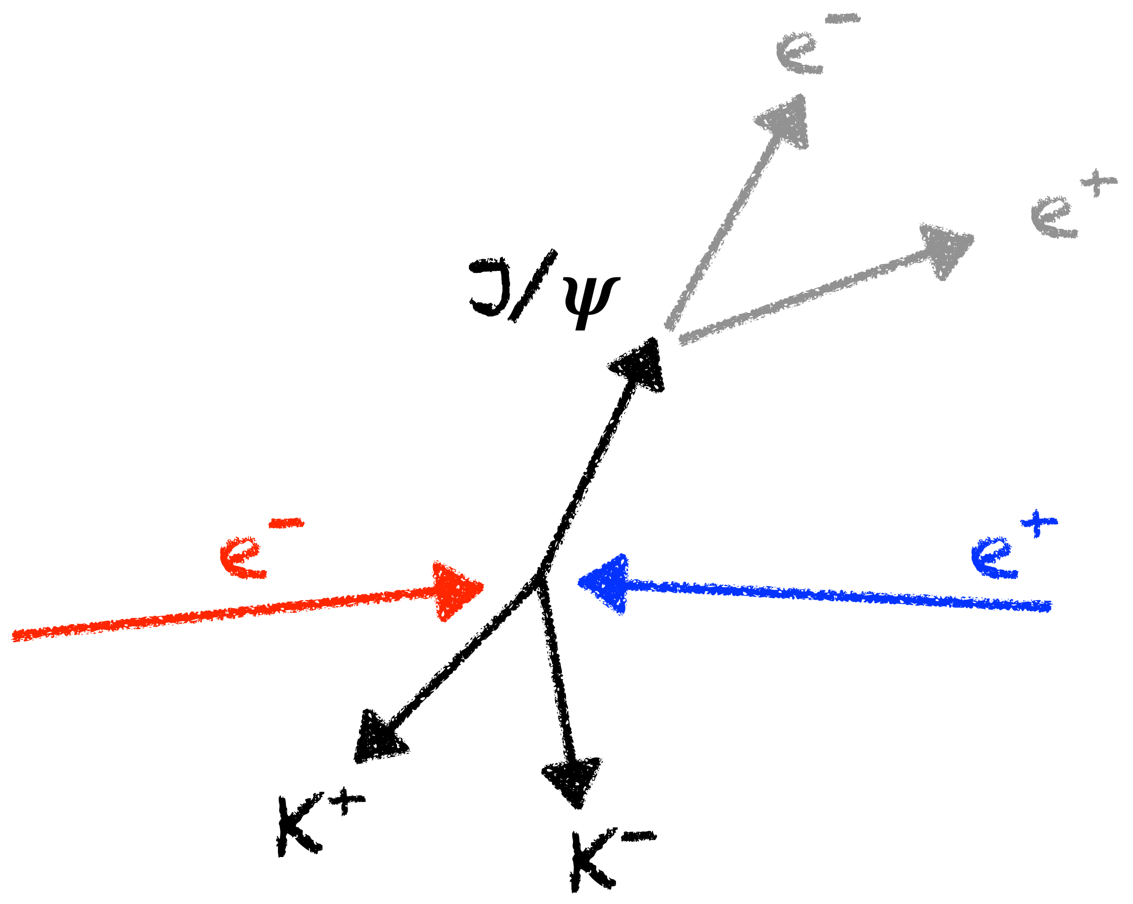

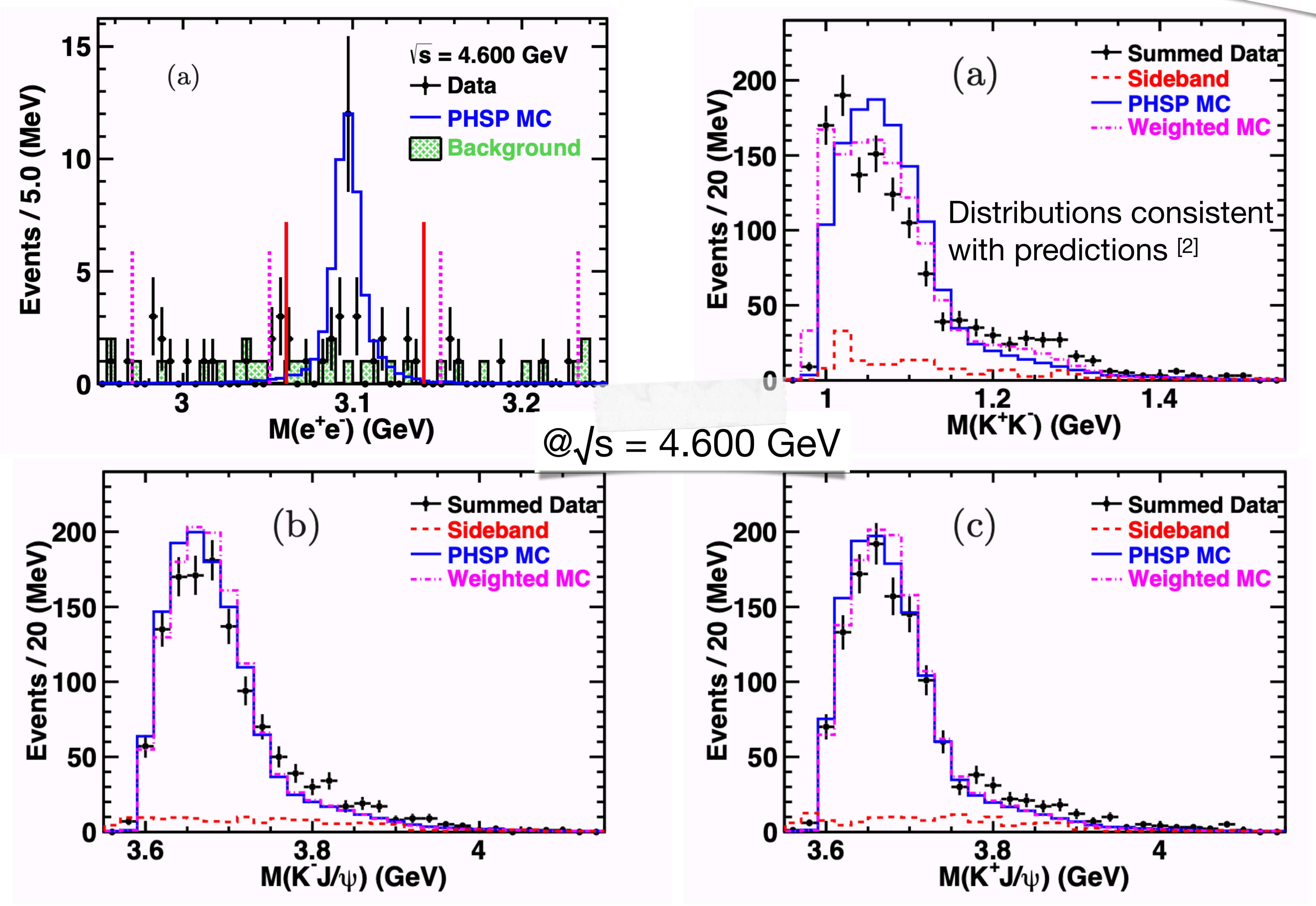

[2] Phys. Rev. D **102**, 016019 (2020)

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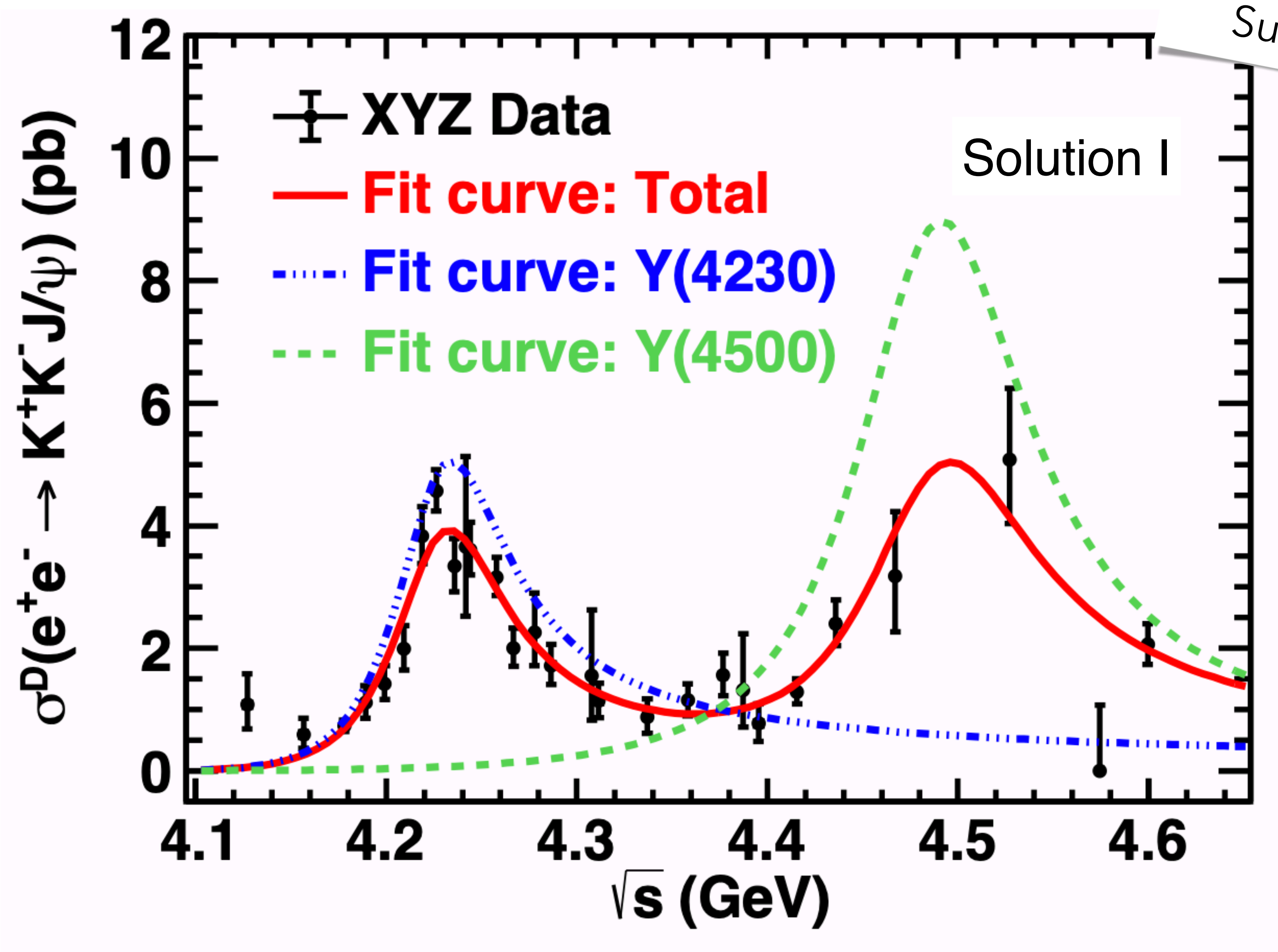
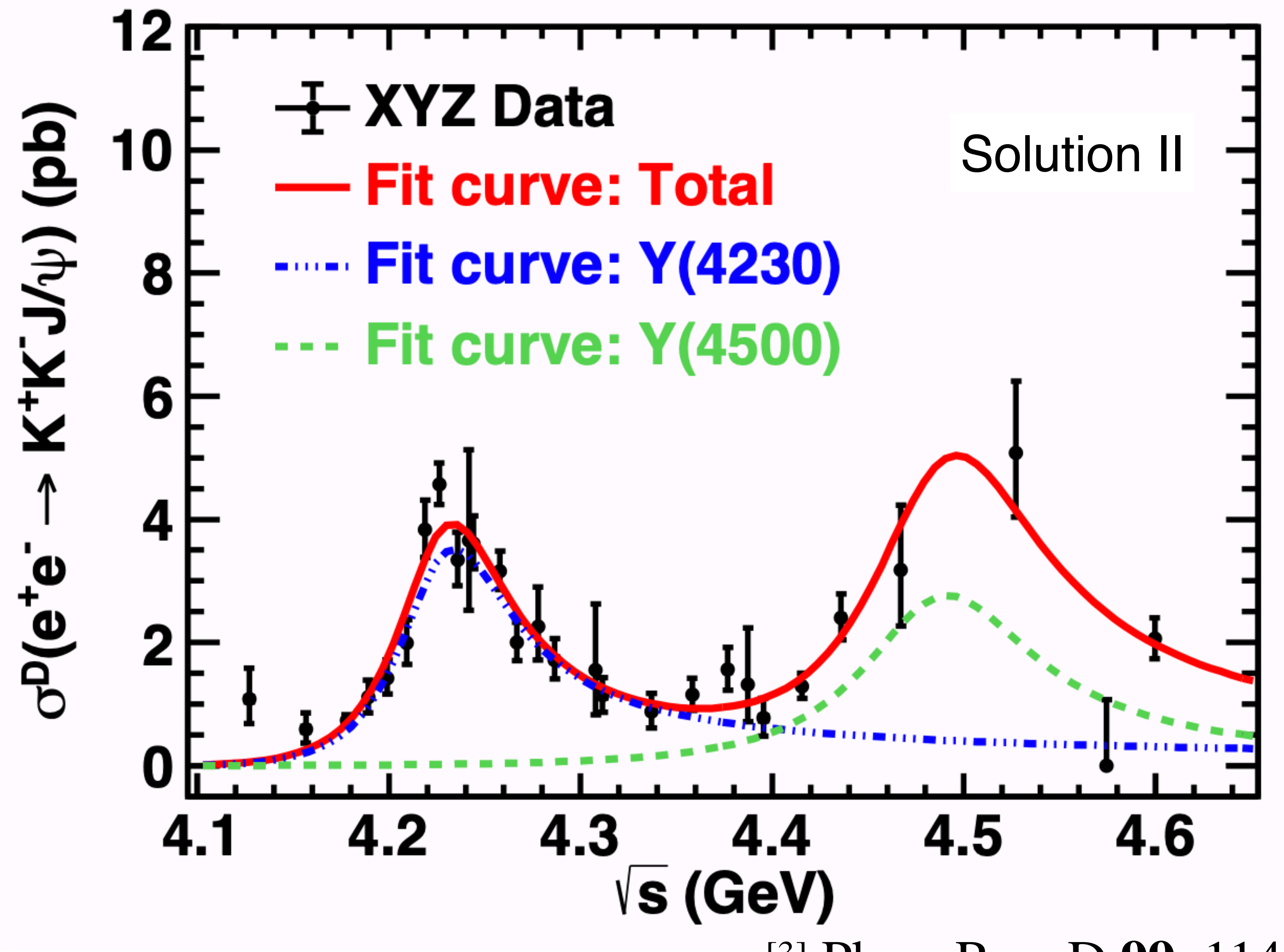
$\sigma^D(e^+e^- \to K^+K^-J/\psi)$ is then fitted and…

	Parameters	Solution I	Solution II
$Y(4230)$ **@29σ**	M(MeV)	$4225.3 \pm 2.3 \pm 21.5$	
	Γ_{tot}(MeV)	$72.9 \pm 6.1 \pm 30.8$	
First time in KKJ/ψ	$\Gamma_{ee}\mathcal{B}$(eV)	$0.42 \pm 0.04 \pm 0.15$	$0.29 \pm 0.02 \pm 0.10$
$Y(4500)$ **@8σ**	M(MeV)	$4484.7 \pm 13.3 \pm 24.1$	
	Γ_{tot}(MeV)	$111.1 \pm 30.1 \pm 15.2$	
First time ever	$\Gamma_{ee}\mathcal{B}$(eV)	$1.35 \pm 0.14 \pm 0.06$	$0.41 \pm 0.08 \pm 0.13$
phase angle	φ(rad)	$1.72 \pm 0.09 \pm 0.52$	$5.49 \pm 0.35 \pm 0.58$

The **Y(4500)** is **consistent with** the **5S-4D** mixing scheme[3], the hadronic **molecule model**[4] and a **hidden-charm hidden-strange** state[5]

arXiv:2204.07800
Submitted to PRL





[3] Phys. Rev. D **99**, 114003 (2019)
[4] Progr. Phys. **41**, 65 (2021)
[5] Phys. Rev. D 73, 094510 (2006)

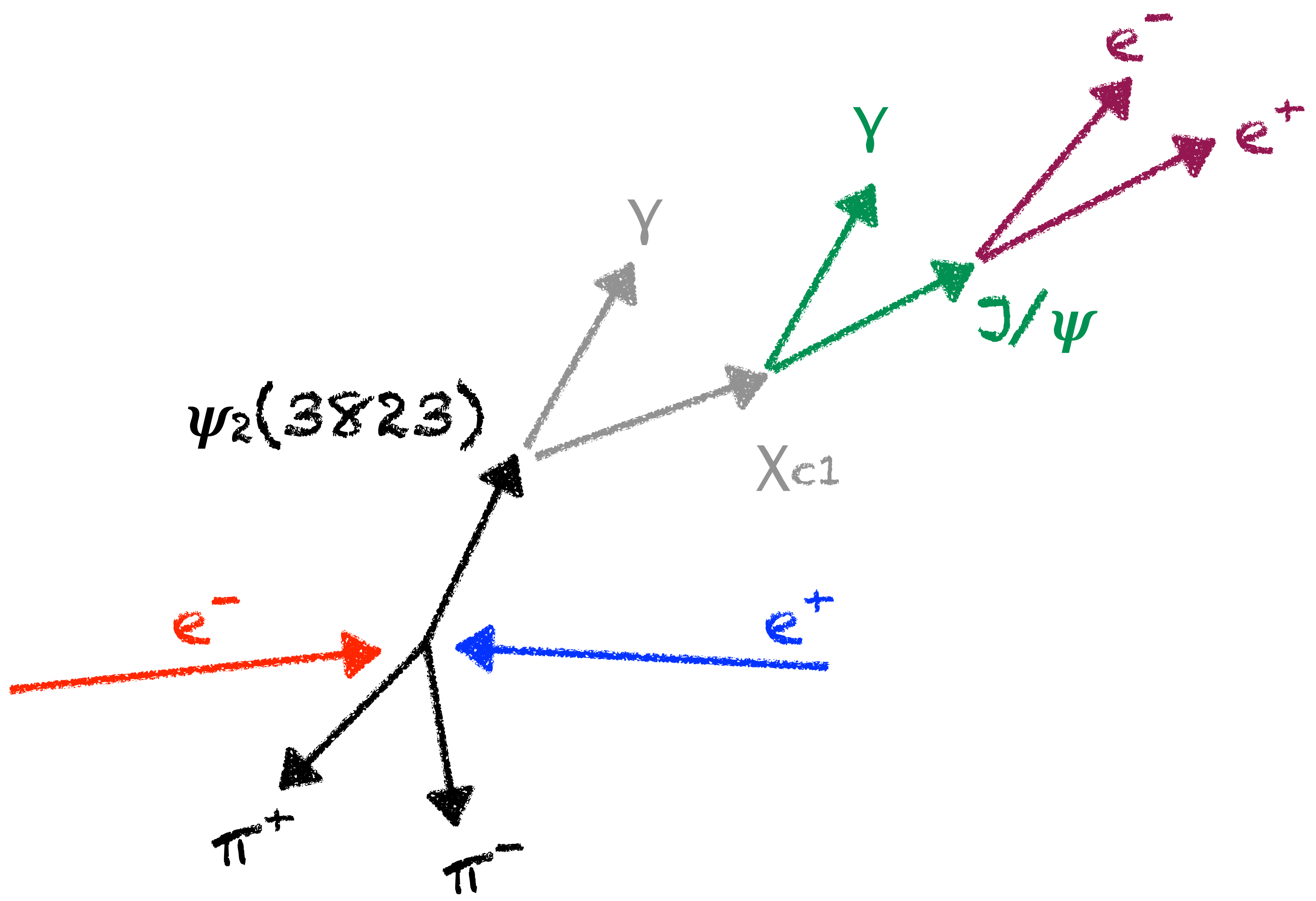
Y and ψ States

arXiv:2203.05815
Submitted to PRL

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 ($\to \ell^+\ell^-$)

Fit to $M^{recoil}(\pi^+\pi^-)$ to estimate $\psi_2(3823)$ mass and $N^{\pi\pi\psi}_{obs}$



Υ and ψ States

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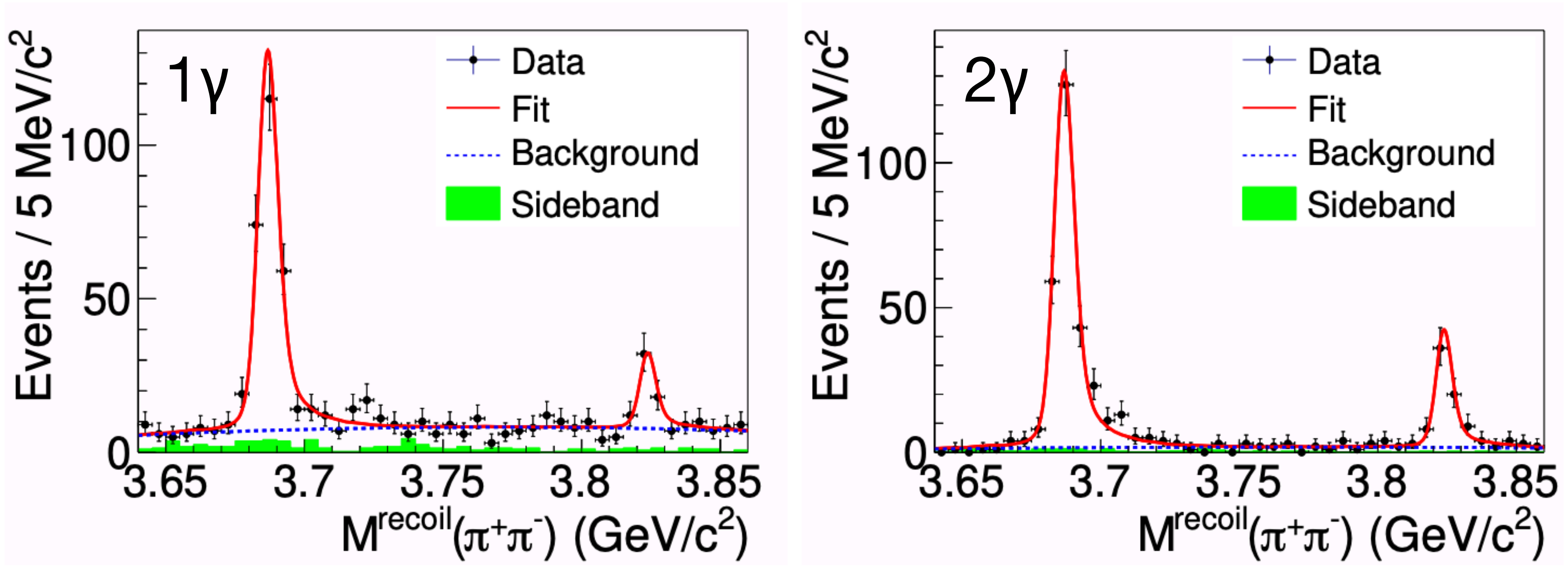

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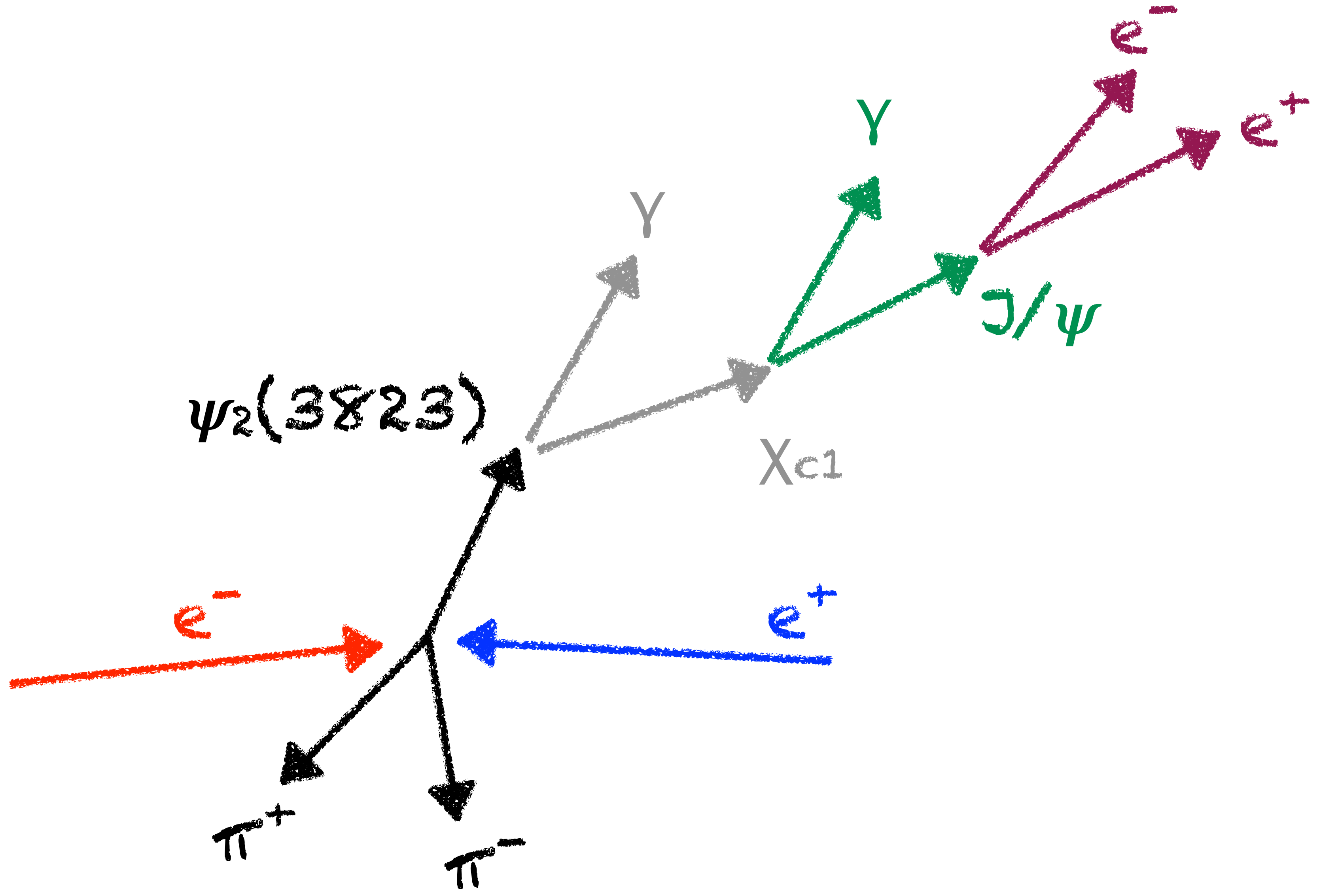

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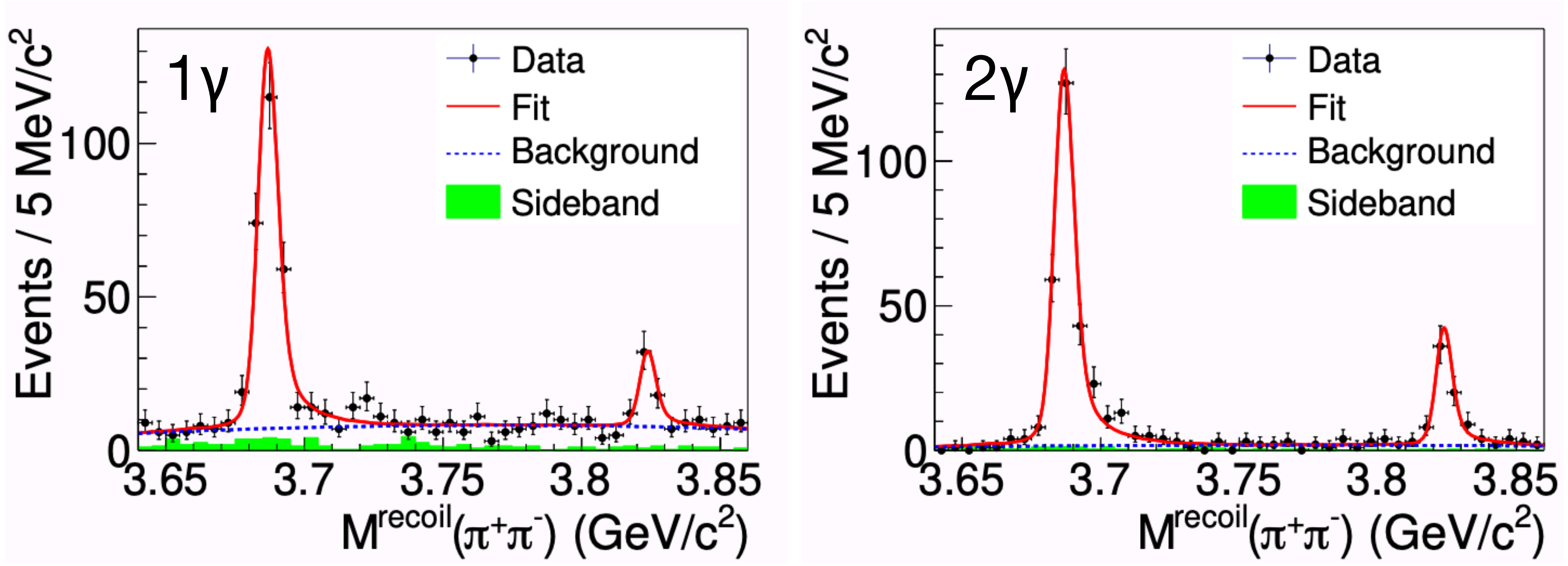

3823.12 ± 0.43 ± 0.13 MeV/c^2
Most precise estimate up to date

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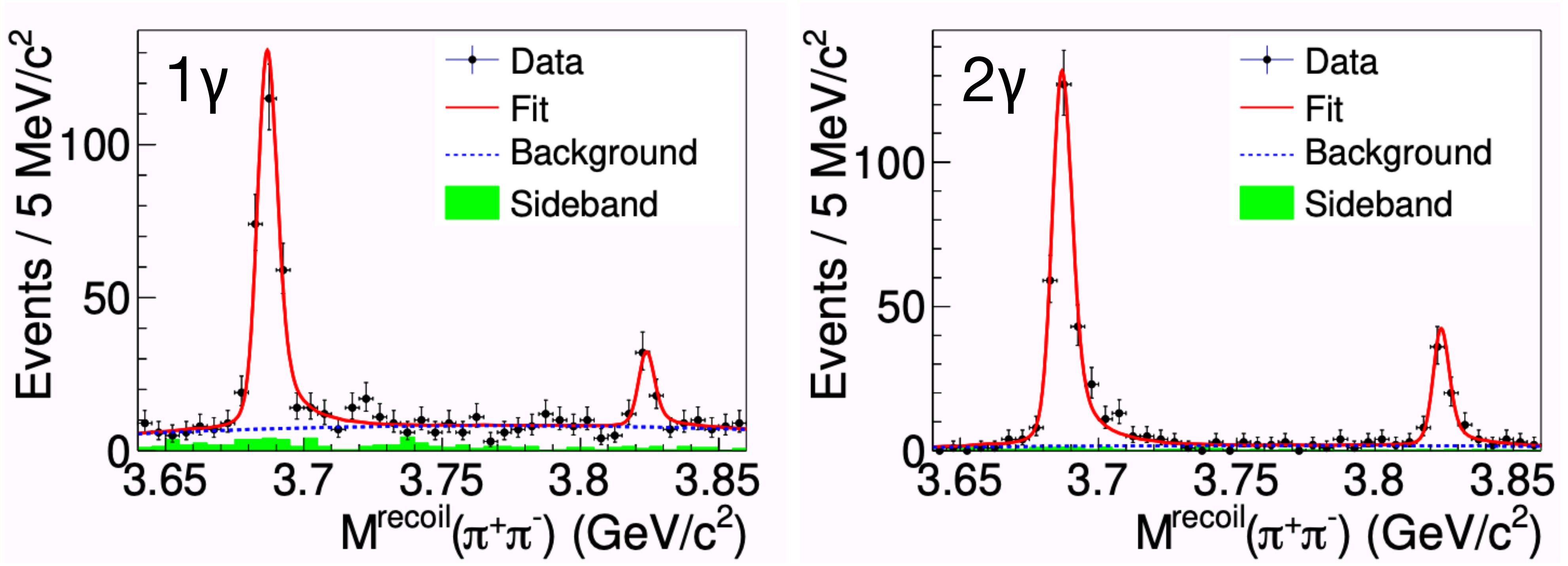
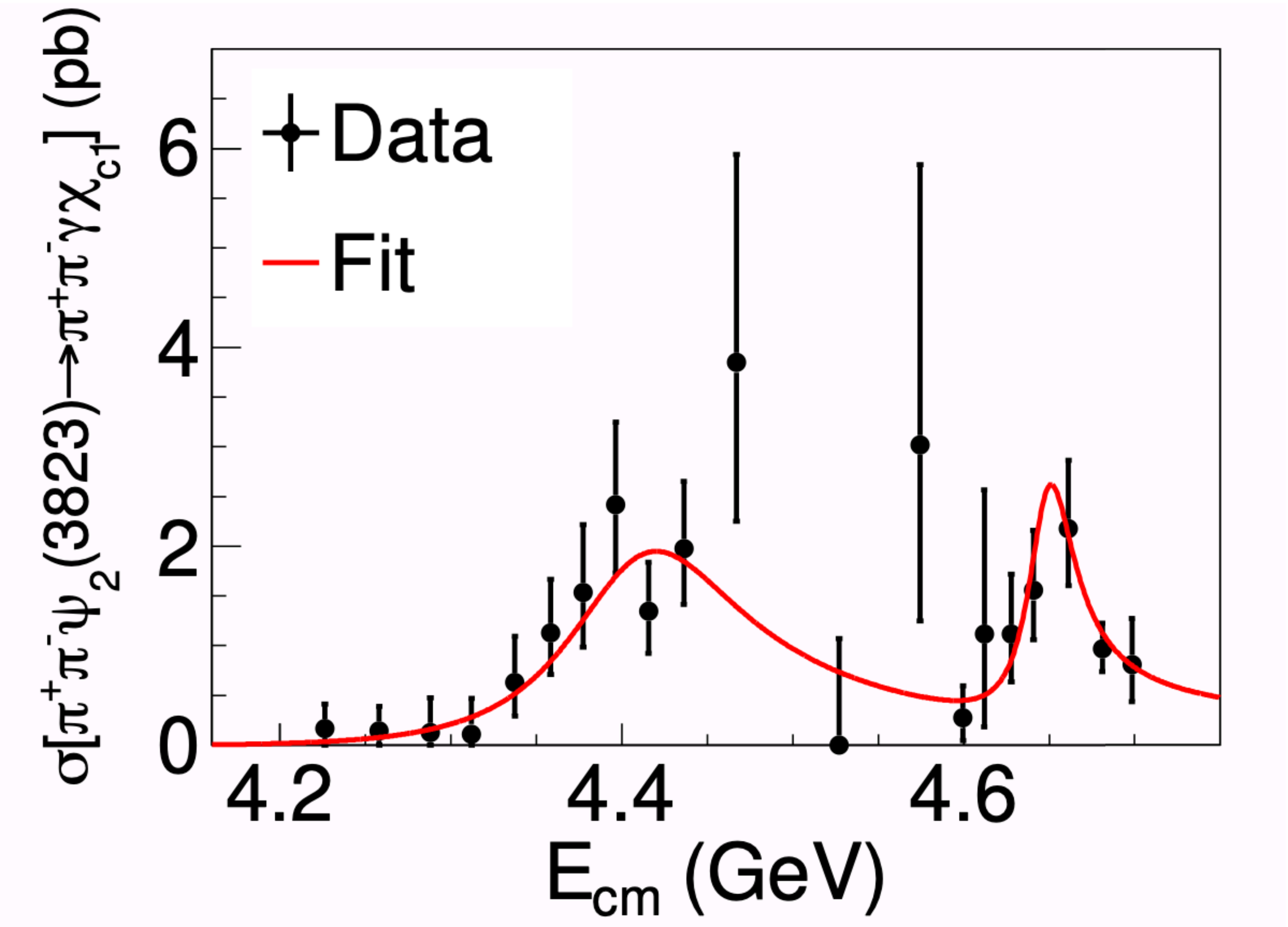


In the $\sigma(e^+e^- \to \pi^+\pi^-\psi_2(3823))$, found structures corresponding to the Y(4360) and Y(4660)

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 $f_0(980)\psi(2S)$ **hadron molecule** interpretation[6] and the extended **baryonium** picture[7]



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

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

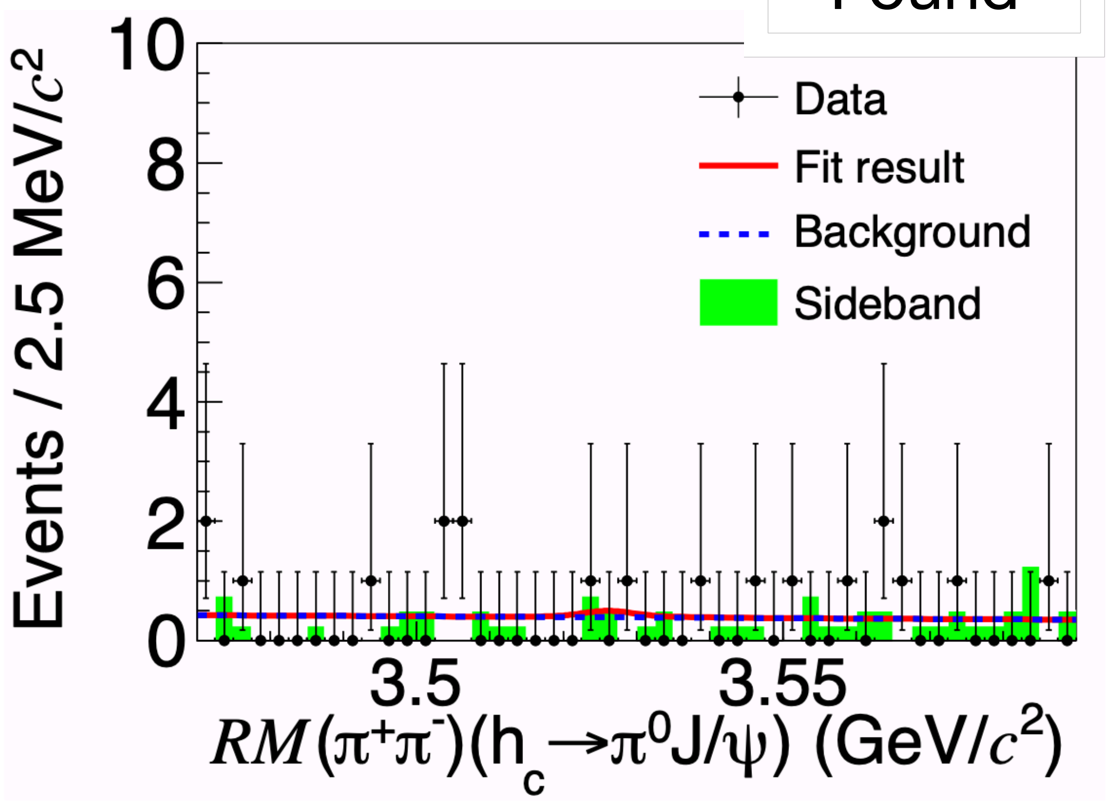
JHEP **2022**, 3 (2022)

$e^+e^- \to \pi^+\pi^- h_c$ 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[8]
Agreement with E835[9]

No Signal Found



[8] Phys. Rev. Lett. **69** (1992) 2337
[9] Phys. Rev. D **72** (2005) 032001

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Using 448 million ψ(2S) events

Non-E1 decays

JHEP **2022**, 3 (2022)

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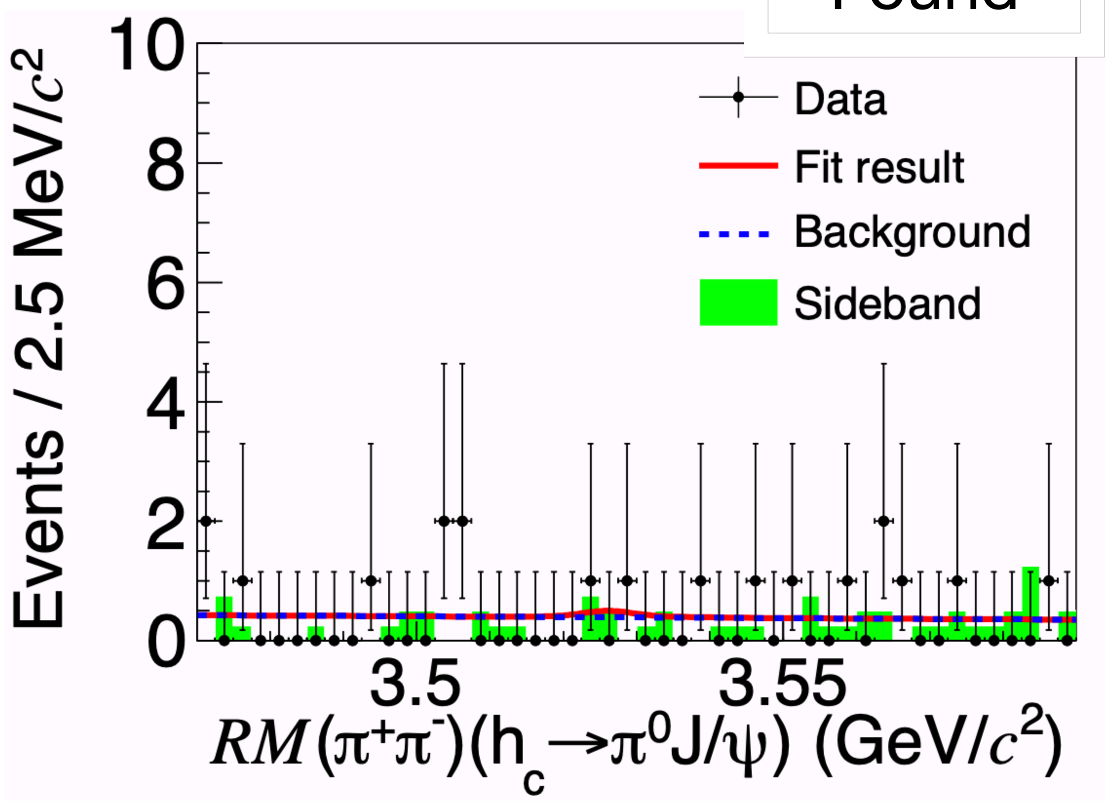
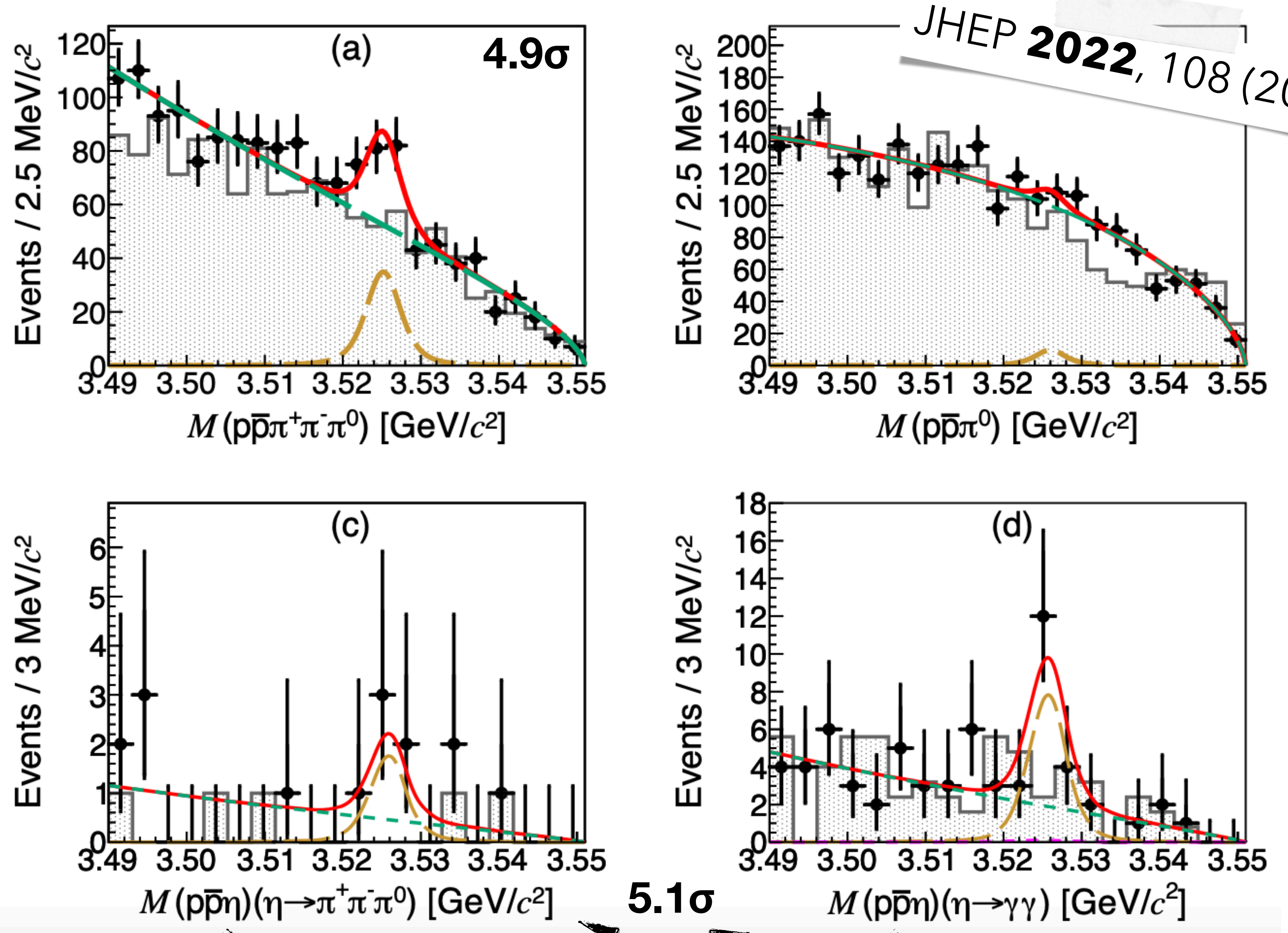


JHEP **2022**, 108 (2022)



5.1σ

[8] Phys. Rev. Lett. **69** (1992) 2337
[9] Phys. Rev. D **72** (2005) 032001

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

Using 448 million ψ(2S) events

Non-E1 decays

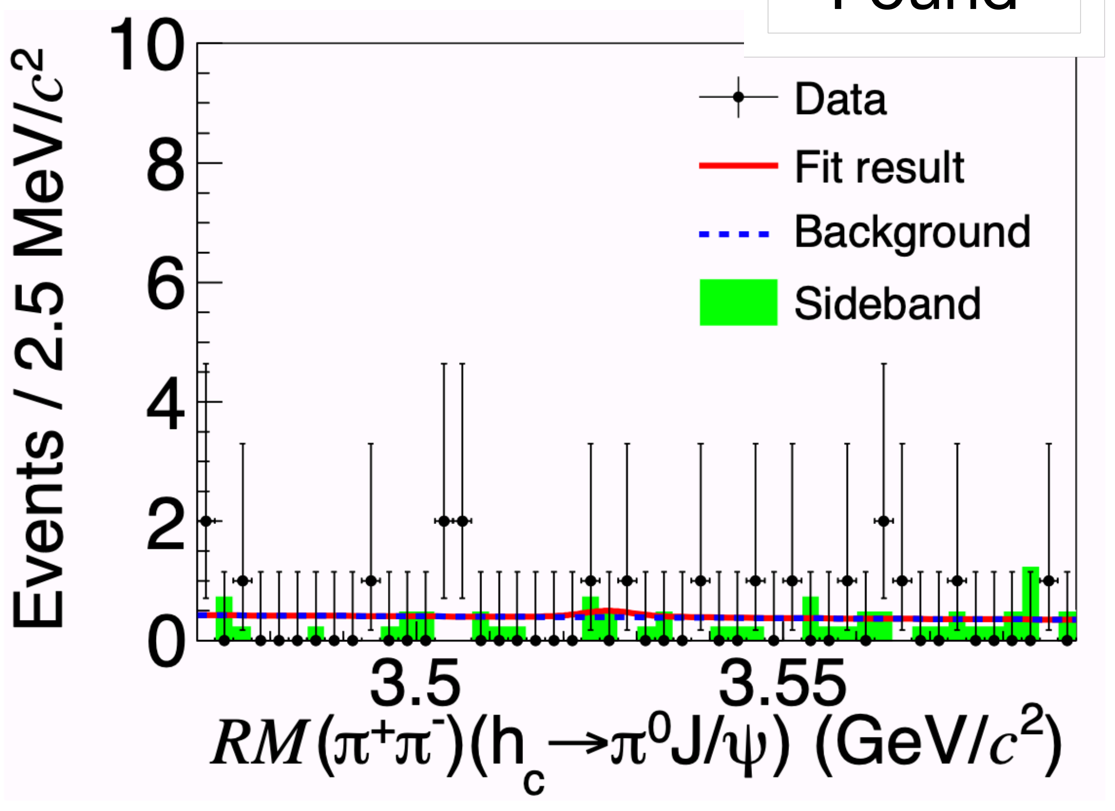
JHEP **2022**, 3 (2022)

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

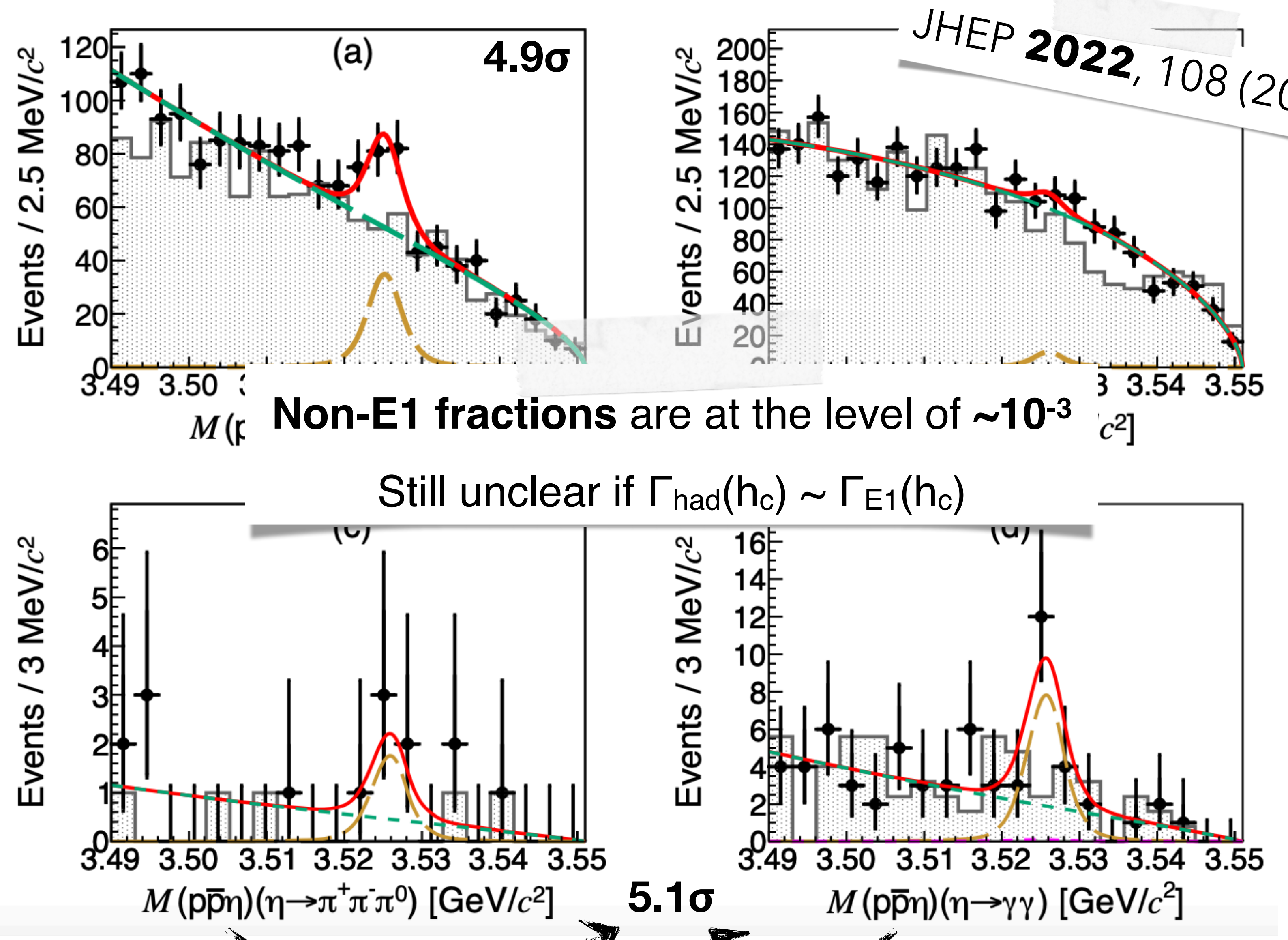
$h_c \rightarrow \pi^0 J/\psi$ @$\sqrt{s}$ = [4.189, 4.437] GeV

Tensions with E760[8]
Agreement with E835[9]

No Signal Found



JHEP **2022**, 108 (2022)



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

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

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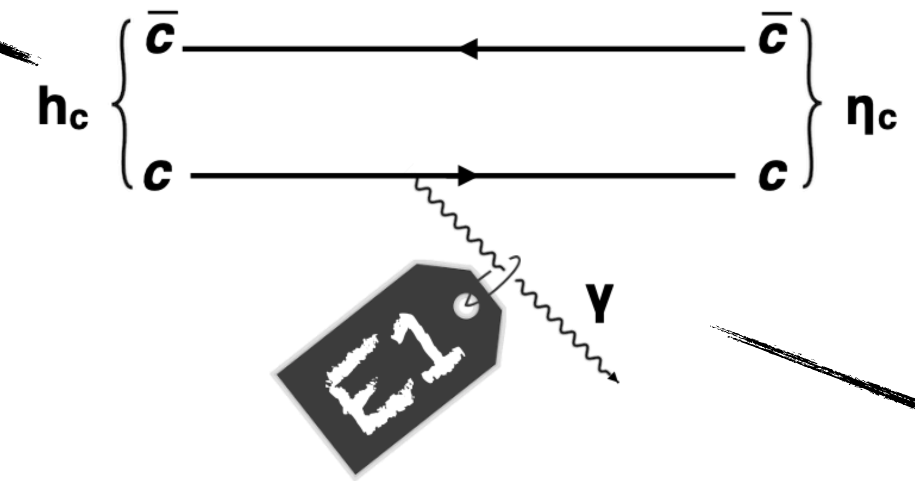

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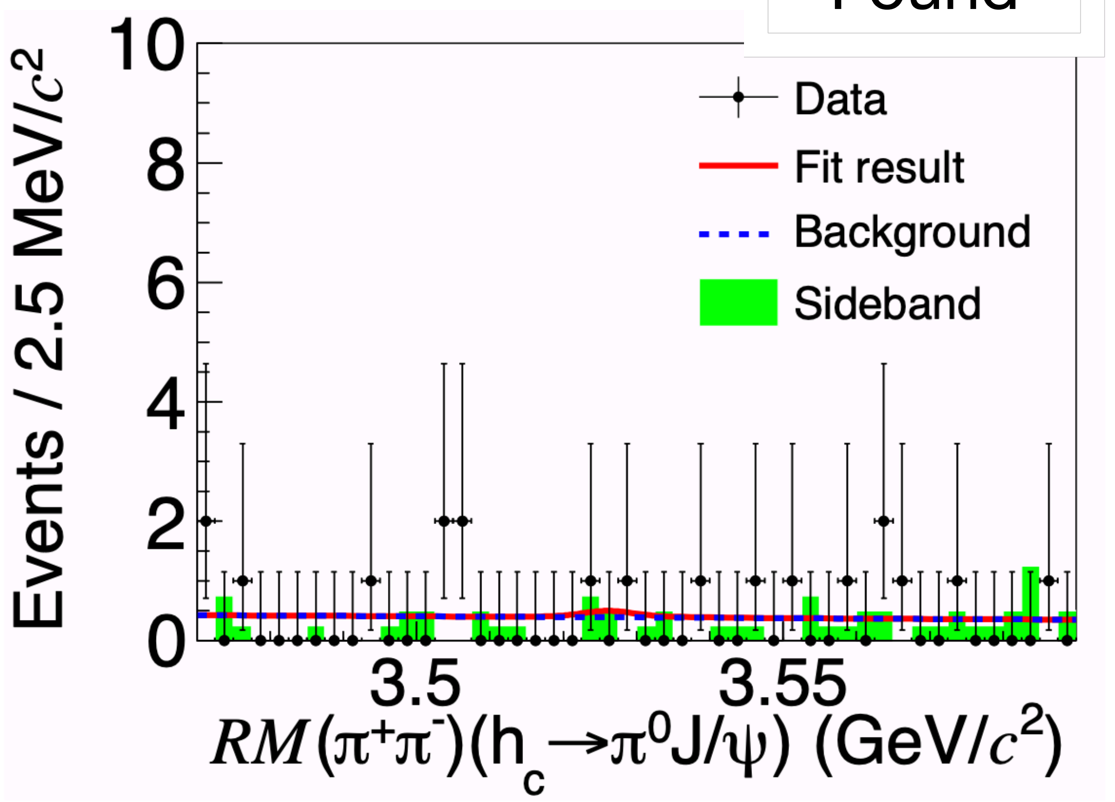
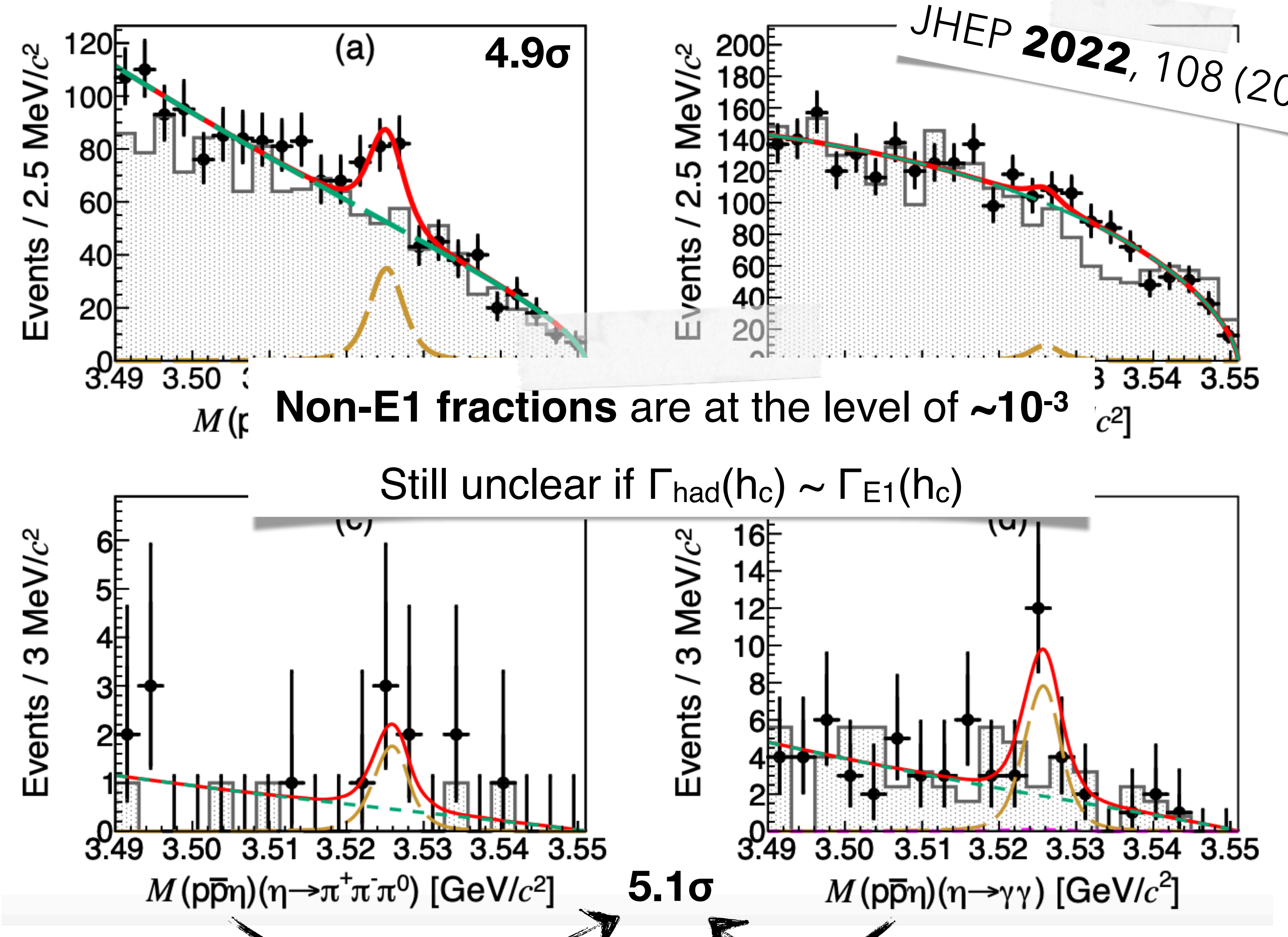


JHEP **2022**, 108 (2022)



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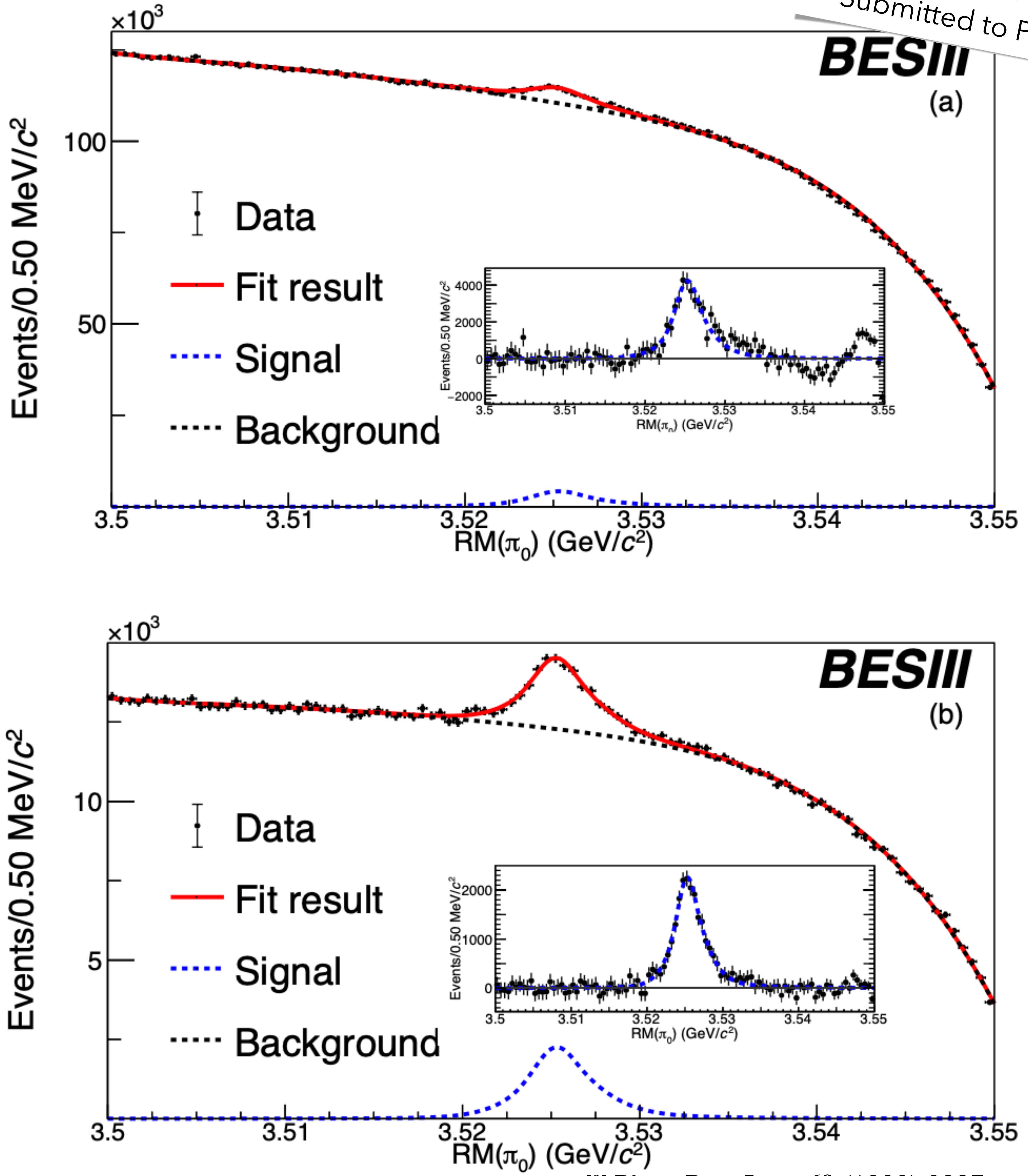
arXiv:2204.09413
Submitted to PRD



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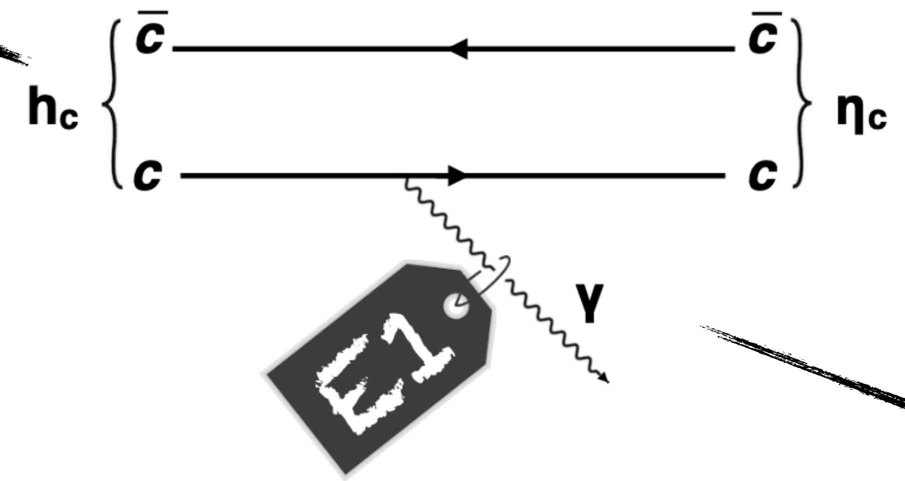

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Variable	Value	PDG
$M(h_c)$ (MeV/c^2)	$3525.32 \pm 0.06 \pm 0.15$	3525.38 ± 0.11
$\Gamma(h_c)$ (MeV)	$0.78\ ^{+0.27}_{-0.24} \pm 0.12$	0.7 ± 0.4
$N_{\rm Tag}(h_c)$	$23118\ ^{+1500}_{-1398}$	—
$\mathcal{B}_{\rm Inc} \times \mathcal{B}_{\rm Tag}$ (10^{-4})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

Non-E1 decays

JHEP **2022**, 3 (2022)

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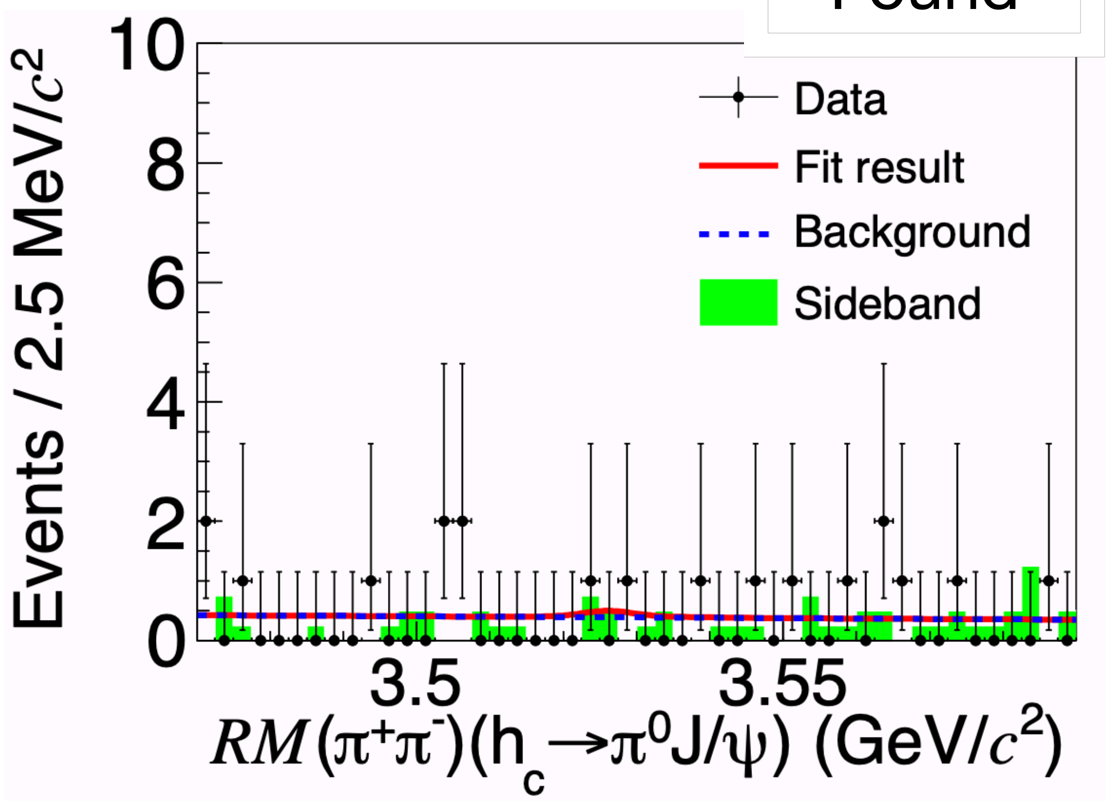

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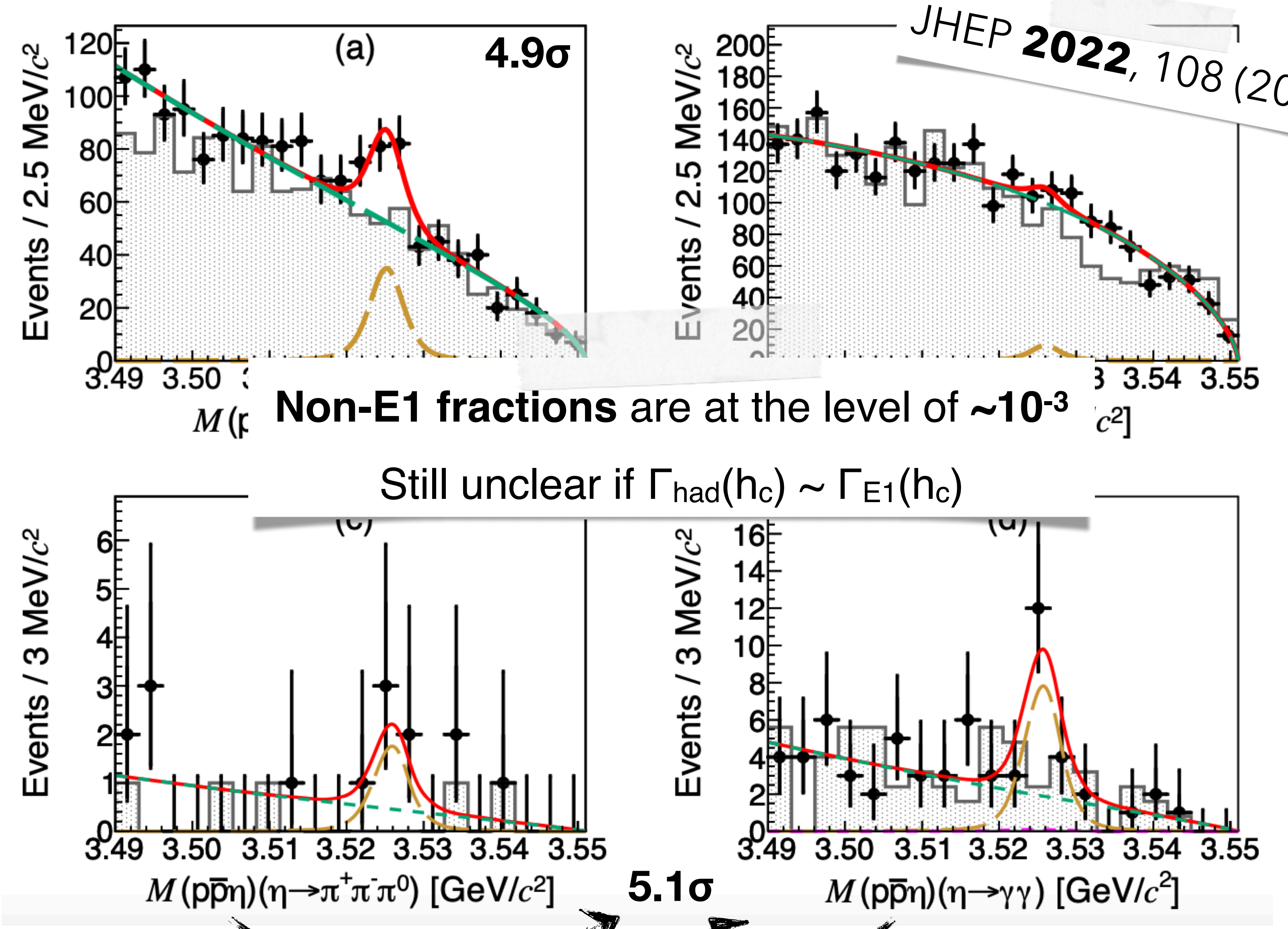

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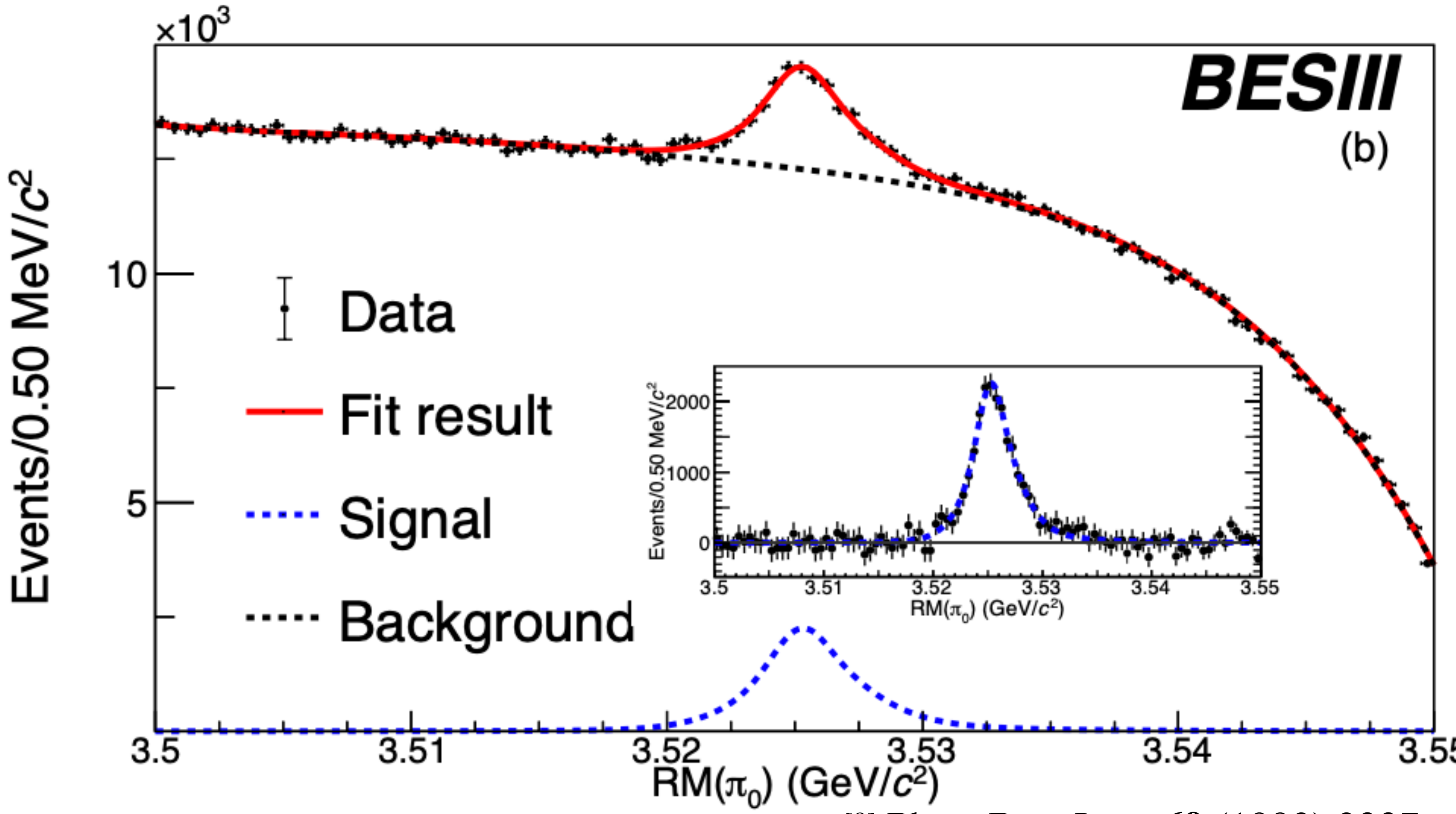
Wrt the **center-of-gravity mass** of the three $\chi_{cJ}(1^3P_J)$ states, **no mass splitting** is observed with this measurement **as** predicted by potential model **calculations**[10]



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[9] Phys. Rev. D **72** (2005) 032001
[10] Ann. Rev. Nucl. Part. Sci. **37**, 325 (1987)

Light Hadrons

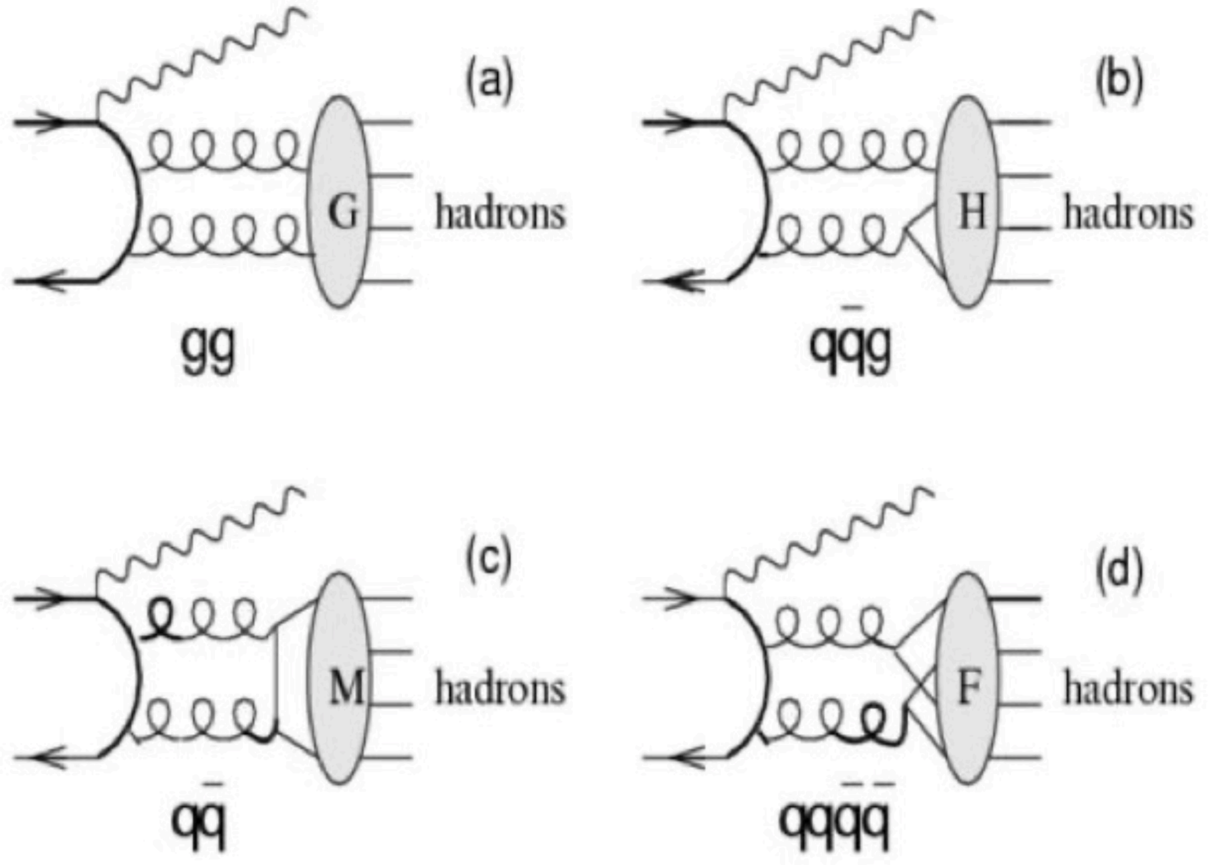
The **Naïve Quark Model** describes **conventional hadrons** containing two or three quarks…

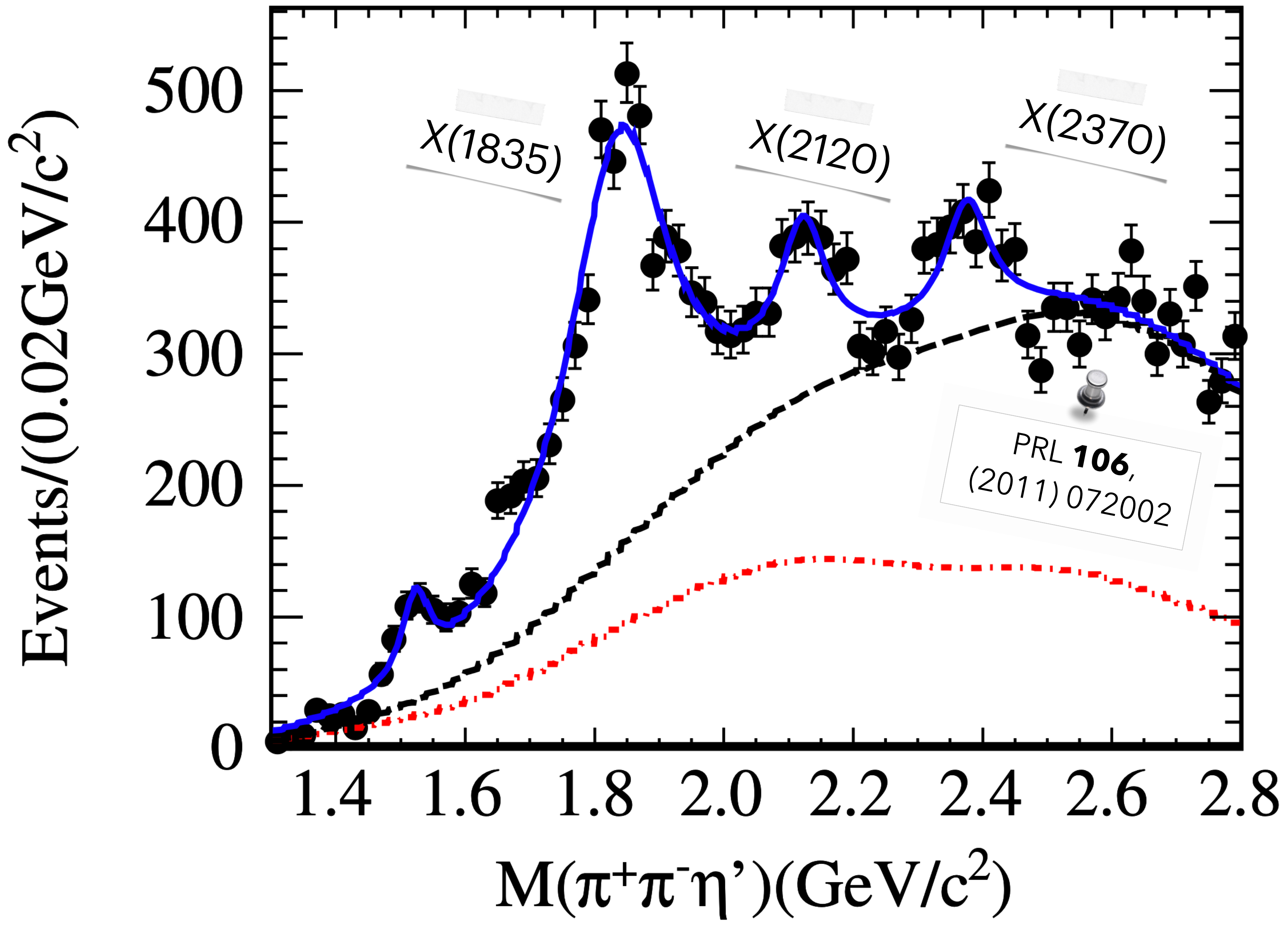
QCD predict an **additional** plethora of ***exotic* states** (*hybrids*, *glueballs*, …)

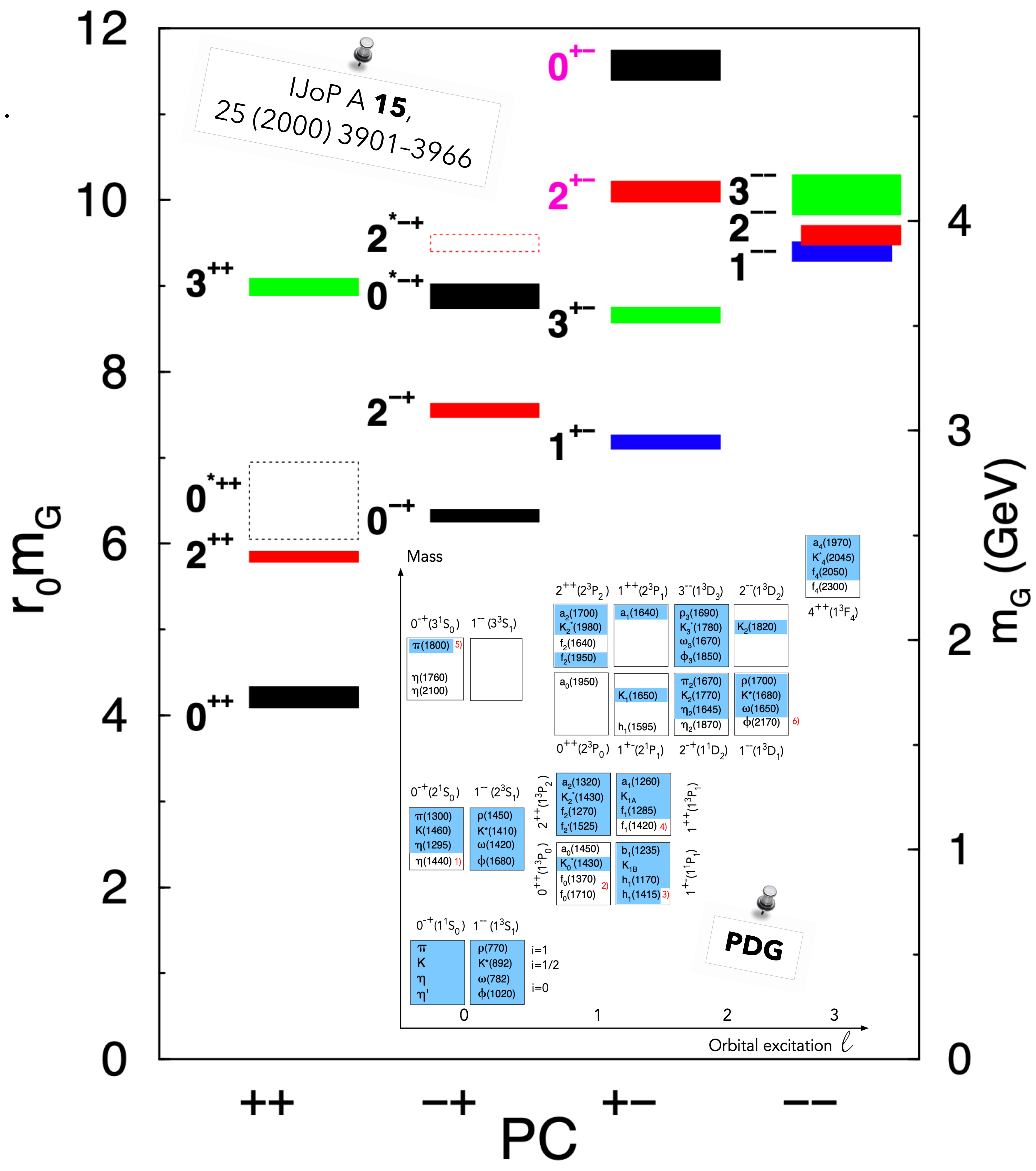
In fact, also below $c\bar{c}$ spectrum many **supernumerary states** are experimentally observes

The **nature** of these exotic states is **hard to determine**, as they have overlapping masses with "regular" states

Radiative J/ψ (→γ + *had*) decays are gluon-rich processes, **ideal** for studying light glueballs and hybrids







A New Incognita… The X(2600) State

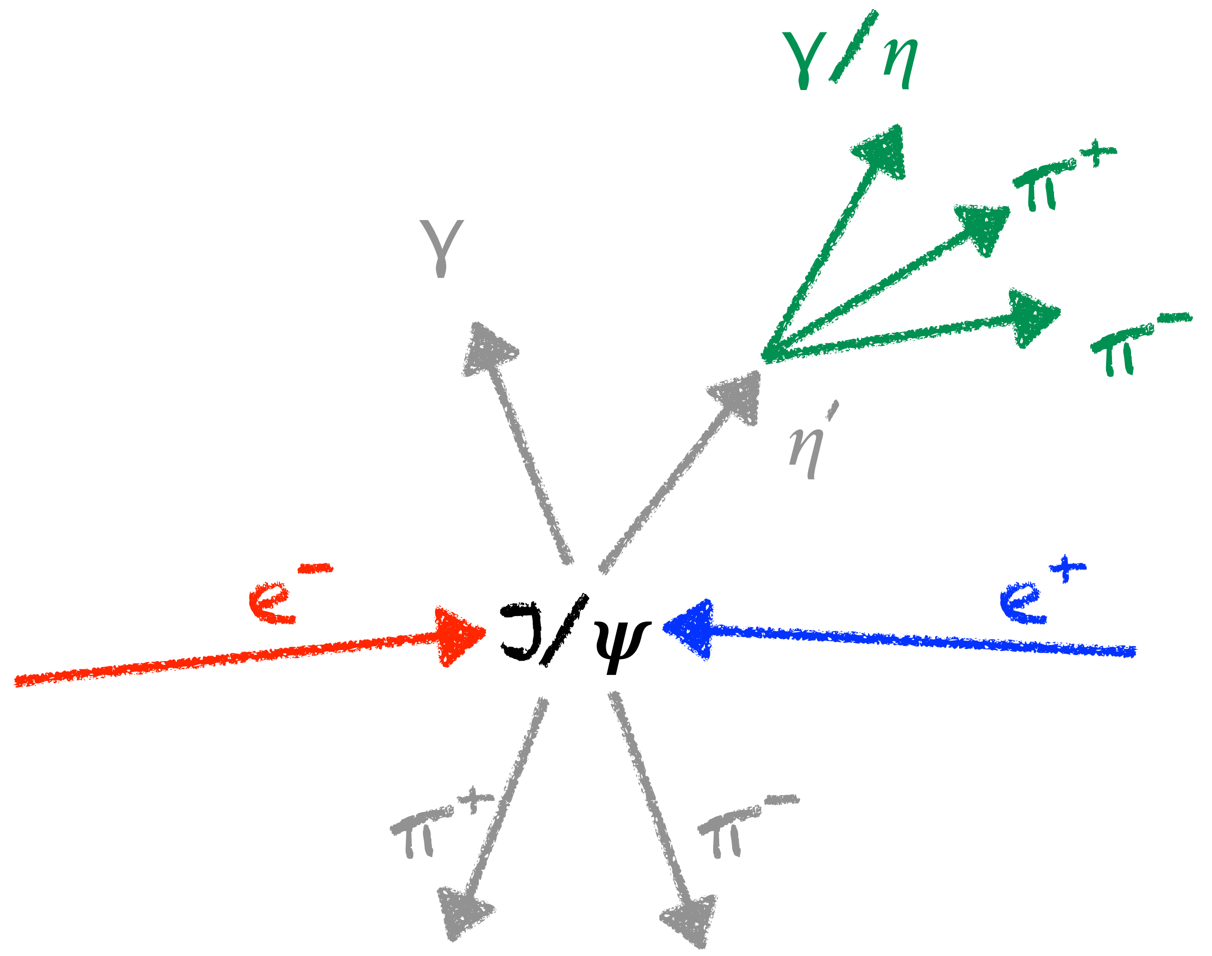
arXiv:2201.10796
Submitted to PRL

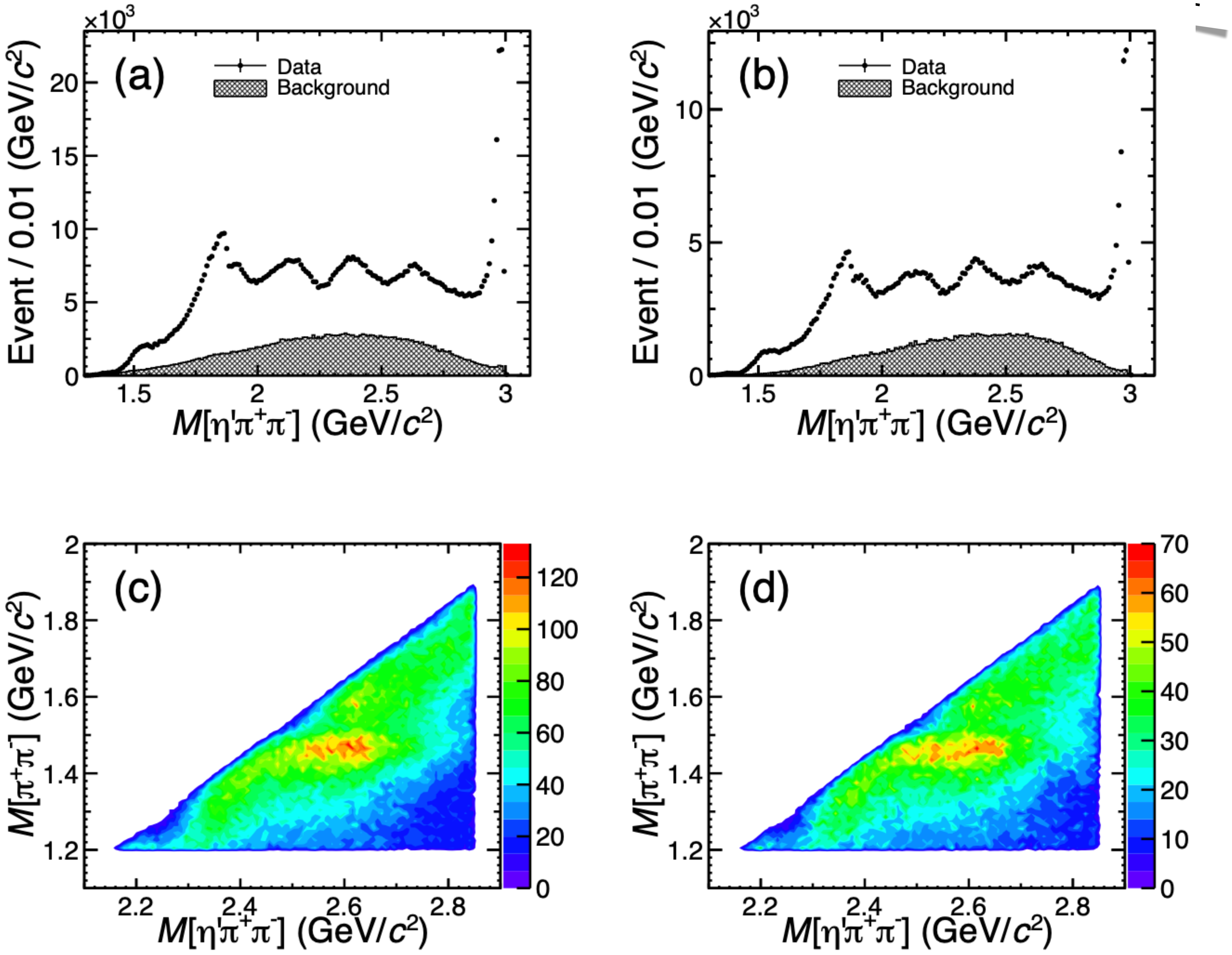
Using the 10 billion J/ψ data set

Study of the radiative J/$\psi \rightarrow \gamma\pi^+\pi^-\eta'$ decay, reconstructing the η' from its $\gamma\pi^+\pi^-$ & $\eta(\rightarrow\gamma\gamma)\pi^+\pi^-$ main decays

X(2600) observed in M($\eta'\pi^+\pi^-$) at 2.6 GeV/c^2 correlated to a structure @1.5 GeV/c^2 in the M($\pi^+\pi^-$) spectrum

To study X(2600) parameters, a simultaneous fit to $\eta\pi^+\pi^-$ and $\pi^+\pi^-$ is performed





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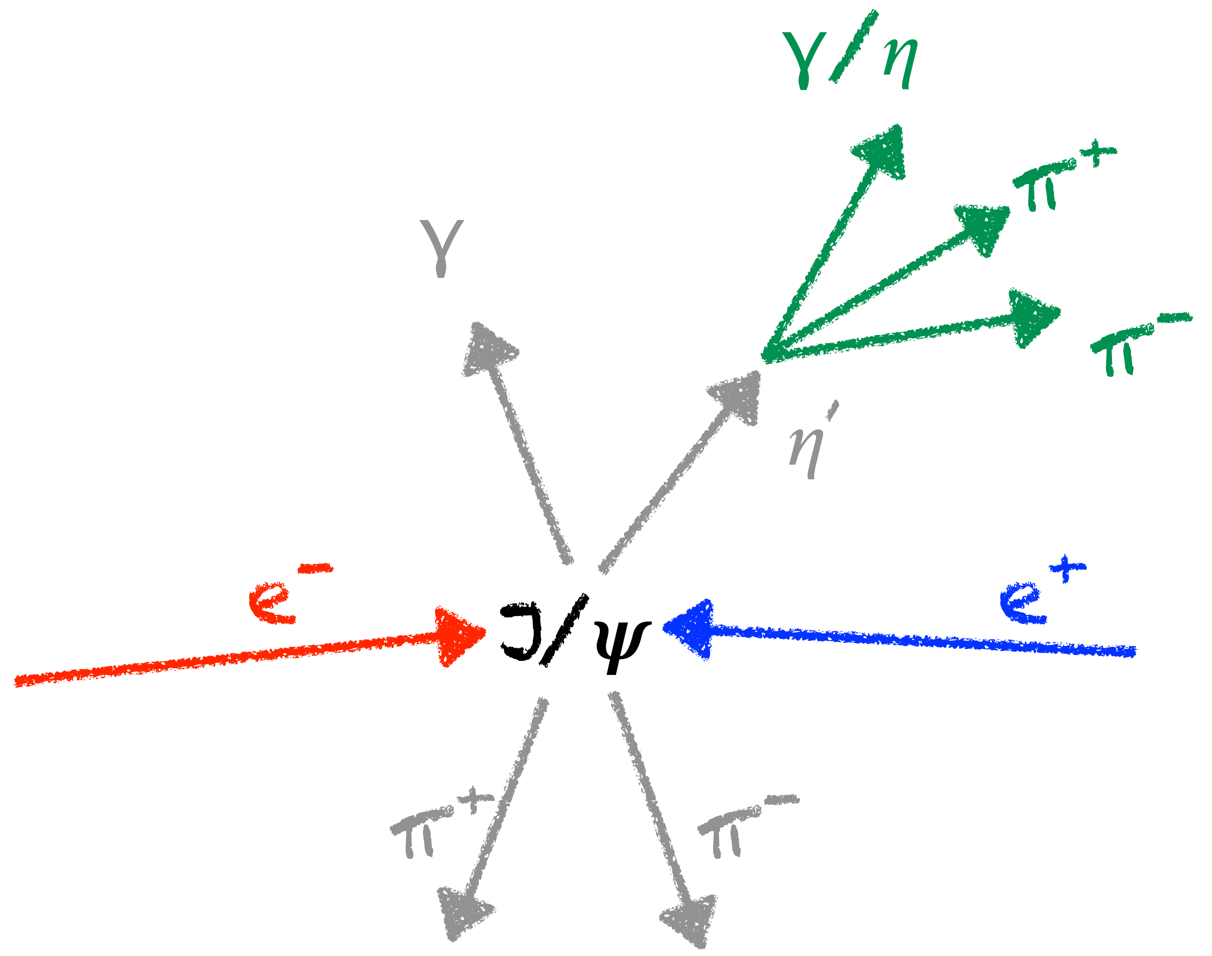

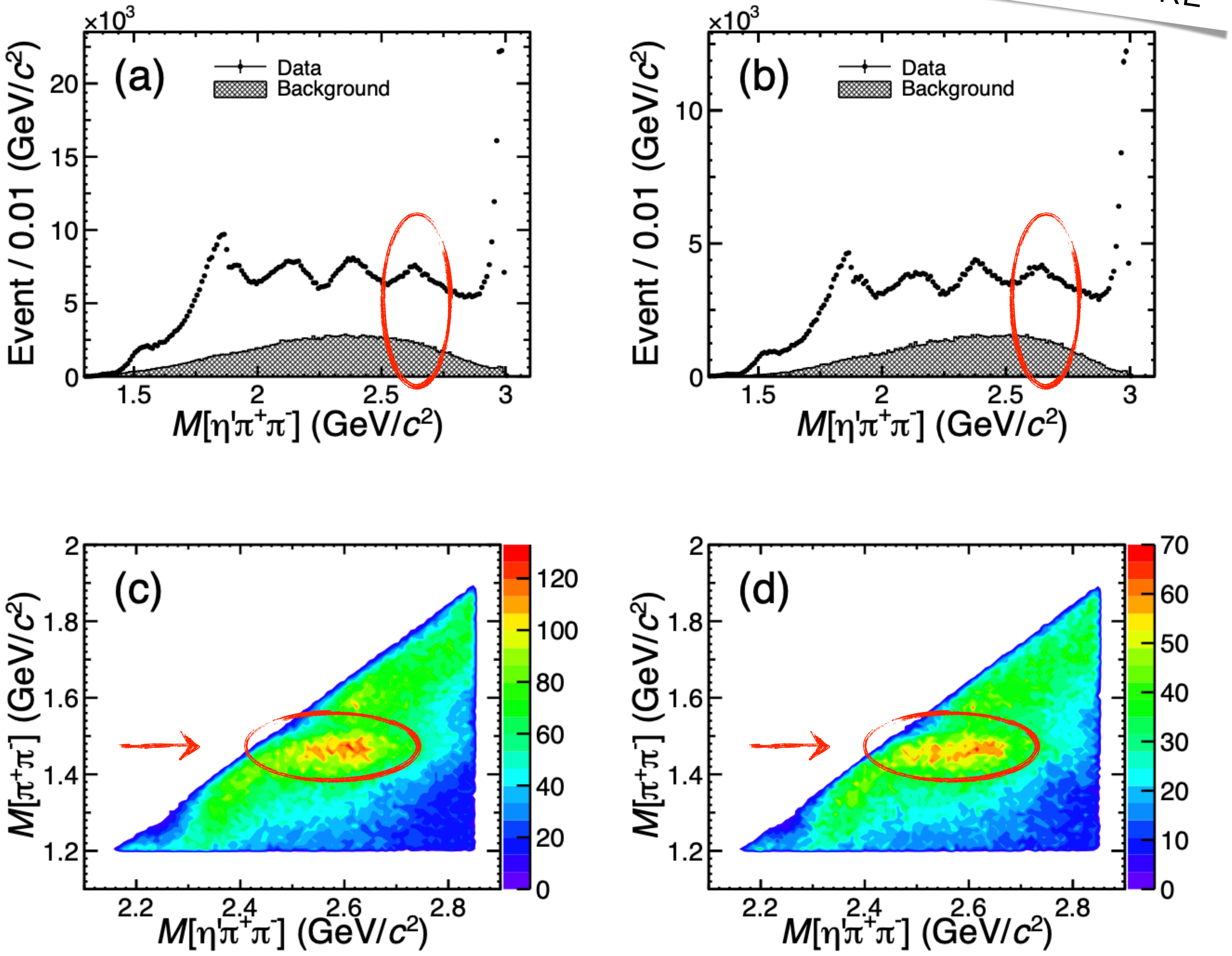

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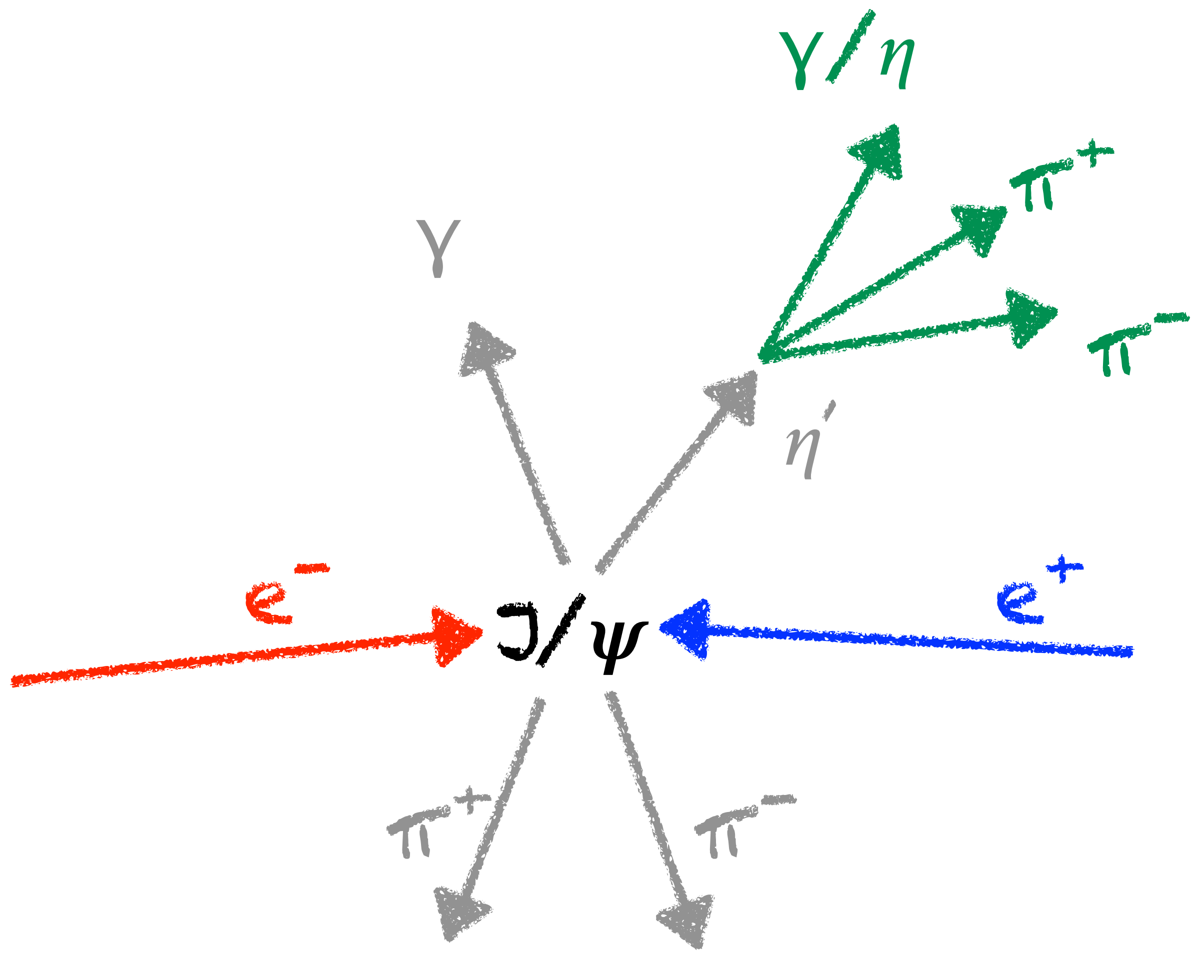

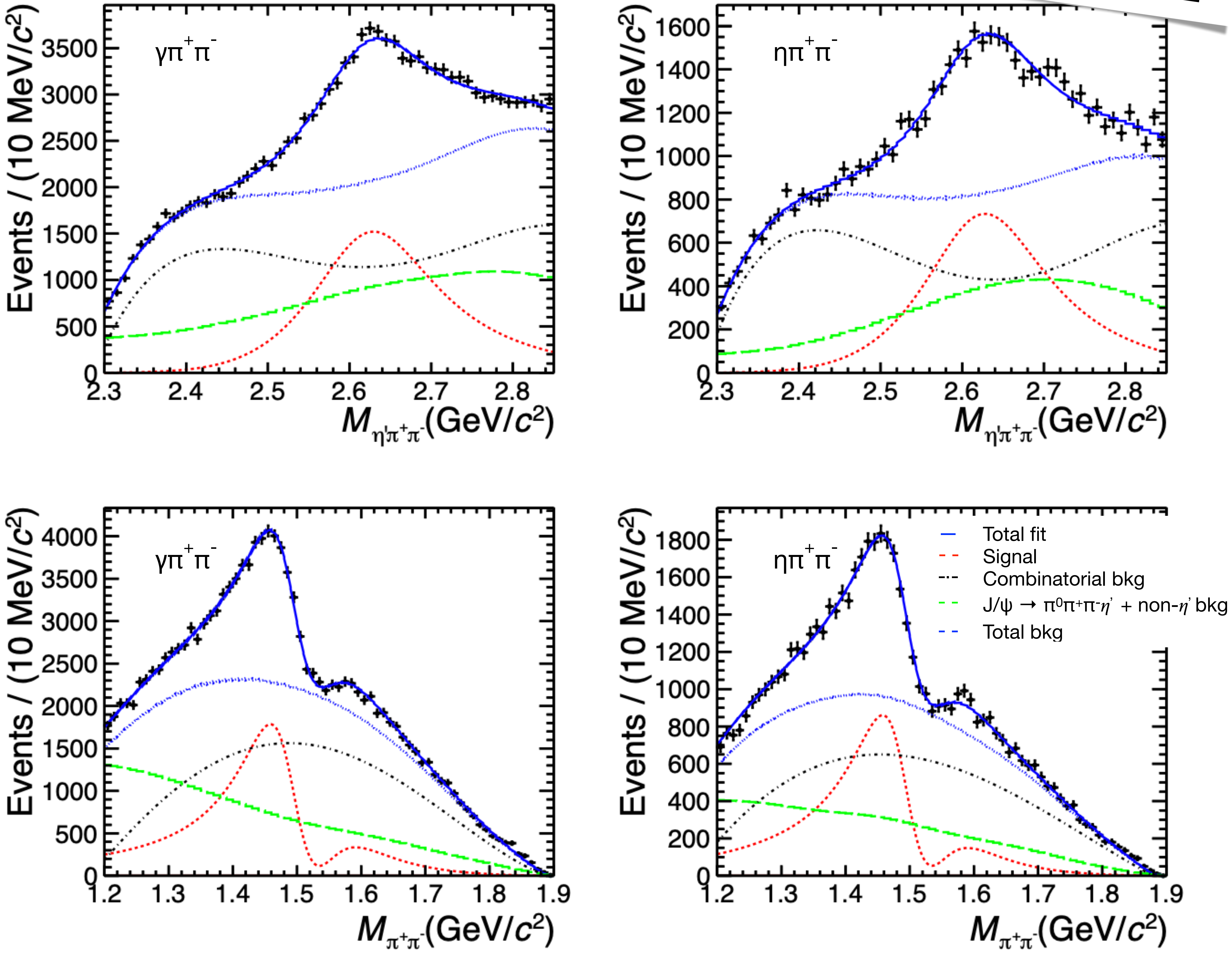

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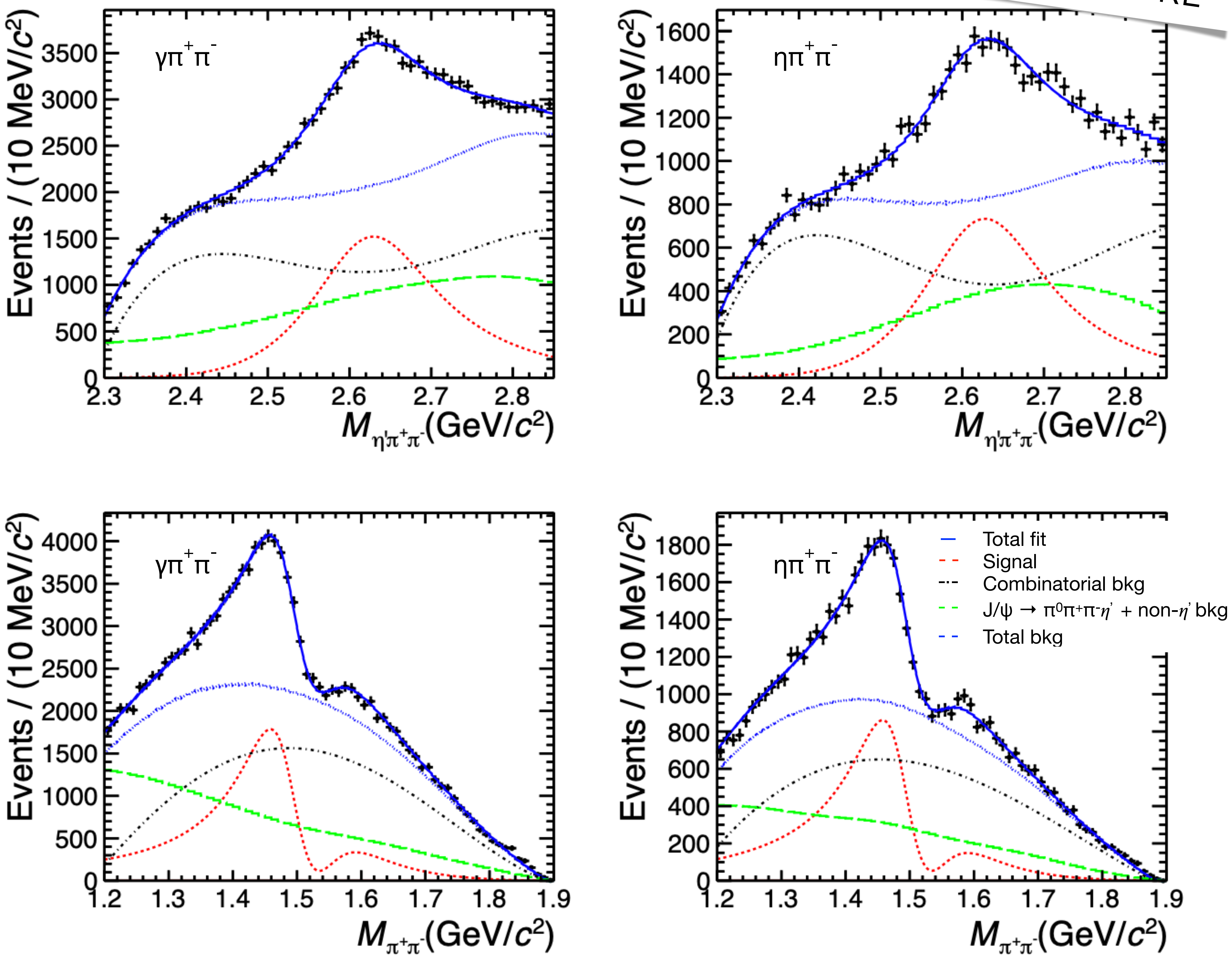
The M($\pi^+\pi^-$) is described by an interference between the f_0(1500) resonance and a X(1540) state

@ > 20σ	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$



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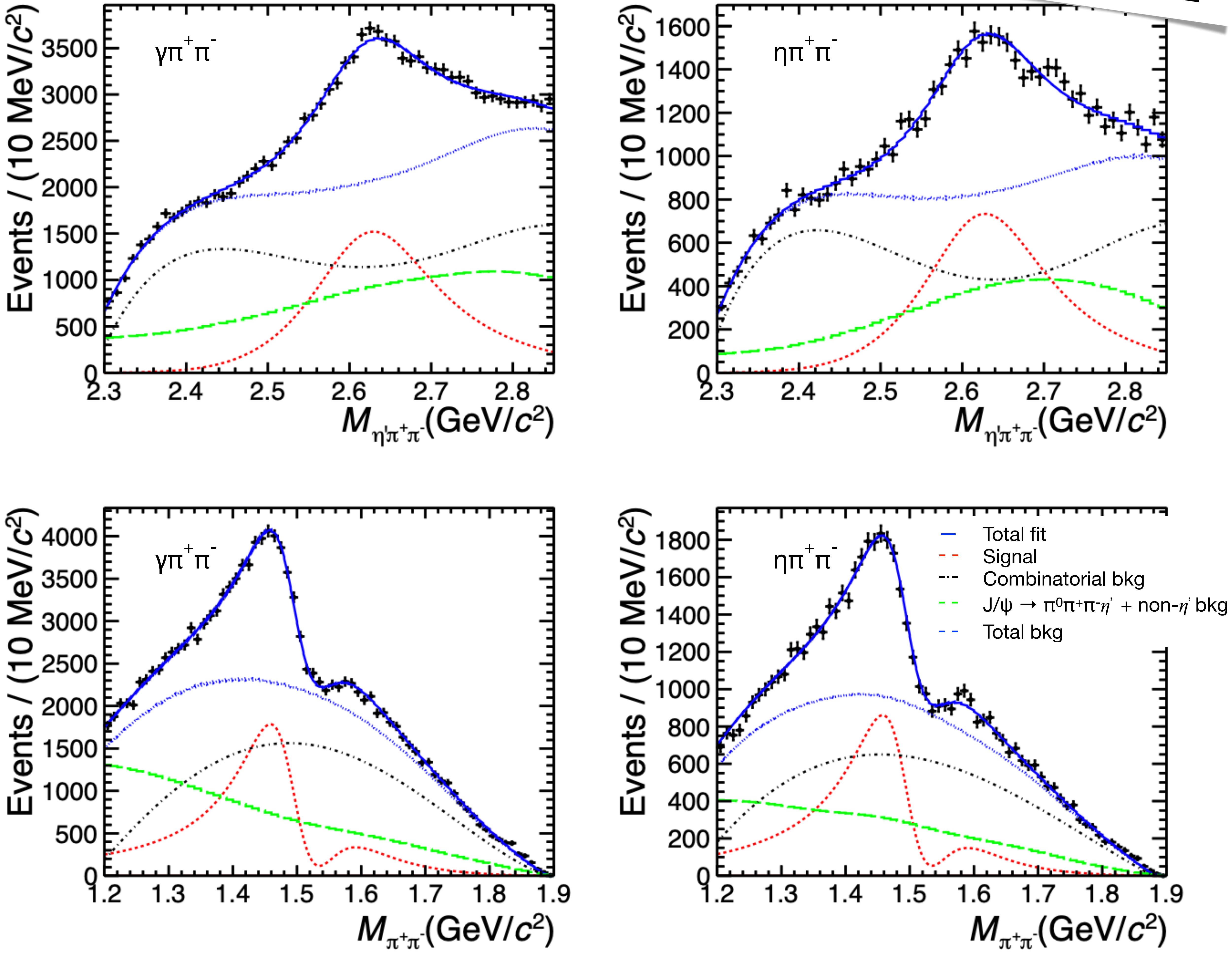
X(2600)
$J^{PC} = 0^{-+}$ or 2^{-+}

X(2600) → η'	$f_0(1500)$	$X(1540)$
Events	24585 ± 1689	21203 ± 1456
BF ($\times 10^{-5}$)	$3.09 \pm 0.21^{+1.14}_{-0.77}$	$2.69 \pm 0.19^{+0.38}_{-1.21}$



Partial Wave Analyses on J/ψ Decays

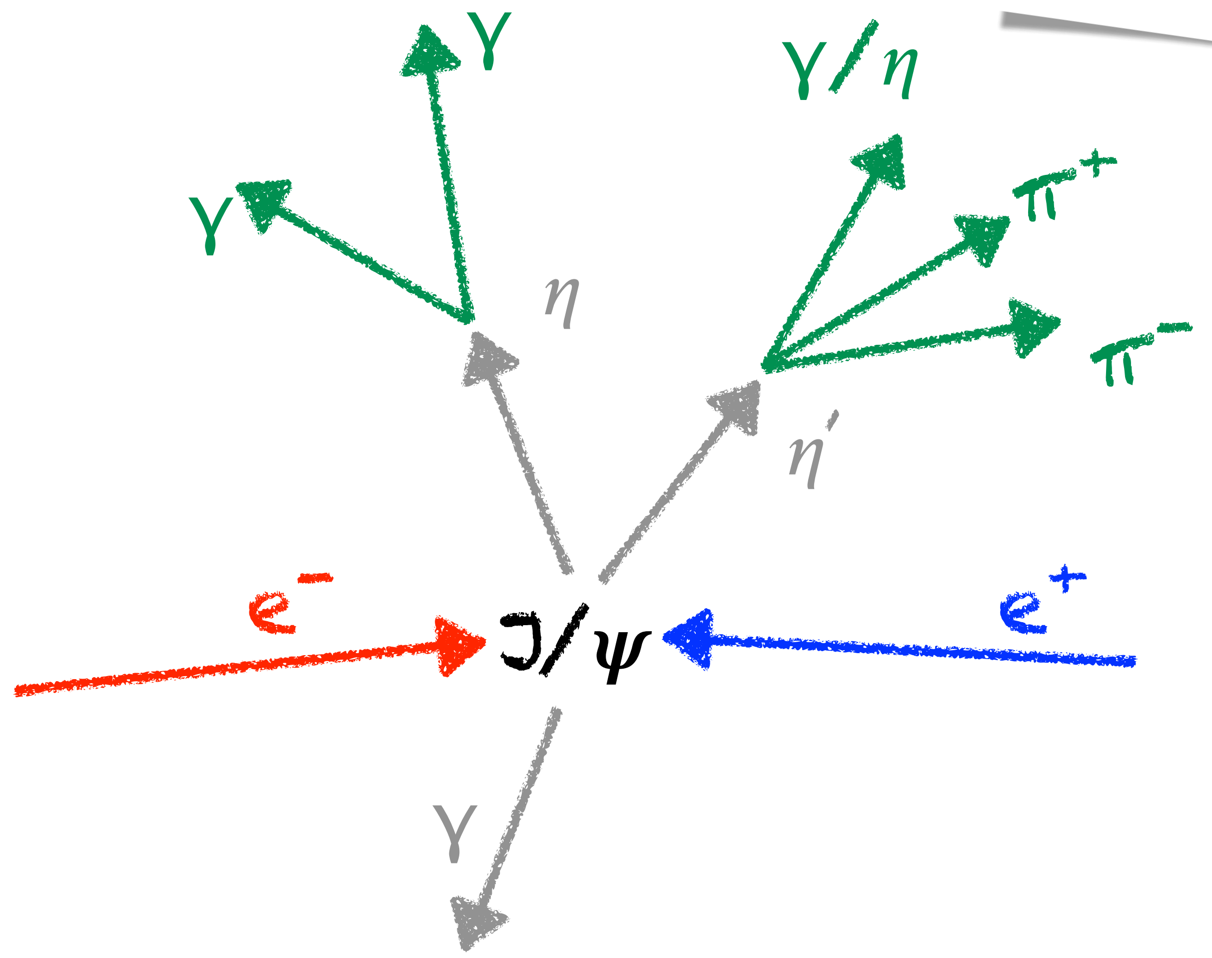
Using the 10 billion J/ψ data set

Via the **isobar model**[11], the total **amplitude** of a **J/ψ** ($\rightarrow\gamma\eta^{(\prime)}\eta^{\prime}$) **decay** is parameterised as a sum of sequential quasi-two-body processes

Study of the J/ψ → $\gamma\eta\eta^{\prime}$ decay, reconstructing the η'

from its $\gamma\pi^+\pi^-$ & $\eta(\rightarrow \gamma\gamma)\pi^+\pi^-$ main decays

arXiv:2202.00623v2
Submitted to PRL



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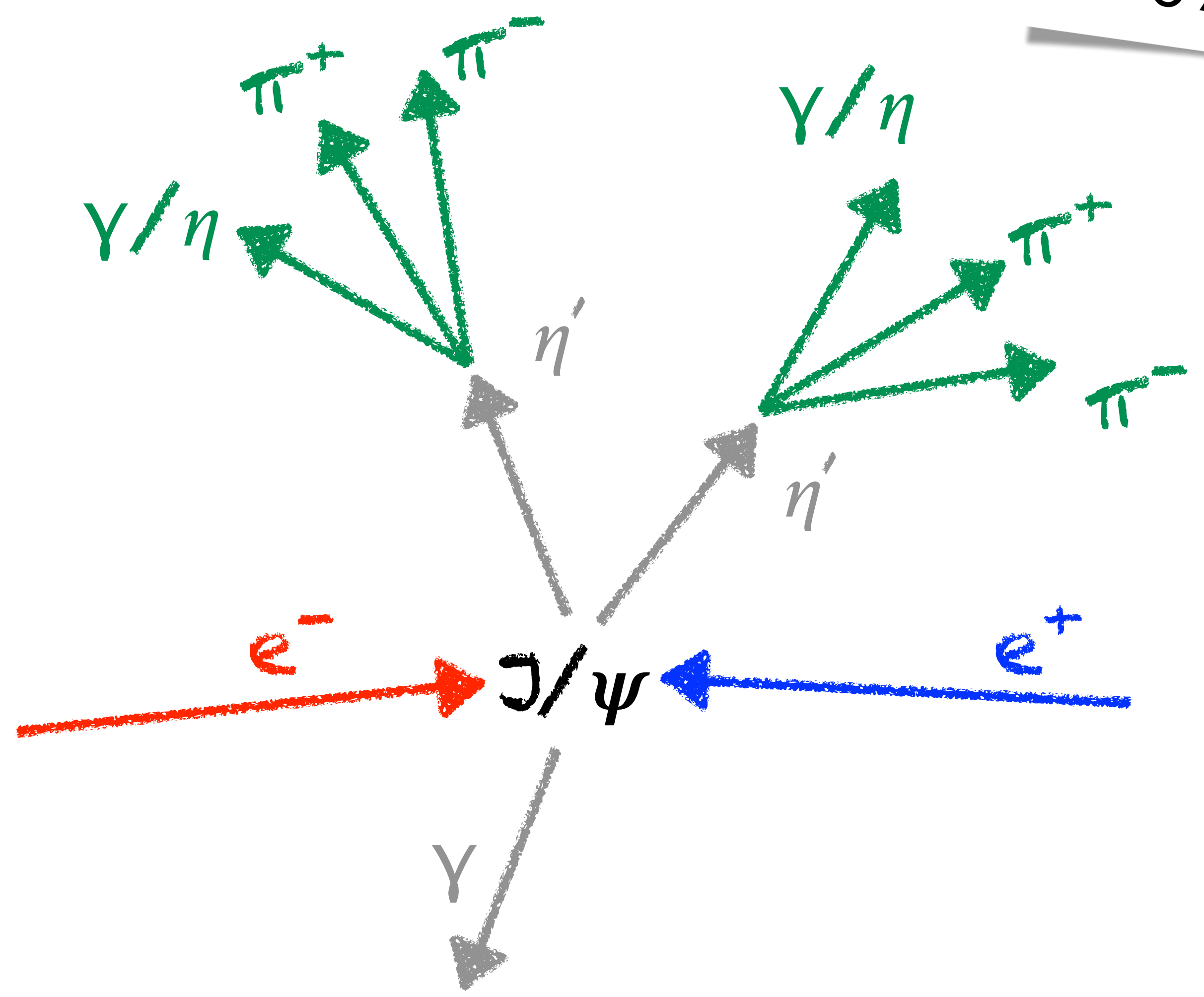
Phys. Rev. D **105**, 072002 (2022)



[11] Eur. Phys. J. A **16**, 537 (2003)

Partial Wave Analyses on J/ψ Decays

$J/\psi \to \gamma\eta\eta'$

arXiv:2202.00623v2
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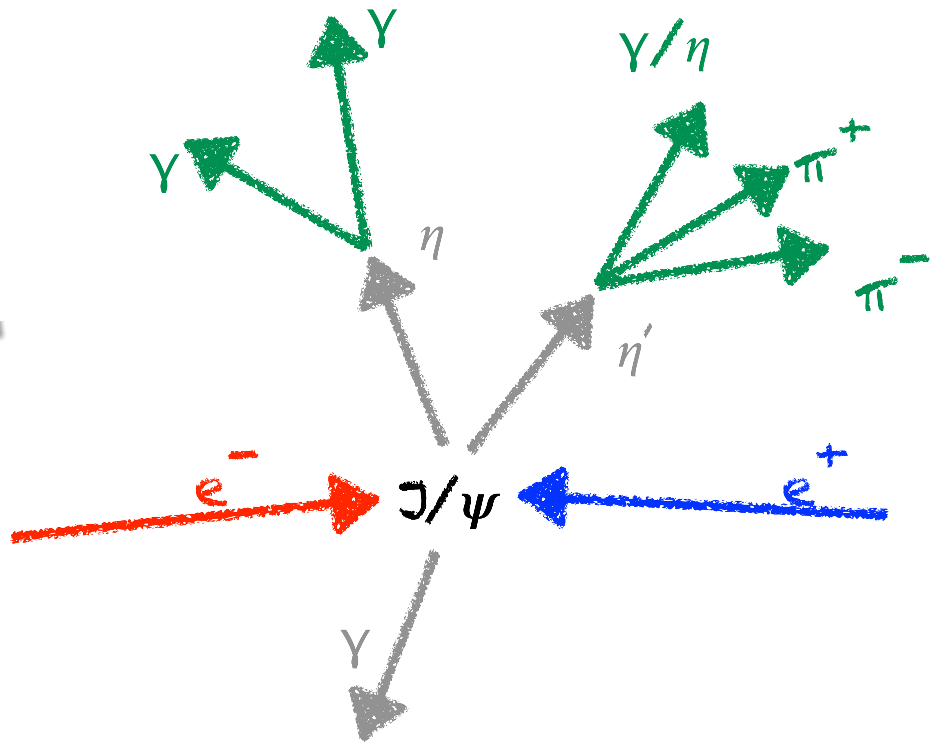

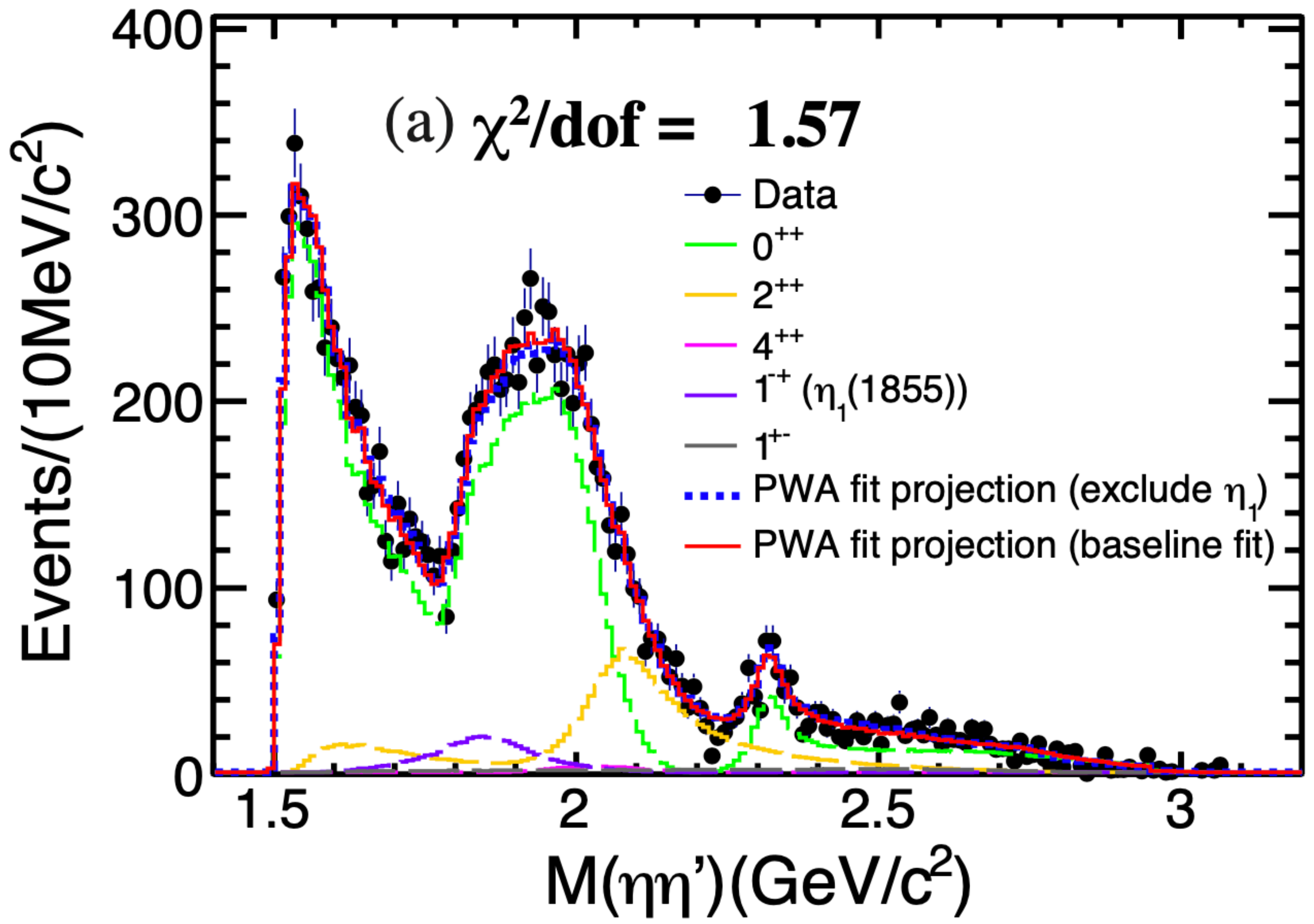

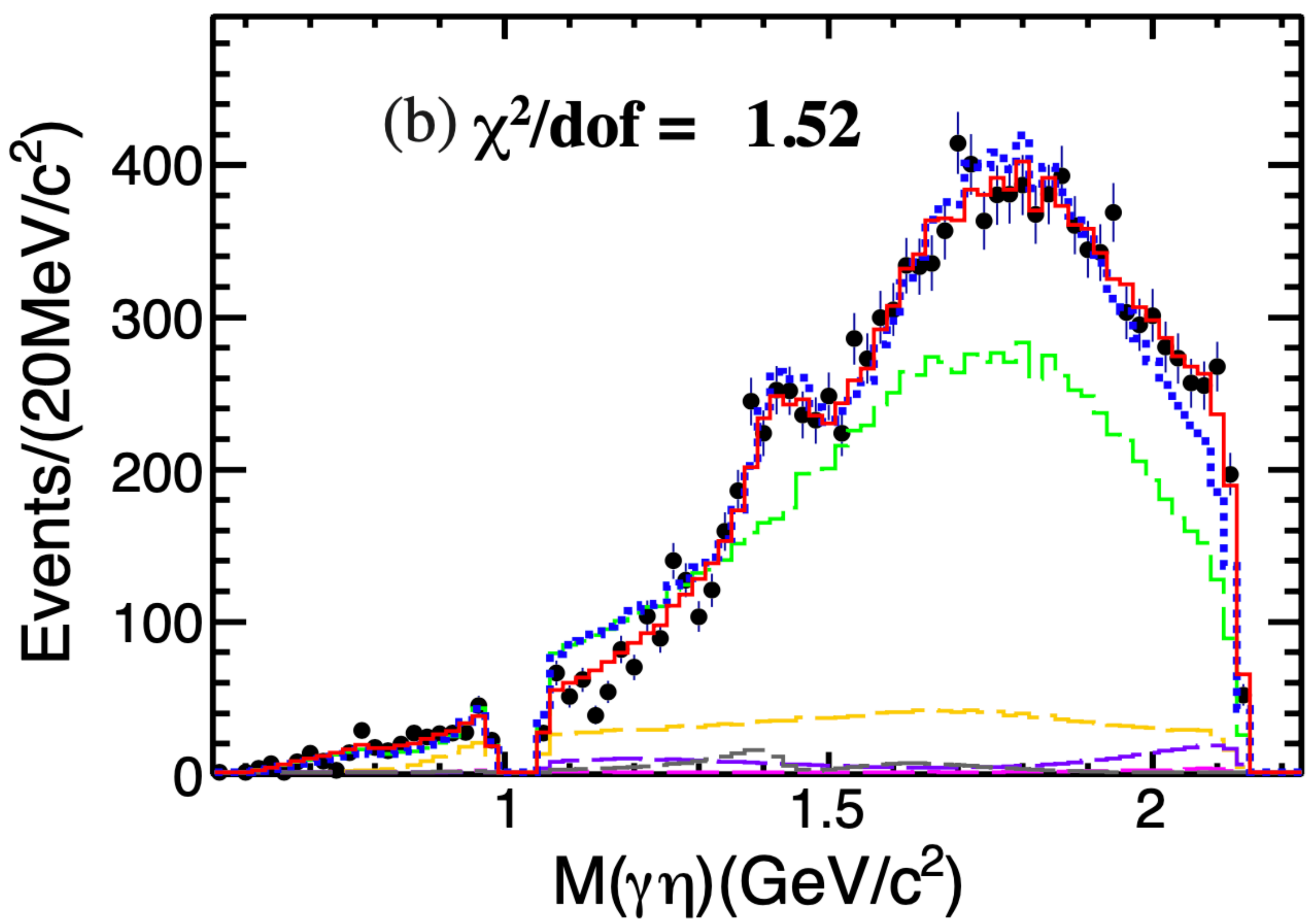

Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	$M_{\rm PDG}$ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV)	B.F. ($\times10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	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

[11] Eur. Phys. J. A **16**, 537 (2003)

Partial Wave Analyses on J/ψ Decays

$J/\psi \rightarrow \gamma\eta\eta'$

arXiv:2202.00623v2
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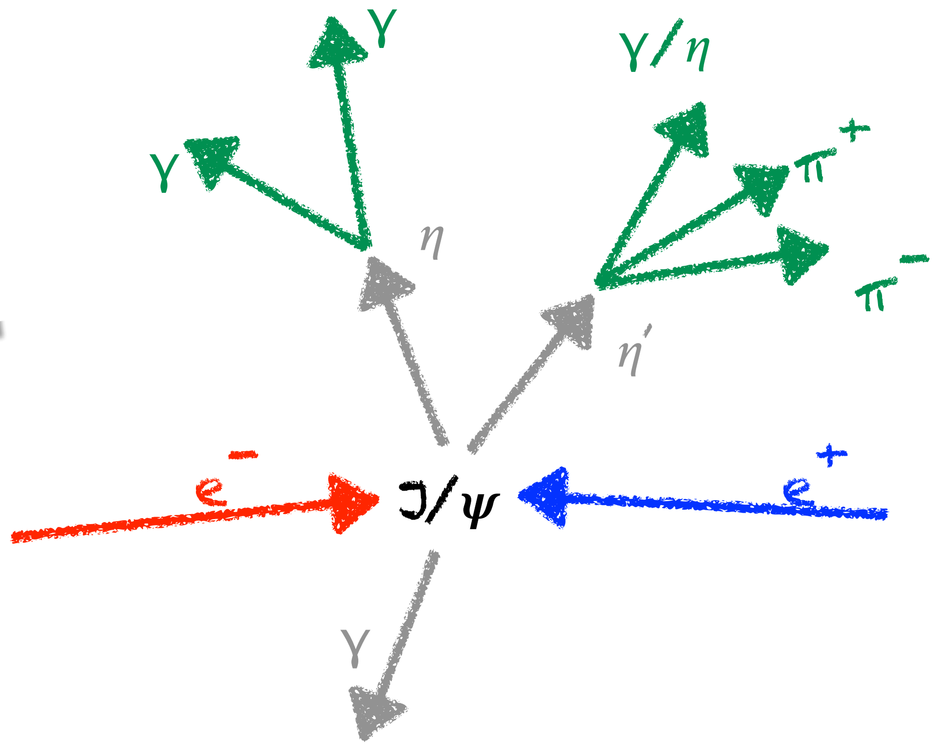

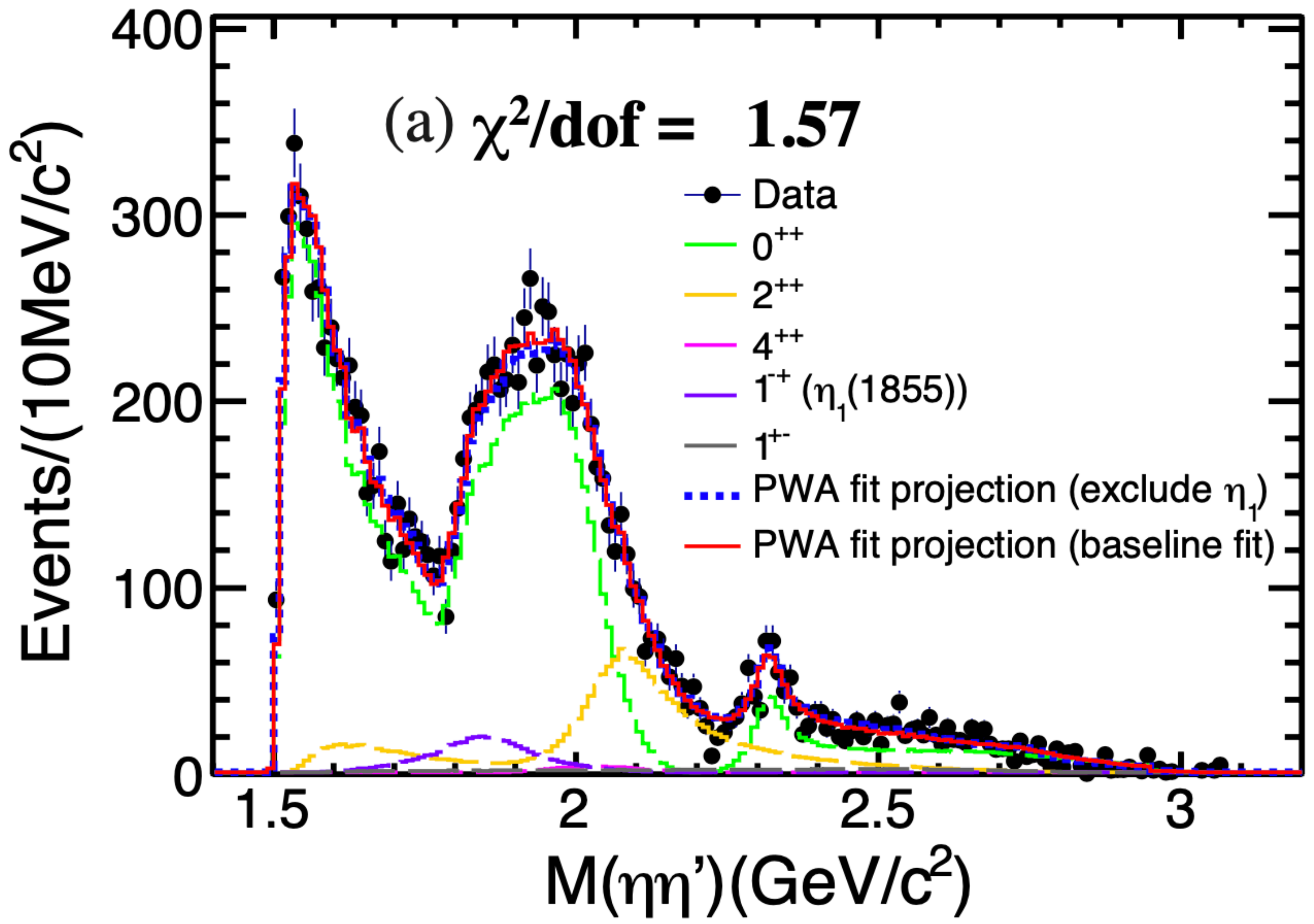

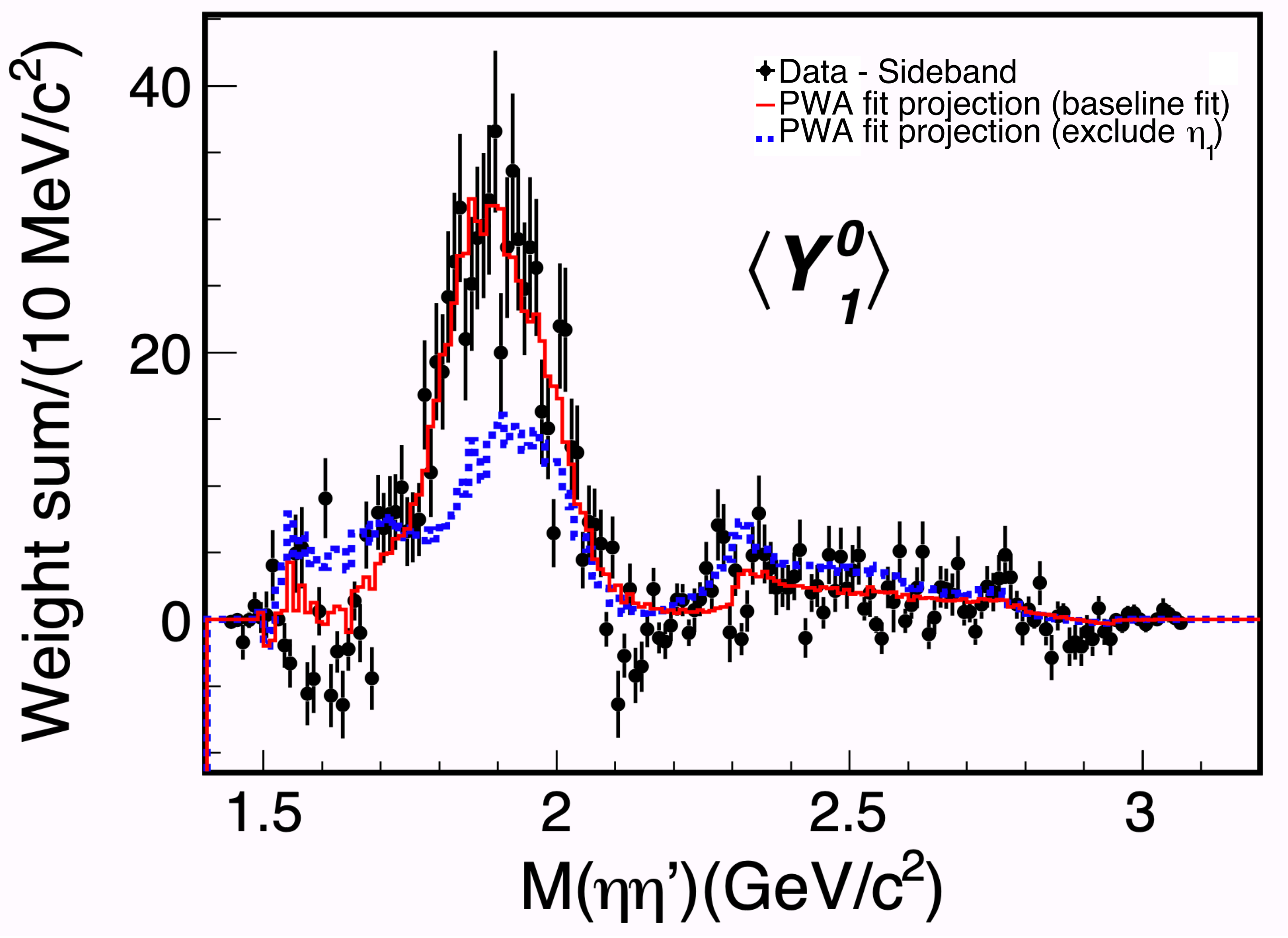

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An ***exotic* isoscalar** state

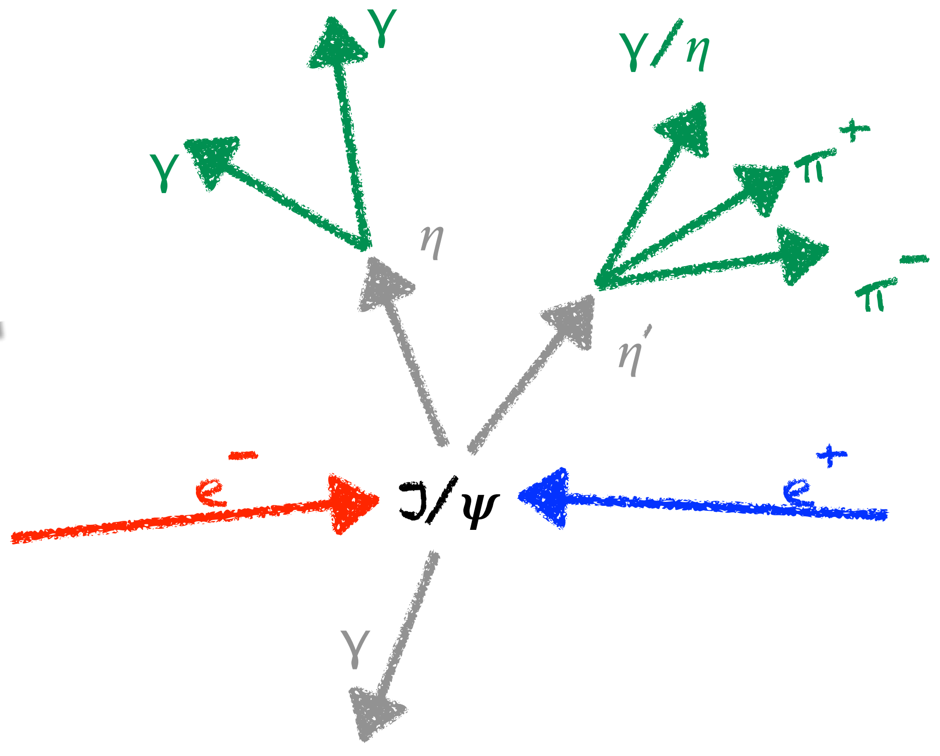
$J^{PC} = 1^{-+}$, whose parameters are **consistent** with **LQCD calculations** for the 1^{-+} hybrid[12]

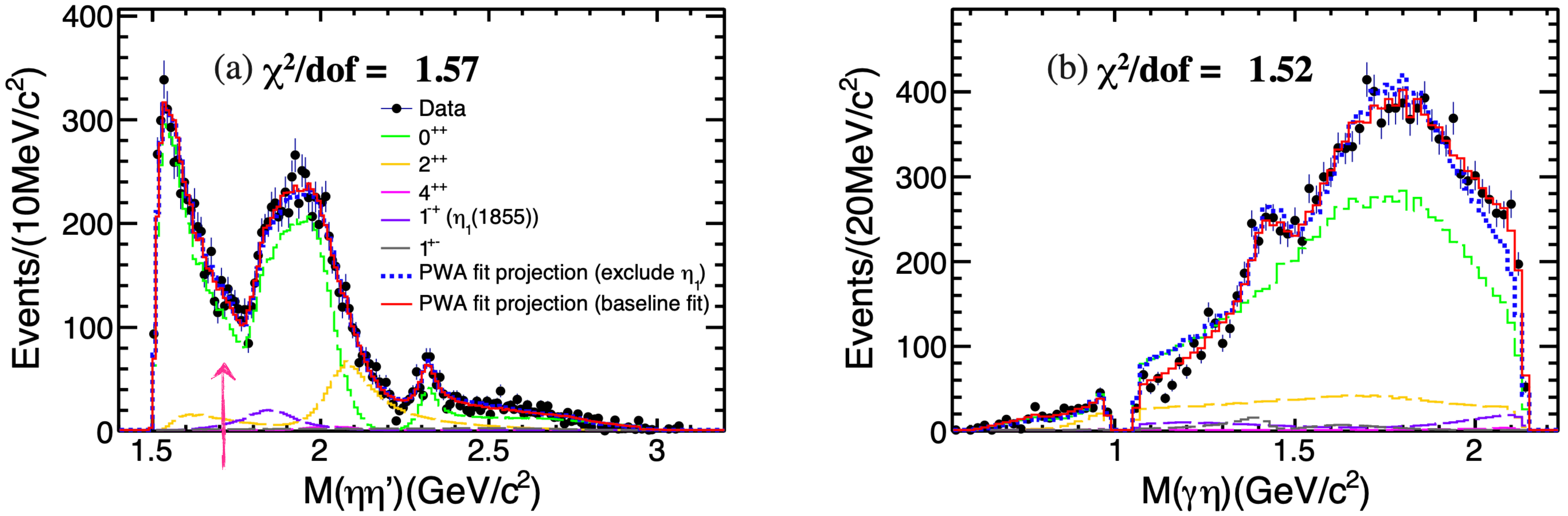
[12] Phys. Rev. D **88**, 094505 (2013)

Partial Wave Analyses on J/ψ Decays

$J/\psi \rightarrow \gamma\eta\eta'$

arXiv:2202.00623v2
Submitted to PRL





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	$f_4(2050)$	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

$$\frac{\mathcal{B}(f_0(1500)\to\eta\eta')}{\mathcal{B}(f_0(1500)\to\pi\pi)} = (8.96^{+2.95}_{-2.87})\times10^{-2}$$

Consistent with PDG

The **absence of $f_0(1710)$** signal allows to set an U.L. (@ 90% C.L.)

$$\frac{\mathcal{B}(f_0(1710)\to\eta\eta')}{\mathcal{B}(f_0(1710)\to\pi\pi)} = 1.61\times10^{-3}$$

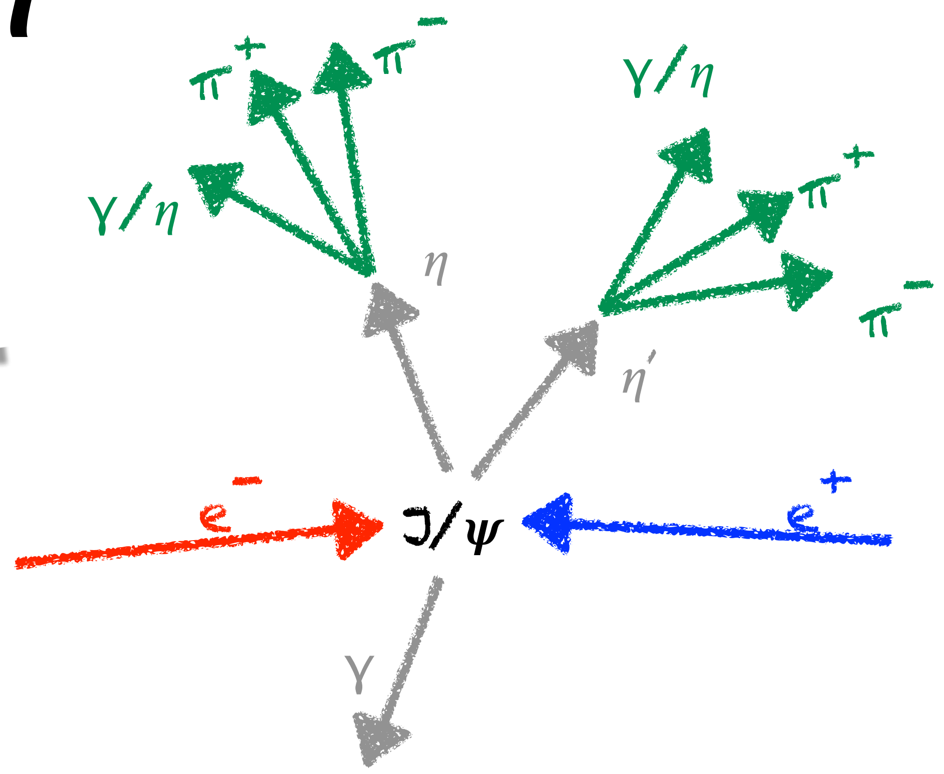
which **supports** to the hypothesis that the **$f_0(1710)$ overlaps with** the ground state scalar (**0^{++}**) **glueball**[13]

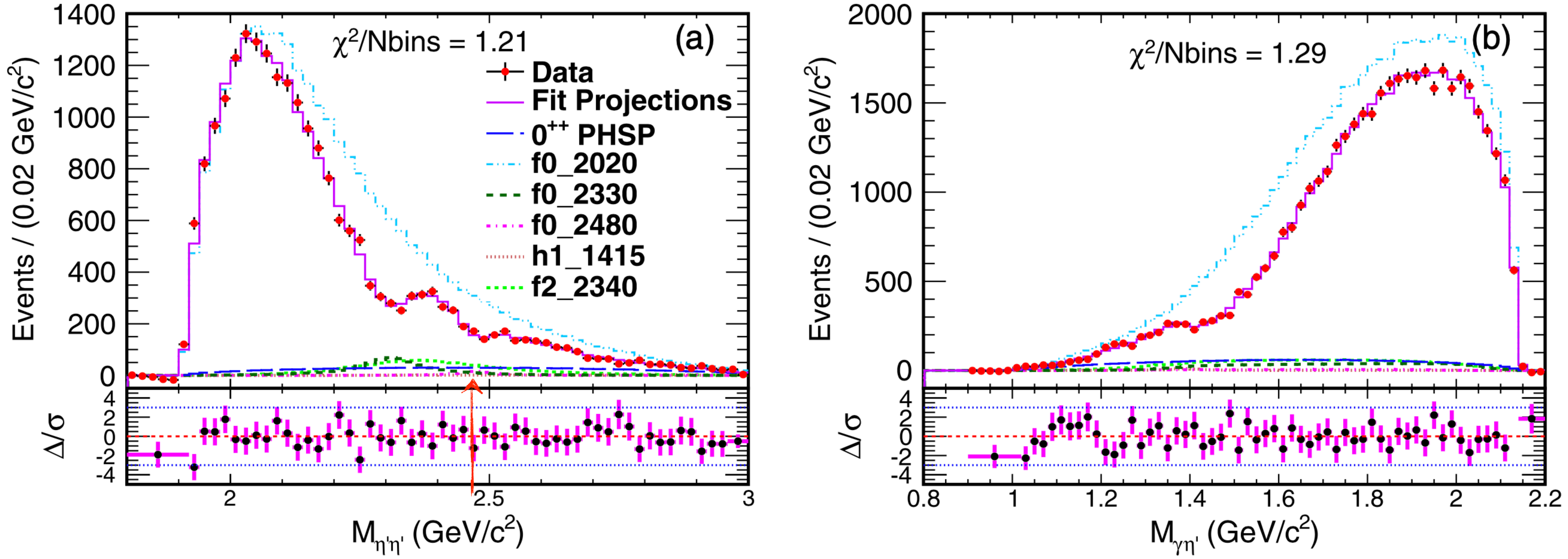
[13] Phys. Rev. D **92**, 114035 (2015)

Partial Wave Analyses on J/ψ Decays

$J/\psi \rightarrow \gamma\eta'\eta'$

Phys. Rev. D **105**, 072002 (2022)





Resonance	M(MeV$/c^2$)	Γ(MeV)	B.F.	Significance (σ)
$f_0(2020)$	$1982 \pm 3^{+54}_{-0}$	$436 \pm 4^{+46}_{-49}$	$(2.63 \pm 0.06^{+0.31}_{-0.46}) \times 10^{-4}$	$\gg$25
$f_0(2330)$	$2312 \pm 2^{+10}_{-0}$	$134 \pm 5^{+30}_{-9}$	$(6.09 \pm 0.64^{+4.00}_{-1.68}) \times 10^{-6}$	16.3
$f_0(2480)$	$2470 \pm 4^{+4}_{-6}$	$75 \pm 9^{+11}_{-8}$	$(8.18 \pm 1.77^{+3.73}_{-2.23}) \times 10^{-7}$	5.2
$h_1(1415)$	$1384 \pm 6^{+9}_{-0}$	$66 \pm 10^{+12}_{-10}$	$(4.69 \pm 0.80^{+0.74}_{-1.82}) \times 10^{-7}$	5.3
$f_2(2340)$	$2346 \pm 8^{+22}_{-6}$	$332 \pm 14^{+26}_{-12}$	$(8.67 \pm 0.70^{+0.61}_{-1.67}) \times 10^{-6}$	16.1
0^{++} PHSP	...	...	$(1.17 \pm 0.23^{+4.09}_{-0.70}) \times 10^{-5}$	15.7

A **new** scalar **resonance** $J^{PC} = 0^{++}$

Charm Mesons for QCD

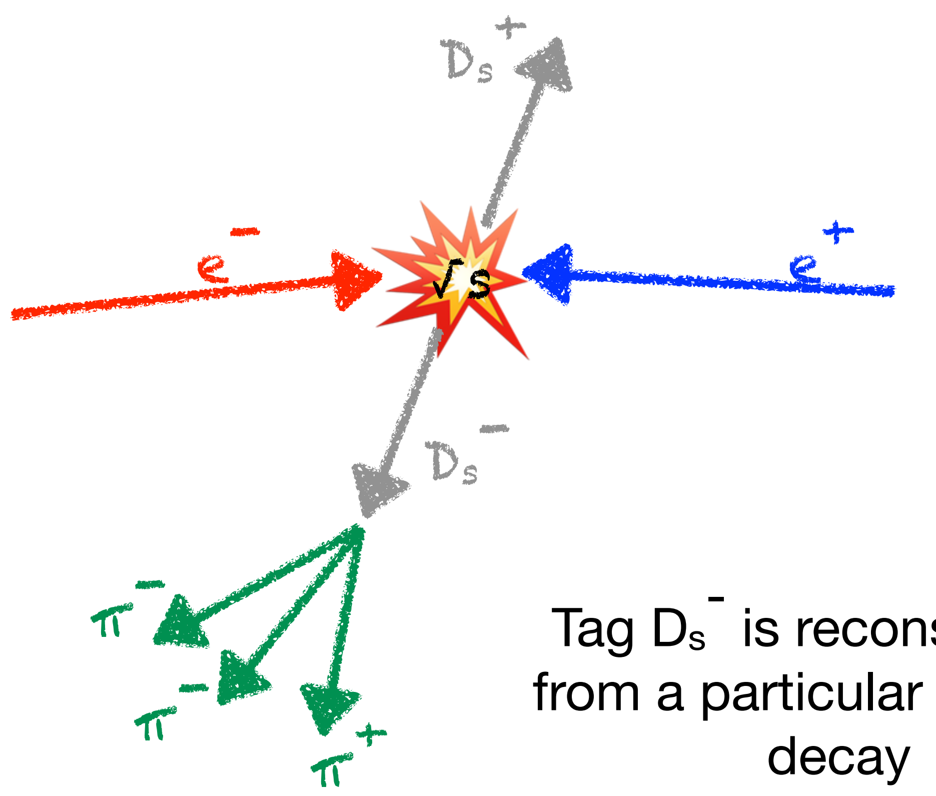
Also **hadronic** and **semi-leptonic D_s decays** are optimal probes for **studying** the **light quarks spectrum**

Amplitude Analysis (AA) is performed on these processes

Single Tag/Double Tag analysis methods are used to measure branching fractions

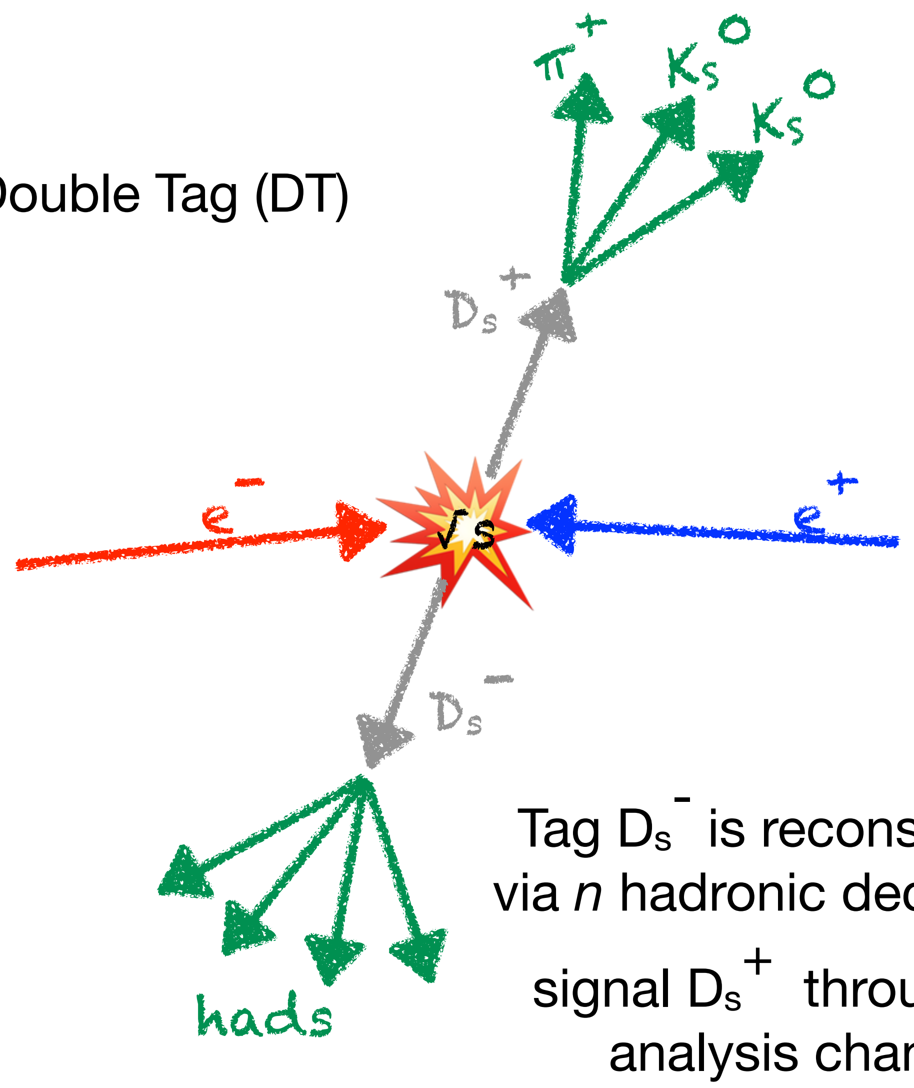
These technique coupled to AA allows to **estimate SU(3) multiplets couplings** and shine a light on their nature

Single Tag (ST)

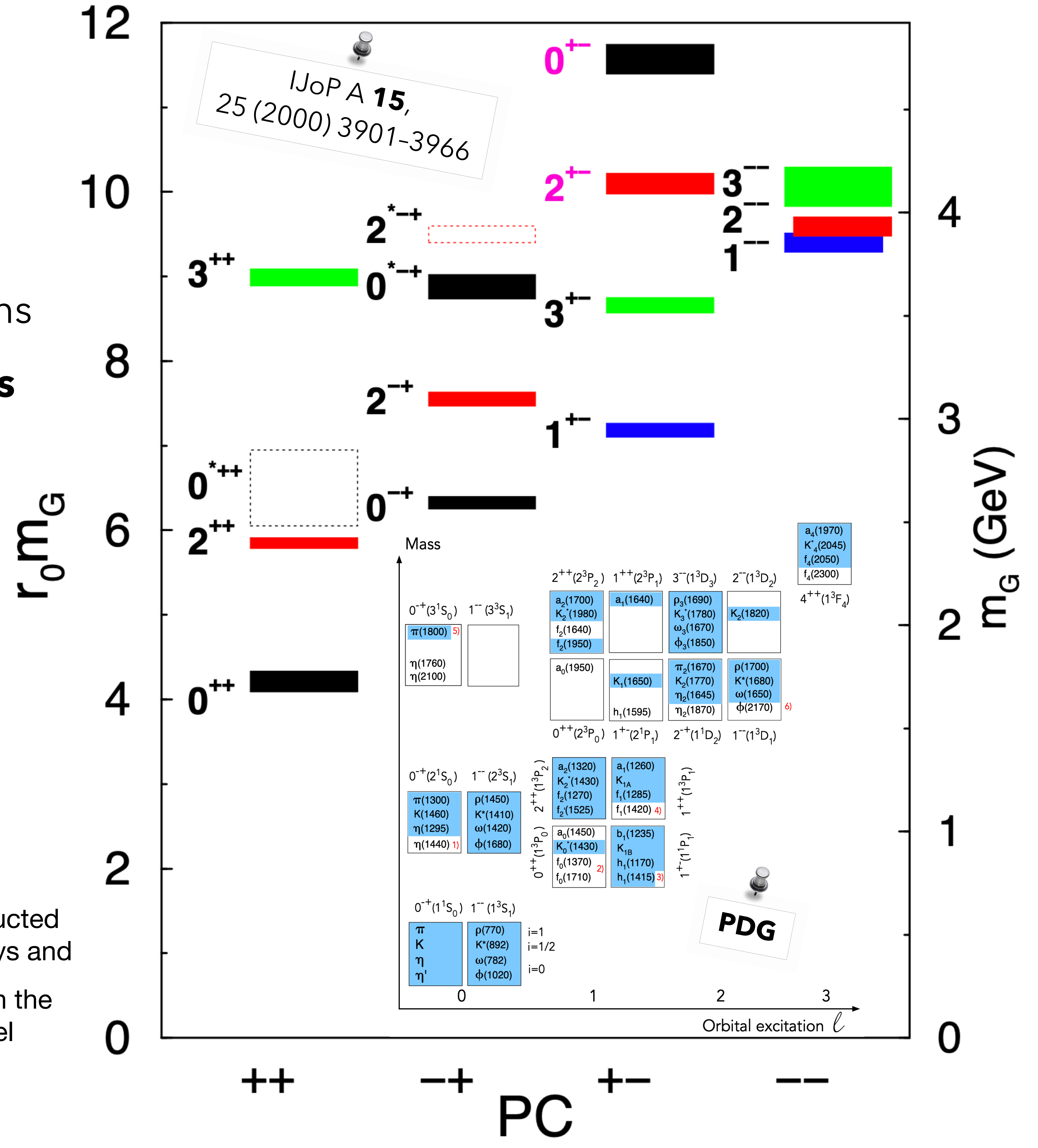


Tag D_s^- is reconstructed from a particular hadronic decay

Double Tag (DT)



Tag D_s^- is reconstructed via *n* hadronic decays and signal D_s^+ through the analysis channel



Back to the $f_0(1710)$

PRD **105**, L051102 (2022)

Using 6 data sets for a $\mathcal{L}_{int}$ = 6.32 fb^{-1} @$\sqrt{s}$ = [4.178, 4.226] GeV

Study the $D_s^+ \to K_S^0 K_S^0 \pi^+$, via the $e^+e^- \to D_s^{*\pm} D_s^{\mp} \to \gamma D_s^{\pm} D_s^{\mp}$ process

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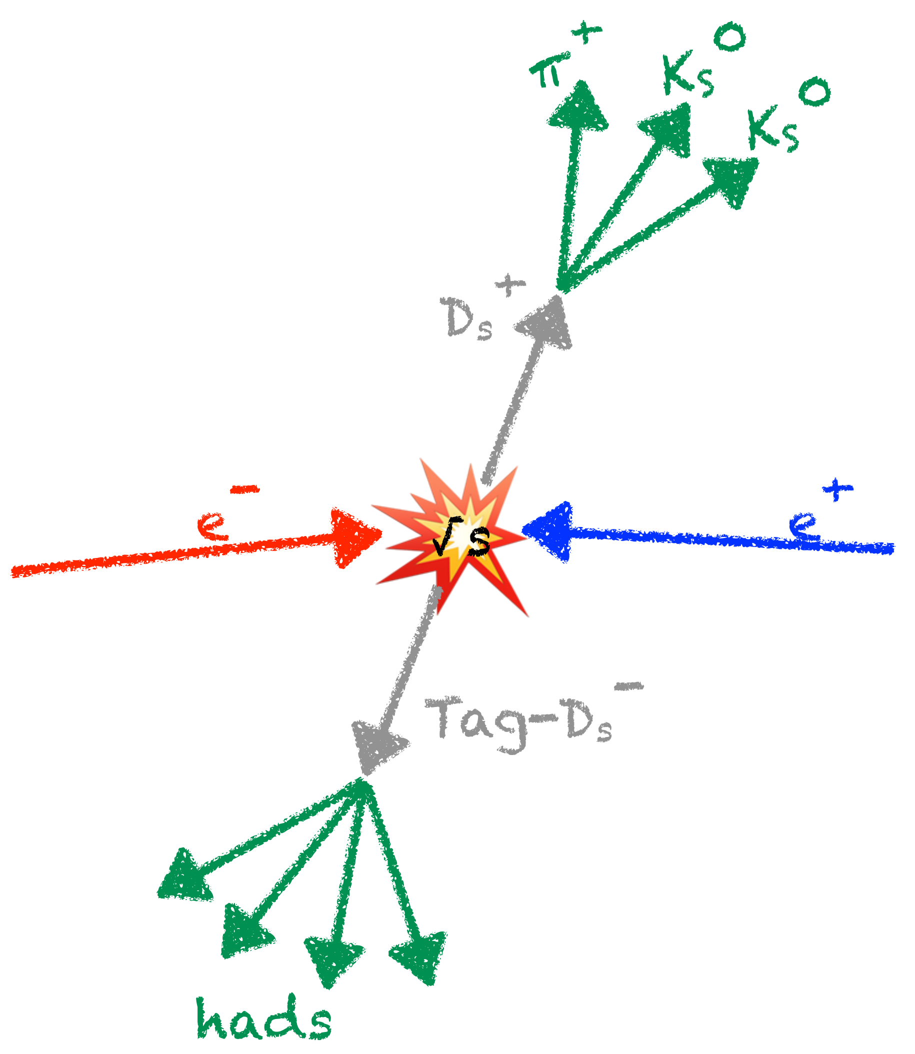
Using the ST sample as normalising factor, it is possible to estimate the branching fraction ($\mathcal{B}_{sig}$) of the whole $D_s^+ \to K_S^0 K_S^0 \pi^+$ process



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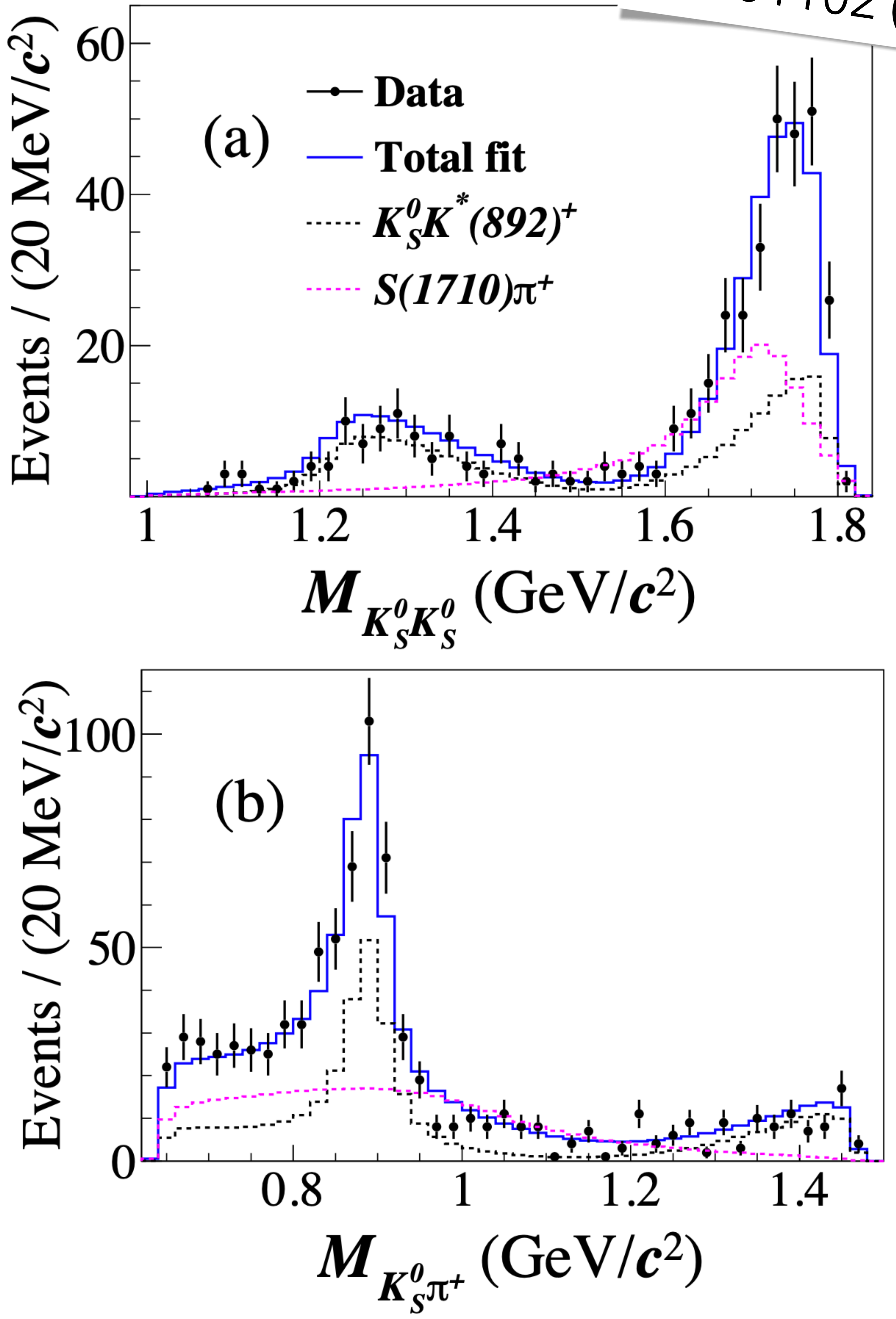
Amplitude	Phase	FF (%)	
$D_s^+ \to K_S^0 K^*(892)^+$	0.0(fixed)	$43.5 \pm 3.9 \pm 0.5$	
$D_s^+ \to S(1710)\pi^+$	$2.3 \pm 0.1 \pm 0.1$	$46.3 \pm 4.0 \pm 1.2$	**@10σ**

S(1710) denotes an admixture of $f_0(1710)$ and $a_0(1710)$



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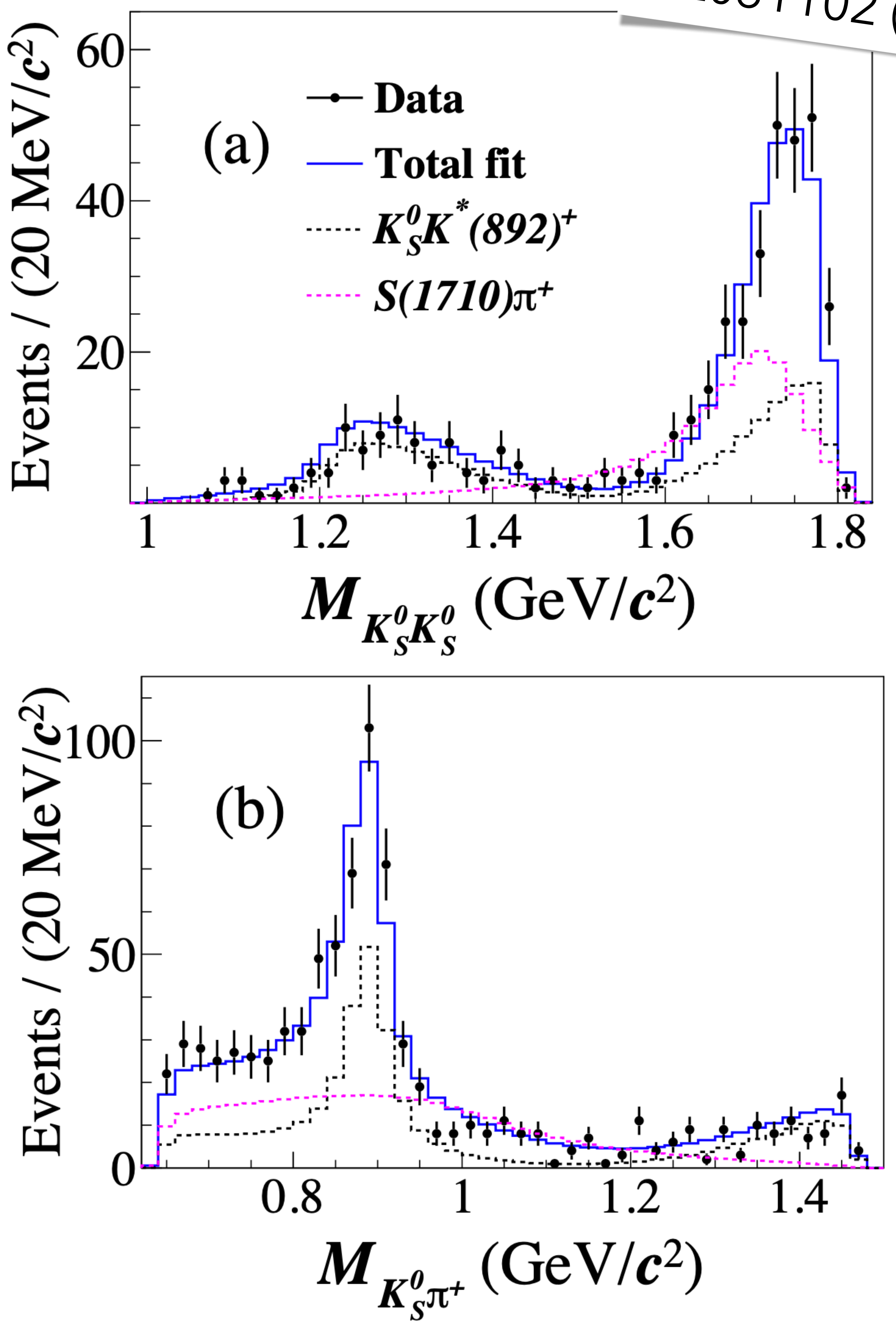
S(1710) denotes an admixture of $f_0(1710)$ and $a_0(1710)$

$$\mathcal{B}_{sig} = \frac{N^{DT}_{total,sig}}{\sum_{\alpha,i} N^{ST}_{\alpha,i}\,\epsilon^{DT}_{\alpha,sig,i}/\epsilon^{ST}_{\alpha,i}} = (0.68 \pm 0.04_{stat} \pm 0.01_{syst})\%$$

Compatible within 1.3σ with CLEO[14]



[14] Phys. Rev. D **88**, 032009 (2013)

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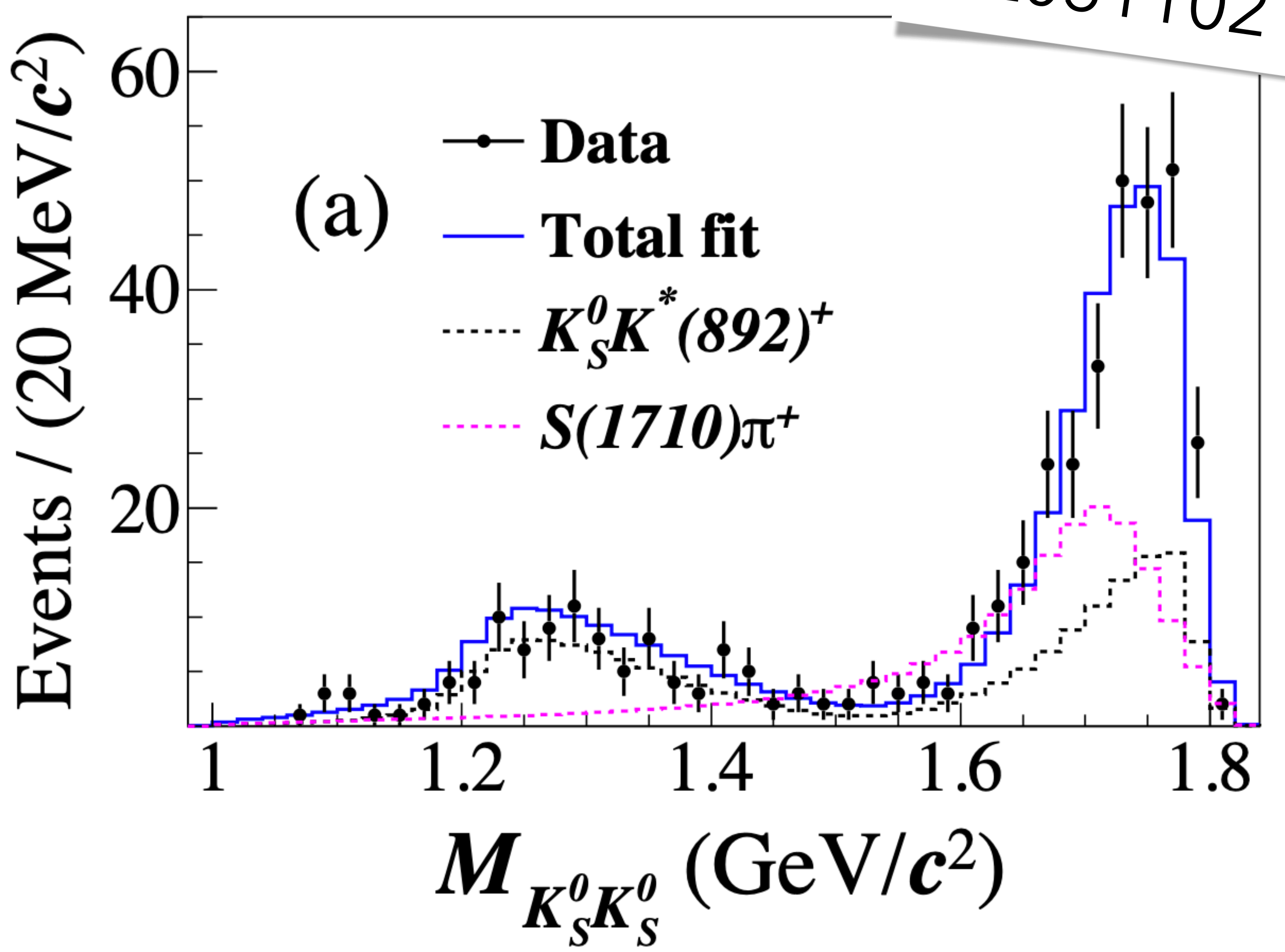
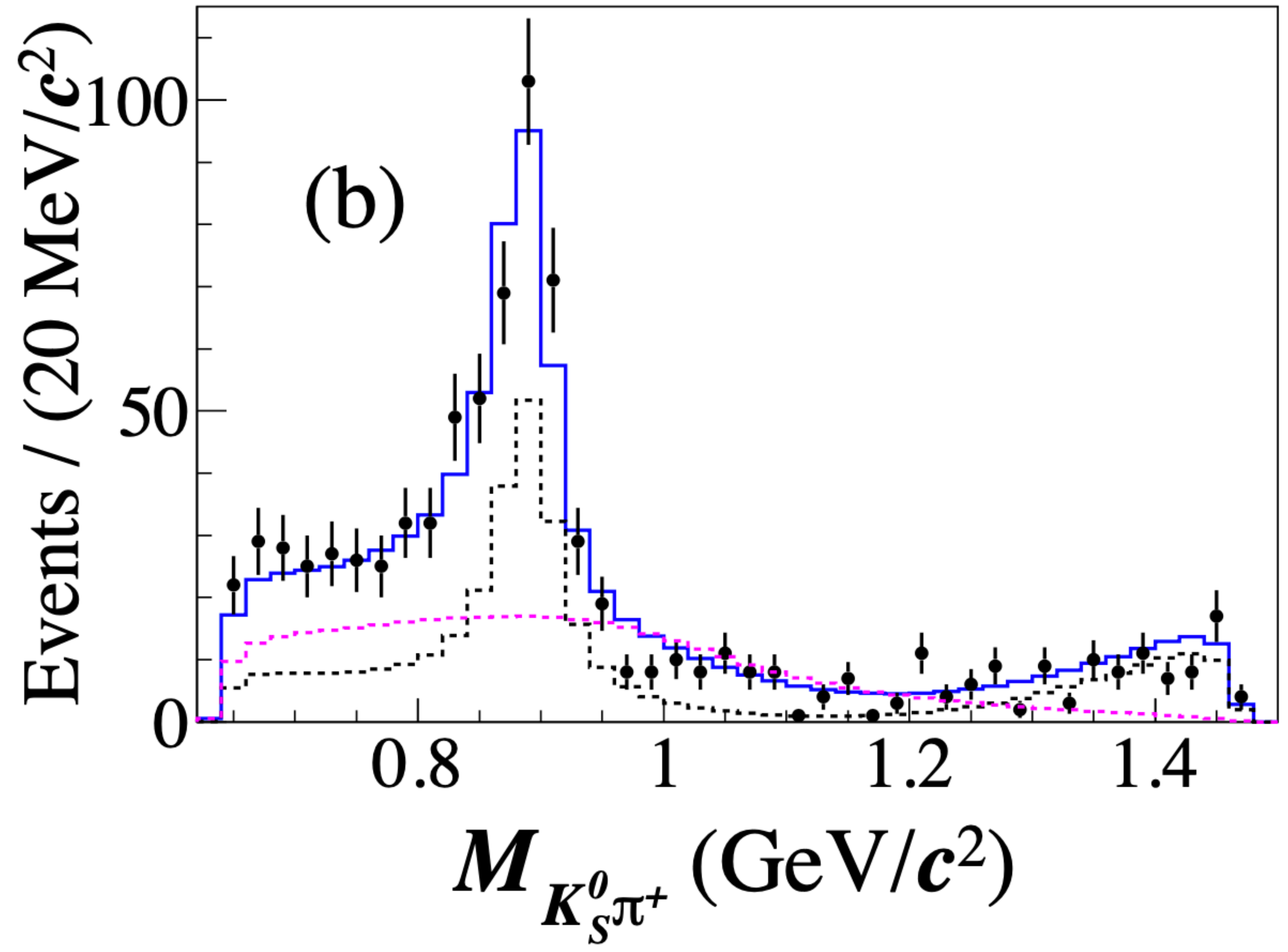
Compatible within 1.3σ with CLEO[14]

Amplitude	BF (10^{-3})
$D_s^+ \to K_S^0 K^*(892)^+ \to K_S^0 K_S^0 \pi^+$	$3.0 \pm 0.3 \pm 0.1$
$D_s^+ \to S(1710)\pi^+ \to K_S^0 K_S^0 \pi^+$	$3.1 \pm 0.3 \pm 0.1$





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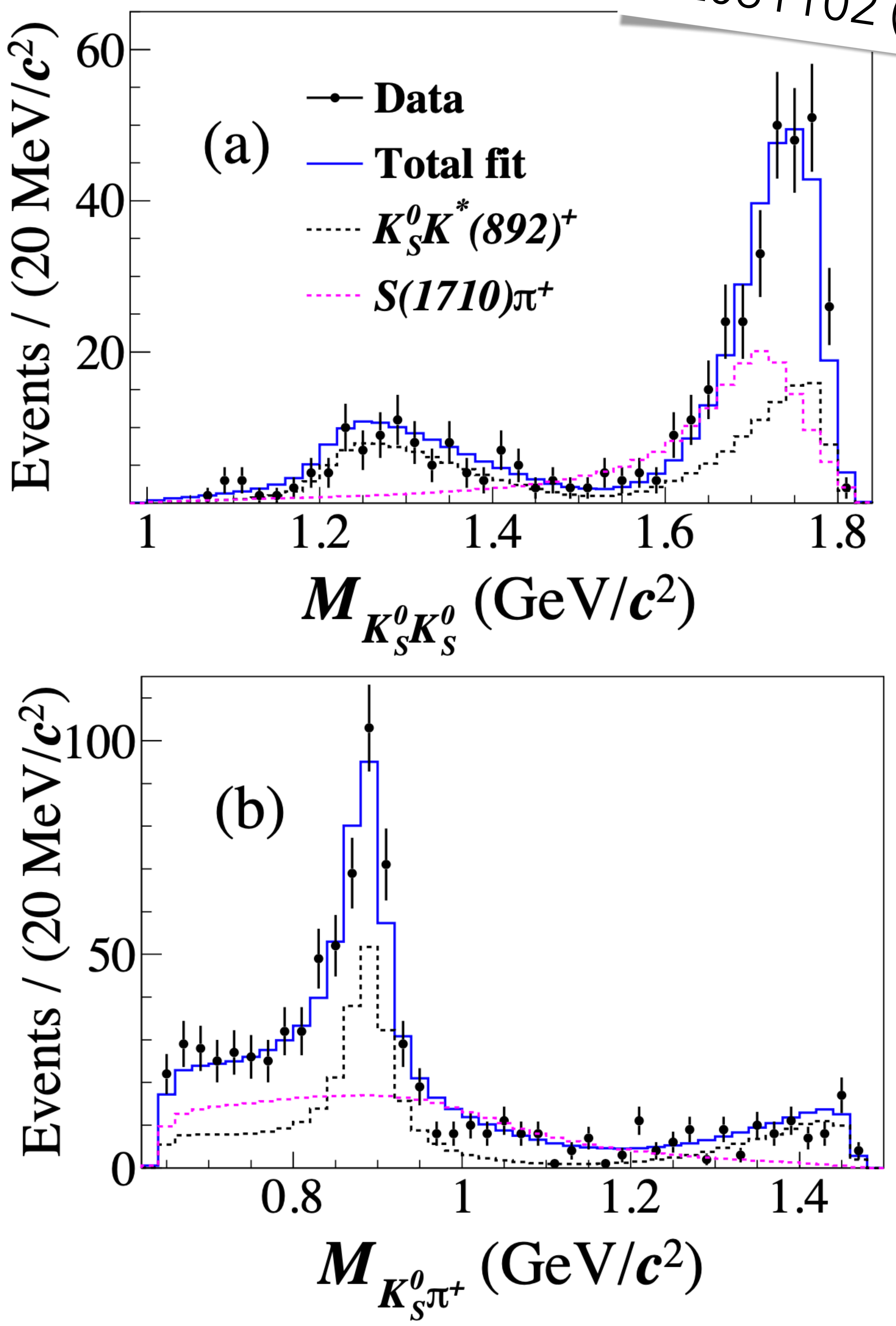

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Amplitude	BF (10^{-3})
$D_s^+ \rightarrow K_S^0 K^*(892)^+ \rightarrow K_S^0 K_S^0 \pi^+$	$3.0 \pm 0.3 \pm 0.1$
$D_s^+ \rightarrow S(1710)\pi^+ \rightarrow K_S^0 K_S^0 \pi^+$	$3.1 \pm 0.3 \pm 0.1$

$$\mathcal{B}_{sig} = \frac{N^{DT}_{total,sig}}{\sum_{\alpha,i} N^{ST}_{\alpha,i} \epsilon^{DT}_{\alpha,sig,i} / \epsilon^{ST}_{\alpha,i}} = (0.68 \pm 0.04_{stat} \pm 0.01_{syst})\%$$

Compatible within 1.3σ with CLEO[14]

$M_{S(1710)} = (1.723 \pm 0.011_{stat} \pm 0.002_{syst})$ GeV/c^2
$\Gamma_{S(1710)} = (0.140 \pm 0.014_{stat} \pm 0.004_{syst})$ GeV/c^2

→ Compatible with PDG estimation for $f_0(1710)$

[14] Phys. Rev. D **88**, 032009 (2013)

Back to the $f_0(1710)$

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Compatible within 1.3σ with CLEO[14]

From Ref. [15], BF($D_s^+ \to f_0(1710)\pi^+ \to K_S^0 K_S^0 \pi^+$) can be estimated as ~ 5 x 10^{-4}, which implies the **existence of an isovector partner**[16] **of the *$f_0(1710)$*** and a **constructive interference** between them when decaying to neutral kaons

$M_{S(1710)} = (1.723 \pm 0.011_{stat} \pm 0.002_{syst})$ GeV/c^2

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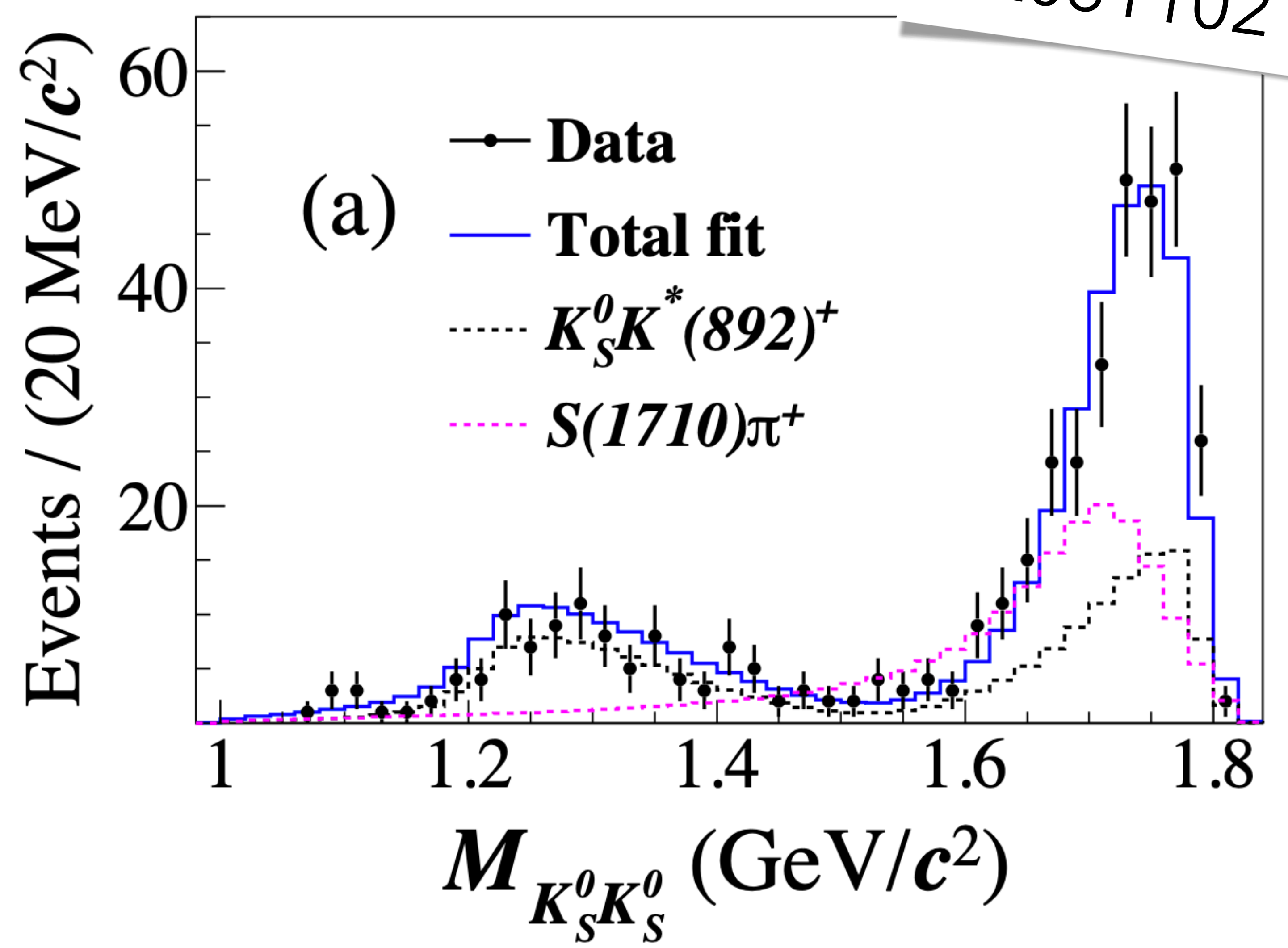

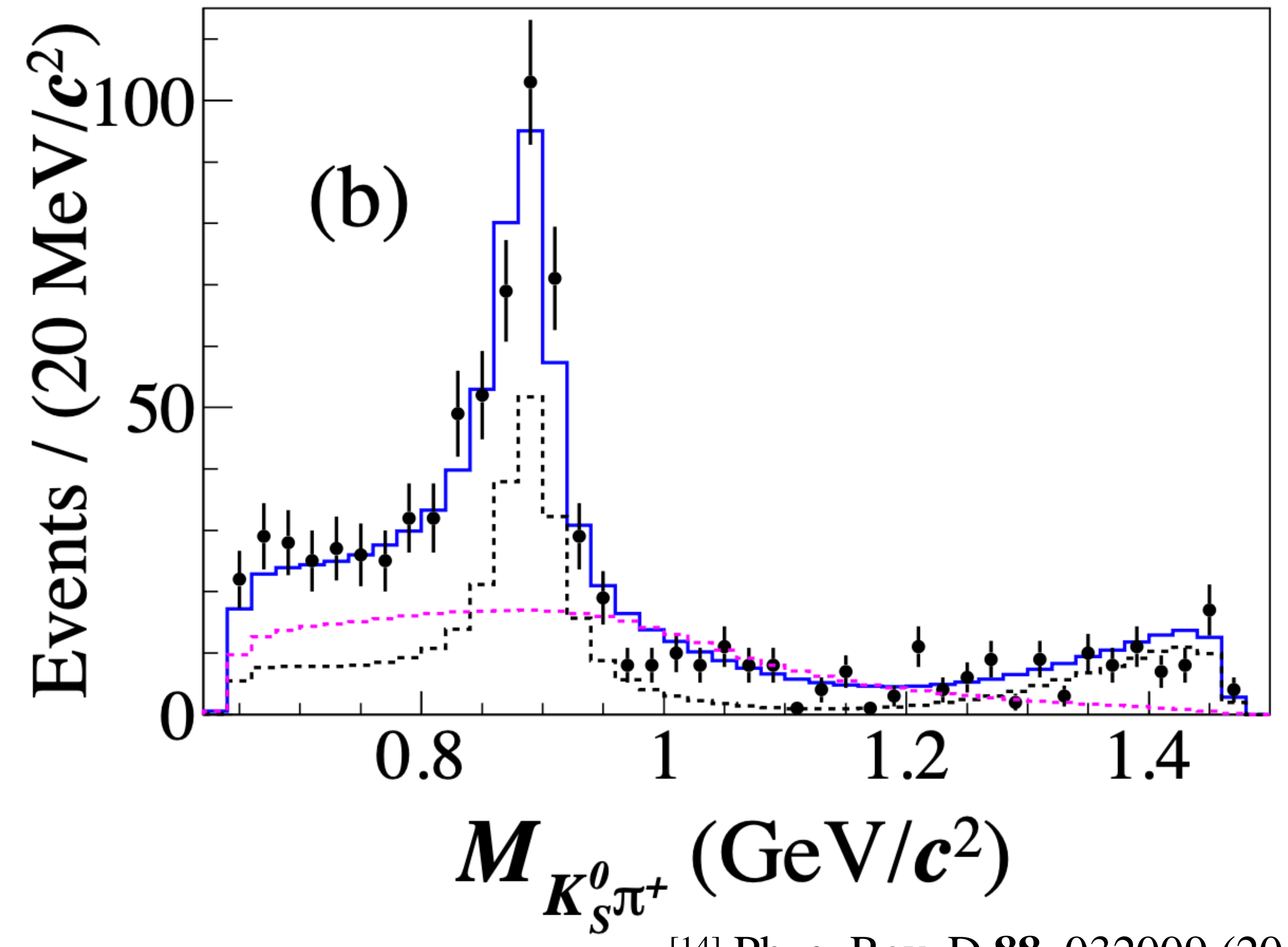

[14] Phys. Rev. D **88**, 032009 (2013)
[15] Phys. Rev. D 104, 012016 (2021)
[16] arXiv:2106.05157 [hep-ex]

The $f_0(1710)$... Glueball, Molecule, or Scalar Meson?

arXiv:2204.09614
Submitted to PRL

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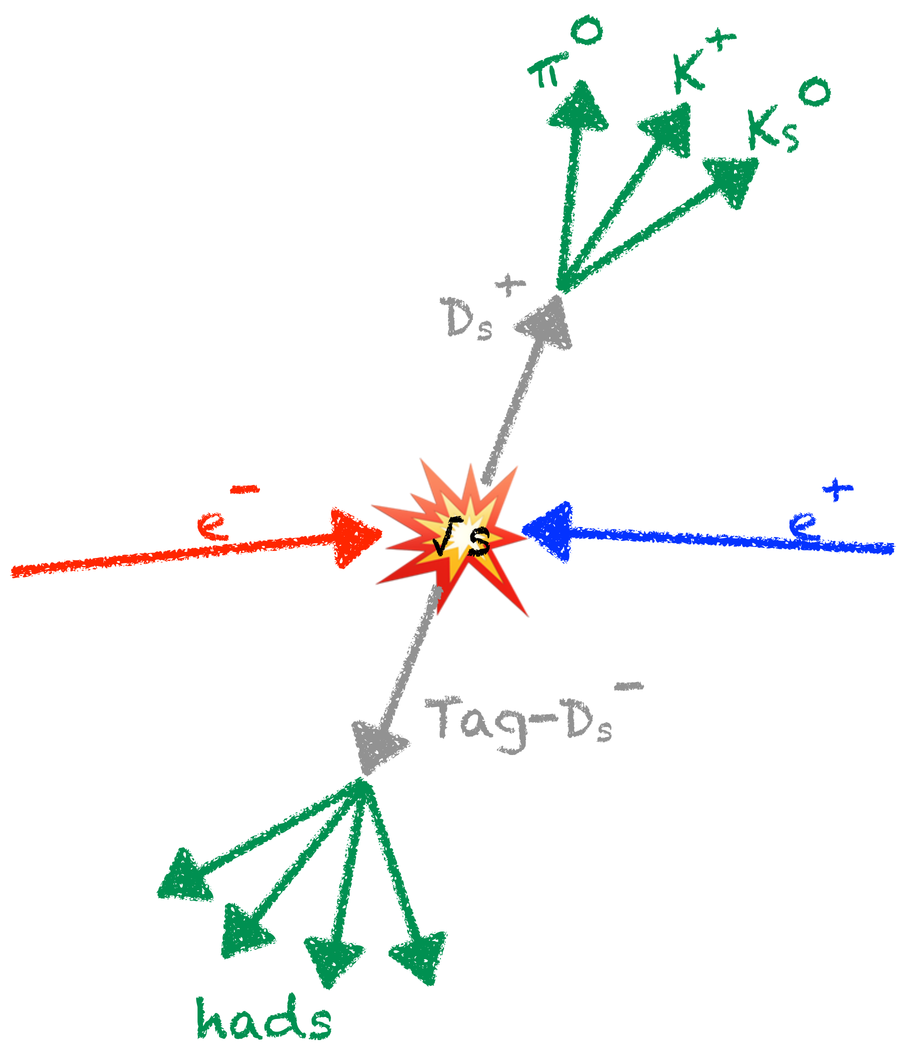

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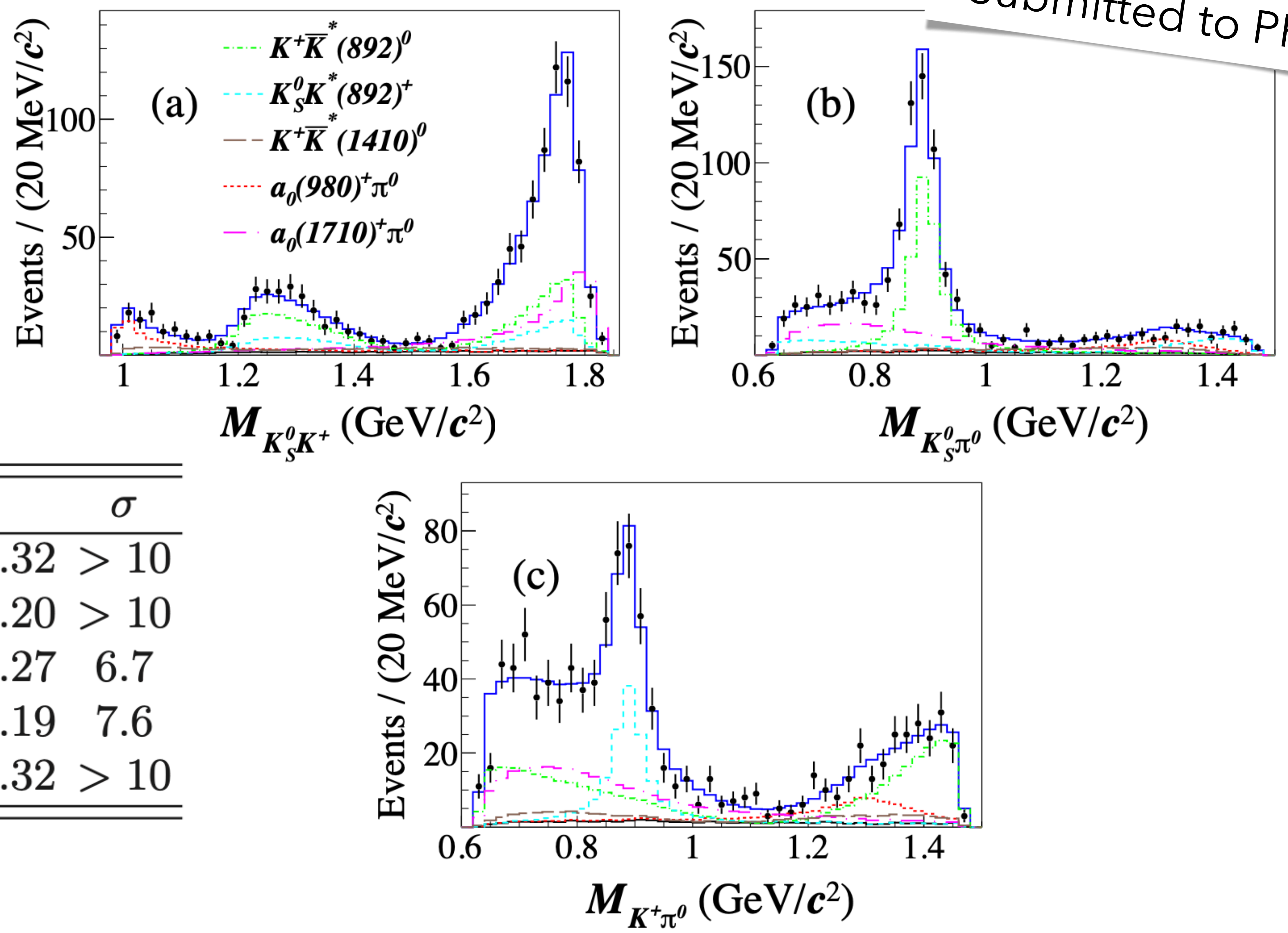

Amplitude	Phase (rad)	FF (%)	BF (10^{-3})	σ
$D_s^+ \to \bar{K}^*(892)^0 K^+$	0.0(fixed)	$32.7 \pm 2.2 \pm 1.9$	$4.77 \pm 0.38 \pm 0.32$	> 10
$D_s^+ \to K^*(892)^+ K_S^0$	$-0.16 \pm 0.12 \pm 0.11$	$13.9 \pm 1.7 \pm 1.3$	$2.03 \pm 0.26 \pm 0.20$	> 10
$D_s^+ \to a_0(980)^+ \pi^0$	$-0.97 \pm 0.27 \pm 0.25$	$7.7 \pm 1.7 \pm 1.8$	$1.12 \pm 0.25 \pm 0.27$	6.7
$D_s^+ \to \bar{K}^*(1410)^0 K^+$	$0.17 \pm 0.15 \pm 0.08$	$6.0 \pm 1.4 \pm 1.3$	$0.88 \pm 0.21 \pm 0.19$	7.6
$D_s^+ \to a_0(1710)^+ \pi^0$	$-2.55 \pm 0.21 \pm 0.07$	$23.6 \pm 3.4 \pm 2.0$	$3.44 \pm 0.52 \pm 0.32$	> 10

$$\mathcal{B}(D_s^+ \to K_S^0 K^+ \pi_0) = (1.46 \pm 0.06_{stat} \pm 0.05_{syst})\%$$

Compatible within 1σ with CLEO[14]

[14] Phys. Rev. D **88**, 032009 (2013)

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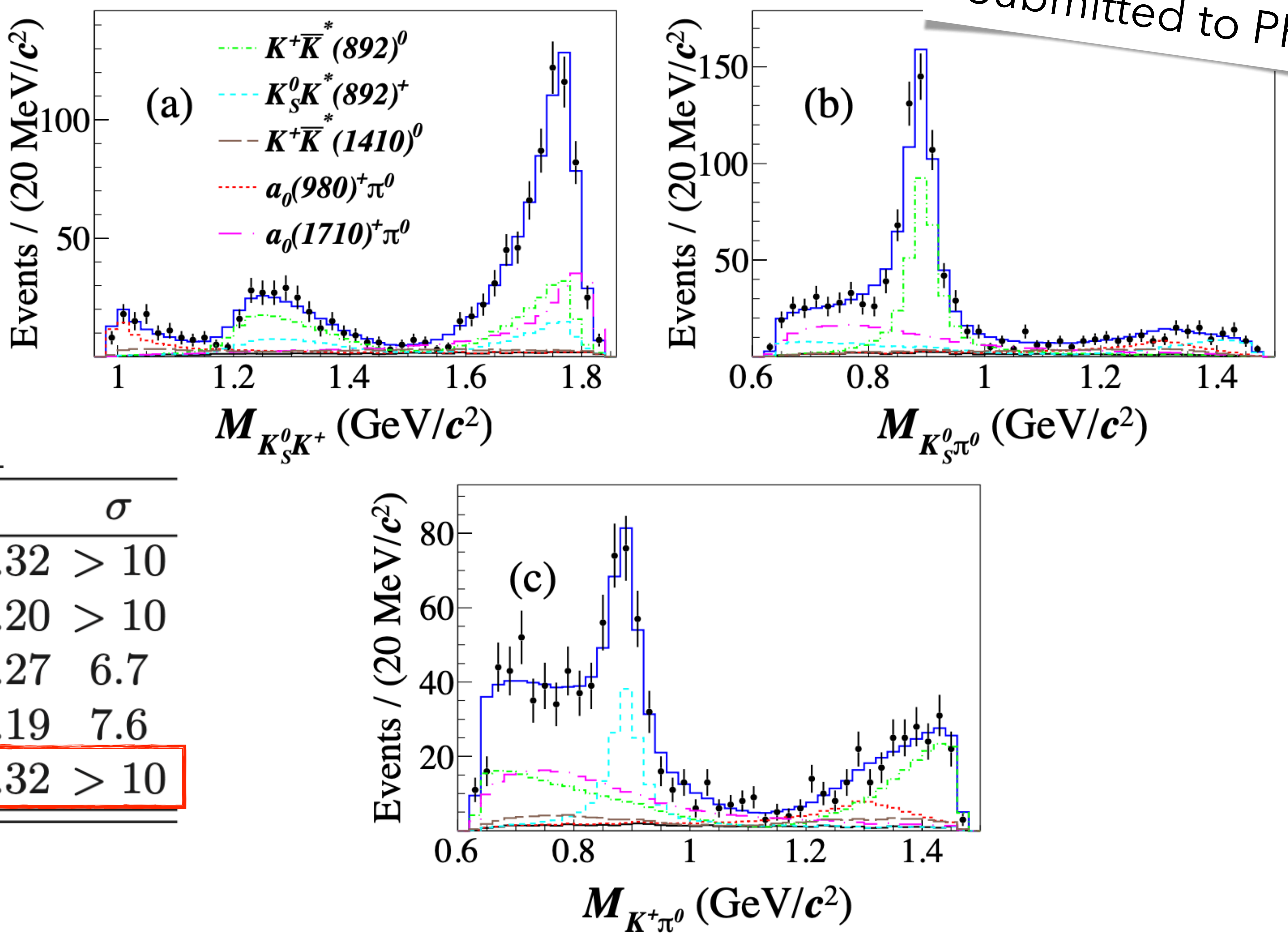

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$$\mathcal{B}(D_s^+ \to K_S^0 K^+ \pi_0) = (1.46 \pm 0.06_{stat} \pm 0.05_{syst})\%$$

Compatible within 1σ with CLEO[14]

$M_{a(1710)} = (1.817 \pm 0.008_{stat} \pm 0.020_{syst})$ GeV/c^2 — 5σ tension
$\Gamma_{a(1710)} = (0.097 \pm 0.022_{stat} \pm 0.015_{syst})$ GeV/c^2 — In agreement

with BaBar measured values[17]

[14] Phys. Rev. D **88**, 032009 (2013)
[17] Phys. Rev. D, **104**, 072002 (2021)

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Submitted to PRL

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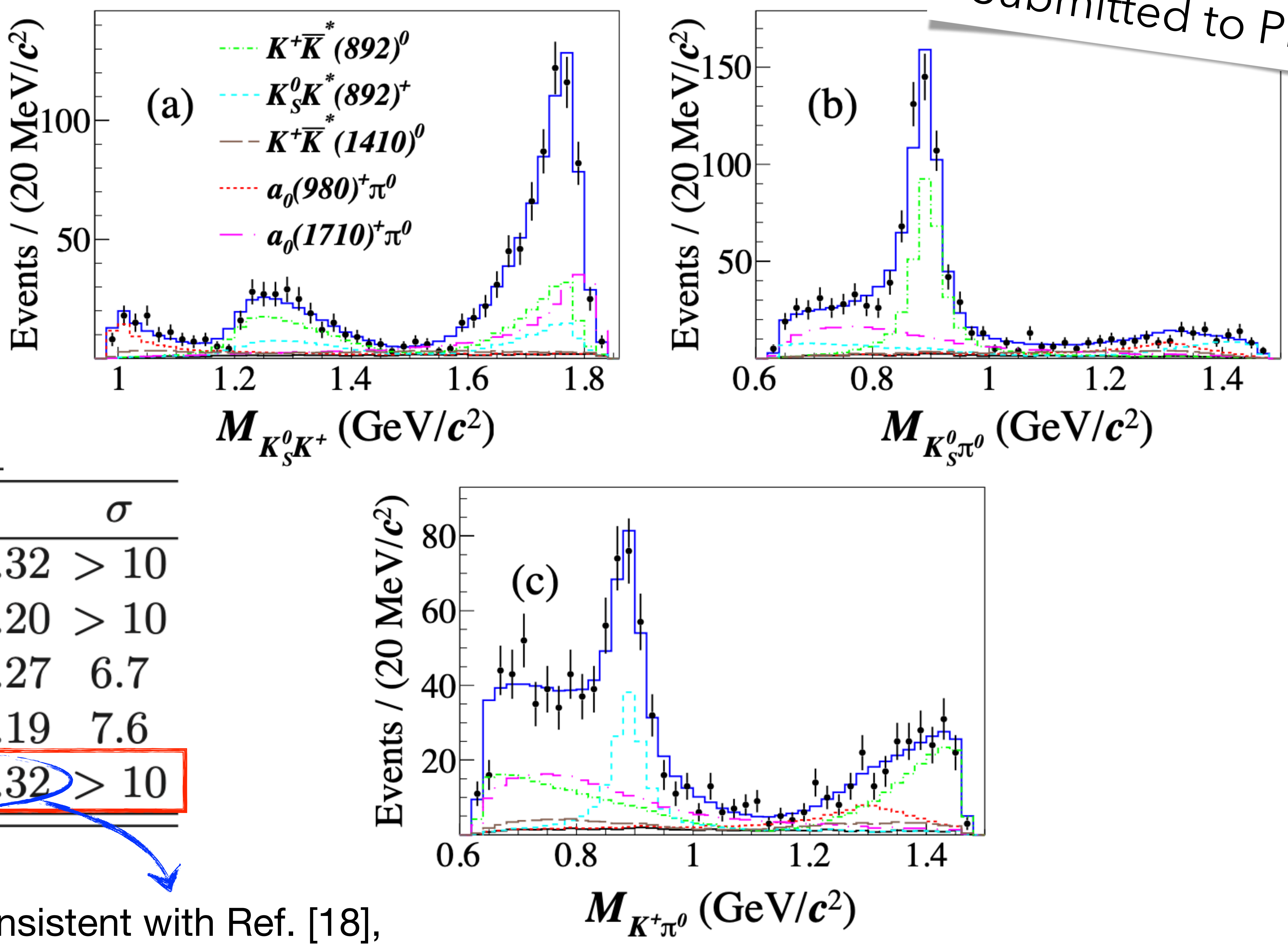

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$$\mathcal{B}(D_s^+ \to K_S^0 K^+ \pi_0) = (1.46 \pm 0.06_{stat} \pm 0.05_{syst})\%$$

Compatible within 1σ with CLEO[14]

Consistent with Ref. [18], predicting (1.3 ± 0.4) x 10^{-4} in the case of the $f_0(1710)$ being a $K^*\bar{K}^*$ molecule

$M_{a(1710)}$ = (1.817 ± 0.008$_{stat}$ ± 0.020$_{syst}$) GeV/c^2 — 5σ tension

$\Gamma_{a(1710)}$ = (0.097 ± 0.022$_{stat}$ ± 0.015$_{syst}$) GeV/c^2 — In agreement

with BaBar measured values[17]

[14] Phys. Rev. D **88**, 032009 (2013)
[17] Phys. Rev. D, **104**, 072002 (2021)
[18] Eur. Phys. J. C **82**, 225 (2022)

The f_0(1710)… Glueball, Molecule, or Scalar Meson?

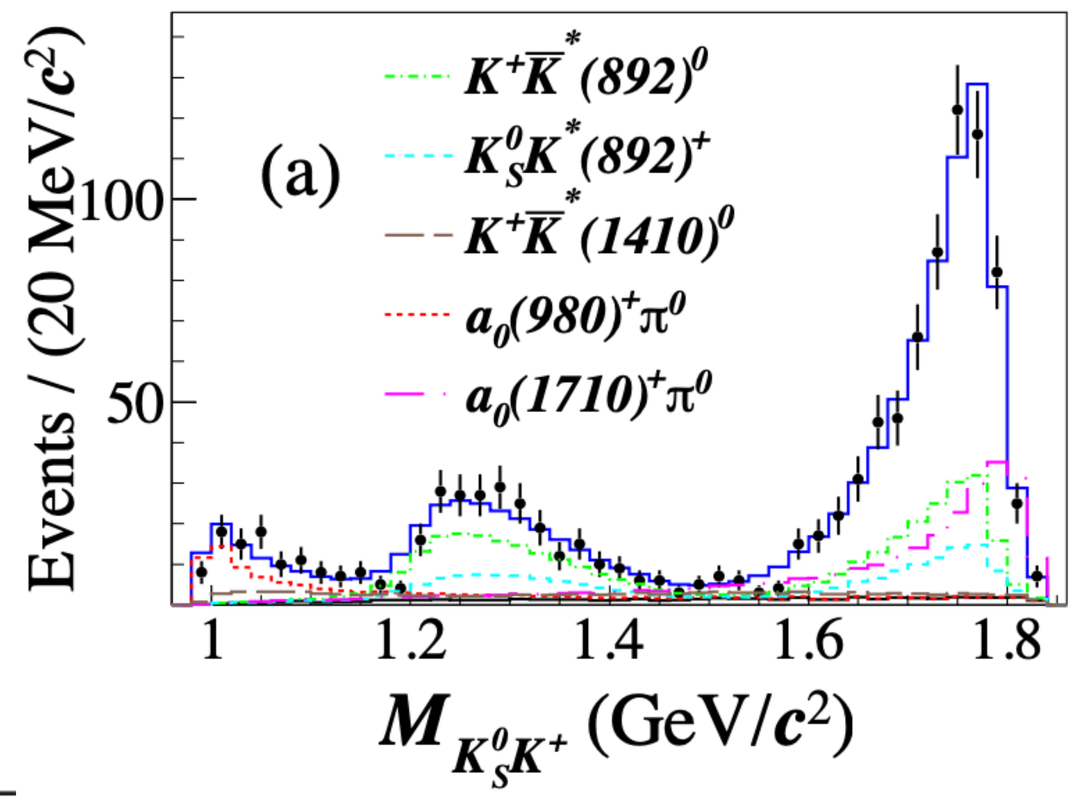
arXiv:2204.09614
Submitted to PRL

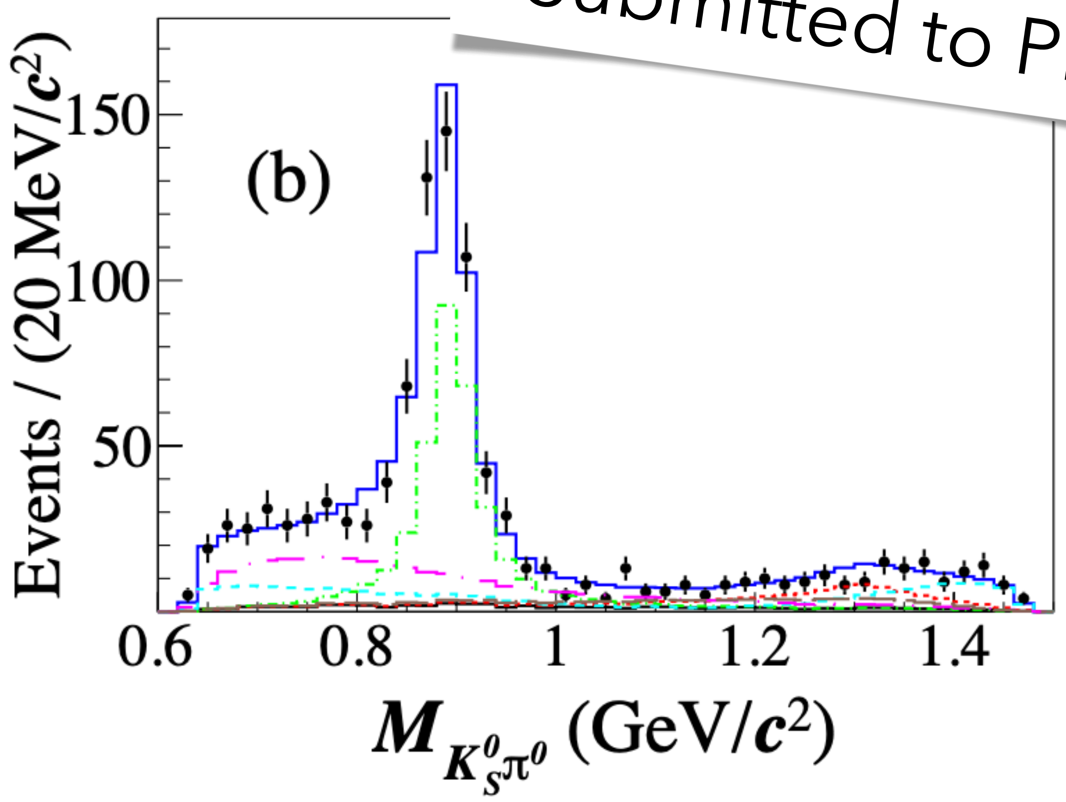
Using 6 data sets for a $\mathcal{L}_{int}$ = 6.32 fb^{-1} @$\sqrt{s}$ = [4.178, 4.226] GeV

Study the $D_s^+ \to K_S^0 K^+ \pi^0$, via the $e^+e^- \to D_s^{*\pm} D_s^{\mp} \to \gamma D_s^{\pm} D_s^{\mp}$ process

AA on M($K_S^0 K^+$), M($K_S^0 \pi^0$), and M($K^+\pi^0$) of a DT sample

Using the ST sample as normalising factor, it is possible to estimate the branching fraction ($\mathcal{B}_{sig}$) of the whole $D_s^+ \to K_S^0 K^+ \pi^0$ process

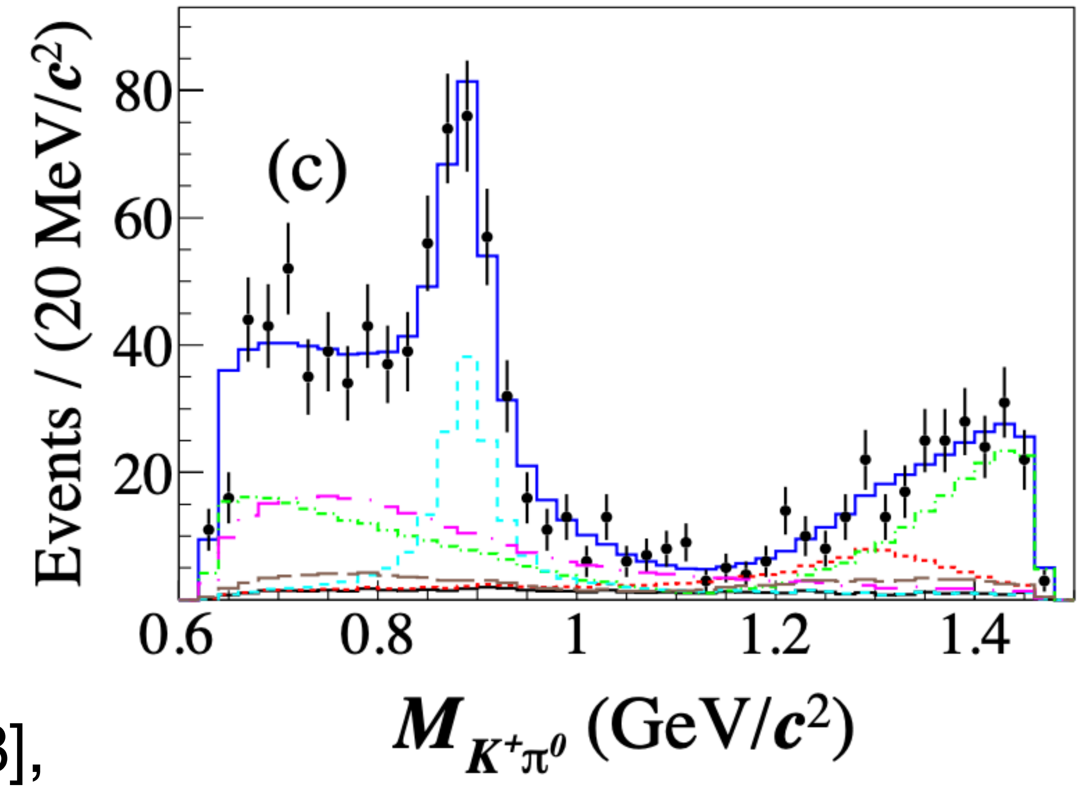




Amplitude	Phase (rad)	FF (%)	BF (10^{-3})	σ
$D_s^+ \to \bar{K}^*(892)^0 K^+$	0.0(fixed)	$32.7 \pm 2.2 \pm 1.9$	$4.77 \pm 0.38 \pm 0.32$	> 10
$D_s^+ \to K^*(892)^+ K_S^0$	$-0.16 \pm 0.12 \pm 0.11$	$13.9 \pm 1.7 \pm 1.3$	$2.03 \pm 0.26 \pm 0.20$	> 10
$D_s^+ \to a_0(980)^+ \pi^0$	$-0.97 \pm 0.27 \pm 0.25$	$7.7 \pm 1.7 \pm 1.8$	$1.12 \pm 0.25 \pm 0.27$	6.7
$D_s^+ \to \bar{K}^*(1410)^0 K^+$	$0.17 \pm 0.15 \pm 0.08$	$6.0 \pm 1.4 \pm 1.3$	$0.88 \pm 0.21 \pm 0.19$	7.6
$D_s^+ \to a_0(1710)^+ \pi^0$	$-2.55 \pm 0.21 \pm 0.07$	$23.6 \pm 3.4 \pm 2.0$	$3.44 \pm 0.52 \pm 0.32$	> 10

$$\mathcal{B}(D_s^+ \to K_S^0 K^+ \pi_0) = (1.46 \pm 0.06_{stat} \pm 0.05_{syst})\%$$

Compatible within 1σ with CLEO[14]



Consistent with Ref. [18], predicting (1.3 ± 0.4) x 10^{-4} in the case of the f_0(1710) being a $K^*\bar{K}^*$ molecule

Ref. [19] predicts it to be the isovector partner of the X(1812)[20] scalar observed in $\omega\phi$ decay channel

$M_{a(1710)}$ = (1.817 ± 0.008$_{stat}$ ± 0.020$_{syst}$) GeV/c^2 — 5σ tension
$\Gamma_{a(1710)}$ = (0.097 ± 0.022$_{stat}$ ± 0.015$_{syst}$) GeV/c^2 — In agreement

with BaBar measured values[17]

[14] Phys. Rev. D **88**, 032009 (2013)
[17] Phys. Rev. D, **104**, 072002 (2021)
[18] Eur. Phys. J. C **82**, 225 (2022)
[19] arXiv:2204.13092 **[hep-ph]**
[20] Phys. Rev. Lett. **96**, 162002 (2006)

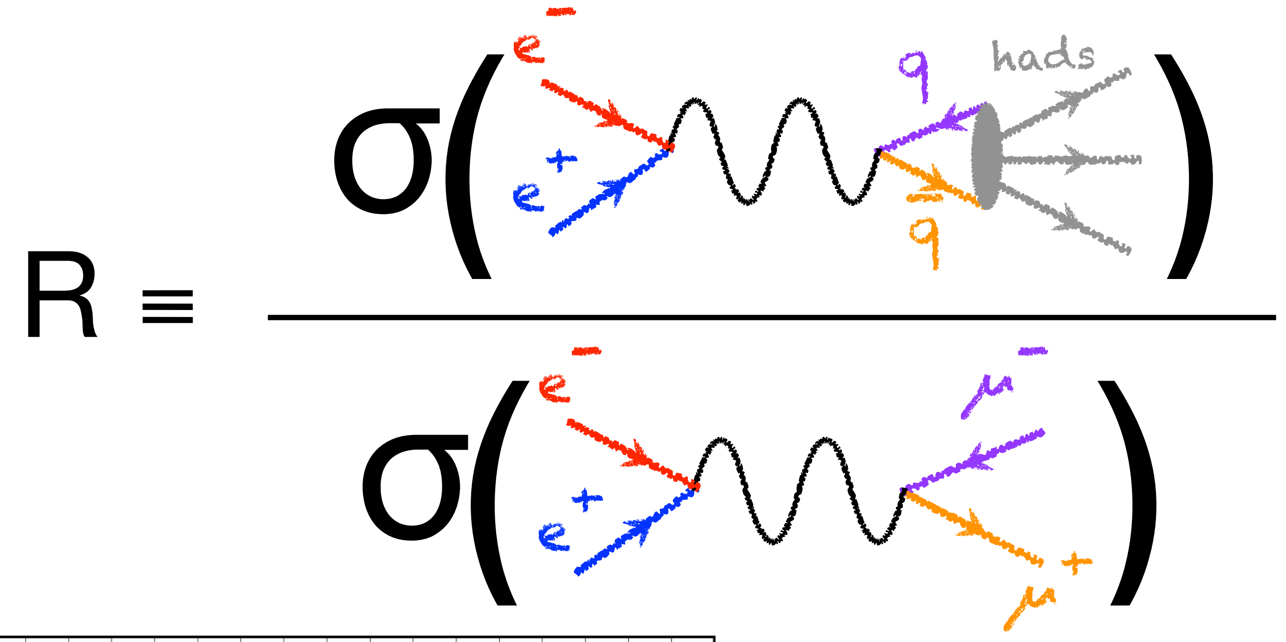
Baryon Studies

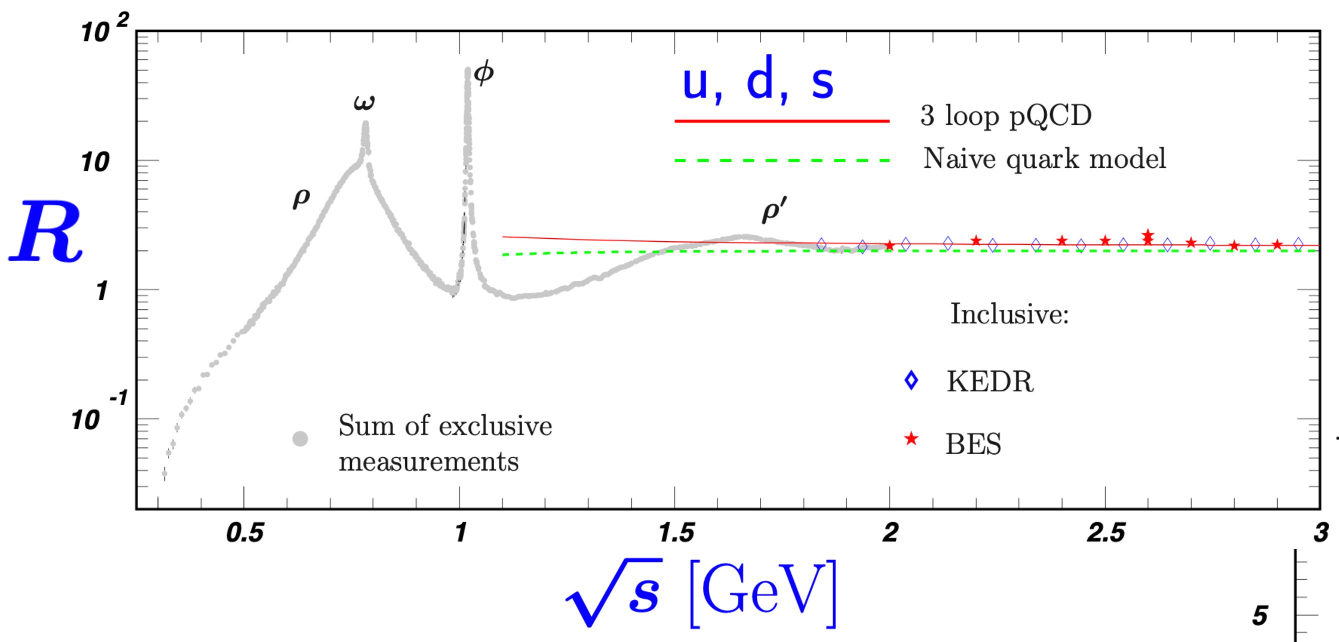
Probing BSM

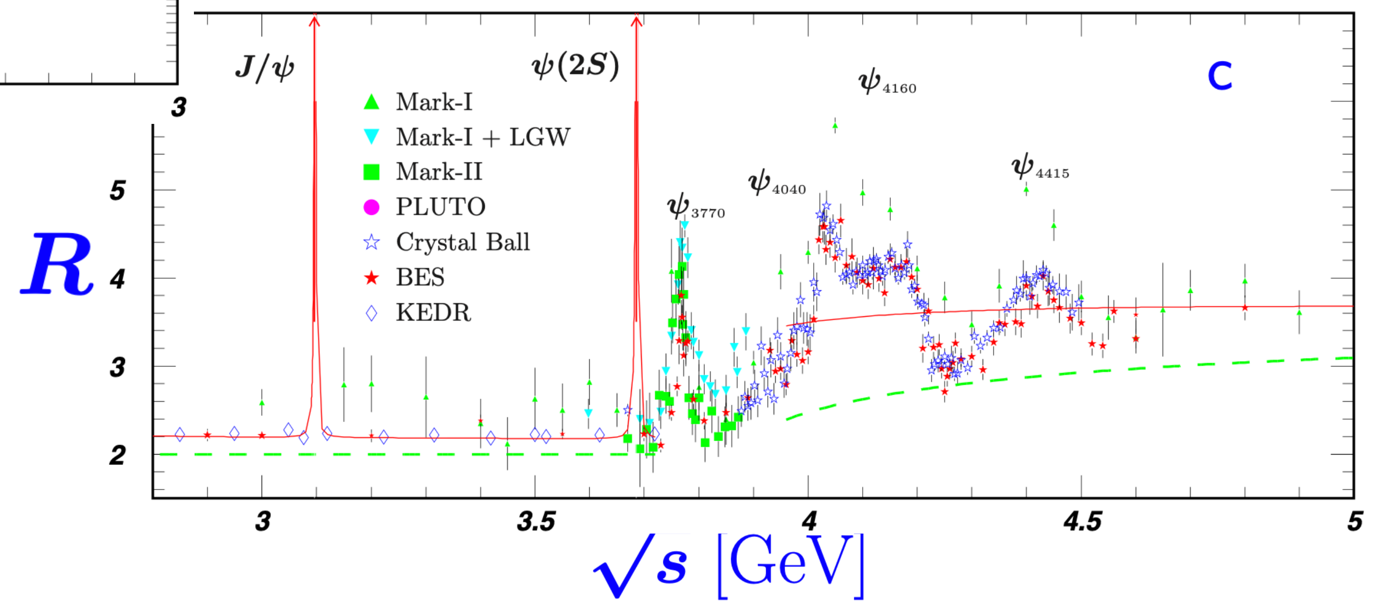
Via **R-Value** measurements

Prediction of the anomalous muon magnetic moment

Determination of the QED running coupling constant





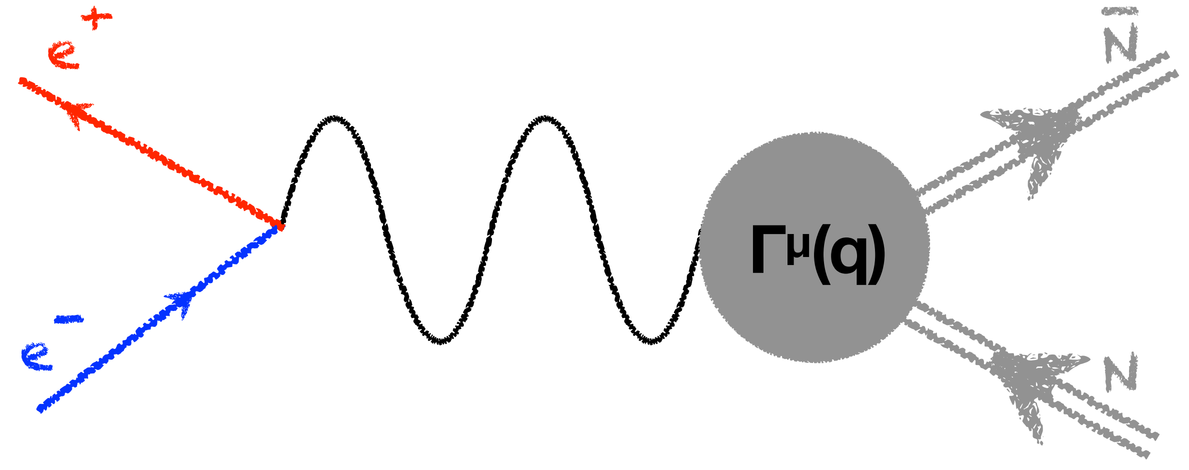


Inspecting Nucleon Internal Structure

With **EM Form Factors** measurements

Complementary tests of pQCD models predictions

@e⁺e⁻ collider EMFFs studied in the timelike region



$\Gamma^{\mu}(q)$ parametrised via the Dirac (*charge*) and Pauli (*magnetisation*) FFs

From which Sachs FFs (G_M and G_E) are derived and allows us to write[21]…

$$\sigma^{B}(s) = \frac{4\pi\alpha^2\beta C}{3s}\left[|G_M(s)|^2 + \frac{1}{2\tau}|G_E(s)|^2\right]$$

$$|G_{\rm eff}(s)| \equiv \sqrt{\frac{2\tau\,|G_M(s)|^2 + |G_E(s)|^2}{2\tau+1}} = \sqrt{\frac{\sigma^{B}(s)}{\frac{4\pi\alpha^2\beta C}{3s}\left[1+\frac{1}{2\tau}\right]}}$$

[21] Rev. Mod. Phys. **35**, 335 (1963)

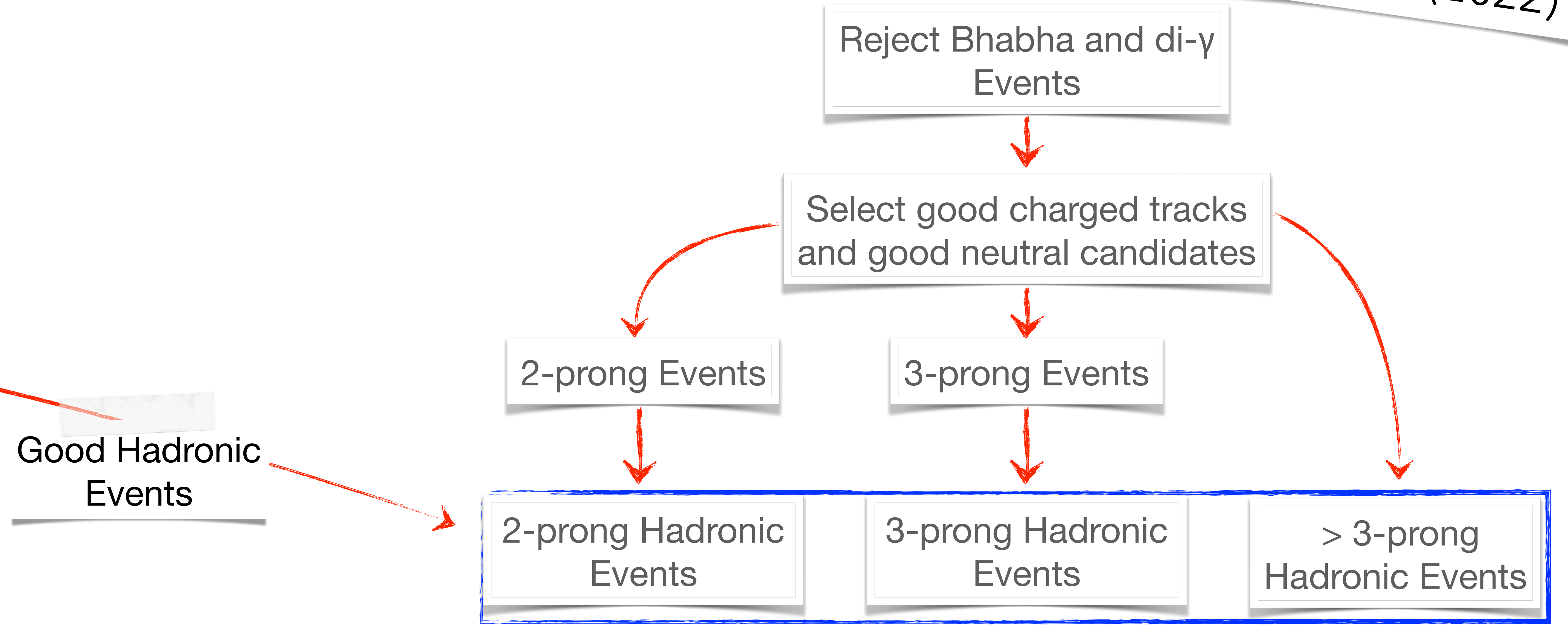
R-Value Estimation

PRL **128**, 062004 (2022)

Using 14 energy points @$\sqrt{s}$ = [2.2324, 3.6710] GeV

The R-Value is measured as follows…

$$R = \frac{N_{\text{had}}^{\text{obs}} - N_{\text{bkg}}}{\sigma_{\mu\mu}^{0}\mathcal{L}_{\text{int}}\varepsilon_{\text{trig}}\varepsilon_{\text{had}}(1+\delta)}$$



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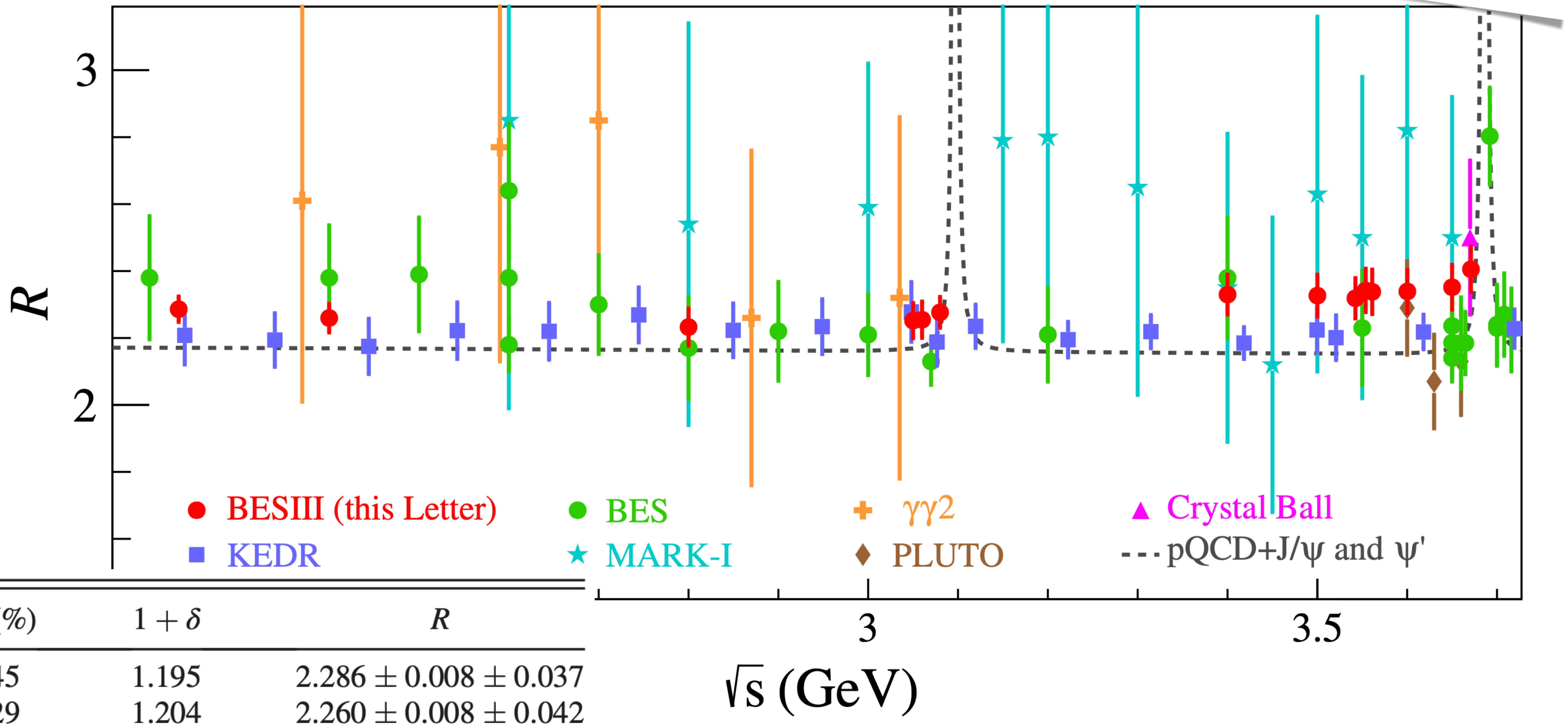


$\sqrt{s}$ (GeV)	$N_{\text{had}}^{\text{obs}}$	N_{bkg}	$\sigma^0_{\mu\mu}$ (nb)	$\mathcal{L}_{\text{int}}$ (pb^{-1})	ε_{had} (%)	$1+\delta$	R
2.2324	83 227	2041	17.427	2.645	64.45	1.195	$2.286 \pm 0.008 \pm 0.037$
2.4000	96 627	2331	15.079	3.415	67.29	1.204	$2.260 \pm 0.008 \pm 0.042$
2.8000	83 802	2075	11.078	3.753	72.25	1.219	$2.233 \pm 0.008 \pm 0.055$
3.0500	283 822	7719	9.337	14.89	73.91	1.193	$2.252 \pm 0.004 \pm 0.052$
3.0600	282 467	7683	9.276	15.04	73.88	1.183	$2.255 \pm 0.004 \pm 0.054$
3.0800	552 435	15 433	9.156	31.02	73.98	1.123	$2.277 \pm 0.003 \pm 0.046$
3.4000	32 202	843	7.513	1.733	74.81	1.382	$2.330 \pm 0.014 \pm 0.058$
3.5000	62 670	1691	7.090	3.633	75.32	1.351	$2.327 \pm 0.010 \pm 0.062$
3.5424	145 303	3872	6.921	8.693	75.58	1.341	$2.319 \pm 0.006 \pm 0.060$
3.5538	92 996	2469	6.877	5.562	75.50	1.338	$2.342 \pm 0.008 \pm 0.064$
3.5611	64 650	2477	6.849	3.847	75.50	1.337	$2.338 \pm 0.010 \pm 0.066$
3.6002	159 644	9817	6.701	9.502	75.73	1.328	$2.339 \pm 0.006 \pm 0.065$
3.6500	78 730	6168	6.519	4.760	76.00	1.308	$2.352 \pm 0.009 \pm 0.067$
3.6710	75 253	6461	6.445	4.628	76.11	1.260	$2.405 \pm 0.010 \pm 0.067$

Accuracy ~2.6% @ $\sqrt{s}$ < 3.1 GeV and ~3.0% @ $\sqrt{s}$ > 3.1 GeV

R-Value consistent with KEDR result[22] and QCD prediction[23]

[22] Phys. Lett. B **788**, 42 (2019)
[23] Phys. Lett. B **714**, 62 (2012)

EM Form Factors

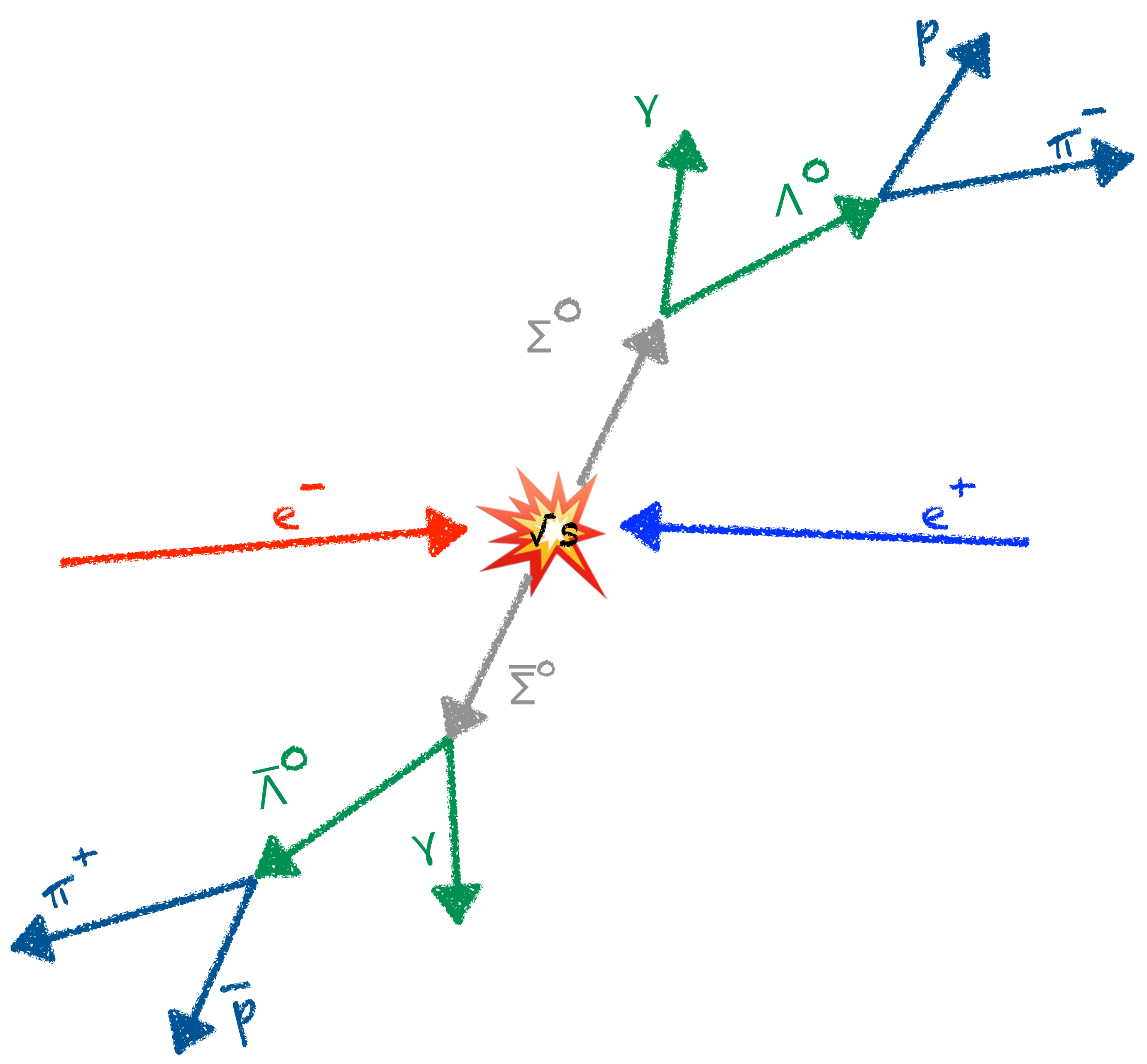
PLB **831**, 137187 (2022)

Using 7 data sets for a $\mathcal{L}_{int}$ = 328.5 pb^{-1} @$\sqrt{s}$ = [2.3864, 3.0200] GeV

Study the $\sigma^{Born}(e^+e^-\to\Sigma^0\bar{\Sigma}^0)$, via

I) Single Tag (ST) method, @$\sqrt{s}$ > 2.3960

II) Reconstructing *soft*-$\pi^\pm$ and $\bar{p}$ interactions products, near threshold



EM Form Factors

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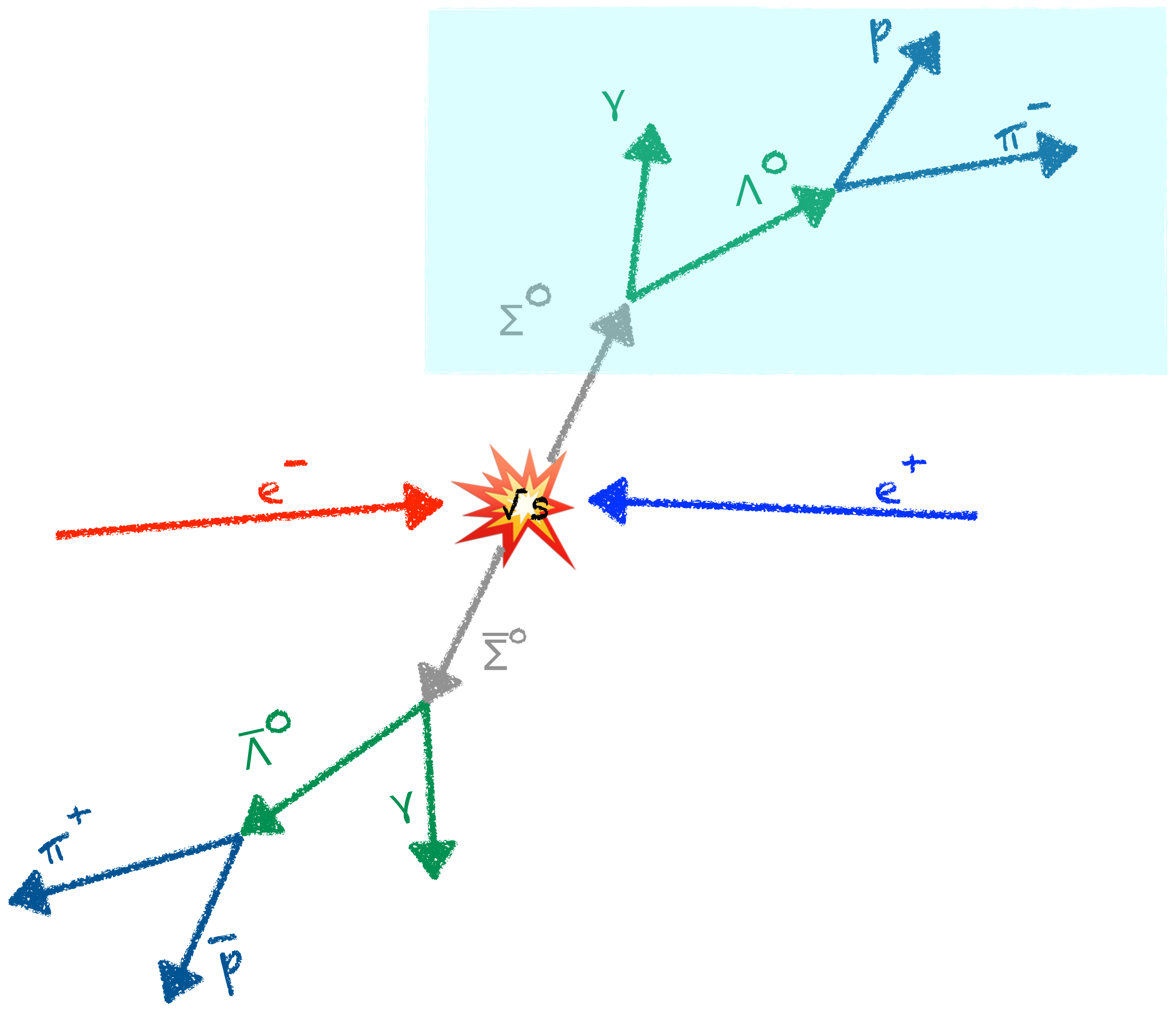
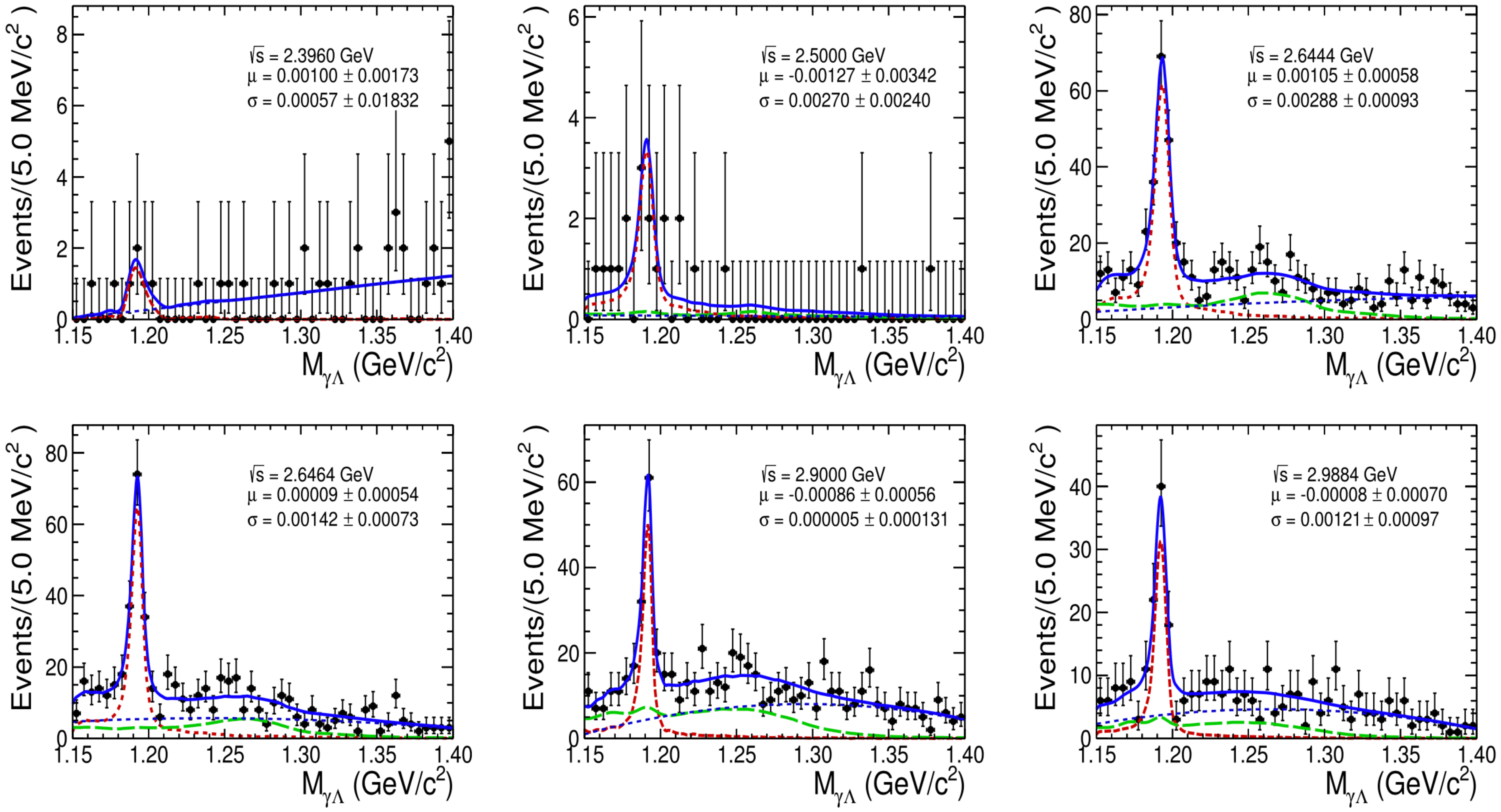


Invariant M(γΛ) spectrum at different √s



EM Form Factors

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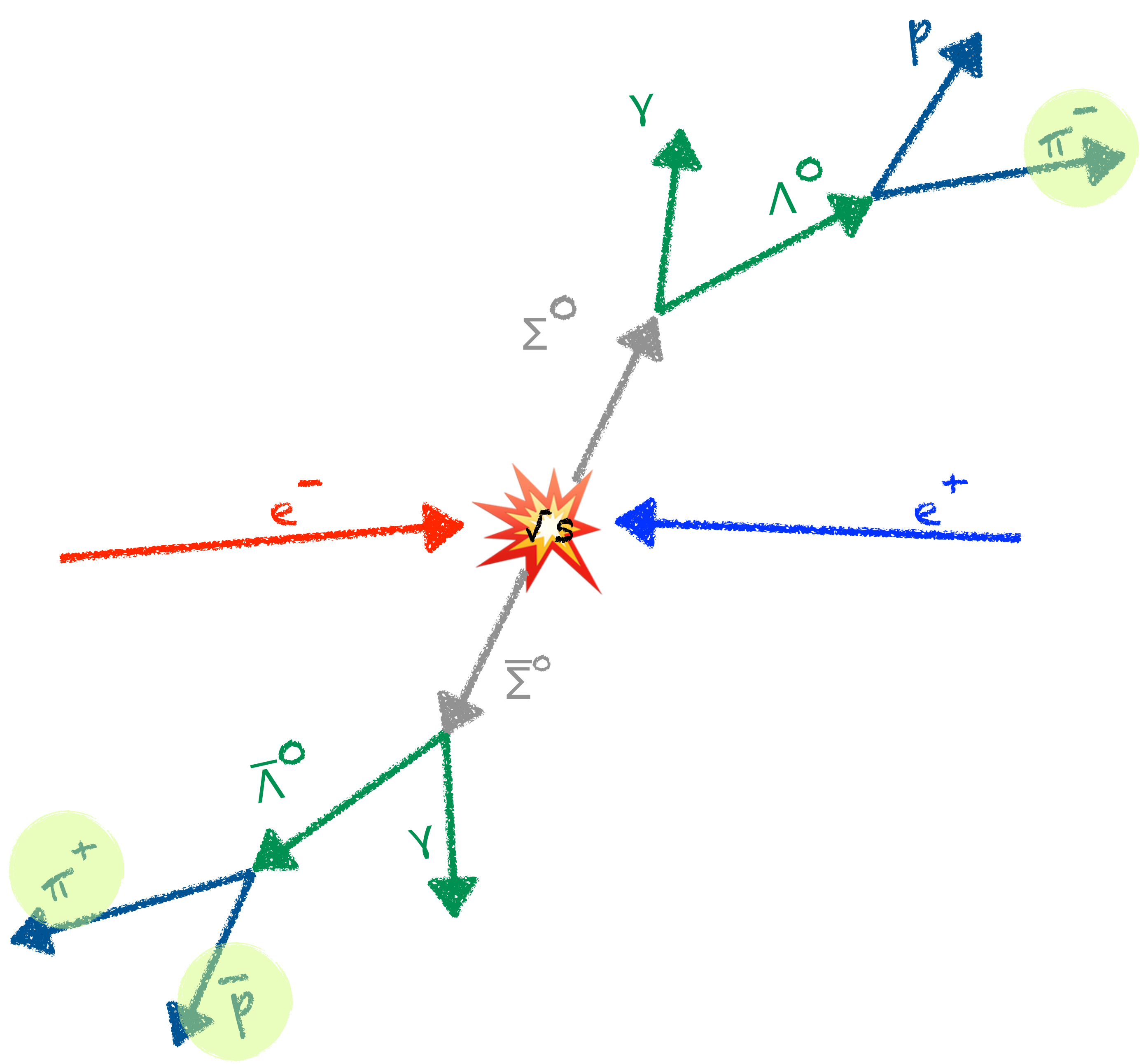
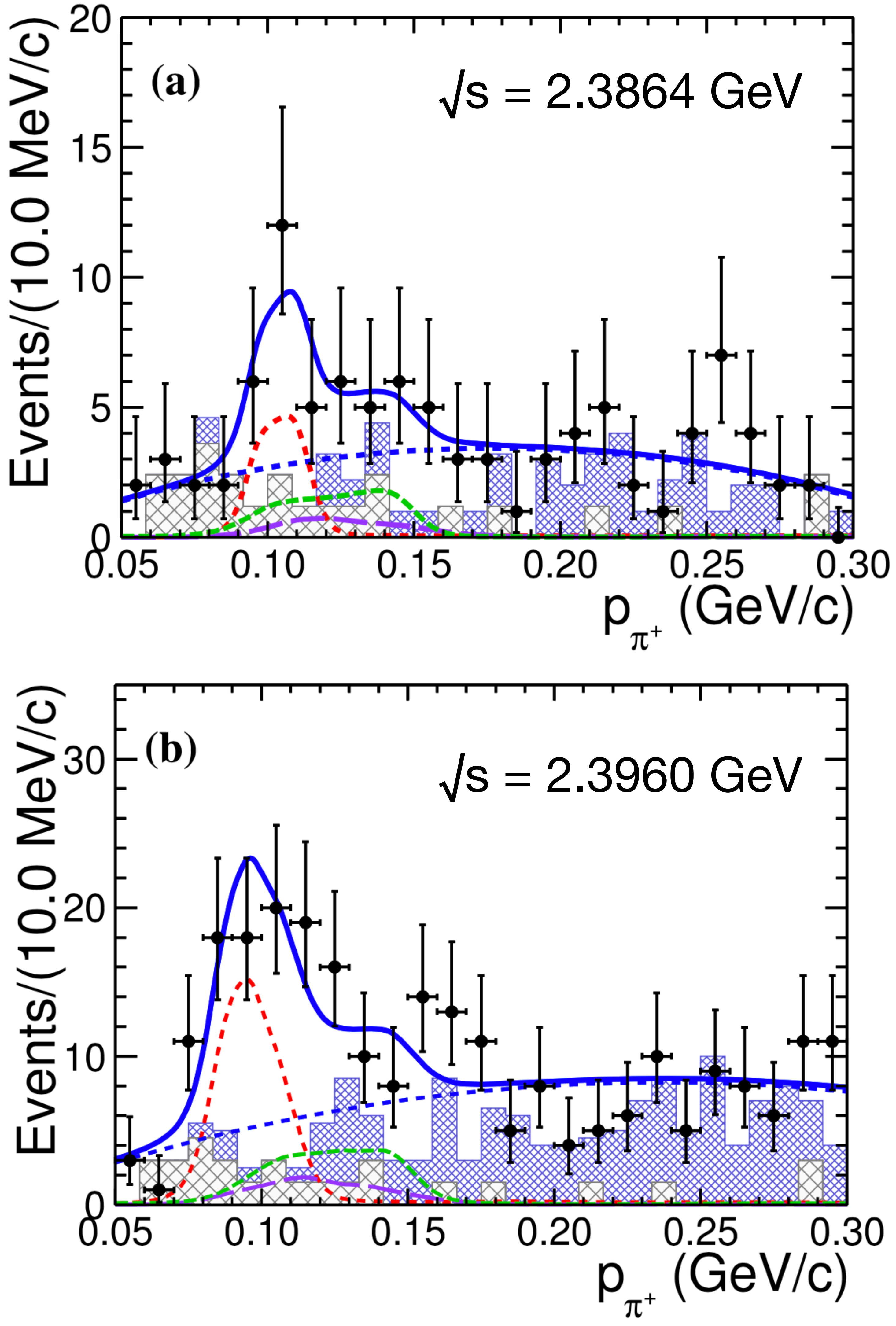




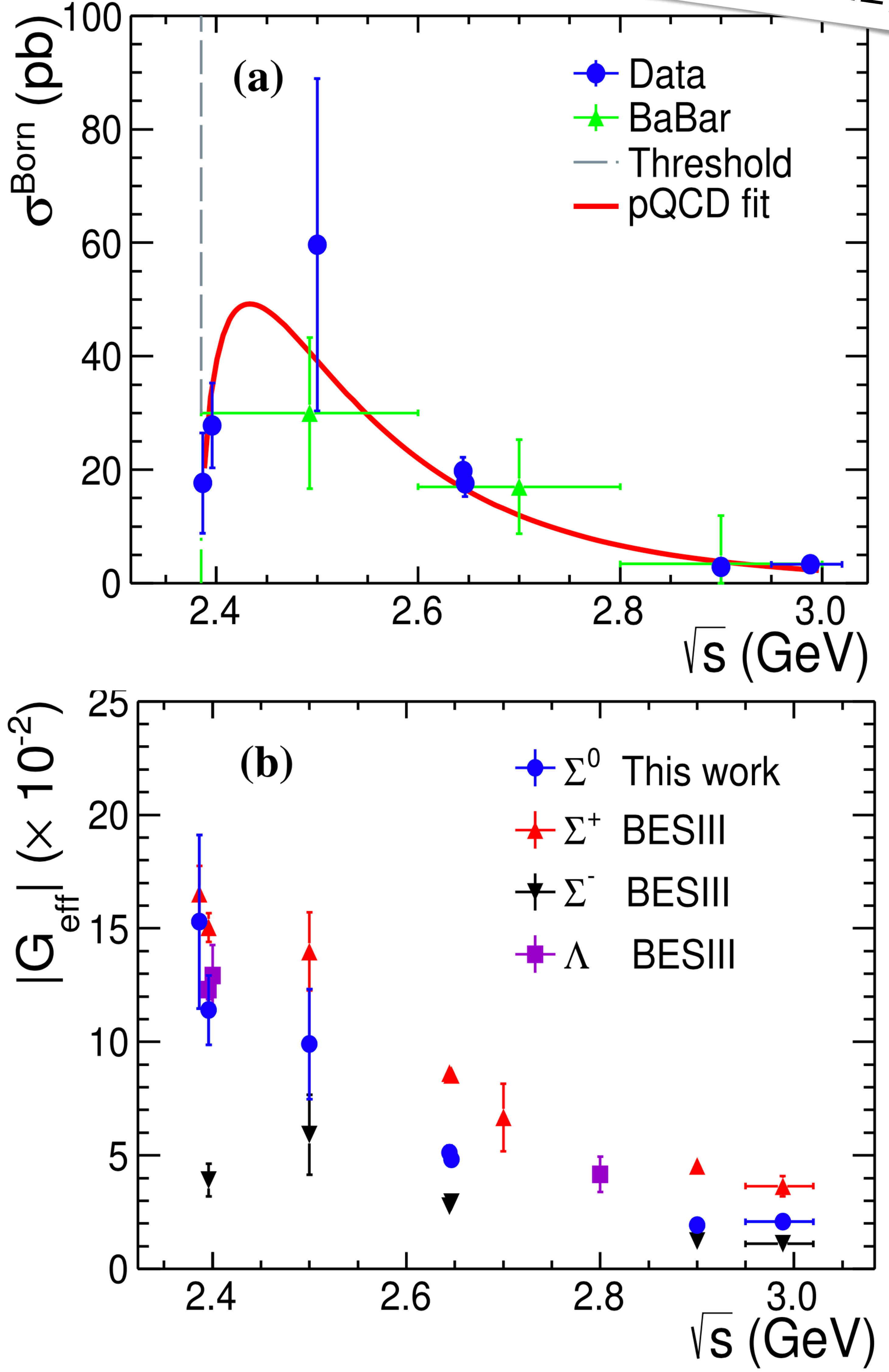
EM Form Factors

PLB **831**, 137187 (2022)

Using 7 data sets for a $\mathcal{L}_{int}$ = 328.5 pb^{-1} @$\sqrt{s}$ = [2.3864, 3.0200] GeV

Study the $\sigma^{Born}(e^+e^- \to \Sigma^0\bar{\Sigma}^0)$…

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	ε (%)	$1+\delta$	$N_{obs}(N_{U.L.})$	σ^B (pb)	$\lvert G_{eff}\rvert$ ($\times 10^{-2}$)	$S(\sigma)$
2.3864	22.55	11.1	0.65	11.7 ± 5.8 (< 28.0)	$17.6 \pm 8.73 \pm 1.58$(< 42.4)	$15.3 \pm 3.79 \pm 0.69$(< 23.7)	2.3
2.3960	66.87	7.7	0.75	45.1 ± 11.2	$28.6 \pm 7.10 \pm 3.26$	$11.5 \pm 1.43 \pm 0.66$	4.5
2.5000	1.10	32.3	0.94	12.7 ± 6.4	$59.6 \pm 30.3 \pm 7.15$	$9.90 \pm 2.52 \pm 0.60$	3.1
2.6444	33.72	47.1	1.10	221 ± 25	$19.8 \pm 2.23 \pm 1.21$	$5.12 \pm 0.29 \pm 0.16$	12.4
2.6464	34.00	46.4	1.10	195 ± 24	$17.6 \pm 2.13 \pm 1.20$	$4.83 \pm 0.29 \pm 0.16$	11.9
2.9000	105.23	40.2	1.44	116 ± 17	$2.98 \pm 0.45 \pm 0.22$	$1.95 \pm 0.15 \pm 0.07$	9.4
2.9884	65.18	34.9	1.62	78.7 ± 13.9	$3.34 \pm 0.59 \pm 0.20$	$2.08 \pm 0.18 \pm 0.06$	9.0



Results are **agreement BaBar**'s[24], but an improved precision (up to 50%)

No threshold effect is observed for this **process**, and it can be **described** by a **pQCD-motivated function**[25]

An **asymmetry G$_{eff}$** of Σ-triplet is observed, as expected from Ref. [25] predicting $G_{eff} \propto \sum_q Q_q^2$

Results **inconsistent** with both the ***Y$\bar{Y}$* potential**[26] (predicting a deviation from the potential model) **and di-quark** correlation **models**[27] (expecting $\sigma_{\Sigma\Sigma} < \sigma_{\Lambda\Lambda}$)

[24] Phys. Rev. D **76** (2007) 092006
[25] Phys. Rep., 550–551 (2015)
[26] Phys. Rev. D **103** (2021) 014028
[27] Rev. Mod. Phys. **65** (1993) 1199

Summary

BESIII started taking data in ’08

Its physics reach spans a **plethora of topics**, some of which have been covered here

Charmonium(-like) studies
Light hadrons spectroscopy and decays
Open charm physics
Precision QCD measurements (such as R-Value or FFs)

BESIII can also provide useful insights outside of the QCD environment

Probing BSM physics
Studying *weak* sector

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

~$2.5x10^9$ @$\psi(2S)$
~$20 fb^{-1}$@$\psi(3770)$

Hence, exciting times wait ahead…

Thank you for the attention!

Backup Slides

BESIII Collaboration

Europe (17)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster
Italy(3): Ferrara University, INFN, University of Turin,
Netherlands(1):KVI/University of Groningen
Russia(2): Budker Institute of Nuclear Physics, Dubna JINR
Sweden(1):Uppsala University
Turkey (1):Turkish Accelerator Center Particle Factory Group
UK(2): University of Manchester, University of Oxford
Poland(1): National Centre for Nuclear Research

Mongolia(1)
Institute of Physics and Technology

Korea(2)
Seoul National University
Chung-Ang University

Japan(1)
Tokyo University

Thailand(1)
Suranaree University of Technology

USA(5)
Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota
University of Rochester

Pakistan(3)
COMSATS Institute of Information Technology
University of the Punjab,
University of Lahore

India(1)
Indian Institute of Technology madras

Chile(1)
University of Tarapaca

China (50)
Beijing Institute of Petro-chemical Technology, Beihang University, Central South University China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, HeBei University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, YunNan University , Zhejiang University, Zhengzhou University

~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)

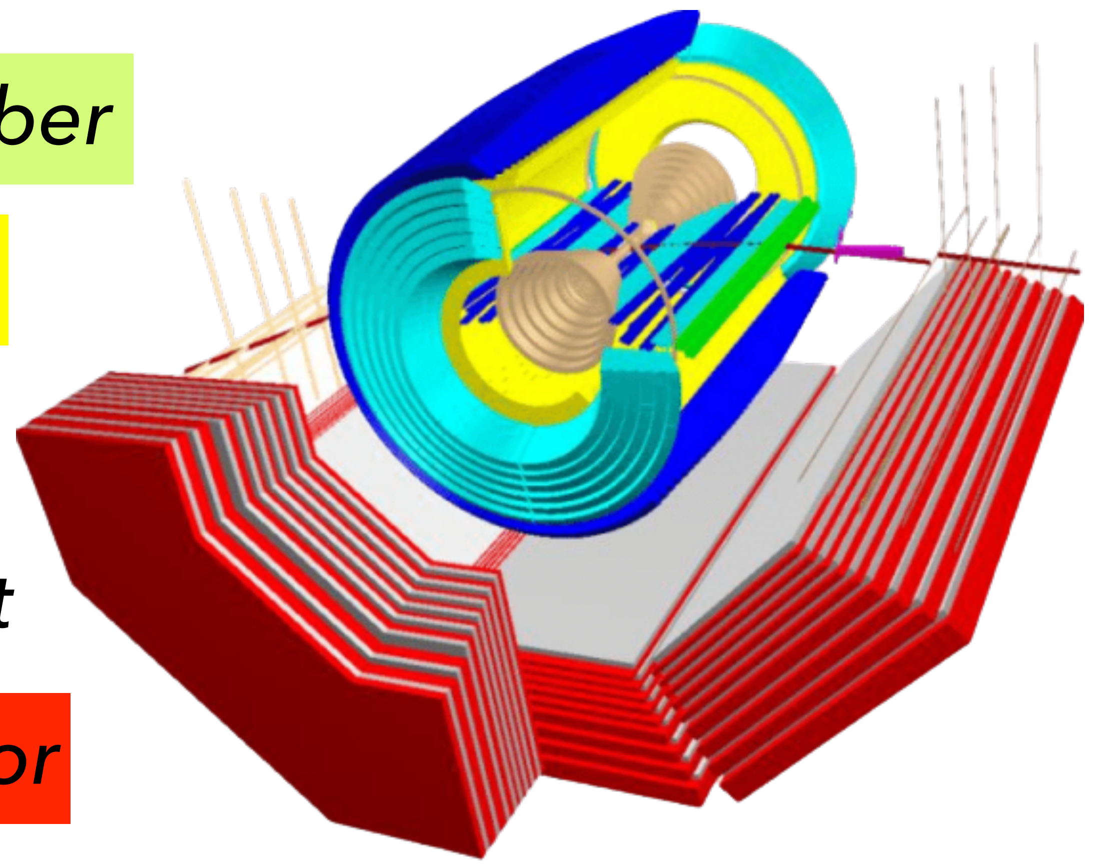
Multi-layer Drift Chamber

Time of Flight Detector

EM Calorimeter

1T Solenoidal Magnet

Muon Detector



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	%

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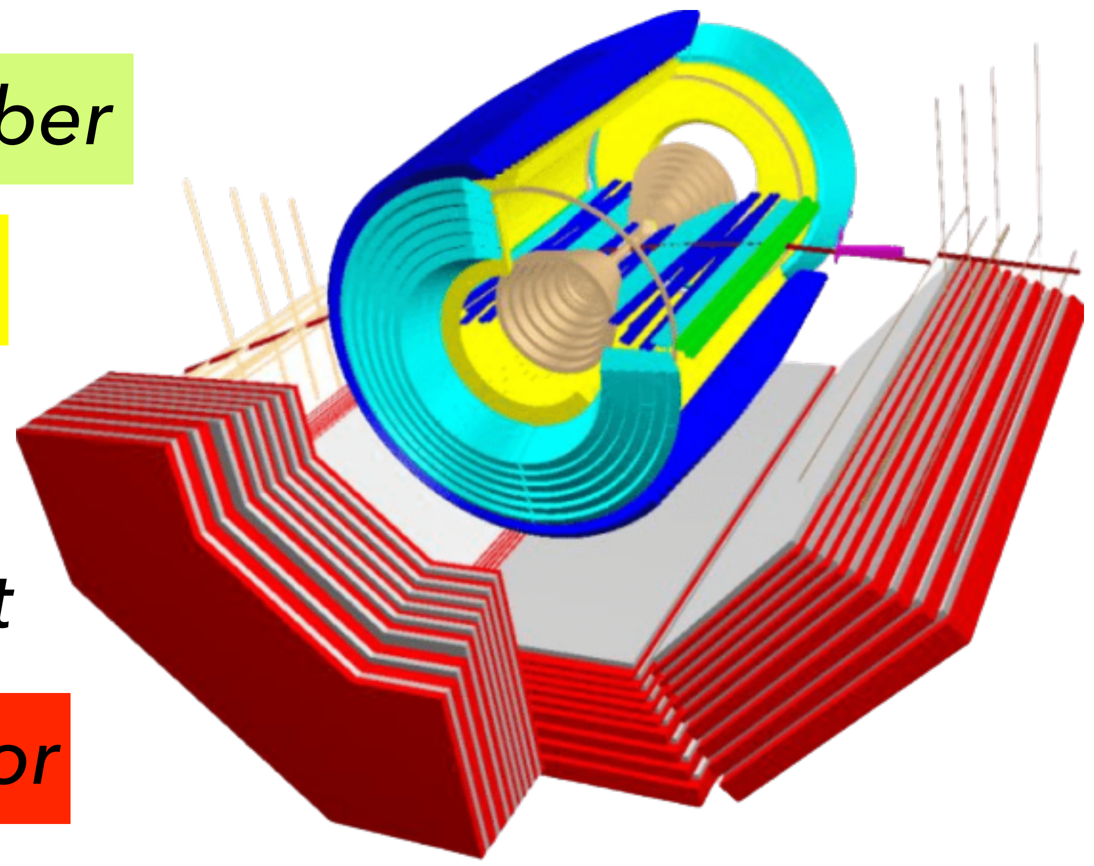


τ-charm factory 2.0 GeV ≤ $\sqrt{s}$ ≤ 4.9 GeV

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

@ $\sqrt{s}$ = 3.77 GeV

Data sets

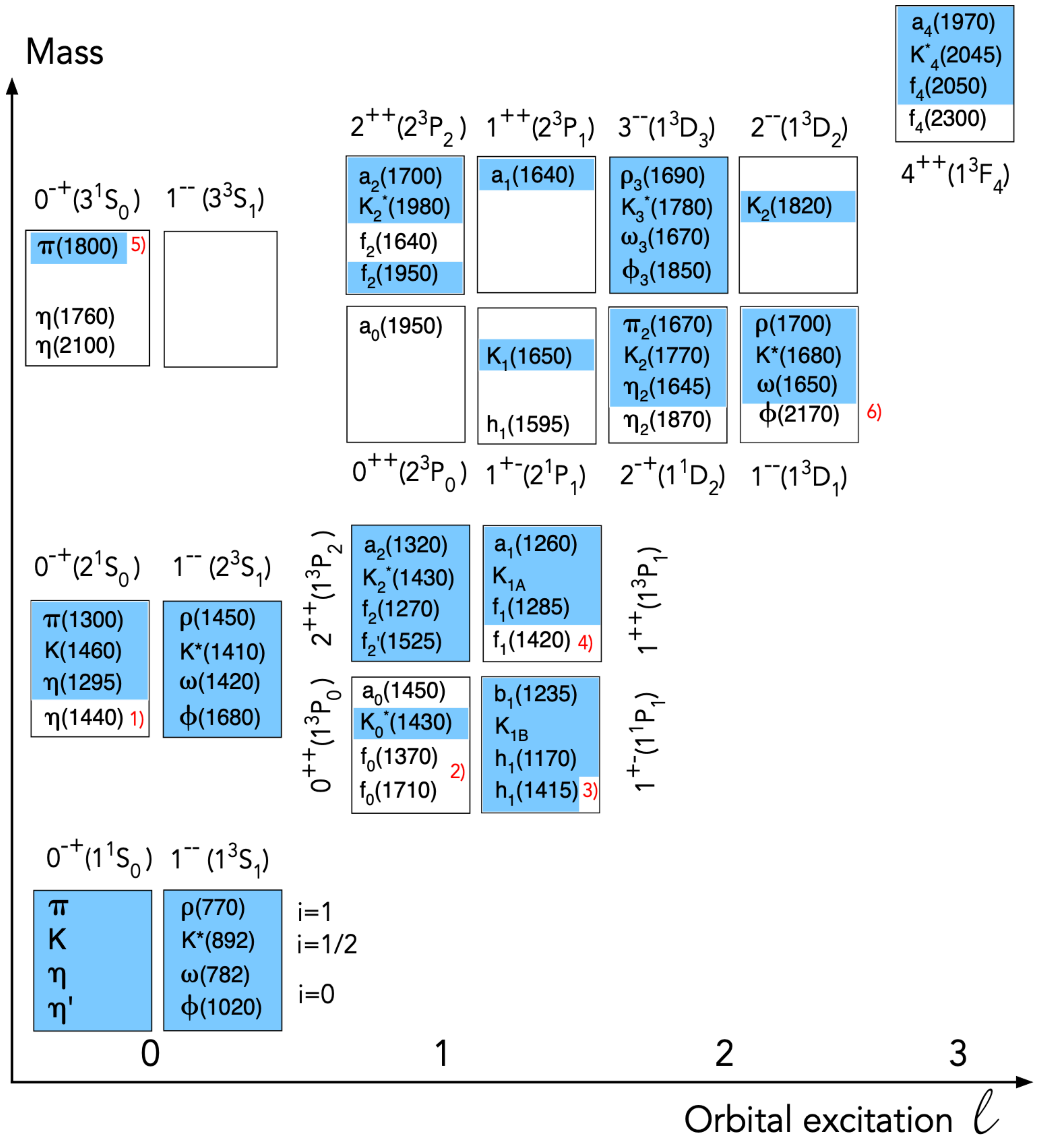
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10×50 pb^{-1} scan 3.81 — 4.42 GeV
2014: 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) $\psi(2S)$

Spectroscopy of Light Meson Resonances

The mesons made of the *u*, *d*, and *s* light quarks are organised nonets with isospin *i*

The established mesons are shown in blue

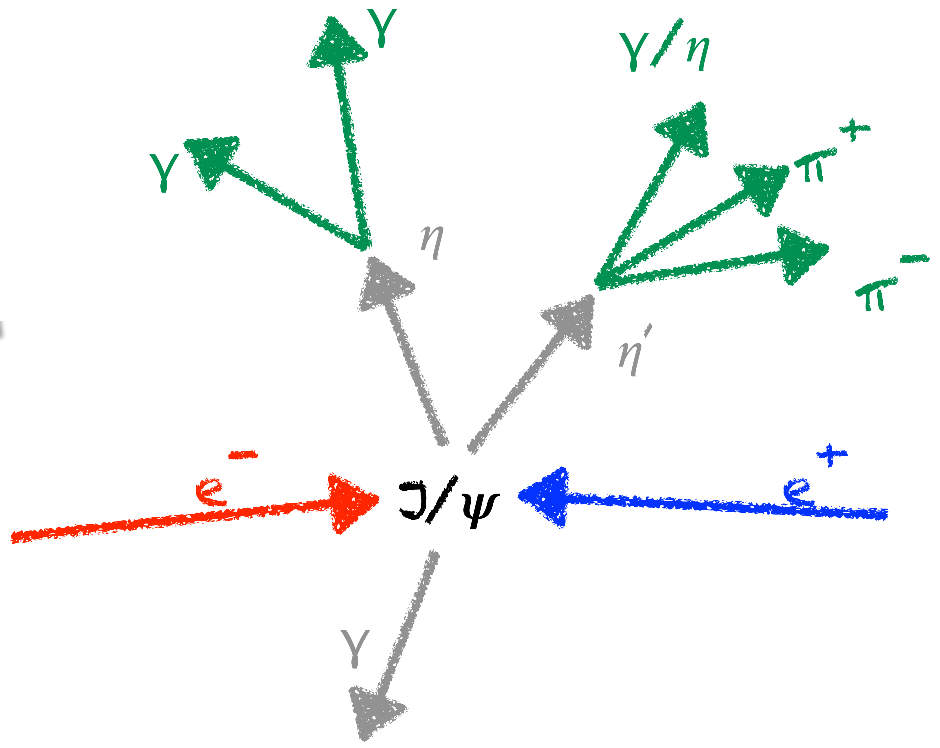
R.L. Workman *et al.* (Particle Data Group)



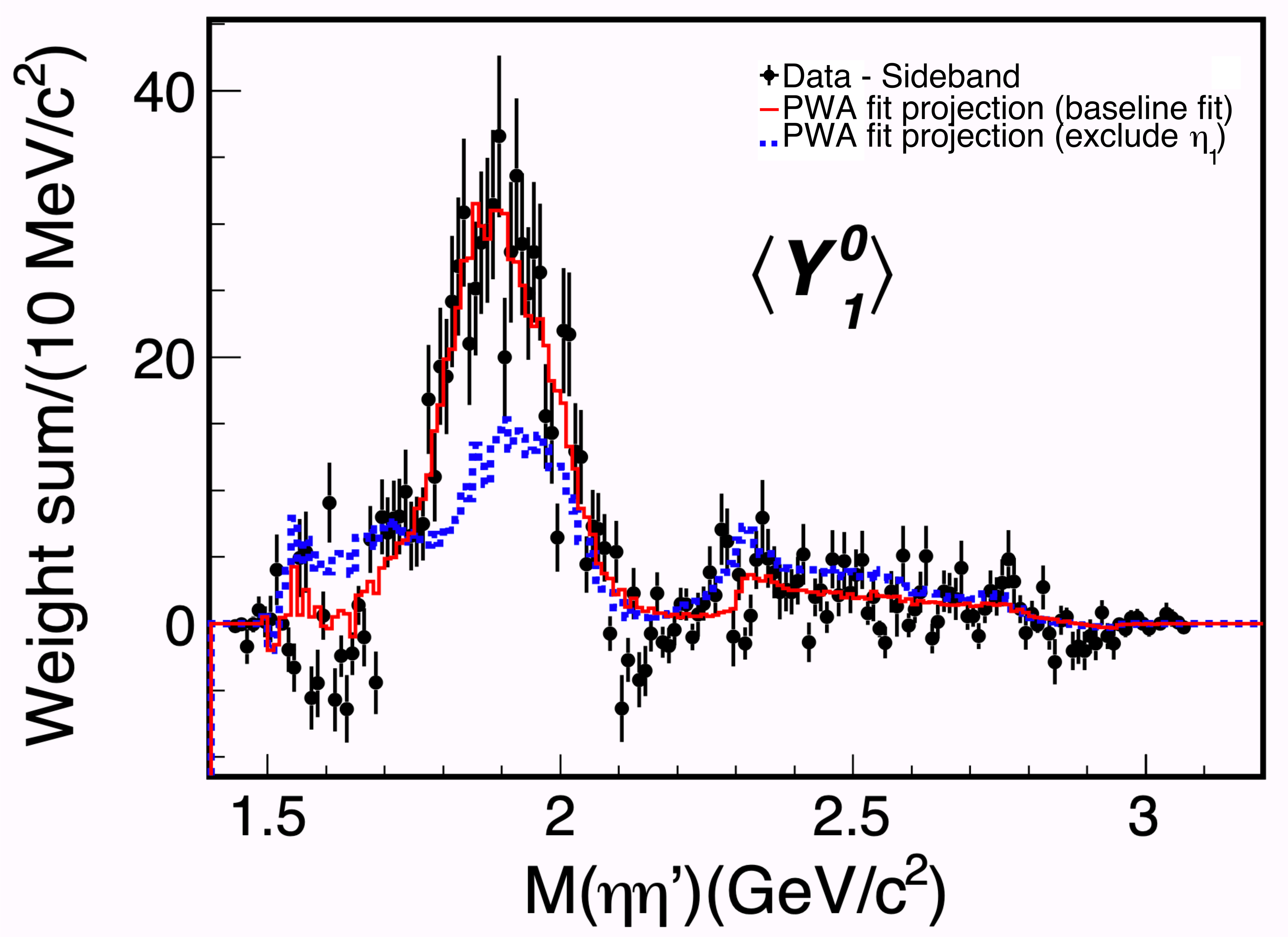
Partial Wave Analyses on J/ψ Decays

$J/\psi \rightarrow \gamma\eta\eta'$

arXiv:2202.00623v2
Submitted to PRL



An ***exotic*** **isoscalar** state $J^{PC} = 1^{-+}$, whose parameters are **consistent** with **LQCD calculations** for the 1^{-+} hybrid[12]



In order to appreciate the agreement between the PWA results and data, one can plot $M(\eta\eta')$ weighted by the Legendre polynomial moments

Within a given $M(\eta\eta')$ region, the unnormalised Legendre moments are expressed as follows…

$$\langle Y_l^0 \rangle \equiv \sum_{i=1}^{N_k} W_i Y_l^0(\cos\theta_\eta^i)$$

where θ_η is the angle of the η momentum in the ηη' helicity coordinate system

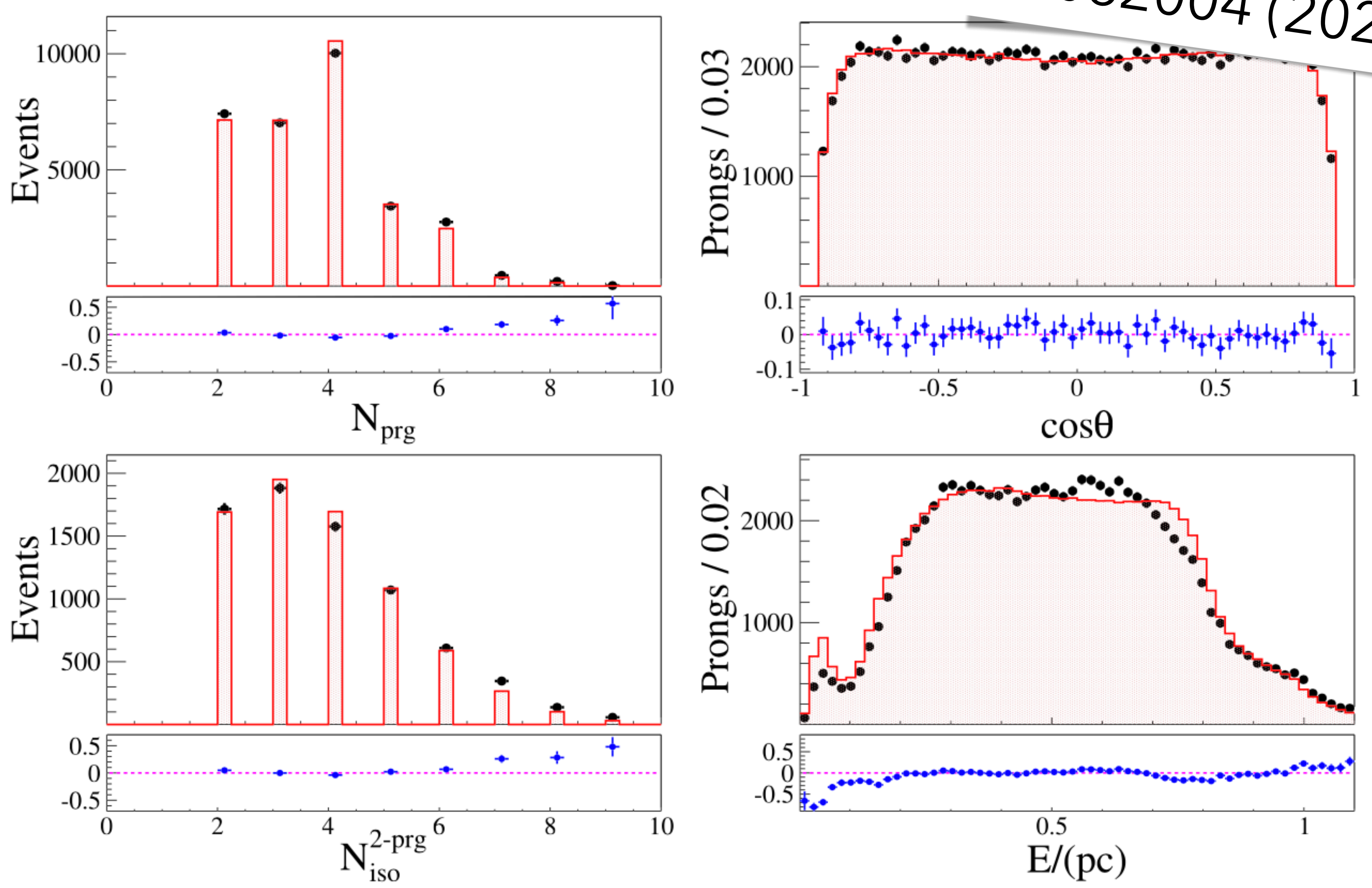
[12] Phys. Rev. D **88**, 094505 (2013)

R-Value Estimation - ISR Correction Factor

PRL **128**, 062004 (2022)

Using 14 energy points @√s = [2.2324, 3.6710] GeV

The hadronisation procedure is studied employing LUARLAW, which is used to calculate ISR correction factors with the Feynman Diagram scheme



LUARLAW vs Data

LUARLAW takes care of both the continuum and the resonances

Flavour and kinematic quantities of hadrons are tuned according to experimental data

Systematic uncertainties contributions

$\sqrt{s}$ (GeV)	Event selection	QED background	Beam background	Luminosity	Trigger efficiency	Signal model	ISR correction	Total
2.2324	0.41	0.23	0.28	0.80	0.10	0.60	1.15	1.62
2.4000	0.55	0.27	0.15	0.80	0.10	1.11	1.10	1.87
2.8000	0.58	0.28	0.34	0.80	0.10	1.97	1.06	2.48
3.0500	0.61	0.33	0.41	0.80	0.10	1.76	1.01	2.33
3.0600	0.60	0.34	0.48	0.80	0.10	1.84	1.00	2.39
3.0800	0.61	0.35	0.35	0.80	0.10	1.31	1.05	2.02
3.4000	0.65	0.33	0.16	0.80	0.10	1.86	1.24	2.49
3.5000	0.60	0.35	0.62	0.80	0.10	2.05	1.16	2.66
3.5424	0.61	0.37	0.01	0.80	0.10	2.05	1.14	2.58
3.5538	0.66	0.31	0.39	0.80	0.10	2.22	1.13	2.74
3.5611	0.74	0.34	0.34	0.80	0.10	2.28	1.12	2.81
3.6002	0.66	0.33	0.38	0.80	0.10	2.27	1.09	2.77
3.6500	0.53	0.35	0.69	0.80	0.10	2.28	1.13	2.83
3.6710	0.61	0.42	0.63	0.80	0.10	2.23	1.04	2.77

R-Value Estimation - ISR Correction Factor

PRL **128**, 062004 (2022)

Using 14 energy points @$\sqrt{s}$ = [2.2324, 3.6710] GeV

The hadronisation procedure is studied employing LUARLAW, which is used to calculate ISR correction factors with the Feynman Diagram scheme

A HYBRID model is developed to estimate ISR uncertainties and consists of:

I. CONEXC: simulates 47 exclusive hadronic process with measured cross section line-shapes;

II. PHOKHARA: takes care of 10 well known $e^+e^- \rightarrow$ multi-π events;

III. LUARLW: generates all of the remaining unknown processes.

pureLUARLW - HYBRID discrepancy < 2.3 % and regarded as systematic uncertainty

Systematic uncertainties contributions

$\sqrt{s}$ (GeV)	Event selection	QED background	Beam background	Luminosity	Trigger efficiency	Signal model	ISR correction	Total
2.2324	0.41	0.23	0.28	0.80	0.10	0.60	1.15	1.62
2.4000	0.55	0.27	0.15	0.80	0.10	1.11	1.10	1.87
2.8000	0.58	0.28	0.34	0.80	0.10	1.97	1.06	2.48
3.0500	0.61	0.33	0.41	0.80	0.10	1.76	1.01	2.33
3.0600	0.60	0.34	0.48	0.80	0.10	1.84	1.00	2.39
3.0800	0.61	0.35	0.35	0.80	0.10	1.31	1.05	2.02
3.4000	0.65	0.33	0.16	0.80	0.10	1.86	1.24	2.49
3.5000	0.60	0.35	0.62	0.80	0.10	2.05	1.16	2.66
3.5424	0.61	0.37	0.01	0.80	0.10	2.05	1.14	2.58
3.5538	0.66	0.31	0.39	0.80	0.10	2.22	1.13	2.74
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3.6500	0.53	0.35	0.69	0.80	0.10	2.28	1.13	2.83
3.6710	0.61	0.42	0.63	0.80	0.10	2.23	1.04	2.77

About the X(1835), the X(2100), and the X(2370)

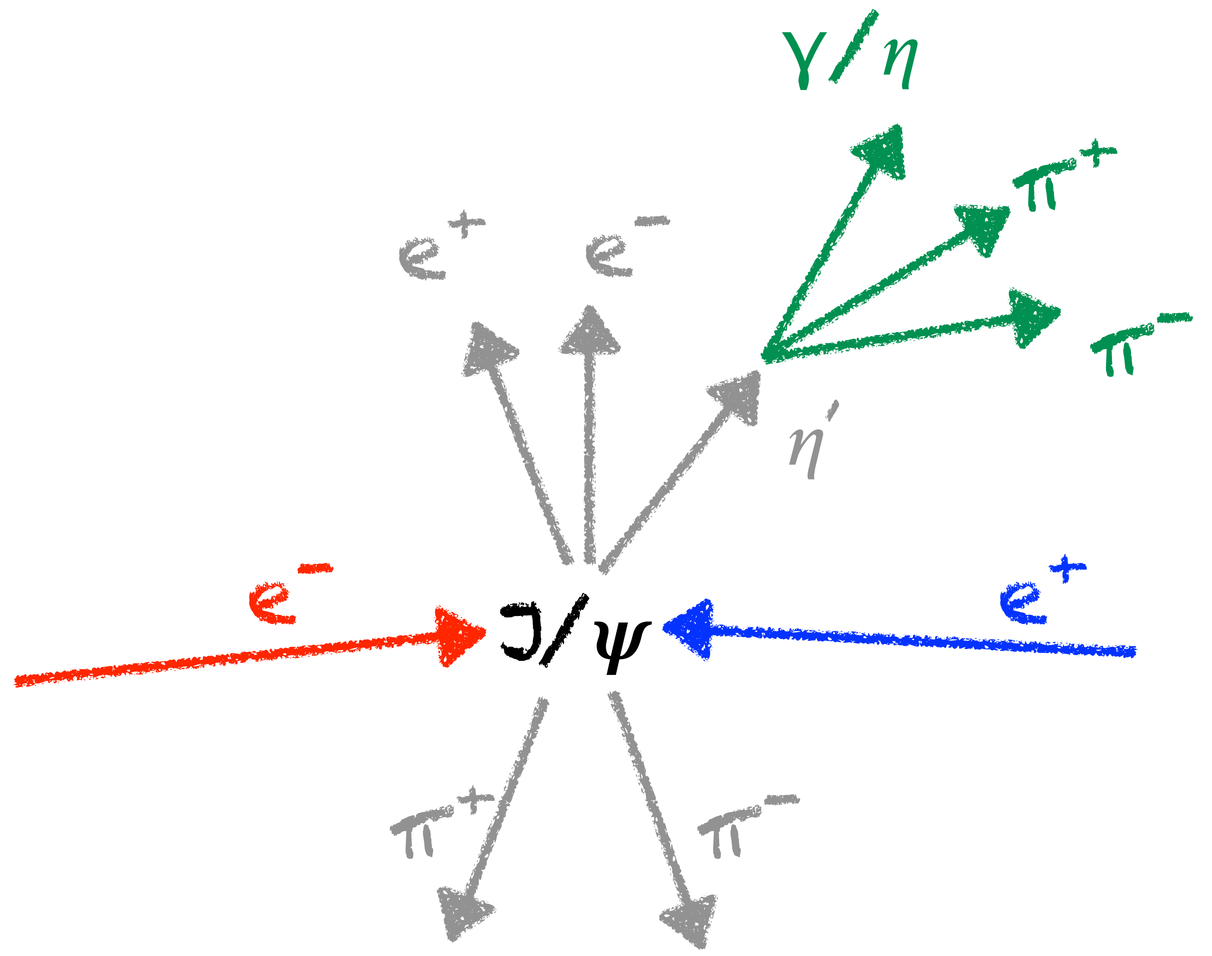
arXiv:2112.14369
Accepted by PRL

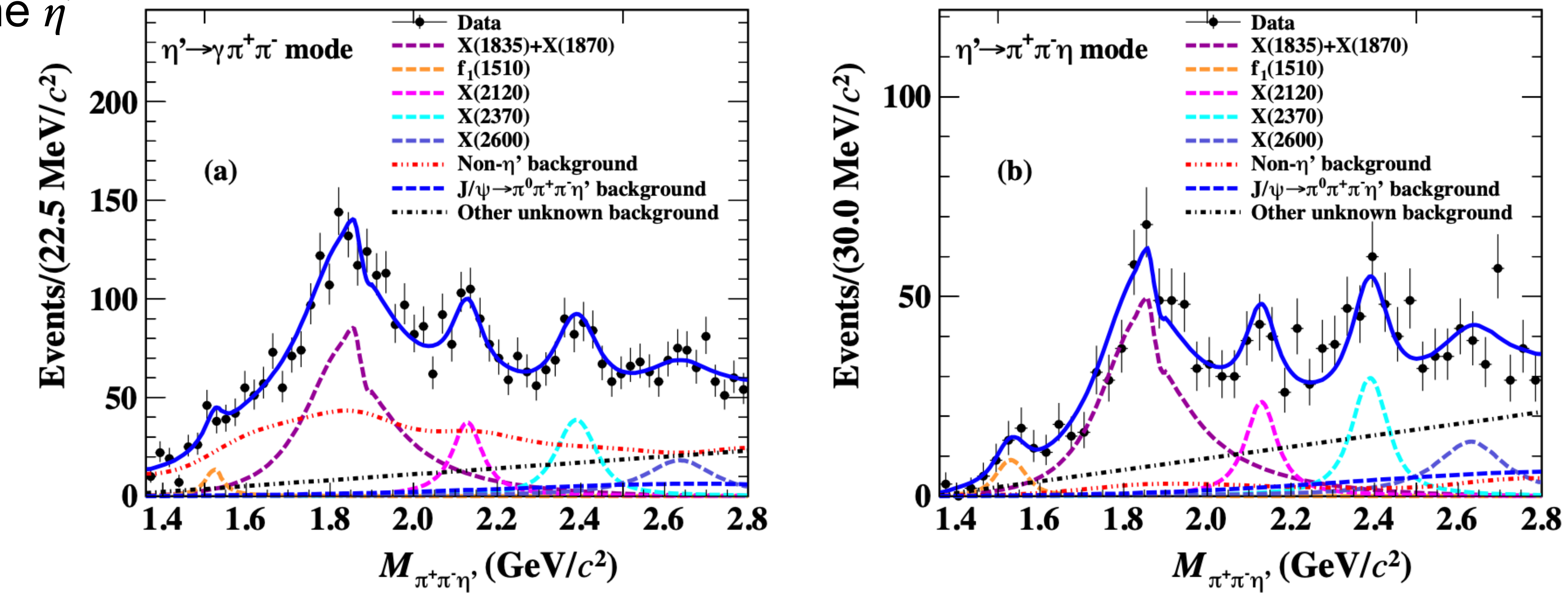
Using the 10 billion J/ψ data set

Study of the EM Dalitz J/ψ → $e^+e^-\pi^+\pi^-\eta'$ decay, reconstructing the η' from its $\gamma\pi^+\pi^-$ & $\eta(\rightarrow\gamma\gamma)\pi^+\pi^-$ main decays

Observation of the X(1835), X(2100), and X(2370) states and measurement of $\mathcal{BR}$(J/ψ → e^+e^-X)

Estimation of the Transition Form Factors for J/ψ → e^+e^-X(1835)





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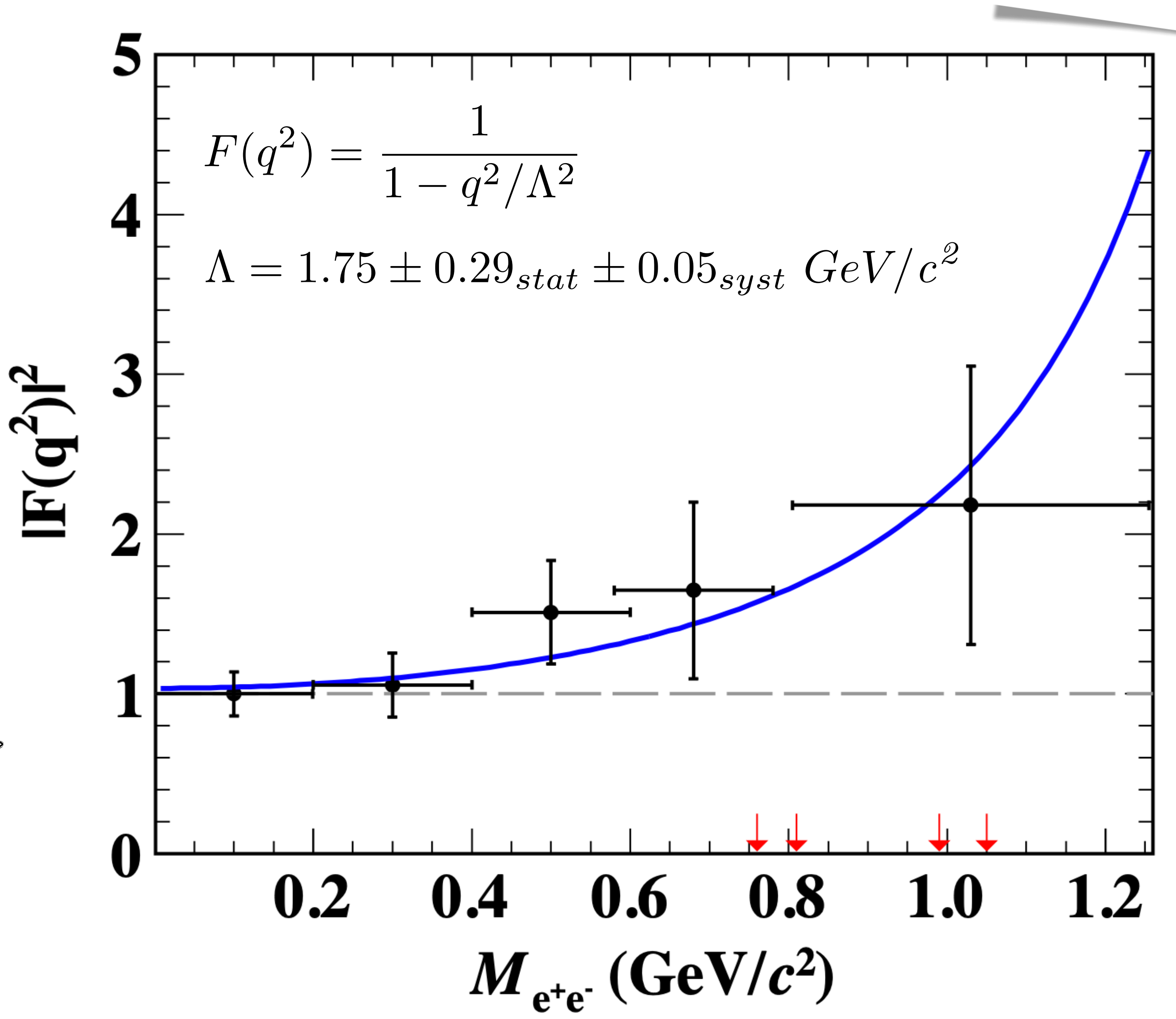


Branching fractions of $J/\psi \to e^+e^-X,\ X \to \pi^+\pi^-\eta'$		
$X = X(1835)$	(solution I)	$(3.58 \pm 0.19 \pm 0.16) \times 10^{-6}$
@15σ	(solution II)	$(4.43 \pm 0.23 \pm 0.19) \times 10^{-6}$
$X = X(2120)$	**@5.3σ**	$(0.82 \pm 0.12 \pm 0.06) \times 10^{-6}$
$X = X(2370)$	**@7.3σ**	$(1.08 \pm 0.14 \pm 0.10) \times 10^{-6}$

Using Ref. [28], one can calculate

$$\frac{\mathcal{B}(J/\psi \to e^+e^-X(1835))}{\mathcal{B}(J/\psi \to \gamma X(1835))} = (1.19 \pm 0.10_{stat} \pm 0.14_{syst}) \times 10^{-2},$$

which is consistent with prediction of Ref. [29] within 2σ

[28] Phys. Rev. Lett. **117**, (2016) 042002
[29] Int. J. Mod. Phys. A **34**, 1950129 (2019)

Probing the Light Quark Spectrum with D_s Semi-leptonic Decays

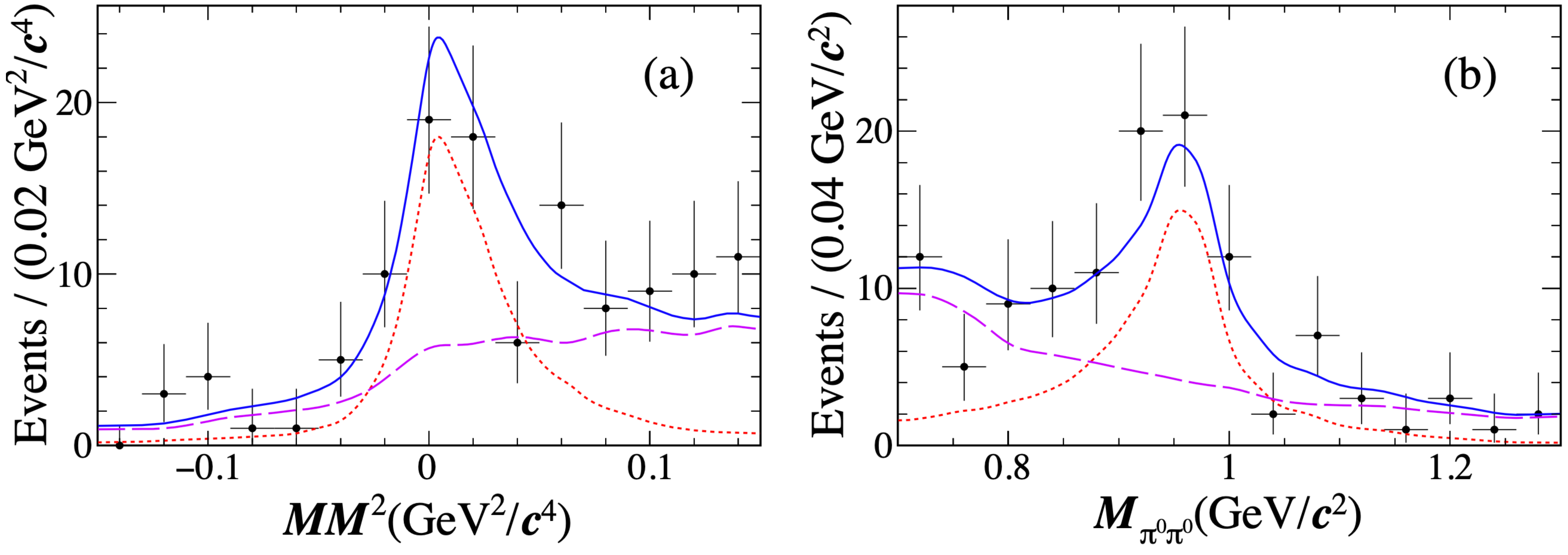
PRD **105**, L031101 (2022)

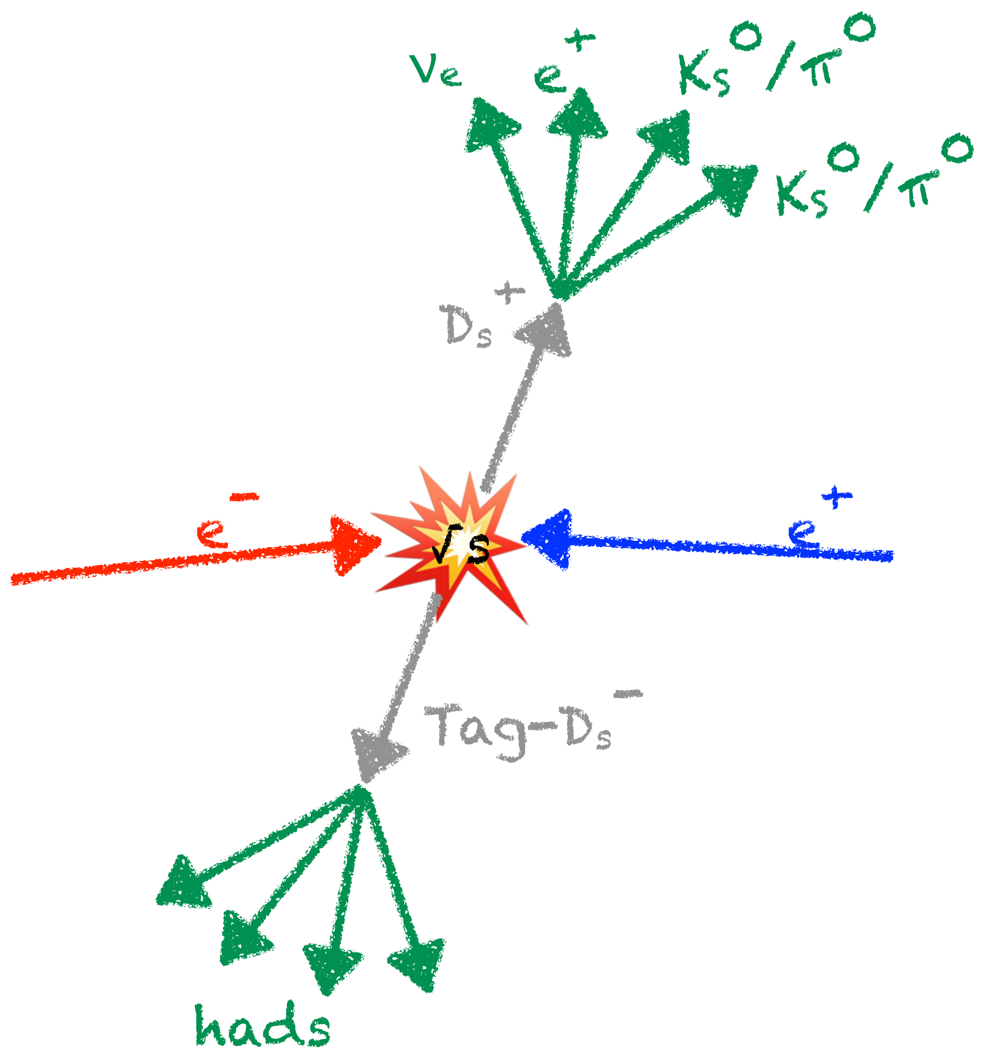
Using 6 data sets for a $\mathcal{L}_{int}$ = 6.32 fb^{-1} @$\sqrt{s}$ = [4.178, 4.226] GeV

Study the $D_s^+ \to (\pi^0\pi^0/K_S^0K_S^0)e^+\nu_e$, via the $e^+e^- \to D_s^{*\pm}D_s^{\mp} \to \gamma D_s^{\pm}D_s^{\mp}$ process

Fit to M($\pi^0\pi^0$) and MM^2 to search for the $f_0(500)$ and $f_0(980) \to \pi^0\pi^0$ decays

$$MM^2 = \frac{1}{c^2}(p_{cm} - p_{tag} - p_e - p_\gamma)$$





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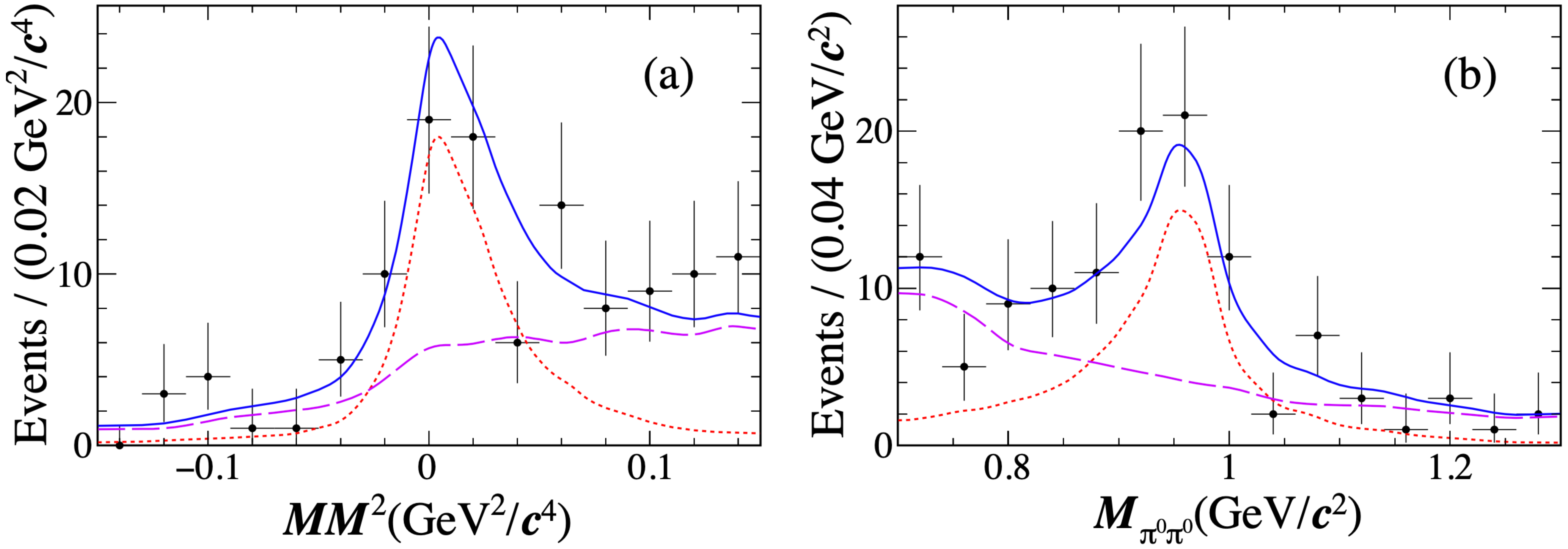

Using the ST sample as normalising factor, it is possible to estimate $\mathcal{BR}_{sig}(D_s^+ \to f_0(980)e^+\nu_e \to \pi^0\pi^0e^+\nu_e)$ process

$$(7.9 \pm 1.4_{stat} \pm 0.4_{syst}) \times 10^{-4}$$

Compatible with

Ref. [30], assuming $f_0(980)$ to be an admixture of $s\bar{s}$ and other light $q\bar{q}$ pairs

Compatible with CLEO[31], according to to isospin symmetry

[30] Phys. Rev. D **102**, 016013 (2020)
[31] Phys. Rev. D **80**, 052009 (2009)

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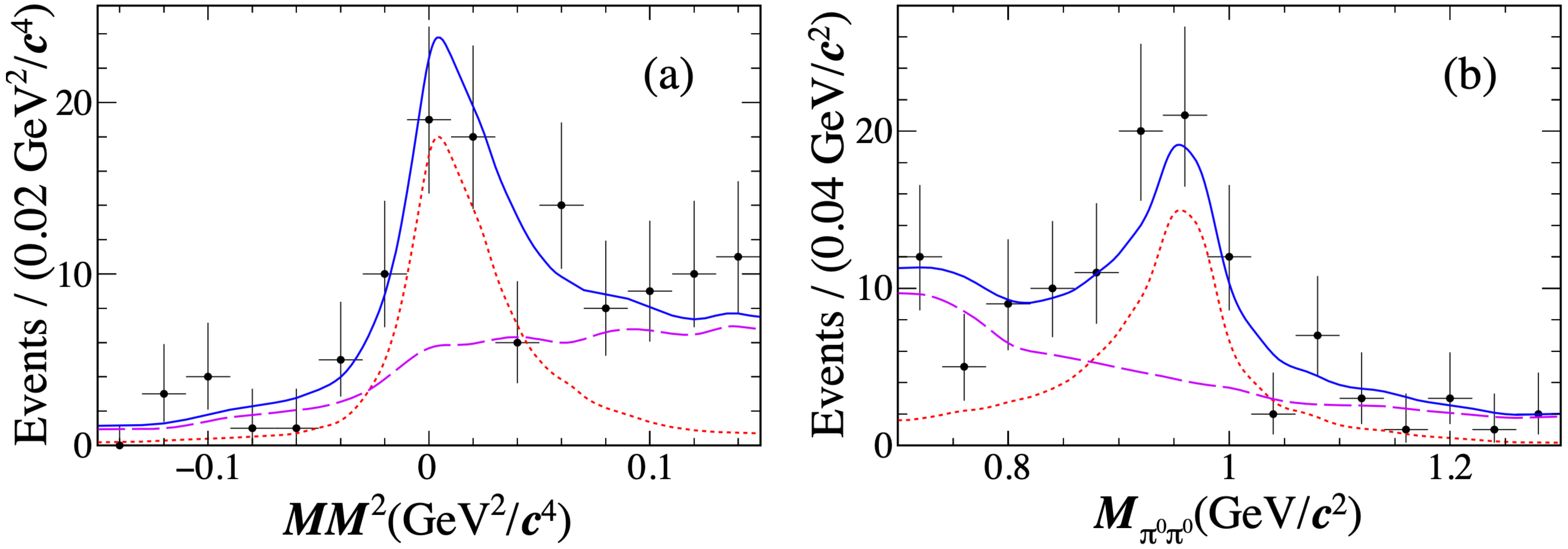

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$$(7.9 \pm 1.4_{stat} \pm 0.4_{syst}) \times 10^{-4}$$

No $D_s^+ \to f_0(500)e^+\nu_e \to \pi^0\pi^0e^+\nu_e$ signal nor $D_s^+ \to K_S^0K_S^0e^+\nu_e$ signal were found

$\mathcal{BR}_{sig}(D_s^+ \to f_0(980)e^+\nu_e \to \pi^0\pi^0e^+\nu_e) < 6.4\times10^{-4}$

Agreeing with Ref. [32], stating $\sigma(s\bar{s} \to f_0(980)) > \sigma(s\bar{s} \to f_0(500))$ and suggesting a four-quark structure for these states

Compatible with

Ref. [30], assuming $f_0(980)$ to be an admixture of $s\bar{s}$ and other light $q\bar{q}$ pairs

Compatible with CLEO[31], according to to isospin symmetry

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[31] Phys. Rev. D **80**, 052009 (2009)

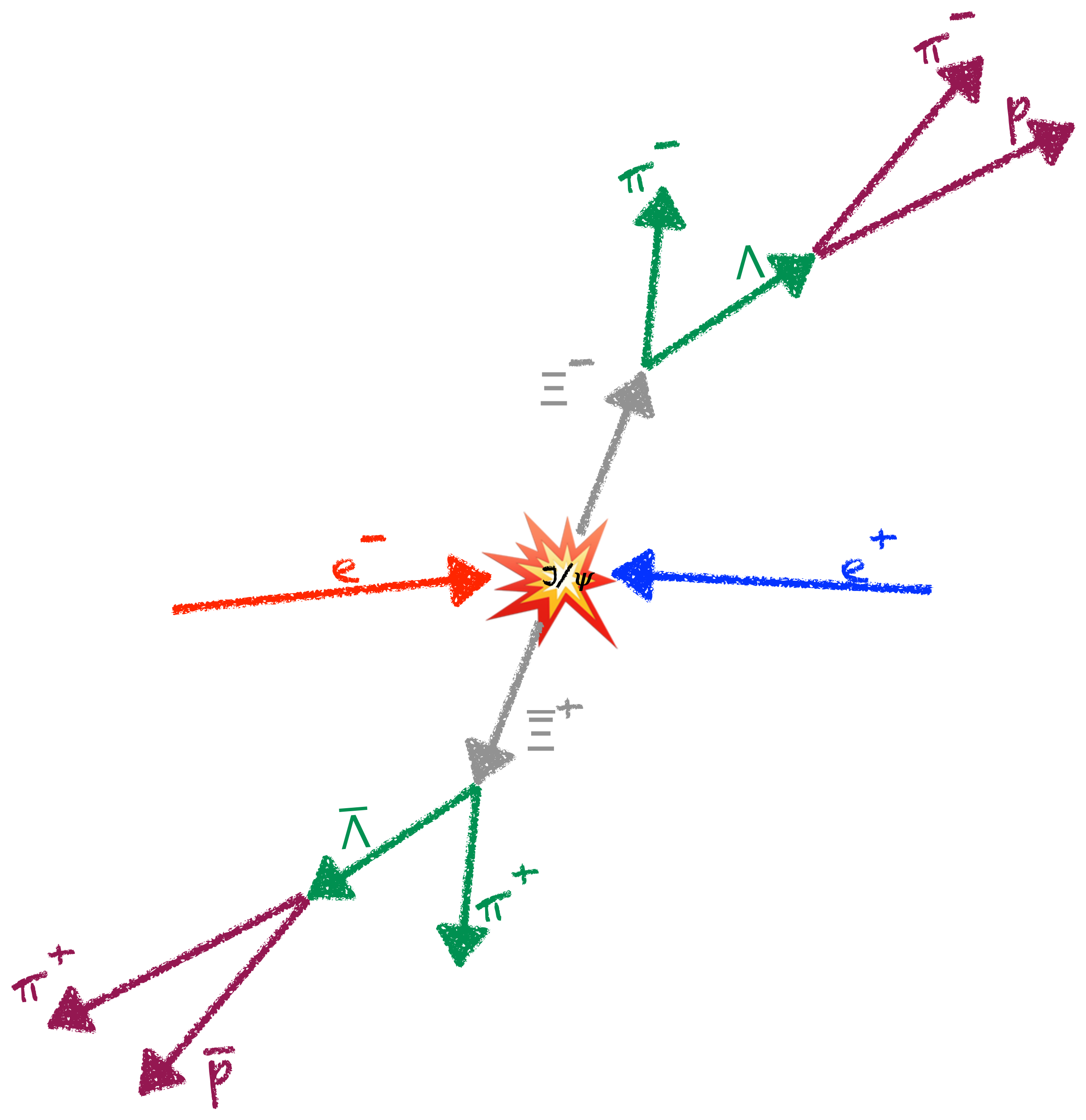
Probing CP Symmetry

Nature **606**, 64–69 (2022)

Using the 1 billion J/ψ data set

Estimate CP symmetry parameters with entangled Ξ hyperons

The entangled state enables a direct measurement of $\bar{\Xi}^+$ and Ξ^- weak decay parameters



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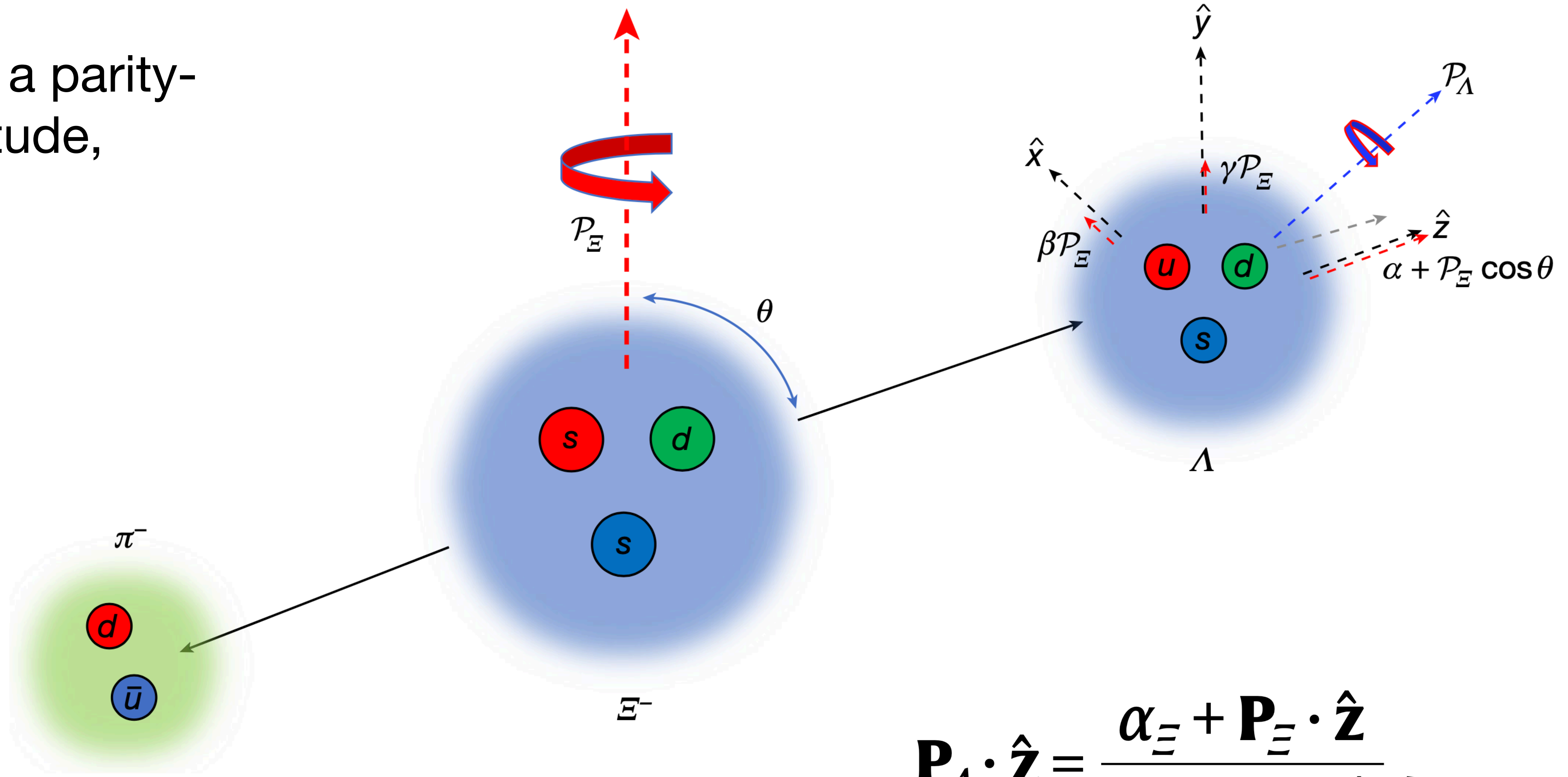
As reported in Ref. [33], Spin-½ baryon decays are described by a parity-conserving (P-wave [*B*]) and a parity-violating (S-wave [*A*]) amplitude, parametrised by[34]…

$$\alpha = 2\,\mathrm{Re}(A^*B)/(|A|^2+|B|^2)$$
$$\beta = -\mathrm{Im}(A^*B)/(|A|^2+|B|^2)$$
$$\gamma = (|A|^2-|B|^2)/(|A|^2+|B|^2)$$

$$\beta_Y = \sqrt{1-\alpha_Y^2}\,\sin\phi_Y, \quad \gamma_Y = \sqrt{1-\alpha_Y^2}\,\cos\phi_Y$$



$$\mathbf{P}_\Lambda \cdot \hat{\mathbf{z}} = \frac{\alpha_\Xi + \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}}{1 + \alpha_\Xi \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}},$$

$$\mathbf{P}_\Lambda \times \hat{\mathbf{z}} = \mathcal{P}_\Xi \sqrt{1-\alpha_\Xi^2}\,\frac{\sin\phi_\Xi \hat{\mathbf{x}} + \cos\phi_\Xi \hat{\mathbf{y}}}{1 + \alpha_\Xi \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}}$$

[33] *Phys. Rev. D* **46**, 1035–1041 (1992). erratum 46, 5209-5210 (1992)
[34] *Phys. Rev.* **108**, 1645–1647 (1957)

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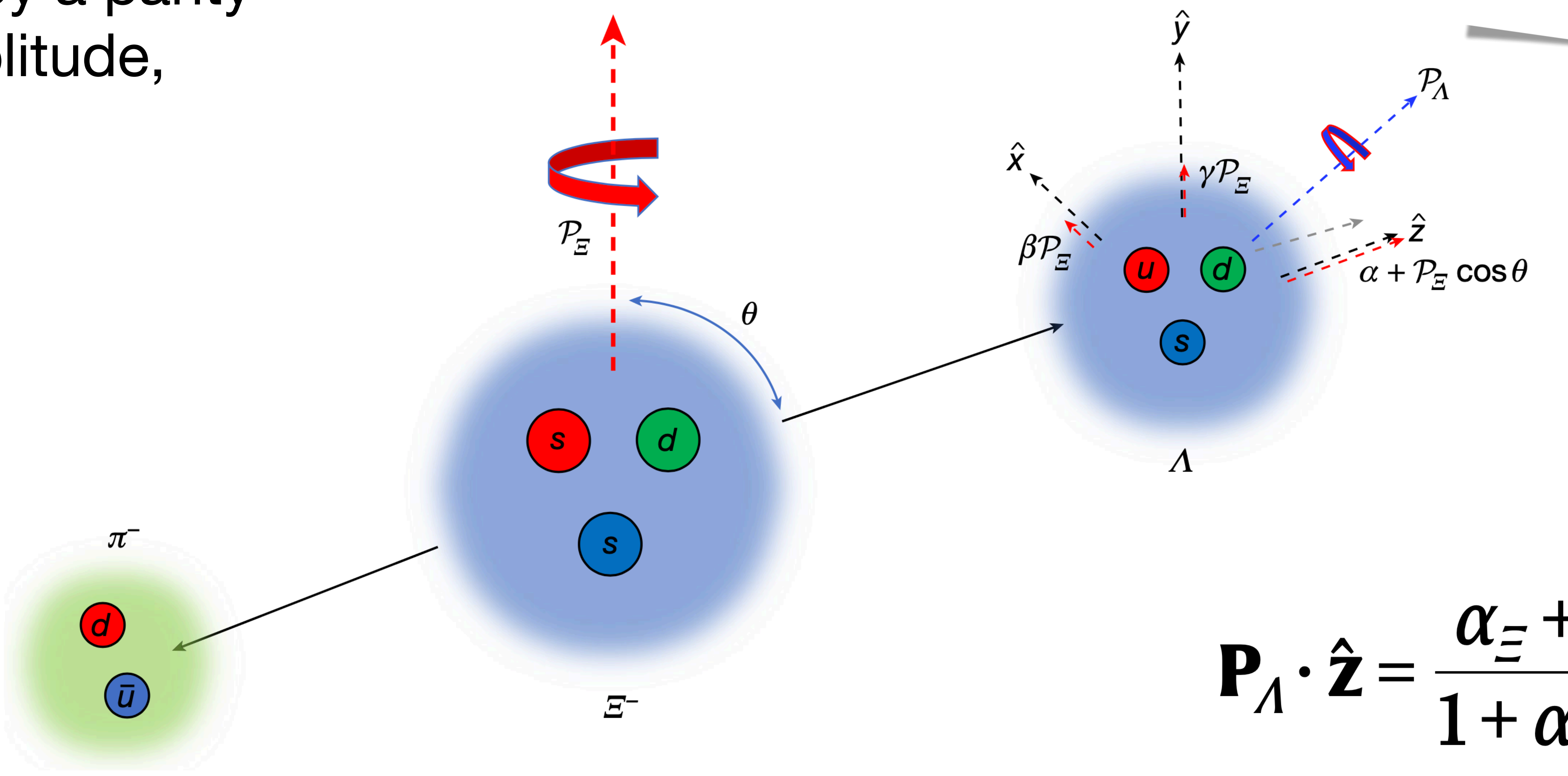

$$\mathbf{P}_\Lambda \cdot \hat{\mathbf{z}} = \frac{\alpha_\Xi + \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}}{1+\alpha_\Xi \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}},$$

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CP violation can be quantified in terms of the observables

$$A_{\mathrm{CP}}^{Y} = \frac{\alpha_Y + \bar{\alpha}_Y}{\alpha_Y - \bar{\alpha}_Y}, \quad \Delta\phi_{\mathrm{CP}} = \frac{\phi_Y + \bar{\phi}_Y}{2}$$

$$A_{\mathrm{CP}}^{\Xi} \approx -\tan(\delta_{\mathrm{P}} - \delta_{\mathrm{S}})\tan(\xi_{\mathrm{P}} - \xi_{\mathrm{S}})$$

Strong-phase difference

Weak-phase difference

If too small (which is the case of the *Ξ* hyperons) CP-violating signals are strongly suppressed

[33] *Phys. Rev. D* **46**, 1035–1041 (1992). erratum 46, 5209-5210 (1992)
[34] *Phys. Rev.* **108**, 1645–1647 (1957)

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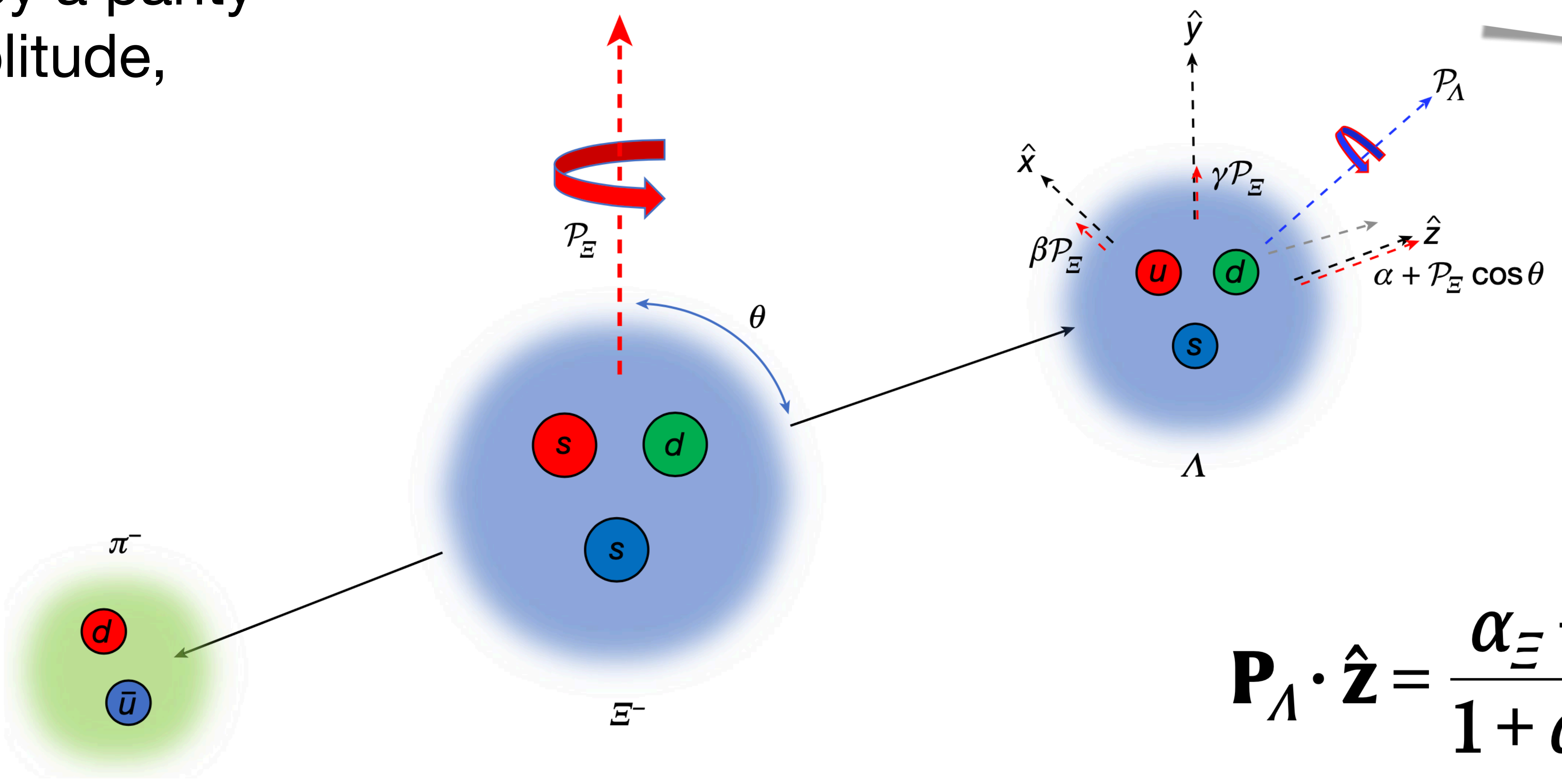

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$$A_{\mathrm{CP}}^\Xi \approx -\tan(\delta_P-\delta_S)\tan(\xi_P-\xi_S)$$

Strong-phase difference

Weak-phase difference

If too small (which is the case of the *Ξ* hyperons)
CP-violating signals are strongly suppressed

$$(\xi_P-\xi_S)_{\mathrm{LO}} = \frac{\beta+\bar{\beta}}{\alpha-\bar{\alpha}} \approx \frac{\sqrt{1-\langle\alpha\rangle^2}}{\langle\alpha\rangle}\Delta\phi_{\mathrm{CP}}$$

[33] *Phys. Rev. D* **46**, 1035–1041 (1992). erratum 46, 5209-5210 (1992)
[34] *Phys. Rev.* **108**, 1645–1647 (1957)

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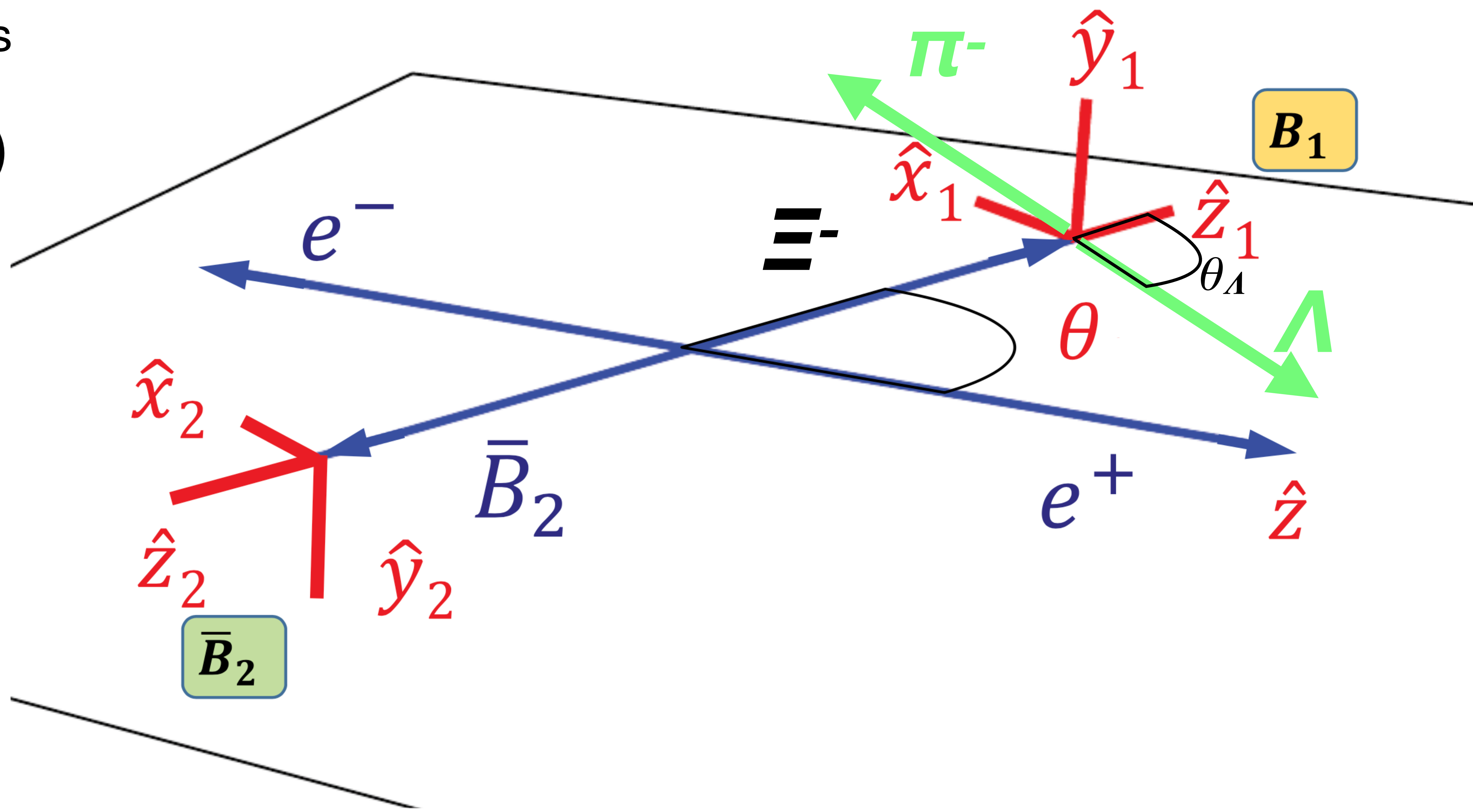
The multi-step 2-body decays can be described by nine helicity angles

$$\boldsymbol{\xi} = (\theta, \theta_{\Lambda}, \varphi_{\Lambda}, \theta_{\bar{\Lambda}}, \varphi_{\bar{\Lambda}}, \theta_{p}, \varphi_{p}, \theta_{\bar{p}}, \varphi_{\bar{p}})$$



[35] Phys. Rev. D **99**, 056008 (2019)

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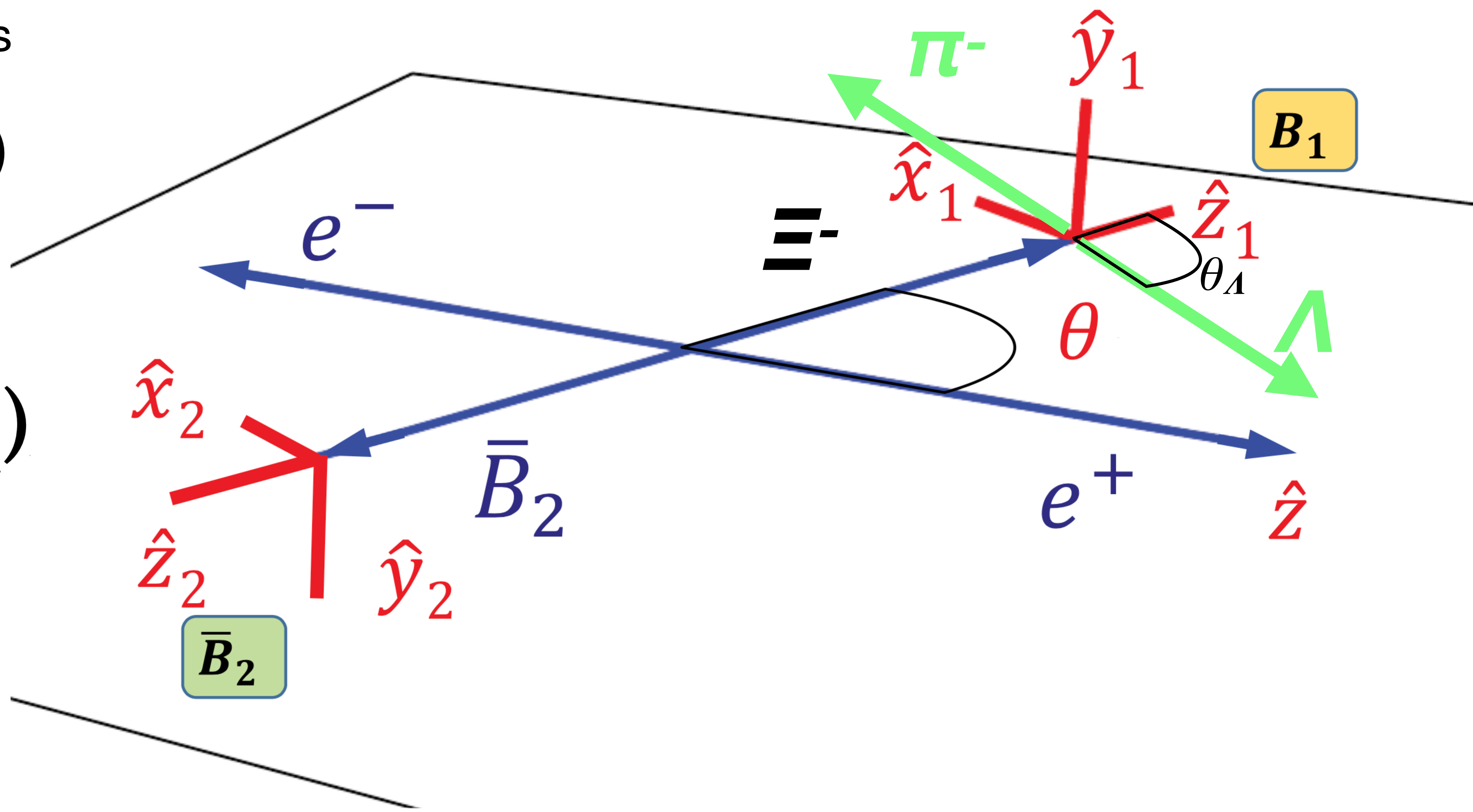
Which can be determined by

$$\boldsymbol{\omega} = (\underbrace{\alpha_{\psi}, \Delta\Phi}, \alpha_{\Xi}, \phi_{\Xi}, \bar{\alpha}_{\Xi}, \bar{\phi}_{\Xi}, \alpha_{\Lambda}, \bar{\alpha}_{\Lambda})$$

Defined in Ref. [35] and related to the two production amplitudes and the angular distribution



[35] Phys. Rev. D **99**, 056008 (2019)

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Most precise tests of the CP symmetry for hyperons…
SM prediction[36] is $(1.8 \pm 1.5) \times 10^{-4}$

To be compared with SM prediction[36]
$(-0.6 \pm 1.6) \times 10^{-5}$

Differs from the HyperCP measurement[37] by 2.6σ

Fit Results

Obtained from Calculations

Parameter	This work	Previous result	Reference
α_ψ	$0.586\pm0.012\pm0.010$	$0.58\pm0.04\pm0.08$	Ref. [38]
$\Delta\Phi$	$1.213\pm0.046\pm0.016$ rad	–	
α_Ξ	$-0.376\pm0.007\pm0.003$	-0.401 ± 0.010	Ref. PDG
ϕ_Ξ	$0.011\pm0.019\pm0.009$ rad	-0.037 ± 0.014 rad	Ref. PDG
$\bar{\alpha}_\Xi$	$0.371\pm0.007\pm0.002$	–	
$\bar{\phi}_\Xi$	$-0.021\pm0.019\pm0.007$ rad	–	
α_Λ	$0.757\pm0.011\pm0.008$	$0.750\pm0.009\pm0.004$	Ref. [39]
$\bar{\alpha}_\Lambda$	$-0.763\pm0.011\pm0.007$	$-0.758\pm0.010\pm0.007$	Ref. [39]
$\xi_P-\xi_S$	$(1.2\pm3.4\pm0.8)\times10^{-2}$ rad	–	
$\delta_P-\delta_S$	$(-4.0\pm3.3\pm1.7)\times10^{-2}$ rad	$(10.2\pm3.9)\times10^{-2}$ rad	Ref. [37]
A^Ξ_{CP}	$(6\pm13\pm6)\times10^{-3}$	**1st Measurement of its kind**	
$\Delta\phi^\Xi_{CP}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–	
A^Λ_{CP}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$	Ref. [39]
$\langle\phi_\Xi\rangle$	$0.016\pm0.014\pm0.007$ rad		

[36] Phys. Rev. D **67**, 056001 (2003)
[37] Phys. Rev. Lett. **93**, 011802 (2004)
[38] *Phys. Rev. D* **93**, 072003 (2016)
[39] *Nat. Phys.* **15**, 631–634 (2019)