强子物理/奇特强子态

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中国科学院高能物理研究所

"强子物理前沿研讨会"
Nov. 5-9, 2018


惟楚有材 于斯为盛

内　容

- 研究动机
- BEPCII升级的物理
- 寻找XYZ粒子间的关系
- 粲介子产生截面的耦合道分析
- Argand 图
- 其他

- **研究动机**

高能所国际评估

New forms of hadrons = exotic states

- Conventional hadrons consist of 2 or 3 quarks：

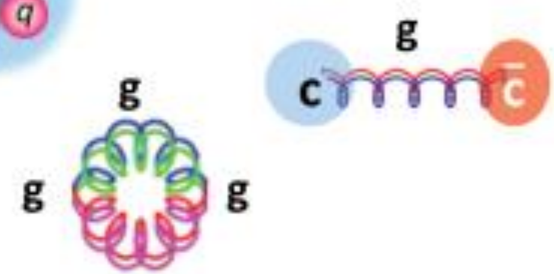
Naive Quark Model：

meson

baryon

- QCD predicts new forms of hadrons:
  - Multi-quark states： Number of quarks >= 4

  - Hybrids： $q\bar{q}g$， $qqqg$ ...
  - Glueballs： gg， ggg ...



Goal of BESIII: establishing these new forms of hadrons

BESIII 973项目

关键科学问题

物质的基本结构和物质间的相互作用

- 研究强子的结构，回答自然界中是否存在超出夸克模型的新型强子这一基本问题。

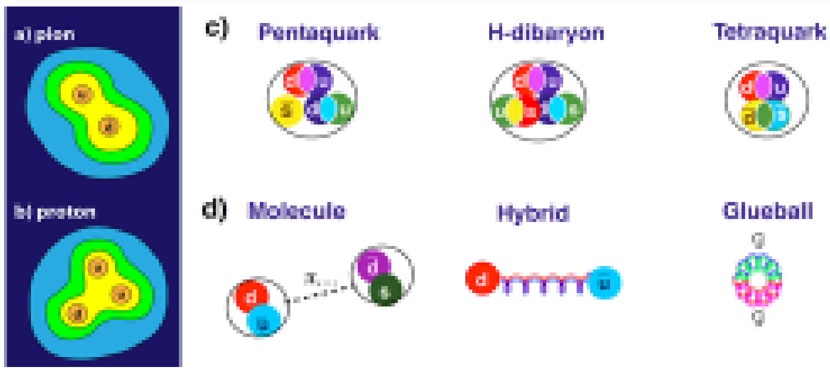
- 精确检验弱电统一理论，精确检验量子色动力学理论，寻找超出标准模型的新物理。

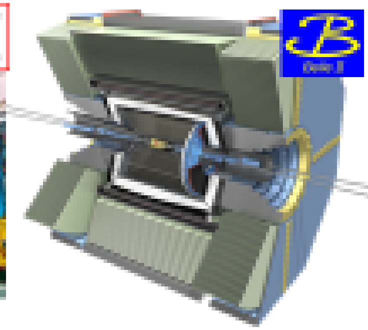
2

物质科学实验室申请报告

全链条研究举例：理解夸克禁闭机制

物质由夸克通过强相互作用组成，夸克怎样组成物质，组成什么物质，是粒子物理的根本问题之一。强子由2个夸克（介子）或3个夸克（重子）组成，理论预期存在胶子球、混杂态、分子态、多夸克态等奇特强子态。





BESIII和Belle II实验为寻找奇特强子创造了条件：

- ✓ BESIII ：能量=2.0-4.9 GeV，L=1x10^{33}/cm^{2}s，2009-202x
- ✓ Belle II：能量= 9.5-11 GeV，L=8x10^{35}/cm^{2}s，2018-203x

重点研究内容：

- ➢ 测量常规强子性质，寻找奇特强子态，深入研究其能谱、产生和衰变性质
- ➢ 与理论研究相结合，理解强相互作用的夸克禁闭机制

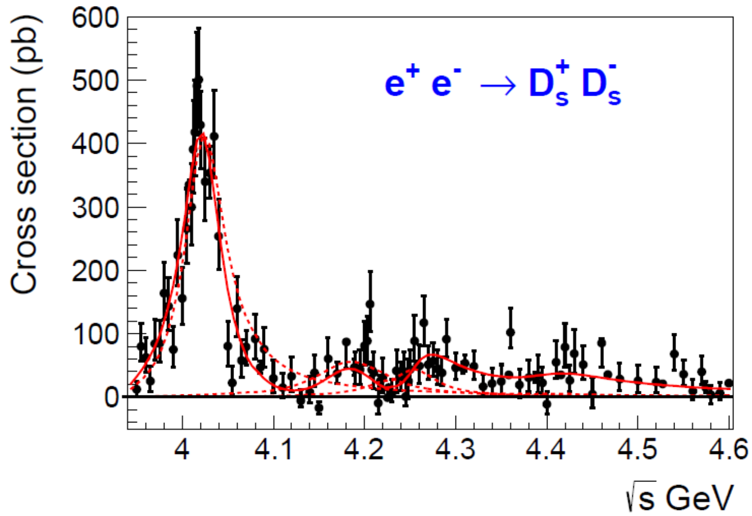
- BEPCII升级的物理
  - 能量升级（4.6-4.9 GeV）—— 已批准
  - 亮度升级（x？）—— 依赖于物理的重要性

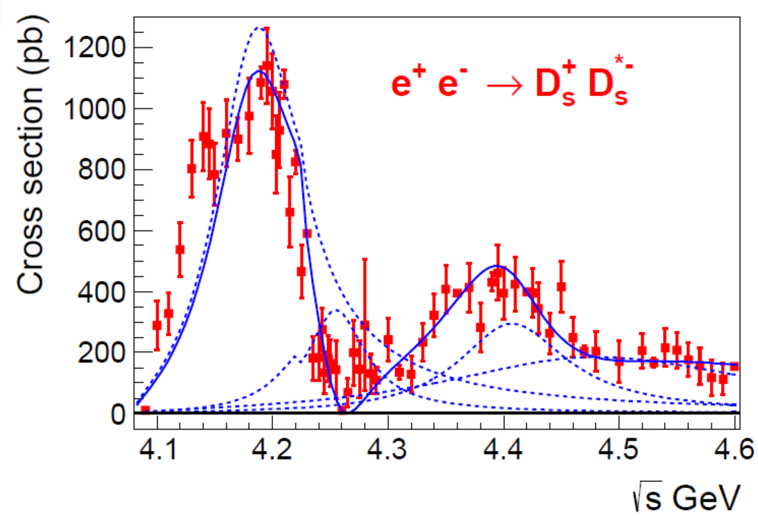
BEPCII Upgrade（能量）

- Increase of beam energy
  - E_{beam}=2.30→2.35→2.45 GeV
  - Plan:
    - get to 2.35 GeV in 2019
    - Get to 2.45 GeV in 2020-21, change ISPB (Interaction region SePtum Bending) magnet, big challenge
  - Funding approved
- Top-up injection
  - Data taking efficiency increases by 20~30%
  - Funding approved

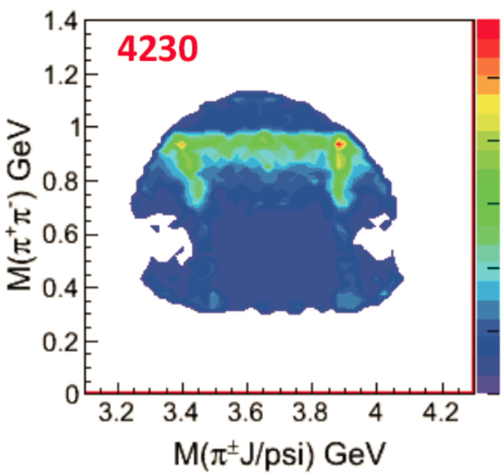
XYZ研究中的关键问题？

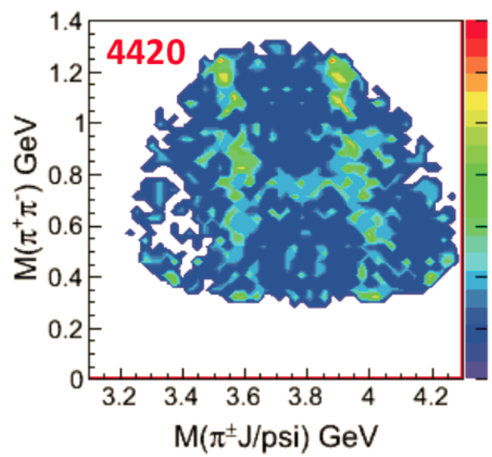
- Y粒子和矢量粲偶素的性质，矢量奇特态的寻找





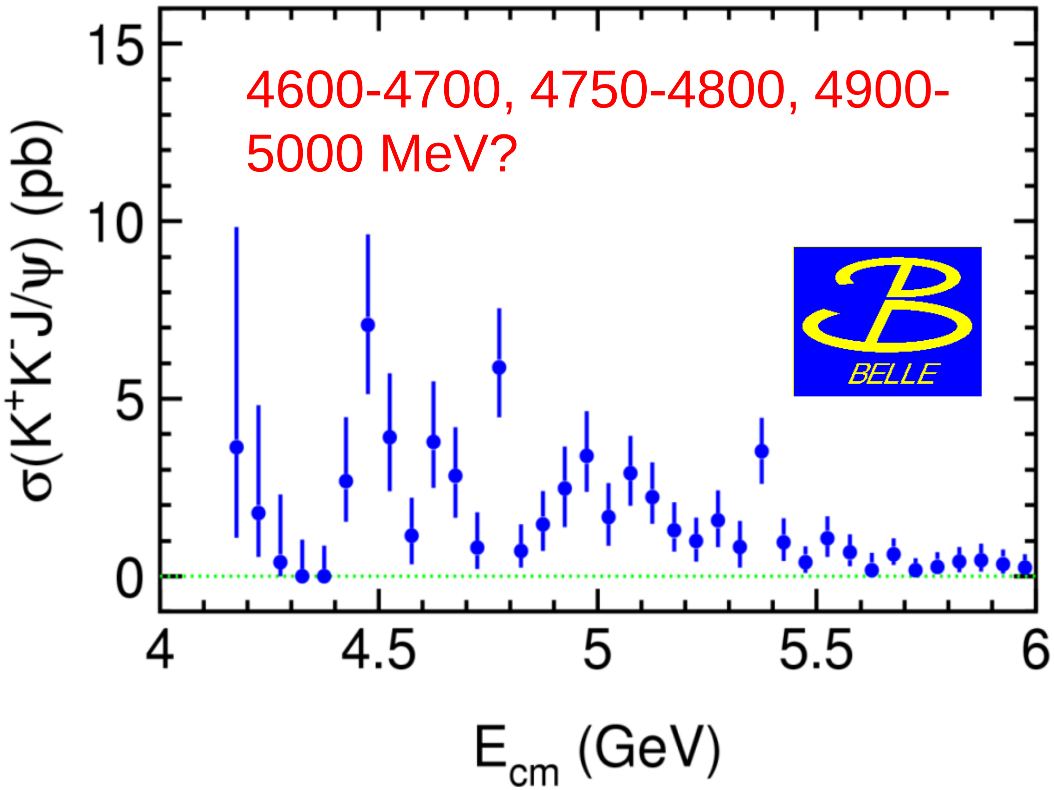
- Zc(3900)、Zc(4020)的产生和衰变性质，新的Zc、Zcs态

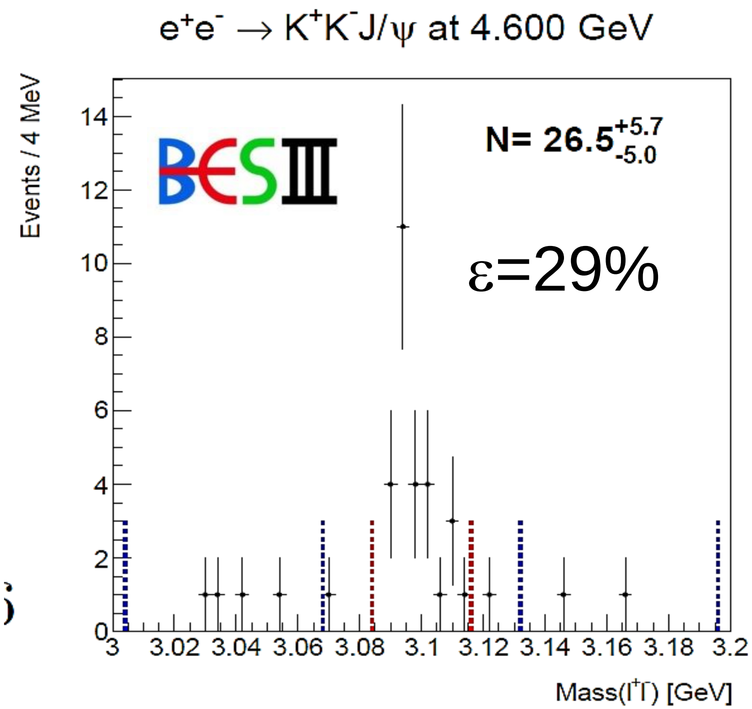




理解这些粒子，需要与理论的密切配合，包括LQCD的协助！

$e^+e^- \to KZ_{cs}$ @ $E_{cm} > 4.5$ GeV

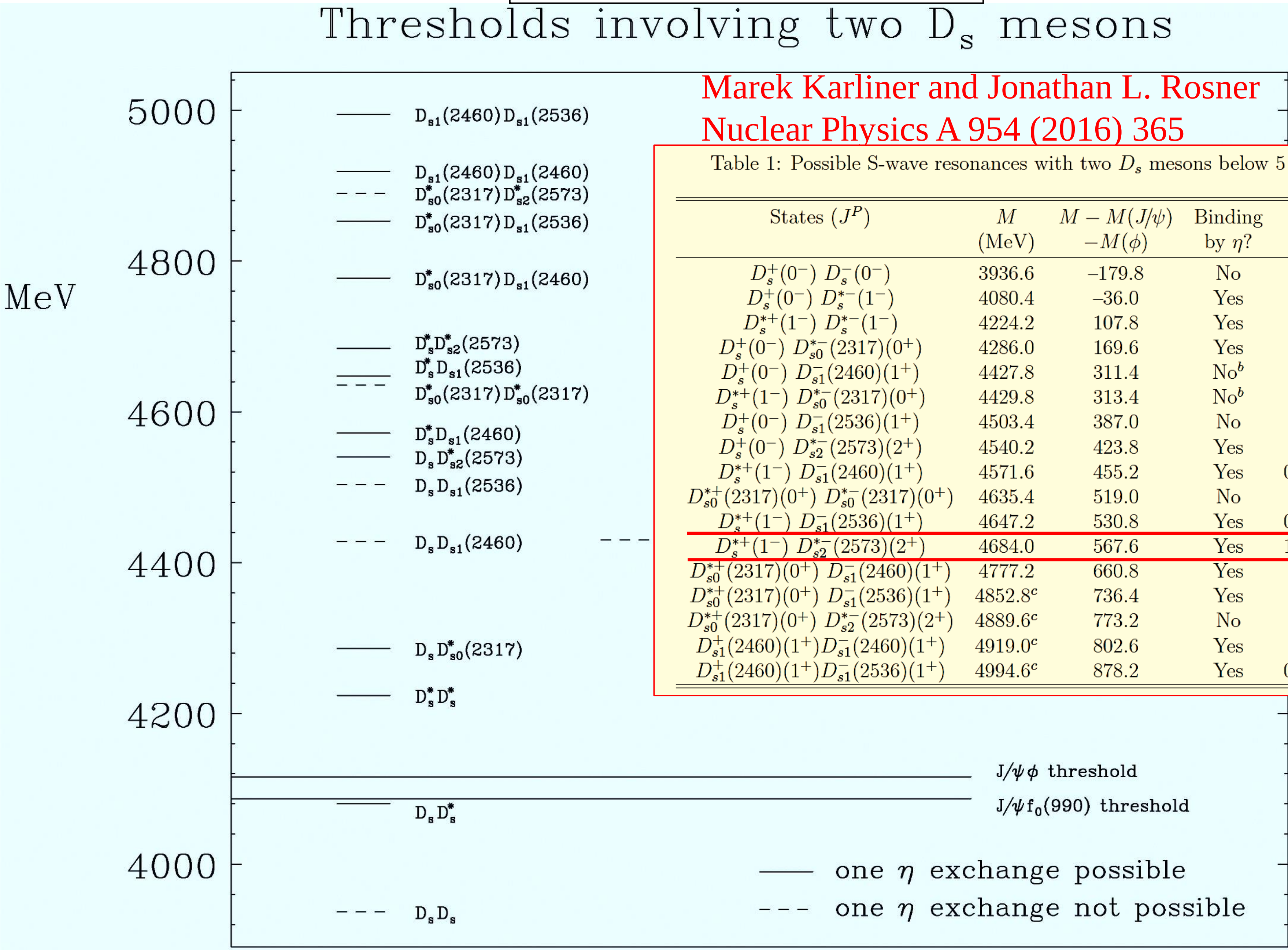




1000 observed evts at 4.66 GeV ~ 10 fb^{-1}
1000 observed evts at 4.79 GeV ~ 5 fb^{-1}
1000 observed evts at 5.00 GeV ~ 10 fb^{-1}

在 K^+K^-J/ψ 中寻找 Z_{cs} $(c\bar{c}u\bar{s})$?

寻找 $Z(c\bar{c}s\bar{s})$?



Marek Karliner and Jonathan L. Rosner
Nuclear Physics A 954 (2016) 365

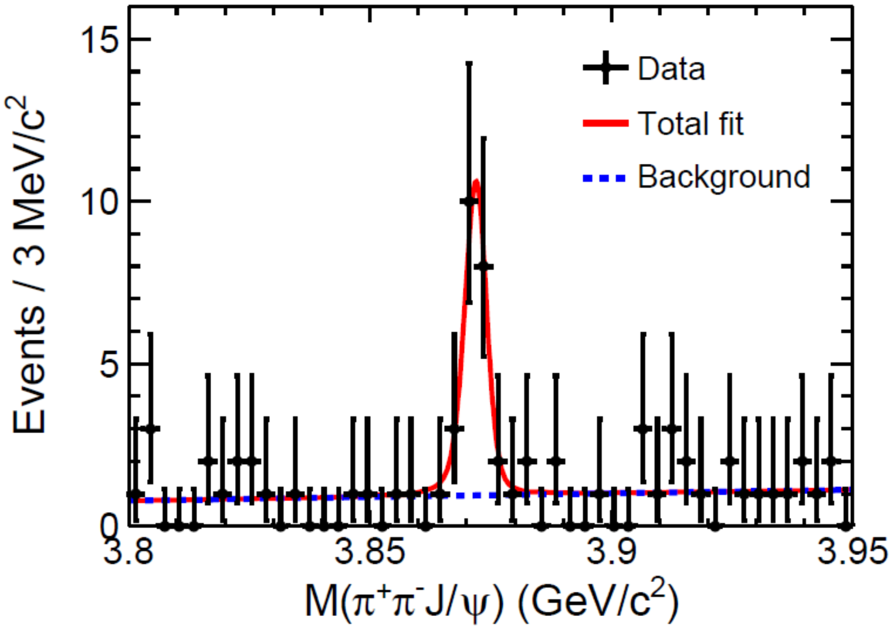
Table 1: Possible S-wave resonances with two D_s mesons below 5 GeV.

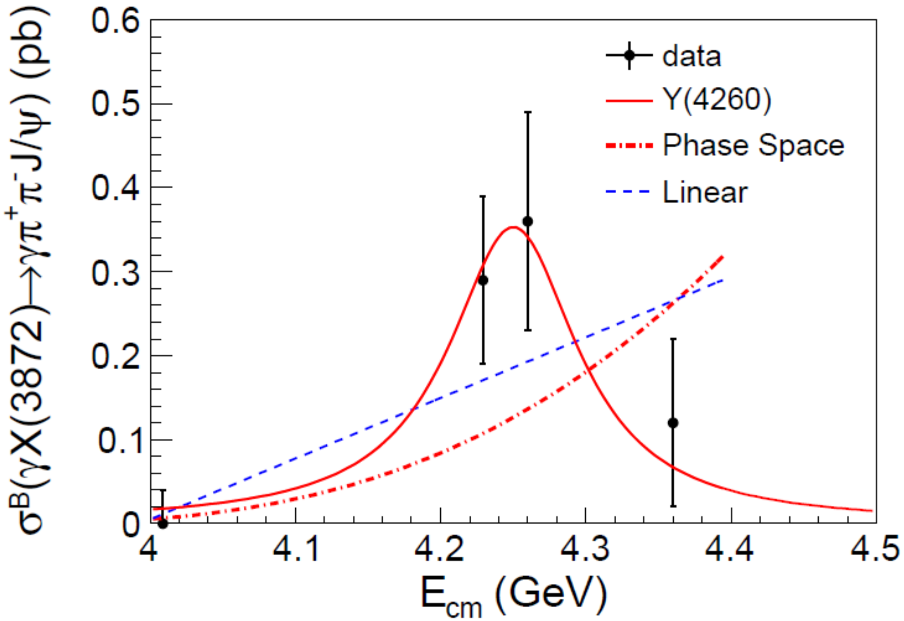
States (J^P)	M (MeV)	$M-M(J/\psi)$ $-M(\phi)$	Binding by η?	Allowed J^P
$D_s^+(0^-)\ D_s^-(0^-)$	3936.6	–179.8	No	–
$D_s^+(0^-)\ D_s^{*-}(1^-)$	4080.4	–36.0	Yes	1^+
$D_s^{*+}(1^-)\ D_s^{*-}(1^-)$	4224.2	107.8	Yes	$0^+, 2^+$ [a]
$D_s^+(0^-)\ D_{s0}^{*-}(2317)(0^+)$	4286.0	169.6	Yes	0^-
$D_s^+(0^-)\ D_{s1}^-(2460)(1^+)$	4427.8	311.4	No[b]	$[1^-]$ [b]
$D_s^{*+}(1^-)\ D_{s0}^{*-}(2317)(0^+)$	4429.8	313.4	No[b]	$[1^-]$ [b]
$D_s^+(0^-)\ D_{s1}^-(2536)(1^+)$	4503.4	387.0	No	–
$D_s^+(0^-)\ D_{s2}^{*-}(2573)(2^+)$	4540.2	423.8	Yes	2^-
$D_s^{*+}(1^-)\ D_{s1}^-(2460)(1^+)$	4571.6	455.2	Yes	$0^-, 1^-, 2^-$
$D_{s0}^{*+}(2317)(0^+)\ D_{s0}^{*-}(2317)(0^+)$	4635.4	519.0	No	–
$D_s^{*+}(1^-)\ D_{s1}^-(2536)(1^+)$	4647.2	530.8	Yes	$0^-, 1^-, 2^-$
$D_s^{*+}(1^-)\ D_{s2}^{*-}(2573)(2^+)$	4684.0	567.6	Yes	$1^-, 2^-, 3^-$
$D_{s0}^{*+}(2317)(0^+)\ D_{s1}^-(2460)(1^+)$	4777.2	660.8	Yes	1^+
$D_{s0}^{*+}(2317)(0^+)\ D_{s1}^-(2536)(1^+)$	4852.8[c]	736.4	Yes	1^+
$D_{s0}^{*+}(2317)(0^+)\ D_{s2}^{*-}(2573)(2^+)$	4889.6[c]	773.2	No	–
$D_{s1}^+(2460)(1^+)D_{s1}^-(2460)(1^+)$	4919.0[c]	802.6	Yes	$0^+, 2^+$ [a]
$D_{s1}^+(2460)(1^+)D_{s1}^-(2536)(1^+)$	4994.6[c]	878.2	Yes	$0^+, 1^+, 2^+$

- 寻找XYZ粒子间的关系

Observation of **Y(4260)**→γX(3872)

PRL 112, 092001 (2014)



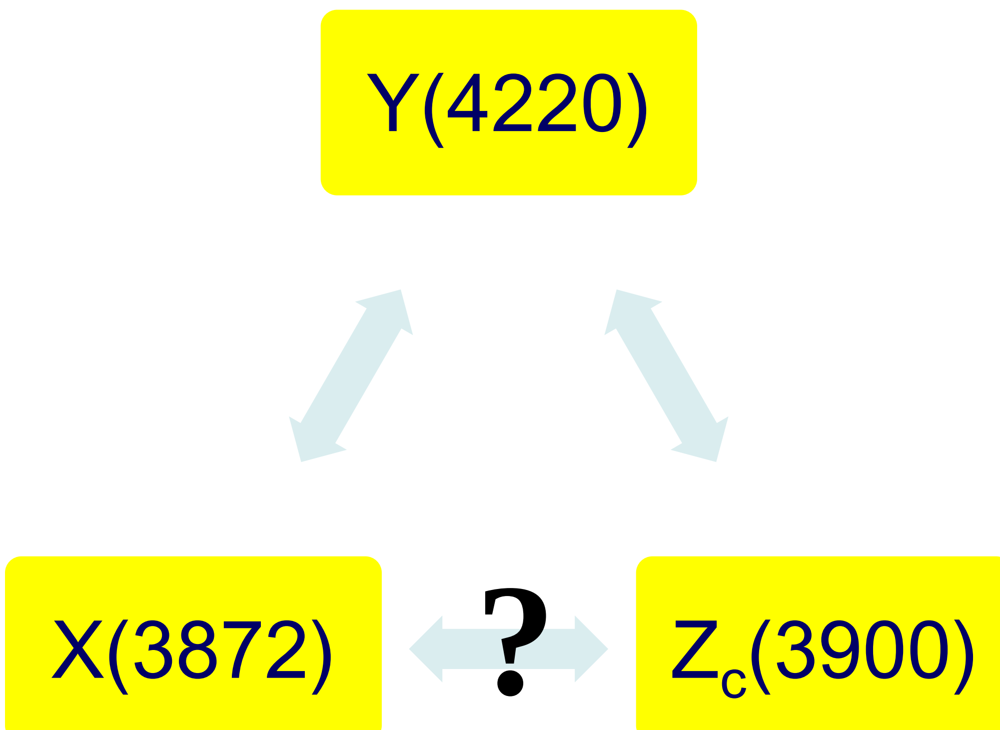


A new Y(4260) decay mode
A new X(3872) production mode

X, Y, Z particles are correlated

Whatever they are, they are very similar.

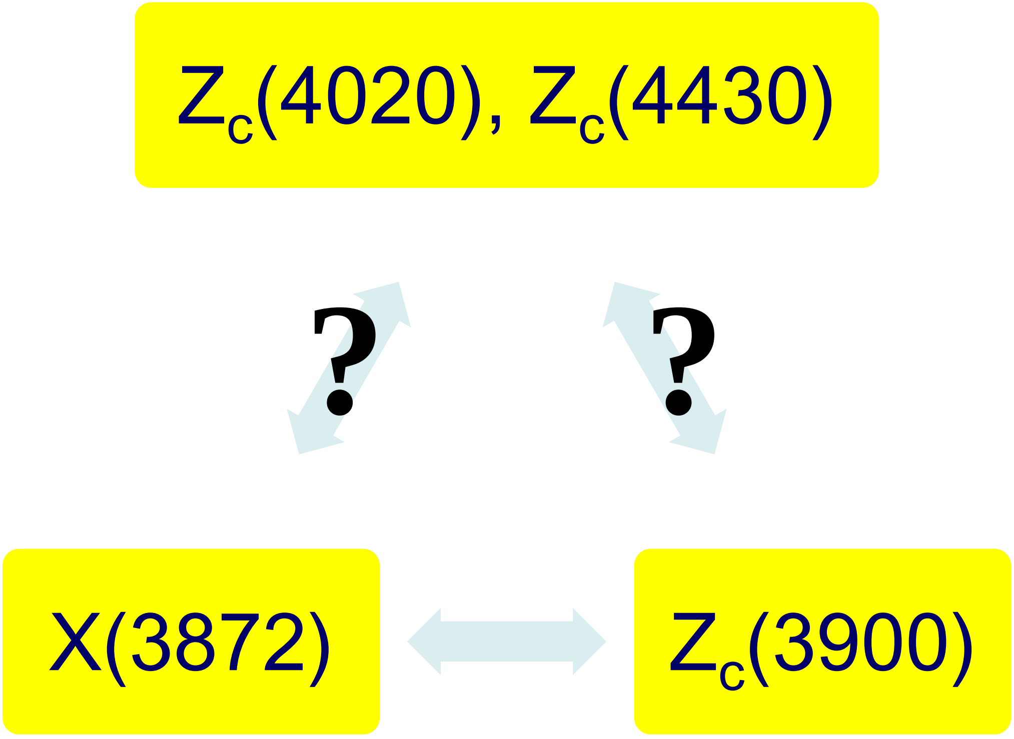
Molecule? Compact tetraquark? Kinematic effect?



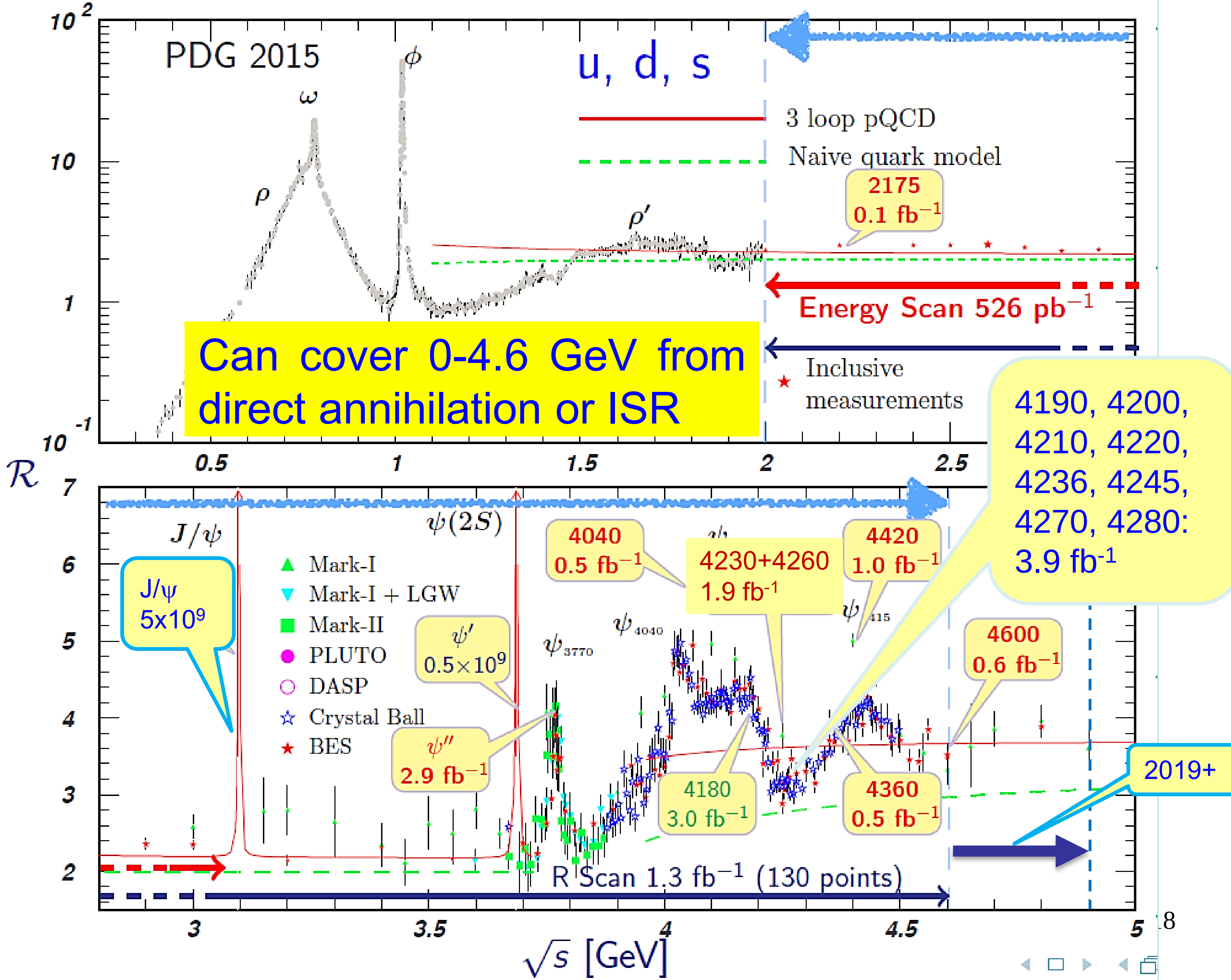
其他X, Y, Z粒子间的关系

$Y(4220) \rightarrow \gamma X(3915)$?

$Y(4360)/\psi(4415) \rightarrow \pi Z_c(4020)$?

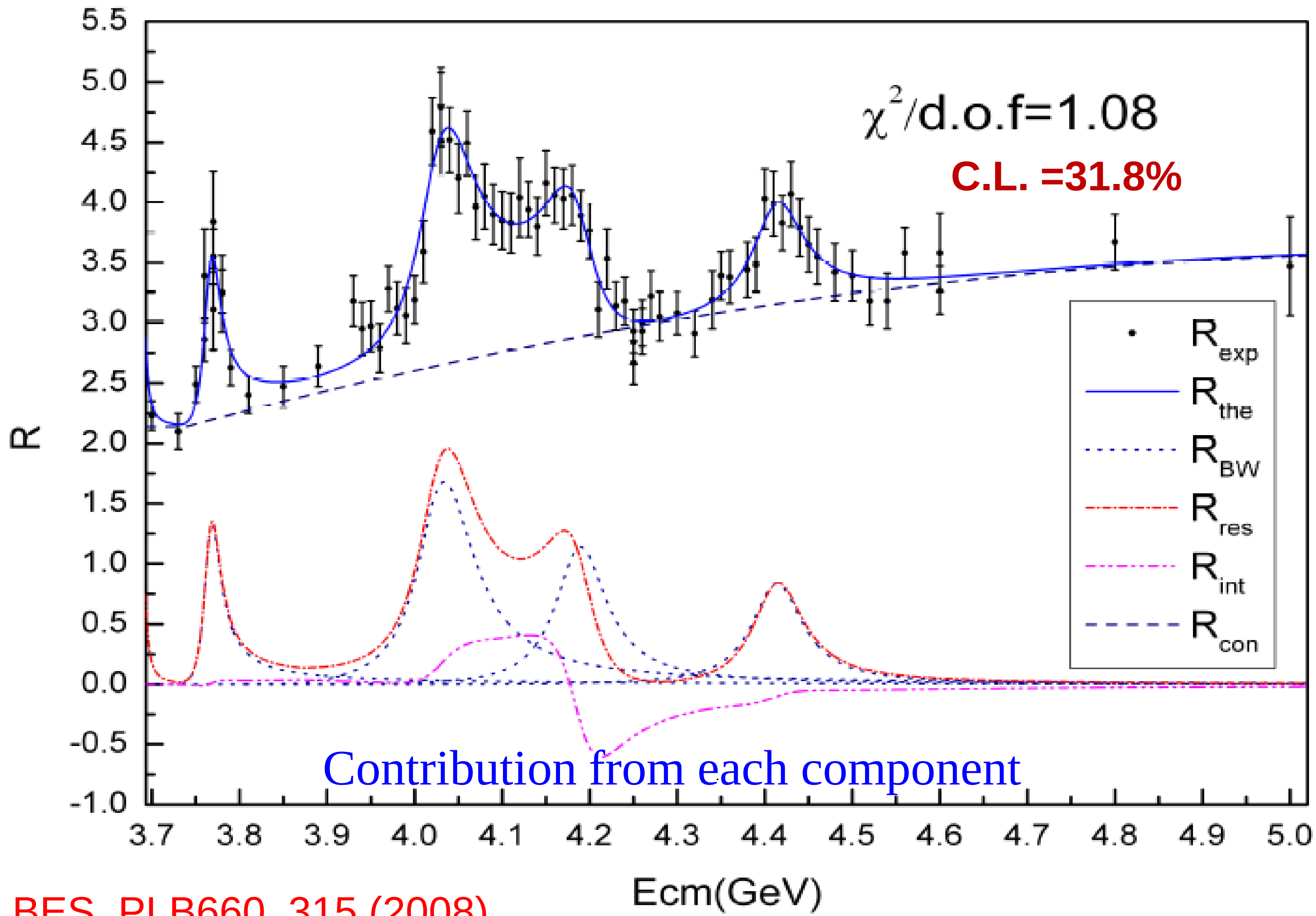


- 粲介子产生截面的耦合道分析
  - 如何参数化复杂共振态？
  - 能否得到Y(4220)的Γ_{ee}，从而得到各个道的分支比？



PDG 2015
u, d, s
3 loop pQCD
Naive quark model
2175 0.1 fb⁻¹
Energy Scan 526 pb⁻¹
Inclusive measurements
Can cover 0-4.6 GeV from direct annihilation or ISR
4190, 4200, 4210, 4220, 4236, 4245, 4270, 4280: 3.9 fb⁻¹
J/ψ 5x10⁹
ψ′ 0.5×10⁹
ψ″ 2.9 fb⁻¹
4040 0.5 fb⁻¹
4230+4260 1.9 fb⁻¹
4420 1.0 fb⁻¹
4600 0.6 fb⁻¹
4180 3.0 fb⁻¹
4360 0.5 fb⁻¹
2019+
R Scan 1.3 fb⁻¹ (130 points)
Mark-I
Mark-I + LGW
Mark-II
PLUTO
DASP
Crystal Ball
BES
√s [GeV]

BESII R values



BES, PLB660, 315 (2008)

ψ resonance parameters from BESII

$$R_{\rm the} = R_{\rm con} + R_{\rm res}$$

Coherent sum of 4 BWs

$$R_{\rm con} = C_0 + C_1(W - 2M_{D^\pm}) + C_2(W - 2M_{D^\pm})^2$$

$$R_{\rm res} = \frac{\sigma_{\rm res}}{\sigma^0_{\mu\mu}} = \frac{12\pi}{s}\left[|\mathcal{T}_{\psi'}|^2 + |\mathcal{T}_{\rm res}|^2\right]$$

Amplitude of r → f

$$|\mathcal{T}_{\rm res}|^2 = \sum_f \left| \sum_r \mathcal{T}_r^f(W) \right|^2$$

$$\mathcal{T}_r^f(W) = \frac{M_r\sqrt{\Gamma_r^{ee}\Gamma_r^f}}{W^2 - M_r^2 + iM_r\Gamma_r} e^{i\delta_r}$$

$$\psi(3770) \Rightarrow D\bar{D};$$
$$\psi(4040) \Rightarrow D\bar{D},\ D^*\bar{D}^*,\ D\bar{D}^*,\ D_s\bar{D}_s;$$
$$\psi(4140) \Rightarrow D\bar{D},\ D^*\bar{D}^*,\ D\bar{D}^*,\ D_s\bar{D}_s,\ D_s\bar{D}_s^*;$$
$$\psi(4415) \Rightarrow D\bar{D},\ D^*\bar{D}^*,\ D\bar{D}^*,\ D_s\bar{D}_s,\ D_s\bar{D}_s^*,\ D_s^*\bar{D}_s^*,\ D\bar{D}_1,\ D\bar{D}_2^*.$$

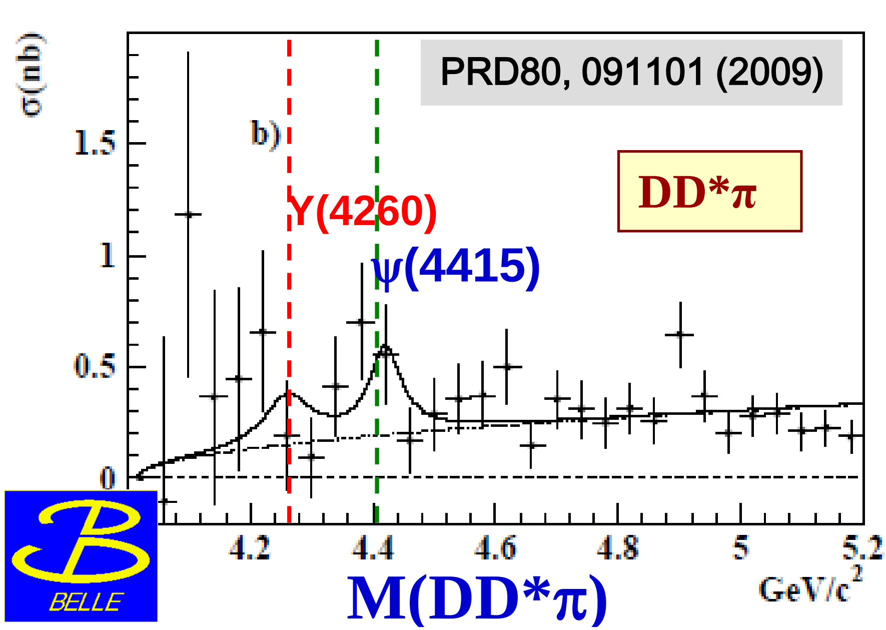
Mass dependent width

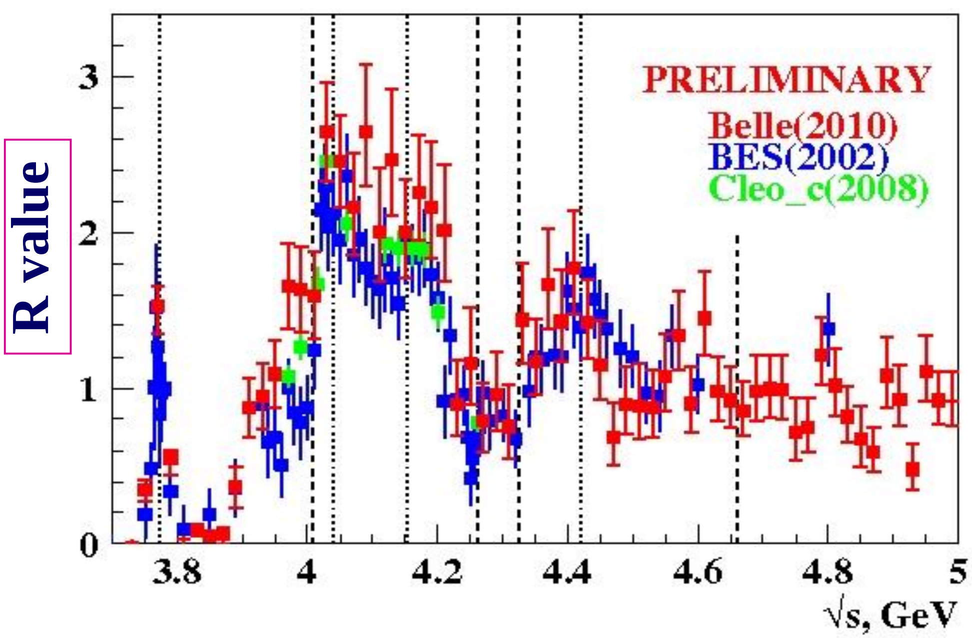
$$\Gamma_r^f(W) = \hat{\Gamma}_r \sum_L \frac{Z_f^{2L+1}}{B_L}$$

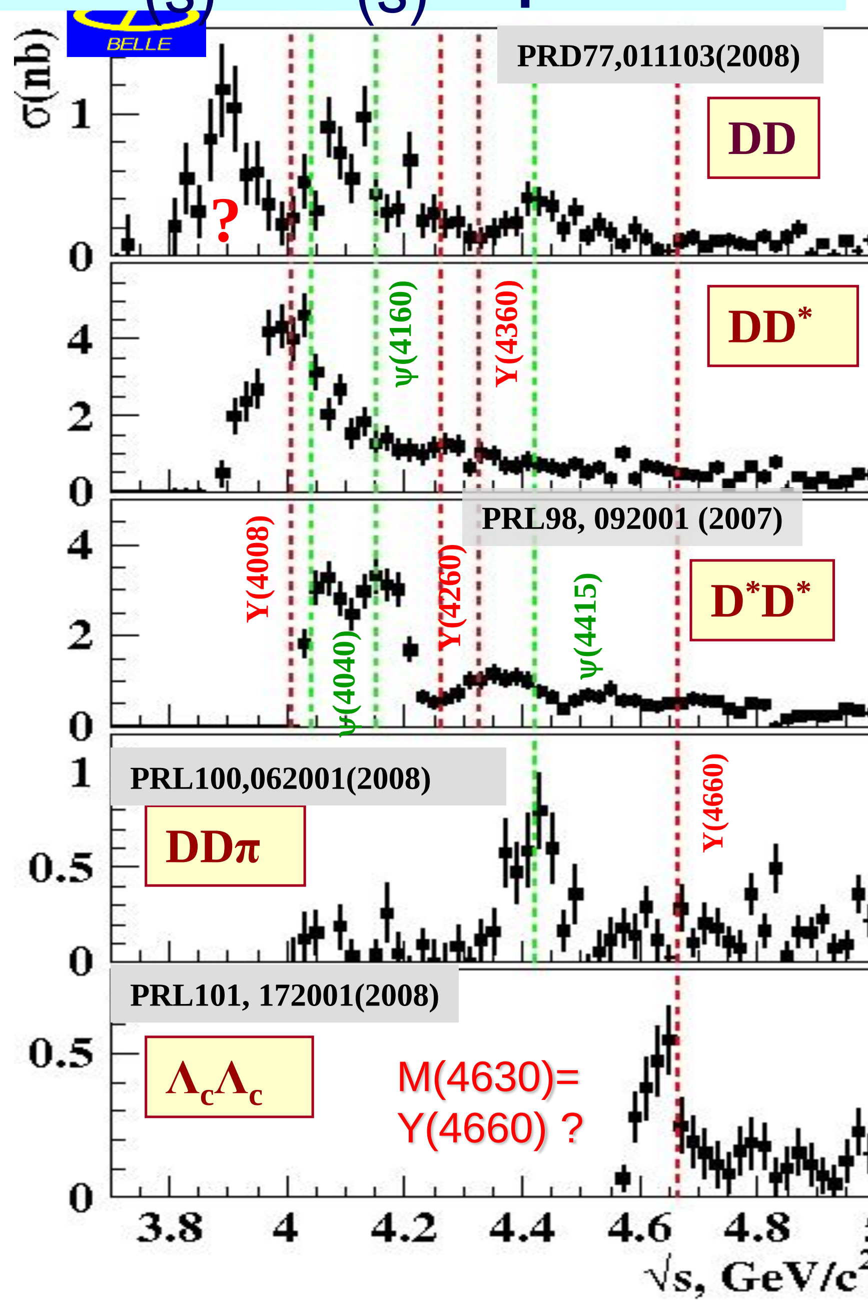
BES, PLB660, 315 (2008)

May use data now!

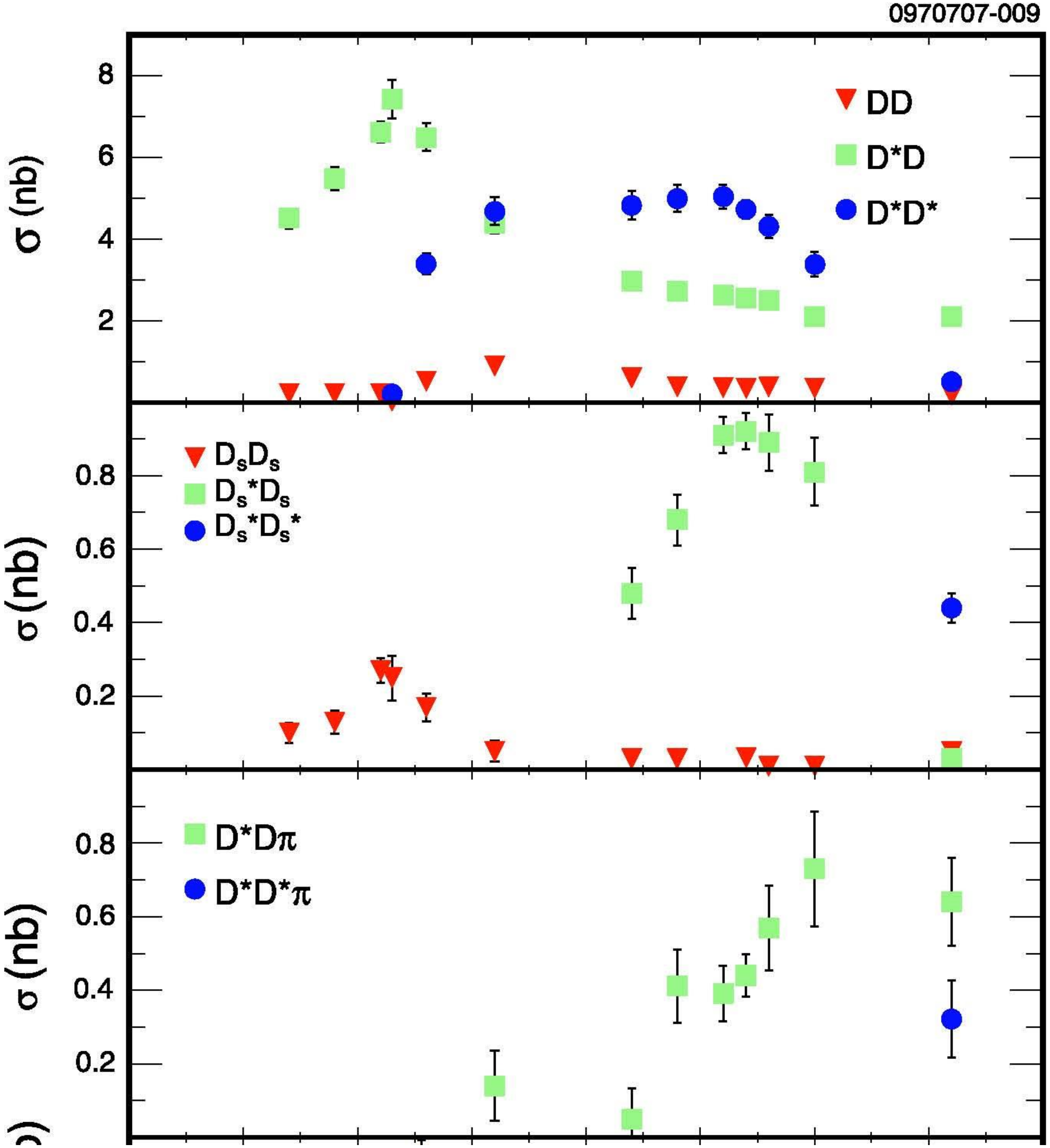
Y states don't match $D_{(s)}^{(*)}D_{(s)}^{(*)}$ peaks





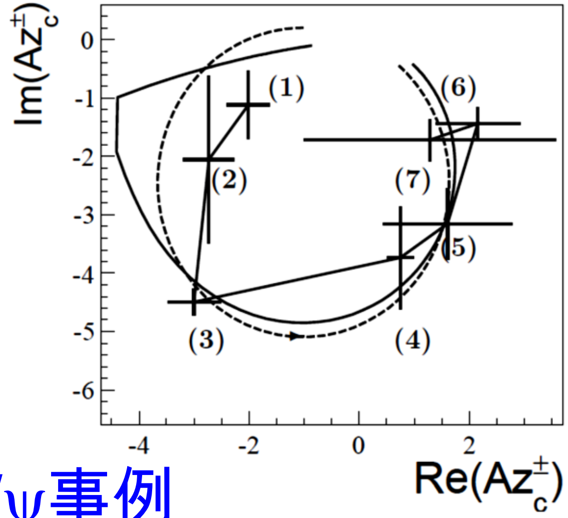


BESIII可以在3.8-4.6GeV精确测量截面



- Argand plot
  - 能否确定Zc是否是个共振态？
  - 能否确定它是分子态还是四夸克态？

Z_c 相关研究

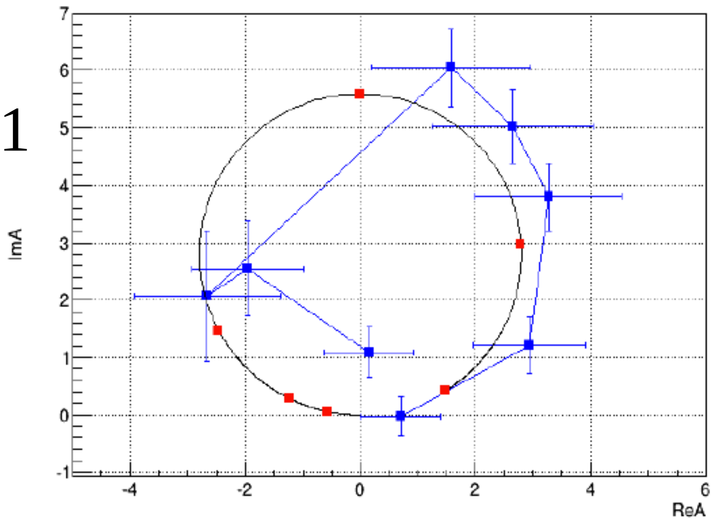


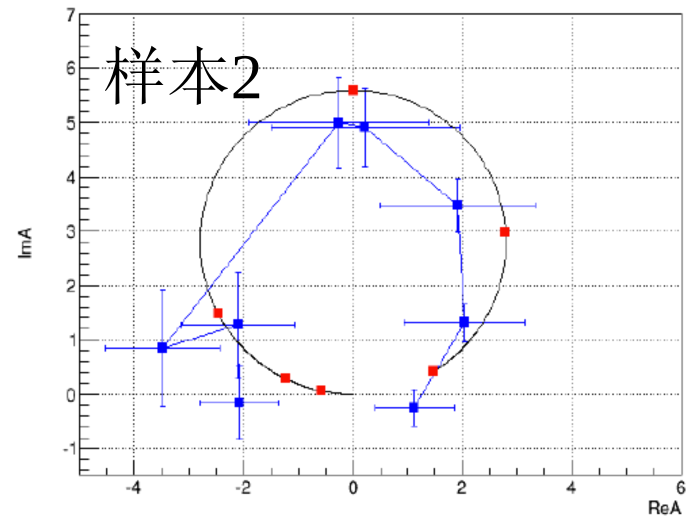
- 阿根图很重要（有决定性作用吗？）
- $Z_c(3900)$
  - 1.9 fb^{-1} @ 4.23/4.26 GeV ~ 6000 $\pi^+\pi^- J/\psi$ 事例
- $Z_c(4020)$
  - 3.5 fb^{-1} @ 4.23/4.26/4.36/4.42 GeV ~ 2000 $\pi^+\pi^-$ hc 事例
- $Z_c(4030)=Z_c(4020)$?
  - 1.0 fb^{-1} @ 4.42 GeV ~ 1000 $\pi^+\pi^- \psi'$ 事例

- 5-8个点确定一个圆，每个点大约？个事例
- Argand plot 能告诉我们什么信息？

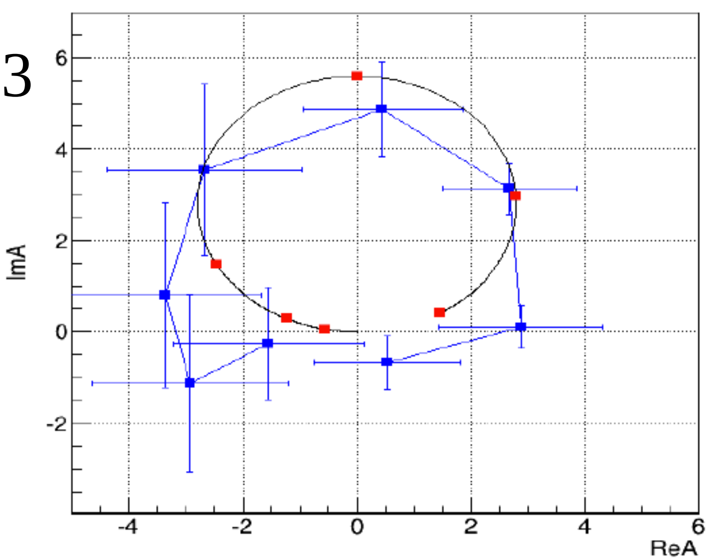
MC检查：1/fb data at 4.23 GeV
（$e^+e^- \rightarrow \pi^+\pi^- J/\psi$，Zc=BW）

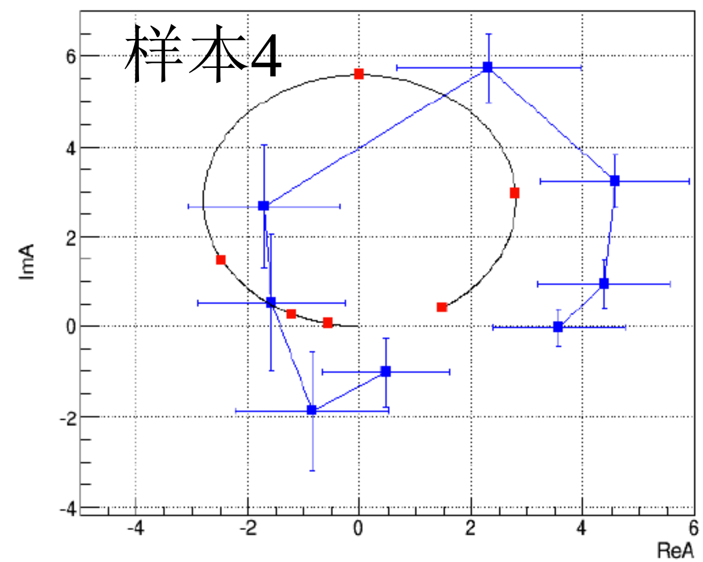
样本1





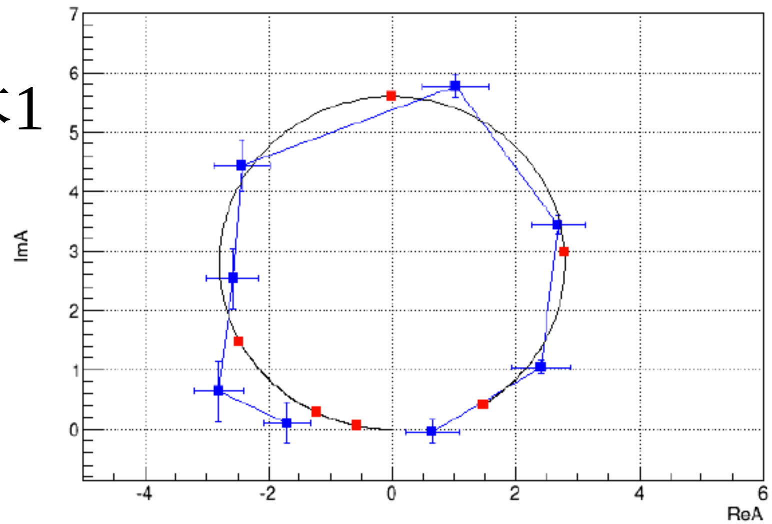
样本3



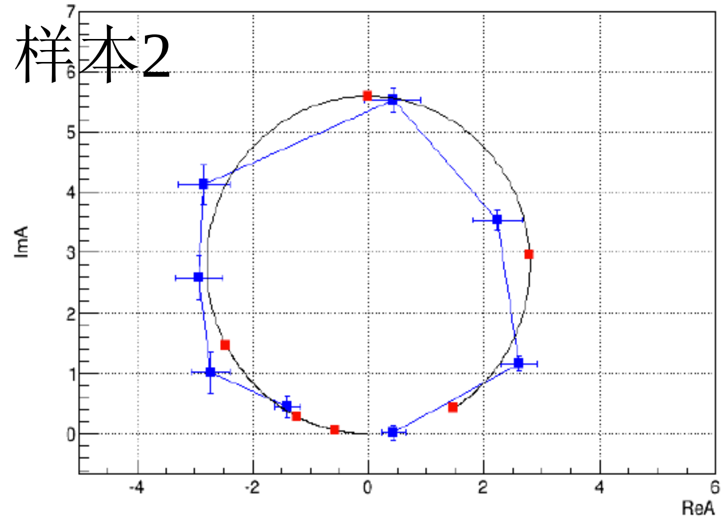


MC检查：10/fb data at 4.23 GeV
（$e^+e^- \to \pi^+\pi^- J/\psi$，Zc=BW ）

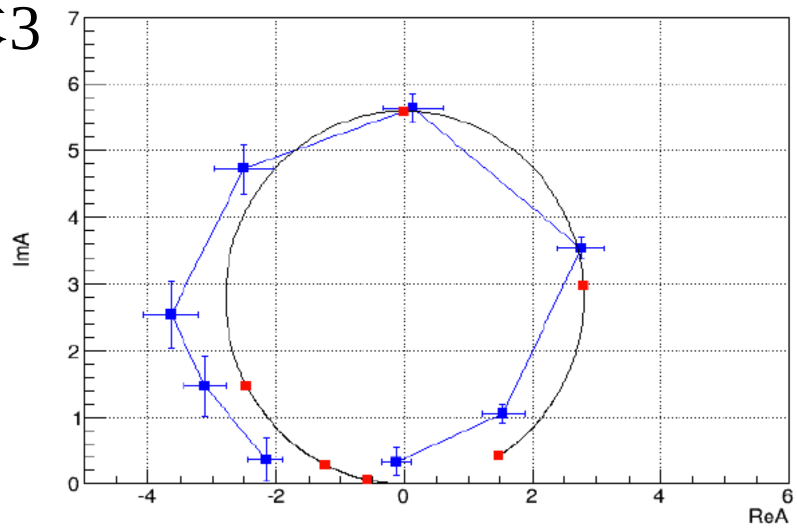
样本1



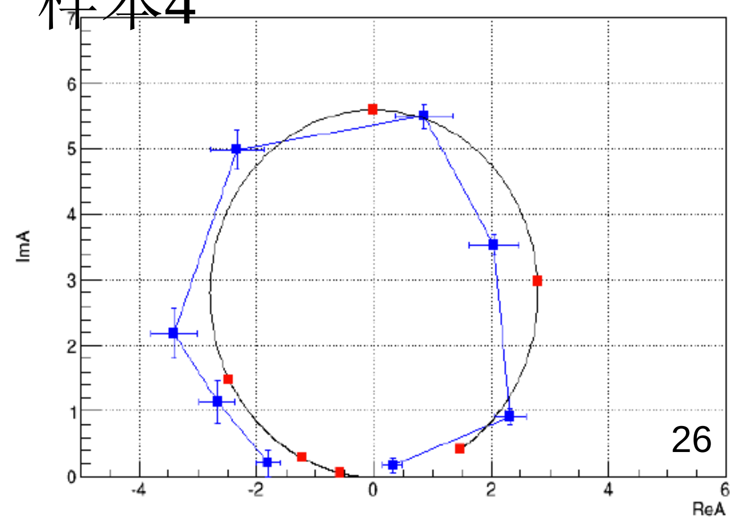
样本2



样本3

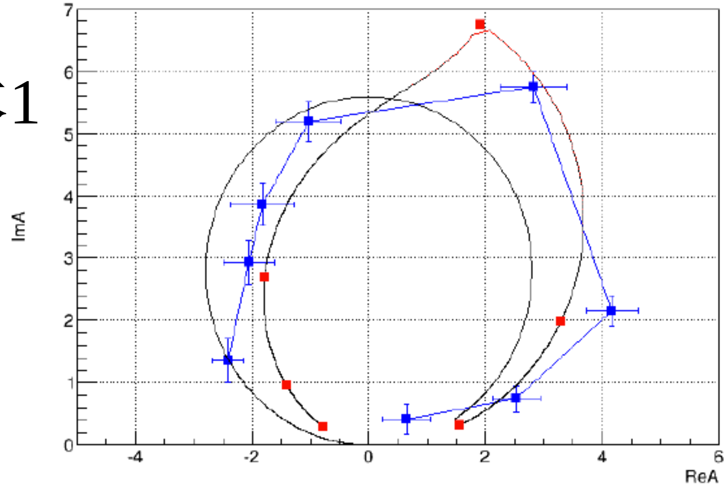


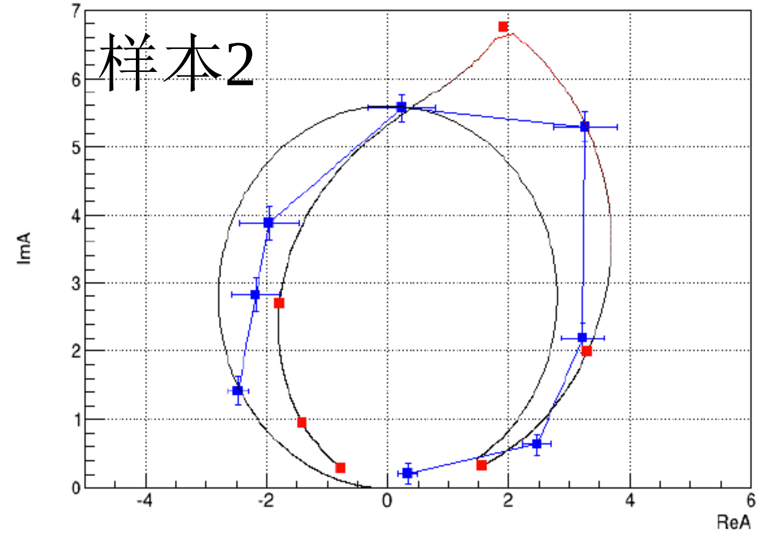
样本4



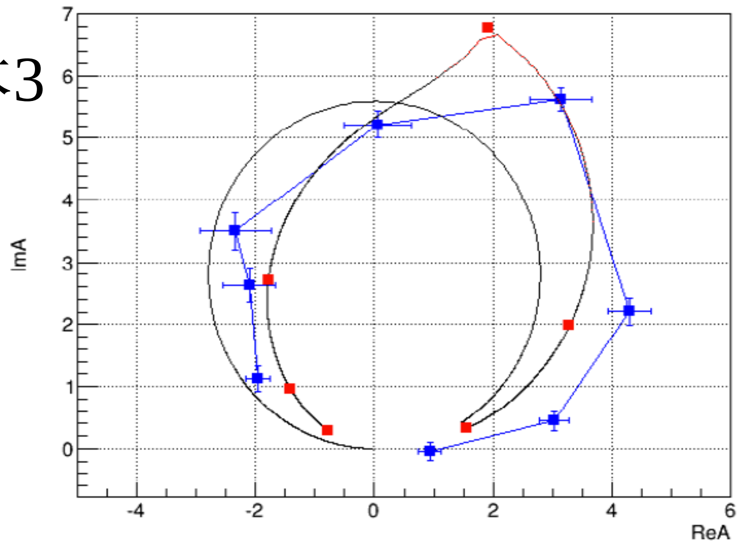
MC检查：10/fb data at 4.23 GeV
（$e^+e^- \rightarrow \pi^+\pi^- J/\psi$，Zc=Flatte ）

样本1





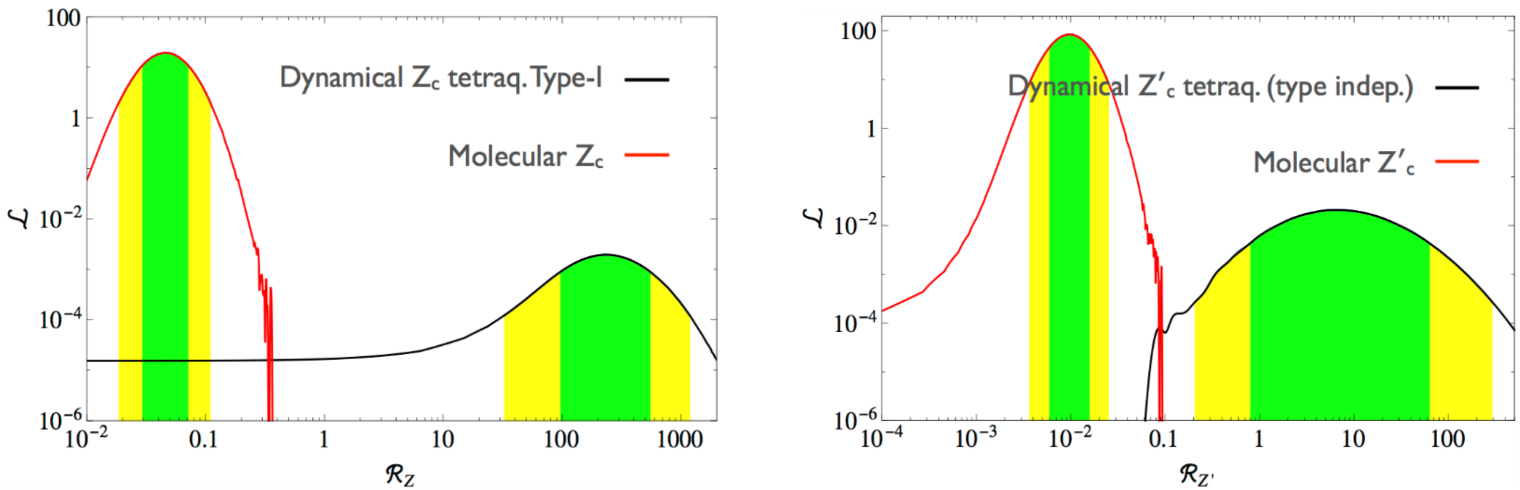
样本3



- **其他**

Search for $Z_c \rightarrow \rho\eta_c$

- Search for new decay mode of $Z_c(3900)$ and $Z_c(4020)$
- The ratios of $Z_c^{(\prime)} \rightarrow \rho\eta_c$ to $Z_c^{(\prime)} \rightarrow \pi J/\psi(\pi h_c)$ may discriminate **the tetra-quark** and **molecule** models.



$$R_z = \frac{B(Z_c \rightarrow \rho\eta_c)}{B(Z_c \rightarrow \pi J/\psi)} \qquad R_{z'} = \frac{B(Z'_c \rightarrow \rho\eta_c)}{B(Z'_c \rightarrow \pi h_c)}$$

A.Esposito, A.L.Guerrieri, A.Pilloni, Phys. Lett. B 746, 194 (2015)

Type II tetraquark model:

neglect the spin-spin interaction outside the diquarks

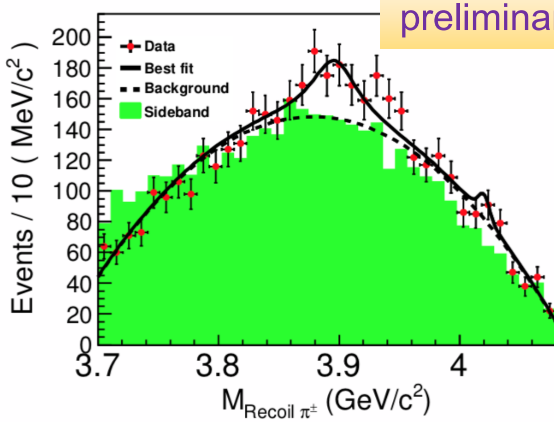
Evidence for $Z_c \to \rho\eta_c$

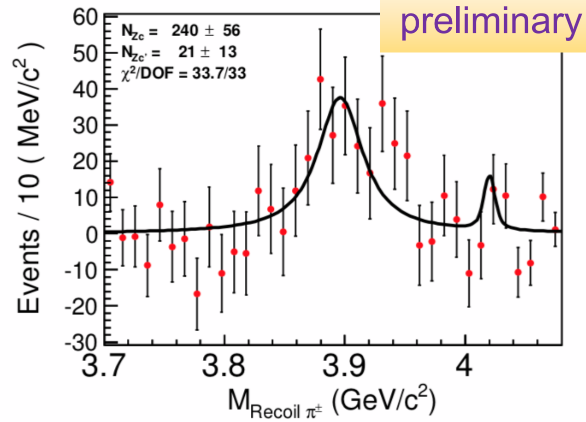
preliminary

- $e^+e^- \to \pi^+\pi^-\pi^0\eta_c$
- $\eta_c \to$ 9 hadronic decays

Decay mode	BR
$\eta_c \to p\bar{p}$	~0.13%
$\eta_c \to 2(K^+K^-)$	~0.15%
$\eta_c \to \pi^+\pi^-K^+K^-$	~1.50%
$\eta_c \to K^+K^-\pi^0$	~1.20%
$\eta_c \to p\bar{p}\pi^0$	~0.18%
$\eta_c \to K_SK\pi$	~1.80%
$\eta_c \to \pi^+\pi^-\eta$	~1.60%
$\eta_c \to K^+K^-\eta$	~0.57%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%

- Strong evidence of $e^+e^- \to \pi Z_c$, $Z_c \to \rho\,\eta_c$ at $\sqrt{s} = 4.23$, statistical significance is 4.3σ. (3.9σ including systematics)
- $e^+e^- \to \pi Z_c', Z_c' \to \rho\,\eta_c$ not seen.





$e^+e^- \to \pi Z_c, Z_c \to \rho\,\eta_c$ @ 4.23 GeV

Evidence for $Z_c \to \rho\eta_c$

preliminary

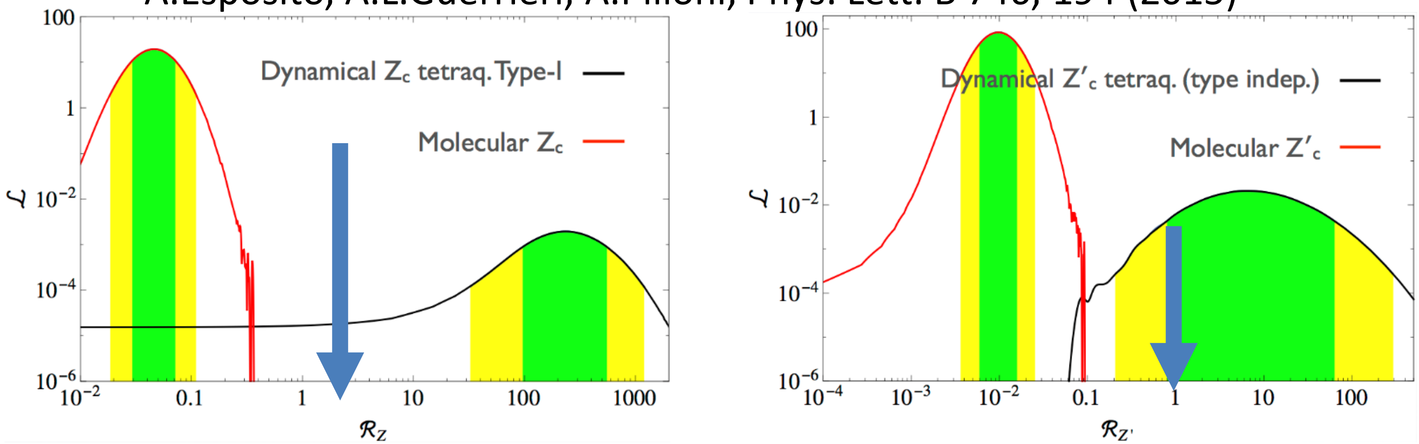
- **Measure Born cross section at 4.23 GeV:**

$$\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c) = (46 \pm 12 \pm 10\,)\ \text{pb}$$

$$\sigma^B(e^+e^- \to \pi Z_c, Z_c \to \rho\,\eta_c) = (47 \pm 11 \pm 11\,)\ \text{pb}$$

	$\sqrt{s} = 4.23\,\text{GeV}$	$\sqrt{s} = 4.26\,\text{GeV}$	$\sqrt{s} = 4.36\,\text{GeV}$	Tetra-quarks-I	Tetra-quarks-II	Molecule
$R_{Z_c(3900)}$	2.1 ± 0.8	< 6.4	...	230^{+330}_{-140}	$0.27^{+0.40}_{-0.17}$	$0.046^{+0.025}_{-0.017}$
$R_{Z_c(4020)}$	< 1.9	< 1.2	< 1.0	$6.6^{+56.8}_{-5.8}$		$0.010^{+0.006}_{-0.004}$

A.Esposito, A.L.Guerrieri, A.Pilloni, Phys. Lett. B 746, 194 (2015)



$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)} \qquad R_{z'} = \frac{B(Z'_c \to \rho\eta_c)}{B(Z'_c \to \pi h_c)}$$

Does this suggest Z_c have both tetraquark and molecule components?

如何宣传

北京正负电子对撞机上的北京谱仪III实验在标量粒子研究中获得重要进展，首次实验发现39年前预言的标量粒子混合信号。7月11日，《物理评论快报》以“编辑推荐”的形式发表了北京谱仪III实验的研究成果“Observation of $a_0^0(980) - f_0(980)$ Mixing ” (PRL121, 022001 (2018))。

谢谢！

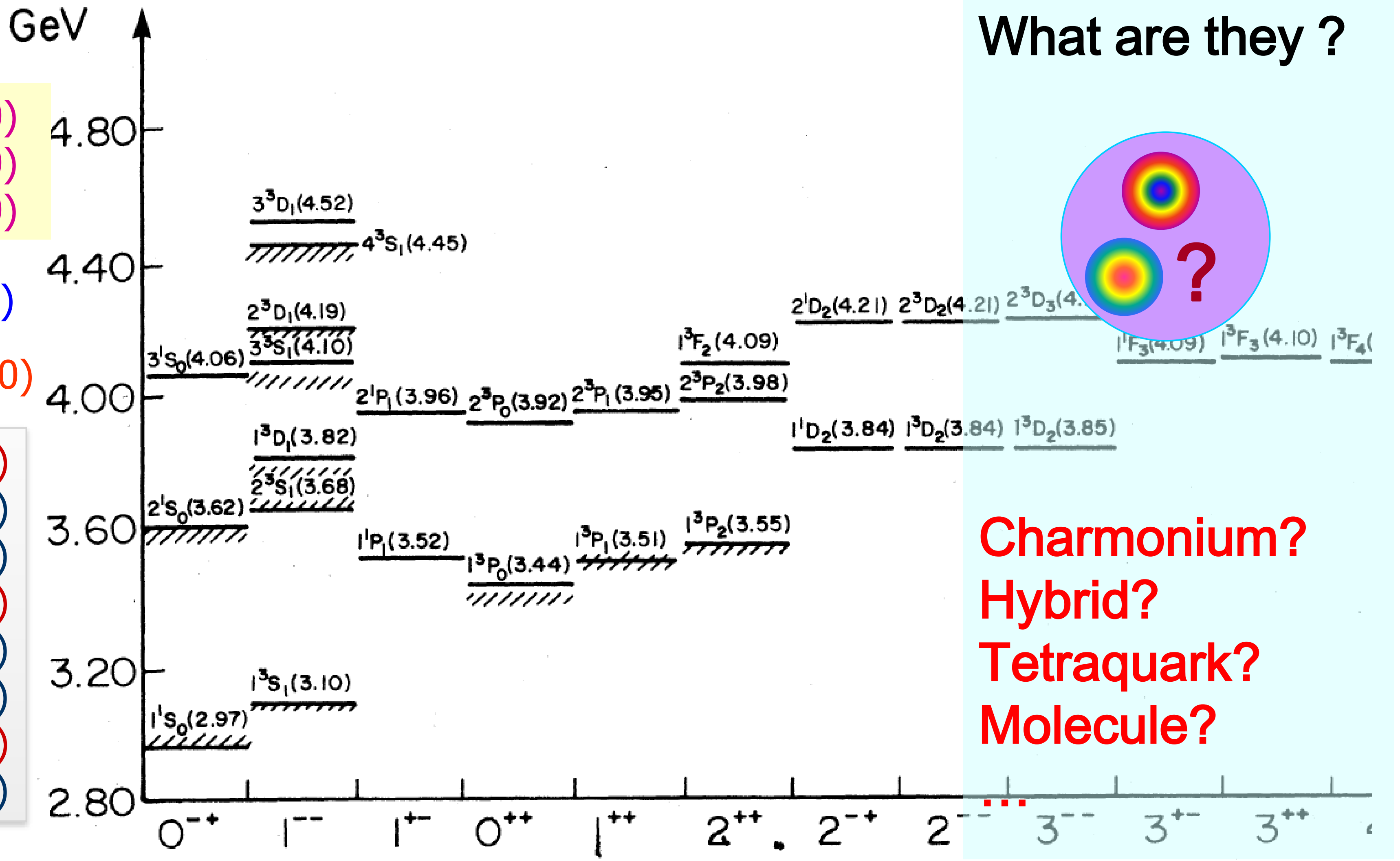
we found lots of XYZ states

Z(4430)
Z(3900)
Z(4020)

X(3872)

XYZ(3940)

X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)



What are they ?

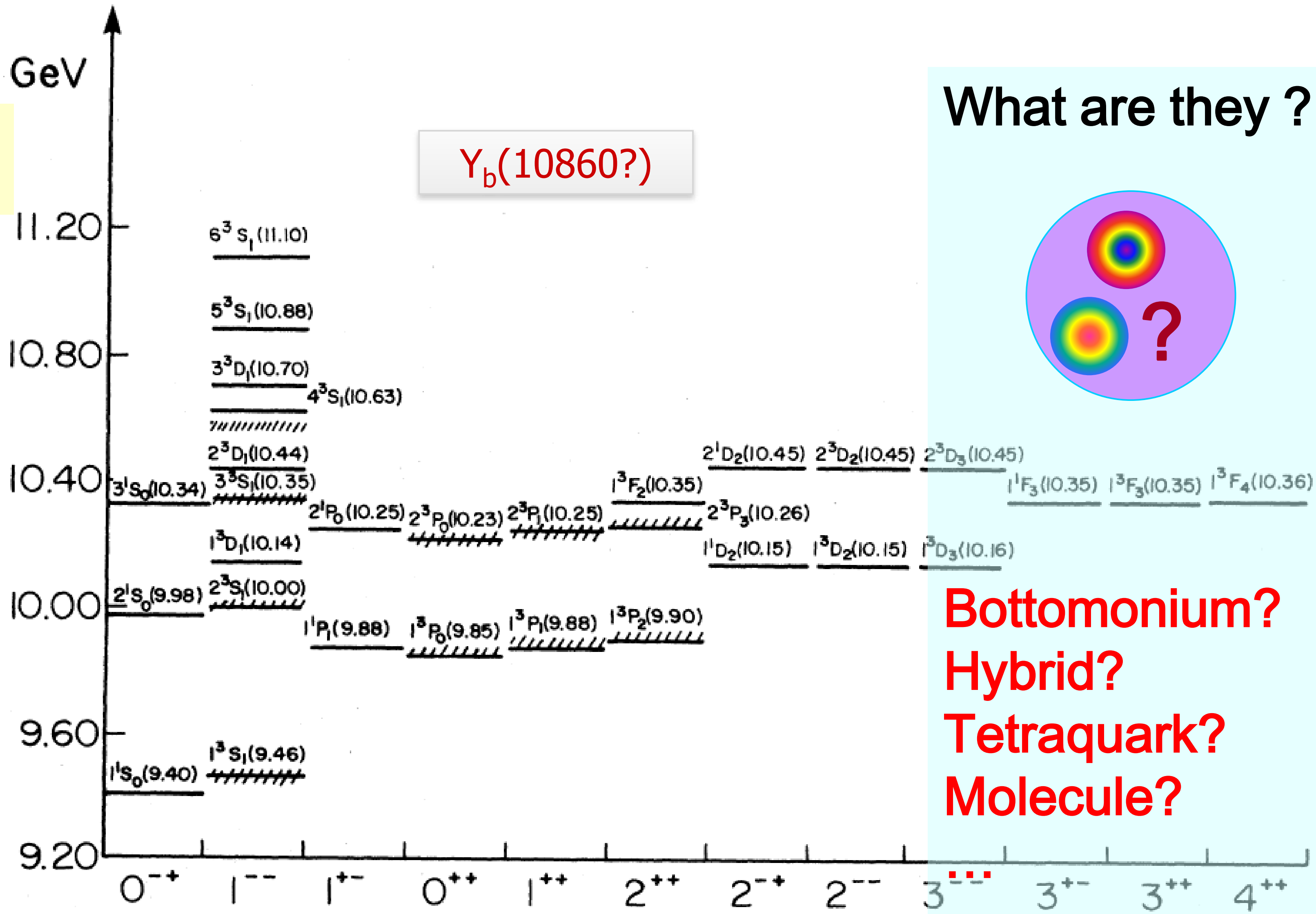
Charmonium?
Hybrid?
Tetraquark?
Molecule?
...

Not all XYZ states are charmonia!

we found $\bar{b}b$-like states

$Z_b(10610)$
$Z_b(10650)$

$Y_b(10860?)$



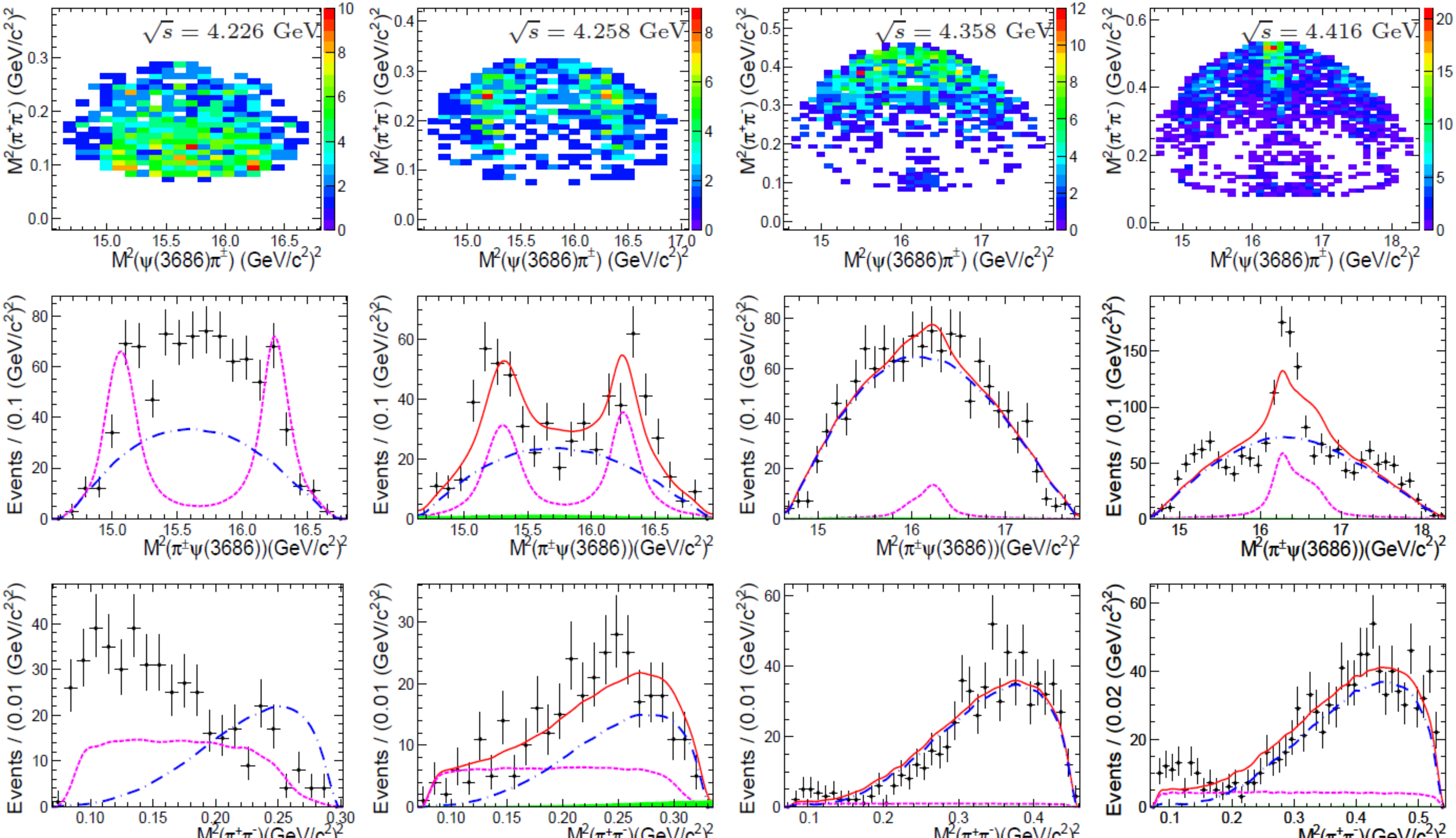
What are they ?

Bottomonium?
Hybrid?
Tetraquark?
Molecule?
...

Are there bottom analogy of XYZ states?

Fit of intermediate state

Interference not considered & fits cannot describe data well!

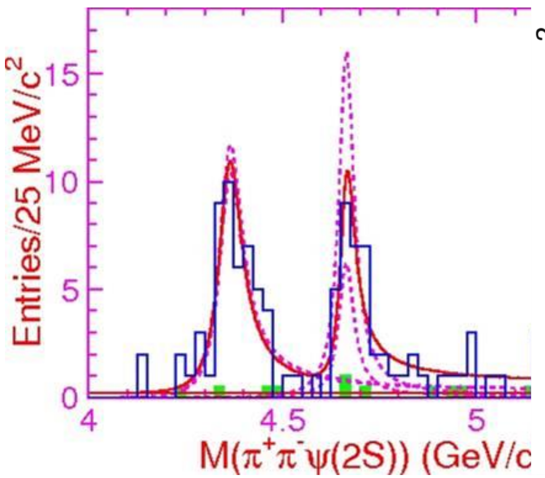


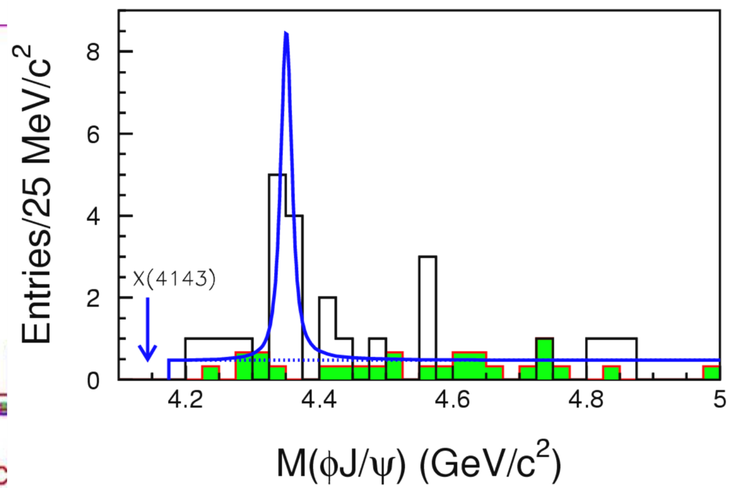
PRD 96, 032004 (2017)

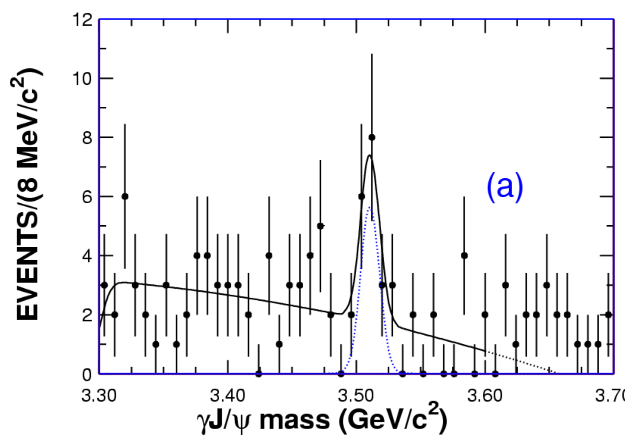
BelleII —利用多种机制研究

粲偶素或类粲偶素粒子有多种产生机制：

1. 初态辐射产生
2. B介子衰变
3. 双光子产生
4. 双粲偶素产生
5. 粲偶素衰变
6. Υ(1S)、Υ(2S)衰变
7. 连续产生







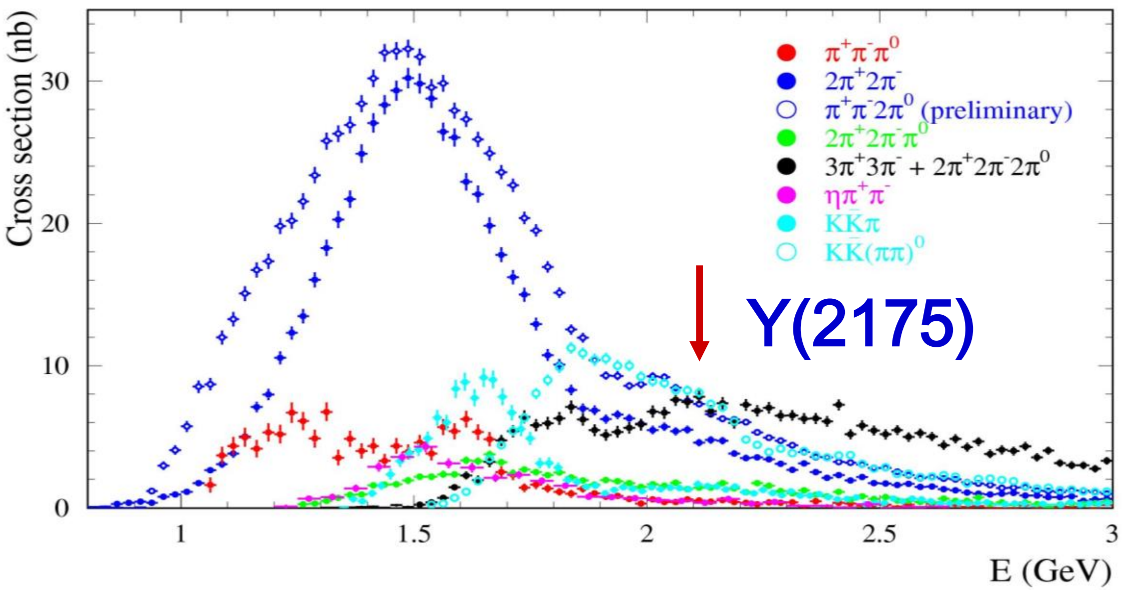
(类)底偶素产生：

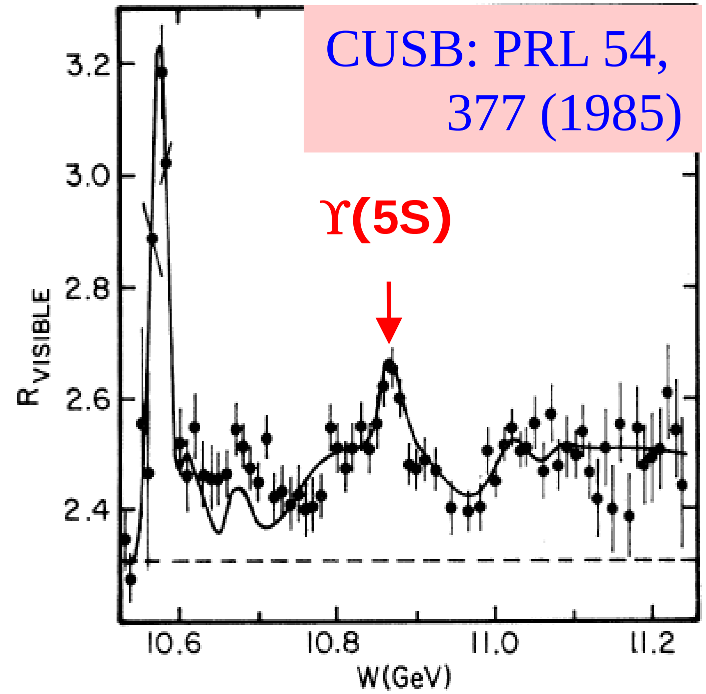
- Υ(5S)、Υ(6S)衰变

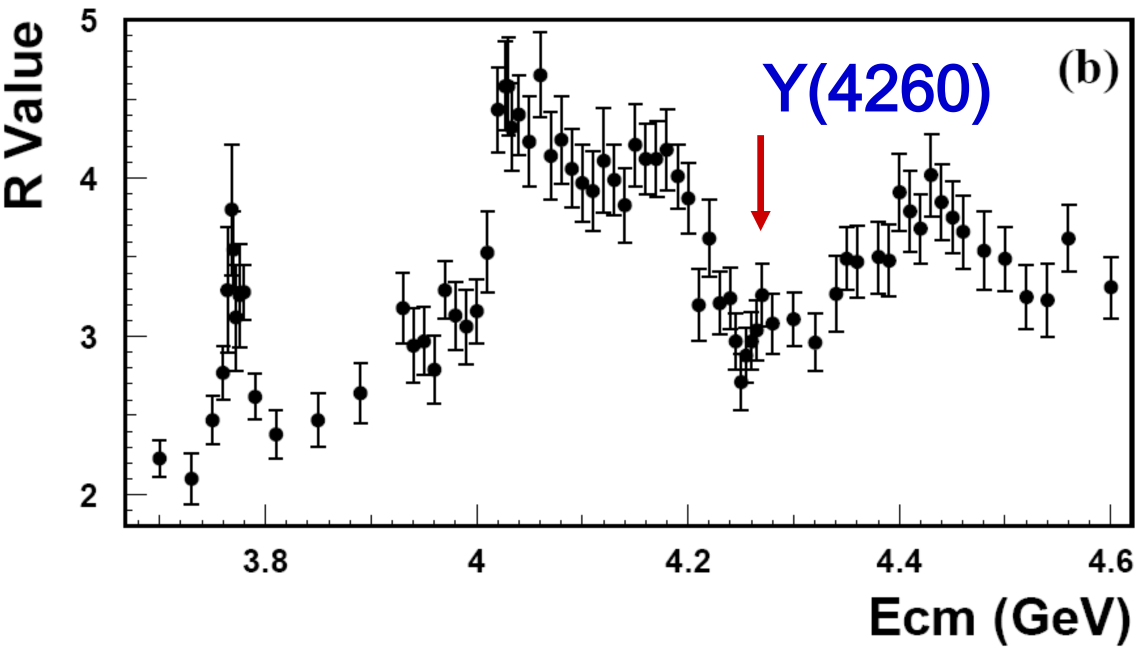
  [SuperKEKB can reach 12 GeV]

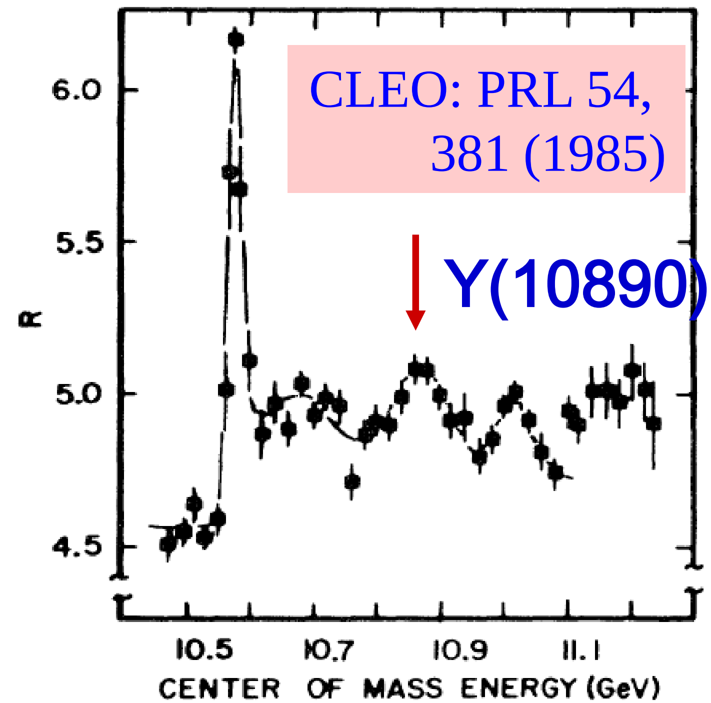
预研究！

Analogy ~ open threshold

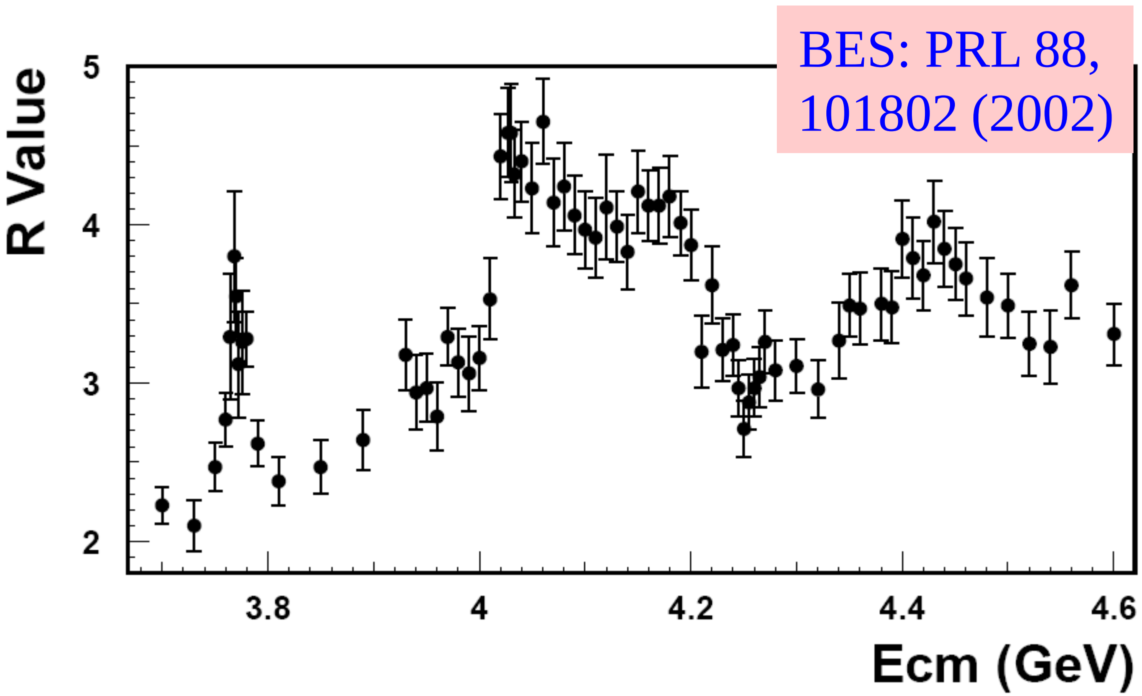


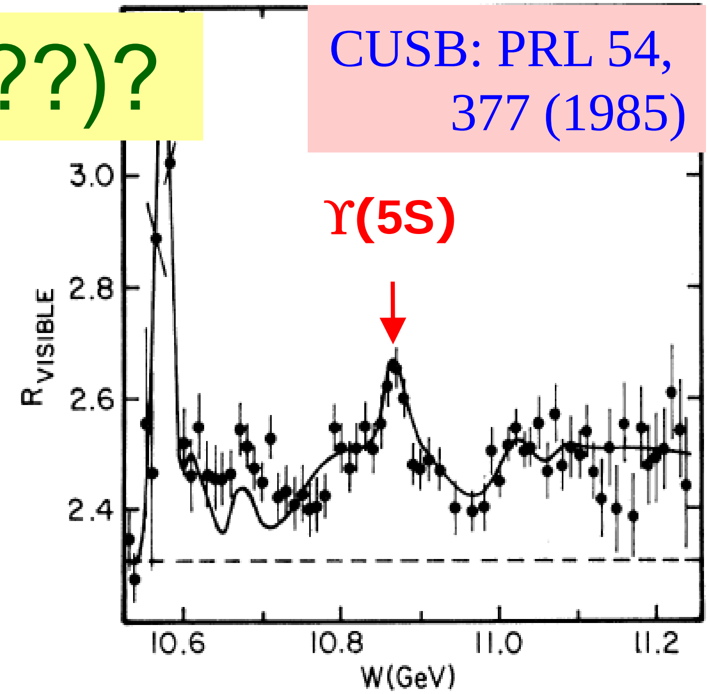


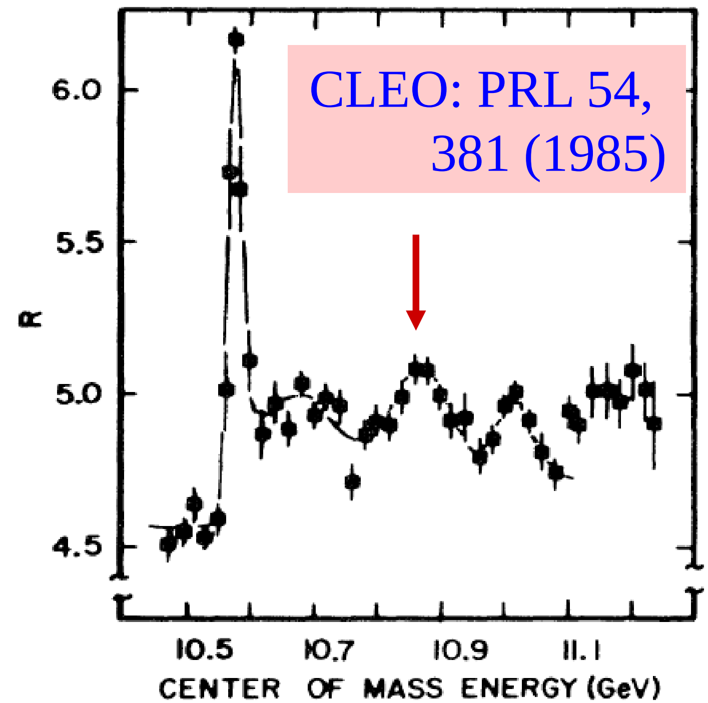




What are ϒ(5S), Y(4260), ϕ(??)?







We are exploring a mass region with many open-flavor thresholds!

Constructive interference between amplitudes?

Need more study!

Inclusive J/ψ at B-factories

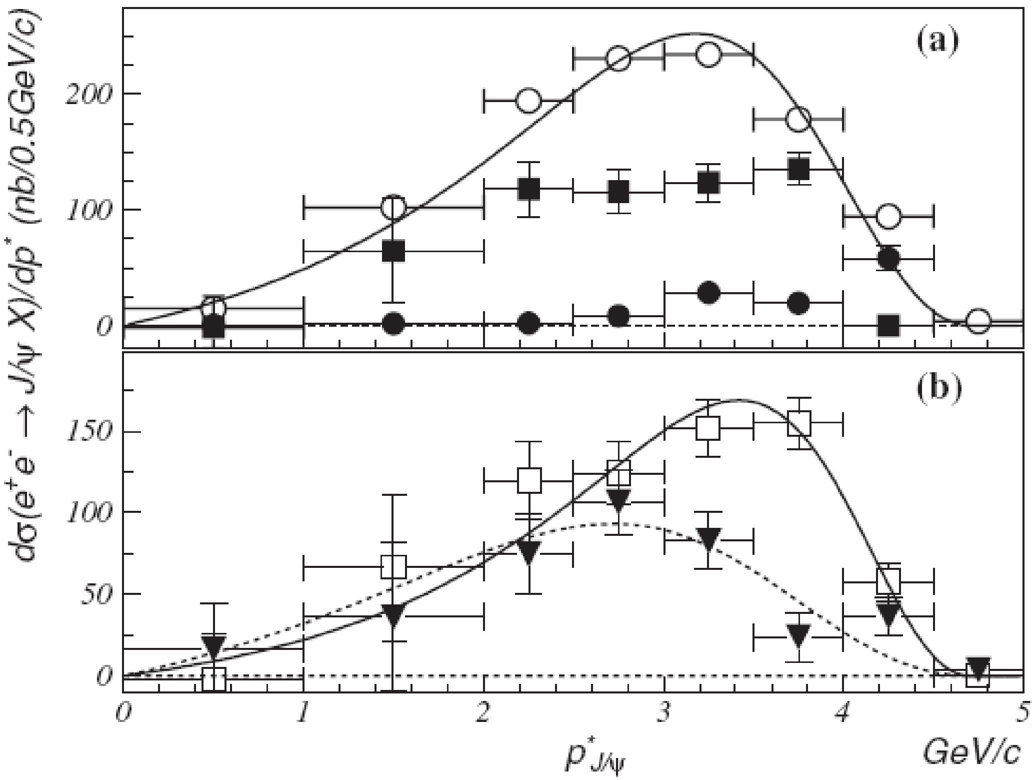


FIG. 3. $p^*_{J/\psi}$ spectra: (a) inclusive (open circles), from $e^+e^- \to J/\psi H_c X$ (filled squares) and from double charmonium production (filled circles); (b) the sum of all $e^+e^- \to J/\psi c\bar{c}$ processes (open squares), from the $e^+e^- \to J/\psi X_{\text{non-}c\bar{c}}$ processes (filled triangles). The fit results are shown in (a) for the inclusive spectrum, and in (b) for the processes $e^+e^- \to J/\psi c\bar{c}$ (solid curve) and $e^+e^- \to J/\psi X_{\text{non-}c\bar{c}}$ (dashed curve).

Belle:
PRD79, 071101 (2009)

Precisions can be further improved at Belle II.

Can momentum distribution be calculated?

Double charmonium at B-factories

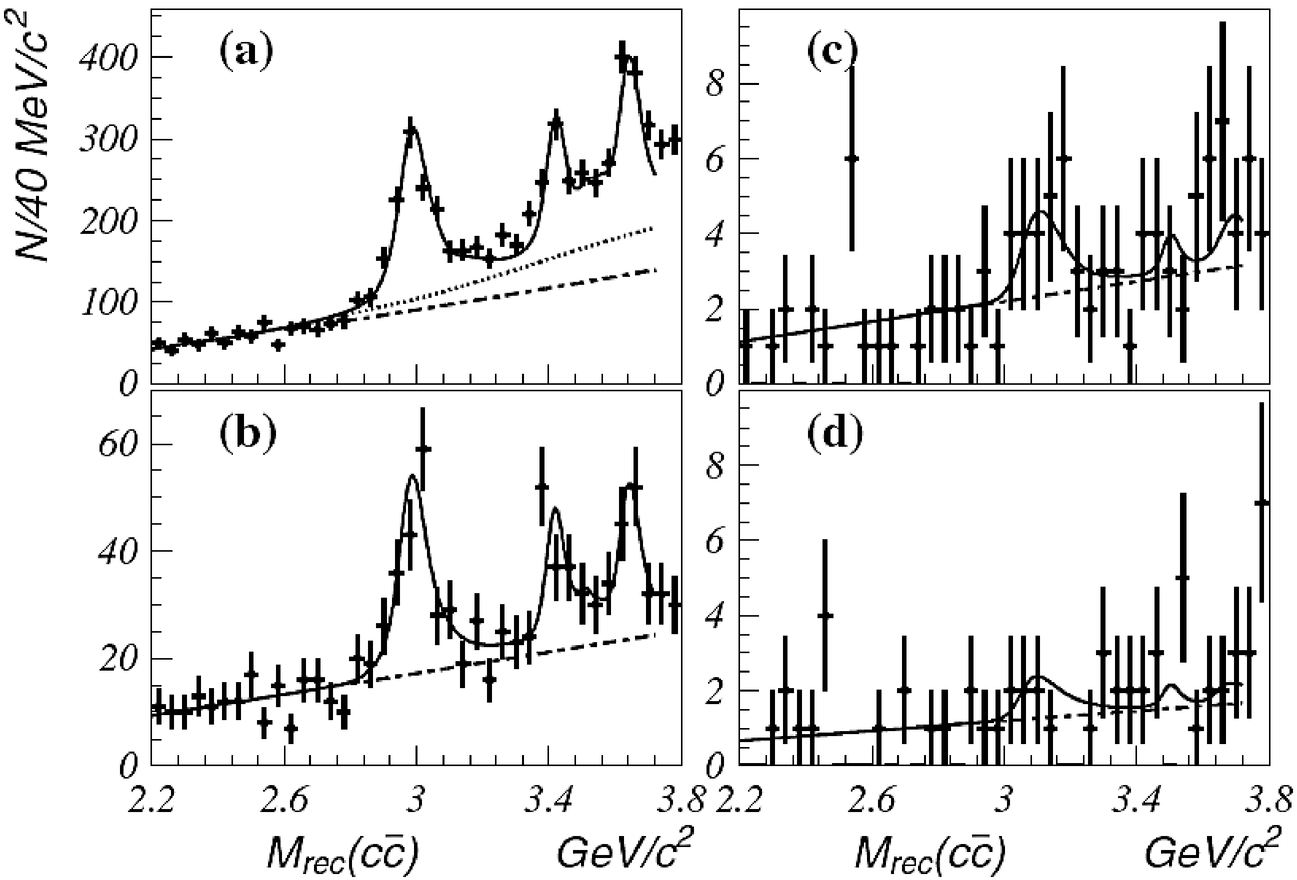


FIG. 1. The $M_{\rm rec}((c\bar{c})_{\rm tag})$ spectra: $(c\bar{c})_{\rm tag}$ = (a) J/ψ, (b) ψ', (c) χ_{c1}, and (d) χ_{c2}. The curves are described in the text.

Belle: PRD79, 071101 (2009)

Many calculations! NLO correction is different for different states.

Cross sections depends on charged-particle multiplicity (CPM) of charmonium decays.

CPM of η_c & χ_c can be measured at BESIII!

The "12% rule"

M. Appelquist and H. D. Politzer, PRL34, 43 (1975)

$$\Gamma_h = |M_h|^2 |\Psi(0)|^2$$

$$= (2/9\pi)(\pi^2 - 9)\tfrac{5}{18}\alpha_s{}^3(\tfrac{4}{3}\alpha_s)^3 m_{\varphi'}. \quad (3)$$

The leptonic width via one photon into $\bar{l}l$ is

$$\Gamma_l = |M_l|^2 |\Psi(0)|^2 = \tfrac{1}{2}(\tfrac{2}{3}\alpha)^2(\tfrac{4}{3}\alpha_s)^3 m_{\varphi'}, \quad (4)$$

where $\alpha \approx \frac{1}{137}$. Although separately these calculations are not trustworthy, the ratio

$$\frac{\Gamma_l}{\Gamma_h} = \frac{\frac{2}{9}\alpha^2}{(2/9\pi)(\pi^2 - 9)5/\alpha_s{}^3} \quad (5)$$

is independent of wave-function effects.

This is the famous (or notorious)

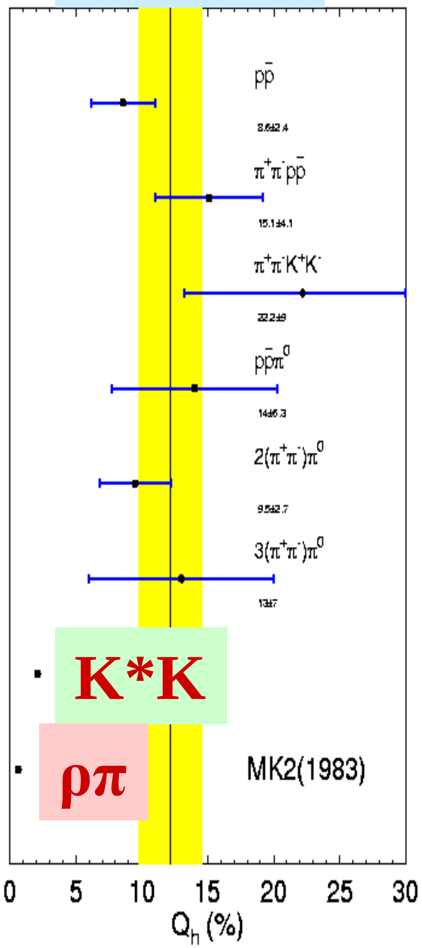
"12% rule".

It's 13% now, was 12%, 14%, or 15%.

$$Q_h = \frac{B_{\psi' \to X}}{B_{J/\psi \to X}} = \frac{B_{\psi' \to e^+e^-}}{B_{J/\psi \to e^+e^-}} = 12\%$$

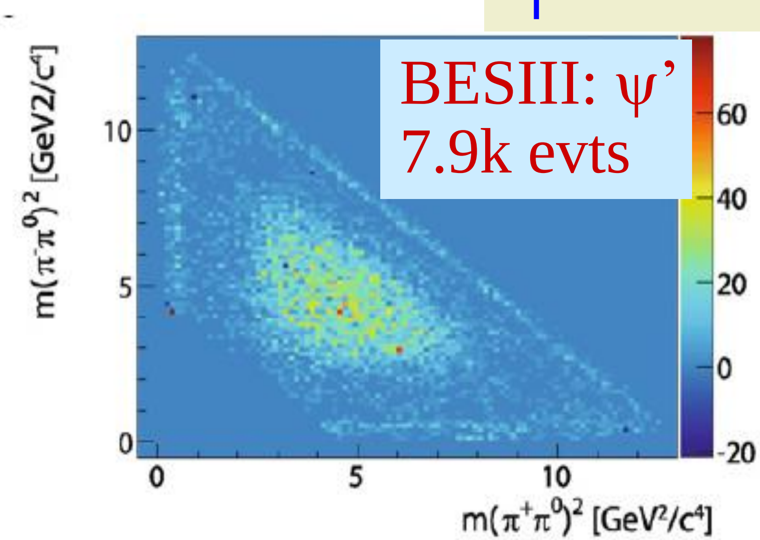
"12% rule" and "$\rho\pi$ puzzle"

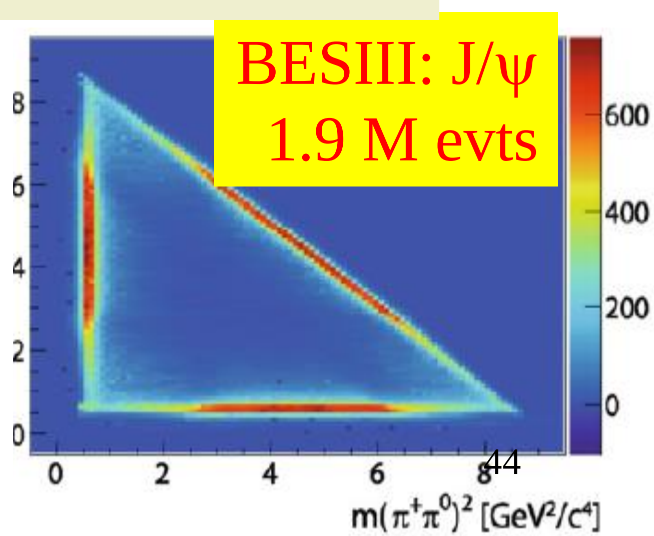
MARK-II



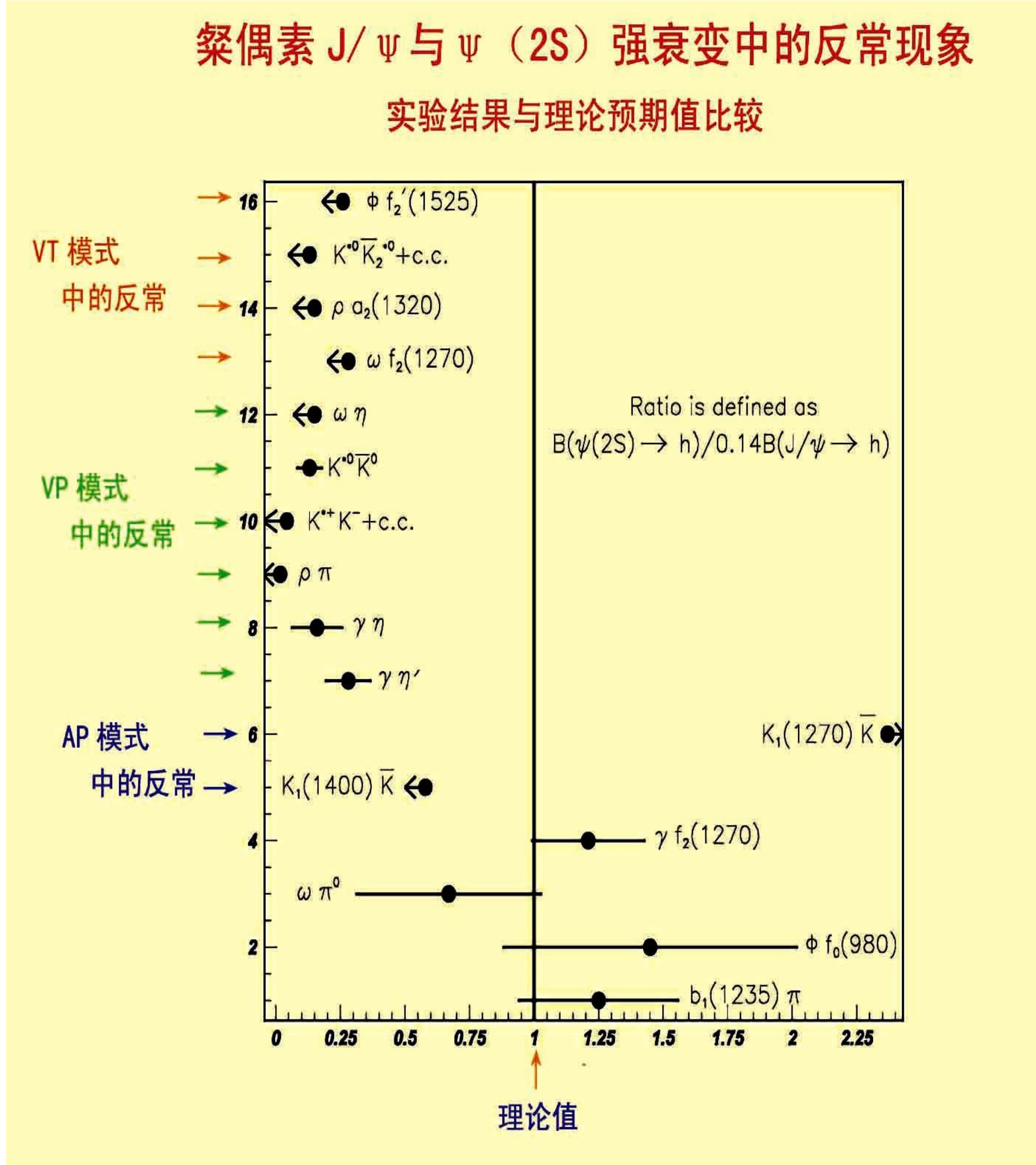
- Violation found by Mark-II , confirmed by BESI at higher sensitivity.
- Extensively studied by BESI/BESII/CLEOc
- More channels, higher precision at BESIII

$$\psi' \,/\, J/\psi \rightarrow \pi^+\pi^-\pi^0$$

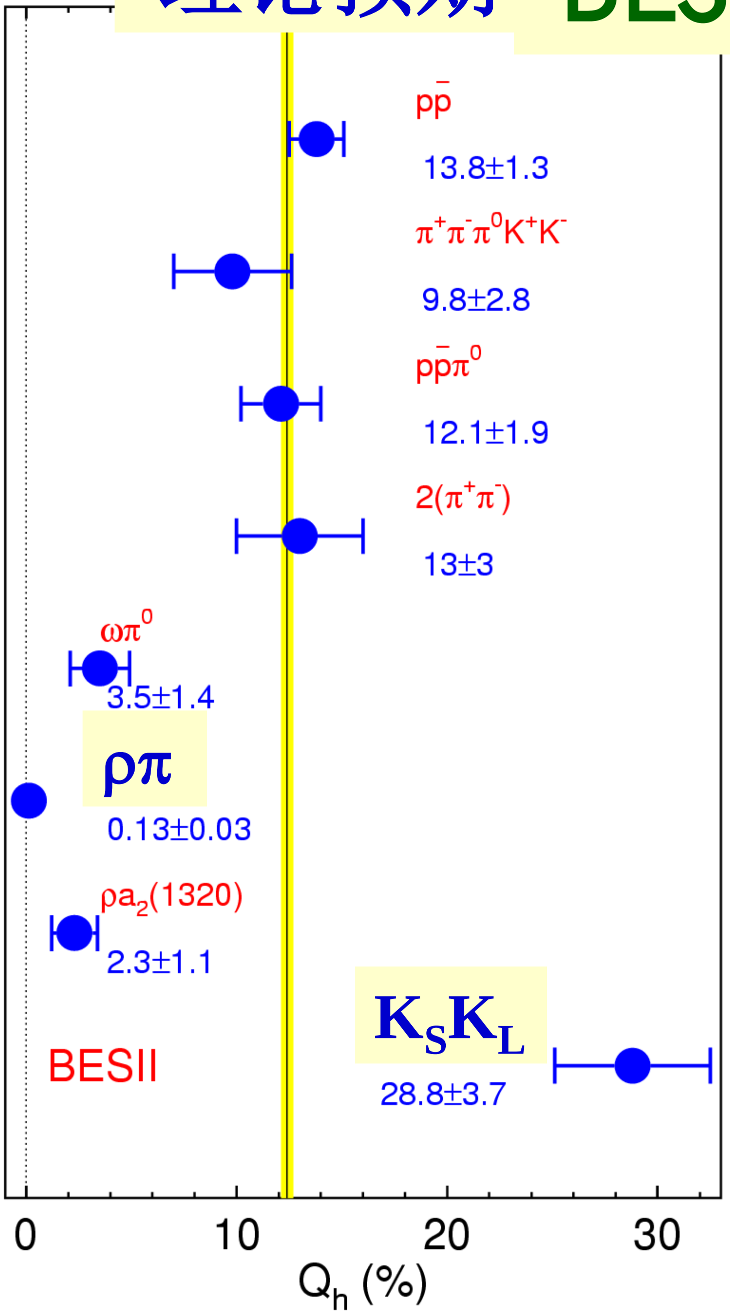




BESI studies of the
“12% rule”



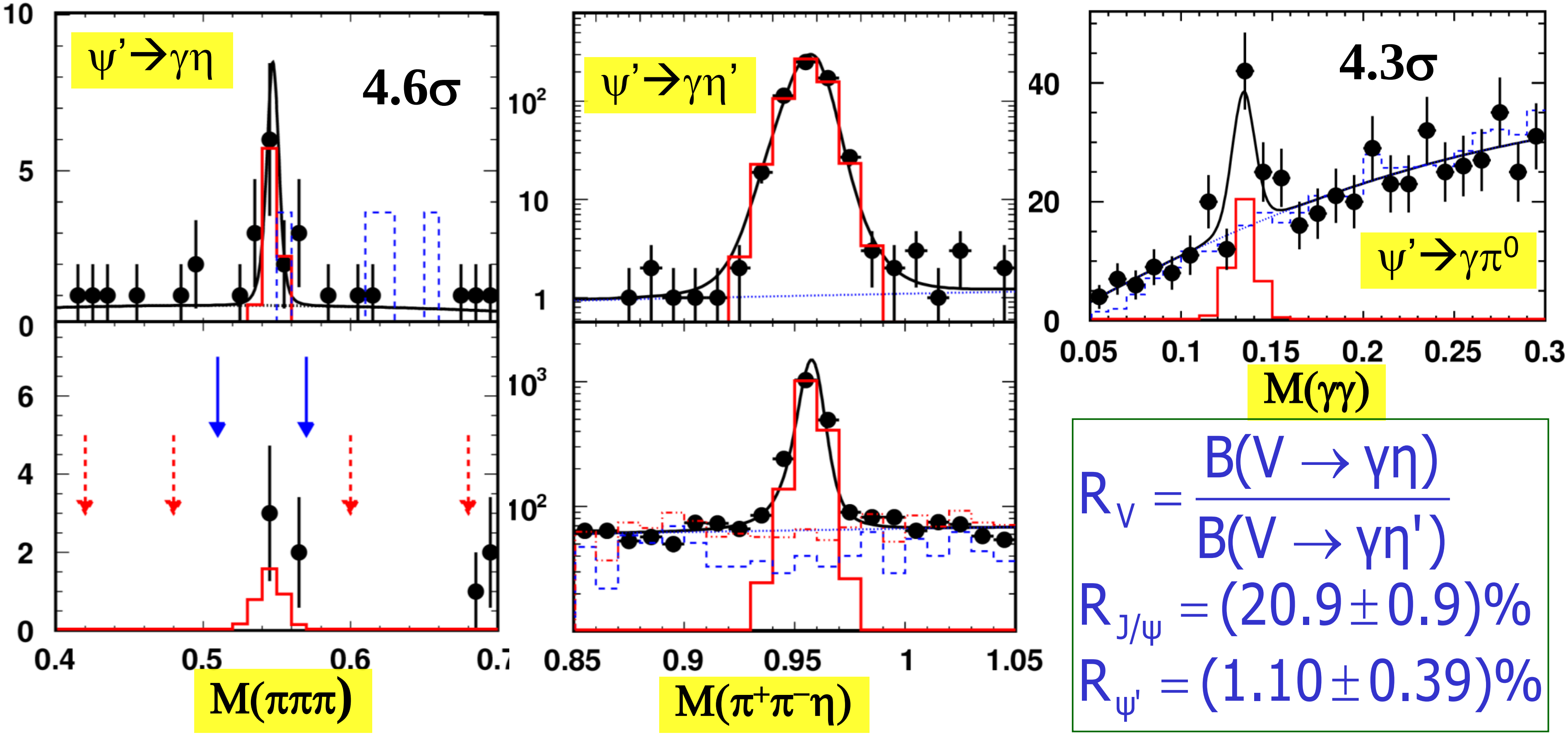
BESII: 强烈压低与反常增强



1. 多数过程满足“12%规则”
2. 首次观测到$\psi(2S)\rightarrow\rho\pi$，发现强烈压低；比“12%规则”压低近两个量级
3. 首次观测到$\psi(2S)\rightarrow VT$，发现中等压低；比“12%规则”压低几倍
4. 首次观测到$\psi(2S)\rightarrow K_S K_L$，相对于理论预期反常增强！

BESIII: J/ψ & ψ'→γπ⁰, γη & γη'

PRL105, 261801 (2010)



$$R_V = \frac{B(V \to \gamma\eta)}{B(V \to \gamma\eta')}$$

$$R_{J/\psi} = (20.9 \pm 0.9)\%$$

$$R_{\psi'} = (1.10 \pm 0.39)\%$$

Mode	B(ψ') [$\times 10^{-6}$]	B(J/ψ) [$\times 10^{-4}$]	Q (%)
$\gamma\pi^0$	1.58±0.42	0.35±0.03	4.5 ± 1.3
$\gamma\eta$	1.38±0.49	11.04±0.34	0.13 ± 0.04
$\gamma\eta'$	126±9	52.8±1.5	2.4 ± 0.2

Interpretation by Q. Zhao, PLB697, 52 (2011)

Extension of the "12% rule" to ψ''

- In Potential model, if J/ψ, ψ', and ψ'' are pure 1S, 2S, and 1D states, one expects [PDG2012]

$$Q_h = \frac{B_{\psi' \to X}}{B_{J/\psi \to X}} = \frac{B_{\psi' \to e^+e^-}}{B_{J/\psi \to e^+e^-}} = (13.0 \pm 0.3)\%$$

$$Q'_h = \frac{B_{\psi'' \to X}}{B_{J/\psi \to X}} = \frac{B_{\psi'' \to e^+e^-}}{B_{J/\psi \to e^+e^-}} = (1.63 \pm 0.12) \times 10^{-4}$$

- but ψ' and ψ'' are known not pure 2S and 1D states

  PRD17, 3090 (1978); 21, 203 (1980); 41, 155 (1990); …
- Let's look at data …

J/ψ, ψ', $\psi'' \to \rho\pi$

- Partial width of ψ″→ρπ is larger than that of ψ′→ρπ!
- hard to understand if ψ″ is pure 1D state, also hard if ψ″ is 2S and 1D mixture.

$$\Gamma(J/\psi \to \rho\pi) \approx 2.1keV$$

$$\Gamma(\psi' \to \rho\pi) \approx 0.014keV$$

$$\Gamma(\psi'' \to \rho\pi) \approx 50keV$$

or

$$\Gamma(\psi'' \to \rho\pi) \approx 0.6keV$$

$$\frac{B(\psi' \to \rho\pi)}{B(J/\psi \to \rho\pi)} = (0.13 \pm 0.05)\%$$

$$Q_e = 13.0\%$$

$$\frac{B(\psi'' \to \rho\pi)}{B(J/\psi \to \rho\pi)} = (9.0 \pm 1.6)\%$$

or

$$\frac{B(\psi'' \to \rho\pi)}{B(J/\psi \to \rho\pi)} = (0.10^{+0.15}_{-0.09})\%$$

$$Q'_e = 0.016\%$$

In S-D mixing model, using mixing angle θ=12°, using Rosner's assumption (12% rule for 1S and 2S), one predicts $Q'_{\rho\pi}$ =(2.7-5.3)% !

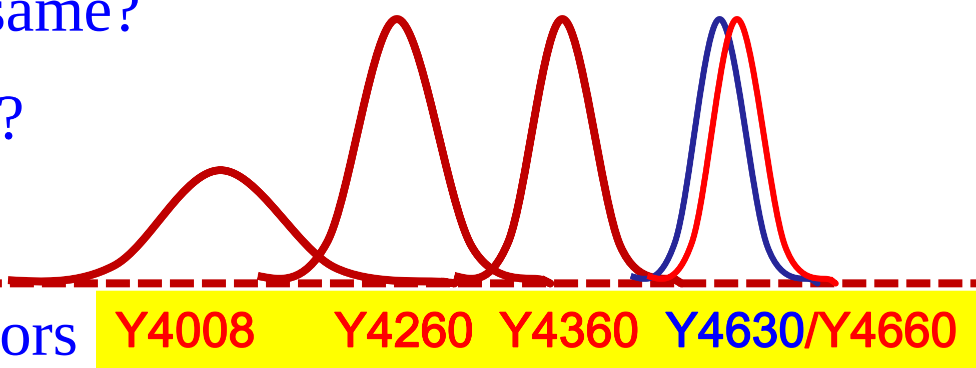
ϕ≠-90° or imperfect model?

Y 相关研究

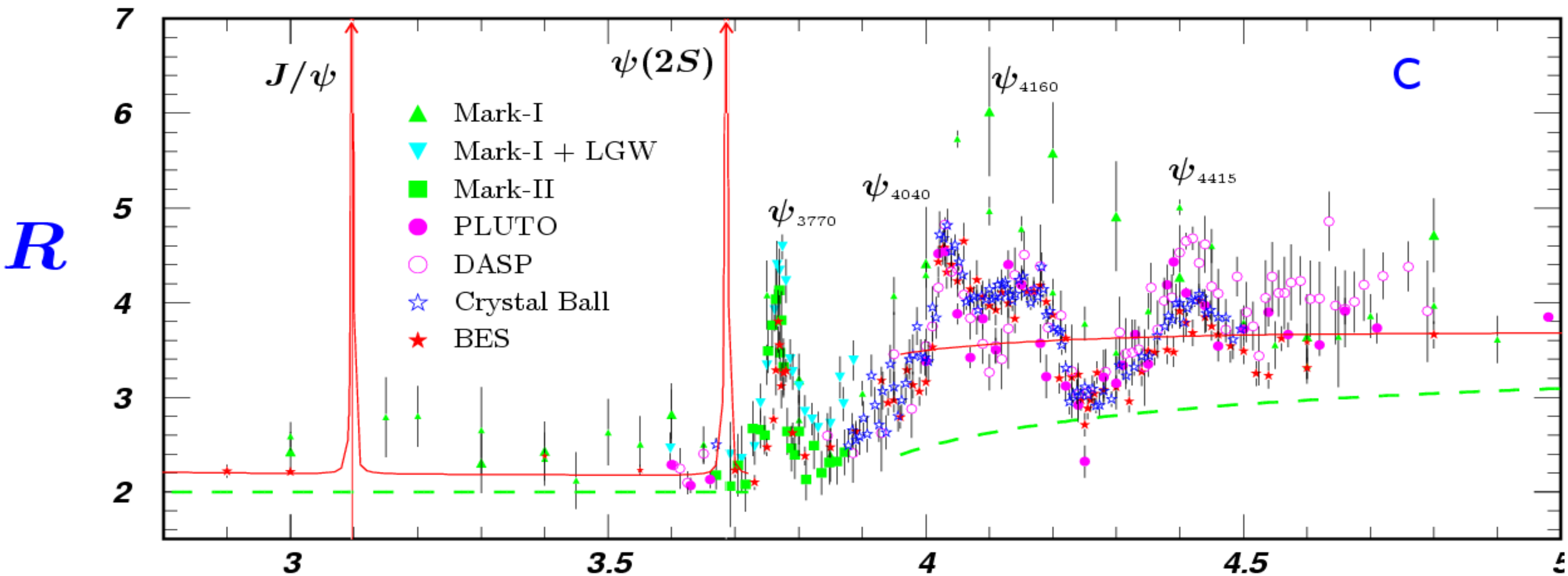
- **4 GeV以上大亮度精细扫描** （2014年提出取数计划）
  - Ecm = 4.0 - 4.7 GeV, 每10 MeV, 0.5 fb^{-1}= 70个点，35 fb^{-1}
  - 已采集 Ecm=4.01, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25, 4.26, 4.27, 4.36, 4.42, 4.60 GeV共14点
  - 还需要 28 fb^{-1}

关键问题:

1. What is the Y(4220), is it a hybrid state?
2. Are the Y(4630) & Y(4660) the same?
3. What is the nature of these states?
4. Other Y states beyond 4.7 GeV?
5. Coupled channel analysis of vectors



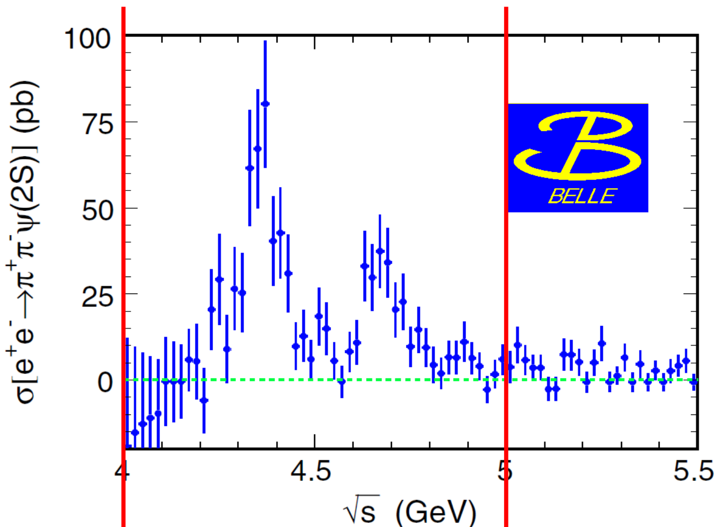
我们需要 ~70 fb^{-1} 数据研究 XYZ 粒子



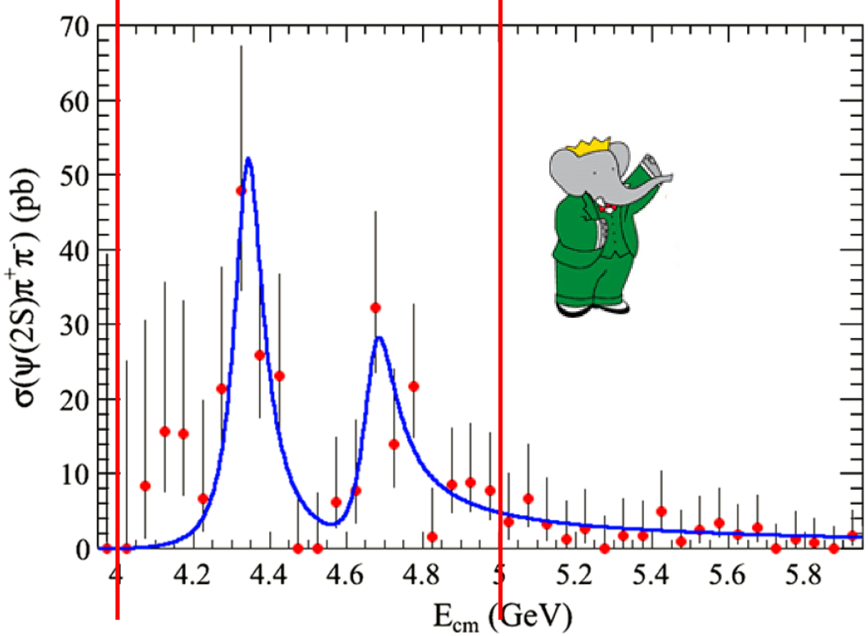
- On X states
  - Nature of X(3872); Production of other X states
- On Y states
  - Is Y(4220) an exotic state? Are there other Y/ψ states?
- On Z states
  - Argand plots of Zc(3900), Zc(4020), Zc(4030); Production and decays of them
  - Search for Zcs states with data at ~4660, 4790, or 4900 MeV

Y(4630) and Y(4660)

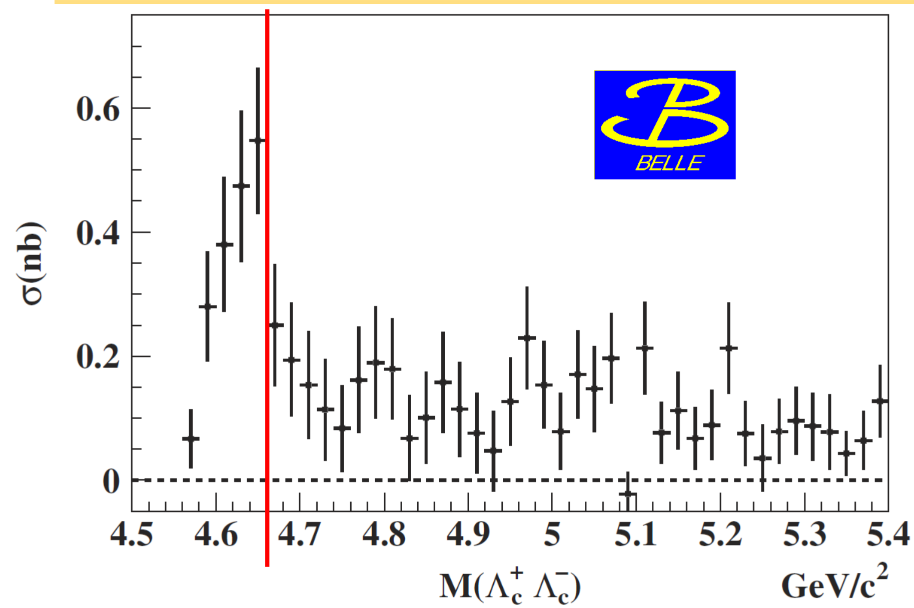
Belle: PRD91, 112007 (2015), 980/fb
BaBar: PRD89, 111103 (2014), 520/fb



PHYSICAL REVIEW D **89,** 111103(R) (2014)



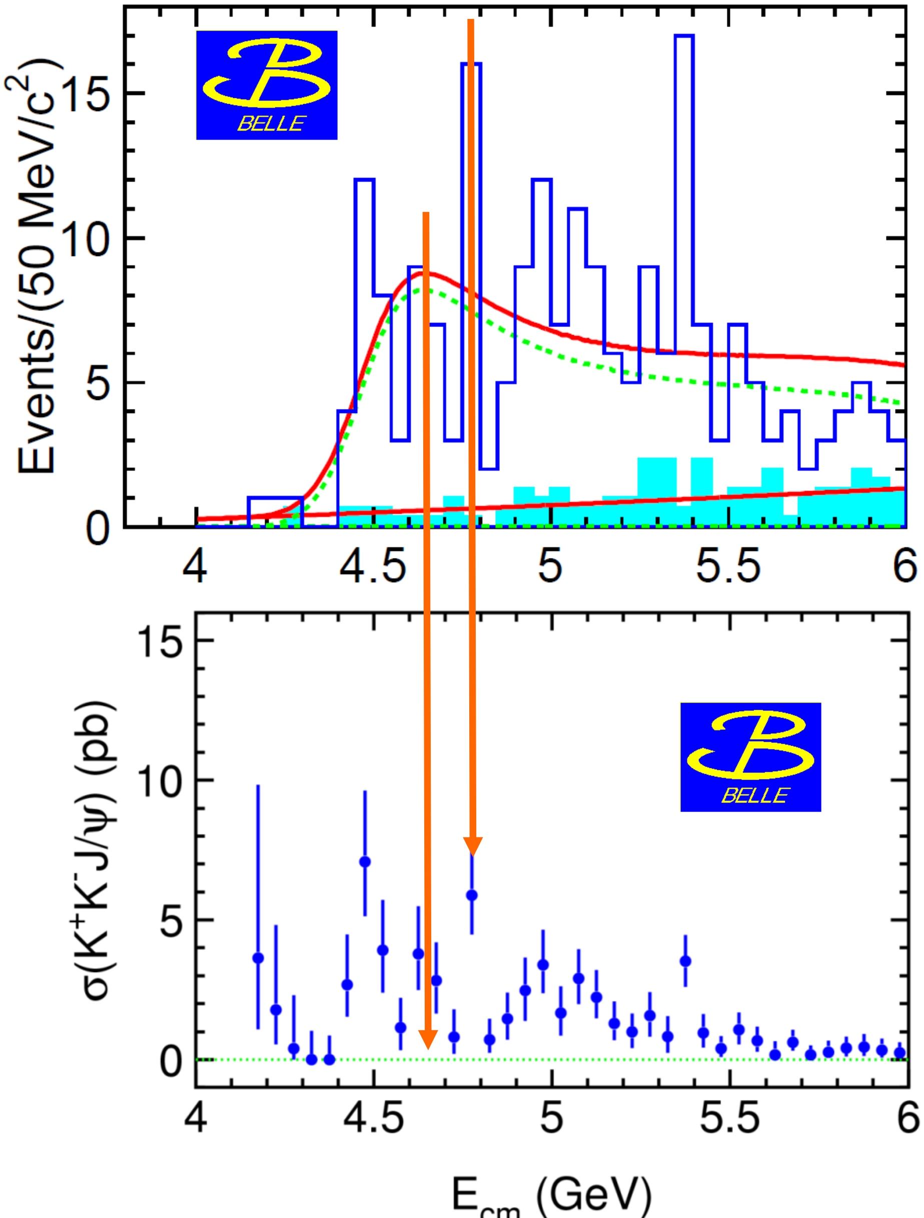
Belle: PRL101, 172001 (2008), 695/fb



Experiment	Mass (MeV)	Width (MeV)
Belle, Y(4630)	$4634^{+8}_{-7}{}^{+5}_{-8}$	$92^{+40}_{-24}{}^{+10}_{-21}$
Belle, Y(4660)	4652±10±8	68±11±1
Babar,Y(4660)	4669±21±3	104±48±10

Y-states in $e^+e^- \to K^+K^-J/\psi$

PRD 89,072015(2014), 980 fb^{-1}

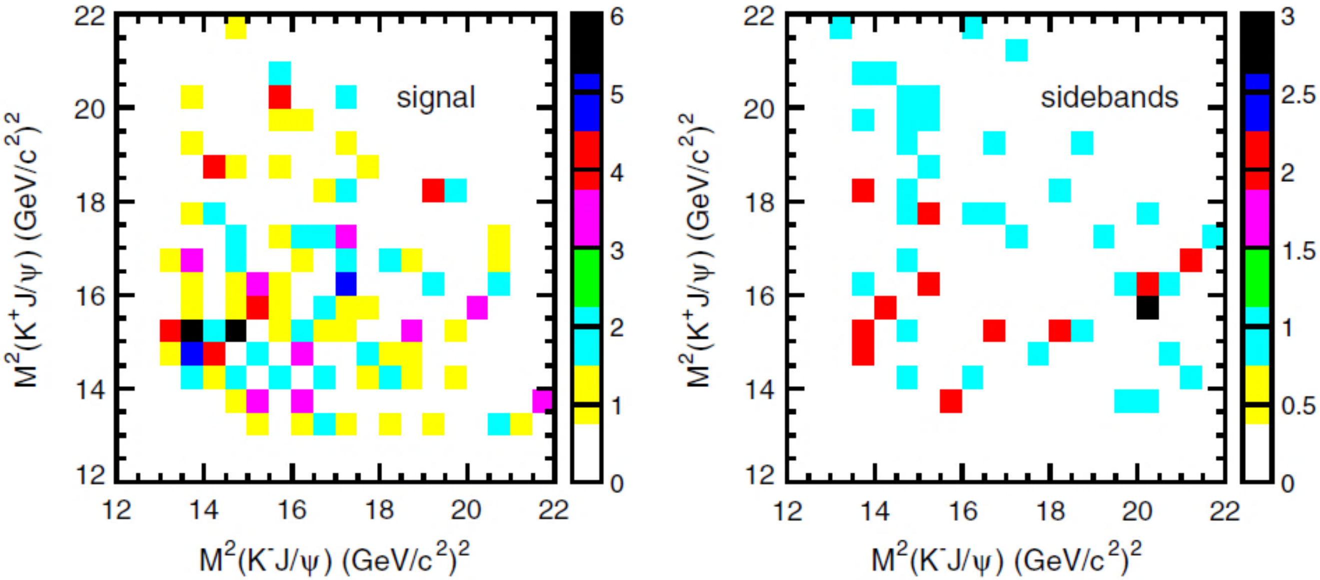


4-6 GeV: 213 events
35 bkg, 178±16 signal

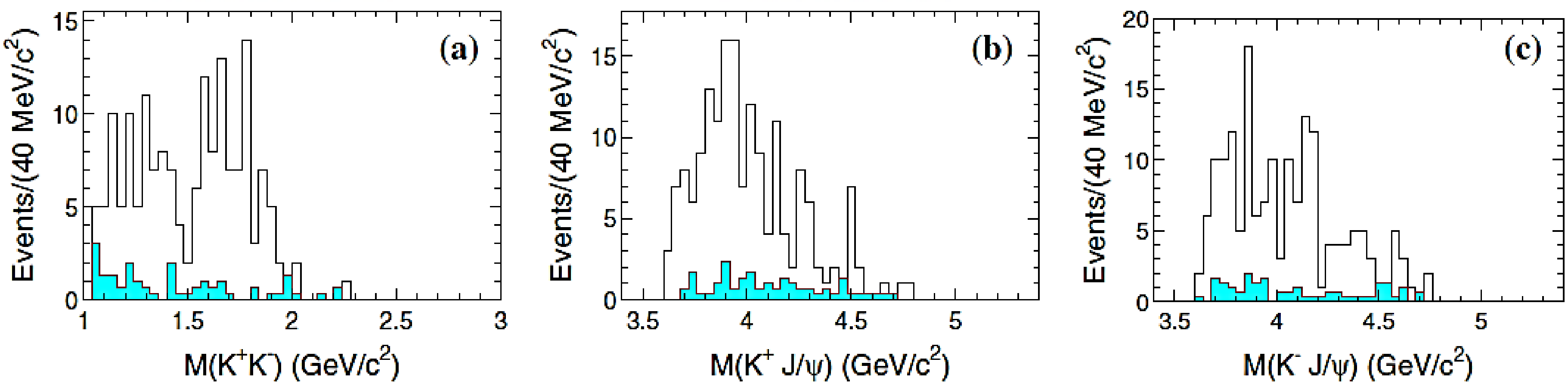
- Evidence for $Y(4660) \to K^+K^-J/\psi$
- Is the one bin jump in 4.75-4.80 GeV a genuine signal?
- Thresholds of charmed-strange meson pairs

Search for $Z_{cs} \rightarrow KJ/\psi$ states

PRD 89, 072015(2014)

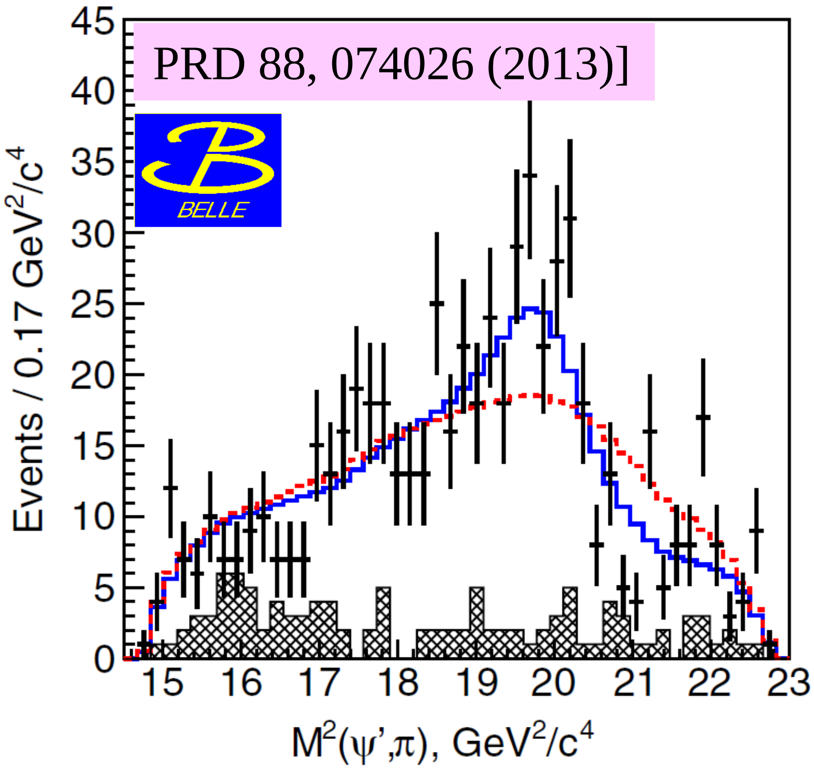


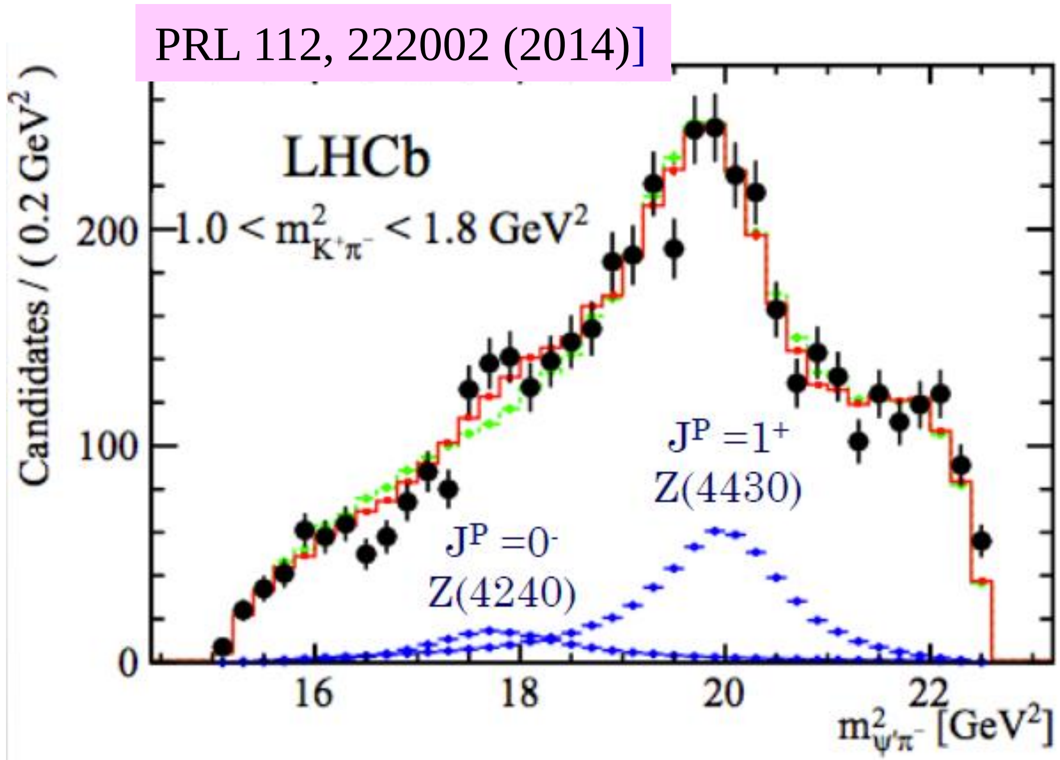
Large data samples at Belle II are needed to understand KJ/ψ and KKJ/ψ structures !



No evident structure in $K^{\pm}J/\psi$ mass distribution under current statistics

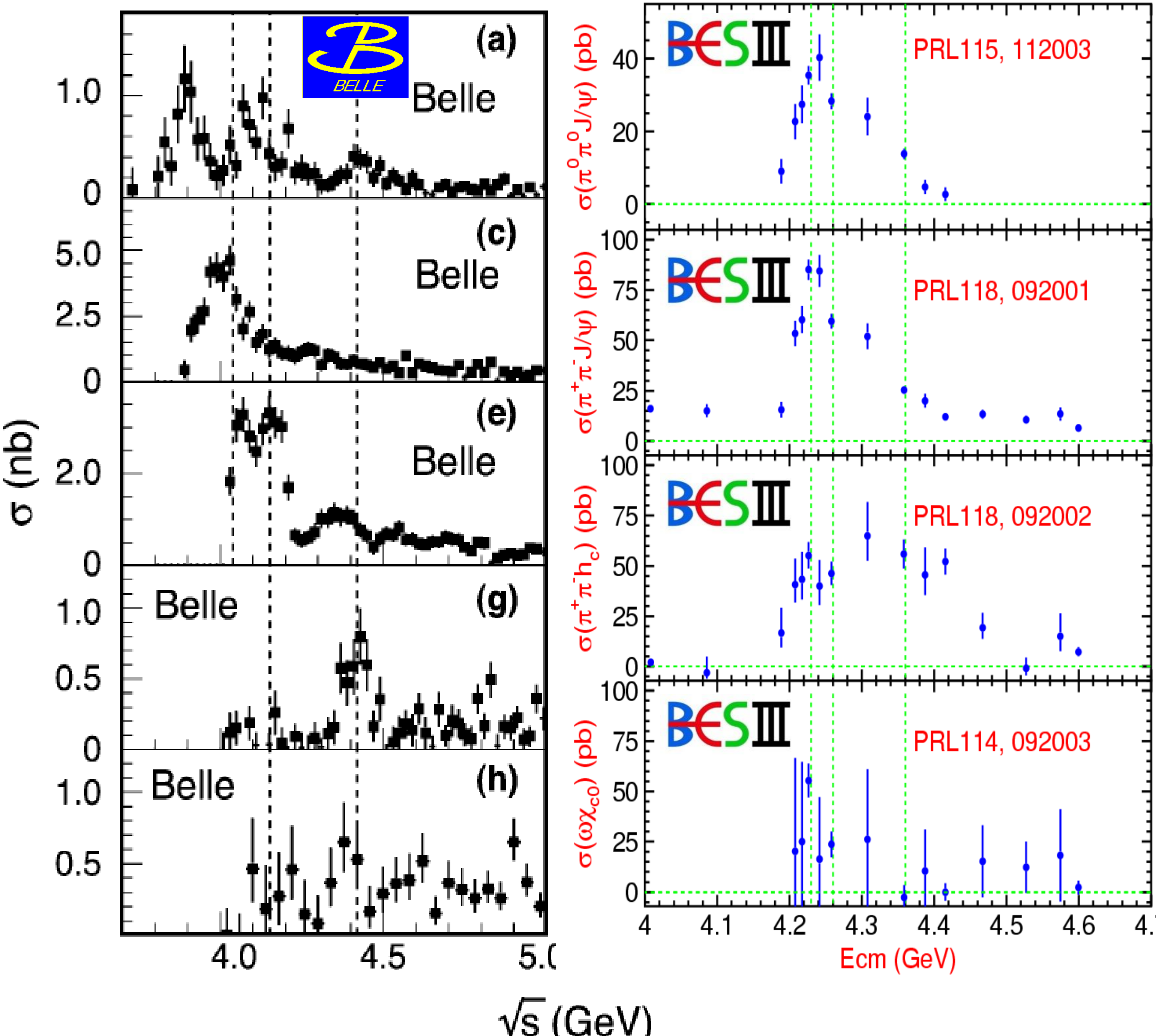
Search for $Z_c(4430) \rightarrow \psi'\pi$ at > 4.8 GeV





Experiment	Mass (MeV)	Width (MeV)
Belle	$4485 \pm 22^{+28}_{-11}$	$200^{+41}_{-46}{}^{+26}_{-35}$
LHCb	$4475 \pm 7^{+15}_{-25}$	$172 \pm 13^{+37}_{-34}$

Threshold from $e^+e^- \rightarrow \pi\, Z(4430) = 4480+200+140 = 4820$ MeV



Left:

a: $\bar{D}D$

c: $\bar{D}D^*$

e: $\bar{D}^*D^*$

g: $\bar{D}D\pi$

h: $\bar{D}D^*\pi$

Right:

$\pi^+\pi^- J/\psi$

$\pi^+\pi^- J/\psi$

$\pi^+\pi^- h_c$

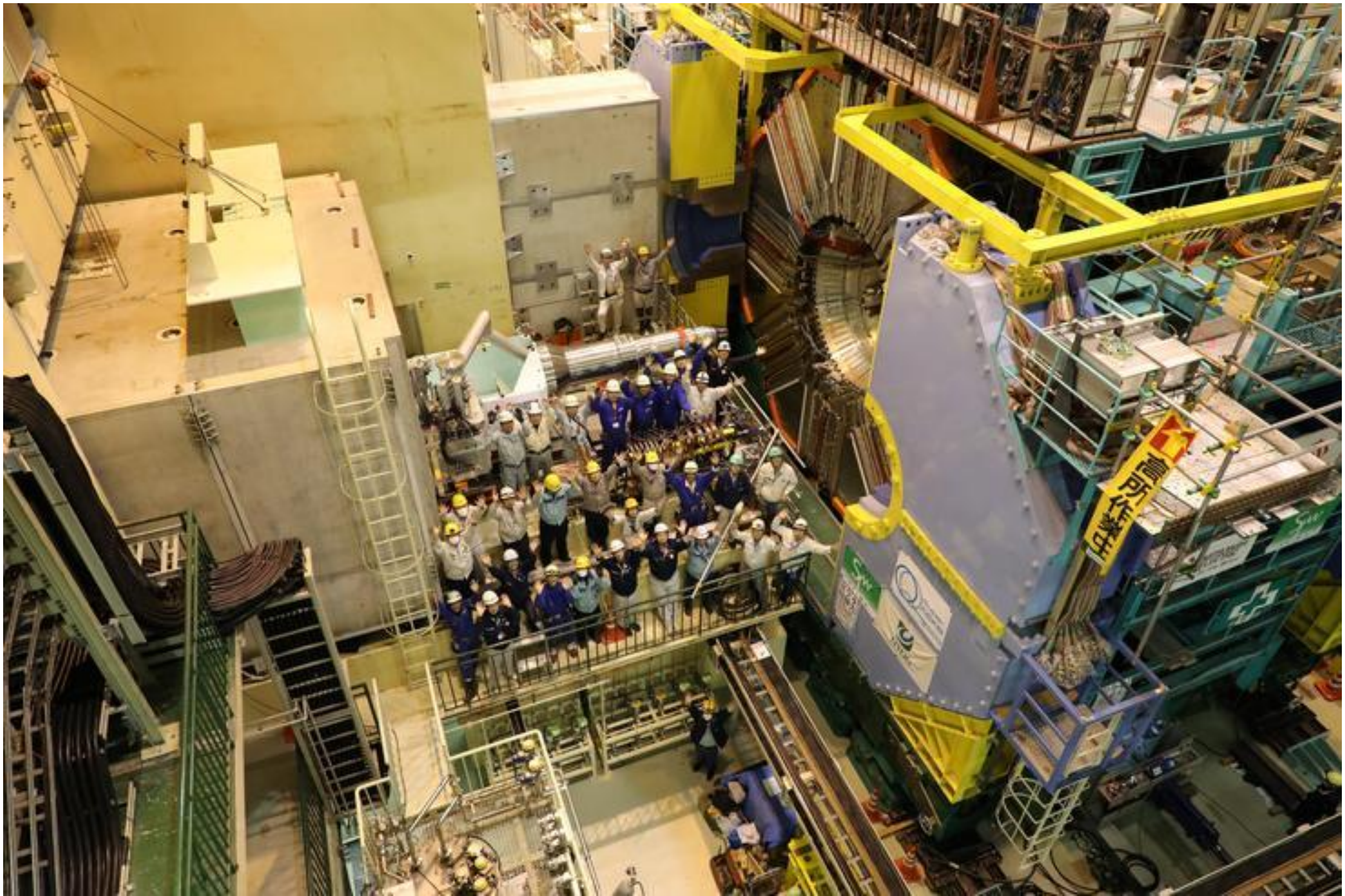
$\omega\chi_{c0}$

Very rich structure!

Is $\bar{c}cg$ already there?

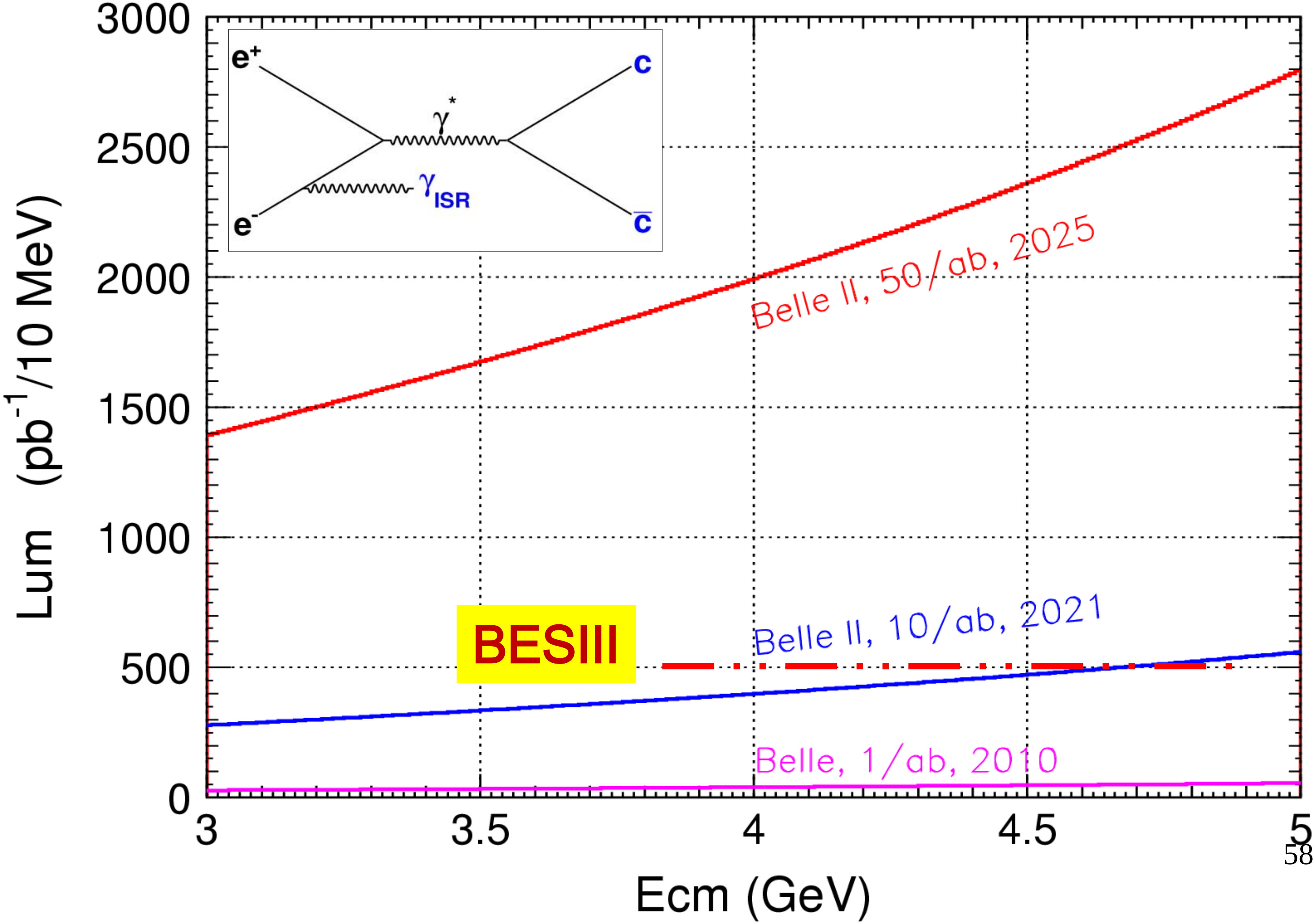
Belle II 探测器推入对撞点

2017年4月11日14:51，进入对撞点，2019年初取数！



Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach



Belle II vs. BESIII in XYZ study

Full Belle II data sample (50 ab^{-1} at 10.58 GeV, ISR events in 10 MeV) compared with 0.5 fb^{-1} at BESIII

ISR mode	$L_{BESIII}/L_{Belle\ II}$	$\varepsilon_{BESIII}/\varepsilon_{Belle\ II}$	$N_{BESIII}/N_{Belle\ II}$
$\pi^+\pi^- J/\psi$ @ 4.26 GeV	0.5 fb^{-1} / 2.2 fb^{-1}	46% / 10%	1.07
$\pi^+\pi^-\psi'$ @ 4.36 GeV	0.5 fb^{-1} / 2.3 fb^{-1}	41% / 5%	1.82
@ 4.66 GeV	0.5 fb^{-1} / 2.5 fb^{-1}	35% / 6%	1.19
$\pi^+\pi^- h_c$ @ 4.26 GeV @ 4.36 GeV	0.5 fb^{-1} / 2.2 fb^{-1}	2.7% / —	> 5
$K^+K^- J/\psi$ @ 4.6 GeV	0.5 fb^{-1} / 2.4 fb^{-1}	29% / 7.5%	0.81
@ 4.9 GeV	0.5 fb^{-1} / 2.7 fb^{-1}	~29% / 10%	0.54
$\Lambda^+_c \Lambda^-_c$ @ 4.6 GeV	0.5 fb^{-1} / 2.4 fb^{-1}	51% / 7.5%	1.42
@ 4.9 GeV	0.5 fb^{-1} / 2.7 fb^{-1}	~37% / 7.5%	0.91