
Discovery of $Z_c(3900)$

Yuping Guo (郭玉萍)

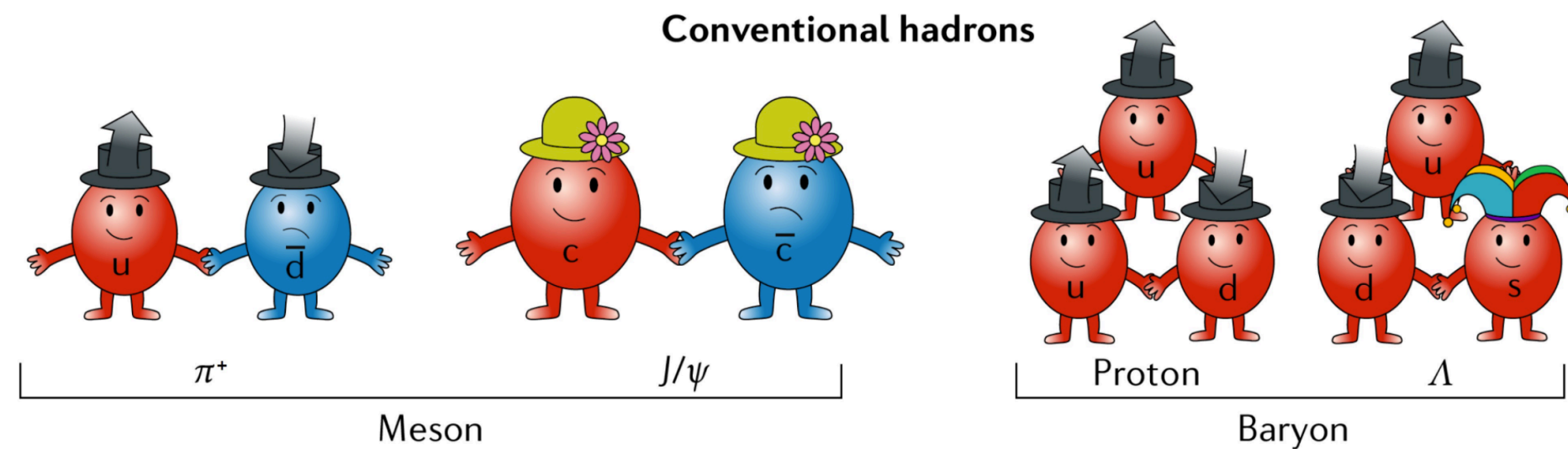
Fudan University

BESIII Celebration Ceremony of the 500 Publications of BESIII Collaboration

2023.05.31 IHEP

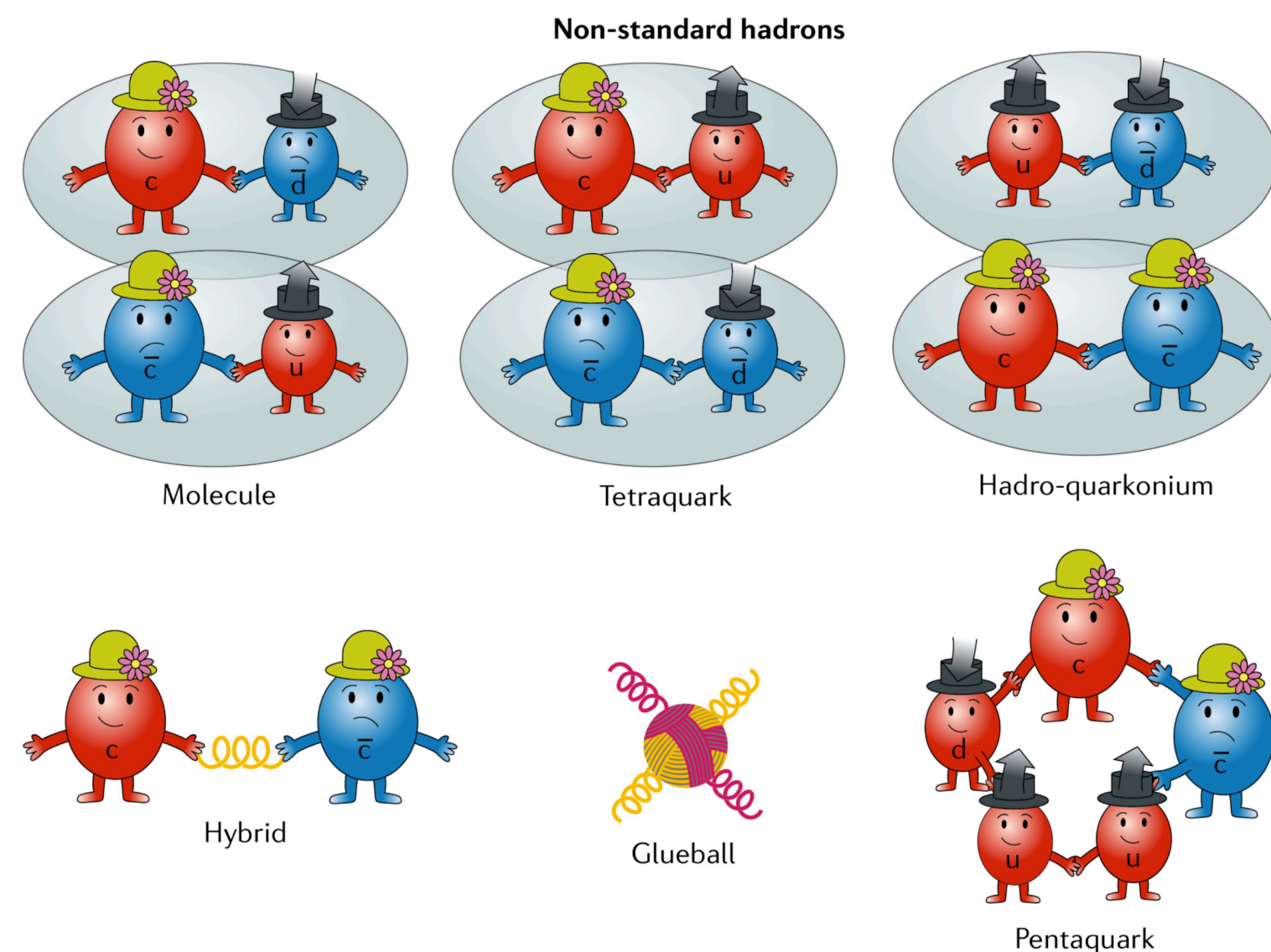
Hadrons and exotic hadrons

- * Conventional hadrons: Meson (a pair of quark-antiquark) & Baryon (three quarks)



quark model - lowest configuration

- * Exotic hadrons

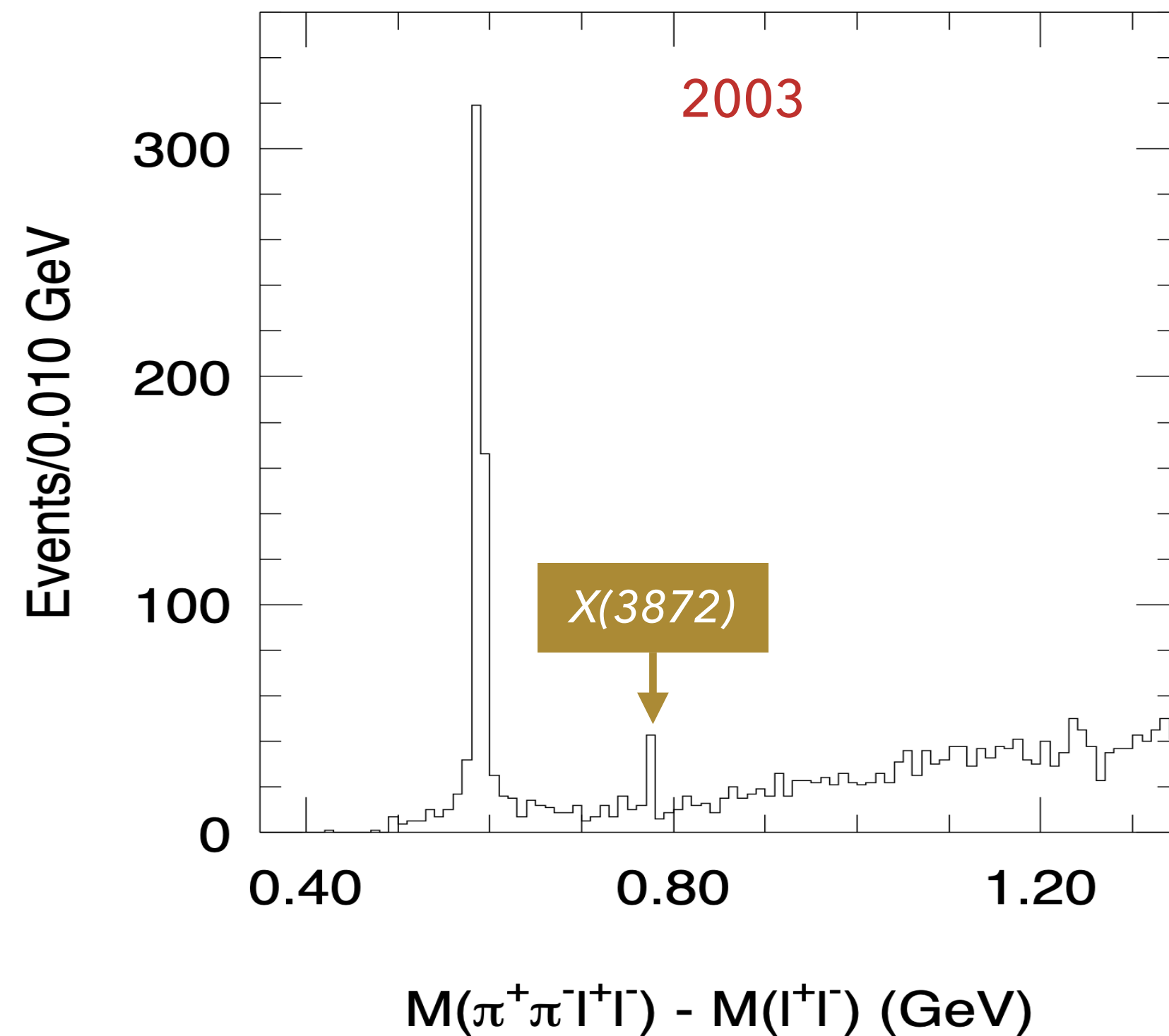


Long history of experimental efforts, no unambiguous examples of light hadrons with exotic nature

- No solid signature of bluebells
- Pentaquark state Θ^+ appeared and disappeared
- With exotic quantum numbers
- With normal quantum numbers: hard to distinguish between conventional and exotic
- ▶ Need clear signature: e.g. charged + heavy quarkonium in the final state

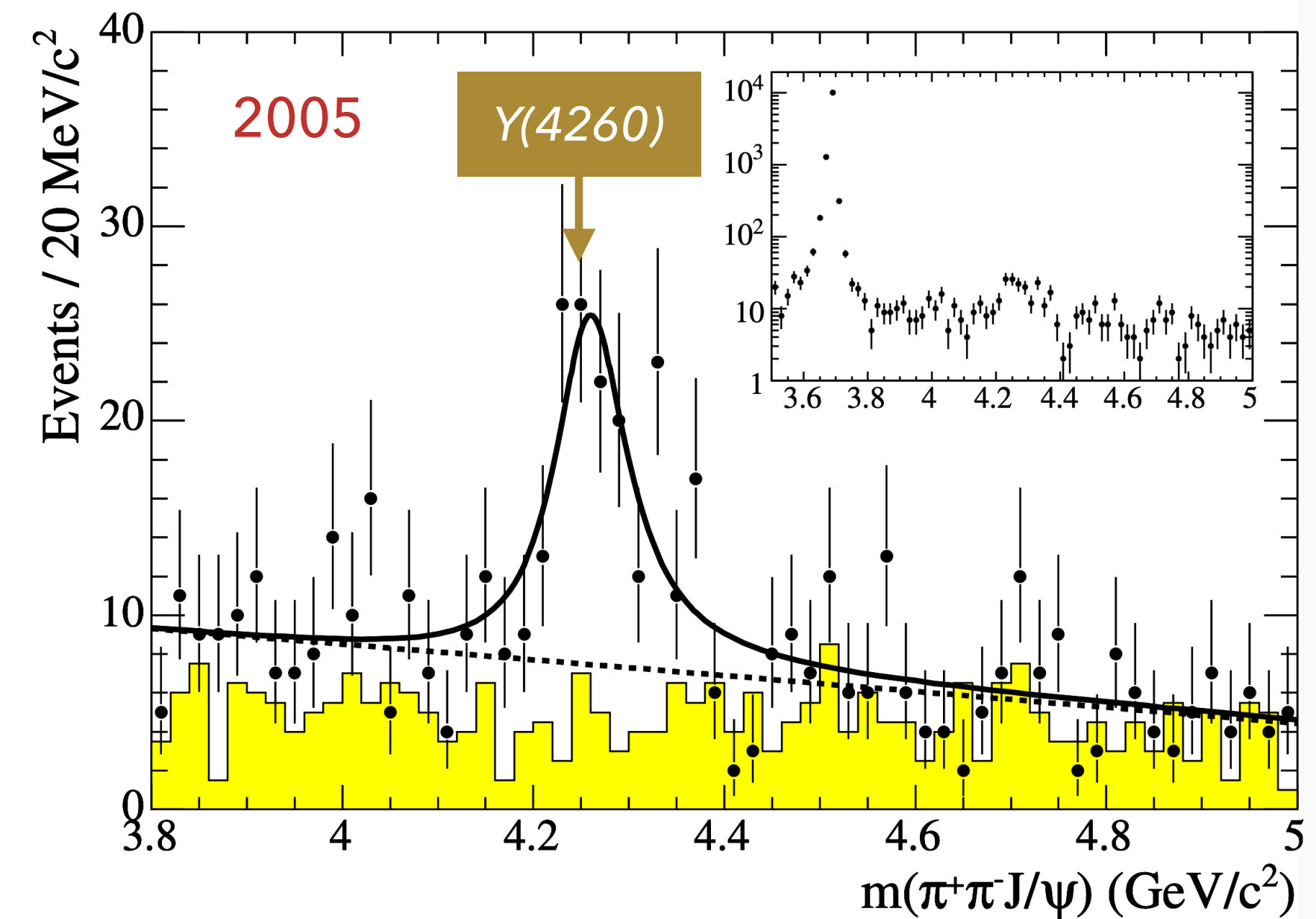
Breakthrough in $Q\bar{Q}$ system

- * Discovery of the $X(3872)$ by Belle



PRL91, 261001 (2003) published 2003 December 23

- * Discovery of the $Y(4260)$ by BaBar



PRL95, 142001 (2005) published 2005 September 28

$\psi(4040)$ data

- * Proposed on 03 June 2010 [*Shenyang*]

Two important issues

- Find excited charmonium states
 - 2P states χ'_{cJ} via $\psi(4040)$ radiative transition
 - S-wave spin-singlet (M1 transition, very hard)
- Understand C-even XYZ
 - Can be produced in $\psi(4040)$ radiative decays
 - For example: inclusive photon spectrum
 - $X(3872) \rightarrow \pi\pi J/\psi, \pi\pi\pi J/\psi, \dots$
 - $XYZ(3940) \rightarrow \omega J/\psi, D\bar{D}, D\bar{D}^*, \dots$
 - $X(3915) \rightarrow \omega J/\psi, \dots$

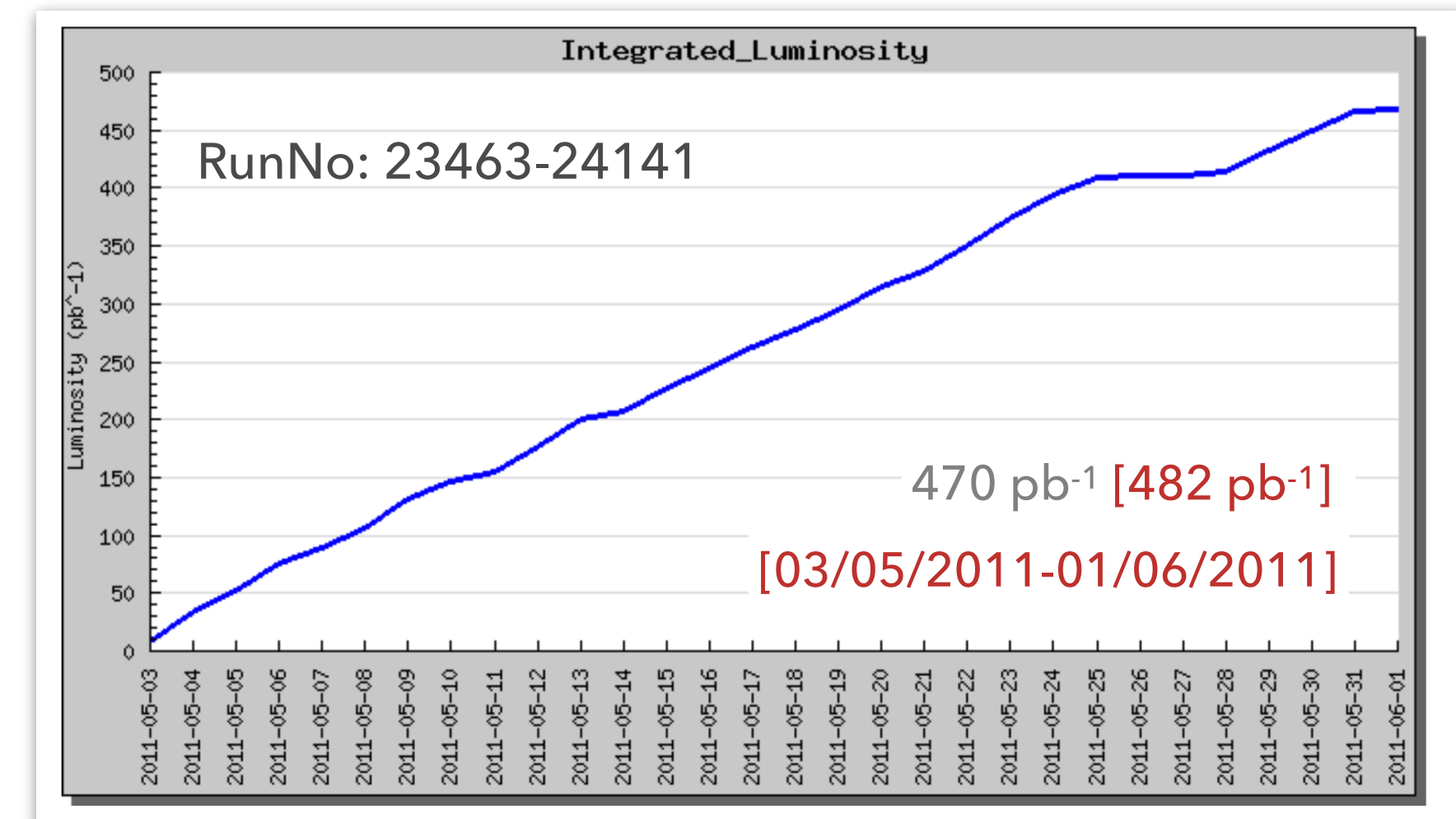
We propose to do these with $\psi(4040)$ data! 6

- * Approved on 25 October 2010 [*IHEP*]

Data taking plan

- **Debugging the BEM system (1 week)**
- **360 pb⁻¹ @ $\psi(4040)$ (1-2 months)**
 - If full energy injection OK
- **1.5 fb⁻¹ @ $\psi(3770)$ (3-4 months)**
- **Tau mass scan(10 days)**

- * Data accumulation



- * Dedicated working group formed
[*first meeting on 17 November 2010*]

- Regular discussion (every two weeks)
- Hadronic transition, radiative transition, and open charm pair production [also D_s physics]
 - ▶ Benchmarks for key processes
 - ▶ Confidence at higher E_{cm}

Data sample at higher energies

- * Initial plan: 600 pb⁻¹ at 6 points from 4210 to 4460 MeV [30/11/2011, IHEP]
- * XYZ working group for sensitivity study
- * Modified to 500 pb⁻¹ each at 2 points, 4260 and 4360 MeV [01/03/2012-IHEP, 10/06/2012-Soochow]

Proposal to Study Decays of the Y(4260) and Y(4360)

We request 500pb⁻¹ (or more) of data at 4260 MeV and 4360 MeV to study decays of the Y(4260) and Y(4360) (*total of ~106 days**).

* based on 4010 running time with
3/4 the current (from Qing Qin's talk)

1. To learn about the Y(4260) and Y(4360).

*(Their masses and widths have been established --
branching ratios are now needed to further explore their composition.)*

Proposed

2. To search for new states in Y(4260) and Y(4360) decays.

Data taking plan for next run

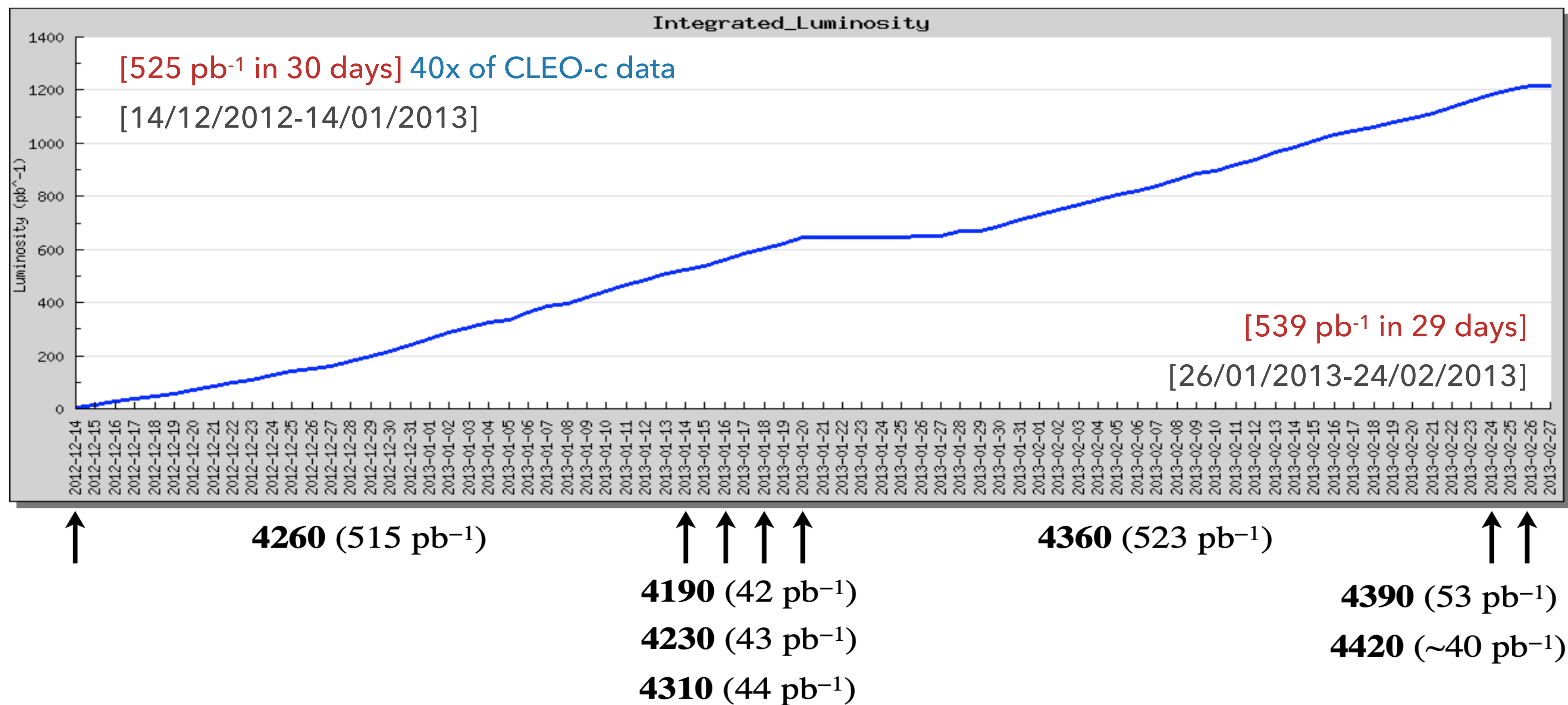
If the machine is able to run @ high mass energy

- 0.5 fb⁻¹ @ 4260 MeV (~50 days)
- tau scan (~15 days) ? (understand BEMS well)
- 0.5 fb⁻¹ @ 4360 MeV (~50 days)
- R scan (25 days)

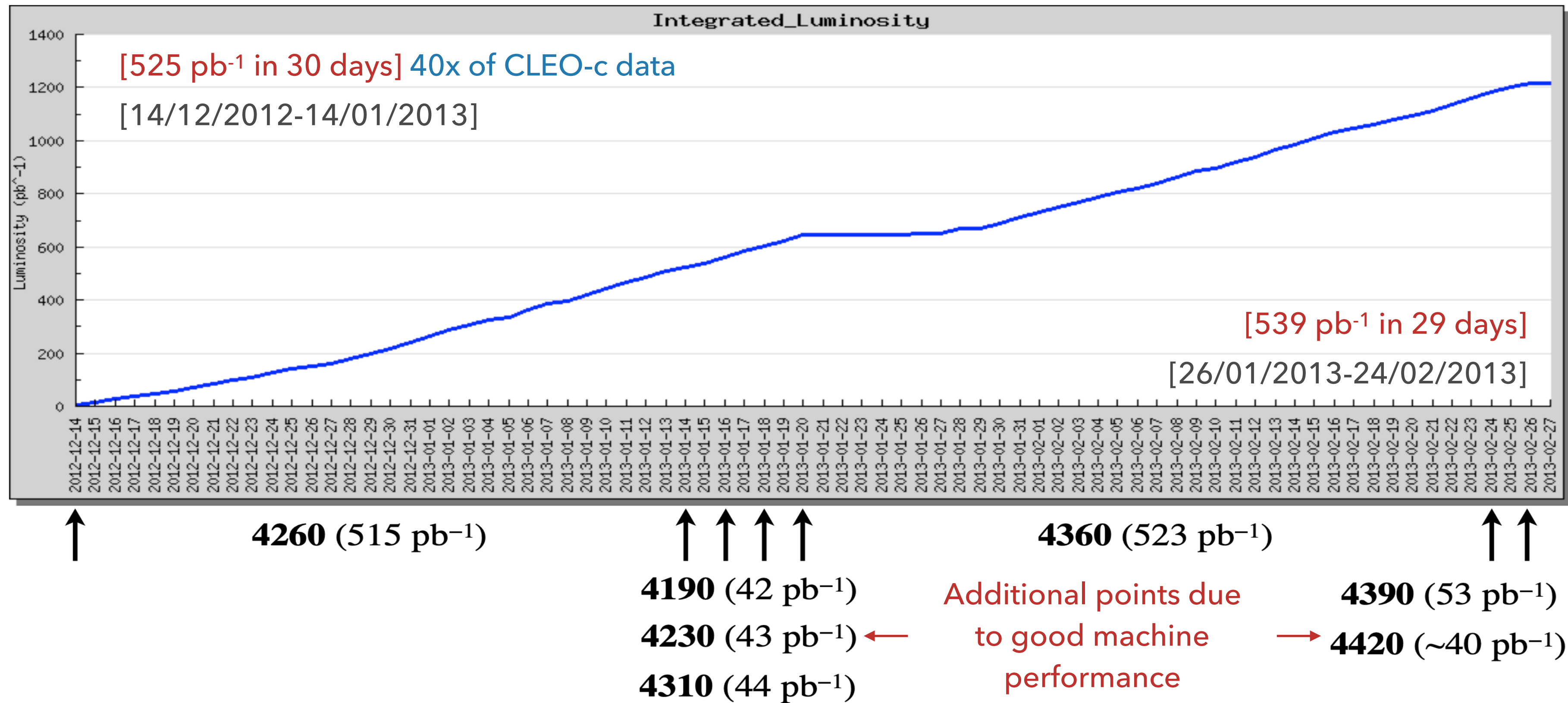
Approved

Otherwise, run @ 4170 MeV (2.4 fb⁻¹)

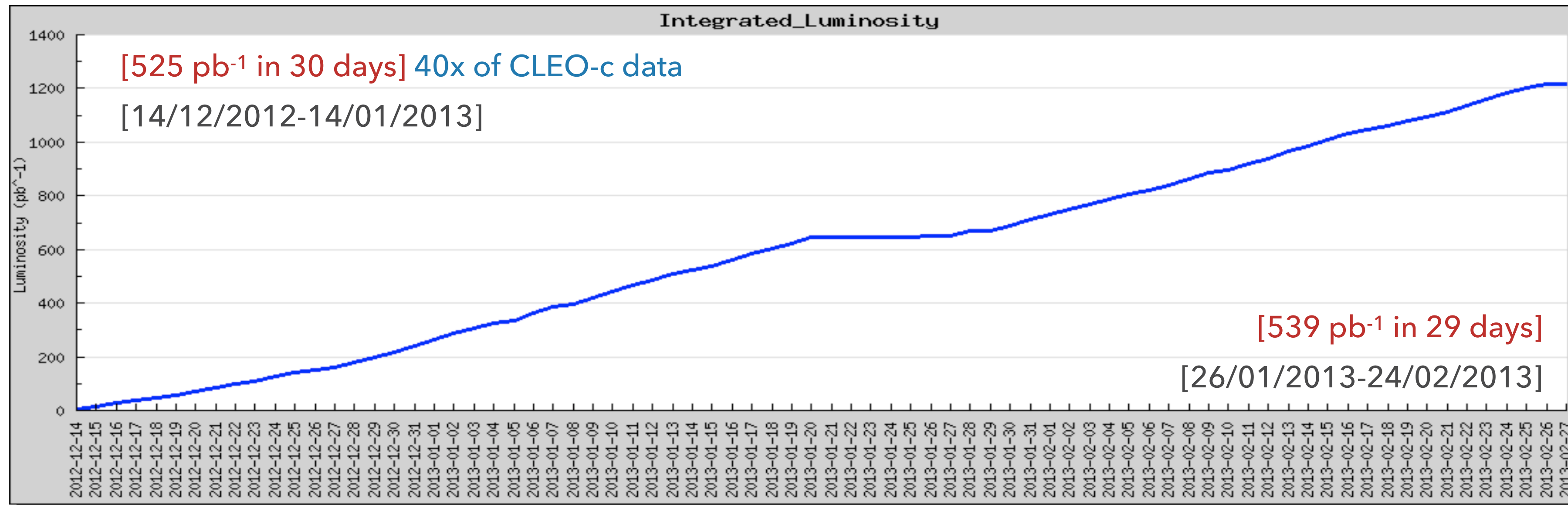
Y(4260) and Y(4360) data



Y(4260) and Y(4360) data

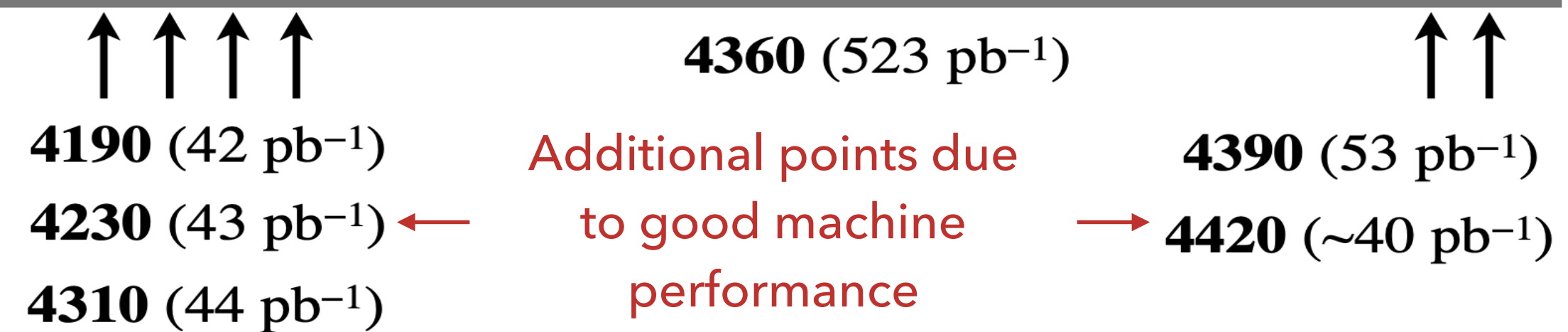
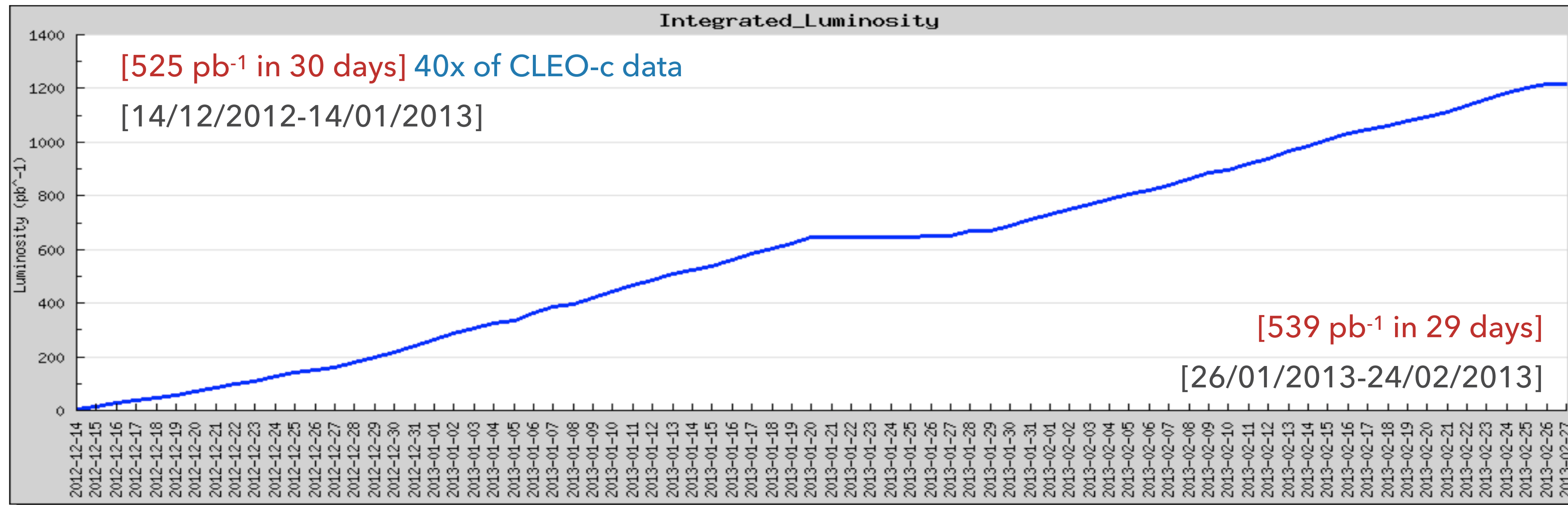


Y(4260) and Y(4360) data



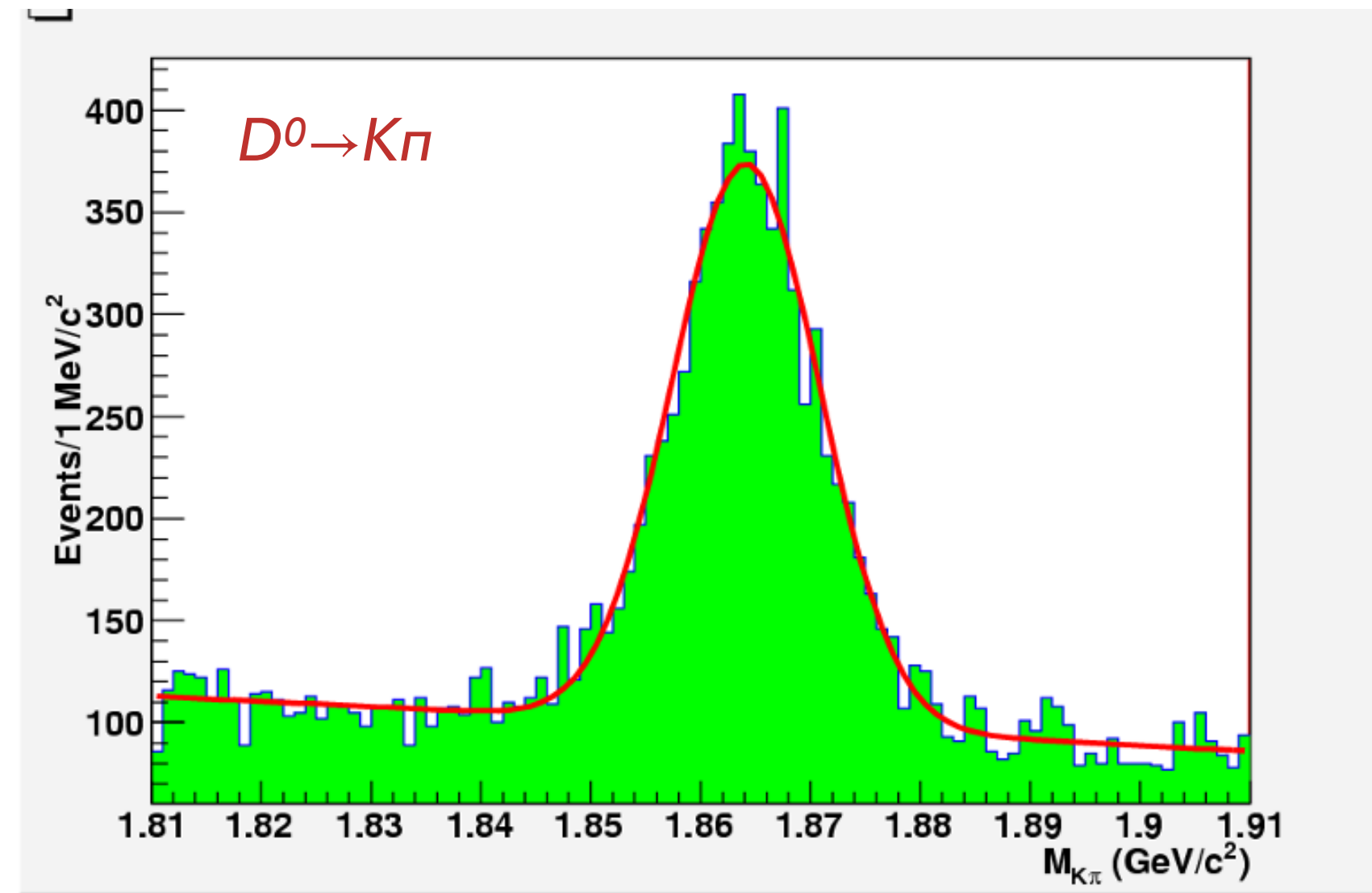
↑ ↑ ↑ ↑ **4360** (523 pb⁻¹) ↑ ↑
4190 (42 pb⁻¹) Additional points due **4390** (53 pb⁻¹)
4230 (43 pb⁻¹) ← to good machine → **4420** (~40 pb⁻¹)
4310 (44 pb⁻¹) performance

Y(4260) and Y(4360) data



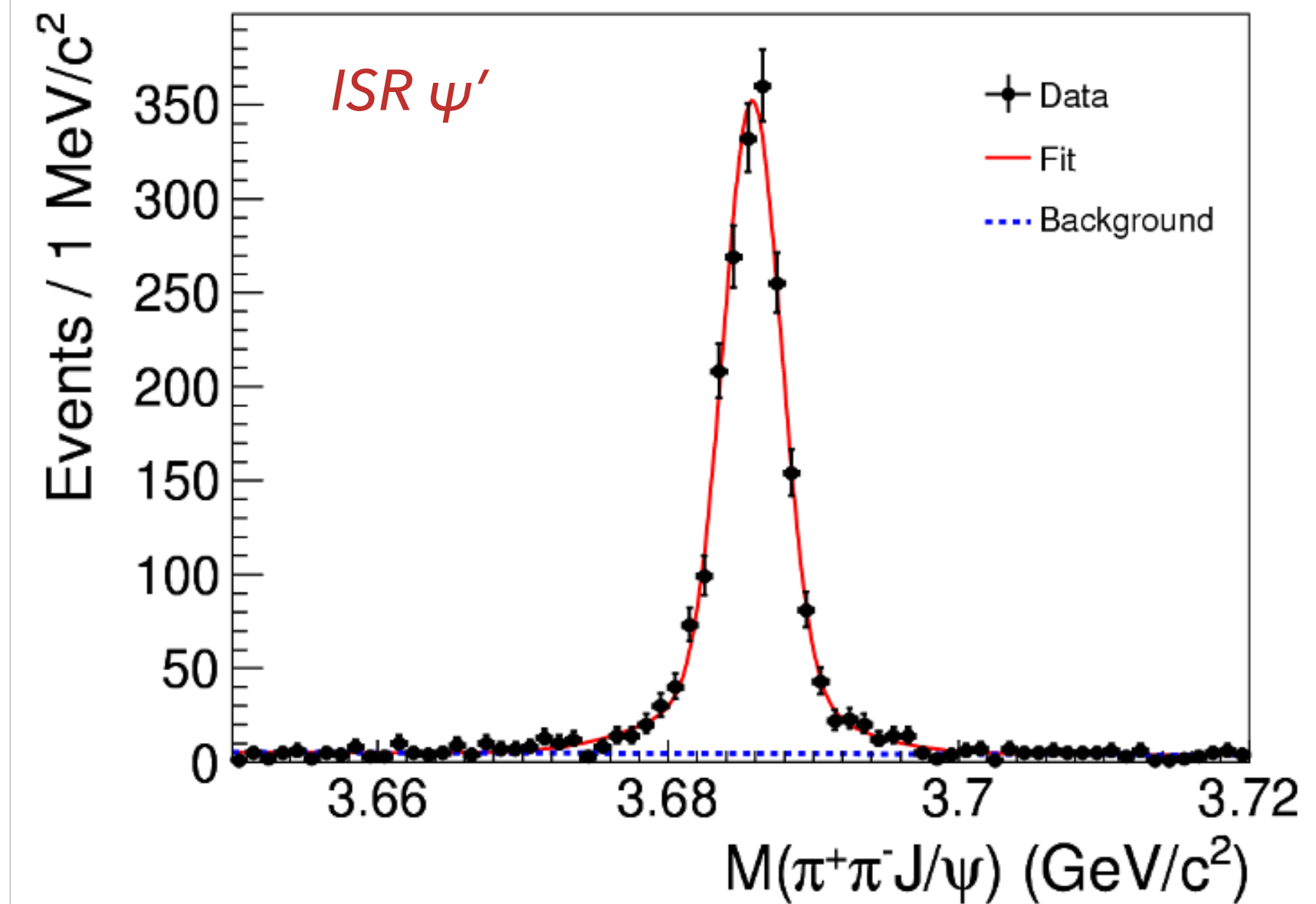
- Highest energy BEPCII ever reach
- BEMS measures E_{cm} at 1MeV level
- Low background, low noise, all sub-detectors excellent

Excellent data quality



$$\Delta M_D = 0.5 \pm 0.2 \text{ MeV}$$

$$\sigma M_D = 6.0 \pm 0.1 \text{ MeV}$$



$$\Delta M_{\psi'} = 0.2 \pm 0.1 \text{ MeV}$$

$$\sigma M_{\psi'} = 2.0 \pm 0.1 \text{ MeV}$$

- * Data calibration, reconstruction, MC simulation were finished shortly after the data taking ...
- * Production version was ready earlier March...

Efficient working group & intensive discussion

The image displays a grid of meeting agendas for the BESIII Collaboration working group. Each agenda is for a specific date and lists the time, topic, and speaker. Topics include data taking status, MC samplings, first looks at 4260 data, open charm cross sections, and various decay channels like $\pi\pi J/\psi$, $\pi\pi\eta_c$, and $\pi\pi\psi(3686)$. Speakers are listed with their affiliations, such as IHEP, Indiana University, and USTC.

WEDNESDAY, JANUARY 9

- 9:00 AM → 9:20 AM **Y(4260) data taking status (2012-12-19 to 2013-01-08)**
Speaker: Chunhua LI (IHEP)
- 9:20 AM → 9:40 AM **study of $\psi(4260)$ to $\pi\pi J/\psi$, hc to $\gamma\eta_c$**
Speaker: Ms Yuping Guo (Nankai University & IHEP)
- 9:40 AM → 10:00 AM **$\pi\pi J/\psi$ at 4.26GeV**
Speaker: Jingzhi Zhang (IHEP)

WEDNESDAY, JANUARY 16

- 9:00 AM → 9:20 AM **Y(4260) data taking status (2013-01-09 to 01-15)**
Speaker: Mr Yujun MO (IHEP)
- 9:20 AM → 9:40 AM **Full Y(4260) data sample**
Speaker: Jingzhi Zhang (IHEP)
- 9:40 AM → 10:00 AM **Preliminary study of $\psi(4260) \rightarrow \pi\pi\psi(3686)$**
Speaker: Mr Liang Yan (USTC)
- 10:00 AM → 10:20 AM **Search for X(3872) in $\psi(4260) \rightarrow \gamma X(3872)$**
Speaker: Dr Ping Rong-Gang (Institute of High Energy Physics of Chinese Academy of Sciences)
- 10:20 AM → 10:40 AM **Y(4260) $\rightarrow D\bar{D}\pi + X$**
Speaker: Dr Gang LI (IHEP)
- 10:40 AM → 11:00 AM **Y4260 $\rightarrow \gamma\chi_{cJ}$**
Speaker: Ms Xiao Ai (cong)
- 11:00 AM → 11:20 AM **$e^+e^- \rightarrow \pi^+\pi^-h_c, h_c \rightarrow \gamma\eta_c, \eta_c \rightarrow \text{anything}$**
Speaker: Ms Yuping Guo (Nankai University & IHEP)
- 11:20 AM → 11:40 AM **$e^+e^- \rightarrow \omega J/\psi + X$**
Speaker: Jingzhi Zhang (IHEP)

WEDNESDAY, JANUARY 23

- 9:00 AM → 9:20 AM **Data taking status**
Speaker: Ms 清高 (ihep)
- 9:20 AM → 9:40 AM **On the MC samplings of $\psi(4260)$**
Speaker: Dr Rong-Gang Ping
- 9:40 AM → 10:00 AM **A First Look at the 4260 Data**
Speaker: Ryan Mitchell (Indiana University)
- 10:00 AM → 10:20 AM **Open charm cross section at 4.26 GeV**
Speaker: Mr weimin song (ihep)
- 10:20 AM → 10:40 AM **Y(4260) data check with 3 photons**
Speaker: Dr Kai Zhu (IHEP)
- 10:40 AM → 11:00 AM **$\pi^+\pi^-J/\psi, \gamma\gamma J/\psi, \gamma\gamma\psi'$ at 4.26 GeV**
Speaker: Mr Zhiqing LIU (IHEP)
- 11:00 AM → 11:20 AM **$\pi^+\pi^-J/\psi$ at 4.26 GeV**
Speaker: Dr Gang LI (IHEP)
- 11:20 AM → 11:40 AM **$\pi^0 h_c$ at 4.01 and 4.26 GeV**
Speaker: Dr aiqiang guo (BES3 collaboration group member)

WEDNESDAY, JANUARY 30

- 9:00 AM → 9:20 AM **Data taking status at 4.36 GeV**
- 9:00 AM → 9:20 AM **Progress on Y(4260) $\rightarrow \pi^+\pi^-J/\psi$**
Speaker: Mr Zhiqing LIU (IHEP)
- 9:20 AM → 9:40 AM **Preliminary studies of searching for $\psi(4260) \rightarrow \text{eat}/\pi^0 + j\psi$**
Speaker: Cong Geng (USTC)
- 9:40 AM → 10:00 AM **A Revised First Look at the 4260 Data**
Speaker: Ryan Mitchell (Indiana University)

WEDNESDAY, JANUARY 23

- 10:00 AM → 10:20 AM **Progress on $\psi(4260)$ to $\pi\pi J/\psi$**
Speaker: Ms Yuping Guo (Nankai University & IHEP)

WEDNESDAY, FEBRUARY 6

- 9:00 AM → 9:20 AM **$\gamma\eta_c$ at $E_{cm}=4.01$ GeV**
Speaker: Manuel Lara (Indiana University)

WEDNESDAY, FEBRUARY 13

- 9:20 AM → 9:40 AM **A Closer Look at $\pi^+\pi^-J/\psi$**
Speaker: Ryan Mitchell (Indiana University)
- 9:40 AM → 10:00 AM **PWA on $\psi(4260) \rightarrow \pi^+\pi^-J/\psi$**
Speaker: Dr Ronggang Ping
- 10:00 AM → 10:20 AM **Y4260 $\rightarrow \pi\pi DD^*$**
Speaker: Xin-Ping Xu (Soochow University (suda))

TUESDAY, FEBRUARY 20

- 9:00 AM → 9:20 AM **Open charm final states at 4.26 GeV**
- 9:20 AM → 9:40 AM **DD+X at 4.26GeV**
- 9:40 AM → 10:00 AM **e^+e^- to $\pi\pi J/\psi$**
- 10:00 AM → 10:20 AM **Progress report about the PWA on $\psi(4260) \rightarrow \pi^+\pi^-J/\psi$**
Speaker: Dr RongGang Ping

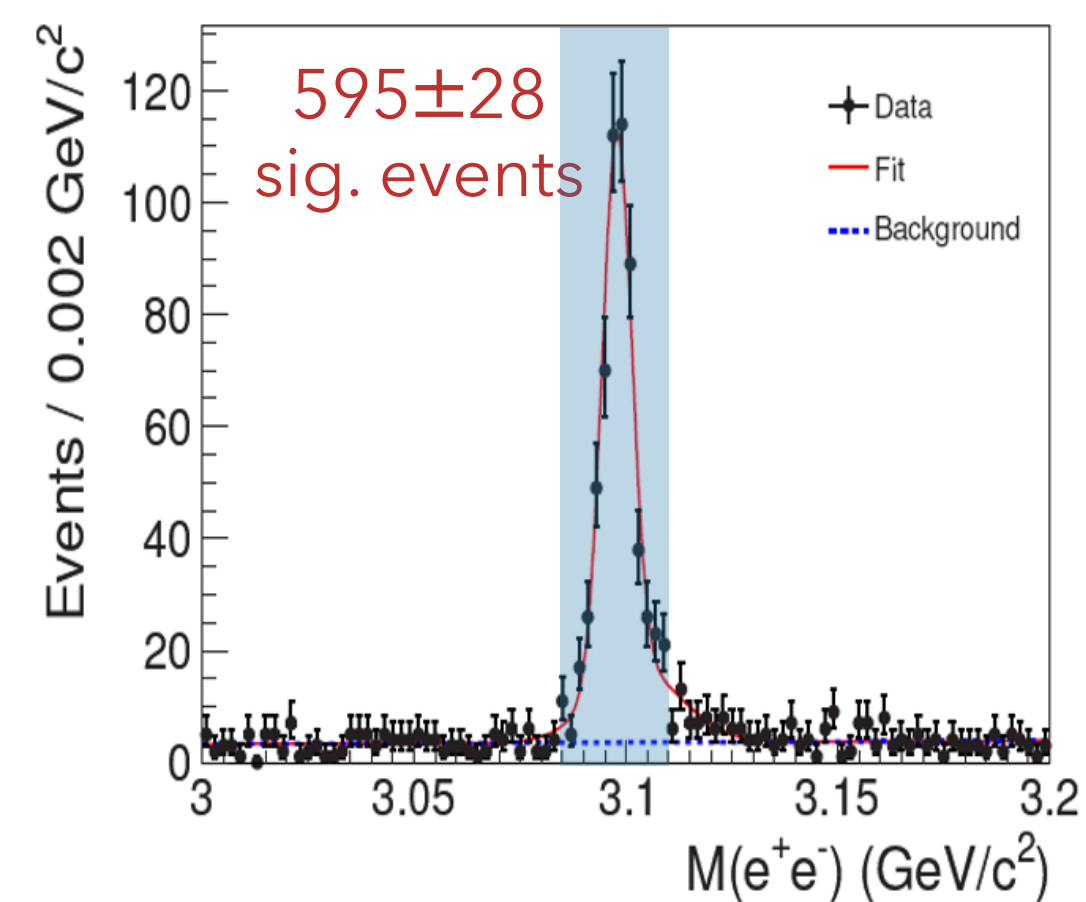
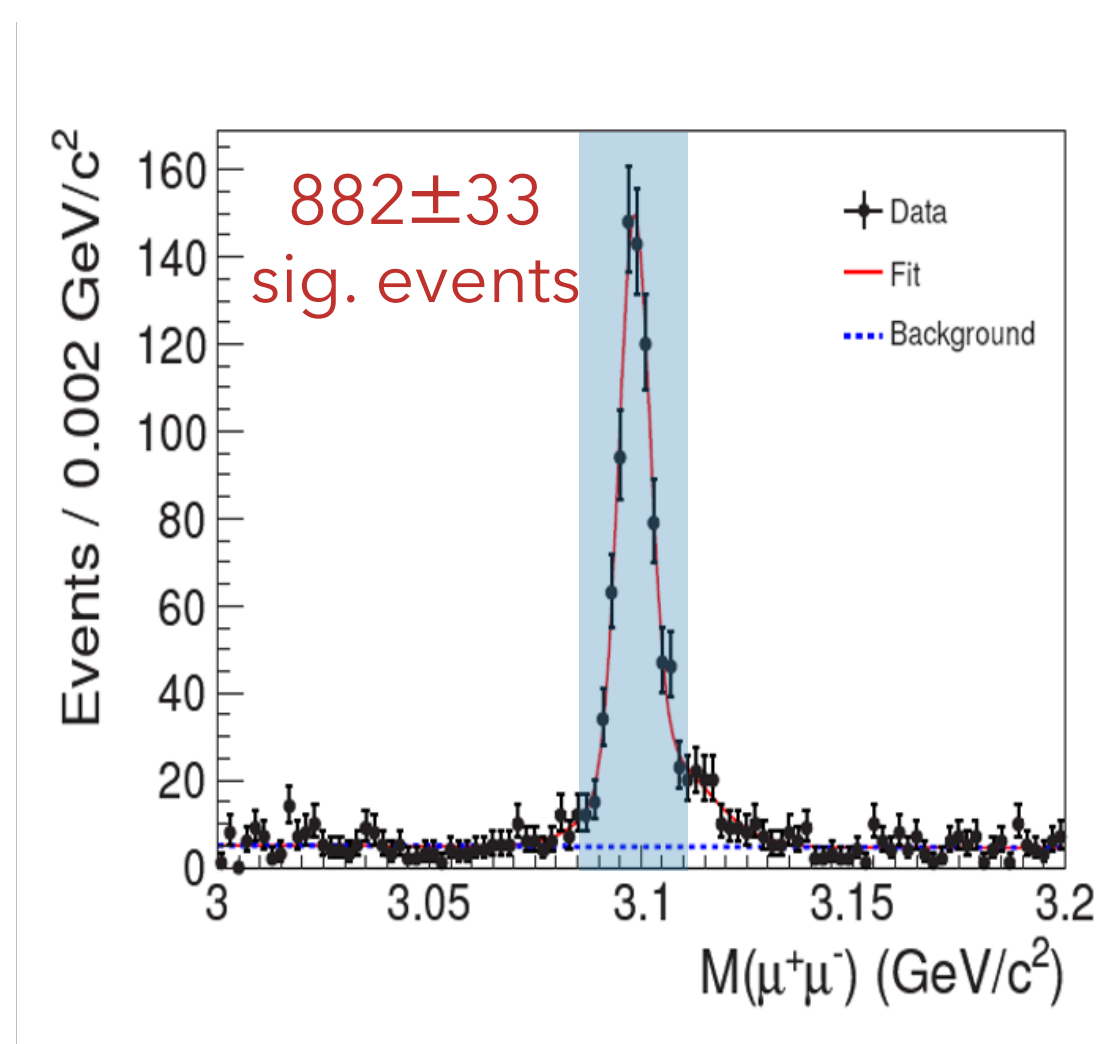
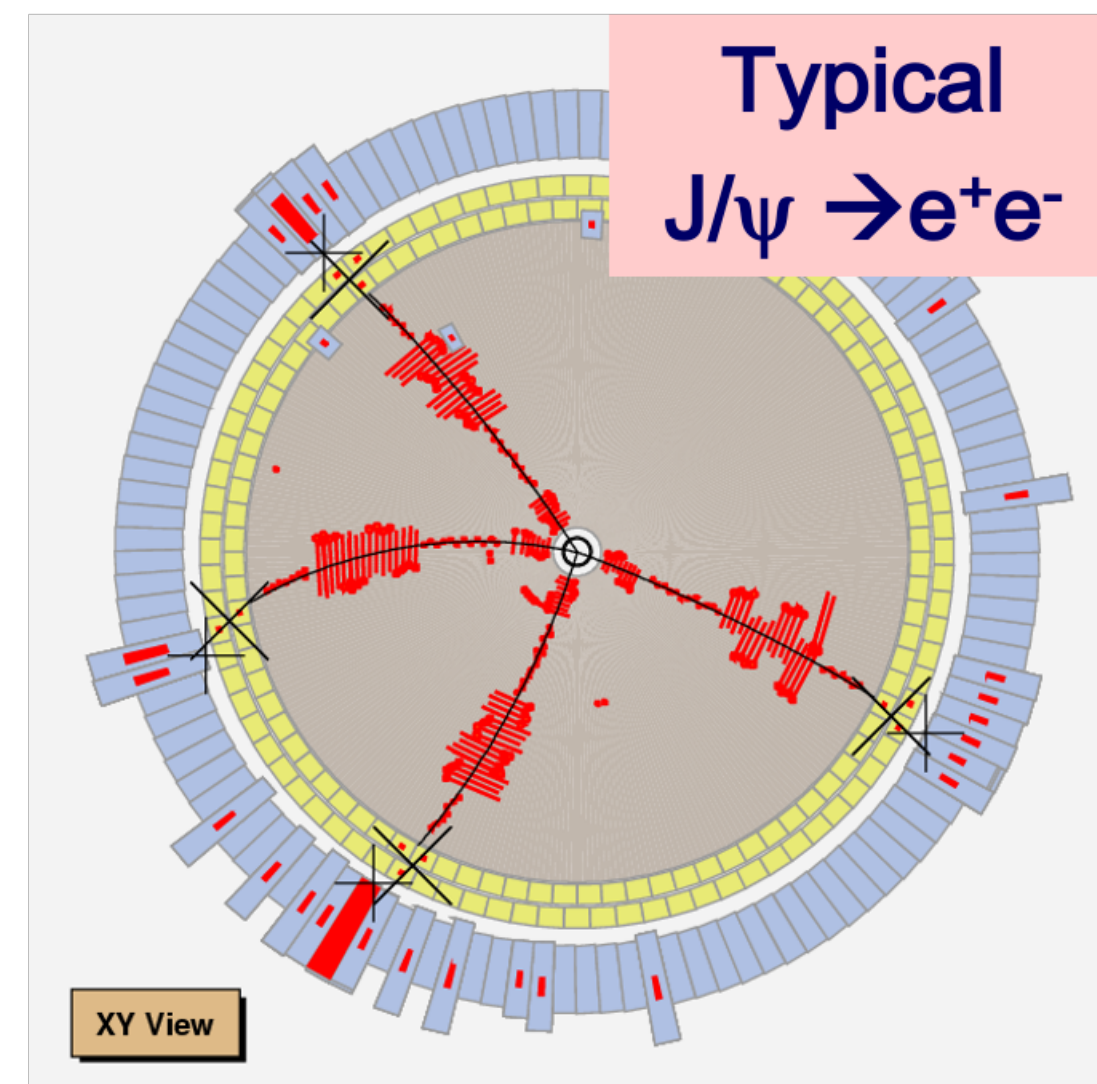
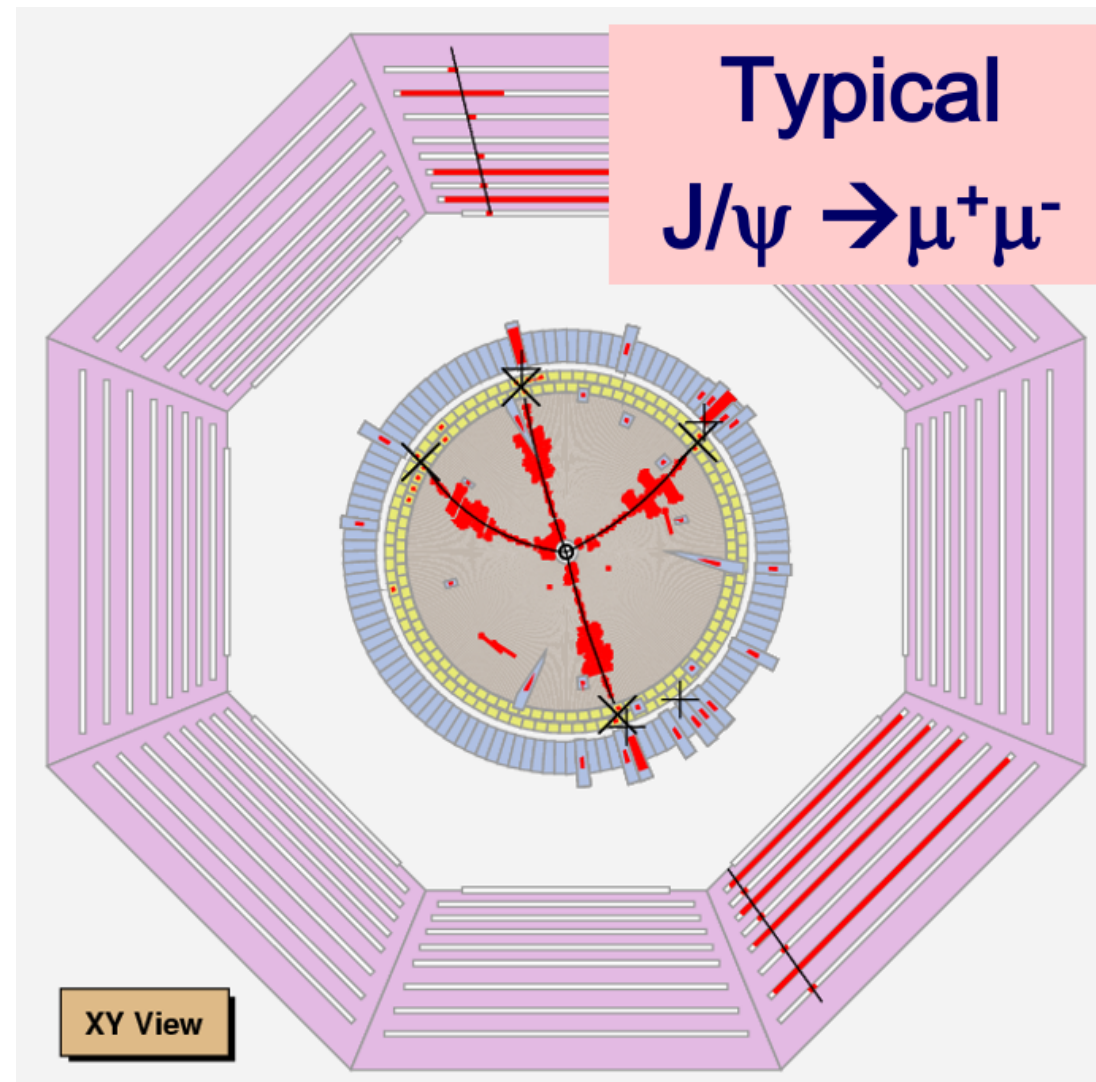
WEDNESDAY, MARCH 13

- 9:00 AM → 9:20 AM **$\pi^0\pi^0 J/\psi$**
Speaker: Mr Jian-Ming Bian (EPC)
- 9:20 AM → 10:00 AM **$\pi^+\pi^-J/\psi$ with Boss663p01 data**
Speaker: Mr Zhiqing LIU (IHEP)
- 10:00 AM → 10:20 AM **e^+e^- to $\eta_c J/\psi$ & $\eta_c \psi'$**
Speaker: Chao Dong (Nankai U)
- 10:20 AM → 10:40 AM **updated result of Y(4260)/Y(4360) $\rightarrow \pi^0\pi^0 J/\psi$**
Speaker: Mr Zhentian Sun (USTC&IHEP)
- 10:40 AM → 11:00 AM **DD π**
Speaker: Xin-Ping Xu (Soochow University (suda))
- 11:00 AM → 11:20 AM **searching for new resonance in $D^*D^*\pi$ final state**
Speaker: weimin song
- 11:20 AM → 11:40 AM **Efficiency and PID study**
Speaker: Xiaorong Zhou
- 11:40 AM → 12:00 PM **First look at D_s @4260**
Speaker: Lei Zhang
- 12:00 PM → 12:20 PM **Study DD structures in open charm region**
Speaker: Dr Xiao-Rui Lu (UCAS)
- 12:20 PM → 12:40 PM **Study of Y(4260) $\rightarrow \pi^+\pi^-\psi(3686)$**
Speaker: Mr Liang Yan (USTC)
- 12:40 PM → 1:00 PM **Update of PWA on $\psi(4260) \rightarrow \pi^+\pi^-J/\psi$**
Speaker: Dr Rong-Gang Ping

Discovery of $Z_c(3900)$ - Timeline

- * **Jan. 14, 2013:**
Data taking at 4260 MeV finished
- * **Feb., 2013:**
Convincing evidence for the $Z_c(3900)$
- * **Feb. 27- Mar. 1, 2013:** [Tsinghua CM]
Discussions of the publication strategy
- * **Mar. 3, 2013:**
First draft of the memo and paper
- * **Mar. 5, 2013:**
Review committee formed
[Xinchou (ch), Yuanning, Fred, Matt]
- * **Mar. 4 - 7, 2013:**
Many iterations on the paper draft; Cross checks by many collaborators [dE/dx , E_{cm} , Luminosity, other E_{cm} , neutral mode, ISR corrections, PWA]
- * **Mar. 18, 2013:**
Referee-author meeting with extensive cross-checks
- * **Mar. 20 - 22, 2013:**
Shorten collaboration-wide review
- * **Mar. 24, 2013:**
Submission to the arXiv and PRL
- * **Mar. 27, 2013:**
Special seminar at IHEP
- * **Mar. 28, 2013:**
Celebration in the BESIII control room
- * **May 2, 2013:**
Paper accepted by PRL
- * **Jun. 17, 2013:**
Published, [PRL 110, 252001 \(2013\)](#)

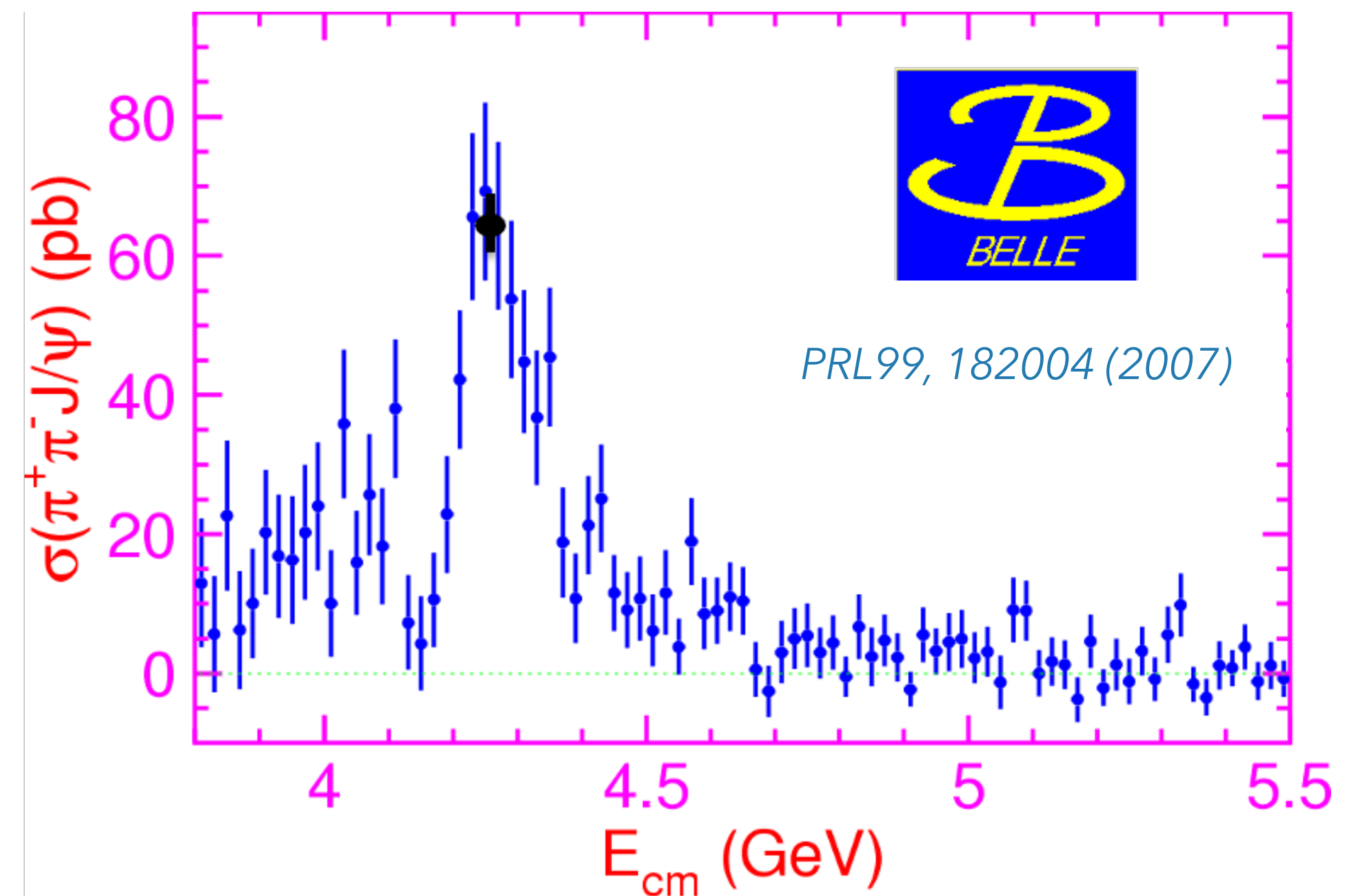
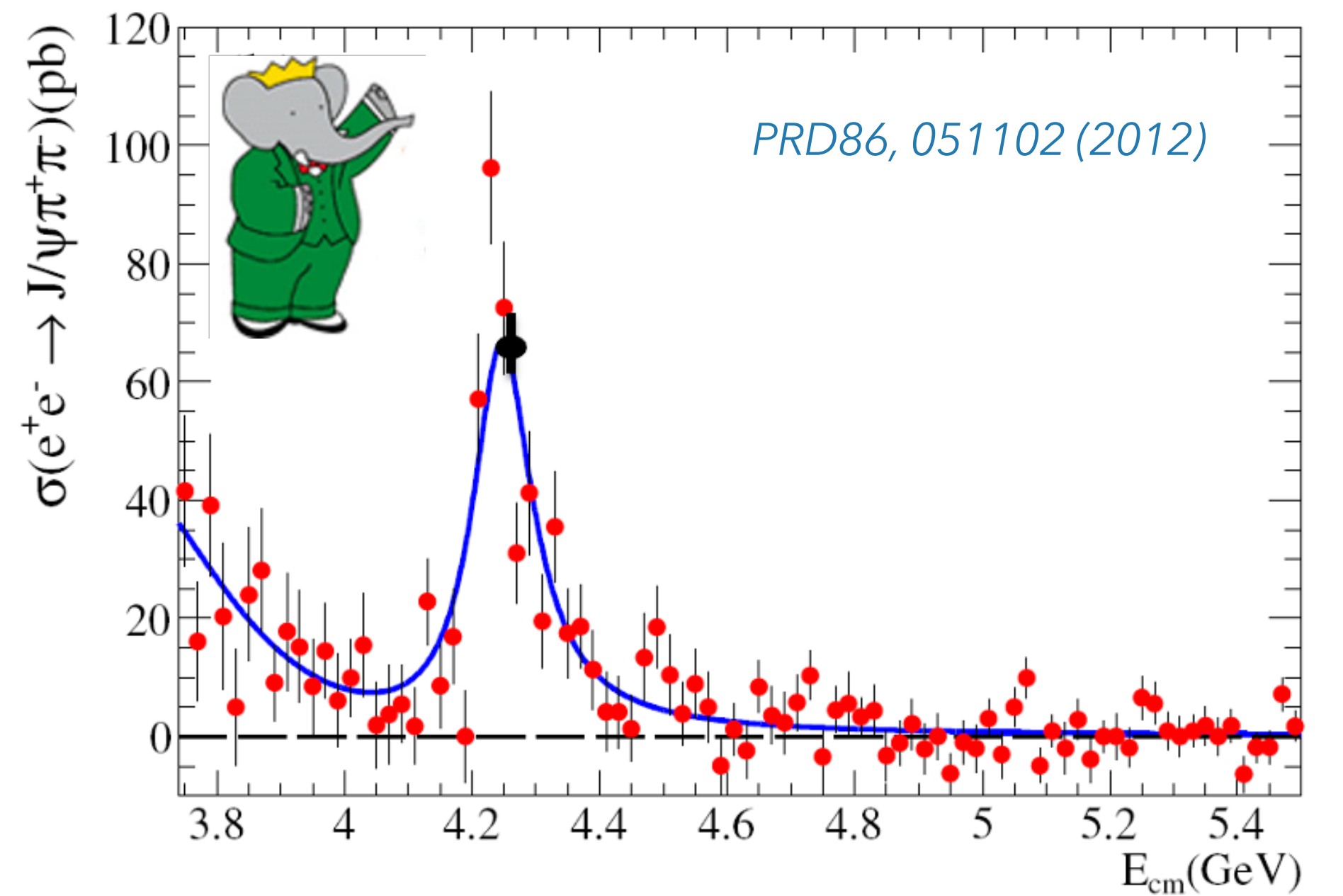
$e^+e^- \rightarrow \pi^+\pi^-J/\psi$ events



- * Select 4 charged tracks and reconstruct J/ψ with lepton pair
- * Only use MDC and EMC information, MC simulation reliable
- * Very clean sample, high detection efficiency
- * At least 4 independent analyses, all get similar results

PRL 110, 252001 (2013)

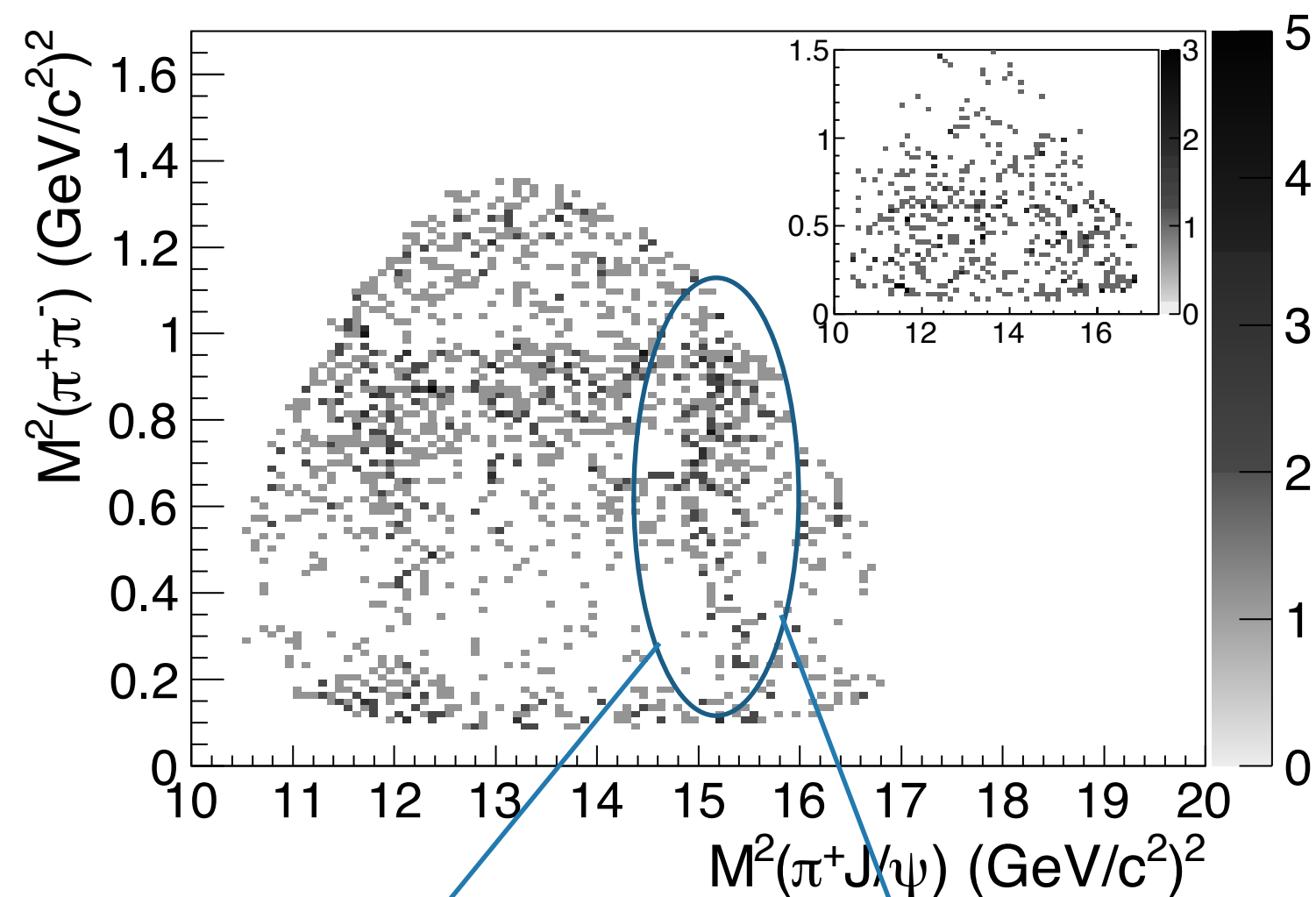
Cross section of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$



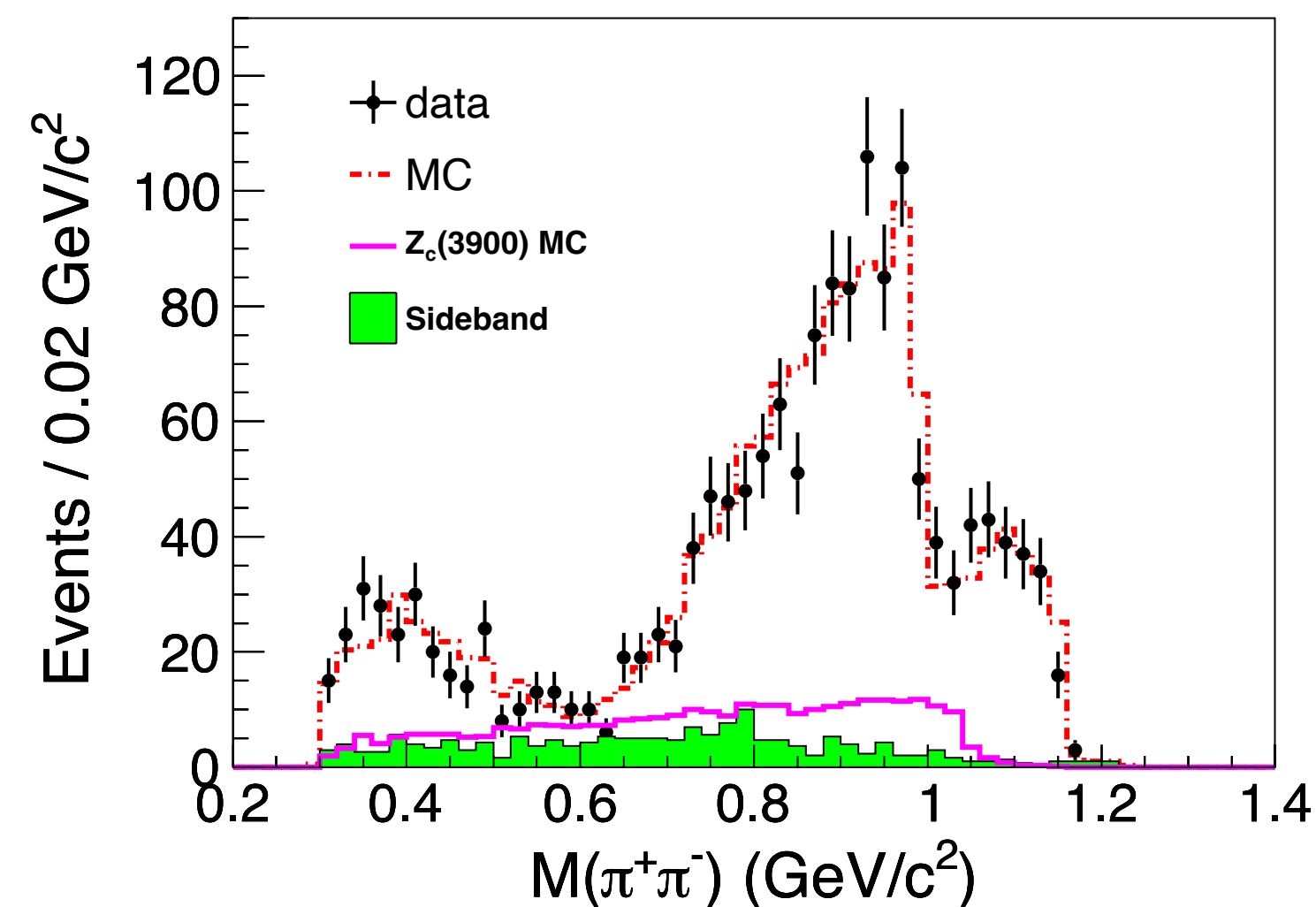
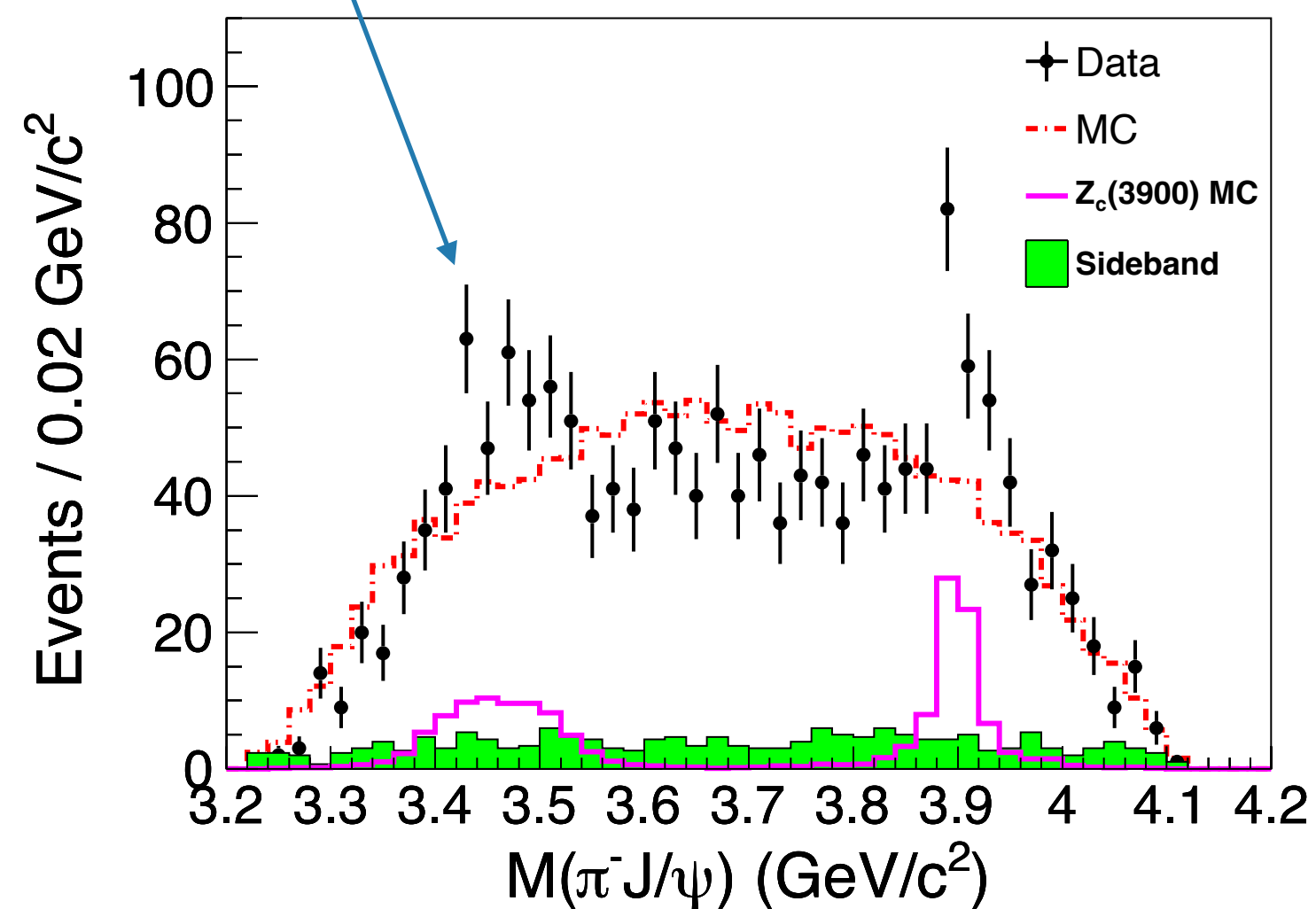
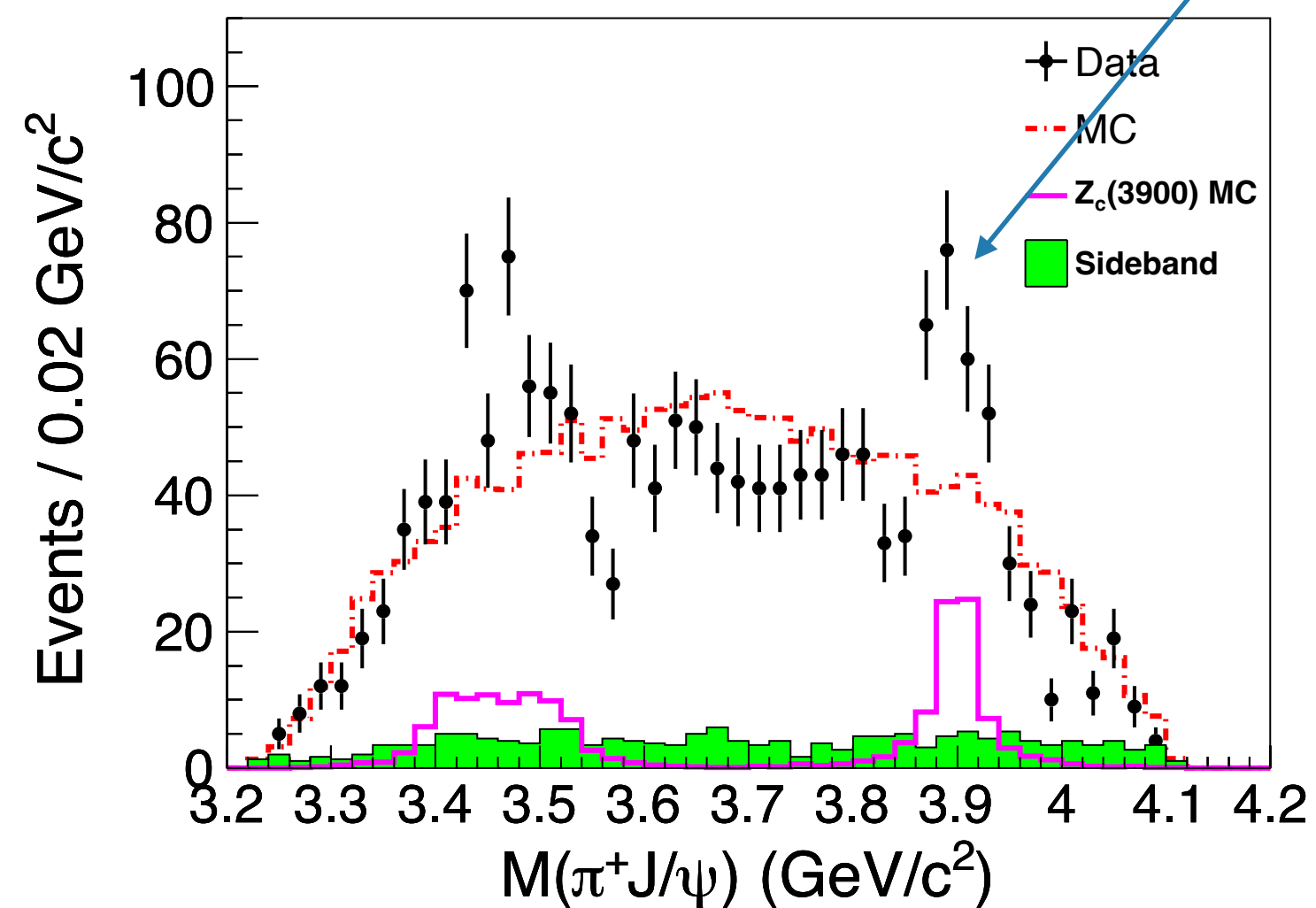
BESIII result: $\sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi) = (62.9 \pm 1.9 \pm 3.7) \text{ pb}$
Consistent with BaBar and Belle results; Best precision

PRL110, 252001 (2013)

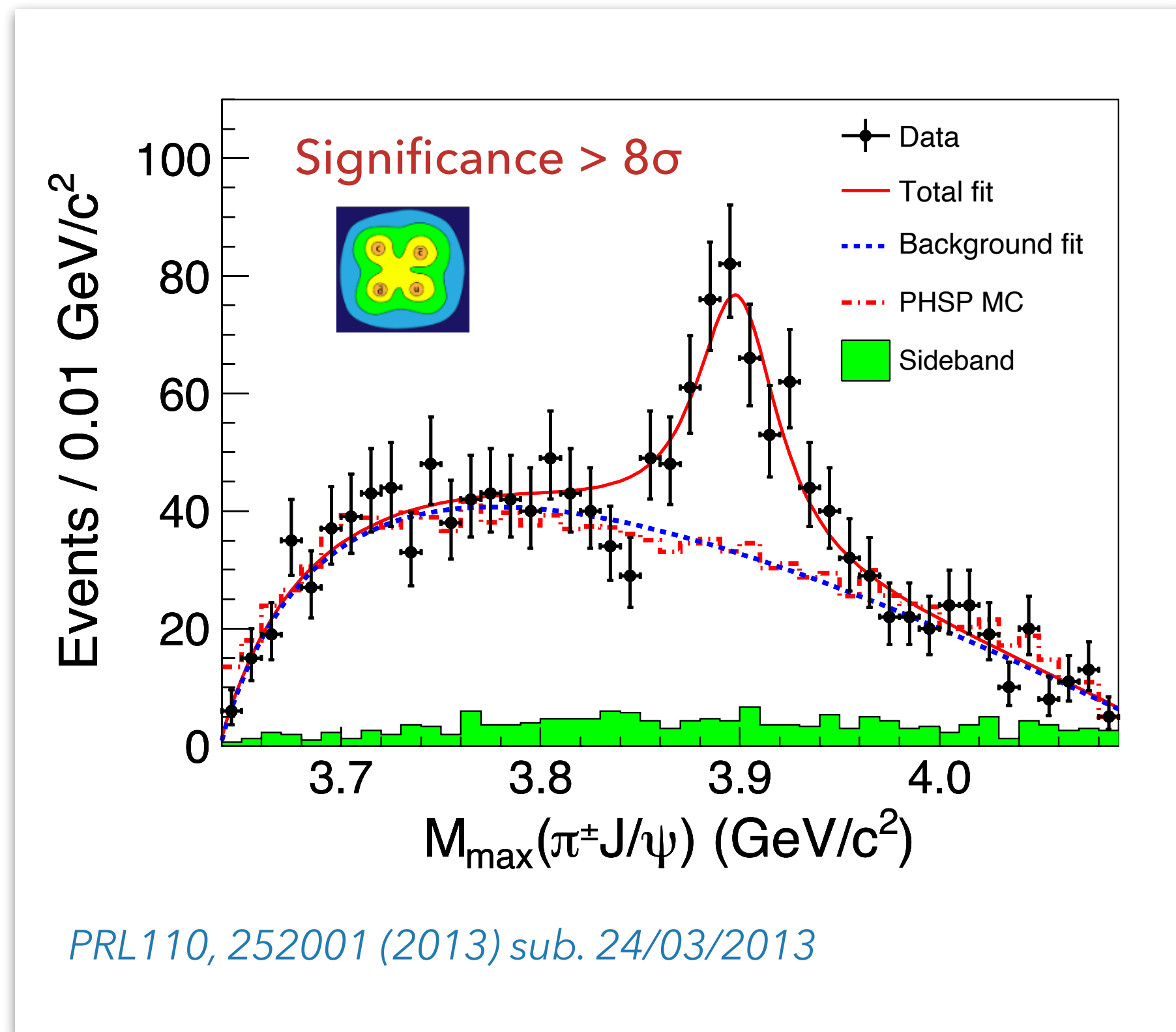
Dalitz plot and 1D projections



PRL 110, 252001 (2013)

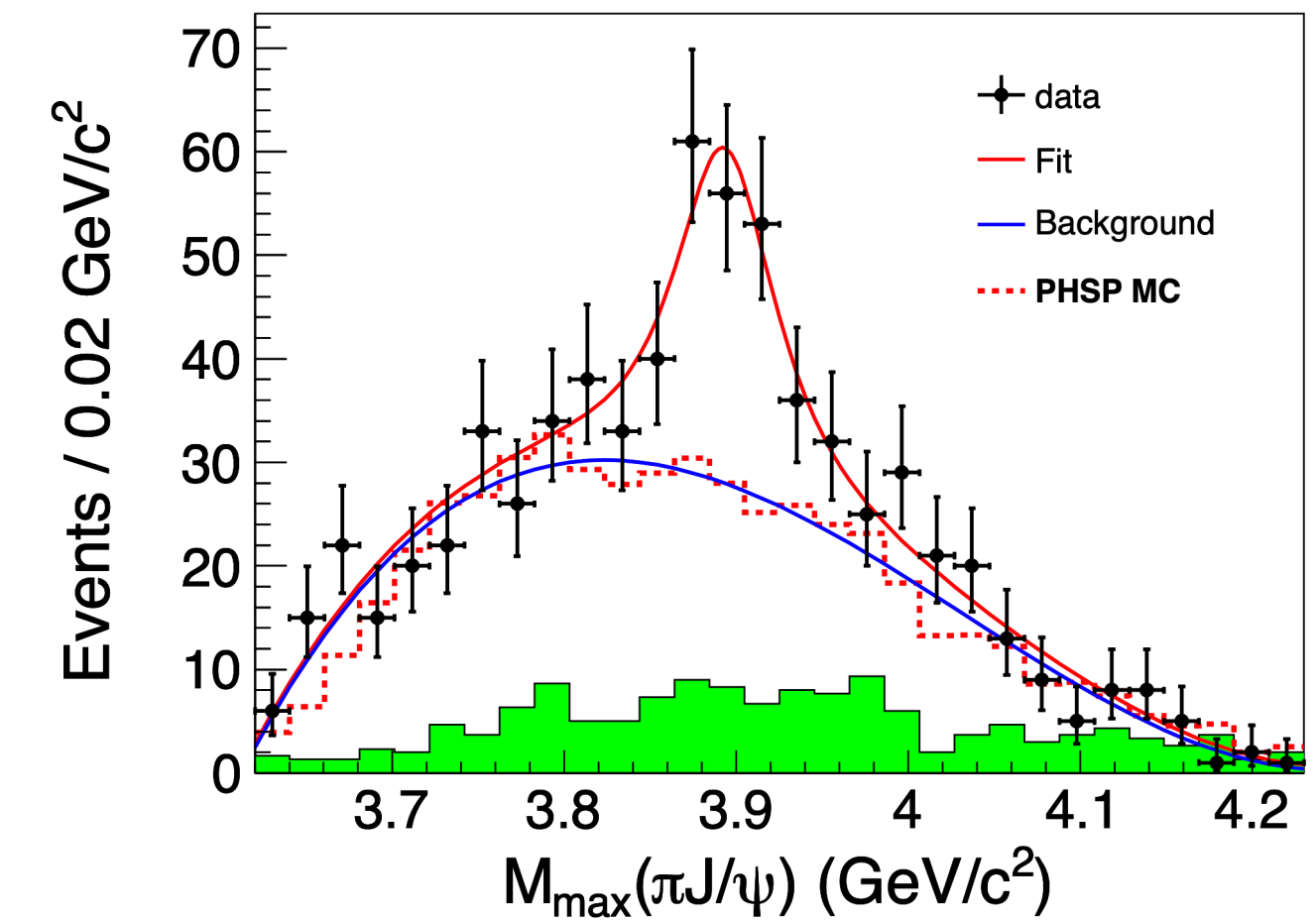


The $Z_c(3900)$ signal



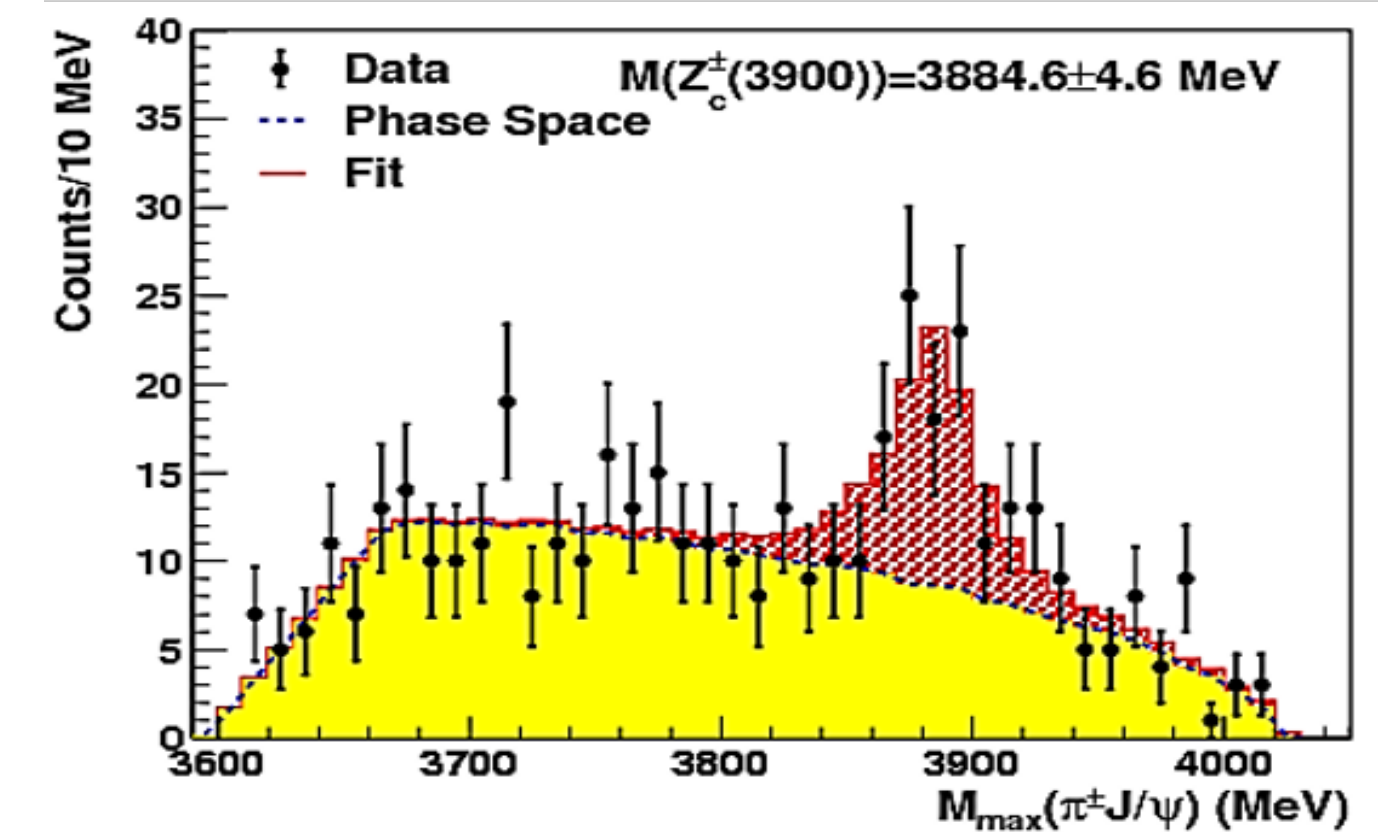
$Z_c(3900)$ at Belle

*PRL110, 252002 (2013)
sub. 30/03/2013*



CLEO-c data @ 4.17 GeV

*PLB, 727, 366 (2013)
sub. 10/04/2013*



Impact

- * Physics Viewpoint: New particle hints at four-quark matter

The screenshot shows the Physics journal website. The header features the 'Physics' logo with the tagline 'spotlighting exceptional research'. Below the header is a navigation menu with links for 'Home', 'About', 'Browse', and 'APS Journals'. The main content area is titled 'Viewpoint: New Particle Hints at Four-Quark Matter' and is authored by Eric Swanson from the University of Pittsburgh. The article is dated June 17, 2013, and has a DOI of 10.1103/Physics.6.69. The text of the article discusses the discovery of a new particle, $Z_c(3900)$, and mentions two experiments that have detected its signature. On the right side of the article, there are two related publications listed: 'Observation of a Charged Charmoniumlike Structure in $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ at $\sqrt{s}=4.26$ GeV' by M. Ablikim et al. (BESIII Collaboration) and 'Study of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ and Observation of a Charged Charmoniumlike State at Belle' by Z. Q. Liu et al. (Belle Collaboration).

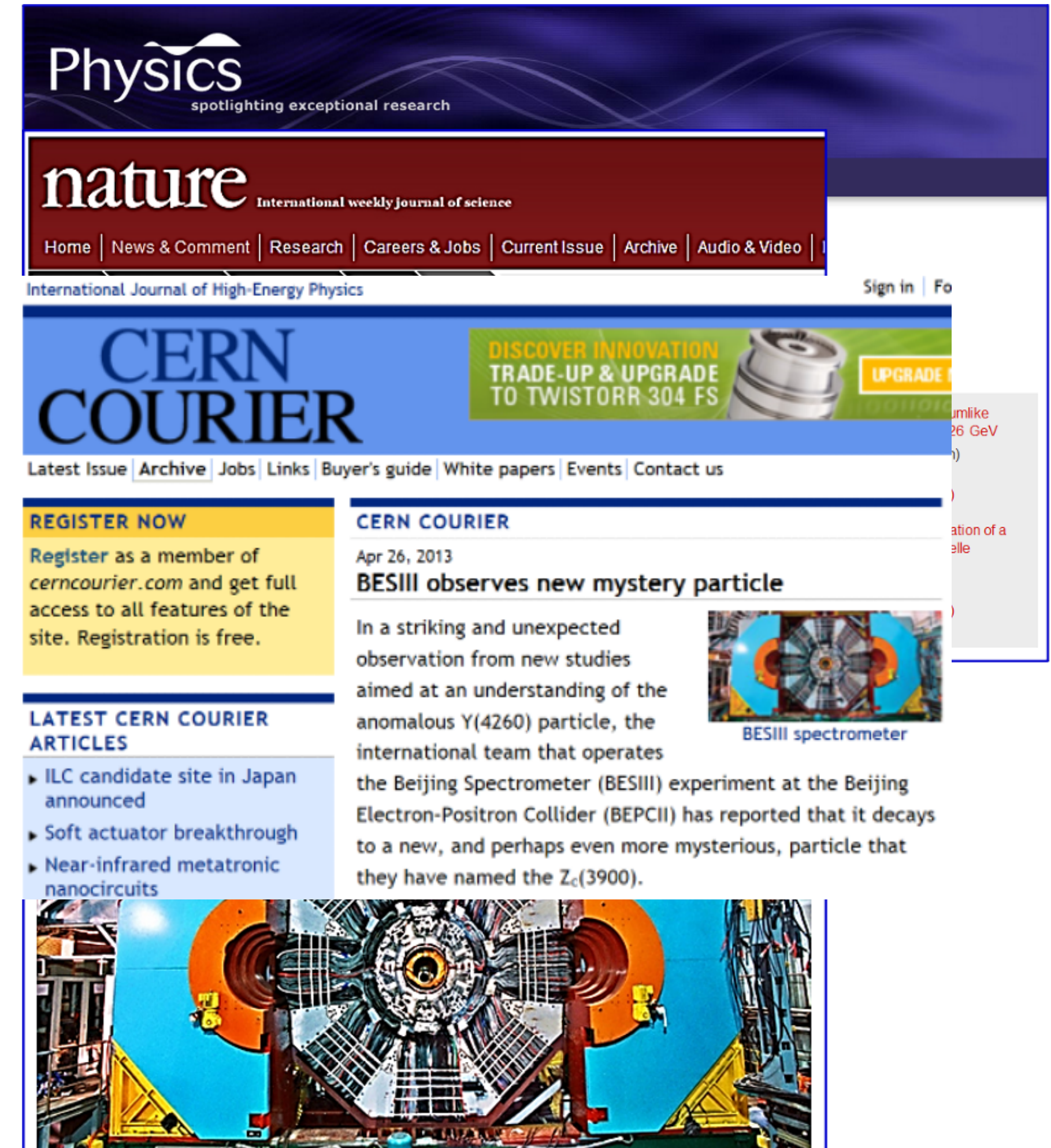
Impact

- * Physics Viewpoint: New particle hints at four-quark matter
- * Nature: Quark quartet opens fresh vista on matter

The image shows a screenshot of a news article on the Nature website. At the top, there is a 'Physics' banner with the tagline 'spotlighting exceptional research'. Below it is the 'nature' logo and the text 'International weekly journal of science'. A navigation bar includes links for 'Home', 'News & Comment', 'Research', 'Careers & Jobs', 'Current Issue', 'Archive', and 'Audio & Video'. A breadcrumb trail shows 'Archive > Volume 498 > Issue 7454 > News > Article'. The article title is 'Quark quartet opens fresh vista on matter' with the subtitle 'First particle containing four quarks is confirmed.' The author is Devin Powell and the date is 18 June 2013. There are buttons for 'PDF' and 'Rights & Permissions'. Below the text is a photograph of a particle detector, likely BESIII, showing a complex structure with blue and orange components. On the right side, there is a sidebar with related articles, including 'Charged Charmoniumlike $\pi^+\pi^-J/\psi$ at $\sqrt{s}=4.26$ GeV (BESIII Collaboration) 10, 252001 (2013) 17, 2013 | PDF (free)' and ' $\pi^+\pi^-J/\psi$ and Observation of a quoniumlike State at Belle (Belle Collaboration) 10, 252002 (2013) 17, 2013 | PDF (free)'.

Impact

- * Physics Viewpoint: New particle hints at four-quark matter
- * Nature: Quark quartet opens fresh vista on matter
- * CERN Courier: BESIII observes new mystery particle



The screenshot shows the CERN Courier website interface. At the top, there are logos for 'Physics' (spotlighting exceptional research) and 'nature' (International weekly journal of science). Below these are navigation links: Home, News & Comment, Research, Careers & Jobs, Current Issue, Archive, and Audio & Video. A blue banner for 'CERN COURIER' is prominent, with a sub-header 'International Journal of High-Energy Physics' and a 'Sign in' link. A green promotional box on the right says 'DISCOVER INNOVATION TRADE-UP & UPGRADE TO TWISTORR 304 FS' with an 'UPGRADE' button. Below the banner, there are links for 'Latest Issue', 'Archive', 'Jobs', 'Links', 'Buyer's guide', 'White papers', 'Events', and 'Contact us'. The main content area features a yellow 'REGISTER NOW' box with text: 'Register as a member of cerncourier.com and get full access to all features of the site. Registration is free.' To the right, the 'CERN COURIER' section is dated 'Apr 26, 2013' and has the headline 'BESIII observes new mystery particle'. The article text reads: 'In a striking and unexpected observation from new studies aimed at an understanding of the anomalous $Y(4260)$ particle, the international team that operates the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider (BEPCII) has reported that it decays to a new, and perhaps even more mysterious, particle that they have named the $Z_c(3900)$.' An image of the BESIII spectrometer is shown with the caption 'BESIII spectrometer'. On the left, a 'LATEST CERN COURIER ARTICLES' section lists: 'ILC candidate site in Japan announced', 'Soft actuator breakthrough', and 'Near-infrared metatronic nanocircuits'. A large image of the BESIII spectrometer is at the bottom of the page.

Impact

- * Physics Viewpoint: New particle hints at four-quark matter
- * Nature: Quark quartet opens fresh vista on matter
- * CERN Courier: BESIII observes new mystery particle
- * Most cited BES & BESIII paper

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International Journal of High-Energy Physics

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CERN COURIER

Apr 26, 2013

BESIII observes new mystery particle

In a striking and unexpected observation from new studies aimed at an understanding of the anomalous $Y(4260)$ particle, the international team that operates the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider (BEPCII) has reported that it decays to a new, and perhaps even more mysterious, particle that they have named the $Z_c(3900)$.

BESIII spectrometer

Citations per year

Citations: 122
Year: 2013

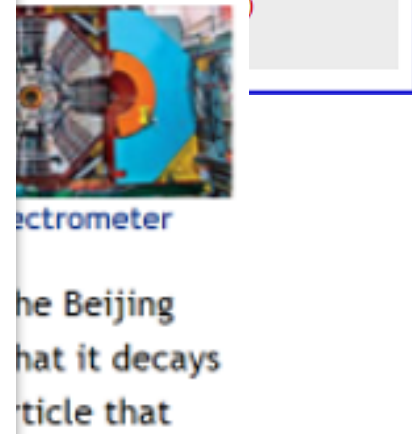
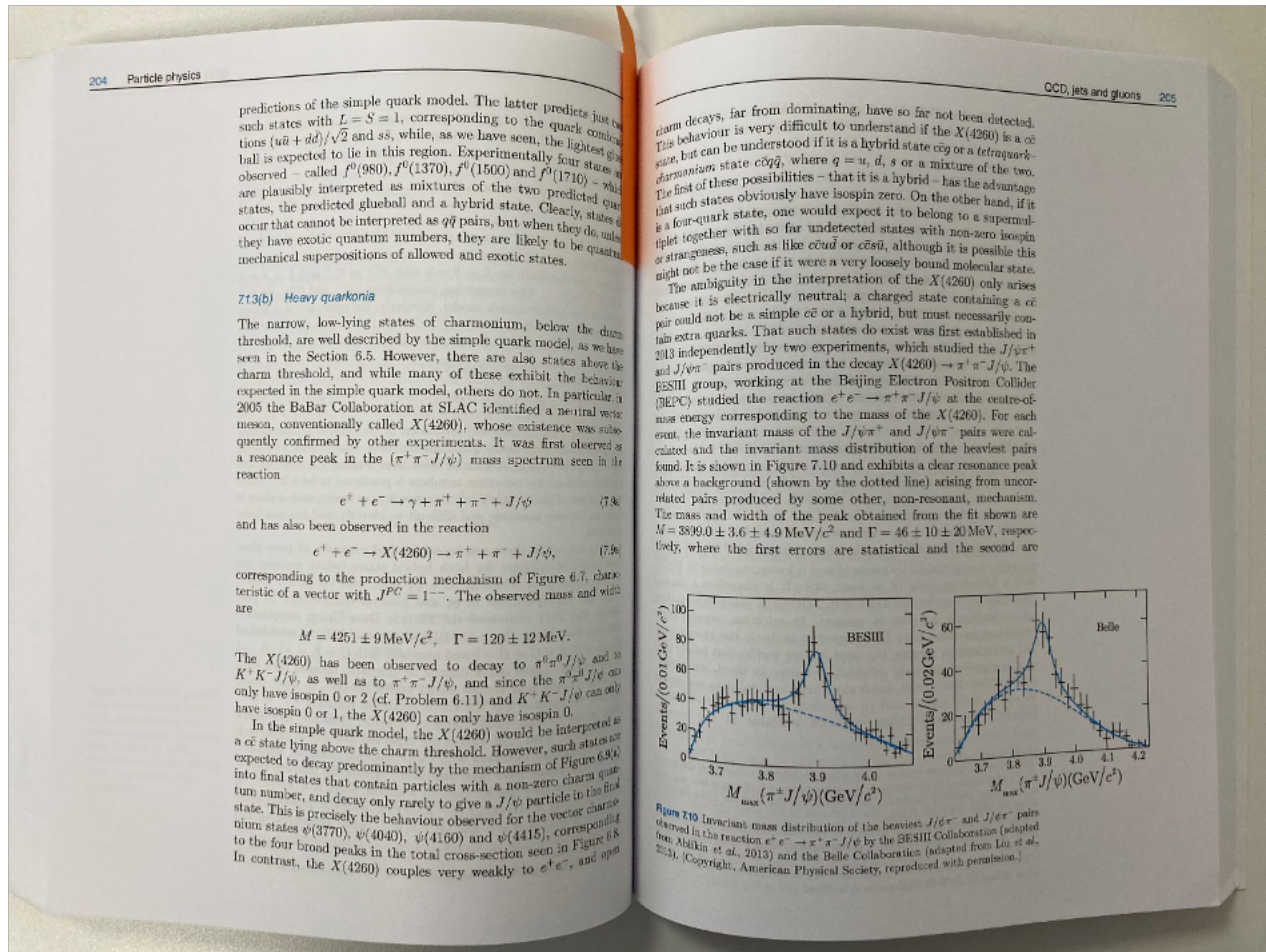
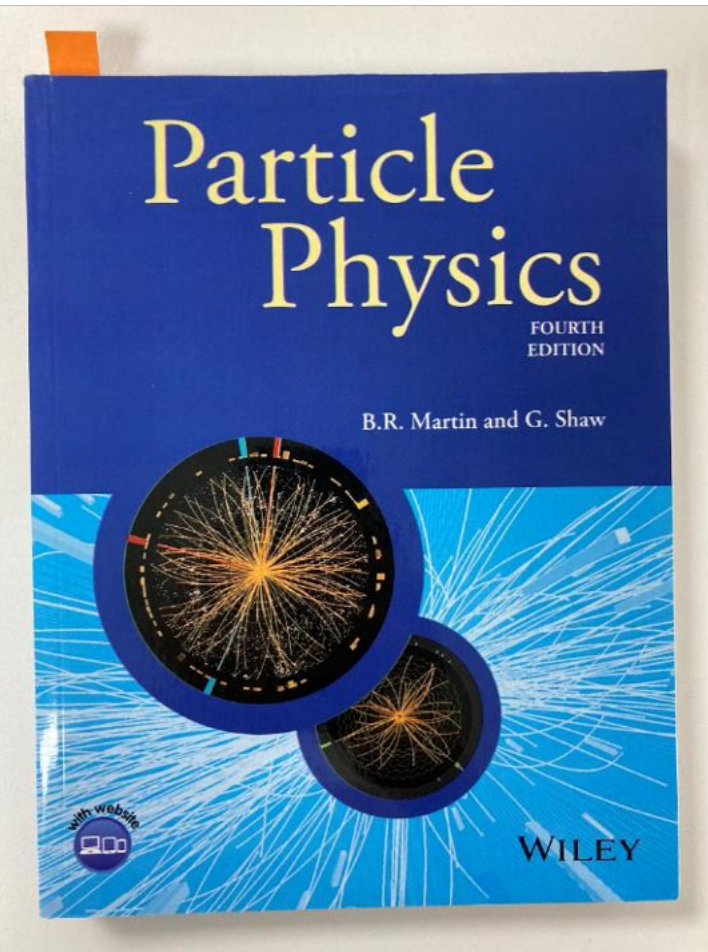
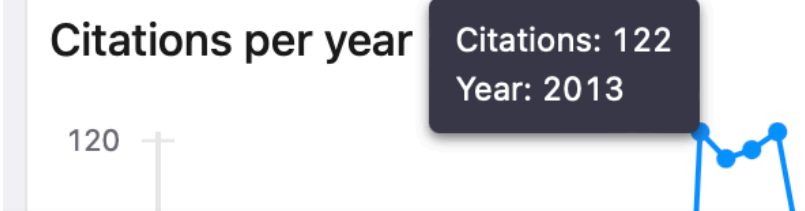
InspireCitation

1992 2000 2008 2016 2023

Impact

- * Physics Viewpoint: New particle hints at four-quark matter
- * Nature: Quark quartet opens fresh vista on matter
- * CERN Courier: BESIII observes new mystery particle
- * Most cited BES & BESIII paper
- * Included in the textbook
- *

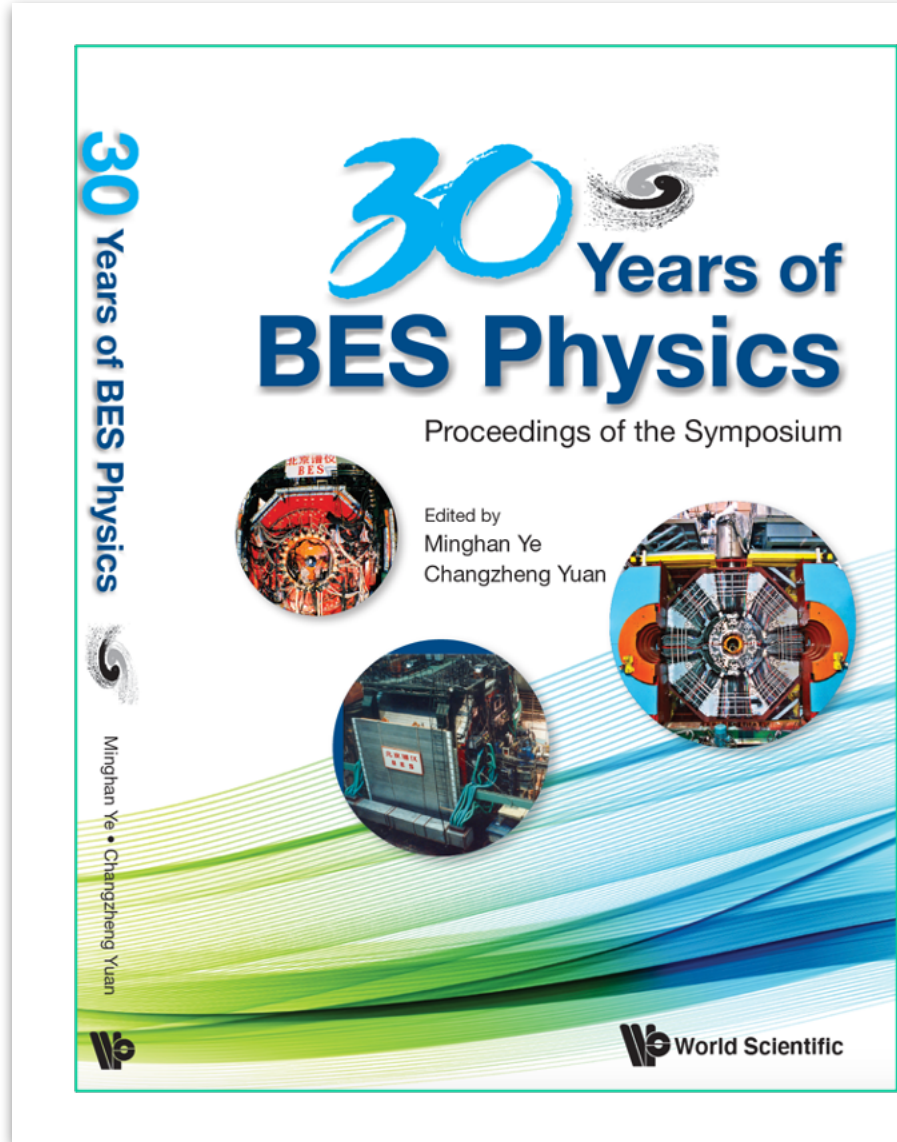
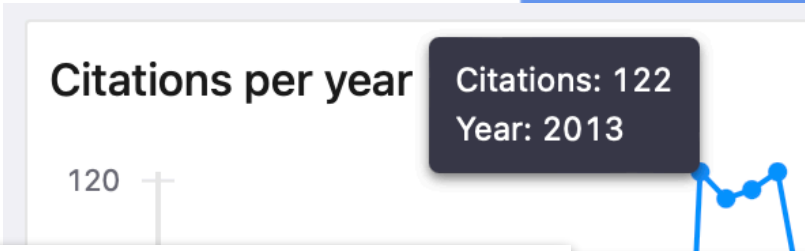
The image shows three overlapping website screenshots. At the top is the 'Physics' website with the tagline 'spotlighting exceptional research'. Below it is the 'nature' website, 'International weekly journal of science', with navigation links for Home, News & Comment, Research, Careers & Jobs, Current Issue, Archive, and Audio & Video. At the bottom is the 'CERN COURIER' website, 'International Journal of High-Energy Physics', featuring a banner for 'DISCOVER INNOVATION TRADE-UP & UPGRADE TO TWISTORR 304 FS' and a news article titled 'BESIII observes new mystery particle' dated Apr 26, 2013.



Impact

- * Physics Viewpoint: New particle hints at four-quark matter
- * Nature: Quark quartet opens fresh vista on matter
- * CERN Courier: BESIII observes new mystery particle
- * Most cited BES & BESIII paper
- * Included in the textbook

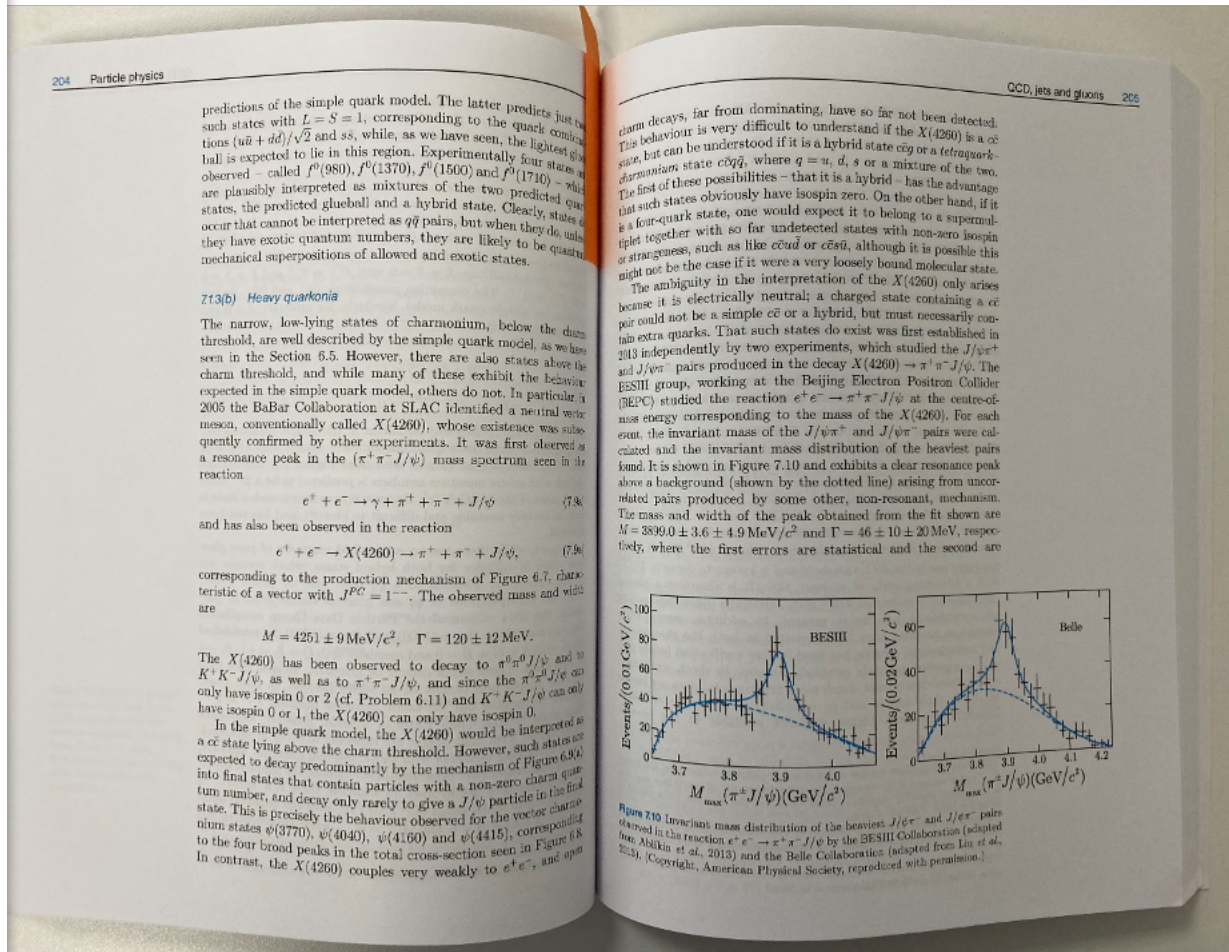
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Preface

The successful completion and operation of Beijing Electron-Positron Collider (BEPC) and Beijing Spectrometer (BES) is a good beginning for the development of high energy physics in China achieving worldwide reputation in this field. In the past 30 years, BES has made remarkable achievements in τ physics, charm physics, as well as hadronic physics. Among them, the accurate determination of τ mass in 1992 was regarded as one of the most important achievements in physics research in that year. The measurement of R value in 1998–1999 is of great importance to the search for Higgs boson. The new resonance state X(1835) discovered in 2005 might be related to baryon pairs, and the $Z_c(3900)$ is a candidate for a new hadronic state. Till 2019, 10 billion J/ψ events have been accumulated representing the largest J/ψ data sample ever collected in electron-positron colliders.

T. D. Lee
August 13th, 2019



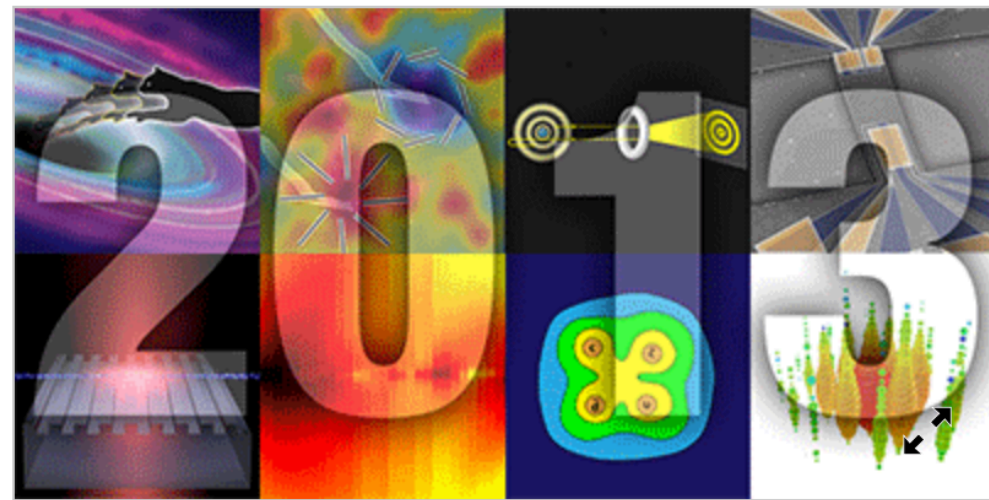
Four-Quark matter - Highlights of the year

NOTES FROM THE EDITORS

Highlights of the Year

December 30, 2013 • *Physics* 6, 139

Physics looks back at the standout stories of 2013.



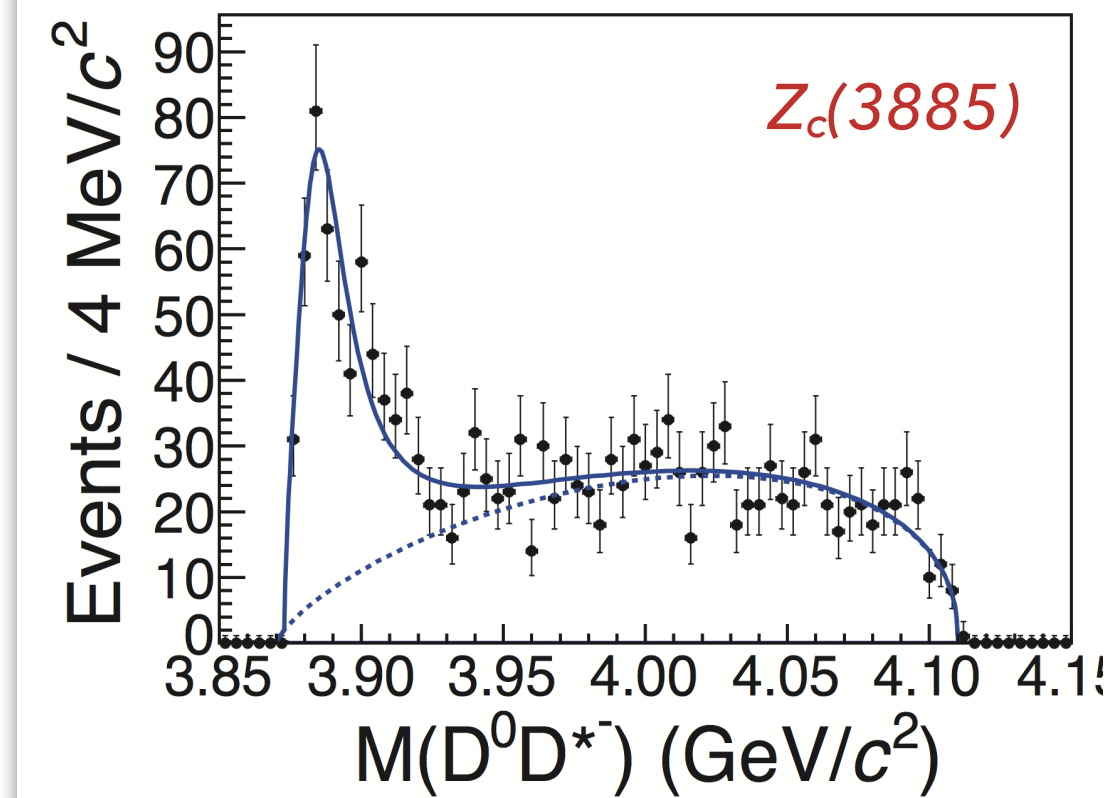
Images from popular *Physics* stories in 2013.

As 2013 draws to a close, we look back on the research covered in *Physics* that really made waves in and beyond the physics community. In thinking about which stories to highlight, we considered a combination of factors: popularity on the website, a clear element of surprise or discovery, or signs that the work could lead to better technology. On behalf of the *Physics* staff, we wish everyone an excellent New Year.

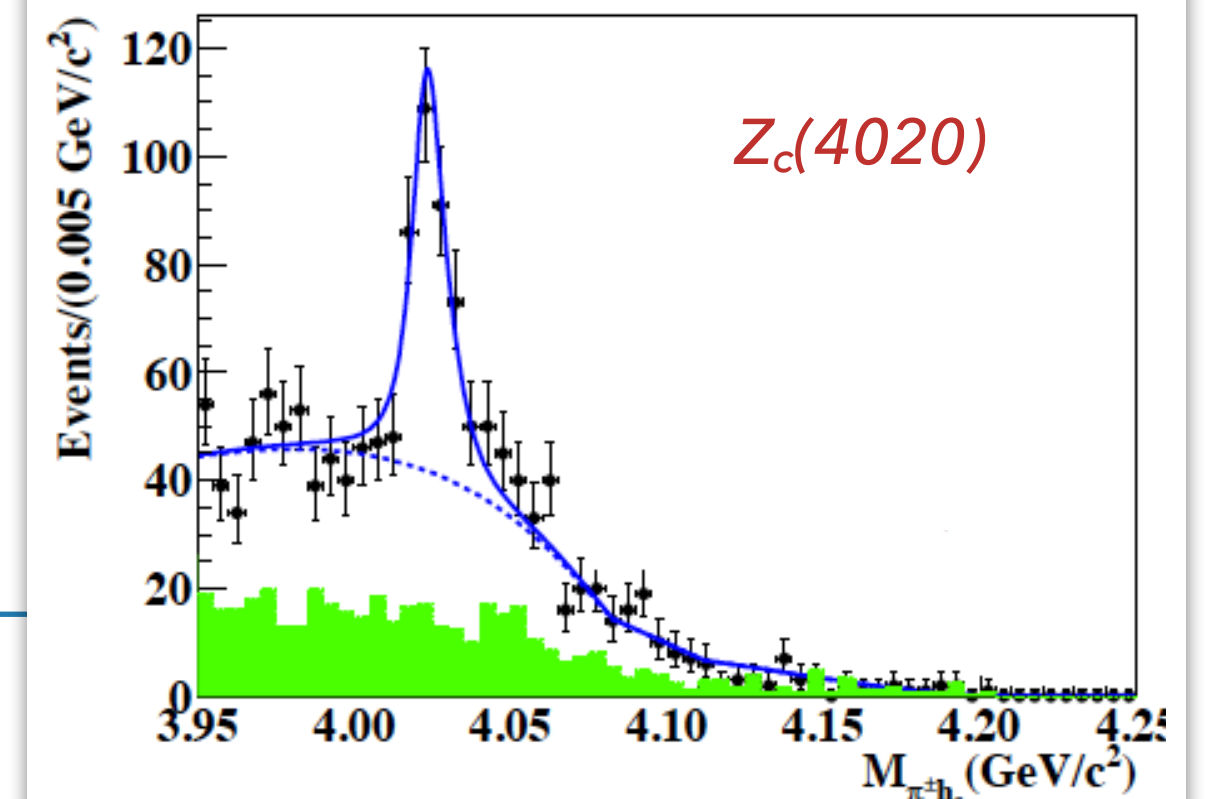
– Matteo Rini and Jessica Thomas

Four-Quark Matter

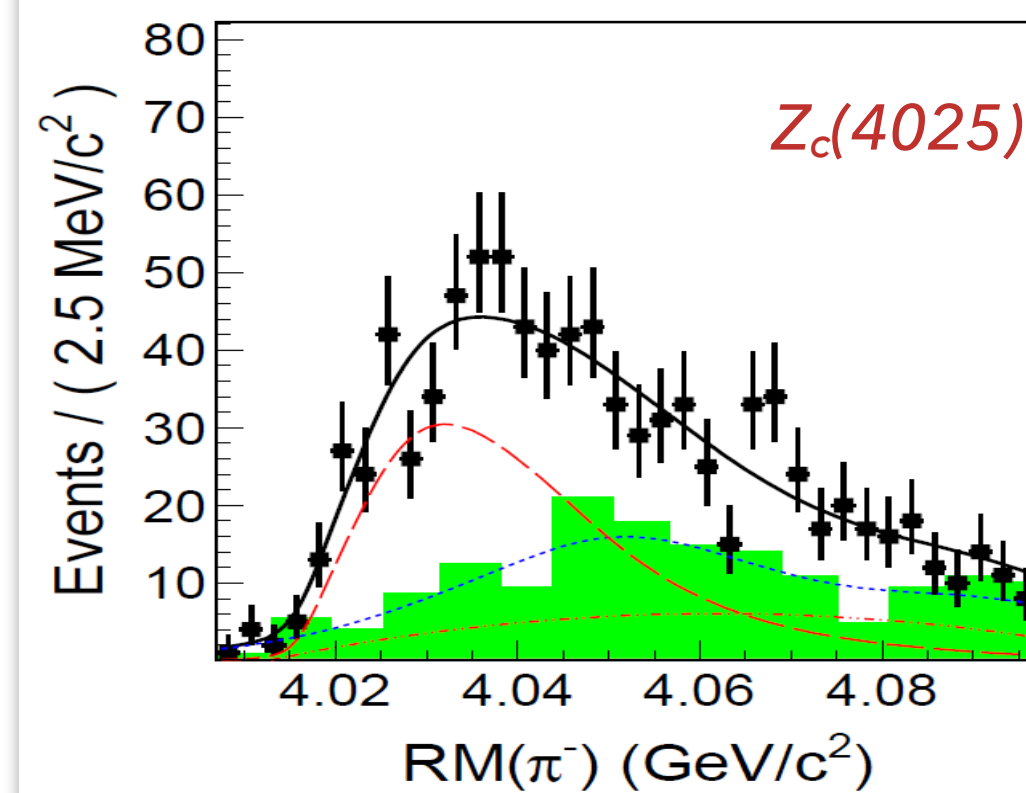
Quarks come in twos and threes—or so nearly every experiment has told us. This summer, the BESIII Collaboration in China and the Belle Collaboration in Japan reported they had sorted through the debris of high-energy electron-positron collisions and seen a **mysterious particle** that appeared to contain four quarks. Though other explanations for the nature of the particle, dubbed $Z_c(3900)$, are possible, the “tetraquark” interpretation may be gaining traction: BESIII has since **seen** a series of other particles that appear to contain four quarks.



*PRL*112, 022001 (2014)



*PRL*111, 242001 (2013)



*PRL*112, 132001 (2014)

Neutral partners observed \Rightarrow
isospin triplets
Top cited physics papers at BESIII

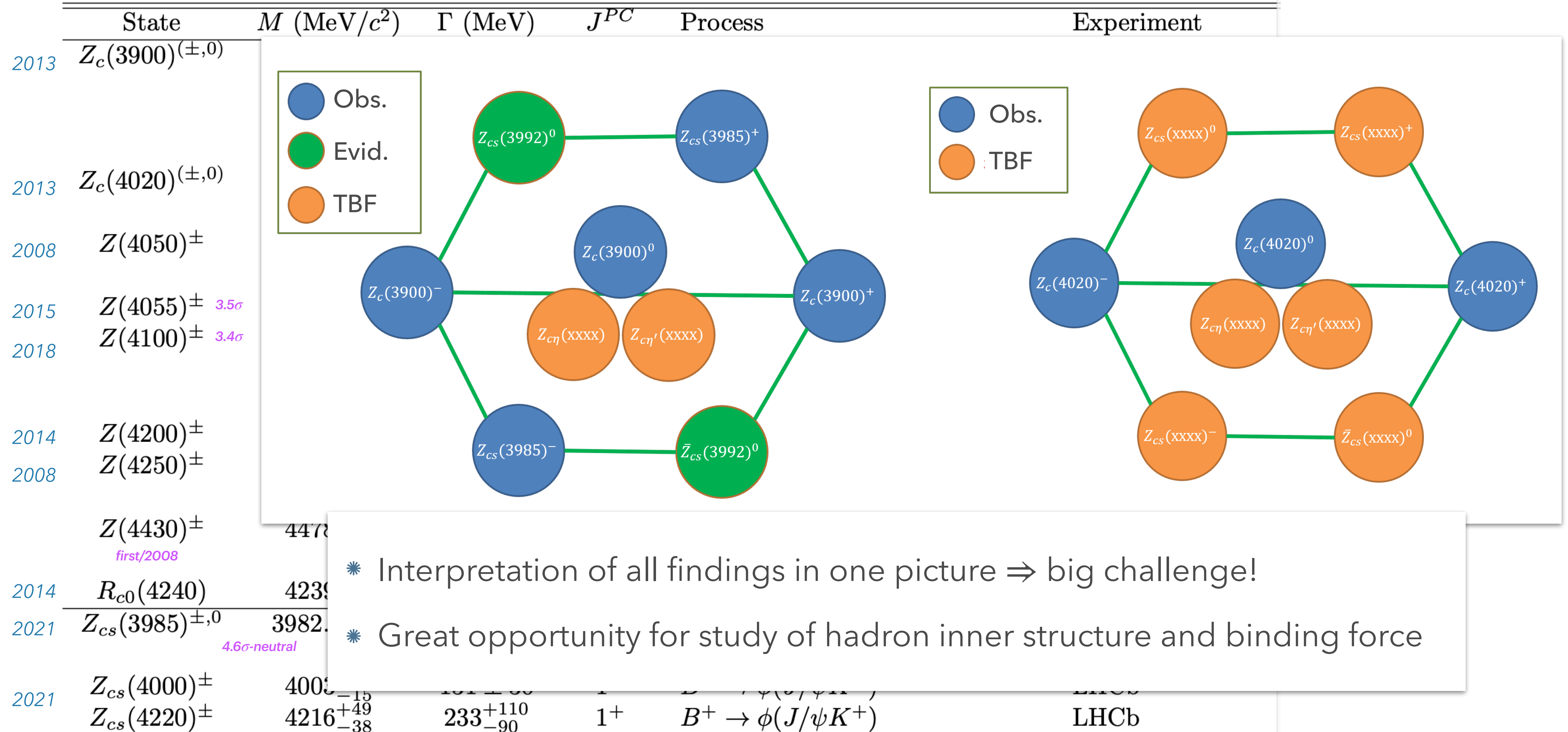
Z_c states at a glance

	State	M (MeV/ c^2)	Γ (MeV)	J^{PC}	Process	Experiment
2013	$Z_c(3900)^{(\pm,0)}$	3888.4 ± 2.5	28.3 ± 2.5	1^{+-}	$e^+e^- \rightarrow \pi^{(+,0)}(\pi^{(-,0)}J/\psi)$ $e^+e^- \rightarrow \pi^{(+,0)}(D\bar{D}^*)^{(-,0)}$ $H_b \rightarrow X\pi^+(\pi^-J/\psi)$ $e^+e^- \rightarrow \pi^+(\eta_c\rho^-)$	BESIII, Belle BESIII D0 BESIII
2013	$Z_c(4020)^{(\pm,0)}$	4024.1 ± 1.9	13 ± 5	$1^{+-} (?)$	$e^+e^- \rightarrow \pi^{(+,0)}(\pi^{(-,0)}h_c)$ $e^+e^- \rightarrow \pi^{(+,0)}(D^*\bar{D}^*)^{(-,0)}$	BESIII, Belle BESIII
2008	$Z(4050)^\pm$	4051^{+24}_{-40}	82^{+50}_{-28}	$?^?+$	$\bar{B}^0 \rightarrow K^-(\pi^+\chi_{c1})$ $e^+e^- \rightarrow \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	Belle BESIII Not Seen!
2015	$Z(4055)^\pm$ 3.5σ	4054 ± 3.2	45 ± 13	$?^?-$	$e^+e^- \rightarrow \pi^+(\pi^-\psi(2S))$	Belle
2018	$Z(4100)^\pm$ 3.4σ	4096 ± 28	152^{+80}_{-70}	$?^??$	$B^0 \rightarrow K^+(\pi^-\eta_c)$ $e^+e^- \rightarrow \pi^{(+,-)}\pi^0(\pi^{(-,+)}\eta_c)$ $e^+e^- \rightarrow \pi^{(+,-)}\eta(\pi^{(-,+)}\eta_c)$	LHCb BESIII Not Seen! BESIII Not Seen!
2014	$Z(4200)^\pm$	4196^{+35}_{-32}	370^{+100}_{-150}	1^{+-}	$\bar{B}^0 \rightarrow K^-(\pi^+J/\psi)$	Belle, LHCb
2008	$Z(4250)^\pm$	4248^{+190}_{-50}	177^{+320}_{-70}	$?^?+$	$\bar{B}^0 \rightarrow K^-(\pi^+\chi_{c1})$ $e^+e^- \rightarrow \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	Belle BESIII Not Seen!
	$Z(4430)^\pm$ <i>first/2008</i>	4478^{+15}_{-18}	181 ± 31	1^{+-}	$B^0 \rightarrow K^+(\pi^-\psi(2S))$ $\bar{B}^0 \rightarrow K^-(\pi^+J/\psi)$	Belle, LHCb Belle
2014	$R_{c0}(4240)$	4239^{+50}_{-21}	220^{+120}_{-90}	0^{--}	$B^0 \rightarrow K^+\pi^-\psi(2S)$	LHCb
2021	$Z_{cs}(3985)^{\pm,0}$ 4.6σ -neutral	$3982.5^{+2.8}_{-3.4}$	$12.8^{+6.1}_{-5.3}$	$?$	$e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$ $e^+e^- \rightarrow K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$	BESIII BESIII
2021	$Z_{cs}(4000)^\pm$	4003^{+7}_{-15}	131 ± 30	1^+	$B^+ \rightarrow \phi(J/\psi K^+)$	LHCb
	$Z_{cs}(4220)^\pm$	4216^{+49}_{-38}	233^{+110}_{-90}	1^+	$B^+ \rightarrow \phi(J/\psi K^+)$	LHCb

Z_c states at a glance

	State	M (MeV/ c^2)	Γ (MeV)	J^{PC}	Process	Experiment
2013	$Z_c(3900)^{\pm,0}$					
2013	$Z_c(4020)^{\pm,0}$					
2008	$Z(4050)^{\pm}$					
2015	$Z(4055)^{\pm}$ 3.5σ					
2018	$Z(4100)^{\pm}$ 3.4σ					
2014	$Z(4200)^{\pm}$					
2008	$Z(4250)^{\pm}$					
	$Z(4430)^{\pm}$ <i>first/2008</i>	4478_{-18}^{+20}	181 ± 31	1^-	$B^0 \rightarrow K^+(\pi^-\psi(2S))$ $\bar{B}^0 \rightarrow K^-(\pi^+J/\psi)$	Belle, LHCb
2014	$R_{c0}(4240)$	4239_{-21}^{+50}	220_{-90}^{+120}	0^{--}	$B^0 \rightarrow K^+\pi^-\psi(2S)$	LHCb
2021	$Z_{cs}(3985)^{\pm,0}$ 4.6σ -neutral	$3982.5_{-3.4}^{+2.8}$	$12.8_{-5.3}^{+6.1}$?	$e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$ $e^+e^- \rightarrow K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$	BESIII
2021	$Z_{cs}(4000)^{\pm}$	4003_{-15}^{+7}	131 ± 30	1^+	$B^+ \rightarrow \phi(J/\psi K^+)$	LHCb
2021	$Z_{cs}(4220)^{\pm}$	4216_{-38}^{+49}	233_{-90}^{+110}	1^+	$B^+ \rightarrow \phi(J/\psi K^+)$	LHCb

Z_c states at a glance



Thank you!

谢谢!