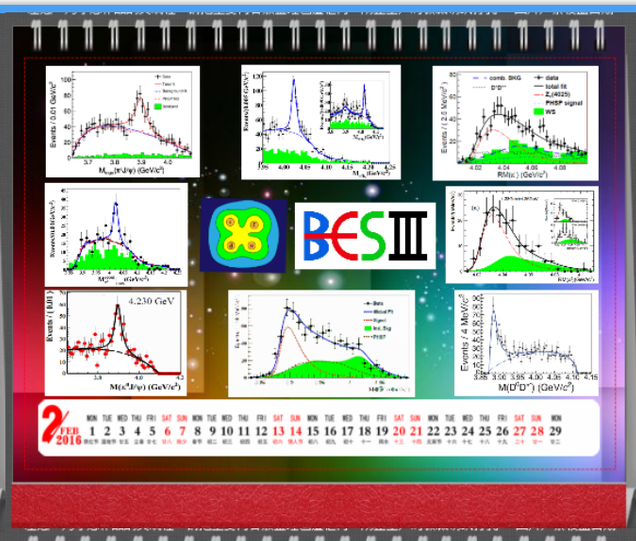
The Initial XYZ Program at BESIII (2010—2014)



Data sample	c.m. energy (MeV)	$\mathcal{L}$ (pb^{-1})
3810	3807.65±0.10±0.58	50.54±0.03
3900	3896.24±0.11±0.72	52.61±0.03
4009	4007.62±0.05±0.66	481.96±0.01
4090	4085.45±0.14±0.66	52.63±0.03
4190	4188.59±0.15±0.68	43.09±0.03
4210	4207.73±0.14±0.61	54.55±0.03
4220	4217.13±0.14±0.67	54.13±0.03
4230	4226.26±0.04±0.65	1091.74±0.15
4245	4241.66±0.12±0.73	55.59±0.04
4260	4257.97±0.04±0.66	825.67±0.13
4310	4307.89±0.17±0.63	44.90±0.03
4360	4358.26±0.05±0.62	539.84±0.10
4390	4387.40±0.17±0.65	55.18±0.04
4420	4415.58±0.04±0.72	1073.56±0.14
4470	4467.06±0.11±0.73	109.94±0.04
4530	4527.14±0.11±0.72	109.98±0.04
4575	4574.50±0.18±0.70	47.67±0.03
4600	4599.53±0.07±0.74	566.93±0.11

30 Years of BES Symposium — September 5, 2019 — Ryan Mitchell

The Initial XYZ Program at BESIII (2010—2014)

Prologue: Two Groundbreaking Discoveries **(2003 — 2005)**

Chapter 1: Studying $\psi(4040)$ Decays **(2010 — 2011)**

Interlude: Three Informative Discoveries **(2010 — 2011)**

Chapter 2: The XYZ Proposal at Higher Energies **(2011 — 2012)**

Chapter 3: The Initial Running at 4260 and 4360 MeV **(2013)**

Chapter 4: Discovery of the $Z_c(3900)$ **(2013)**

Chapter 5: Further Analyses of the 2013 XYZ Data **(2013 — 2014)**

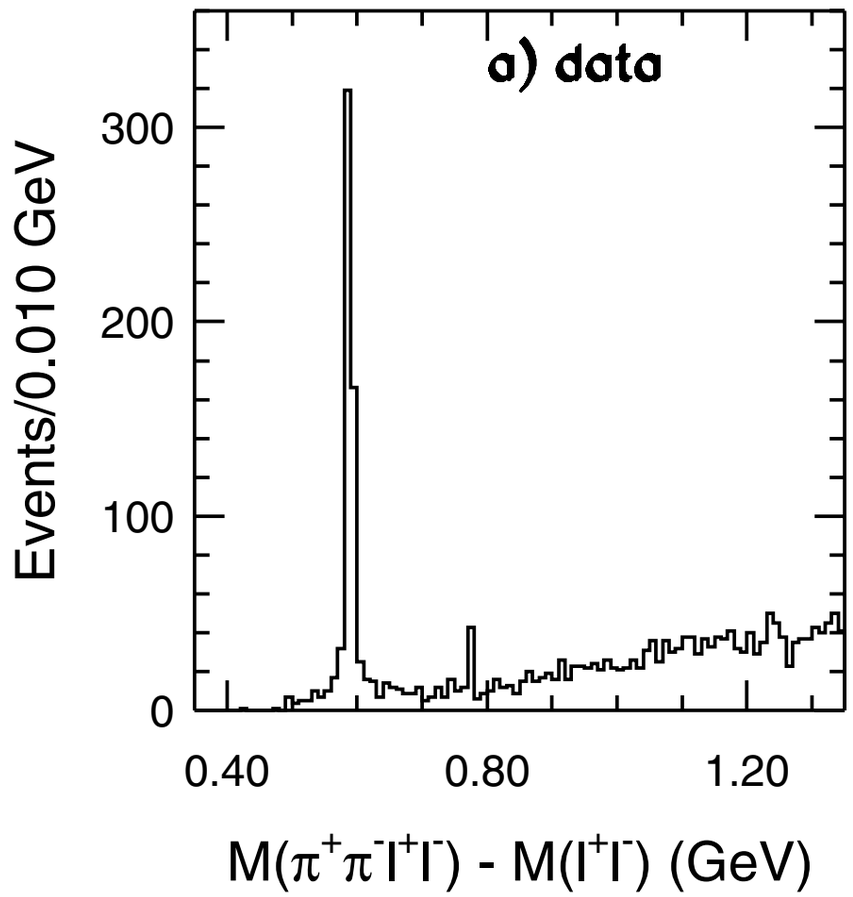
Postscript: The XYZ Program at BESIII

Prologue: Two Groundbreaking Discoveries

Timeline

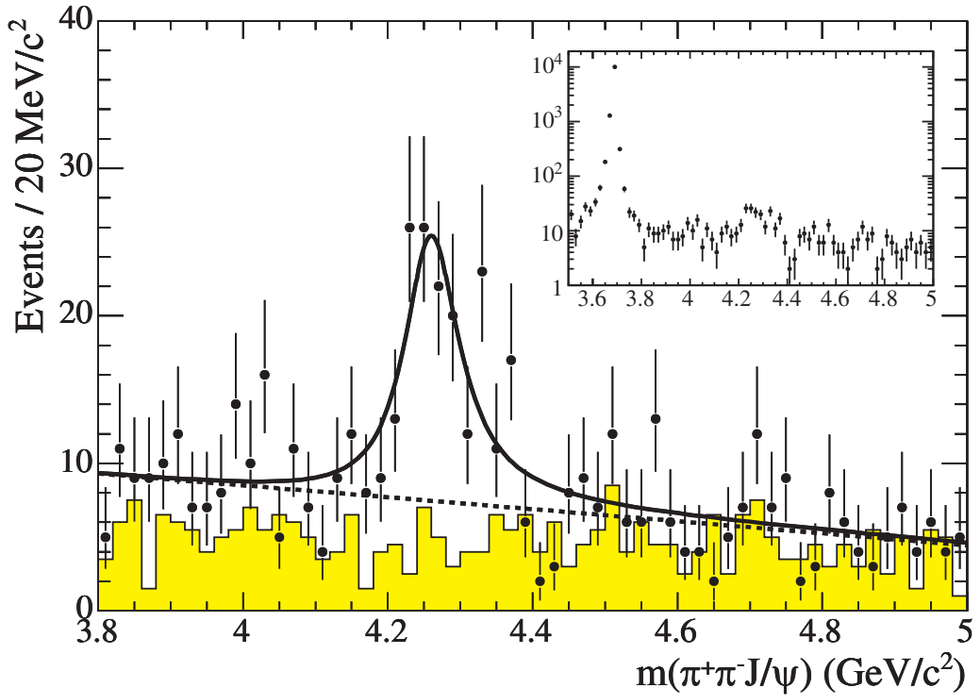
2003: Discovery of the X(3872) by Belle
2005: Discovery of the Y(4260) by BaBar

Discovery of the X(3872) by Belle



published December 2003
(PRL91,262001(2003))

Discovery of the Y(4260) by BaBar



published September 2005
(PRL95,142001(2005))

Chapter 1: Studying ψ(4040) Decays (2010 – 2011)

Timeline

June 3, 2010: ψ(4040) proposal talk by Changzheng (Shenyang collaboration meeting)

Two important issues

- Find excited charmonium states
  - 2P states χ'_{cJ} via ψ(4040) radiative transition
  - S-wave spin-singlet (M1 transition, very hard)
- Understand C-even XYZ
  - Can be produced in ψ(4040) radiative decays
  - For example: inclusive photon spectrum
  - X(3872)→ππJ/ψ, ππJ/ψ, …
  - XYZ(3940)→ωJ/ψ, DDbar, DD*, …
  - X(3915)→ωJ/ψ, …

We propose to do these with ψ(4040) data!

Let's do it!

- Study of charmonium spectroscopy & XYZ particles is one of the hot topics in HEP
- ψ(4040) data can also be used for
  - Ds study (BES yellow book)
  - R & Rc measurement (Zhengguo's talk)
- Accelerator experts: do not you want to see if you can reach high energy?
- Accumulating 200/pb data only needs two (2) months, but the physics is rich!

Thanks a lot!

- Join us and/or support us!

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Changzheng — June 3, 2010 (Shenyang collaboration meeting)

Chapter 1: Studying ψ(4040) Decays (2010 – 2011)

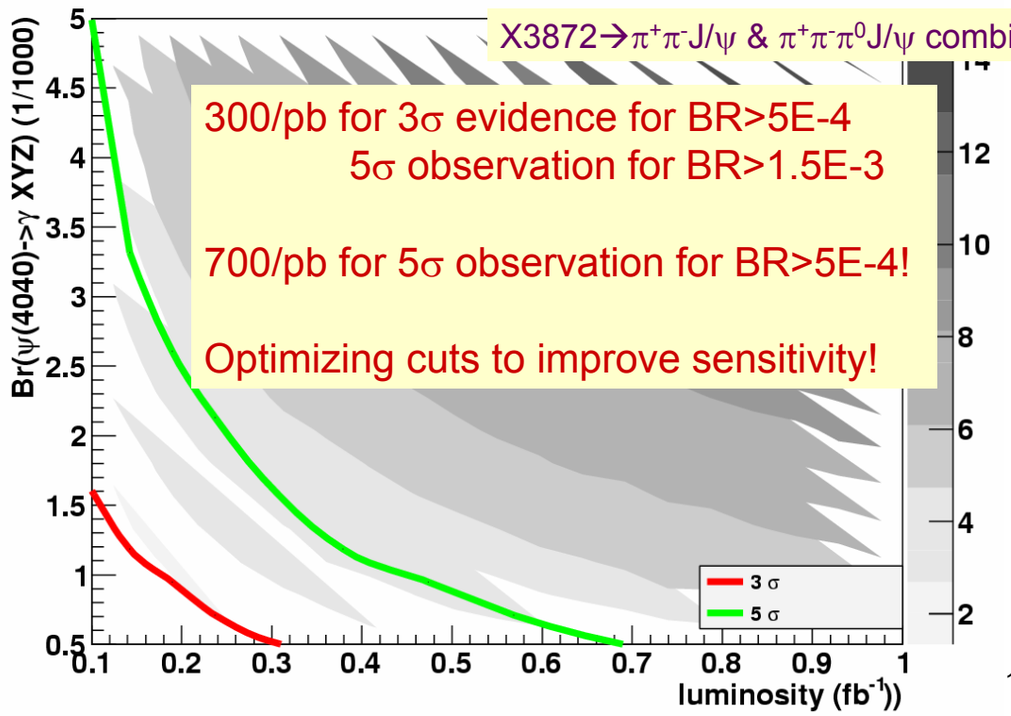
Timeline

October 21-24, 2010: Charm 2010 conference at IHEP (observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$ at CLEO)
October 25, 2010: $\psi(4040)$ proposal talk by Changzheng (approved)(IHEP collaboration meeting)
November 17, 2010: First meeting of the $\psi(4040)$ working group (Liangliang)

Sensitivity versus Luminosity

Significance depending on lum and Br

From Zhu Kai



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Let's do it!

- Study of charmonium spectroscopy & XYZ particles is one of the hot topics in HEP
- ψ(4040) data can also be used for
  - D_s study (Yellow book/Roy@Charm2010)
  - R & R_c measurement (Zhengguo@Shenyang)
  - DDbar structure at 3.86 GeV (BESI, Lingjun's thesis)
  - Surprise! (see next page!)
- Accelerator experts: do not you want to see if you can reach high energy?
- Accumulating ~300/pb data only needs two (2) months, but the physics is rich!
- Join us and/or support us!

Thanks!

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Changzheng — October 25, 2010 (IHEP collaboration meeting)

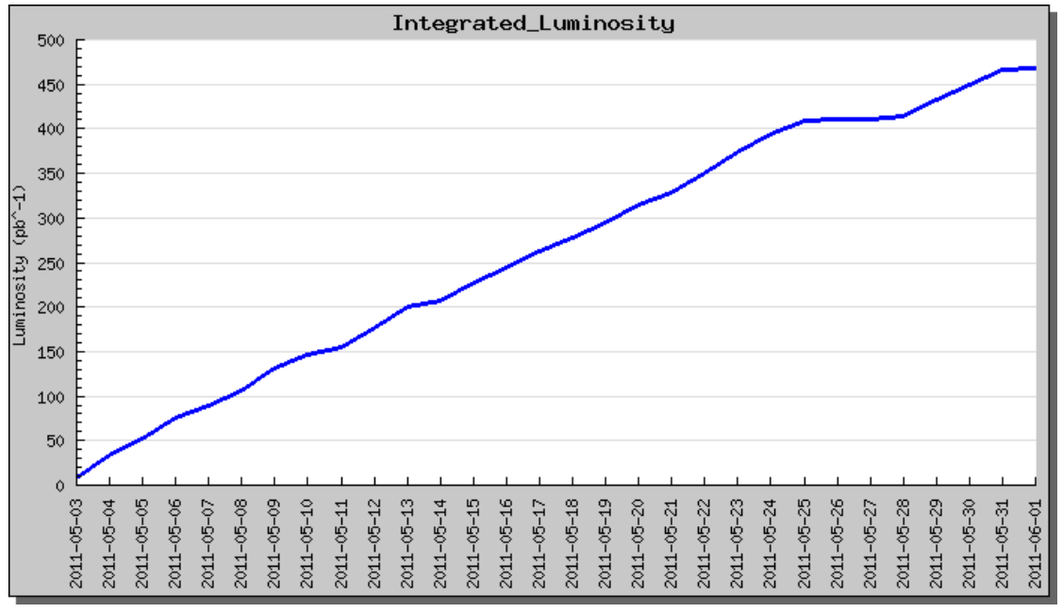
Chapter 1: Studying ψ(4040) Decays (2010 – 2011)

Timeline

May 3 – June 1, 2011: Collect 470 pb^{-1} *[482]* of data at 4010 MeV *[4007.6]*

Data accumulation

- From 3rd May 2011, RUN 23463, to 1st June
- About 470 pb^{-1} ψ(4040) been collected around 4.010 GeV CMS



Kai – June 5, 2011 (Nanjing collaboration meeting)

Chapter 1: Studying $\psi(4040)$ Decays (2010 – 2011)

Timeline

June – September, 2011: Initial analyses of the 4010 data

Summary

Very preliminary results

- $\sigma(\psi(4040) \to \pi^+\pi^- J/\psi) = 12.7 \pm 0.7(uu)/12.2 \pm 1.1(ee)$ pb at 4.009 GeV
- $\sigma(\psi(4040) \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi) < 0.08(uu)/0.14(ee)$ pb at 90% C.L.
- $\sigma(e^+e^- \to \gamma_{ISR}\psi') = 719.3 \pm 5.5(uu)/688.3 \pm 8.8(ee)$ pb, agree well with theoretical expectation.
- $\sigma(\psi(4040) \to \pi^+\pi^- h_c) < 2.6$ pb at 90% C.L.

Lots need to do: understanding the difference between $\mu\mu$ and ee in ISR process (around 3σ in terms of statistical errors only, could be due to the systematic error of PID), input-output check, estimate the systematic uncertainties, etc.

Thanks!

Legacy of $\psi(4040)$ running

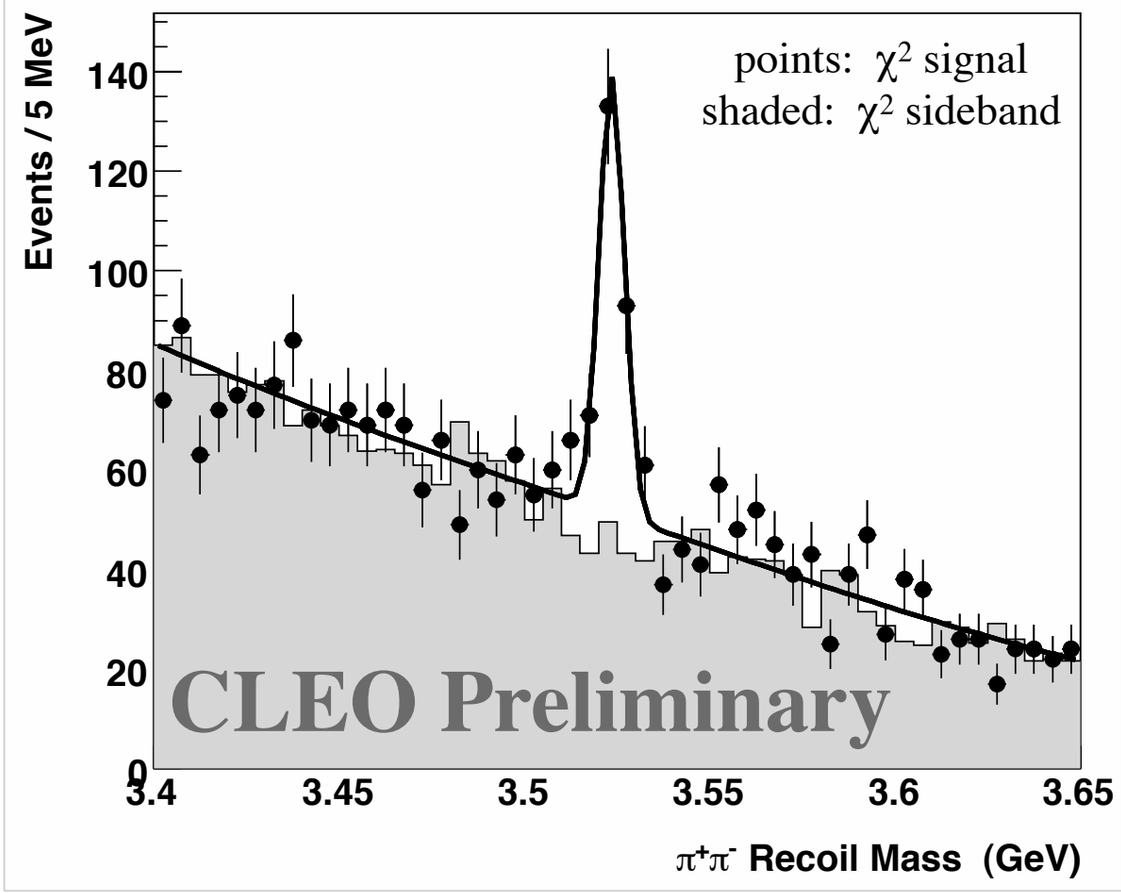
- the $\psi(4040)$ working group
- confidence at higher E_{cm}
- benchmarks for key processes
- a large $\eta J/\psi$ cross section
- [D_s physics (also in WG)]

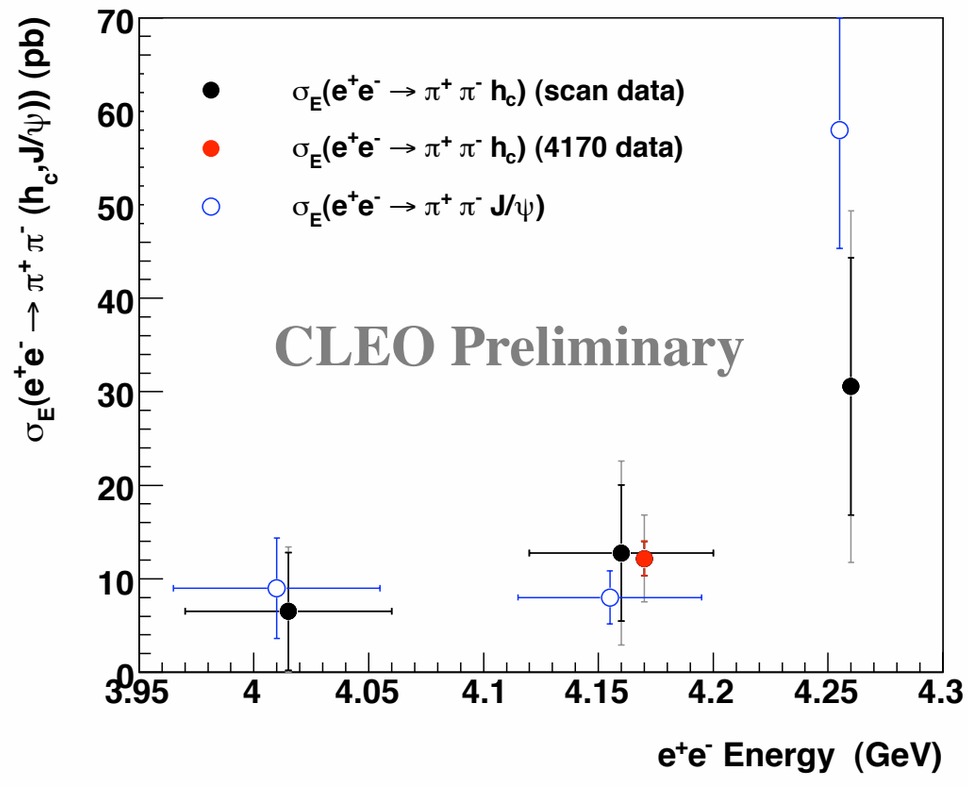
Kai and Yuping — September 15, 2011 (PKU collaboration meeting)

Interlude: Three Informative Discoveries

Timeline

October 21, 2010: Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$ at CLEO (Charm 2010 conference at IHEP)





Statistics are poor, but there is a suggestive rise at 4260!
(reminiscent of $\pi^+\pi^- J/\psi$??)

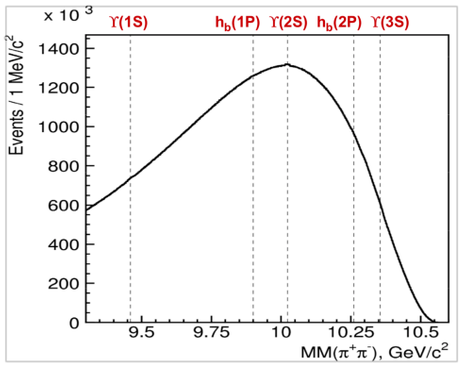
Ryan — October 21, 2010 (Charm 2010)

published July 2011
(PRL107,041803(2011))

Interlude: Three Informative Discoveries

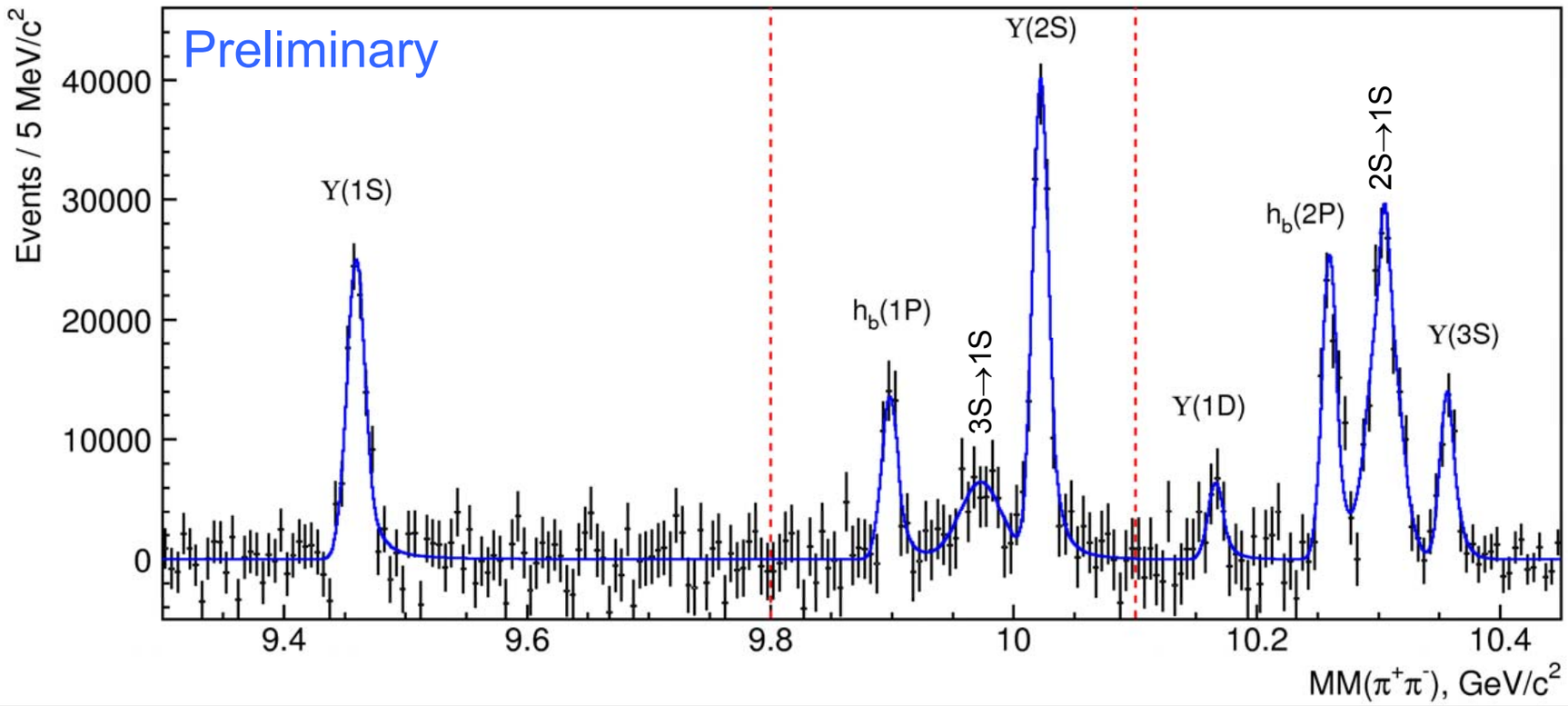
Timeline

March 2, 2011: Observation of $e^+e^- \to \pi^+\pi^- h_b(1P,2P)$ at Belle (La Thuile 2011)



Results

121.4 fb^{-1}



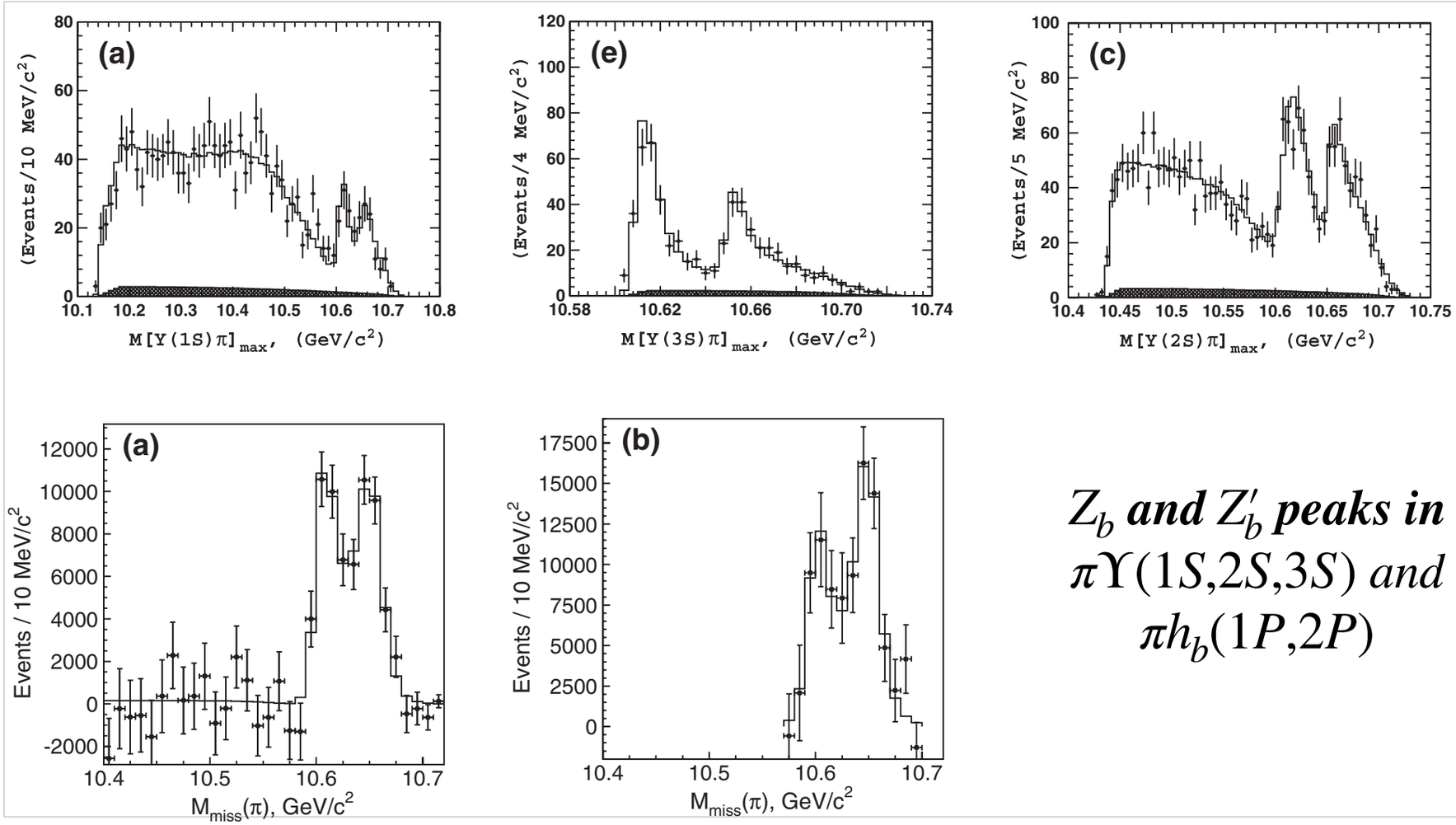
Roman Mizuk — March 2, 2011 (La Thuile)

published January 2012
(PRL108,032001(2012))

Interlude: Three Informative Discoveries

Timeline

(≤) May 2011: Observation of Z_b and Z_b' at Belle (arXiv:1105.4583)



Z_b and Z_b' peaks in $\pi\Upsilon(1S,2S,3S)$ and $\pi h_b(1P,2P)$

published March 2012
(PRL108,122001(2012))

Chapter 2: The XYZ Proposal at Higher Energies (2011–2012)

Timeline

2011: Initial discussions about running at higher E_{cm} (concurrent with $\psi(4040)$ analyses)

OVERVIEW and GOALS

I. Three sources of inspiration *(leaving many unanswered questions)*:

A. **BaBar** and **Belle** ISR data ⇒ **Y(4260)** and **Y(4360)**

B. **CLEO** 4170 data (and a little 4260 data) ⇒ **Y(4260)** and **h_c(1P)**

C. **Belle** "ϒ(5S)" data ⇒ **Y_b(10890)**, **h_b(1P)**, **h_b(2P)**, **$Z_b^{\pm}$(10610)**, **$Z_b^{\pm}$(10650)**

⇒ ***Interesting times!***

II. Unique opportunities at **BESIII** to pick up this line of development:

A. Study the **Y(4260)**

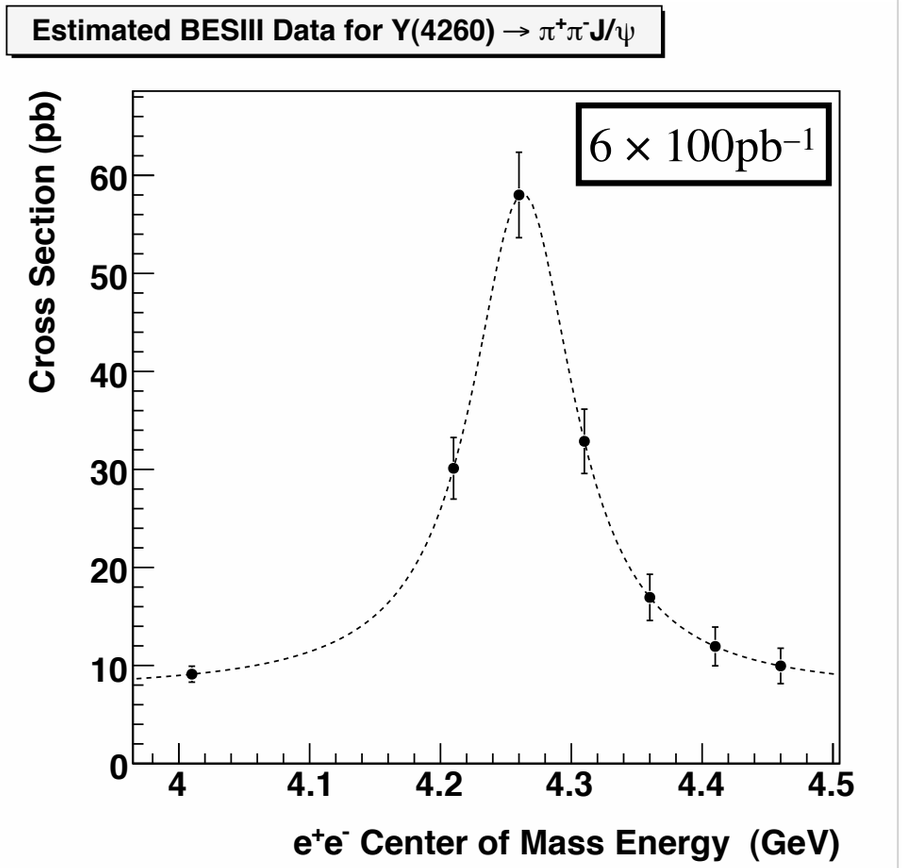
B. Search for **Z_c** states

C. Study the **Y(4360)**

D. Search for the **h_c(2P)**

⇒ Luminosity required is **~600pb^{-1}**: *(~100pb^{-1} at 4210, 4260, 4310, 4360, 4410, 4460 MeV)*

2



Ryan — November 30, 2011 (IHEP collaboration meeting)

Chapter 2: The XYZ Proposal at Higher Energies (2011–2012)

Timeline

Late 2011 – 2012: Meetings for the XYZ proposal (alternating with $\psi(4040)$ group meetings)
March 1, 2012: XYZ proposal talk by Ryan (IHEP collaboration meeting)

BESIII Data-Taking Proposal

PROPOSAL: Take ~500pb^{-1} (or more) of data at two energy points – 4260 and 4360 MeV.

Example uses:

- Use the large sample at 4260 MeV to study the Y(4260) → $\pi^+\pi^-$J/ψ Dalitz plot.
- Use the large sample at 4360 MeV to study the Y(4360) → $\pi^+\pi^-\psi$(2S) Dalitz plot.
- Use the large sample at 4360 MeV to search for Y(4360) → $\pi^+\pi^-h_c$(2P).
- To establish other Y(4260) decay modes, use the 4260 data as "on-resonance" and the 4360 data as "off-resonance" data (and vice-versa for Y(4360) decays).
- *(Also use other datasets (3770, 4010, D_s points, etc.) as "off-resonance" data.)*

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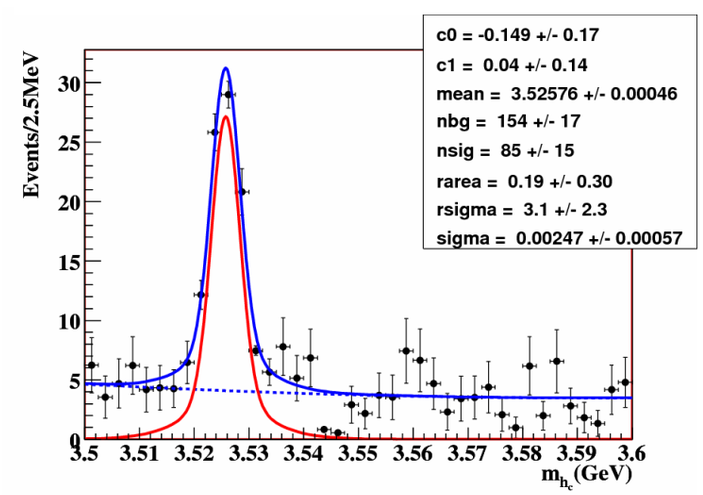
3. Y(4260) → $\pi^+\pi^-h_c$(1P) (III)

We can do better by a factor of 2–3 by reconstructing 16 η_c(1S) decay modes:



(from Yuping Guo)

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Ryan — March 1, 2012 (IHEP collaboration meeting)

Chapter 2: The XYZ Proposal at Higher Energies (2011–2012)

Timeline

March – June, 2012: Formal XYZ proposals developed by the XYZ working group
June 12, 2012: Approval for 4260 and 4360 MeV running (Suzhou collaboration meeting)
(initial estimate is 50 days each for 500 pb^{-1})

Proposal to Study Heavy States of Charmonium Using Data at 4260 MeV and 4360 MeV

XYZ Group
(Dated: June 1, 2012)

We propose to collect two sets of data using e^+e^- collisions with center of mass energies 4260 and 4360 MeV – corresponding to the $Y(4260)$ and $Y(4360)$, respectively – each with integrated luminosities of at least 500 pb^{-1}. This would provide us with unique samples of $Y(4260)$ and $Y(4360)$ decays. These decays are not only important for investigating the mysterious nature of the $Y(4260)$ and $Y(4360)$ states themselves, which are strong hybrid meson candidates, but they would also allow a number of searches for exotic charged charmonium states (Z_c), searches for conventional charmonium states (for example, the $h_c(2P)$), and new studies of open charm cross sections, among other topics.

Measurement of resonances parameters of excited ψs and the Ys and search for XYZ states

ABC[1]

(XYZ working group)

[1] *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing*

(Dated: May 1, 2012)

Abstract

We propose BESIII take data between 3.8 GeV and 5.0 GeV for a precision measurement of the resonance parameters of the excited ψ states ($\psi(4040)$, $\psi(4160)$, and $\psi(4415)$) and the Y states ($Y(4008)$, $Y(4260)$, $Y(4360)$, and $Y(4660)$). With data accumulated at some resonance peaks, the C-parity even charmonium and charmoniumlike states can be searched for via radiative transitions, while some other states, such as the isospin-one charmoniumlike state Z_c and the P-wave spin-singlet states $h_c(2P)$, can be studied via hadronic transitions.

Ecm energy (GeV)	Lum (pb^{-1})	Note
3.800	50	
3.820	50	
3.840	50	
3.860	50	
3.864	50	
3.868	50	
3.872	50	$D^*\bar{D}$ threshold
3.876	50	
3.880	50	
3.885	50	
3.900	50	$G(3900)$
3.910	50	
3.920	50	
3.930	50	
3.940	50	
3.950	50	
3.960	50	
3.970	50	
3.980	50	
3.990	50	
4.000	50	
4.005	50	
4.009	500	$\psi(4040)$, taken
4.015	50	D^*D^* threshold
4.020	50	
4.025	50	
4.030	50	
4.040	50	$\psi(4040)$
4.050	50	
4.060	50	
4.070	50	
4.080	50	$D_sD_s^*$ threshold
4.090	50	
4.100	50	
4.110	50	
4.120	50	
4.130	50	
4.140	50	
4.150	50	
4.160	500	$\psi(4160)$
4.170	50	
4.180	50	
4.190	50	

Ecm energy (GeV)	Lum (pb^{-1})	Note
4.210	50	
4.220	50	
4.225	50	$D_s^*D_s^*$
4.230	50	
4.240	50	
4.250	50	
4.260	500	$Y(4260)$
4.270	50	
4.280	50	
4.290	50	
4.300	50	
4.310	50	
4.320	50	
4.330	50	
4.340	50	
4.350	50	
4.355	50	
4.360	500	$Y(4360)$
4.365	50	
4.370	50	
4.380	50	
4.390	50	
4.400	50	
4.410	50	
4.415	500	$\psi(4415)$
4.420	50	
4.430	50	
4.440	50	
4.450	50	
4.460	50	
4.470	50	
4.480	50	
4.490	50	

Ecm energy (GeV)	Lum (pb^{-1})	Note
4.510	50	
4.530	50	
4.550	50	
4.570	50	
4.575	50	Λ_c threshold
4.580	50	
4.590	50	
4.600	50	
4.610	50	
4.620	50	
4.630	500	$Y(4630)$
4.640	50	
4.650	50	
4.660	500	$Y(4660)$
4.670	50	
4.680	50	
4.690	50	
4.710	50	
4.730	50	
4.750	50	
4.770	50	
4.790	50	
4.810	50	
4.860	50	
4.910	50	Σ_c threshold
4.920	50	
4.940	50	
4.960	50	
5.000	50	

Chapter 3: The Initial Running at 4260 and 4360 MeV (2013)

Timeline

December 14, 2012 — January 14, 2013: Collect 515 pb^{-1} [524] at 4260 MeV [4258]
January 14 — 20, 2013: Collect 3 × ~50 pb^{-1} at points near 4260 MeV
January 27 — February 24, 2013: Collect 523 pb^{-1} [539] at 4360 MeV [4358]
February 24 — 27, 2013: Collect 2 × ~50 pb^{-1} at points near 4360 MeV
(additional points due to good machine performance)

Party at the BEPC control room — January 15, 2013

Chapter 3: The Initial Running at 4260 and 4360 MeV (2013)

Timeline

January – February, 2013: Intense investigations of the initial data (long XYZ meetings)

Wednesday, 23 January 2013

09:00 - 09:20 Data taking status *20'*
Speaker: Ms. 清 高 (ihep)
Material: **Slides**

09:20 - 09:40 On the MC sampes of psi(4260) *20'*
Speaker: Dr. Rong-Gang Ping
Material: **Slides**

09:40 - 10:00 A First Look at the 4260 Data *20'*
Speaker: Ryan Mitchell (Indiana University)
Material: **Slides**

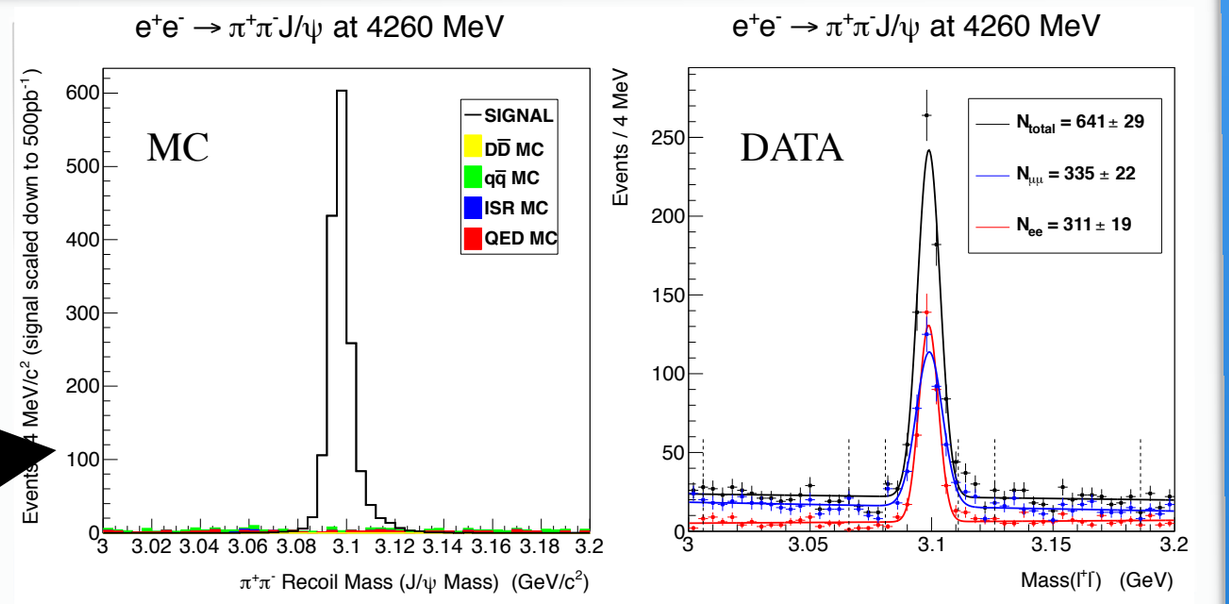
10:00 - 10:20 Open charm cross section at 4.26 GeV *20'*
Speaker: Mr. weimin song (ihep)
Material: **Slides**

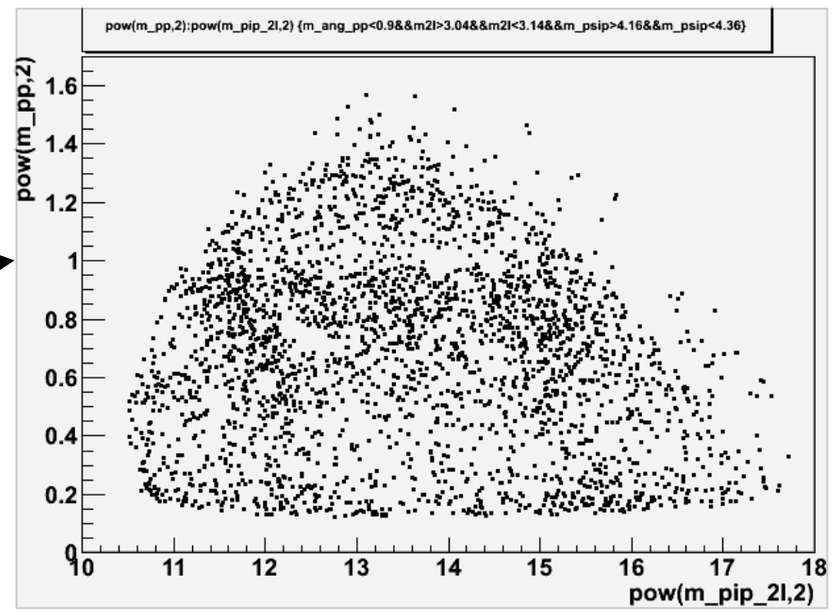
10:20 - 10:40 Y(4260) data check with 3 photons *20'*
Speaker: Dr. Kai Zhu (IHEP)
Material: **Slides**

10:40 - 11:00 pi+pi-J/psi, gamma gamma J/psi, gamma gamma psi'
Speaker: Mr. Zhiqing LIU (IHEP)
Material: **Slides**

11:00 - 11:20 pi+pi-J/psi at 4.26 GeV *20'*
Speaker: Dr. Gang LI (IHEP)

11:20 - 11:40 pi0 h_c at 4.01 and 4.26 GeV *20'*
Speaker: Dr. aiqiang guo (BES3 collaboration grounp member)
Material: **Slides**

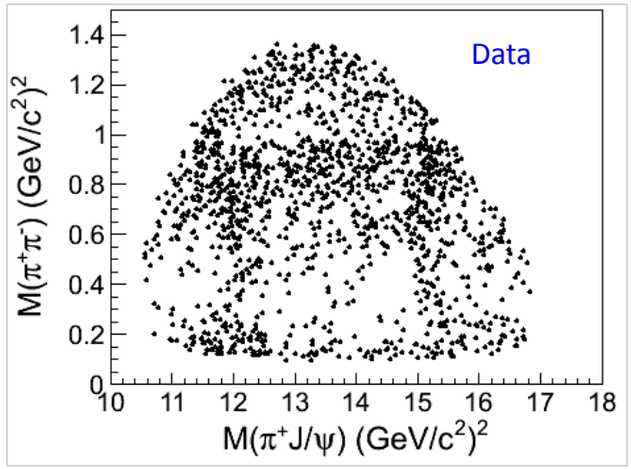




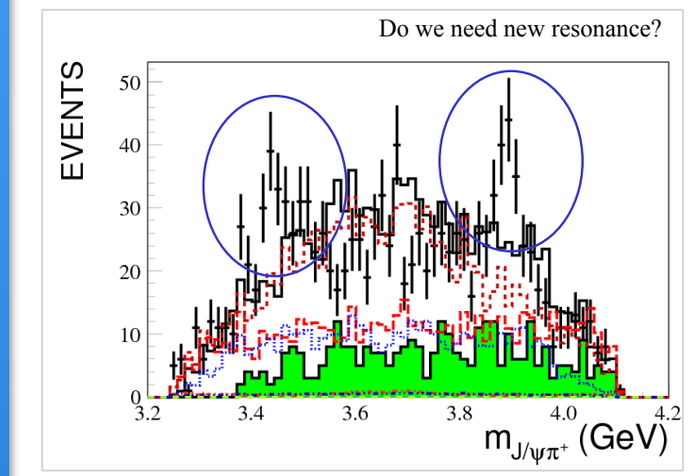
Chapter 3: The Initial Running at 4260 and 4360 MeV (2013)

Timeline

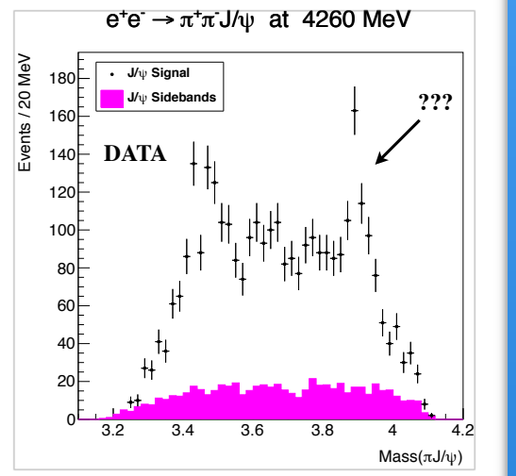
January – February, 2013: Intense investigations of the initial data (long XYZ meetings)



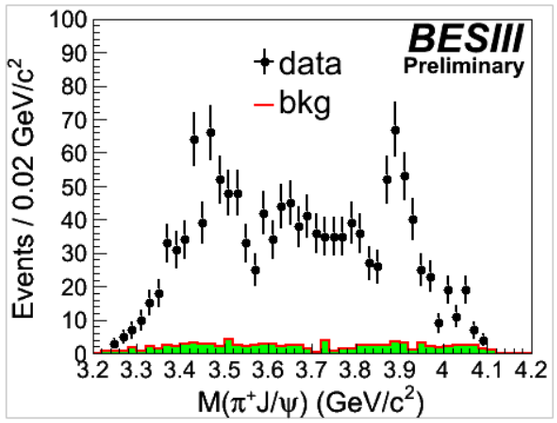
Zhiqing – January 30, 2013



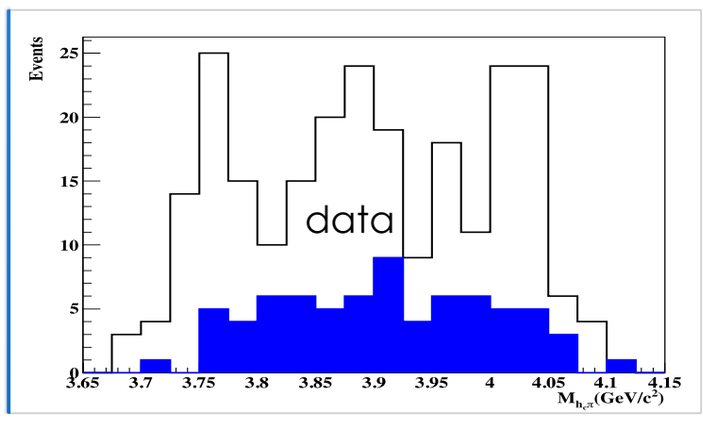
Ronggang – February 20, 2013



Ryan – February 27, 2013



Zhiqing – February 27, 2013



Yuping – February 27, 2013

Chapter 3: The Initial Running at 4260 and 4360 MeV (2013)

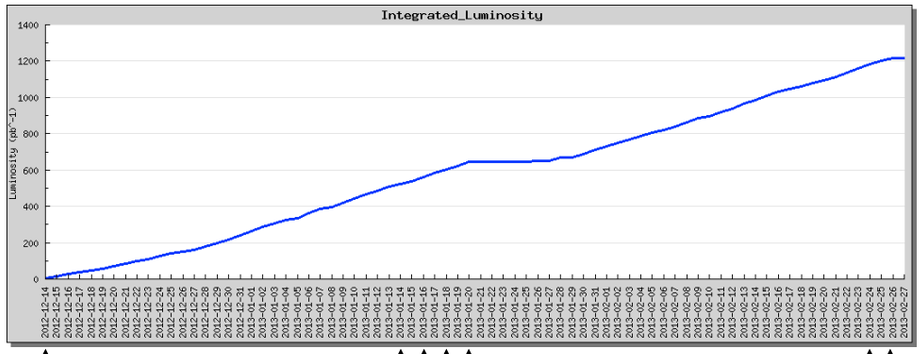
Timeline

February 27, 2013: A long list of intriguing results shown at the Tsinghua meeting
February 28, 2013: XYZ group writes a new proposal during the Tsinghua meeting banquet
March 1, 2013: Propose to extend the XYZ run period (approved)

What could we learn if we had three more months of data at 4260 MeV?

Official XYZ Data-Taking Ended ***Yesterday***

At this meeting, we presented ***eight talks*** with many interesting preliminary findings.
What could we learn with an additional ***three months*** of data at 4260 MeV?
Use existing data for lineshapes; use additional data to really focus on the Y(4260) peak.



4260 (515 pb^{-1})
4190 (42 pb^{-1})
4230 (43 pb^{-1})
4310 (44 pb^{-1})
4360 (523 pb^{-1})
4390 (53 pb^{-1})
4420 (~40 pb^{-1})

2

With ***three more months*** of 4260 data...

1. We could firmly establish the existence of the charged charmonium structure in $\pi^{\pm}J/\psi$ and conclusively measure its quantum numbers.

2. We would have a good chance of finding an isospin partner in $\pi^0 J/\psi$.

3. We could further investigate the rich substructure in the $\pi^+\pi^- h_c$ decay.

4. We could confirm the very preliminary evidence of a charged charmonium state decaying to **D*D**.

5. We double our sensitivity to **Y(4260) radiative decays**, probably our most conclusive test of the nature of the Y(4260).

6. We could definitively establish **KKJ/ψ** decays of the Y(4260).

Will we become systematics limited? *NO*.

Ryan — March 1, 2013 (Tsinghua collaboration meeting)

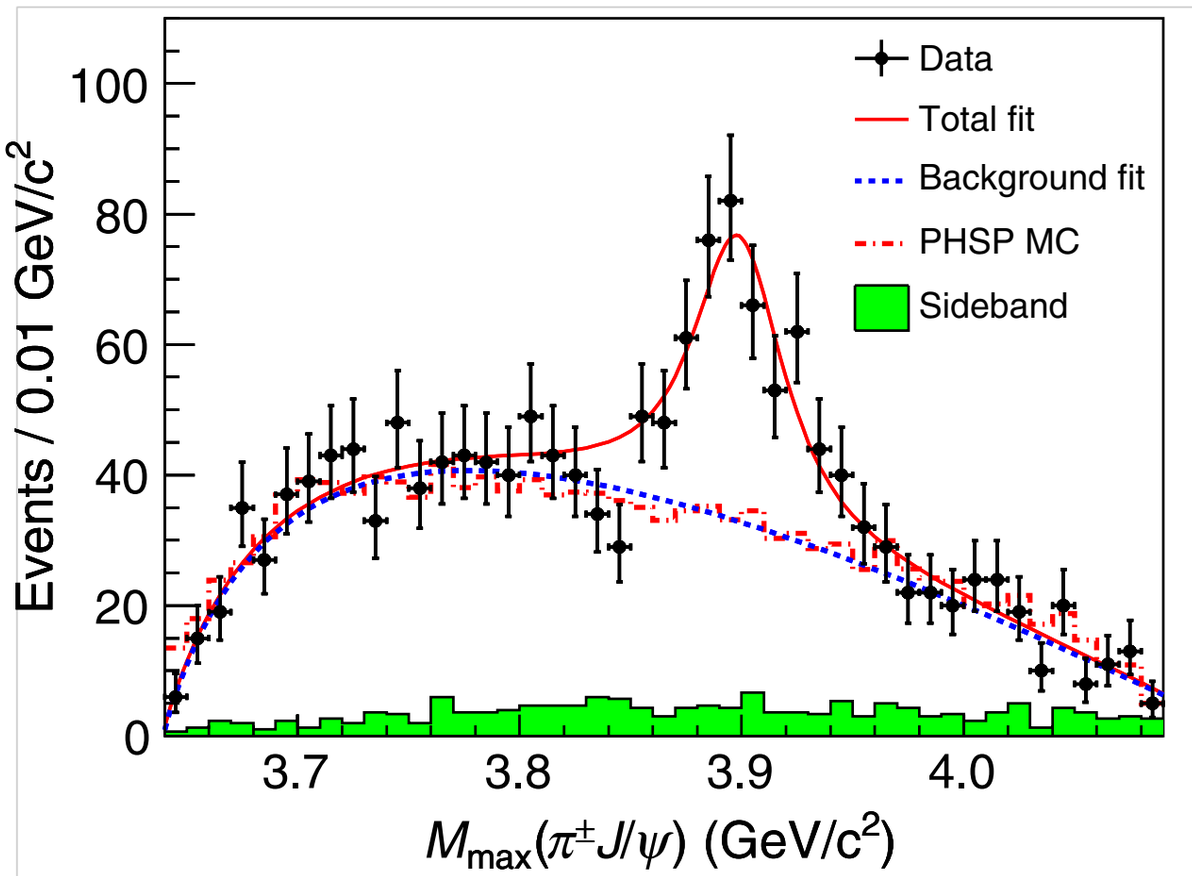
Chapter 4: Discovery of the $Z_c(3900)$ (2013)

Timeline

February, 2013:
Convincing evidence for the $Z_c(3900)$
February 27 — March 1, 2013 (Tsinghua):
Discussions of publication strategy
March 3, 2013:
First draft of the memo and paper
March 5, 2013:
Review committee formed
(Xinchou(ch), Yuanning, Fred, Matt)
March 4 — 7, 2013:
Many iterations on the paper draft
March 4 — 7, 2013:
Many studies by many people
(dE/dx, E_{CM}, Luminosity, other E_{CM}, neutral mode, ISR corrections, PWA)
March 8, 2013:
Zhiqing talk at the P&S meeting
March 18, 2013:
Referee-author meeting with extensive cross-checks
March 20 — 22, 2013:
Shortened collaboration-wide review
March 24, 2013:
Submission to the arXiv and PRL
March 27, 2013:
Special seminar at IHEP
March 28, 2013:
XYZ party in the BESIII control room

Timeline

May 2, 2013:
BESIII Paper accepted by PRL



published June 2013
(PRL110,252001(2013))

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Timeline

→ **March 30, 2013:**
Belle $Z_c(3900)$ paper submitted to arXiv
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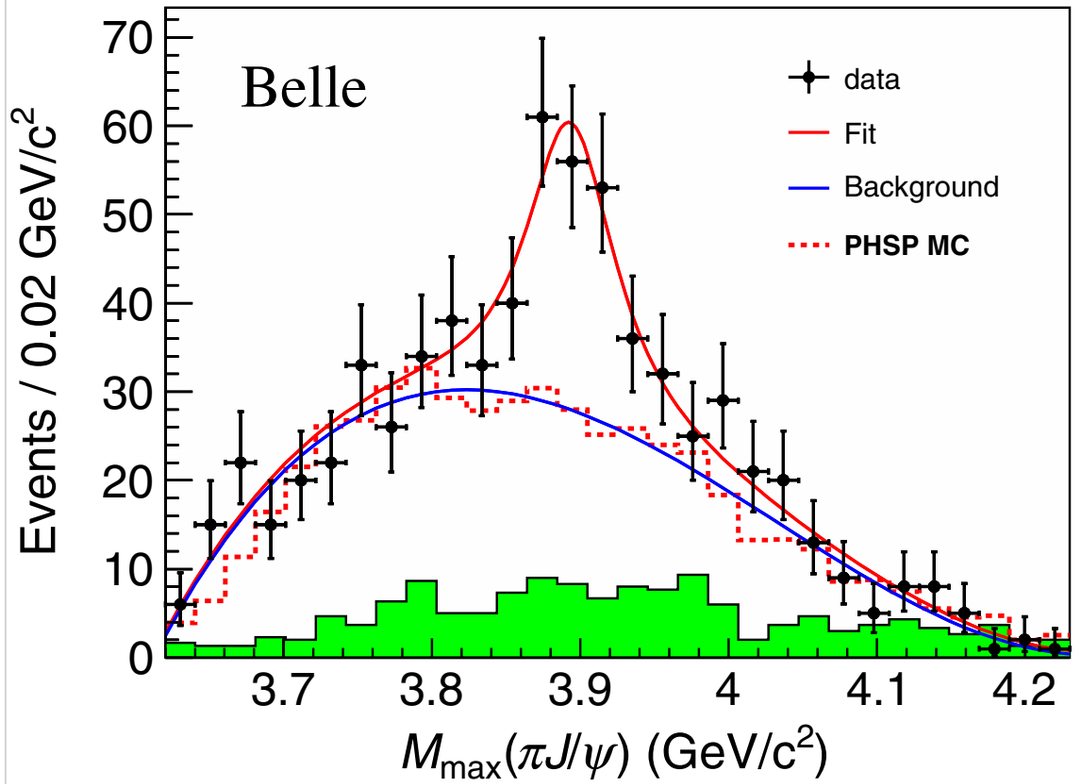


published June 2013
(PRL110,252002(2013))

Chapter 4: Discovery of the $Z_c(3900)$ (2013)

Timeline

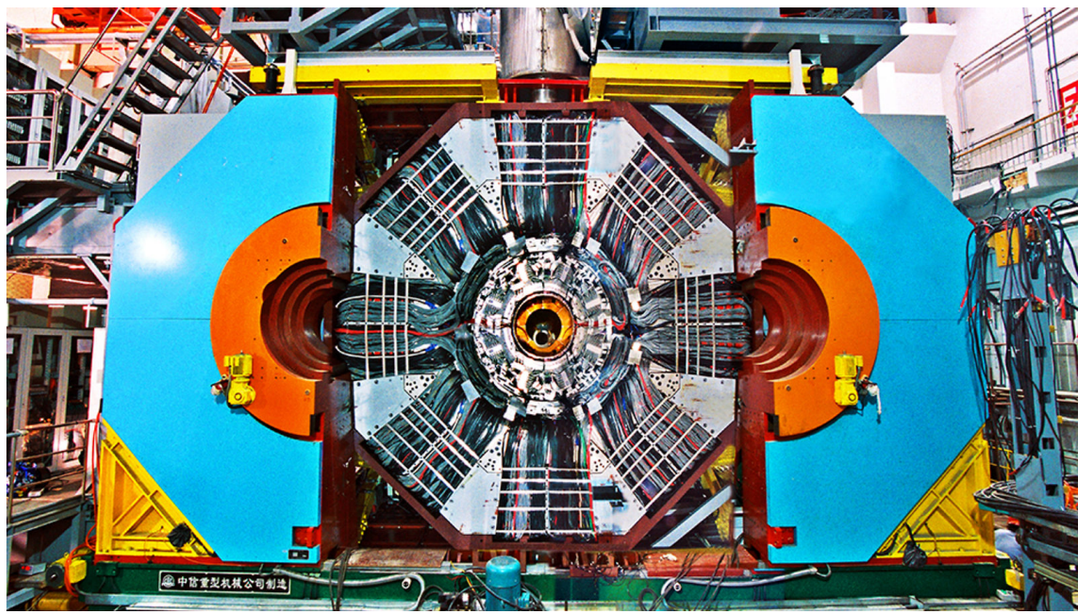
December, 2013: Discovery of the $Z_c(3900)$ named a "Highlight of the Year"

symmetry
dimensions of particle physics

Chinese collider expands particle zoo

12/09/13 | By Kelen Tuttle

China's Beijing Electron-Positron Collider seems to be hosting a reunion; members of a poorly understood family of particles keep popping up in their data, which may help clarify the properties of this reclusive family.

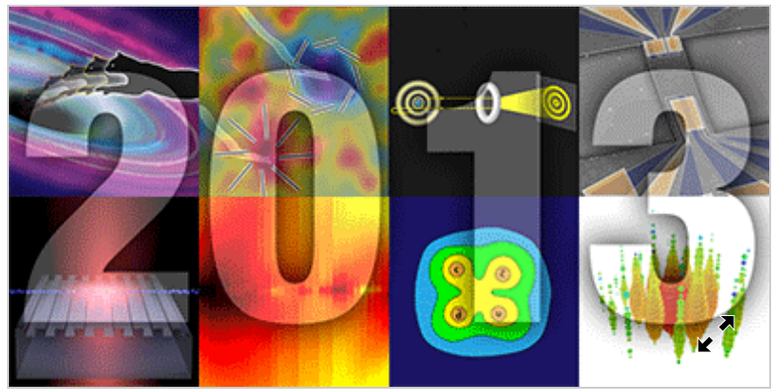


BESIII Collaboration

Notes from the Editors: Highlights of the Year

December 30, 2013 • *Physics* 6, 139

***Physics* looks back at the standout stories of 2013.**



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.

Chapter 5: Further Analyses of the 2013 XYZ Data (2013—2014)

Timeline

March — June, 2013: Extensive XYZ meetings and an explosion of analyses
June, 2013: XYZ group disbanded

Tuesday, 7 May 2013

09:00 - 09:20 luminosity measurement *20'*
Speaker: Ms. 清 高 (ihep)
Material: Slides

09:20 - 09:40 Search for X(3872) and X(3823) from excited Y/psi
Speaker: Mr. Zhiqing LIU (IHEP)
Material: Slides

09:40 - 10:00 search for psi(4260) to gamma chicj *20'*
Speaker: Mr. zhenya he (nankai university)
Material: Slides

10:00 - 10:10 Comparison of pi0 pi0 hc and pi+ pi- hc *10'*
Speaker: Ryan Mitchell (Indiana University)
Material: Slides

10:10 - 10:20 A Quick Look at gamma X(3872) *10'*
Speaker: Ryan Mitchell (Indiana University)
Material: Slides

10:20 - 10:40 e+e- -> pi+ pi- psip *20'*
Speaker: Mr. Liang Yan (USTC)
Material: Slides

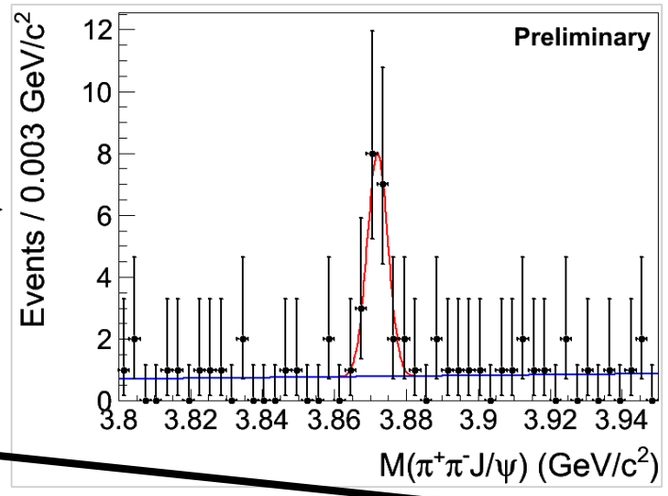
10:40 - 11:00 Observation of e+e- to gamma X(3872) *20'*
Speaker: Dr. Ke Li (Shandong University)
Material: Slides

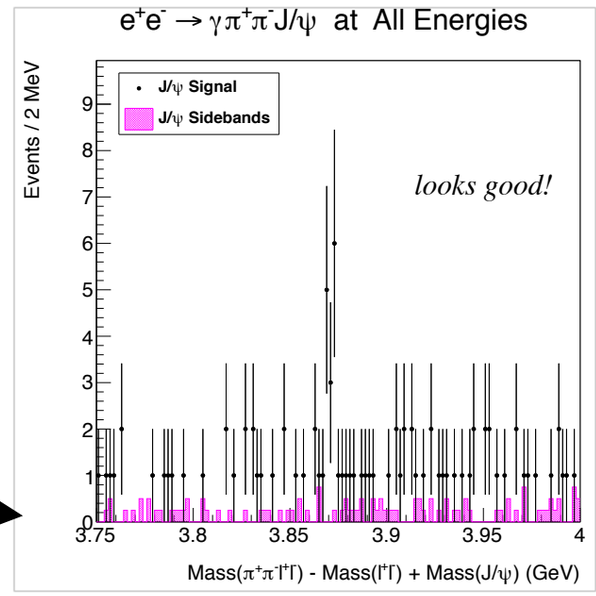
11:00 - 11:20 update on pi0pi0J/psi *20'*
Speaker: Jianming Bian
Material: Slides

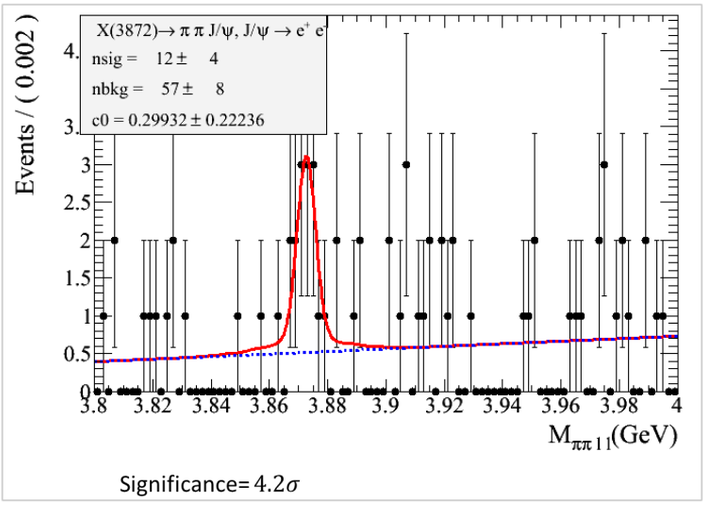
11:20 - 11:40 measurement of D*D*pi lineshape *20'*
Speaker: Pei-Rong Li (UCAS)
Material: Slides

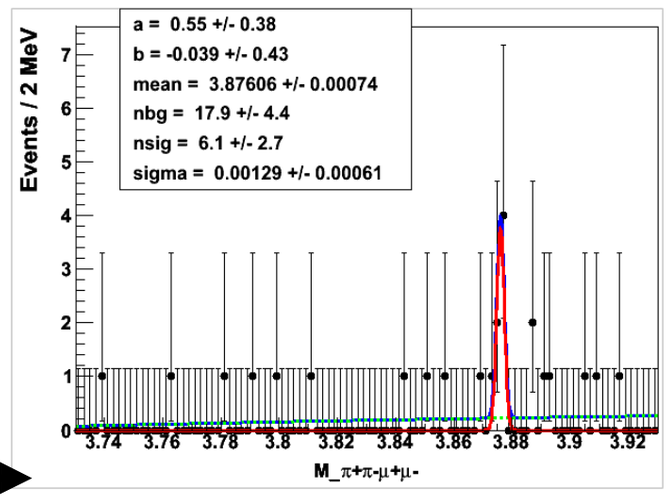
11:40 - 12:00 Further investigation on piDD* *20'*
Speaker: Xin-Ping Xu (Soochow University (suda))
Material: Slides

12:00 - 12:20 ee->gamma X(3872) at 4.26GeV *20'*
Speaker: Ms. 清 高 (ihep)
Material: Slides





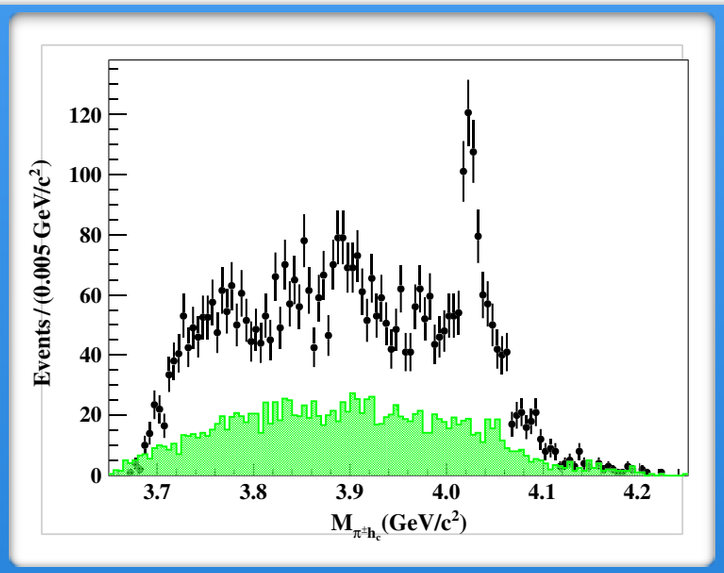




Chapter 5: Further Analyses of the 2013 XYZ Data (2013—2014)

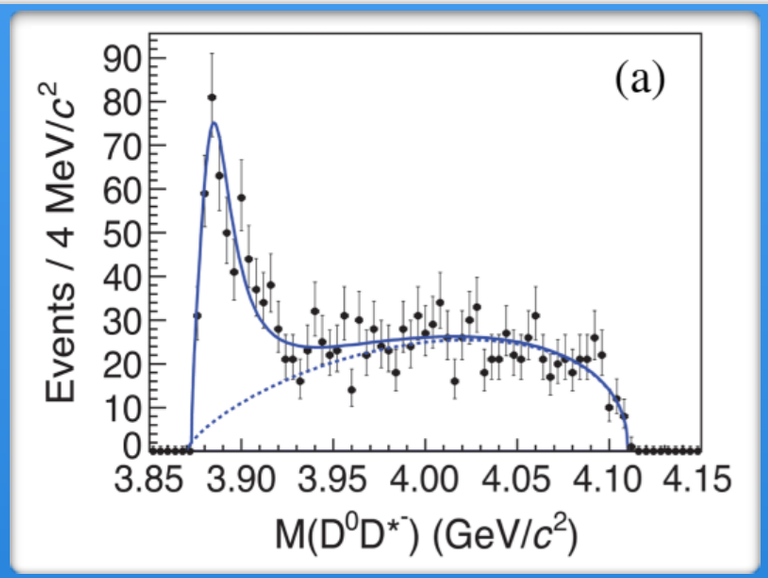
$e^+e^- \to \pi^\mp Z_c'^\pm;\quad Z_c'^\pm \to \pi^\pm h_c(1P)$

published December 2013 (PRL111,242001(2013))



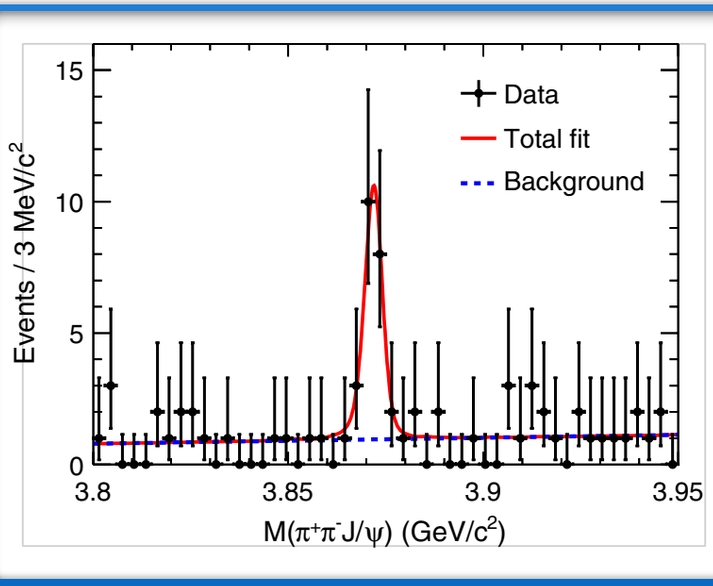
$e^+e^- \to \pi^\mp Z_c^\pm;\quad Z_c^\pm \to (D\bar{D}^*)^\pm$

published January 2014 (PRL112,022001(2014))



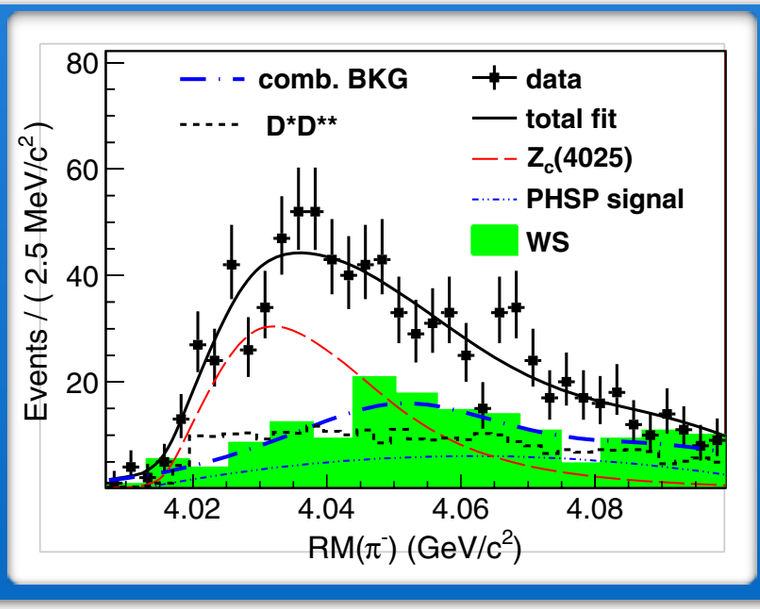
$e^+e^- \to \gamma X(3872);\quad X(3872) \to \pi^+\pi^- J/\psi$

published March 2014 (PRL112,092001(2014))

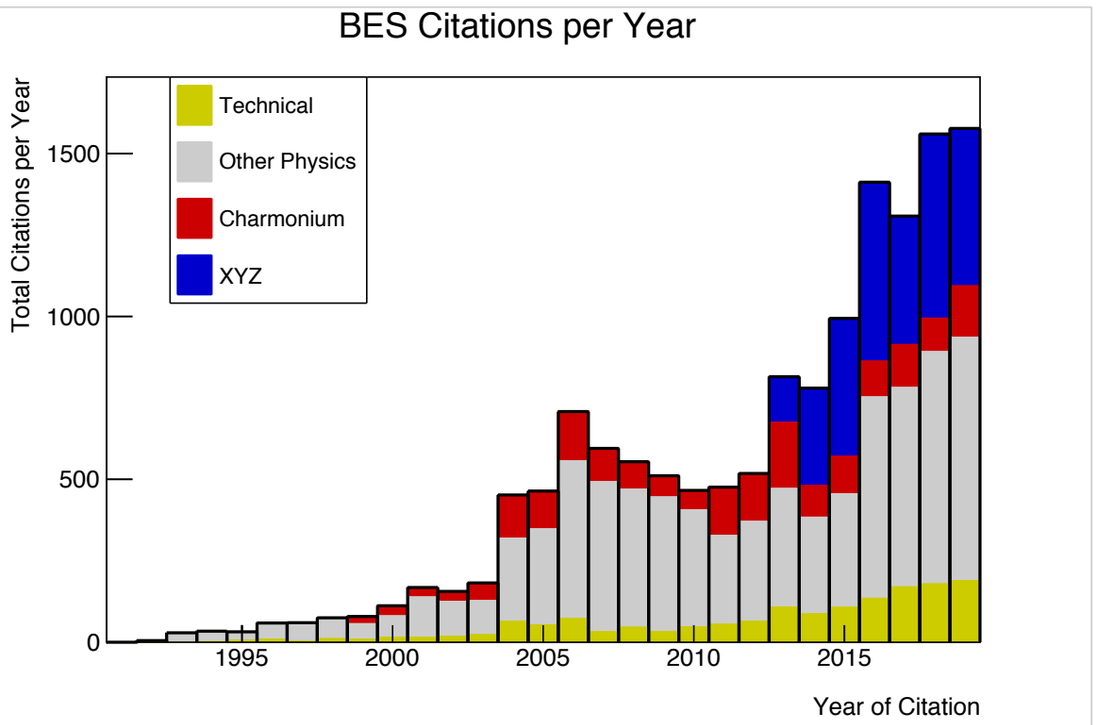


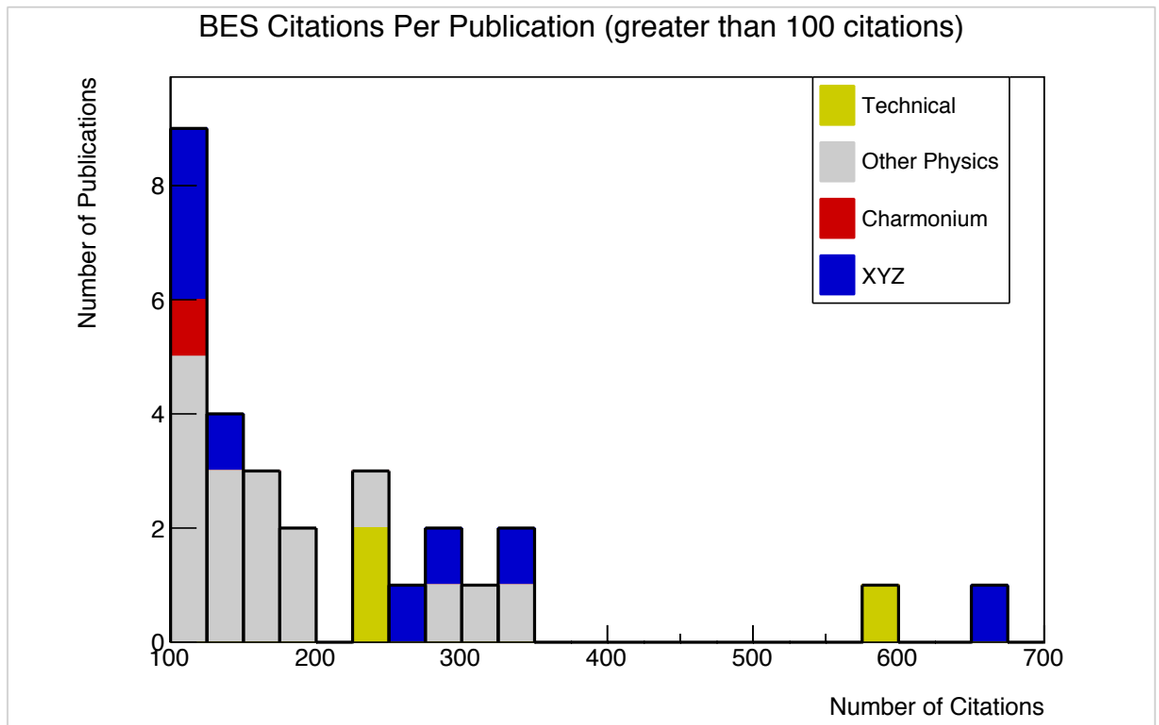
$e^+e^- \to \pi^\mp Z_c'^\pm;\quad Z_c'^\pm \to (D^*\bar{D}^*)^\pm$

published April 2014 (PRL112,132001(2014))



Postscript: The XYZ Program at BESIII





The XYZ program has grown into an important component of BESIII physics!