Collecting more data for XYZ study at BESIII

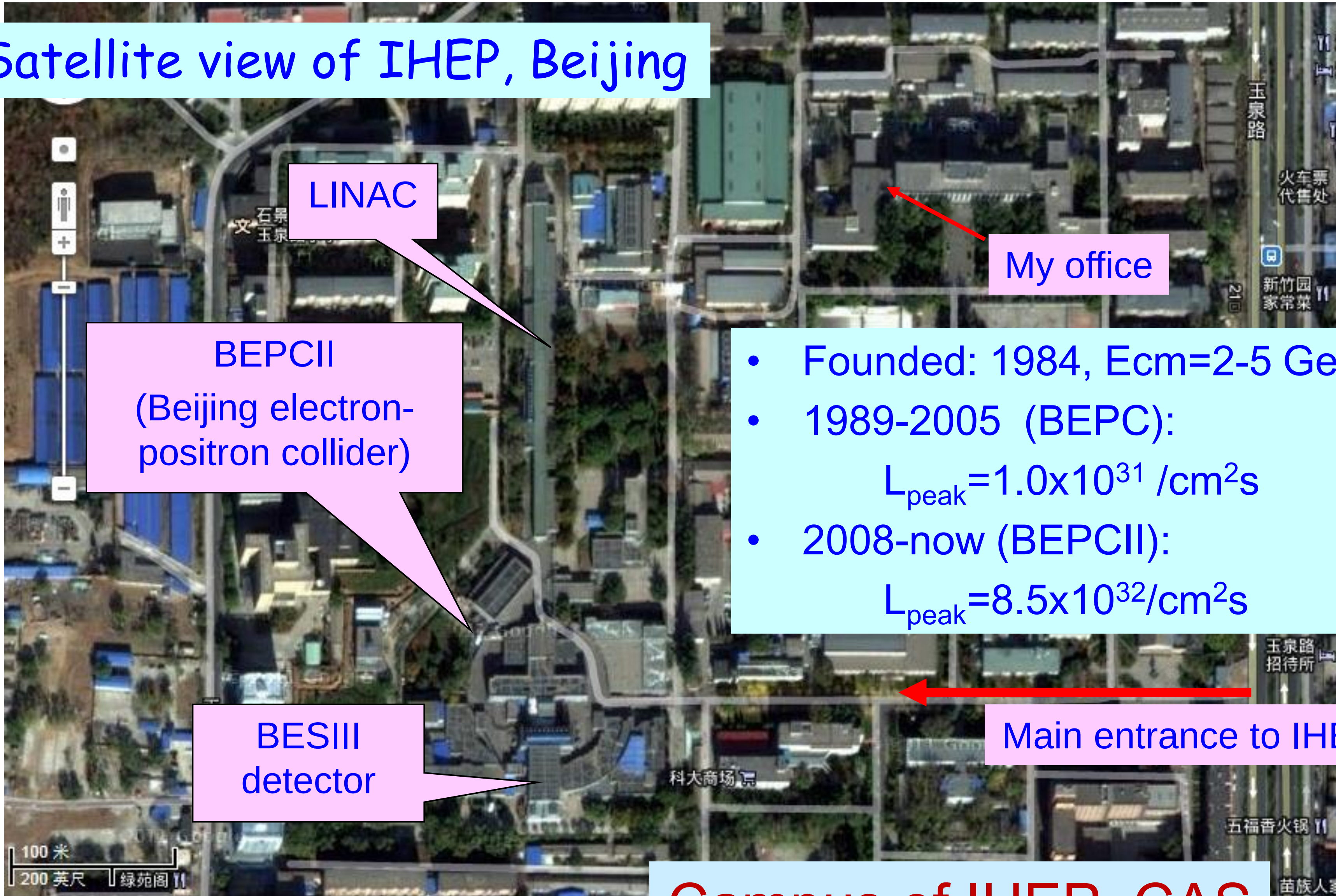
Changzheng Yuan

IHEP, Beijing

QCD & Exotics, Jinan, China

June 8-12, 2015

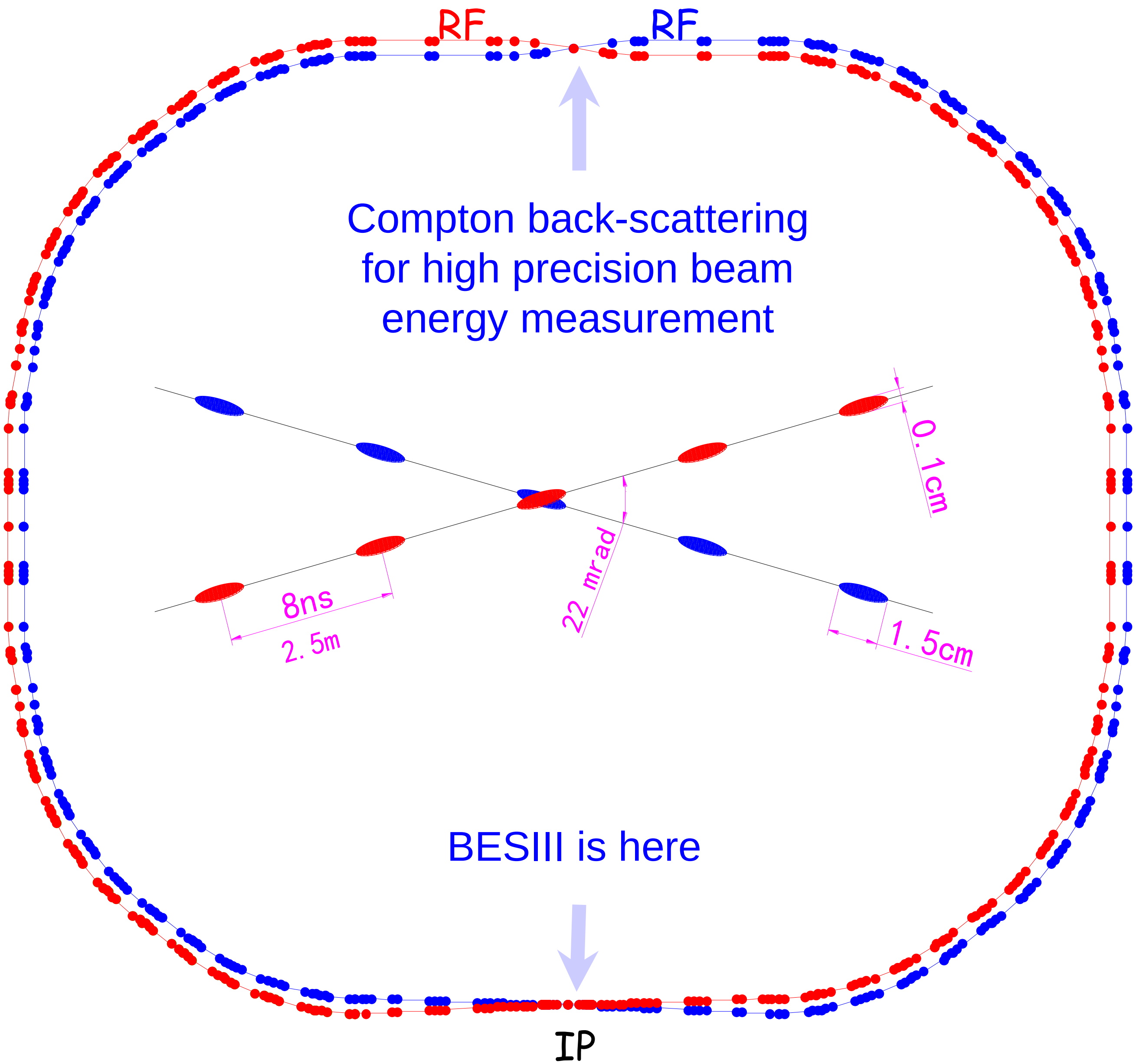
北京正负电子对撞机（BEPC）



- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  $L_{peak}=1.0\text{x}10^{31}\ /\text{cm}^2\text{s}$
- 2008-now (BEPCII):
  $L_{peak}=8.5\text{x}10^{32}/\text{cm}^2\text{s}$

Campus of IHEP, CAS

BEPC II: double-ring e^+e^- collider



Beam energy:
- 1-2.3 GeV

Luminosity:
- 1×10^{33} cm^{-2}s^{-1}

Optimum energy:
- 1.89 GeV

Energy spread:
- 5.16×10^{-4}

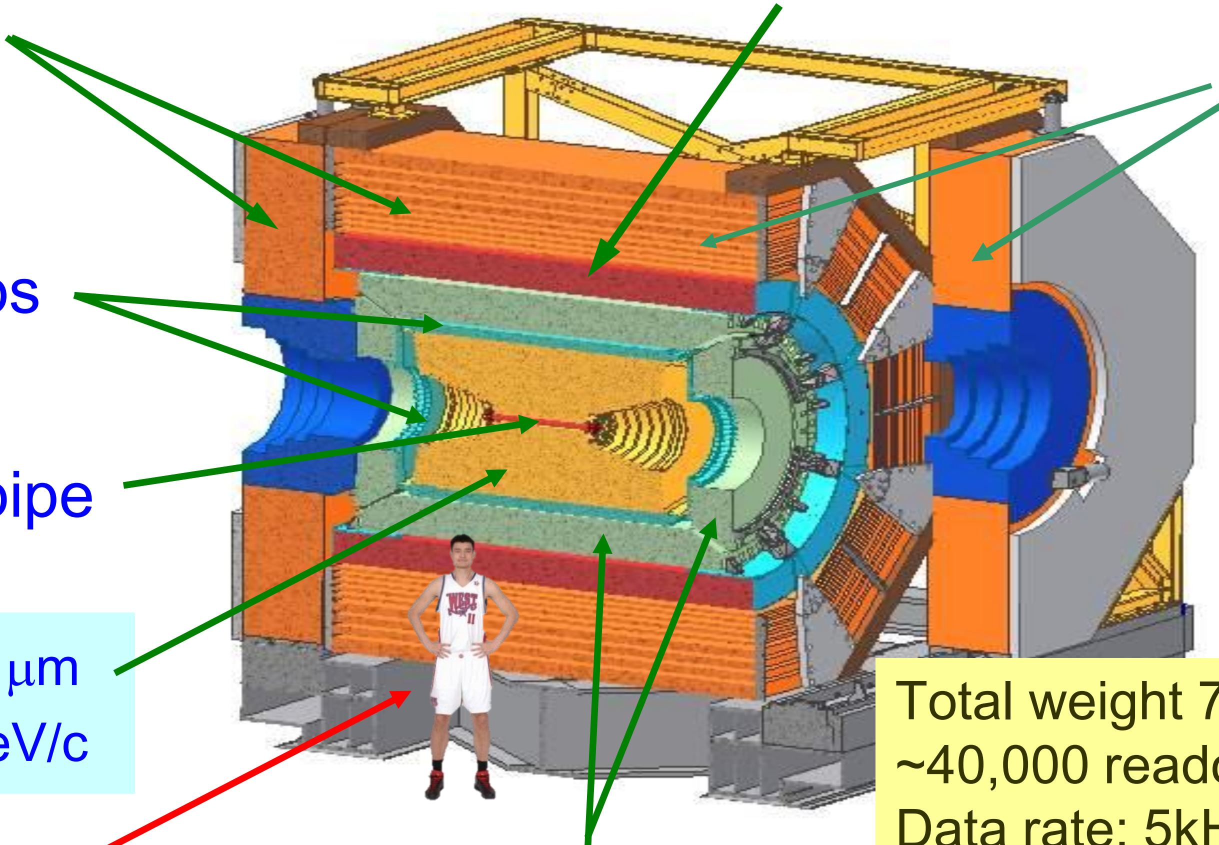
No. of bunches:
- 93

Bunch length:
- 1.5 cm

Total current:
- 0.91 A

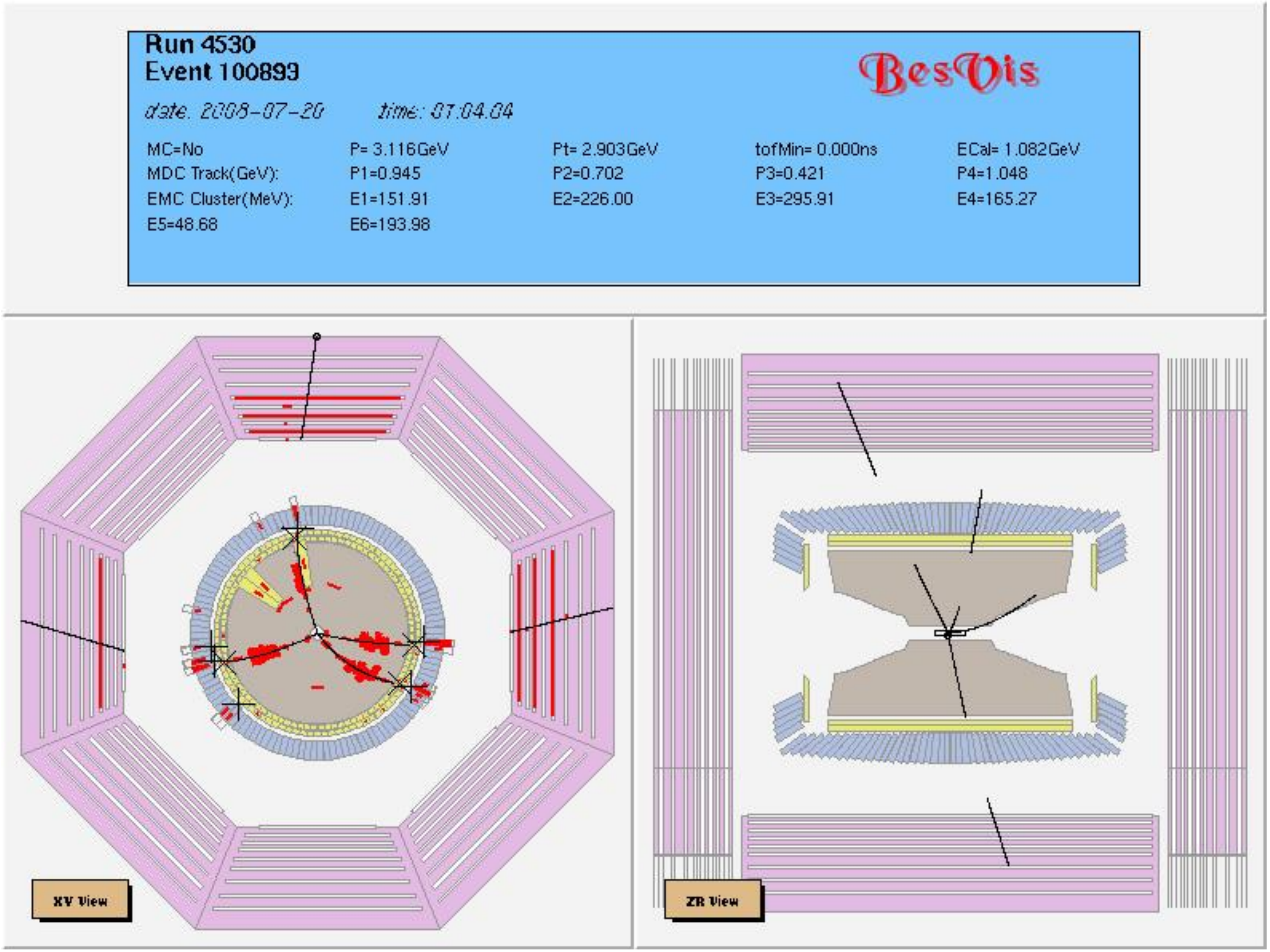
SR mode:
- 0.25A @ 2.5 GeV

BESIII detector



Total weight 730 ton,
~40,000 readout chnls,
Data rate: 5kHz, 50Mb/s

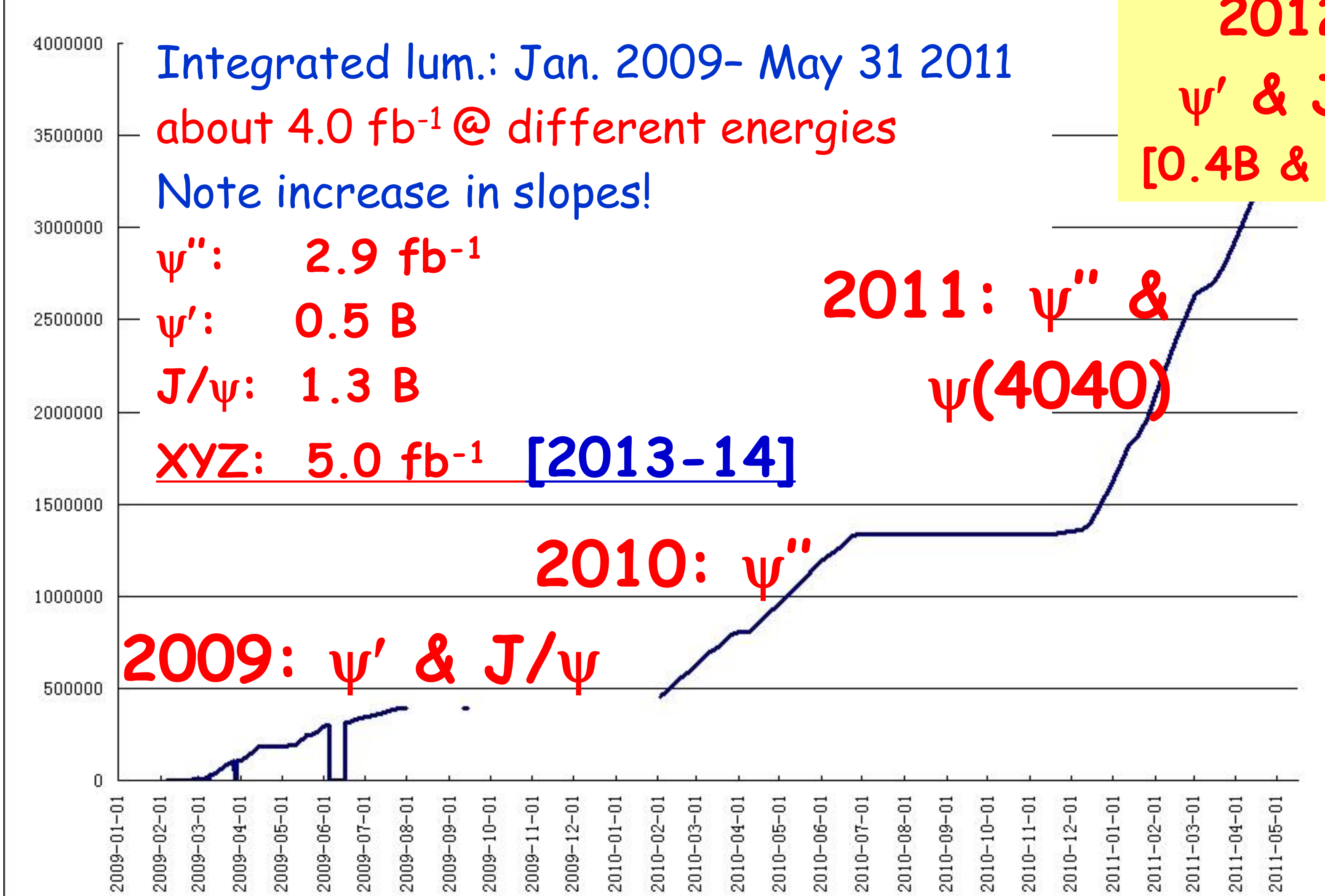
First event: July 20, 2008



BESIII data samples

Note that luminosity is lower at J/ψ, and machine is optimal near ψ'' peak

2012: ψ′ & J/ψ [0.4B & 1.1B]



What is next?

Without major upgrade, the typical lifetime of an e^+e^- collider is ~ 10 years!

- LEP: 11 yrs [LEP, LEPII]
- SLC: 9 yrs
- KEKB: 11 yrs
- PEP-II: 9 yrs
- CESR: 23 yrs [CLEO, CLEOII, CLEOIII]
- CESR-c: 6 yrs
- BEPC: 16 yrs [BES, BESII]
- BEPCII: 2008 ➔ 2018 (10yrs)? 2022 (14yrs)?

What is the best data sample for BESIII in 3-7 yrs to achieve more in physics?

Estia Eichten @ this workshop

Two requests

- To BES: Measure the line shape ΔR_c in the threshold region. Give results for each individual channel for:
  - pairs of narrow states of the heavy-light systems + pions
  - Quarkonium bound states + light hadrons.
  - It is the theorist challenge to make their model fit the data.

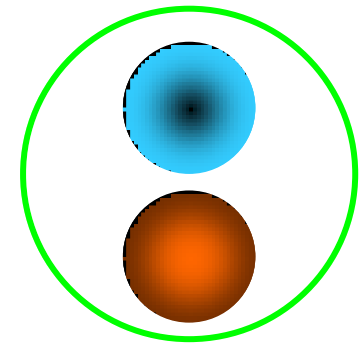
- To Lattice QCD: Calculate the behavior of scattering of heavy-light meson pairs in the threshold region.
  - Consider S-wave amplitudes (at first)
  - Include the mixing between two HL mesons and quarkonium + a single light hadron.
  - This is an difficult but not impossible challenge.

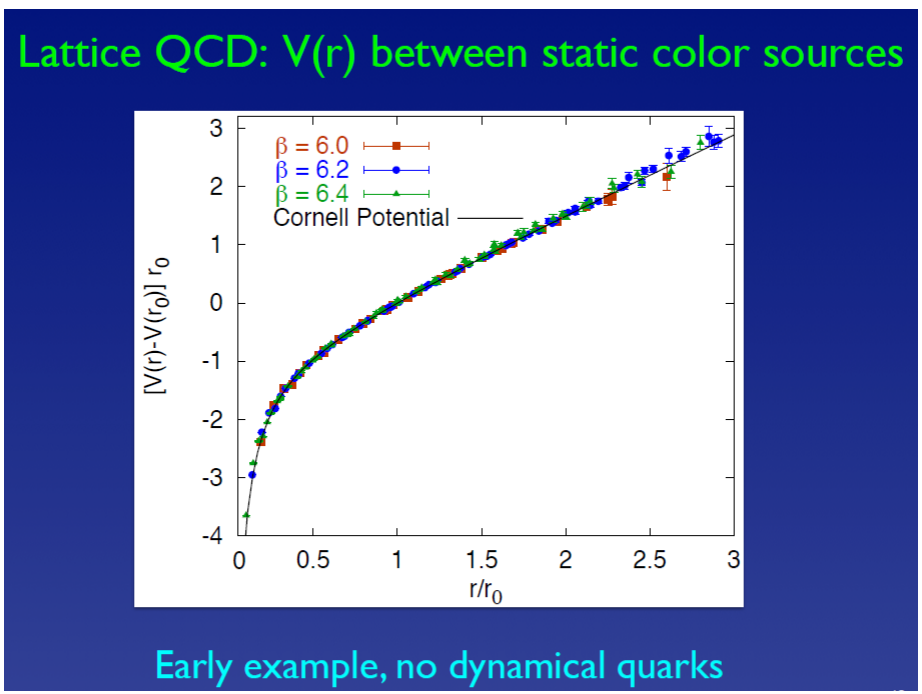
One proposal from BESIII collab. meeting in 2014

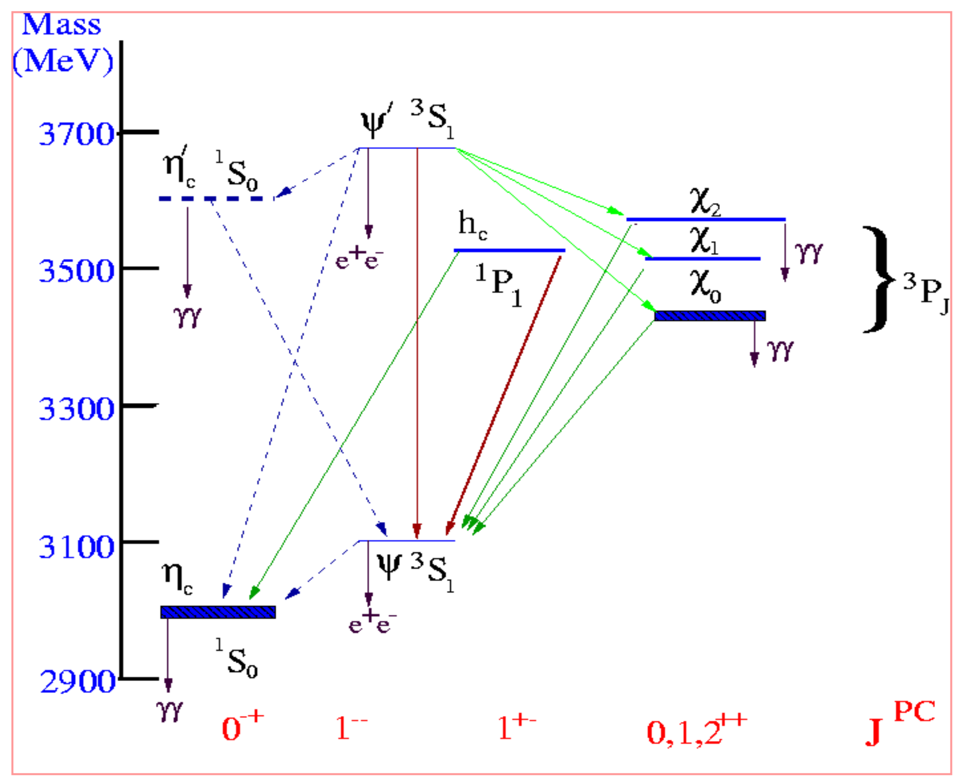
- We propose a long term data taking plan at BESIII for a better understanding of the strong interaction!
  - Start from 4.0 GeV to Emax of BEPCII [>4.6 GeV]
  - with 10 MeV step
  - 500/pb per point
  - Understand the XYZ, charmonia, and more!
- The arguments follow …

The heavy quarkonium system

- At short distance
  Cornell model works pretty well
  $V(r) = -4\alpha_s/3r + kr$



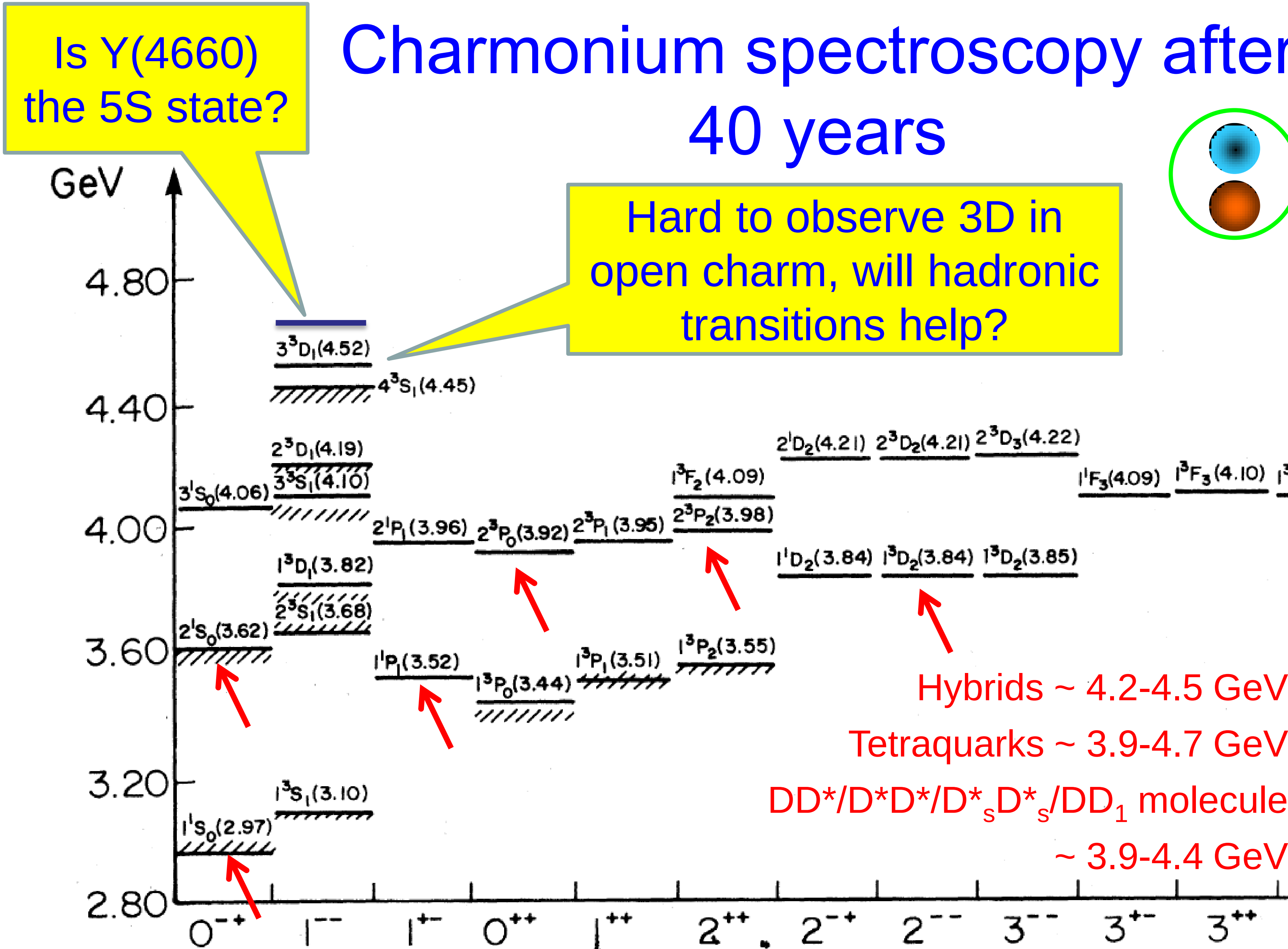




The quarkonium system

- When distance becomes larger
  - Theory 1: screened potential
  - Theory 2: hybrids with excited gluons
  - Theory 3: tetraquark states
  - Theory 4: meson molecules
  - Theory 5: cusps
  - Theory 6: final state interaction
  - Theory 7: coupled-channel effect
  - Theory 8: mixing
  - Theory 9: mixture of all these above effects
  - Theories …
- Need data to test and develop theory

Charmonium spectroscopy after 40 years



Godfrey & Isgur, PRD32, 189 (1985)

Where are these states?

- $^1D_2$ (2^{-+}): mass ~ 3830 MeV should be narrow
  $^3D_3$ (3^{--}): $^3D_2$ (2^{--}) observed recently, $^3D_3$ soon?
- Where are the 2P, 3P spin-triplet states?
- Where are the 3S, 2P, 3P spin-singlets?
- Can we identify F-wave states?

- P-wave spin-triplets from S-wave E1 transition
- P-wave spin-singlets from S-wave hadronic transition
- $^1D_2$ may be produced in $h_c(2P)$ E1 transition
- Are there hybrids (1^{--}, other J^{PC})?

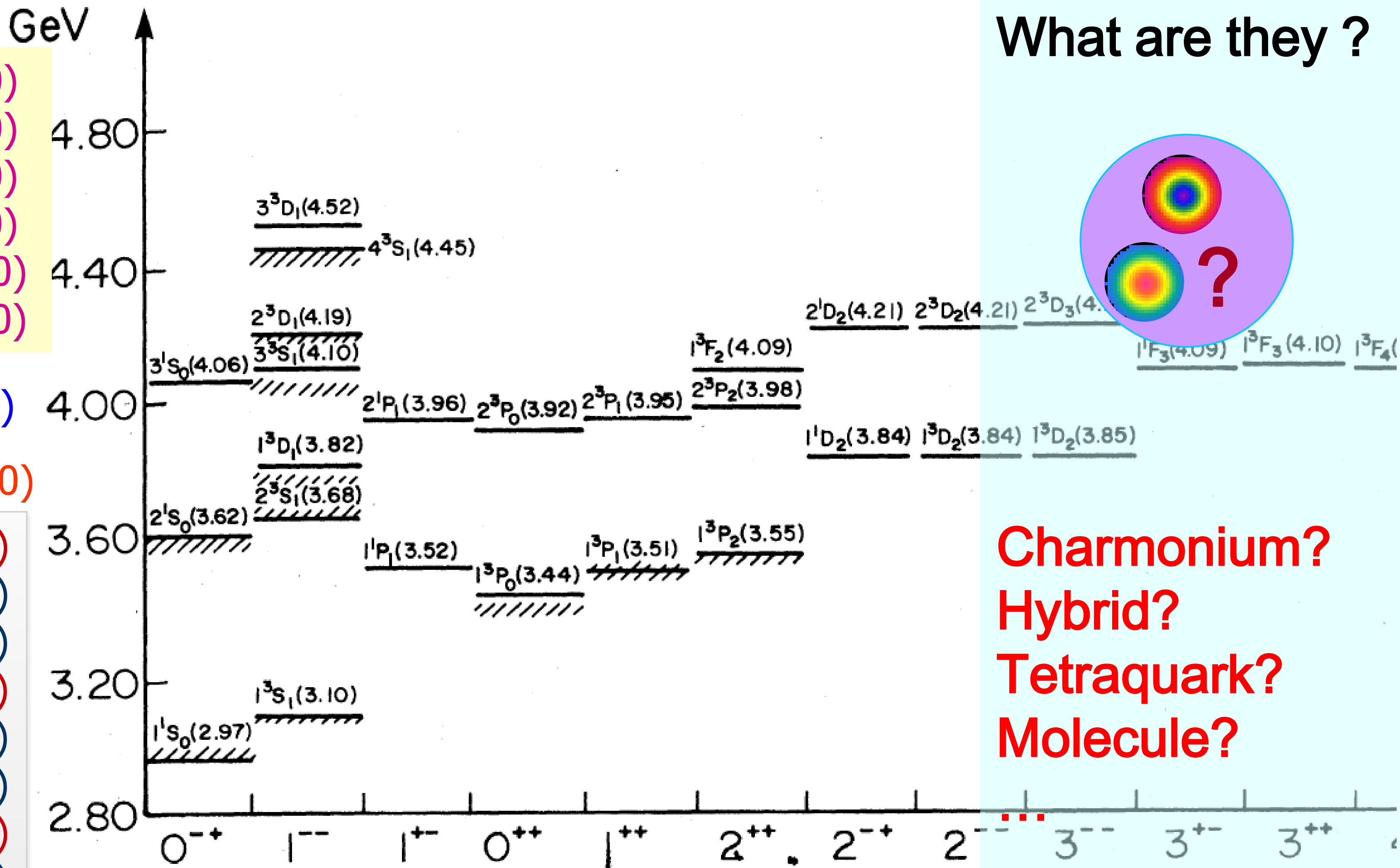
The XYZ states

Z(4430)
Z(4250)
Z(4050)
Z(4200)
Zc(3900)
Zc(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?
...

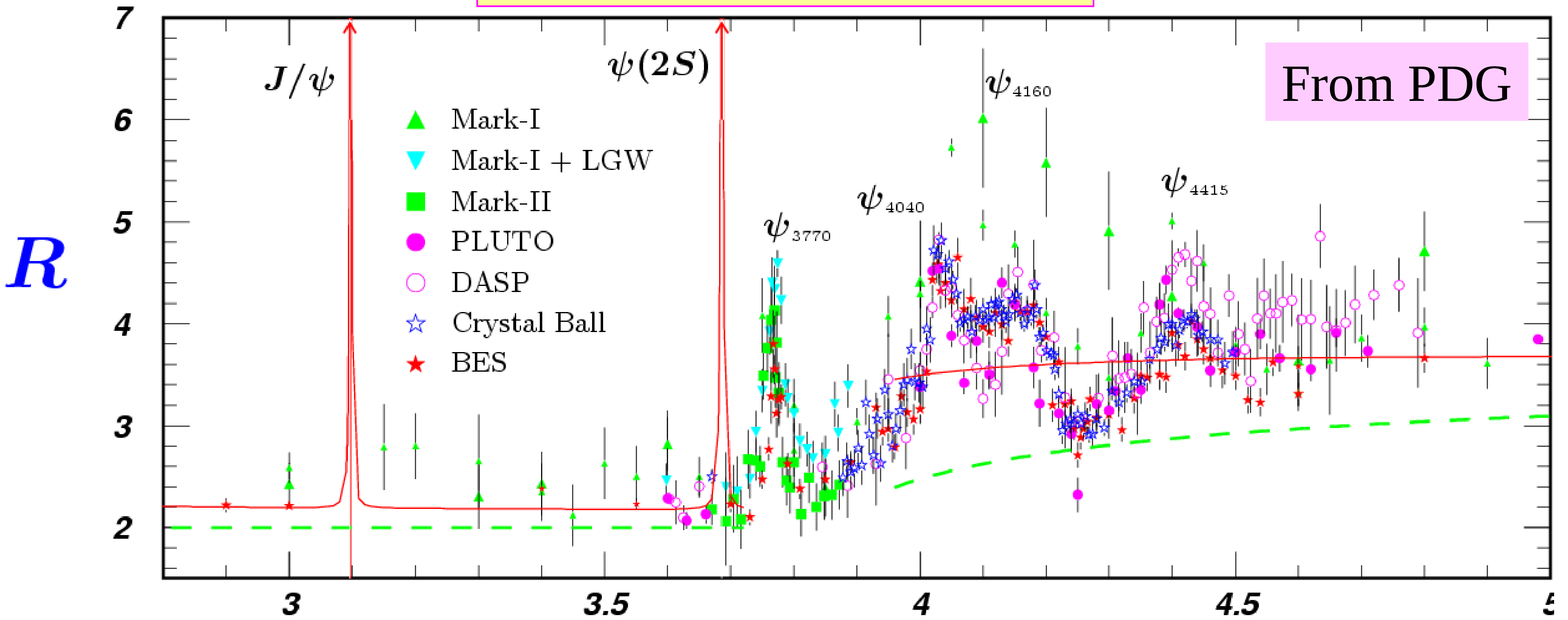
Not all XYZ states are charmonia!

XYZ particles

Name	J^{PC}	Γ(MeV)	Decay modes	Experiments	interpretation
X(3872)	1^{++}	<1.2	$\pi\pi J/\psi$, $\gamma J/\psi$, DD^*, …	Belle/CDF/D0/BaBar/LHCb	$\bar{D}D^*$ molecule?
X(3940)	$0^{?+}$	~37	DD^* (not DD, $\omega J/\psi$)	Belle	η_c''(?)
Y(3940)	$?^{?+}$	~30	$\omega J/\psi$ (not DD^*)	Belle/BaBar	
Y(4140)	$?^{?+}$	~11	$\phi J/\psi$	CDF & CMS & BaBar	$c\underline{c}s\underline{s}$?
X(4160)	$0^{?+}$	~140	D^*D^* (not DD, DD^*)	Belle	η_c''(?)
Y(4008)	1^{--}	~220	$\pi\pi J/\psi$	Belle (not Babar)	$\psi(4040)$?
Y(4260)	1^{--}	~80	$\pi\pi J/\psi$	BaBar/CLEO/Belle	$c\underline{c}g$ hybrid?
X(4350)	$?^{?+}$	~13	$\gamma\gamma$, $\phi J/\psi$	Belle	$c\underline{c}s\underline{s}$?
Y(4360)	1^{--}	~75	$\pi\pi\psi(2S)$	BaBar/Belle	
Y(4660)	1^{--}	~50	$\pi\pi\psi(2S)$, $\Lambda_c\Lambda_c$ (?)	Belle/BaBar	
$Z^{\pm}(4430)$	1^{+}	~100	$\psi(2S)\pi^{\pm}$	Belle/LHCb	4-quark?
$Z^{\pm}(4050)$	1^{+}	~80	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(4250)$	1^{+}	~180	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(3900)$	1^{+}	~40	$J/\psi\pi^{\pm}$	BESIII/Belle/CLEOc	4-quark?
$Z^{\pm}(4020)$	$?^{?}$	~10	$h_c\pi^{\pm}$	BESIII	4-quark?

R values/ψ states/Y states

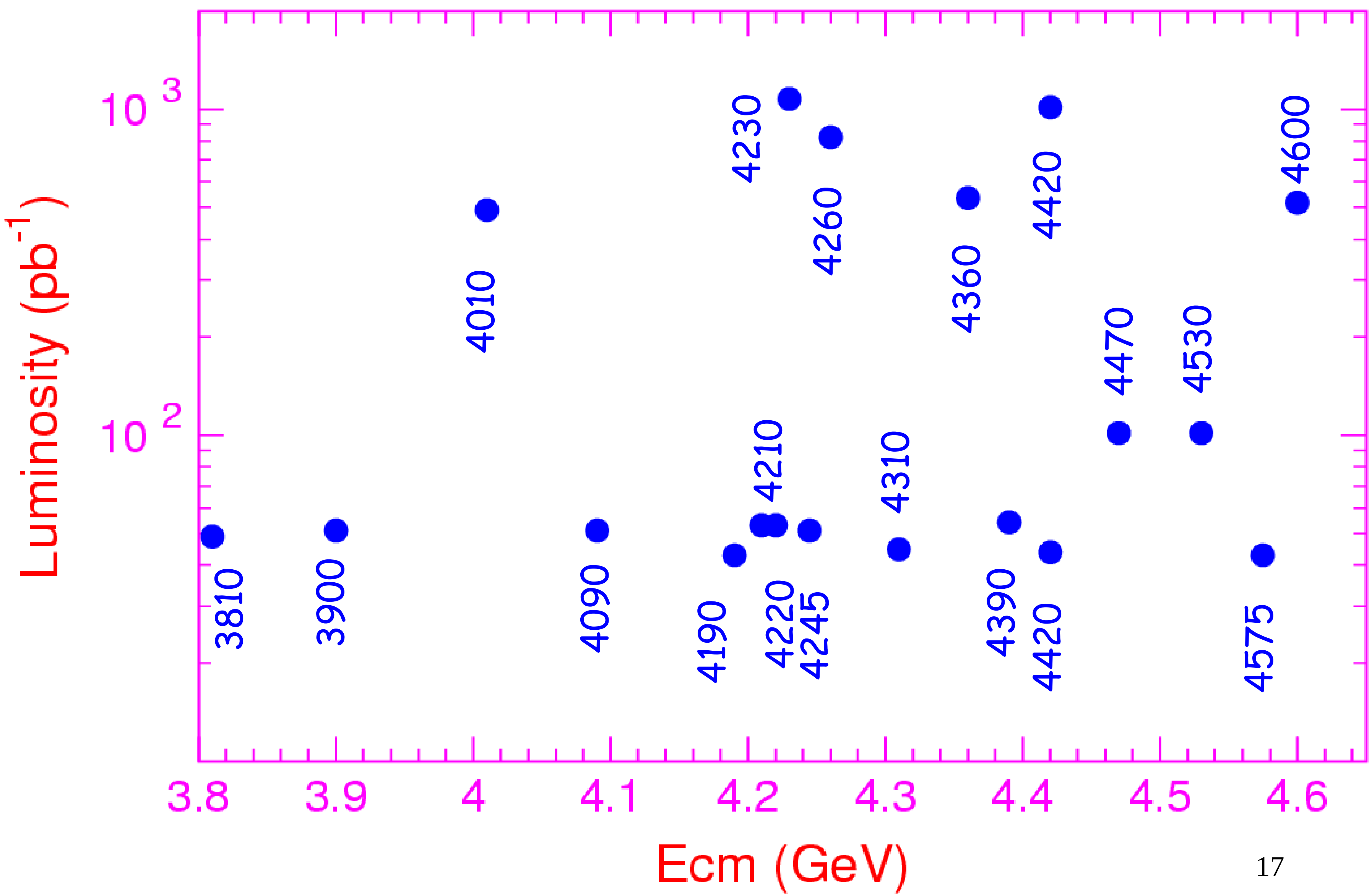
$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



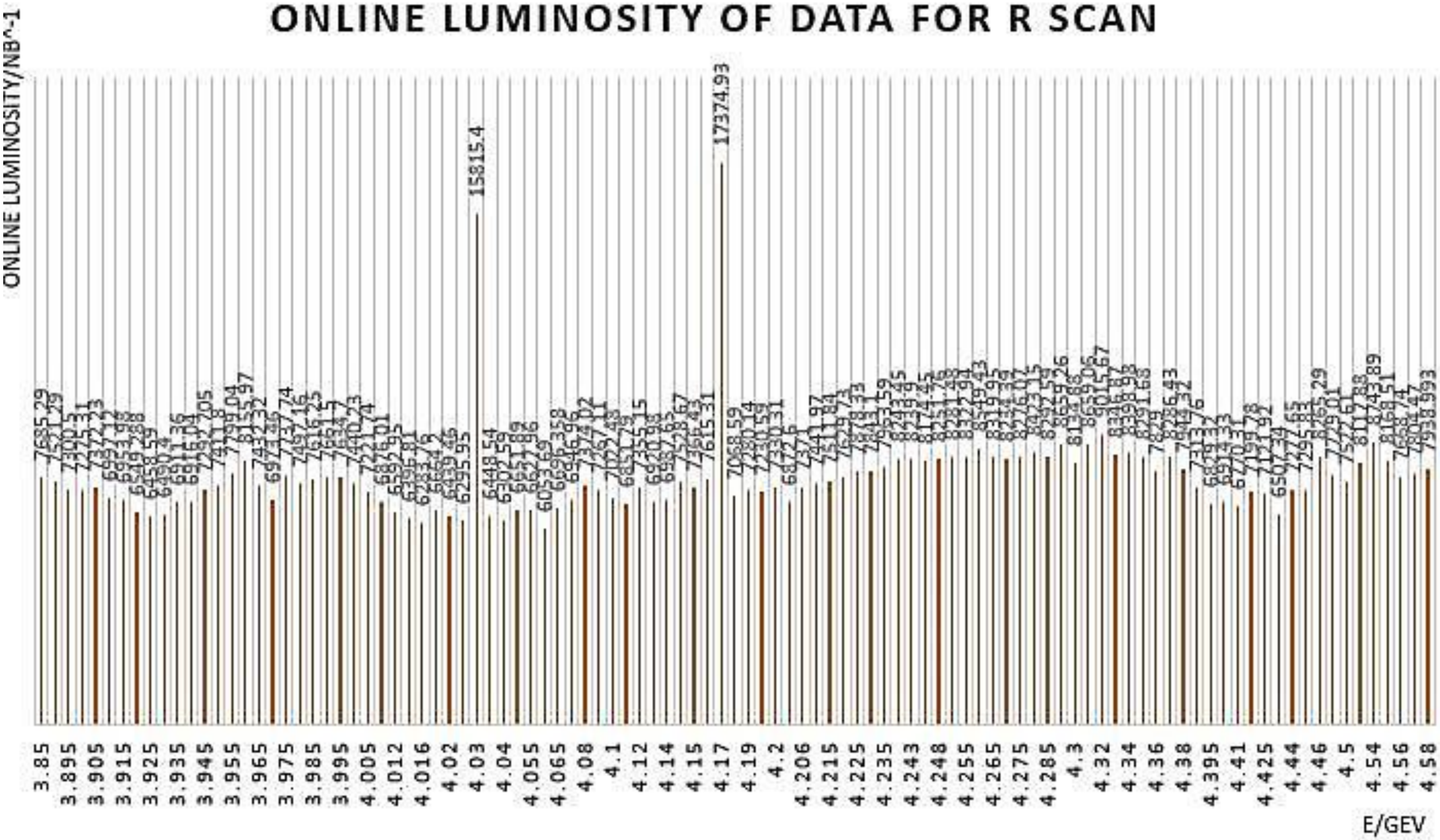
Information between 4.0 & 4.7 GeV is very limited!

BESIII can contribute!

We collected 5/fb above 4 GeV



We collected 0.8/fb at >100 energy points



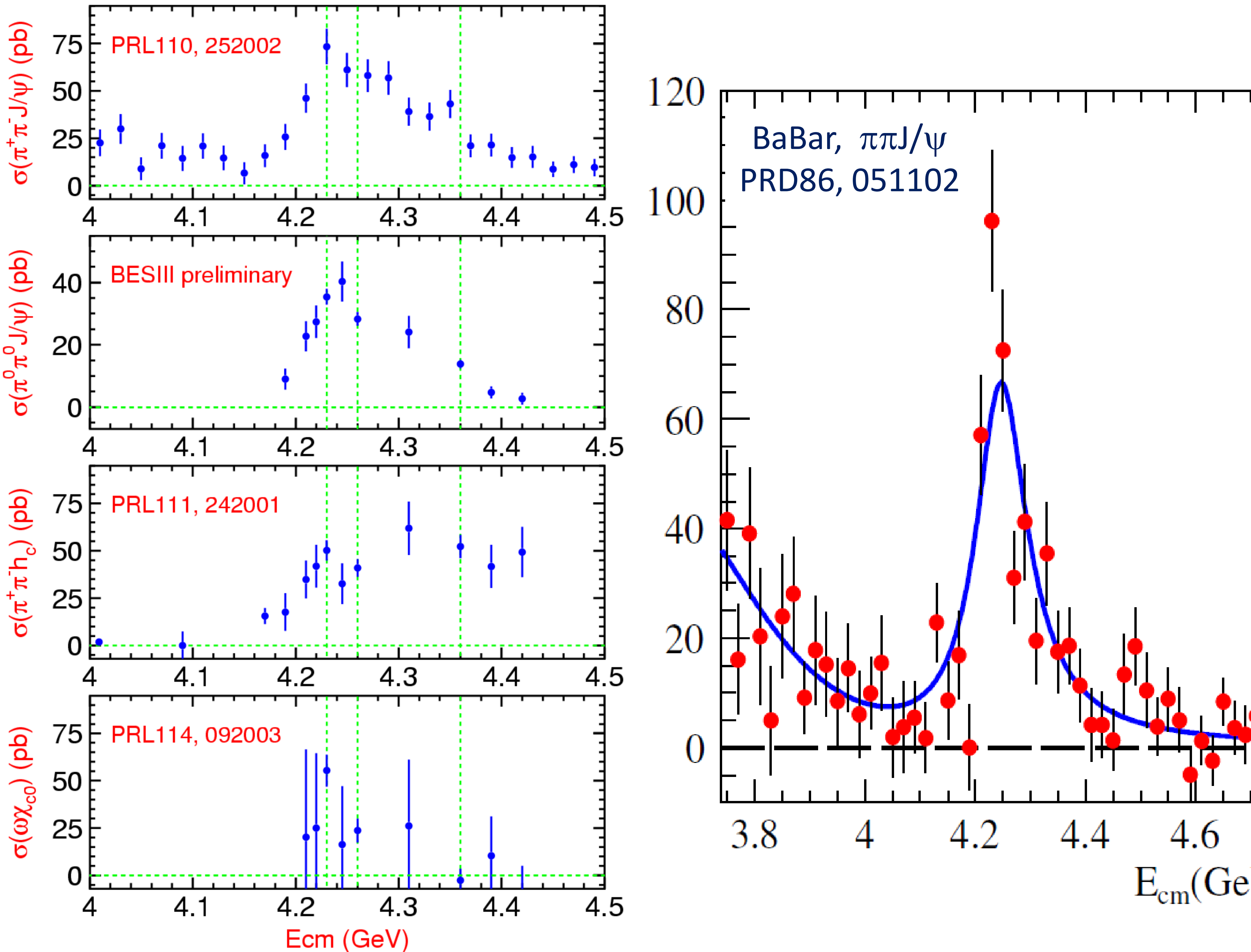
We've done a lot with these samples

- Observation of $Z_c(3900) \to \pi^{\pm} J/\psi$, $\pi^0 J/\psi$, $\bar{D}D^*$
- Observation of $Z_c(4020) \to \pi^{\pm} h_c$, $\pi^0 h_c$, $\bar{D}^*D^*$
- Observation of $Z_c(4050) \to \pi\psi'$, $Y(4260) \to \gamma$X(3872)
- Observation of $\psi(1^3D_2)$=X(3823)
- Observation of $e^+e^- \to \omega\chi_{cJ}$, $\phi\chi_{cJ}$, ηh_c
- Observation of $e^+e^- \to \eta J/\psi$, $\eta' J/\psi$, $\eta\psi'$
- Observation of $e^+e^- \to KKJ/\psi$ possibly from Y(4260)
- Search for radiative transitions γX(4140), $\gamma\eta_c$, $\gamma\chi_{cJ}$
- Search for Z_{cs}, search for $Z \to$ light hadrons
- Search for $\pi\pi h_c(2P)$, $\pi\pi\chi_{cJ}$, $\pi\pi\pi\chi_{cJ}$, $\gamma\eta_{c2}(^1D_2)$, …
- Search for missing charmonium states
- Charm meson production and decay; Charm baryons
- ψ, $Y \to$ Light hadrons
- …

XYZ+C

We also found more questions to answer

- In the X sector
  - Where the X(3872) & X(3823) come from? Resonance decays or continuum production?
  - May other X states be produced and where?
- In the Y/ψ sector
  - Is the Y(4260) a single resonance? Is Y(4008) a real structure?
  - Does the Y(4360) decay only to ππψ'? Not to ηJ/ψ ?
  - What is hidden behind $\pi\pi h_c$?
  - Correlation between charm production & charmonium transitions?
  - May we observe the charmonium 3^3D_1 state at ~4.5 GeV?
- In the Z sector
  - Are the Z_c and Z_c' from resonance decays or continuum prod.?
  - Are there more Z_c states and Z_{cs} states [KJ/ψ, D^*D_s , or DD_s^*]?
- In the C sector
  - Charm spectroscopy: D*, D_0, D_1, D_2, D_{s0}, D_{s1}, D_{s2}, ...
  - Charm decays: D_s and Λ_c samples are too small …

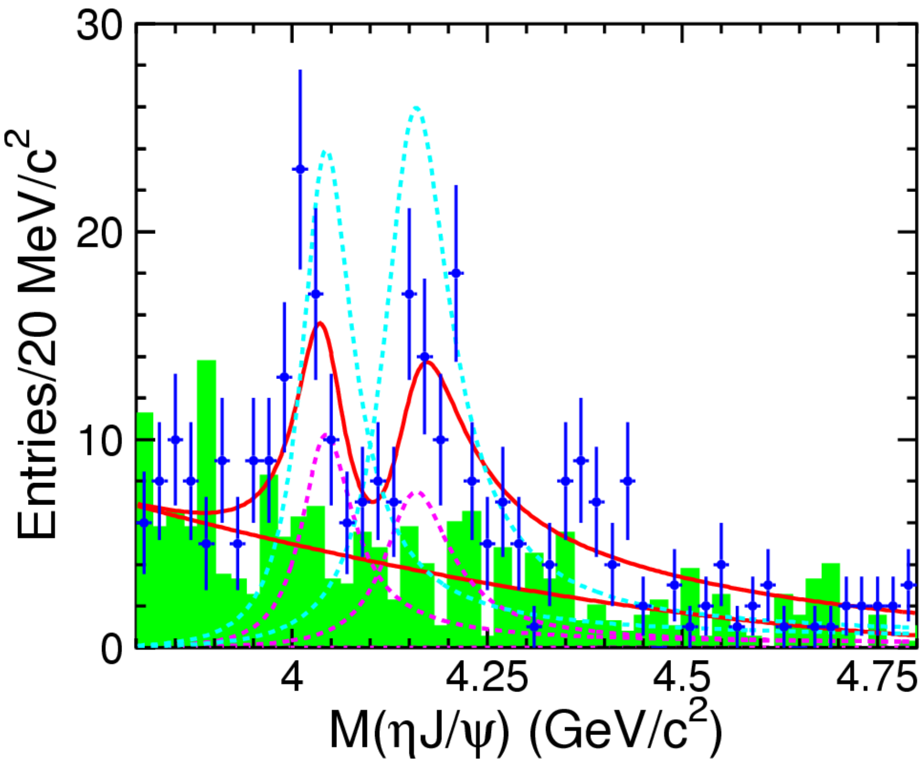

PRL110, 252002
BESIII preliminary
PRL111, 242001
PRL114, 092003
Ecm (GeV)
BaBar, ππJ/ψ
PRD86, 051102
Ecm(Ge

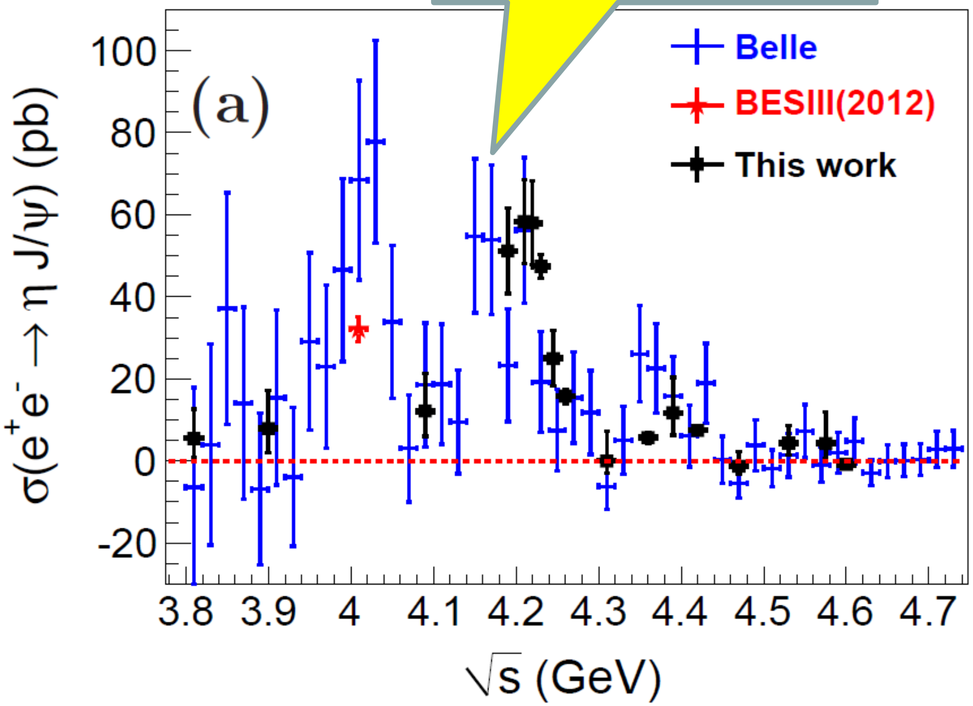
$e^+e^- \to \eta J/\psi$

arXiv: 1210.7550
PRD87, 051101

BESIII:
arXiv: 1503.06644

What is going on here?





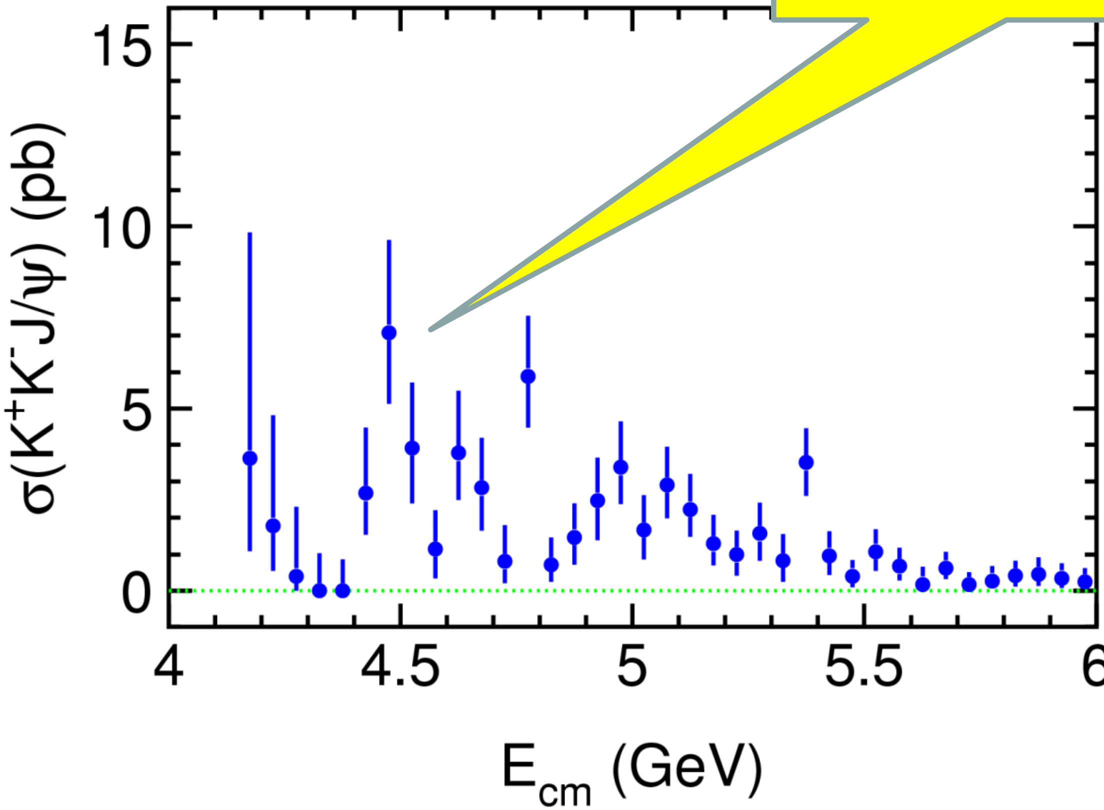
BESIII: Can do better in the full energy range!

Cross sections of $e^+e^- \to K^+K^-J/\psi$

BELLE

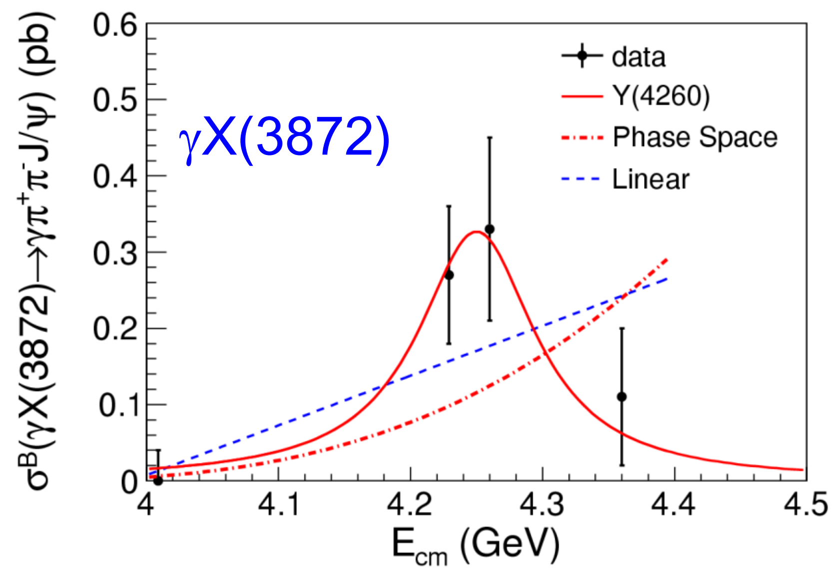
arXiv: 1402.6578
PRD89, 072015

What's the cross section here? Any structure?



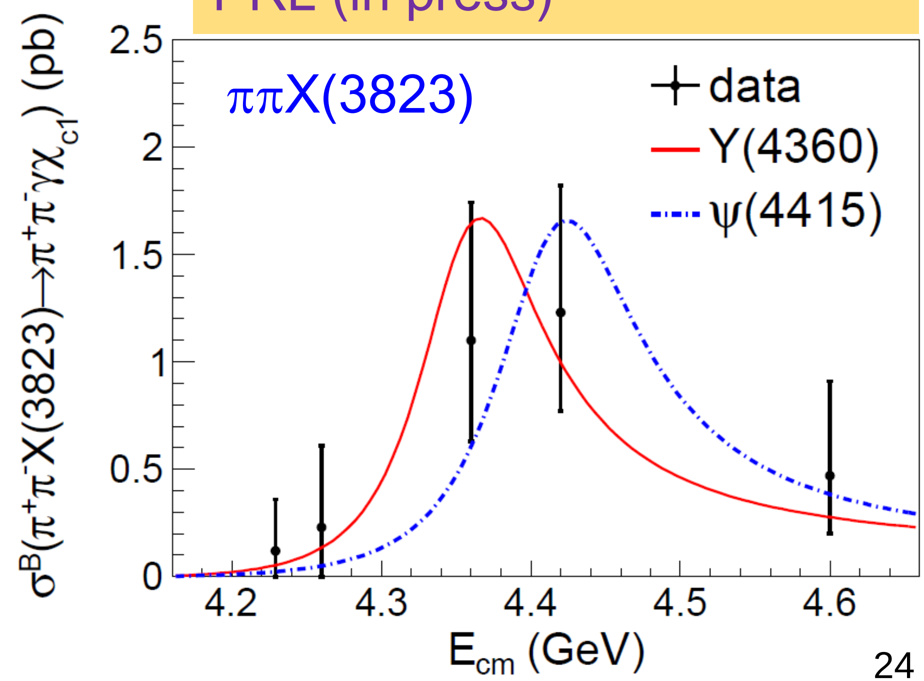
BESIII: Y(4260)+ψ(4415)+?

$e^+e^- \to \gamma X(3872)$ & $\pi\pi X(3823)$ & $\omega\chi_{c0}$

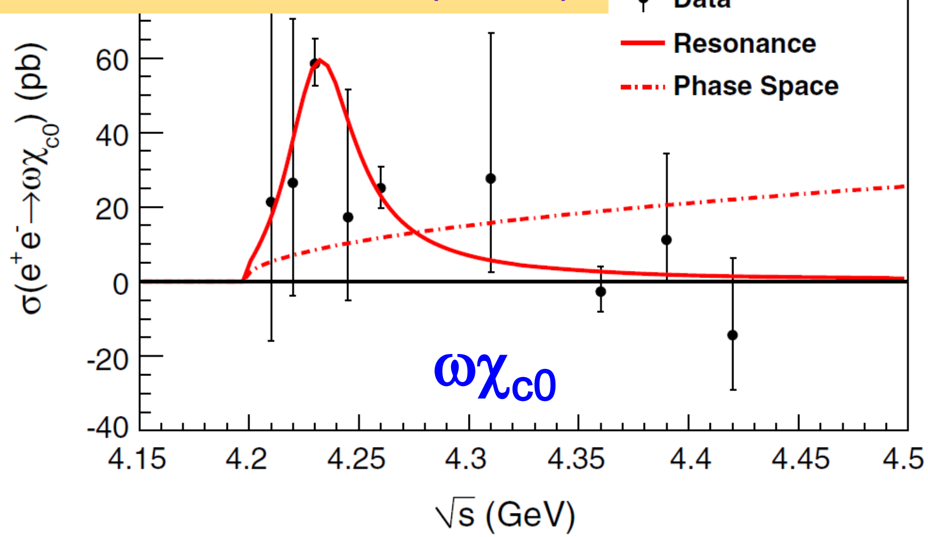


BESIII:
PRL 112, 092001 (2014)

BESIII: arXiv: 1503.08203,
PRL (in press)

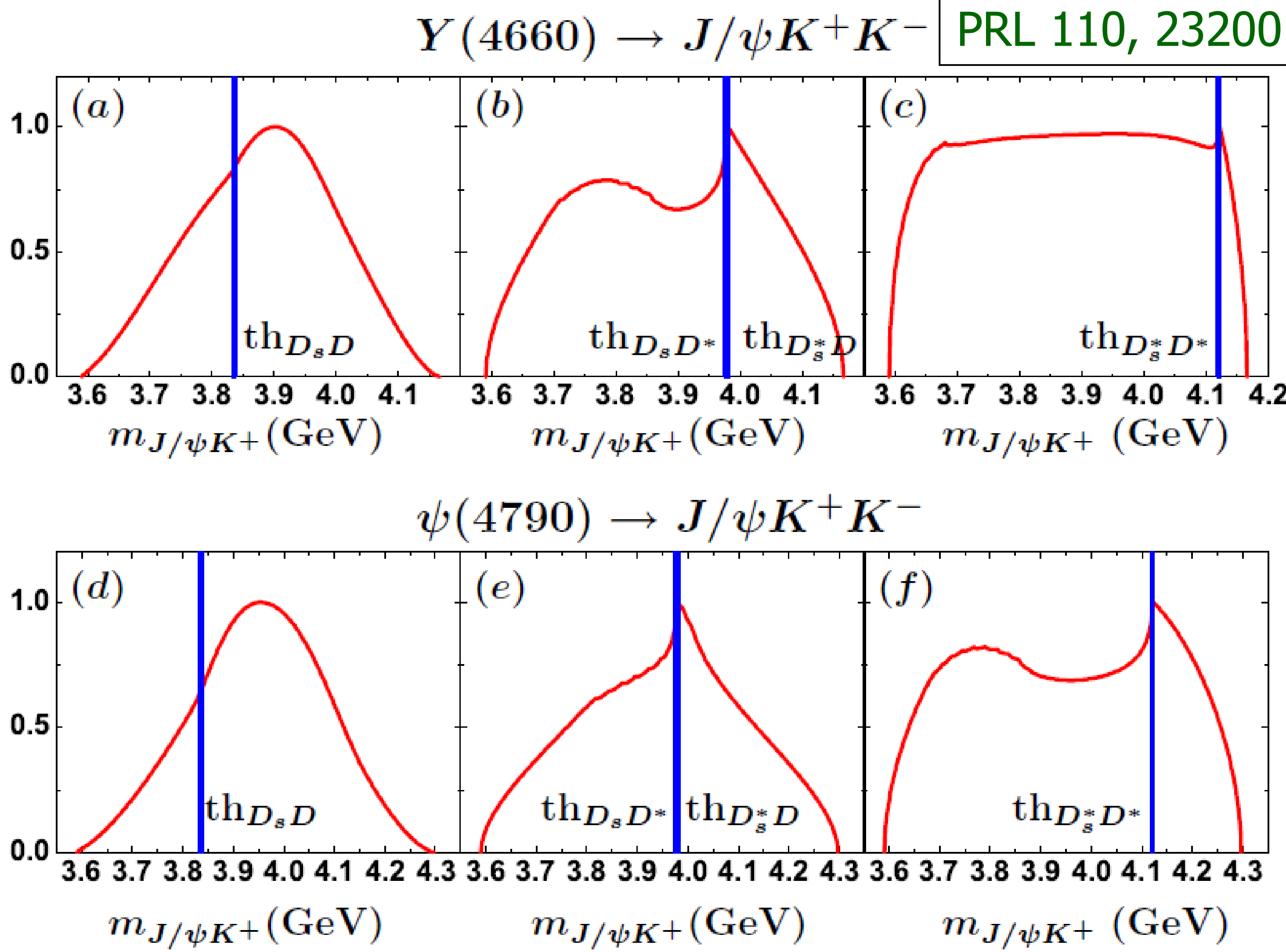


BESIII:
PRL 114, 092003 (2015)



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

Chen, Liu, Matsuki:
PRL 110, 232001 (2013)



BESIII: May we find excited Zc & Zcs?

We need data

- To understand
  - The ψs
  - The Υs
  - The other XYZ particles via hadronic and radiative transitions of the ψs or/and Υs or continuum
  - The C-even charmonium states

- More data points between 4 GeV and 4.6 [4.8] GeV
- At each point, we need more luminosity

The Big Plan

- Start from 4.0 GeV up to the maximum energy BEPCII can reach ($\geq$ 4.6 GeV)
- 10 MeV step (slight adjust ~ thresholds, skip those 6 points we have already collected large samples)
- 500 pb^{-1}/point (from the size of the existing samples!)

- Year 1: 4.0-4.1 GeV
- Year 2: 4.1-4.2 GeV
- Year 3: 4.2-4.3 GeV
- Year 4: 4.3-4.4 GeV
- Year 5: 4.4-4.5 GeV
- Year 6: 4.5-4.6 GeV
- Years 7, 8, ...: >4.6 GeV

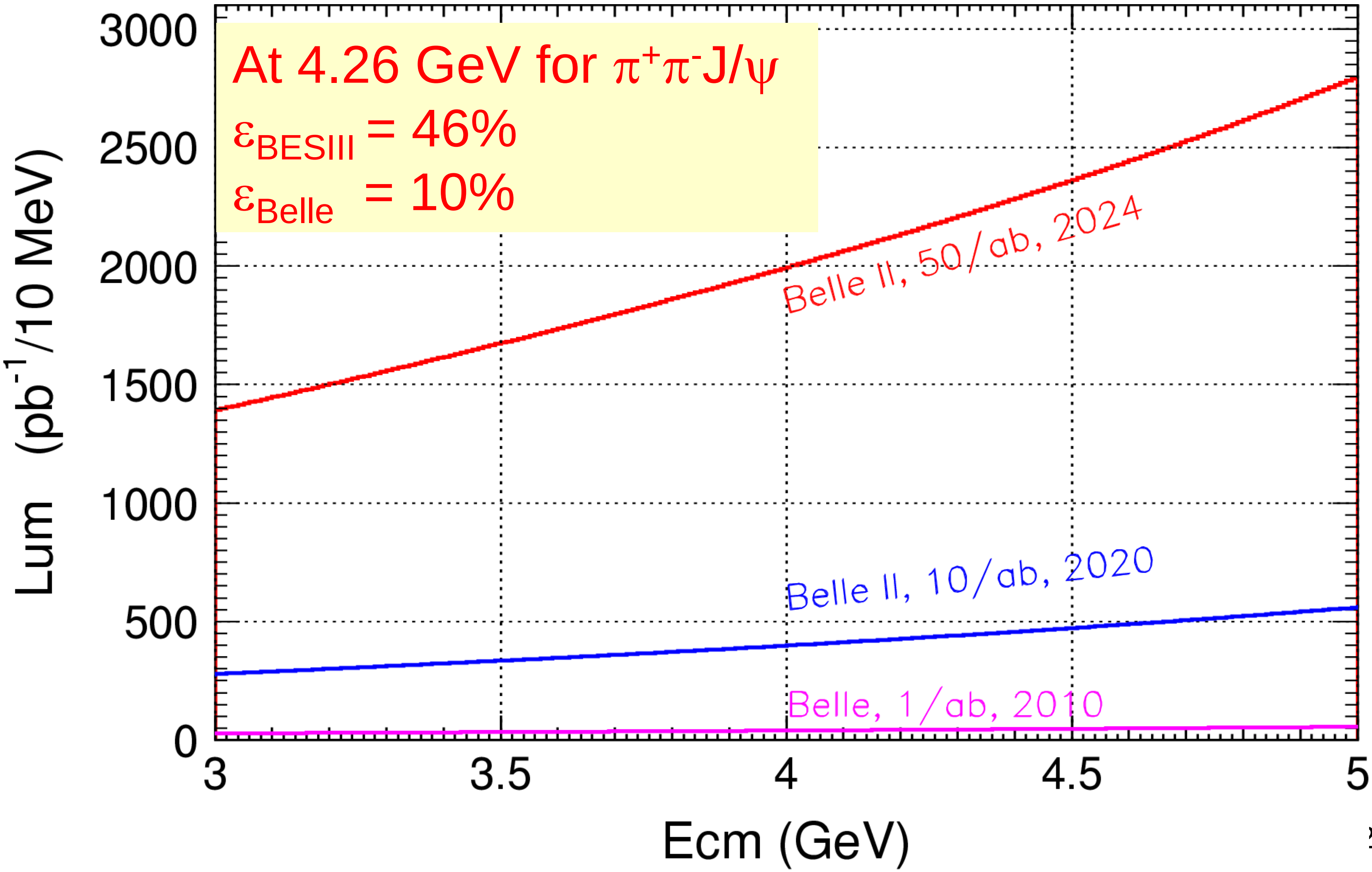
- ~ 4.5/fb per year!
- A bit conservative than BEPCII design luminosity (5/fb/yr)!
- Top-up injection allows more integrated luminosity!
- If “Year 1” = 2015, we finish 4.6 GeV data taking in 2021!

The 2015-16 plan

- BESIII is going to take 3.0/fb data for Ds study at ~4.17 GeV
- May we instead take 500 pb^{-1}/point at 6 or more points for XYZ study too?
- This is part of the 2^{nd} year of the big plan
- Will be discussed at the collab. meeting next week

Charmonium region at Belle II

ISR produces events at all CM energies BESIII can reach



Summary

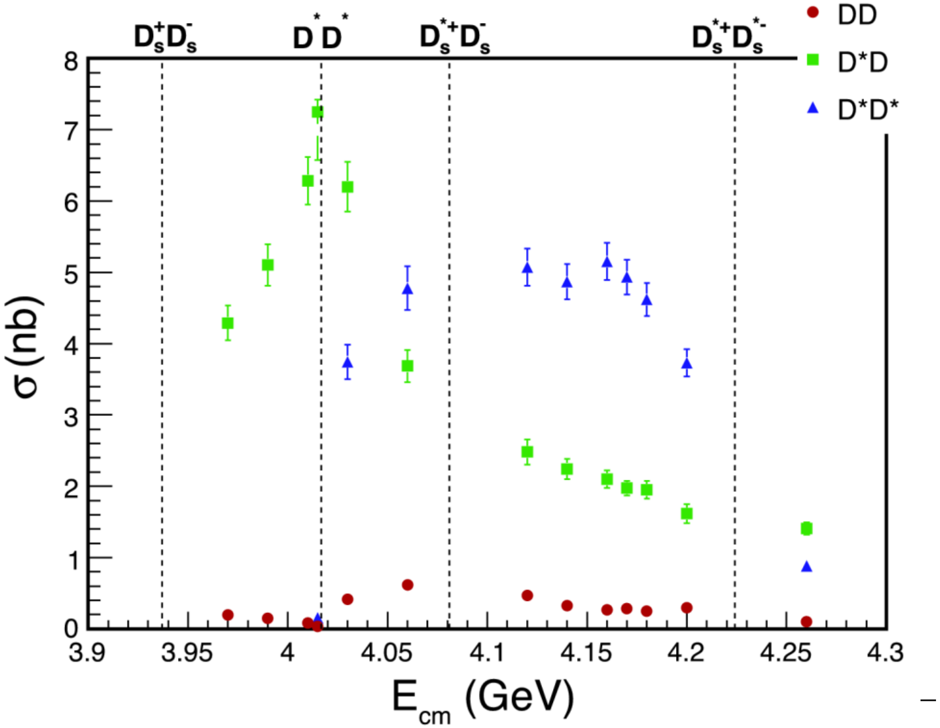
- We are proposing a long term data taking plan at BESIII for a better understanding of the strong interaction!
  - Start from 4.0 GeV to Emax of BEPCII
  - with 10 MeV step
  - 500/pb per point
  - Understand the XYZ, charmonia, and more!
- Please let us know if you have any new/crazy idea to use these data, or any other suggestions on the plan!

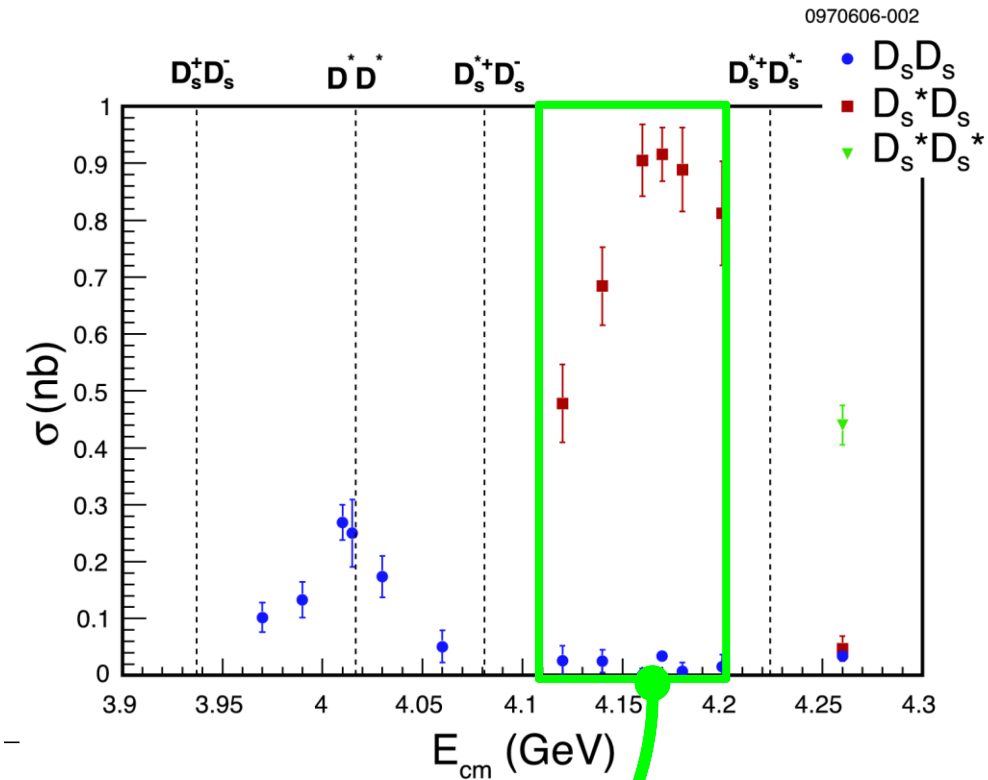
The end

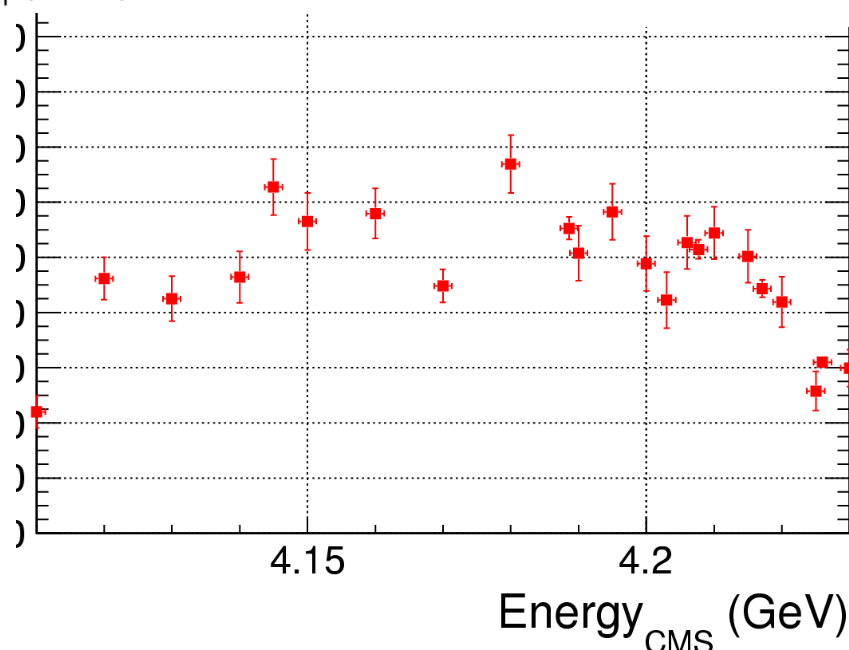
Start from low energy

- Accelerator optimized at low energy, gain experience step by step to run at high energy
- No saturation in detector at low energy
- Also important sample for Ds and D studies
- Radiative correction is necessary in all cross section measurements
- Radiative correction at s depends on cross sections at s'<s

CLEO hep-ex/ 0702008







$H_{ccg} \rightarrow \gamma\eta_c$ & $\gamma\chi_{c0}$

- $\sigma(e^+e^- \rightarrow H_{ccg}) \sim$ O(10-100) pb [???]
- $B(H_{ccg} \rightarrow \gamma\eta_c) \sim 2x(B(H_{ccg} \rightarrow \gamma\chi_{c0}) \sim 4x10^{-4}$

  [in H, $\bar{c}c$ in spin-singlet! LQCD by Dudek'09]
- Scan $e^+e^- \rightarrow \gamma\eta_c$ and $\gamma\chi_{c0}$ for exotic structures
- $\varepsilon B \sim 10\%$ for $\gamma\eta_c$ and $\gamma\chi_{c0} \rightarrow \gamma$+hadrons

- Maybe a topic of next generation TauC-factory!

Multiple points vs. one point with large luminosity

- This is equivalent to total vs. differential cross section
- More information in the differential distribution
- One point is good if focus on one topic
- Multiple points are better for search

- May affect a bit the Ds analysis