Collecting more data for XYZ study at BESIII

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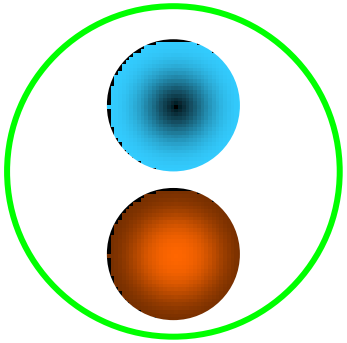
There are four interactions!

- It all started with the big bang! ➔ Gravity governed by General Relativity (it was good!)
- Let there be light: and there was light! ➔ Electromagnetic and weak interactions governed by Electroweak theory (it was good!)
- Let there be quarks and gluons! ➔ strong interaction governed by QCD (it was good at short distance only!)

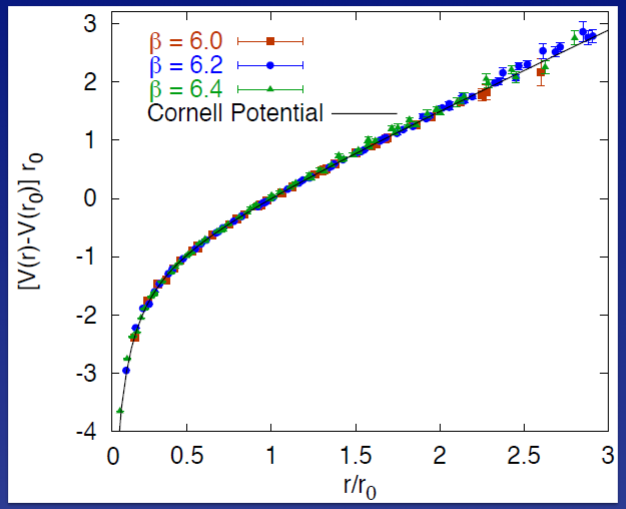
- Yes, let's study the strong interaction at long distance — non-perturbative part of QCD!

The heavy quarkonium system

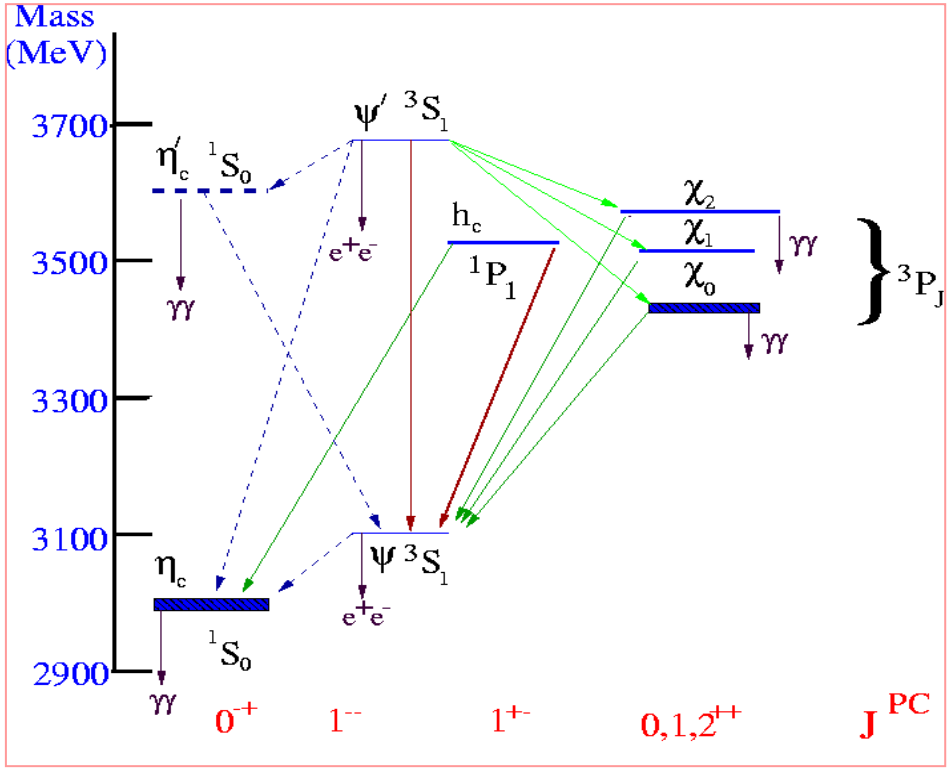
- At short distance
  Cornell model works pretty well
  $V(r) = -4\alpha_s/3r + kr$



Lattice QCD: V(r) between static color sources



Early example, no dynamical quarks



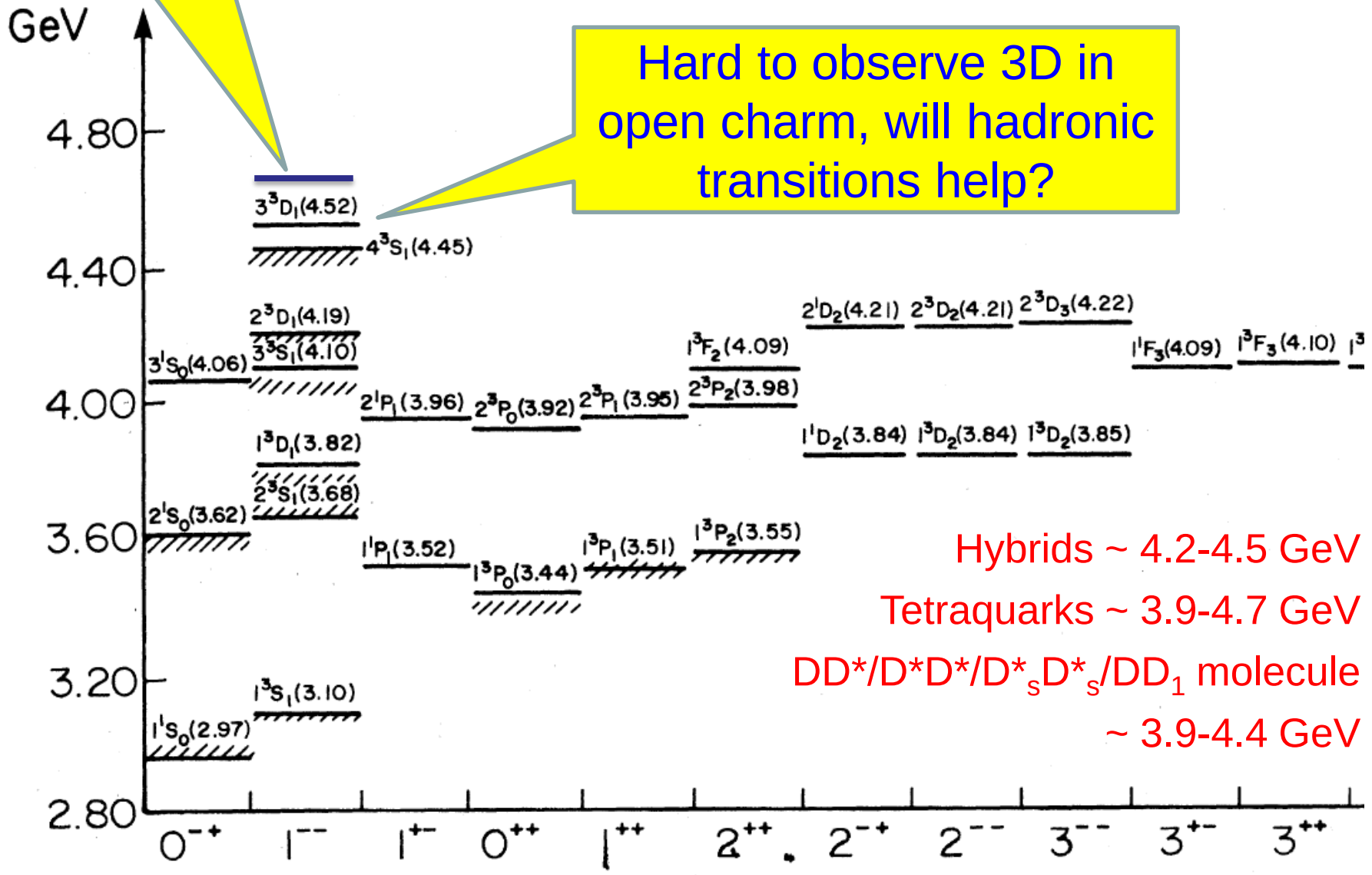
The quarkonium system

- When distance becomes larger
  - Theory 1: let there be screened potential
  - Theory 2: let there be hybrids with excited gluons
  - Theory 3: let there be tetraquark states
  - Theory 4: let there be meson molecules
  - Theory 5: let there be cusps
  - Theory 6: let there be final state interaction
  - Theory 7: let there be coupled-channel effect
  - Theory 8: let there be mixing
  - Theory 9: let there be mixture of all these effects
  - Theories …
- The world is not that good! Need data to develop theory.

All these happen in 4.0-4.7 GeV

Is Y(4660) the 5S state?

Hard to observe 3D in open charm, will hadronic transitions help?



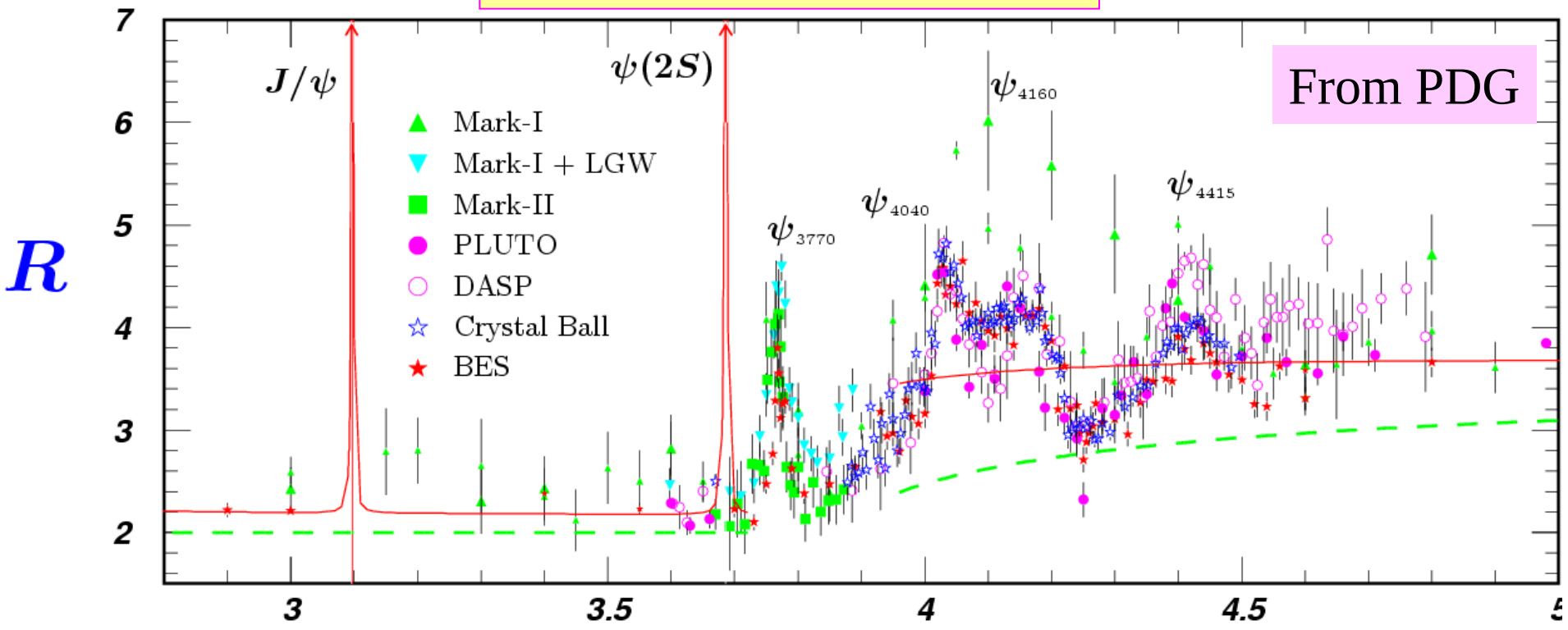
Hybrids ~ 4.2-4.5 GeV

Tetraquarks ~ 3.9-4.7 GeV

$DD^*/D^*D^*/D^*_sD^*_s/DD_1$ molecule ~ 3.9-4.4 GeV

R values/ψ states/Y states

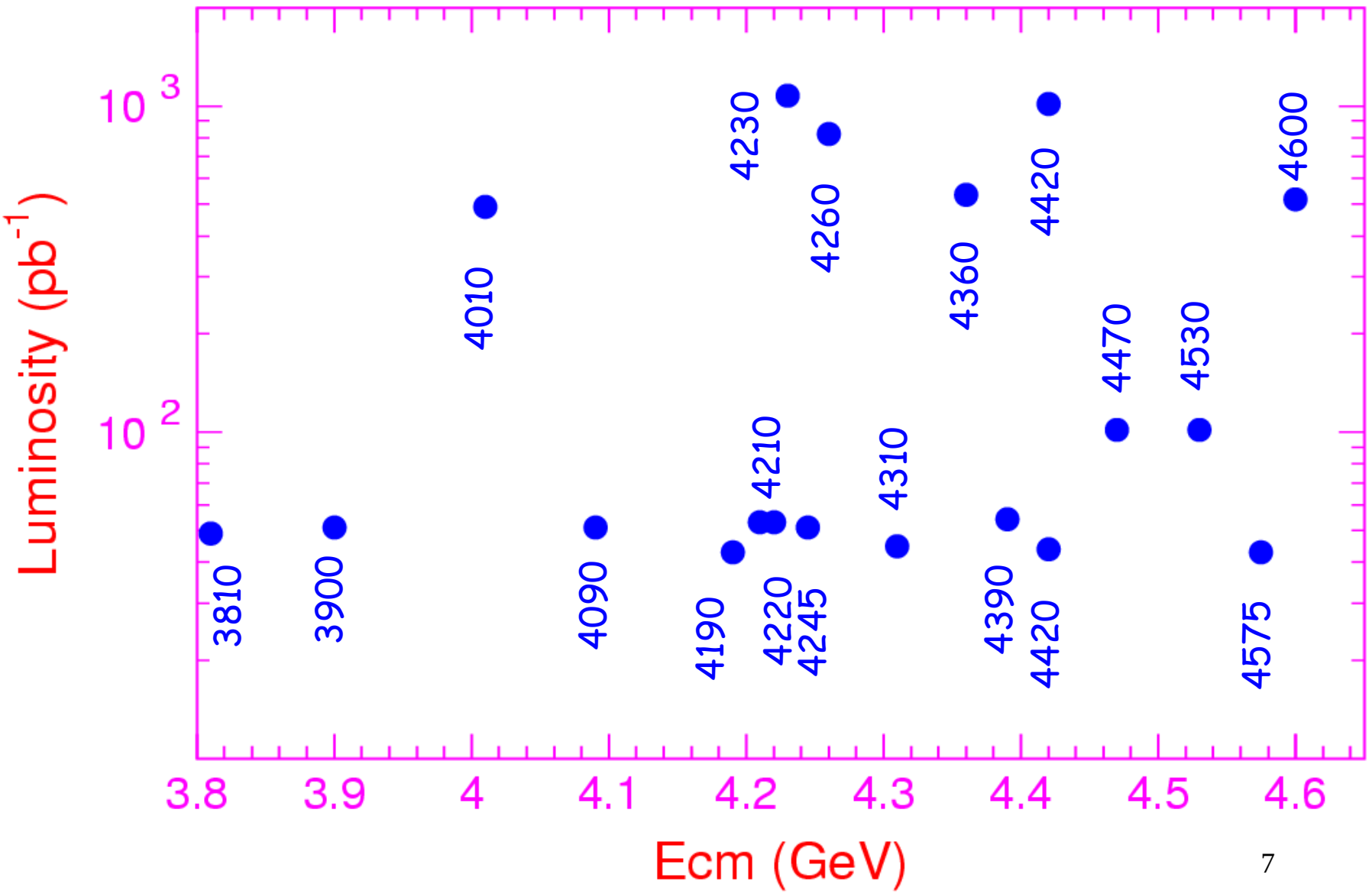
$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



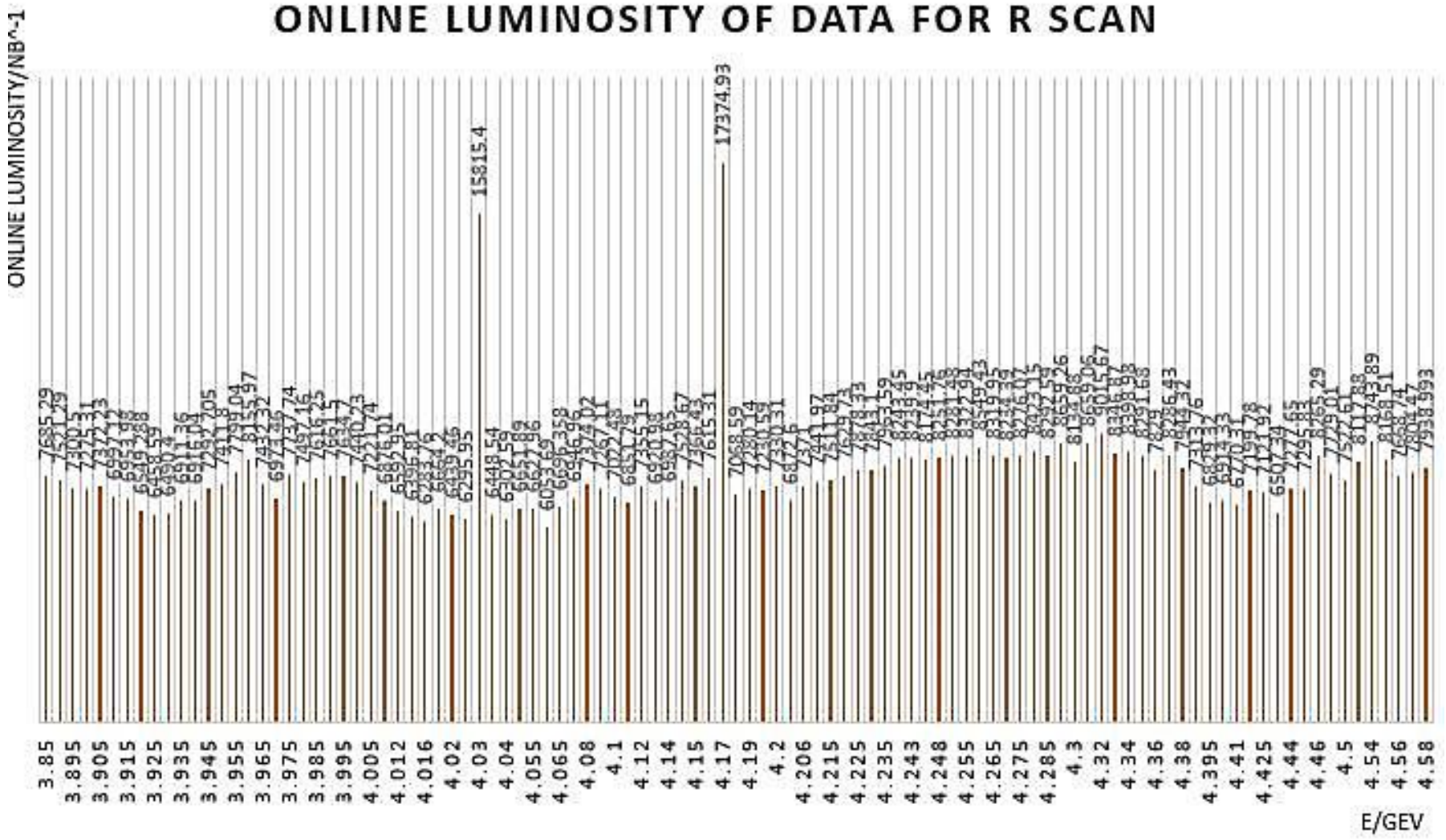
Information between 4.0 & 4.7 GeV is very limited!

BESIII can contribute!

We've collected 5/fb above 4 GeV



We collected 0.8/fb at >100 energy points



We've done a lot with these samples

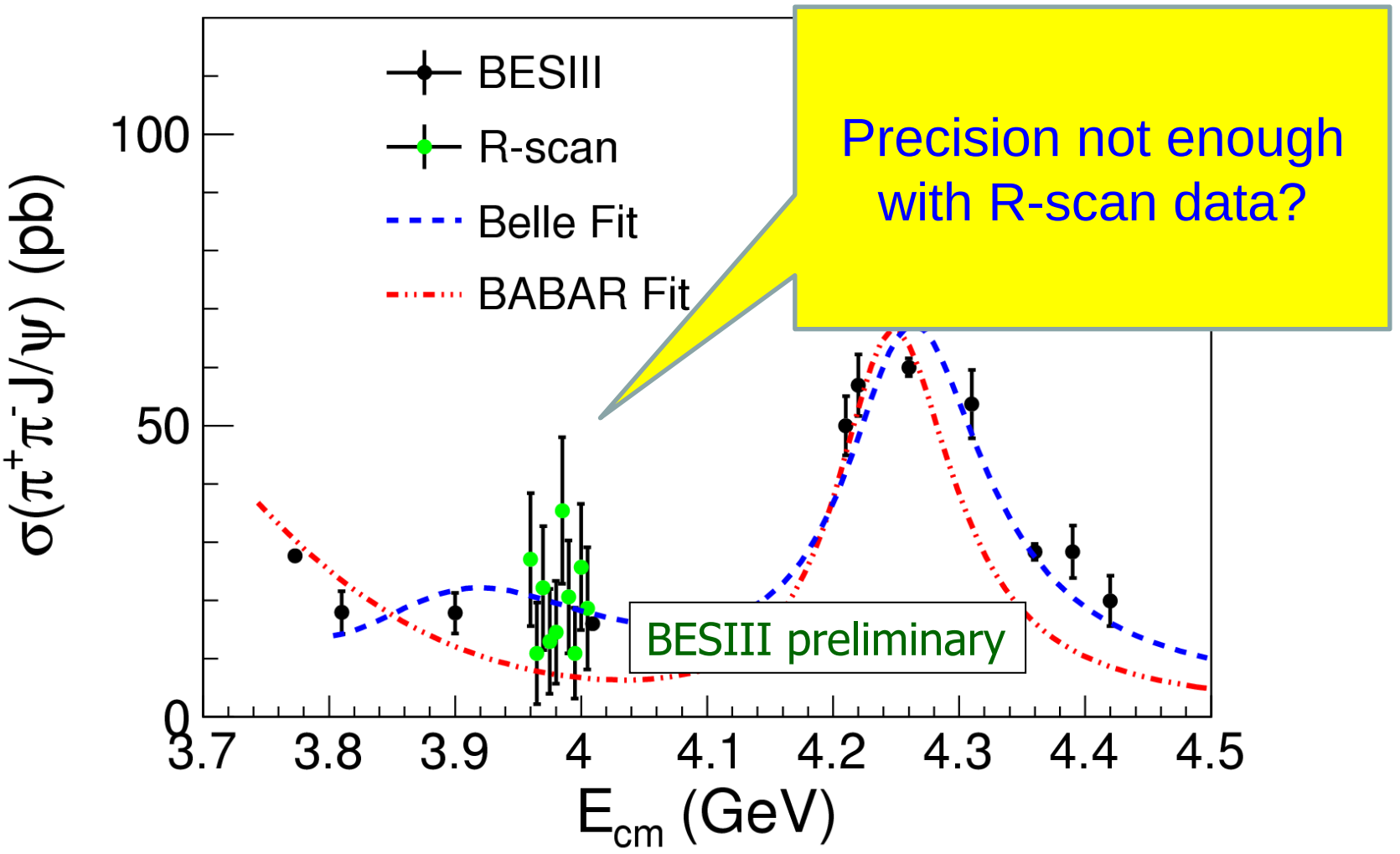
- Observation of $Z_c(3900) \rightarrow \pi^{\pm} J/\psi$, $\pi^0 J/\psi$, $\bar{D}D^*$
- Observation of $Z_c(4020) \rightarrow \pi^{\pm} h_c$, $\pi^0 h_c$, $\bar{D}^* D^*$
- Observation of $Z_c(4050) \rightarrow \pi\psi'$, $Y(4260) \rightarrow \gamma X(3872)$
- Observation of $\psi(1^3D_2) = X(3823)$
- Observation of $e^+e^- \rightarrow \omega\chi_{cJ}$, $\phi\chi_{cJ}$, ηh_c
- Observation of $e^+e^- \rightarrow \eta J/\psi$, $\eta' J/\psi$, $\eta\psi'$
- Observation of $e^+e^- \rightarrow KKJ/\psi$ possibly from Y(4260)
- Search for radiative transitions $\gamma X(4140)$, $\gamma\eta_c$, $\gamma\chi_{cJ}$
- Search for Z_{cs}, search for $Z \rightarrow$ 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, $Y \rightarrow$ Light hadrons
- …

XYZ+C

We also found more questions to answer

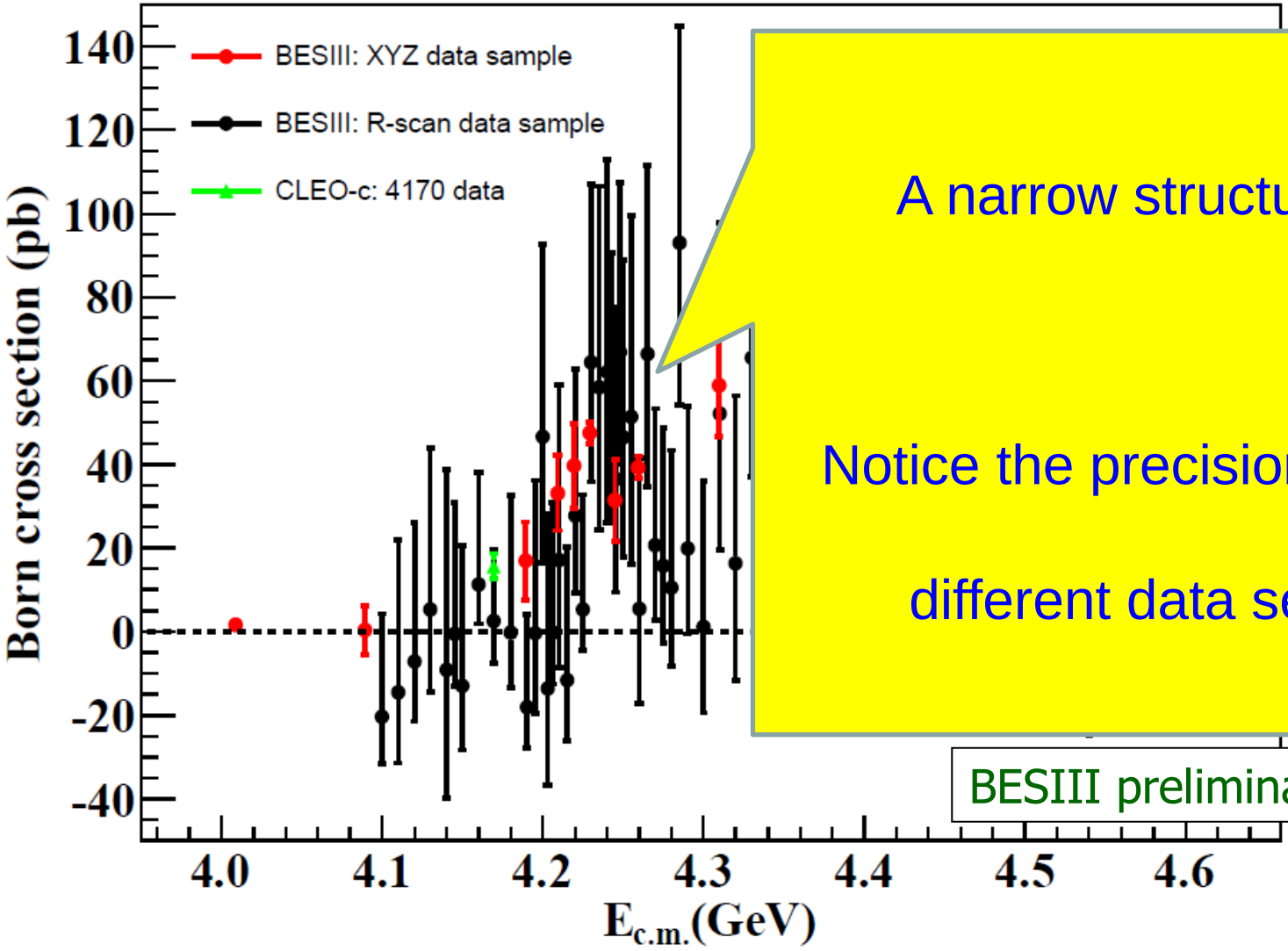
- In the X sector
  - Where the X(3872) & X(3823) come from? Resonance decays or continuum production?
  - May other X states be produced and where?
- In the Y/ψ sector
  - Is the Y(4260) a single resonance? Is Y(4008) a real structure?
  - Does the Y(4360) decay only to ππψ'? Not to ηJ/ψ ?
  - What is hidden behind $\pi\pi h_c$? Large coupling to spin-singlet, is a hybrid state observed?
  - 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 excited Z_c states and Z_{cs} states [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 …

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



BESIII: more complicated than Y4260+X?

Cross sections of $e^+e^- \to \pi^+\pi^- h_c(^1P_1)$



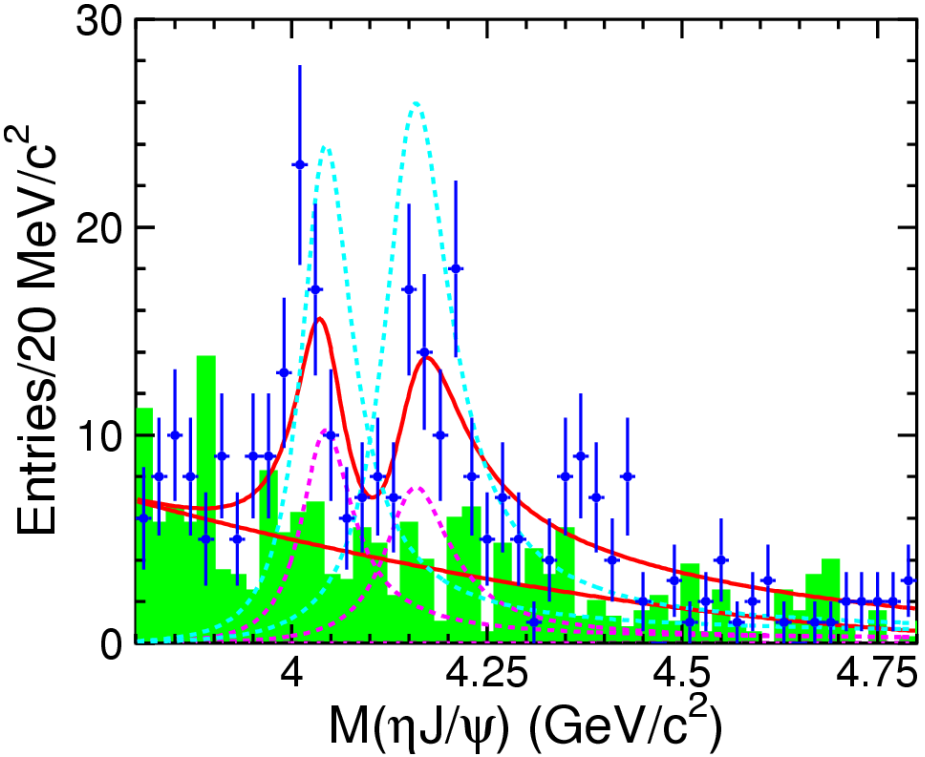
BESIII: What is the line shape?

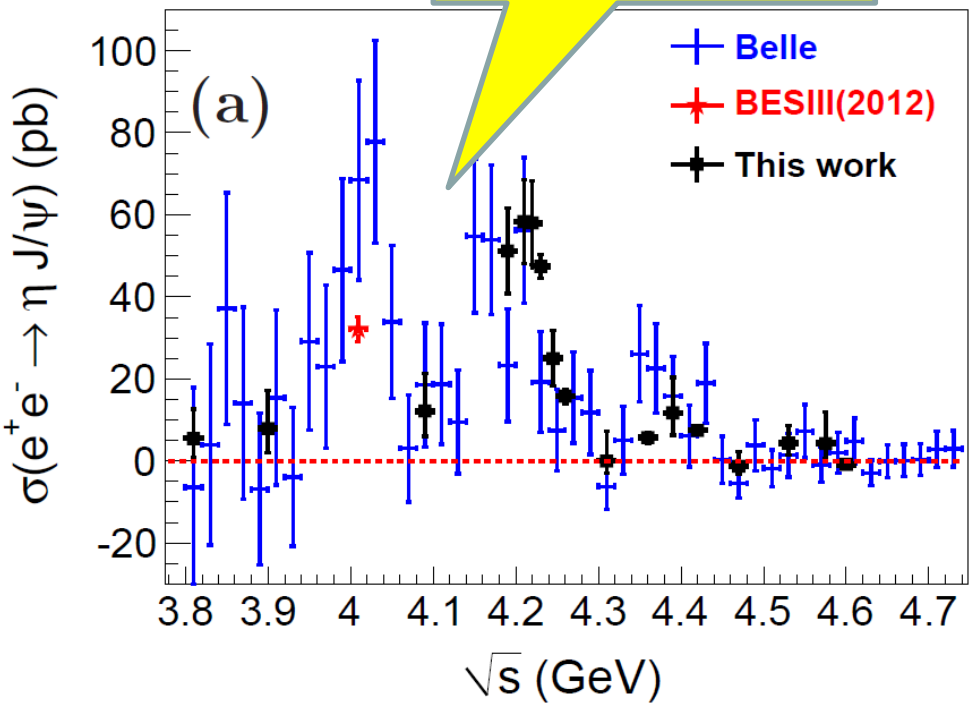
$e^+e^- \to \eta J/\psi$

arXiv: 1210.7550
PRD87, 051101

BESIII:
arXiv: 1503.06644

What is going on here?



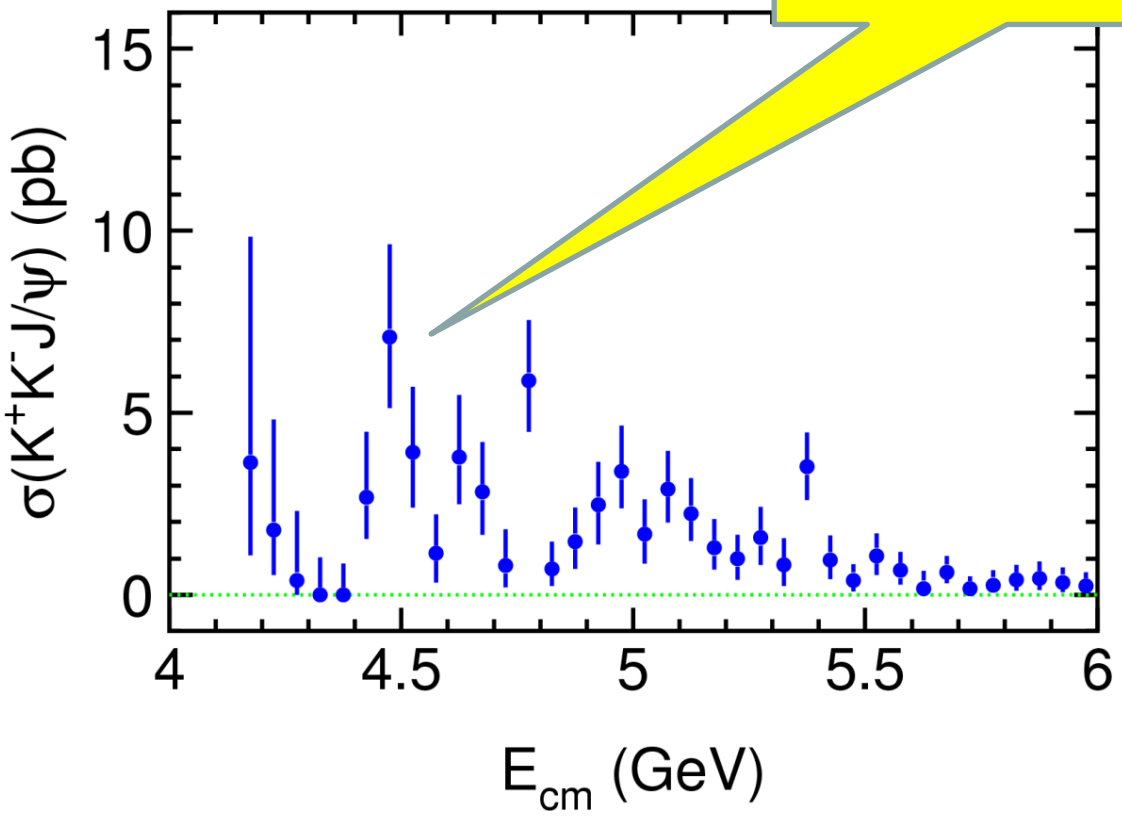


BESIII: Can do better in the full energy range!

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

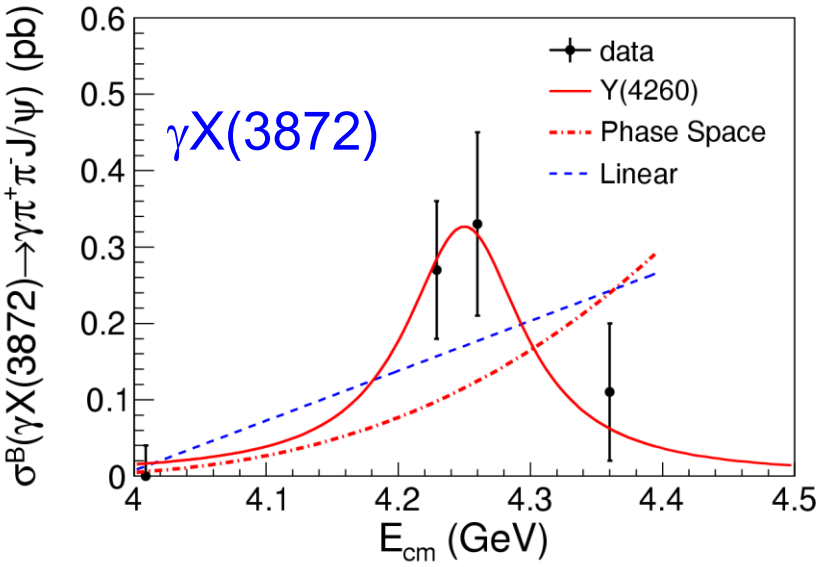
arXiv: 1402.6578
PRD89, 072015

What's the cross section here? Any structure?



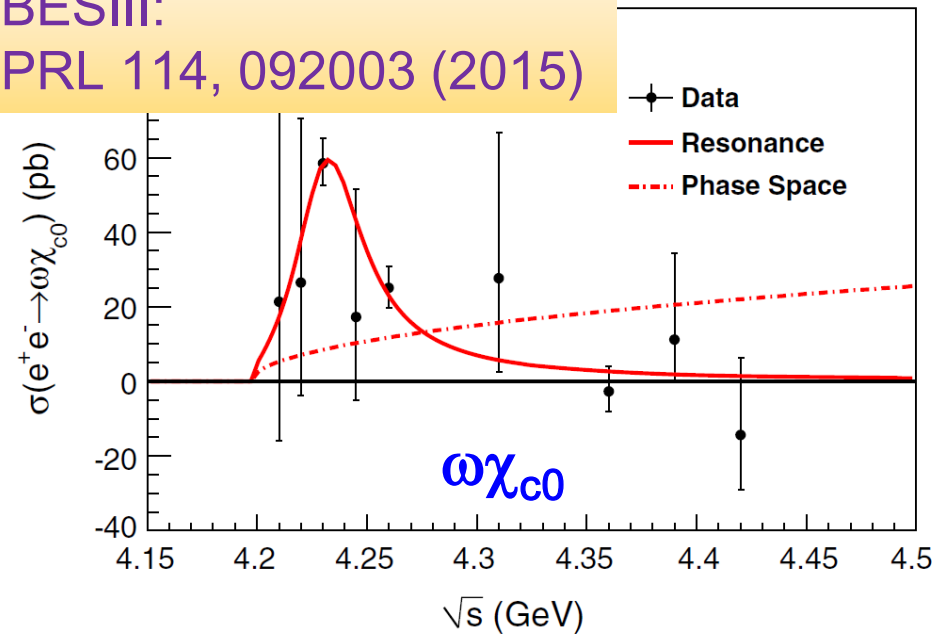
BESIII: Y(4260)+ψ(4415)+?

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

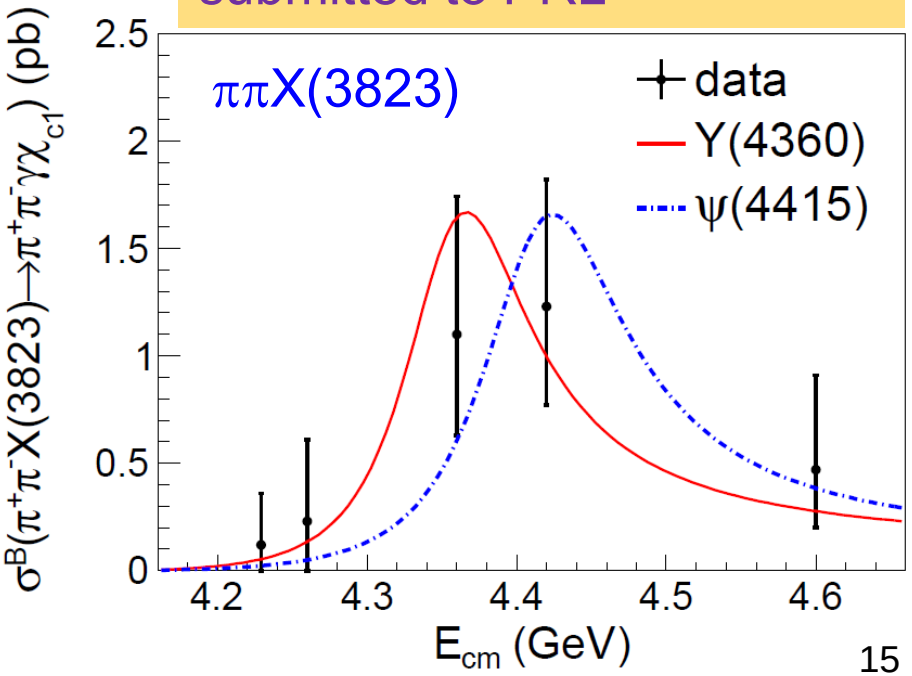


BESIII:
PRL 112, 092001 (2014)

BESIII:
PRL 114, 092003 (2015)



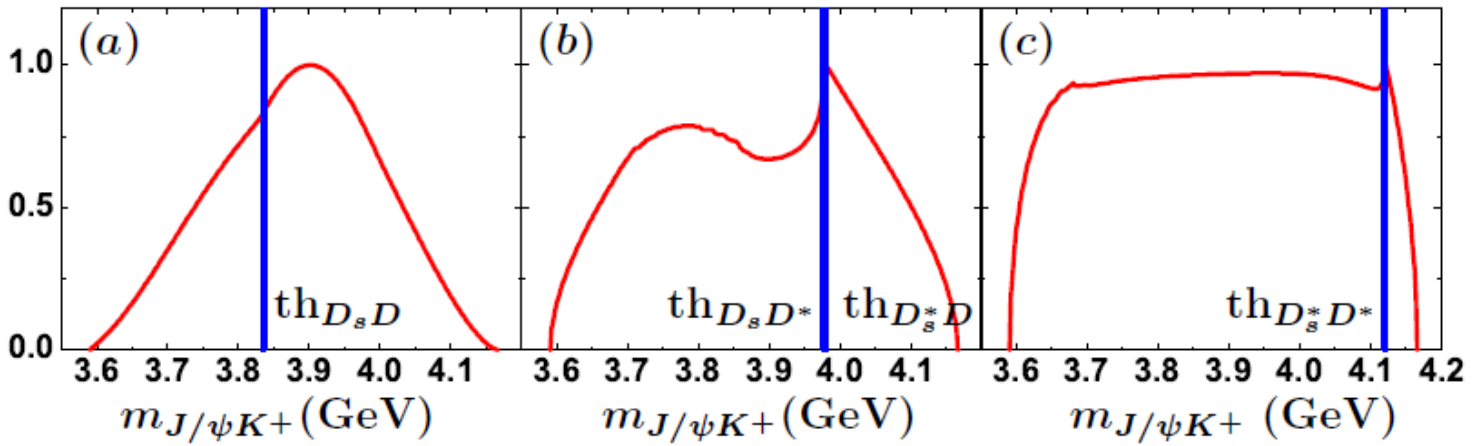
BESIII: arXiv: 1503.08203,
submitted to PRL



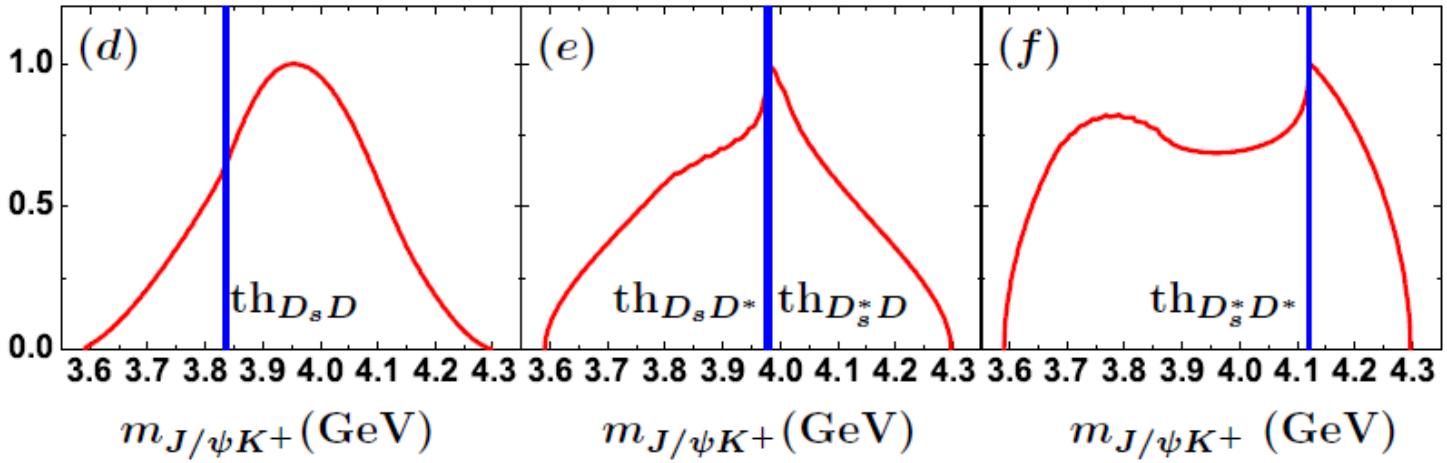
$e^+e^- \to KZ_{cs}$ @ E_{cm}>4.5 GeV

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

$Y(4660) \to J/\psi K^+K^-$



$\psi(4790) \to J/\psi K^+K^-$



BESIII: May we find excited Zc & Zcs?

We need data

- To understand
  - The ψs
  - The Ys
  - The other XYZ particles via hadronic and radiative transitions of the ψs or/and Ys 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 plan

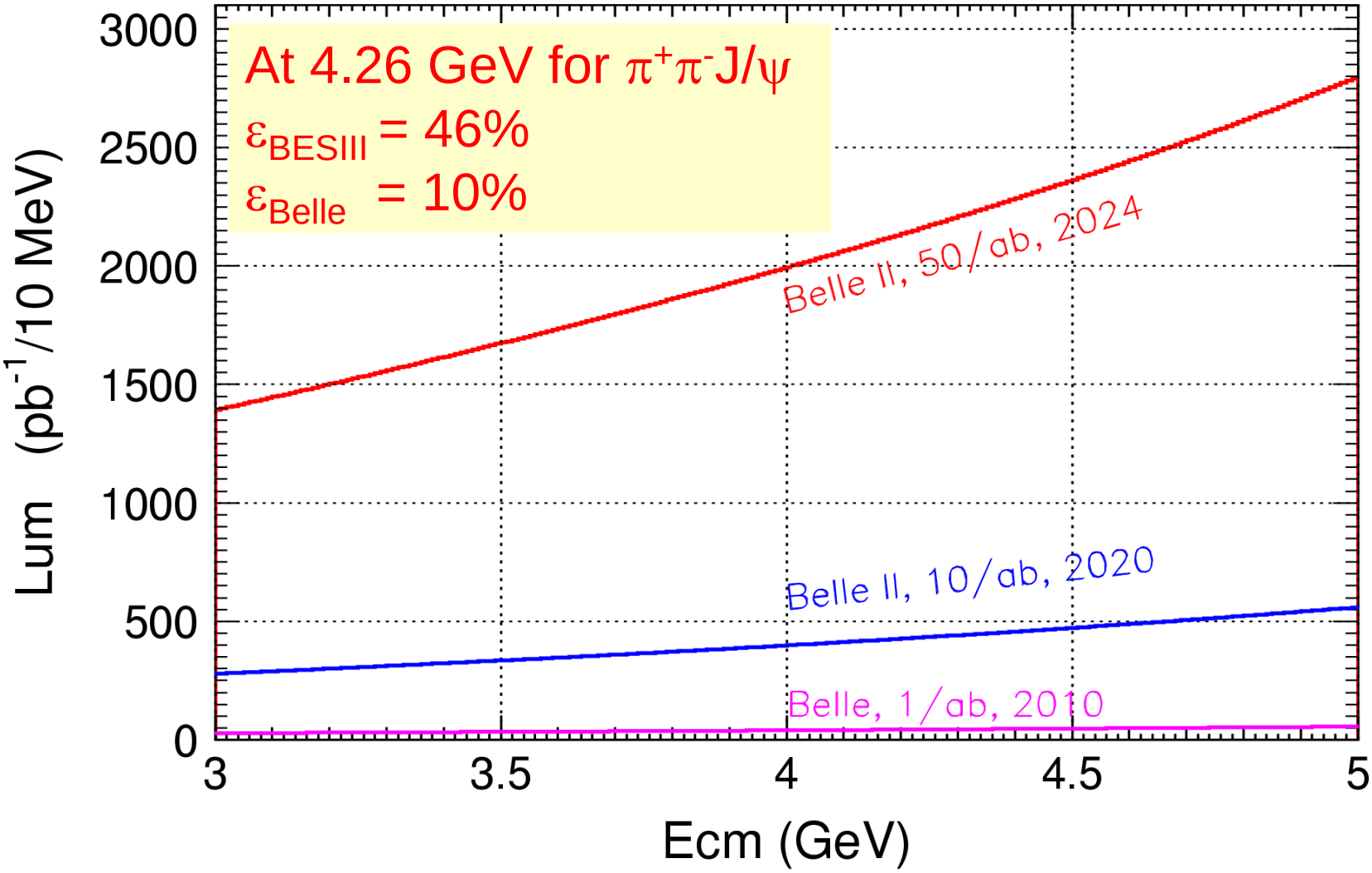
- Start from 4.0 GeV up to the maximum energy BEPCII can reach (≥ 4.6 GeV)
- 10 MeV step (slight adjust ~ thresholds, skip those 6 points we have already collected large samples)
- 500 pb^{-1}/point (from the size of the existing samples!)

- 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!

Belle II is coming

ISR produces events at all CM energies BESIII can reach



Summary

- Let's make a long term data taking plan 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!

It is time to use a net!

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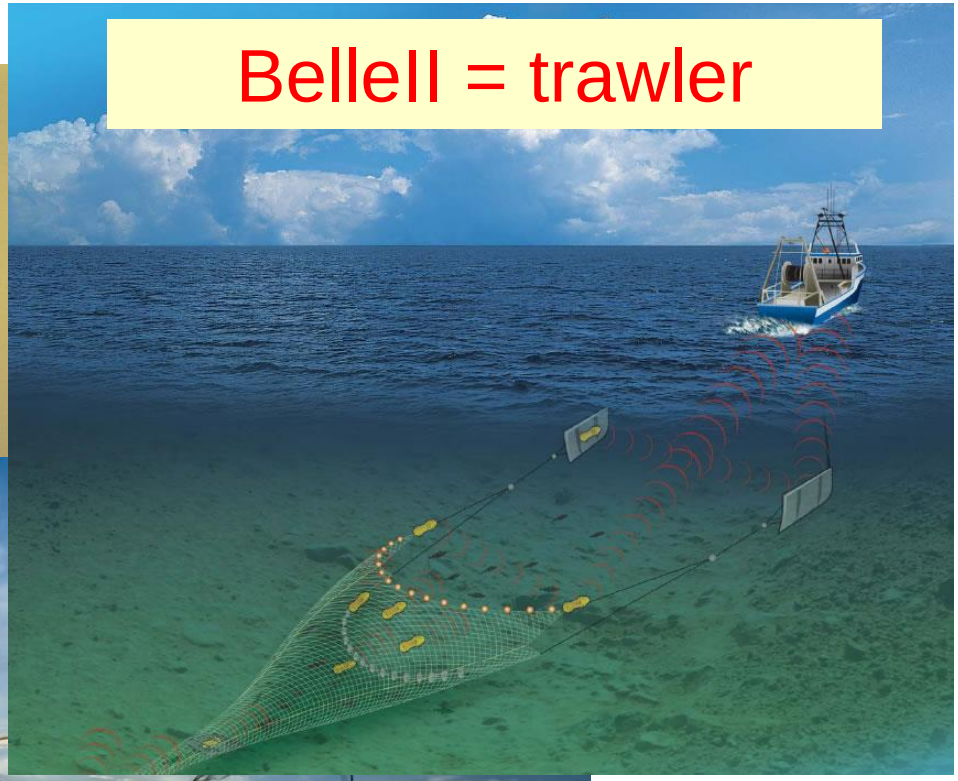


The end

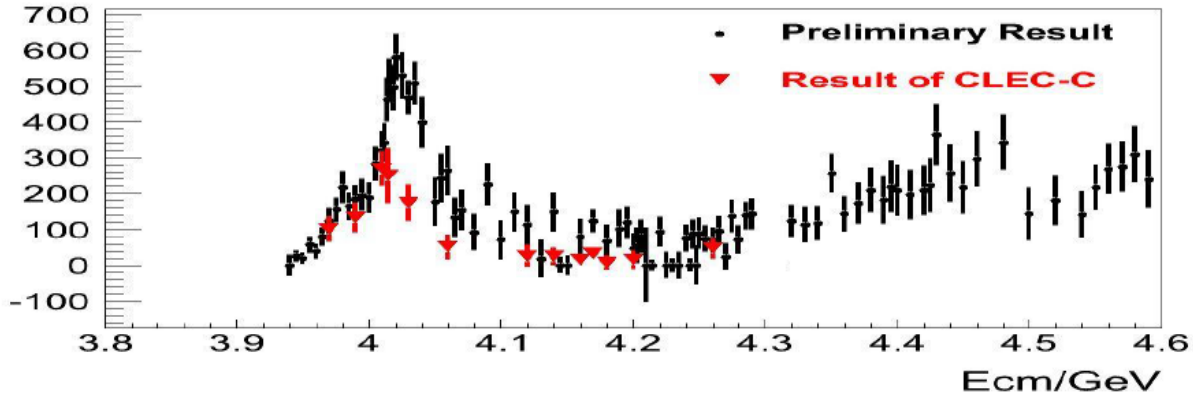
Start from low energy

- 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

Samples for Ds physics

- Charm proposal of 3/fb at 4.17 GeV for Ds
  - N_{Ds}=3/fbx0.92nb = 2.8M
- 0.5/fb each 10 MeV at 4.02-4.04, 4.15-4.19 GeV=4/fb
  - N_{Ds}=1.5/fbx0.5nb+2.5/fbx0.9nb = 3.0M

Cross section of Ds+Ds- :



Cross section of Ds+*Ds- :