XYZ in the future at BESIII

Kai Zhu (IHEP)

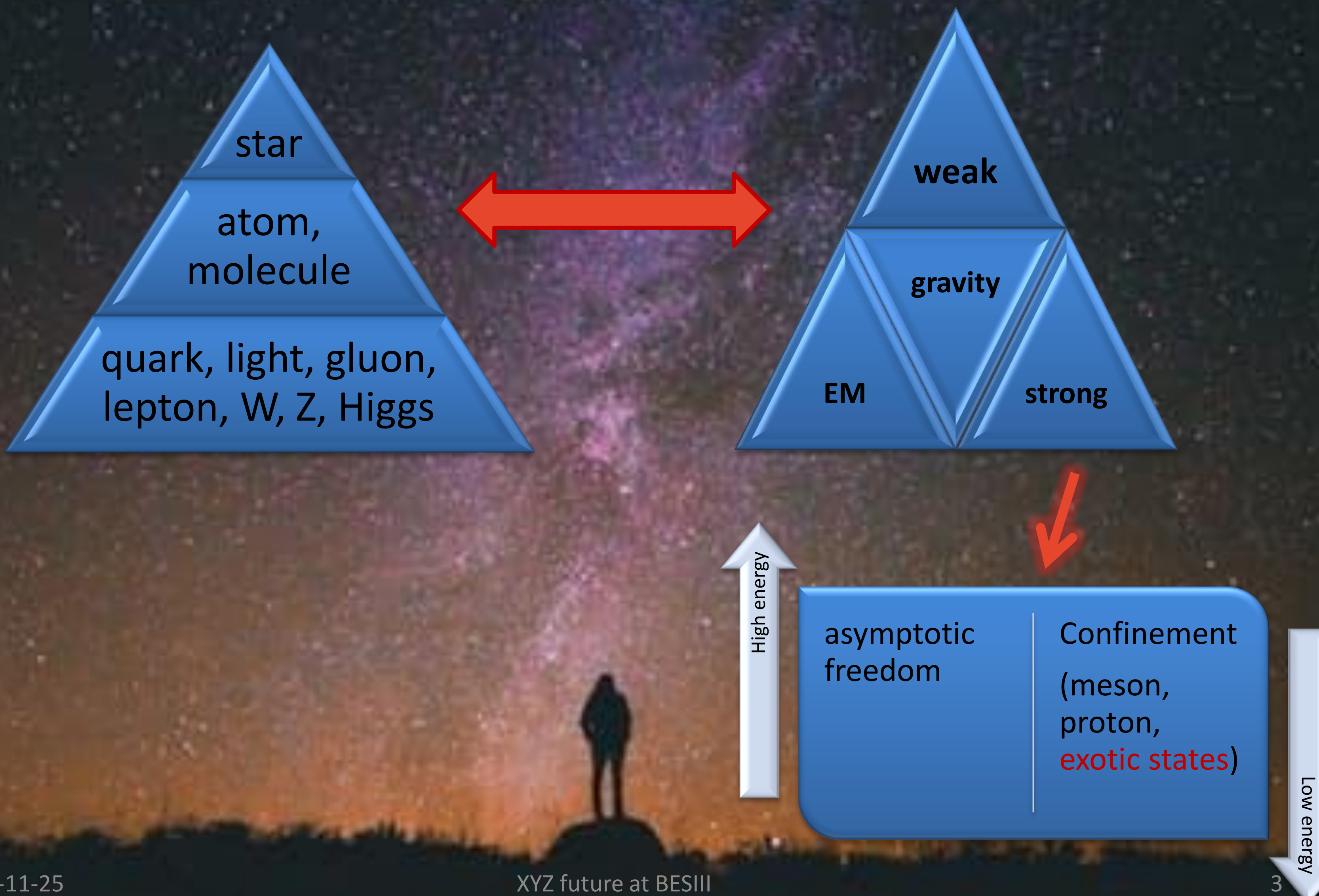
4th workshop on the XYZ particles

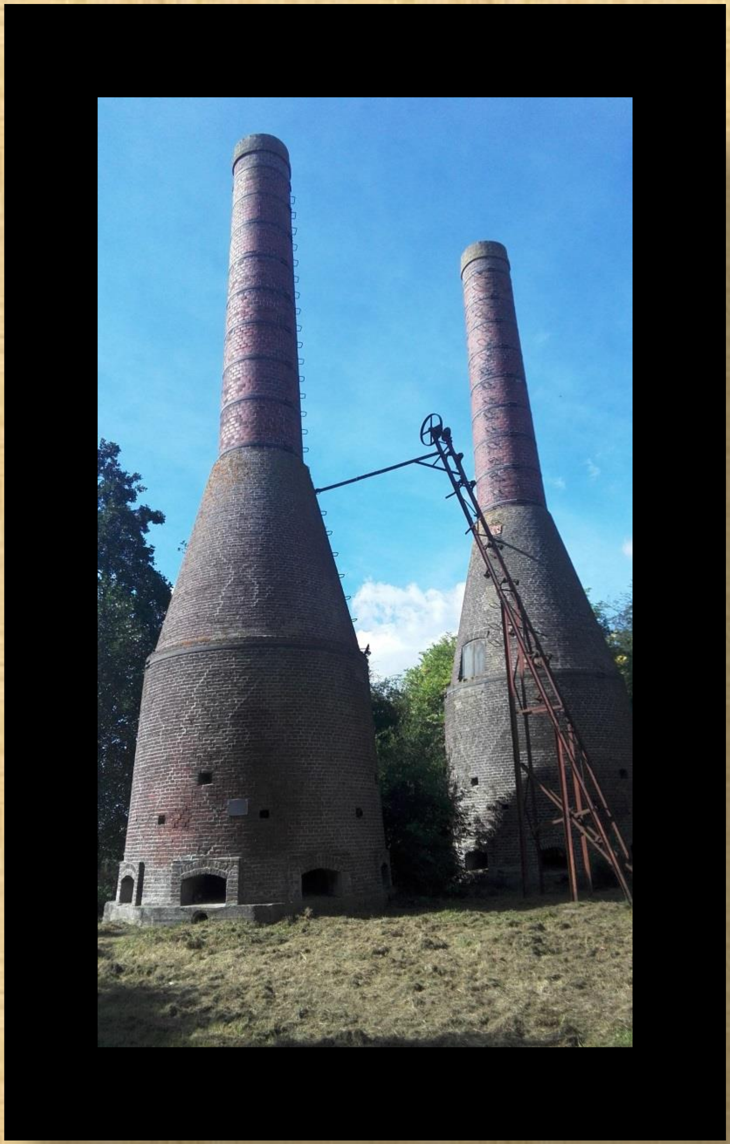
2016Nov. 23-25,北京航空航天大学

Some fundamental questions

- Who am I?
- What is the meaning of life?
- Where are we from?
- Where are we going to?
- How shall I go through my short/long pitiful/brilliant life?
- ……..

Try to understand the universe



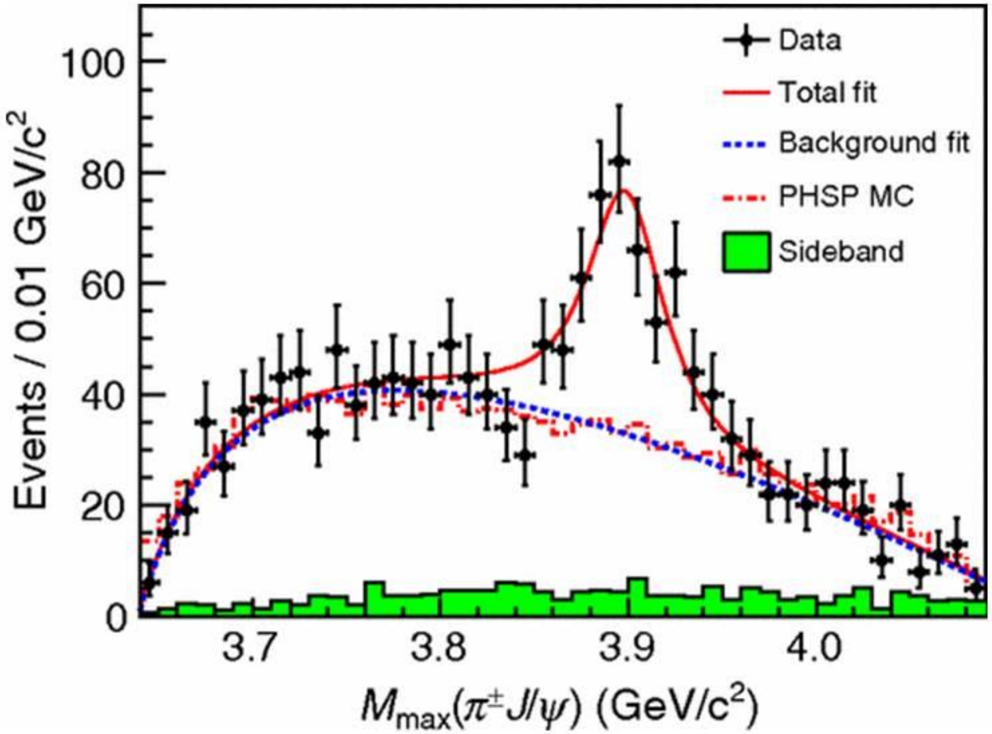


Normal Exotic?

Selected XYZ @ BESIII

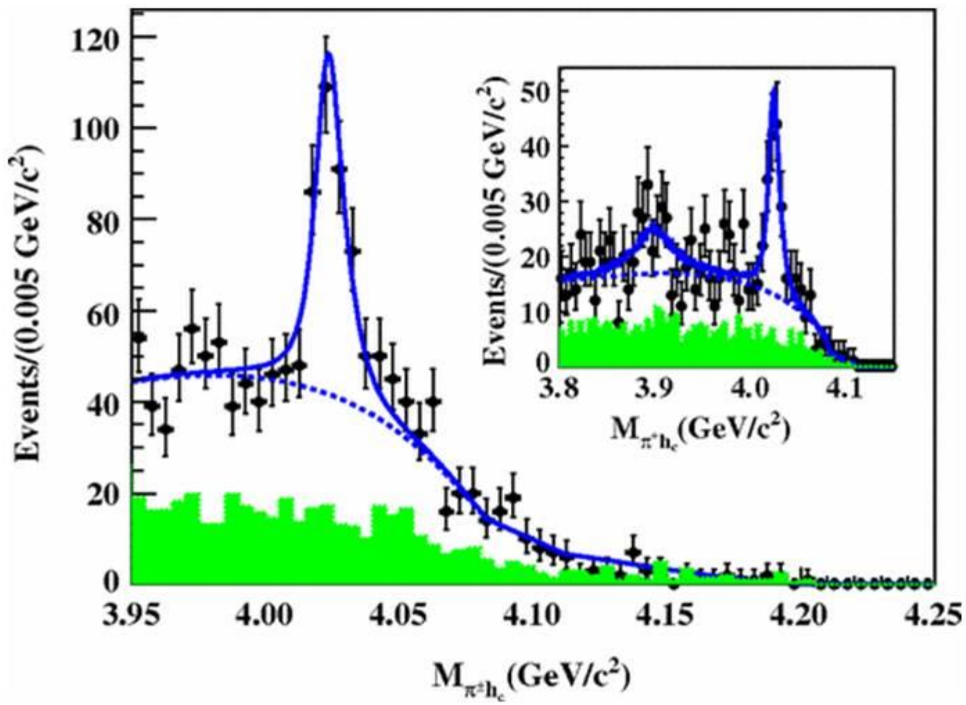
Discovery of the $Z_c(3900)$ in $\pi^+\pi^- J/\psi$

PRL 110, 252001 (2013)



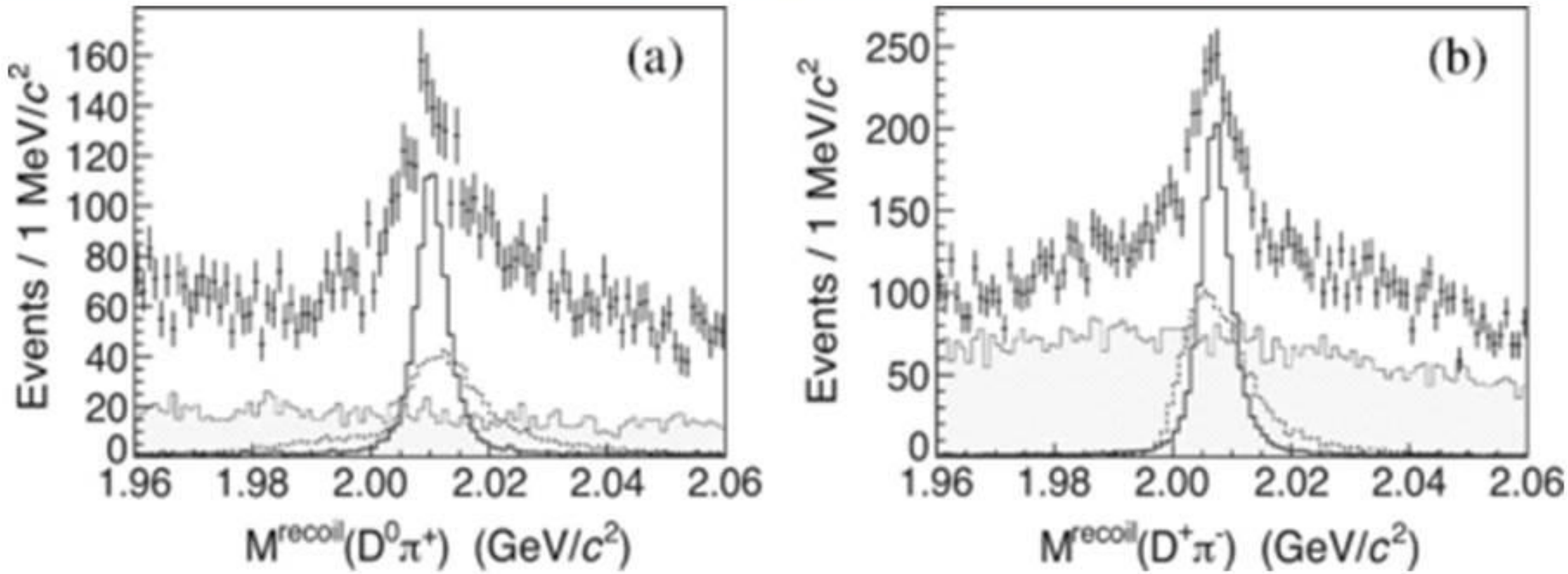
Selected XYZ @ BESIII

Discovery of $Z_c(4020)$
PRL 111, 242001 (2013)



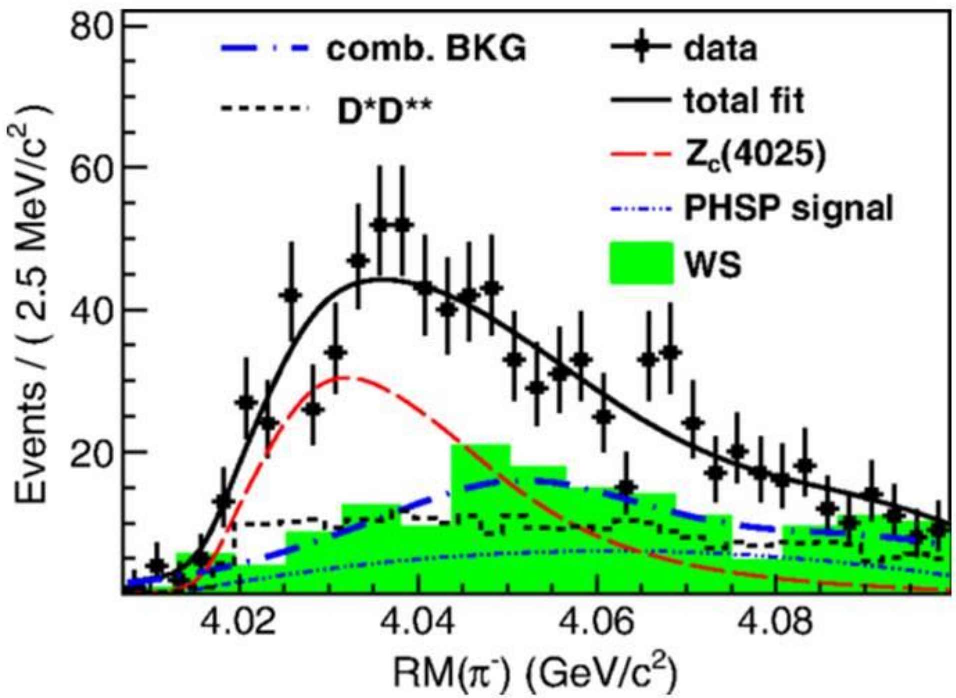
Selected XYZ @ BESIII

Discovery $Z_c(3885)$ in open-charm model
PRL 112, 022001 (2014)



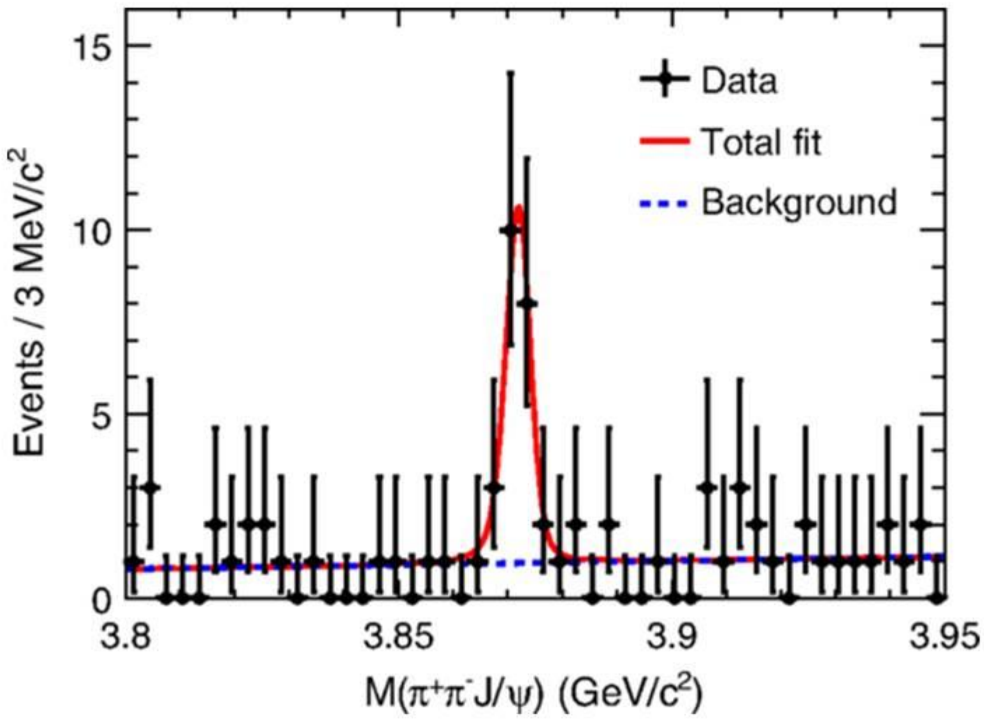
Selected XYZ @ BESIII

Discovery of $Z_c(4025)$ in open-charm
PRL 112, 132001 (2014)



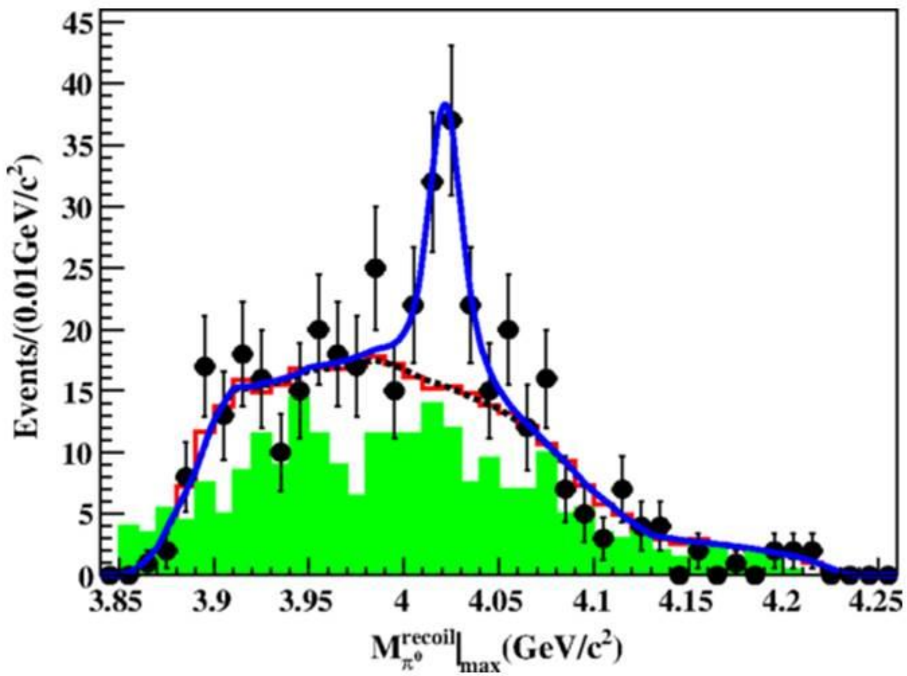
Selected XYZ @ BESIII

Observation of $e^+e^- \to \gamma X(3872)$
PRL 112, 092001 (2014)



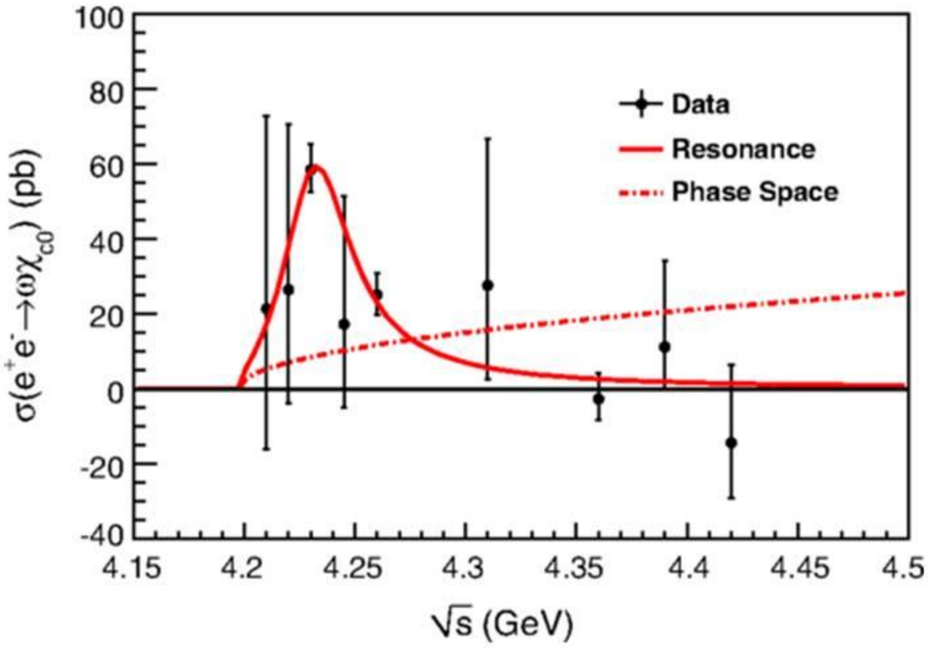
Selected XYZ @ BESIII

Neutral Z_c^0 (4020) in $\pi^0\pi^0 h_c$
PRL 113, 212002 (2014)



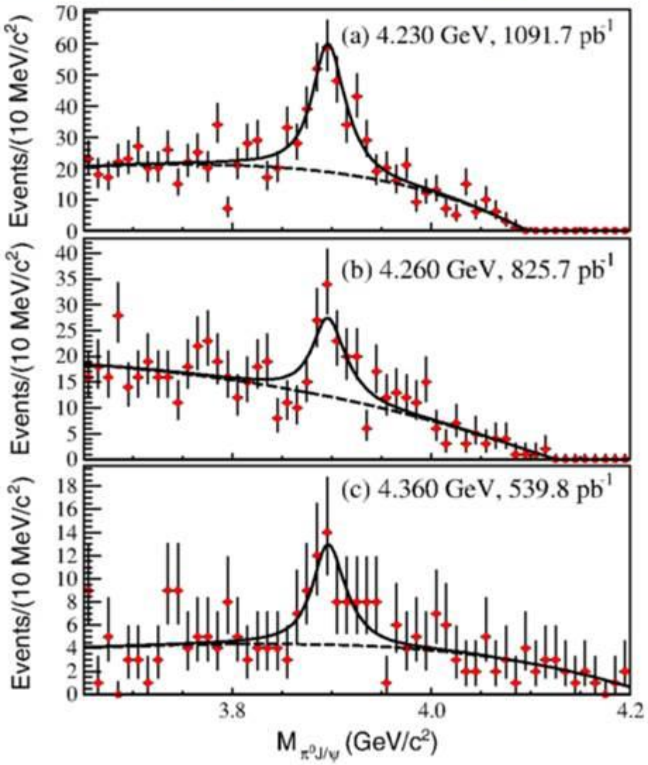
Selected XYZ @ BESIII

Discovery of a peak in $e^+e^- \to \omega\chi_{c0}$
PRL 114, 092003 (2015)



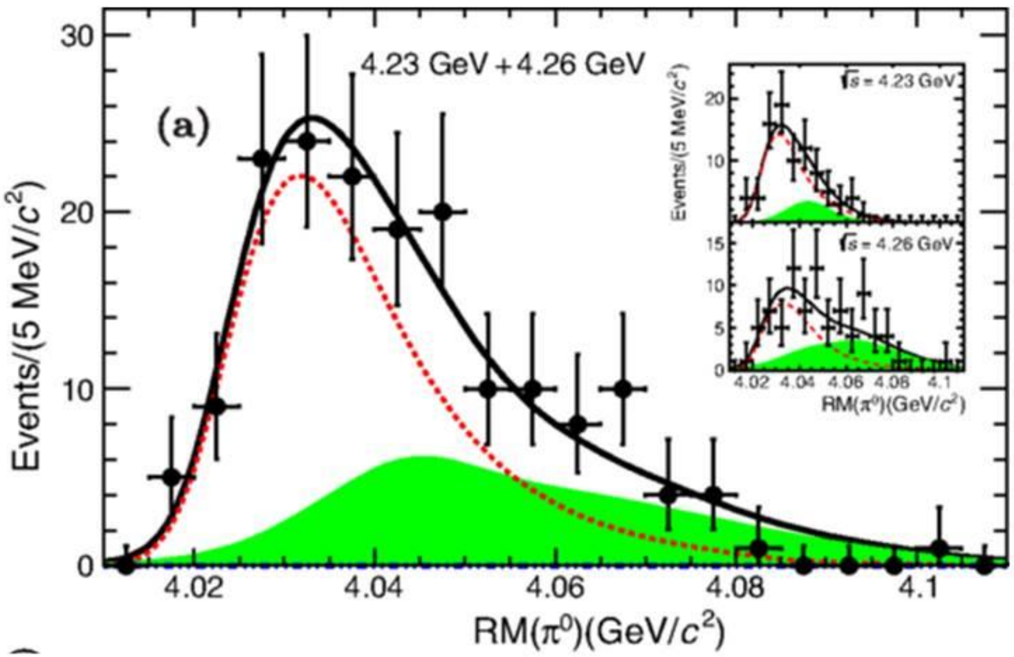
Selected XYZ @ BESIII

Neutral $Z_c(3900)$ in $\pi^0\pi^0 J/\psi$
PRL 115, 112003 (2015)



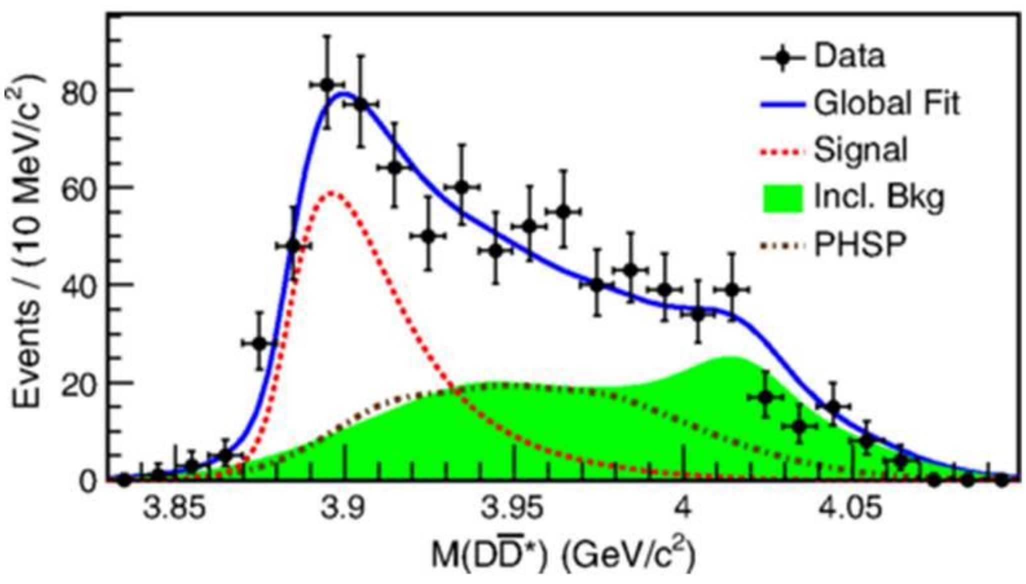
Selected XYZ @ BESIII

Neutral $Z_c(4025)$ open-charm mode
PRL 115, 182002 (2015)



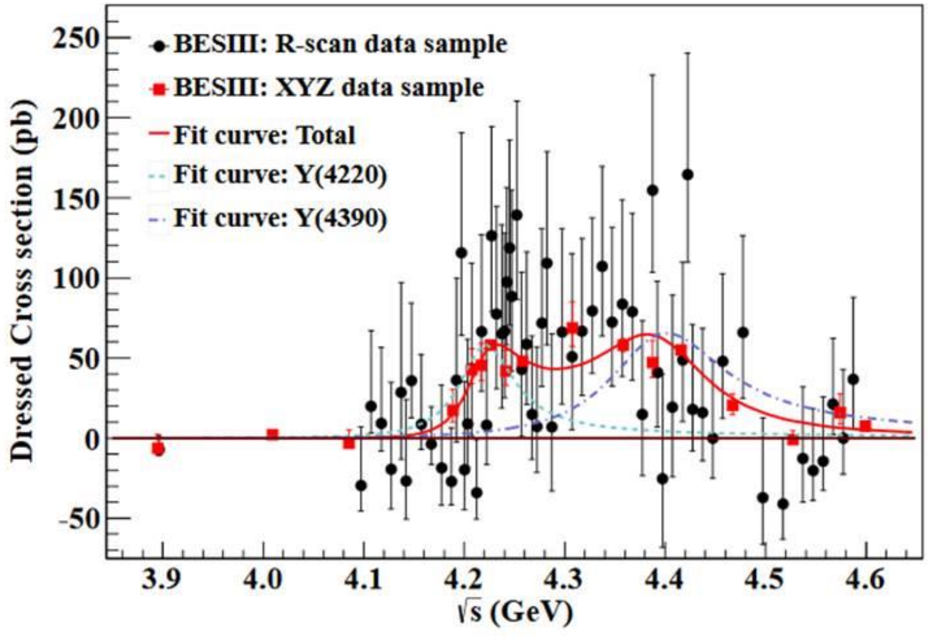
Selected XYZ @ BESIII

Neutral $Z_c(3885)$ in open-charm mode
PRL 115, 222002 (2015)



Selected XYZ @ BESIII

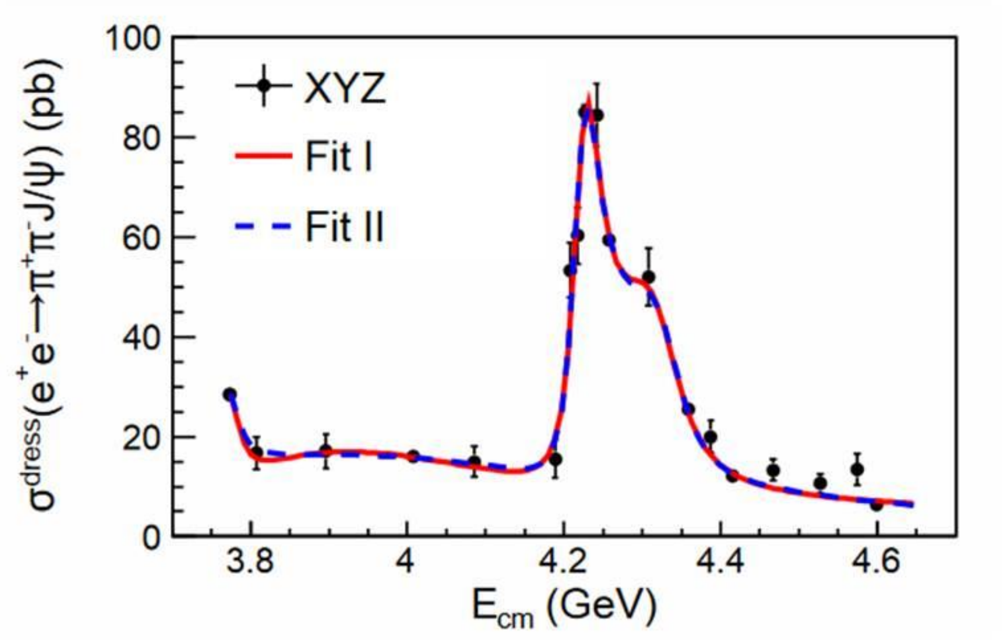
Observation of structures in $e^+e^- \to \pi^+\pi^- h_c$
arXiv:1610.07044, submitted to PRL



Selected XYZ @ BESIII

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

arXiv:1611.01317, submitted to PRL



Characteristics and trends in XYZ study at BESIII

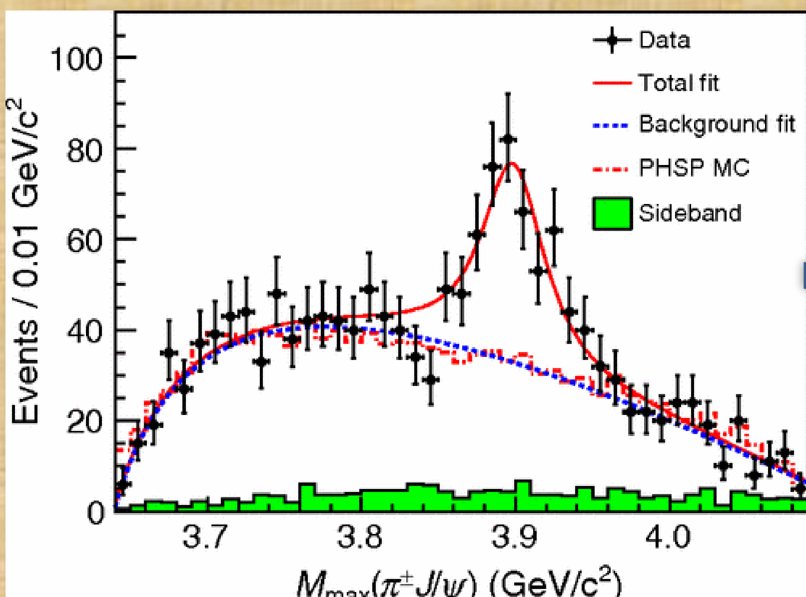
- Systematic

Ex.

$$\gamma \quad \times \begin{pmatrix} \pi^0 \\ \eta \\ \eta' \\ \pi^+\pi^- \\ \eta\eta \\ \pi^+\pi^-\pi^0(\omega) \\ \eta\pi\pi \\ \pi^0\pi^0 \\ K^+K^-(\phi) \end{pmatrix} \times \begin{pmatrix} \eta_c \\ J/\psi \\ \chi_{cJ} \\ h_c \\ \psi' \\ D^{(*)}D^{(*)} \end{pmatrix}$$

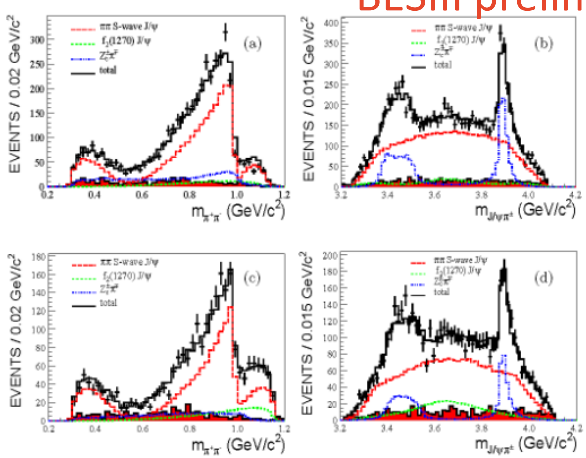
Characteristics and trends in XYZ study at BESIII

- More amplitude analyses



- Fit results and signal yields

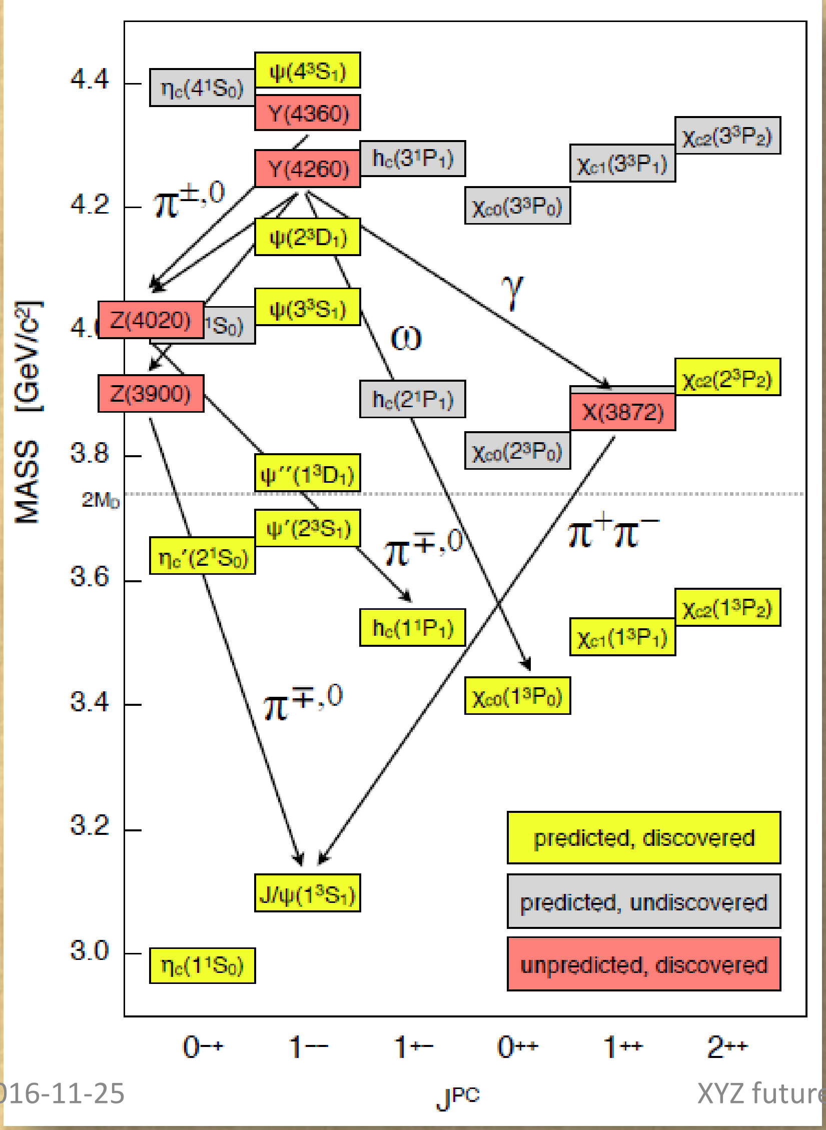
BESIII preliminary



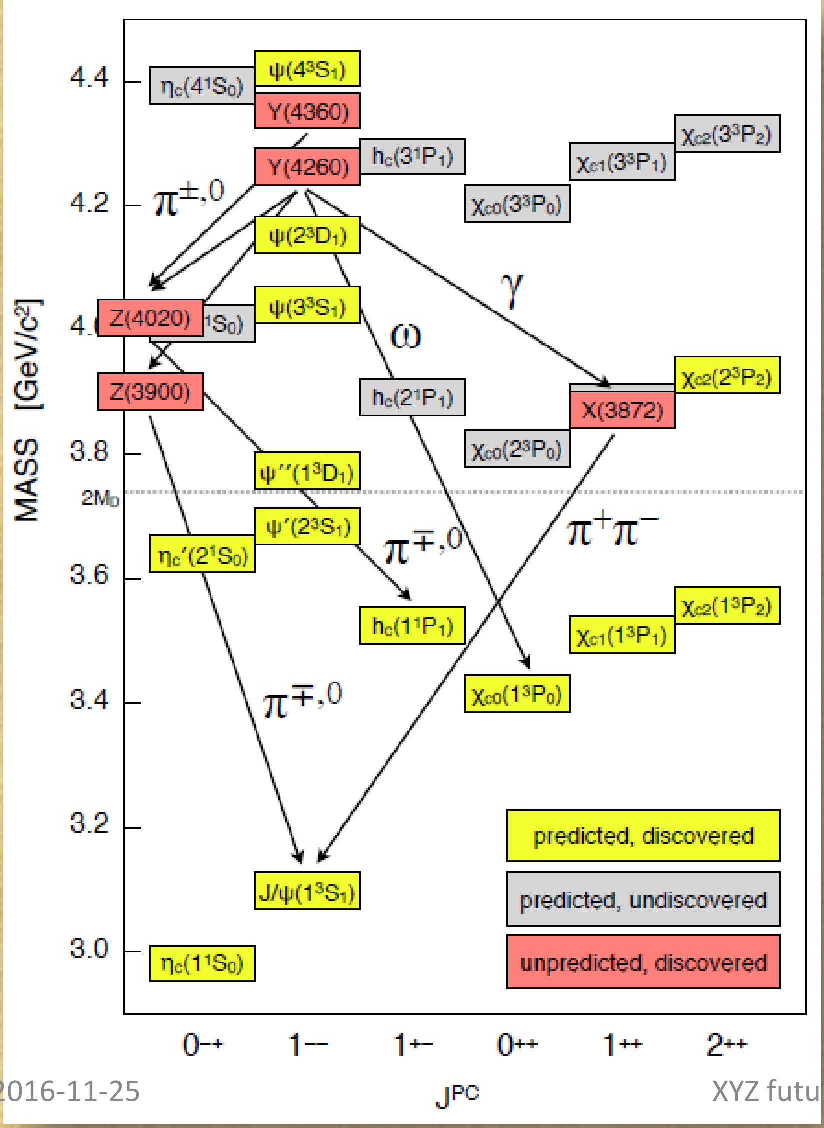
The signal yields corresponding for each mode with the $Z_c^\pm$ assignment $J^P = 1^+$

$\sqrt{s}$	σ	$f_0(980)$	$f_2(1270)$	$f_0(1370)$	$Z_c^+ + Z_c^-$	$\pi^+\pi^- J/\psi$
4.23 GeV	1576.9±431.2	1050.2±157.8	4356.2±549.4	273.2±85.1	875.2±84.8	6.2±7.6
4.26 GeV	1121.5±112.0	465.1 ± 53.2	2236.8±157.6	308.8±108.2	314.2±21.2	15.9±39.3

Our knowledge of XYZ is improved!



Our understanding of XYZ is correct?



- Tetra-quark states
- Cusp effects
- Final states interaction
- Traditional Charmonia
- Hybrids
- Meson molecule
- Coupled channel effect
- Mixing

……

The "Y problem" and the "Z problem"

For XYZ physics, we currently have two problems:

1. The Y Problem:

e^+e^- cross sections as a function of E_{CM} have become increasingly complex *(especially between 4.2 and 4.3 GeV)*.

- Even the Y(4260) no longer looks like a simple peak.
- The $\pi\pi h_c$ cross section is clearly inconsistent with the "Y(4260)".
- Open charm cross sections are even more intriguing.

⇒ We should take a more systematic approach *(and pay special attention to the larger open charm channels)*.

2. The Z Problem:

At 4.23 and 4.26 GeV, we found evidence for the $Z_c(3900)$ and the $Z_c(4020)$, but at 4.42 GeV the Dalitz plots are generally more complex.

- $\pi\pi J/\psi$ shows a new structure at a lower mass (but diagonal in the Dalitz plot)???
- $\pi\pi\psi(2S)$ shows a structure at 4040 (but we can't easily fit it)???

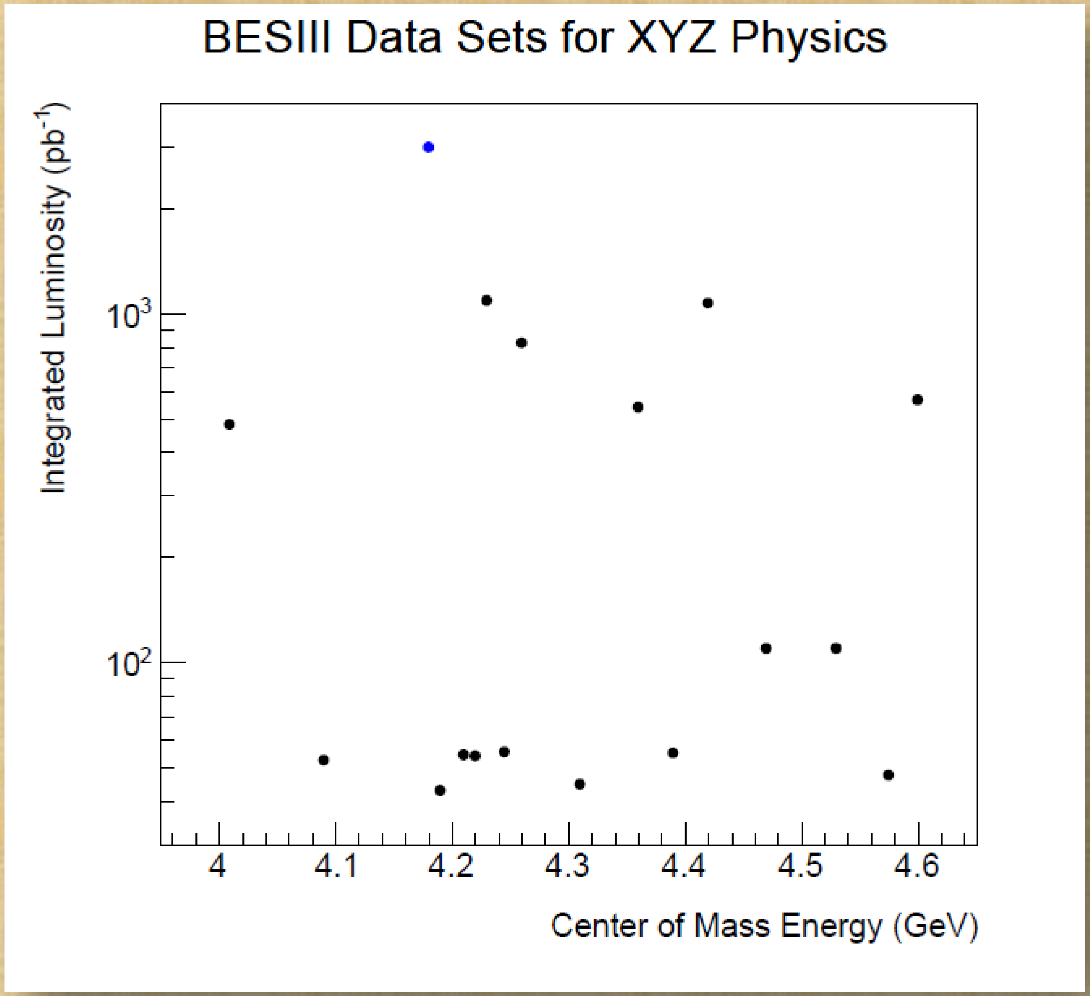
⇒ We need to develop the methodology to handle this *(perhaps with outside help)*. This is not necessarily a problem that statistics alone can solve!

Other puzzles

- One Z_c states or two? Such as $Z_c(3885)$ and $Z_c(3900)$, $Z_c(4020)$ and $Z_c(4025)$.
- Two structures or one around 4.23 GeV?
- The peaks from different channels are from same resonance?
- No light hadron final states involved?
- Why no obvious Z_c signal is observed in some channels as expected? Such as $K^+K^-J/\psi, \pi^+\pi^-\psi'$.
- Is there possible to observe $P_c, Y(4360), Y(4660), Z_c^+(4200), Z_c^+(4430)$, more decay modes of X(3872), Z(3940), etc. at BESIII?
- Which one is physics when there is two solutions?
- ……

We need more data to tackle these puzzles!

Data we already have ~9 fb^{-1}



\+ R-scan data sets

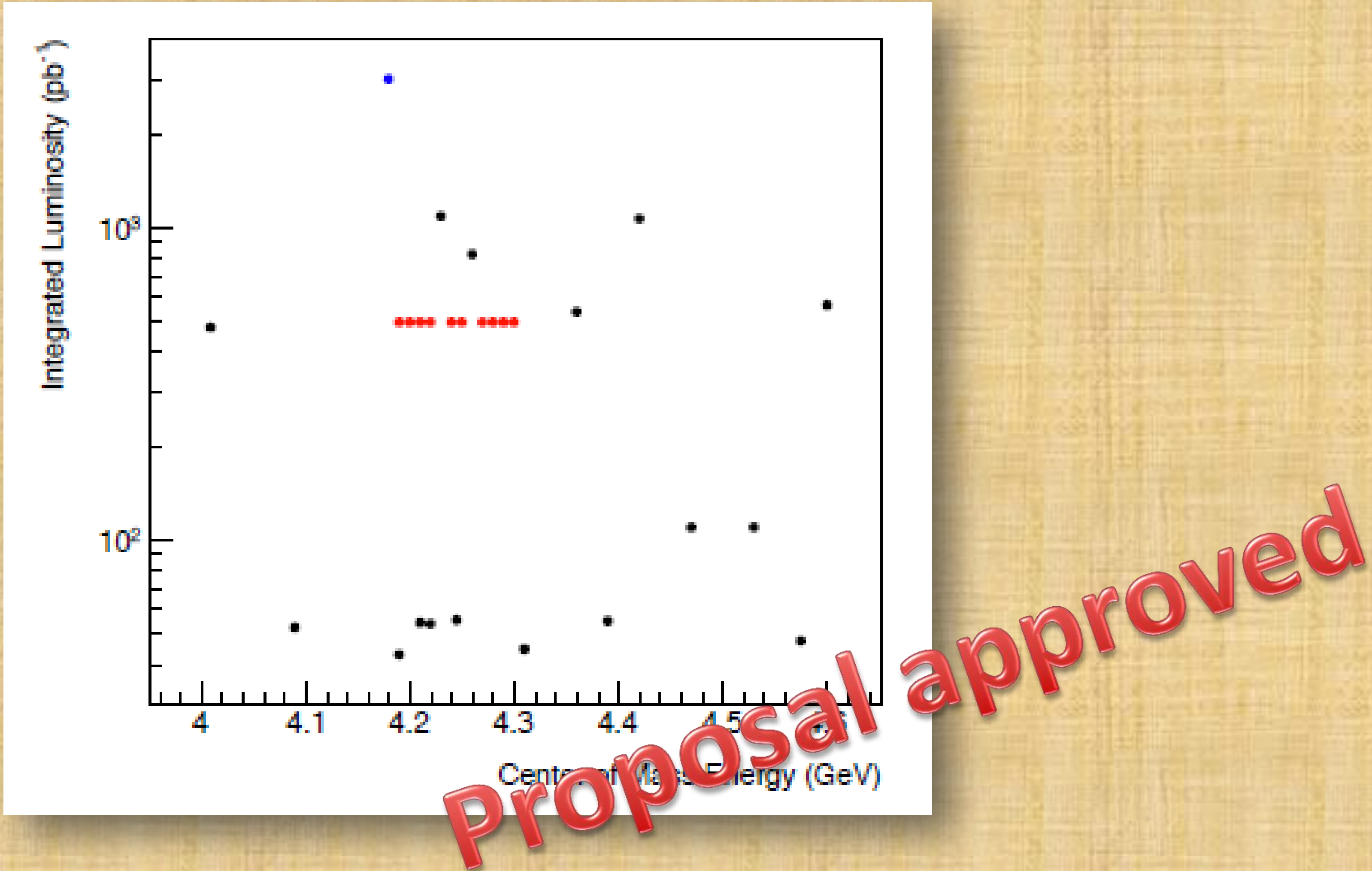
A big plan for XYZ

- 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!

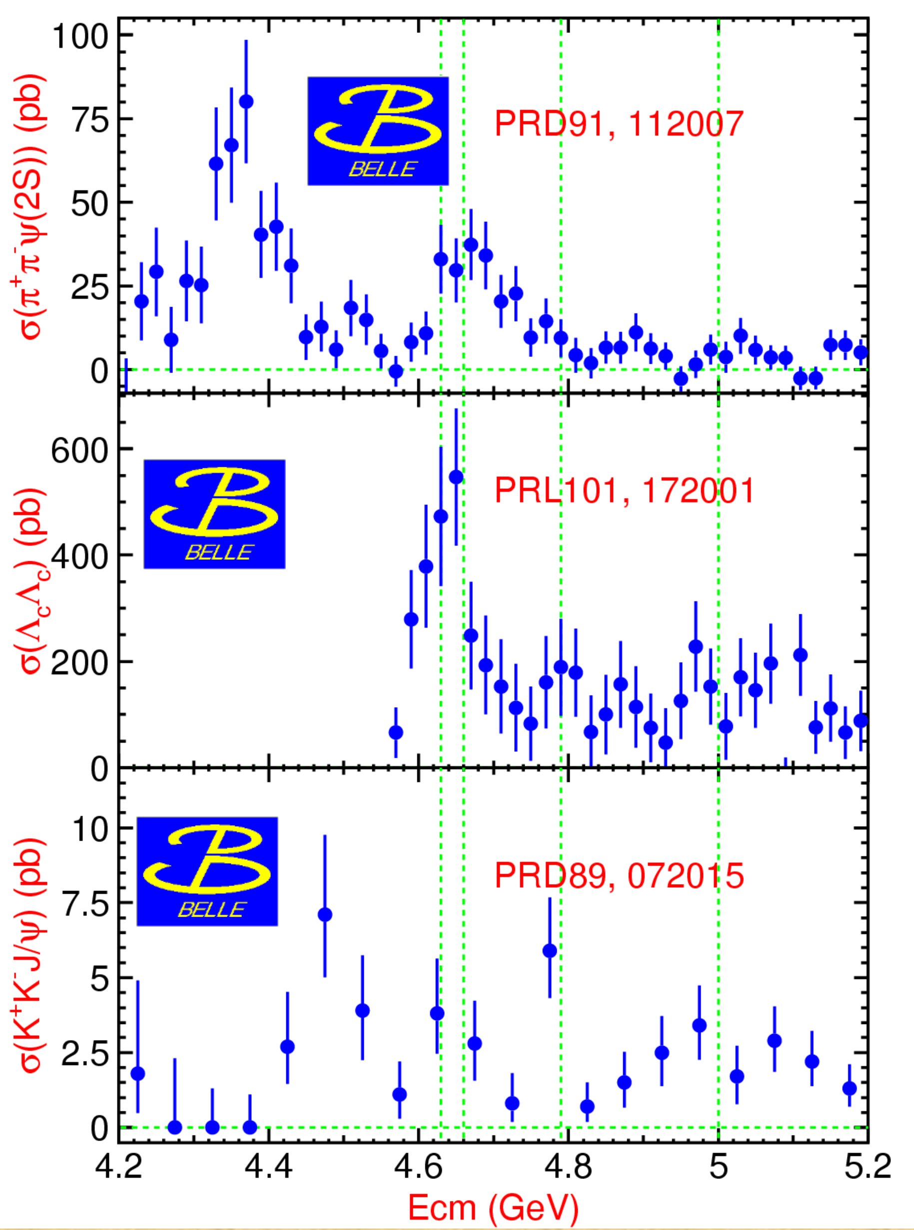
Data will come in 2017



Further plan?

- A few high statistics points (around 4.2, 4.3 4.4 GeV?)
  - Primary focus: further study on Z_c states.
- More high energy data (between 4.5 and 4.6 GeV?)
  - Primary focus: lineshapes, $\Lambda_c\Lambda_c$ threshold, more phase space
- > 4.6 GeV (the present upper energy of BEPCII)?
  - See next slide
- Others (suggestions from theorists?)
  - Specific predictions are extremely welcome.

We need E>4.6 GeV data to study Y&Z states



- On Y states
  - Is Y(4660)=Y(4630)? What are they?
  - Are there other Y/ψ states?
  - Are there states related to charmed-strange meson pairs?
- On Z states
  - Search for Zcs states with data at ~4660 or 4790 MeV
  - Search for Zc from Y(4660) decays
  - Search for Zc(4430)
- Ecm up to 4.8 GeV will be very helpful (full cover Y(4660))!
- It would be great if Ecm can reach 5 GeV!

Status of BESIII & BEPCII

- BESIII detectors
  - Aging as expected (running another 8 years?)
  - New end-cap TOF (better time resolution)
  - Replace inner MDC? CGEM?
  - Software is working on to reduce systematic uncertainties (more and more difficult)
- BEPCII
  - Averaged integrated luminosity @ 4.2 GeV: about 30 pb^{-1} each day
  - Replace west RF cavity in 2017 summer
    - Need time to recover
    - More stable and then higher averaged luminosity after this replacement?
  - Operation above 2.3 GeV. (Applying)

XYZ in the future at BESIII

- With more data (inputs from theorists are important)
  - More or less number of XYZ states.
  - More production and decay modes.
  - Improved precision of mass, width, cross section, etc.
  - Solve or create puzzles?
- Better understanding of these exotic states!

backup

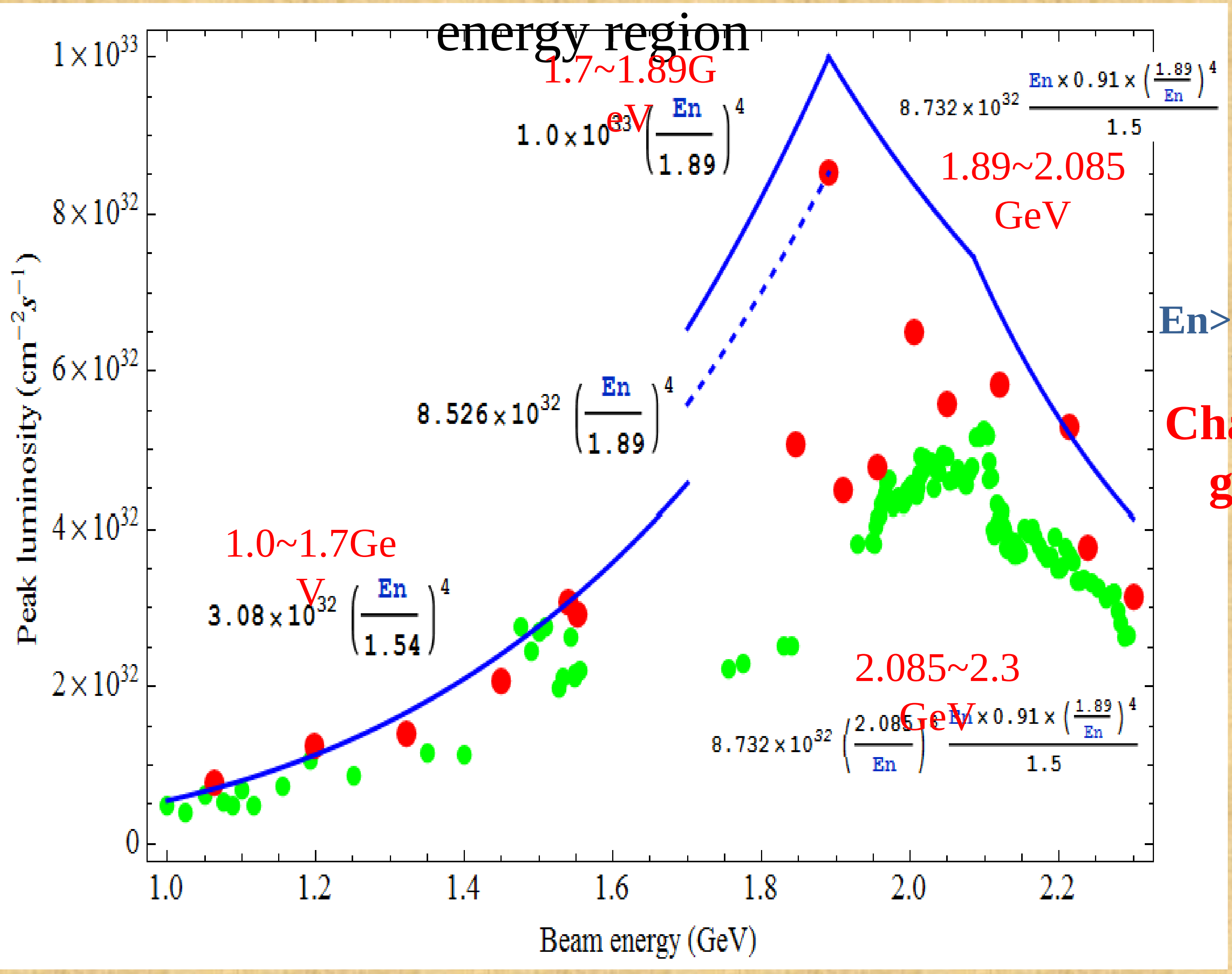
Status of BEPCII

- The online recovery of west RF cavity was successful. ~90% performance was reached below 1.55MV. Long time is needed to recover the performance of west RF cavity. The backup RF cavity is planned to replace it next summer.
- The luminosity will be low in the beginning of this run until the vacuum recovery of BPR.
- Stability studies will be performed during this run.
- Future upgrades

  Operation at the energy above 2.3GeV. (Applying)

  Topup operation during the data taking.

Peak luminosity estimation within different beam energy region



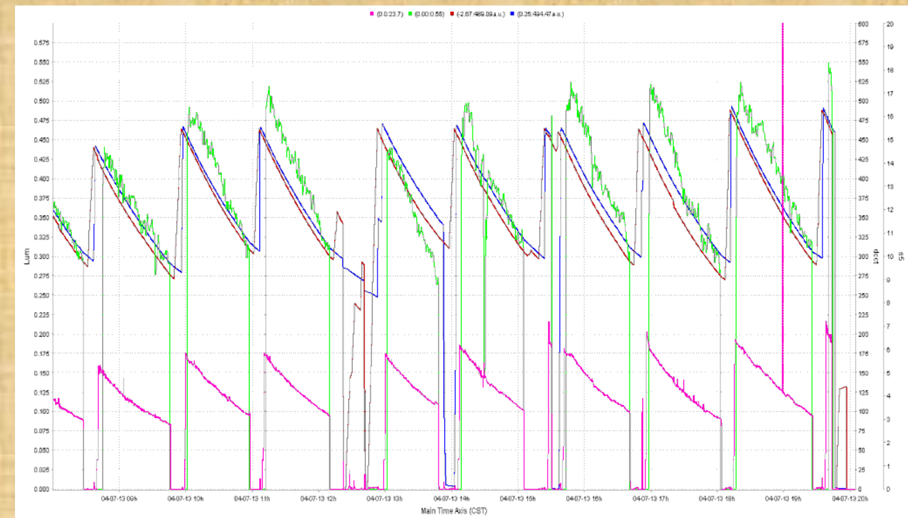
En>1.7GeV

Challenge !

Integral luminosity estimation

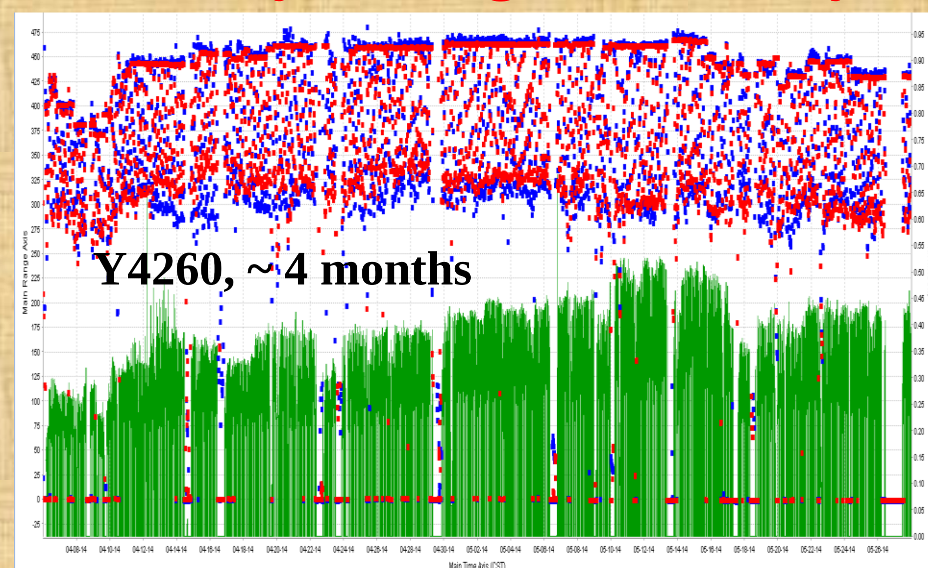
For **each fill** the average luminosity is 2/3 of fill peak luminosity, and there are 20 hours data taking time every day.

$$\text{Max.} \int L/\text{day} = \text{PeakLuminosity} * \frac{2}{3} * (2 * 10 * 60 * 60) * \frac{1}{10^{36}}\ \text{pb}^{-1}$$



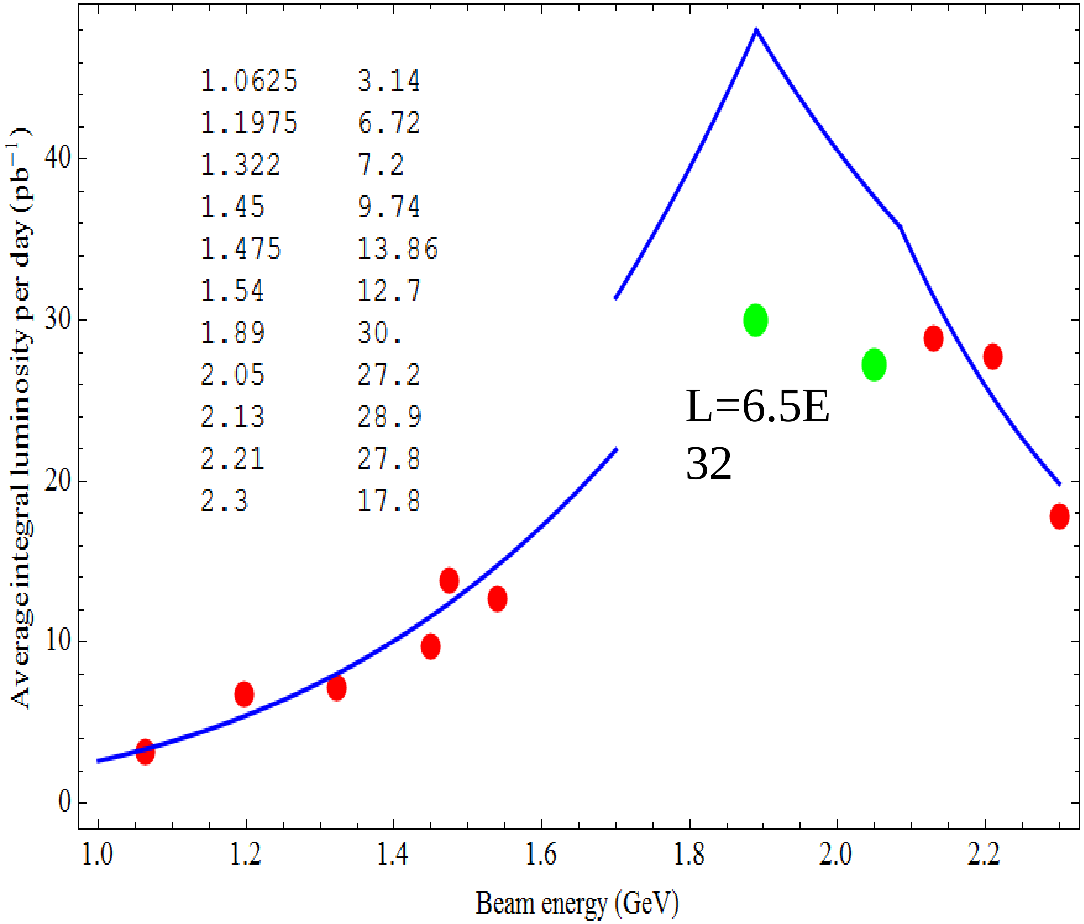
Assume machine efficiency=90%, and **day average luminosity** is 2/3 of the maximum.

$$\text{Ave.} \int L/\text{day} = \text{Max.} \int L/\text{day} * \frac{2}{3} * \frac{90}{100}$$



Peak integral luminosity per day

Energy	Int. luminosity b^{-1})
1.	2.62851
1.05	3.19497
1.1	3.8484
1.15	4.59727
1.2	5.45047
1.25	6.41725
1.3	7.50728
1.35	8.7306
1.4	10.0977
1.45	11.6193
1.5	13.3068
1.55	15.1718
1.6	17.2262
1.65	19.4825
1.7	21.9535
1.7	31.4188
1.715	32.5425
1.73	33.696
1.745	34.8799
1.76	36.0948
1.775	37.3411
1.79	38.6195
1.805	39.9303
1.82	41.2743
1.835	42.6519
1.85	44.0637
1.865	45.5103
1.88	46.9922



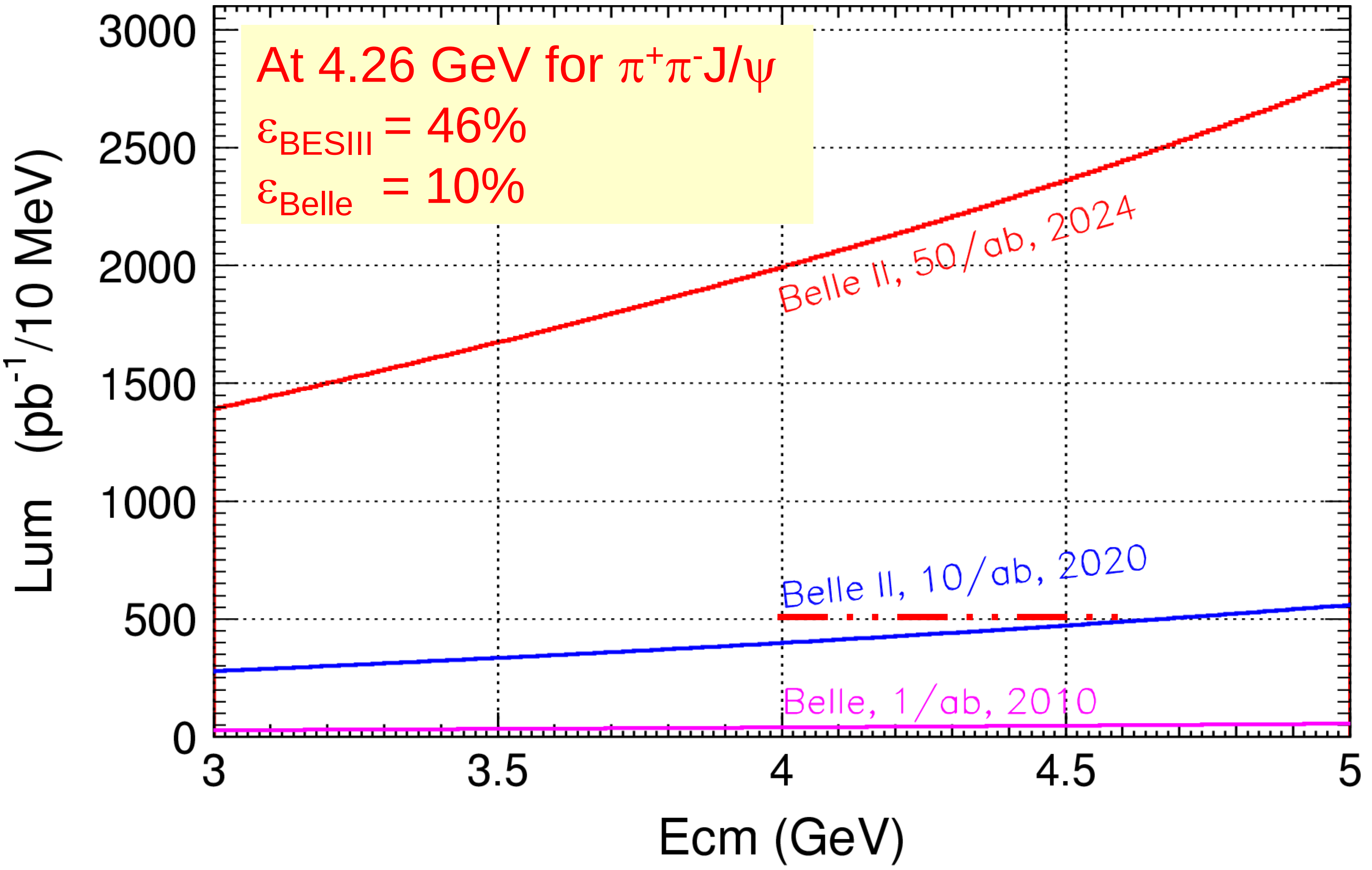
Energy	Int. luminosity $^{-1}$)
1.89	48.0581
1.905	46.9318
1.92	45.8404
1.935	44.7826
1.95	43.7571
1.965	42.7627
1.98	41.7981
1.995	40.8624
2.01	39.9544
2.025	39.073
2.04	38.2175
2.055	37.3867
2.07	36.5798
2.085	35.796
2.1	34.289
2.115	32.8555
2.13	31.4915
2.145	30.193
2.16	28.9566
2.175	27.7789
2.19	26.6567
2.205	25.587
2.22	24.567
2.235	23.5942
2.25	22.666
2.265	21.7802
2.28	20.9344
2.295	20.1268

Estimation and realization

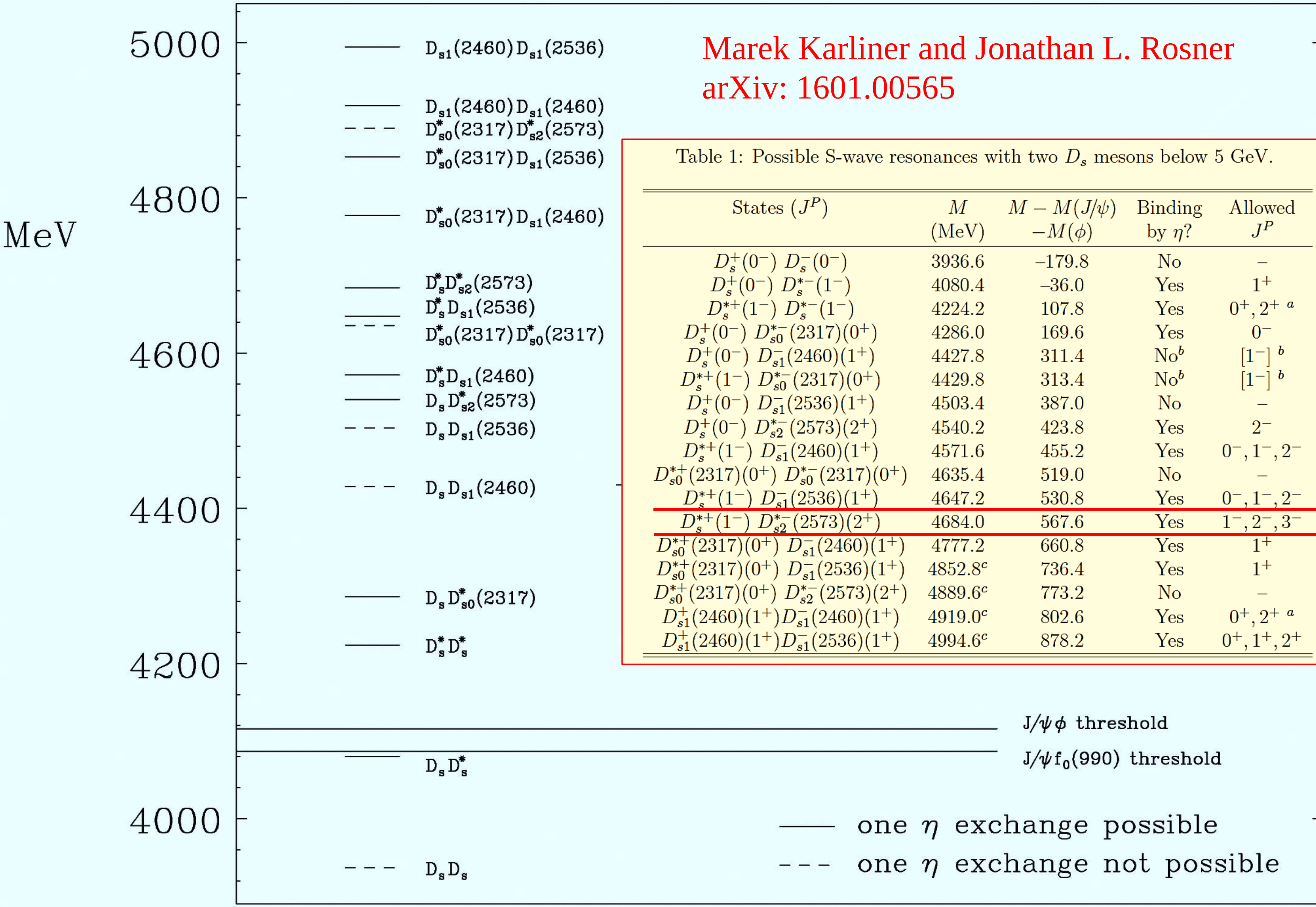
Red: After optics upgrade, **Green**: Before optics upgrade

ISR at Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach



Thresholds involving two D_s mesons



Marek Karliner and Jonathan L. Rosner
arXiv: 1601.00565

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	$0^+, 1^+, 2^+$