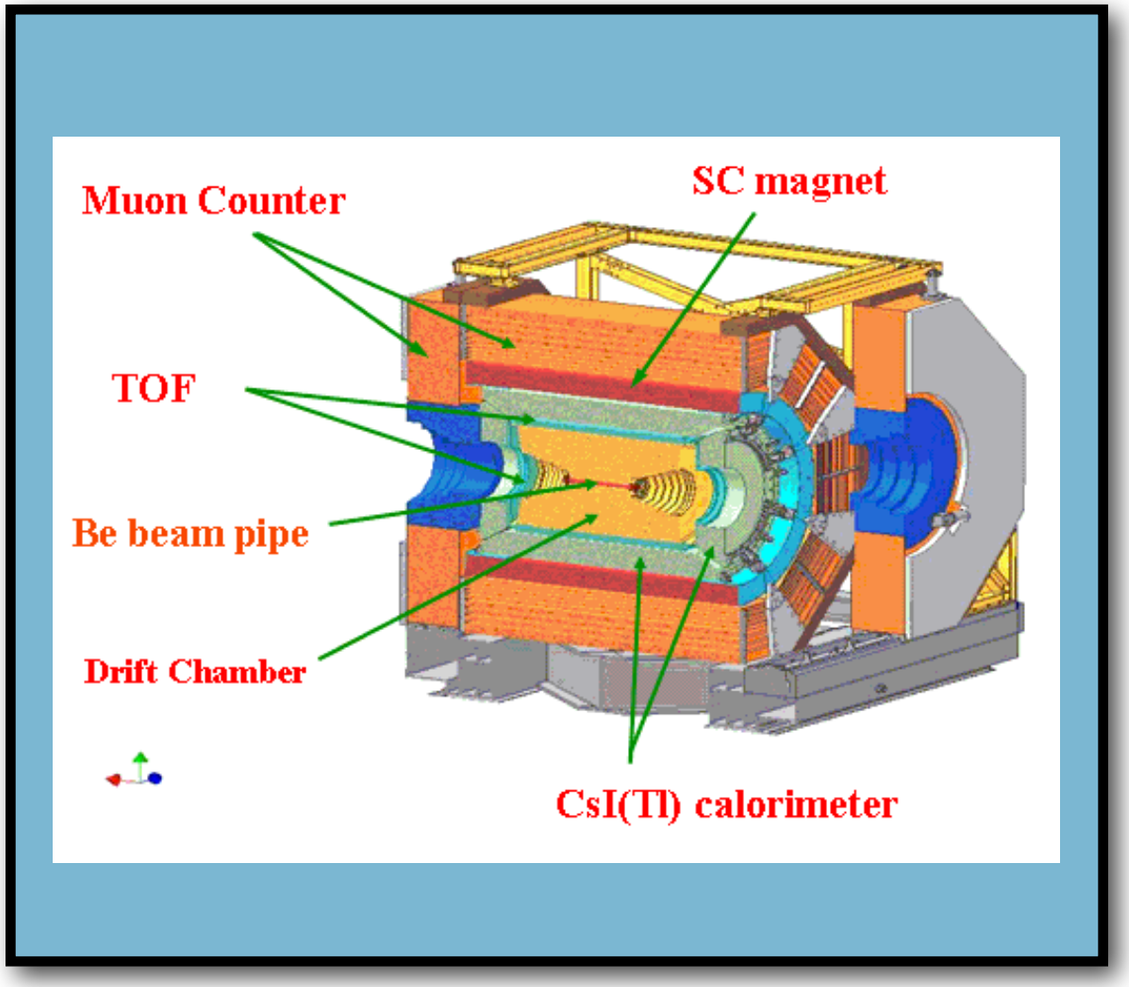
Spectroscopy at the BESIII Experiment

Ryan Mitchell
Indiana University

BEPCII: Beijing Electron Positron Collider
symmetric e^+e^-collisions at E_{CM} between 2.0 and 4.7 GeV

BESIII: Beijing Spectrometer
a versatile detector covering 93% of 4π



running since 2009 at the Institute of High Energy Physics in Beijing, China

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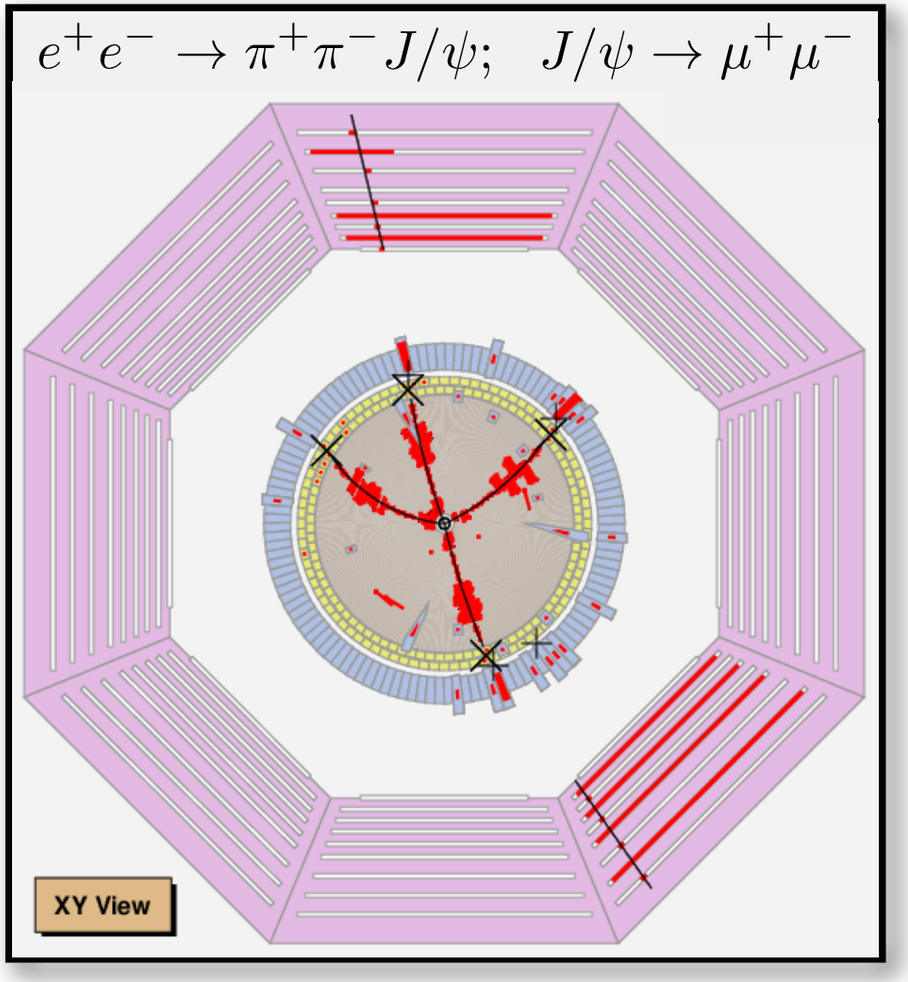

running since 2009 at the Institute of High Energy Physics in Beijing, China

BESIII Collaboration Statistics

PHYSICAL REVIEW LETTERS **124,** 242001 (2020)

Study of Open-Charm Decays and Radiative Transitions of the $X(3872)$

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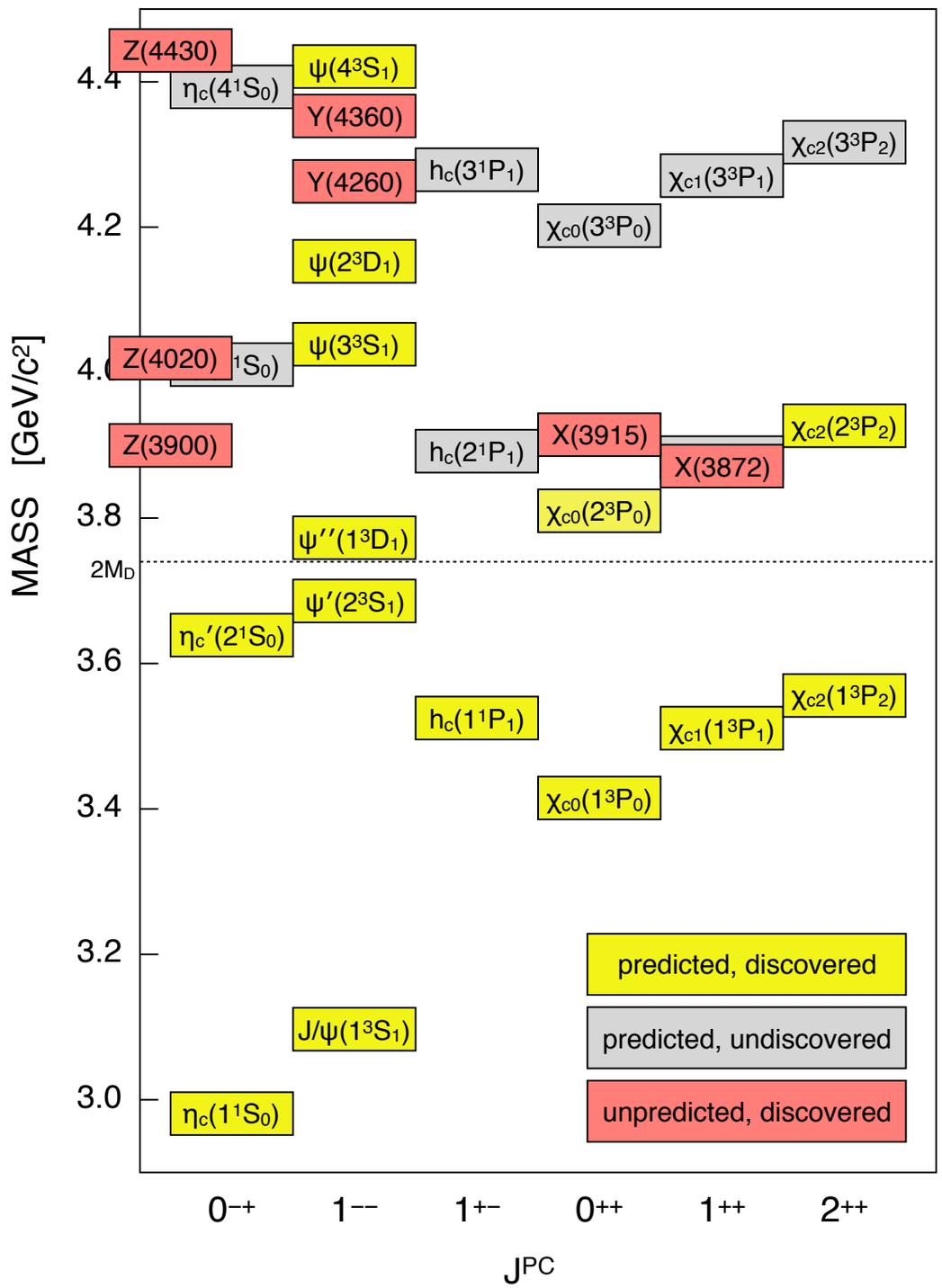
Primary Data Sets at BESIII

Charmonium Spectrum

predictions based on PRD 72, 054026 (2005)
measurements from PDG



BESIII Data Sets (primary):

(e^+e^- collisions at E_{CM} between 2.0 and 4.7 GeV)

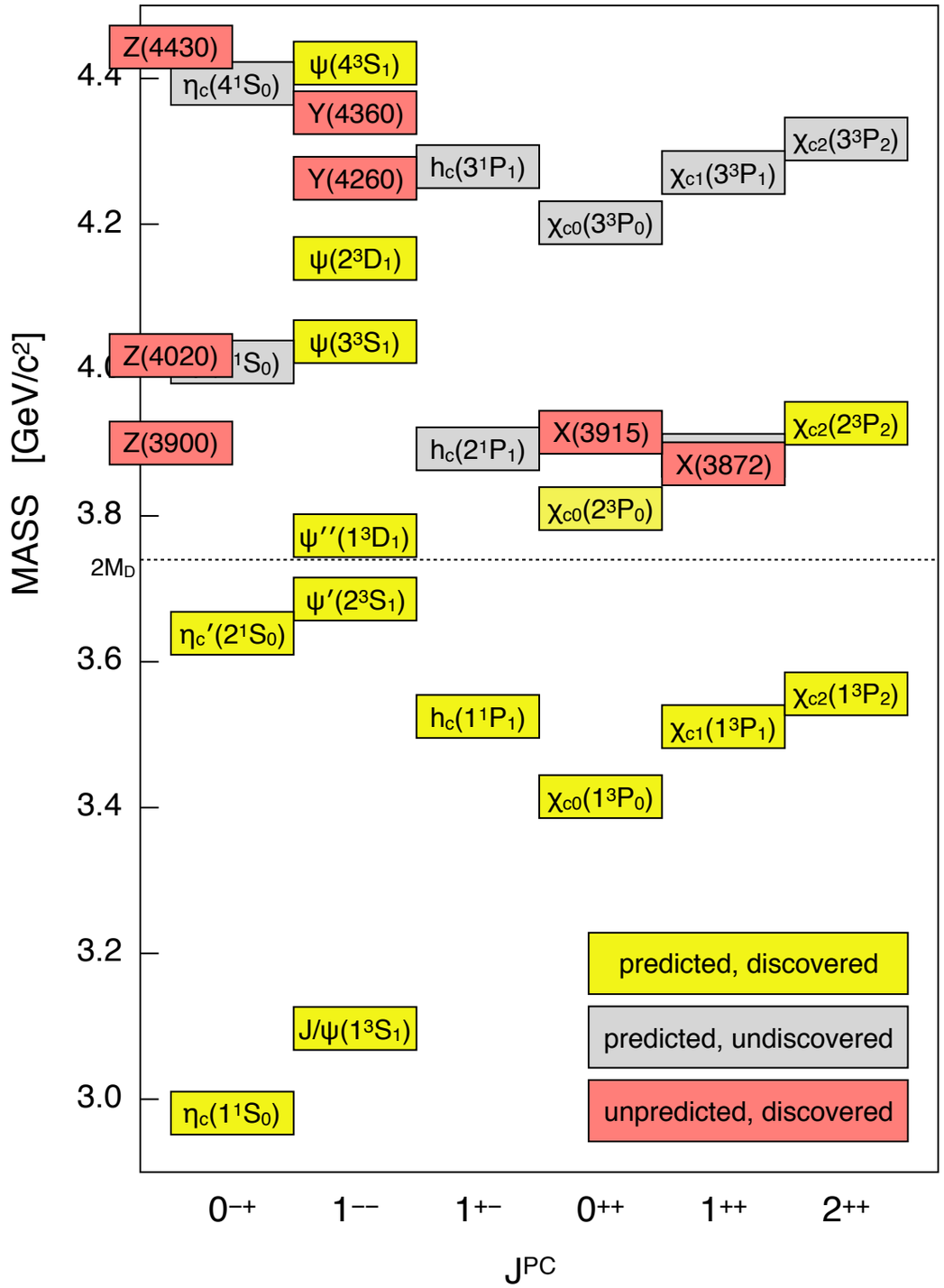
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10 × 50 pb^{-1} scan 3.81 — 4.42 GeV
2014: 1029 pb^{-1} at 4.42 GeV
110 pb^{-1} at 4.47 GeV
110 pb^{-1} at 4.53 GeV
48 pb^{-1} at 4.575 GeV
567 pb^{-1} at 4.6 GeV
0.8 fb^{-1} R-scan 3.85 — 4.59 GeV
2015: R-scan 2 — 3 GeV + 2.175 GeV
2016: ~3fb^{-1} at 4.18 GeV (for D_s)
2017: 7 × 500 pb^{-1} scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
8 × 500 pb^{-1} scan 4.13, 4.16, 4.29 — 4.44 GeV
2020: 5 × 500 pb^{-1} scan 4.63 — 4.70 GeV *(+ extra)*

Many topics!
spectroscopy
(light and heavy),
flavor physics,
new physics,
R scans,
τ physics, etc.

Primary Data Sets at BESIII

Charmonium Spectrum

predictions based on PRD 72, 054026 (2005)
measurements from PDG



Primary Data for Spectroscopy:

Light Quark Spectroscopy

10 billion J/ψ

Precision Charmonium Physics

450 million $\psi(2S)$

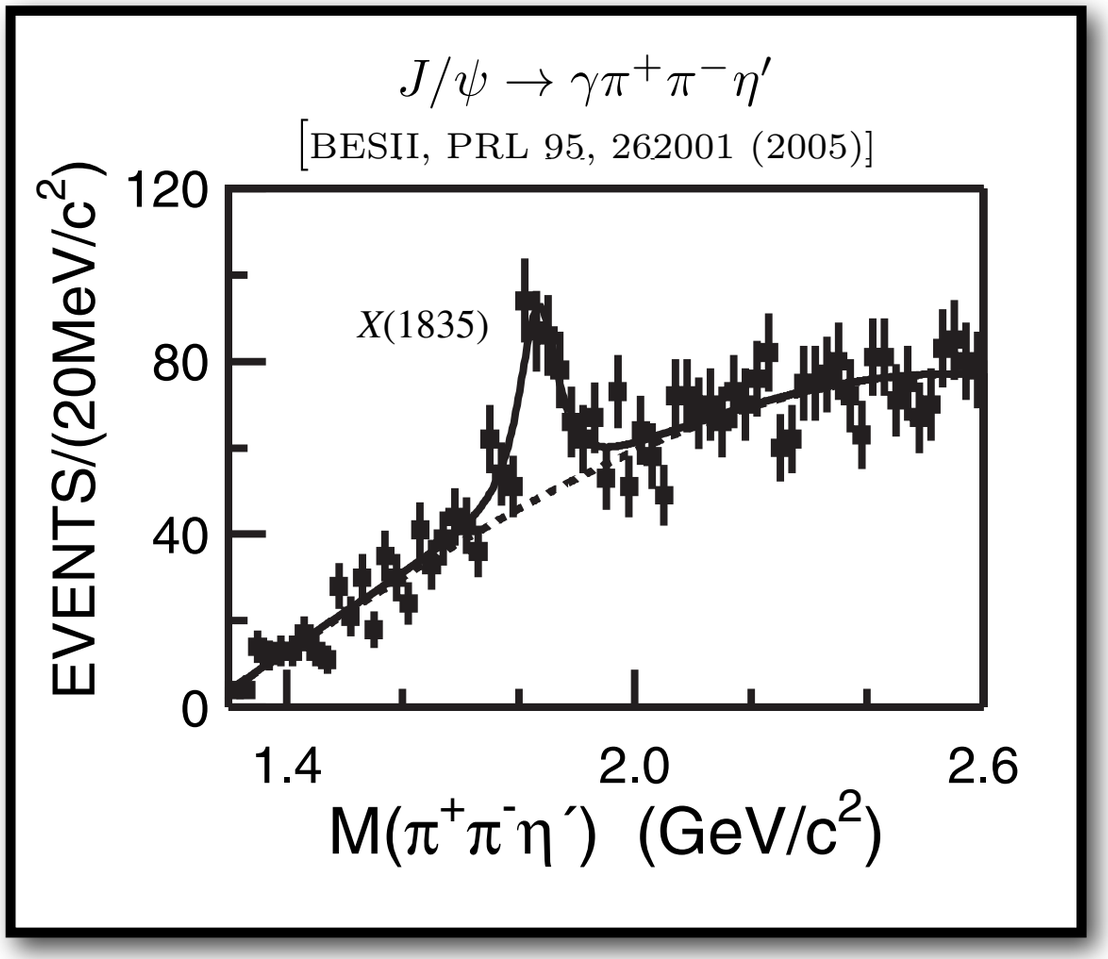
Charmonium (XYZ) Spectroscopy

$\geq 500\ \mathrm{pb}^{-1}$ at 27 points
between 4.0 and 4.7 GeV

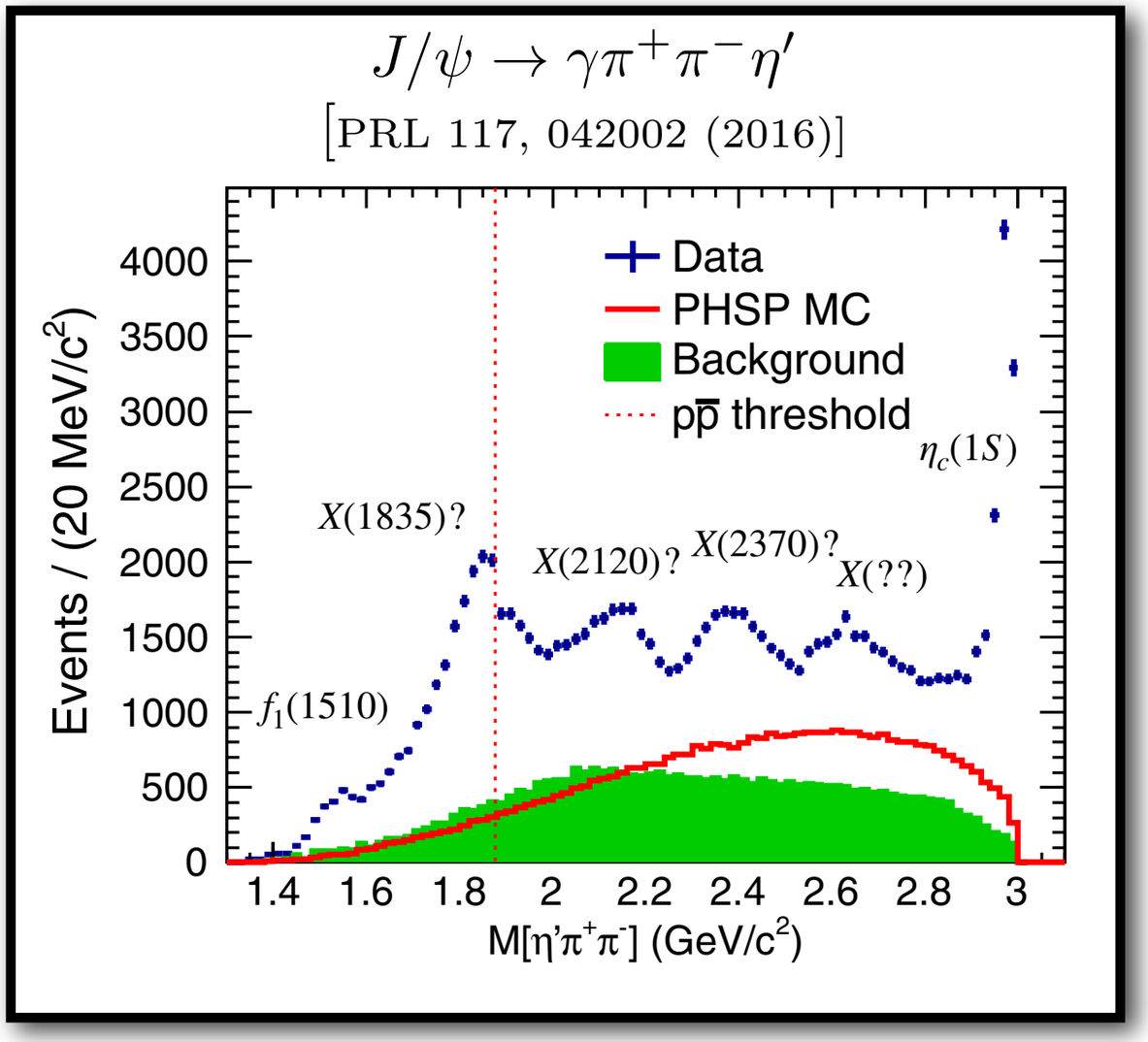
Light Quark Spectroscopy

Hundreds of light quark channels are produced in J/ψ hadronic and radiative decays.

From BESII *(with 58M J/ψ decays)…*



To BESIII *(with 1.1B J/ψ decays)…*

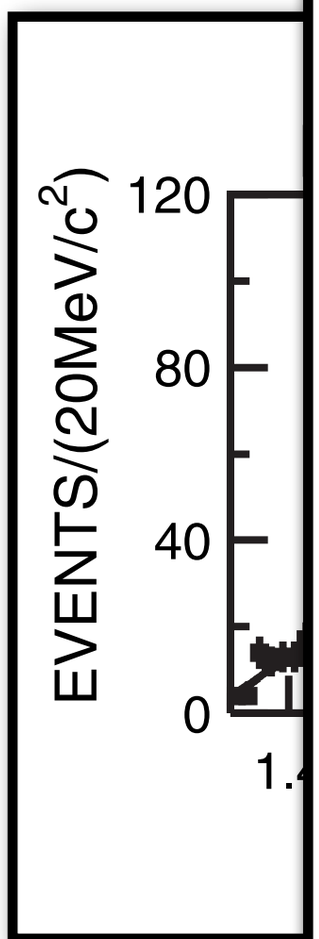


And now to 10B J/ψ decays! A "legacy" data set.

Light Quark Spectroscopy

Hundreds of light quark channels are produced in J/ψ hadronic and radiative decays.

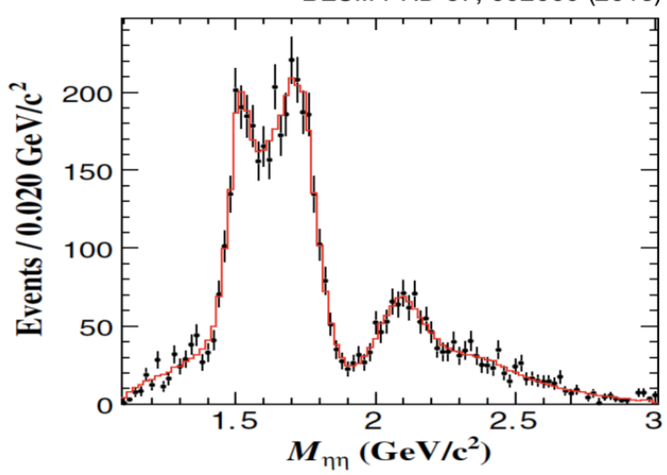
From BES



Progress in searches for glueballs (from Beijiang's talk 9/30):

Amplitude analysis of $J/\psi \to \gamma\eta\eta/K_S^0K_S^0$

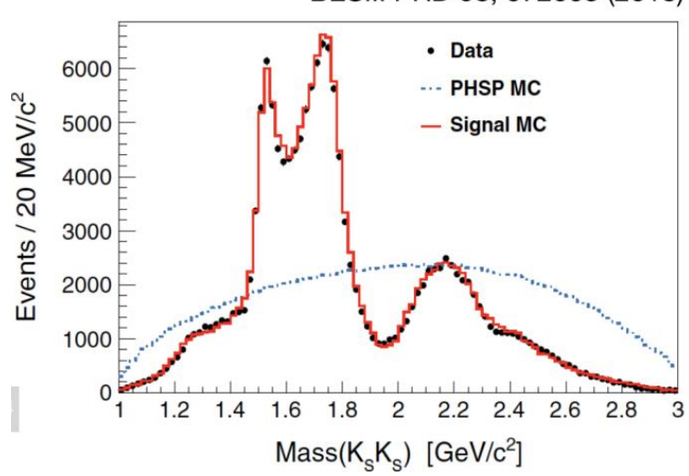
BESIII PRD 87, 092009 (2013)



Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+[illegible]}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

Br of $f_0(1710)$ ~10x larger than $f_0(1500)$

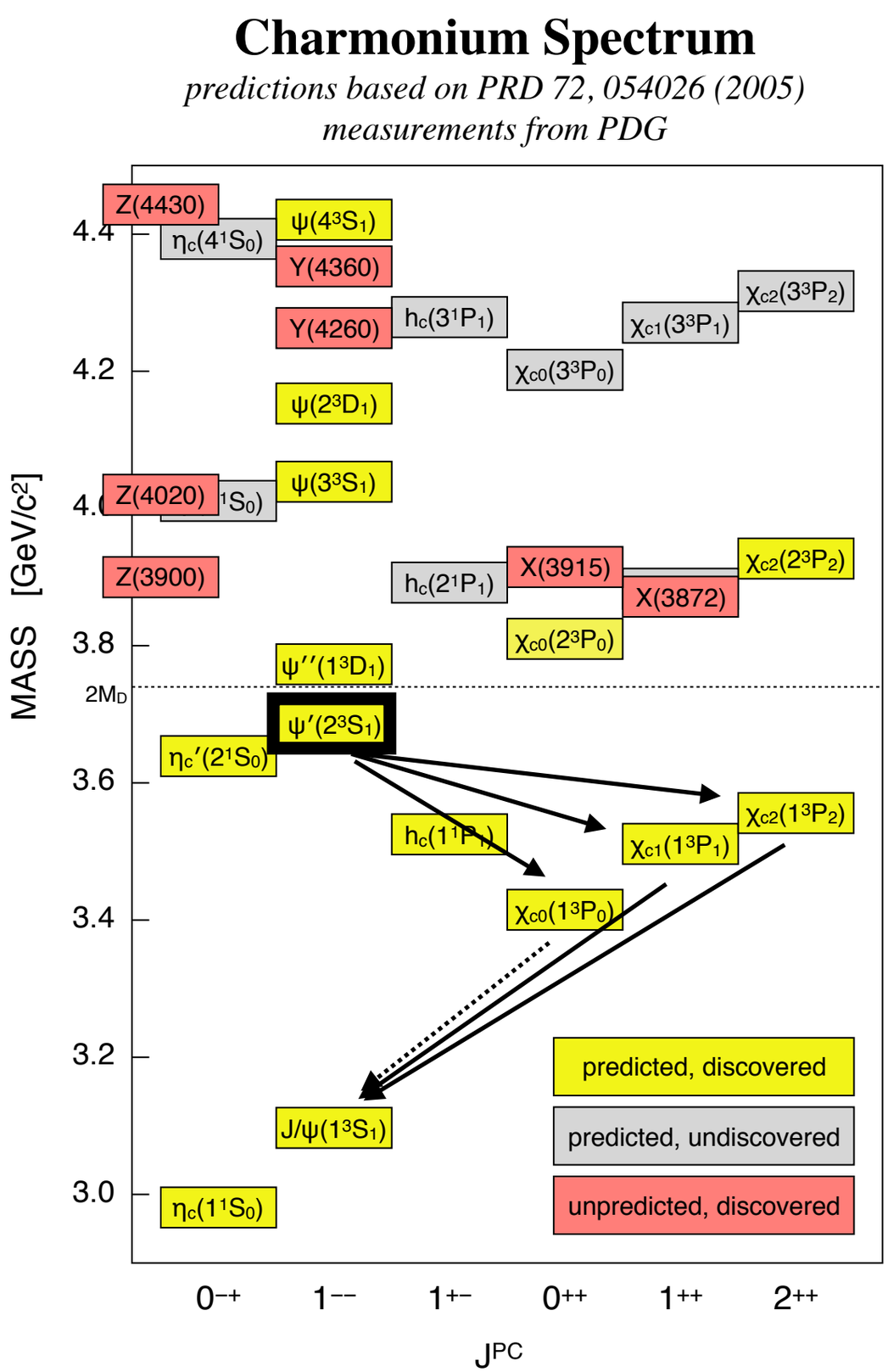
BESIII PRD 98, 072003 (2018)



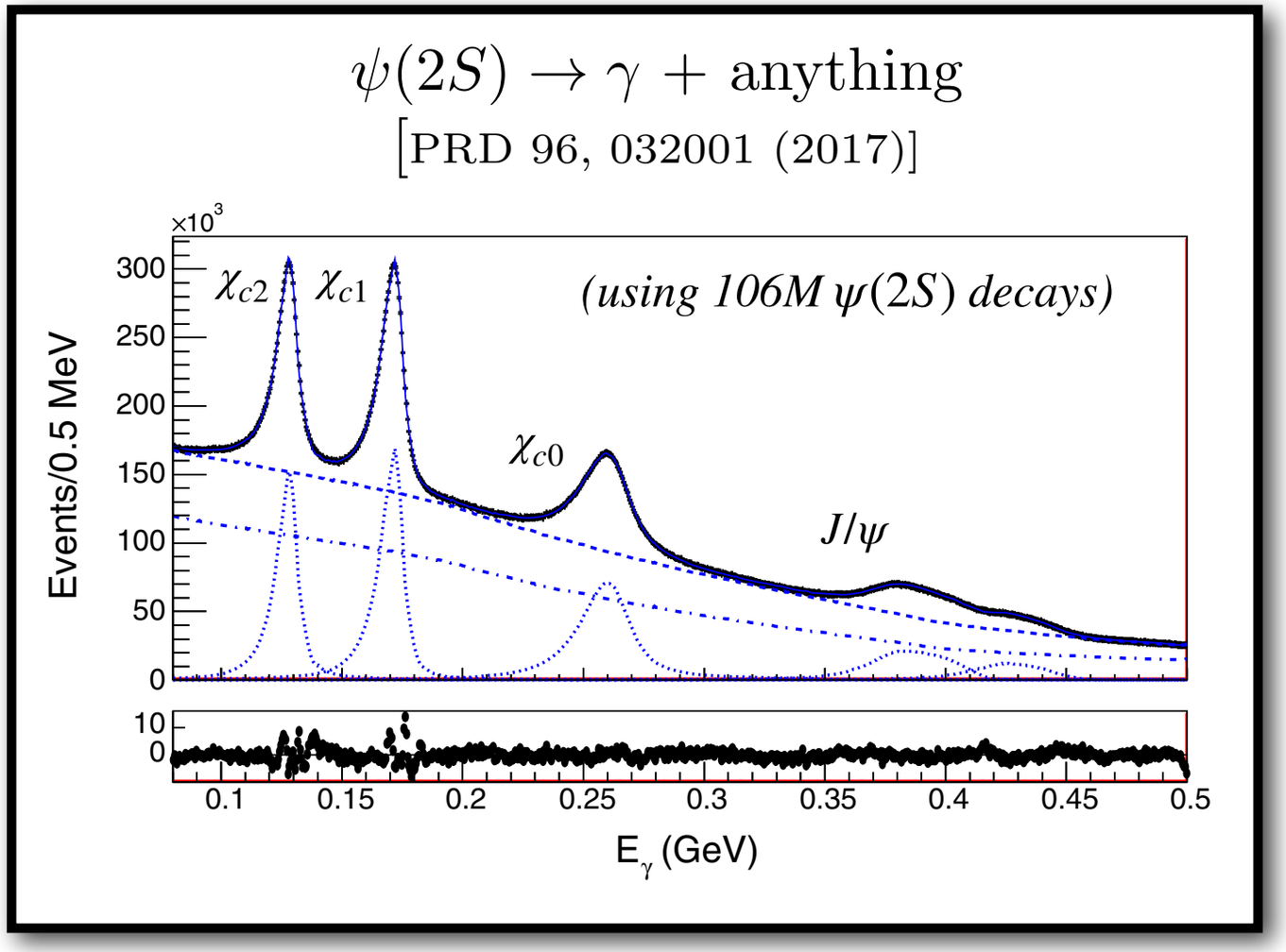
Resonance	M (MeV/c^2)	M_{PDG} (MeV/c^2)	Γ (MeV/c^2)	Γ_{PDG} (MeV/c^2)	Branching fraction	Significance
$K^*(892)$	896	895.81 ± 0.19	48	47.4 ± 0.6	$(6.28^{+0.16+0.59}_{-0.17-0.52}) \times 10^{-6}$	35σ
$K_1(1270)$	1272	1272 ± 7	90	90 ± 20	$(8.54^{+1.07+2.35}_{-1.20-2.13}) \times 10^{-7}$	16σ
$f_0(1370)$	$1350 \pm 9^{+12}_{-2}$	1200 to 1500	$231 \pm 21^{+28}_{-48}$	200 to 500	$(1.07^{+0.08+0.36}_{-0.07-0.34}) \times 10^{-5}$	25σ
$f_0(1500)$	1505	1504 ± 6	109	109 ± 7	$(1.59^{+0.16+0.18}_{-0.16-0.56}) \times 10^{-5}$	23σ
$f_0(1710)$	$1765 \pm 2^{+1}_{-1}$	1723^{+6}_{-5}	$146 \pm 3^{+7}_{-1}$	139 ± 8	$(2.00^{+0.03+0.31}_{-0.02-0.10}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(1790)$	$1870 \pm 7^{+2}_{-3}$	...	$146 \pm 14^{+7}_{-15}$	...	$(1.11^{+[illegible]}_{-0.06-0.32}) \times 10^{-5}$	24σ
$f_0(2200)$	$2184 \pm 5^{+4}_{-2}$	2189 ± 13	$364 \pm 9^{+4}_{-7}$	238 ± 50	$(2.72^{+0.08+0.17}_{-0.06-0.47}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(2330)$	$2411 \pm 10 \pm 7$	...	$349 \pm 18^{+23}_{-1}$	...	$(4.95^{+0.21+0.66}_{-0.21-0.72}) \times 10^{-5}$	35σ
$f_2(1270)$	1275	1275.5 ± 0.8	185	$186.7^{+2.2}_{-2.5}$	$(2.58^{+0.08+0.59}_{-0.09-0.20}) \times 10^{-5}$	33σ
$f_2'(1525)$	1516 ± 1	1525 ± 5	$75 \pm 1 \pm 1$	73^{+6}_{-5}	$(7.99^{+0.03+0.69}_{-0.04-0.50}) \times 10^{-5}$	$\gg 35\sigma$
$f_2(2340)$	$2233 \pm 34^{+9}_{-25}$	2345^{+50}_{-40}	$507 \pm 37^{+18}_{-21}$	322^{+70}_{-60}	$(5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$	26σ
0^{++} PHSP	...	...	...	...	$(1.85^{+0.05+0.68}_{-0.05-0.26}) \times 10^{-5}$	26σ
2^{++} PHSP	...	...	...	...	$(5.73^{+0.99+4.18}_{-1.00-3.74}) \times 10^{-5}$	13σ

And now to 10B J/ψ decays! A "legacy" data set.

Precision Charmonium Physics



The $\psi(2S)$ provides easy access to the $\eta_c(1S,2S)$, J/ψ, $h_c(1P)$, and $\chi_{cJ}(1P)$ charmonium states.



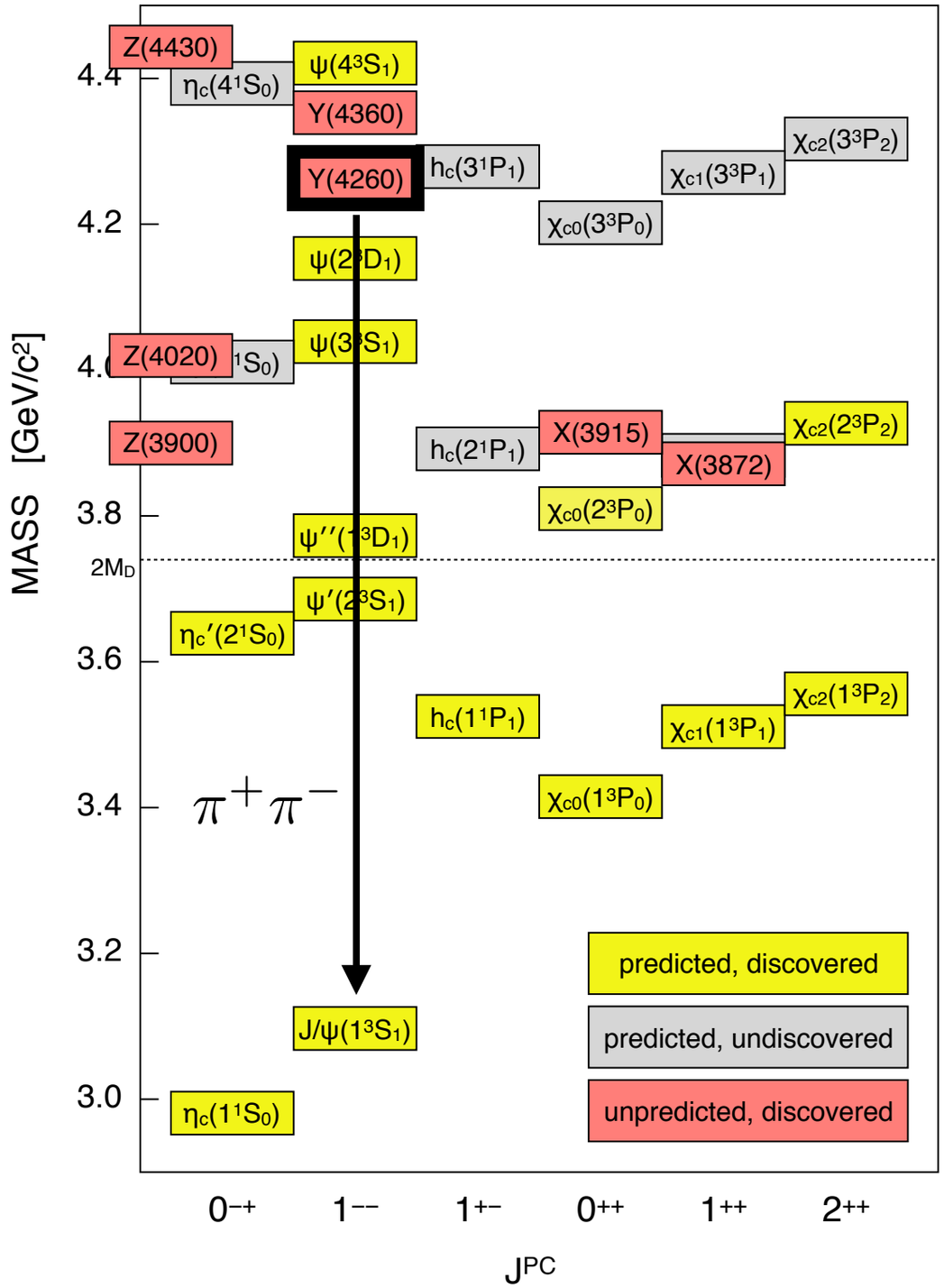
Expect 3-5B $\psi(2S)$ decays within the next several years.

precision transitions (radiative and hadronic),
precision decays, rare decays
→ tests of effective field theories (like NRQCD), etc.

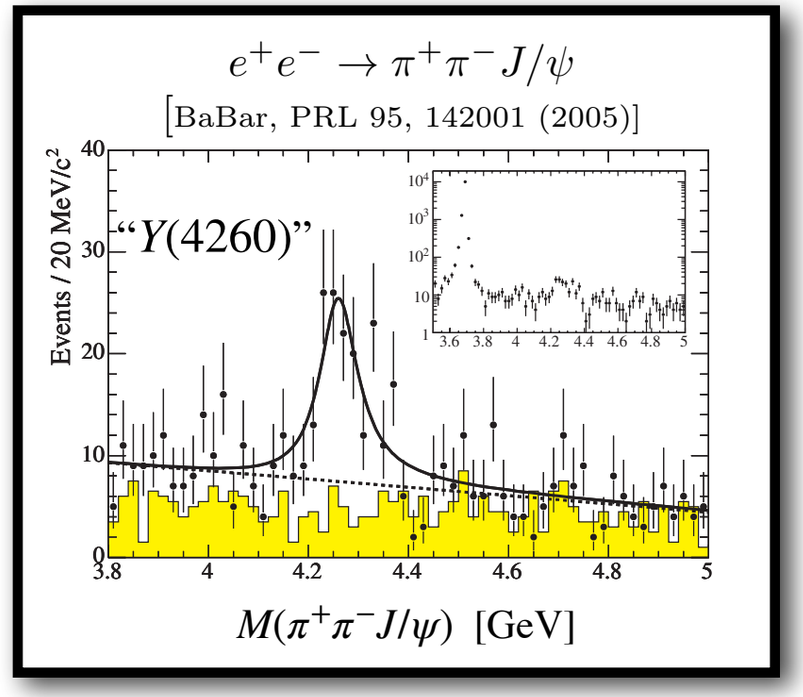
Charmonium Spectroscopy: Y States

Charmonium Spectrum

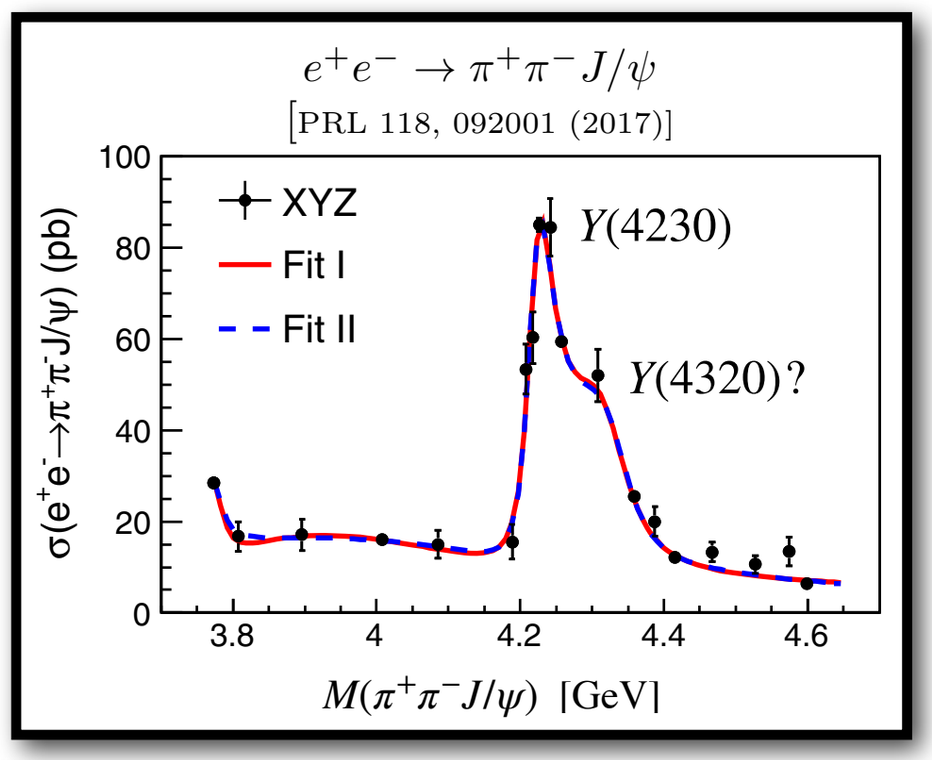
predictions based on PRD 72, 054026 (2005)
measurements from PDG



Charmonium vector states can be produced directly and scanned in e^+e^- annihilation.



Discovery of the "Y(4260)" by BaBar using ISR
measure a wide range of energies imprecisely



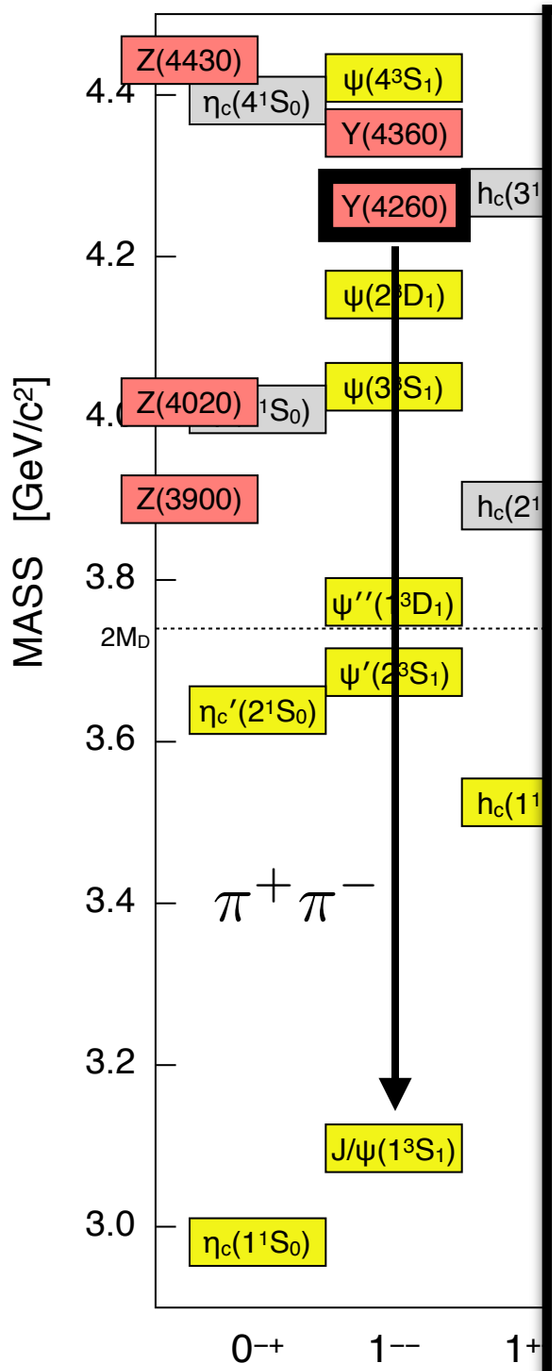
Discovery of Fine Structure at BESIII
measure narrow ranges of energy precisely

Charmonium Spectroscopy: Y States

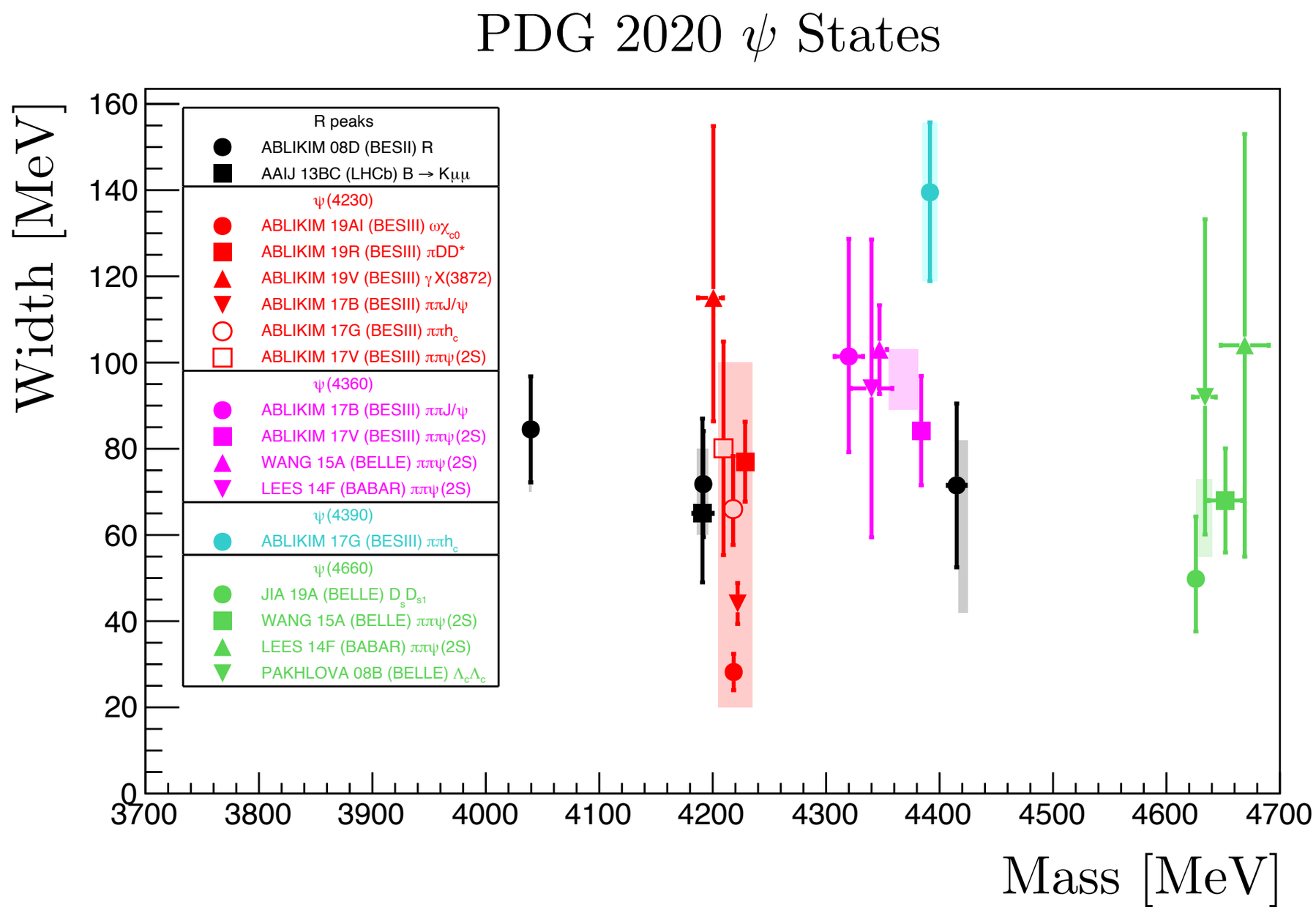
Charmonium vector states can be produced directly and scanned in e^+e^- annihilation.

Charmonium Spectrum

predictions based on PRD 72, 054026 (2005)
measurements from PDG



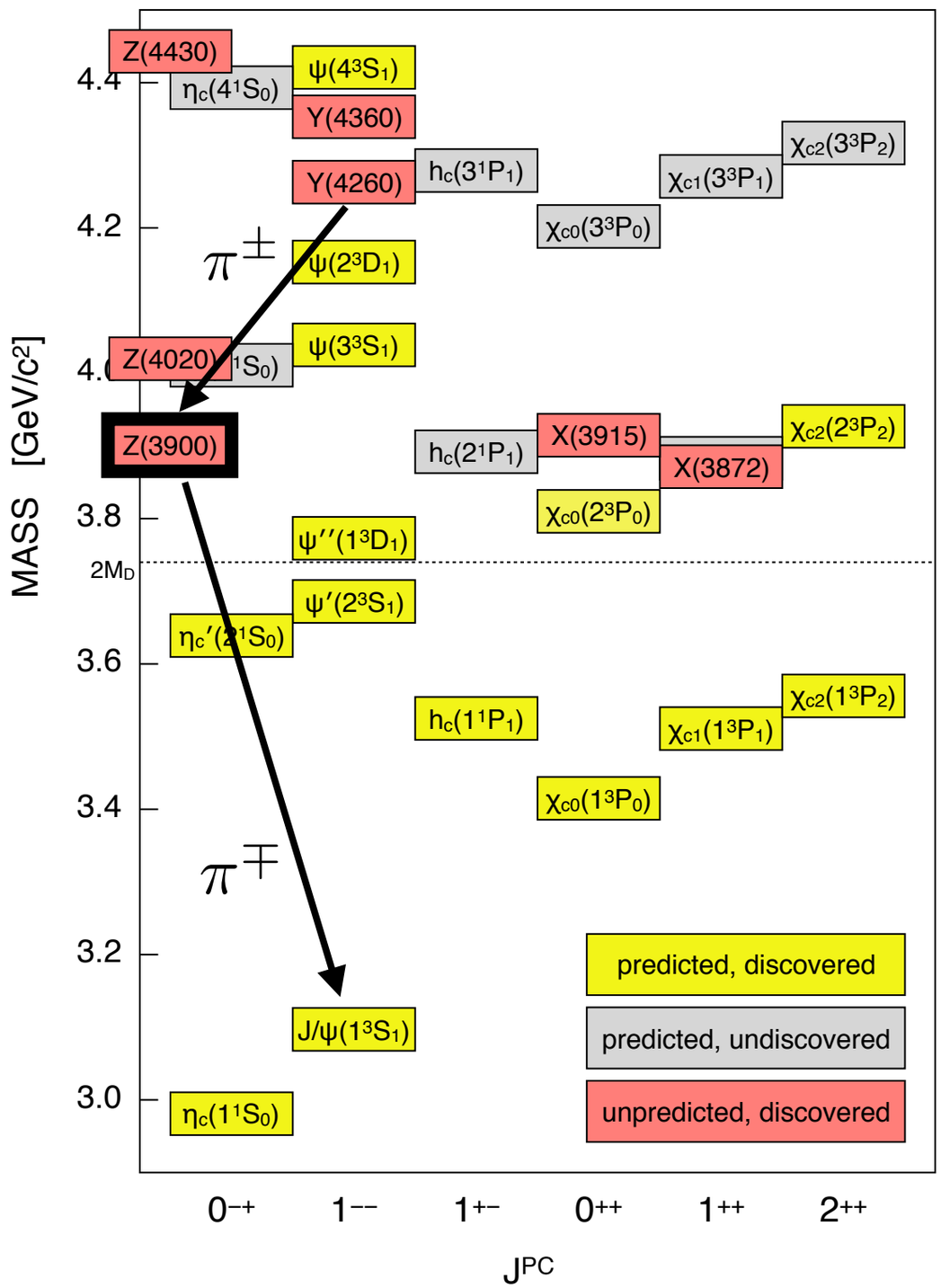
BESIII is now the major contributor in studies of the Y states.



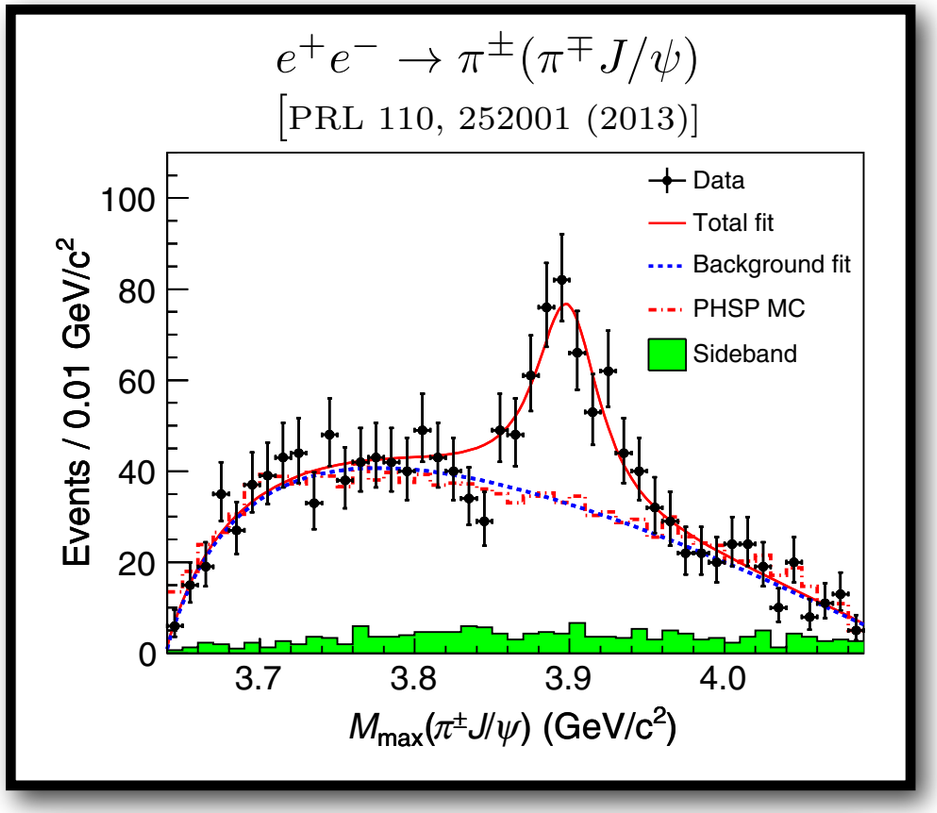
Charmonium Spectroscopy: Z States

Charmonium Spectrum

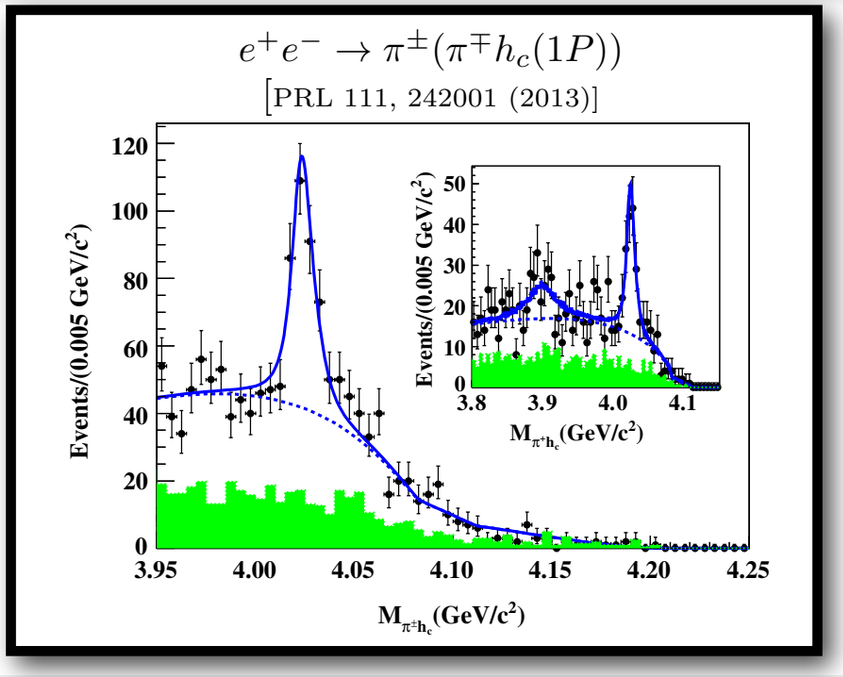
predictions based on PRD 72, 054026 (2005)
measurements from PDG



Decays of the Y states show evidence for electrically charged structures near open charm thresholds.

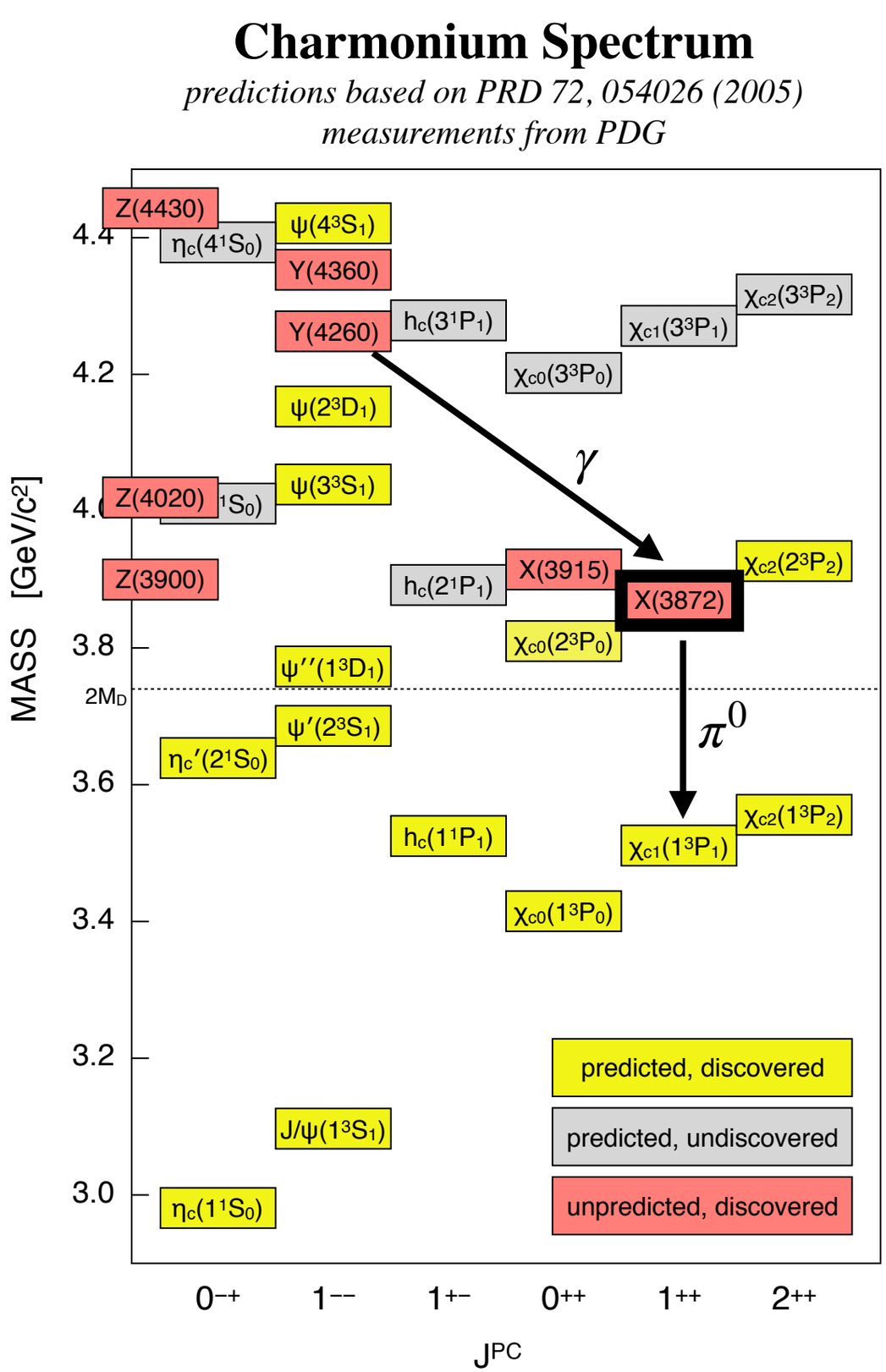


The $Z_c(3900)$ is near the $D\overline{D}^*$ threshold.

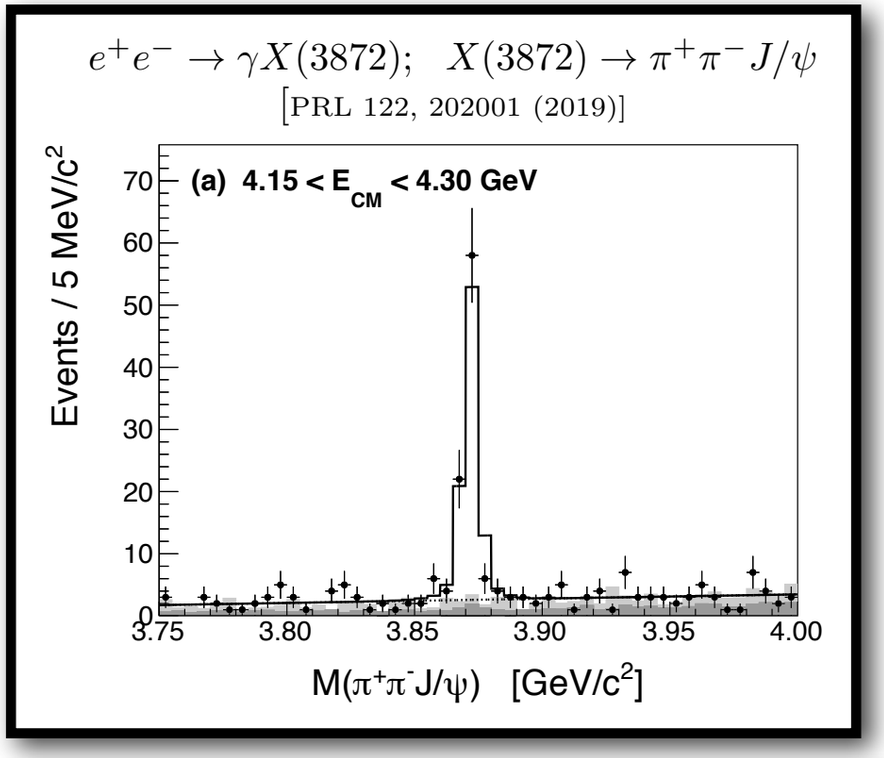


The $Z_c(4020)$ is near the $D^*\overline{D}^*$ threshold.

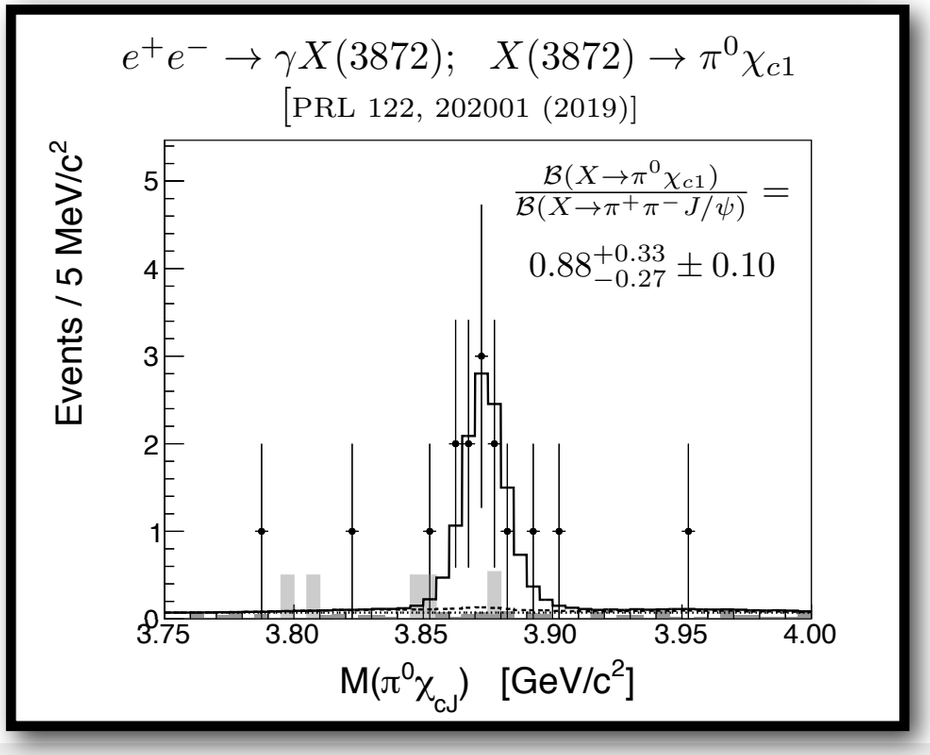
Charmonium Spectroscopy: X States



Radiative transitions from the Y states provide access to X states.



Establish the $X(3872)$ is produced in radiative transitions.



Then search for new $X(3872)$ decay modes.

The Future

The BESIII Experiment:

* is still extremely active — 61 publications in 2019! (https://inspirehep.net/literature/1770442)
* maximum energy will be upgraded from 4.7 to 4.9 GeV *(this summer)*
* a proposal exists for a 3× luminosity upgrade to BEPCII *(timing and funding is uncertain)*
* no official end date *(unofficial end date is 5-10 years from now)*

Super tau-charm factories

are being discussed in China (USTC) and Russia (BINP):

* a recent joint workshop on the two proposals: https://mosphys.ru/indico/event/3/overview
* luminosity expected to be $0.5 - 1.0 \times 10^{35}$ (50 -100× BEPCII)
* CDRs have been developed
* R&D is funded and active
* timeline would be ~10 years to physics, depending on funding

(concept drawing for a tau-charm factory in Hefei, China)

Tau-charm factories offer clean and complimentary environments to study both light and heavy quark spectroscopy, as well as a diverse array of other topics (flavor physics, new physics, etc.)!

Notes on BESIII Spectroscopy at Snowmass

1) Physics part relevant to RF7 and ideas behind your LoI

BESIII has substantial physics efforts in:

I. Light Quark Spectroscopy: 10 billion J/ψ decays are a legacy sample

II. Charmonium Physics: 500 million $\psi(2S)$ decays will be increased to 3-5 billion

III. XYZ Spectroscopy: unique E_{cm} offers opportunities to scan e^+e^- energies

2) What will you work on between now and Snowmass Summer Study meeting in July 2021, and your rough schedule for developing a white paper
3) Any joint efforts (collaborative or in parallel) that would amplify the success of your proposal

We hope to work together with other groups, from both experiment and theory, to take a critical look at the ***future directions of hadron spectroscopy***.

We don't (at least now) have plans to develop a dedicated BESIII white paper on spectroscopy. [A recent BESIII white paper on future directions is here: https://inspirehep.net/literature/1770442]

4) From the point of view of your proposal, what would you like to come out of the Snowmass process

We would like to help ***raise the profile of hadron spectroscopy in HEP*** *(and raise the profile of BESIII as one of the major contributors to the field)*.