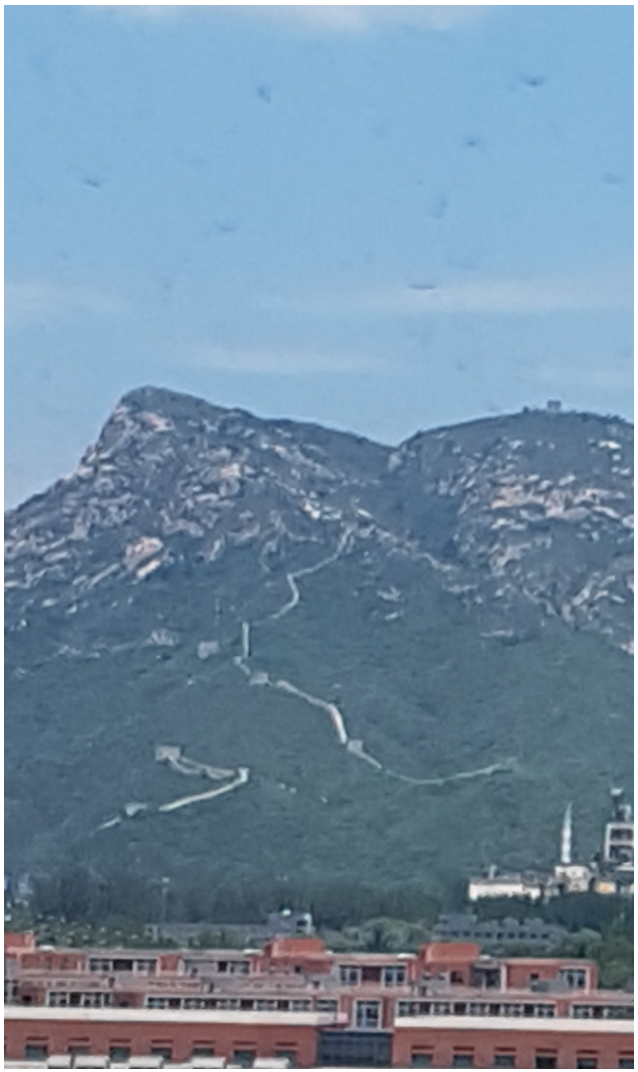
Opportunities for XYZ Physics at HIEPA



Stephen Lars Olsen UCAS

HIEPA2018 Huairou CHINA, Mar 19-21,2018

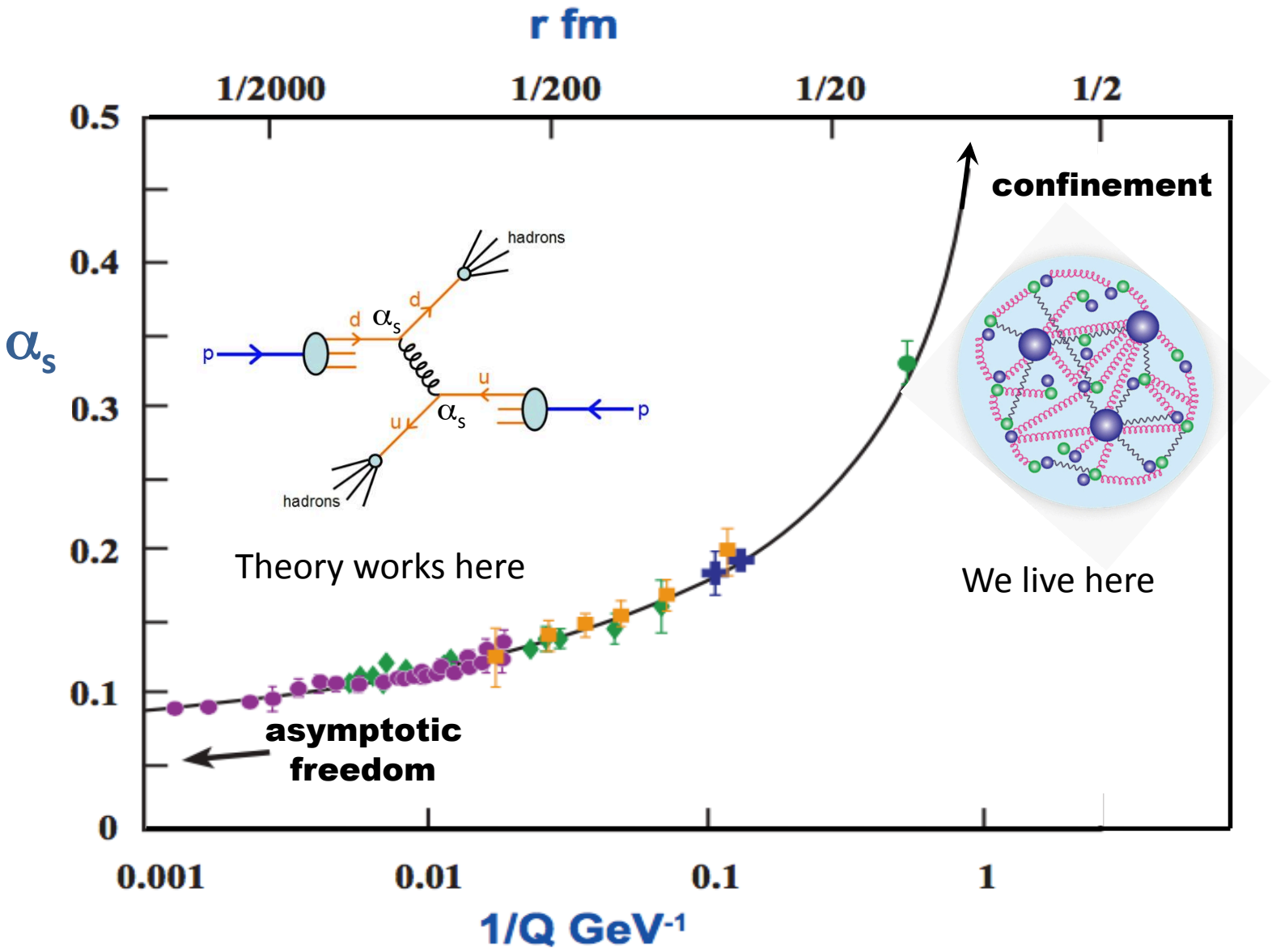
Disclaimer

Physics at *BES-III*

Editors
Kuang-Ta Chao and Yifang Wang

In 2008 we published an 814 page book that listed the physics opportunities at at BESIII, which we estimated would take 10 years. Now, 10 years later, we still have a 10-year-long list of physics to explore, but most of these were never mentioned in book and the consequences of unexpected discoveries we made and surprises we encountered during BESIII's 1st 10 years.

The QCD “dilemma”

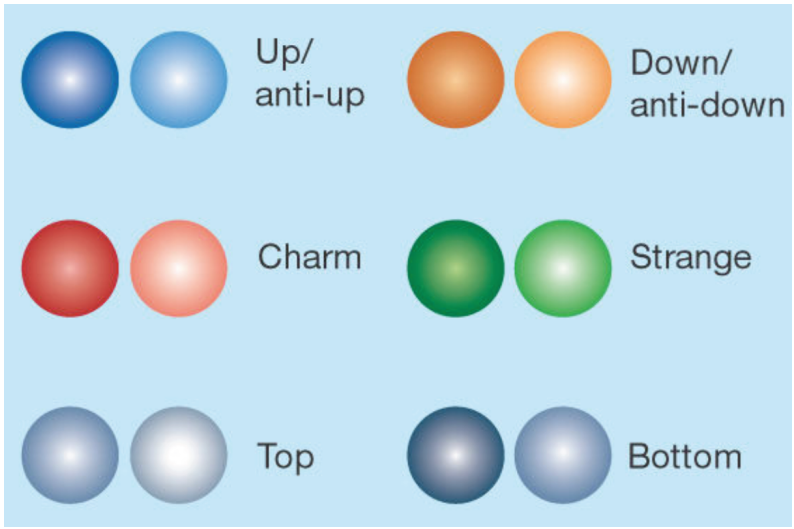


“psychological” problem

-- theory is divorced from reality --

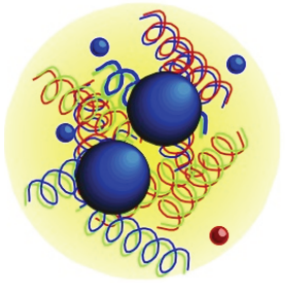
strongly interacting particles of the Standard Model

quarks



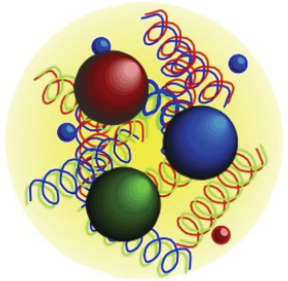
gluons

strongly interacting particles in Nature



mesons

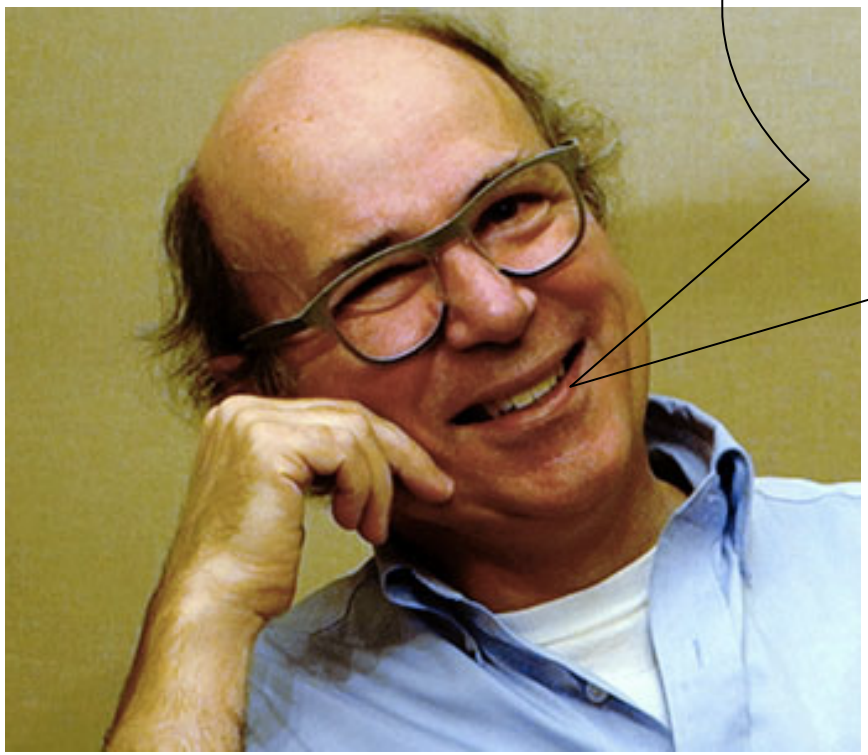
no useful 1st-principle relation connects these



baryons

Frank Wilczek (on long-distance QCD)

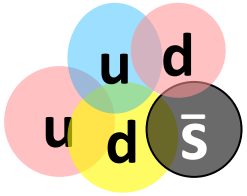
https://www.edge.org/conversation/frank_wilczek-power-over-nature



We have something called a standard model, but its foundations are kind of scandalous. We have not known how to define an important part of it mathematically rigorously,…

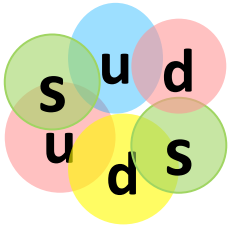
In the absence of rigorous QCD sol'ns 'QCD-motivated' models are used

QCD-motivated models differ in their predictions of non $q\bar{q}$ (qqq) shadons

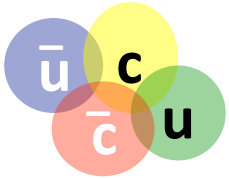


pentaquarks

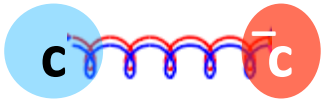
glueballs



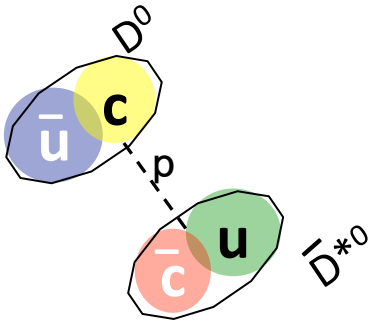
H-dibaryon



diquark-diantiquarks



hybrids



molecules

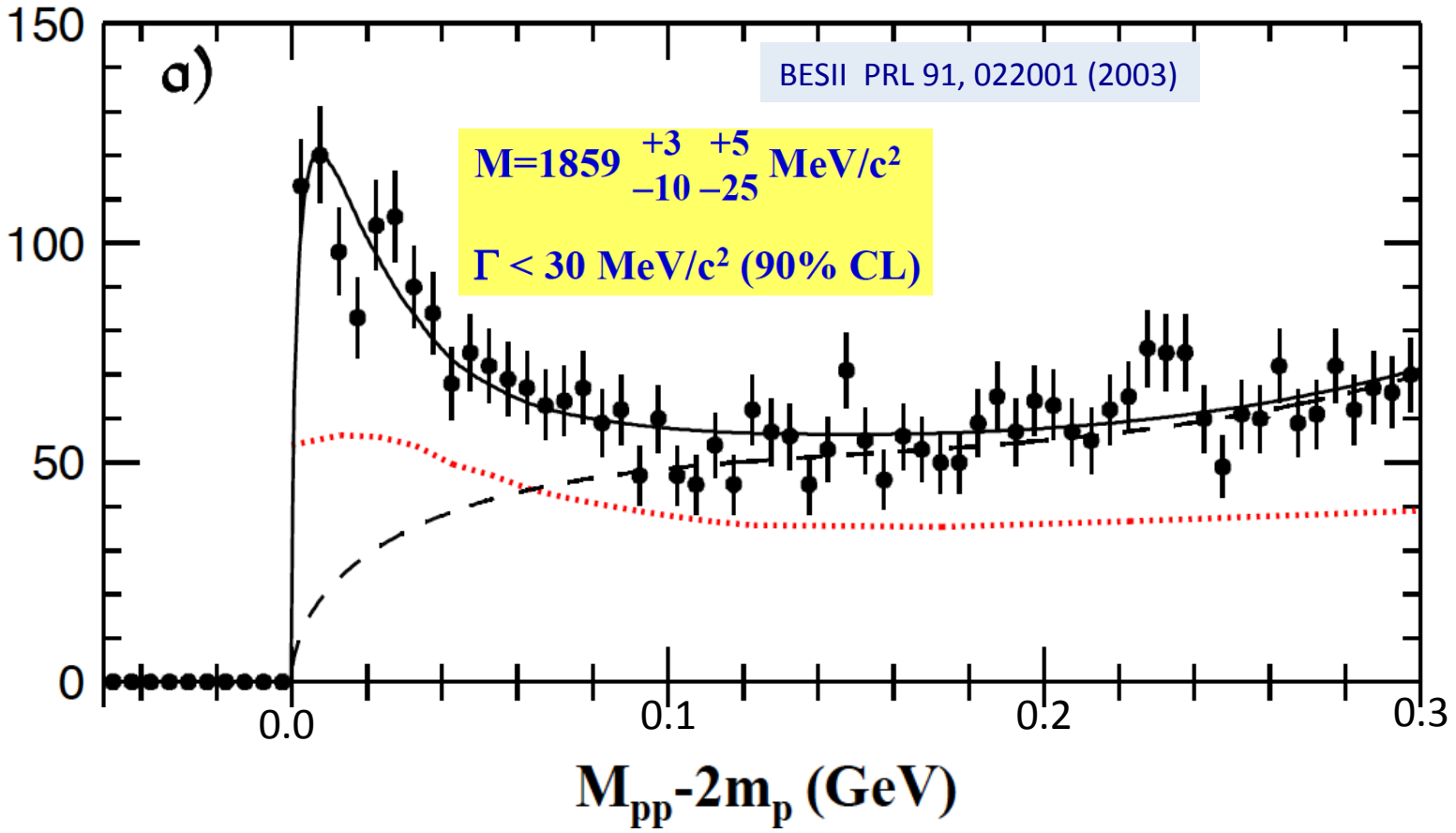
non-$q\bar{q}$ & non-qqq color-singlet combinations

1st: the *other* XY mesons

baryonium states discovered at BESII & BESII?

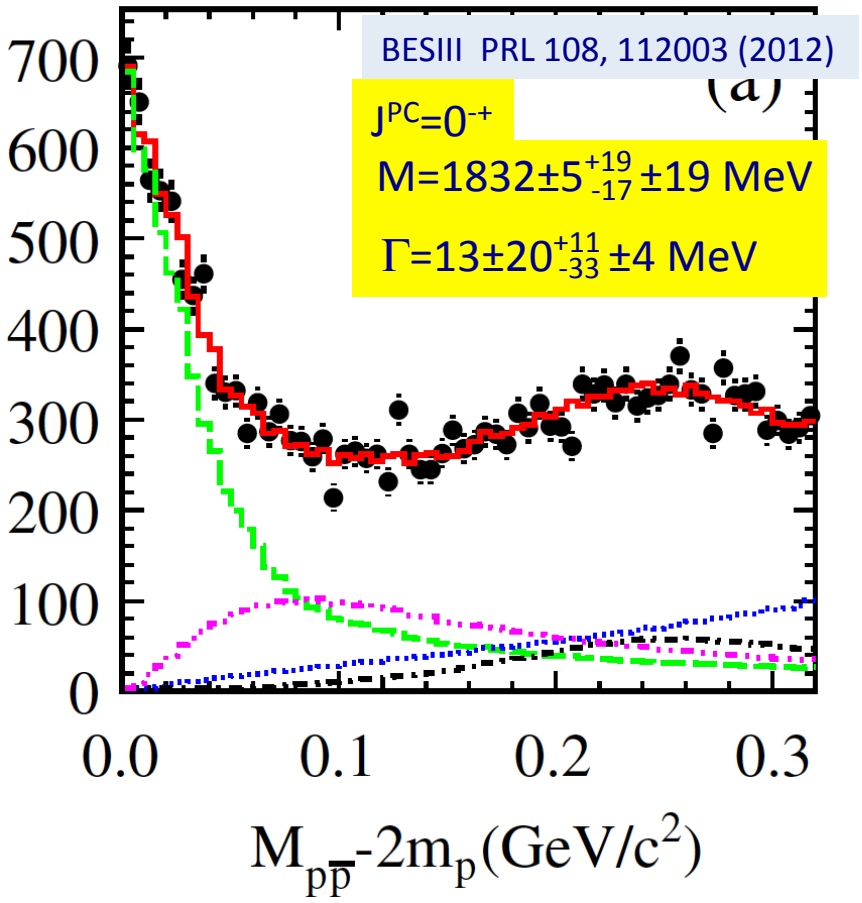
$J/\psi \rightarrow \gamma p\bar{p}$ at BESII

-- with 58M J/ψs --



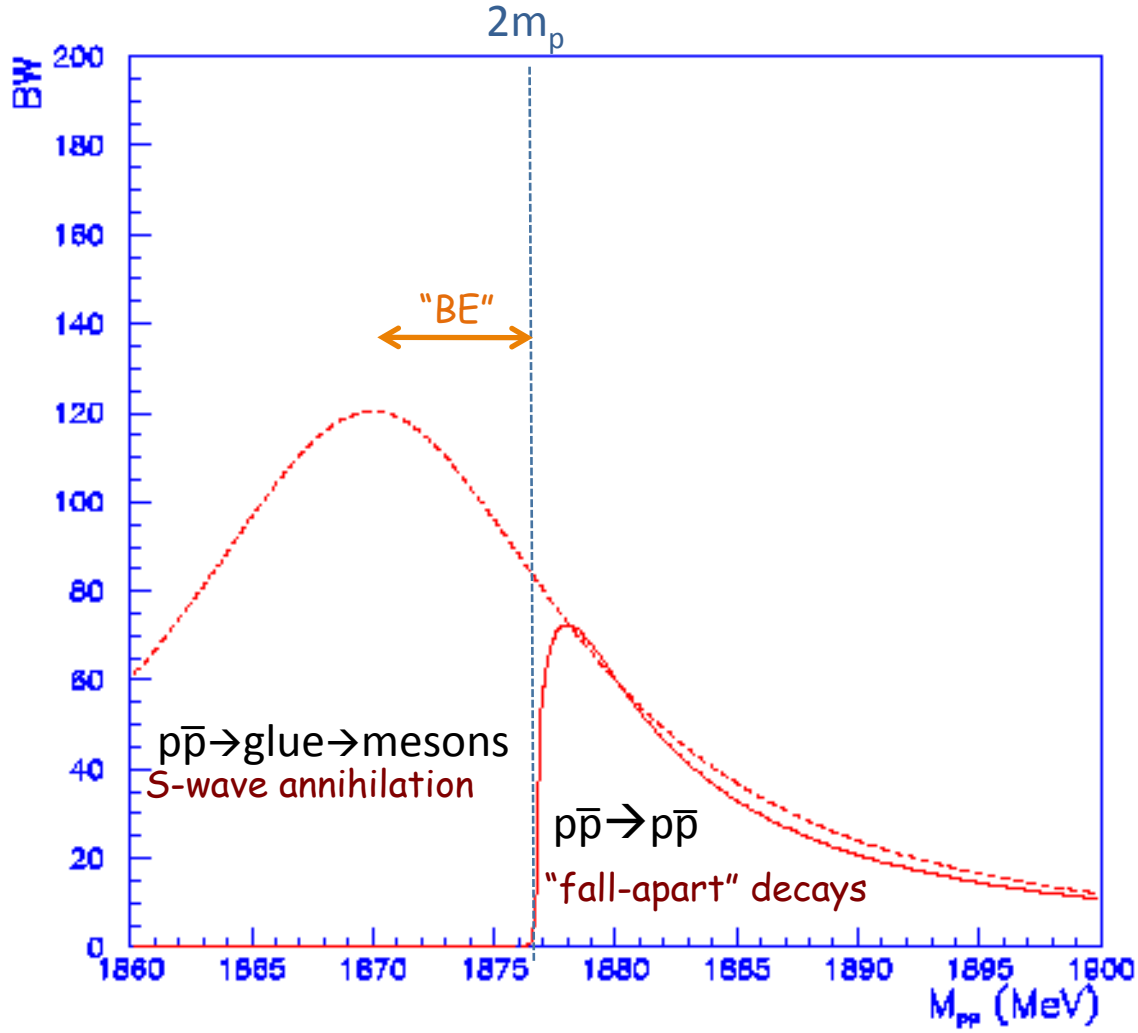
$J/\psi \rightarrow \gamma p\bar{p}$ at BESIII (PWA)

-- with 225M J/ψs --



FSI included: A. Sibirtsev et al, PRD71, 054010 (2005)

“protonium:” a $p\bar{p}$ bound state?



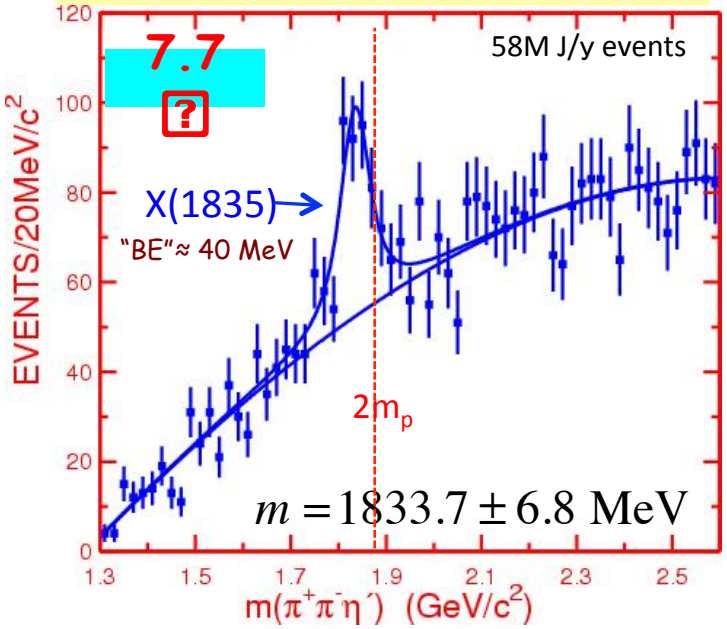
G.J. Ding & M.L. Yan Phys. Rev. C 72, 015208

X(1835)→$\pi^+\pi^-\eta'$

-- with 58M J/ψs --

BESII observation of X(1835) in

$$J/\psi \to \gamma \pi^+ \pi^- \eta'$$



BESII PRL 95, 262001 (2005)

X(1835)→$\pi^+\pi^-\eta'$

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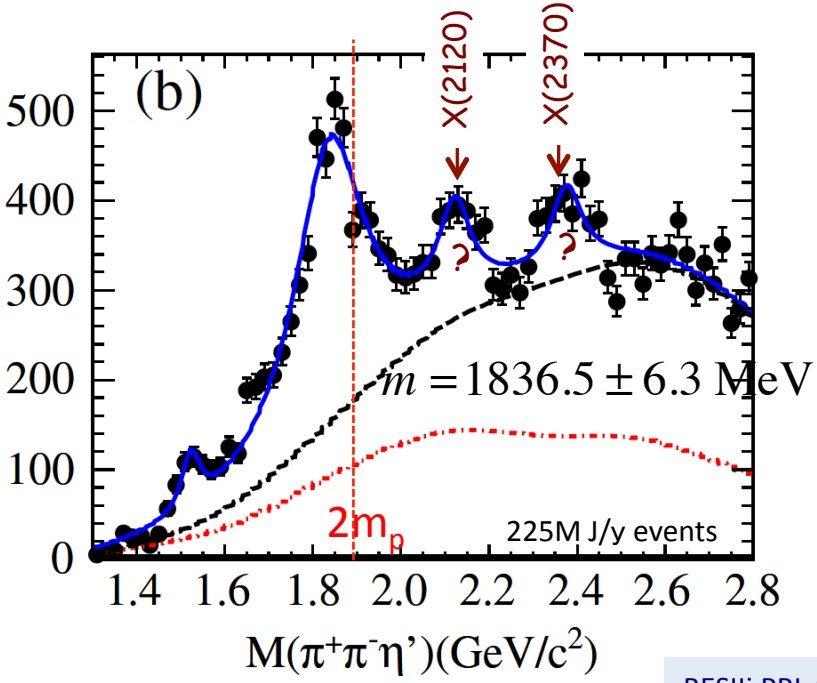
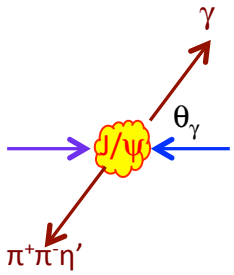
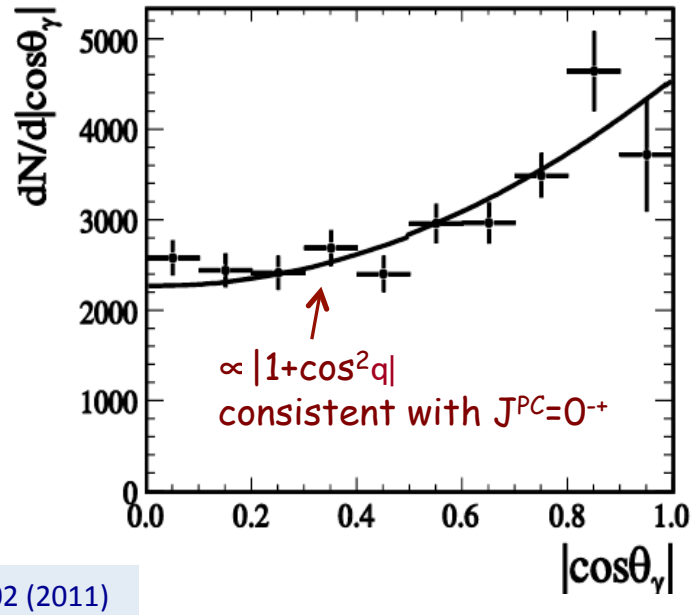
BESIII observation of X(1835) in

$$J/\psi \to \gamma\pi^+\pi^-\eta'$$





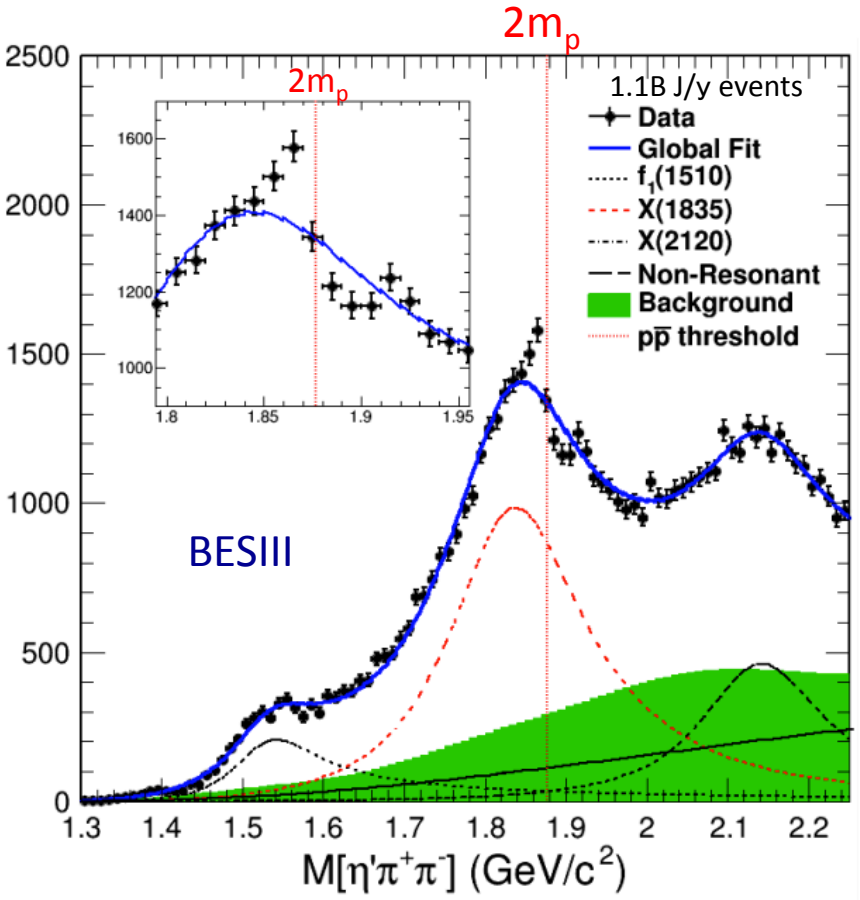


BESIIi PRL 106, 072002 (2011)

X(1835)→$\pi^+\pi^-\eta'$

-- with 1.1B J/ψs --

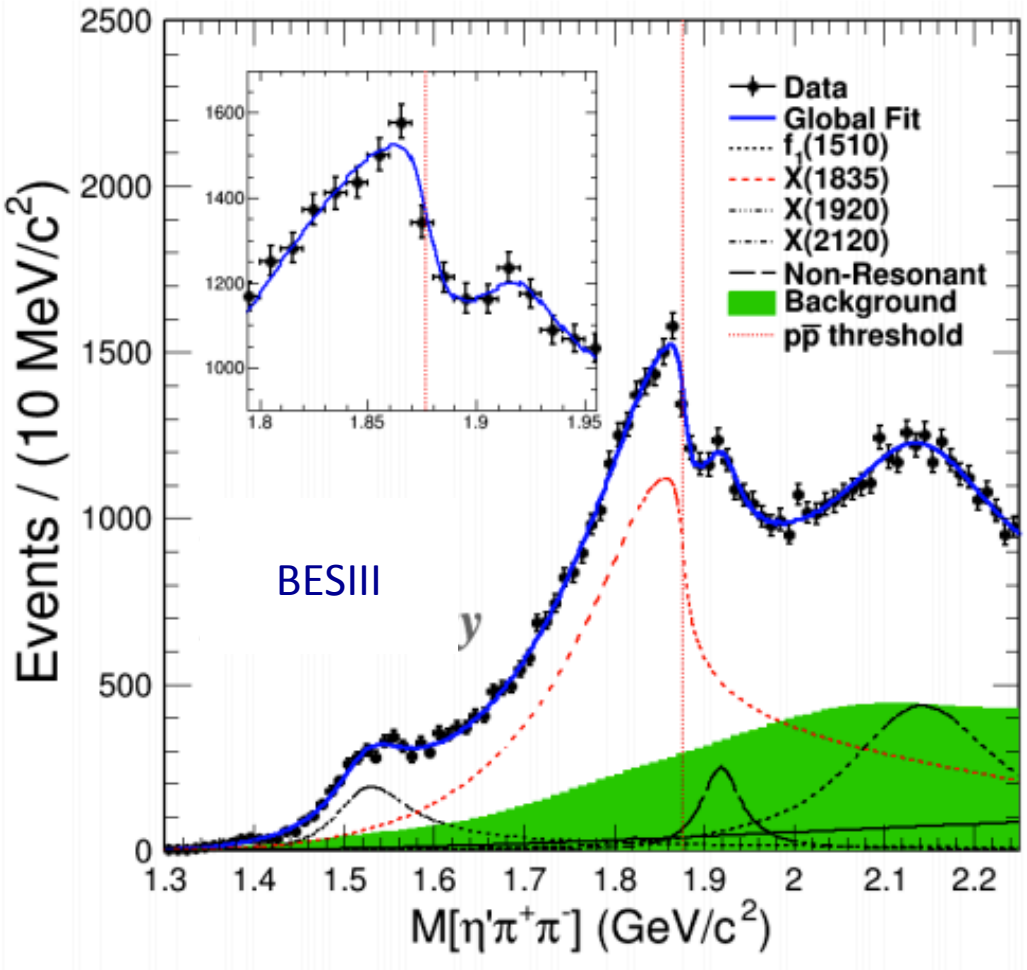
$$J/\psi \to \gamma \pi^+ \pi^- \eta'$$



Flatté formula fit:

$$T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}, \sum_k g_k^2 \rho_k \simeq g_0^2(\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2}\rho_{p\bar{p}})$$

S.M. Flatté PLB 63, 224 (1976)



Fit results:

X coupling to $p\bar{p}$

$$\frac{g_{p\bar{p}}^2}{g_0^2} = 2.31 \pm 0.37$$

X coupling to everything else

Flatté formula fit:

$$T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}, \sum_k g_k^2 \rho_k \simeq g_0^2(\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2}\rho_{p\bar{p}})$$

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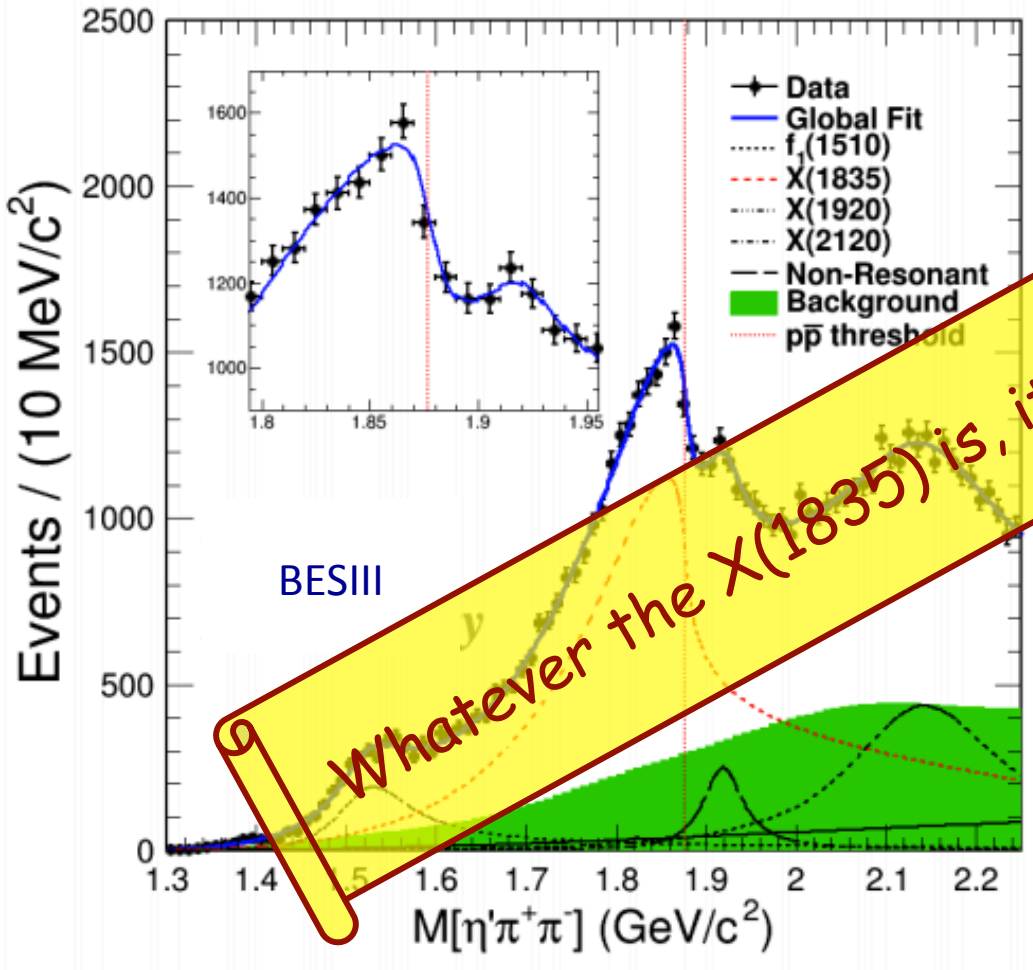


Fit results:

coupling to $p\bar{p}$

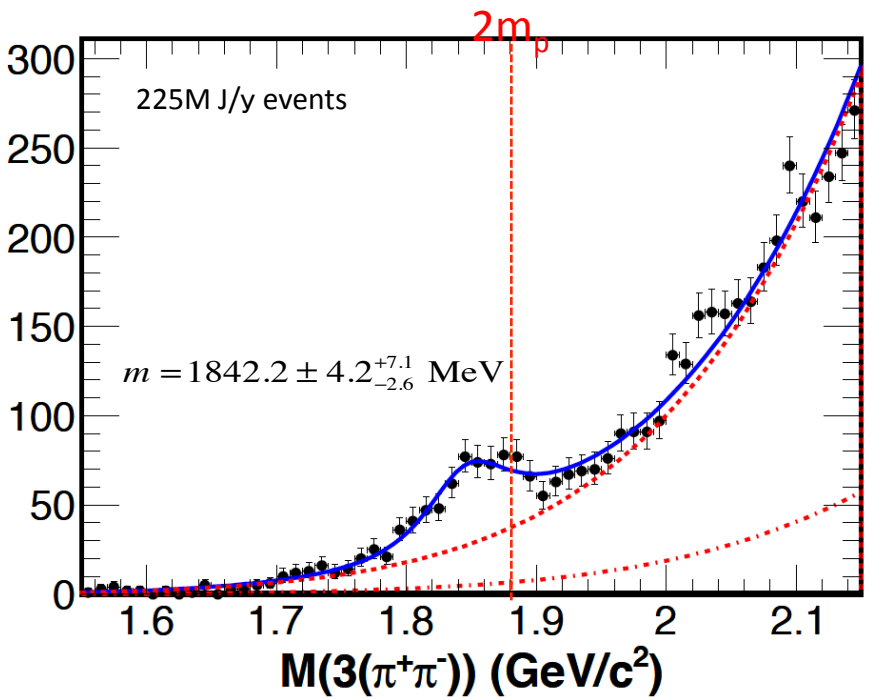
$$\frac{g_{p\bar{p}}^2}{g_0^2} = 2.31 \pm 0.37$$

X coupling to everything else

Whatever the X(1835) is, it has a large coupling to pp

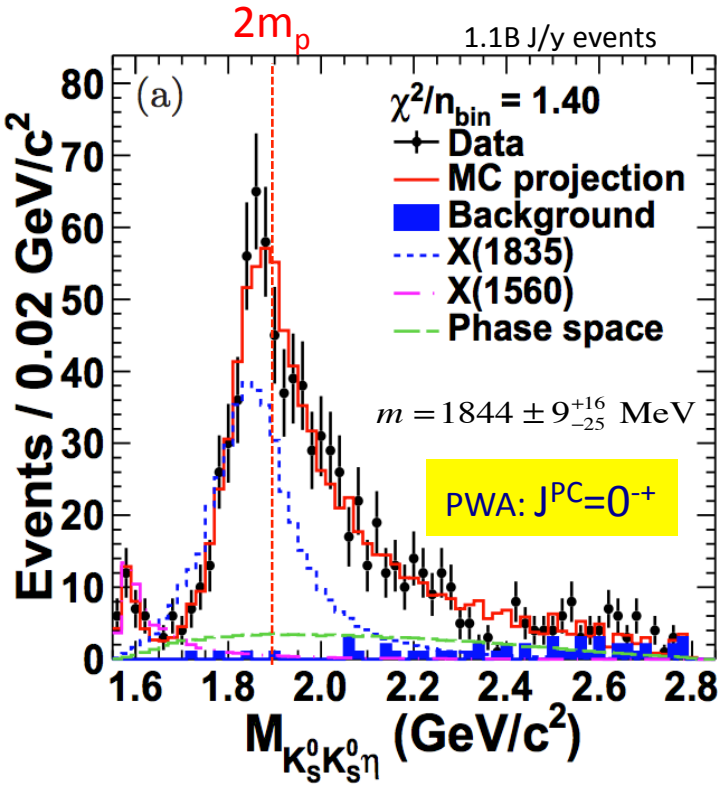
X(1835) in other channels?

$J/\psi \to \gamma 3(\pi^+\pi^-)$



BESIII PRD 88, 091502 (2013)

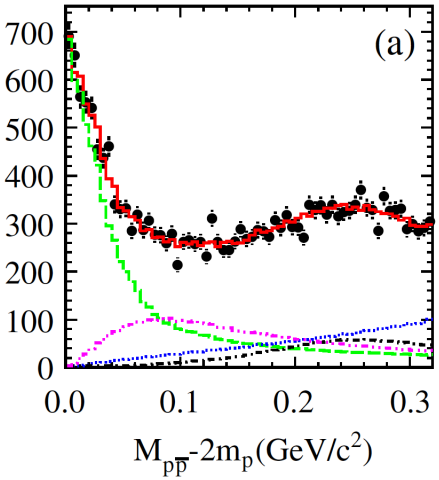
$J/\psi \to \gamma K_S^0 K_S^0 \eta$



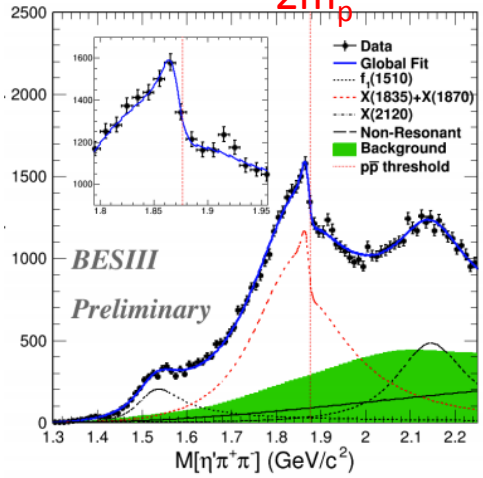
BESIII arXiv:1506.04807 [hep-ex]

need coupled channel analyses

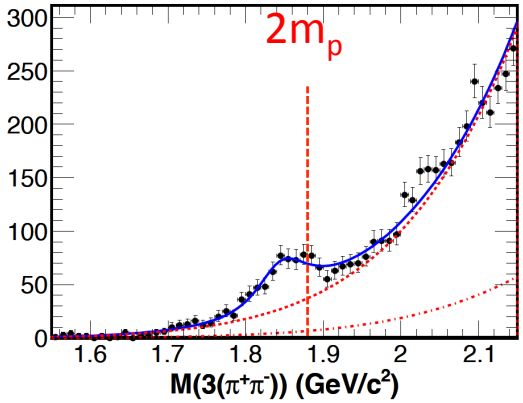
$J/\psi \to \gamma p\bar{p}$



$J/\psi \to \gamma \pi^+\pi^-\eta'$

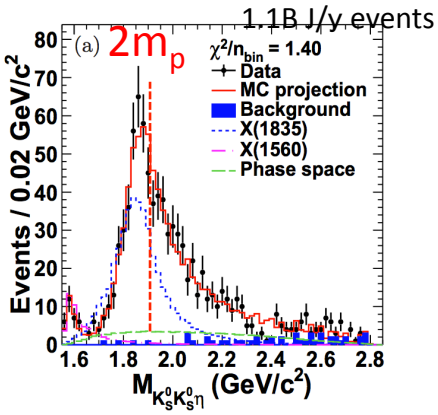


$J/\psi \to \gamma 3(\pi^+\pi^-)$



$J/\psi \to \gamma K_S^0 K_S^0 \eta$

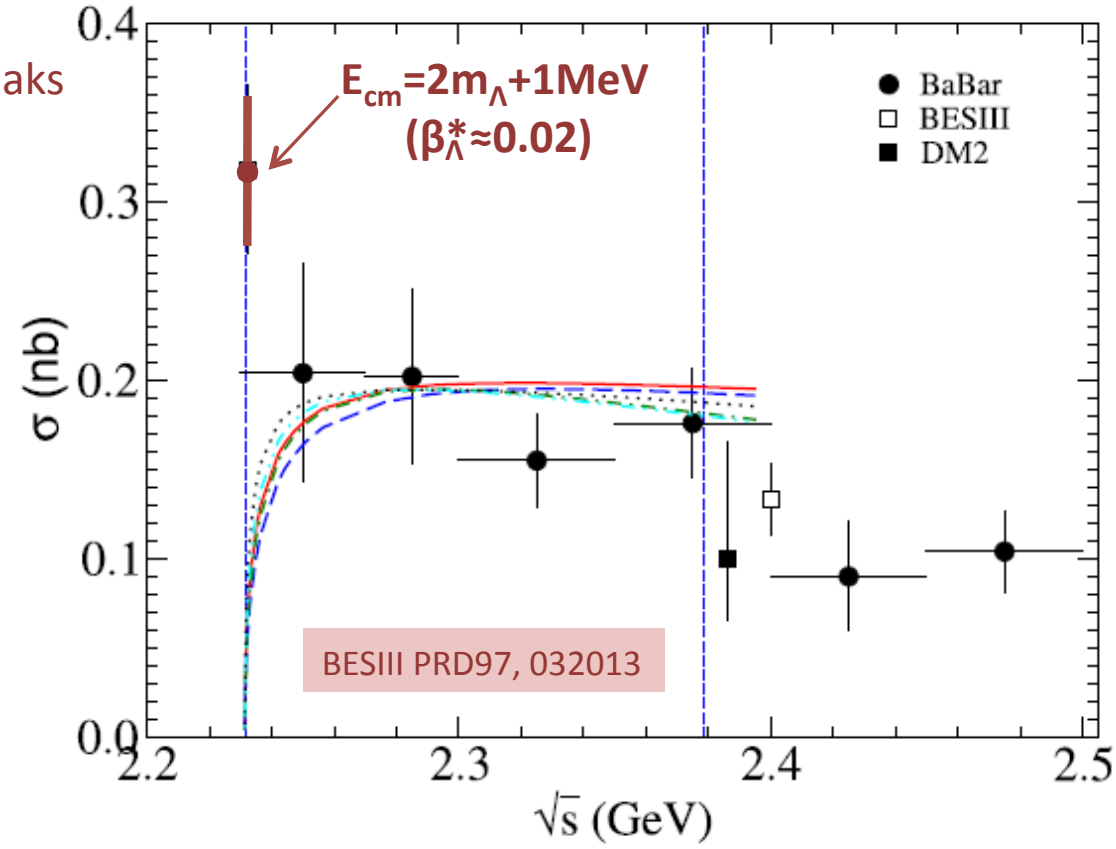
1.1B J/ψ events



1^{--} $\Lambda\bar{\Lambda}$ threshold state?

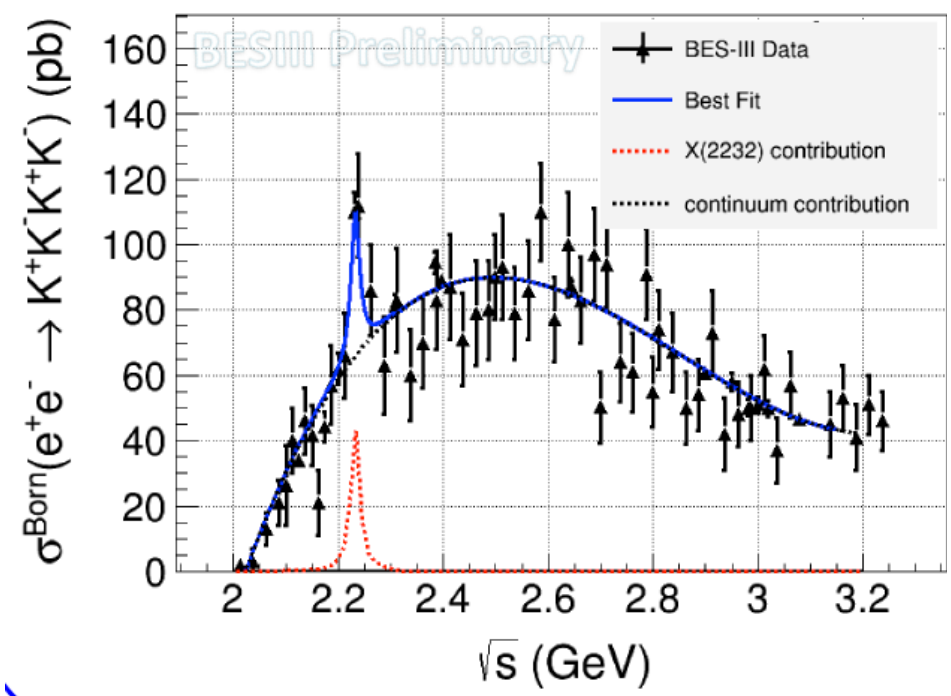
$\sigma(e^+e^- \to \Lambda\bar{\Lambda})$

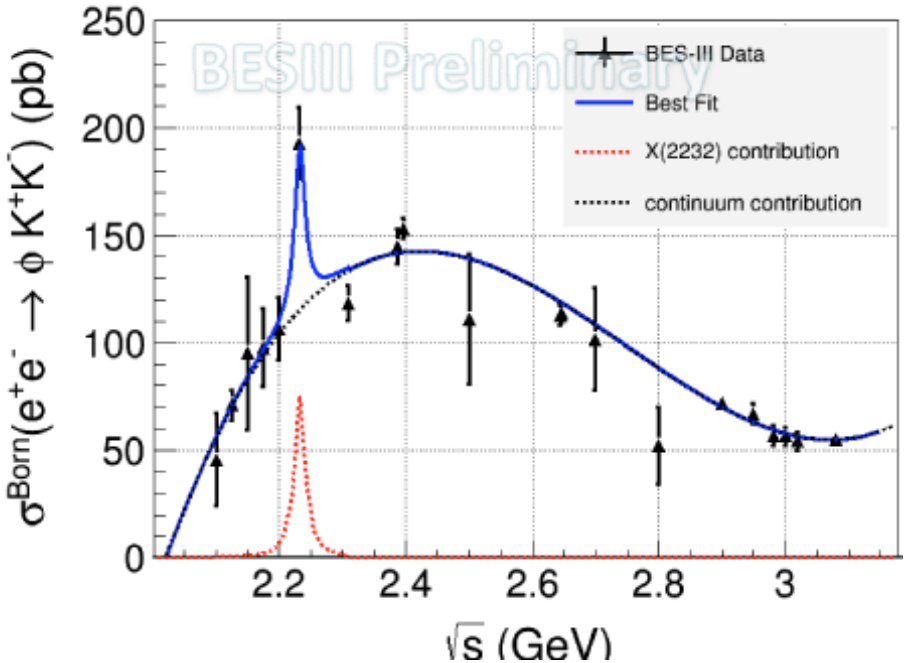
cross section peaks at threshold!!



$M=2m_\Lambda$ peaks in $e^+e^- \to 2(K^+K^-)$ & ϕK^+K^- ?

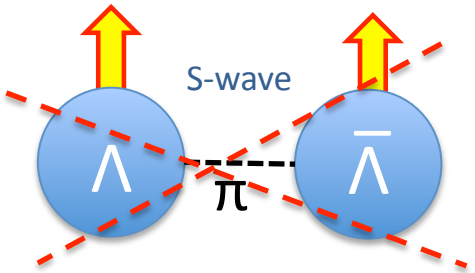
M=2.232 ±3.5 MeV ($2m_\Lambda$=2.2314 MeV)





$\Lambda\bar{\Lambda}$ molecule??

$J^{PC}=1^{--}$



π-exchange
is not allowed

lacks a credible binding mechanism

a spectroscopy of baryonium states?

BESII: strong evidence for a 0^{+-} bound $p\bar{p}$ state

BESIII: strong evidence for a 1^{--} bound $\Lambda\bar{\Lambda}$ state

a spectroscopy of baryonium states?

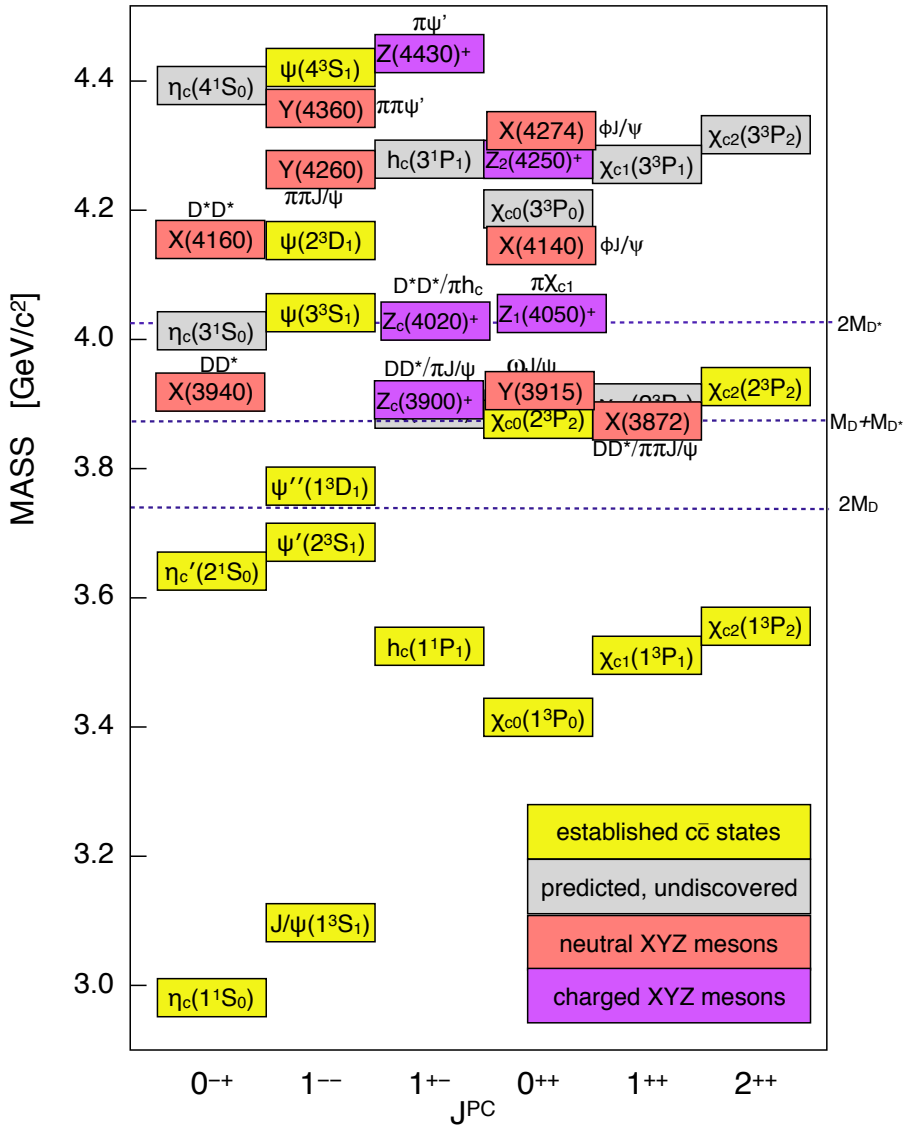
BESII: strong evidence for a 0^{+-} b

BESIII: strong evide

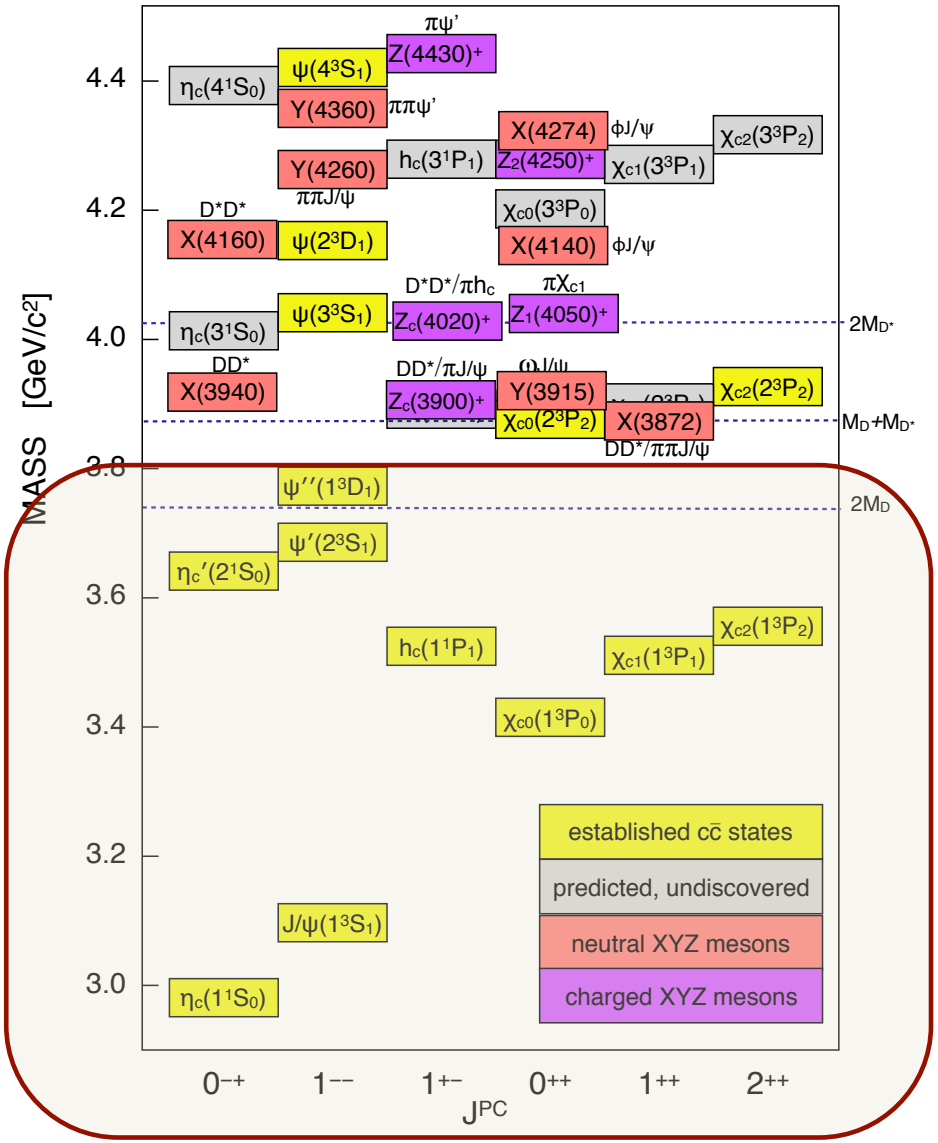
Opportunity: establish and map out baryonium spectrum

the hidden charm XYZ states

hidden charm XYZ states

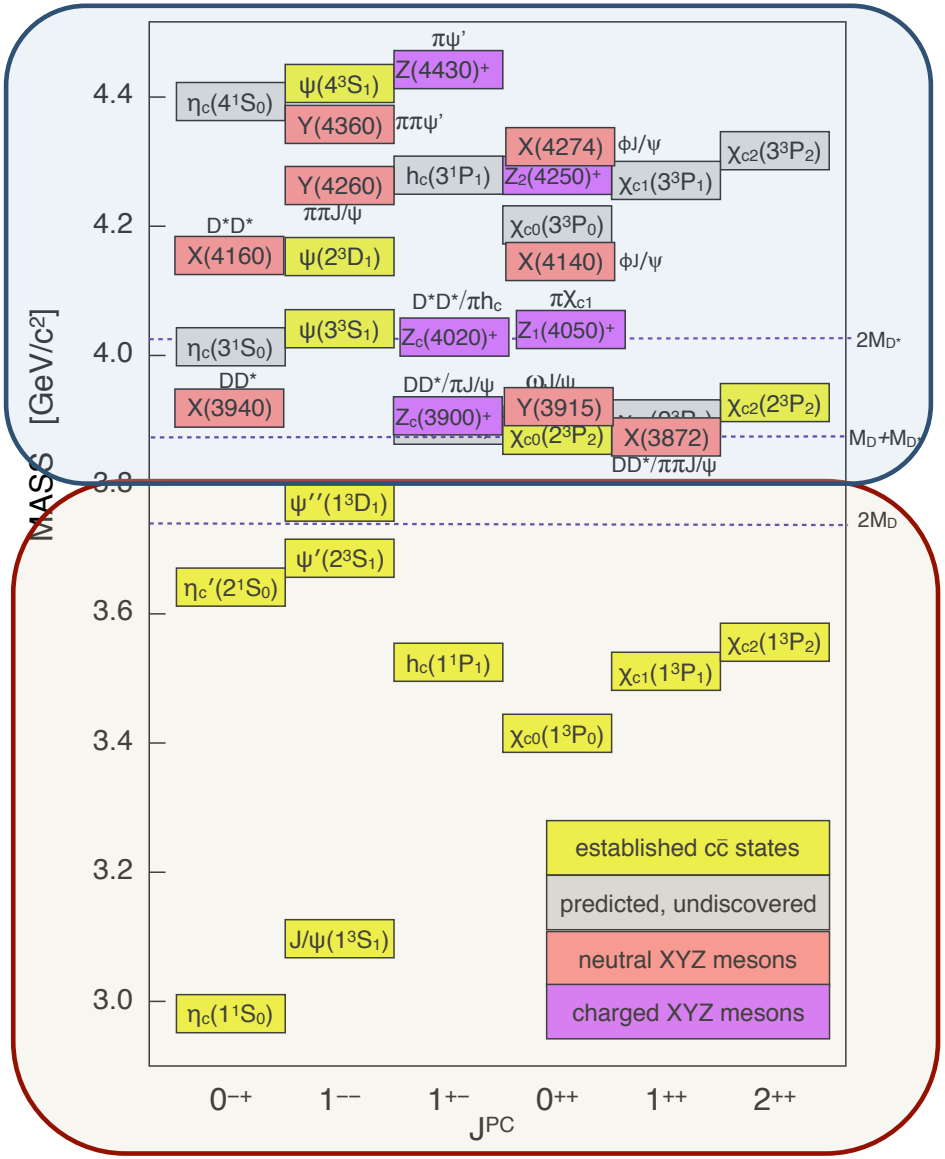


hidden charm XYZ states



20th century physics

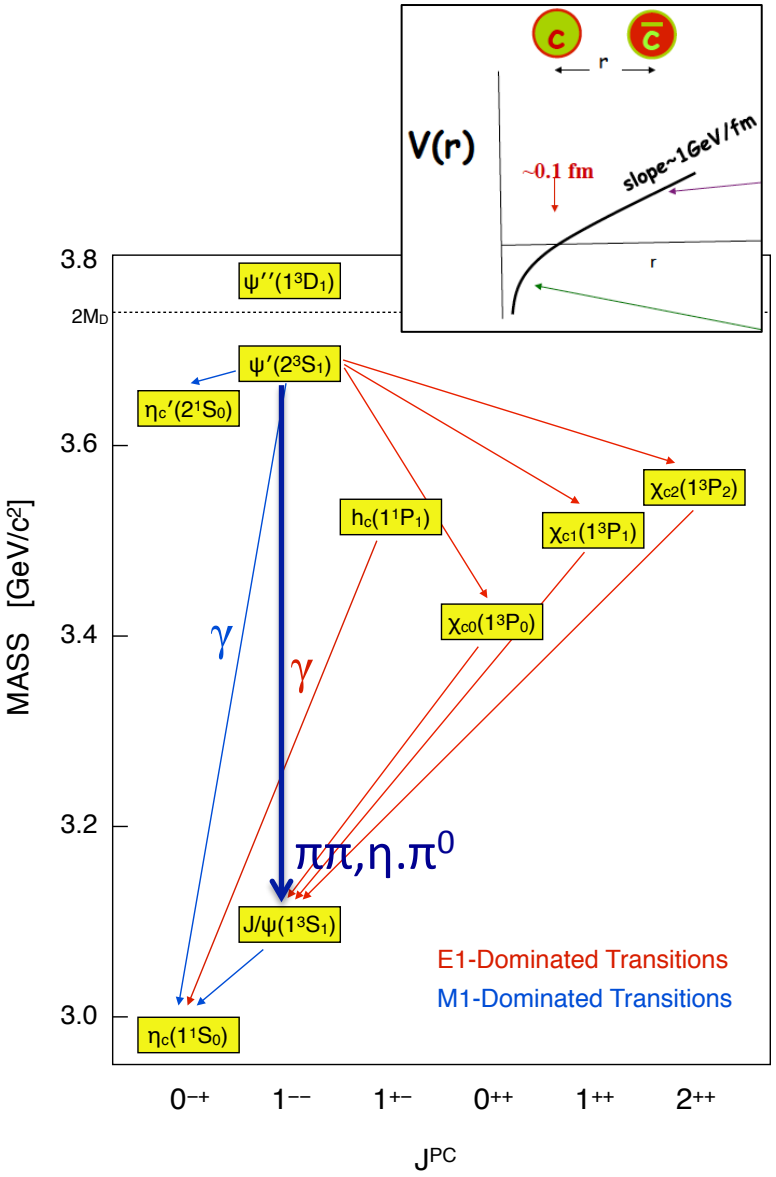
hidden charm XYZ states



21st century physics

20th century physics

20th century physics: charmonium



Potential model; very successful

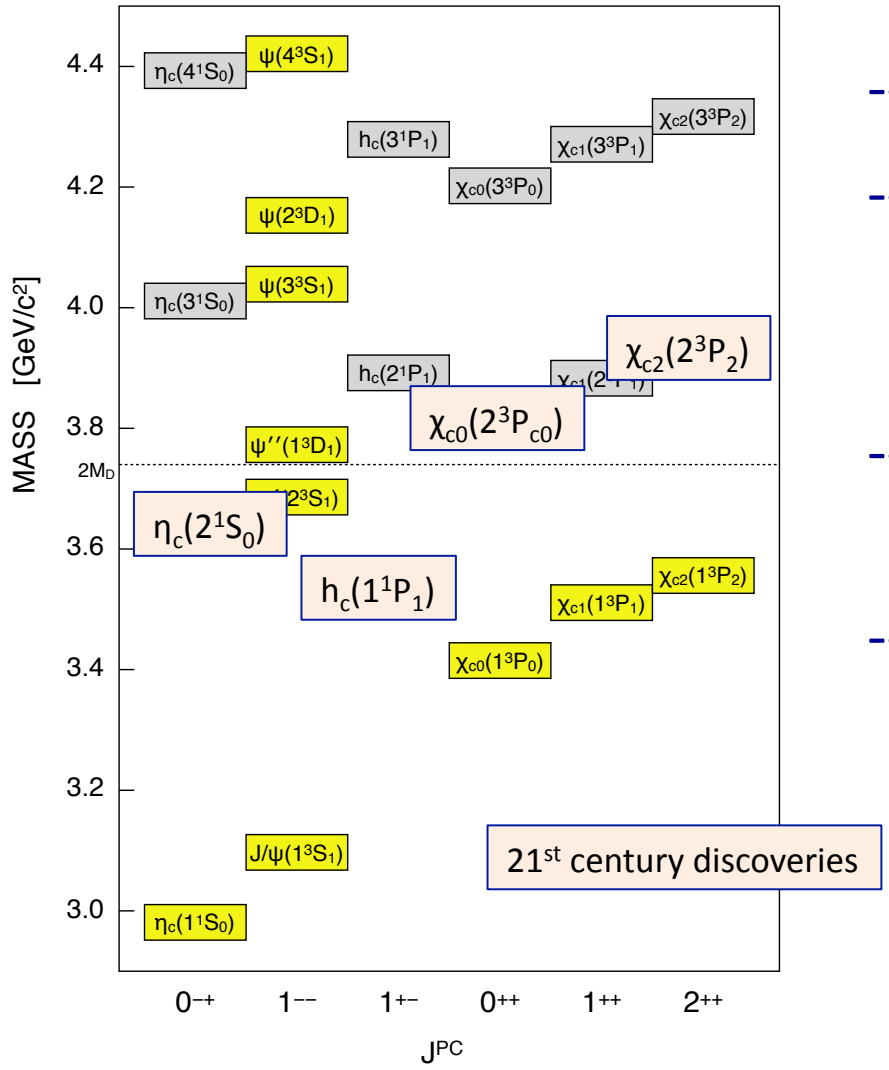
forty years plus
many, many hours of work

potential model works

all low-level states discovered
at predicted mass values

OZI-rule applies, no exceptions

20th century expectations for 21st century experiments



-- few (≈10) more states to find

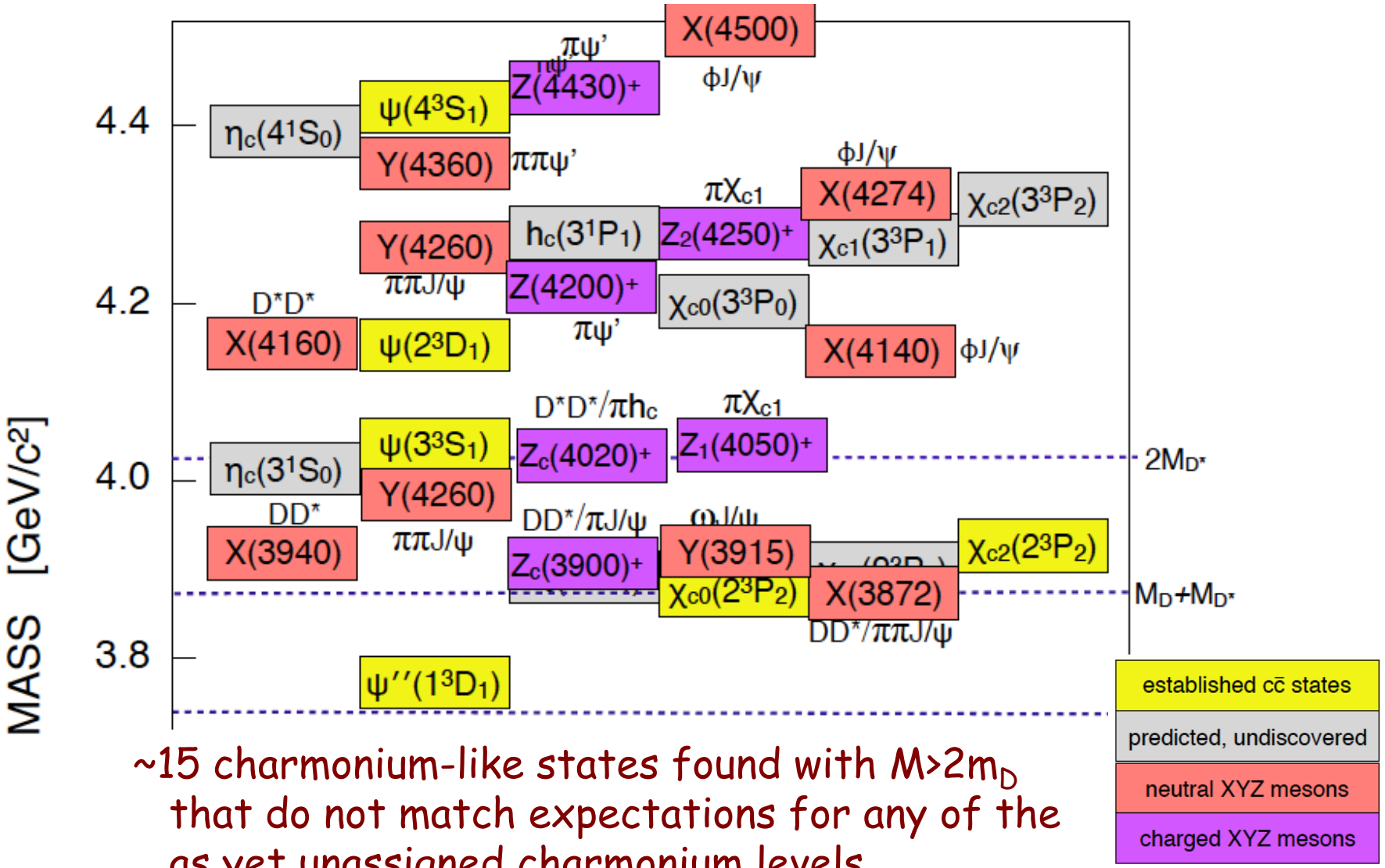
-- decays dominated by $D^{(*)}D^{(*)}$
tiny rates for ππJ/ψ, γJ/ψ(χcJ),…
(ala OZI-rule expectations)

-- masses similar to potential model values (modified by $D^{(*)}D^{(*)}$loops)

-- broader & broader widths

[η_c(2S) discovered in 2002;
h_c(1P) in 2005; χ_{c2}(2P) in 2006
& χ_{c0}(2P) in 2017 ←all with
expected properties}

21st century: reality strikes



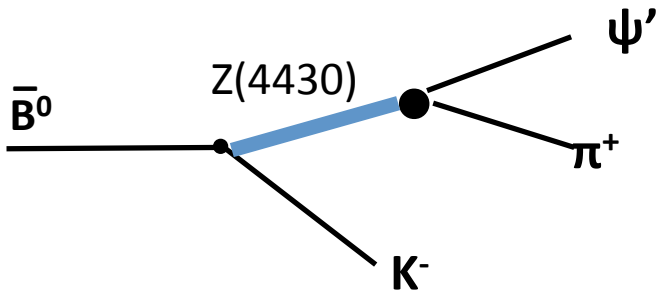
~15 charmonium-like states found with $M>2m_D$ that do not match expectations for any of the as yet unassigned charmonium levels

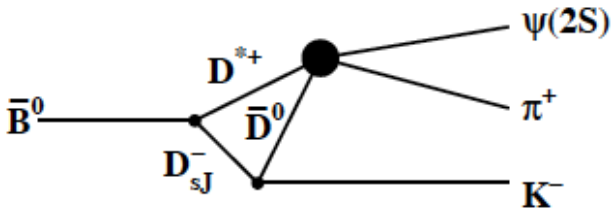
Characteristics of the new "XYZ" states

- Decays to open charm are suppressed
- Decays to hidden charm are enhanced
  -- Large apparent OZI-rule violations
- They are relatively narrow
- Some are near 2-particle thresholds,
  but others are not

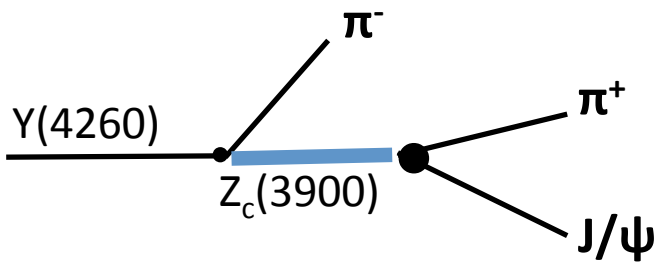
General issue with XYZ mesons

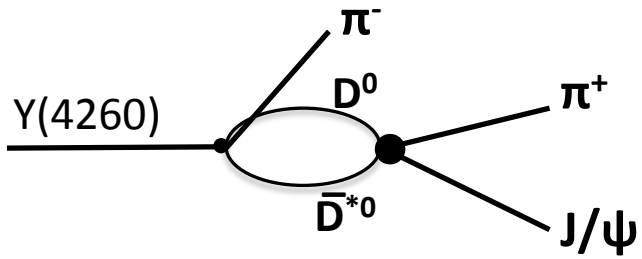
true resonances? … or kInematical effects?





Landau singularity?

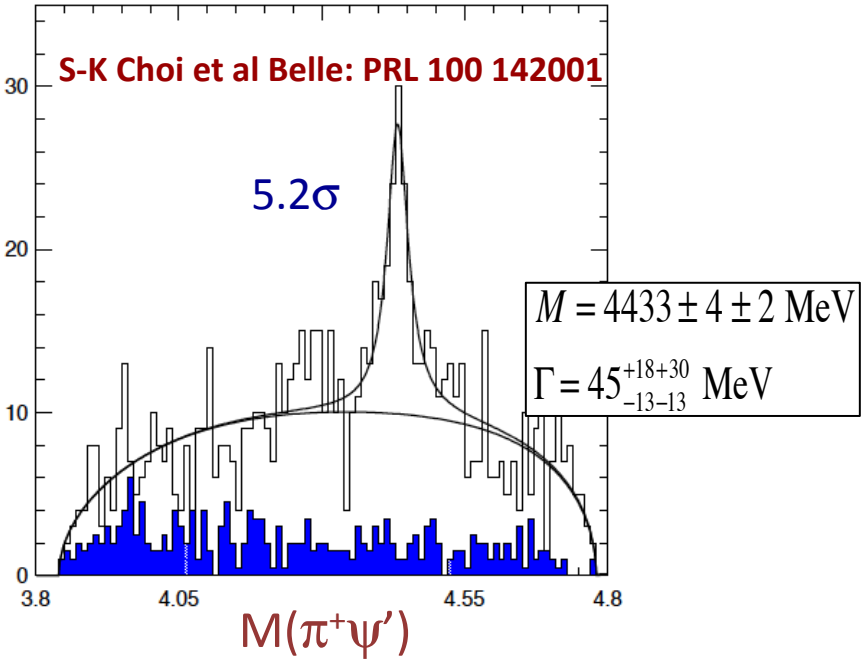




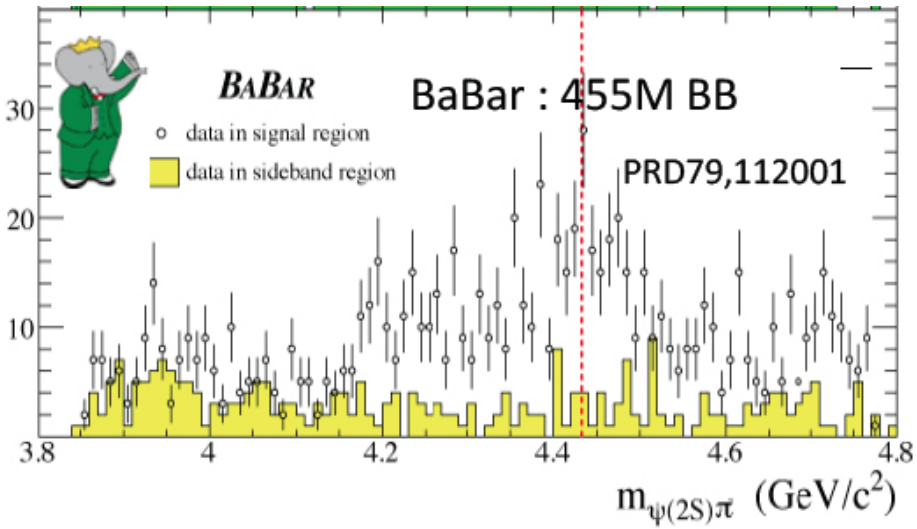
Threshold cusp?

The Z(4430) story

seen by Belle



not confirmed by BaBar (only a 1.9σ "hint")



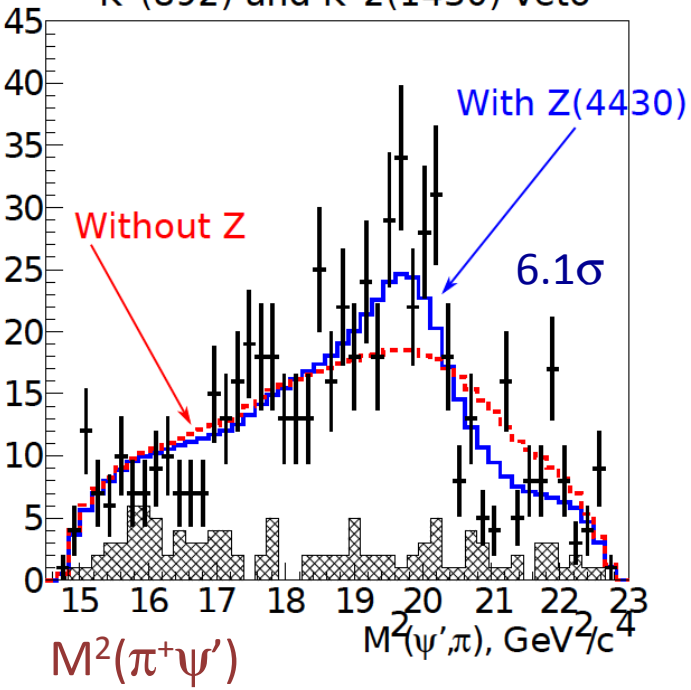
"Belle analysis too naïve?"

More sophisticated Belle analysis

K Chilikin et al Belle: PRD 88 074026

2013: 4-dim amplitude analysis

K*(892) and K*2(1430) veto

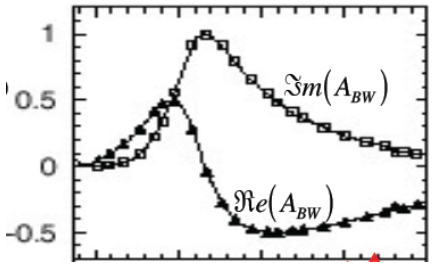


$$M = 4485^{+22+28}_{-22-11}\ \text{MeV}$$

$$\Gamma = 200^{+41+26}_{-46-35}\ \text{MeV}$$

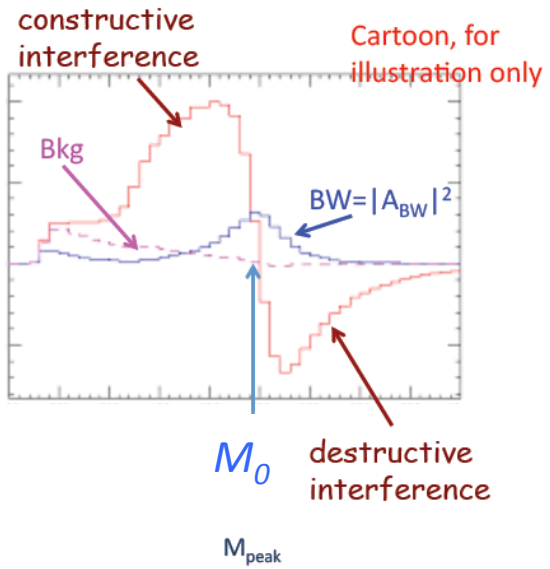
BW resonance + background

$$BW \propto \frac{\Gamma M}{(M^2 - M_0^2) + iM\Gamma}$$



if $|A_{bkg}| > |BW|$:

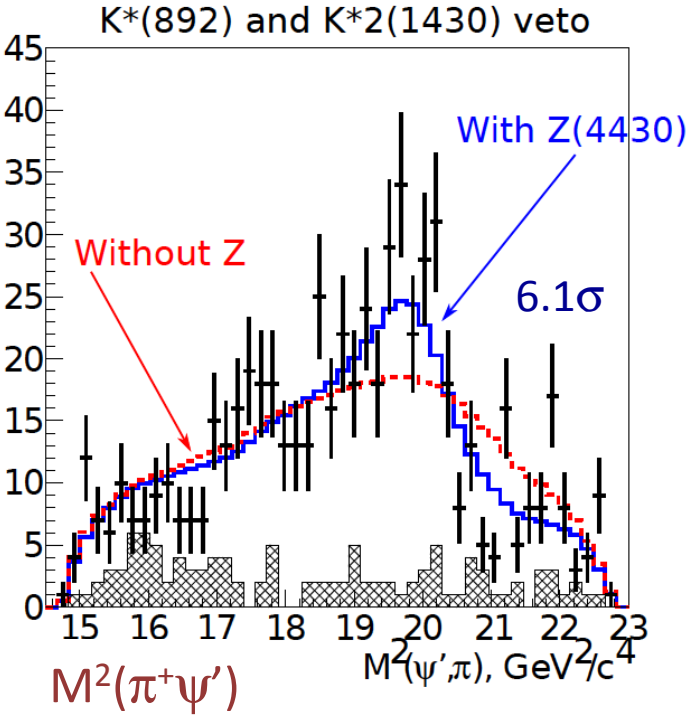
$$\left|BW + A_{bkg}\right|^2 \approx \left|A_{bkg}\right|^2 + 2\mathcal{R}e(A_{bkg}BW)$$



a genuine resonance or a kinematical effect?

K Chilikin et al Belle: PRD 88 074026

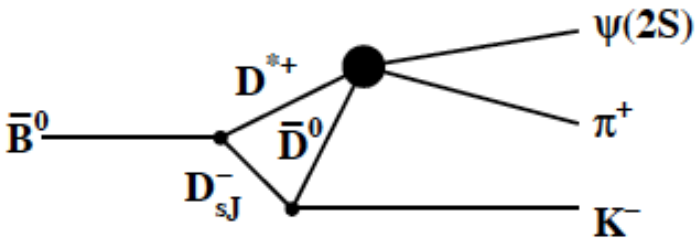
2013: 4-dim amplitude analysis



$$M = 4485^{+22+28}_{-22-11}\ \text{MeV}$$

$$\Gamma = 200^{+41+26}_{-46-35}\ \text{MeV}$$

"a real BW or a rescattering process?"

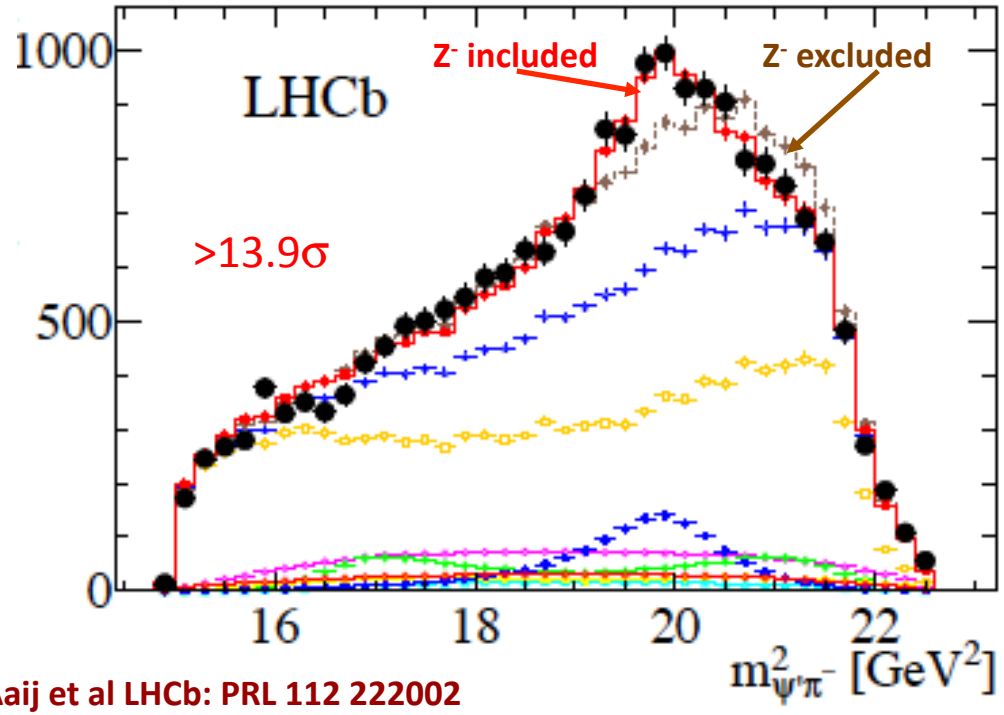


Pakhlov &Uglov, PLB 183 (2015)

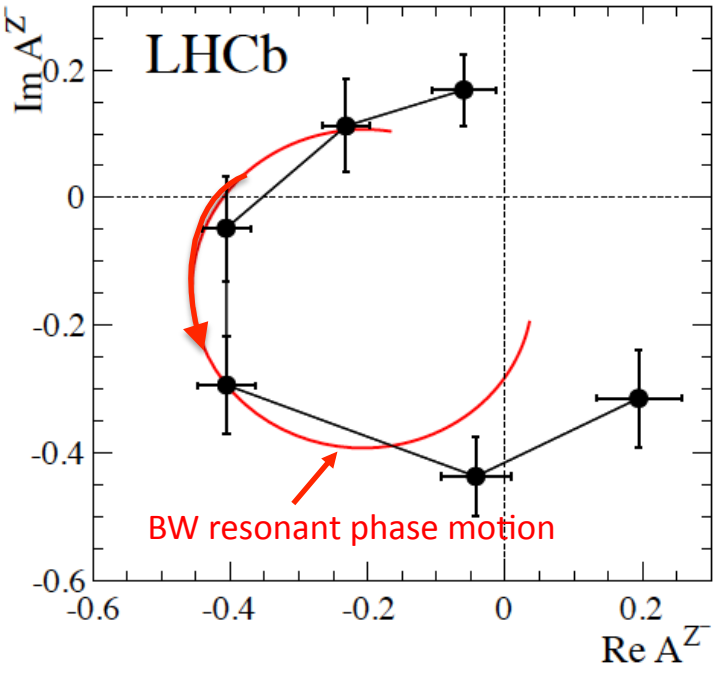
LHCb with 10x Belle's statistics

-- confirms Belle & shows phase motion --

$B \to K^+\pi^- \psi'$ 4-dim amplitude analysis



Model-ind. Argand plot



R. Aaij et al LHCb: PRL 112 222002

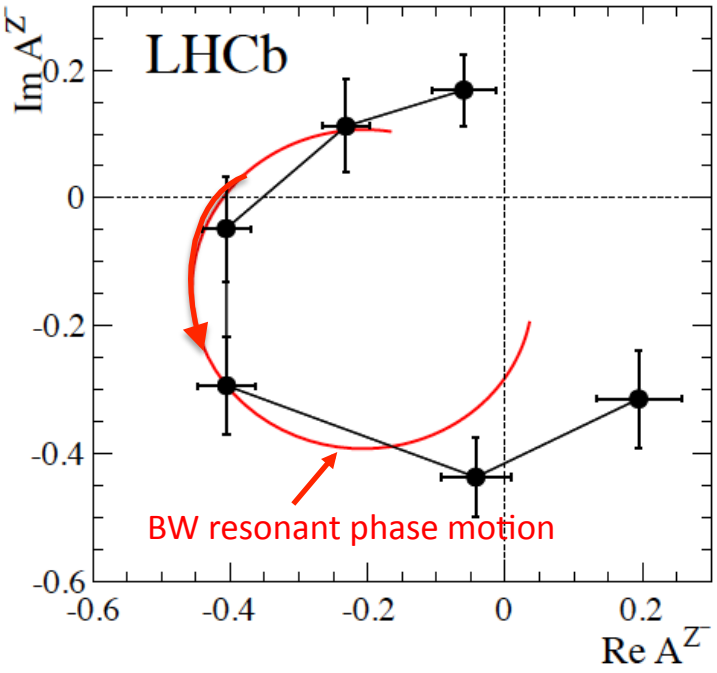
$$J^P = 1^+$$

$$M = 4475 \pm 7^{+15}_{-25}\ \text{MeV}$$

$$\Gamma = 172 \pm 13^{+37}_{-34}\ \text{MeV}$$

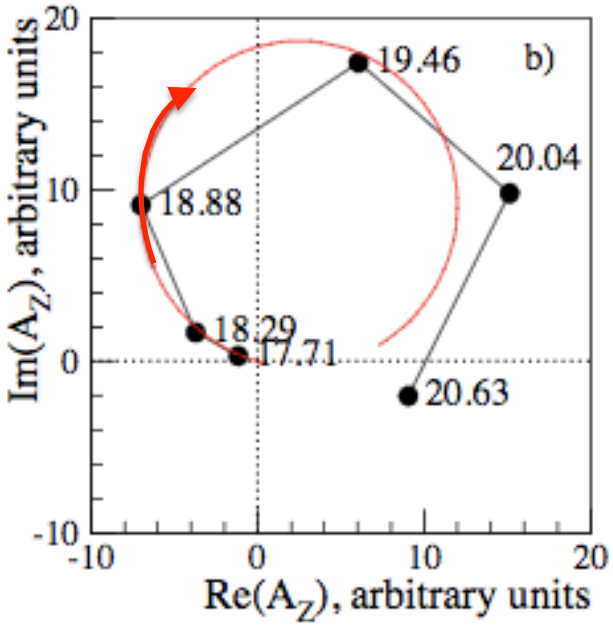
phase motion settled the issue

Model-ind. Argand plot



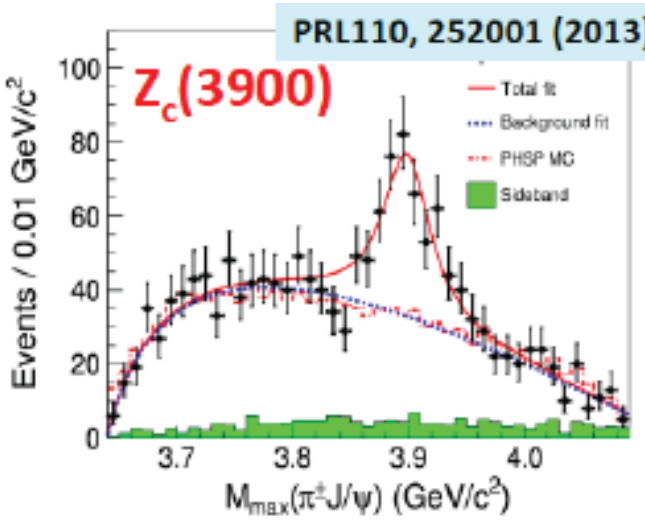
BW-like counter-clockwise phase motion is clearly established

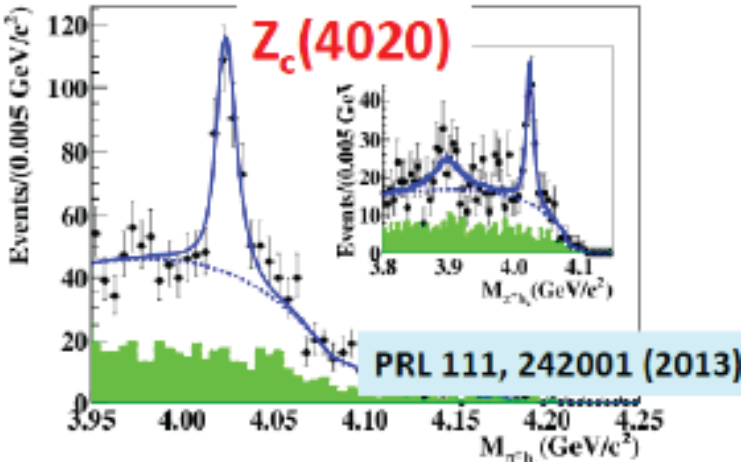
rescattering process predicts clockwise phase motion

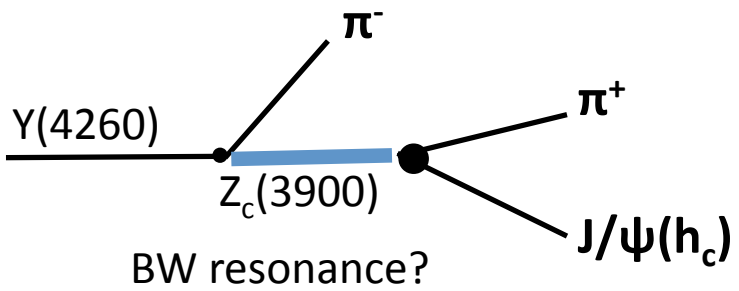


Pakhlov &Uglov, PLB 183 (2015)

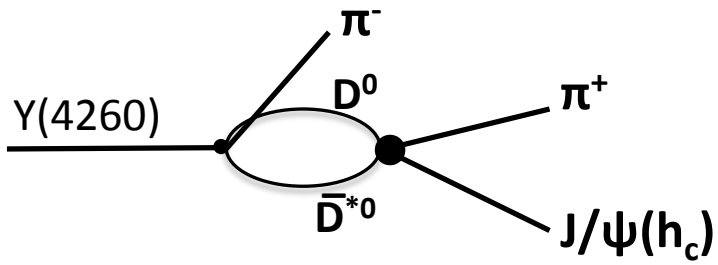
$Z_c(3900)$ & $Z_c(4020)$: resonances or Cusps







BW resonance?

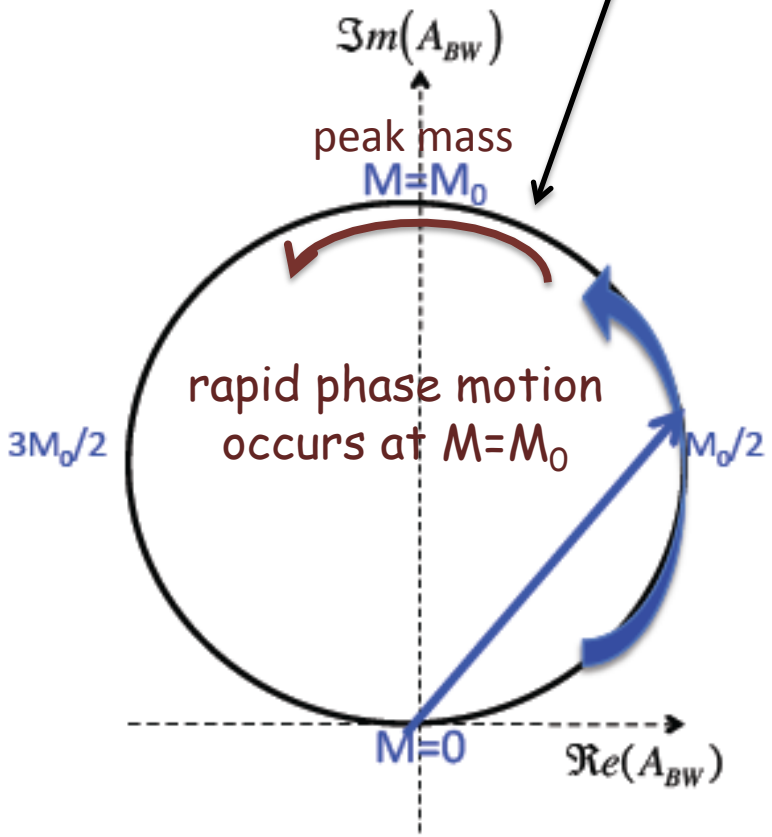


Threshold cusp?

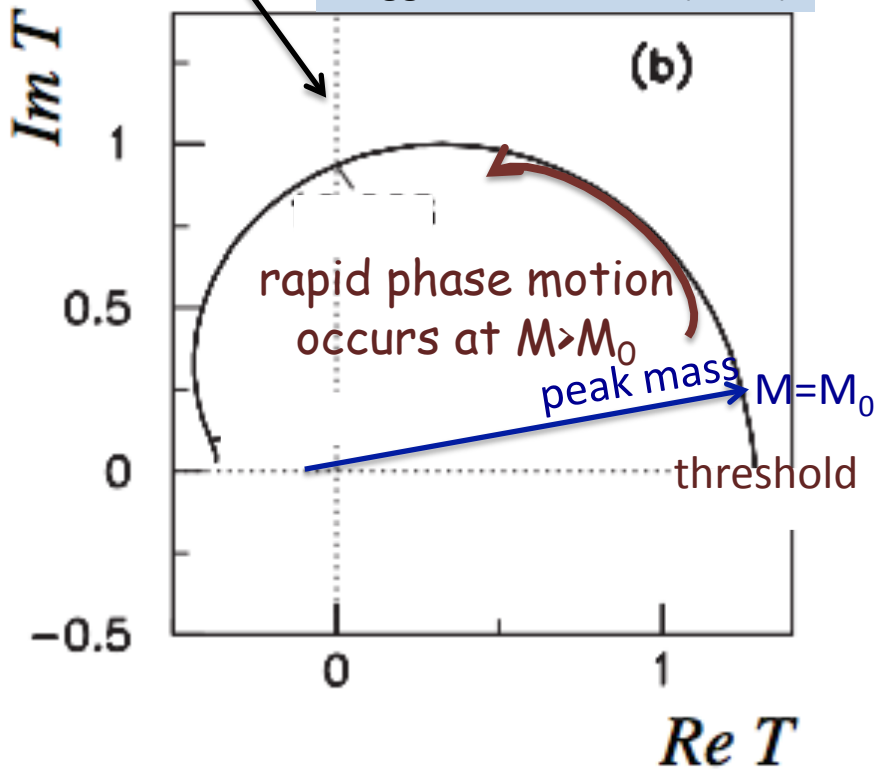
D. Bugg, Europhys. Lett. 96, 11002 (2011)

E. Swanson. PRD 91, 034009 (2015)

BW vs Cusps



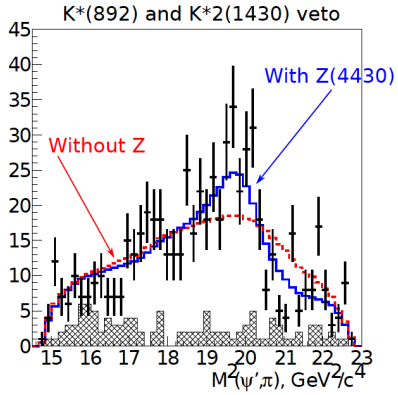
Bugg: EPL 96 11002 (2011)



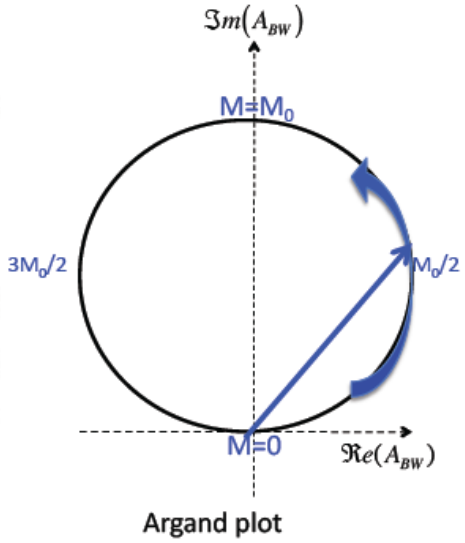
Argand plots require ***large*** statistics; distinguishing BW- from Cusp-phase motion will require ***huge*** data samples

Lessons for HIEPA

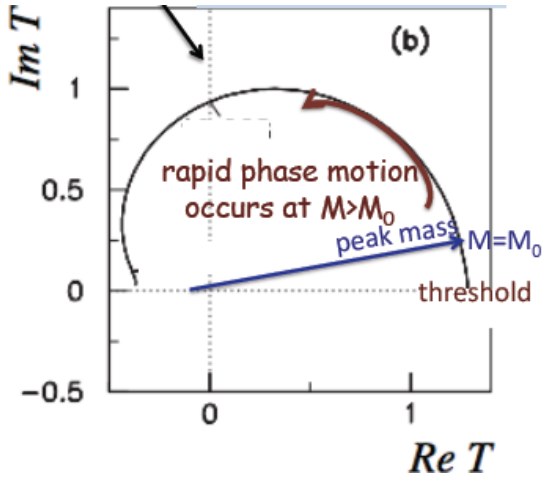
Bump hunting is out! multi-dimensional coupled-channel amplitude analyses are required.



High statistics phase-motion measurements are essential.

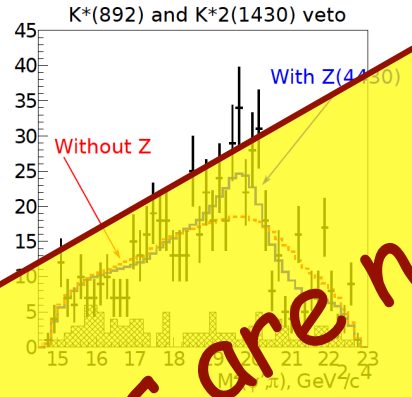


vs



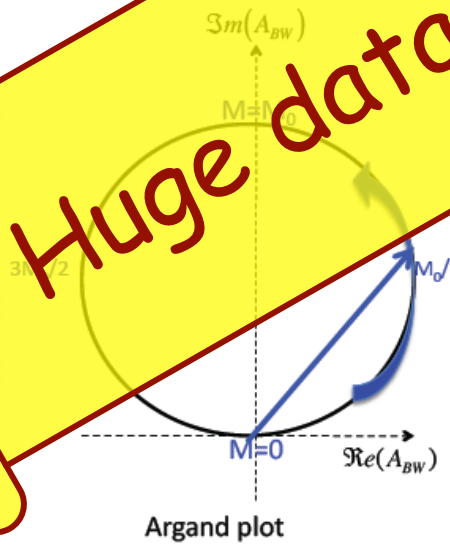
Lessons for HIEPA

Bump hunting is out! multi- dimensional amplitude analyses are required.

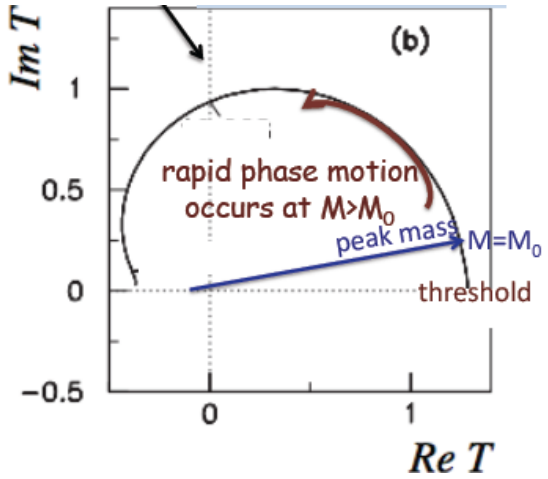


Huge data sets are needed

High statistics phase-motion measurements are essential.

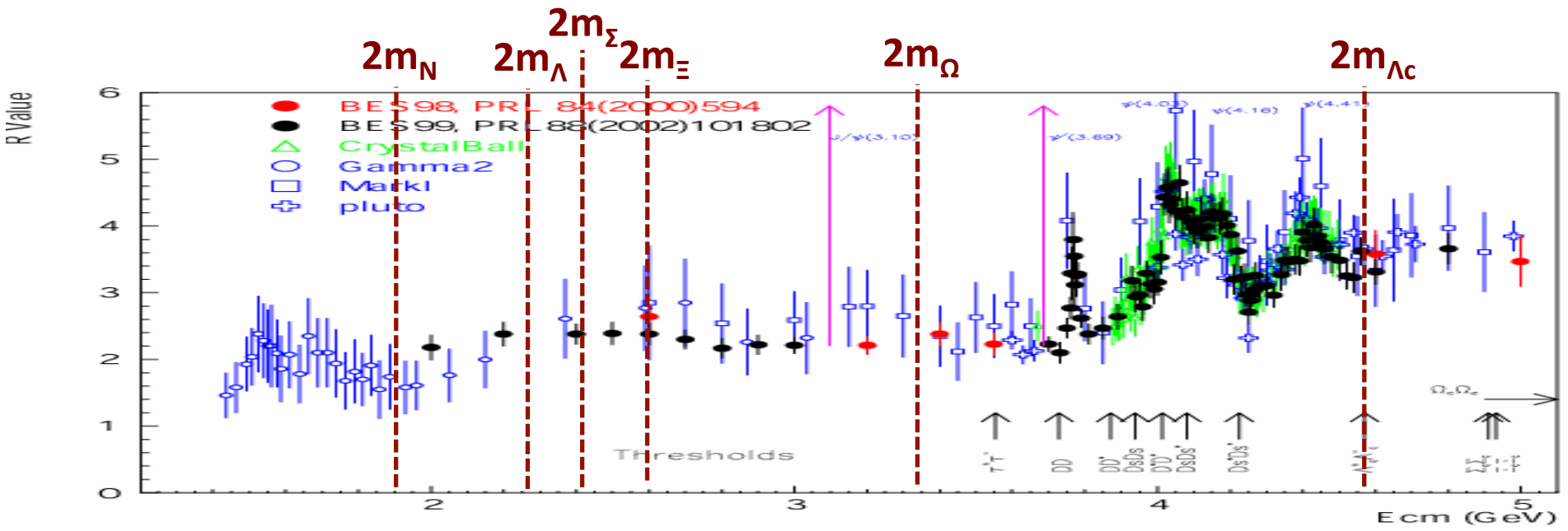


vs



Experiments at HIEPA

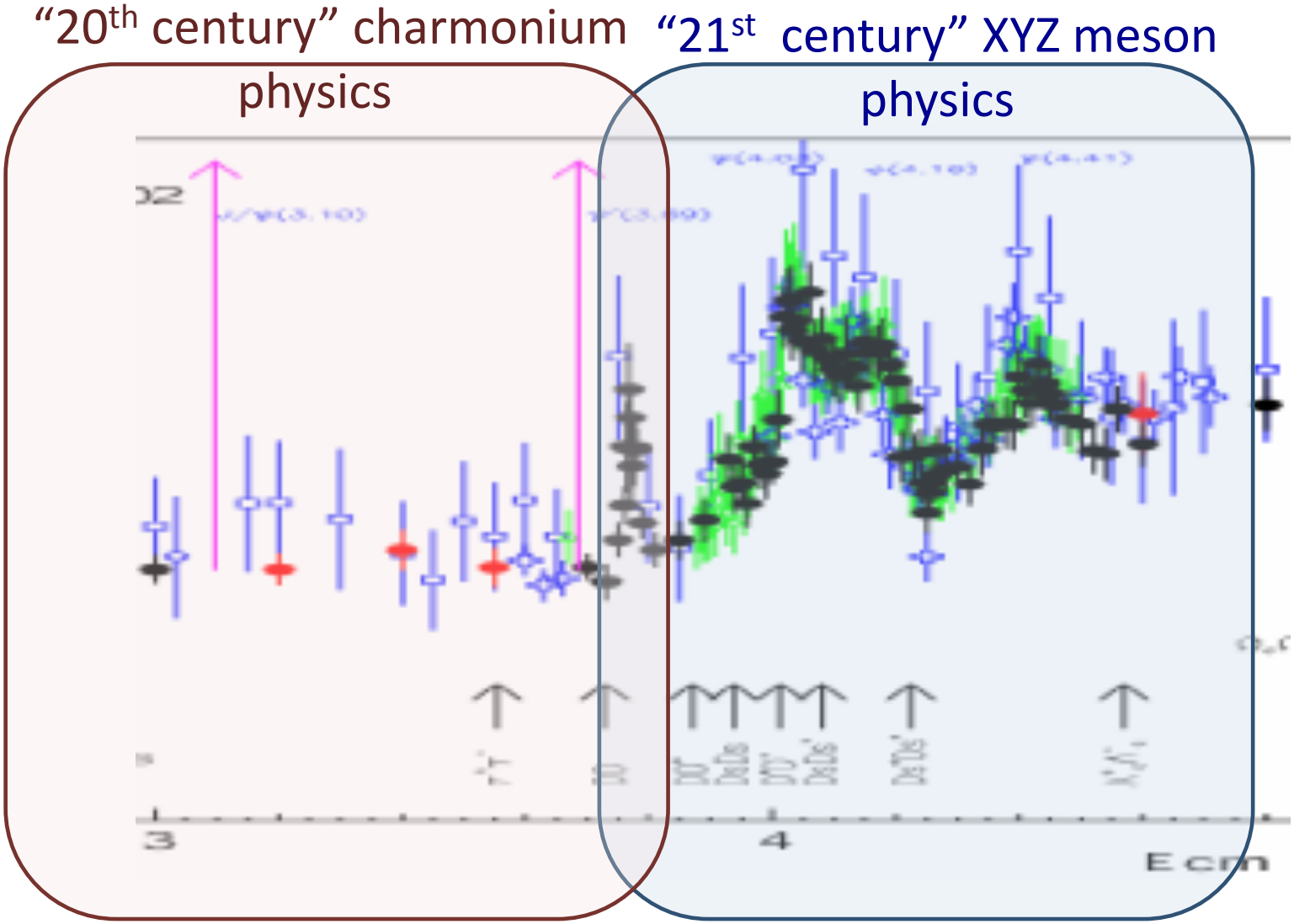
Spectroscopy roadmap for HIEPA



baryon-antibaryon thresholds for baryonium studies

requires $E=2m_p \longrightarrow$ >4.6 GeV≈

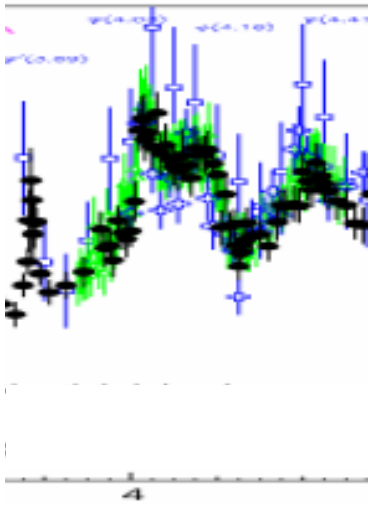
hidden charm spectroscopy roadmap



Opportunity at HIEPA

- totally map out what is happening in
  e^+e^-→ hadrons for $2m_D<E_{cm}<\approx 4.6$ GeV

- multi-dimensional, coupled-channel amplitude analyses for many final states.



These data are "teeming" wit XYZ states

e^+e^-→ Y states ← established
Y states → hadrons+ Z_c states ←established
Y states → γ+ X(3872) ←established
Y states → γ+X(3915) ←seen?

other, new ones likely are there,
waiting to be discovered

Comments

- BESII and BESIII results indicate interesting features at the $p\bar{p}$ and $\Lambda\bar{\Lambda}$ (& other) thresholds.
  - -- HIEPA will offer unique opportunities for high-statistics studies of all stable baryon-antibaryon threshholds
- The charmonium model, a great success of 21st century physics, can't describe the $M>2m_D$ hidden charm spectrum
- e^+e^- annihilations for $2m_D<E_m<4.6$ GeV are a prolific source of many of the XYZ states
- A thorough experimental characterization of e^+e^- hadrons for $E_{cm}>2m_D$ will provide important clues about XYZ physics.
  - --this can only be done at a facility like HIEPA

Thank You