university of groningen

kvi - center for advanced radiation technology

Hunting for Exotic Matter with the BESIII

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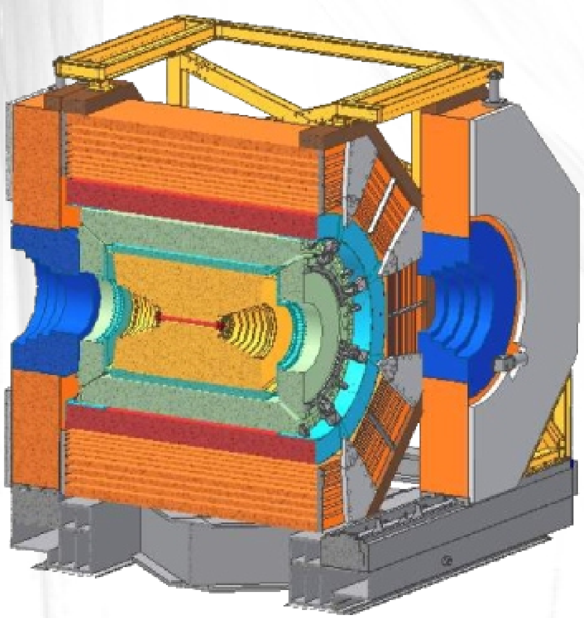
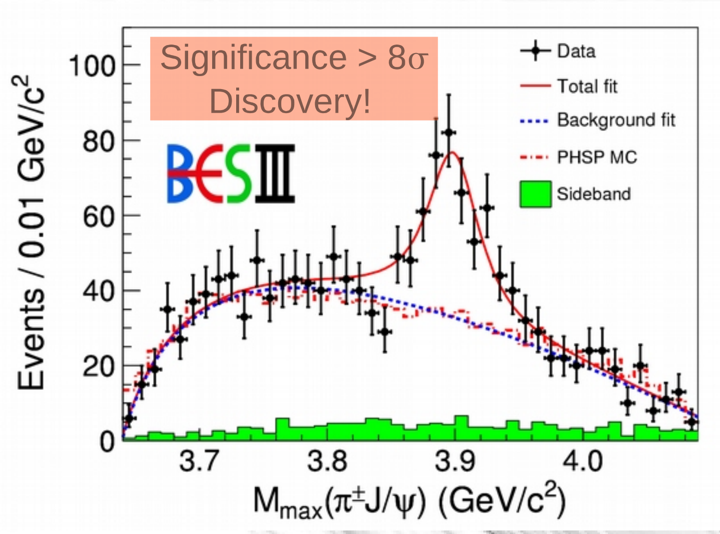
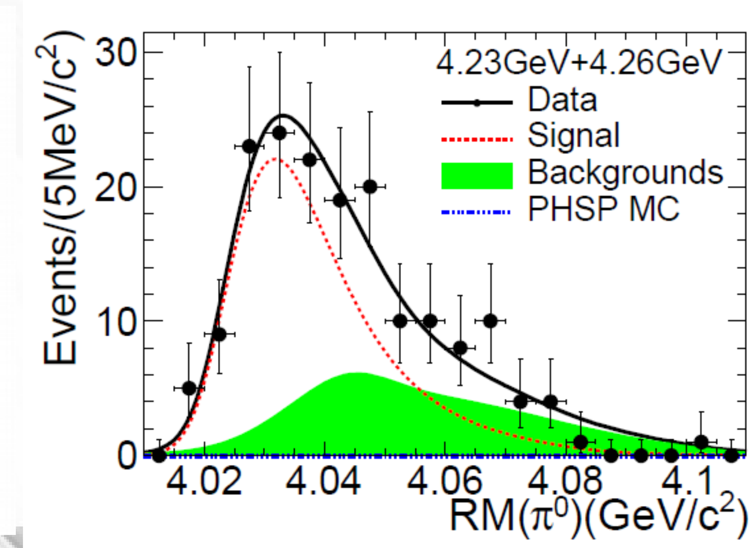
KVI – Center for Advanced Radiation Technology, University of Groningen

For the BESIII collaboration





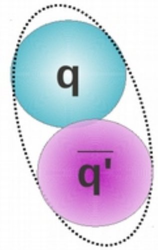


Hadron Matter

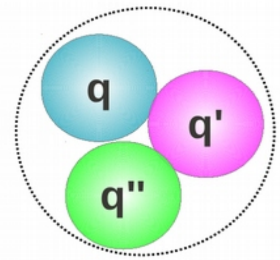
Colour-neutral states allowed by QCD

Conventional matter

Pions, charmonium, etc



Meson

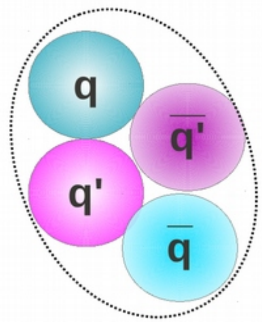


Baryon

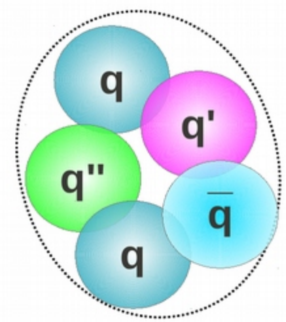
Protons, neutrons, etc

Exotic matter

Z_c and Z_b states



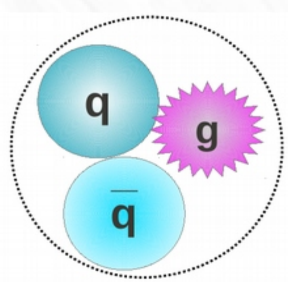
Four-quark state



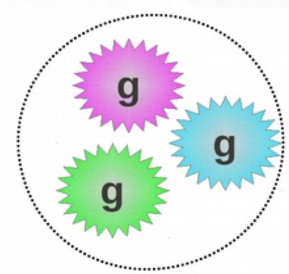
Five-quark state

Pentaquark?

XY states?



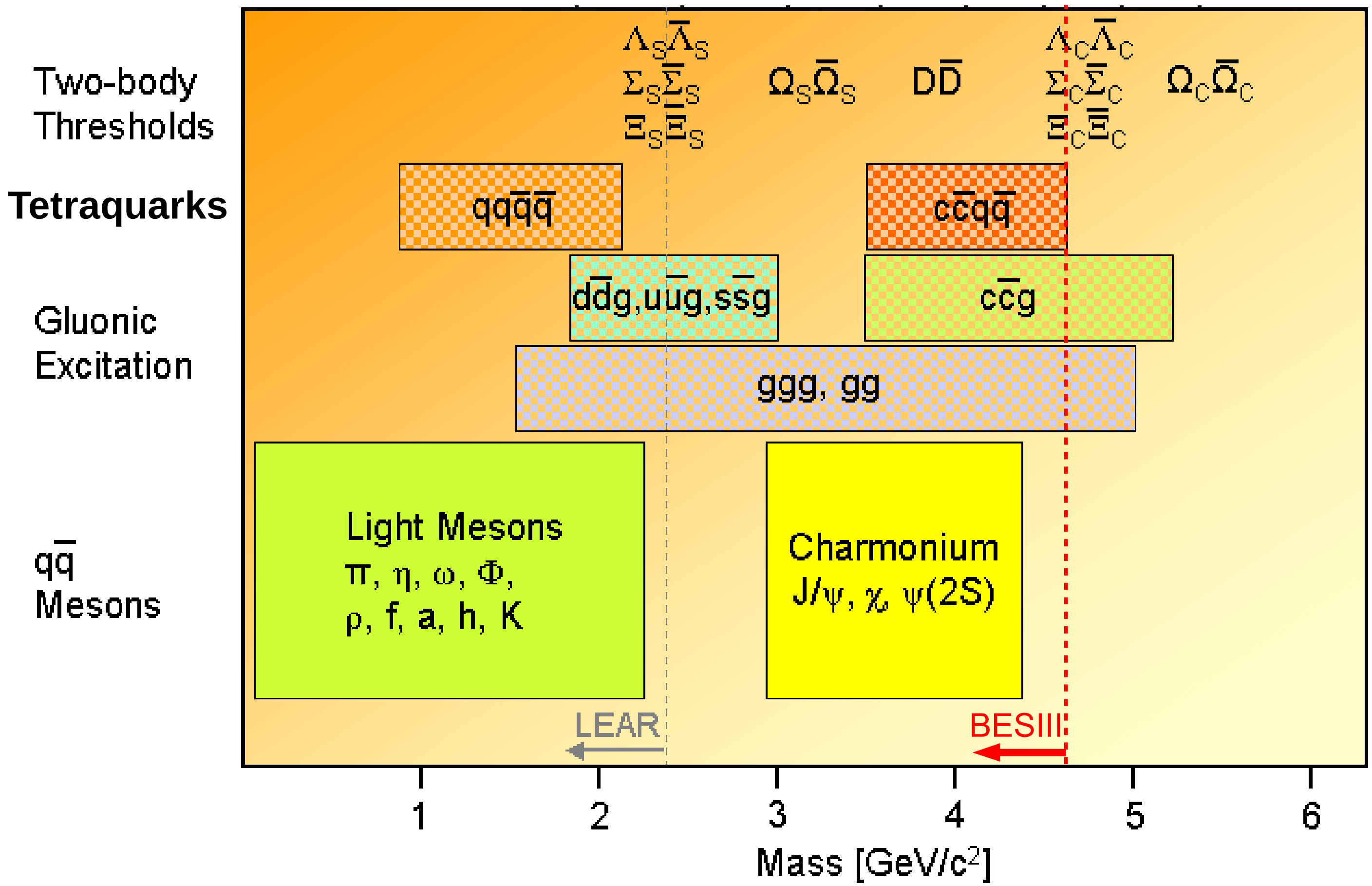
Hybrid



Glueball

$f_0(1500)$?
$f_0(1500)$?
XY states?
...

Hadron Landscape



Hadron-physics challenges:

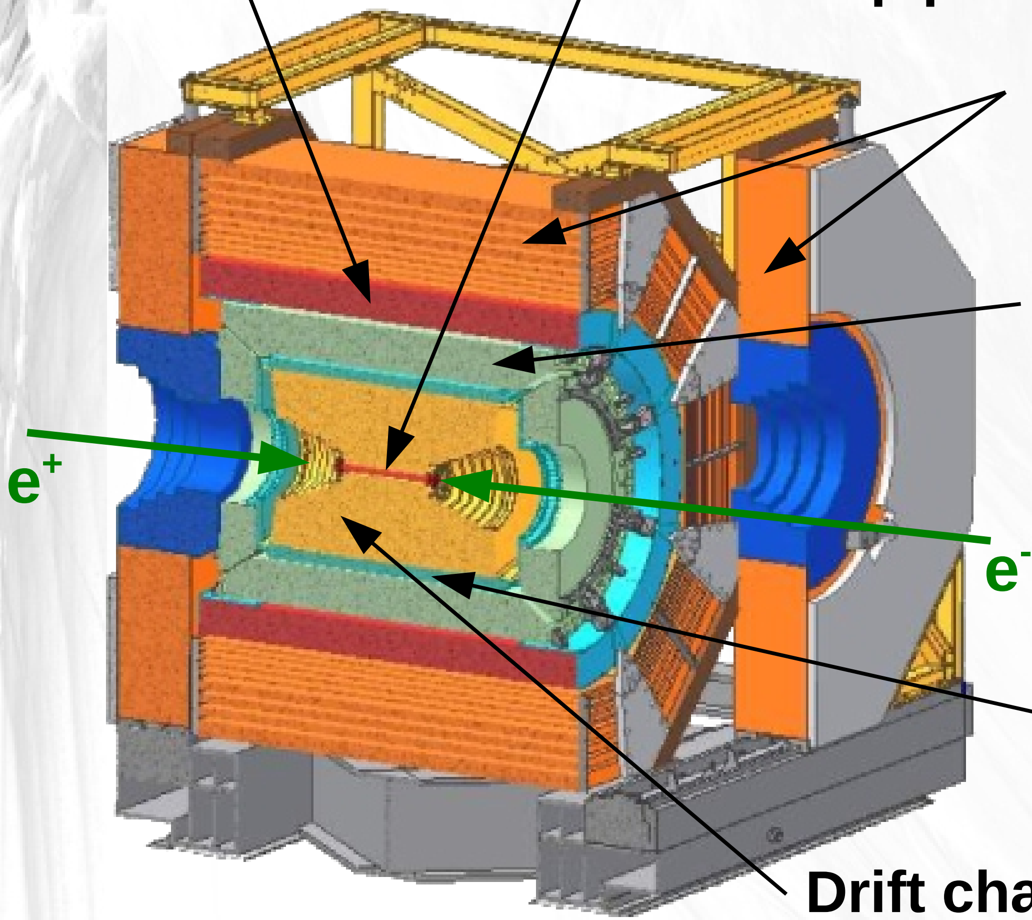
- Understanding of established states: precision spectroscopy
- Nature of exotic states: search and spectroscopy of unexpected states

Clean environment and high luminosity are required for resolving puzzle of exotic matter

BESIII Detector

1.0 Tesla **super-conducting magnet**

Be beam pipe



Muon counters:
9/8 RPC layers (barrel/endcaps)
Cut-off momentum: 0.4 GeV/c

CsI(Tl) **ElectroMagnetic Calorimeter:**
σ_E/E (at 1 GeV): 2.5 %
$\sigma_{z,\phi}$ (at 1 GeV): 6 mm

Time Of Flight (TOF):
σ_T: 100/110 ps (barrel/endcaps)

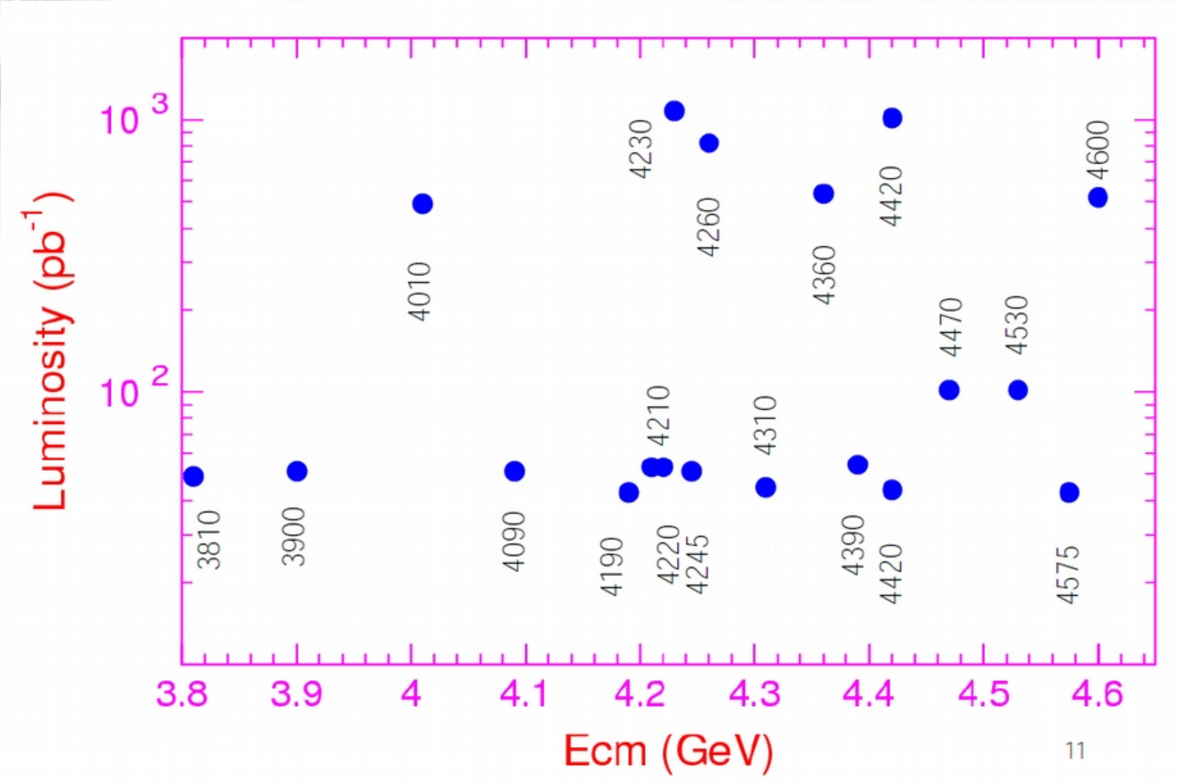
Drift chambers (MDC):
σ_p/p (at 1 GeV): 0.5 %
$\sigma_{dE/dx}$: 6 %

M. Ablikim *et al.*, Nucl. Instr. and Meth. **A 614** (2010) 345–399

BESIII: Collected Data

July 18, 2008: First $e^+ e^-$ collision event in BESIII

~ 0.6 B	Ψ' events	~ 24×CLEO-c
~ 1.2 B	J/Ψ events	~ 21×BESII
~ 42pb^{-1}	at 3.65 GeV	
~ 2.9fb^{-1}	Ψ''	~ 11×CLEO-c
~ 70pb^{-1}	scanning of the Ψ'' region	



- 104 energy points between **3.85** and **4.6 GeV**
- ~20 energy points between **2.0** and **3.1 GeV**

Record Luminosity so far:
8.5×10^{32} cm^{-2} s^{-1}

(design value: 10^{33} cm^{-2} s^{-1})

BESIII: Collected Data

July 18, 2008: First $e^+ e^-$ collision event in BESIII

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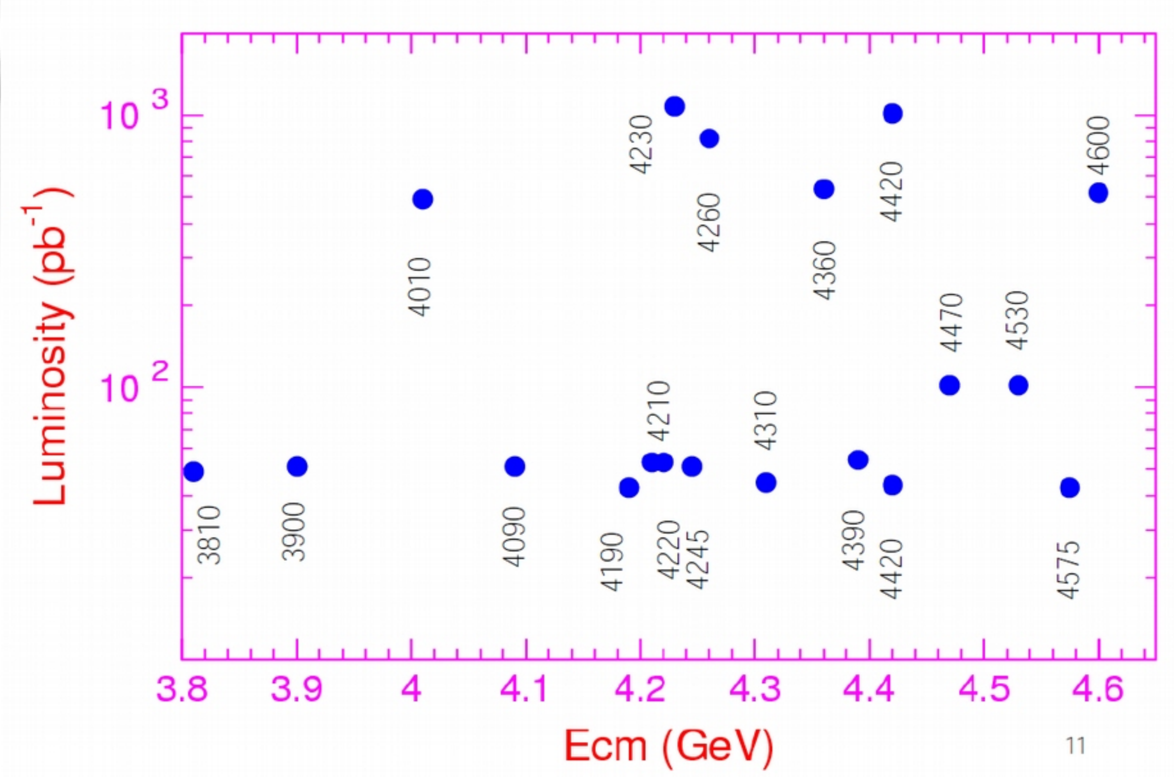


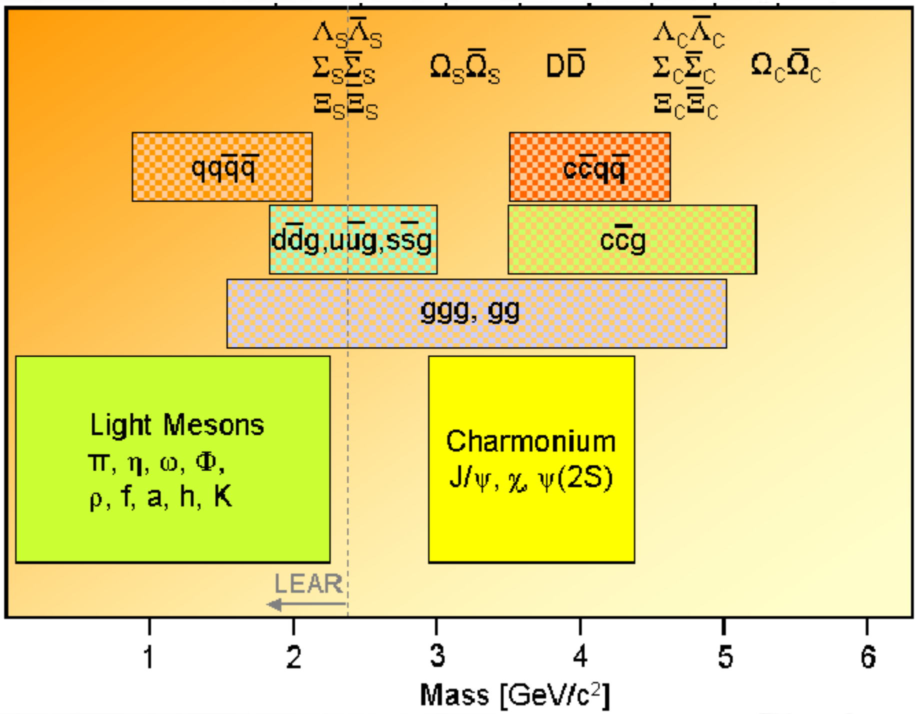
High luminosity,
clean environment

Access to precise measurements of rare processes:

Key to understanding of exotic matter

Physics Topics at BESIII

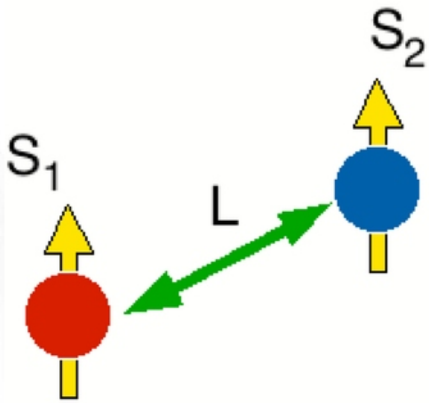
- **Hadron spectroscopy**
  - search for the new forms of hadrons
  - meson spectroscopy
  - baryon spectroscopy



- **Study of the production and decay mechanisms of charmonium states:** J/Ψ, $\Psi(2S)$, $\eta_C(1S)$, $\chi_{C\{0,1,2\}}$, $\eta_C(2S)$, $h_C(^1P_1)$, $\Psi(3770)$, etc.
  - XYZ states

- **Precise measurement of R values, τ mass, hadron FF**
- **Precise measurement of CKM matrix**
- **Search for DDbar mixing, CP violation, etc.**

Meson Spectroscopy:
light-quark sector



$S = S_1 + S_2$

$J = L + S$

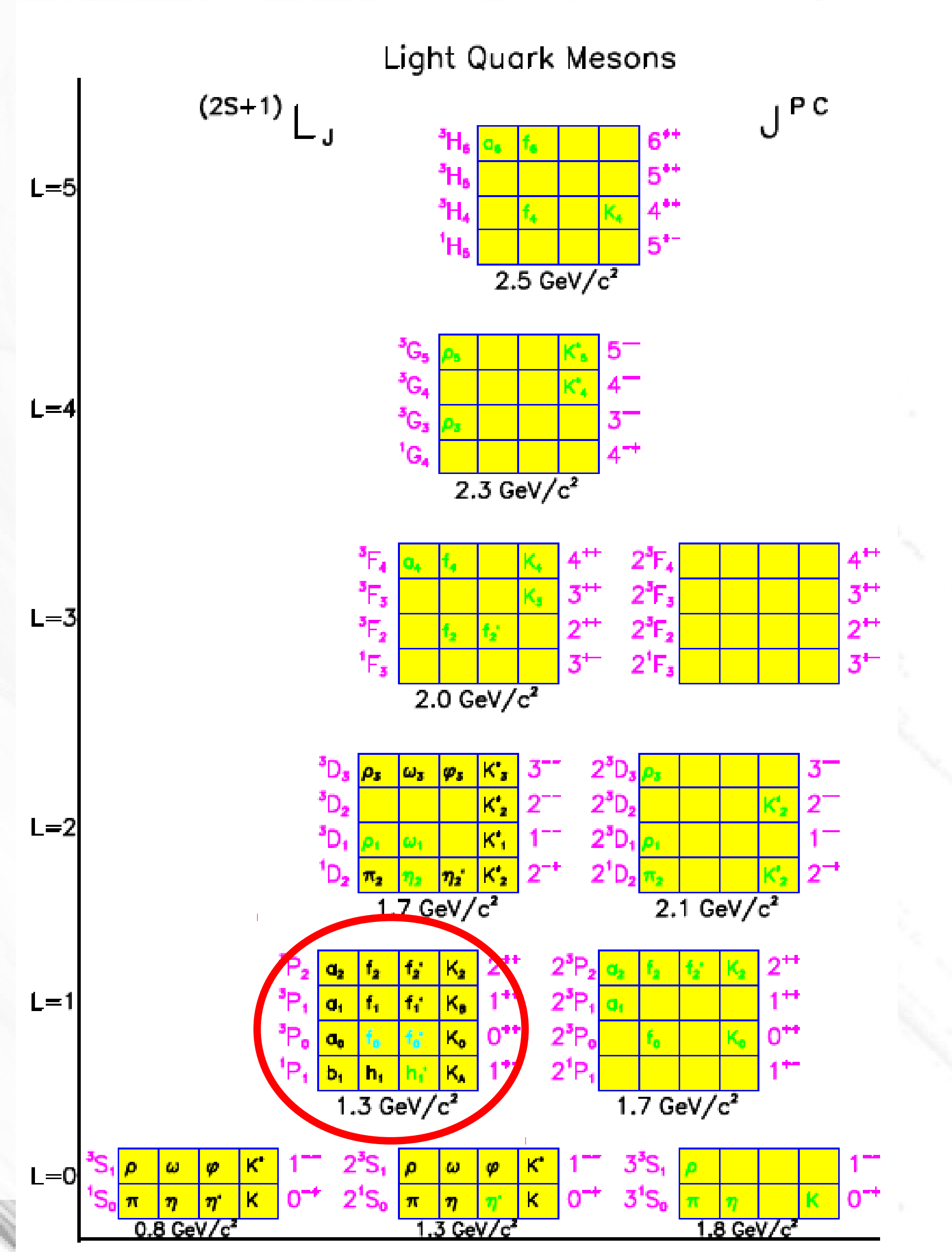
$P = (-1)^{L+1}$

$C = (-1)^{L+S}$

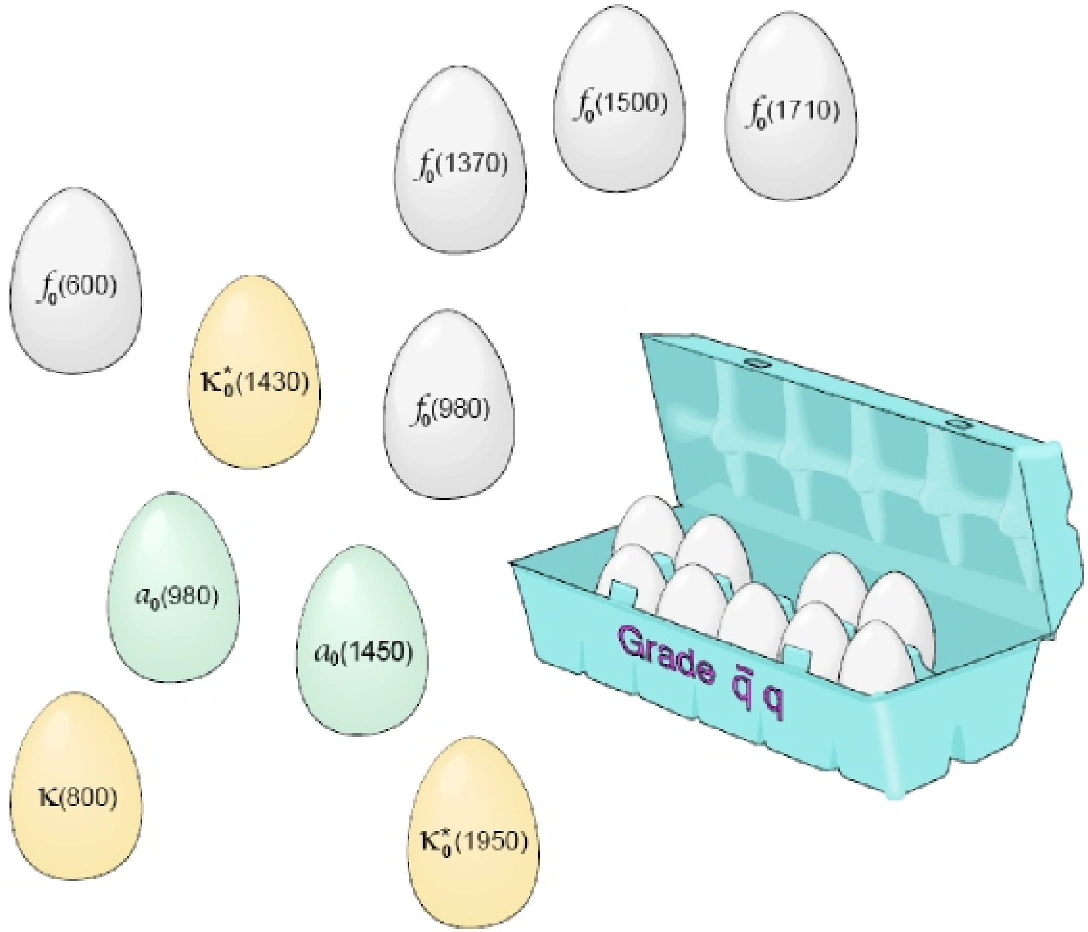
Classification in SU(3) nonets

Spectrum consists of increasingly larger number of overlapping states from 1-2 GeV/c²

A Partial-Wave Analysis and exploiting variety of final states and production mechanisms are needed to disentangle the light-quark mesons



Over-population?

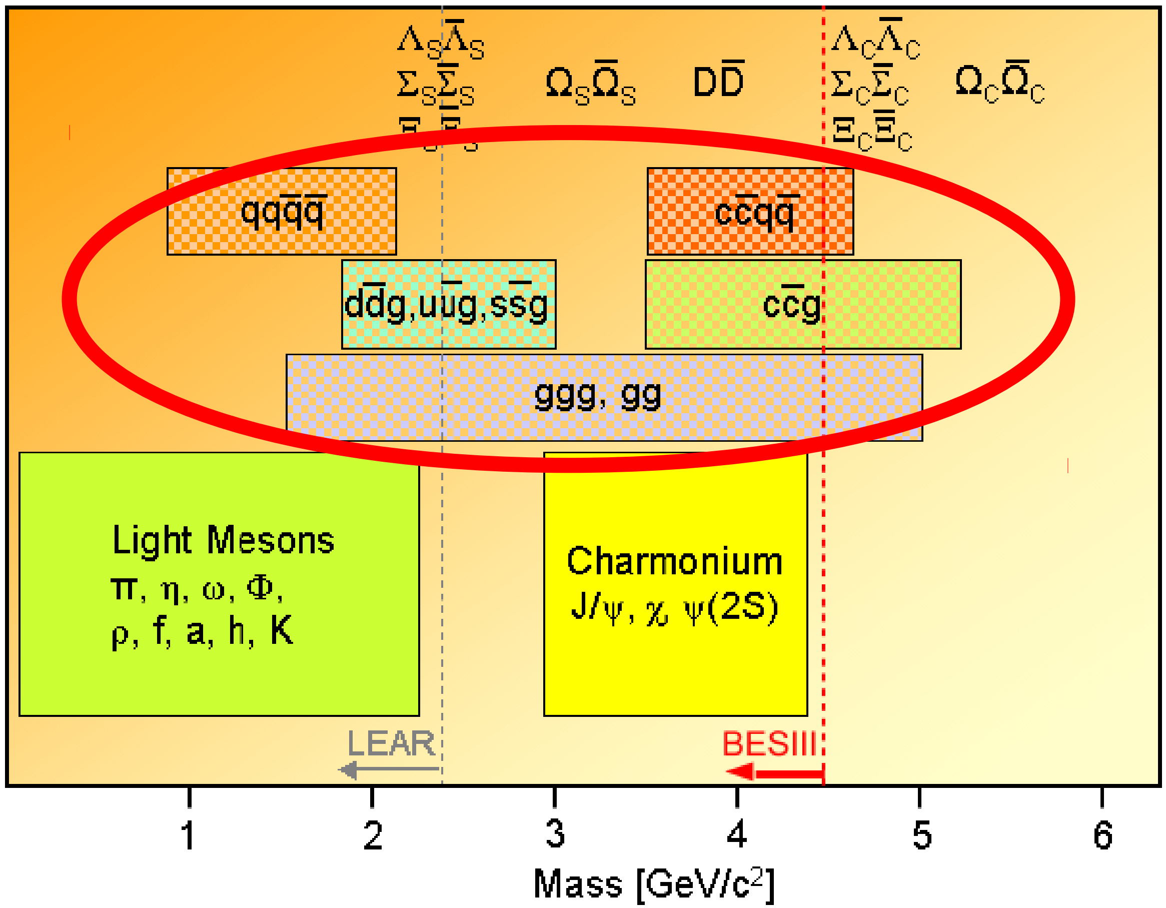


	$(u\bar{d}, u\bar{u}-d\bar{d}, d\bar{u})$	$(u\bar{u}+d\bar{d}, s\bar{s})$		$(u\bar{s}, s\bar{u}, d\bar{s}, s\bar{d})$
2^{++}	a_2 1320	f_2 1270	f'_2 1525	K^*_2 1430
1^{++}	a_1 1260	f_1 1285	f'_1 1510	K_{1A}
1^{+-}	b_1 1235	h_1 1170	h'_1 1380	K_{1B}
0^{++}	a_0	f_0	f'_0	K^*_0 1430

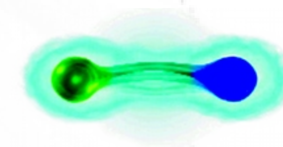
$a_0(980)$ $f_0(1370)$ $f_0(980)$
$a_0(1450)$ $f_0(1500)$ $f_0(1710)$

L = 1

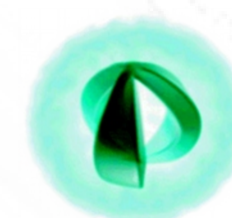
New forms of hadrons



$|\bar{c}\,c\rangle$



$|\bar{c}\,c\,g\rangle$

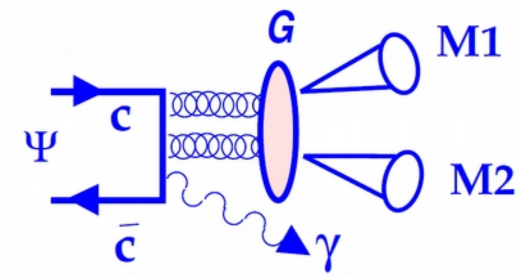


$|g\,g\,g\rangle$

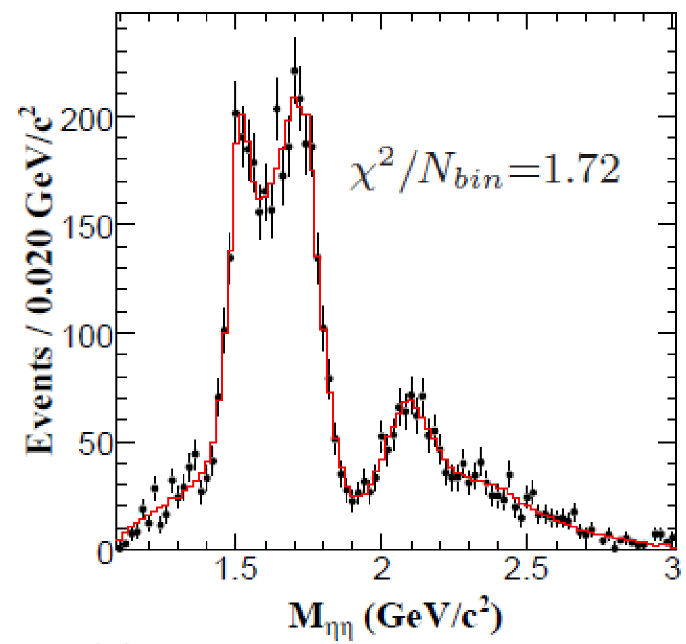
Glueball Searches with BESIII

PWA of $J/\Psi \rightarrow \gamma\eta\eta$

Radiative J/Ψ decay – a gluon-rich process →
one of the most promising hunting grounds for glueballs



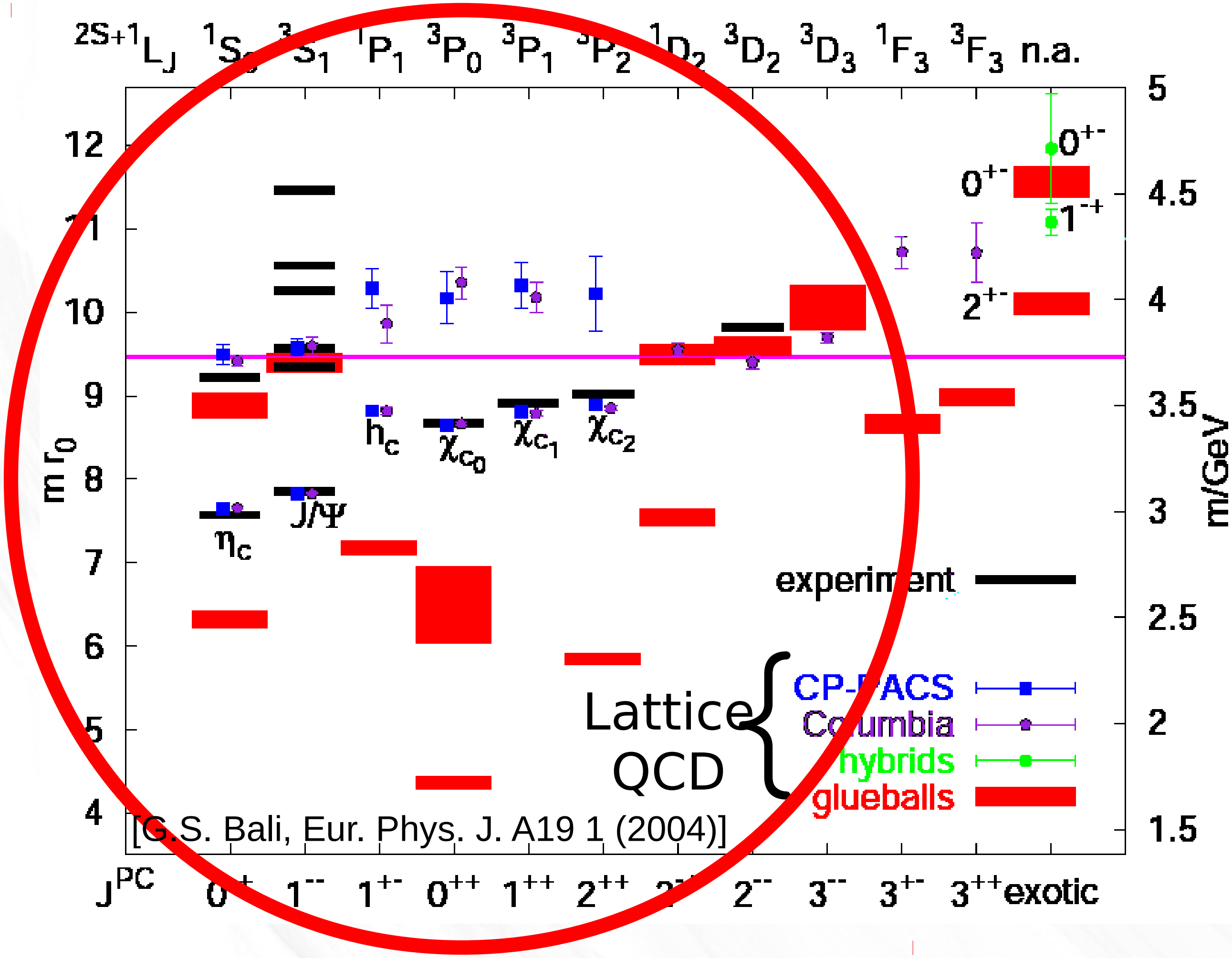
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	$8.2\ \sigma$
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	$25.0\ \sigma$
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	$13.9\ \sigma$
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	$11.0\ \sigma$
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	$6.4\ \sigma$
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	$7.6\ \sigma$



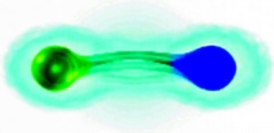
[Phys. Rev. D 87, 092009 (2013)]

- Scalar contributions mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$
- Production rate of $f_0(1710)$ consistent with predicted glueball production
  [Phys. Rev. Lett. 110, 021601 (2013)] →
  $f_0(1710)$ has a larger overlap with the glueball
  compared to other glueball candidates

Exotics in Light-Hadron Sector



$|\bar{c}\,c\rangle$



$|\bar{c}\,c\,g\rangle$

$|g\,g\,g\rangle$

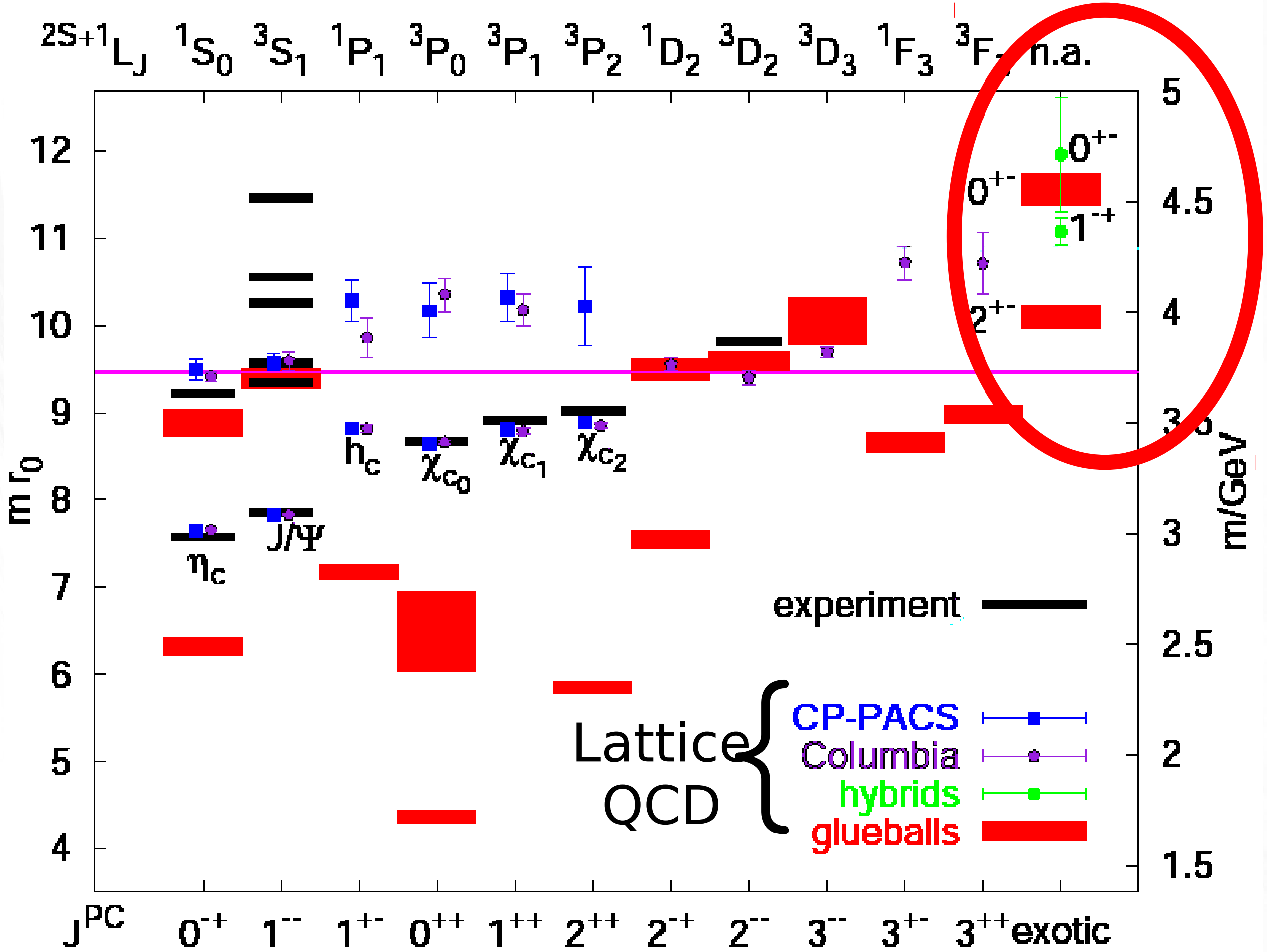
Difficult to uniquely identify:

mixed with “normal” states

Any hope for unique identification?

BESIII

Unique spin-symmetry properties



Antiproton beam with high resolution will allow to directly populate and analyse charmonium and exotic states (full range of quantum numbers)

AntiProton Annihilation at DArmstadt (PANDA)

PANDA spectrometer employs fixed target and **cooled antiproton** beam:

momentum range 1.5 GeV/c to 15 GeV/c

Luminosity: $2 \cdot 10^{32}$ cm^{-2}s^{-1} ($\sigma_{\bar{p}}/\bar{p} \leq 2 \cdot 10^{-4}$)

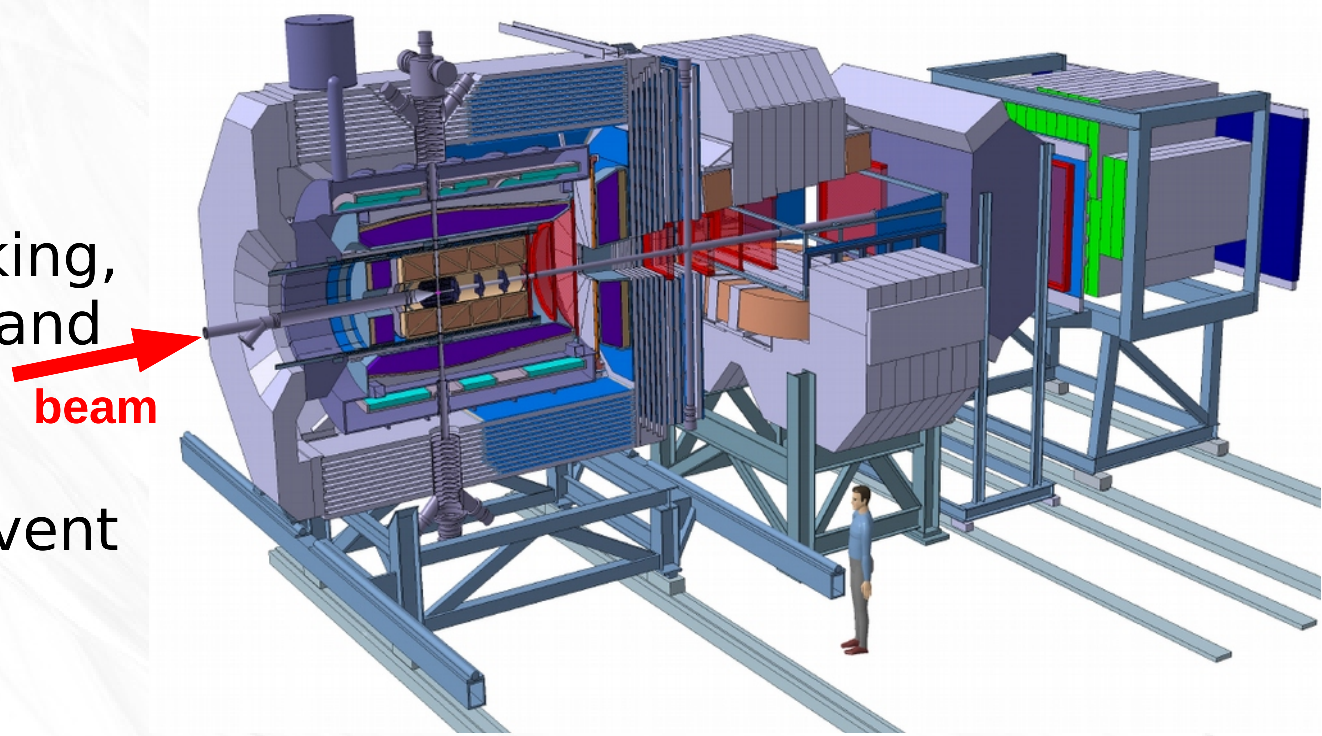
$2 \cdot 10^{31}$ cm^{-2}s^{-1} ($\sigma_{\bar{p}}/\bar{p} \leq 2 \cdot 10^{-5}$)

PANDA is:

- high resolution
- 4π spectrometer

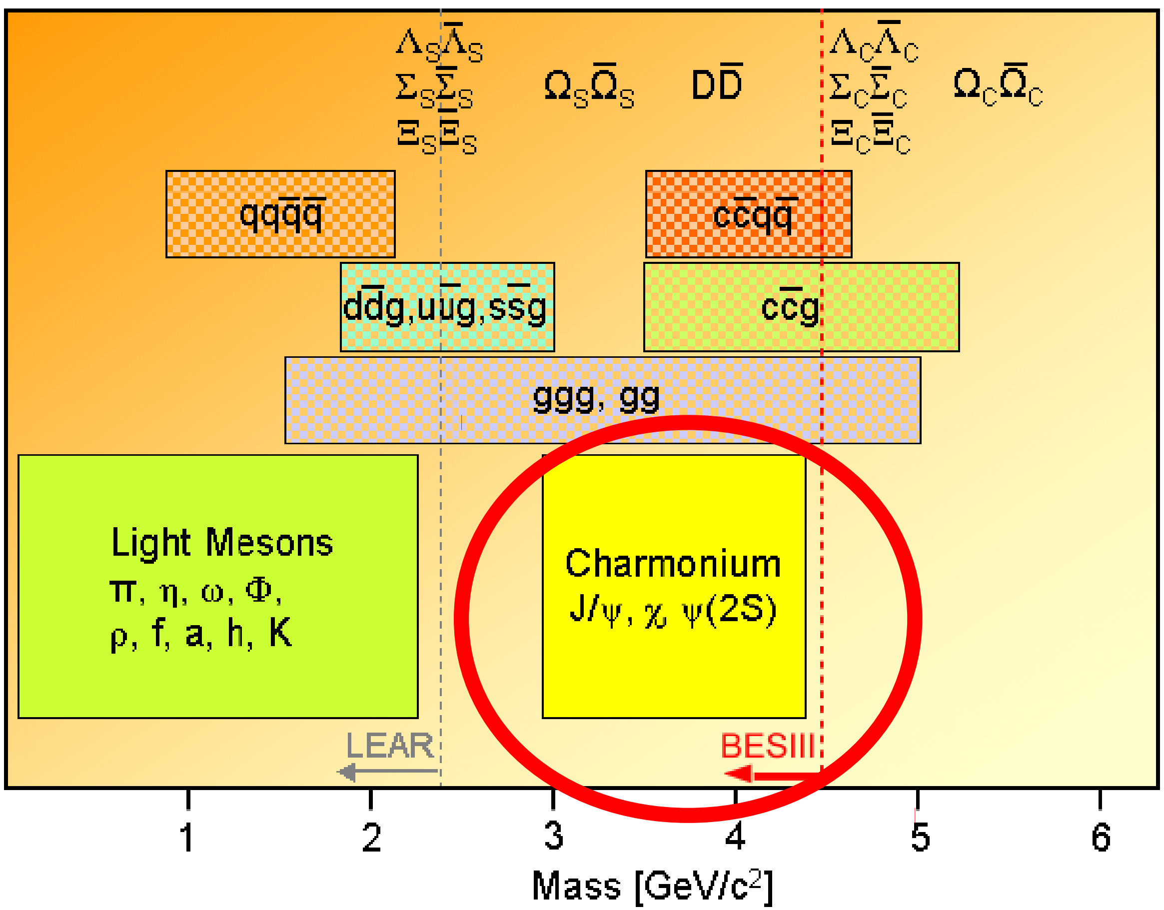
Designed to achieve:

- high resolution for tracking, particle identification and calorimetry
- high rate capability
- versatile readout and event selection



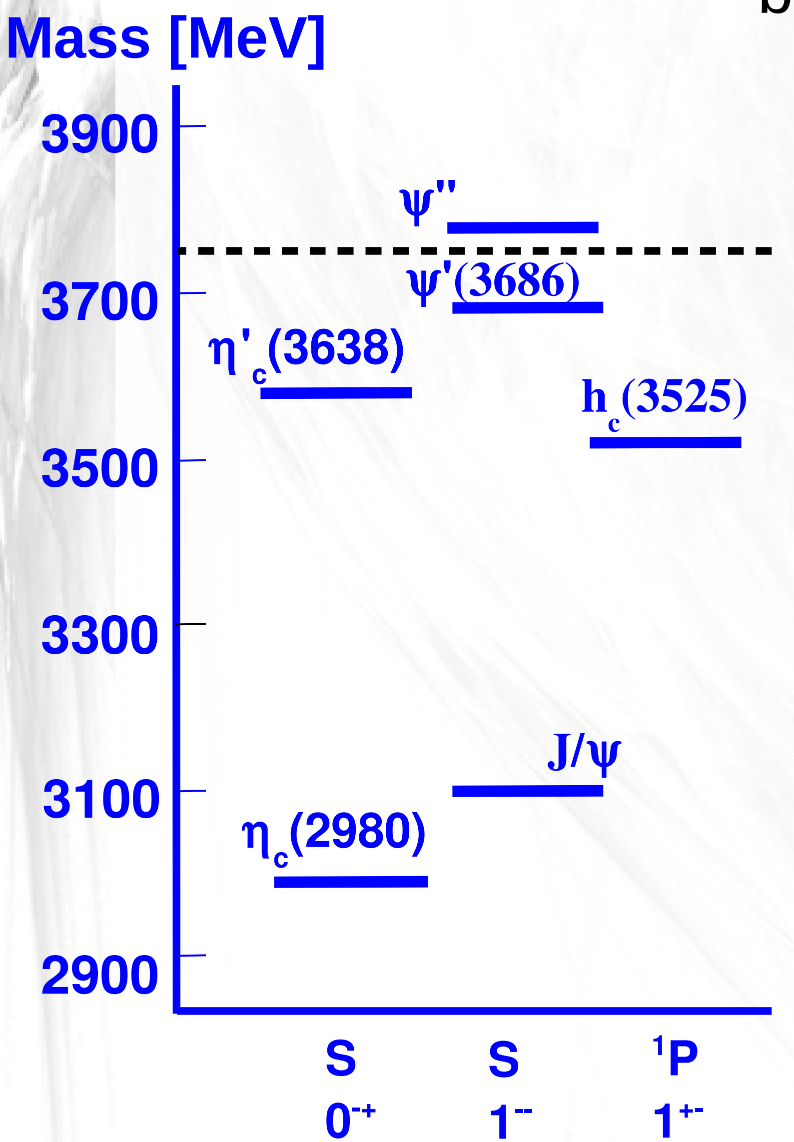
PANDA will have a direct access to exotic hadrons at a price of huge hadron background

Precision charmonium spectroscopy

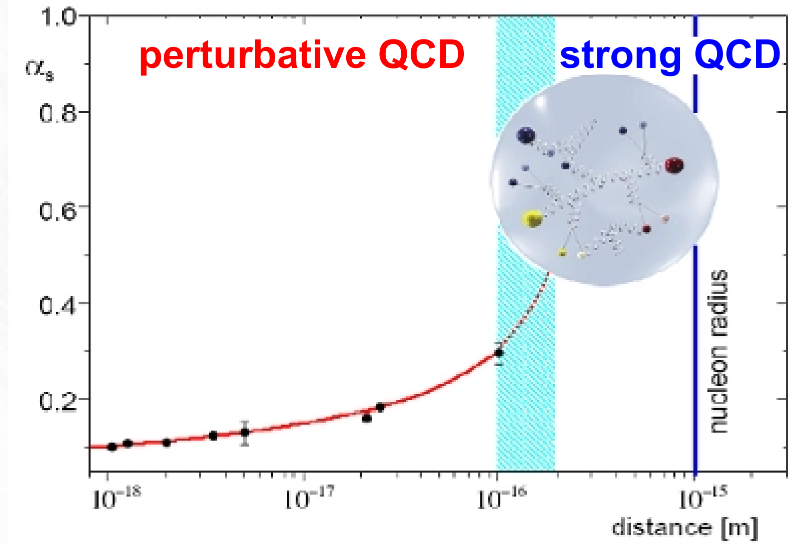


Charmonium Physics

Charmonium (a bound state of $c\bar{c}$ quarks) –
bridge between perturbative and strong QCD



Strong-interaction coupling constant



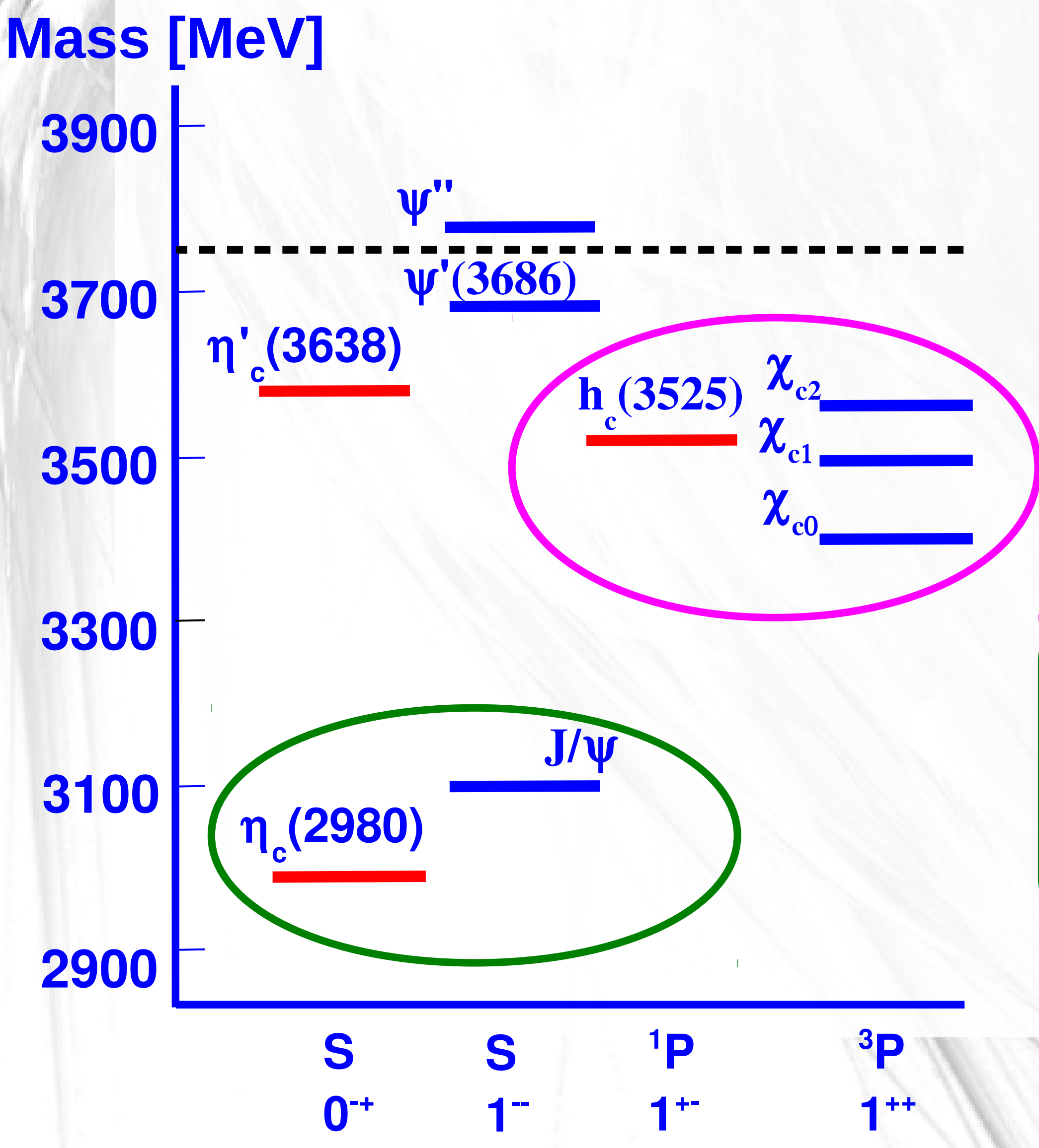
Precise data on the key charmonium states and transitions

Insight into the strong interactions at long-distance scales (test of Potential models, lattice QCD, EFT)

State Properties as a Probe

BESIII

Precise measurement of charmonium masses and widths → **Test of potential models and lattice QCD**



Potential model: if P-wave spin-spin interaction is non-zero:

$$\Delta M_{hf}(1P) = M(h_c) - \langle m(1\,^3P_J)\rangle \neq 0$$

$$\langle m(1^3P_J)\rangle = \sum_{J=0}^{2} M_{\chi cJ}(2J+1)/9$$

Expected value $\Delta M_{hf}(1P) = 0$

Hyperfine splitting: **M(J/Ψ) – M(η_c)**: important input to test lattice QCD, **dominated by error on M(η_c)!**

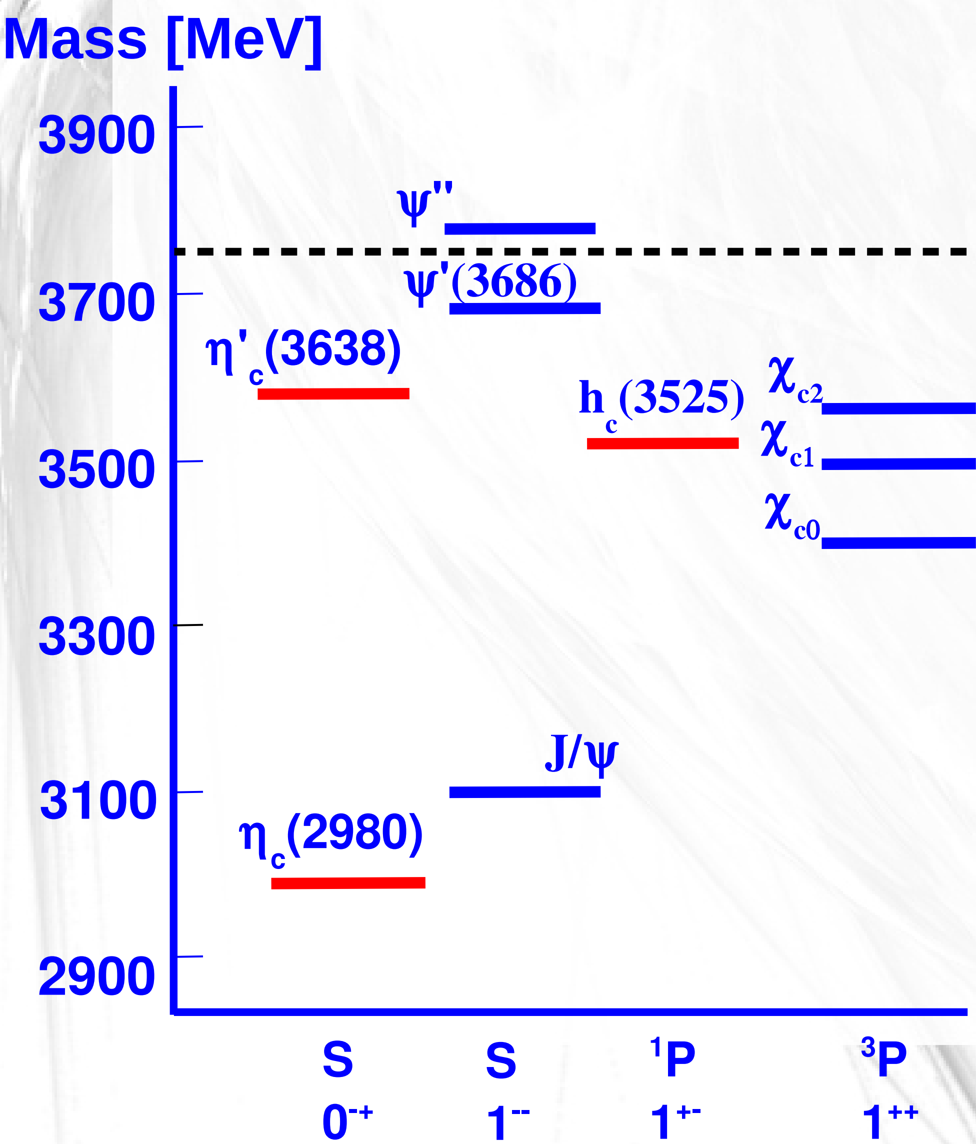
LQCD prediction:

$\Delta M(1S) = 116.5 \pm 3.2$ MeV

[Phys. Rev. D 86, 094501 (2012)]

State Properties as a Probe

Mass and width measured with comparable or better precision:



η$_c$'(3638)

[Phys. Rev. Lett. 109, 042003 (2012)]

- **M = 3637.6 ± 2.9 ± 1.6 MeV**
- **Γ = 16.9 ± 6.4 ± 4.8 MeV**

h$_c$(3525)

[Phys. Rev. Lett. 104, 132002 (2010)]

- **M = 3525.40 ± 0.13 ± 0.18 MeV**
- **Γ = 0.73 ± 0.45 ± 0.28 MeV**

first measurement!

[Phys. Rev. D 86, 092009 (2012)]

- **M = 3525.31 ± 0.11 ± 0.14 MeV**
- **Γ = 0.7 ± 0.28 ± 0.22 MeV**

η$_c$(2980)

[Phys. Rev. Lett. 108, 222002 (2012)]

- **M = 2984.3 ± 0.6 ± 0.6 MeV**

understood resonance shape!

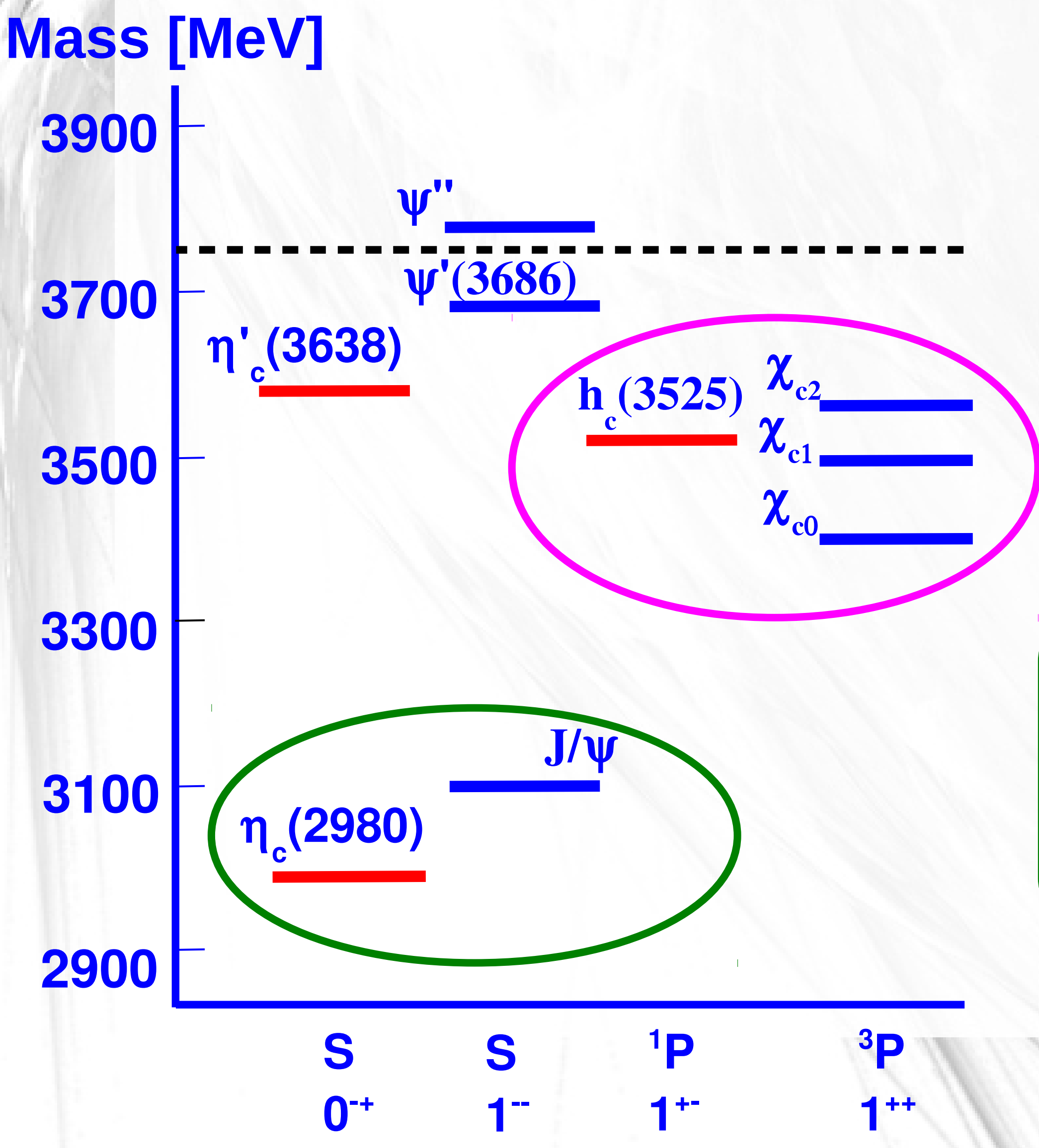
- **Γ = 32.0 ± 1.2 ± 1.0 MeV**

[Phys. Rev. D 86, 092009 (2012)]

- **M = 2984.49 ± 1.16 ± 0.52 MeV**
- **Γ = 36.4 ± 3.2 ± 1.7 MeV**

State Properties as a Probe

Precise measurement of charmonium masses and widths → **Test of potential models and lattice QCD**



Potential model: if P-wave spin-spin interaction is non-zero:

$$\Delta M_{hf}(1P) = M(h_c) - \langle m(1\,^3P_J)\rangle \neq 0$$

$$\langle m(1^3P_J)\rangle = \sum_{J=0}^{2} M_{\chi_{cJ}}(2J+1)/9$$

$\Delta M_{hf}(1P) = -0.01 \pm 0.11 \pm 0.15$ MeV

Consistent with zero!

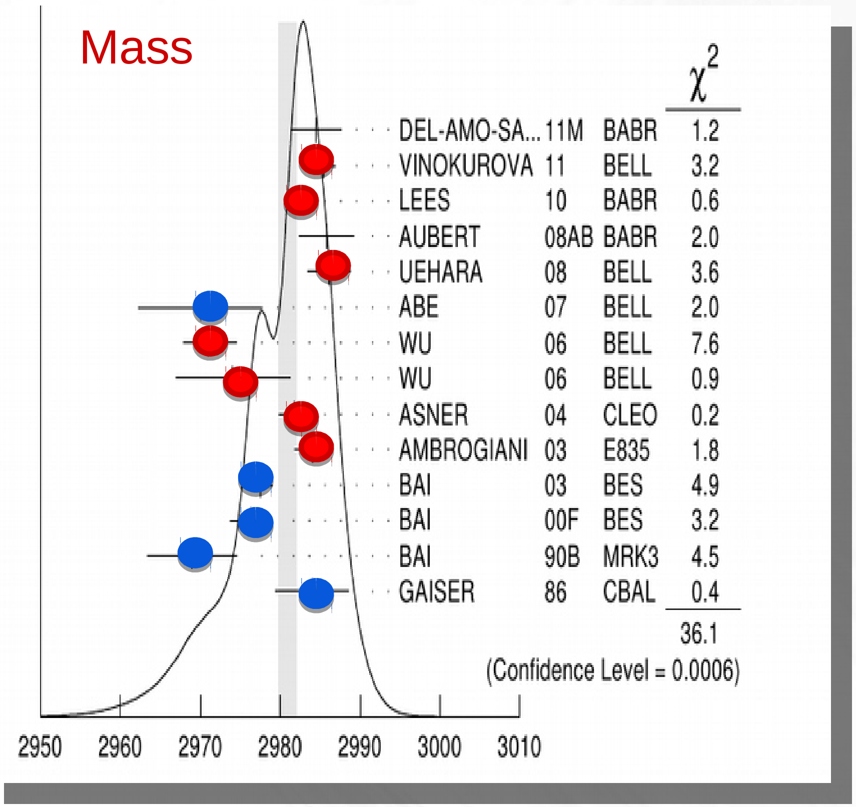
Hyperfine splitting: **$M(J/\Psi) - M(\eta_c)$**: important input to test lattice QCD, **dominated by error on $M(\eta_c)$!**

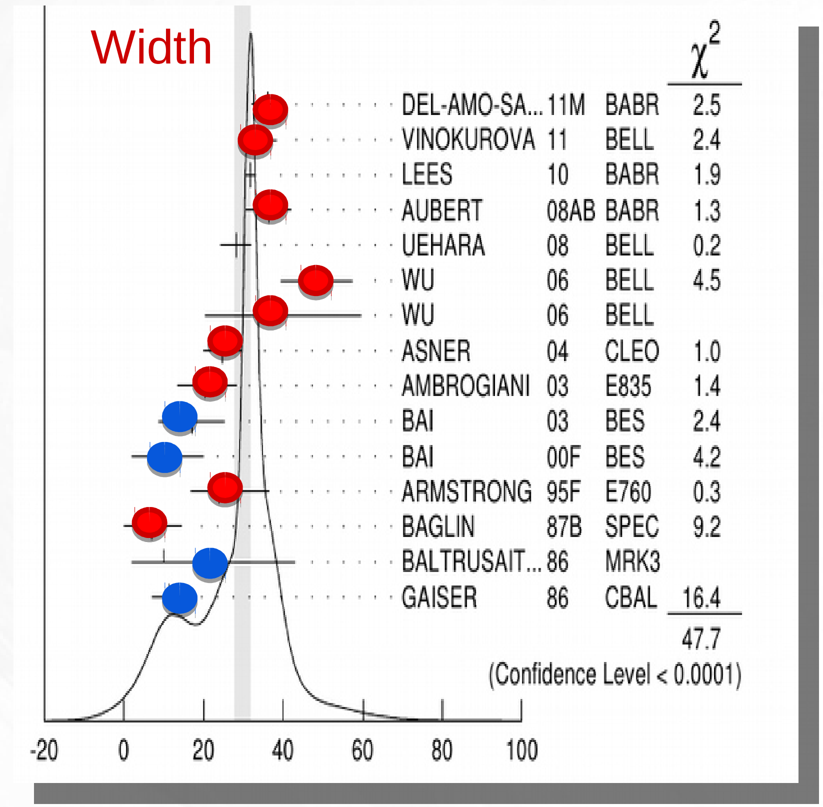
$\Delta M(1S) = 112.5 \pm 0.8$ MeV

Good agreement with LQCD

Better precision than LQCD!

Puzzle of the η_c Properties





● **J/ψ radiative transition**

● **γ γ processes, PP, B→Kη_c**

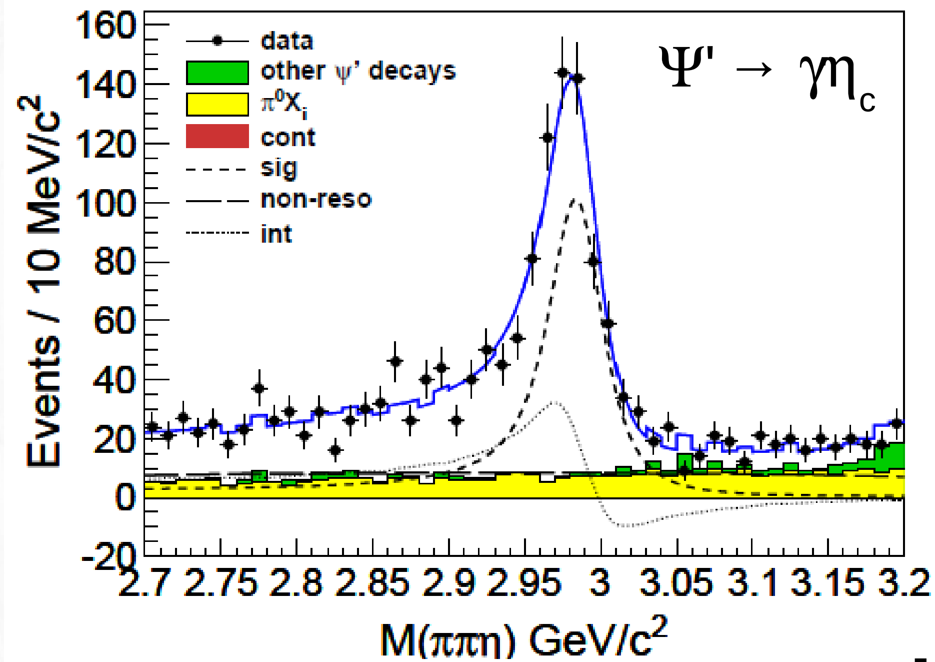
Measurements in different decay modes yielded not consistent values

- η_c-resonance: interference with non-resonant backgrounds → difficult to measure

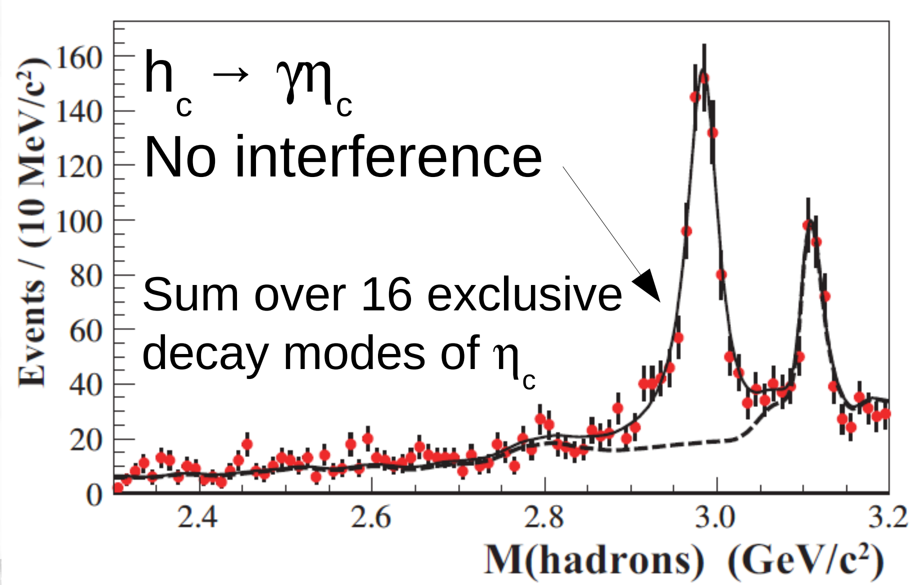
- Only recently consistent results were obtained [Phys. Rev. Lett. 102, 011801 (2009), Phys. Lett. B 706, 139 (2011), Phys. Rev. D 84, 012004 (2011), **Phys. Rev. Lett. 108, 222002 (2012)**]

- $h_c \to \gamma\eta_c$ E1 transition: small non-resonant background → the η_c line shape is less distorted

- Consistent and precise measurement of h_c and η_c parameters
- Determined branching ratios for 16 exclusive η_c decays (5 measured for the first time)



[Phys. Rev. Lett. 108, 222002 (2012)]

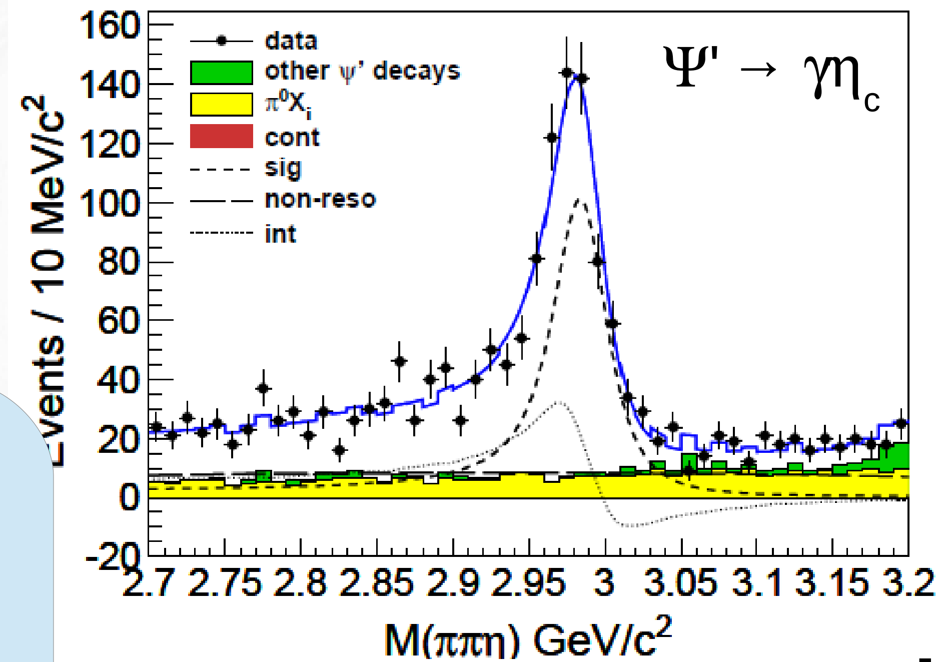


[Phys. Rev. D 86, 092009 (2012)]

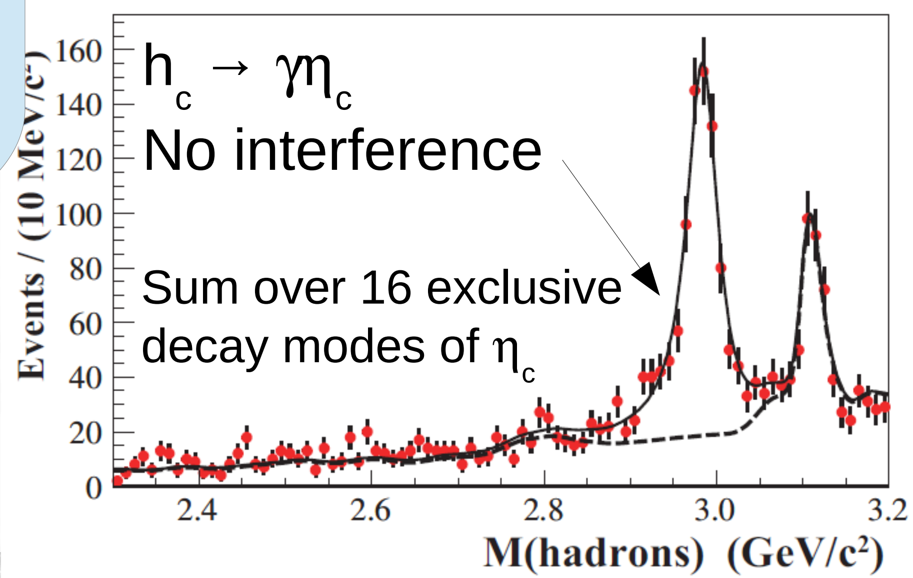
$\Psi' \to \pi^0 h_c,\ h_c \to \gamma\eta_c$

This puzzle could be related to the non-pQCD mechanisms

Systematic studies of the η_c line shape in different channels is ongoing at BESIII



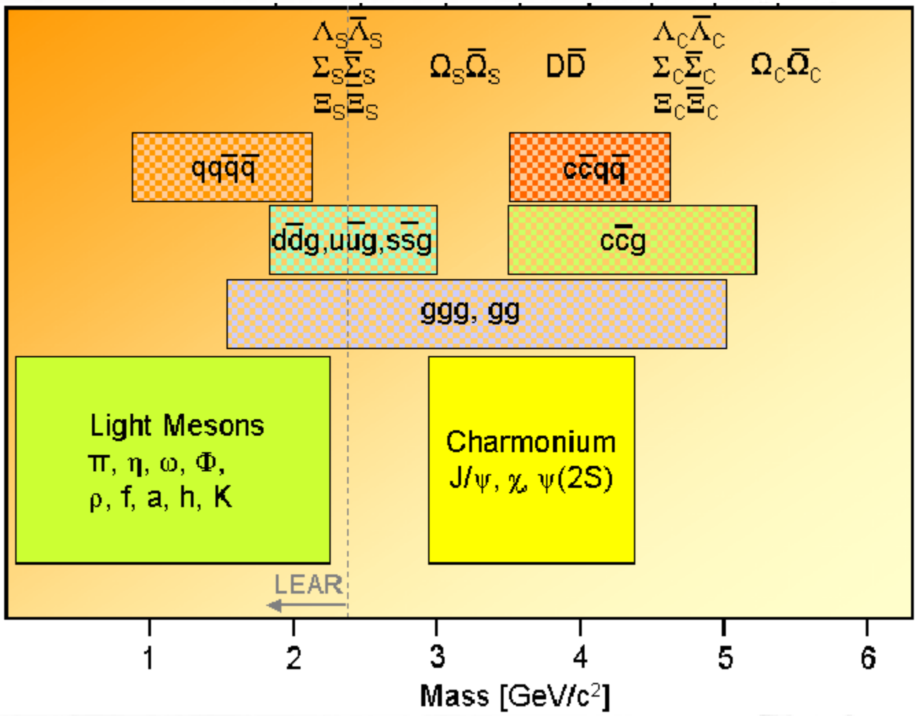
[Phys. Rev. Lett. 108, 222002 (2012)]



[Phys. Rev. D 86, 092009 (2012)]

Physics Topics at BESIII

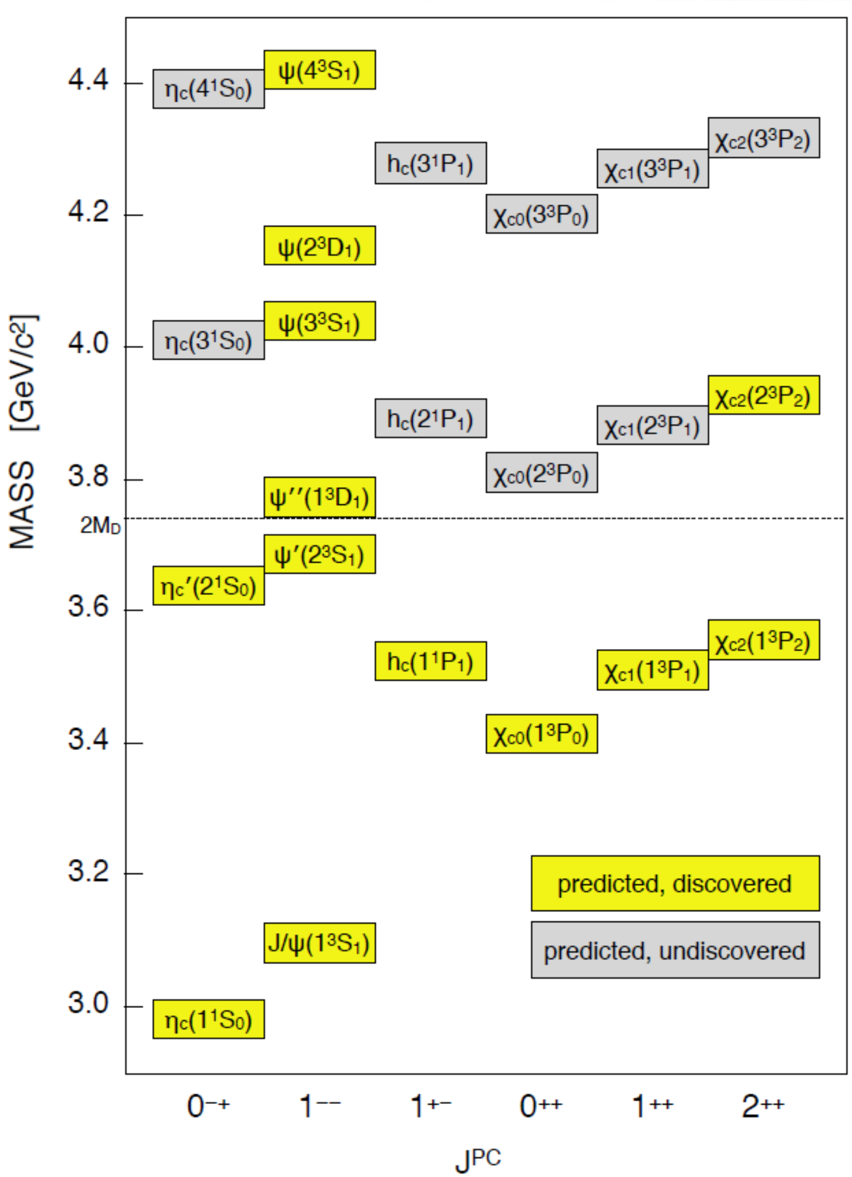
- **Hadron spectroscopy**
  - search for the new forms of hadrons
  - meson spectroscopy
  - baryon spectroscopy



- **Study of the production and decay mechanisms of charmonium states:** J/Ψ, Ψ(2S), $\eta_C(1S)$, $\chi_{C\{0,1,2\}}$, $\eta_C(2S)$, $h_C(^1P_1)$, Ψ(3770), etc.
  - XYZ states

- **Precise measurement of R values, τ mass, hadron FF**
- **Precise measurement of CKM matrix**
- **Search for DDbar mixing, CP violation, etc.**

Charmonium Region



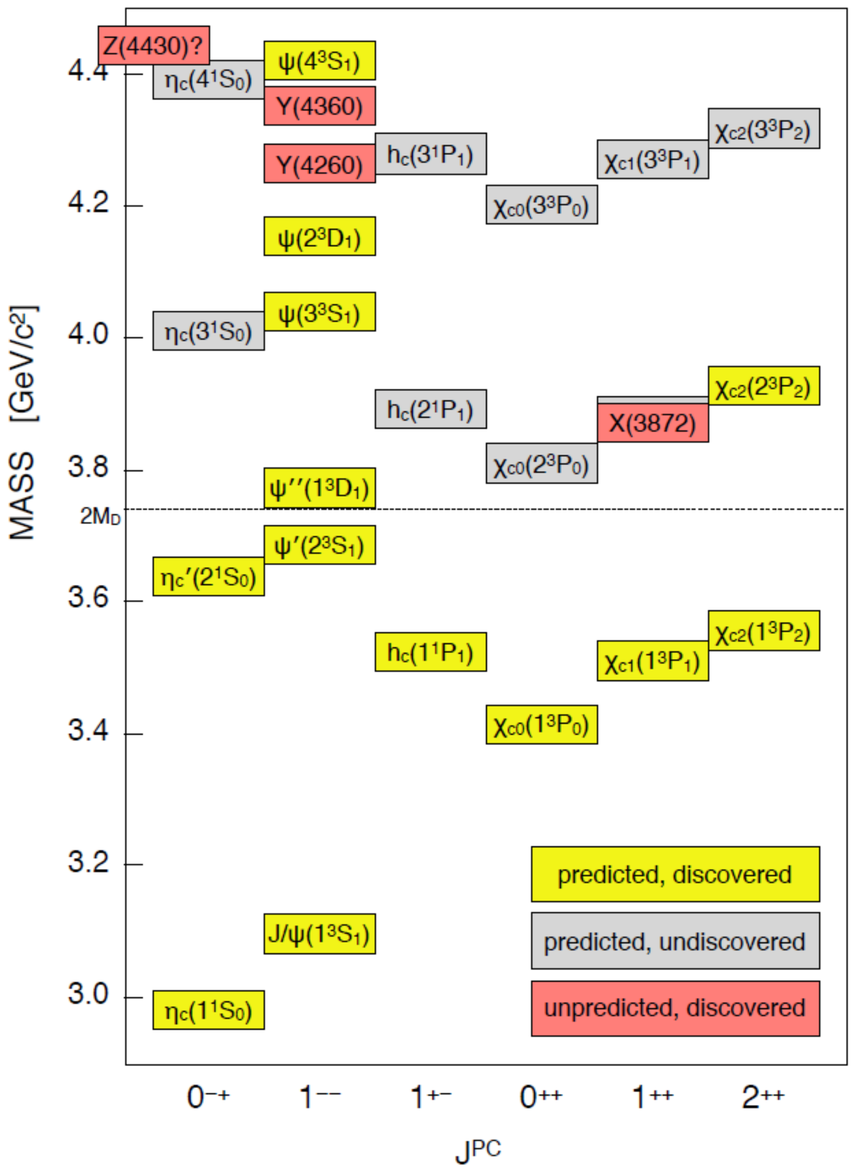
Hidden-charm region of the spectrum is well understood,

however,

in the open-charm region there are predicted states, but not yet seen...

Moreover...

Charmonium Region



Hidden-charm region of the spectrum is well understood,

however,

in the open-charm region there are predicted states, but not yet seen...

Moreover...

In the last decade there were found not-predicted charmonium-like states with unexpected properties

XYZ States, Nomenclature

Conventional quarkonium ($c\bar{c}$), meson molecule ($c\bar{q}$ + $\bar{c}q$), tetraquark ($c\bar{c}q\bar{q}$), hybrid state ($c\bar{c}$ + g ...) et.al.

e^+e^- annihilation

↓

X: 1^{++}, et. al ← **Y: 1^{--}** → **Z: isospin triplet**

Radiative or hadronic transitions:
Y → γ X(3872)

Hadronic transitions:
Y → π Z_c(3900)

Mysterious XYZ States...

… **unexpectedly narrow for mesons in the open-charm region, strongly coupled to charmonium: What is their nature?**

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
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				$B\to K(\omega J/\psi)$	Belle [92] (4.3), BABAR [93] (4.0)		
				$B\to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), BABAR [96] (4.9)		
				$B\to K(\gamma J/\psi)$	Belle [92] (4.0), BABAR [97, 98] (3.6)		
				$B\to K(\gamma\psi(2S))$	BABAR [98] (3.5), Belle [99] (0.4)		
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B\to K(\omega J/\psi)$	Belle [100] (8.1), BABAR [101] (19)	2004	OK
				$e^+e^-\to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007	NC!
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					Belle [104] (15)		
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[EPJ C71, 1534 (2011)]

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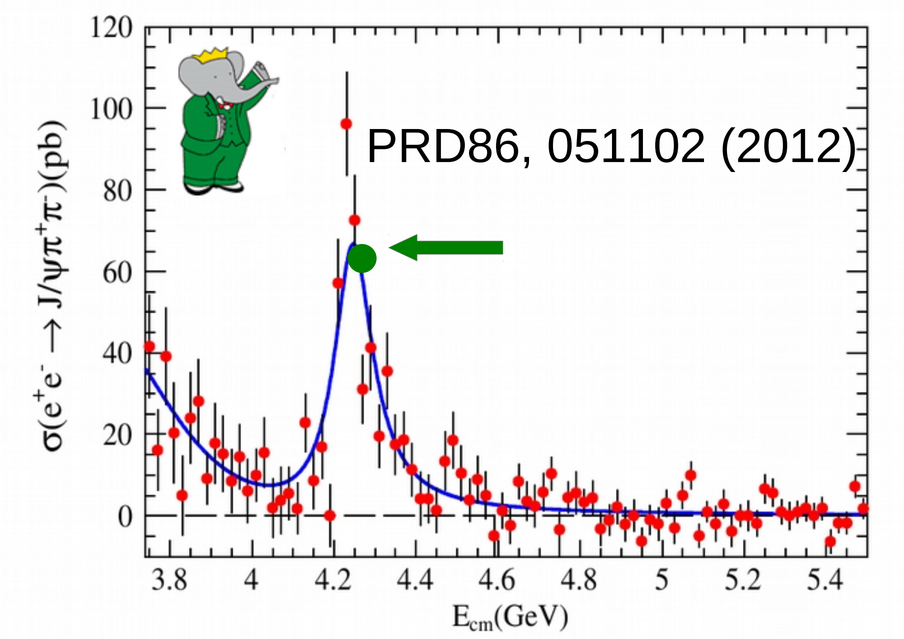
Systematic studies at BESIII of Y(4260), Y(4360)

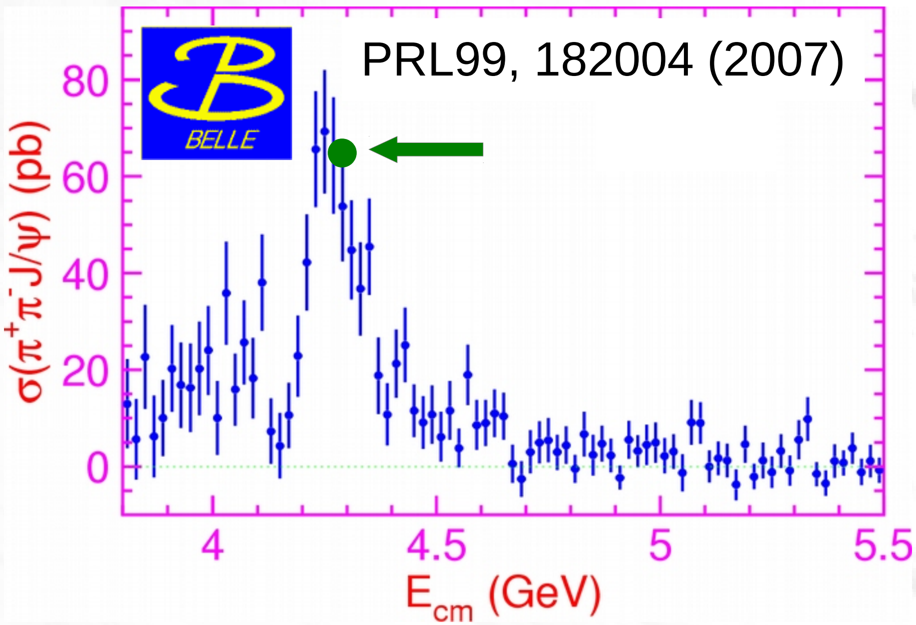
[EPJ C71, 1534 (2011)]

Studies of Y(4260) at BESIII

Y(4260):

- Does not fit any potential model.
- Has a small coupling to open charm
- $J^{PC} = 1^{--}$
- A hybrid candidate according to Lattice QCD calculations!
  [JHEP 1207, 126 (2012)]

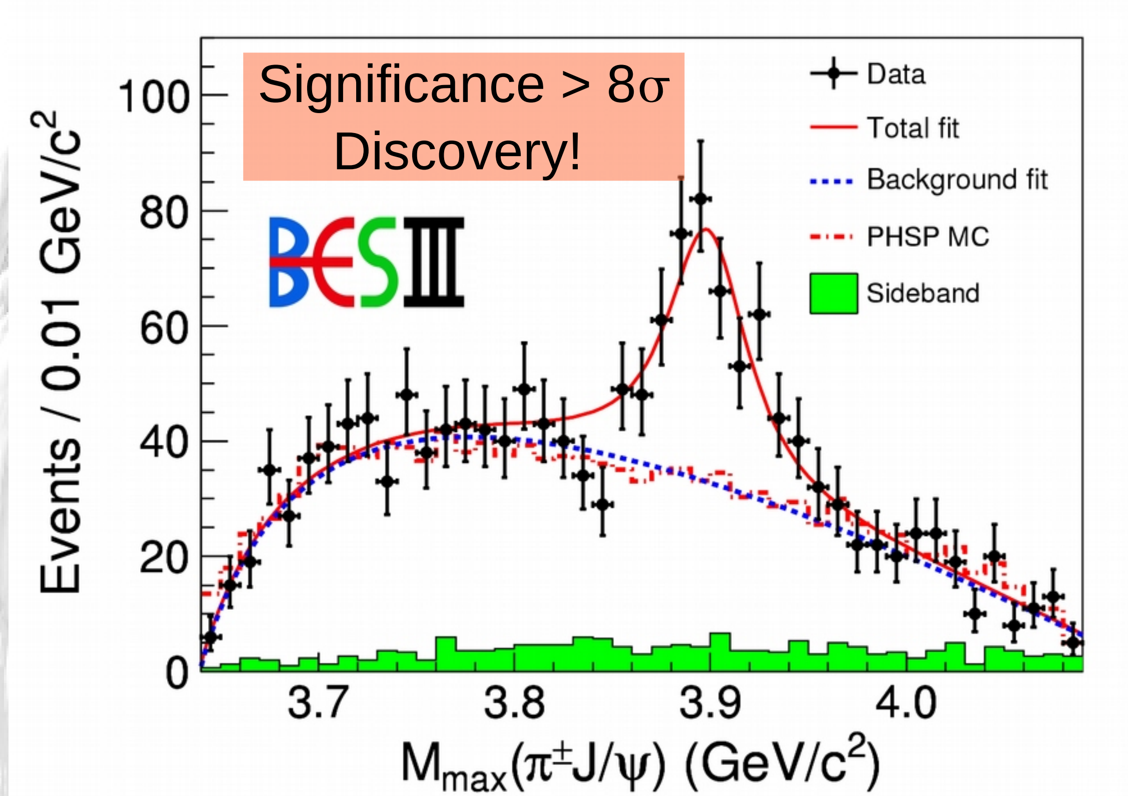




BESIII: $\sigma^B = 62.9 \pm 1.9 \pm 3.7$ pb

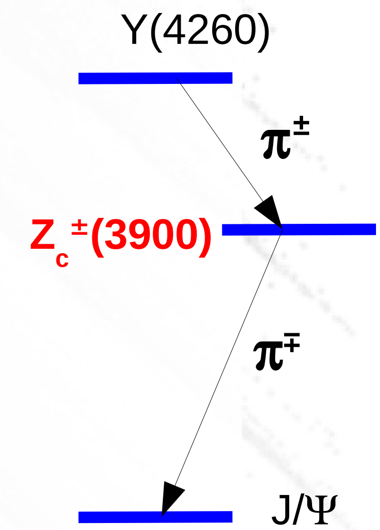
[Phys. Rev. Lett. 110, 252001 (2013)]

The $Z_c(3900)^{\pm}$

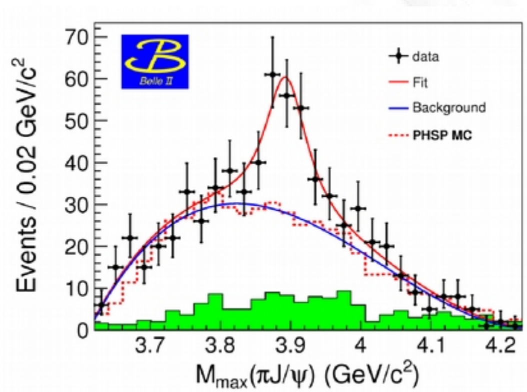


[Phys. Rev. Lett. 110, 252001 (2013)]

- Fit with S-wave Breit-Wigner
- **M = (3899.0±3.6±4.9) MeV/c²**
- **Γ = (46±10±20) MeV**



Discovered by BESIII, promptly confirmed by:



Belle: **[Phys. Rev. Lett. 110, 252002 (2013)]**

M = 3894.5 ± 6.6 ± 4.5 MeV/c²

Γ = 63 ± 24 ± 26 MeV

CLEO-c: **[Phys. Lett. B 727, 366 (2013)]**

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$Z_c(3900)$ – first confirmed Z state!

[EPJ C71, 1534 (2011)]

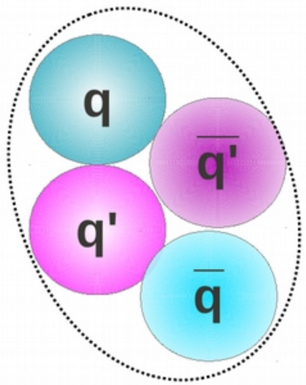
$Z_c(3900)$ Structure?

… **unexpectedly narrow for mesons in the open-charm region, strongly coupled to charmonium: What is their nature?**

Z states:

- Charged states
- Strongly coupled to charm

can not be conventional mesons

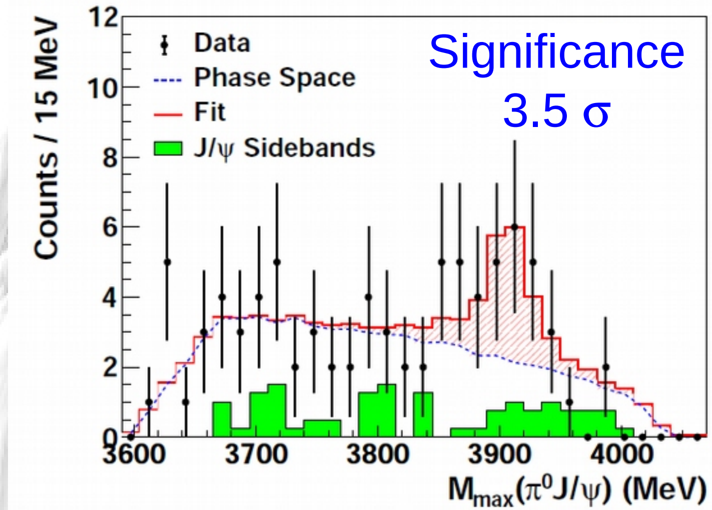


Four-quark state

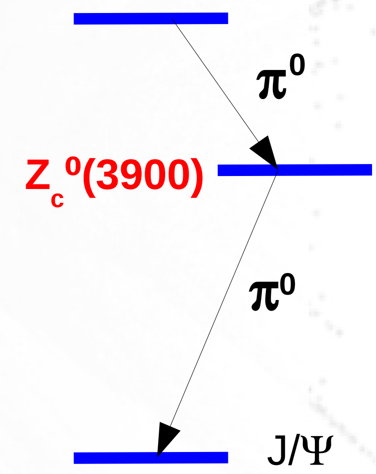
?

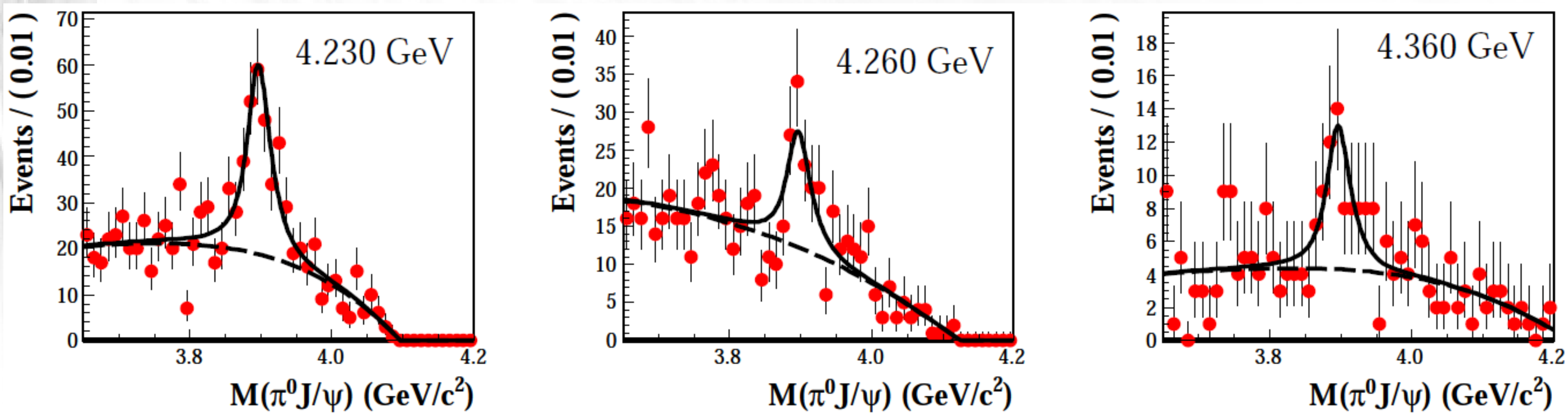
Does a neutral partner $Z_c(3900)^0$ exists?

The $Z_c(3900)^0$



Evidence for $Z_c(3900)^0$ is seen by the CLEO-c
[Phys. Lett. B 727, 366 (2013)]





BESIII preliminary

Structure is seen in $\pi^0 J/\Psi$ (10σ significance):

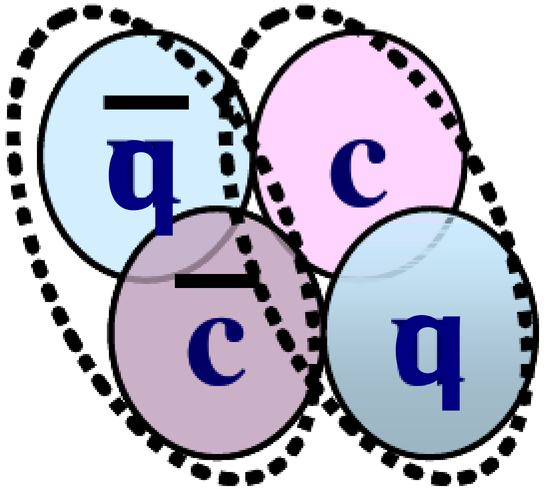
- **$M = (3894.0 \pm 2.3 \pm 2.7)$ MeV/c^2**
- **$\Gamma = (29 \pm 8.2 \pm 8.2)$ MeV**

$Z_c(3900)$ – four-quark isospin triplet?

Nature of the $Z_c(3900)$

Most popular models

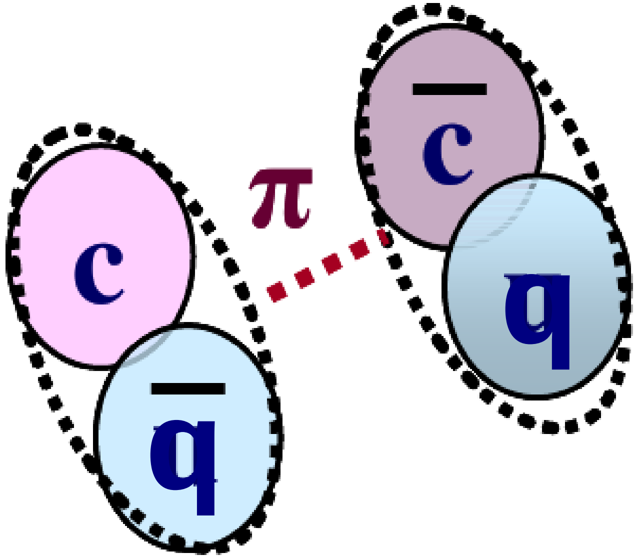
Tetraquark



Interact by gluonic color force
[PRD 87, 111102(R) (2013)]
[arXiv:1304.0345, 1304.1301]

[arXiv: 1304.0380]

Hadronic molecule



2 color-neutral mesons
Interact by pion exchange
[PRD 88, 054007 (2013)]
[Phys. Lett. B726, 326 (2013)]
[arXiv:1304.1850]

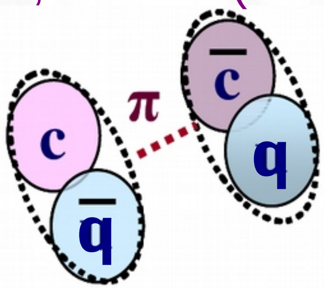
Other models:

- Meson loop **[arXiv: 1303.6355, 1304.4458]**
- Initial State Pion Emission (ISPE) model **[PRL 110, 232001 (2013), PRD 88, 036008 (2013)]**
- Hadro-charmonium **[M. B. Voloshin]**

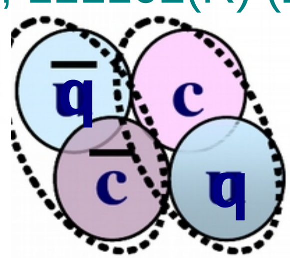
Nature of the $Z_c(3900)$

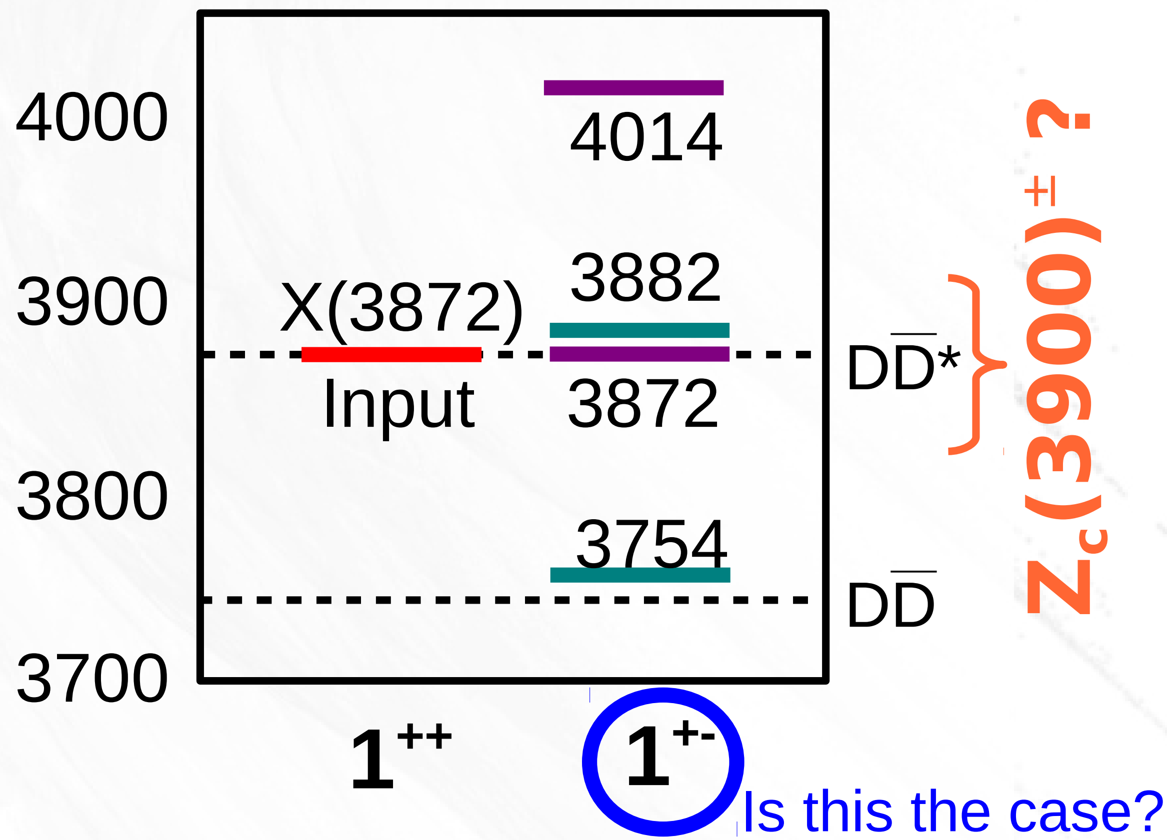
Sensitive probes?

- **Heavier/lighter states**
  - Hadronic molecule
    [PRD 77, 014029 (2008)]



  - Tetraquark
    [PRD 87, 111102(R) (2013)]





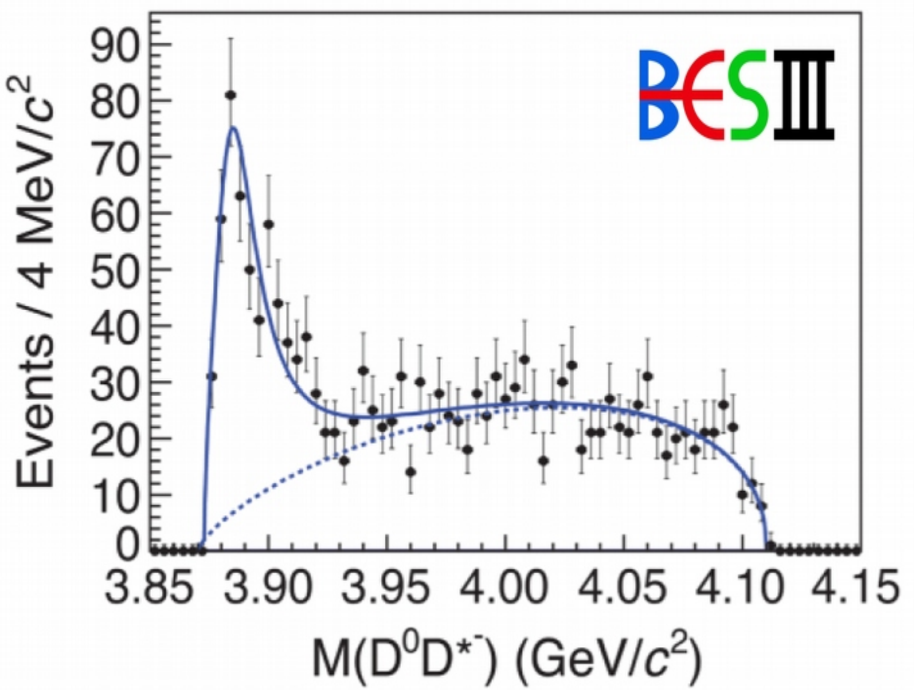
- **Decay modes and rates**
  - Hadronic molecule:
    decays mainly to its constituents
  - Tetraquark: $\Gamma(Z_c^+ \to \pi^+ J/\psi) \approx$ **29 MeV**
    $\Gamma(Z_c^+ \to D^+\bar{D}^{*0}, \bar{D}^0 D^{*+}) \approx$ **4 MeV**

Can we find missing puzzle pieces with BESIII ?

$Z_c(3900)$ Decay Rates

$e^+e^- \to (D\bar{D}^*)^\pm\pi^\mp$

$\sqrt{s}$ = 4.26 GeV



- **M = (3883.9±1.5±4.2) MeV/c^2**
- **Γ = (24.8±3.3±11) MeV**

[Phys. Rev. Lett. 112, 022001 (2014)]

Reconstruction method:

- Reconstruct π^+ and **$D^0 \to K^-\pi^+$**
- Infer **D^{*-}**
- Analyse as well **$\pi^+D^-D^{*0}$**

- **Is found structure** (referred as $Z_c(3885)$) **different decay mode of the $Z_c(3900)$?**

$Z_c(3900)^\pm$ properties:

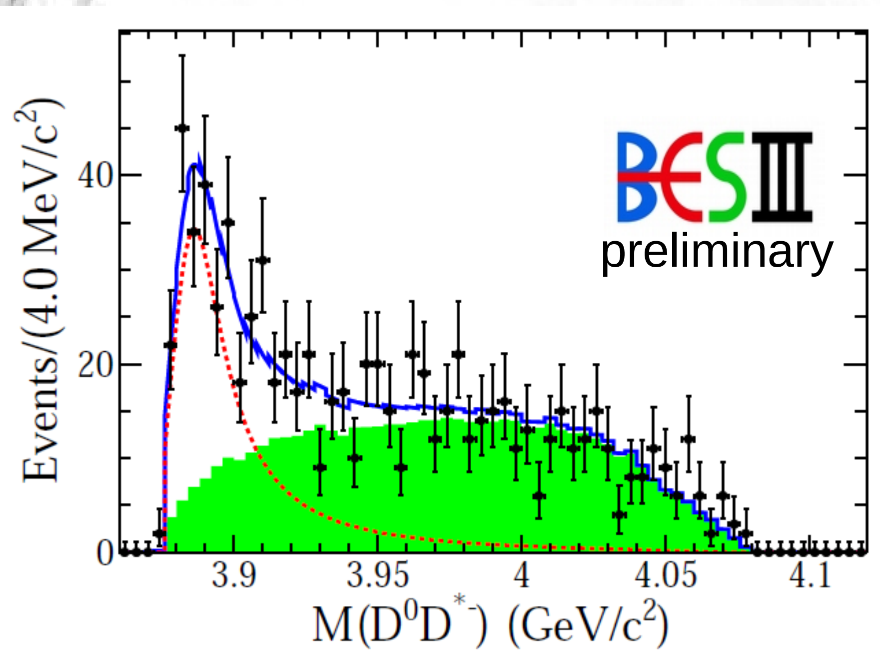
- M = (3899.0±3.6±4.9) MeV/c^2
- Γ = (46±10±20) MeV

- Assuming it is, the partial width ratio: **$\Gamma(Z_c \to DD^*)/\Gamma(Z_c \to \pi J/\Psi)$ = 6.2±1.1±2.7**

Tetraquark model disfavoured ?

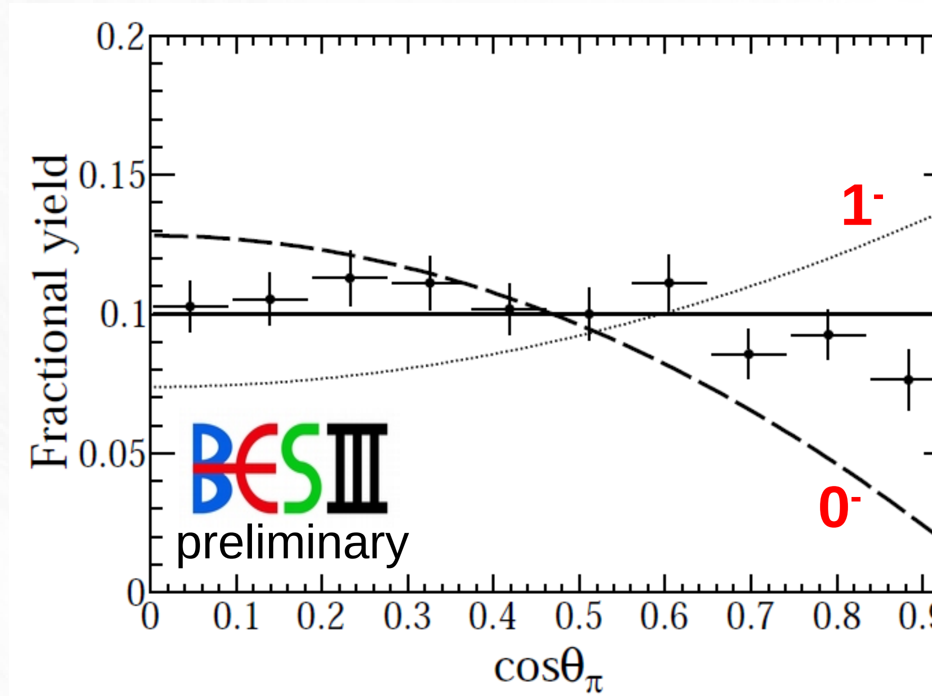
Z_c(3900) Quantum Numbers

$e^+e^- \to (D\bar{D}^*)^\pm\pi^\mp$
$\sqrt{s}$ = 4.23 and 4.26 GeV



- **M = (3884.3±1.2±1.8) MeV/c^2**
- **Γ = (23.8±2.1±2.6) MeV**

Fits to |cosθ| distributions for
$\pi^+D^0\,D^0$ – tagged events



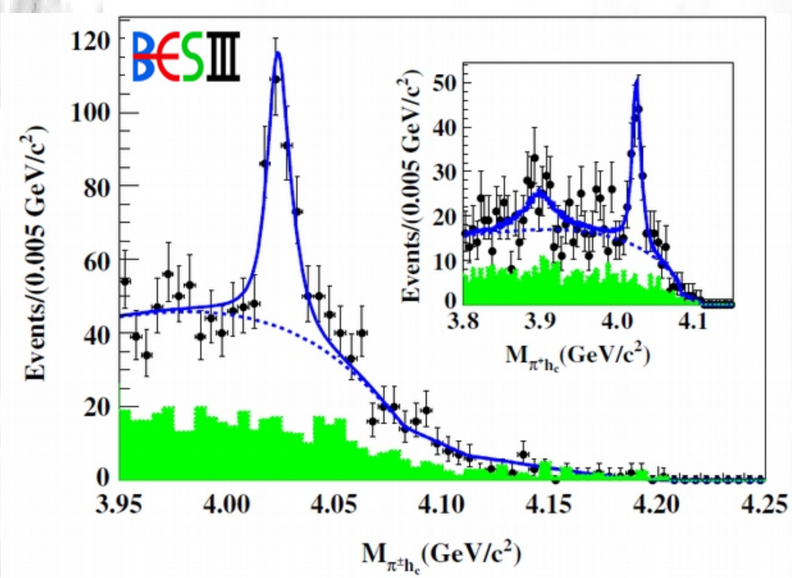
Spin-parity of Z_c(3895) 1$^+$
Confirms expectations!

Reconstruction method:
- Complete reconstruction of decay

$Z_c(4020)^{\pm}$ seen by the BESIII

$e^+e^- \rightarrow \pi^-\pi^+h_c$

$\sqrt{s}$ = 3.9 – 4.42 GeV

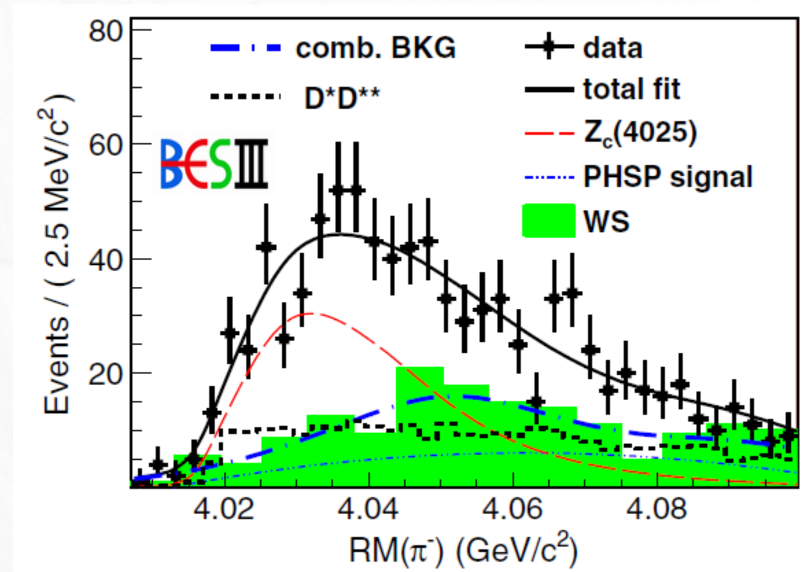


- M = (4022.9±0.8±2.7) MeV/c^2
- Γ = (7.9±2.7±2.6) MeV

[Phys. Rev. Lett. 111, 242001 (2013)]

$e^+e^- \rightarrow (D^*\bar{D}^*)^{\pm}\pi^{\mp}$

$\sqrt{s}$ = 4.26 GeV



- M = (4026.3±2.6±3.7) MeV/c^2
- Γ = (24.8±5.6±7.7) MeV

[Phys. Rev. Lett. 112, 132001 (2014)]

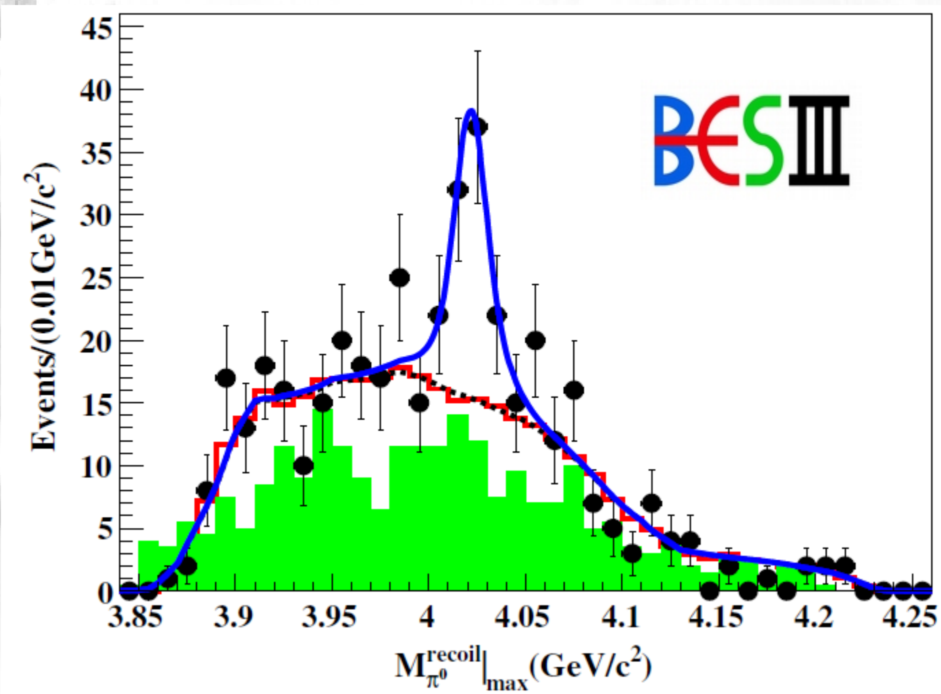
Assuming found structures correspond to the same state the open-charm decay-mode is favoured but suppressed in comparison with established open-charm states, e.g. Ψ(4040)

Is there a neutral partner?

$Z_c(4020)^0$ seen by the BESIII

$e^+e^- \rightarrow \pi^0\pi^0h_c$

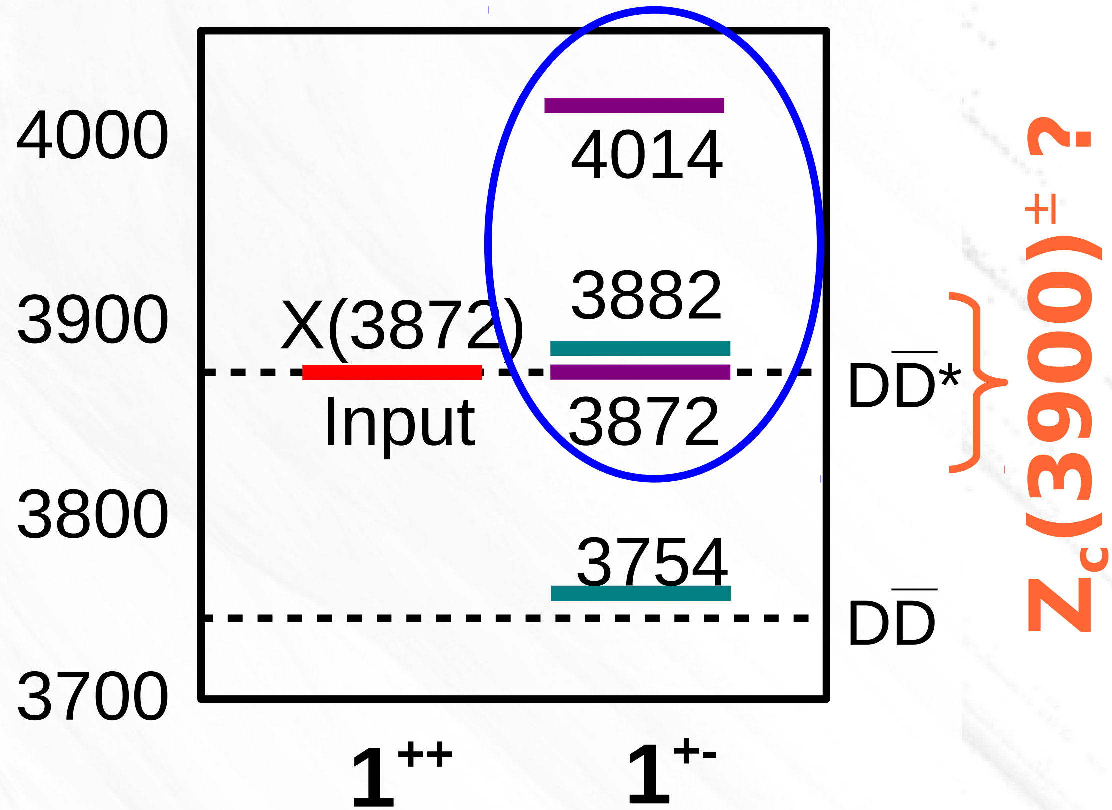
$\sqrt{s}$ = 4.23 – 4.36 GeV



- M = (4023.9±2.2±3.8) MeV/c^2

[Phys. Rev. Lett. 113, 212002 (2014)]

$Z_c(4020)$ – another four-quark isospin triplet found?



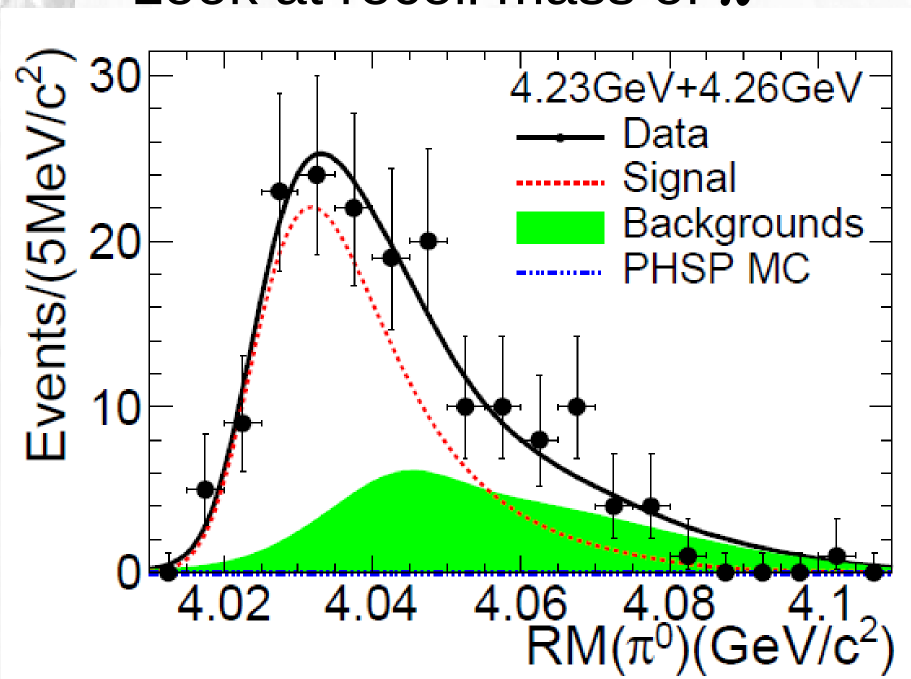
Is $Z_c(4020)$ – a partner state to $Z_c(3900)$, predicted by the hadronic-molecule model?

Open-Charm decay of $Z_c(4020)^0$

$e^+e^- \rightarrow (D^*\bar{D}^*)^\pm \pi^0$

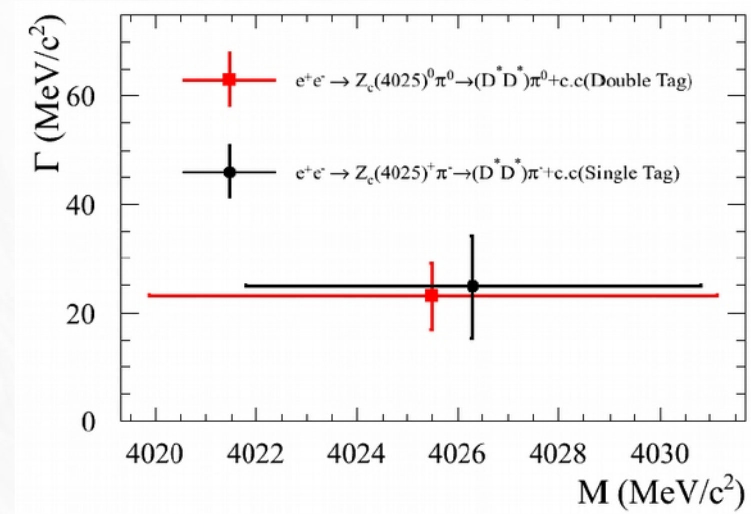
Analysis strategy:

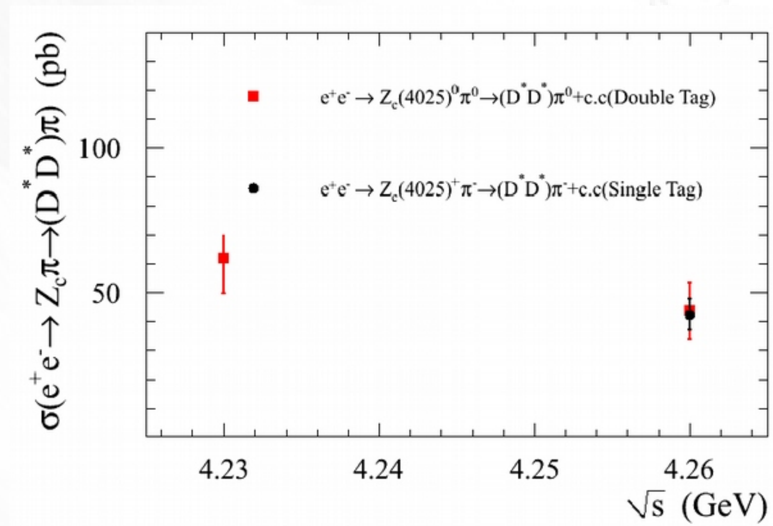
- Detect **D** (decay products of **D***)
- Look at recoil mass of π^0



preliminary

Comparison between observed and $Z_c(4020)^\pm$ states

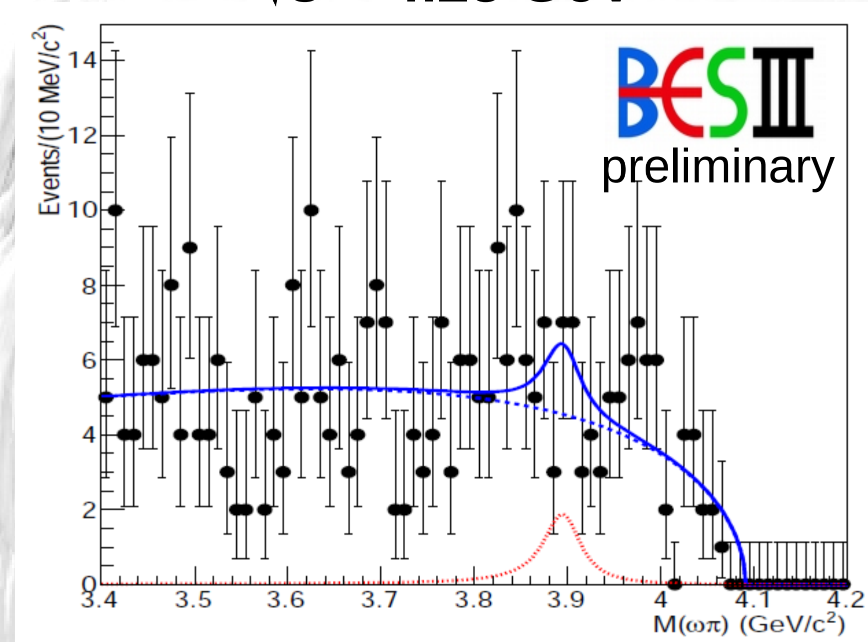




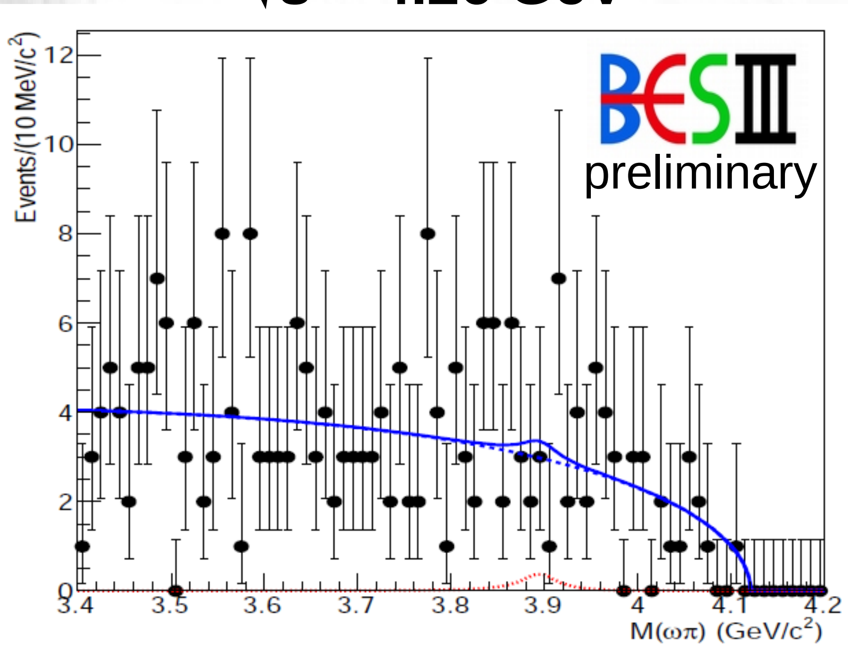
Observed state has mass and width close to $Z_c(4020)^0$ → good candidate for isospin partner of $Z_c(4020)^\pm$

More Mysteries of $Z_c(3900)$

√s = 4.23 GeV



√s = 4.26 GeV



Search for $Z_c(3900) \rightarrow \pi^{\pm}\omega$

There are three important decay modes for charmonium-like states:

- the fall-apart to open charm mesons;
- the cascade to hidden charm mesons;
- decays to light hadrons via intermediate gluons.

Since **Z_c(3900)** decays to J/Ψπ, a sizeable annihilation rate could be expected with c̄c in S − wave (as for χ_c)

No significant signal observed:
$\Gamma(Z_c(3900) \rightarrow \omega\pi) < 0.2\%\ \Gamma(Z_c(3900))$

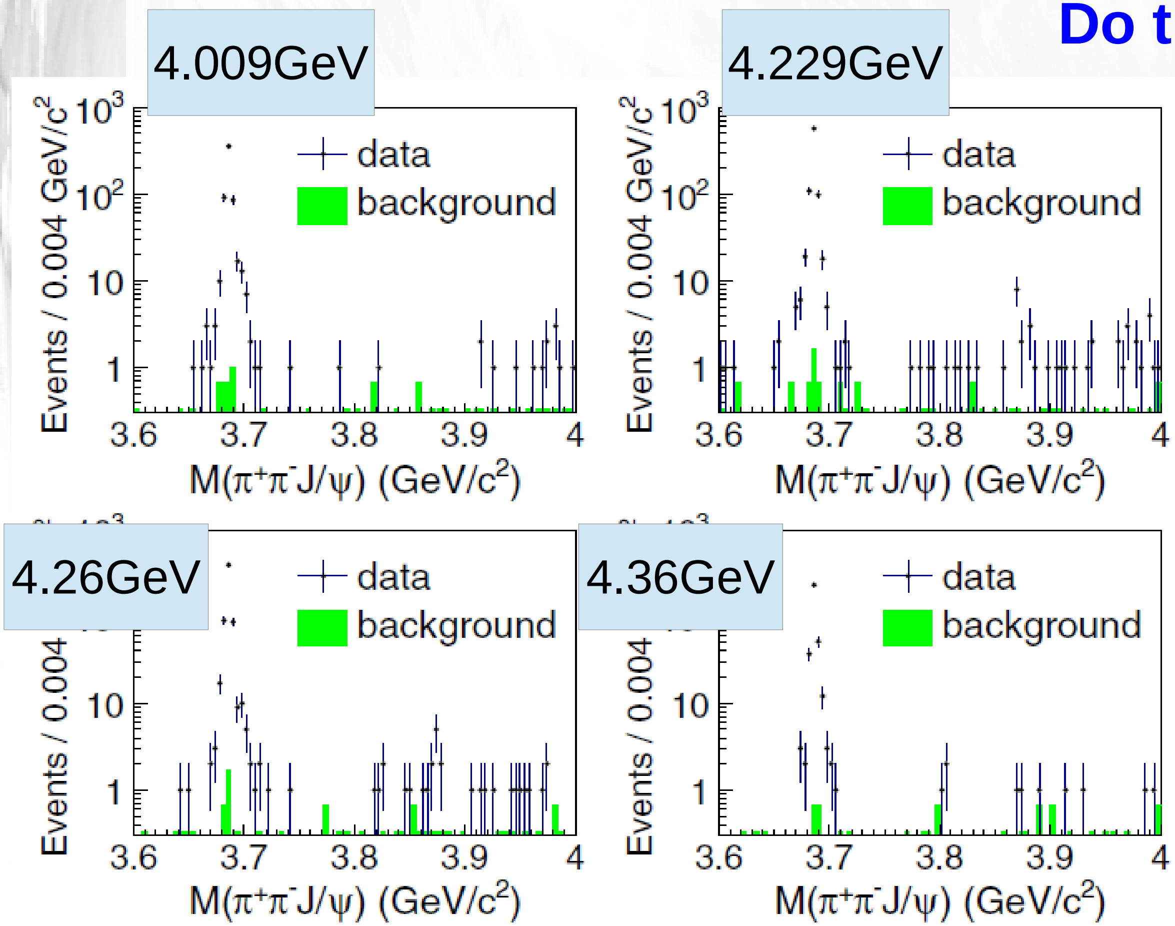
Annihilation to c̄c is suppressed?

Shedding Light on X(3872)

X(3872) – the first discovered unconventional charmonium-like state so far seen in B-meson decays of hadron collisions:

- $J^{PC} = 1^{++}$, measured by LHCb and CDF
- Interpreted as a candidate for a tetraquark or hadronic molecule
- Most probably Y(4260) and Y(4360) couple with exotic Z_c states

Do they couple with X(3872)?

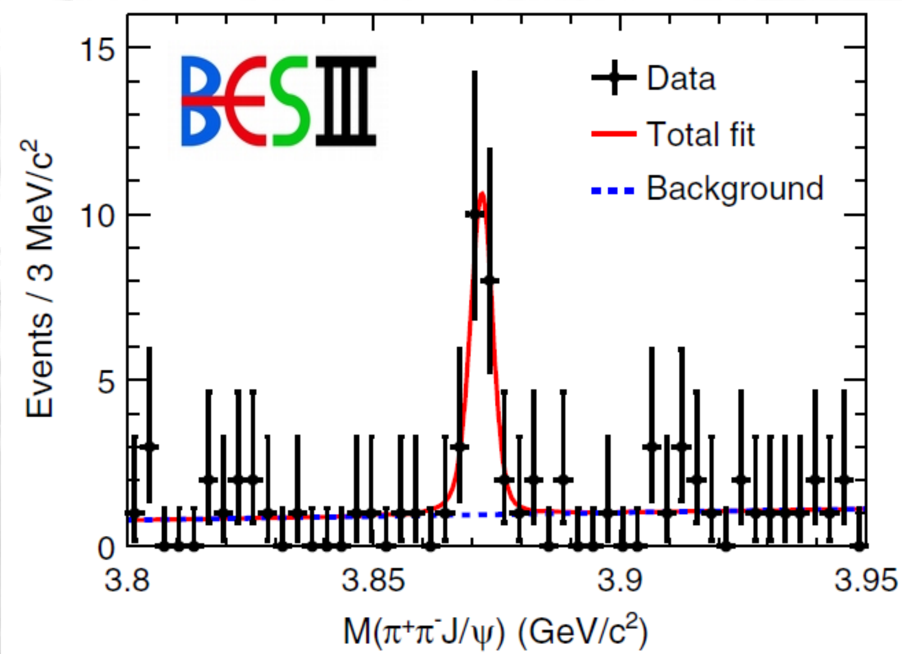


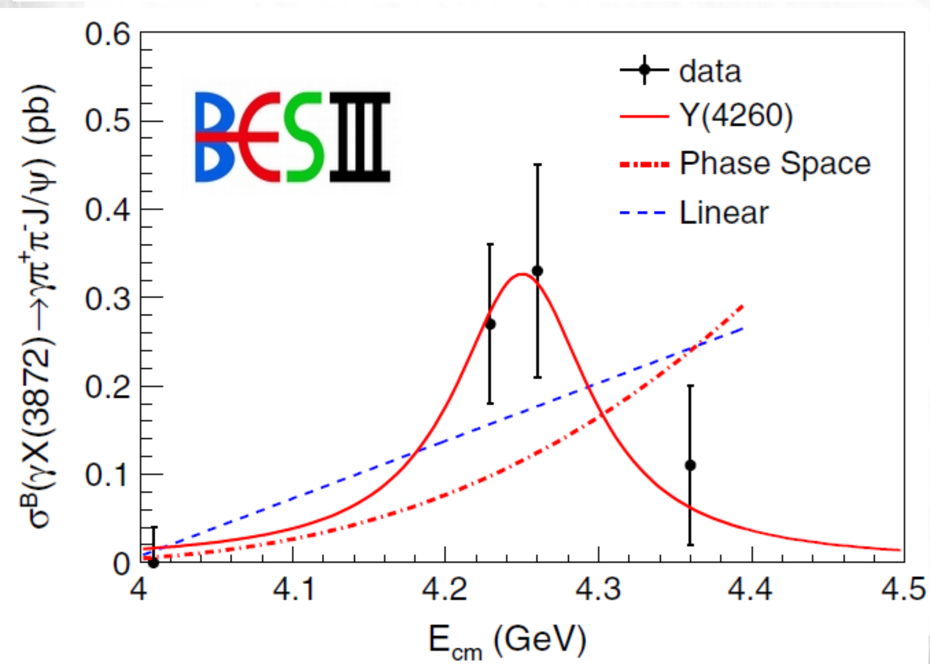
$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma J/\Psi \pi^+\pi^-$

Ψ\` signal is used for analysis validation

[Phys. Rev. Lett. 112, 092001 (2014)]

Shedding Light on X(3872)



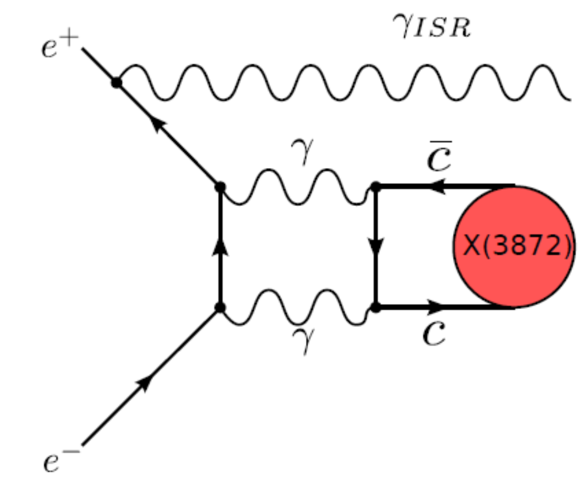


- **The X(3872) signal is clearly observed: significance 6.3σ**
- **Cross-section hints radiative transition between Y(4260) and X(3872)**
- **Existence of transitions between Y(4260) X(3872) and Zc states suggest that there might be some commonality in the nature of these three different states**
- **Assuming that measured transition is from Y(4260):**

$$\frac{B(Y(4260)\rightarrow\gamma X(3872))}{B(Y(4260)\rightarrow\pi^+\pi^- J/\psi)} \sim 0.1$$

[Phys. Rev. Lett. 112, 092001 (2014)]

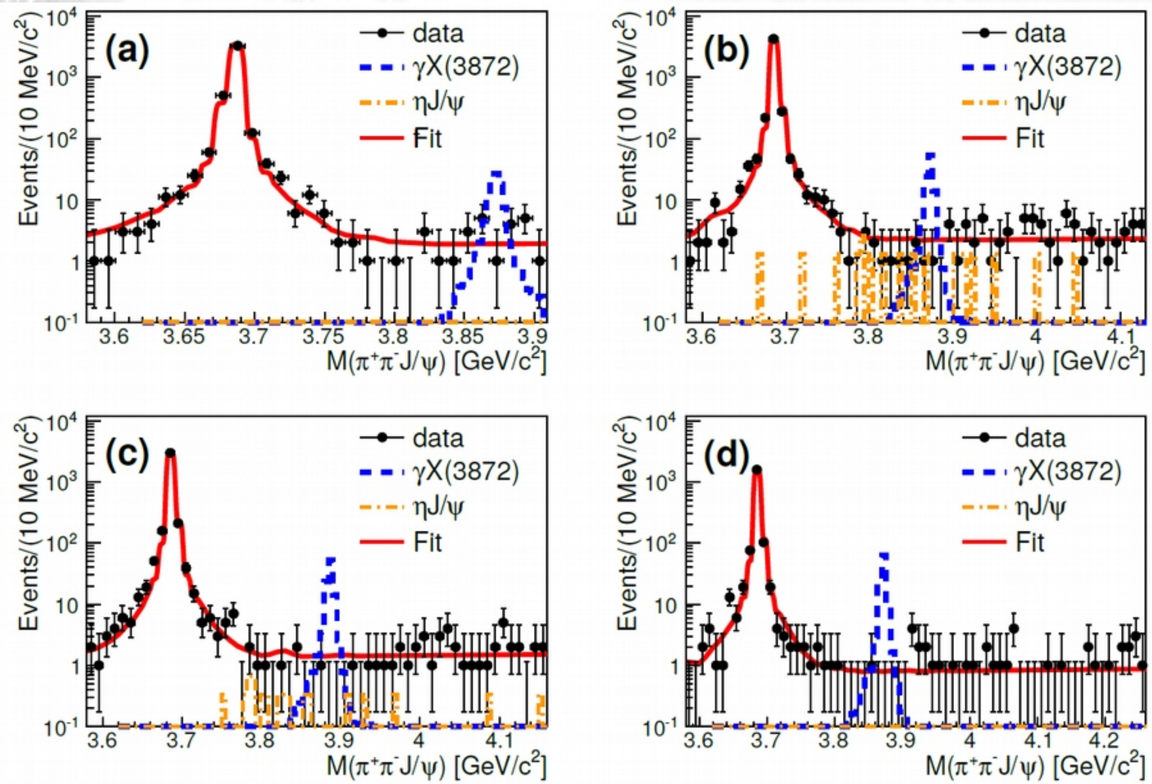
X(3872): Γ_{ee} Measurement



Γ_{ee} may help to understand the nature of X(3872):

- Theory predicts $\Gamma_{ee} \sim 0.03$ eV
- Current measurement: $\Gamma_{ee} < 280$ eV [PLB 579, 74]
- Never been observed directly in e^+e^- anaihilation

ISR measurement at BESIII



No obvious signal observed.
Upper limit (at 90% C.L.):
$\Gamma_{ee} < 0.13$ eV

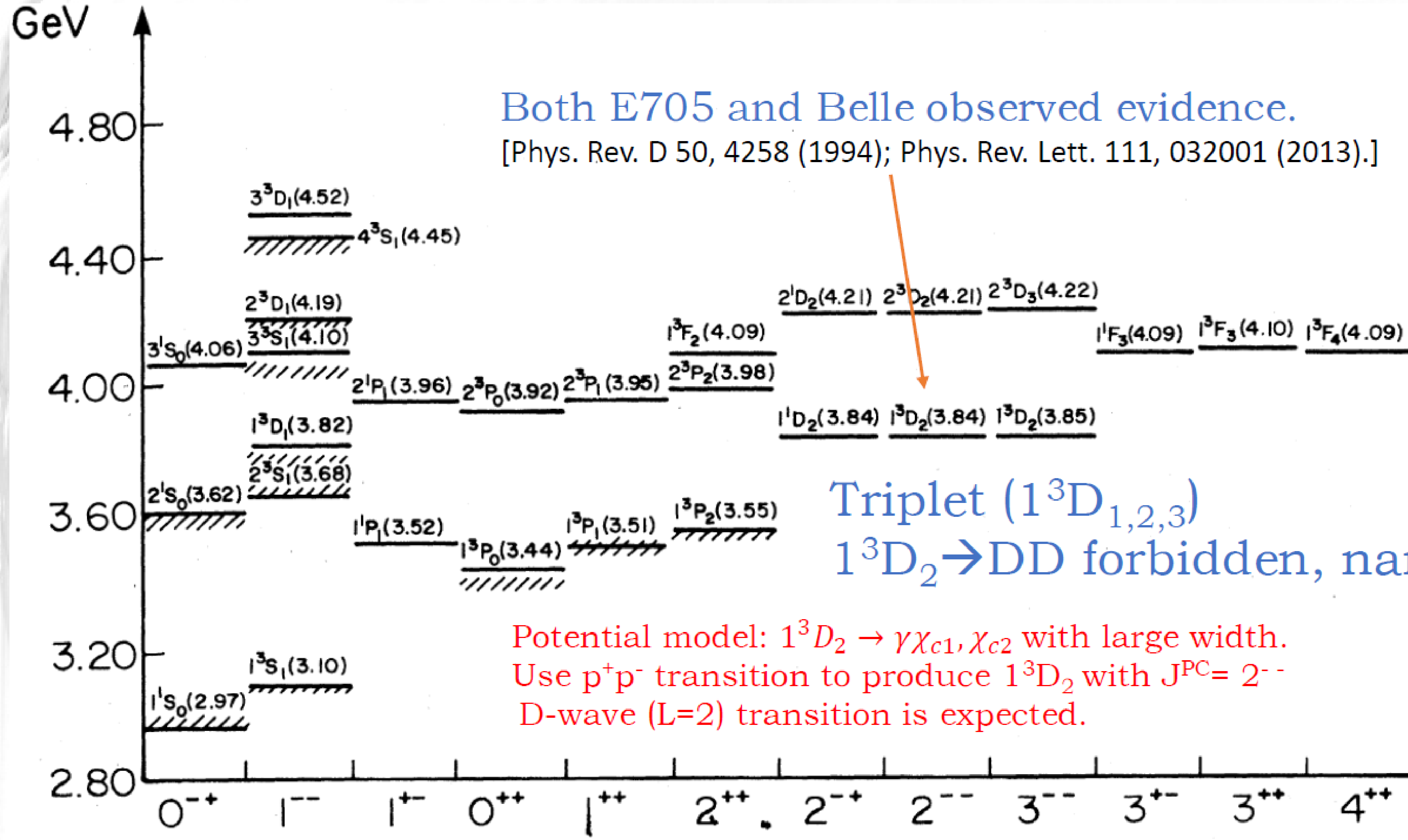
Even now we can reach eV level!

With more data we can do better...

[arXiv:1505.02559]

Filling Gaps in Charmonium Spectrum

BESIII



Both E705 and Belle observed evidence.

[Phys. Rev. D 50, 4258 (1994); Phys. Rev. Lett. 111, 032001 (2013).]

Triplet ($1^3D_{1,2,3}$)

$1^3D_2 \rightarrow DD$ forbidden, narrow

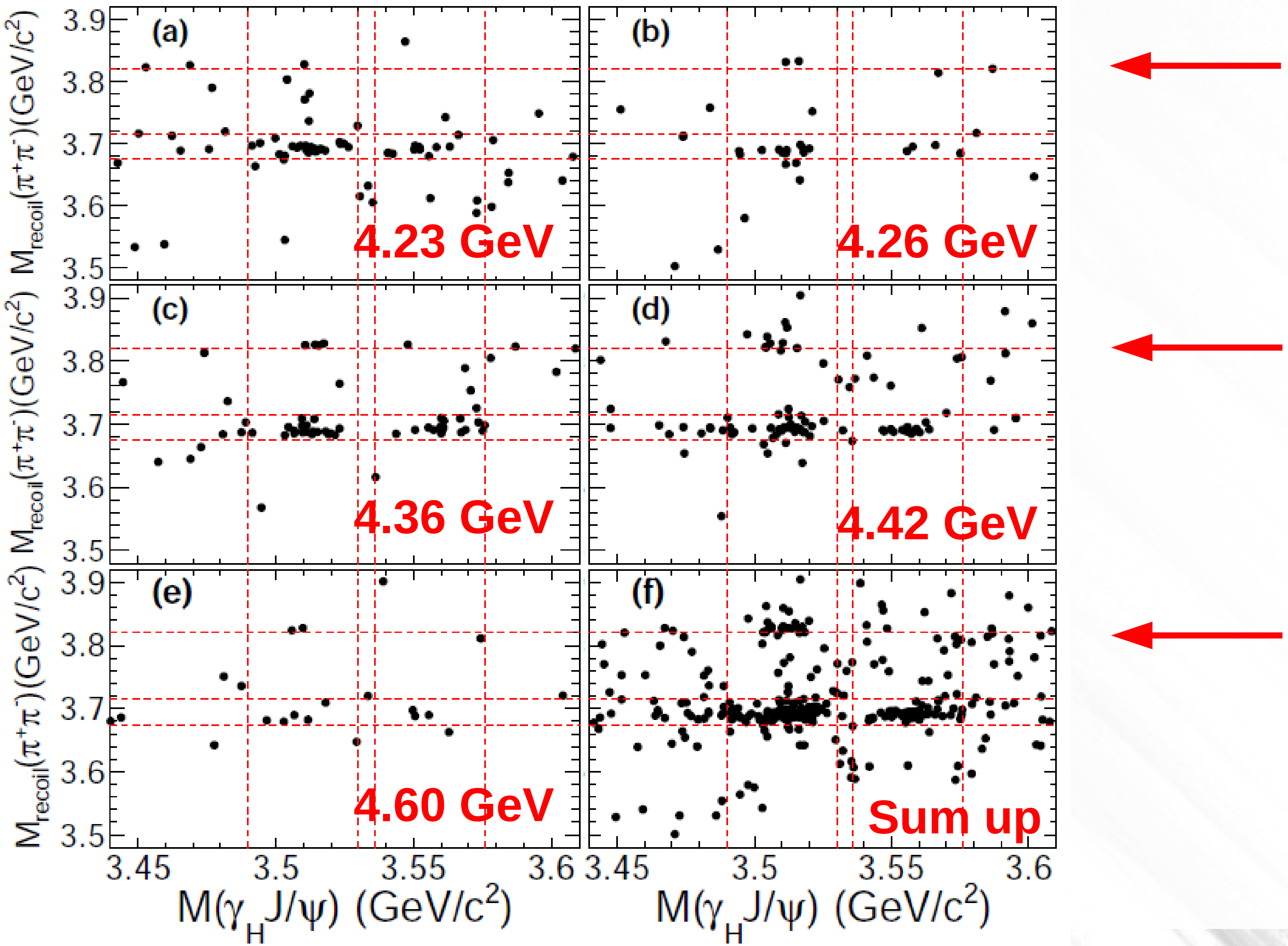
Potential model: $1^3D_2 \rightarrow \gamma\chi_{c1}, \chi_{c2}$ with large width.

Use p^+p^- transition to produce 1^3D_2 with $J^{PC}= 2^{--}$

D-wave (L=2) transition is expected.

Observation of X(3823)

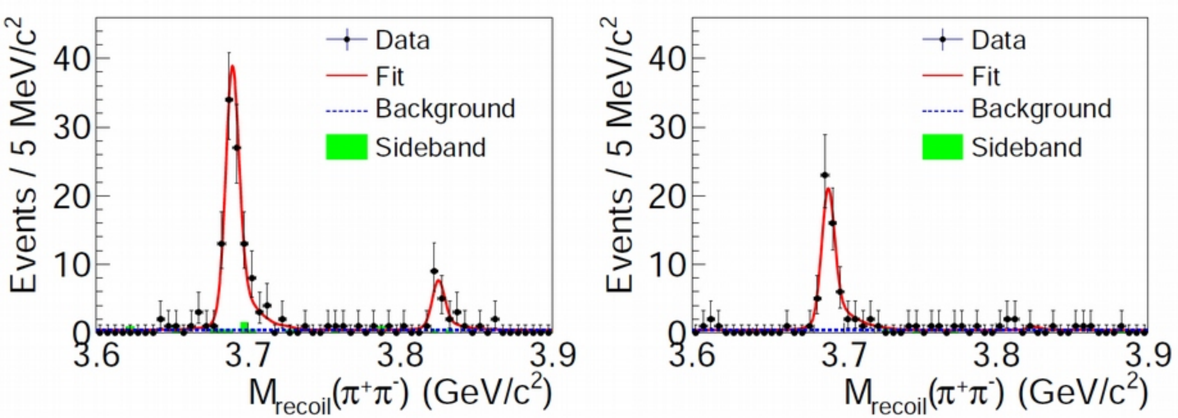
$e^+e^- \to \pi^+\pi^- X,\ X \to \gamma\chi_{CJ},\ \chi_{CJ} \to \gamma J/\Psi$



[arXiv:1503.08203]

Observation of X(3823)

Simultaneous fit of $\gamma\chi_{c1}$ (left) and $\gamma\chi_{c1}$ (right) events

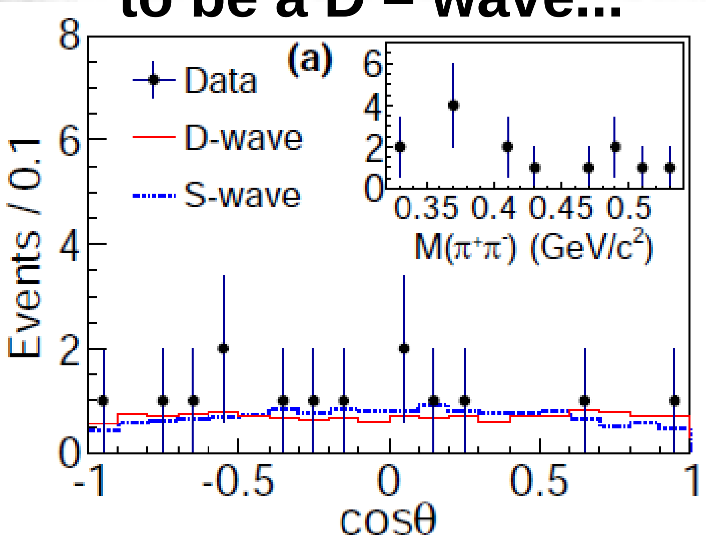


- **M = (3821.7±1.3±0.7) MeV/c²**
- **Γ < 16 MeV (at 90% C.L.)**

[arXiv:1503.08203]

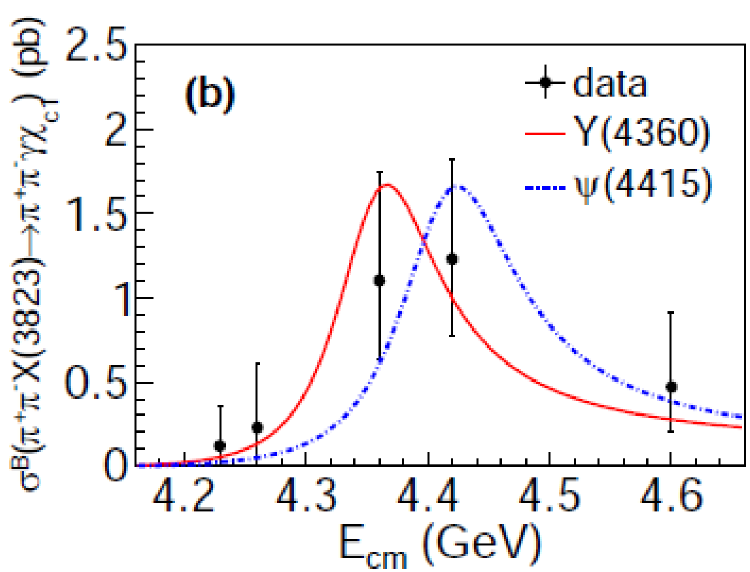
Observed narrow resonance is a good candidate for the $\Psi(^1D_3)$ charmonium.

$\Psi(^1D_3)$ is expected to be a D – wave...



Too limited statistics to conclude...

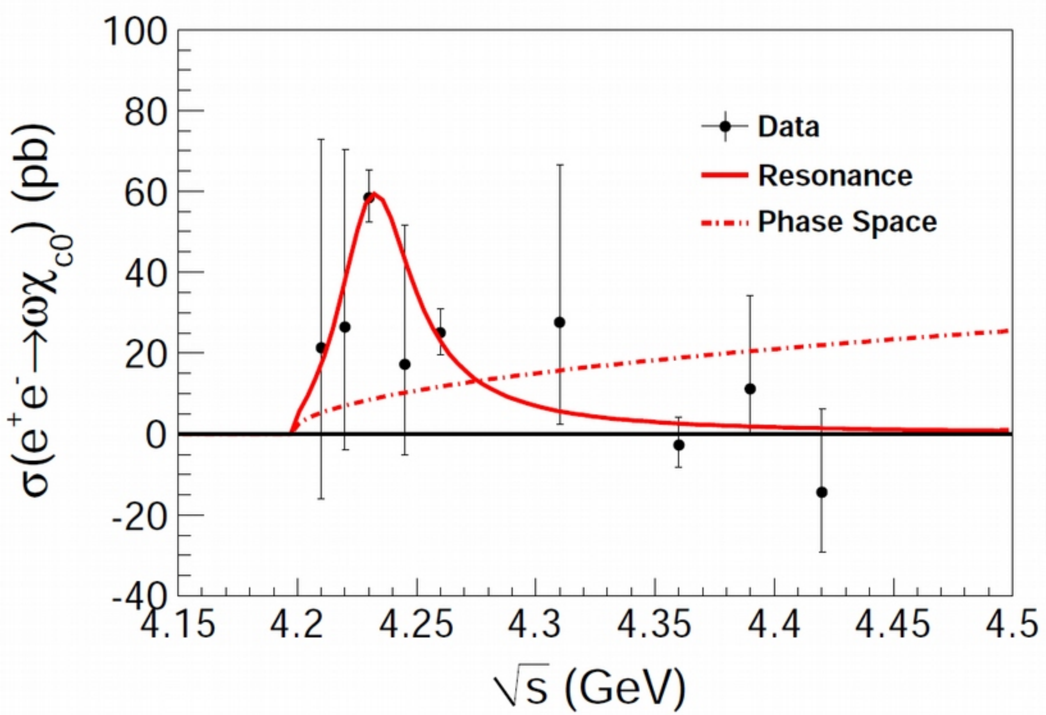
Energy-dependent cross-section



Measured cross-sections consistent with transitions from Y(4360) and Ψ(4415)

Y states: $e^+e^- \to \omega\chi_{C0}$

Energy-dependent cross-section



Resonance structure is observed (significance > 9σ)!
Assuming single BW:

- **M = (4230±8±6) MeV/c^2**
- **Γ = (38±12±2) MeV**

[Phys. Rev. Lett. 114, 092003 (2015)]

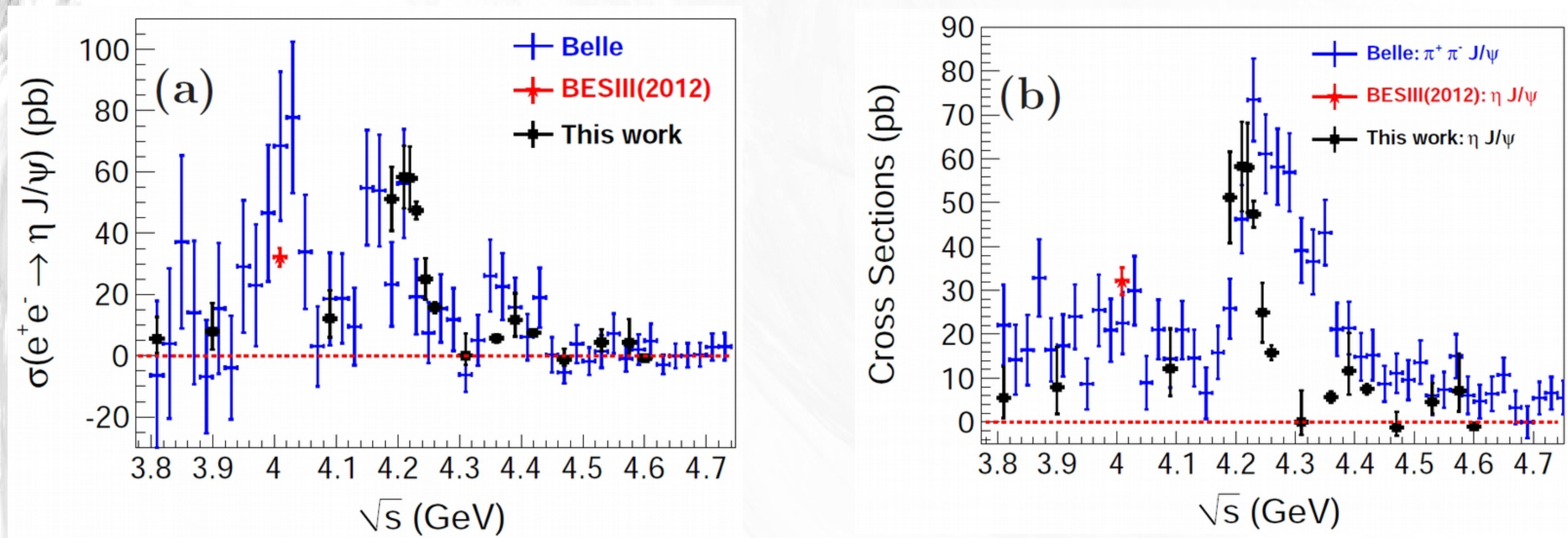
Inconsistent with Y(4260) from ππJ/Ψ

No significant signals for $e^+e^- \to \omega\chi_{C1,2}$

Y states: $e^+e^- \to \eta J/\Psi$

Energy-dependent cross-section compared to Belle data obtained in:

$\eta J/\Psi$ and **$\pi^+\pi^- J/\Psi$**



- **Agree with previous results with improved precision.**
- **Non-trivial structure around 4.2 GeV:**
  This could indicate the existence of a rich spectrum of Y states in this energy region with different coupling strengths to the various decay modes.

A lot of interesting results are already published by the BESIII collaboration

Systematic studies of unexpected states allows BESIII to collects pieces of “exotic-matter” puzzle

New exciting results are coming soon!

Summary

- BESIII is operational since 2008
  and already has world's largest data samples of various Y and charmonium states in a clean environment (e^+e^- annihilation)

- BESIII – an ideal tool for precision studies of suppressed channels:
  - clean environment
  - well controlled systematics

- A lot of interesting results have been obtained:
  - Precise measurements of resonance properties
  - Discovery of unexpected states
  - Systematic studies of XYZ states in charmonium region

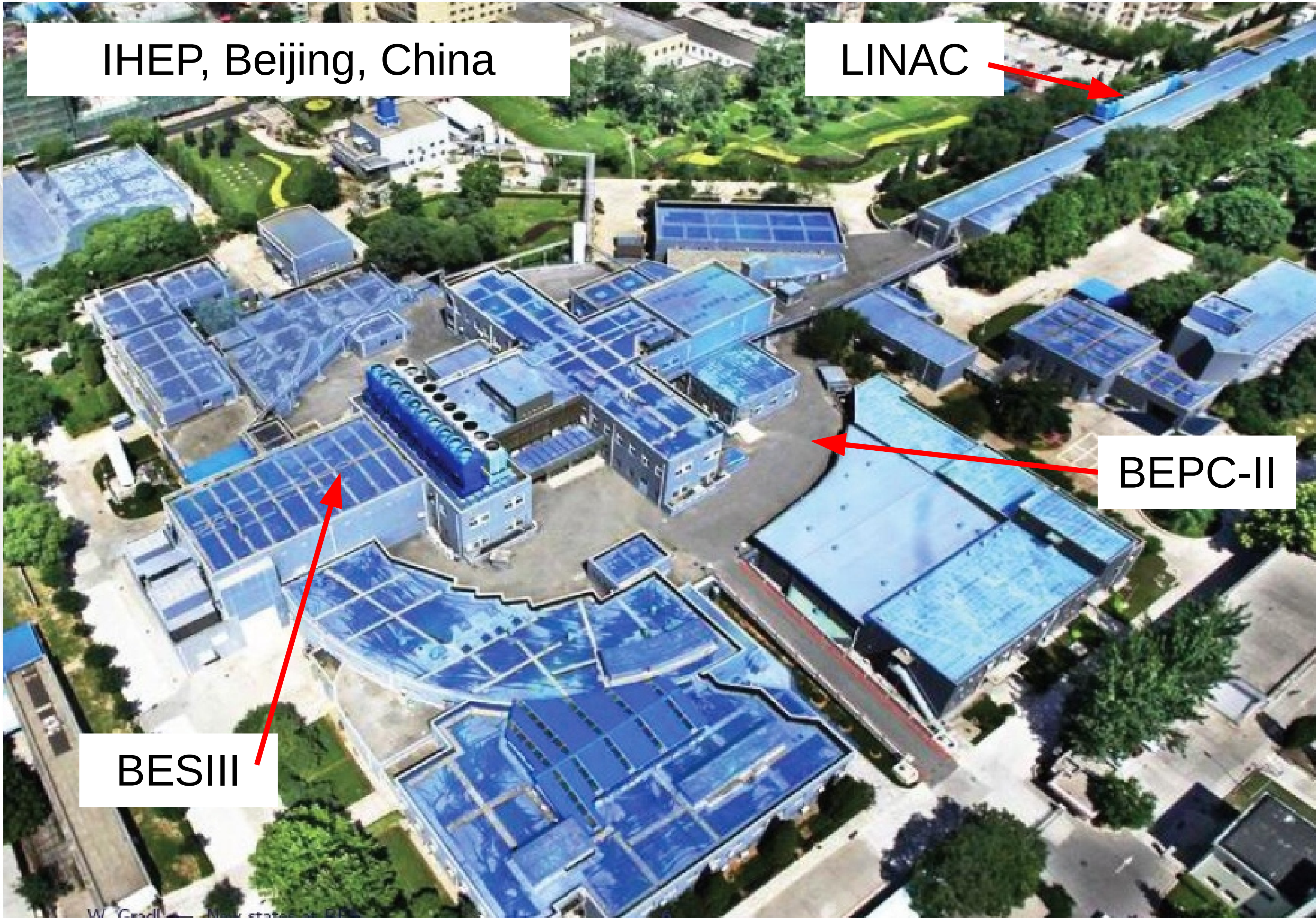
- ... and we are looking forward to the future:
  - More data available than presented in current analysis

Stay tuned!

Thank you for your attention and to the BESIII collaboration!

BESIII collaboration: >360 members in 53 institutions from 11 countries

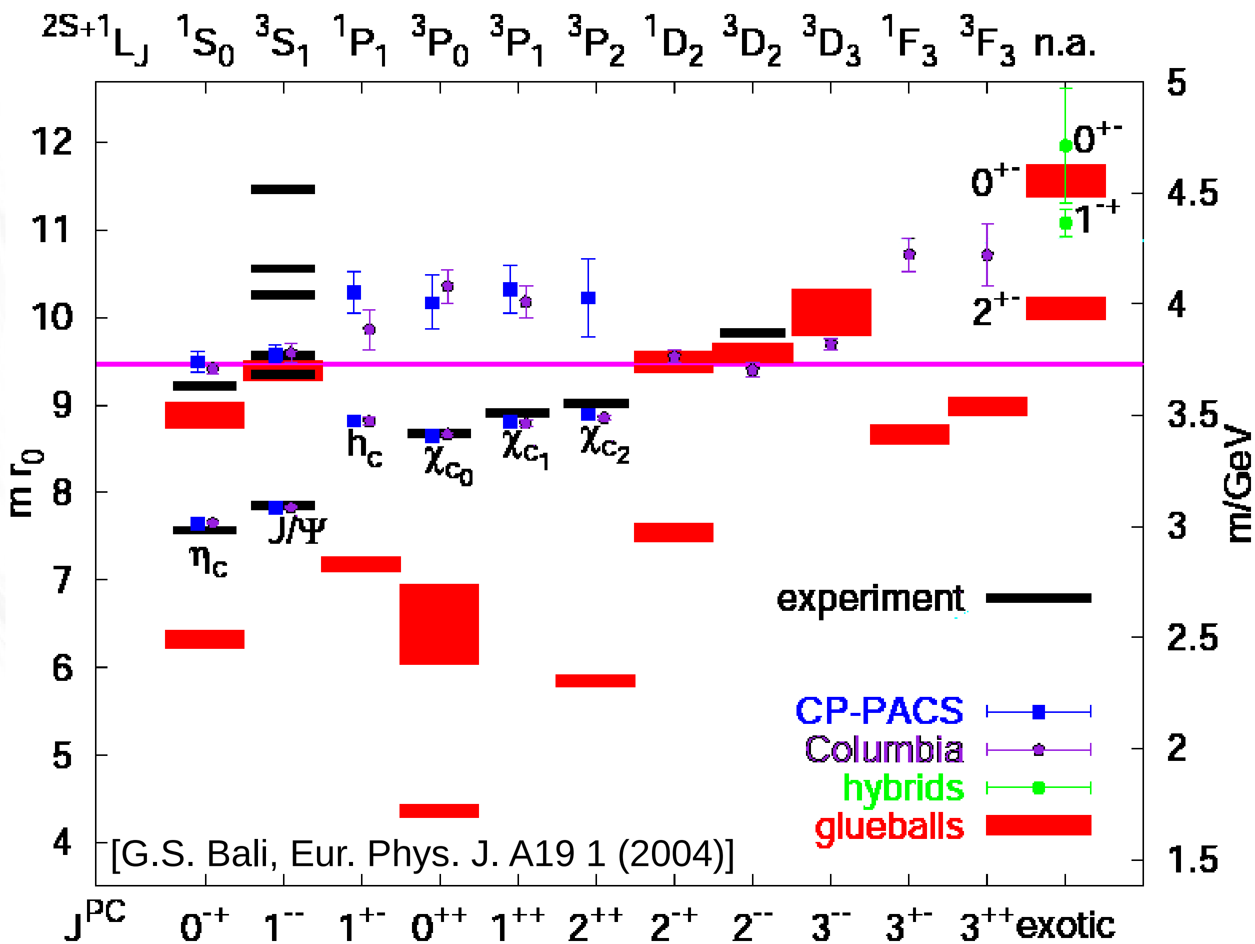
BESIII at BEPC-II

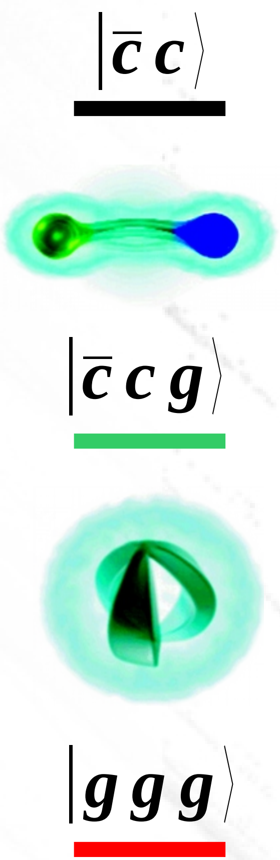


Other QCD Exotic Objects

QCD predicts exotic objects:
- hybrids (resonances of quark-antiquark and excited glue)
- glueballs (excited states of glue)

D $\bar{D}$ threshold →





Glueballs and hybrids properties are determined by the long-distance features of QCD → Insight into QCD vacuum