Latest Results from BESIII

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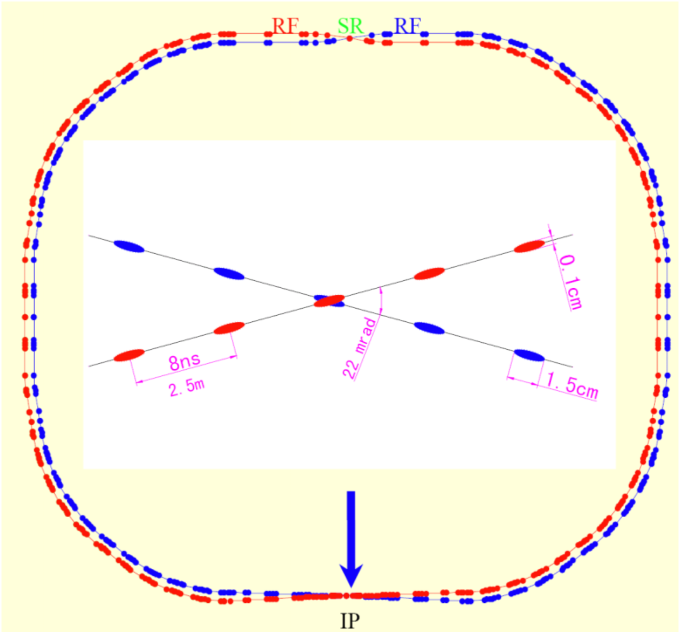
Peñiscola, Valencian Community (Spain)

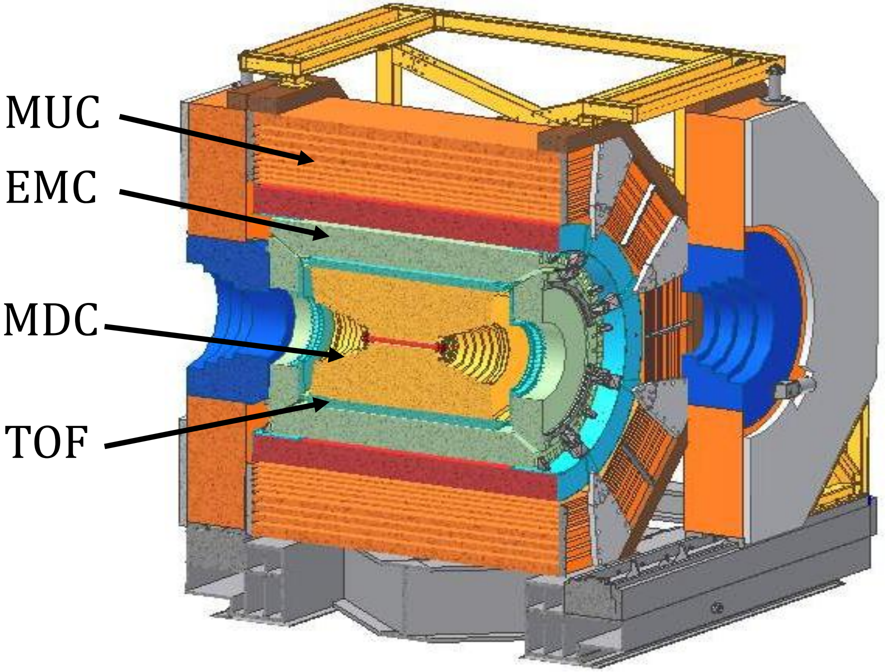
Outline

- Introduction
- Selected recent results
  - Charmonium transitions and decays
  - “Exotic” charmonium states
  - Excited baryon program → For details, see Wenlong’s talk @ parallel B5
- Summary and Outlook

BEPCII -- A High Luminosity Double-ring Collider

BEPCII and BESIII Detector





BEPCII:

- $\sqrt{s}$: **2.0-4.6 GeV**
- **Luminosity:**

Design: 1×10^{33} $cm^{-2}s^{-1}$

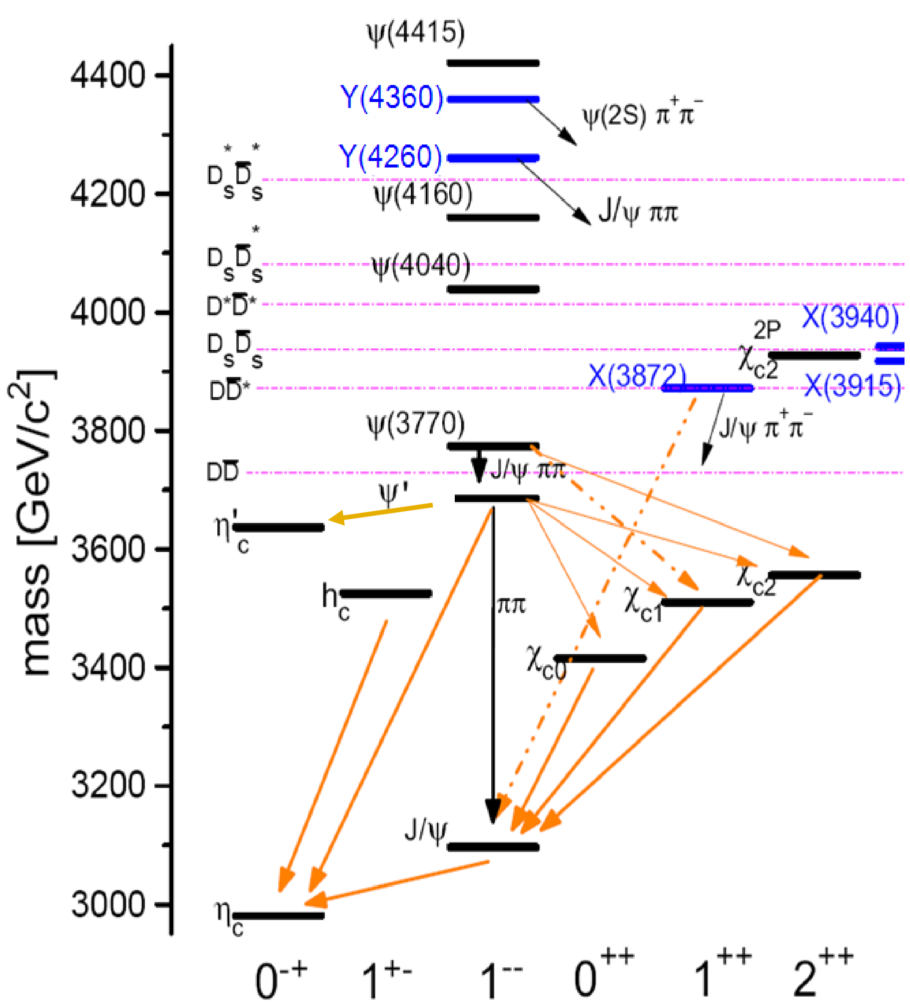
Achieved: ~7.08×10^{32} $cm^{-2}s^{-1}$

BESIII:

- **MDC:** **σ_p/p = 0.5% @ 1GeV/c**
- **EMC:** **σ_E/E = 2.5% at 1GeV**
- **TOF:** **80ps(barrel), 110ps(endcap)**
- **MUC:** **9 layers RPC for barrel, 8 for endcap**

BESIII Collaboration

Physics in the Charm Region



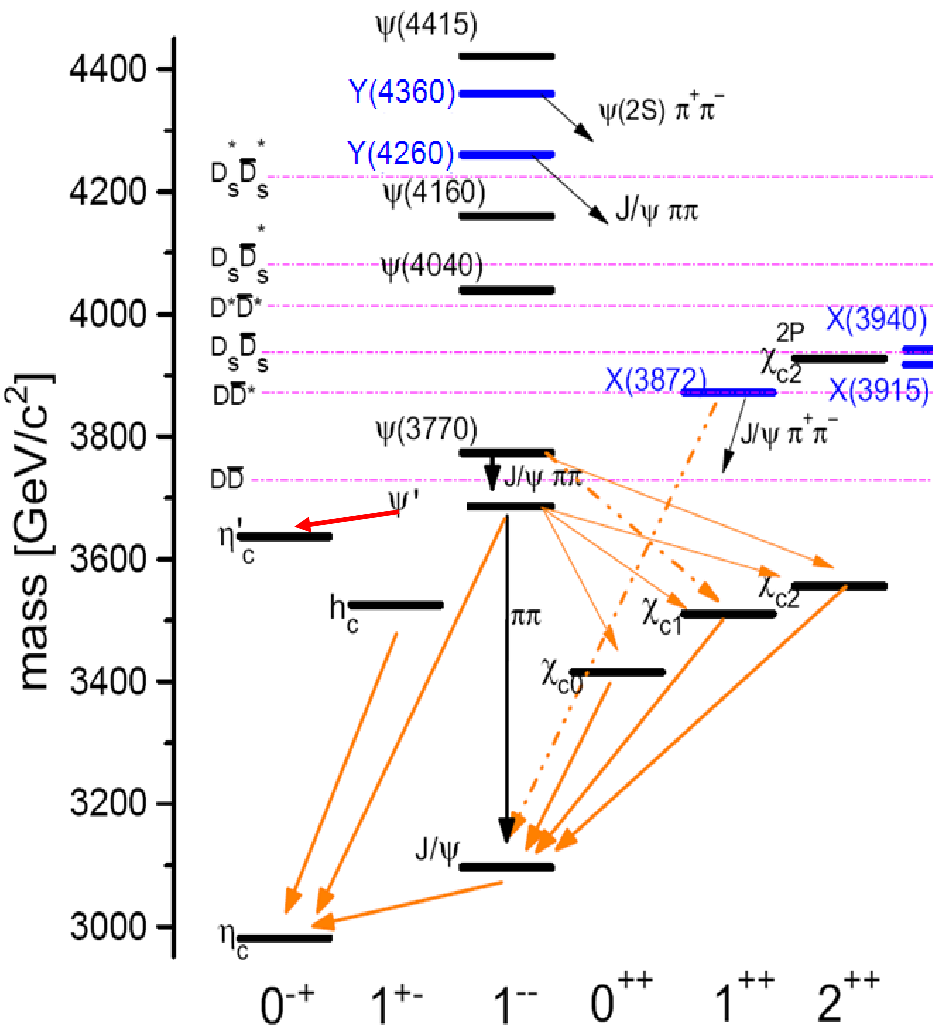
- Charmonium physics:
  - **Spectroscopy, transitions, decays**
  - **"Exotic" charmonium states**
- Light hadron physics: (using charmonium as source to produce light hadrons)
  - meson & **baryon spectroscopy**
  - glueball & hybrid
- Open Charm physics:
- QCD & Tau physics:
- …

BESIII Data Samples

Energy	Topics (Highlight)	Analyzed	Collected
J/ψ	light hadron	225M decays	1.2B decays
Ψ'	charmonium, light hadron	106M decays	600M decays
Ψ(3770)	open charm	2.9 fb^{-1}	
E_{cm} = 4010MeV	Exotic charmonium states	482pb^{-1}	
E_{cm} = 4260MeV	Exotic charmonium states	525pb^{-1}	2fb^{-1} (ongoing)
E_{cm} = 4360MeV	Exotic charmonium states		520pb^{-1}

* Other energy points for line scan studies, etc.

Charmonium Transitions and Decays



- EM transitions and decays: clean, relatively simple.
  - potential models
  - lattice QCD calculations
  - EFT

    $\psi(2S) \rightarrow \gamma\eta_c'$

    $J/\psi \rightarrow \gamma\gamma\gamma$
- Baryon-involving decays
  - test pQCD
  - helicity selection rules(HSR)

    $\eta_c \rightarrow$ Baryon + anti-Baryon

First Observation of $\psi' \rightarrow \gamma\eta_c'$

- Magnetic dipole transition, $\psi' \rightarrow \gamma\eta_c'$
  - $\eta_c' \rightarrow K_s K\pi$ / $K^+K^-\pi^0$
- E_γ ~ 50 MeV: high background
  - data driven technique
- Combined significance: > 10σ
- Measure: $B(\psi' \rightarrow \gamma\eta_c')*B(\eta_c' \rightarrow \bar{K}K\pi)$

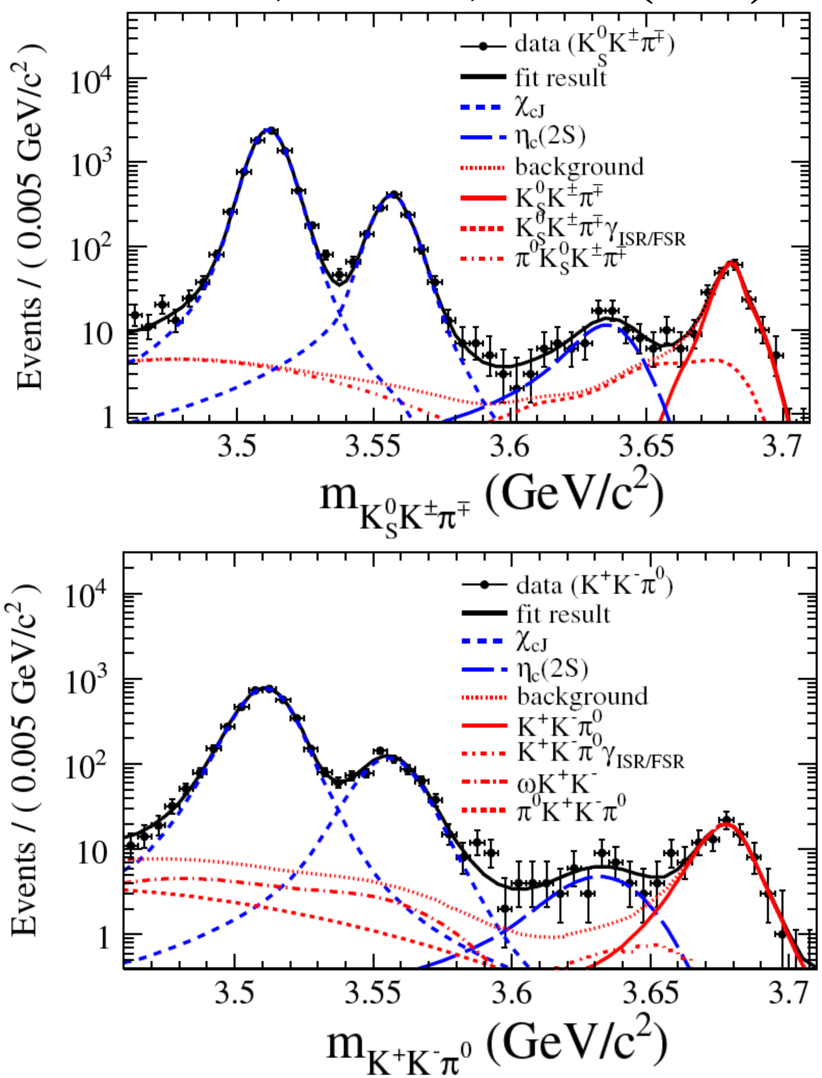
  $=(2.98 \pm 0.57 \pm 0.48)*10^{-6}$
- Combined with BaBar measurement

  of $B(\eta_c' \rightarrow KK\pi)$ to obtain:

  $B(\psi' \rightarrow \gamma\eta_c')=(6.8 \pm 1.1 \pm 4.5)*10^{-4}$
- Consistent with potential model

  prediction: $(0.1\text{-}6.2)*10^{-4}$ [1]

BESIII, PRL 109, 042003(2012)



[1] arXiv: 0909.2812

J/ψ → γ γ γ

- Test of non-perturbative QCD with first order corrections

$$\mathcal{R} \equiv \frac{\mathcal{B}(J/\psi \to 3\gamma)}{\mathcal{B}(J/\psi \to e^+e^-)} = \frac{64(\pi^2-9)}{243\pi}\alpha\left(1 - 7.3\frac{\alpha_s(r)}{\pi}\right)$$

$\alpha_s \sim 0.19$: $R \sim 3.0*10^{-4}$

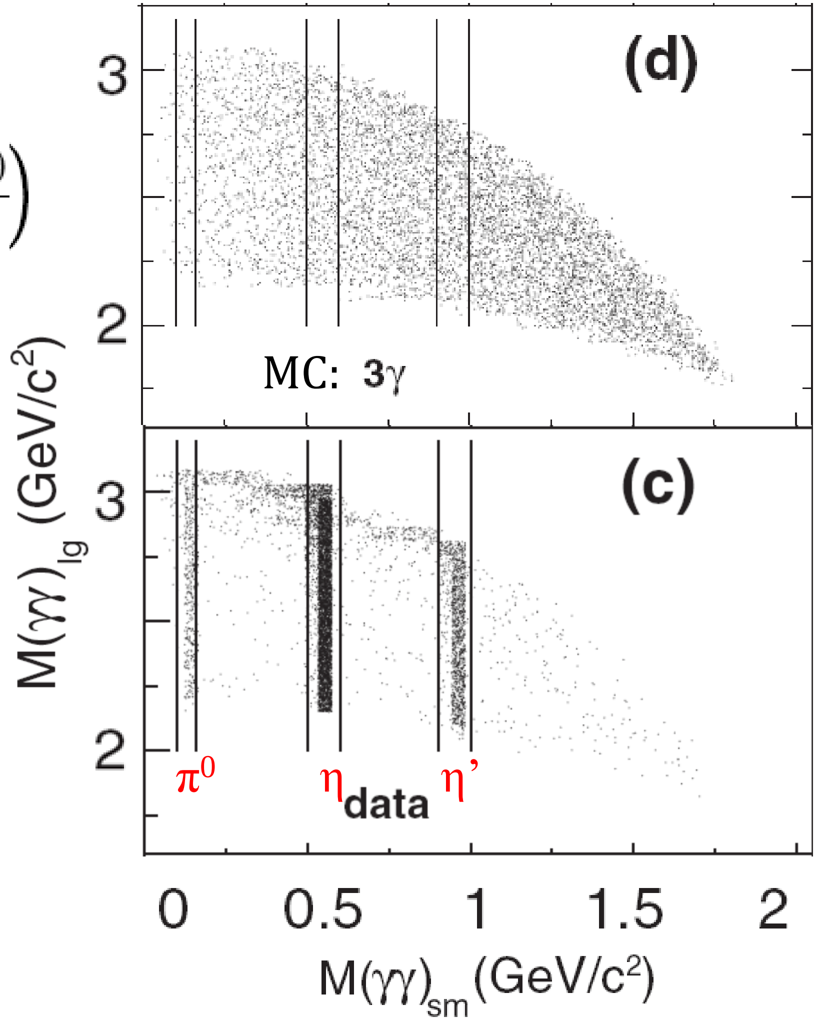
- Suppress EM bkg. by using J/ψ from ψ'

Measure: $B(J/\psi \to \gamma\gamma\gamma)=(11.3\pm1.8\pm2.0)*10^{-6}$

- BESIII + CLEOc: $R = (1.95\pm0.37) * 10^{-4}$
- Need radiative and relativistic correction
- Evidence for $\eta_c \to \gamma\gamma$; complementary to two-photon fusion measurements

$B(\eta_c \to \gamma\gamma)=(2.6\pm0.7\pm0.7)*10^{-4}$

BESIII, PRD87, 032003(2013)



$\eta_c \rightarrow$ Baryon + anti-Baryon

- HSR prohibition

- Charmed-meson loop model explains $\eta_c \rightarrow$ ppbar, ΛΛbar

$$J/\Psi \rightarrow \gamma\eta_c \qquad \eta_c \rightarrow \begin{cases} \Sigma^+\overline{\Sigma}^- \\ \Xi^+\overline{\Xi}^- \end{cases}$$

$$\Sigma^+ \rightarrow p\pi^0$$

$$\Xi^- \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^-$$

- Measurements:

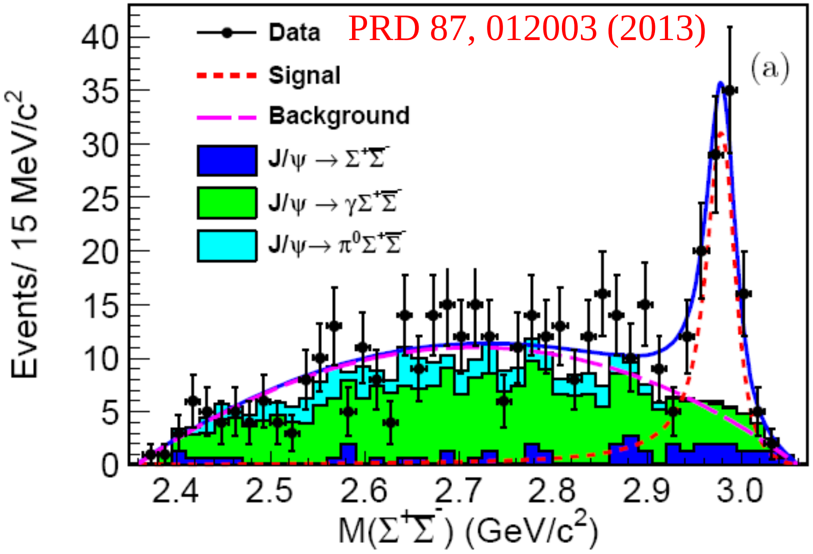
$$Br(\eta_c \rightarrow \Sigma^+\overline{\Sigma}^-) = (2.11 \pm 0.28 \pm 0.18 \pm 0.50) \times 10^{-3}$$

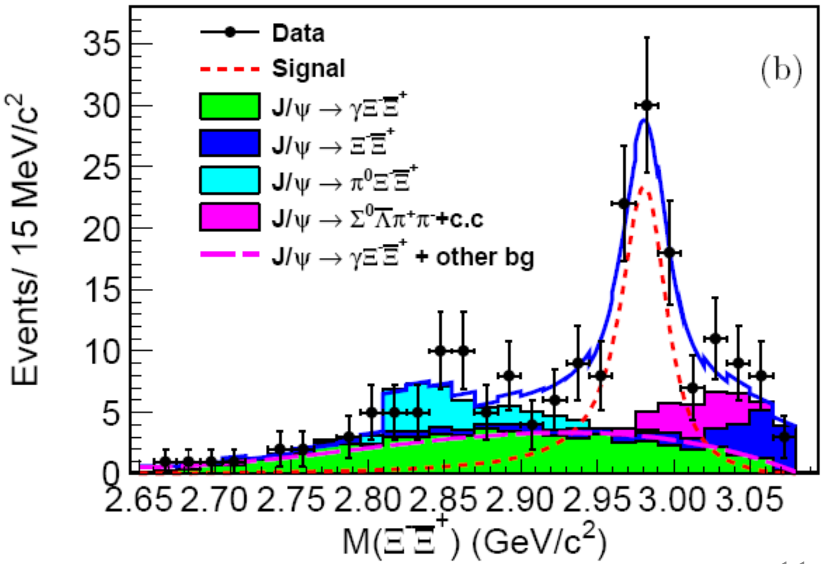
$$Br(\eta_c \rightarrow \Xi^+\overline{\Xi}^-) = (0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}$$

- Charmed-meson loop prediction:

$$Br(\eta_c \rightarrow \Sigma^+\overline{\Sigma}^-) = (0.51 - 1.00) \times 10^{-3}$$

$$Br(\eta_c \rightarrow \Xi^+\overline{\Xi}^-) = (0.48 - 0.96) \times 10^{-3}$$





Charmonium Spectroscopy

arXiv: 1010.5827

- Many charmonium states above $\bar{D}D$ threshold discovered
- Production in e+e- and B decay (Belle, BaBar, CDF, D0, CLEO)
- Some are likely conventional $\bar{c}c$ states, e.g. $\chi_{cJ}(2P)$
- Some have surprising properties
- Many need confirmation (NC!) , spin-parity determination and search for other states to complete the spectrum. Statistical capability of current B-factory data sets is limited

Review from Quarkonium Working Group

State	m (MeV)	Γ (MeV)	J^{PC}	Year	Status
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6 (<2.2)	$1^{++}/2^{-+}$	2003	OK
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	2004	OK
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	2007	NC!
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	2008	NC!
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	2005	OK
... .	....	....	......	......	...

- Complementary to light quark systems:
Is there evidence for gluonic degrees of freedom in the spectrum of charmonium?

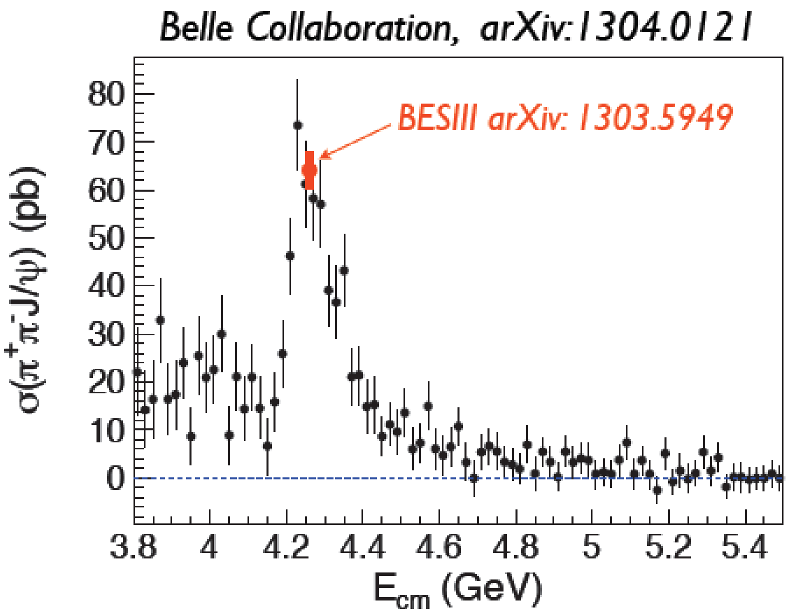
Y(4260) and Y(4360)

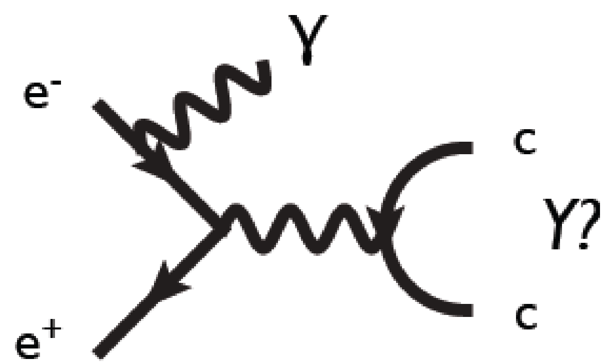
- Y(4260), anomalous enhancement in $J/\psi\pi\pi$ cross section discovered by BaBar in initial state radiation (ISR) e+e- production (confirmed by Belle and CLEO)

- Must be a 1^{--} state
  - overpopulates 1^{--} charmonium states
  - above $D\bar{D}$ threshold but does not couple to $D\bar{D}$ like others

- Similarly mysterious Y(4360) in $\psi'\pi\pi$

- Study at BESIII by collecting data at fixed E_{cm} = 4.26 and 4.36 GeV.
  - study systematically looking at many channels





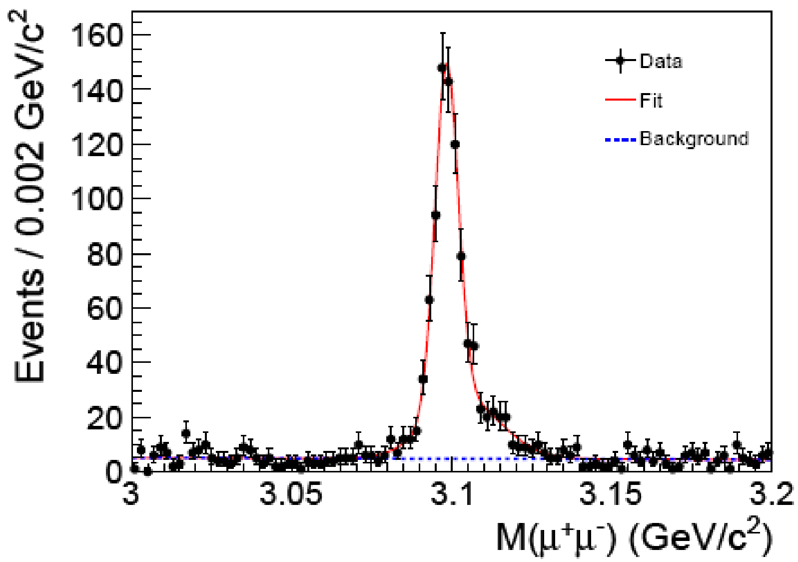
ISR production (BaBar, Belle)

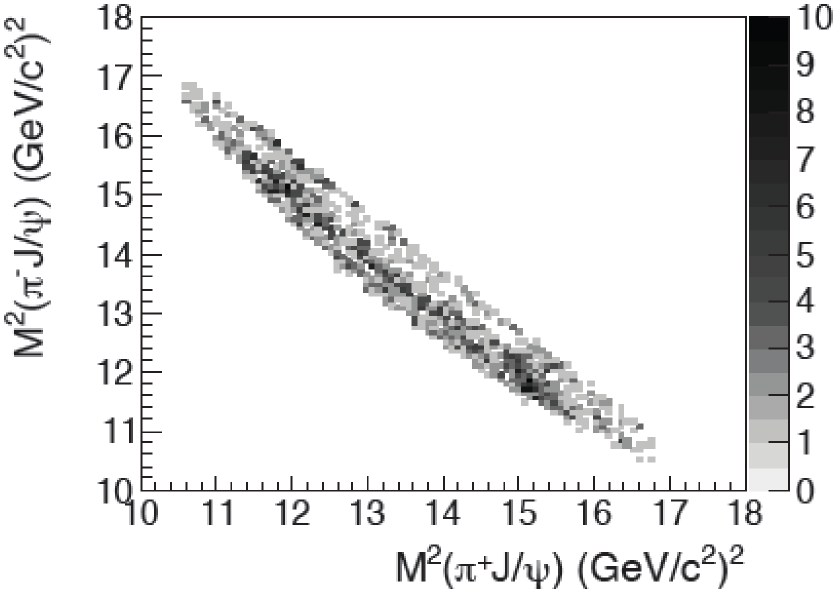
$Z_c(3900)$ in $Y(4260) \rightarrow J/\psi\pi^+\pi^-$

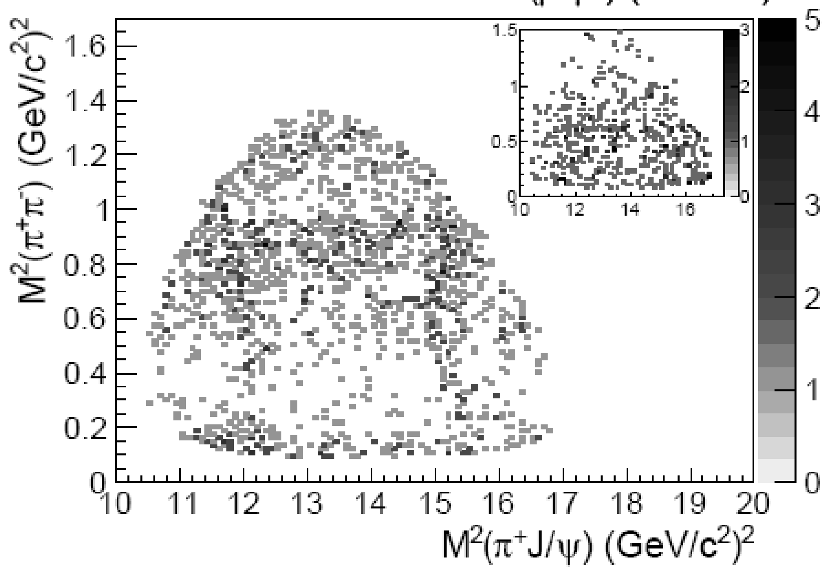
BESIII arXiv: 1303.5949
Accepted by PRL

$\sigma^B(e^+e^- \rightarrow \pi^+\pi^- J/\psi) = 62.9 \pm 1.9 \pm 3.7$ pb agrees with Babar & Belle.

Observe structures in both π^+J/ψ and $\pi^- J/\psi$ invariant mass spectra.





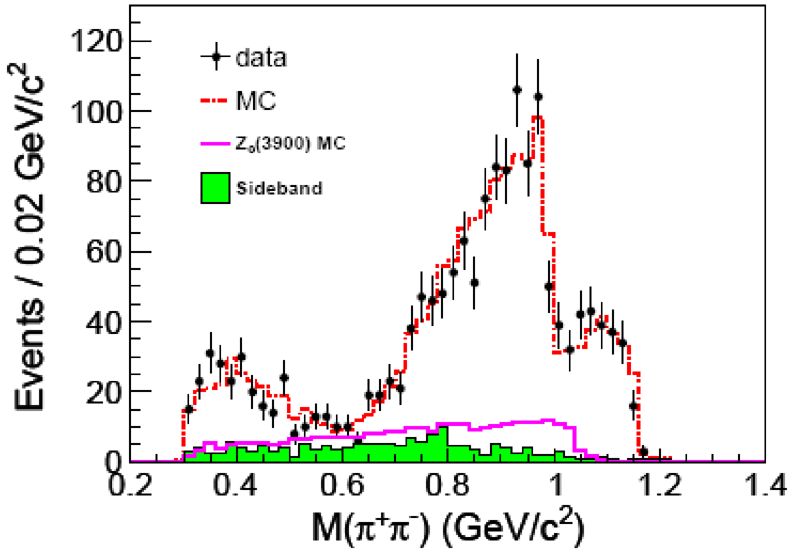


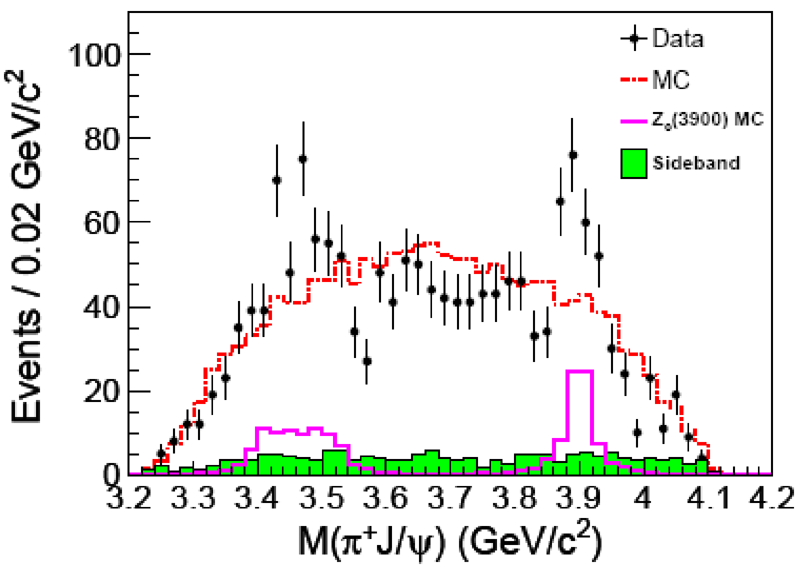
$Z_c(3900)$ in $Y(4260) \rightarrow J/\psi\pi^+\pi^-$

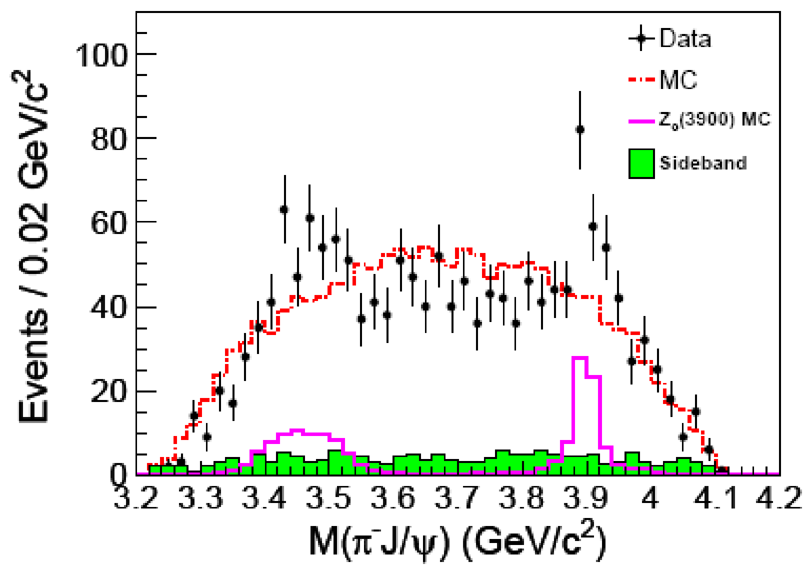
BESIII arXiv: 1303.5949
Accepted by PRL

- $\pi^+\pi^-$ mass spectrum: f0(980), σ(500), generate no peak in $\pi^{\pm}J/\psi$ spectrum.

- $\pi^{\pm}J/\psi$ mass spectrum: peak at 3.9GeV/c^2 ($Z_c(3900)$); the wider peak at low mass is a kinematic reflection of the $Z_c(3900)$.





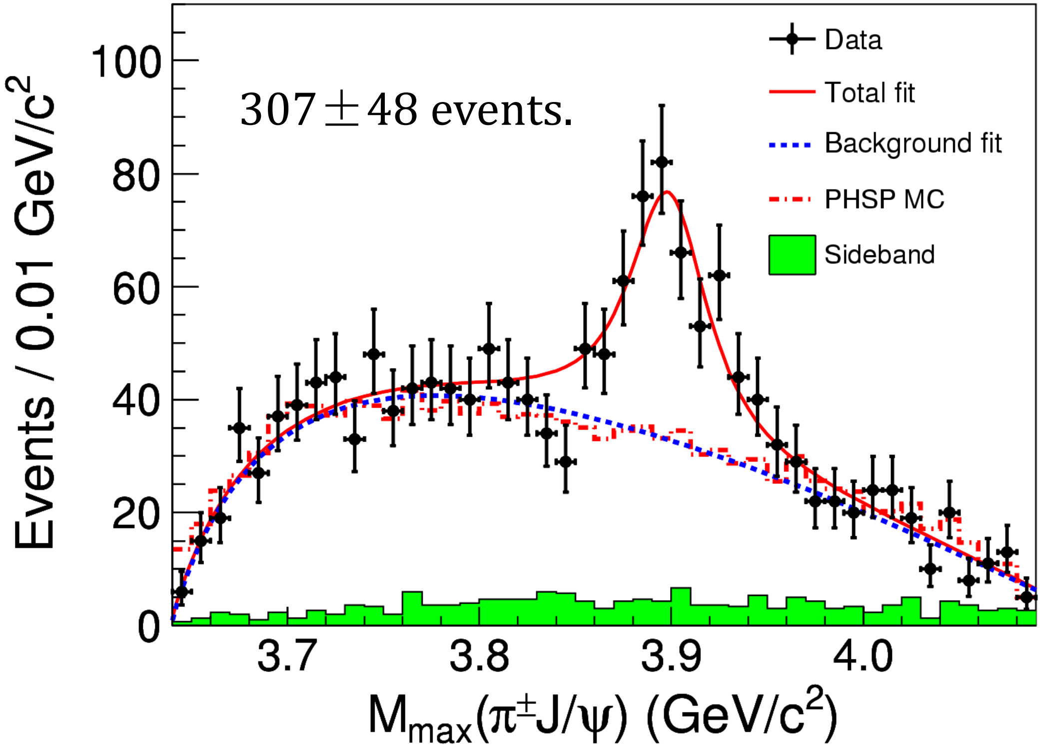


$Z_c(3900)$ in $Y(4260) \rightarrow J/\psi\pi^+\pi^-$

BESIII arXiv: 1303.5949
Accepted by PRL

- Fit projection to obtain:
- $M(Z_c) = 3899 \pm 3.6 \pm 4.9$ MeV/c^2
- $\Gamma(Z_c) = 46 \pm 10 \pm 20$ MeV/c^2
- Significance: > 8σ

At 4260 MeV production of $Z_c\pi^\pm$ is $(21.5 \pm 3.3)\%$ of the $J/\psi\pi^+\pi^-$ cross section



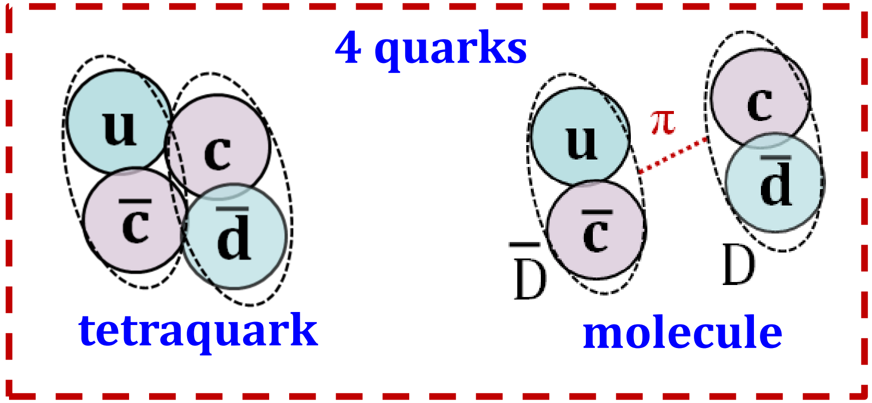
- Couples to ccbar
- Has electric charge
- Interpretation:
  4-quark states?
  DD* interaction at threshold?

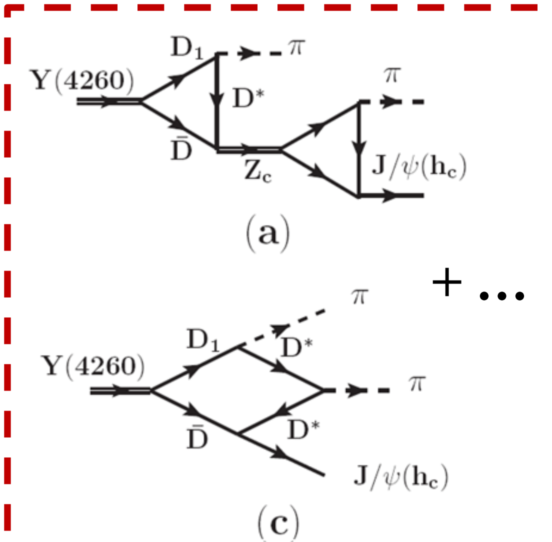
- Confirmed by Belle(arXiv:1304.0121) in ISR Y(4260) production and by Kam Seth (arXiv: 1304.3036) using 586 pb^{-1} of CLEO data taken at a CM energy of 4170MeV.

The nature of $Z_c(3900)$?

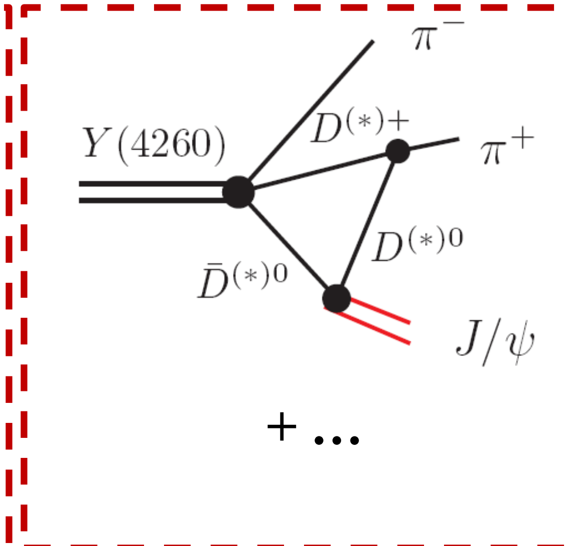
From SPIRE HEP Database (17th, May)

1. Tetraquarks
   arXiv: 1110.1333, 1303.6857
   arXiv: 1304. (0345, 1301, 6433, 7080, 7816)
2. Hadronic molecules
   arXiv: 1303.6608,
   arXiv: 1304.(2882, 1850, 5748, 7467)
3. Four quark state (1 or 2)
   arXiv: 1304.0380
4. Meson loop
   arXiv: 1303.6355, 1304.4458
5. Initial State Pion Emission (ISPE) model
   arXiv: 1303.6842, 1304.5845





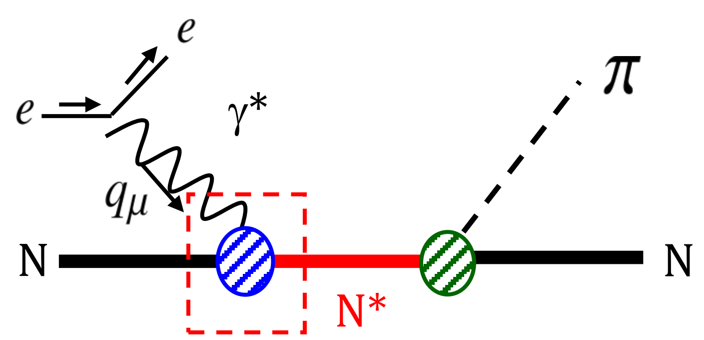
meson loop

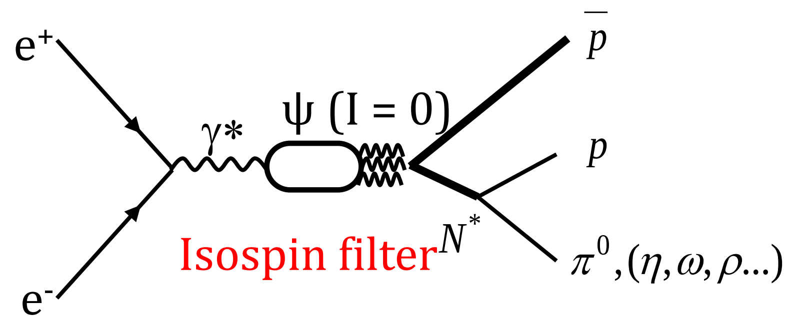


ISPE model

With more data presently analysed, BESIII will be able to exclude various interpretations of the Zc(3900)!

Excited Baryon Program using charmonium decays





Advantages of excited baryon study using charmonium decay:

1: Isospin filter : less states, less complicated.

ψ (I = 0)→ p (I=1/2) $\bar{p}\,\pi^0$ (I=1/2) N* --yes, Δ* -- no

2: Study by many decay channels, such as π^0N, ηN, η'N, ωN…

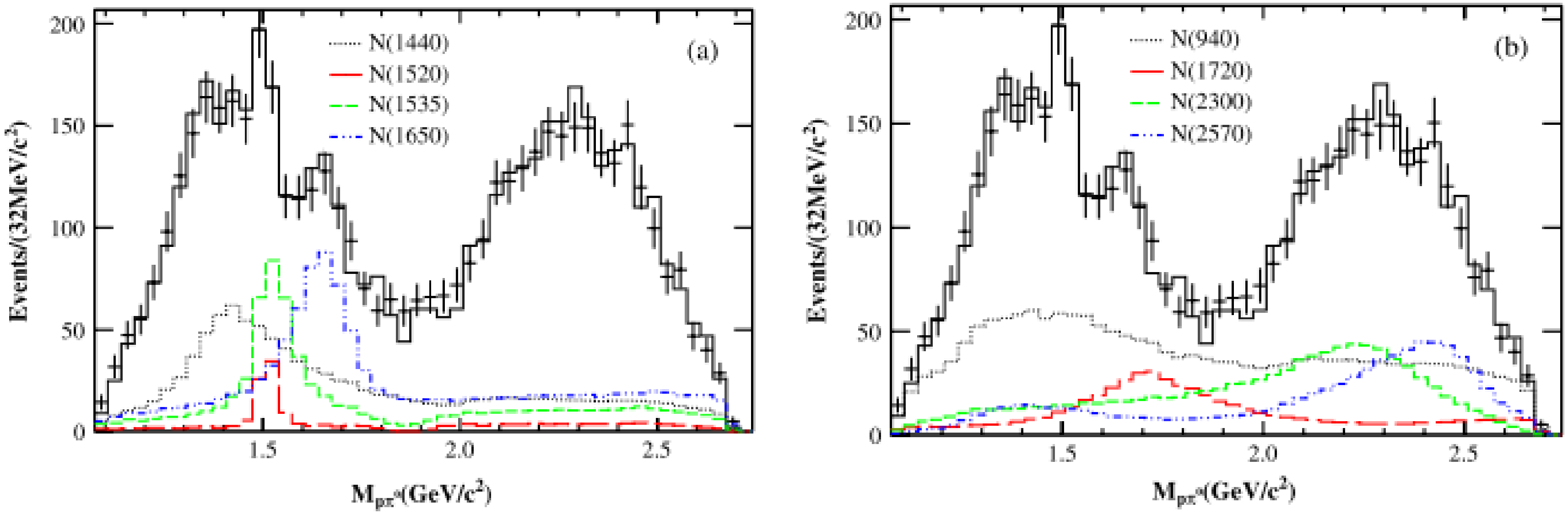
3: Large statistics for charmonium states

4: Study of N*, Λ*, Σ*, Ξ*

See Wenlong's talk @parallel B5

N* in ψ’ → p $\bar{p}$ π^0

Phys. Rev. Lett. 110, 022001 (2013)



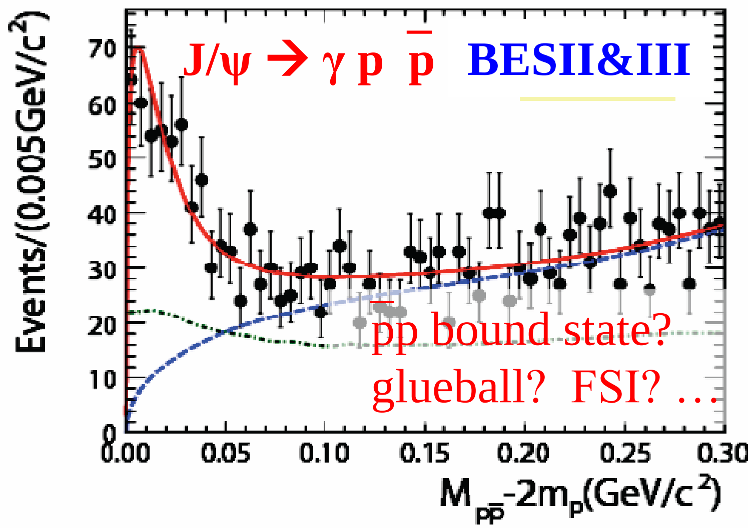
- Full partial wave analysis.
- Two new N* states observed.

See Wenlong’s talk
@parallel B5

Resonance	M(MeV/c^2)	Γ(MeV/c^2)	Sig.	J^P
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	11.5σ	1/2+
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	5.0σ	3/2-
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	9.3σ	1/2-
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	12.2σ	1/2-
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	9.6σ	3/2+
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	$\mathbf{15.0\sigma}$	1/2+
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	$\mathbf{11.7\sigma}$	5/2-

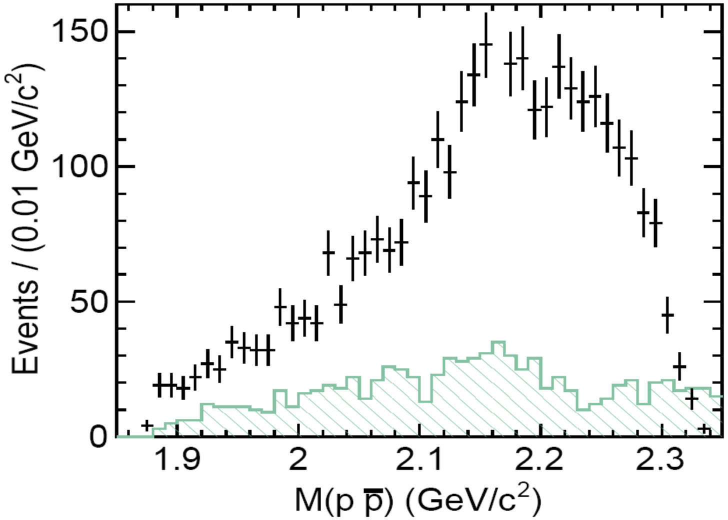
J/ψ → ω p $\bar{p}$

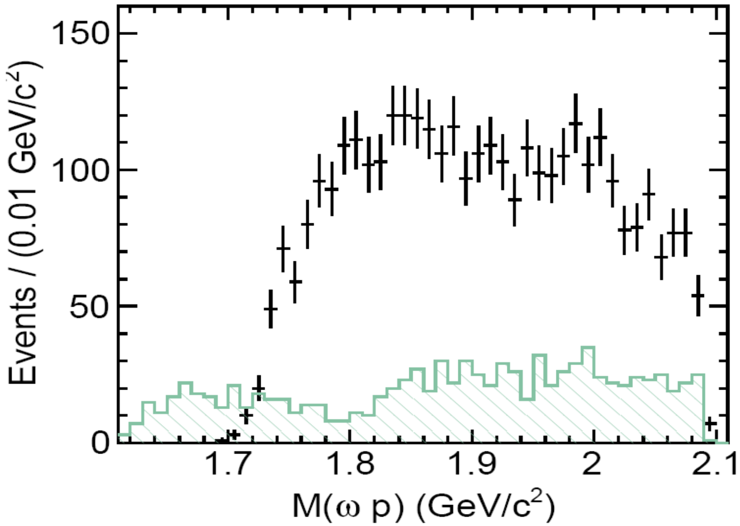
arXiv: 1303.3040
Accepted by PRD



- J/ψ → ω p $\bar{p}$ → γ π^0 p $\bar{p}$
- No obvious p $\bar{p}$ threshold enhancement

  B(J/ψ → ωX(p $\bar{p}$) → ω p $\bar{p}$) < 3.9*10^{-6}
- Disfavors Pure FSI interpretation
- No obvious structures in M_pω





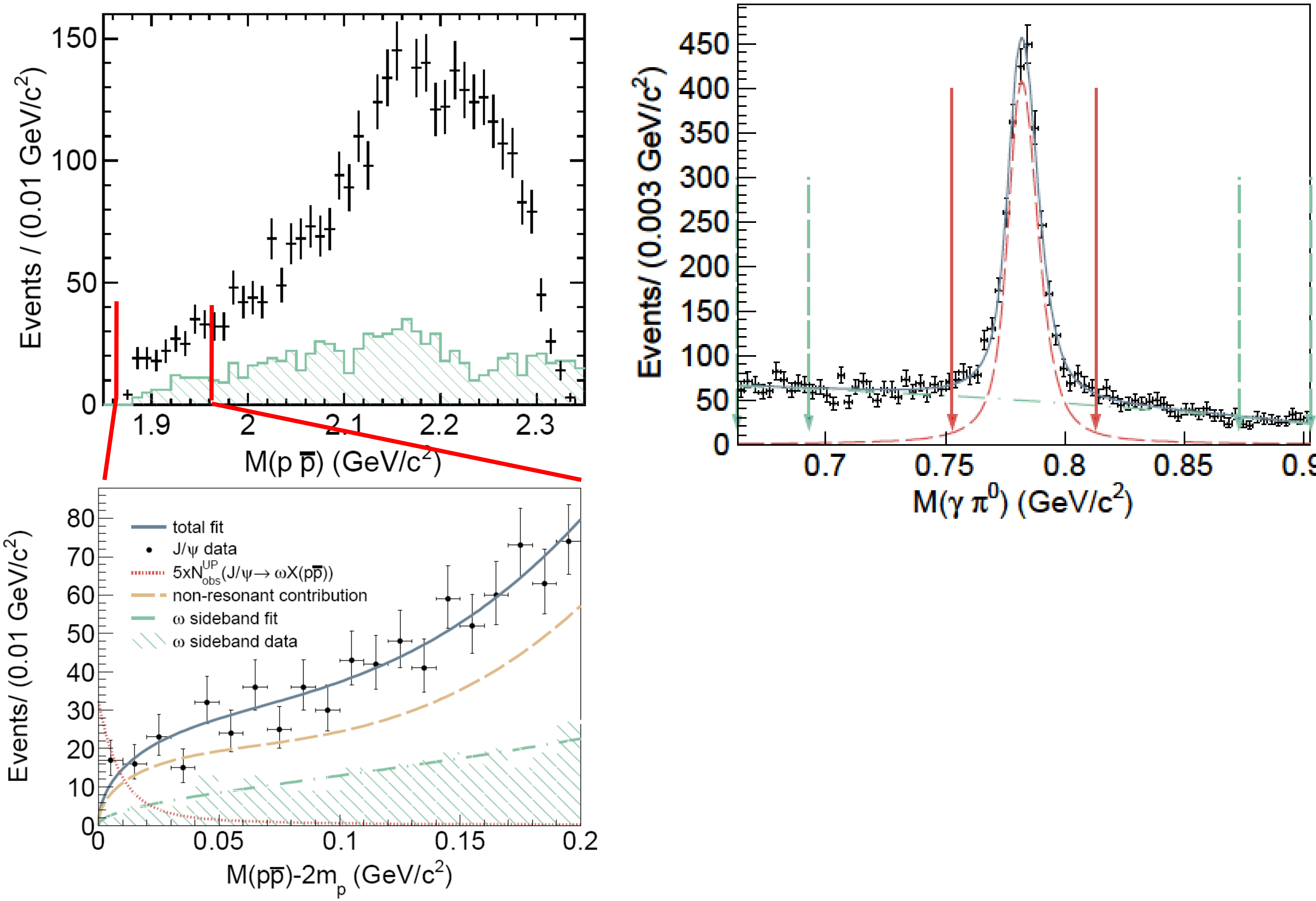
Summary and Outlook

- Diverse program of hadron physics ongoing at BESIII
  - new or more precise experimental tests of calculations of charmonium transitions and decays
  - an unexpected result in the charmonium spectrum: a charged charmonium-like state
  - many ongoing N* studies using J/ψ or ψ' decay
- Expect vibrant program headed into the future:
  - already have at least 4X statistics in both J/ψ and ψ' decays
  - analysis has started on Ecm = 4360 MeV
  - expect 4X statistics at Ecm = 4260 MeV by the end of summer

Thank you!

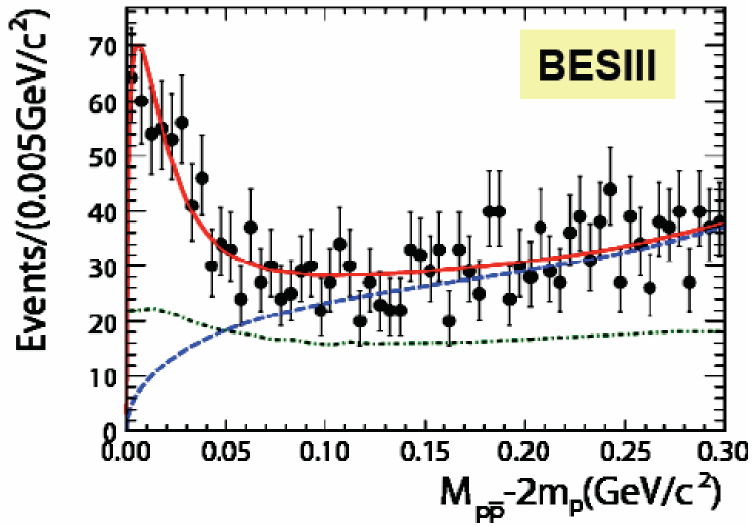
$J/\psi \to \omega\ \bar{p}p$

arXiv: 1303.3040
Accepted by PRD



$\bar{p}p$ mass threshold structure in $J/\psi \to \gamma \bar{p}p$

- Confirmed by BESIII, Chinese Physic C 34, 421(2010)



Theoretical interpretation:

- conventional meson?
- $p\bar{p}$ bound state/multiquark
- glueball
- Final state interaction (FSI)
- ...

- PWA of $J/\psi \to \gamma$ppbar was first performed, PRL 108, 112003(2012)

$J^{pc} = 0^{-+}$ → >6.8σ better than other J^{pc} assignments.

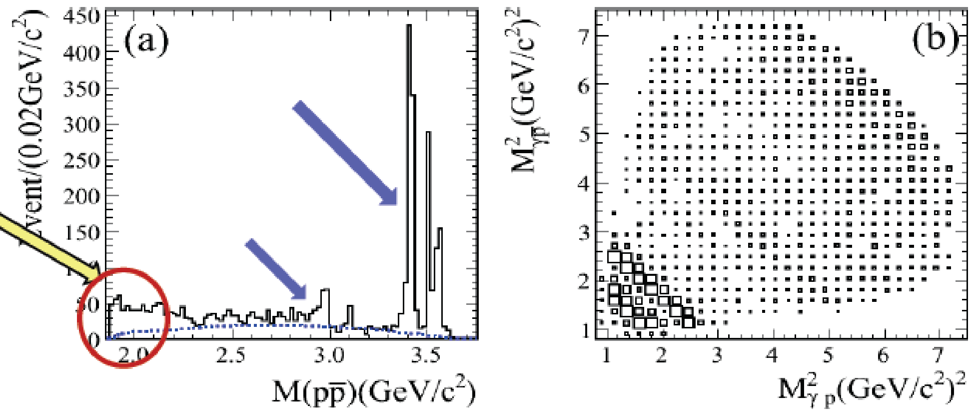
$$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{mod})\text{MeV}/c^2$$

$$\Gamma = 13 \pm 20(\text{stat})^{+11}_{-33}(\text{syst}) \pm 4(\text{mod})\text{MeV}/c^2 \text{ or } \Gamma < 76\text{MeV}/c^2 \ @90\%\, C.L.$$

$$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$$

Mp$\bar{p}$ threshold structure of $\psi' \to \gamma p\bar{p}$ @BESIII

Obviously different line shape of p$\bar{p}$ mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X(p$\bar{p}$) is > 6.9σ.
- The production ratio R:

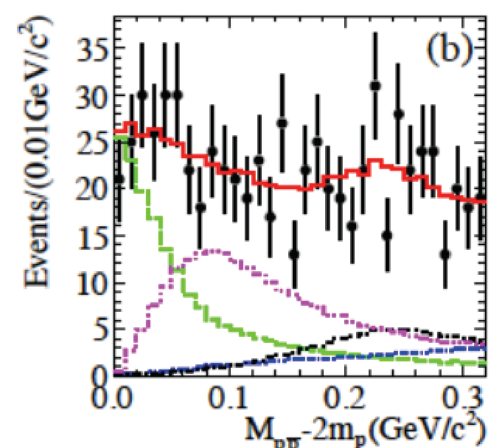
first measurement

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{syst}) \pm 0.12(\text{mod}))\%$$

- It is suppressed compared with "12% rule".

PWA Projection:

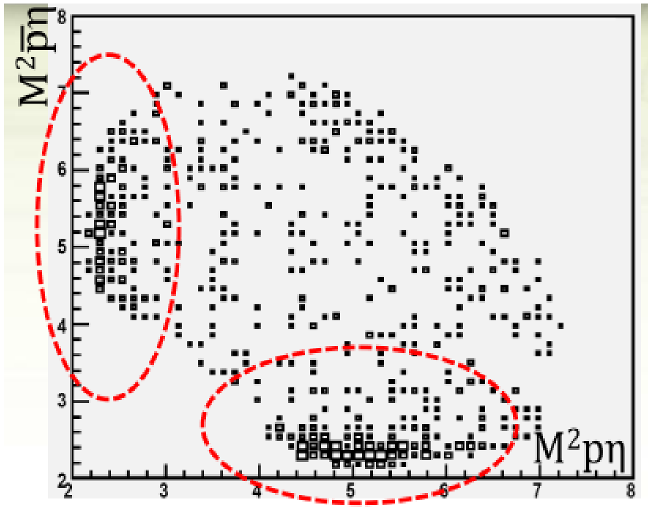


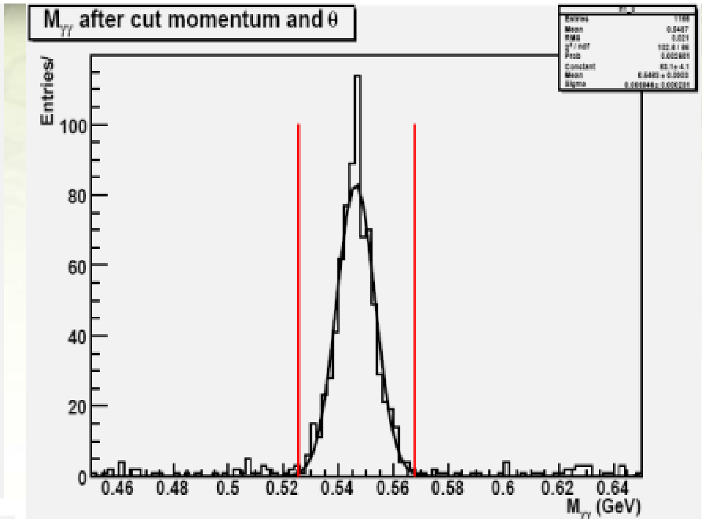
PRL 108,112003(2012)

N* in ψ' → p p̄ η

BESIII arXiv: 1304.1973

See Wenlong's talk @parallel B5

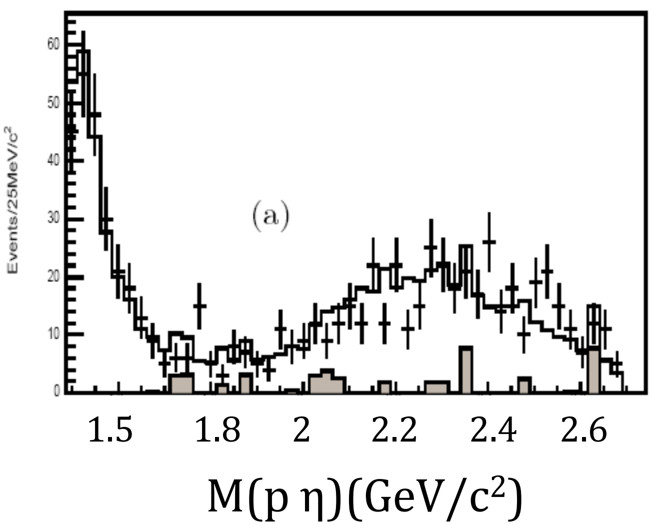


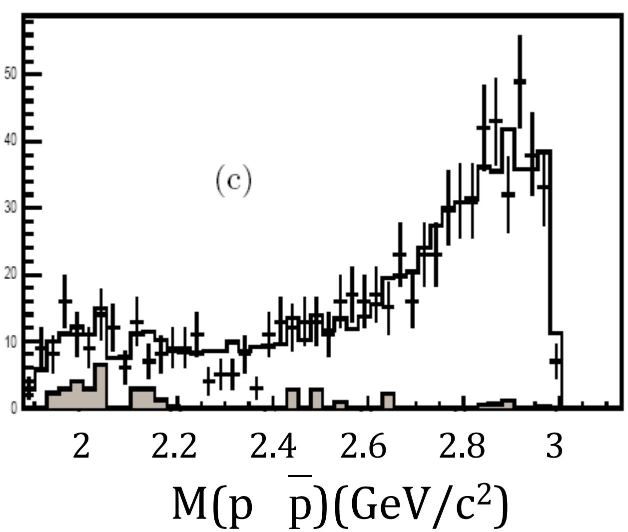


A full PWA is performed.

Two components:

1. N(1535) ½-
2. PHSP





Mass:

$1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV/C²

Width:

$0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

PDG:

M=1.535±0.01GeV/c²

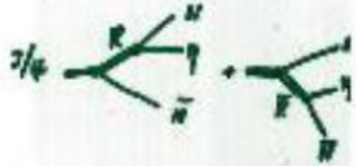
Γ = 125~175MeV/c²

For ψ decay to baryons:

- Construction of PWA amplitudes.

Rarita-Schwinger covariant tensor formalism.

(1) $\frac{1}{2}^{\pm}$ N^*.



$$\mathcal{L}_{\eta N R} = -i g_{\eta N R} \bar{N} \Gamma R \eta + h.c.$$

$$\mathcal{L}_{\psi N R} = -g_{V_1} \bar{R} \Gamma_\mu N \psi^\mu + \frac{i g_{V_2}}{M_R + M_N} \bar{R} \Gamma_{\mu\nu} \xi^\nu_\psi N \psi^\mu + h.c.$$

where

$\Gamma = 1, \quad \Gamma_\mu = \gamma_5 \gamma_\mu, \quad \Gamma_{\mu\nu} = \gamma_5 \sigma_{\mu\nu}$ for $\frac{1}{2}^-$ N^*,

$\Gamma = \gamma_5, \quad \Gamma_\mu = \gamma_\mu, \quad \Gamma_{\mu\nu} = \sigma_{\mu\nu}$ for $\frac{1}{2}^+$ N^*.

$$A_{\frac{1}{2}^-} = G_1 \bar{u} \left[\frac{\not k_1 + \not k_3 + M_{N^*}}{M_{N^*}^2 - s_{13} - i M_{N^*}\Gamma_{N^*}} \gamma_5 \gamma_\mu \varepsilon^\mu + \gamma_5 \not\varepsilon \frac{-\not k_2 - \not k_3 + M_{N^*}}{M_{N^*}^2 - s_{23} - i M_{N^*}\Gamma_{N^*}} \right] v$$

$$+ G_2 \bar{u} \left[\frac{\not k_1 + \not k_3 + M_{N^*}}{M_{N^*}^2 - s_{13} - i M_{N^*}\Gamma_{N^*}} \gamma_5 \sigma_{\mu\nu} \xi^\mu_\psi \varepsilon^\nu + \gamma_5 \sigma_{\mu\nu} \xi^\mu_\psi \varepsilon^\nu \frac{-\not k_2 - \not k_3 + M_{N^*}}{M_{N^*}^2 - s_{23} - i M_{N^*}\Gamma_{N^*}} \right] v$$

$A_{\frac{1}{2}^+} = \cdots$

Three basic elements for constructing amplitudes:

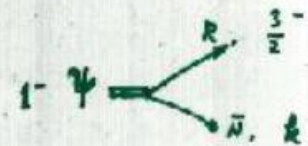
Wave fuctions, propagators, effective couplings.

(2) $\frac{3}{2}$ N^*

Wave function: $u_\mu(p, s_0) = \sum_{\lambda, s} (1\lambda \tfrac{1}{2} s | \tfrac{3}{2} s_0)\, e_\mu(p,\lambda)\, u(p,s)$

propagators: $P_{\mu\nu} = \frac{\not p + M_0}{p^2 - M_0^2 + i M_0 \Gamma_0} \left[g_{\mu\nu} - \frac{1}{3}\gamma_\mu \gamma_\nu - \frac{2 p_\mu p_\nu}{3 M_0^2} + \frac{p_\mu \gamma_\nu - p_\nu \gamma_\mu}{3 M_0} \right]$

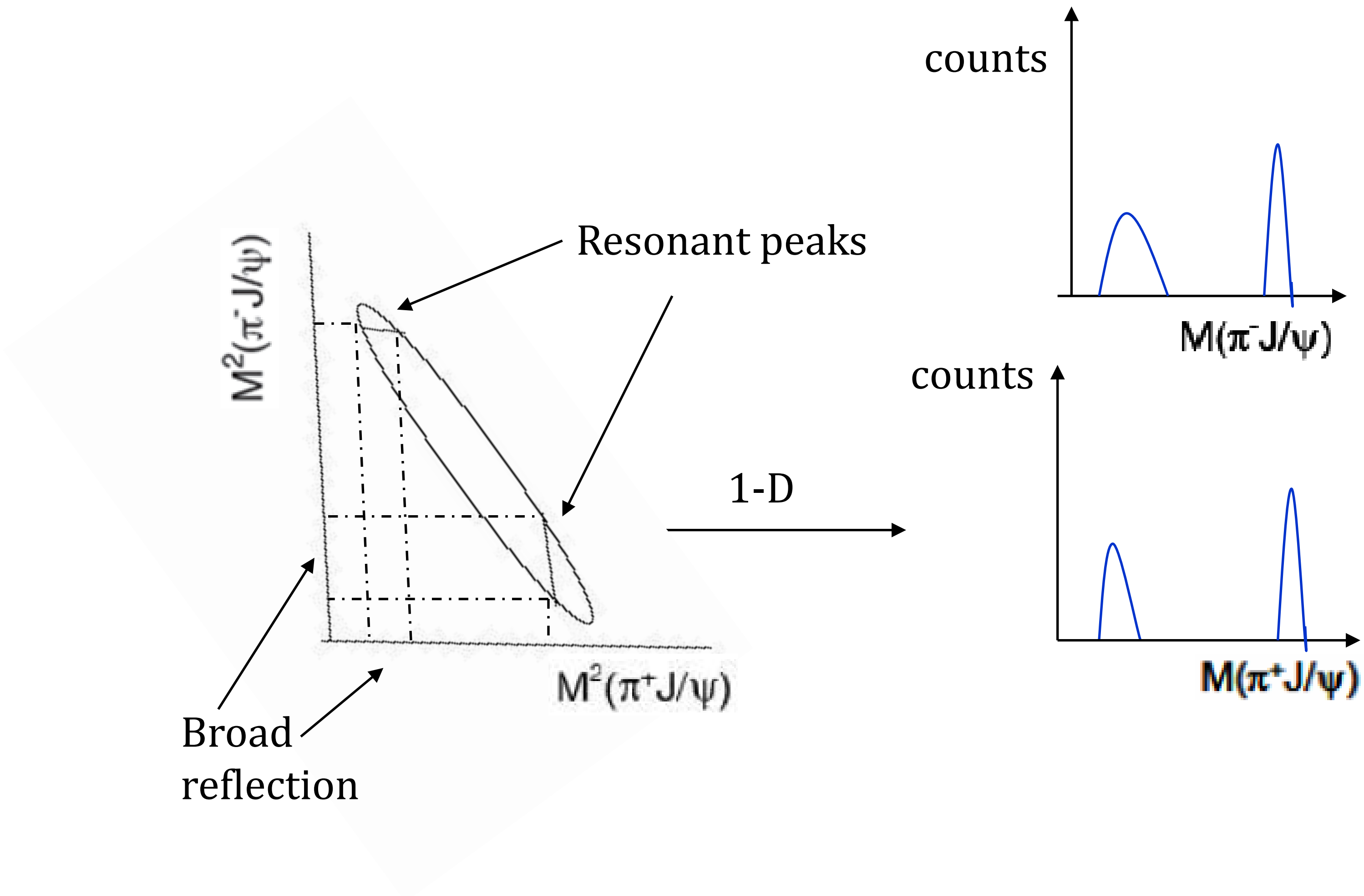
effective couplings:



(1) $\bar{R}^\mu \psi^\nu g_{\mu\nu} N$	$\bar{R}^\mu \psi^\nu g_{\mu\nu} \gamma_5 N$
(2) $\bar{R}^\mu \psi^\nu \gamma_\nu k_\mu N$	$\bar{R}^\mu \psi^\nu \gamma_\nu k_\mu \gamma_5 N$
(3) $\bar{R}^\mu \psi^\nu k_\mu k_\nu N$	$\bar{R}^\mu \psi^\nu k_\mu k_\nu \gamma_5 N$

$i\bar{N} \phi \gamma_5 k_\mu R^\mu$	$i\bar{N} \phi k_\mu R^\mu$

Kinematic reflections



J. Phys. G: Nucl. Part. Phys. **38** (2011) 035007

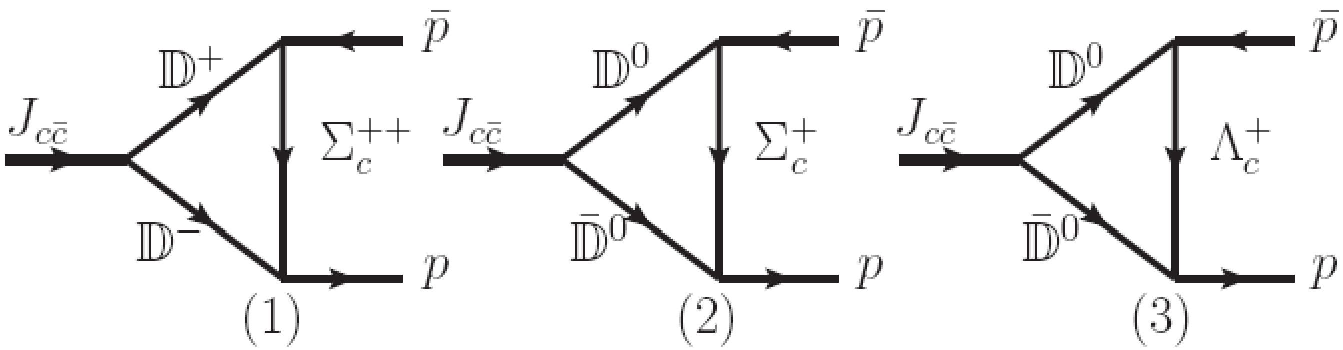


Figure 1. Charmed hadron loop diagrams that describe the long-distance transitions in $J_{c\bar{c}} \to p\bar{p}$.

Helicity Selection Rule

According to the perturbative method of QCD, V.L. Chernyark et al. have ever obtained the asymptotic behavior for some exclusive processes, e.g.

$$BR_{J_{c\bar{c}}(\lambda)\to h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2}$$

Phys. Rept. 112, 173 (1984)

The leading order will contribute when $\lambda_1+\lambda_2=0$, while the helicity configurations that do not satisfy this relation will be suppressed.

An alternative description of this selection rule with the quantum number named "naturalness"

$$\sigma \equiv P(-1)^J$$

The selection rule requires that

$$\sigma^{initial} = \sigma_1\sigma_2$$

Take the process $J/\psi\to VP$ as an example $(\sigma^{initial} \neq \sigma_1\sigma_2)$

$$\mathcal{M}_{J/\psi(\lambda_\psi)\to V(\lambda_V)P(\lambda_P)} \propto \epsilon_{\mu\nu\alpha\beta}p^\mu_\psi\epsilon^\nu_\psi(p_\psi,\lambda_\psi)p^\alpha_V\epsilon^{*\beta}_V(p_V,\lambda_V)$$

In the rest frame of initial state, if $\lambda_V=0$, ε_V can be approximately expressed as a linear combination of the final state momenta. Then the contraction of the Lorentz indices will result in a vanishing amplitude.

S and P-wave Charmonium Decays

	PP	PV	VV
η_c	-	$(\surd)$	ϵ
J/ψ	$(\surd)$	ϵ	$(\surd)$
χ_{c0}	$\surd$	-	$\surd$
χ_{c1}	-	$(\surd)$	ϵ
χ_{c2}	$\surd$	(ϵ)	$\surd$

Inconsistent with exp.

Zhao et al. 0812.4902

Zhang et al. PRL102, 172001

which we will discuss in this talk.

T. Feldmann & P. Kroll

PRD62, 074006 (2000)

$$BR(\chi_{c1}\to K^{*0}\bar{K}^{*0}) = (1.6\pm0.4)\times10^{-3}$$ PDG

$\eta_c(\chi_{c0}, h_c) \to \bar{B}B$

- $\bar{B}B$ represents the $J^P=1/2^+$ octet baryon-antibaryon pairs
- These processes also violate the helicity selection rule
- Some attempts have been made to understand this contradiction
  - quark-diquark model M. Anselmino et al.
  - quark mass correction F. Murgia; M. Anselmino et al.
  - mixing with glueball M. Anselmino et al.
  - quark pair creation model R.G. Ping et al.