Hadron Physics from BESIII

Simonetta Marcello

Torino University and INFN
On behalf of the
BESIII Collaboration

The 10th International Workshop on the Physics of Excited Nucleons

Osaka, May 25 – 28, 2015

OUTLINE

A selection of recent results

- **Time-like Proton Form Factors**
- **Phase in J/ψ decays**
- **Light hadrons: Baryon and Meson Spectroscopy**
- **X Y Z States**

Summary

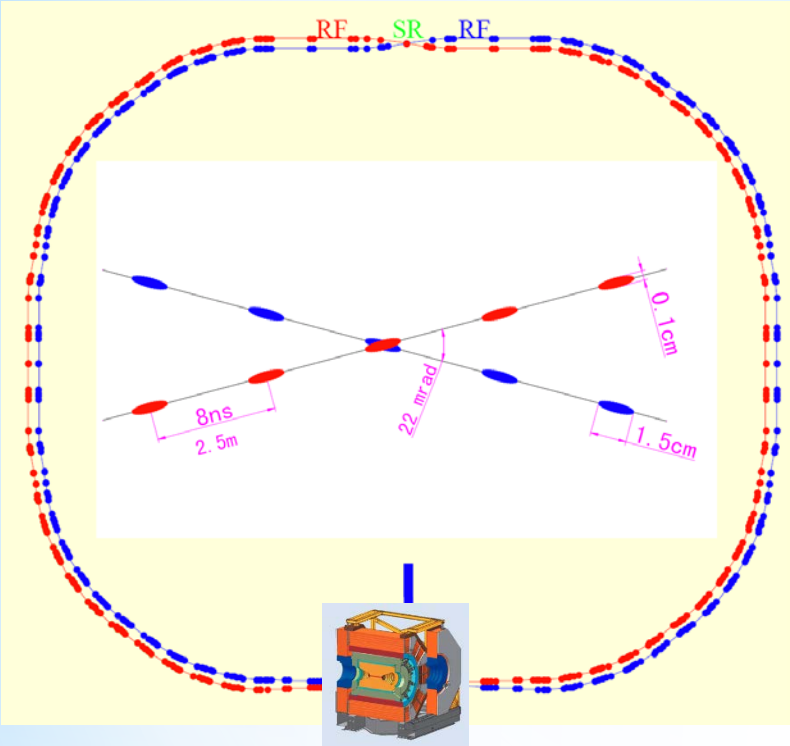
BESIII Talks in Parallel Sessions

- **Proton pair production cross sections** by Xiao Rong Zhou
- **Baryonic spectroscopy** by Fang Liu

BESIII / BEPCII at IHEP in Beijing

BESIII @ BEPCII

Beijing e^+e^- Collider



- Double Ring
  237 m circumference
- Large crossing angle: ±11 mrad
- Beam energy
  1.0 – 2.3 GeV
- Design Luminosity
  1×10^{33} cm^{-2} s^{-1} @ ψ(3770)
- Achieved Luminosity
  0.85×10^{33} cm^{-2} s^{-1}
- Optimum Energy
  1.89 GeV
- Energy Spread
  5.16×10^{-4}
- No. of Bunches 93
- Bunch length 1.5 cm
- Total current 0.91 A
- SR mode 0.25A @ 2.5 GeV

Physics goals cover a diverse range:

- **Charmonium physics: XYZ, spectroscopy, decays to study QCD**
- **Open Charm physics: D^0-$\bar{D}^0$ mixing, (semi)leptonic+hadronic decays, …**
- **Light hadron: meson & baryon spectroscopy, Time-like e.m. form factors, …**
- **τ physics: most precise mass measurement …**
- **… and many more**

$\sqrt{s}$ = 2 - 4.6 GeV

BESIII SPECTROMETER

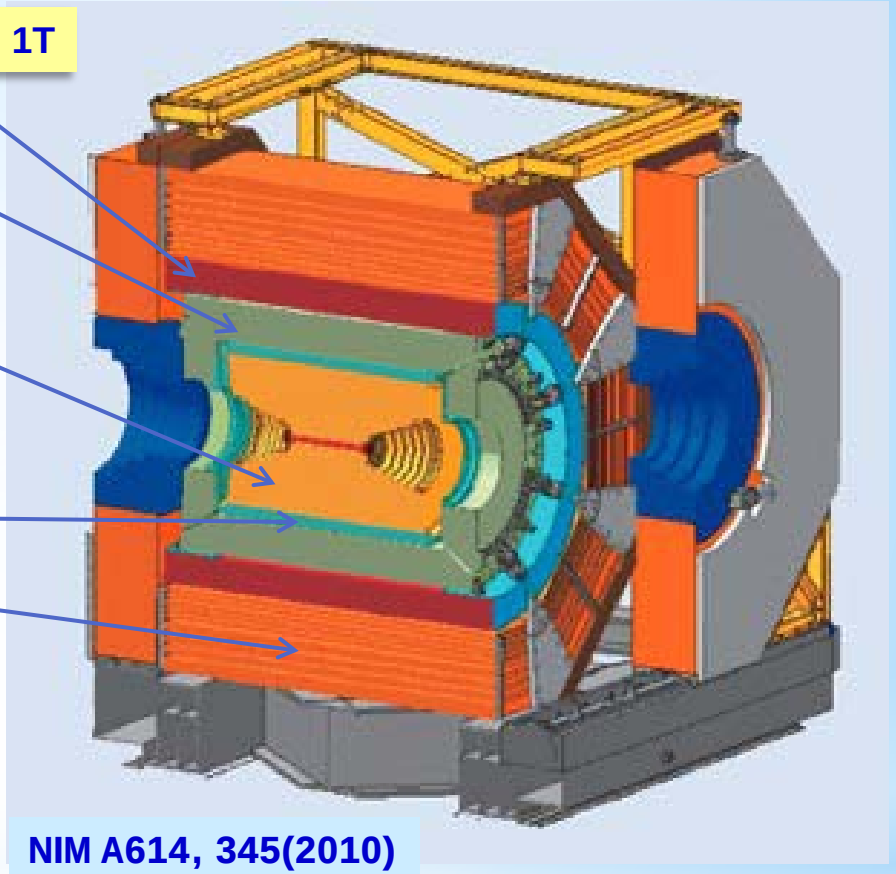
EMC CsI(Tl) crystals
- Energy resolution 2,5% @1GeV
- Spatial resolution 6mm

MDC
- Spatial resolution σ_{xy} = 120μm
- Momentum resolution 0.5% @1GeV
- dE/dx resolution 6%

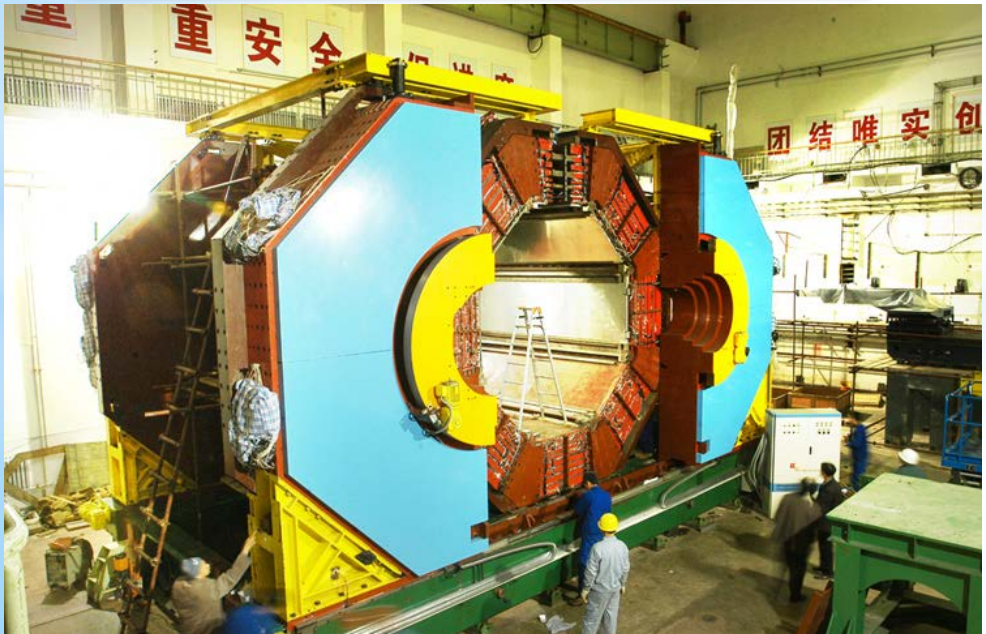
TOF
- Time resolution 80(110) ps barrell (endcaps)

Muon Counter RPC (9)Barrel, (8)Endcaps
- Spatial resolution 1.5 cm

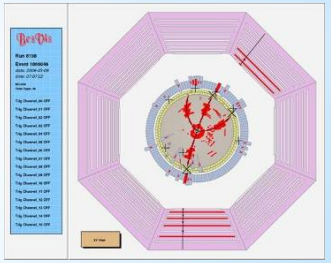
SC Magnet 1T



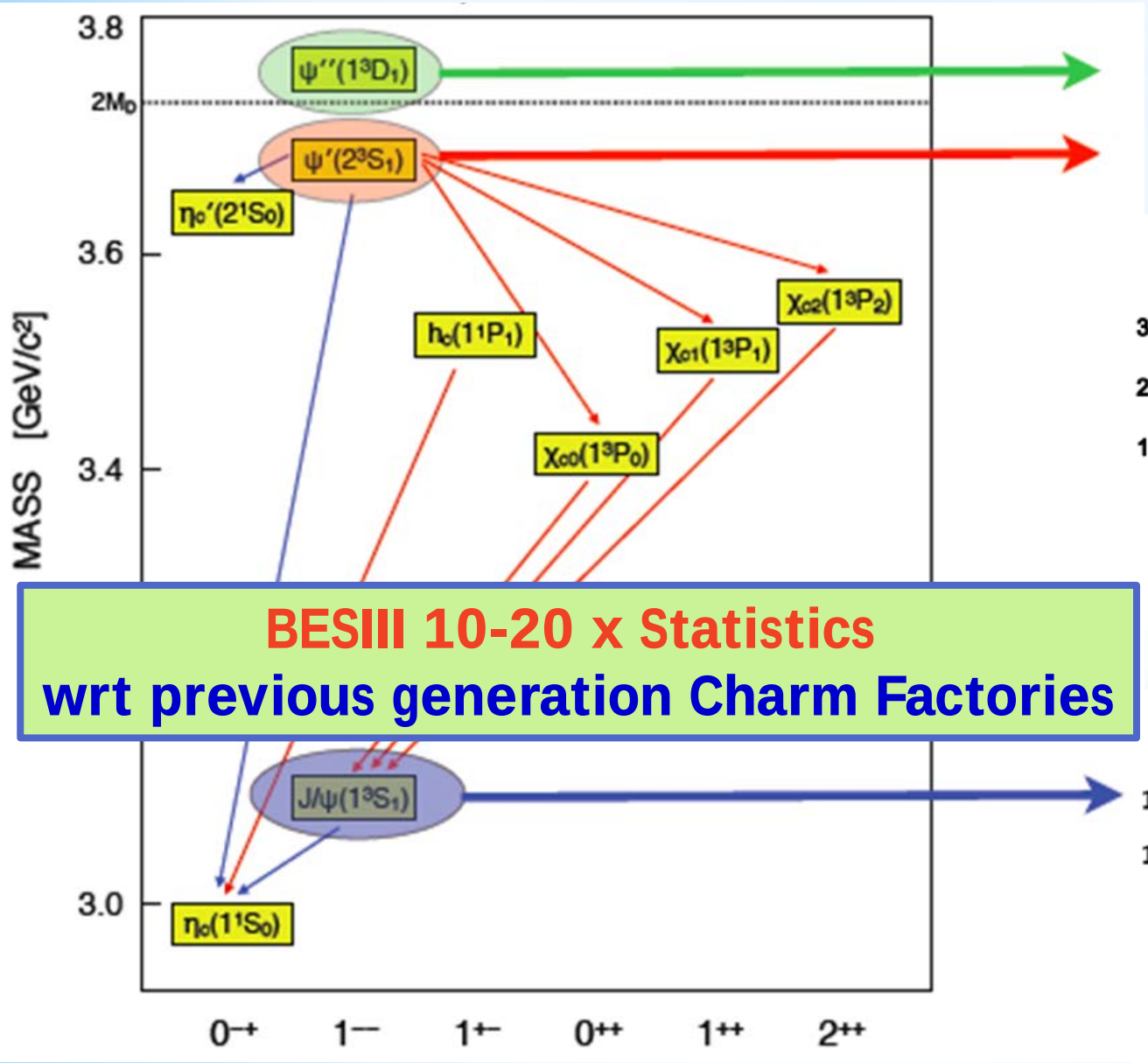
NIM A614, 345(2010)



Excellent performance detector



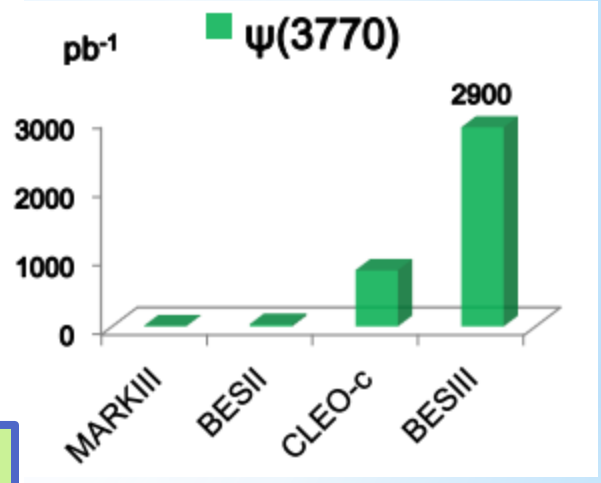
BESIII wrt other Experiments



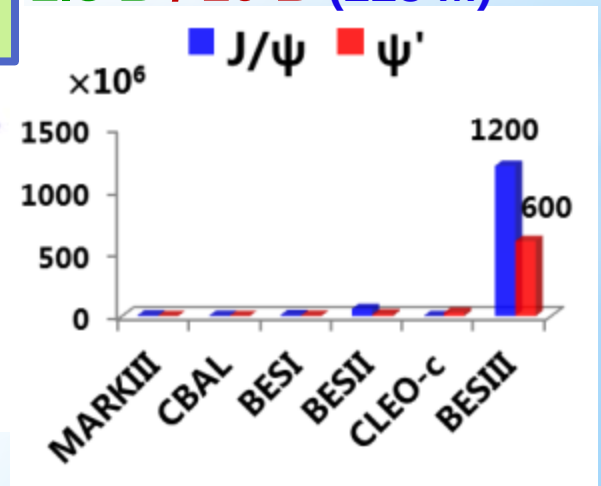
BESIII 10-20 x Statistics
wrt previous generation Charm Factories

2.9 fb^{-1} / 20 fb^{-1}

0.6 B / 3 B (106 M)

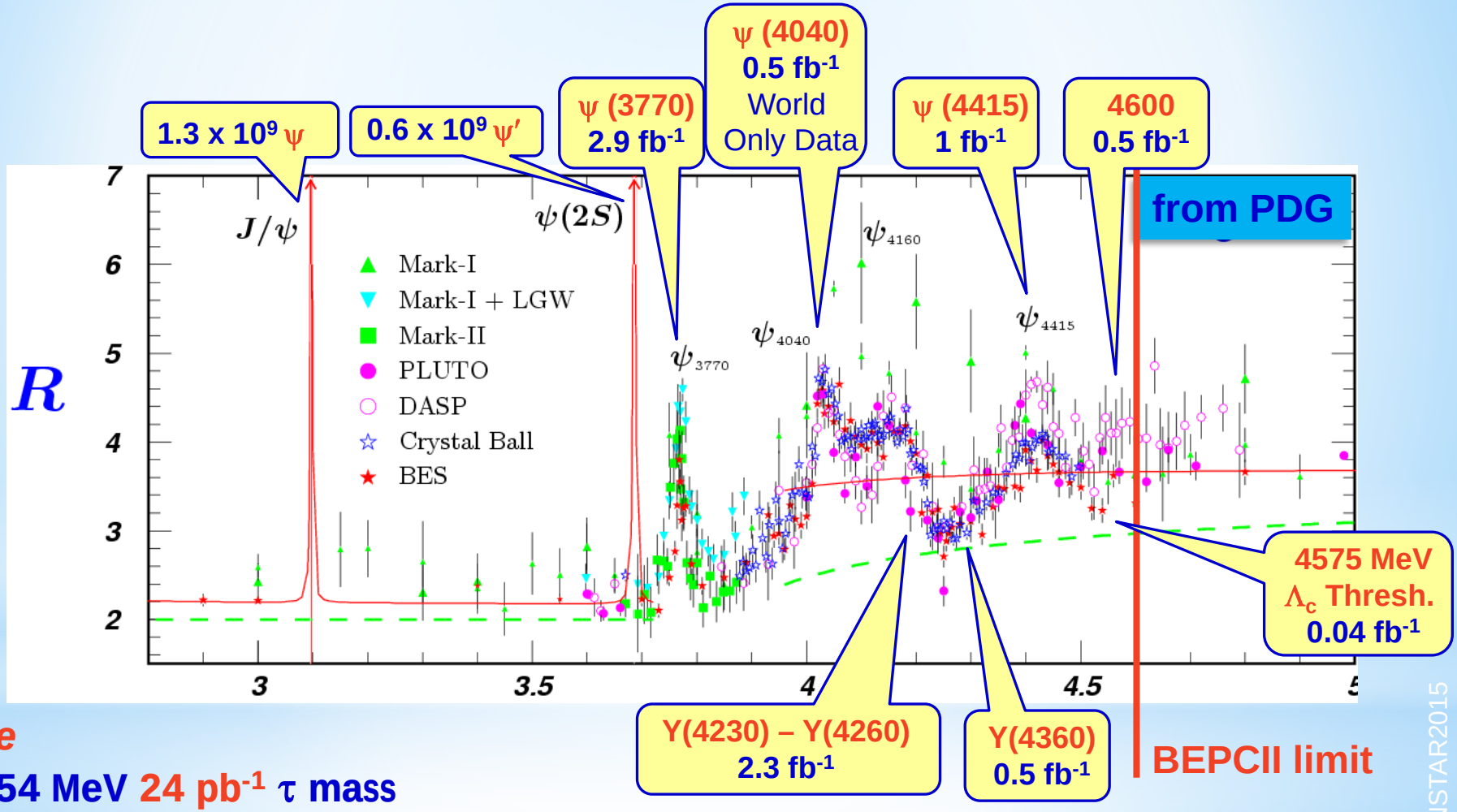


1.3 B / 10 B (225 M)



DATA SAMPLES

BESIII Production of Charmonium-like States



More

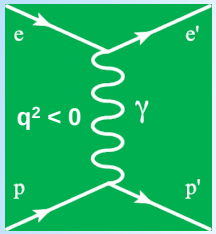
- 3554 MeV 24 pb^{-1} τ mass
- 4100-4400 MeV 0.5 fb^{-1} coarse scan
- 3850-4590 MeV 0.8 fb^{-1} fine R scan (104 points)
- 2.0-3.08 GeV 0.5 fb^{-1} + 2.23-3.4 GeV 12 pb^{-1} R Scan at low energies

PROTON FORM FACTORS

TIME-LIKE FORM FACTORS

e.m. Form Factors of the Nucleon to probe its internal structure and dynamics

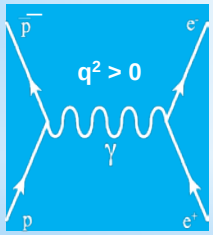
- **Test of non-pQCD and phenomenological models**



Space-like FF real

e p→e' p

- **Major progress recently achieved using polarised beam or target**
- **New data show different electric and magnetic distributions for the p**
- **$\mu G_E/G_M$ deviates linearly from a constant at least up to $q^2 \sim 6$ (GeV/c)^2**
- **Discrepancy between polarised and unpolarised measurements due to radiative correction, as Two Photon Exchange, suppressed by a factor of α_e, it could be important at high q^2**



Time-like FF complex

$\bar{p}p \leftrightarrow e^+e^-$

- **Scarce data and large errors**
- **Time-like ← Analiticity → Space-like continuous transition predicted and equality at asymptotic $|q^2|$**
- **Determination of $|G_E|$ and $|G_M|$ requires angular distributions of outgoing proton**
- **$R = |G_E| / G_M|$ sensitivity decreases at increasing q2**

In the approximation of One Photon Exchange

$$d\sigma/d\Omega \propto [\,|G_M|^2 (1+\cos^2\theta_p) + (4m_p^2/q^2)\,|G_E|^2 \sin^2\theta_p\,]$$

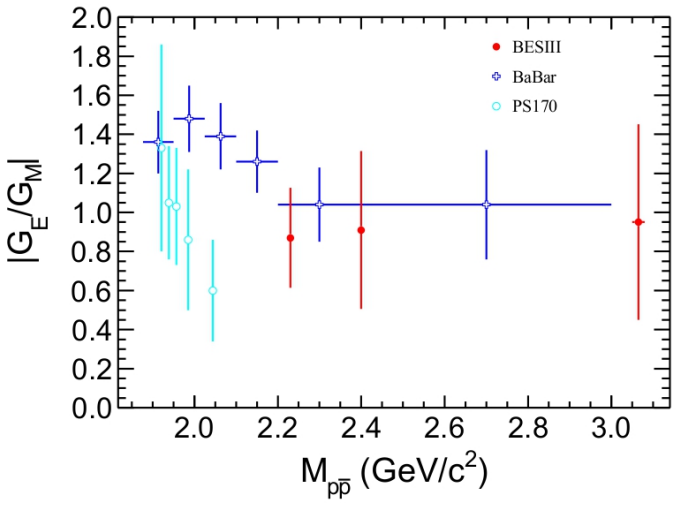
Measurement of the Cross Sections allows to access FF moduli

$$\sigma_{TOT} \propto [\,|G_M|^2 + (2m_p^2/q^2)\,|G_E|^2]$$

PROTON FORM FACTORS

- **Study of $e^+e^- \to \bar{p}p$ @ 12 c.m. energies from 2232.4 MeV to 3671.0 MeV**

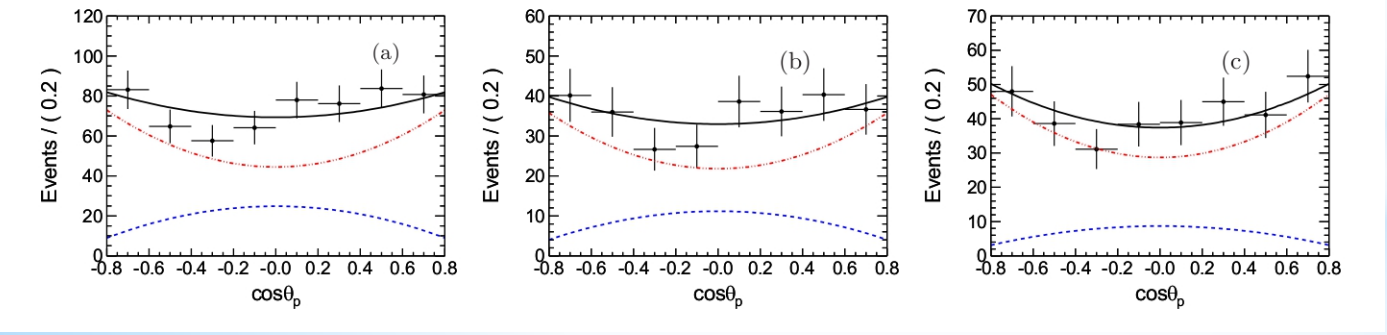
arXiv:1504.02680



- **$|G_E|$ / $|G_M|$ ratios close to unity, consistent with BaBar**
  ⇒ data are consistent with the assumption $|G_E| = |G_M|$

- **Precision is improved: 25% - 50% at $\sqrt{s} \leq$ 3.08 GeV wrt BaBar (via ISR): improvement by ~ 30%.**
  Precision dominated only by statistics.

2232.4 MeV | 2400.0 MeV | Combined data 3050.0 -3080.0 MeV



Electric FF
Magnetic FF

New energy scan foreseen between 2.0 - 3.1 GeV to increase statistics

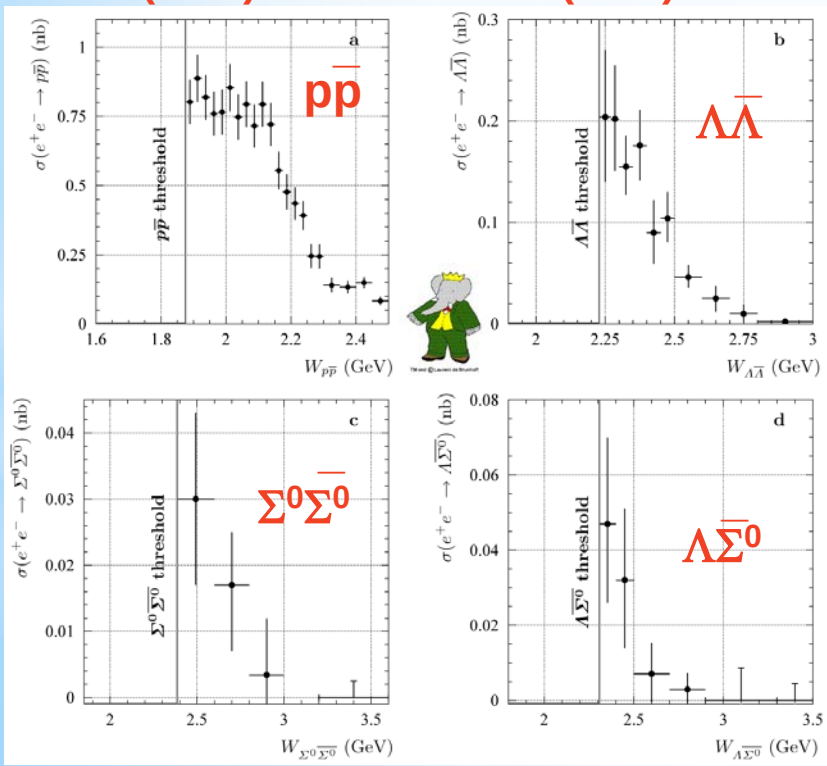
More details in the Parallel Session talk by Xiao Rong Zhou

TIME-LIKE FORM FACTORS

Studies of $e^+e^- \to \Lambda\bar{\Lambda}$, $\Xi^-\bar{\Xi}^+$, $\Lambda^+_c\,\Lambda^-_c$ at threshold are ongoing with BESIII

Unexpected neutral baryon non-zero cross section near threshold with BaBar
⇒ Coulomb interaction at quark level ?

BaBar
PRD 73(2006) 012005 - PRD 76(2006) 092006



- $e^+e^- \to p\bar{p}$: Coulomb FSI largely dominate cross section and $|G^p(4M^2_p)| \sim 1$
- $e^+e^- \to \Lambda\bar{\Lambda}$: Coulomb interaction consistent with a valence quark enhancement factor

Baldini et al. EPJ A39 (2009) 315

BESIII can measure hyperons at threshold

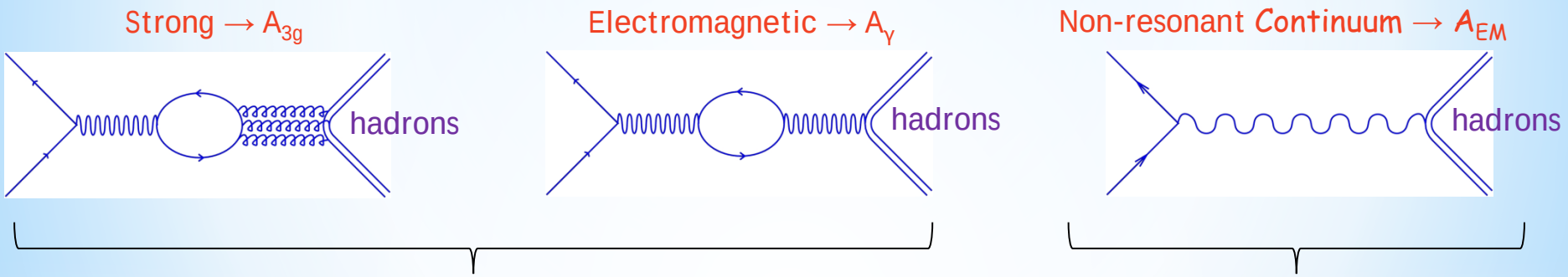
- **Non zero detection efficiency**
- **Very good c.m. energy resolution (<1MeV)**

Phase in J/ψ Decays

PHASE IN J/ψ DECAYS

Measurement of the Phase between Strong and Electromagnetic J/ψ decay amplitudes

Validity of pQCD approach can be investigated in the energy region around J/ψ



Resonant contributions

Non-resonant continuum

$\Gamma_{J/\psi}$ ~ 93 keV → pQCD holds in this energy region

pQCD regime

$A_{EM} \in \Re$

pQCD: all amplitudes expected almost real [1,2]

QCD -> Φ_p ~ 10° [1]

Interference already observed in J/ψ → leptons at SPEAR and at BESII

[1] J. Bolz and P. Kroll, WU B 95-35.
[2] S.J. Brodsky, G.P. Lepage, S.F. Tuan, Phys. Rev. Lett. 59, 621 (1987).

PHASE IN J/ψ DECAYS

Resonant and non resonant Amplitudes

- **Both real values, $\Phi_p \sim 0°/180°$ → Interference pattern**
- **$\Phi_p \sim 90°$ → No interference pattern**

Experimental data suggest an unexpected relative phase of ~ 90°

$J/\psi \rightarrow NN$	$(\frac{1}{2}^+ \frac{1}{2}^-)$	$\Phi_p = 89° \pm 15°$ [1]; $89° \pm 9°$ [2]
$J/\psi \rightarrow VP$	$(1^- 0^-)$	$\Phi_p = 106° \pm 10°$ [3]
$J/\psi \rightarrow PP$	$(0^- 0^-)$	$\Phi_p = 89.6° \pm 9.9°$ [4]
$J/\psi \rightarrow VV$	$(1^- 1^-)$	$\Phi_p = 138° \pm 37°$ [4]

No interference pattern

[1] PLB 404(1997)362; PLB 444(1998)111

[2] BESIII, J/ψ -> $p\bar{p}, n\bar{n}$ PRD 86(2012)032014

[3] Phys. Rep. 174 (1989)67; PRD 41(1990)1389

[4] PRD 60(1999)051501

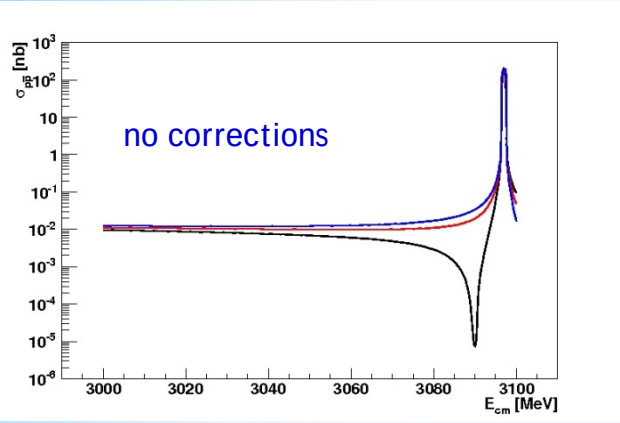
Vector / Pseudo-scalar meson, **N**ucleon

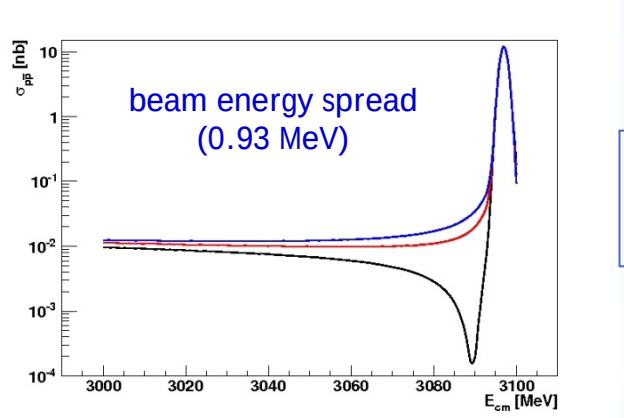
- **Up to now Results are model dependent**
- **A model independent test is needed**
- **Inclusive Set of exclusive final states is needed, since inteference vanishes in inclusive measurement**

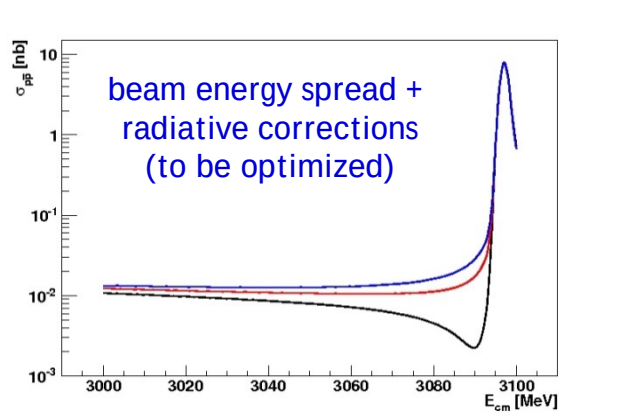
To explore different experimental scenario: focus on $e^+e^- \rightarrow p\bar{p}$, $\rho\pi$ and 5π

- **Processes with different cross sections in the non-resonant continuum region around 3 GeV**
- **Different branching fractions in the J/ψ peak**

PHASE IN J/ψ DECAYS







Simulated Yields for $e^+e^- \to p\bar{p}$

$\Delta\varphi = 0°$

$\Delta\varphi = 90°$

$\Delta\varphi = 180°$

continuum reference
σ ~ 11 pb

Selection of the energy points is crucial
11 points on the J/ψ peak and 5 points out of the peak

3050, 3060 MeV (to fix the continuum)

3083 MeV (dip on $\rho\pi$)

3090 MeV (dip on $p\bar{p}$)

3093 MeV (start of J/ψ , also dip on 5π)

Stay tuned !

BARYON SPECTROSCOPY

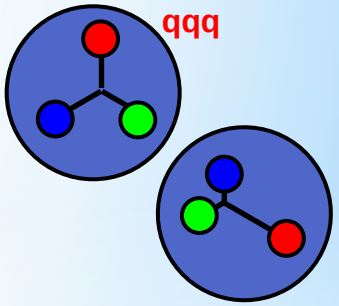
BESIII Talk in Parallel Session

- **Baryonic spectroscopy by Fang Liu**

BARYON SPECTROSCOPY

Understanding of the Baryon excitation spectrum is one of the prime goal of non-perturbative QCD

- **Quark Models, SU(3) symmetry**
  - Most of data are available in the Nucleon sector
  - Some low-lying states are not at the predicted energies
  - Predicted higher lying states not seen experimentally
- **Possible explanation**
  - quark-diquark structure $\Rightarrow$ reduced number of internal degrees of freedom $\Rightarrow$ reduced number of states
  - Dynamical generatation ?



Excited Baryon States $\leftrightarrow$ Meson-Baryon State ? Mixing of states?

- **Hyperon sector**

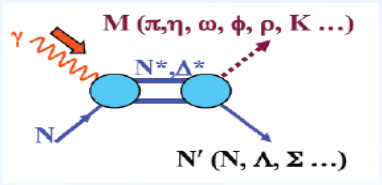
Little is known about excited states of Λ and Σ, and even less about Ξ and Ω

- **Most of the data comes from π N experiments**

BARYON SPECTROSCOPY

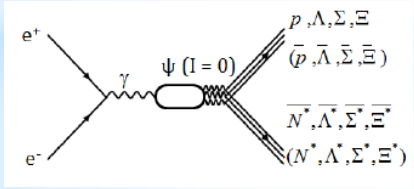
JLab, ELSA, MAMI, GRAAL, Spring-8, …

- Mixture of I =1/2 and 3/2 ⇒ complicated analysis
- Resonances with weak coupling to γN cannot show up



BESIII Advantages

- Pure isospin 1/2 filter ⇒ easier analysis
- ψ decays: glue-rich environment ⇒ favourable to search for hybrid baryons and «missing» N*
- In addition to N*, Λ*, Σ*, access to Ξ*
- Different decay channels at the same time
- High statistics for different charmonium states



Two body decays

- $J/\psi \to \Lambda \bar{\Sigma}^0$ + c.c.
- $\chi_{cJ} \to \Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0, \Sigma^+\bar{\Sigma}^-$
- $\eta_c \to \Sigma^+\bar{\Sigma}^-, \Xi^-\bar{\Xi}^+$
- $J/\psi \to p\bar{p}, n\bar{n}$
- …

Three body decays

- $J/\psi, \psi' \to \Lambda\bar{\Lambda}\pi^0/\eta$
- $\psi' \to \bar{p}K^+\Sigma^0$
- $\chi_{cJ} \to \bar{p}K^+\Lambda$
- $\psi' \to \Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$ + c.c.
- $\psi' \to (\gamma)K^-\Lambda\bar{\Xi}^+$ + c.c.
- $\psi' \to p\bar{p}\pi^0/\eta$
- $J/\psi \to a_0(980)p\bar{p}$

RECENT RESULTS

BESIII By charmonium decays a novel insight into baryons and complementary information to other experiments

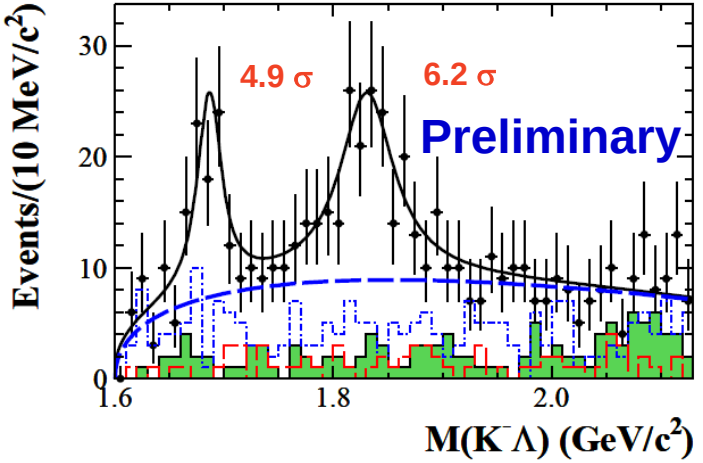
BARYON SPECTROSCOPY

Observation of $\Xi^-(1690)$ and $\Xi^-(1820)$

arXiv:1504.02025

- **Study of the decay $\psi' \to K^- \Lambda \bar{\Xi}^+ + c.c.$**
- **Resonance parameters consistent with PDG**
- **Branching fraction measured for the first time**

$\mathcal{B}(\psi' \to K^- \Lambda \bar{\Xi}^+) = (3.86 \pm 0.27) \times 10^{-5}$



This is the first observation in ψ' decays
Previous measurements in **K-p** interactions and recently in Λ_c^+ **decay** (BaBar)

Spin-parity not well determined

$\Xi^-(1690)$ BaBar reported evidence for $1/2^-$

$\Xi^-(1820)$ CERN-SPS experiment favored negative parity in case of J = 3/2

data sample: 1.06 x 10^8 ψ'

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	1687.7±3.8±1.0	1826.7±5.5±1.6
$\Gamma(\mathrm{MeV})$	27.1±10.0±2.7	54.4±15.7±4.2
Event yields	74.4±21.2	136.2±33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}$ (10^{-6})	5.21±1.48±0.57	12.03±2.94±1.22
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690±10	1823±5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	<30	24^{+15}_{-10}

Decay of $\psi' \to (\gamma) K^-\Lambda \bar{\Xi}^+ + c.c.$
First measurement of Branching Fractions
$\psi' \to K^-\Sigma^0 \bar{\Xi}^+$
$\psi' \to \gamma \chi_{cJ} \to \gamma K^-\Lambda\bar{\Xi}^+$

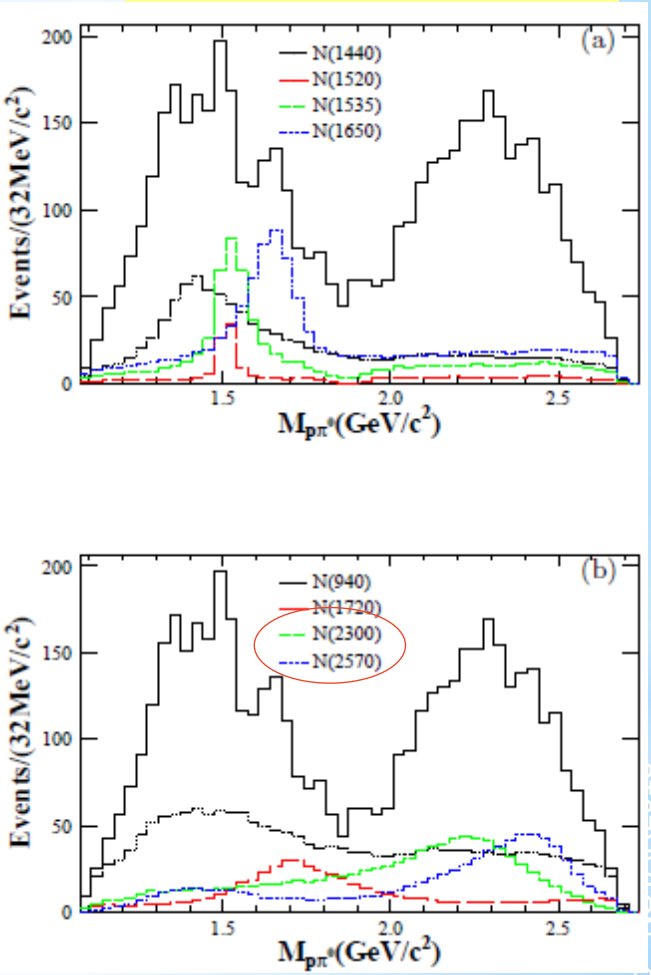
Decays to hyperons useful for a better understanding of charmonium decay mechanism

BARYON SPECTROSCOPY

Observation of two new N* resonances N(2300) (1/2+) and N(2570) (5/2-)

PRL 110 (2013) 022001

- Study of the decay $\psi' \to p\bar{p}\pi^0$
- Full PWA performed
- Best values of J^P: ½ $^+$ and 5/2$^-$
- Mass and width of 5 well known N* have been measured
- No clear evidence of N(1885) and N(2065)



Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

data sample: 1.06 x 10^8 ψ'

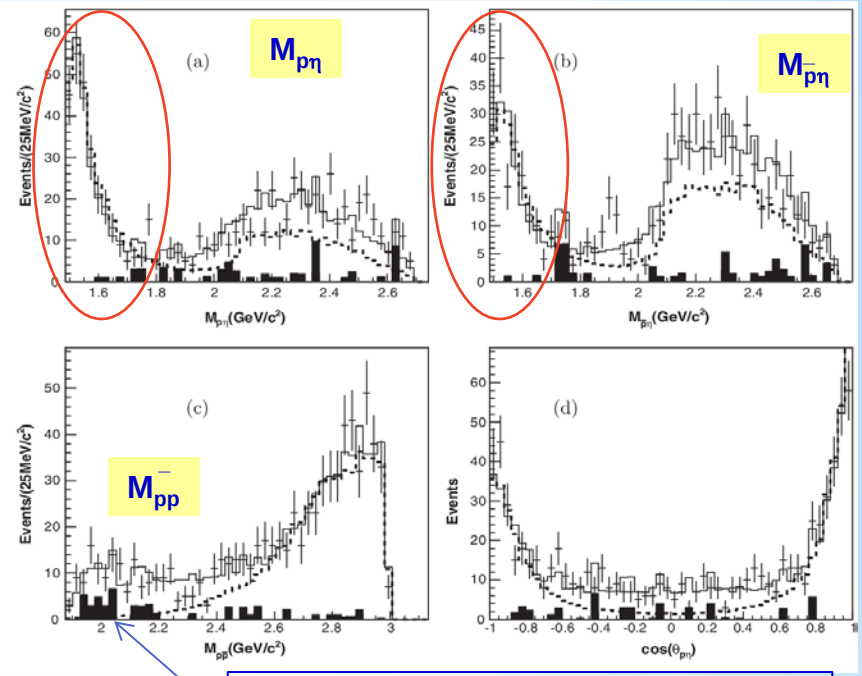
BARYON SPECTROSCOPY

Observation of N(1535)

PRD 88 (2013) 032010

- Study of the decay $\psi' \to p \bar{p} \eta$
- First BESII measured branching fraction
- Full PWA performed

  $\Rightarrow$ N(1535) contribution is dominant
- No evidence of a $p\bar{p}$ resonance
- Branching fractions have been measured



Enhancement explained with the Interference between N(1535) and PHS

data sample: 1.06 x 10^8 ψ'

Production Branching fraction

$\mathcal{B}(\psi' \to p\,\mathbf{N(1535)}) \times \mathcal{B}(\psi' \to p\bar{p}\eta) = (5.2 \pm 0.3\,^{+3.2}_{-1.2}) \times 10^{-5}$

Branching fraction

$\mathcal{B}(\psi' \to p\bar{p}\eta) = (6.4 \pm 0.2 \pm 0.6) \times 10^{-5}$

BESIII

$m = 1524 \pm 5\,^{+10}_{-4}$ MeV/c^2

$\Gamma = 130 + ^{+27}_{-24}\,^{+57}_{-10}$ MeV

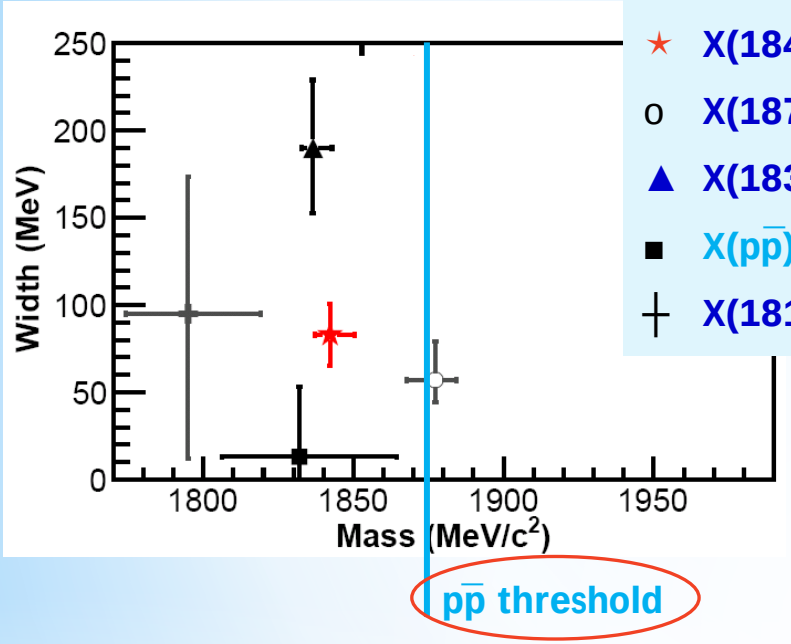
Consistent with PDG

Results on $N^*(1535)$, $N^*(2300)$, $N^*(2570)$, $\Xi^-(1690)$ and $\Xi^-(1820)$ show that charmonium decays offer a unique place to study Baryon Spectroscopy

MESON SPECTROSCOPY

X(1840)

Structures around 1.85 GeV observed in J/ψ radiative decays



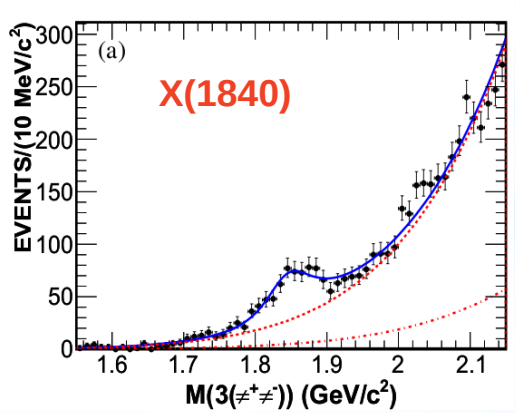
- ★ X(1840): J^P unknown, $J/\psi \to \gamma\, 3(\pi^+\pi^-)$
- o X(1870): J^P unknown, in $J/\psi \to \omega\,(\eta\,\pi\pi)$
- ▲ X(1835): $J^P=0^-$, in $J/\psi \to \gamma\,(\eta'\pi^+\pi^-)$
- ■ X(pp̄): $J^P=0^-$, in $J/\psi \to \gamma\,(p\bar{p})$
- ┼ X(1810): $J^P=0^+$, in $J/\psi \to \gamma(\omega\phi)$

PRD 88(2013) 091502
PRL 107(2011) 182001
PRL 106(2011) 072002
PRL 108(2012) 112003
PRD 87(2013) 032008

X(pp̄) first observed by BESII
confirmed by CLEOc and BESIII, very narrow
Standard meson, multi-quark, glueball ?
or pp̄ bound state ?

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

- **J/ψ radiative decays**
- **Not found in ψ′ radiative decays**
- **Not a pure FSI**
- **PWA is needed**



PRD 88(2013) 091502

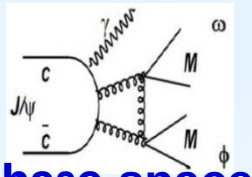
data sample: 2.25 x 10^8 J/ψ

X(1840)
m=1842.2 ± 4.2 $^{+7.1}_{-2.6}$ MeV/c^2
Γ = 83 ± 14 ± 11 MeV
Significance 7.6 σ

All X(18??) are near the pp̄ threshold. Are they the same particle ?

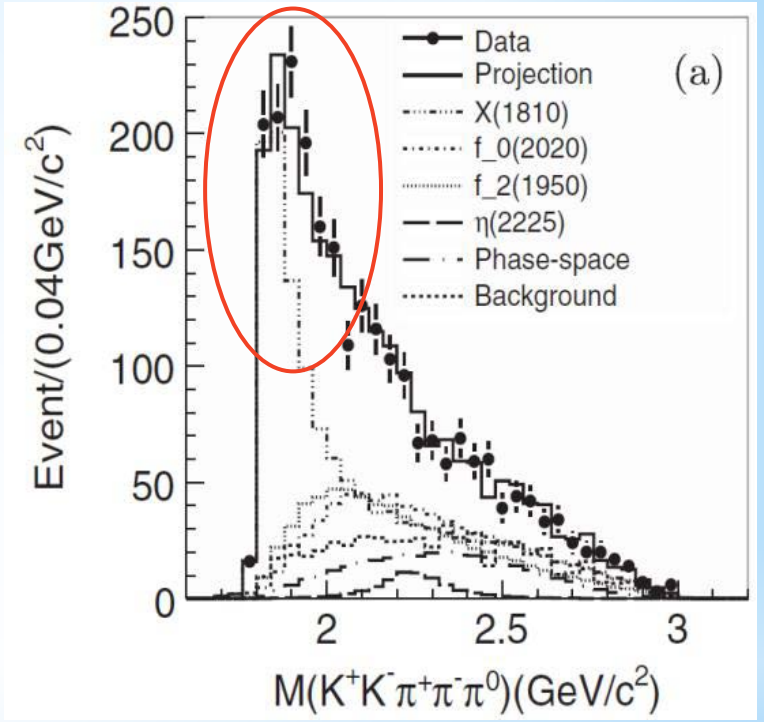
X(1810)

Study of $J/\psi \to \gamma\,\omega\,\phi$ decay



- **Doubly OZI process**
- **Strong deviation from 3-body phase space near the $\omega\phi$ mass threshold is observed**
- **Spin-parity 0^{++} has been determined**
- **Enhancement not compatible with X(1835) and X($p\bar{p}$) (different mass and J^P)**
- **Contributions from 0^{++}, 0^{-+}, 2^{++} are needed in the fit (assigned to $f_0(2020)$, $\eta(2225)$ and $f_2(1950)$)**

PRD 87(2013) 032008



data sample: 2.25 x 10^8 J/ψ

Product Branching fraction

$\mathcal{B}(J/\psi \to \gamma\, X(1810)) \times \mathcal{B}(X(1810) \to \omega\,\phi)$

$\mathcal{B} = [2.00 \pm 0.08\ ^{+0.45}_{-1.00} \pm 1.30\ (\text{model})] \times 10^{-4}$

$m = 1795 \pm 7\ ^{+13}_{-5} \pm 19(\text{model})\ \text{MeV}/c^2$

$\Gamma = 95 \pm 10\ ^{+21}_{-34} \pm 75(\text{model})\ \text{MeV}$

Significance > 30 σ

- Dynamical effect arising from intermediate meson rescattering
- Exotic state: tetraquark, hybrid, glueball ?
- The same as $f_0(1710)/f_0(1790)$

Consistent with previous BESII measurement

A new state ?

X, Y, Z STATES

CHARMONIUM SPECTROSCOPY

- **Below the $D\bar{D}$ thereshold all expected states have been observed with properties in good agreement with theory**

- **Incomplete picture above $D\bar{D}$ threshold**

Many unexpected states, X, Y, Z, have been reported (Belle, BaBar, CLEO, D0, CDF, BES, ...)
Unclear interpretation: molecule, tetraquarks, ...

- **Many predicted states are still missing**

- **X states**

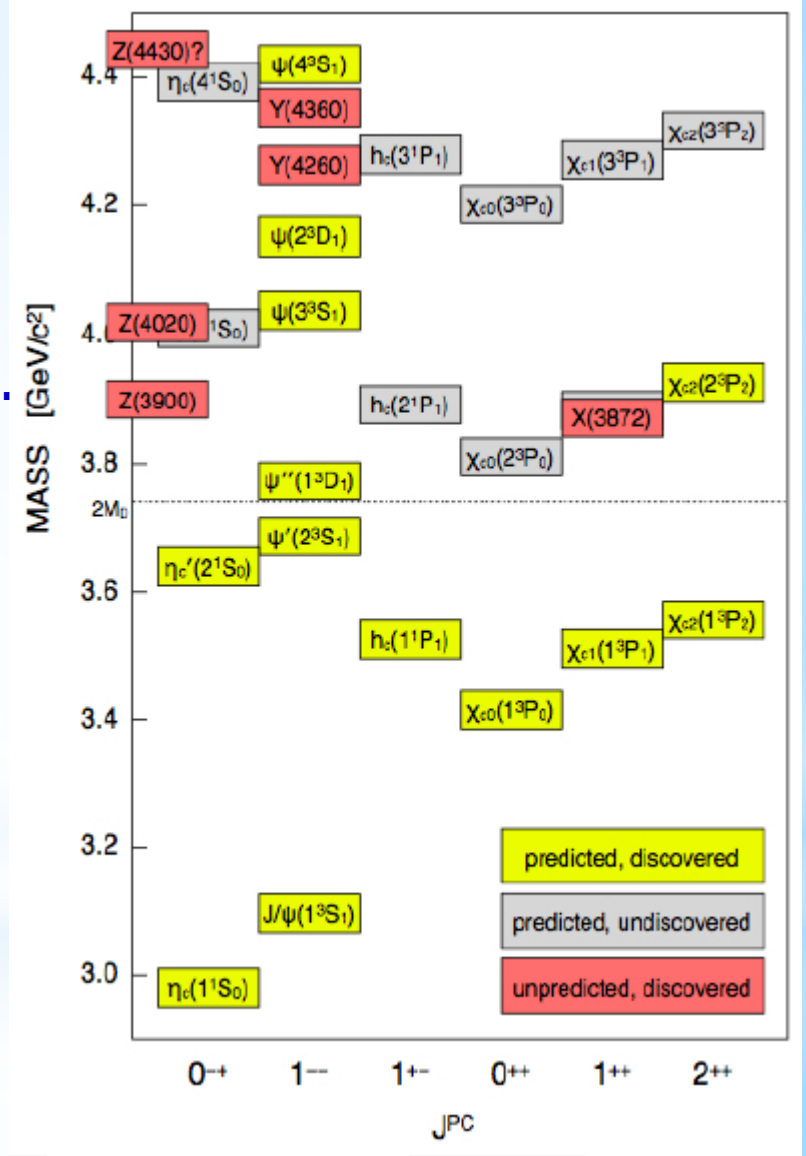
charmonium-like, $J^{PC} \neq 1^{--}$
observed in B decays, pp and $p\bar{p}$ collisions

- **Y states**

charmonium-like, $J^{PC} = 1^{--}$
observed in direct e^+e^- annihilation or in ISR

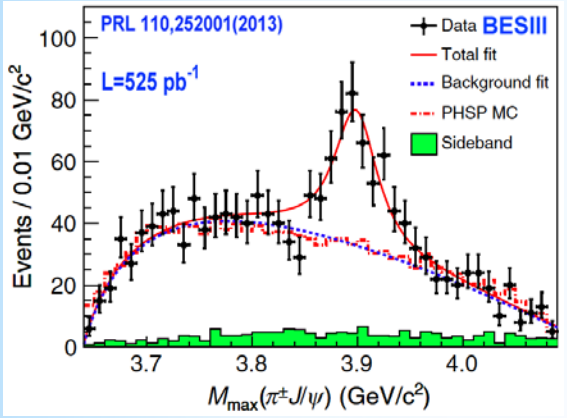
- **Z states**

charmonium-like, carrying electric charge
Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair



$Z_c(3900)$ isospin triplet

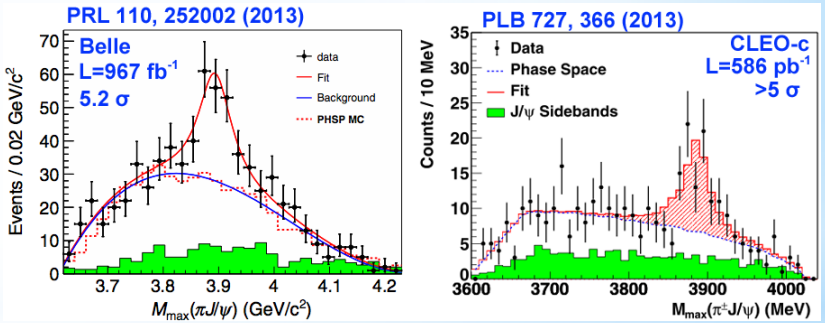
- Study of $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s}$ = 4.260 GeV using 525 pb $^{-1}$
- Study of $e^+e^- \to \pi^0\pi^0 J/\psi$ at 4.230, 4.260, 4.360 GeV using 2.5 fb $^{-1}$ data sample



$Z_c(3900)^\pm$ Discovered by BESIII, confirmed by Belle and CLEOc

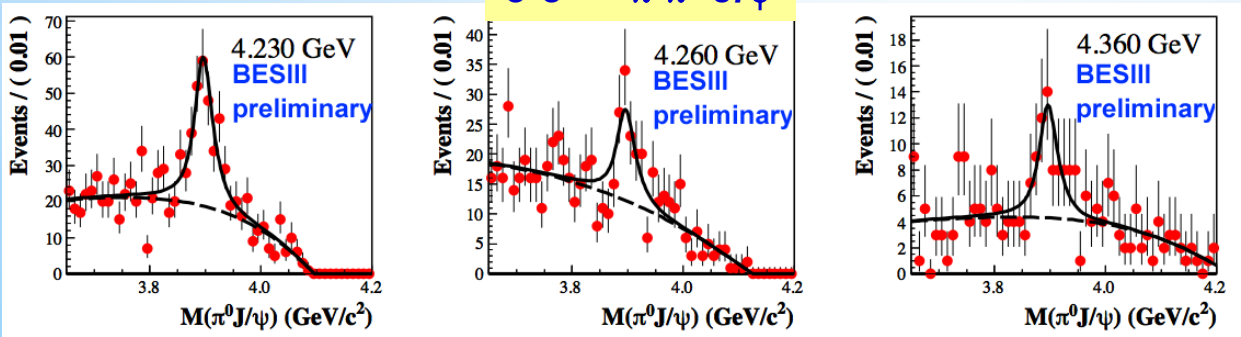
PRL 110(2013) 252001

$Z_c(3900)^\pm$	M	Γ	
BESIII	3899.0 ± 3.6 ± 4.9 MeV/c^2	46 ± 10 ± 20 MeV	8σ
Belle	3894.5 ± 6.6 ± 4.5 MeV/c^2	63 ± 24 ± 26 MeV	5.2 σ
CLEOc	3886 ± 4 ± 2 MeV/c^2	37 ± 4 ± 8 MeV	>5 σ



- Mass close to the DD* threshold
- Decay into J/ψ → contains $c\bar{c}$
- Electric charge → contains $u\bar{d}$
- Tetraquark state, DD* molecule or Hadro-charmonium ?

$e^+e^- \to \pi^0\pi^0 J/\psi$



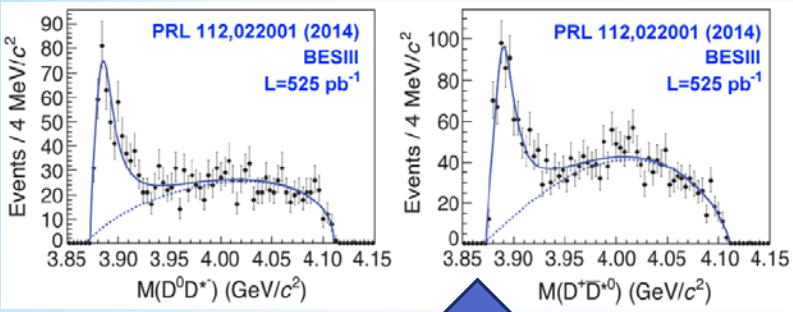
Neutral $Z_c(3900)^0$ First observed by CLEOc

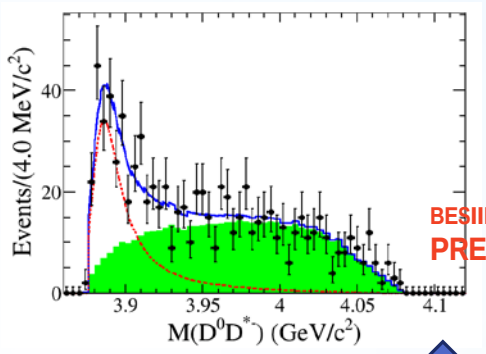
BESIII	$Z_c(3900)^0$
m=3894.8 ± 2.3 ± 2.7 MeV/c^2	
Γ = 29.6 ± 8.2 ± 8.2 MeV	
Significance > 10σ	

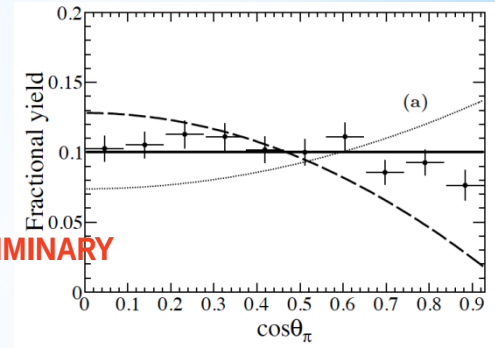
Isospin triplet established

Observation of $Z_c(3885)$

- **Study of $e^+e^- \to \pi^\pm (D\bar{D}^*)^\mp$ $\sqrt{s}$ =4.26 GeV using 525 pb^{-1}** — PRL 112(2014) 022001
  - **Single D tag analysis: Reconstructed π and one final state D, D* by missing mass**
- **Study of $e^+e^- \to \pi^\pm (D\bar{D}^*)^\mp$ using 1090 fb^{-1} at 4.23 GeV and 827 fb^{-1} at 4.26 GeV**
  - **Double D tag analysis: Reconstructed π and $D\bar{D}^*$ pair, more D decays available to suppress Background**







Single D tag analysis

BESIII $Z_c(3885)^\pm$
m=3883.9 ± 1.5 ± 4.2 MeV/c^2
Γ = 24.8 ± 3.3 ± 11 MeV
Significance > 18σ
Favours $J^P = 1^+$ (disfavour 0^- and 1^-)

Compatible analysis

But more precise

Double D tag analysis

BESIII $Z_c(3885)^\pm$
m=3884.3 ± 1.2 ± 1.8 MeV/c^2
Γ = 23.8 ± 2.1 ± 2.6 MeV
Significance > 10σ
Clearly Favours $J^P = 1^+$

$$\frac{\mathcal{B}(Z_c \to D^* \bar{D})}{\mathcal{B}(Z_c \to J/\psi\,\pi)} = 6.2 \pm 1.1 \pm 2.7$$

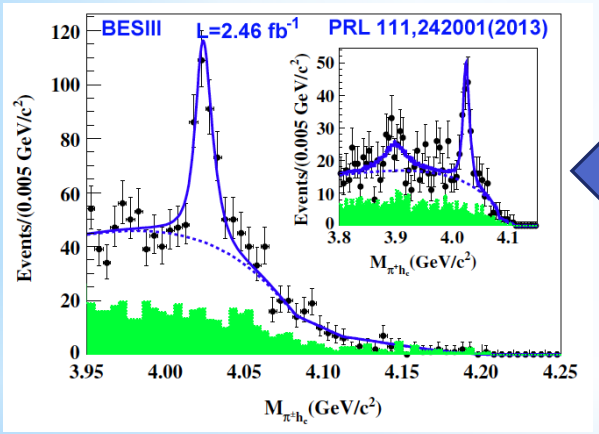
$$\frac{\mathcal{B}(\psi(4040) \to D^{(*)} \bar{D}^{(*)})}{\mathcal{B}(\psi(4040) \to J/\psi\,\eta)} = 192 \pm 27$$

Are $Z_c(3900)$ and $Z_c(3883)$ the same state ?
Open charm decays clearly suppressed
different dynamics in Y(4260) – Zc(3900) system !

Observation of $Z_c(4020)$ isospin triplet

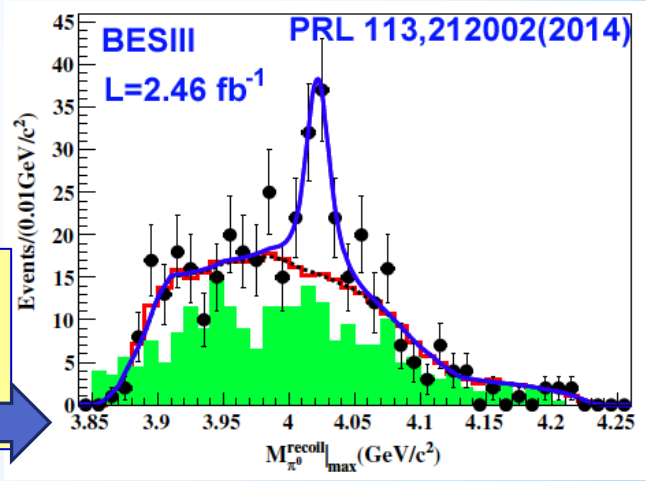
- Study of $e^+e^- \to \pi^+\pi^- h_c$ from 3.90 to 4.42 GeV 2.46 fb^{-1}
- Study of $e^+e^- \to \pi^0\pi^0 h_c$ at $\sqrt{s}$ = 4.23 , 4.26 GeV , 4.36 GeV 2.46 fb^{-1}
- $h_c \to \gamma \eta_c$ reconstructed through 16 hadronic modes
- Simultaneous fit to the πh_c spectrum for the three samples

PRL 111(2013) 242001
and
PRL 113(2014) 212002



BESIII $Z_c(4020)^{\pm}$
m=4022.9 ± 0.8 ± 2.7 MeV/c^2
Γ = 7.9 ± 0.8 ± 2.6 MeV
Significance > 8.9σ

BESIII $Z_c(4020)^0$
m=4023.9 ± 2.2 ± 3.8 MeV/c^2
Γ = 7.9 MeV Fixed to $\Gamma(Z_c(4020)^{\pm})$
Significance > 5σ



Born cross sections agree with expectations from isospin symmetry

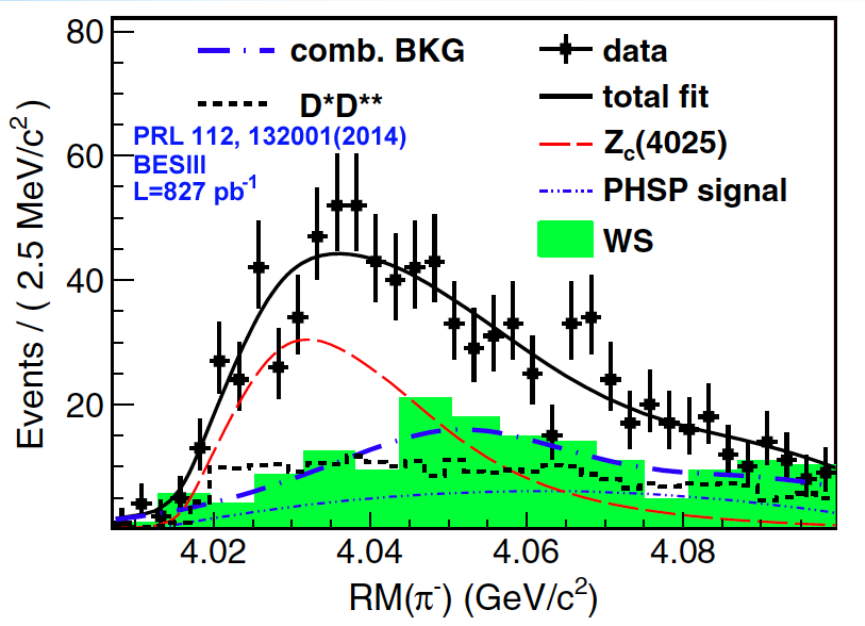
$$\frac{\sigma(e^+e^- \to \pi^0\pi^0 h_c)}{\sigma(e^+e^- \to \pi^+\pi^- h_c)} = 0.63 \pm 0.9 \text{ (expect 0.5)}$$

One more Isospin triplet established

- Correlation of $\pi\pi$ h_c with Y(4260) and Y(4360) is unclear
- Could be a combination of them or something else ?

Observation of $Z_c(4025)^{\pm}$

- Study of $e^+e^- \to \pi^{\pm} (D^*\bar{D}^*)^{\mp}$ at 4.26 GeV using 827 pb $^{-1}$
- Only the bachelor π^-, the D^+ decaying from $D^{*+} \to D^+ \pi^0$ and at least one soft π^0 from $D^{*+} \to D^+ \pi^0$ or $\bar{D}^{*0} \to \bar{D}^0 \pi^0$ decays are reconstructed



PRL 112(2014) 132001

BESIII
m=4026.3 ± 2.6 ± 3.7 MeV/c^2
Γ = 24.8± 5.6 ± 7.7 MeV
Significance 13σ

A rigorous spin analysis is required based on a larger data sample to validate the establishment of $Z_c(4025)$

SUMMARY OF Z_c STATES

Charmonium-like Z_c states

$Z_c \rightarrow$	M(MeV/c^2)	Γ(MeV)	
$Z_c(3900)$			
$\pi^{\pm} J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	BESIII
$\pi^0 J/\psi$	3894.8 ± 2.3 (Prel.) BESIII	29.6 ± 8.2 (Prel.)	CLEO-c
$Z_c(3885)$			
$(D\bar{D}^*)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$	BESIII
$Z_c(4020)$			
$\pi^{\pm} h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	BESIII
$\pi^0 h_c$	$4023.9 \pm 2.2 \pm 3.8$		BESIII
$Z_c(4025)$			
$(D^*\bar{D}^*)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	BESIII

- Both $Z_c(3900)$ and $Z_c(4020)$ have been established as isospin triplet states
- $Z_c(3900)$ and $Z_c(4020)$ are close to the $D\bar{D}^*$ and $D^*\bar{D}^*$ mass threshold
- Similar structures are seen in the $D\bar{D}^*$ and $D^*\bar{D}^*$ mass spectra
- However, we cannot conclude that $Z_c(3900)$ / $Z_c(3885)$ and $Z_c(4020)$ / $Z_c(4025)$ are the same states
- Spin parity analysis is needed to determine the nature of these structures

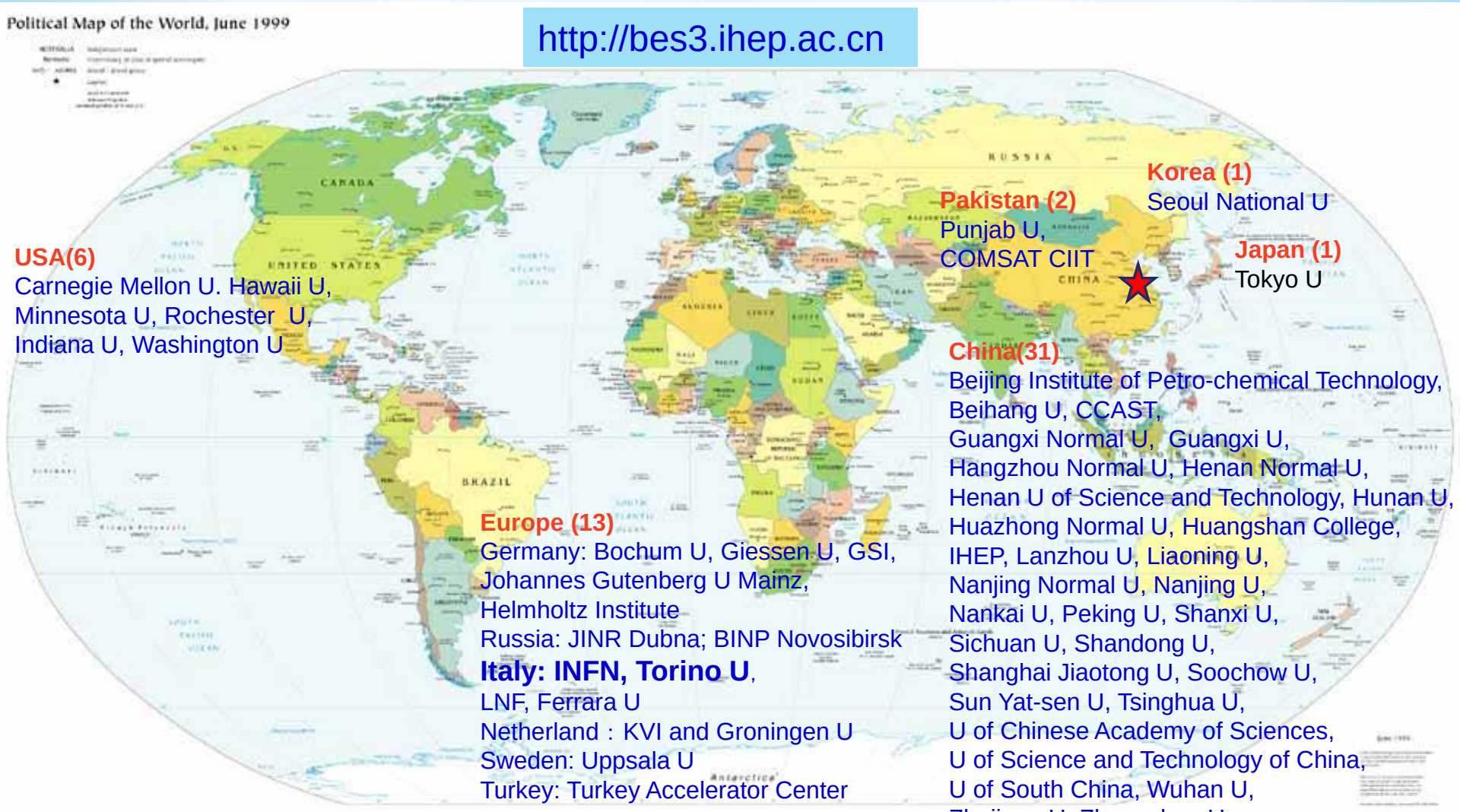
SUMMARY

- Spectrometer with excellent performance allows a wide physics programme
- Large data samples of J/ψ and ψ' availbale at BESIII
- Timelike-FF: $p\bar{p}$ investigated at high q^2 confirm BaBar results with higher precision. In the near future: $\Lambda\bar{\Lambda}$ and $\Xi^-\bar{\Xi}^+$, production at threshold
- Phase in J/ψ decays: A model independent analysis is ongoing
- Light Hadron Spectroscopy: J/ψ and ψ' decays are an excellent lab, complementary to photoproduction and hadron scattering
- XYZ states: A lot of progress in the study of Charmonium-like states at BESIII
- BESIII may continue data taking until 2020-2022

BESIII PEOPLE

~350 Members • 53 Institutions • 11 Countries

http://bes3.ihep.ac.cn



USA(6)
Carnegie Mellon U. Hawaii U,
Minnesota U, Rochester U,
Indiana U, Washington U

Pakistan (2)
Punjab U,
COMSAT CIIT

Korea (1)
Seoul National U

Japan (1)
Tokyo U

China(31)
Beijing Institute of Petro-chemical Technology,
Beihang U, CCAST,
Guangxi Normal U, Guangxi U,
Hangzhou Normal U, Henan Normal U,
Henan U of Science and Technology, Hunan U,
Huazhong Normal U, Huangshan College,
IHEP, Lanzhou U, Liaoning U,
Nanjing Normal U, Nanjing U,
Nankai U, Peking U, Shanxi U,
Sichuan U, Shandong U,
Shanghai Jiaotong U, Soochow U,
Sun Yat-sen U, Tsinghua U,
U of Chinese Academy of Sciences,
U of Science and Technology of China,
U of South China, Wuhan U,
Zhejiang U, Zhengzhou U

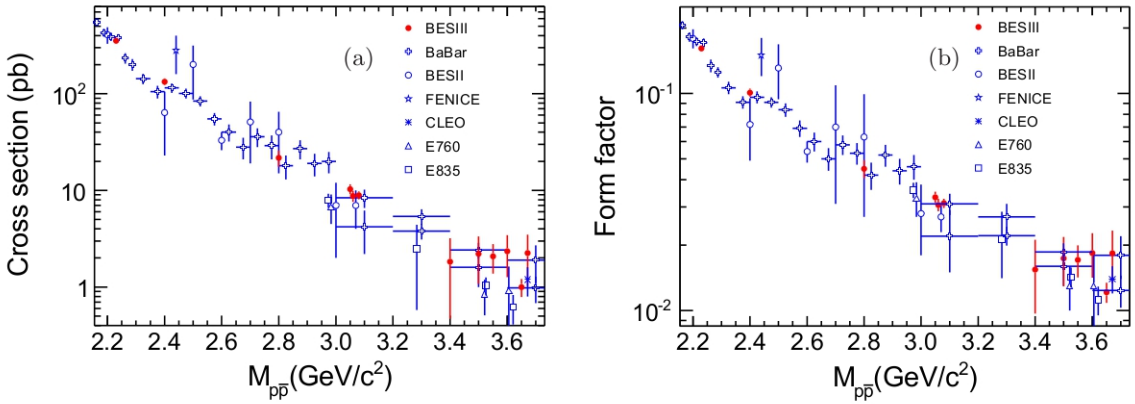
Europe (13)
Germany: Bochum U, Giessen U, GSI,
Johannes Gutenberg U Mainz,
Helmholtz Institute
Russia: JINR Dubna; BINP Novosibirsk
Italy: INFN, Torino U,
LNF, Ferrara U
Netherland：KVI and Groningen U
Sweden: Uppsala U
Turkey: Turkey Accelerator Center

BACKUP SLIDES

PROTON FORM FACTORS

- **Study of $e^+e^- \to \bar{p}p$ @ 12 c.m. energies from 2232.4 MeV to 3671.0 MeV**

arXiv:1504.02680



Comparison to previous measurements

- **(a) Born cross sections**
- **(b) Effective Form Factor $|G| = |G_E| = |G_M|$ |**
- **Precision is improved by 30% (dominated only by statistics)**

New energy scan foreseen between 2.0 - 3.1 GeV to increase statistics

BARYON SPECTROSCOPY

Observation of Λ^* and Σ^* in the $\Lambda\pi$ and $\Sigma\pi$ mass spectra

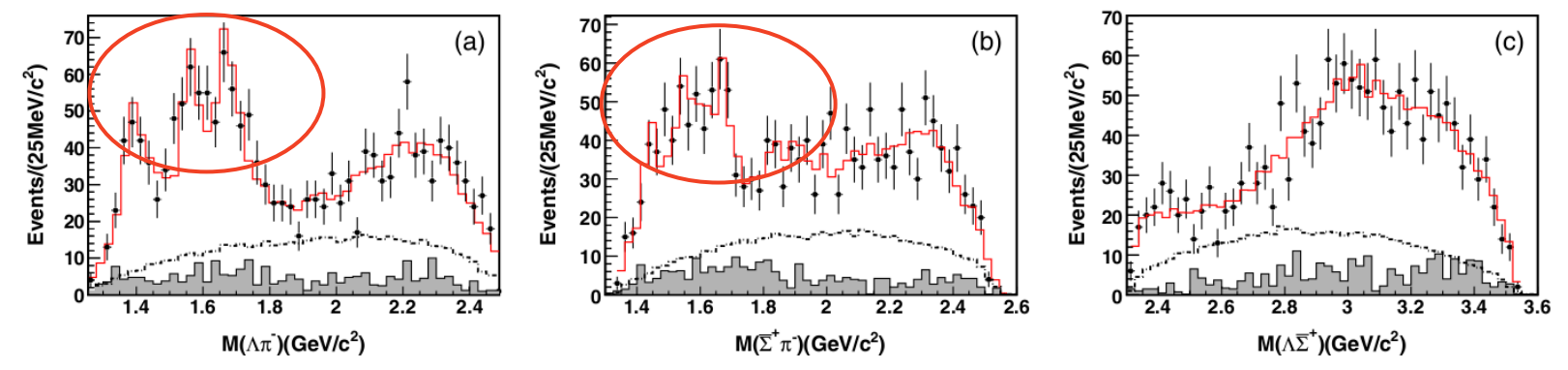
PRD 88(2013) 112007

- **Study of the decays**

  $\psi' \to \Lambda \bar{\Sigma}^+\pi^-$ **+ c.c. and** $\psi' \to \Lambda \bar{\Sigma}^-\pi^+$ **+ c.c.**

  data sample: 1.06 x 10^8 ψ'

- **Branching fractions have been measured for the first time**



Peaks around 1.4 to 1.7 GeV/c^2

16 Y* possible intermediates states with at least 2 stars are included in the PWA

Branching fractions

$\mathcal{B}(\psi' \to \Lambda \bar{\Sigma}^+\pi^- + \text{c.c.}) = (1.40 \pm 0.03 \pm 0.13)10^{-4}$

$\mathcal{B}(\psi' \to \Lambda \bar{\Sigma}^-\pi^+ + \text{c.c.}) = (1.54 \pm 0.04 \pm 0.13)10^{-4}$

Test of the 12% Rule for decay into $\Lambda\,\Sigma^-\pi^+$

$$Q_h = \frac{\mathcal{B}(\psi' \to \Lambda \bar{\Sigma}^-\pi^+ + \text{c.c.})}{\mathcal{B}(J/\psi \to \bar{\Lambda}\,\Sigma^-\pi^+ + \text{c.c.})\ \text{[PDG]}} = (9.3 \pm 1.2)\%$$

- Large **violation of the 12% Rule** has been found (MARKII, CLEO, BES), mostly in $\rho\pi$ decay
- Theoretical explanations unsatisfactory

BARYON SPECTROSCOPY

Above $D\bar{D}$ threshold

Search for baryonic decays of $\psi(3770)$ and $\psi(4040)$ including:

$\Lambda\bar{\Lambda}\,\pi^+\pi^-$, $\Lambda\bar{\Lambda}\,\pi^0$, $\Lambda\bar{\Lambda}\,\eta$, $\Sigma^+\,\Sigma^-$, $\Sigma^0\,\Sigma^0$, $\Xi^+\,\bar{\Xi}^-$, $\Xi^0\,\bar{\Xi}^0$

PRD 87(3013) 112011

Motivation: shed light on the nature of $\psi(3770)$ studying the large non-$D\bar{D}$ component of decays, which conflicts with theoretical predictions

- **BES** measured the branching fraction for $\psi(3770)$ decay to non-$D\bar{D}$ to be $(15 \pm 5)\%$ under the hypothesis that only one simple $\psi(3770)$ resonance exists in the c.m. energy region 3.70-3.87 GeV
- **CLEOc** measured branching fraction < 9% at 90% CL

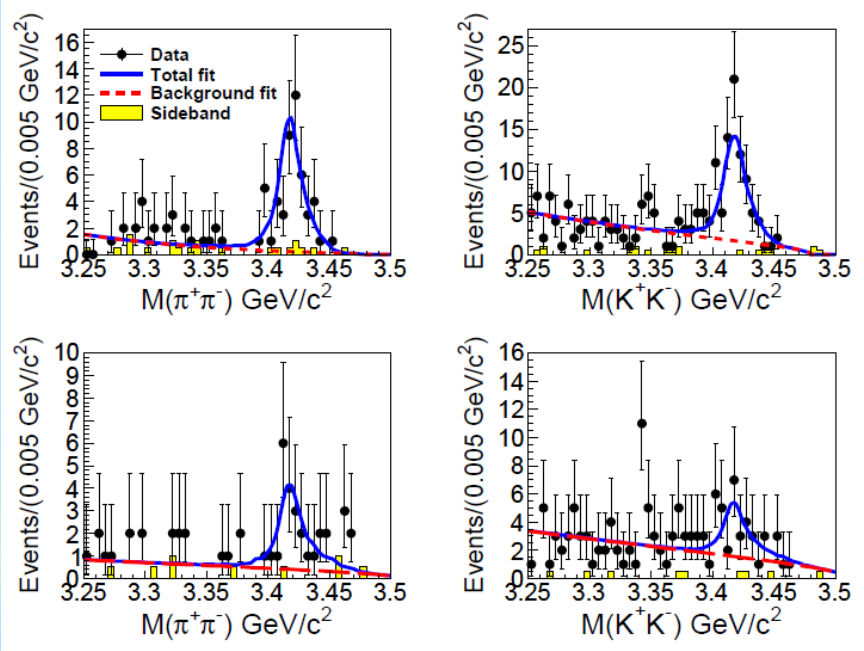
Data sample:
2.9 pb^{-1} at $\sqrt{s}$ = 3.773 GeV
482 pb^{-1} at $\sqrt{s}$ = 4.009 GeV
67 pb^{-1} at $\sqrt{s}$ = 3.542, 3.553, 3.561, 3.600 and 3.650 GeV

No baryonic states have been observed, U.L. are set at 90% CL

Observation of $e^+e^- \to \omega\chi_{c0}$

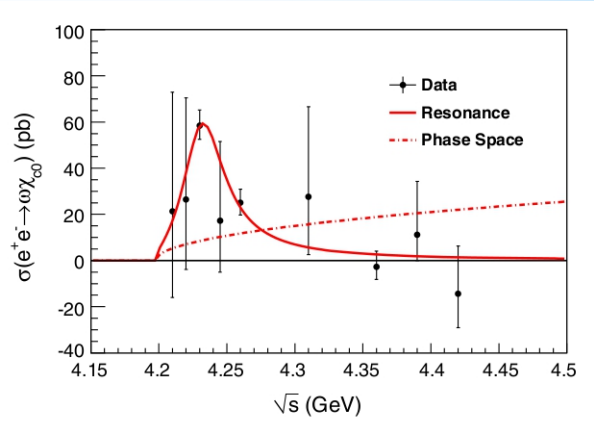
- Study of $e^+e^- \to \omega\chi_{cJ}$ @ 4.21 - 4.42 GeV
- $\omega \to \pi^+\pi^-\pi^0$; $\chi_{cJ} \to \pi^+\pi^-$ and K^+K^- ; $\chi_{c1,c2} \to \gamma$ J/ψ

PRL 114(2015) 9,092003



Observed for the first time

- $\sigma(e^+e^- \to \omega\chi_{c0})$=55.4±6.0±5.9pb 4.23 GeV
- $\sigma(e^+e^- \to \omega\chi_{c0})$=23.7±5.3±3.5pb 4.26 GeV
- no significant signals at other energies
- $\sigma(e^+e^- \to \omega\chi_{c1,c2})$ = no significant signals



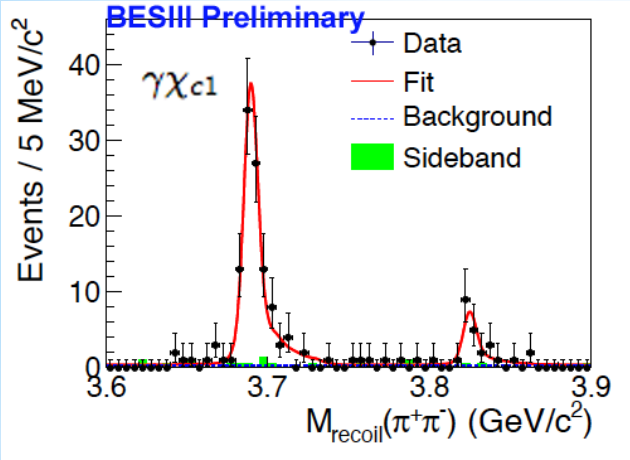
- Study of the energy dependent cross section
- Line shape inconsistent with Y(4260)
- Mass and width extracted assuming the $\omega\chi_{c0}$ signal is from a single resonance

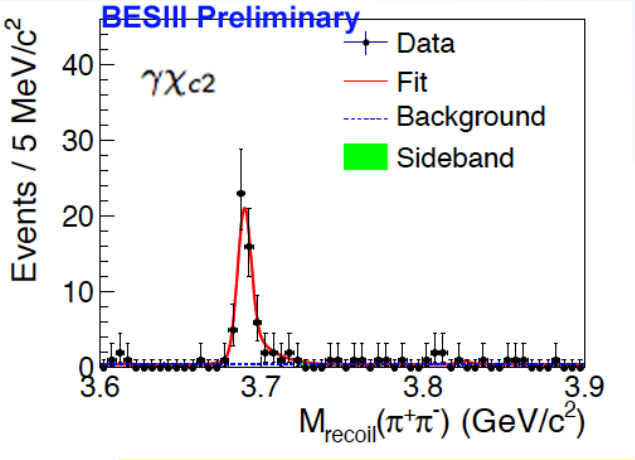
m = 4229 ± 11 ± 6 MeV/c^2
Γ = 40 ± 14 ± 2 MeV
Significance > 9σ

BESIII Observation of $e^+e^- \to \pi^+\pi^-$ X(3823)

- X(3823) discovered by Belle in B $\to \chi_{c1}\,\gamma\,K$, J^{PC} = ?? PRL 111,032001(2013)
- Mass and width consistent with the missing $\psi(1^3D_2)$ state
- BESIII study of $e^+e^- \to \pi^+\pi^-$ X(3823), X(3823) $\to \gamma\,\chi_{c1,c2}$ @ $\sqrt{s}$ = 4.23 - 4.6 GeV

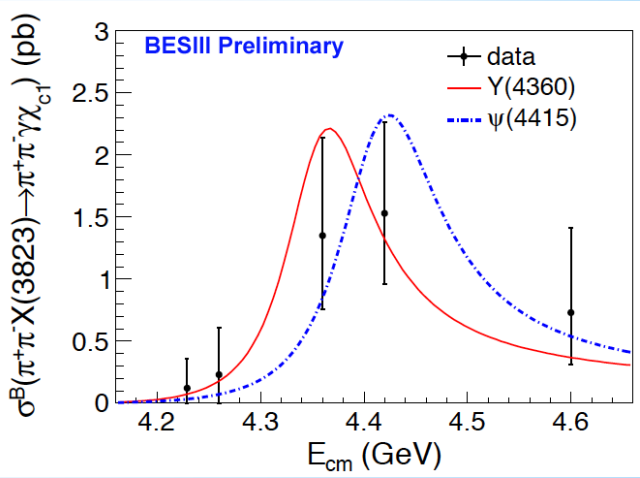
4.67 fb^{-1}





m=3821.7 ± 1.3 ± 0.7 MeV/c²
Γ < 16 MeV at 90% CL
Significance 6.7σ

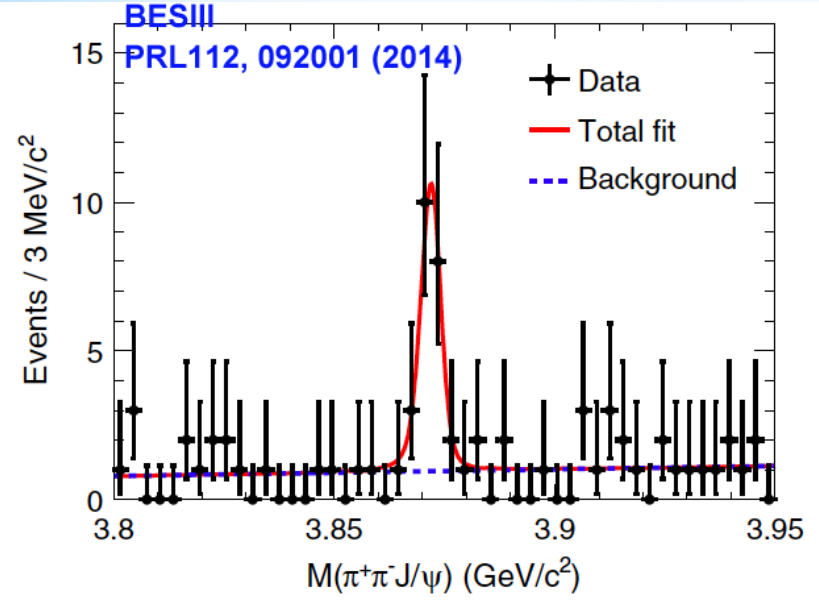
arXiv:1503.08203



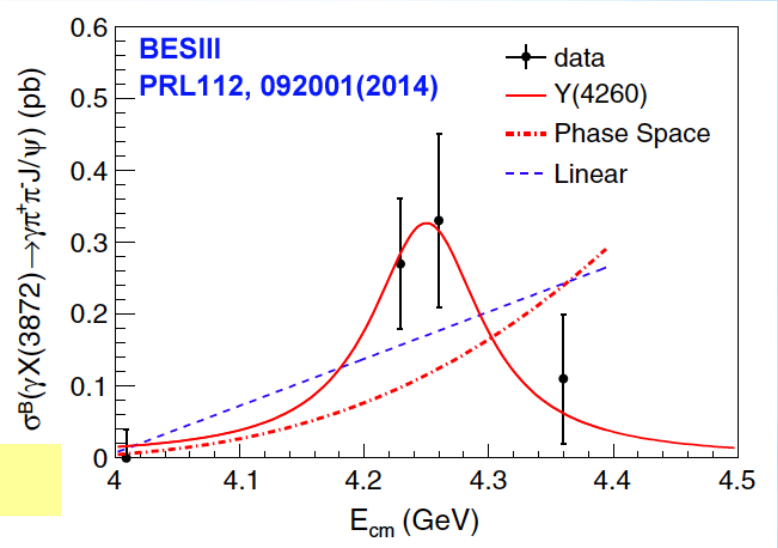
- Study of the energy dependent cross section $e^+e^- \to \pi^+\pi^-$ X(3823)
- The fit with a Y(4360) and $\psi(4415)$ gives a good description of the data
- The X(3823) is a good candidate for the $\psi(1^3D_2)$ charmonium state
- Until now no definitive observation of its two D-wave spin-triplet partner states

BESIII Observation of $e^+e^- \to \gamma$ X(3872)

- X(3872) discovered by Belle in $J/\psi\,\pi^+\,\pi^-$, $J^{PC} = 1^{++}$ PRL 110,252002(2013)
- BESIII study of X(3872) $\to J/\psi\,\pi^+\,\pi^-$ @ $\sqrt{s}$ = 4.009 - 4.420 GeV



m=3871.9 ± 0.7 ± 0.2 MeV/c^2
Γ < 2.4 MeV at 90% CL
Significance 6.3σ



PRL 112, 092001(2014)

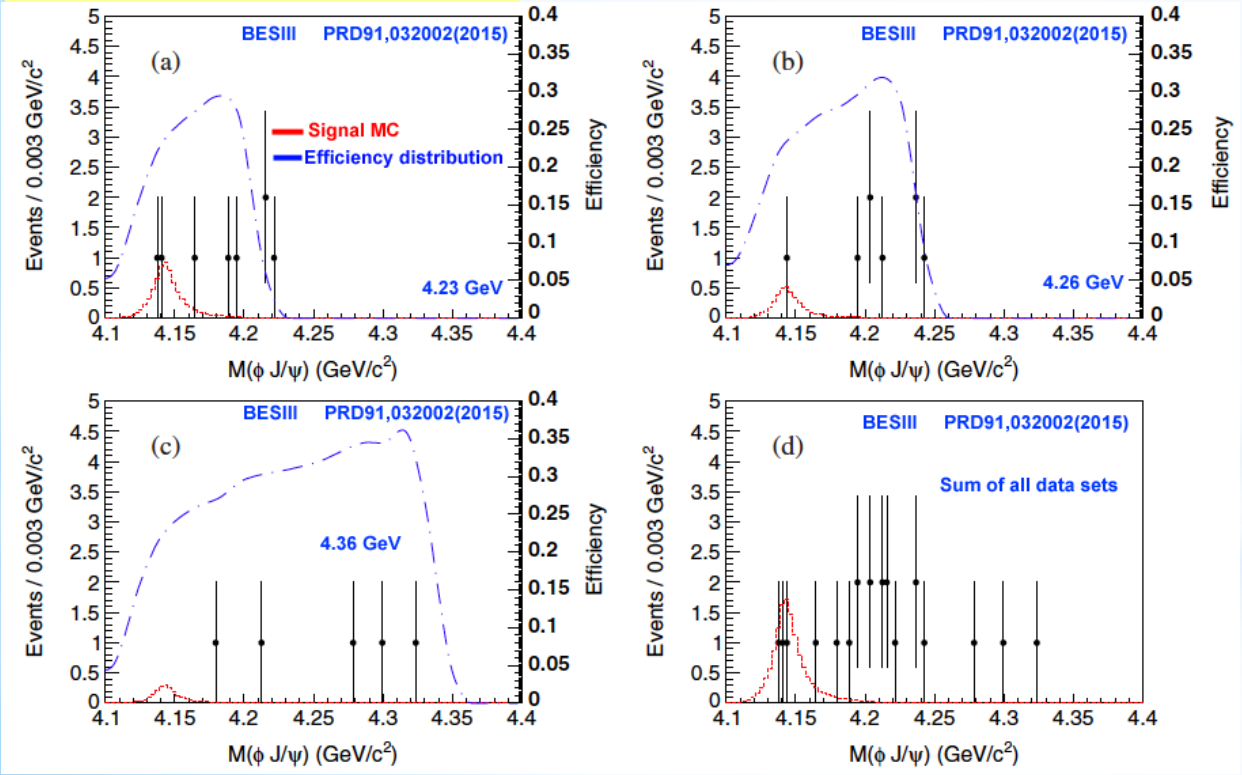
- Study of the energy dependence cross section
- The fit with a Y(4260) resonance gives a better description of the data (χ^2/ndf = 0.49=3 at 90% CL)
- These observations strongly support the existence of the radiative transition process Y(4260) $\to \gamma$X(3872)

BESIII Search of Y(4140) via $e^+e^- \to \gamma\,\phi\,J/\psi$

- **Y(4140) discovered by CDF in $B^+ \to \phi\,J/\psi\,K^+$, PRL 102,242002(2015)**
- **Not observed by Belle and LHCb**
- **BESIII: search of Y(4140) decay into $\phi\,J/\psi$ via $e^+e^- \to \gamma\,\phi\,J/\psi$**

PRD 91, 032002(2015)

$$\sigma^B \bullet \mathcal{B} = \sigma(e^+e^- \to \gamma\,Y(4140) \bullet \mathcal{B}(Y(4140 \to \phi\,J/\psi)$$



1094 pb^{-1} @ 4.23 GeV

$\sigma < 0.35$ pb at 90% CL

827 pb^{-1} @ 4.26 GeV

$\sigma < 0.28$ pb at 90% CL

545 pb^{-1} @ 4.36 GeV

$\sigma < 0.33$ pb at 90% CL

Compared with X(3872)

@ 4.23 GeV

$\sigma = 0.27 \pm 0.09 \pm 0.02$ pb

@ 4.26 GeV

$\sigma = 0.33 \pm 0.12 \pm 0.02$ pb