Baryon Spectroscopy at BESIII

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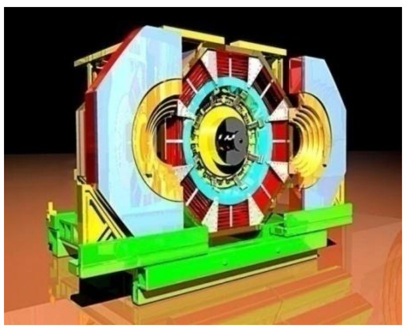
on behalf of the BESIII Collaboration



BARYONS 2016

International Conference on the Structure of Baryons

Tallahassee, Florida, USA

May 16-20, 2016

Baryonic States

- All ground baryonic states are well estabilished
  - Good agreement between experimental data and quark model
- The excited spectrum is much less clear
  - Many more states predicted than observed
- Insight to hadron structure

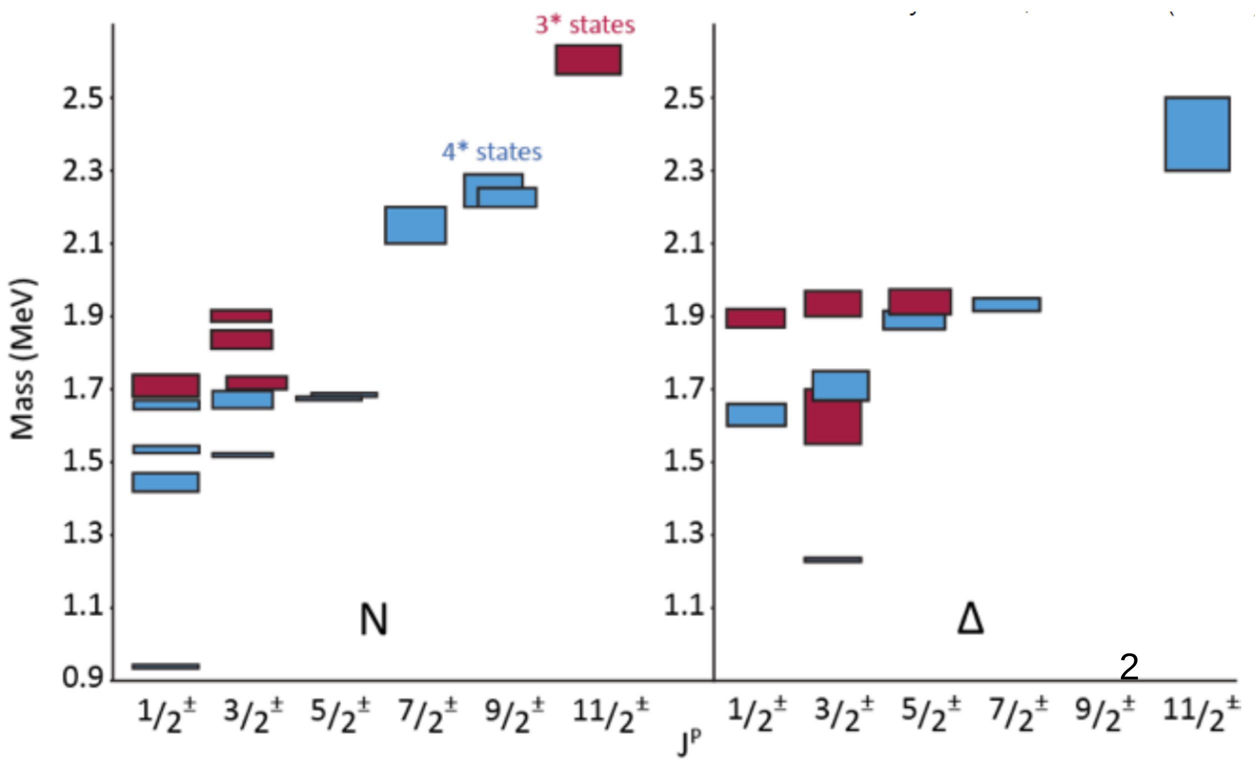
Chin. Phys. C 38 090001 (2014)

Up to 2.5 GEV:

45 N states predicted

15 estabilished

10 tentative



Missing Resonances

- Many of the predicted resonances were not observed experimentally
- Experimental and theoretical efforts

- **Experimentally**:

  baryon resonances may couple very weakly to single pions
- **Theoretically**:

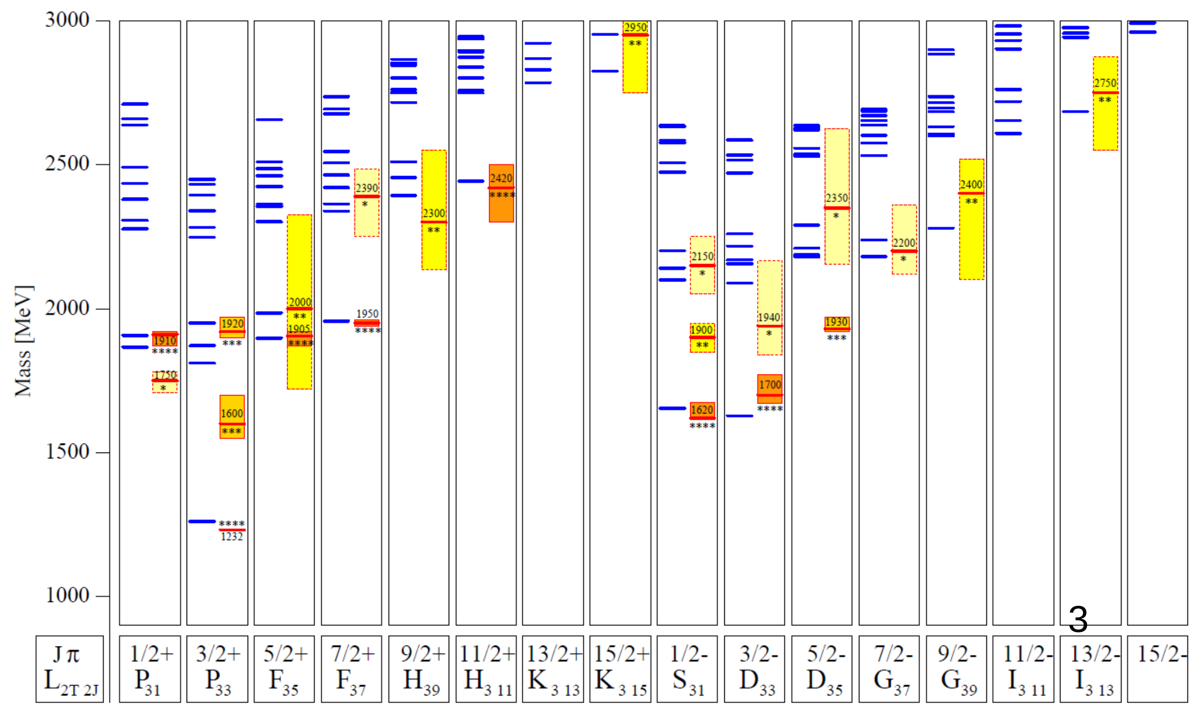
  the baryon spectrum can be modeled with *fewer effective degrees of freedom* (quark-diquark or Y/Δ-type models)

Relativistic quark model

Δ-resonance spectrum

Potential model: A

EPJ A10, 395-446 (2001)



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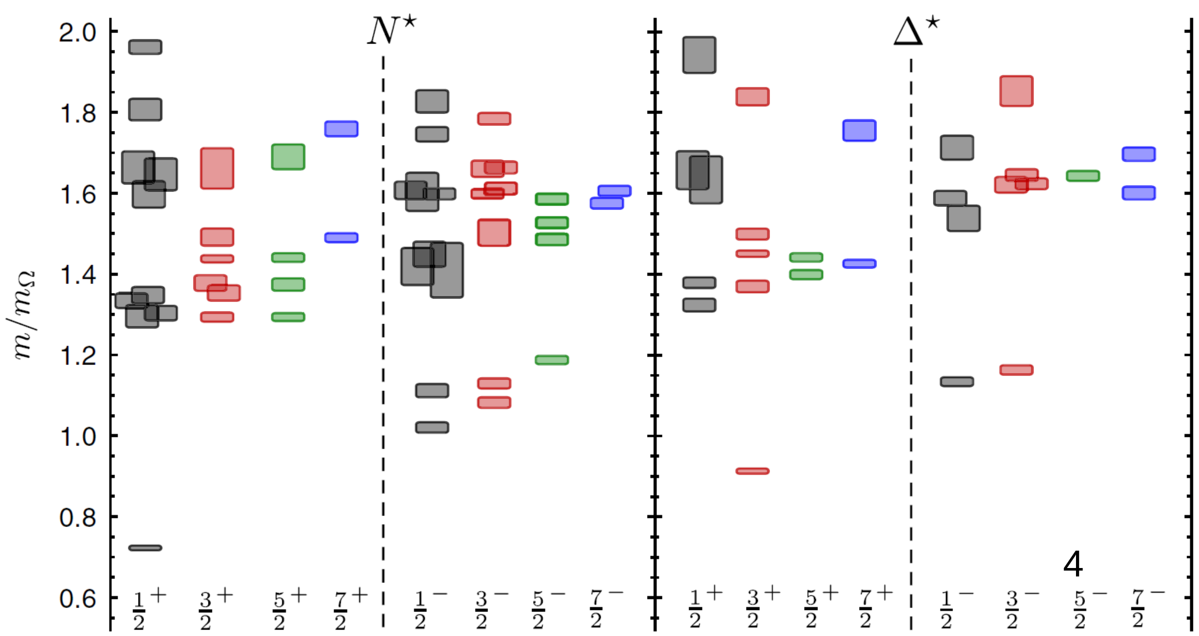
Lattice QCD

Δ and *N* spectrum

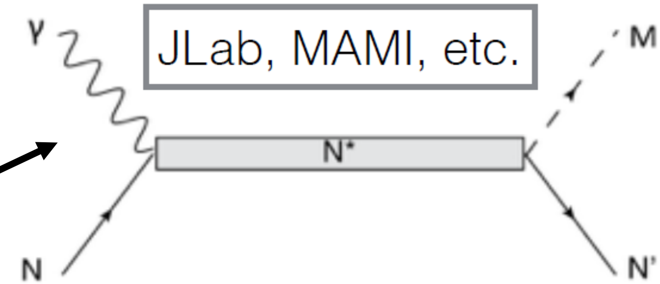
m_π = 396 MeV

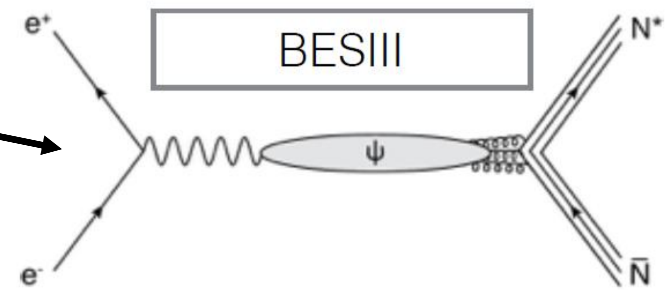
Phys Rev D84, 074508 (2011)

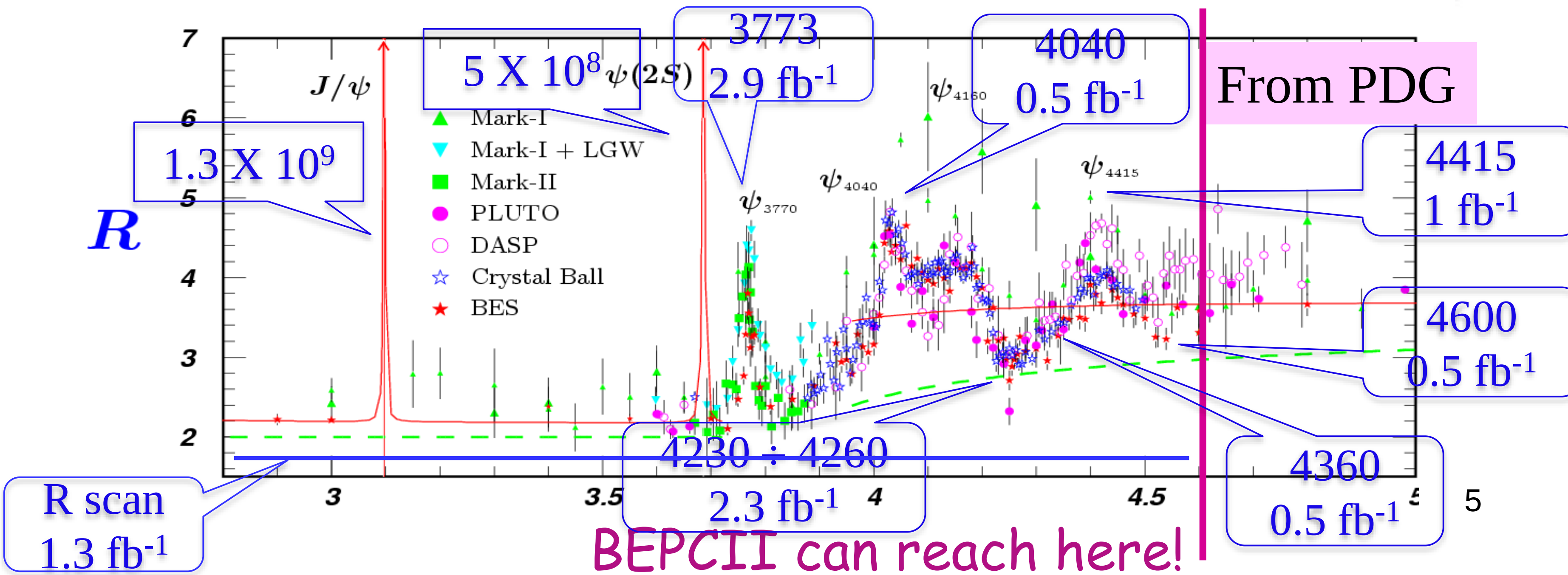


BESIII: Baryon Production

- Charmonium decays offer complementary information to existing data
  - Coupling of unobserved states through conventional production channels could be small, but coupling may be large to ggg$N$:
    $\psi \longrightarrow N\bar{N}(\pi/\eta/\eta'/\omega/\phi)$, $\bar{p}\Sigma\pi$, $\bar{p}\Lambda K$
  - High statistics available at BESIII



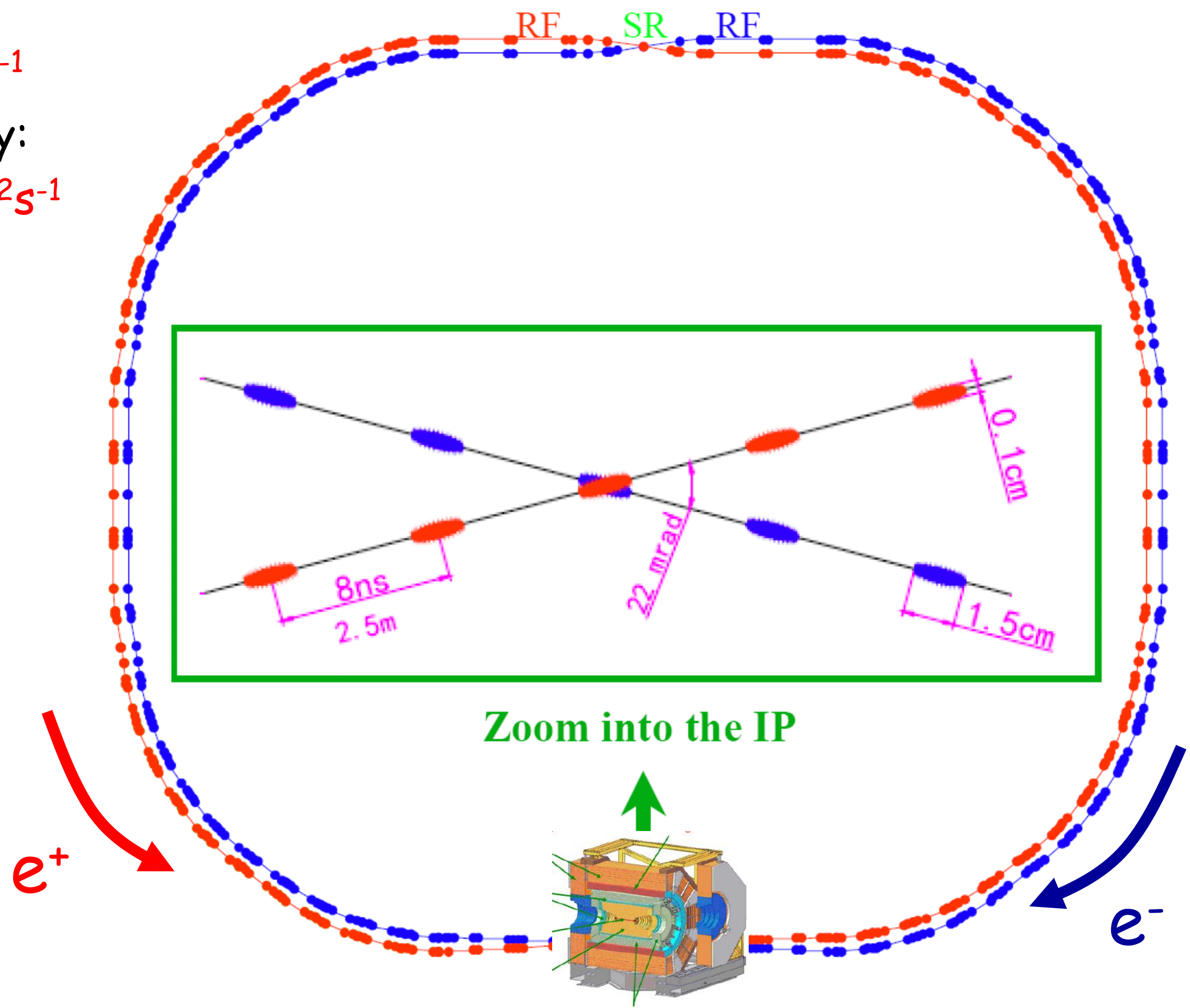




BEPCII Storage Rings

Beijing Electron-Positron Collider II

- Beam energy:
  1.0-2.3 GeV
- Design Luminosity:
  $1 \times 10^{33}\ cm^{-2}s^{-1}$
- Achieved Luminosity:
  $\sim 1 \times 10^{33}\ cm^{-2}s^{-1}$
- 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
- Circumference:
  237m

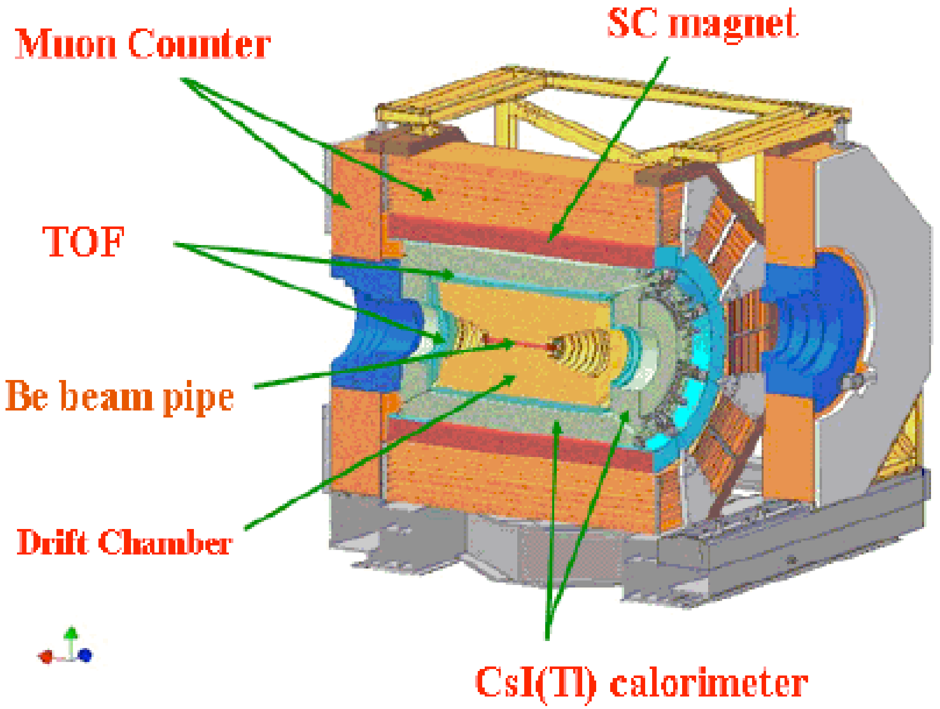


The BESIII Spectrometer @ IHEP

BEijing Spectrometer III

e^+e^- collisions

$\sqrt{S}$ tuned depending on energy



Physics program

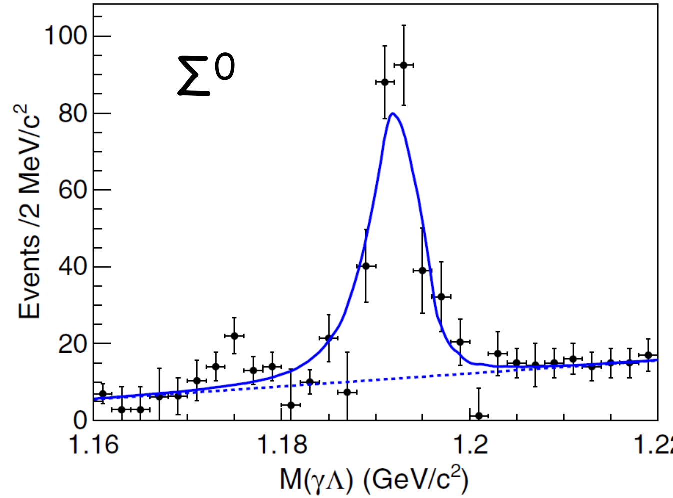
- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- τ-Physics
- ...

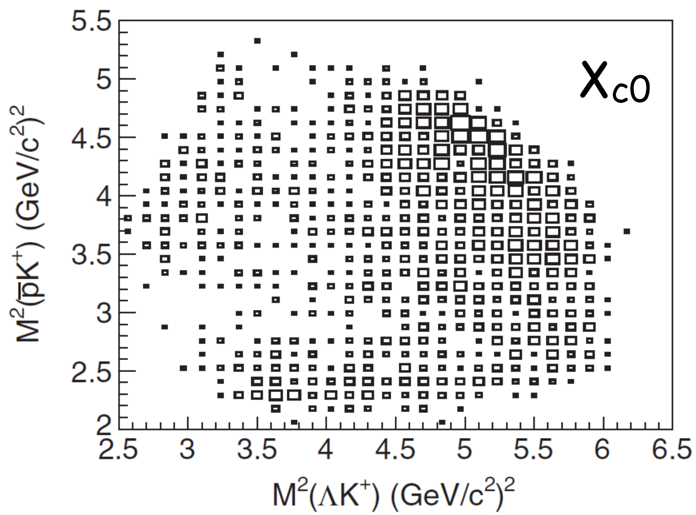
D.M. Asner et al, Physics at BES-III, arXiv:0809.1869v1 [hep-ex] (2008)

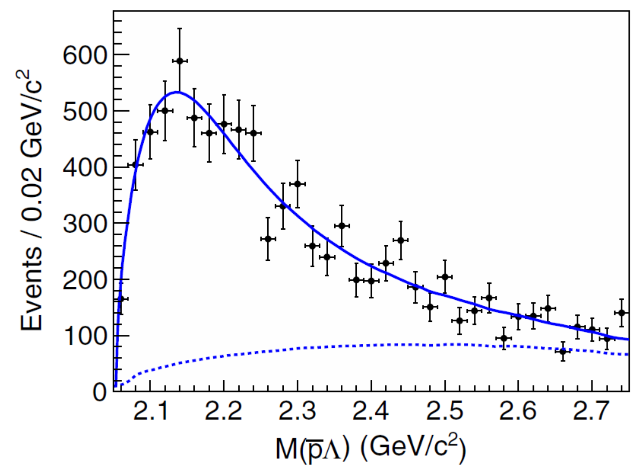
$\psi(3686) \to \bar{p}K^+\Sigma^0$ and $\chi_{cJ} \to \bar{p}K^+\Lambda$

PRD 87, 012007 (2013)

- $\psi(3686) \to \bar{p}K^+\Sigma^0$: first measurement
- $\chi_{cJ} \to \bar{p}K^+\Lambda$: BR improvement
- $\chi_{c0} \to \bar{p}K^+\Lambda$: anomalous enhancement close to threshold
- Possible reasons:
  - quasi bound dibaryon state
  - final state interactions
  - interference of high mass N* and Λ* states







Channel	$\psi' \to \bar{p}K^+\Sigma^0$ + c.c.	$\chi_{c0} \to \bar{p}K^+\Lambda$ + c.c.	$\chi_{c1} \to \bar{p}K^+\Lambda$ + c.c.	$\chi_{c2} \to \bar{p}K^+\Lambda$ + c.c.
$\mathcal{B}$(BESIII)	$(1.67 \pm 0.13 \pm 0.12) \times 10^{-5}$	$(13.2 \pm 0.3 \pm 1.0) \times 10^{-4}$	$(4.5 \pm 0.2 \pm 0.4) \times 10^{-4}$	$(8.4 \pm 0.3 \pm 0.6) \times 10^{-4}$
PDG		$(10.2 \pm 1.9) \times 10^{-4}$	$(3.2 \pm 1.0) \times 10^{-4}$	$(9.1 \pm 1.8) \times 10^{-4}$

$\psi(3686) \to \Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$

PRD 88, 112007 (2013)

- BR first measurements:

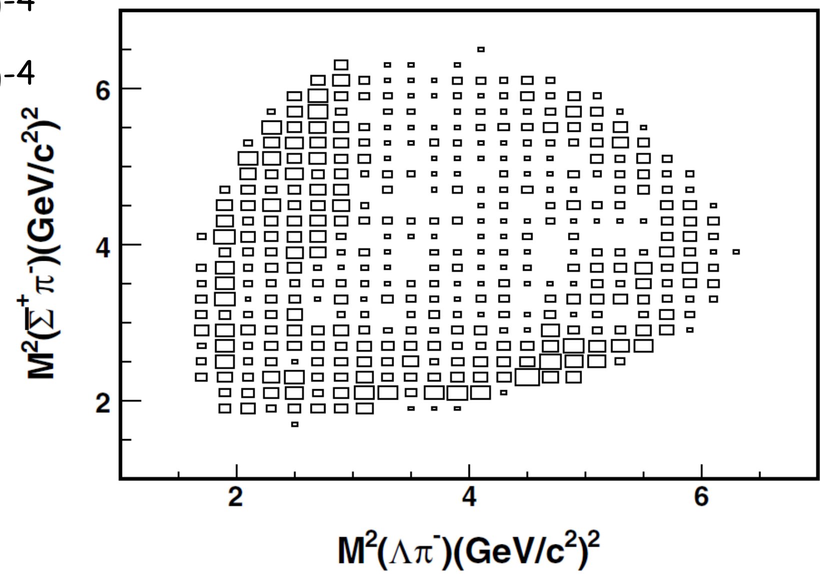
  $B(\psi(3686)\to\Lambda\bar{\Sigma}^{+}\pi^{-}+cc) = (1.40\pm0.03\pm0.13)\times10^{-4}$

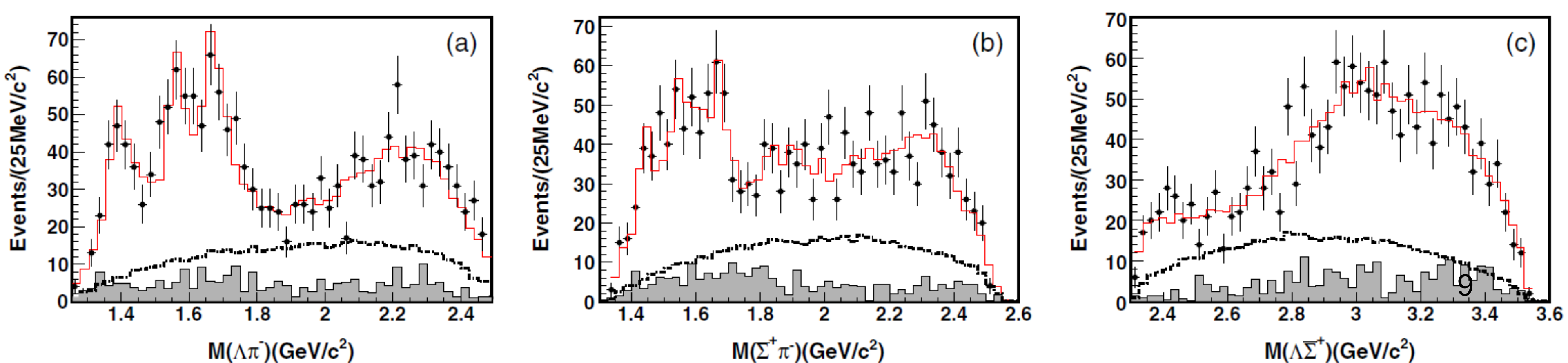
  $B(\psi(3686)\to\Lambda\bar{\Sigma}^{-}\pi^{+}+cc) = (1.54\pm0.04\pm0.13)\times10^{-4}$

$$Q_{\Lambda\bar{\Sigma}^-\pi^+} = \frac{\mathcal{B}(\psi(3686)\to\Lambda\bar{\Sigma}^-\pi^+)}{\mathcal{B}(J/\psi\to\Lambda\bar{\Sigma}^-\pi^+)} = (9.3\pm1.2)\%$$

- PWA used to determine detection efficiency

  - Includes 16 possible intermediate excited states with at least two stars according to the PDG, with parameters fixed to world averages

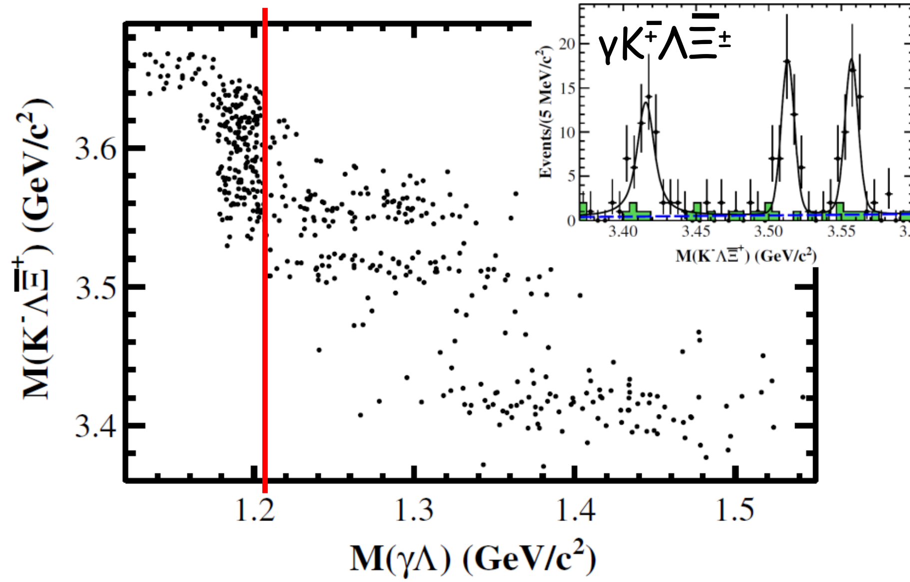


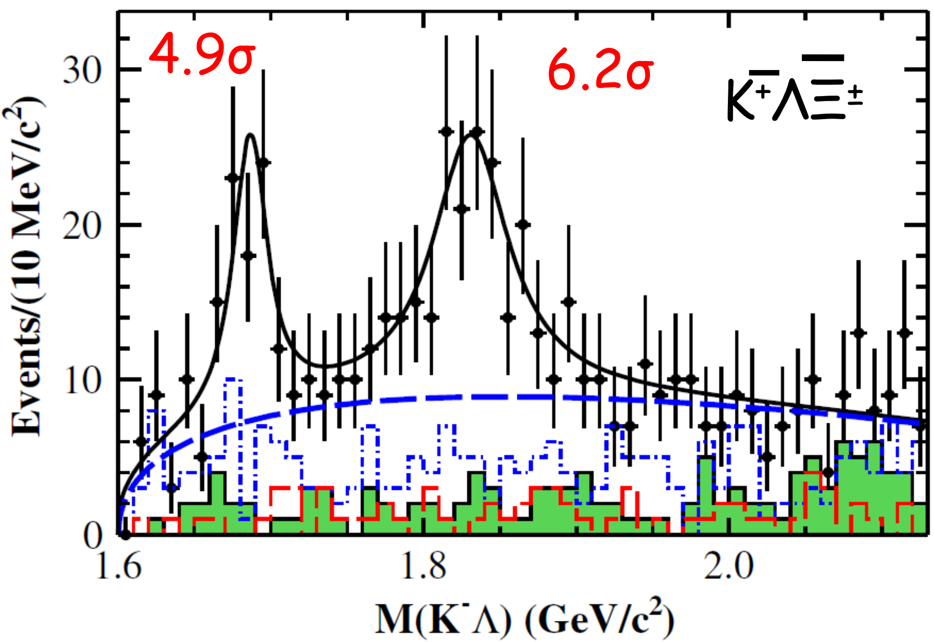


ψ(3686) -> (γ)$K^{\mp}\Lambda\bar{\Xi}^{\pm}$

PRD 91, 092006 (2015)

Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+$, $\Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+$, $\Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0}, \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1}, \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2}, \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$





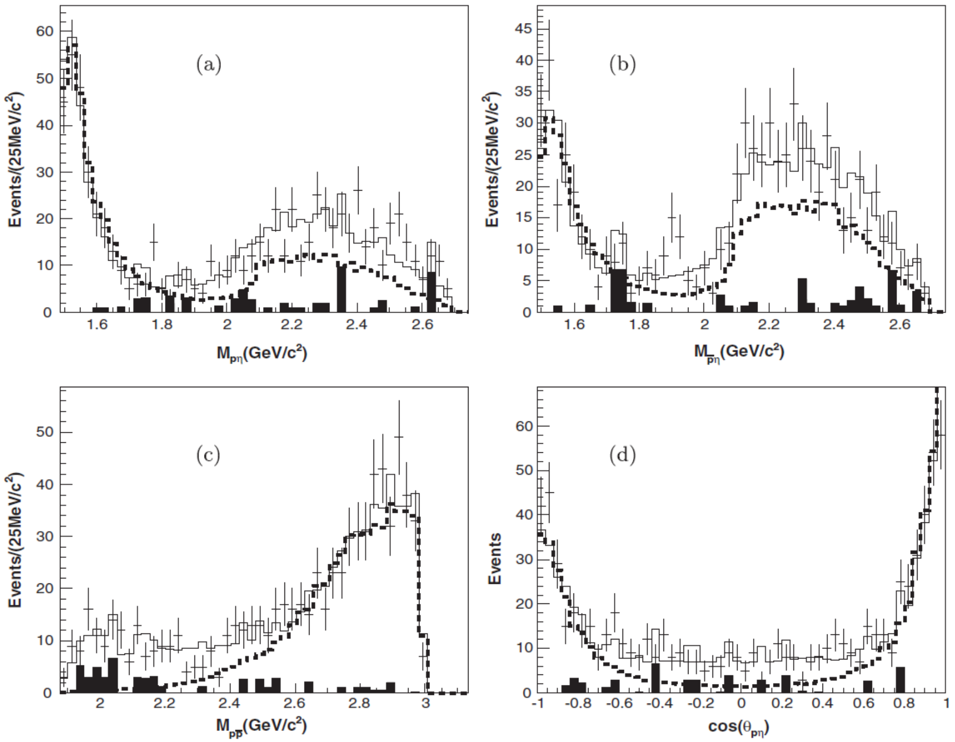
- Ξ(1690) and Ξ(1820) observed in M(KΛ)
- Both are well established states
- Resonance parameters consistent with PDG

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

$\psi(3686) \to p\bar{p}\eta$

PRD 88, 032010 (2013)

- Intermediate state N(1535) -> pη is dominant
- No evidence for a $p\bar{p}$ resonance, Indicating that the threshold Enhancement in previous results May be explained by interference Between the N(1535) and phase space



Mass and width of N(1535)

- $M = 1524 \pm 5^{+10}_{-4}\ \mathrm{MeV}/c^2$
- $\Gamma = 130^{+27+57}_{-24-10}\ \mathrm{MeV}/c^2$

PDG value:

- $M = 1525$ to $1545\ \mathrm{MeV}/c^2$
- $\Gamma = 125$ to $175\ \mathrm{MeV}/c^2$

$$Q_{p\bar{p}\eta} = \frac{B(\psi(2S) \to p\bar{p}\eta)}{B(J/\psi \to p\bar{p}\eta)} = (3.2 \pm 0.4)\%$$

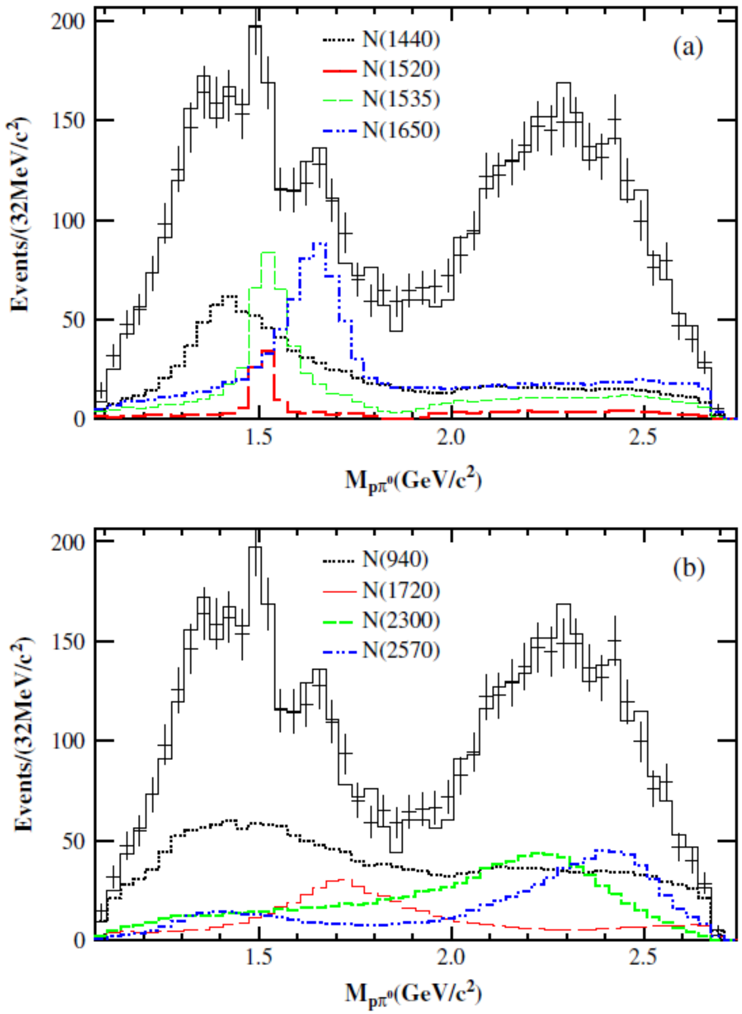
$$B(\psi(2S) \to N(1535)\bar{p}) \times B(N(1535) \to p\eta)$$
$$= \frac{N_{\mathrm{obs}}}{\varepsilon \cdot N_{\psi(2S)} \cdot B(\eta \to \gamma\gamma)} = (5.2 \pm 0.3^{+3.2}_{-1.2}) \times 10^{-5}$$

$\psi(3686) \to p\bar{p}\pi^0$

PRL 110, 022001 (2013)

- In photon or meson beam studies, isospin 1/2 and 3/2 resonances are excited, complicating the analysis
- Δ resonances suppressed in charmonium decays to $p\bar{p}\pi^0$, giving a cleaner spectrum
  - Thought to be dominated by two body decays involving N* intermediate states
  - Also consider $p\bar{p}$ resonances ($\psi(3686) \to R\pi^0$)
- Seven N* states observed in partial wave analysis
  - Two new resonances, N(2300) with JP = 1/2⁺ and N(2570) with JP = 5/2⁻
  - Other five consistent with previous results

Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	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)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$



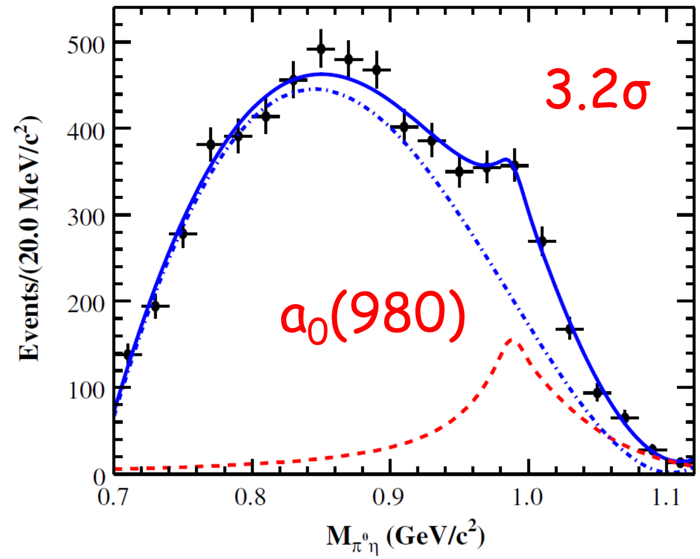
$\psi(3686)$ -> $p\bar{p}a_0(980)$

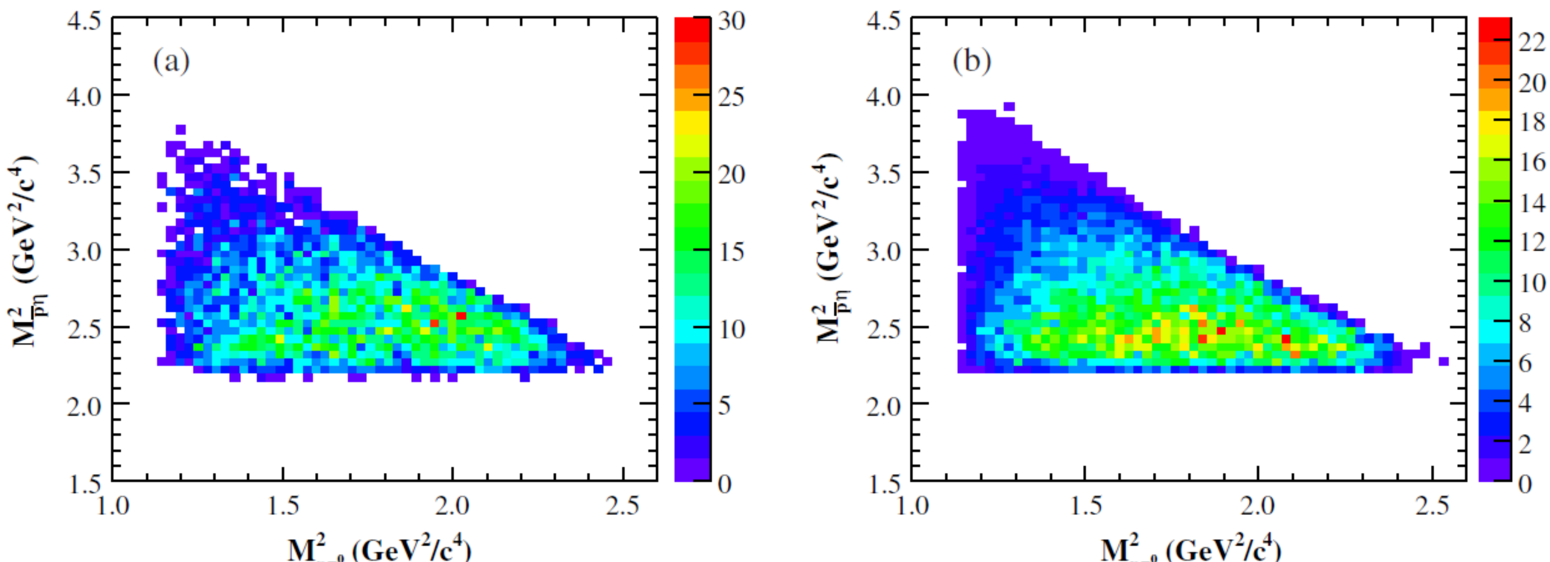
PRD 90, 052009 (2014)

- First observation of $J/\psi \to p\bar{p}a_0(980)$, $a_0(980) \to \pi^0\eta$
- Applies a chiral unitary coupled channel approach
  - Four-body decays $J/\psi \to N\bar{N}MM$
  - $a_0(980)$ generated through Final State Interactions
  - Provides useful information on dynamics of
  - Four-body FSI processes

$$\mathrm{Br}(J/\psi \to p\bar{p}a_0(980) \to p\bar{p}\pi^0\eta)$$

$$= (6.8 \pm 1.2 \pm 1.3) \times 10^{-5}$$

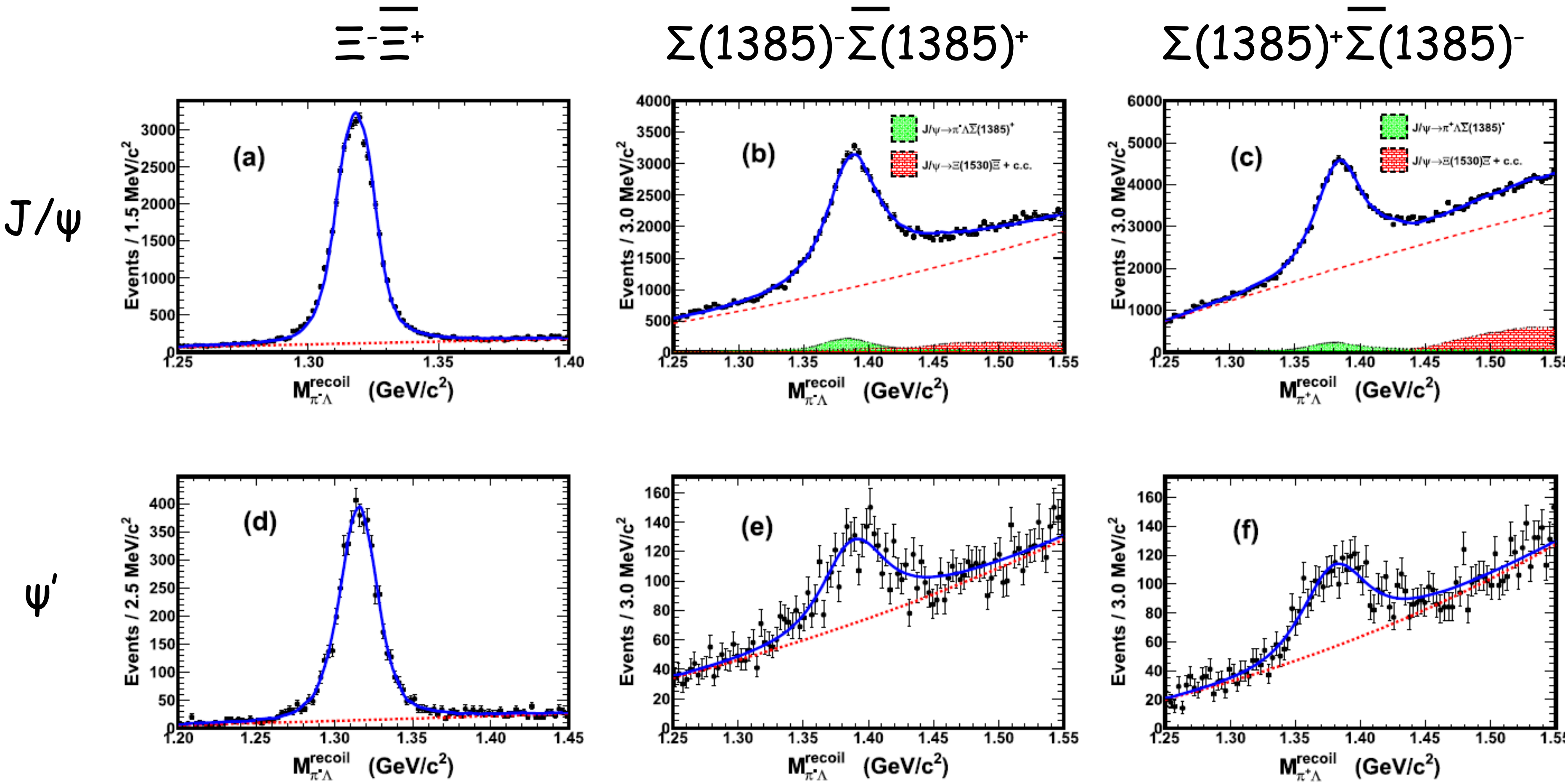




$J/\psi(\psi(3686)) \to \Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

PRD 93, 072003 (2016)

- First observation of ψ(3686) into Σ(1835) states
- Single tag method
- BR and angular distribution investigations
- Most precise measurements available



$J/\psi(\psi(3686)) \to \Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

PRD 93, 072003 (2016)

12% rule

$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
26.73%	7.76%	6.68%

Branching Ratios

Mode	$J/\psi \to$			$\psi(3686) \to$		
	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
This work	$10.40 \pm 0.06 \pm 0.74$	$10.96 \pm 0.12 \pm 0.71$	$12.58 \pm 0.14 \pm 0.78$	$2.78 \pm 0.05 \pm 0.14$	$0.85 \pm 0.06 \pm 0.06$	$0.84 \pm 0.05 \pm 0.05$
MarkI [5]	14.00 ± 5.00	...	...	< 2.0	...	...
MarkII [6]	$11.40 \pm 0.80 \pm 2.00$	$8.60 \pm 1.80 \pm 2.20$	$10.3 \pm 2.4 \pm 2.5$	...	...	...
DM2 [7]	$7.00 \pm 0.60 \pm 1.20$	$10.00 \pm 0.40 \pm 2.10$	$11.9 \pm 0.4 \pm 2.5$	...	...	...
BESII [8,12]	$9.00 \pm 0.30 \pm 1.80$	$12.30 \pm 0.70 \pm 3.00$	$15.0 \pm 0.8 \pm 3.8$	$3.03 \pm 0.40 \pm 0.32$	...	...
CLEO [9]	...	...	...	$2.40 \pm 0.30 \pm 0.20$	...	...
BESI [26]	...	...	...	$0.94 \pm 0.27 \pm 0.15$	...	...
PDG [3]	8.50 ± 1.60	10.30 ± 1.30	10.30 ± 1.30	1.80 ± 0.60	...	...

Angular distributions

Mode	$J/\psi \to$			$\psi(3686) \to$		
	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
This work	$0.58 \pm 0.04 \pm 0.08$	$-0.58 \pm 0.05 \pm 0.09$	$-0.49 \pm 0.06 \pm 0.08$	$0.91 \pm 0.13 \pm 0.14$	$0.64 \pm 0.40 \pm 0.27$	$0.35 \pm 0.37 \pm 0.10$
BESII [8]	$0.35 \pm 0.29 \pm 0.06$	$-0.54 \pm 0.22 \pm 0.10$	$-0.35 \pm 0.25 \pm 0.06$	...	...	...
MarkIII [6]	0.13 ± 0.55	...	...	...	...	...
Claudson *et al.* [10]	0.16	0.11	0.11	0.32	0.29	0.29
Carimalo [11]	0.27	0.20	0.20	0.52	0.50	0.50

Summary

- BESIII collected 0.5×10^9 $\psi(3686)$ and 1.3×10^9 J/ψ events
- Overview of our recent measurements
- Charmonium decays as powerful tool to investigate excited nucleons and hyperons
  - Discover new states
  - Provide complementary information to other experiments

- Stay tuned for new results!!