Progress in Baryon Spectroscopy at BESIII

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The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon
July 25-30, 2016, Kyoto, Japan

Outline

- Introduction
- Recent BESIII results in Baryon Spectroscopy:
  - Observation of $\psi' \to \Lambda\bar{\Sigma}^{\pm}\pi^{\mp} + c.c.$
  - Observation of $J/\psi \to p\bar{p}a_0(980)$
  - Measurement of $\psi' \to (\gamma)K^{-}\Lambda\bar{\Xi}^{+} + c.c.$
  - Measurement of $J/\psi(\psi') \to \Xi^{-}\bar{\Xi}^{+}, \Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$
  - PWA of $\psi' \to p\bar{p}\pi^{0}$
  - PWA of $\psi' \to p\bar{p}\eta$
- Summary

All results based on the data taken in 2009: 225×10^6 J/ψ events and 106×10^6 ψ' events

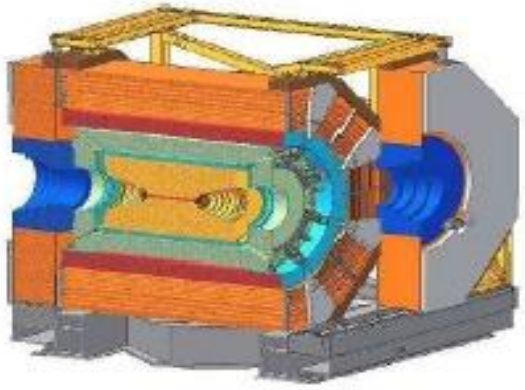
BEPCII and BESIII

Linac

Storage ring

Beam energy: 1-2.3 GeV
Design Luminosity: $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

BESIII at BEPCII



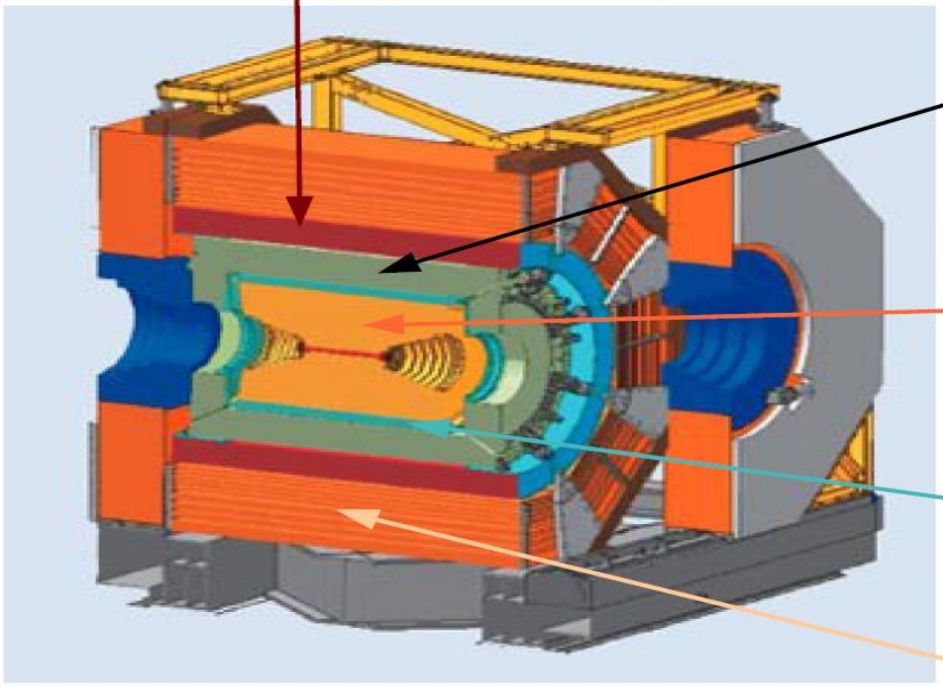
BESIII physics program

- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

The BESIII detector

NIM A614, 345(2010)

Super conducting magnet: 1 T



EMC: CsI cristal
- 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: **80ps** (barrel)
110ps (endcaps)

Muon ID:
9 layers RPC, 8 for endcaps

Baryon spectroscopy

- Baryon spectroscopy is an important field to understand the internal structure of hadrons
- The established baryons are described by three-quark (qqq) configurations
- Non-relativistic quark model:

  - It is quite successful in interpreting baryon resonances

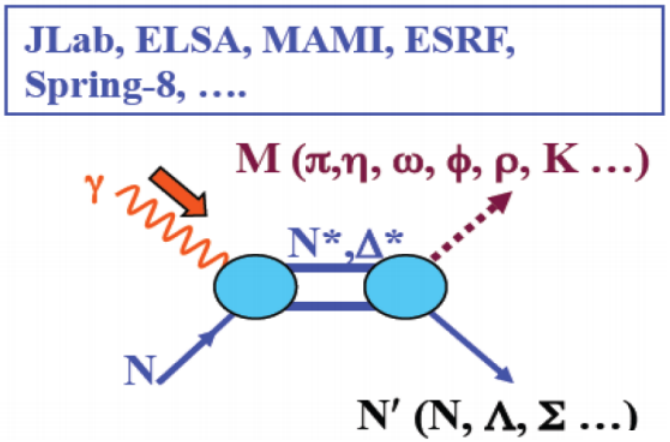
  - It also provides an explicit classification for light baryons in terms of group symmetry.

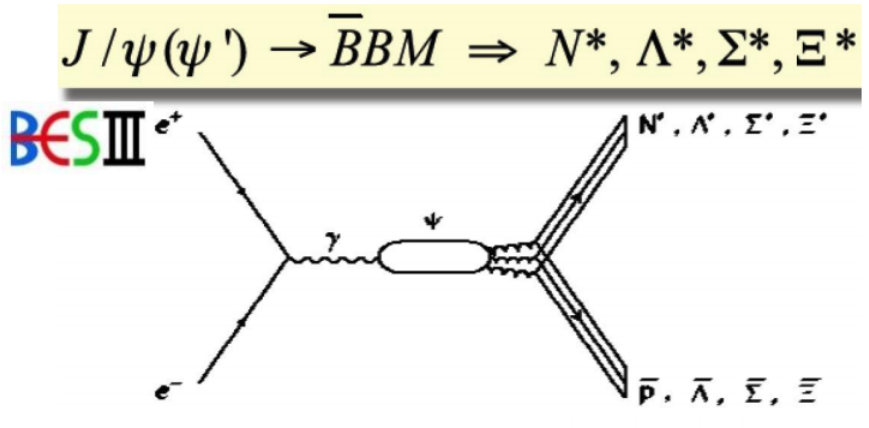
  - It tends of predict far more excited states than are found experimentally ("missing resonances problem")

➢ Theoretically: may indicate that the baryon spectrum can be modeled with fewer effective degrees of freedom (quark-diquark models)

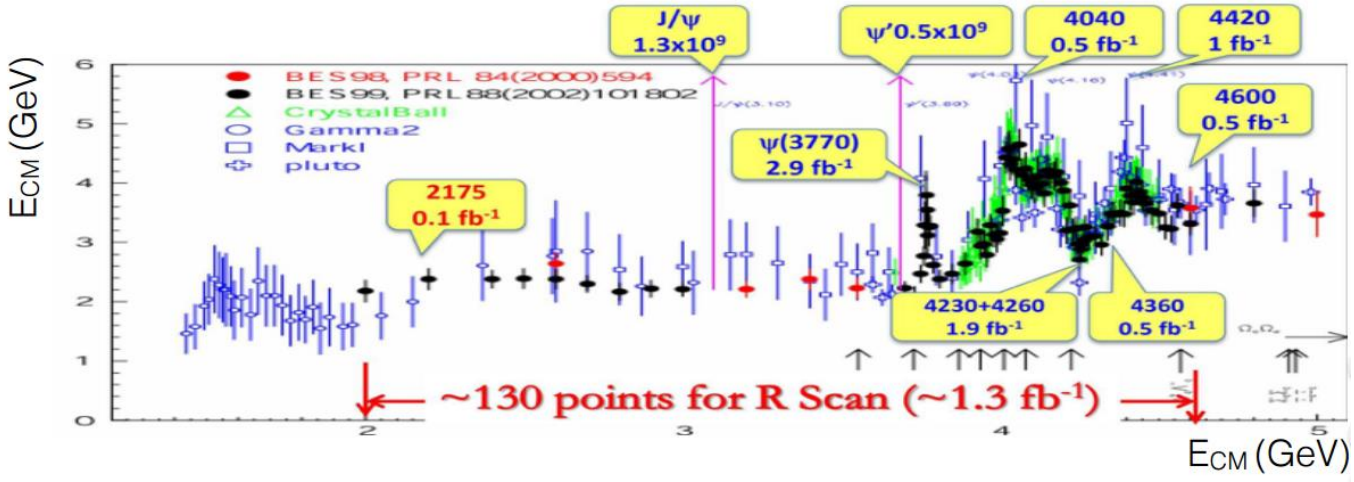
➢ Experimentally: baryon resonances may couple very weakly to single pions

Baryon production



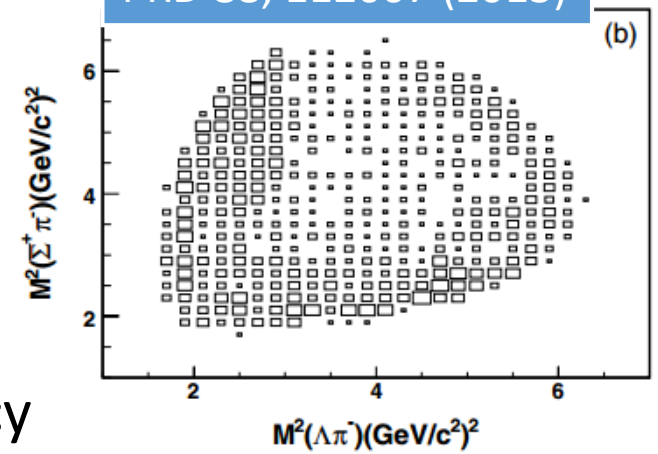


- Missing N*: maybe with small couplings to πN and γN, but large coupling to gggN: $\psi \to N\bar{N}\pi/\eta/\eta'/\omega/\phi, \bar{p}\Sigma\pi, \bar{p}\Lambda K \ldots$
- High statistics of charmonimum at BESIII



$\psi' \to \Lambda\bar{\Sigma}^{\pm}\pi^{\mp} + c.c.$

PRD 88, 112007 (2013)



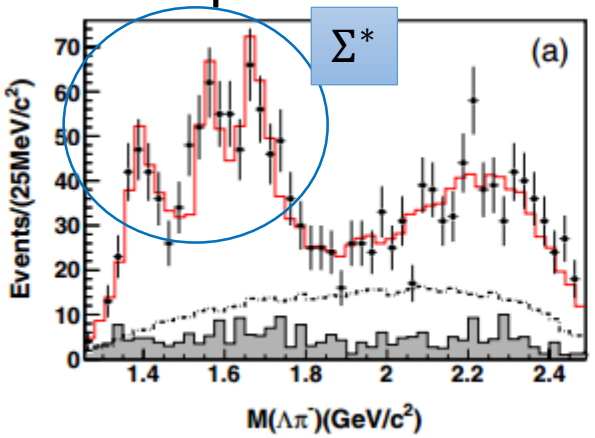
- BR first measurements:

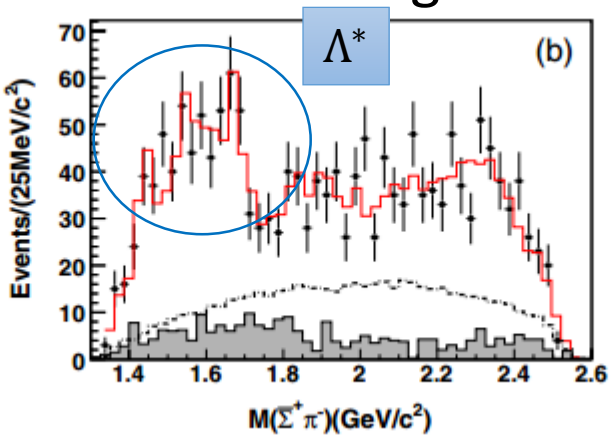
$$\mathcal{B}(\psi' \to \Lambda\bar{\Sigma}^{+}\pi^{-} + c.c.) = (1.40 \pm 0.03 \pm 0.13) \times 10^{-4}$$

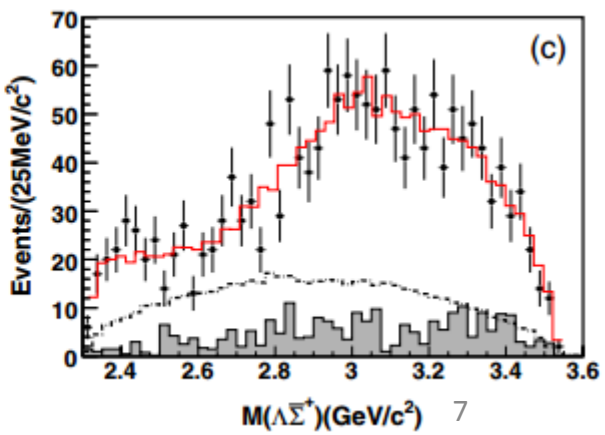
$$\mathcal{B}(\psi' \to \Lambda\bar{\Sigma}^{-}\pi^{+} + c.c.) = (1.54 \pm 0.04 \pm 0.13) \times 10^{-4}$$

$$Q_{\Lambda\bar{\Sigma}^{-}\pi^{+}} = \frac{\mathcal{B}(\psi' \to \Lambda\bar{\Sigma}^{-}\pi^{+})}{\mathcal{B}(J/\psi \to \Lambda\bar{\Sigma}^{-}\pi^{+})} = (9.3 \pm 1.2)\%$$

- 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





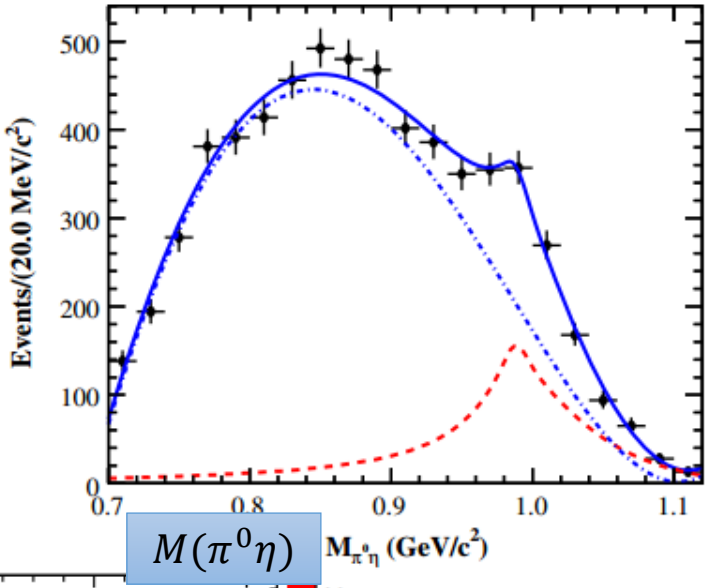


Observation of $J/\psi \to p\bar{p}a_0(980)$

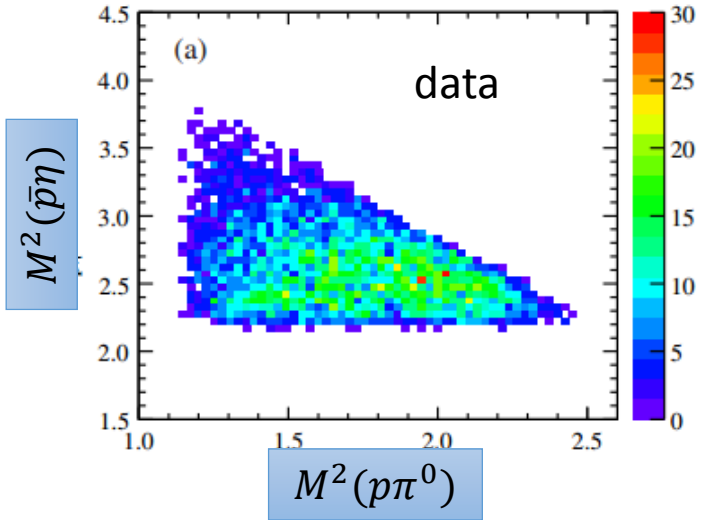
- First observation of $J/\psi \to p\bar{p}a_0(980)$, via $a_0(980) \to \pi^0\eta$ PRD 90, 052009 (2014)

$$\mathcal{B}(J/\psi \to p\bar{p}a_0(980) \to p\bar{p}\pi^0\eta) = (6.8 \pm 1.2 \pm 1.3) \times 10^{-5}$$

- 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

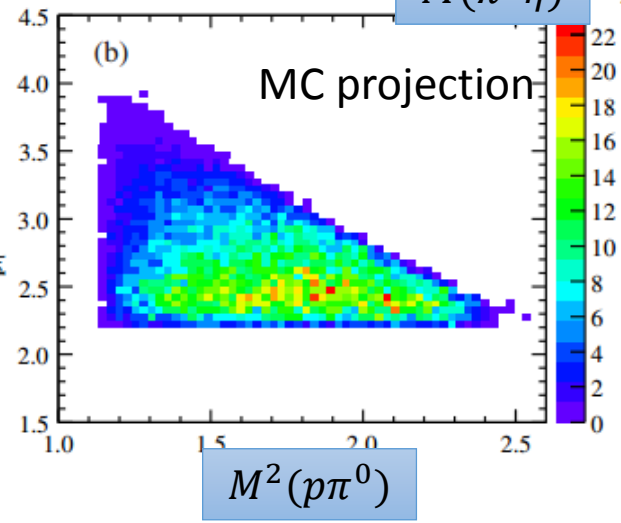


$M(\pi^0\eta)$



$M^2(\bar{p}\eta)$

$M^2(p\pi^0)$

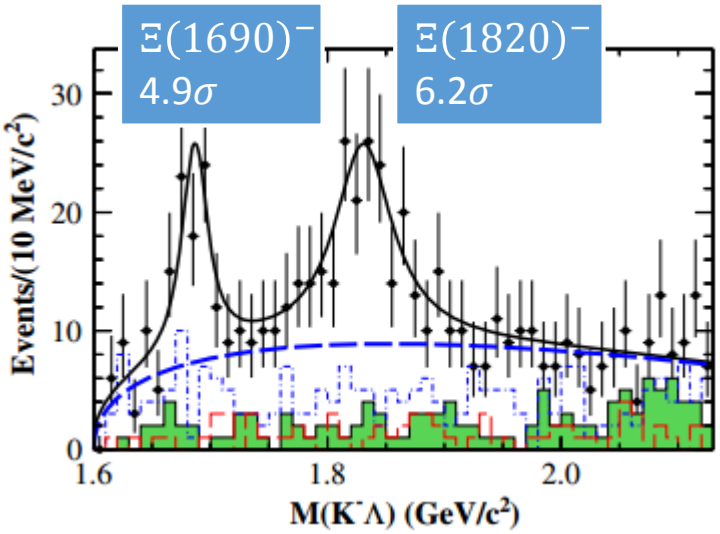


$M^2(\bar{p}\eta)$

$M^2(p\pi^0)$

$\psi' \to K^- \Lambda \bar{\Xi}^+ + c.c.$

- Two hyperons are observed in $M(K\Lambda)$: $\Xi(1690)$ and $\Xi(1820)$
- Both are well established states
- Resonance parameters consistent with PDG



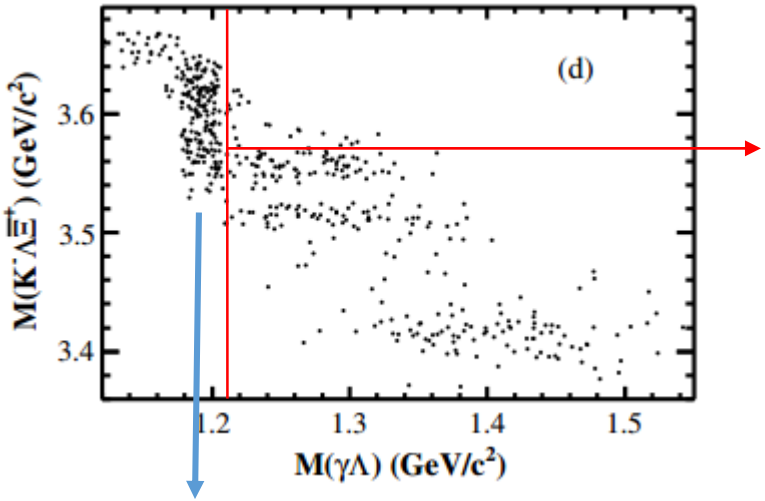
PRD 91, 092006 (2015)

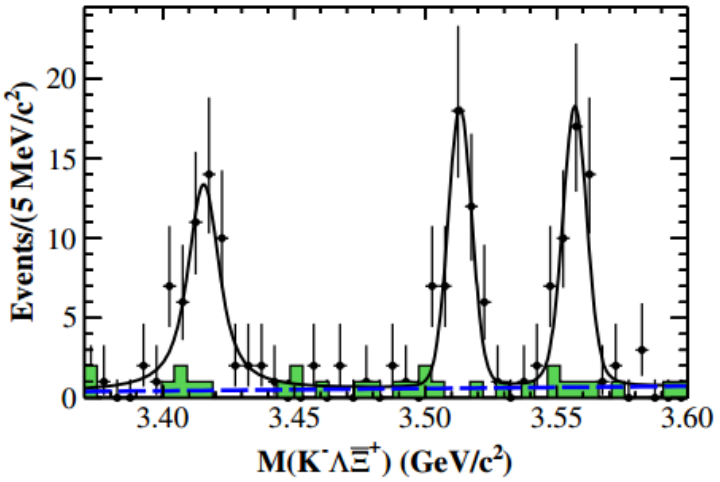
	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\mathrm{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}(10^{-6})$	$5.21 \pm 1.48 \pm 0.57$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

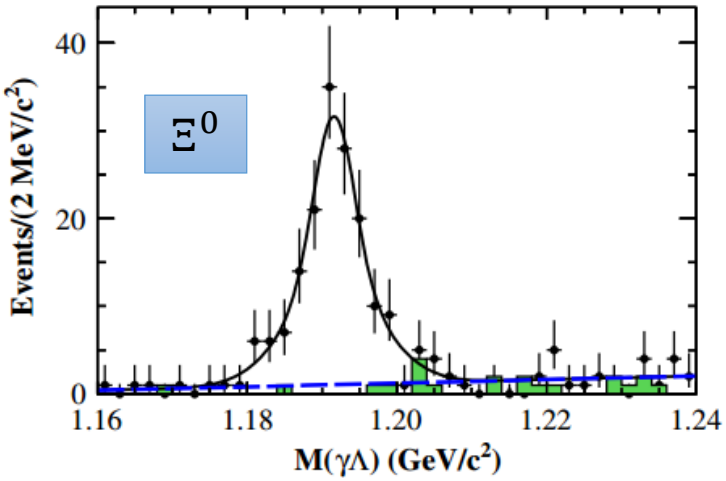
- First measurement of branching ratio:
- $\mathcal{B}(\psi' \to K^- \Lambda \bar{\Xi}^+ + c.c.) = (3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$

$\psi' \to \gamma K^- \Lambda \bar{\Xi}^+ + c.c.$

PRD 91, 092006 (2015)







- Measured branching ratios (first time):

$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0}, \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1}, \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2}, \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$

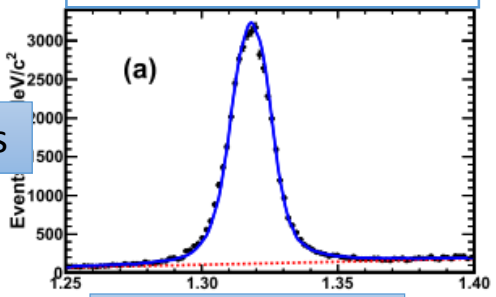
$J/\psi(\psi') \to \Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

- First observation of ψ' into $\Sigma(1385)$ states
- Single tag method
- BR and angular distribution investigations
- Most precise measurement available

PRD 93, 072003 (2016)

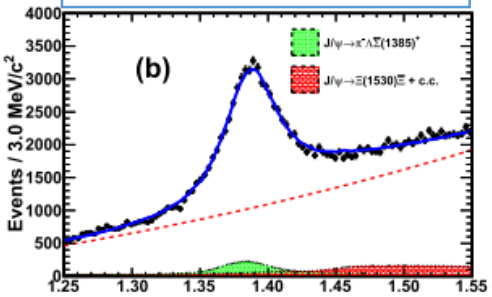
J/ψ decays

$\Xi^-\bar{\Xi}^+$



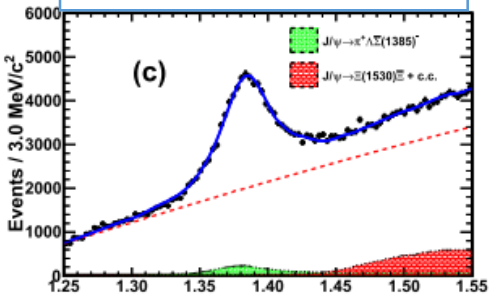
$M(\pi^-\Lambda)$ recoil

$\Sigma(1385)^-\bar{\Sigma}(1385)^+$



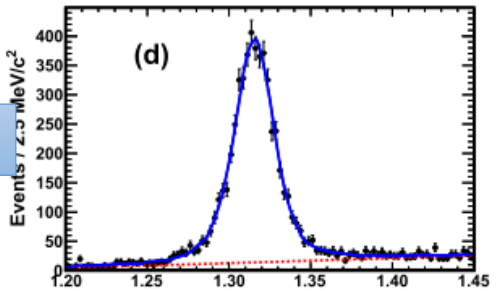
$M(\pi^-\Lambda)$ recoil

$\Sigma(1385)^+\bar{\Sigma}(1385)^-$

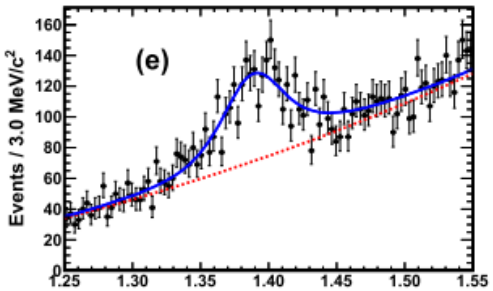


$M(\pi^+\Lambda)$ recoil

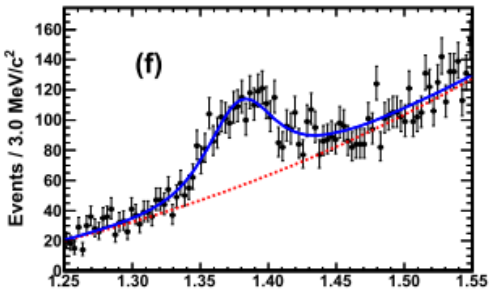
ψ' decays



$M(\pi^-\Lambda)$ recoil



$M(\pi^-\Lambda)$ recoil



$M(\pi^+\Lambda)$ recoil

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

PRD 93, 072003 (2016)

12% rule

$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
$(26.73 \pm 0.50 \pm 2.30)\%$	$(7.76 \pm 0.55 \pm 0.68)\%$	$(6.68 \pm 0.40 \pm 0.50)\%$

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	…	…

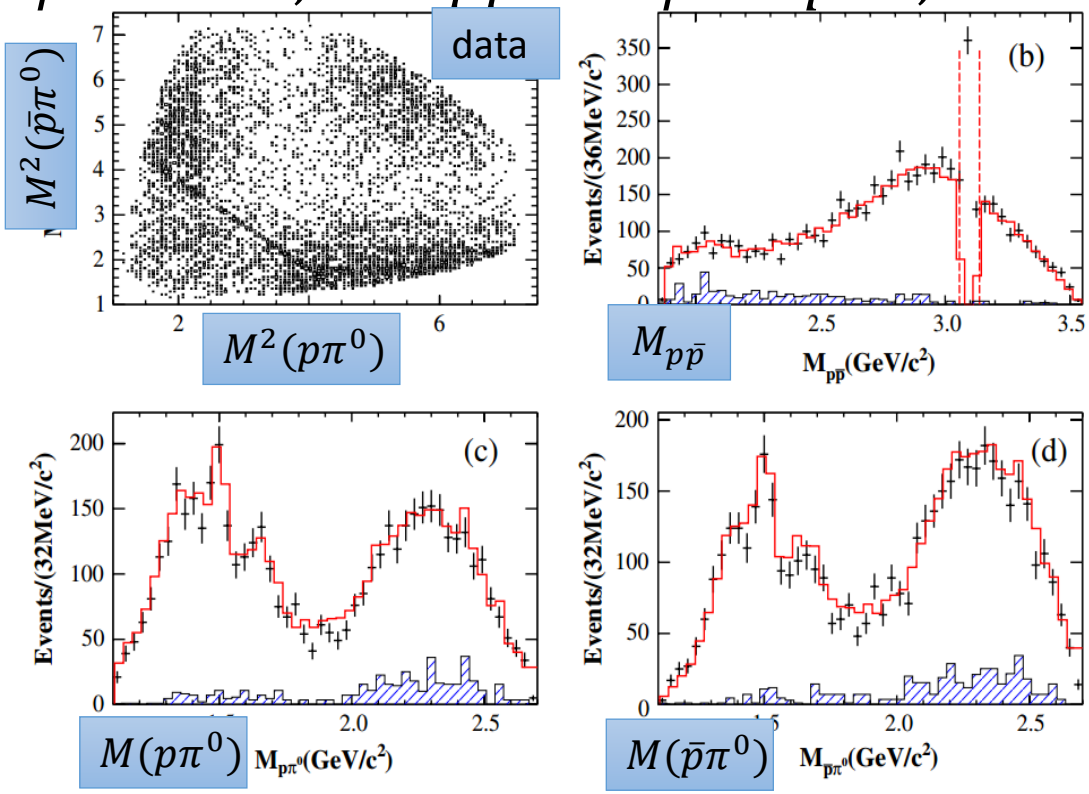
Angular distributions: $dN/d\cos\theta \propto 1 + \alpha\cos^2\theta$

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

PWA of $\psi' \to p\bar{p}\pi^0$

- In photon or meson beam studies, isospin ½ 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
- Considering the following decay in PWA:

$\psi' \to X\pi^0, X \to p\bar{p}$ and $\psi' \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0 + c.c.$



PRL 110, 022001 (2013)

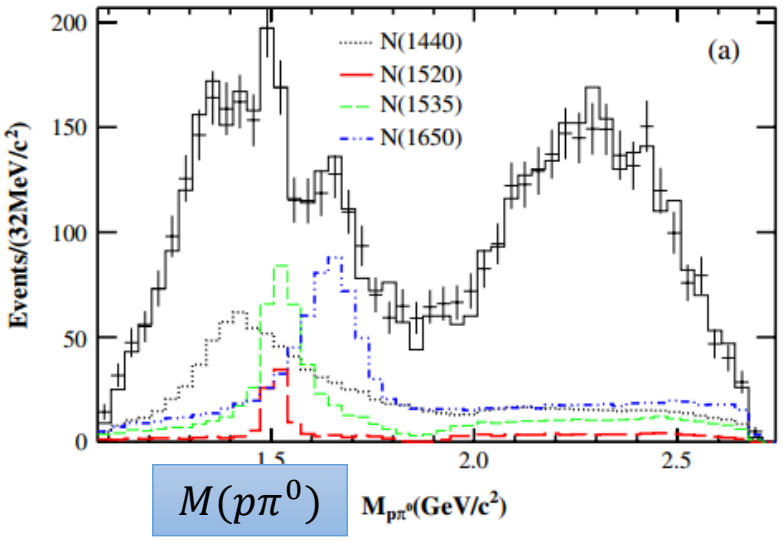
- Crosses represent data
- Shaded histograms show the background
- Histograms in red solid line are the fit result

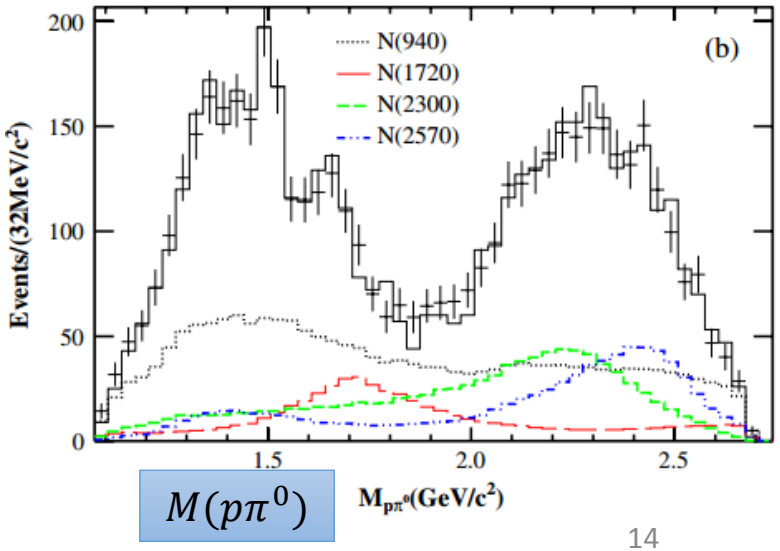
PWA of $\psi' \to p\bar{p}\pi^0$

PRL 110, 022001 (2013)

- ✓ Seven N* states are observed:
- Two new N* states: N(2300) and N(2570)
- Five well established N* states

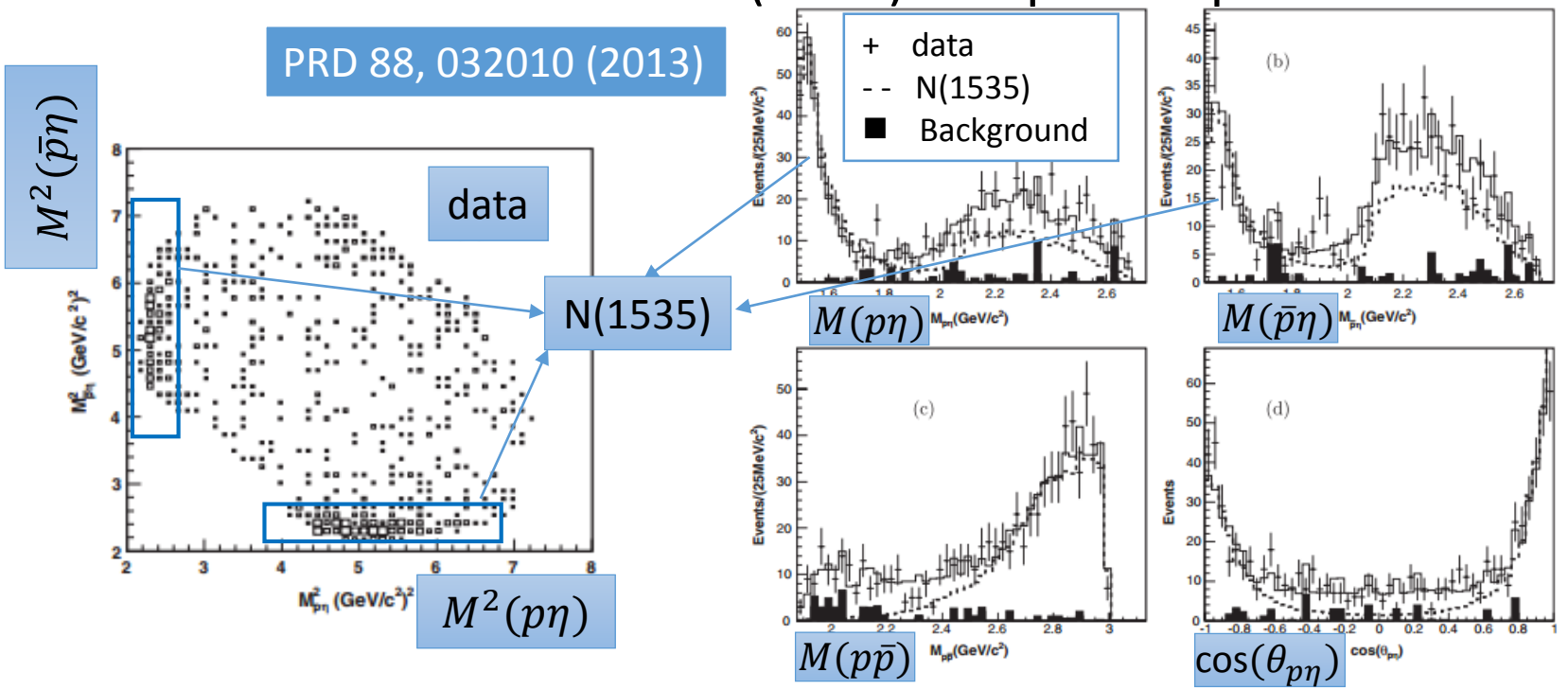
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	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
1/2+ **N(2300)**	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
5/2- **N(2570)**	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$





PWA of $\psi' \to p\bar{p}\eta$

- Intermediate state $N(1535) \to p\eta$ is dominant
- $N(1535)$ combined with an interfering phase space is sufficient to describe the data
- 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



PWA of $\psi' \to p\bar{p}\eta$

- N(1535) description:

$$BW(s) = \frac{1}{M_{N^*}^2 - s - iM_{N^*}\Gamma_{N^*}(s)}, \Gamma_{N^*} = \Gamma_{N^*}^0 (0.5\frac{\rho_{N\pi}(s)}{\rho_{N\pi}(M_{N^*}^2)} + 0.5\frac{\rho_{N\eta}(s)}{\rho_{N\eta}(M_{N^*}^2)}),$$

- $\rho_{N\pi}/\rho_{N\eta}$ is the phase space factor for the $N\pi/N\eta$ final states:

$$\rho_{NX}(s) = \frac{2q_{NX}(s)}{\sqrt{s}} = \frac{\sqrt{(s-(M_N+M_X)^2)(s-(M_N-M_X)^2)}}{s}$$

- N(1535) mass, width and product branching ratio:
- $M = 1524 \pm 5^{+10}_{-4}\mathrm{MeV}/c^2$
- $\Gamma = 130^{+27+57}_{-24-10}\ \mathrm{MeV}/c^2$
- $\mathcal{B}(\psi' \to N(1535)\bar{p}) \times \mathcal{B}(N(1535) \to p\eta) = (5.2 \pm 0.3^{+3.2}_{-1.2}) \times 10^{-5}$

Consistent with previous measurements

Summary

- BESIII collected 0.45 billion ψ' events and 1.3 billion J/ψ events
- Overview of recent results in the baryon spectroscopy
- Charmonium decays as powerful tool to investigate excited nucleons and hyperons

  - Discover new states

  - Provide complementary information to other experiments
- New results will be coming soon!

Thank you