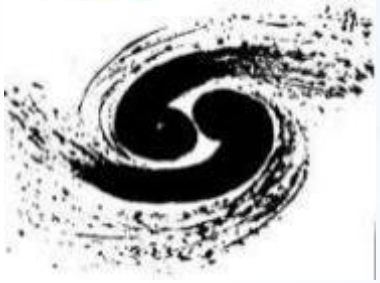
Baryon Decays and Spectroscopy at BESIII

Shuangshi FANG

(for the BESIII Collaboration)



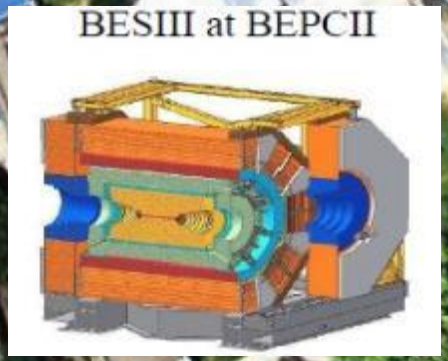
Institute of High Energy Physics

NSTAR2019, 10-15 June, Bonn, Germany

OUTLINE

- BEPCII/BESIII status
- Baryon decays
- Baryon spectroscopy
- Summary & Prospects

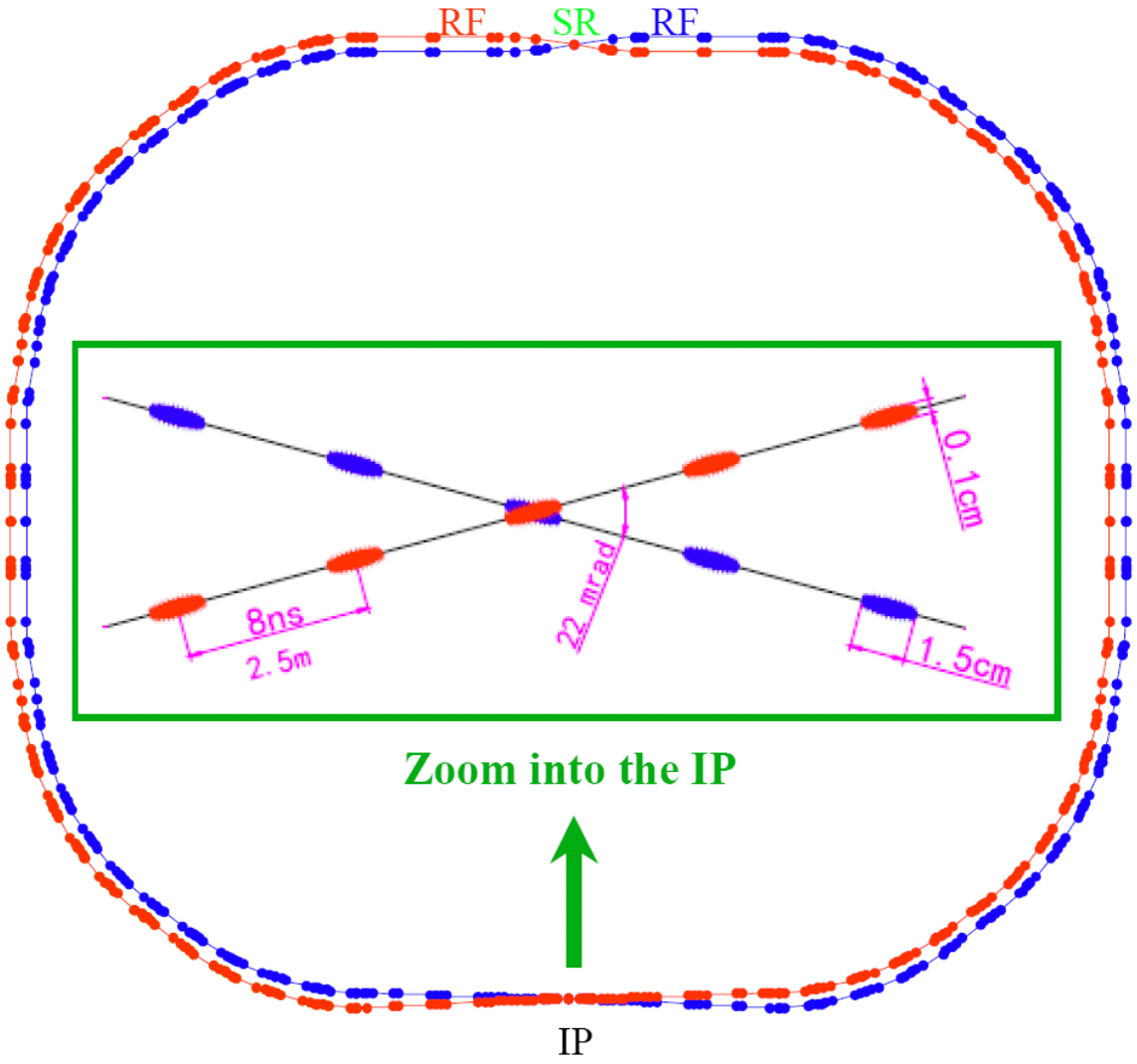
Bird view of BEPCII



BESIII physics

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

BEPCII storage rings



Beam energy:
1.0-2.3 GeV
Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
(achieved on 5th April,2016)
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

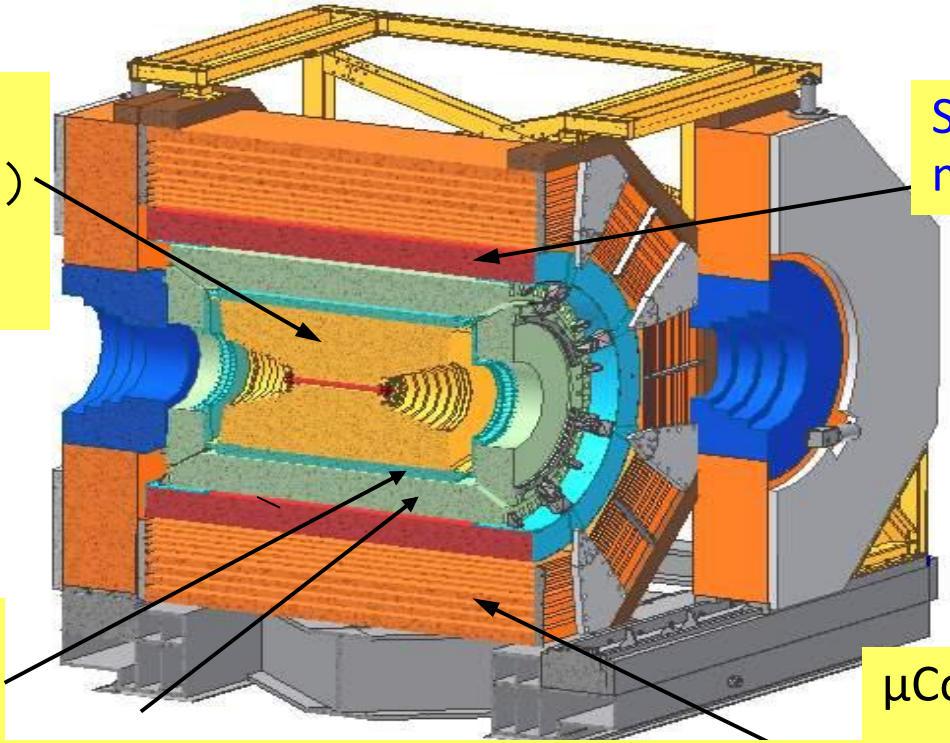
NIM A614, 345 (2010)

The BESIII Detector

Drift Chamber (MDC)

$\sigma P/P\ (^0/_0) = 0.5\%(1GeV)$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$



Super-conducting magnet (1.0 tesla)

Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ GeV)$

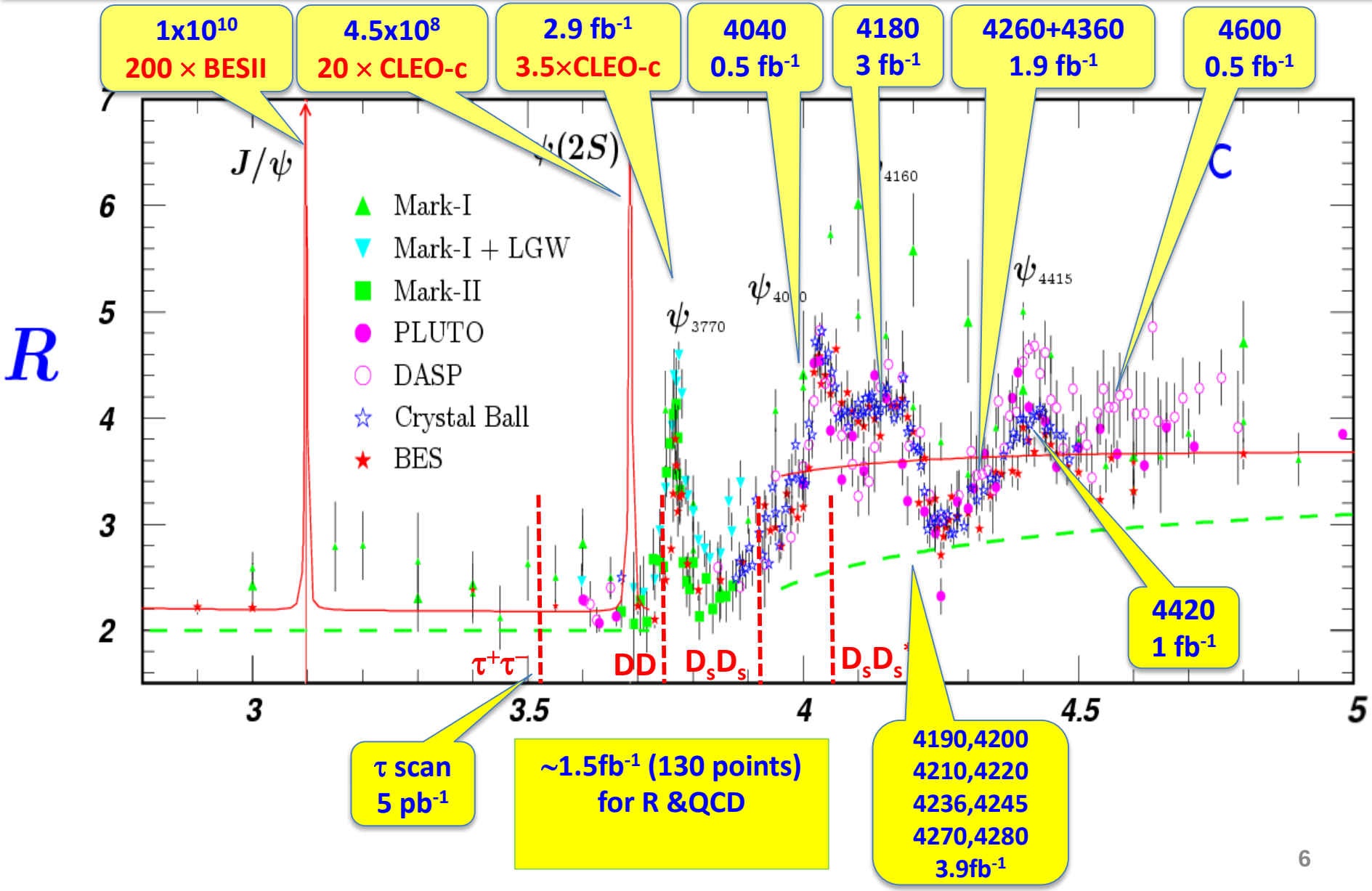
(CsI) $\sigma_{z,\phi}(cm) = 0.5 - 0.7\ cm/\sqrt{E}$

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

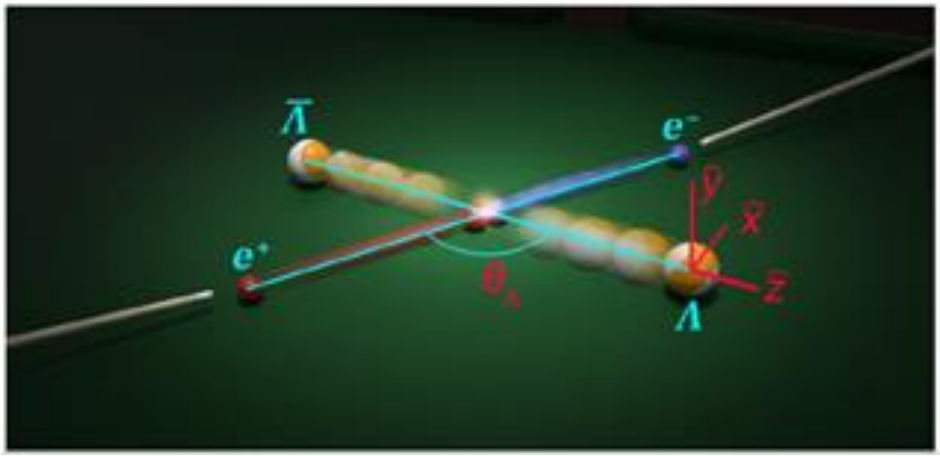
World largest data sample directly collected in the tau-charm region

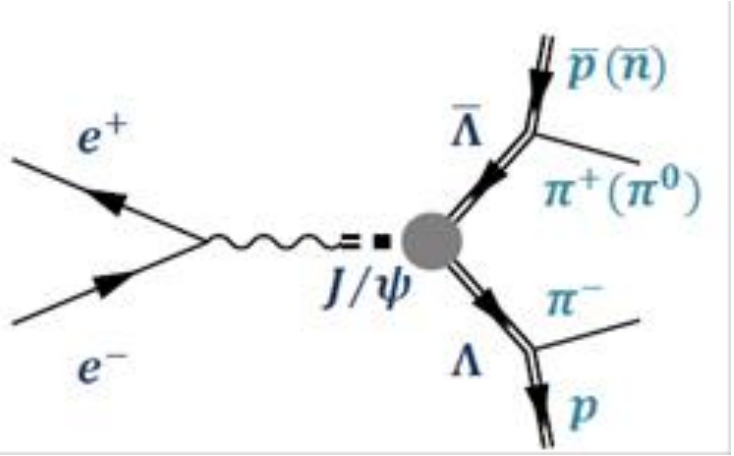


Baryon Decays

- Λ decay asymmetry parameters
- Λc decay asymmetry parameters
- Λc BFs at BESIII

Λ polarization in $J/\psi \rightarrow \Lambda\ \bar{\Lambda}$



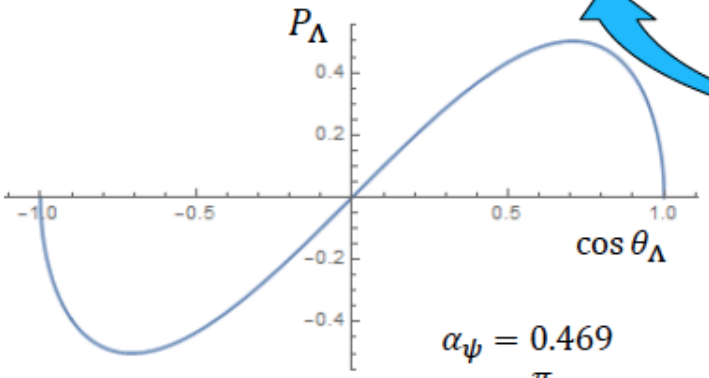


Transition between e+e- and $\Lambda\ \bar{\Lambda}$ including helicity conserving and -flip amplitudes

For unpolarized e+e- beams

$$\bar{P}_\Lambda(\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi}\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi \cos^2\theta_\Lambda} \sin(\Delta\Phi)\hat{y}$$

$\Delta\Phi \neq 0$



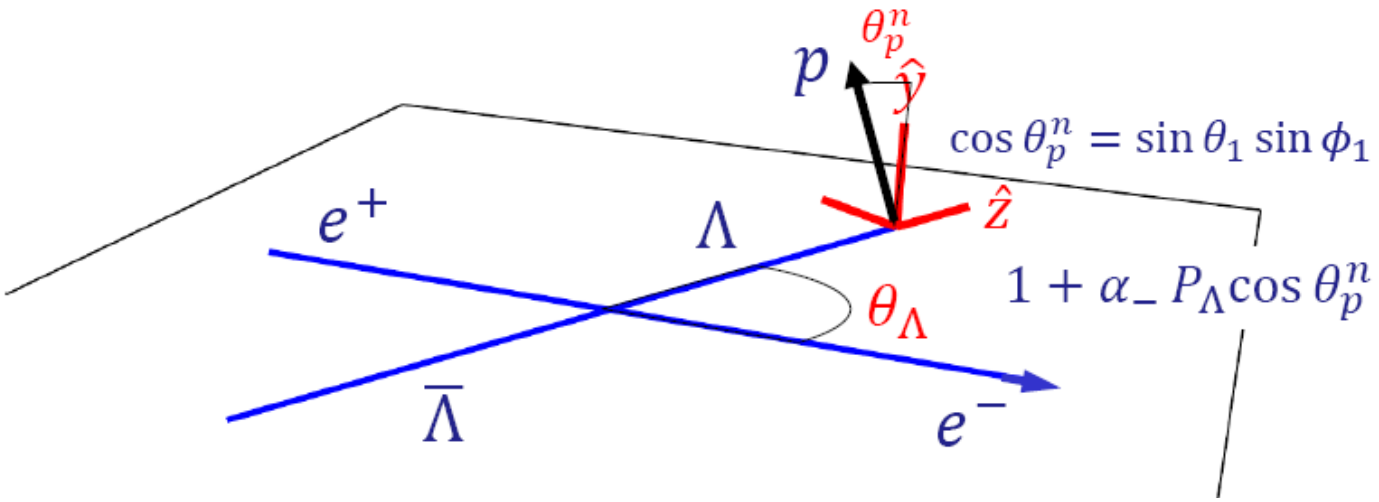
$\alpha_\psi = 0.469$

$\Delta\Phi = \frac{\pi}{2}$

G. Faldt EPJA51,74(2015), A52,141(2016)

8

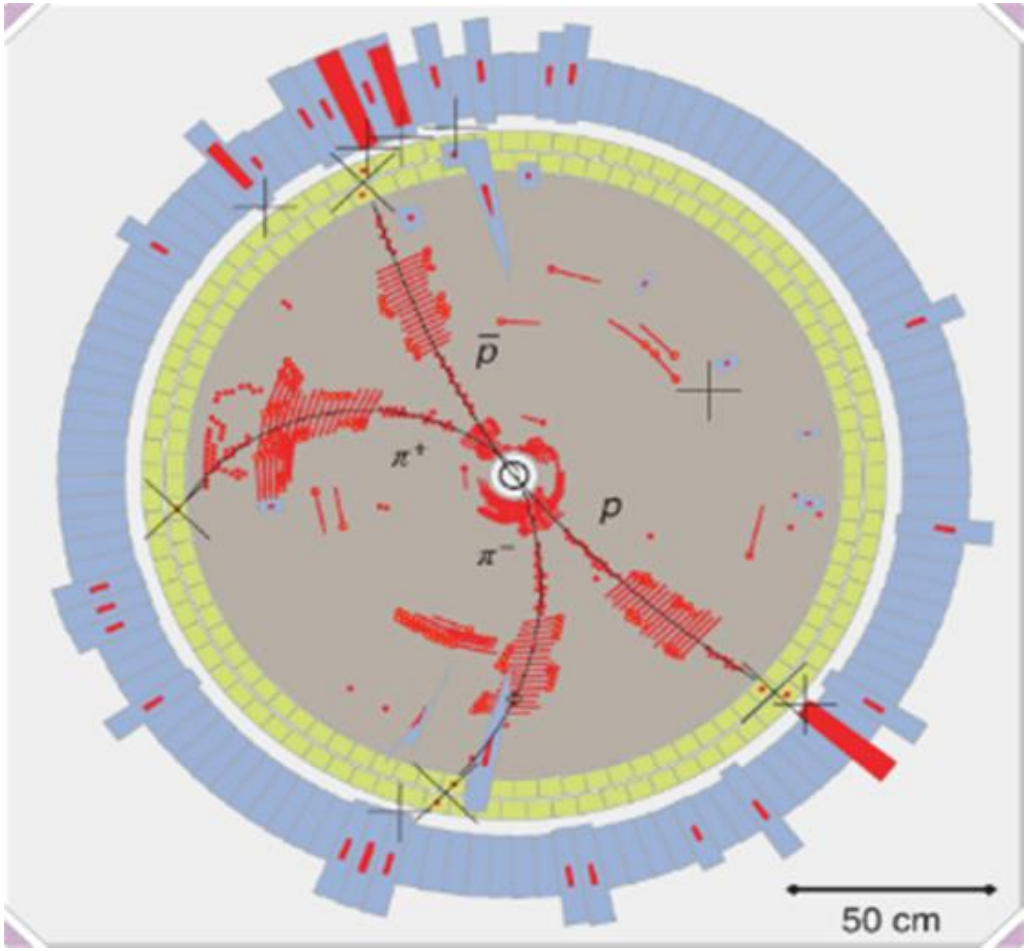
$e^+e^- \to (\Lambda \to p\pi^-)\,\bar{\Lambda}$



Hyperon polarization determined using angular distribution of the baryon from weak decay

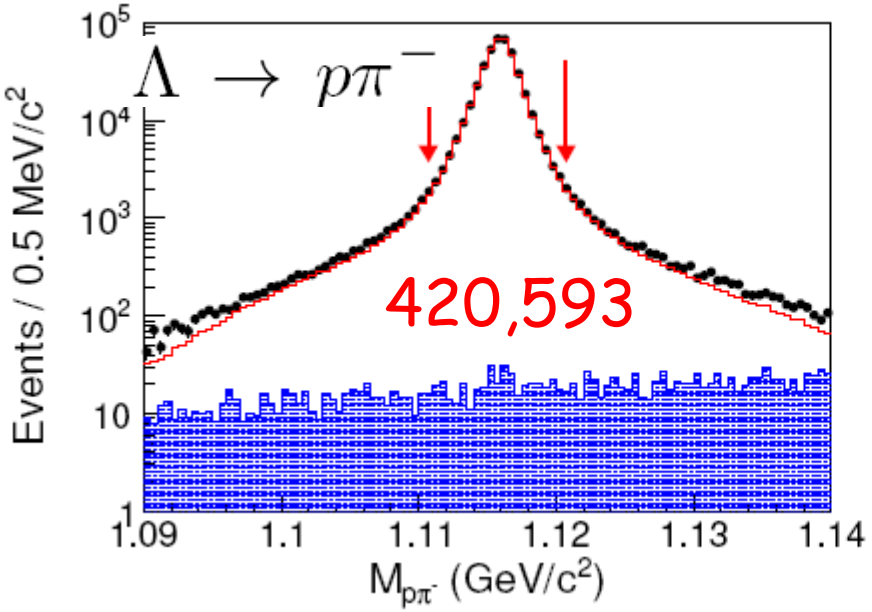
$$\begin{aligned}\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) =& 1+\alpha_\psi\cos^2\theta_\Lambda \\ &+ \alpha_-\alpha_+\left[\sin^2\theta_\Lambda\,(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y})+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right] \\ &+ \alpha_-\alpha_+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\,(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}) \\ &+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\,\sin\theta_\Lambda\cos\theta_\Lambda\,(\alpha_-n_{1,y}+\alpha_+n_{2,y})\,,\end{aligned}$$

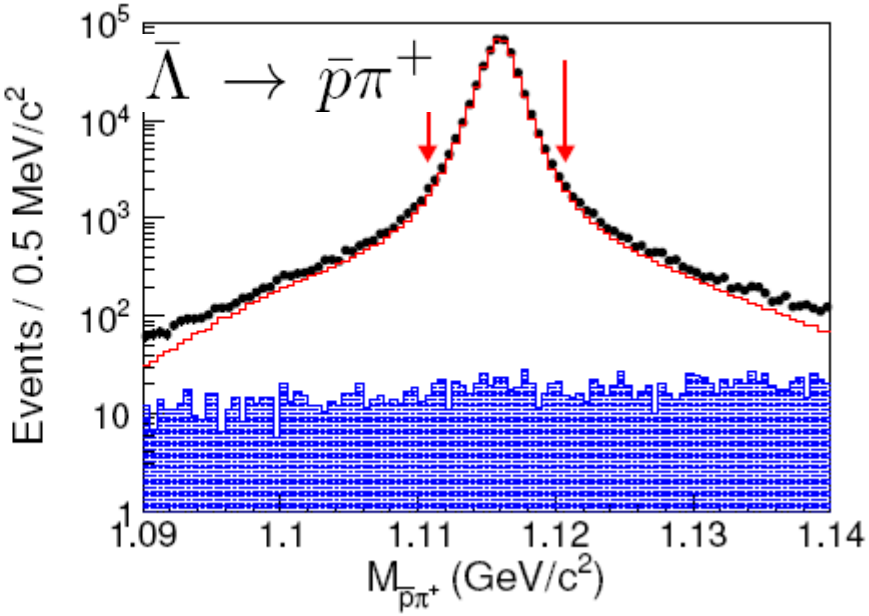
A typical $J/\psi \rightarrow \Lambda \bar{\Lambda}$ event

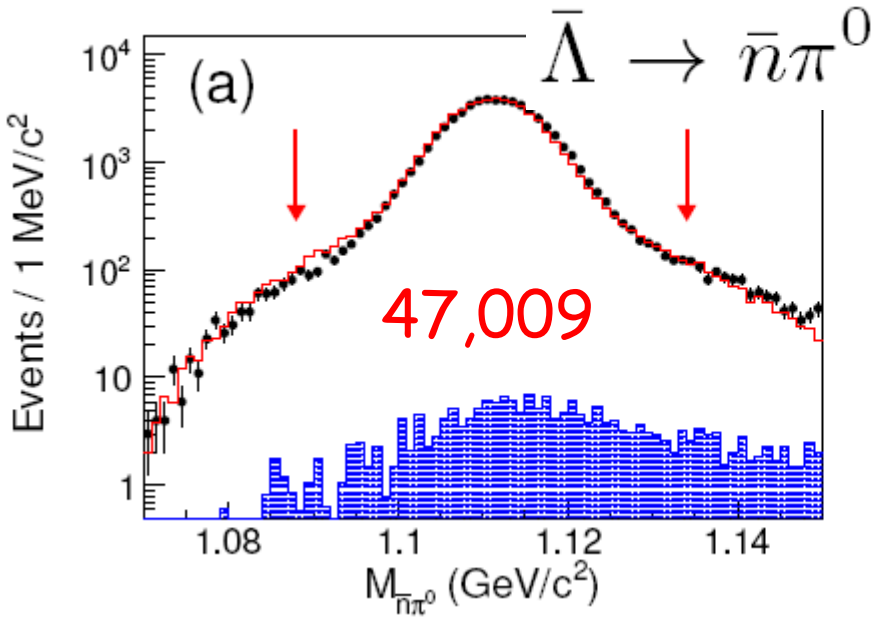


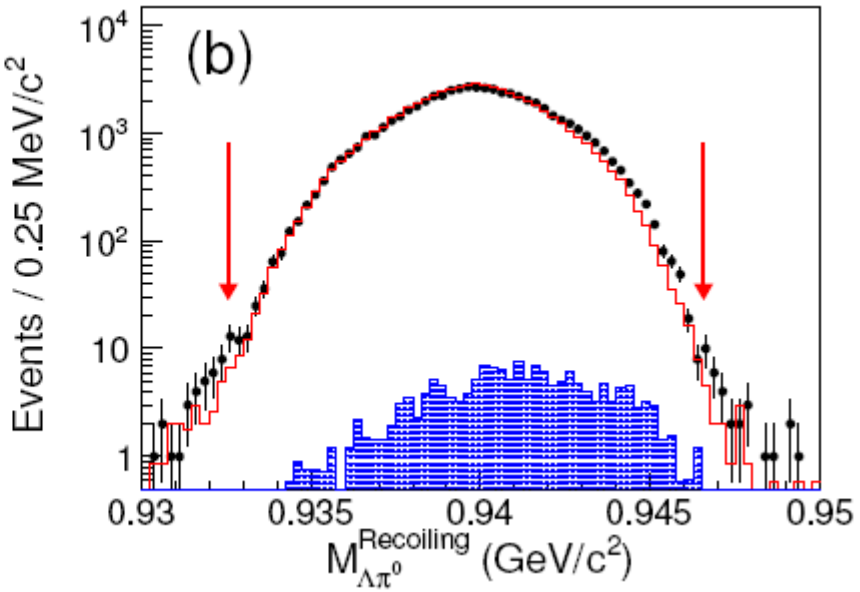
$J/\psi \to \Lambda\ \bar{\Lambda}$

1.3 B J/ψ events





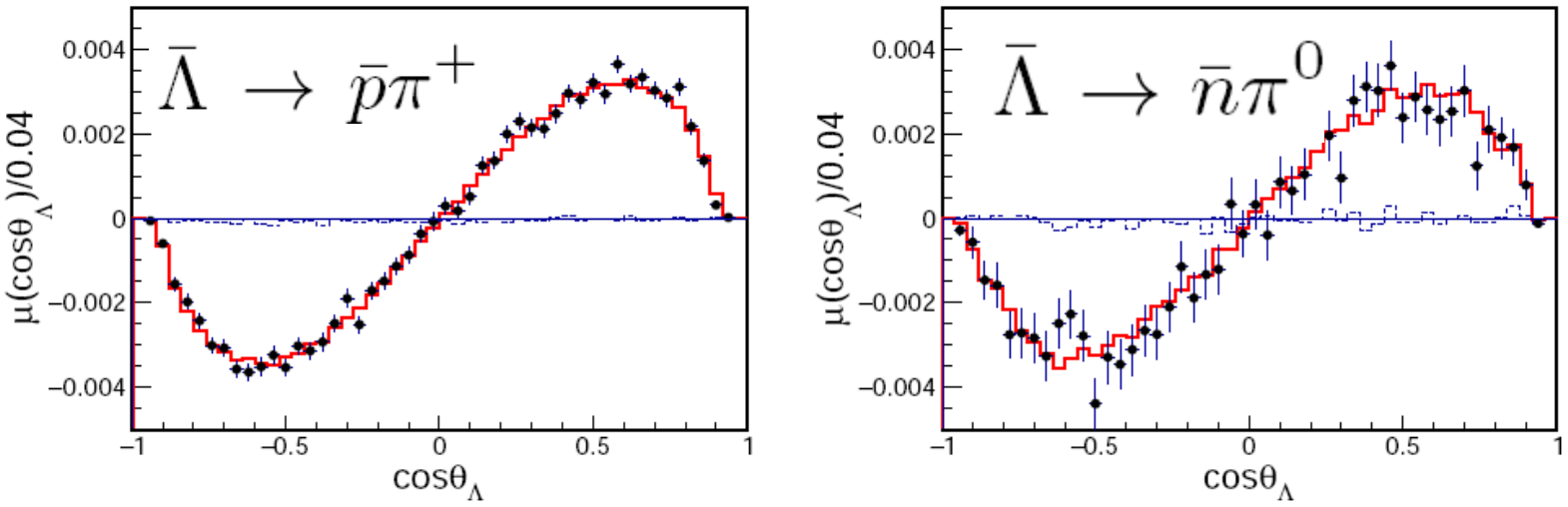




First observation Λ polarization in $J/\psi \to \Lambda\ \bar{\Lambda}$

Nature physics (2019) arXiv:1808.08917

$$\Delta\Phi = (42.4 \pm 0.6 \pm 0.5)^\circ$$



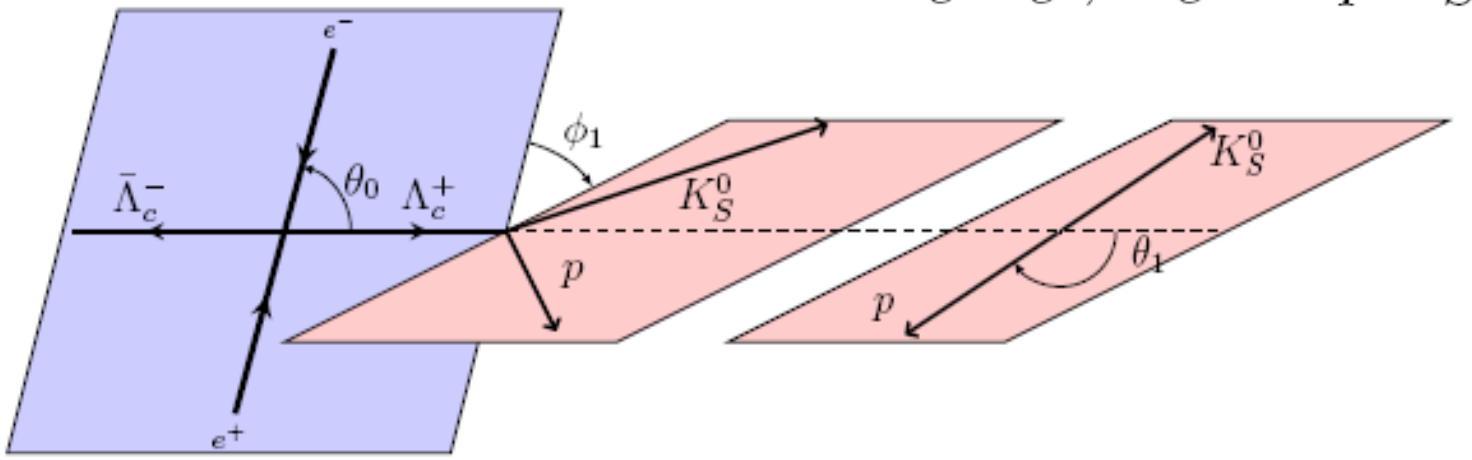
Decay asymmetry

$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$$

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [25]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [27]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [27]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [27]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Λ_c decay asymmetry parameters

$$e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-,\ \Lambda_c^+ \to pK_S^0$$



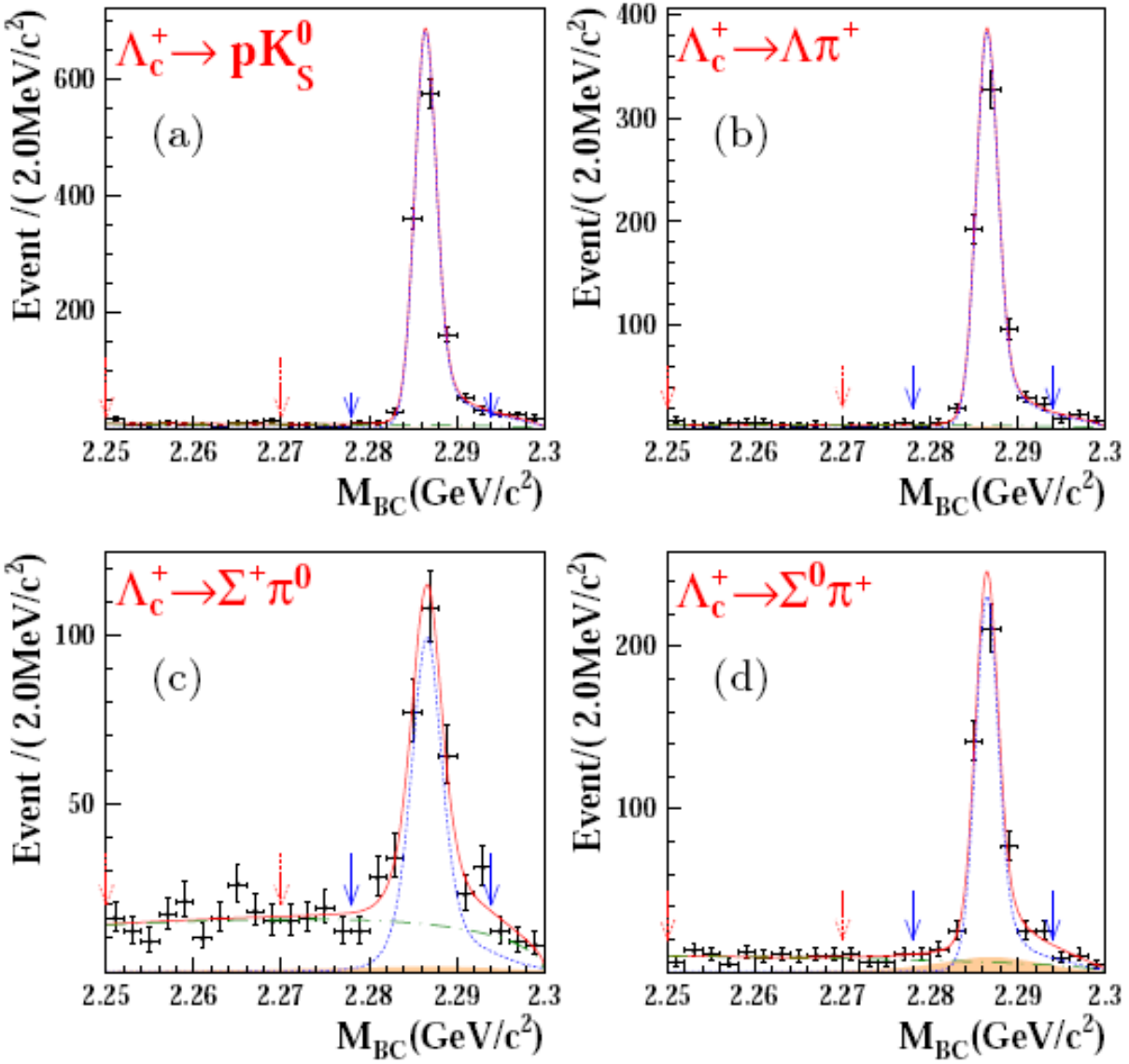
CM frame Λ_c^+ rest frame

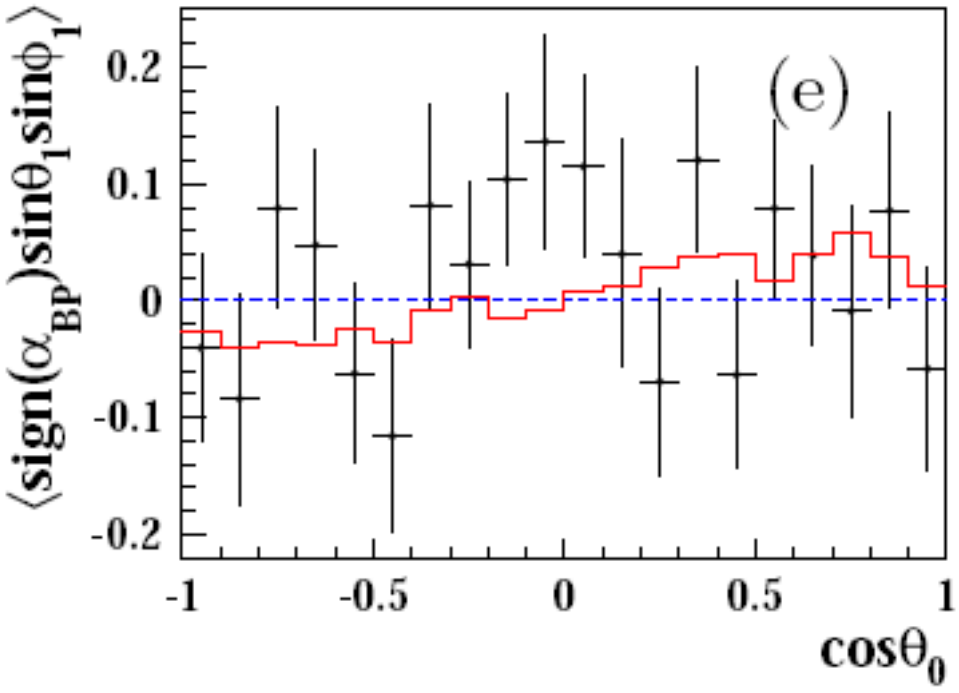
Goran Fald, arXiv:1709.0180

$$\frac{d\Gamma}{d\cos\theta_0 d\cos\theta_1 d\phi_1} \propto 1 + \alpha_0 \cos^2\theta_0 + \mathcal{P}_T \alpha^+_{pK^0_S} \sin\theta_1 \sin\phi_1,$$

$$\mathcal{P}_T = \sqrt{1-\alpha_0^2}\cos\theta_0 \sin\theta_0 \sin\Delta_0,$$

Λc signals 567fb-1 @4.6 GeV



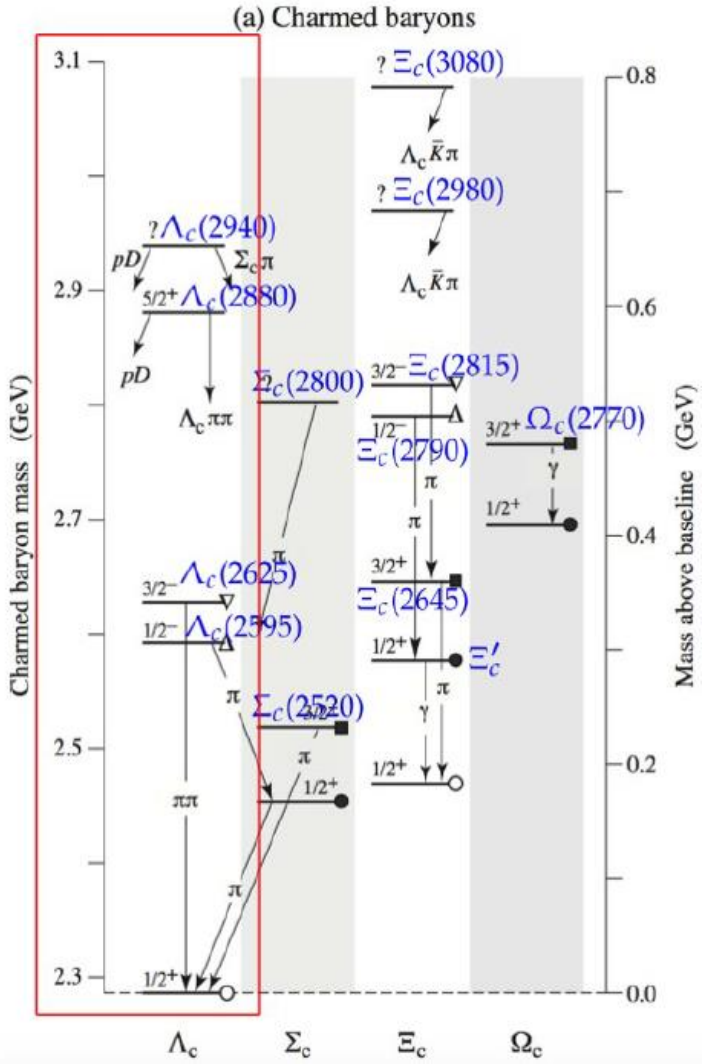


No evident Λ_c polarization

$$\Delta_0 = -0.28 \pm 0.13 \pm 0.03$$

$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	-1.0 [16], 0.51 [11] -0.49 [10], -0.90 [10] -0.49 [17], -0.97 [18] -0.66 [19], -0.90 [30] -0.99 [20], -0.91 [31]	-0.70 [16], -0.67 [11] -0.95 [10], -0.99 [10] -0.96 [17], -0.95 [18] -0.99 [19], -0.86 [30] -0.99 [20], -0.94 [31]	0.71 [16], 0.92 [11] 0.79 [10] -0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], -0.76 [30] -0.31 [20], -0.47 [31]	0.70 [16], 0.92 [11] 0.78 [10], -0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], -0.76 [30] -0.31 [20], -0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$
Δ_1^{BP}(rad)	This work		$3.0 \pm 2.4 \pm 1.0$	$4.1 \pm 1.1 \pm 0.6$	$0.8 \pm 1.2 \pm 0.2$
β_{BP}	This work		$0.06^{+0.58+0.05}_{-0.47-0.06}$	$-0.66^{+0.46+0.22}_{-0.25-0.02}$	$0.48^{+0.35+0.07}_{-0.57-0.13}$
γ_{BP}	This work		$-0.60^{+0.96+0.17}_{-0.05-0.03}$	$-0.48^{+0.45+0.21}_{-0.42-0.04}$	$0.49^{+0.35+0.07}_{-0.56-0.12}$

Λ_c decay before 2014



- Λ_c^+ was observed in 1979
- All decays of Λ_c^+ were measured with high energy data and relative to $pK^-\pi^+$, which suffers an error of 25%. No absolute measurement using threshold Λ_c^+ data
- Only about 60% decays are known

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states				
$p\overline{K}^0$		(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a]	(5.0 ± 1.3) %		823
$p\overline{K}^*(892)^0$	[b]	(1.6 ± 0.5) %		685
$\Delta(1232)^{++}K^-$		(8.6 ± 3.0) × 10^{-3}		710
$\Lambda(1520)\pi^+$	[b]	(1.8 ± 0.6) %		627
$pK^-\pi^+$ nonresonant		(2.8 ± 0.8) %		823
$p\overline{K}^0\pi^0$		(3.3 ± 1.0) %		823
$p\overline{K}^0\eta$		(1.2 ± 0.4) %		568

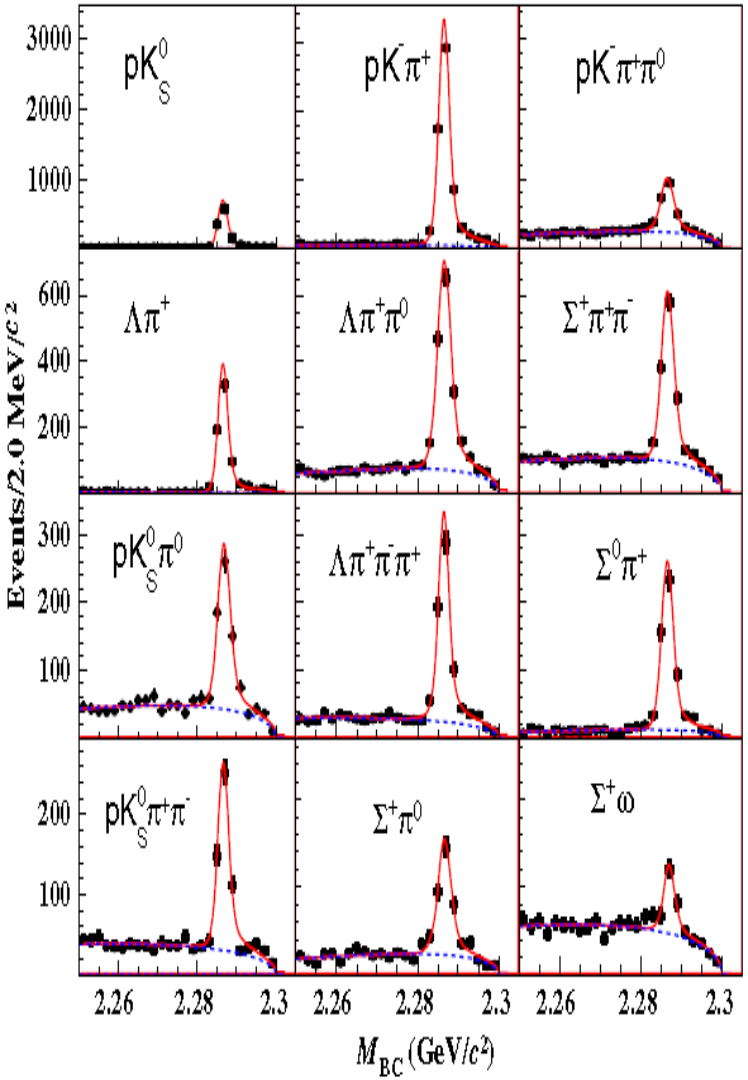
Systematic studies of Λ_c^+, search for new decays, absolute BF measurements are important to explore Λ_c^+ decay mechanisms

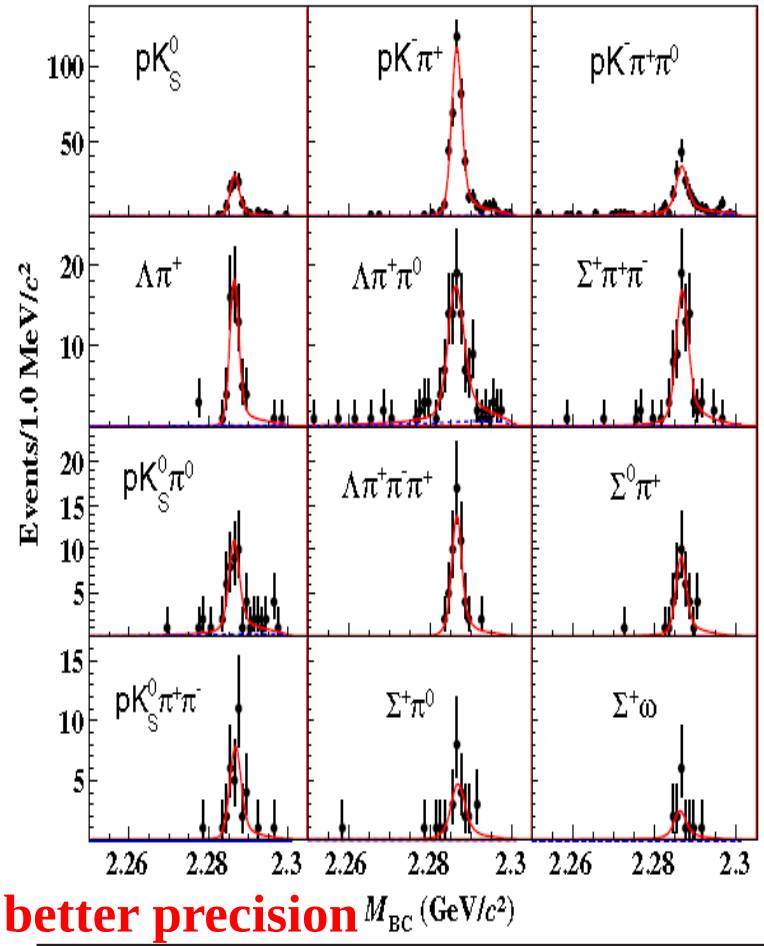
Λ_c^+ hadronic decays

BESIII, PRL116(2016)052001

ST: ~15000

DT: ~1000



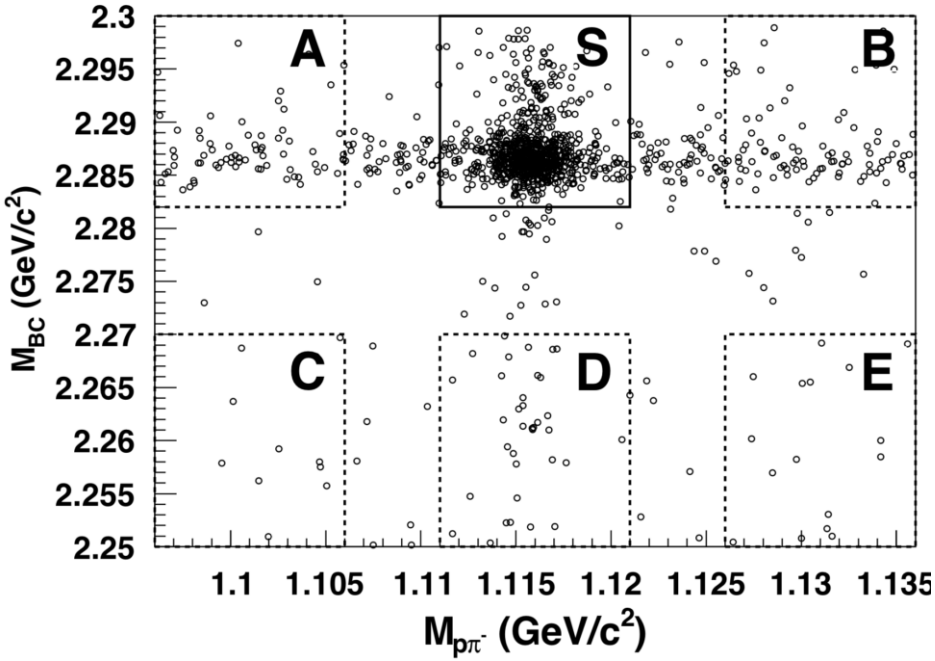


Much better precision

Mode	This work (%)	PDG (%)
pK^0_S	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK^0_S\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK^0_S\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0

Absolute measurement of $\Lambda c \rightarrow \Lambda + anything$

PRL 121, 062003 (2018)



PDG: (33±11)%

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) = (38.2^{+2.8}_{-2.2} \pm 0.8)\%.$$

Sum of excl. decays: ~25%, 13% of them still unknown

$$A_{CP} \equiv \frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}$$

$A_{cp} = (2.1^{+7.0}_{-6.6} \pm 1.4)\%$

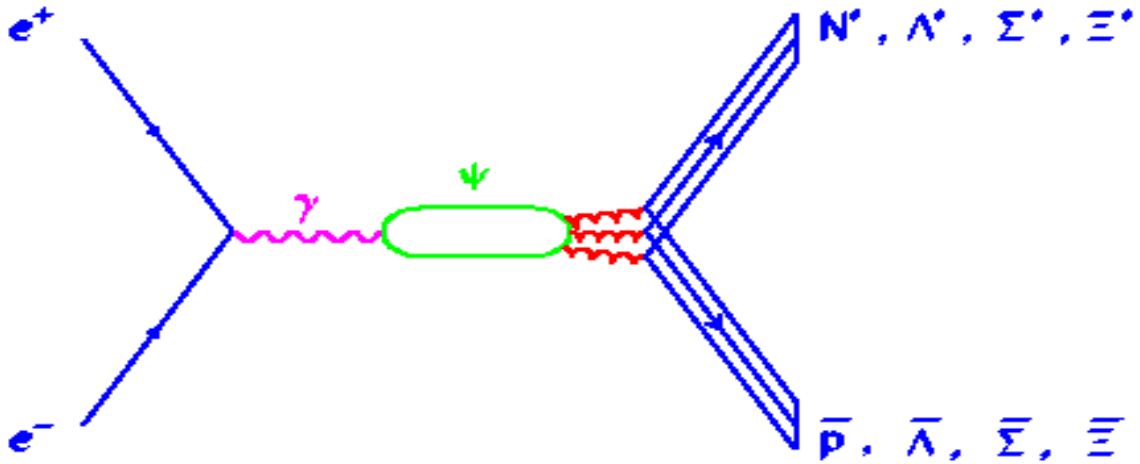
(No CPV is observed.)

Baryon spectroscopy

- Non-relativistic quark model is successful in interpreting of the excited baryons
- Predicted more excited stated ("missing resonance problem")
- J/ψ (ψ') decays offers an window to search for the missing resonance

Ideal isospin filter

$$J/\Psi \rightarrow \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$$

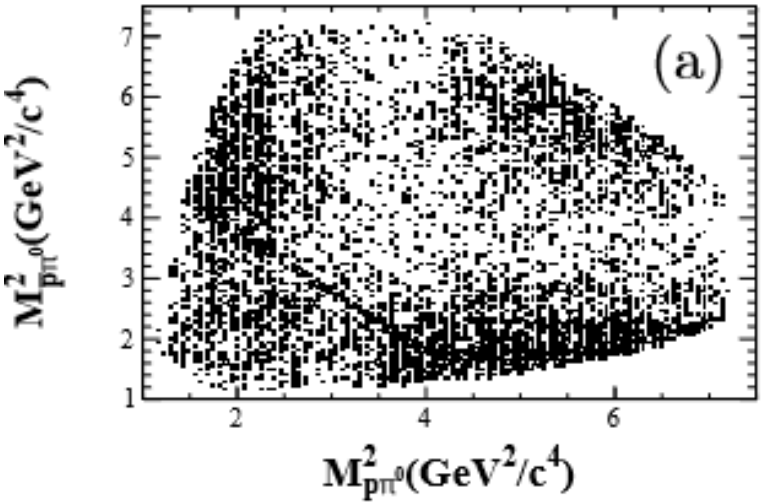


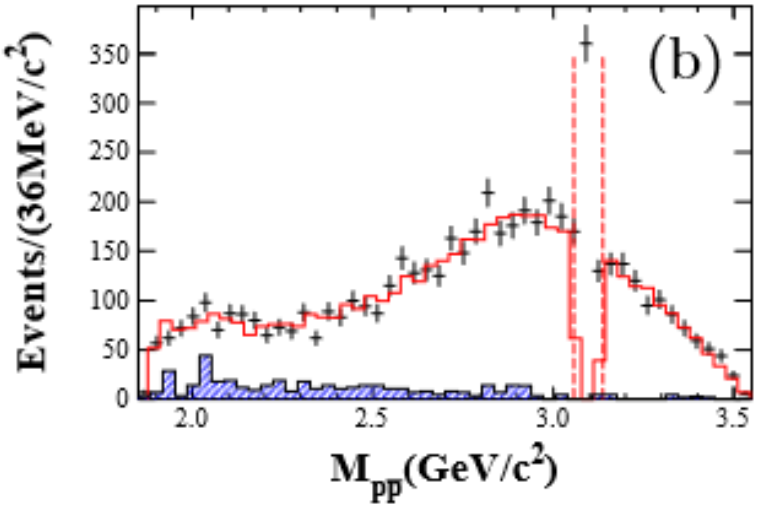
N* in $\psi' \to \pi^0 p \bar{p}$

PRL 110 (2013) 022001

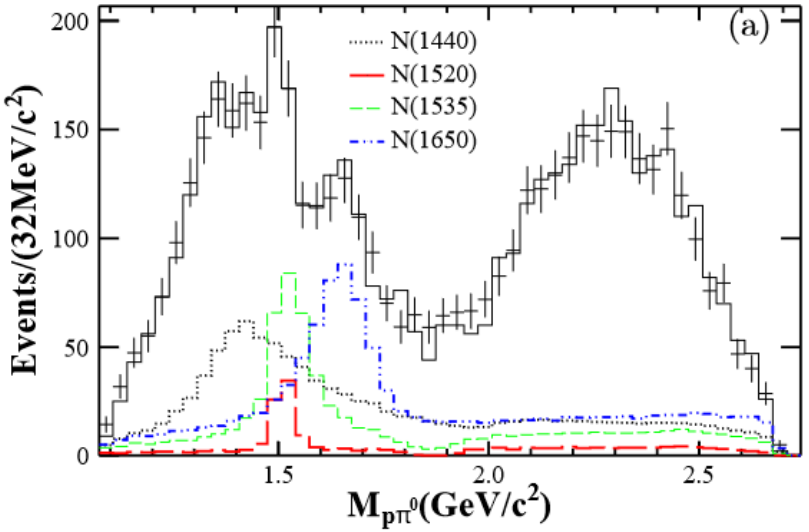
- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation:
  Δ suppressed

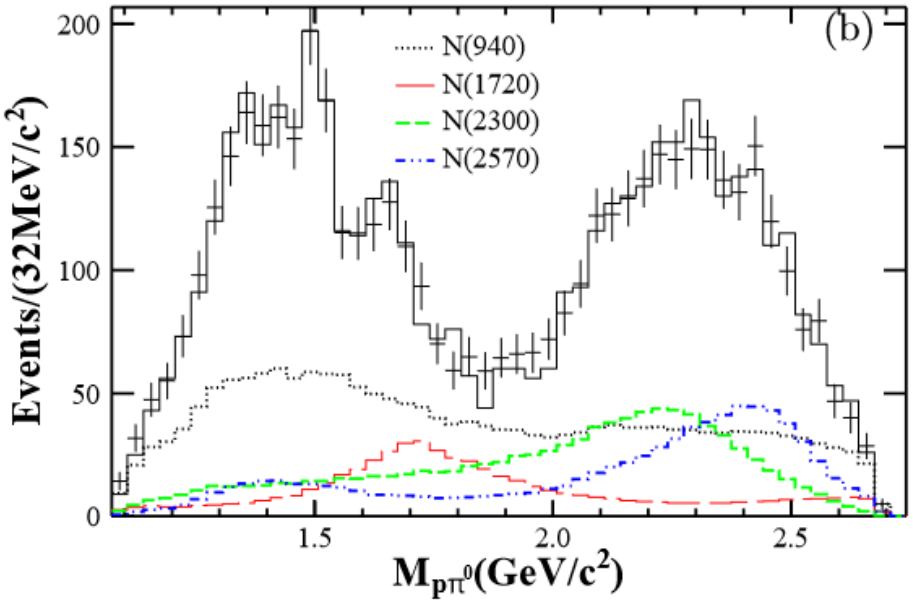
106 M ψ' events





N* in $\psi' \to \pi^0 p \bar{p}$ 106 M ψ' events





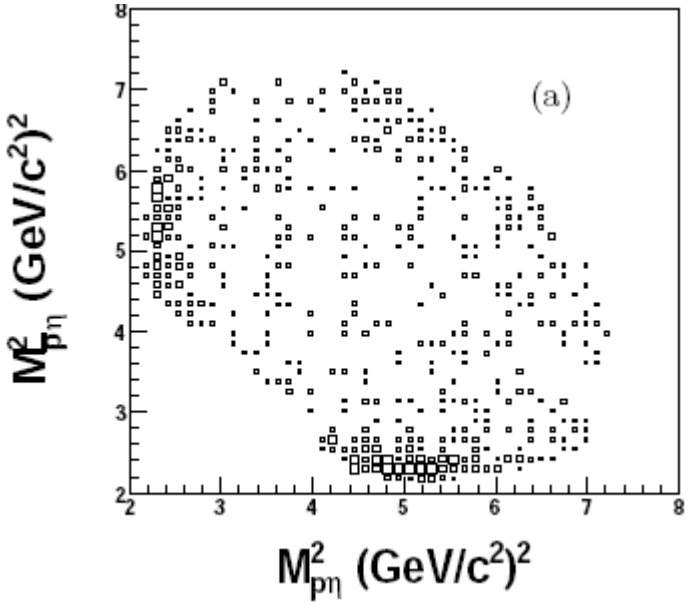
Two new baryonic excited states are observed !

Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	C.L.
$N(1440)$	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

N* in $\psi' \to \eta p \bar{p}$

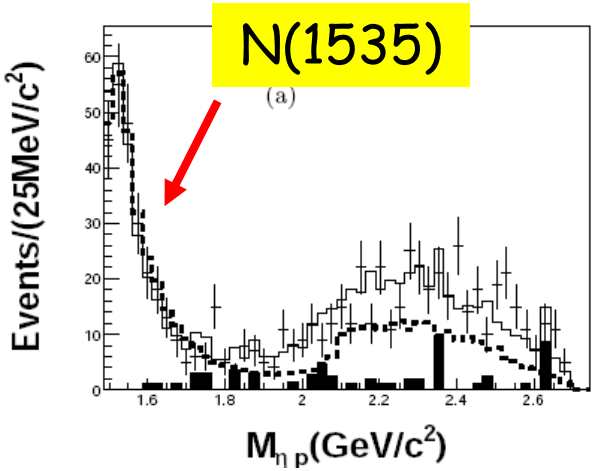
106 M ψ' events

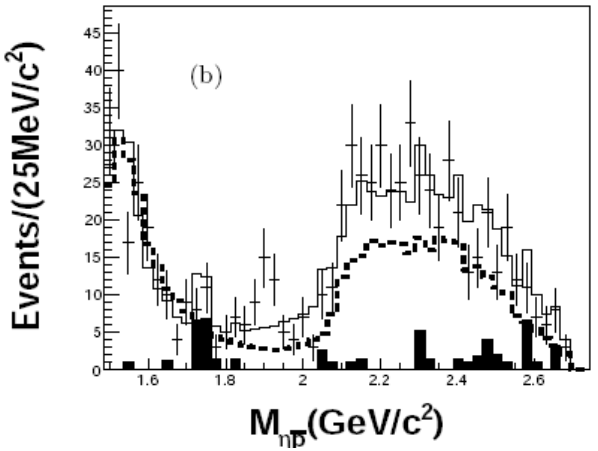
PRD 88, 032010(2013)

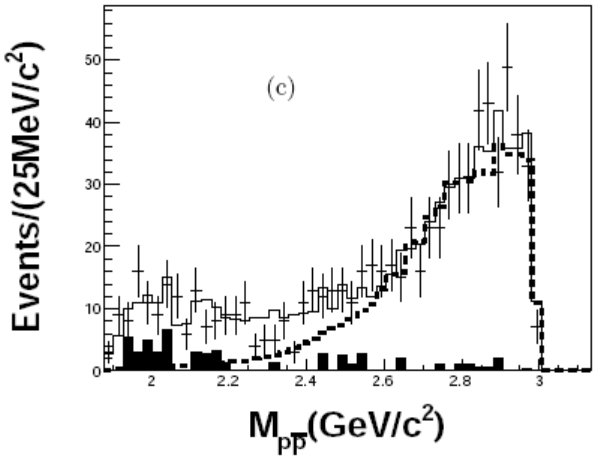


Mass: $1524 \pm 5^{+10}_{-4}$ MeV/c^2

Width: 130^{+27+57}_{-24-10} MeV/c^2

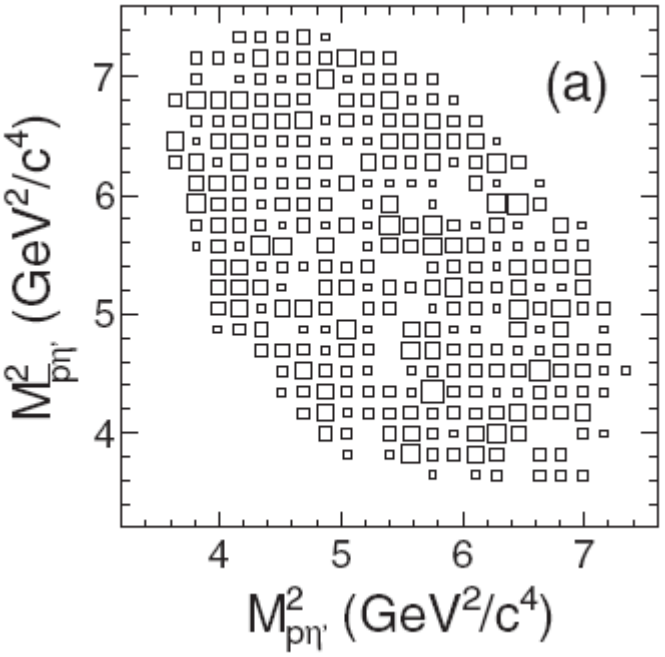




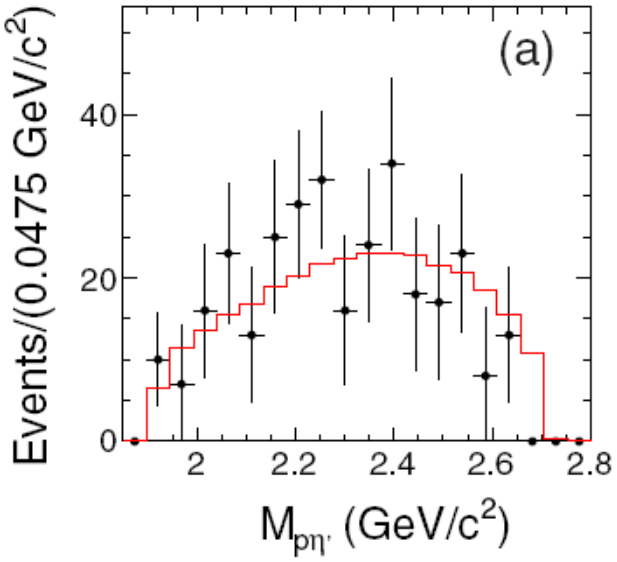


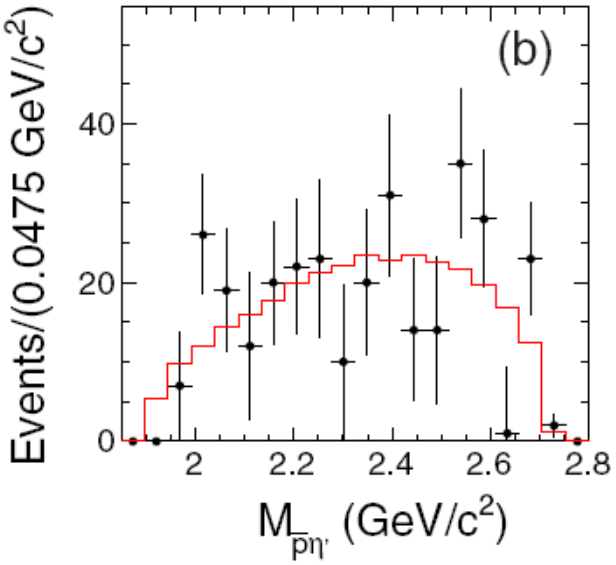
N* in $\psi' \to \eta' p \bar{p}$

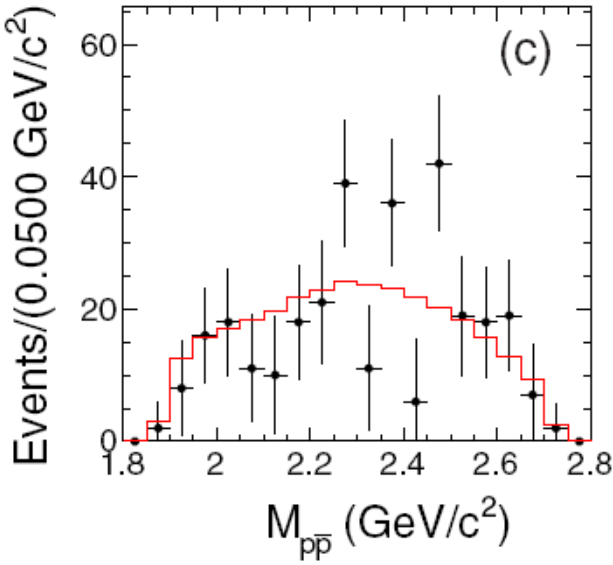
450 M ψ' events



Phys. Rev. D 99, 032006 (2019)

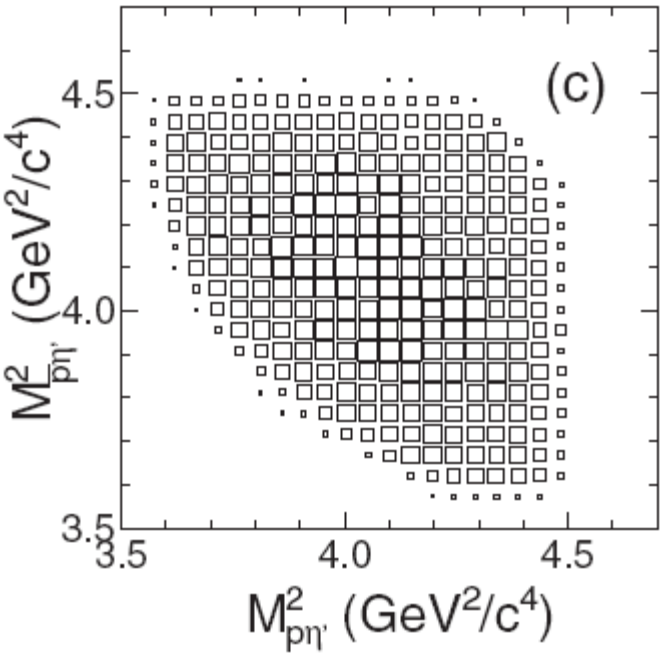






N* in $J/\psi \to \eta' p \bar{p}$

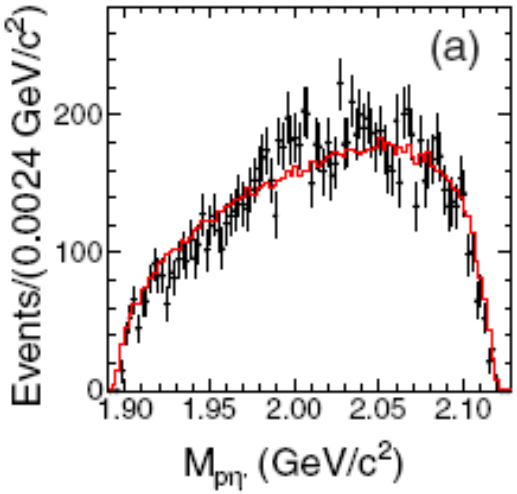
Phys. Rev. D 99, 032006 (2019)

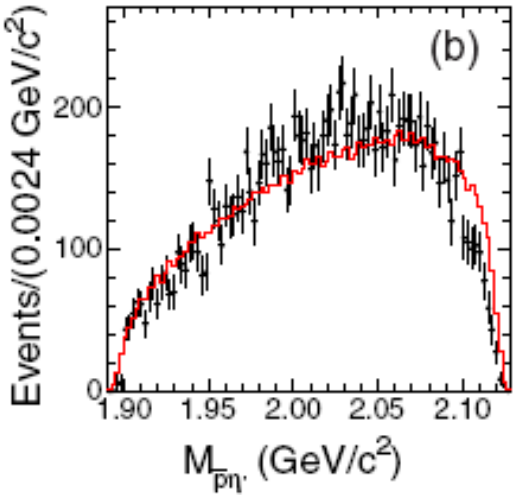


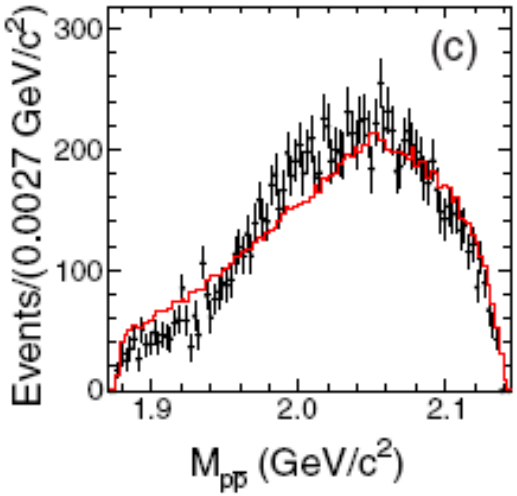
No evident structures were observed

1.3 B J/ψ events

$$\mathcal{B}(J/\psi \to p\bar{p}\eta') = (1.26 \pm 0.02 \pm 0.07) \times 10^{-4}$$



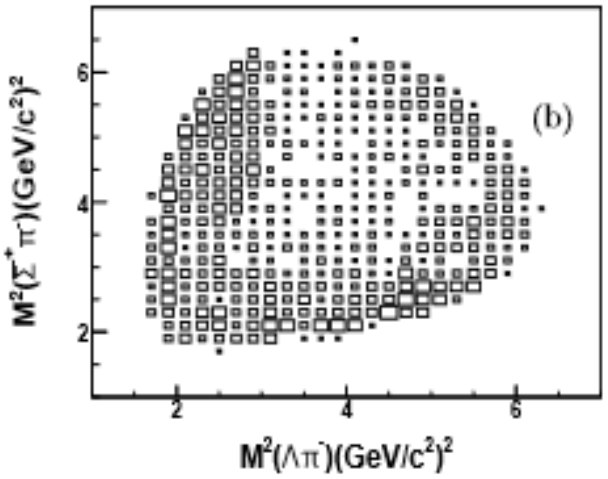


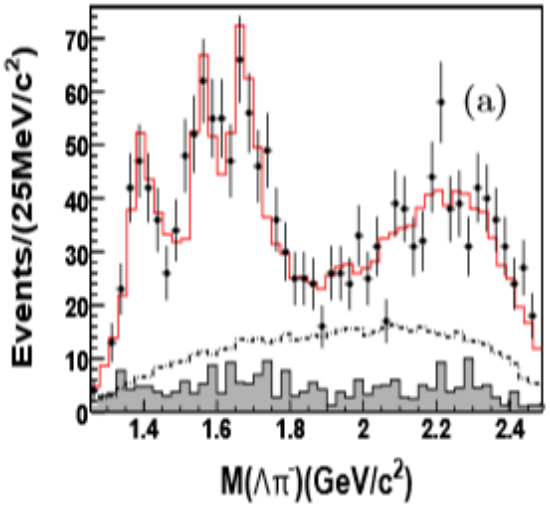


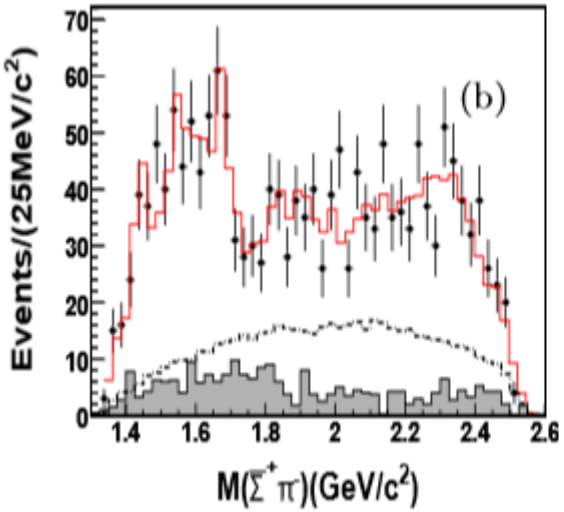
Σ^*s, Λ^*s in $\psi' \to \Lambda\, \bar{\Sigma}\pi$

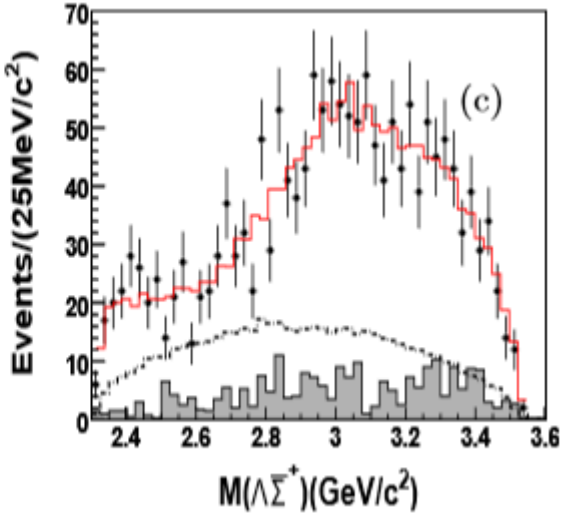
106 M ψ' events

PRD 88, 112007 (2013)







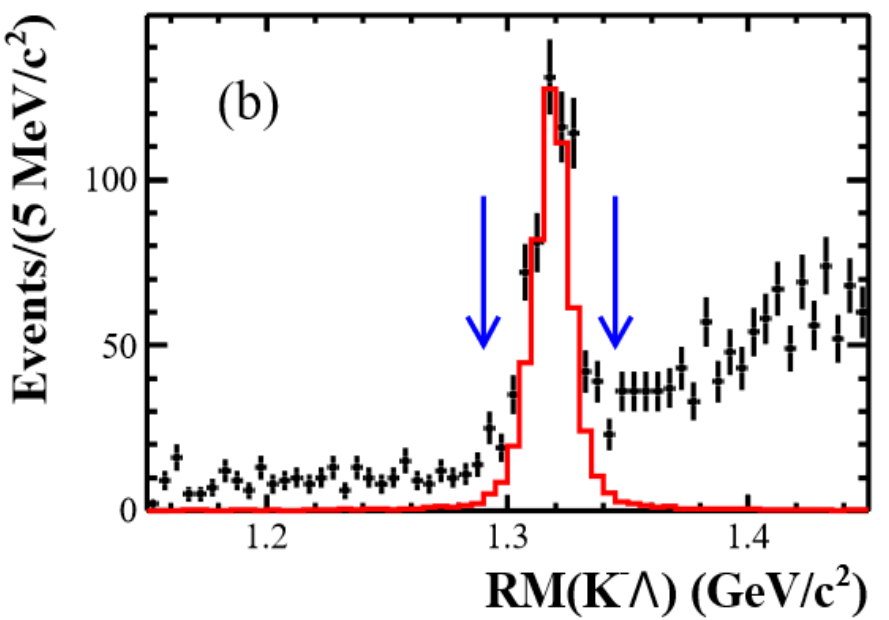


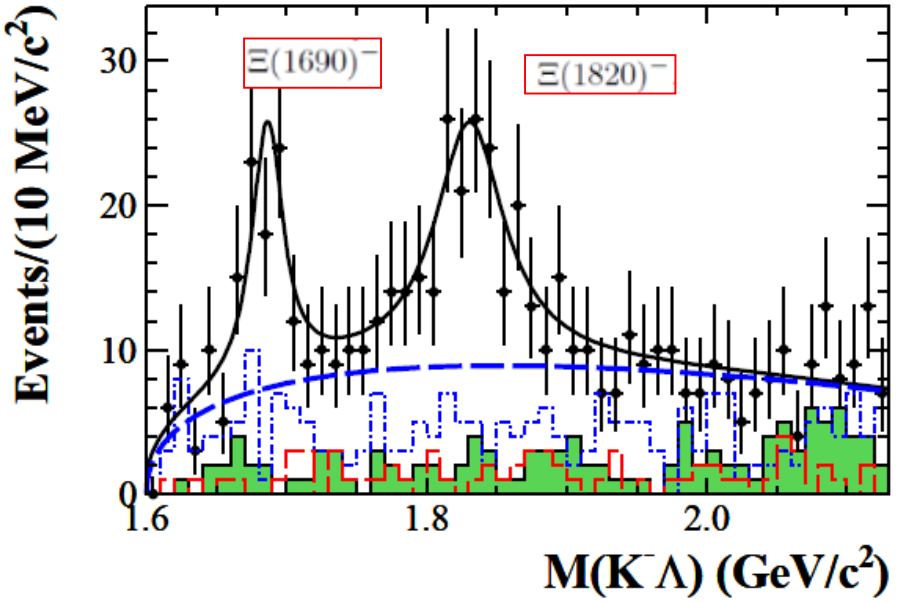
- **Clear structures were observed**

Ξ*s in ψ′→KΛΞ

450 M ψ′ events

PRD91 (2015) 092006





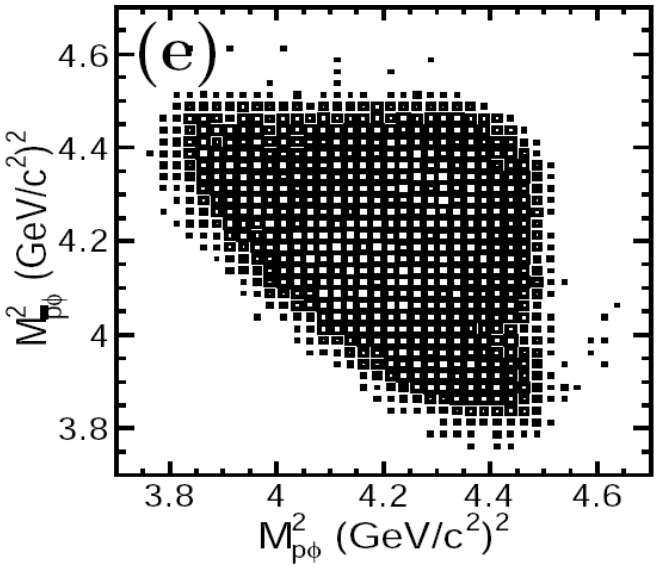
	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	1687.7±3.8±1.0	1826.7±5.5±1.6
$\Gamma(\mathrm{MeV})$	27.1±10.0±2.7	54.4±15.7±4.2
Event yields	74.4±21.2	136.2±33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}$ (10^{-6})	5.21±1.48±0.57	12.03±2.94±1.22
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$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

1.3 B J/ψ events

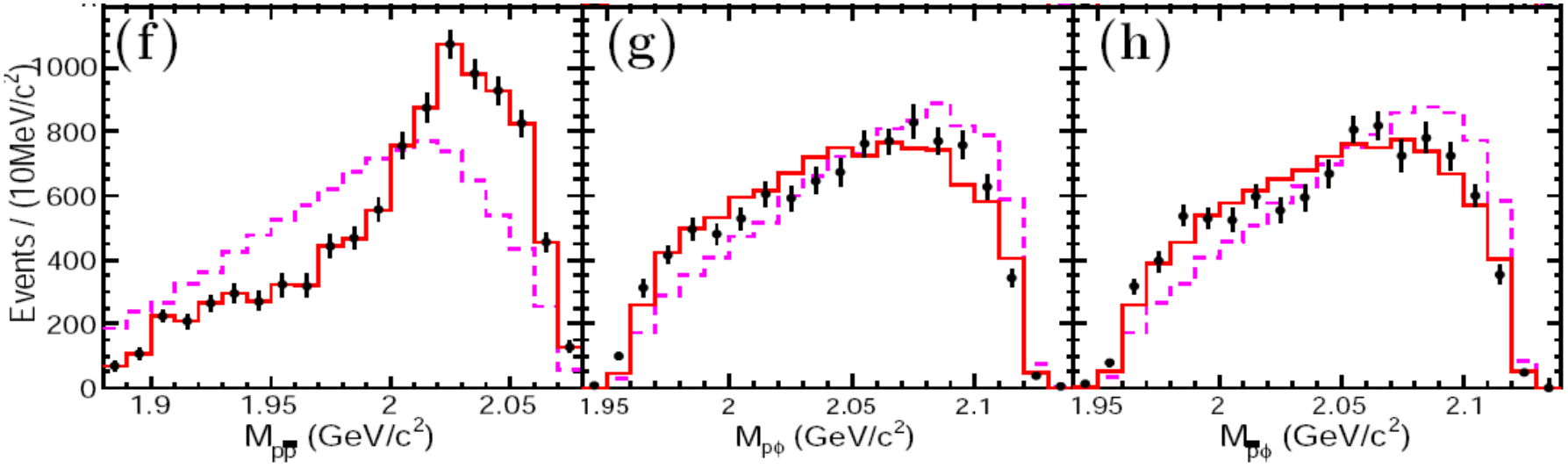
Search for exotics in $J/\psi \to \phi p \bar{p}$

Phys. Rev. D 93, 052010 (2016)

- BESII: $p\bar{p}$ mass threshold enhancement
- LHCb: Pc states



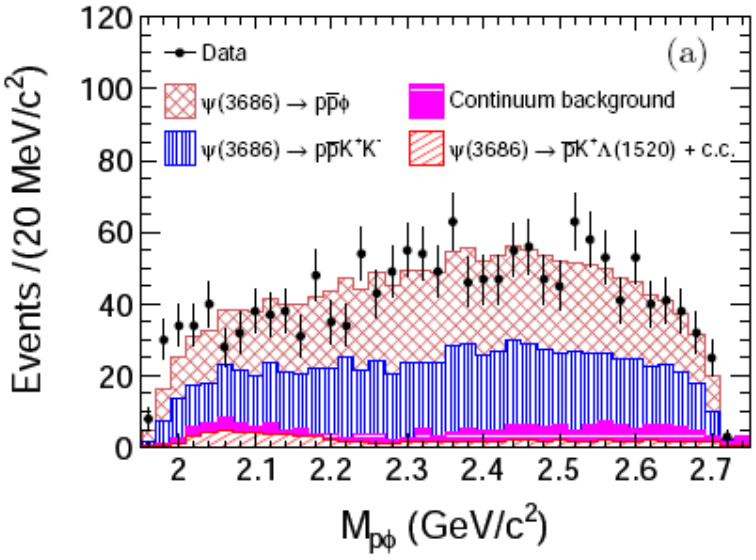
No evident enhancement observed

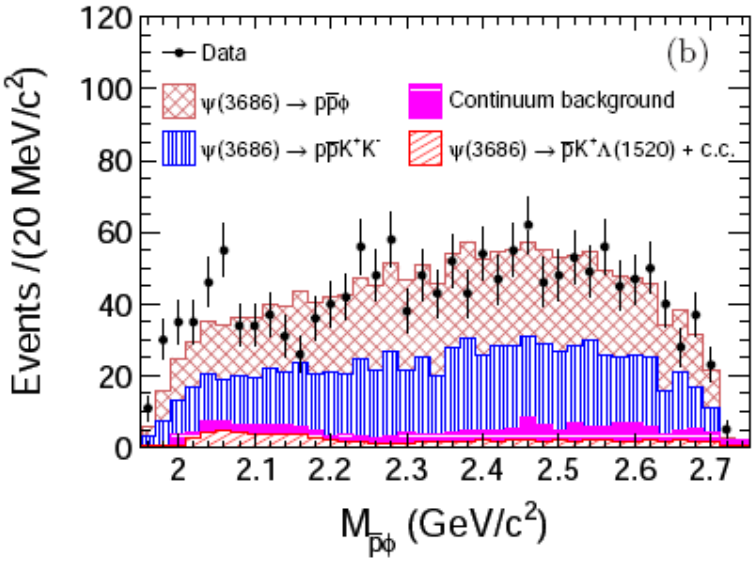


Search for exotics in $\psi' \to \phi p \bar{p}$

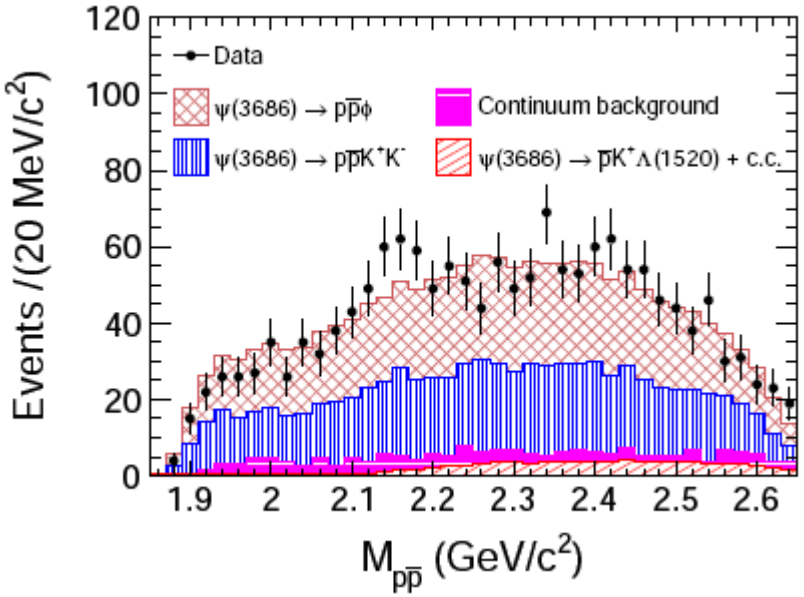
450 M ψ' events

arXiv:1902.09756





No evident enhancement observed

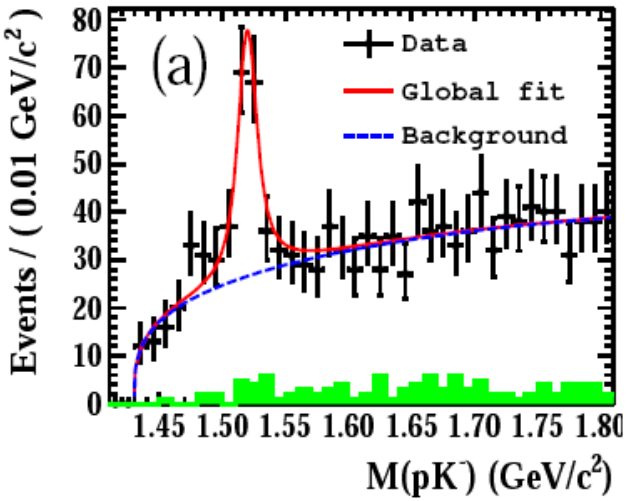


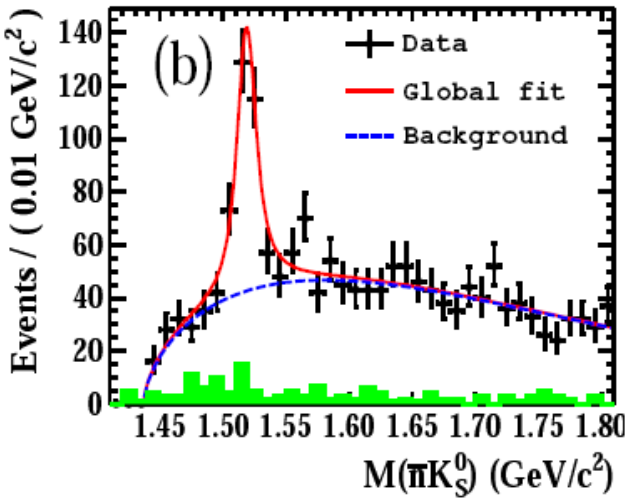
Hyperons in e+e-→pKs $\bar{n}K^-$ @3.773 GeV and >4 GeV

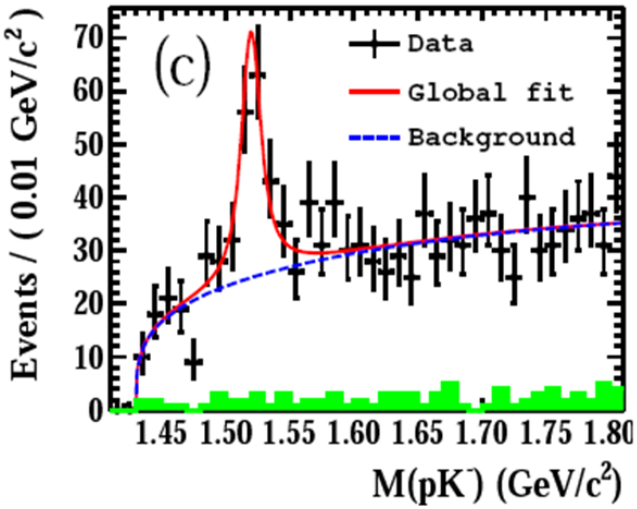
Phys. Rev. D 98, 032014 (2018)

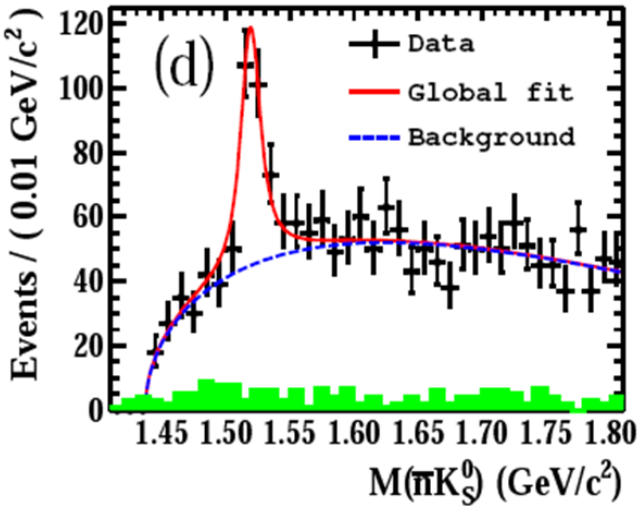
E=3.773 GeV

E >4 GeV

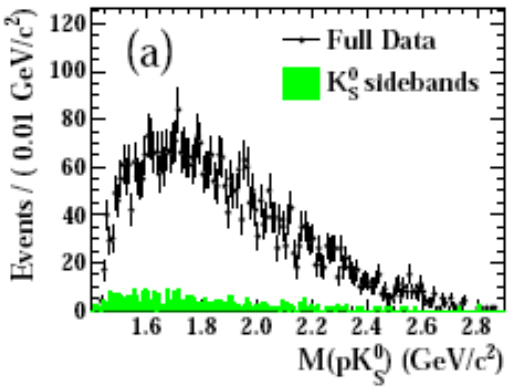


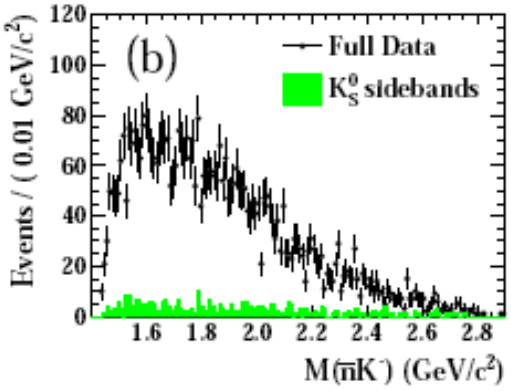


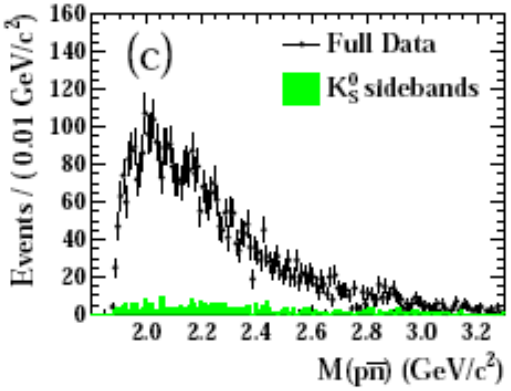


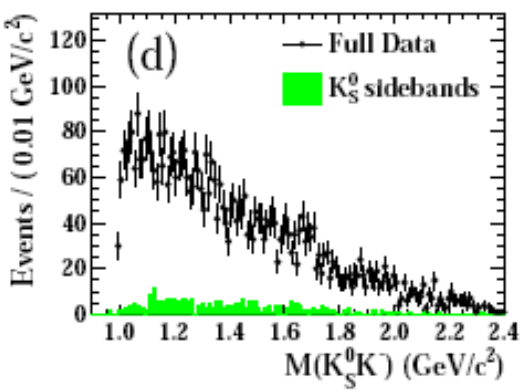


No evident peaks in mass spectra of pKs, $\bar{n}K^-$, $p\bar{n}$, KsK

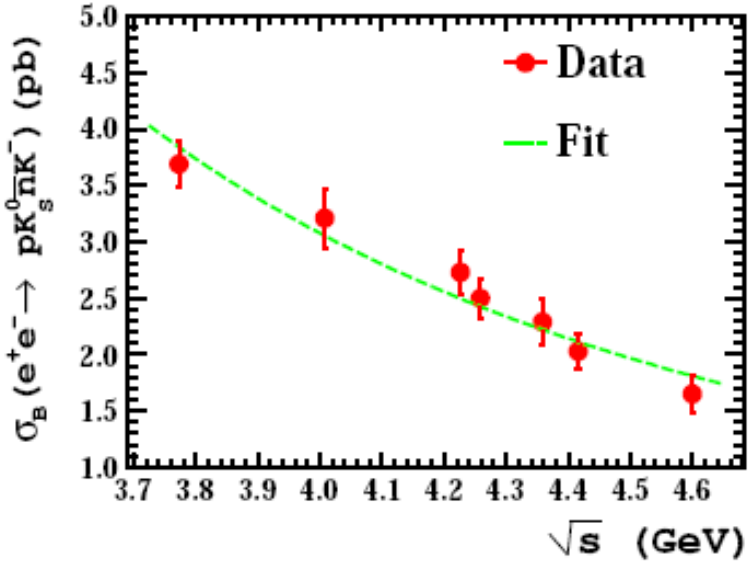








$$e^+e^- \to pK^0_S\bar{n}K^-$$



Summary& Prospects

- BESIII is successfully operating since 2008
  - World largest data samples at J/ψ, ψ',ψ(3770), ψ(4040), Y(4260) already collected
  - Provides novel insights into baryon decays/spectroscopy
  - Offers complementary information to the other experiments
- Recent results are presented
  - Decay asymmetry parameters of Lambda/Lambdac
  - test of the fundamental symmetries
  - N*, Λ*, Σ*, Ξ*
  - Search for the exotic baryons

Summary& Prospects

- Till 2019 June: 10 billion J/ψ events, 0.45 billion ψ′ events, >15fb^{-1} above charm threshold
- Upgrades: CGEM → inner MDC tracker,

  BEPCII: Luminosity? 4.6 →4.7 GeV ?
- BESIII: a unique place for baryon decays/spectroscopy
  - ✓ $J/\psi(\psi')\to\pi^0 p\bar{p}, p\bar{n}\pi$, $pK\Lambda$, $pK\Sigma$……
  - ✓ Ω^* using the data above charm threshold
  - ✓ Rare decays of baryons (Λ_c)
  - ✓ Σ, Ξ polarizations in e+e- annihilations
- **More results are expected to come soon !**

Many thanks for your attention !