Baryonic spectroscopy at BESIII

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The 10th International Workshop on the Physics of Excited Nucleons, Suita Campus, Osaka University, Osaka, Japan

May 25-28, 2015

OUTLINE

- Status of BEPCII/BESIII
- Baryonic spectroscopy
  - ✓ Two hyperons in $\psi(3686)\to K^-\Lambda\,\Xi^+$
  - ✓ Two new baryonic excited states in $\psi(3686)\to p\bar{p}\pi^0$
  - ✓ N(1535) in $\psi(3686)\to p\bar{p}\eta$
  - ✓ Excited strange baryons in $\psi(3686)\to\Lambda\bar{\Sigma}^+\pi^-$
- Summary and perspective

The BEPCII Collider

BEMS (beam energy measurement system):
based on Compton backscattering

Beam energy: 1.0 - 2.3 GeV

Peak Luminosity:

achieved: $0.85\times10^{33}cm^{-2}s^{-1}$@3770 MeV

Optimum energy: 1.89 GeV

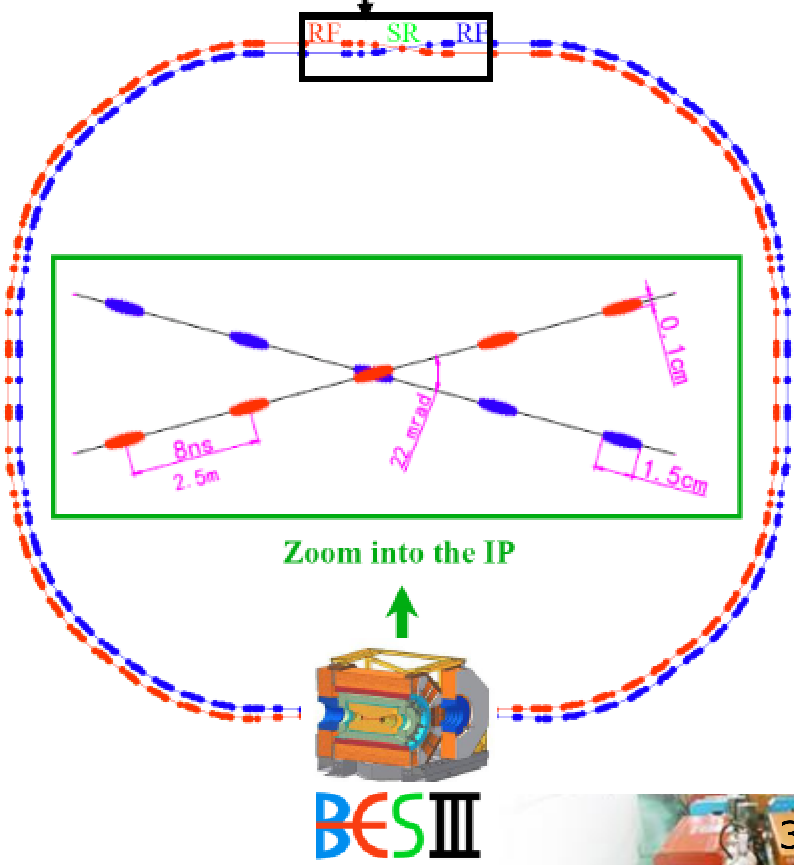
Energy spread: 5.16×10^{-4}

No. of bunches: 93

Bunch length: 1.5 cm

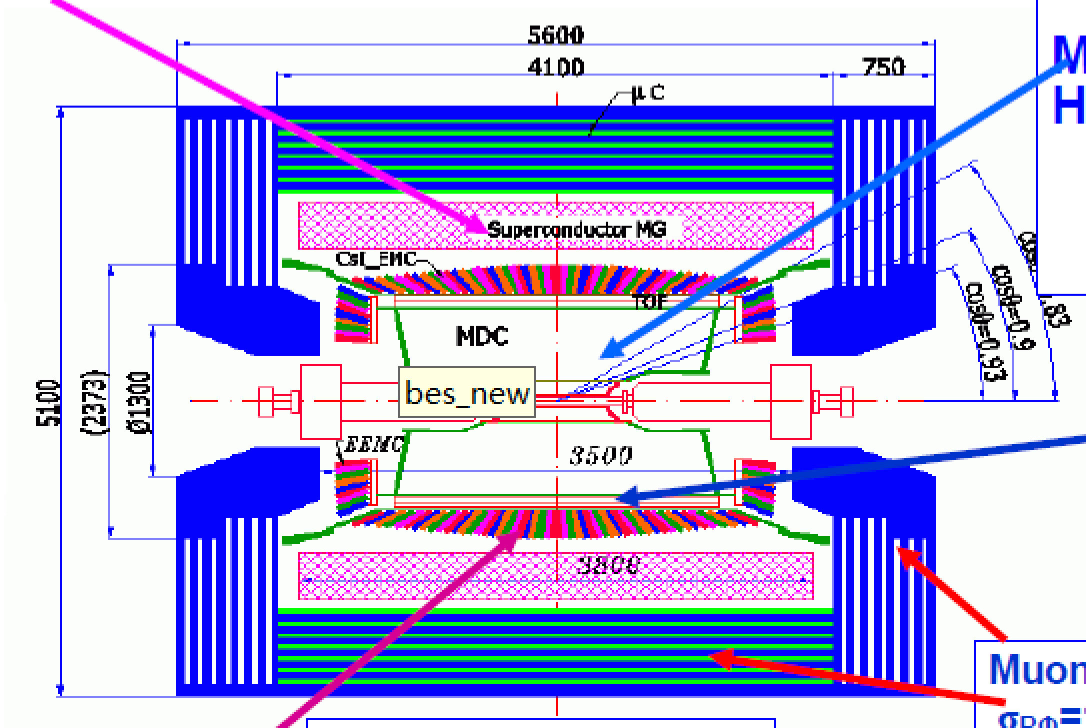
Total current: 0.91 A

Circumference: 237m



The BESIII detector

Solenoid Magnet: 1 T Super conducting



MDC: small cell & He gas

σ_{xy}=130 μm
$\delta p/p$ = 0.5% @1GeV
dE/dx=6%

TOF:

σ_T = 90 ps Barrel
110 ps Endcap

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

EMCAL: CsI crystal
$\Delta E/E$ = 2.5% @1 GeV
$\sigma_{\varphi,z}$ = 0.5~0.7 cm/$\sqrt{E}$

Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

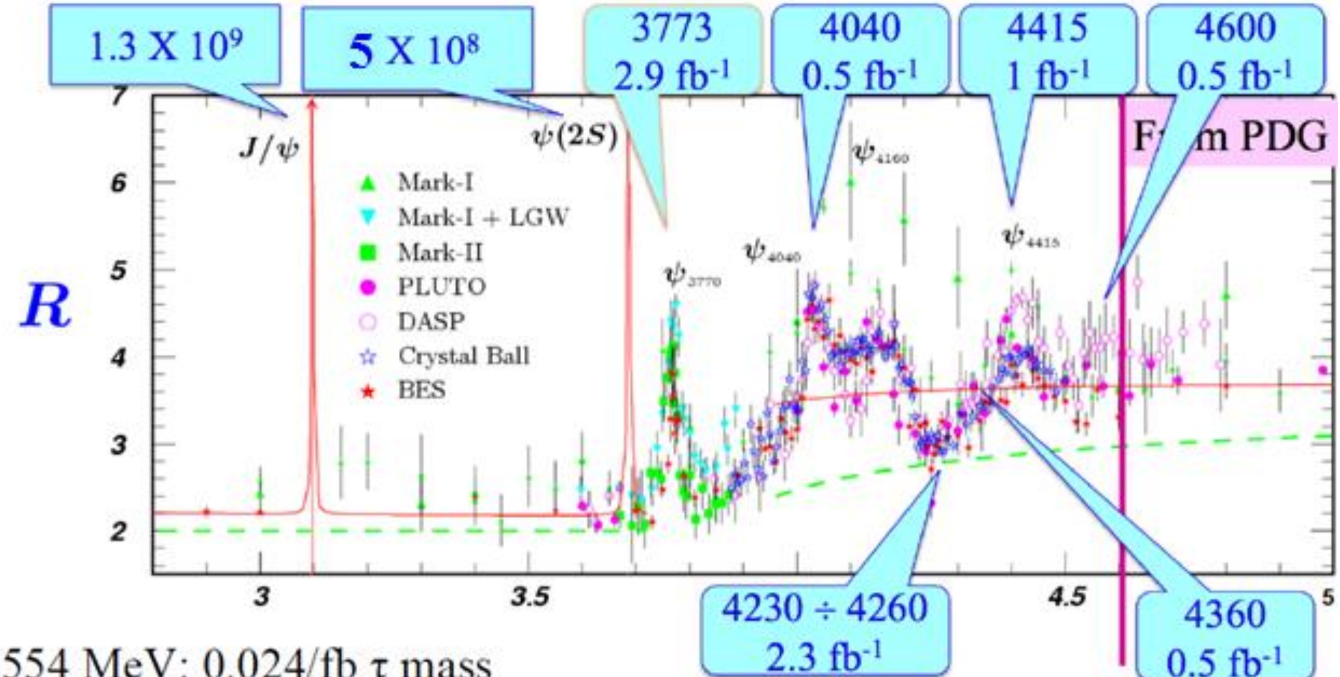
Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

Baryon spectroscopy

- The established baryons are described to 3-quark (qqq) configurations
- Non-relativistic quark model is successful in interpreting of the excited baryons
- Also provides an explicit classification for light baryons in terms of group symmetry
- Predicts more excited stated and the number of observed baryons is significantly small (“miss resonance problem”)
- Are the states missing because our models do not capture the correct degrees of freedom?
- Or have the resonances simply escaped detection?

Baryon spectroscopy



- 3554 MeV: 0.024/fb τ mass
- 4100~4400 MeV: 0.5/fb coarse scan
- 3850~4590 MeV: 0.5/fb fine scan
- In 2015, we are doing energy scan at 2000~3000 MeV

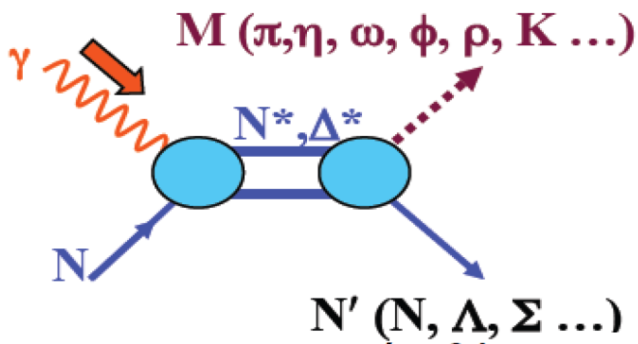
High statistics of charmonium @BESIII provide an opportunity to study the baryon

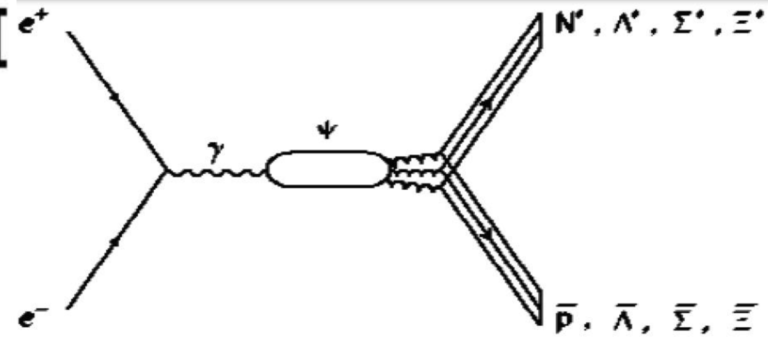
Baryon spectroscopy

JLab, ELSA, MAMI, ESRF, Spring-8, ….

$J/\psi(\psi') \to \bar{B}BM \;\Rightarrow\; N^*, \Lambda^*, \Sigma^*, \Xi^*$

BESIII





- ✓ Pure isospin 1/2 filter ⇒easier analysis
- ✓ Missing N* with small couplings to πN & γN , but large coupling to gggN : $\psi \to N\bar{N}\pi/\eta/\eta'/\omega/\phi, \bar{p}\Sigma\pi, \bar{p}\Lambda K$ …
- ✓ Interference between N* and N*bar bands in $\psi \to N\bar{N}\pi$ Dalitz plots may help to distinguish some ambiguities in PWA of πN

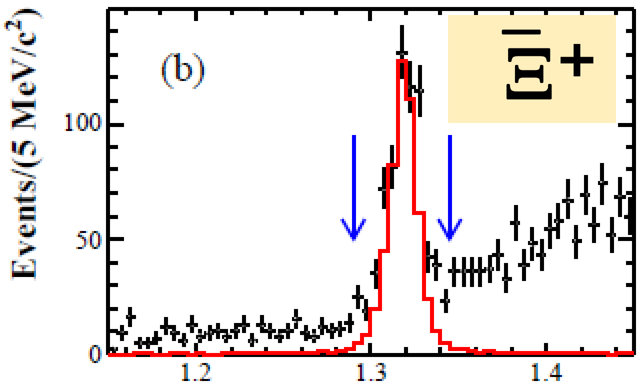
Not only N*, but also Λ*, ∑*, Ξ* @BESIII

Charmonium decays can give novel insights into baryons and give complementary information to other experiments

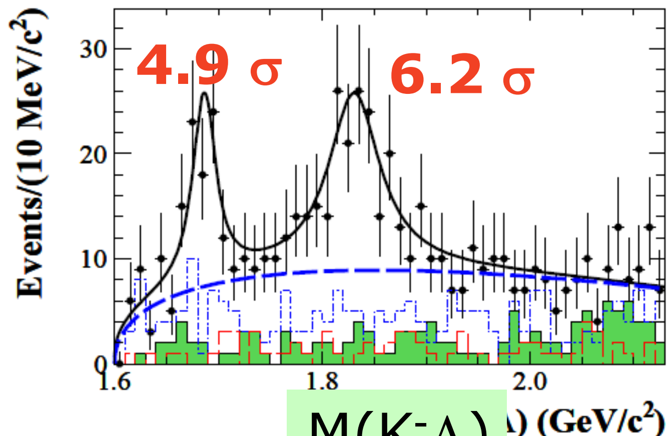
Observation of two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c.

data sample: $106\times10^6\ \psi'$

arXiv:1504.02025 is accepted by PRD



$K^-\Lambda$ recoiling mass



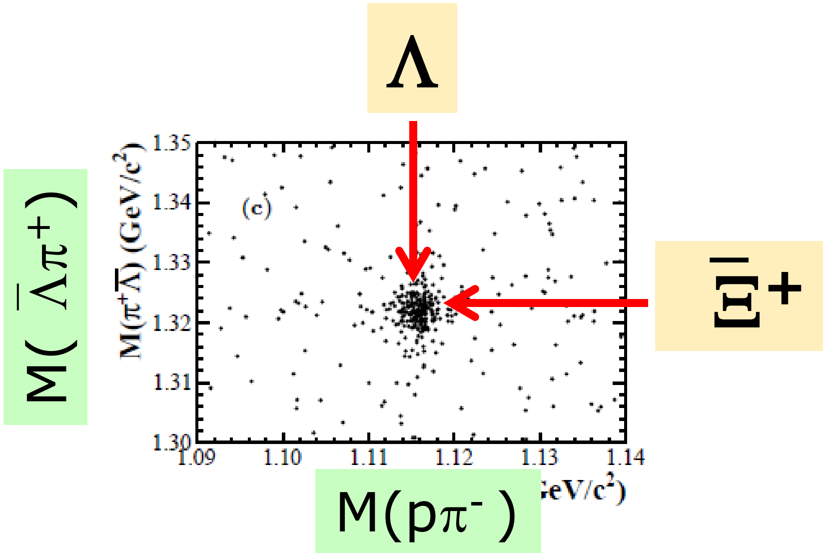
$M(K^-\Lambda)$

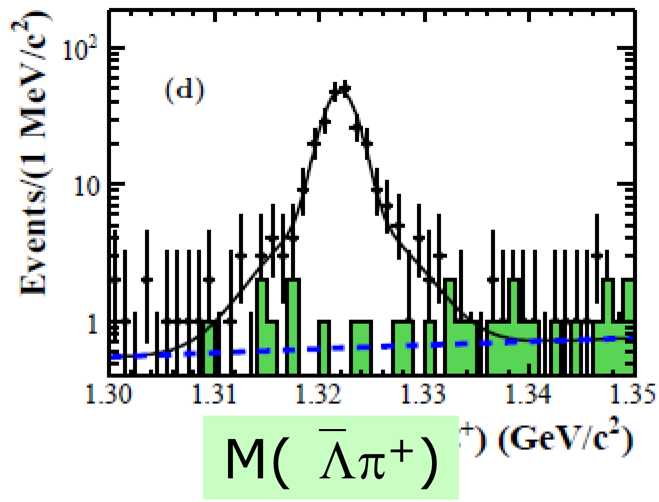
	$\Xi(1690)^-$	$\Xi(1820)^-$
M(MeV/c^2)	1687.7±3.8±1.0	1826.7±5.5±1.6
Γ(MeV)	27.1±10.0±2.7	54.4±15.7±4.2
Event yields	74.4±21.2	136.2±33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}$ (10^{-6})	5.21±1.48±0.57	12.03±2.94±1.22
M_{PDG}(MeV/c^2)	1690±10	1823±5
Γ_{PDG}(MeV)	<30	24^{+15}_{-10}

- Two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ are observed in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c
- Resonance parameters consist with PDG

Observation of two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c.

arXiv:1504.02025



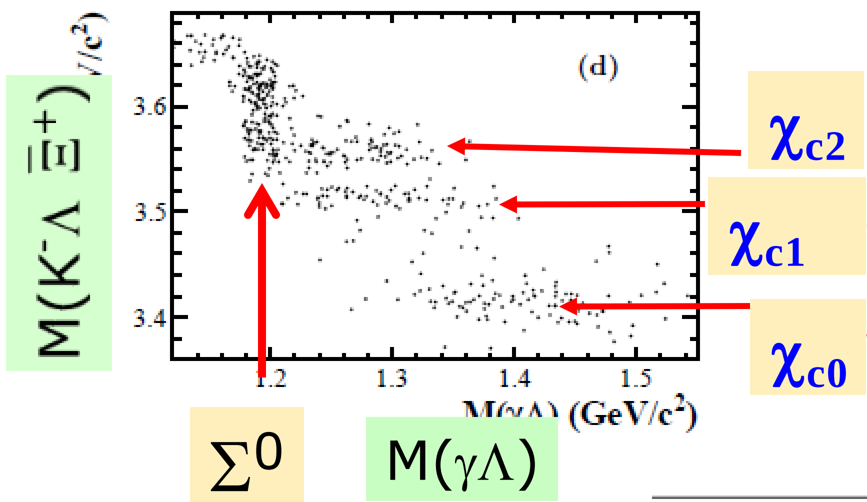


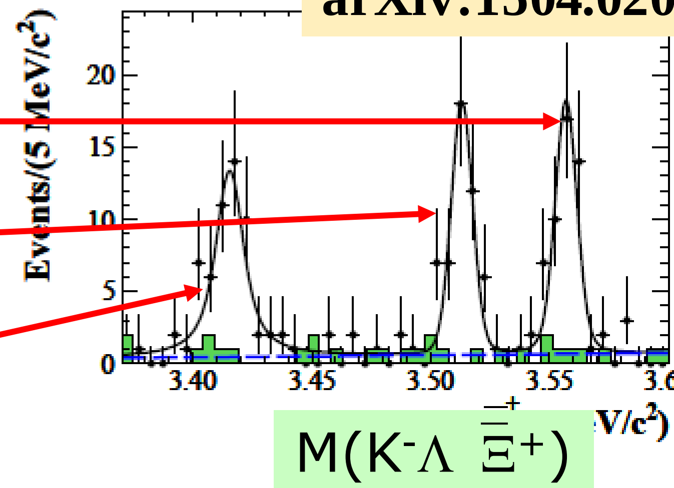
$B(\psi(3686)\to K^-\Lambda\bar{\Xi}^+\text{+c.c.})=(3.86\pm0.27\pm0.32)\times10^{-5}$

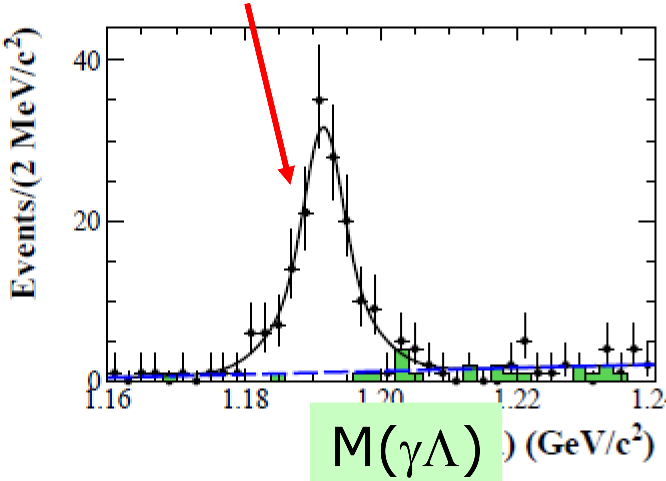
Measurement of the branching fraction for the first time

Measurement of $\psi(3686)\to\gamma K^-\Lambda\bar{\Xi}^+$+c.c.

arXiv:1504.02025







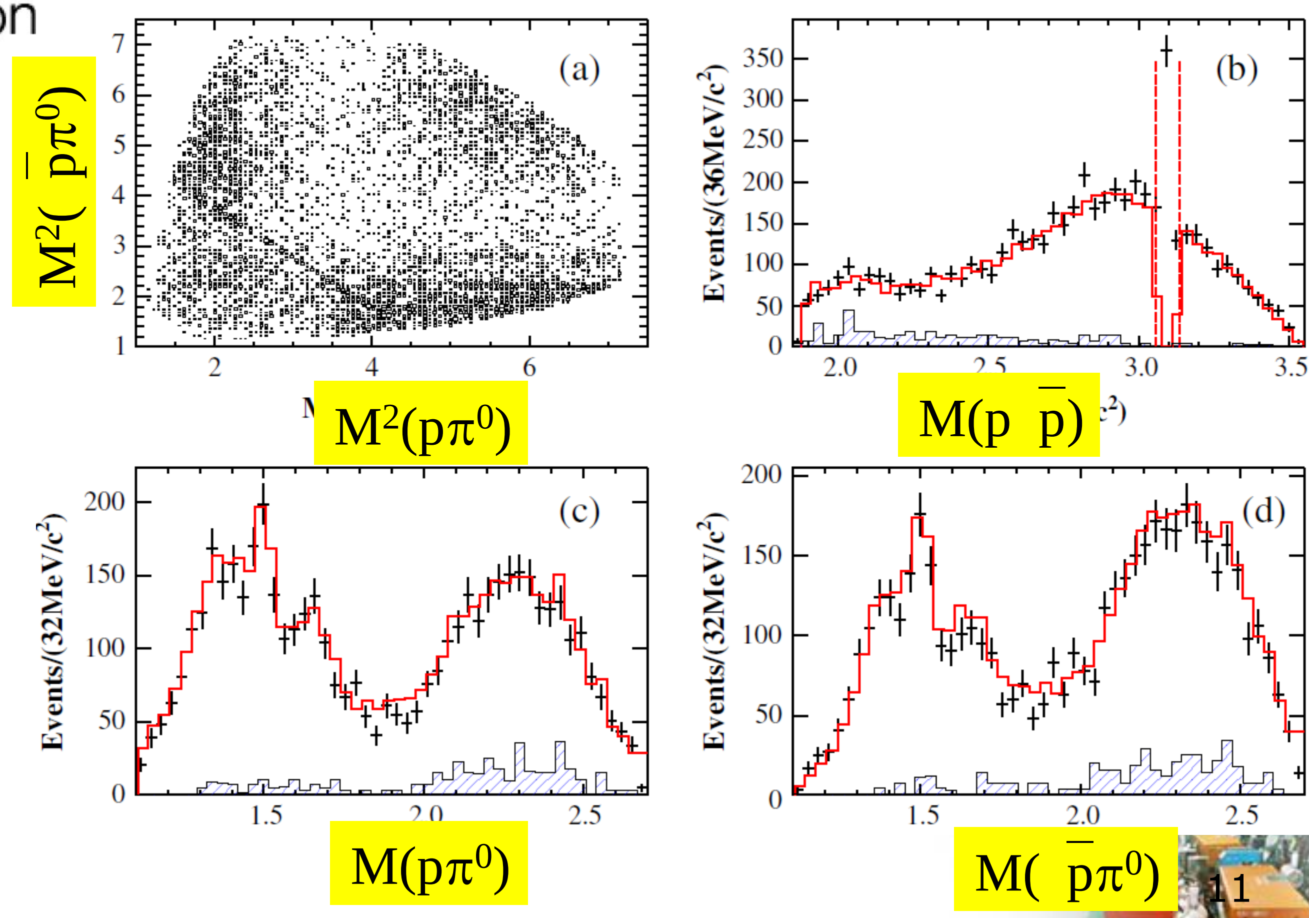
Decay	Branching fraction
$\psi(3686)\to K^-\Sigma^0\bar{\Xi}^+$	$(3.67\pm0.33\pm0.28)\times10^{-5}$
$\psi(3686)\to\gamma\chi_{c0},\ \chi_{c0}\to K^-\Lambda\bar{\Xi}^+$	$(1.90\pm0.30\pm0.16)\times10^{-5}$
$\psi(3686)\to\gamma\chi_{c1},\ \chi_{c1}\to K^-\Lambda\bar{\Xi}^+$	$(1.32\pm0.20\pm0.12)\times10^{-5}$
$\psi(3686)\to\gamma\chi_{c2},\ \chi_{c2}\to K^-\Lambda\bar{\Xi}^+$	$(1.68\pm0.26\pm0.15)\times10^{-5}$

Measurement of the branching fractions of $\psi(3686)\to K^-\Sigma^0\bar{\Xi}^+$+c.c. and $\psi(3686)\to\gamma\chi_{cJ}\to\gamma K^-\Lambda\bar{\Xi}^+$+c.c. (J=0,1,2) for the first time

Observation of two new baryonic excited states in $\psi(3686) \to p\bar{p}\pi^0$

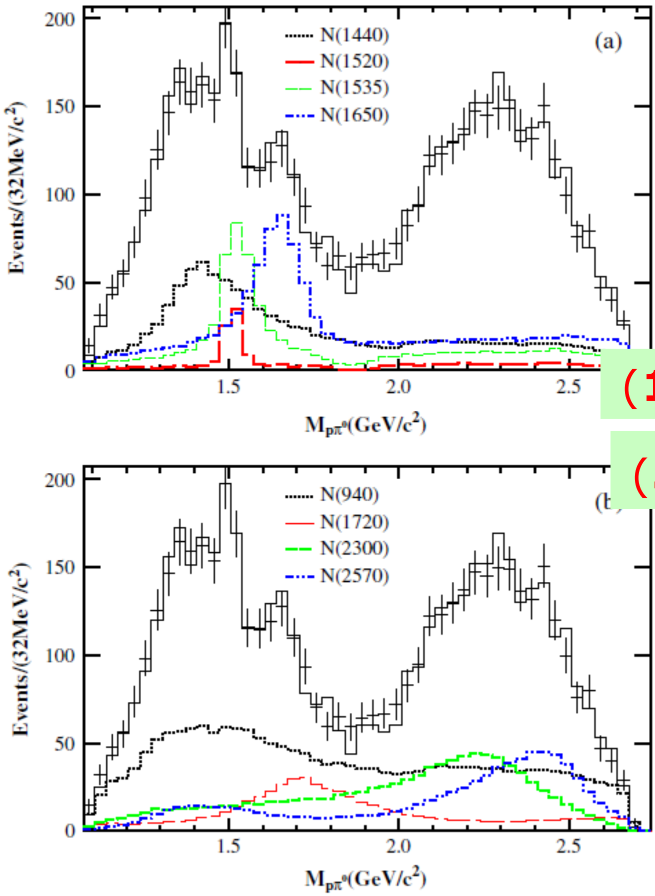
- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation
  Δ suppressed

Phys.Rev.Lett. 110 (2013) 022001



Observation of two new baryonic excited states N(2300) and N(2570) in $\psi(3686) \to p\bar{p}\pi^0$

Phys.Rev.Lett. 110 (2013) 022001



(1/2+)

(5/2-)

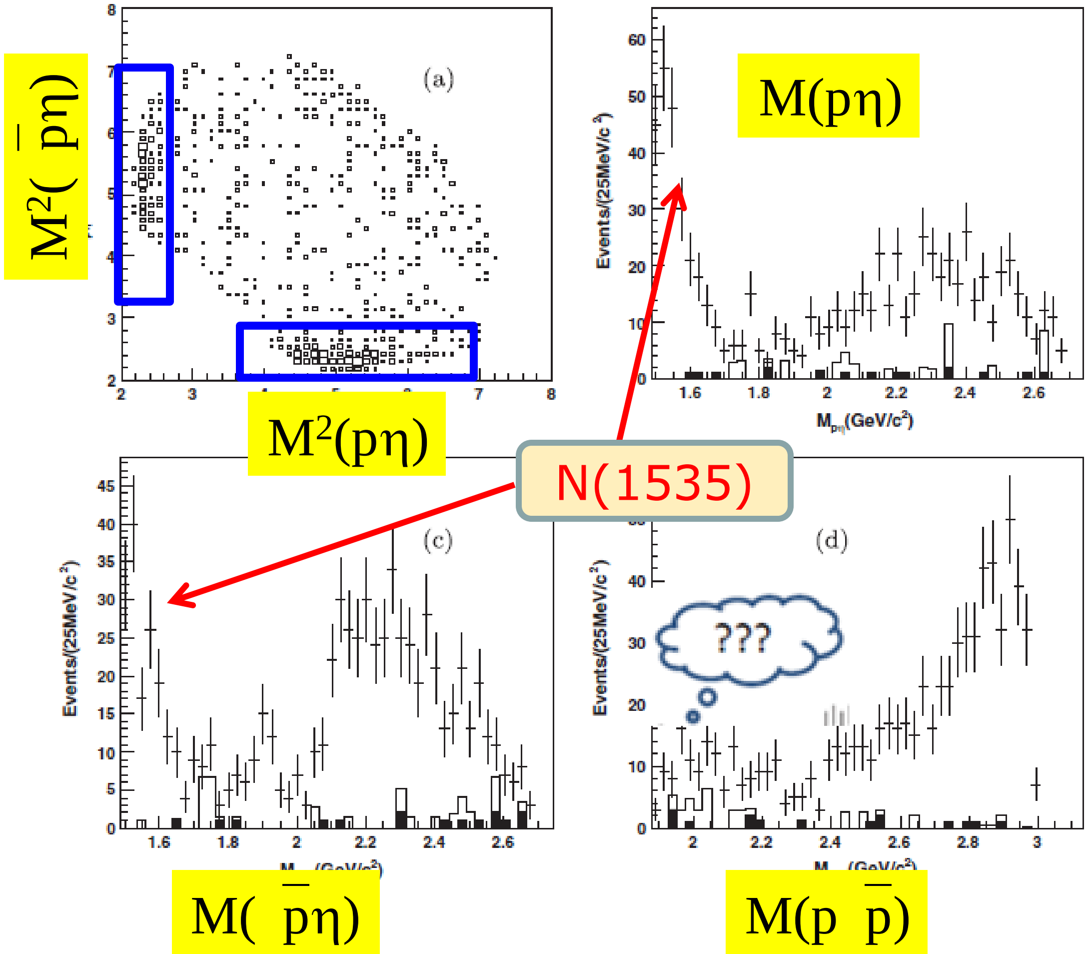
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	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**	$\mathbf{11.7\sigma}$

- **5 well known N* are measured**
- **Two new baryonic excited states N(2300)($1/2^+$) and N(2570)($5/2^-$) are observed!**
- **The ppbar threshold enhancement most likely is due to interference of N* intermediate resonance**

Observation of N(1535) in $\psi(3686) \to p\bar{p}\eta$

data sample: $106\times10^{6}\,\psi'$

PR D 88, 032010 (2013)



Observation of N(1535) in $\psi(3686)\to p\bar{p}\eta$

N(1535)

For $N(1535)$ with its mass close to the threshold of its dominant decay channel $N\eta$, the approximation of a constant width is not very good. Thus, a phase-space-dependent width for $N(1535)$ is also used

$$\mathrm{BW}(s) = \frac{1}{M_{N^*}^2 - s - iM_{N^*}\Gamma_{N^*}(s)}.$$

The phase-space-dependent widths can be written as

$$\Gamma_{N^*}(s) = \Gamma_{N^*}^0\left(0.5\frac{\rho_{N\pi}(s)}{\rho_{N\pi}(M_{N^*}^2)} + 0.5\frac{\rho_{N\eta}(s)}{\rho_{N\eta}(M_{N^*}^2)}\right),$$

where $\rho_{N\pi}$ and $\rho_{N\eta}$ are the phase space factors for the $N\pi$ and $N\eta$ final states, respectively,

$$\rho_{NX}(s) = \frac{2q_{NX}(s)}{\sqrt{s}}$$

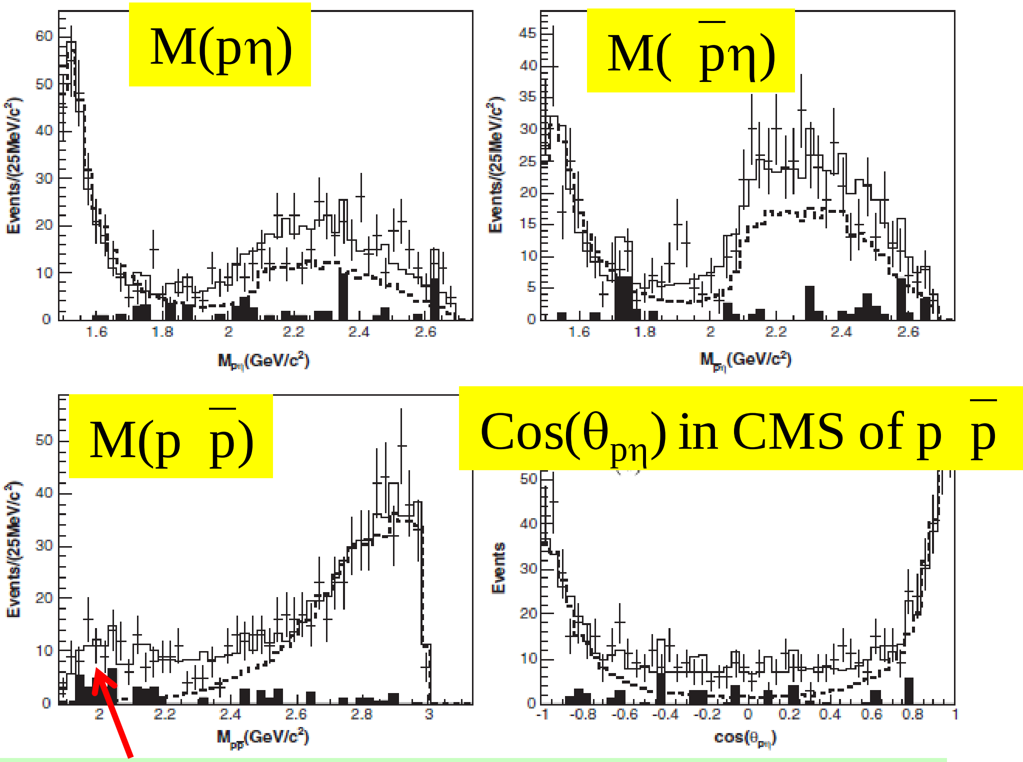
$$= \frac{\sqrt{(s-(M_N+M_X)^2)(s-(M_N-M_X)^2)}}{s}$$

Observation of N(1535) in $\psi(3686)\to p\bar{p}\eta$

- N(1535) and PHSP(1/2-) are dominant

PR D 88, 032010 (2013)

- No evidence for a ppbar resonance



explained by interference between N(1535) and phase space

Mass and width of N(1535)

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

PDG value:

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

Branching fraction:

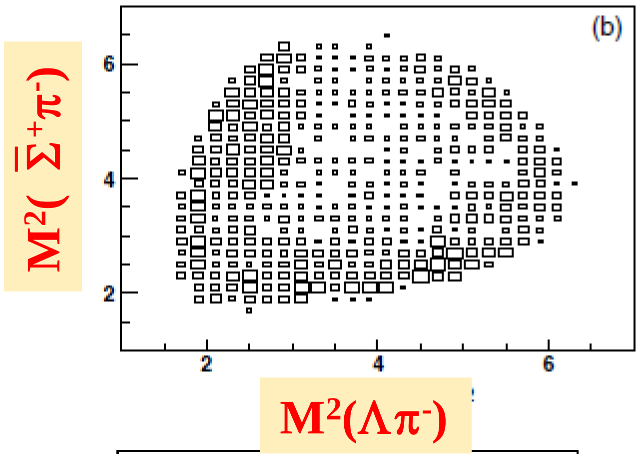
- $B(\psi' \to N(1535)\bar{p}) \times B(N(1535) \to p\eta) + c.c.$

$$= (5.2 \pm 0.3^{+3.2}_{-1.2} \times 10^{-5})$$

Observation of excited strange baryons Λ^* and Σ^* in $\psi(3686)\to\Lambda\bar{\Sigma}^+\pi^-$+c.c.

data sample: $106\times10^6\,\psi'$

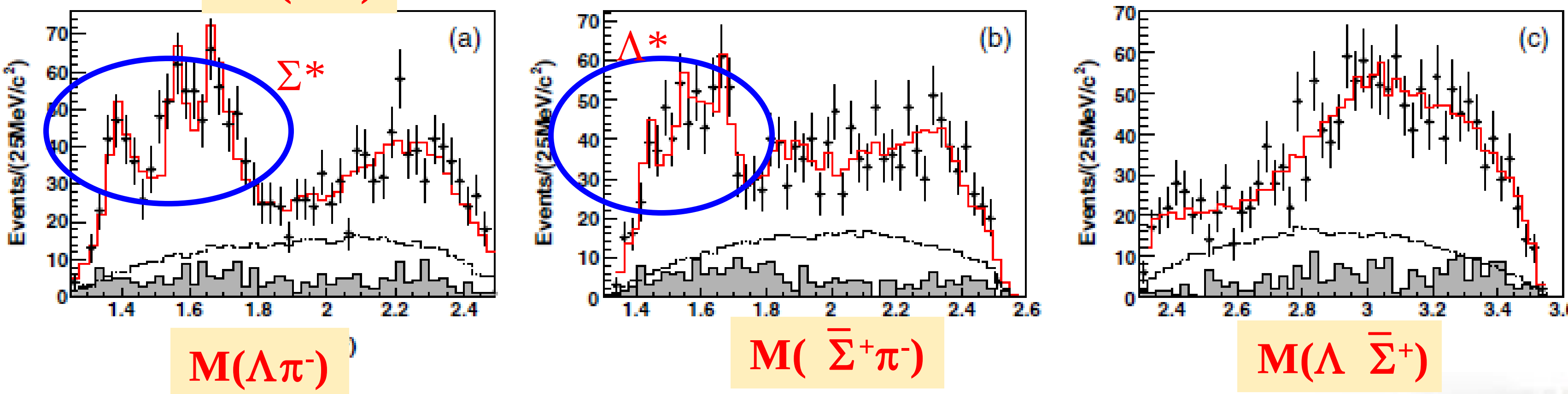
PRD 88, 112007 (2013)



- **Branching fractions are measured for the first time.**

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

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



- **Excited strange baryons around 1.5 to 1.7GeV/c^2 are observed**

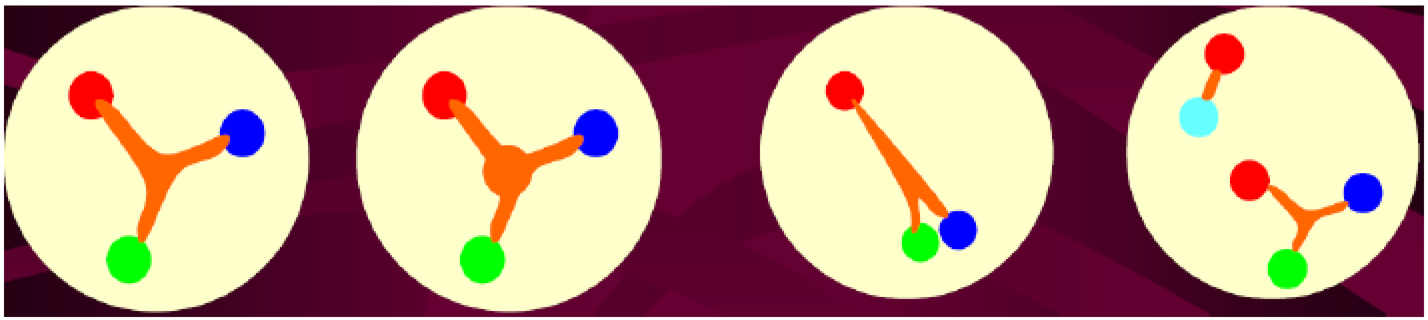
Summary and perspective

- **BESIII collected 0.5×10^9 $\psi(2S)$ and 1.3×10^9 J/ψ events.**
- **Many baryonic states are presented:**
  - $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c.
  - baryon excited states N(2300) and N(2570) in $\psi(3686)\to p\bar{p}\pi^0$
  - N(1535) in $\psi(3686)\to p\bar{p}\eta$
  - excited strange baryons Λ^* and Σ^* in $\psi(3686)\to\Lambda\bar{\Sigma}^+\pi^-$+c.c.
- **Charmonium decays have proven to be a good lab for studying not only excited nucleon states, but also excited hyperons.**
- **provide complementary information to other experiment**
- **Expect more results from BESIII.**

Back up

Baryon spectroscopy

- Are the states missing in the predicted spectrum because our models do not capture the correct degrees of freedom?



…

1, 3 quarks | 2, quarks and flux tubes | 3, quark-diquark | 4, multi quarks

$N_{predictied}$: $N_4 > N_2 > N_1 > N_3$, $N_{observed} << N_1$

- Or have the resonances simply escaped detection?

Nearly all existing data result from πN experiments

Observation of two new baryon excited states N(2300) and N(2570) in $\psi(3686) \to p\bar{p}\pi^0$

Selection of $p\bar{p}\pi^0$

Phys.Rev.Lett. 110 (2013) 022001

data sample: $1.06\times10^8\ \psi'$

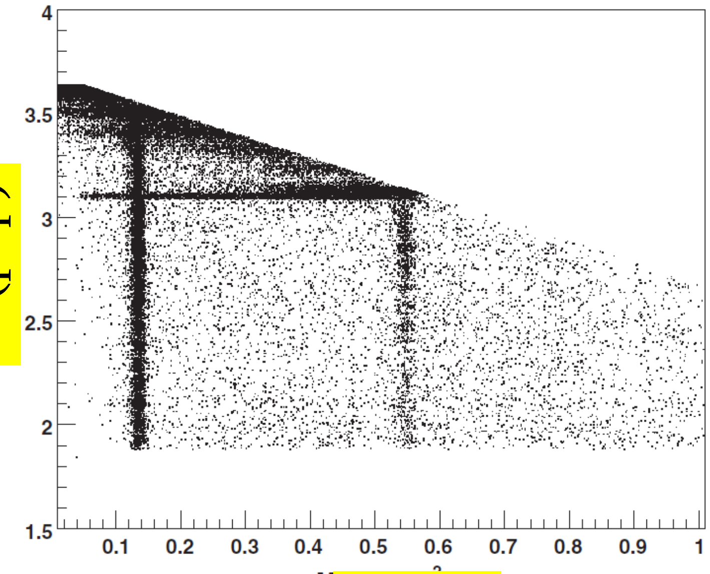
- **Proton and anti-proton are identified**
- **using dE/dx and TOF information**

$$Pt > 300MeV/c^2 \quad (\text{for } p, \bar{p})$$
$$|cos(\theta)| < 0.8$$

- **4C-kinematic fit:**

$$\chi^2_{4C}(\gamma\gamma p\bar{p}) < 20$$

- $|M_{\gamma\gamma} - M_{\pi^0}| < 15MeV/c^2$
  $|M_{p\bar{p}} - M_{J/\Psi}| > 0.04GeV/c^2$



$M(p\bar{p})$

$M(\gamma\gamma)$

Two vertical bands: $\psi' \to \pi^0 p\bar{p}\ ,\eta p\bar{p}$

Horizontal band: : $\psi' \to X + J/\psi\ ,J/\psi \to p\bar{p}$

Measurement of $\psi(3686)\to K^-\Lambda\ \bar{\Xi}^+ + C.C.$

$$\psi(3686)\to K^-\Lambda\ \bar{\Xi}^+ + C.C.$$

$$\Lambda\to p\ \pi^-$$

$$\bar{\Xi}^+\to\ \bar{\Lambda}\pi^+,\ \bar{\Lambda}\to\ \bar{p}\ \pi^+$$

N(940) into virtual proton + pi0

are also considered. According to the framework of soft π meson theory [22], the off-shell decay process is needed in this channel. Thus, $N(940)$ with a mass of 940 MeV/c^2 and zero width is included. The $N(940)$ represents a virtual proton, which could emit a π^0. The Feynman diagram of this process can be found in Ref. [15].

[15] M. Ablikim *et al.* (BES Collaboration), Phys. Rev. D **80**, 052004 (2009).

In summary, we studied the intermediate resonances, including their masses, widths, and spin parities, in the decay $\psi(3686) \rightarrow p\bar{p}\pi^0$. Two new N^* resonances are observed, in addition to five well-known N^* resonances. The masses and widths as well as the spin parities of the two new N^* states have been measured. The branching fractions of $\psi(3686) \rightarrow p\bar{p}\pi^0$ and the product branching fractions through each intermediate N^* state are measured. No clear evidence for $N(1885)$ or $N(2065)$ has been found. The hypothetical $p\bar{p}$ resonance has a significance of less than 4σ, indicating that the threshold enhancement most likely is due to interference of N^* intermediate resonances.