Baryon Spectroscopy at BESIII

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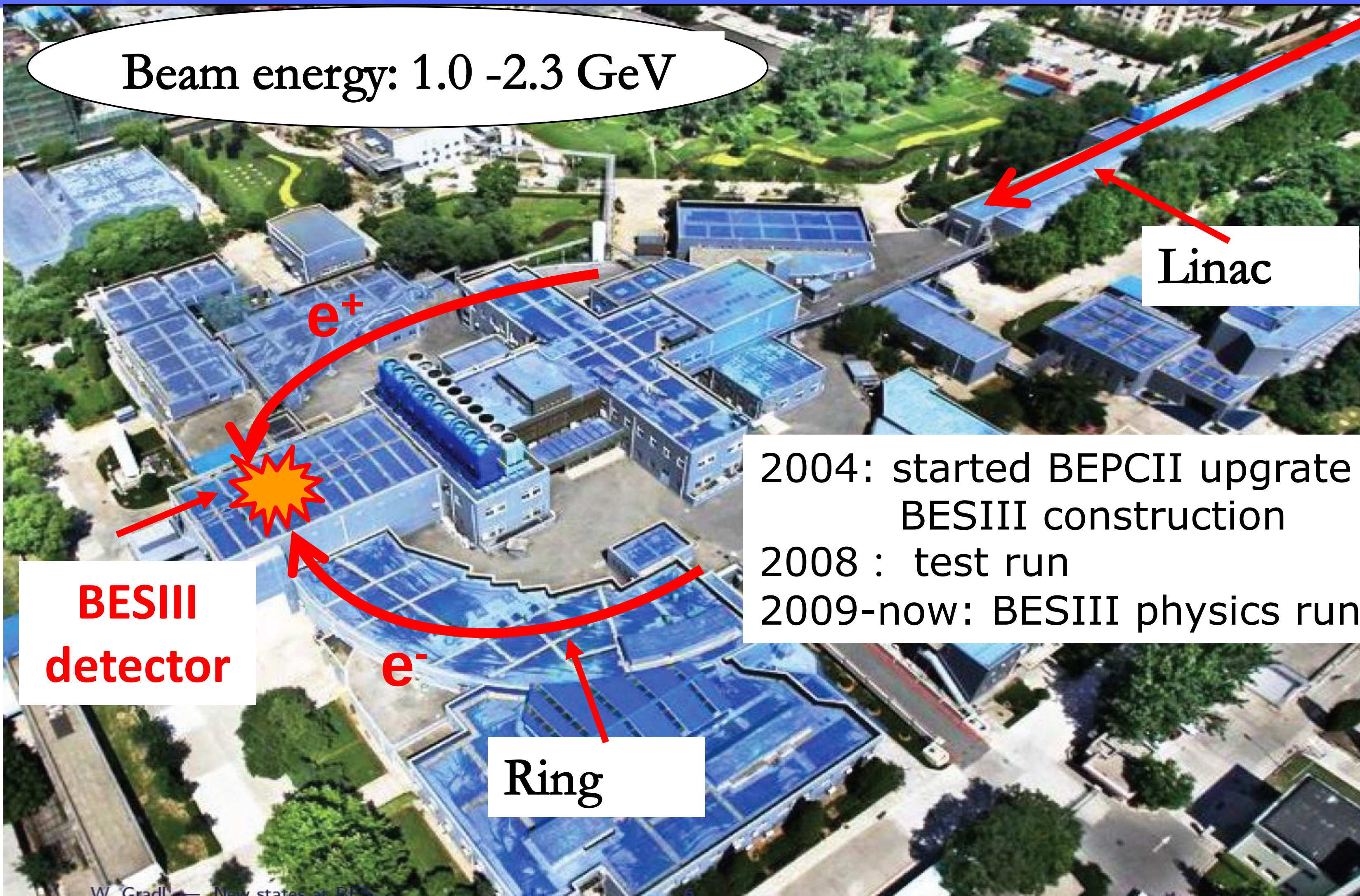
Outline

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

Beijing Electron Positron Collider (BEPCII)



The BEPCII Collider

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

Beam energy: 1.0 - 2.3 GeV

Peak Luminosity:

achieved: $0.85 \times 10^{33} cm^{-2} s^{-1}$@3770 MeV

Optimum energy: 1.89 GeV

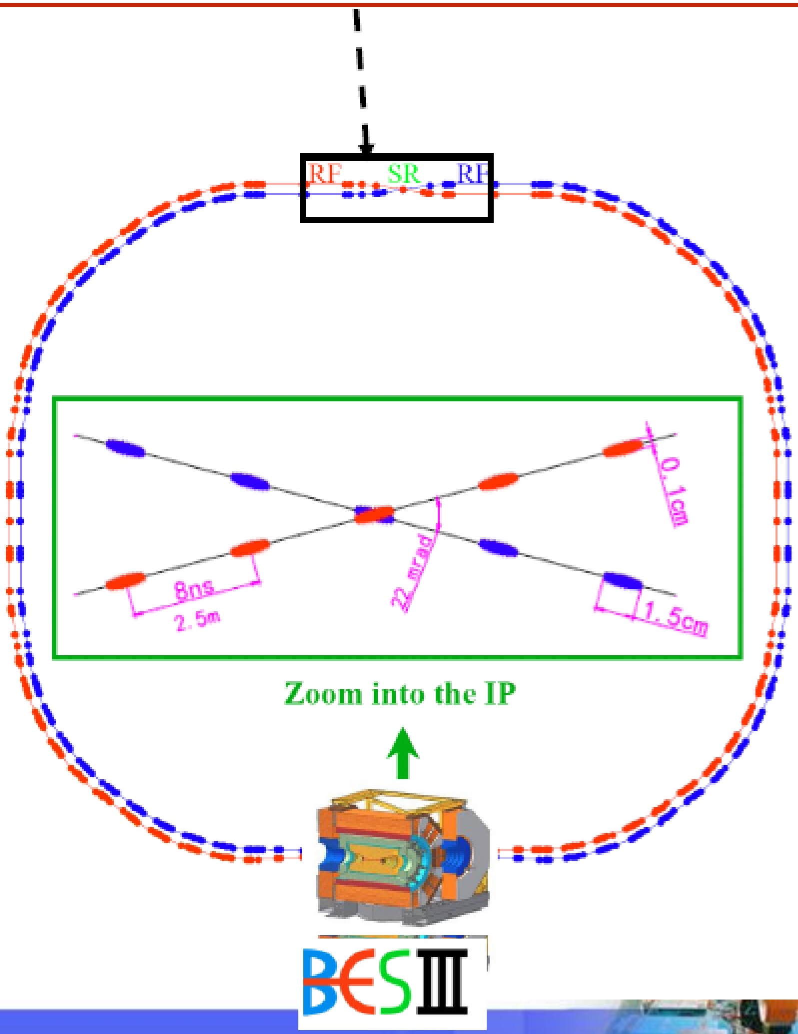
Energy spread: 5.16×10^{-4}

No. of bunches: 93

Bunch length: 1.5 cm

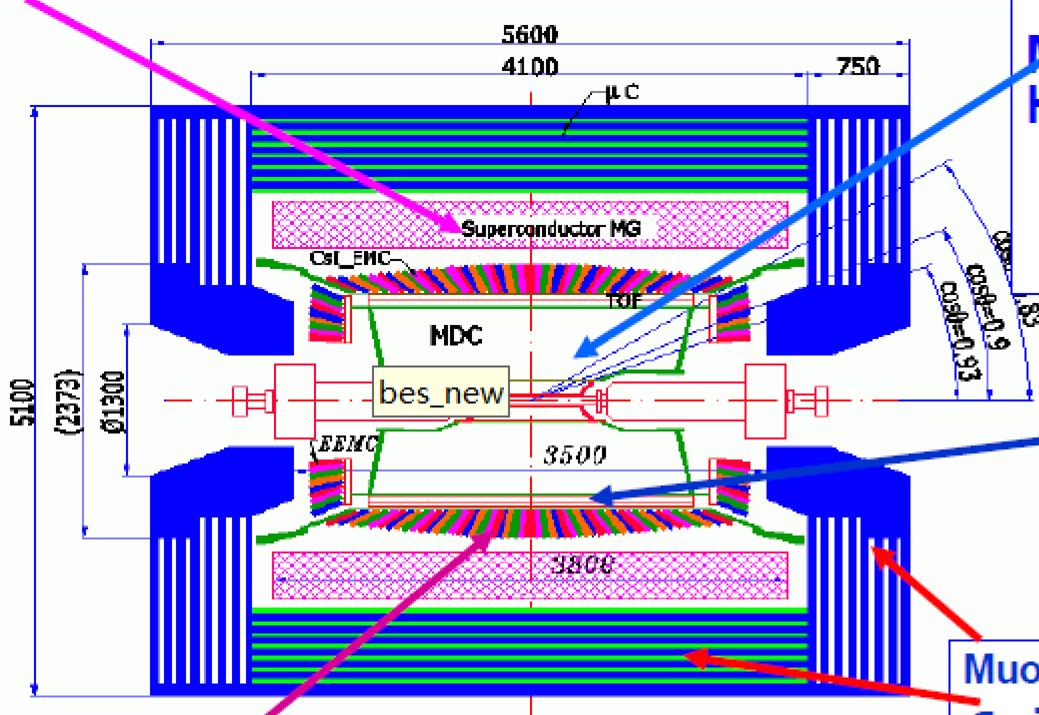
Total current: 0.91 A

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.

BESIII Collaboration

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Mongolia (1)

Institute of phys. & Tech.

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

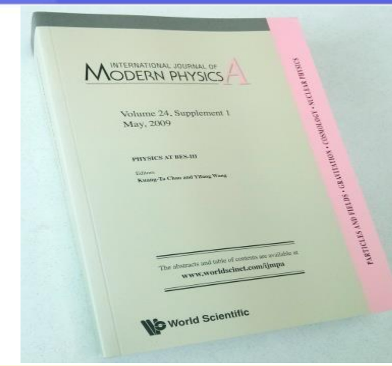
Univ. of Punjab
COMSAT CIIT

China(32)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.

~400 members
from 55 institutions in 12 countries

Physics Topics at BESIII



Int. J. Mod. Phys. A 24 (2009)

- **Hadron spectroscopy**
  - **search for the new forms of hadrons**
  - **meson spectroscopy**
  - **baryon spectroscopy**
- **Study of the production and decay mechanism of charmonium states : J/ψ, $\psi(2S)$, $\eta_c(1S)$, $\chi_{c\{0,1,2\}}$, $\eta_c(2S)$, $h_c(1P_1)$, $\psi(3770)$ etc**

  Calibrate QCD

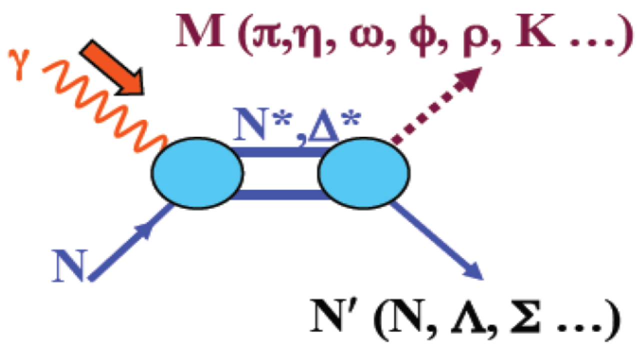
  New states above open charm threshold: XYZ
- **Precision measurement of R values, hadronic FF, …**
- **Charm physics, charmed baryon**
- **Rare decays, new physics**

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 three-quark model of baryon:**
  - **quite successful in interpreting low-lying baryon resonances.**
  - **provide an explicit classification for light baryons in terms of group symmetry.**
  - **tend to predict far more excited states than are found experimentally ("miss resonance problem").**
- **Theoretically, this could be due to a wrong choice of the degrees of freedom describing internal structure of baryons.**
- **Experimentally, the situation is very complicated due to the large number of broad and overlapping states that are observed.**

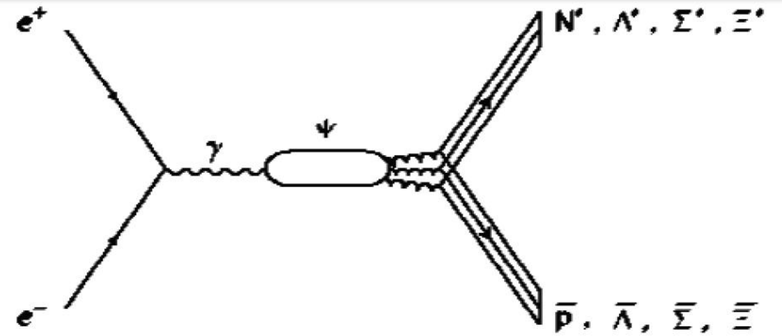
Baryon Spectroscopy

JLab, ELSA, MAMI, ESRF,
Spring-8, ….



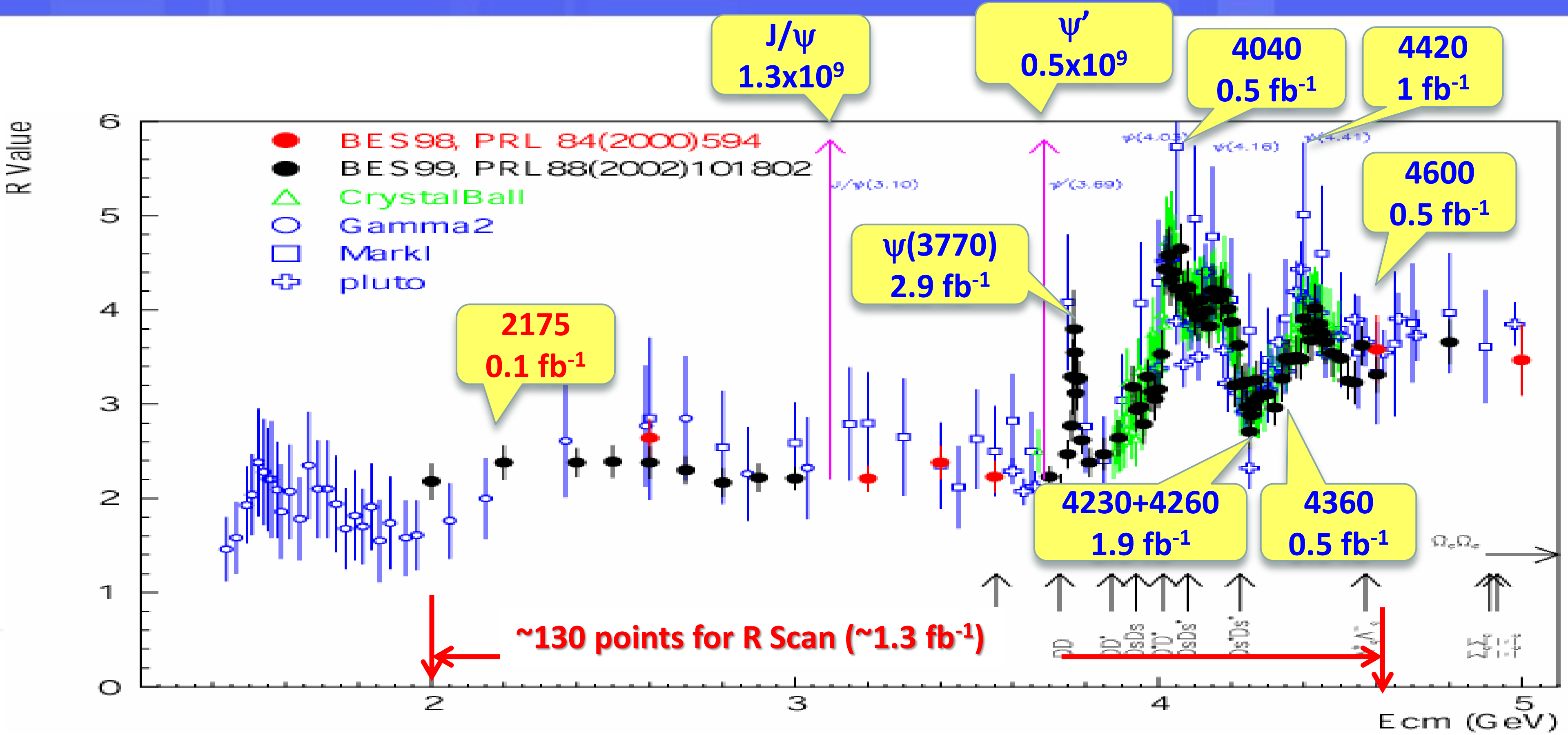
$$J/\psi(\psi') \to \bar{B}BM \;\Rightarrow\; N^*, \Lambda^*, \Sigma^*, \Xi^*$$

BESIII



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

BESIII Data Samples



World largest samples J/ψ, ψ(2S), ψ(3770), Y(4260), … produced directly from e^+e^- collision

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

Theoretically : Quark model predicts over 30 Ξ^* states,

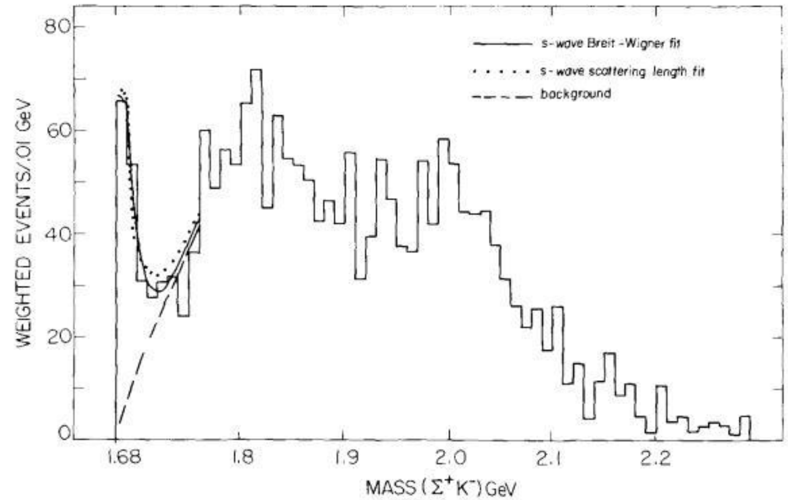
Experimentally: 11 Ξ^* states observed to date, few of them are well established with spin parity determined

Particle	J^P	Overall status	Status as seen in $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$		*	*				
$\Xi(1690)$		***		***	**		
$\Xi(1820)$	3/2−	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

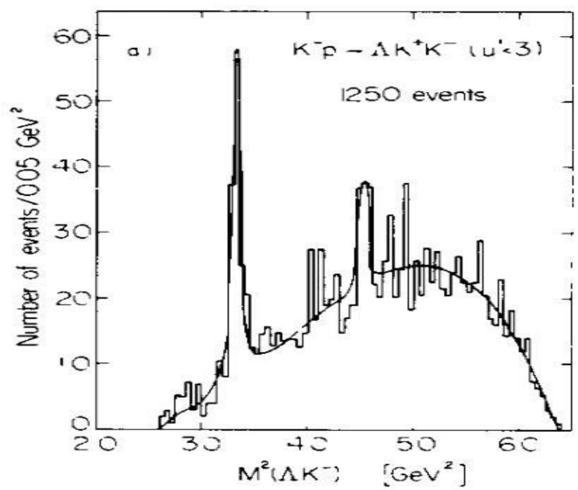
Most observations and measurements from bubble chamber experiment or diffractive Kp interaction.

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

- **In 1978,** the **$\Xi(1690)$ was first observed in the $(\Sigma\bar{K})$ final state in the reaction $K^-p\to(\Sigma\bar{K})K\pi$ at CERN**
- **Its existence has been confirmed by other experiments, WASA89, Belle, but its spin parity was not well determined.**



- **In 2008, BABAR determined spin-parity of $\Xi(1690)$ to be $J^p = ½^-$ in $\Lambda_c^+\to\Xi^-\pi^+K^+$**



- **In 1976, $\Xi(1820)$ was first observed in $K^-\Lambda$ mass spectrum in Kp scattering at CERN.**
- **In 1987, CERN-SPS experiment indicated that $\Xi(1820)$ favors negative parity of J = 3/2 .**

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

- **At present $\Xi(1690)$ and $\Xi(1820)$ are firmly established.**

- **Further investigation of their properties is important to the understanding of Ξ^* states.**

- **Besides from scattering experiments, decays from charmonium states offer a good opportunity to search for additional Ξ^* states.**

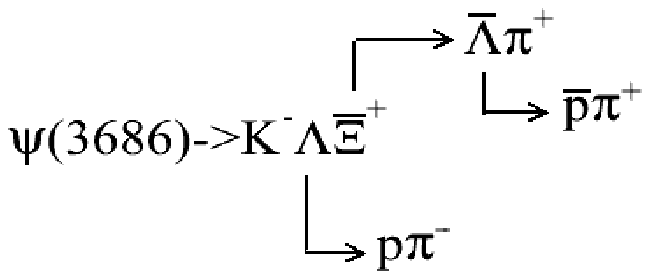
- **Our knowledge of charmonium decays into hadrons, especially to hyperons , is limited. The precise measurements of the branching fractions may help to provide a better understanding of the decay mechanism.**

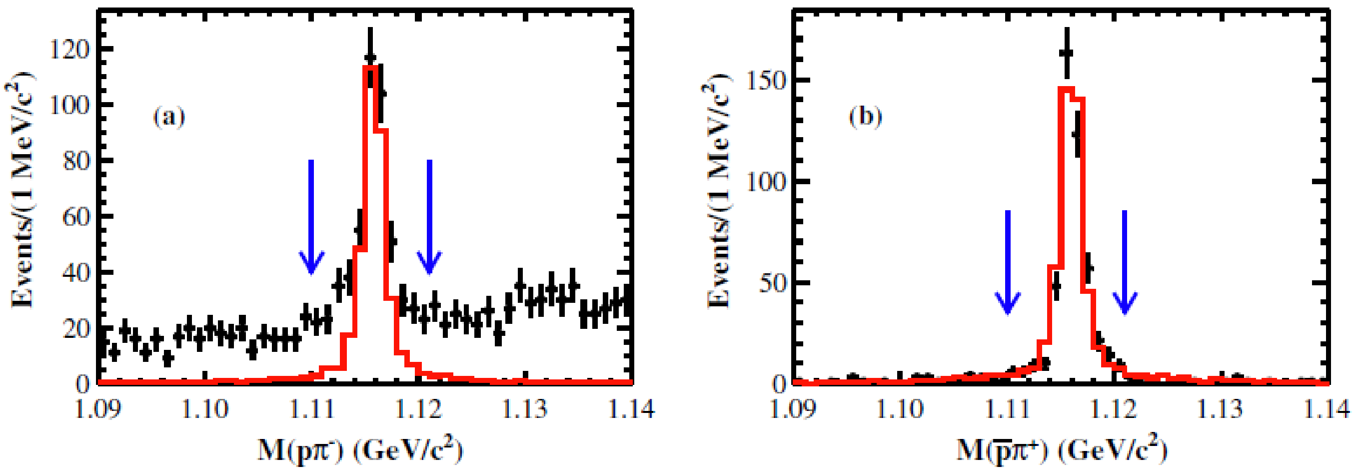
1. Observation of two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c.

data sample: 106×10^6 ψ'

PRD 91, 092006 (2015)

The decays is reconstructed from cascade decay:





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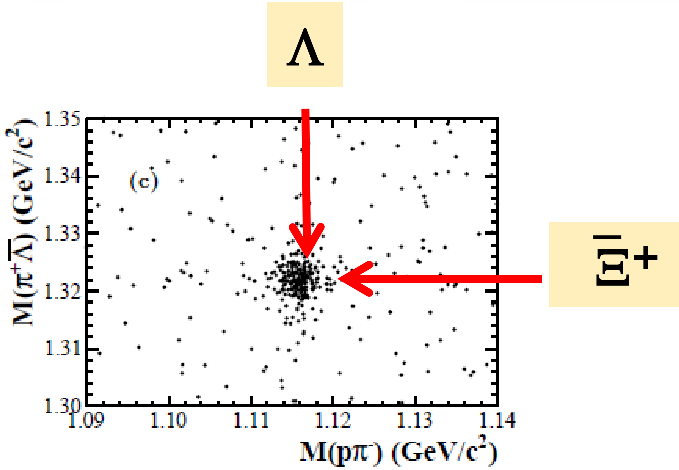
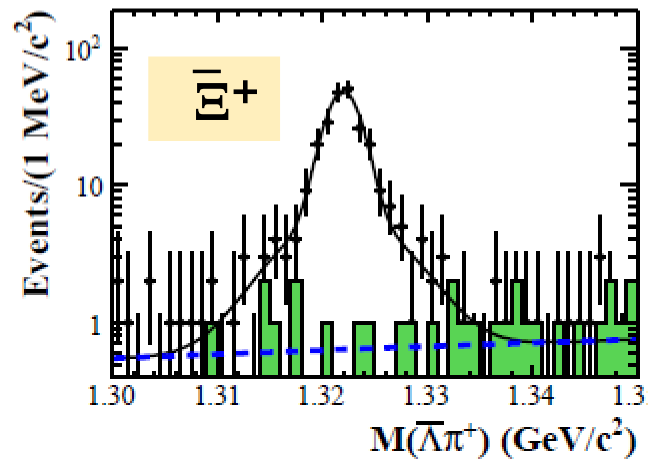


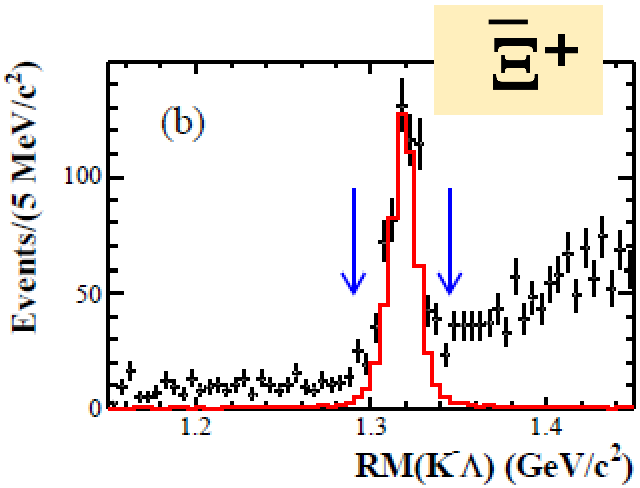
an extended unbinned maximum likelihood fit is performed.



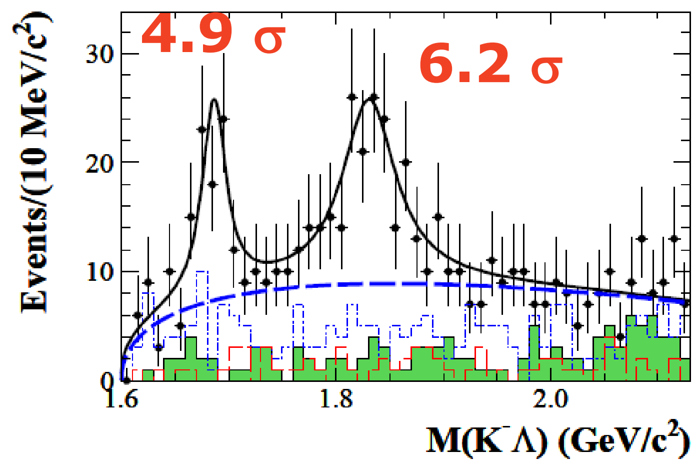
- **Signal: double Gaussian function.**
- **bg: a first order Chebychev polynomial**
- **bg sudied: the $\psi(3686)$ inclusive MC sample, Λ sidebands and data taken at 3.65 GeV.**

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

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



an extended un-binned maximum likelihood fit is performed to determine the resonance parameters and event yields of the exited hyperons Ξ^*



	$\Xi(1690)^-$	$\Xi(1820)^-$
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
$M_{\rm PDG}$(MeV/c^2)	1690±10	1823±5
$\Gamma_{\rm PDG}$(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

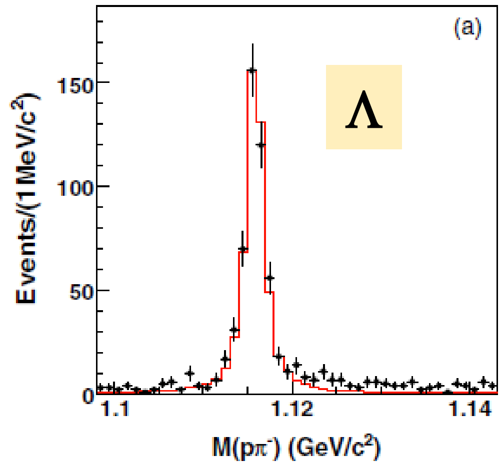
2. Observation of the decay $\psi(3686)\to\Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$ + c.c.

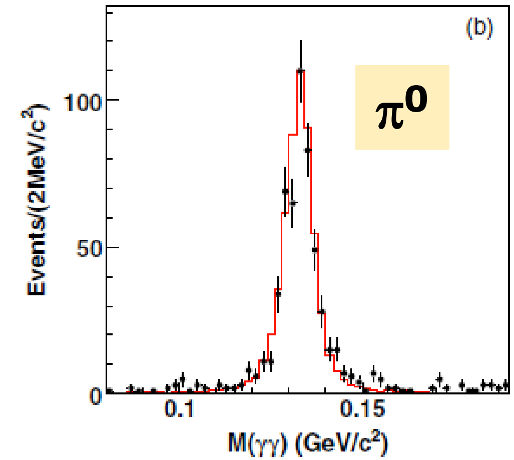
PRD 88, 112007 (2013)

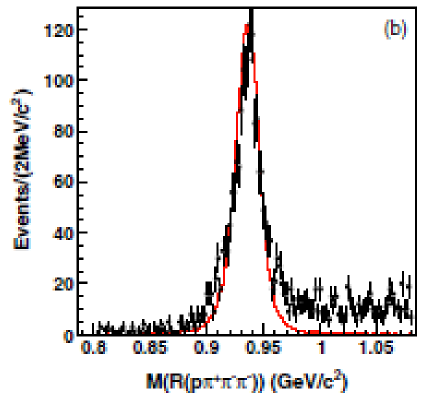
data sample: 106×10^6 ψ'

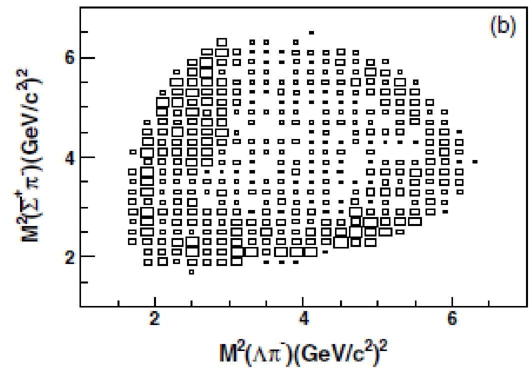
The candidate events are reconstructed in six modes:

$\psi(3686)\to$
$\Lambda\bar{\Sigma}^{+}\pi^{-}(\bar{\Sigma}^{+}\to\bar{n}\pi^{+})$
$\bar{\Lambda}\Sigma^{-}\pi^{+}(\Sigma^{-}\to n\pi^{-})$
$\Lambda\bar{\Sigma}^{-}\pi^{+}(\bar{\Sigma}^{-}\to\bar{n}\pi^{-})$
$\bar{\Lambda}\Sigma^{+}\pi^{-}(\Sigma^{+}\to n\pi^{+})$
$\Lambda\bar{\Sigma}^{-}\pi^{+}(\bar{\Sigma}^{-}\to\bar{p}\pi^{0})$
$\bar{\Lambda}\Sigma^{+}\pi^{-}(\Sigma^{+}\to p\pi^{0})$

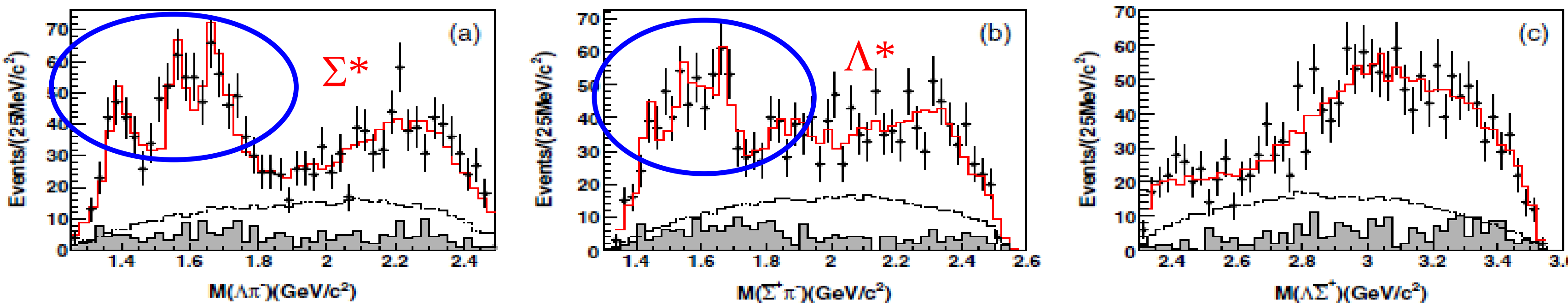








2. Observation of the decay $\psi(3686)\to\Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$ + c.c.



- **Partial wave analysis (PWA) is performed in order to determine the correct detection efficiency**
- **Excited strange baryons around 1.4 to 1.7GeV/c^2 are observed**

TABLE I. The branching fractions and the values used in the calculation for each decay mode, where the first errors are statistical and the second ones systematic.

$\psi(3686)\to$	N_{obs}	N_{sid}	N_{QED}	$\varepsilon(\%)$	$\mathcal{B}(\times 10^{-5})$
$\Lambda\bar{\Sigma}^{+}\pi^{-}(\bar{\Sigma}^{+}\to\bar{n}\pi^{+})$	1594 ± 48	43 ± 10	64 ± 16	20.25 ± 0.15	$6.91\pm0.25\pm0.65$
$\bar{\Lambda}\Sigma^{-}\pi^{+}(\Sigma^{-}\to n\pi^{-})$	1637 ± 47	44 ± 10	54 ± 14	20.55 ± 0.15	$7.05\pm0.24\pm0.61$
$\Lambda\bar{\Sigma}^{-}\pi^{+}(\bar{\Sigma}^{-}\to\bar{n}\pi^{-})$	898 ± 35	28 ± 6	25 ± 12	10.03 ± 0.11	$7.93\pm0.36\pm0.70$
$\bar{\Lambda}\Sigma^{+}\pi^{-}(\Sigma^{+}\to n\pi^{+})$	891 ± 35	29 ± 6	32 ± 11	10.22 ± 0.11	$7.64\pm0.35\pm0.69$
$\Lambda\bar{\Sigma}^{-}\pi^{+}(\bar{\Sigma}^{-}\to\bar{p}\pi^{0})$	458 ± 23	18 ± 5	26 ± 10	5.34 ± 0.078	$7.29\pm0.47\pm0.72$
$\bar{\Lambda}\Sigma^{+}\pi^{-}(\Sigma^{+}\to p\pi^{0})$	554 ± 26	13 ± 5	33 ± 11	6.22 ± 0.081	$7.68\pm0.67\pm0.71$

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

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

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

- In 2000, BESII started baryon resonance research program with the study of N(1535) and N(1650) in the decay of $J/\psi\to p\bar{p}\eta$ by PWA.

- In 2006, BESII observed a new exited nucleon, N(2065), in the decay $J/\psi\to p\bar{n}\pi^-$ +c.c. , and subsequently confirmed in $J/\psi\to p\bar{p}\pi^0$.

- BESII also studied $\psi(3686)\to p\bar{p}\gamma\gamma$, where both $p\bar{p}\pi^0$ and $p\bar{p}\eta$ were observed, and $\psi(3686)\to p\bar{p}\eta$ for the first time. In both decays, there was weak evidence for a $p\bar{p}$ threshold mass enhancement, but no PWA was performed.

- Using 24.5×10^6 $\psi(3686)$ events, CLEO-c collaboration reported the analysis of $\psi(3686)\to\gamma p\bar{p}$, $p\bar{p}\pi^0$, $p\bar{p}\eta$, in which N(1535) and a $p\bar{p}$ enhancement were investigated.

These results show that J/ψ and $\psi(3686)$ are ideal place for studying excited states N*

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

data sample: 106×10^6 ψ'

PRL 110, 022001 (2013)

- **Proton and anti-proton are identified using dE/dx and TOF informations**
- **At least two photos are selected**

➢ **To better understand the components of this decay, PWA is pursued.**

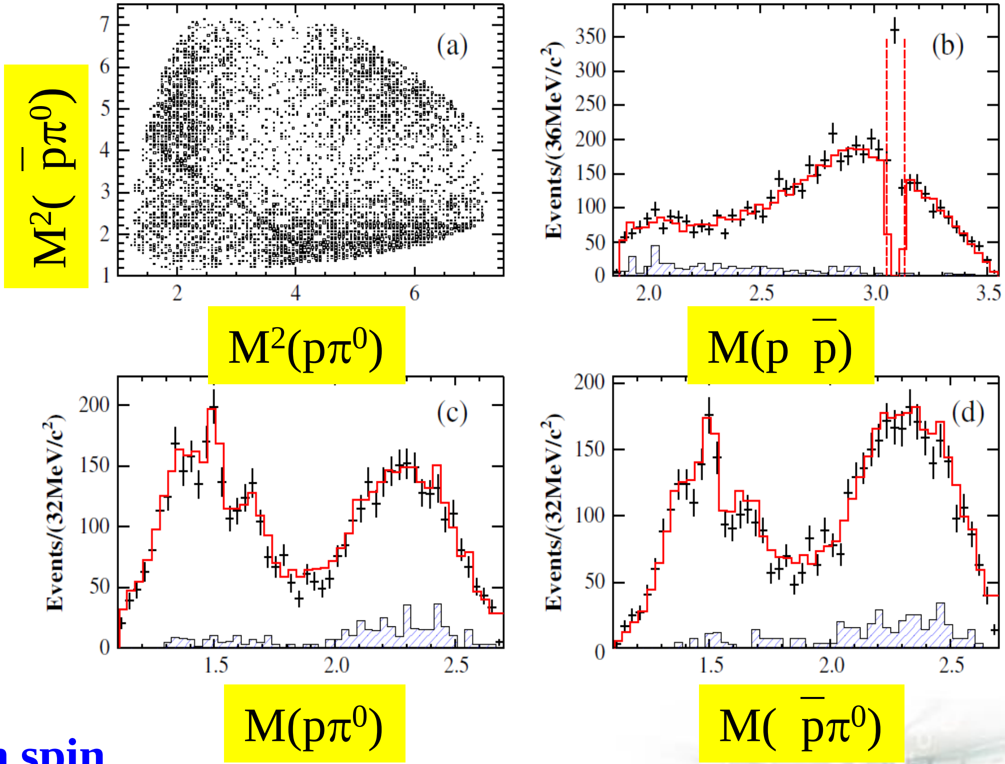
➢ **Dominated by two-body decays:**

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

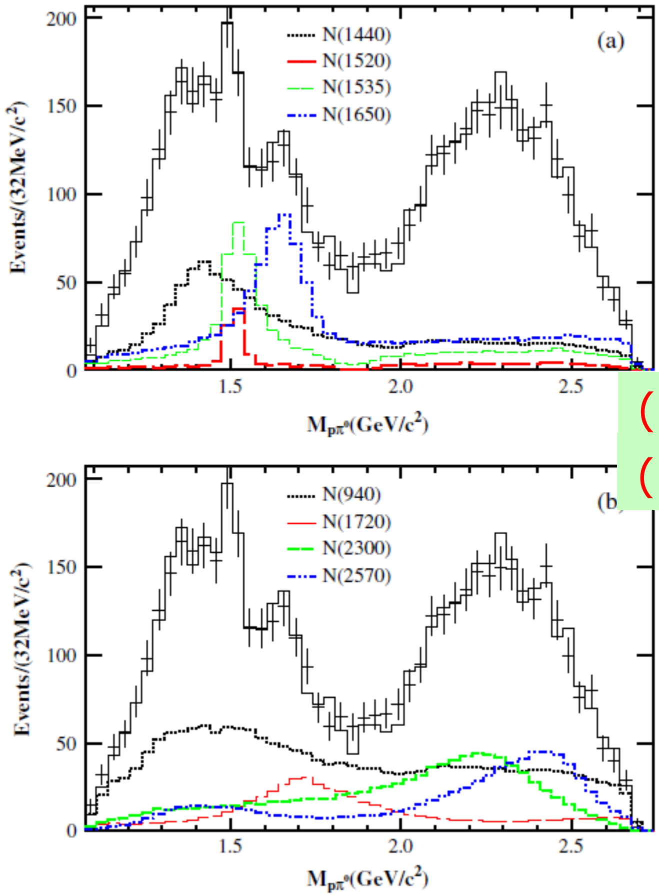
$\psi(3686)\to p\bar{N}^*(\bar{p}N^*)$

$N^*(\bar{N}^*)\to p\pi^0$ ($\bar{p}\pi^0$)

➢ **All N* resonances up to 2.2 GeV with spin up to 5/2 listed in PDG are considered.**



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



(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**	$\mathbf{11.7\sigma}$

- **two new N* resonances: N(2300)($1/2^+$) and N(2570)($5/2^-$) are observed!**
- **ppbar threshold enhancement most likely is due to interference of N* resonances**

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

$B(\psi(3686)\to p\bar{p}\pi^0) = (1.65\pm0.03\pm0.15)\times10^{-4}$

Resonance	N	$\epsilon(\%)$	B.F.$(\times 10^{-5})$
$N(940)$	$1870^{+90+487}_{-90-327}$	27.5 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.9 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	28.0 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	25.8 ± 0.4	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	27.2 ± 0.4	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	26.9 ± 0.4	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	34.2 ± 0.4	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	35.3 ± 0.4	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	4515 ± 93	25.8 ± 0.4	$16.5\pm0.3\pm1.5$

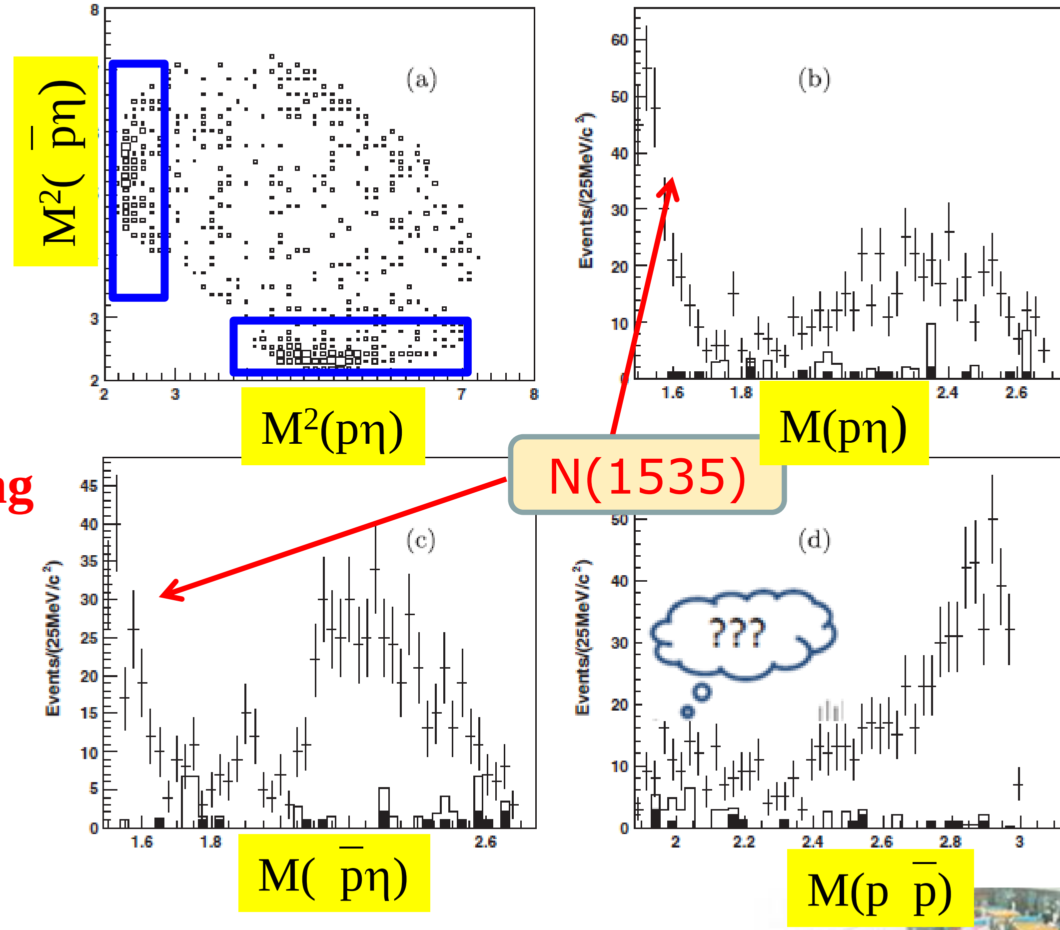
4. Study N(1535) in $\psi(3686)\to p\bar{p}\eta$ decay

data sample: 106×10^6 ψ'

PRD 88, 032010 (2013)

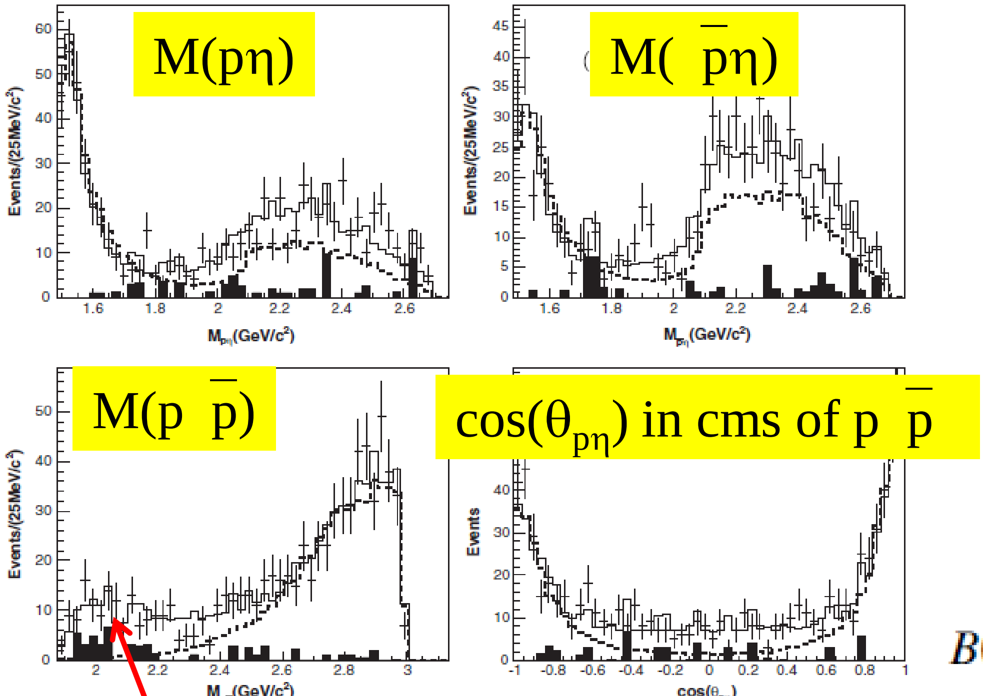
- ✓ **The decay topology is quite simple, $p\bar{p}\gamma\gamma$.**

- ✓ **Two clusters corresponding to the $p\eta$ mass threshold enhancement are visible.**



4. Study N(1535) in $\psi(3686)\rightarrow p\bar{p}\eta$ decay

- ✓ **PWA is performed, the dominant contributions is from N(1535)**
- ✓ **The best solution indicates that N(1535) combined with an interfering PHSP is sufficient to describe the data**



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 $175\ \mathrm{MeV}/c^2$

Branching fraction:

- $B(\psi' \rightarrow N(1535)\bar{p}) \times B(N(1535) \rightarrow p\eta) + c.c.$
$= (5.2 \pm 0.3^{+3.2}_{-1.2} \times 10^{-5})$

$$B(\psi(2S) \rightarrow p\bar{p}\eta) = (6.4 \pm 0.2 \pm 0.6) \times 10^{-5}$$

explained as interference between N(1535) and phase space, no evidence for $p\bar{p}$ resonance

Summary and perspective

- **BESIII collected 0.5×10^9 $\psi(2S)$ and 1.3×10^9 J/ψ events.**
- **Baryon states are presented:**
  - $\Xi^-(1690)$ and $\Xi^-(1820)$ hyperons in $\psi(3686)\to K^-\Lambda\bar{\Xi}^+$+c.c.
  - excited strange baryons Λ^* and Σ^* in $\psi(3686)\to\Lambda\bar{\Sigma}^\pm\pi^\mp$
  - excited baryon states N(2300) and N(2570) in $\psi(3686)\to p\bar{p}\pi^0$
  - N(1535) in $\psi(3686)\to p\bar{p}\eta$
- **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 experiments.**
- **Expect more results from full data sample.**

Thank You!