Light Baryon Spectroscopy at BESIII

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BESIII@BEPCII

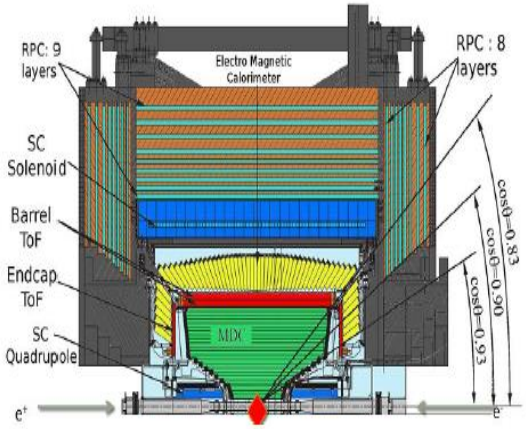
- 1989-2004 (BEPC):

  L_{peak}=1.0x10^{31} /cm^2s

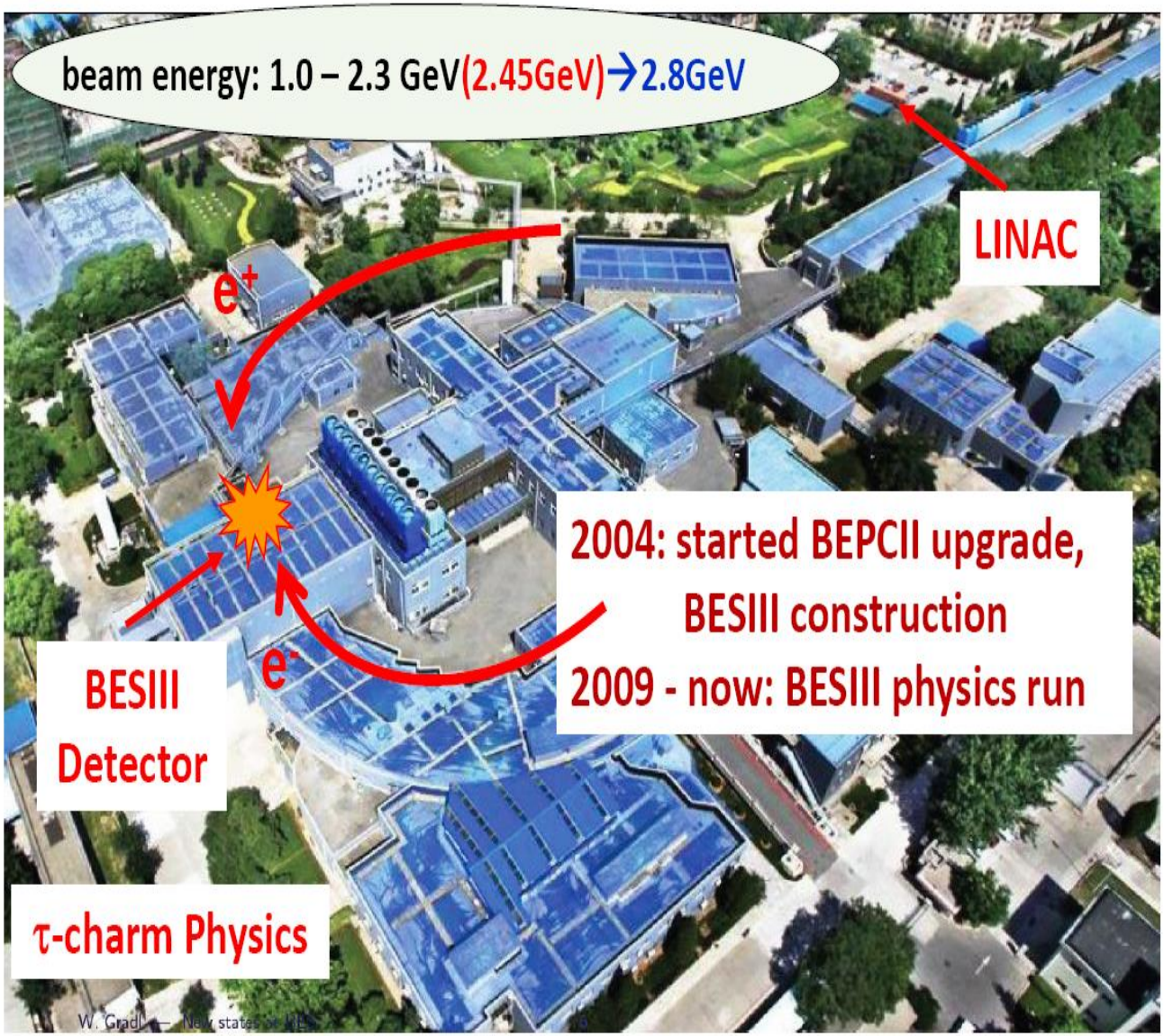
- 2009-now (BEPCII):

  L_{peak}= 1.0 x10^{33}/cm^2(2016)

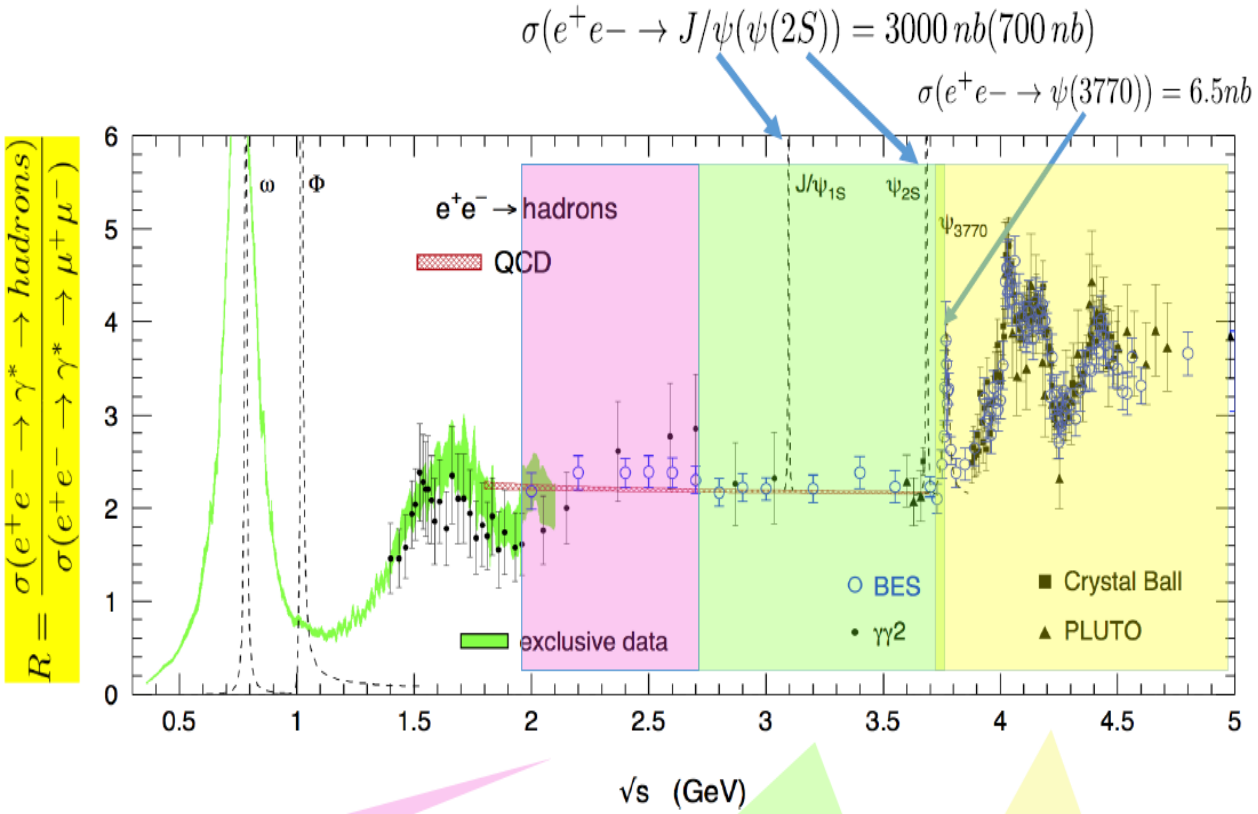
  L_{peak}= 1.1 x10^{33}/cm^2(2023)



MDC: spatial reso. 115μm
dE/dx reso: 5%
EMC: energy reso.: 2.4%
BTOF: time reso.: 70 ps
ETOF: time reso.: 60 ps



BESIII physics program and data samples



- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with τ lepton

- XYZ particles
- Charm mesons
- Charm baryons

BEPCII Energy Region

- Rich of resonances: charmonia, charm mesons, charm baryons
- Transition between smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the gluonic matters and XYZ's
- Threshold characteristics (pairs of τ, D, D_s, Λ_c...) Fixed initial and final states, low background

1. Physics at BES-III, *Int.J.Mod.Phys.A* 24 (2009) S1-794
2. Future Physics Programme of BESIII, Chinese Physics C, 44, 040001

Outline

This talk based on $(2712.4 \pm 14.3) \times 10^6$ $\psi(3686)$ data sample

- N^* in $\psi(3686) \to \bar{p}p\pi^0$, $\bar{p}p\,\eta$

BESIII, PRD, 111, 032011 (2025).

- Λ^*, Σ^* in $\psi(3686) \to \Lambda\,\bar{\Sigma}^0\pi^0 + c.c.$

BESIII, JHEP 02(2025), 212

Focus on $N(1535)$ and $\Lambda(1380), \Lambda(1405), \Lambda(2325)$ states

For theoretical review, see plenary talk by Anthony W. Thomas

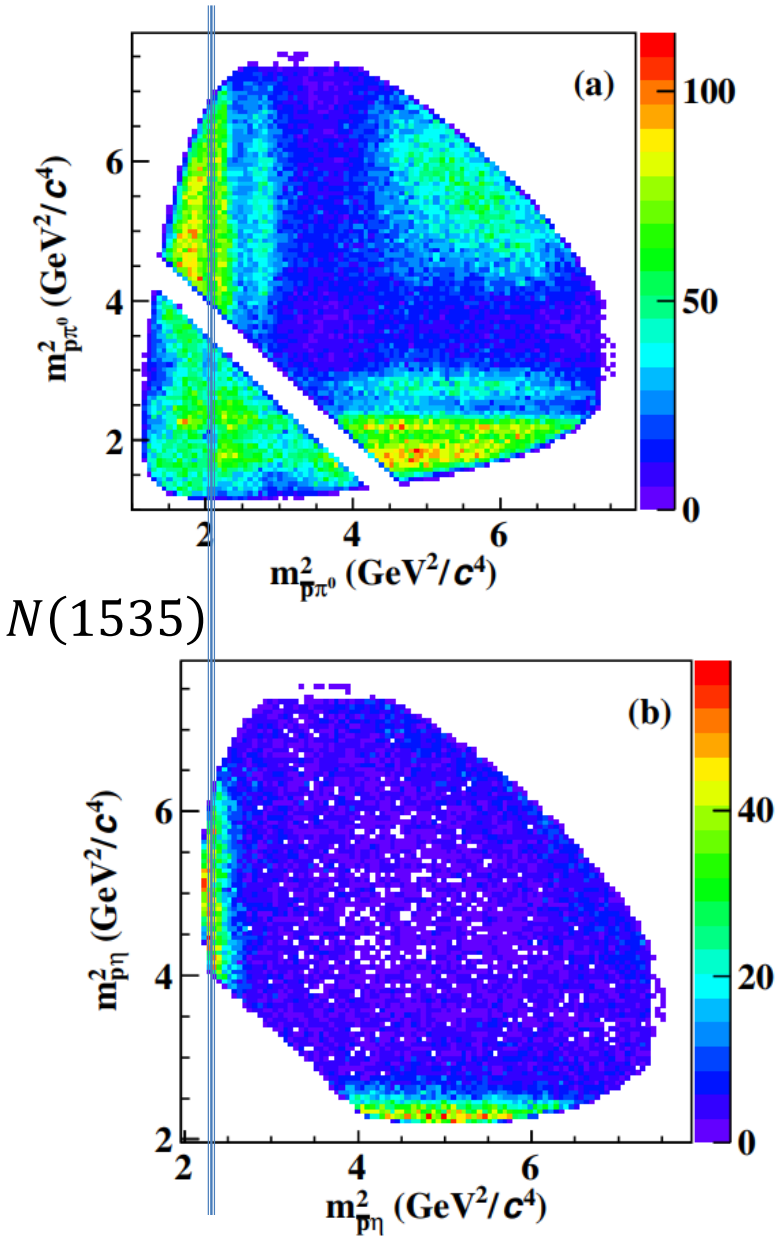
The exotic properties of $N(1535)$

- $N(1535)$: $\Gamma_{N\eta}/\Gamma_{N\pi} = 1.0 \pm 0.4$, $m_{K\Lambda} \sim 1.61$ GeV

Resonance	Br($N^* \to N\pi$)	Br($N^* \to N\eta$)	Br($N^* \to N\pi\pi$)
$N(1440)\frac{1}{2}^+$	(55-75) %	$< 1\%$	$(17-50)\%$
$N(1520)\frac{3}{2}^-$	(55-65) %	(0.05-0.07) %	(25-35) %
$N(1535)\frac{1}{2}^-$	(32-52) %	(30-55) %	(4-31) %

- Inverted mass order
  $N(1440)$: $\sim$ 1.37 GeV, $N(1535)$: $\sim$ 1.51GeV
- Theoretical investigations
  - dynamical generated bound states in $K\Lambda - K\Sigma$ channel
  - Pentaquark $uuds\bar{s}$
  - Lattice QCD simulation

$N(1535)$ in $\psi(3686) \to p\bar{p}\pi^0, p\bar{p}\eta$

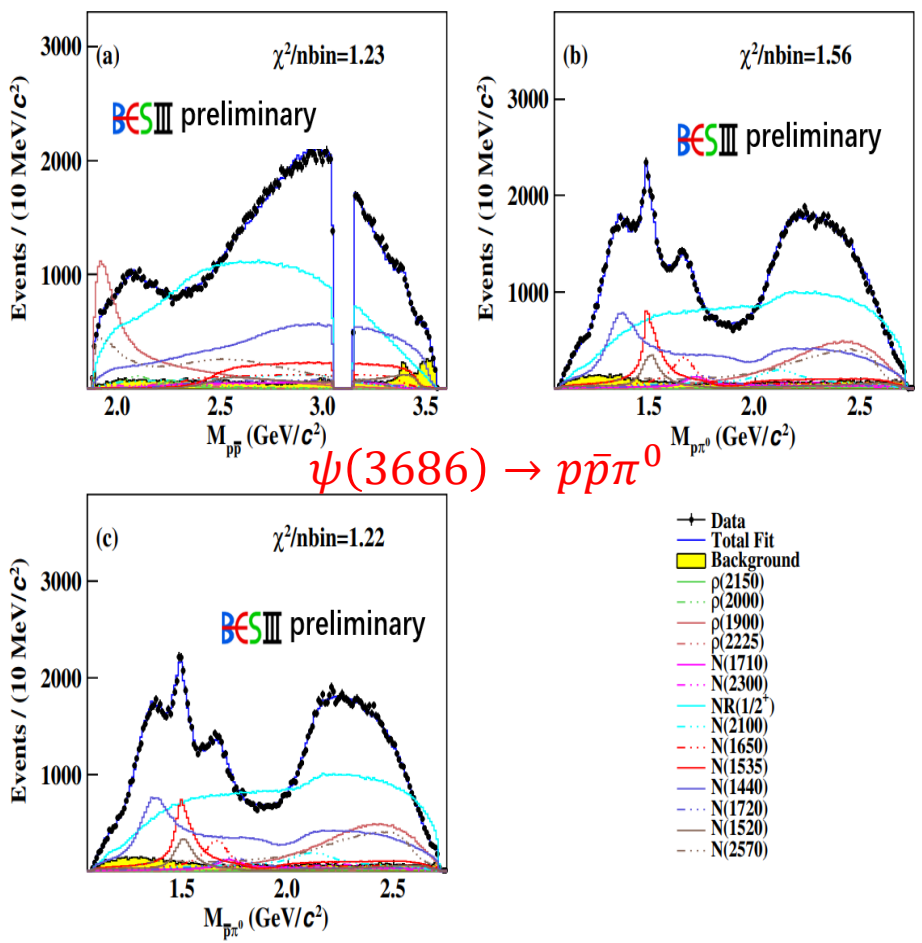


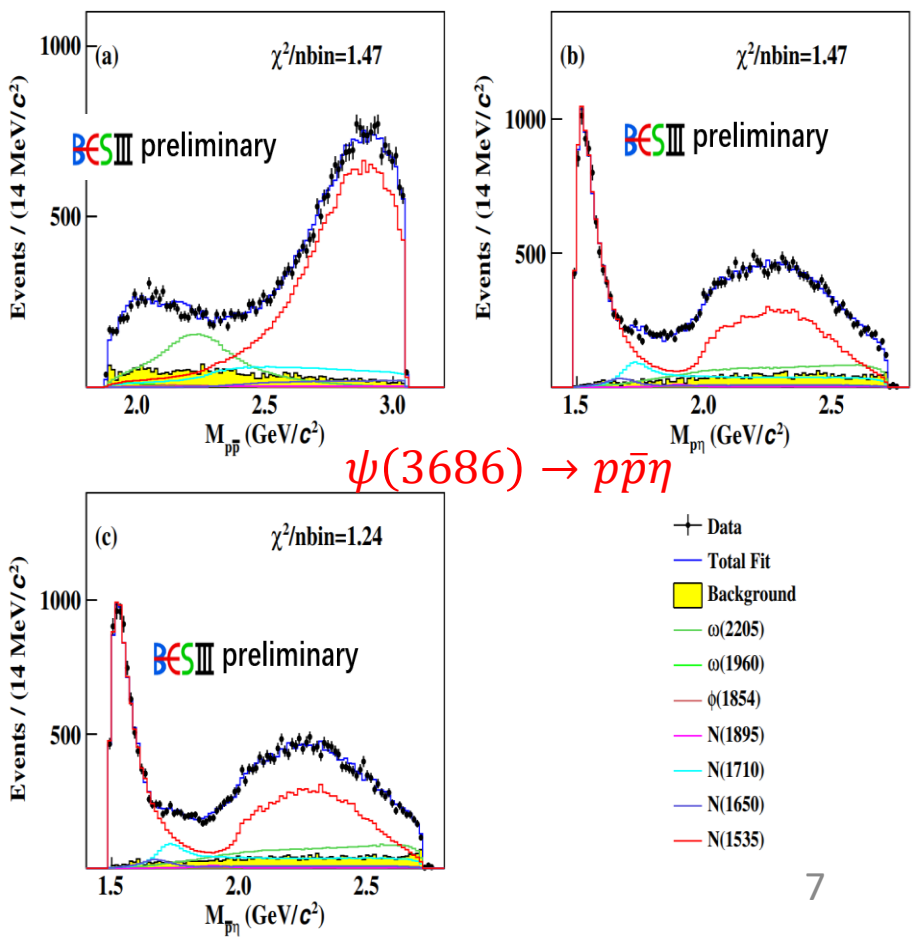
Resonance state	Mass (MeV/c^2)	Width (MeV)	$I^G(J^{PC})$
$\rho(1900)$	1880±30	130±30	$1^+(1^{--})$
$\rho(2000)$	2078±6	149±21	$1^+(1^{--})$
$\rho(2150)$	2254±22	109±76	$1^+(1^{--})$
$\rho(2225)$	2225±35	335±100	$1^+(2^{--})$
$\phi_3(1850)$	1854±7	87±28	$0^-(3^{--})$
$\omega(1960)$	1960±25	195±60	$0^-(1^{--})$
$\omega(2205)$	2205±30	350±90	$0^-(1^{--})$
NR($\frac{1}{2}^+$)	—	—	$\frac{1}{2}(\frac{1}{2}^+)$
$N(1440)$	1406±3	314±9	$\frac{1}{2}(\frac{1}{2}^+)$
$N(1520)$	1512±2	121±3	$\frac{1}{2}(\frac{3}{2}^-)$
$N(1535)$	1525±2	147±5	$\frac{1}{2}(\frac{1}{2}^-)$
$N(1650)$	1666±3	133±7	$\frac{1}{2}(\frac{1}{2}^-)$
$N(1710)$	1710±30	140±60	$\frac{1}{2}(\frac{1}{2}^+)$
$N(1720)$	1720±30	250±100	$\frac{1}{2}(\frac{3}{2}^+)$
$N(1895)$	1895±25	120±80	$\frac{1}{2}(\frac{1}{2}^-)$
$N(2100)$	2100±50	260±60	$\frac{1}{2}(\frac{1}{2}^+)$
$N(2300)$	2300±116	340±114	$\frac{1}{2}(\frac{1}{2}^+)$
$N(2570)$	2570±39	250±70	$\frac{1}{2}(\frac{5}{2}^-)$

PWA of $\psi(3686) \to p\bar{p}\pi^0/\eta$

- ✓ Data can be well described with Several N^*& $\rho^*/\omega^*/\phi^*$ states.
- ✓ Three lowest lying N^* is described with KSU model: $\Gamma(\sqrt{s}) = \Gamma_0 \times \sum r_i \times \frac{\rho_i(\sqrt{s})}{\rho_i(m_0)}$
- ✓ **To measure $\Gamma_{N\eta}/\Gamma_{N\pi}$ of $N(1535)$**

BESIII, PRD, 111, 032011 (2025).

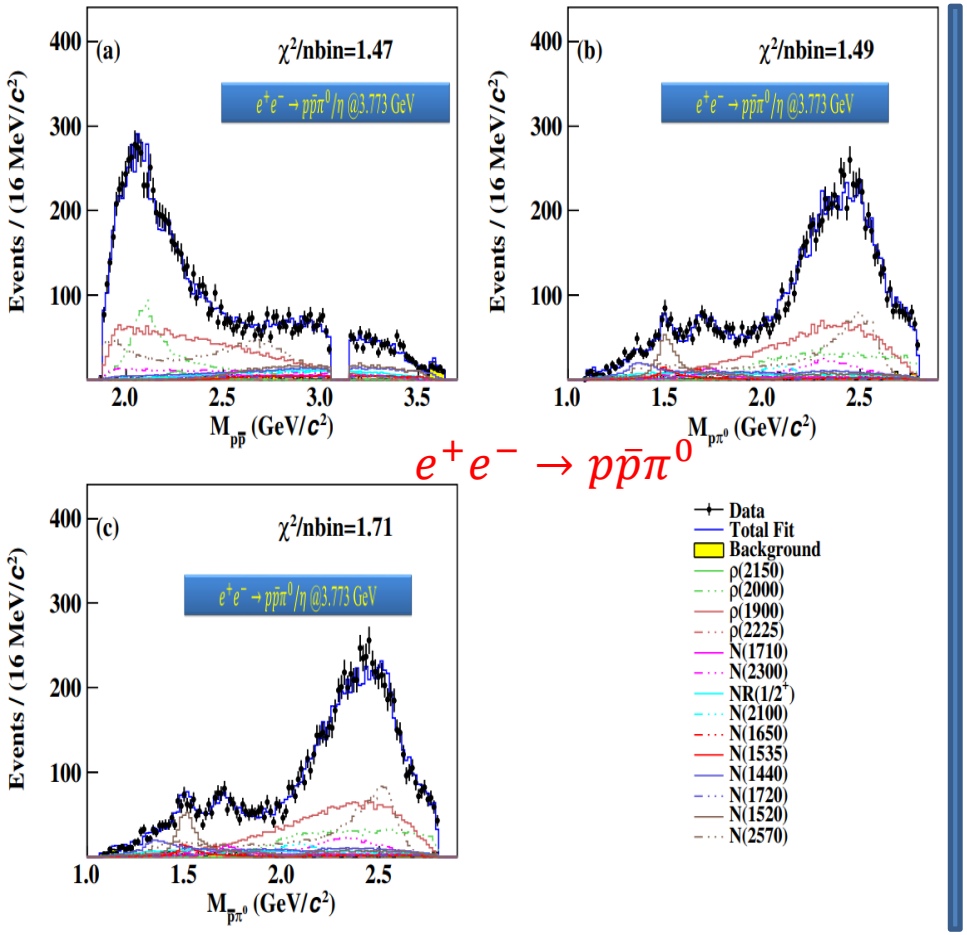


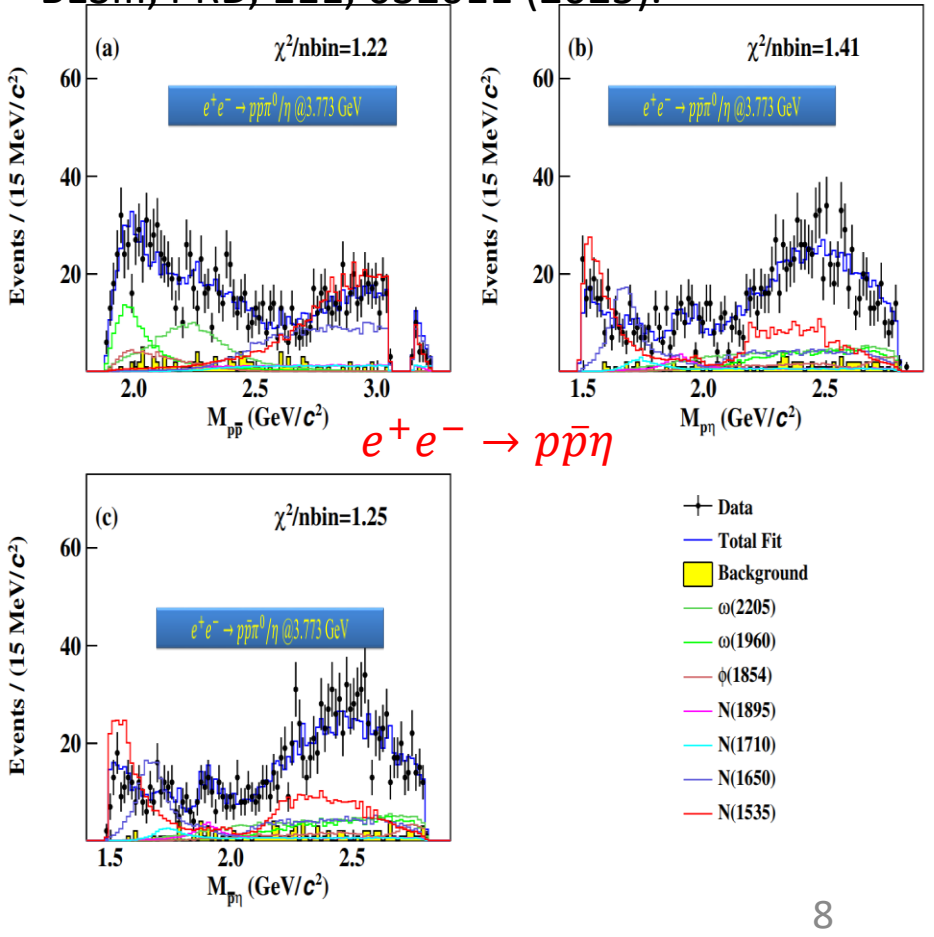


$e^+e^- \to p\bar{p}\pi^0/\eta$ @3.773 GeV

- ✓ **PWA fit is performed @$\sqrt{s} = 3.773$ GeV with 2.93 fb^{-1} to estimate continuum background**
- ✓ **Ignore potential contributions from $\psi(3773) \to p\bar{p}\pi^0/\eta$[12]**
- ✓ **The same sets of intermediate states are considered as @$\sqrt{s} = 3.686$ GeV**

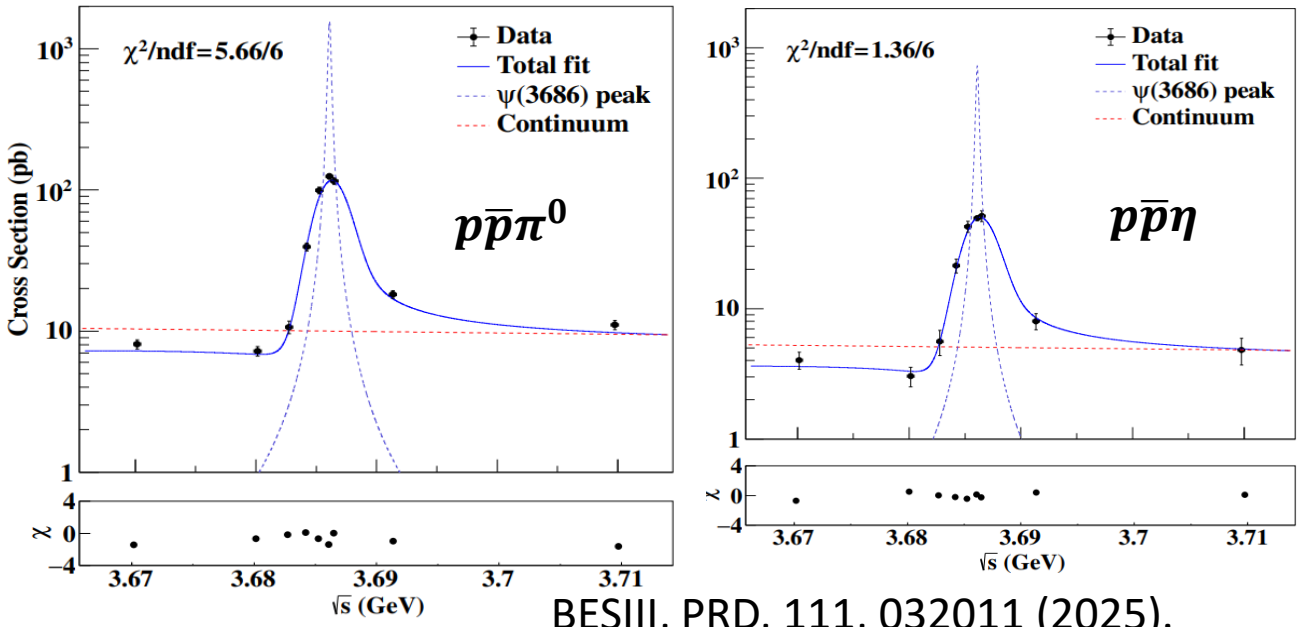
BESIII, PRD, 111, 032011 (2025).





$e^+e^- \to p\bar{p}\pi^0/\eta$ @$\sqrt{s} = 3.67 \sim 3.709$ GeV

$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})
3670.16	84.7
3680.14	84.8
3682.75	28.7
3684.22	28.7
3685.26	26.0
3686.10	3877.1
3686.50	25.1
3691.36	69.4
3709.76	70.3



BESIII, PRD, 111, 032011 (2025).

- ✓ The $\frac{\Gamma_{N(1535)\to N\eta}}{\Gamma_{N(1535)\to N\pi}}$ **is determined to be $0.99 \pm 0.05_{sta.}$**, confirms the fixed target experiment results listed by PDG.
- ✓ The strong coupling to Nη suggest a **significant $s\bar{s}$ component** in $N(1535)$, possibly $uud + s\bar{s}$? Need to be confirmed in $K\Lambda$ final state!
- ✓ The other N^* structures in $\psi' \to p\bar{p}\pi^0/\eta$ are studied & branching fraction measured.
- ✓ $\frac{B(\psi(3686))}{B(J/\psi)}$ ~12% confirmed by $p\bar{p}\pi^0$ channel, but violated by $p\bar{p}\eta$ channel.

Status of Λ^* and Σ^* states

- Λ, Σ hyperon excited states PDG entries

$\Lambda(1710)$	$1/2^+$	*	$\Sigma(1780)$	$3/2^+$	*	Σ^+	$1/2^+$	****
$\Lambda(1800)$	$1/2^-$	***	$\Sigma(1880)$	$1/2^+$	**	Σ^0	$1/2^+$	****
$\Lambda(1810)$	$1/2^+$	***	$\Sigma(1900)$	$1/2^-$	**	Σ^-	$1/2^+$	****
$\Lambda(1820)$	$5/2^+$	****	$\Sigma(1910)$	$3/2^-$	***	$\Sigma(1385)$	$3/2^+$	****
$\Lambda(1830)$	$5/2^-$	****	$\Sigma(1915)$	$5/2^+$	****	$\Sigma(1580)$	$3/2^-$	*
$\Lambda(1890)$	$3/2^+$	****	$\Sigma(1940)$	$3/2^+$	*	$\Sigma(1620)$	$1/2^-$	*
$\Lambda(2000)$	$1/2^-$	*	$\Sigma(2010)$	$3/2^-$	*	$\Sigma(1660)$	$1/2^+$	***
$\Lambda(2050)$	$3/2^-$	*	$\Sigma(2030)$	$7/2^+$	****	$\Sigma(1670)$	$3/2^-$	****
$\Lambda(2070)$	$3/2^+$	*	$\Sigma(2070)$	$5/2^+$	*	$\Sigma(1750)$	$1/2^-$	***
$\Lambda(2080)$	$5/2^-$	*	$\Sigma(2080)$	$3/2^+$	*	$\Sigma(1775)$	$5/2^-$	****
$\Lambda(2085)$	$7/2^+$	**	$\Sigma(2100)$	$7/2^-$	*			
$\Lambda(2100)$	$7/2^-$	****	$\Sigma(2160)$	$1/2^-$	*			
$\Lambda(2110)$	$5/2^+$	***	$\Sigma(2230)$	$3/2^+$	*			
$\Lambda(2325)$	$3/2^-$	*	$\Sigma(2250)$		***			
$\Lambda(2350)$	$9/2^+$	***	$\Sigma(2455)$		**			
$\Lambda(2585)$		**	$\Sigma(2620)$		**			
			$\Sigma(3000)$		*			
			$\Sigma(3170)$		*			

4 Λ^* and 8 Σ^* exist certainly

****: Existence is certain, and properties are measured.
***: Existence is very likely, but QN, BRs, etc. are not clearly determined.
**: Evidence of existence is only fair.
*: Evidence of existence is poor.

Two-pole structure of $\Lambda(1380)$ and $\Lambda(1405)$

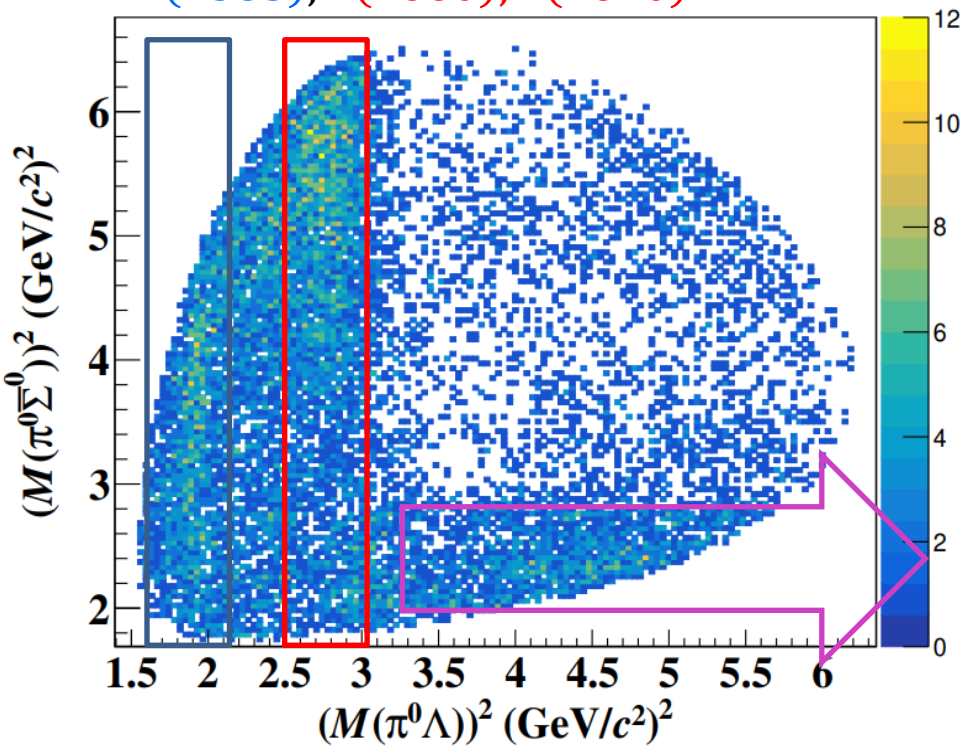
- $\Lambda(1405)$ is the lightest baryon excitation in the strangeness $S = -1$ region, located below the $\bar{K}N$ threshold.
- The conventional quark model hard to explain its mass and properties, indicting it might be a dynamically generated state from strong interactions.
- The chiral unitary approach reveals it is not a single resonance, but consists of two poles, corresponding to:
  - $\Lambda(1405)$: Narrower, located at ~1420 MeV
  - $\Lambda(1380)$: Broader, located at ~1380 MeV

Refs.	pole 1 [MeV]	pole 2 [MeV]
PLB706,63;NPA881,98	$1424^{+7}_{-23} - i\ 26^{+3}_{-14}$	$1381^{+18}_{-6} - i\ 81^{+19}_{-8}$
PRC87,035202	$1421^{+3}_{-2} - i\ 19^{+8}_{-5}$	$1388^{+9}_{-9} - i\ 114^{+24}_{-25}$
EPJA51,30	$1434^{+2}_{-2} - i\ 10^{+2}_{-1}$	$1330^{+4}_{-5} - i\ 56^{+17}_{-11}$
EPJA51,30	$1429^{+8}_{-7} - i\ 12^{+2}_{-3}$	$1325^{+15}_{-15} - i\ 90^{+12}_{-18}$

Λ^*, Σ^* in $\psi(3686) \to \Lambda\bar{\Sigma}^0\pi^0$

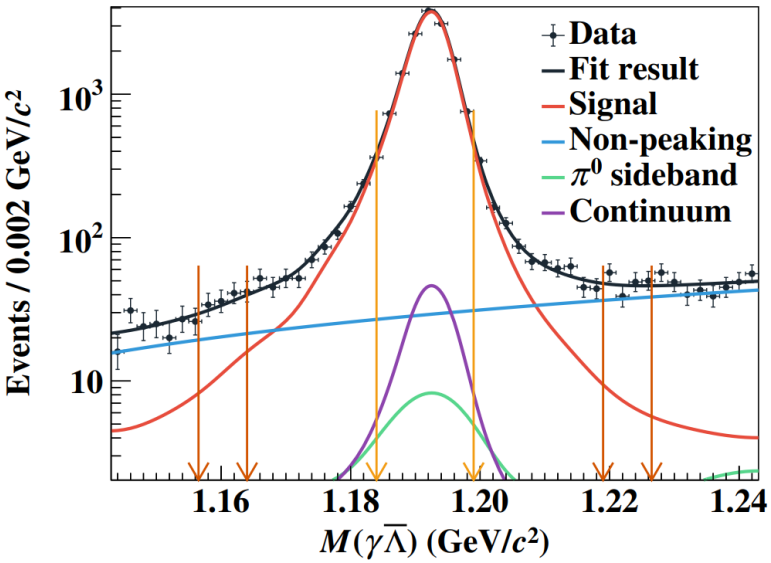
- Using $(2712.4 \pm 14.3) \times 10^6$ $\psi(3686)$ data sample
- To reconstruct decay with $\Sigma^0 \to \gamma\Lambda, \Lambda \to p\pi^-$ and $\pi^0 \to \gamma\gamma$
- 14,414 event from data, and 235 continuum background events.
- Helicity amplitude analysis

$\Sigma(1385), \Sigma(1660), \Sigma(1670)$



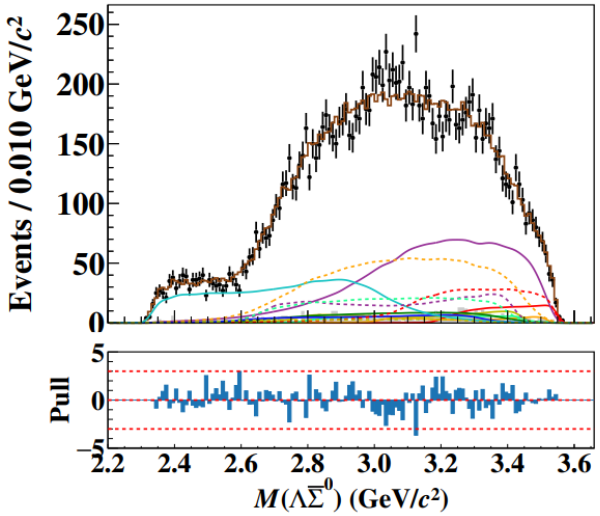
$\Lambda(1405), \Lambda(1520),$
$\Lambda(1670), \Lambda(1690)$

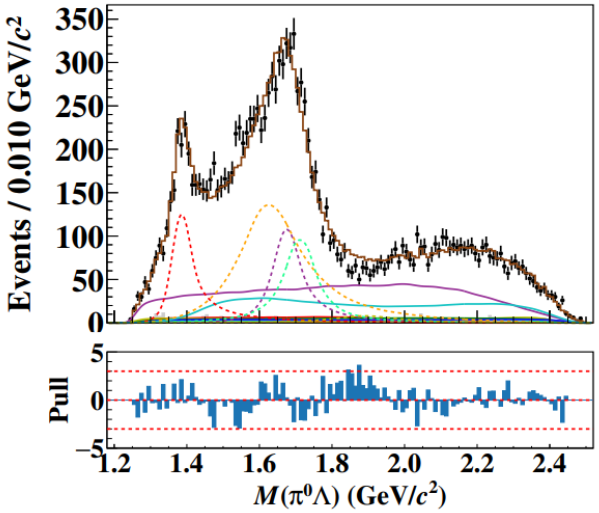
Σ signal region and sideband

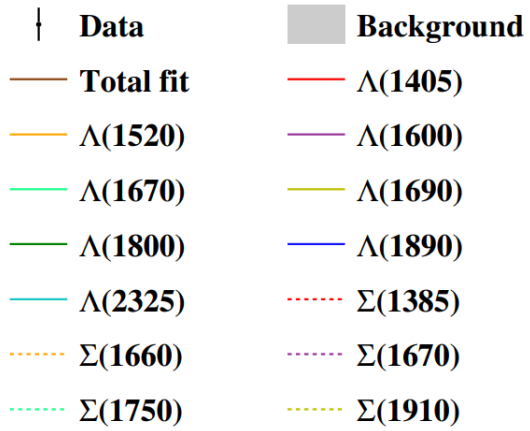


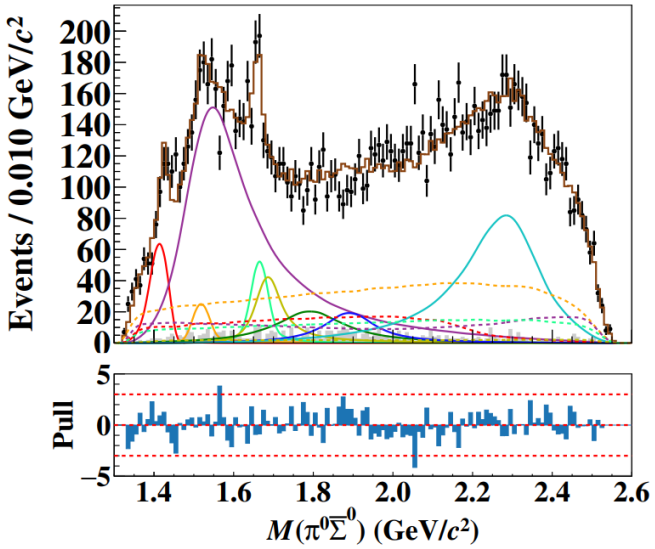
BESIII, JHEP 02(2025), 212

Λ^*, Σ^* in $\psi(3686) \to \Lambda\bar{\Sigma}^0\pi^0$









- Background subtraction from $-\ln\mathcal{L}$
- Nominal fit: $> 5\sigma$
- Masses and widths are float
- $M(\Lambda\bar{\Sigma})$ description without ρ^* or a^*
- $M(\pi^0\Lambda)$ description with Σ^* below 2.0 GeV.
- Need $\Lambda(2325)$ in high mass region

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$\Lambda(1380), \Lambda(2325)$ in $\psi(3686) \to \Lambda\bar{\Sigma}^0\pi^0$

- Two-pole structure of $\Lambda(1380)$

  Nominal fit: chiral dynamics model

  Breit-Wigner → $R(m) = [I - GV]^{-1}$, Ref. Nuclear Physics A 725 (2003) 181
  Significance test: 11.1σ, ratio: $(3.0 \pm 3.3)\%$

  Alternative fit: Flatte-like formula, coupling to $\pi\Sigma$ and $\bar{K}N$ channels
  Significance test: 11.2σ, ratio: $(6.7 \pm 0.9)\%$

- Observation of $\Lambda(2325)$

  $M = 2306.5 \pm 6.3 \pm 17.1$ MeV, $\Gamma = 227.1 \pm 12.2 \pm 47.8$ MeV

J^P	ΔNLL	$\Delta N_{\rm dof}$	Significance (σ)
$1/2^-$	188.0	6	18.7
$1/2^+$	186.8	6	18.6
$3/2^-$	208.3	8	19.5
$3/2^+$	198.8	8	19.1

J^P is determined to be: $\frac{3}{2}^-$

Summary

- $N(1535)$ shows large $N\eta$ coupling ($\Gamma(N\eta)/\Gamma(N\pi) \approx 0.99$), suggesting exotic $\bar{s}s$ content.
- $\Lambda(1380)$ observed ($> 11\sigma$) in $\psi(3686) \to \Lambda\bar{\Sigma}^{0}\pi^{0}$, supporting $\Lambda(1405)$ two-pole structure; new $\Lambda(2325)$ with $J^{\mathrm{P}} = 3/2^{-}$ identified.
- Systematic Λ/Σ spectroscopy advances light baryon understanding via high-precision PWA.
- More light baryon spectrum analysis ongoing

Thanks for your attention !