QNP2022 - The 9th International Conference on Quarks and Nuclear Physics

Baryon in Charmonium decays at BESIII

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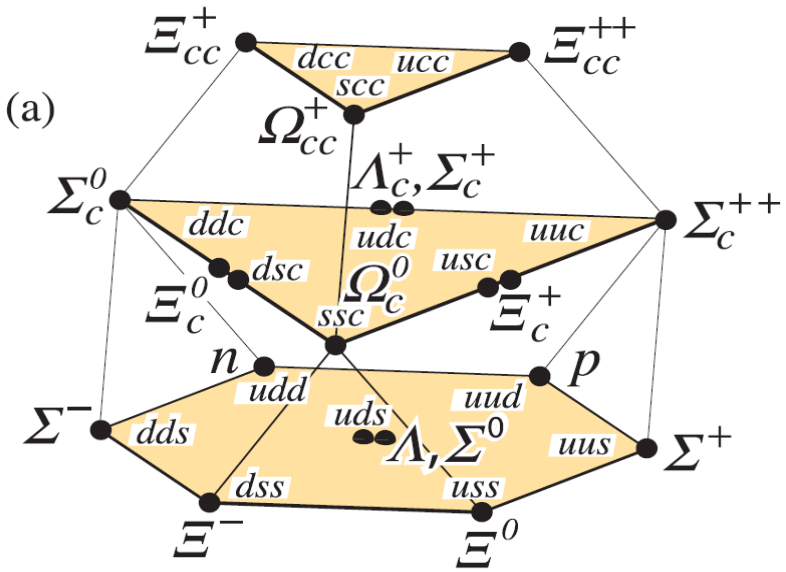
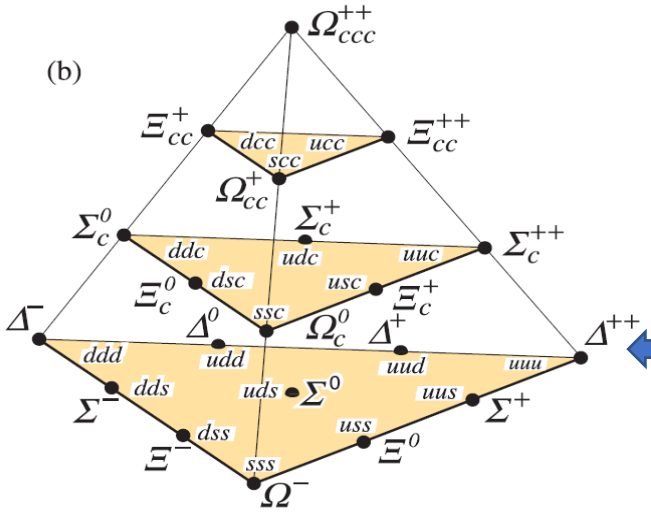
Baryon spectroscopy





First glimpse in 1952, Reveal the color degrees of freedom

Issues in baryon spectroscopy:

- N^* **missing states**
- **Roper resonance** $N_{1/2^+}$ (1440)
- $N_{1/2^-}(1535)$
- $\Lambda_{1/2^-}(1405)$
- **.....**

Bayon excitation in J/ψ and ψ' decays

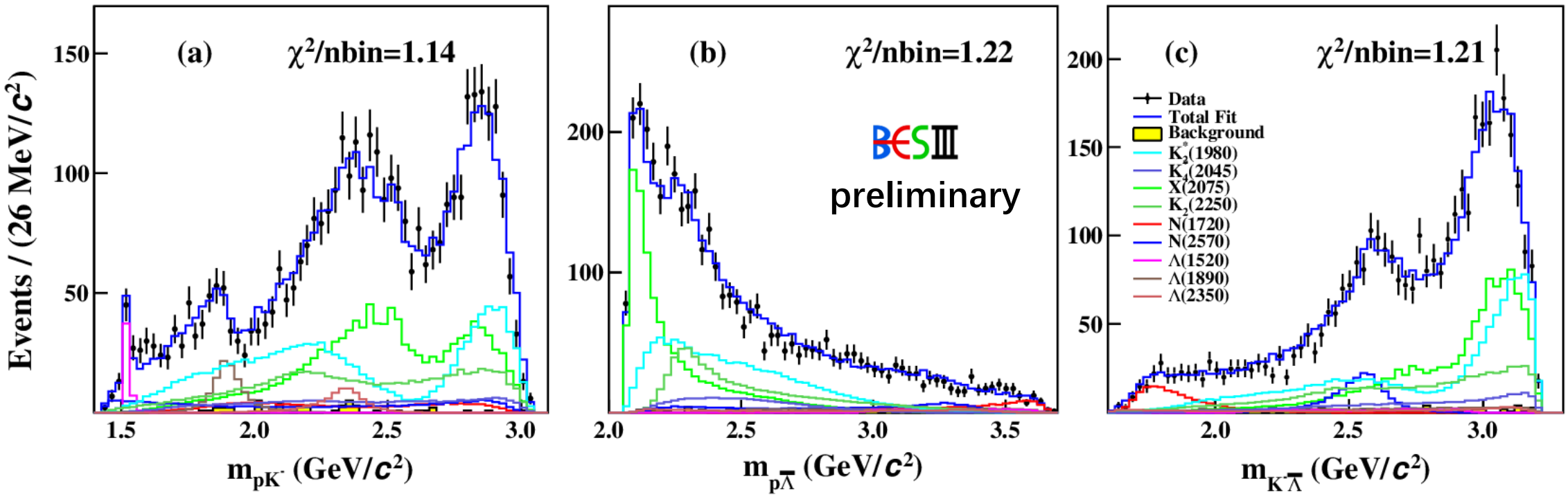
Candidate produced in 10 billion J/ψ and 3 billion $\psi(2S)$

X	$N(J/\psi \to X) \times 10^6$	$N(\psi' \to X) \times 10^6$
$N\bar{N}\pi$	97	2.28
$p\bar{p}\pi^+\pi^-$	60	1.8
$N\bar{N}\eta$	41.8	0.17
$\Lambda\bar{\Lambda}\eta$	1.6	0.075
$pK^-\bar{\Lambda} + \mathrm{c.c.}$	8.6	0.3
$pK^-\bar{\Sigma}^0$	2.9	0.051
$\Sigma\bar{\Lambda}\pi$	8.3	0.462

Big challenge for PWA
Software : Feynman Diagram Calculation (FDC)

Λ^* and N^* in $e^+e^- \to pK^-\bar{\Lambda} + c.c.$ at 4.178 GeV

- Using continuum data of 3189/pb, reconstruct decay with $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$.
- Partial wave analysis performed to 3833 candidates



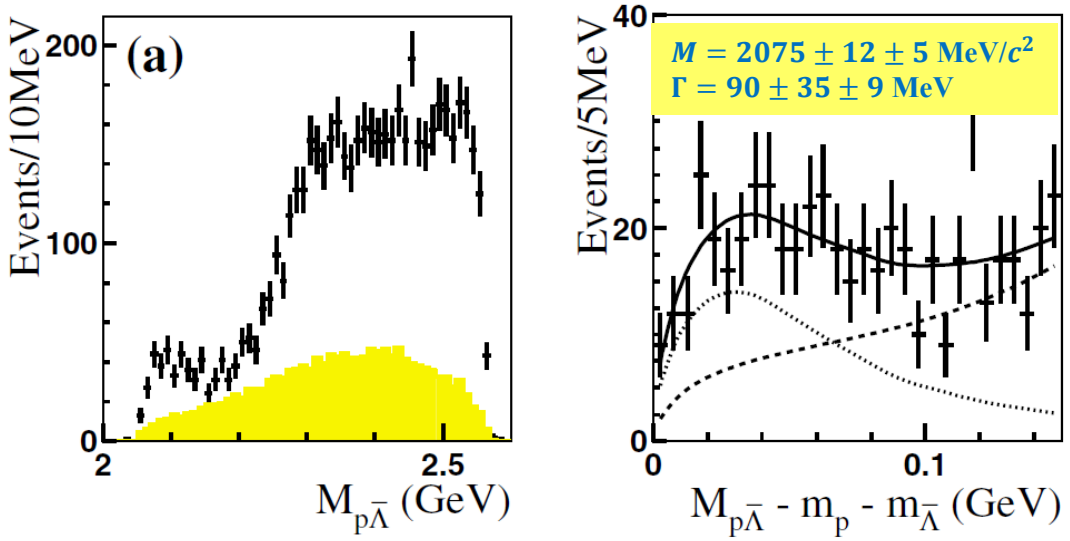
$\Lambda(1520), \Lambda(1890), \Lambda(2350)$

$K_2^*(1980), K_4^*(2045), X(2045)$
$K_2(2250)$

$N(1720), N(2570)$

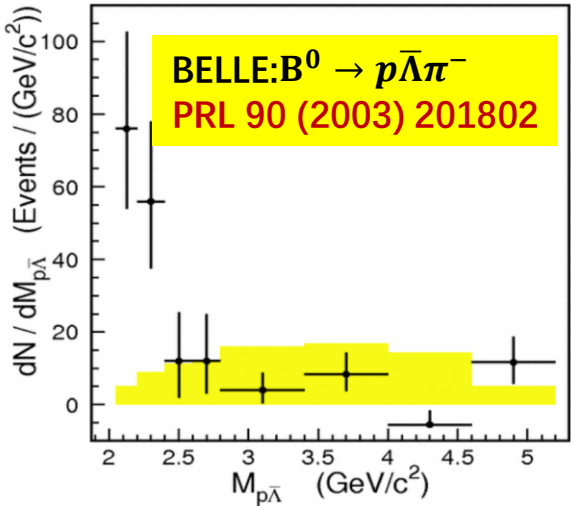
$p\bar{\Lambda}$ threshold enhancement $X(2075)$

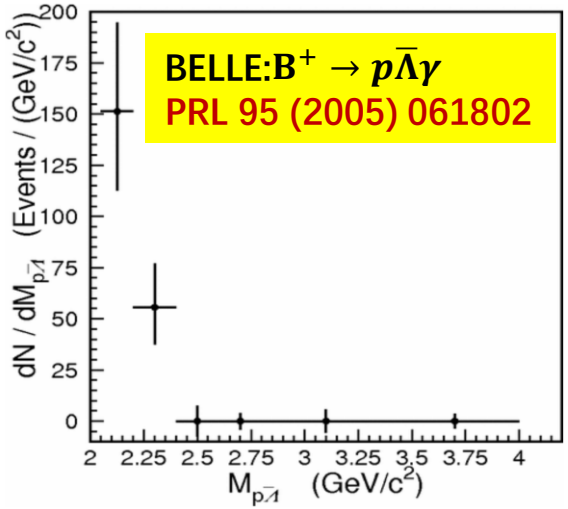
BESII: $J/\psi \to pK^-\bar{\Lambda} + c.c.$
PRL 93 (2004) 112002

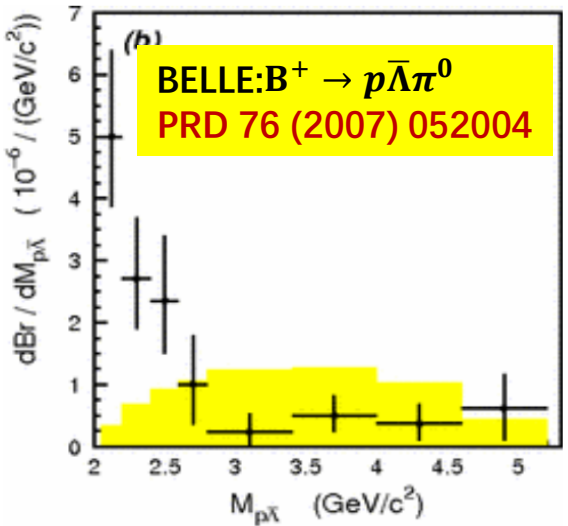


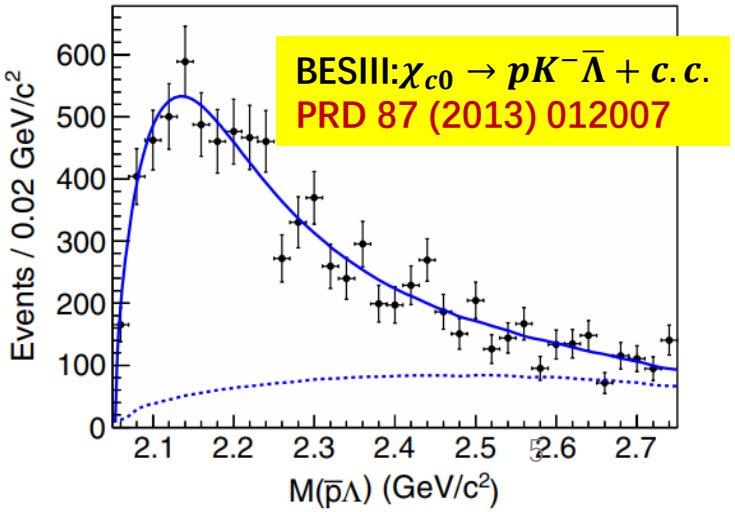
Motivation

- Observed at BESII in 2004
- Similar structure was seen in several B meson and charmonium decays
- Investigated theoretically under scenario of quark model, FSI and chiral effective theory









Λ^* and N^* in $e^+e^- \to pK^-\bar{\Lambda} + c.c.$ at 4.178 GeV

Resonance	M (MeV/c^2)	Γ(MeV)	Significance	FF(%)
$X(2075)$	2122 ± 7	144 ± 12	>20	28.8 ± 2.3
$K(1980)$	1995	349	8.2	29.7 ± 2.6
$K(2045)$	2048	199	6.7	6.1 ± 2.0
$K(2250)$	2247	180	8.8	17.7 ± 1.4
$N(1720)$	1720	250	5.8	4.0 ± 0.8
$N(2570)$	2570	250	6.1	5.2 ± 1.0
$\Lambda(1520)$	1519	16	7.8	1.2 ± 0.4
$\Lambda(1890)$	1890	120	5.2	3.0 ± 0.5
$\Lambda(2350)$	2350	150	5.0	2.1 ± 0.7

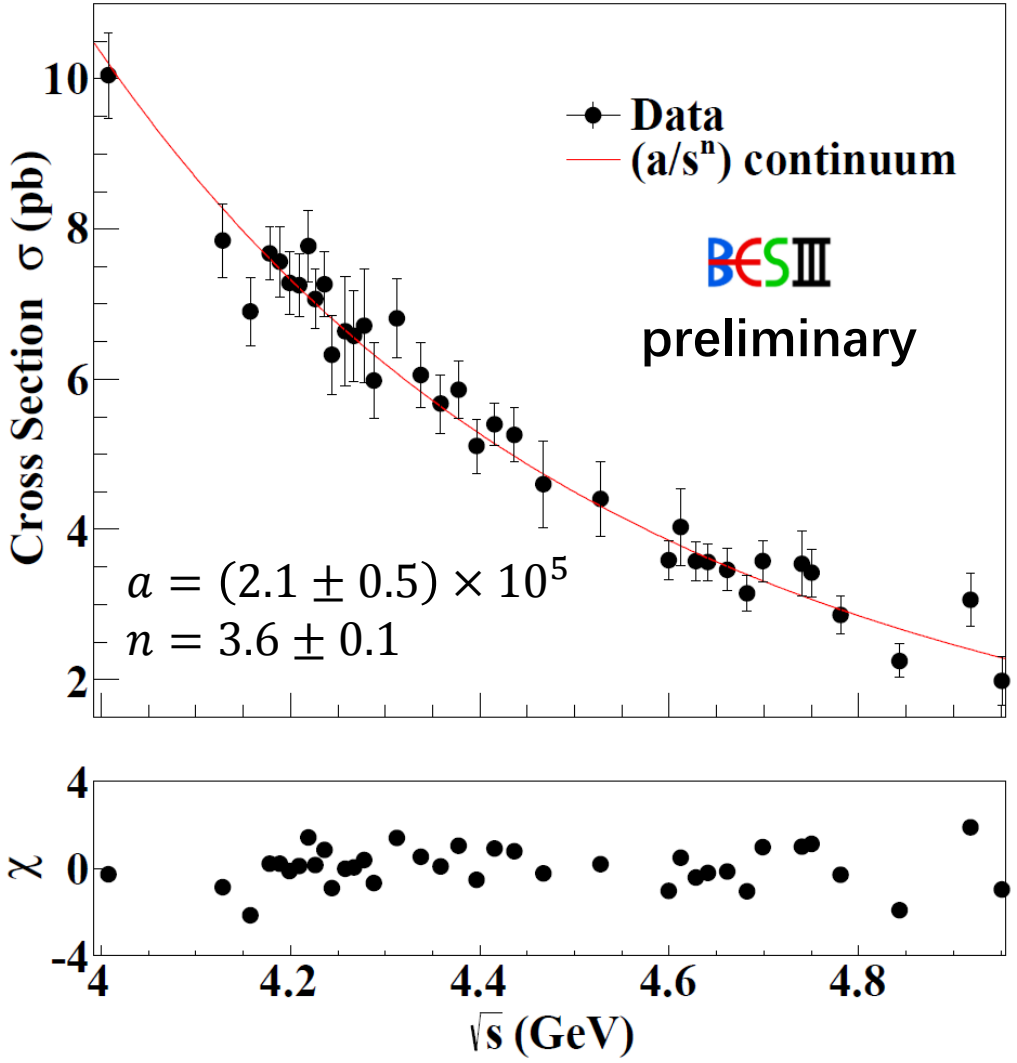
BESIII preliminary:

- **N^* contribution up to ~9%**
- **Λ^* up to ~6%**
- **dominant K^* contribution: ~80%**

- **Statistical significance of $X(2075) > 20\sigma$**
- $X(2075)$ **described with a Breit-Wigner function of mass-dependent width**
  $M_{pole} = 2085 \pm 6 \pm 6$ **MeV/c^2;** $\Gamma_{pole} = 62 \pm 10 \pm 16$ **MeV**
- **J^P is determined to be 1^+ ($> 5\sigma$), P-wave structure, with significance >5σ over other J^P numbers.**

J^P	$\sqrt{\Delta(-2\ln L)}$
1^+	---
0^-	9.3
1^-	8.1
2^+	9.8
2^-	5.7

The Born cross sections of $e^+e^- \to pK^-\bar{\Lambda} + c.c.$



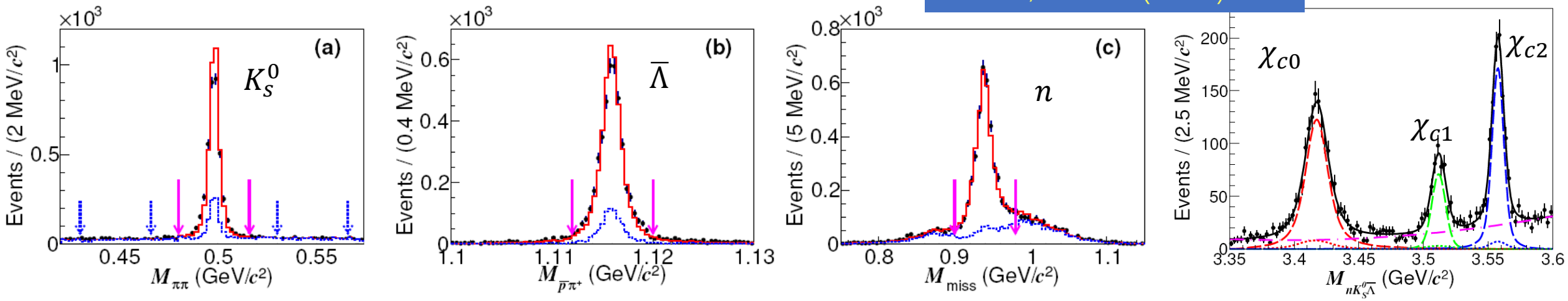
- Born cross sections of $e^+e^- \to pK^-\bar{\Lambda} + c.c.$ are measured at 37 energy points within $\sqrt{s}$=4.009-4.946 GeV with $\sum\mathcal{L} = 21.7\ fb^{-1}$
- Several well-established charmonium-(like) states are checked, none of which yields significance greater than 1.8σ.

Resonance	χ^2/ndf	Significance
Continuum only	60.96/35	---
$\psi(4160)$	56.73/33	1.6
$\psi(4230)$	60.96/33	<0.1
$\psi(4260)$	60.25/33	0.4
$\psi(4360)$	55.72/33	1.8
$\psi(4415)$	55.97/33	1.7
$\psi(4660)$	60.96/33	<0.1

N^* and Λ^* in $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

- **Using hadronic decays to test χ_{cJ} color-octet decay mechanisms**
- **Search for threshold enhancement of baryon pairs, e.g. $J/\psi \to \gamma p\bar{p}$**
- **448 million $\psi(3686)$ decays**
- **reconstruct $\chi_{cJ} \to pK_S^0\bar{\Lambda} + c.c.$ Via $\psi(3686) \to \gamma\chi_{cJ}$ decays, using $K_S^0 \to \pi^+\pi^-$ and $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$**

BESIII, JHEP11(2021)217



Mode	$\mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda})(\times 10^{-4})$	$\mathcal{B}(\chi_{cJ} \to nK_S^0\Lambda + c.c)(\times 10^{-4})$	$\frac{\mathcal{B}(\chi_{cJ} \to pK^-\bar{\Lambda} + c.c.)}{\mathcal{B}(\chi_{cJ} \to nK_S^0\Lambda + c.c.)}$
χ_{c0}	$3.64 \pm 0.10 \pm 0.10 \pm 0.07$	$6.65 \pm 0.26 \pm 0.41$	$1.98 \pm 0.09 \pm 0.14$
χ_{c1}	$1.31 \pm 0.06 \pm 0.06 \pm 0.03$	$1.66 \pm 0.12 \pm 0.12$	$2.71 \pm 0.24 \pm 0.20$
χ_{c2}	$1.91 \pm 0.08 \pm 0.17 \pm 0.04$	$3.58 \pm 0.16 \pm 0.23$	$2.35 \pm 0.14 \pm 0.16$

Mode	$N_{1,J}$
χ_{c0}	1284 ± 50
χ_{c1}	399 ± 30
χ_{c2}	879 ± 40

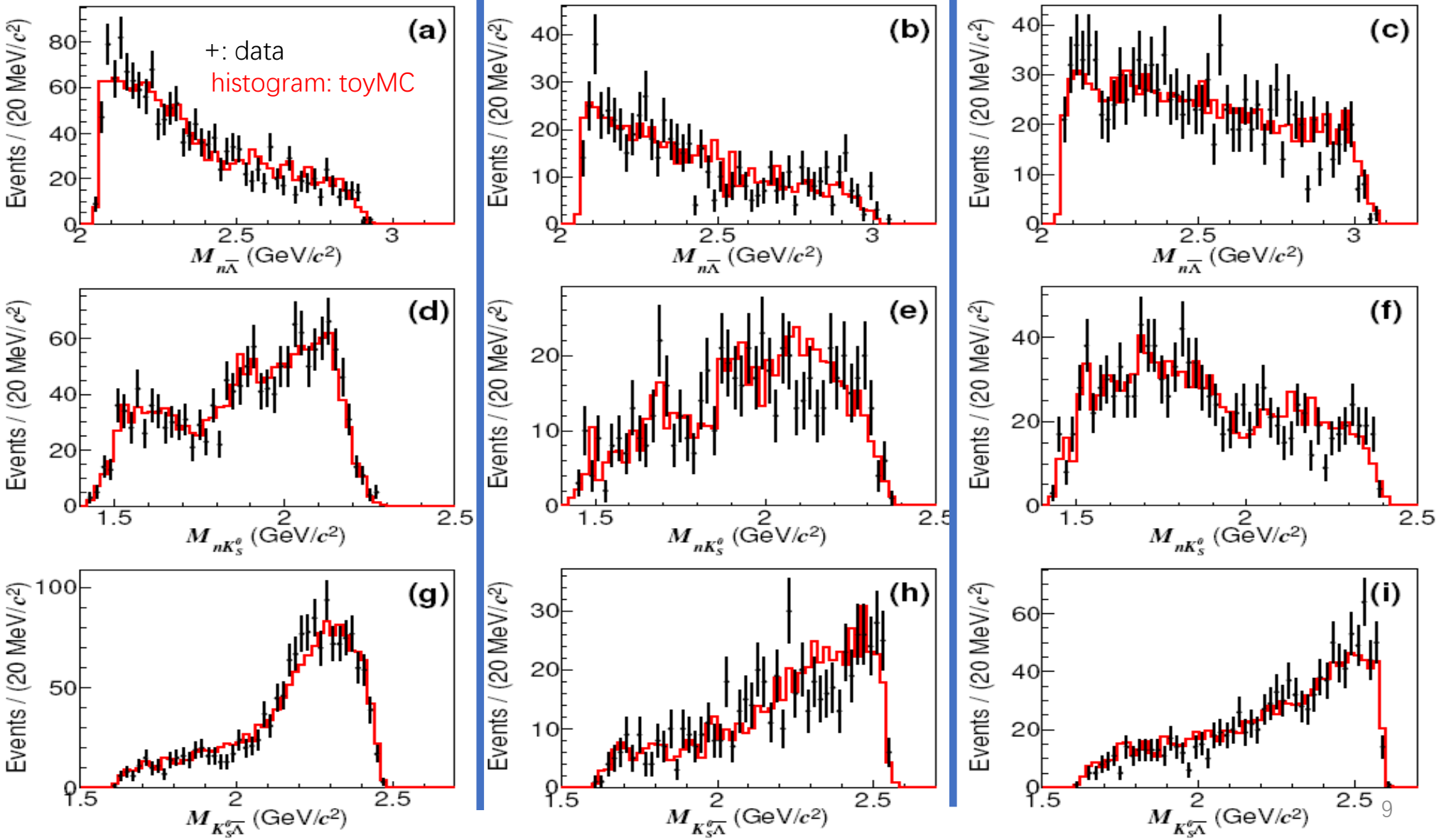
N^* and Λ^* in $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

χ_{c0} χ_{c1} χ_{c2}

$K_2(2250)$

$\Lambda(1405)$, $\Lambda(1520)$
$\Lambda(1600)$, $\Lambda(1670)$
$\Lambda(1690)$, $\Lambda(1800)$
$\Lambda(1890)$, $\Lambda(2000)$
$\Lambda(2020)$, $\Lambda(2100)$
$\Lambda(2110)$, $\Lambda(2325)$
$\Lambda(2350)$

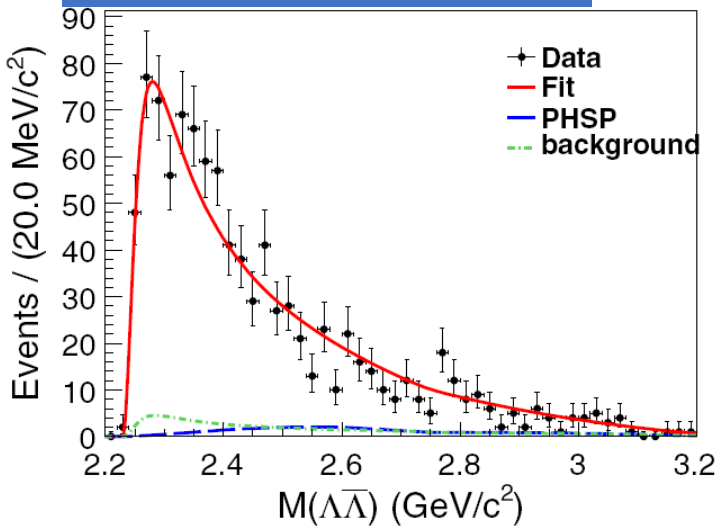
$N^*(2300)$

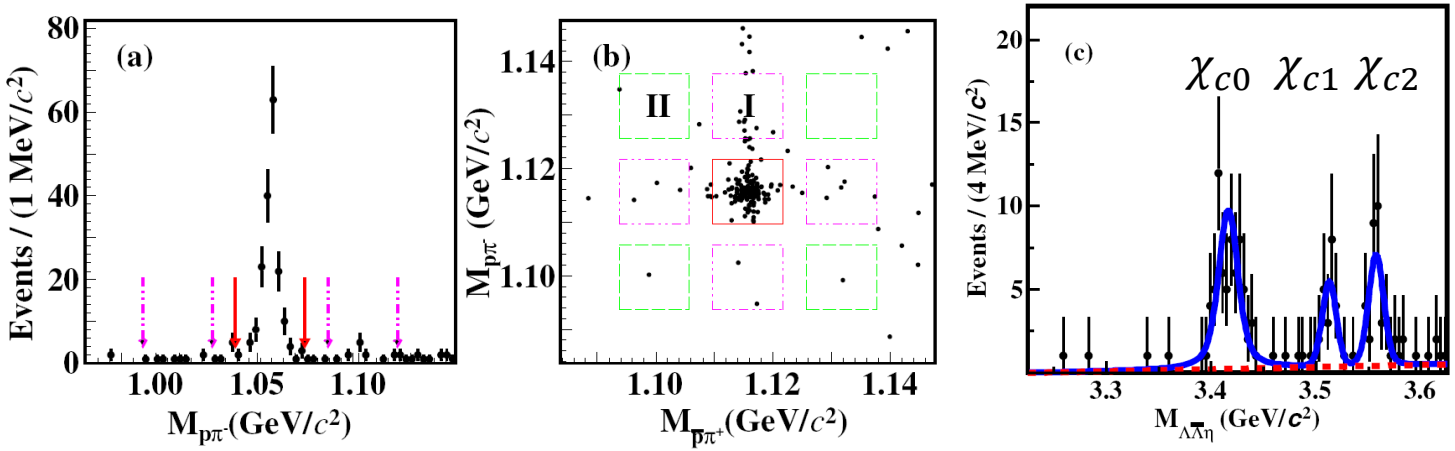


Λ^* in $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$ decays

- **A strong threshold enhancement observed in** $e^+e^- \to \phi\Lambda\bar{\Lambda}$**,**
- $J^{PC} = 0^{-+}/0^{++}$ **rejected with significance** $> 7\sigma$**, veto** $\eta(2225) \to \Lambda\bar{\Lambda}$
- **Using 448 million decays, search for** $\Lambda\bar{\Lambda}$ **enhancement** $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$
- **Reconstruct decay using** $\psi(3686) \to \gamma\chi_{cJ}$**, and** $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+), \eta \to \gamma\gamma$

BESIII, PRD104, 052006 (2021)





Signal yields:

$\chi_{c0}: 66.9 \pm 8.8, \chi_{c1}: 21.3 \pm 5.0$

$\chi_{c2}: 31.6 \pm 6.2$

$\mathcal{B}(\chi_{c0} \to \Lambda\bar{\Lambda}\eta) = (2.31 \pm 0.30 \pm 0.21) \times 10^{-4}$

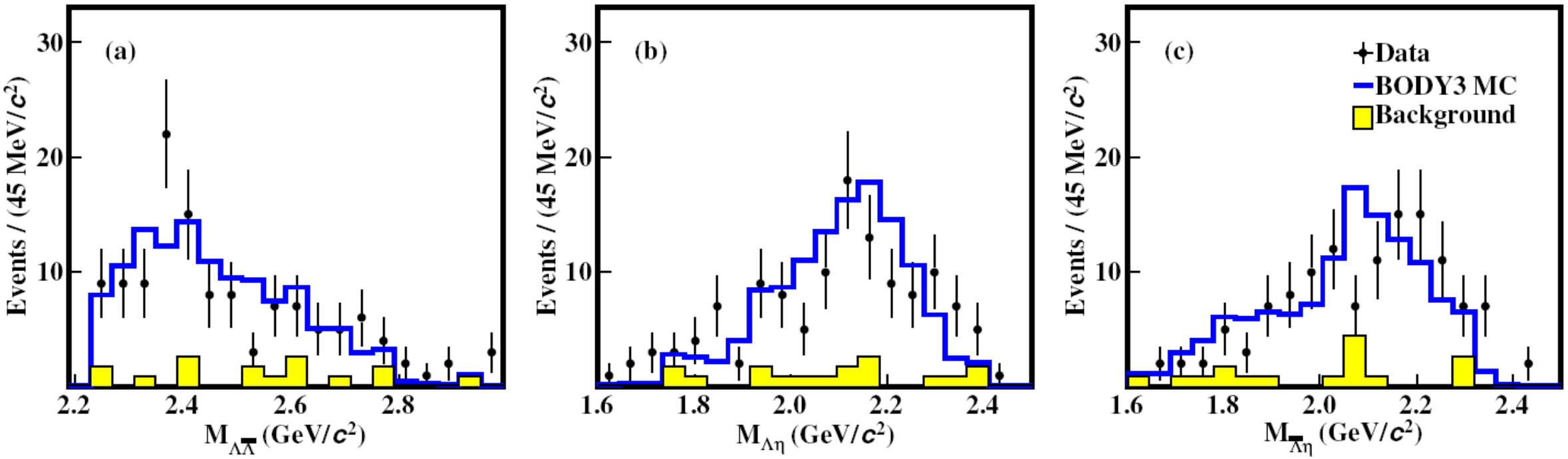
$\mathcal{B}(\chi_{c1} \to \Lambda\bar{\Lambda}\eta) = (5.86 \pm 1.38 \pm 0.68) \times 10^{-5}$

$\mathcal{B}(\chi_{c2} \to \Lambda\bar{\Lambda}\eta) = (1.05 \pm 0.21 \pm 0.15) \times 10^{-4}$

Λ^* in $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$ decays

Mass spectrum in the mass regions of three χ_{cJ} states

BESIII: arXiv: 2206.12255



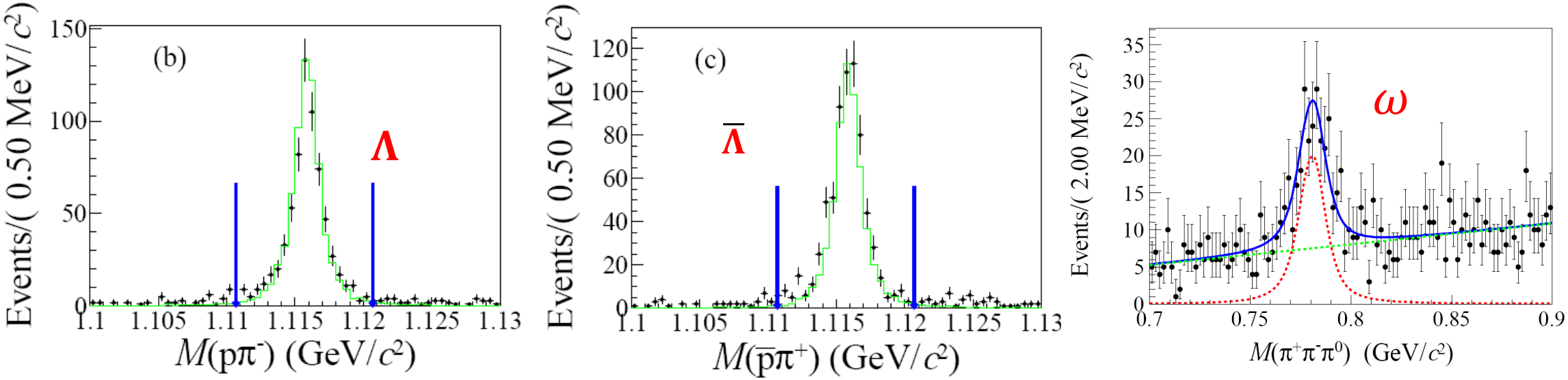
Evidence for

- $\Lambda\bar{\Lambda}$ **mass threshold enhancement**
- $\Lambda(1890)\frac{3}{2}^-$ $\Lambda(2100)\frac{7}{2}^-$, $\Lambda(2110)\frac{5}{2}^+$ **may contribute to** $\Lambda\eta$ $(\bar{\Lambda}\eta)$ **spectrum**
- **More data is need to do PWA**

Evidence for $\Lambda^* \to \Lambda\omega$ in $\psi(3686) \to \Lambda\bar{\Lambda}\omega$

- **Close to $\Lambda\omega$ mass threshold, two Λ^* states observed decays to $\Lambda\omega$, e.g.** $\Lambda(2100)\ 7/2^-, \Lambda(2110)\ 5/2^+$**.**
- **Using 448 million $\psi(3686)$ decays, and reconstruct decay with $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$, $\omega \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$.**

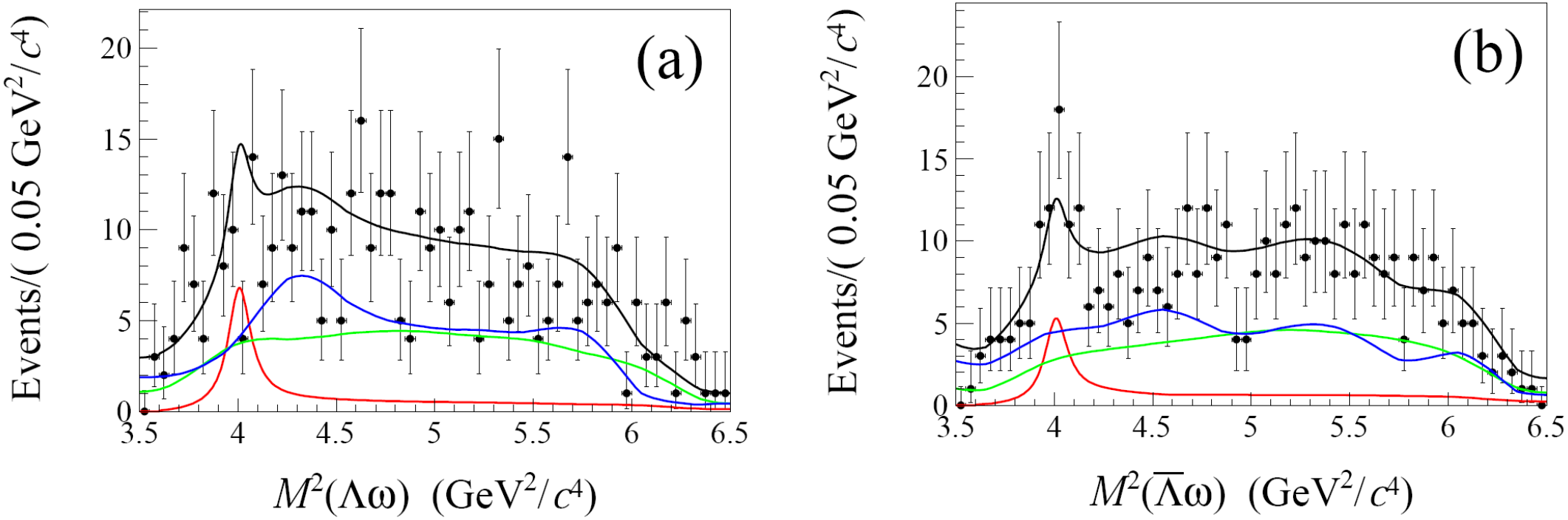
BESIII, arXiv: 2207.11666



$$Br(\psi(3686) \to \Lambda\bar{\Lambda}\omega) = (3.30 \pm 0.34 \pm 0.29) \times 10^{-5}$$

Evidence for $\Lambda^* \to \Lambda\omega$ in $\psi(3686) \to \Lambda\bar{\Lambda}\omega$

BESIII, arXiv: 2207.11666



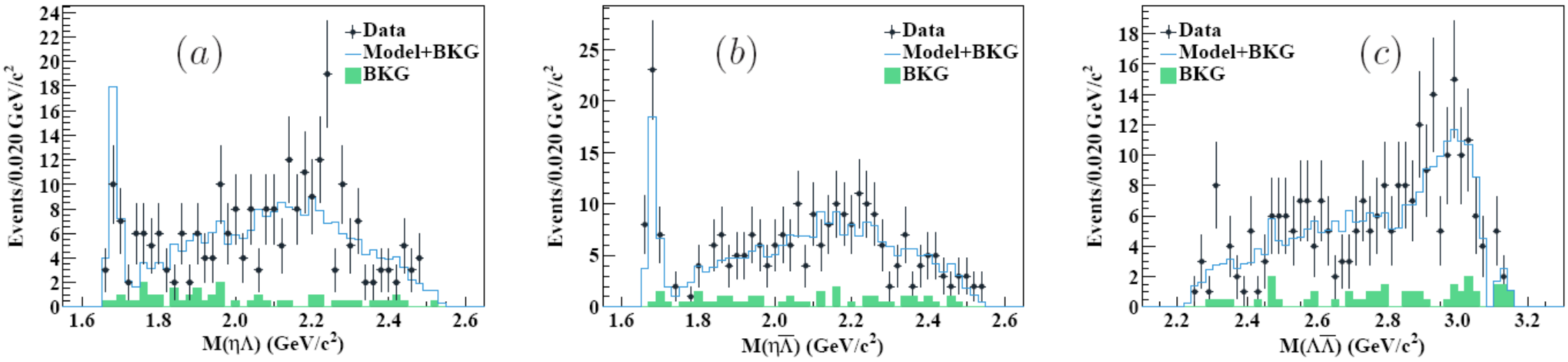
- **Dimensional fit to Dalitz plot with S-wave Breit-Wigner function yields** $M = 2.001 \pm 0.007_{stat}$ **GeV,** $\Gamma = 0.036 \pm 0.014$ **GeV. Significance ~ 3.1σ.**
- $Br(\psi(3686) \to \Lambda\Lambda^* + c.c. \to \Lambda\bar{\Lambda}\omega) < 1.40 \times 10^{-5}$ **@ 90% C.L.**
- **More events need to resolve this structure.**

$\Lambda(1670) \to \Lambda\eta$ in $\psi(3686) \to \Lambda\bar{\Lambda}\eta$

- **Using 448 million $\psi(3686)$ decays, reconstruct decay using $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$ and $\eta \to \gamma\gamma$.**
- **Partial wave analysis performed to 218 ± 17 events yields**

  $M = (1672 \pm 5 + 6)$ **MeV,** $\Gamma = (38 \pm 10 \pm 19)$ **MeV**

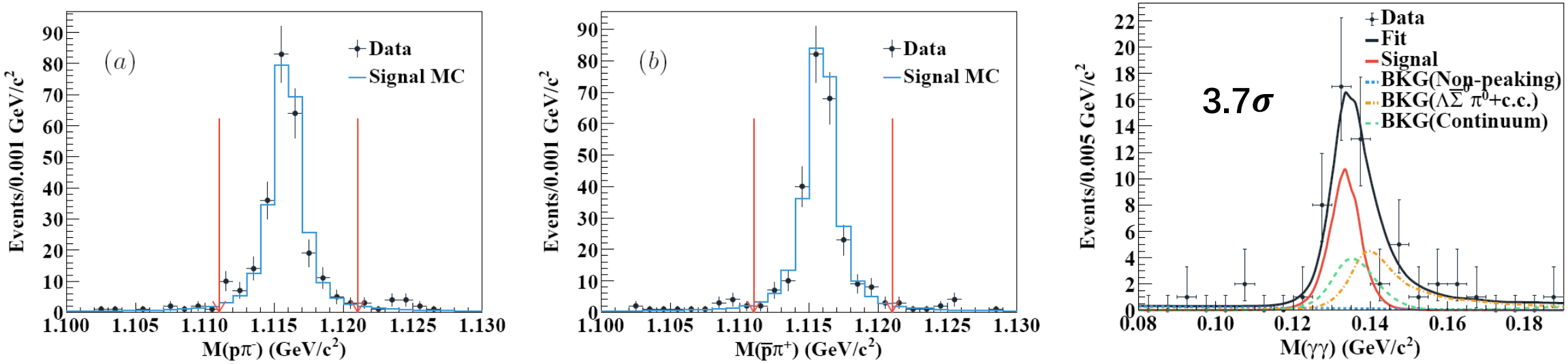
  $Br(\psi(3686) \to \Lambda(1670)\bar{\Lambda} + c.c. \to \Lambda\bar{\Lambda}\eta) = (1.29 \pm 0.31 \pm 0.62) \times 10^{-5}$



BESIII, arXiv:2207.14350

Evidence of decay $\psi(3686) \to \Lambda\bar{\Lambda}\pi^0$

- **Using 448 million $\psi(3686)$ decays, reconstruct decay using $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$ and $\pi^0 \to \gamma\gamma$.**



$$Br(\psi(3686) \to \Lambda\bar{\Lambda}\pi^0) < 2.47 \times 10^{-6}$$ **at 90% C.L**

BESIII, arXiv:2207.14350

Summary

- charmonium baryonic decays at BESIII provide a huge samples to study baryon spectrum.
- Continuum data can be used to search for high excited baryon sates.
- PWA using 10 billion J/ψ, 3 billion $\psi(3686)$ ongoing