Cross section measurement of $\Lambda\bar{\Lambda}$ production at BESIII

based on Phys. Rev. D 97, 032013 (2018)

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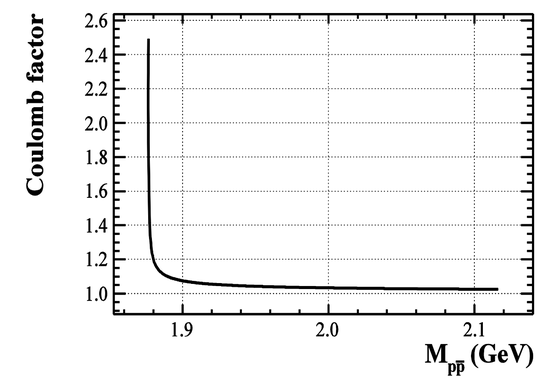
Baryon pair production

- The Born cross section for $e^+e^- \to \gamma^* \to B\bar{B}$ (B spin ½), can be expressed in terms of electromagnetic form factor G_E and G_M :

$$\sigma_{B\bar{B}}(q) = \frac{4\pi\alpha^2 C\beta}{3q^2}\left[|G_M(q)|^2 + \frac{1}{2\tau}|G_E(q)|^2\right]$$

- The Coulomb factor C= $\begin{cases} \frac{\pi\alpha}{\beta}\frac{1}{1-\exp(-\frac{\pi\alpha}{\beta})} & \text{for a charged } B\bar{B} \text{ pair} \\ 1 & \text{for a neutral } B\bar{B} \text{ pair} \end{cases}$



- Electromagnetic FFs (analytic): $G_E(q^2) = F_1(q^2) + \tau\kappa F_2(q^2)$, $G_M(q^2) = F_1(q^2) + \kappa F_2(q^2)$

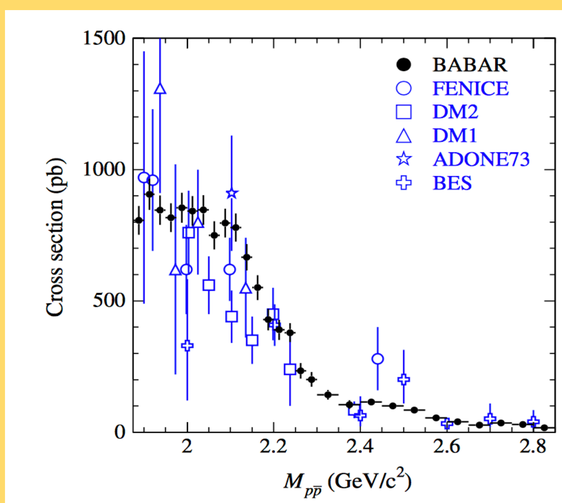
$\tau = \frac{q^2}{4m^2}$, $\kappa = \frac{g-2}{2}$, $g = \frac{\mu}{J}$

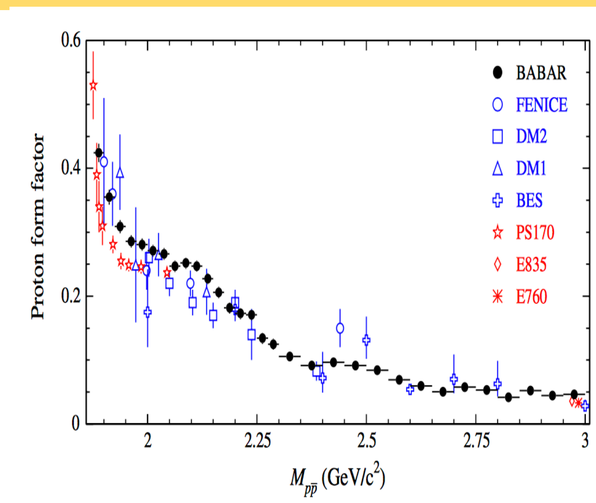
- Properties at threshold ($q^2 = 4m^2$):
  - $G_E(4m^2) = G_M(4m^2)$, angular distribution of B isotropic
  - $\sigma^{th} = \frac{4\pi\alpha^2 C}{3q^2\tau}\left[1 + \frac{1}{2\tau}\right]|G^N_{eff}(q^2)|^2 = \sigma^N_{point}(q^2)|G^N_{eff}(q^2)|^2$
  - The point-like cross sections at threshold: $\sigma_{point}(q^2) = \frac{2\pi^2\alpha^2 C}{q^2}$
  - The cross section for neutron baryon production is zero

Threshold effects

- $e^+e^- \to p\bar{p}$ via ISR at Babar
  - Flat cross section near threshold $\sigma^{th} = \sigma^{p}_{\text{point}}(4{m_p}^2)$
  - Near-threshold enhancement of FF

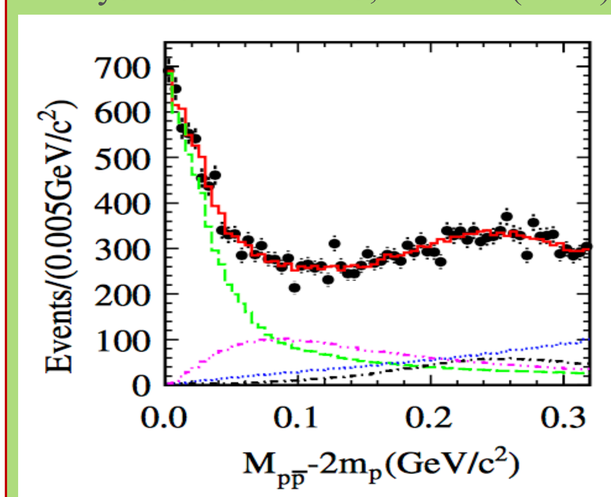
Phys. Rev D **87**, 092005 (2013)



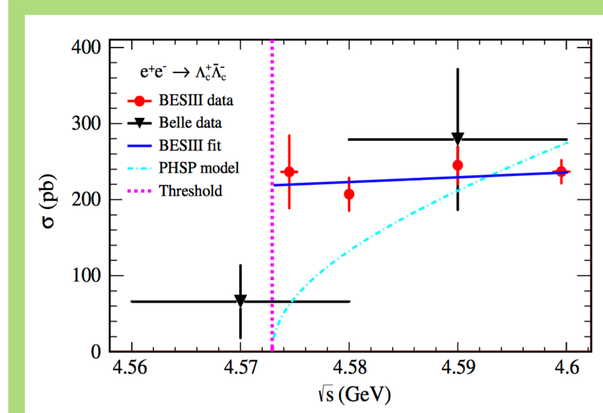


- $J/\psi \to \gamma p\bar{p}$ at BESIII
  - 0^{-+} state near-threshold enhancement determined
  - With Julich-FSI effect included.
- $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ precision measurement at BESIII

Phys. Rev. Lett. **108**, 112003 (2012)

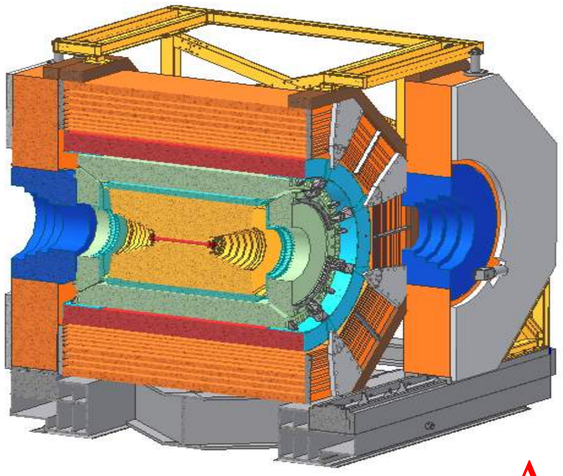


Phys. Rev. Lett. **120**, 132001 (2018)



- Possible explanations
  - Tail of a narrow resonance below threshold (baryonium, meson?)
  - Dominance of π exchange in final state interaction
  - Underestimation of the Coulomb correction factor
  - …

The BESIII Detector and Data Samples



- Main drift Chamber (MDC) : $\sigma_{dE/dx} = 6\%, \sigma_{xy} = 130\ \mu m, \sigma_p/p$=0.5%
- Time of flight system (TOF): $\delta_{t,barrel} = 80$ ps, $\delta_{t,endcaps} = 65$ ps
- Electromagnetic Calorimeter: $\sigma_E = 2.5\%$, $\sigma_l = 6$ mm
- Superconducting Solenoid: B =1.0 T
- RPC muon chamber: $\delta_R = 1.48$ cm

A new Cylindrical GEM inner tracker will be installed for BESIII!

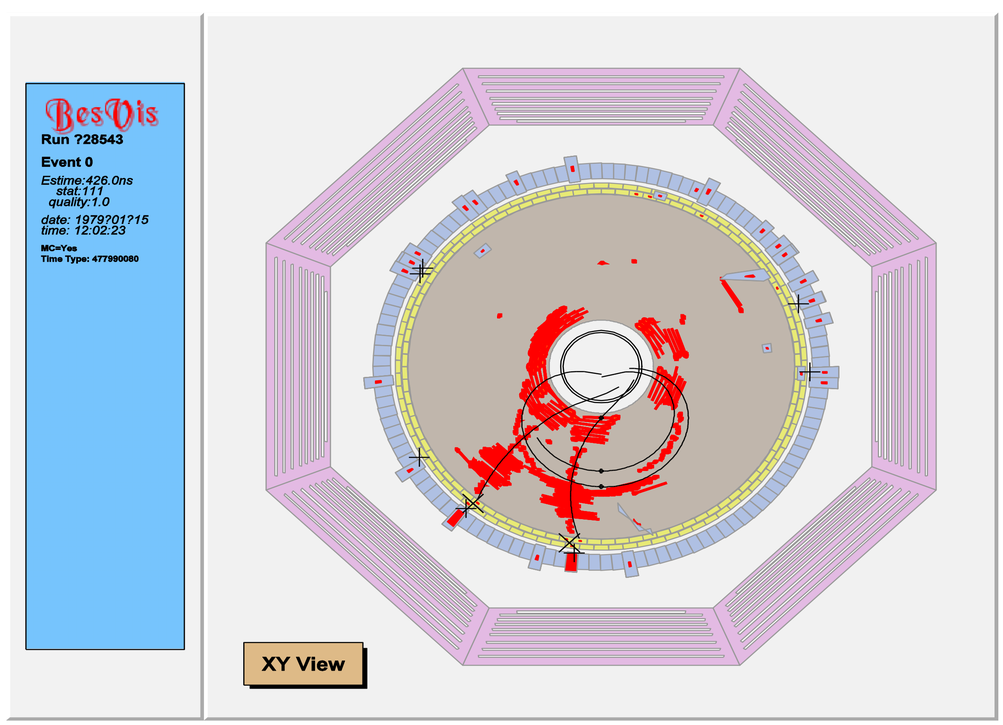
- Data samples
  - Four energy points from $\sqrt{s}$=2.2324 to 3.08 GeV
  - The total integrated luminosity is 40.8 pb^{-1}

- MC simulation
  - $e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.2324 GeV with PHSP, at $\sqrt{s}$ =2.40, 2.80 and 3.08 GeV with Conexc.
  - $e^+e^- \to l^+l^-(l = e, \mu)$ and $e^+e^- \to \gamma\gamma$ with Babayaga
  - hadronic final states with Lundarlw

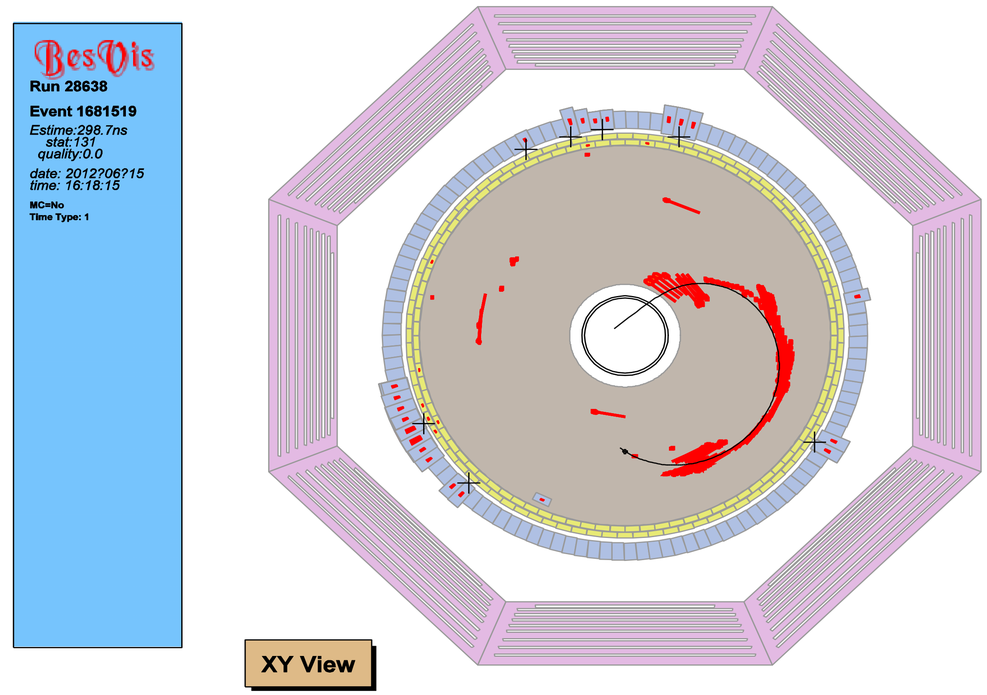
$e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.2324 GeV

- Near threshold production ($2M_\Lambda$ +1.0 MeV) and small PHSP in $\Lambda/\bar{\Lambda}$ decays
  - Indirect search for antiproton in $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$
  - Search for mono-energetic π^0 in $\bar{\Lambda} \to \bar{n}\pi^0$

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

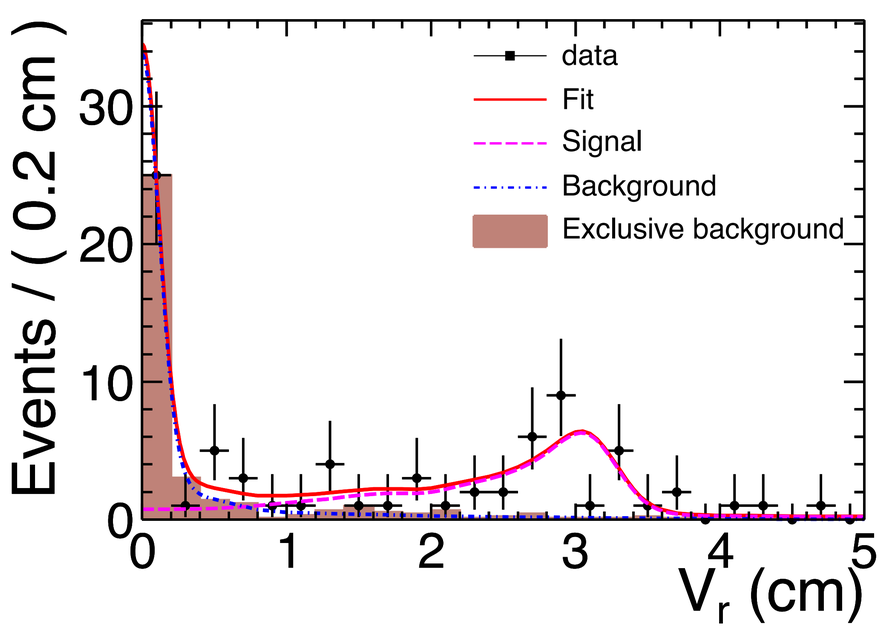


$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{n}\pi^0$

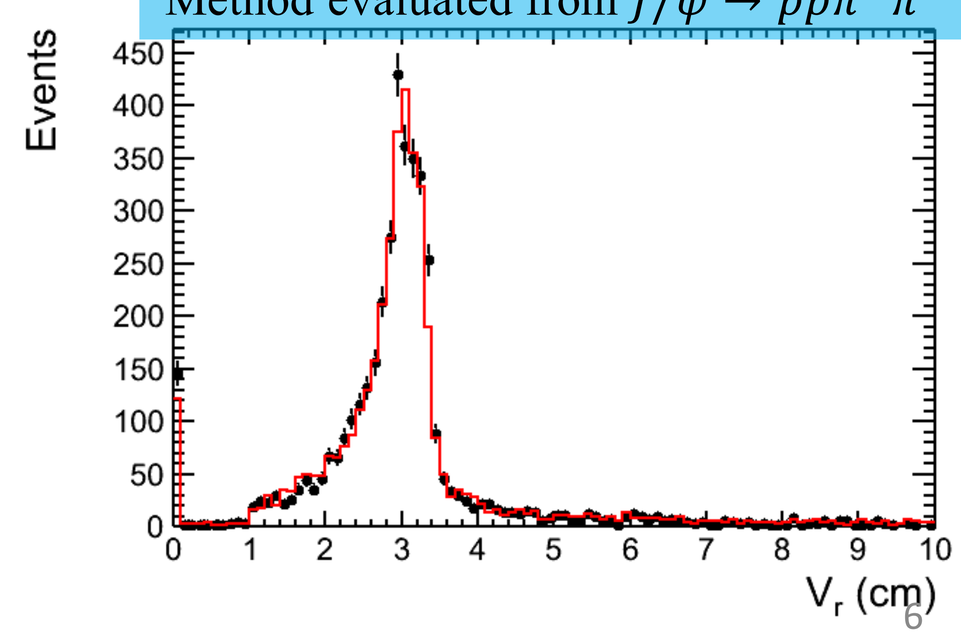


Reconstruction of $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$ (mode I)

- Charged track: $|V_{xy}| < 1$ cm, $|V_z| < 10$ cm, $|\cos\theta|<0.93$, $N_{chrg} = 2$
- PID: dE/dx+TOF, $N_{\pi^+} = N_{\pi^-} = 1$
- Momentum of π : [0.08, 0.11] GeV/c
- Secondary particles: Select the largest V_{xy} of all tracks, shows enhancement around 3 cm (interaction between $\bar{p}$ and beam pipe)
- Observable: the largest V_{xy}, fit with MC shape

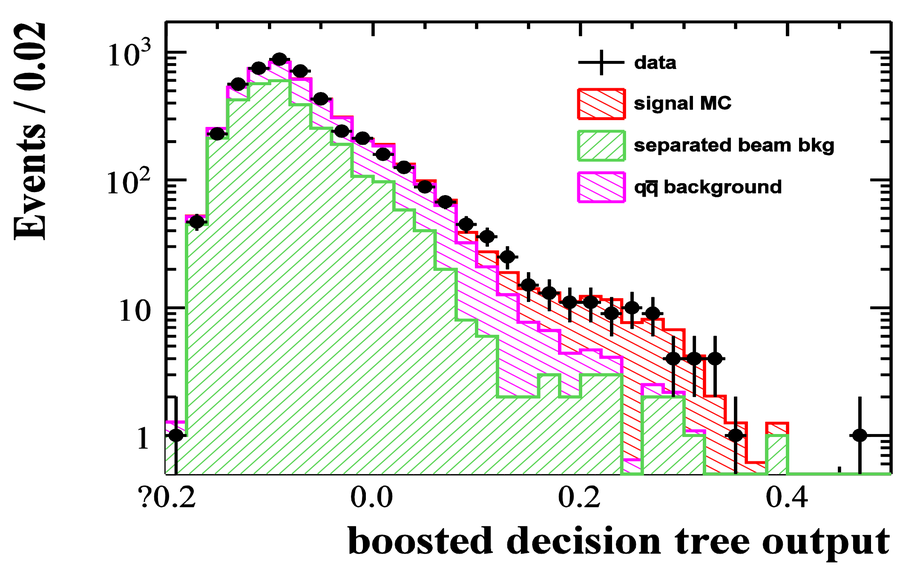


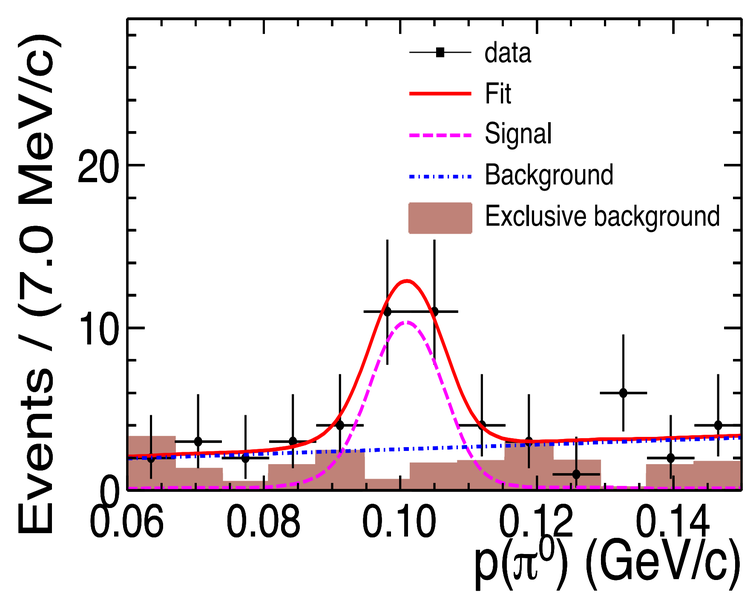
Method evaluated from $J/\psi \to p\bar{p}\pi^+\pi^-$



Reconstruction of $\bar{\Lambda} \to \bar{n}\pi^0$ (mode II)

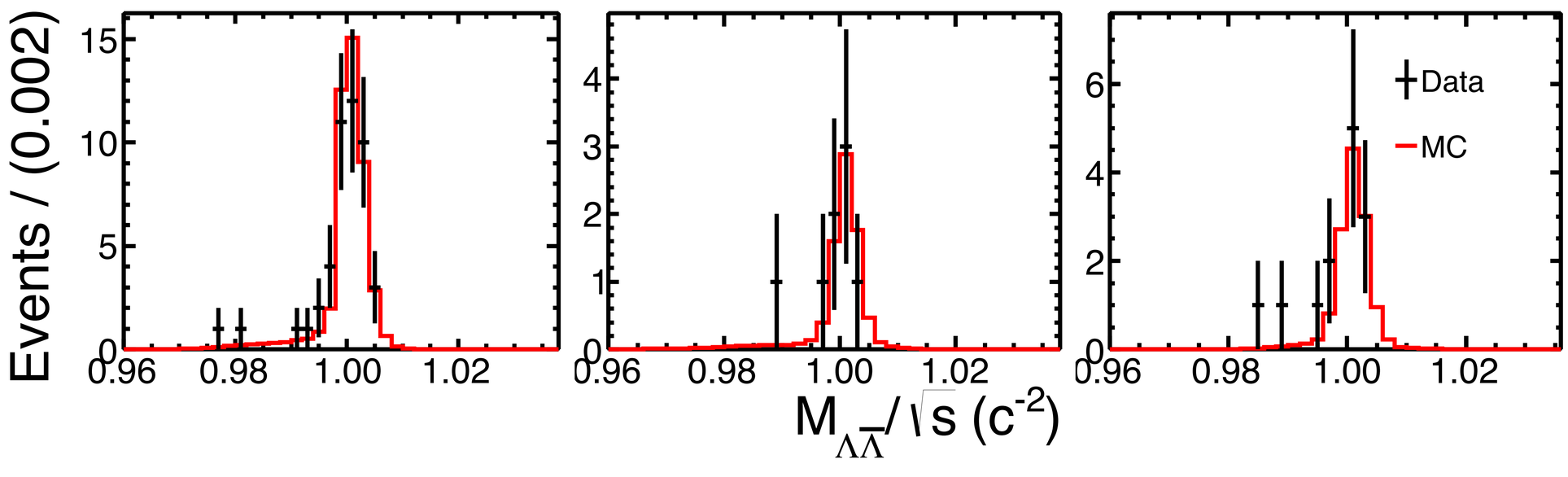
- Charged track: $|V_{xy}| < 1\ cm$, $|V_z| < 10$ cm, $|\cos\theta|<0.93$, $N_{chrg} \leq 1$
- Neutral track: $E_{barrel} > 25$ MeV, $E_{endcap} > 50$ MeV, Angle$> 10^{\circ}$
- Most energetic shower as $\bar{n}$ candidate, BDT booked for $\bar{n}/\gamma$ separation
- π^0 reconstruction: 1C kinematic fit on π^0 mass, $\frac{|E_{\gamma_1}-E_{\gamma_2}|}{p_{\pi^0}} < 0.95$, $\chi^2_{1C} < 20$, Angle between $\bar{n}$ and π^0 larger than 140°
- Observable: the momentum of π^0, fit with MC shape





$e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.40, 2.80, 3.08 GeV

- Charged track: $|V_{xy}| < 10$ cm, $|V_z| < 30$ cm, $|\cos\theta|<0.93$, $N_{chrg} = 4$
- PID: dE/dx+TOF, $N_p = N_{\bar{p}} = N_{\pi^+} = N_{\pi^-} = 1$
- Secondary vertex fit applied for $\Lambda/\bar{\Lambda}$
- Mass window cut $|M_{p\pi^-/\bar{p}\pi^+} - M_\Lambda| < 0.01$ GeV$/c^2$
- Opening angle between $\Lambda/\bar{\Lambda}$ in c.m.system: $\theta_{\Lambda\bar{\Lambda}} > 170^\circ, 176^\circ, 178^\circ$ at $\sqrt{s}$ =2.40, 2.80, 3.08 GeV
- Observable: $M_{\Lambda\bar{\Lambda}}/\sqrt{s}$, background free, counting method



Cross section for $e^+e^- \to \Lambda\bar{\Lambda}$

- The Born cross section for $e^+e^- \to \Lambda\bar{\Lambda}$ is determined from:

$$\sigma^B = \frac{N_{obs}}{\mathcal{L}_{int} \cdot \varepsilon \cdot (1+\delta) \cdot \mathcal{B}}$$

The effective FF is defined by

$$|G| = \sqrt{\frac{|G_M|^2 + 1/2\tau |G_E|^2}{1+1/2\tau}} = \sqrt{\frac{3s\sigma^B}{4\pi\alpha^2\beta} \cdot \frac{1}{1+1/2\tau}}$$

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm int}$ ($\rm pb^{-1}$)	$N_{\rm obs}$	$\epsilon(1+\delta)$ (%)	$\sigma^{\rm B}$ (pb)	$\lvert G\rvert$ ($\times 10^{-2}$)
2.2324_1	2.63	43 ± 7	12.9	$312 \pm 51^{+72}_{-45}$	
2.2324_2	2.63	22 ± 6	8.25	$288 \pm 96^{+64}_{-36}$	
2.2324_c				$305 \pm 45^{+66}_{-36}$	$61.9 \pm 4.6^{+18.1}_{-9.0}$
2.400	3.42	45 ± 7	25.3	$128 \pm 19 \pm 18$	$12.7 \pm 0.9 \pm 0.9$
2.800	3.75	8 ± 3	36.1	$14.8 \pm 5.2 \pm 1.9$	$4.10 \pm 0.72 \pm 0.26$
3.080	30.73	13 ± 4	24.5	$4.2 \pm 1.2 \pm 0.5$	$2.29 \pm 0.33 \pm 0.14$

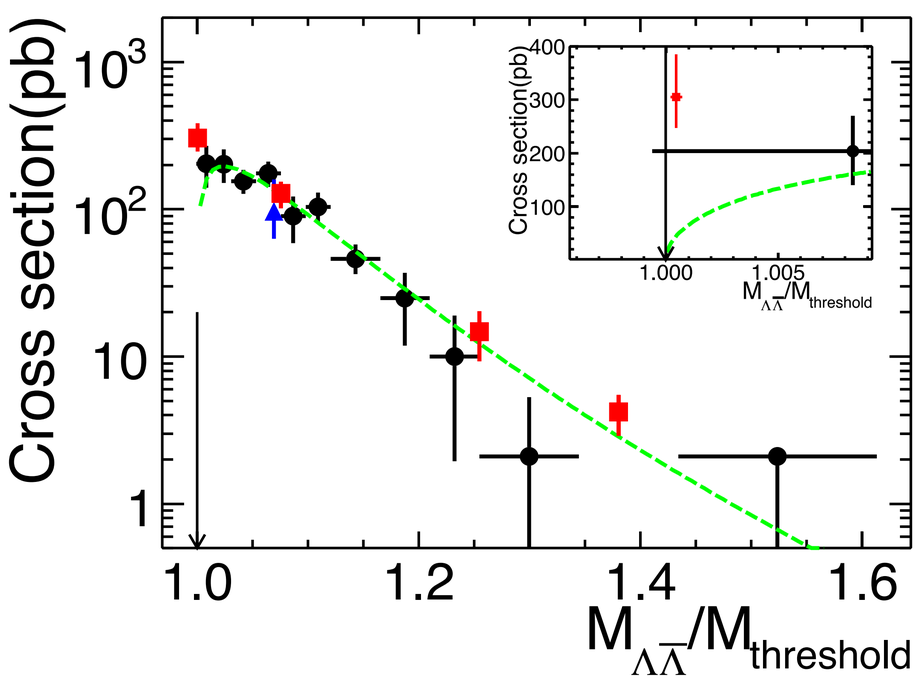
Two modes at $\sqrt{s}$=2.2324 GeV are combined taking into account the correlation between the uncertainties of the two decay modes

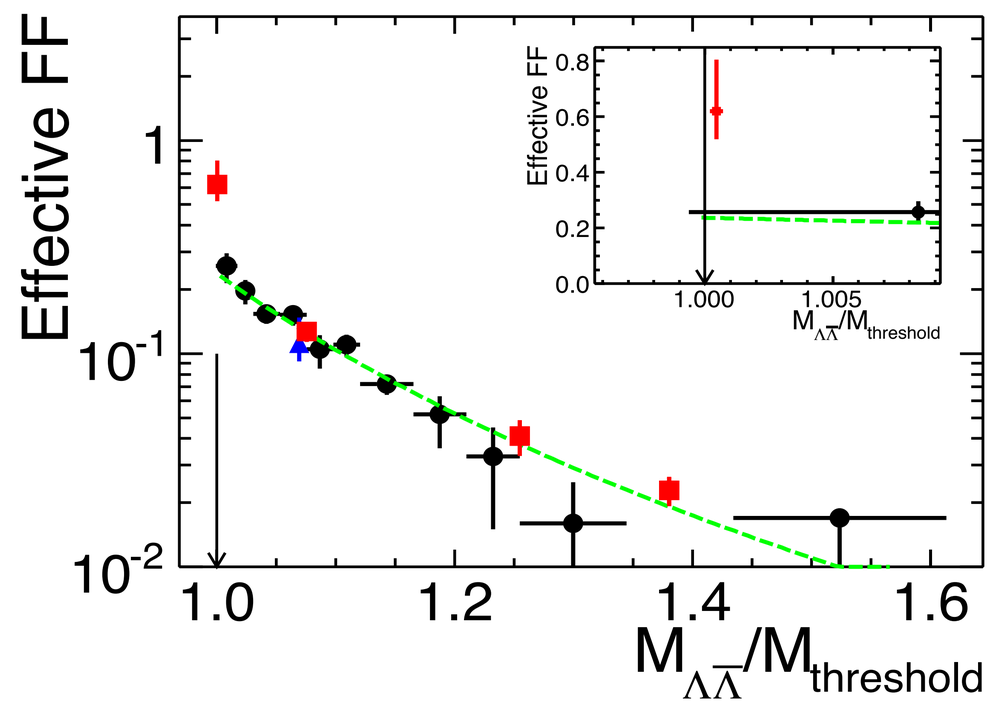
Interpretation of line-shape

- A phenomenological fit, according to the pQCD driven energy power:

$$\sigma^B = \frac{p_1\beta}{(M_{\Lambda\bar{\Lambda}} - p_2)^{10}}, (p_1, p_2 \text{ are float parameters})$$

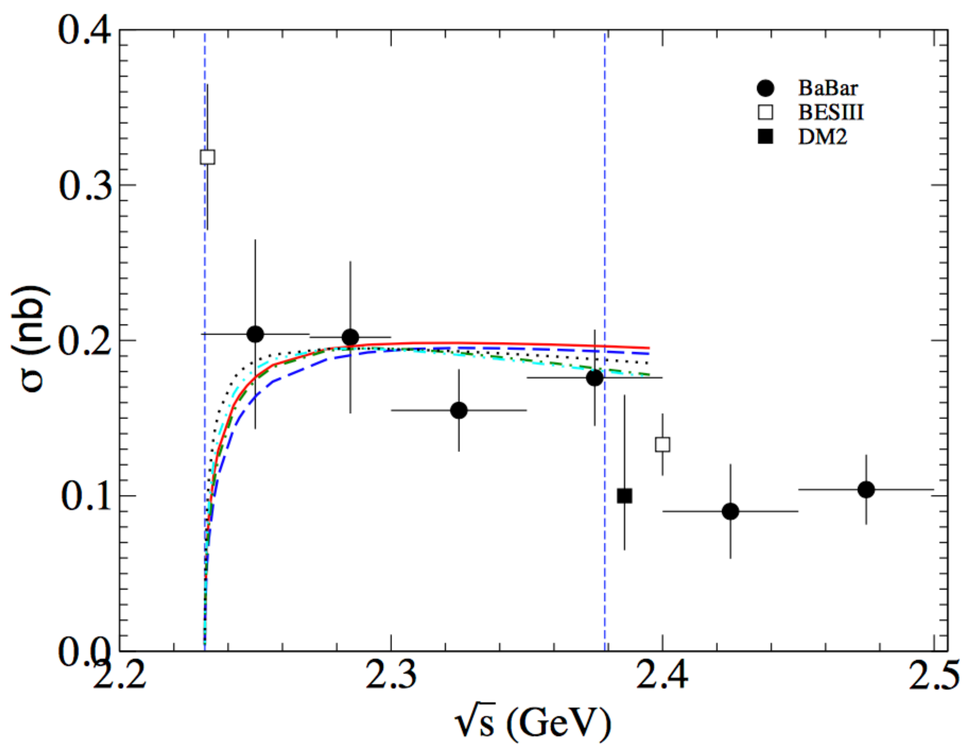
The anomalous behavior differing from the pQCD prediction at threshold is observed.

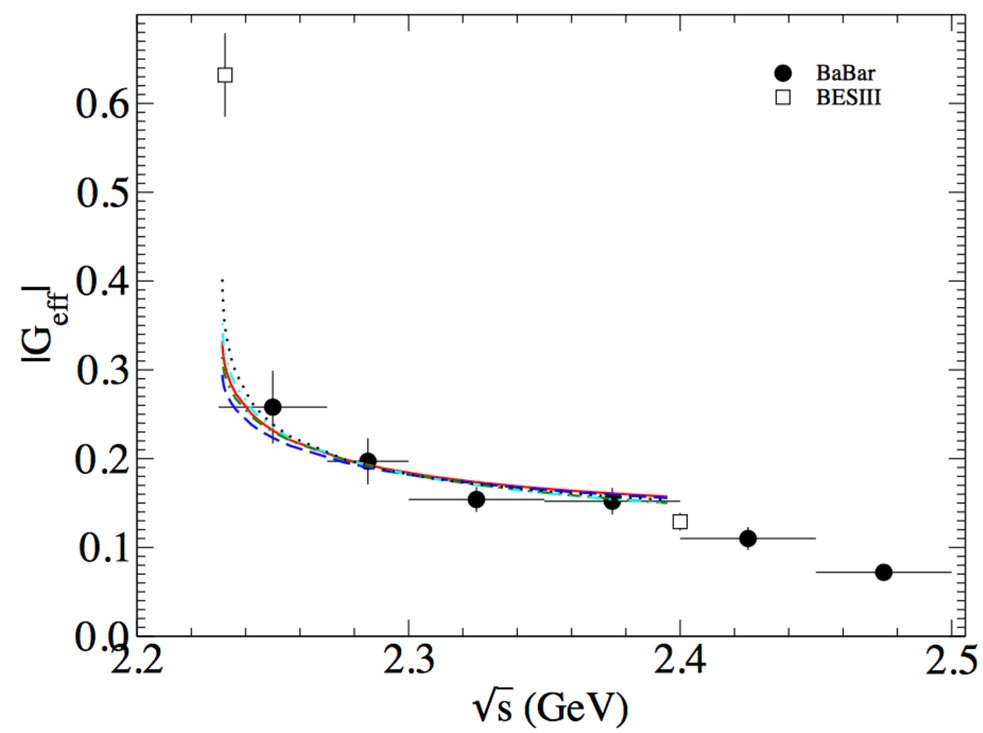




Theoretical discussion on $e^+e^- \to \Lambda\bar{\Lambda}$

- The calculation on of $e^+e^- \to \Lambda\bar{\Lambda}$ is investigated:
  - One-photon approximation
  - the effects of $\Lambda\bar{\Lambda}$ interaction is considered

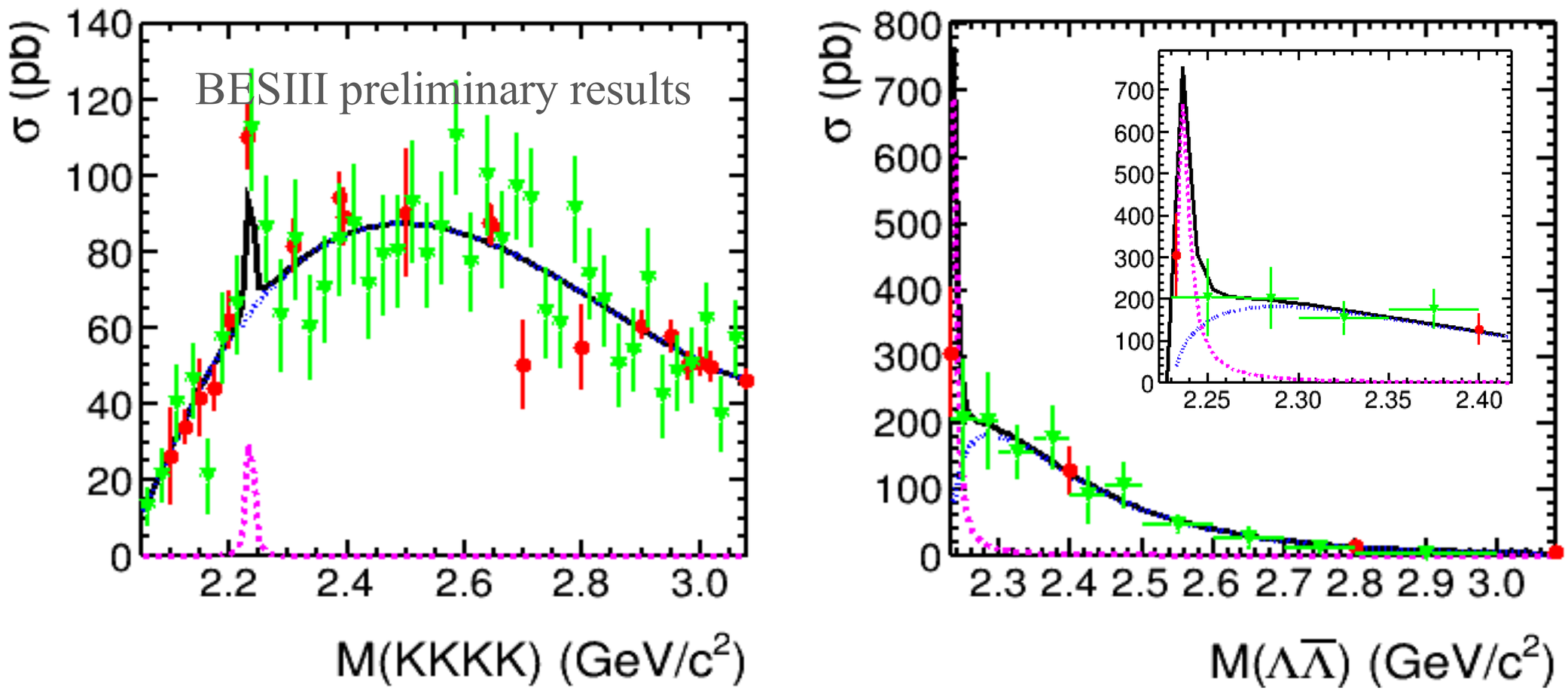




From J. Haidenbauer, U. G. Meissner, Phys. Lett. B **761**, (2016) 456-461

Search for a related structure in $e^+e^- \to K^+K^+K^-K^-$

the Lake Louise Winter Institute 2018

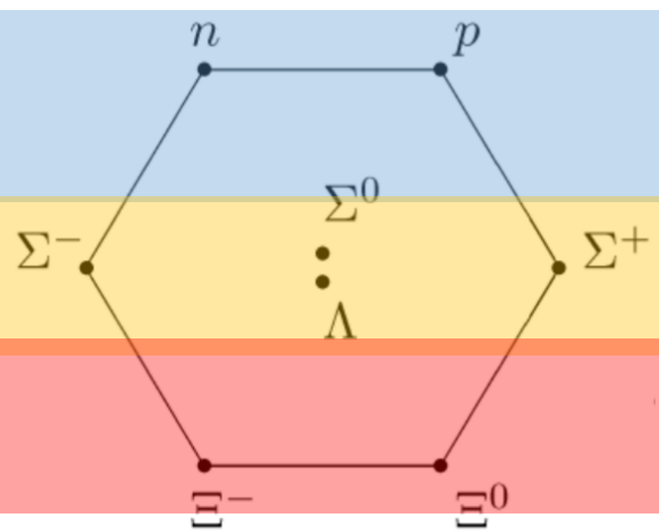


$$M = 2234.7 \pm 2.0\ \mathrm{MeV}/c^2$$
$$\Gamma = 7.5^{+13.1}_{-7.5}\ \mathrm{MeV}$$

Summary and prospect

- The cross section for $e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.2324 GeV ($2M_\Lambda + 1$ MeV) is measured to be $305 \pm 45^{+66}_{-36}$ pb
- The observed threshold enhancement implies a more complicated underlying physics scenario.
- The cross section for $e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.40, 2.80 and 3.08 GeV are consistent with *BABAR* and DM2 experiments.

■ Topics can be explored at BESIII (on baryon pair production near threshold)



- Nucleon (p, n): ISR method by using data at $\sqrt{s} \geq 3.773$ GeV
- pN^*: $p\bar{p}\pi^0$ PWA analysis with data from $\sqrt{s}$=2.0 to 3.08 GeV
- $\Sigma\bar{\Sigma}$: scan method with data at $\sqrt{s}$=2.3864, 2.396 GeV
- $\Lambda\bar{\Sigma}$: scan method with data at $\sqrt{s}$=2.3094 GeV
- $\Xi\bar{\Xi}$: scan method with data at $\sqrt{s}$=2.6444, 2.6464 GeV

Thanks for your attention!

Systematic uncertainty at $\sqrt{s}$ =2.2324 GeV

Sources	Mode I	Mode II
Tracking & PID (Control sample $J/\psi \to p\bar{p}\pi^+\pi^-$)	12.3%	-
Largest V_{xy} sel. (Control sample $J/\psi \to p\bar{p}\pi^+\pi^-$)	0.3%	-
$\bar{n}$ selection (Control sample $J/\psi \to p\bar{n}\pi^-$)	-	2.2%
π^0 selection (Control sample $\psi(3686) \to \pi^0\pi^0 J/\psi$)	-	2.3%
BDT requirement (Control sample $J/\psi \to p\bar{n}\pi^-$)	-	4.8%
Trigger (Weight according to E_{tot})	-	1.0%
Fit procedure (Varying PDF and range)	4.6%	8.8%
ISR correction (Change line shape in generator)	$^{+18.5}_{-3.6}$%	
Energy spread (An alternative energy spread from ψ scan)	2.0%	
Energy measurement (determined from J/ψ lineshape)	3.9%	
Luminosity (Large-angle Bhabha events)	1.0%	
Total	$^{+23.2}_{-14.4}$%	$^{+22.1}_{-12.6}$%

- For the uncertainty from Energy spread and Energy measurement, large uncertainties are considered due to rapid variation of velocity β

Systematic uncertainty at $\sqrt{s}$ =2.40, 2.80 and 3.08 GeV

Sources	2.40 GeV	2.80 GeV	3.08 GeV
Reconstruction of Λ	3.8%		
Reconstruction of $\bar{\Lambda}$	3.4%		
Mass window cut of Λ	2.5%		
Mass window cut of $\bar{\Lambda}$	3.0%		
Angular distribution	12.7%	10.8%	11.4%
ISR correction	2.2%	4.0%	2.9%
Luminosity	1.0%		
Total	14.0%	13.0%	13.0%

- The unknown $|G_E/G_M|$ ratio lead to large uncertainty of anguar distribution.

Fit on $e^+e^- \to \Lambda\bar{\Lambda}$