The polarization of hyperons at BESIII

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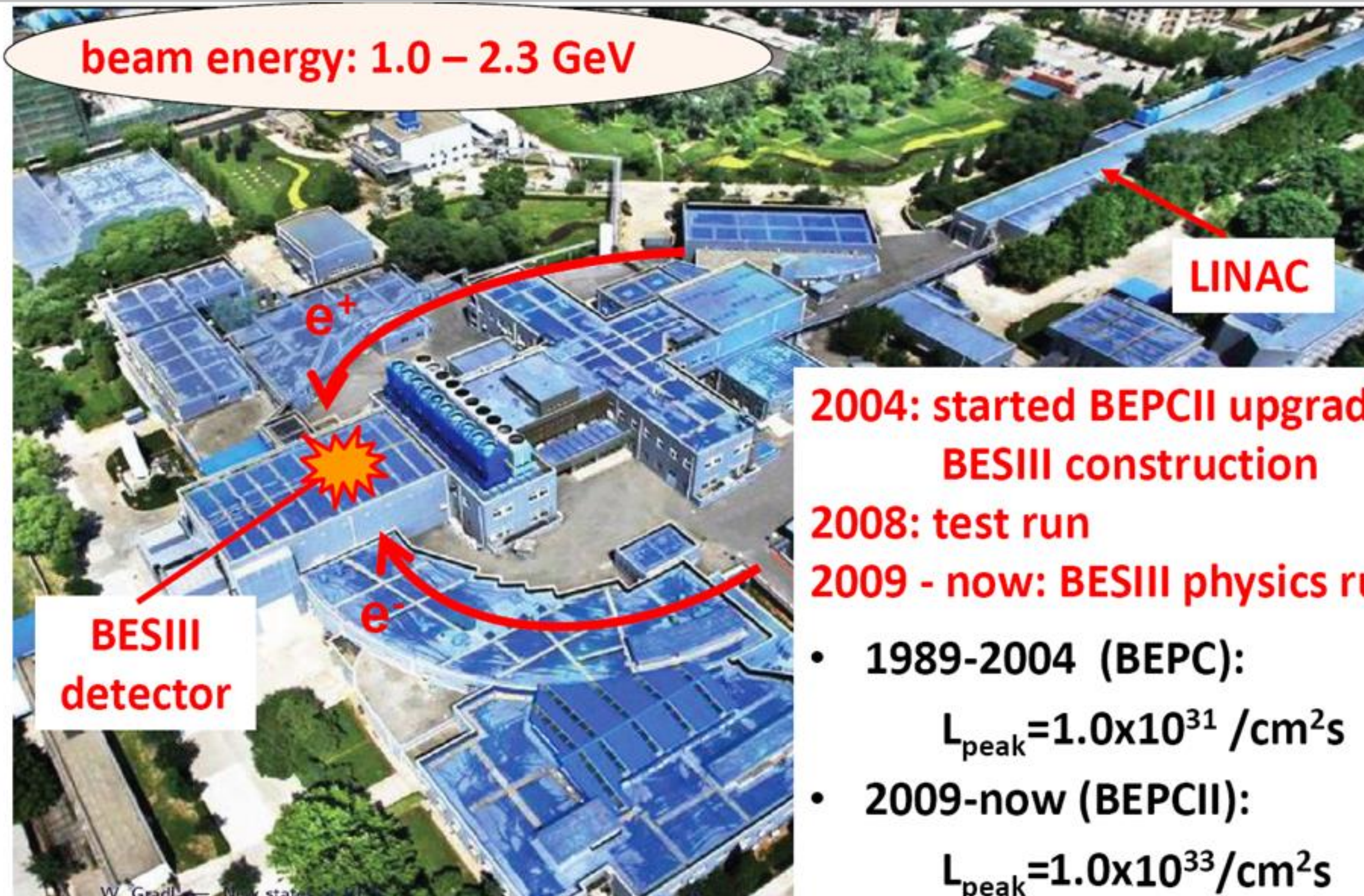
Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

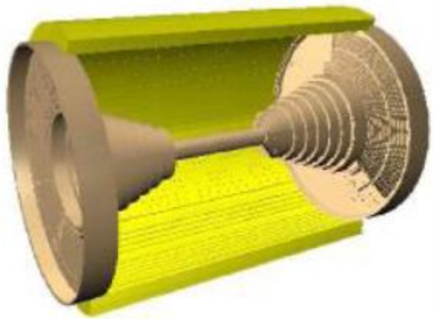
  $L_{peak}=1.0 \times 10^{31}\ /cm^2s$

- 2009-now (BEPCII):

  $L_{peak}=1.0 \times 10^{33}/cm^2s$

BESIII Detector

MDC

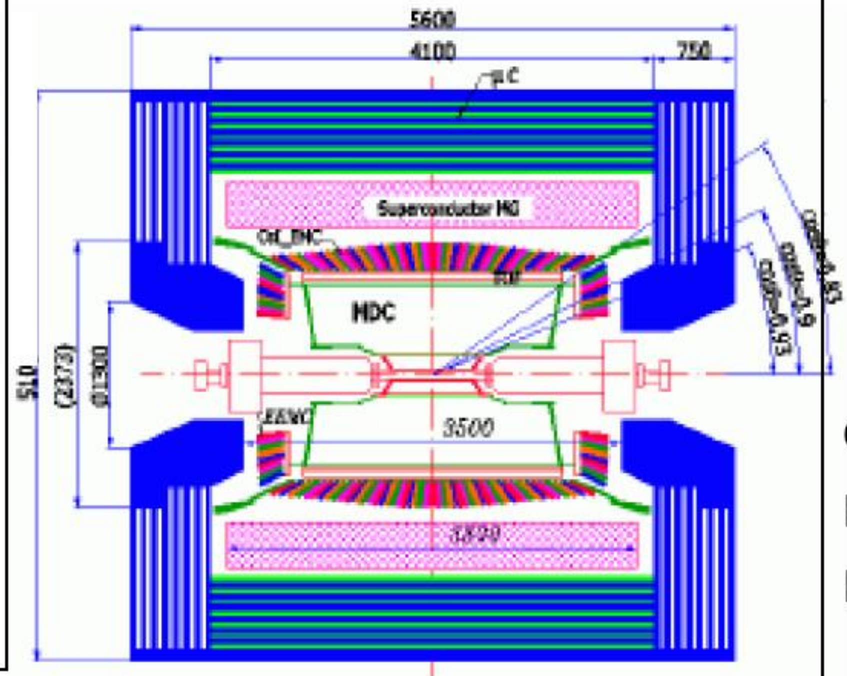


R inner: 63mm ;

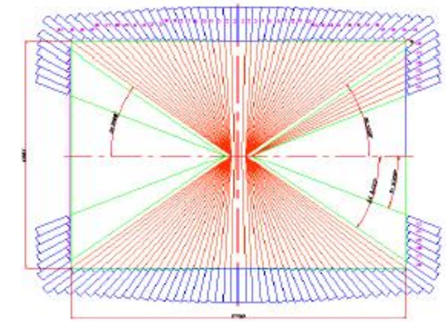
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



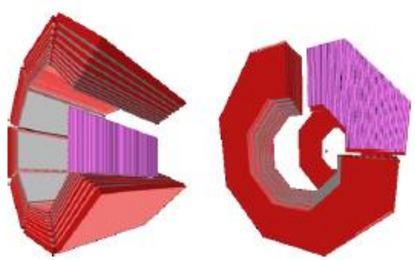
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

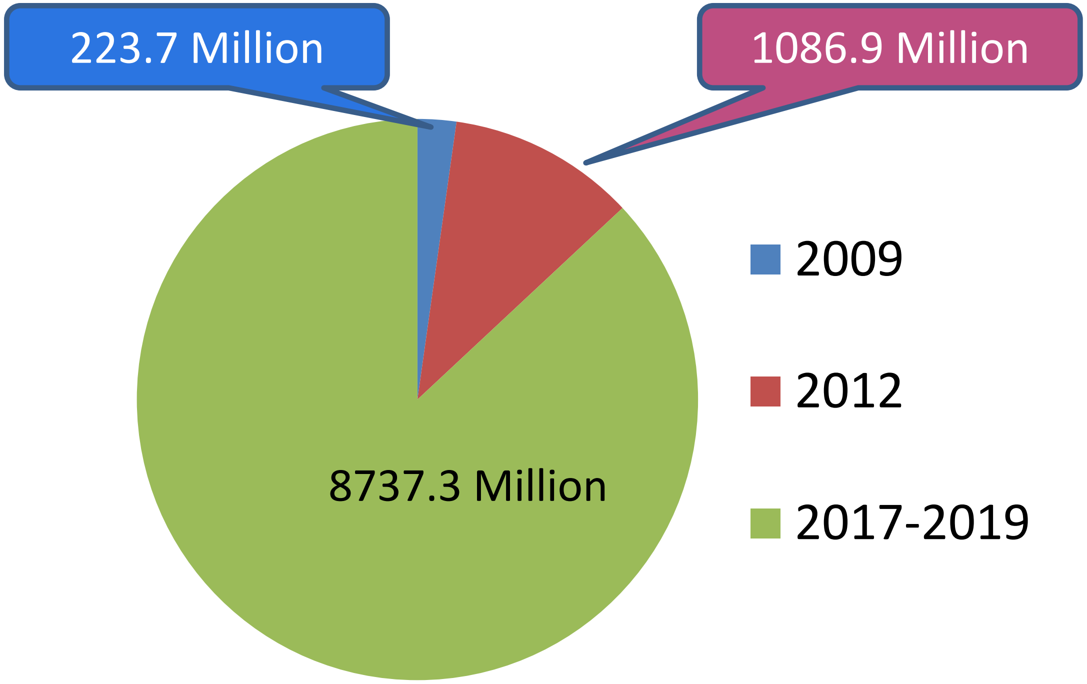
TOF

BTOF: two layers

ETOF: 48 scintillators for each

MRPC --- new ETOF

BESIII $J/\psi, \psi'$ data sets



The analysis based on 2009+2012 J/ψ data:

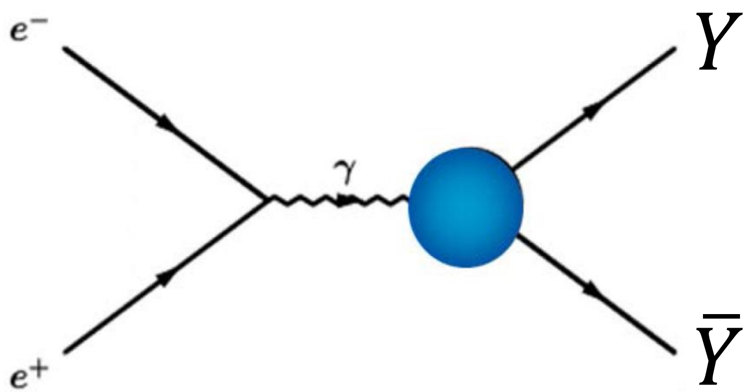
$\sim$1.31 billion decays

J/ψ : Total 10.047 billion J/ψ decays

ψ': 448 million decays

Hyperon pair production at BESIII

- $e^+e^- \to \gamma^* \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}, \Lambda_c^+\bar{\Lambda}_c^-,$ @ $\sqrt{s} = 2.0 \sim 4.6$ GeV, or update for $\Lambda_c^+\bar{\Sigma}_c^-$, $\Sigma_c\bar{\Sigma}_c$



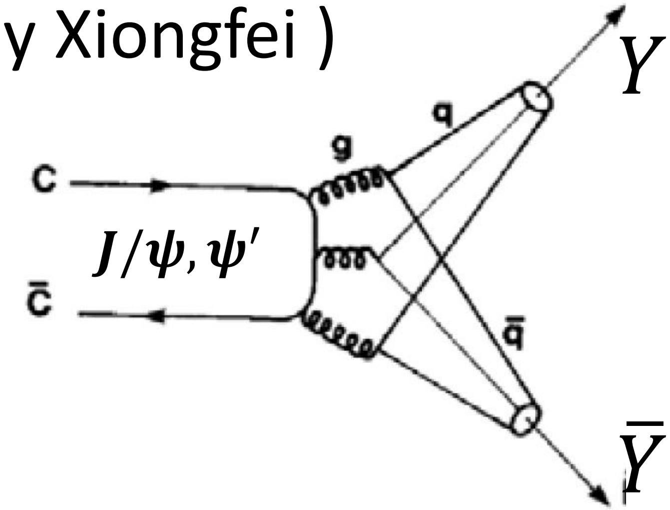
- Threshold enhancement
- Form factor
- EPR test ....

- $J/\psi, \psi' \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}$, (talk by Xiongfei)

e.g. 10 billion J/ψ decays:

Selected events

3.4×10^6	$\Lambda\bar{\Lambda}$
1.0×10^6	$\Xi^0\bar{\Xi}^0$
0.8×10^6	$\Sigma^0\bar{\Sigma}^0$
0.3×10^6	$\Xi^-\bar{\Xi}^+$



Role of polarization physics

- Probing of spin degree freedom

  Test the dynamic of SM and low energy hadron interaction

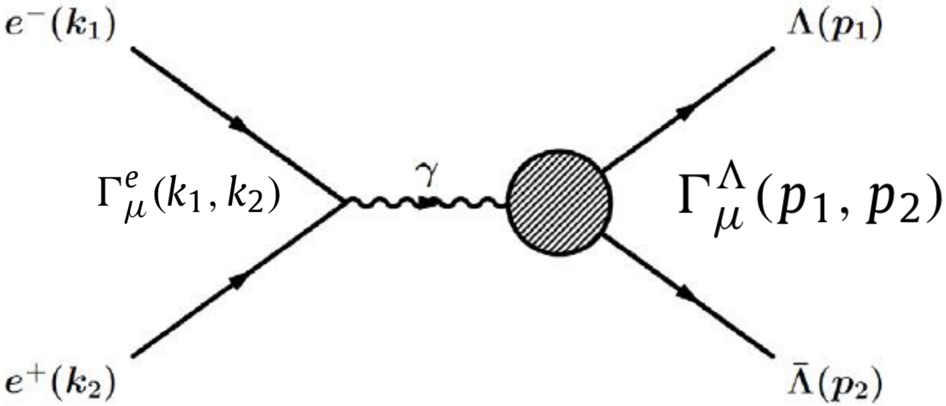
  Existant exp. : RHIC, Jlab, GRAAL, CERN and DESY
  Spin observable, spin-dependent structure function and parton distribution
  Spin crisis at eighties

- BEPCII/BESIII, unpolarized beam, inaccessible polarization of final state by BESIII

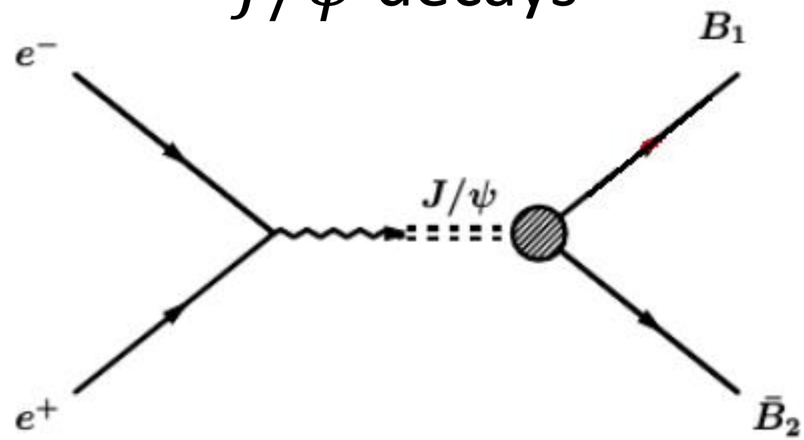
  - Polarized beam for post-BEPCII options, CPV in tau decay, Hyperon weak decay,……
  - Useful tool: transverse polarization of hyperon, spontaneous production at e^+e^- collision
  - $\Lambda \to p\pi^-$ decay plays important role in particle physics

Transverse polarization (TP) of baryons in e^+e^- collisions

FFs in continuum



J/ψ decays



Time likespin ½ baryon FFs:

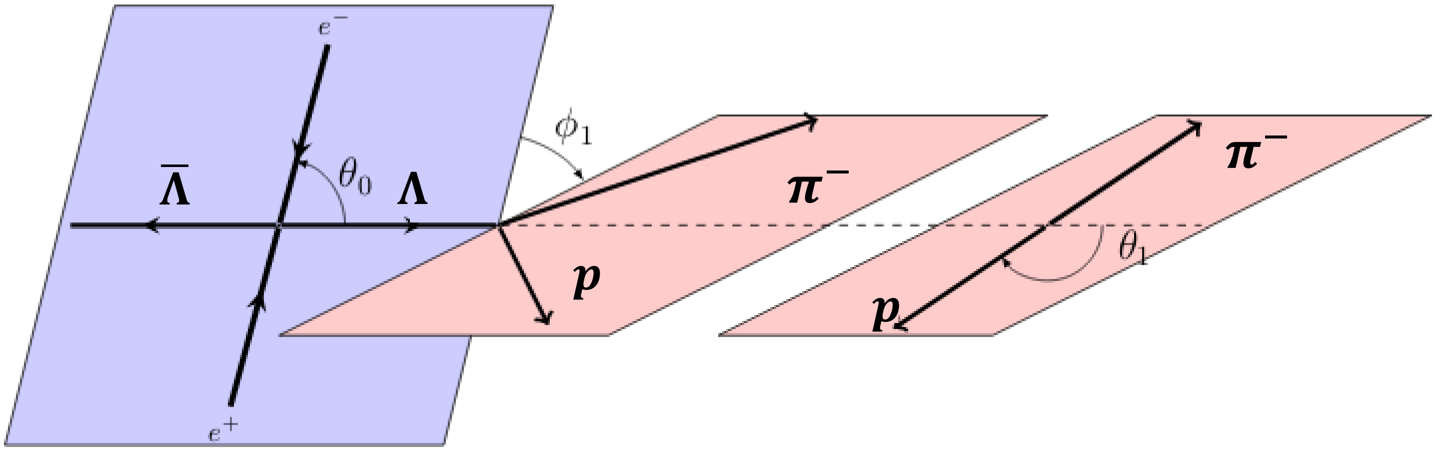
Dubnickova, Dubnicka, Rekalo
Nuovo Cim. A109 (1996) 241
W. Lu, et.al., Phys.Lett., B368, 261 (1996)
Gakh, Tomasi-Gustafsson Nucl.Phys. A771 (2006) 169
Czyz, Grzelinska, Kuhn PRD75 (2007) 074026
FäldtEPJ A51 (2015) 74; EPJ A52 (2016)141
Fäldt, G. & Kupsc, A, Phys. Lett. B 772 (2017) 16

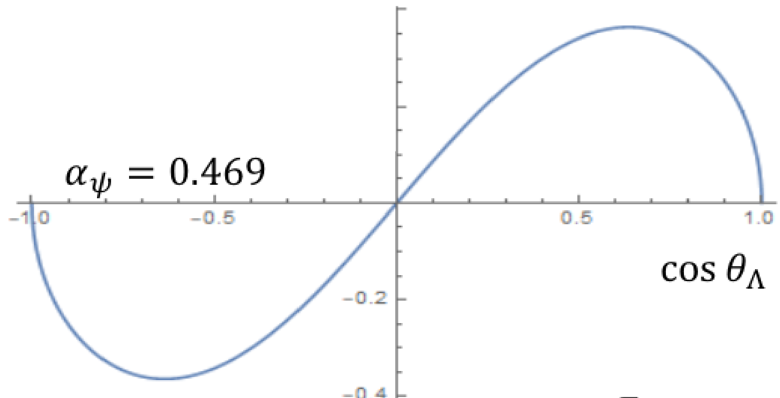
$$\Gamma^e_\mu(k_1, k_2) = -ie_\psi \gamma_\mu$$

$$\Gamma^\Lambda_\mu(p_1, p_2) =$$

$$-ie_g\left[G^\psi_M \gamma_\mu - \frac{2M}{Q^2}(G^\psi_M - G^\psi_E)Q_\mu\right]$$

Transverse polarization of baryons in e^+e^- collisions





Unpolarized e^+e^- beam ➔ transverse polarization baryon

Max P_Λ= 36.4%   if $\Delta\Phi = \frac{\pi}{2}$

$$\bar{P}_Y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi{}^2}\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}\sin(\Delta\Phi)$$

P_Y along $\boldsymbol{k}_{e^+} \times \boldsymbol{p}_\Lambda$

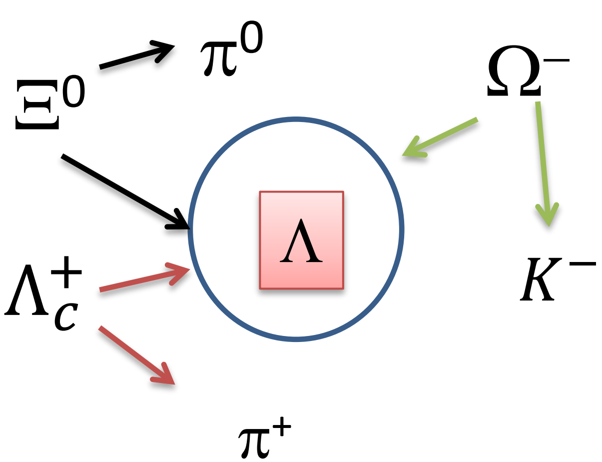
$\Lambda \to p\pi^-$ as polarimeter

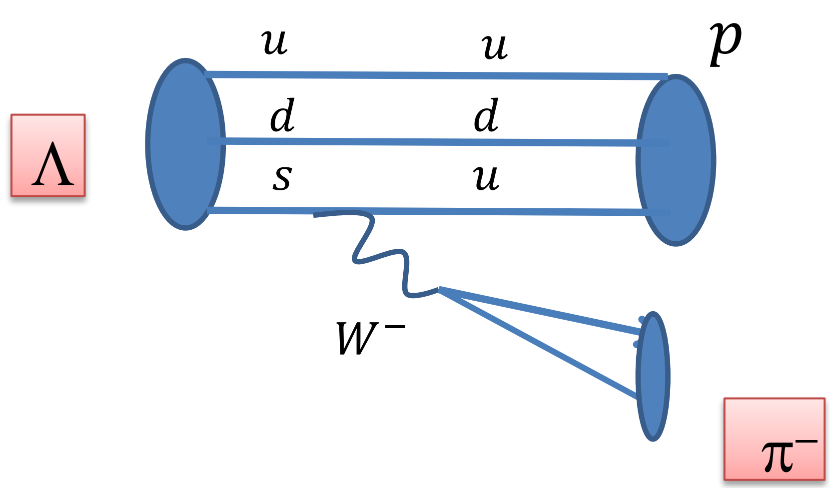
$$\frac{dN}{d\Omega} = \frac{1}{4\pi}\left(1 + \alpha_\Lambda \vec{P} \cdot \hat{q}\right) = \frac{1}{4\pi}\left(1 + \alpha_\Lambda P_\Lambda cos\theta_p\right)$$

Lee-Yang parameters:

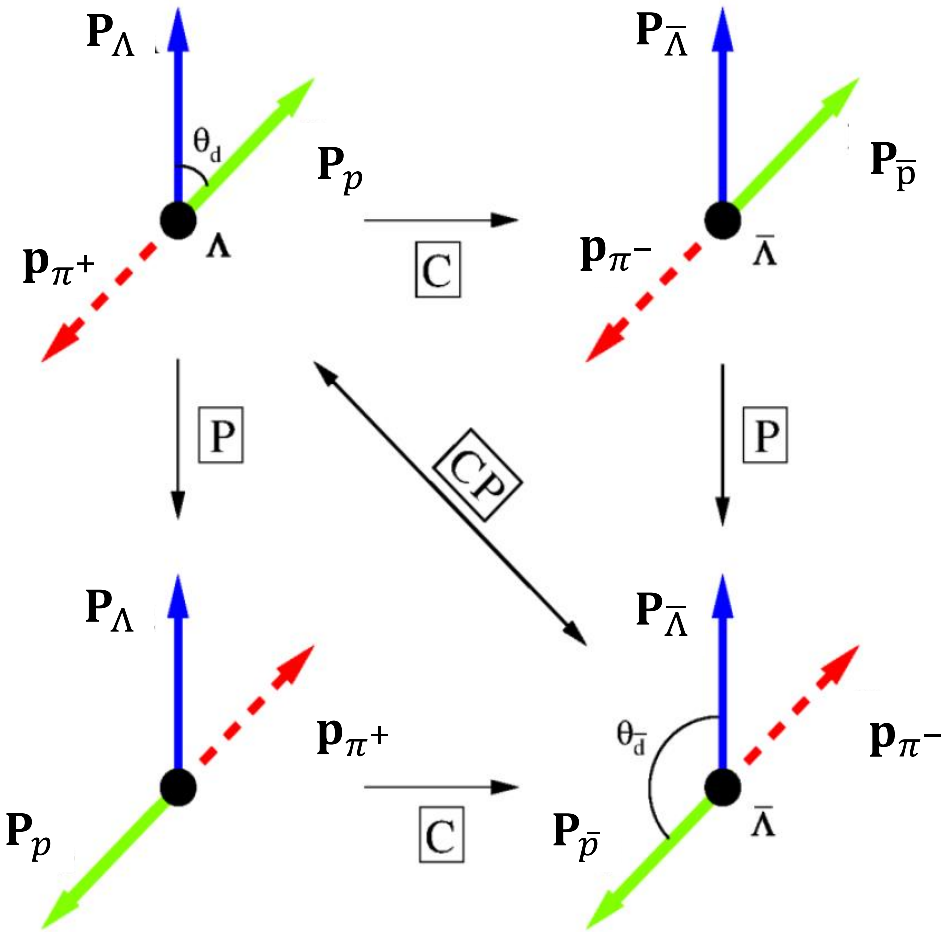
$$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\,\mathrm{Im}(S^*P)}{|S|^2 + |P|^2}, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

Note: $\alpha^2 + \beta^2 + \gamma^2 = 1$





C- and P- transformation



$$\alpha_\Lambda = \frac{|B_+|^2 - |B_-|^2}{|B_+|^2 + |B_-|^2}, \alpha_{\bar\Lambda} = \frac{|\bar B_+|^2 - |\bar B_-|^2}{|\bar B_+|^2 + |\bar B_-|^2}$$

CP **invariance:**

$$\bar B_{-\lambda_p} = \eta_\Lambda \eta_p \eta_\pi (-1)^{s_\Lambda - s_p - s_\pi} B_{\lambda_p} = -B_{\lambda_p}$$

If CP invariance:

$$\alpha_\Lambda = -\alpha_{\bar\Lambda}$$

CP-odd observables

$$\Delta = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}} \qquad \mathrm{A} = \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}}$$

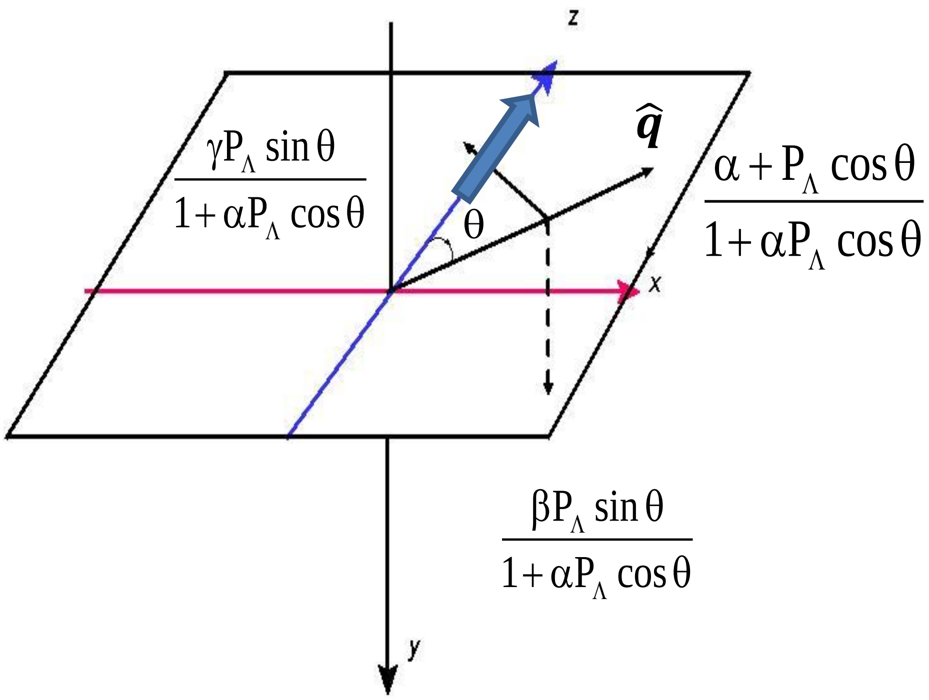
$$\mathrm{B} = \frac{\beta + \overline{\beta}}{\beta - \overline{\beta}} \qquad \mathrm{B}' = \frac{\beta + \overline{\beta}}{\alpha - \overline{\alpha}}$$

- **A_Λ at 10^{-5} level by CKM matrix, PDG: 0.006 ± 0.021**
- **Asymmetries B, B' require knowledge of both parent and daughter polarization**

Proton polarization from $\Lambda \to p\pi^-$

$$\vec{P}_p = \frac{(\alpha + \vec{P}_\Lambda \cdot \hat{q})\hat{q} + \beta\,(\vec{P}_\Lambda \times \hat{q}) + \gamma\,\hat{q} \times (\vec{P}_\Lambda \times \hat{q})}{(1 + \alpha \vec{P}_\Lambda \cdot \hat{q})}$$

- If $P_\Lambda = 0$ then $P_p = \alpha P_\Lambda \cdot q$
- T – odd transverse polarization
  $\beta \neq 0$
- If CP is conserved:
  $\alpha = -\bar{\alpha},\ \beta = -\bar{\beta},$
  $\gamma = \bar{\gamma}$ and $\Gamma = \bar{\Gamma}$



Previous Measurements

2018 PDG list

α_- FOR $\Lambda \to p\pi^-$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.642 \pm 0.013}$	**OUR AVERAGE**				
0.584 ± 0.046	8500	ASTBURY	1975	SPEC	
0.649 ± 0.023	10325	CLELAND	1972	OSPK	
0.67 ± 0.06	3520	DAUBER	1969	HBC	From Ξ decay
0.645 ± 0.017	10130	OVERSETH	1967	OSPK	Λ from $\pi^- p$
0.62 ± 0.07	1156	CRONIN	1963	CNTR	Λ from $\pi^- p$

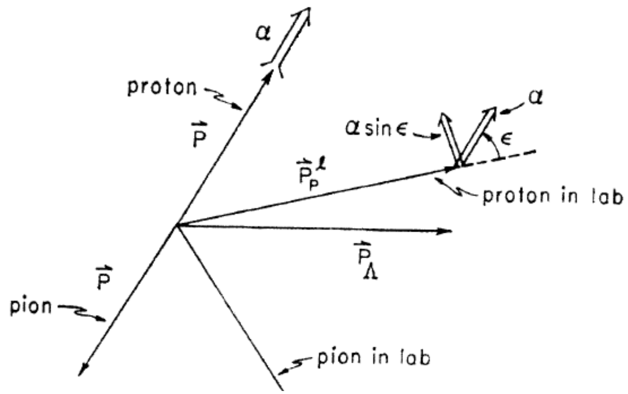
α_+ FOR $\overline{\Lambda} \to \overline{p}\pi^+$

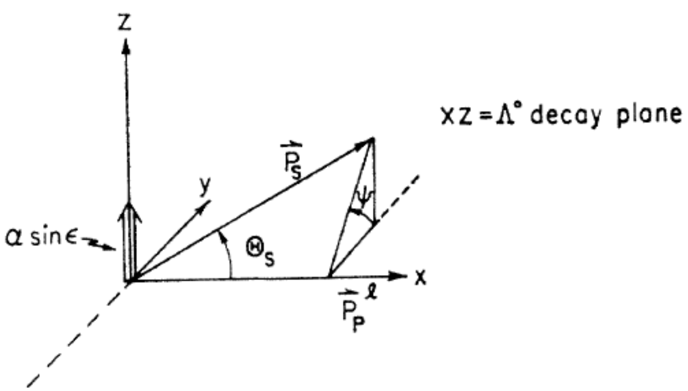
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{-0.71 \pm 0.08}$	**OUR AVERAGE**				
$-0.755 \pm 0.083 \pm 0.063$	$\approx$ 8.7k	ABLIKIM	2010	BES	$J/\psi \to \Lambda\overline{\Lambda}$
-0.63 ± 0.13	770	TIXIER	1988	DM2	$J/\psi \to \Lambda\overline{\Lambda}$

Most earlier measurement on α_{-}

- CNTR exp., $\pi^- + p \rightarrow \Lambda + K^0$
- Unpolarized $\Lambda \rightarrow p\pi^-$
- Proton polarization measured with carbon-plate spark chamber

Phys.Rev. 129 (1963) 1795-1807





$$W(\psi) = 1 + \alpha\, S \sin\epsilon \cos\psi$$

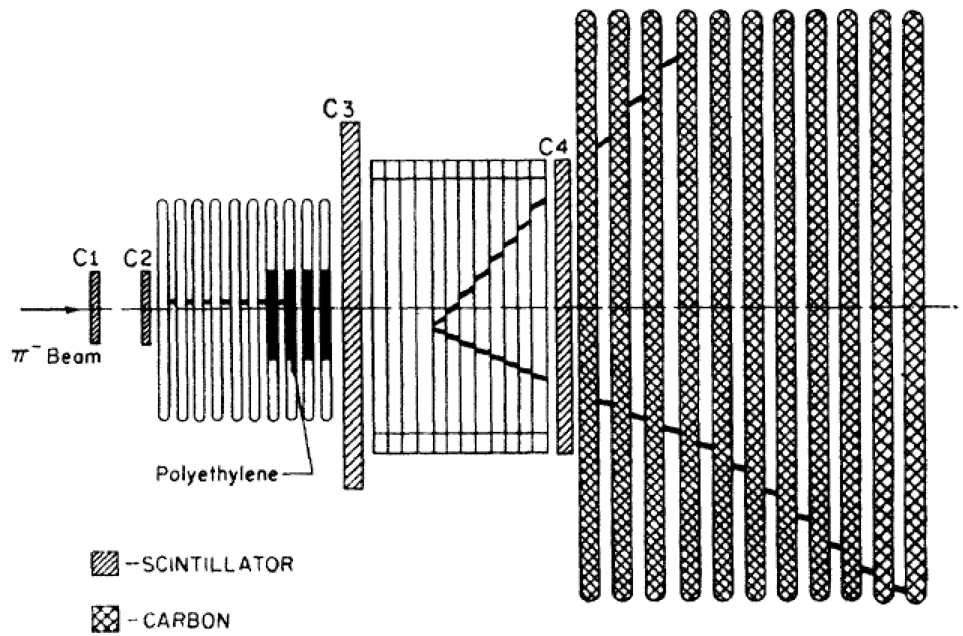


FIG. 1. Schematic diagram showing arrangement of apparatus. An example of an event has been sketched in.

$$\boxed{\alpha = \frac{2}{\pi}\,\frac{1}{\langle S\rangle\langle\sin\epsilon\rangle}\,\frac{N_+ - N_-}{N_+ + N_-},}$$

1156 events

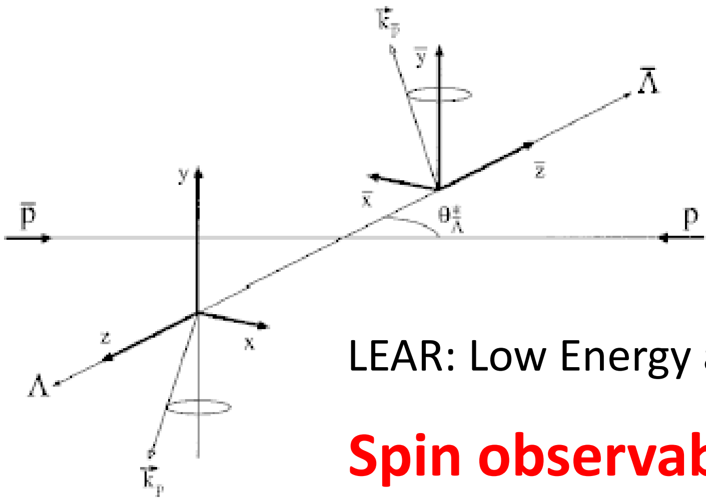
$\langle S\rangle = 0.565$

$\langle\sin\epsilon\rangle = 0.84,$

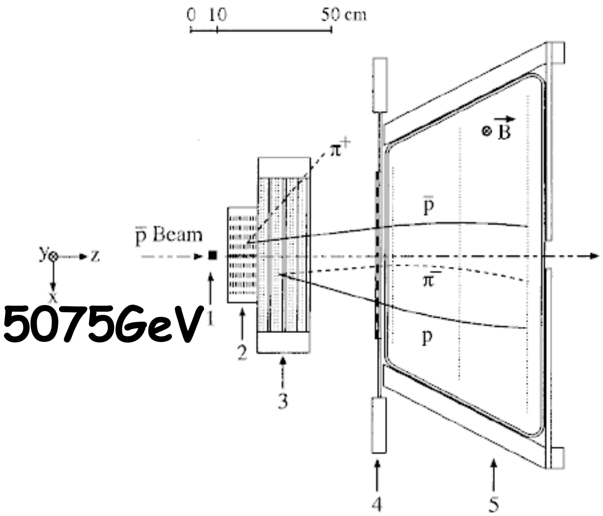
$\alpha = 0.62.$

PS185 at LEAR : $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$

Assuming C invariance in the production $P_{y\Lambda} = P_{y\bar{\Lambda}}$



$\bar{p}$ momentum : 1.4765GeV ~ 1.5075GeV



LEAR: Low Energy antiproton Ring

Spin observables were shown

$$I(\theta_p) = I_0(1 + \alpha P_y \cos\theta_p)$$

Extraction of αP_y: $\alpha P_y = \dfrac{\sum \cos\theta_y^{(i)}}{\sum \cos^2\theta_y^{(i)}}$

requires $\eta(\theta_y) = \eta(\pi - \theta_y)$

From a combined total sample of 95832 events:

$$A_\Lambda \approx \frac{\alpha_\Lambda P_\Lambda + \alpha_{\bar{\Lambda}} P_{\bar{\Lambda}}}{\alpha_\Lambda P_\Lambda - \alpha_{\bar{\Lambda}} P_{\bar{\Lambda}}} = 0.013 \pm 0.022$$ (PRC54,1877(1996))

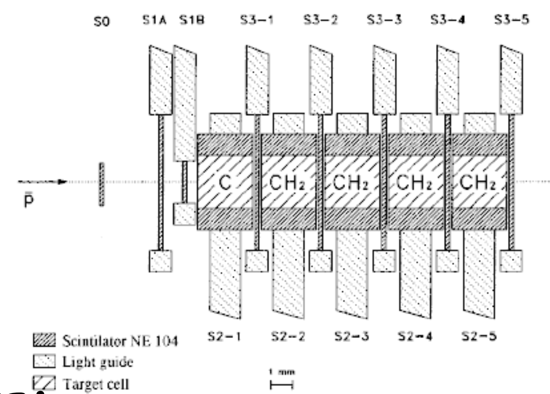


FIG. 1. Overview of the PS185 detector system. (1) segmented neutral trigger target, (2) multiwire proportional chambers (MWPC's), (3) multiwire drift chambers (MWDC's), (4) scintillation hodoscope, and (5) solenoid "baryon indentifier" with drift chambers. The lower part of the figure shows a detail of the segmented target.

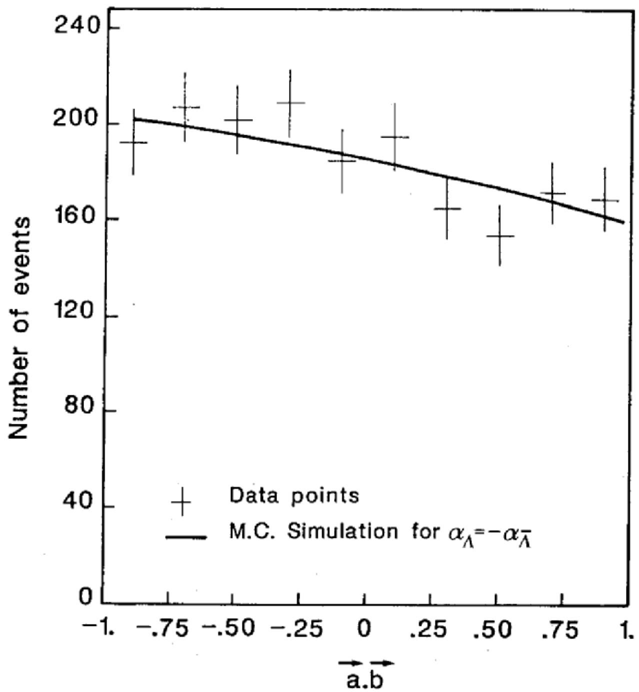
DM2 : $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

- 1847 $\Lambda\bar{\Lambda} \to p\pi^- \bar{p}\pi^+$ from 8.6× 10^6 $e^+e^- \to J/\psi$
- No explicit assumption about Λ and $\bar{\Lambda}$ polarization needed
- CP violation signal appears in the product $\alpha_\Lambda\alpha_{\bar{\Lambda}}$ **a·b,** where **a** and **b** are the p and $\bar{p}$ unit vector in the Λ and $\bar{\Lambda}$ rest frame
- Not consider the transverse polarization of Λ and $\bar{\Lambda}$

Fixing α_Λ =0.642 and fit yields

$$\boldsymbol{\alpha_{\bar{\Lambda}} = -0.63 \pm 0.13}.$$

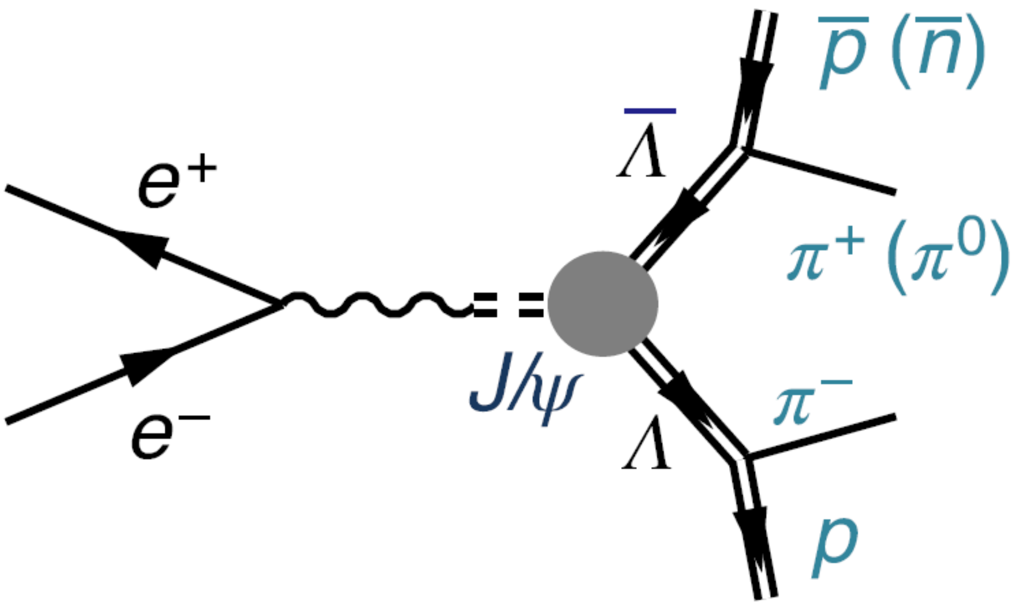
$$\Rightarrow \boldsymbol{A_\Lambda = 0.01 \pm 0.10}$$

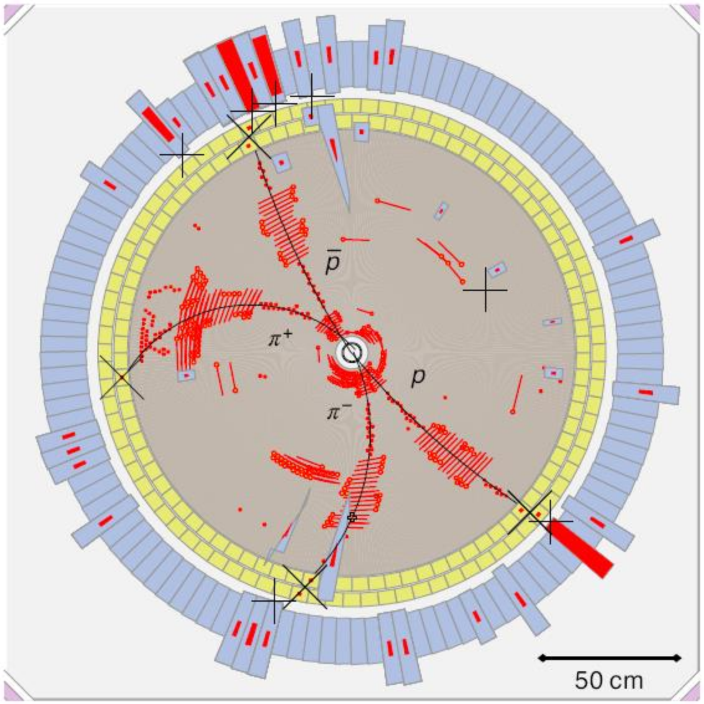


Hyperon decay parameters @ BESIII

$$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda} \rightarrow p\bar{p}\pi^+\pi^-$$

Event selection:





- ✓ No PID request for charged tracks
- ✓ $\Lambda/\bar{\Lambda}$ reconstructed with second vertex fit
- ✓ Events reconstructed with kinematic fit

Hyperon decay parameters @ BESIII

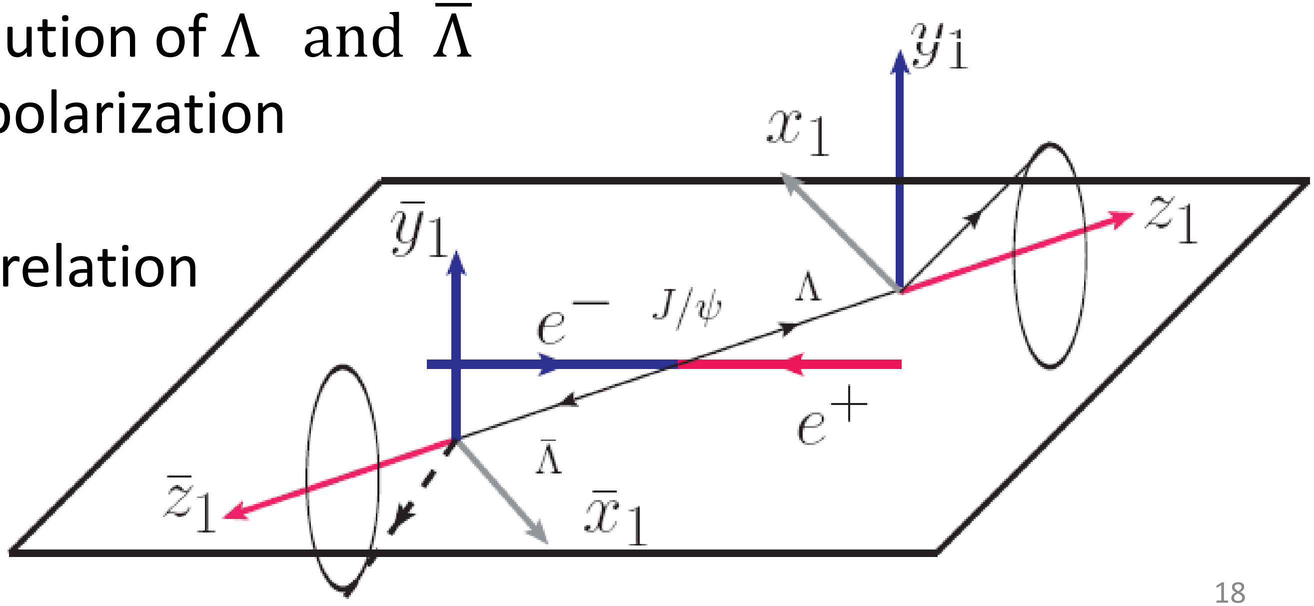
$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$$

G. Faldt and A. Kupsc
PLB,772, 16 (2017)
EPJA, 52, 141 (2016)
EPJA, 51, 74 (2015).

$$\frac{d\sigma}{d\Omega} \propto T_0 + \sqrt{1-\alpha_{J/\psi}^2}\sin(\Delta)(\alpha_\Lambda T_3 + \alpha_{\bar{\Lambda}} T_4) + \alpha_\Lambda \alpha_{\bar{\Lambda}}[T_1 + \sqrt{1-\alpha_{J/\psi}^2}\cos(\Delta) T_2 + \alpha_{J/\psi} T_5],$$

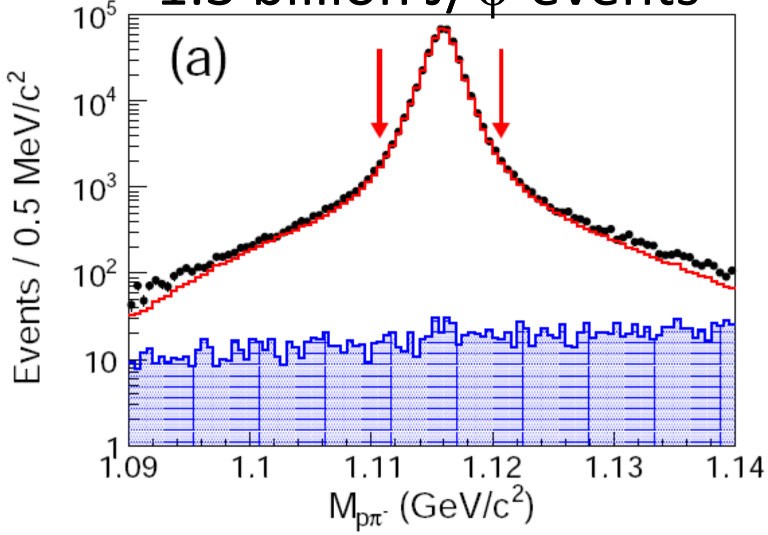
T_0: angular distribution of Λ and $\bar{\Lambda}$
T_3, T_4, transverse polarization

T_1, T_2, T_5: spin correlation

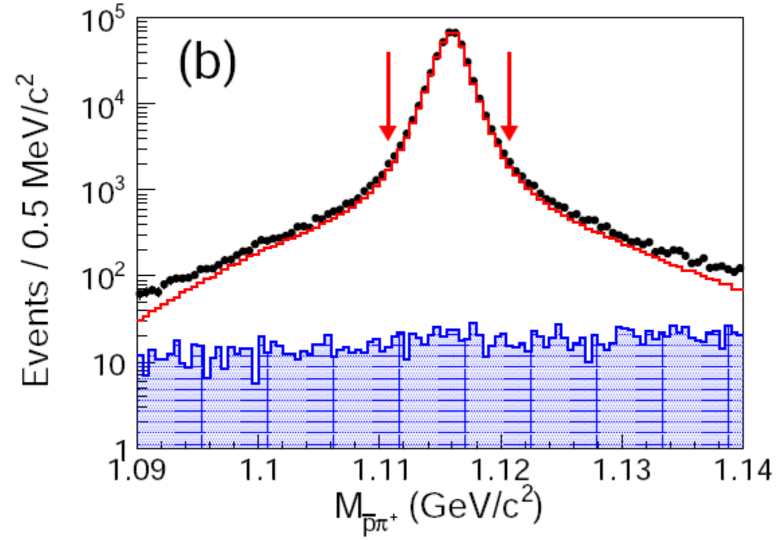


$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-,\ p\bar{n}\pi^-\pi^0$

1.3 billion J/ψ events

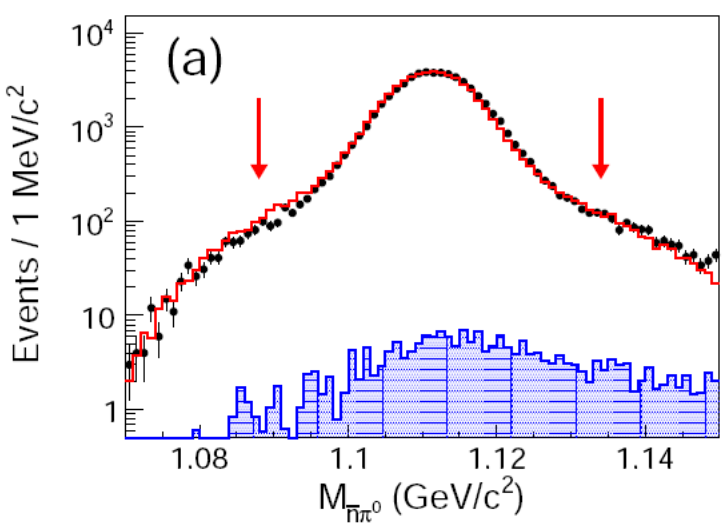


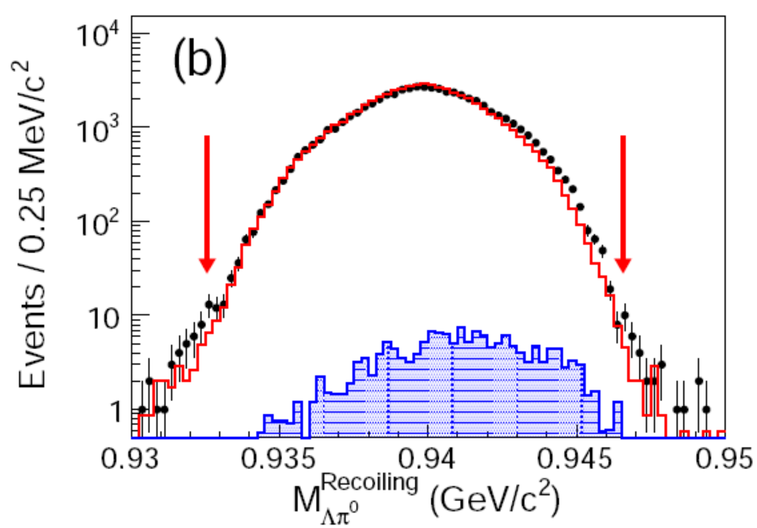
420,593 events selected



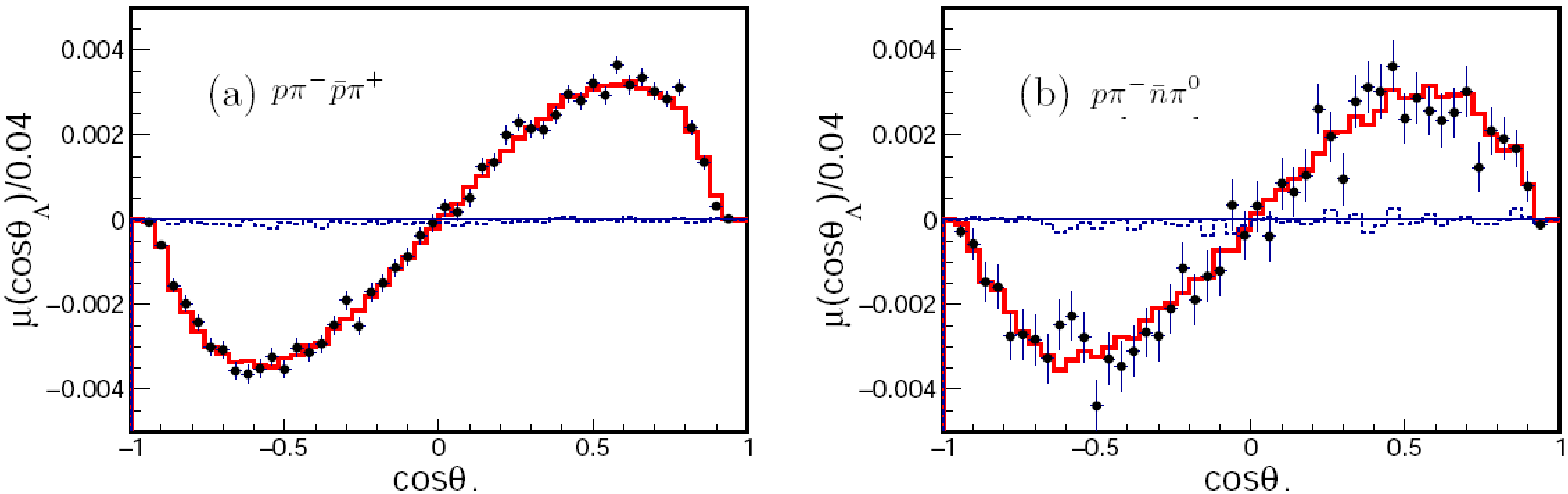
$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{n}\pi^0\pi^+$

47,009 events selected





Results of simultaneous fit to two data sets



Parameters	This measurement	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [19]
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [8]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [8]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	——
$\Delta\Phi$ (rad)	$0.740 \pm 0.010 \pm 0.008$	$\Delta\Phi = 42.4^\circ \pm 0.6^\circ(sta) \pm 0.5^\circ(sys.)$
A_Λ	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [8]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	——

Systematic uncertainties

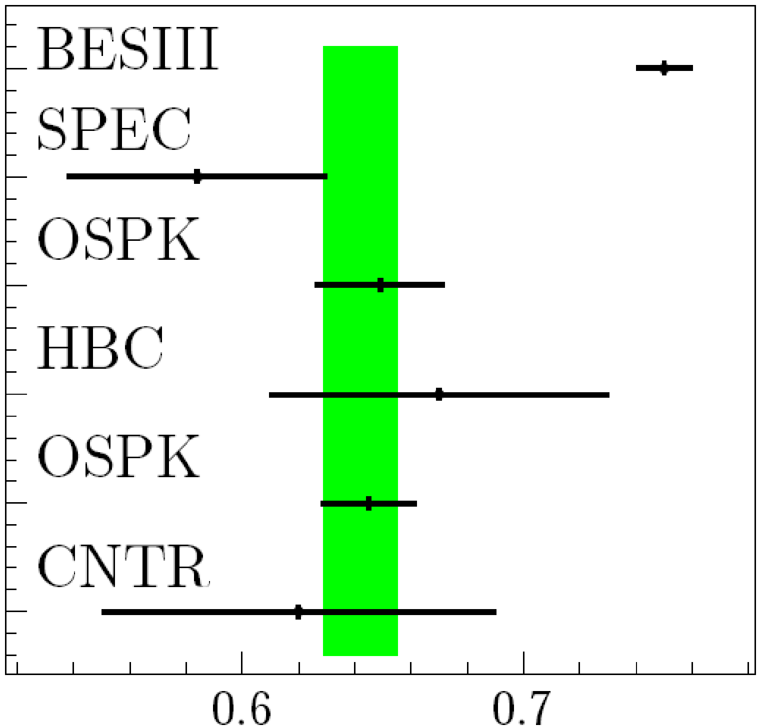
- Challenge to estimate detector asymmetry in tracking, and kinematic fit
- Systematic uncertainties well controlled

Relative systematic uncertainties (%)

Source	α_ψ	α_-	α_+	$\bar{\alpha}_0$	$\Delta\Phi$
Tracking,π^0, $\bar{n}$	1.5	0.1	0.3	0.6	1.1
Kinematic fit	0.2	0.1	0.8	0.6	0.0
Fit method	0.0	0.5	0.4	0.4	0.1
Total	1.5	0.5	0.9	0.8	1.1

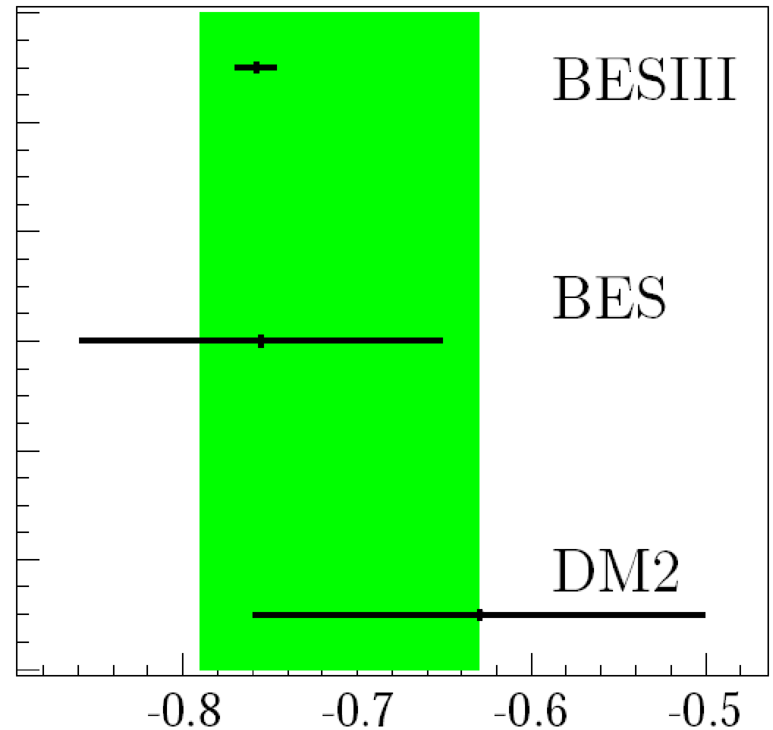
- Justify results with $J/\psi \to \Xi^-\bar{\Xi}^+ \to \Lambda\bar{\Lambda}\pi^+\pi^- \to p\bar{p}2(\pi^+\pi^-)$

BESIII: 0.750±0.010



(a) α_- for $\Lambda \to p\pi^-$

BESIII: -0.758 ± 0.012



(b) α_+ for $\bar{\Lambda} \to \bar{p}\pi^+$

BESIII, [Nature Phys. 15 (2019) 631-634]

arXiv: 1808.08917

Quick response from PDG2019

α_- FOR $\Lambda \to p\pi^-$

2019 PDG list

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.750 \pm 0.009 \pm 0.004$	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\overline{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.584 ± 0.046	8500	ASTBURY	1975	SPEC	
0.649 ± 0.023	10325	CLELAND	1972	OSPK	
0.67 ± 0.06	3520	DAUBER	1969	HBC	From Ξ decay
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α_+ FOR $\overline{\Lambda} \to \overline{p}\pi^+$

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$-0.755 \pm 0.083 \pm 0.063$	$\approx$ 8.7k	ABLIKIM	2010	BES	$J/\psi \to \Lambda\overline{\Lambda}$
-0.63 ± 0.13	770	TIXIER	1988	DM2	$J/\psi \to \Lambda\overline{\Lambda}$

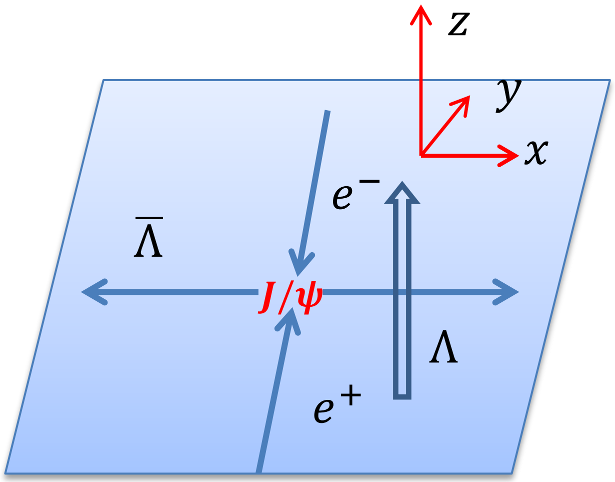
Where does the TP come from?

- From the e^+/e^- beam ?
  - ✘ No, BEPC beams unpolarized
- From the e^+/e^- natural polarization when circulating in the BEPCII storage ring ?
  - ✘ Sokolov-Ternov effects: 4.3 hs @ψ' peak, but beam lifetime ~ 2.0 hs
- From the J/ψ spin transfer ?
  - ✓ Yes, it does from the J/ψ tensor polarization

J/ψ polarization: $\mathcal{P}_z = 0,\ T_{zz} = \frac{1}{\sqrt{6}}$

Λ transverse polarization:

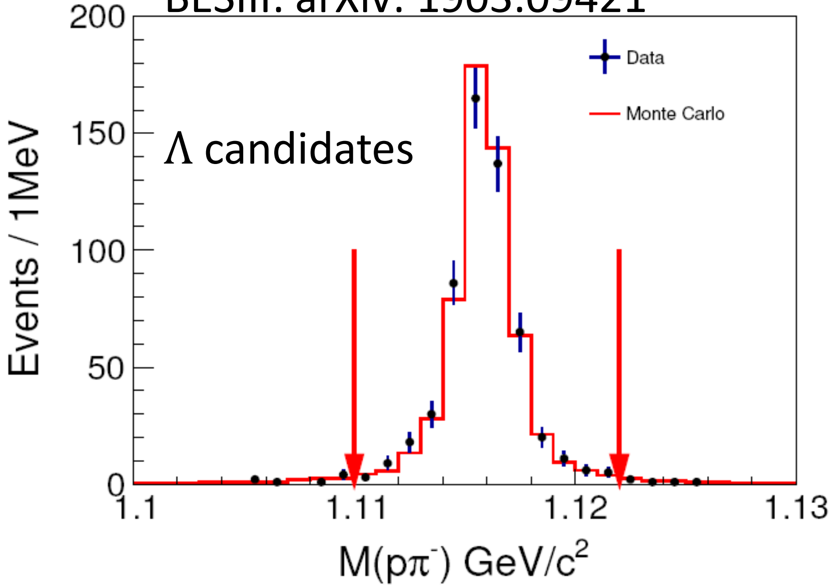
$$\mathcal{P}_y = \sqrt{6}\frac{T_{zz}\sin\theta\cos\theta\sin\Delta\sqrt{1-\alpha_\psi^2}}{1+\alpha_\psi\left[\frac{1}{3}+\frac{1}{\sqrt{6}}T_{zz}(1+3\cos 2\theta)\right]}$$



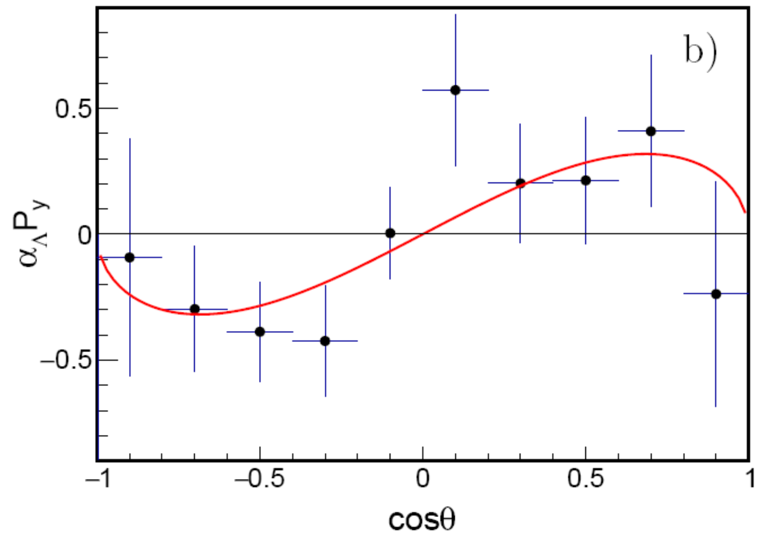
$\mathcal{P}_y$ manifest if $\sin\Delta \neq 0$

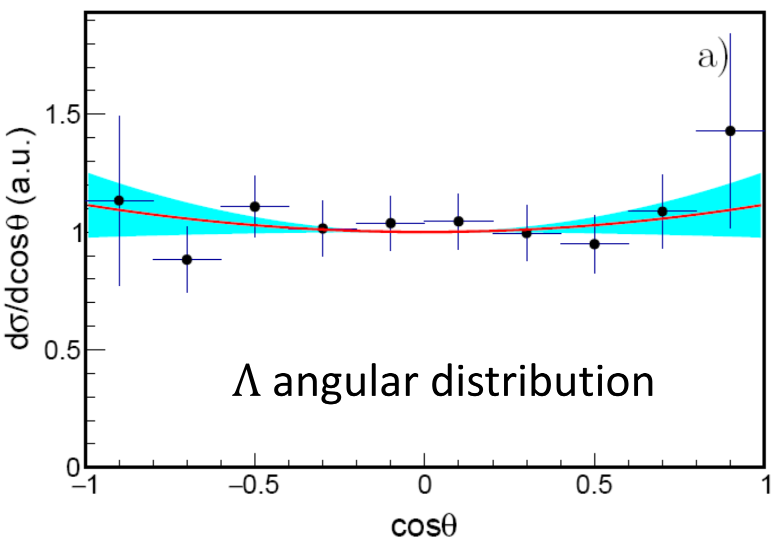
$e^+e^- \to \gamma^* \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$

BESIII: arXiv: 1903.09421



Λ transverse polarization





- data set: 2.396 GeV, L=66.9 pb^{-1}
- 555 candidate events
- $\Delta\Phi = 37^{\circ} \pm 12^{\circ} \pm 6^{\circ}$
- Maximum polarization degree is $\sim$30%

Open questions for understading Λ TP

- What physics behind the Λ transverse polarization?
- Is the phase difference Δ predictable in physics?
- What's relationship between the Λ TP and the Λ fragmentation function?
- How to simply understand the Λ TP in naïve quark model?
- How to predict the charmed hyper TP in e^+e^- experiments.

Ongoing polarization analyses at BESIII

- $J/\psi, \psi' \to \Sigma^- \bar{\Sigma}^+$ (talk by Liang Yan)
- $J/\psi \to \Xi^- \bar{\Xi}^+$ (Ξ, Λ asymmetry par., CP test)
- $\psi' \to \Omega^- \bar{\Omega}^+$ (polarization analysis)
- $\eta_c \to \Lambda \bar{\Lambda}$ (EPR test)
- $e^+ e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$
  - $\Lambda_c^+ \to \Lambda \pi^+, \Sigma^+ \pi^0, \Sigma^0 \pi^+, K_S p$, (talk by Binglong Wang)
  - Λ_c spin
- future baryon program (talk by Andrezj)

Summary

- $\Lambda/\bar{\Lambda}$ transverse polarization significantly observed at BESIII in J/ψ or continuum processes
- BESIII 10 billion J/ψ data provides us chances to access hyperon physics.
- Extension study to charmed hyperon are ongoing.
- Polarized beam in the future super-tau charm facility (STCF) help to improve the precision.

Thanks for your attention!