中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

BESIII

BESIII 上超子的横向极化和 CP 破坏研究

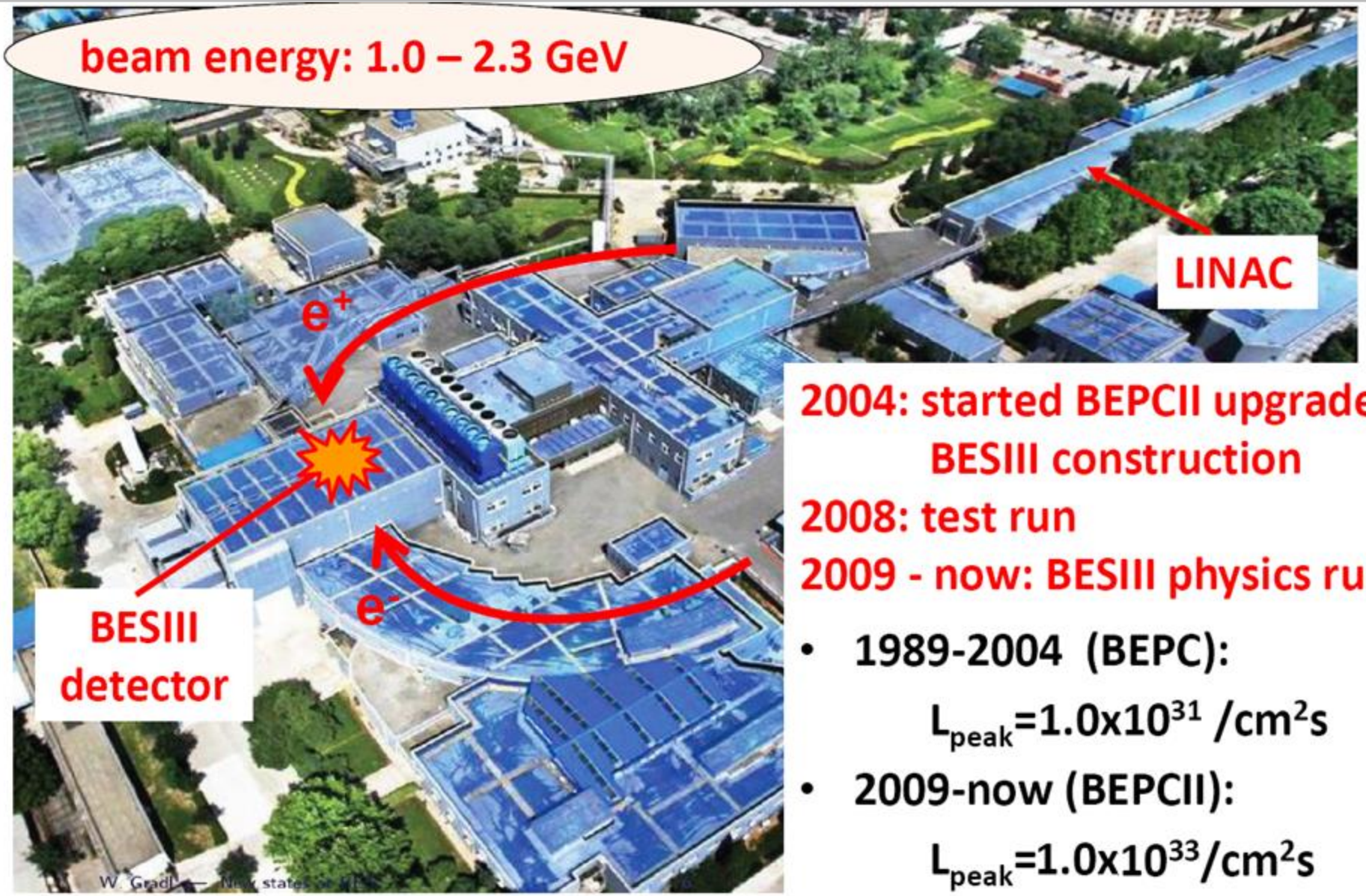
平荣刚

(For BESIII Collaboration)

Institute of High Energy Physics, CAS

pingrg@ihep.ac.cn

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

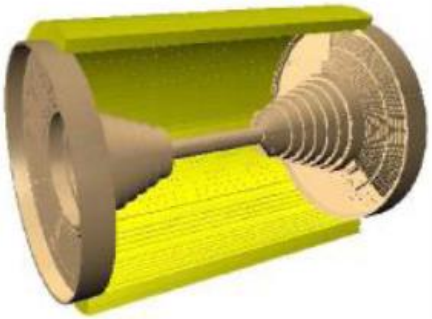
  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- 2009-now (BEPCII):

  $L_{peak}=1.0\times10^{33}$/cm^{2}s

BESIII Detector

MDC

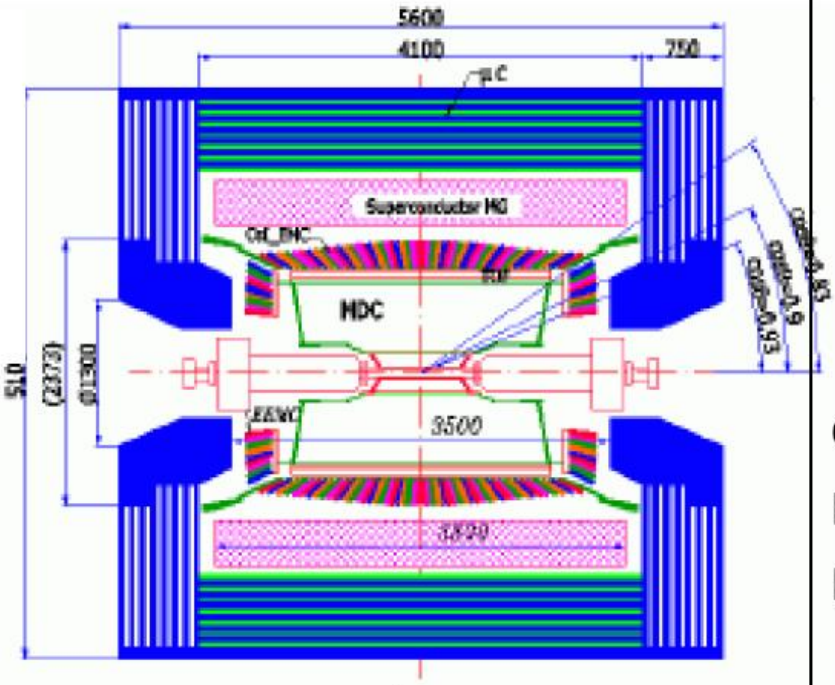


R inner: 63mm ;

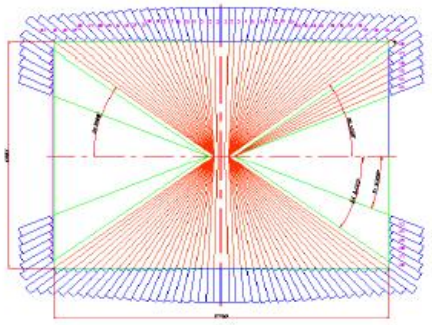
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



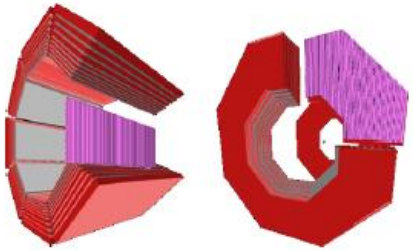
Crystals: 28 cm(15 X_0)

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

Endcap:

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

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

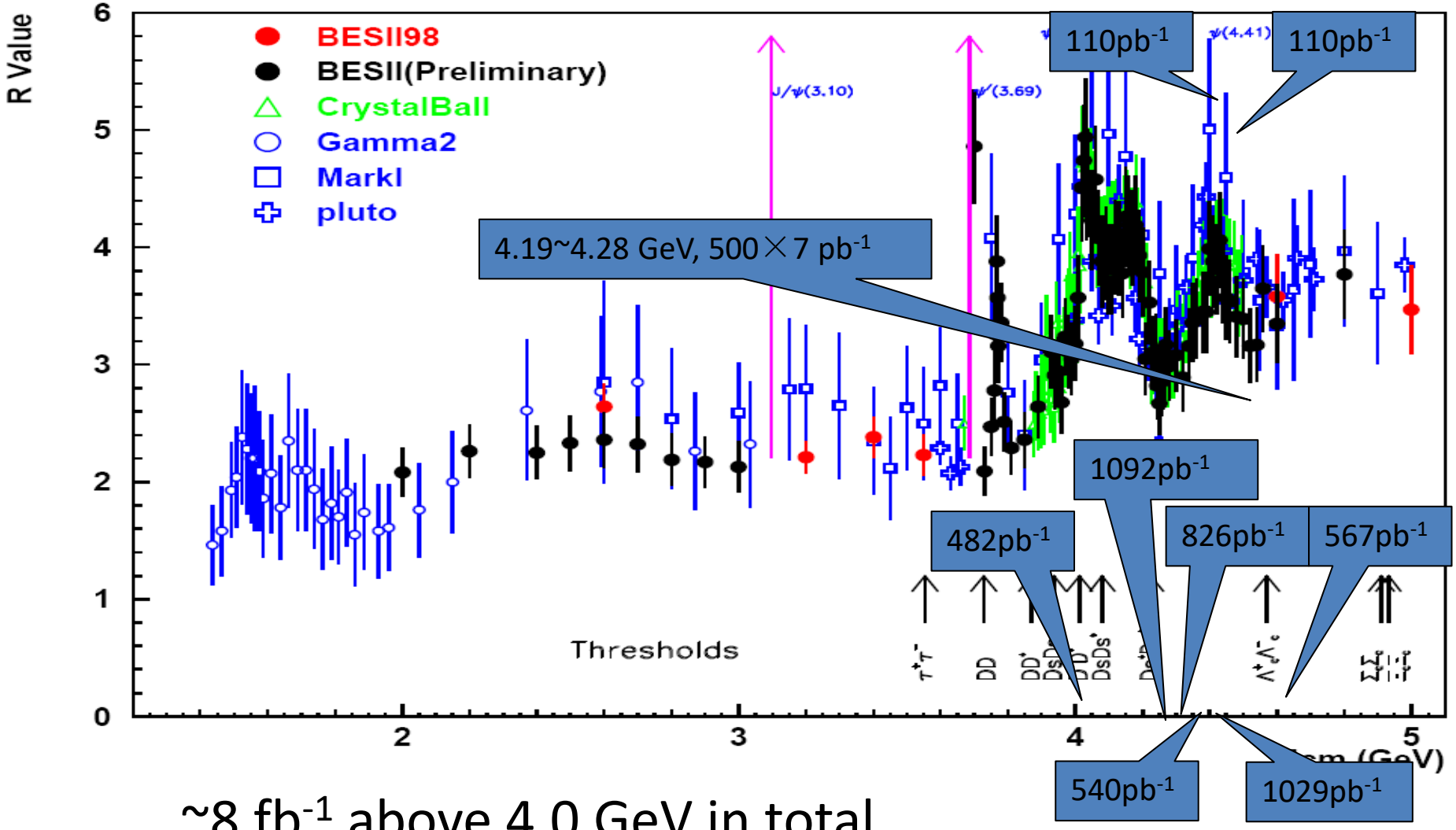
TOF

BTOF: two layers

ETOF: 48 scintillators for each

MRPC --- new ETOF

Data sets for *XYZ* study



~8 fb^{-1} above 4.0 GeV in total

~ 6 billion J/ψ events

Role of polarization physics

- Probing of spin degree freedom: test the dynamic of SM

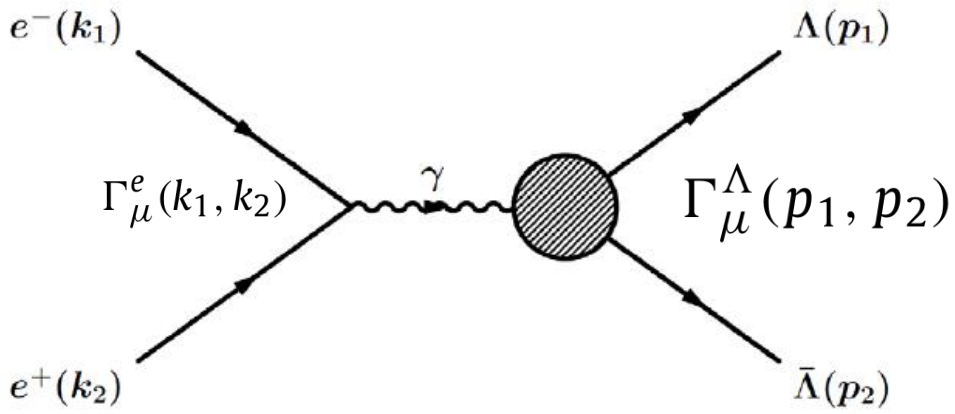
  Existant exp. : RHIC, Jlab, GRAAL, CERN and DESY
  Spin observable, spin-dependent structure function and parton distribution
  Spin crisis at eighties

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

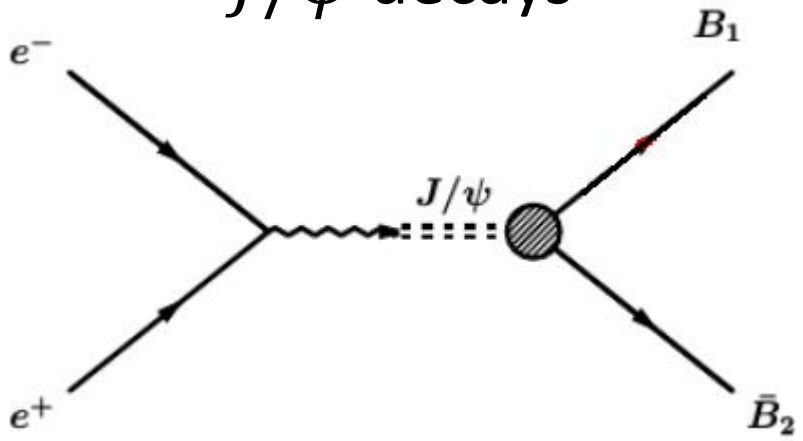
  - Polarized beam for post-BEPCII options, CPV in tau decay, Hyperon weak decay,……
  - Useful tool: transverse polarization of hyperon, spontaneous production at e^+e^- collision

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

FFs in continuum



J/ψ decays



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

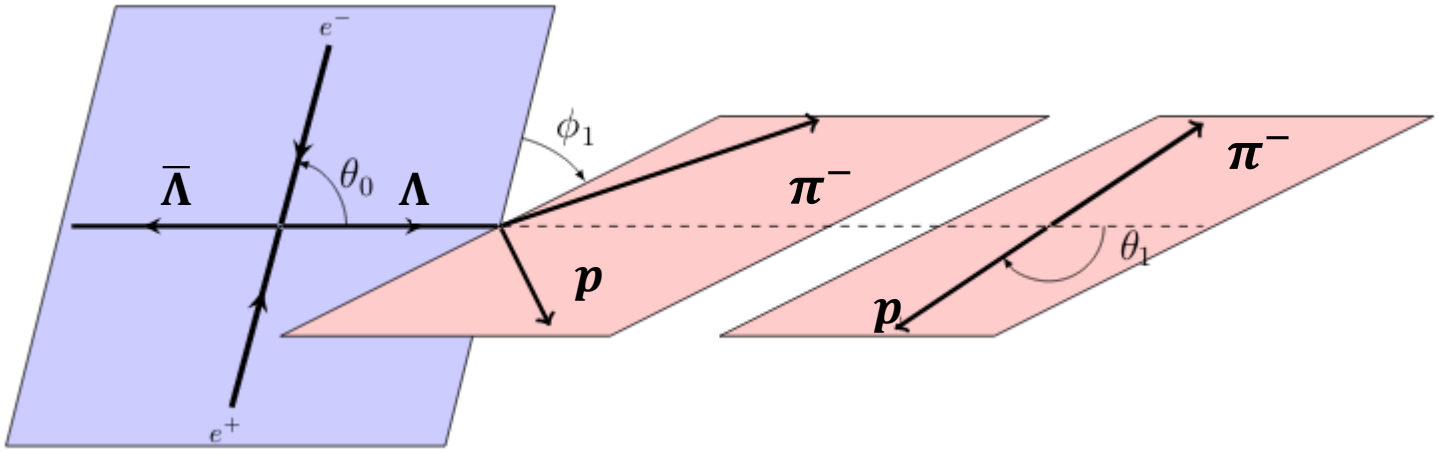
Time likespin ½ baryon FFs:

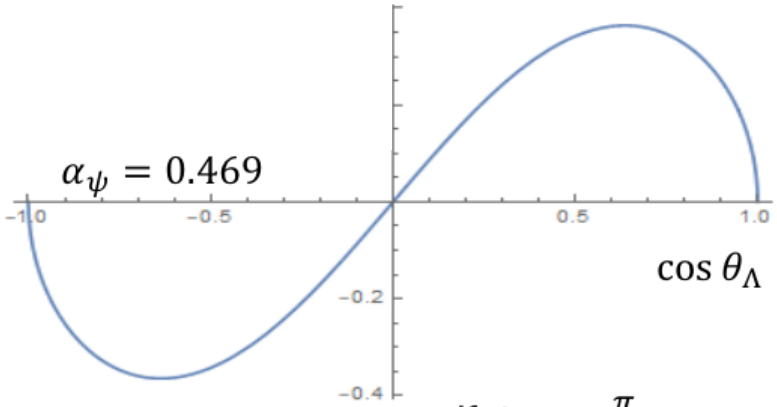
Dubnickova, Dubnicka, Rekalo
Nuovo Cim. A109 (1996) 241
Gakh, Tomasi-Gustafsson Nucl.Phys. A771 (2006) 169
Czyz, Grzelinska, Kuhn PRD75 (2007) 074026
FäldtEPJ A51 (2015) 74; EPJ A52 (2016)141
W. Lu, et.al., Phys.Lett., B368, 261 (1996)

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

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

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





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

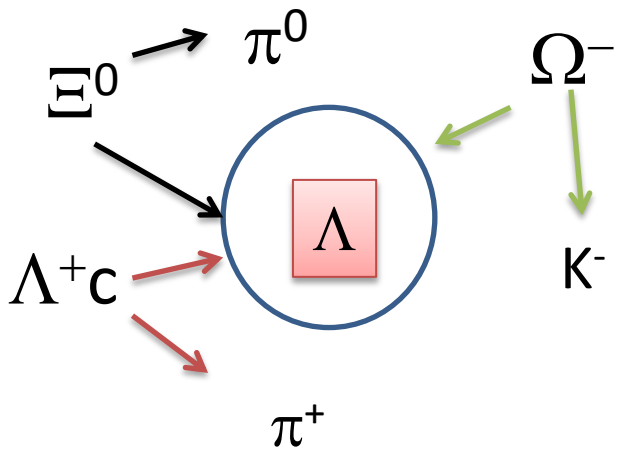
Max P_Λ= 36.4%

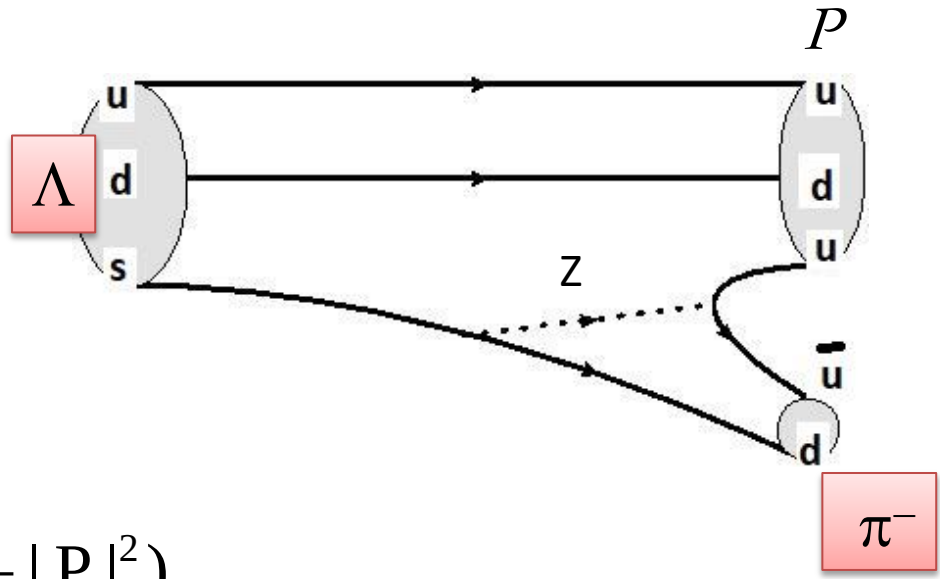
if $\Delta\Phi = \frac{\pi}{2}$

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

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

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





$$\Gamma = G_F^2 m_\pi^4 \frac{p_d (E_d + m_d)}{4\pi m_p} (|S|^2 + |P|^2)$$

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

Asymmetry angular distribution

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

C- and P- transformation

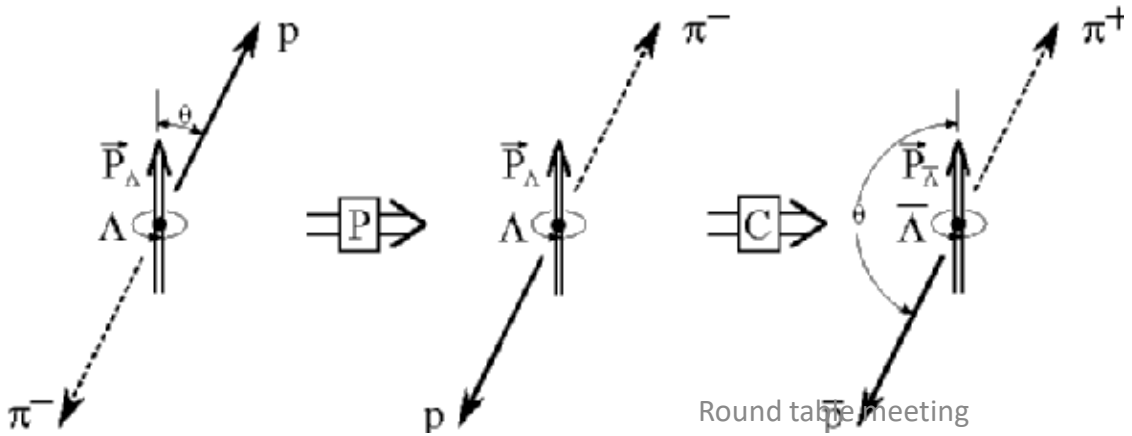
$$\alpha_\Lambda = \frac{|B_+|^2 - |B_-|^2}{|B_+|^2 + |B_-|^2}, \alpha_{\bar{\Lambda}} = \frac{|\bar{B}_+|^2 - |\bar{B}_-|^2}{|\bar{B}_+|^2 + |\bar{B}_-|^2}$$

CP **invariance**:

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

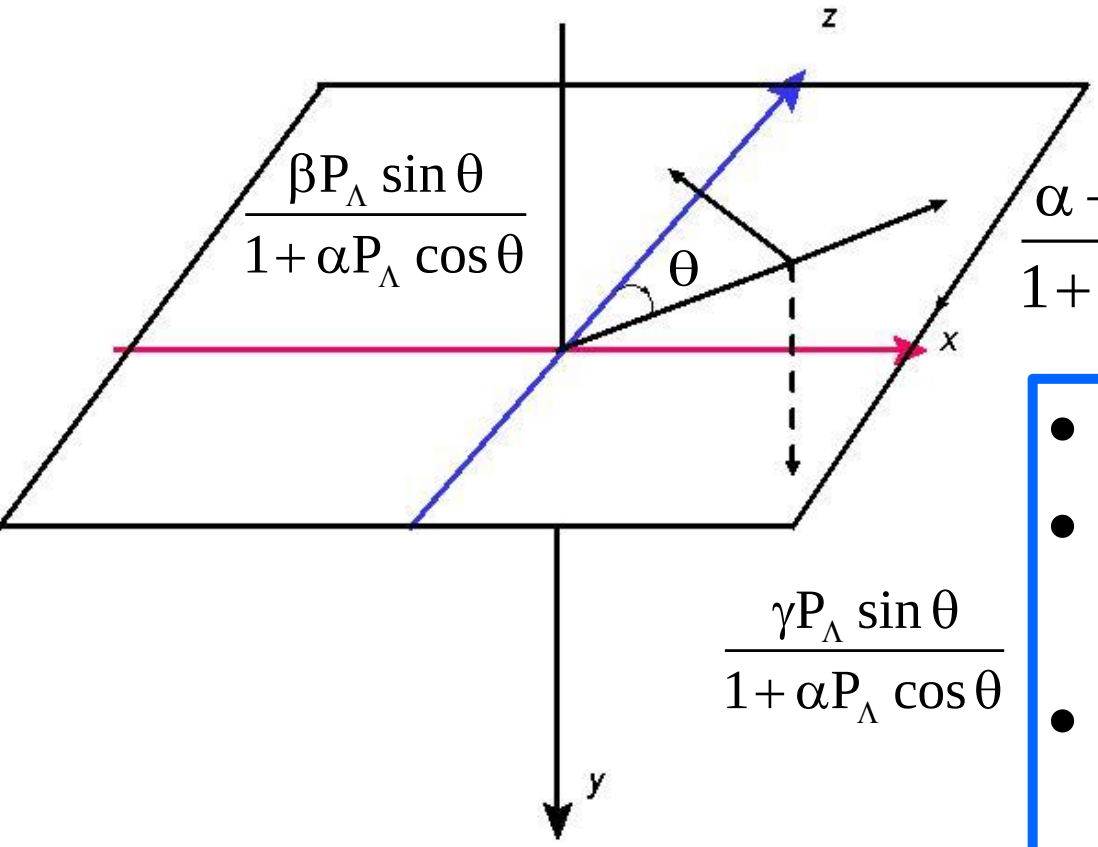
If CP invariance:

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



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

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



$$\frac{\beta P_\Lambda \sin\theta}{1 + \alpha P_\Lambda \cos\theta}$$

$$\frac{\alpha + P_\Lambda \cos\theta}{1 + \alpha P_\Lambda \cos\theta}$$

$$\frac{\gamma P_\Lambda \sin\theta}{1 + \alpha P_\Lambda \cos\theta}$$

- If $P_\Lambda = 0$ then $P_p = \alpha p \cdot q$
- T – odd transverse polarization

  $\beta \neq 0$
- If CP is conserved :

  $\alpha = -\bar{\alpha}$, $\beta = -\bar{\beta}$,

  $\gamma = \bar{\gamma}$ and $\Gamma = \bar{\Gamma}$

CP-odd observables

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

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

- 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

Previous Measurements

α_- FOR $\Lambda \to p\pi^-$

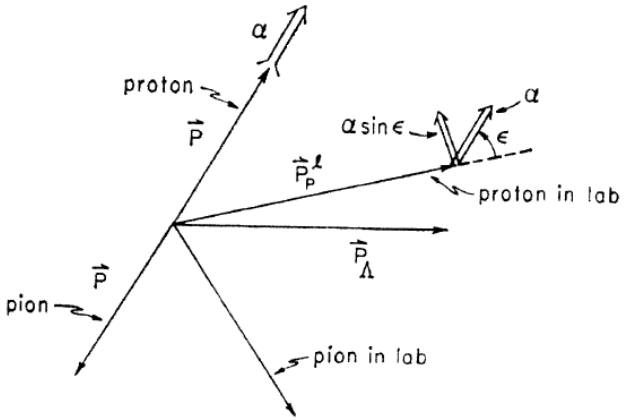
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.642 ± 0.013	**OUR AVERAGE**				
0.584 ± 0.046	8500	ASTBURY	1975	SPEC	
0.649 ± 0.023	10325	CLELAND	1972	OSPK	
0.67 ± 0.06	3520	DAUBER	1969	HBC	From Ξ decay
0.645 ± 0.017	10130	OVERSETH	1967	OSPK	Λ from $\pi^- p$
0.62 ± 0.07	1156	CRONIN	1963	CNTR	Λ from $\pi^- p$

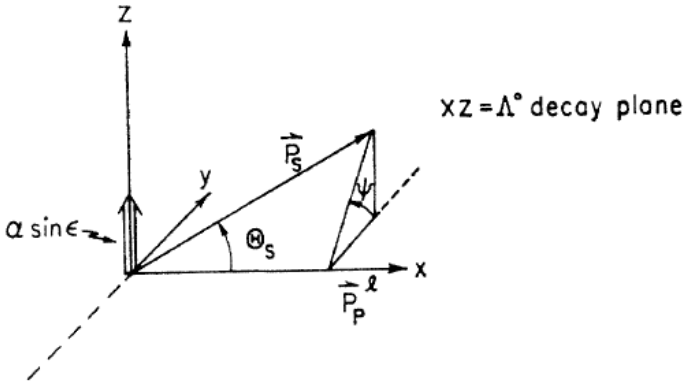
α_+ FOR $\overline{\Lambda} \to \overline{p}\pi^+$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
-0.71 ± 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 实验， $\pi^- + p \to \Lambda + K^0$
- 非极化的Λ衰变产生的p的极化为α, 末态p的极化可以通过火花室测量





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

Phys.Rev. 129 (1963) 1795-1807

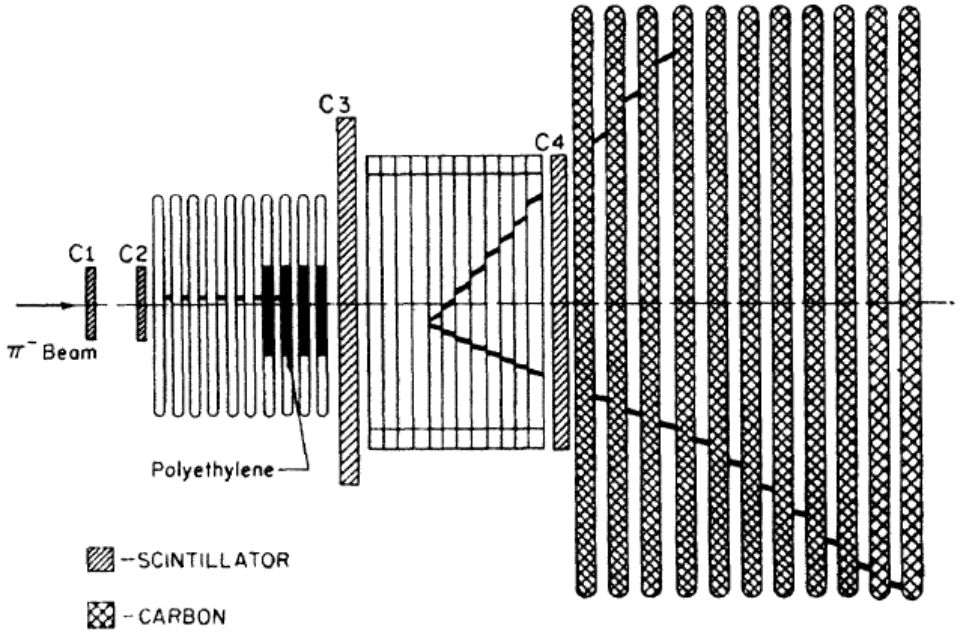


FIG. 1. Schematic diagram showing arrangement of apparatus. An example of an event has been sketched in.

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

1156 events

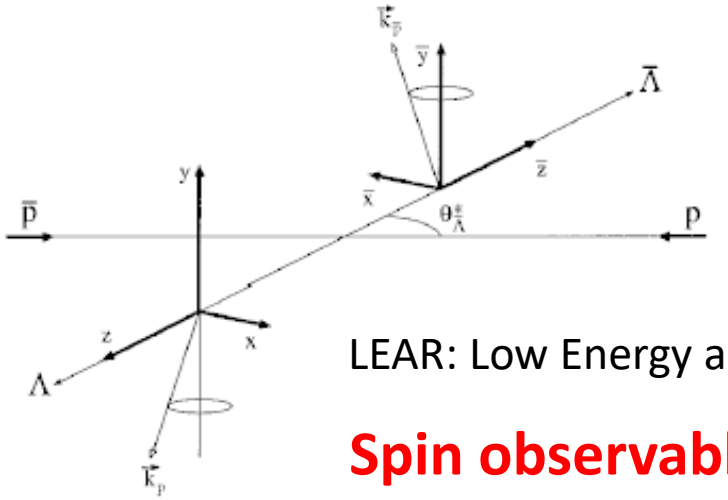
$\langle S\rangle = 0.565$

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

$\alpha = 0.62.$

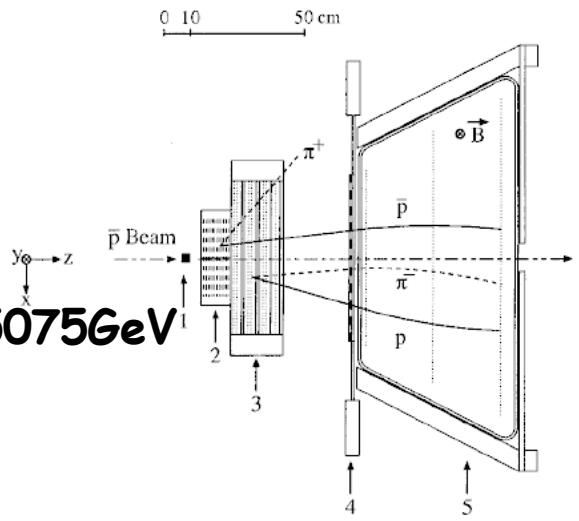
PS185 at LEAR : $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$

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



p̄ 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))**

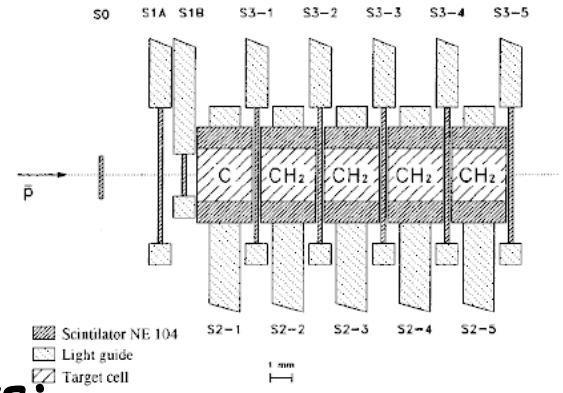


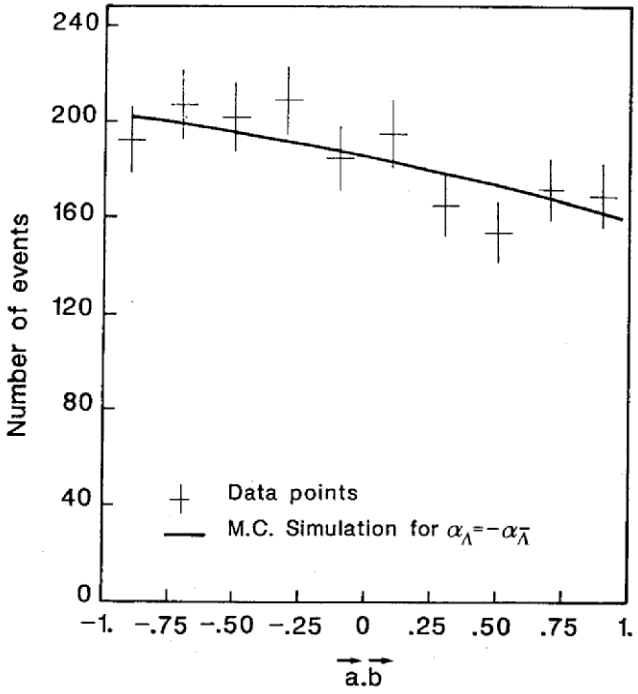
FIG. 1. Overview of the PS185 detector system. (1) segmented neutral trigger target, (2) multiwire proportional chambers (MWPC's), (3) multiwire drift chambers (MWDC's), (4) scintillator hodoscope, and (5) solenoid "baryon indentifier" with drift chambers. The lower part of the figure shows a detail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

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

- 1847 $\Lambda\bar{\Lambda} \to p\pi^-\ p\pi^+$ 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 varying $\alpha_{\bar{\Lambda}}$ in MC generation of $\boldsymbol{a \cdot b}$

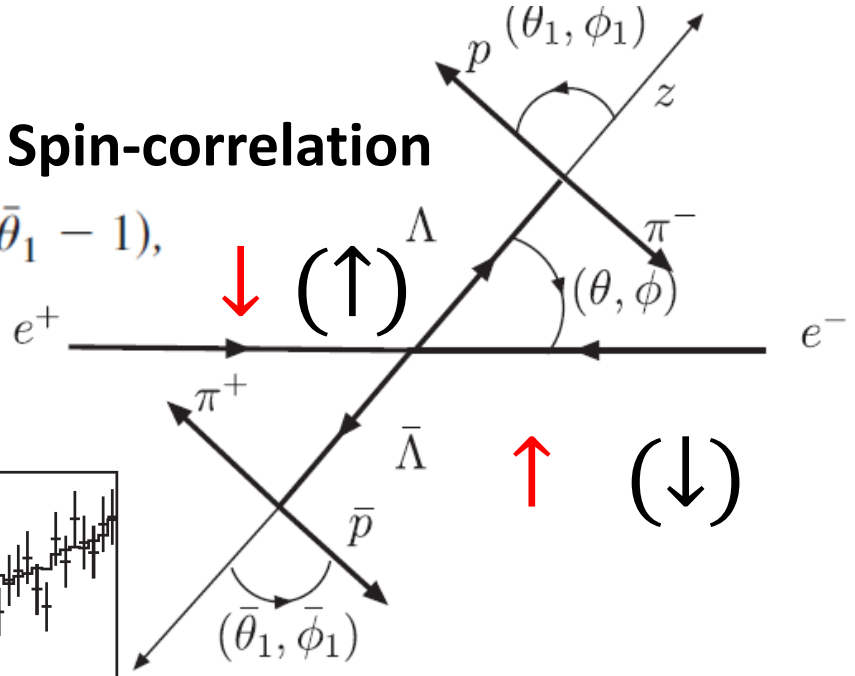
$$\boldsymbol{A_\Lambda = 0.01 \pm 0.10}$$



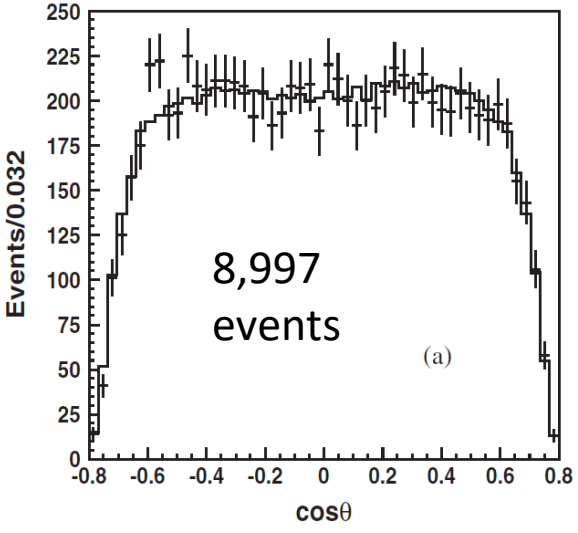
BESII with 58 million J/ψ decays

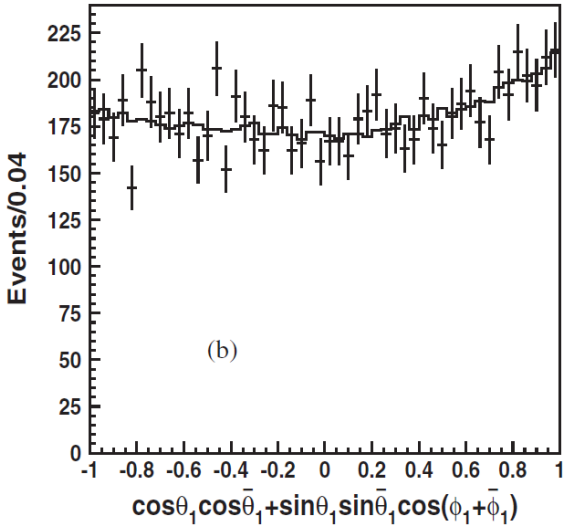
$$\frac{d\sigma}{d\Omega} \propto (1-\alpha)\sin^2\theta[1+\alpha_\Lambda\alpha_{\bar\Lambda}(\cos\theta_1\cos\bar\theta_1 + \sin\theta_1\sin\bar\theta_1\cos(\phi_1+\bar\phi_1))] - (1+\alpha)(1+\cos^2\theta)(\alpha_\Lambda\alpha_{\bar\Lambda}\cos\theta_1\cos\bar\theta_1 - 1),$$

Spin-correlation



Same as DM2





$$\alpha_{\bar\Lambda} = -0.755 \pm 0.083 \pm 0.063,$$
$$A = -0.081 \pm 0.055 \pm 0.059,$$

PRD 81, 012003 (2010)

Hyperon decay parameters @ BESIII

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

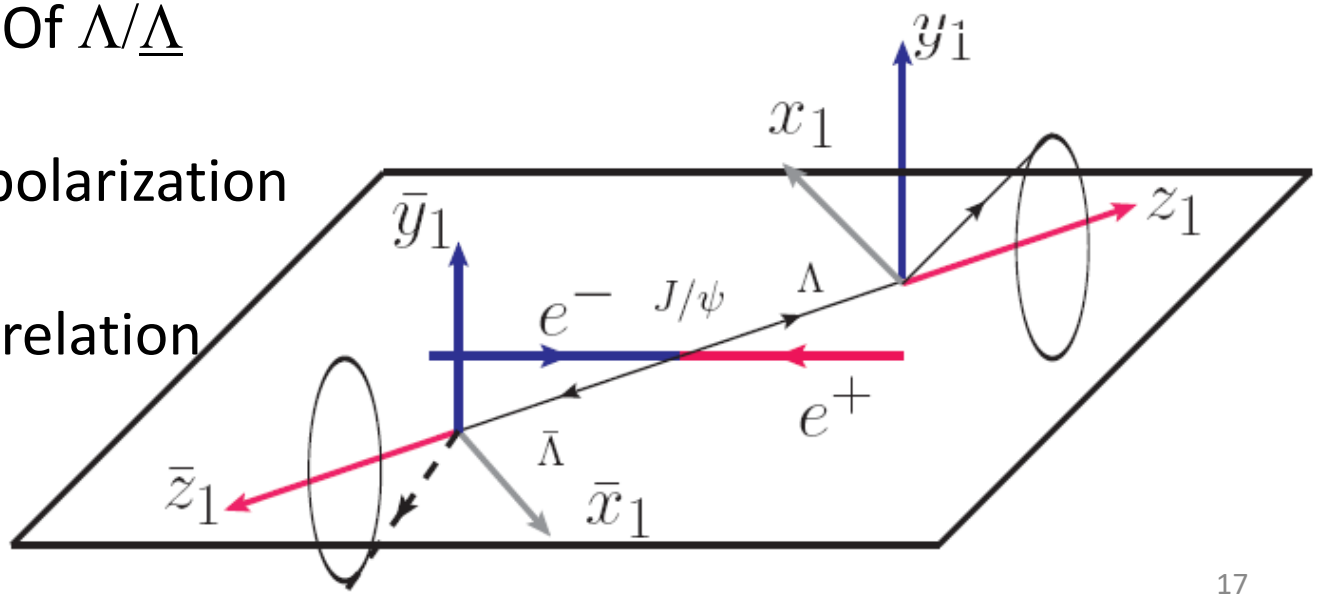
G. Faldt and A. Kupsc
PLB,772, 16 (2017)
EPJA, 52, 141 (2016)
EPJA, 51, 74 (2015).

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

T_0: angular distri. Of $\Lambda/\underline{\Lambda}$

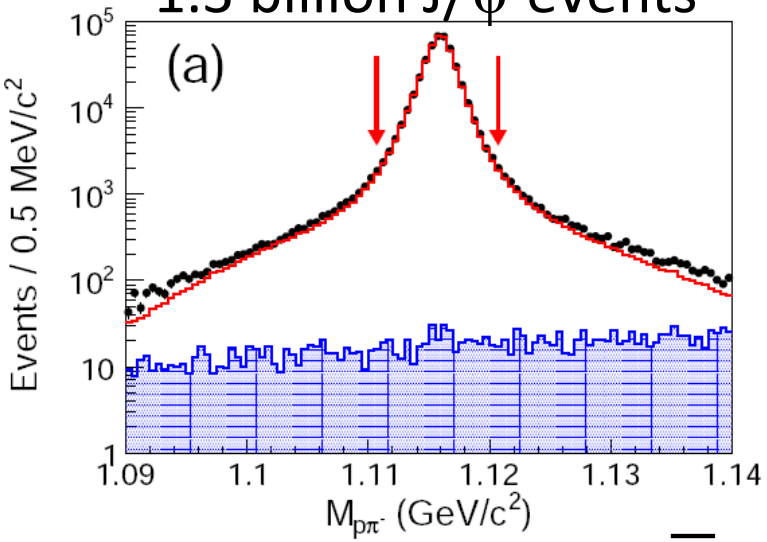
T_3, T_4, transverse polarization

T_1, T_2, T_5: spin correlation

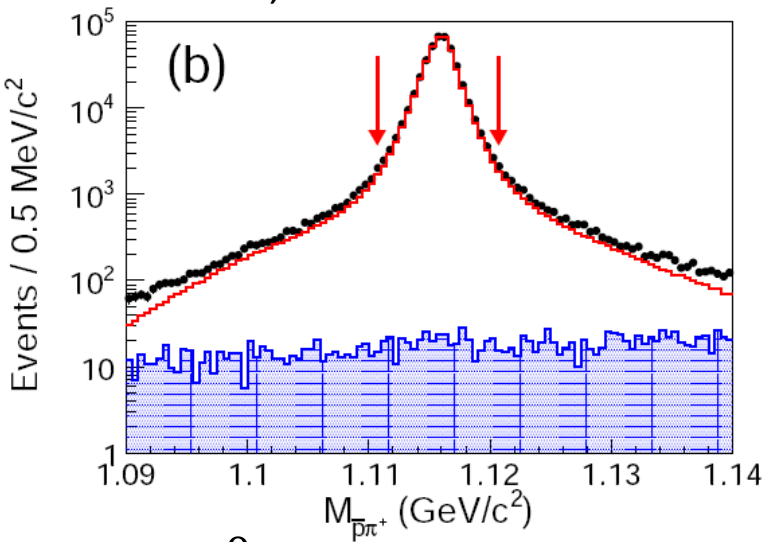


$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$

1.3 billion J/ψ events

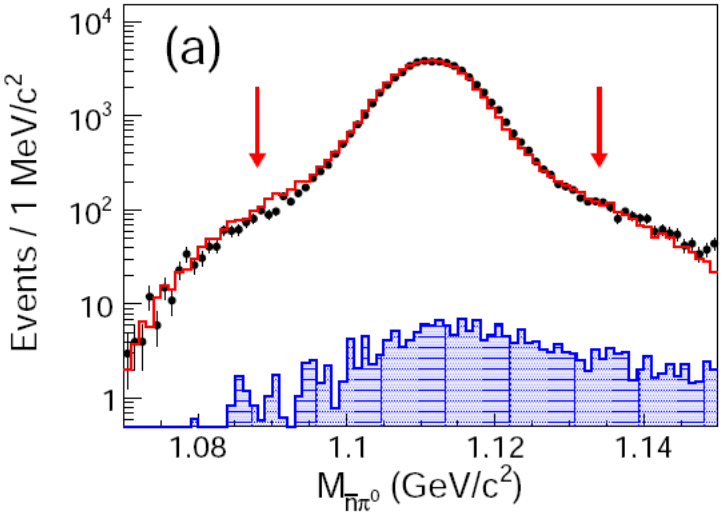


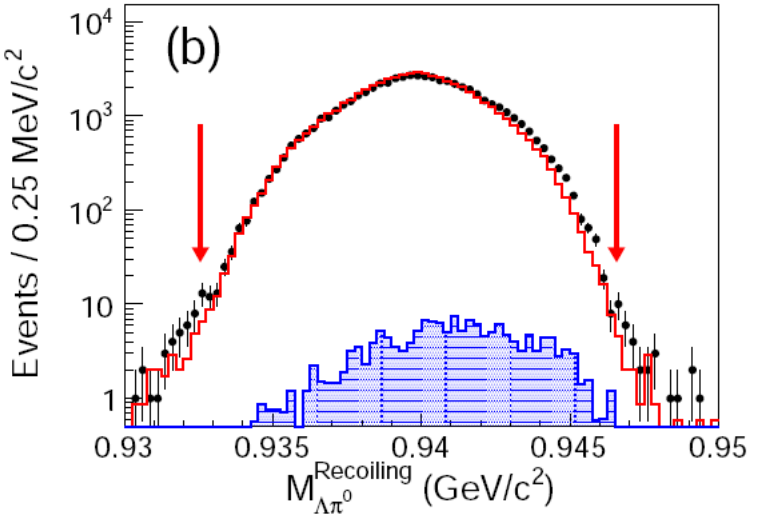
420,593 events selected



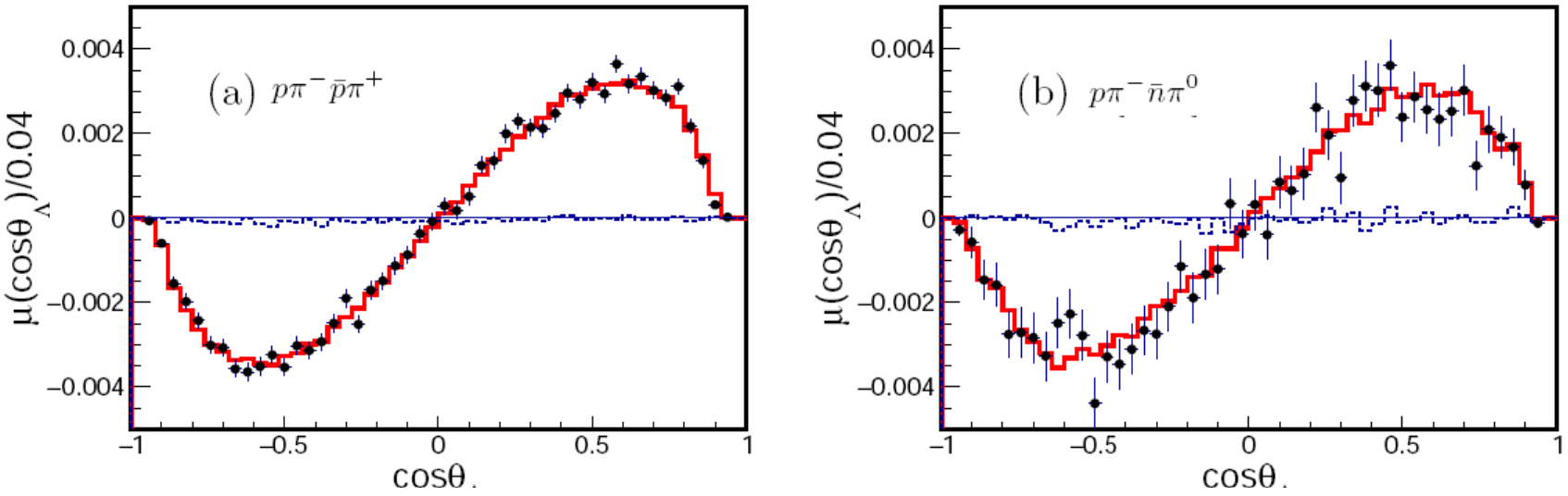
$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{n}\pi^0\pi^-$

47,009 events selected





Results of simultaneous fit to two data sets



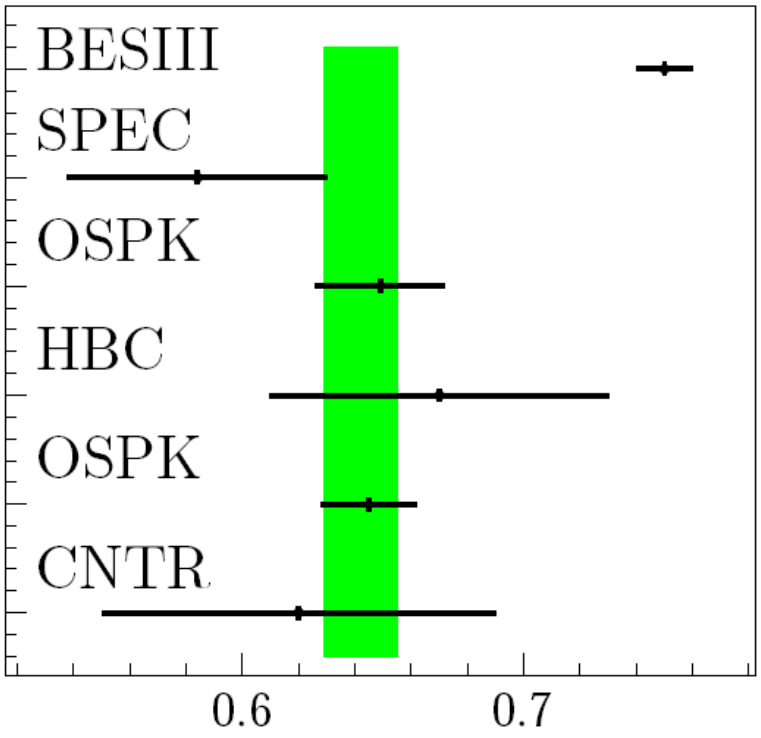
Parameters	This measurement	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [19]
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [8]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [8]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	——
$\Delta\Phi$ (rad)	$0.740 \pm 0.010 \pm 0.008$	$\Delta\Phi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

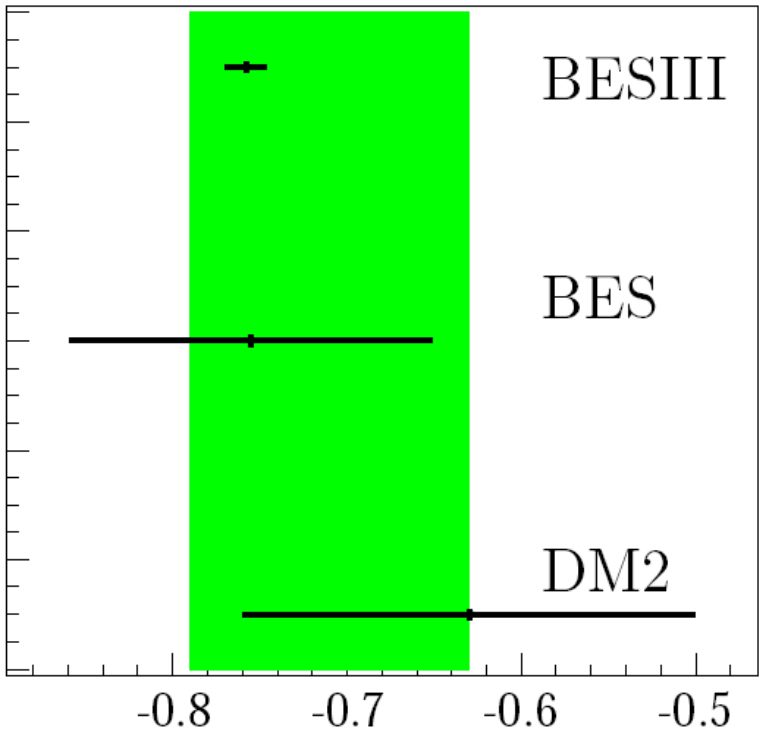
- Challenge to estimate detector asymmetry in tracking, and kinematic fit
- Systematic uncertainties well controlled

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



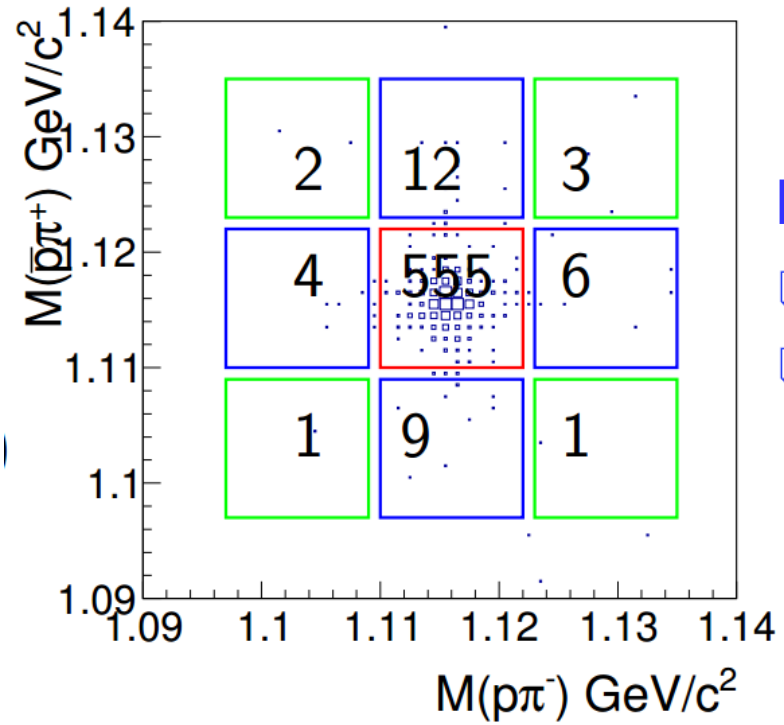
(a) α_- for $\Lambda \to p\pi^-$



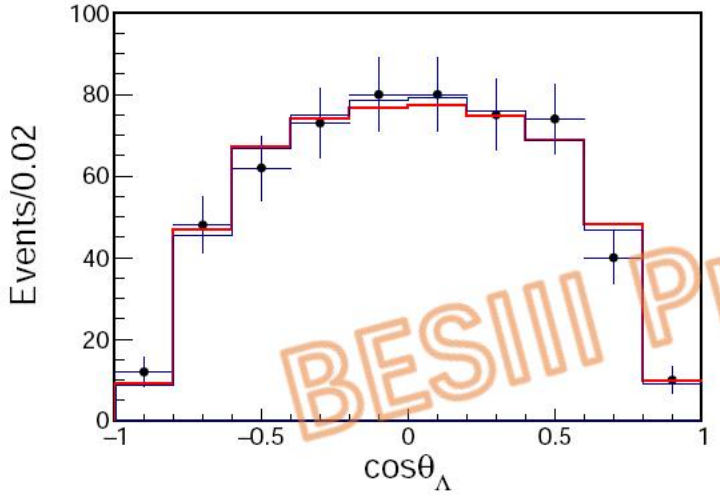
(b) α_+ for $\bar{\Lambda} \to \bar{p}\pi^+$

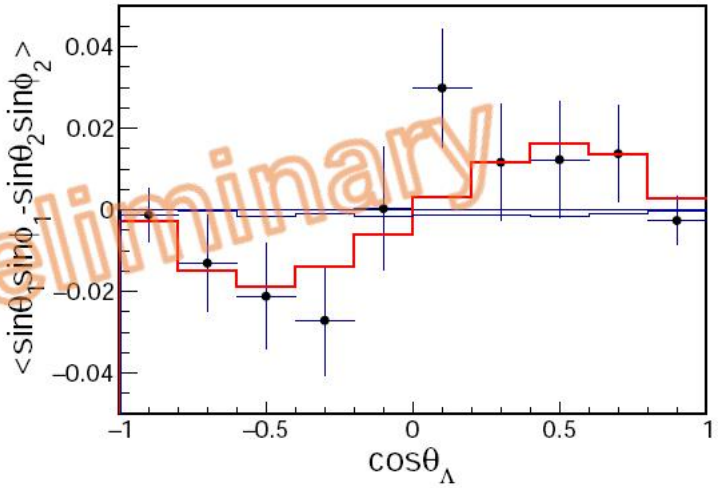
BESIII, arXiv: 1808.08917,
Submit to Nature Physics
Positive comments from referees received.

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



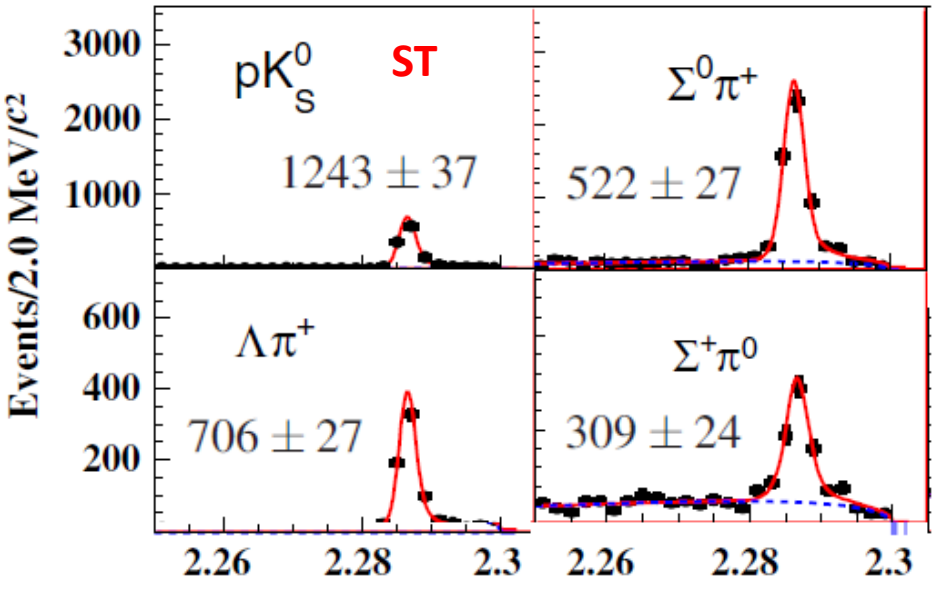
- data set: 2.396 GeV, L=66.9 pb^{-1}
- $\Delta\Phi = 42^{\circ} \pm 16^{\circ}(stat.) \pm 8^{\circ}(sys.) \pm 6^{\circ}(\alpha_\Lambda)$
- The statistical significance of $\Delta\Phi$ is 4.3σ.

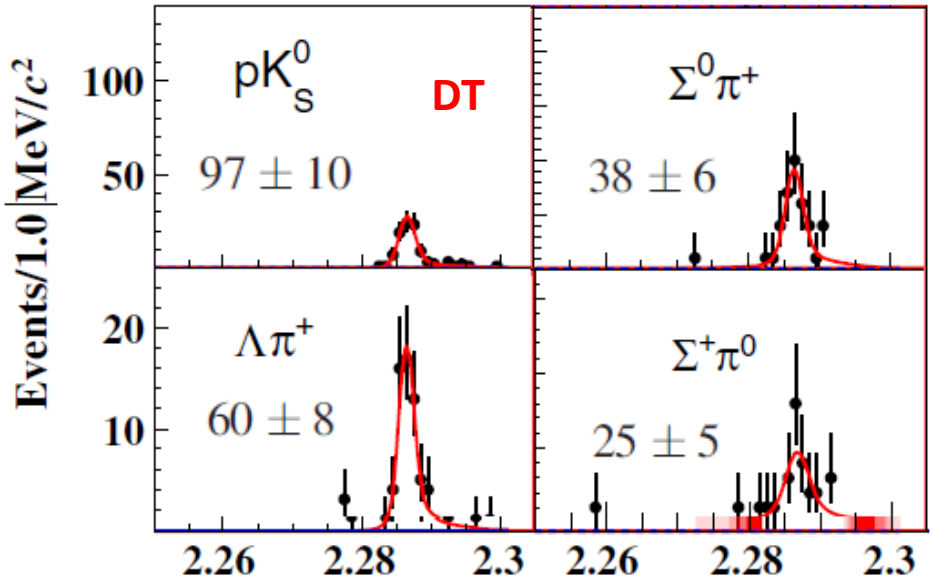




Λ_c decay asymmetry parameters

Double tag (DT) and single tag (ST) applied to 567 pb^{-1} at BESIII





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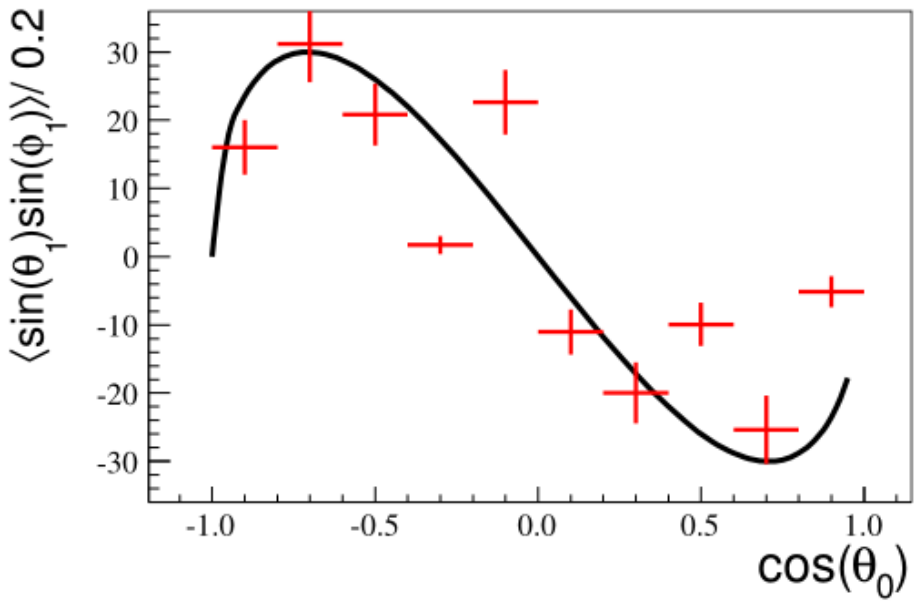
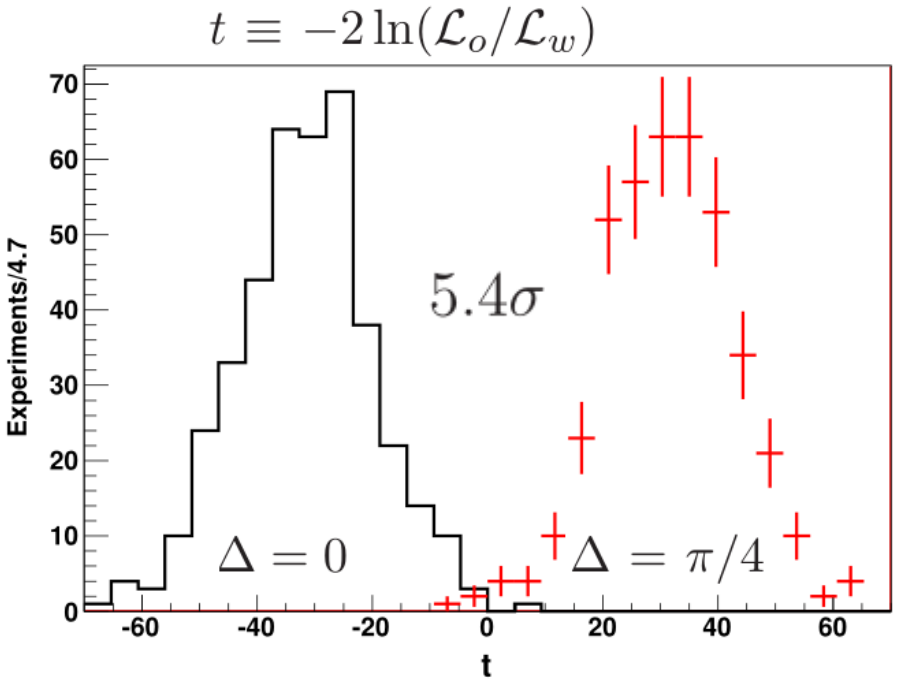
Λ_c^+ decay asymmetry parameters

$\Lambda_c^+ \to$	pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
PDG		-0.91 ± 0.15[10]	-0.45 ± 0.32 [10]	

ToyMC study





Decays	Br [11]	$\alpha^{[\Lambda_c^+]}_{[BM]}$	$N^{\rm obs}$ [24]
$\Lambda_c^+ \to pK_S^0$	$(1.58 \pm 0.08)\%$	-0.75 [?]	1243
$\Lambda_c^+ \to \Lambda\pi^+$	$(1.29 \pm 0.07)\%$	-0.91 ± 0.15 [11]	706
$\Lambda_c^+ \to \Sigma^0\pi^+$	$(1.28 \pm 0.07)\%$	-0.45 ± 0.32 [11]	522

$\alpha^{[\Lambda_c^+]}_{[BP]} = -0.71$

$\Rightarrow 5.4\sigma$

$\alpha^{[\Lambda_c^+]}_{[BP]} = -0.1$

$\Rightarrow 0.4\sigma.$

Ongoing analyses at BESIII

- $J/\psi \to \Lambda\bar{\Lambda}$, submitted, arXiv: 1808.08917
- $e^+e^- \to \Lambda\bar{\Lambda}$, BAM-00312
- $J/\psi, \psi' \to \Sigma^-\bar{\Sigma}^+$, BAM-00272
- $J/\psi, \psi' \to \Xi^-\bar{\Xi}^+$, report to Collaboration meeting
- $\psi' \to \Omega^-\bar{\Omega}^+$, report to Collaboration meeting
- $\Lambda_c^+ \to \Lambda\pi^+, \Sigma^+\pi^0, \Sigma^0\pi^+, K_S p$, BAM-251

Summary

- $\Lambda/\ \overline{\Lambda}$ transverse polarization (TP) significantly observed at BESIII in J/ψ or continuum processes
- In the case of absence of polarized beam, TP provide us with a powerful tool to study the CP violation in s- / c- hyperon decays
- Polarized beam in the future super-tau charm facility (STCF) help to improve the precision

Thanks for your attention!