Spin-Related Effect in hadron production at BESIII

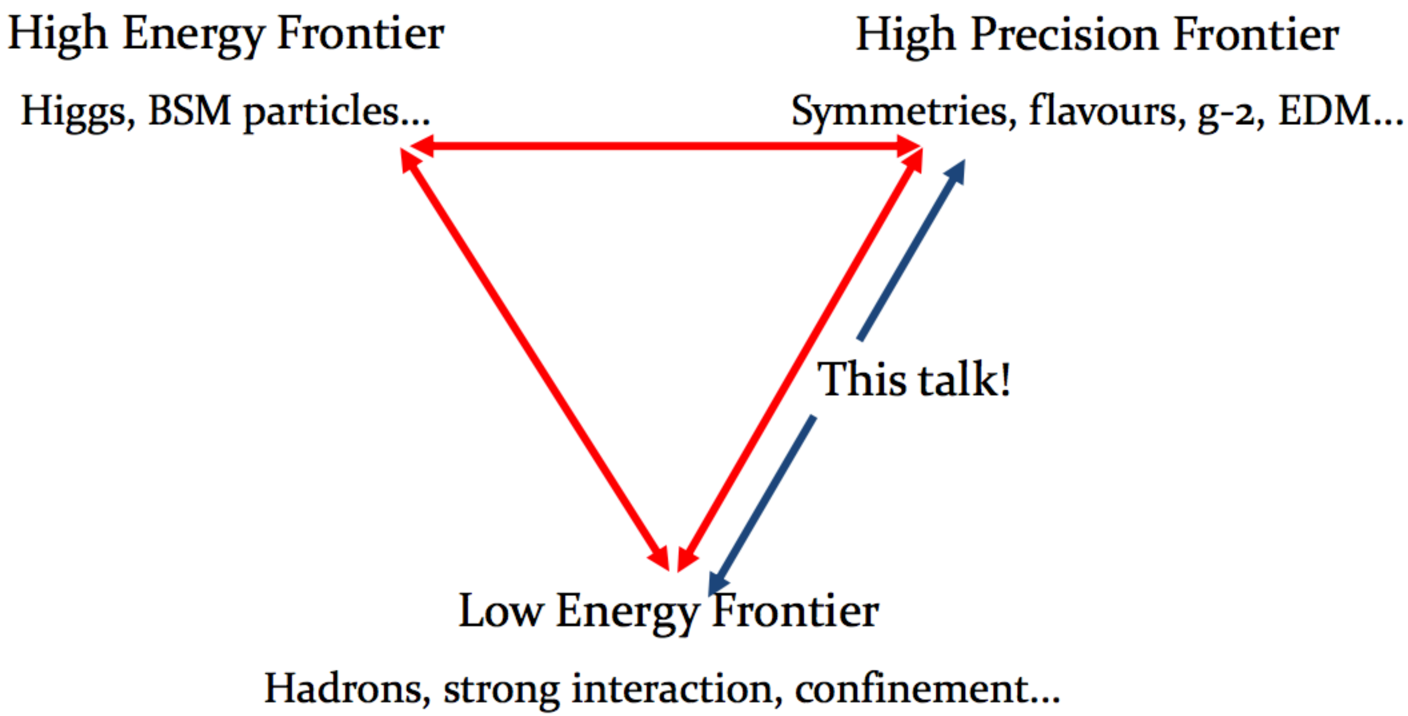
Xiao-Rui Lyu (吕晓睿)
(E-mail: xiaorui@ucas.ac.cn)
University of Chinese Academy of Sciences (UCAS), Beijing

(On Behalf of the BESIII collaboration)

Outline

- Introduction
- BEPCII/BESIII
- (Spin) Physics at BESIII
- Collins effect measurement
- $\Lambda_{(c)}$ polarization measurement
- Summary and Outlook

Frontiers of the Standard Model

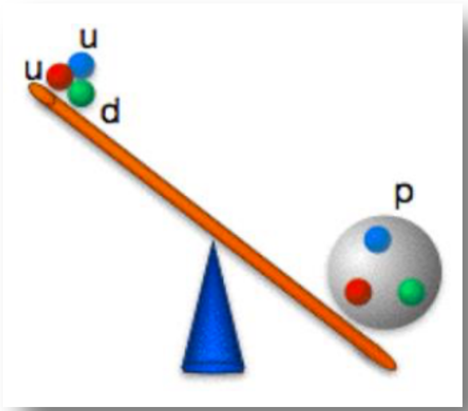


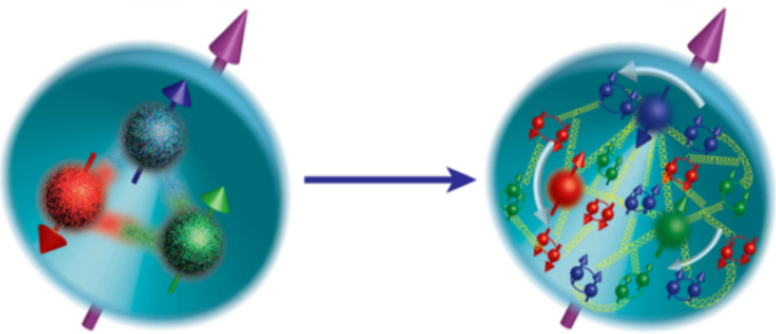
The Nucleon

Many challenges in modern physics manifest themselves in the nucleon:

- Challenging to describe from first principles

– Its abundance	High Precision
– Its mass	
– Its spin	Low Energy / Non-pQCD
– It structure	
– Its radius ?	





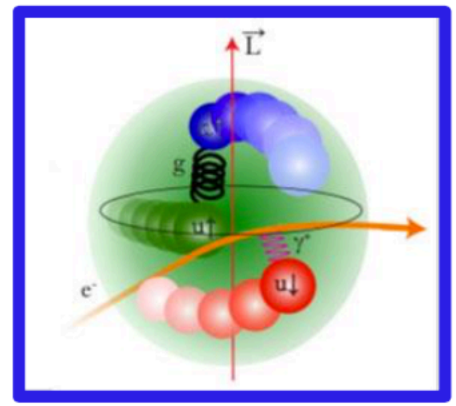
Approaches

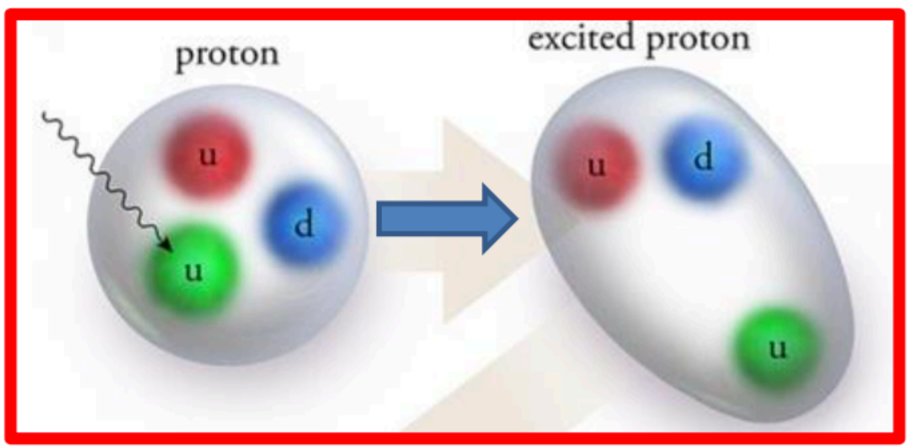
When you don't understand a system, you can*

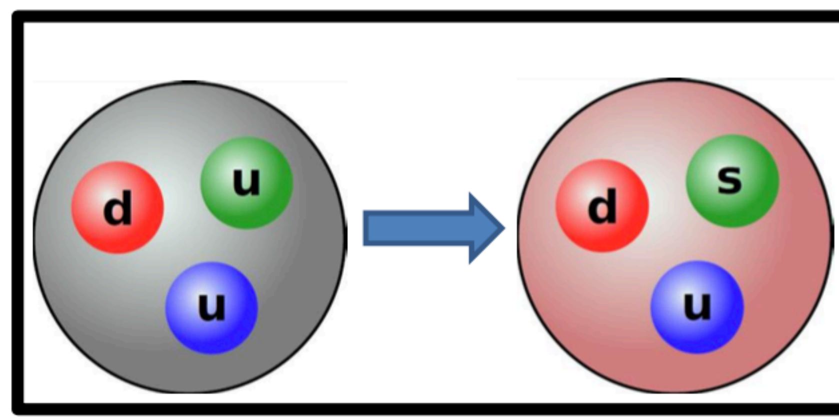
– Scatter on it

– Excite it

– Replace building blocks



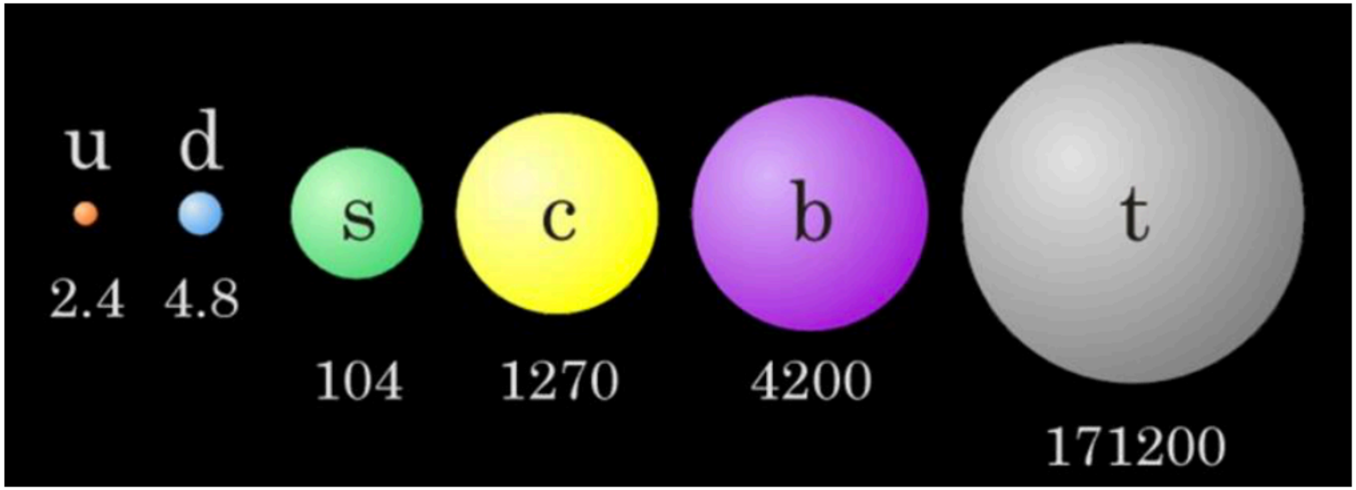




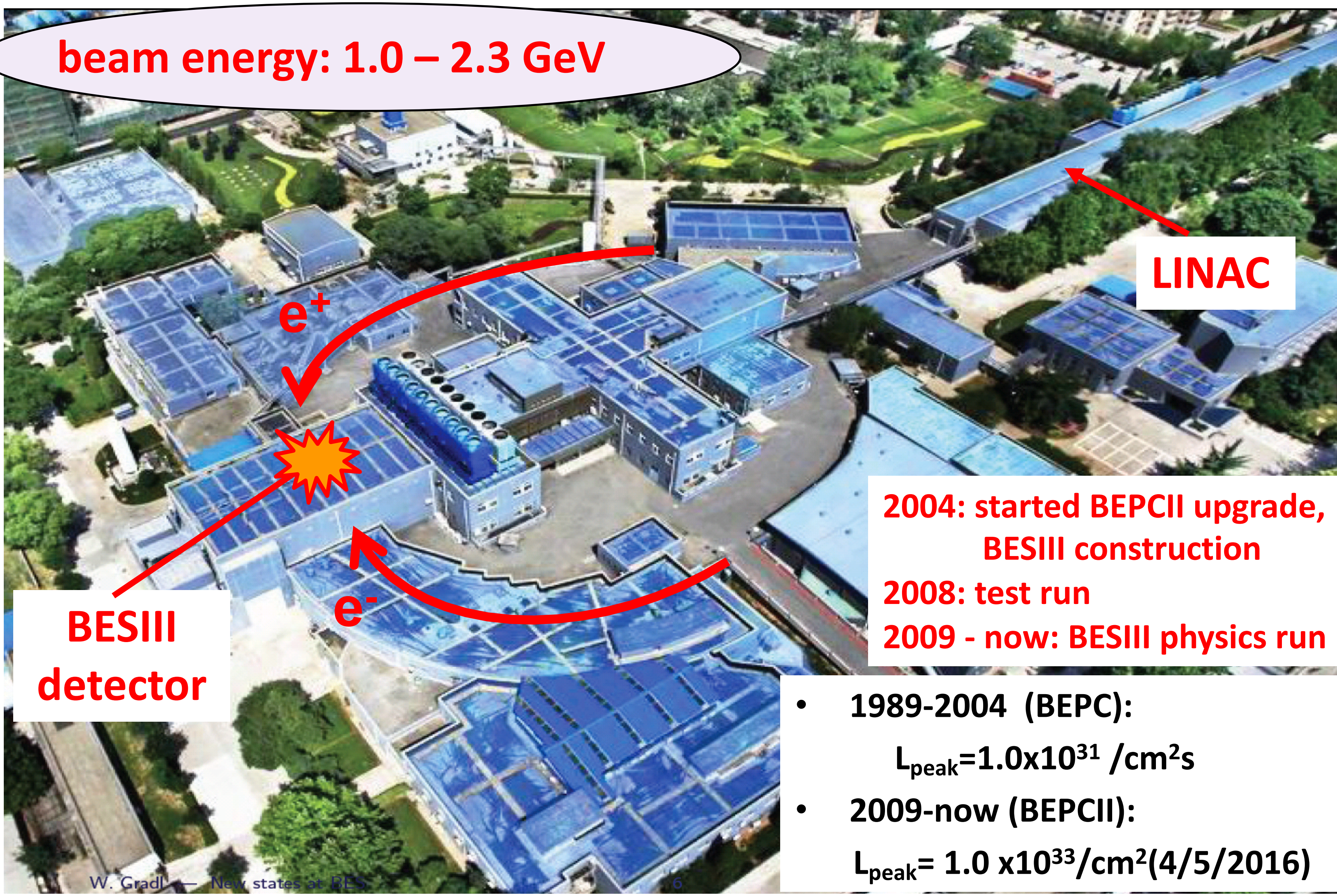
*C. Granados et al., EPJA 53, 117 (2017)

Hyperons – key to the strong interaction

- Systems with strangeness
  - Scale: $m_s \approx 100$ MeV ~ $\Lambda_{QCD} \approx 200$ MeV: Relevant degrees of freedom?
  - **Probes QCD in the confinement domain.**
- Systems with charm
  - Scale: $m_c \approx 1300$ MeV: Quarks and gluons more relevant.
  - **Probes QCD just below pQCD.**



Beijing Electron Positron Collider (BEPC)

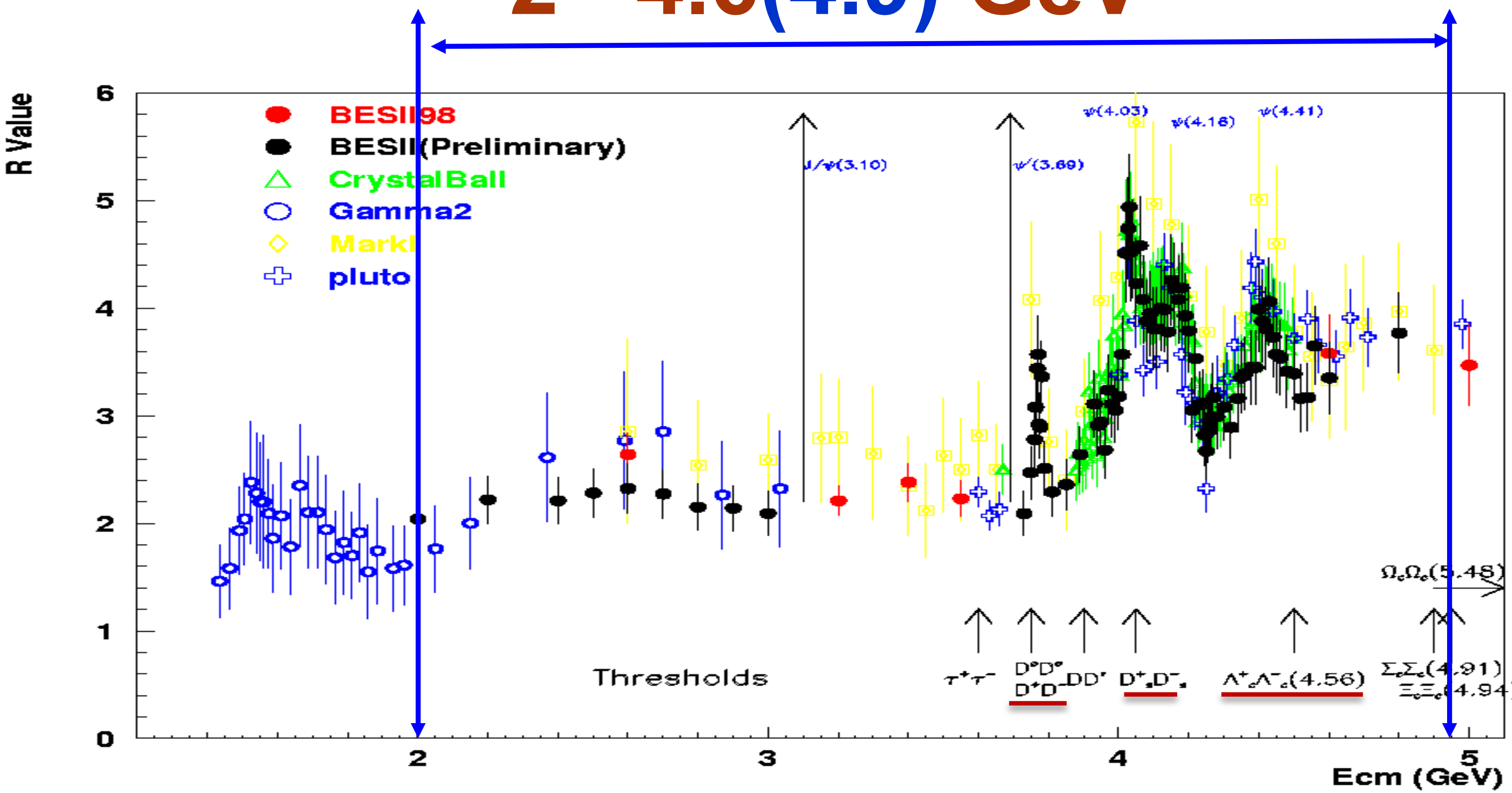


2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

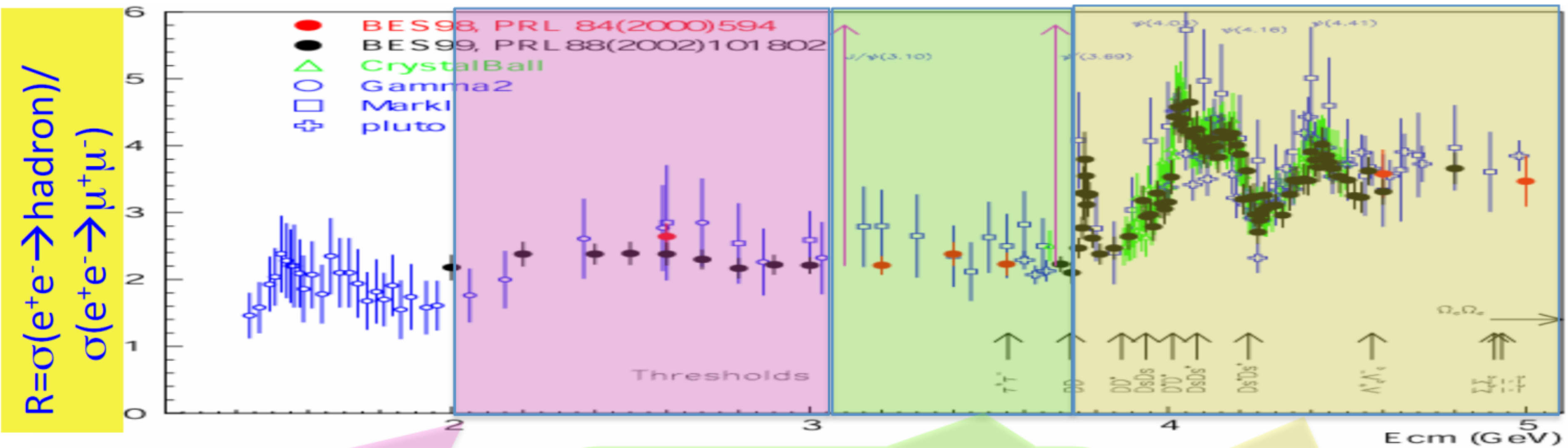
- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

Energies of the BEPCII Collider

2 ~4.6(4.9) GeV



Physics at tau-charm Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

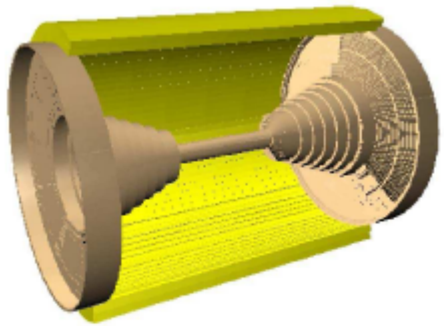
- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

… and more

- Form factor
  - ✓ An important observable of hadron structure
  - ✓ To access time-like form factor through (ISR) electron-position annihilation process (*more details in Z. Meng's talk on Tuesday*)
    - To test the analyticity of G_E and G_M
    - Near threshold measurement of baryons: nucleon/hyperon
    - Unique hyperon data: Λ, Λc
  - ✓ *To extract Space-Like transition form factor using* $\gamma\gamma^* \rightarrow P$
- Fragmentation functions (FF)
  - – Single hadron inclusive production
    ➔ unpolarized FF
    - ✓ Constrain FF at low energy scale and high z: $K^{\pm/0}/\pi^{\pm/0}$+X
    - ✓ New data for inclusive $\eta/\phi/\Lambda$ production…
  - – Two hadron inclusive production
    ➔ correlation of two FF
    - ✓ To probe spin-dependent FF, eg, Collins FF

BESIII Detector

MDC

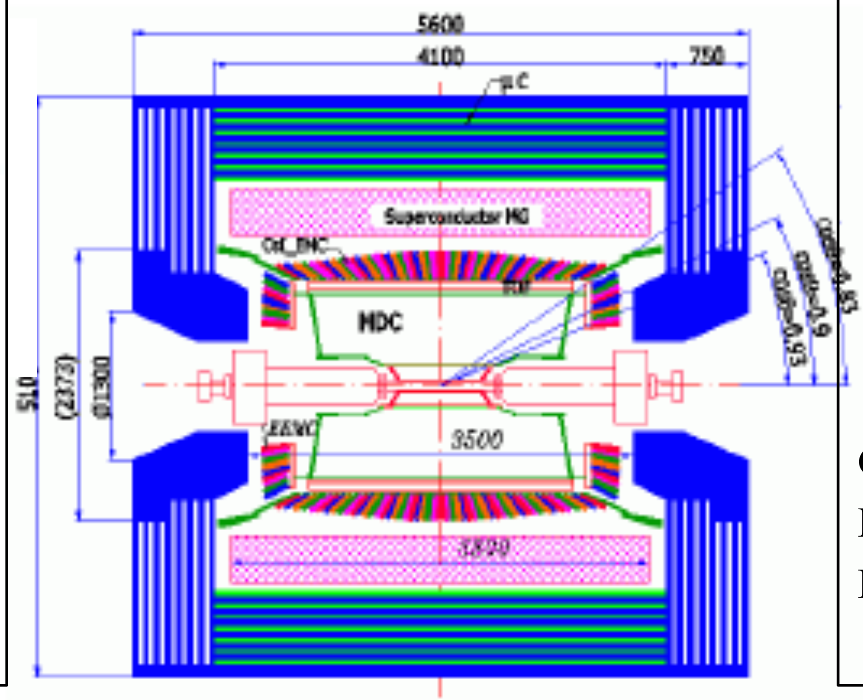


R inner: 63mm ;

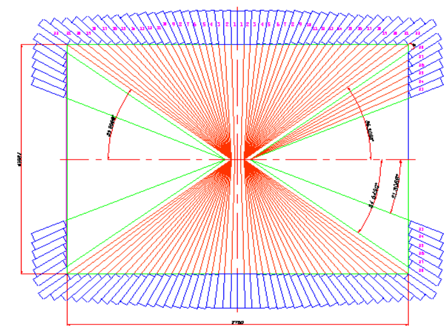
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



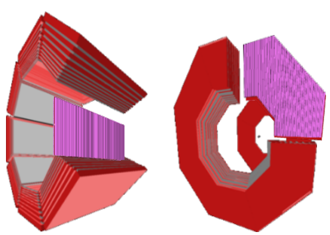
Crystals: 28 cm(15 X_0)

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

Endcap:

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

RPC MUC



BMUC: 9 layers – 72 modules

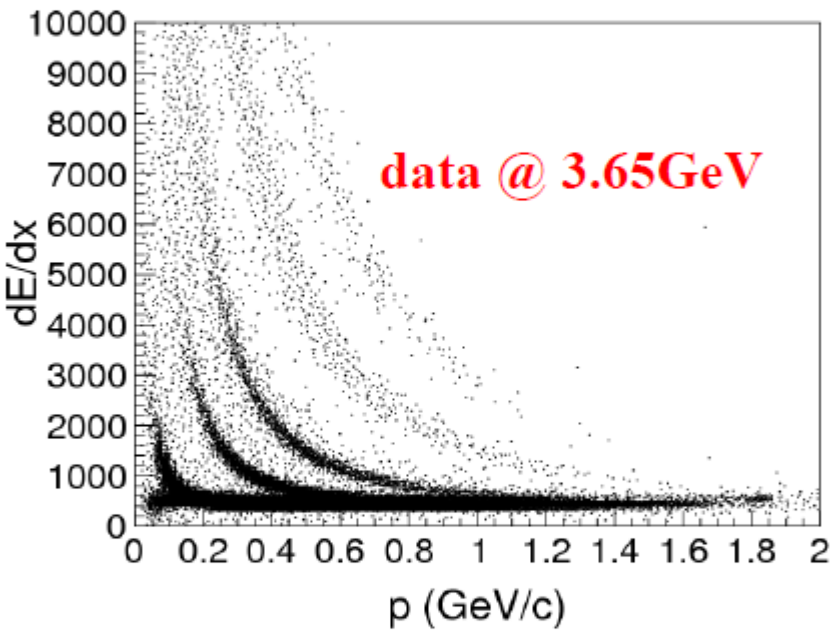
EMUC: 8 layers – 64 modules

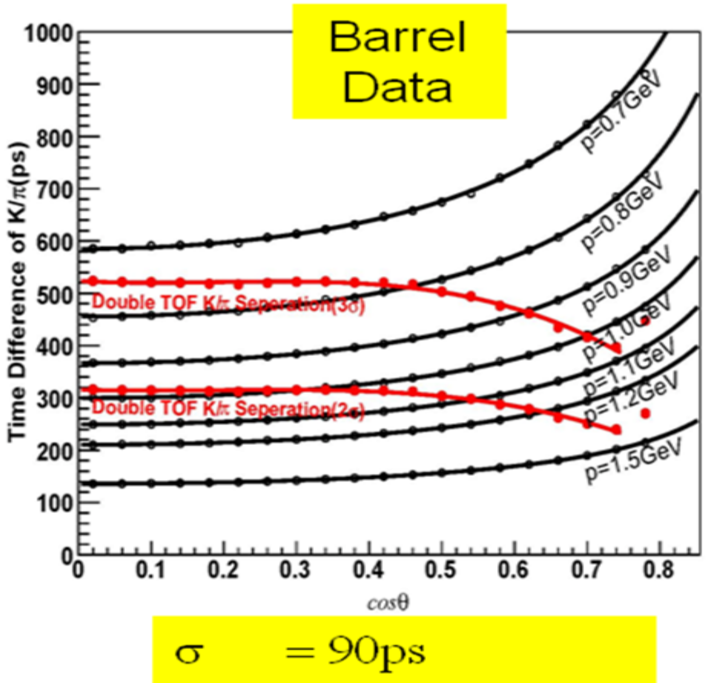
TOF

BTOF: two layers

ETOF: 48 crys. for each

Particle ID Capacity

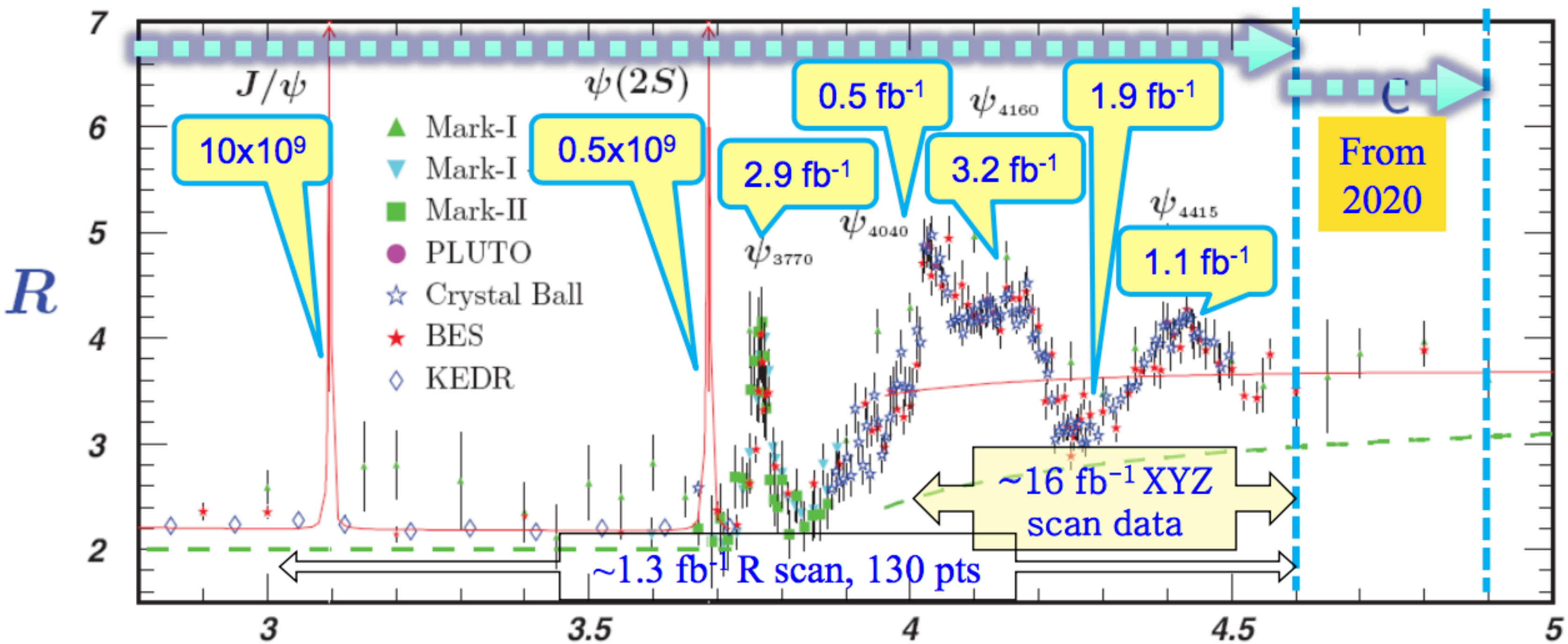




- dE/dx & TOF for PID

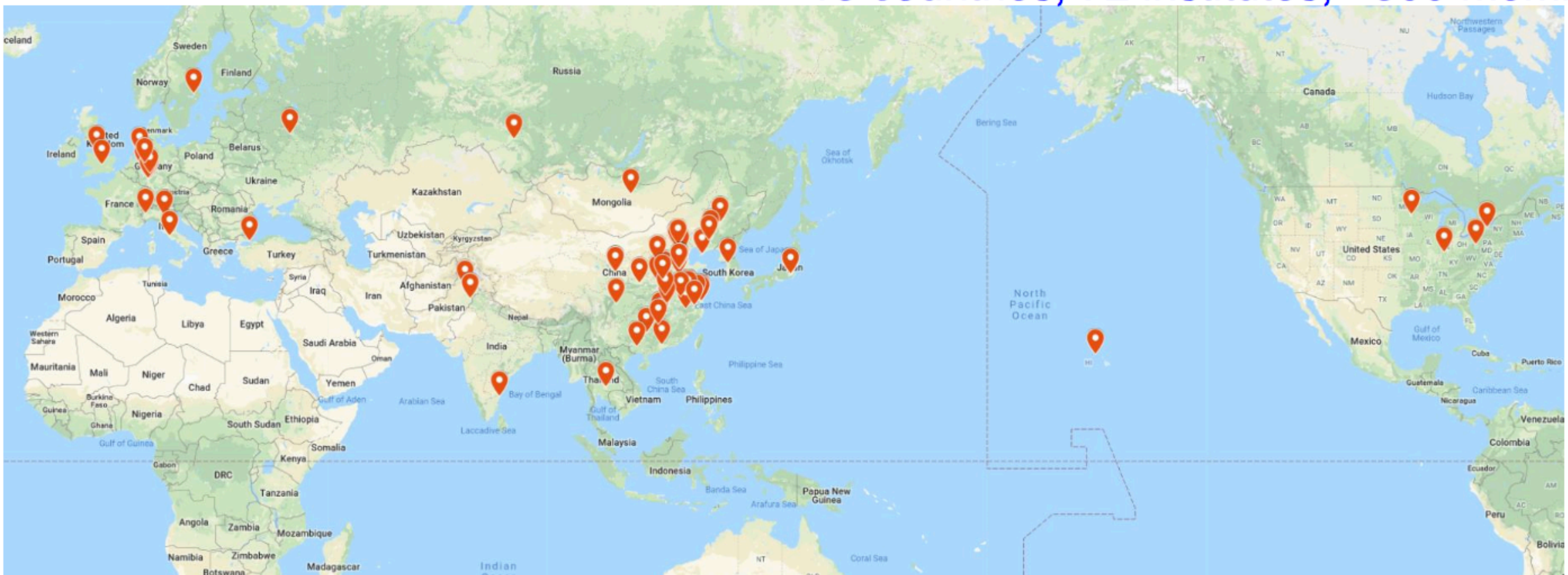
- Work well on K/π <1.0GeV

BESIII data taking

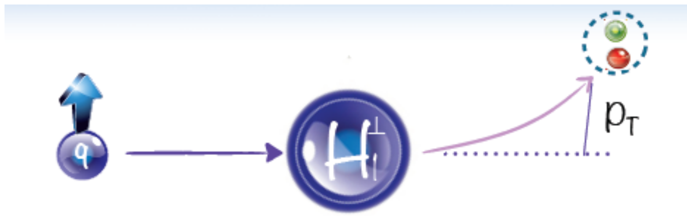


The BESIII Collaboration

15 countries, 72 institutes, ~500 members



Collins Fragmentation Function (FF)



J. C. Collins, Nucl.Phys. B396, 161 (1993)

$$D_{hq^{\uparrow}}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2)\frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{zM_h},$$

D_1: the unpolarized FF

H_1: Collins FF

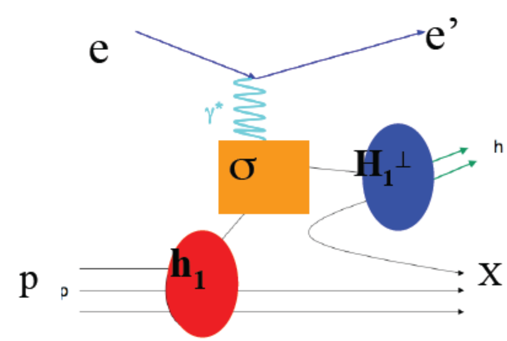
→ describes the fragmentation of a transversely polarized quark into a spinless hadron *h*.

→ depends on $z = 2E_h/\sqrt{s}$, $\mathbf{P}_{h\perp}$

→ leads to an azimuthal modulation of hadrons around the quark momentum.

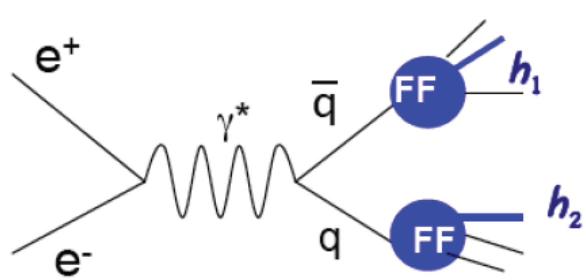
SIDIS

Transversity ⊗ Collins FF



e+ e-

Collins FF ⊗ Collins FF

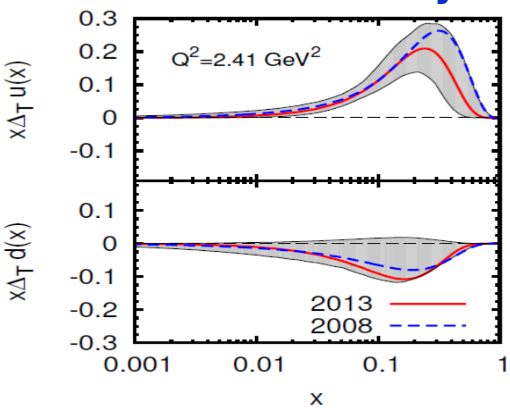


Global Analysis on Collins FF

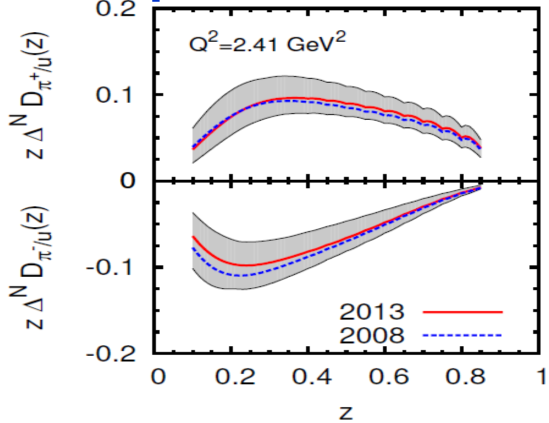
- The Q^2 evolution of Collins FFs need to be improved and validated
- Low Q^2 data from e^+e^- collider is useful.

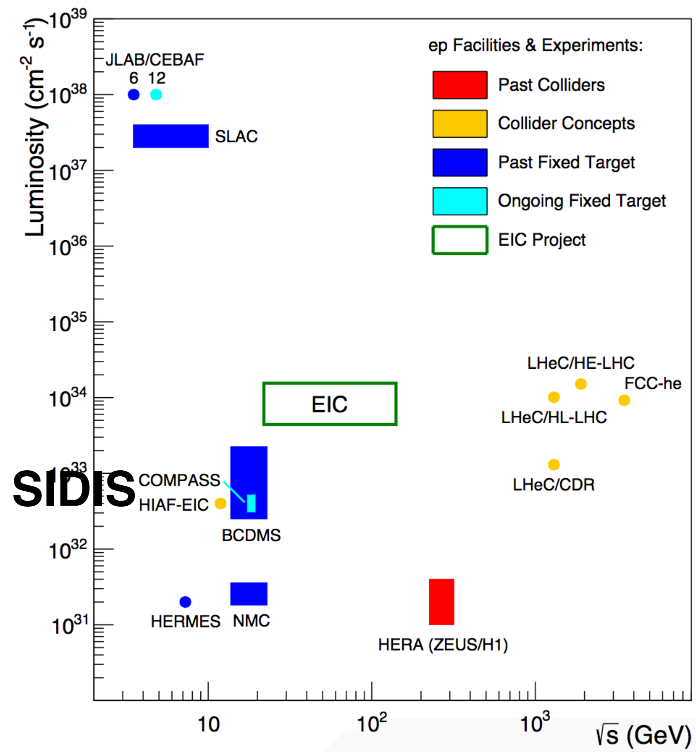
Anselmino et al., PRD 87, 094019 (2013)

Transversity

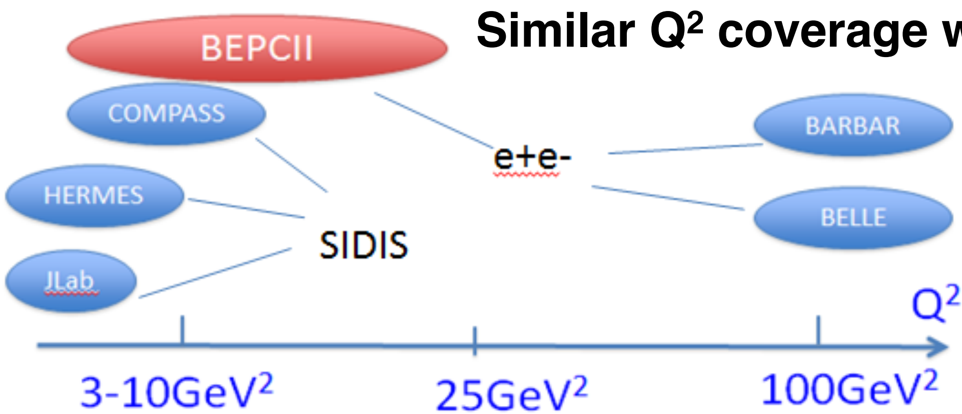


pion Collins FF



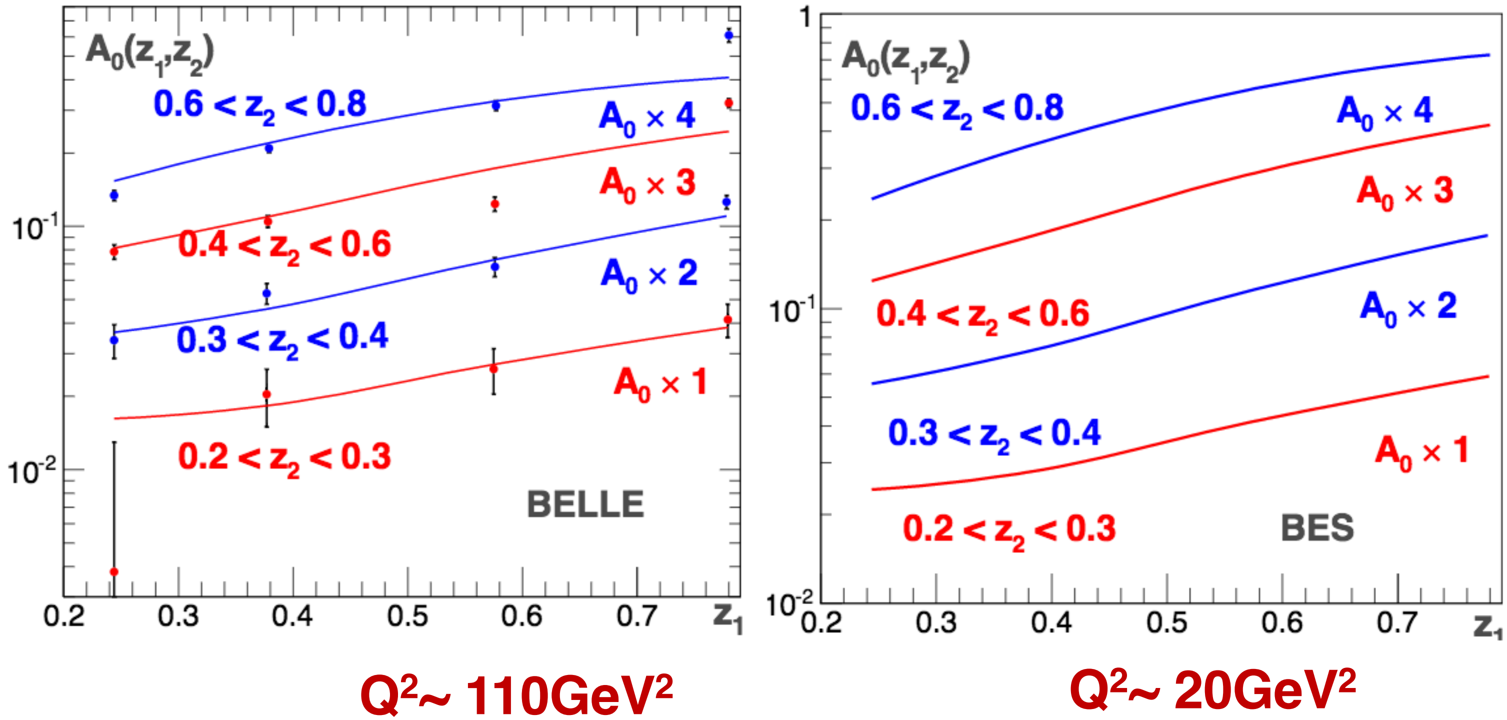


Similar Q^2 coverage with SIDIS



Predicted Collins Asymmetries

P. Sun and F. Yuan, Phys. Rev. D 88, 034016 (2013).

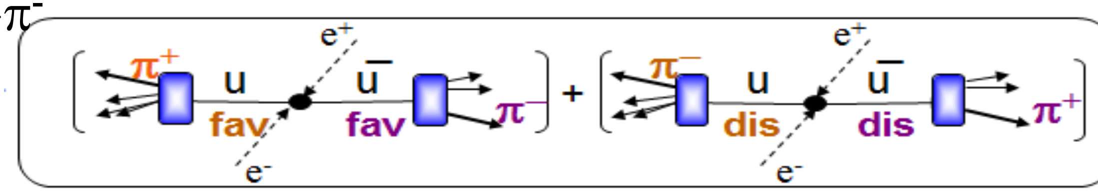


- Collins asymmetry is predicted larger at lower Q2 region!
- Asymmetries increase as z grows

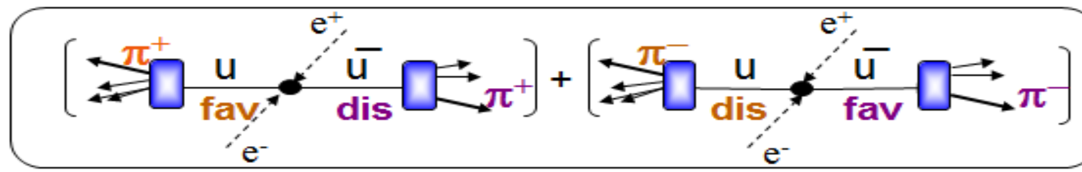
Product of Two Collins FFs

- **Favored** fragmentation process describes the fragmentation of a quark of flavor q into a hadron with a valence quark of the same flavor: i.e.: $u \to \pi+$, $d \to \pi-$
- **Disfavored** for $d \to \pi^+$, $u \to \pi^-$

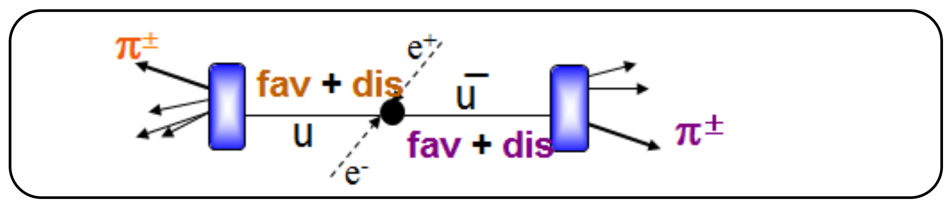
Unlike-sign pairs= **U:**
$\pi^{\mp}\pi^{\pm}$: (fav x fav)+(dis x dis)



Like-sign pairs = **L:**
$\pi^{\pm}\pi^{\pm}$: (fav x dis)+(dis x fav)



All charged pairs= C (U+L):
$\pi\pi$: (fav + dis)x(fav + dis)
$\pi = \pi^{\pm}$



- **All charged pion pairs are divided into:**
  - **Unlike-sign pairs** $(\pi^+\pi^-)$
  - **Like-sign pairs** $(\pi^+\pi^+ \ and \ \pi^-\pi^-)$
  - **All Charged pairs** $(\pi\,\pi)$

Data Sample and Event Selection

PRL 116, 042001 (2016)

~62 pb^{-1} @3.65GeV

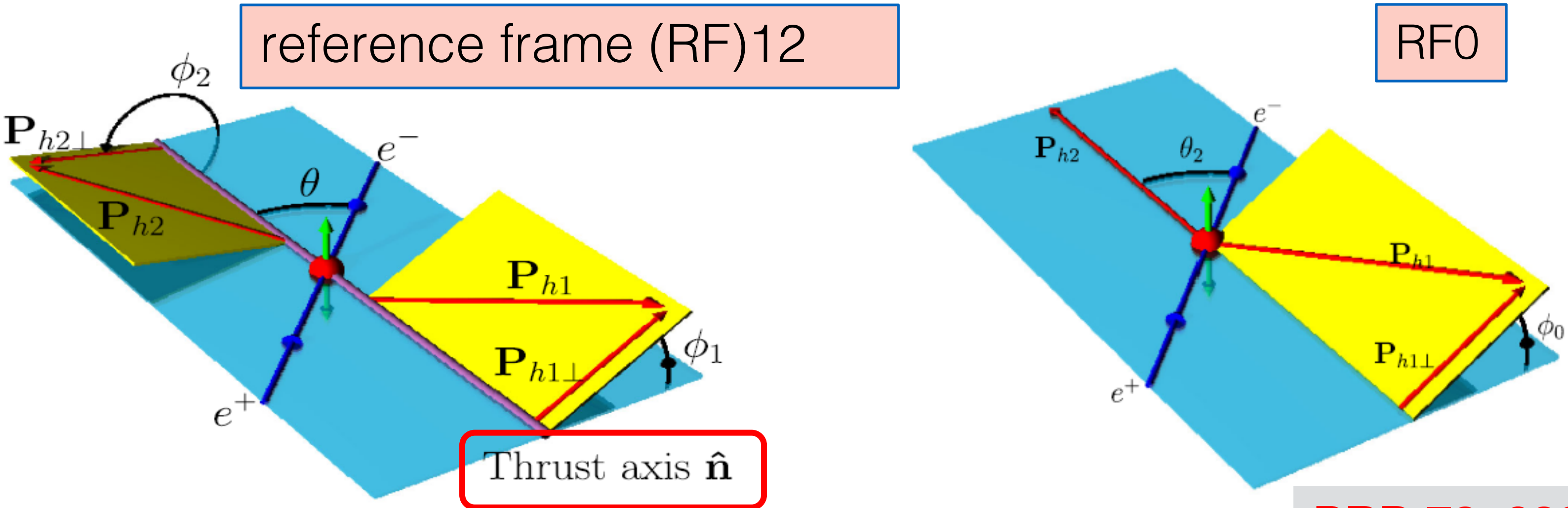
- **continuum region in-between J/psi and psi(2S) peaks**
- **fewer charm backgrounds!**

- **# of charged tracks >=3**
- **# of charged pion>=2**
- **No electron to suppress Bhabha**
- **The total visible energy >1.5GeV.**

to suppress resonance decays to dipions, we require **the charged pions**

- **$0.2 < z = 2E_h/\sqrt{s} < 0.9$**
- **open angle >120° to select back-to-back pion-pair.**

Double Collins Asymmetries (DCA)

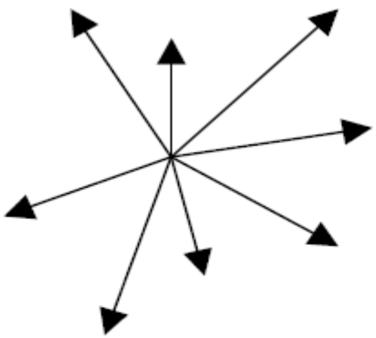


PRD 78, 032011

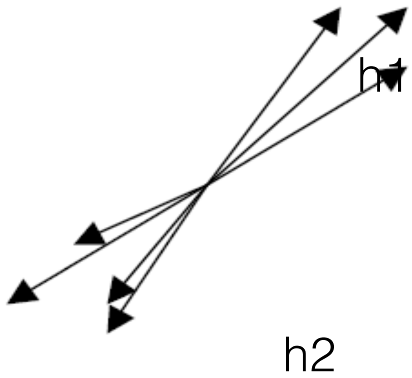
- The spin correlation of hadron fragmented from quark and anti-quark in opposite hemisphere follows a cos(ϕ1+ϕ2) modulation in RF12 or a cos($2\phi_0$) modulation in RF0
  - ➢ DCA were observed in both definitions by Belle and BaBar

Belle Collaboration: Phys. Rev. Lett. 96, 232002 (2006); Phys. Rev. D 78, 032011 (2008); Phys. Rev. D 86, 039905(E) (2012).
BaBar Collaboration: Phys. Rev. D 90, 052003 (2014)

Difficulties---event shape is not jetty



BEPCII energy

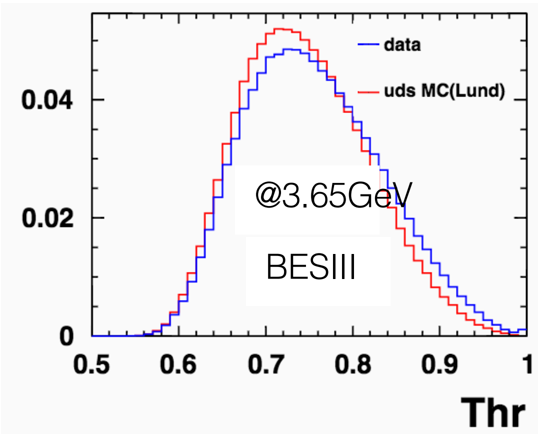


Belle/Babar

$$e^+e^- \to q\bar{q} \to h_1 h_2 X$$

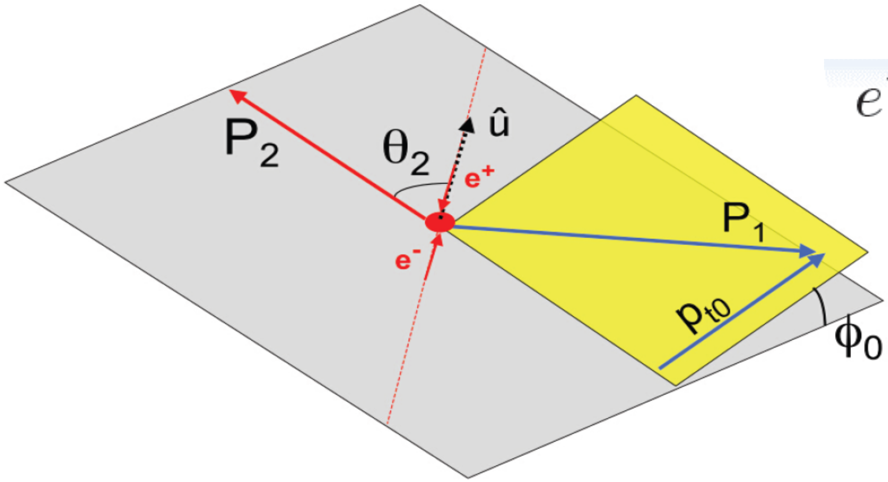
$$T \stackrel{\max}{=} \frac{\sum_h |\mathbf{P}_\mathbf{h}^{\mathrm{CMS}} \cdot \hat{\mathbf{n}}|}{\sum_h |P_h^{\mathrm{CMS}}|},$$

- ✓ In B factories, the thrust axis is used as a approximation of the q-qbar axis
  - ➢ not needed in RF0, hence RF0 is adopted
- ✓ At BESIII, continuum process events distribute in a more isotropic way
  ➔ very different situation compared to Belle/BaBar



The Reference Frame

D. Boer, Nucl. Phys. B 806, 23 (2009)



$$e^+e^- \rightarrow q\,\bar{q} \rightarrow h_1\,h_2\,X$$

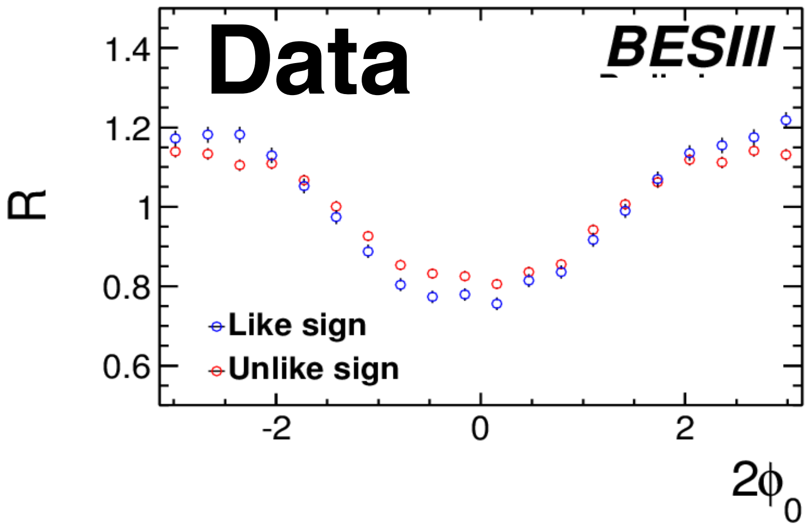
$$\sigma \sim 1 + \frac{\sin^2\theta_2}{1+\cos^2\theta_2}\cos(2\phi_0)\mathcal{F}\left[\frac{H_1^\perp(z_1)\bar{H}_1^\perp(z_2)}{D_1(z_1)\bar{D}_1(z_2)}\right]$$

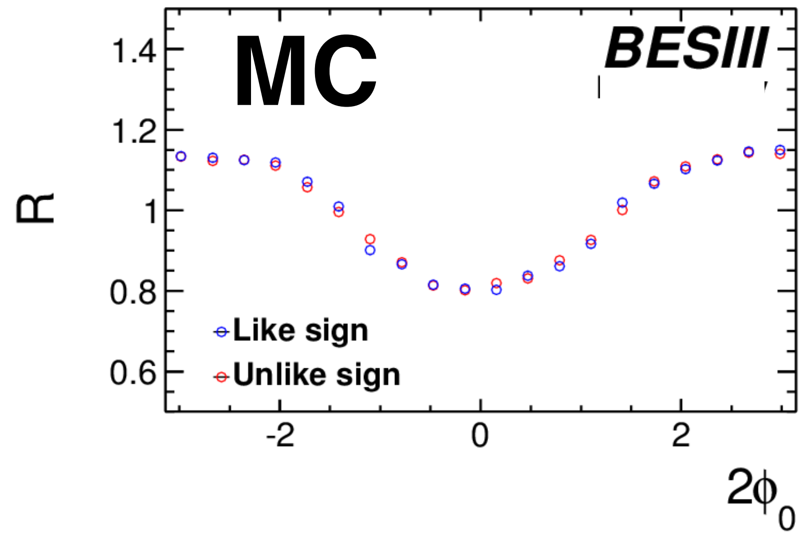
$$\mathcal{F}[X] = \sum_{q\bar{q}}\int[2\hat{\mathbf{h}}\cdot\mathbf{k_{T1}}\hat{\mathbf{h}}\cdot\mathbf{k_{T2}} - \mathbf{k_{T1}}\cdot\mathbf{k_{T2}}]$$
$$d^2\mathbf{k_{T1}}d^2\mathbf{k_{T2}}\,\delta^2(\mathbf{k_{T1}}+\mathbf{k_{T2}}-\mathbf{q_T})X$$

$$k_{Ti} = z_i\,p_{Ti}$$

Collins effect: cosine modulation.

$2\phi_0$ Raw Distribution



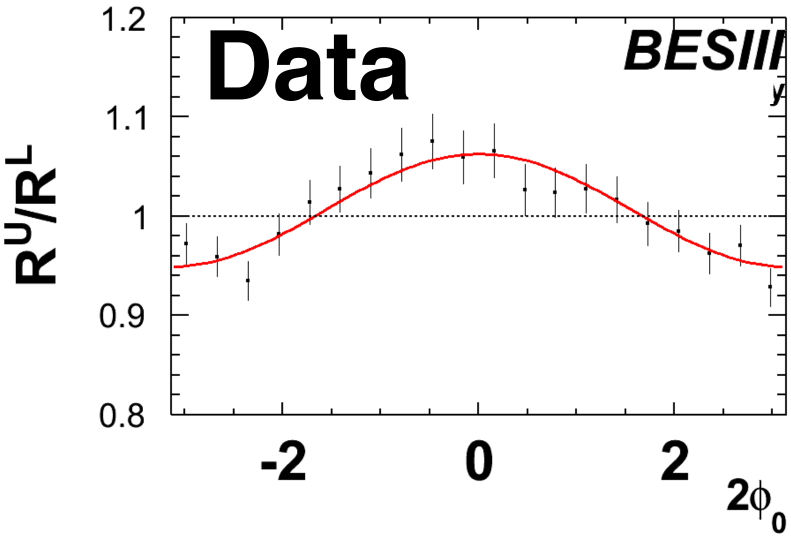


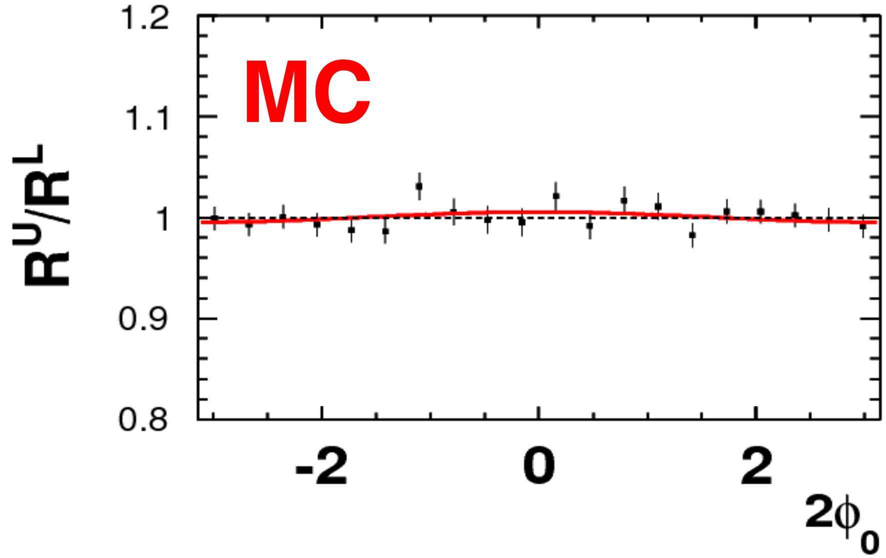
- **The normalized ratio**

$$R := \frac{N(2\phi_0)}{\langle N_0 \rangle}$$

  - **For Charged, Unlike-sign and Like-sign pairs, we have R^U, R^C, R^L**
- **Raw $2\phi_0$ distributions are subjected to the limited acceptance and non-uniform efficiencies of the detector!**
- **The MC simulation does not include the Collins effect.**
- **Small deviations in Like and Unlike in data indicate asymmetries.**

Double Ratio (DR)





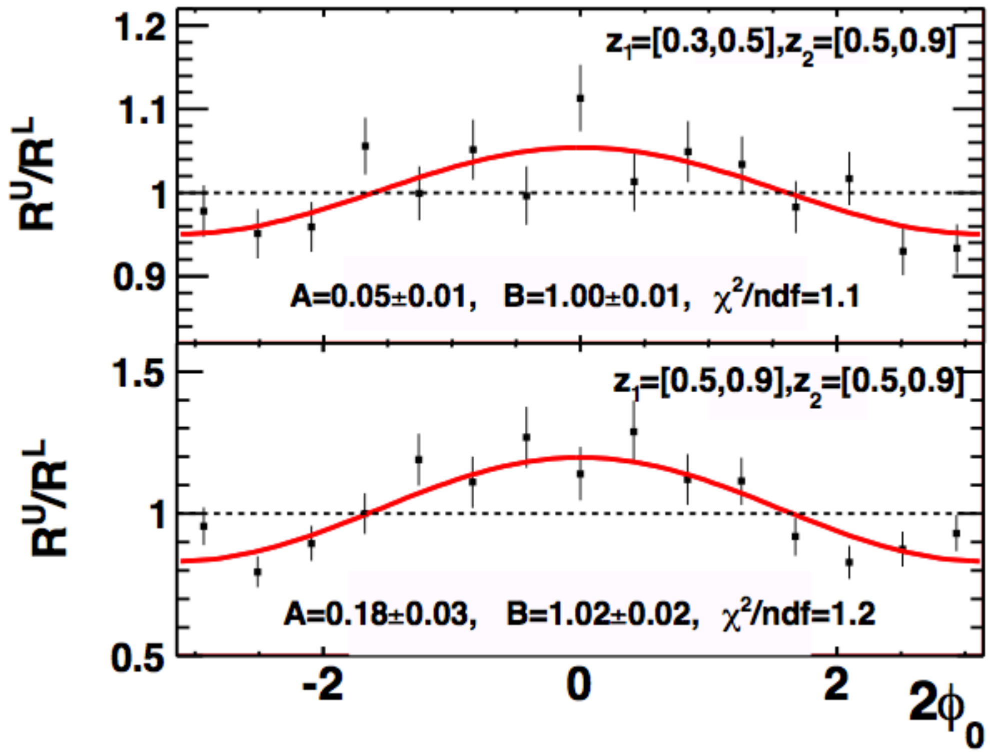
- **Acceptance effects and radiation effects can be reduced by performing the ratio of Unlike/Like sign pion pairs (R^U/R^L) or Unlike/Charged pairs (R^U/R^C)**

$$\frac{R^U}{R^L} \simeq 1 + \frac{\sin^2\theta}{1+\cos^2\theta}\cos(2\phi_0)(G^U - G^L) \qquad \frac{R^U}{R^C} \simeq 1 + \frac{\sin^2\theta}{1+\cos^2\theta}\cos 2\phi_0 (G^U - G^C)$$

- **DRs are fitted by** $\frac{R^U}{R^{L(C)}} = a\cos(2\phi_0) + b,$

- $A_{UL(C)} = \frac{a}{b}$ **represents the asymmetries of interest.**

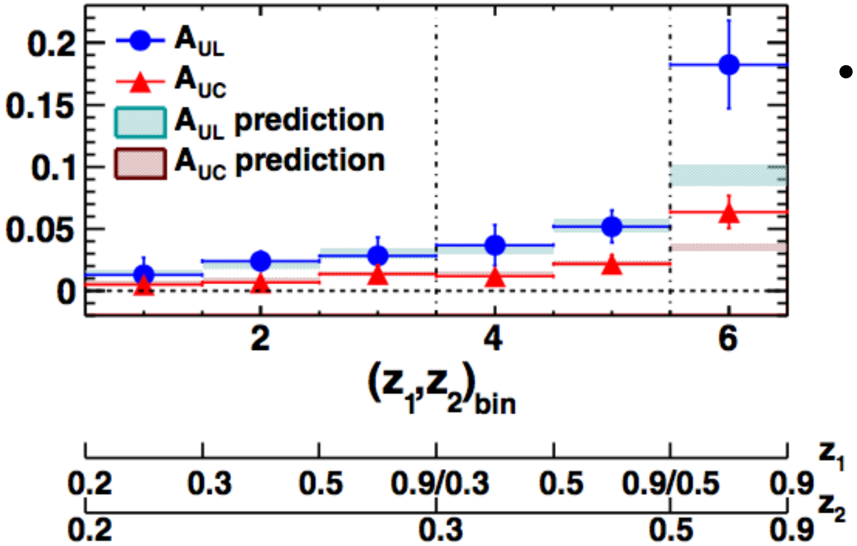
Fit to DR in Different z Bins



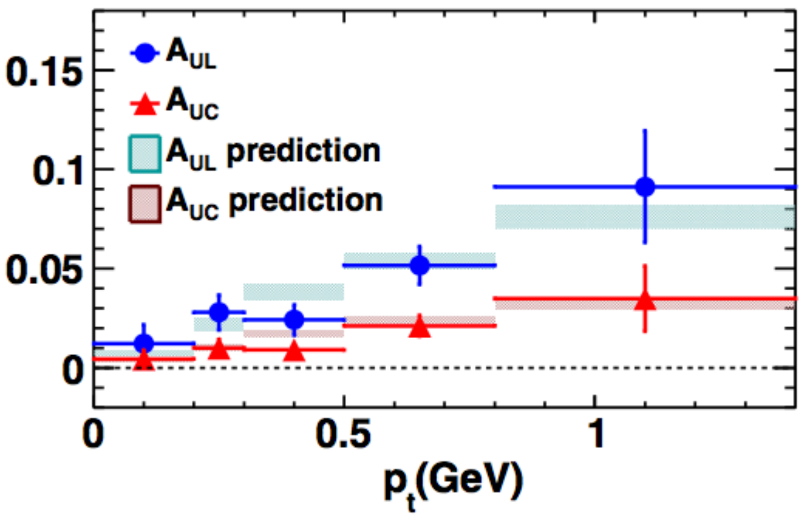
$$\frac{R^{\mathrm{U}}}{R^{\mathrm{L(C)}}} = A\cos(2\phi_0) + B,$$

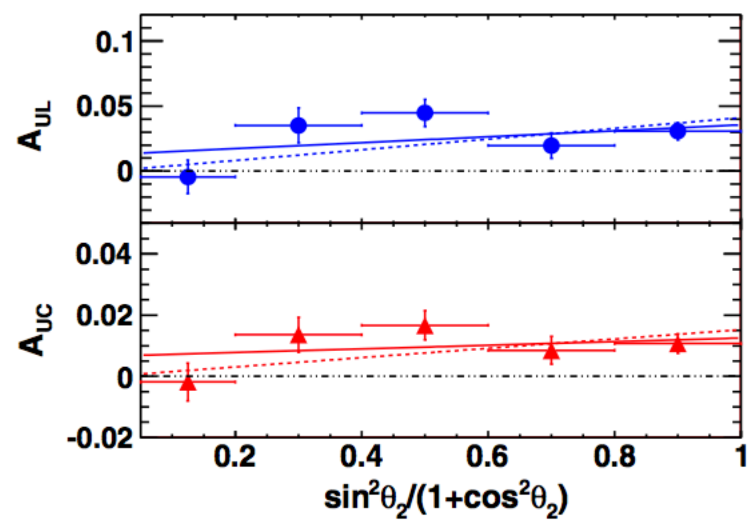
Extraction of the Asymmetries

PRL 116, 042001 (2016)



- Collins asymmetry measured as functions of
  - ✓ 6 symmetric (z_1, z_2) bins
  - ✓ 5 bins of p_{t0}
  - ✓ Asymmetry v.s. $\sin^2\theta_2/(1+\cos^2\theta_2)$
  - ✓ Comparison with prediction in PRD 93, 014009 (2016)



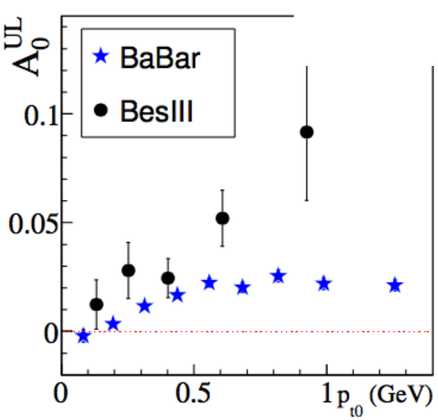


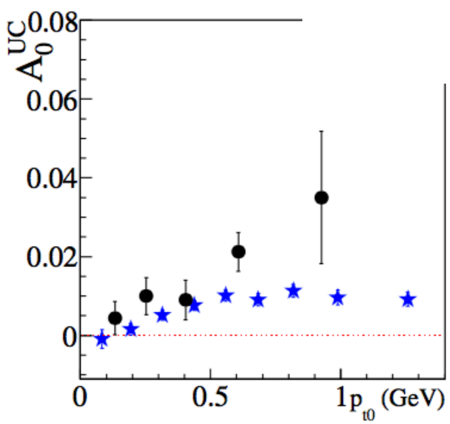
Comparisons of Asymmetries

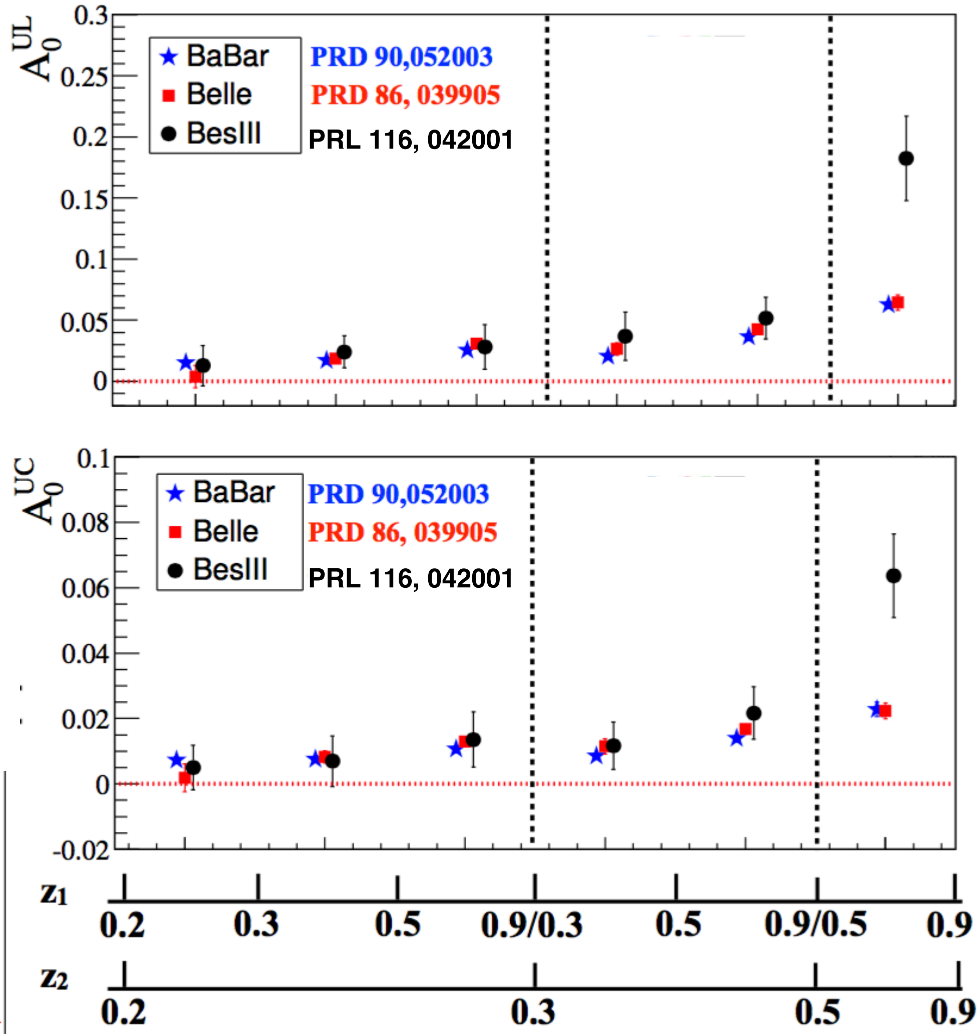
Comparison between different results obtained at different Q^2:

- **BaBar and Belle @ $Q^2 \sim 110$ GeV^2**
- **BESIII @ $Q^2 \sim 13$ GeV^2**

- BaBar and Belle results that fall in the larger BESIII z-bins are averaged taking into account the statistical and systematic uncertainties
- Good agreement between different data set for low z
- BESIII larger asymmetries in the last z-bins: consistent with the prediction reported in *arXiv:1505.05589*







Relevant Future Analyses

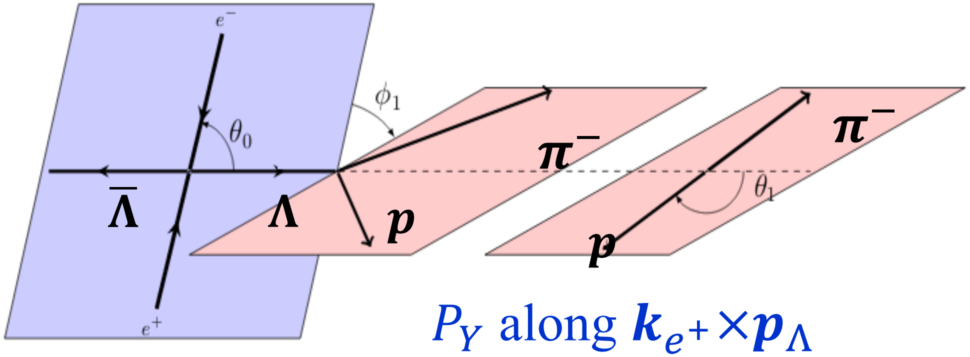
- ~360/pb data @ $\sqrt{s}$ =3.51GeV, which will improve precision of the dipion Collins asymmetry
- Simultaneous measurement of charged KK, Kπ and ππ Collins asymmetries (PID unfolding)
- Including neutral particles (π^0, η, Ks) in final states
- Potential of data above charm threshold (up to Q^2~25 GeV^2) can be explored

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

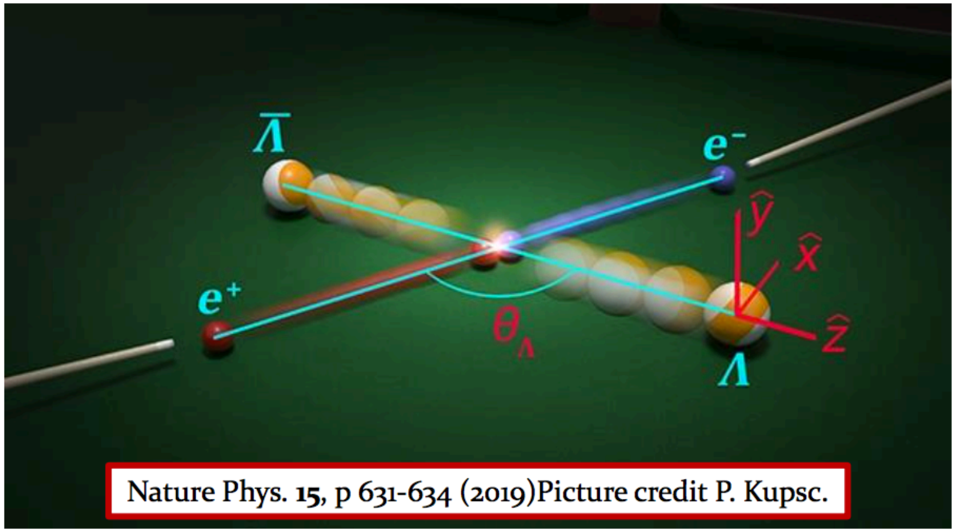
Unpolarized e^+e^- annihilations:

- entangled $\Lambda\bar{\Lambda}$ production
- more sensitive to access transverse polarization baryon

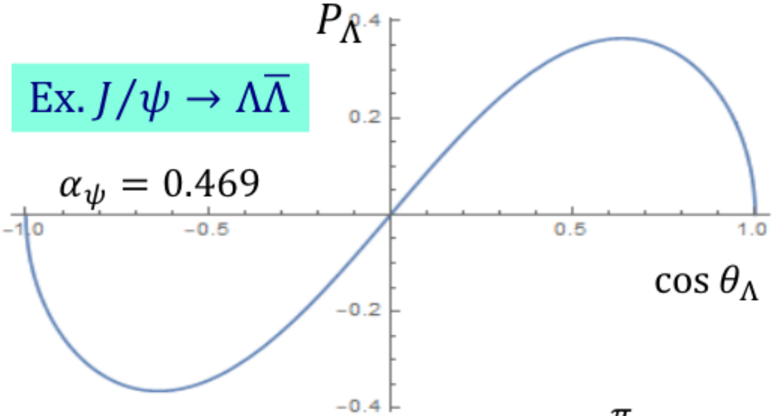
$$|\Lambda\bar{\Lambda}\rangle^{C=-1} = \chi_1 \frac{1}{\sqrt{2}}[|\Lambda\rangle|\bar{\Lambda}\rangle - |\bar{\Lambda}\rangle|\Lambda\rangle],$$



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



Nature Phys. 15, p 631-634 (2019)Picture credit P. Kupsc.



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

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

$\Delta\Phi$: complex phase between two helicity amplitudes: $A_{\frac{1}{2},\frac{1}{2}}$ and $A_{\frac{1}{2},-\frac{1}{2}}$

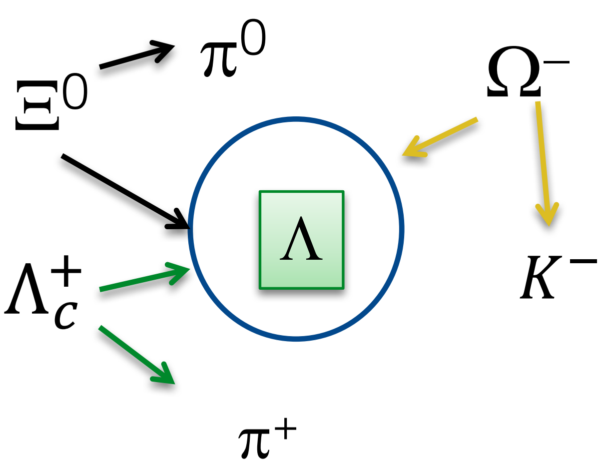
$\Lambda \to p\pi^-$ as Polarimeter

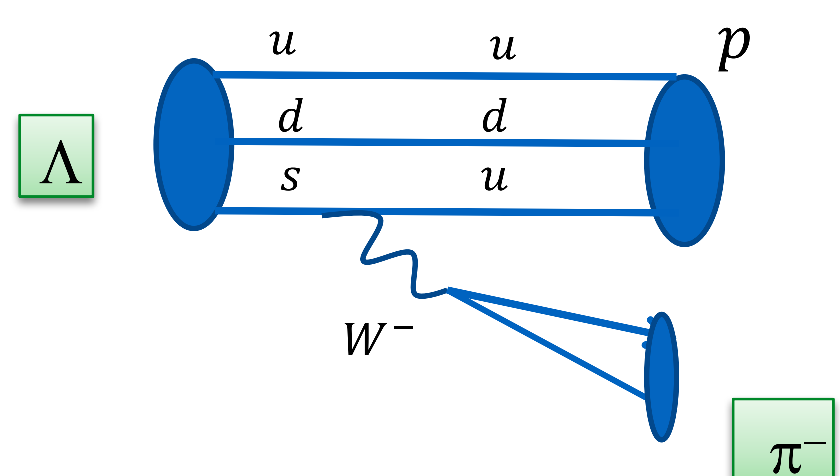
$$\frac{dN}{d\Omega} = \frac{1}{4\pi}\left(1 + \alpha_\Lambda \vec{P} \cdot \hat{q}\right) = \frac{1}{4\pi}\left(1 + \alpha_\Lambda P_\Lambda cos\theta_p\right)$$

Lee-Yang parameters:

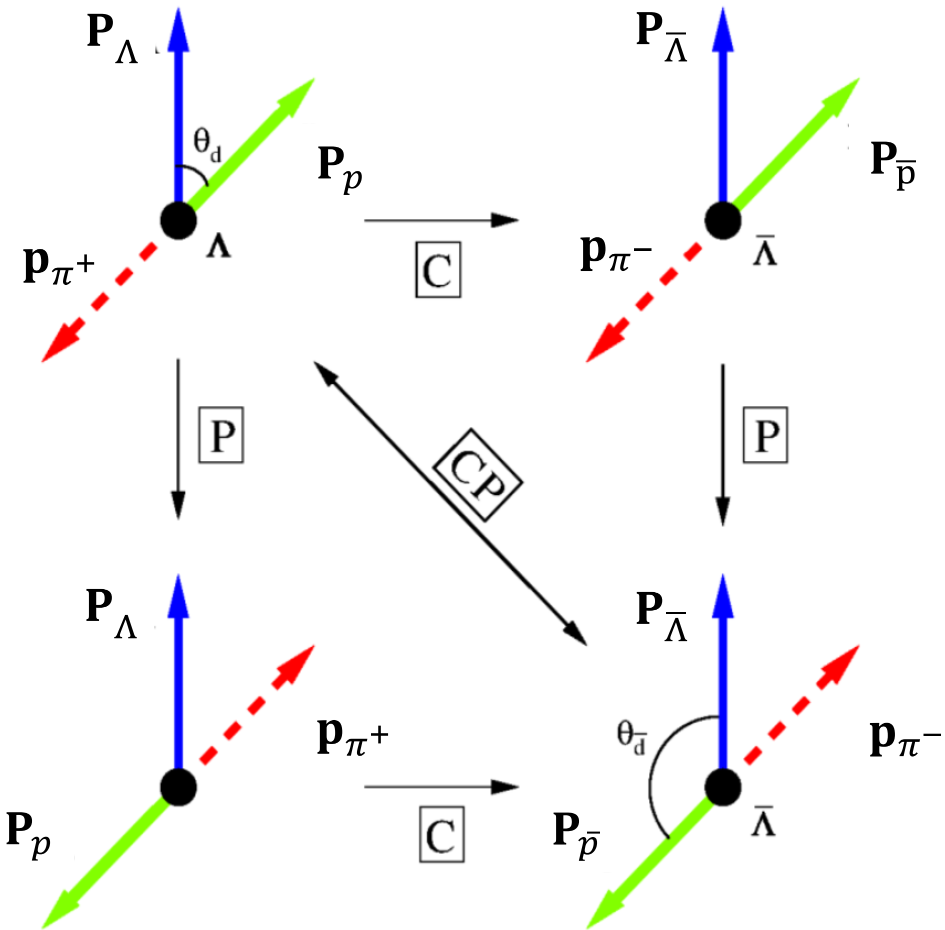
$$\alpha = \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2}, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

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:

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

Previous Measurements

2018 PDG list

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

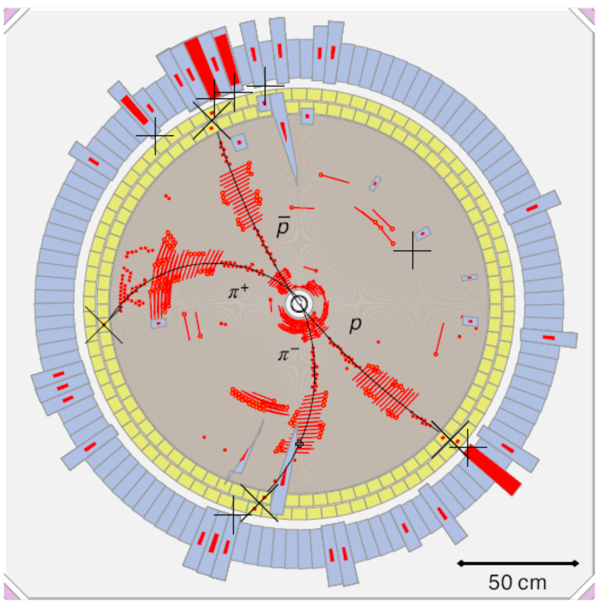
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
-0.71 ± 0.08	**OUR AVERAGE**				
$-0.755 \pm 0.083 \pm 0.063$	$\approx$ 8.7k	ABLIKIM	2010	BES	$J/\psi \to \Lambda\overline{\Lambda}$
-0.63 ± 0.13	770	TIXIER	1988	DM2	$J/\psi \to \Lambda\overline{\Lambda}$

Hyperon decay parameters @ BESIII

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

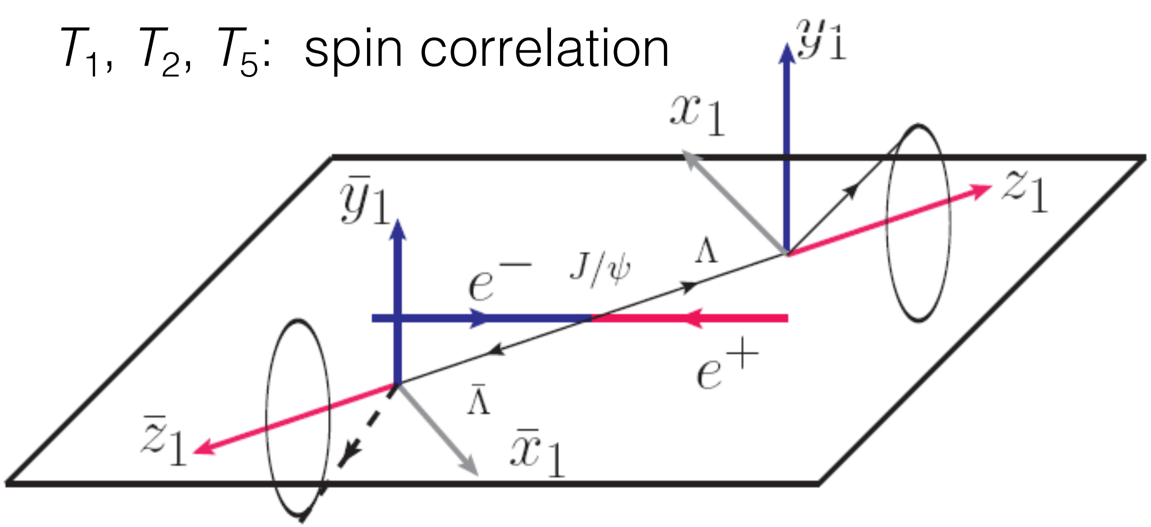
$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$$

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



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

T_1, T_2, T_5: spin correlation

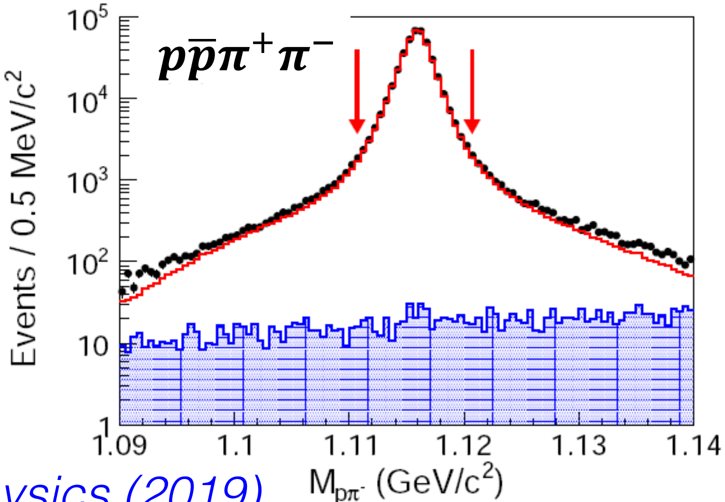


$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-,\ p\bar{n}\pi^-\pi^0$

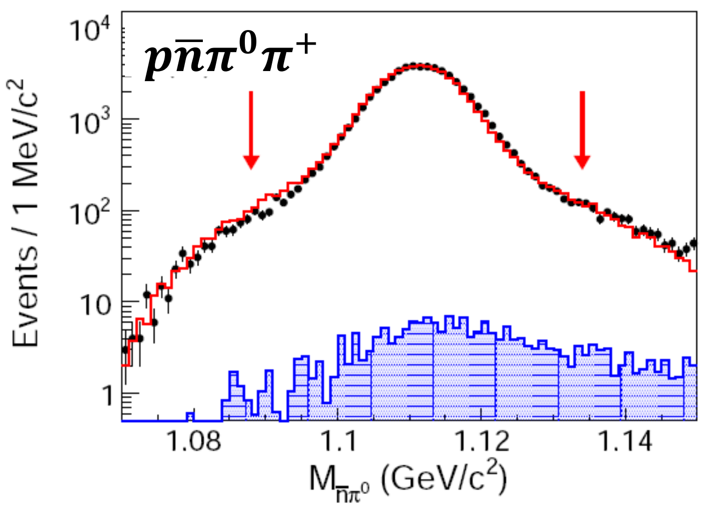
1.3 billion J/ψ events

simultaneous fit to the two data samples

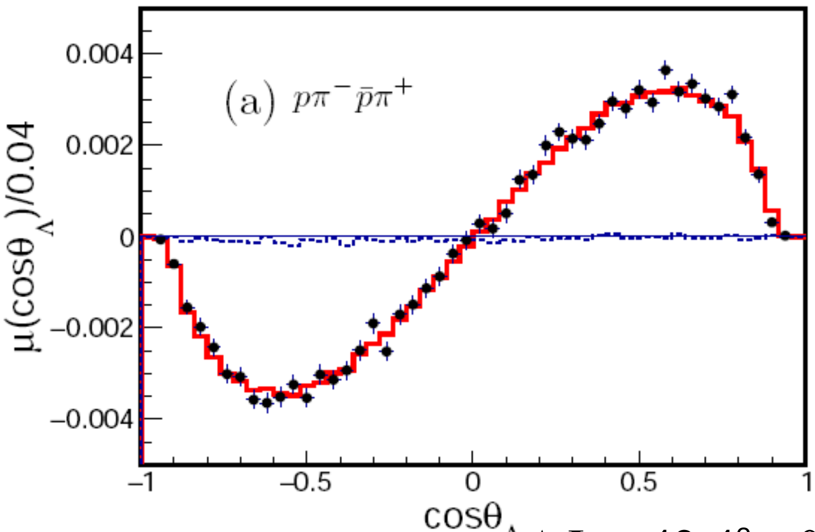
420,593 events selected

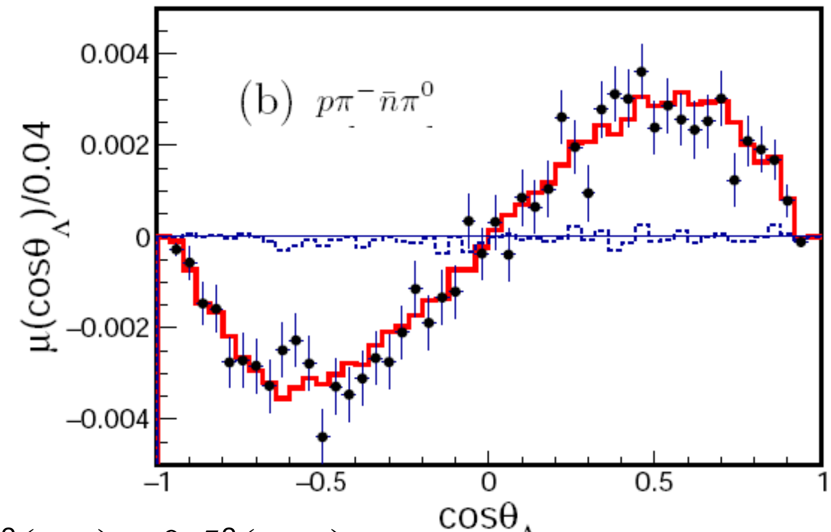


47,009 events selected



[Nature Physics (2019)]



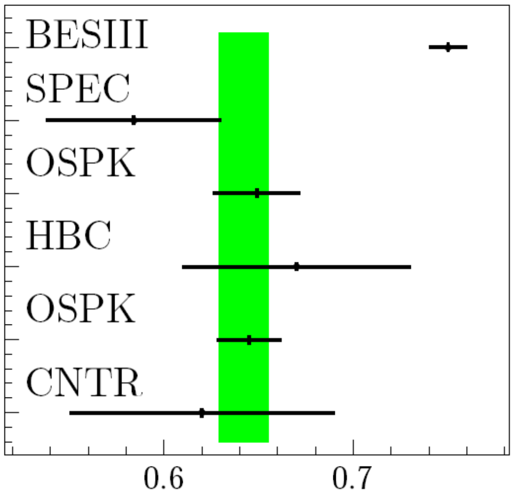


$$\Delta\Phi = 42.4^\circ \pm 0.6^\circ(sta) \pm 0.5^\circ(sys.)$$

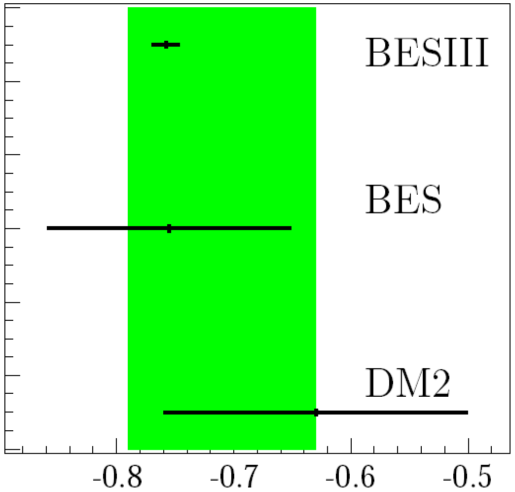
Fitting results and Λ decay asymmetries

Nature Physics (2019)

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)	$0.740 \pm 0.010 \pm 0.008$	——
A_Λ	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [8]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	——



(a) α_- for $\Lambda \to p\pi^-$



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

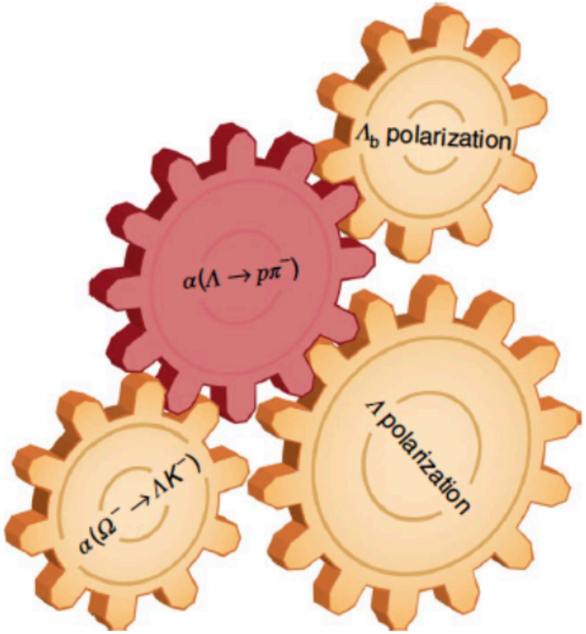
Consequences

PARTICLE PHYSICS

Anomalous asymmetry

A measurement based on quantum entanglement of the parameter describing the asymmetry of the Λ hyperon decay is inconsistent with the current world average. This shows that relying on previous measurements can be hazardous.

Ulrik Egede



New input for many other measurements:

1) polarization

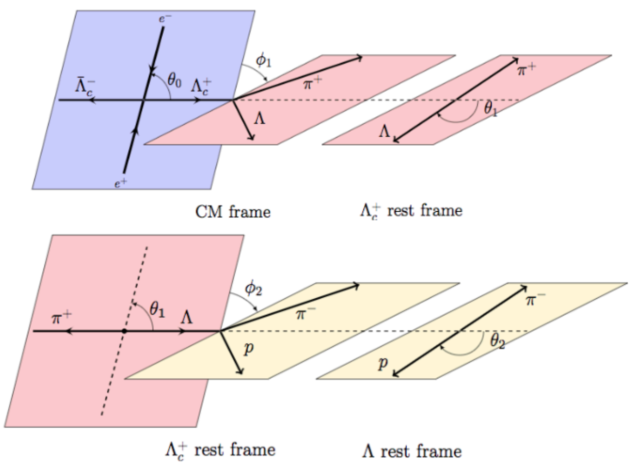
2) Asymmetry of the Λ_b and Λ_c

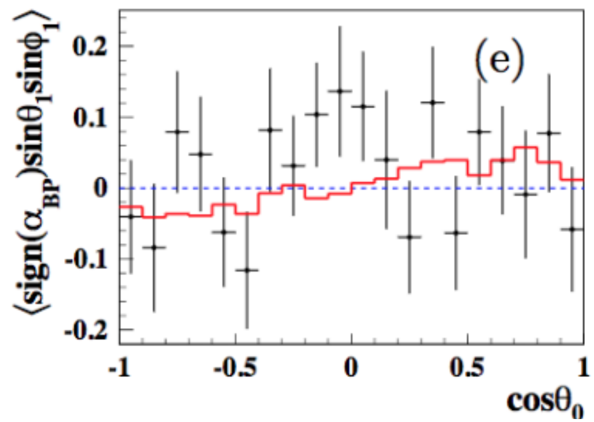
3) CPV in Λ_b and Λ_c decays

4) Decays of other charmed and beauty baryons

More analyses

- Update measurements using 10 billion J/ψ
  - A_Λ sensitivity: 5×10^{-3}
- $J/\psi, \psi(2S) \rightarrow \Sigma^+\bar{\Sigma}^-, \Xi^0\bar{\Xi}^0, \Xi^-\bar{\Xi}^+$
- $\psi(2S) \rightarrow \Omega^-\bar{\Omega}^+$
- Polarization of Λ_c^+: $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-, \Lambda_c^+ \rightarrow \Lambda\pi^+, \Sigma^+\pi^0, \Sigma^0\pi^+, K_S p$ @4.6GeV [arXiv:1905.04707]





$\sin\Delta_0 = -0.28 \pm 0.13 \pm 0.03$

$\Lambda_c^+ \rightarrow$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11] −0.49 [10], −0.90 [10] −0.49 [17], −0.97 [18] −0.66 [19], −0.90 [30] −0.99 [20], −0.91 [31]	−0.70 [16], −0.67 [11] −0.95 [10], −0.99 [10] −0.96 [17], −0.95 [18] −0.99 [19], −0.86 [30] −0.99 [20], −0.94 [31]	0.71 [16], 0.92 [11] 0.79 [10] −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −0.31 [20], −0.47 [31]	0.70 [16], 0.92 [11] 0.78 [10], −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

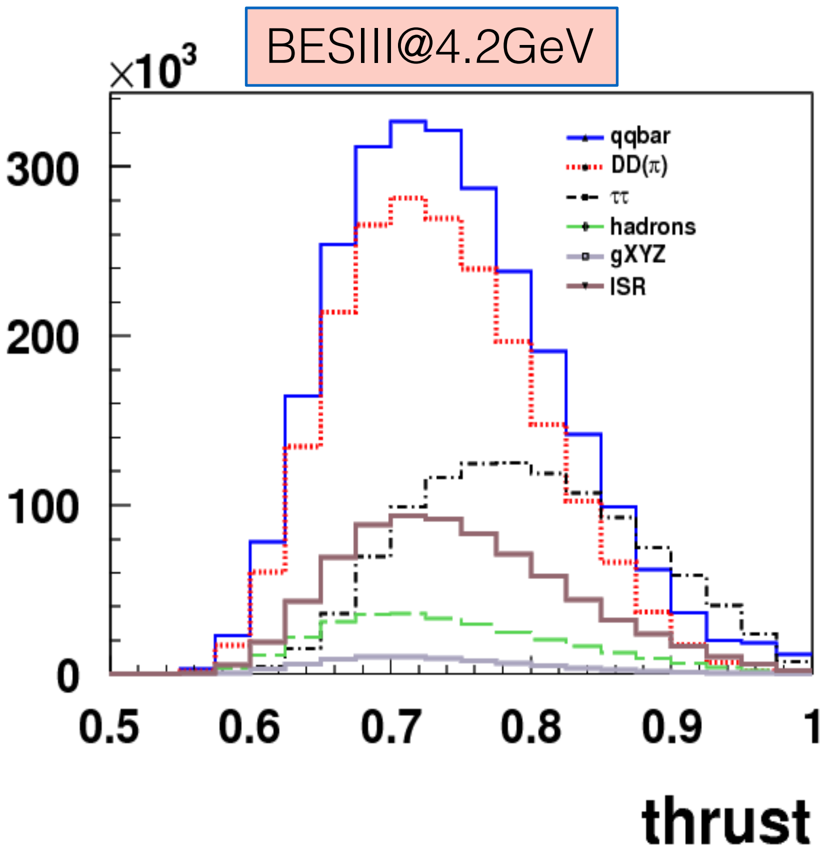
Summary and Outlook

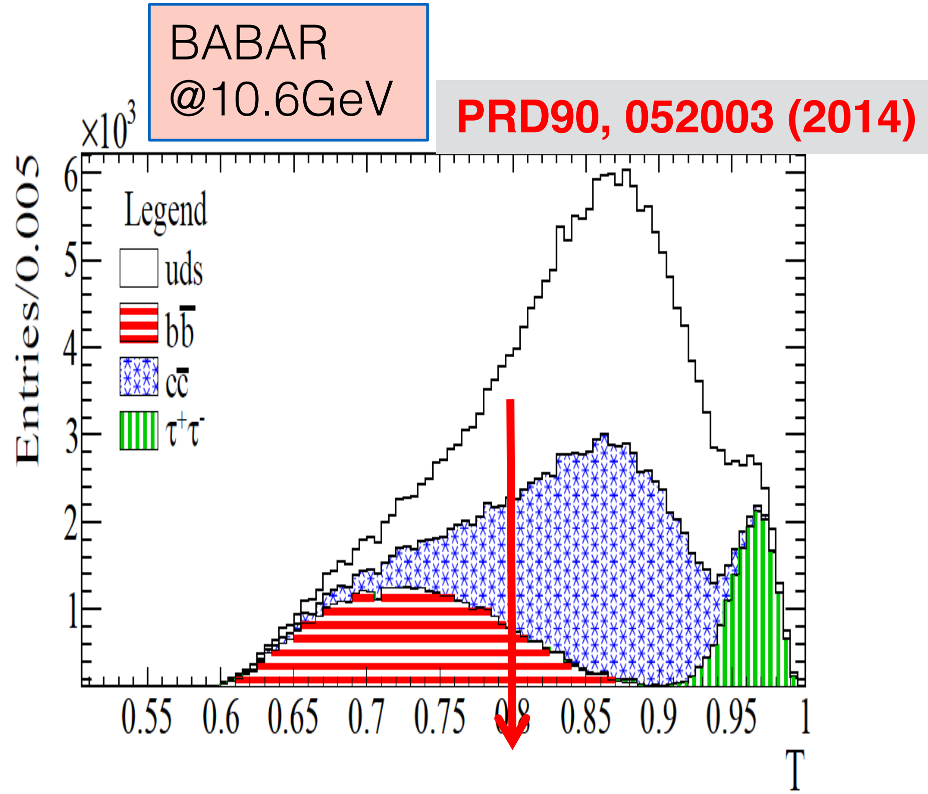
- **Collins effects measurement has been implemented using BESIII data @3.65GeV.**
  - Nonzero Collins asymmetries were observed.
  - First measurement at medium energy, which is closer to SIDIS experiments
  - It allows to study the evolution of TMD objects
  - Further extensions include high *Lumi*. data and more types of final states
- **Hyperon Spin correlations in production**
  - Observation of Λ transverse polarization in $J/\psi \to \Lambda\bar{\Lambda}$ decays
  - New way to study Hyperon CPV
  - Already rewritten the PDG book for Λ decays
  - Future results using 10B J/ψ decays will improve the CPV search
  - Plan to update the results with more data set and do the same for Ξ /**Σ**

Thank you!

谢谢！

Difficulties at higher energy





✓ Thrust value is used to suppress backgrounds at Belle/BaBar.

✓ However, it is not a good cut criterion at BESIII

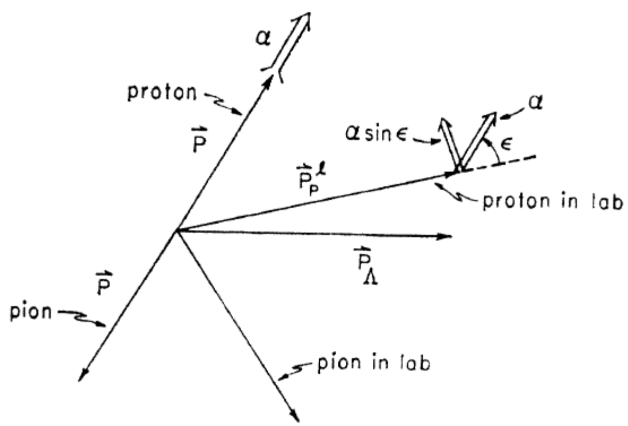
Other considerations and checks

- Misidentification of K and π: unfolding the measurement of $A^{\pi\pi}$ and $A^{K\pi}$
- Gluon radiation effect: subtracting normalized yields $R^{U} - R^{L(C)}$
- Higher harmonic terms: including in the fit function
- Possible charge-dependent acceptance effects: studying double ratio of positively over negatively charged pion pairs
- Beam polarization: studying the angular distribution of $e^{+}e^{-} \to \mu^{+}\mu^{-}$
- Several zero asymmetry tests

Most earlier measurement on α_-

- CNTR: $\pi^- + p \to \Lambda + K^0$

Phys.Rev. 129 (1963) 1795-1807



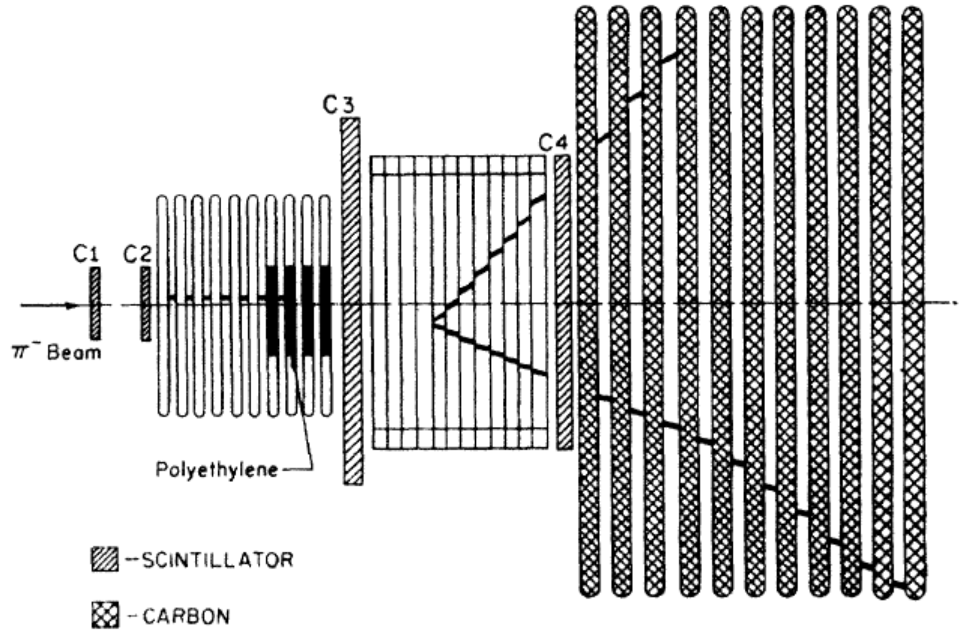
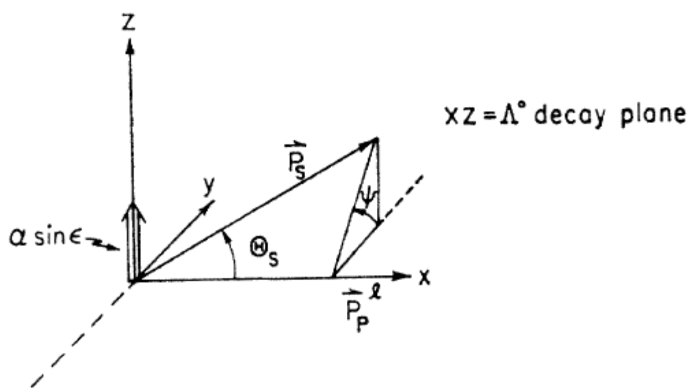


FIG. 1. Schematic diagram showing arrangement of apparatus. An example of an event has been sketched in.



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

1156 events

$\langle S\rangle = 0.565$

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

$\alpha = 0.62.$

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

Quick response from PDG2019

2019 PDG list

α_{-} FOR $\Lambda \rightarrow p\pi^{-}$

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
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 $\overline{\Lambda} \rightarrow \overline{p}\pi^{+}$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.758 \pm 0.010 \pm 0.007$	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\overline{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-0.755 \pm 0.083 \pm 0.063$	≈ 8.7k	ABLIKIM	2010	BES	$J/\psi \rightarrow \Lambda\overline{\Lambda}$
-0.63 ± 0.13	770	TIXIER	1988	DM2	$J/\psi \rightarrow \Lambda\overline{\Lambda}$

Why hyperons using J/psi decays

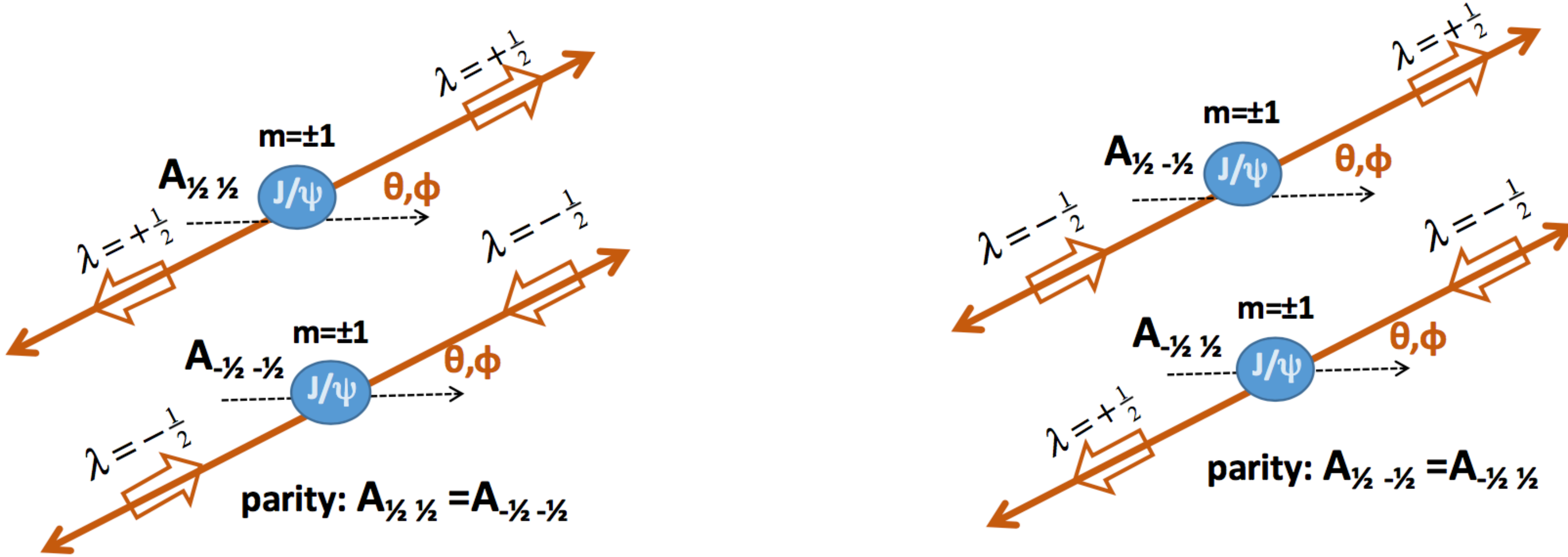
10 billion J/psi events collected

- Large BRs in J/ψ decays
- Quantum correlated pair productions
- Background free

Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_{\mathcal{B}}\ (\times 10^{6})$	Efficiency	Number of reconstructed
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5	40%	3200 X 10^3
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9	25%	600 X 10^3
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4	24%	640 X 10^3
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5		
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2		
$J/\psi \to \Xi^0\Xi^0$	1.20 ± 0.24	12.0 ± 2.4	14%	670 X 10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0	19%	810 X 10^3
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4		
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5		
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03		

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

Production: **2 independent helicity amplitudes: $A_{½\ ½}$, $A_{½\ -½}$**



Δ= complex phase between $A_{½\ ½}$ and $A_{½\ -½}$

$$\frac{d|\mathcal{M}|^2}{d\cos\theta} \propto (1+\alpha_{J/\psi}\cos^2\theta), \quad \text{with} \quad \alpha_{J/\psi} = \frac{|A_{1/2,-1/2}|^2 - 2|A_{1/2,1/2}|^2}{|A_{1/2,-1/2}|^2 + 2|A_{1/2,1/2}|^2}$$