8th Workshop on Hadron Physics in China and Opportunities Worldwide
Aug 8-11., 2016, CCNU, Wuhan

Physics and prospects of Collins asymmetry at BESIII

Kai Zhu
(email:zhuk@ihep.ac.cn)
On behalf of the BESIII Collaboration
Institute of High Energy Physics

PRL 116, 042001

Outline

- Introduction of Collins Function
- BEPCII and BESIII detector
- Analysis overview
  - Reference frame
  - Measurement
  - Results
  - Systematics
- Summary

Beijing Spectrometer
not Beam Energy Scan

Fragmentation Functions

- **First** set: cross section observables in semi-inclusive e^+e^- annihilation $e^+e^- \to \gamma/Z \to h + X$

$$\frac{1}{\sigma_0}\frac{d^2\sigma^h}{dx\, d\cos\theta} = \frac{3}{8}(1+\cos^2\theta)F_T^h(x,s) + \frac{3}{4}\sin^2\theta\, F_L^h(x,s) + \frac{3}{4}\cos\theta\, F_A^h(x,s)$$

- **Second** set: final state parton distribution

$$\frac{1}{\sigma_0}\frac{d\sigma^h}{dx} = F^h(x,s) = \sum_i \int_x^1 \frac{dz}{z} C_i(z, \alpha_s(\mu), \frac{s}{\mu^2}) D_i^h(\frac{x}{z}, \mu^2) + \mathcal{O}(\frac{1}{\sqrt{s}})$$

probability parton *i* fragments into a hadron *h*

K.A. Olive *et al.* (PDG), Chin. Phys. **C38**, 090001 (2014) (http://pdg.lbl.gov)

Spin-dependent Fragmentation

* Relate the polarization of the quark to that of the final hadron
  * Longitudinal polarization
  * Transverse polarization

- Non-perturbative QCD
- Spontaneous breaking of chiral symmetry

Collins FF

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

Unpolarized FF

J. Collins, Nucl. Phys. B936, 161 (1993)

Measurements

- Global analysis (universality of the Collins FF)

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

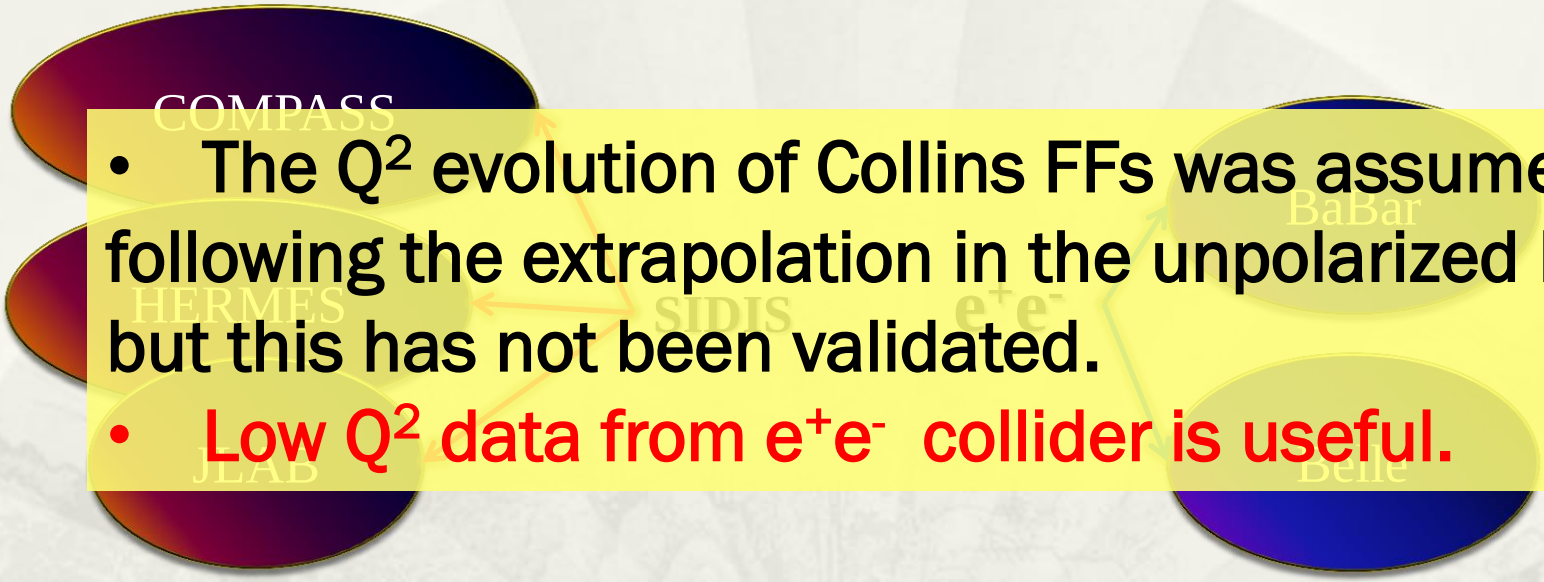
Collins function ⊗ transversity distribution
(charge and quark distribution)

Direct Collins function

1-10 GeV^2 25 GeV^2 100 GeV^2

Measurements

- Global analysis (universality of the Collins FF)



- The Q^2 evolution of Collins FFs was assumed following the extrapolation in the unpolarized FF, but this has not been validated.
- Low Q^2 data from e^+e^- collider is useful.

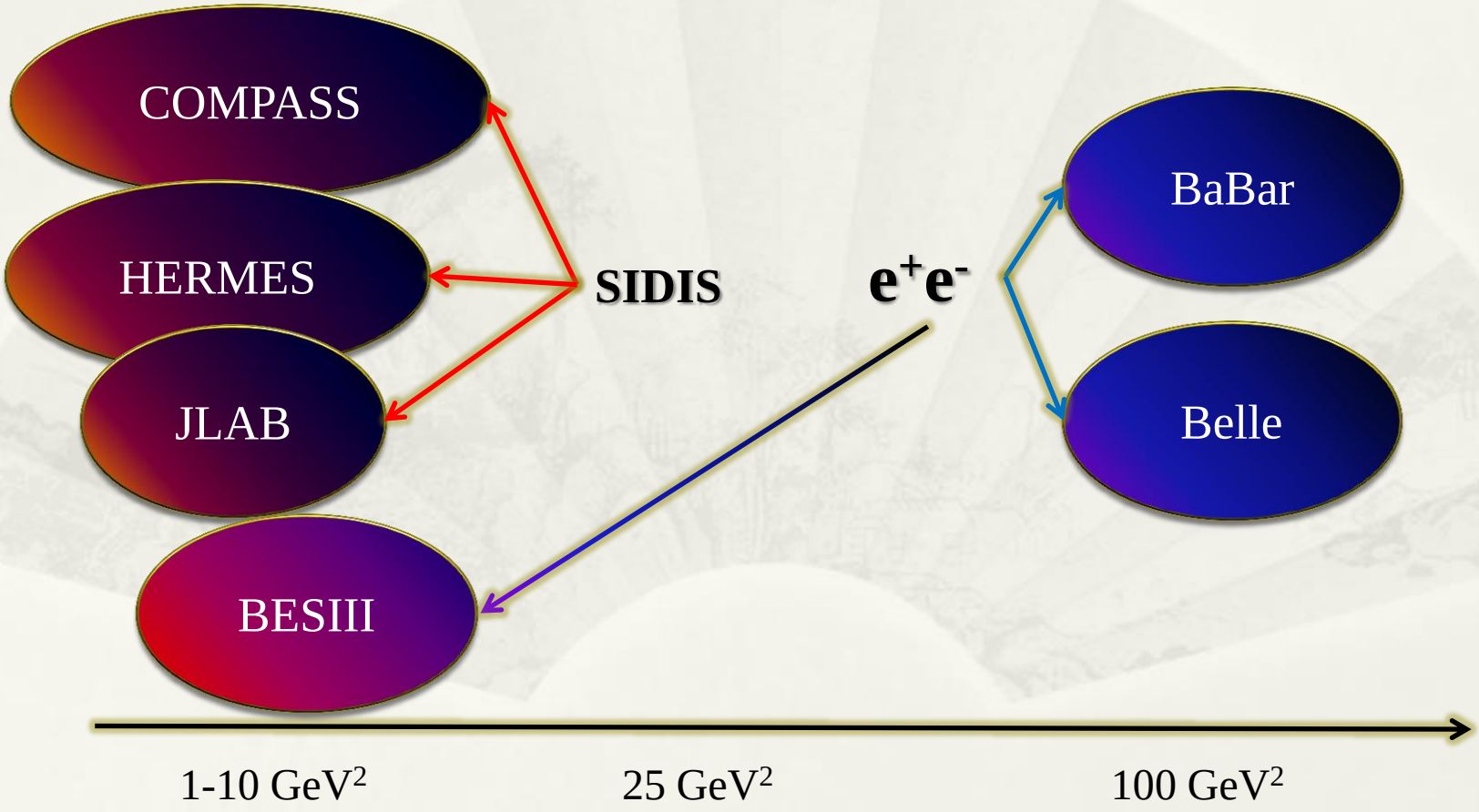
Collins function ⊗ transversity distribution (charge and quark distribution)

Direct Collins function

1-10 GeV^2 25 GeV^2 100 GeV^2

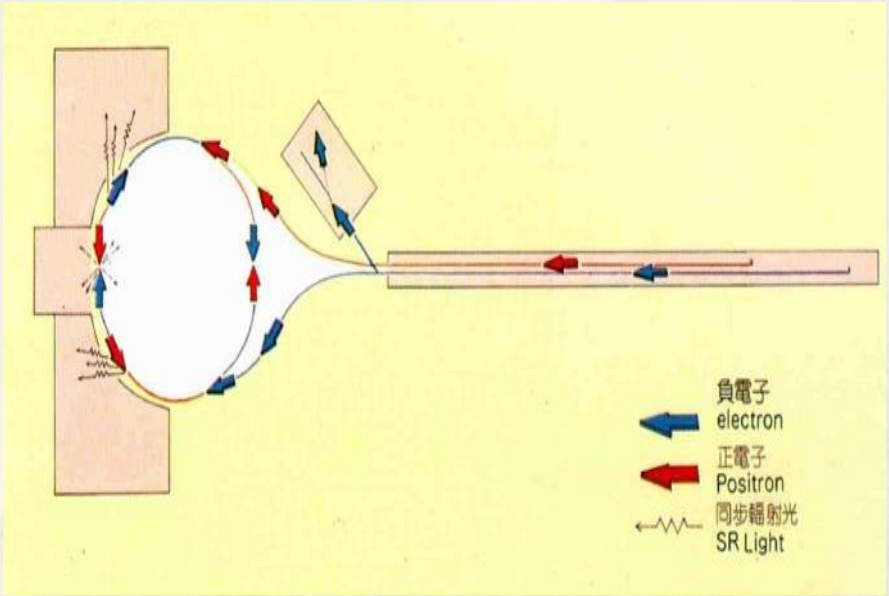
Measurements

- Global analysis (universality of the Collins FF)

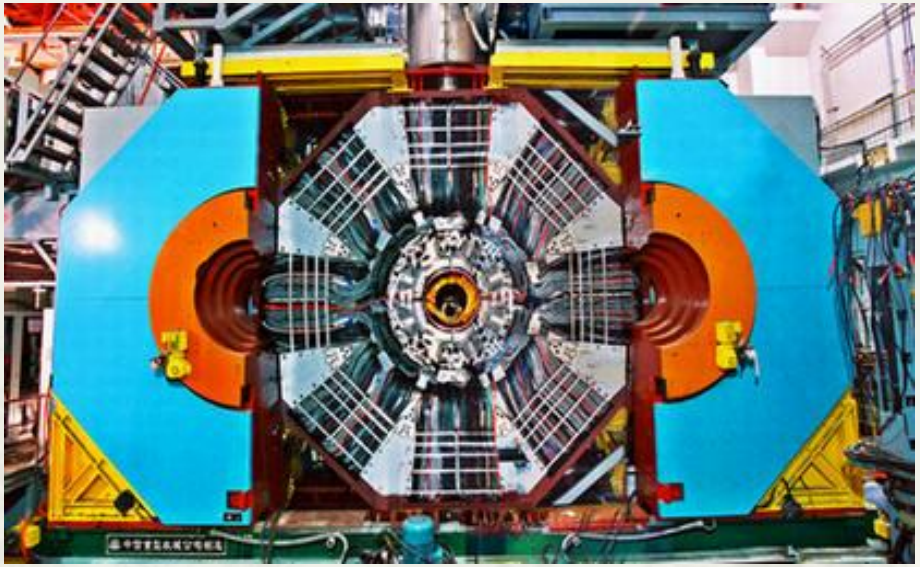


BEPCII & BESIII

BEPCII

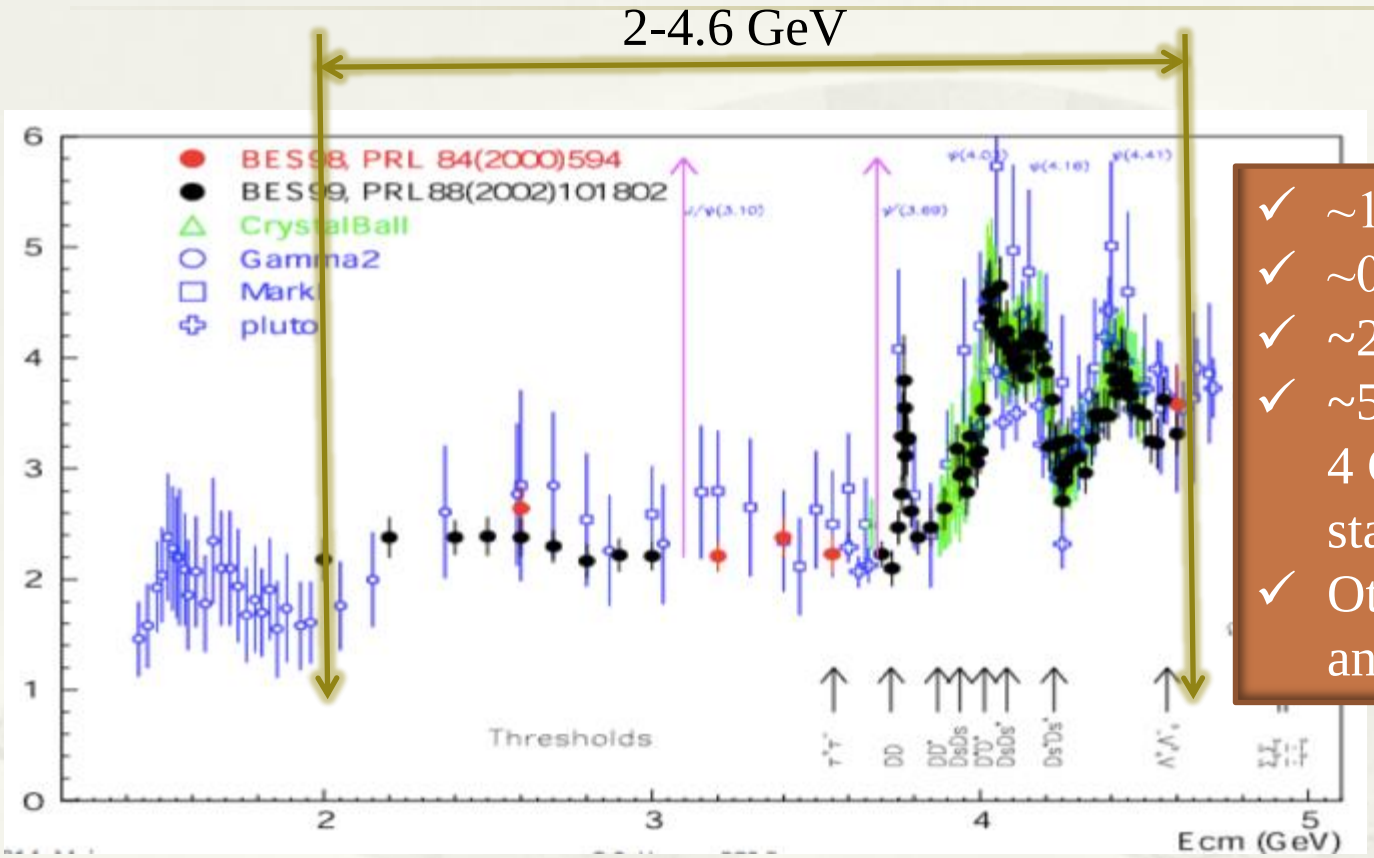


BESIII



$\sqrt{s} = 2$~4.6 GeV, rich physics potential .
Light hadron, charmonium, charm, R & QCD.

BESIII (data samples)



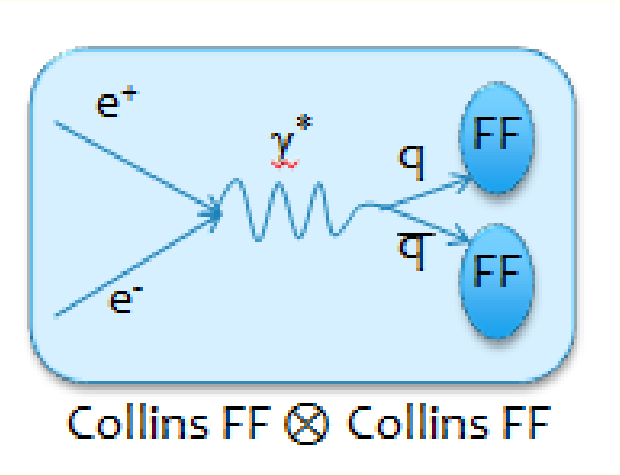
- ✓ ~1.3 B J/ψ
- ✓ ~0.45 B ψ(3686)
- ✓ ~2.9 fb^{-1} @ ψ(3770)
- ✓ ~5 fb^{-1} collected above 4 GeV, mainly for XYZ states
- ✓ Others include R scan and continuum data, etc.

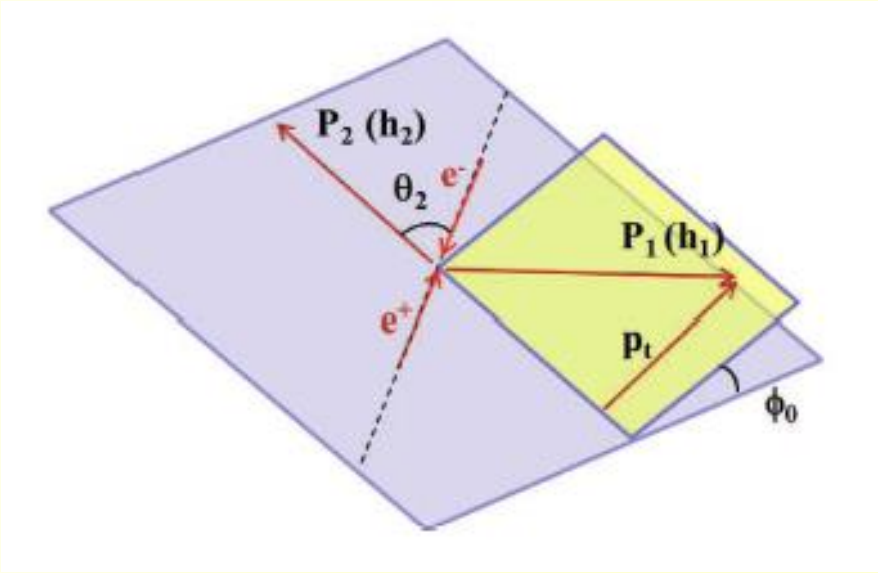
62 pb^{-1} @ 3.65 GeV
(used by this work)

Reference Frame and method

Collins Effect: transverse quark spin relates to an azimuthal asymmetry

$e^+e^- \rightarrow q\bar{q} \rightarrow hX$ (with unpolarized beams)
Impossible: Collins effect of single (anti-)quark
Possible: Correlation of quark and anti-quark



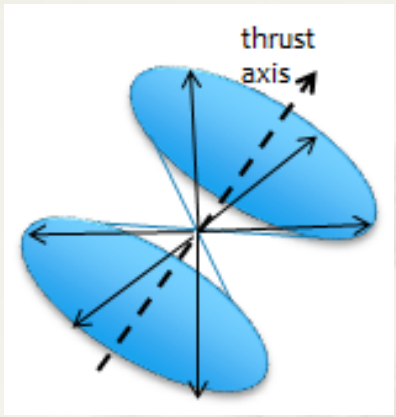


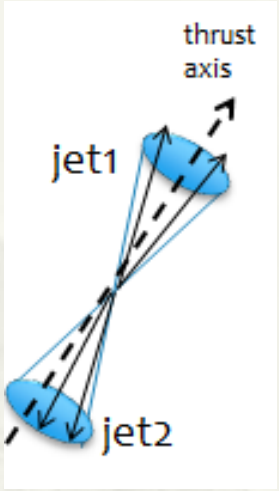
Parameterization: $a\cos(2\phi_0) + b$

$$a = a\,(\theta_2, z_1, z_2)$$

$$z = 2E_h/Q$$

Difference due to energy scale





1-10 GeV^2 100 GeV^2

At BESIII:

- No obvious thrust axis
- π dominant

To select $e^+e^- \rightarrow \pi\pi X$

- Charged tracks from MDC
- Photons from EMC
- PID by combined information of dE/dx and TOF

- $N_{trk} \geq 3$ && $N_\pi \geq 2$ && $N_e = 0$
- $E_{vis} > 1.5$ GeV

Pion pair:

- Fractional energy $0.3 < z < 0.9$ $(z \equiv 2E_h/\sqrt{s})$
- Open angle $\theta_{\pi\pi} > 120°$
- Save all possible combinations

Two definitions

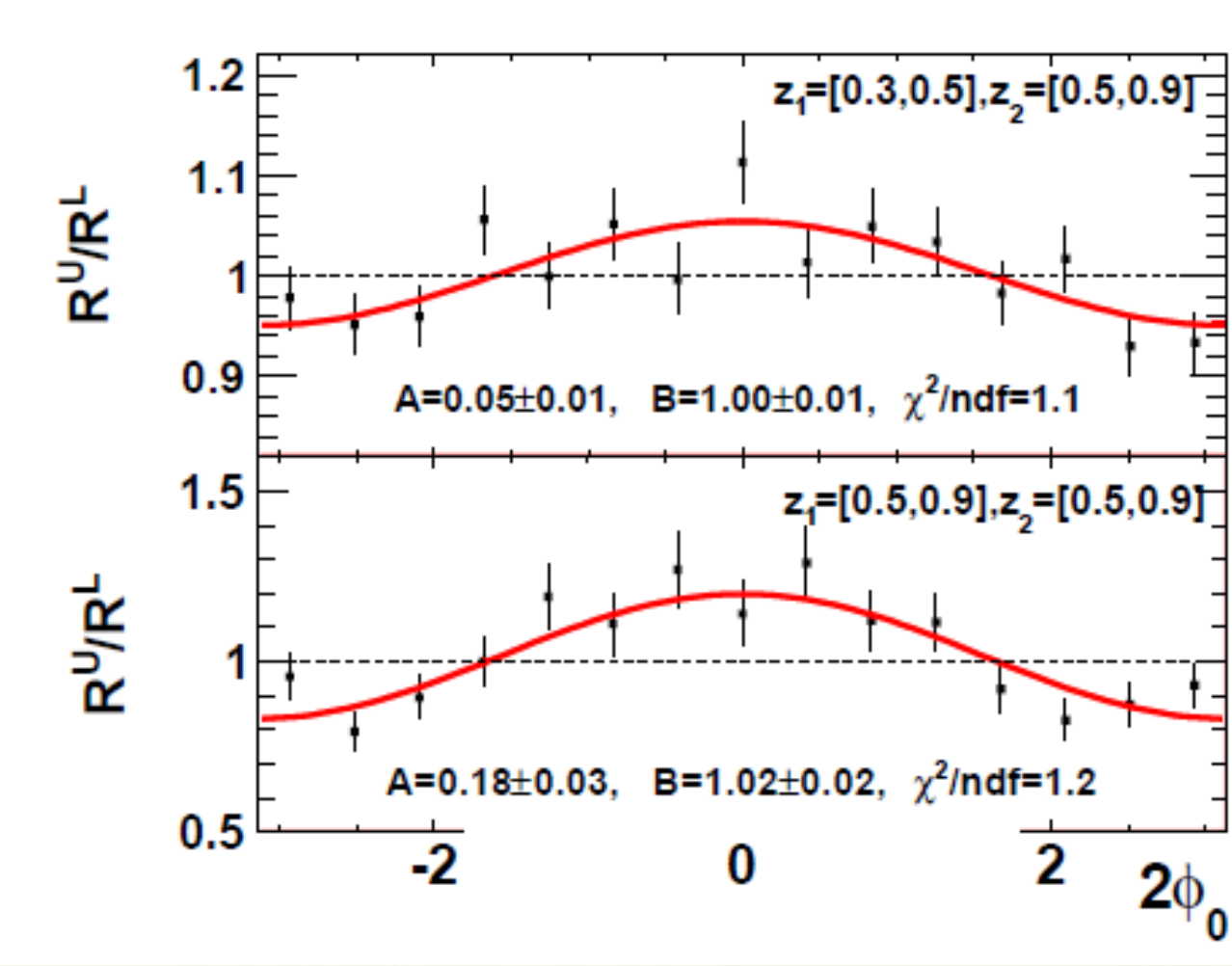
- Normalized ratio $R = \frac{N(2\phi_0)}{\langle N_0 \rangle}$
  - $N(2\phi_0)$: di-π yield in each $2\phi_0$ subdivision
  - $\langle N_0 \rangle$: averaged bin content
  - Three types of ratio
    - R^U: unlike-sign $(\pi^{\pm}\pi^{\mp})$
    - R^L: like-sign $(\pi^{\pm}\pi^{\pm})$
    - R^C: all pion-pairs $(\pi\pi)$
- Double ratio (to reduce acceptance and radiation effect)

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

$A^{UL(UC)}$ mainly contains the Collins effect
B should be consistent with unity

Phys. Rev. Lett. 116, 042001

Results

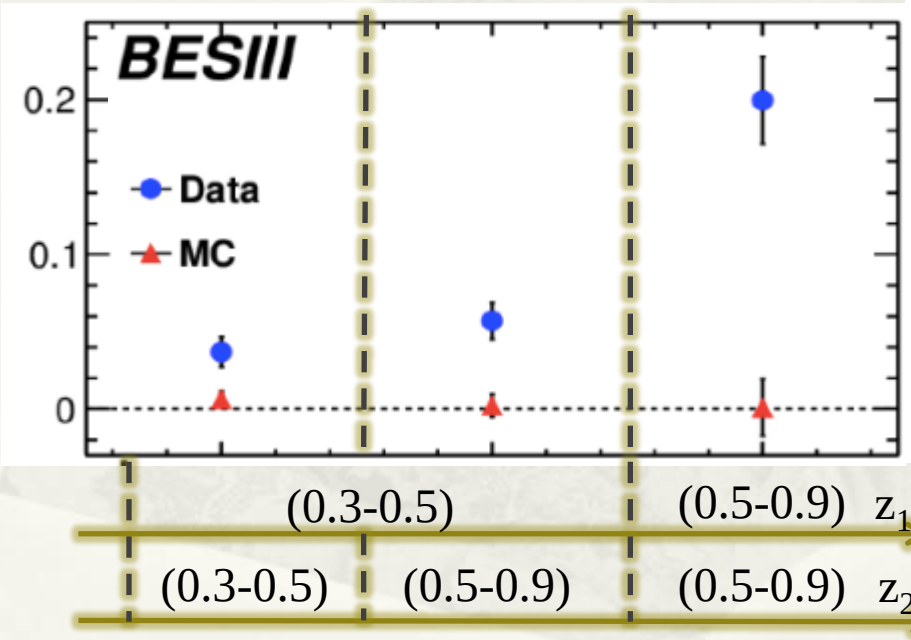


Obvious asymmetry is observed!

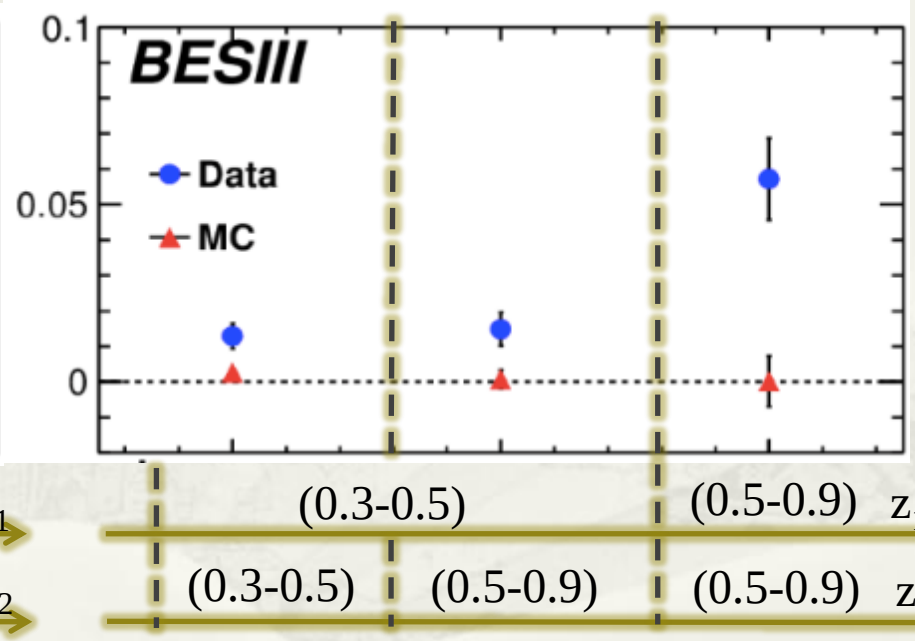
Data/MC comparison

MC is generated without Collins effect.

$A^{UL} = R^U/R^L$



$A^{UC} = R^U/R^C$

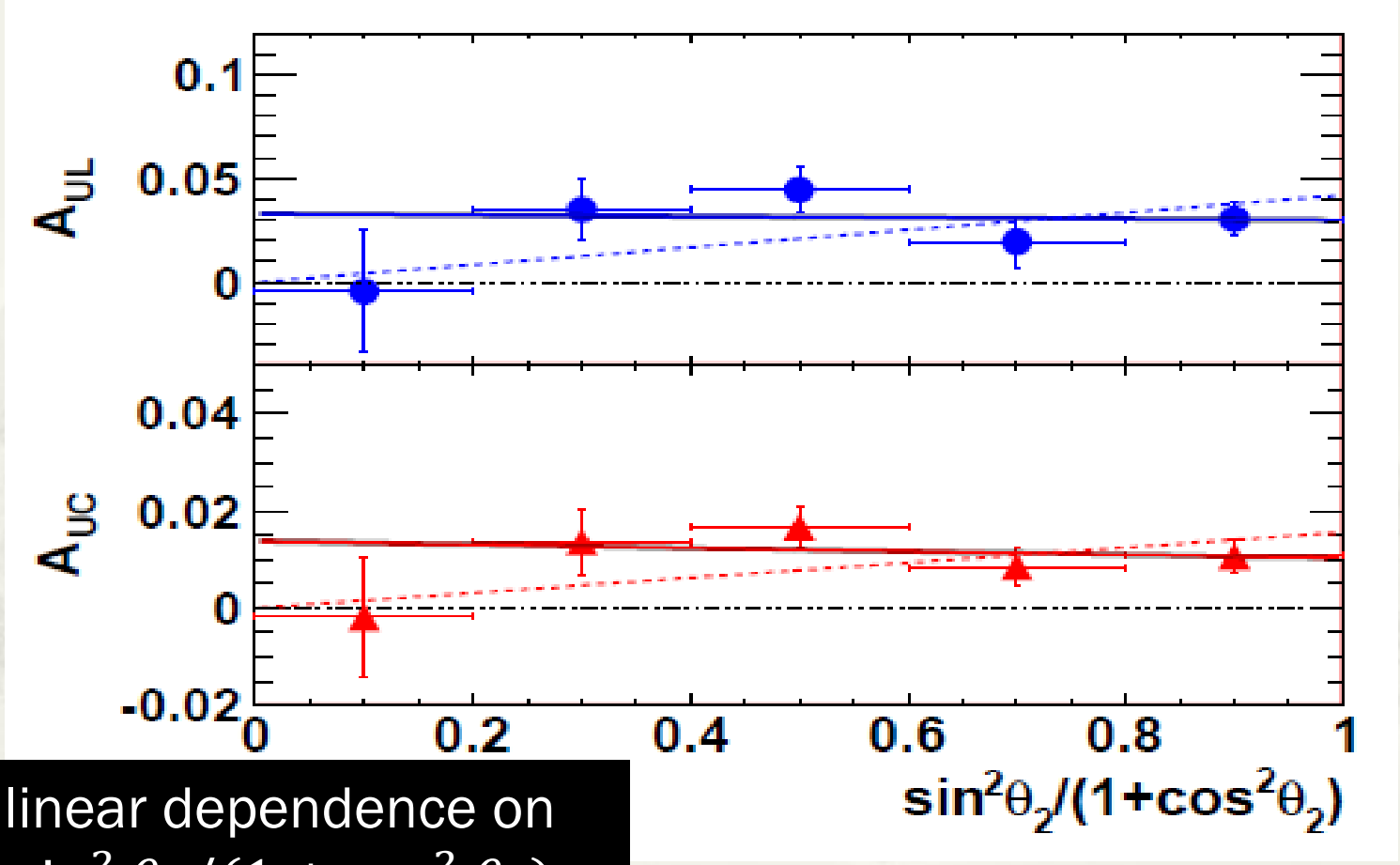


Other considerations and checks

- 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; combining pion pair randomly
- Beam polarization: studying the angular distribution of $e^{+}e^{-} \to \mu^{+}\mu^{-}$

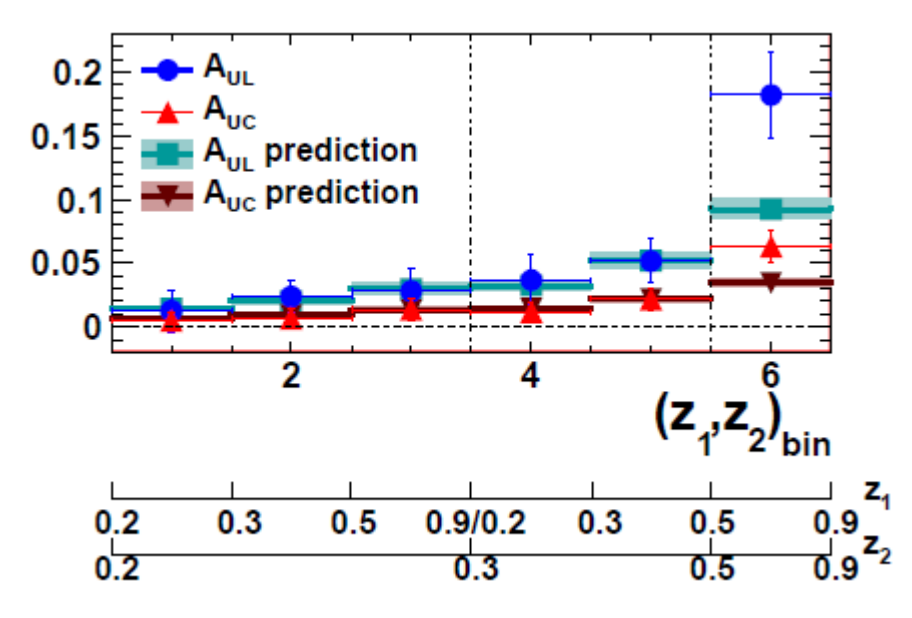
Phys. Rev. Lett. 116, 042001

Linear dependence

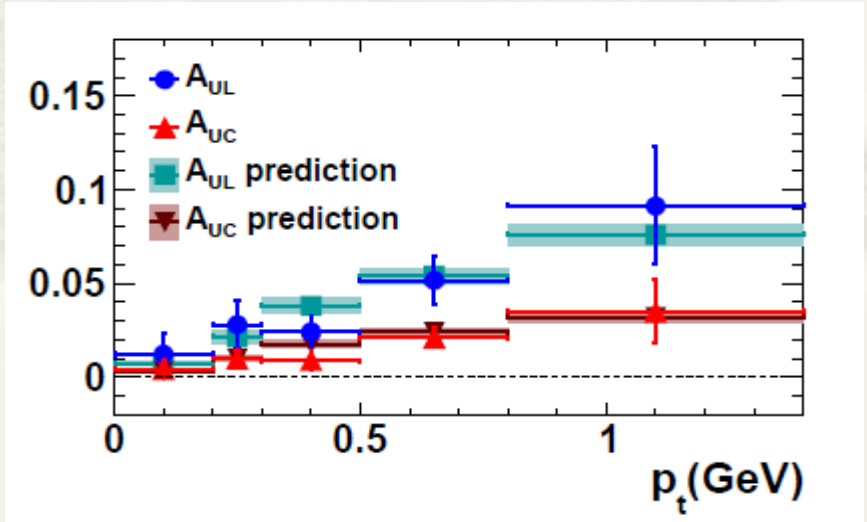


A linear dependence on $\sin^2\theta_2/(1+\cos^2\theta_2)$ is expected

Compare with theory



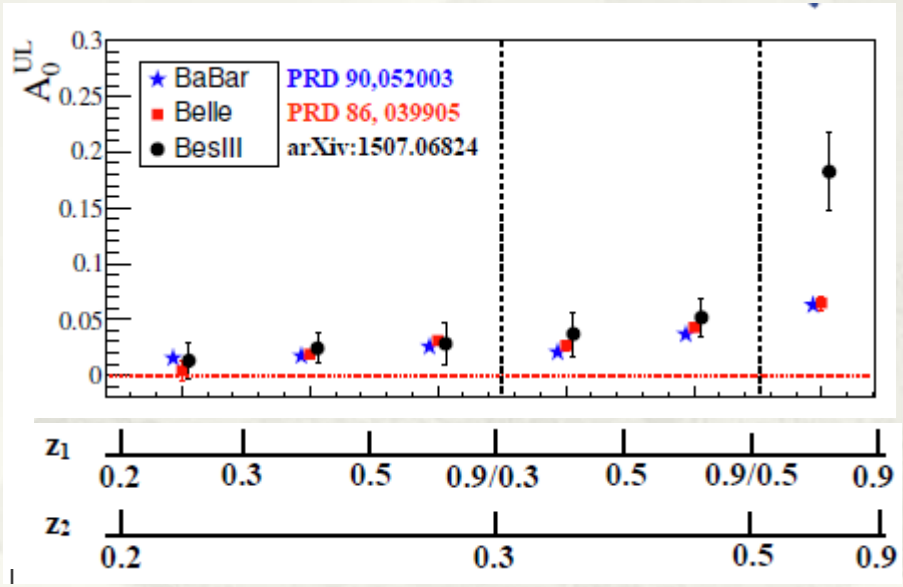
Prediction is from Z. B. Kang, A. Prokudin, P. Sun, F. Yuan Phys. Rev. D 93, 014009 (2016)

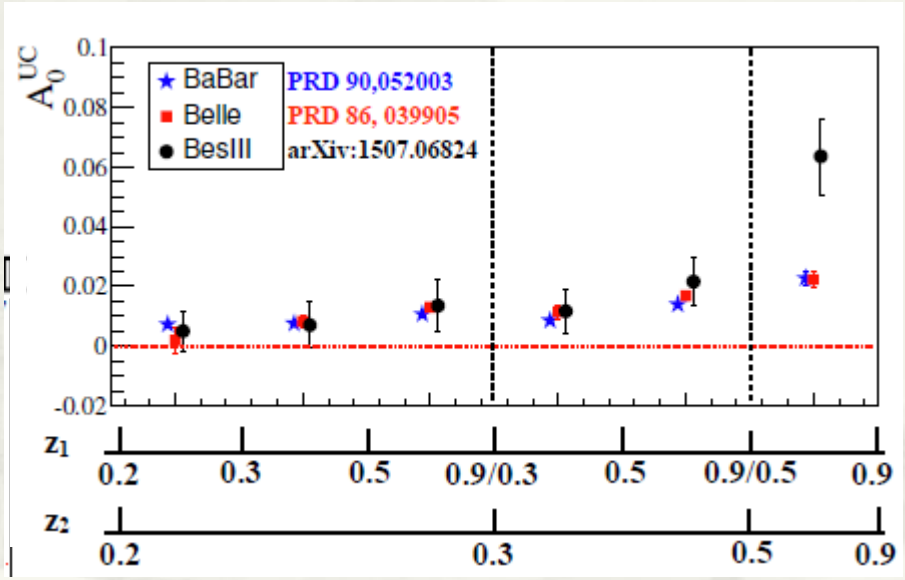


Asymmetry dependence on transverse momentum

Compare with other experiments

Comparison between different results obtained at different Q^2
- BaBar Belle @ $Q^2 \sim 110\ GeV^2$
- BESIII @ $Q^2 \sim 13\ \mathrm{GeV}^2$





From I. Garzia, INFN

Predicted in Collins original paper:
-Larger asymmetry at lower Q^2 region
-Asymmetries increase as z grows

Summary

Phys. Rev. Lett. 116, 042001

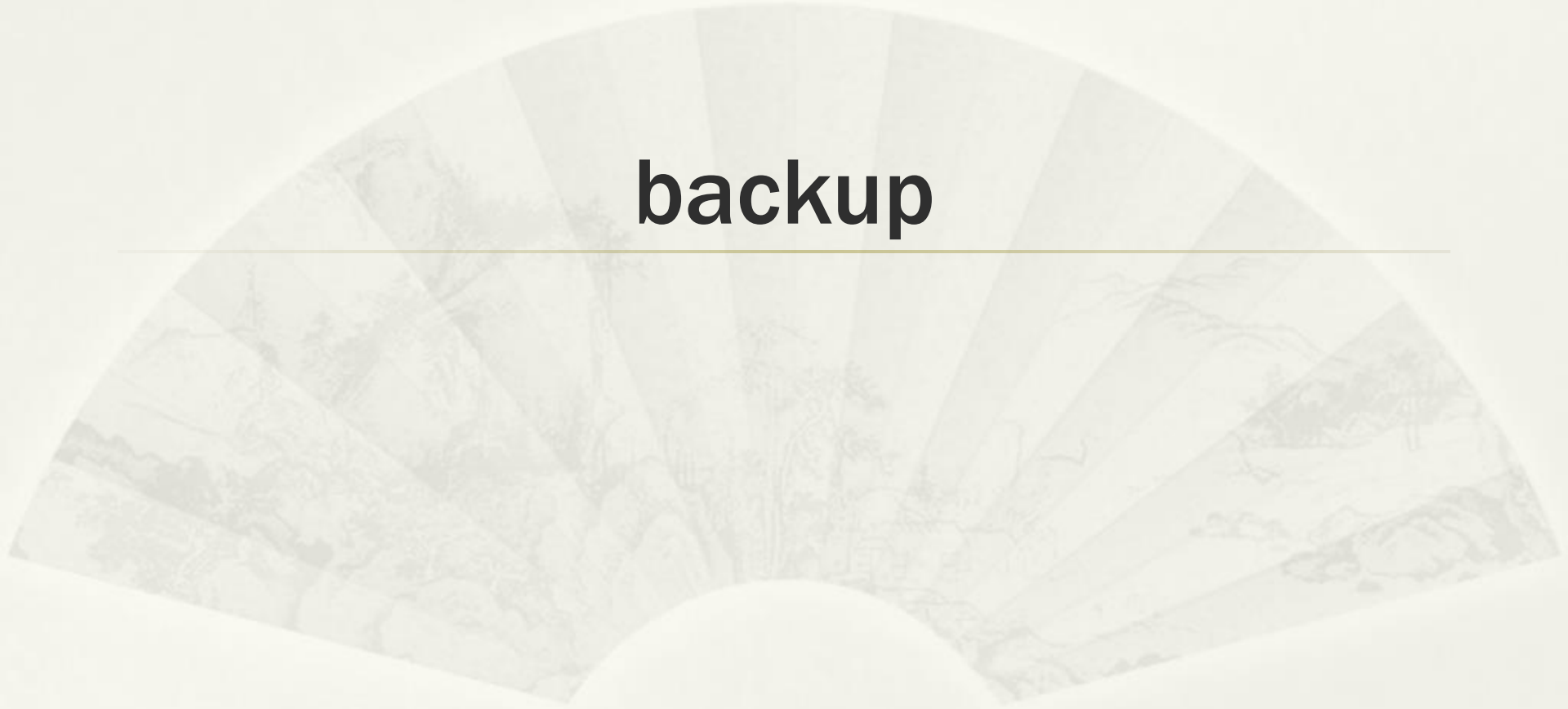
* We measure the Collins asymmetry by using 62/pb BESIII data @ 3.65 GeV
  * Obvious asymmetry is observed.
  * First measurement with e^+e^- experiment at medium energy region.
  * Compared with other experimental results, one can extract transversity in nucleon, check the universality of CFF, explore Q^2 evolution and p_t dependence, then shed light on the fragmentation processes.

Outlook

- Collins asymmetries with KK, $K\pi$ and $\pi\pi$ (maybe simultaneous measurement)
- Including π^0 in final states
- Data at higher energy regions
- BESIII will take more data @ $\sqrt{s}$ =3.51 GeV, which will improve precision of this measurement.

THANKS FOR YOUR ATTENTION

backup



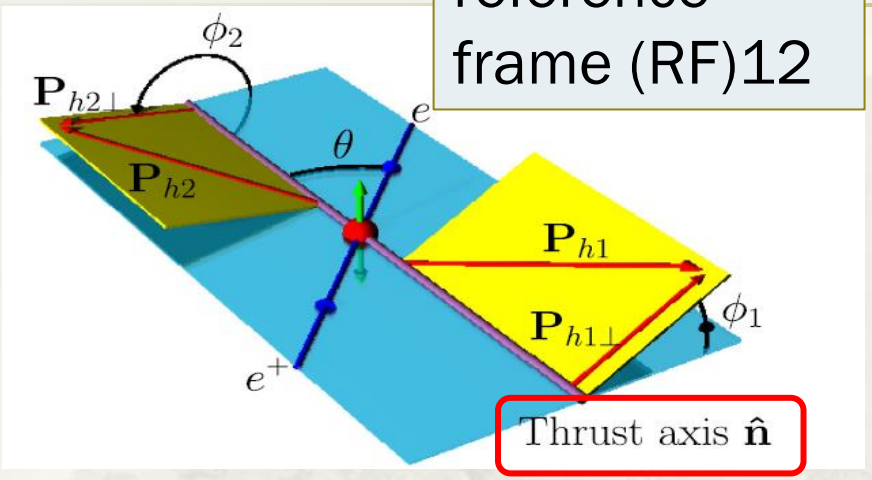
Phys. Rev. Lett. 116, 042001

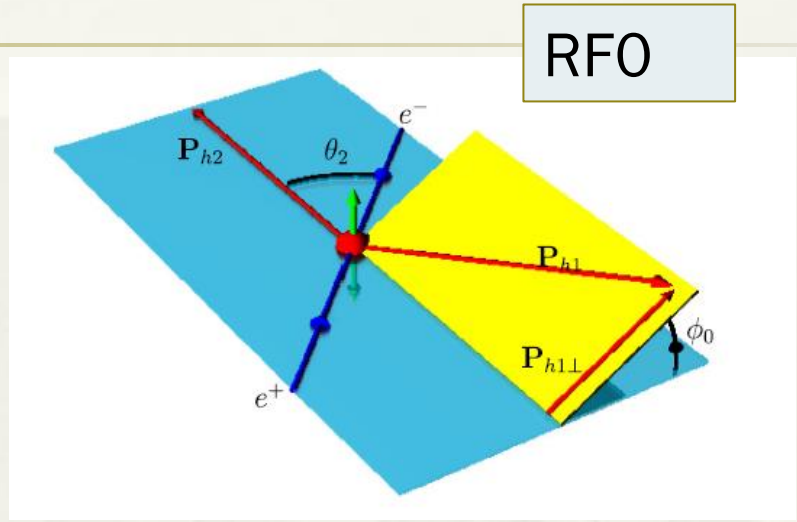
TABLE I. Results of A_{UL} and A_{UC} in each (z_1, z_2) and p_t bin. The uncertainties are statistical and systematic, respectively. The averages $\langle z_i \rangle$, $\langle p_t \rangle$ and $\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle}$ are also given.

$z_1 \leftrightarrow z_2$	$\langle z_1 \rangle$	$\langle z_2 \rangle$	$\langle p_t \rangle$ (GeV)	$\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle}$	$A_{UL}(\%)$	$A_{UC}(\%)$
$[0.2, 0.3][0.2, 0.3]$	0.245	0.245	0.262	0.589	$1.28 \pm 0.93 \pm 1.38$	$0.50 \pm 0.32 \pm 0.60$
$[0.2, 0.3][0.3, 0.5]$	0.311	0.311	0.329	0.576	$2.40 \pm 0.74 \pm 1.08$	$0.67 \pm 0.27 \pm 0.72$
$[0.2, 0.3][0.5, 0.9]$	0.428	0.426	0.444	0.572	$2.81 \pm 1.44 \pm 1.10$	$1.36 \pm 0.54 \pm 0.64$
$[0.3, 0.5][0.3, 0.5]$	0.379	0.379	0.388	0.563	$3.69 \pm 1.07 \pm 1.65$	$1.17 \pm 0.39 \pm 0.62$
$[0.3, 0.5][0.5, 0.9]$	0.498	0.499	0.479	0.564	$5.18 \pm 1.32 \pm 1.08$	$2.17 \pm 0.47 \pm 0.65$
$[0.5, 0.9][0.5, 0.9]$	0.625	0.628	0.499	0.570	$18.24 \pm 3.19 \pm 1.36$	$6.37 \pm 0.99 \pm 0.82$
p_t (GeV)	$\langle p_t \rangle$ (GeV)	$\langle z_1 \rangle$	$\langle z_2 \rangle$	$\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle}$	$A_{UL}(\%)$	$A_{UC}(\%)$
$[0.00, 0.20]$	0.133	0.291	0.348	0.574	$1.22 \pm 1.02 \pm 0.48$	$0.44 \pm 0.36 \pm 0.20$
$[0.20, 0.30]$	0.253	0.285	0.344	0.579	$2.79 \pm 0.89 \pm 0.93$	$1.00 \pm 0.32 \pm 0.34$
$[0.30, 0.45]$	0.405	0.327	0.346	0.570	$2.41 \pm 0.79 \pm 0.43$	$0.90 \pm 0.26 \pm 0.43$
$[0.45, 0.80]$	0.610	0.453	0.349	0.571	$5.16 \pm 0.95 \pm 0.87$	$2.11 \pm 0.41 \pm 0.27$
$[0.80, 1.40]$	0.923	0.646	0.334	0.584	$9.13 \pm 2.74 \pm 1.52$	$3.50 \pm 0.98 \pm 1.37$

PRD 78, 032011

Double Collins Asymmetries (DCA)





- The spin correlation of hadron fragmented from quark and anti-quark in opposite hemisphere follows a $\cos(\phi1+\phi2)$ 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)

From Xiao-rui Lyu