Fragmentation Functions at BESIII

Yinghui Guan(管颖慧) [a], Haibo Li [a],
Xiao-Rui Lyu [b] , Wenbiao Yan [c], Isabella Garzia [d]
a. Institute of High Energy Physics(IHEP)
b. University of Chinese Academy of Sciences(UCAS)
c. University of Science and Technology of China(USTC)
d. Ferrara University, INFN
(for the BESIII Collaboration)

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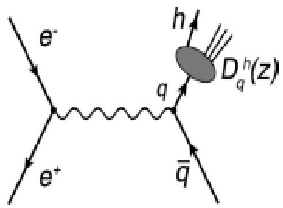
Outline

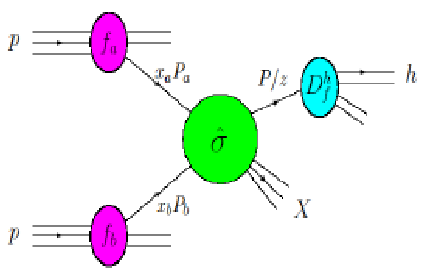
- **Introduction**
  - Fragmentation Function(FF)
  - Motivation
- **BEPCII and BESIII**
- **Physics topics about FF at BESIII:**
  - Inclusive hadron(π/π^0/K/K_S…) production
  - Double Collins Asymmetries(DCA) measurement
- **Summary and Outlook**

Fragmentation Function(FF)

- **Fragmentation Function**s (FFs) describe the probability for a parton to fragment into a hadron carrying a certain fraction z of the parton momentum



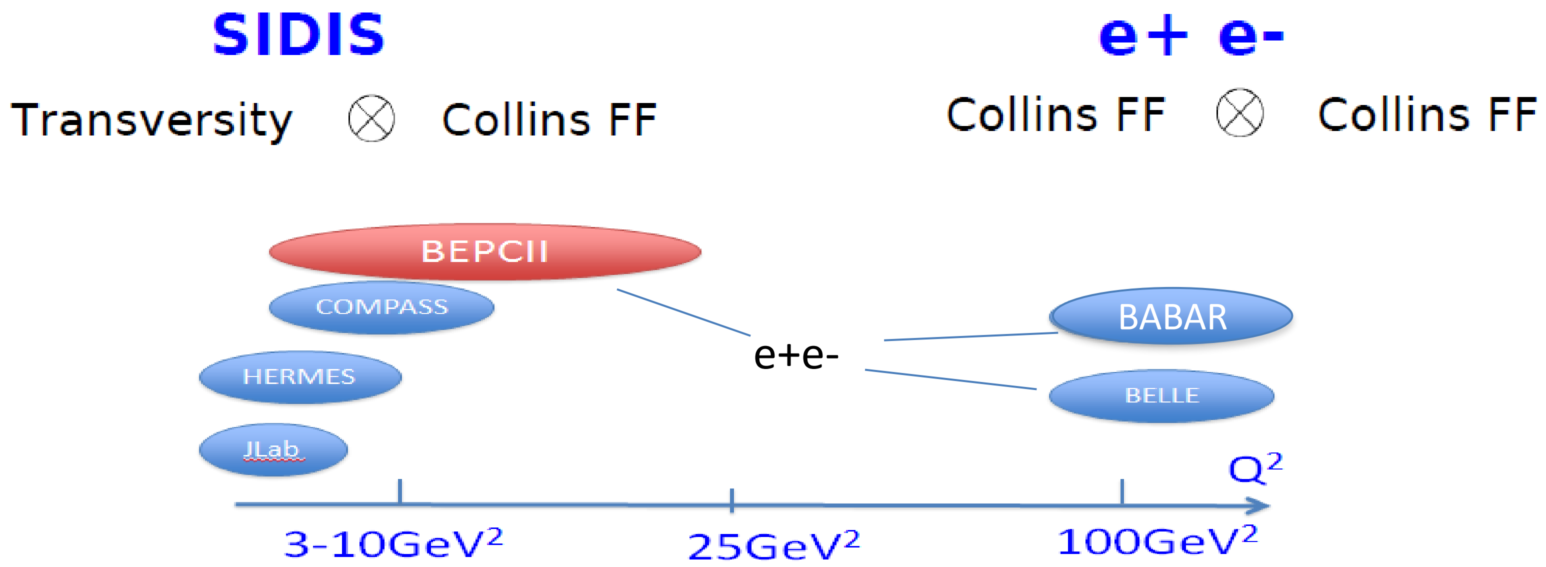
LO $$\frac{d\sigma}{dz}(e^-e^+\rightarrow hX) = \sum_q \sigma(e^-e^+\rightarrow q\bar{q})\left[D_q^h(z) + D_{\bar{q}}^h(z)\right]$$



$$\sigma = \sum_{a,b,c} f_a(x_a,Q^2)\otimes f_b(x_b,Q^2) \otimes\hat{\sigma}(ab\rightarrow cX)\otimes D_c^{\pi}(z,Q^2)$$

- FF are nonperturbetive in nature, important information in our understanding of hadron production and parton distribution
- Fitting: parametrization & experimental data (e+e-, SIDIS, pp)
- **Universality:** process independent (SIDIS, pp, ee annihilation)
- **Energy evolution:** evolved from a defined energy scale

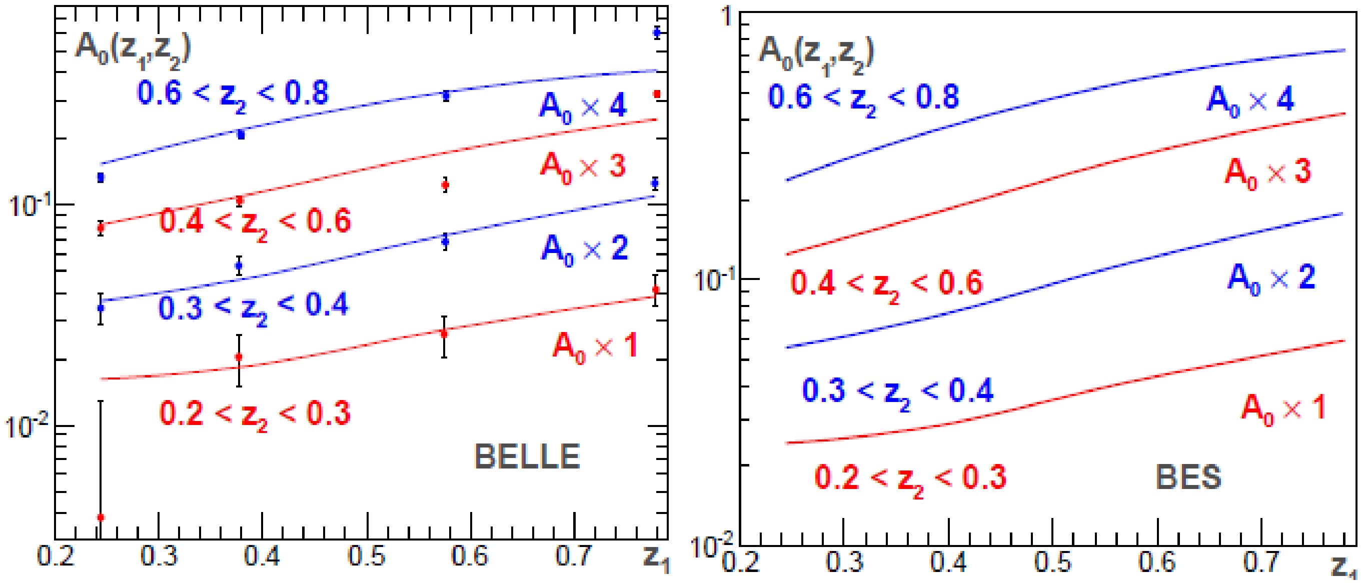
Motivation



- **SIDIS experiments: HERMES, JLab, low Q^2, to extract PDFs, need FFs from e+e- annihilations.**
- **Existing information of FFs: BABAR, Belle etc., high Q^2, need energy evolution for SIDIS.**
- **BEPCII: similar energy coverage with SIDIS. Input for extracting the parton distribution without energy evolution! Proposed by PRD 88. 034016 (2013)**
- **Combined efforts to measurement Transversity distribution**

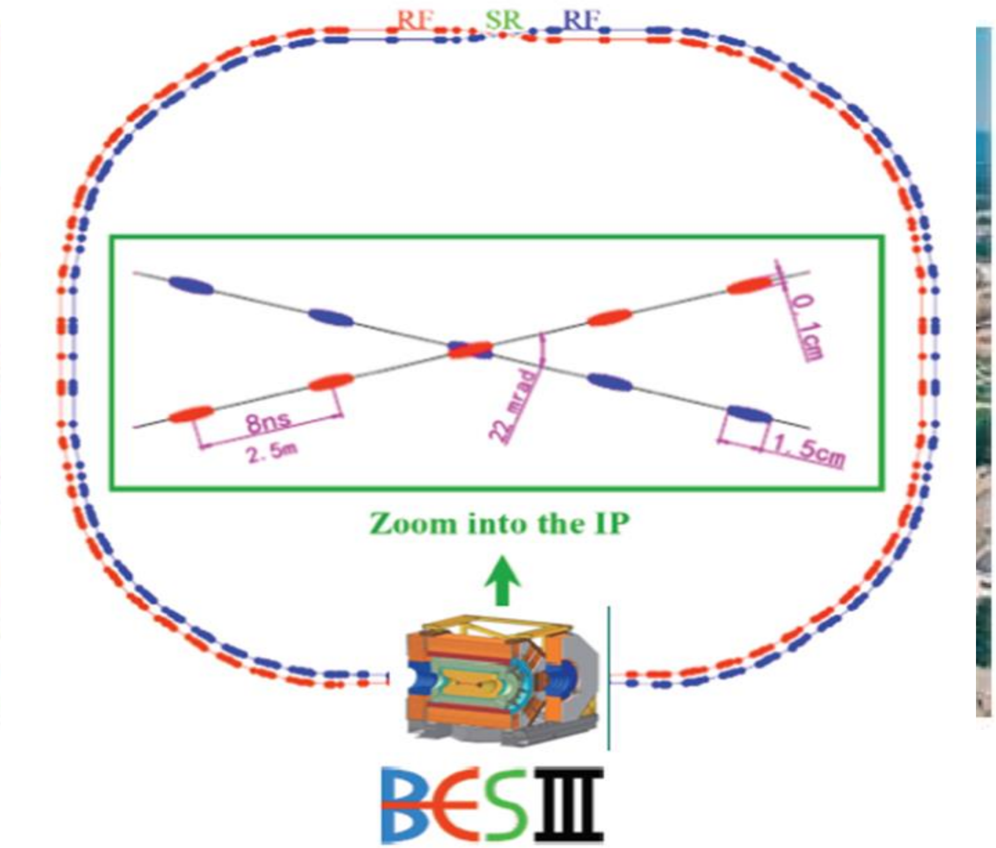
Motivation

PRD 88. 034016 (2013) P. Sun, F. Yuan



- **The Collins asymmetries in di-pion azimuthal angular distributions in e+e− annihilation processes, Ec.m. =4.6GeV,**
- **Because of energy evolution effect, it will be larger than that at Belle by a factor 2**
- **The experimental results from BEPCII will provide an important test.**

Beijing Electron Positron Collider-II (BEPCII)



- e+e- annihilation , unpolarized beams, symmetric collider,
- Beam energy: 1.0-2.3GeV (Q: ~2.0-4.6GeV)
- Achieved luminosity: 0.7×10^{33} $cm^{-2}s^{-1}$@3.770GeV

NIM A614, 345 (2010)

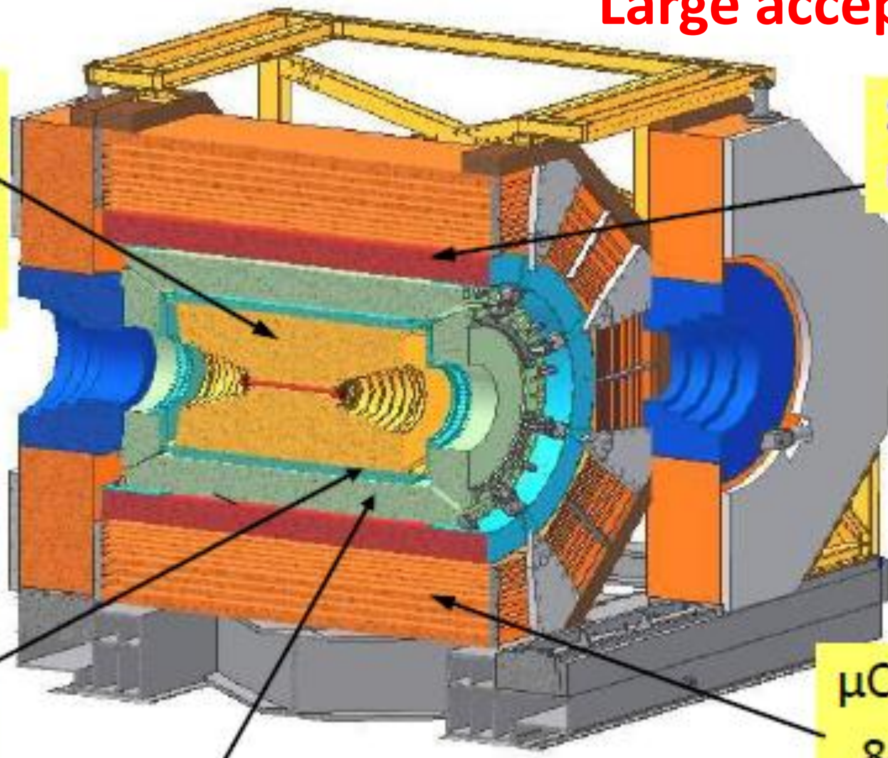
The BESIII Detector

Large acceptance: 93% *4π

Drift Chamber (MDC)
$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 6%

- **Tracking**
- **PID**

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)
σ_T : 90 ps Barrel
110 ps endcap

- **PID**

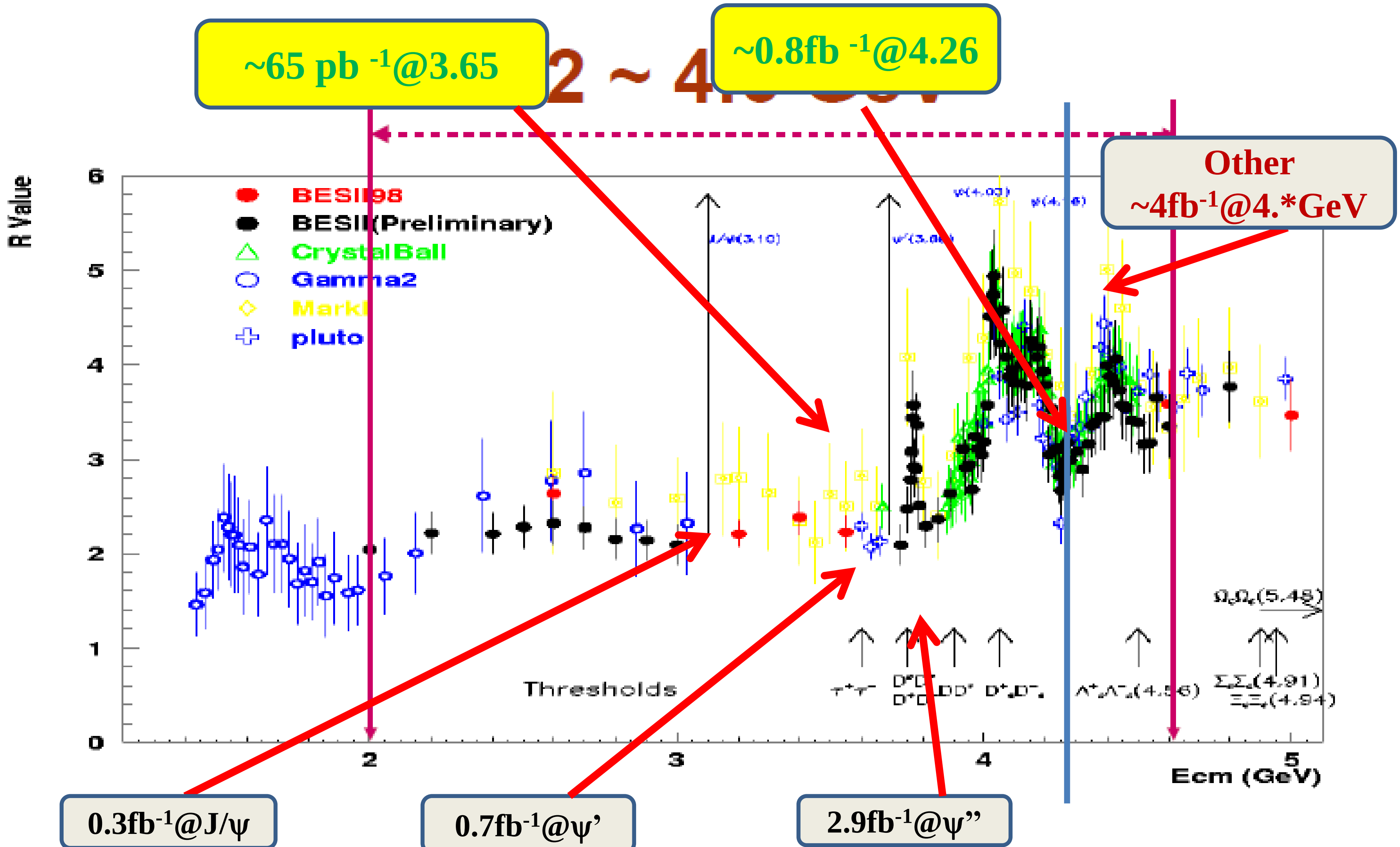
µCounter
8- 9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

- **muon PID**

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

- **Neutral showers reconstruction**

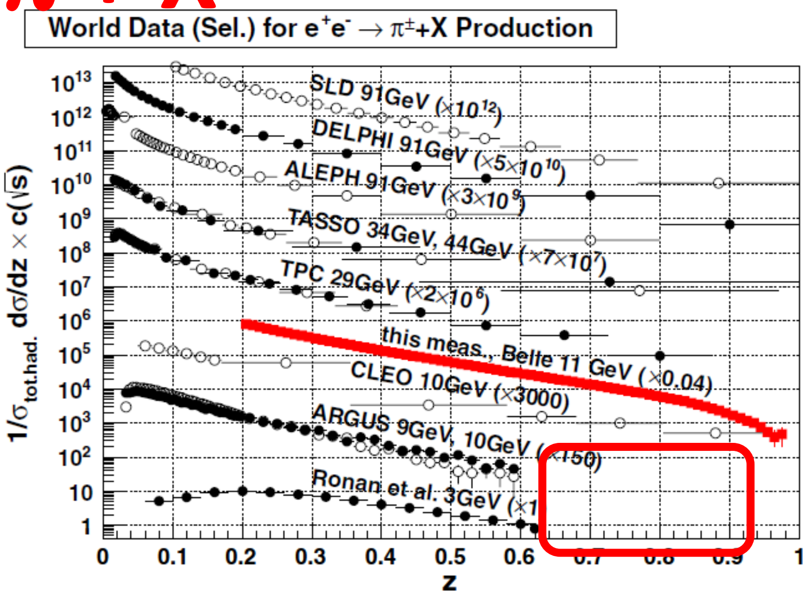
Data Samples We Have



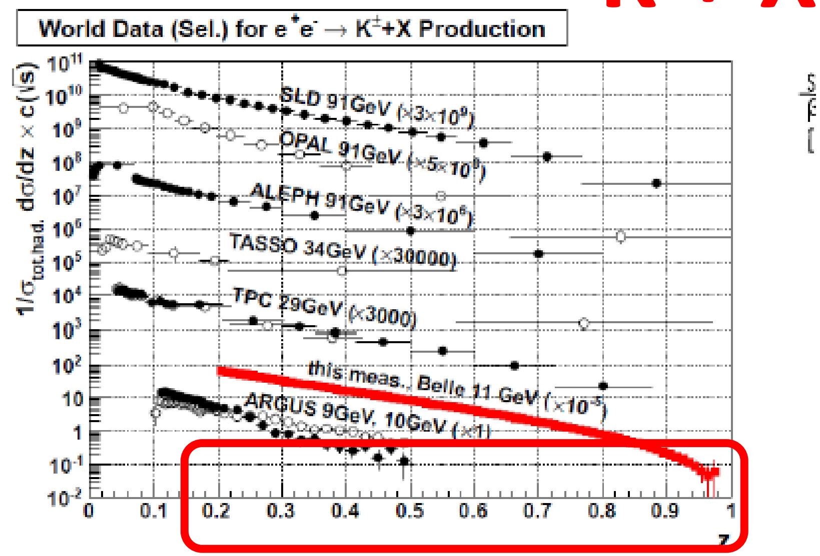
Inclusive Hadron Production

e+e- → π/K + X

π + X



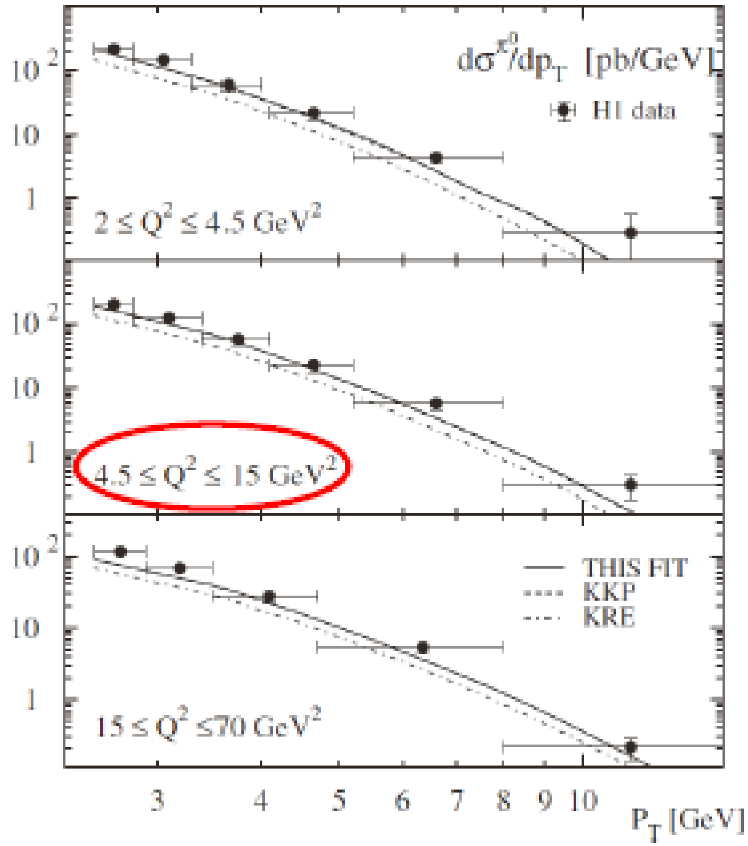
K + X



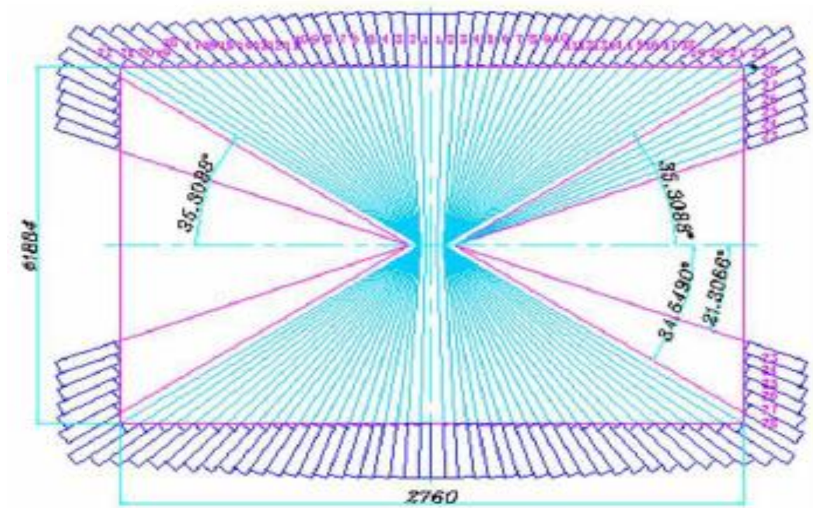
PRL 111 062002 (2013)

- **Lack of low energy scale, high z** $z=2E_{hadron}/\sqrt{s}$
  - **BESIII can contribute**
- **PID problem at high z**
  - **High error rate of PID for the charged tracks with high momentum.**

$e^+e^- \to \pi^0 + X$



PRD 75 114010 (2007)

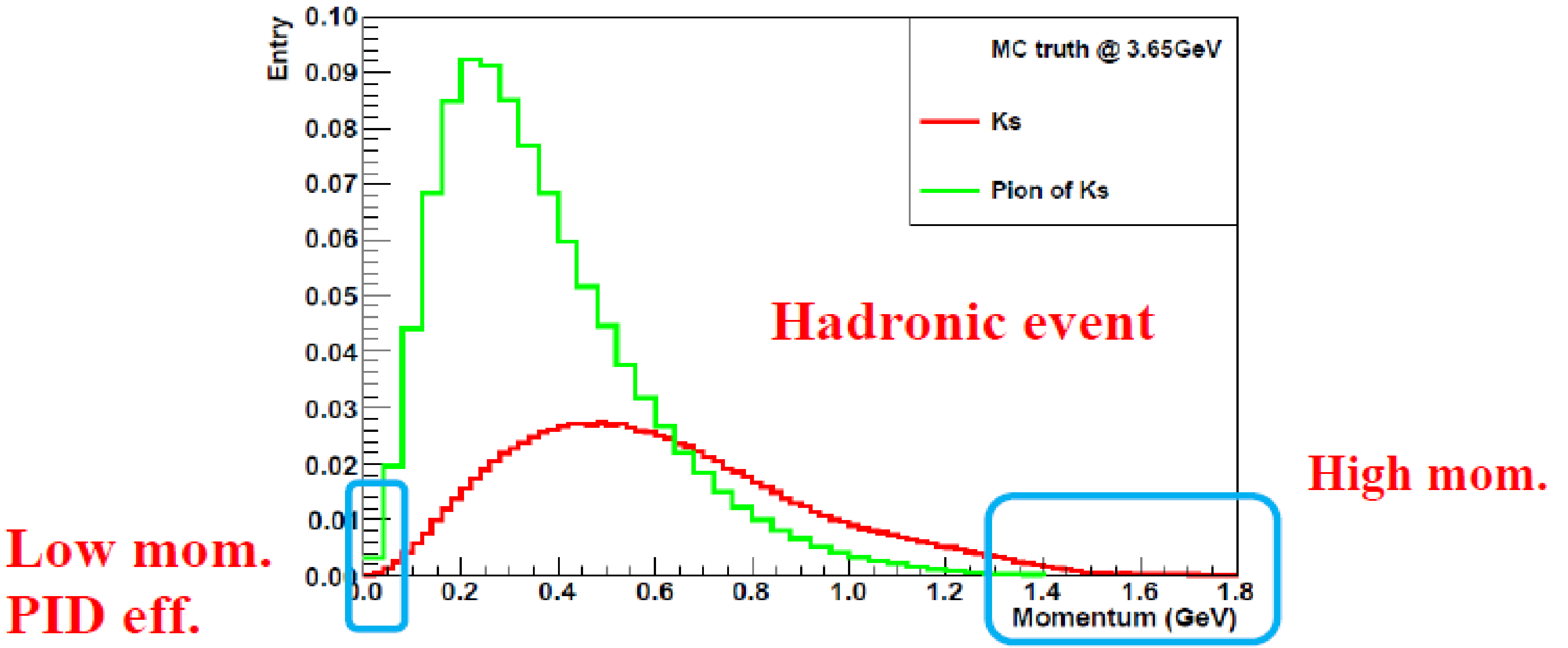


Resolution	Energy	Position
Barrel	2.5%@1GeV	6mm@1GeV
Endcap	5.0%@1GeV	9mm@1GeV

- $\pi^0 \to 2\gamma$ with EMC
- $e^+e^- \to \pi^0 + X$ @BESIII

- **PID is not needed (crucial issue for charged π/K, especially at high z)**
- **At BESIII, good performance of EMC on measuring neutral showers**

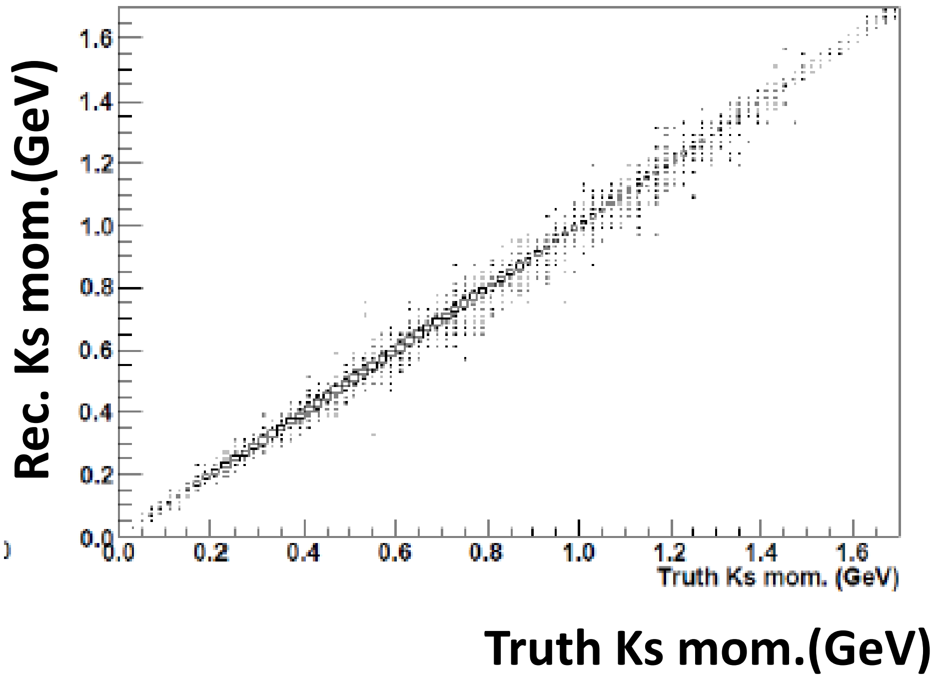
$e^+e^- \to K_s + X \to \pi^+\pi^- + X$ (in progress)



- Ks + X: clean process, low backgrounds level
- Second vertex to suppress backgrounds

$e^+e^- \to K_s + X \to \pi^+\pi^- + X$ (in progress)

	Ks candidate no. @[0.47-0.53]
$(\gamma)e^+e^-$	1667/0.56%
$(\gamma)\mu^+\mu^-$	110/0.037%
$(\gamma)\ \gamma\ \gamma$	140/0.047%
$(\gamma)\ \tau^+\tau^-$	4156/1.40%
e^+e^-+X	248/0.084%
Non-phys.	2453/0.83%



- **Binning to get the cross section depending on the momentum of Ks**
- **The resolution of Ks momentum is good enough**
- **Preliminary data results are not shown**
- **Data set @3.65GeV**

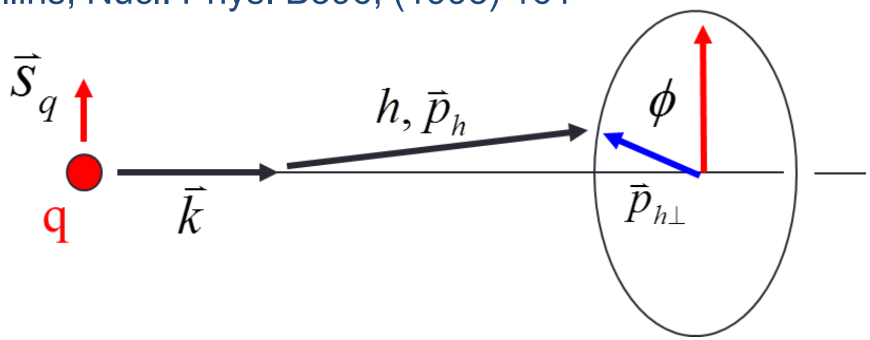
Probe Collins Effect

(in progress)

- **We only focus on the di-pion currently.**

Collins Fragmentation Function

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



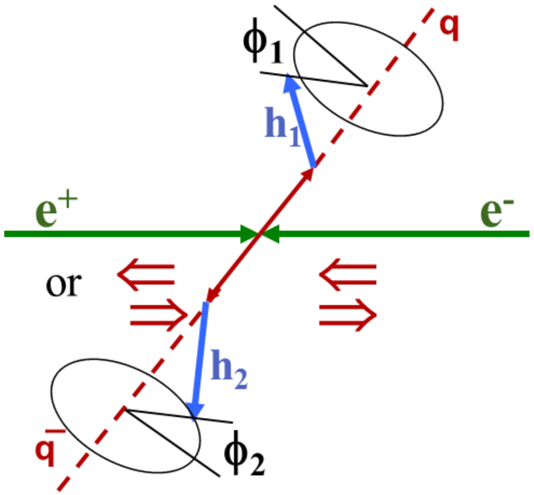
- It describes the relation between the transverse spin of the fragmenting quark and the azimuthal distribution of the final state hadrons around the quark momentum

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

- H: Collins Fragmentation Function
- z: fractional energy of hadron $z = 2E_h/\sqrt{s}$,
- $\mathbf{P}_{h\perp}$:transverse momentum of the hadron

Probe Collins Effect in e^+e^- Annihilation

- In e^+e^- annihilation, γ^* (spin-1) $\rightarrow$ spin-1/2 q and $\bar{q}$
  - In a given event, the spin directions are unknown, but they must be parallel
  - Exploit this correlation by using hadrons in opposite jets



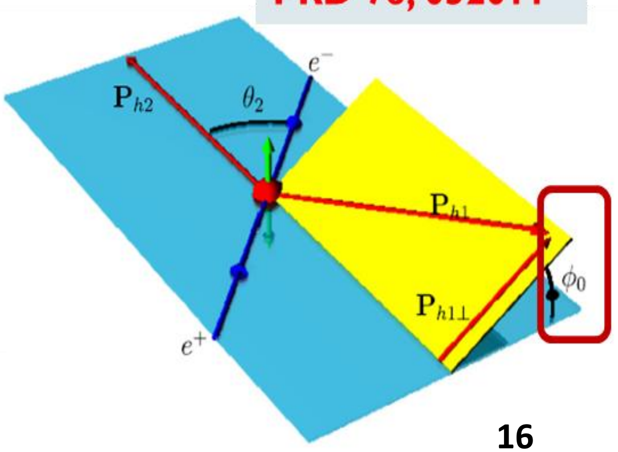
- The correlation of quark and anti-quark Collins functions give a product of $\cos(2\phi_0)$ modulation

PRD 78, 032011

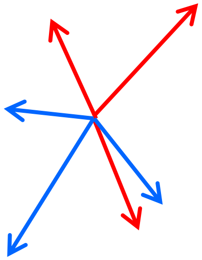
$e^+e^- \rightarrow q\bar{q} \rightarrow h_1 h_2 X$ (q=u, d, s) ==>

$\sigma \propto \cos(2\phi_0) H_1^{\perp}(z_1) \otimes H_1^{\perp}(z_2)$,

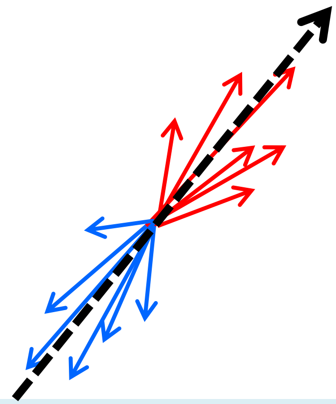
$$\frac{d\sigma(e^+e^- \rightarrow h_1 h_2 X)}{d\Omega dz_1 dz_2 d^2\mathbf{q}_T} = \frac{3\alpha^2}{Q^2} z_1^2 z_2^2 \Big\{ A(y)\mathcal{F}[D_1\bar{D}_2] + B(y) \times \cos(2\phi_0)\mathcal{F}\Big[(2\hat{\mathbf{h}}\cdot\mathbf{k}_T\hat{\mathbf{h}}\cdot\mathbf{p}_T - \mathbf{k}_T\cdot\mathbf{p}_T)\frac{H_1^{\perp}\bar{H}_2^{\perp}}{M_1M_2}\Big]\Big\},$$



Event Shape



BEPCII energy



High energy scale

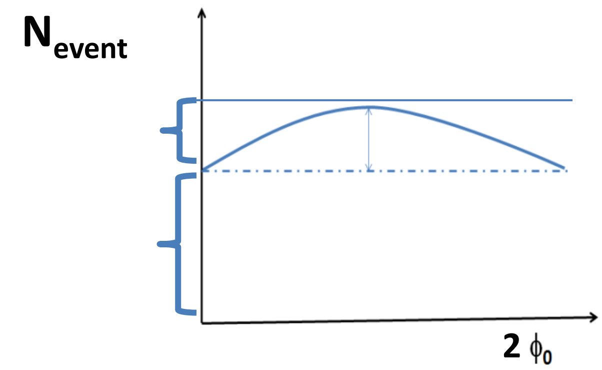
$$T \overset{\max}{=} \frac{\sum_h |\mathbf{P}_{\mathbf{h}}^{\mathrm{CMS}} \cdot \hat{\mathbf{n}}|}{\sum_h |P_h^{\mathrm{CMS}}|},$$

- ✓ **At Belle/BABAR, with two-jets events**
  - ✓ **High Thrust value is useful to suppress backgrounds.**
  - ✓ **Thrust axis is used to separate the hadrons from opposite jets (h1 and h2)**
- ✓ **At BESIII, different situation**
  - ➢ **Low energy, low multiplicity, $q\bar{q}$ event shape is not jetty!**
  - ➢ **Mis-combination problem: $h_1 h'_1$ or $h_2 h'_2$ combination from same quark which are not of interest. Dilute the measured asymmetries.**
  - ➢ **Require large Open Angle(OA) of π-pair to suppress mis-combination; Choosing the leading hadrons**
  - ➢ **Mis.com. could be suppressed, but still be a problem**

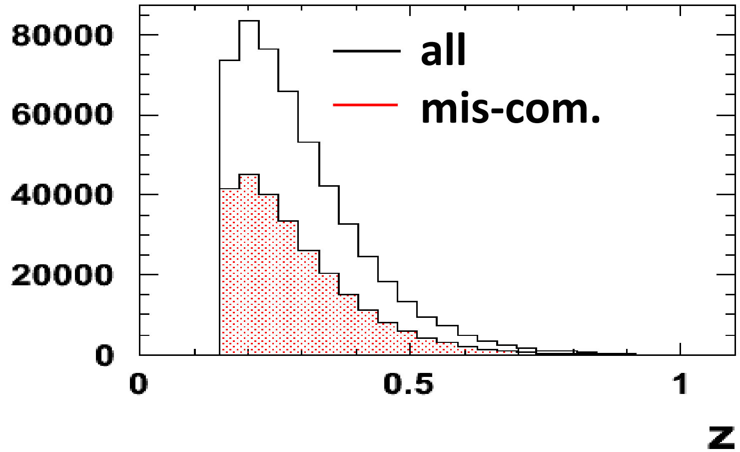
Estimation of Mis-combination Rate

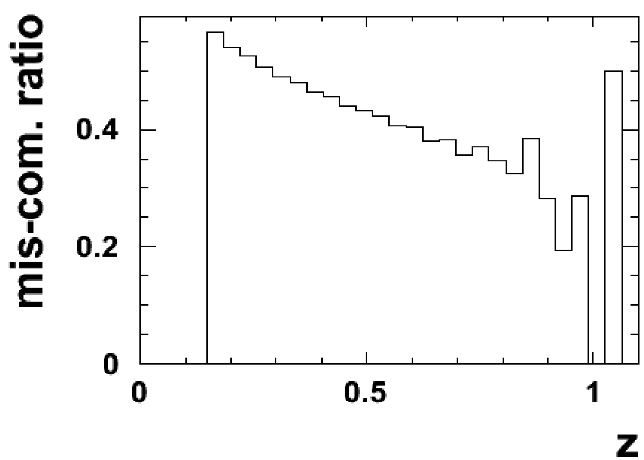
- The rate of the mis-combination($R_{mis.}$) need to be known

$$A_{ture} = (1 + R_{mis.})A_{mea.}$$



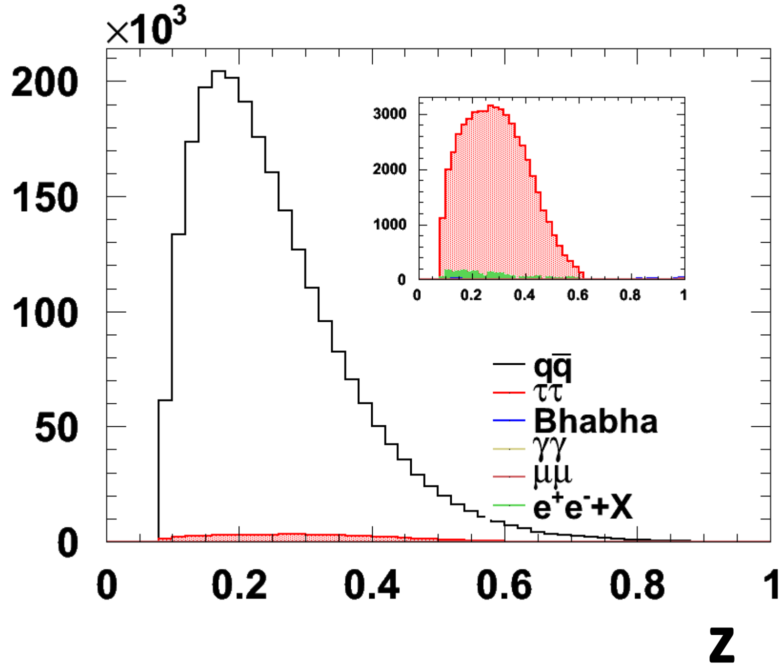
- **This estimation relies on MC**
  - We trace the final hadrons back to the initial parton in Pythia to find π-pair that come from the same quark .
  - Need more check and will be used to correct asymmetries measured in data



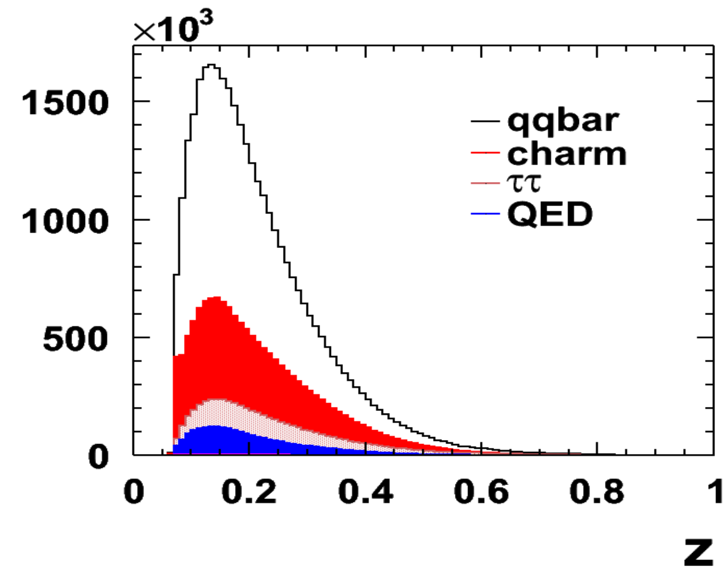


Backgrounds

@3.65GeV



@4.26GeV



✓ Need to check asymmetries contributed by background.

$$A_{\alpha}^{\mathrm{meas}} = \left(1 - \sum_i F_i\right) \cdot A_{\alpha} + \sum_i F_i \cdot A_{\alpha}^{i}$$

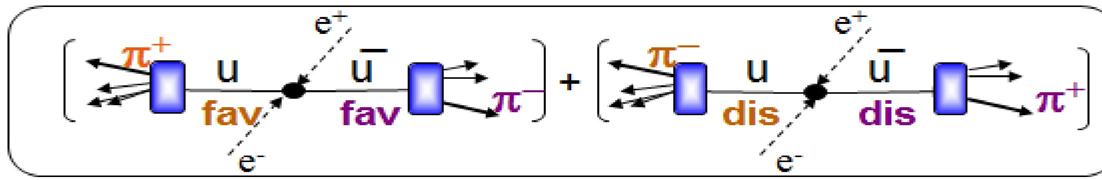
Fraction of background — The true asymmetries — Asymmetries from background

Double Ratio

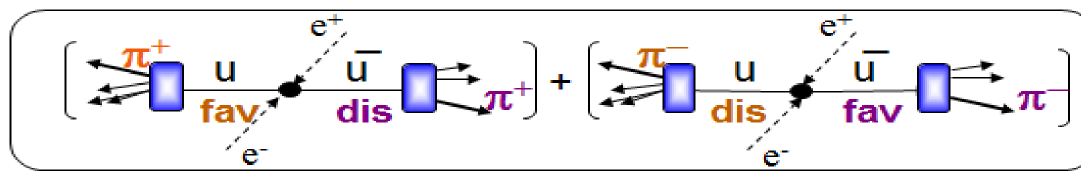
Slide from Isabella

- **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→π+, d→π-
- **Disfavored** for d→π^+, u→π^-

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



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



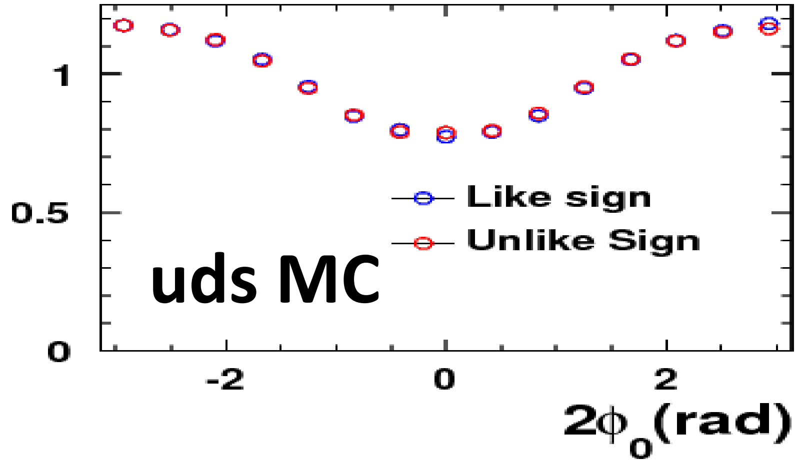
– **Normalized Ratio R** $R_0(2\phi_0) = \frac{N(2\phi_0)}{\langle N_0 \rangle}.$

– **Double Ratio(DR) (R^U/R^L)to cancel detector effects and QCD radiative effects which are charged independent**

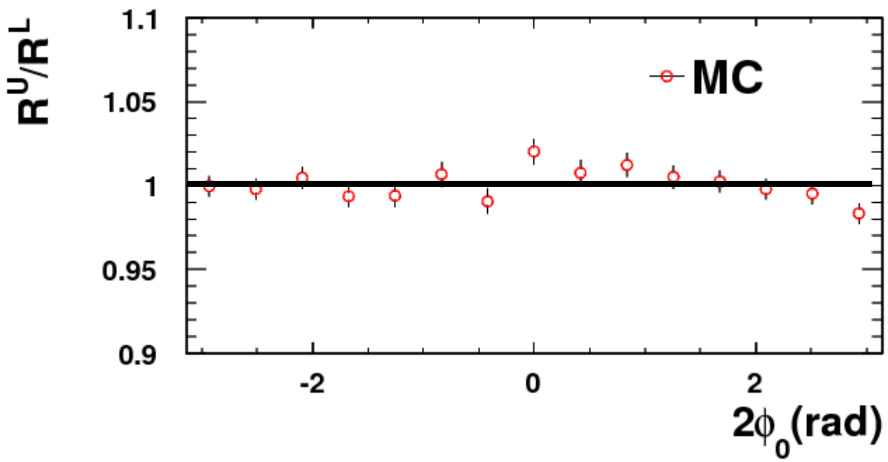
$$R_0^U/R_0^L = 1 + \cos(2\phi_0)\frac{\sin^2\theta}{1+\cos^2\theta} \times \left\{ \frac{f(H_1^{\perp,\mathrm{fav}}\bar{H}_1^{\perp,\mathrm{fav}} + H_1^{\perp,\mathrm{dis}}\bar{H}_1^{\perp,\mathrm{dis}})}{(D_1^{\mathrm{fav}}\bar{D}_1^{\mathrm{fav}} + D_1^{\mathrm{dis}}\bar{D}_1^{\mathrm{dis}})} - \frac{f(H_1^{\perp,\mathrm{fav}}\bar{H}_1^{\perp,\mathrm{dis}})}{(D_1^{\mathrm{fav}}\bar{D}_1^{\mathrm{dis}})} \right\};$$

$2\phi_0$ Distributions (MC)

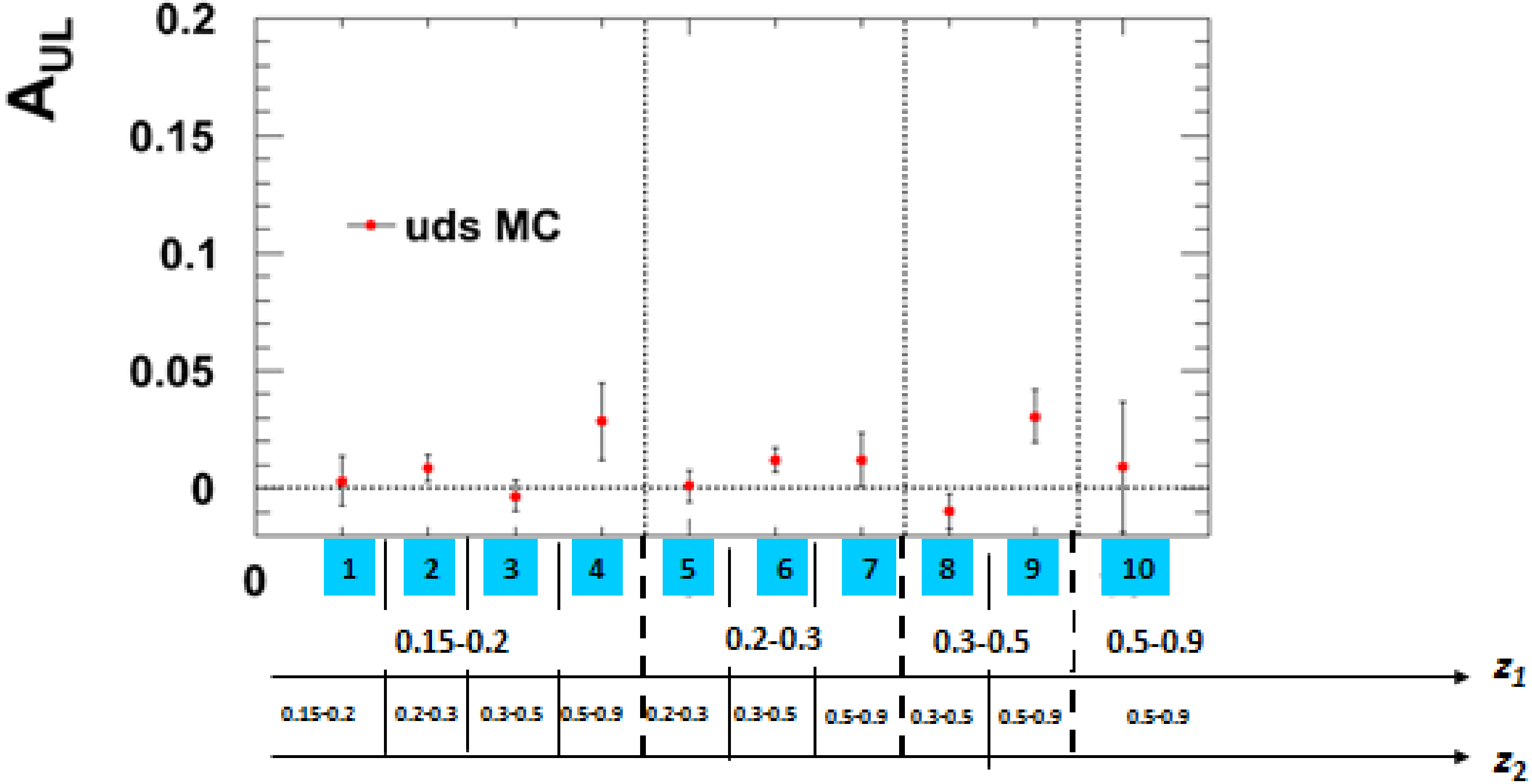
- **Normalized Raw distribution:**



- **Double Ratio:**



MC Validation



- Statistic uncertainties only. Consistent with zero as expected.
- In the last z bin, assume 15% asy. ,sensitivity > 3 sigma

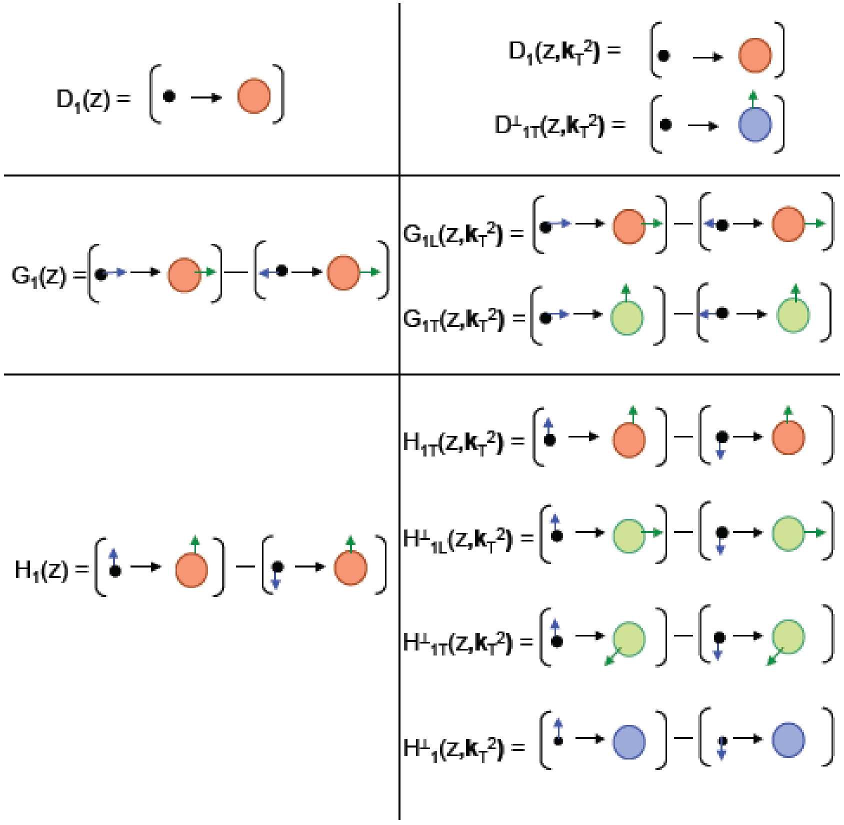
Summary and Outlook

- **BESIII data can provide:**
  - Data at low energy scale
  - Test energy evolution effect of FF
  - Combined effort to measurement Transversity distribution
- **What we are working on:**
  - Ks + X cross section
  - Double Collins asymmetries in inclusive charged π production
- **Outlook**
  - Spin 2014 Conference
  - ~ $0.36 fb^{-1}$ off-resonance data, 2015/2016

THANKS!

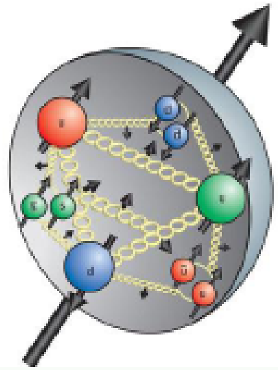
BACKUP

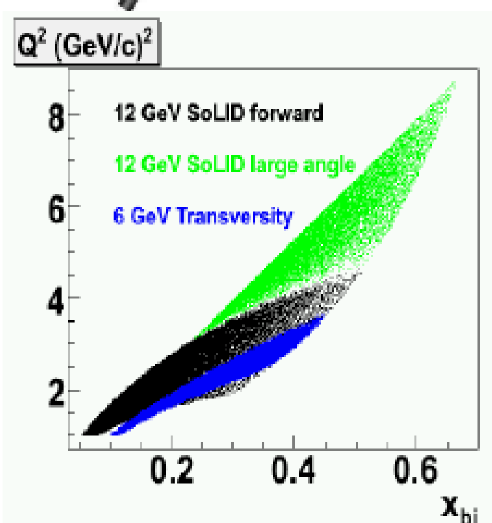
TMD-PFFs

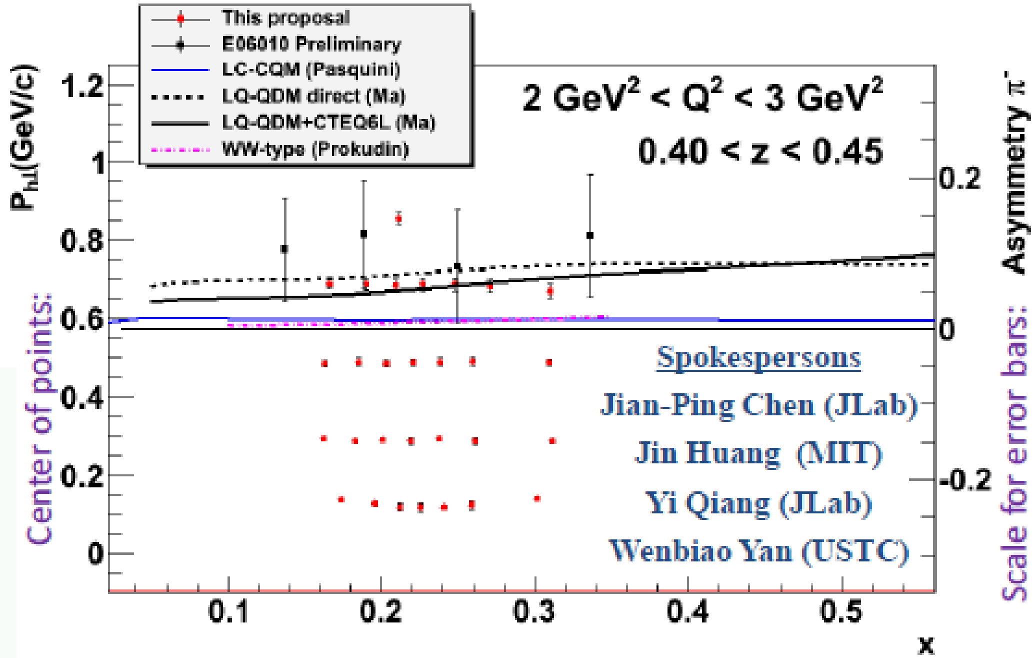


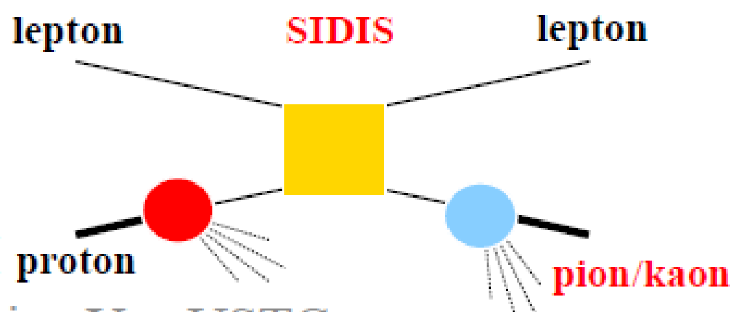
D1(z) =
D1(z,kT2) =
D⊥1T(z,kT2) =
G1(z) =
G1L(z,kT2) =
G1T(z,kT2) =
H1(z) =
H1T(z,kT2) =
H⊥1L(z,kT2) =
H⊥1T(z,kT2) =
H⊥1(z,kT2) =

Spin structure of neculon





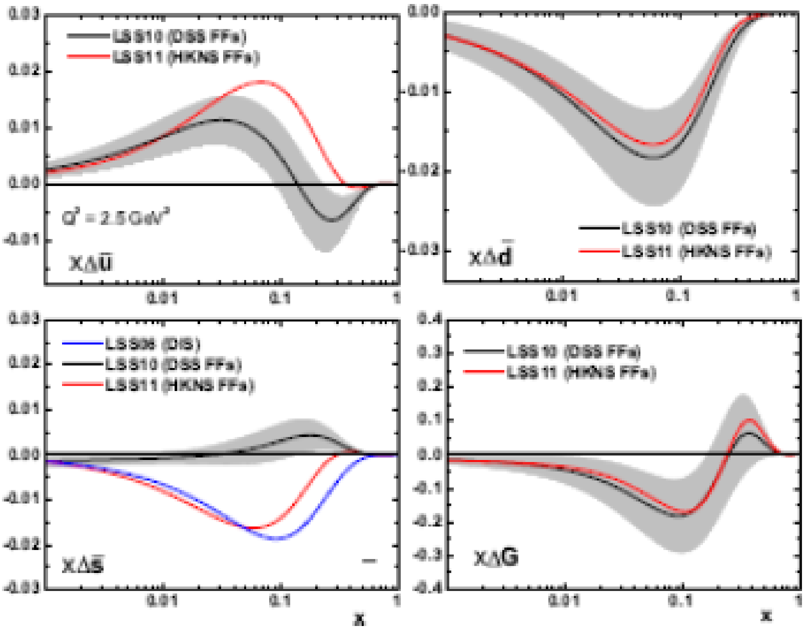




Born level $Q \backsim \sqrt{s}$ **@ BESIII**

Strange quark polarization puzzle

- sum of polarization strange parton PDFs: Δs(x)+Δs(x)
  - ➢polarized inclusive DIS: negative for all values of x
  - ➢Semi-inclusive DIS: positive for most of measured x
  - } puzzle
  - ➢PRD 84 014002 (2011) : HKNS FF, negative for SIDIS



PRD 84 014002 (2011)

- Inclusive DIS: e+N→e'+X
  - ➢parton density function PDF
- Semi-inclusive DIS: e+N→e'+h+X
  - ➢PDF and FF

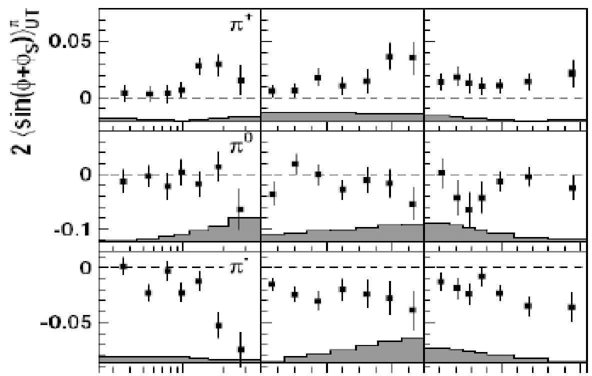
Inclusive kaon production

Motivation

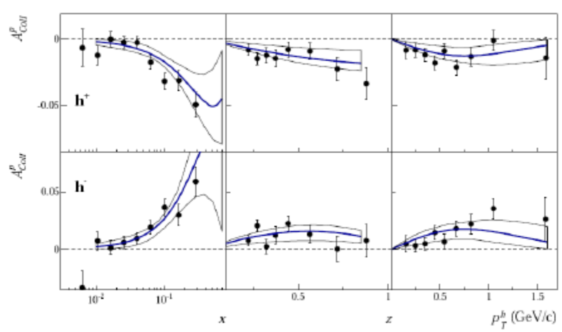
SIDIS

Transversity ⊗ Collins FF

PRL 94: 012002, PLB693,11-16



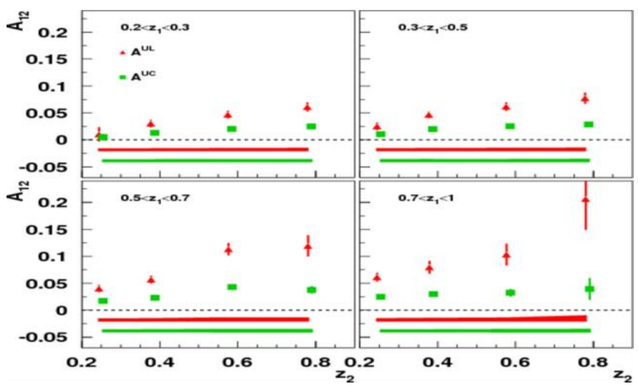
COMPASS, PLB 2012

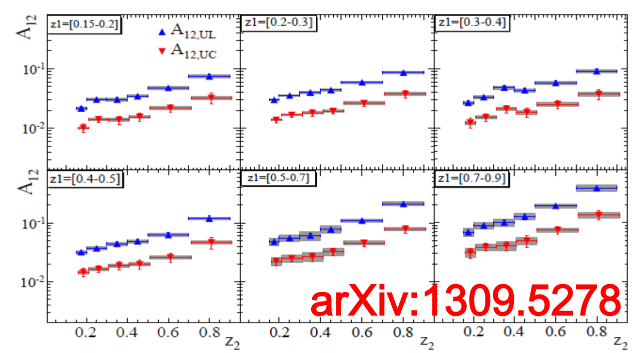


e+ e-

Collins FF ⊗ Collins FF

PRL96: 232002, PRD 78:032011



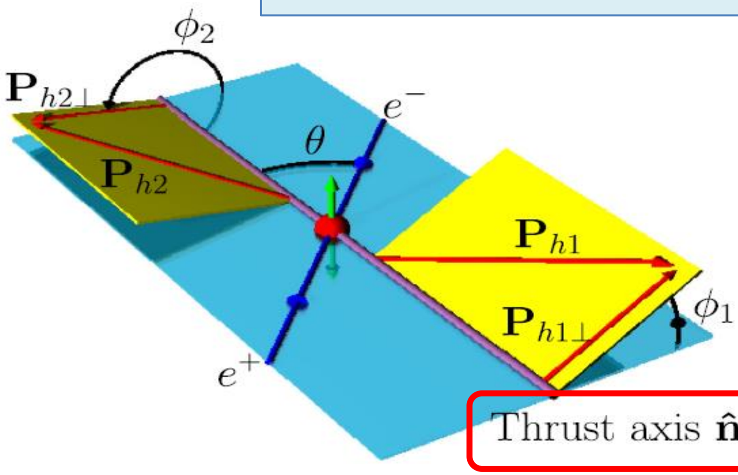


- **FF from e+e- as input for extracting the parton distribution**

PRD 78, 032011

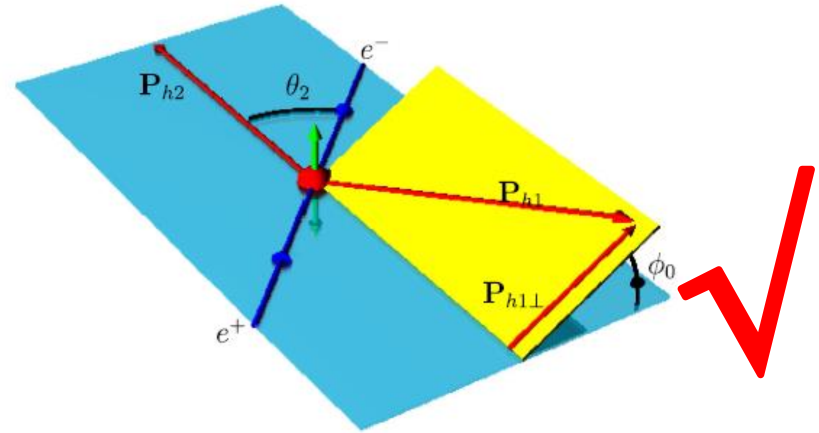
Double Collins Asymmetries(DCA)

The Thrust frame



Thrust axis $\hat{\mathbf{n}}$

The second hadron frame



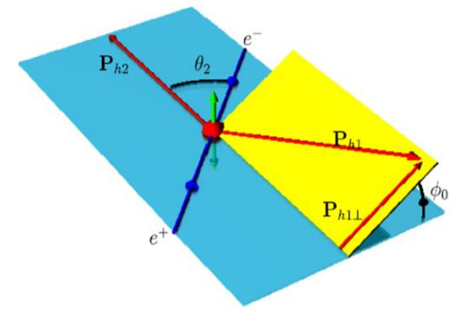
$$\frac{d\sigma(e^+e^-\to h_1h_2X)}{d\Omega dz_1dz_2d\phi_1d\phi_2} = \sum_{q,\bar q}\frac{3\alpha^2}{Q^2}\frac{e_q^2}{4}z_1^2z_2^2\{(1+\cos^2\theta)D_1^{q,[0]}(z_1)\bar D_1^{q,[0]}(z_2)+\sin^2\theta\cos(\phi_1+\phi_2)H_1^{\perp,[1],q}(z_1)\bar H_1^{\perp,[1],q}(z_2)\},$$

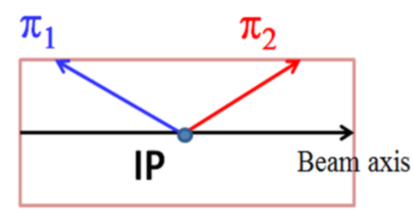
$$\frac{d\sigma(e^+e^-\to h_1h_2X)}{d\Omega dz_1dz_2d^2\mathbf{q}_T} = \frac{3\alpha^2}{Q^2}z_1^2z_2^2\Big\{A(y)\mathcal{F}[D_1\bar D_2]+B(y)\times\cos(2\phi_0)\mathcal{F}\Big[(2\hat{\mathbf{h}}\cdot\mathbf{k}_T\hat{\mathbf{h}}\cdot\mathbf{p}_T-\mathbf{k}_T\cdot\mathbf{p}_T)\frac{H_1^\perp\bar H_2^\perp}{M_1M_2}\Big]\Big\},$$

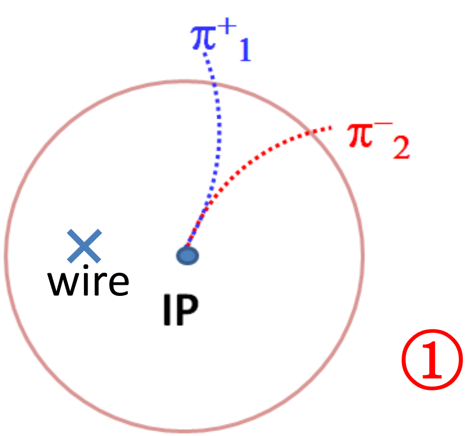
- **The correlation of quark and anti-quark Collins Functions**
- **By looking the two hadrons in opposite jets**
- **Only the second method could be performed at BESIII**

Detector Effects(1)

- From MC, we confirmed two kinds of detector effects which can not be cancelled out in Double Ratio:
  - **Case 1.** when the azimuthal angle in the detector (φ) of two π are very close, opposite-charged $\pi^+\pi^-$ have higher efficiencies than same-charged $\pi^-\pi^-$ (or $\pi^+\pi^+$)







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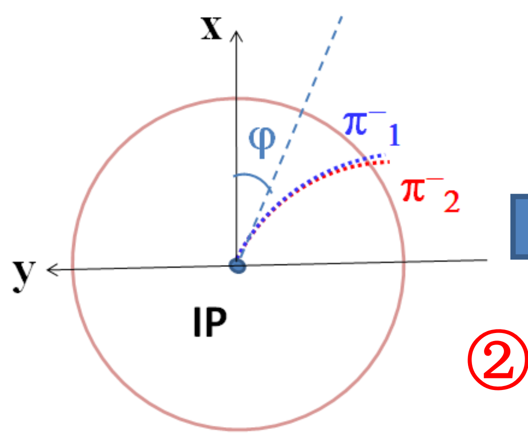
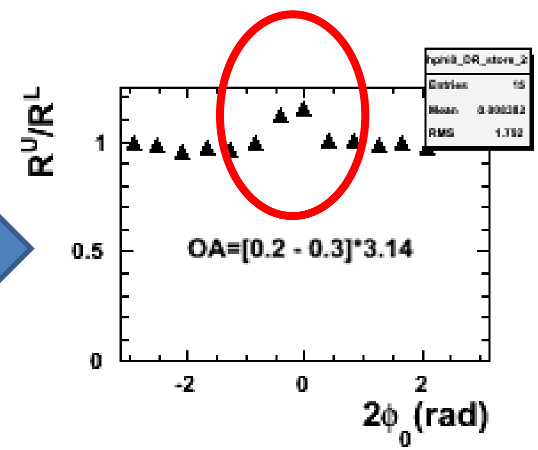


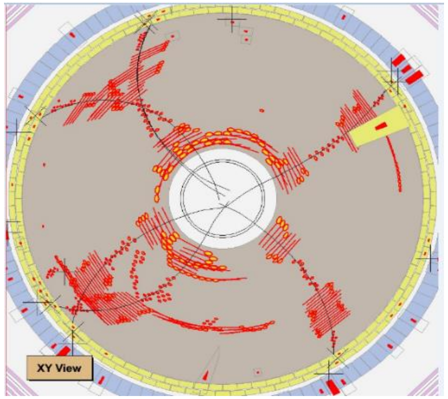


Note that , ϕ_0 is calculated in C.M.S frame. φ is defined in lab. frame.

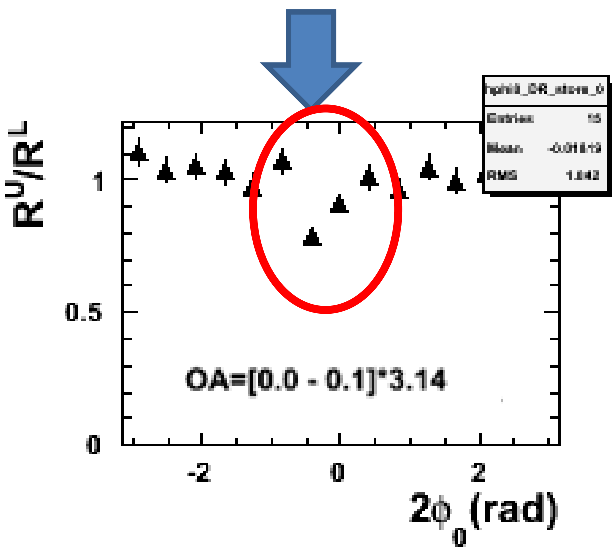
Detector Effects(2)

- **Case 2.** Ghost tracks produce extra same-charged π pairs ($\pi^-\pi^-$ or $\pi^+\pi^+$)

- These two detectors effects:
  - contaminate the $2\phi_0$ distribution, especially in **small open angle**
  - require **large open angle** of the two π
  - these effects can be suppressed, **but still there,** assumed as systematic errors



Ghost tracks



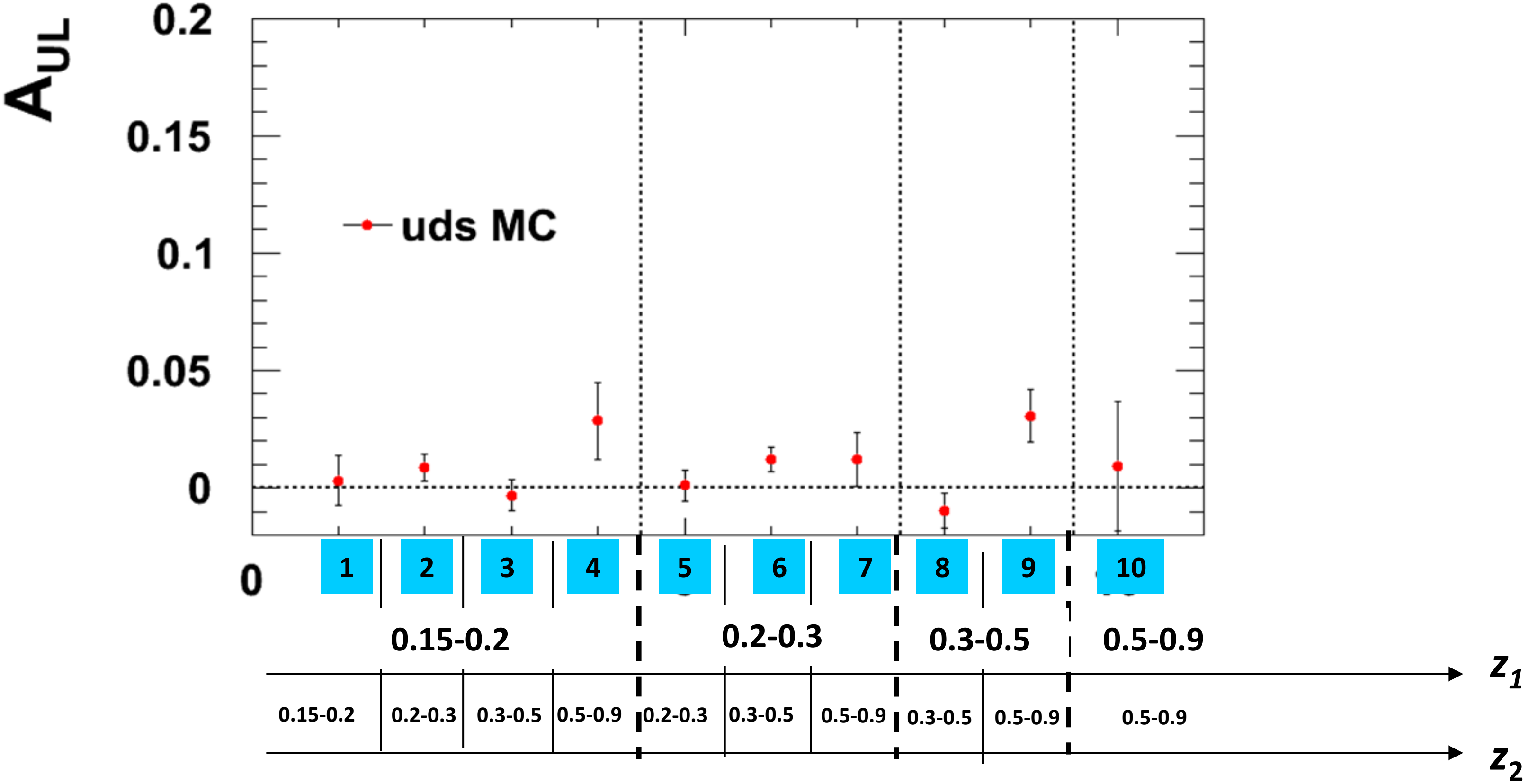
Event Selection

- Charged tracks :
  - $|V_r|<1.0cm$, $|V_z|<10.0cm$
  - $|\cos\theta|<0.93$
  - nGood>=3

- Further requirements:
  - $N_{electron}$ ==0 to suppress Bhabha
  - The total visible energy $E_{vis}>1.5GeV$ to suppress $\tau\tau$

- PID of π
  - de/dx, TOF1, TOF2
  - Prob(π)>0&&Prob(π)>Prob(K)
- $N\pi >= 2$
- open angle of the π-pair: OA>120^o

MC Validation



- **Statistic uncertainties only. Consistent with zero as expected.**
- **Assume 15% asy. in the last z bin, sensitivity > 3 sigma.**