Measurements of chiral-odd fragmentation functions at Belle

~~DIS2005~~

~~April. 27 – May 1st, Madison, WI~~

SIR2005

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For BELLE Collaboration

Outline

- Motivation
  - Global transversity analysis
  - Feasibility → LEP analysis [hep-ph/9901216]
- The BELLE detector
- Collins analysis
  - Angular definitions and cross sections
  - Double Ratios to eliminate radiative/momentum correlation effects
  - An experimentalist's interpretation
- Summary

Motivations for the measurement

Except for DY/di-jet which measure transversity*Transversity

RHIC measures the same combinations of quark Distribution (DF) and Fragmentation Functions (FF) (plus unpolarized DF)

SIDIS experiments (HERMES, COMPASS, JLab) measure $\delta q(x)$ together with either Collins FF and Interference FF

Due to Chiral-odd nature, these always measure Transversity * FF

Universality appears to be proven in LO by Collins and Metz: [**PRL93:(2004)252001**]

Global Analysis to extract Transversity

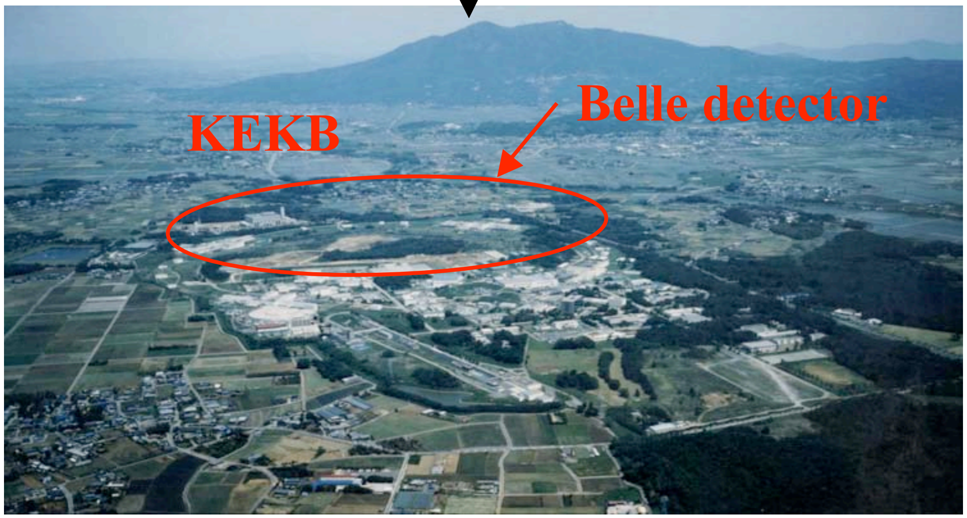
Belle experiment (e+e-) measure Collins FF^2 and Interference FF^2

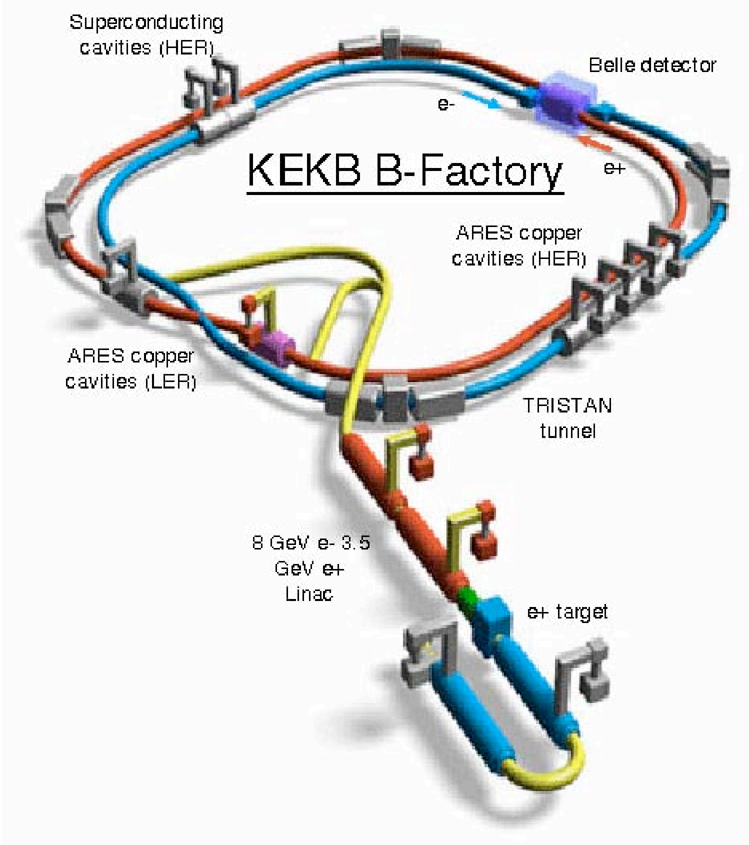
Spin & BLT Sum rule
Lattice QCD
Siver's function

KEKB: L>1.5x10^{34}cm^{-2}s^{-1} !!

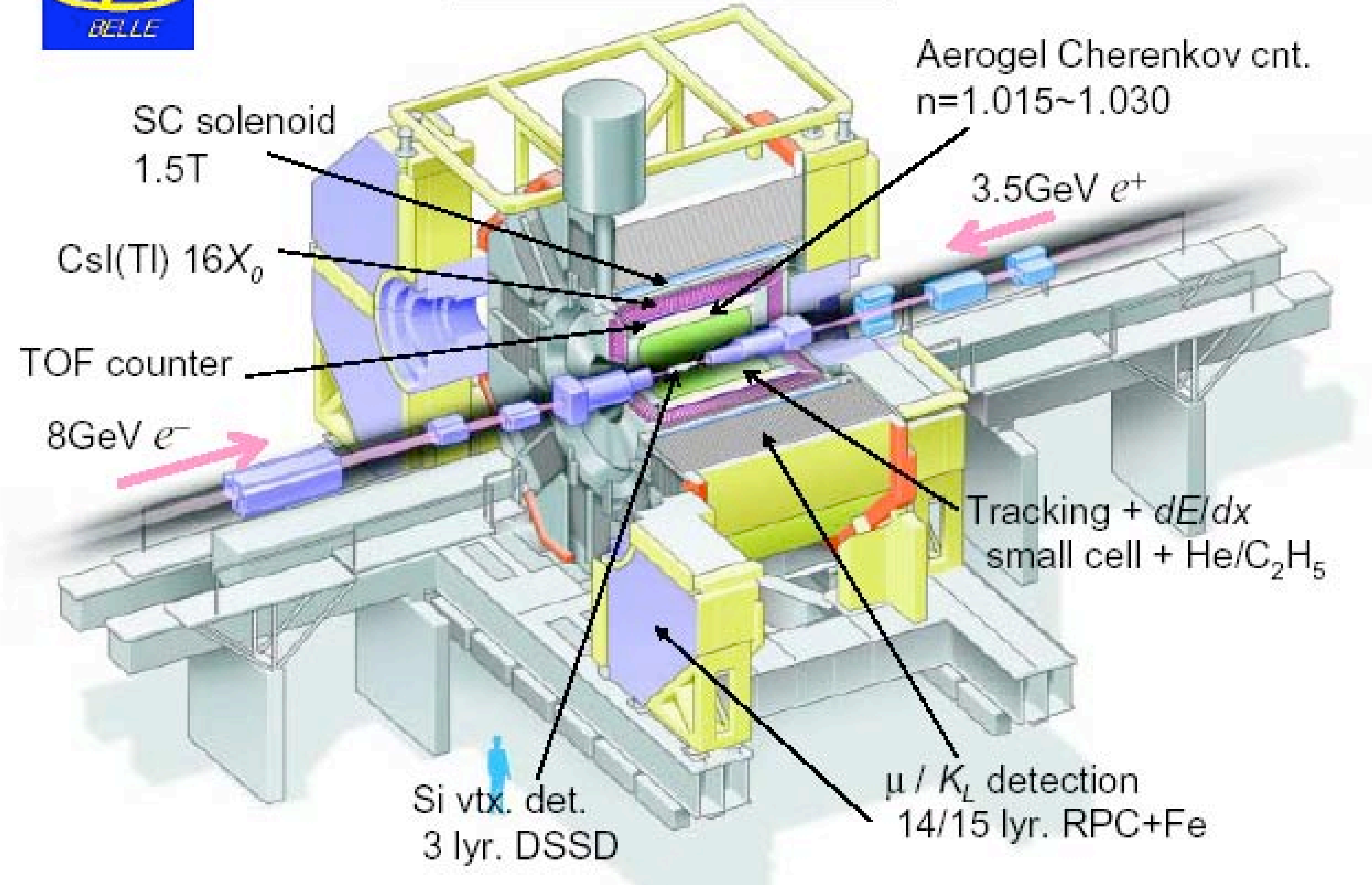
- KEKB
  - Asymmetric collider = 8GeV e^- + 3.5GeV e^+
  - *"On resonance"* : $\sqrt{s}$ = 10.58GeV $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ (plus light quarks)
  - *"Off-resonance"* : $\sqrt{s}$ = 10.52 GeV $e^+e^- \rightarrow q\bar{q}$ (u,c, and some d,s,b)
  - Integrated Luminosity: >400 fb^{-1}
    >30fb^{-1} => off-resonance

Mount Tsukuba





Belle Detector



Good tracking and particle identification!

Belle is well suited for FF measurements:

- Good detector performance (acceptance, momentum resolution, pid)
- Jet production from light quarks
  → off-resonance (60 MeV below resonance) ~10% of all data
  → on-resonance (on $\Upsilon(4S)$) ~ 90% of data, removing bs are relatively easy
- Intermediate Energy
  → Sufficiently high scale ($Q^2 \sim 110\ GeV^2$)
    - can apply pQCD
  → Not too high energy ($Q^2 << M_Z^2$)
    -avoids additional complication from Z interference
- Sensitivity = $A^2 sqrt(N)$ ~ x19 *(x60)* compared to LEP
  A_{Belle} / A_{LEP} ~ x2 (A scales as ~ $\ln Q^2$)
  L_{Belle} / L_{LEP} ~ x23 *(x230)*

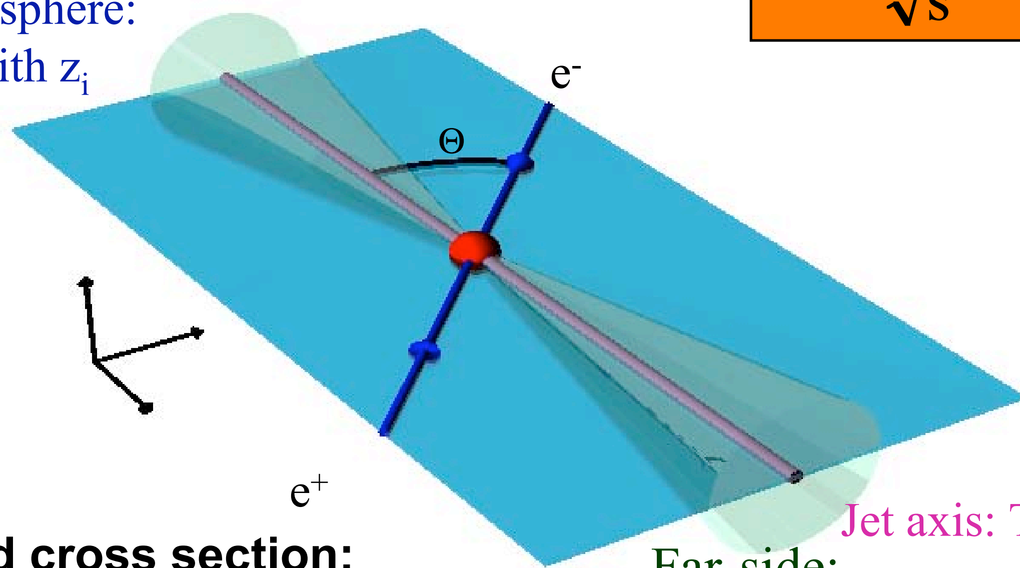
→ Current preliminary results are from off resonance data

Event Structure at Belle

e^+e^- CMS frame:

$$z = \frac{2E_h}{\sqrt{s}}, \quad \sqrt{s} = 10.52\ \boldsymbol{GeV}$$

Near-side Hemisphere: h_i, $i=1,N_n$ with z_i



$\langle N_{h+,-} \rangle = 6.4$

Far-side: h_j, $j=1,N_f$ with z_j

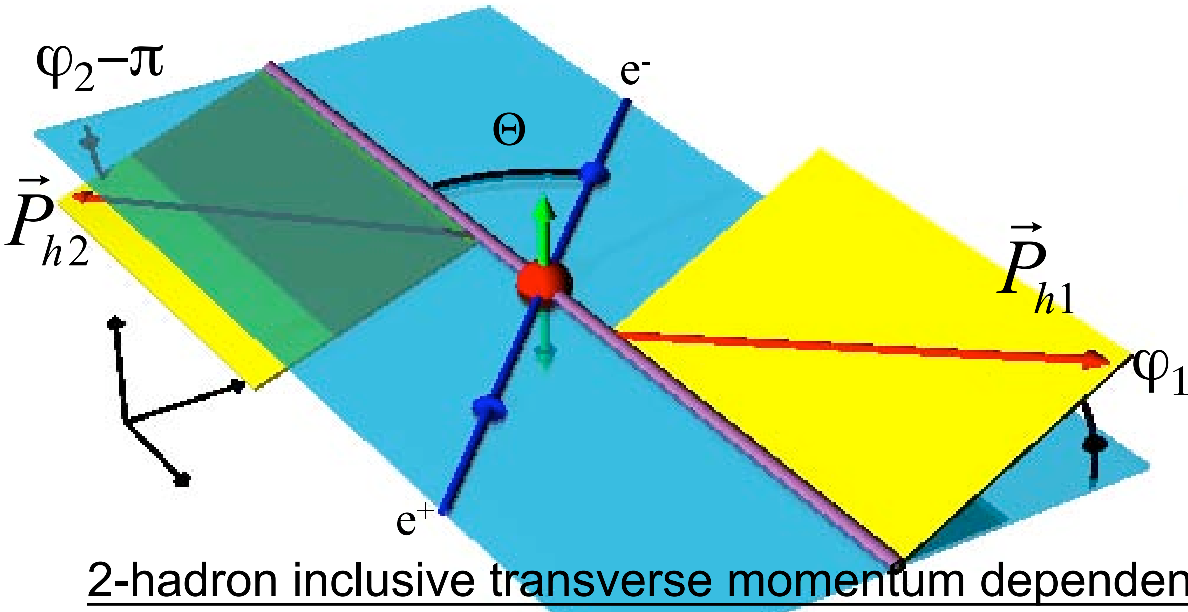
Spin averaged cross section:

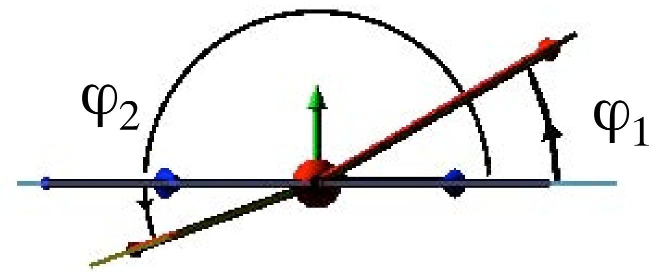
$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2} = \frac{3\alpha^2}{Q^2} A(y) \sum_{a,\bar{a}} e_a^2 D_1(z_1) \overline{D}_1(z_2)$$

$$A(y) = \left(\frac{1}{2} - y + y^2\right) \stackrel{(cm)}{=} \frac{1}{4}\left(1 + cos^2\Theta\right)$$

Collins fragmentation: Angles and Cross section cos(ϕ_1+ϕ_2) method

e^+e^- CMS frame:





2-hadron inclusive transverse momentum dependent cross section:

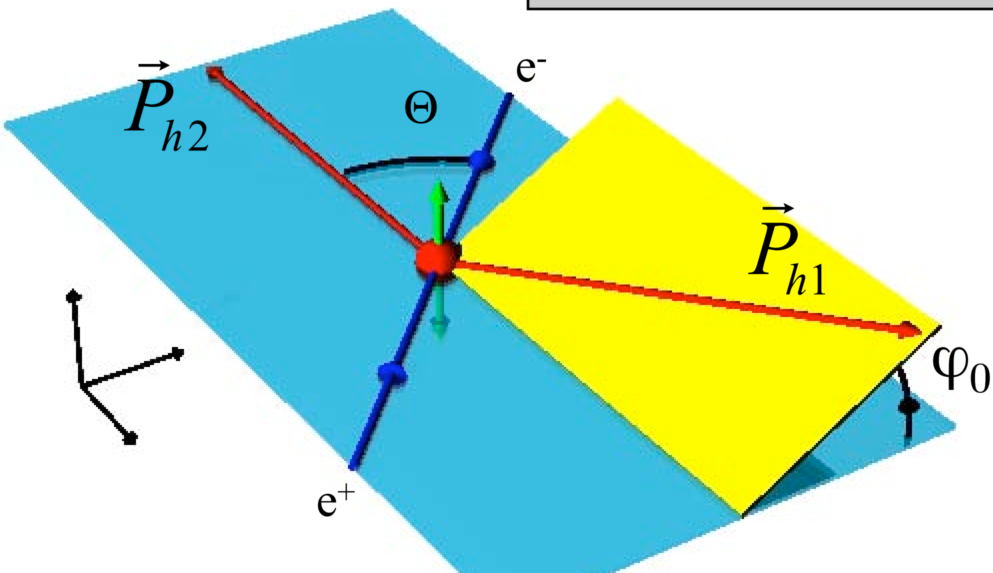
$$\frac{d\sigma(e^+e^- \to h_1h_2X)}{d\Omega\, dz_1\, dz_2\, d^2\boldsymbol{q}_T} = \cdots B(y)\cos(\varphi_1+\varphi_2) H_1^{\perp[1]}(z_1)\bar{H}_1^{\perp[1]}(z_2)$$

$$B(y) = y(1-y) \overset{cm}{=} \frac{1}{4}\sin^2\Theta$$

Net anti-alignment of transverse quark spins

Collins fragmentation: Angles and Cross section $\cos(2\phi_0)$ method

<u>e^+e^- CMS frame:</u>



- •Independent of thrust-axis
- •Convolution integral I over transverse momenta involved

<u>2-hadron inclusive transverse momentum dependent cross section:</u>

$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2 d^2\boldsymbol{q}_T} = \cdots B(y) \cos(2\varphi_0) I\left[\left(2\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T - \boldsymbol{k}_T\cdot\boldsymbol{p}_T\right)\frac{H_1^\perp \overline{H}_1^\perp}{M_1 M_2}\right]$$

$$B(y) = y(1-y) \overset{cm}{=} \frac{1}{4} \sin^2\Theta$$

Net anti-alignment of transverse quark spins

Applied cuts, binning

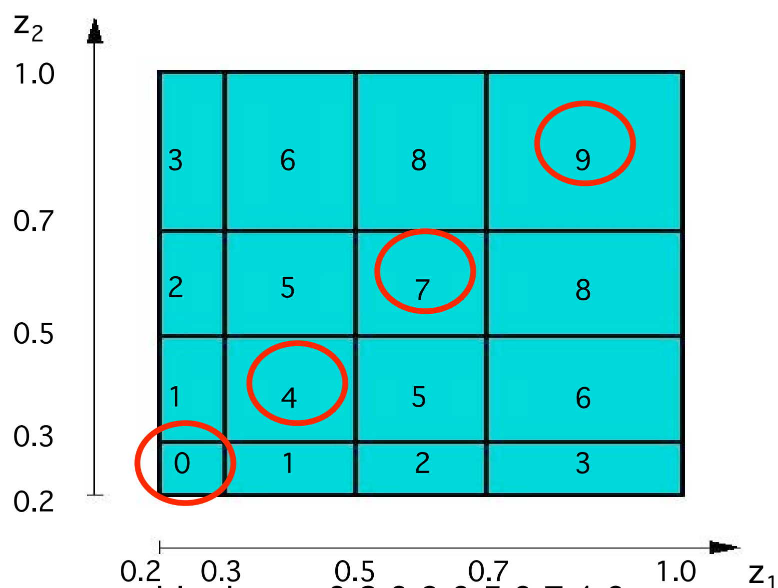
- Off-resonance data (in the future also resonance)
- Track selection:
  - pT > 0.1GeV
  - vertex cut: dr<2cm, |dz|<4cm
- Acceptance cut
  - $-0.6 < \cos\theta_i < 0.9$
- Event selection:
  - Ntrack ≥ 3
  - Thrust > 0.8
  - $Z_1, Z_2 > 0.2$
  - E(visible)>7GeV

- Hemisphere cut

$$(P_{h2}\cdot\hat{n})\hat{n}\cdot(P_{h1}\cdot\hat{n})\hat{n} < 0$$

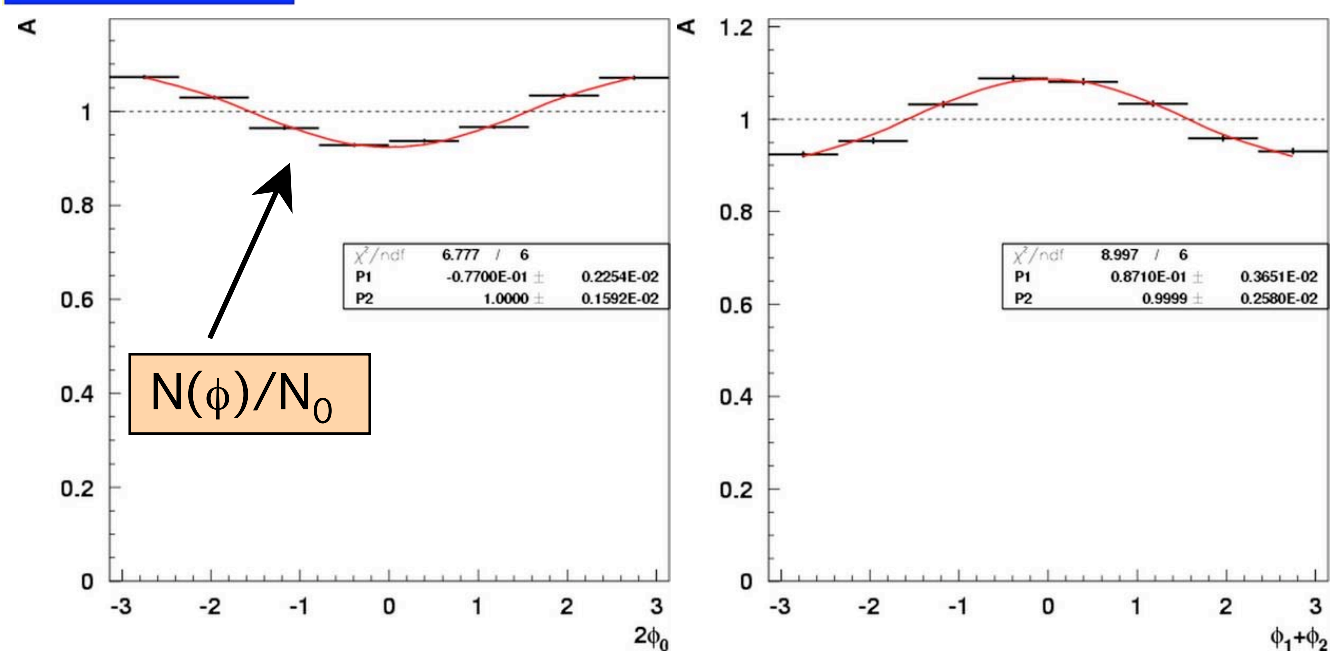
- Opening angule cuts:
  - $\cos(2\phi_0)$ method: $\psi > 120°$
  - $\cos(\phi_1+\phi_2)$ method: $\psi_1 < 60°, \psi_2 > 120°$

= Diagonal bins



z-binning: 0.2 0.3 0.5 0.7 1.0

Examples of fitting the azimuthal asymmetries



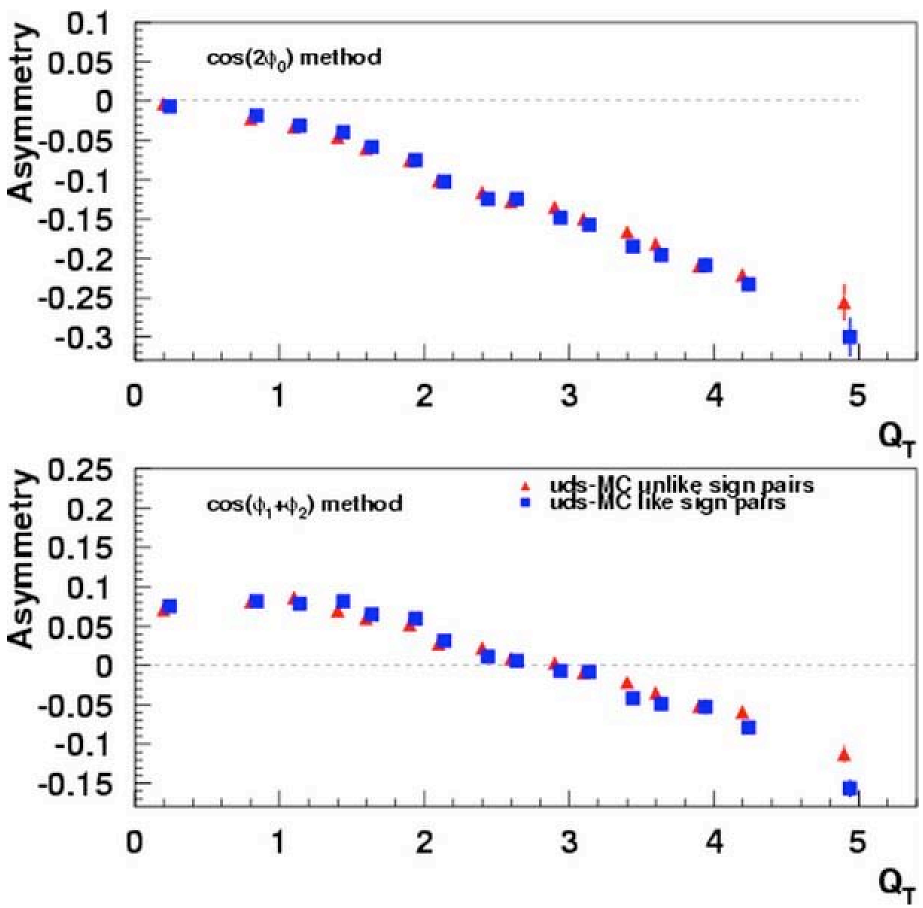
- Cosine modulations clearly visible
- No change in cosine moments when including higher harmonics (even though double ratios will contain them)

$$\frac{N(\phi)}{N_0} = \frac{aD_1\overline{D_1} + cos(2\phi)\left(bH_1\overline{H_1} + cD_1\overline{D_1}\right)}{aD_1\overline{D_1}} = P2 + P1\cos(2\phi)$$

D_1 : spin averaged fragmentation function,

H_1: Collins fragmentation function

Raw asymmetries vs Q_T



•uds MC (ππ) Unlike sign pairs

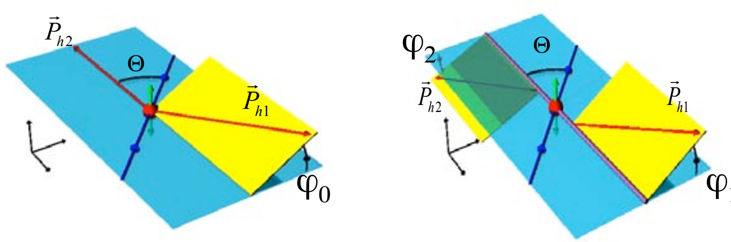
·uds MC (ππ) Like sign pairs

· Q_T describes transverse momentum of virtual photon in ππ CMS system

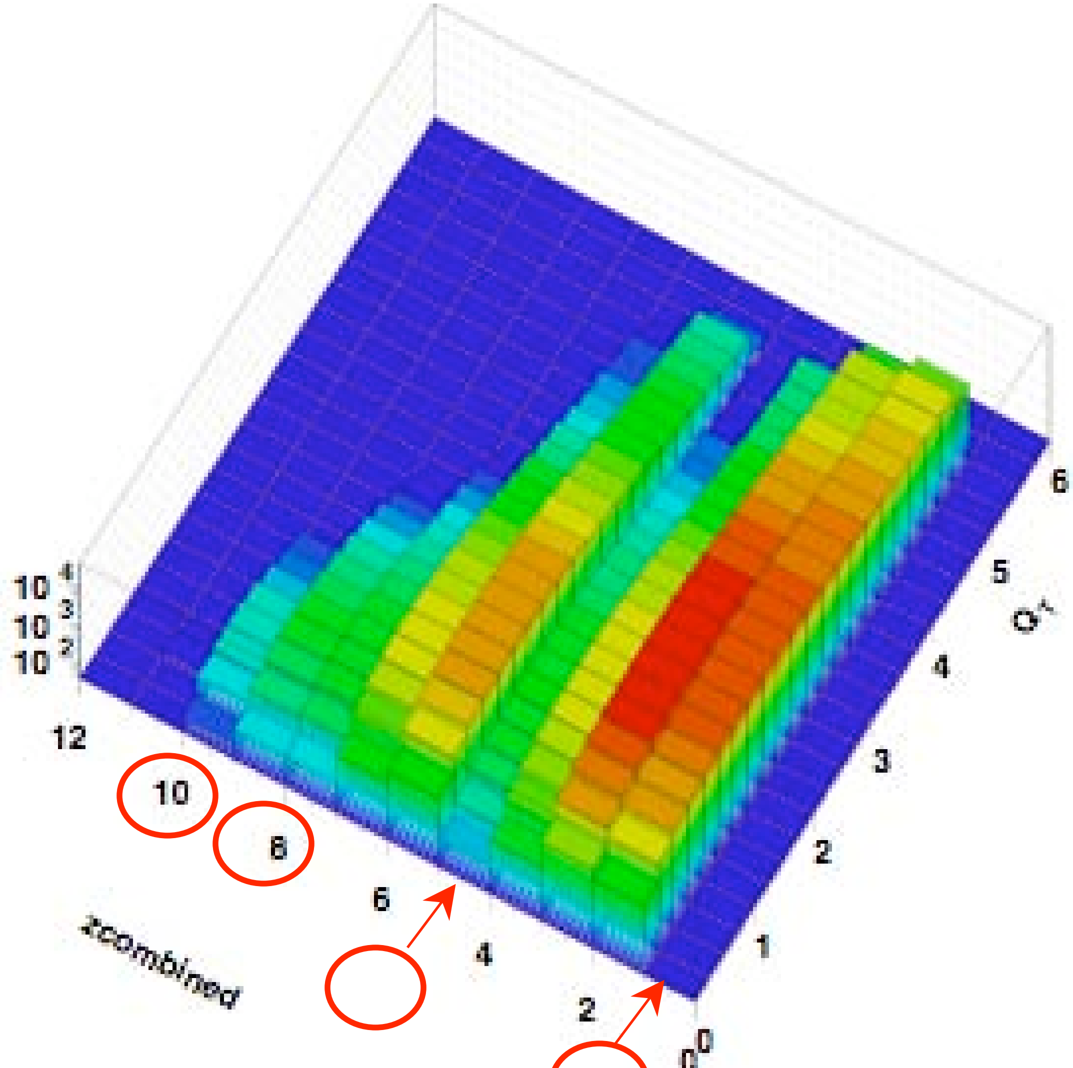
·Significant nonzero Asymmetries visible in MC (w/o Collins)

·Acceptance, radiative and momentum correlation effects similar for like and unlike sign pairs

$$\frac{dN}{d\Omega} \propto \sin^2\theta \cos(2\phi_0)\frac{Q_T^2}{Q^2+Q_T^2}$$



Z vs photon momentum Q_T



= Diagonal bins

Methods to eliminate gluon contributions: Double ratios and subtractions between

Unlike-sign pair (Fav*Fav + Unfav*Unfav)
and Like-sign pair (Fav*Unfav)

Double ratio method:

$$R := \frac{\frac{N^{Unlike}(\phi)}{N_0^{Unlike}}}{\frac{N^{Like}(\phi)}{N_0^{Like}}} \approx 1 + F\left(\frac{H_1^{\perp,fav}(z)}{D_1^{fav}(z)}, \frac{H_1^{\perp,unfav}(z)}{D_1^{unfav}(z)}\right) + \mathcal{O}\left(F(Q_T)^2)\right)$$

Pros: Acceptance cancels out

Cons: Works only if effects are small (both gluon radiation and signal)

Subtraction method:

$$S := \frac{N^{Unlike}(\phi)}{N_0^{Unlike}} - \frac{N^{Like}(\phi)}{N_0^{Like}} = F\left(\frac{H_1^{\perp,fav}(z)}{D_1^{fav}(z)}, \frac{H_1^{\perp,unfav}(z)}{D_1^{unfav}(z)}\right)$$

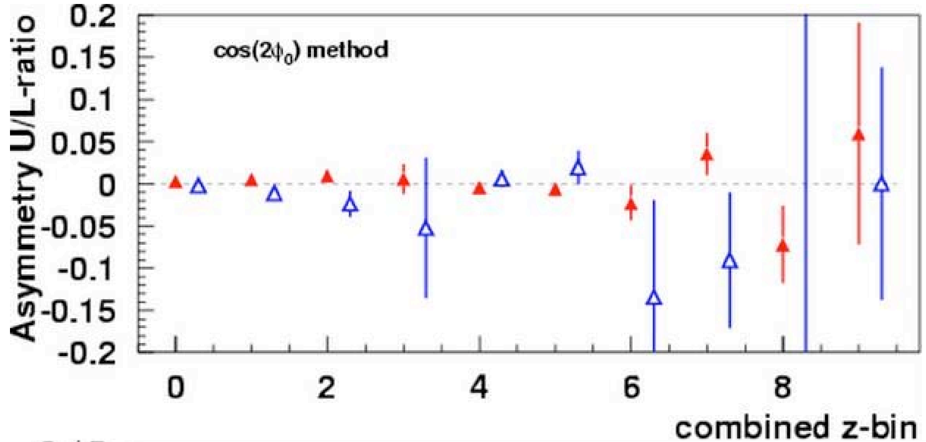
Pros: Gluon radiation cancels out exactly

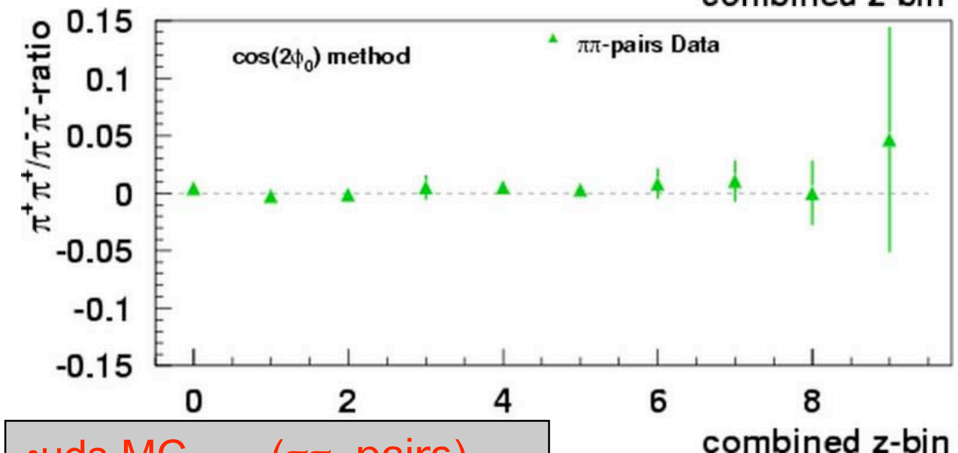
Cons: Acceptance effects remain

2 method gives very small difference in the result

$$F = \frac{\sin^2(\theta)}{1+\cos^2(\theta)}\left[\frac{\sum_q e^2(H^{Fav}\cdot\overline{H}^{Fav} + H^{Unf}\cdot\overline{H}^{Unf})}{\sum_q e^2(D^{Fav}\cdot\overline{D}^{Fav} + D^{Unf}\cdot\overline{D}^{Unf})} - \frac{\sum_q e^2(H^{Fav}\cdot\overline{H}^{Unf} + H^{Unf}\cdot\overline{H}^{Fav})}{\sum_q e^2(D^{Fav}\cdot\overline{D}^{Unf} + D^{Unf}\cdot\overline{D}^{Fav})}\right]$$

Testing the double ratios with MC





- Asymmetries do cancel out for MC
- Double ratios of $\pi^+\pi^+/\pi^-\pi^-$ compatible to zero
- Mixed events also show zero result
- Asymmetry reconstruction works well for τ MC (weak decays)
- Single hemisphere analysis yields zero

➔Double ratios are safe to use

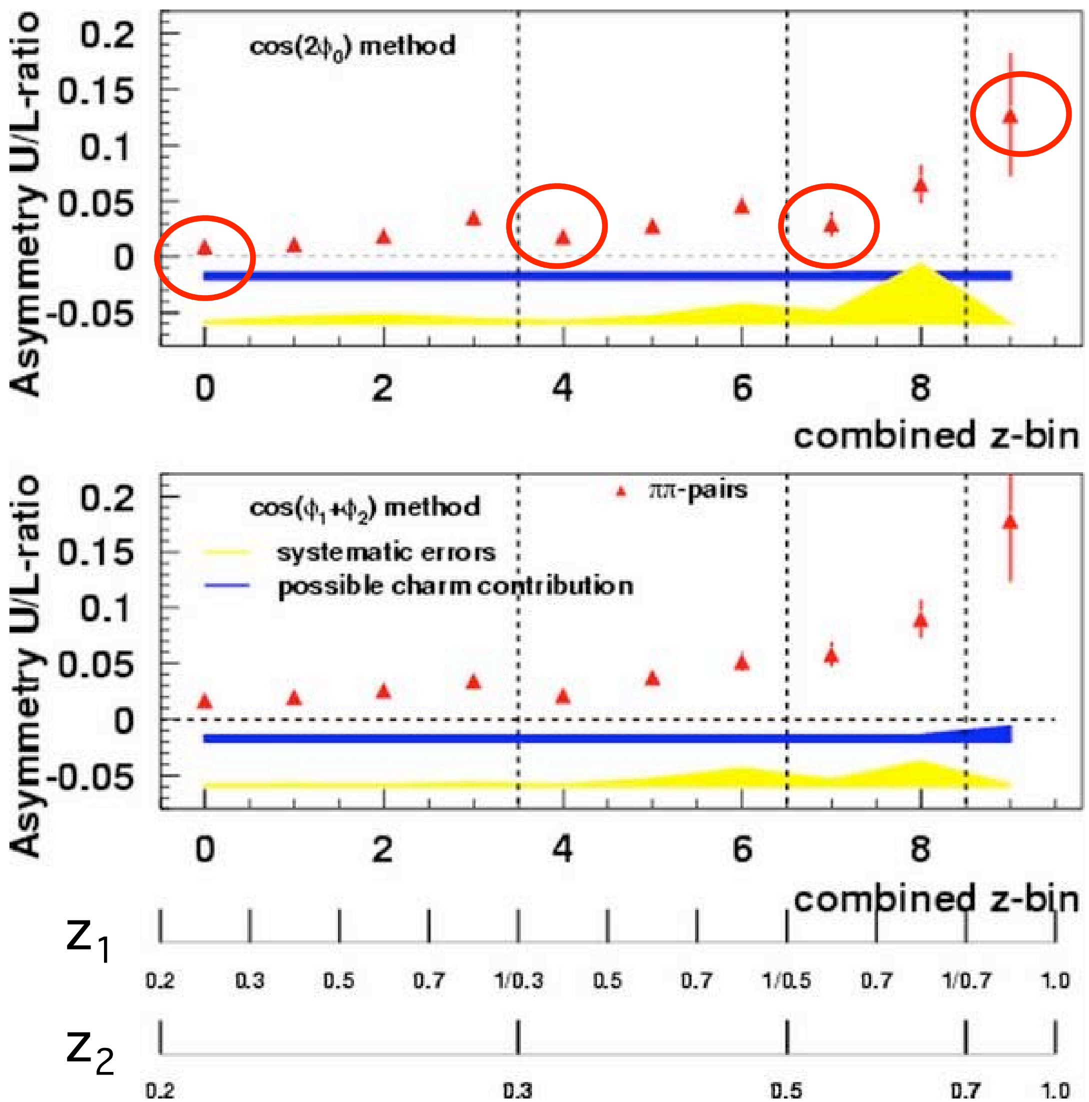
•uds MC (ππ–pairs)

•charm MC (ππ–pairs)

•Data ($\pi^+\pi^+/\pi^-\pi^-$)

	ππ uds	ππ charm	ππ mixed	kk mixed
constant	0.26%±0.19%	-0.45%±0.33%	0.06%±0.09%	0.01%±0.16%
reduced χ^2	1.17	1.35	1.14	1.2

Results for π-pairs for $30fb^{-1}$



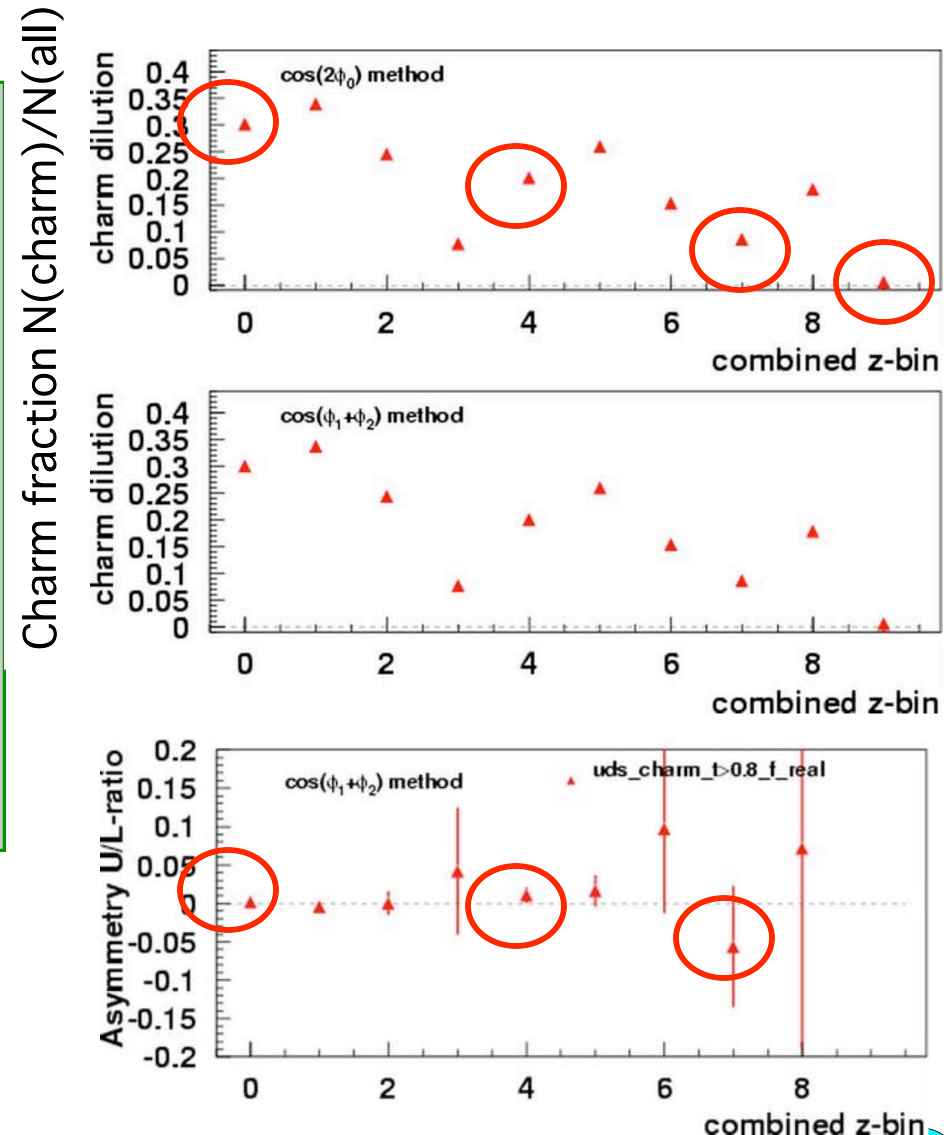
- Significant non-zero asymmetries
- Rising behaviour vs. z
- $\cos(\phi_1+\phi_2)$ double ratios only marginally larger
- First direct measurement of the Collins function

Systematics: charm contribution?

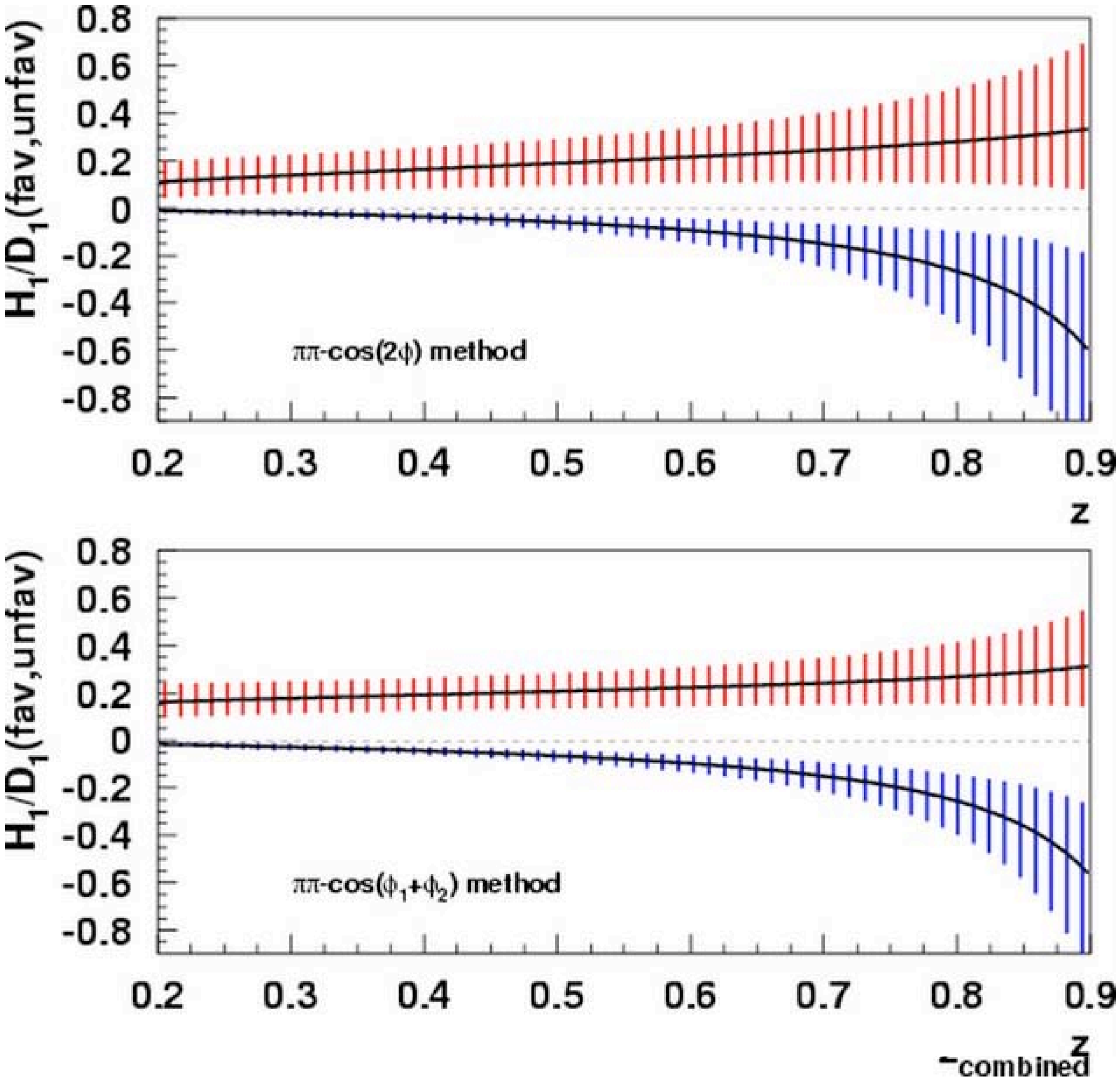
- Weak (parity violating) decays could also create asymmetries (seen in $\tau\bar{\tau} \rightarrow \pi\pi\nu\bar{\nu}$, overall τ dilution 5%)
- Especially low dilution in combined z-bins with large pion asymmetry
- Double ratios from charm MC compatible to zero

➔ Charm decays cannot explain large double ratios seen in the data

➔ Systematic errors from charm are preliminary



An experimentalist's toy interpretation: fitting parameterizations of the Collins function(s)



- Take unpolarized parameterizations (Kretzer at Q^2=2.5GeV^2)
- Assume $H_1^{\perp,fav} = a\ z^b\ (1-z)^c$ (PDF-like behaviour)
- Assume $H_1^{\perp,fav} > 0$
- Assume $H_1^{\perp,unfav} / H_1^{\perp,fav}$ = - 0.1
- Sensitivity studies in progress

Summary and outlook

Summary:

- Double ratios:
  - double ratios from data
  - most systematic errors cancel
  - checked with subtraction method
- Analysis procedure passes zero tests
- Main systematic uncertainties understood
- Significant non-zero Collins asymmetries observed

➔ Naive LO analysis shows significant Collins effect

Outlook:

- Finalize analysis
- On resonance →10 x statistics
- Include π^0 into analysis:

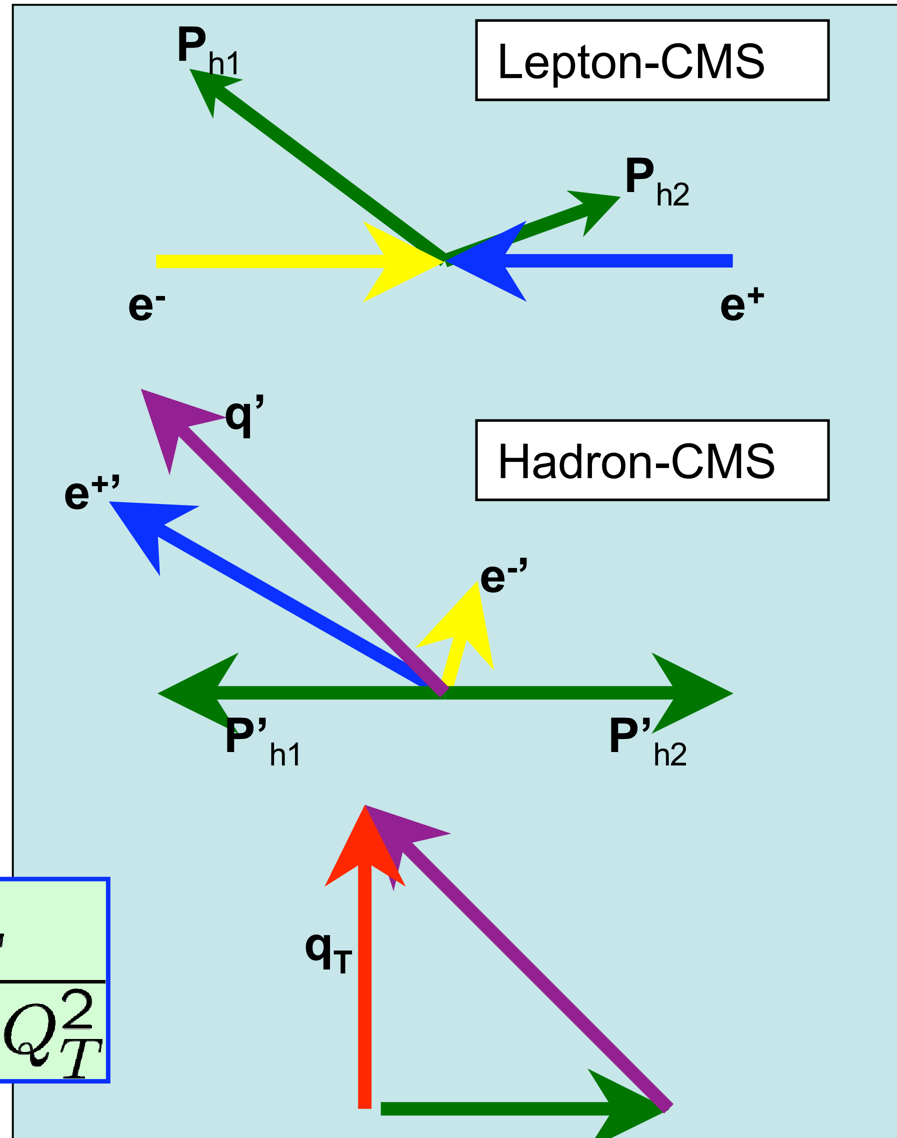
  ➔ Better distinction between favored and disfavored Collins function
- Include VMs into analysis:

  ➔ Possibility to test string fragmentation models used to describe Collins effect
- Expansion of analysis to Interference fragmentation function is straightforward
- And more (Kaon Collins FF, Tau, unpol FF @ high z, …)

What is the transverse momentum Q_T of the virtual photon?

- In the lepton CMS frame
  $e^- = -e^+$ and the virtual photon is only time-like:
  $q^\mu = (e^{-\mu} + p^{+\mu}) = (Q,0,0,0)$
- Radiative (=significant BG) effects are theoretically best described in the hadron CMS frame where
  $P_{h1} + P_{h2} = 0$
  $\rightarrow q^{\mu\prime} = (q'_0, \mathbf{q}')$
- Inclusive Cross section for radiative events (acc. to D.Boer):

$$\frac{dN}{d\Omega} \propto \sin^2\theta \cos(2\phi_0) \frac{Q_T^2}{Q^2 + Q_T^2}$$



Different charge combinations →additional information

- Unlike sign pairs contain either only favored or only unfavored fragmentation functions on quark and antiquark side:

$$D_1^{fav}(z_1)\overline{D_1^{fav}(z_2)} + D_1^{unfav}(z_1)\overline{D_1^{unfav}(z_2)}$$

- Like sign pairs contain one favored and one unfavored fragmentation function each:

$$D_1^{fav}(z_1)\overline{D_1^{unfav}(z_2)} + D_1^{unfav}(z_1)\overline{D_1^{fav}(z_2)}$$

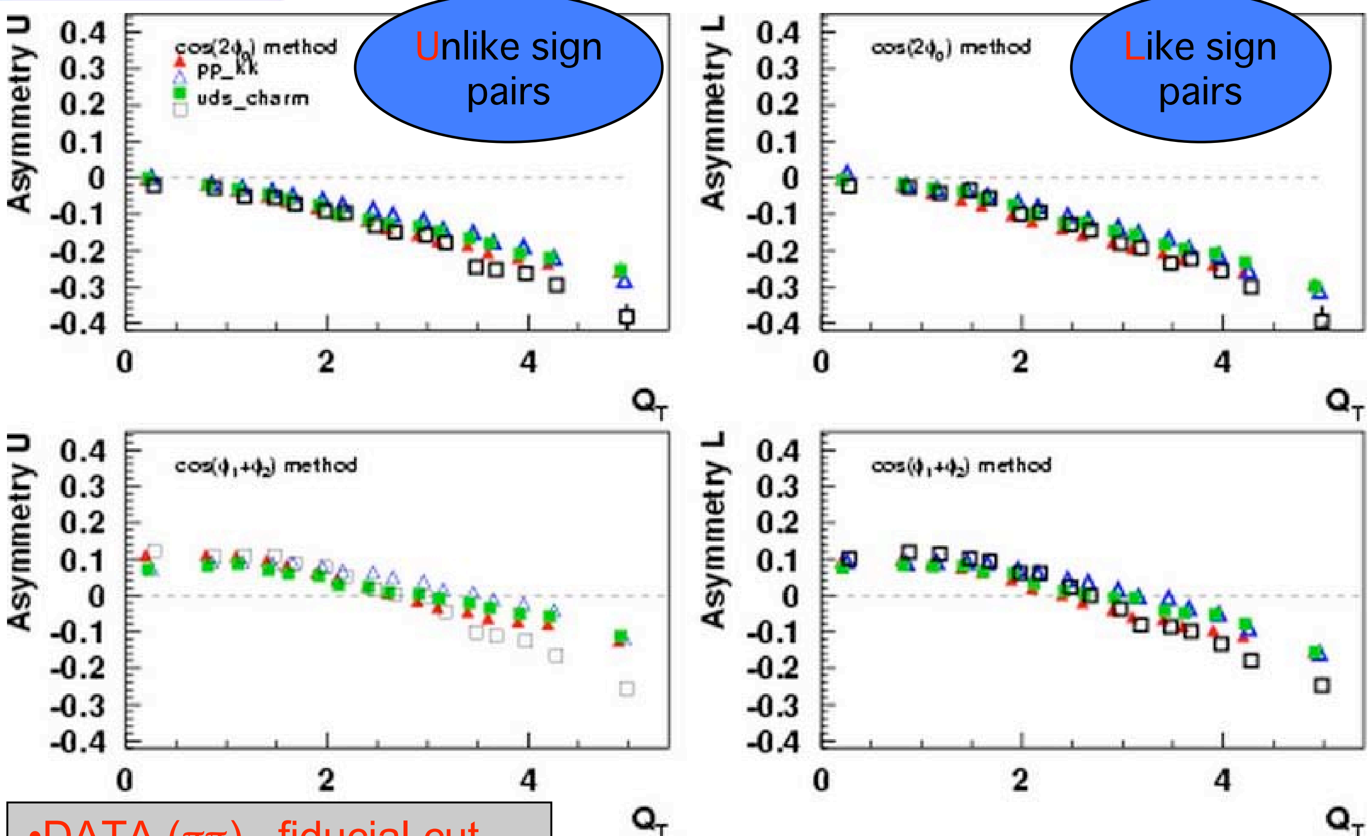
Favored = u→π⁺,d→π⁻,cc.

Unfavored = d→π⁺,u→π⁺,cc.

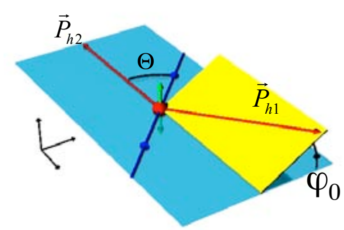
$$\frac{N(\phi)}{N_0} = \frac{aD_1\overline{D_1} + cos(2\phi)\left(bH_1\overline{H_1} + cD_1\overline{D_1}\right)}{aD_1\overline{D_1}}$$

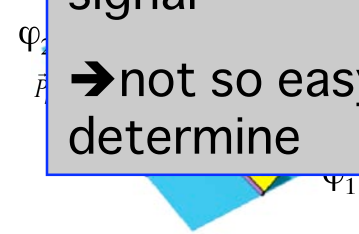
$$\frac{N(\phi)}{N_0} = 1 + cos(2\phi)\left(\frac{bH_1\overline{H_1}}{aD_1\overline{D_1}} + c/a\right)$$

Raw asymmetries vs transverse photon momentum Q_T



- •DATA (ππ) fiducial cut
- ・DATA (KK) fiducial cut
- •UDS-MC fiducial cut
- •CHARM-MC fiducial cut





- ・Already MC contains large asymmetries
- ・Strong dependence against transverse photon Momentum Q_T
- ・Expected to be due to radiative effects
- ・Difference of DATA and MC is signal
- ➔not so easy to determine