Measurements of the Collins asymmetries for kaons and pions in e^+e^- annihilations at *BABAR*

Alessandra Filippi
INFN Torino
On behalf of the *BABAR* Collaboration

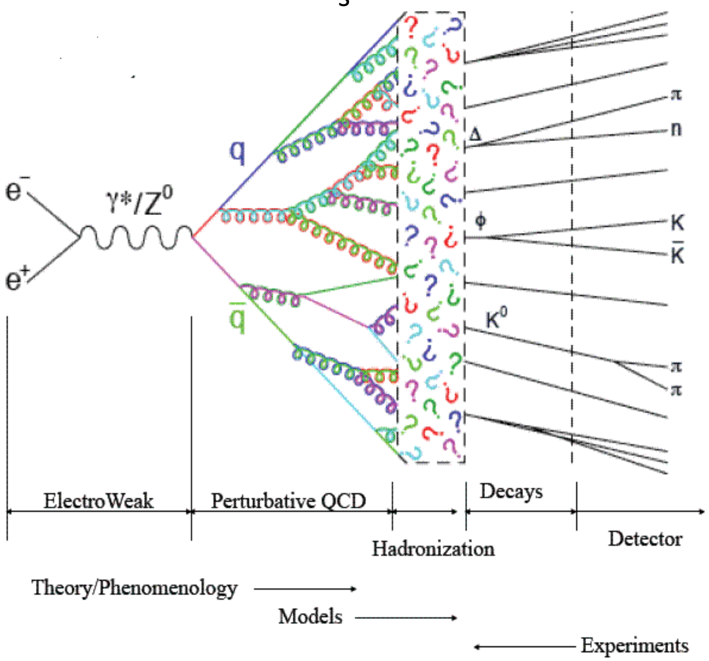
ISMD2015, Wildbad Kreuth (Germany), 4-9 Oct 2015

Outline

- Introduction
  - The fragmentation process and its description
  - Transverse degrees of freedom: the Collins effect
- Analysis overview
  - Method
  - *BABAR* data: data selection and background evaluation
  - Asymmetries extractions, corrections and study of systematic uncertainties
- Results
- Conclusions

Fragmentation processes in e^+e^- annihilation

At first order in α_s:



- Fragmentation: hard quarks/gluons from a virtual photon (Z^0) radiate partons which combine into colorless hadrons
- Description via fragmentation functions
  - Universal functions
  - Cannot be calculated by perturbative QCD
  - To be determined by experiments

- For the factorization theorem:

$$\frac{d\sigma}{dz}(e^+e^- \to hX) = \sum_q \sigma(e^+e^- \to q\overline{q}) \cdot \left[D_q^h(z,Q^2) + D_{\overline{q}}^h(z,Q^2)\right]$$

- Parton spins and transverse degrees of freedom in the parton motion provide important information for the determination of these probability functions

Collins fragmentation function

- Collins function: related to the probability that a transverse polarized quark will fragment into a spinless (or unpolarized) hadron $q^{\uparrow} \to hX$
- For the fragmentation of a polarized quark $q^{\uparrow}$ into spinless hadrons (π, K) one has:

$$D_1^{q\uparrow}(z,\mathbf{P}_\perp;s_q) = \overbrace{\boxed{D_1^q(z,\mathbf{P}_\perp)}}^{\text{Unpolarized FF}} + \frac{P_\perp}{zM_h}\underbrace{\boxed{H_1^{\perp q}(z,P_\perp)\,\mathbf{s}_q\cdot(\mathbf{k}_q\times\mathbf{P}_\perp)}}$$

- Part dependent on a spin-orbit coupling
- Leads to a cosine dependence in the angular distribution of the final state particles: Collins effect

$H_1^\perp$ polarized fragmentation function or **Collins FF**

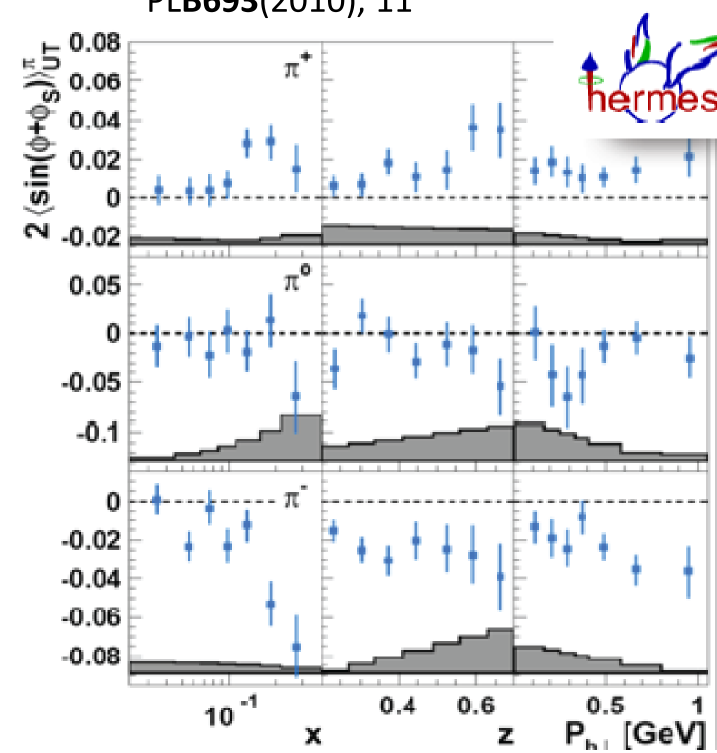
(J.C. Collins, NP**B396**, 161 (1993))

The Collins effect

- The Collins function embeds the correlation between the fragmenting quark spin and the transverse momentum of the produced hadron
- **Chiral-odd function**
- Collins effect: azimuthal modulation
  - observable in **SIDIS** and **e^+e^- annihilation**

$Q^2 \sim 3$ GeV^2

PL**B693**(2010), 11



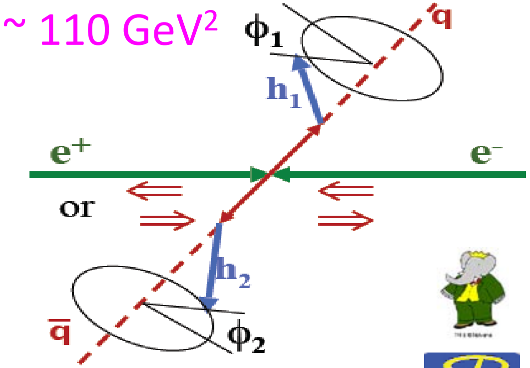
SIDIS: unpolarized lepton beam off transversely polarized target

- HERMES, COMPASS (on d)
- Spin direction known
- Non-zero Collins effect but entangled with transversity
- Convolution of two chiral odd functions, one of them must be measured independently

$$\sigma \propto \sin(\phi_h + \phi_s) \cdot h_1(x_B) \otimes H_1^{\perp}(z_1)$$

Collins effect in $e^+e^- \rightarrow q\bar{q}$

$Q^2 \sim 110\ \mathrm{GeV}^2$



PRL**96** (2006),232002

arXiv:1507.06824

- Golden channel: no hadrons in the initial state
- Quark spin unknown
- Two quark spins parallel
- Quark transverse spin component: ~$\sin^2\theta$
- Correlation between hadrons in opposite jets:

$$e^+e^- \rightarrow q\bar{q} \rightarrow h_1^{\pm} h_2^{\mp(\pm)} X \qquad (q = u, d, s; \quad h = \pi, K)$$

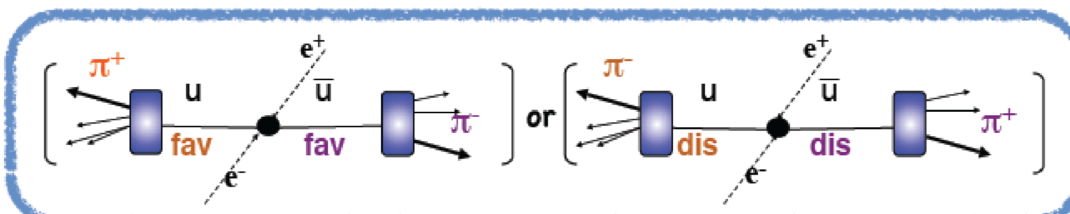
$$\sigma \propto \boxed{\cos(\phi_1 + \phi_2)}\, H_1^{\perp h1}(z_1) \otimes H_2^{\perp h2}(z_2)$$

Azimuthal modulation wrt quark spin direction

Final states with particle pairs with like (L) and unlike (U) signs

Collins asymmetries for $\pi\pi$

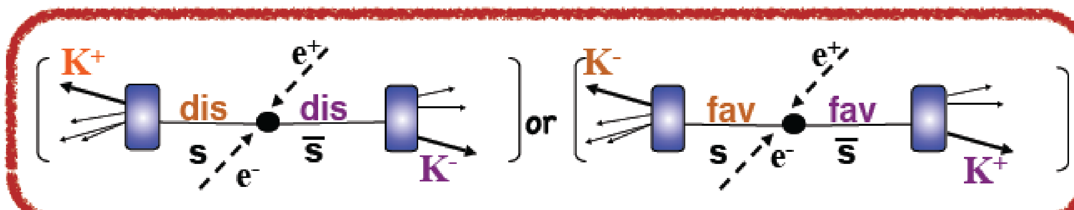
PR**D90**, 052003 (2014)



Collins asymmetries for KK & Kπ

First measurement ever

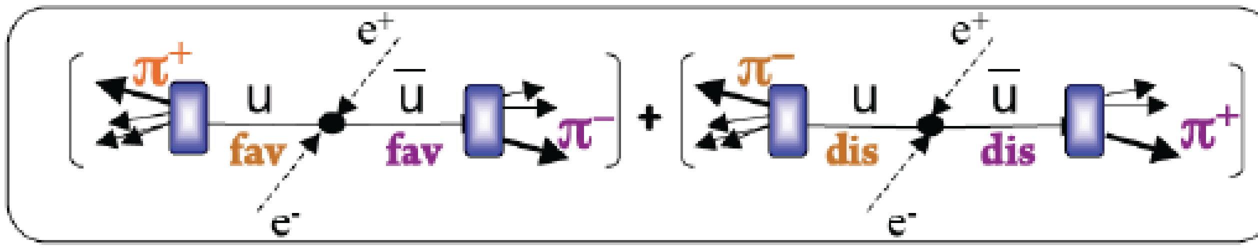
Fragmentation of the s quark to strange/non strange mesons



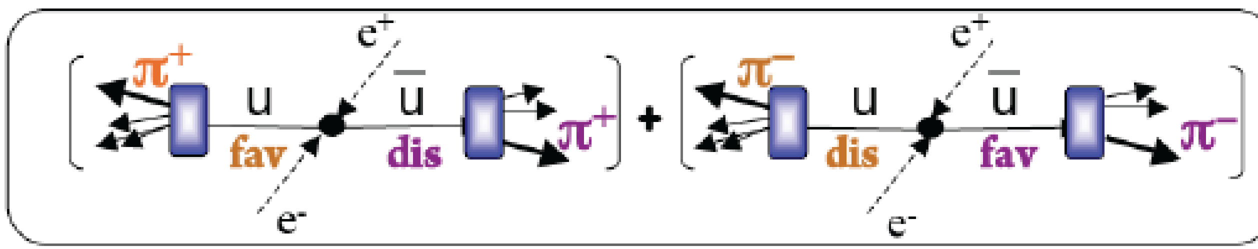
Favored vs disfavored fragmentation functions

- **Favored FF**: the parent quark matches a valence quark of the produced hadron $u \rightarrow \pi^+$, $d \rightarrow \pi^-$, $s \rightarrow K^-$, ...
- **Disfavored**: no match $u \rightarrow \pi^-$, $d \rightarrow \pi^+$, $s \rightarrow \pi^\pm$, ...

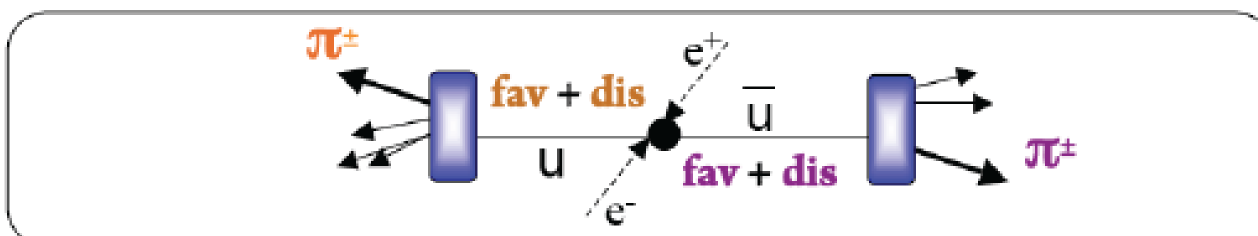
Unlike sign pions U:
fav x fav + dis x dis



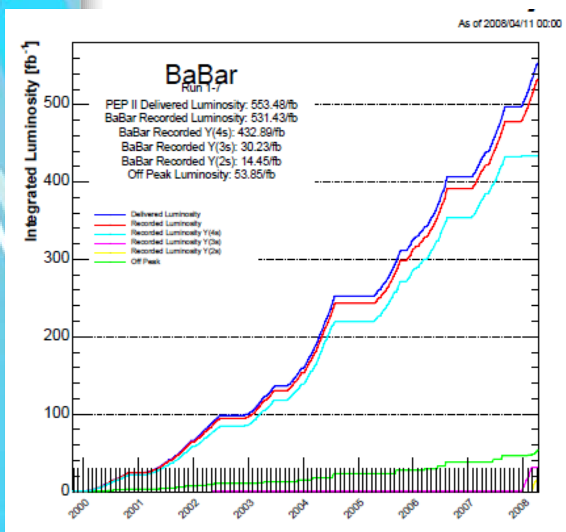
Like sign pions L:
fav x dis + dis x fav

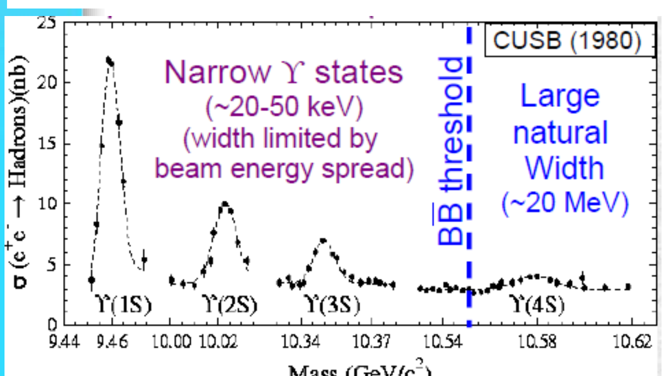


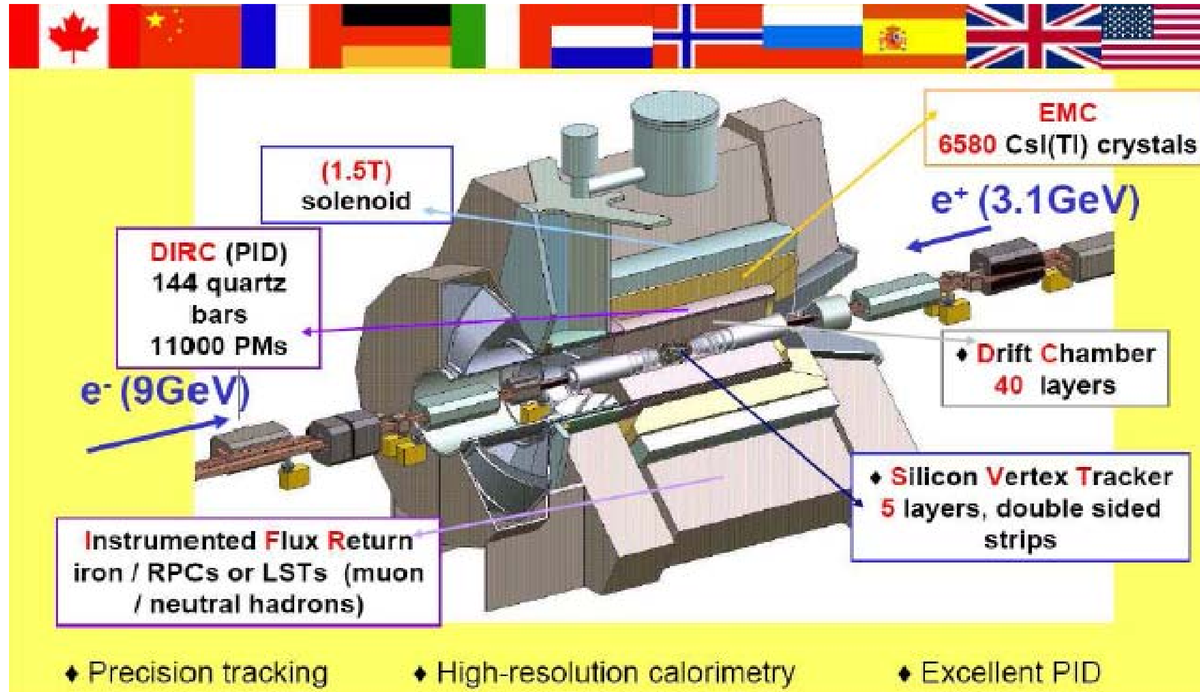
All charge combinations:
(fav + dis) x (fav+dis)



The *BABAR* experiment at PEP-II, SLAC







NIM **A479**, 1 (2002); NIM **A729**, 615 (2013)

PEP-II and *BABAR* operated from Oct 1999 to Apr 2008

~ 500 fb^{-1} integrated luminosity

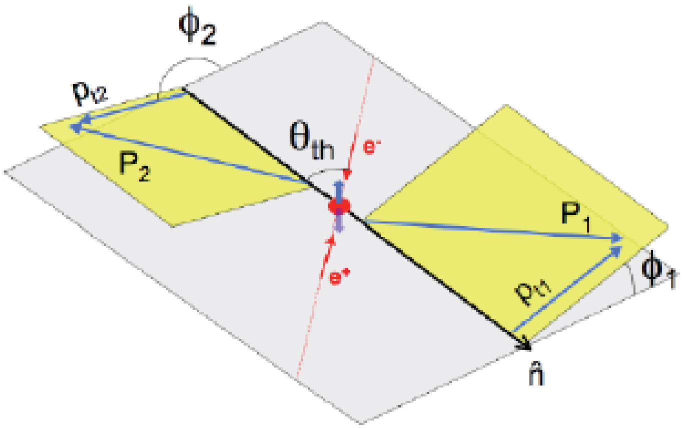
- ~470 $\times 10^6$ $\Upsilon(4S)$
- ~120 $\times 10^6$ $\Upsilon(3S)$ (10x BELLE)
- ~100 $\times 10^6$ $\Upsilon(2S)$ (10x CLEO)
- ~18 $\times 10^6$ $\Upsilon(1S)$ from $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$

Present analysis: 468 fb^{-1}

Reference frames

all quantities in e^+e^- center of mass

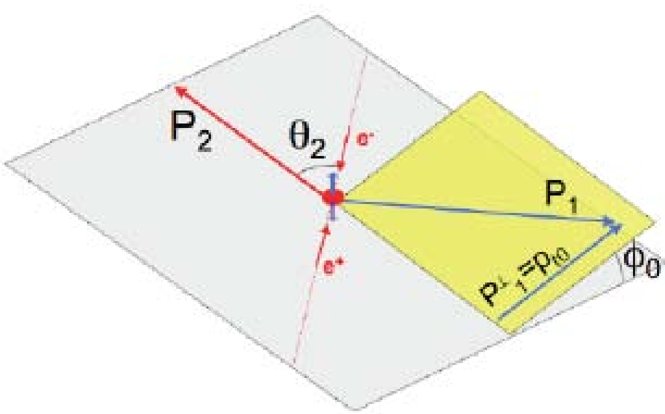
THRUST REFERENCE FRAME (RF12)



- $\bar{q}q$ direction approximated by the thrust axis
- Angles defined wrt thrust beam plane
  - θ_{th}: angle between e^+e^- and thrust axes
  - $\phi_{1,2}$: azimuthal angles between $p_{th1(h2)}$ and the scattering plane

$$\sigma \approx 1+\frac{\sin^2\theta_{th}}{1+\cos^2\theta_{th}}\boxed{\cos(\phi_1+\phi_2)}\frac{H_1^\perp(z_1)\overline{H}_1^\perp(z_2)}{D_1(z_1)\overline{D}_1(z_2)}$$

SECOND HADRON RF (RF0)



- Consider just one track in a pair (h2)
- θ_2: angle between e^+e^- and P_{h2}
- ϕ_0: angle between the plane formed by P_{h2} and e^+e^-, and the P_{h1} component transverse to P_{h2}

$$\sigma \approx 1+\frac{\sin^2\theta_{th}}{1+\cos^2\theta_{th}}\boxed{\cos(2\phi_0)}\mathcal{F}\left[\frac{H_1^\perp(z_1)\overline{H}_1^\perp(z_2)}{D_1(z_1)\overline{D}_1(z_2)}\right]$$

Analysis strategy

Goal: simultaneous measurement of Collins asymmetry for $\pi\pi$, πK and KK pairs

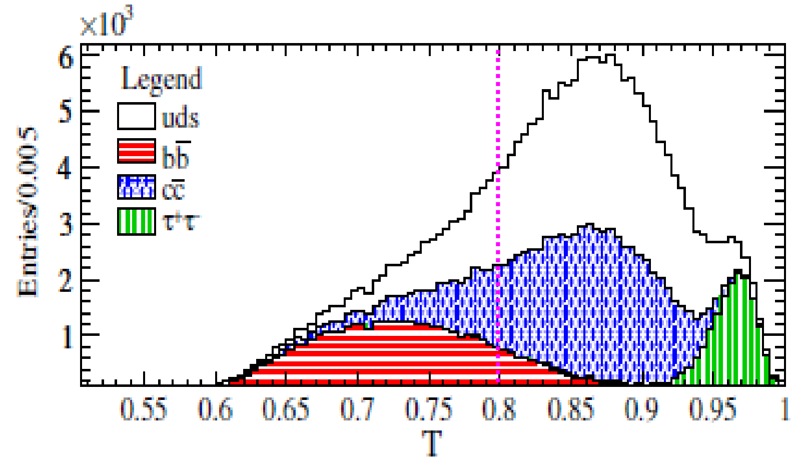
1. Event and track selection: identification of inclusive events with hadron pairs in opposite jets wrt to thrust axis
2. Particle identification and misidentification probabilities
3. Extraction of normalized raw distributions of the azimuthal angles ϕ_α (2 RFs) for L, U and C pairs
4. Calculation of ratios of normalized distributions: U/L & U/C
5. Extract Collins asymmetries corrected for K/π misidentification, background contributions, …
6. Estimation of systematic effects

Results

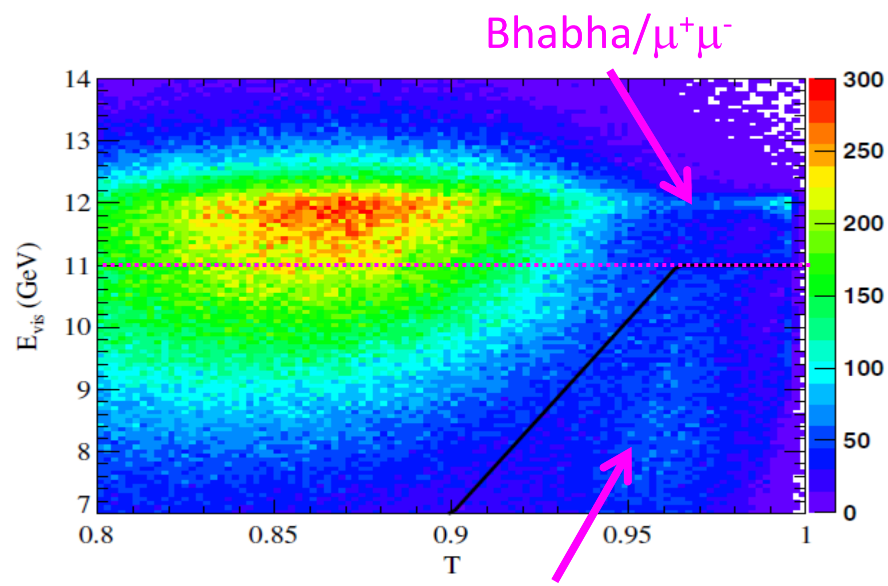
- A^{UL} and A^{UC} in 4x4 (z_1,z_2) bins ($z_h = 2E_h/\sqrt{s}$) in both RF12 and RF0
  - z_1, z_2 studied ranges: [0.15,0.2], [0.2,0.3], [0.3,0.5],[0.5,0.9] GeV

1. Event and track selection

- **Event selection**
  - >2 charged tracks
  - 2 jets topology: event shape T > 0.8
  - $|\cos\theta_{thrust}| < 0.6$
  - $E_{vis} > 11$ GeV
    - Rejects 2γ, $\tau^+\tau^-$, ISR/$q\bar{q}g$ events with one γ/jet along the beam line
  - $E_\gamma < 2$ GeV



- **Track selection**
  - $\mu^\pm/e^\pm$ events removed
  - Events in the $\tau^+\tau^-$ region excluded
  - K and π in the DIRC acceptance region
  - K/π fractional energy z: $0.15 < z < 0.9$ GeV
  - Opening angle wrt to thrust: 45°
  - $Q_t < 3.5$ GeV/c (transverse momentum of the virtual photon)



2. Particle identification

- Identification of π/K via energy loss through ionization in DCH and Cherenkov radiation in DIRC
- Charged particles selected in the detector acceptance: $0.45 < \theta_{lab} < 2.46$ rad
- Minimal misidentification of electrons (<2%) and muons (<4%)
- Large identification efficiency for kaons (~80%) and pions (~90%)
- Estimation through MC of the π/K pairs misidentification probabilities
  - They enter in the definition of the asymmetries:

$$\xi_{hh,generated}^{h'h',reconstructed}$$

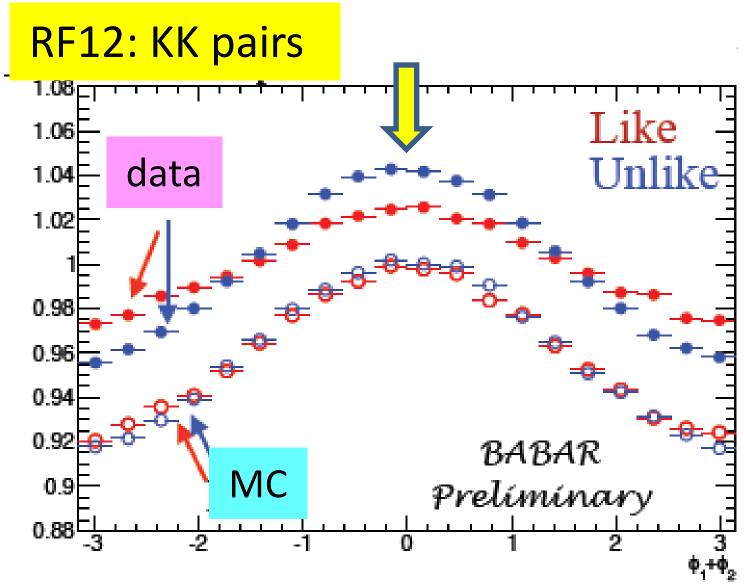
$$\xi_{KK}^{KK} \sim 86\% - 91\% \qquad \xi_{K\pi}^{KK} \sim 1.5\% - 5\% \qquad \xi_{\pi\pi}^{KK} \sim 0.01\% - 0.1\%$$

$$\xi_{KK}^{K\pi} \sim 7.6\% - 13\% \qquad \xi_{K\pi}^{KK} \sim 78\% - 90\% \qquad \xi_{\pi\pi}^{K\pi} \sim 3.5\% - 4.5\%$$

$$\xi_{KK}^{\pi\pi} \sim 0.3\% - 1.3\% \qquad \xi_{K\pi}^{KK} \sim 7.3\% - 16\% \qquad \xi_{\pi\pi}^{\pi\pi} \sim 95\% - 97\%$$

3. Measurement of Collins effect: raw asymmetries

ArXiv:1506.05864



- In both the RF's (α= 12,0)
- Measure the normalized azimuthal distributions of inclusive hadron pairs produced in two opposite jets, with
  - **Same charges (like L)**
  - **Opposite charges (unlike U)**
  - **Sum of the two (C)**

$$R_\alpha = \frac{N(\phi_\alpha)}{\langle N_\alpha \rangle} = a + \boxed{b} \cdot \cos\phi_\alpha$$

b ~ convolution of the 2 Collins FF

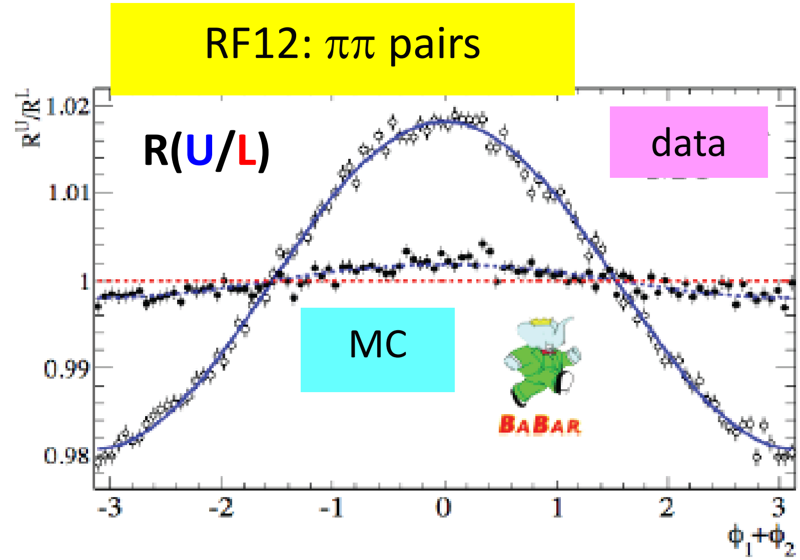
- If no Collins effect is present: no difference between different charge combinations
  - As in uds-MC (JETSET) where no simulation of Collins is inserted
    - Visible modulations due to detector acceptance, gluon radiations & other effects
    - Effects not related to Collins asymmetries are charge independent
- If different: Collins effect
  - Different contributions of fav and dis FF for L, U, C pairs

4. Double ratios

ArXiv:1506.05864

- To reduce acceptance effects: ratios of **Unlike**/**Like** sign (or **Unlike**/**Charged**) hadron pairs

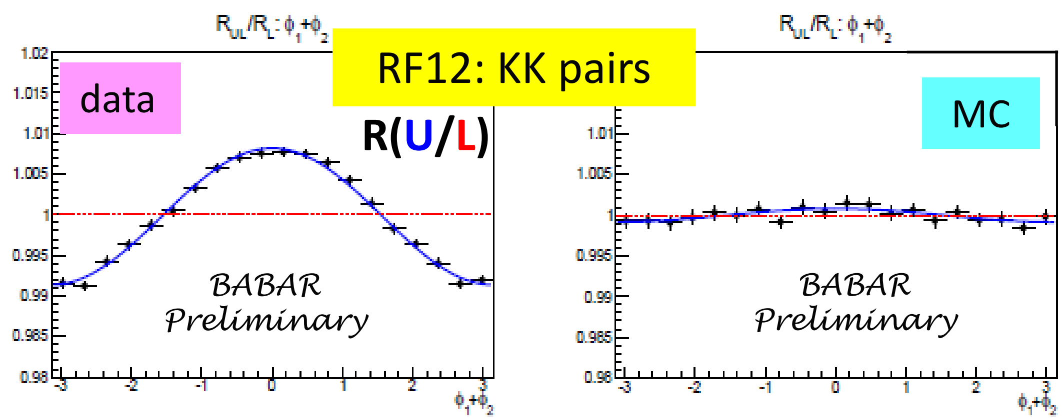
- MC: small deviations from zero, almost consistent with a flat distribution
- Data: sizeable modulation visible, still a cosine distribution



$$\frac{R_\alpha^U}{R_\alpha^{L(C)}} = \frac{N^U(\phi_\alpha)/\langle N^U(\phi_\alpha)\rangle}{N^{L(C)}(\phi_\alpha)/\langle N^{L(C)}(\phi_\alpha)\rangle}$$

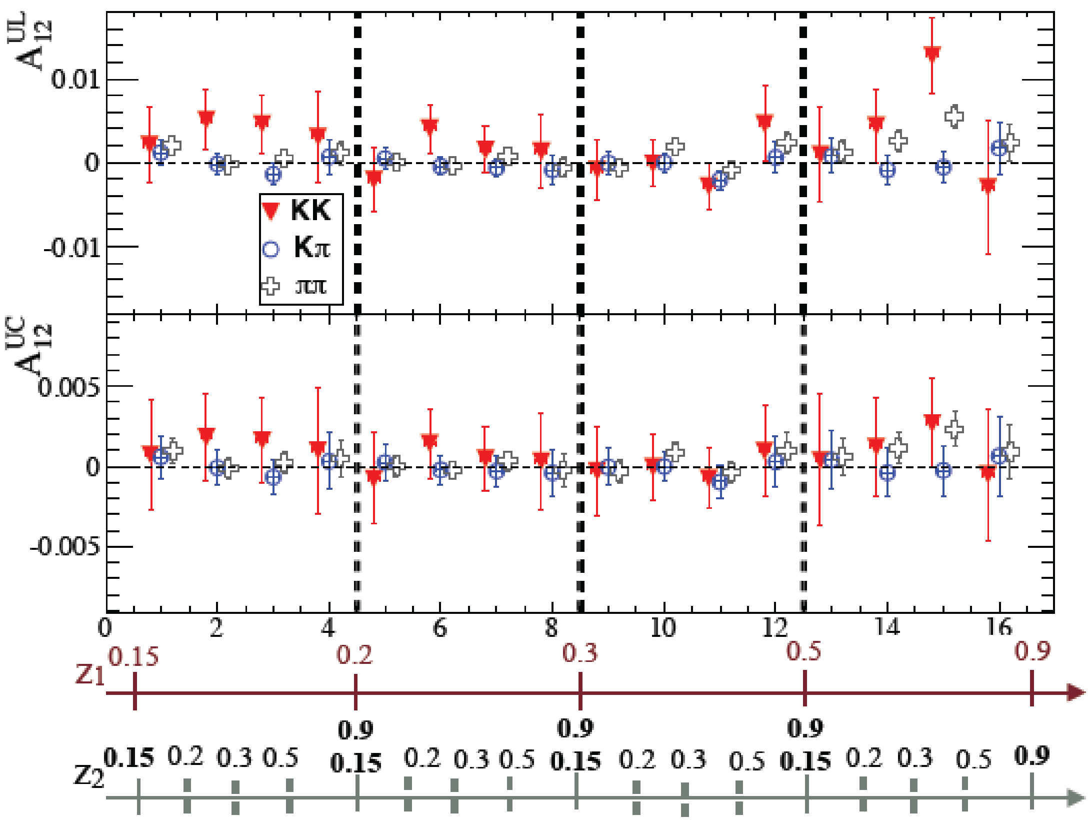
$$\Rightarrow B_\alpha^{UL(UC)} + \boxed{A_\alpha^{UL(UC)}} \cos\phi_\alpha$$

A contains the Collins + other radiative effects



Study of MC asymmetries

- Small modulations (<< real data) observed also in MC samples, even though not directly simulated



- Largest source of asymmetry: ISR photon emission
- Limited requiring E_{vis} > 11 GeV in the KK sample
- Affects both RF12 and RF0 evaluations
- Corrections to be included as systematic contributions

5. Asymmetries extraction

- **Goal: simultaneous extraction of asymmetries for ππ, Kπ, KK in each interval of (z_1, z_2), corrected for backgrounds and particle misidentification**
- The measured asymmetries, obtained from a fit of the double ratio distributions, may be decomposed in the sum of **uds Collins** + **background contributions**:

$$A_{KK}^{meas} = \boxed{F_{uds}^{KK}} \cdot \boxed{A_{KK}^{Collins}} + \boxed{\sum_i F_i^{KK} \cdot A_{KK}^i}$$

Fraction of hadron pairs (MC)

Collins asymmetry

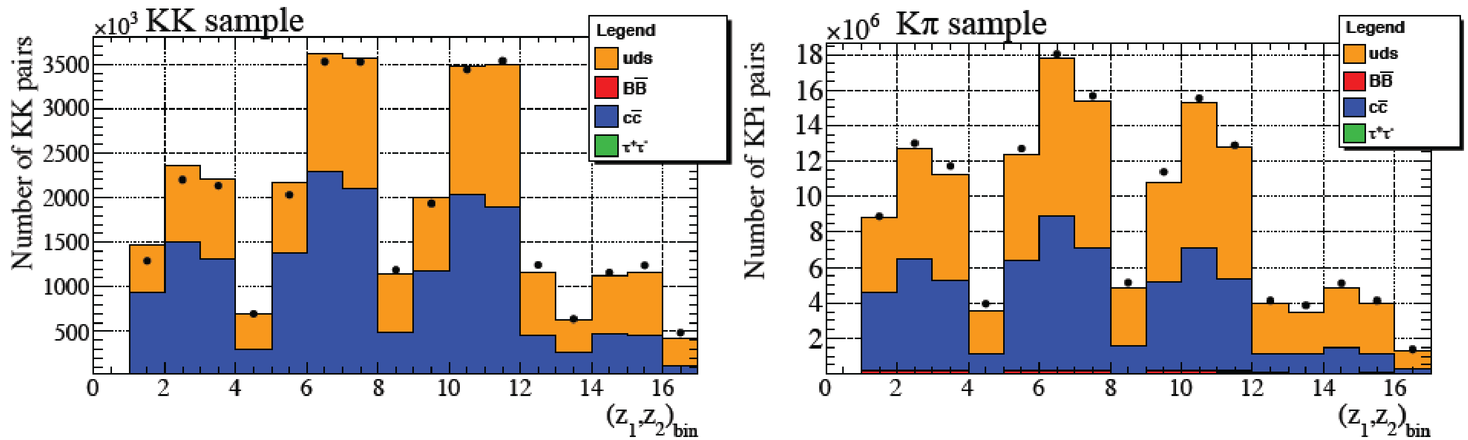
sum of "i" background contributions

- But, due to non-negligible particle misidentification:

$$A_{KK}^{Collins} = \sum_{nm} \xi_{nm}^{KK} \cdot \boxed{A_{nm}^{Collins}} \quad \text{and} \quad A_{KK}^{i} = \sum_{nm} \xi_{nm}^{KK} \cdot \boxed{A_{nm}^{i}}$$

Background contributions

- Data include pairs coming from:
  - uds signal events
  - $c\bar{c}$ events
  - $B\bar{B}$ events (small, mainly at low z)
  - $\tau^+\tau^-$ events (important at high z)
- Fraction evaluation: $F_i = \dfrac{N_i^{MC}}{N_{data}} \quad , \sum_i F_i + F_{uds} = 1$

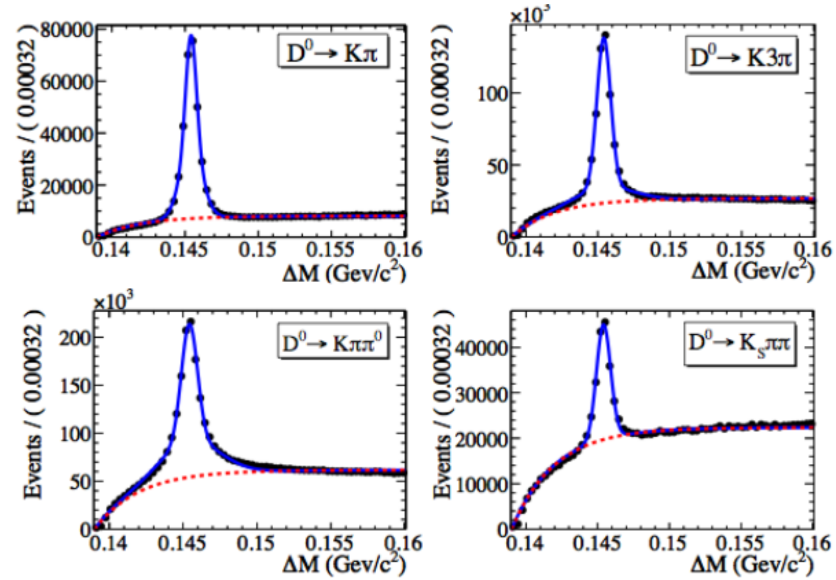


- MC-data difference assigned in each bin as systematic error
  - $A^{B\bar{B}} = 0$
  - $\tau^+\tau^-$ contribution negligible in simulations: $A^{\tau+\tau-} = 0$
  - Sizeable contribution from charm source: >30%

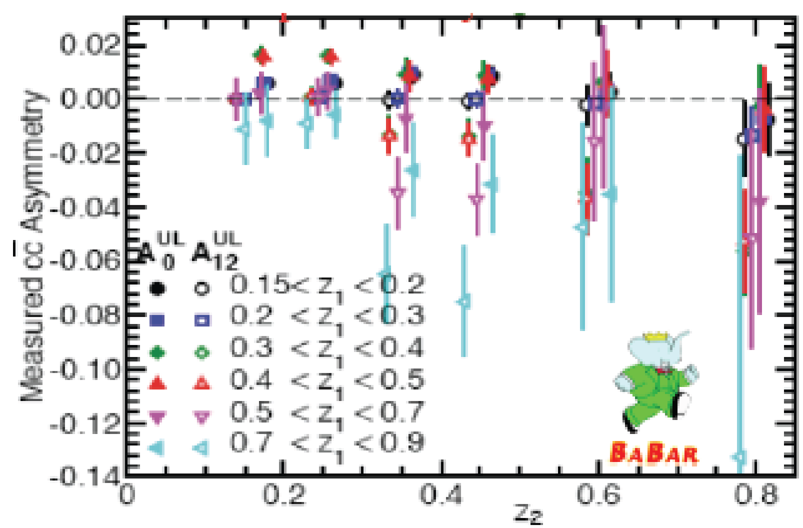
Background contribution: charm

- Charm contribution introduces azimuthal modulations due both to fragmentation and weak decays

- Estimation of effect in a D*-enhanced control sample, bin-by-bin
  - Mostly from $c\bar{c}$ + a part from $B\bar{B}$
  - $D^{*\pm} \to D^0\pi^\pm$ + 4 decay modes of D^0
    - $D^0 \to K\pi$
    - $D^0 \to K3\pi$
    - $D^0 \to K\pi\pi^0$
    - $D^0 \to K_s\pi\pi$



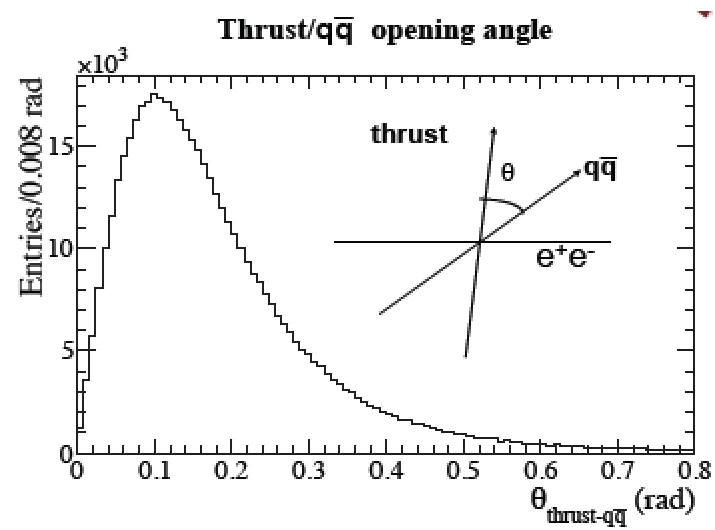
$$A_\alpha^{D^*} = f_{charm} \cdot A_\alpha^{charm} + (1 - f_{charm} - f_B) A_\alpha$$

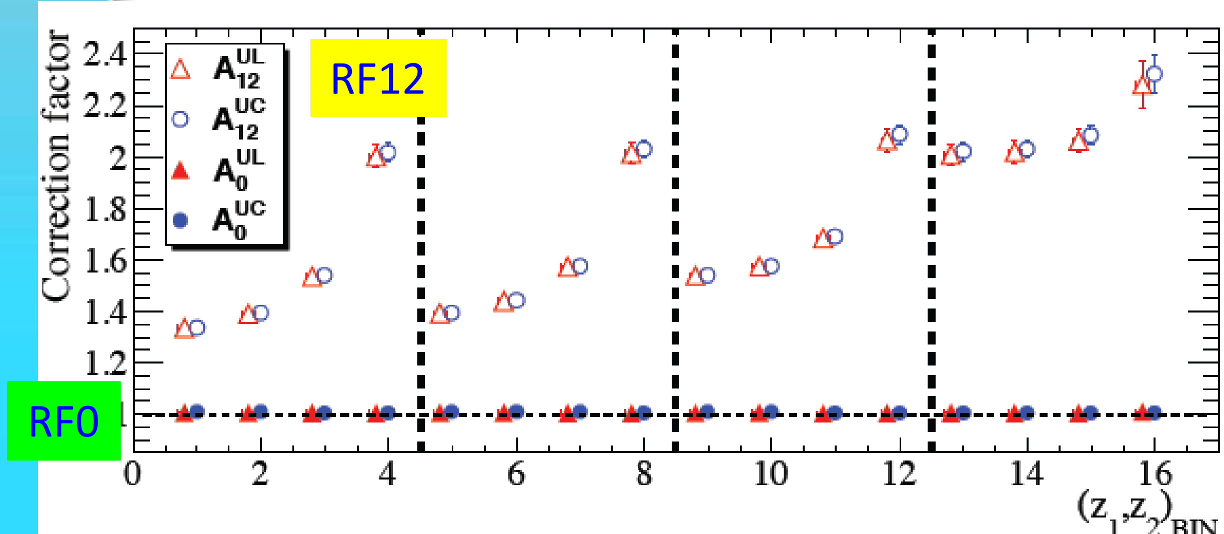


- **A^{charm} are very small – slightly negative**

6. Asymmetry dilution: effect of thrust axis

- RF12: thrust axis taken in place of $q\bar{q}$ axis (unknown)
- Approximation: introduces a dilution of the measured asymmetry
- Correction through MC studies
  - Several values of asymmetries are injected
  - Checked the difference between generated ($q\bar{q}$) and reconstructed (thrust) modulations

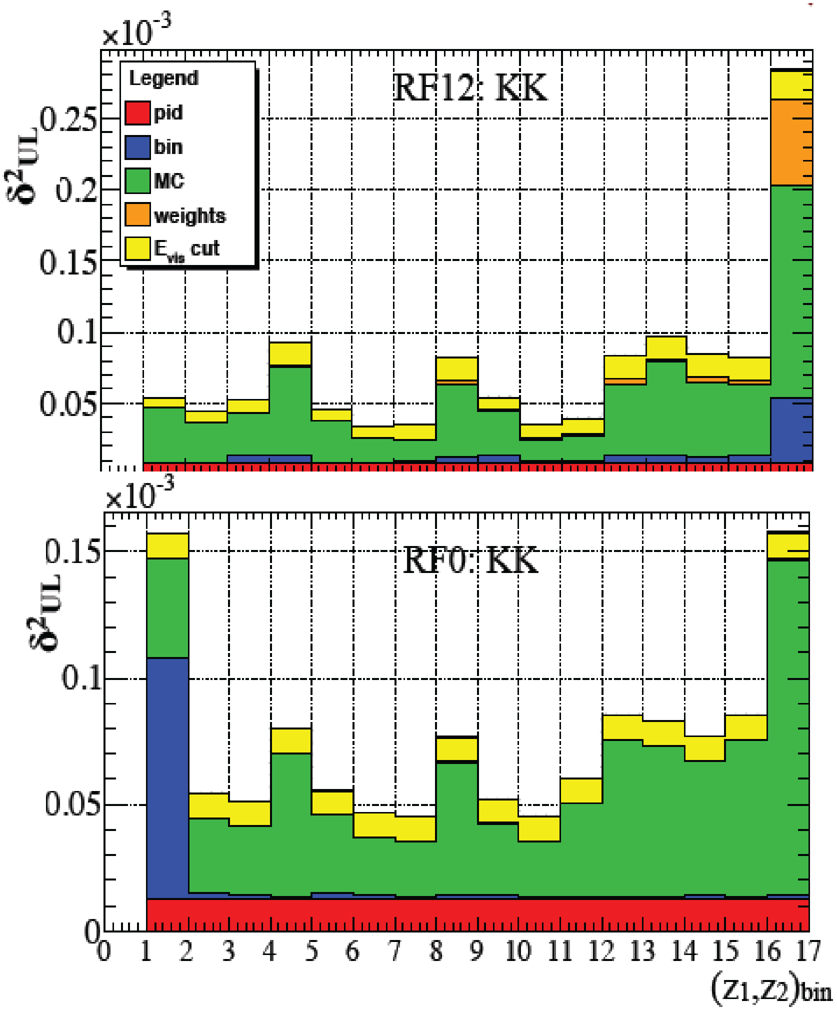




- Effect seen only in RF12
  - Corrections increasing with z, 1.3 → 2.3

- Same correction factors applied to all data samples

Systematic uncertainties

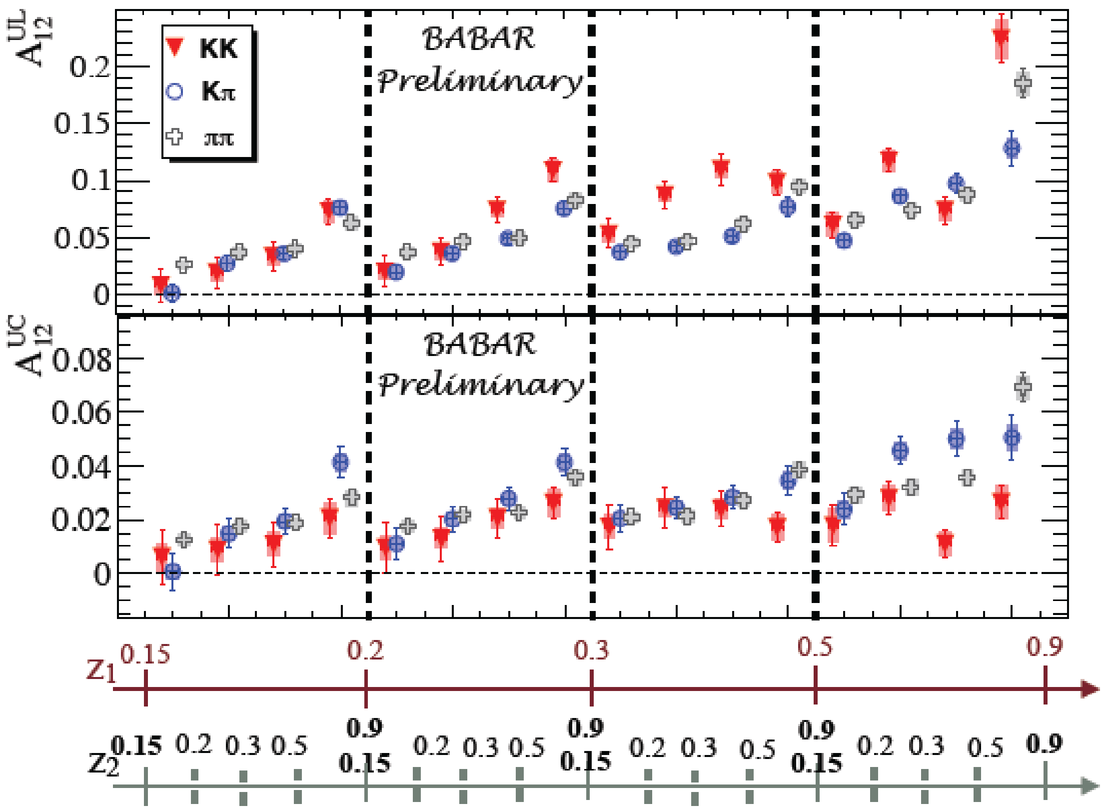


- Several sources of systematic uncertainties
  - Larger effects
    - MC uncertainties
    - PID efficiencies
    - Fit procedures
    - Dilution evaluation
    - Cuts on E_{vis}
  - Minor effects:
    - Beam polarization
    - Asymmetry fluctuations in different data taking periods
    - Couplings between Collins asymmetry and detector effects (2^{nd} order)
    - Higher harmonics in the fits
    - …

- Absolute uncertainties at 1-2% level, relevant in higher z bins
- Maximum relative total uncertainty: ~10%

Results: A_{12} vs (z_1, z_2)

ArXiv:1506.05864
submitted for publication



A^{UC} and A^{UL} significantly $\neq 0$ in all the channels

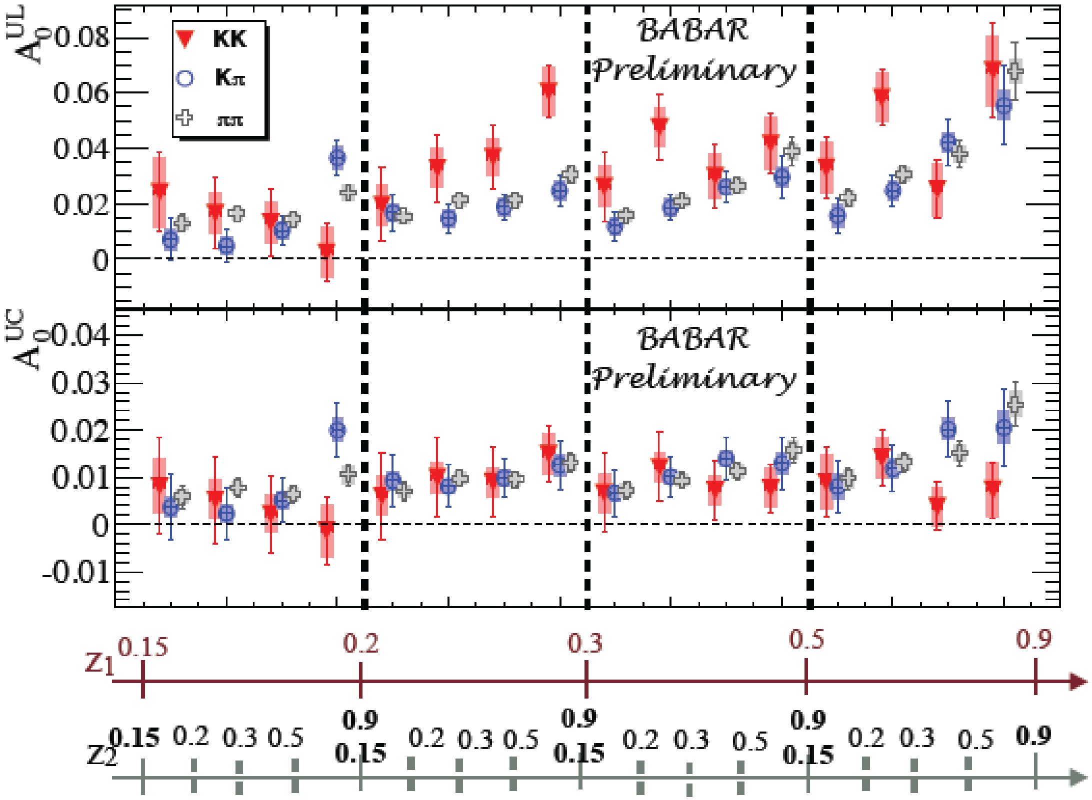
Consistent
z_1 vs z_2
symmetry

correlated asymmetries
(same exp. samples)

- Similar magnitude of the asymmetries in KK, Kπ, ππ
- KK asymmetries almost consistent with zero at low energies
- Increase of the asymmetry with z, more pronounced for U/L
- $A^{UC} < A^{UL}$
- A^{UL} KK, Kπ > A^{UL} ππ at large z: strange quark contribution

Results: A_0 vs (z_1, z_2)

ArXiv:1506.05864
submitted for publication



A^{UC} and A^{UL} significantly $\neq 0$ in all the channels

Consistent
z_1 vs z_2
symmetry

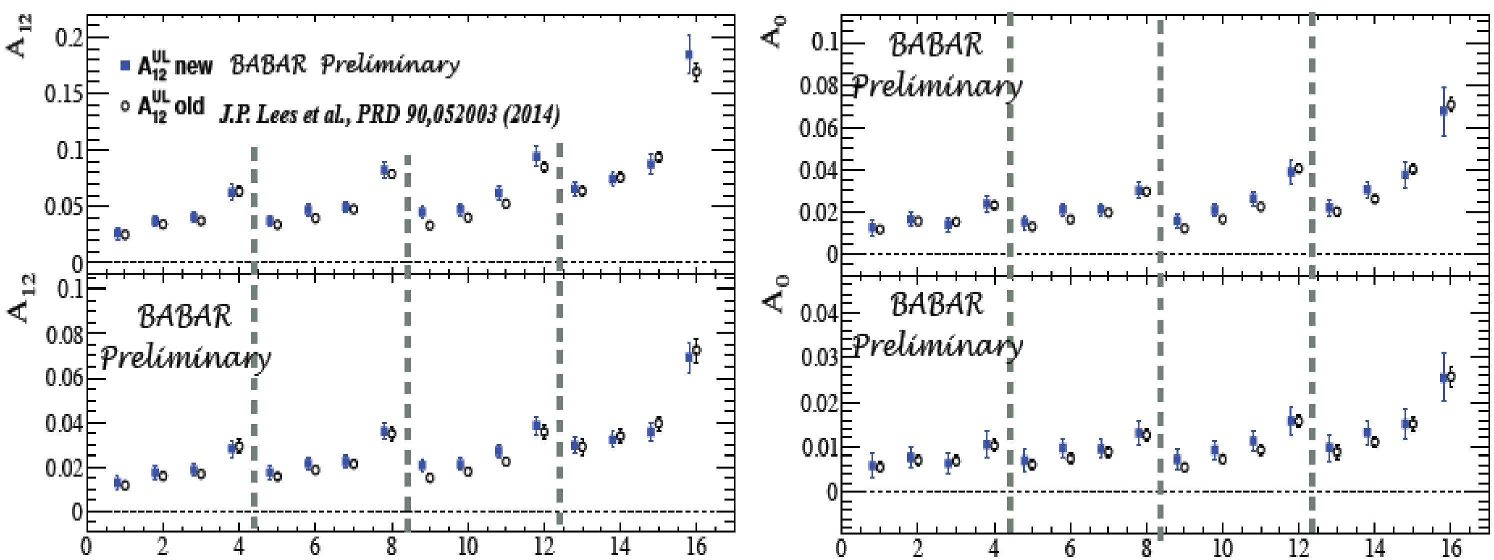
correlated asymmetries
(same exp. samples)

- **$A_0 < A_{12}$**
- Similar magnitude of the asymmetries in KK, Kπ, ππ
- Increase of the asymmetry with z
- A^{UL} KK large: related to strange quark favored FF

$\pi\pi$ consistency check

- Comparison of new $\pi\pi$ asymmetry evaluations with first *BABAR* published data (PR**D90** (2014))
  - Different kinematic regions, (z_1, z_2) intervals: rescaling needed by a factor depending on θ_{th}

$$\frac{R^{UL}}{R^{L}} = 1 + \cos(\phi_1 + \phi_2) \cdot \boxed{\frac{\langle \sin^2 \theta_{th} \rangle}{\langle 1 + \cos^2 \theta_{th} \rangle}} \cdot \frac{H_1^{\perp}(z)\overline{H}_1^{\perp}(z)}{D_1(z)\overline{D}_1(z)}$$



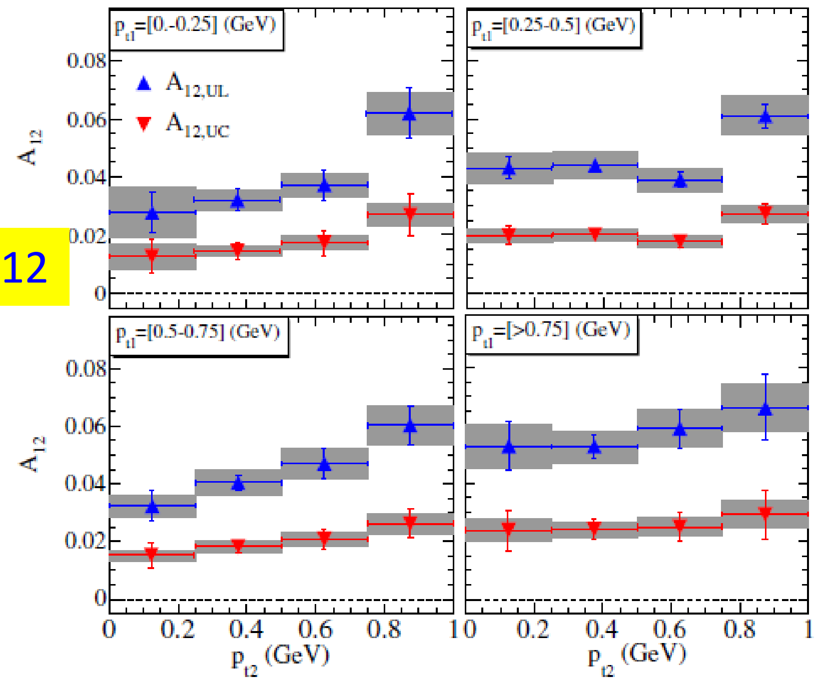
- Results after rescaling are consistent
- confidence in new results for KK and Kπ

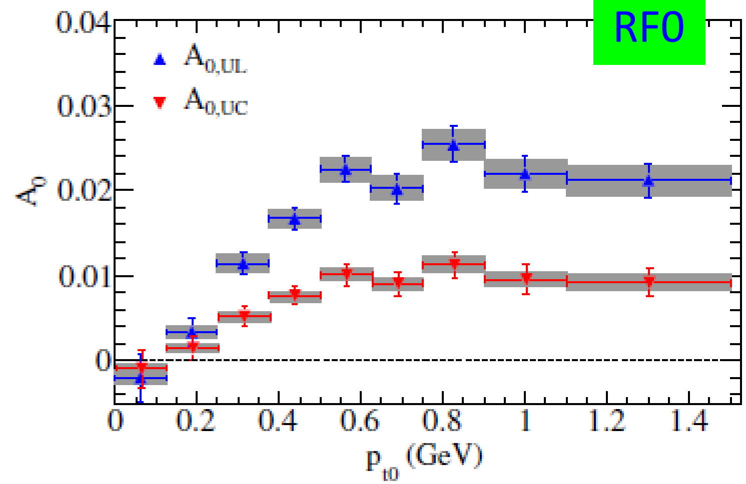
PRD90, 052003 (2014)

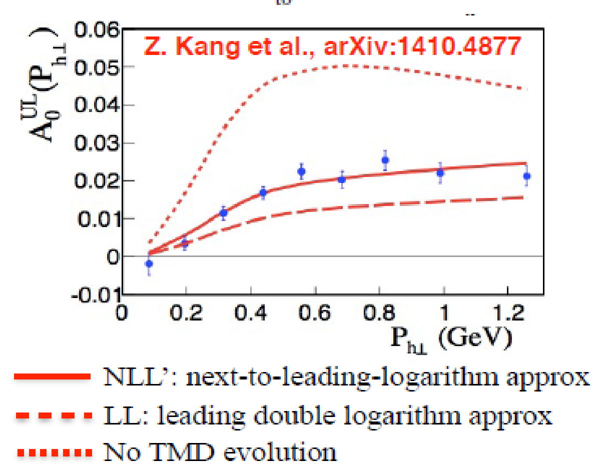
$\pi\pi$ asymmetries vs transverse momenta

- First measurement of Collins asymmetries vs p_t in e^+e^- annihilation @ Q^2 ~ 110 GeV^2 (time-like region)
- **$A^{UL}, A^{UC} \neq 0$**
- agreement with theoretical expectations

RF12





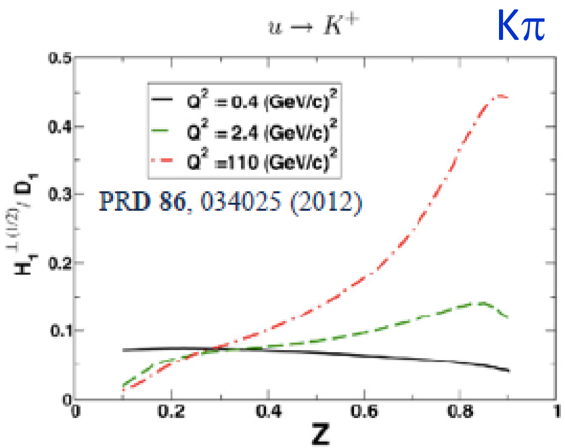


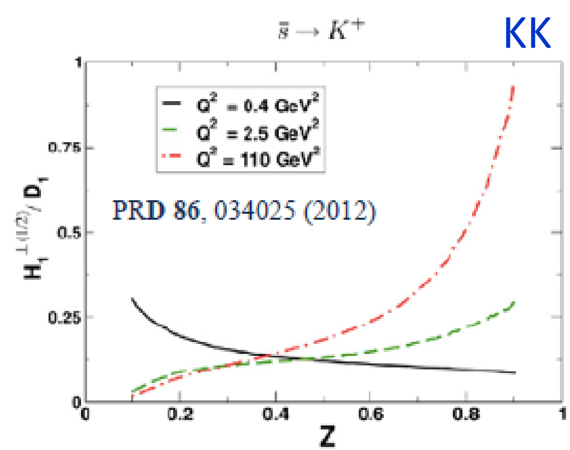
- **$A^{UC} < A^{UL}$**
- **$A_0 < A_{12}$**
- Interesting trend of A_0 vs p_{t0}

Summary and conclusions

- *BABAR* measured Collins asymmetries for charged hadron pairs in two-jets events, in two different reference frames
- The A^{UL} asymmetries are increasing with fractional energies for $\pi\pi$, πK and KK, the same cannot be concluded for A^{UC} for KK pairs
  - $\pi\pi$ results consistent with Belle results and also first new results from BESIII
- **First results for kaons**

Much better constraints can be provided to theory for the determination of the fragmentation functions of strange quarks



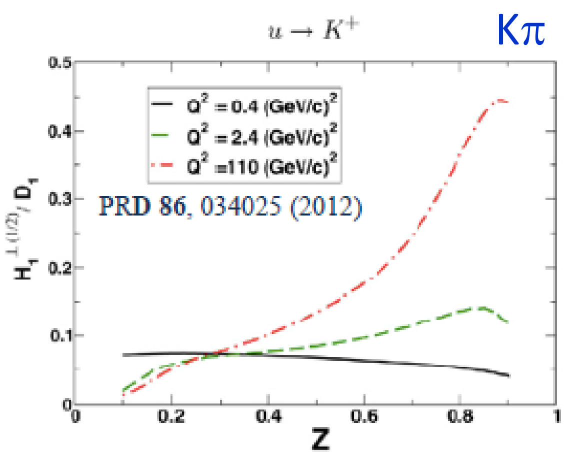


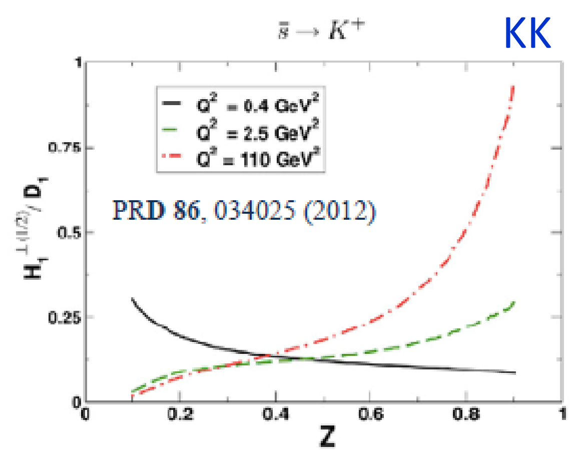
- Final goal: global fit of SIDIS data + e^+e^- data to extract both the Collins fragmentation functions and transversity PDF and improve the knowledge on hadron structures
- New results submitted to Phys Rev., ArXiv:1506.05864

Summary and conclusions

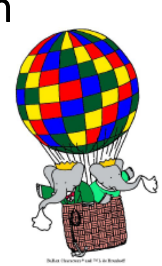
- *BABAR* measured Collins asymmetries for charged hadron pairs in two-jets events, in two different reference frames
- The A^{UL} asymmetries are increasing with fractional energies for $\pi\pi$, πK and KK, the same cannot be concluded for A^{UC} for KK pairs
  - $\pi\pi$ results consistent with Belle results and also first new results from BESIII
- **First results for kaons**

Much better constraints can be provided to theory for the determination of the fragmentation functions of strange quarks





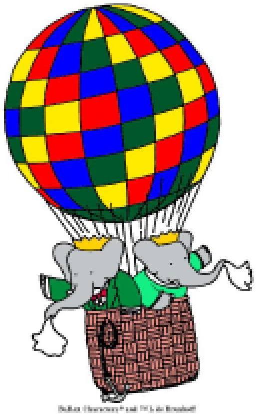
- Final goal: global fit of SIDIS data + e^+e^- data to extract both the Collins fragmentation functions and transversity PDF and improve the knowledge on hadron structures
- New results submitted to Phys Rev., ArXiv:1506.05864



THANK YOU FOR YOUR ATTENTION!

Credits: I. Garzia, D. N. Brown

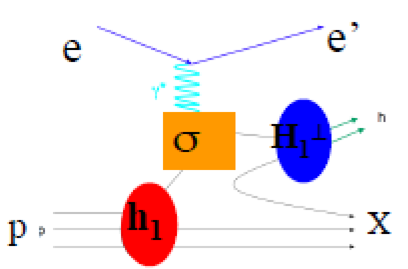
backup slides



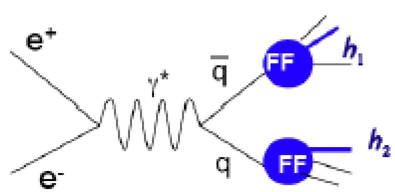
Global fits for FF extraction from data

- Global analyses determine simultaneously the Collins function and the transversity PDF based on
  - SIDIS data
  - e^+e^- annihilation data

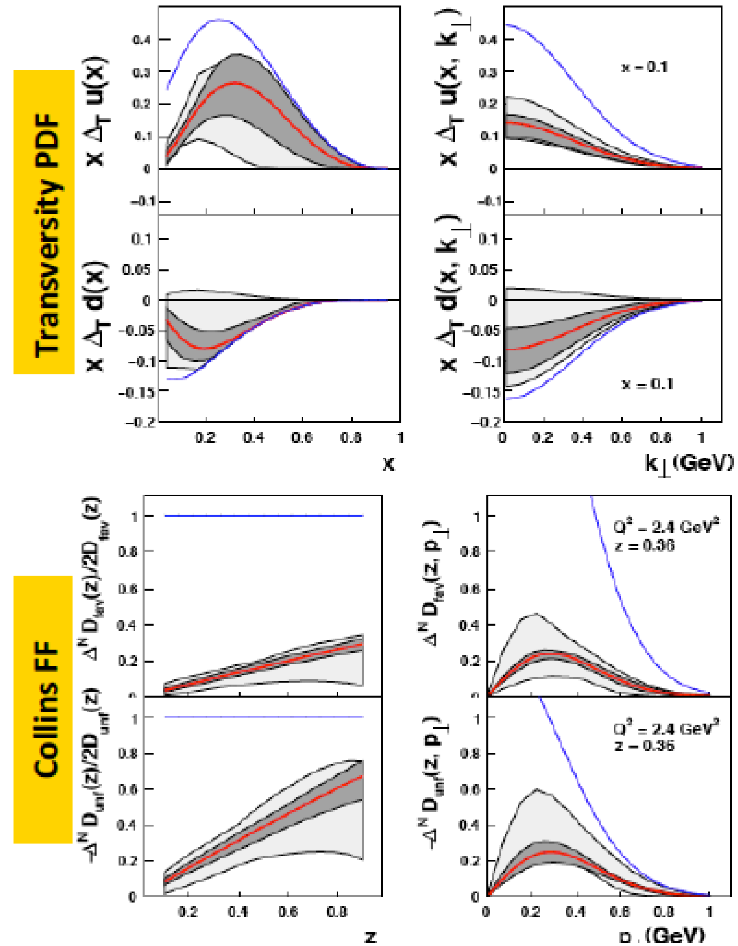
M. Anselmino et al.,
PR**D75**, 054032 (2007), NP Proc. Supp. **191**, 98



HERMES
PRL**94**, 012002 (2005)
COMPASS
NP**B765**, 31 (2007)



Belle
PRL**96**, 232002(2006)
PR**D78**, 03201 (2008)



- Advantages with new *BaBar* data:
  - Larger number of fractional energy intervals
  - First measurement ever of Collins asymmetries vs pion transverse momentum

Extraction of asymmetries

The uds Collins asymmetries for the three samples are the six unknowns of the following system of six equations

= Collins asymmetries for light hadrons

uds sample

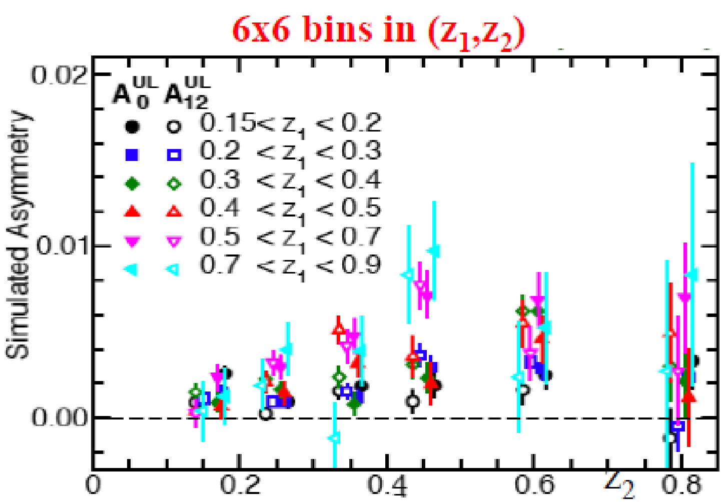
$$
\left\{
\begin{aligned}
A_{KK}^{meas} = {} & F_{uds}^{KK} \cdot (\xi_{KK}^{(KK)} A_{KK} + \xi_{K\pi}^{(KK)} A_{K\pi} + \xi_{\pi\pi}^{(KK)} A_{\pi\pi}) + \\
& F_{c\bar{c}}^{KK} \cdot (\xi_{KK}^{(KK)c\bar{c}} A_{KK}^{ch} + \xi_{K\pi}^{(KK)c\bar{c}} A_{K\pi}^{ch} + \xi_{\pi\pi}^{(KK)c\bar{c}} A_{\pi\pi}^{ch}) \\
A_{K\pi}^{meas} = {} & F_{uds}^{K\pi} \cdot (\xi_{KK}^{(K\pi)} A_{KK} + \xi_{K\pi}^{(K\pi)} A_{K\pi} + \xi_{\pi\pi}^{(K\pi)} A_{\pi\pi}) + \\
& F_{c\bar{c}}^{K\pi} \cdot (\xi_{KK}^{(K\pi)c\bar{c}} A_{KK}^{ch} + \xi_{K\pi}^{(K\pi)c\bar{c}} A_{K\pi}^{ch} + \xi_{\pi\pi}^{(K\pi)c\bar{c}} A_{\pi\pi}^{ch}) \\
A_{\pi\pi}^{meas} = {} & F_{uds}^{\pi\pi} \cdot (\xi_{KK}^{(\pi\pi)} A_{KK} + \xi_{K\pi}^{(\pi\pi)} A_{K\pi} + \xi_{\pi\pi}^{(\pi\pi)} A_{\pi\pi}) + \\
& F_{c\bar{c}}^{\pi\pi} \cdot (\xi_{KK}^{(\pi\pi)c\bar{c}} A_{KK}^{ch} + \xi_{K\pi}^{(\pi\pi)c\bar{c}} A_{K\pi}^{ch} + \xi_{\pi\pi}^{(\pi\pi)c\bar{c}} A_{\pi\pi}^{ch})
\end{aligned}
\right.
$$

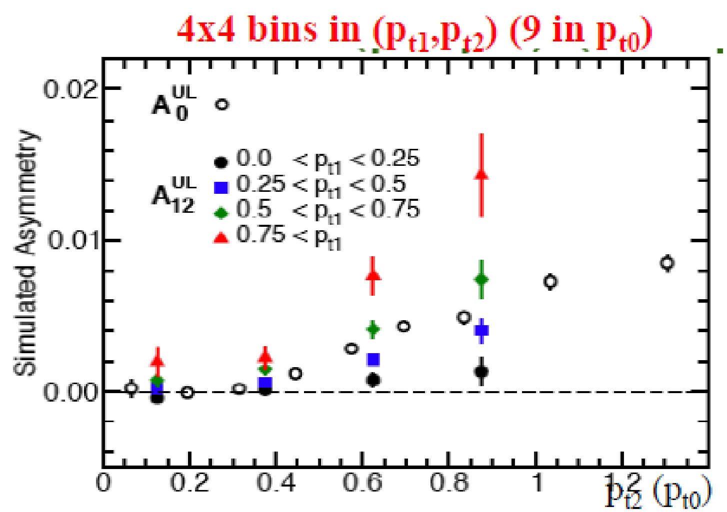
c enhanced sample

$$
\left\{
\begin{aligned}
A_{KK}^{D^*} = {} & f_{uds}^{KK} \cdot (\xi_{KK}^{(KK)D^*} A_{KK} + \xi_{K\pi}^{(KK)D^*} A_{K\pi} + \xi_{\pi\pi}^{(KK)D^*} A_{\pi\pi}) + \\
& f_{c\bar{c}}^{KK} \cdot (\xi_{KK}^{(KK)c\bar{c}-D^*} A_{KK}^{ch} + \xi_{K\pi}^{(KK)c\bar{c}-D^*} A_{K\pi}^{ch} + \xi_{\pi\pi}^{(KK)c\bar{c}-D^*} A_{\pi\pi}^{ch}) \\
A_{K\pi}^{D^*} = {} & f_{uds}^{K\pi} \cdot (\xi_{KK}^{(K\pi)D^*} A_{KK} + \xi_{K\pi}^{(K\pi)D^*} A_{K\pi} + \xi_{\pi\pi}^{(K\pi)D^*} A_{\pi\pi}) + \\
& f_{c\bar{c}}^{K\pi} \cdot (\xi_{KK}^{(K\pi)c\bar{c}-D^*} A_{KK}^{ch} + \xi_{K\pi}^{(K\pi)c\bar{c}-D^*} A_{K\pi}^{ch} + \chi_{\pi\pi}^{(K\pi)c\bar{c}-D^*} A_{\pi\pi}^{ch}) \\
A_{\pi\pi}^{D^*} = {} & f_{uds}^{\pi\pi} \cdot (\xi_{KK}^{(\pi\pi)D^*} A_{KK} + \xi_{K\pi}^{(\pi\pi)D^*} A_{K\pi} + \xi_{\pi\pi}^{(\pi\pi)D^*} A_{\pi\pi}) + \\
& f_{c\bar{c}}^{\pi\pi} \cdot (\xi_{KK}^{(\pi\pi)c\bar{c}-D^*} A_{KK}^{ch} + \xi_{K\pi}^{(\pi\pi)c\bar{c}-D^*} A_{K\pi}^{ch} + \xi_{\pi\pi}^{(\pi\pi)c\bar{c}-D^*} A_{\pi\pi}^{ch})
\end{aligned}
\right.
$$

Asymmetry binning and MC corrections

- The Collins effect for pions is analyzed in bins of
  - Fractional energy: 6x6 (z_1,z_2)
  - Transferred momentum: 4x4 (pt_1, pt_2) (9 in p_{t0})
  - Polar angle: $\cos\theta_{th}$ or $\cos\theta_2$

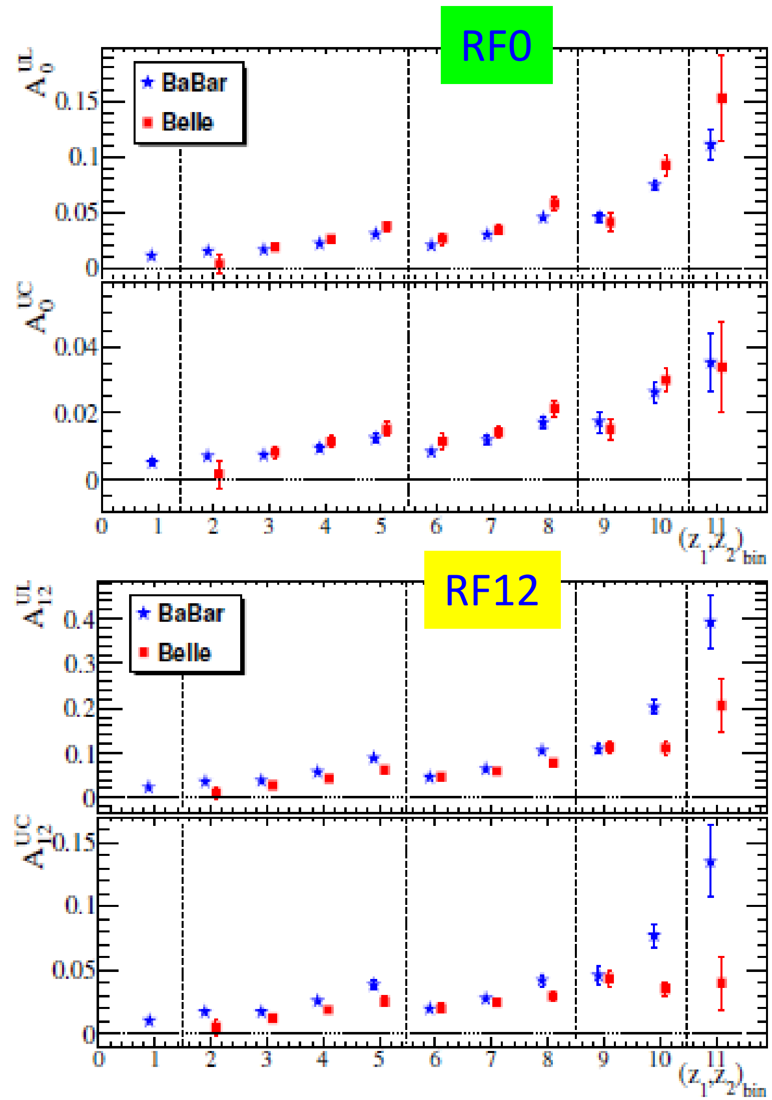




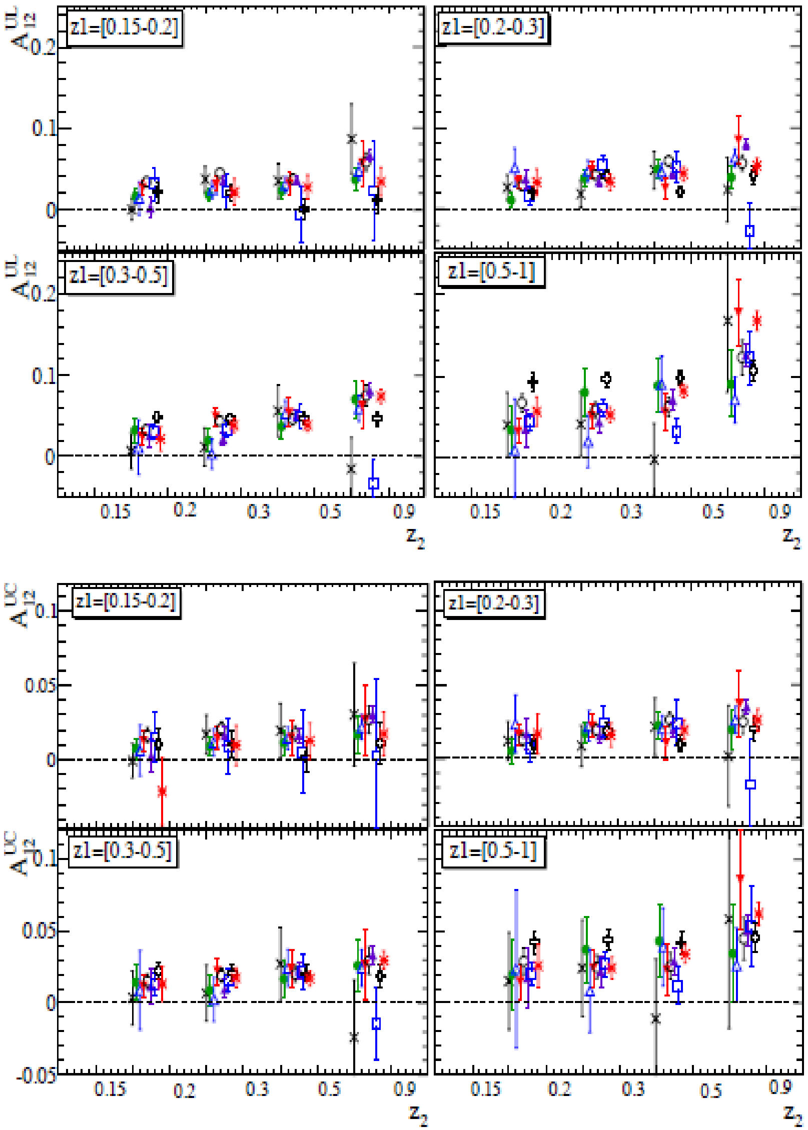
- The simulated data show the same dependence
  - Detector acceptance effects
  - Bin-by-bin correction needed
  - Source of systematic uncertainties

Comparison of *BaBar* vs Belle asymmetries for pions

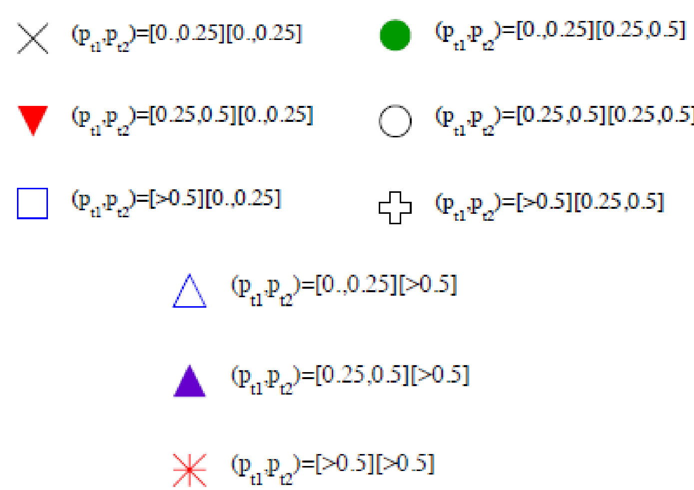
- Same Q^2 (110 GeV^2):
  - *BaBar*: 468 fb^{-1}
  - Belle: 547 fb^{-1}
    - PR**D86**, 039905(E)(2012)
- RF0
  - Good agreement
- RF12
  - Large discrepancy in the last two z bins
    - Different correction applied for the dilution due to thrust axis
    - Different maximum momentum selection



p_t and z dependence of pion asymmetries

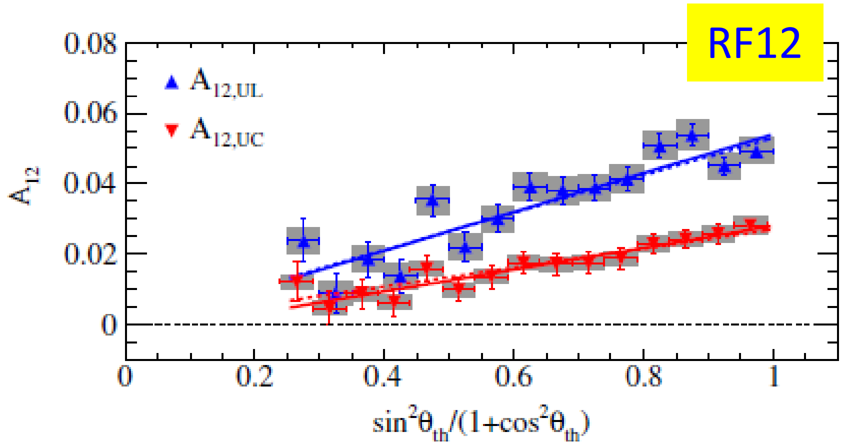


- Study in RF12
- $4(z_1,z_2) \otimes 3(p_{t1},p_{t2})$ intervals
- Test of the factorization of Collins functions
- Tool to access p_t vs z correlations

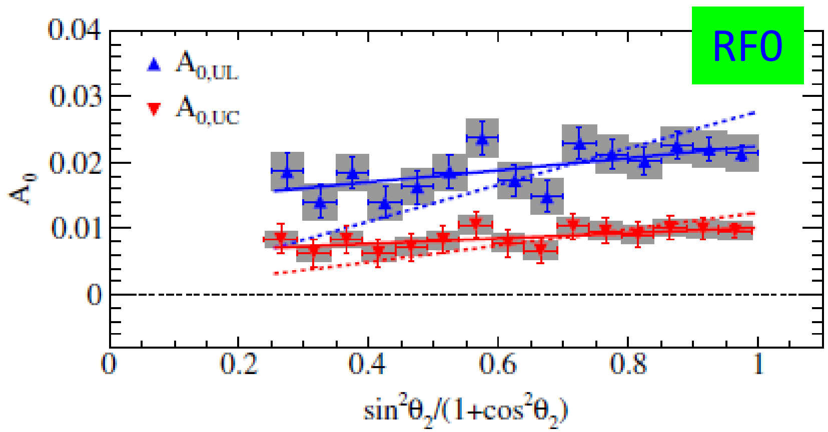


$\pi\pi$ asymmetries vs polar angle

- Angular dependence studied after integration over fractional energies and transverse momenta



- A_{12} ~ $\cos(\phi_1+\phi_2)\langle\sin^2\theta\rangle/\langle 1+\cos^2\theta\rangle$
- Linear fit: intercept consistent with zero
- Agreement with first Belle results (PR**D86**, 039905 (2012))



- A_0 ~ $\cos(2\phi_0)\langle\sin^2\theta\rangle/\langle 1+\cos^2\theta\rangle$
- Linear fit: intercept is non-zero
- Worse estimation of the $q\bar{q}$ direction in RF0
- Agreement with first Belle results (PR**D86**, 039905 (2012))