DIS 2015 - XXIII International Workshop on Deep-Inelastic Scattering and Related Subjects

Collins asymmetries in inclusive charged KK and Kπ pairs at BaBar

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on behalf of the BaBar Collaboration

Introduction: the Collins effect

Our understanding of the hadronic physics depends strongly on what we know about the parton distributions functions (PDFs) and **fragmentation functions** (FFs)

- Universal
- Non-perturbative objects

Transverse Momentum Dependent (TMD) FFs ⇒ to study the spin-dependent observables

- when only spinless hadrons (π, K) are considered, we have:

q↑→hX: $$D_1^{q\uparrow}(z,\mathbf{P}_\perp;s_q) = D_1^q(z,P_\perp) + \frac{P_\perp}{zM_h}H_1^{\perp q}(z,P_\perp)\,\mathbf{s}_q\cdot(\mathbf{k}_q\times\mathbf{P}_\perp)$$

Unpolarized FF

Collins FF [NP**B 396**, 161 (1993)]: chiral-odd function, related to the probability that a transversely polarized quark (q↑) fragments into a spinless hadron

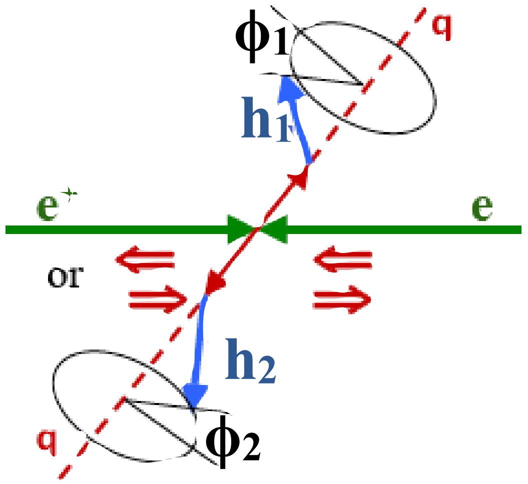
Physics motivation:

- e^+e^- annihilation experiments are the most clean environment to study fragmentation processes
- evolution of TMD objects
- Global analysis (PRD 78,032011 (2007); PRD 87,094019 (2013), PRD 91,014034 (2015)):
  - combines Semi Inclusive Deep Inelastic Scattering (SIDIS) and e^+e^- data
  - extraction of $H^\perp{}_1$ and transversity parton distributions h_1 for the "u" and "d" quarks

Collins effect in e^+e^- annihilation

In $e^+e^- \rightarrow q\bar{q}$, spins unknown, but $s_q \parallel s_{\bar{q}}$ whit transverse spin component ~ $\sin^2\theta$

- exploit this correlation by using hadrons in opposite jets
- define **favored** ($u \rightarrow \pi^+$, $d \rightarrow \pi^-$) and **disfavored** ($d \rightarrow \pi^+$, $u \rightarrow \pi^-$, $s(\bar{s}) \rightarrow \pi^\pm$) FFs

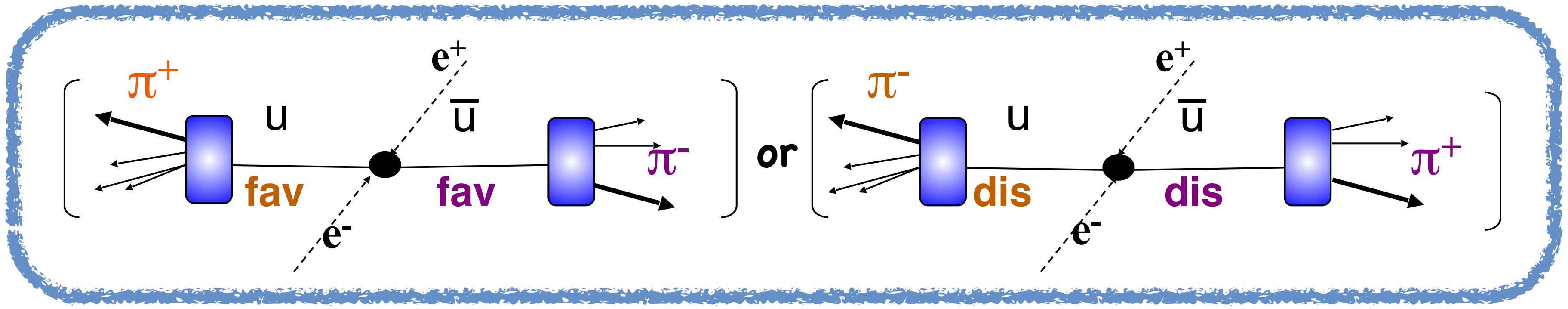


$$e^+e^- \rightarrow q\bar{q} \rightarrow h_1 h_2 X \;\; (q=u,d,s) \;\; \Rightarrow \sigma \propto \underbrace{\cos(\phi_1+\phi_2)}\, H_1^{\perp(h1)} \times H_1^{\perp(h2)}$$

Azimuthal modulation wrt the quark spin direction:
Collins effect (or Collins asymmetry)

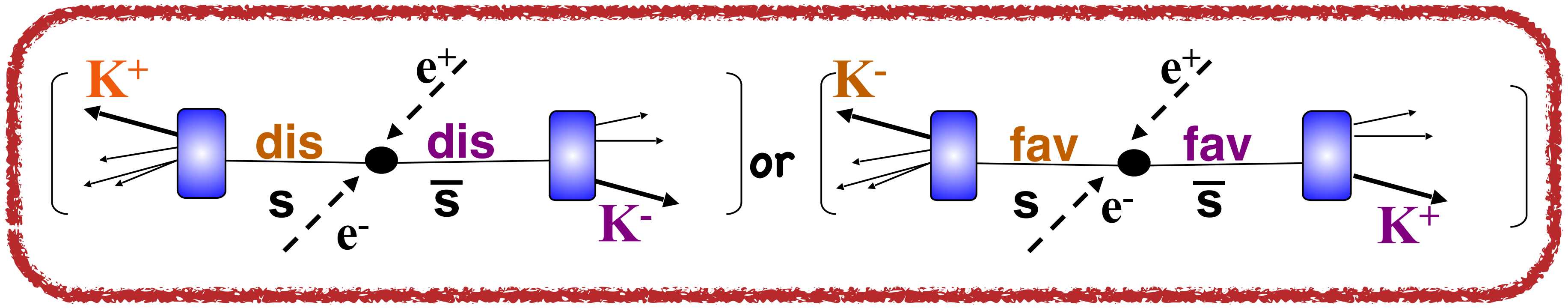
Example: Unlike $\pi\pi$ pairs (U)

Collins asymmetry for $\pi\pi$
PRD 90,052003 (2014)



Example: Unlike KK pairs (U)

Collins asymmetry for KK:
Favored contribution to the fragmentation of the strange quark

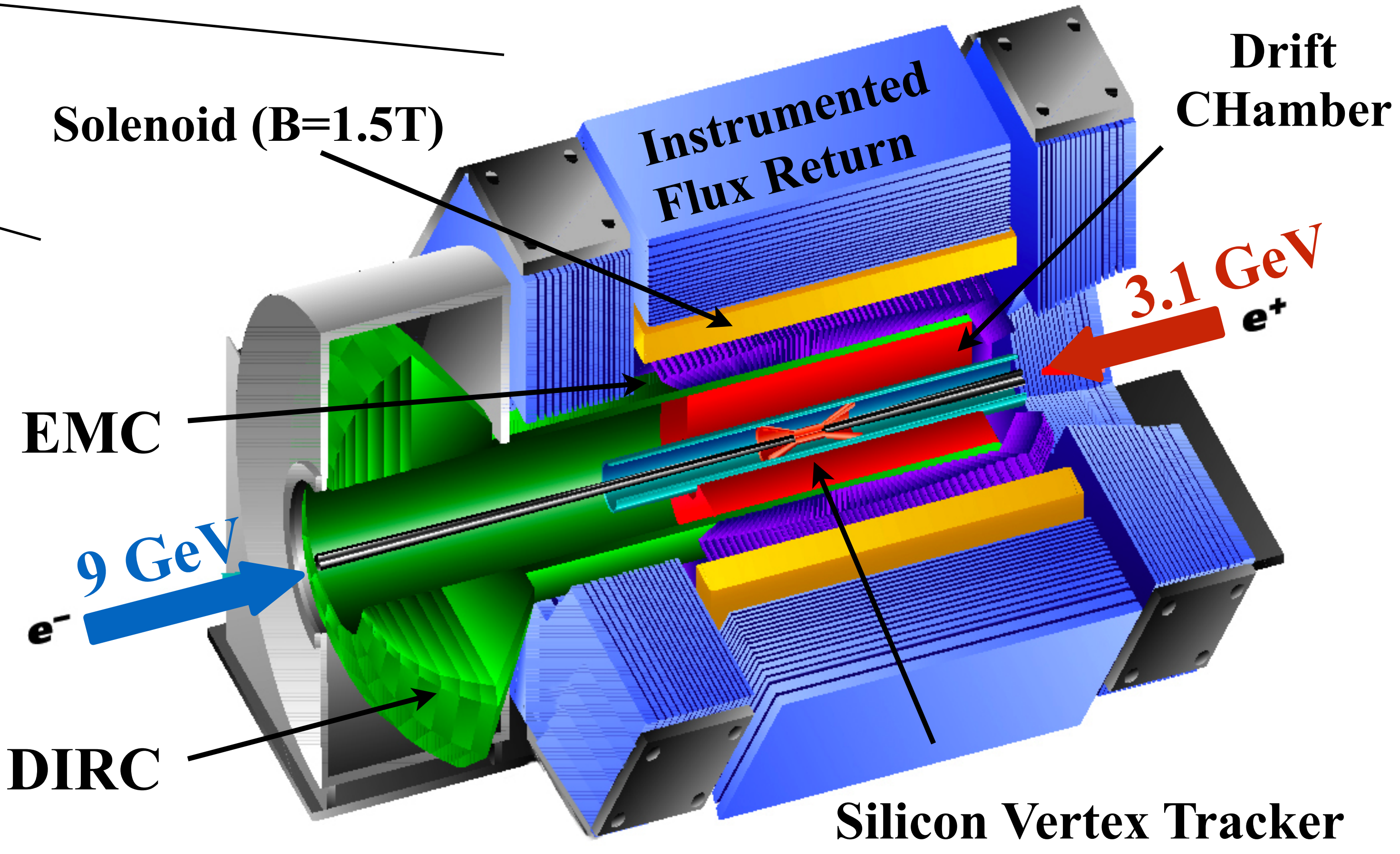


Collins asymmetries for KK pairs not yet available

PEP-II and BaBar Detector

- Asymmetric e^+e^- collider operating at the $\Upsilon(4S)$ resonance ($\sqrt{s}$=10.58 GeV)
  - High Energy Ring (**HER**): 9.0 GeV e^-
  - Low Energy Ring (**LER**): 3.1 GeV e^+
  - c.m.-lab boost, $\beta\gamma \approx 0.56$

- High luminosity: $\mathcal{L}$ ~ **468 fb^{-1}** used here

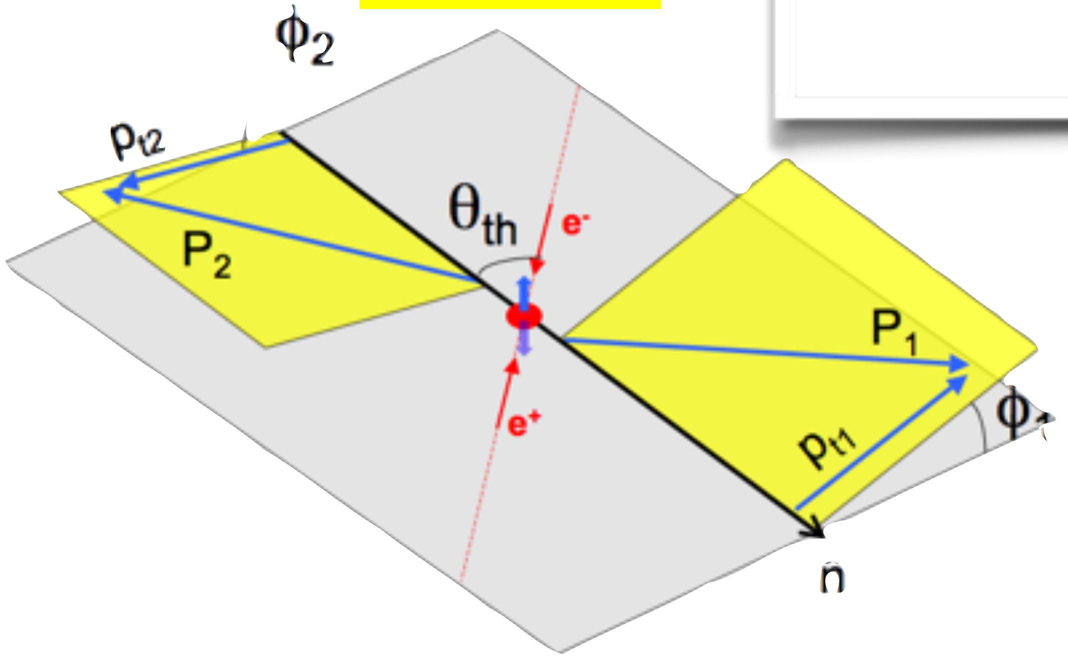


- Asymmetric detector
  - c.m. acceptance $-0.9<\cos\theta^*<0.85$ wrt e^- beam
- Excellent performance
  - good tracking, mass resolution
  - good γ, π^0 reconstruction
  - full e, μ, π, K, and p identification

NIM A479,1 (2002),
update: NIM A729, 615 (2013)

Reference frames

RF12

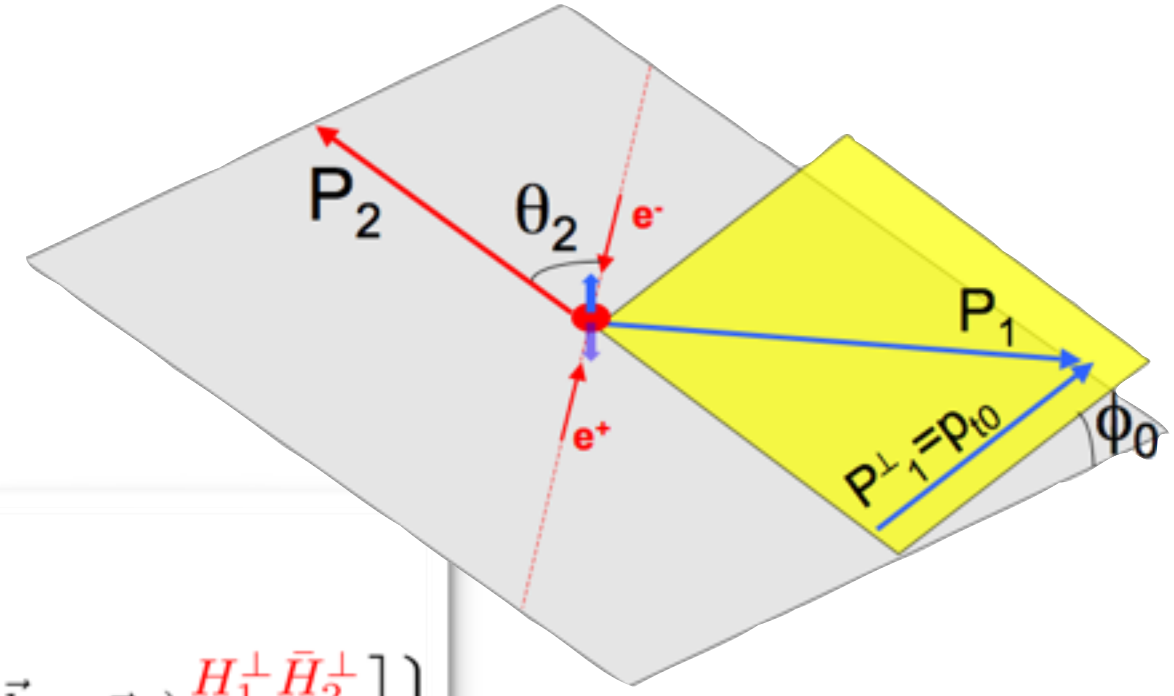


$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2 d\phi_1 d\phi_2} = \sum_{q,\bar{q}} \frac{3\alpha^2}{Q^2}\frac{e_q^2}{4} z_1^2 z_2^2 \Big[(1+cos^2\theta) D_1^{q,(0)}(z_1)\bar{D}_1^{q,(0)}(z_2) + \\ + \quad sin^2(\theta) cos(\phi_1+\phi_2) H_1^{\perp,(1),q}(z_1)\bar{H}_1^{\perp,(1),q}(z_2)\Big]$$

All quantities in e+e- center of mass

θ: angle between the e^+e^- axis and the thrust axis;
$\varphi_{1,2}$: azimuthal angles between $P_{h1(h2)}$ and the scattering plane

RF0



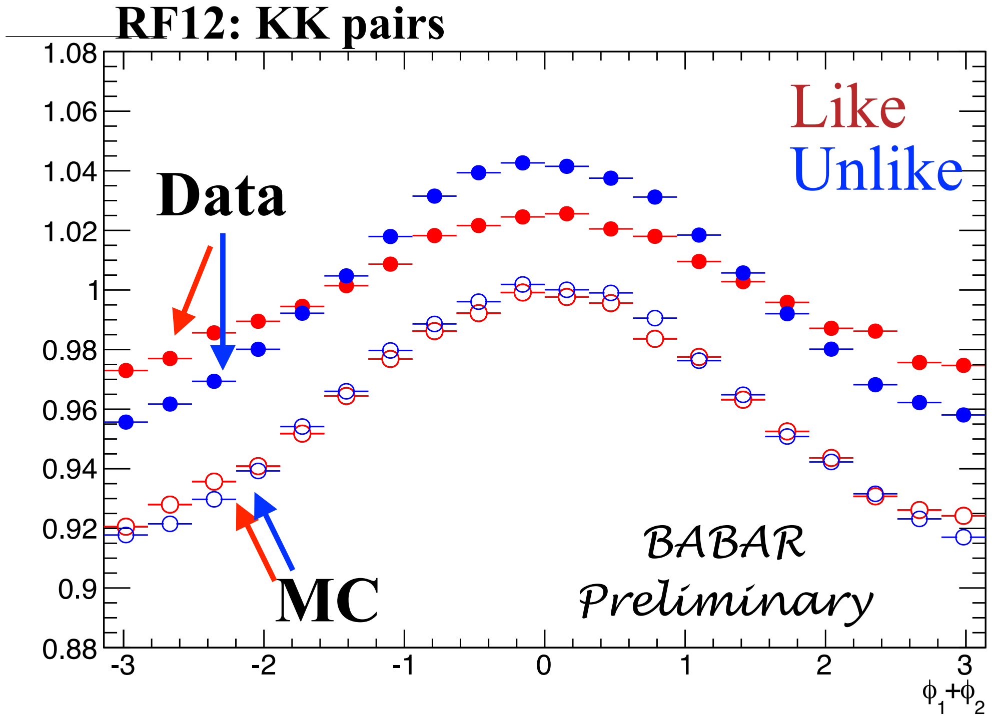
θ_2: angle between the e^+e^- axis and P_{h2};
φ_0: angle between the plane spanned by P_{h2} and the e^+e^- axis, and the direction of P_{h1} perpendicular to P_{h2}.

All quantities in e+e- center of mass

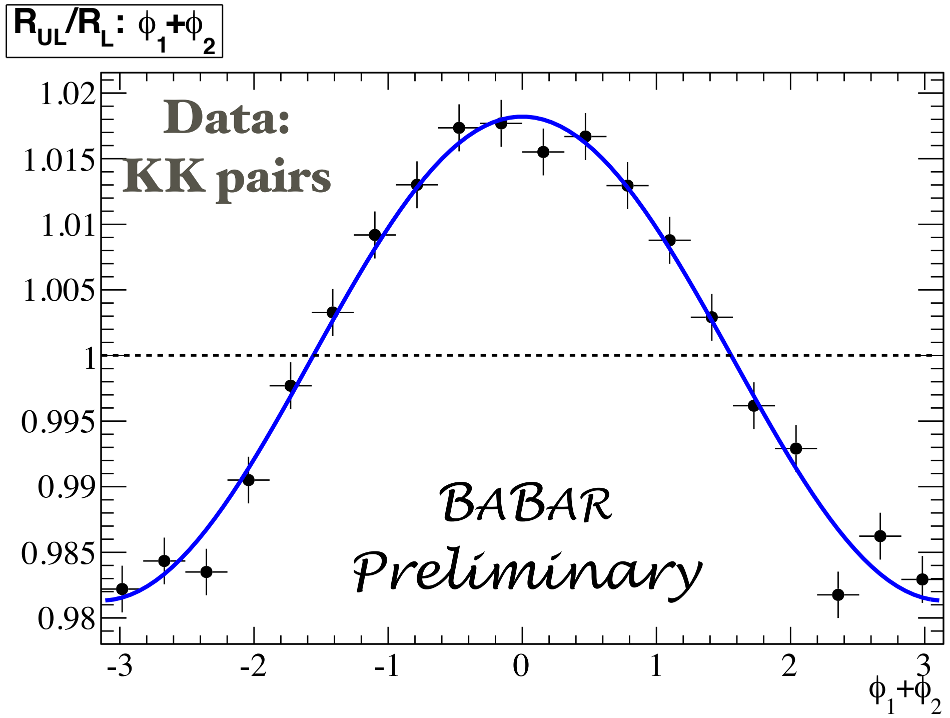
$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2 d^2\vec{q}_T} = \frac{3\alpha^2}{Q^2} z_1^2 z_2^2 \Big\{A(y)\mathcal{F}[D_1\bar{D}_2] + \\ + \quad B(y) cos(2\phi_0)\mathcal{F}\Big[(2\hat{h}\cdot\vec{k}_T\hat{h}\cdot\vec{p}_T - \vec{k}_T\cdot\vec{p}_T)\frac{H_1^\perp \bar{H}_2^\perp}{M_1 M_2}\Big]\Big\}$$

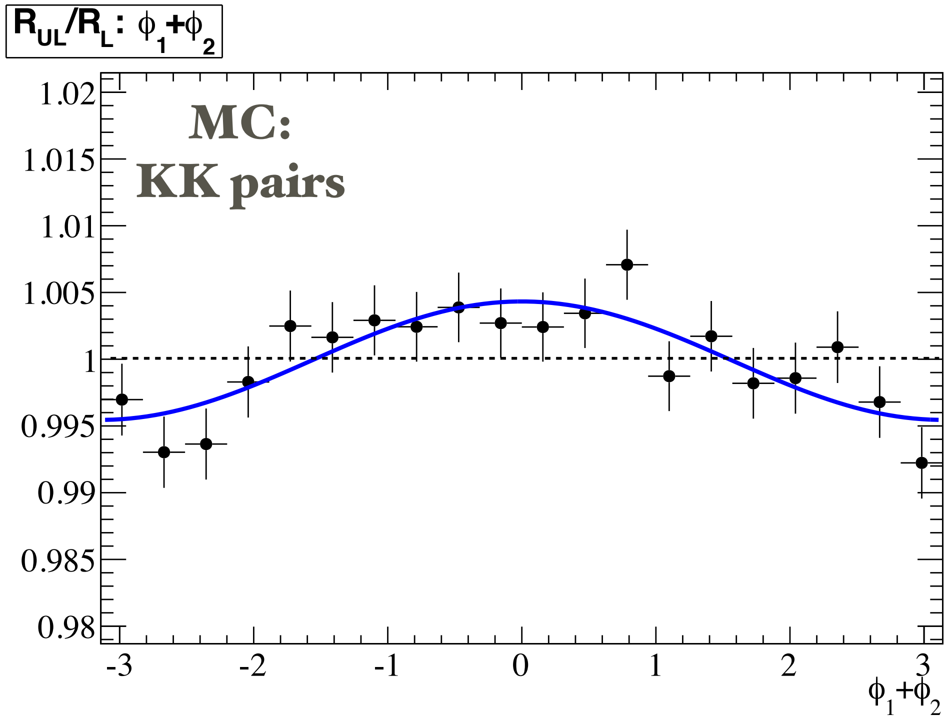
Measurement of Collins effect

- Normalized azimuthal distribution for hadron pair with same charge (L), opposite charge (U), and the sum of the two samples (C)
- Collins effect is not simulated in uds-MC → strong azimuthal MC modulation principally due to the detector acceptance
- nonzero Collins effect in data sample → different combinations of fav and dis FF for L, U, and C



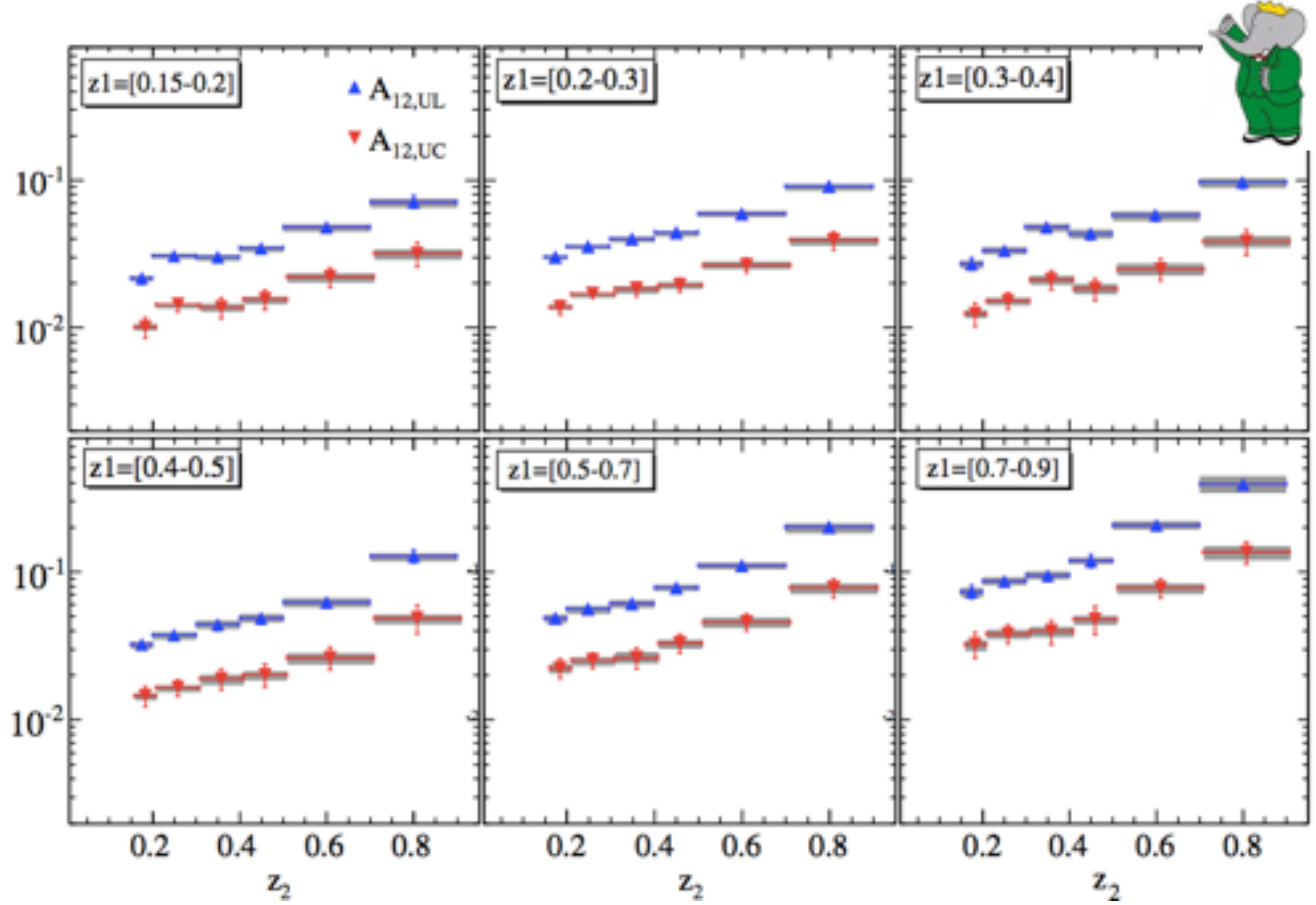
Double ratio of U/L and U/C normalized distributions: Collins effect measured by fitting the double ratio distributions with the function B+A·cos(ϕ_i)



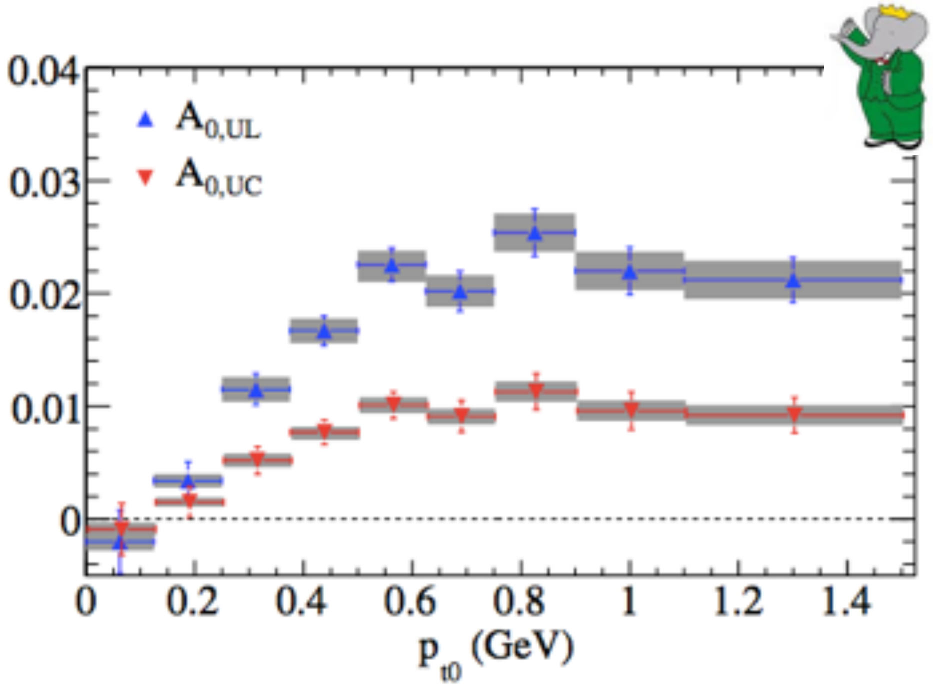


BaBar results for ππ pairs

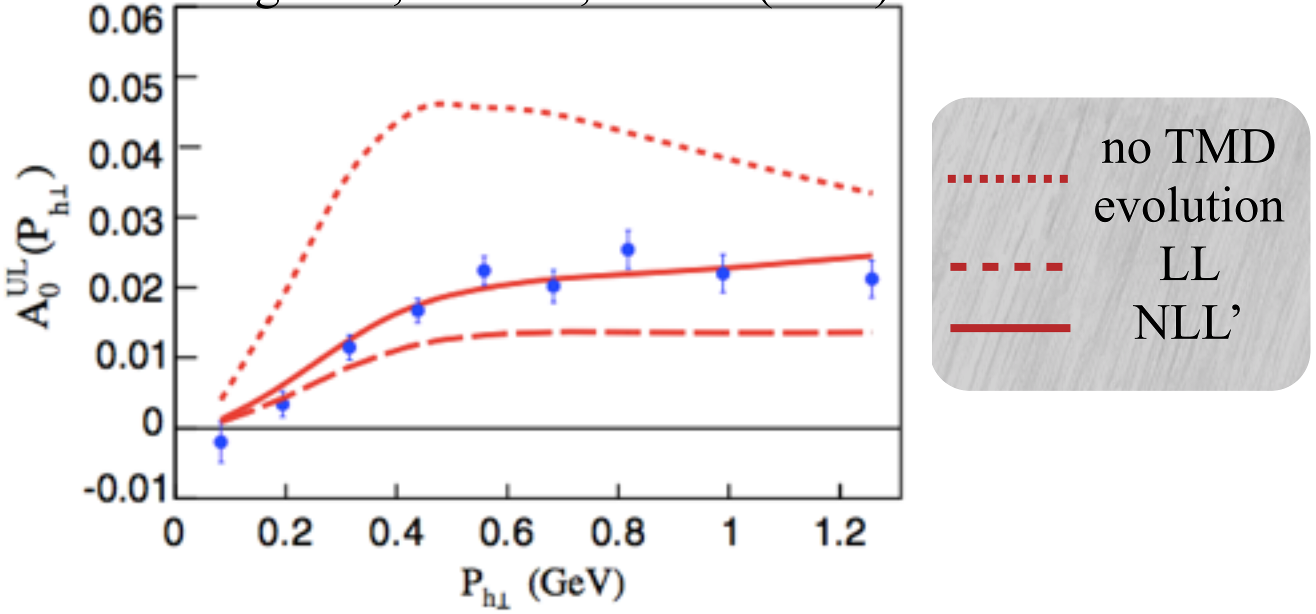
PRD 90,052003 (2014)



- Collins asymmetry measured as function of
  - 6×6 bins of pion fractional energy (similar behavior in RF0, for both UL and UC)
  - 4×4 bins of (p_{t1},p_{t2}) in RF12
  - 9 bins of p_{t0} in RF0
  - asymmetry vs. $\sin^2\theta_{th}/(1+\cos^2\theta_{th})$ and $\sin^2\theta_2/(1+\cos^2\theta_2)$



Kang et al., PRD 91,071501 (2015)



Analysis Strategy

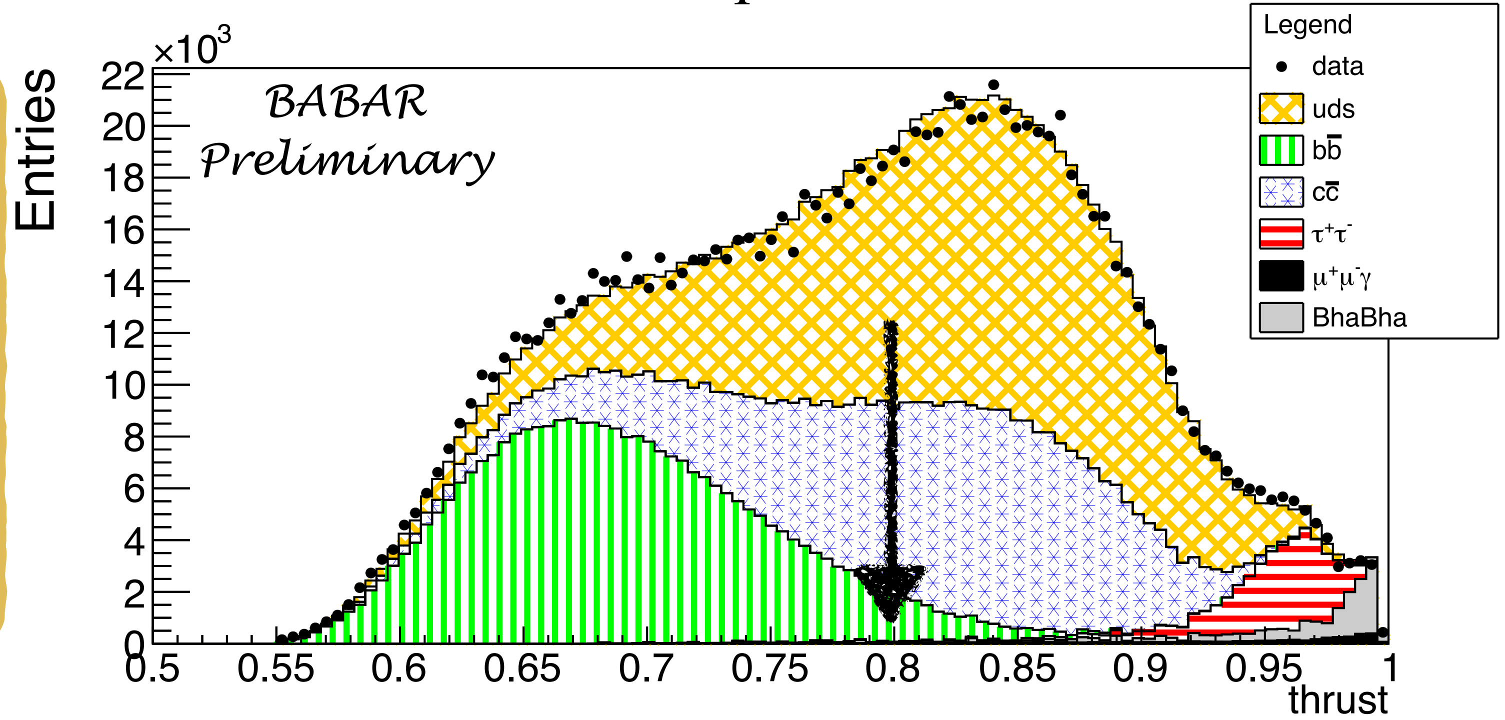
- Goal: **simultaneous measurement of KK, Kπ**, and **ππ** pairs
  - Event and track selection
  - we identify the three sample of hadron pairs (KK, Kπ, ππ), and we divide the two hadrons in opposite jets using the thrust axis
  - we measure the azimuthal angles ϕ_1 and ϕ_2 in RF12, and ϕ_0 in RF0
  - we construct the normalized raw distributions for like (L), Unlike (U) and Charged (C=U+L) hadron pairs: $R^i=N^i(\phi)/<N>$
  - we calculate the ratios of normalized distributions: U/L and U/C and we fit these distributions
  - we extract the Collins asymmetries and we correct for the K/π misidentification, background contributions,…
  - we study systematic effects
- RESULTS: **4x4 (z_1,z_2) bins, where $z_{1,2}=2E_h/\sqrt{s}$ is the hadron fractional energy**
  - **$z_{1,2}$ = (0.15-0.2), (0.2-0.3), (0.3-0.5), (0.5-0.9)**
  - **RF12 and RF0**
  - **A^{UL} and A^{UC}**

Event and track selection

More stringent cuts optimized in order to reduce biases on the KK pairs

EVENT SELECTION

- Number of charged tracks > 2
- Selection of two jets topology: thrust > 0.8
- **$|\cos\theta_{thrust}|<0.6$**
- **Visible energy $E_{vis} > 11$ GeV**
- **Most energetic photon $E_{\gamma} < 2$ GeV**



Thrust axis: charged tracks + neutral candidates; thrust axis direction chosen random

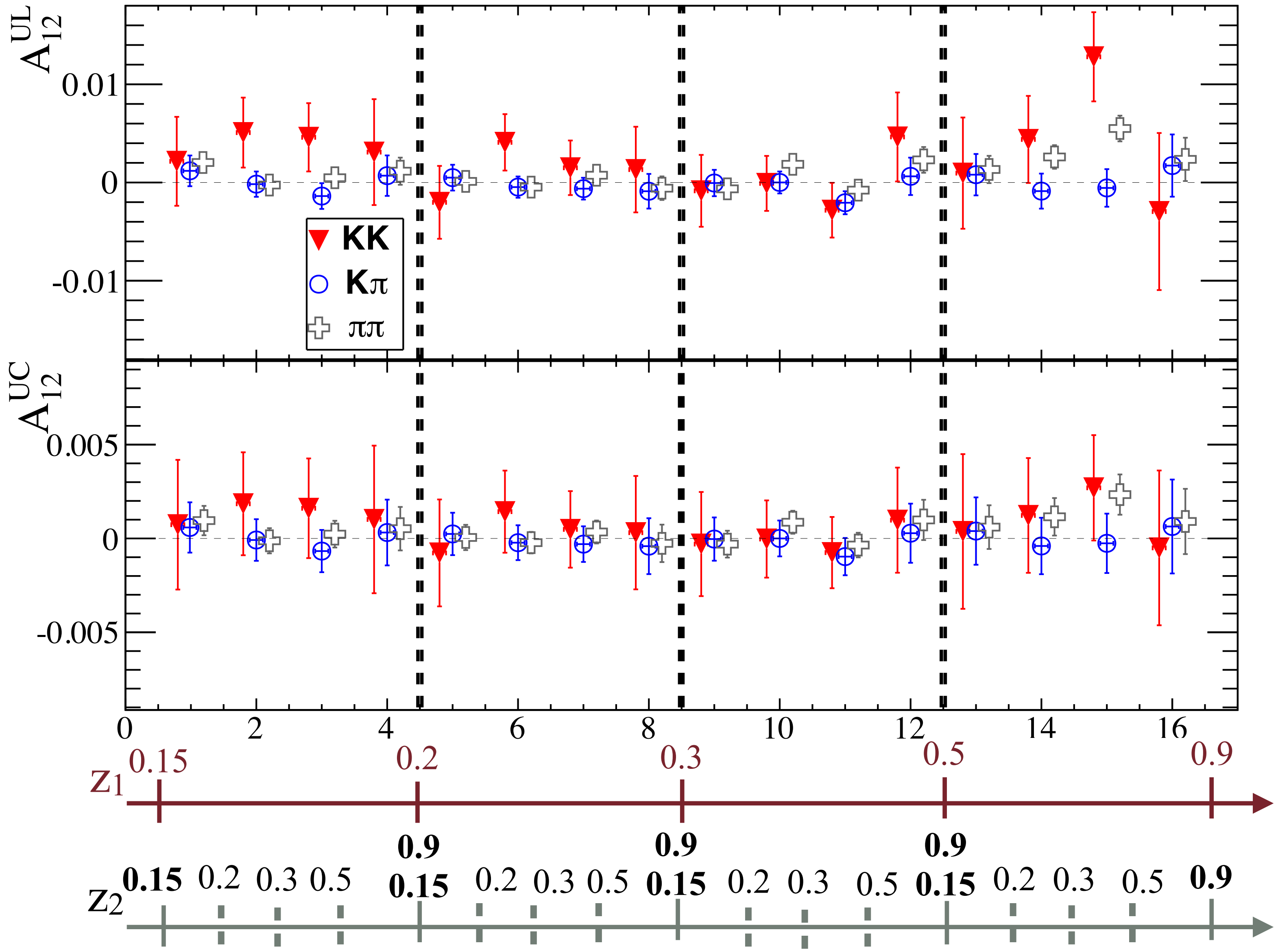
TRACK SELECTION

- Electrons and muons veto
- K and π in the DIRC acceptance region
- K/π fractional energy z: $0.15 < z < 0.9$
- Opening angle $\theta_{h\text{-}thrust}$ of hadron with respect to the thrust axis < 45°
- $Q_t<3.5$ GeV, where Q_t is the transverse momentum of the virtual photon in the two hadrons center-of-mass energy

Study of MC asymmetry

Small asymmetry measured in the MC sample

- always much smaller than asymmetry measured in data



Linear configuration of (z_1,z_2) bins used for the comparison

Detailed studies show that the main source of the MC asymmetries come from ISR

- E_{vis} >11 GeV to reduce this contribution for KK pairs

- Similar distributions in the RF0 frame
- Final results will be corrected for the small residual MC bias

Extraction of KK, Kπ and ππ asymmetries (I)

GOAL: simultaneous extraction of the asymmetries corrected for backgrounds and K/π misidentification for each interval of fractional energy

- 3 samples: KK, Kπ, ππ
- we fit independently the double ratio distributions of the three samples

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

background contribution

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$$A^{\text{meas}}_{KK} = F^{\text{KK}}_{uds} \cdot A^{Collins}_{KK} + \sum_i F^{KK}_i \cdot A^i_{KK}$$

background contribution

1. **Background sources:**
   - mainly from **$e^+e^- \rightarrow c\bar{c}$ events** (more than 30%); smaller contribution from $B\bar{B}$, $\tau^+\tau^-$ (A_{bb}~A_τ~ 0)
     - we construct a D^*-enhanced MC and data control samples
     - we calculate from MC the fraction ($F(f)_{\text{sig/bkg}}^{\text{hh}}$) of hadron pairs coming from signal (uds) and background events ($c\bar{c}$, $B\bar{B}$, $\tau^+\tau^-$)

$D^{*\pm} \rightarrow D^0\pi^\pm$, $D^0 \rightarrow K\pi$, $D^0 \rightarrow K3\pi$, $D^0 \rightarrow K\pi\pi^0$, $D^0 \rightarrow K_S\pi\,\pi$

$$\begin{cases} A^{\text{meas}}_{KK} = F^{KK}_{uds} \cdot A^{Collins}_{KK} + F^{KK}_{c\bar{c}} \cdot A^{charm}_{KK} \\ A^{D^*}_{KK} = f^{KK}_{uds} \cdot A^{Collins}_{KK} + f^{KK}_{c\bar{c}} \cdot A^{charm}_{KK} \end{cases}$$

Fraction of hadron pairs in the data sample (D^*-enhanced sample)

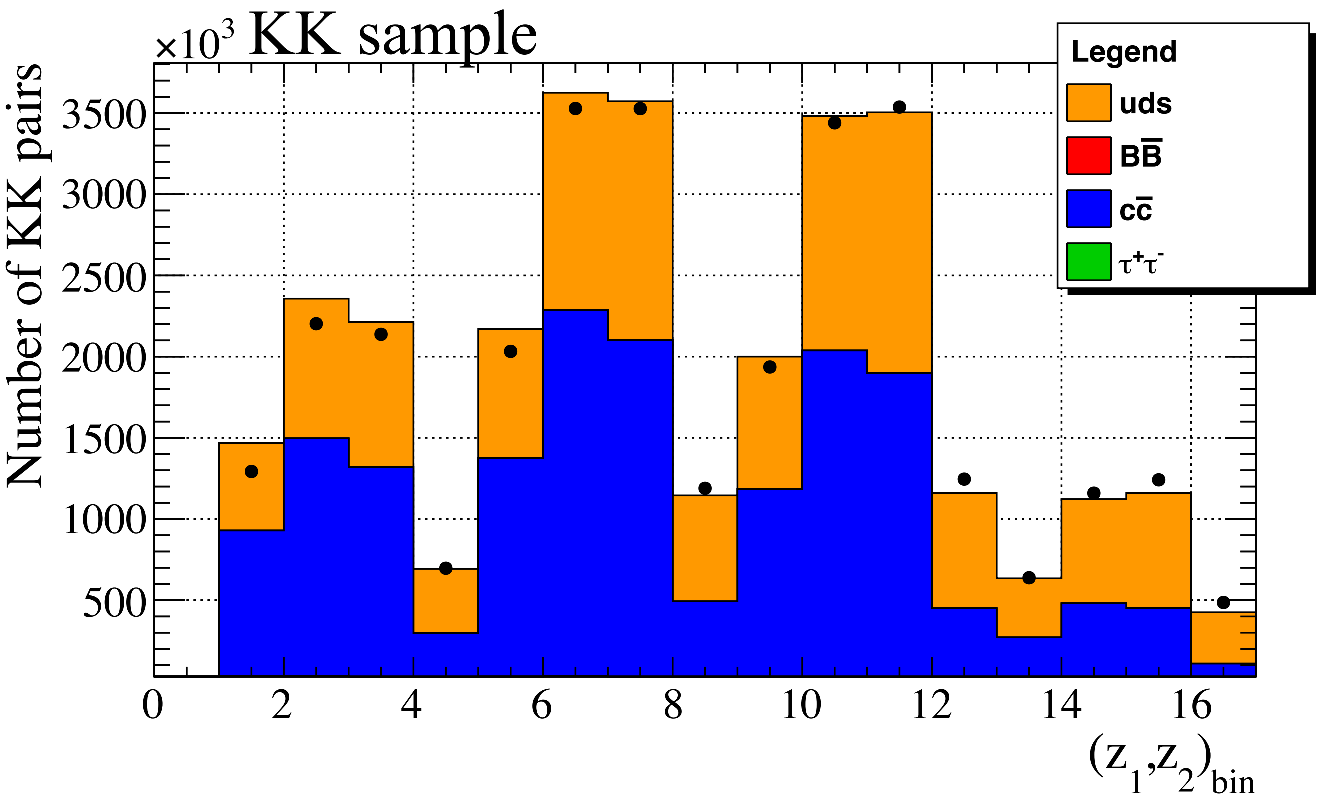
$$F(f)_{\text{sig/bkg}}^{\text{hh}}$$

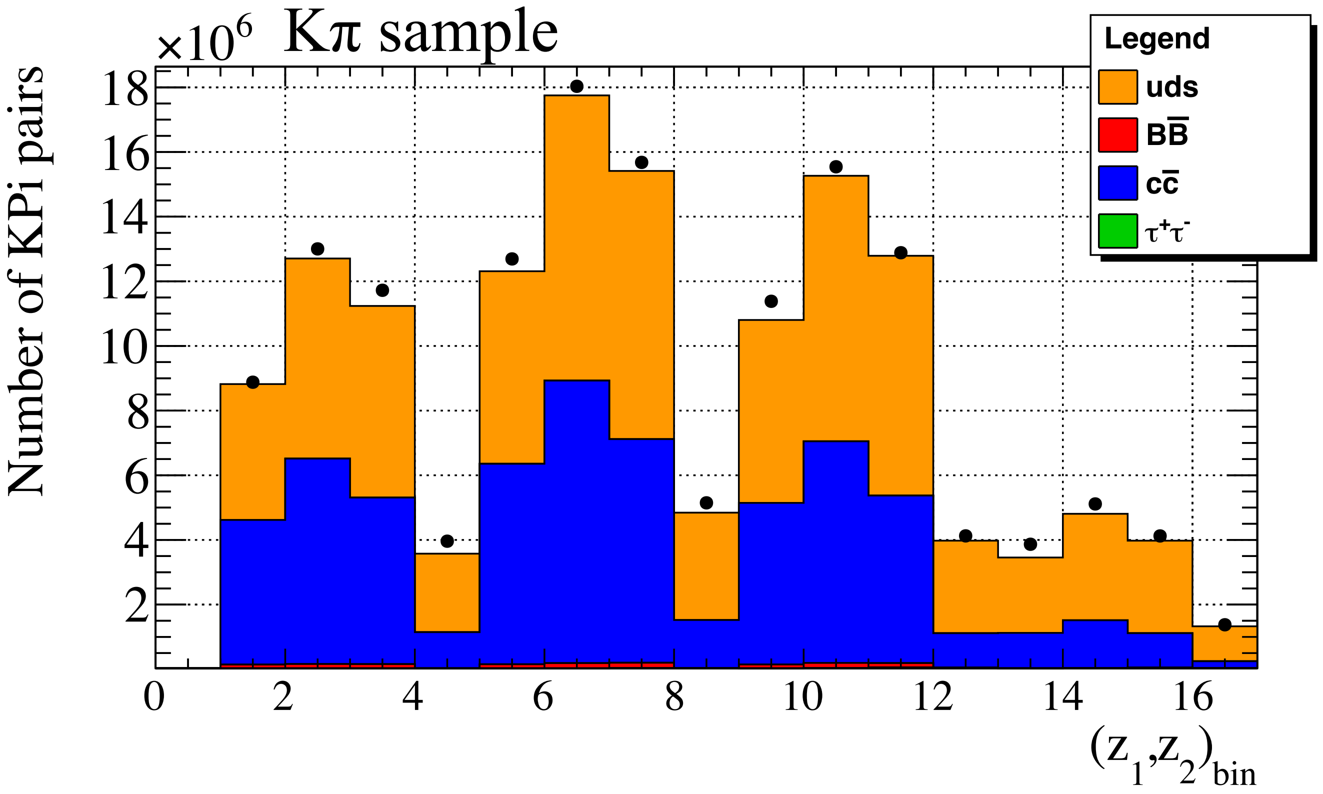
$\rightarrow$ uds, $c\bar{c}$, $B\bar{B}$, $\tau^+\tau^-$

Fractions of hadron pairs

From MC samples, we calculate the number of hadron pairs (KK, K**π** and **ππ**) coming from light quarks and background events:

$$F_i = \frac{N_i^{(MC)}}{N_{data}}$$





Similar distribution for D*-enhanced and ππ samples

Extraction of KK, Kπ and ππ asymmetries (II)

GOAL: simultaneous extraction of the asymmetries corrected for backgrounds and K/π contamination for each intervals of fractional energy

- 3 samples: KK, Kπ, ππ
- we fit independently the double ratio distributions of the three samples

$$A^{meas}_{KK} = F_{uds} \cdot A^{Collins}_{KK} + \sum_i F_i^{KK} \cdot A^i_{KK}$$

background contribution

2. **K/π misidentification:**
   - we evaluate from MC the fraction ($\xi_{hh}{}^{(hh)}$) that a given hadron pair is reconstructed as KK, Kπ, or ππ pair

$$A^{meas}_{KK} = F_{uds} \cdot \left(\sum_{nm} \xi^{(KK)}_{nm} \cdot A^{Collins}_{nm} \right) + F^{KK}_{c\bar{c}} \cdot \left(\sum_{nm} \xi^{(KK)}_{nm} \cdot A^{charm}_{nm} \right)$$

$$\xi_{hh}{}^{(hh)}$$

reconstructed hadron pairs

generated hadron pairs

The fractions are evaluated in all samples used in the analysis: uds ($\xi_{hh}{}^{(hh)}$), D*-uds ($\xi_{hh}{}^{(hh)D^*}$), $c\bar{c}$ ($\xi_{hh}{}^{(hh)c\bar{c}}$), $c\bar{c}$-D* ($\xi_{hh}{}^{(hh)c\bar{c}\text{-}D^*}$)

$\xi_{KK}{}^{KK}$ ~ 86% - 91%
$\xi_{KK}{}^{K\pi}$ ~ 7.6% - 13%
$\xi_{KK}{}^{\pi\pi}$ ~ 0.3% - 1.3%

$\xi_{K\pi}{}^{KK}$ ~ 1.5% - 5%
$\xi_{K\pi}{}^{KK}$ ~ 78% - 90%
$\xi_{K\pi}{}^{KK}$ ~ 7.3% - 16%

$\xi_{\pi\pi}{}^{KK}$ ~ 0.01% - 0.1%
$\xi_{\pi\pi}{}^{K\pi}$ ~ 3.5% - 4.5%
$\xi_{\pi\pi}{}^{\pi\pi}$ ~ 95% - 97%

Simultaneous extraction of asymmetry

Three samples (KK, Kπ, ππ) + background + K/π misidentification ⇒ **system of six equations and six unknown parameters**

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

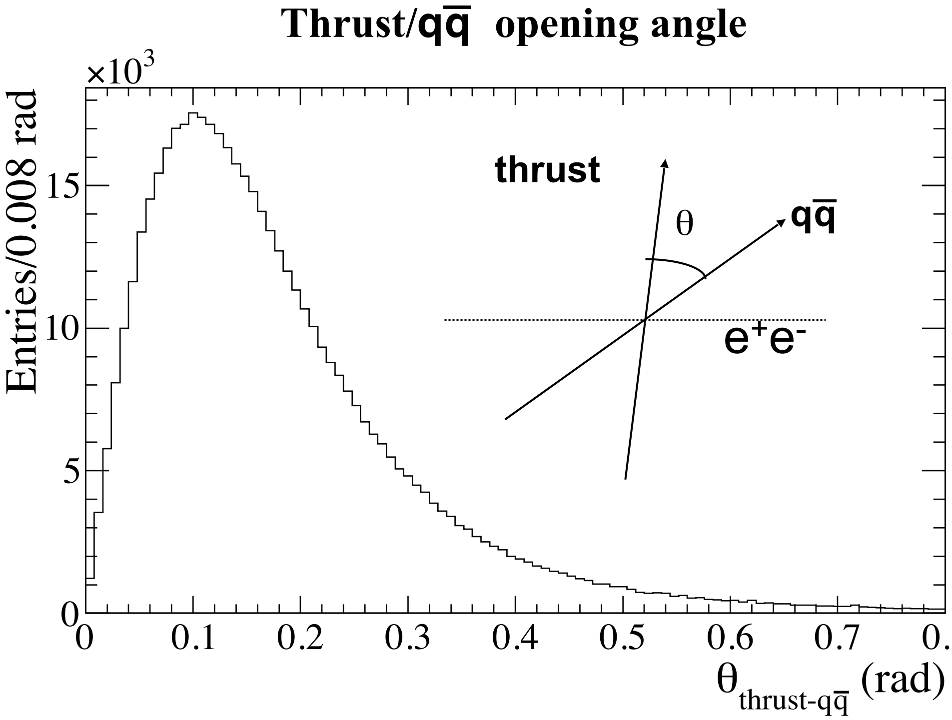
◯ = Collins asymmetries for light hadrons

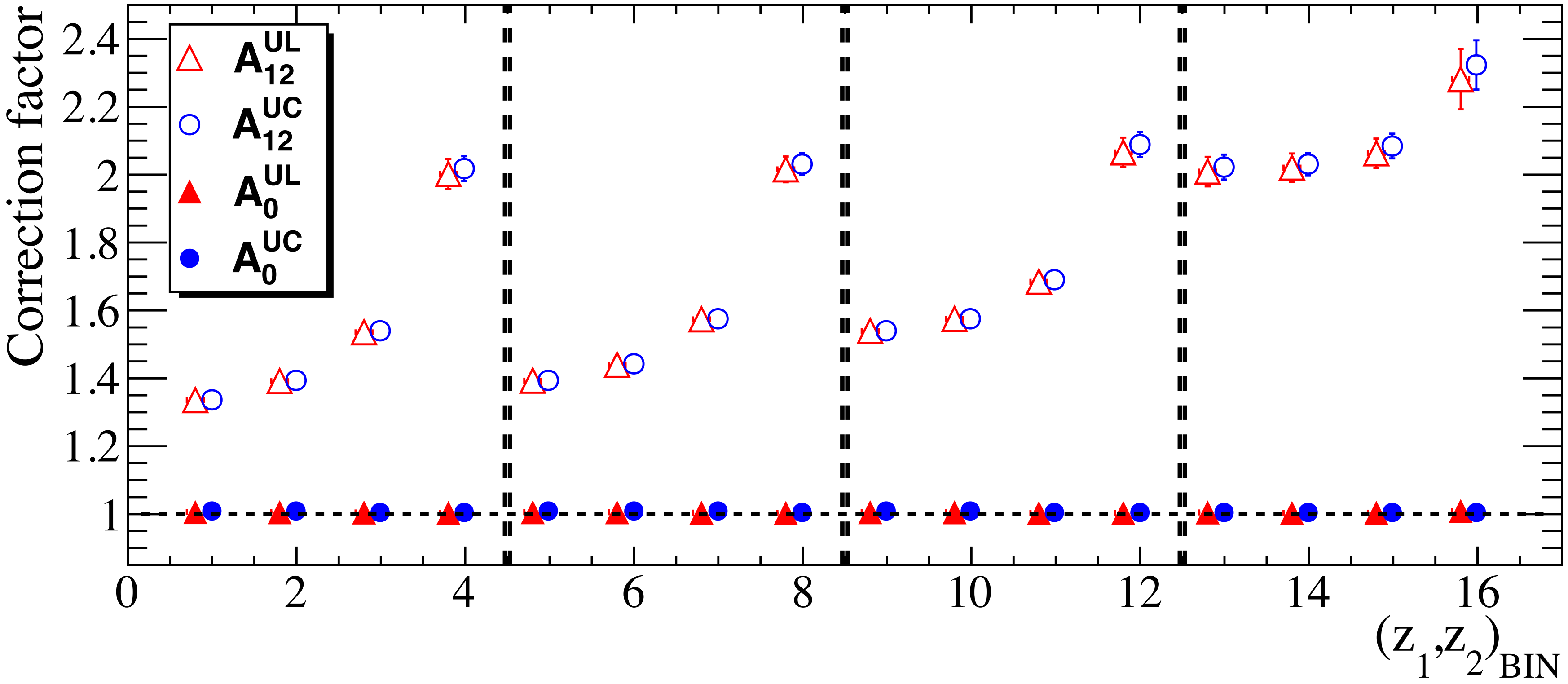
Effect of the thrust axis reconstruction

The experimental method assumes the thrust axis as $q\bar{q}$ direction, but this is only a rough approximation

- RF12: the azimuthal angles are calculated respect to the thrust axis → large smearing;
- RF0: no thrust axis needed → smearing due only to PID and tracking resolution.

⇒ Using the MC sample,we introduce in the simulation several values of asymmetries, and we study the differences between the simulated anc he reconstructed ones





- RF12: strong dilution observed
  - correction ranges between 1.3 to 2.3 for increasing z
- RF0: no dilution observed
  - no correction needed

Same corrections applied for the three hadron pair combinations

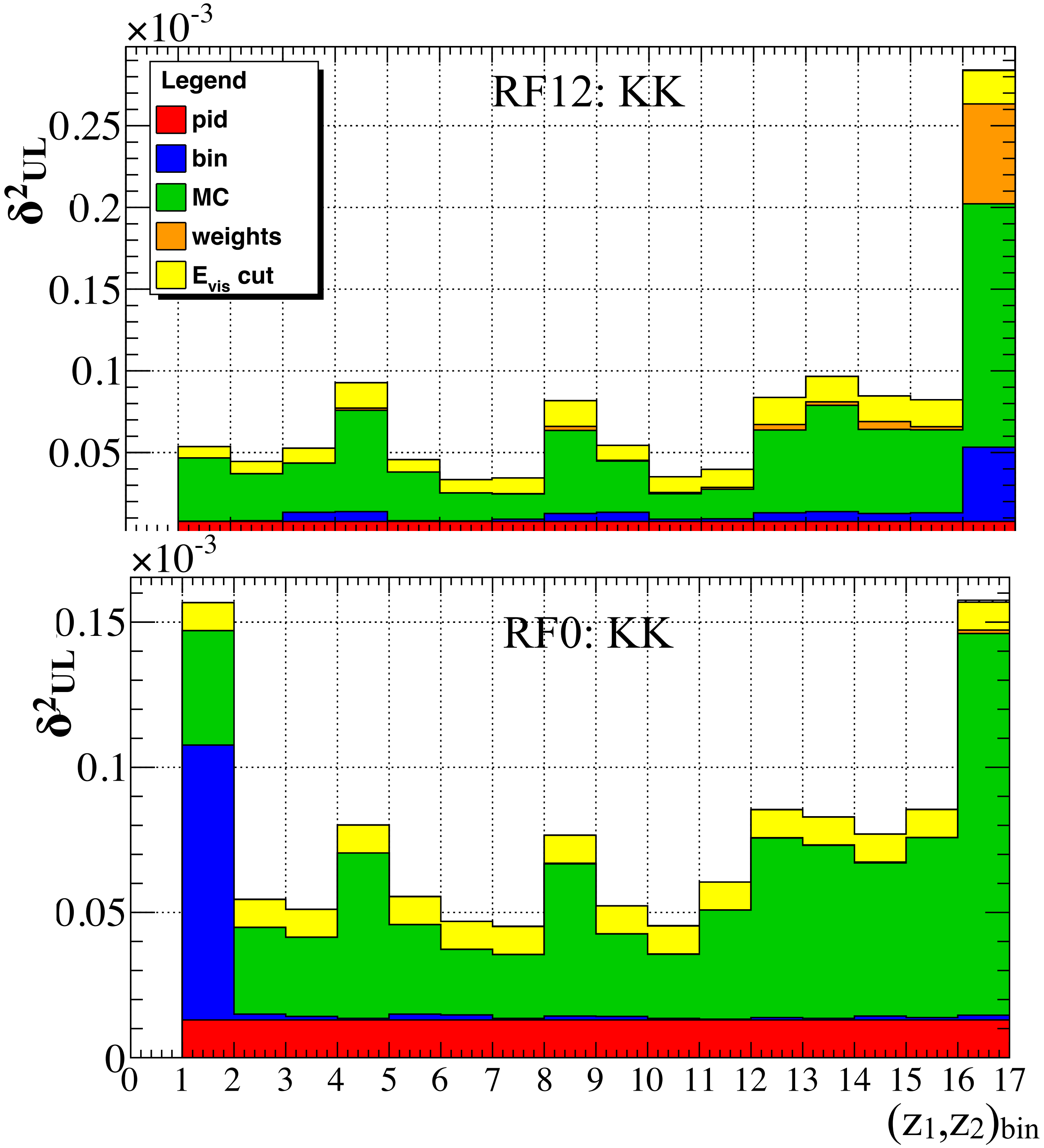
Systematic uncertainties

A large number of systematic checks were done. The main contributions come from:

- MC uncertainties
- Particle identification (PID)
- Fit procedure
- Dilution method
- E_{vis} cut

Additional check (negligible contributions):

- Beam polarization studies
- Asymmetry consistency between different data taking period
- Possible coupling between Collins and detector effect
- …

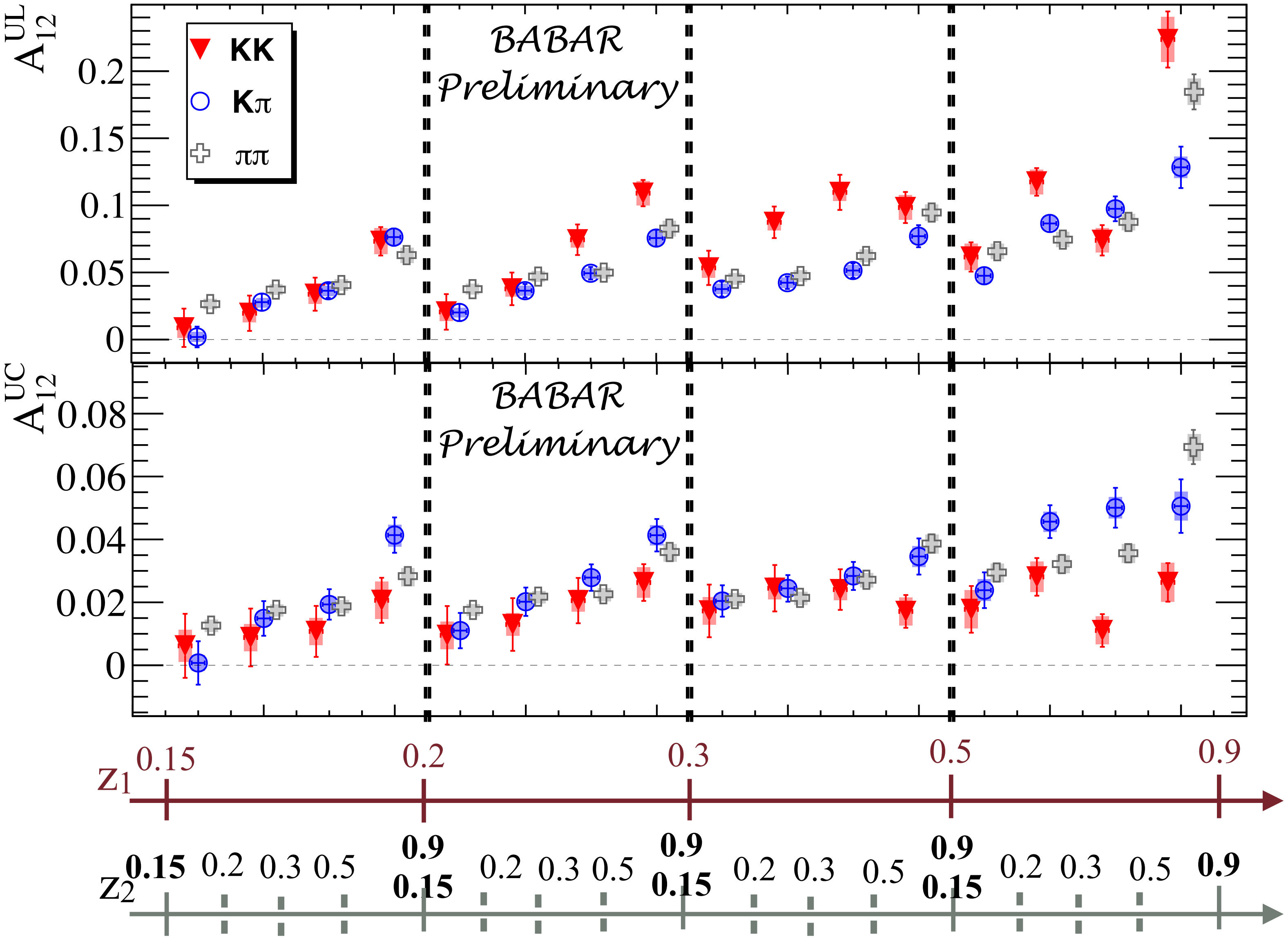


Sum in quadrature of systematic uncertainties

Results: RF12

Simultaneous measurement of KK, Kπ and ππ Collins asymmetries

- all corrections are applied



- Rising of the asymmetry as a function of z:
  - more pronounced for U/L
- A^{UL} KK asymmetry slightly higher than pion asymmetry for high z
- KK asymmetry consistent with zero at lower z

Note that A^{UL} and A^{UC} asymmetries are obtained using the same data sample, and are strongly correlated

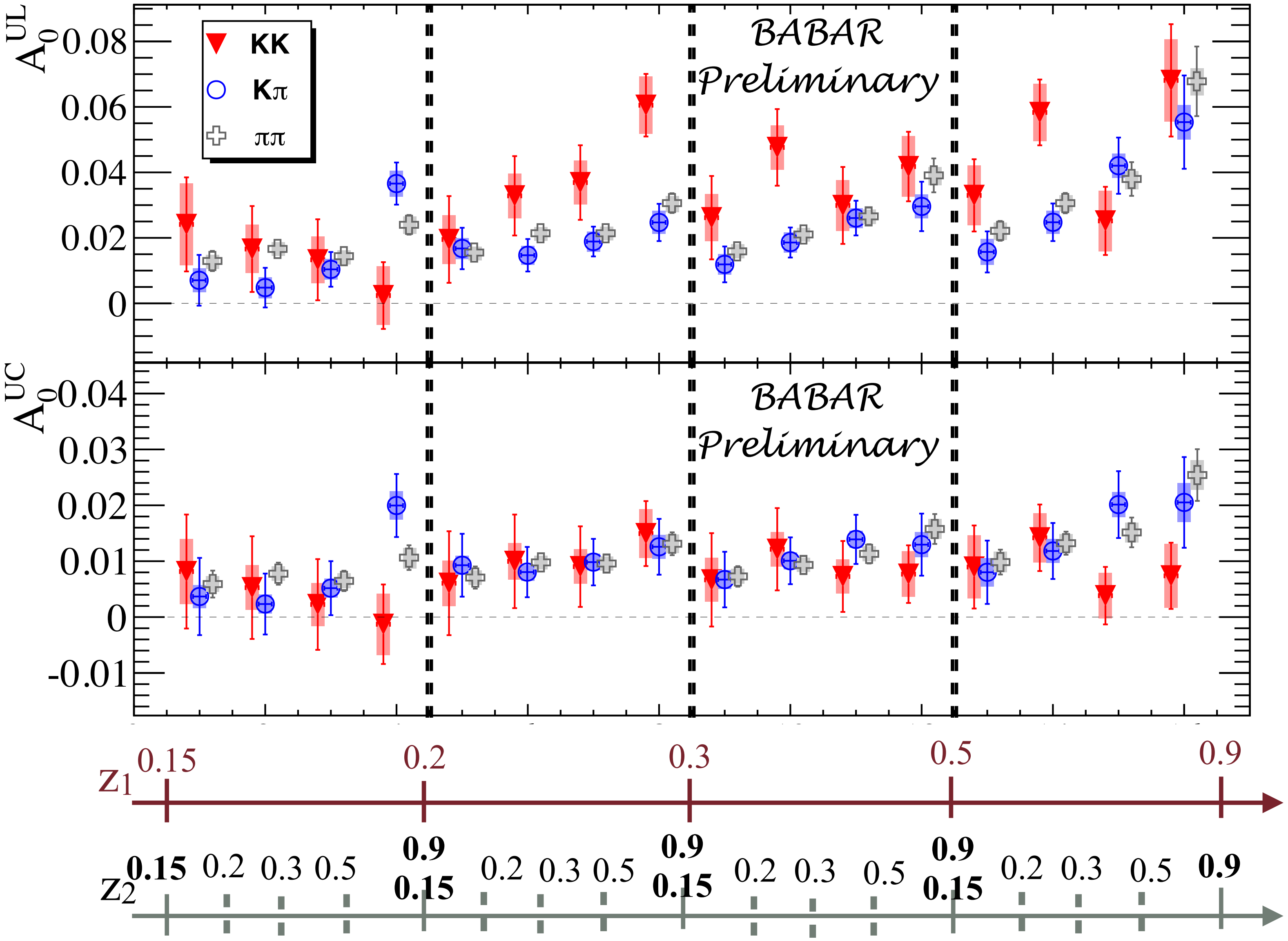
Results: RF0

Simultaneous measurement of KK, Kπ and ππ Collins asymmetries

- all corrections are applied

- Rising of the asymmetry as a function of *z*:
  - more pronounced for U/L
- A^{UL} KK asymmetry slightly higher than pion asymmetry for high z
- KK asymmetry consistent with zero at lower z

Note that A^{UL} and A^{UC} asymmetries are obtained using the same data sample, and are strongly correlated

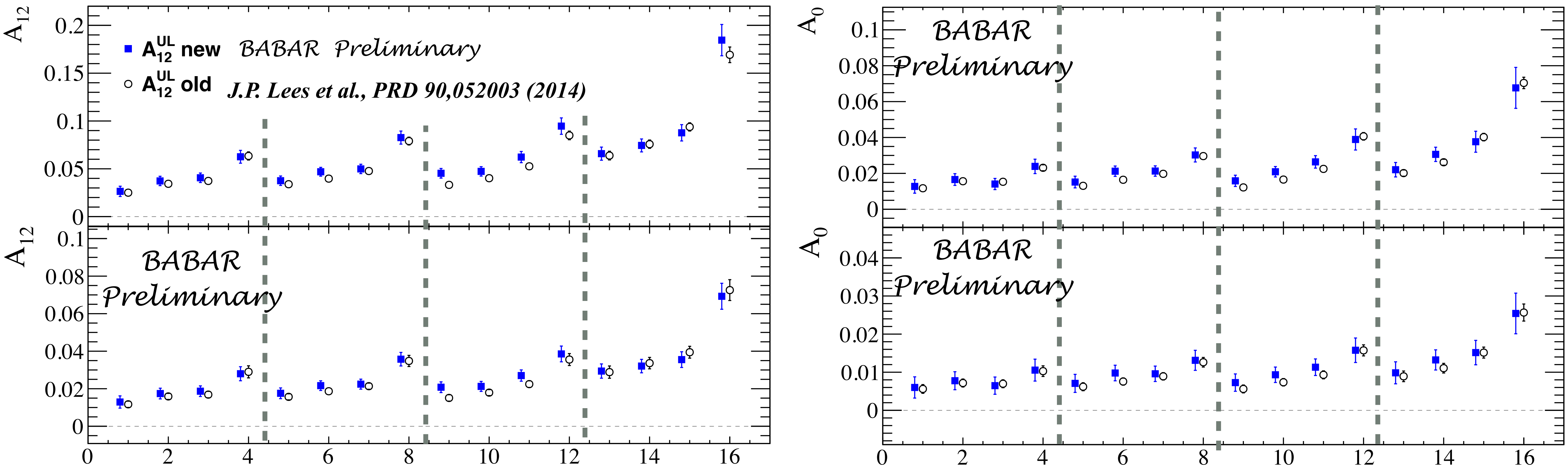


$\pi\pi$ consistency check

Comparison of the $\pi\pi$ asymmetries with those measured in the previous BaBar analysis: **PRD 90, 052003 (2014)**

- Different kinematic regions: asymmetries rescaled for $<\sin^2\theta>/<1+\cos^2\theta>$
- Average values of the data in the new (z_1,z_2) intervals

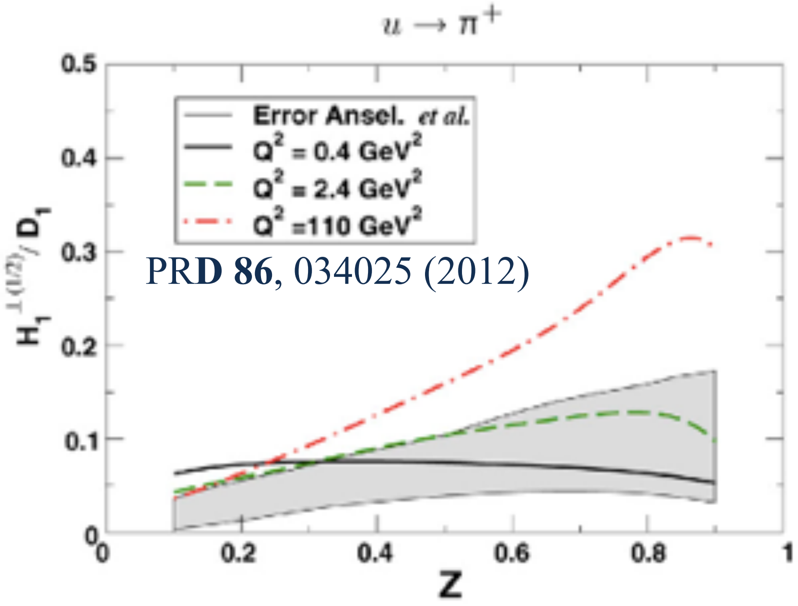
$$\frac{R^{UL}}{R^L} = 1 + \cos(\phi_1+\phi_2)\cdot \underline{A_{12}^{UL}} = 1+\cos(\phi_1+\phi_2)\cdot \underline{\frac{\langle \sin^2\theta_{th}\rangle}{\langle 1+\cos^2\theta_{th}\rangle}\cdot\frac{H_1^\perp(z)\overline{H}_1^\perp(z)}{D_1(z)\overline{D}_1(z)}}$$



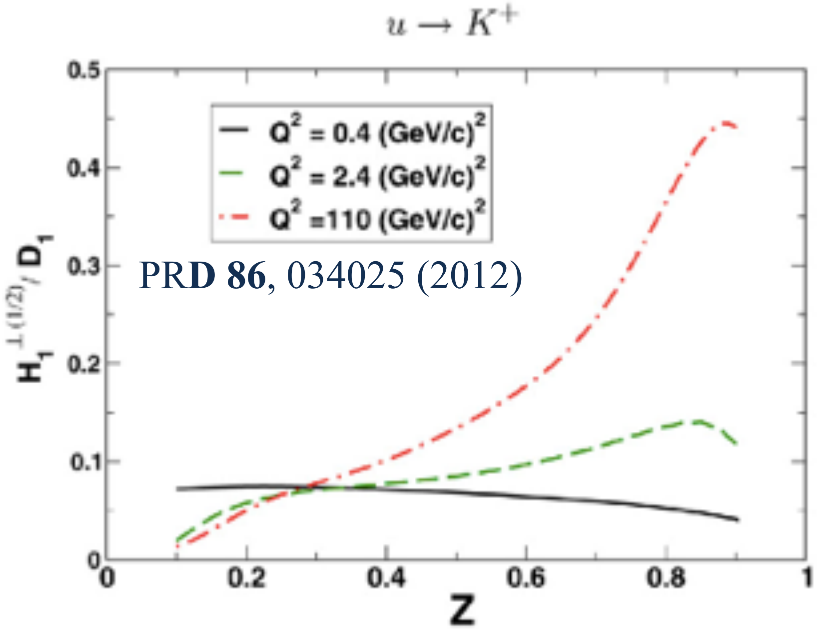
- New and previous results are in good agreement each other
  - we averaged those values falling in the new interval
- Cross check ⇒ make us confident about the goodness of the simultaneous extraction of KK, Kπ and $\pi\pi$

Conclusions

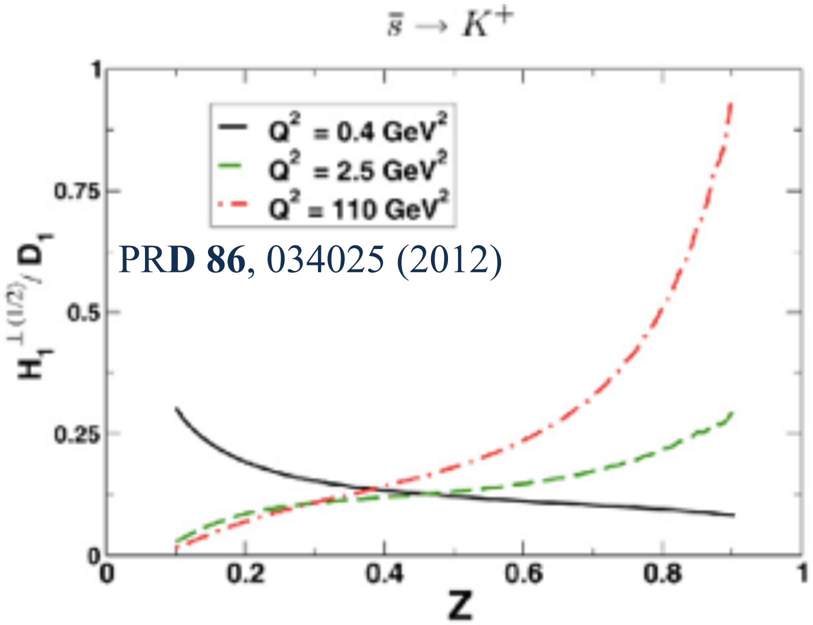
- Simultaneous extraction of A_{KK}, $A_{K\pi}$, and $A_{\pi\pi}$ Collins asymmetry
  - Two reference frames: RF12 and RF0
  - 16 (z_1,z_2)-bins
  - Good agreement with previous BaBar results (PRD 90,052009 (2014))



PRD **86**, 034025 (2012)



PRD **86**, 034025 (2012)



PRD **86**, 034025 (2012)

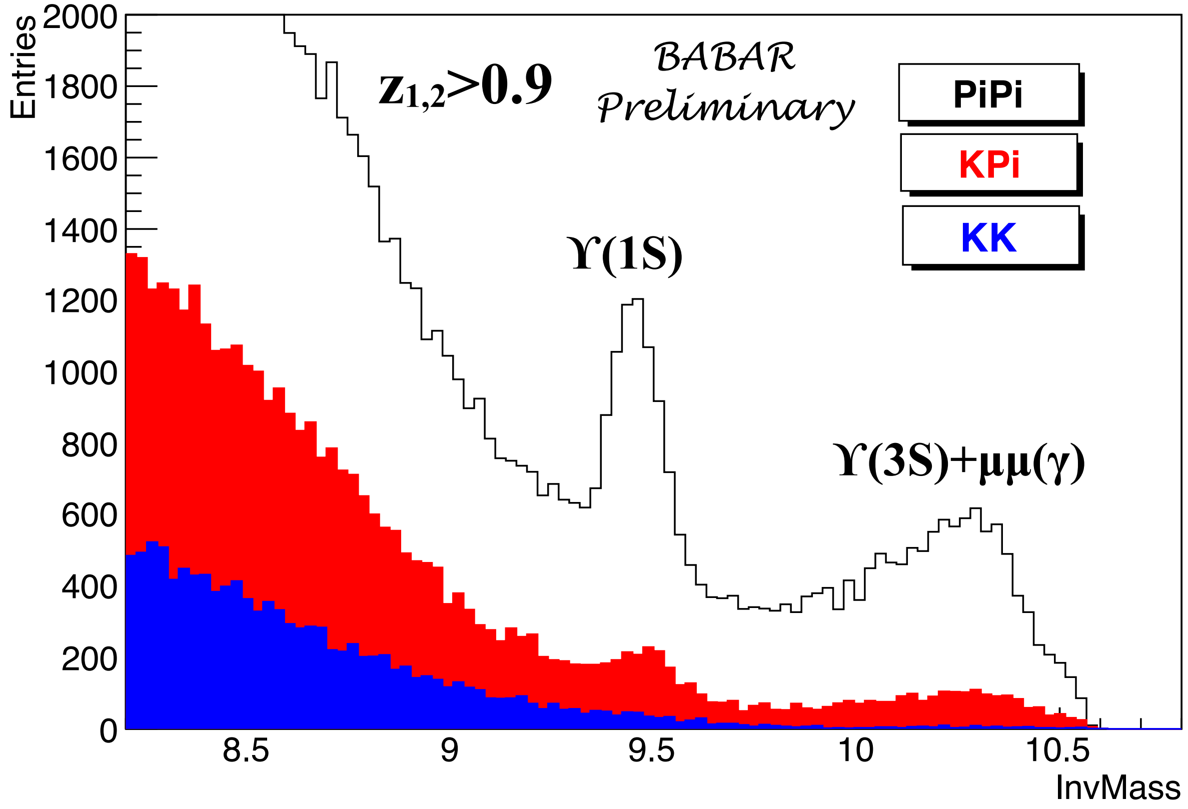
- Agreement with theoretical prediction !? [*PL **B659**, 234 (2008); PRD **86**, 034025 (2012)*]
  - A^{UL} asymmetry for KK are slightly **larger** than ππ
  - A^{UC} asymmetry for KK are slightly **lower** than ππ

These results will be submitted for publication

Stay tuned and
Thanks for your attention

Track selection

ON-PEAK DATA SAMPLE: h_1h_2 invariant mass distribution



TRACK SELECTION

- Electrons and muons veto
- K and π in the DIRC acceptance region
- K/π fractional energy z: **$0.15 < z < 0.9$**
- Opening angle $\theta_{\text{h-thrust}}$ of hadron with respect to the thrust axis < 45°
- Q_t<3.5 GeV, where Q_t is the transverse momentum of the virtual photon in the two hadrons center-of-mass energy

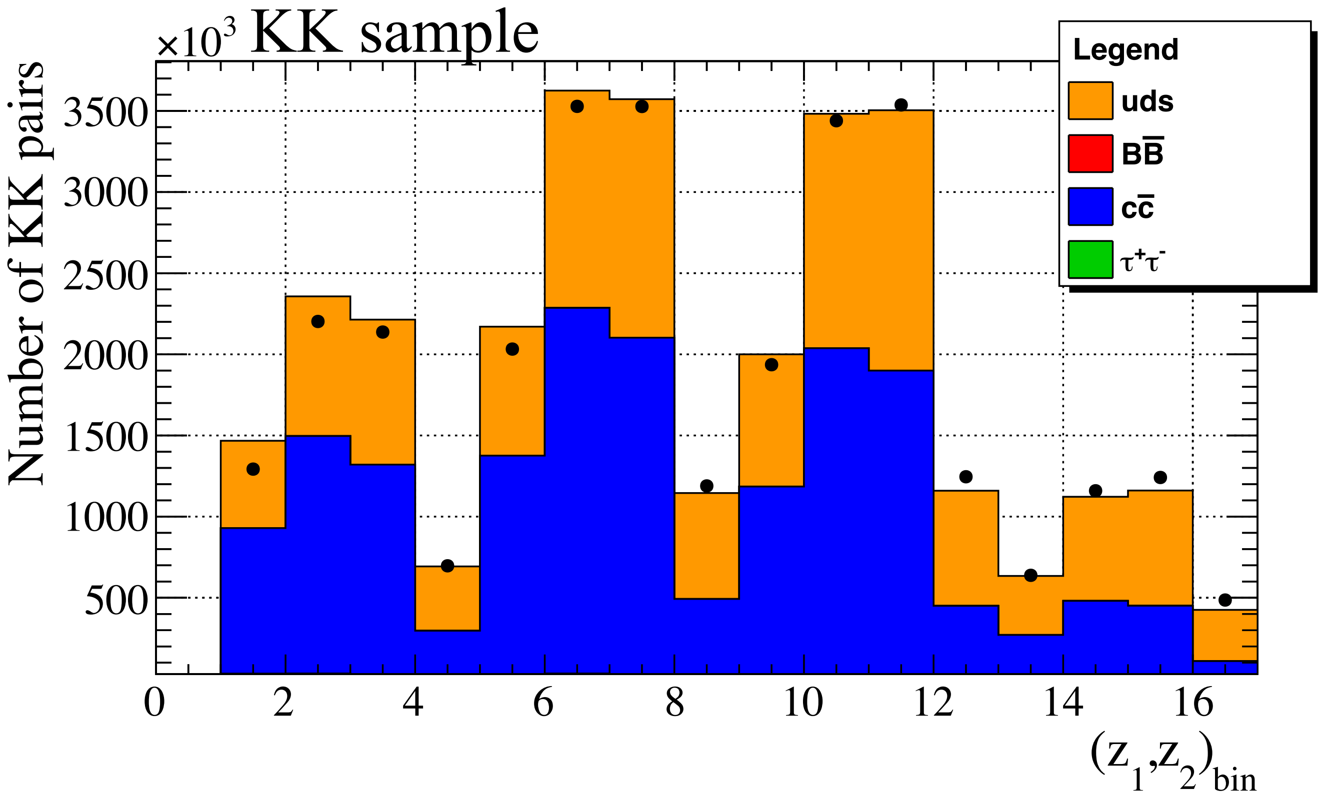
Fractions of hadron pairs

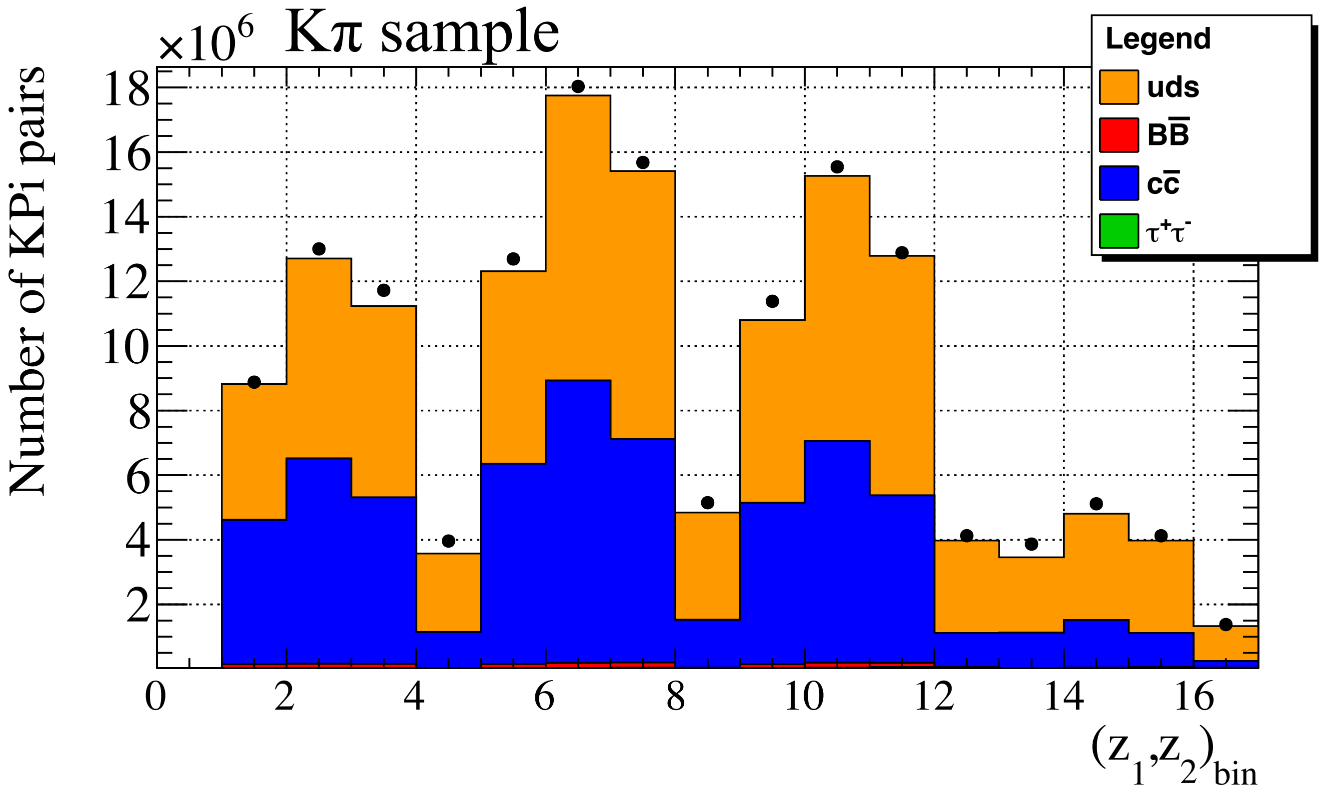
From MC samples, we calculate the number of hadron pairs (KK, K**π** and **ππ**) coming from light quarks and background events:

$$F_i = \frac{N_i^{(MC)}}{N_{data}}$$

We then calculate the corrected fractions in order to take into account the condition that their sum is equal to 1:

$$F_i^{corr} = F_i + \frac{(1 - \sum_{j=uds}^{cc,bb,\tau} F_j) * \sigma_i^2}{\sum_{j=uds}^{cc,bb,\tau} \sigma_j^2}$$


KK sample

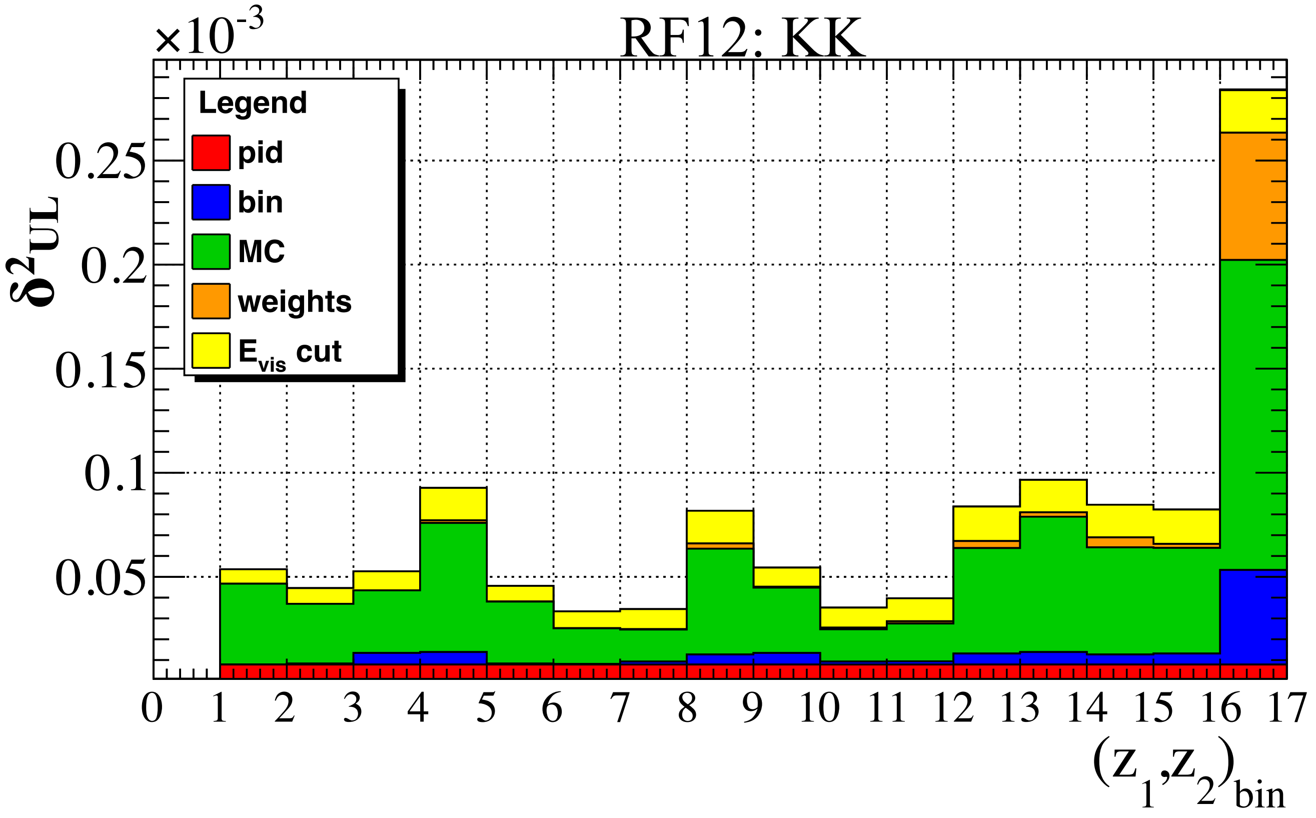

Kπ sample

Similar distribution for D*-enhanced and ππ samples

Systematic uncertainties

- **MC uncertainties:** we check the bias by using different track selection requirements:
  - different acceptance region for tracks and different E_{vis} cuts applied
  - the largest deviation of the bias w.r.t. the standard selection is combined in quadrature with the MC statistical error and taken as systematic uncertainties
- **Particle identification (PID)**: few percent change in the asymmetry by changing the PID cuts
  - new K/π fractions calculated using the corresponding selectors
  - we calculate the "final asymmetry" (after all correction applied), and we take the average difference as systematic contribution

- **Fit procedure:** different angular bin size, higher arming contributions
- **Dilution method:** the error on the correction factors is assigned as systematic uncertainty
- **E_{vis} cut:** we compare the MC-corrected asymmetry in the data sample by changing the E_{vis} requirements



Sum in quadrature of systematic uncertainties

Additional check (negligible contributions):

- Beam polarization studies
- Asymmetry consistency between different data taking period
- Possible coupling between Collins and detector effect

Systematic uncertainties (II)

Additional check (negligible contributions):

- Beam polarization studies
- Asymmetry consistency between different data taking period
- Higher harmonic contribution and possible coupling between Collins and detector effect

function used to parameterize
the detector dependence

Collins effect: $\sigma(\theta,\phi) \sim 1 + \frac{\sin^2\theta}{1+\cos^2\theta} A_{Coll}\cos(2\phi)$ Detector effect: $\epsilon(\theta,\phi) \sim 1 + f(\theta) A_{acc}\cos(2\phi)$

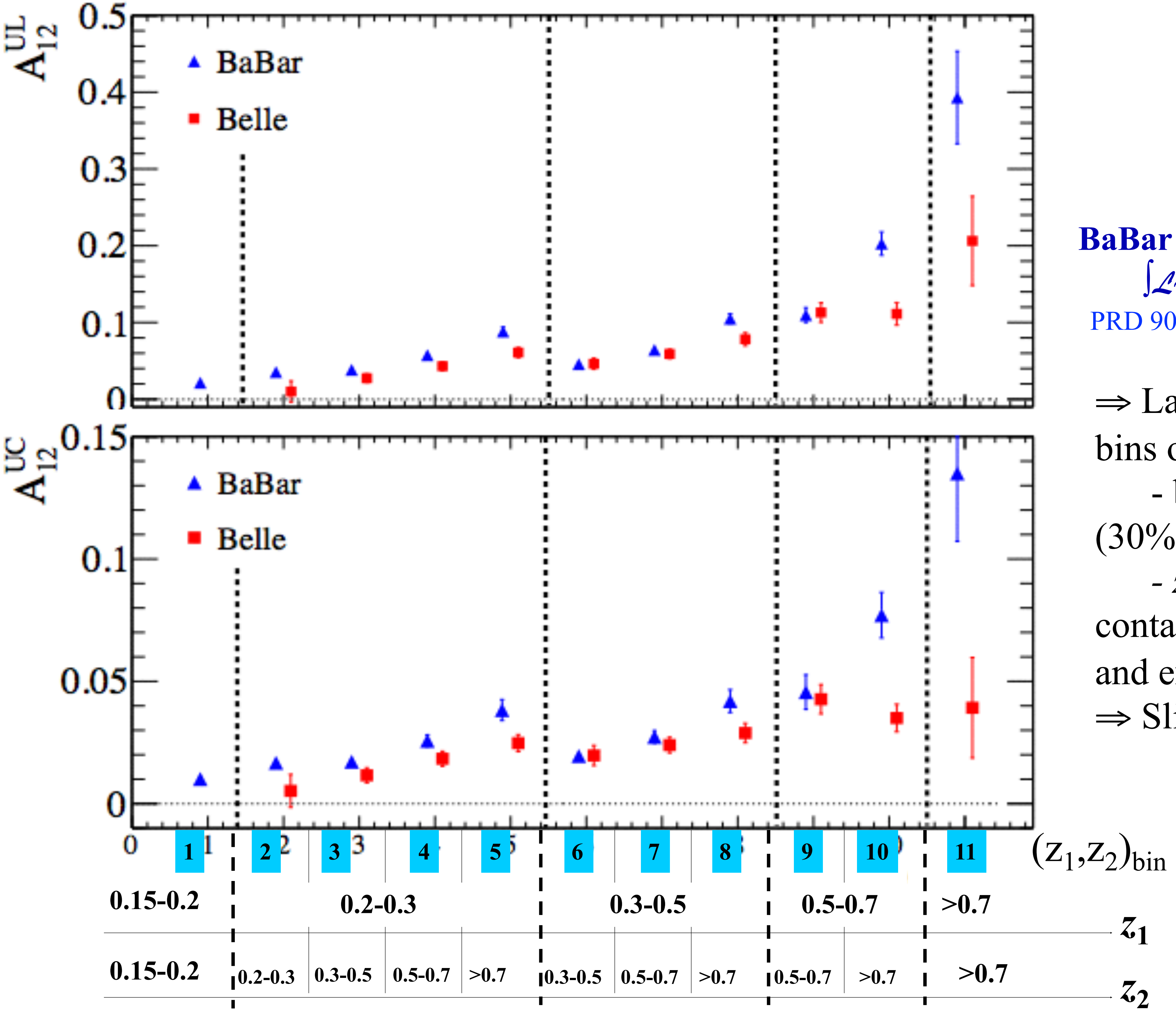
$$\sigma\cdot\varepsilon = \; 1 + \frac{\sin^2\theta}{1+\cos^2\theta} A^i_{Coll}\cos(\phi) + f^i(\theta) A^i_{acc}\cos(\phi) + + \frac{\sin^2\theta}{1+\cos^2\theta} f^i(\theta)\cdot A^i_{Coll} A^i_{acc}\cdot\cos^2(\phi)$$

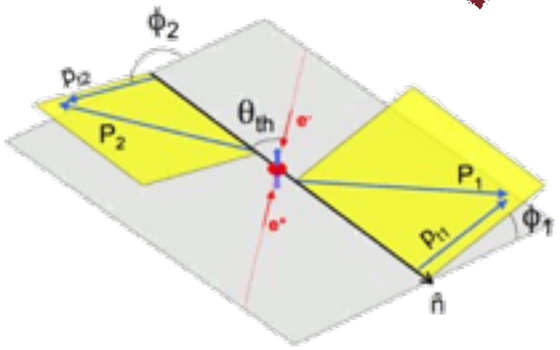
$$U/L \sim 1 + [f^U A^U_{acc} - f^L A^L_{acc}]\cos(\phi) + \frac{\sin^2\theta}{1+\cos^2\theta}[A^U_{Coll} - A^L_{Coll}]\cos(\phi)$$

$$\boxed{+ \frac{\sin^2\theta}{1+\cos^2\theta}[A^U_{Coll}\cdot f^U(\theta) A^U_{acc} - A^L_{Coll}\cdot f^L(\theta) A^L_{acc}]\cos^2(\phi).}$$

extra term

RF12: comparison of $\pi\pi$ asymmetry from previous results





BaBar (0.15<z<0.9)
$\int\mathcal{L}$~468 fb^{-1}
PRD 90, 052003(2014)

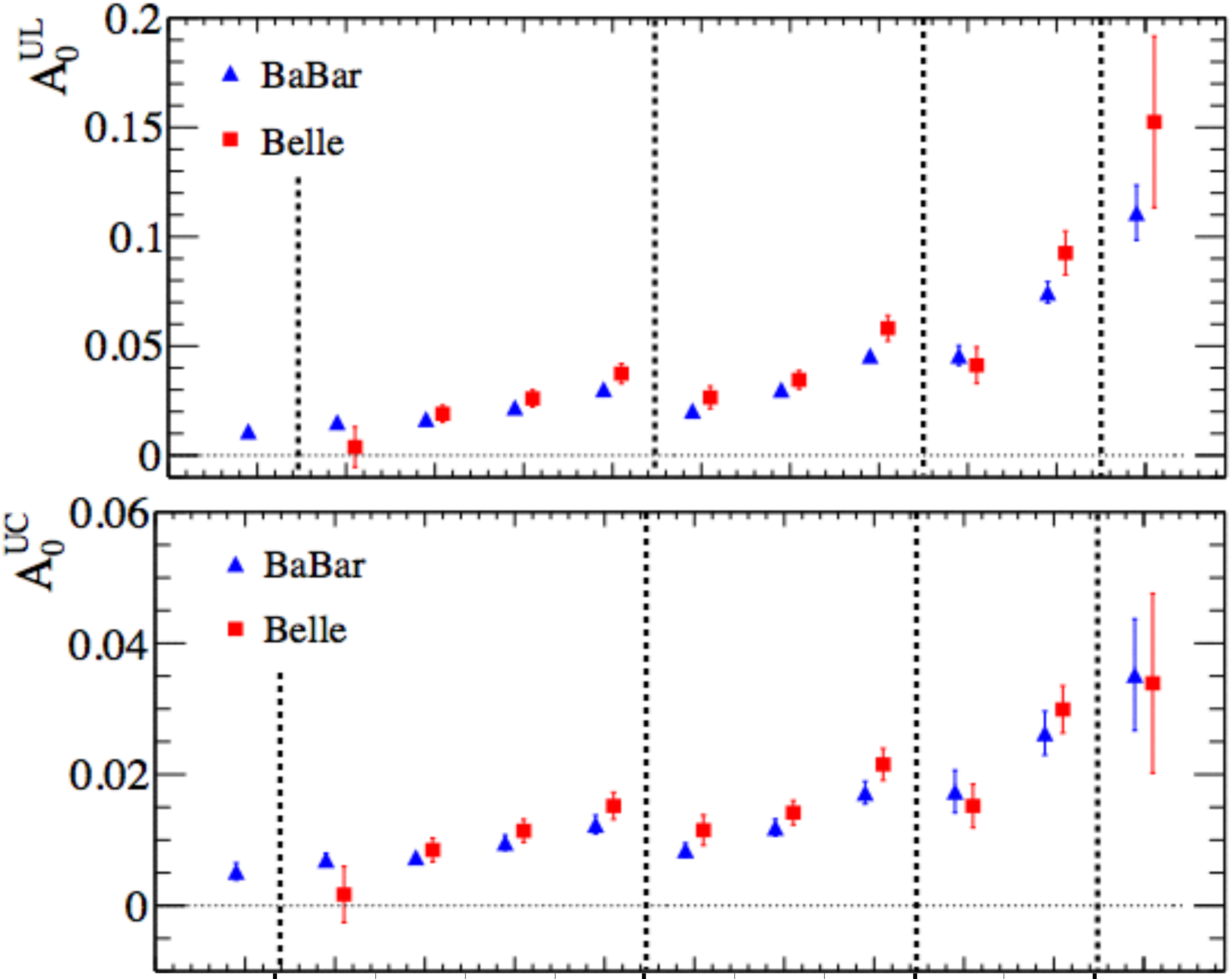
Belle (0.2<z<1)
$\int\mathcal{L}$~547 fb^{-1}
PRD 86, 039905(E) (2012)

⇒ Large discrepancy in the last two bins of z:

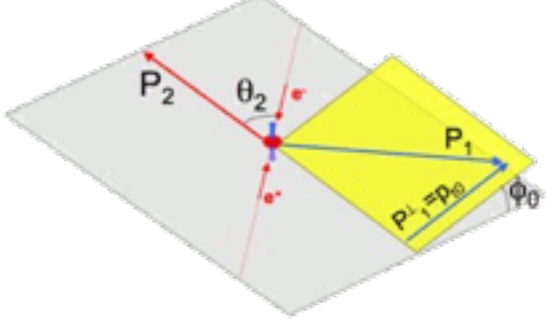
- bin-by-bin correction factors (30%)
- z<0.9 to remove the contamination from $\mu\mu\gamma$ background and exclusive events

⇒ Slightly higher at lower z

RF0: comparison of $\pi\pi$ asymmetry from previous results



$(z_1,z_2)_{bin}$	1	2	3	4	5	6	7	8	9	10	11
z_1	0.15-0.2	0.2-0.3				0.3-0.5			0.5-0.7		>0.7
z_2	0.15-0.2	0.2-0.3	0.3-0.5	0.5-0.7	>0.7	0.3-0.5	0.5-0.7	>0.7	0.5-0.7	>0.7	>0.7



BaBar ($0.15<z<0.9$)
$\int\mathcal{L}$~468 fb^{-1}
PRD 90, 052003(2014)

Belle ($0.2<z<1$)
$\int\mathcal{L}$~547 fb^{-1}
PRD 86, 039905(E) (2012)

In order to perform this comparison, we used 10 (+1) symmetrized *z*-bin subdivisions, averaging the measured Belle and BaBar asymmetries which fell in the same symmetric bins

A_0^{UL} and A_0^{UC} : good agreement between the BaBar asymmetries and the Belle results.