

Non-identical particle correlations in STAR as a probe of emission asymmetries and radial flow

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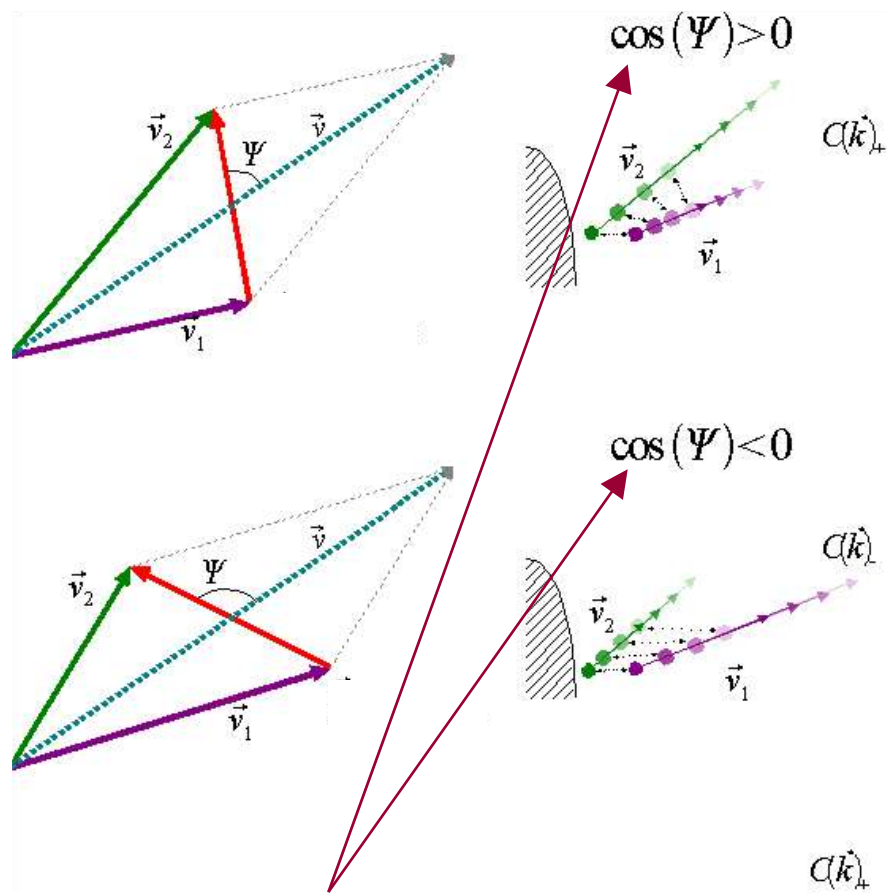
for the **STAR experiment** and
STAR HBT group



Outline

- Non-identical particle correlations
 - Measuring emission asymmetry
 - Connection to flow
- Data analysis at STAR
 - Pion-Kaon
 - Pion-Proton
 - Preliminary Kaon-Proton
- Fitting procedure
- Modeling emission asymmetry
 - Blast-wave – the flow baseline
 - Rescattering models
 - Comparing with data
- Summary

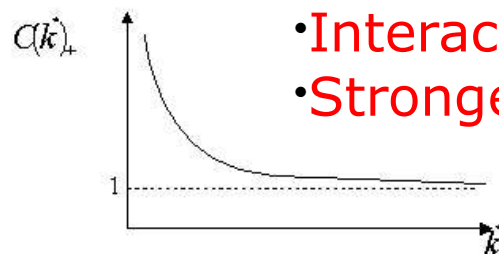
The asymmetry analysis



**Kinematics selection
on any variable**
e.g. k_{Out} , k_{Side} , $\cos(v, k)$

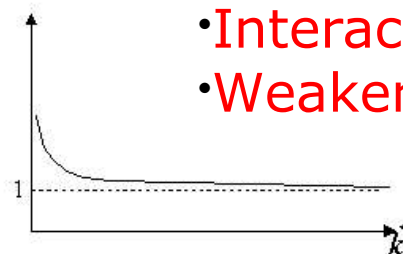
Catching up

- Interaction time larger
- Stronger correlation



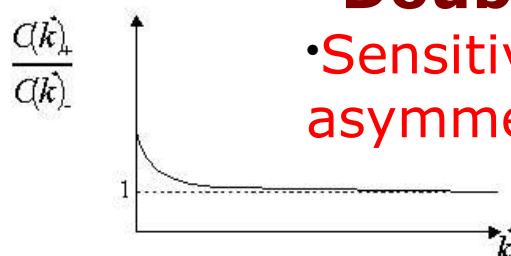
Moving away

- Interaction time smaller
- Weaker correlation



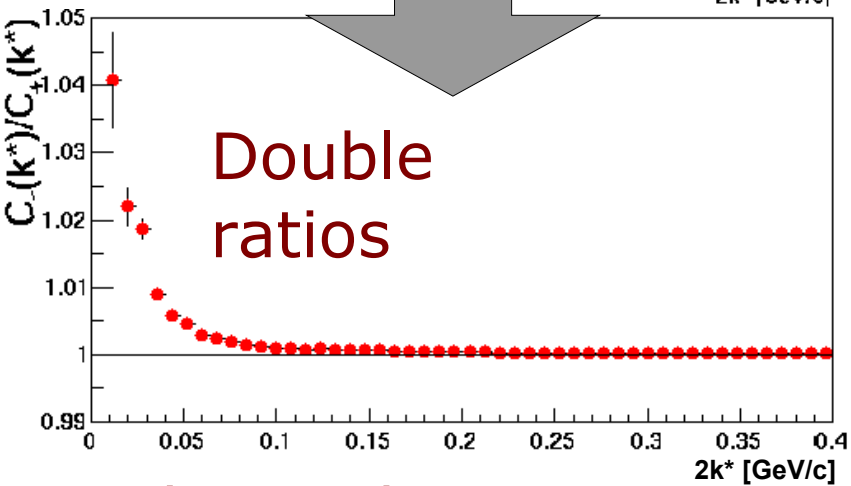
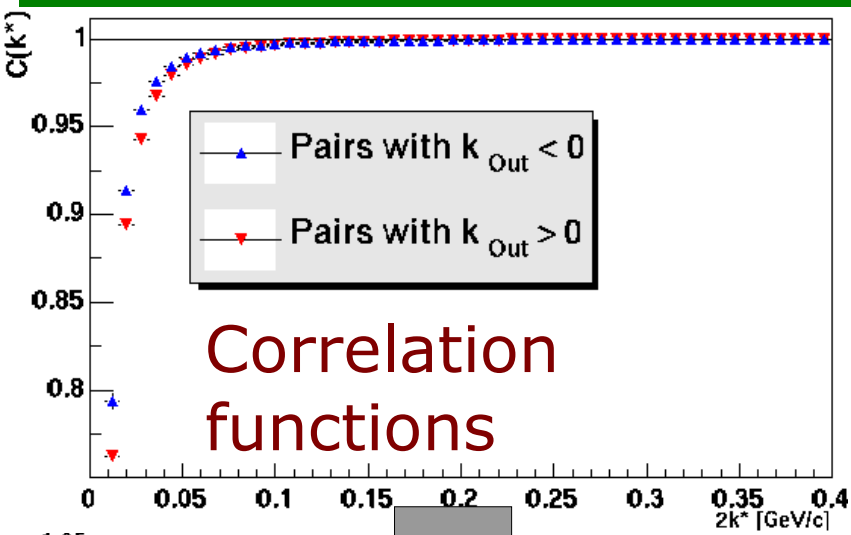
"Double" ratio

- Sensitive to the space-time asymmetry in the emission process

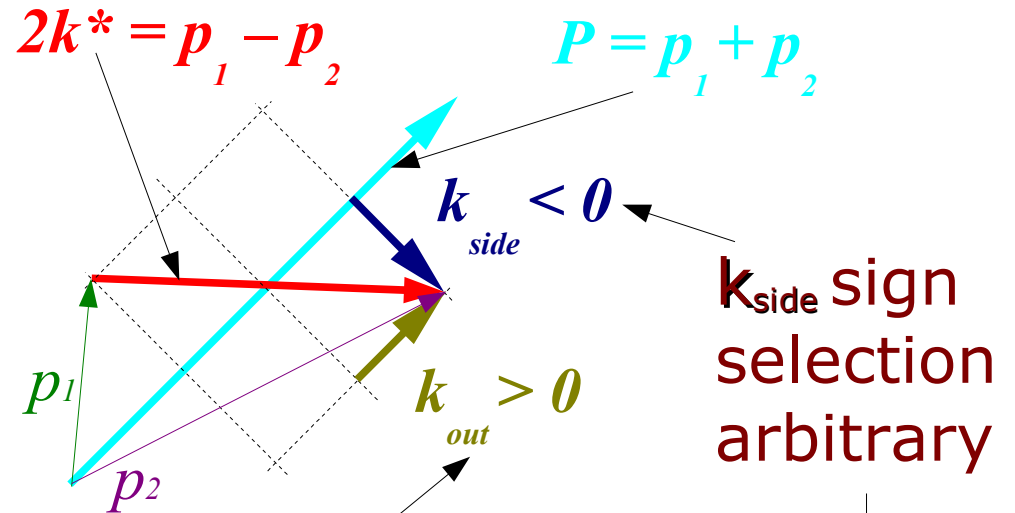


R.Lednicky, V. L.Lyuboshitz,
B.Erazmus, D.Nouais,
Phys.Lett. B373 (1996) 30.

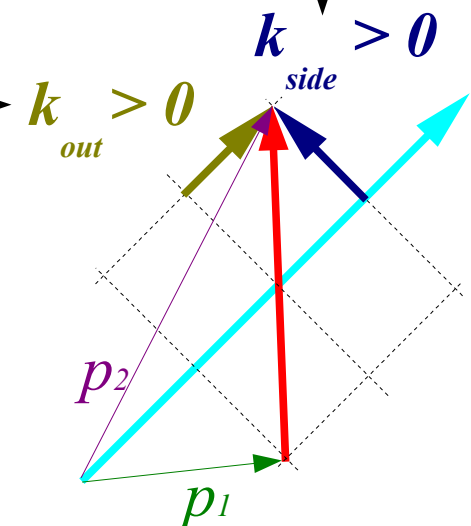
Double ratio definitions



k_{long} is the z component of the momentum of first particle in LCMS



k_{out} sign selection determined by the direction of the pair momentum P



What to expect from double ratios

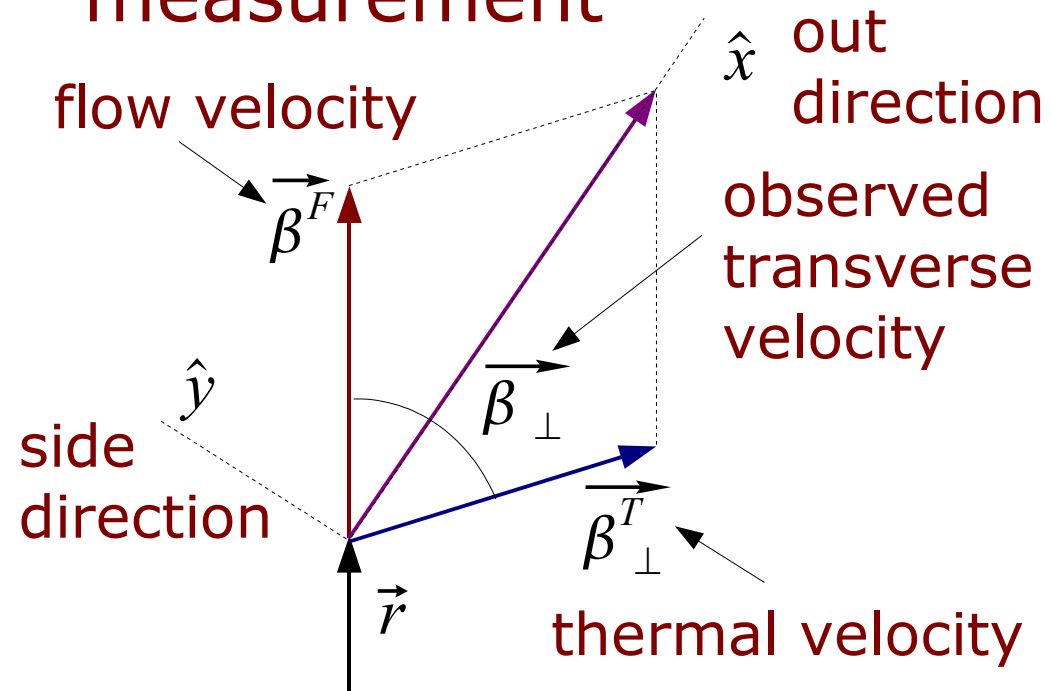
- Initial separation in Pair Rest Frame (measured) can come from time shift and/or space shift in Source Frame (what we want to obtain)
- We are directly sensitive to time shift, the space shift arises from radial flow – possibility of a new radial flow measurement

$$\langle \Delta x^* \rangle = \langle \Delta x \rangle + v_T \langle \Delta t \rangle$$

$$\begin{aligned} \langle x \rangle &\equiv \langle \vec{r} \cdot \hat{x} \rangle \approx \left\langle r \frac{\beta^F + \beta_{\perp}^T \cos(\phi)}{\beta_{\perp}} \right\rangle \\ &\approx \left\langle r \frac{\beta^F}{(\beta^{F2} + \beta_{\perp}^{T2})^{1/2}} \right\rangle \end{aligned}$$

$$\langle y \rangle = \langle \vec{r} \cdot \hat{y} \rangle = \left\langle r \frac{\beta_{\perp}^T \sin(\phi)}{\beta_{\perp}} \right\rangle = 0$$

$$\langle z \rangle = \langle \tau_s \sinh(y_s) \rangle \approx \langle \sinh(y_s) \rangle \langle \tau_s \rangle = 0$$



Blast wave: a flow model

Pion

$$p_t = 0.15 \text{ GeV}/c$$

$$\beta_t = 0.73$$

Kaon

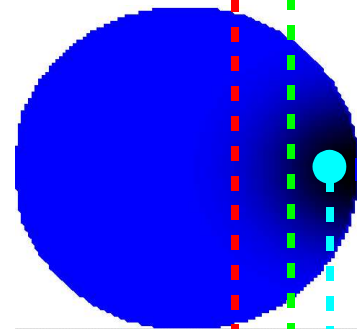
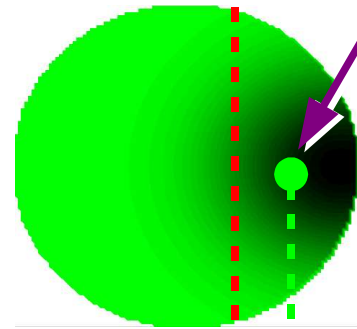
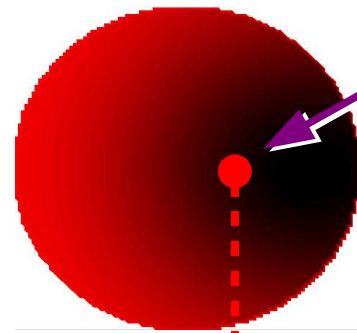
$$p_t = 0.5 \text{ GeV}/c$$

$$\beta_t = 0.71$$

Proton

$$p_t = 1. \text{ GeV}/c$$

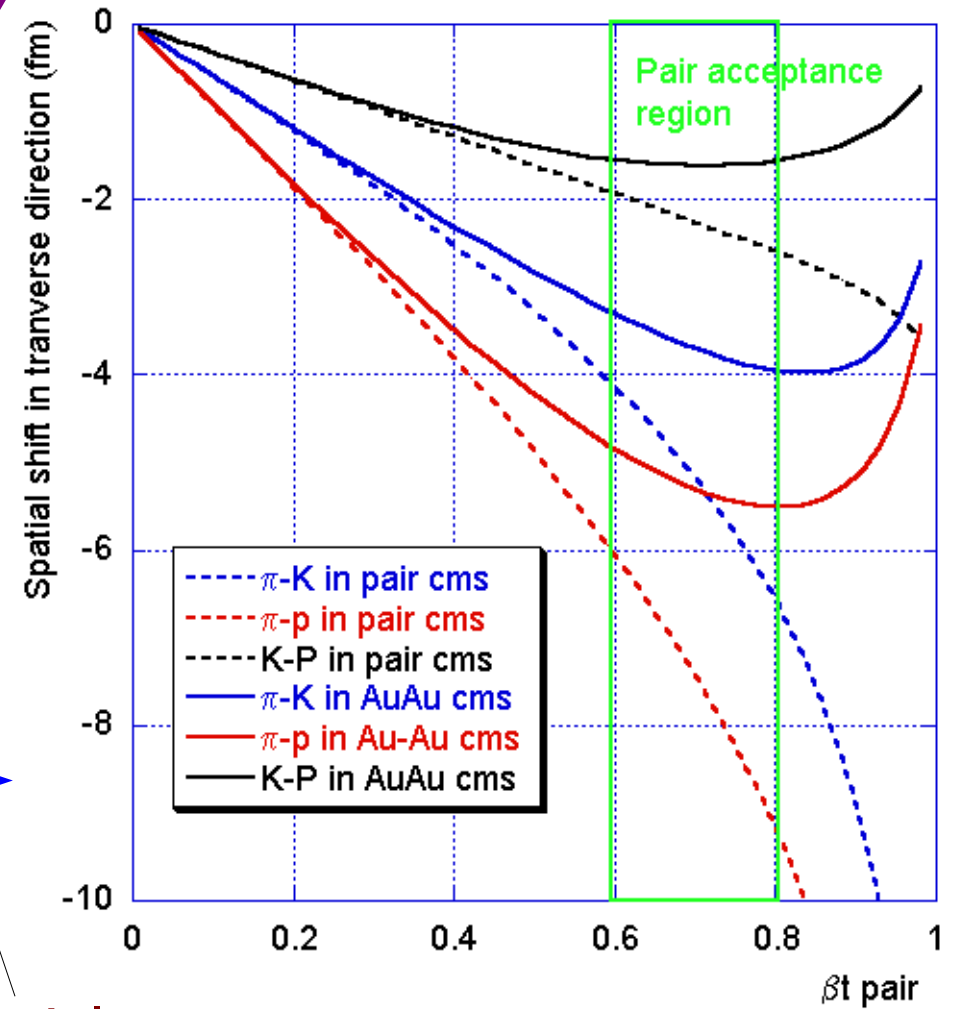
$$\beta_t = 0.73$$



Average emission points

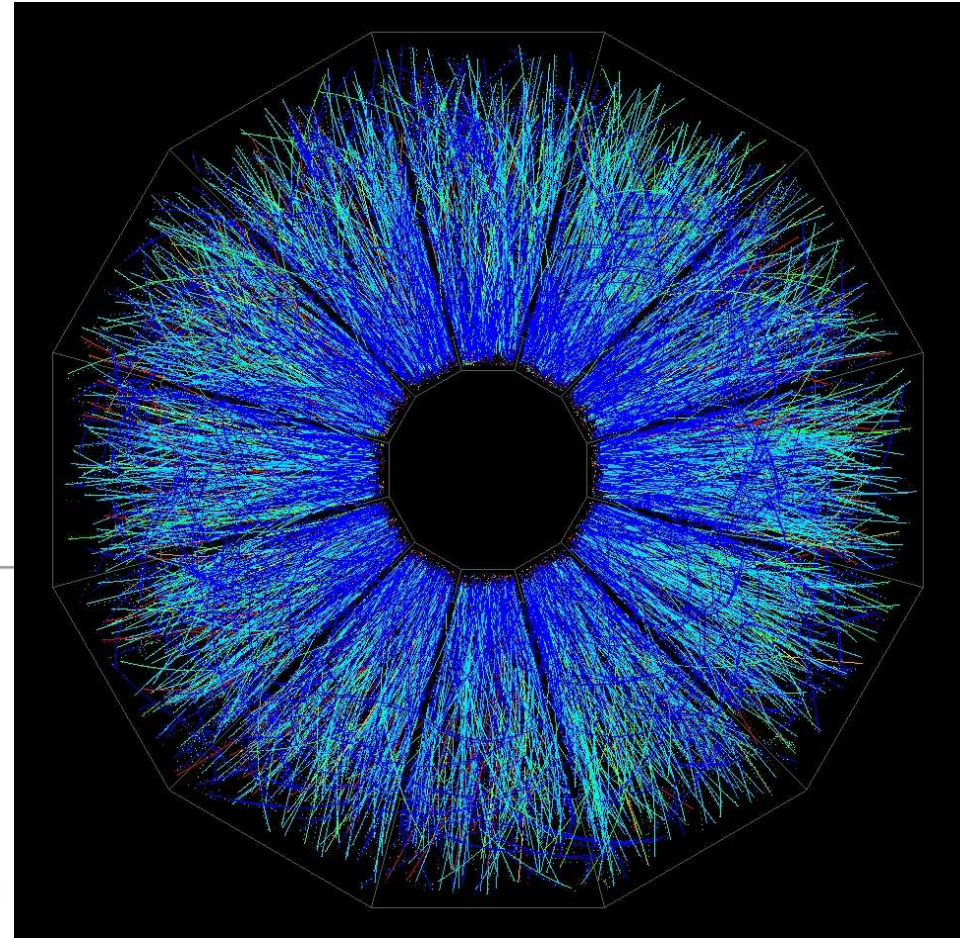
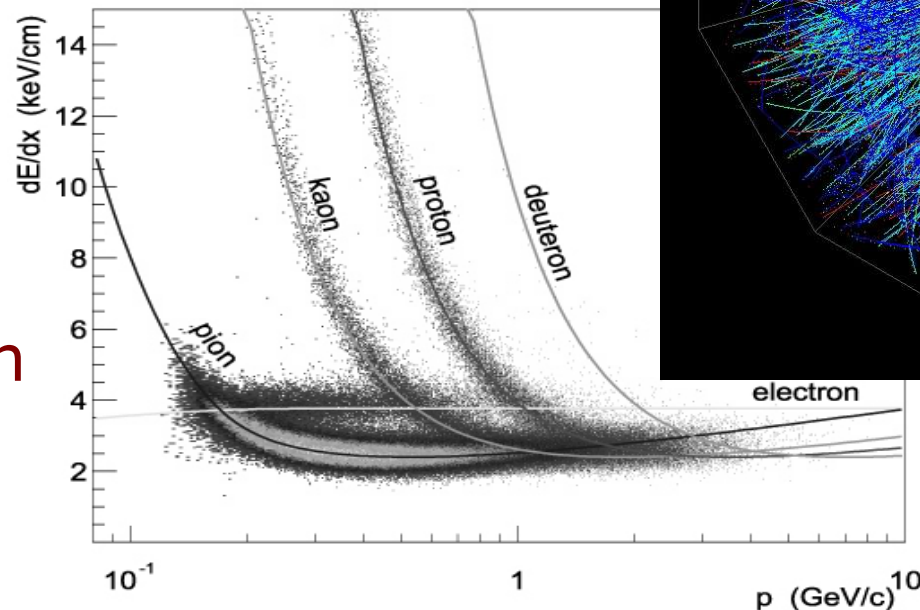
Spatial shifts (Δr)

Particle momentum



Non-identical particle correlations at STAR

- We present data from Year1
– 130 AGeV
- Central events – 13% of total cross-section
- Mid-rapidity particles from the TPC ($|y| < 0.5$)
- Particles identified by the dE/dx information

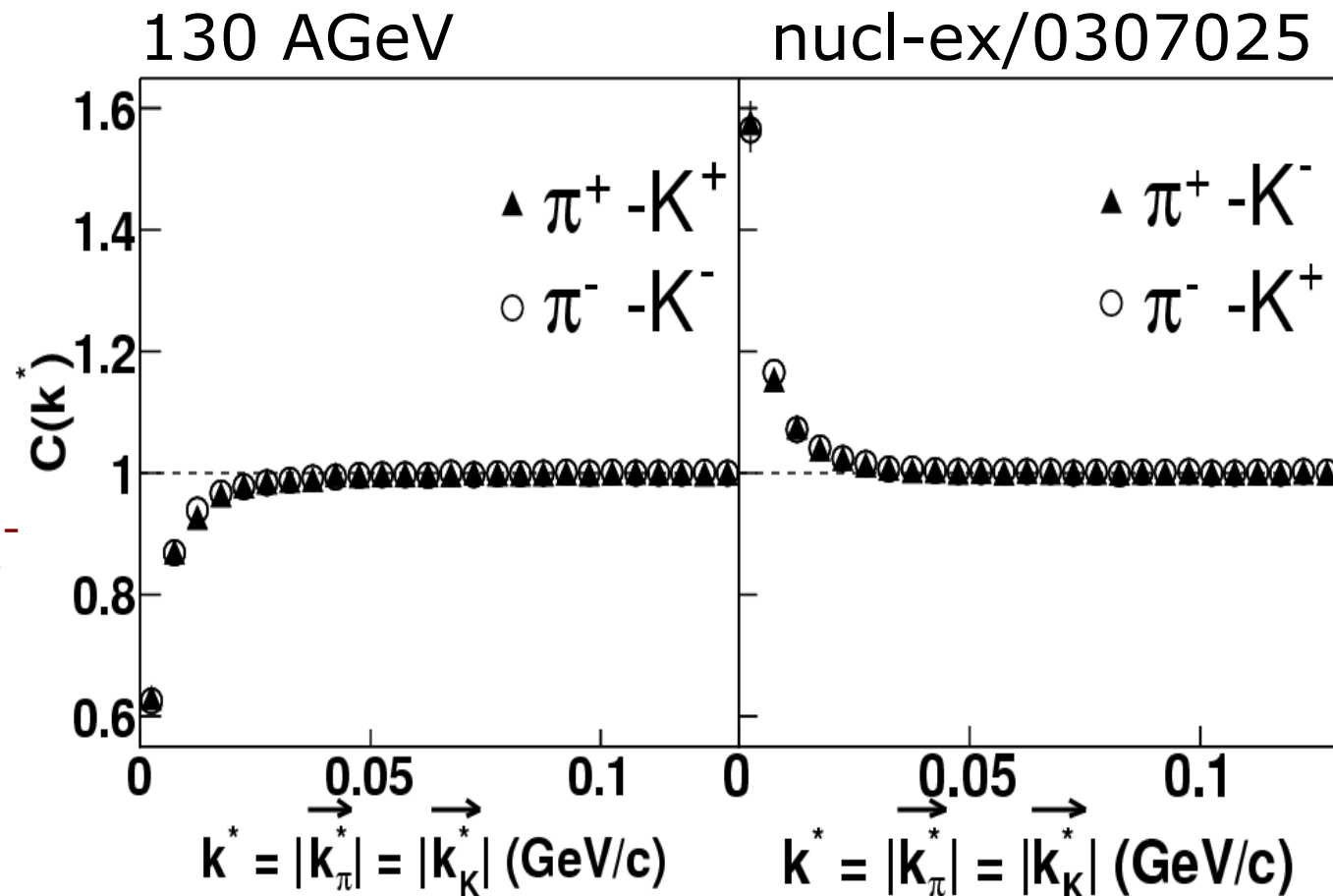


Technical Issues

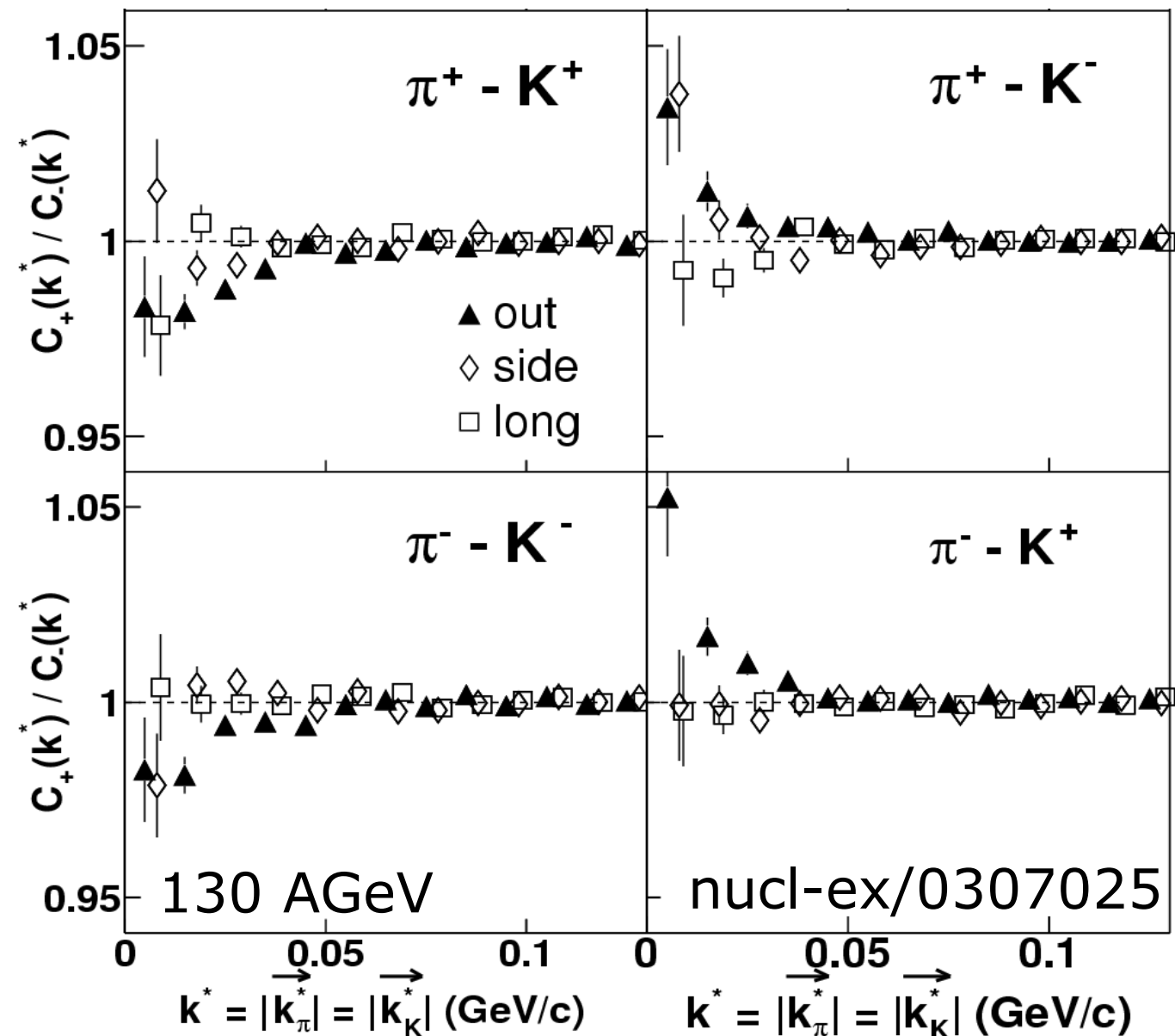
- Particle purity must be carefully studied
- We use dE/dx PID probability
 - Pair cuts: π -K or π -P pair probability > 0.6
 - Removal of correlated pairs from γ decay: probability of $e^+e^- < 0.01$
- Detector issues corrections
 - Two-track effects:
 - elimination of tracks with possible shared hits in the TPC
 - Particle purity
 - PID probability for kaons
 - PID probability + estimation of weak decay products for pions
 - Momentum resolution

Correlation functions

- The correlation functions are dominated by Coulomb – identical for the same charge combinations
- The agreement within the charge combination points to a very similar K^+ and K^- emission mechanism



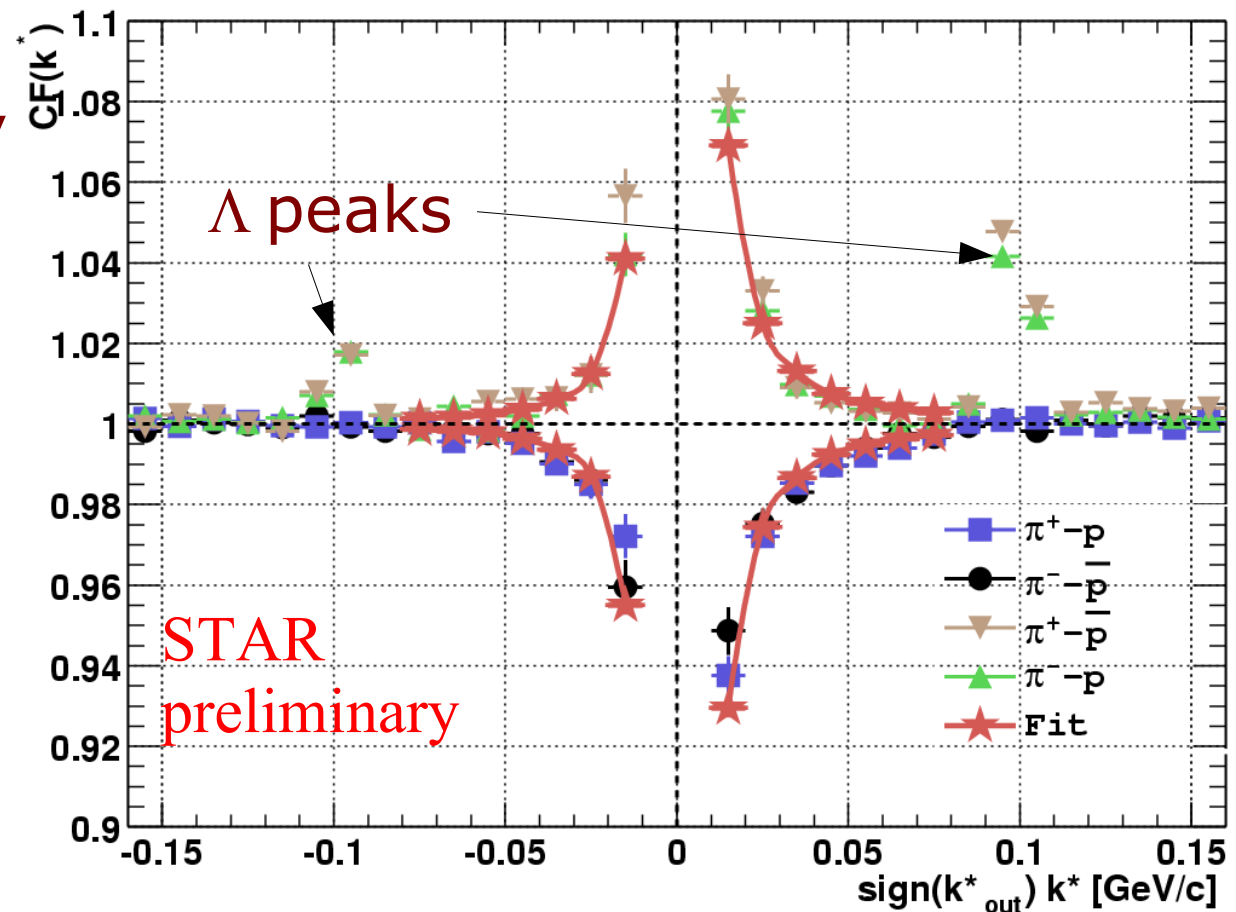
Double ratios



- Clear deviation from unity for Out – sign of asymmetry
- Side and Long – flat as expected (cross-check)

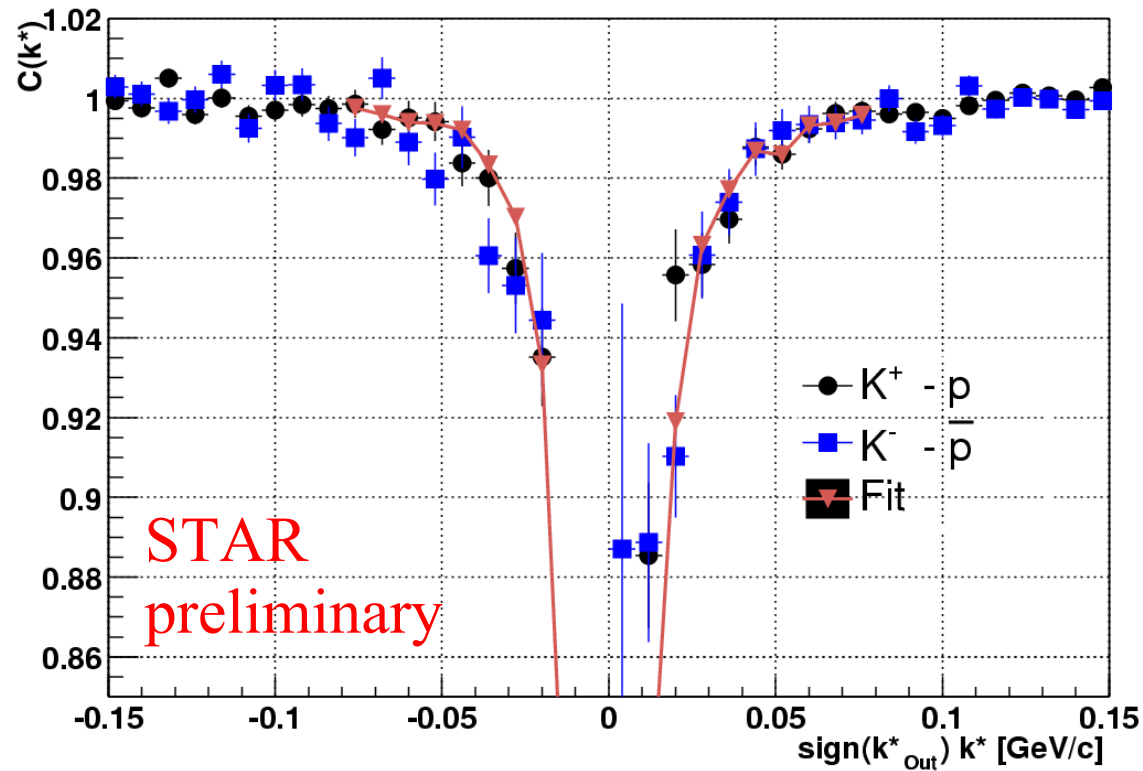
Results for Pion-Proton

- Similar preliminary analysis done for pion-proton
- We observe Lambda peaks at $k^* \sim m_{\text{inv}}$ of Λ
- Good agreement for identical and non-identical charge combinations



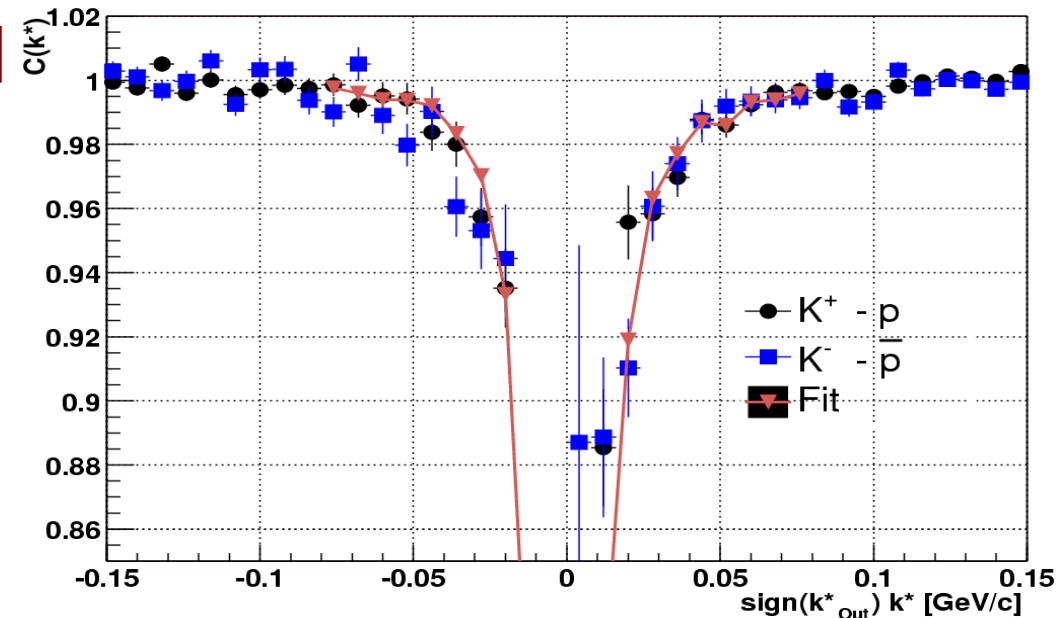
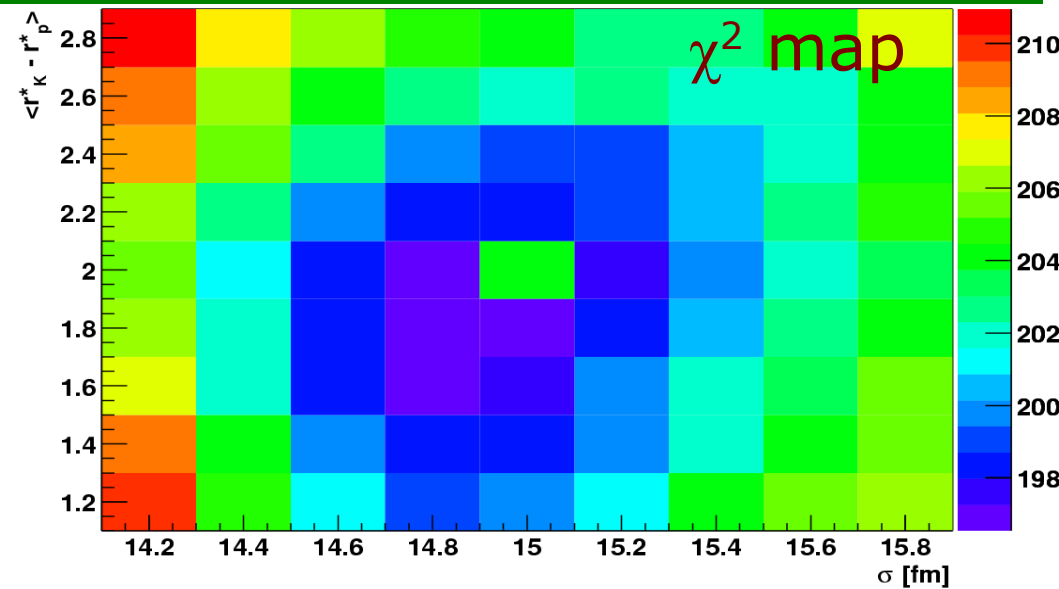
Preliminary results for Kaon-Proton

- Using data from Year2 (200 AGeV) – sufficient statistics
- No corrections for purity and/or momentum resolution done
- No error estimation yet – fit indicates theoretical expectations



Fitting procedure

- No analytic form of correlation function
- Need to generate correlation functions using experimental momentum distributions, Monte-Carlo methods and Lednicky's pair weights
- Best fit parameters are taken at the minimum χ^2 value

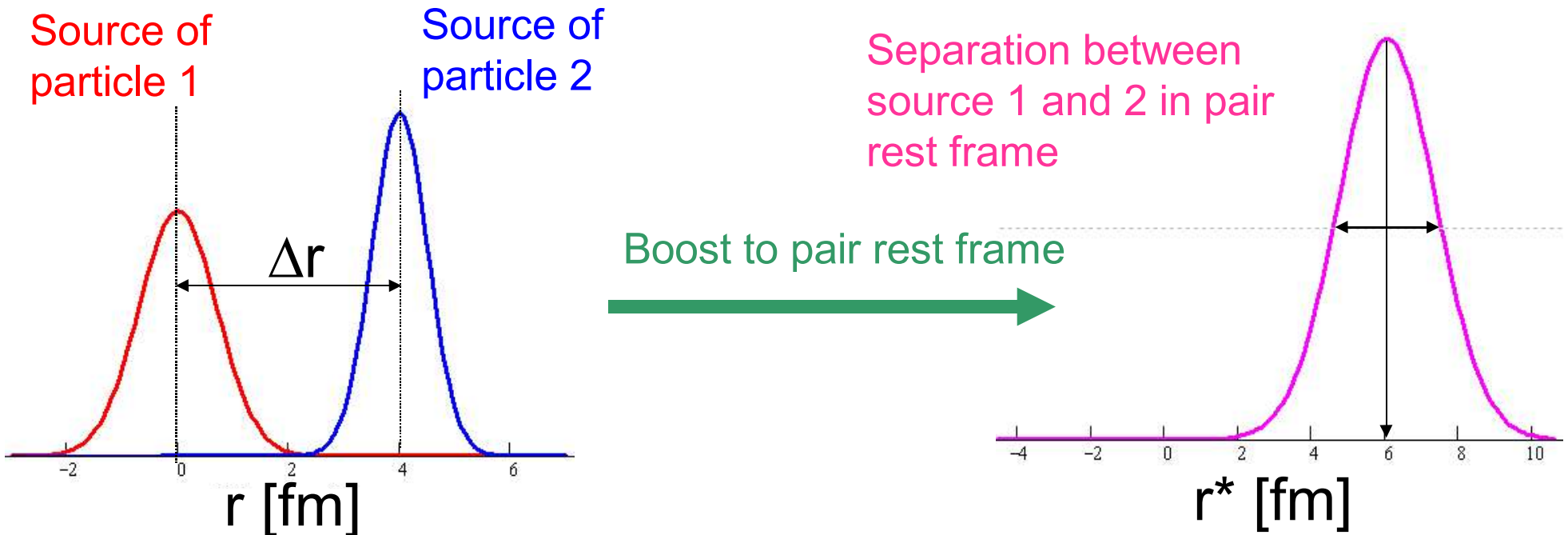


Modeling the emission asymmetry

- Need models producing strong transverse radial flow:
 - Blast-wave as a baseline
 - RQMD
 - UrQMD
 - T. Humanic's rescattering model
- What do we measure and how to compare it to the models?
- Is our fitting method working? And if yes, what does it tell us?
- Need to disentangle flow and time shift

1D relativistic view

What can be probed?



$$\Delta r^* = \gamma_{\text{pair}} (\Delta r - \beta_{\text{pair}} \Delta t)$$

Δr^* separation in pair rest frame

Function of $\gamma_{\text{pair}}(\beta_{\text{pair}})$ which depend on the pair acceptance

- 2 parameters

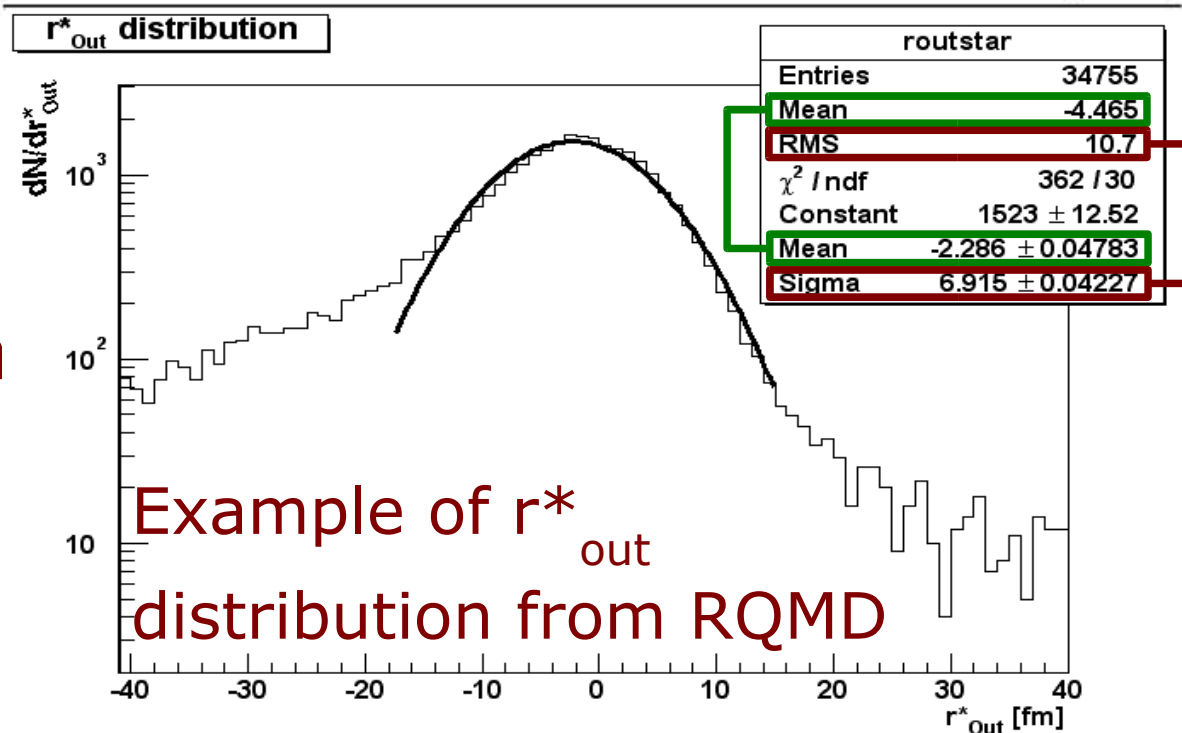
 - Mean shift ($\langle \Delta r^* \rangle$)
 - Sigma (σ_{r^*})

Fitting and quantitative comparisons

nucl-ex/0307025

- Fits assume gaussian source in PRF
- r_{out}^* distributions have non-gaussian tails
- Use the same fitting procedure for models and data - correlation functions constructed with "Lednicky's weights"

	σ (fm)	$\langle \Delta r_{out}^* \rangle$ (fm)	χ^2 / dof
Data	$12.5 \pm 0.4^{+2.2}_{-3}$	$-5.6 \pm 0.6^{+1.9}_{-1.3}$	134.5/110
RQMD	11.8 ± 0.4	-8.0 ± 0.6	205/54
RQMD no rescattering	5.8 ± 0.1	-2.0 ± 0.3	940/54
BWP	9.9 ± 0.1	-6.9 ± 0.3	1020/118



Do we see time shifts, spatial shifts, or both?

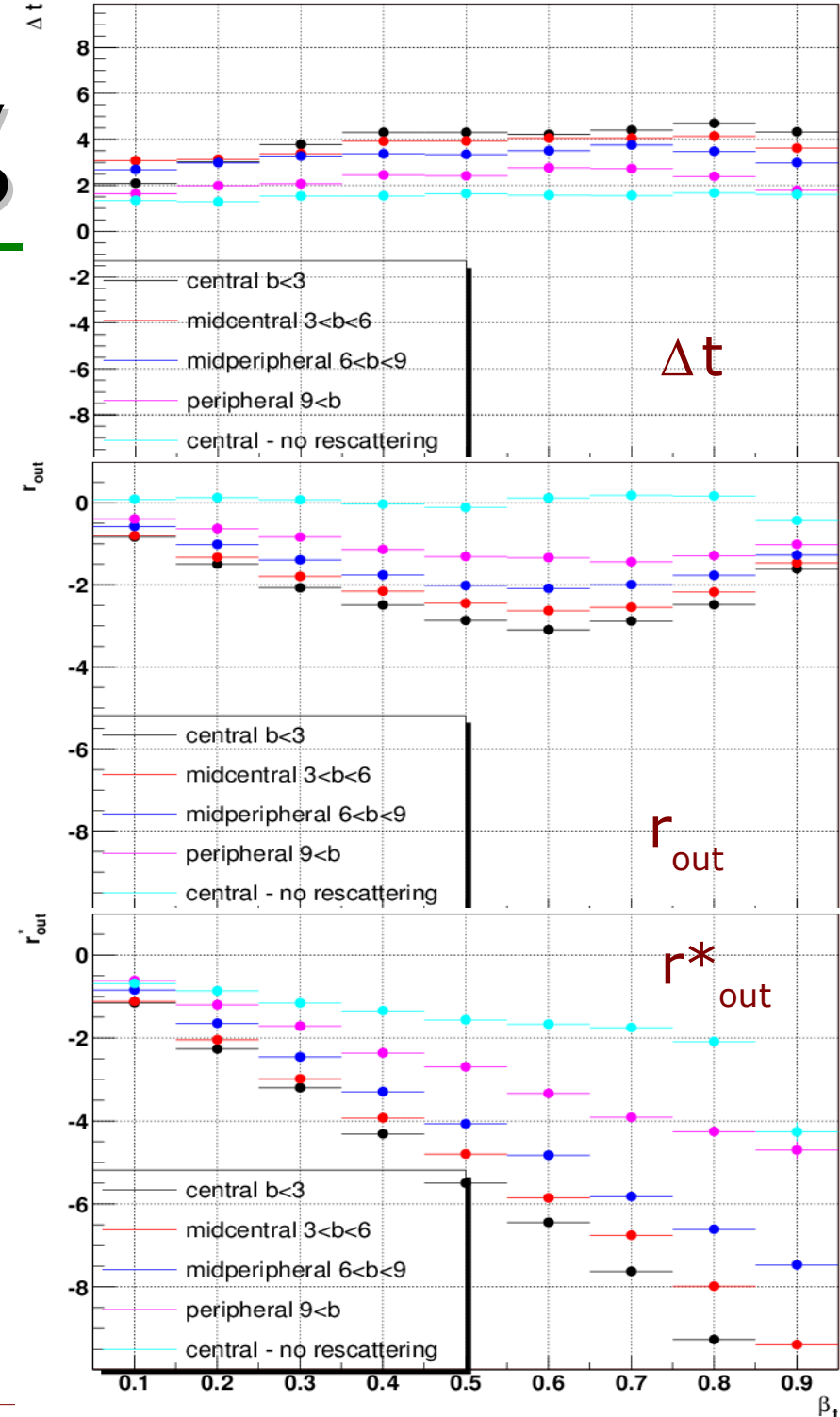
The general formula:

$$\Delta r^* = \gamma_{\text{pair}} (\Delta r - \beta_{\text{pair}} \Delta t)$$

r_{out} is a measure of flow

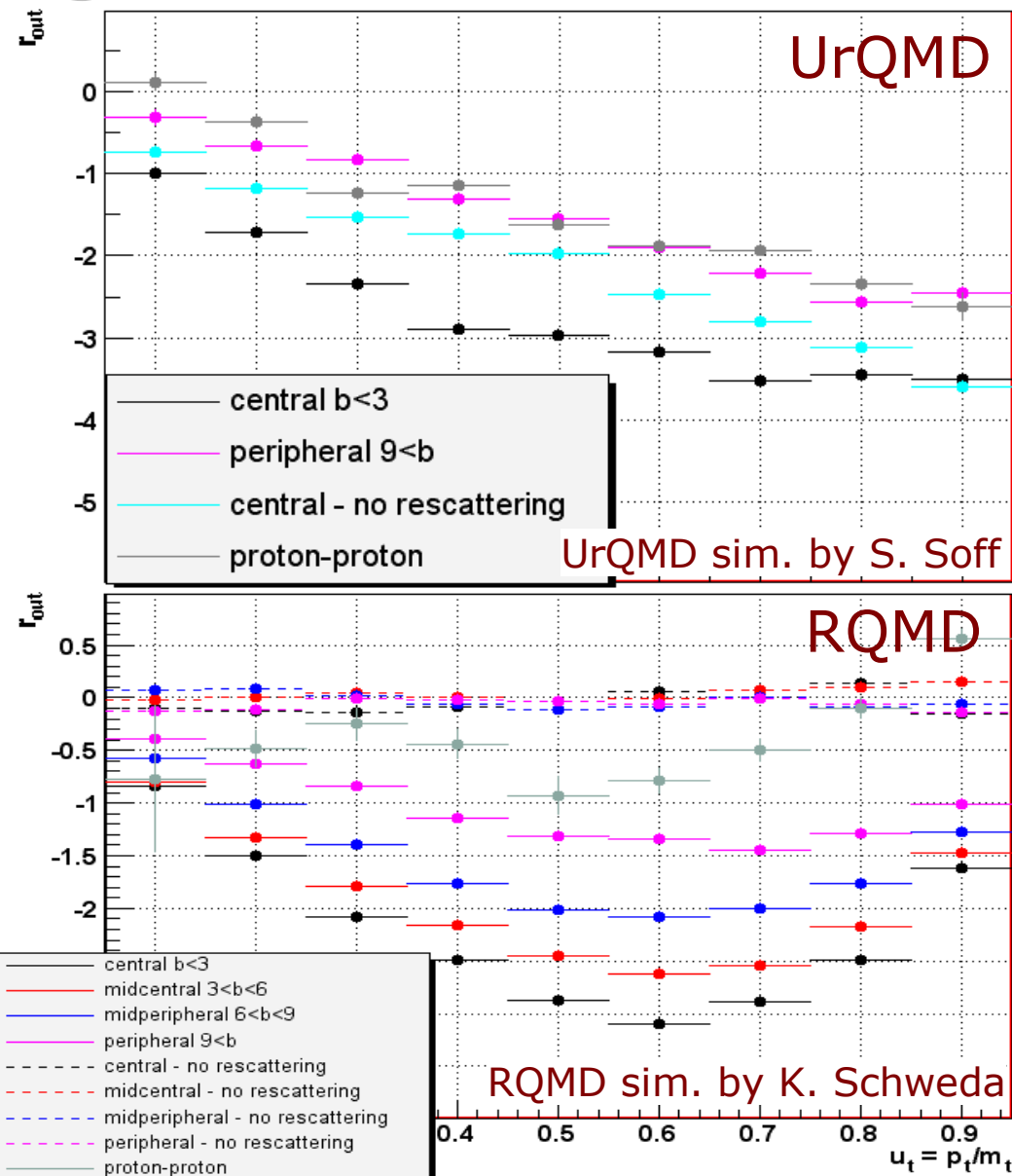
Turning off rescattering shuts down flow and decreases time shifts

We measure r_{out}^* , which combines time shifts and spatial shifts (from space-momentum ϕ correlations)



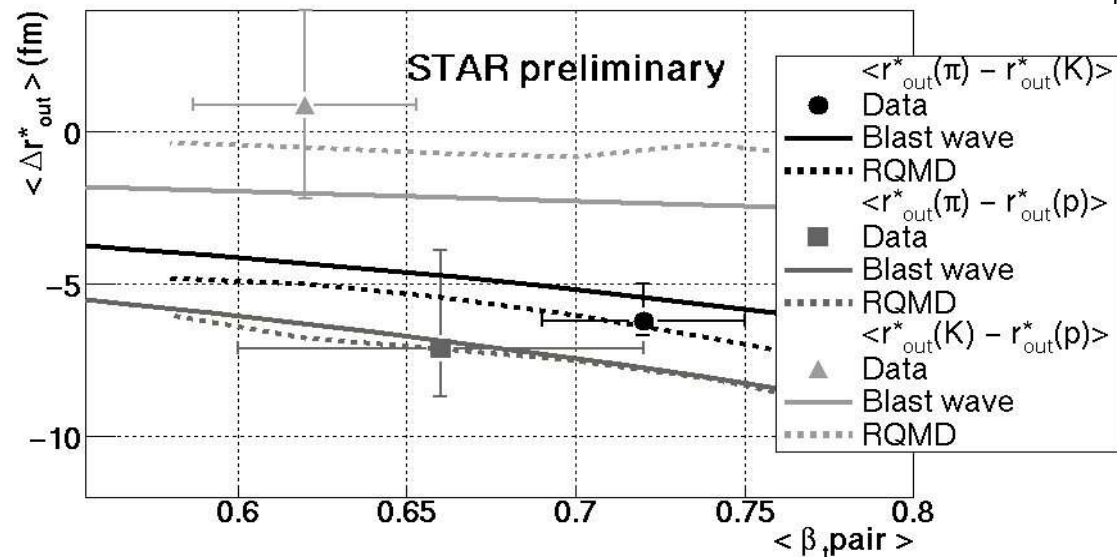
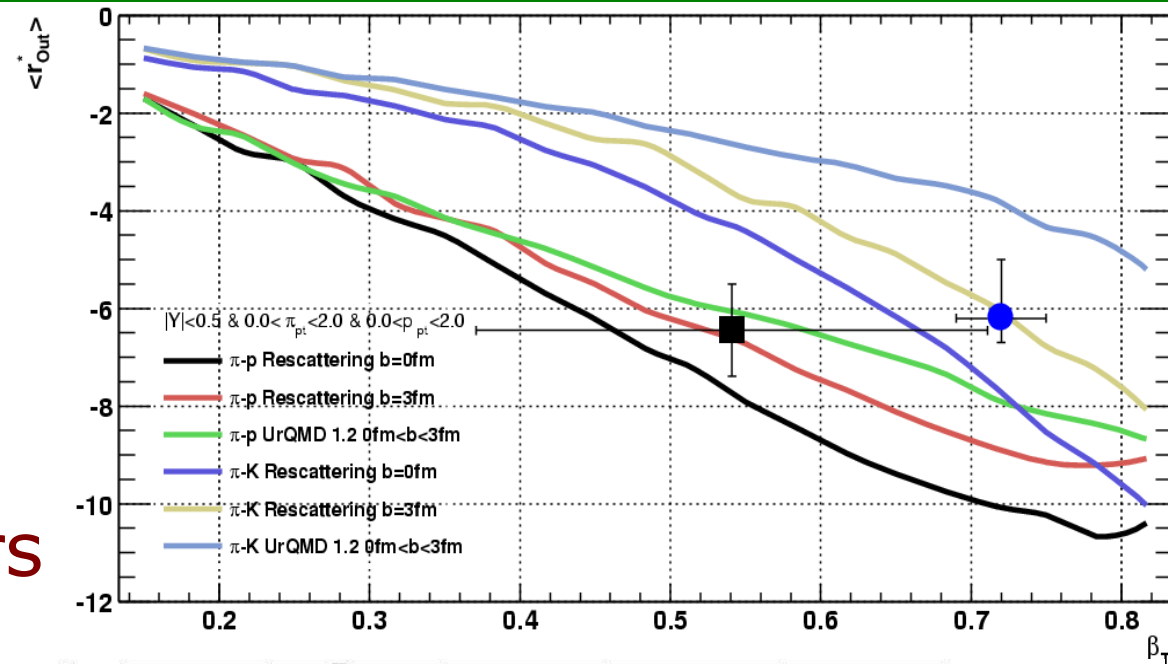
Rescattering models

- Both models produce significant flow
- Flow intensity scales with centrality
- RMQD w/o rescattering produced no flow
- pp collisions produce space-momentum correlations – jets?



Comparing models to data

- Rescattering models and blast-wave are able to reproduce the data
- Blast wave parameters constrained by other measurements from STAR
- In all models flow is required to reproduce the data

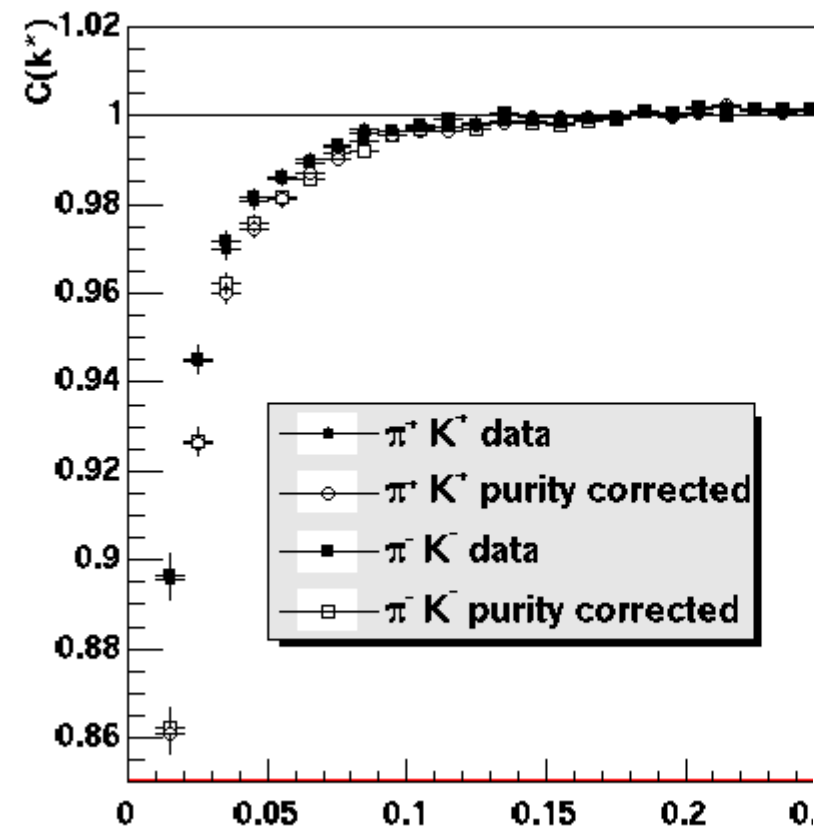


Summary and outlook

- Non-identical particle correlations give qualitatively new information: emission asymmetries, and an independent measurement of space-momentum correlations (transverse radial flow)
- Emission asymmetry was observed at STAR for pion-kaon and pion-proton pairs
- Rescattering models and blast-wave are consistent with the data, because they produce radial flow
- More systems (e.g. Proton-Lambda, Pion-Cascade), more statistics, higher collision energy data coming

Purity correction

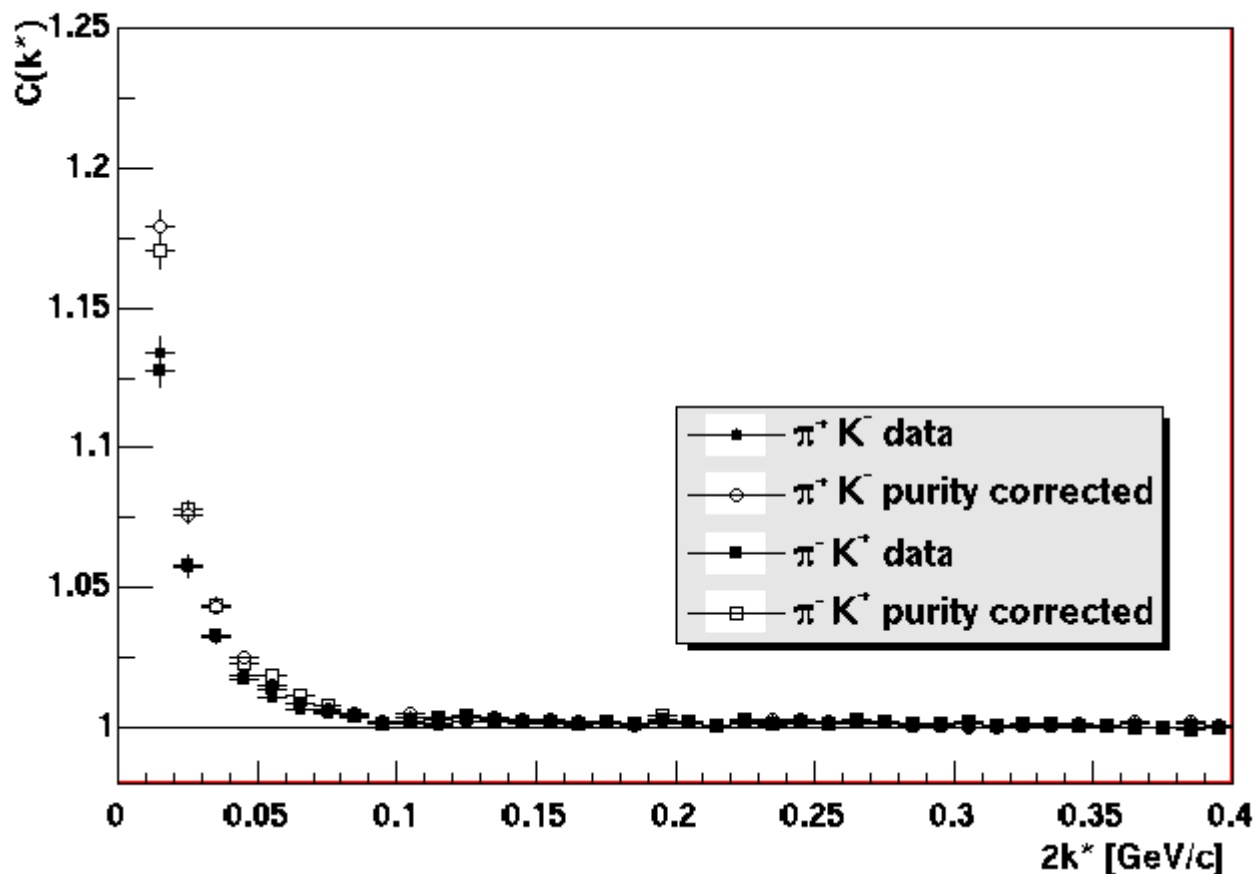
$\pi - K$ correlation functions



$$C_{corrected} = \frac{C_{measured} - (1 - P) * 1.0}{P}$$

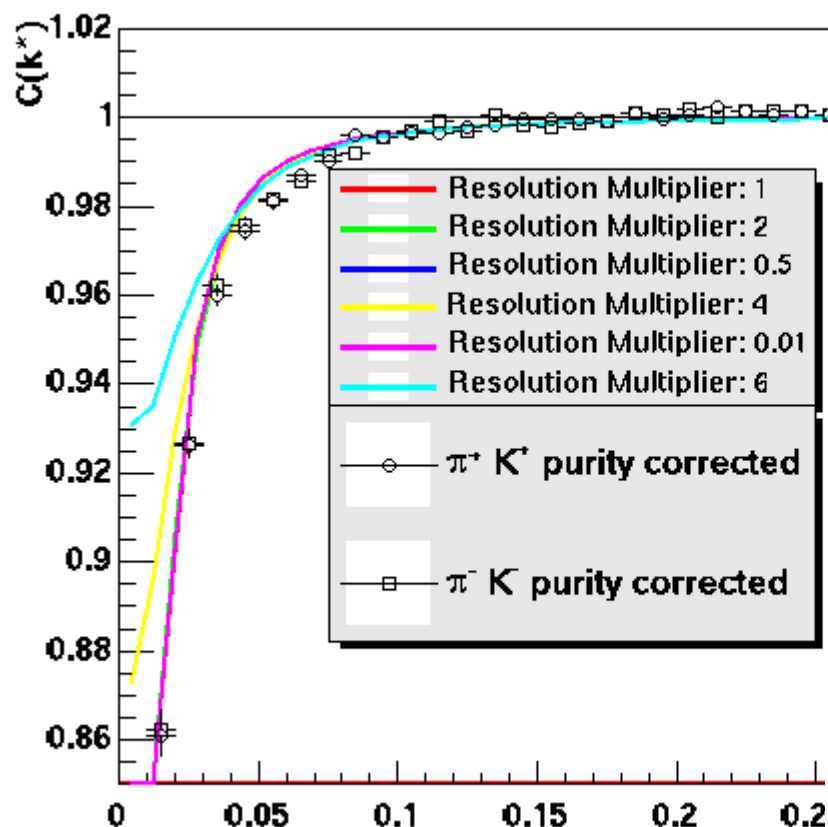
Average pair
purity = **0.75**

$\pi - K$ correlation functions



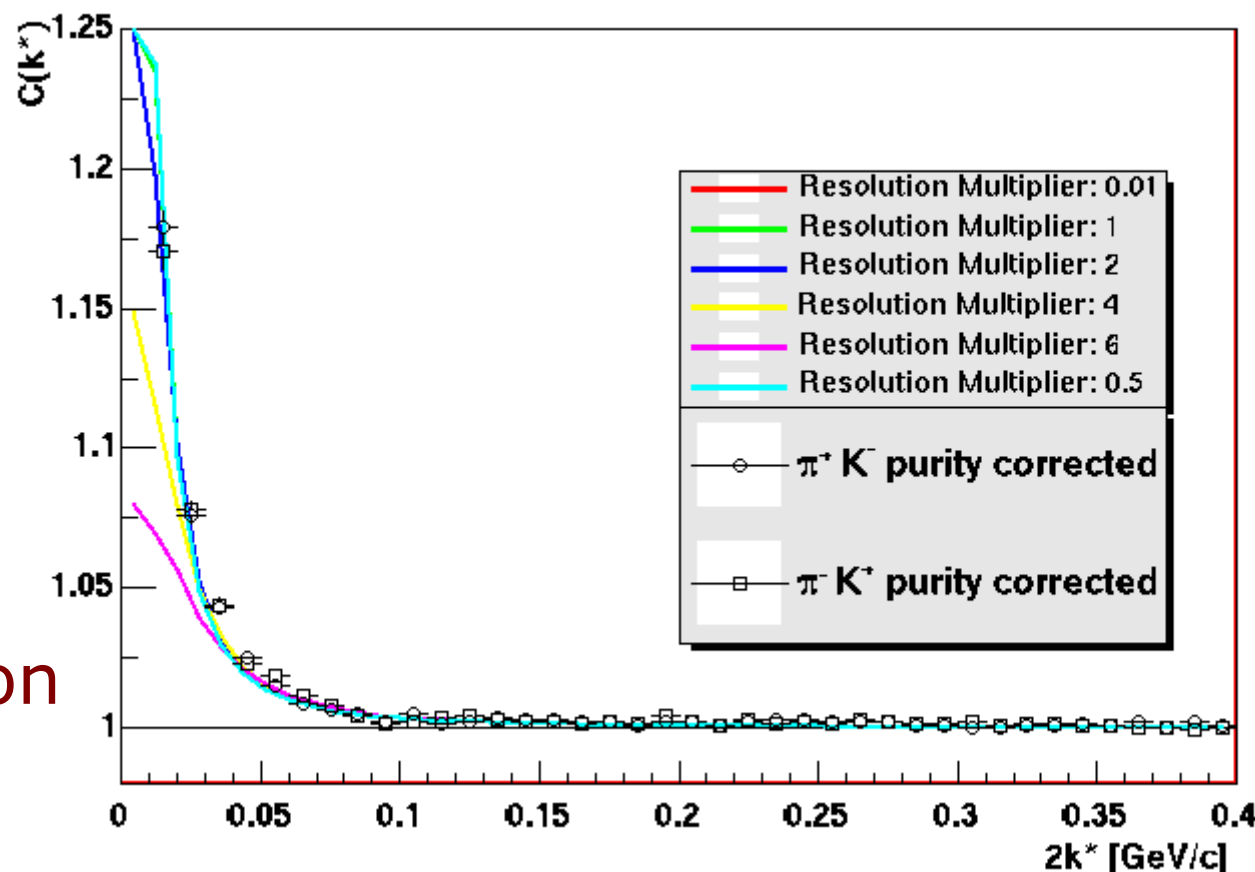
Momentum resolution

$\pi - K$ correlation functions



Momentum smearing
and low p_T shift

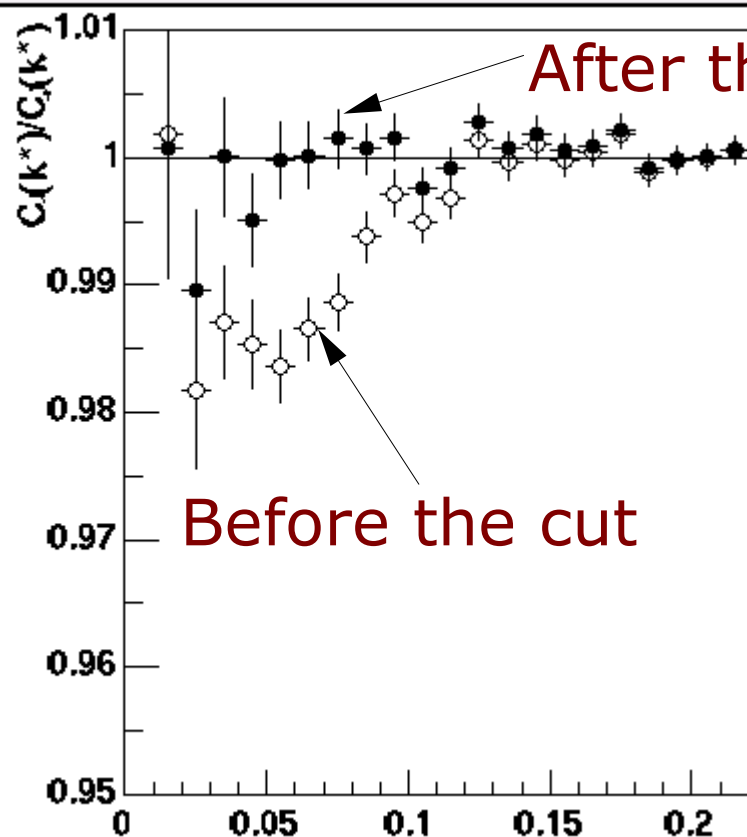
$\pi - K$ correlation functions



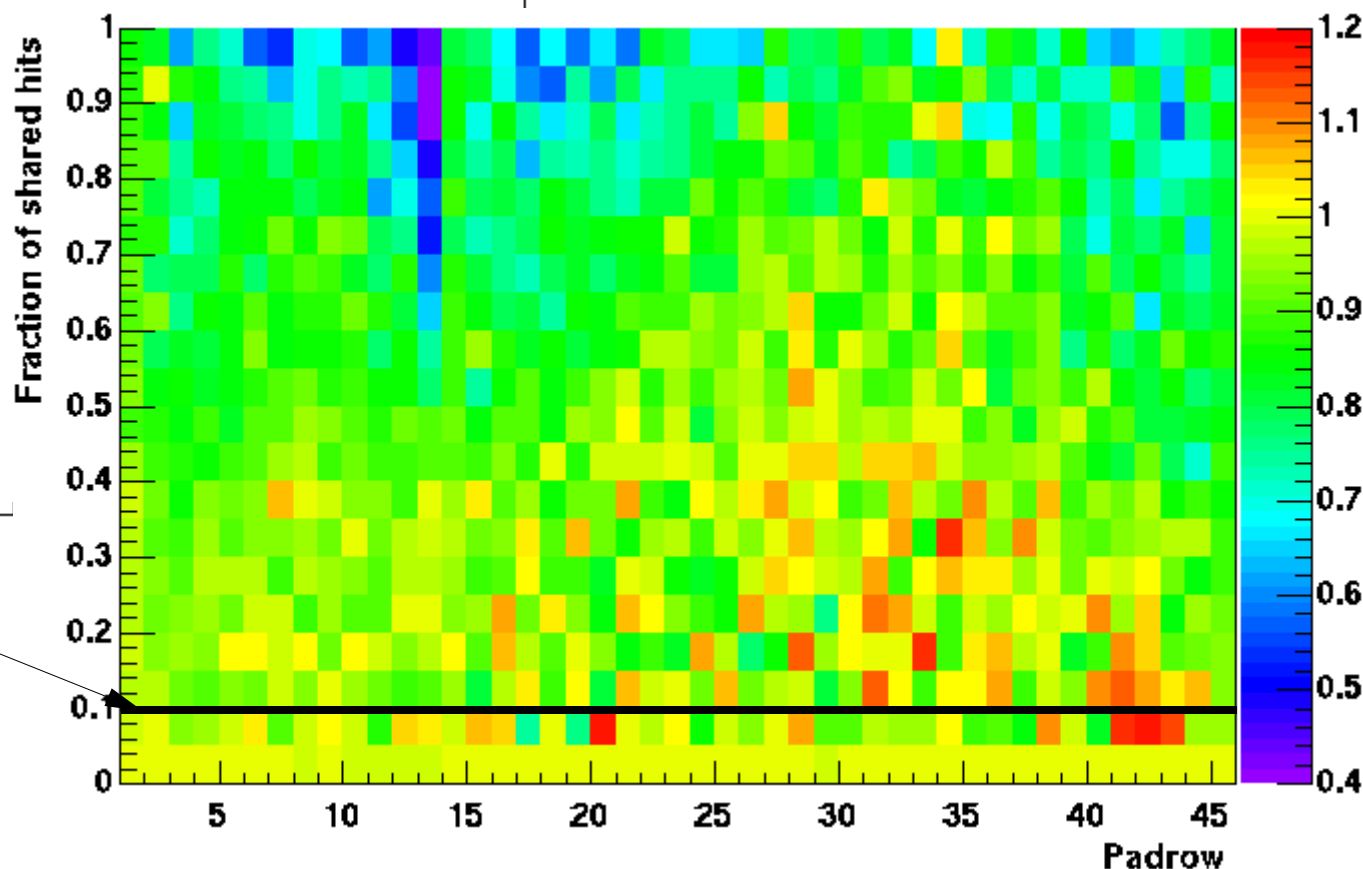
No change until resolution
4x worse than STAR

Hit sharing cut effect on Side ratio

Padrow cut effect on Side NOOverP double ratio

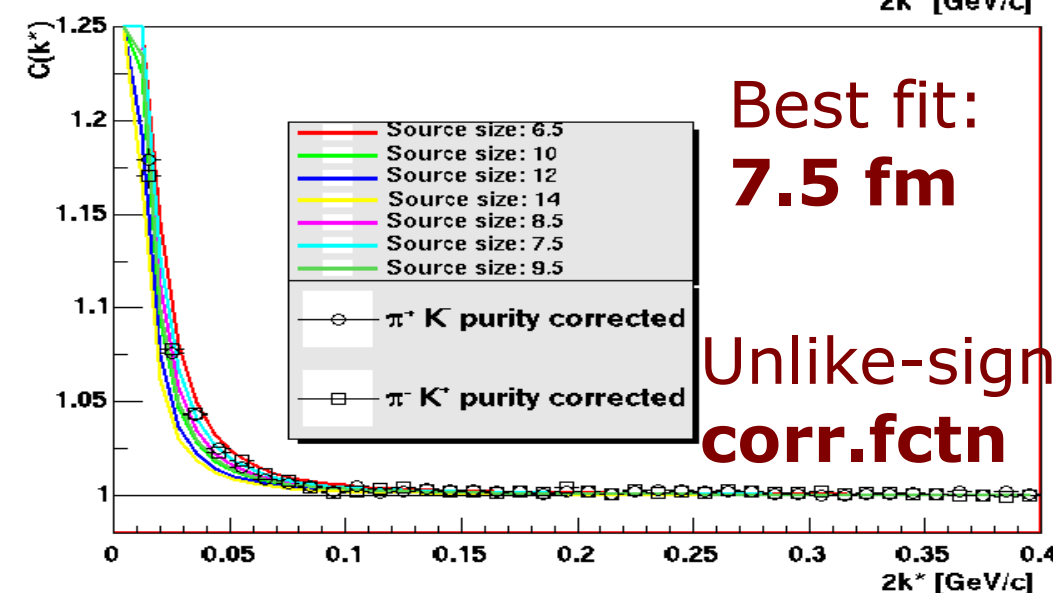
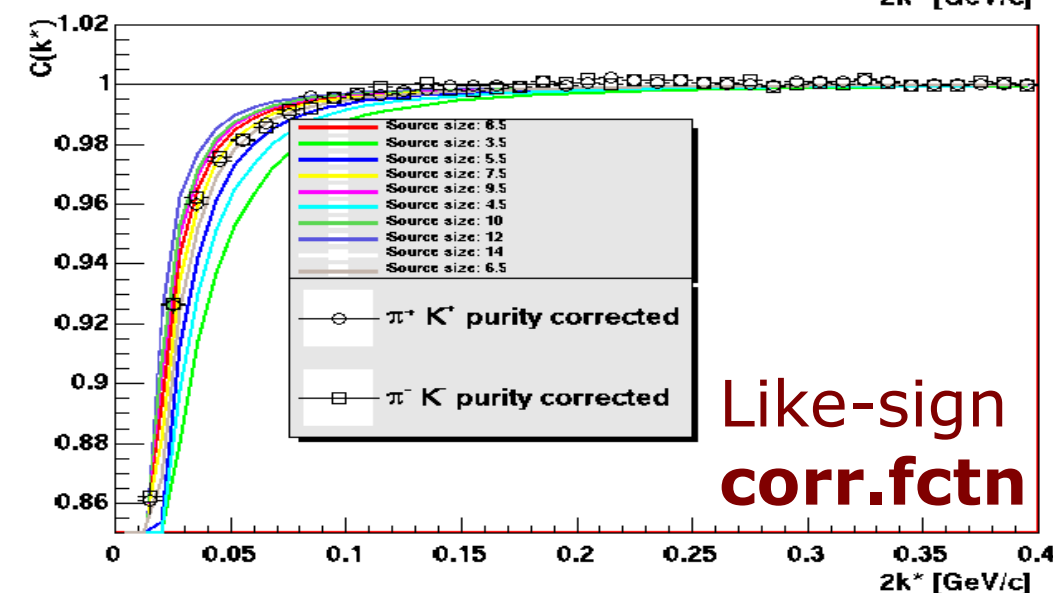
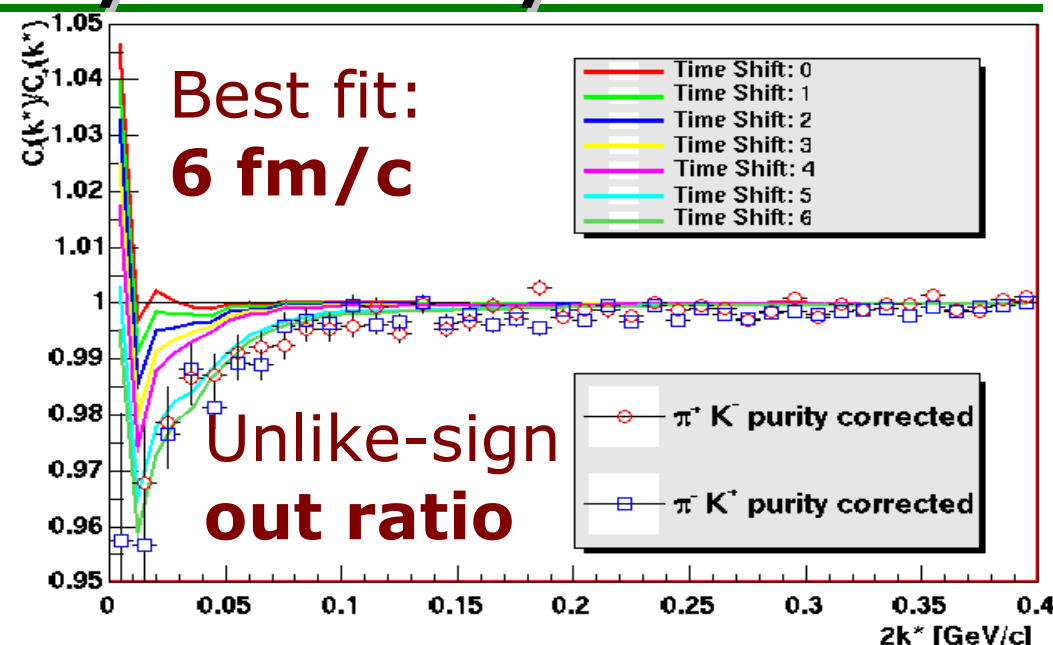
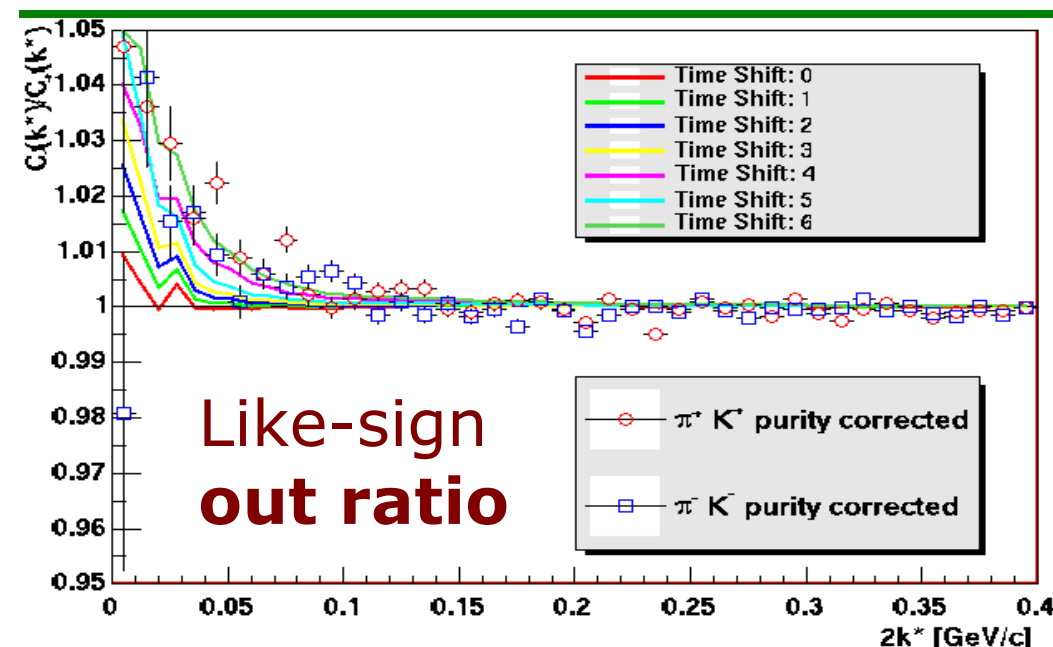


Maximum number of shared hits between two tracks = 10%



Should be at 1.0 as there is no physics effect that can cause the asymmetry

Static source - time shift can be the cause for asymmetry



Hydro + RQMD pure and scrambled can we disentangle time shift and flow

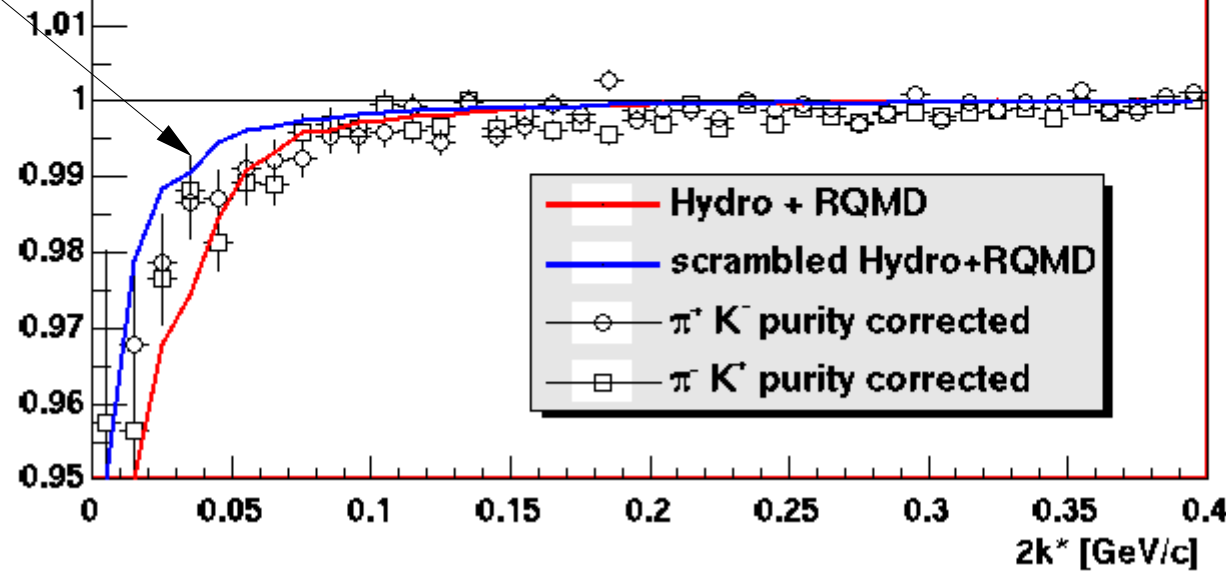
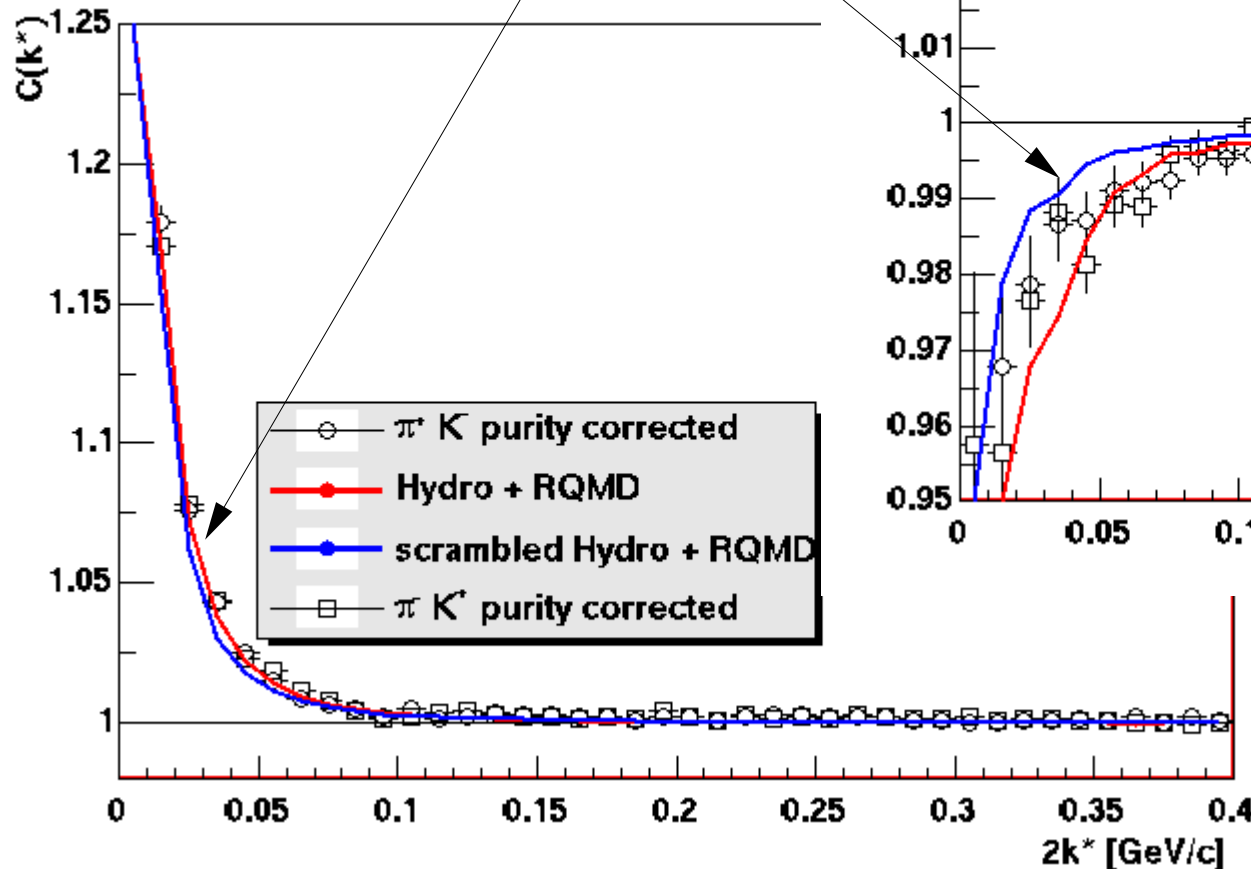
Scrambling the positions
removes some of the
Out asymmetry

$\pi - K$ Out NOverP ratio

$C(k^*)C_2(k^*)$

Out asymmetry comes from the
combination of time shift and
position-momentum correlations

$\pi - K$ correlation functions



phi scrambling does not
remove all momentum-
position correlation

Hydro inspired parametrization - radial flow produces asymmetry

