Non-identical particle correlations in 130 and 200 AGeV collisions at STAR

Adam Kisiel
Warsaw University of Technology

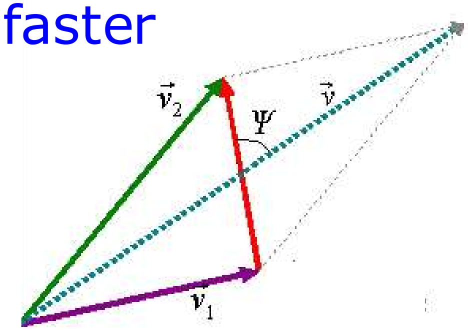
for the **STAR experiment**

Outline

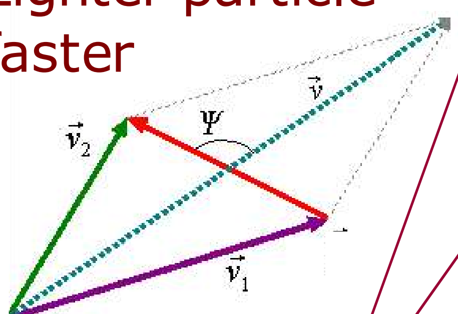
- Physics motivation
  - Emission asymmetry measurement
  - Measuring flow as space-momentum correlations
  - Determining interaction potentials
- Current results
  - 130 AGeV data
  - 200 AGeV data
- Flow in models
  - Blast-wave parameterization
  - RQMD – transport model
- Exotic correlation functions
  - Proton-Lambda and antiproton-Lambda
  - Pion-Cascade

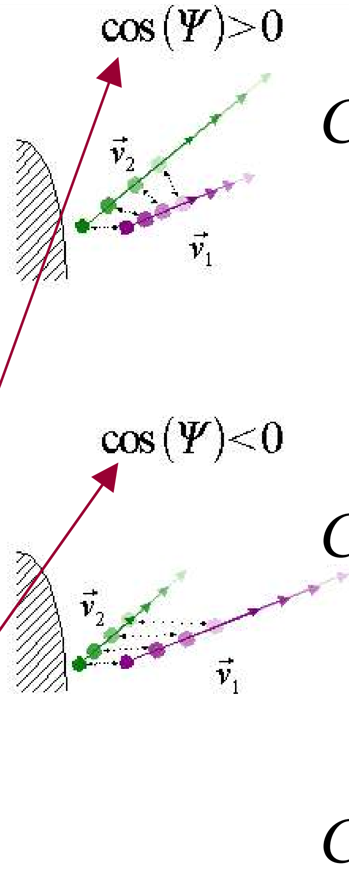
The asymmetry analysis

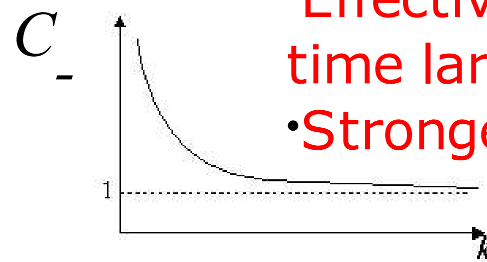
Heavier particle faster



Lighter particle faster

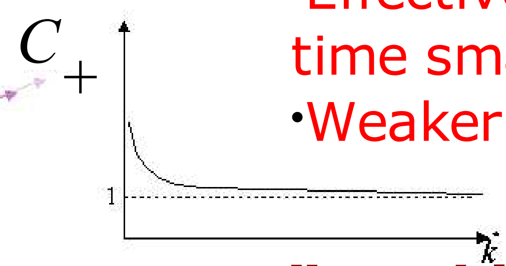






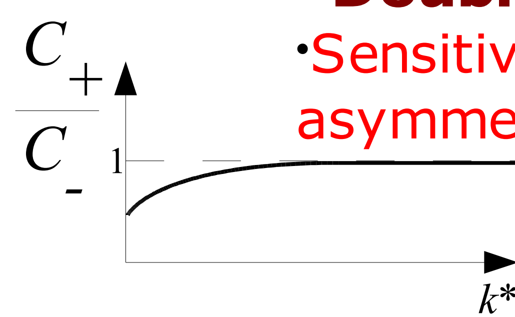
Catching up

- Effective interaction time larger
- Stronger correlation



Moving away

- Effective Interaction time smaller
- Weaker correlation



"Double" ratio

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

Kinematics selection along some direction

e.g. k_{Out}, k_{Side}, cos(v,k)

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

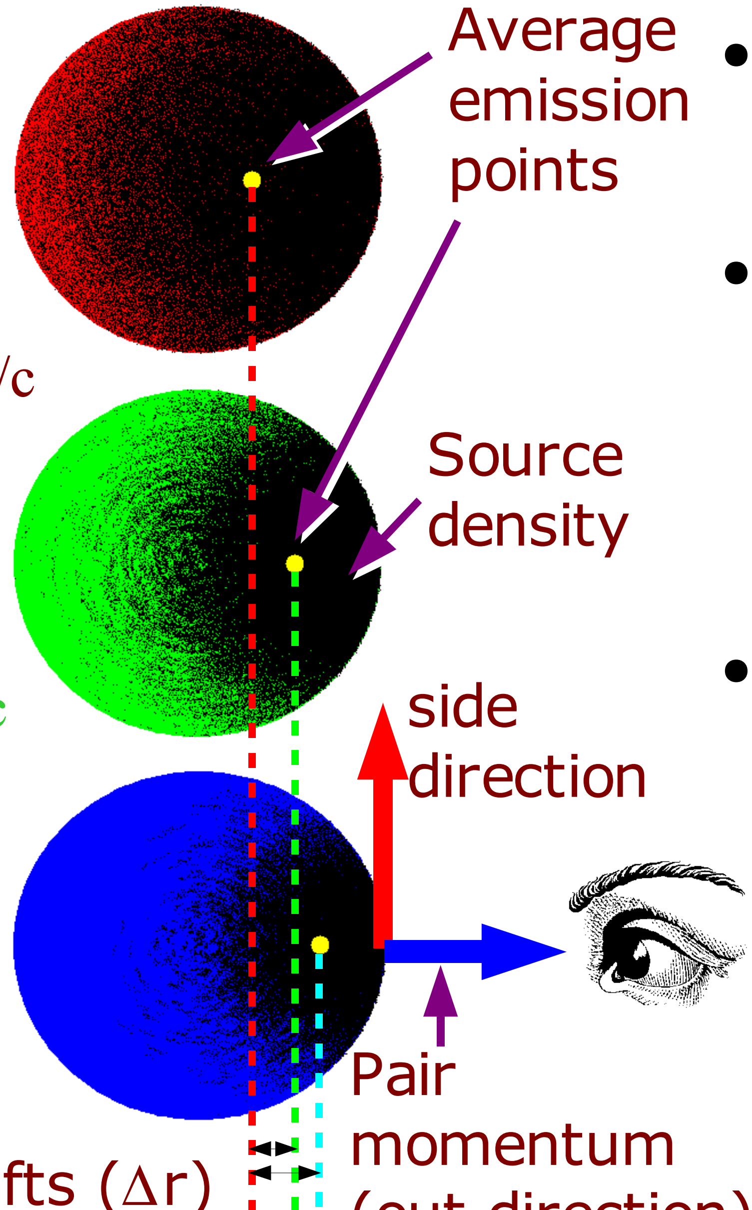
Flow in the transverse plane

nucl-th/0312024
F. Retiere,
M. Lisa

Pion
$<\beta_t> = 0.7$
$p_t = 0.15$ GeV/c

Kaon
$<\beta_t> = 0.7$
$p_t = 0.5$ GeV/c

Proton
$<\beta_t> = 0.7$
$p_t = 1.$ GeV/c



Spatial shifts (Δr)

- Flow produces emission asymmetries in space Δr
- Observed asymmetry r* can come from emission time difference Δt too

$$\langle r^* \rangle = \gamma(\langle \Delta r \rangle - \beta_T \langle \Delta t \rangle)$$

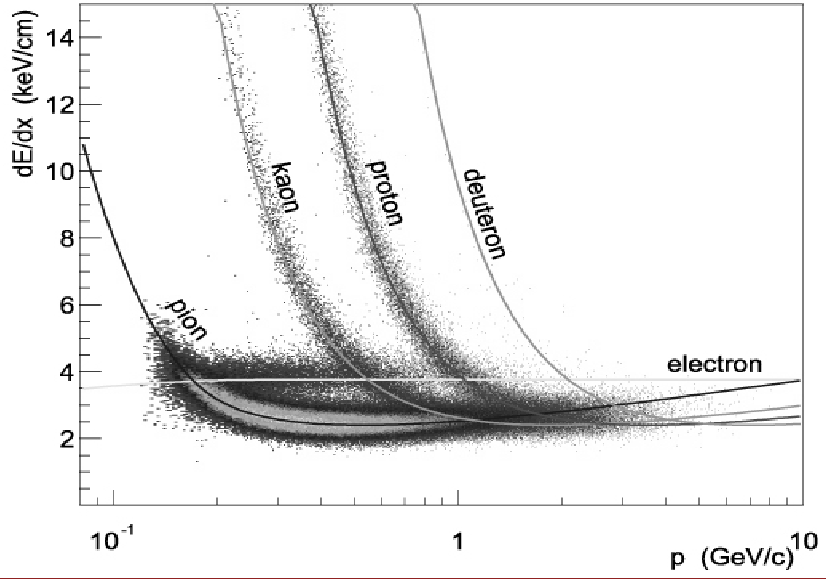
- We expect asymmetry in "out" direction, but not in "side", due to symmetry

S.Voloshin, R.Lednicky, S. Panitkin, N.Xu, Phys.Rev.Lett.**79**(1997)30

R. Lednicky, nucl-th/0305027

Data sample

- Central AuAu collisions
  - 130 AGeV – 0.7 Mevents
  - 200 AGeV – 2.2 Mevents
- Identification probability from dE/dx in STAR TPC
  - Purity cuts on particle level
  - $\gamma \rightarrow e^+e^-$ removal on pair level

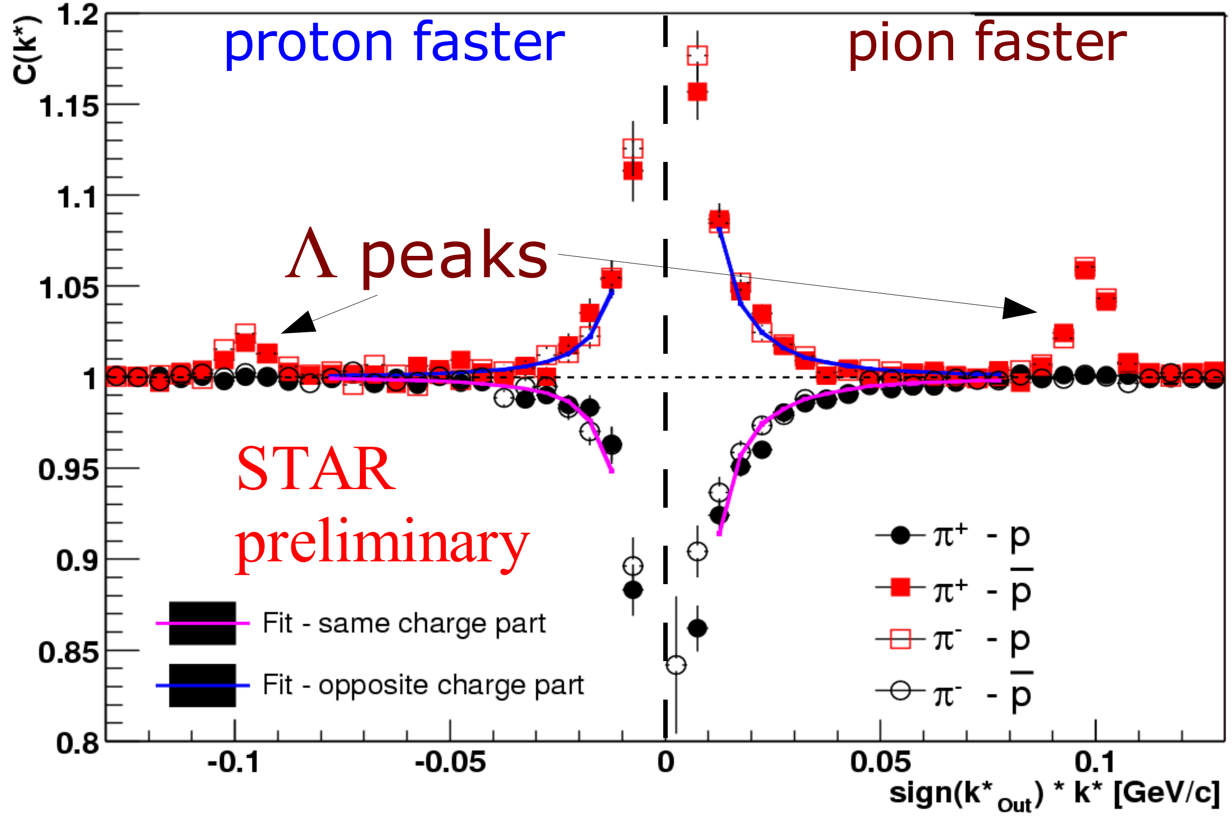


- Midrapidity data |y|< 0.5
- Momentum range [GeV/c]
  - Pions (0.13, 0.5)
  - Kaons (0.3, 1.0)
  - Protons (0.4, 1.2)
- Detector corrections
  - Two-track effects:
    - elimination of pairs possibly sharing hits in the TPC
  - Particle purity
    - PID probability (all), estimation of contamination from weak decay (pions, protons)
  - Momentum resolution

Pion-Proton 130 AGeV

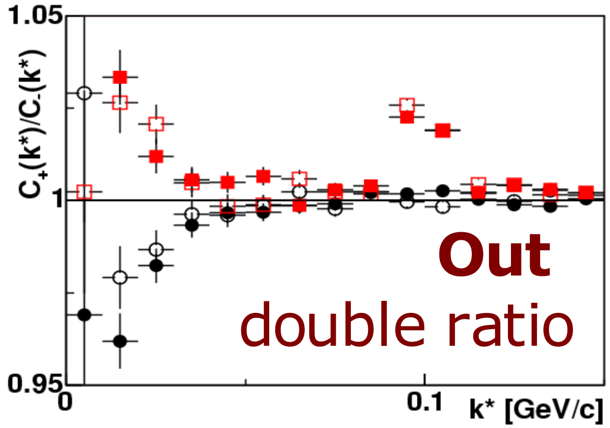
- Good agreement for identical and opposite charge combinations

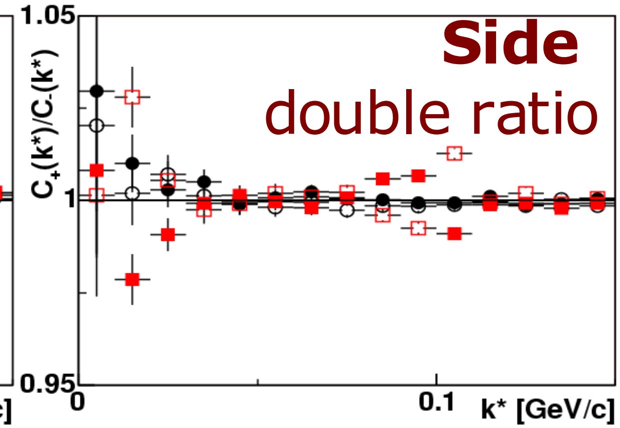
- We observe Lambda peaks at k*~decay momentum of Λ



Sigma: **15.1** ± **0.4** $^{+1.0 \text{ syst.}}_{-1.5 \text{ syst.}}$ fm
Mean: **-7.4** ± **0.9** $^{+1.9 \text{ syst.}}_{-3.4 \text{ syst.}}$ fm

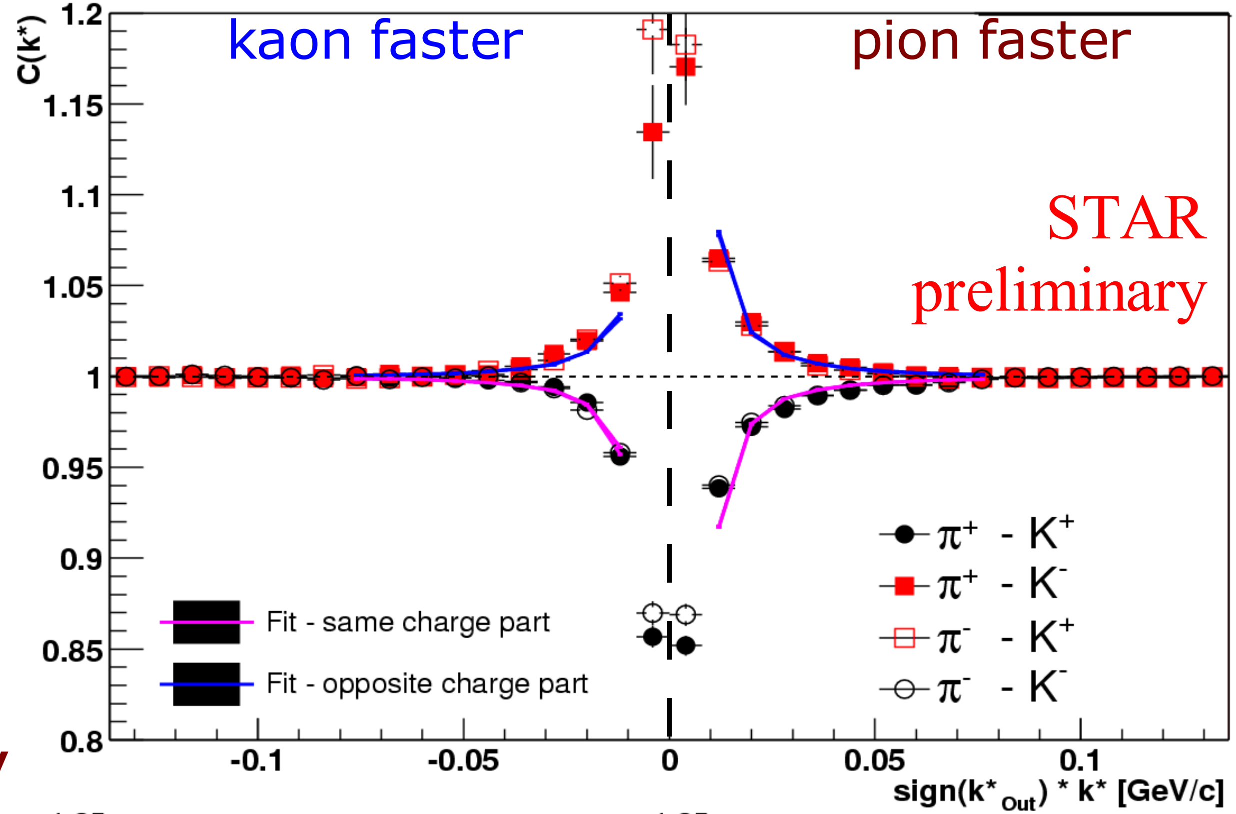
Fit assumes source is a gaussian in r^*_{out}

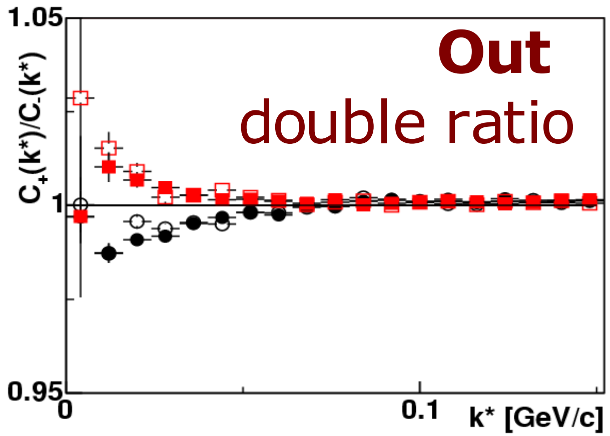


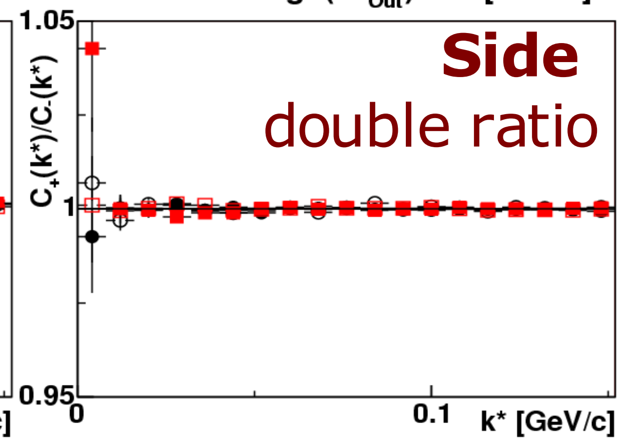


Pion-Kaon at 200 AGeV

- Good agreement for same-charge combinations
- Clear emission asymmetry signal
- Systematic error under study – influenced by purity and fits to all CFs separately







Sigma: **17.3** ± **0.8** $^{+0.9\ \text{syst.}}_{-1.6\ \text{syst.}}$ fm

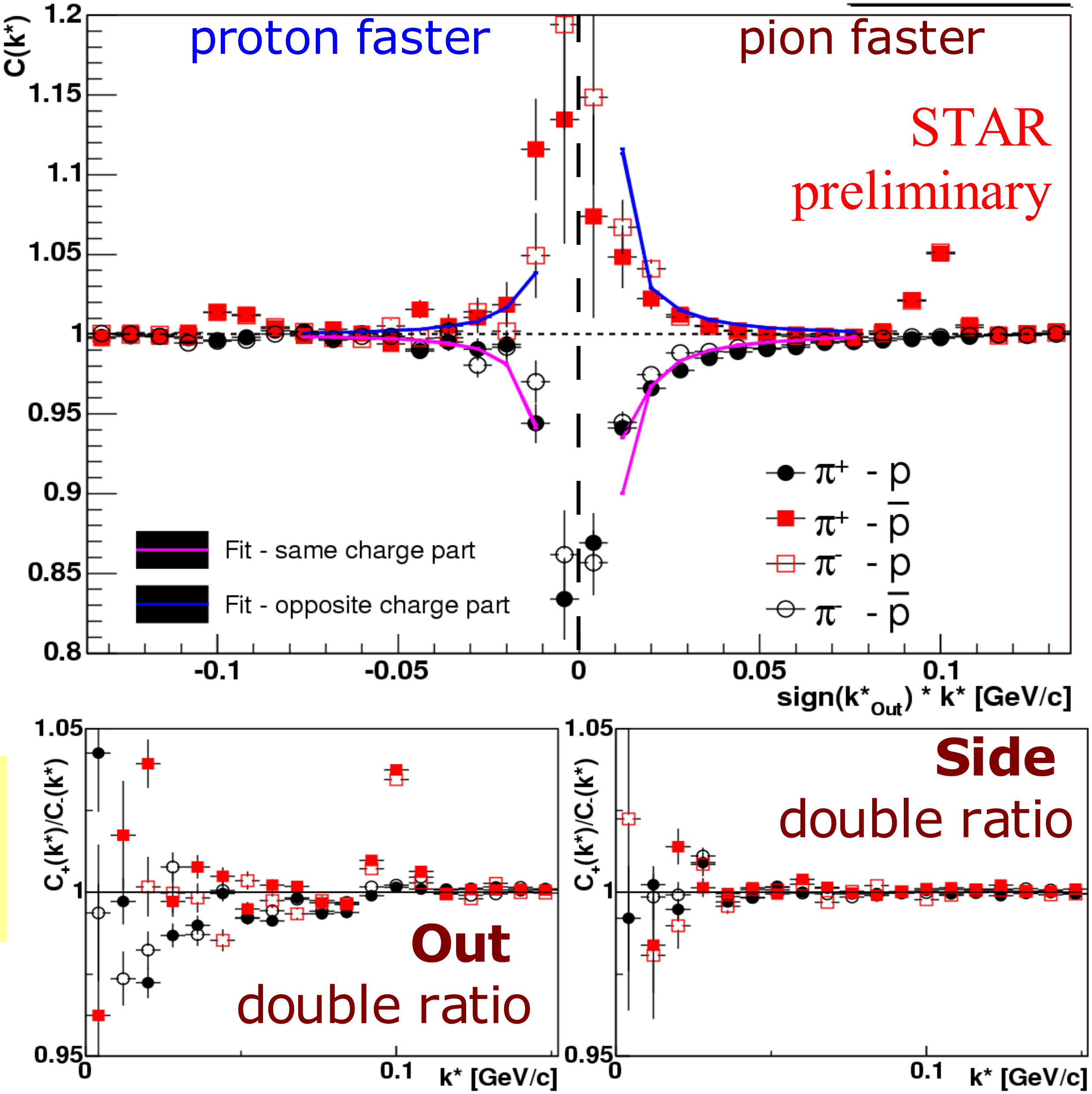
Mean: **-7.0** ± **1.2** $^{+6.1\ \text{syst.}}_{-4.0\ \text{syst.}}$ fm

Pion – Proton at 200 AGeV

- Good agreement for same-charge combination pairs
- Double ratios influenced by e^+e^-
- Systematic error under study

Sigma: **14.8 ± 0.5** $^{+4.0\ \text{syst.}}_{-3.0\ \text{syst.}}$ fm

Mean: **-6.0 ± 1.5** $^{+3.0\ \text{syst.}}_{-5.5\ \text{syst.}}$ fm

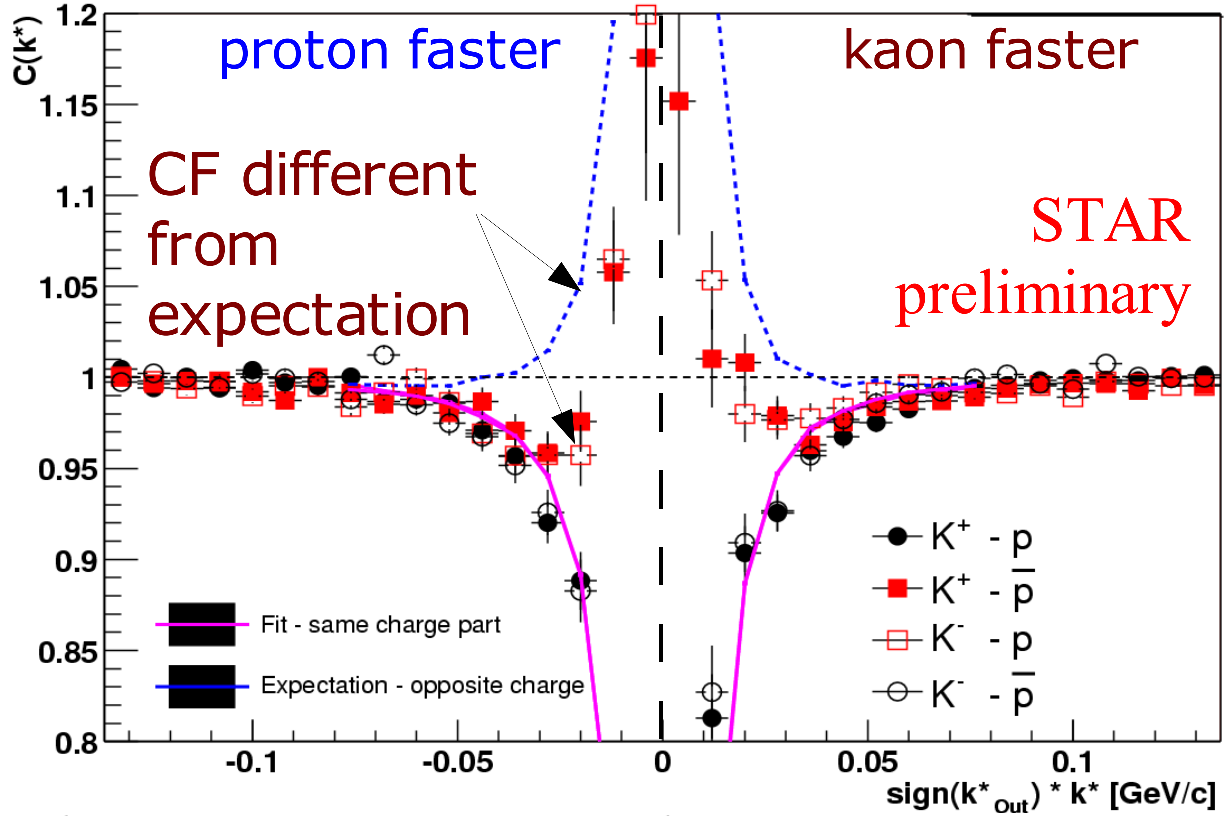


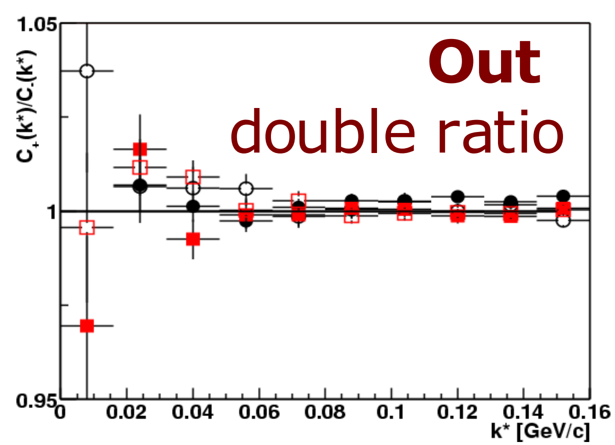
Kaon-Proton at 200 AGeV

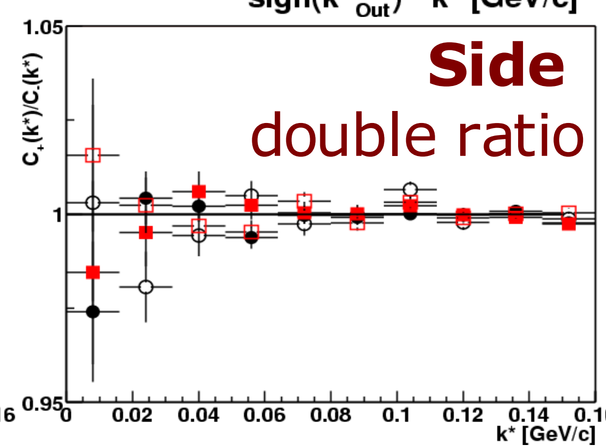
- Only like-sign data well described by theory and fitted
- Surprising correlation shape for unlike-sign – a question to theorists
- Mean shift opposite to pi-K and pi-p

Sigma: $\mathbf{10.6 \pm 0.6}\ ^{+1.4\ \text{syst.}}_{-2.1\ \text{syst.}}$ fm

Mean: $\mathbf{0.7 \pm 1.5}\ ^{+1.6\ \text{syst.}}_{-0.6\ \text{syst.}}$ fm







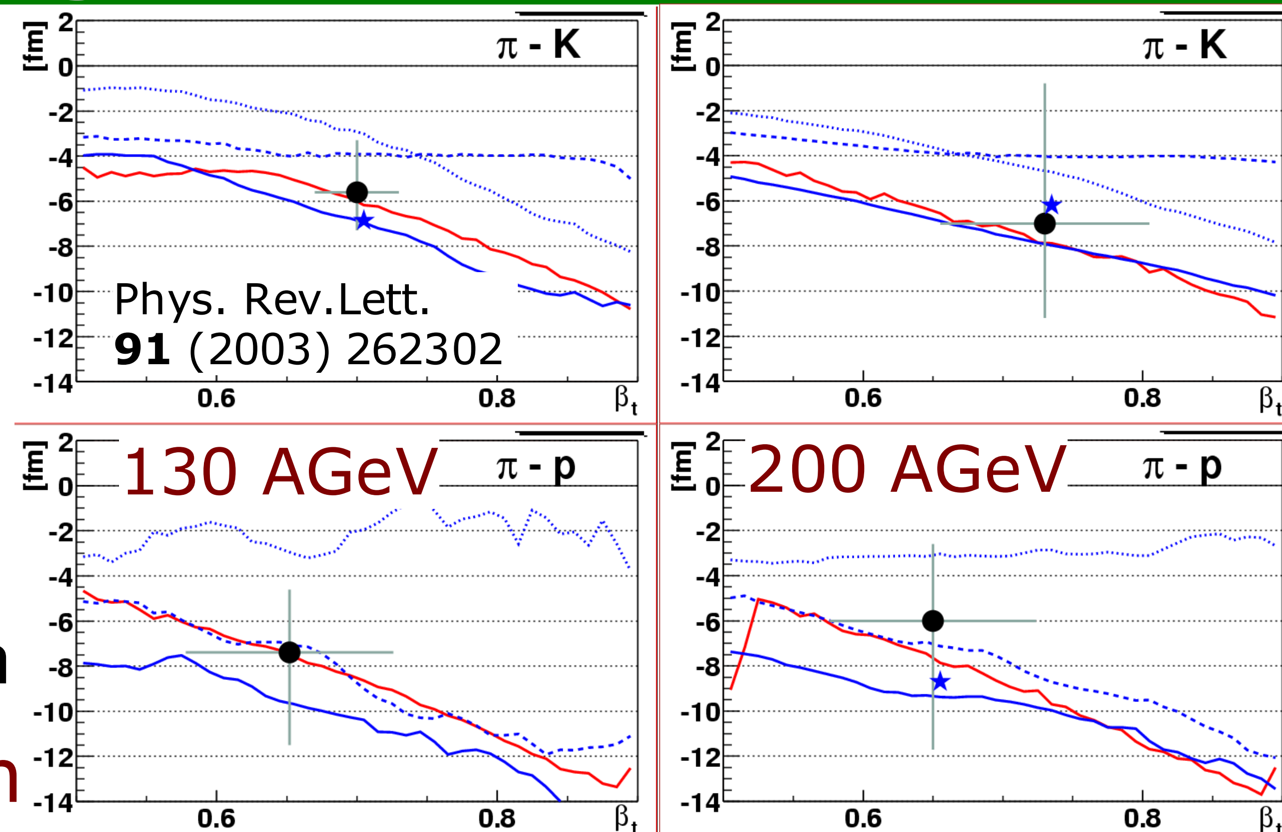
Modeling the emission asymmetry

- Are we measuring time shifts, space shifts (flow) or both?
- Is the flow hypothesis consistent with the data?
- How do we compare theory and experiment?

- Need models producing strong transverse radial flow:
  - Blast-wave – hydro-like flow
  - RQMD – flow through interactions

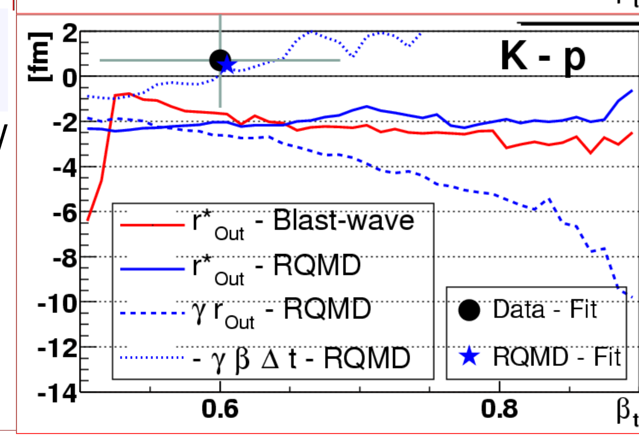
Comparing models to data

- We do see space-momentum correlations:
  - Data and blast-wave consistent
  - RQMD needs flow to reproduce data
- Time difference can explain K-p
- Correct comparison - same fitting for RQMD and data

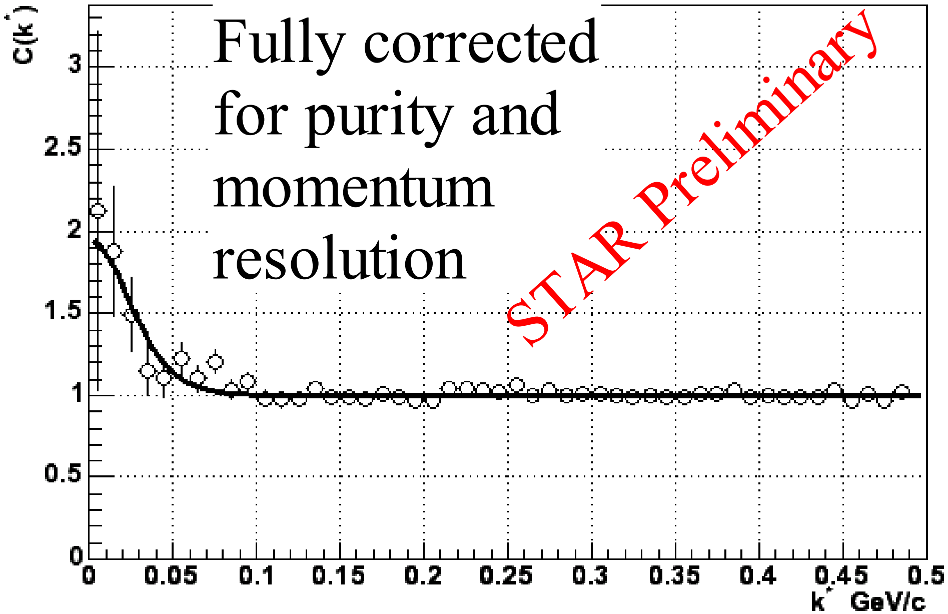


Blast-wave: nucl-th/0312024
F. Retiere, M. Lisa

	130 AGeV	200 AGeV
Temperature	104 MeV	100 MeV
Flow intensity	0.9 .	1.0 .
System radius	12.9 fm	13.0 fm
Evolution time	8.9 fm/c	10.0 fm/c
Emission duration	0.002 fm/c	3.5 fm/c



Proton – Lambda at 200 AGeV



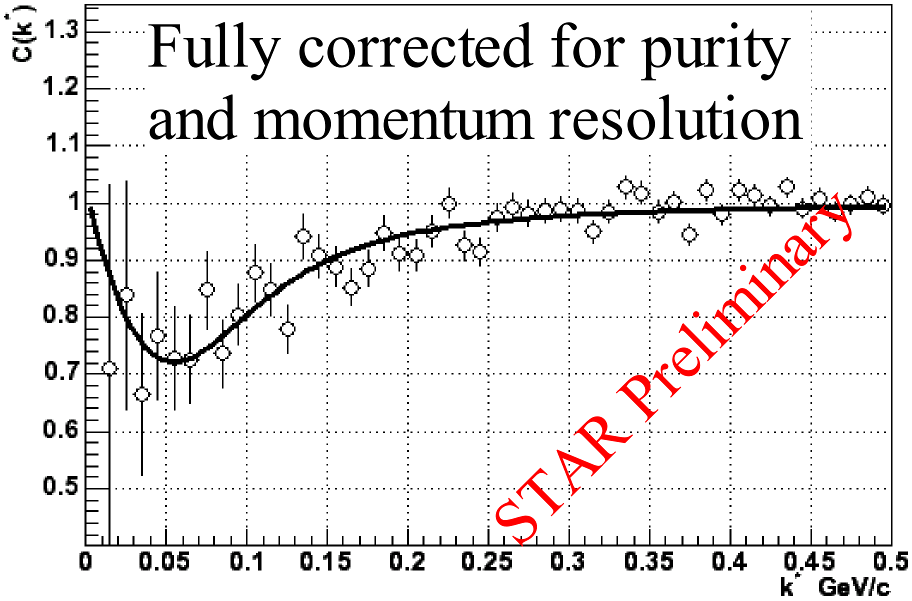
- Confirm measurements from NA49 and E895.
- Fit using analytical model of proton-lambda correlation:

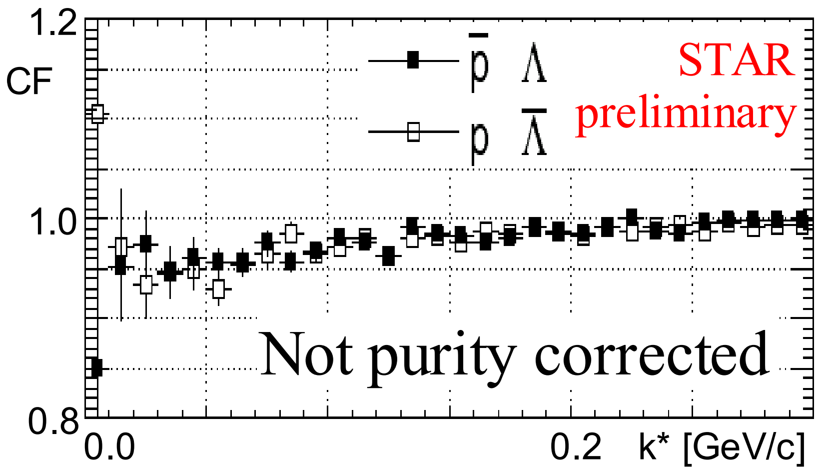
$R_{inv} = 2.8 \pm 0.3\ (+1.0\ -1.4)\ fm$

(see poster HBT9 by S. Bekele)

- Interaction potential parameters from: F. Wang, S. Pratt, Phys. Rev. Lett. 83 (1999) 3138-3141
- Main challenge is particle purity, feed-down from from Lambda-Lambda accounted for
- Good agreement between proton-lambda and anti-proton anti-lambda correlation functions

Anti-Proton Lambda at 200 AGeV



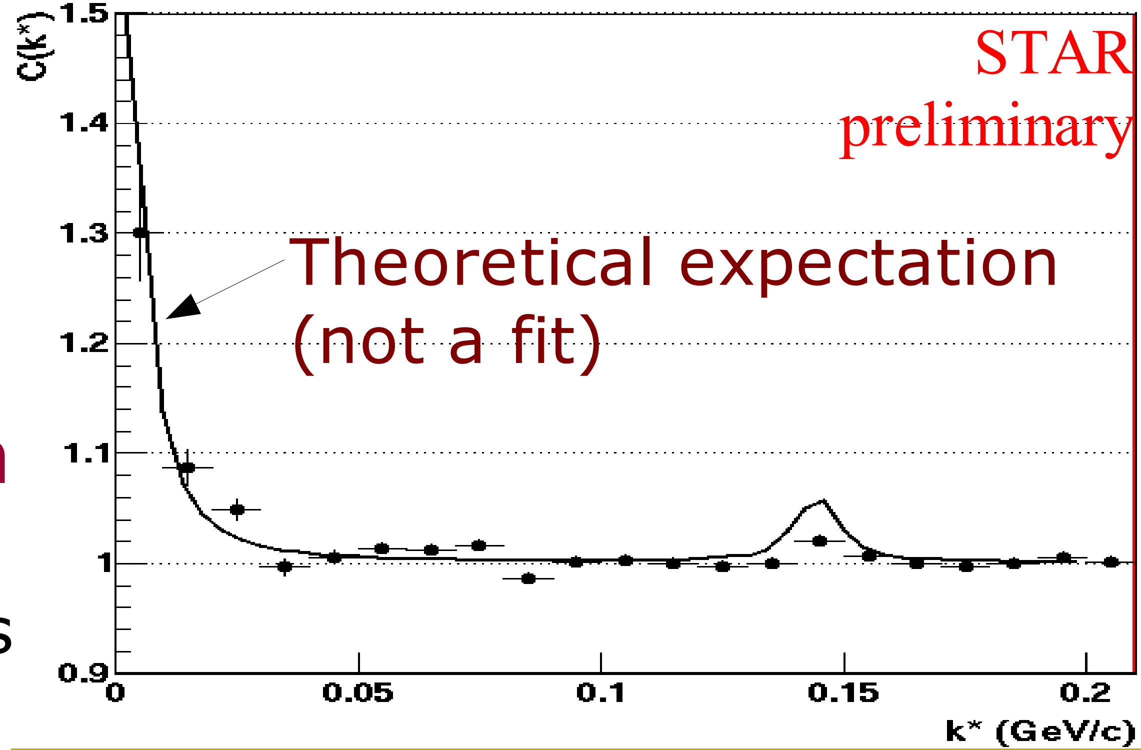


- First time measurement of anti-proton lambda CF
- Fit with the same analytical model as pΛ – interaction potentials extracted from fit

  $R_{inv} = 1.5 \pm 0.07\ (+0.5\ -0.9)\ fm$
- Early drop of correlation function signals significant annihilation
- A new way to extract unknown interaction potential parameters

Pion – Xi at 200 AGeV

- Also a first time measurement
- Will enable to address the question of Ξ flow
- Theoretical expectation with assumptions:
  - Source size as for pions
  - Significant Ξ flow
  - Coulomb + strong interaction
  - Gives input onto cross-sections similar to proton-lambda case



Calculation using S.Pratt's code

Combined π^+-Ξ^- and π^--Ξ^+

Purity assumed = 50%±25%

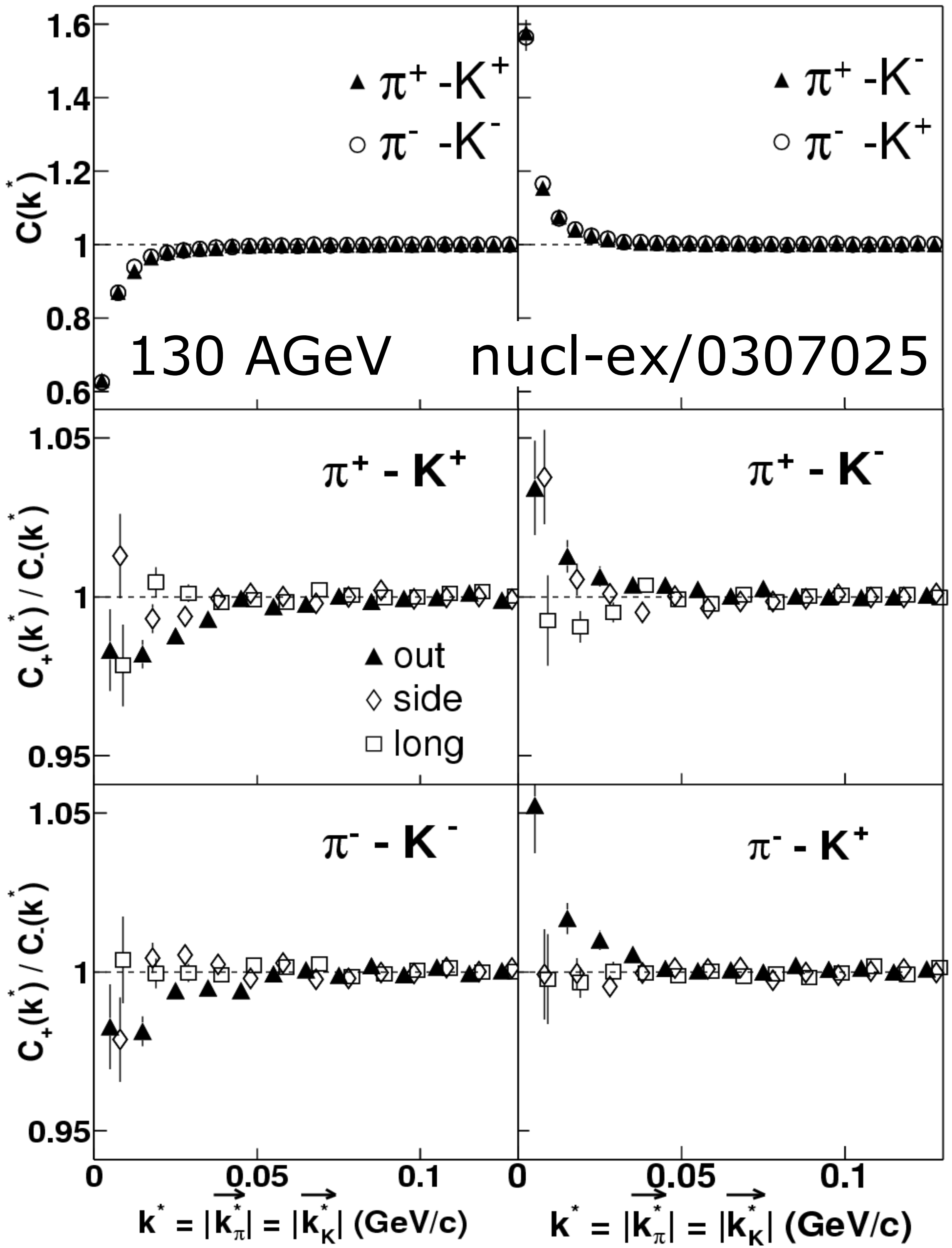
No momentum resolution correction

Summary and outlook

- Measured correlations for πK, πp and Kp pairs at 130 and 200AGeV AuAu collisions
  - Clear asymmetry of emission observed for all pairs
  - Space-momentum correlations from transverse radial flows present a consistent description of emission asymmetries for all systems
  - Emission time differences found to be important, but not enough to explain the data
- New way to measure system interactions: $p\Lambda$, *anti-*$p\Lambda$, Kp (unlike sign), $\pi\Xi$
- New, non-HBT size estimation method for $p\Lambda$, *anti-*$p\Lambda$
- $\pi\Xi$ function promises new information in future

Extra slides

Pion-Kaon at 130 AGeV

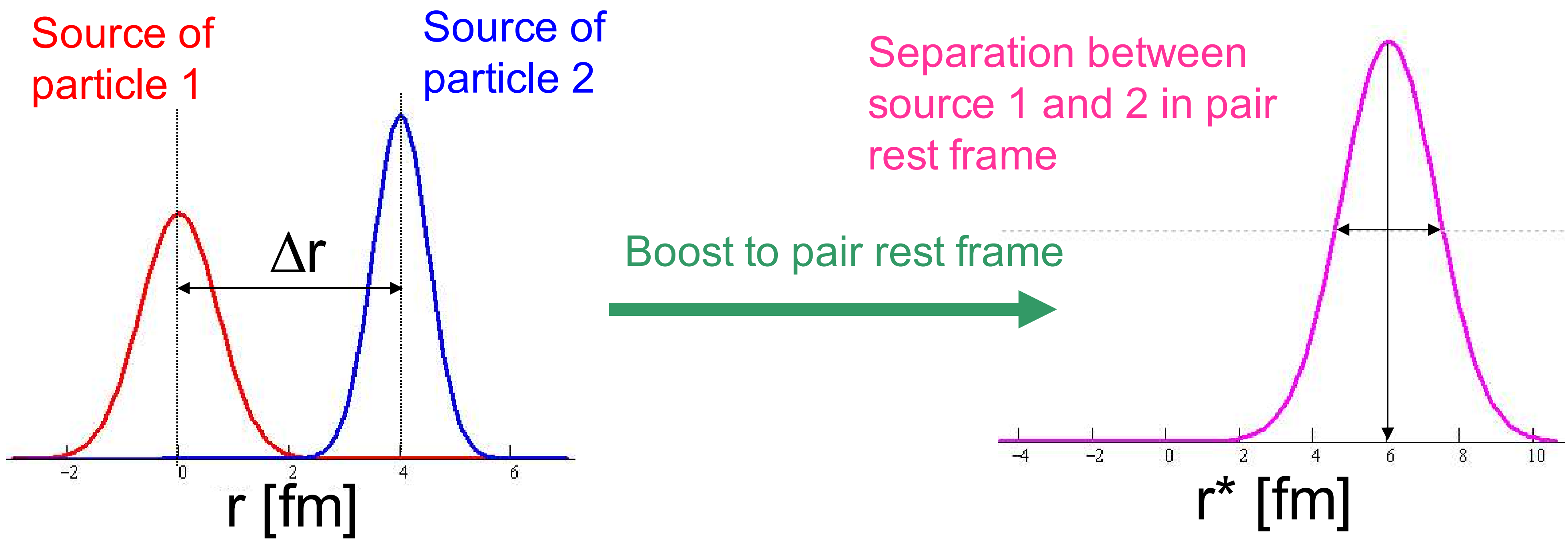


- Correlation functions consistent for same and opposite charge
- Clear asymmetry signature
- Side and Long "double ratio" flat as expected

Sigma: $12.5 \pm 0.4^{+2.2}_{-3}$ fm

Mean: $-5.6 \pm 0.4^{+1.9}_{-1.3}$ fm

1D relativistic view
What can be probed?



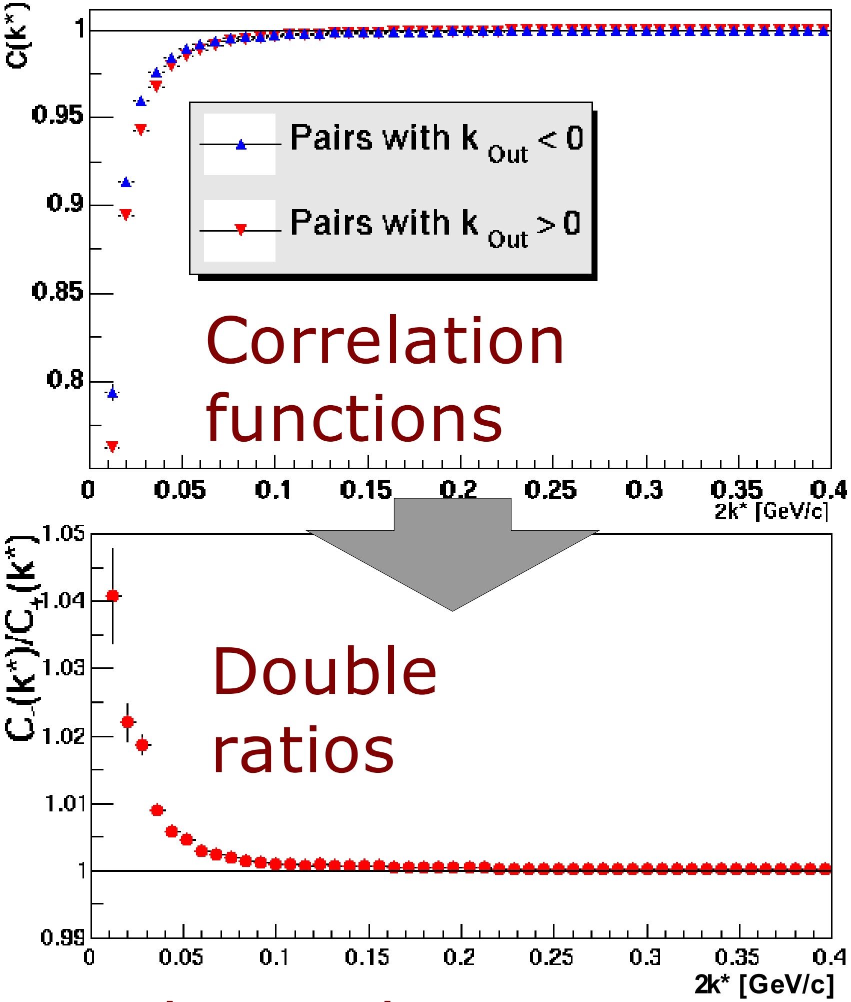
$r^* = \gamma_{pair} (\Delta r - \beta_{pair} \Delta t)$

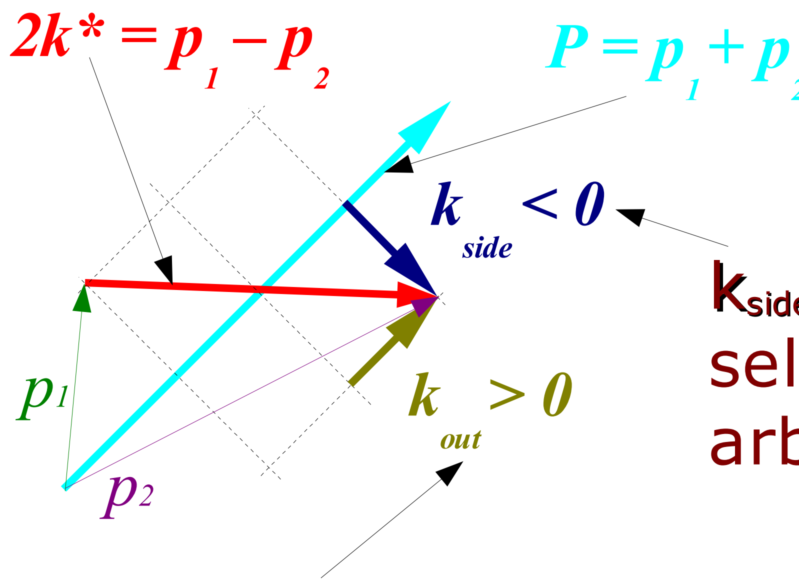
r^* separation in pair rest frame

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

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

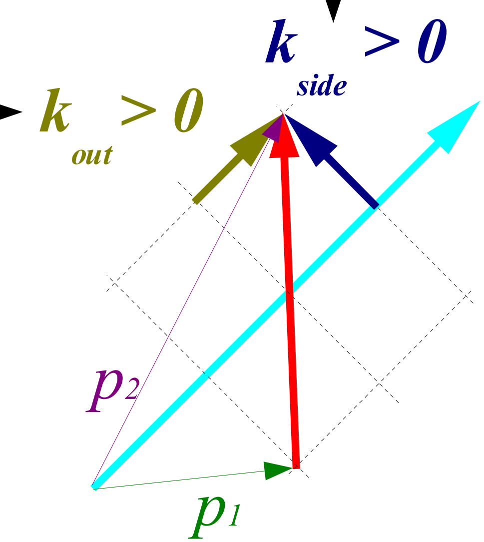
Double ratio definitions





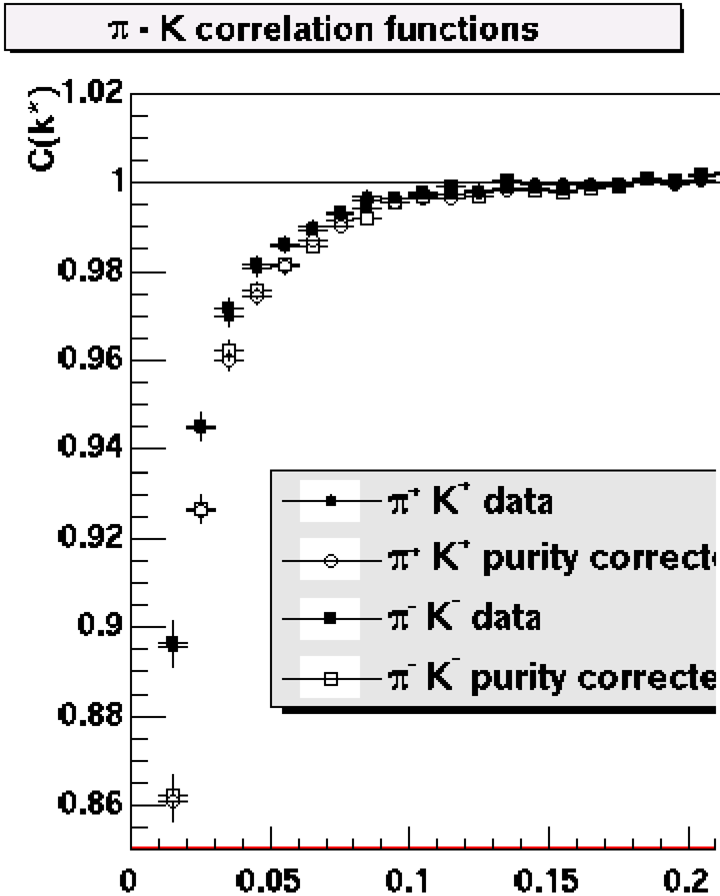
k_{side} sign selection arbitrary

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

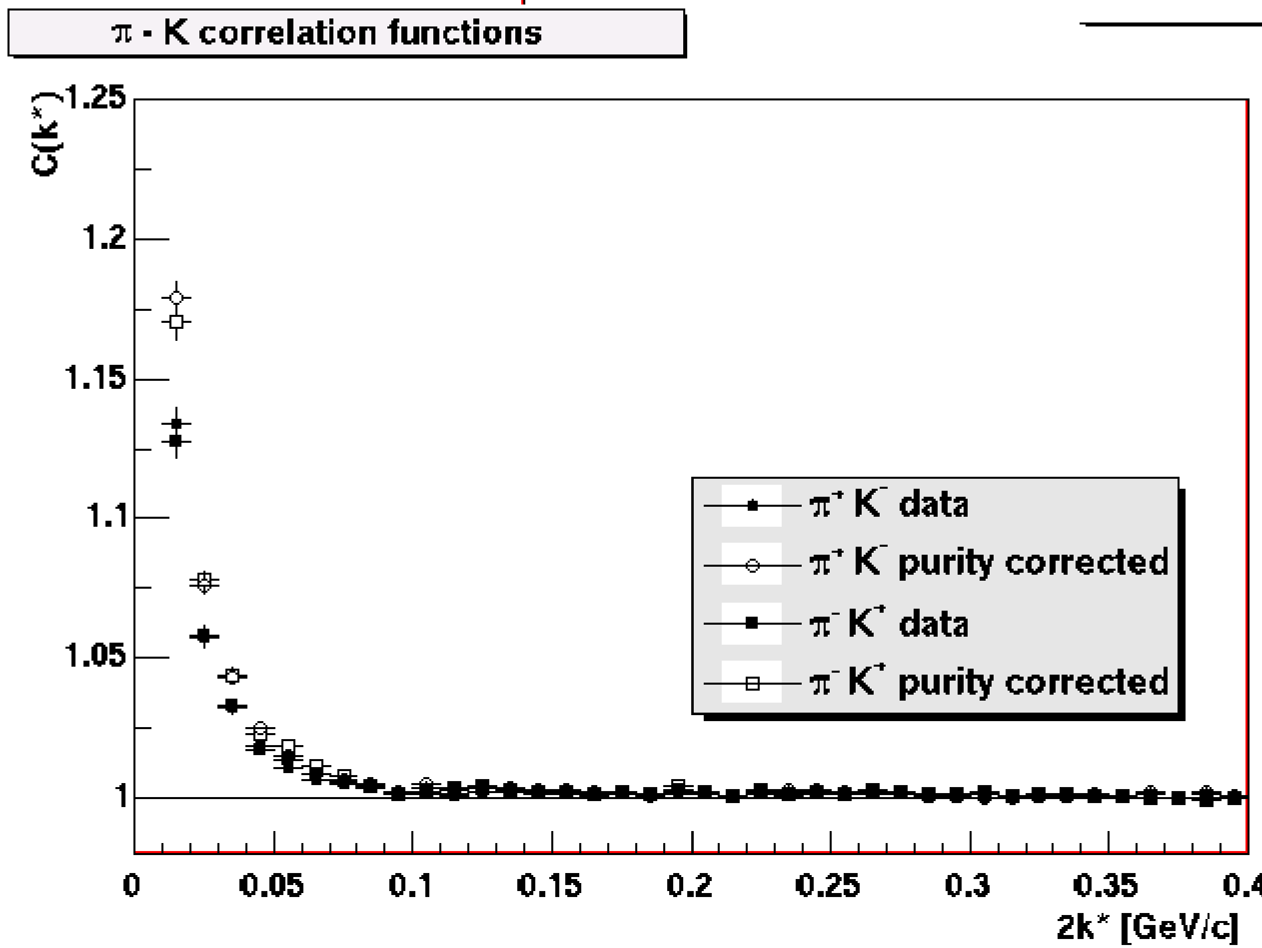


k_{long} is the z component of the momentum of first particle in LCMS

Purity correction

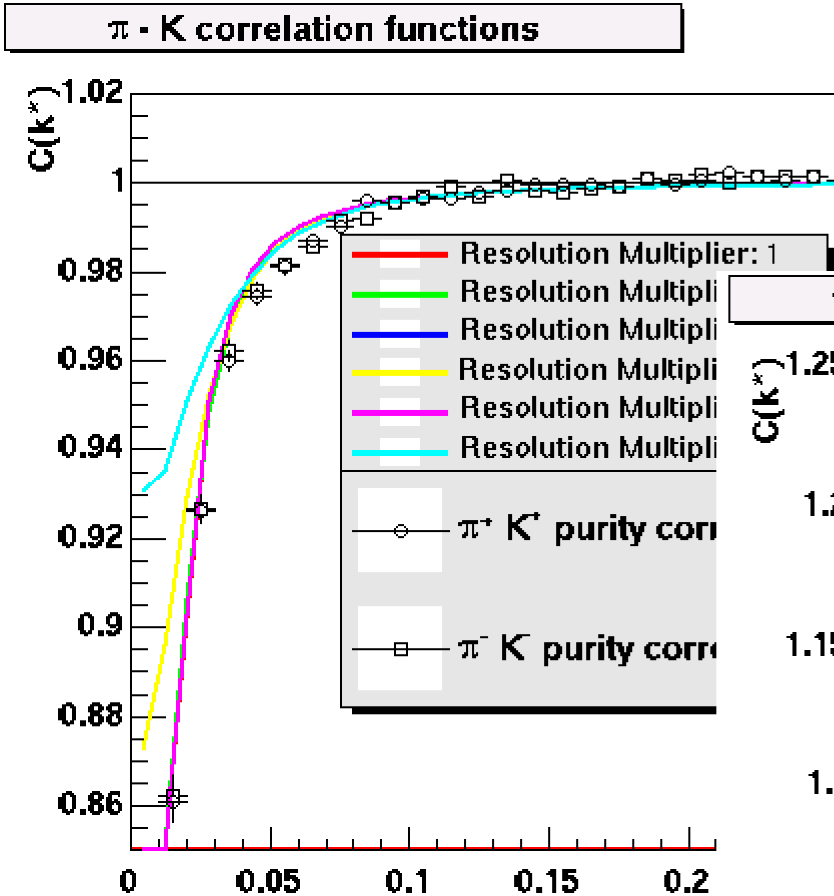


Average pair purity = **0.75**

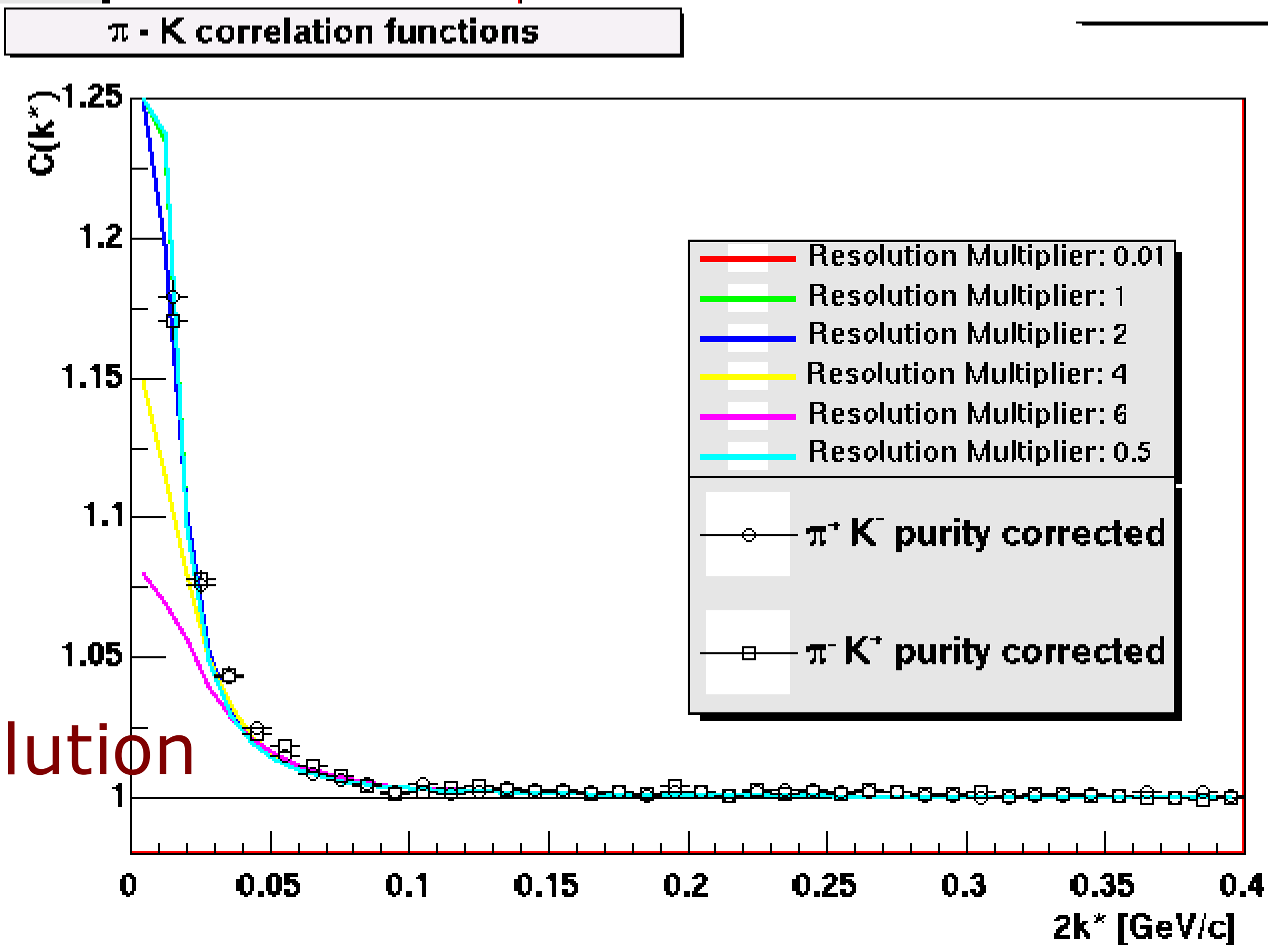


$$C_{corrected} = \frac{C_{measured} - (1-P) * 1.0}{P}$$

Momentum resolution



Momentum smearing and low p_T shift



No change until resolution 4x worse than STAR

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)

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

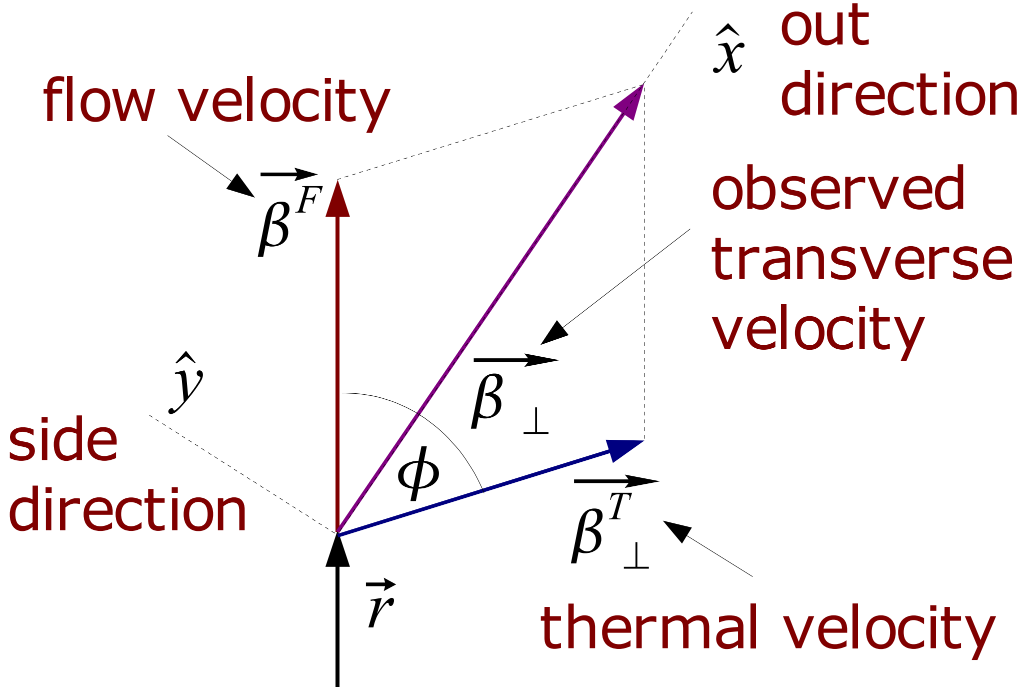
$$\langle x \rangle \equiv \langle \vec{r} \cdot \hat{x} \rangle \approx \langle r \frac{\beta^F + \beta^T_\perp \cos(\phi)}{\beta_\perp} \rangle$$

$$\approx \langle r \frac{\beta^F}{\beta_\perp} \rangle$$

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

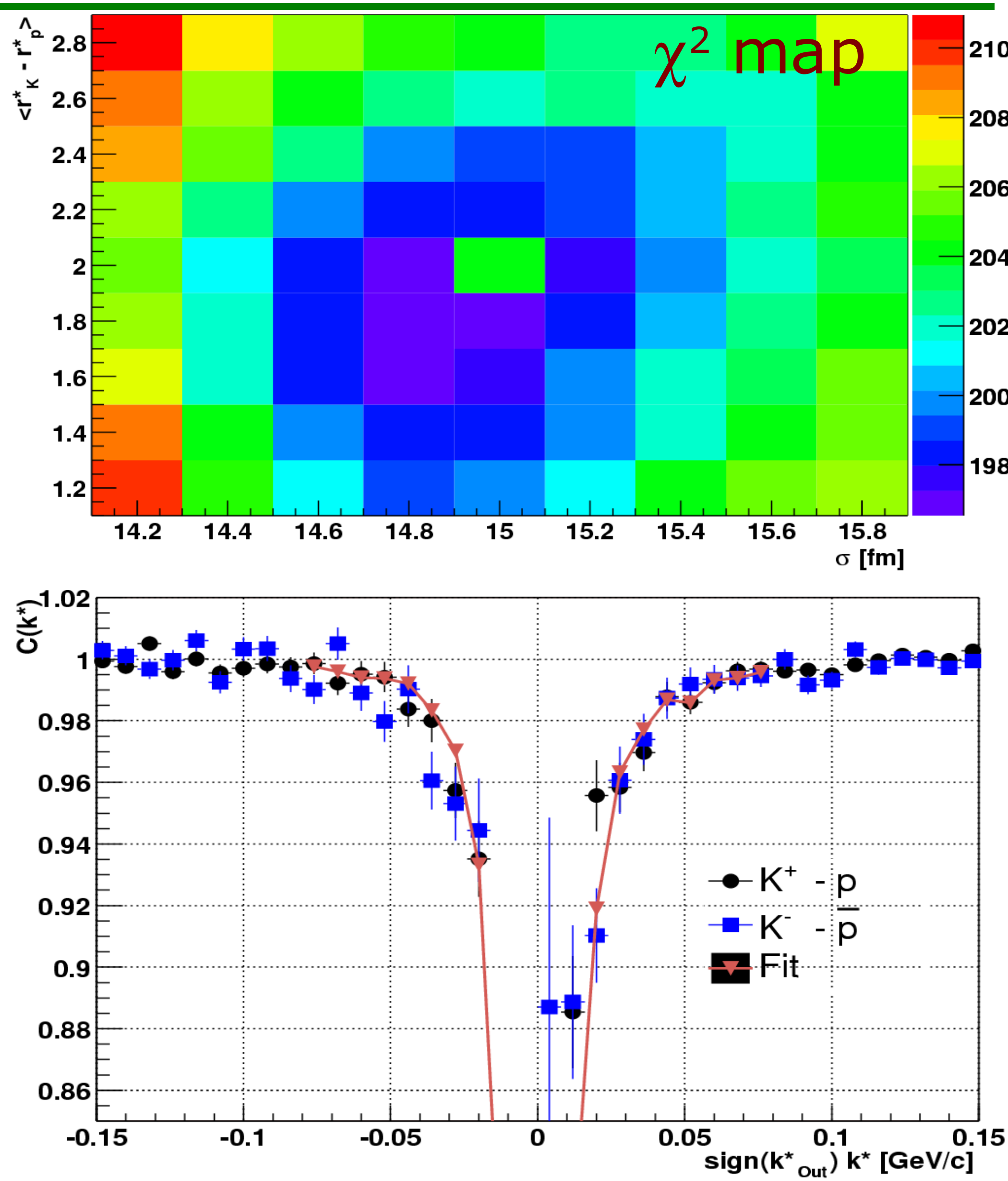
$$\langle z \rangle = \langle \tau_S \sinh(y_S) \rangle \approx \langle \sinh(y_S) \rangle \langle \tau_S \rangle = 0$$

- We are directly sensitive to time shift, the space shift arises from radial flow – possibility of a new radial flow measurement



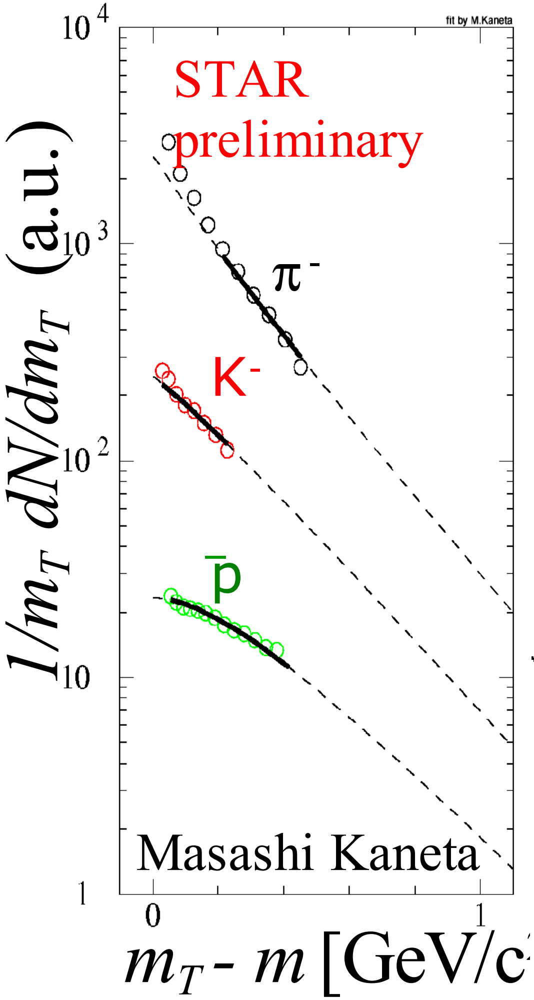
Fitting procedure

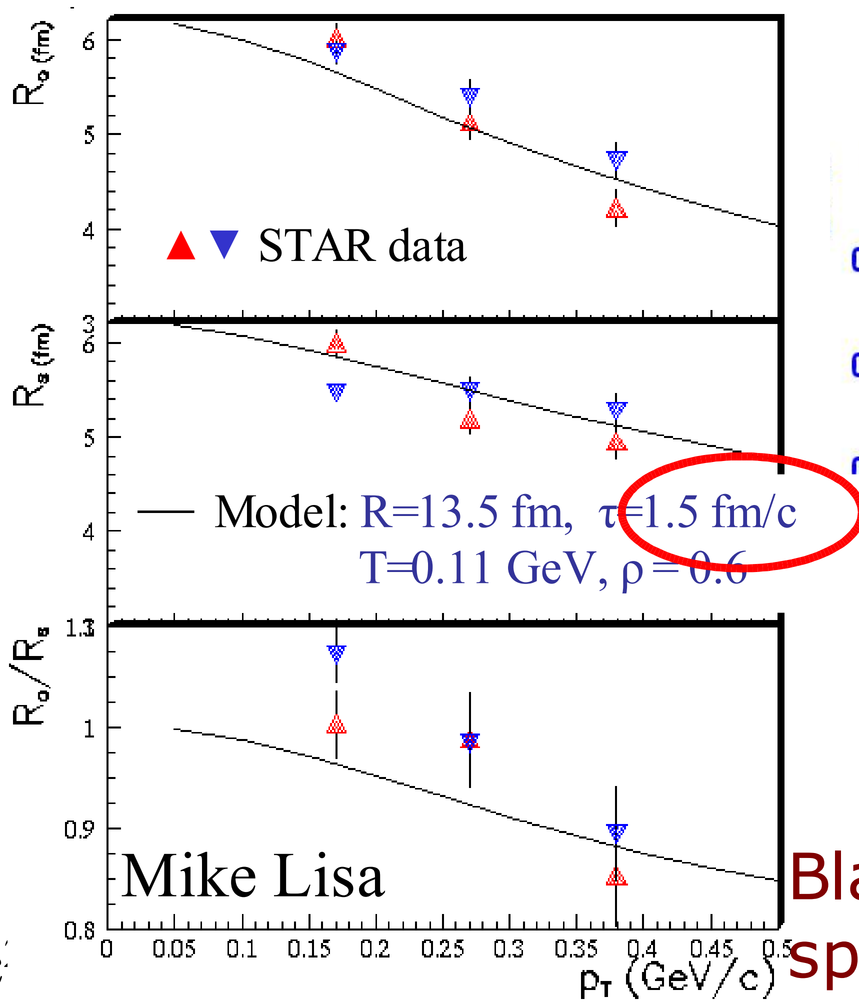
- No analytic form of correlation function
- Need to generate correlation functions using experimental momentum distributions, Monte-Carlo methods and Lednicky's pair weights
- Best fit parameters are taken at the minimum χ^2 value



Successes of the blast wave parameterization

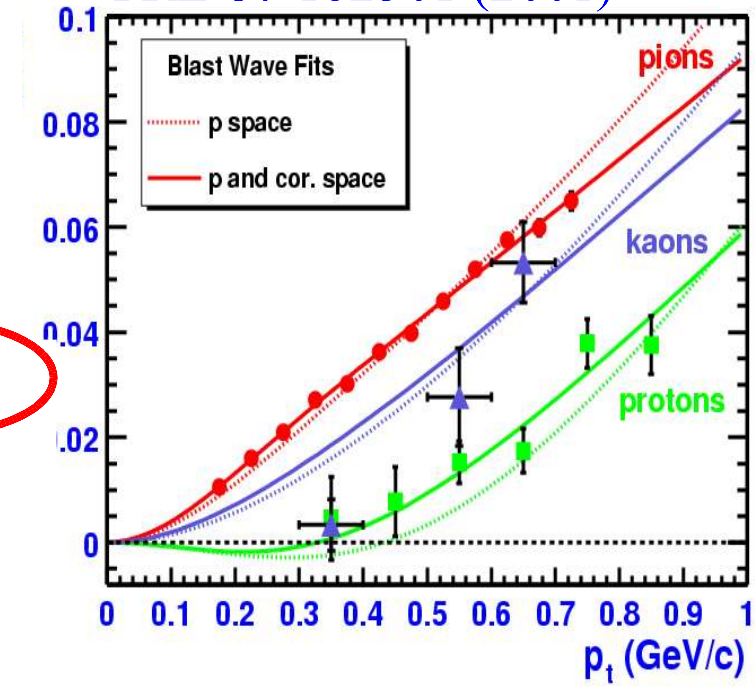
- Spectra
- Pion source size
- Elliptic flow





Short emission duration

STAR Collaboration,
PRL **87** 182301 (2001)



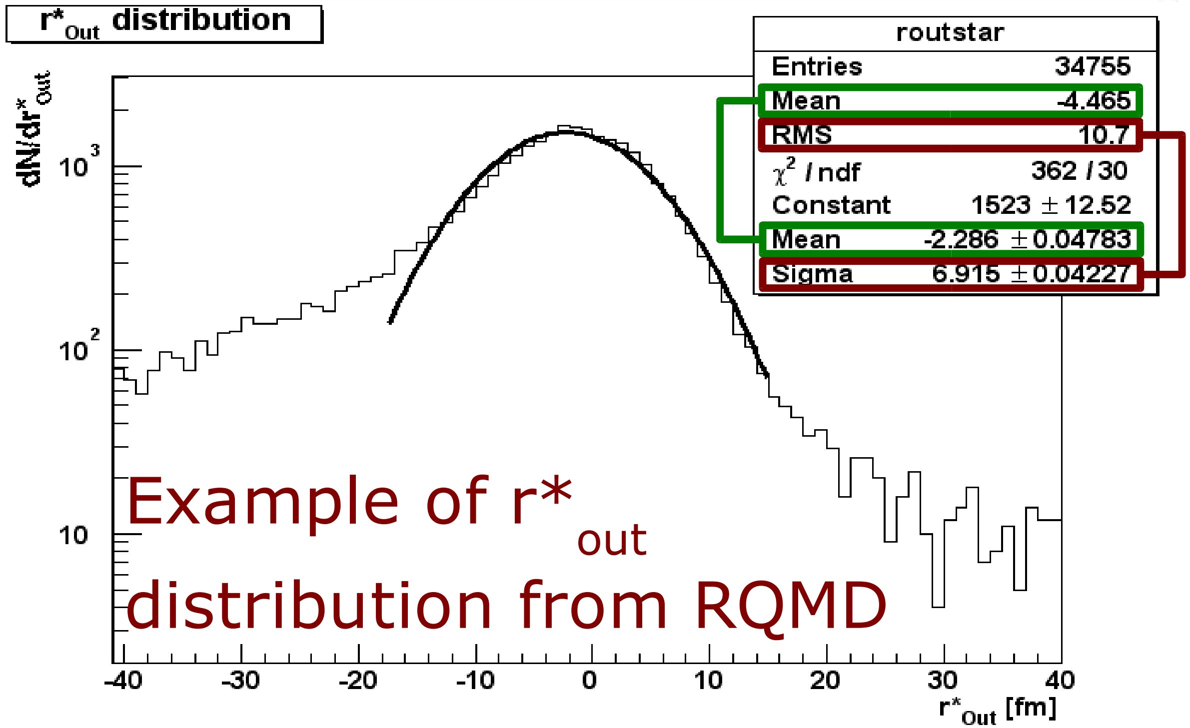
Blast wave fit including space and momentum anisotropy

Fitting and quantitative comparisons

nucl-ex/0307025

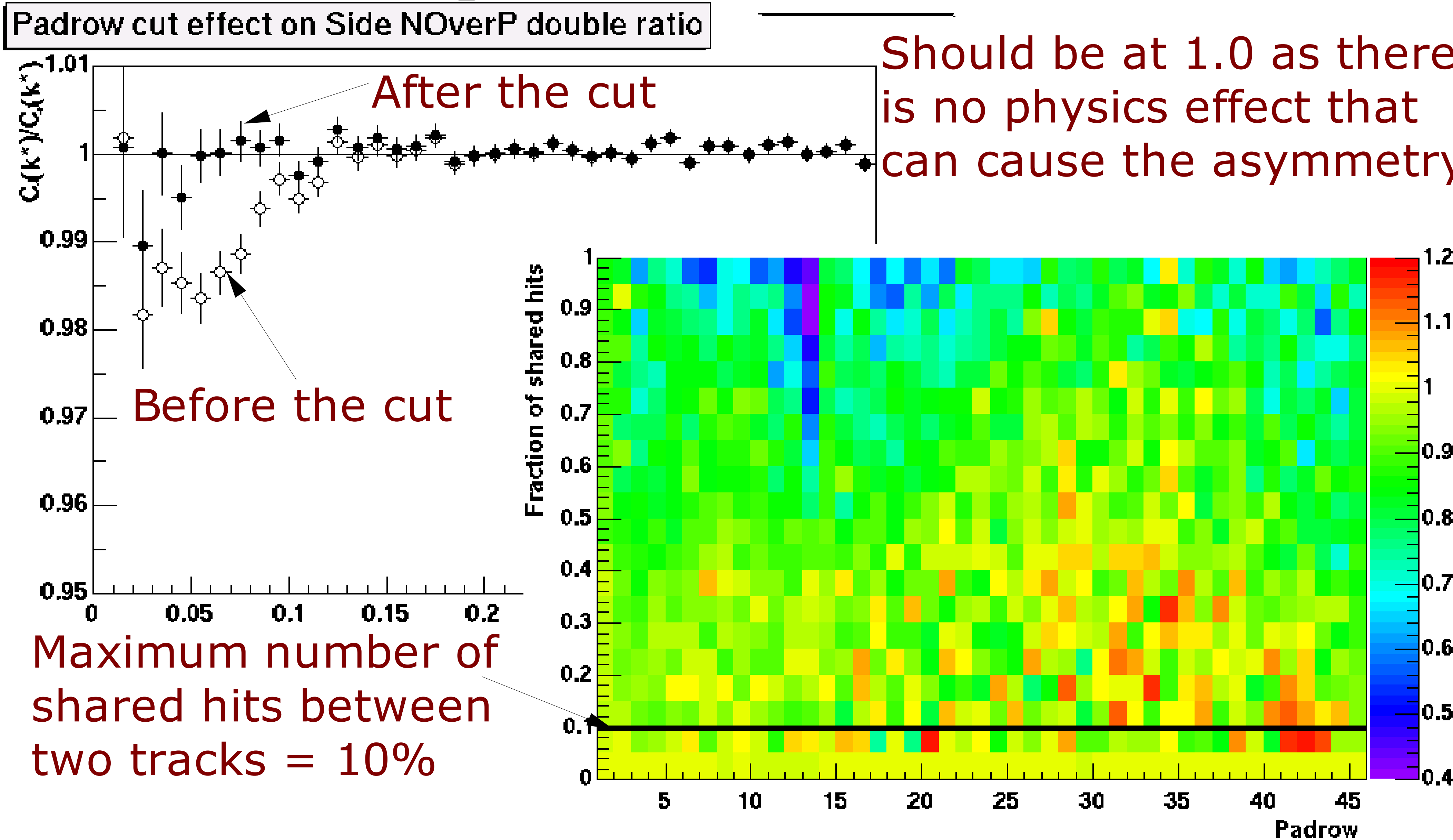
- Fits assume gaussian source in PRF
- r^*_{out} distributions have non-gaussian tails
- Use the same fitting procedure for models and data - correlation functions constructed with “Lednicky's weights”

	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



Example of r^*_{out} distribution from RQMD

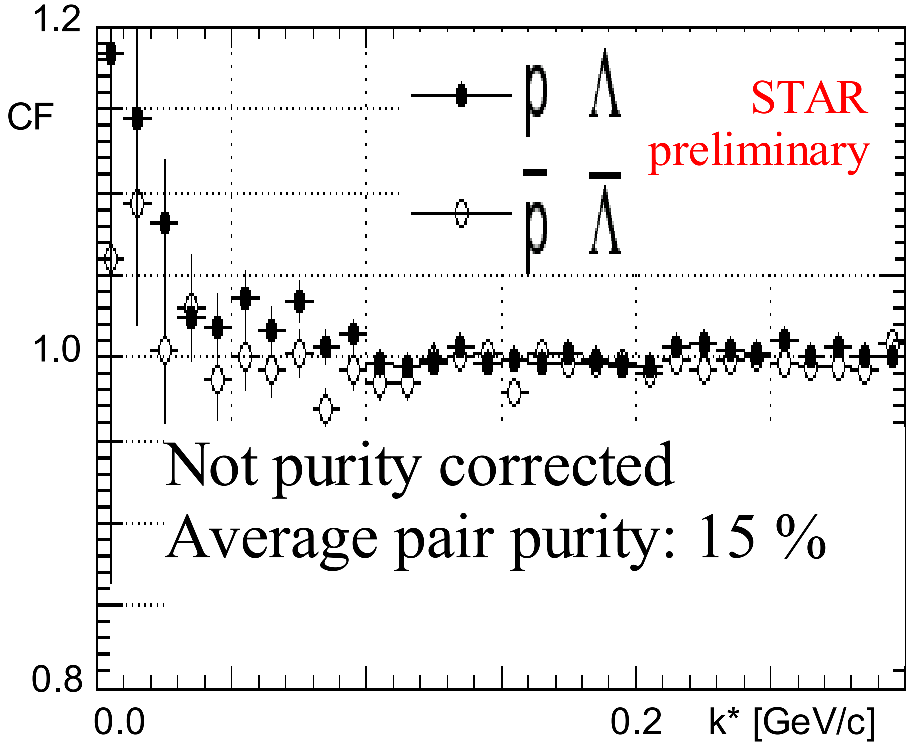
Hit sharing cut effect on Side ratio



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

Maximum number of shared hits between two tracks = 10%

Proton-Lambda raw CF



- Proton-lambda and anti-proton – anti-lambda in good agreement
- Both show positive correlation