The particle interferometry method as a tool reflecting the evolution of hadron source

Hanna Paulina Gos

Faculty of Physics
Warsaw University of Technology

SUBATECH

Outline

- Baryon- baryon correlations:
  - identical: p-p, pBar-pBar,
  - nonidentical: p-pBar

- Nonidentical particle correlations
  - basics of technique,
  - connections to flow,
  - examples of symmetry: $\pi^+\pi^-$, p-pBar,
    and asymmetry: π-p

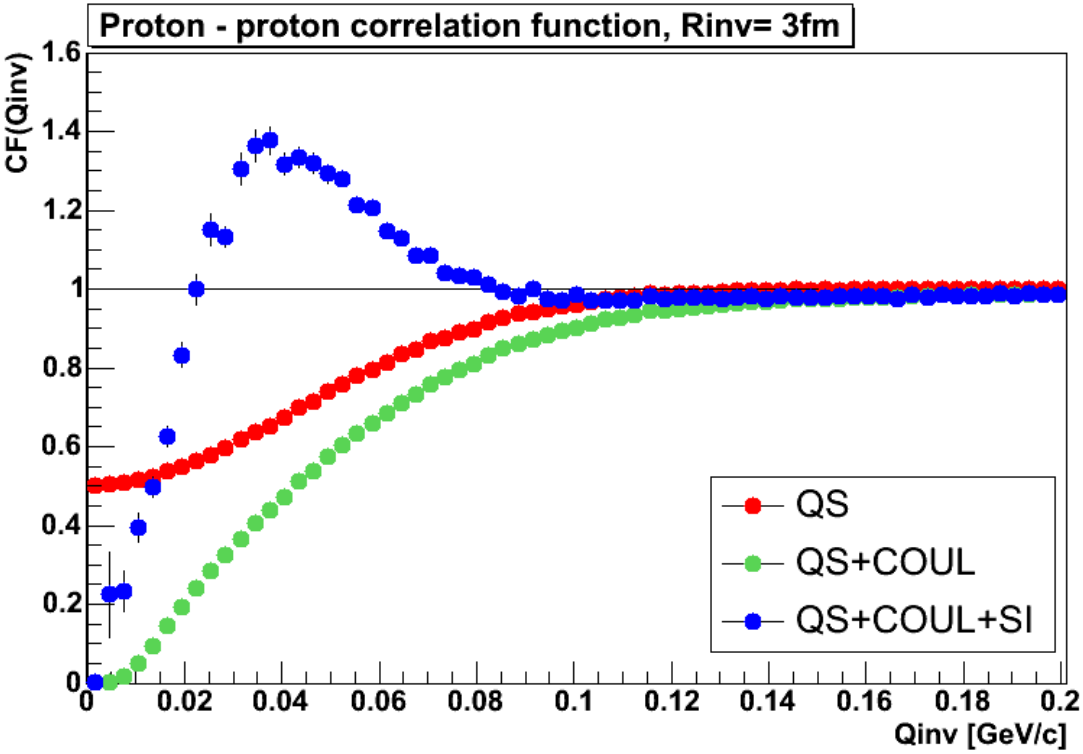
- Dynamics in EPOS model (p+p and d+Au collision)
  - learning about the source via
    single and double particle distributions
  - accessing the source via correlations

Proton- (anti)proton correlations

Identical baryon- baryon

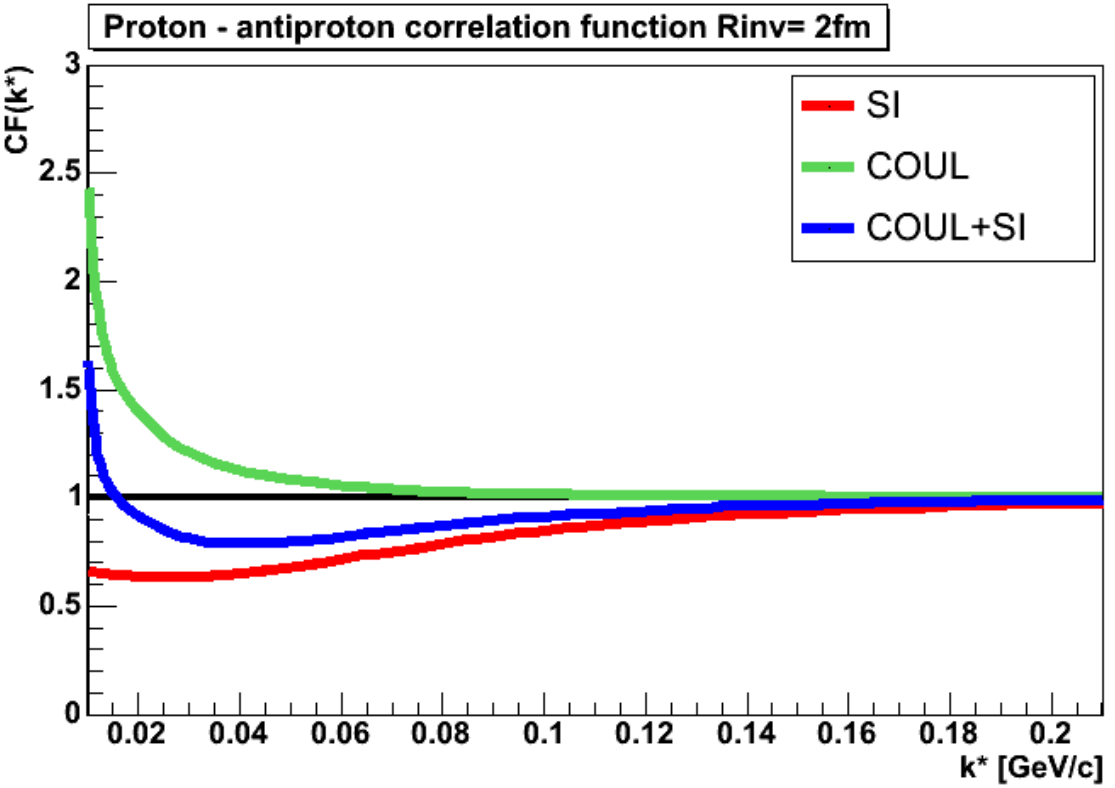
- Quantum Statistics- **QS**

- Final State Interactions- **FSI**
  - **Coulomb**
  - **Strong**

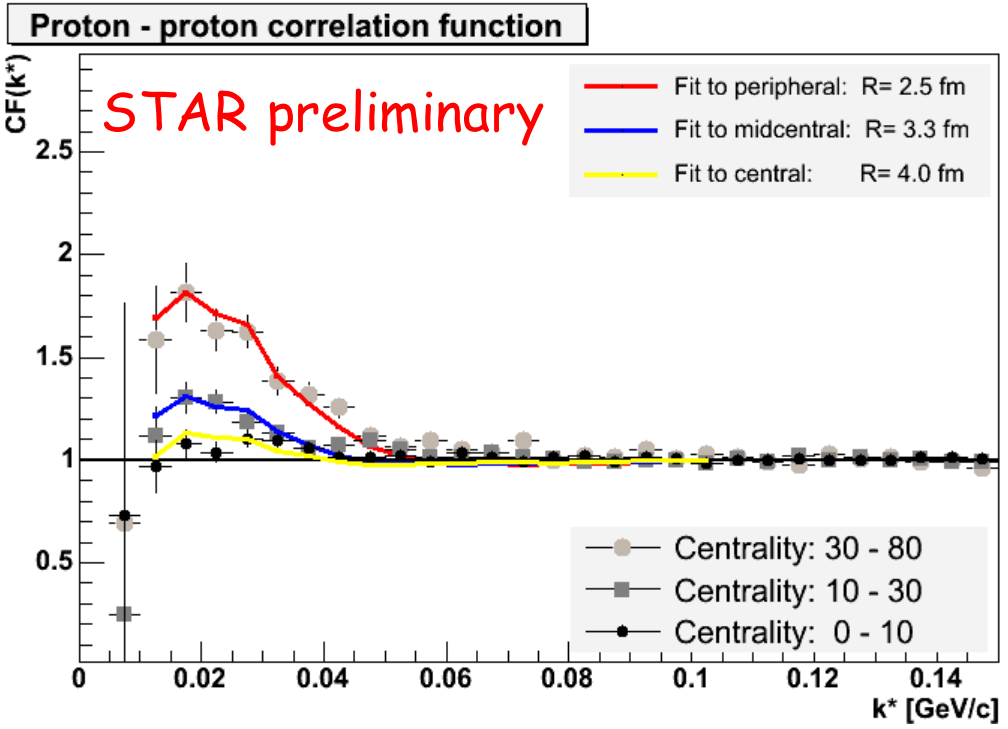


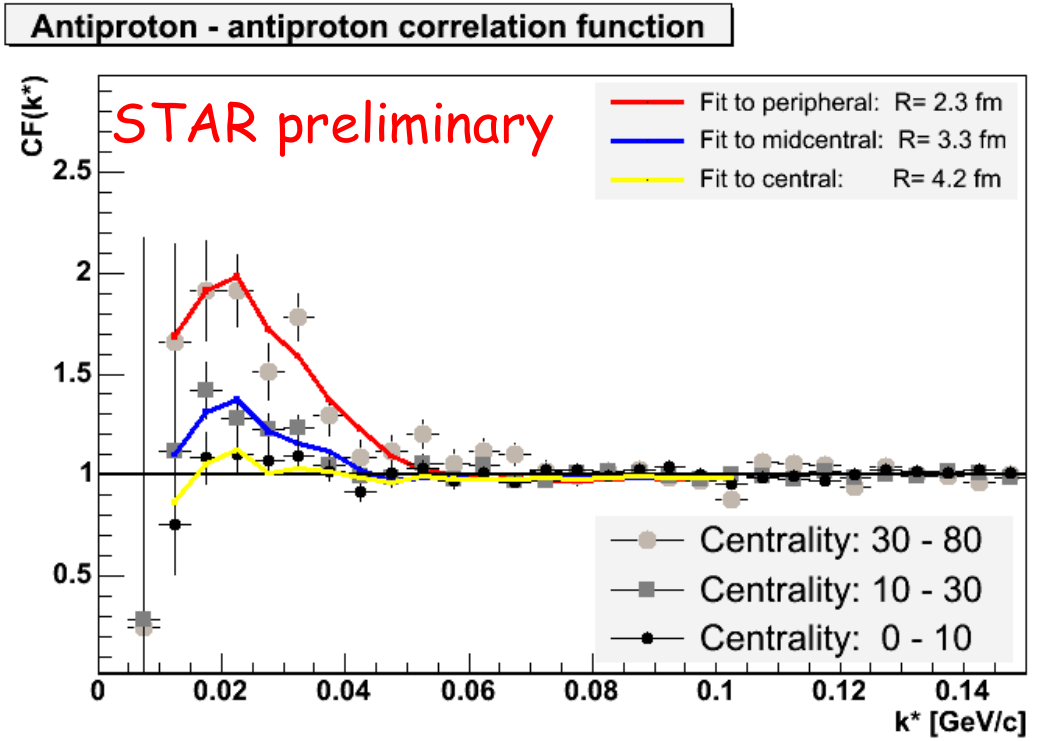
Nonidentical baryon- (anti)baryon

- Final State Interactions- **FSI**
  - **Coulomb**
  - **Strong**



(Anti)proton- (anti)proton correlations @200GeV in Au+Au collision

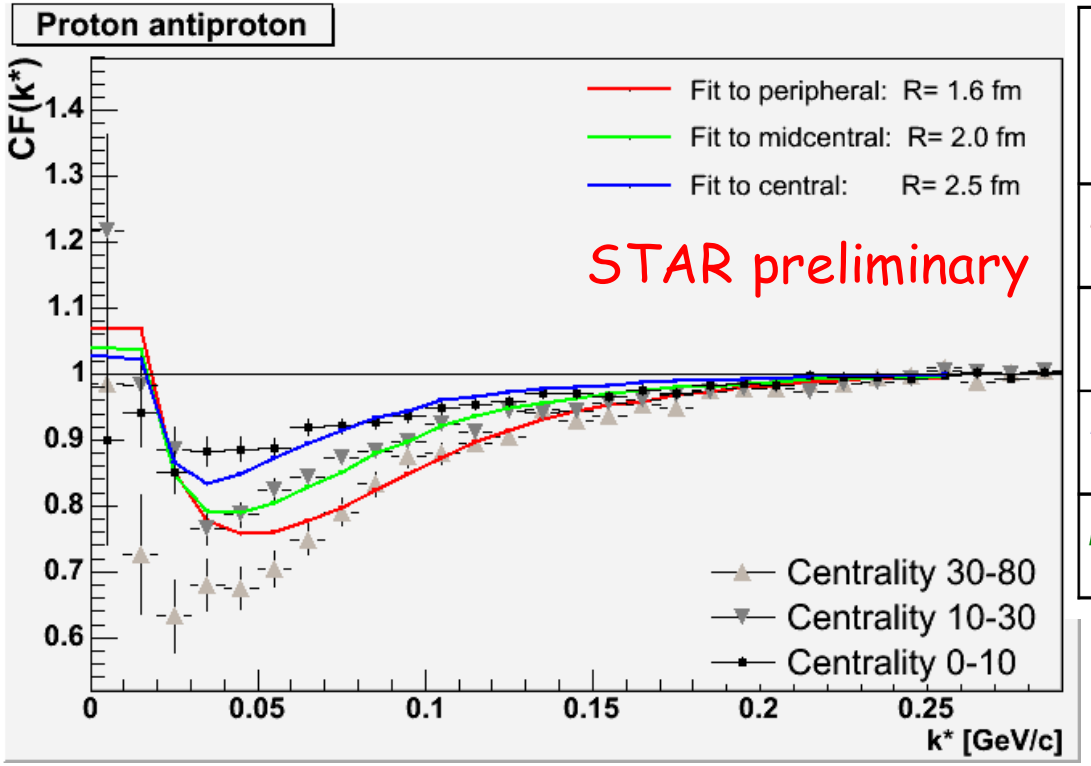




Systematic errors taking into account the stability of purity correction are estimated to be 0.1 fm

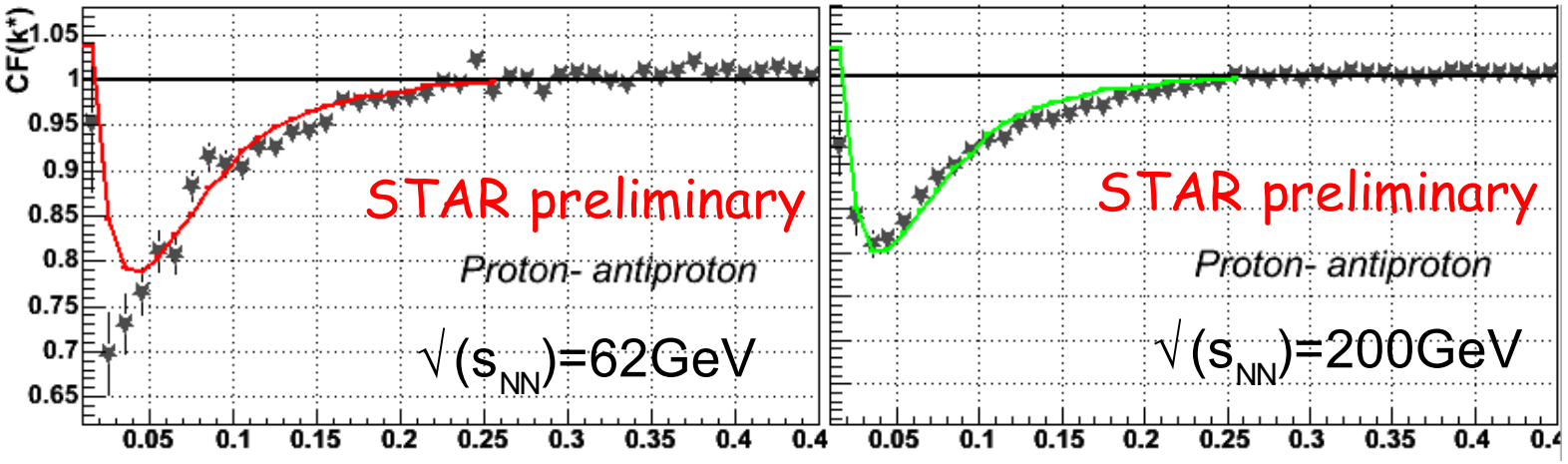
Centrality	Radius [fm]		
	$\sqrt{(s_{NN})}$ = 62 GeV	$\sqrt{(s_{NN})}$ = 200 GeV	
	p-p	p-p	$\bar{p}$-$\bar{p}$
minimum bias	$3.1^{+0.2}_{-0.1}$	$3.4^{+0.1}_{-0.2}$	$3.4^{+0.2}_{-0.2}$
central: 0-10%	$3.6^{+0.2}_{-0.2}$	$4.0^{+0.1}_{-0.3}$	$4.2^{+0.2}_{-0.3}$
midcentral: 10-30%	$3.1^{+0.2}_{-0.2}$	$3.3^{+0.2}_{-0.1}$	$3.3^{+0.2}_{-0.2}$
peripheral: 30-80%	$2.3^{+0.2}_{-0.3}$	$2.5^{+0.2}_{-0.1}$	$2.3^{+0.3}_{-0.2}$

Proton- antiproton correlations @200GeV in Au+Au collision

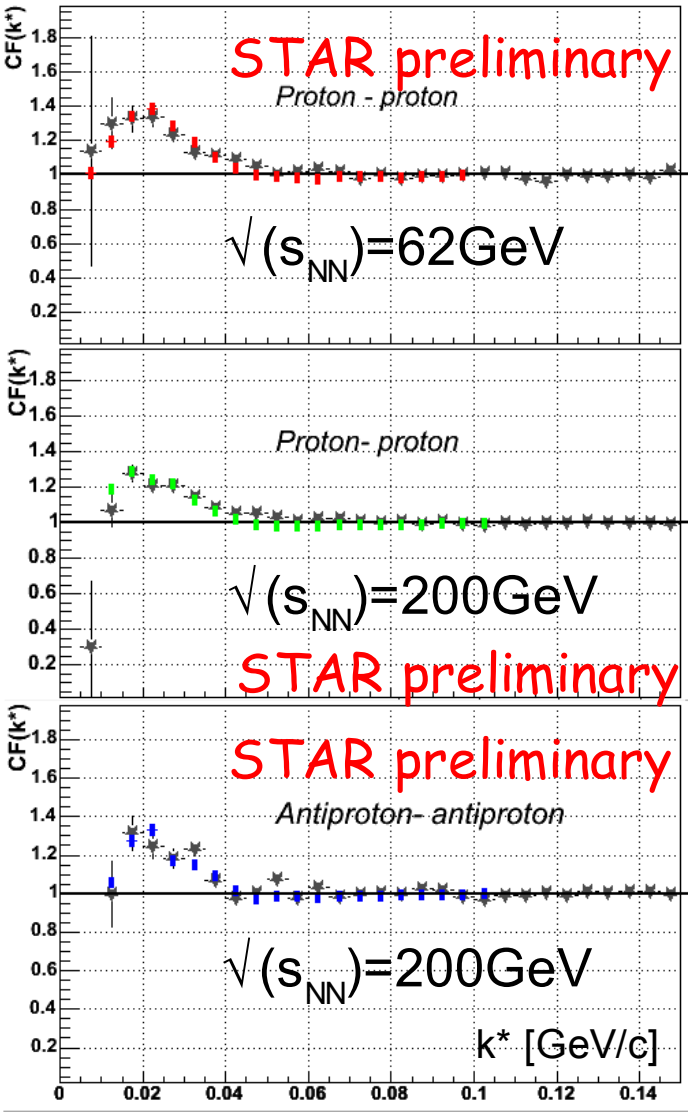


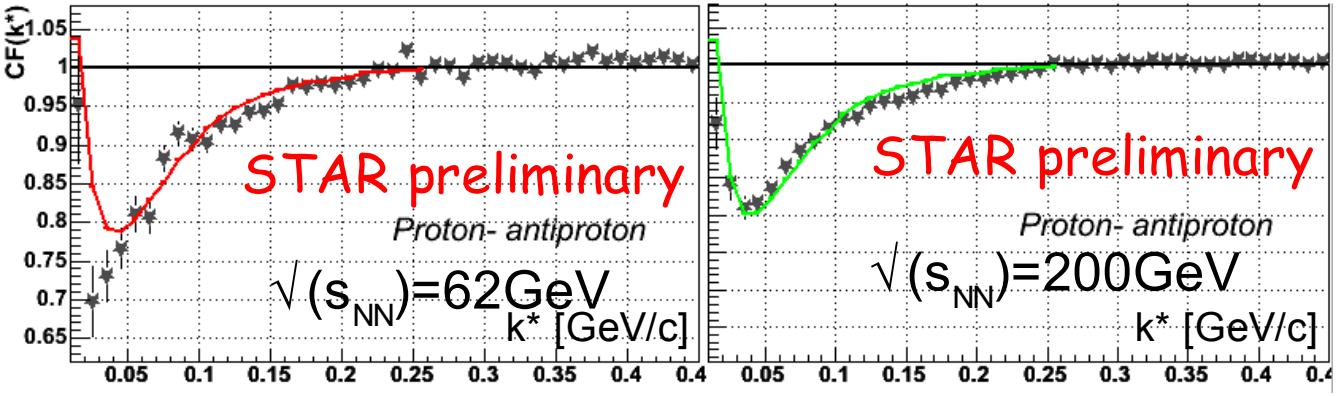
Centrality	Radius [fm]	
	$\sqrt{(s_{NN})}$ = 62 GeV	$\sqrt{(s_{NN})}$ = 200 GeV
	p-$\bar{p}$	p-$\bar{p}$
minimum bias	$2.0^{+0.1}_{-0.1}$	$2.1^{+0.1}_{-0.1}$
central: 0-10%	$2.3^{+0.1}_{-0.2}$	$2.5^{+0.2}_{-0.1}$
midcentral: 10-30%	$1.9^{+0.2}_{-0.1}$	$2.0^{+0.1}_{-0.1}$
peripheral: 30-80%	$1.6^{+0.2}_{-0.2}$	$1.6^{+0.3}_{-0.2}$

Systematic errors taking into account the stability of purity correction are estimated to be 0.1 fm



Proton- (anti)proton correlations in Au+Au collision



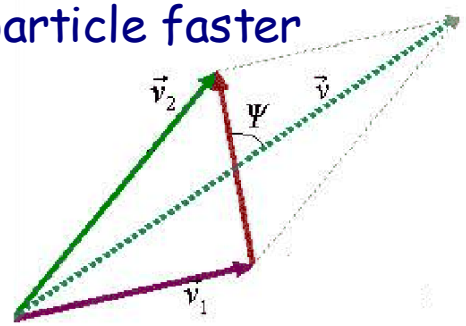


Centrality	Radius [fm]				
	$\sqrt{(s_{NN})}$ = 62 GeV		$\sqrt{(s_{NN})}$ = 200 GeV		
	p-$\bar{p}$	p-p	p-p	$\bar{p}$-$\bar{p}$	p-$\bar{p}$
minimum bias	$2.0^{+0.1}_{-0.1}$	$3.1^{+0.2}_{-0.1}$	$3.4^{+0.1}_{-0.2}$	$3.4^{+0.2}_{-0.2}$	$2.1^{+0.1}_{-0.1}$
central: 0-10%	$2.3^{+0.1}_{-0.2}$	$3.6^{+0.2}_{-0.2}$	$4.0^{+0.1}_{-0.3}$	$4.2^{+0.2}_{-0.3}$	$2.5^{+0.2}_{-0.1}$
midcentral: 10-30%	$1.9^{+0.2}_{-0.1}$	$3.1^{+0.2}_{-0.2}$	$3.3^{+0.2}_{-0.1}$	$3.3^{+0.2}_{-0.2}$	$2.0^{+0.1}_{-0.1}$
peripheral: 30-80%	$1.6^{+0.2}_{-0.2}$	$2.3^{+0.2}_{-0.3}$	$2.5^{+0.2}_{-0.1}$	$2.3^{+0.3}_{-0.2}$	$1.6^{+0.3}_{-0.2}$

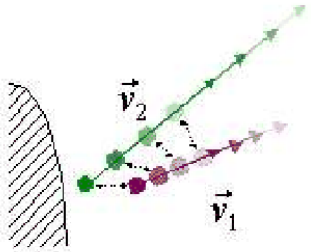
Systematic errors taking into account the stability of purity correction are estimated to be 0.1 fm

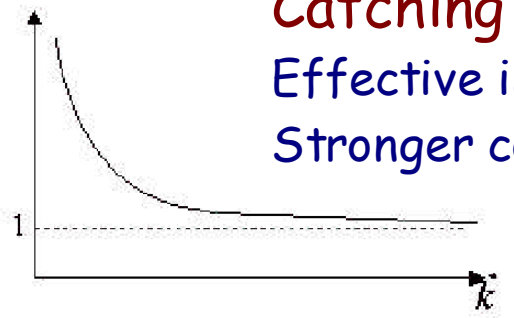
The asymmetry analysis

Second type particle faster



$\cos(\Psi)>0$ $C(\vec{k})_+$



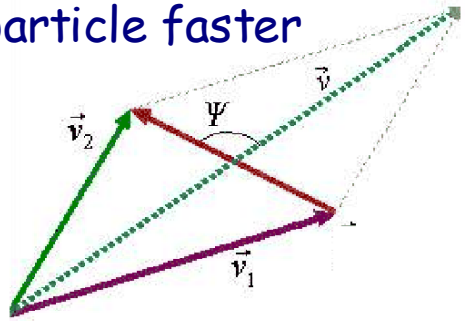


Catching up

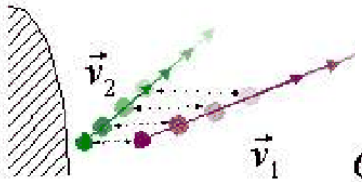
Effective interaction time larger

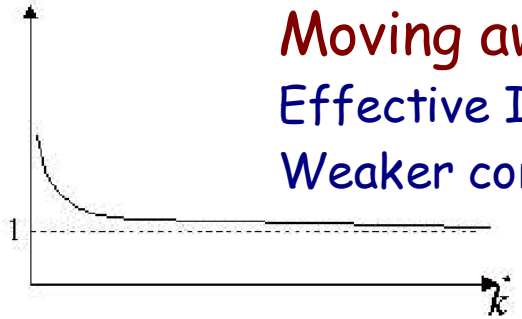
Stronger correlation

First type particle faster



$\cos(\Psi)<0$ $C(\vec{k})_-$



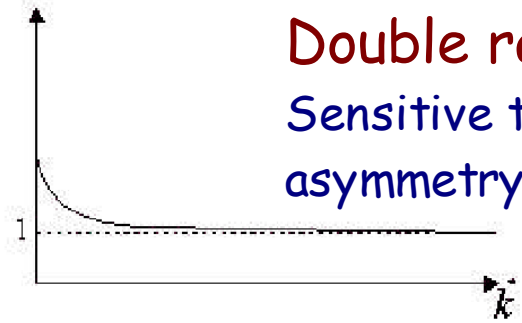


Moving away

Effective Interaction time smaller

Weaker correlation

$\frac{C(\vec{k})_+}{C(\vec{k})_-}$



Double ratio

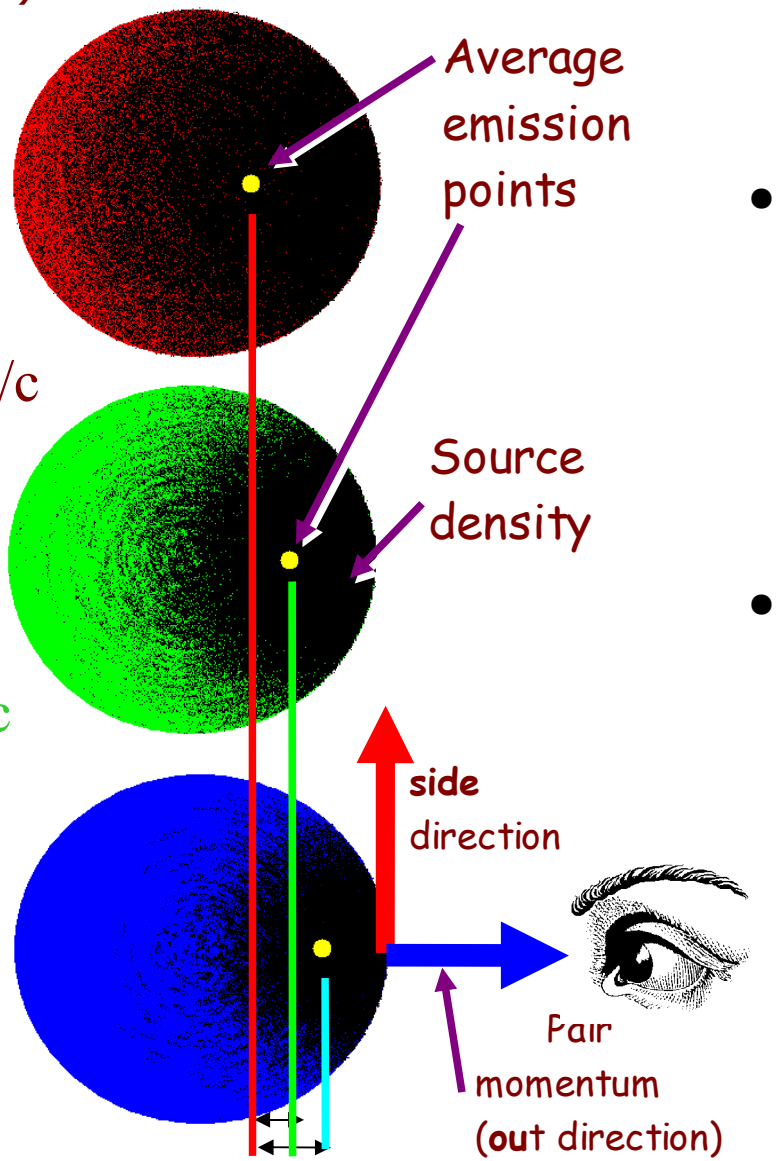
Sensitive to the space-time asymmetry in the emission process

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

Connections to flow

Spatial shifts (Δr)

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



Pion
$\langle\beta_t\rangle = 0.7$
$p_t = 0.15$ GeV/c

Kaon
$\langle\beta_t\rangle = 0.7$
$p_t = 0.5$ GeV/c

Proton
$\langle\beta_t\rangle = 0.7$
$p_t = 1.$ GeV/c

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

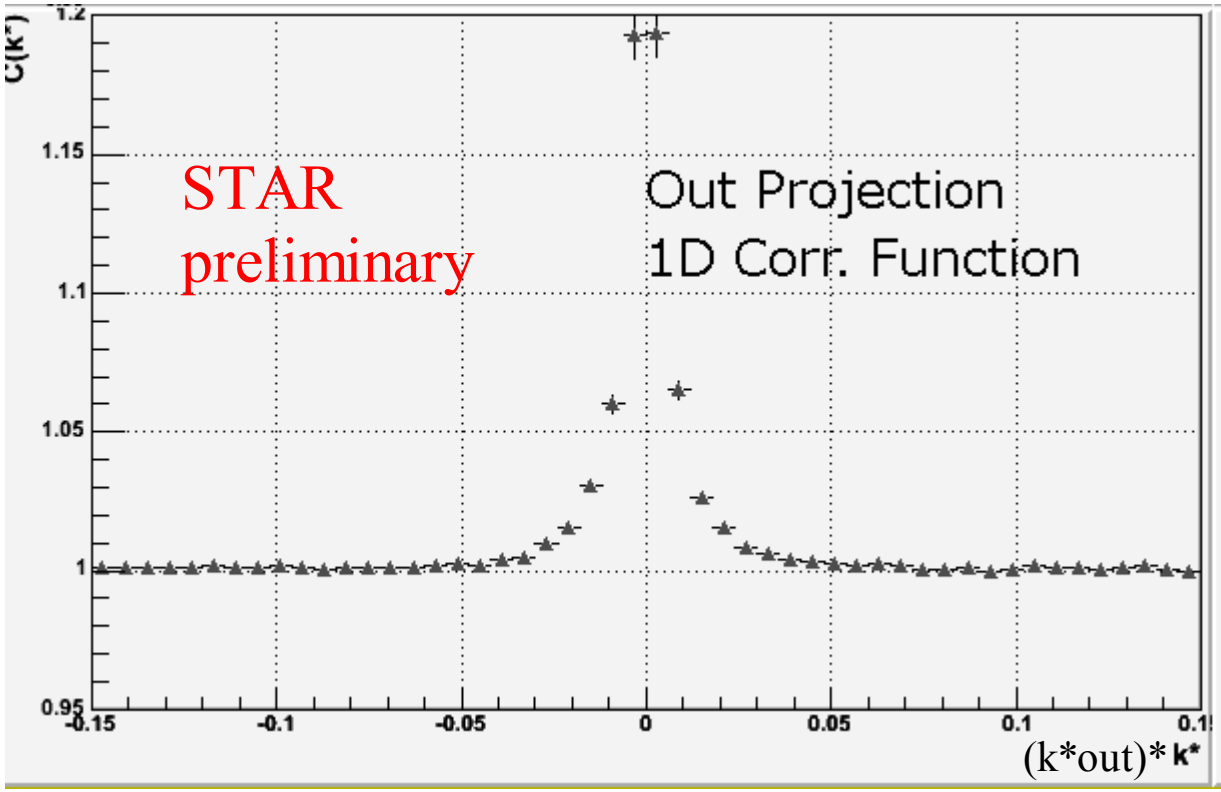
$$\langle r^* \rangle = \gamma(\langle \Delta r \rangle - \beta_T \langle \Delta t \rangle)$$

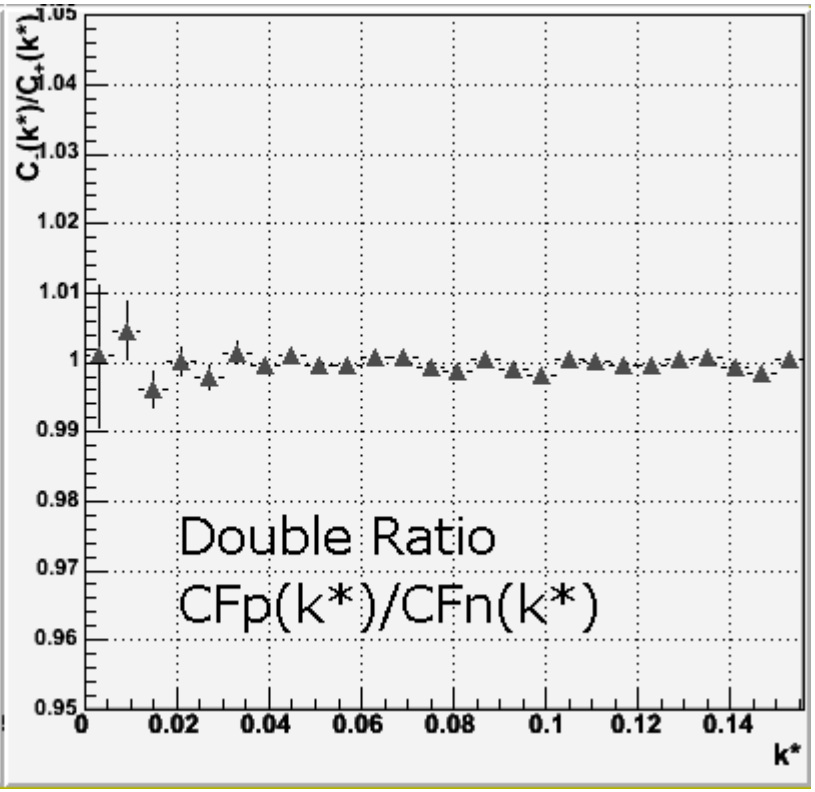
- We expect asymmetry in "out" direction, but not in "side", which is used as cross-check

R. Lednicky,
nucl-th/0305027

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

Pion – Pion at 130 AGeV





Sigma: **15.5 ±0.4** $^{+\ 2.3\ \text{syst.}}_{-\ 1.7\ \text{syst.}}$ fm

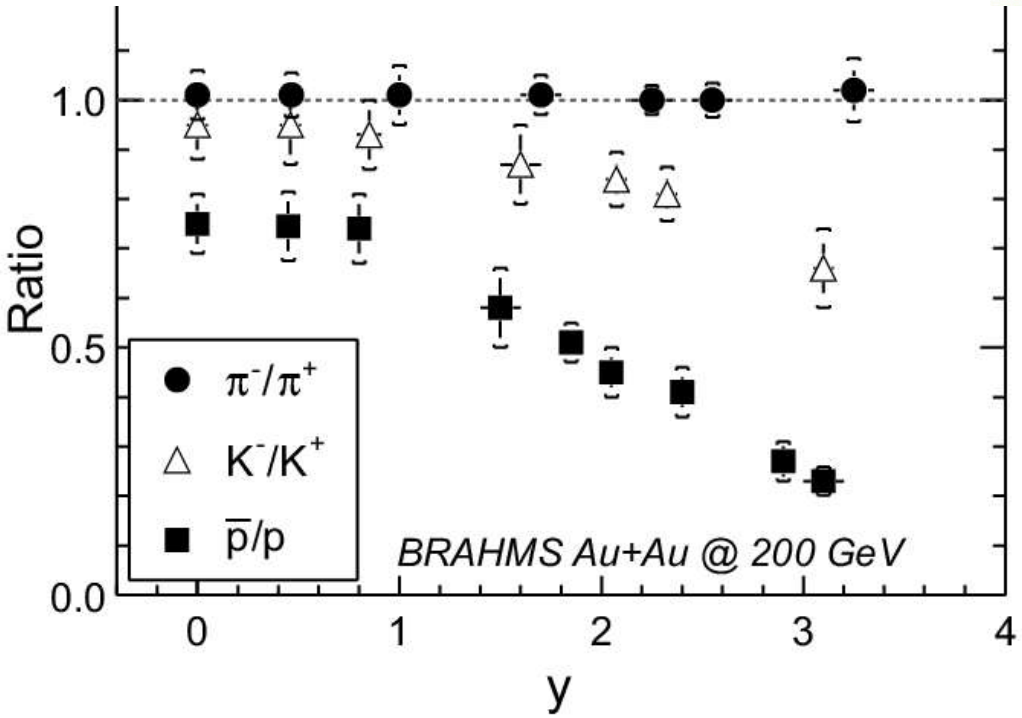
Mean: **0.2 ±0.2** $^{+\ 0.2\ \text{syst.}}_{-\ 0.4\ \text{syst.}}$ fm

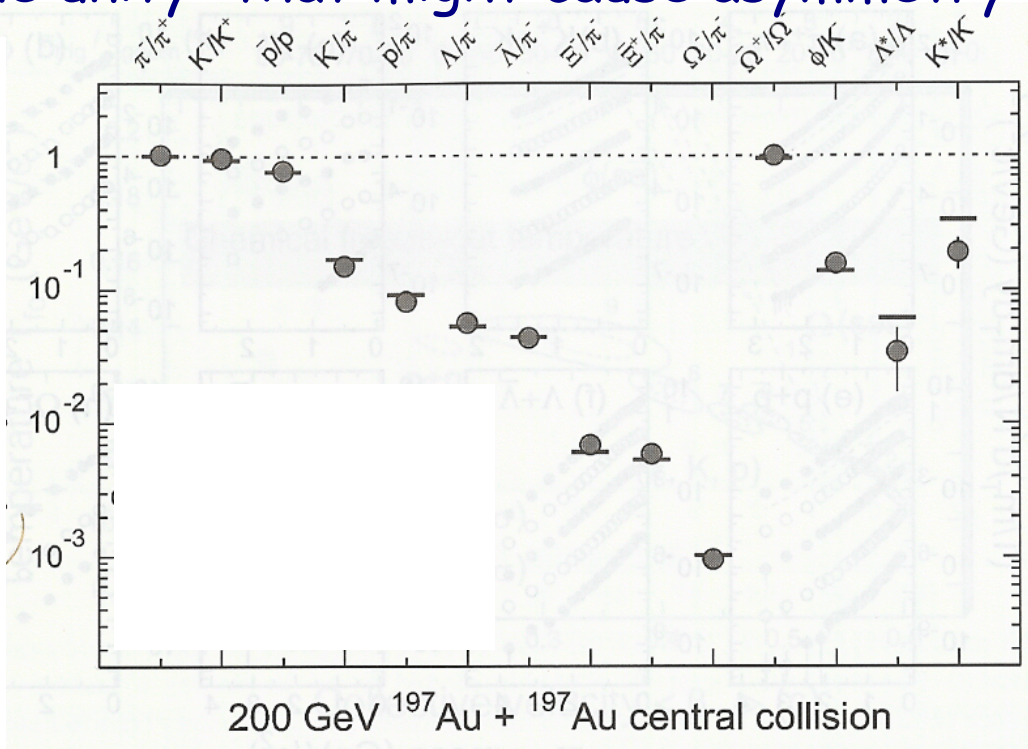
Fit assumes source is a gaussian in r^*_{out}

No differences in emission between positive and negative pions

Hadron yields at RHIC

The ratio of pBar/p is NOT equal the unity- that might cause asymmetry





There are several reson of asymmetry in p-pBar correlations:

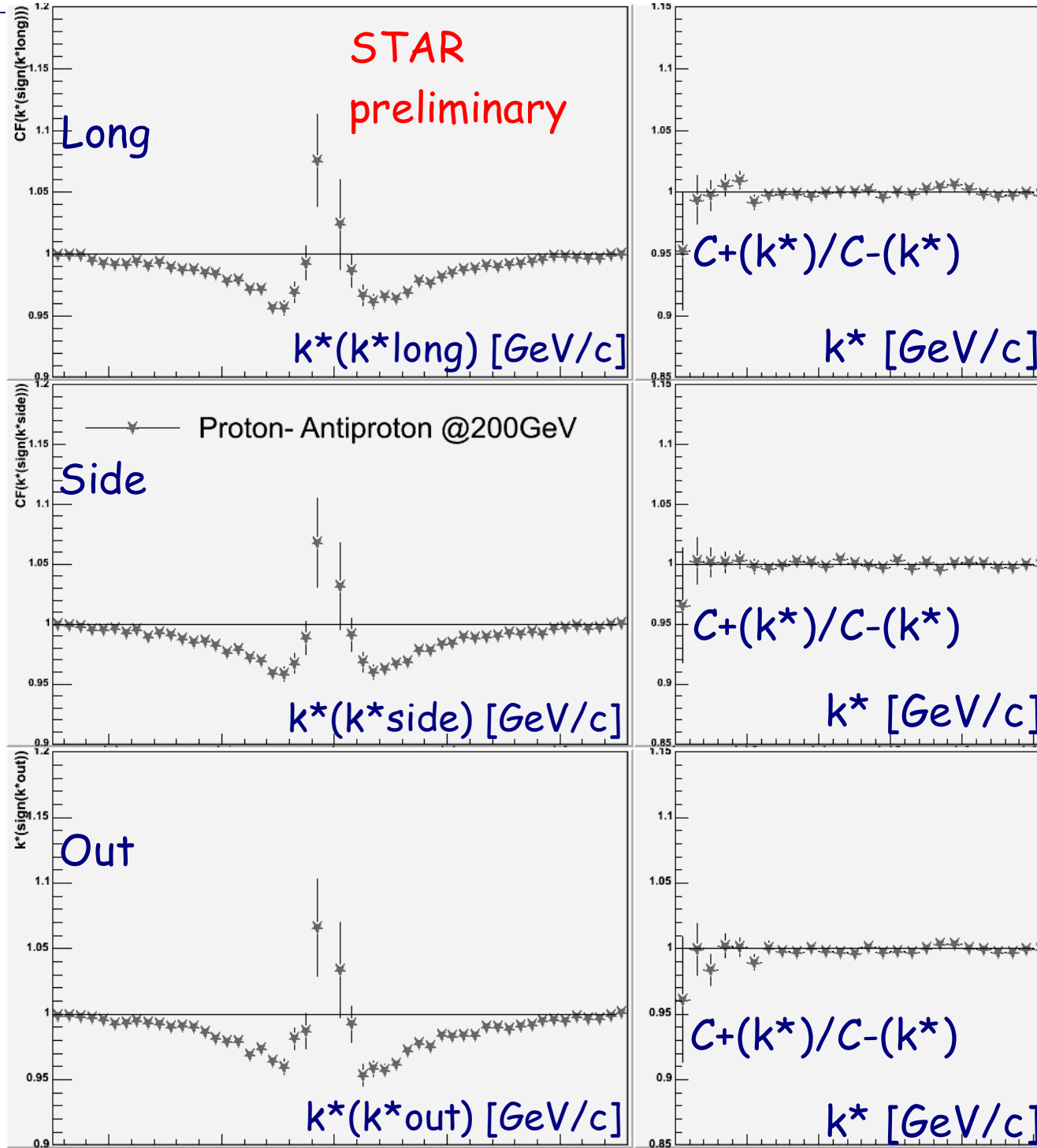
- nonidentical number of particles and antiparticles,
- the interaction with nuclear remnants,
- known from low energies: the third body influence,
- (possible) different hadronization

Non- identical baryon correlations @200GeV

Long "double ratio" is flat because STAR has symmetric rapidity acceptance.

Side "Double ratio" must be flat as a result of azimutal symmetry of space.

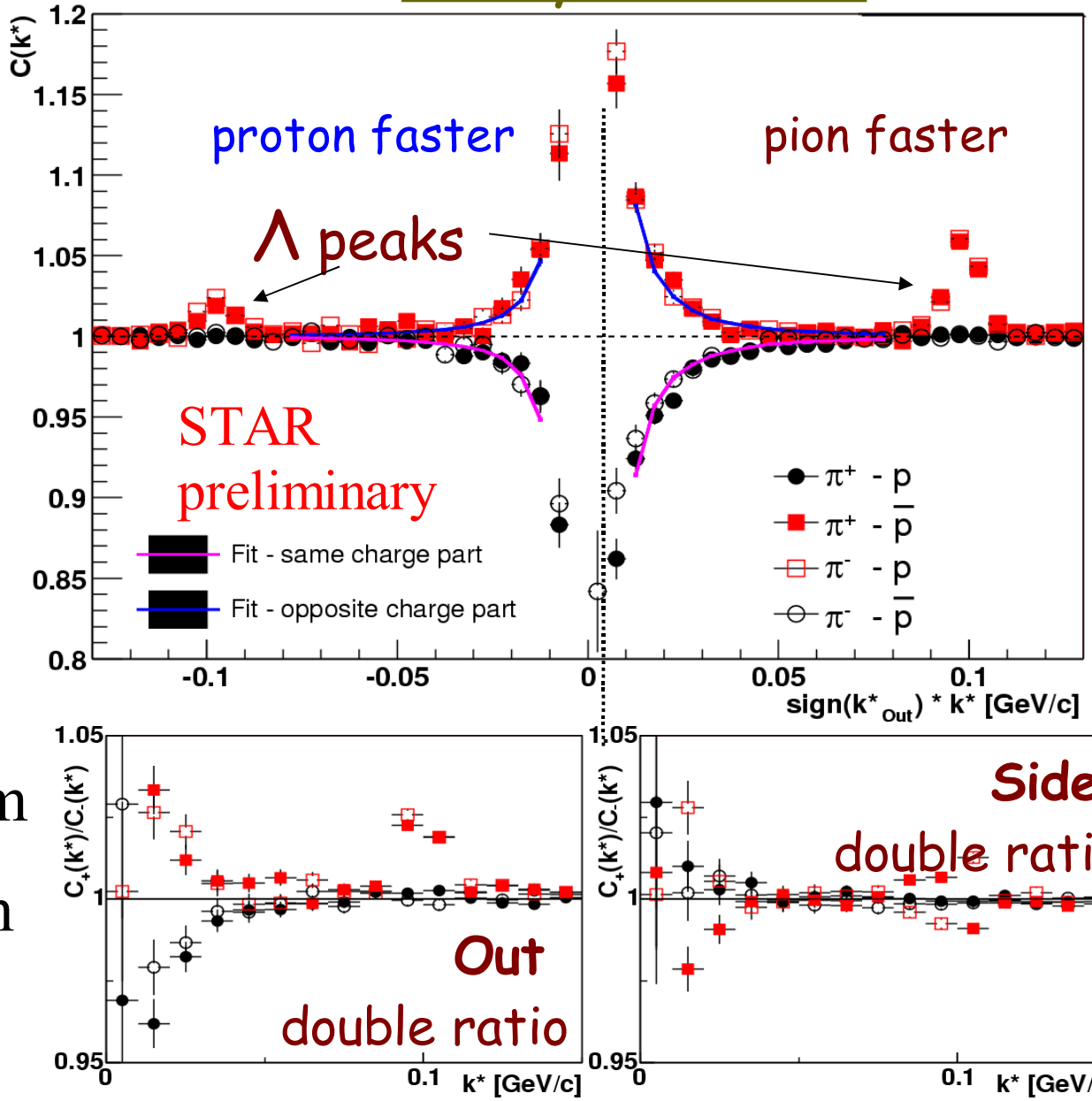
Any asymmetry in emission precess is visible in Out direction => No asymmetry in proton- antiproton system.



Pion-Proton 130 AGeV

Taken from QM 2004
Talk by Adam Kisiel

- Lambda peaks at $k^* \sim m_{inv}$ of Λ
- Good agreement for identical and non-identical combinations of charge



Sigma: $\mathbf{15.1 \pm 0.4}^{+\ 1.0\ \text{syst.}}_{-\ 1.5\ \text{syst.}}$ fm

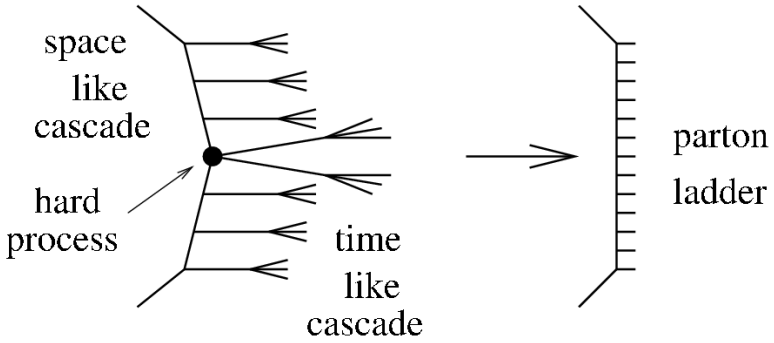
Mean: $\mathbf{-7.4 \pm 0.9}^{+\ 1.9\ \text{syst.}}_{-\ 3.4\ \text{syst.}}$ fm

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

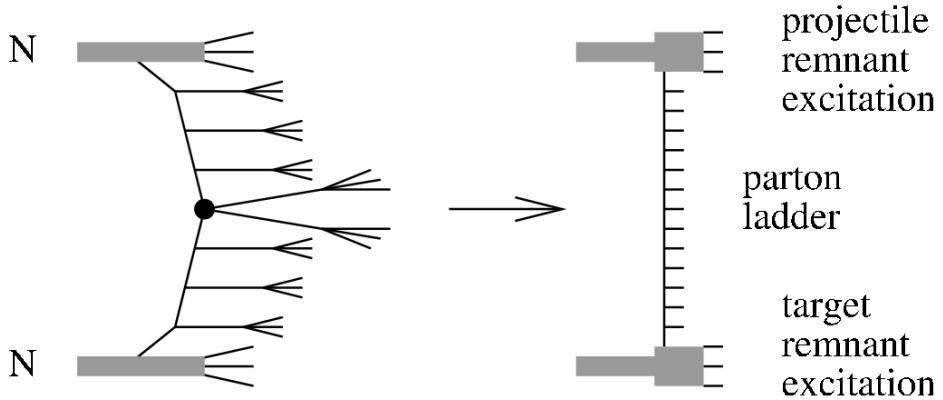
Basics of EPOS (parton model)

Improved Parton Model with Remnants:

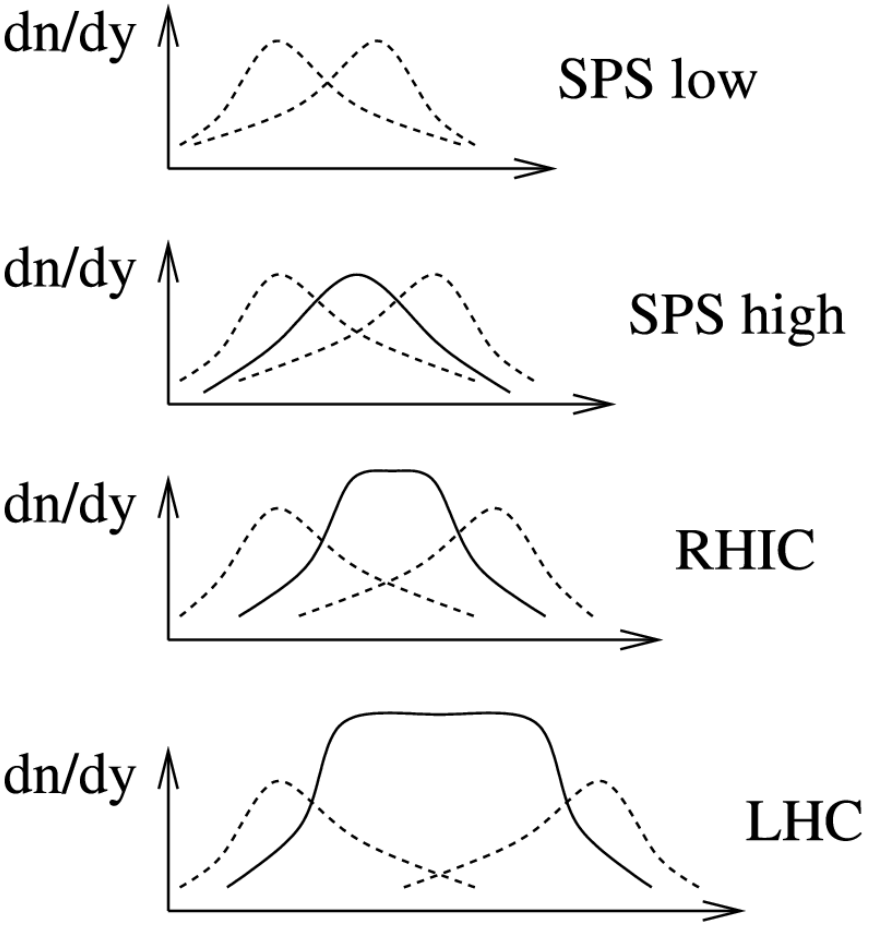
Energy conserving quantum mechanical multiple scattering approach based on Partons (parton ladder)
Off-shell remnants
Splitting of parton ladder



Elementary parton-parton scattering, the hard scattering in the midlle preceded by parton emmisions, then partons emit further partons-> PARTON LADDER

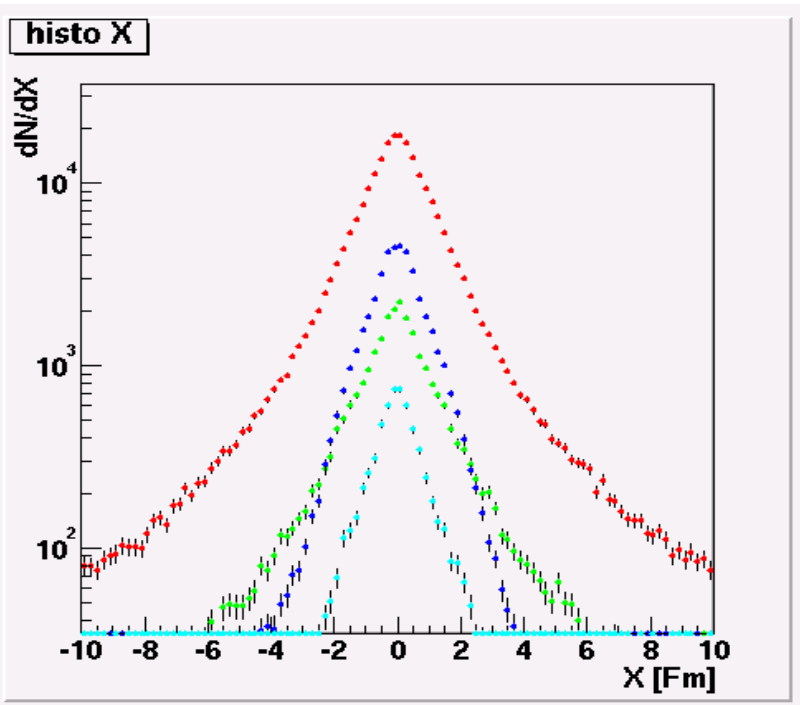


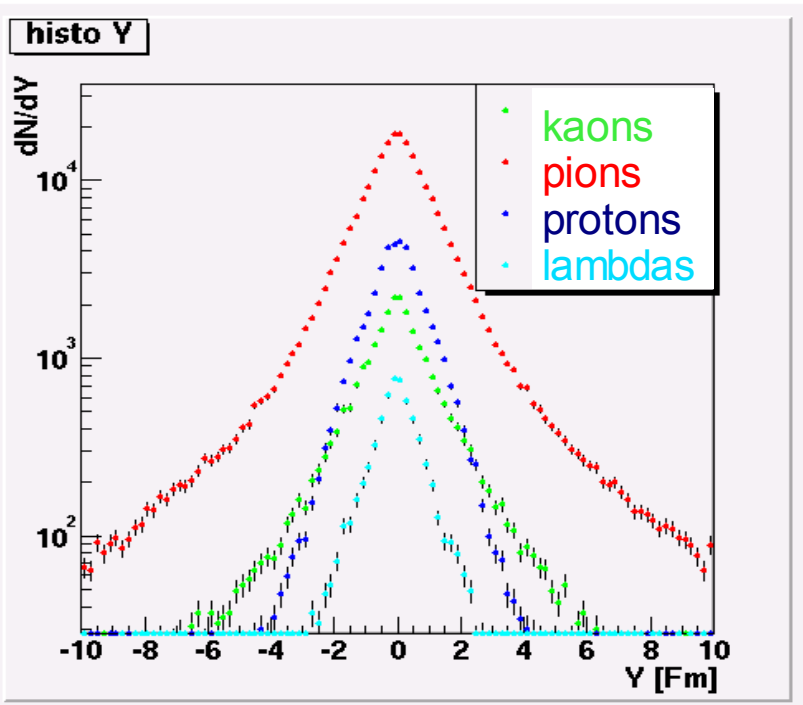
K.Werner, F-M. Liu, T. Pierog, hep-ph/0506232

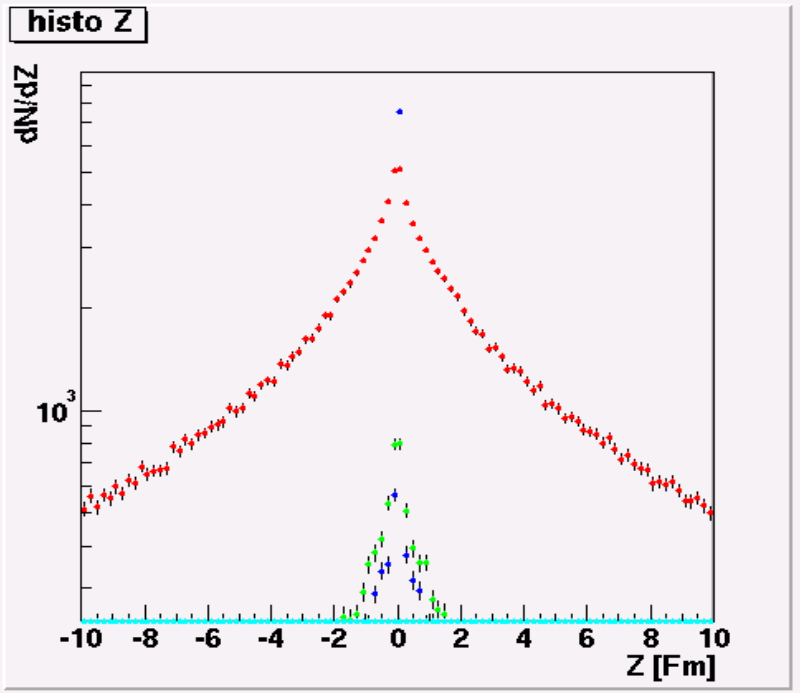


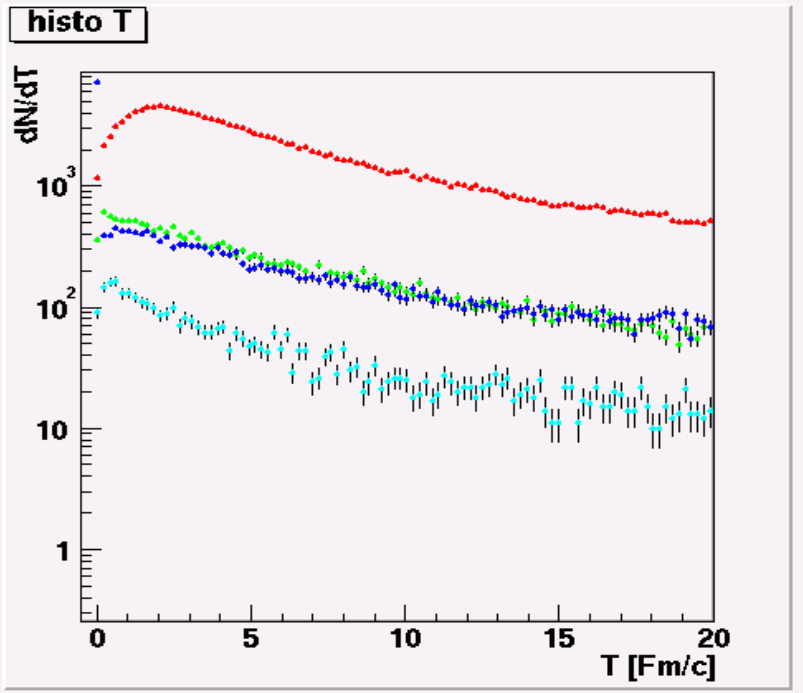
Inner contributions from the parton ladder (full lines) and the "outer" contribution, from remnants (dashed lines).

EPOS: one- particle distribustions for p+p collision





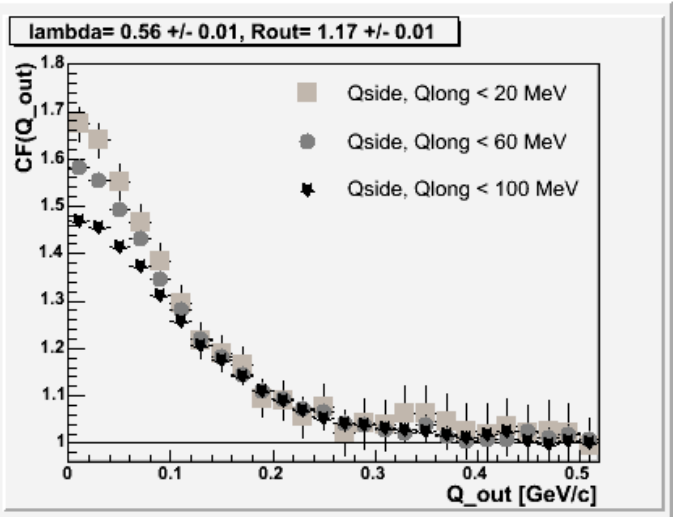


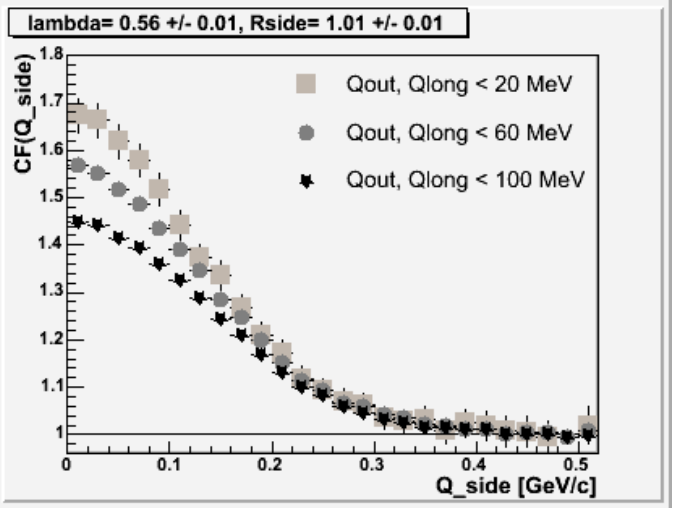


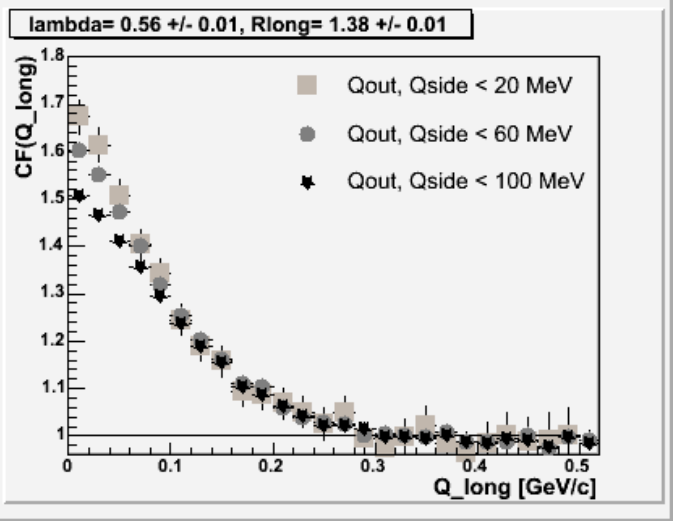
Space- time components of freezeout

by Pierre-Olivier BREVET

EPOS: pi+pi+ correlation function







We can reduced histogrammed pairs up to ones only from correlated region.

For pions the region is reduced to 300 MeV.

EPOS: two- particle distributions (π+ π+) for p+p collision

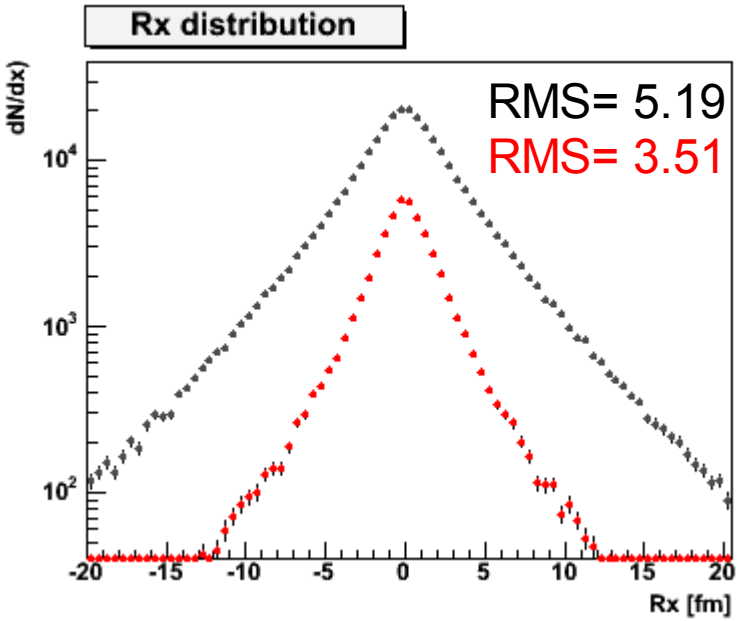
Space-time coordinates of particles: x, y, z, t.

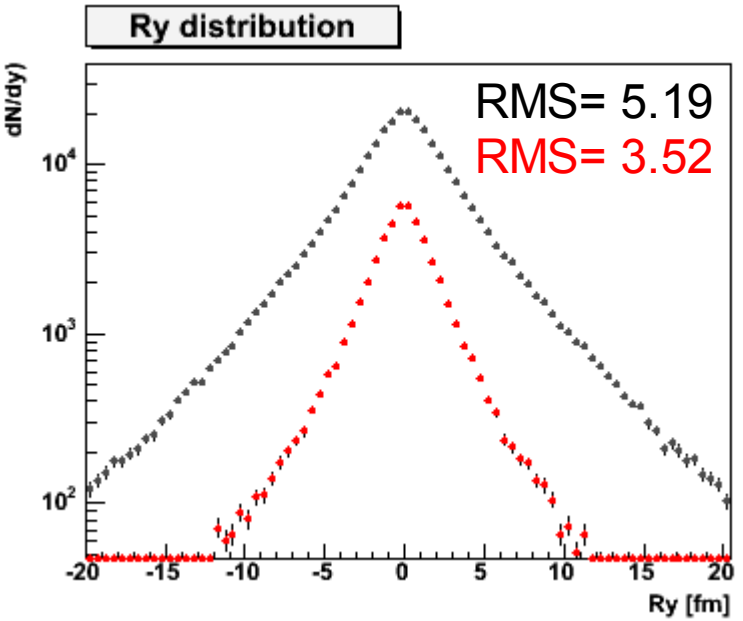
$R_x = x_1 - x_2$

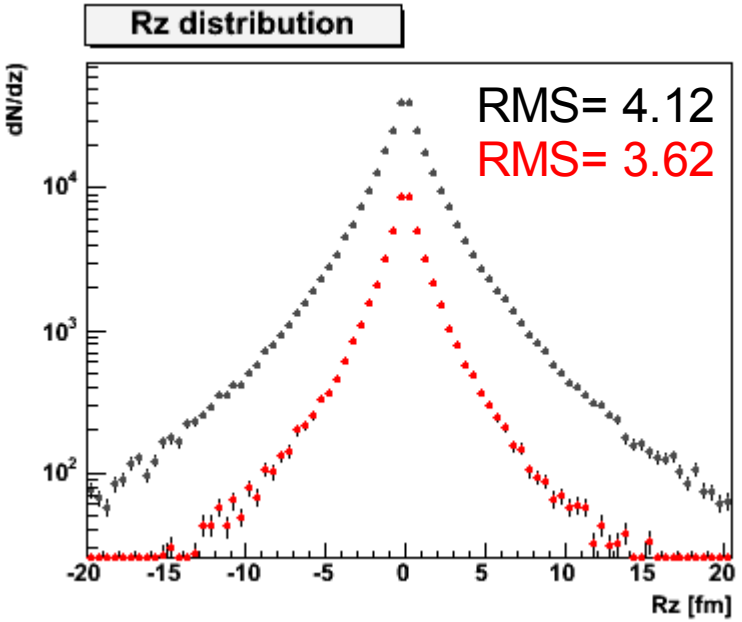
$R_y = y_1 - y_2$

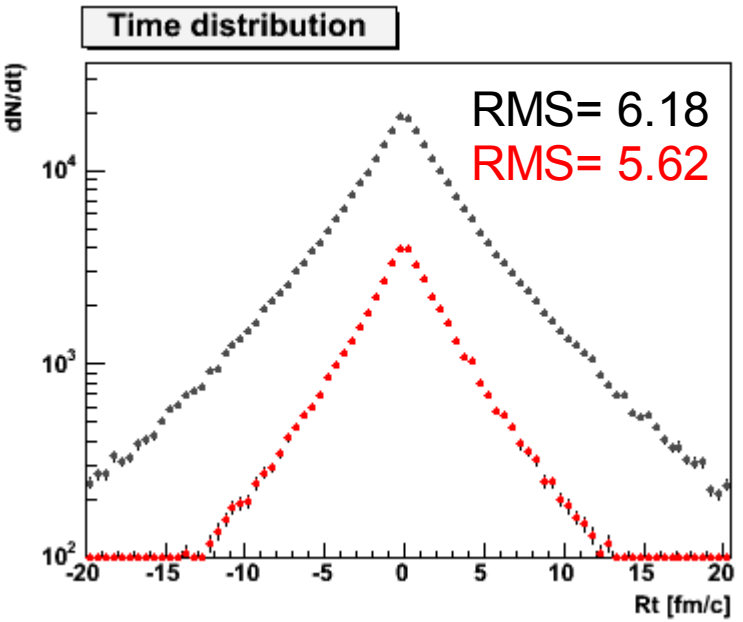
$R_z = z_1 - z_2$

$R_t = t_1 - t_2$

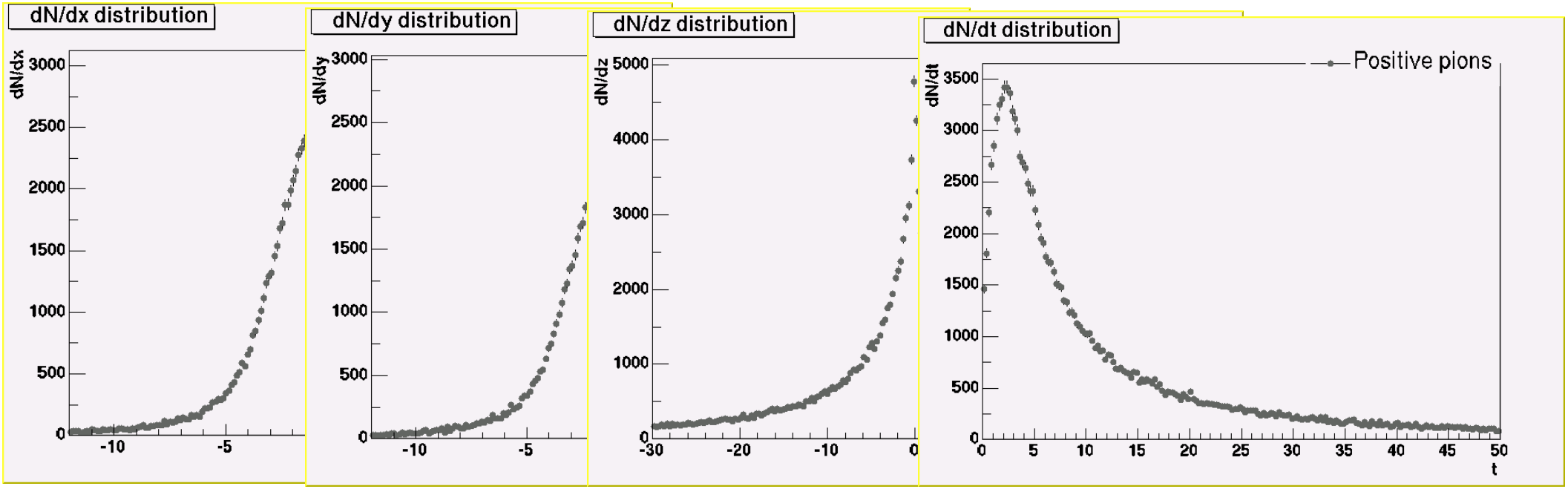


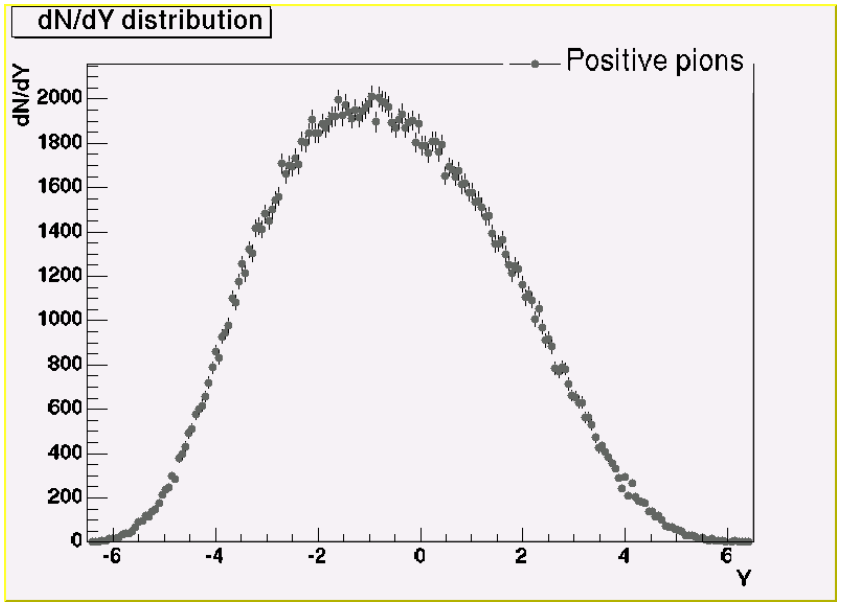


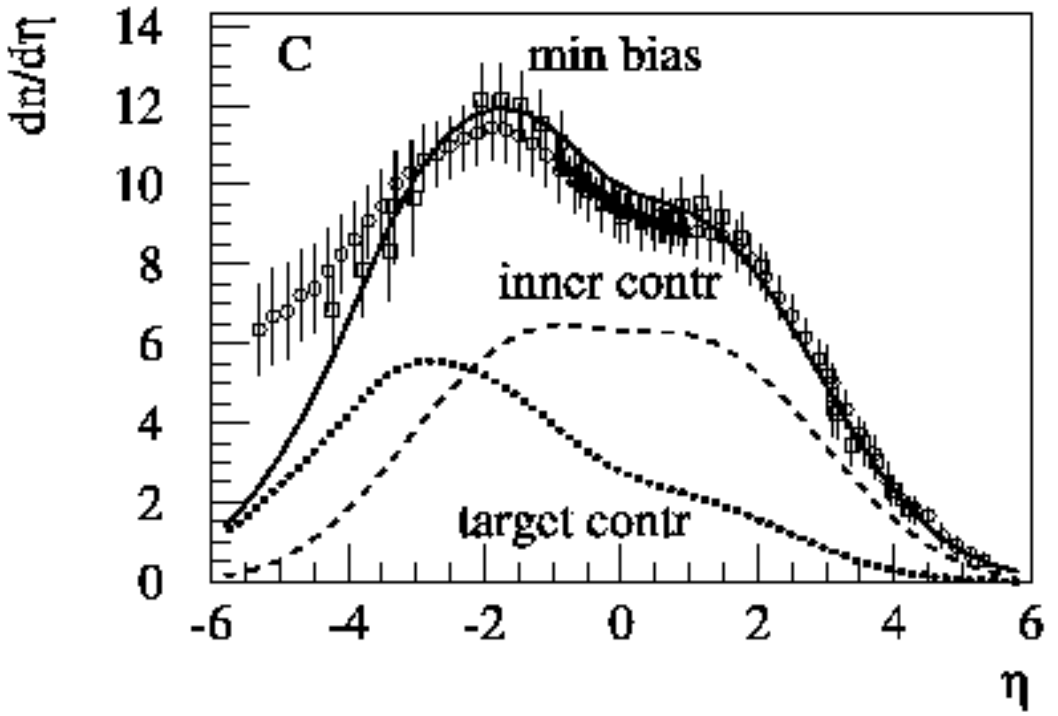




EPOS: one- particle distribustions for d+Au collision







EPOS: two- particle distributions (π+ π+) for d+Au collision

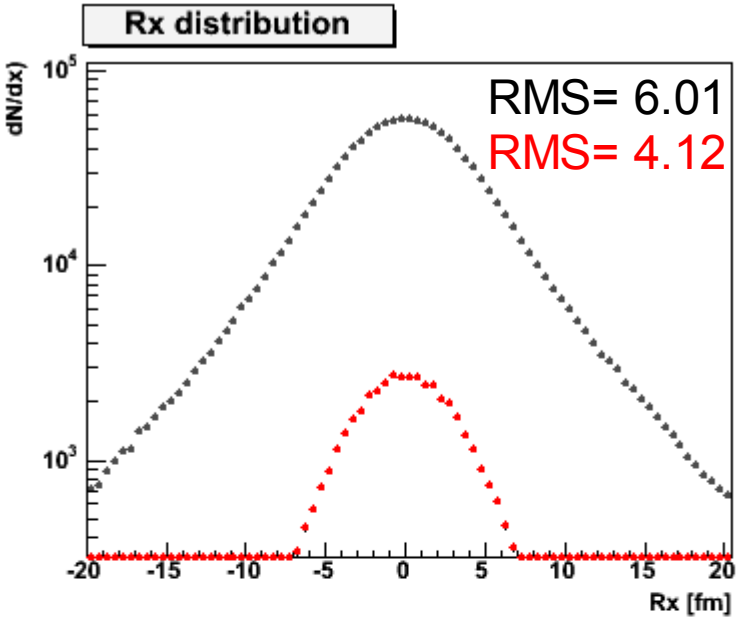
Space-time coordinates of particles: x, y, z, t.

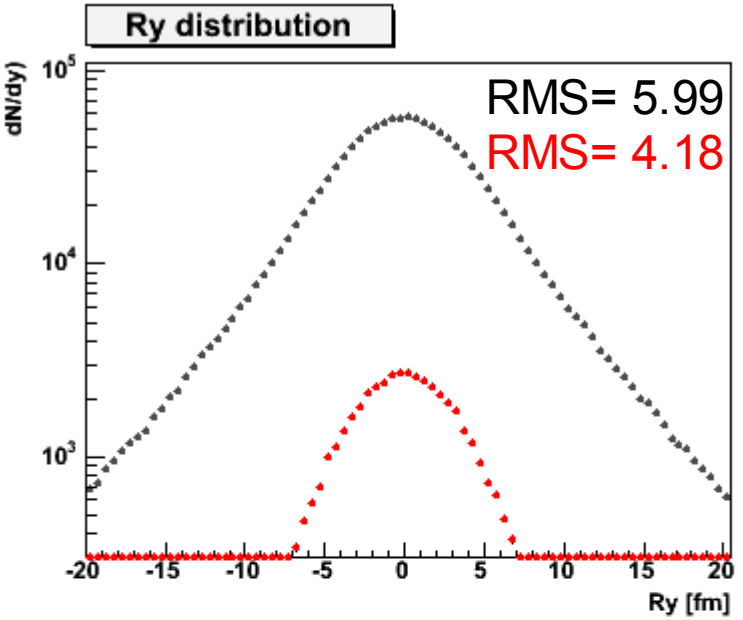
$R_x = x_1 - x_2$

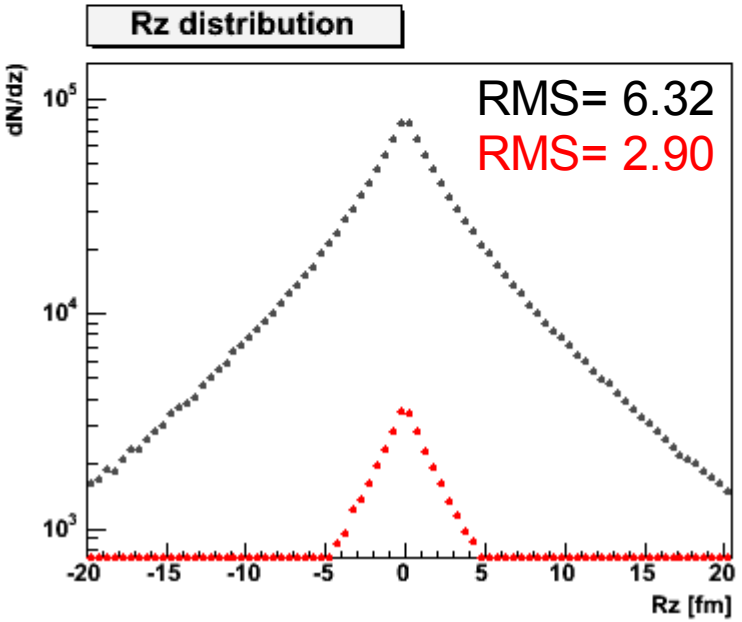
$R_y = y_1 - y_2$

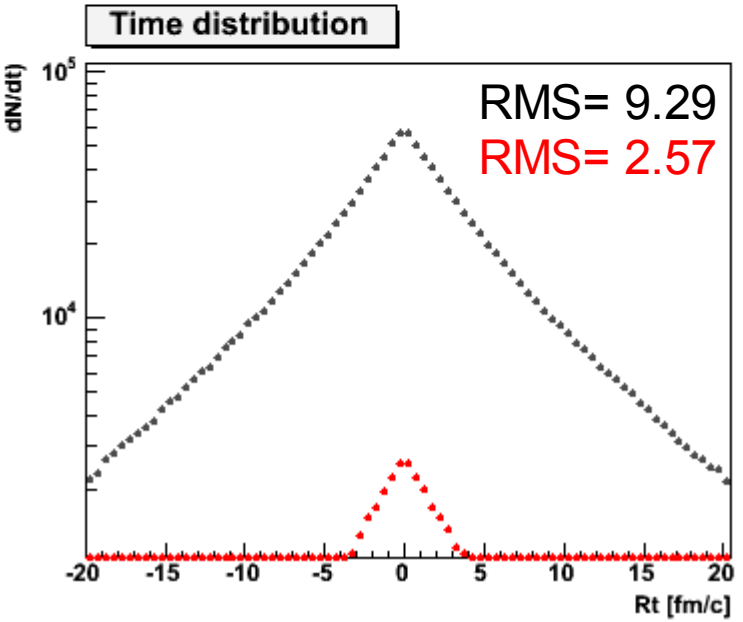
$R_z = z_1 - z_2$

$R_t = t_1 - t_2$



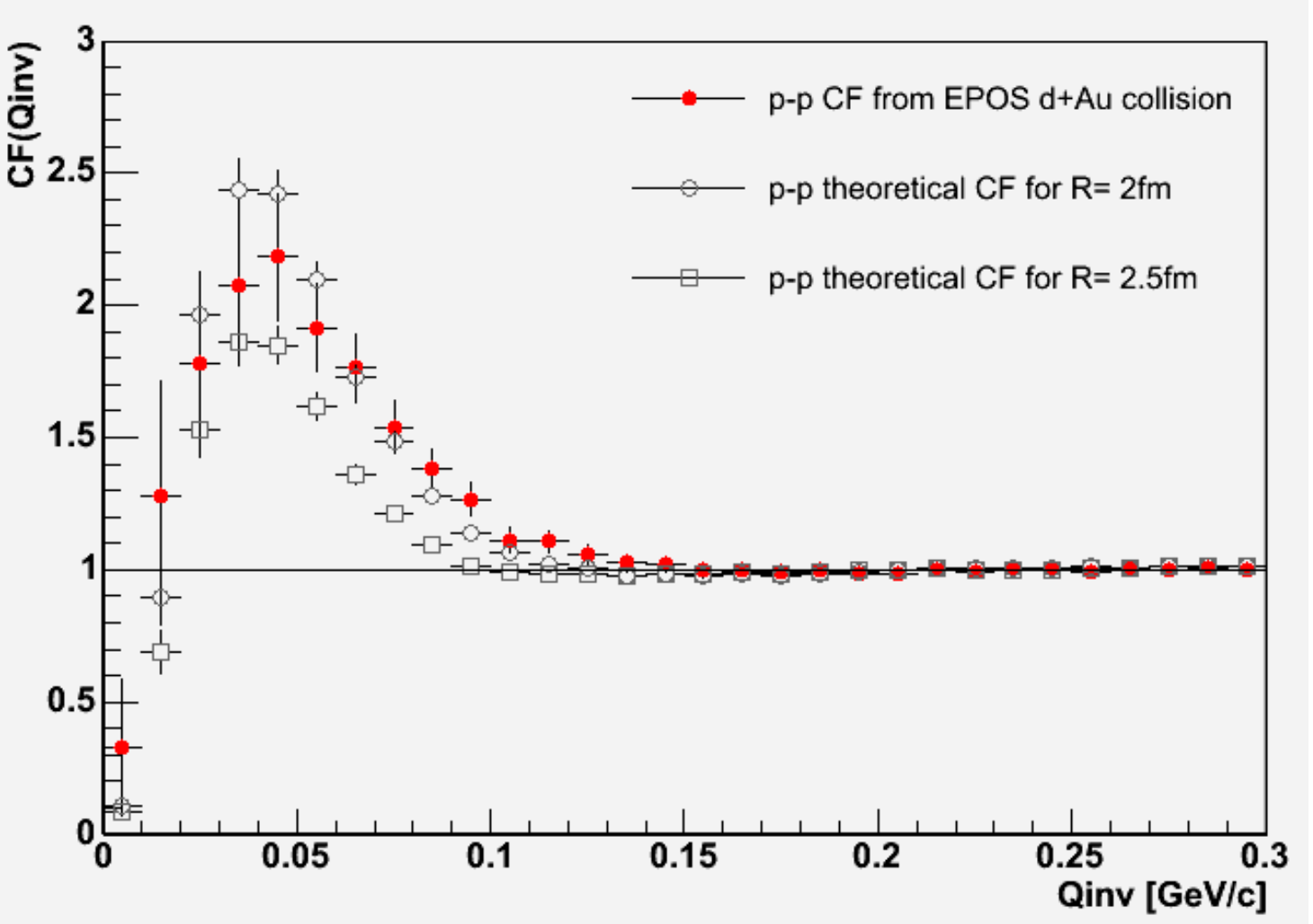






EPOS: p-p correlation function for d+Au collisions

The p-p correlation function from EPOS is compared to ones calculated in assumption that the source is a gaussian.



Summary

Results are consistent for both energies (62GeV and 200GeV) and all centrality bins.

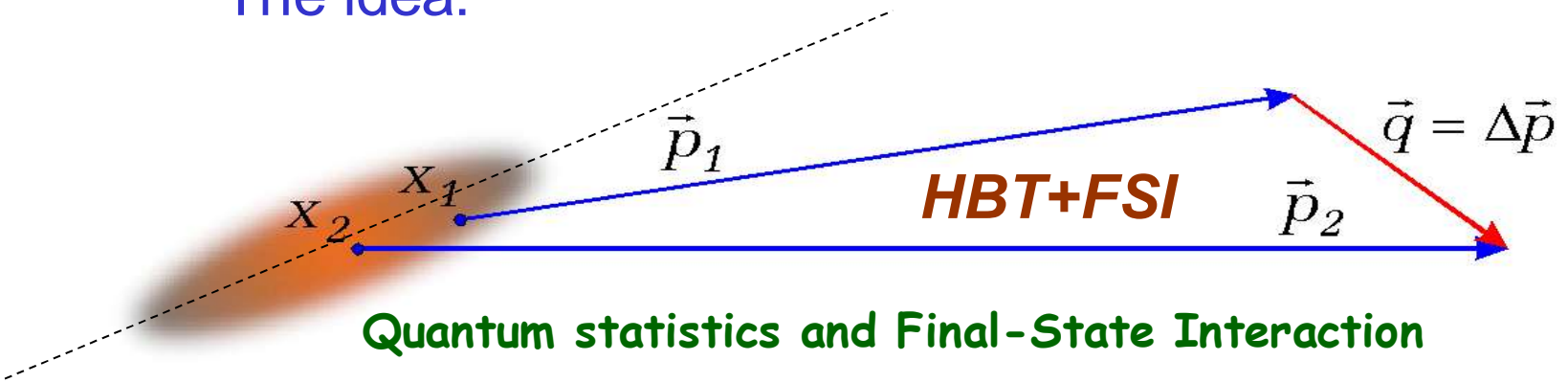
Current fits give different sizes for identical and nonidentical systems.

Nonidentical particle correlations method provides powerful tool that helps to probe asymmetry in emission process.
(see the session about Nonidentical Particle Correlations)

The study to compare EPOS to data results are underway.

Particle correlations as a tool to explore the space-time geometry and dynamics

The idea:



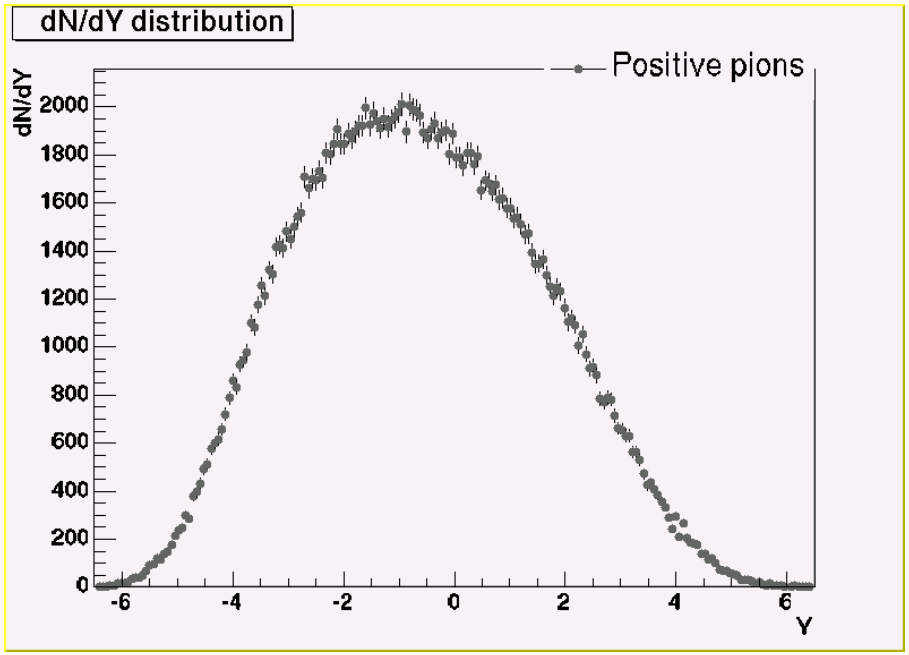
Quantum statistics and Final-State Interaction

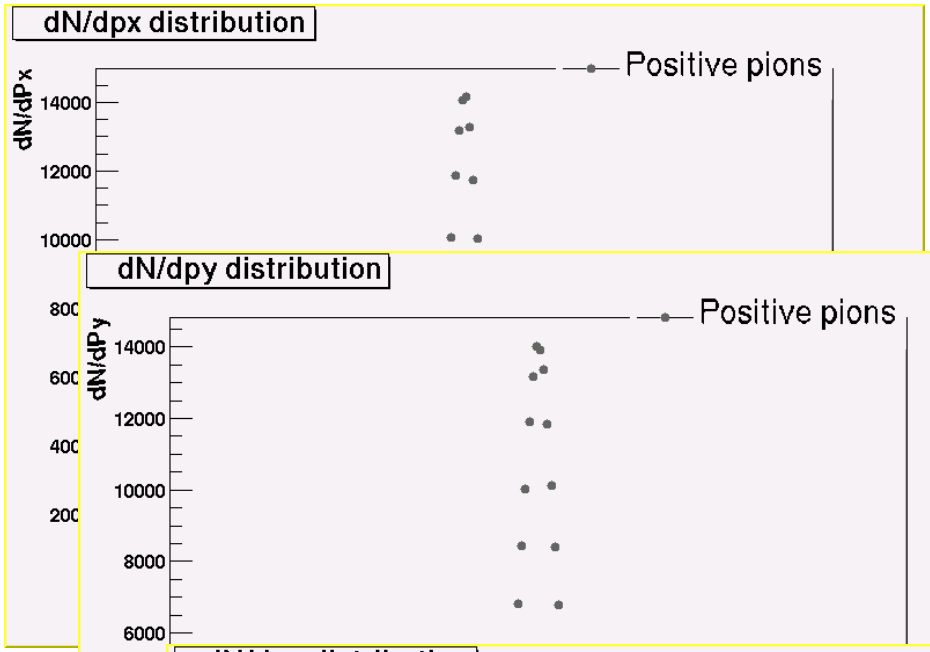
Space-time sizes and dynamics (cannot be measured directly)

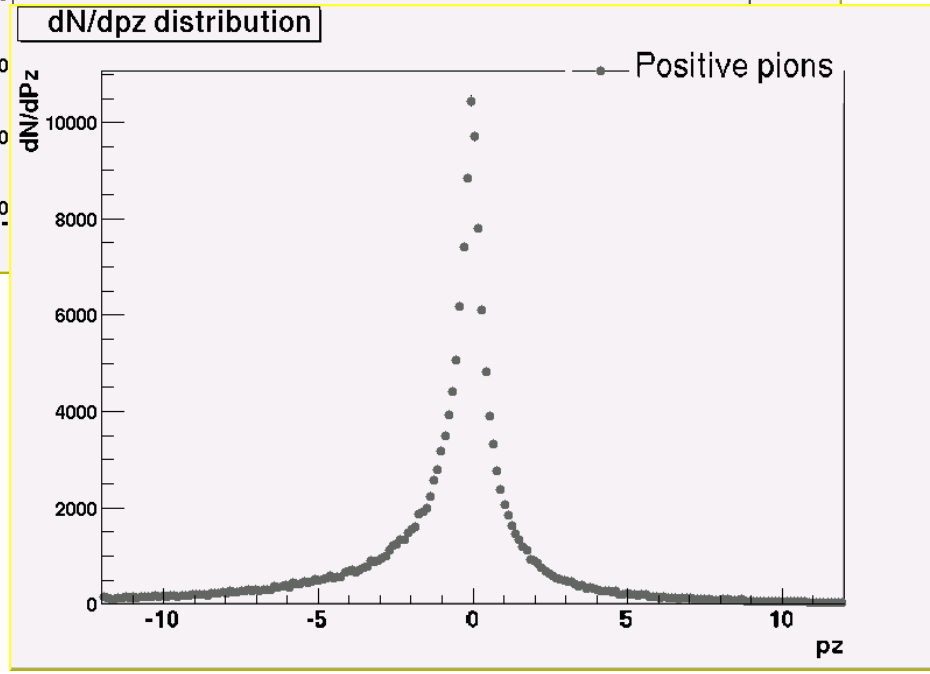
close velocity correlations

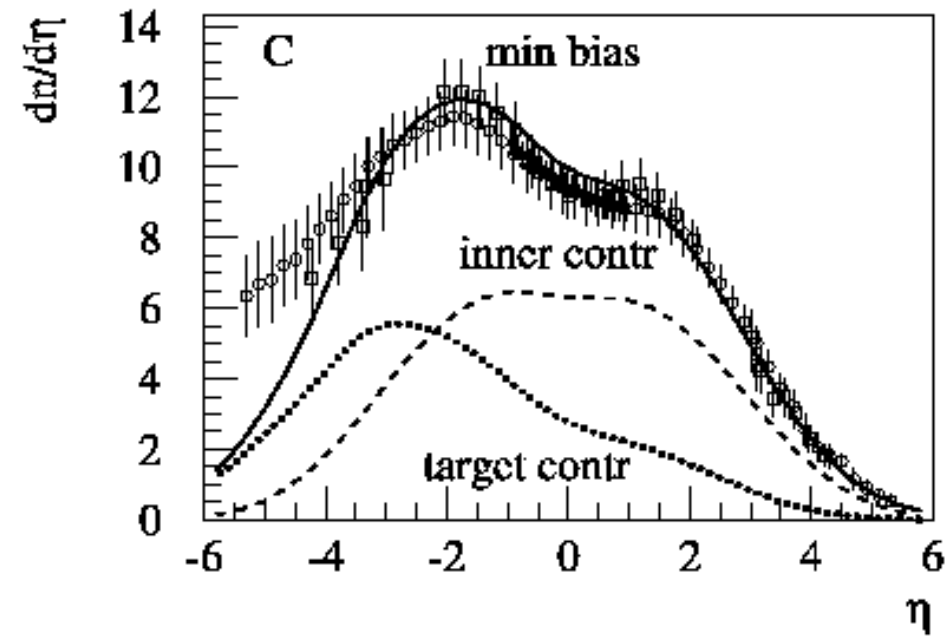
Momenta and momentum difference (can be measured)

EPOS: one- particle distributions for d+Au collision

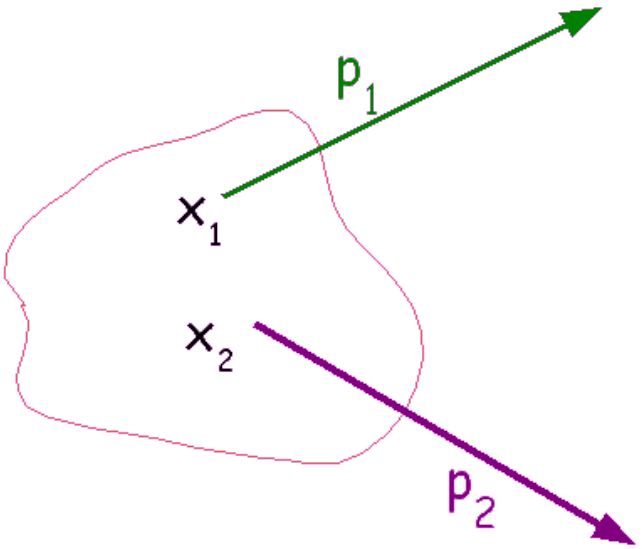


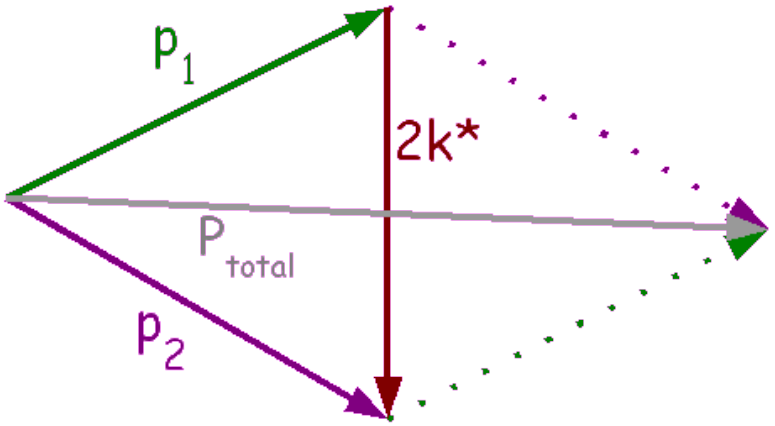






Few words about correlation technique..





The particle interferometry method provides a powerful tool for the investigation of the properties of the matter produced in heavy ion collisions at ultra-relativistic energies.

The correlation function is constructed as a function of momenta differences between two particles in pair (2k*).

By studing correlations in small relative momenta of pair we are able to conlude about space and time properties of region from where they are emmited.

Particle correlation technique is a powerfull tool to conlude about source characteristics that we are not able measure.

Any asymmetry can be visible in Out direction.

"Double ratio" in Side direction must be flat as a result of space anisotropy.

As a result of symetry in rapidity also Long "double" ratio must be flat

By Adam Kisiel

Initial separation in PRF system
<Δx*> (measured) come fromtime shift <Δt> and space shift<Δx>

$$\begin{aligned}
\langle \Delta x^* \rangle &= \langle \Delta x \rangle + v_T \langle \Delta t \rangle \\
\langle x \rangle &\equiv \langle \vec{r} \cdot \hat{x} \rangle = \left\langle r \frac{\beta^F + \beta_\perp^T \cos(\phi)}{\beta_\perp} \right\rangle \\
&\approx \left\langle r \frac{\beta^F}{\left(\beta^{F2} + \beta_\perp^{T2}\right)^{1/2}} \right\rangle \\
\langle y \rangle &= \langle \vec{r} \cdot \hat{y} \rangle = \left\langle r \frac{\beta_\perp^T \sin(\phi)}{\beta_\perp} \right\rangle = 0 \\
\langle z \rangle &= \langle \tau_S \sinh(y_S) \rangle \approx \langle \sinh(y_S) \rangle \langle \tau_S \rangle = 0
\end{aligned}$$