Pion femtoscopy in p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the STAR experiment

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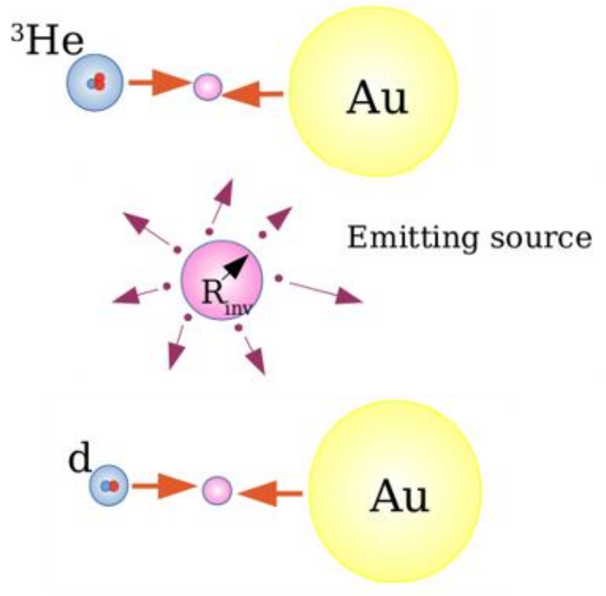
The 5th International Conference on Particle Physics and Astrophysics (ICPPA-2020)

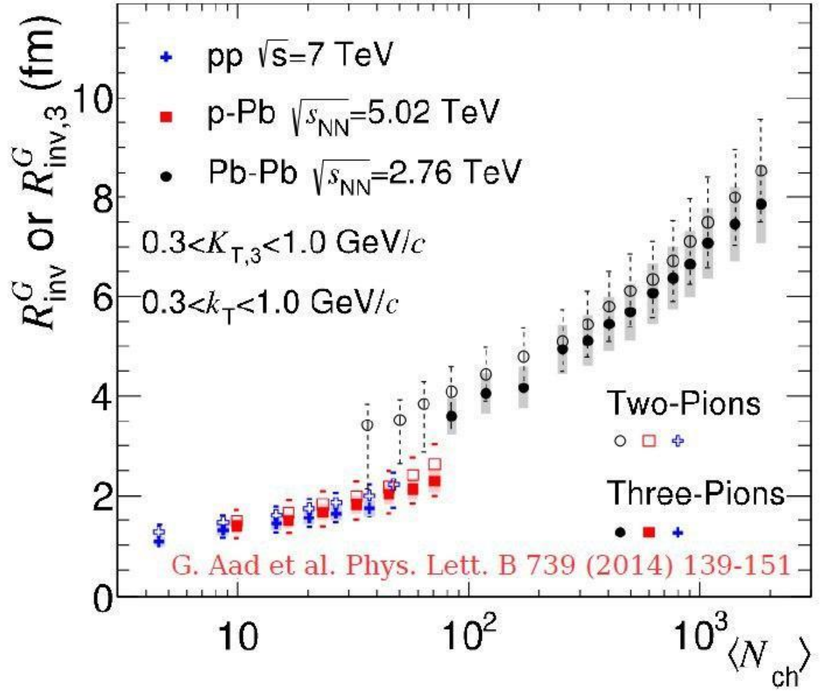
09.10.2020

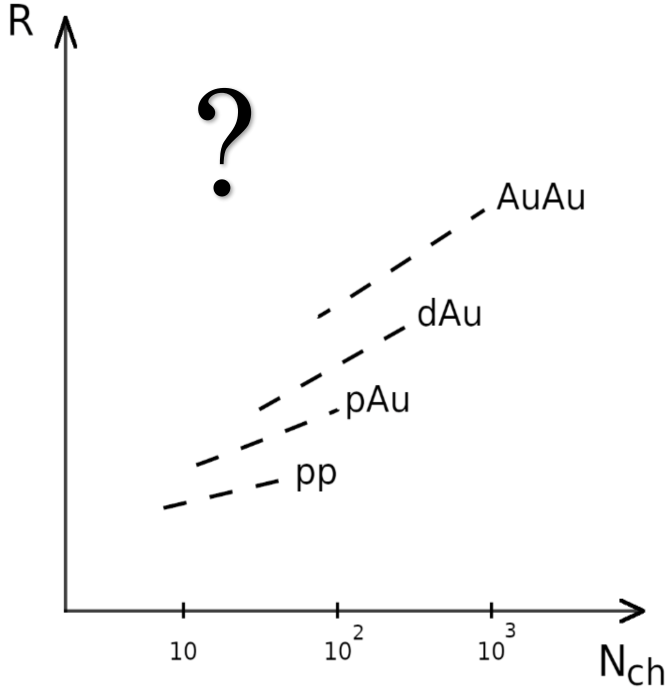
Outline

- Motivation
- Femtoscopy
- Correlation functions and their fits
- Systematic uncertainty
- k_T dependence of R_{inv} and λ
- System comparison

Motivation







Examination of the spatial and temporal scales of the particle-emitting source is one of the ways to study the process of particle production.

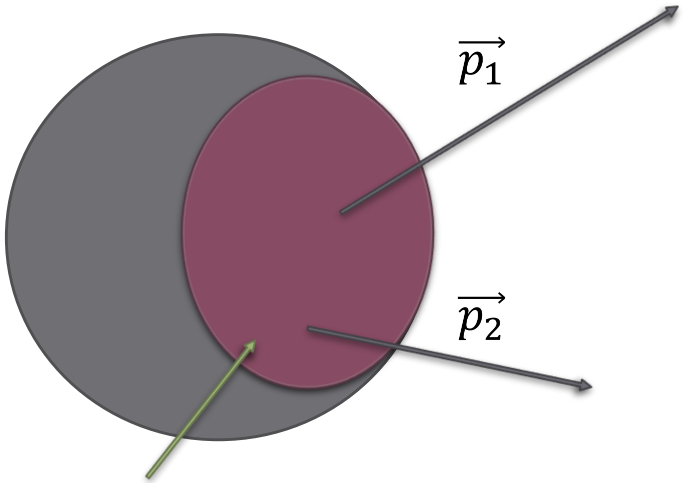
M. Podgoretky 1989 Particles & Nuclei 20 630-68

In small systems (like p+p or d+Au) a collision area size is sensitive to fluctuations of initial conditions. Therefore, the detailed nature of particle production becomes important.

A. Bzdak et al. 2013 Phys. Rev. C 87, 064906

C. Plumberg 2020 arXiv:2008.01709

Femtoscopy



Extracted radii measure the homogeneity lengths of the source
Akkelin SV, Sinyukov YM. Phys. Lett. B356:525 (1995)

- Femtoscopy allows one to measure:
  - Size of the emission source
  - Source shape & orientation
  - Lifetime & Emission duration
- System expansion dynamics are influenced by:
  - Transport properties
  - Phase transition/Critical point
  - Initial-state event shape

Analysis technique

Construction of the correlation function:

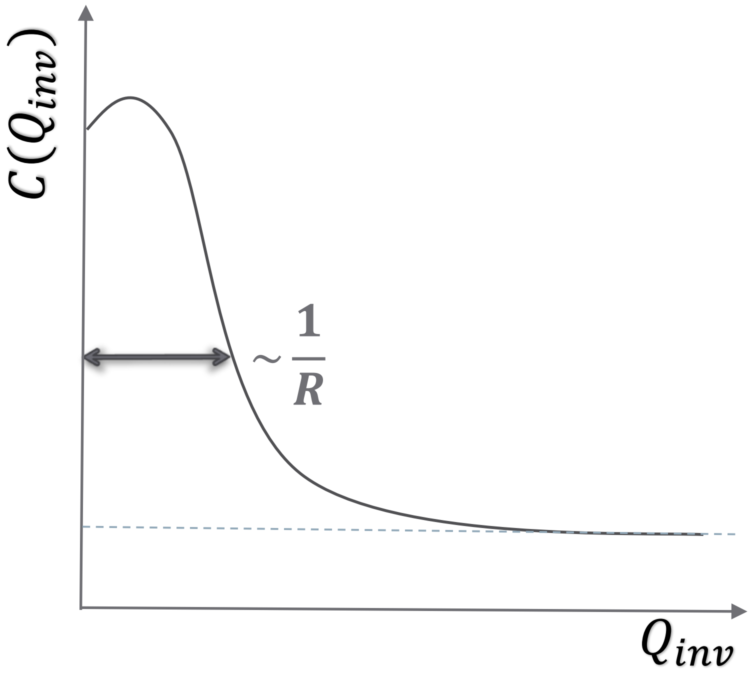
1)

$$C(Q_{inv}) = \frac{A(Q_{inv})}{B(Q_{inv})}$$

$$Q_{inv} = \sqrt{(\vec{p_1} - \vec{p_2})^2 - (E_1 - E_2)^2}$$

- $A(Q_{inv})$ – Q_{inv} distribution with Bose-Einstein statistics (and final-state interactions – Coulomb and strong)
- $B(Q_{inv})$ – Q_{inv} distribution without it (reconstructed by event-mixing technique)

Schematic view



Fit of the correlation function:

2)

$$C(Q_{inv}) = N\left(1 - \lambda + \lambda K_{Coul}(Q_{inv})\left(1 + G(Q_{inv})\right)\right) D(Q_{inv})$$

$$G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2}$$

N – normalization factor

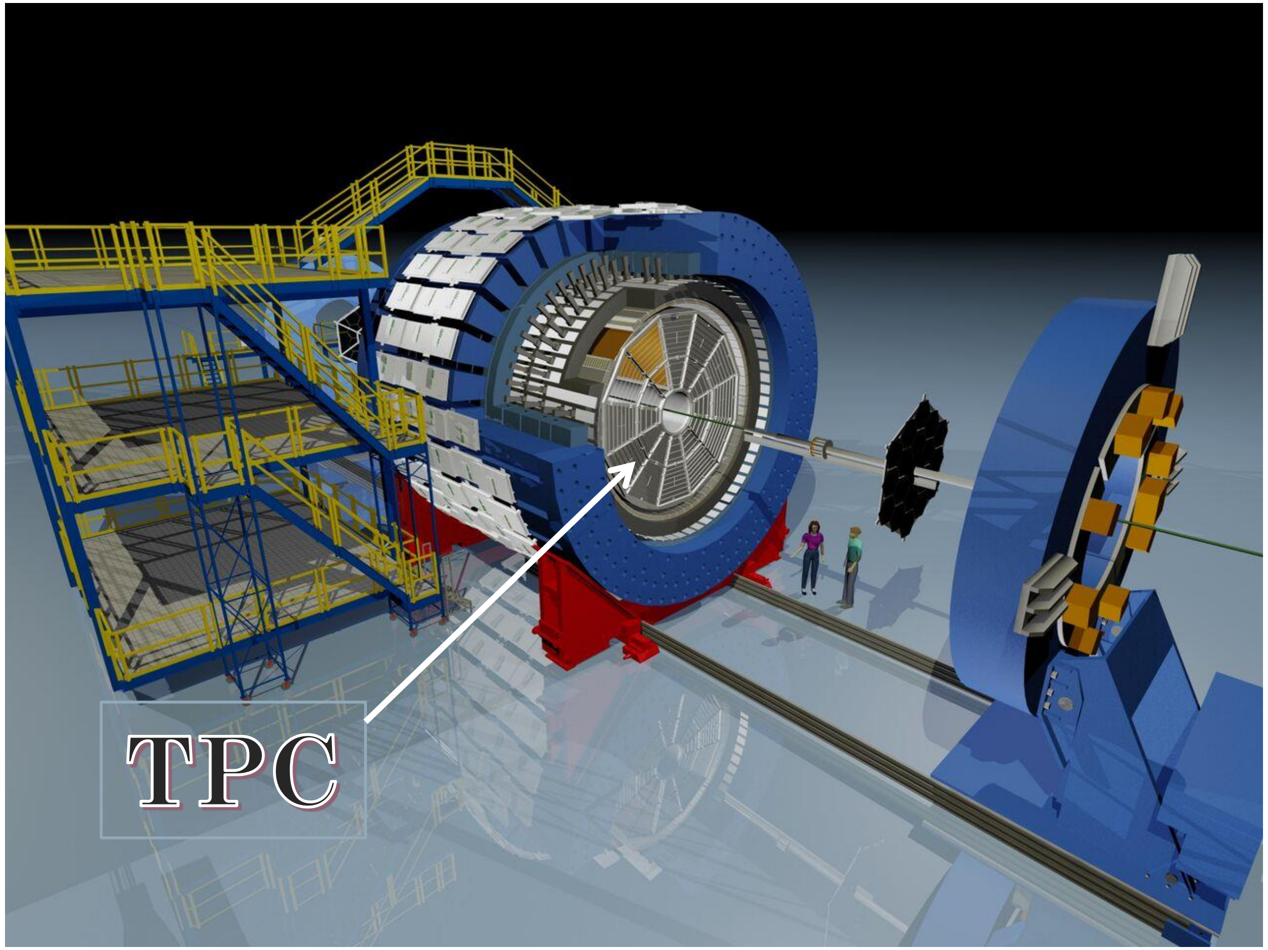
λ – correlation strength parameter

K_{Coul} - is a squared like-sign pion pair Coulomb wave-function integrated over a spherical Gaussian source

Lednicky R. et al. B 1998 Phys. Lett. B 432 248-257
Bowler M 1998 Phys. Lett. B 270 69-74

$D(Q_{inv}) = 1$ (*in this analysis*) – Non-femtoscopic correlations

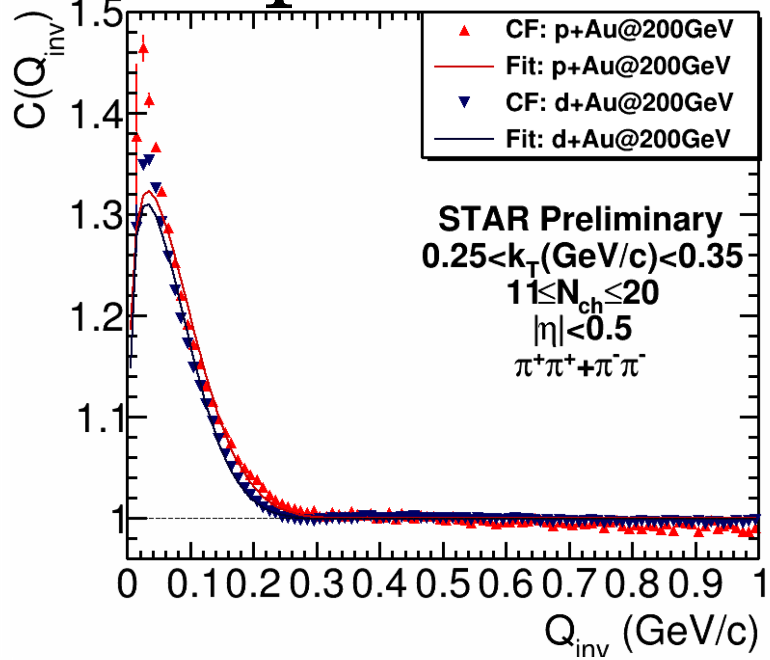
The STAR experiment



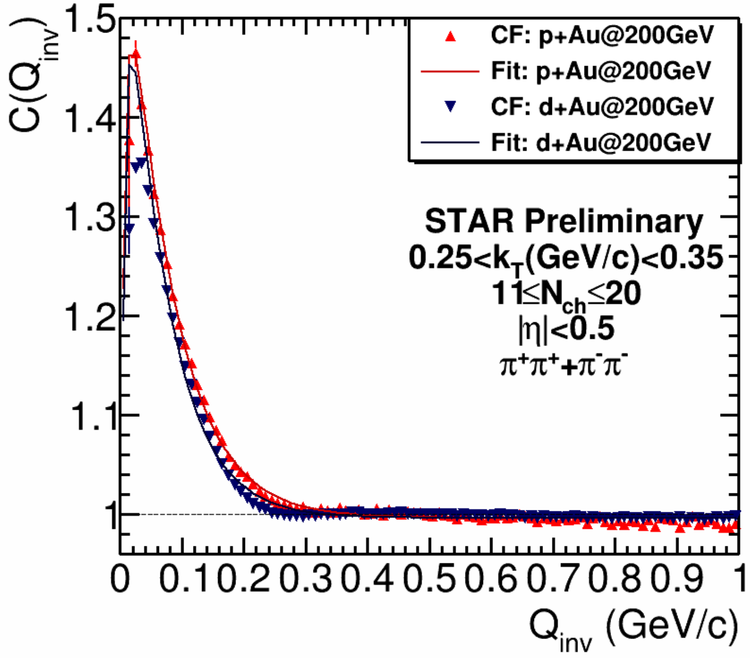
- Colliding systems:
  - d+Au@200 GeV
  - p+Au@200 GeV

- Pion identification:
  - Time Projection Chamber (TPC) - main tracking detector, $|\eta| < 1.0$, full azimuth

Example of the correlation functions and fits



Gaussian fit assumption: $G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2}$



Lorentzian fit assumption: $G(Q_{inv}) = e^{-q_{inv} R_{inv}}$

d+Au and p+Au systems comparison

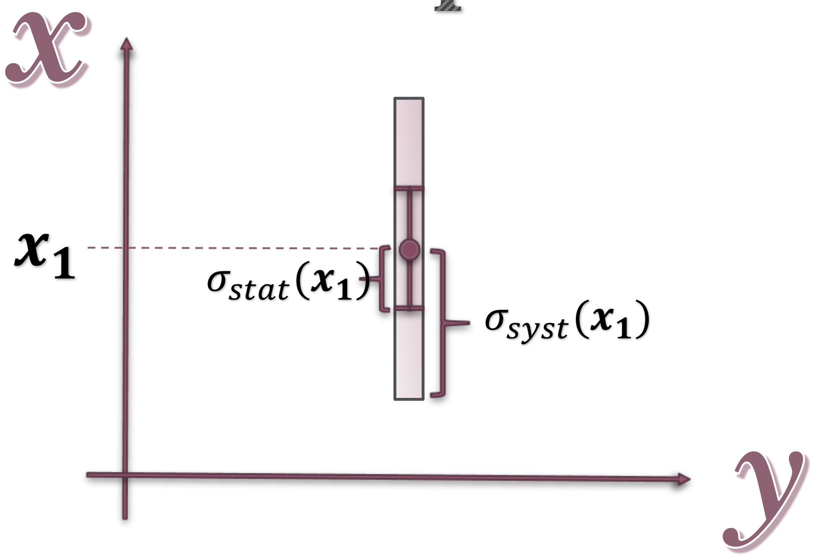
Correlation functions and their fits look reasonable

$$\vec{k}_T = \frac{\overrightarrow{p_1}_T + \overrightarrow{p_2}_T}{2}$$

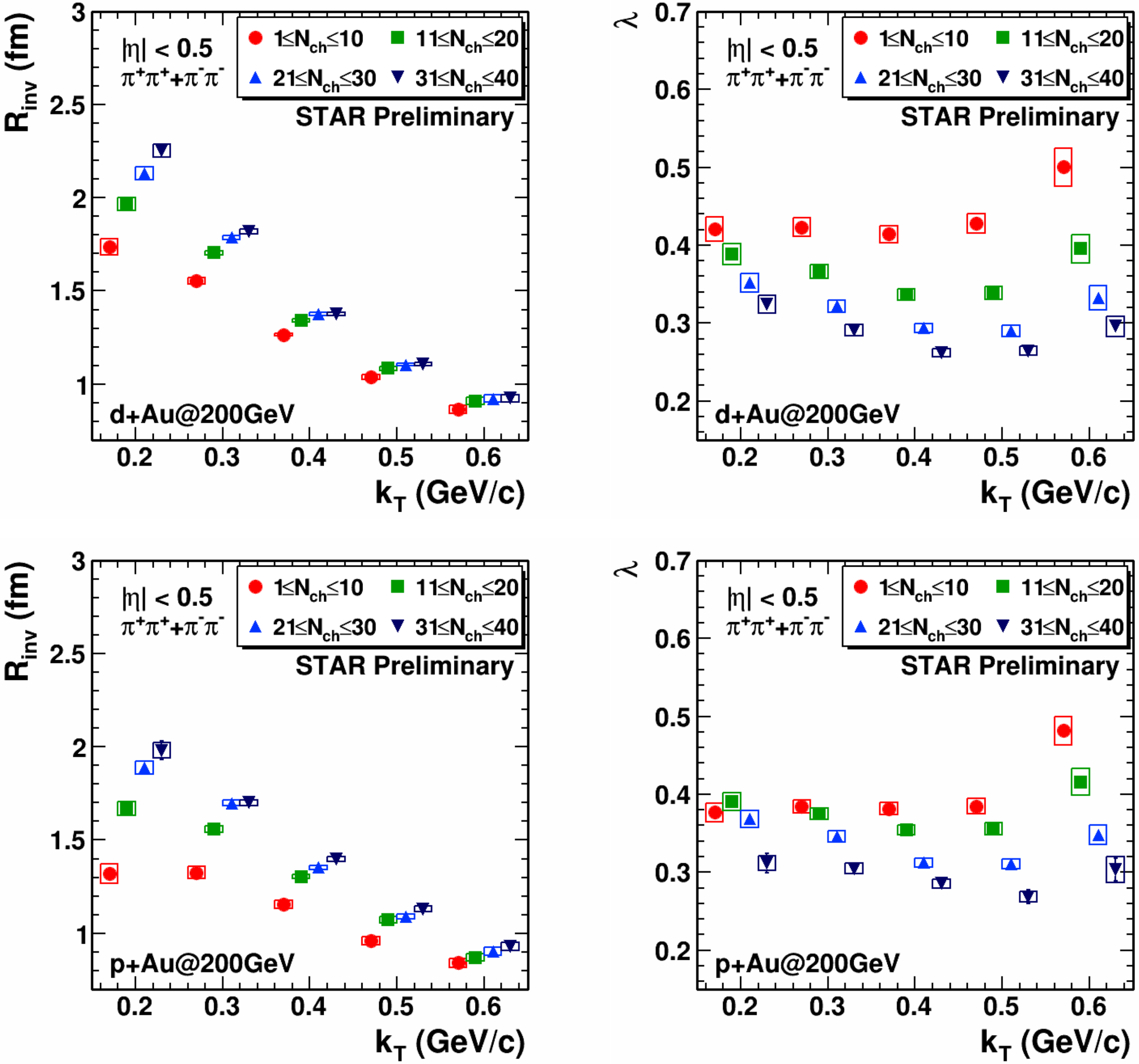
Statistical and systematic uncertainty

- For almost all cases statistical uncertainty smaller than marker size
- Sources of the systematic uncertainty:
  - Selection criteria of the events (position of the primary vertex): < 5%
  - Selection criteria of the tracks (momentum of the tracks, tracking efficiencies): < 6%
  - Selection criteria of the pairs (two track effects – merging, splitting): < 2%
  - Fit range: < 3%
  - Coulomb radius: < 3%
- Plan to investigate single track momentum resolution

Example:



k_T dependence of R_{inv} and λ

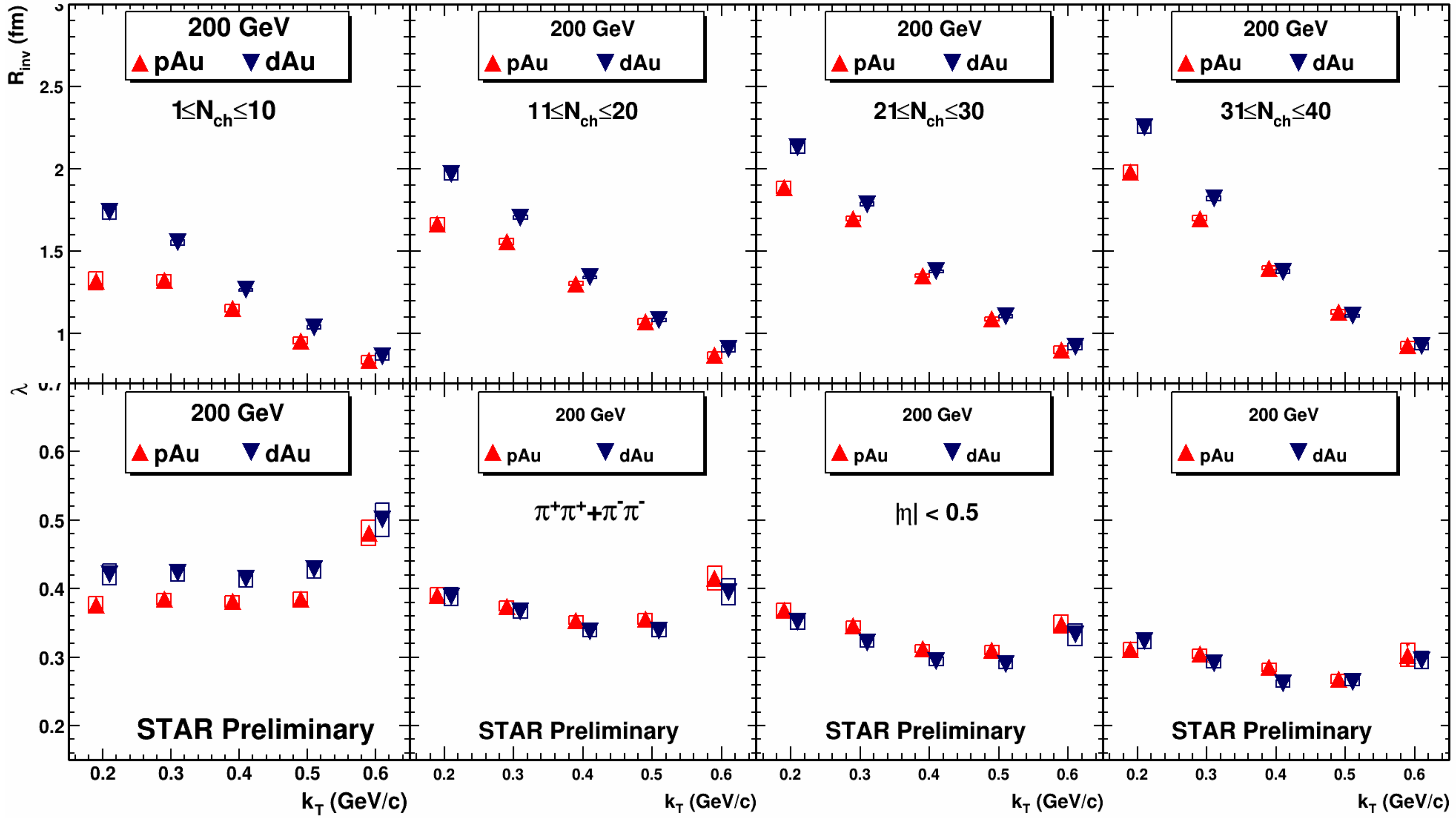


– d+Au@200GeV

- Radius decreases with increasing k_T
- Radius increases with increasing particle multiplicity
- Correlation strength parameter decreases with particle multiplicities
  - Influences of the resonances increases?

– p+Au@200GeV

System comparison (R_{inv} Vs. k_T)



- Weak radius dependence on colliding system
- Radii increase with increasing size of the colliding system
- The femtoscopic radii difference between colliding species becomes smaller with increasing k_T

Summary

- Femtoscopic parameters were obtained for p/d+Au systems
- The k_T dependence of the R_{inv} shows the dynamic of the system (system expansion) and allows to probe the different regions of the homogeneity in both p/d+Au systems
- Radius increases with increasing particle multiplicity
- The femtoscopic radii difference between colliding species becomes smaller with increasing k_T

Thank you for your attention!

Back-up slide

Selection criteria

Event cuts	Track cuts	Pair cuts	Pion TPC cuts
$\|Z_{TPC}\|$ (cm) < 40	$N_{Hits} > 15$	-0.5 < Splitting Level (quality) < 0.6	$\|n\sigma_{pion}\| < 2$
$\sqrt{X_{TPC}^2 + Y_{TPC}^2}$ (cm) < 2	$N_{Hits}/N_{HitsFit} > 0.51$	0.15 < k_T (GeV/c) < 1.05	$\|n\sigma_{other}\| > 2$
$\|Z_{TPC} - Z_{VPD}\|$ (cm) < 5	DCA < 2 cm	Average Separation of two tracks within TPC volume (cm) > 10	
	$\|\eta\| < 0.5$	-1.1 < Fraction of Merged Hits (%) < 0.1	
	0.15 < p (GeV/c) < 0.8		

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