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

Eugenia Khyzhniak

(for the STAR collaboration)

National Research Nuclear University MEPhI

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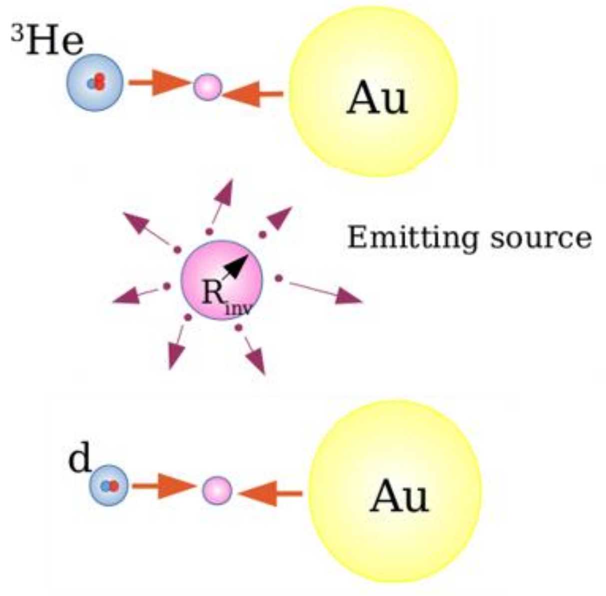
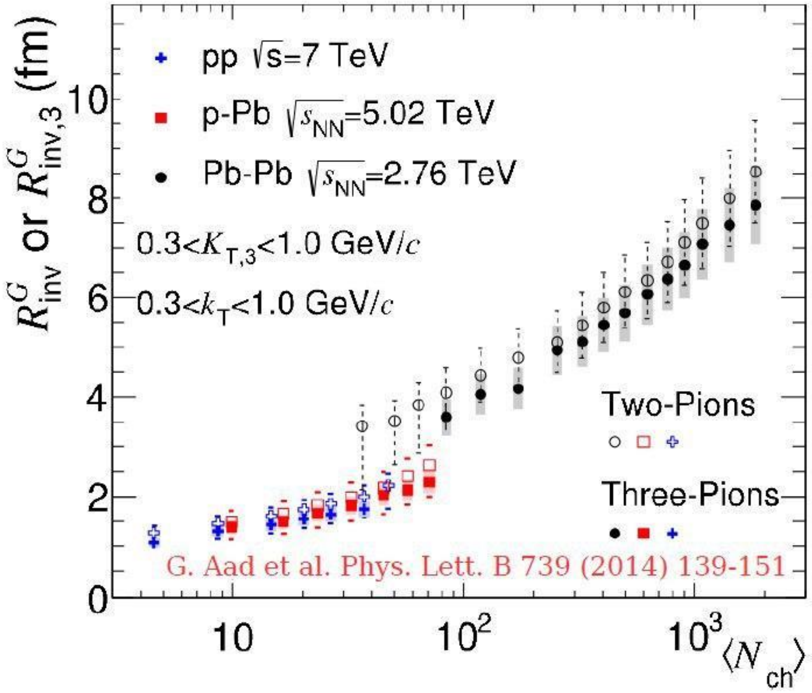
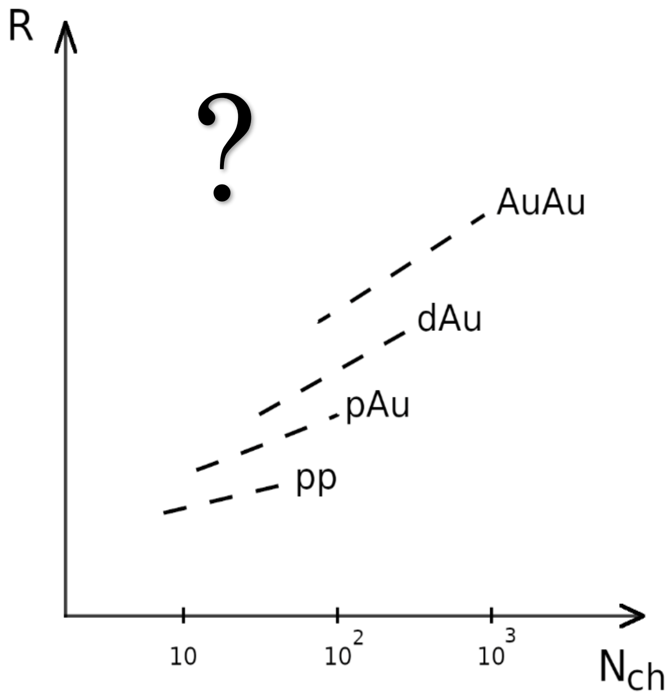
# Outline

- Motivation
- Femtoscopy
- Correlation functions and their fits
- Systematic uncertainty
- $k_T$ dependence of $R_{inv}$ and $\lambda$
- 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.

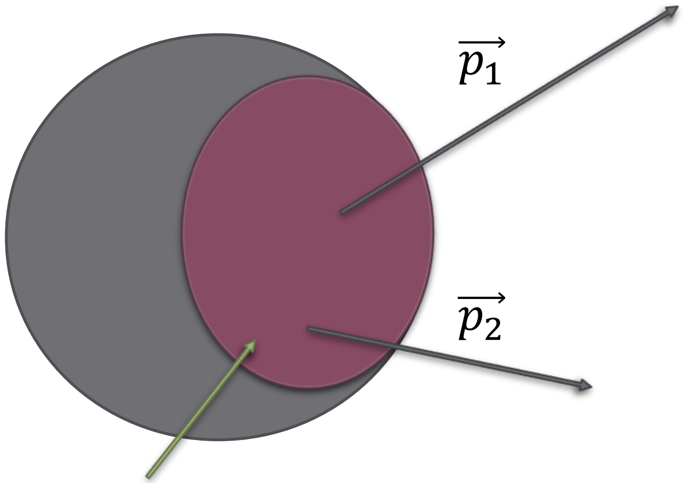
M. Podgoretky 1989 Particles & Nuclei 20 630-68

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

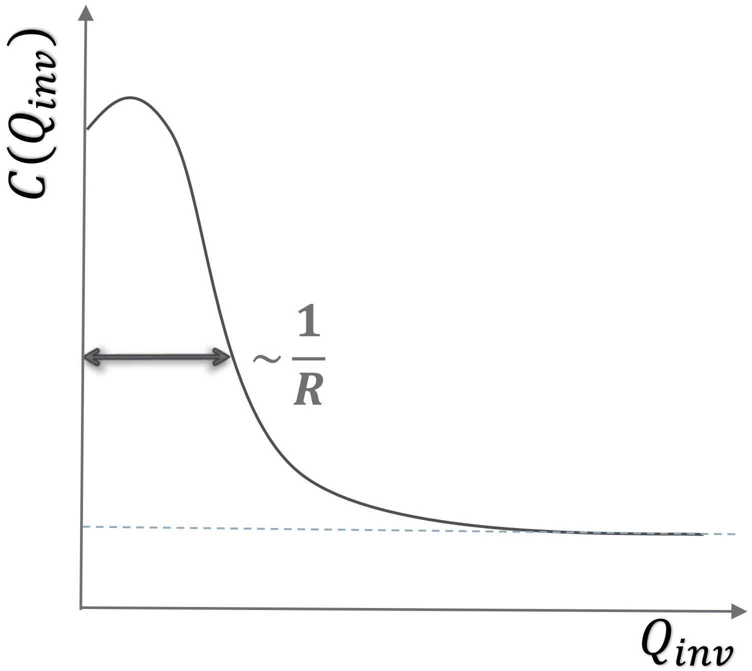



Extracted radii measure the homogeneity lengths of the source
Akkelin SV, Sinyukov YM. Phys. Lett. B356:525 (1995)

- 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

## Schematic view




1)

## Construction of the correlation function:

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

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

- $A(Q_{inv})$ – $Q_{inv}$ 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)

2)

## Fit of the correlation function:

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

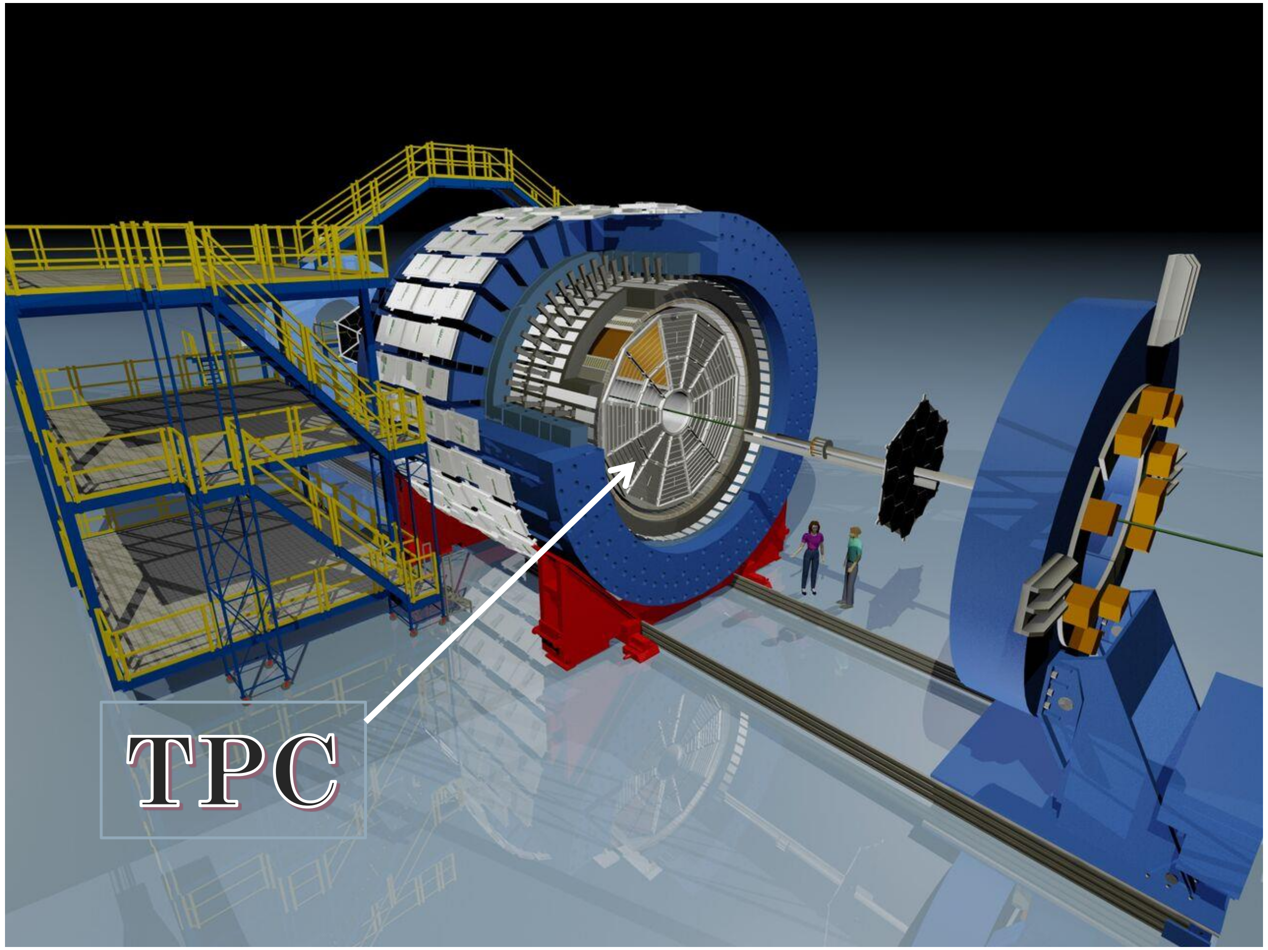
$$G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2}$$

$N$ – normalization factor
$\lambda$ – 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



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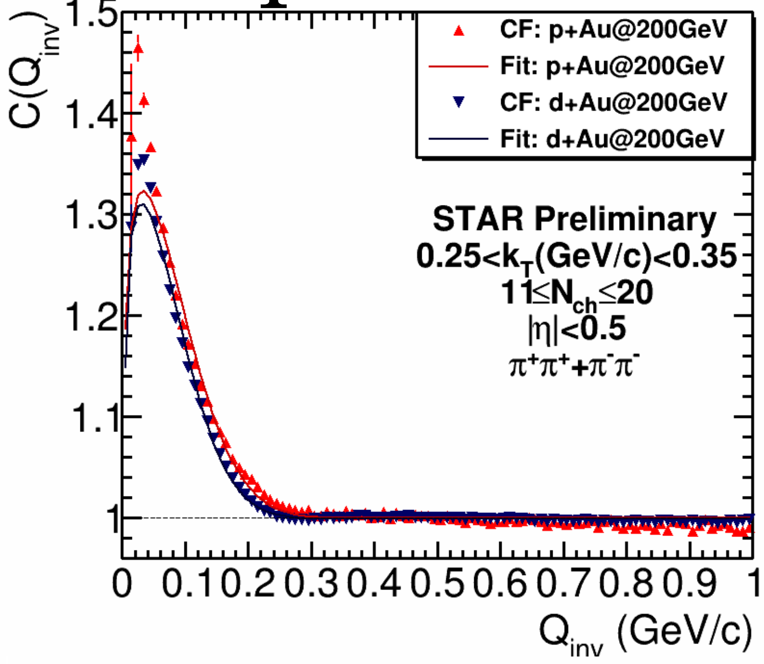
# Example of the correlation functions and fits

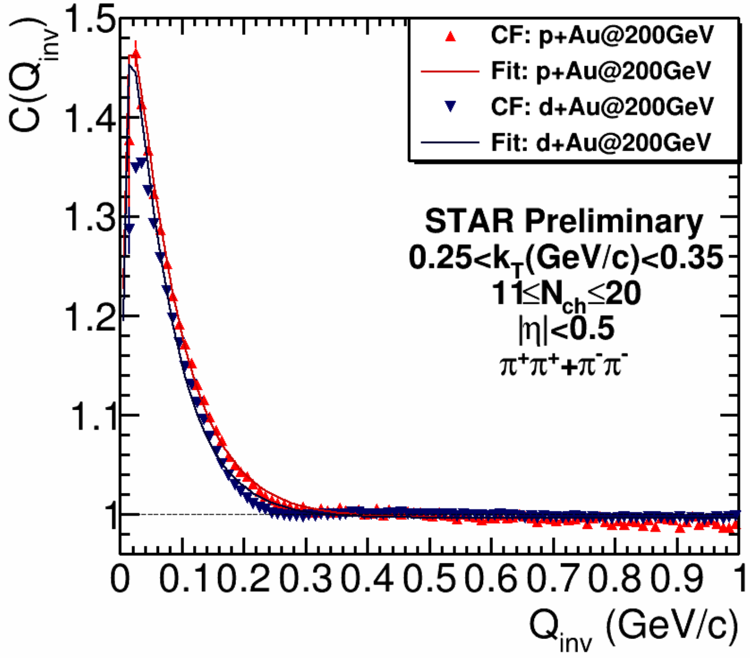



Gaussian fit assumption: $G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2}$

# d+Au and p+Au systems comparison

Correlation functions and their fits look reasonable

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




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

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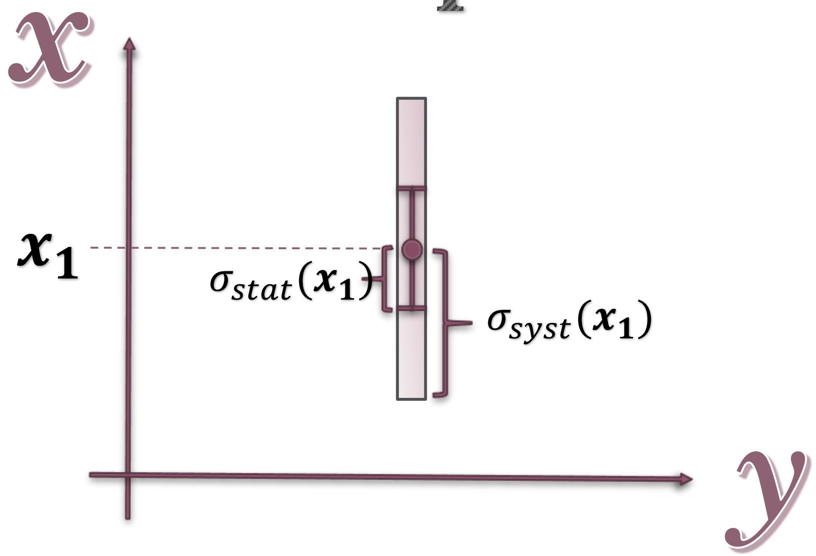
# Statistical and systematic uncertainty

- 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:**

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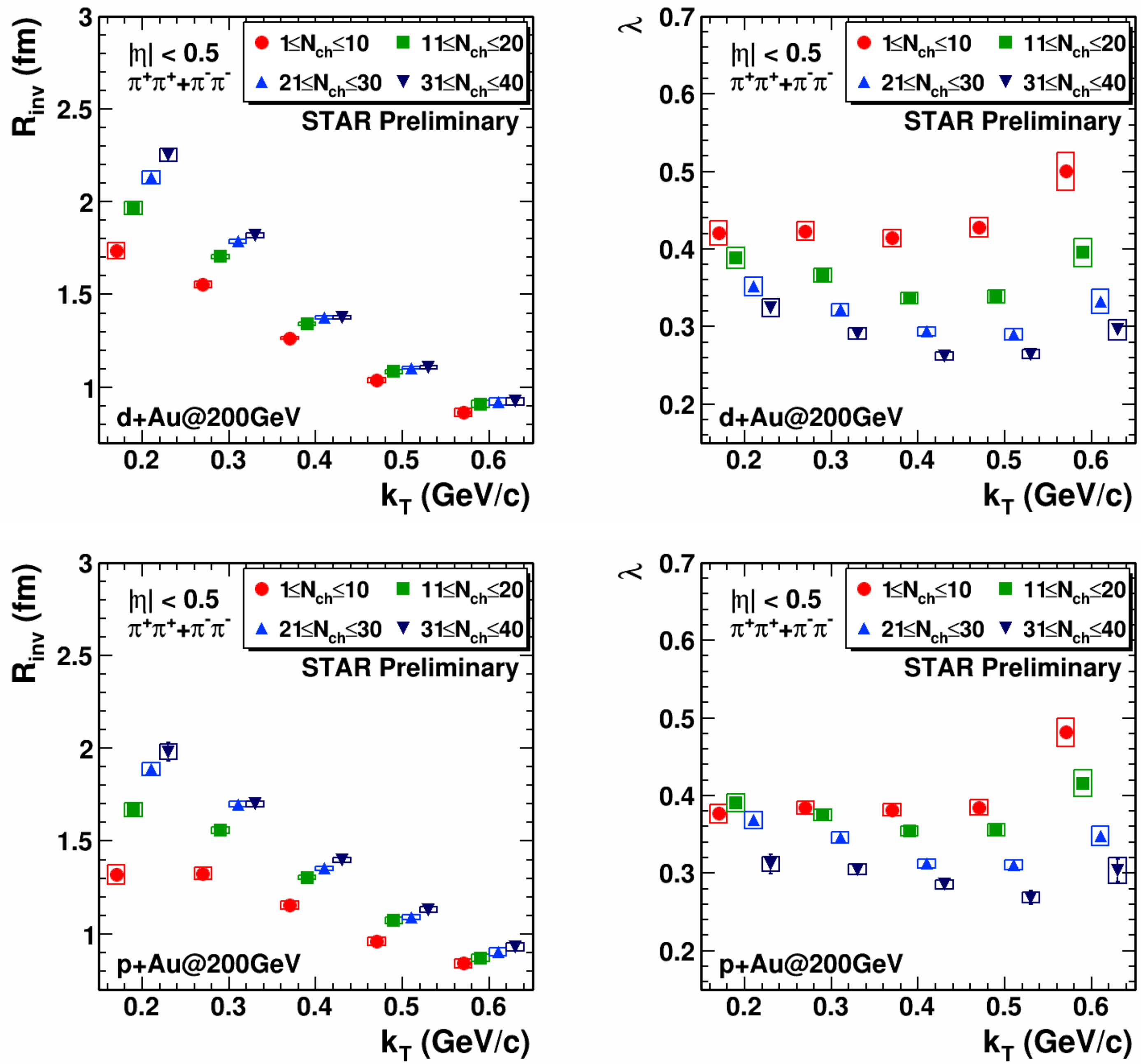
# $k_T$ dependence of $R_{inv}$ and $\lambda$




— d+Au@200GeV

- Radii decrease with increasing $k_T$
- Radii increase with increasing particle multiplicity
- Correlation strength parameter $\lambda$ decreases with particle multiplicities
  - Influence of the resonances increases?

— p+Au@200GeV

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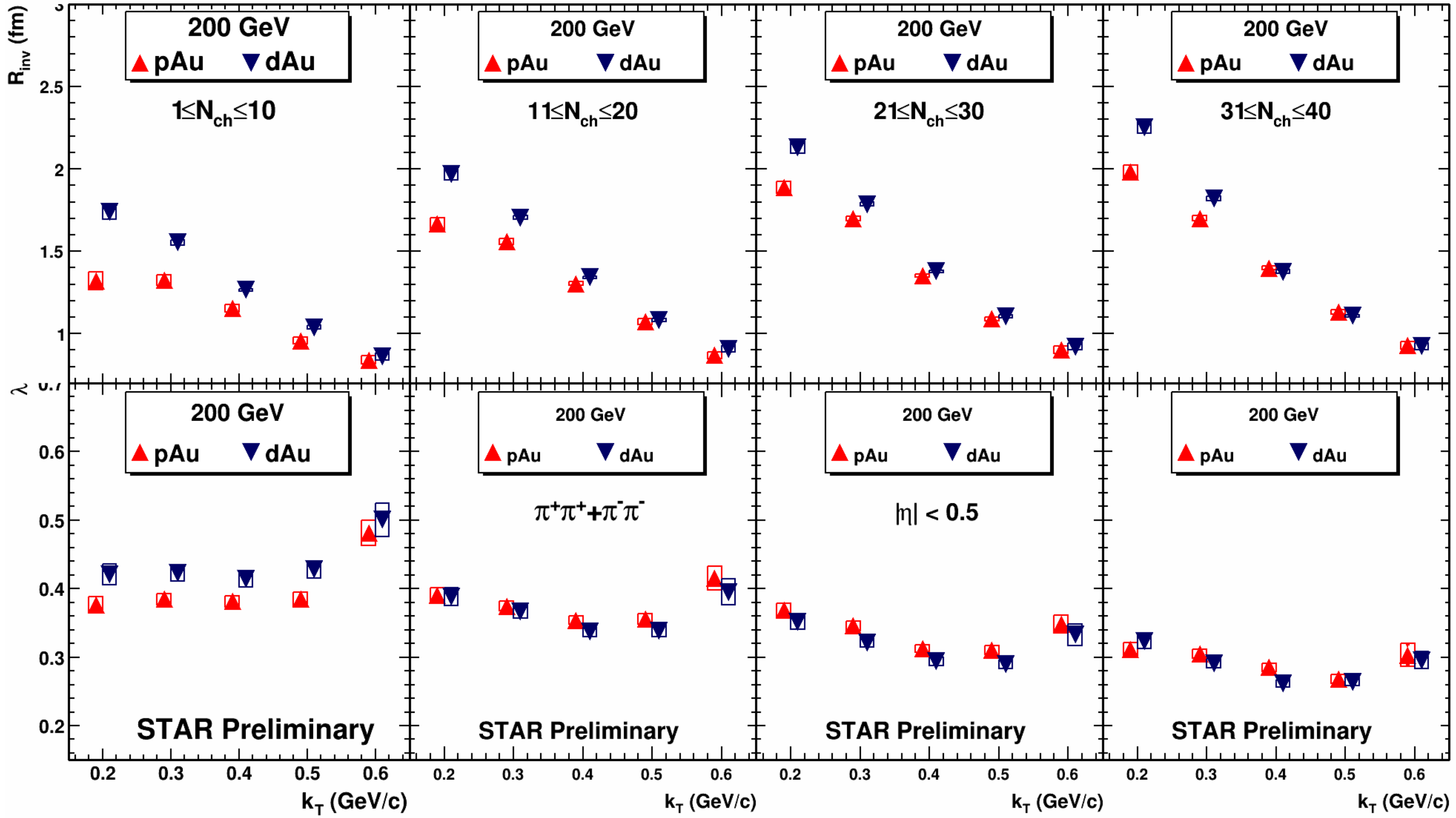
# System comparison ($R_{inv}$ vs. $k_T$ )




- Radii increase with increasing size of the colliding system
- Weak radius dependence on colliding system (especially for $k_T >$ 0.35GeV/c)
- The femtoscopic radii difference between colliding species becomes smaller with increasing $k_T$

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# Summary

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

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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 | | |