Recent results of elliptic flow and femtoscopy measurements from STAR

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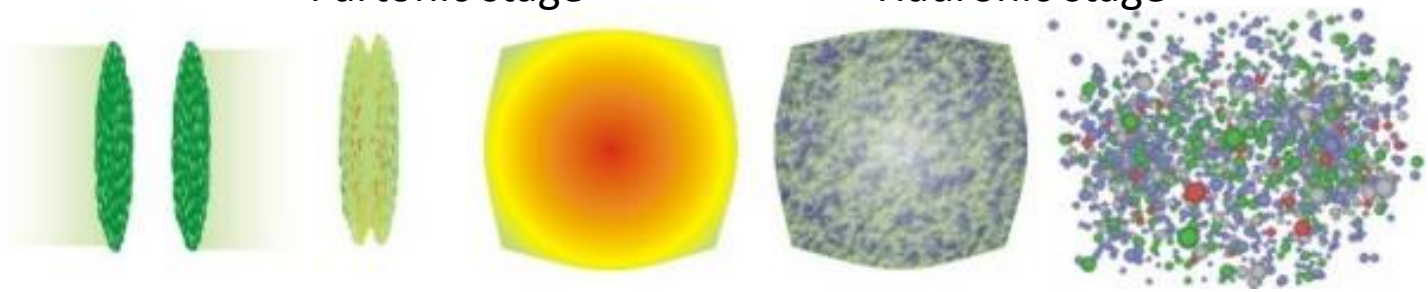
Hadron Structure and QCD, Gatchina, Russia, June 27 – July 1, 2016

Outline

- Introduction
- Elliptic flow:
  - Energy and centrality dependence of identified particle elliptic flow
  - Particle vs antiparticle v_2
- Correlation femtoscopy:
  - Energy dependence of the femtoscopic radii
  - Measurement of interaction between antiprotons
- Summary

Heavy ion collision evolution

Partonic stage | Hadronic stage



Observables

Elliptic flow (v_2):

- Initial spatial anisotropy is reflected in the momentum anisotropy
- Multi-strange hadrons and φ meson are less sensitive to late hadronic rescattering
- Sensitive to the early stages

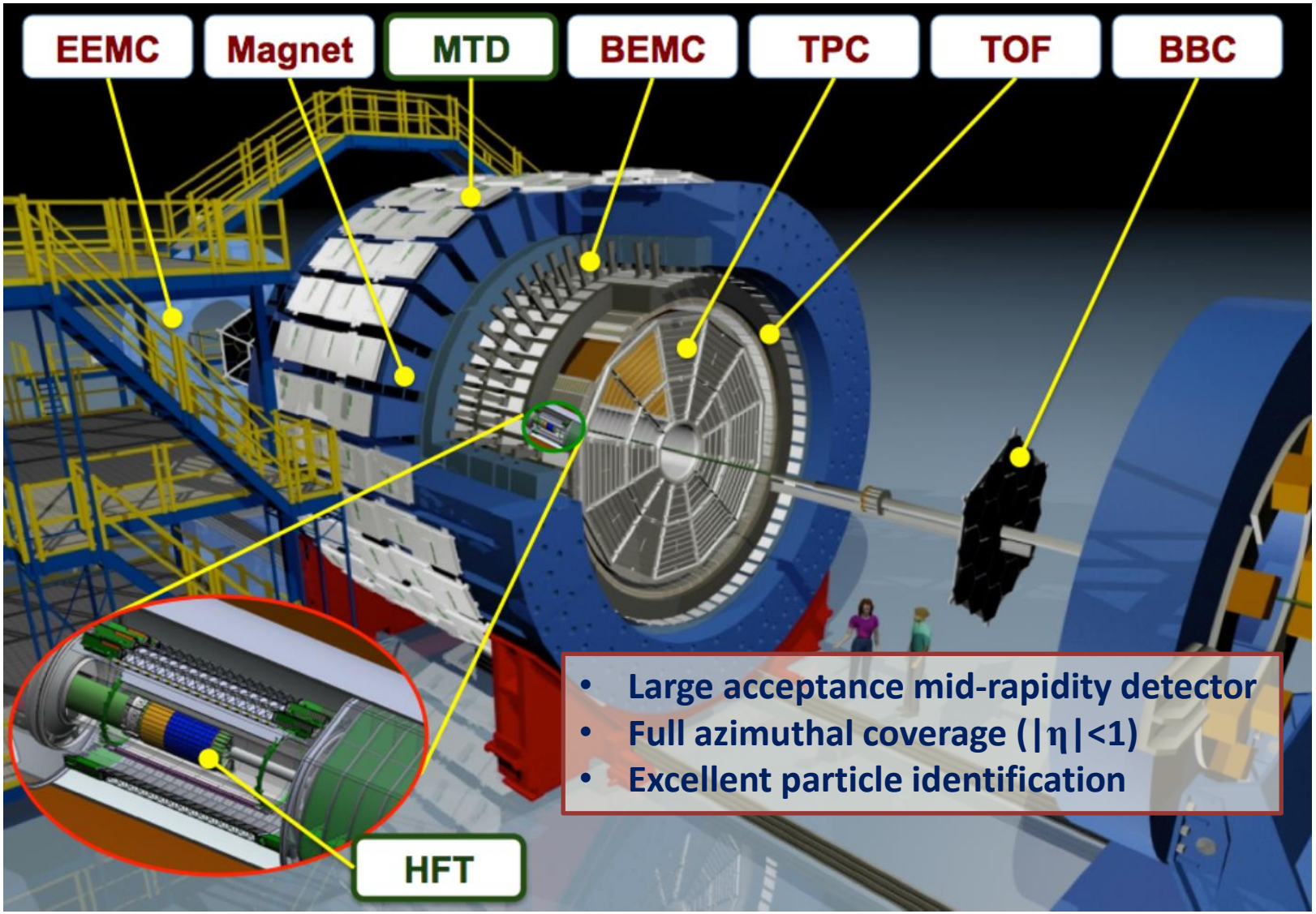
Probe of the early (partonic) stage of the collision

Correlation femtoscopy:

- Using quantum-statistical correlations of particles to extract spatial and temporal characteristics of the emitting source
- Sensitive to the final state interactions

Probe of the late (hadronic) stage of the collision

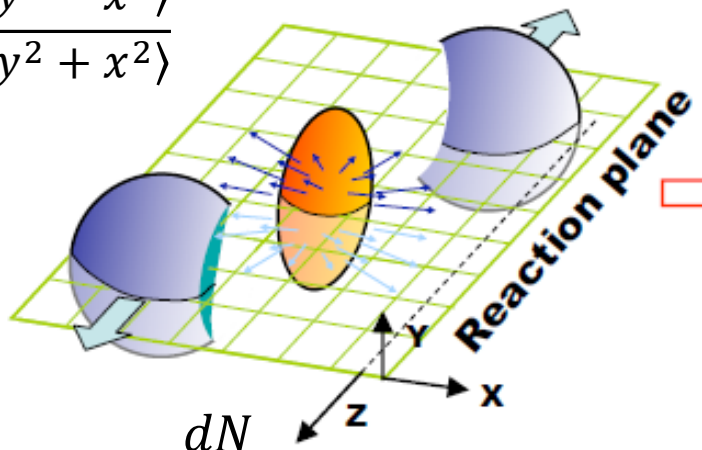
STAR detectors

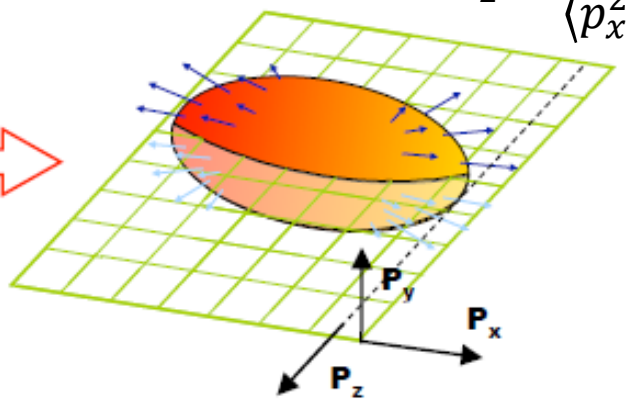


Elliptic flow

$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \frac{\langle p_x^2 - p_y^2 \rangle}{\langle p_x^2 + p_y^2 \rangle}$$



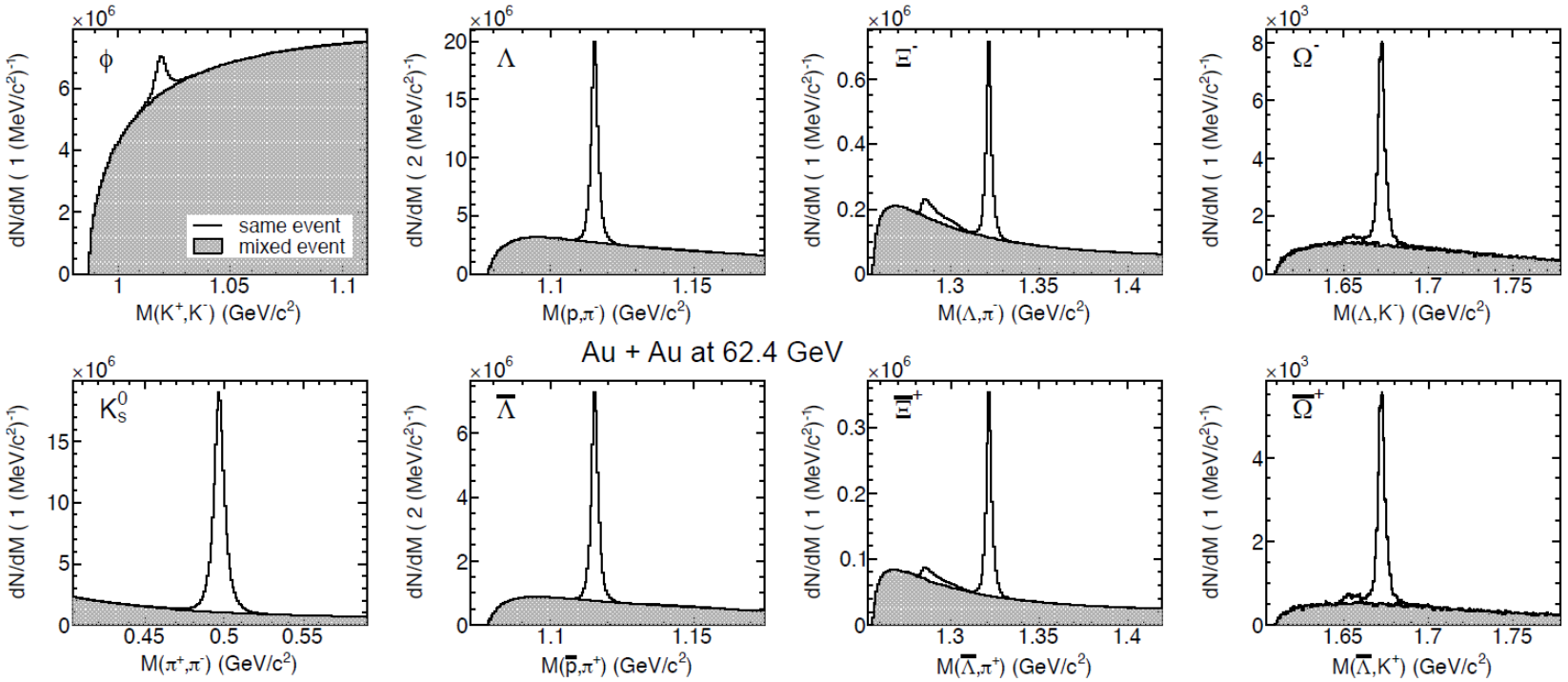


$$\frac{dN}{d(\phi - \Psi)} \propto 1 + 2v_1 \cos(\phi - \Psi) + \boxed{2v_2 \cos(2\phi - 2\Psi)} + \cdots$$

- Elliptic flow: Initial spatial anisotropy ⟶ final momentum anisotropy
  - Characterized by v_2 coefficient of Fourier expansion of azimuthal particle distribution with respect to the reaction plane
- Probe of early collision dynamics
  - Degrees of freedom (partonic/hadronic), Equation of State, degrees of thermalization, …

Particle selection

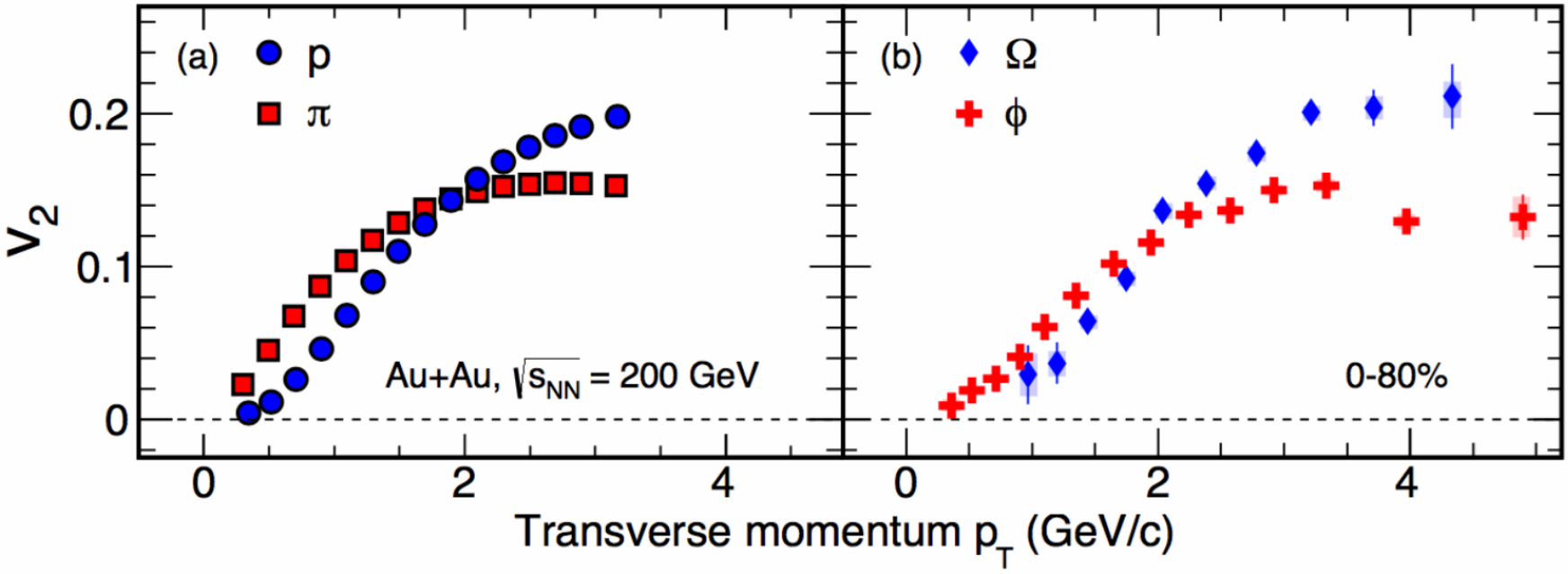
STAR: Phys. Rev. C 88 (2013) 014902



- Clear signal for multi-strange hadrons and φ meson
- φ mesons: invariant mass
- Weak decay particles: topological cuts + invariant mass

Partonic collectivity

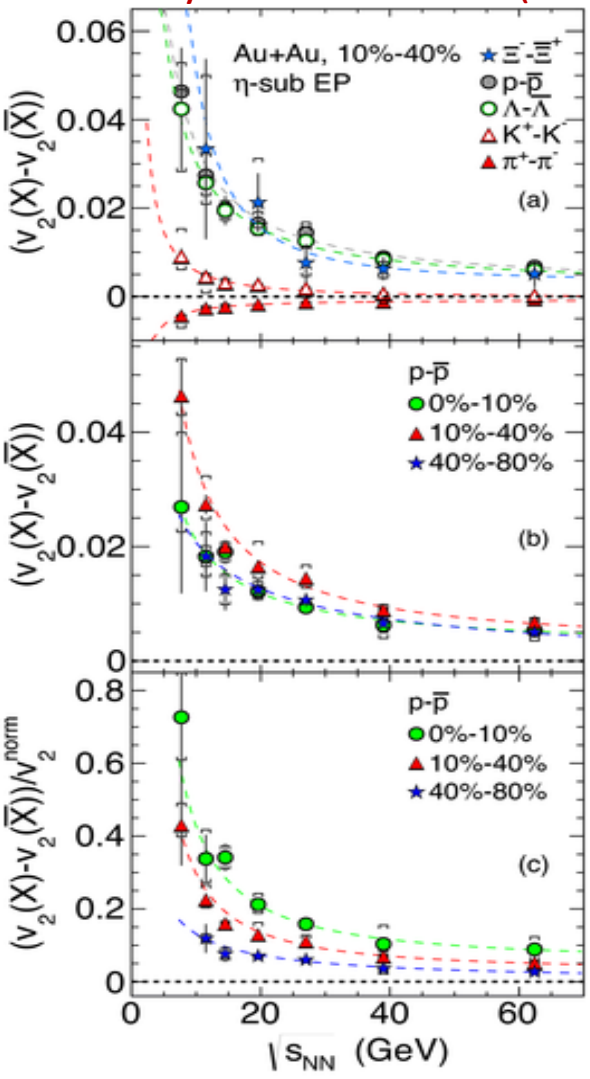
STAR: Phys. Rev. Lett. 116 (2016) 062301



- Mass ordering at p_T<2 GeV/c
- Baryon/meson splitting at 2<p_T<5 GeV/c
- New! Ω follows the baryon/meson splitting

v_2: particle vs antiparticle

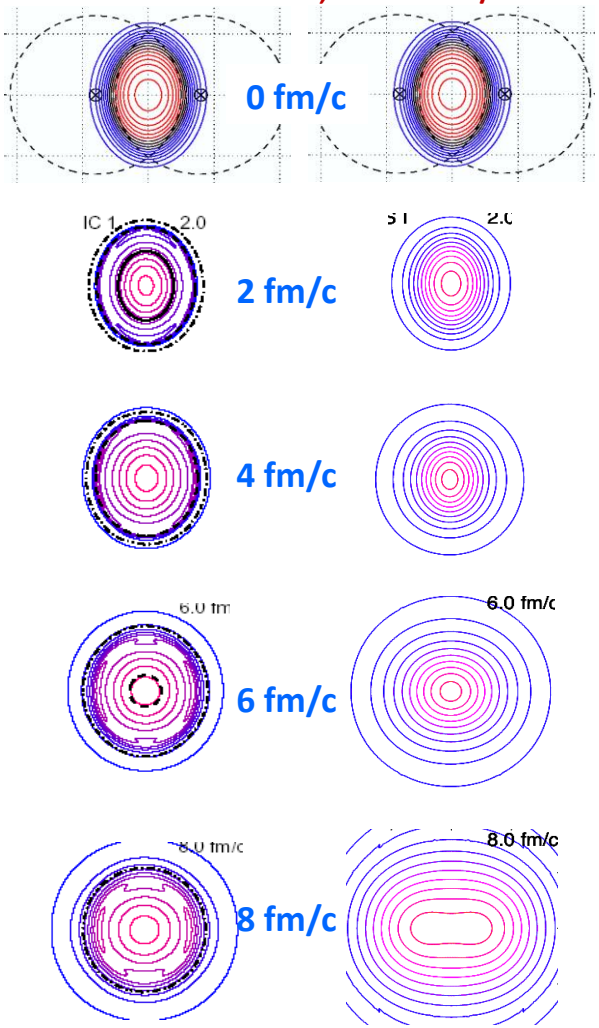
STAR: Phys. Rev. C 93 (2016) 014907
STAR: Phys. Rev. Lett. 110 (2013) 142301



- The Au+Au collisions recorded at $\sqrt{s_{NN}}$=14.5 GeV in 2014 are consistent with the data from BES taken in 2010-11
- Big difference of baryon and antibaryon v_2 is observed for low energies
- Clear centrality dependence of p-$\bar{p}$ v_2 after the normalization. Difference is bigger for the more central collisions

Correlation femtoscopy

Kolb & Heinz: 2003, nucl-th/0305084



With 1st order phase transition

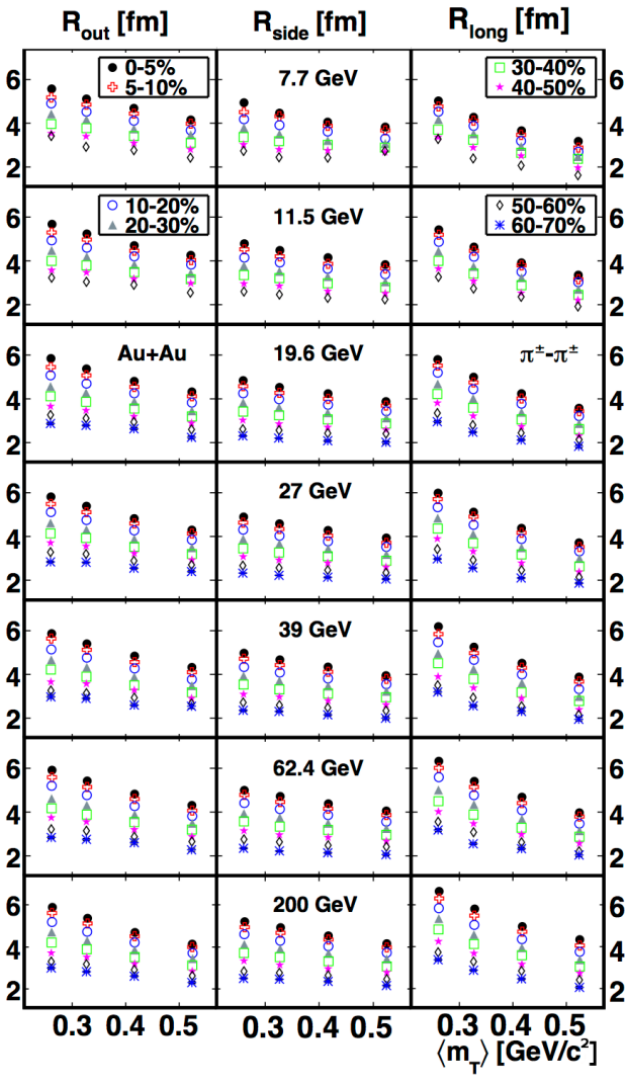
Without 1st order phase transition

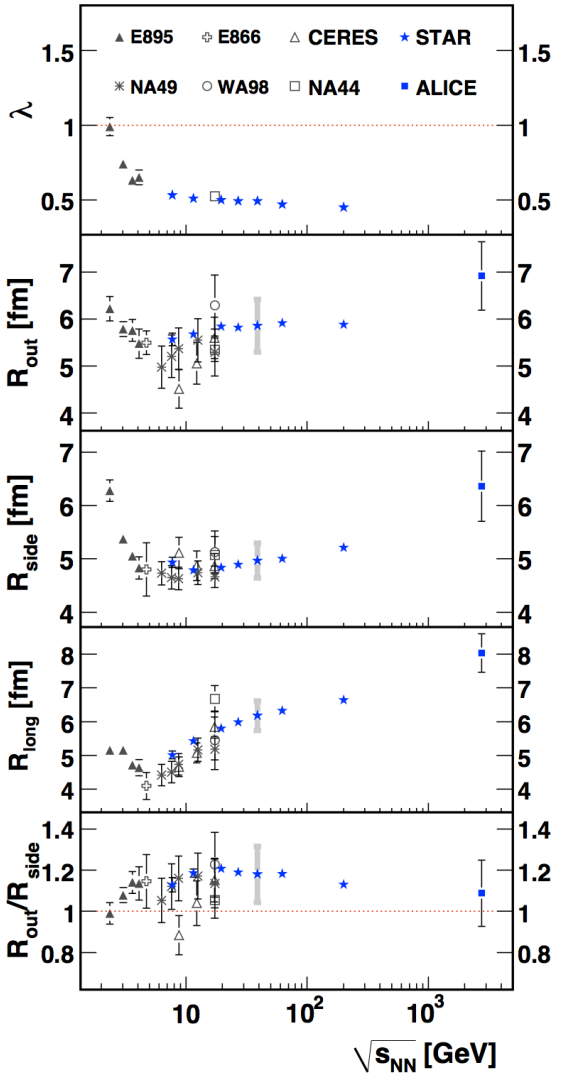
- Evolution of the initial shape depends on:
  - Pressure anisotropy
  - Lifetime
- Using the momentum correlations to measure spatial and temporal parameters of the emitting source
- Sensitive to the final state interactions
- Sensitive to the phase transition

Correlation femtoscopy

STAR: Phys. Rev. C 92 (2015) 014904

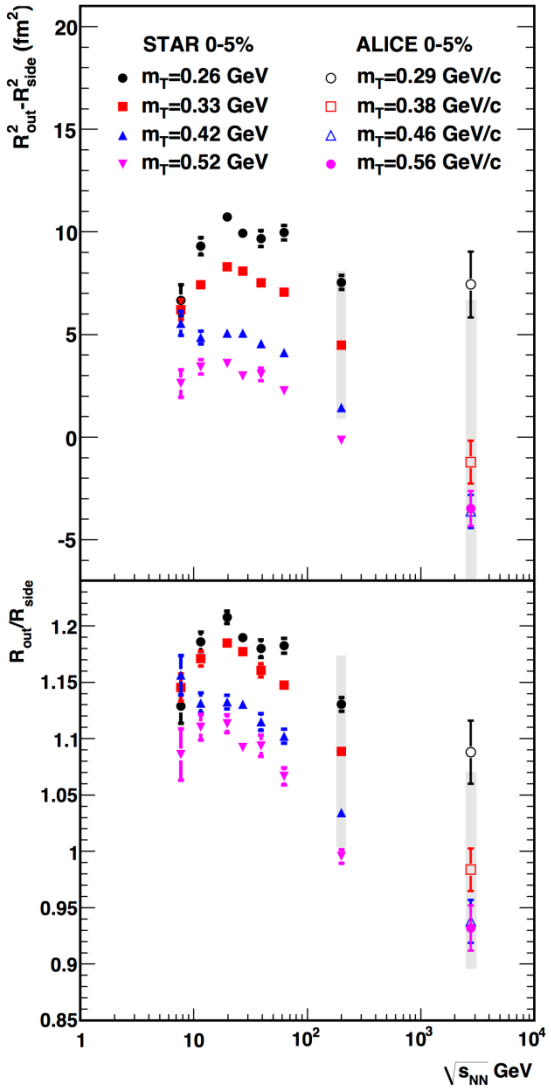
- Systematic measurement of the femtoscopic radii
- The decrease in transverse and longitudinal radii at higher m_T are attributed to transverse and longitudinal flow
- Different beam energies show similar trends for R_{out} and R_{side} in magnitude and slope
- R_{long} increases with energy for all centralities





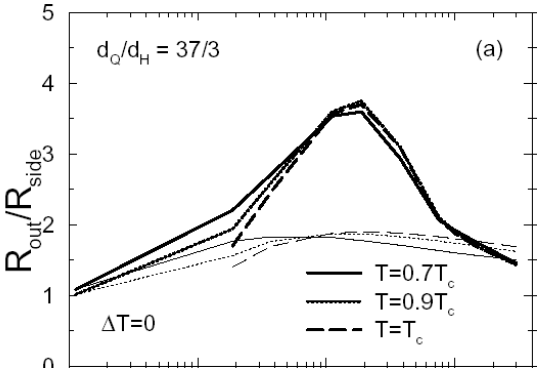
Particle emission duration

STAR: Phys. Rev. C 92 (2015) 014904



3D+1 Hydrodynamics

Rischke & Gyulassy: NPA 608 (1996) 479



Initial energy density ε_0

- R_{out}/R_{side} is sensitive to the emission duration
- Predicted to exhibit a peak when energy density of the system is close to the threshold of the phase transition
- Intriguing non-monotonic behavior at around $\sqrt{s_{NN}}$≈20 GeV for all m_T ranges.

p and $\bar{p}$ femtoscopy

Measured — Real proton correlation function — Contamination from pΛ and ΛΛ

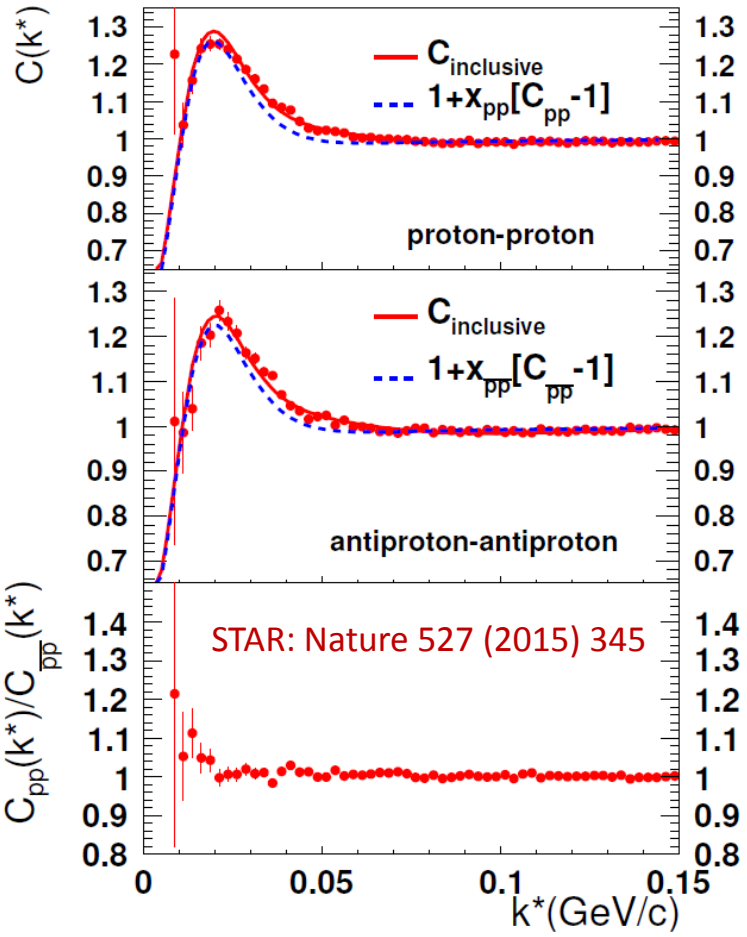
$$C_{\text{inclusive}}(k^*) = 1 + x_{pp}[C_{pp}(k^*; R_{pp}) - 1] + x_{p\Lambda}[C_{p\Lambda}(k^*; R_{p\Lambda}) - 1] + x_{\Lambda\Lambda}[C_{\Lambda\Lambda}(k^*) - 1]$$

- $C_{pp}(k^*;R_{pp})$ and $C_{p\Lambda}(k^*,R_{p\Lambda})$ are calculated by the Lednický and Lyuboshitz model

  Lednický ,Lyuboshitz: Sov. J. Nucl. Phys. 35 (1982) 770
- $C_{\Lambda\Lambda}(k^*)$ is taken from ΛΛ femtoscopic measurement

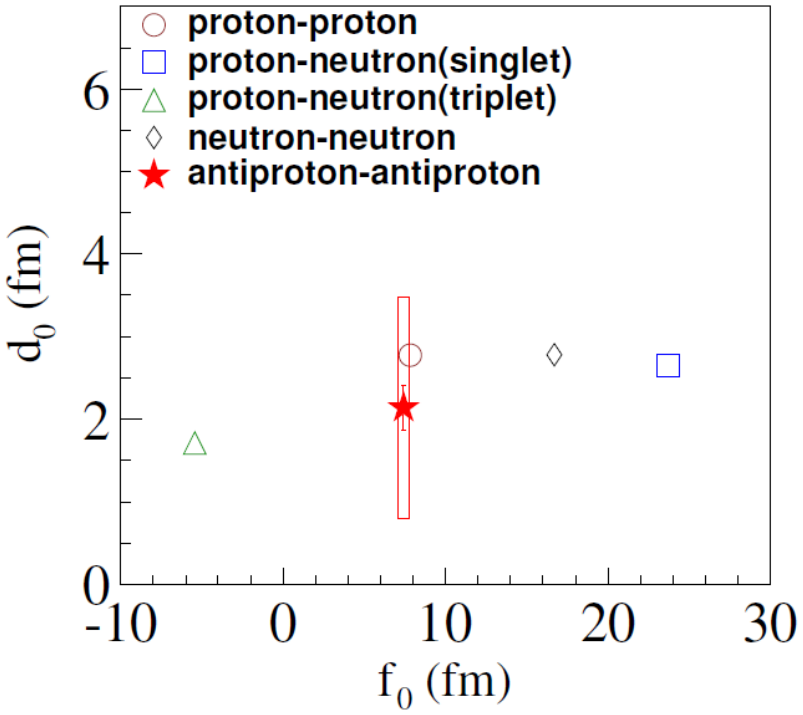
  STAR: Phys. Rev. Lett. 114 (2015) 022301
- R_{pp} and $R_{p\Lambda}$ assumed to be the same

Also see Richard Lednický talk



f_0 and d_0 for antiproton-antiproton

STAR: Nature 527 (2015) 345



- Within the uncertainties, the f_0 and d_0 parameters for the antiproton-antiproton interaction are consistent with the parameters for the proton-proton interaction
- First measurement of the simplest system of anti-nucleons (nuclei)

Summary

Elliptic flow

- The p_T dependence of φ and Ω v_2 is similar to π and p
  - Large amount of collectivity is developed in the initial partonic phase
- The v_2 of baryons is larger than for antibaryons for all collision energies <62 GeV
- Centrality dependence of relative p-$\bar{p}$ v_2 difference

Correlation femtoscopy

- The particle emitting source radii are extracted from two-pion femtoscopic measurement
  - Similar m_T dependencies for all collision energies and centralities
  - Intriguing behavior of the R_{out}/R_{side} at around $\sqrt{s_{NN}}$≈20 GeV
- First measurement of the antiproton-antiproton strong interaction