XII Workshop on Particle Correlations and Femtoscopy
12-16 June 2017, Nikhef

Examination of heavy-ion collisions using EPOS model in the frame of the BES program at RHIC

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in cooperation with

Subatech

Wydział Fizyki
POLITECHNIKA WARSZAWSKA

PW

Abstract

- Motivation
- EPOS generator
- Beam Energy Scan program
- Methods of analysis and results
  - p_T spectra
  - Femtoscopy correlations
  - Azimuthal Anisotropy
- Conclusion

Motivation

- EPOS - model for LHC & top RHIC energies
- What about lower energies?

Motivation

- EPOS - model for LHC & top RHIC energies
- What about lower energies?

Studies of:

EPOS simulations vs **STAR experiment**

EPOS generator

Energy conserving quantum mechanical multiple scattering approach,
based on **P**artons (parton ladders), **O**ff-shell remnants,
and **S**aturation of parton ladders.

Gribov - Regge theory

- Soft aspects of particle collisions
- Multiple scattering
- Interactions described with Pomerons
- …

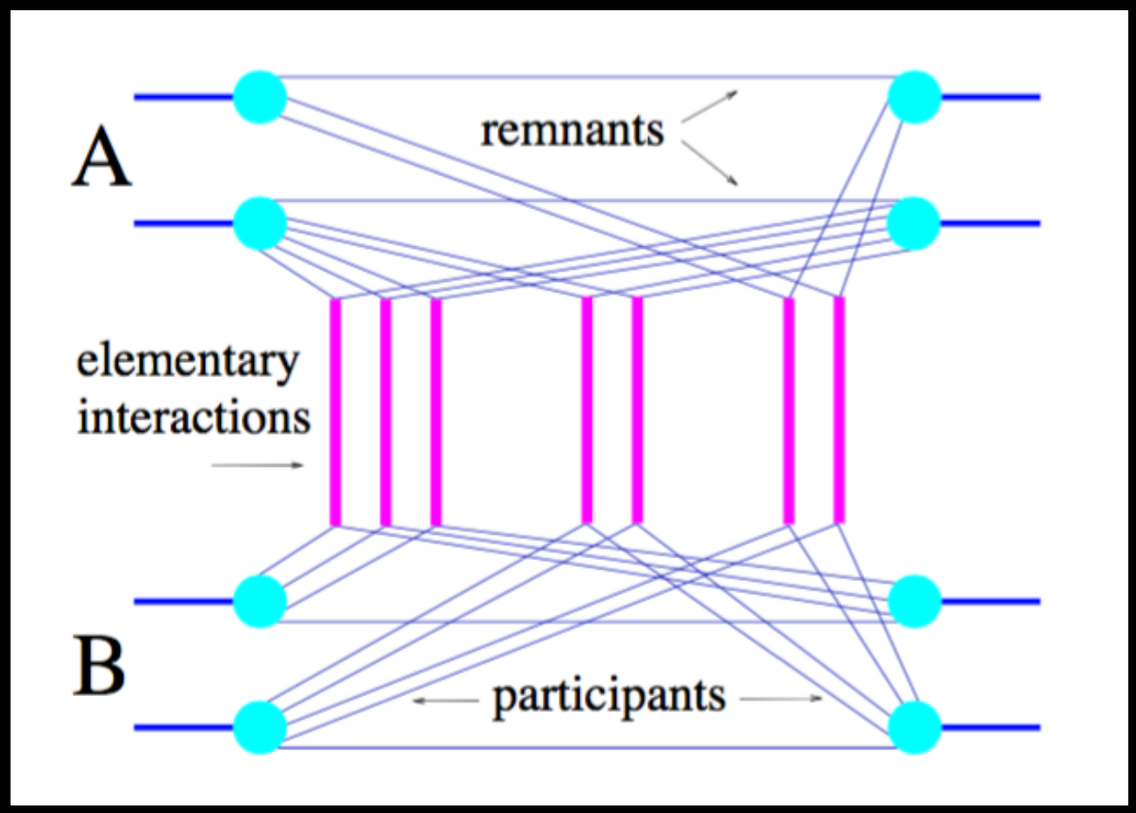
Parton-based theory

- Partons: quarks & gluons
- Calculation of parton jets
- QCD & QED
- …

EPOS generator

Parton-based Gribov-Regge theory

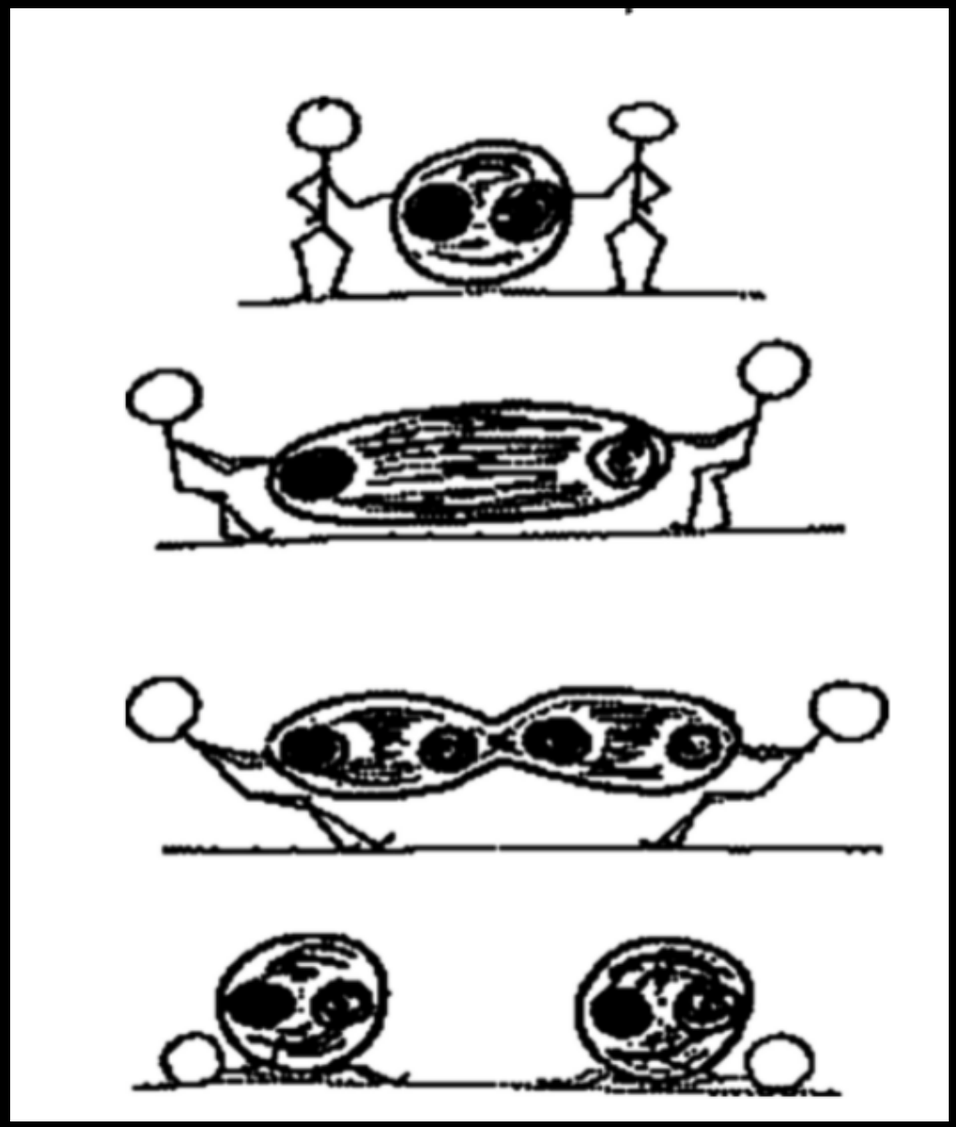
- Conservation of energy



EPOS generator

Parton-based Gribov-Regge theory

- Conservation of energy
- Relativistic strings



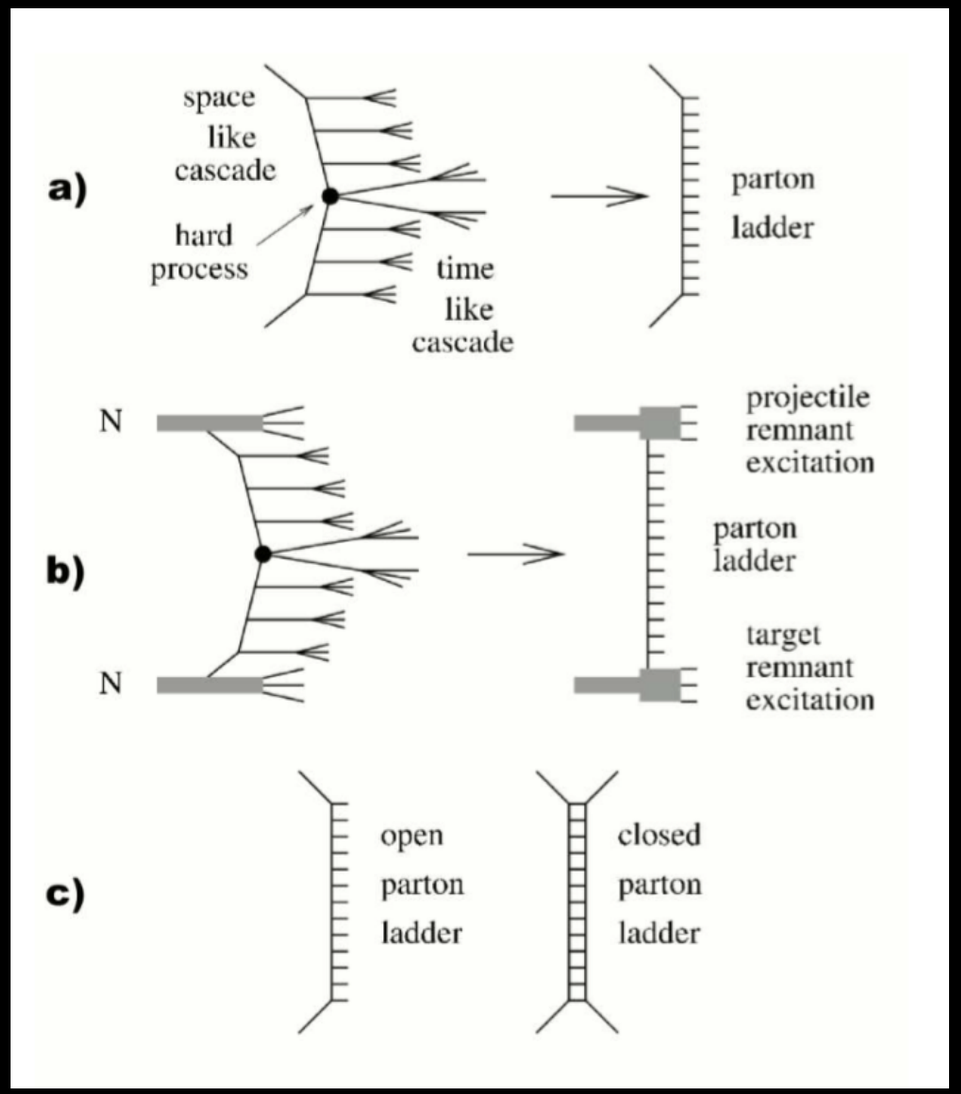
S. Mrówczyński

EPOS generator

Parton-based Gribov-Regge theory

- Conservation of energy
- Relativistic strings
- Open and closed ladders

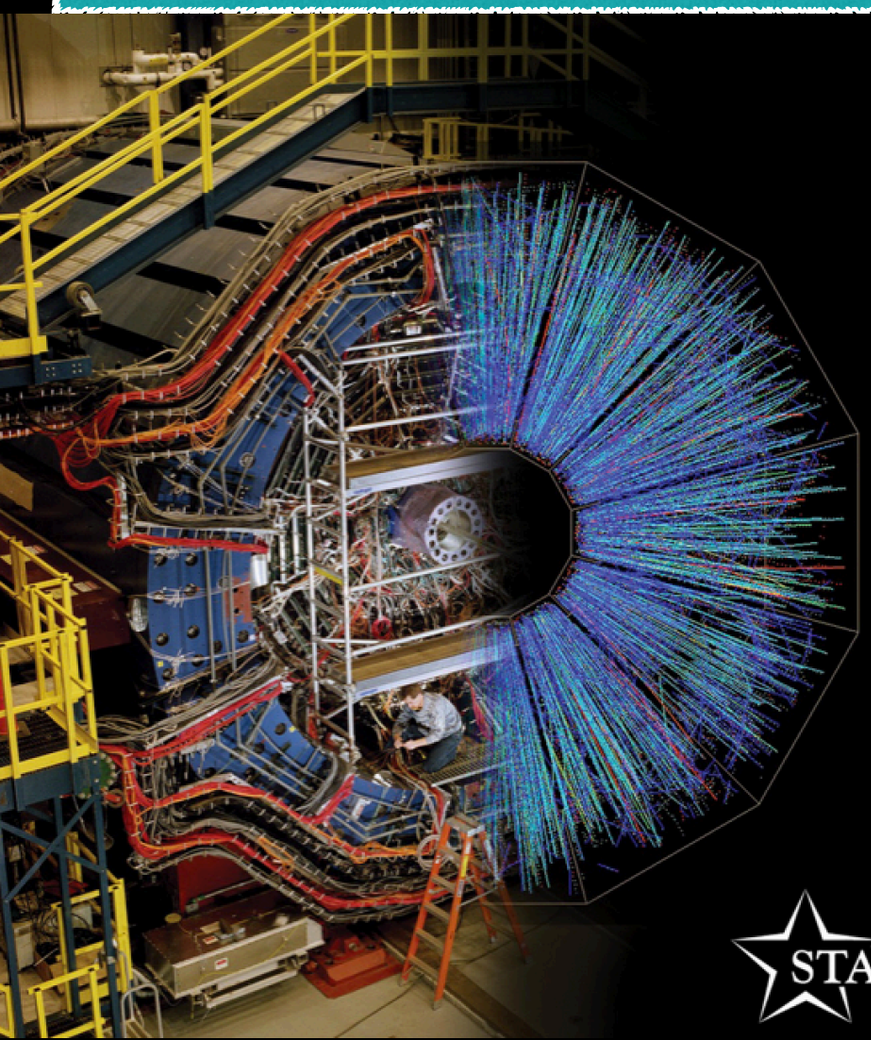
inelastic and elastic scattering

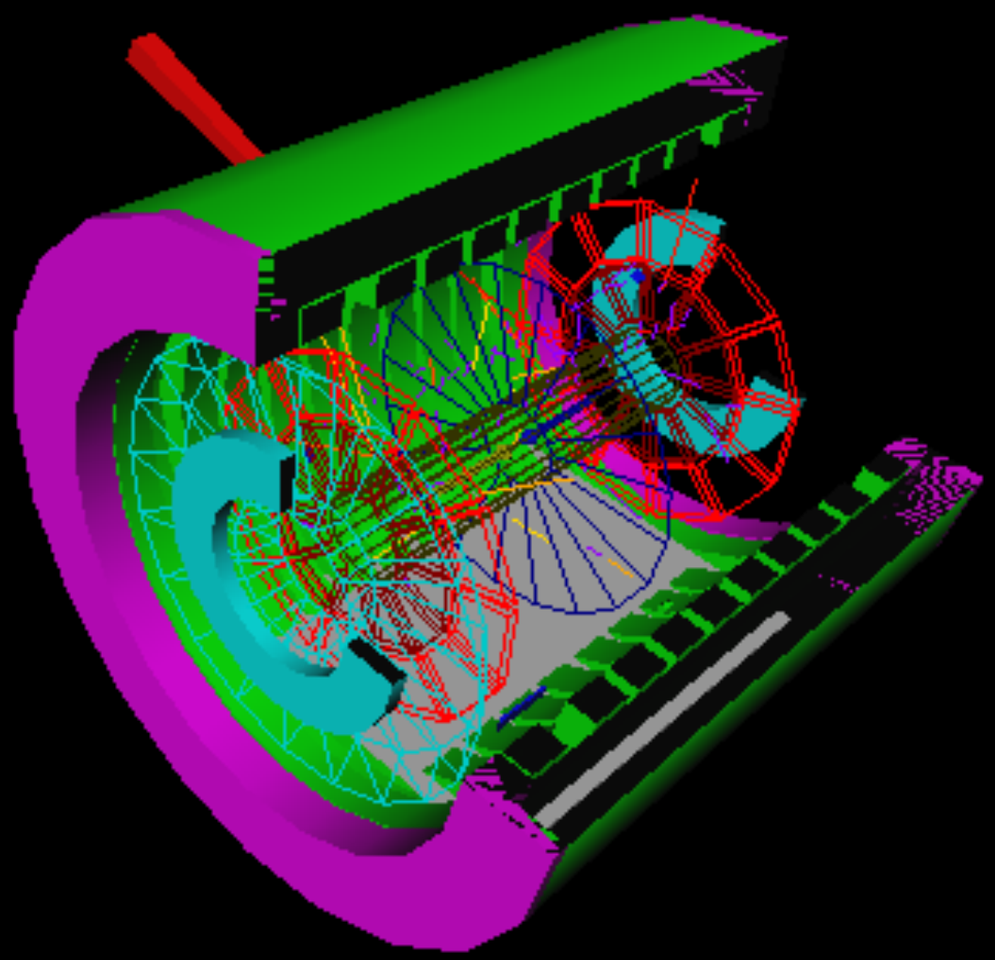


Beam Energy Scan

BES program:

- Run at RHIC in Brookhaven National Laboratory
- Collisions of: Au + Au





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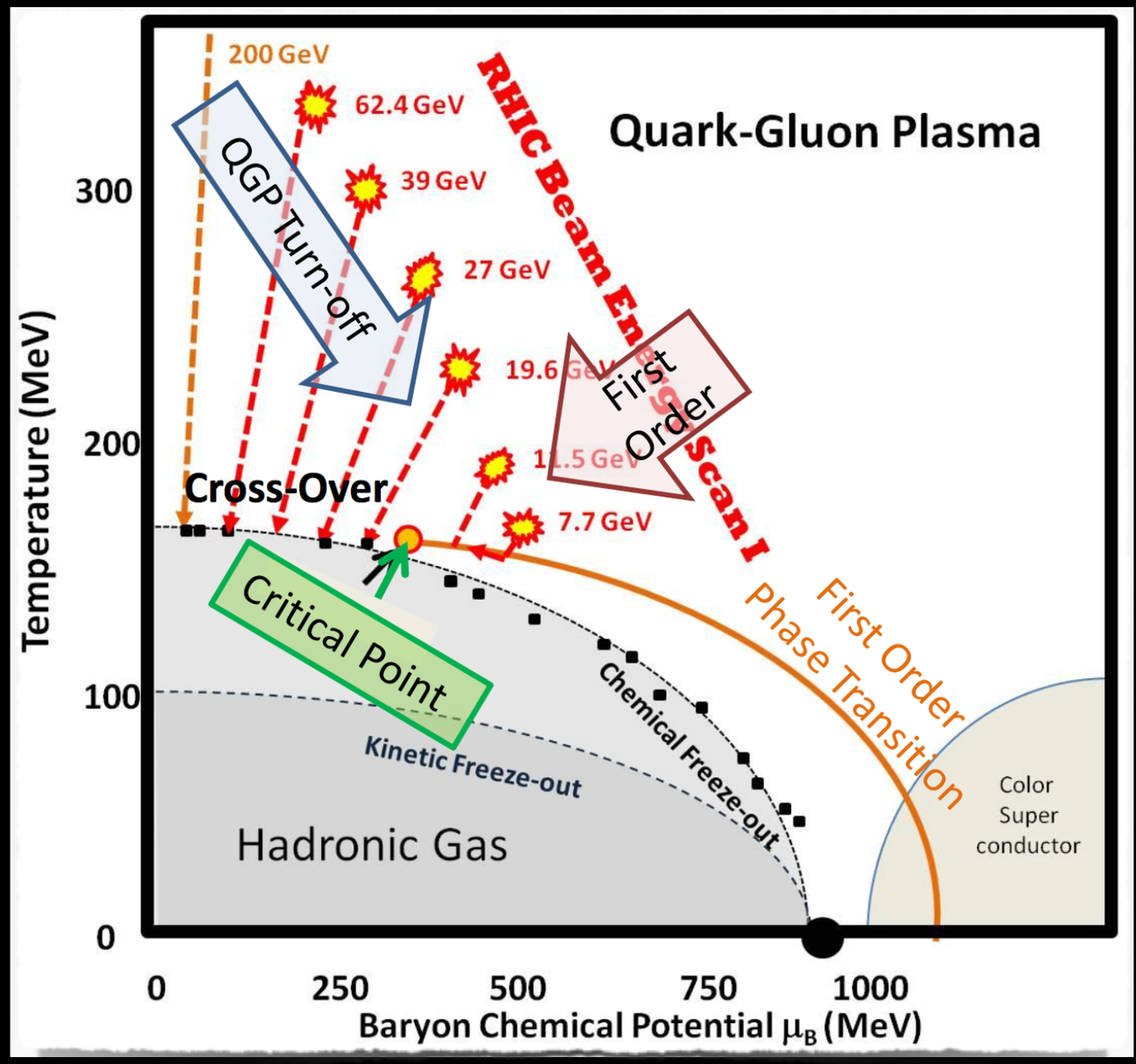
Beam Energy Scan

BES program:

- Run at RHIC in Brookhaven National Laboratory
- Collisions of: Au + Au

Three Goals:

- Turn-off QGP signatures
- Find critical point
- Examine First order phase transition



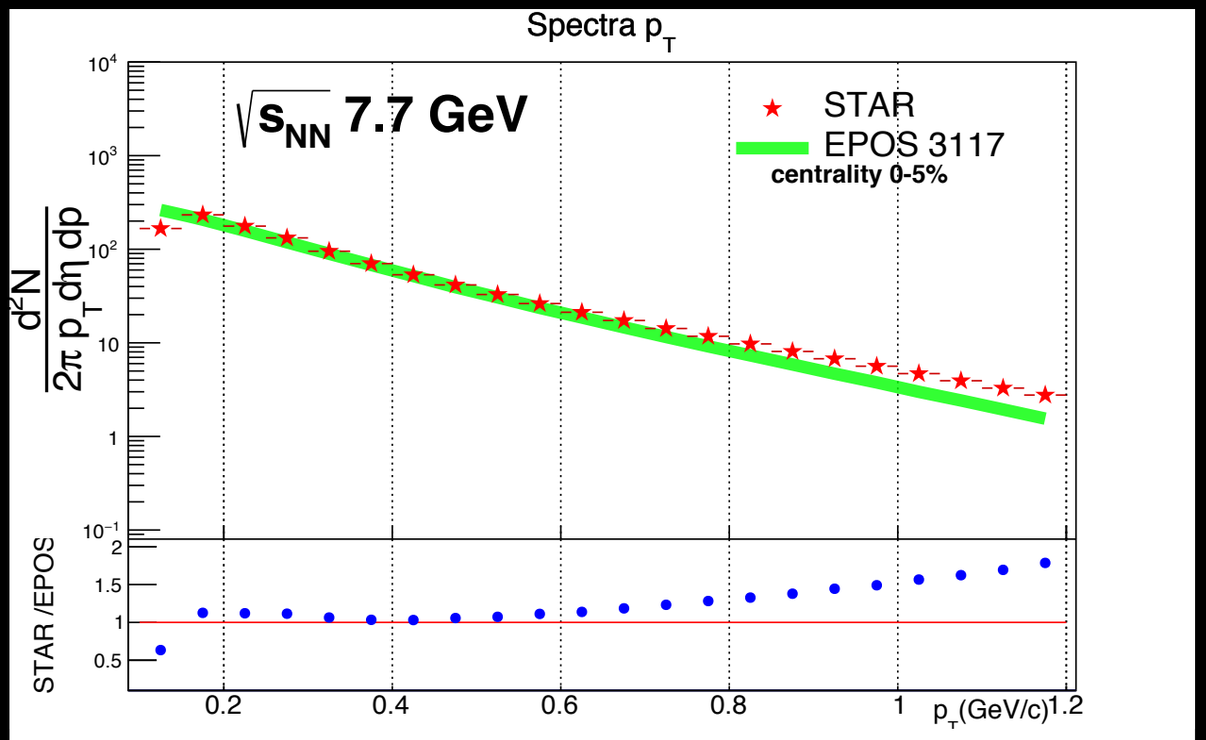
Analysis & Results

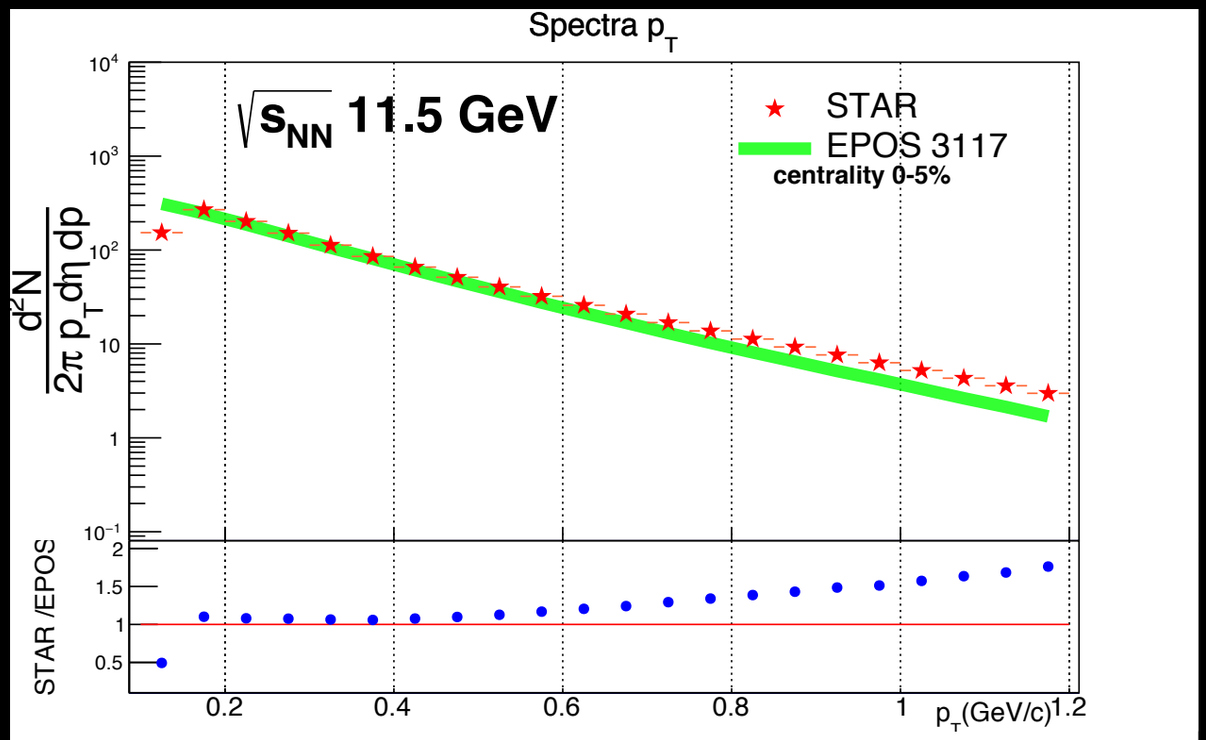
$$p_T = \sqrt{p_x^2 + p_y^2}$$

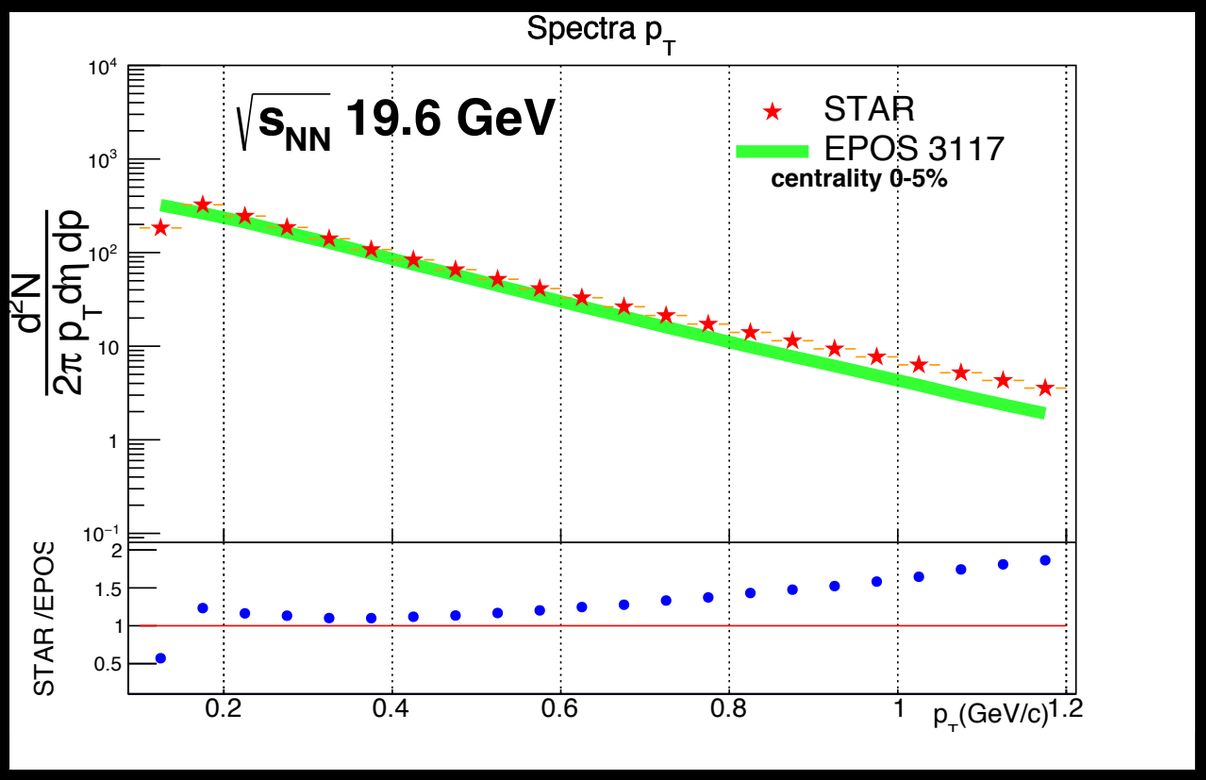
Au+Au Analysis

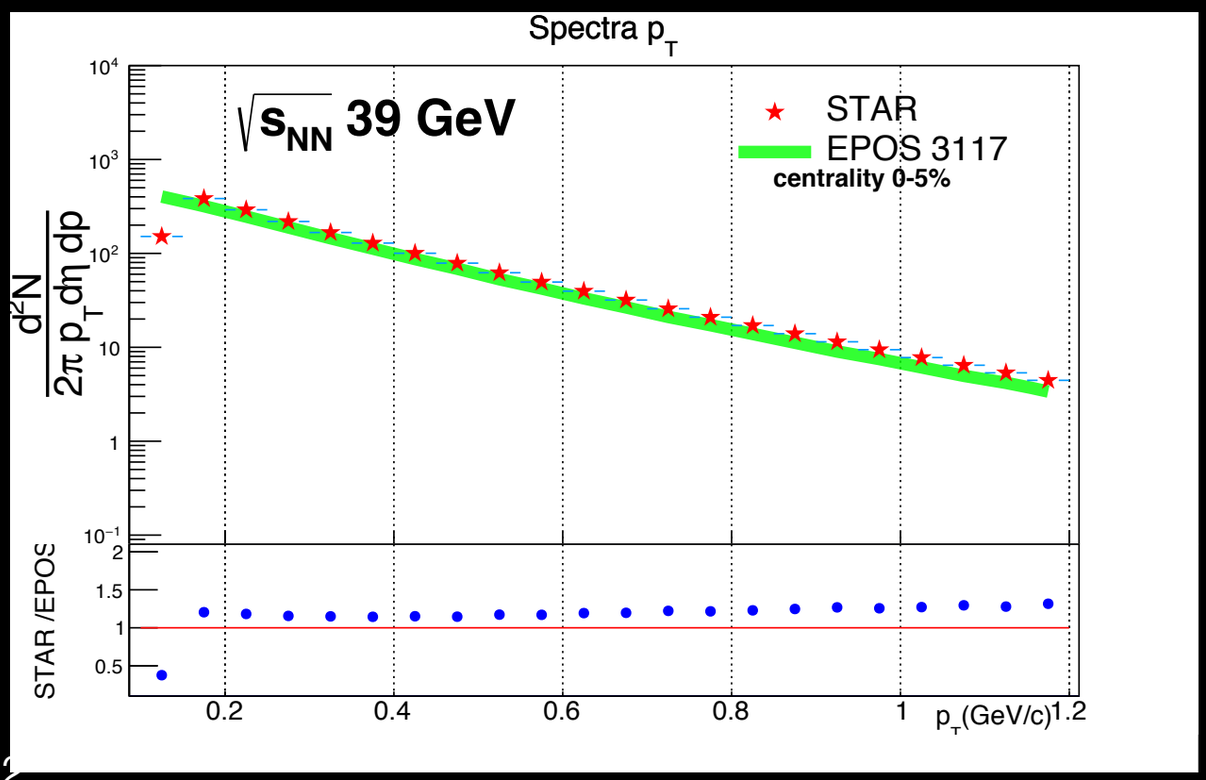
STAR data : J. Phys. Conf. Ser., 446:012017, 2013

central 0-5%









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Au+Au Analysis

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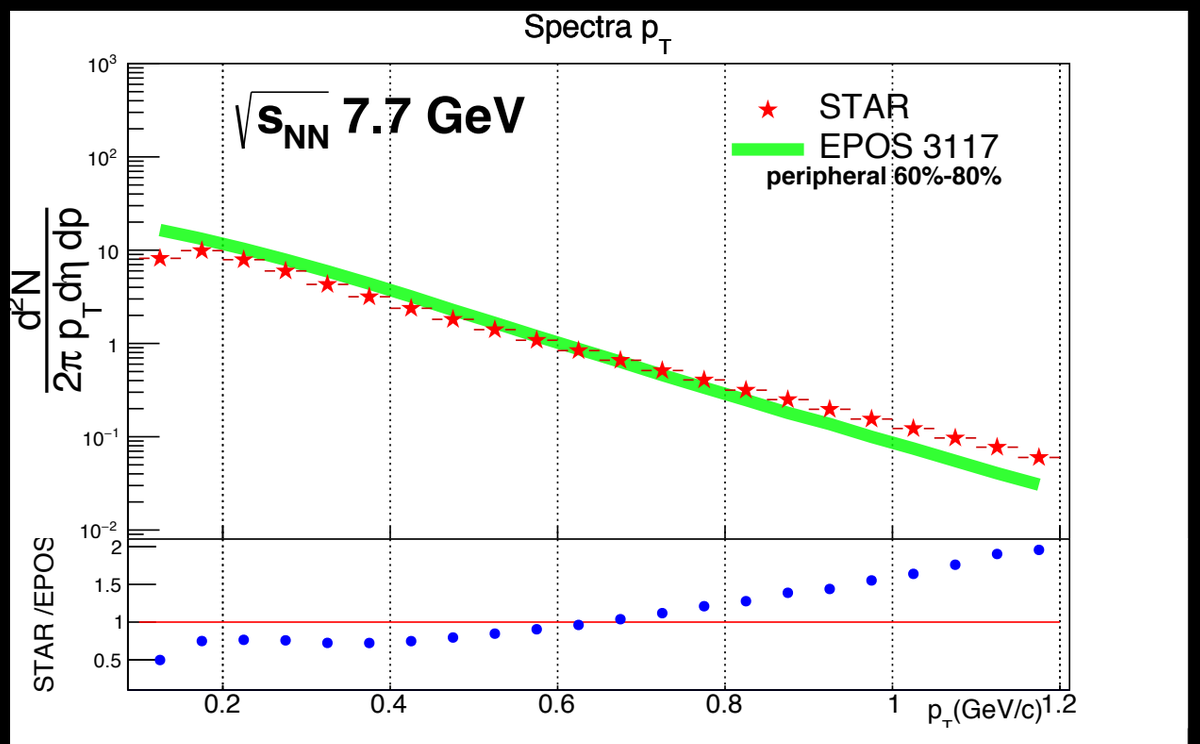
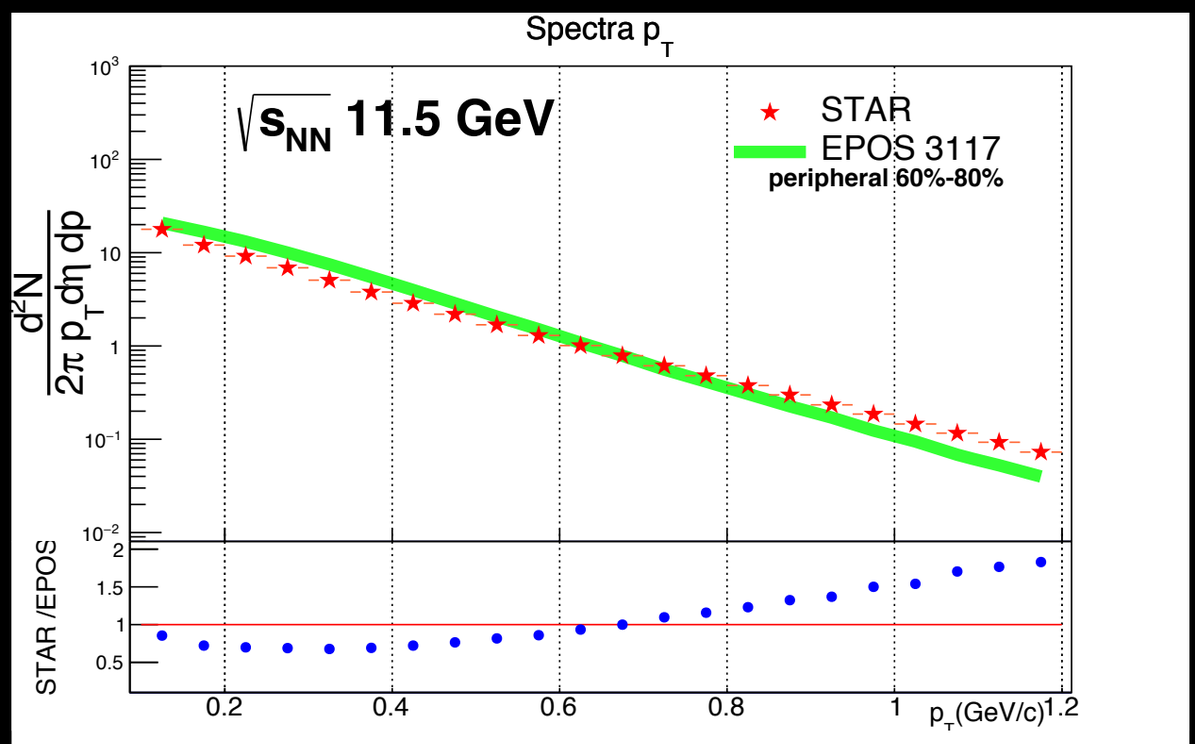
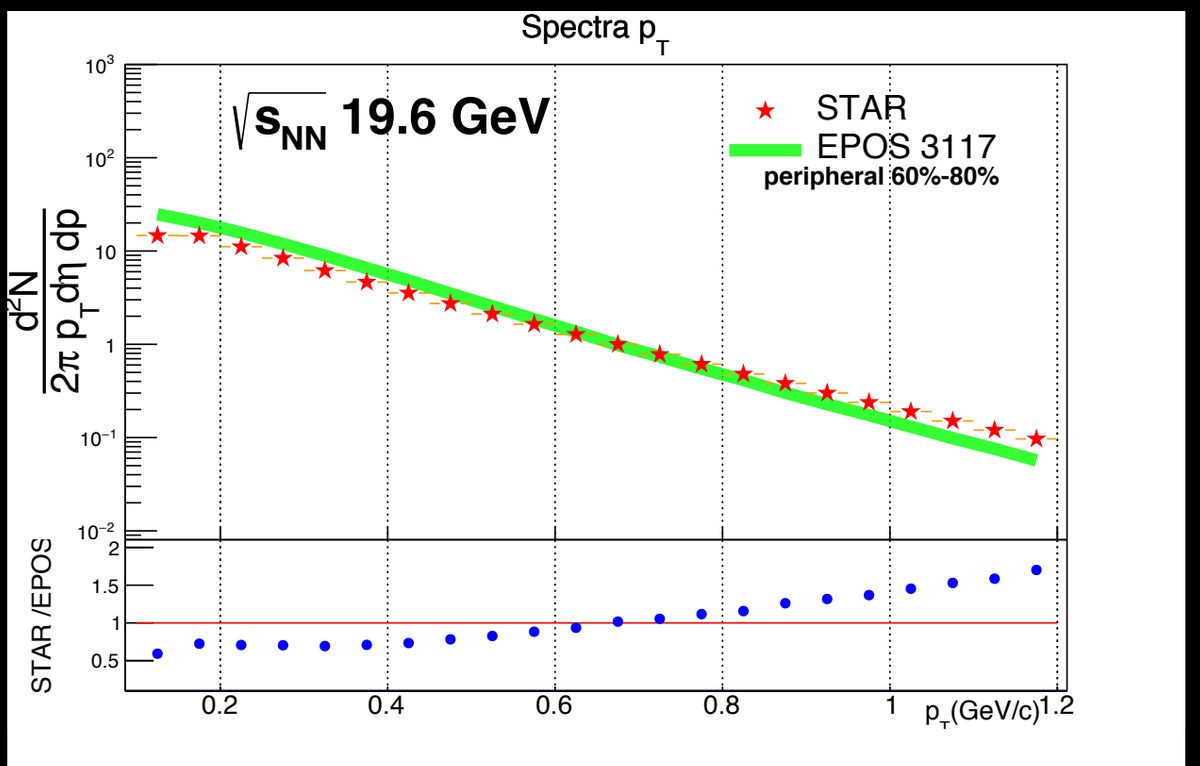
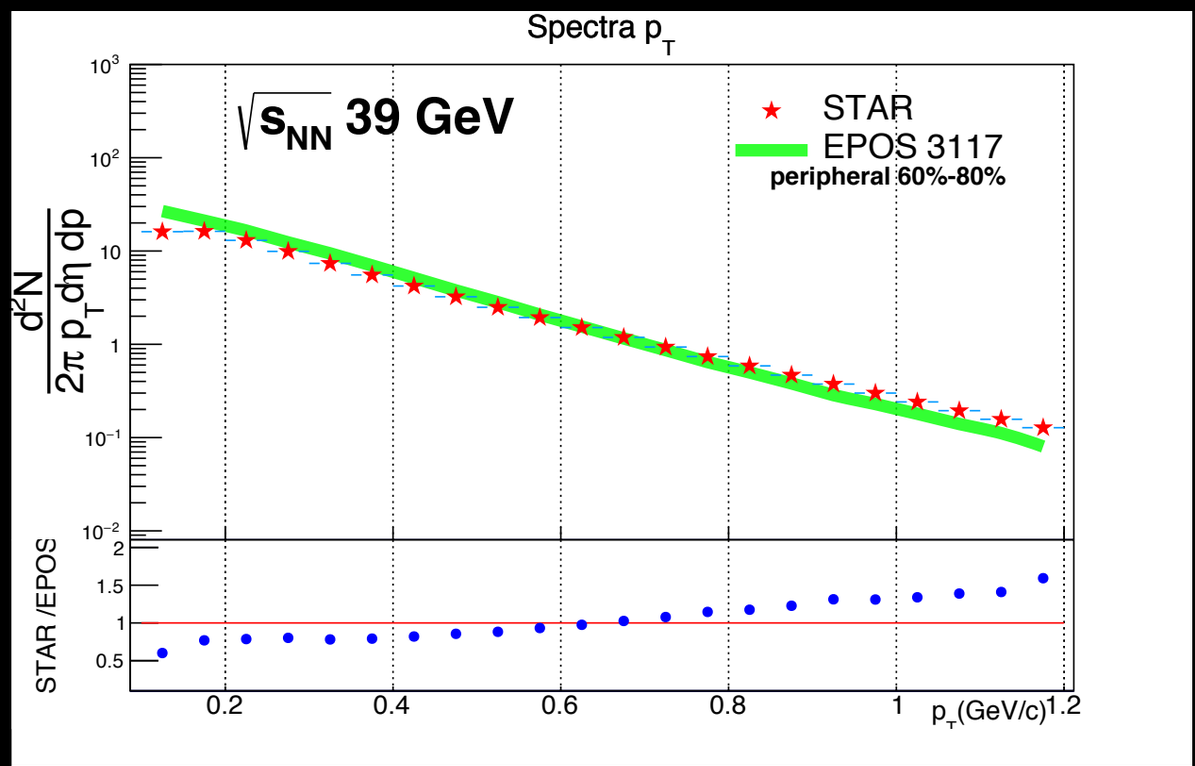
peripheral 60%-80%









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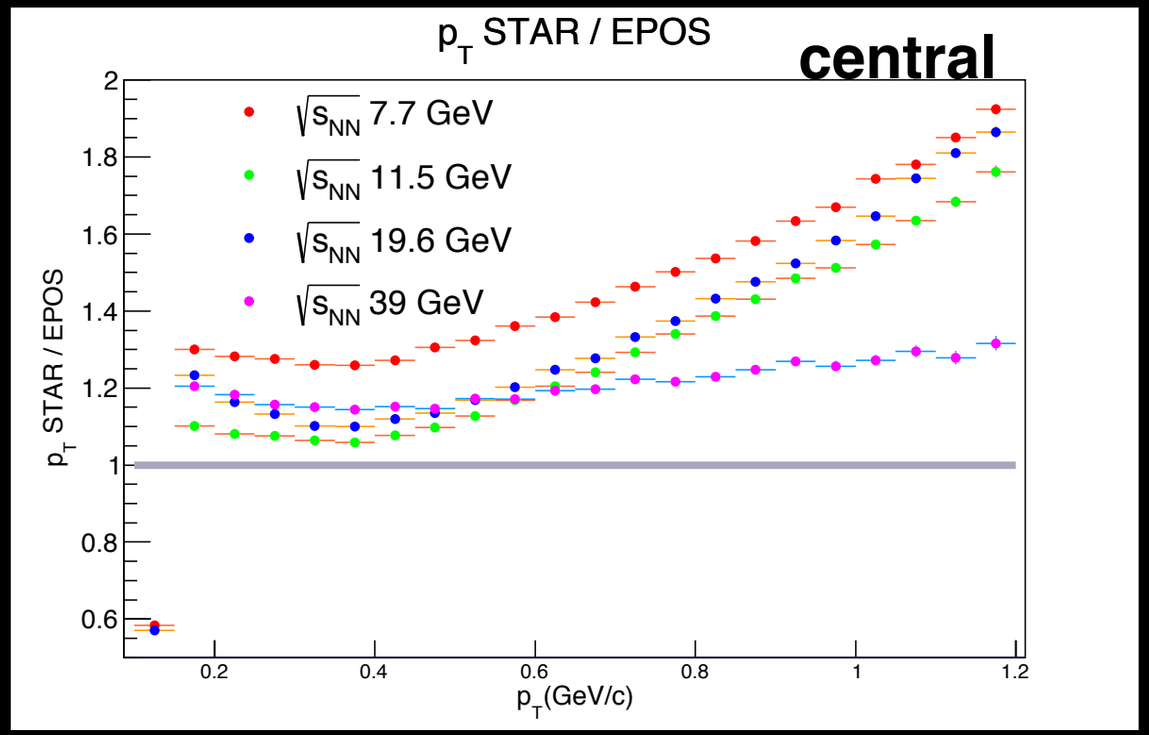
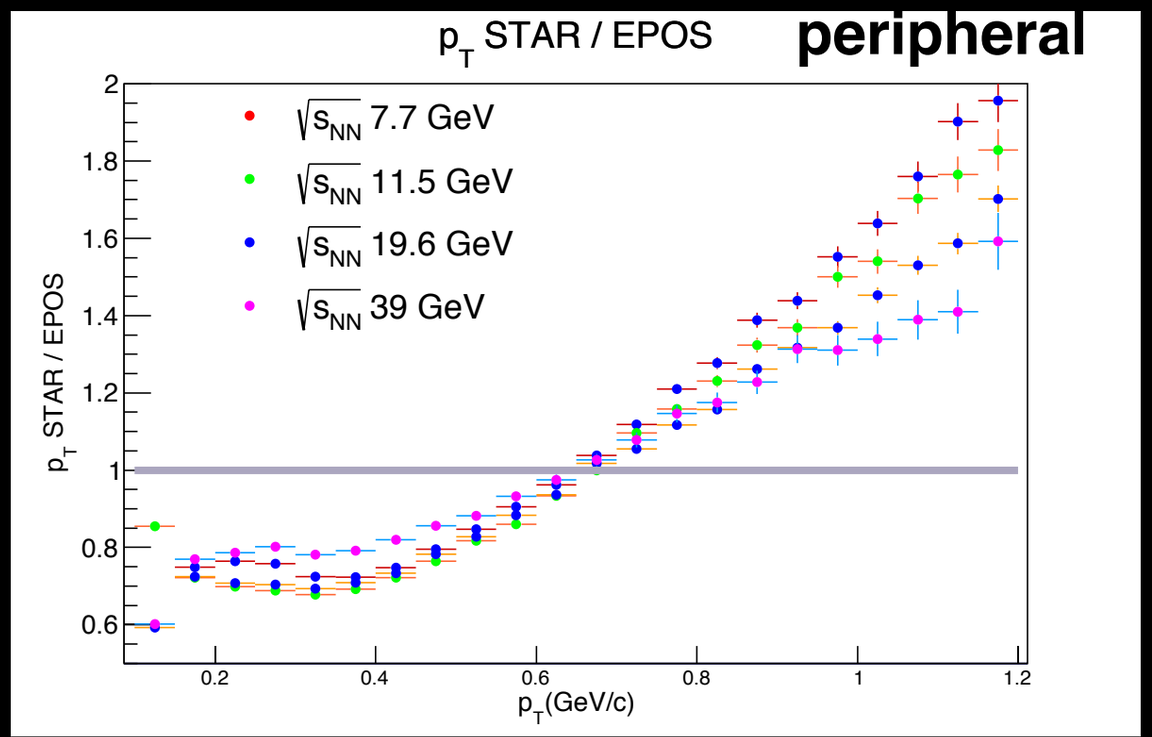
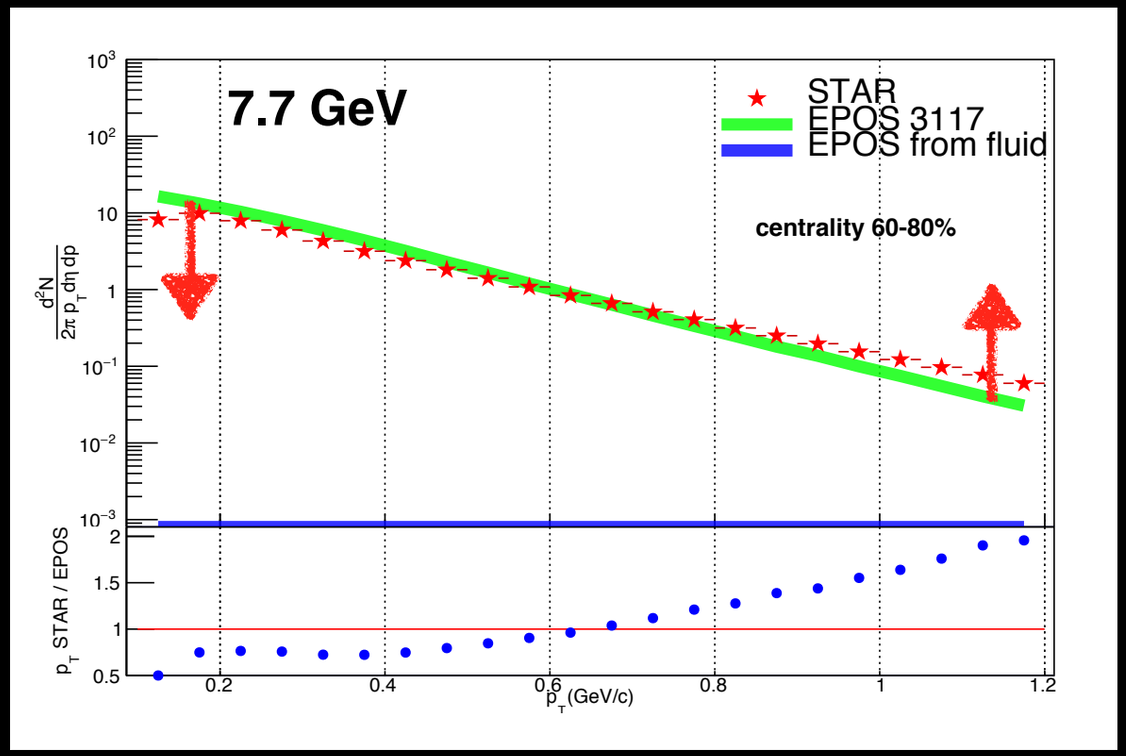




More particles derived from QGP



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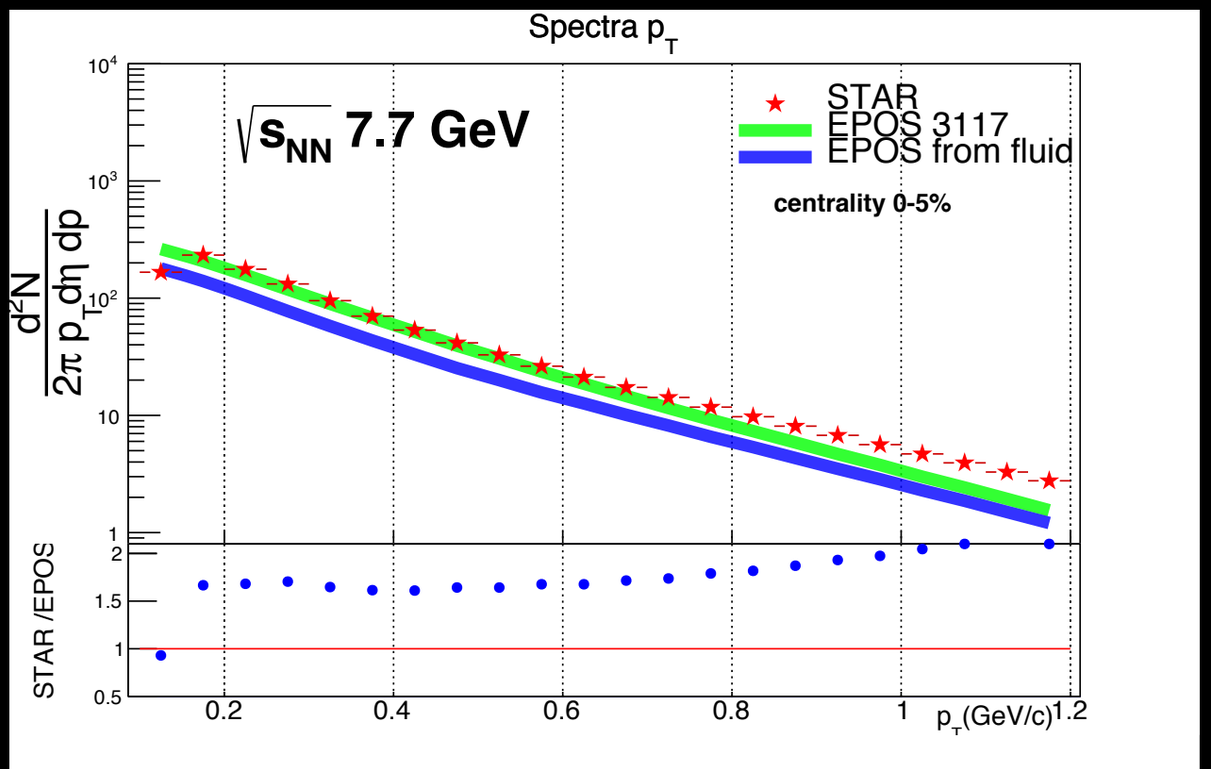

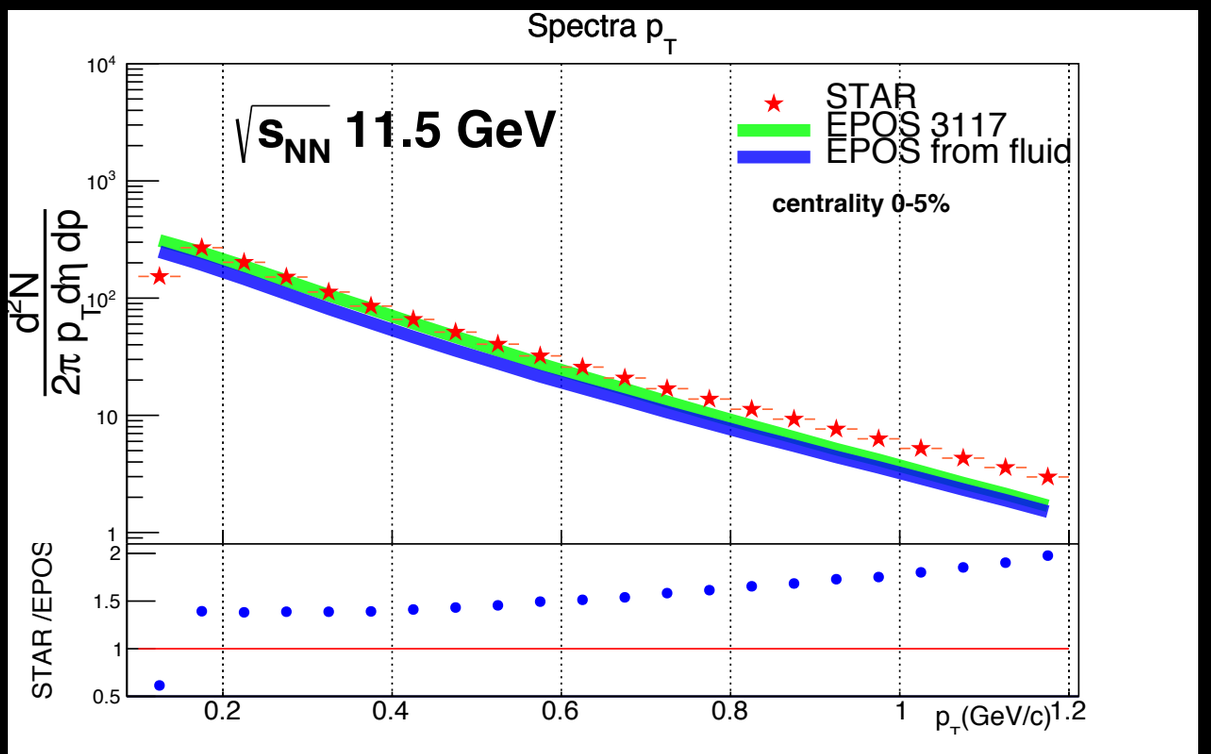

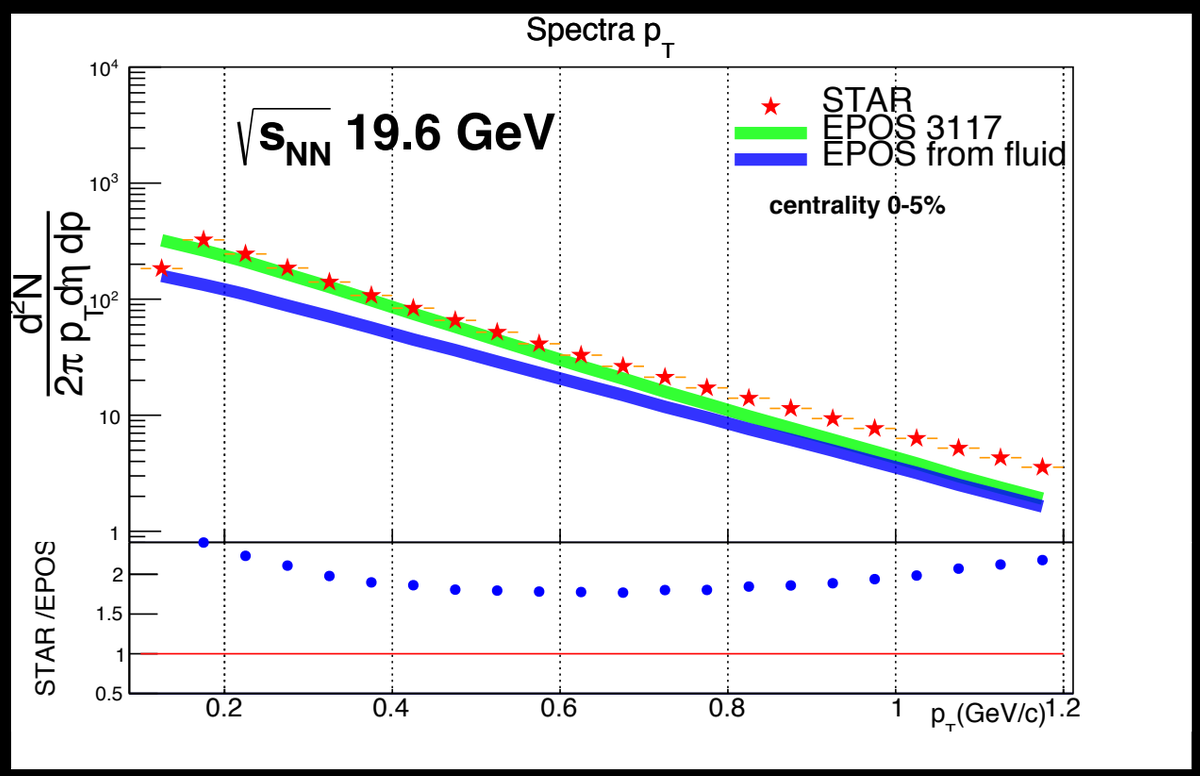

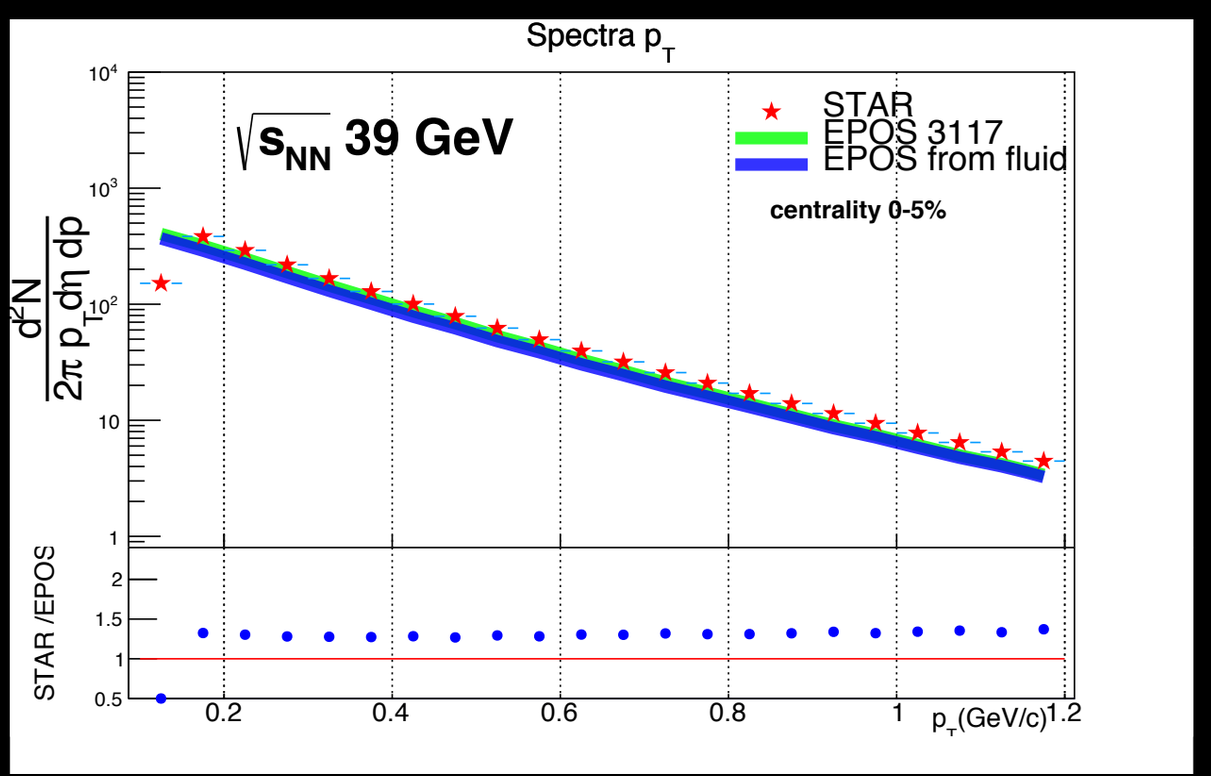

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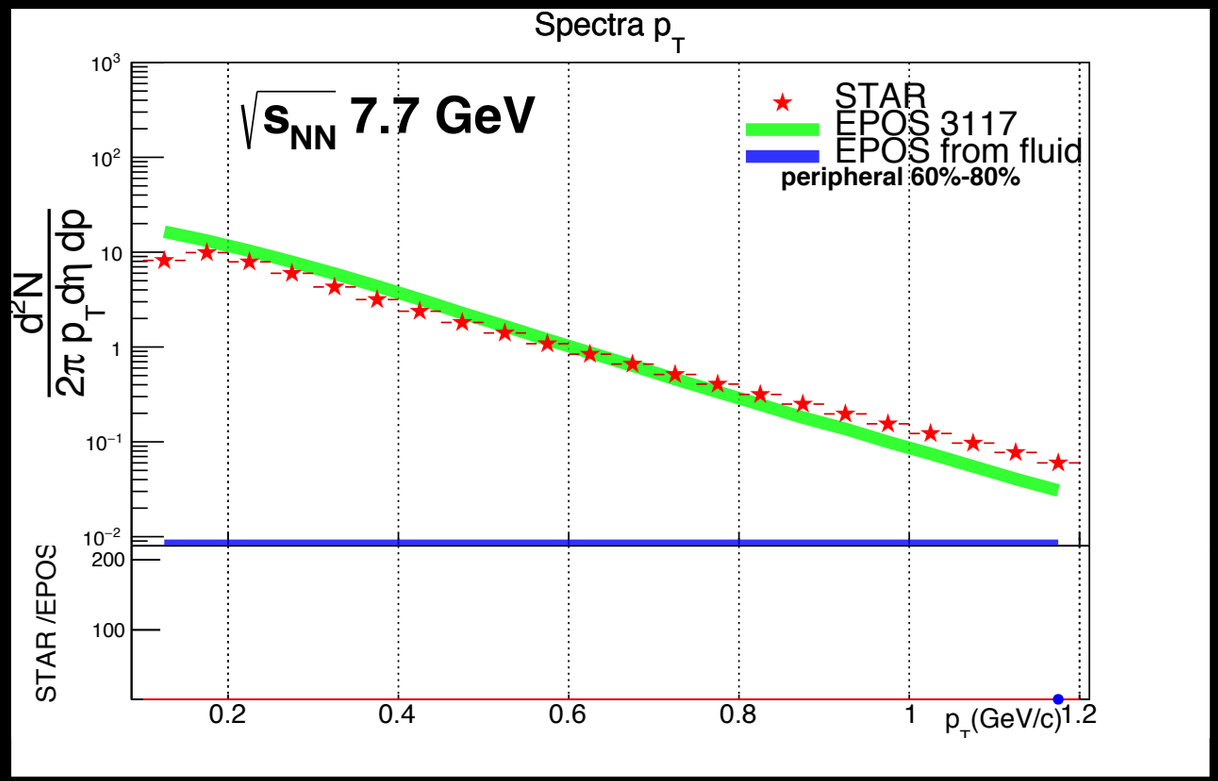

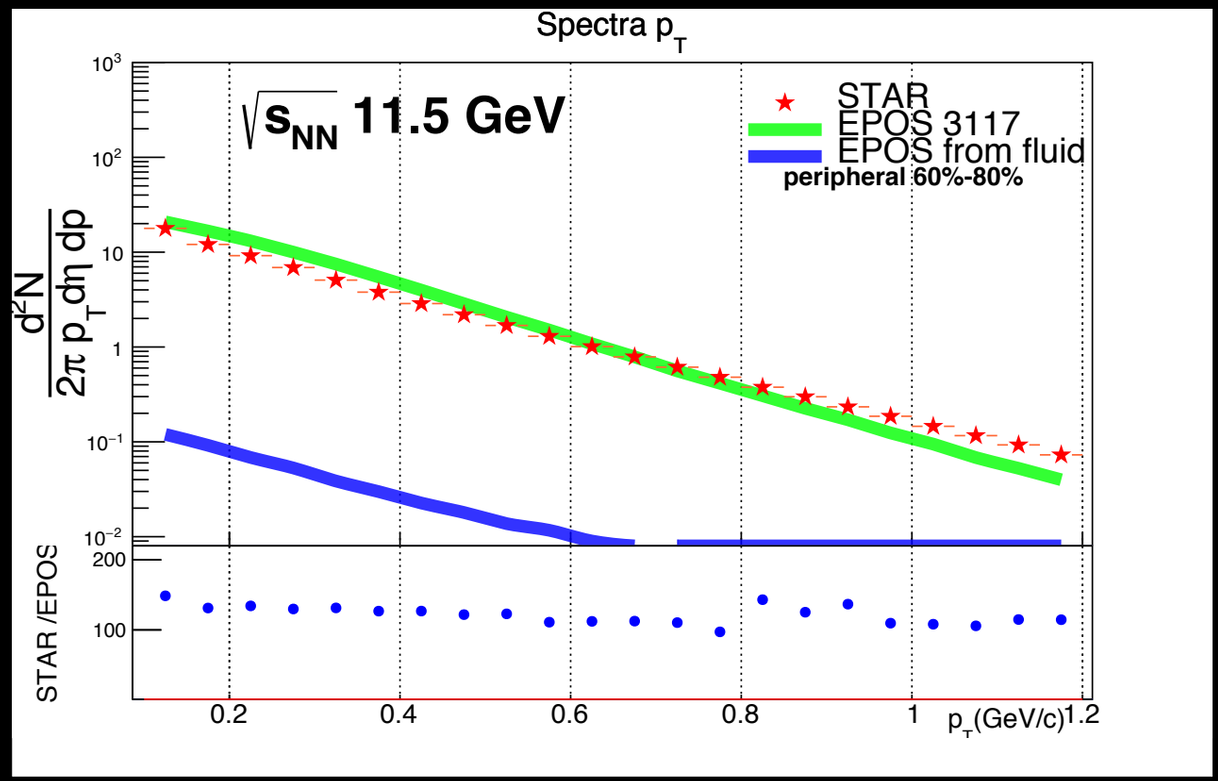

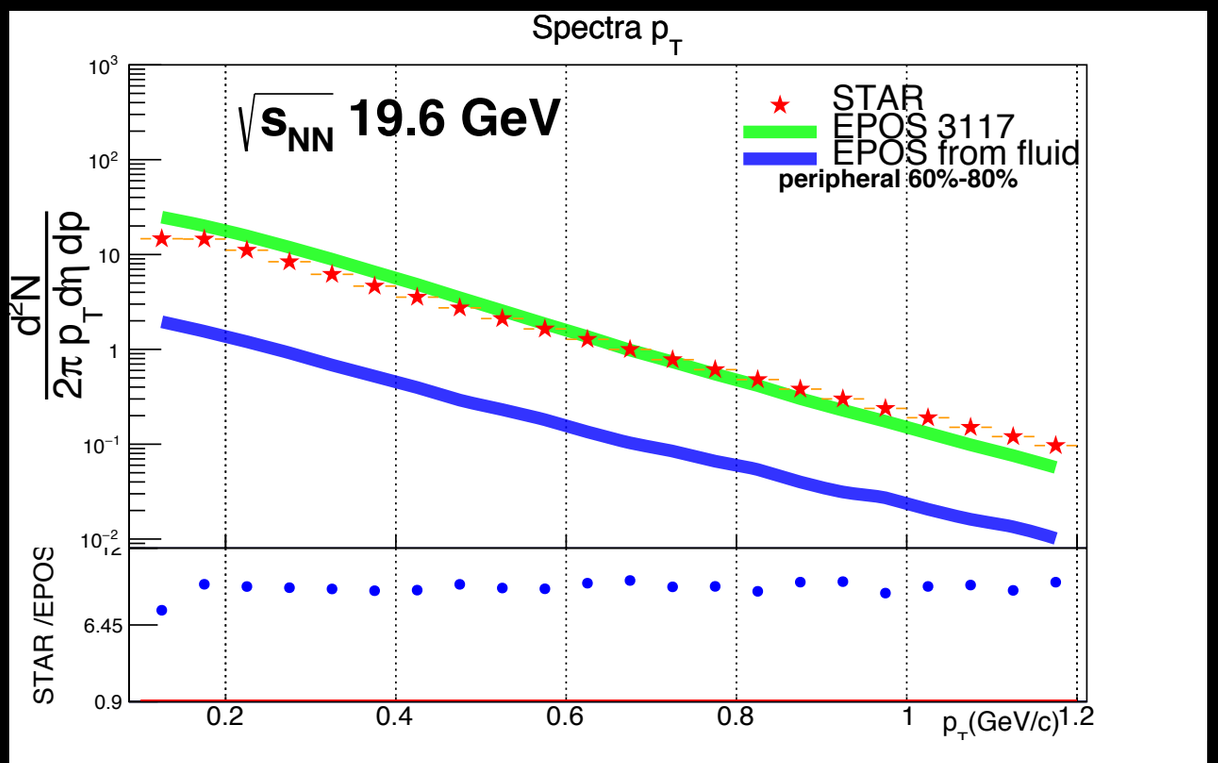

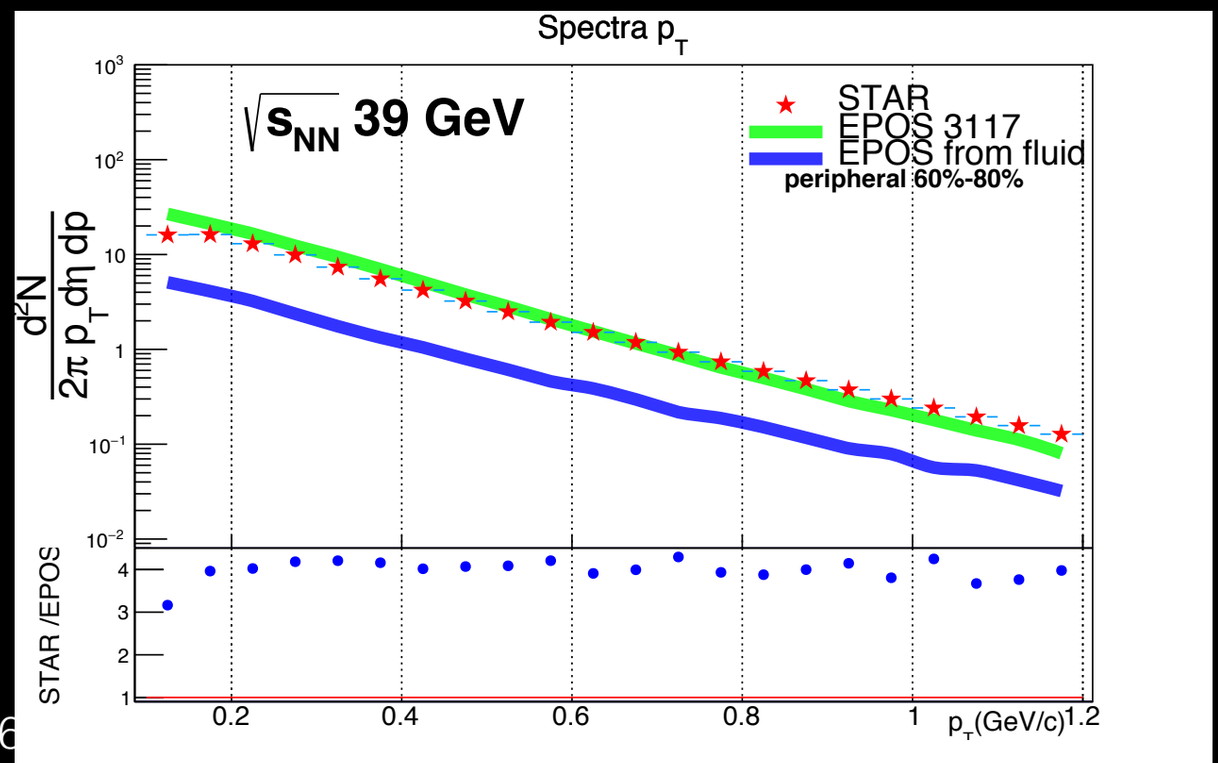

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Au+Au Analysis

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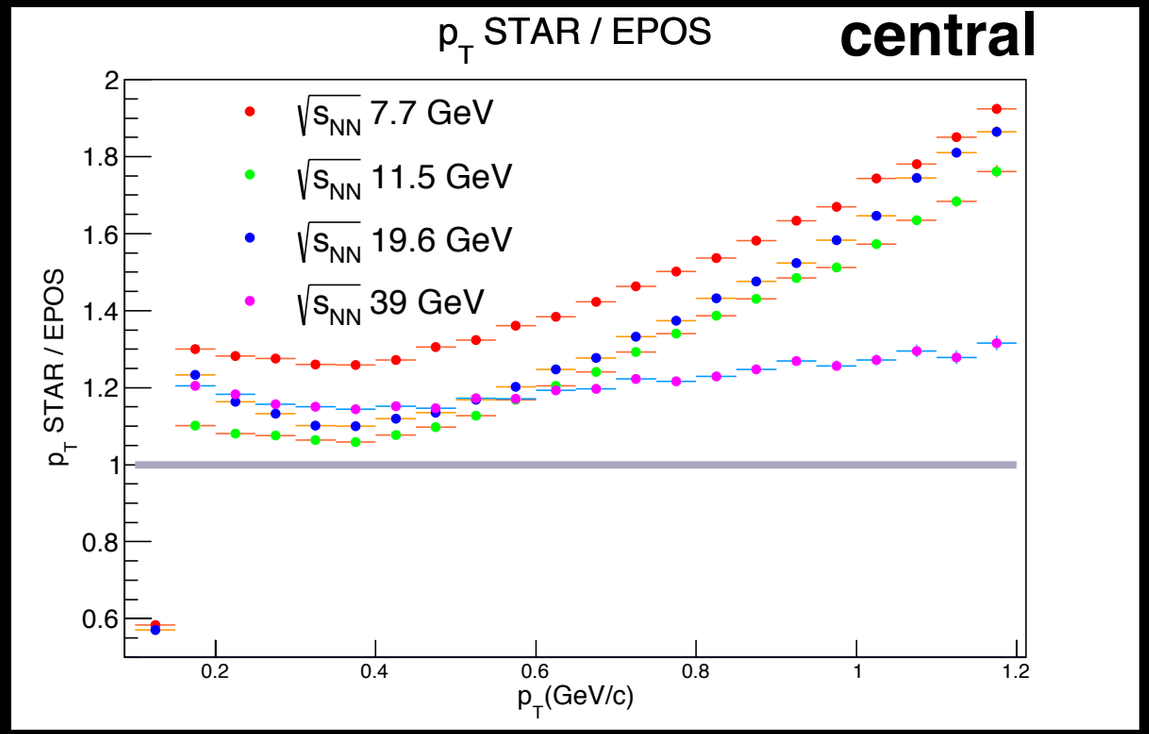

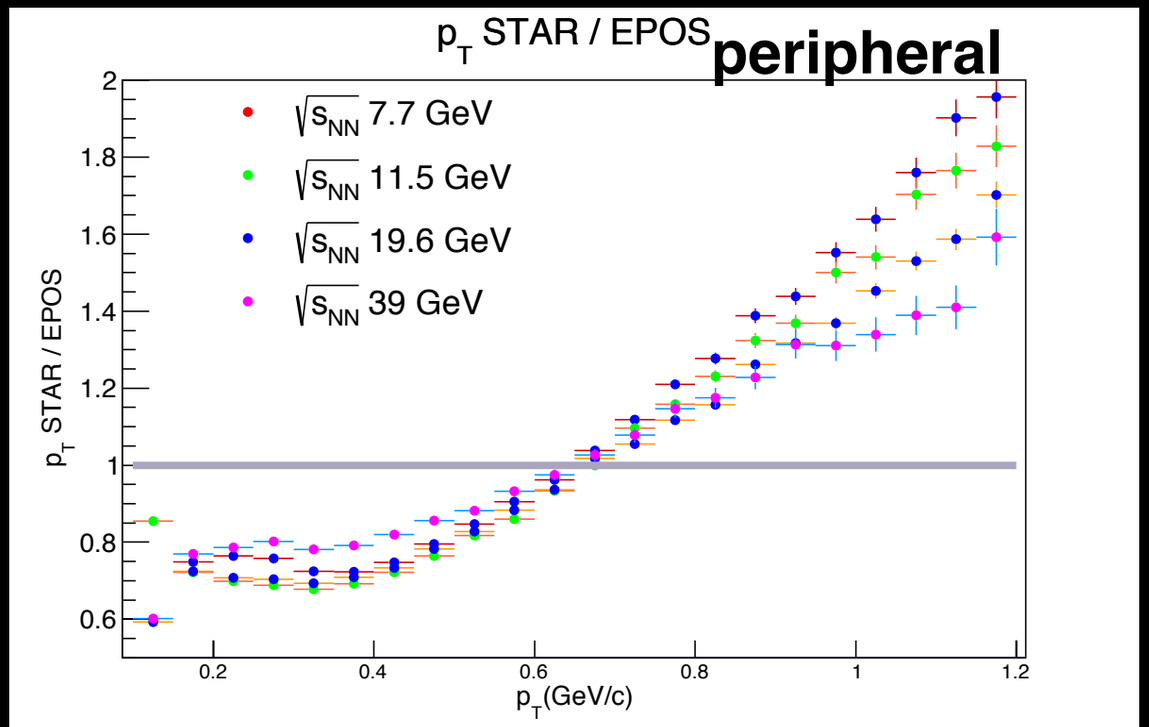

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Au+Au Analysis

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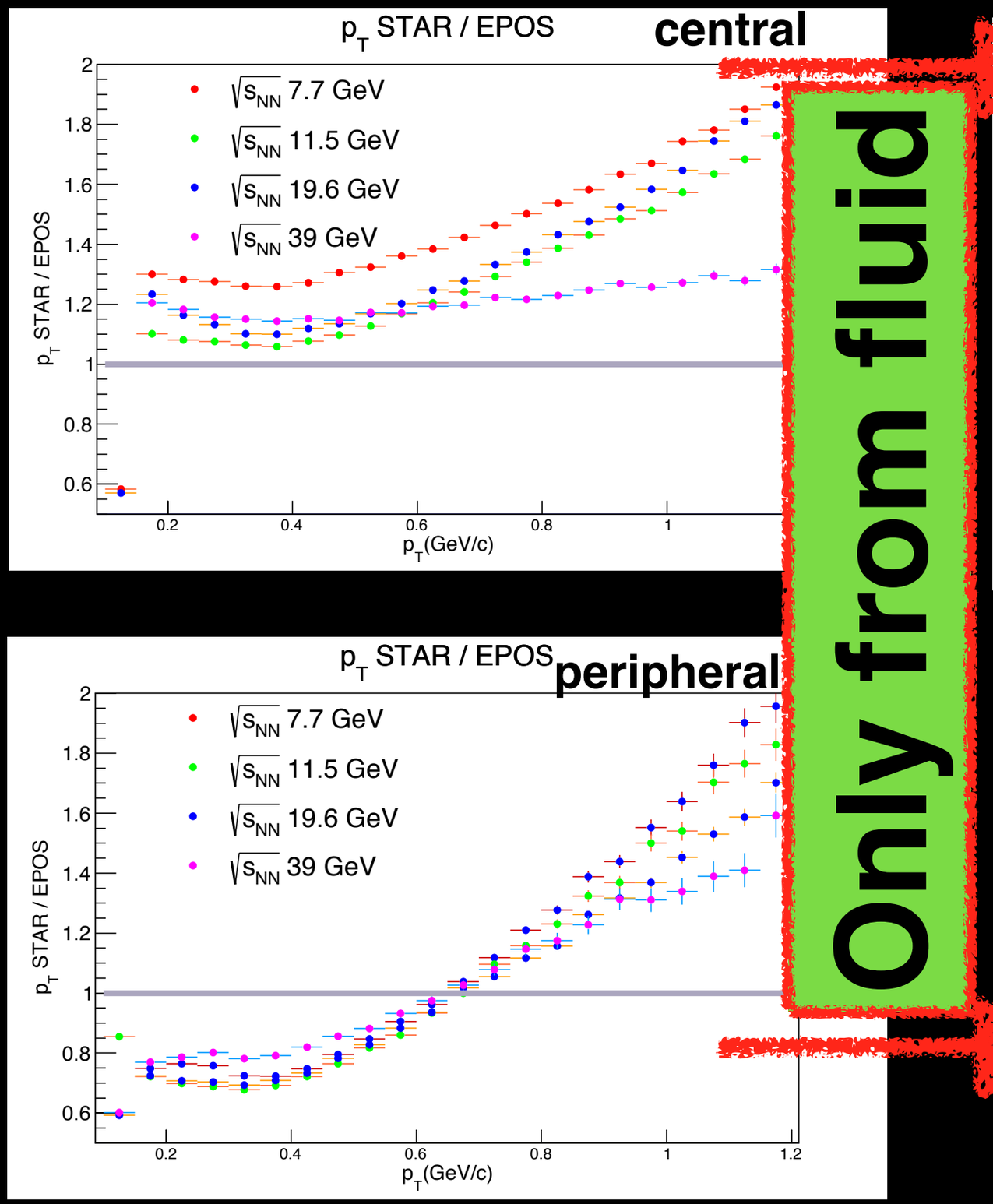

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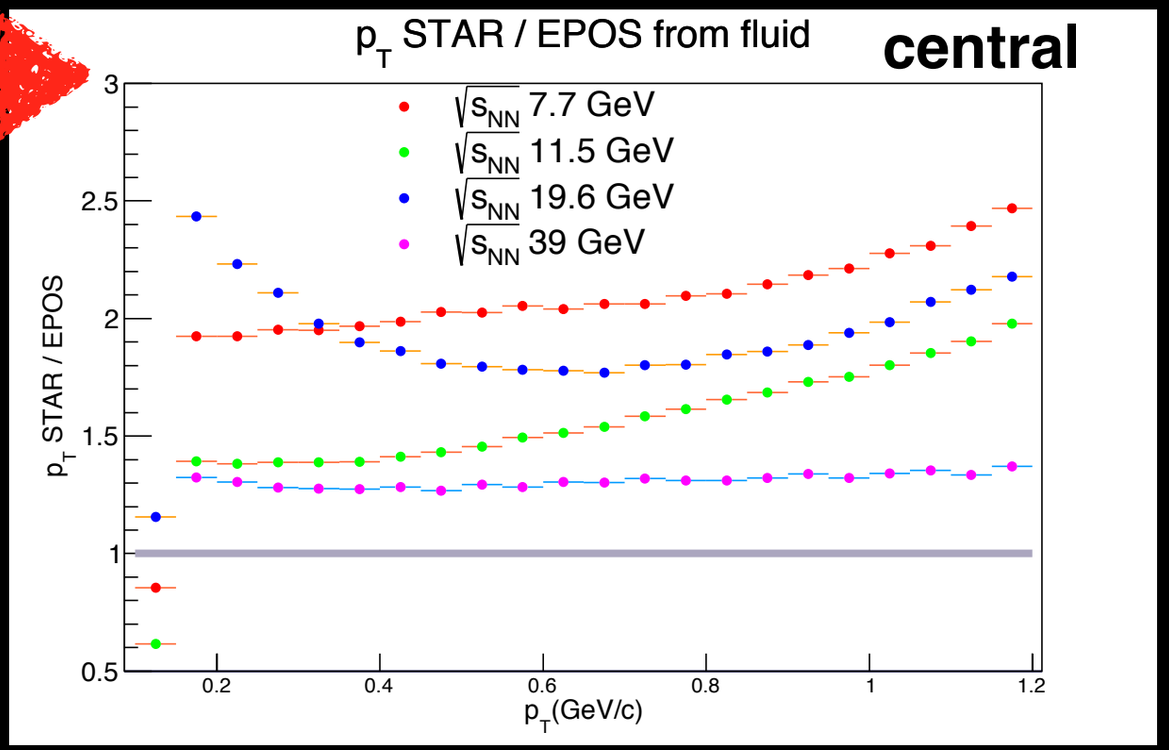
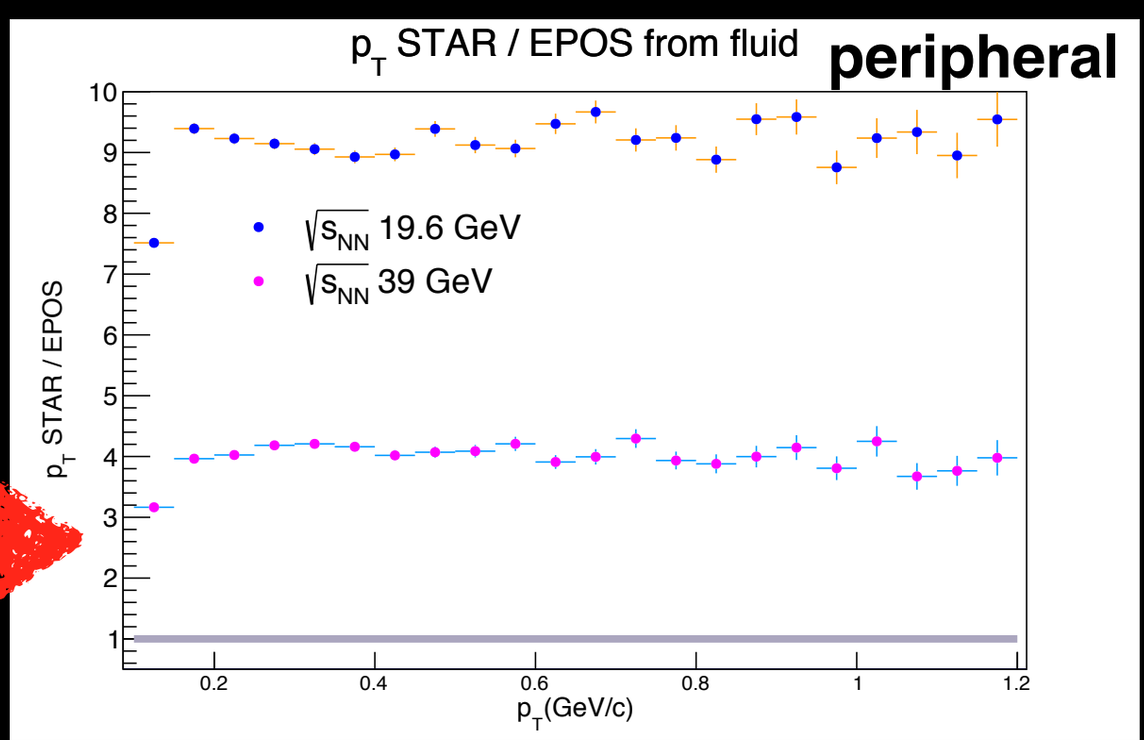
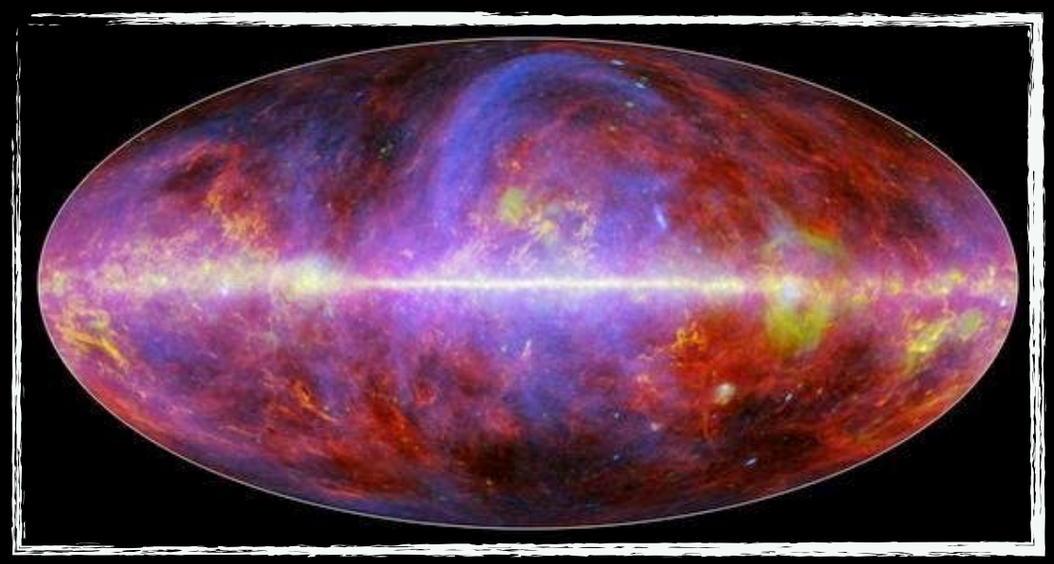




Analysis

HBT method

R.**H**anbury **B**rown and R.Q.**T**wiss

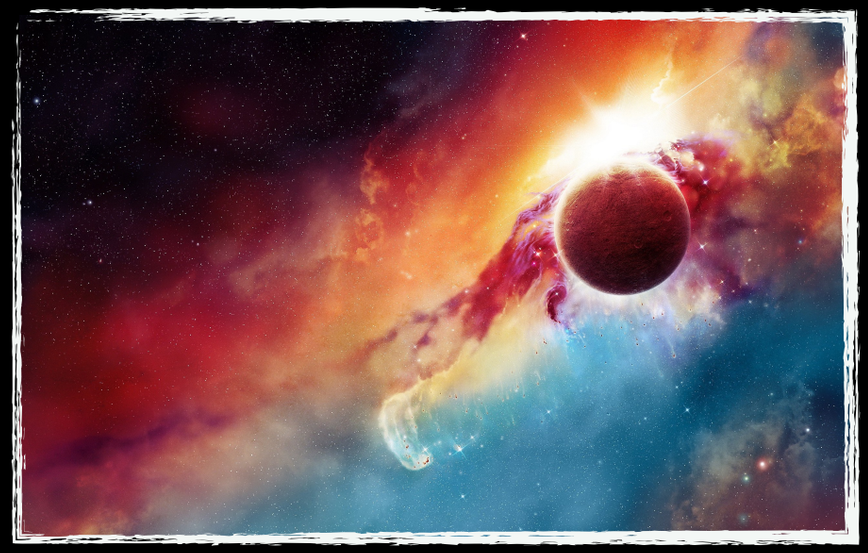


HBT method

Analysis

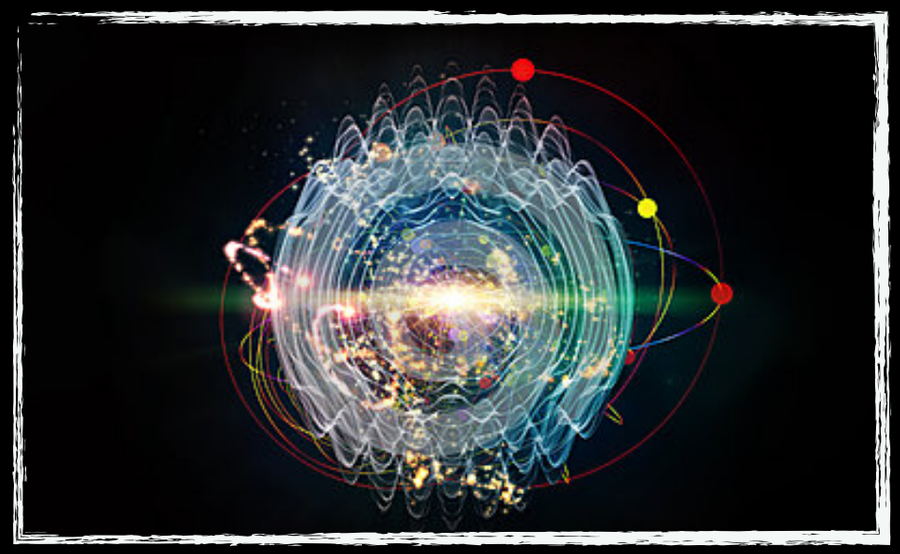
HBT Method

~ 10^{15} m



Femtoscopy correlations

~ 10^{-15} m

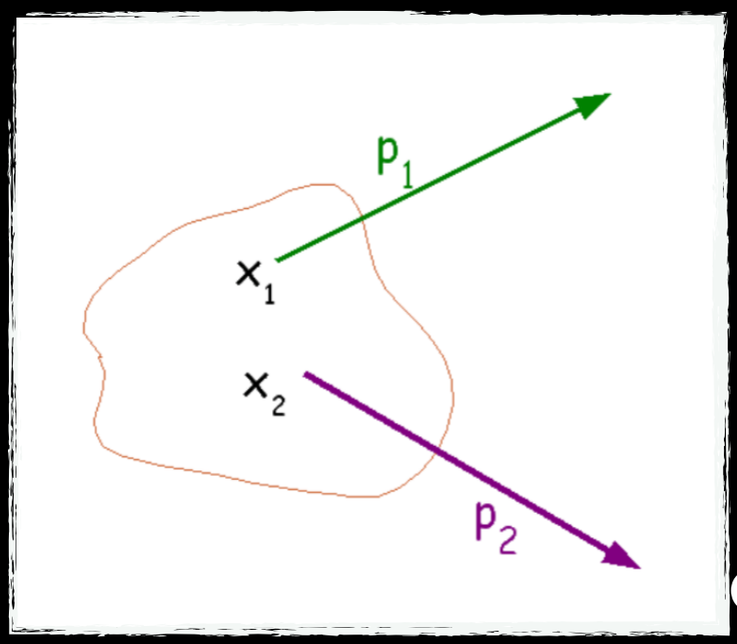


HBT method

Analysis

Two-particle distribution

$$P_2(p_1,p_2)=E_1E_2\frac{dN}{d^3p_1d^3p_2}=\int d^4x_1S(x_1,p_1)d^4x_2S(x_2,p_2)\Phi(x_2,p_2|x_1,p_1)$$



$$C(p_1,p_2)=\frac{P_2(p_1,p_2)}{P_1(p_1)P_1(p_2)}$$

One-particle distribution

$$P_1(p)=E\frac{dN}{d^3p}=\int d^4x\,S(x,p)$$

S(x,p) – emission function: the distribution of source density probability of finding particle with x and p

HBT method

Analysis

In experiment:

Signal, distribution of the difference of particles' momentums derived from the SAME collision

$$C_2(\vec{q}) = \frac{A(\vec{q})}{B(\vec{q})}$$

$$\vec{q} = \overrightarrow{p_1} - \overrightarrow{p_2}$$

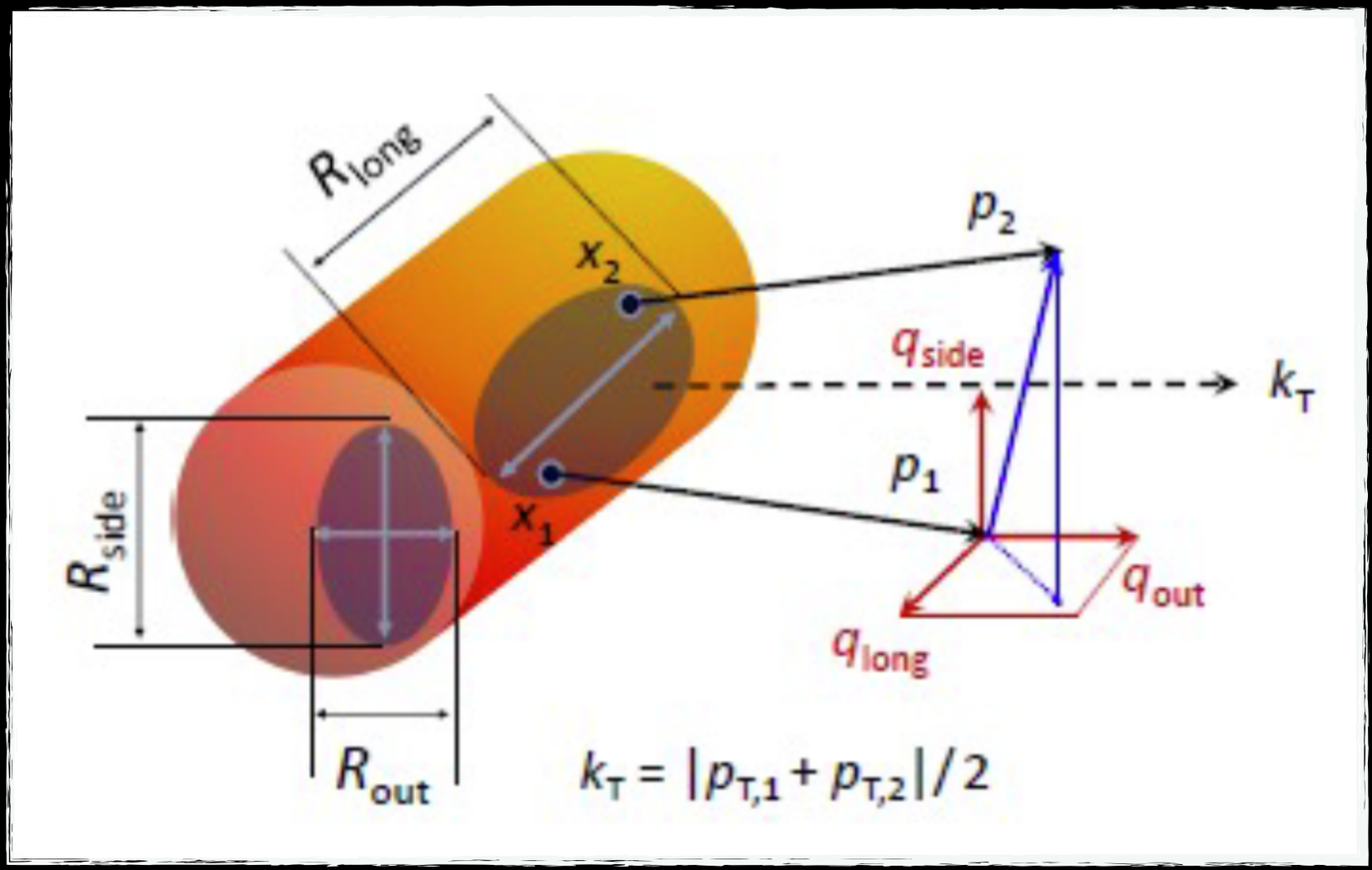
Background, distribution of the difference of particles' momentums derived from DIFFERENT collisions

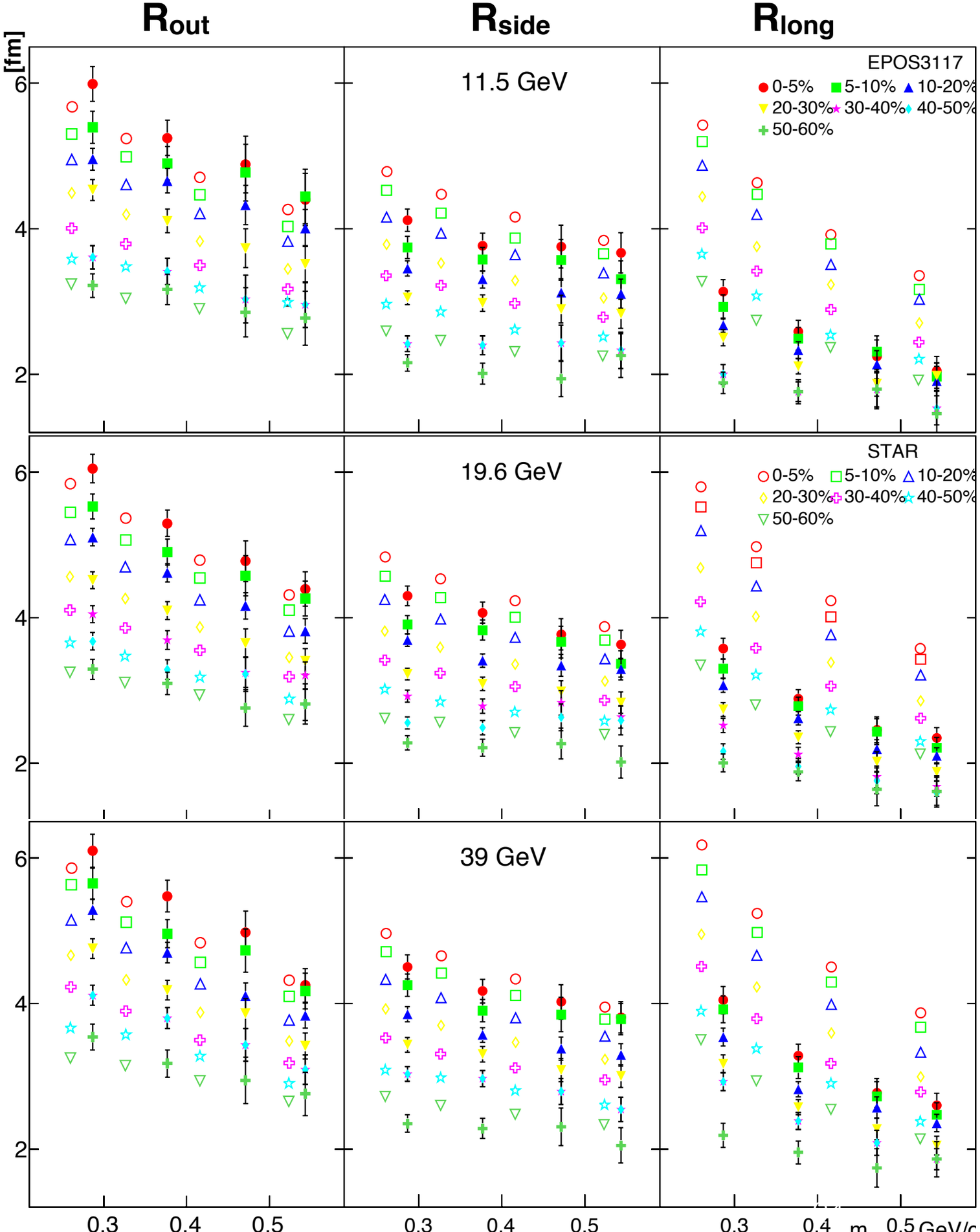
HBT method

Analysis

Parametrization:

$$C(q_{out}, q_{side}, q_{long}, \lambda) = 1 + \lambda exp(-q_{out}^2 r_{out}^2 - q_{side}^2 r_{side}^2 - q_{long}^2 r_{long}^2)$$

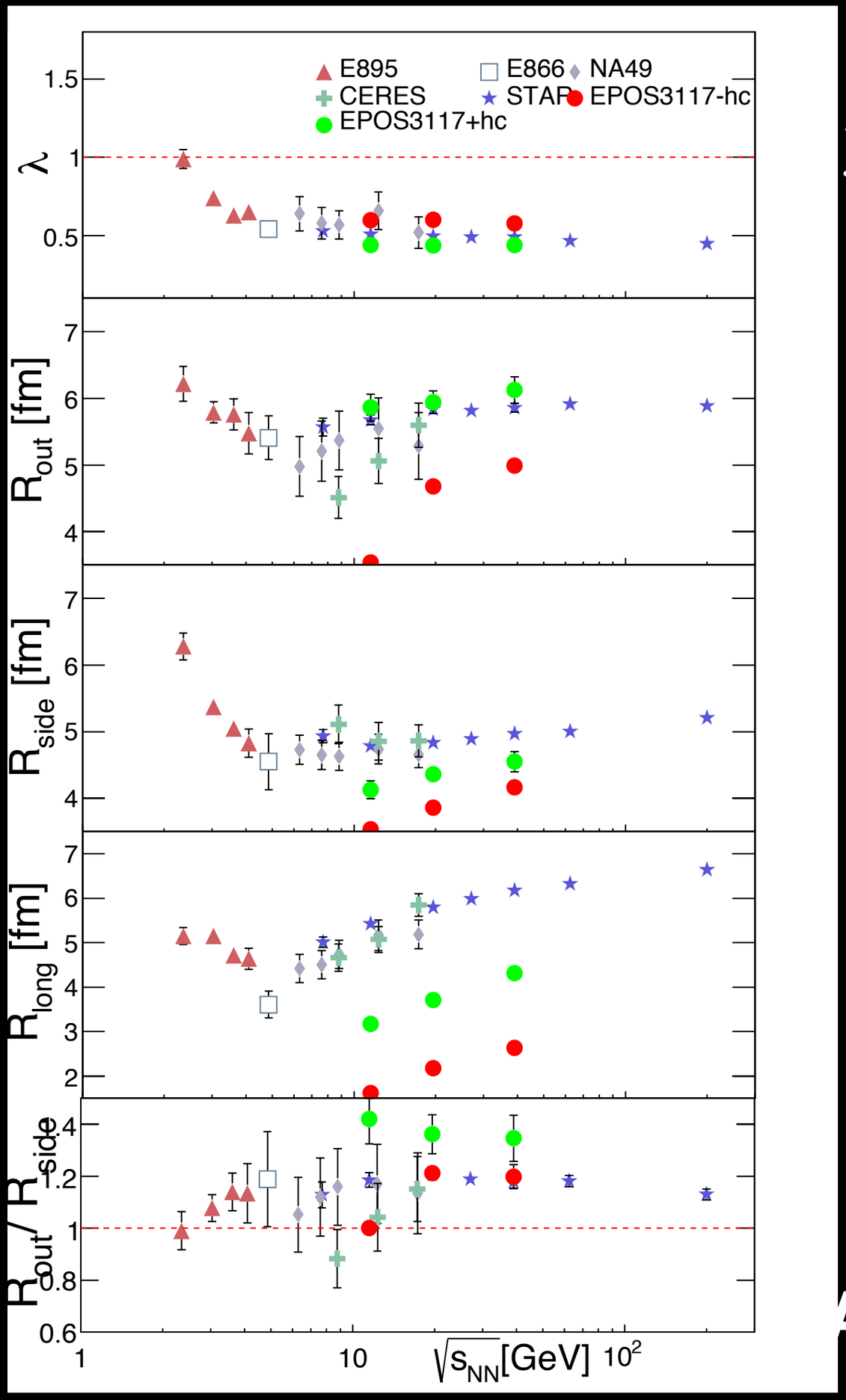




HBT method

Au+Au $\pi^+\pi^+$

STAR data: arXiv:1403.4972



Analysis

HBT method

arXiv:1403.4972

Lambda comparable!

R_{out} comparable!

R_{side} slightly lower

R_{long} relevantly lower

Impact of the *hadron cascades*

Au+Au $\pi^+\pi^+$ $k_T \approx 0.225$ GeV/c

Analysis

Elliptic flow

- *event plane* method

One way of studying the azimuthal anisotropy is the Fourier decomposition, where each of coefficients reports to the shape of matter flow.

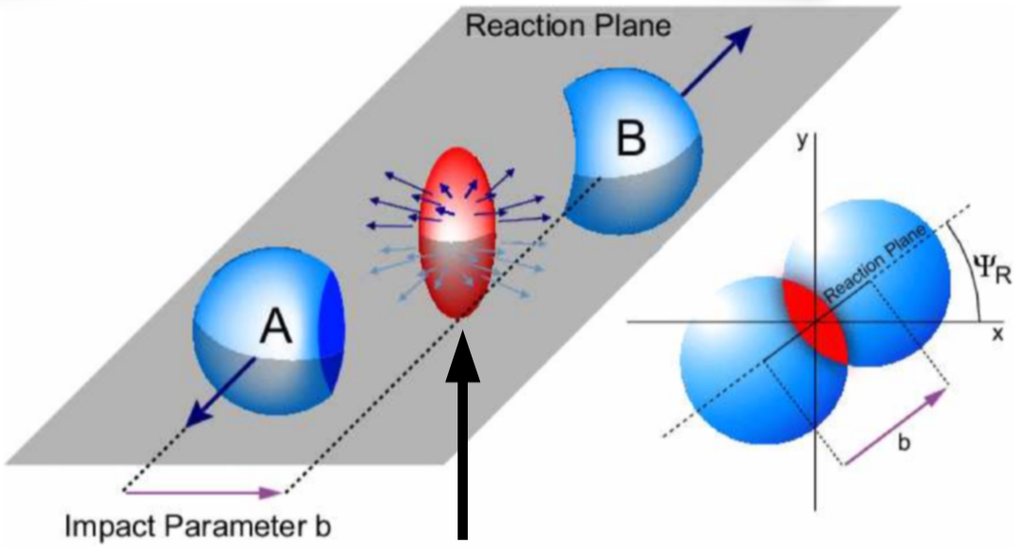
$$\frac{dN}{d(\phi - \Phi_{RP})} = \frac{N_0}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[(\phi - \Phi_{RP})]\right)$$

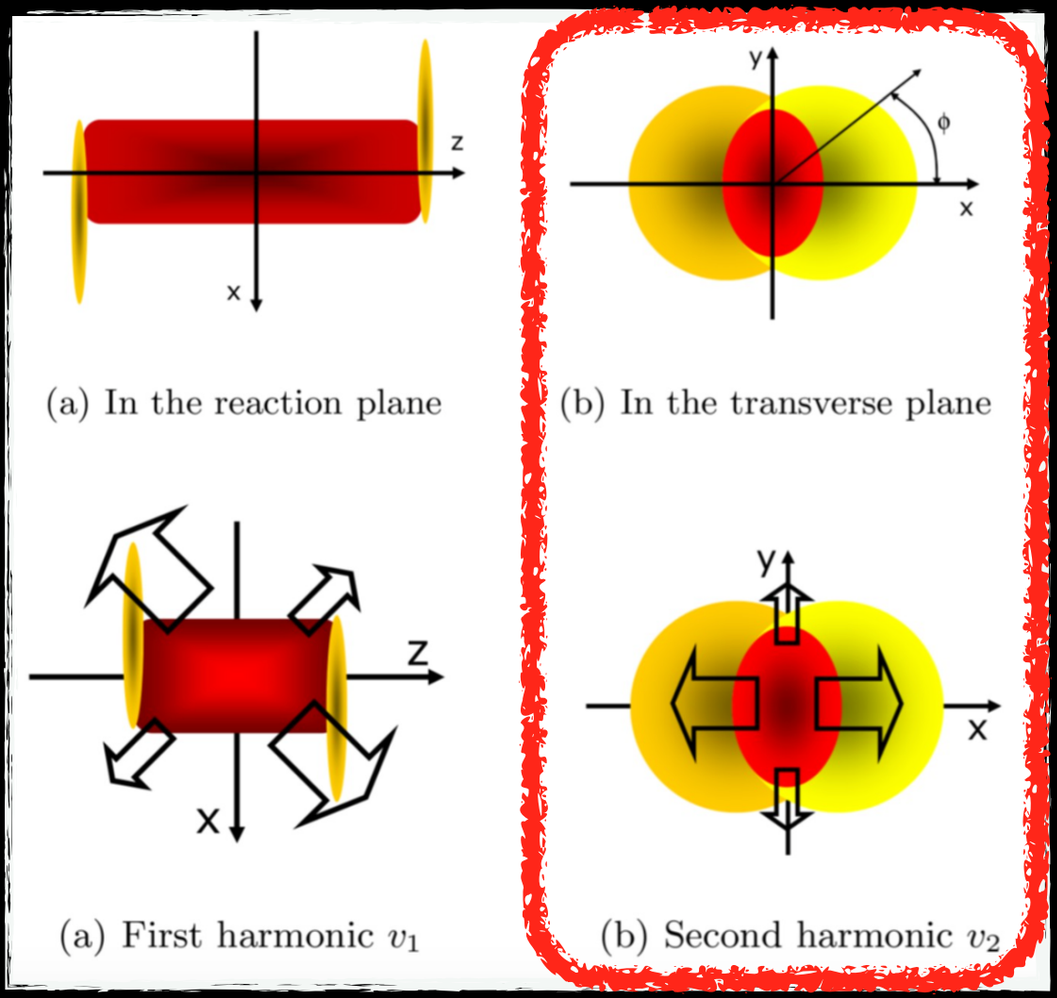
N_0 - number of particles

v_n - n-th harmonic coefficient

ϕ - azimuthal angle of particles

Φ_{RP} - azimuthal angle of the reaction plane





- **Estimate *event plane* with equation (Fourier coefficient n = 2, elliptic flow)**

$$\Phi_2 = \tan^{-1}\left(\frac{\sum_i w_i sin(2\phi_i)}{\sum_i w_i cos(2\phi_i)}\right)/2$$

Elliptic flow

Analysis

In analyze of elliptic flow were used η−sub method:

- from all measured particles there are selected two groups with ”forward” and ”backward” pseudorapidity with a gap between them.
- To express the observed v_2 of particles with respect to already investigated event plane one uses:

$$v_2^{obs}(p_T, y) = \langle \cos[2(\phi_i - \Phi_2)] \rangle$$

- As a consequence of the final multiplicity limitation in the investigation of the angle of the reaction plane, the correction of v_2 with event plane resolution have to be done.

$$R_2 = \sqrt{\langle \cos[2(\Phi_2^A - \Phi_2^B)] \rangle}$$

Φ_n^A - *event plane* calculated only using ”forward-pseudorapidity” particles while Φ_n^B - with ”backward-pseudorapidity” ones.

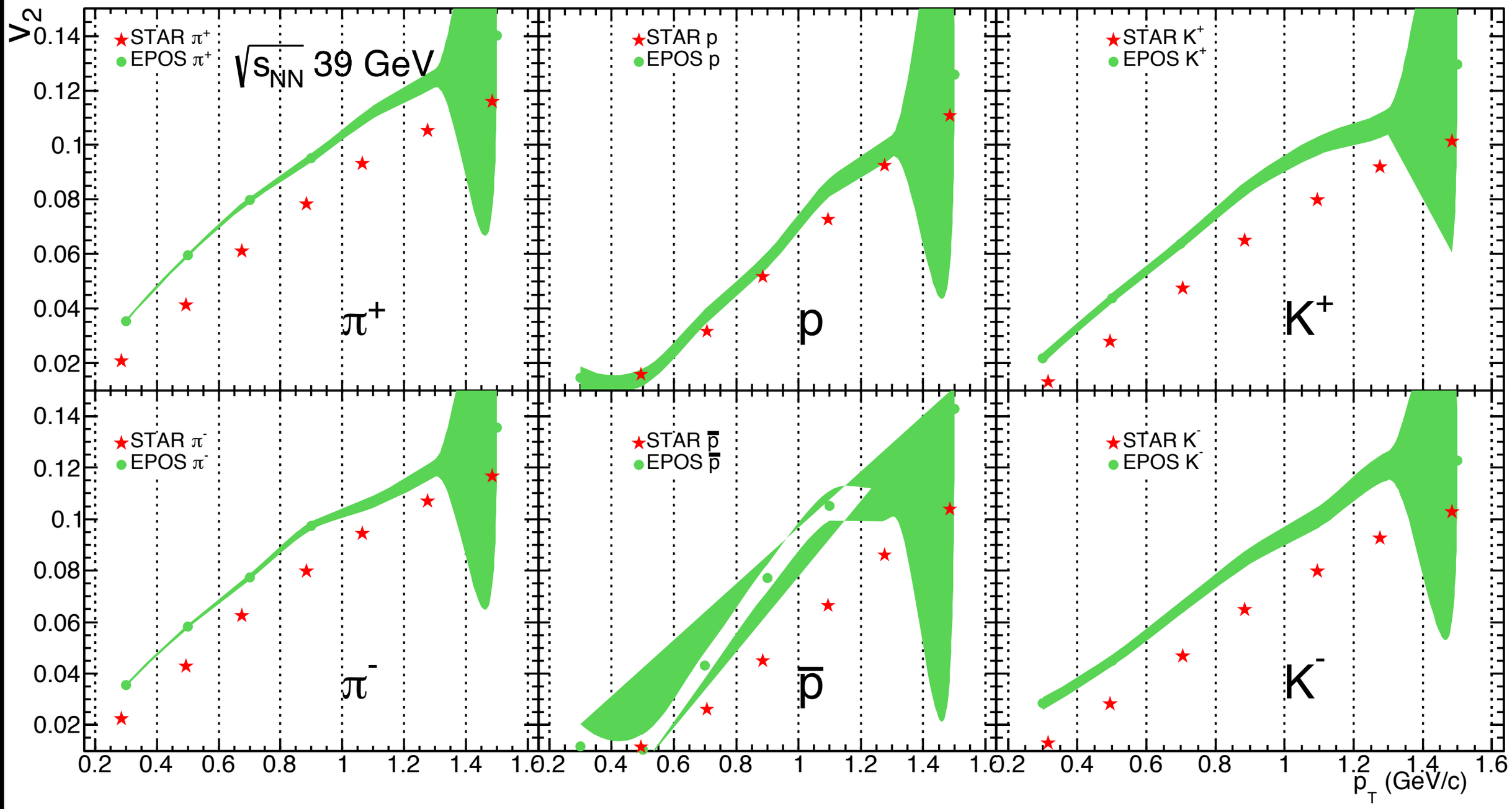
- Finally:

$$v_2 = \frac{v_2^{obs}}{R_2}$$

Elliptic flow

Analysis

STAR data published in Phys. Rev., C88:014902, 2013



Au+Au

centrality: 0-80% p ∈ (0.15, 5 GeV/c) $|\eta| \in (0.05,1)$

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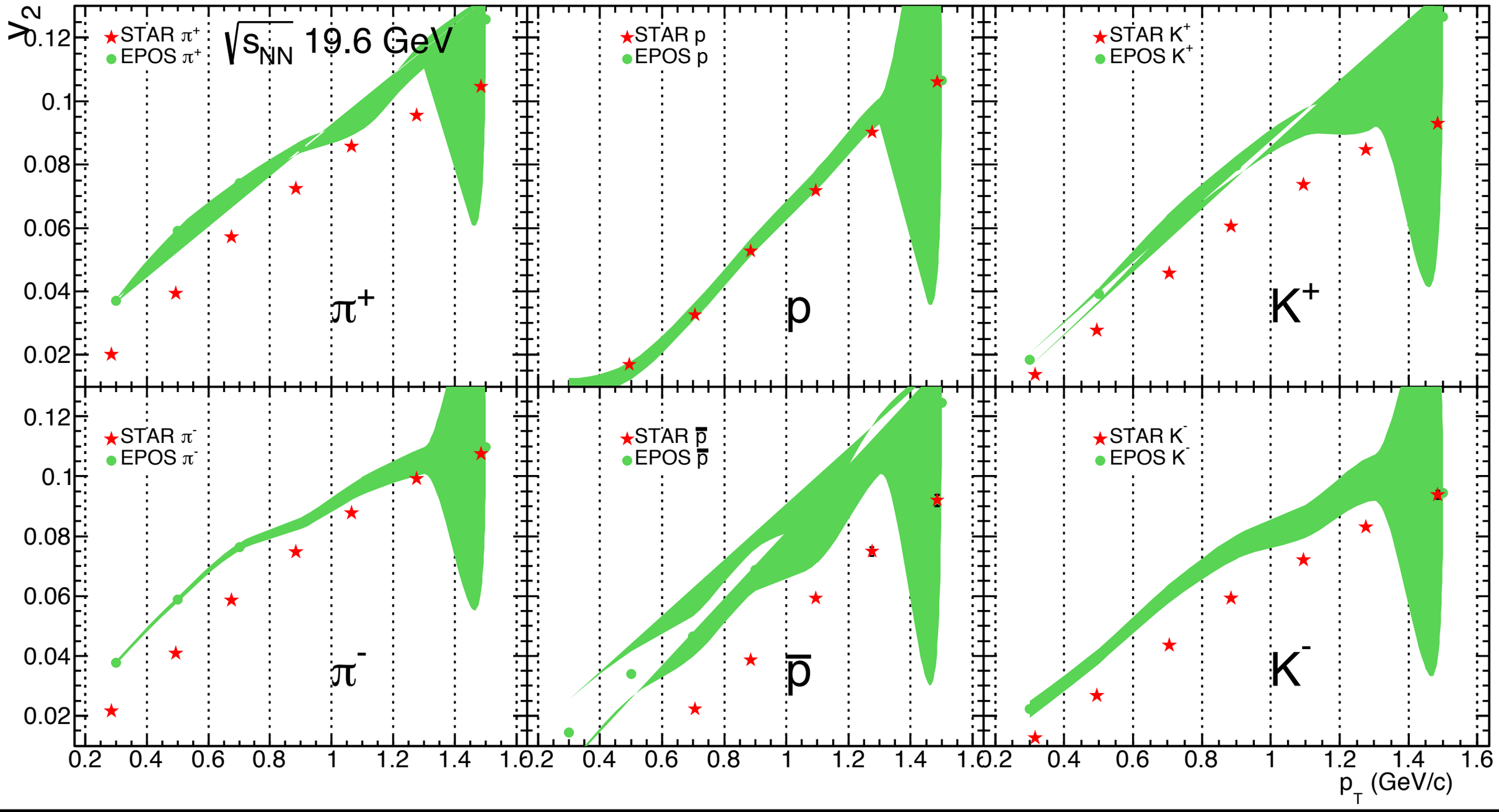

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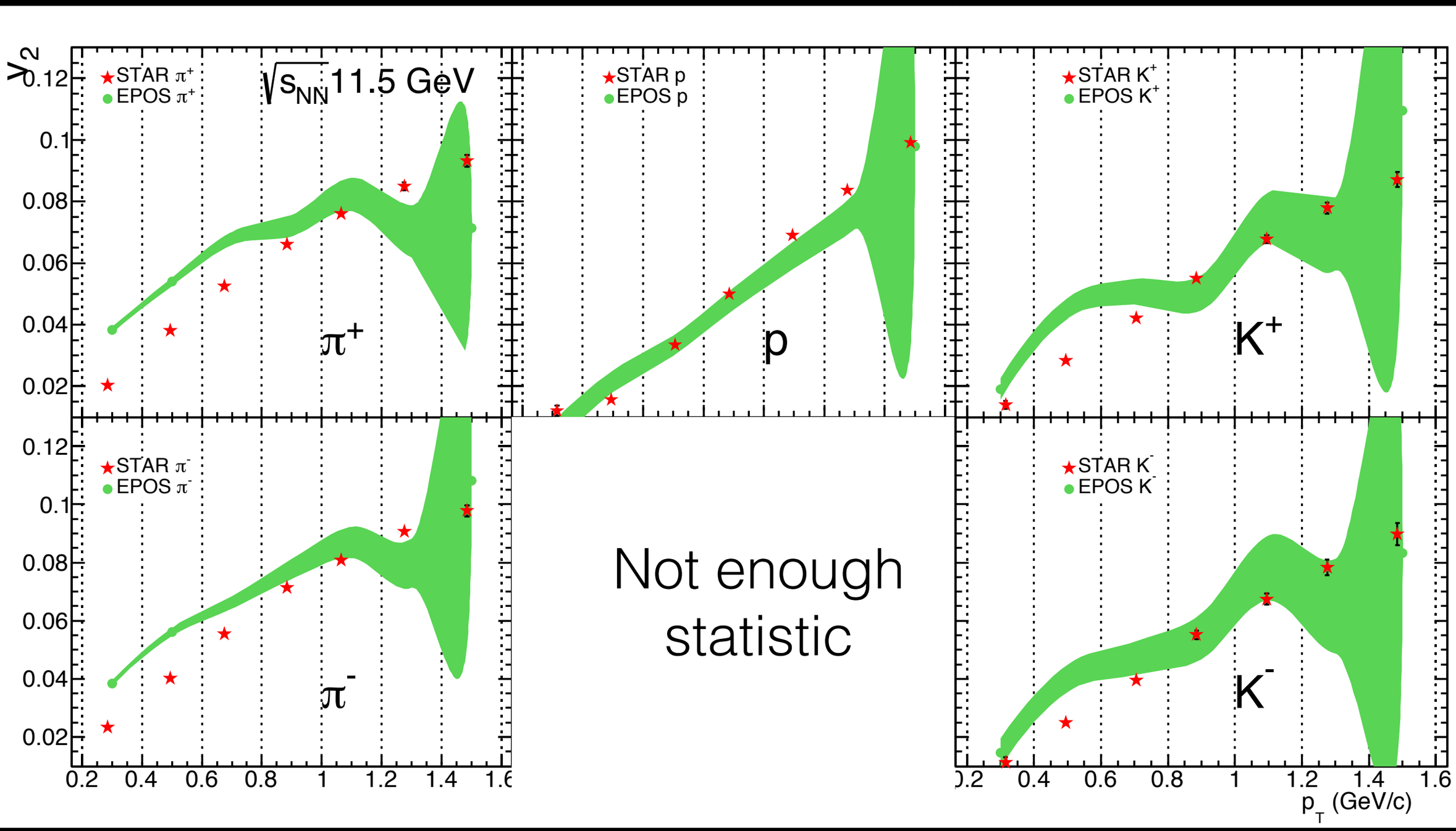

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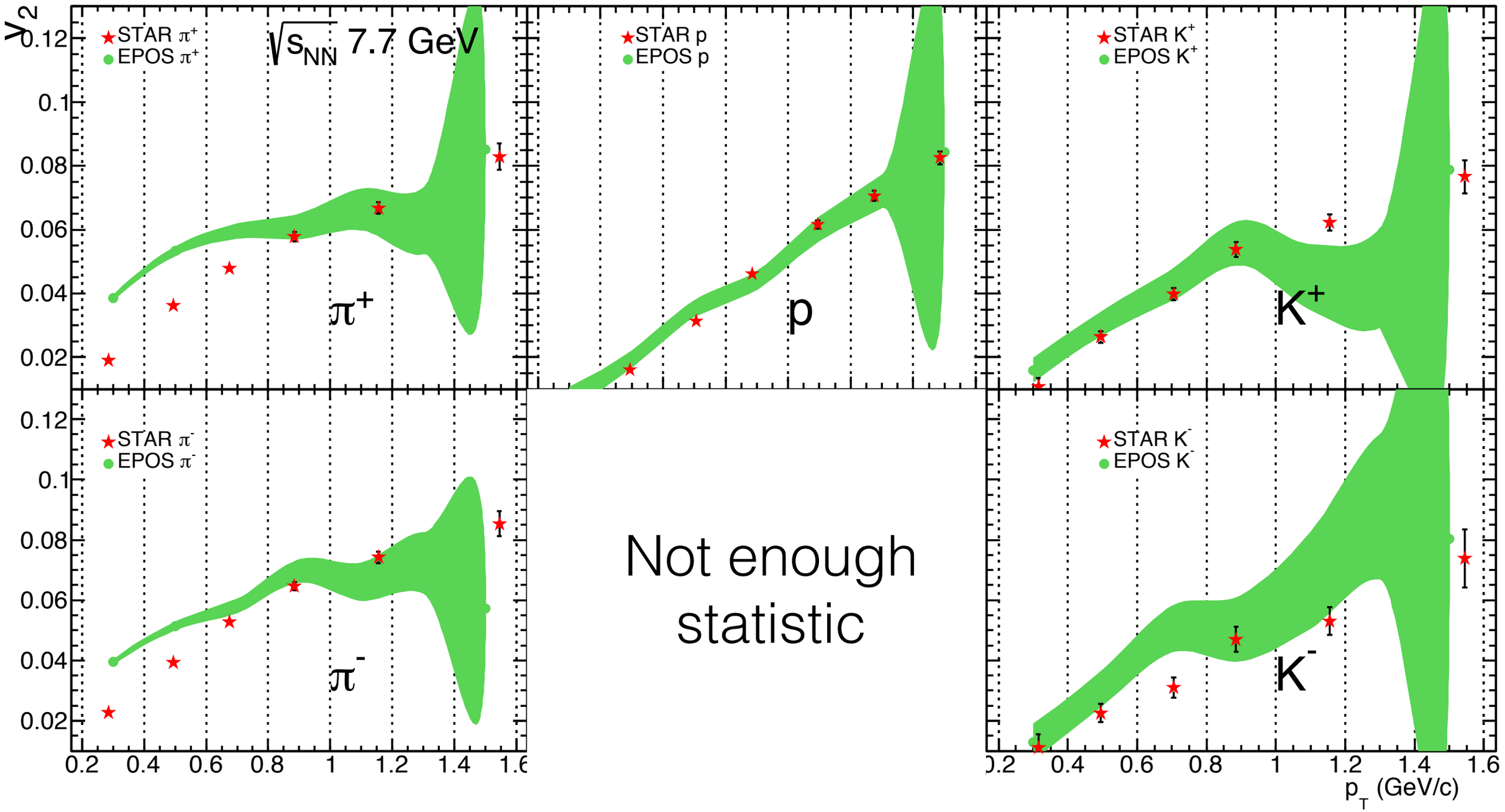
Elliptic flow

Analysis



Au+Au

centrality: 0-80% $p \in (0.15, 5\ \text{GeV/c})$ $|\eta| \in (0.05,1)$

Conclusion

- Three different methods were used:
    - transverse momentum spectra
    - elliptic flow
    - femtoscopy correlations
- Decreasing energy of collision results in more relevant differences between simulated and STAR data?

p_T spectra: Not enough particles created in fluid in case of the peripheral collisions

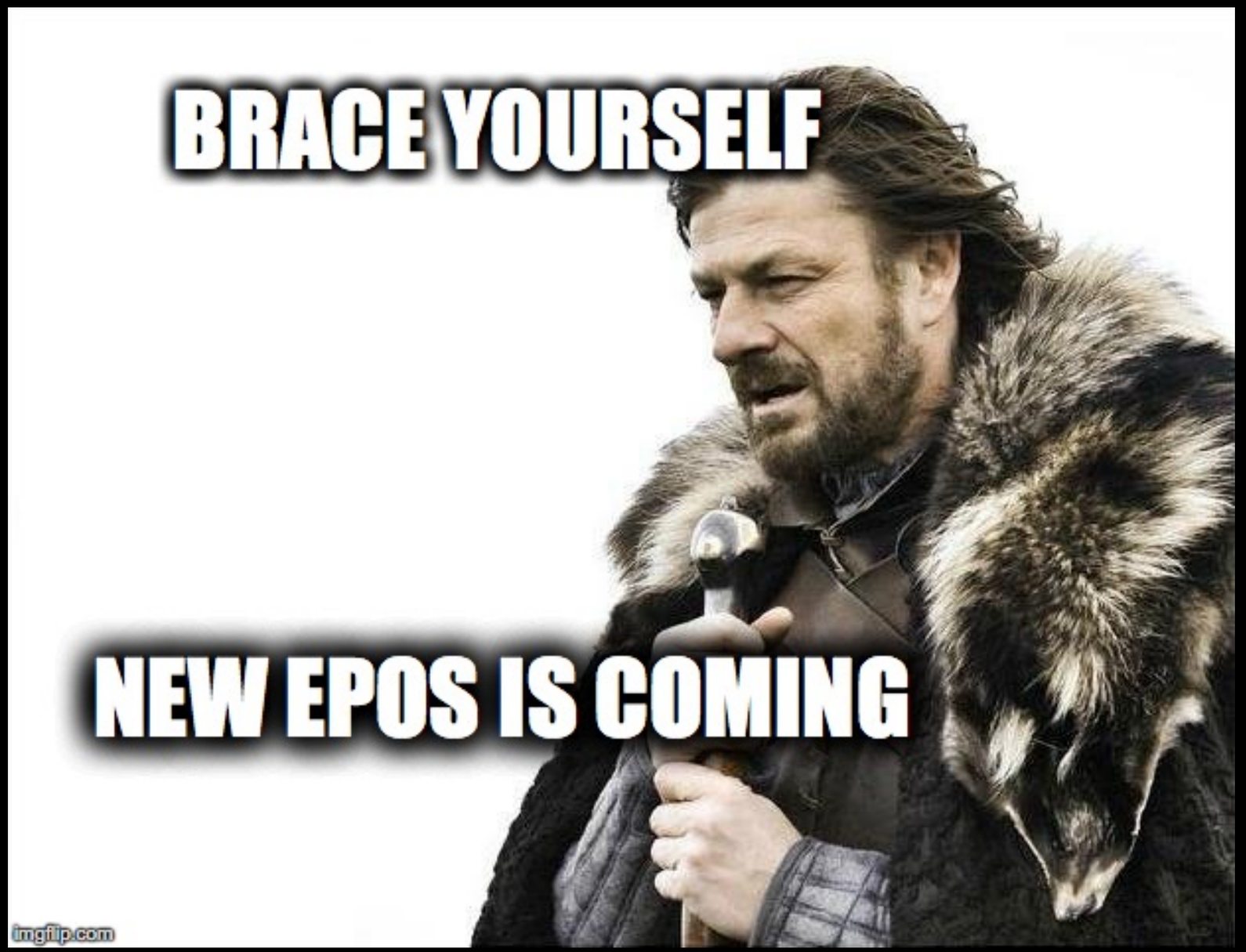
femtoscopy:

- Relevant discrepancy in R_{long} between the simulated and experimental data
- Huge impact of the hadron cascades on the homogeneity length

ecliptic flow:

- too high values for the lighter particles
- protons in range of expectation

Future plans



Thank you for your attention!

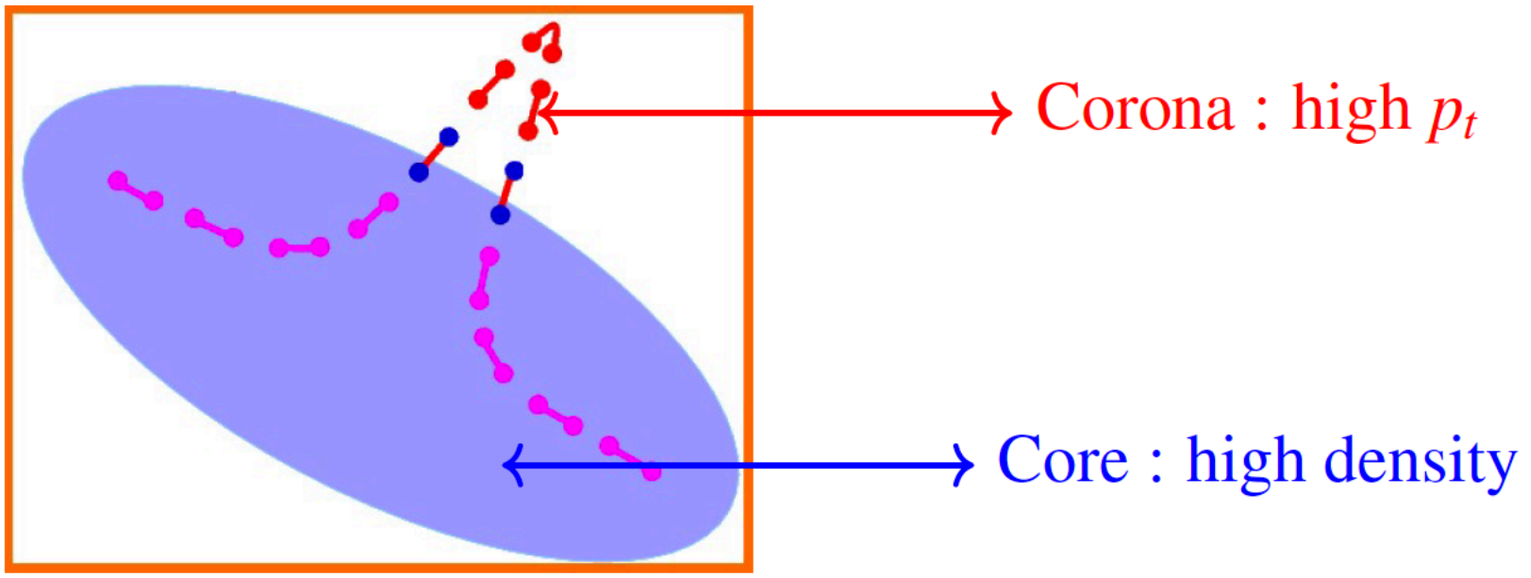
Backup

Core-Corona Approach

- Statistical hadro
- Final state hadro

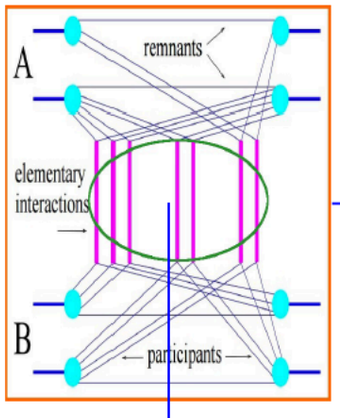
Using hydrodynamic → the Core is treated as a fluid

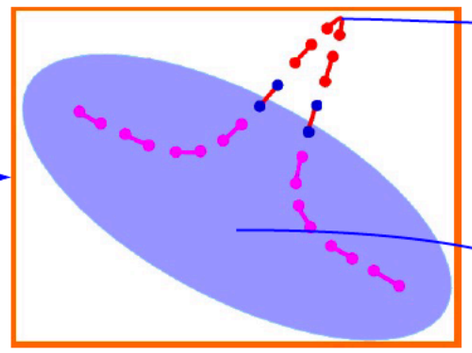
Corona becomes Jet ⇒ Later Hadrons !



B. Guiot and K. Werner, J. Phys. Conf. Ser. **589** (2015) no.1

One Event





Jet → UrQMD

Hydrodynamic Expansion

Hadronization
& Rescattering
→ UrQMD