

# XIII Polish Workshop on Relativistic Heavy-Ion Collisions

## Wrocław 2018

# EXAMINATION OF HEAVY-ION COLLISIONS USING EPOS MODEL IN THE FRAME OF BES PROGRAM

**Maria Stefaniak**

Under supervision of: Hanna Zbroszczyk & Klaus Werner



**Wydział  
Fizyki**

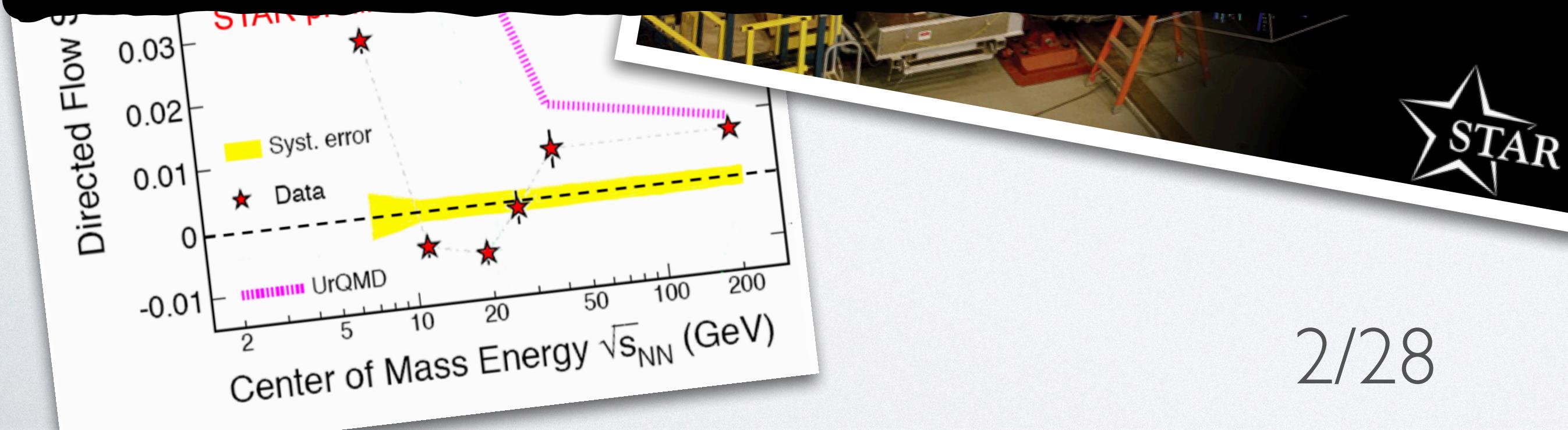
POLITECHNIKA WARSZAWSKA



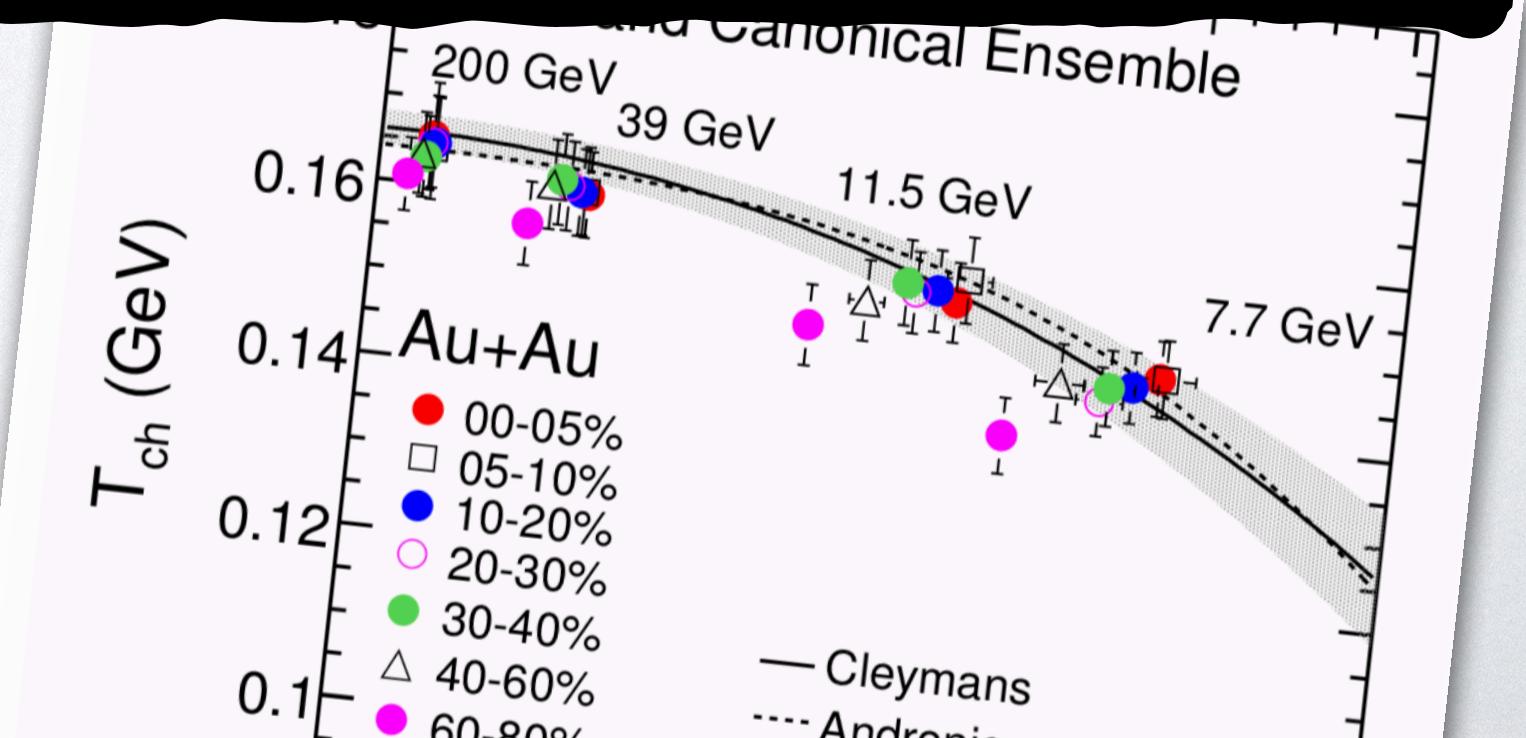
# EPOS3



## BEAM ENERGY SCAN



2/28

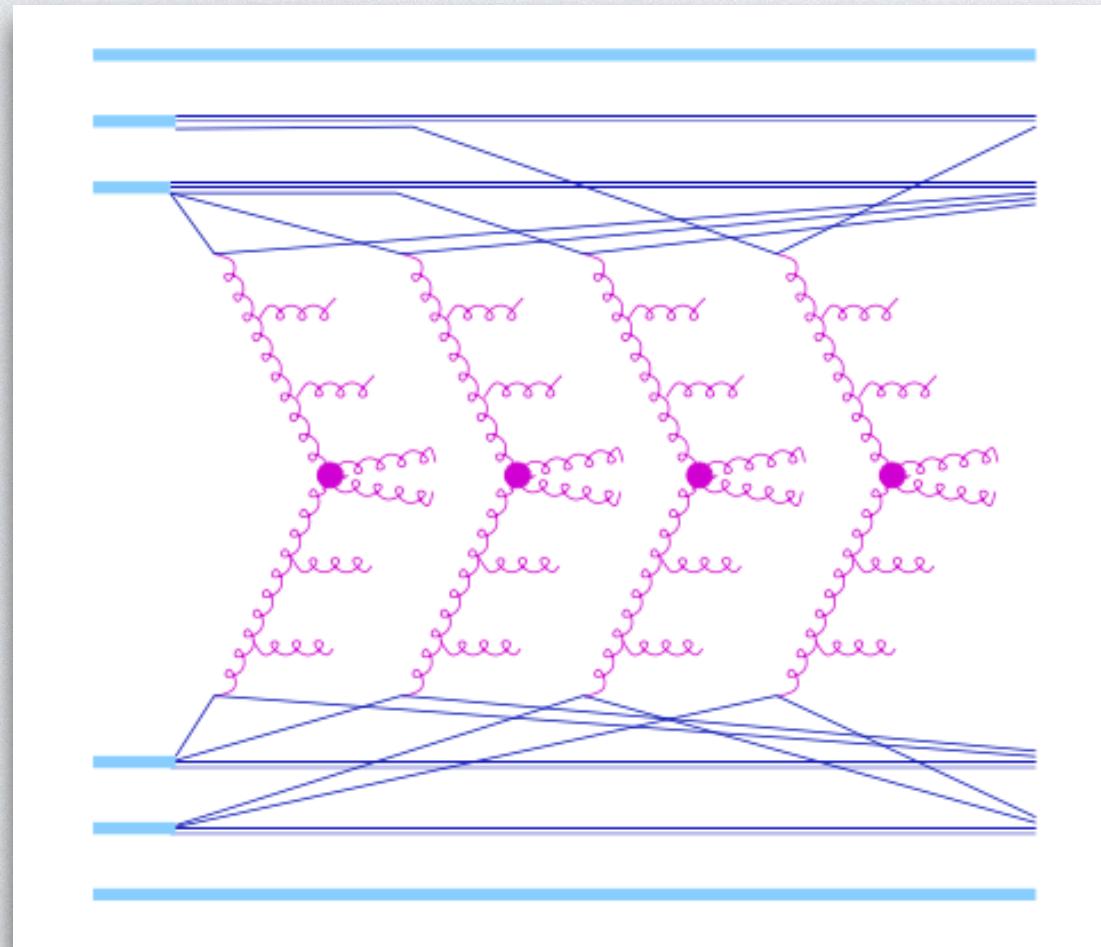


# **EPOS3**

# EPOS3

## Gribov-Regge multiple scattering approach

- Pomerons
- Parton ladders
- Strings



*J. Phys.: Conf. Ser. 736 012009*

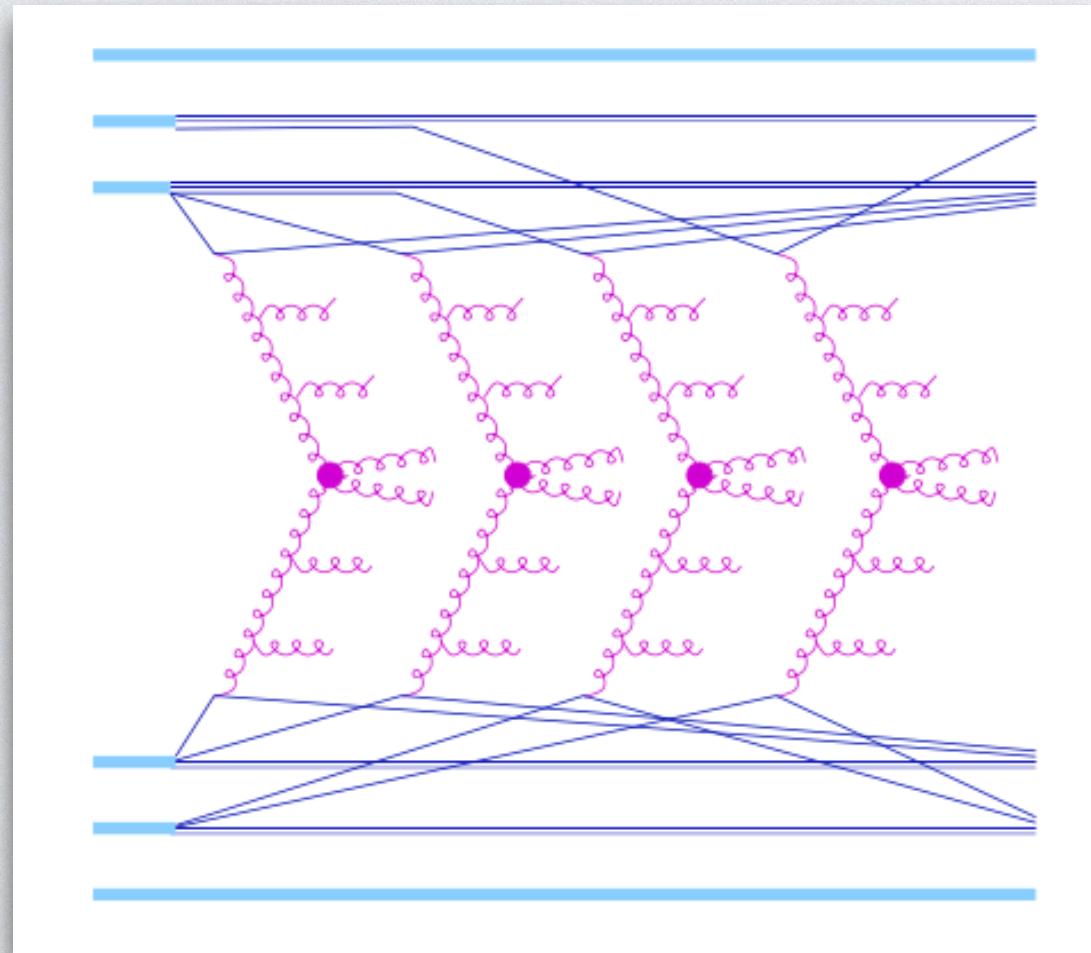
## Core-Corona approach

## Viscous hydrodynamic expansion

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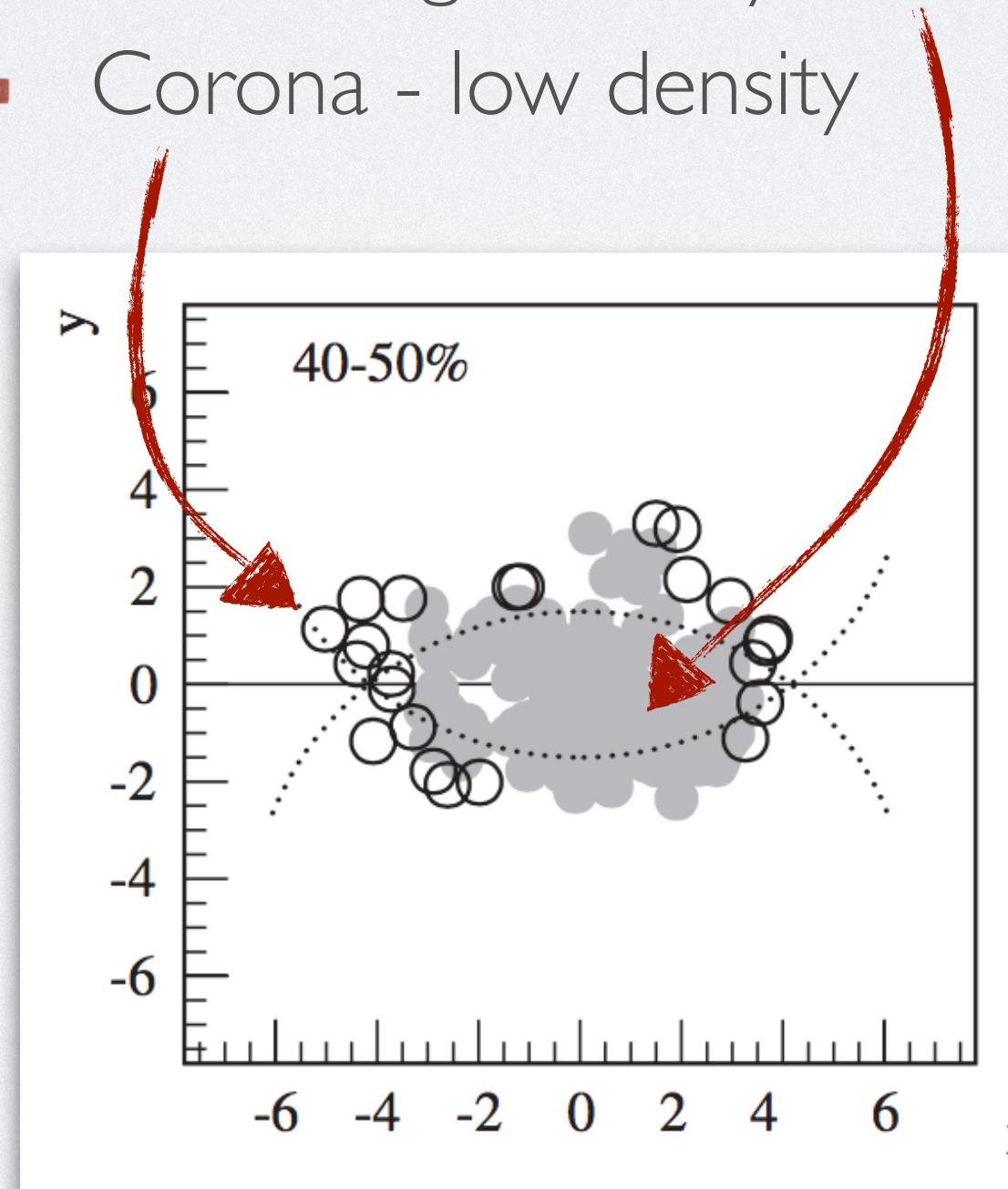


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## Core-Corona approach

Strings segment in:

- Core - high density area
- Corona - low density



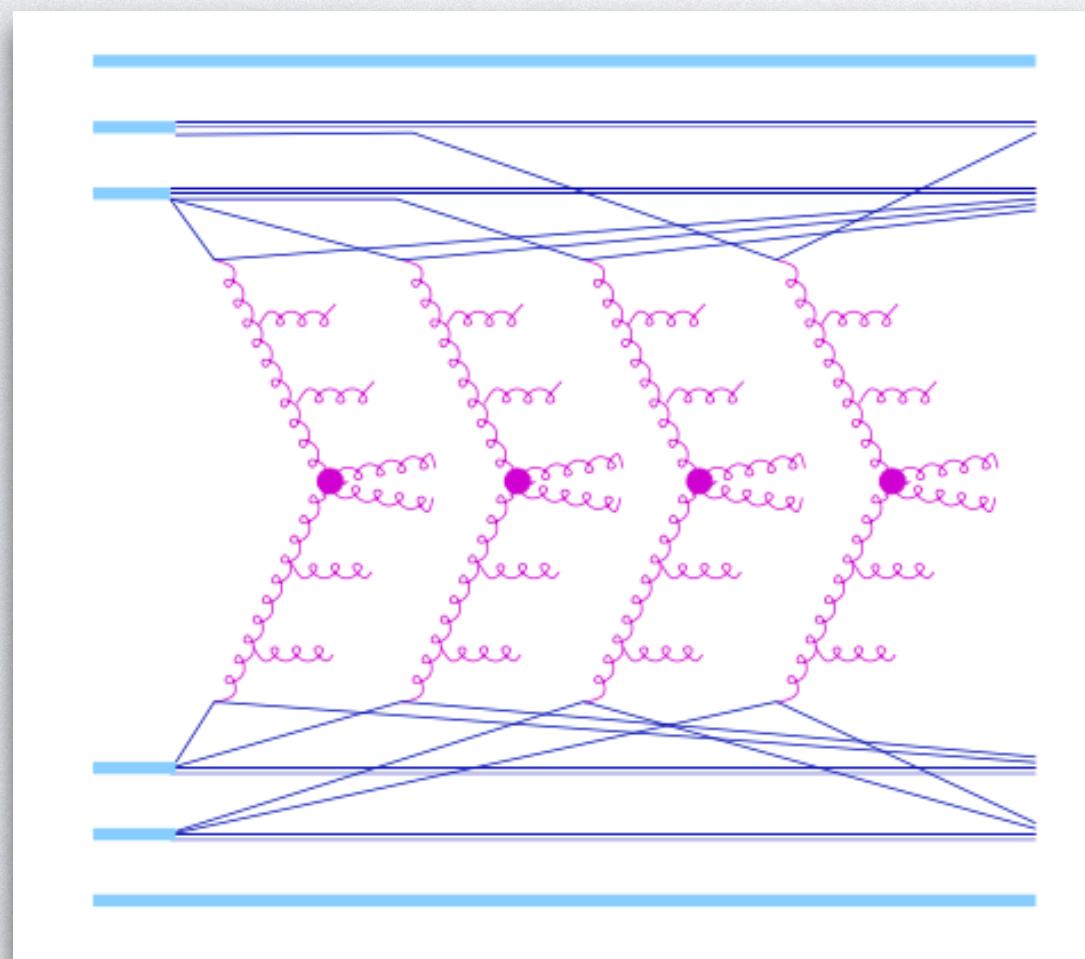
*PhysRevLett.98.152301*

## Viscous hydrodynamic expansion

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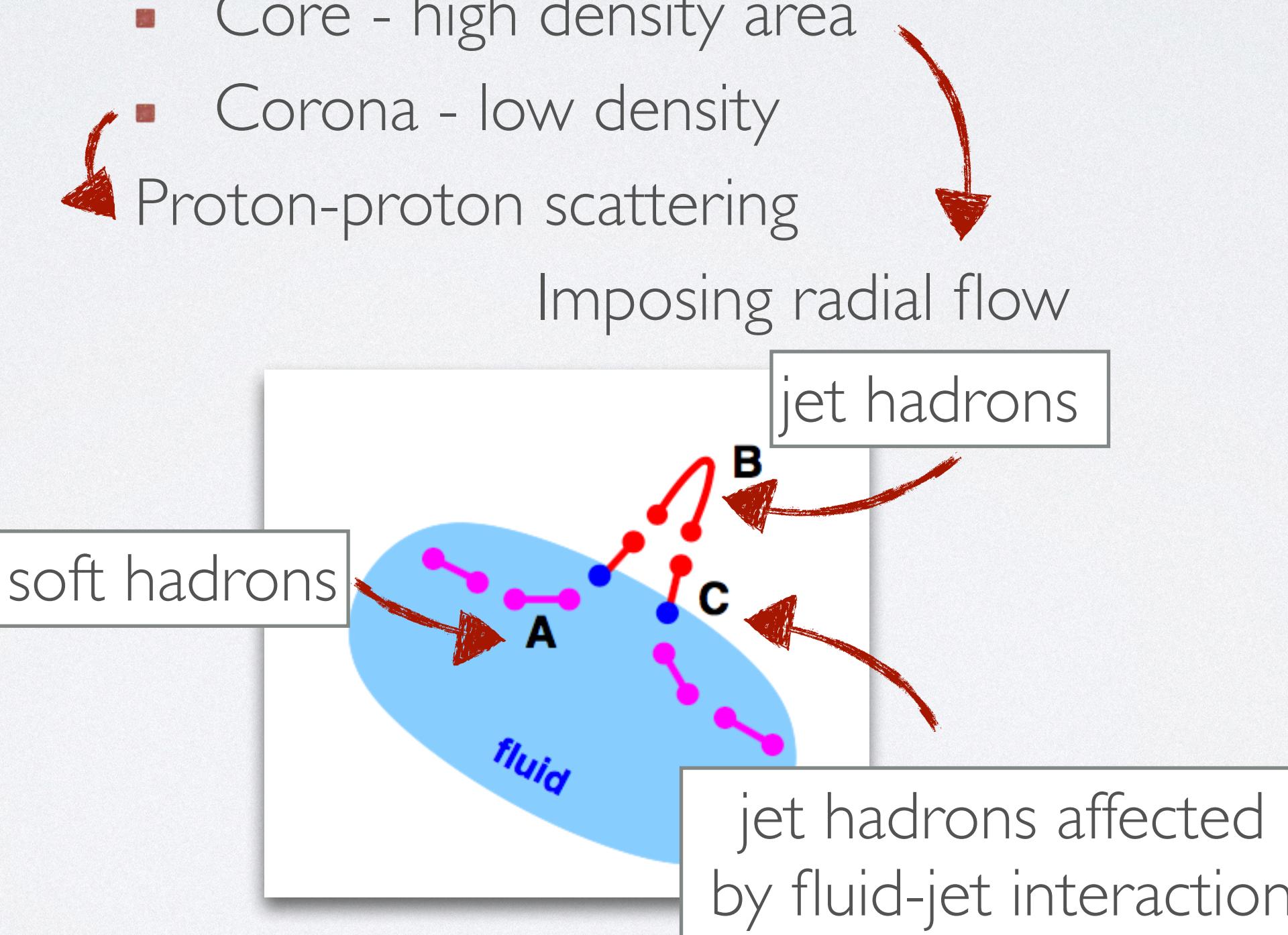


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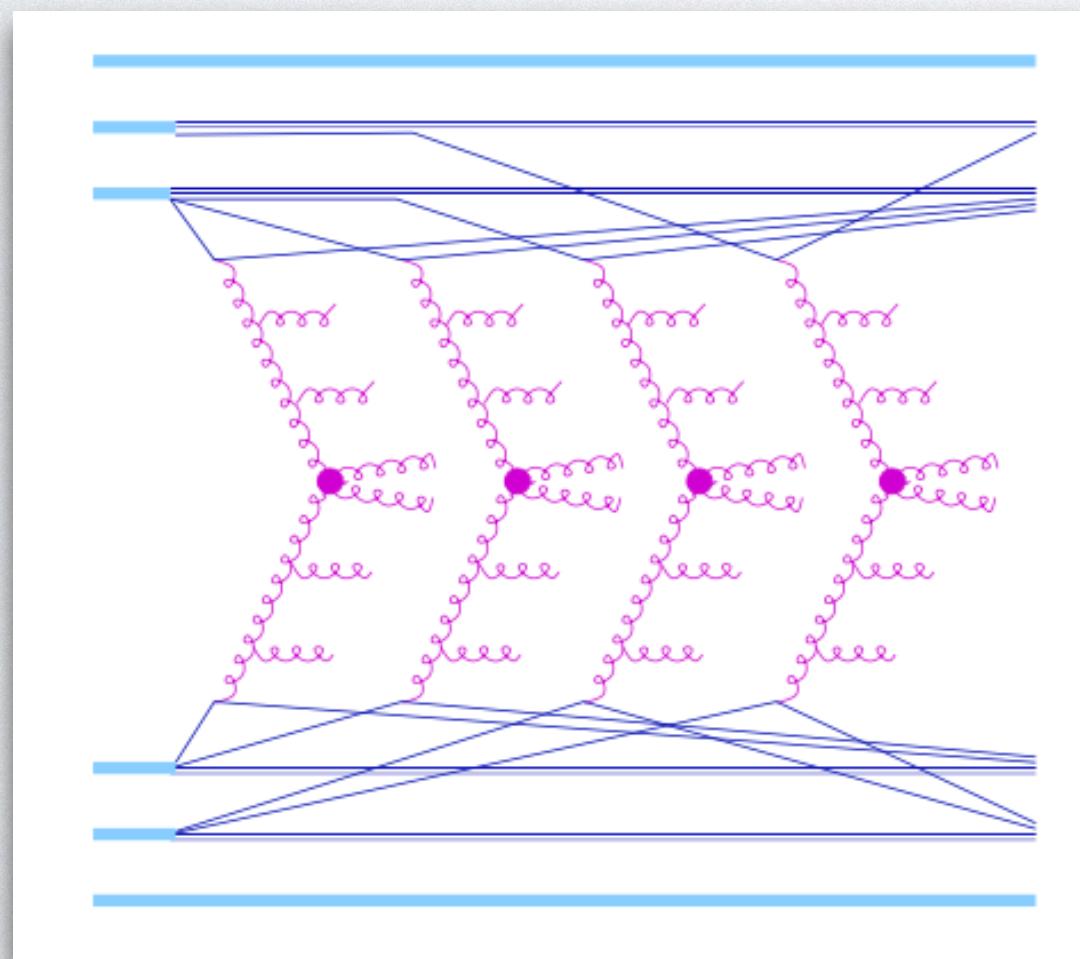
*Journal of Physics: Conference Series 422 (2013) 012001*

## Viscous hydrodynamic expansion

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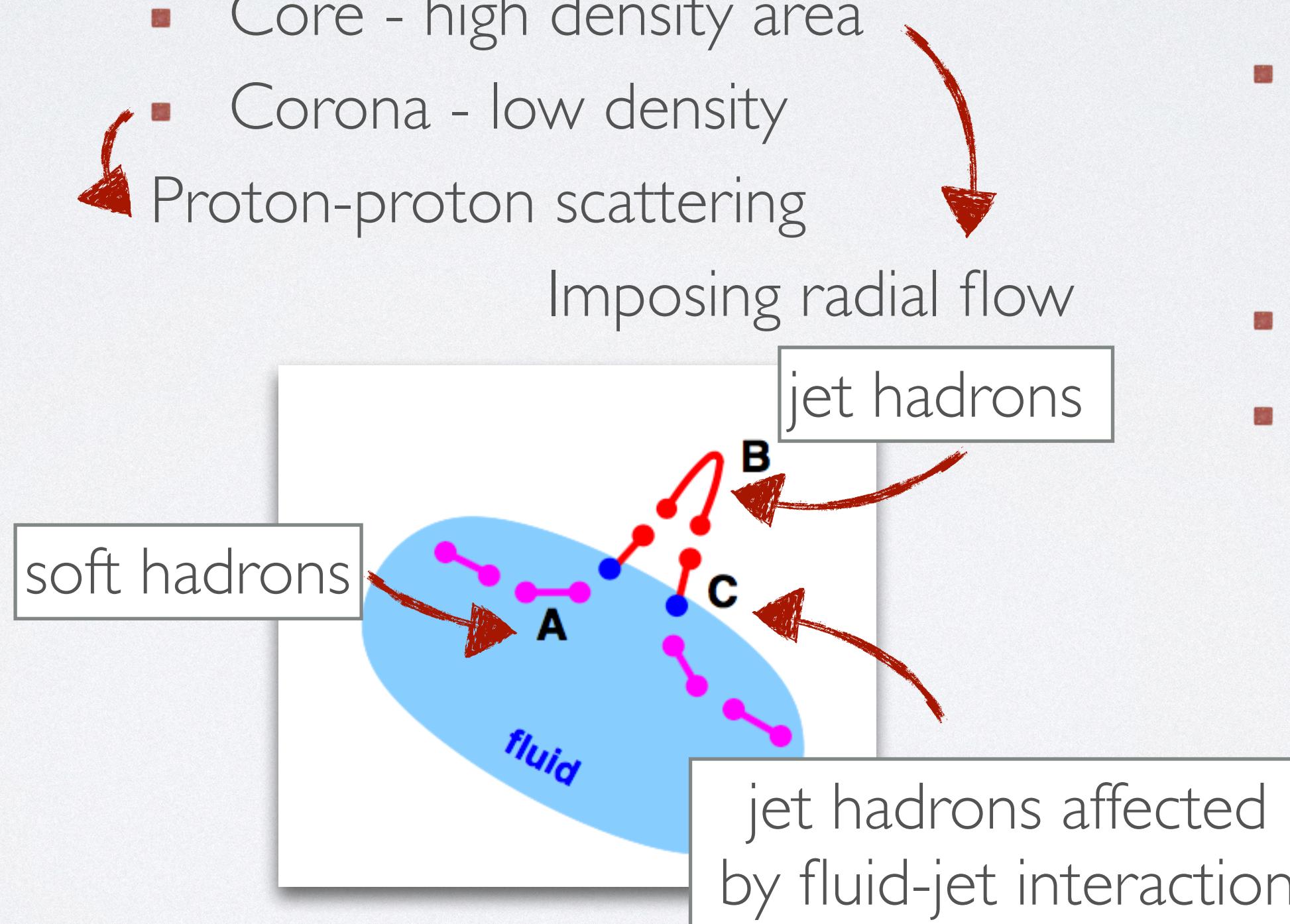
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## Viscous hydrodynamic expansion

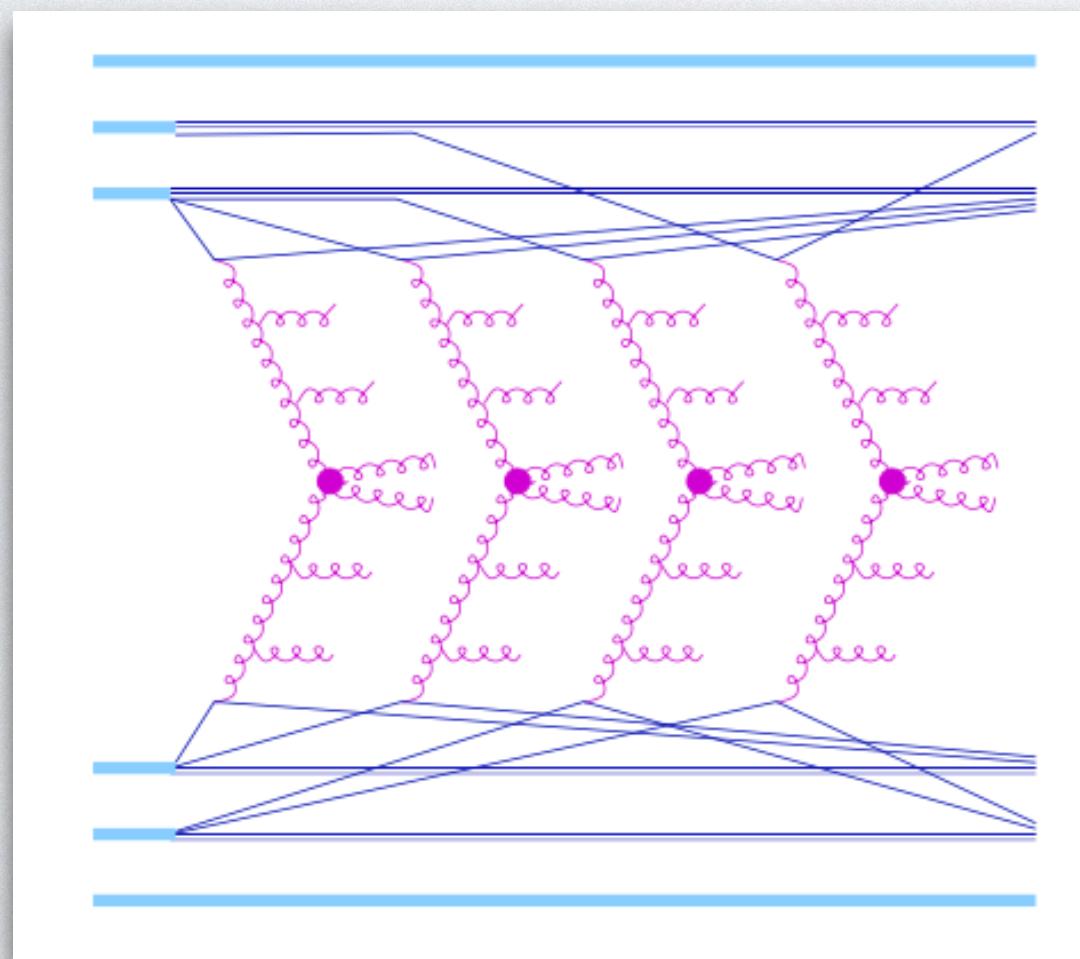
- Initial time  $\tau_0$
- Evolution of system according to the eq. of relativistic viscous hydrodynamics
- $\eta/s = 0.08$
- cross-over equation-of-state, compatible with lattice QCD

# EPOS3



## Gribov-Regge multiple scattering approach

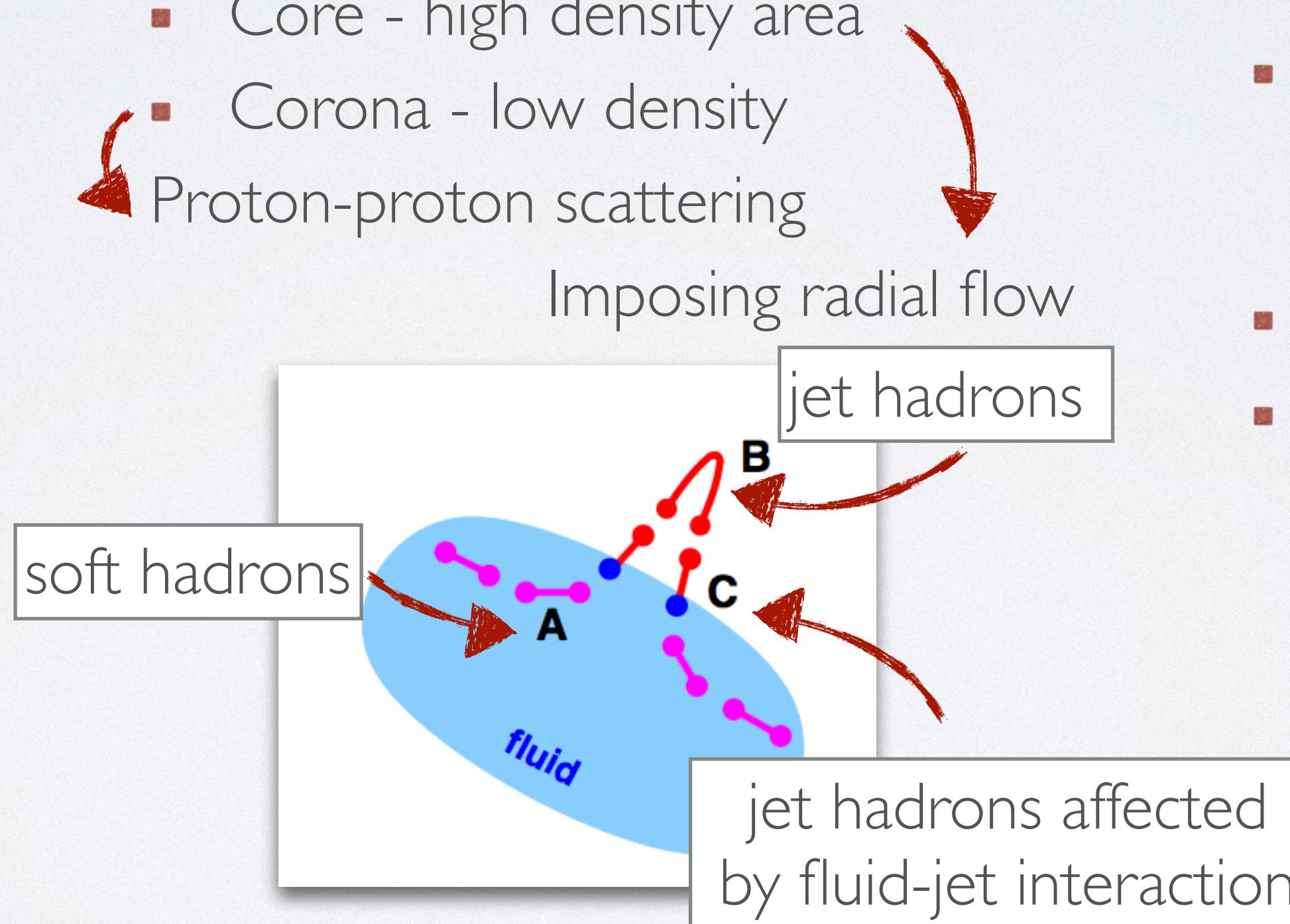
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# EPOS3

## Statistical hadronization

Core matter:

- hadronization on hypersurface with constant  $T_H$
- Cooper-Frye procedure

## Final state Hadronic Cascade

*Phys. Rev. C 83, 044915 (2011)*

# EPOS3

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If hadron density big enough  
hadron-hadron rescattering

**URQMD model**

*Phys. Rev. C 83, 044915 (2011)*

*J. Phys. G25 (1999) 1859,*

*Phys. Rev. C78 (2008) 044901*

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*Phys. Rev. C 83, 044915 (2011)*

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Phys. Rev. C78 (2008) 044901*

*Experimental data: Phys.Rev. C92 (2015) no.1, 014904*

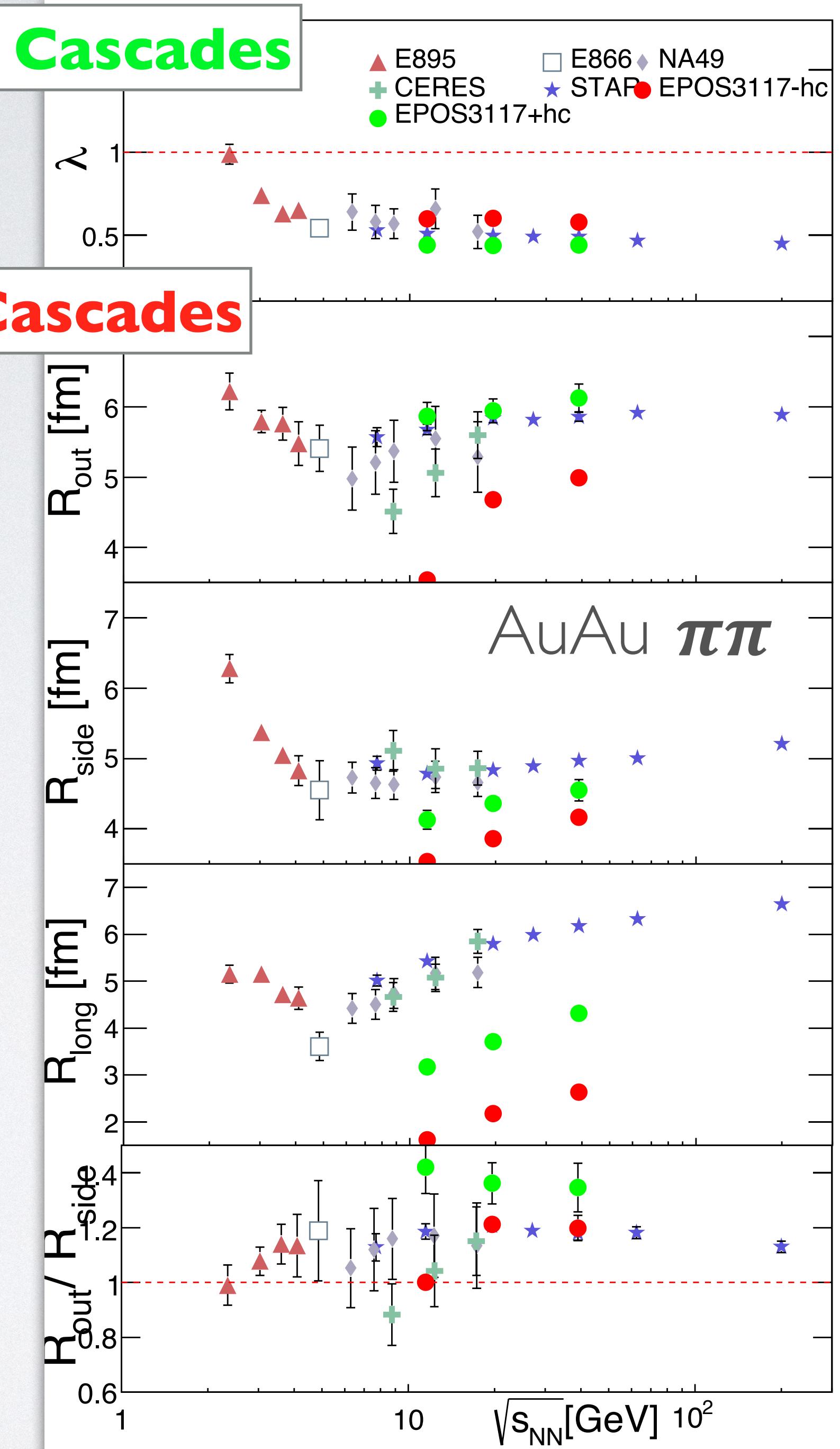
## With Hadronic Cascades

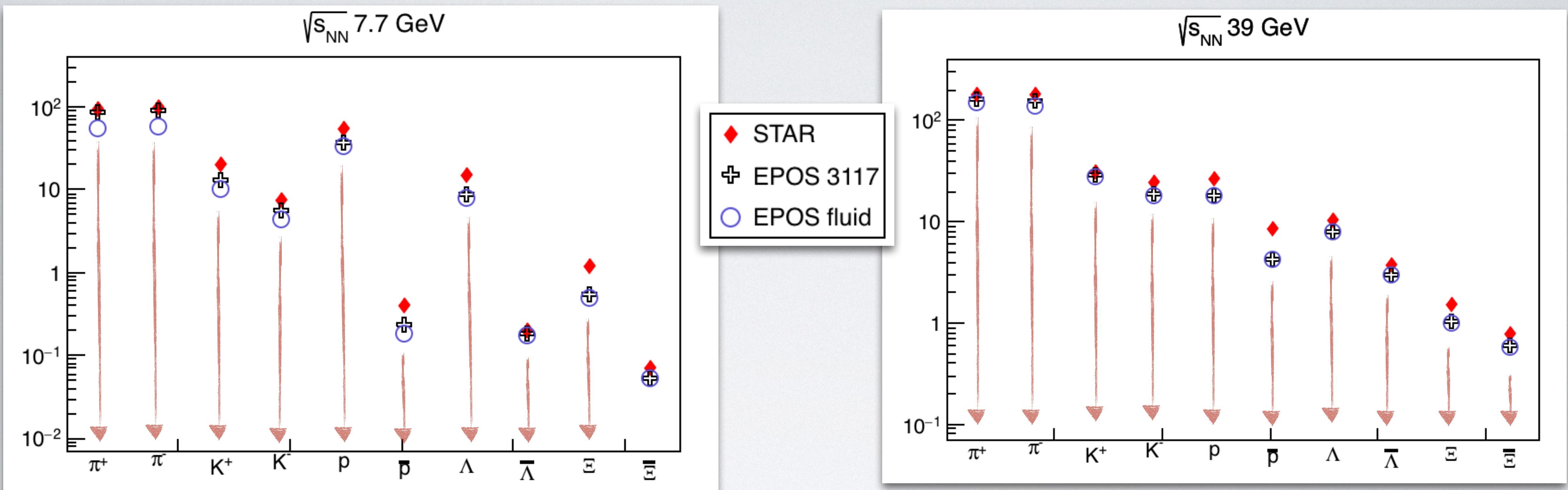
# EPOS3

## NO Hadronic Cascades

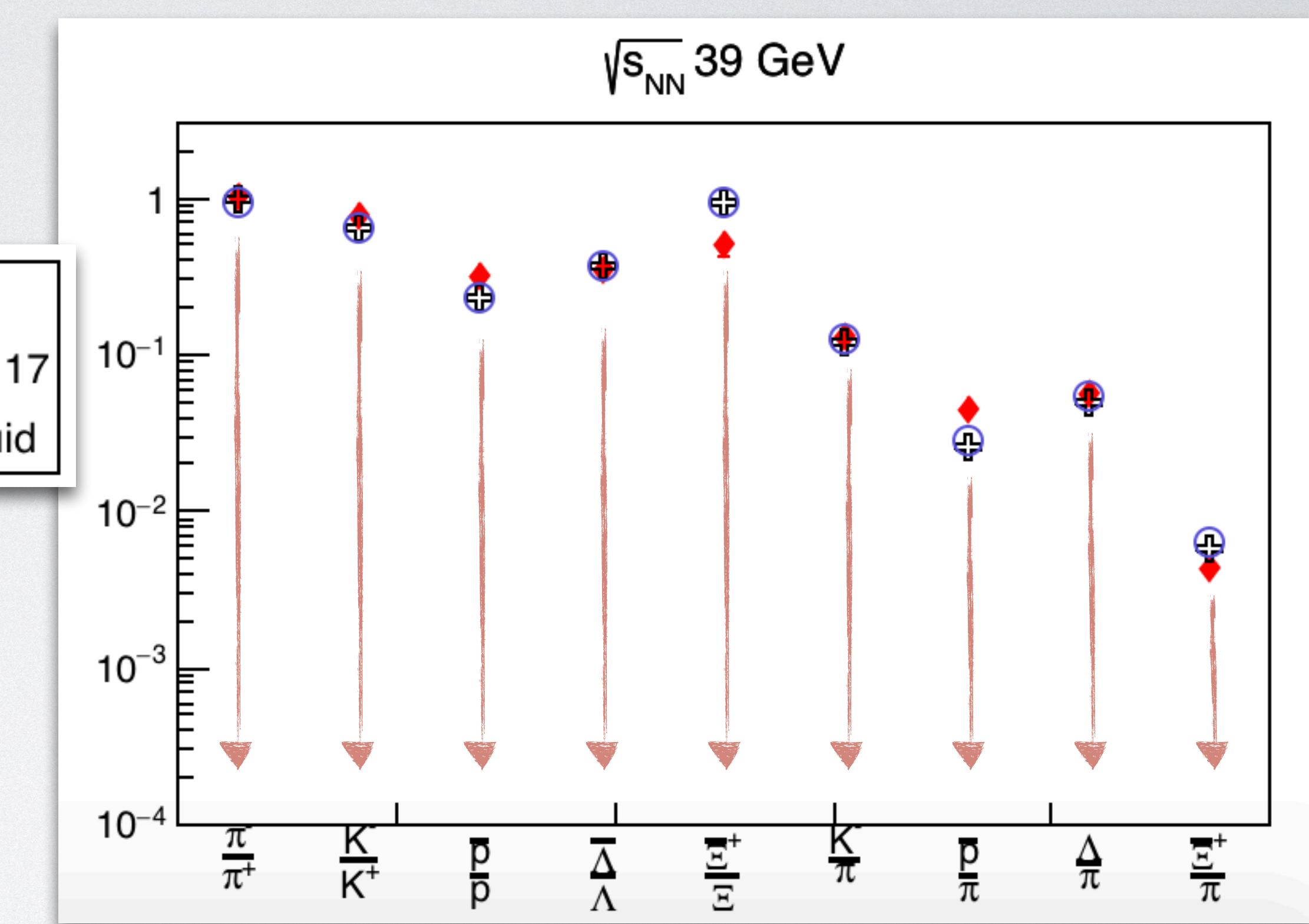
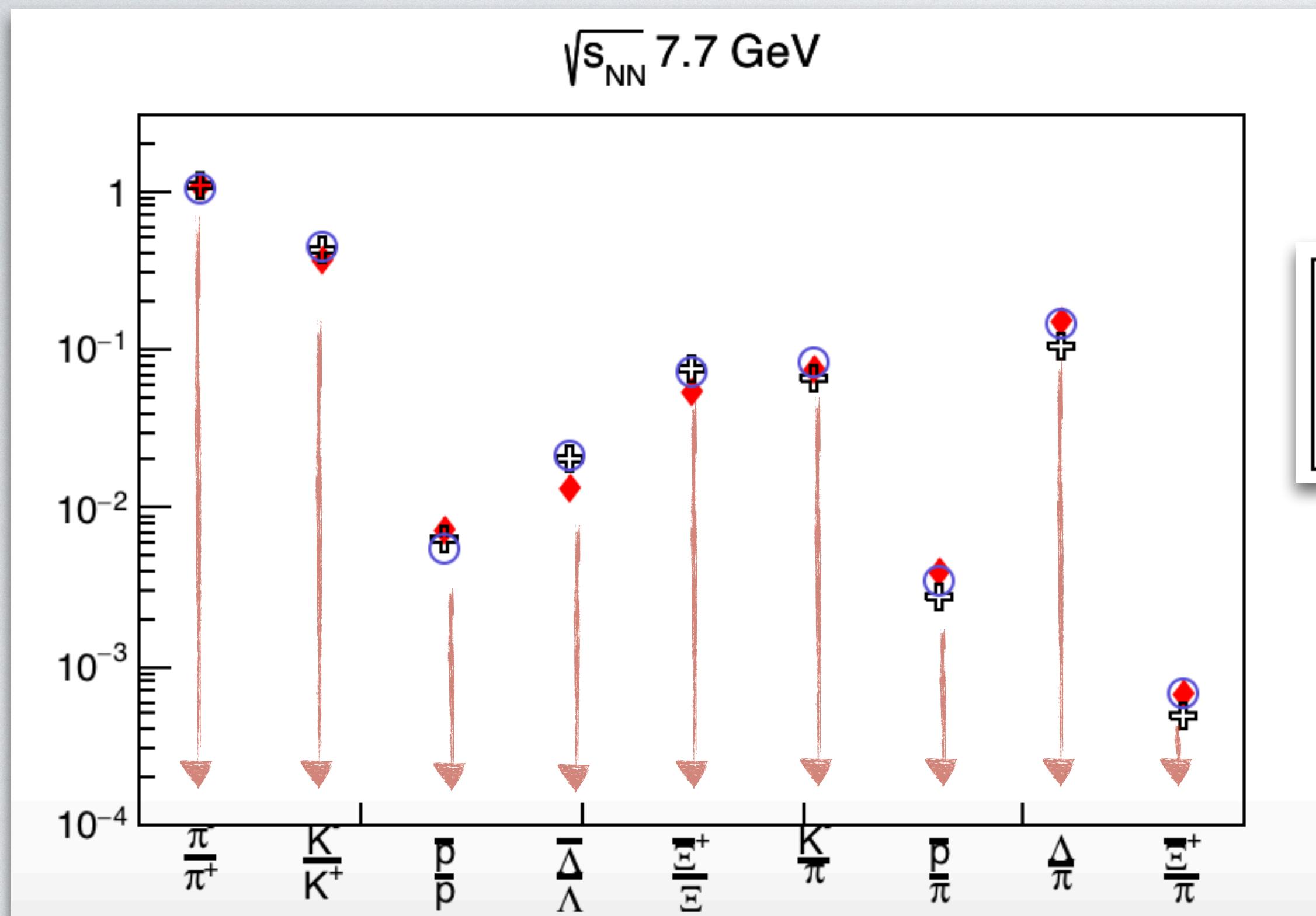
### Final state Hadronic Cascade

If hadron density big enough  
hadron-hadron rescattering  
**URQMD model**





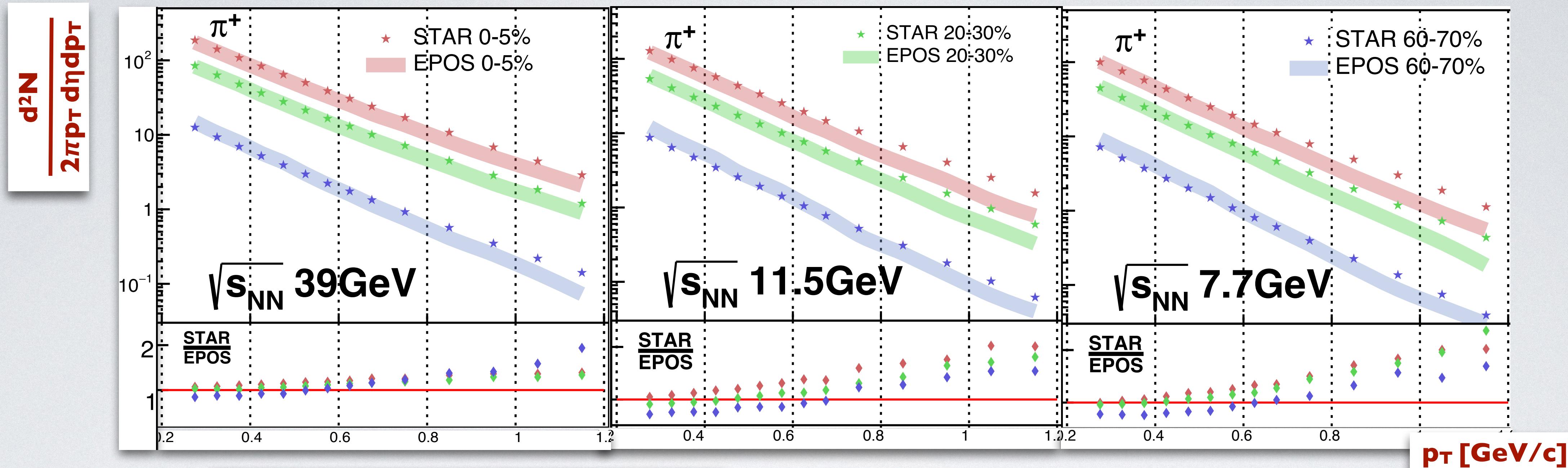
- Simulated and Experimental data nearly overlap
- Nr of particles:  
**EPOS < STAR**
- Big fraction of fluid-particles for 7.7 GeV



- Ratio comparable
- antiparticle particle

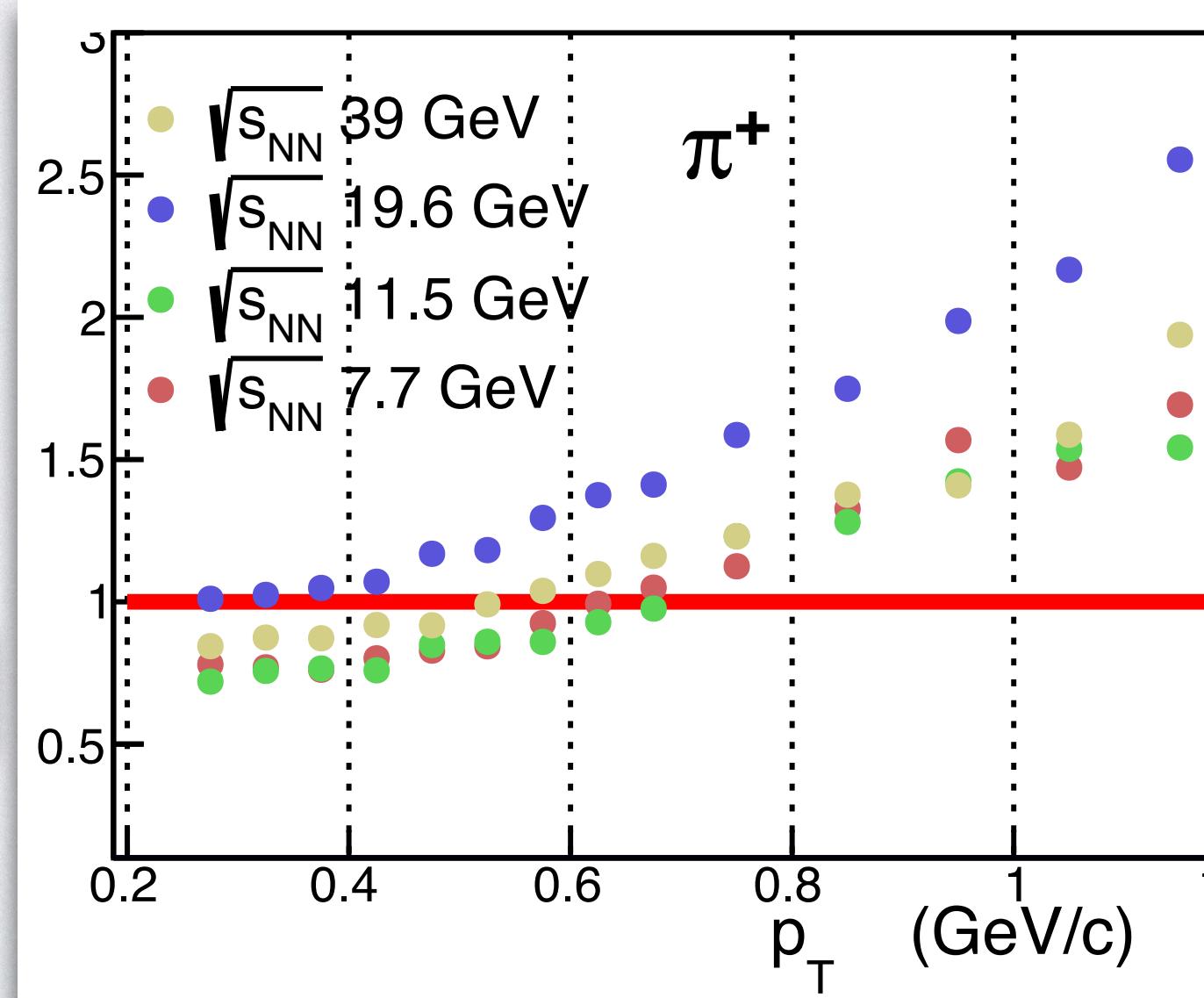
# SPECTRA $P_T \pi^+$

arXiv:1701.07065 Au+Au



**STAR**  
**EPOS**

Centrality: 60-70%



- Small differences, for **39GeV in the range of expectations!**
- In **peripheral collisions** visible discrepancies of **slope** for **all energies** in **whole  $p_T$  range**

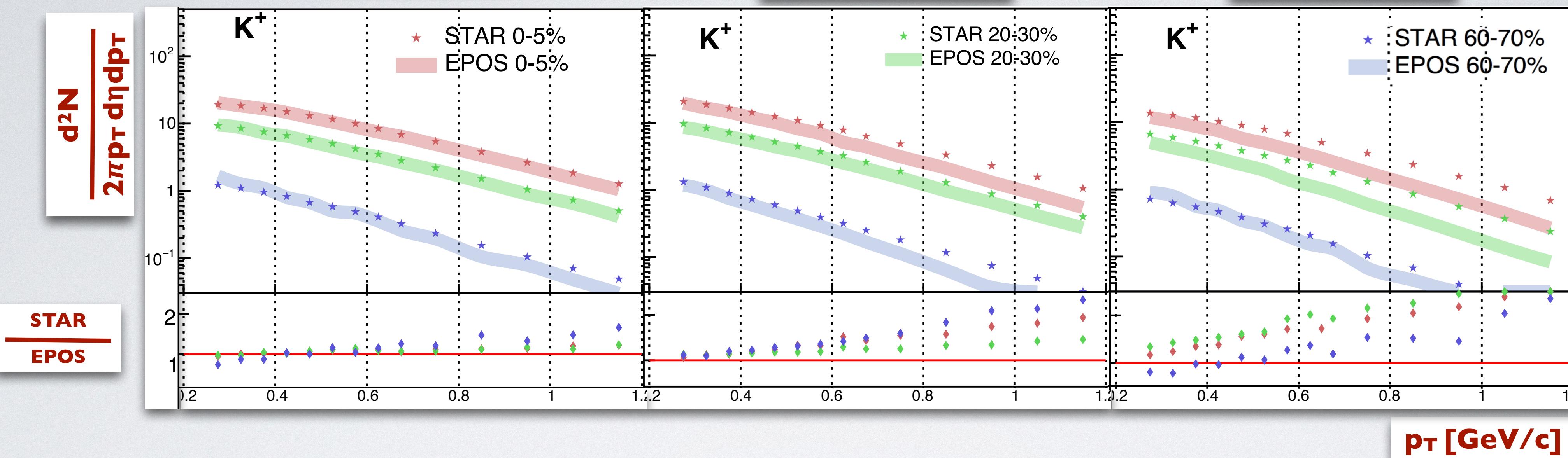
# SPECTRA $P_T$ $K^+$

Au+Au

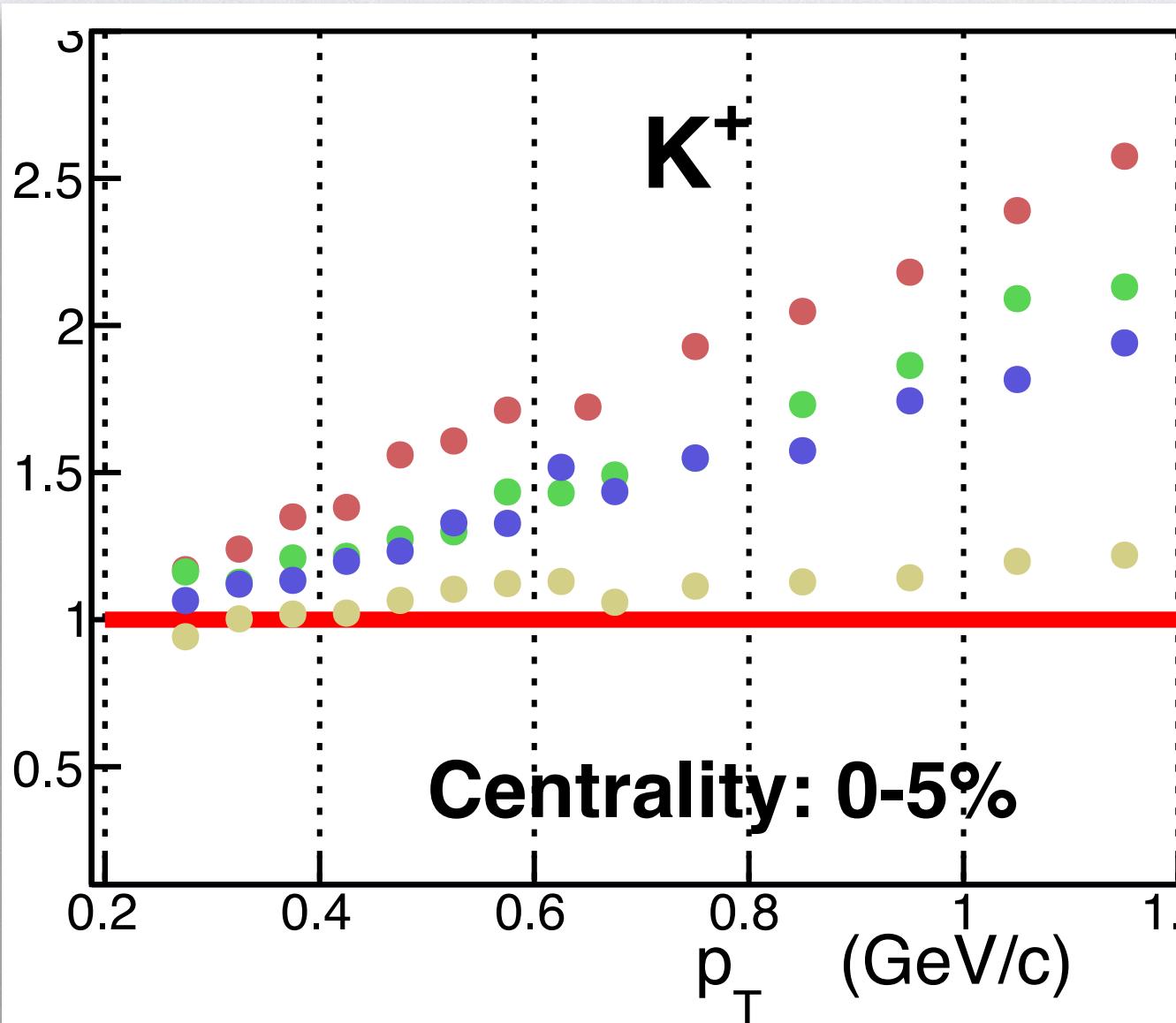
$\sqrt{s_{NN}}$  39 GeV

$\sqrt{s_{NN}}$  19.6 GeV

$\sqrt{s_{NN}}$  7.7 GeV



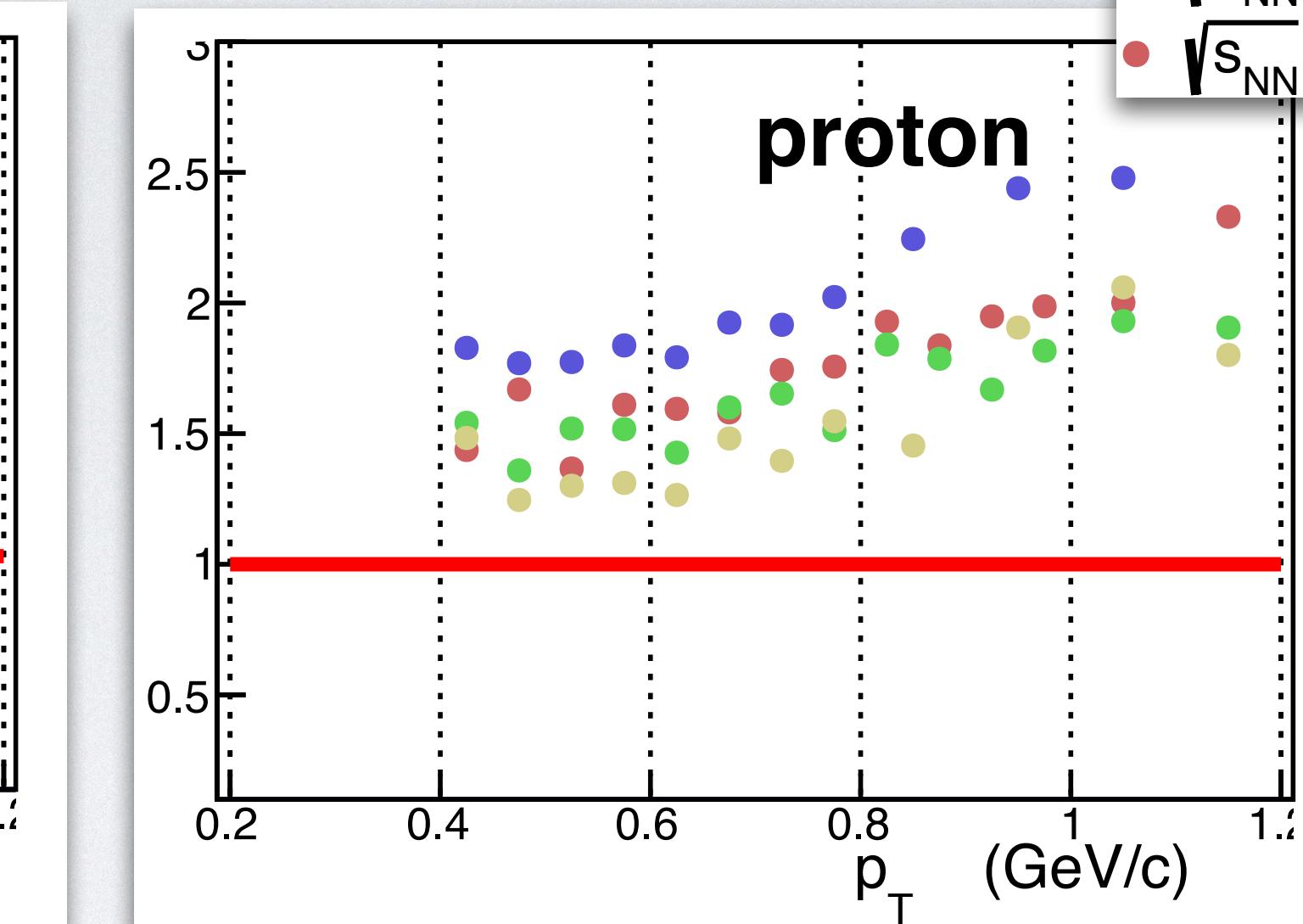
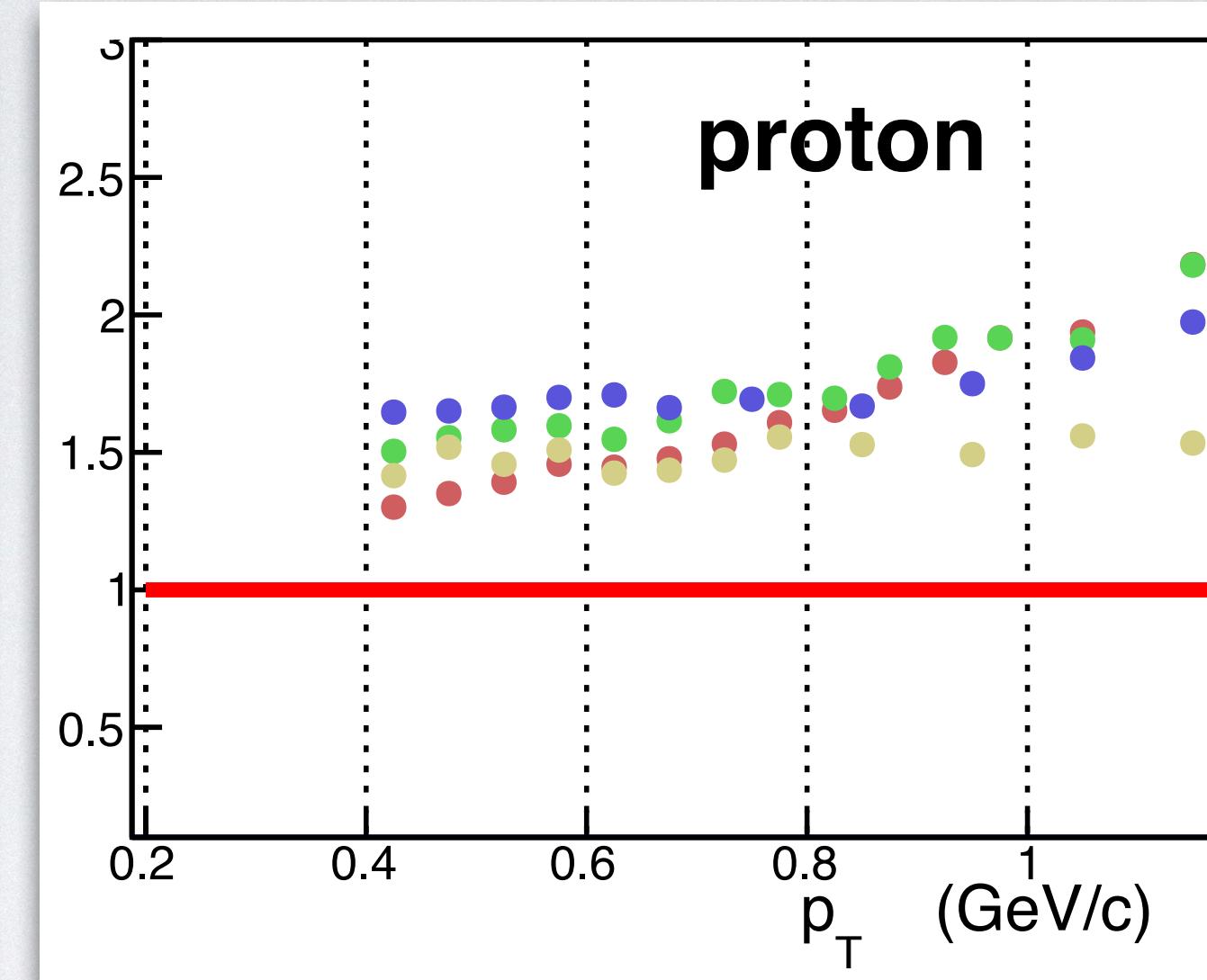
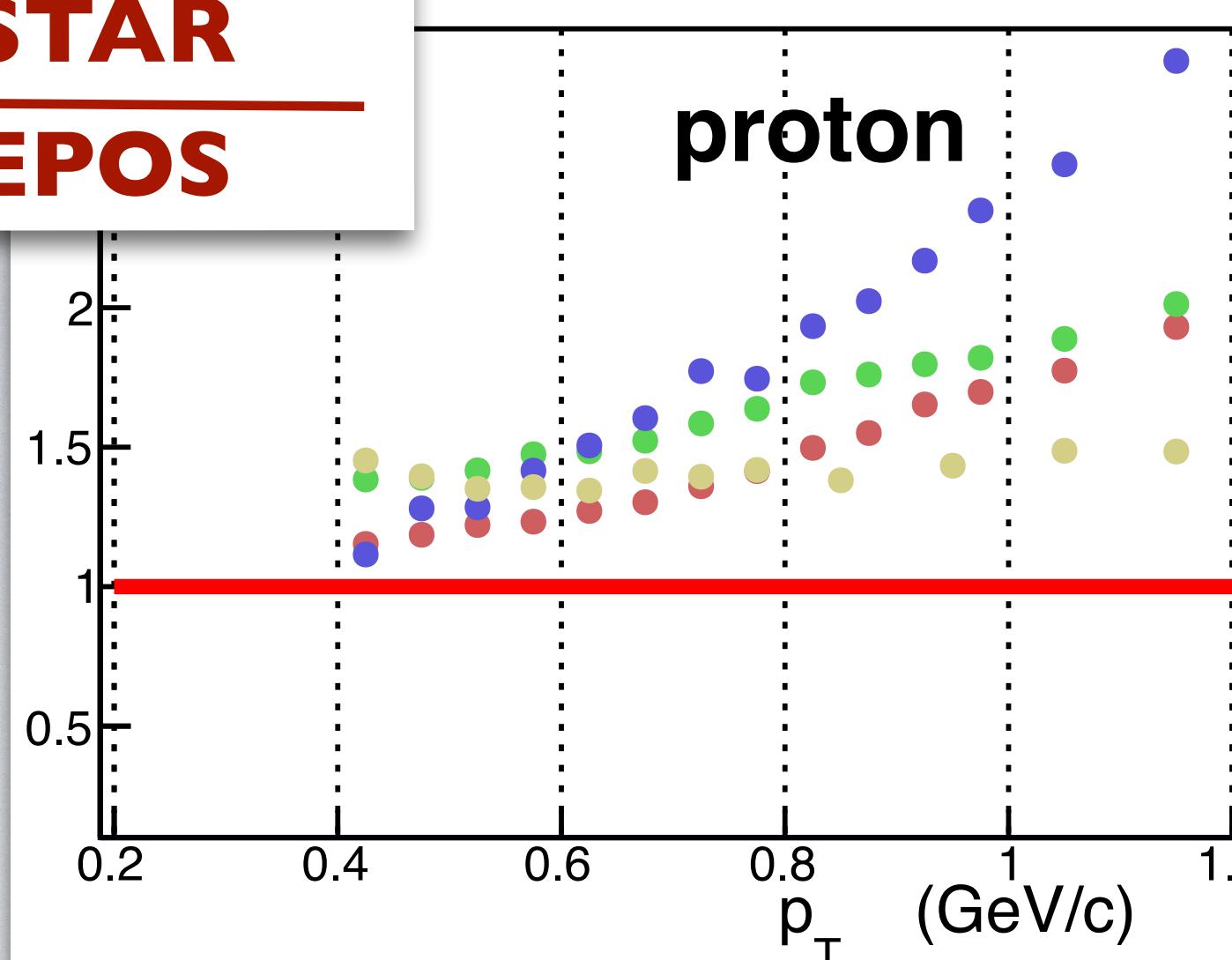
**STAR**  
—  
**EPOS**



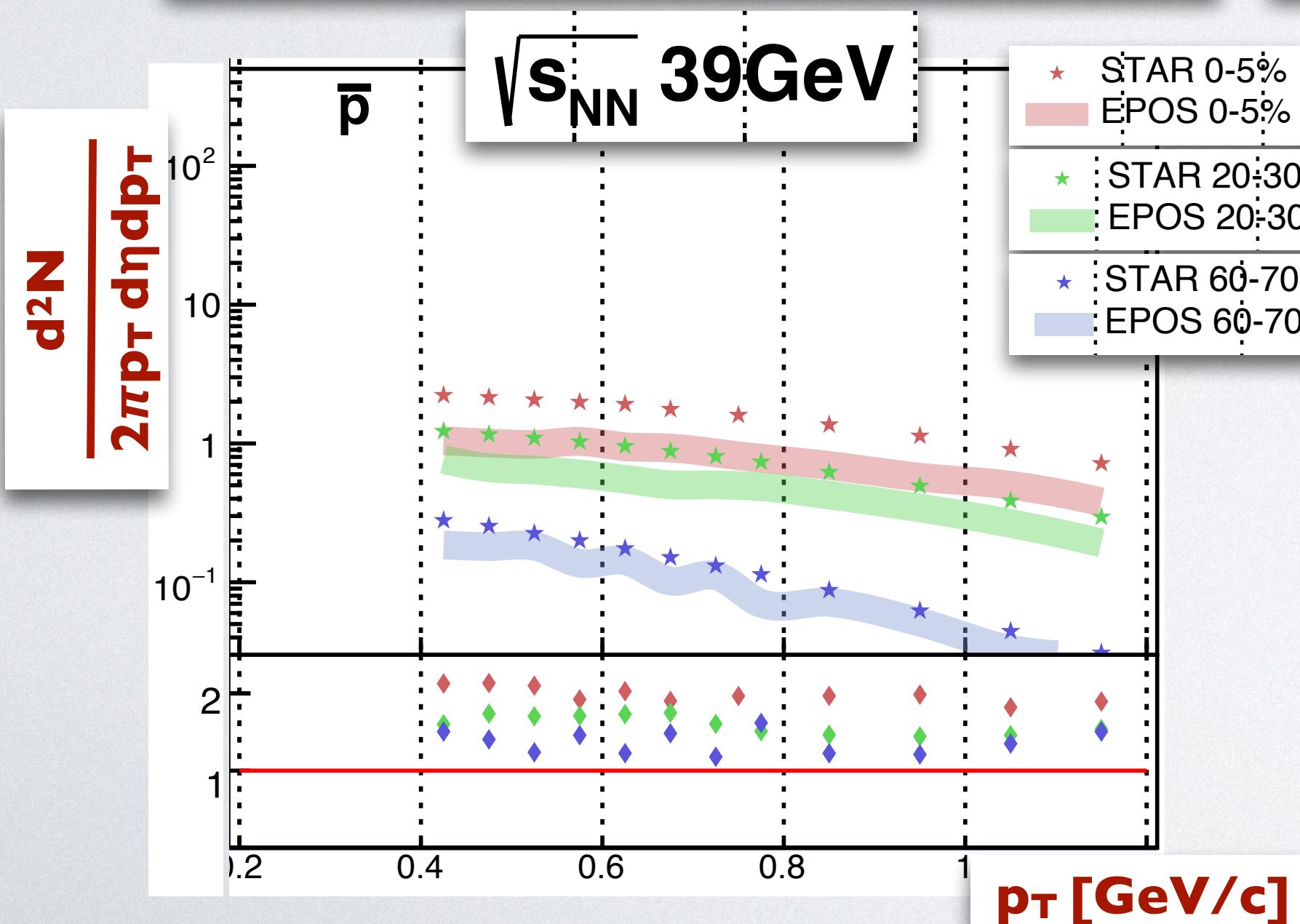
- Increasing with  $p_T$  difference in **slope**
- Size of discrepancies depend on **energy**
- $K$  not from resonances

**Au+Au**

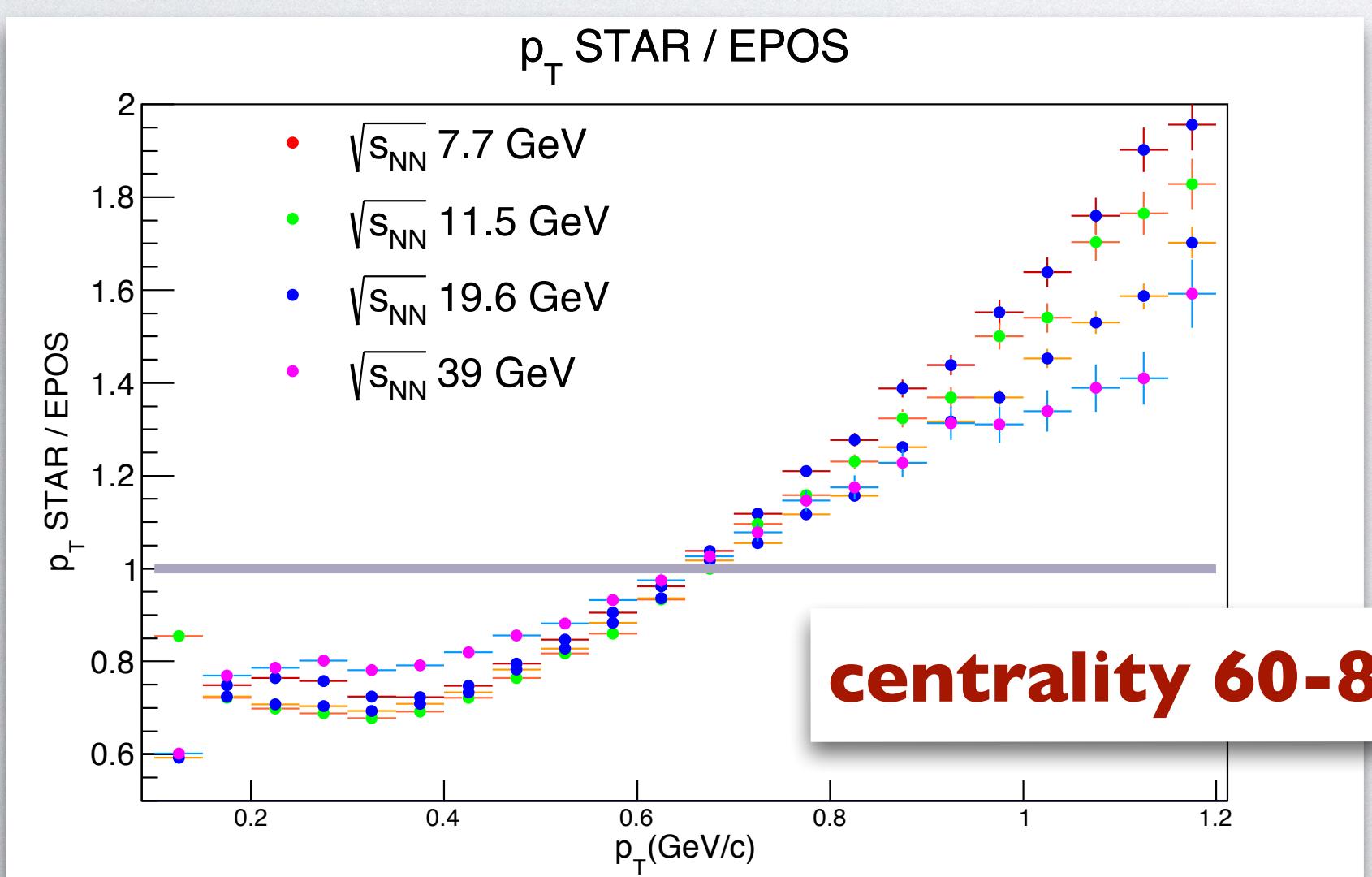
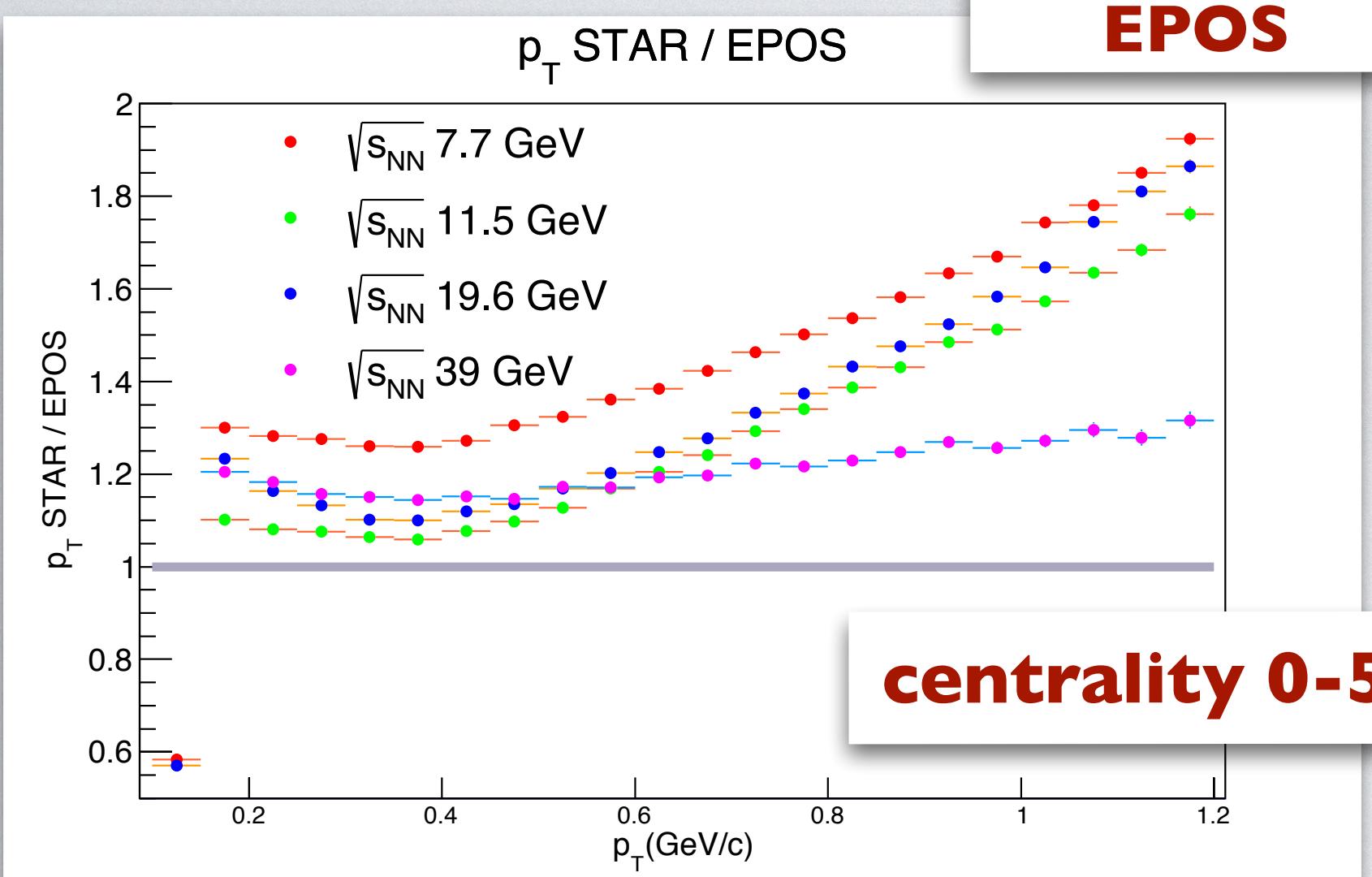
# SPECTRA P<sub>T</sub> (ANTI)PROTONS

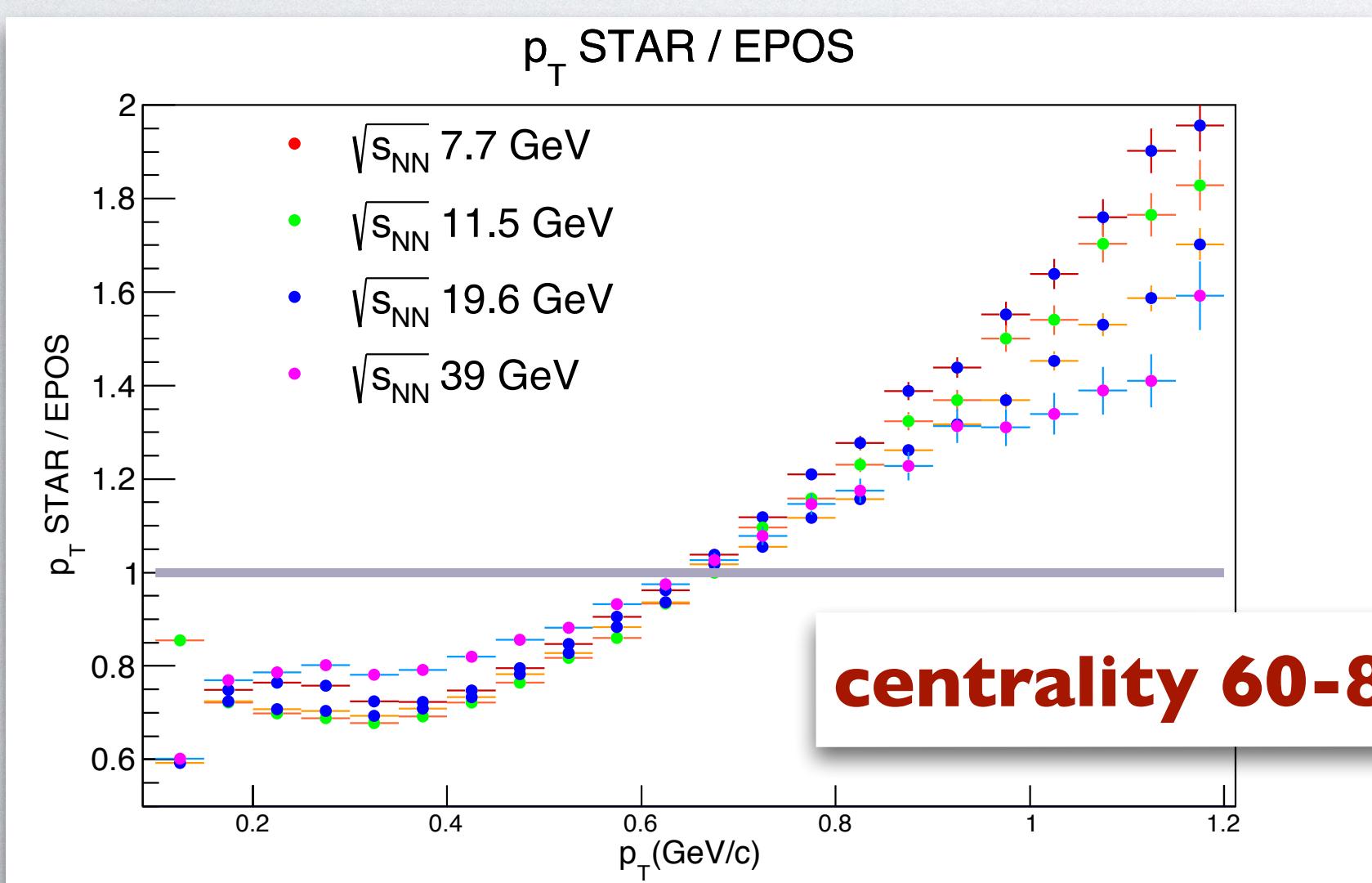
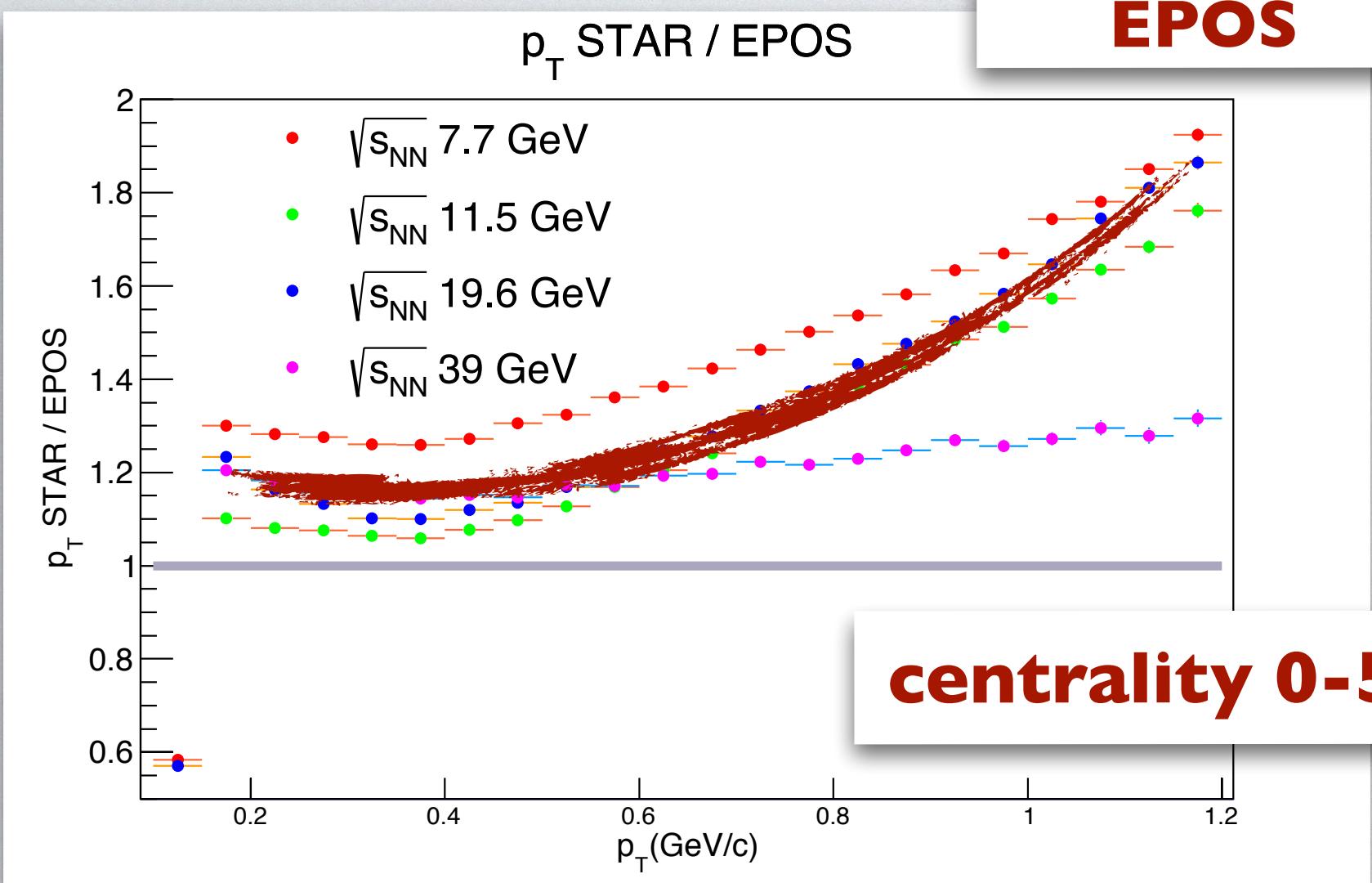
**Centrality: 0-5%****Centrality: 20-30%****Centrality: 60-70%****STAR  
EPOS**

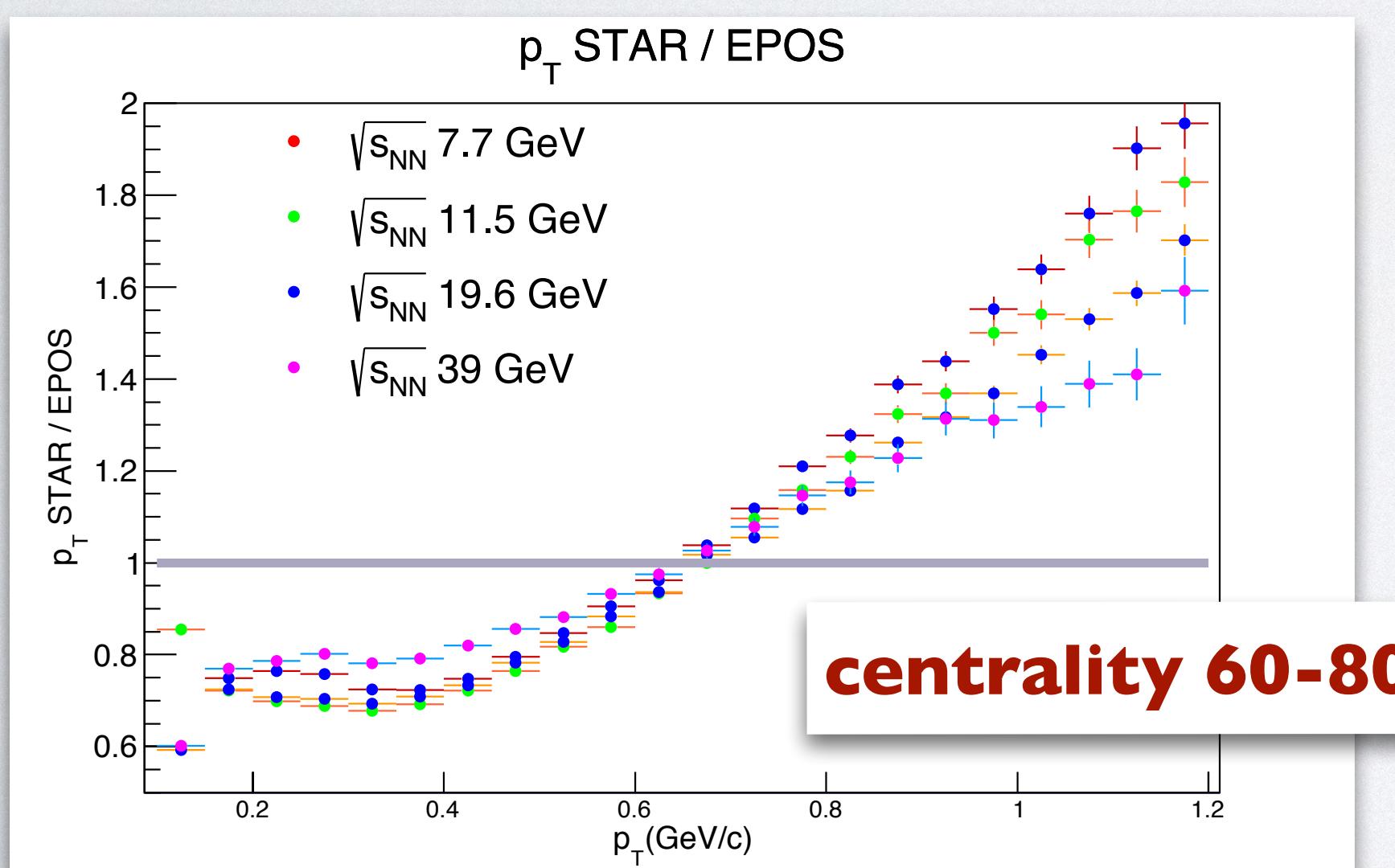
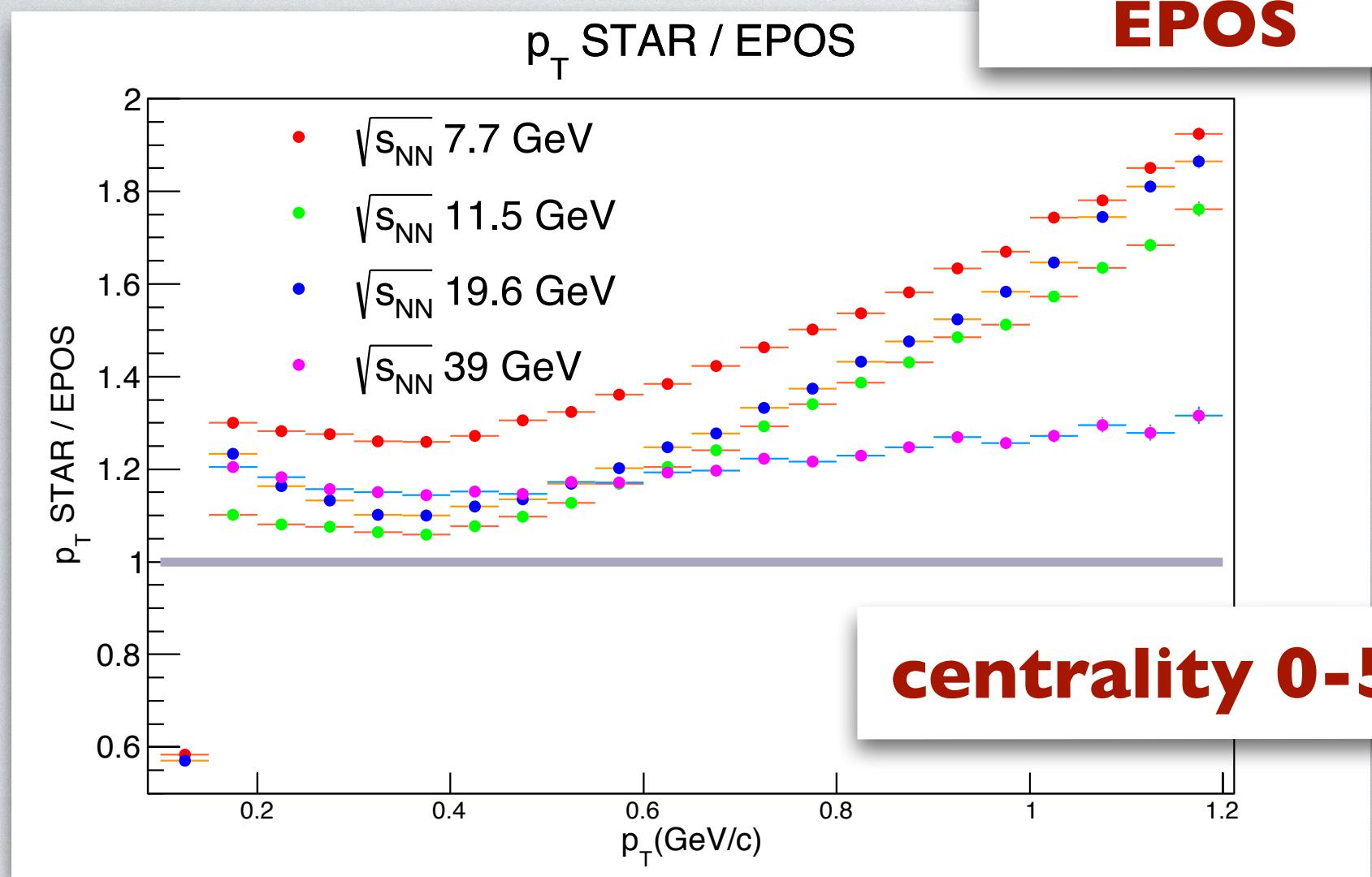
■	$\sqrt{s}_{NN}$	39 GeV
■	$\sqrt{s}_{NN}$	19.6 GeV
■	$\sqrt{s}_{NN}$	11.5 GeV
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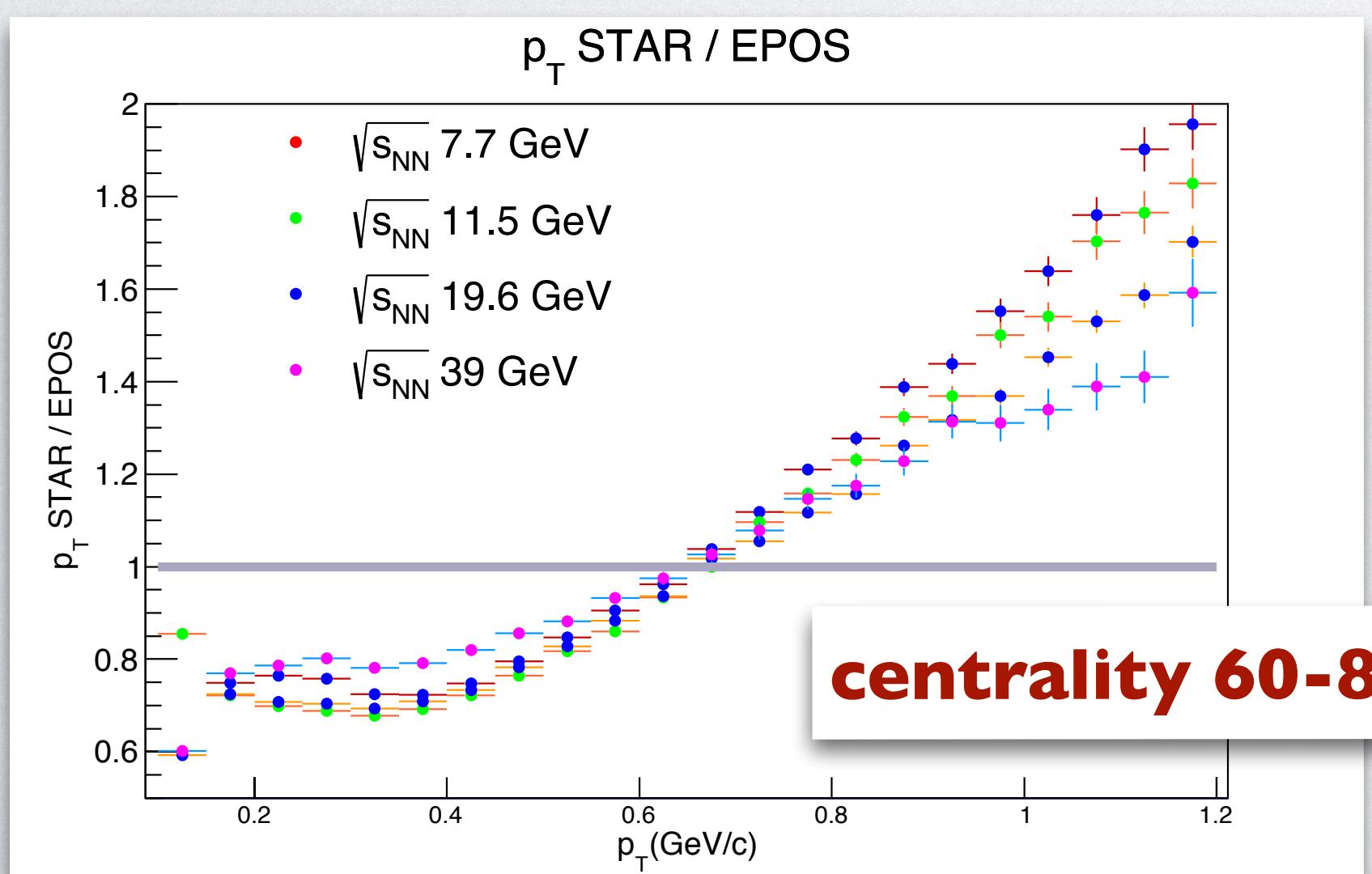
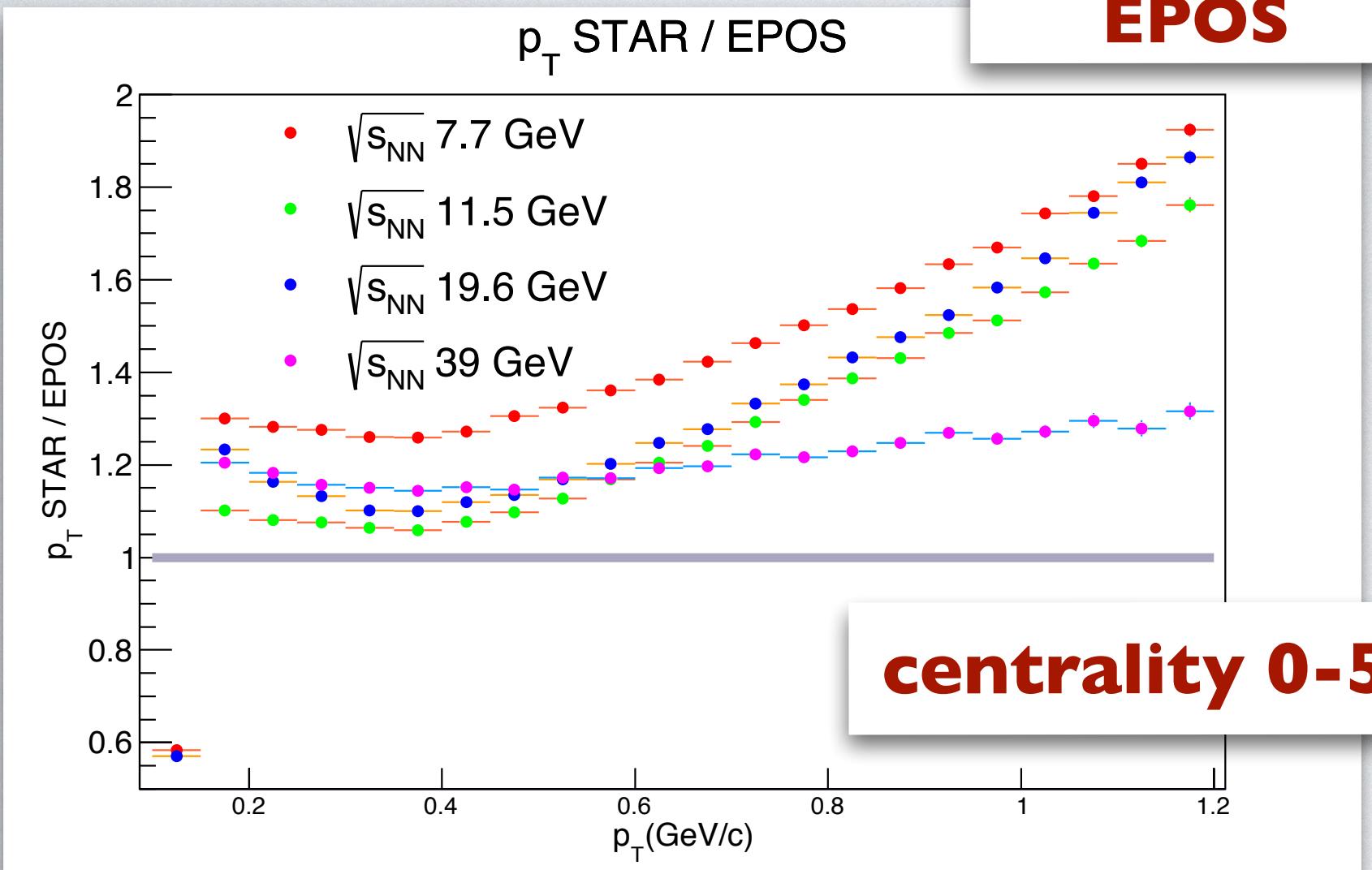
*arXiv:1701.07065*

- **p: slope** different for each **centrality**
- **p:** differences does **not** depend on **energy**
- **p: slopes agreeable!**





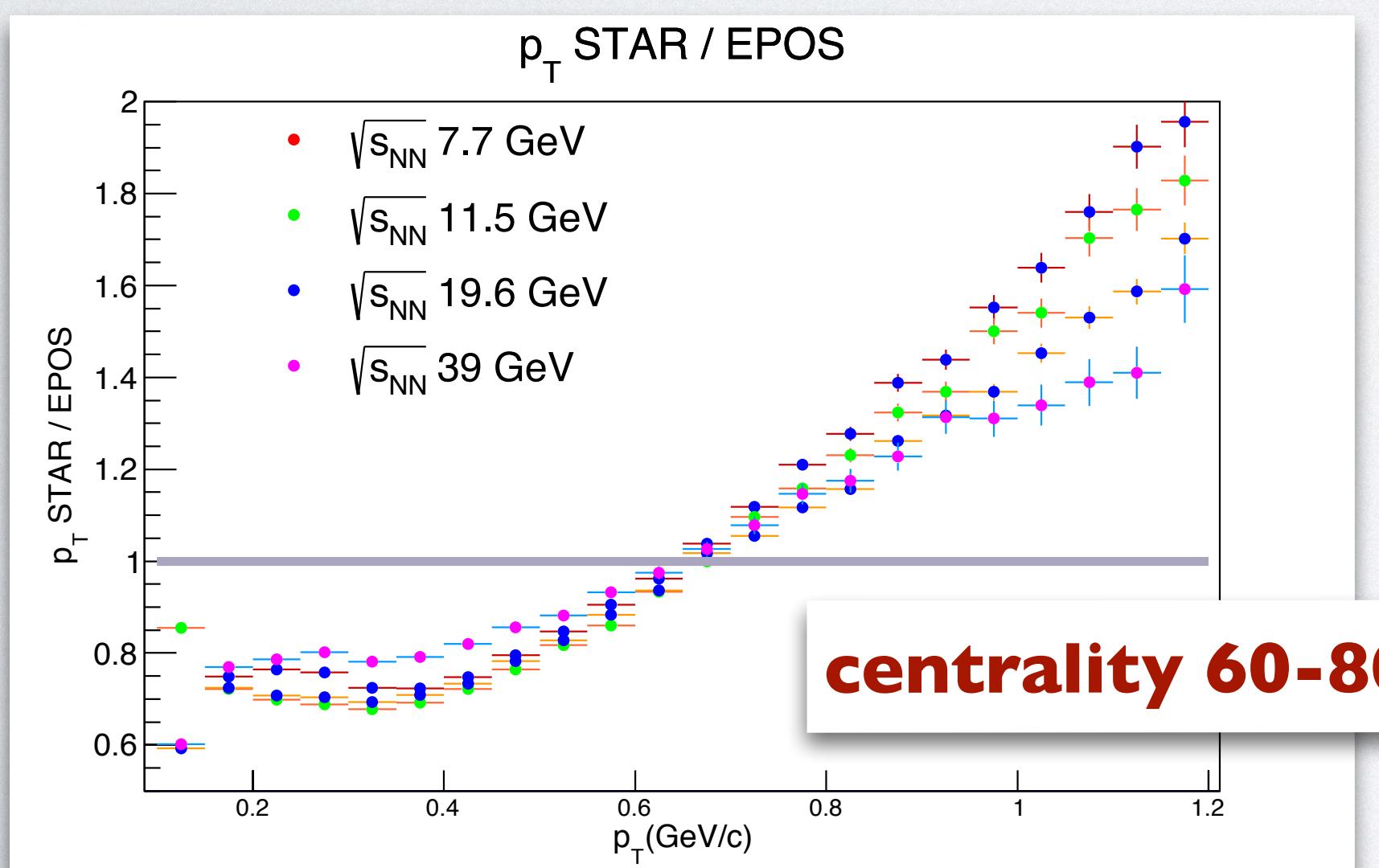
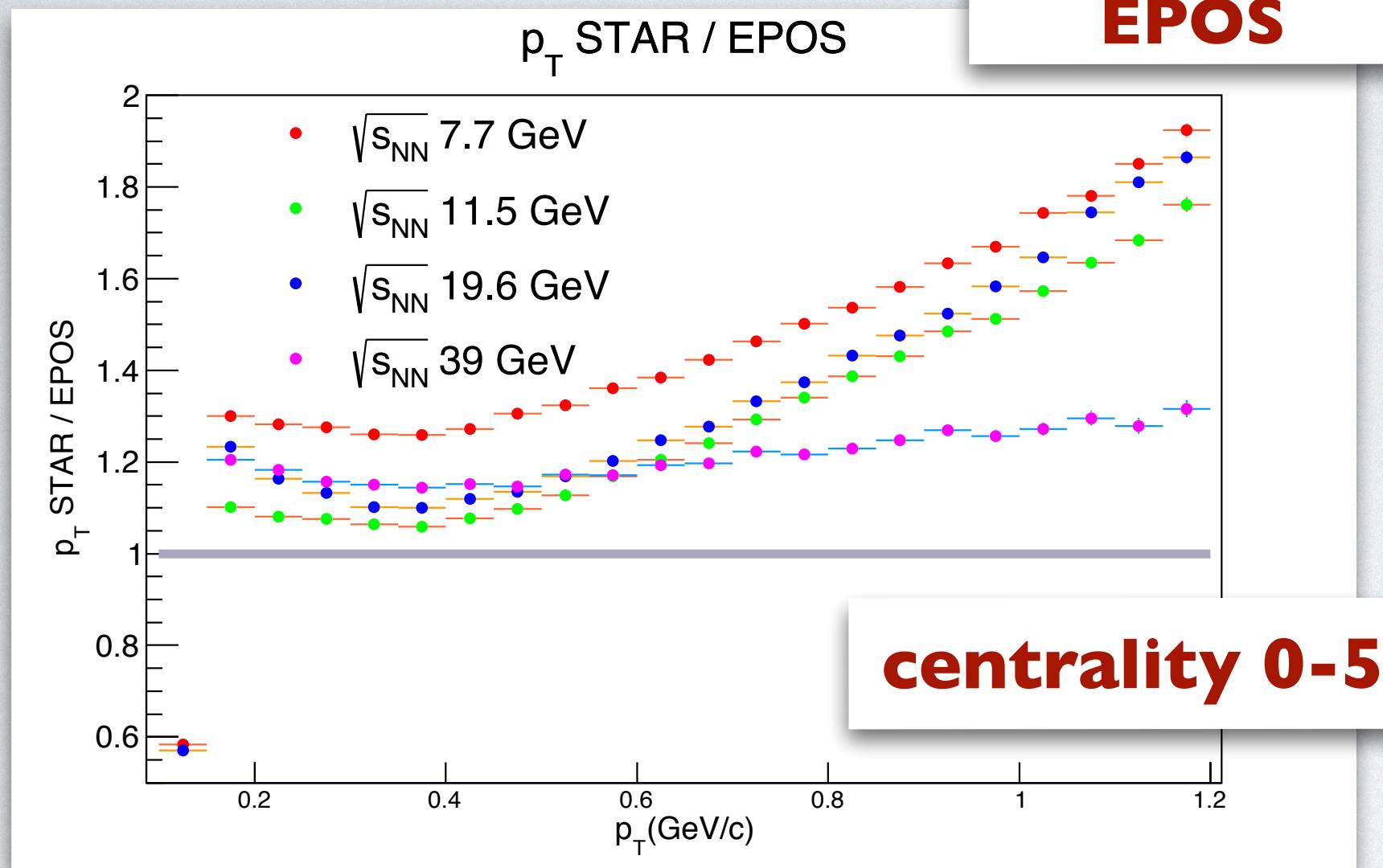




# Impact of **core**

# SPECTRA $P_T$

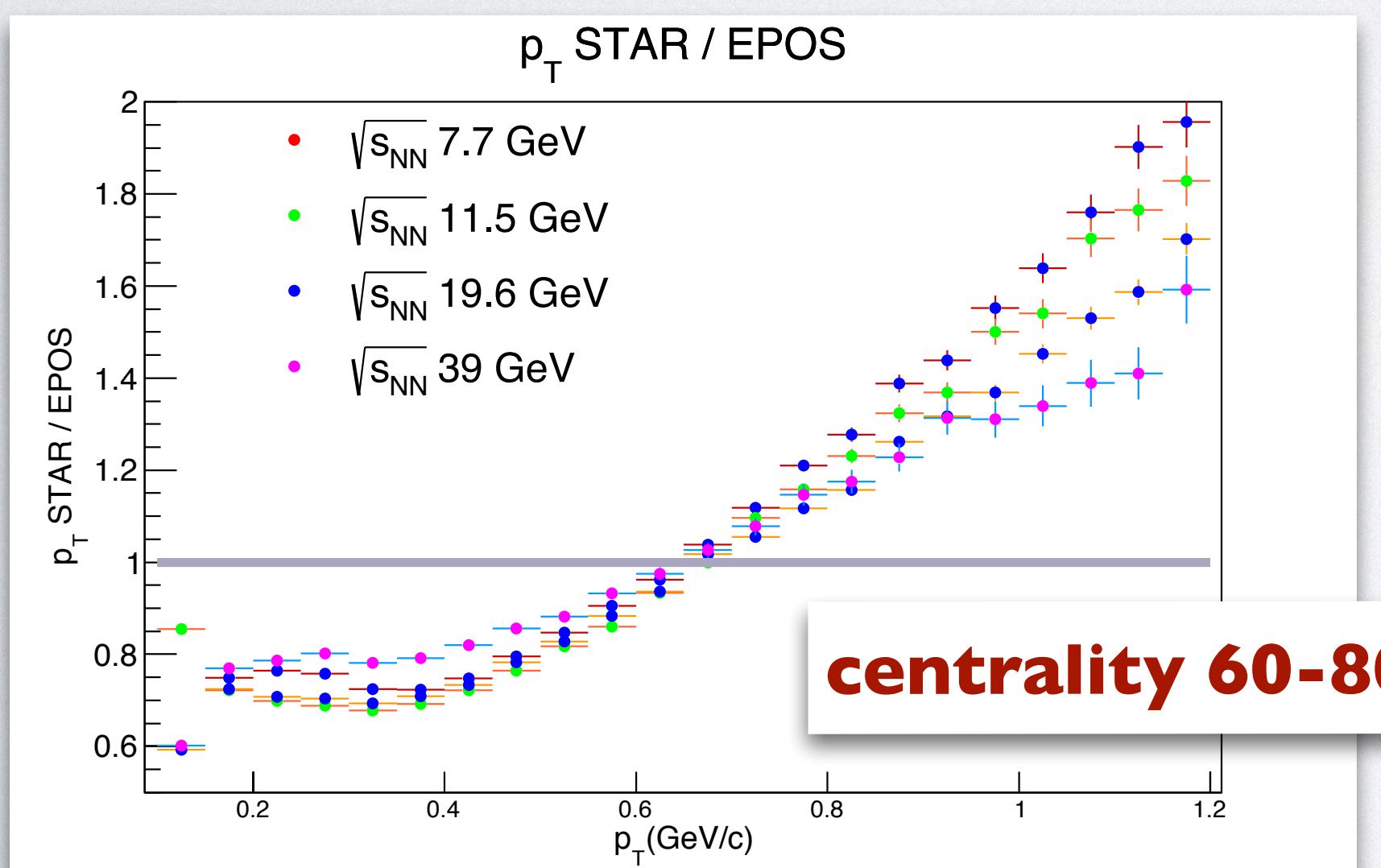
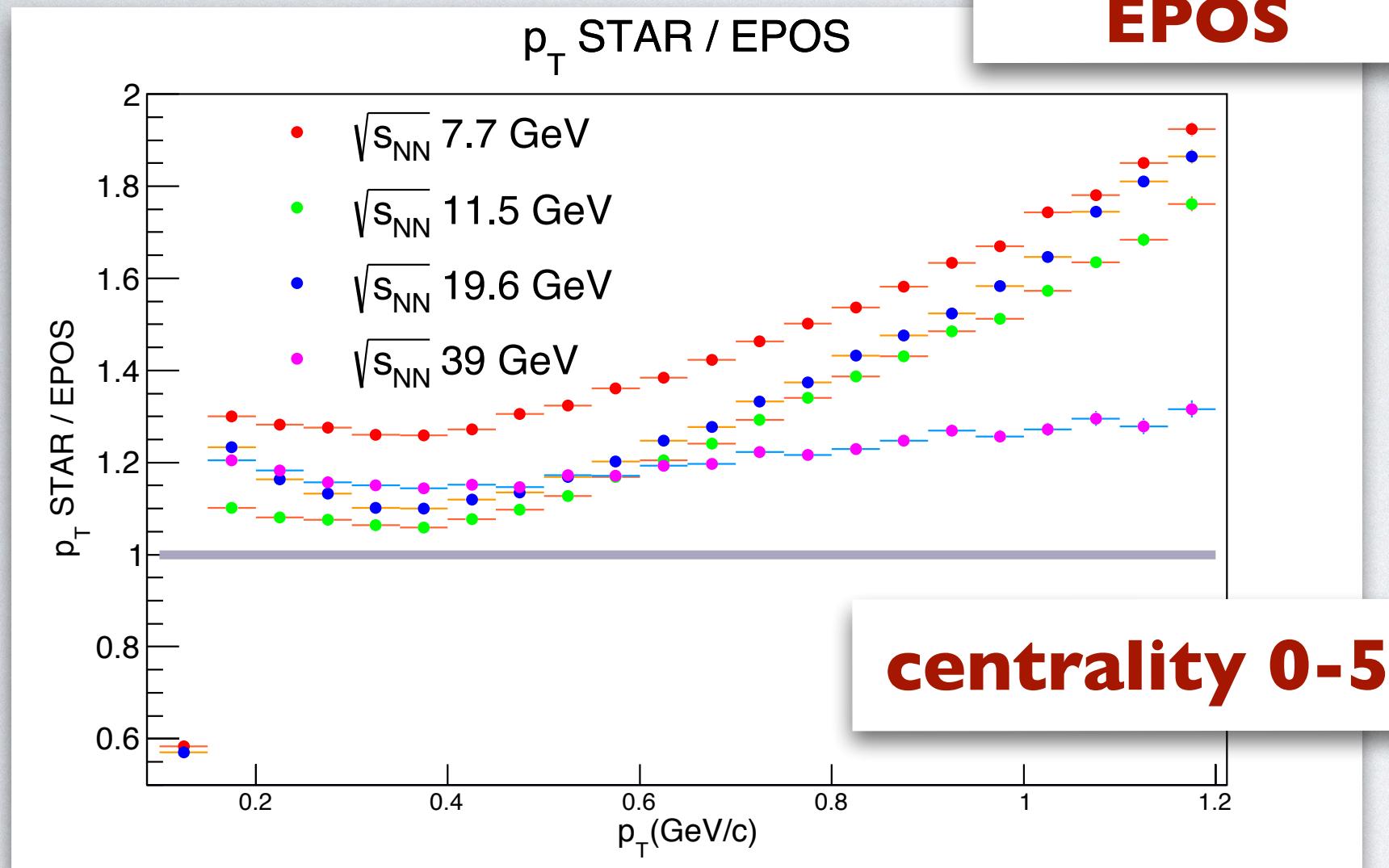
**$h^+ + h^-$**   
2

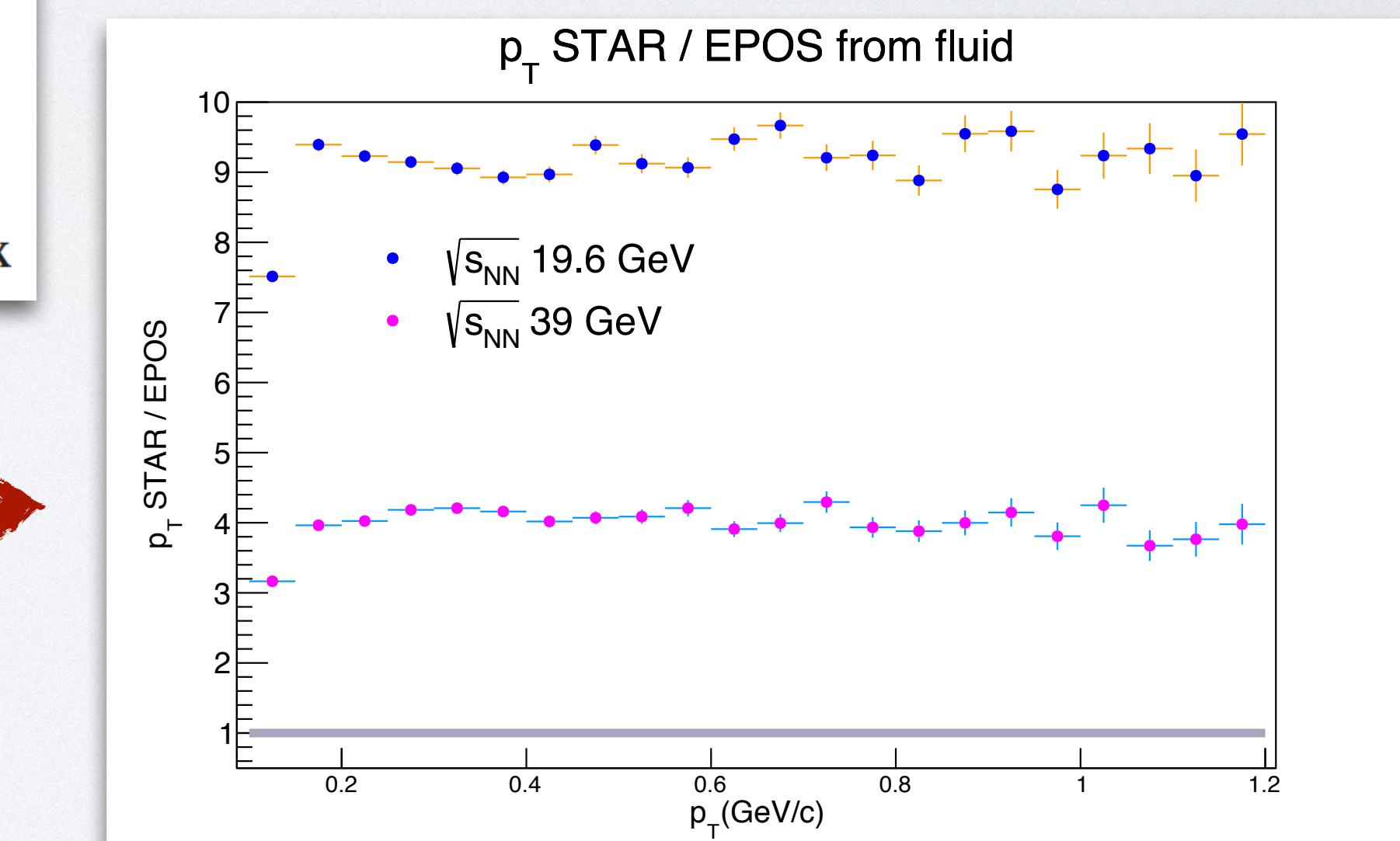
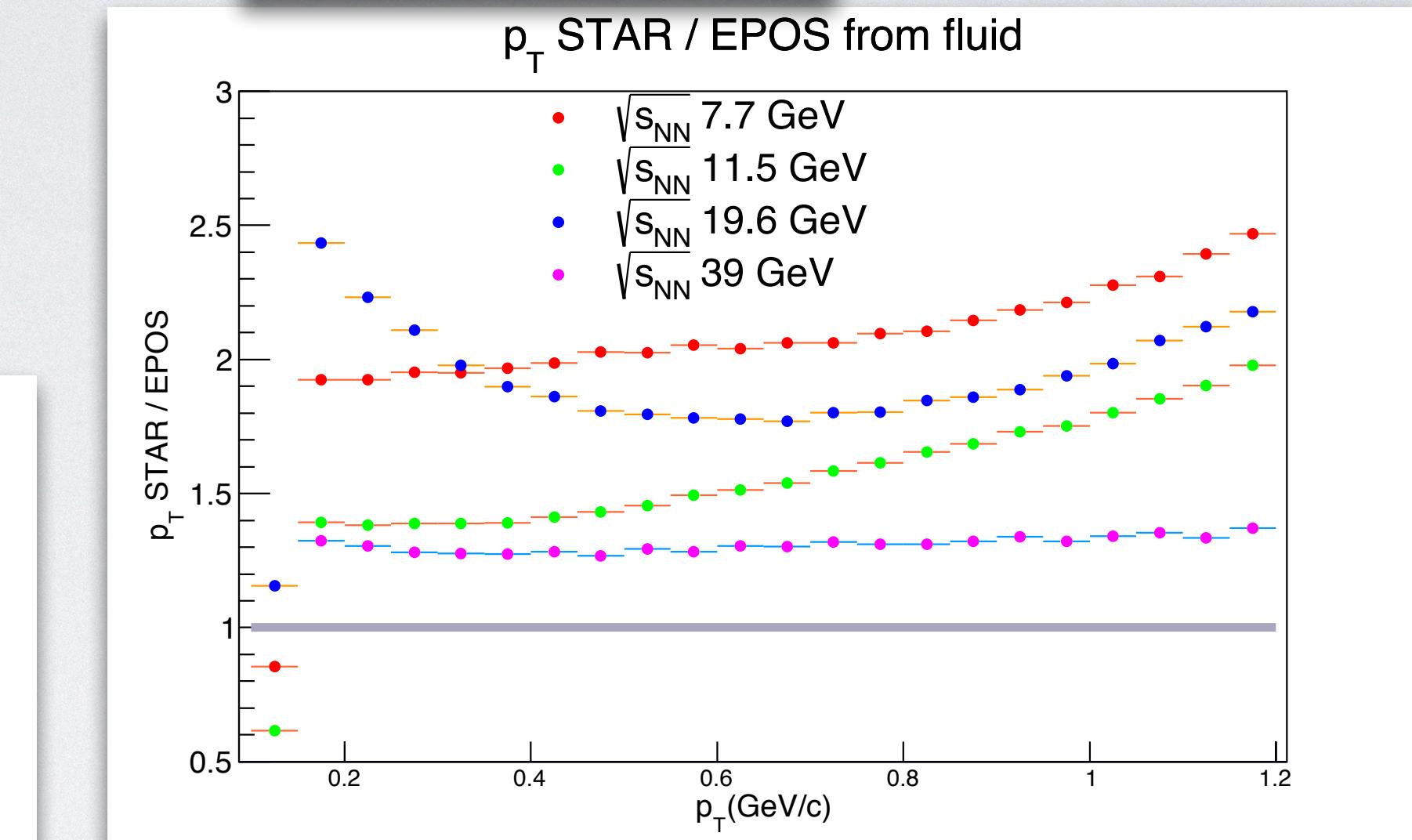
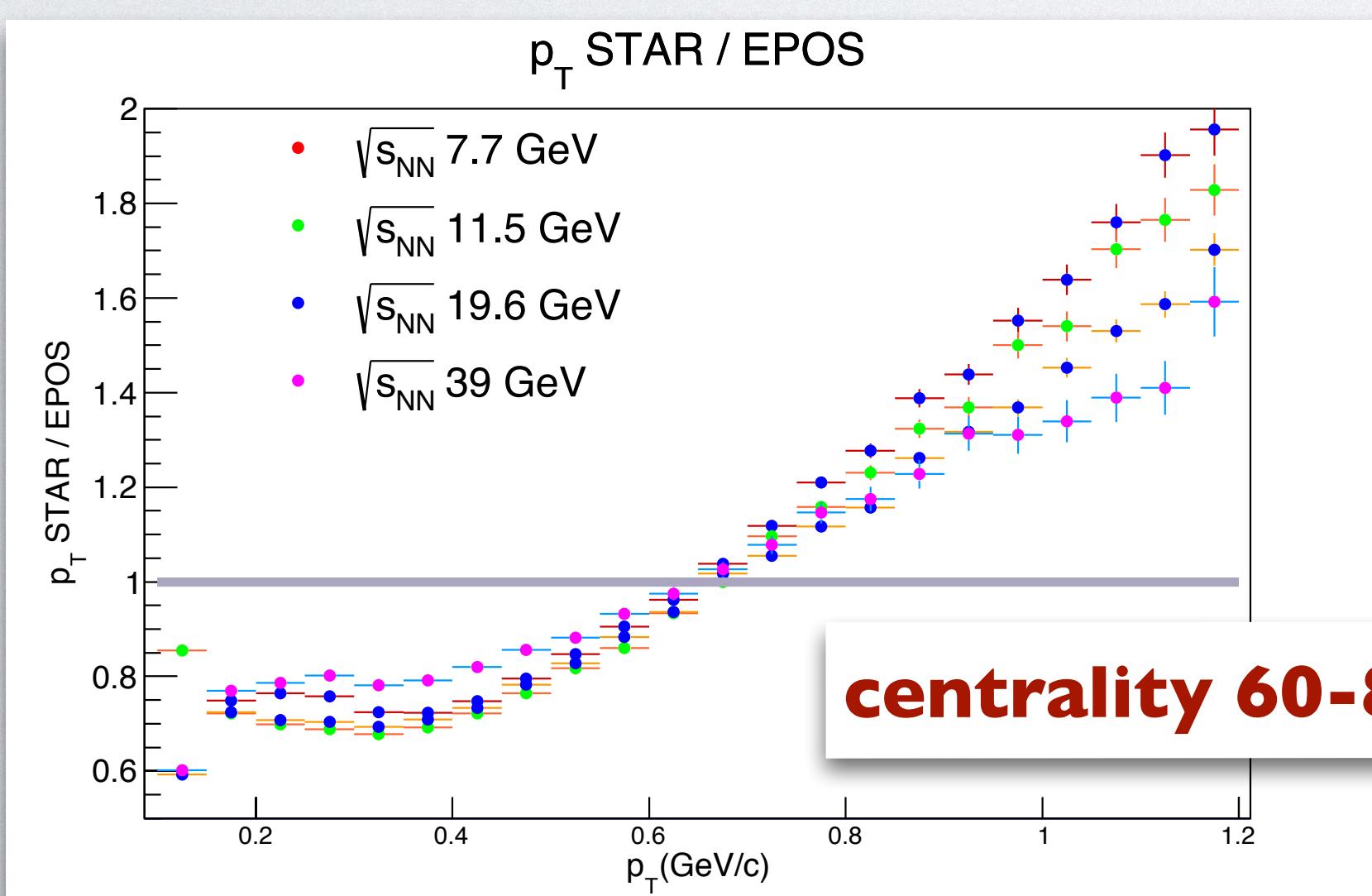
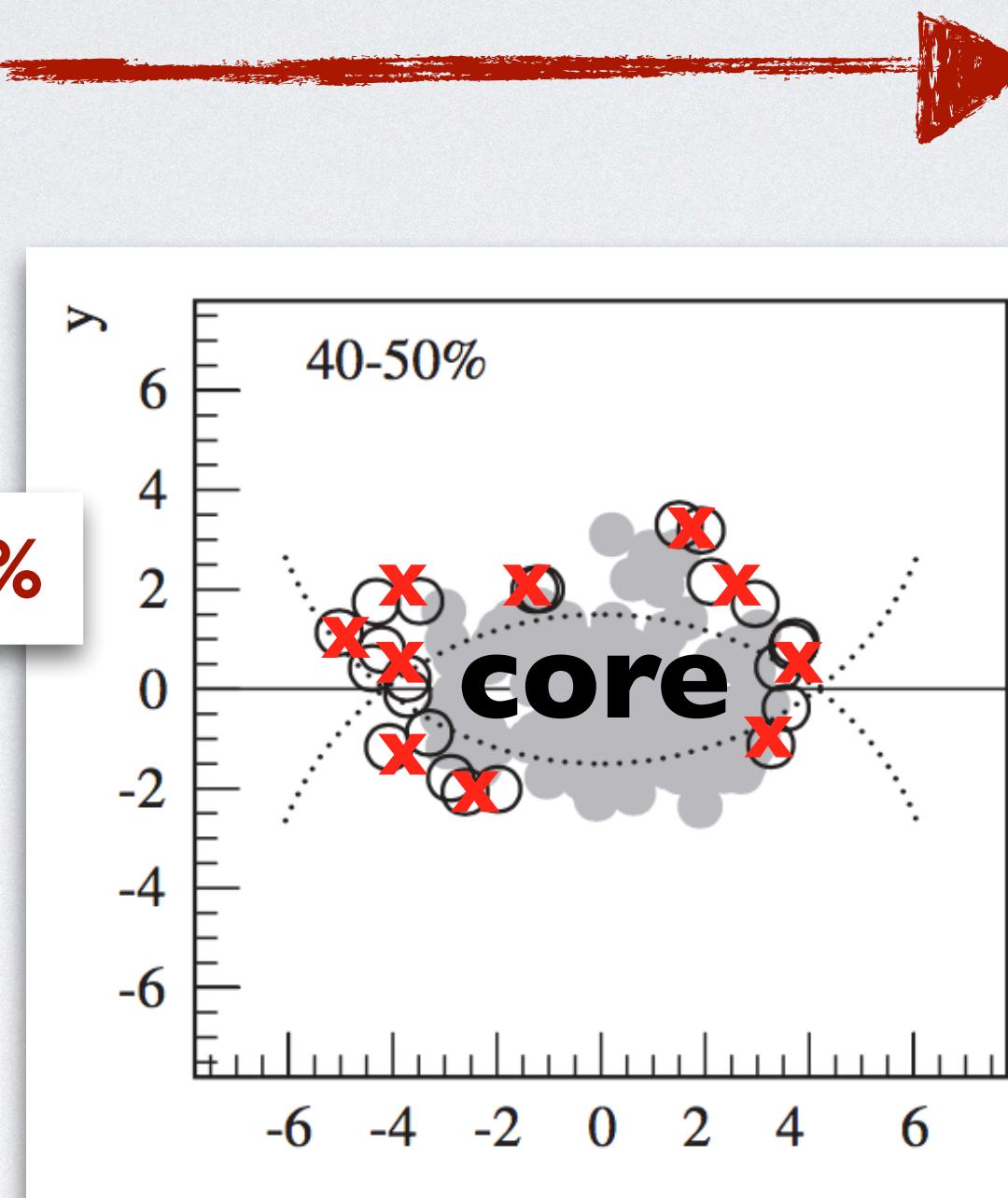
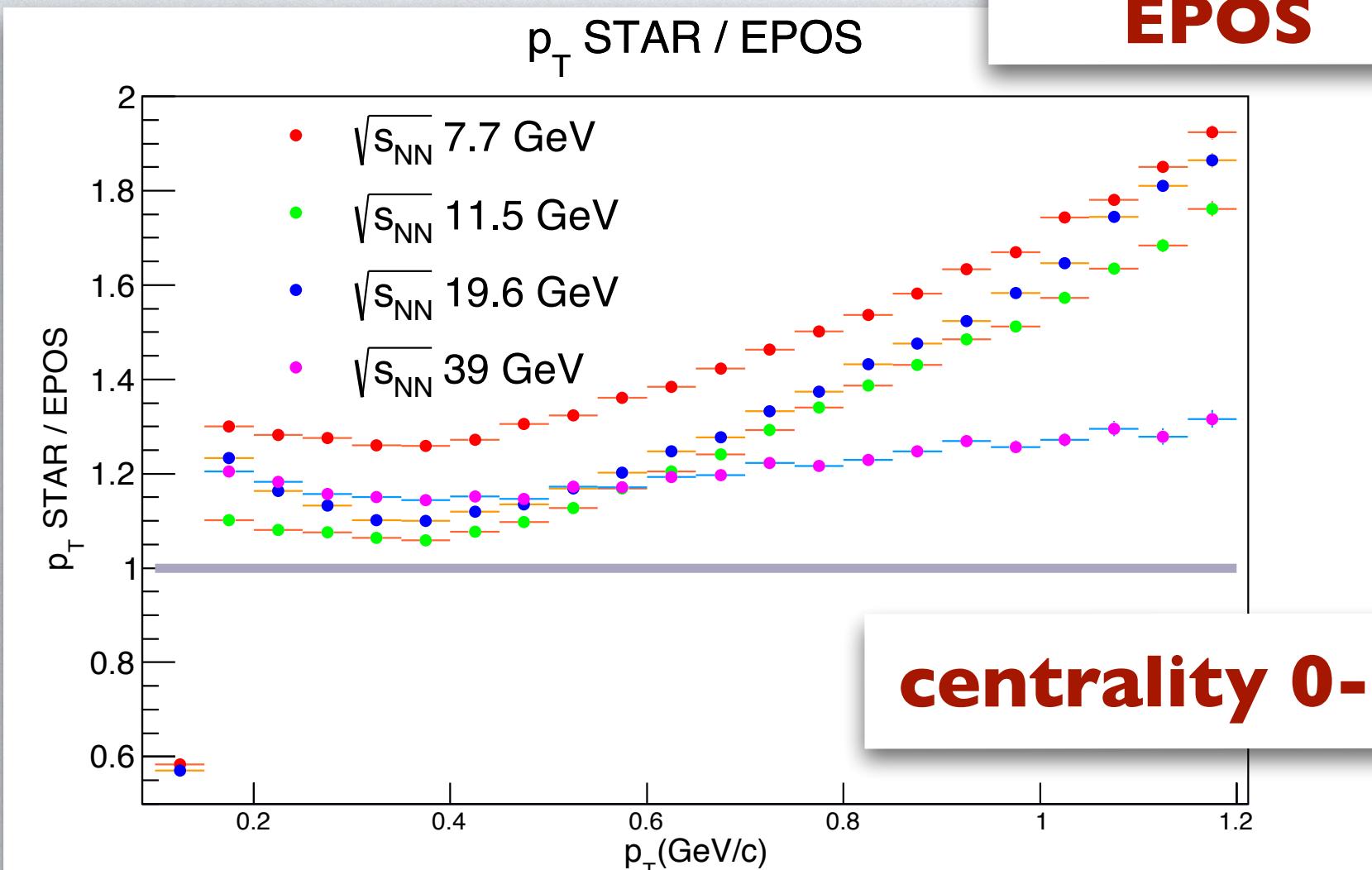


# Impact of **core**

# SPECTRA $P_T$

$$\frac{h^+ + h^-}{2}$$

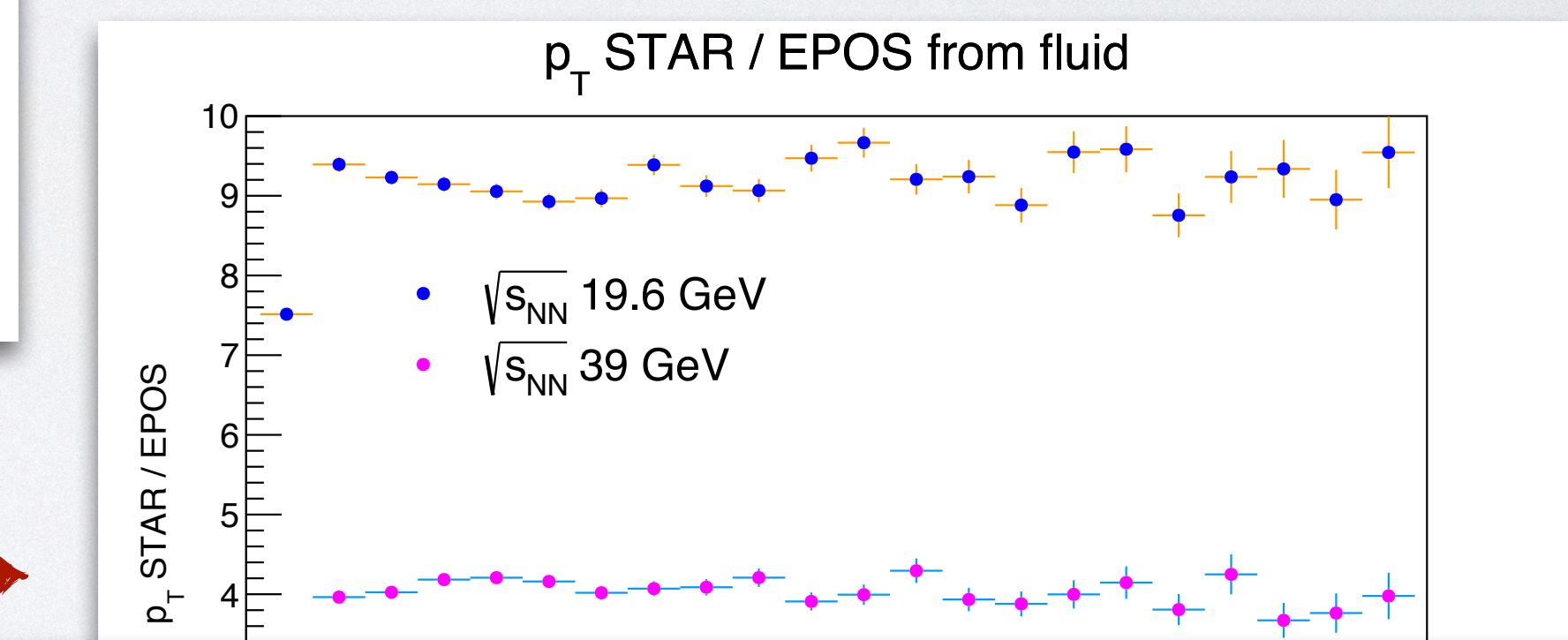
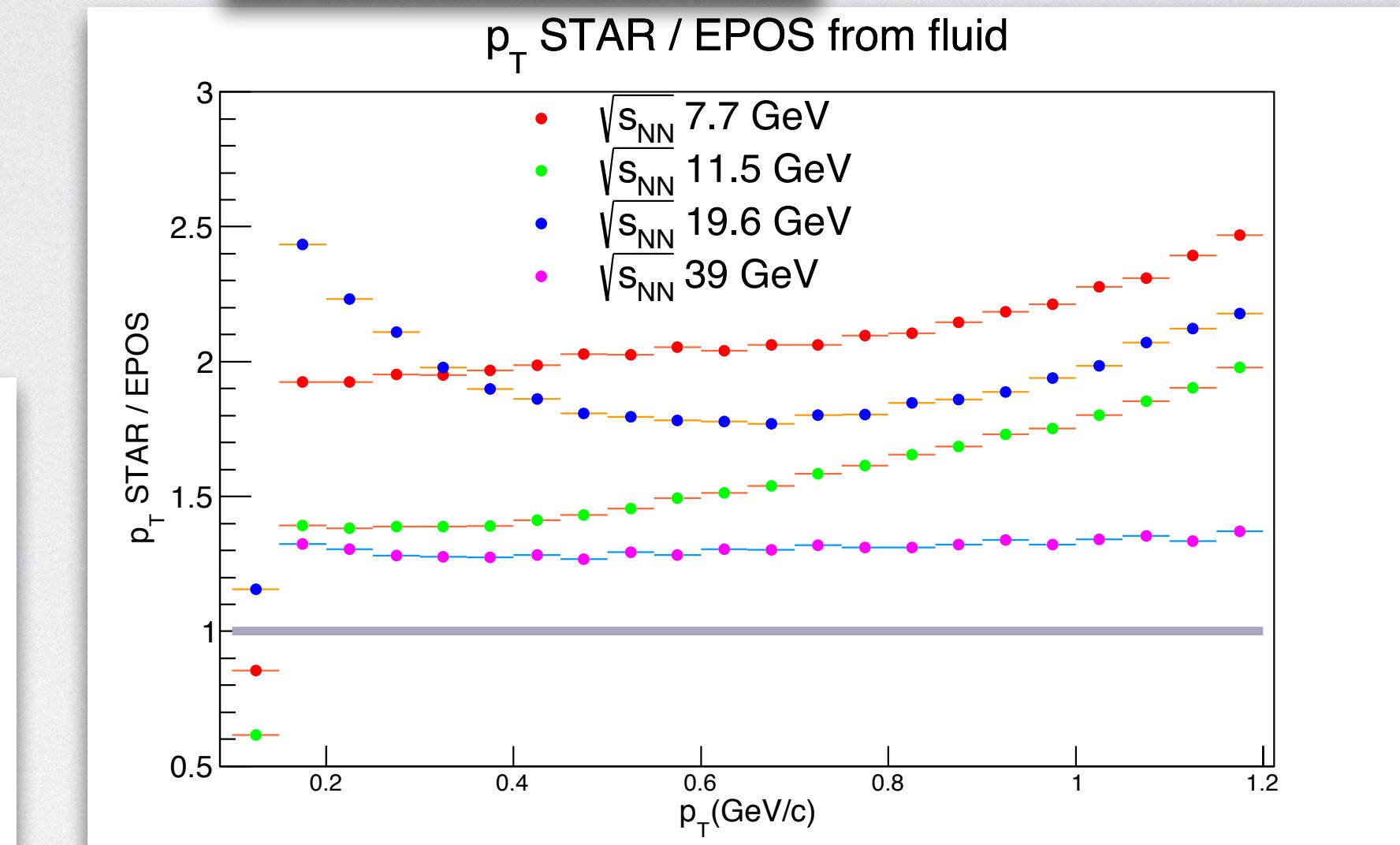
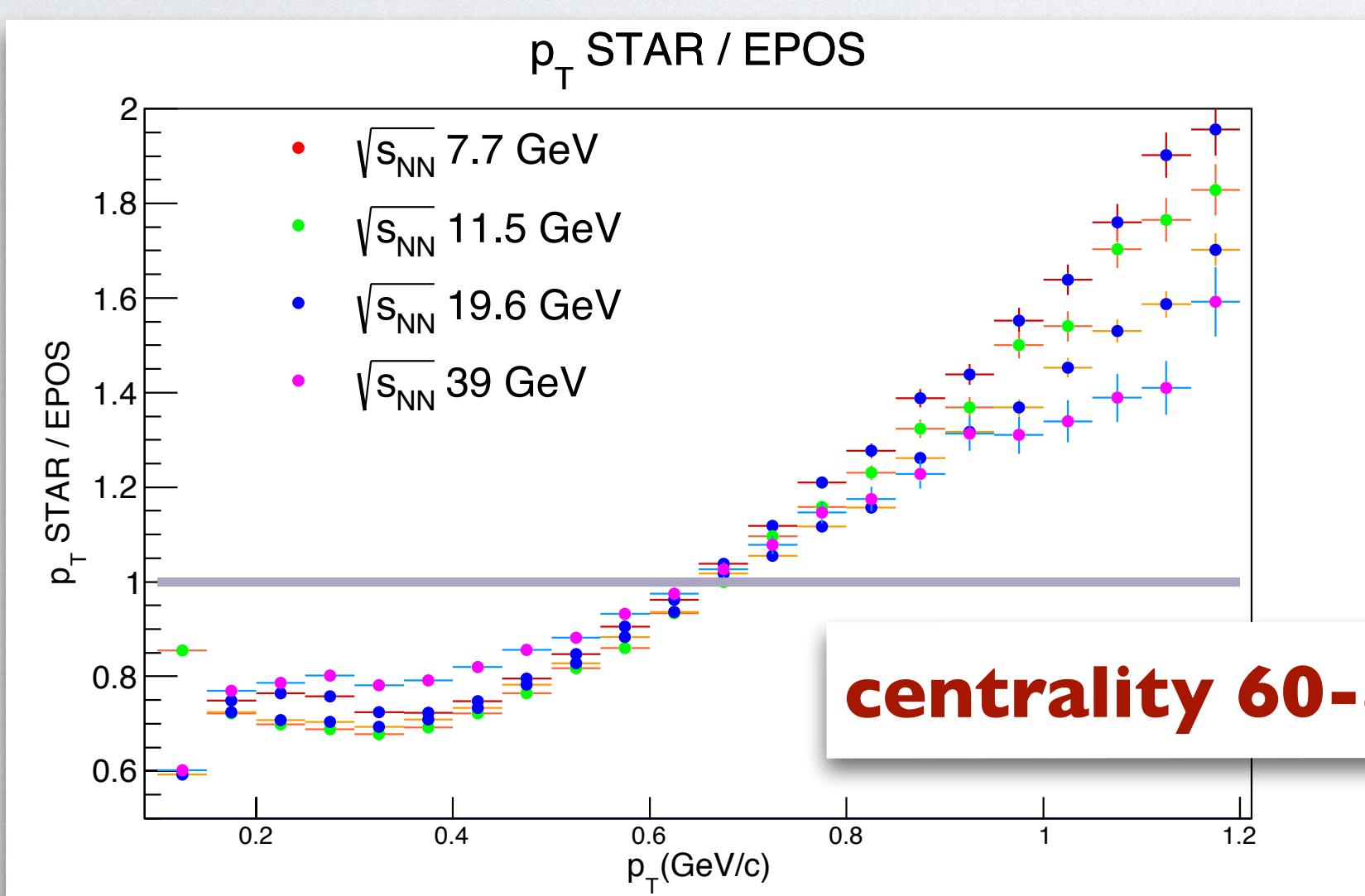
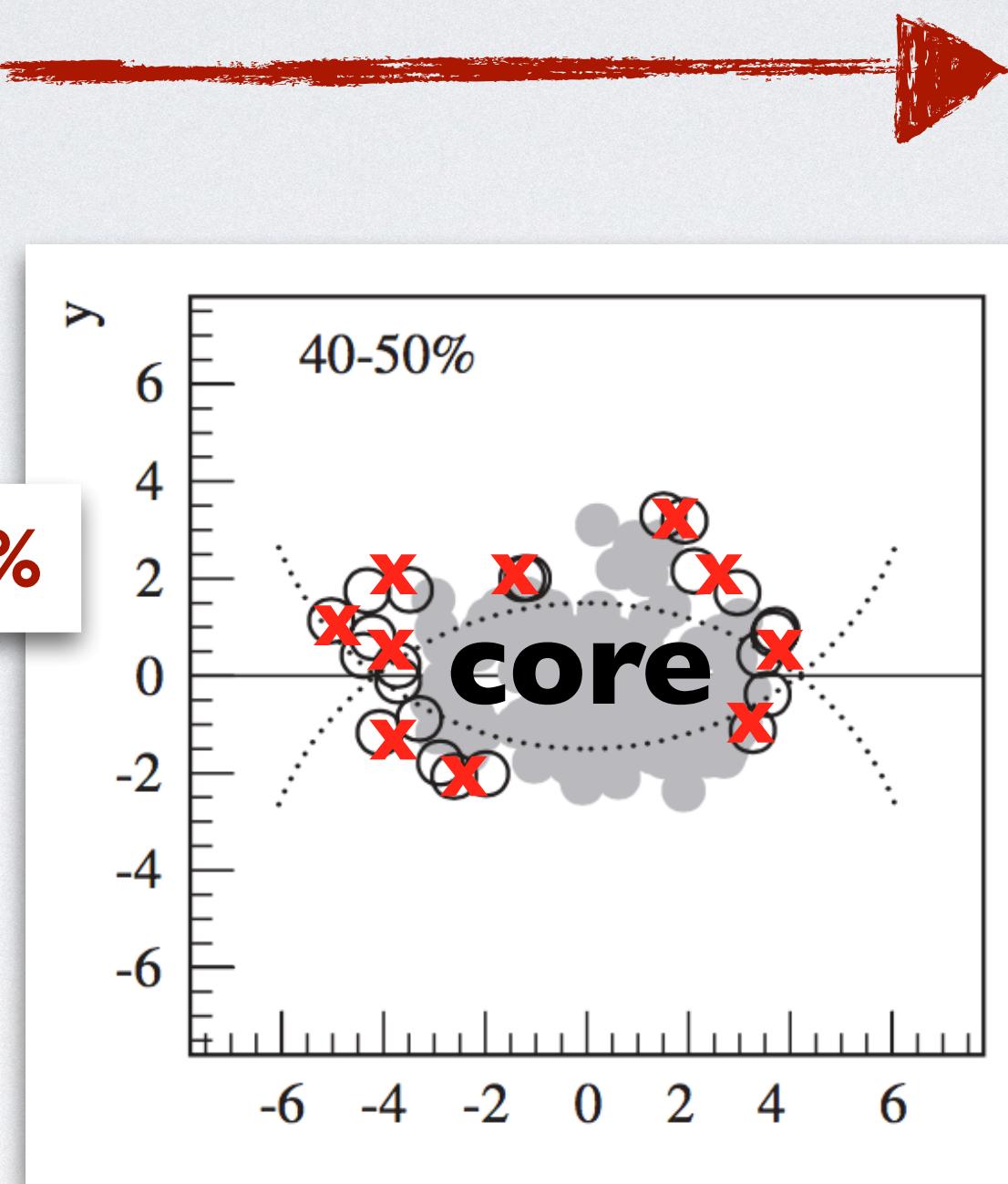
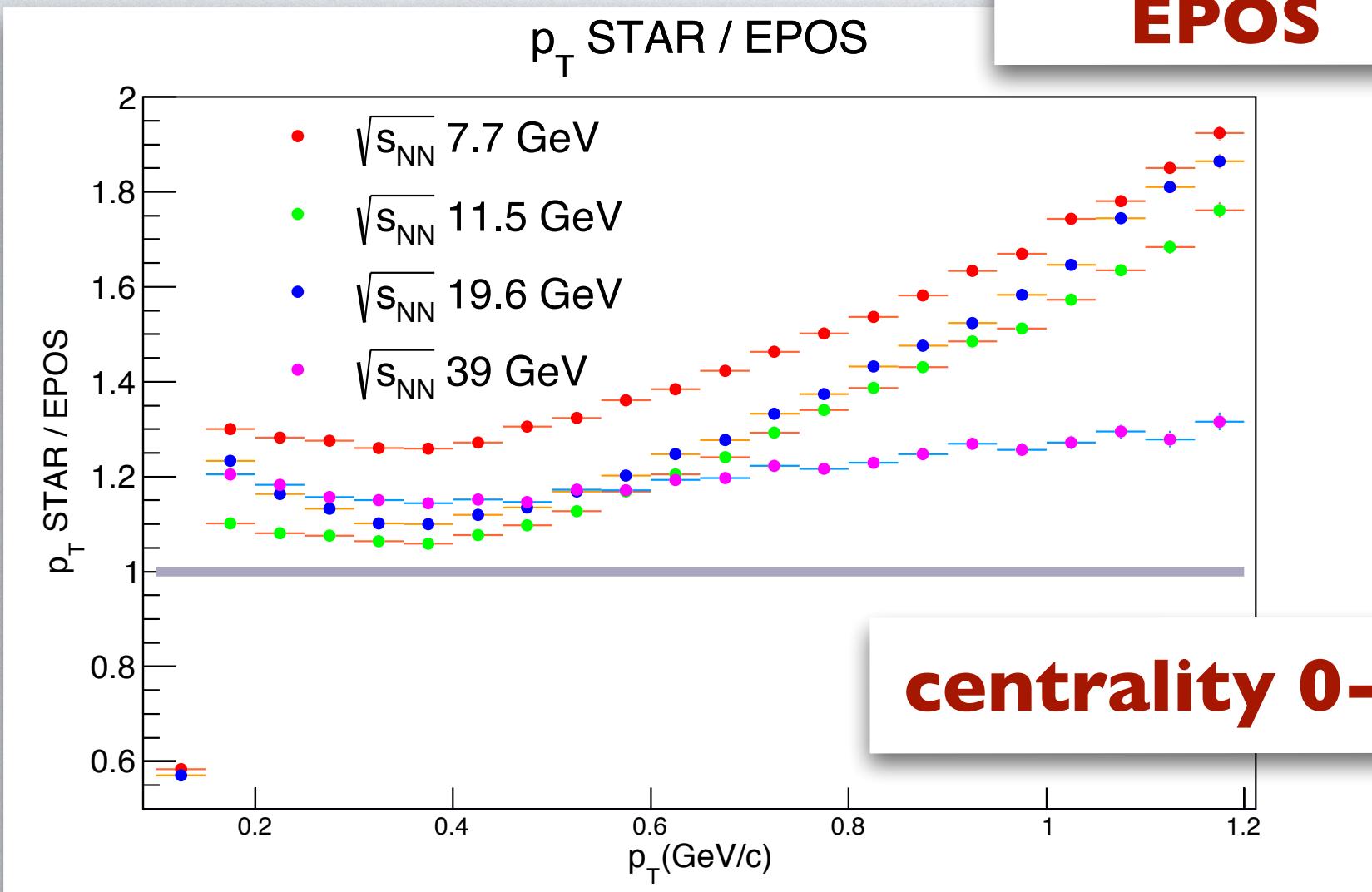




# Impact of **core**

# SPECTRA $P_T$

**$h^+ + h^-$**   
**2**



**What about flow?**

# ELLIPTIC FLOW

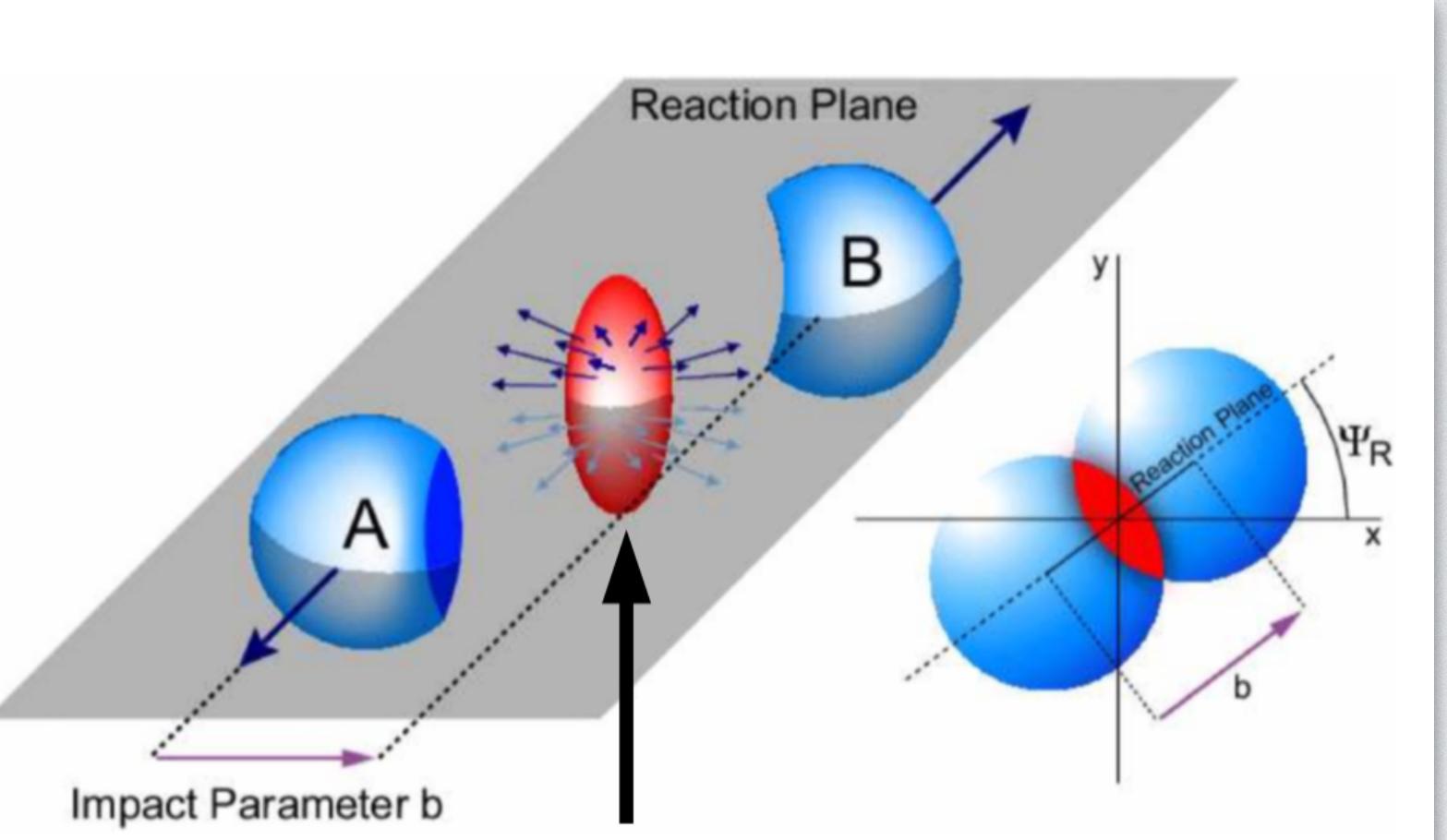
$$\frac{dN}{d(\phi - \Phi_{RP})} = \frac{N_0}{2\pi} \left( 1 + 2 \sum_{n=1}^{\infty} v_n \cos[(\phi - \Phi_{RP})] \right)$$

$N_0$  - number of particles

$v_n$  - n-th harmonic coefficient

$\phi$  - azimuthal angle of particles

$\Phi_{RP}$  - azimuthal angle of the reaction plane



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

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

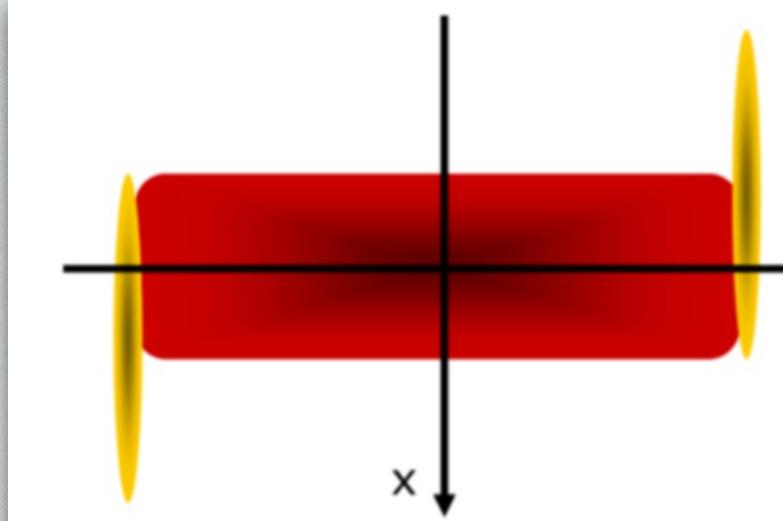
$\Phi_n^A$  - event plane calculated only using "forward-pseudorapidity" particles while

$\Phi_n^B$  - with "backward-pseudorapidity" ones.

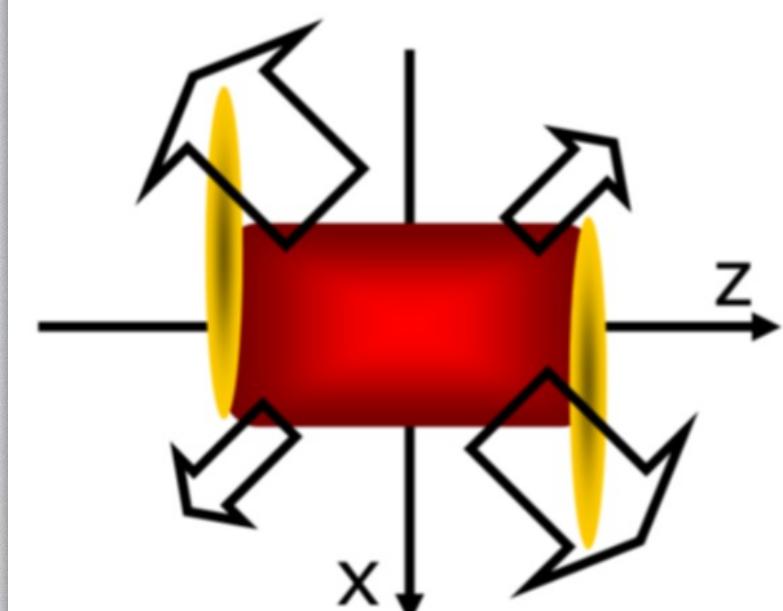
**$\eta$ -sub method**



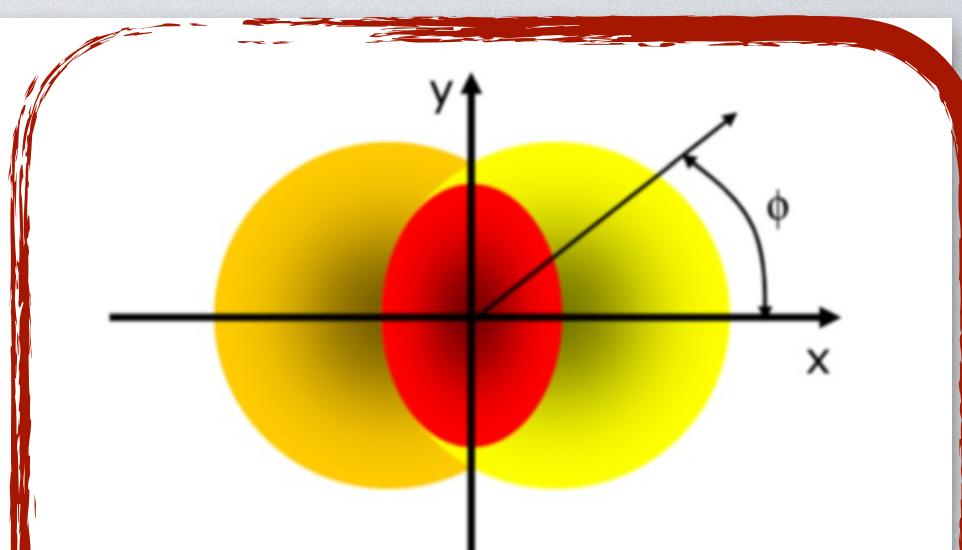
**$\eta$ -gap:  $|\eta| > 0.05$**



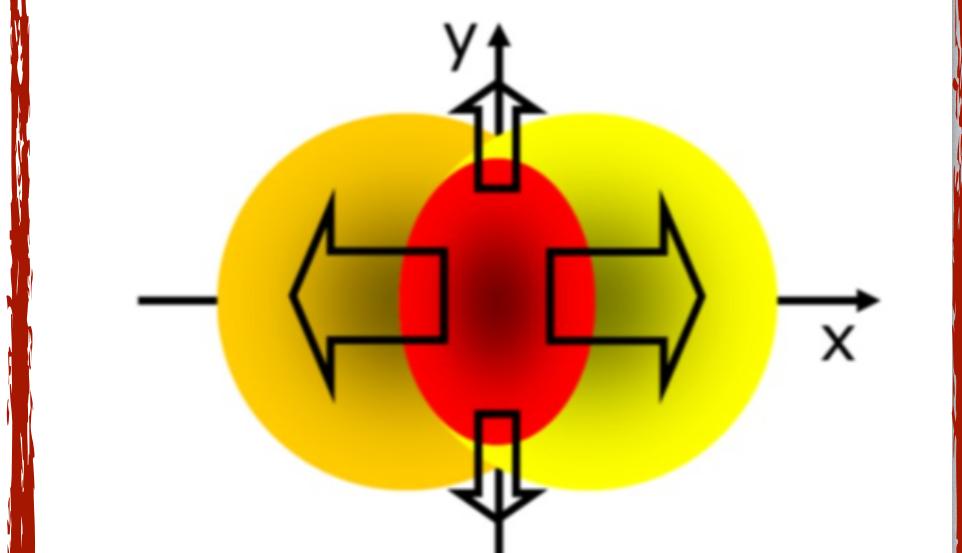
(a) In the reaction plane



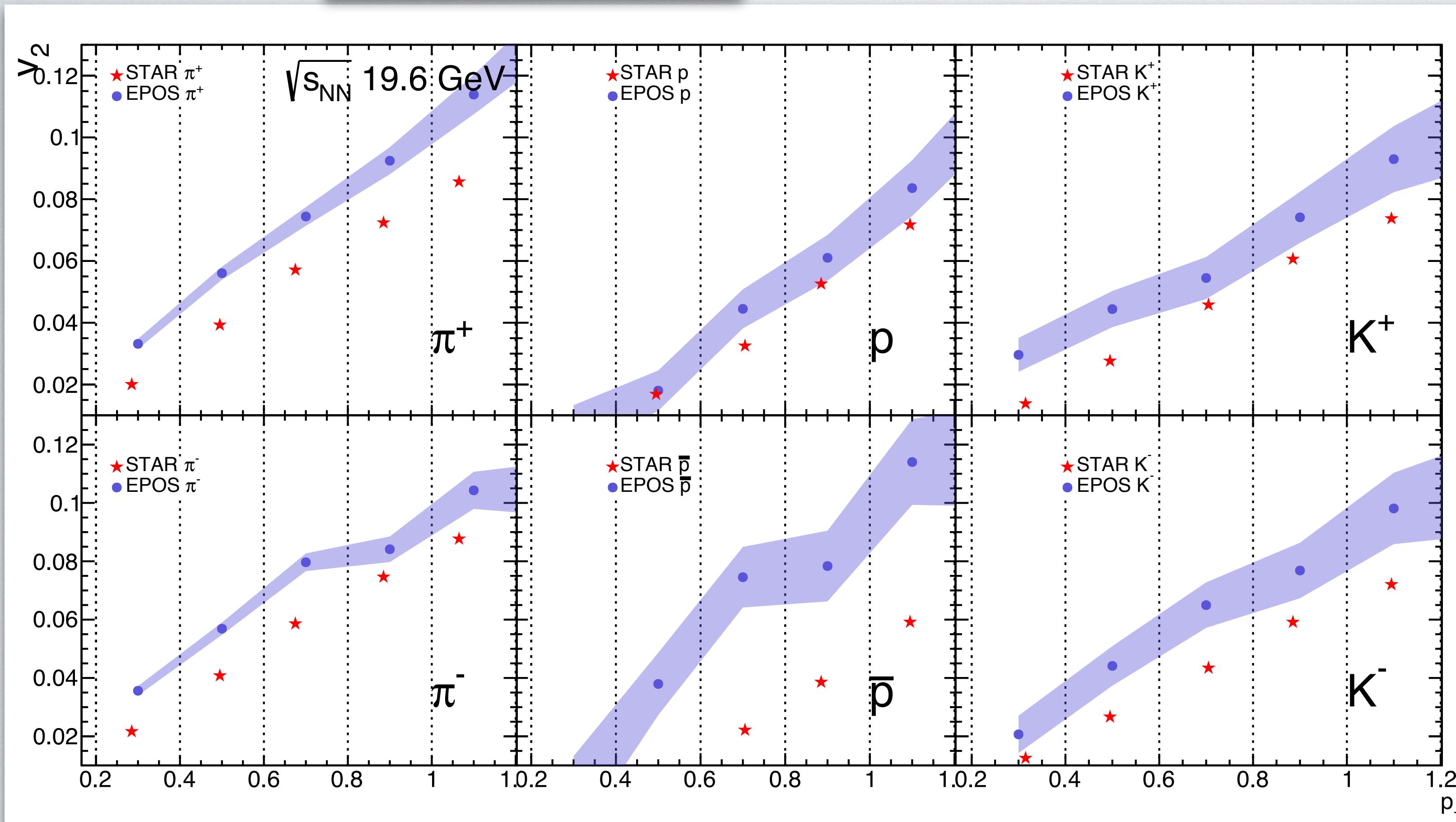
(a) First harmonic  $v_1$



(b) In the transverse plane



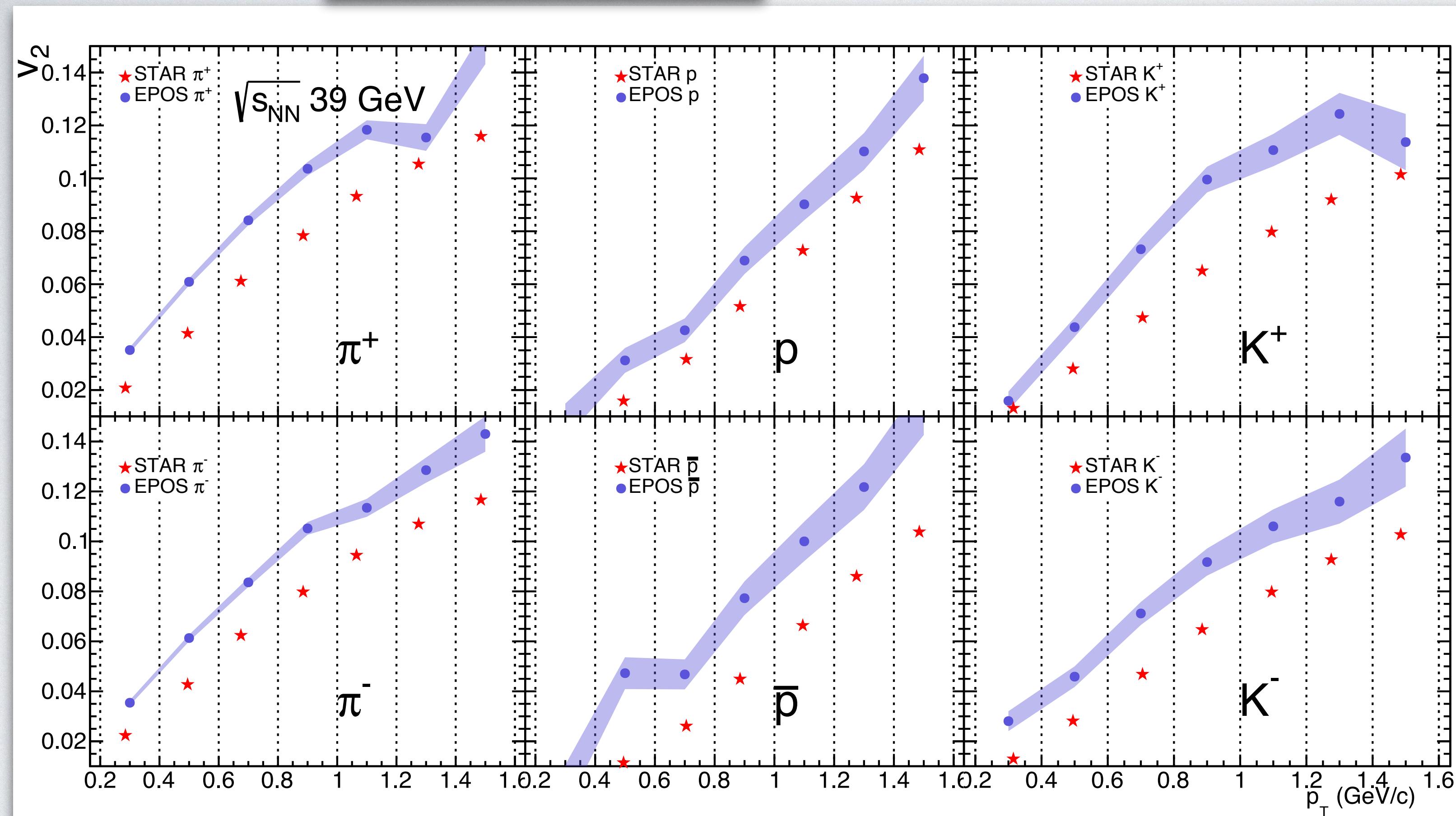
(b) Second harmonic  $v_2$

$\sqrt{s_{NN}} = 19.6 \text{ GeV}$ **EPOS > STAR**

- **Protons:** comparable!
- less mass → bigger differences

centrality: 0-80%

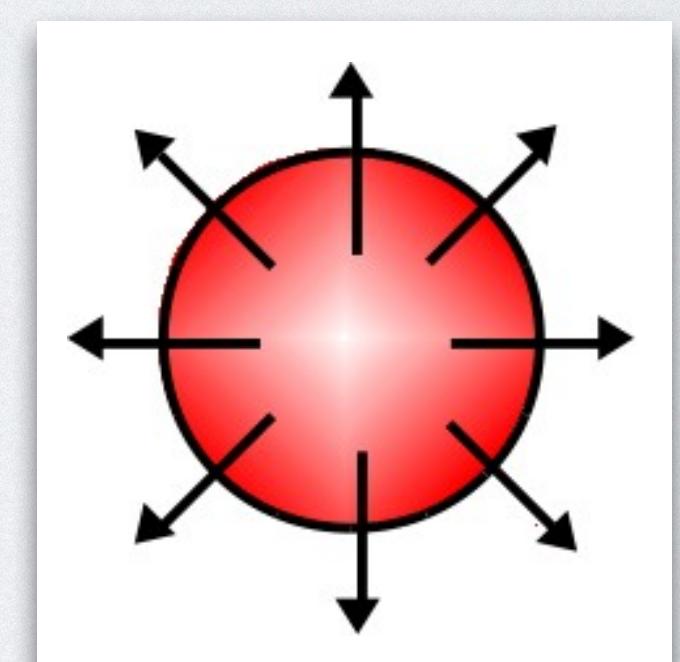
 $p \in (0.15, 5 \text{ GeV}/c)$  $|\eta| \in (0.05, 1)$

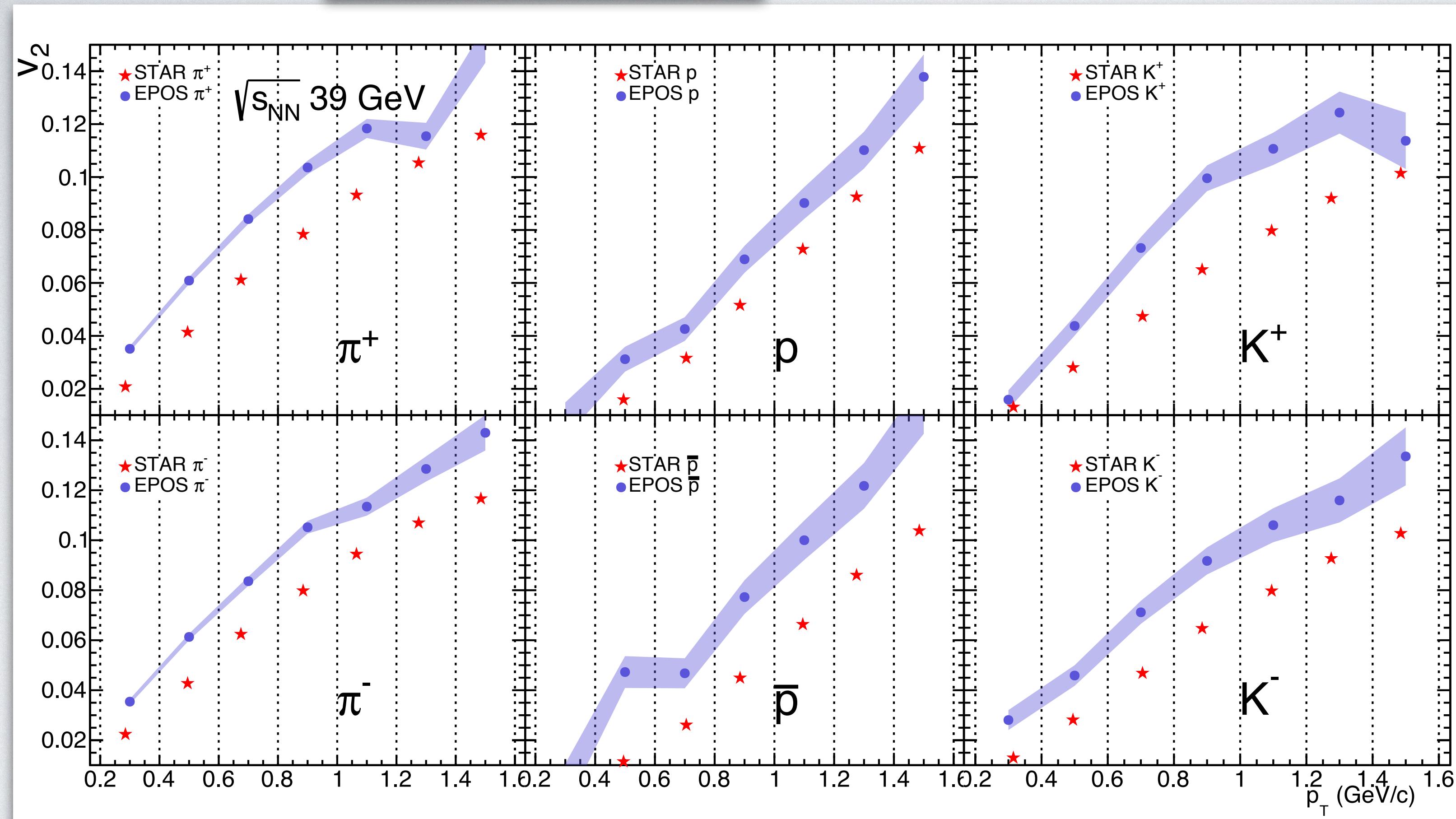
$\sqrt{s_{NN}} = 39\text{GeV}$ 

centrality: 0-80%

 $p \in (0.15, 5 \text{ GeV}/c)$  $|\eta| \in (0.05, 1)$ **EPOS > STAR**

- less mass  $\rightarrow$  bigger differences
- Fluid-particles
- Radial flow



$\sqrt{s_{NN}} = 39\text{GeV}$ 

centrality: 0-80%

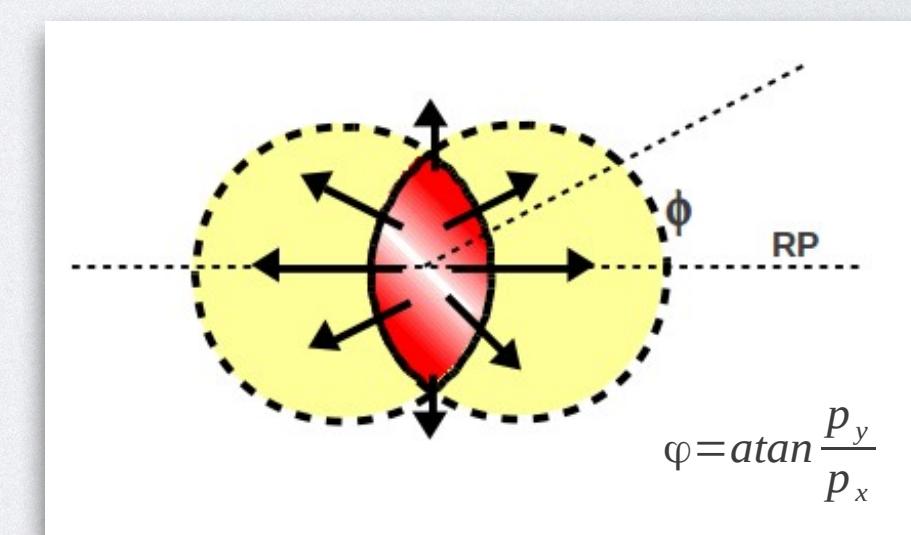
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EPOS &gt; STAR

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Fluid-particles

Radial flow



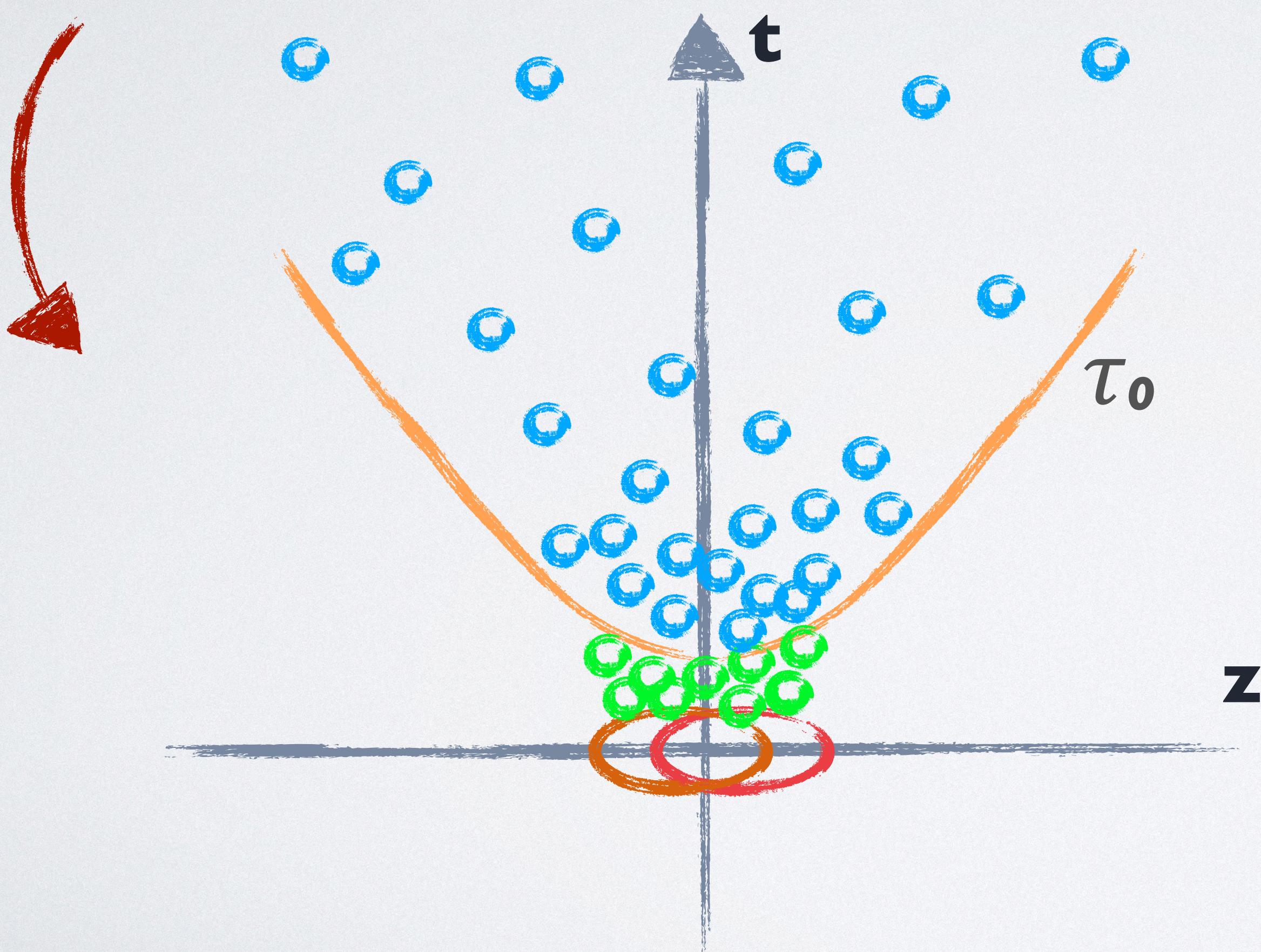
Elliptic flow?

Decrease of energy:

- Initial time
- Equation of state
- .....

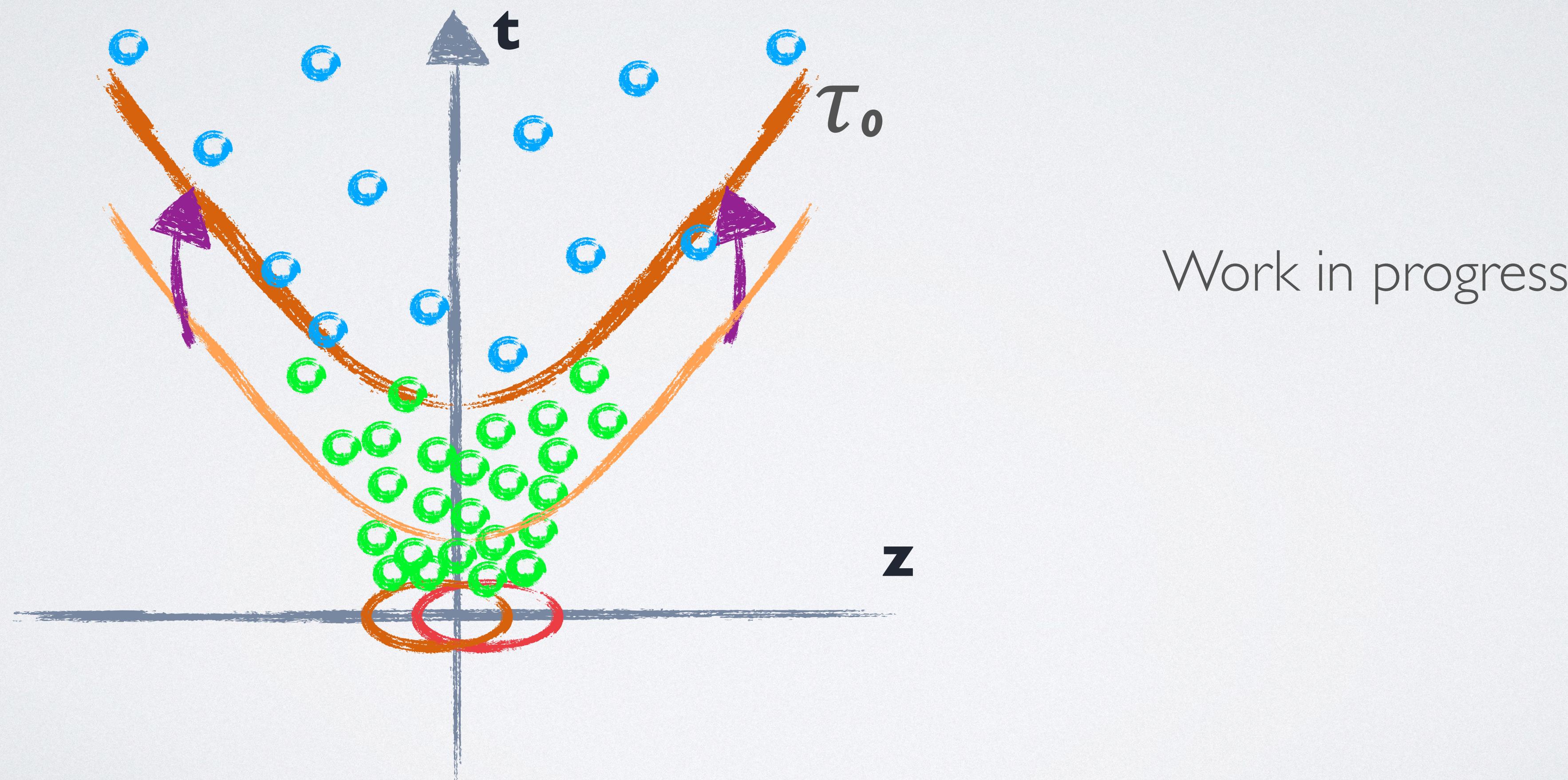
# INITIAL TIME $\tau_0$

- Core fraction starts at some early proper **initial time  $\tau_0$**
- The fluid (**core**) is separated & the hadrons are escaping (also hadron jets - **corona**)



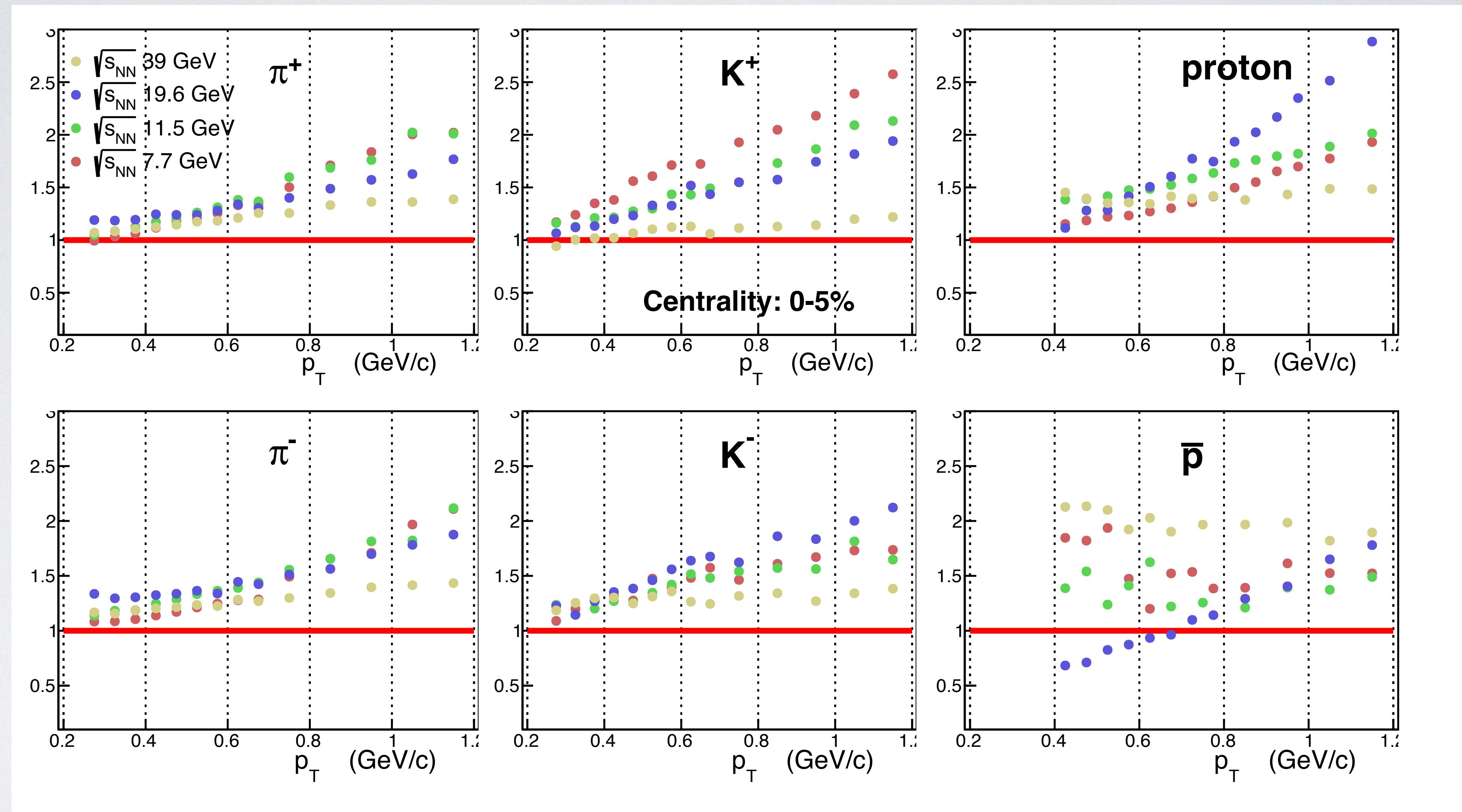
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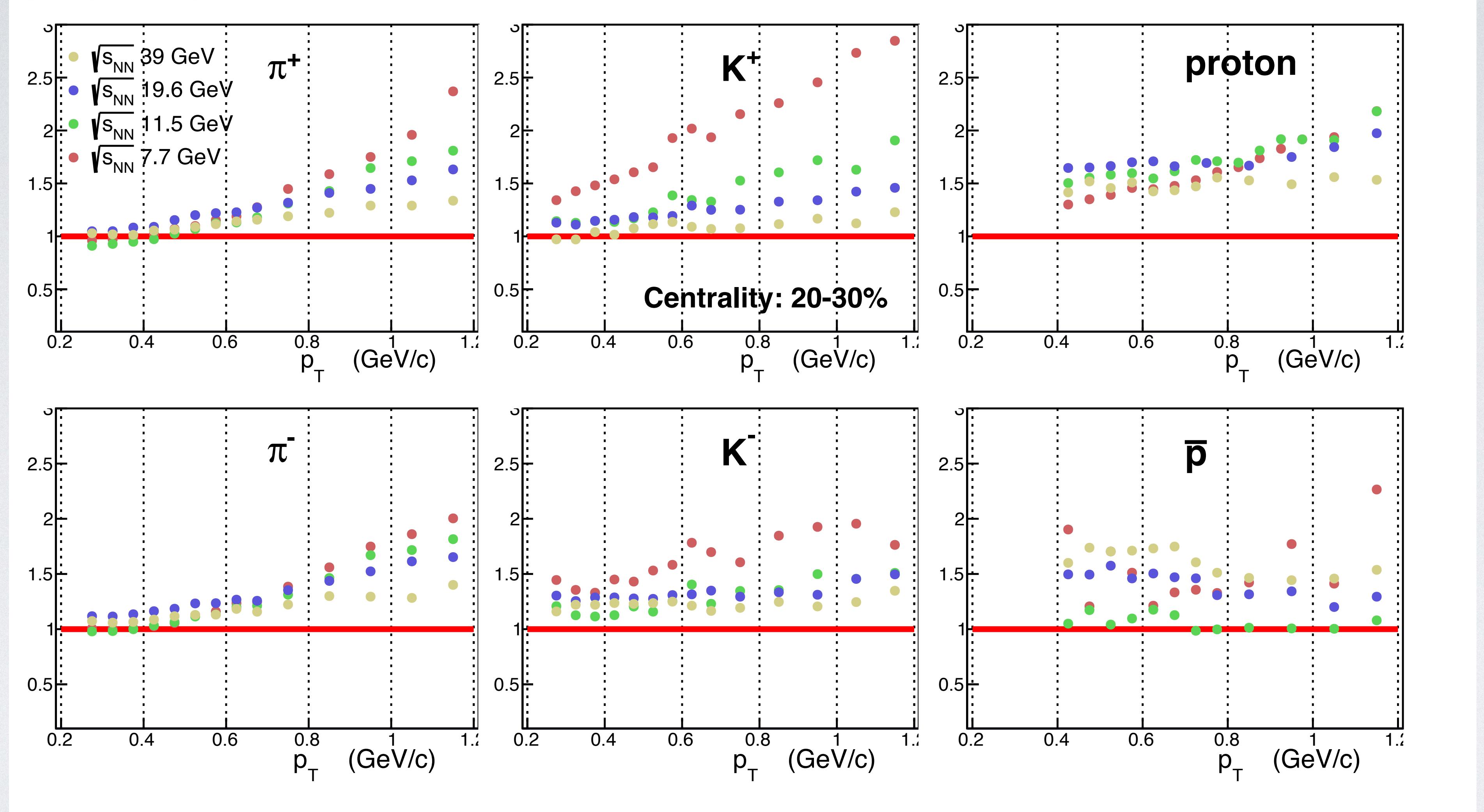


THANK YOU for your attention!

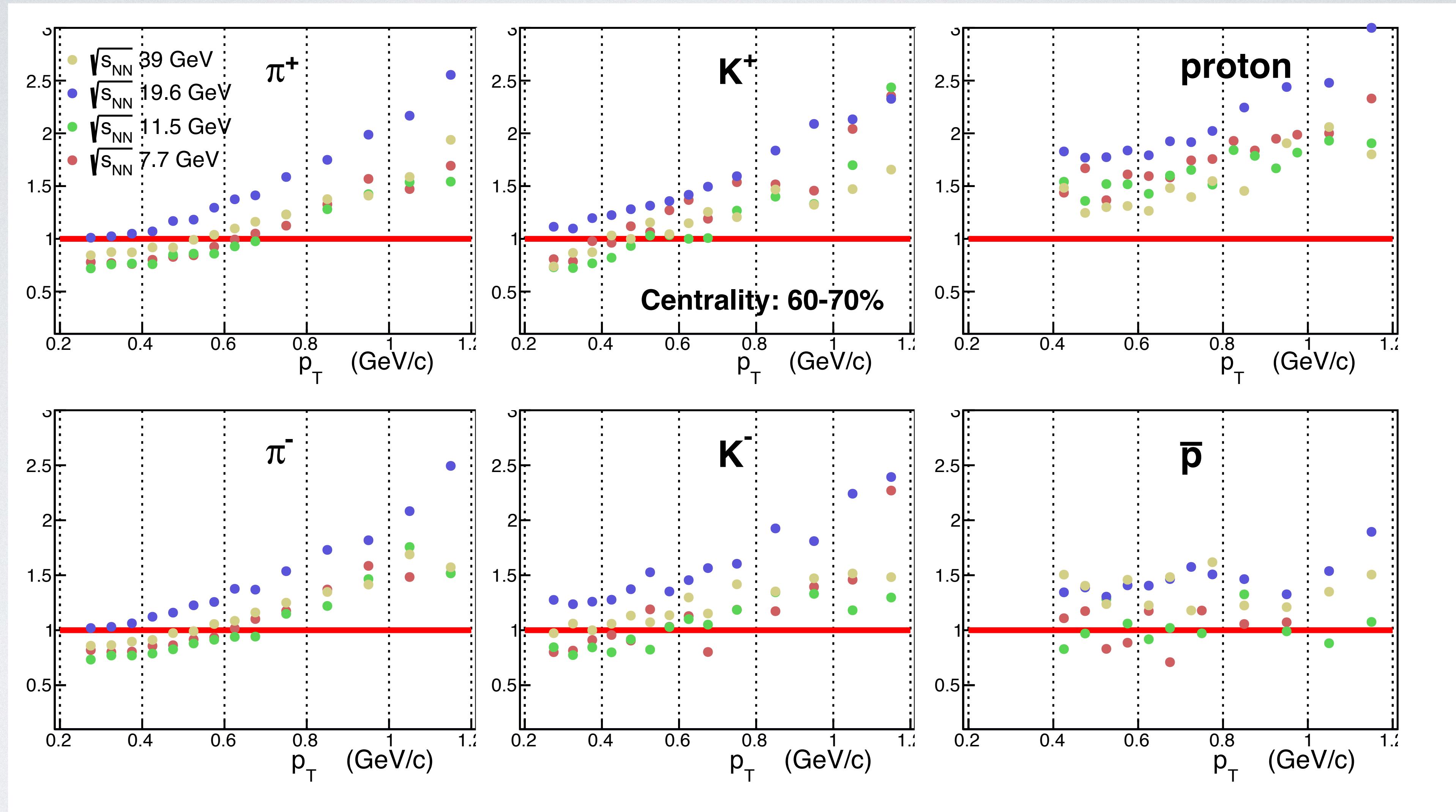
# BACK UP



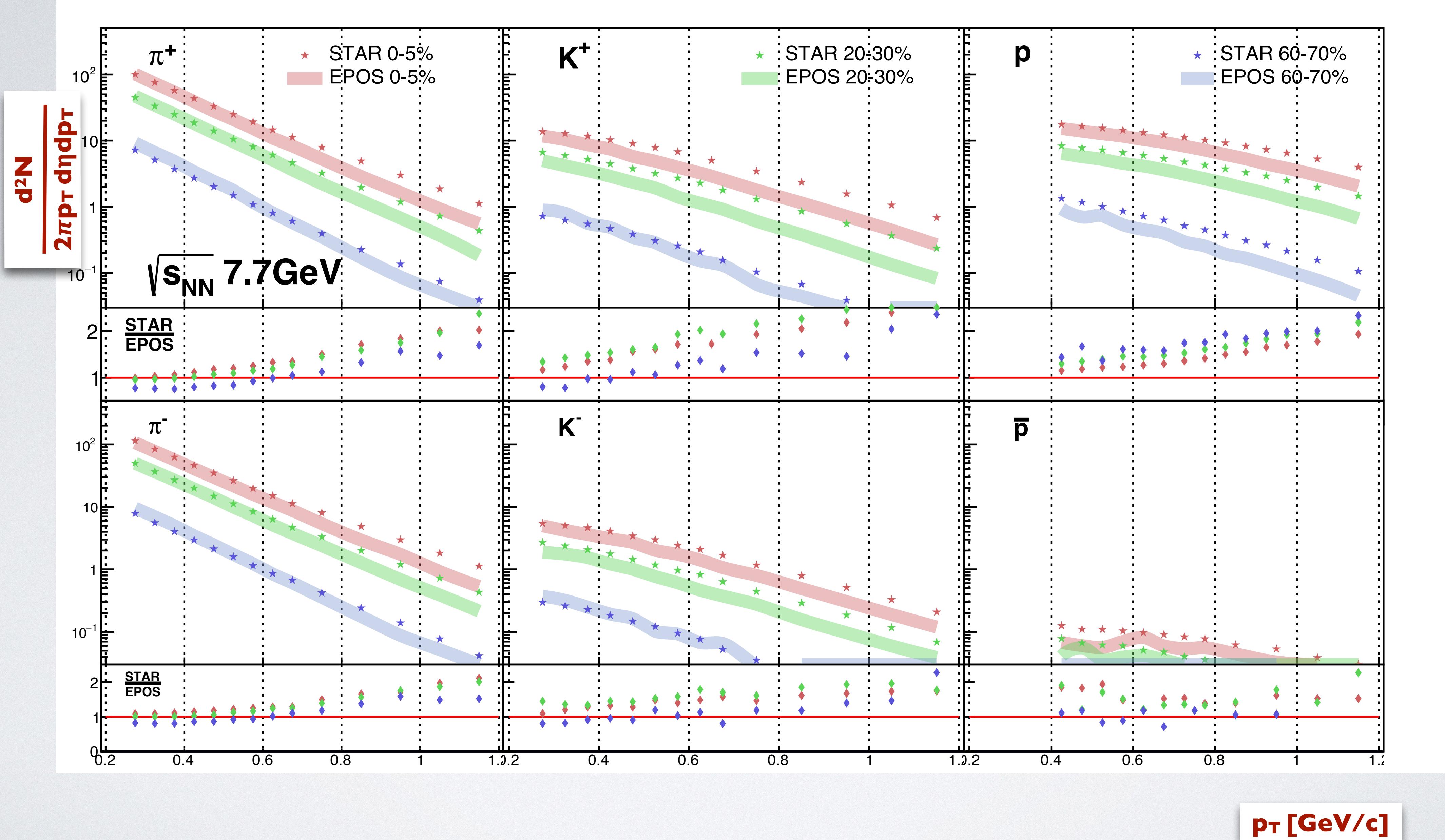
$p_T$  [GeV/c]

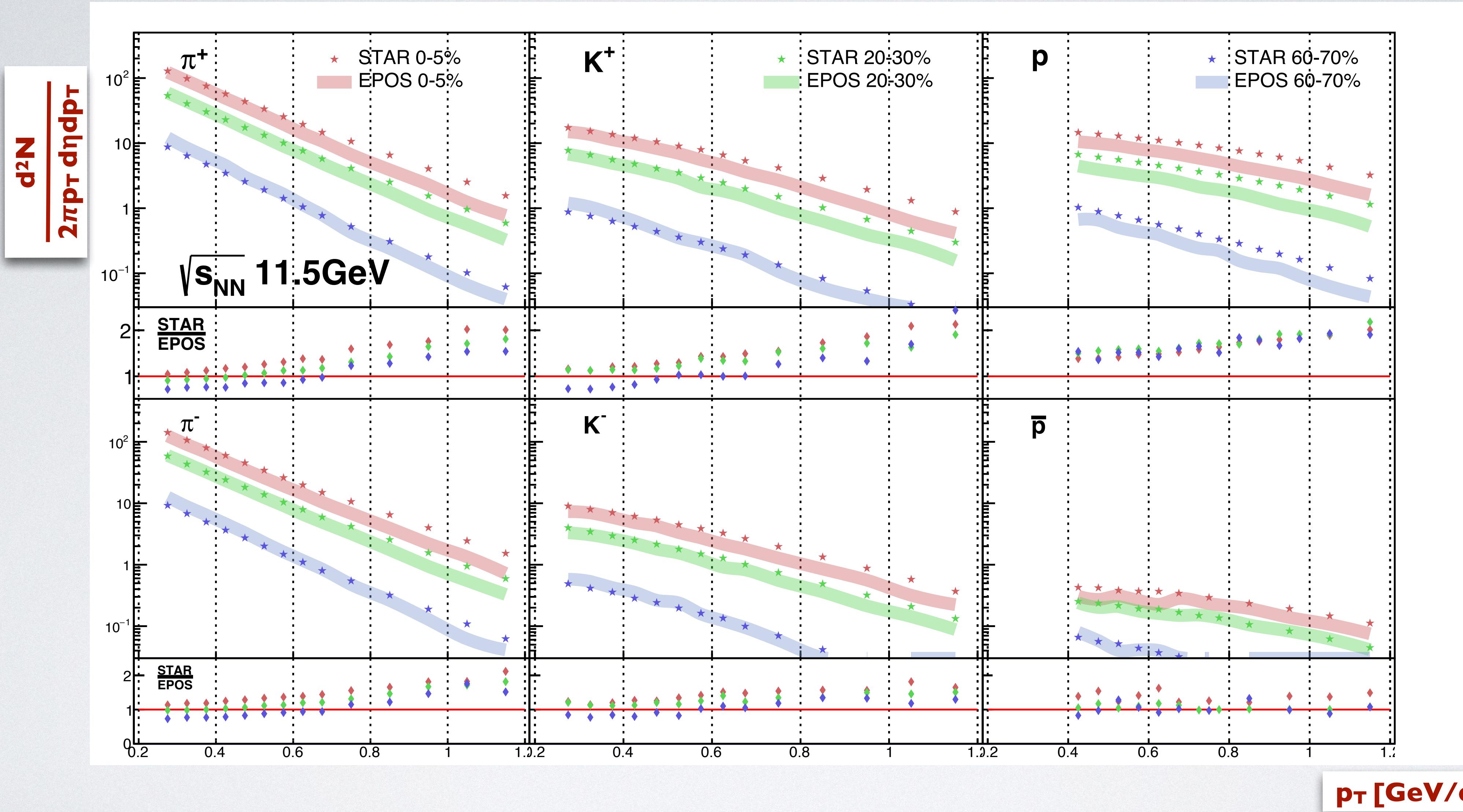


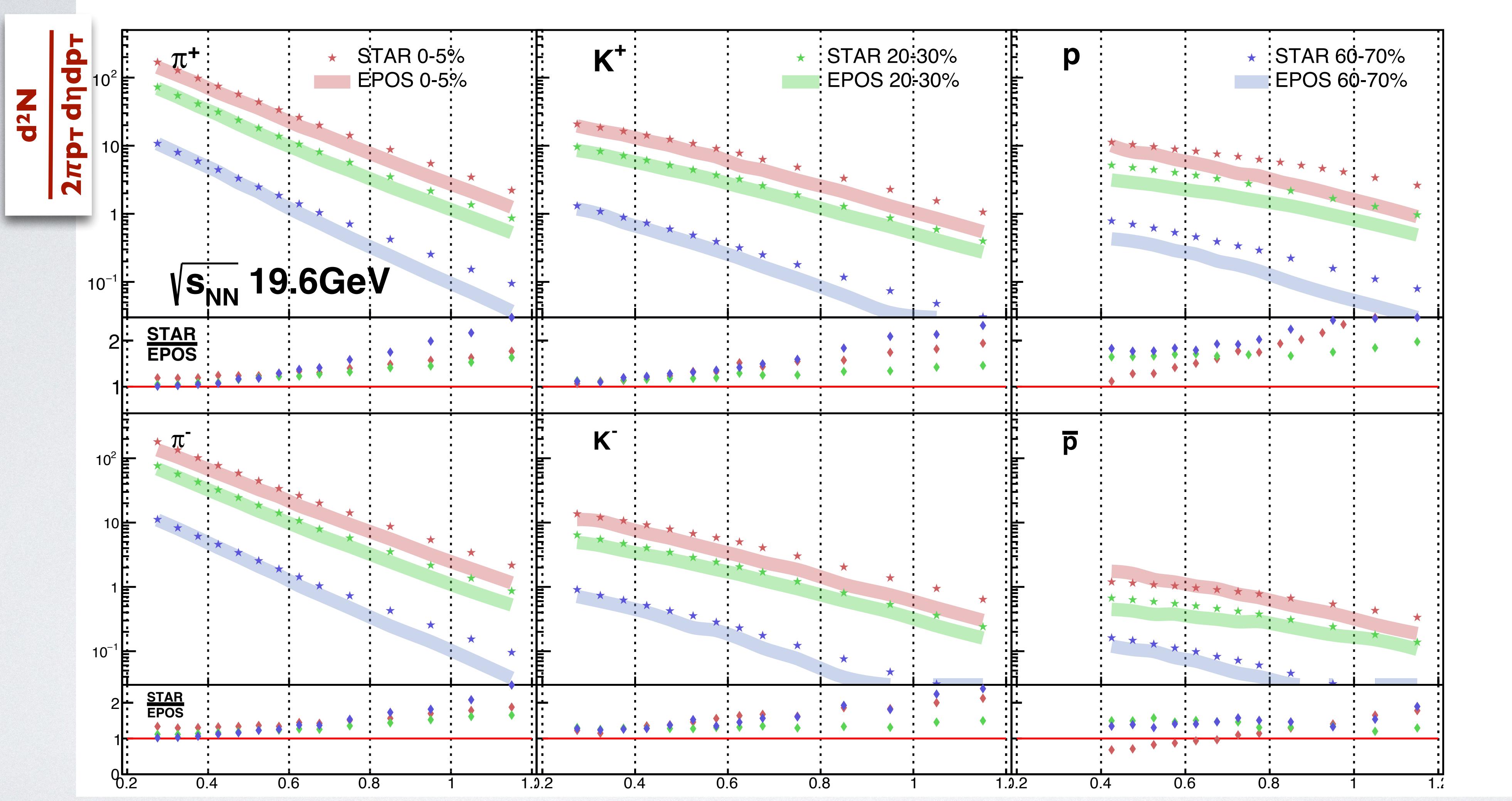
$p_T$  [GeV/c]



**$p_T$  [GeV/c]**







$p_T [\text{GeV}/c]$

