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Multiplicity fluctuations and collective flow in small colliding systems

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In collaboration with

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Contents

- Introduction
- Integrated dynamical model
- Results
- Summary

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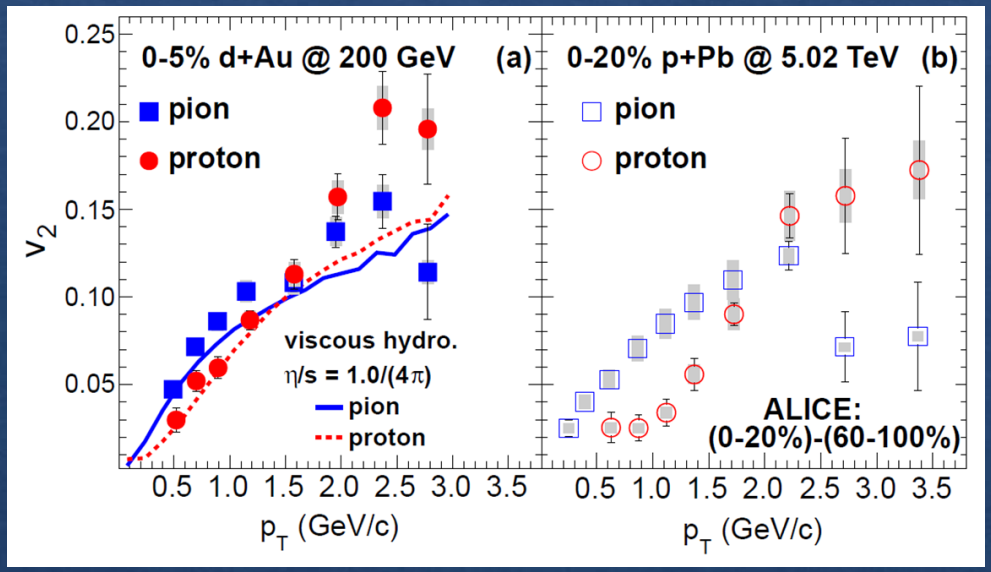
Collectivity in small systems



A. Adare *et al.*, Phys. Rev. Lett. 114,192301(2015).

Mass ordering for identified hadrons

Consistent with hydrodynamic flow picture

P. Bozek, W. Broniowski, P. Romatschke, K. Werner, B. Schenke, R. Venugopalan, G. Y. Qin, ….

*Caveat: Mass ordering without flow

B.Schenke *et al.*, Phys.Rev.Lett. 117, 162301 (2016) .

Purpose of this study

Analysis of collectivity in small colliding systems from an integrated dynamical model

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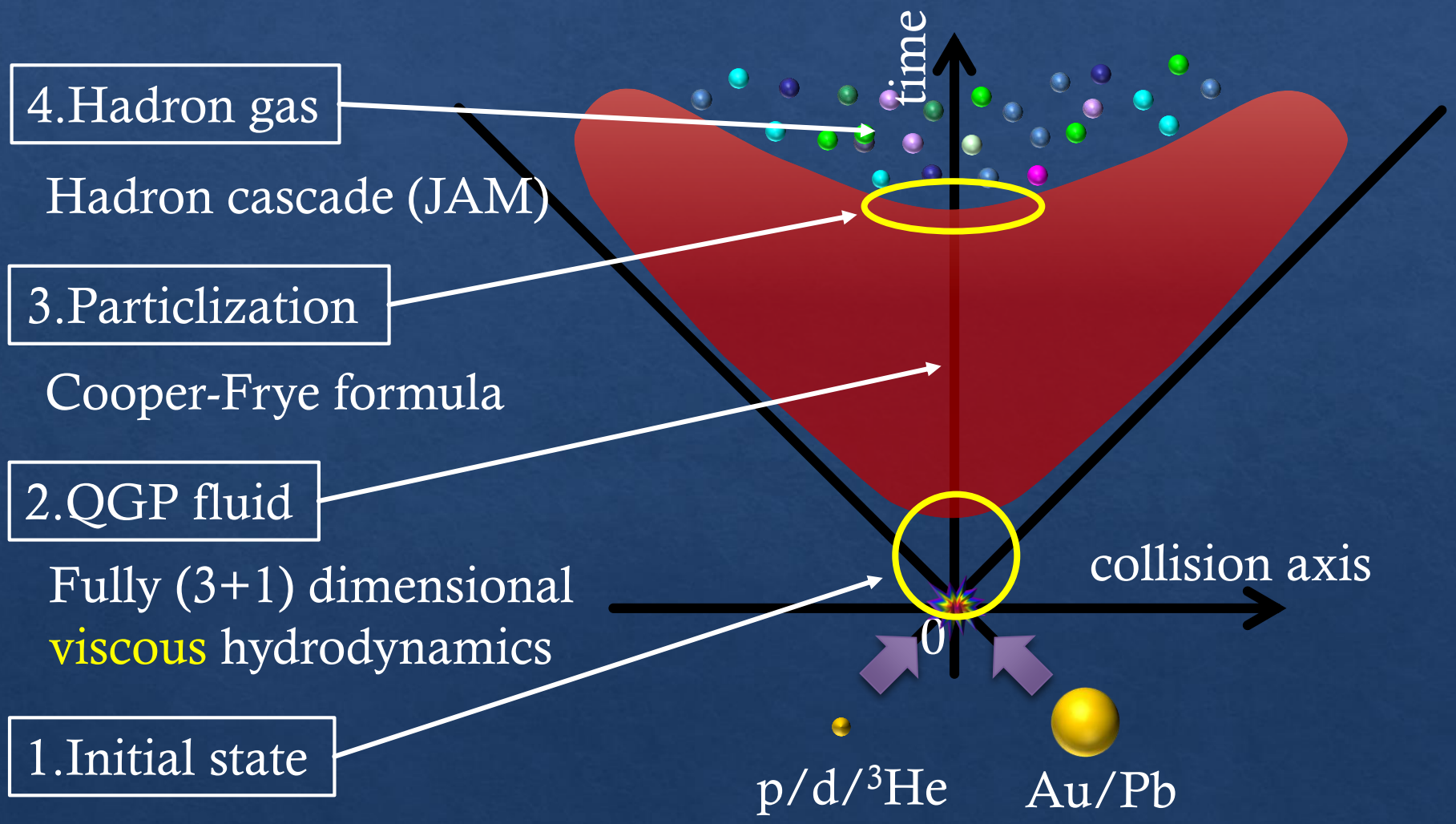
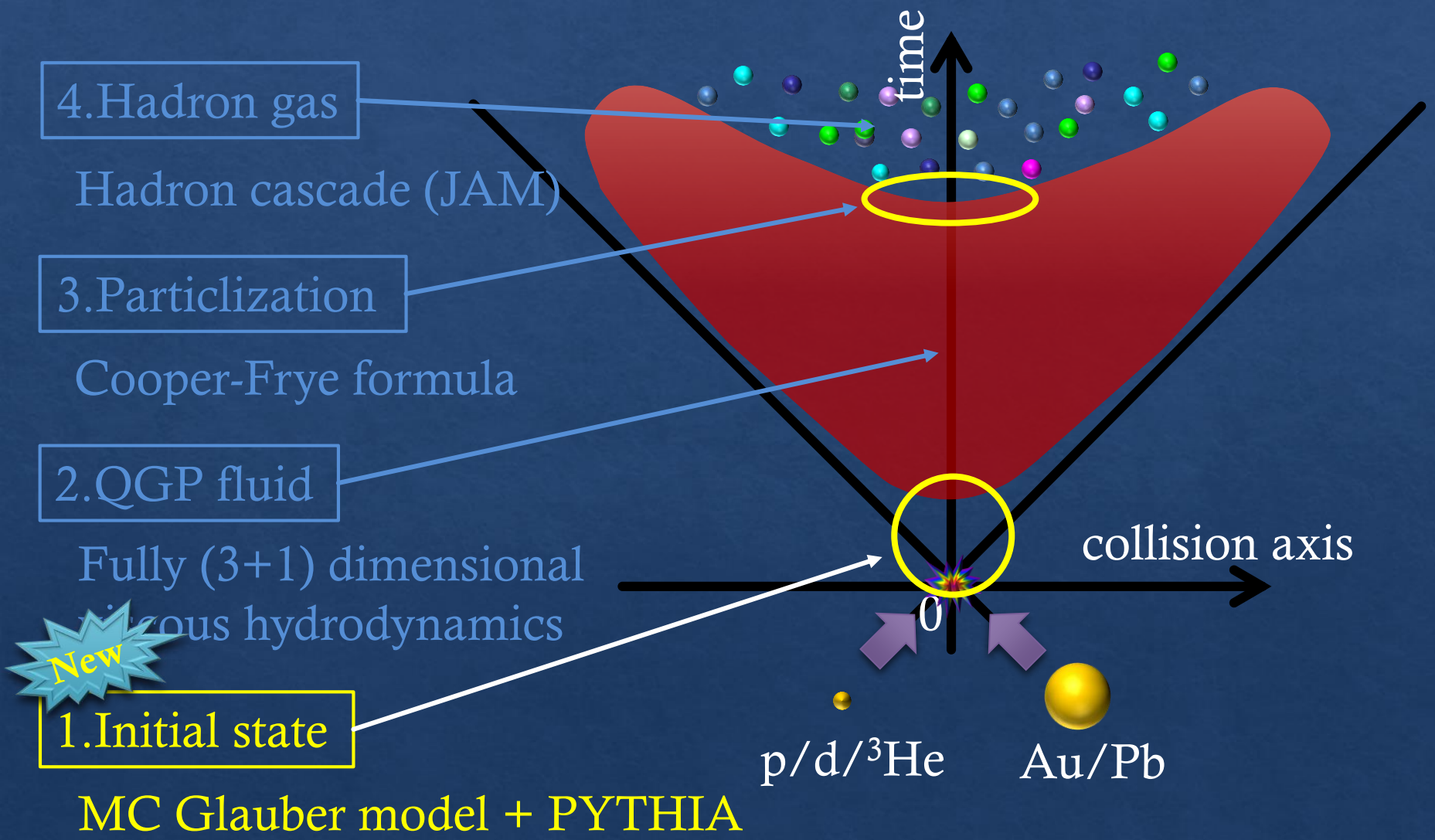
Integrated dynamical model



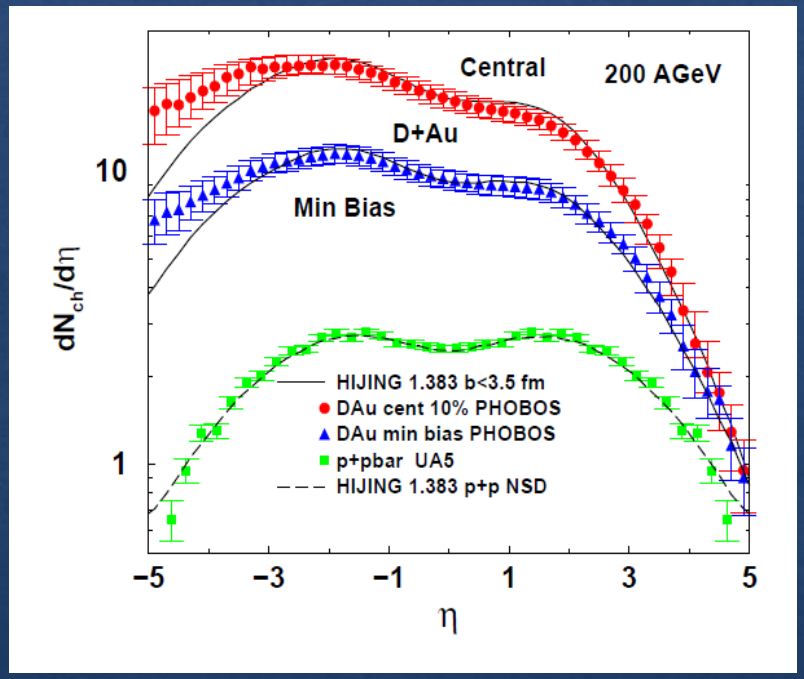
T. Hirano *et al.*, Prog. Part. Nucl. Phys. 70, 108 (2013).

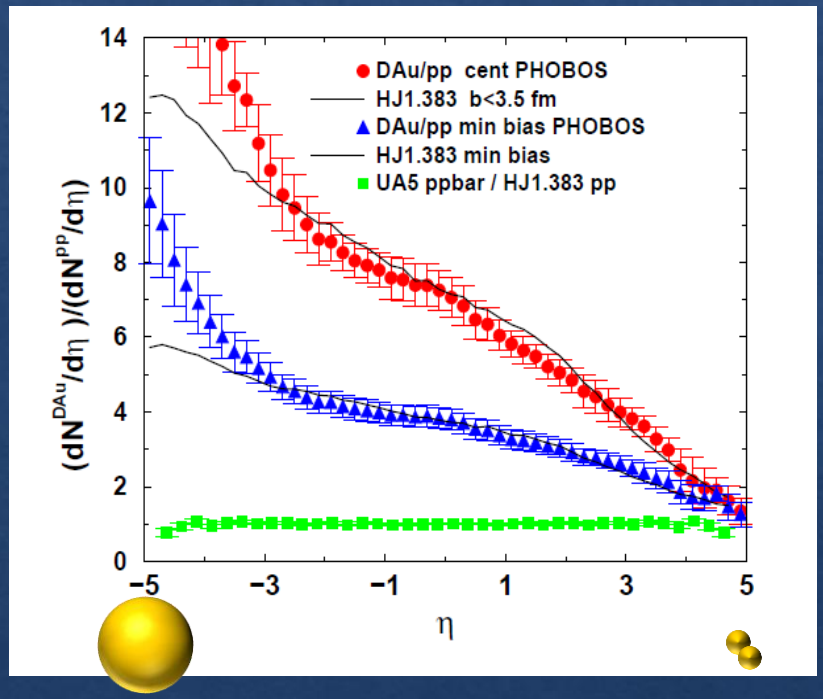
Integrated dynamical model



T. Hirano *et al.*, Prog. Part. Nucl. Phys. 70, 108 (2013).

Asymmetric longitudinal profile



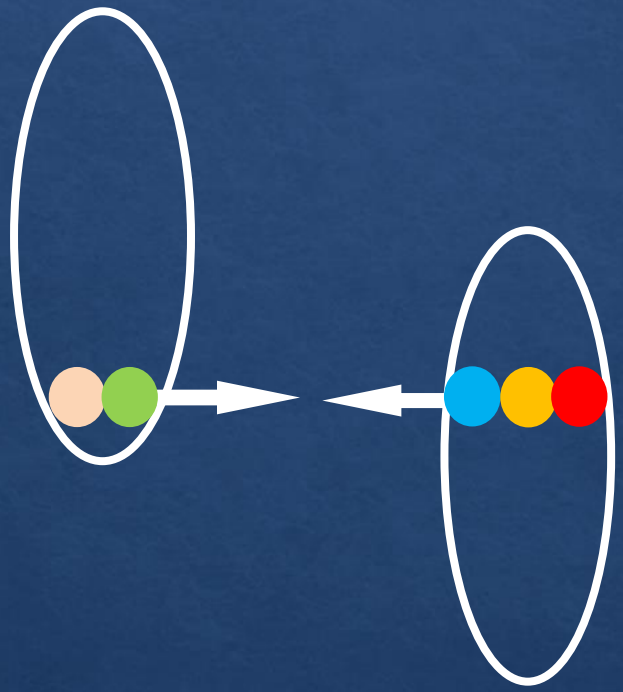


Au side d side

Rapidity triangle/trapezoid clearly observed in d+Au collision at RHIC

A.Adil and M.Gyulassy, Phys. Rev. C **72,** 034907 (2005).

Modified BGK model



Hadronic string formation

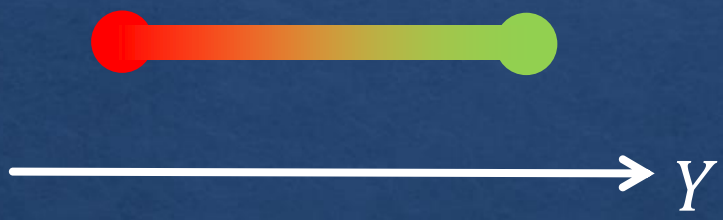
$-Y_{\mathrm{beam}}$ ← rapidity → Y_{beam}

Number of participants $(N_{\mathrm{A}}, N_{\mathrm{B}})$
from MC-Glauber model

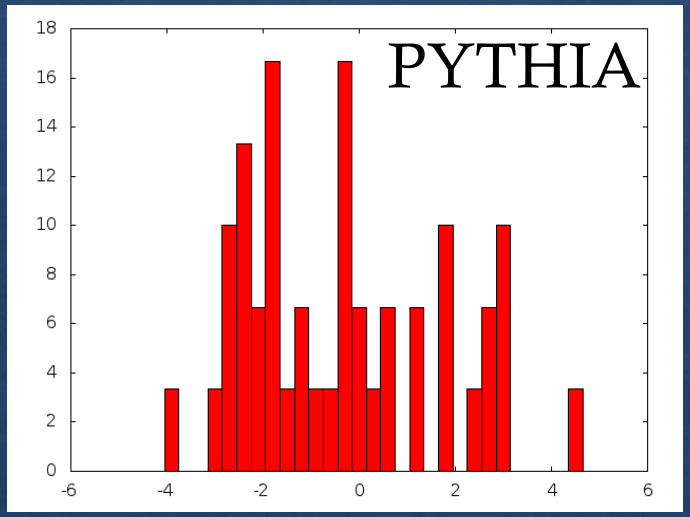
S.J.Brodsky, J.F.Gunion and J.H.Kuhn, Phys.Rev.Lett.**39**, 1120 (1977).
T.Hirano *et al.*, Phys.Lett.B **636**, 299 (2006).

Rapidity dependence

One string formation

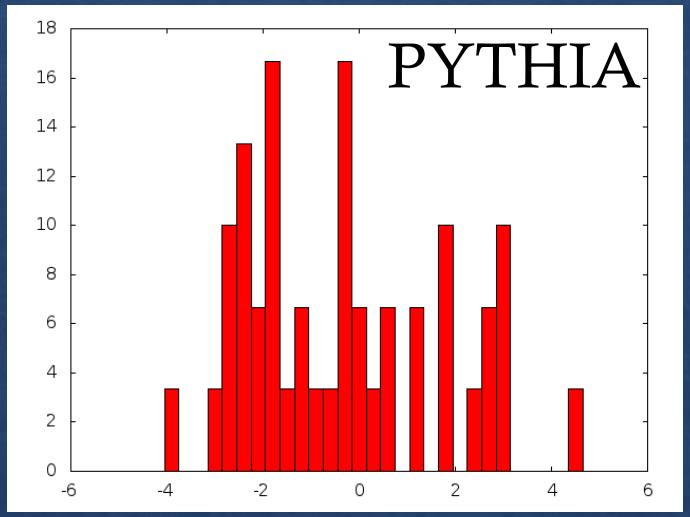


Rapidity dependence



Rapidity distribution
in a pp collision at 200 GeV

Rapidity dependence



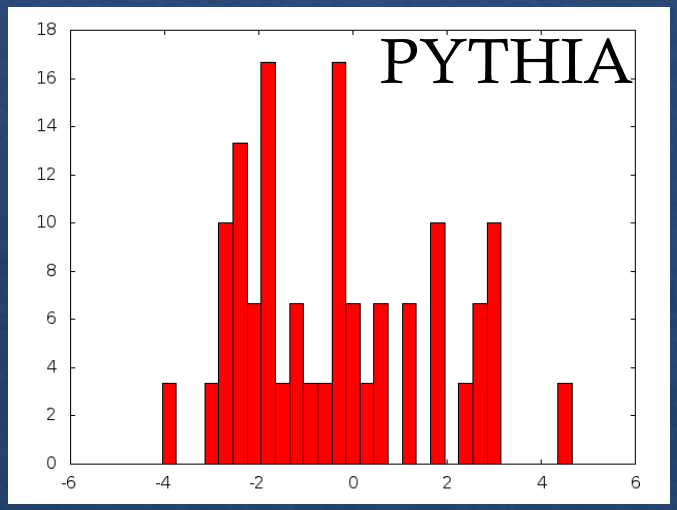
$\frac{dN^{pp}}{dY}$

Y

$-Y_{\text{beam}} \leftarrow$ rapidity $\rightarrow Y_{\text{beam}}$

Rapidity distribution
in a pp collision at 200 GeV

Rapidity dependence



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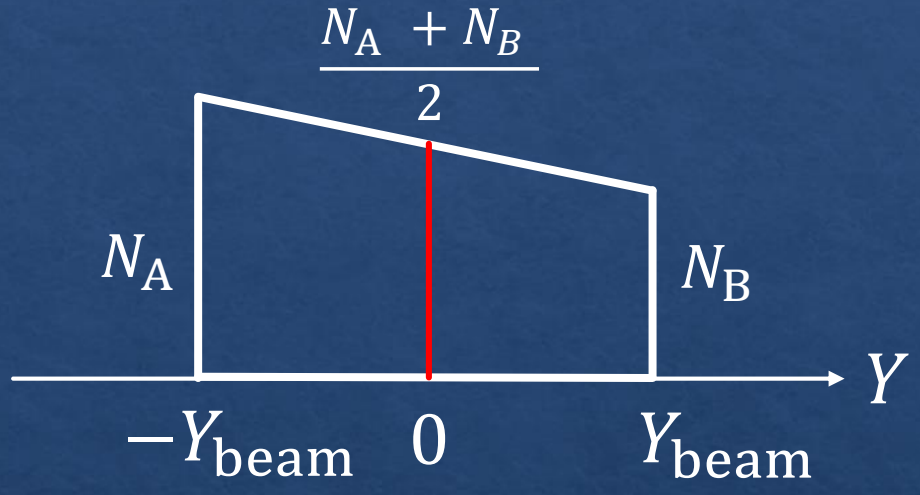


Rapidity triangle/trapezoid
Multiplicity scaling in rapidity space

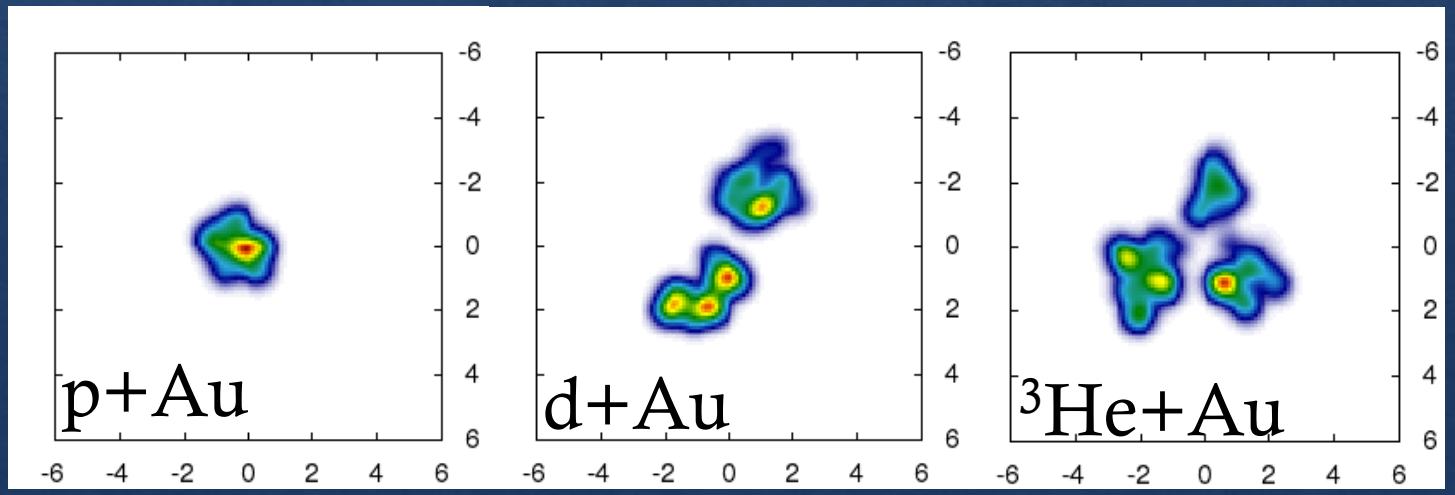
Fluctuations of multiplicity and longitudinal profile

Initial profile

Particles generated by PYTHIA

- Each particle associated with Gaussian function
- Initial entropy density distributions

Transverse profile $(\eta_s = 0)$



Setting

◆Collision systems: p/d/^{3}He+Au at $\sqrt{s_{NN}} = 200$ GeV (RHIC)
p+Pb at $\sqrt{s_{NN}} = 5.02$ TeV (LHC)

◆Initial conditions: MC Glauber model + PYTHIA

◆Viscous hydrodynamics:

- EoS: *s*95*p*-v1.1 [Lattice QCD (HotQCD)
  Resonance gas (JAM)
- Shear viscosity: $\eta/s = 1/4\pi$
- Initial time: $\tau_0 = 0.6$ [fm]

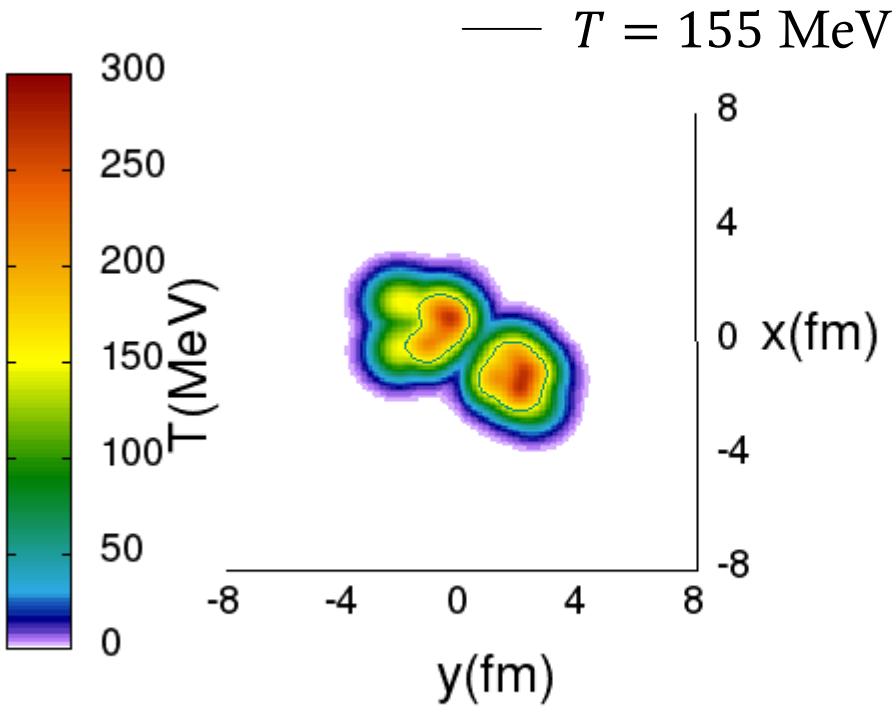
◆Cooper-Frye formula:

Switching temperature $T_{\mathrm{sw}} = 155$ [MeV]

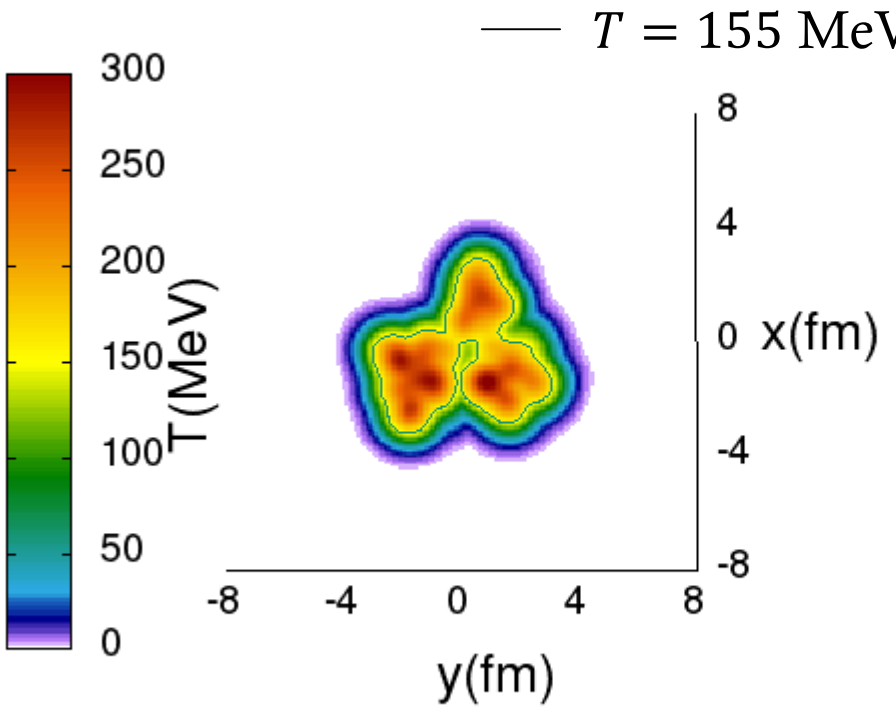
◆Hadron cascade: JAM

Viscous hydrodynamic simulations

d+Au 200 GeV



^{3}He+Au 200 GeV



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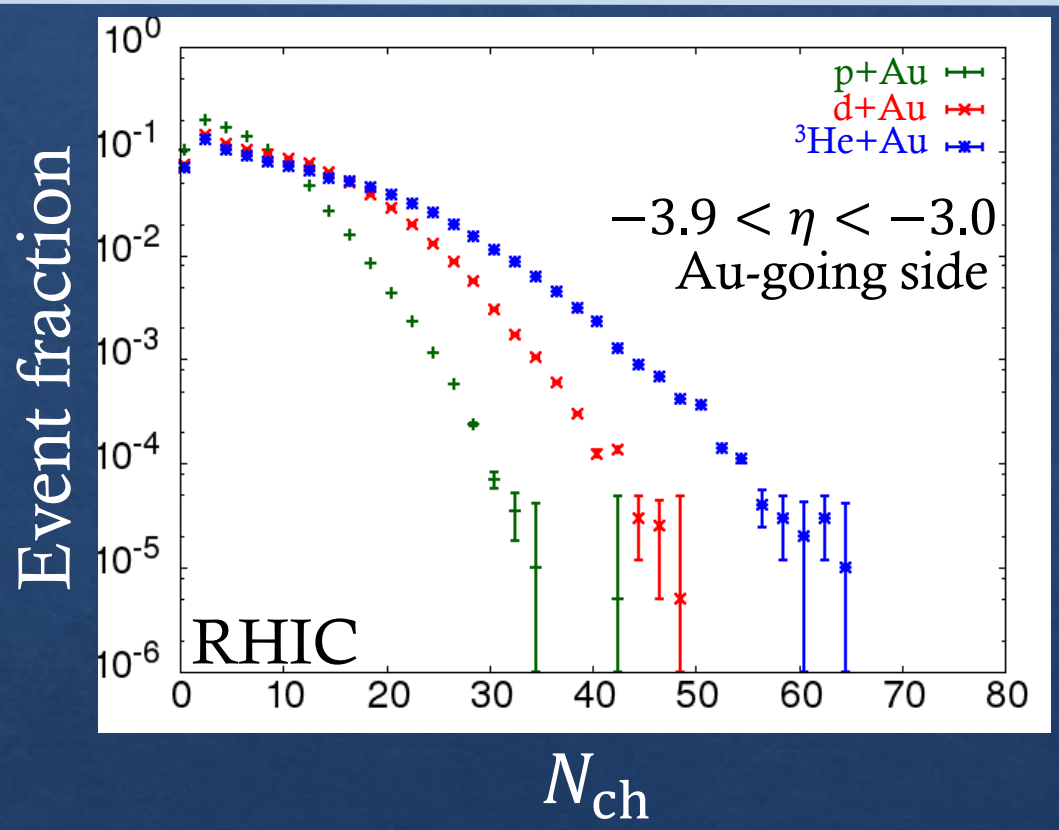
Multiplicity distributions

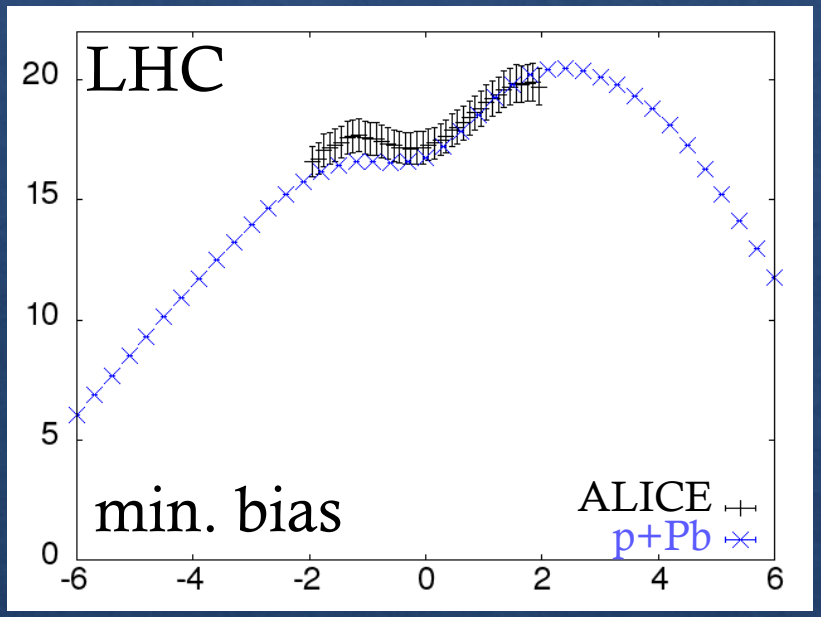


- Fluctuations of multiplicity
- The larger colliding nucleus, the higher multiplicity

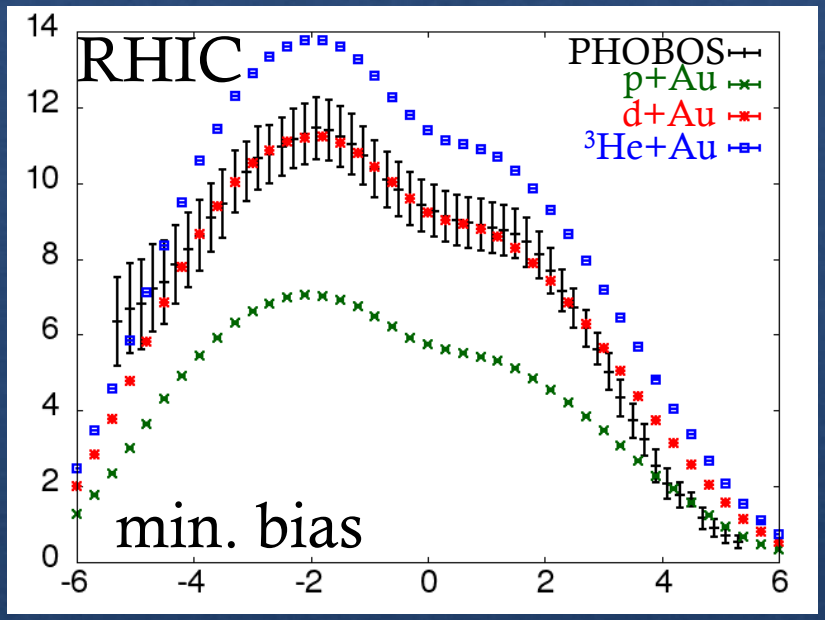
Utilization for centrality cut

Pseudorapidity distributions

$\frac{dN_{\mathrm{ch}}}{d\eta}$



η

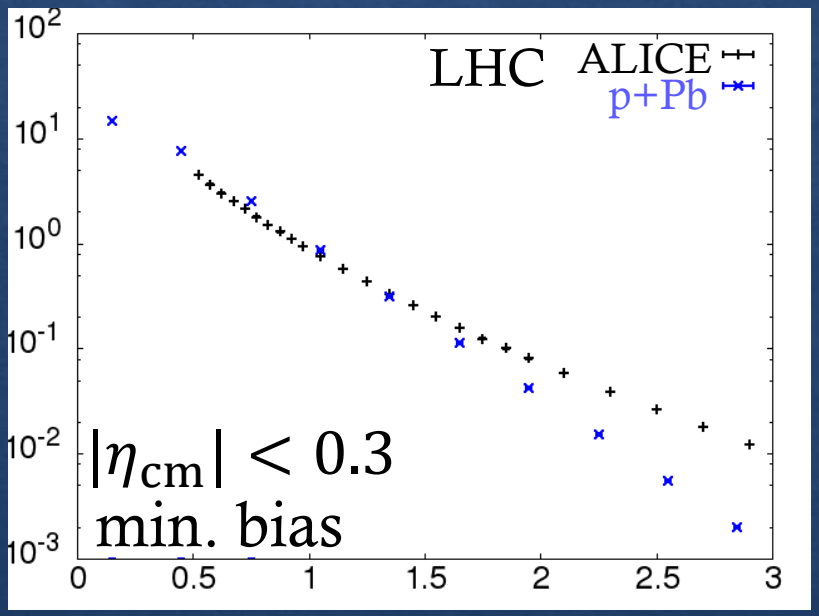


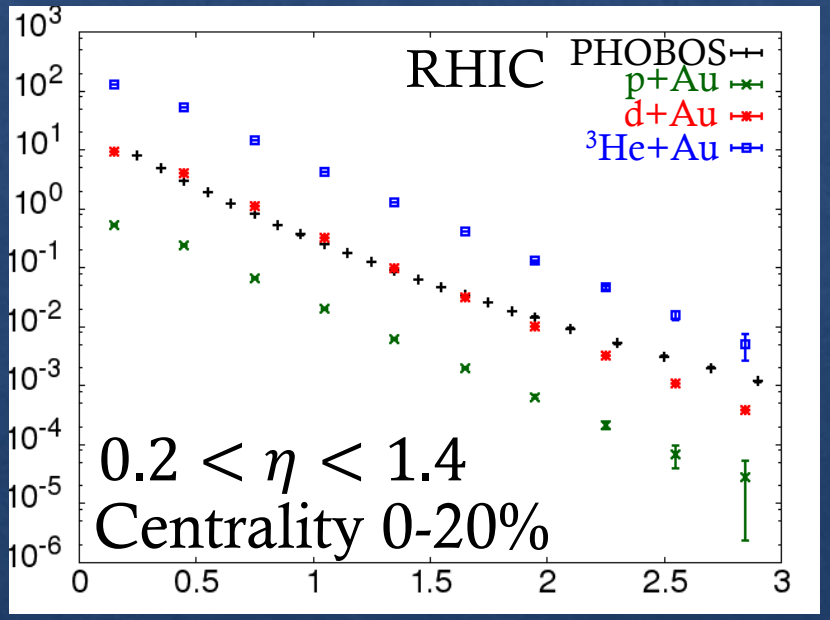
η

Rapidity triangle/trapezoid picture works quite well

B.Abelev *et al.* (ALICE Collaboration), Phys.Rev.Lett. 110, 032301 (2013).
B.B. Back *et al.* (PHOBOS Collaboration),Phys. Rev. C 72, 031901 (2005).

p_T distributions

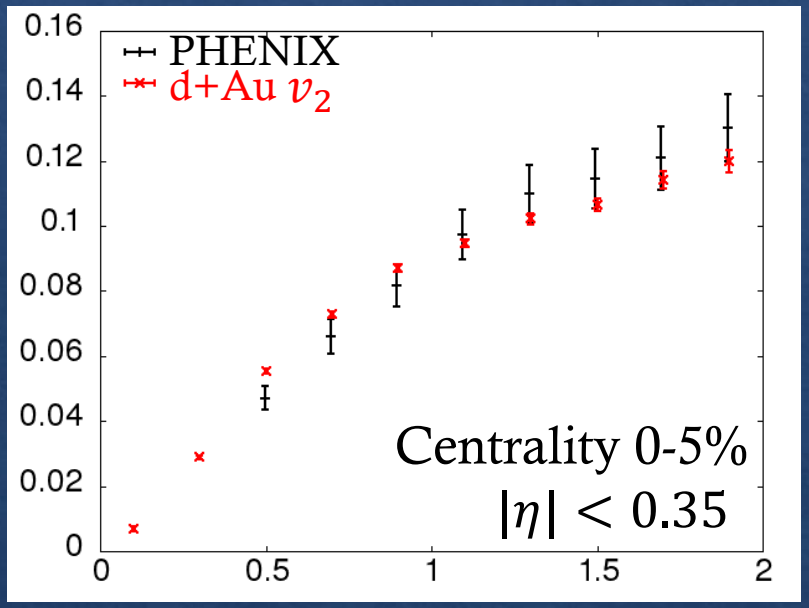


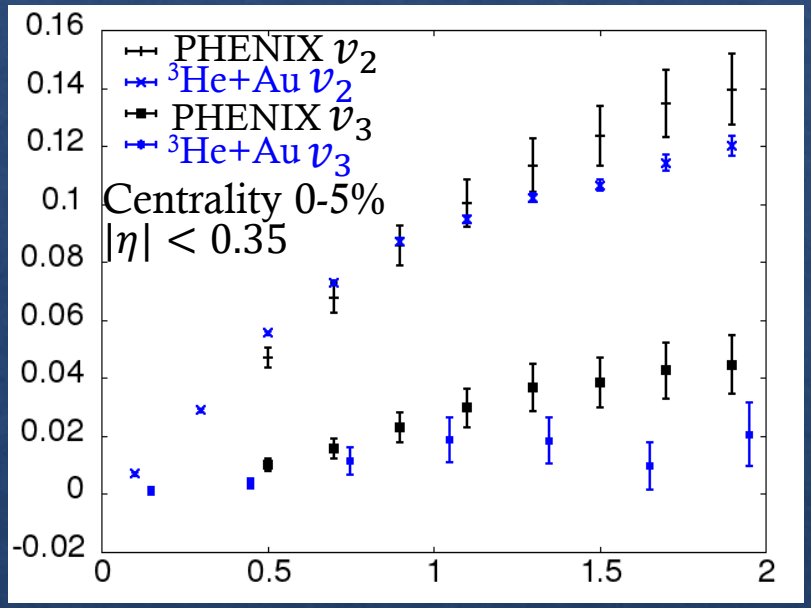


Reasonable description of transverse dynamics

B.Abelev *et al.* (ALICE Collaboration) Phys.Rev.Lett. 110, 082302 (2013).
B.B. Back *et al.* (PHOBOS Collaboration),Phys. Rev. 91, 072302 (2003).

Flow harmonics vs p_T in d/^{3}He+Au

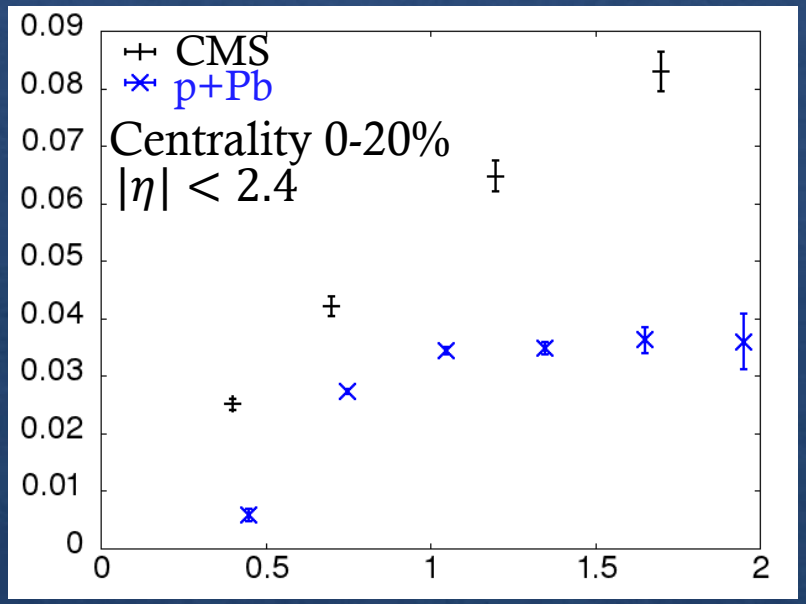


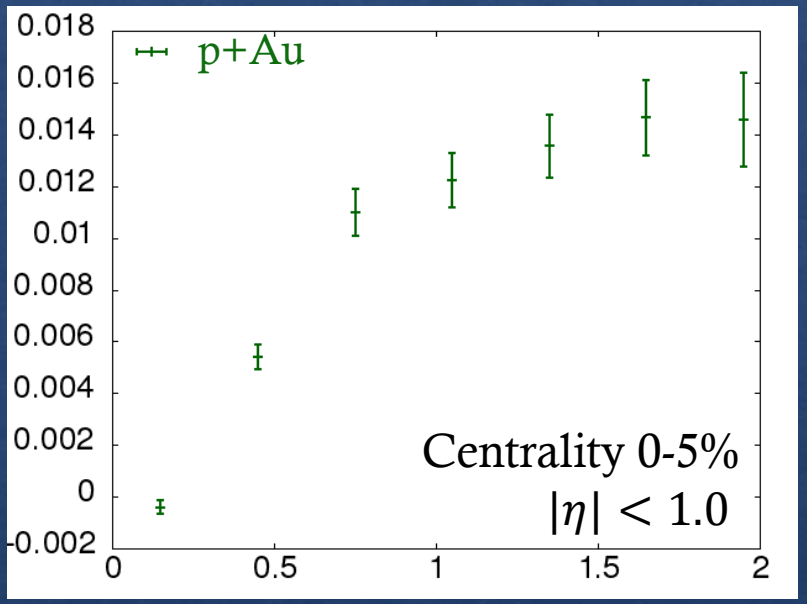


QGP fluid + hadronic gas picture works in d/^{3}He+Au collisions

A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **115**, 142301 (2013).

v_2 vs p_T in p+A



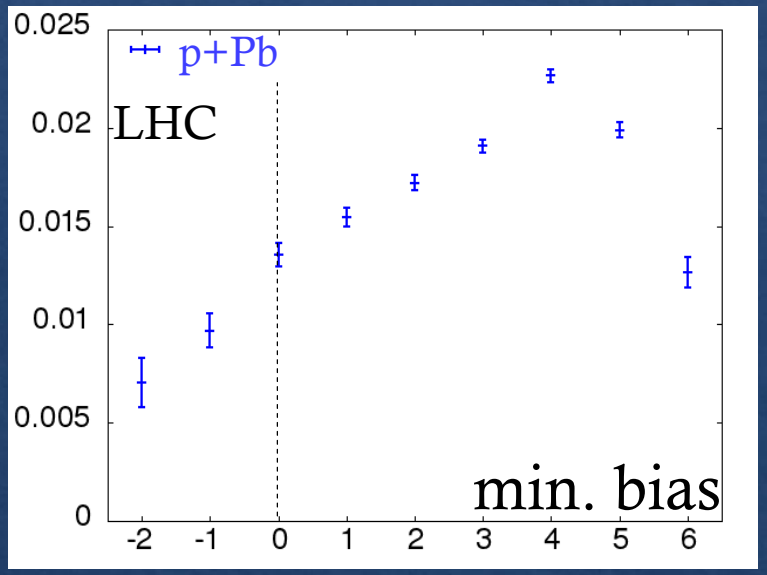


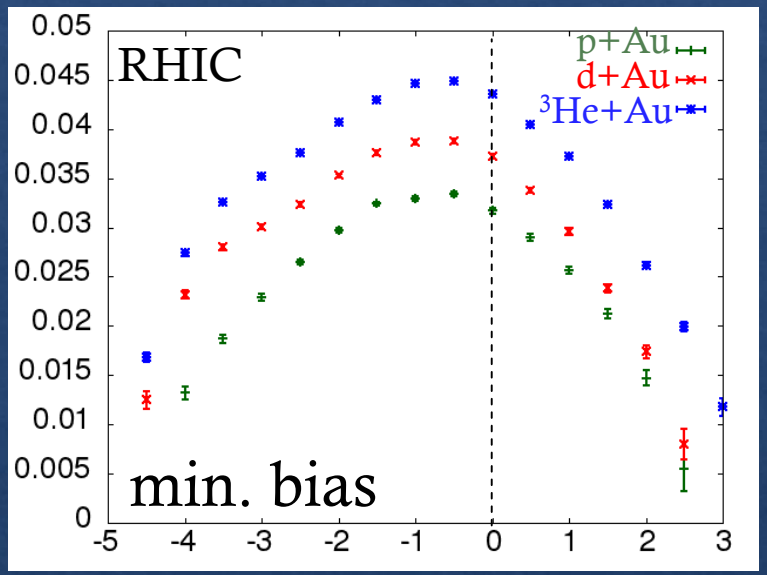
Smaller than experimental results

Need a sophisticated model in p+A collisions

S. Chatrchvan *et al.* (CMS Collaboration), Phys.Lett. B724 (2015).

v_2 vs pseudorapidity





Asymmetric shape of $v_2(\eta)$

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Summary

- Analysis of flow observables in small colliding systems at LHC and RHIC energy
- Development of a new hydrodynamic initialization model based on MC-Glauber + PYTHIA

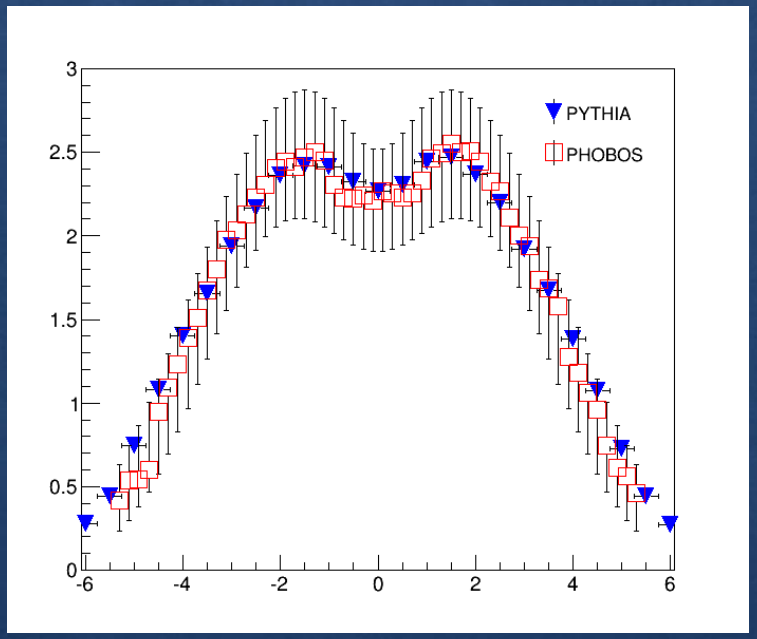
QGP fluid + hadronic gas picture works in d/^{3}He+Au collisions

Our results smaller than experimental data in p+A collisions

Back up

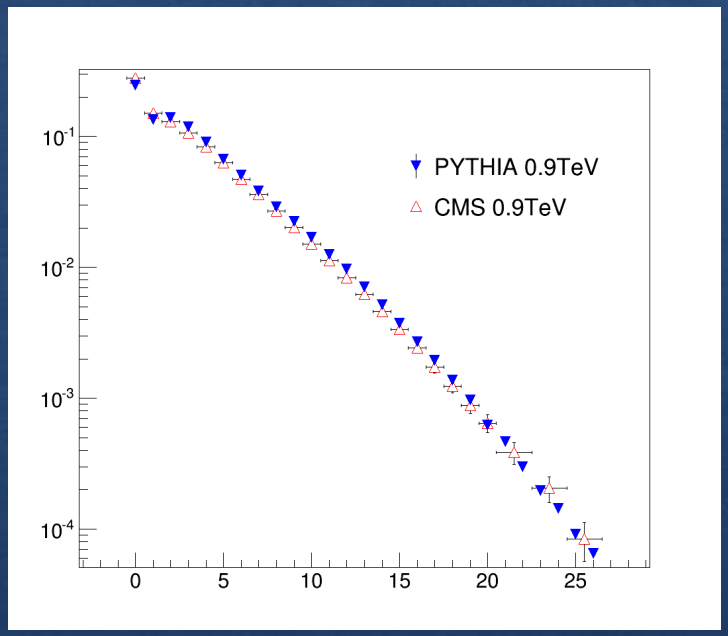
Event generator PYTHIA8

$|\eta| < 0.5$



$\frac{dN_{\mathrm{ch}}}{d\eta}$

η



N_{event}

N_{ch}

PYTHIA work very well at the RHIC energy

T. Sjöstrand *et al.*, Comput. Phys. Commun. 191, 159 (2015).

B. B. Back *et al.* (PHOBOS Collaboration),Phys. Rev. C **72**, 031901 (2005).

Initial entropy density

$$s_0(\tau_0, \eta_s, x_\perp)$$

$$= \frac{K}{\tau_0} \sum_i \frac{1}{\sqrt{2\pi {\sigma_\eta}^2}} \frac{1}{2\pi {\sigma_\perp}^2} \exp\left[- \frac{\left(x - x^i\right)^2 + \left(y - y^i\right)^2}{2{\sigma_\perp}^2} - \frac{\left(\eta_s - {\eta_s}^i\right)^2}{2{\sigma_\eta}^2} \right]$$

- Normalization
  - $K = 5.6$ for RHIC energy
  - $= 5.0$ for LHC energy
- Smearing parameters
  - $\sigma_\perp = 0.1$ [fm]
  - $\sigma_\eta = 0.3$
- Position
  - ${x^i}, {y^i}, {\eta_s}^i$ from MC Glauber + PYTHIA
- Initial time
  - $\tau_0 = 0.6$ [fm]

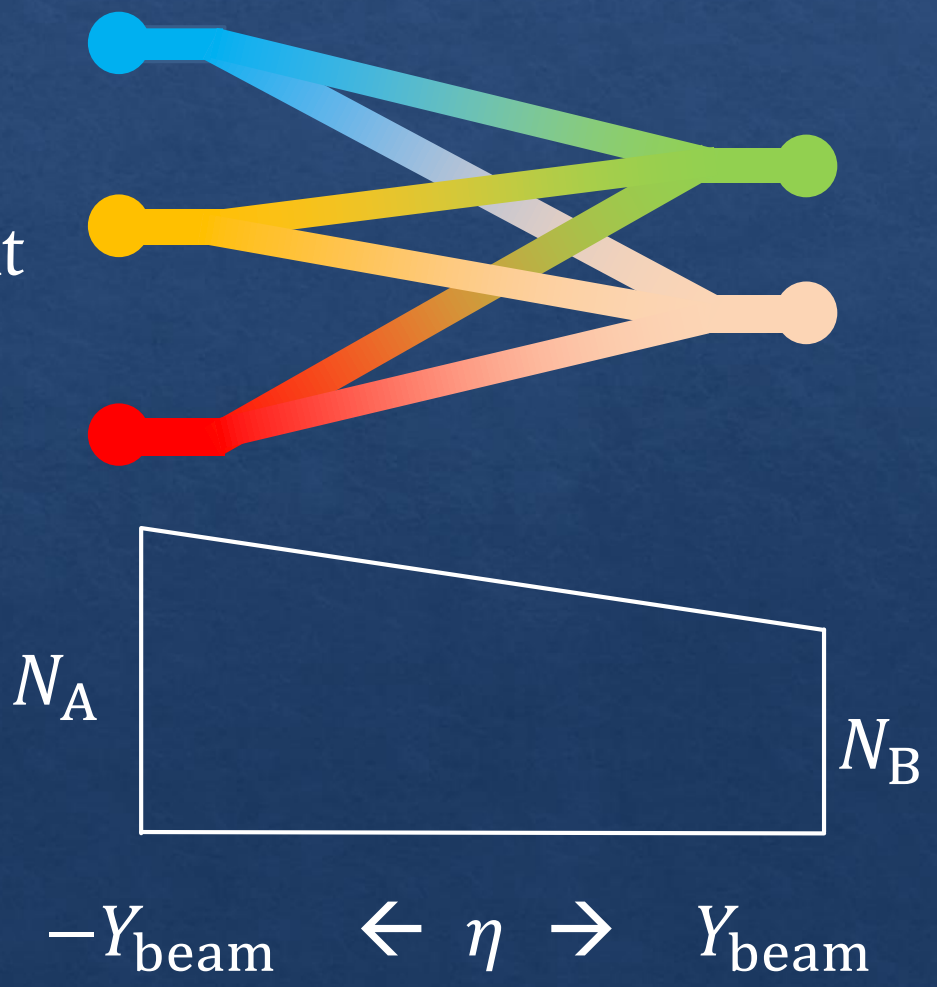
Rejection sampling

One AA event
→ $N_A \times N_B$ PYTHIA events

Weight in one PYTHIA event

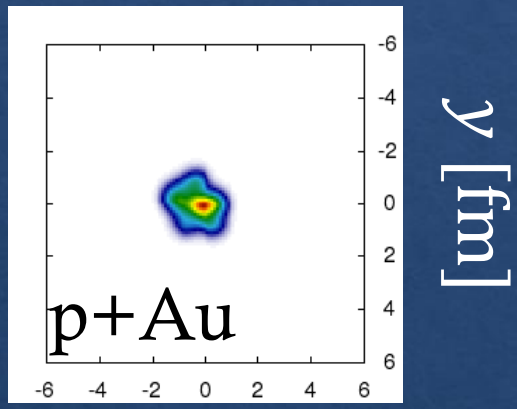
$$w(\eta) = \frac{1}{2}\left(\frac{Y_\mathrm{b}+\eta}{Y_\mathrm{b}}\frac{1}{N_\mathrm{A}} + \frac{Y_\mathrm{b}-\eta}{Y_\mathrm{b}}\frac{1}{N_\mathrm{B}}\right)$$

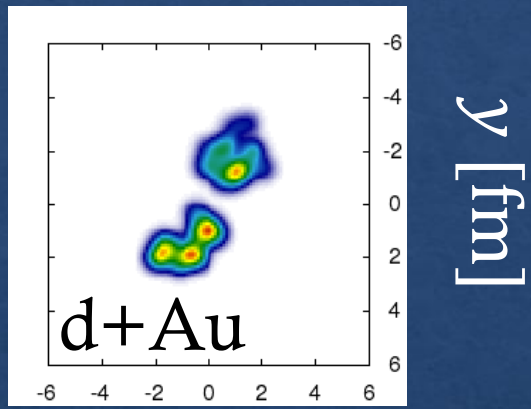
$$N_\mathrm{A}N_\mathrm{B}w(\eta) = \begin{cases} N_\mathrm{A}\ (\eta = -Y_\mathrm{b}) \\ N_\mathrm{B}\ (\eta = Y_\mathrm{b}) \end{cases}$$

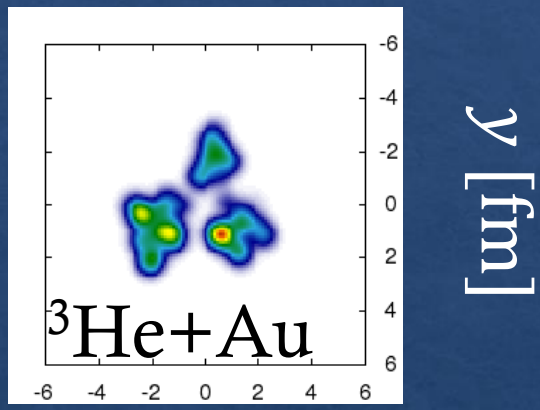


Initial profile at RHIC

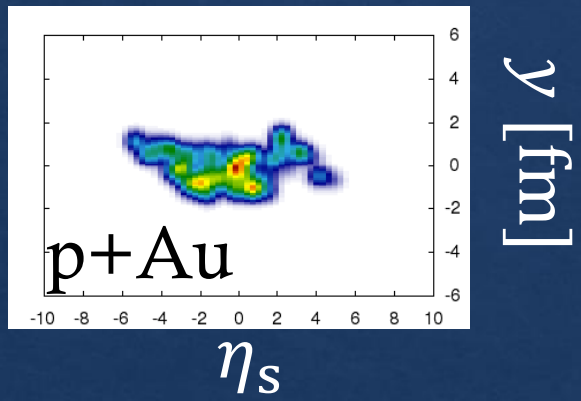
Transverse profile ($\eta_s = 0$)

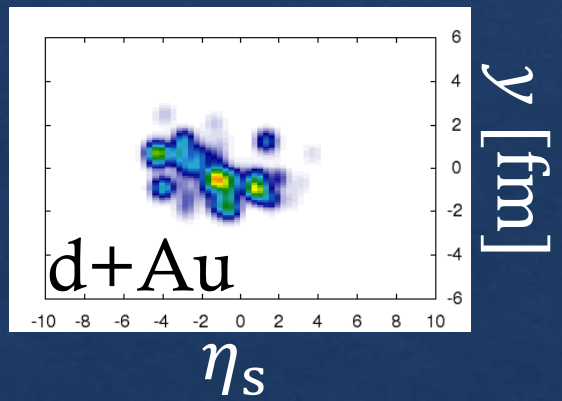


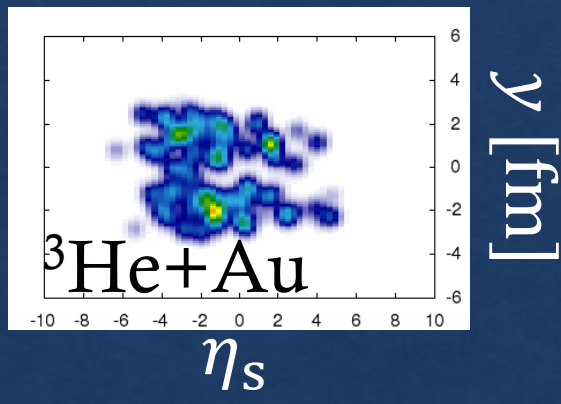




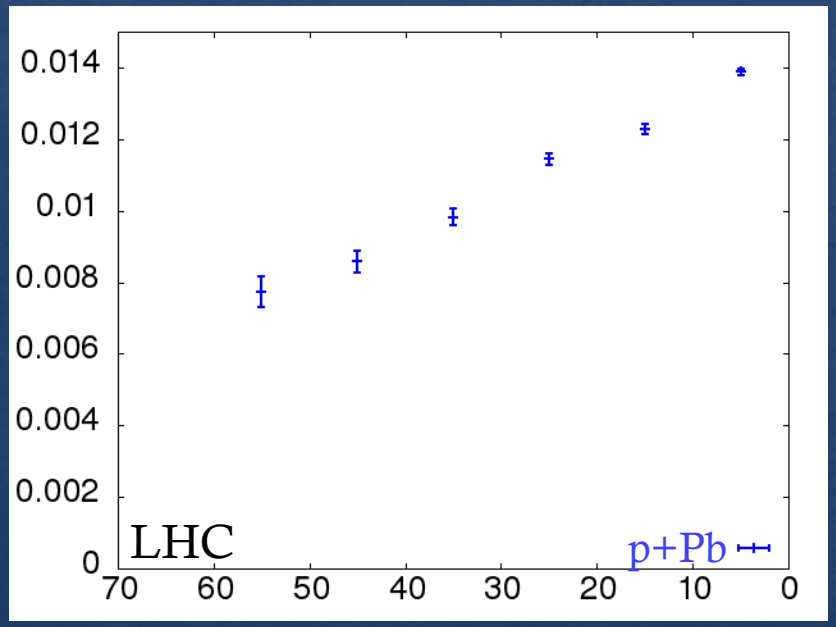
Longitudinal profile ($x = 0$ [fm])

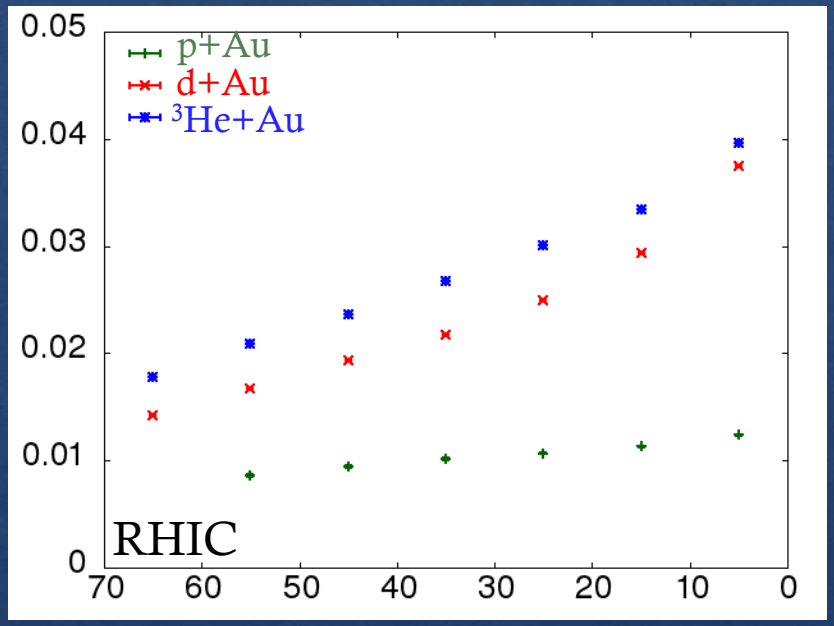






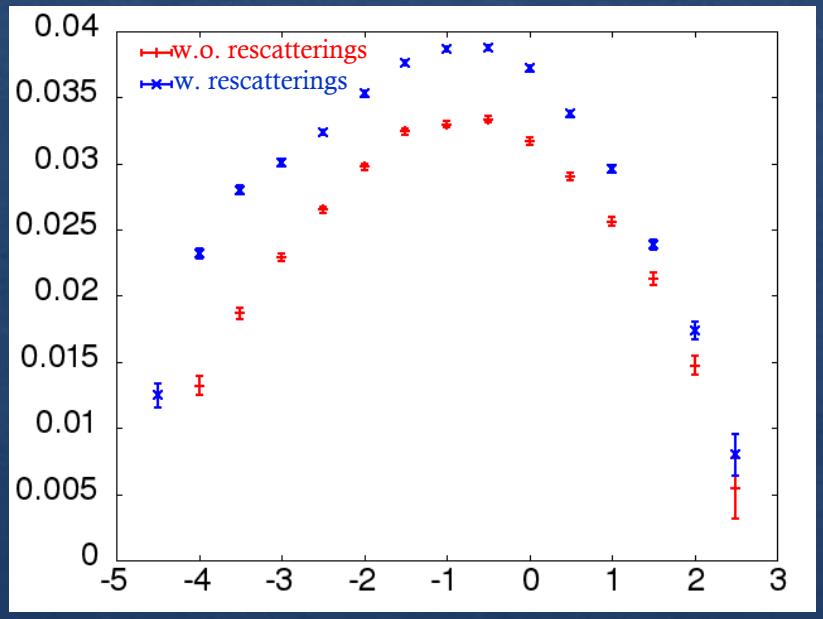
v_2 vs centrality





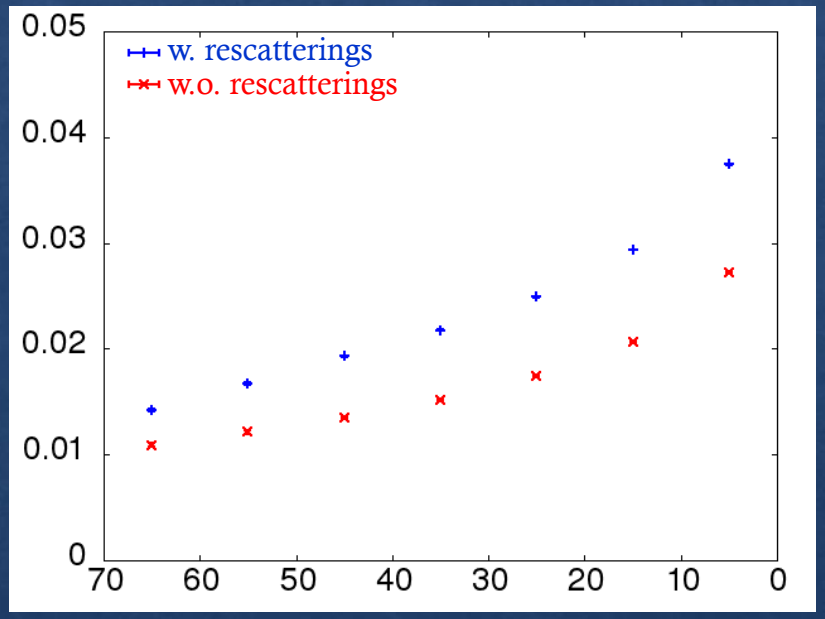
Increase of v_2 with multiplicity

Hadron cascade effects in d+Au



$v_2\{2\}$

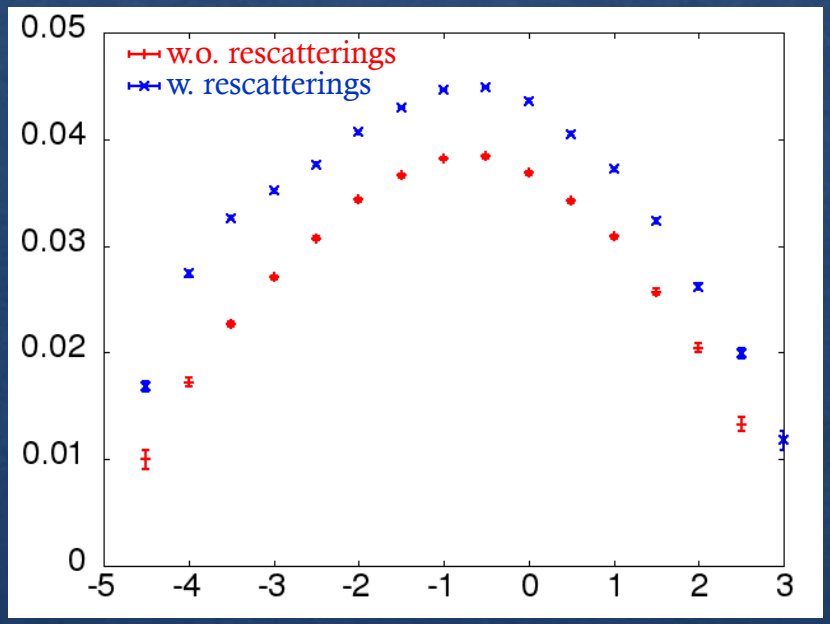
η

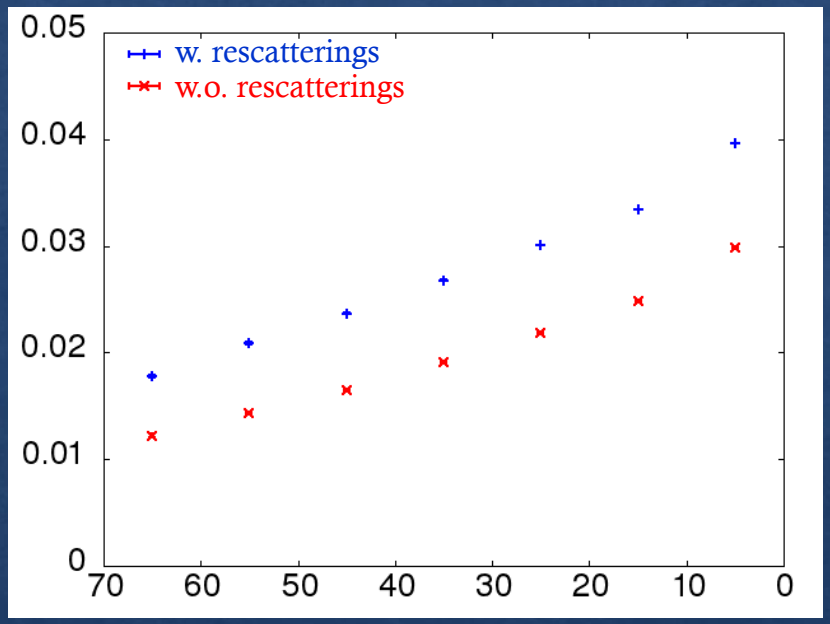


Centrality [%]

Large fraction of v_2 generated in QGP fluid

Hadron cascade effects in ^{3}He+Au





Large fraction of v_2 generated in QGP fluid