JAM:an event generator for high energy nuclear collisions

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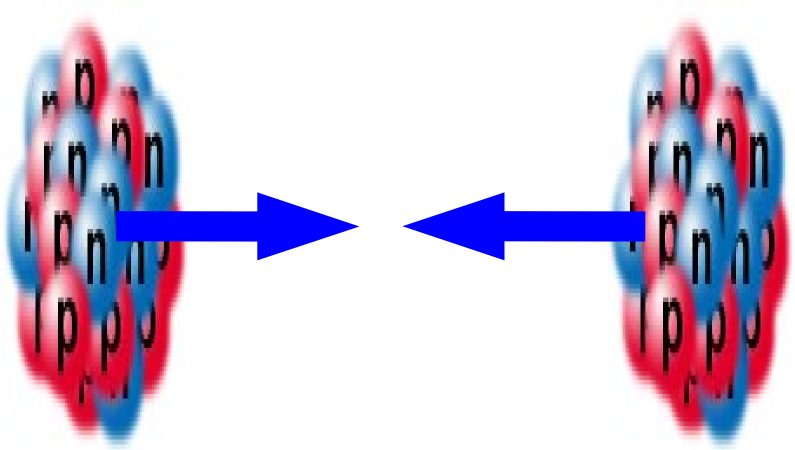
- Introduction: JAM event generator
- JAM+hydro: A new dynamically integrated transport model
- Equation of state (EoS) controlled collision term
- Pythia8 for the next version of JAM

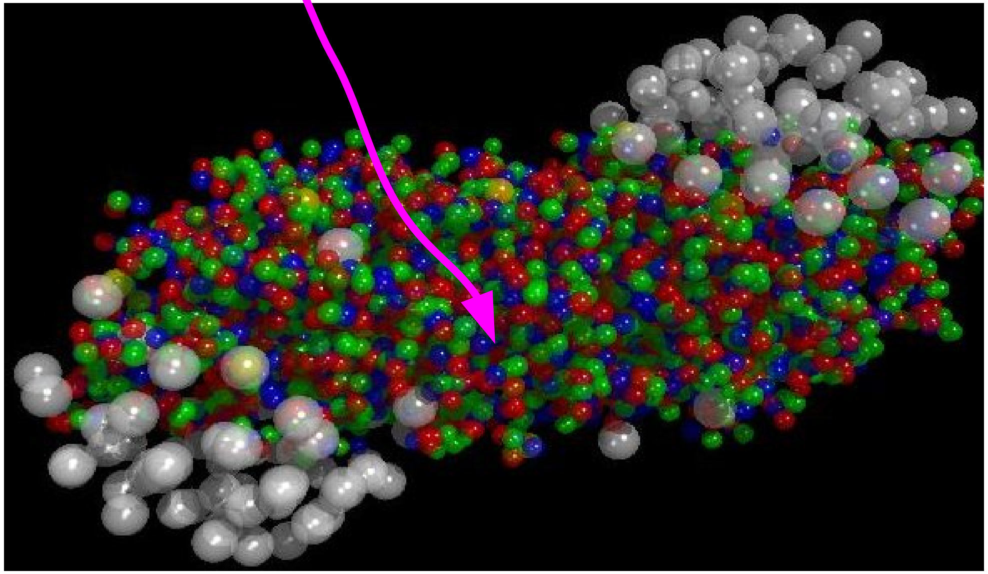
ISVHECR2018 at Nagoya May. 241-25, 2018

Hith energy Heavy ion collisions

The 3.8 km circumference



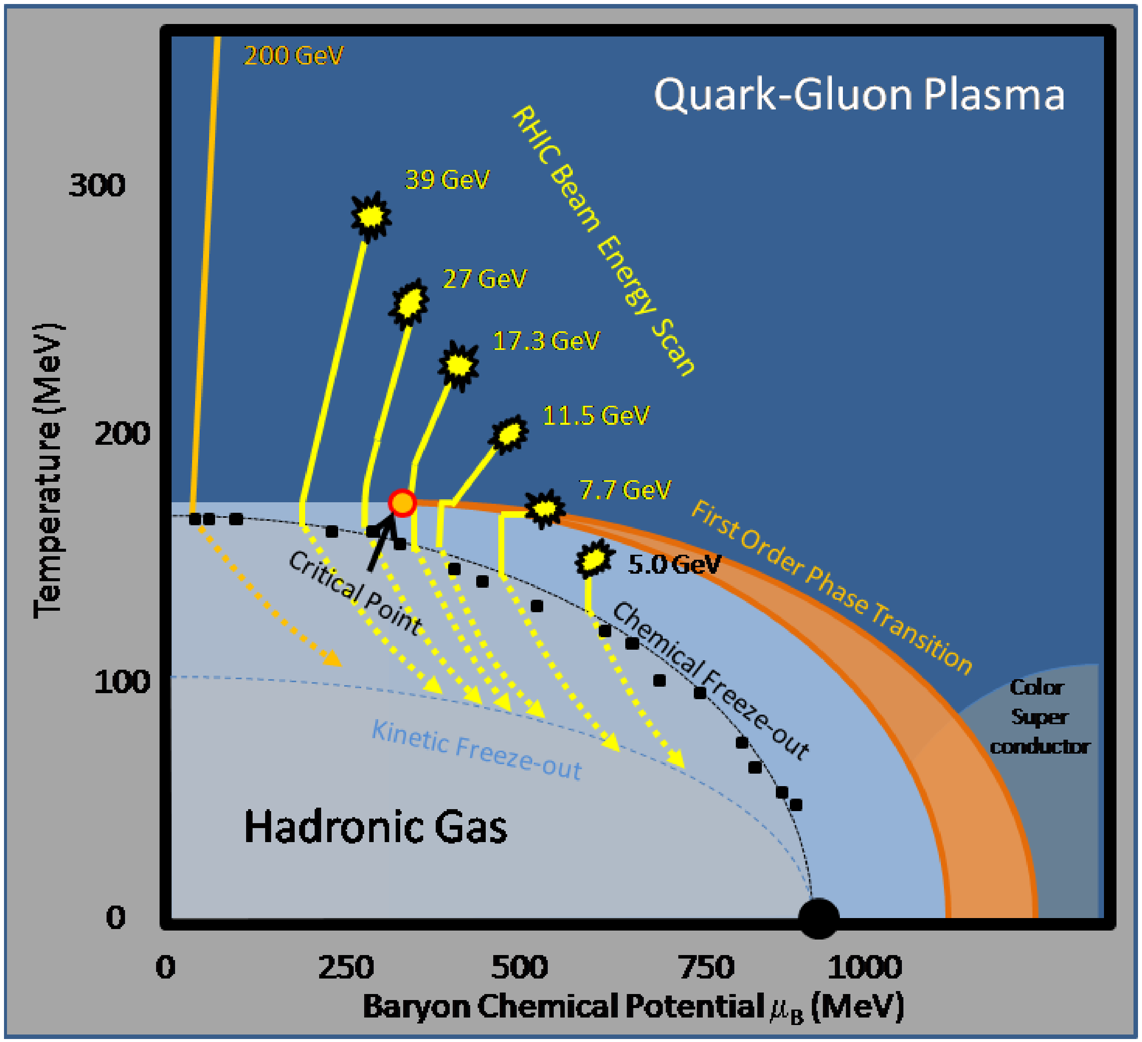
Creation of Hot and dense matter.



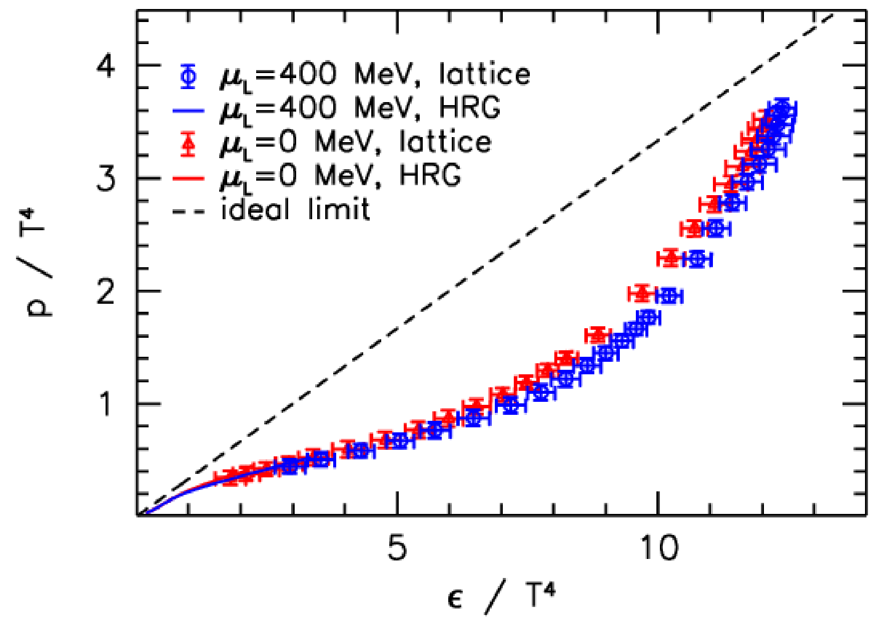
RHIC: Au+Au at C.M. Energy
 of 200GeV per nucleon.
d+Au, Cu+Cu

LHC: Pb+Pb at C.M. Energy
 Of 2.76, 5.04TeV per nucleon.
p+Pb, Xe+Xe

Search for the QCD equation of state (EoS) by the beam energy scan



Location of the critical point?



EoS from lattice QCD
Sz.Borsanyi, et.al JHEP 1208(2013)053

Effective models:

NJL, PNJL, PQM,
Quasi-particle model………..

JAM microscopic transport model

- spece-time propagation of particles based on cascade method
- Resonance (up to 2GeV) and string excitation and decays
- Re-scattering among all hadrons
- DPM type string excitation law as in HIJING.
- Use Pythia6 for string fragmentation
- Propagation by the hadronic mean-fields within RQMD/S formulation
- EoS controlled collision term

$$\dot{\boldsymbol{r}}_i = \frac{\boldsymbol{p}_i}{p_i^0} + \sum_j \frac{m_j}{p_j^0}\frac{\partial V_j}{\partial \boldsymbol{p}_i} \qquad \dot{\boldsymbol{p}}_i = -\sum_j \frac{m_j}{p_j^0}\frac{\partial V_j}{\partial \boldsymbol{r}_i} \qquad p_i^0 = \sqrt{\boldsymbol{p}_i^2 + m_i^2 + 2m_i V_i}$$

Arguments of potential $\boldsymbol{r}_i - \boldsymbol{r}_j$ and $\boldsymbol{p}_i - \boldsymbol{p}_j$ are replaced by the distances in the two-body c.m.

Next version of JAM

- Use Pythia8
- JAM + viscous hydrodynamics (dynamically integrated transport approach)

A new approach: JAM+hydro model

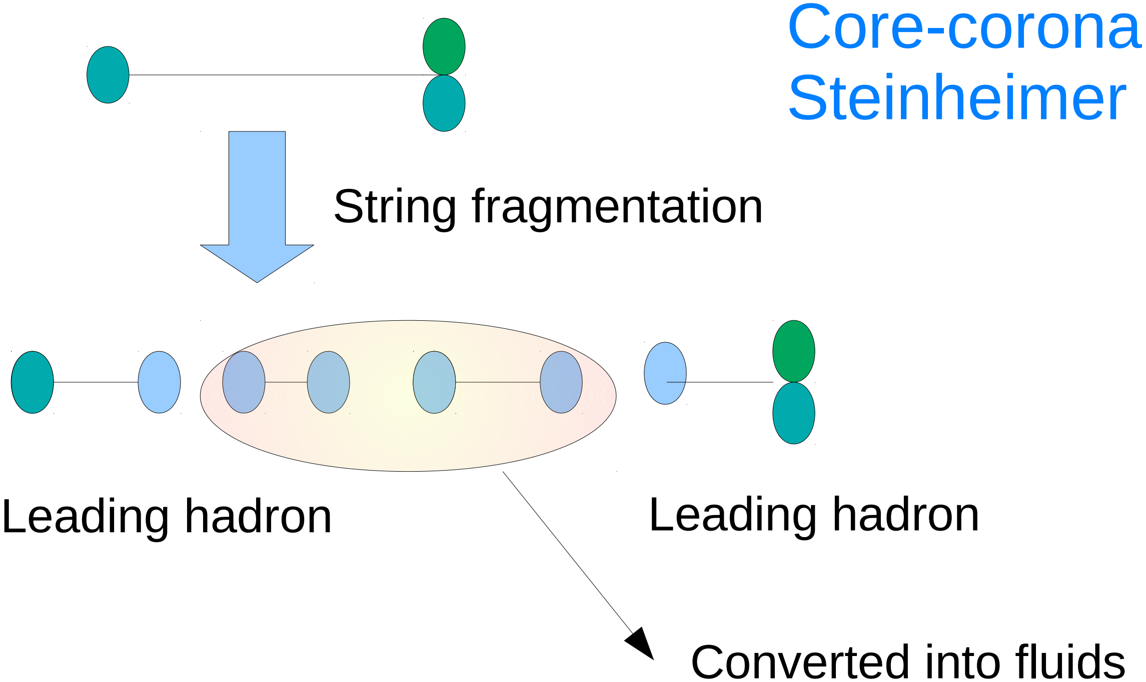
Dynamical coupling of fluids through source terms

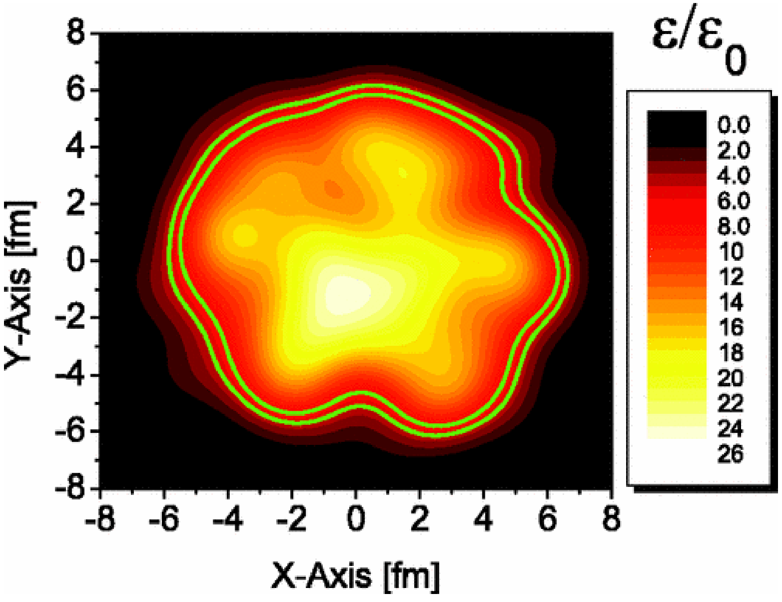
$$\partial_\mu T_f^{\mu\nu} = J^\nu, \quad \partial_\mu N_B^\mu = \rho_B$$

Time dependent Core-corona separation

Put Hadrons from string or resonance decay into fluids after their formation time
except leading hadrons when local energy density exceeds a hydronization energy density

Core-corona separation (K. Werner, 2007)
Steinheimer and Bleicher (2011)





Model parameters

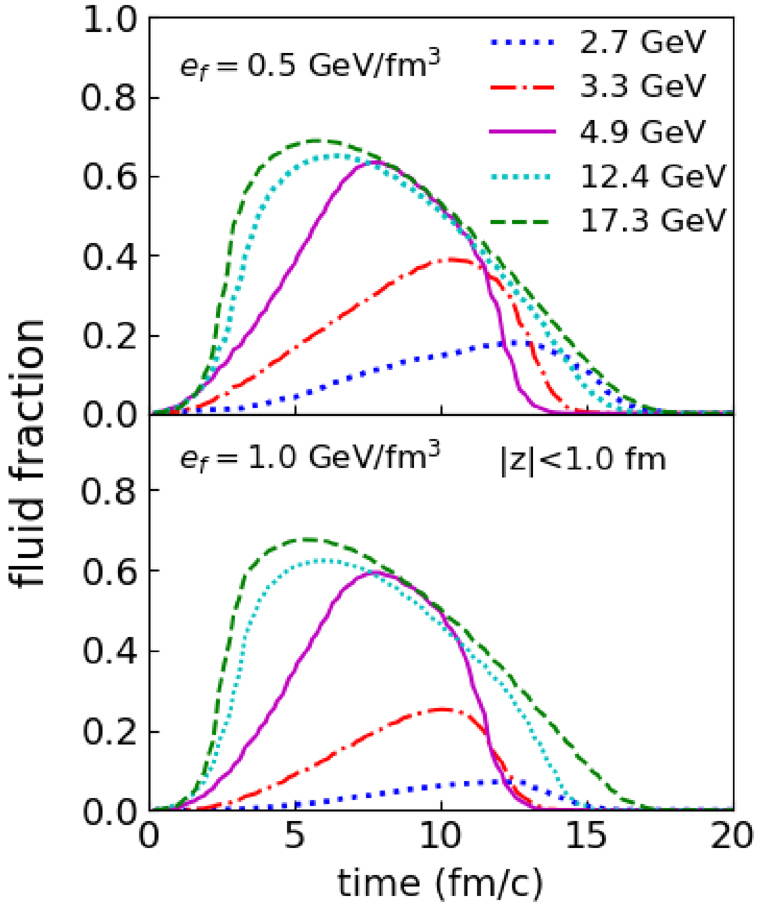
1) fluidization energy density

$$e_f = 0.5 - 1.0\ \mathrm{GeV/fm^3}$$

2) particlization energy density

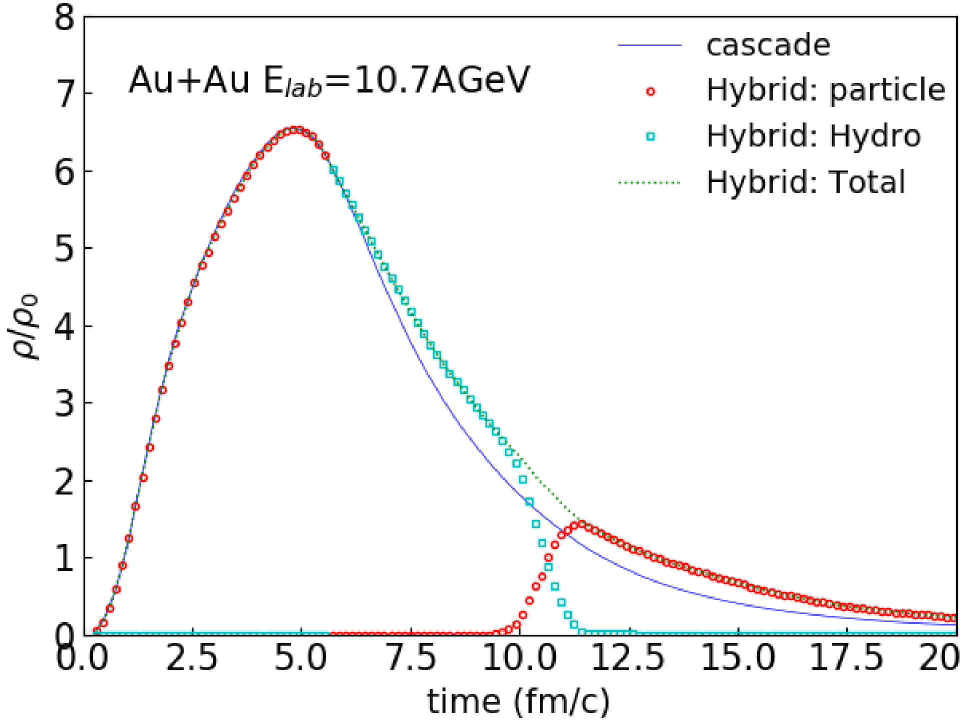
$$e_p = 0.5\ \mathrm{GeV/fm^3}$$

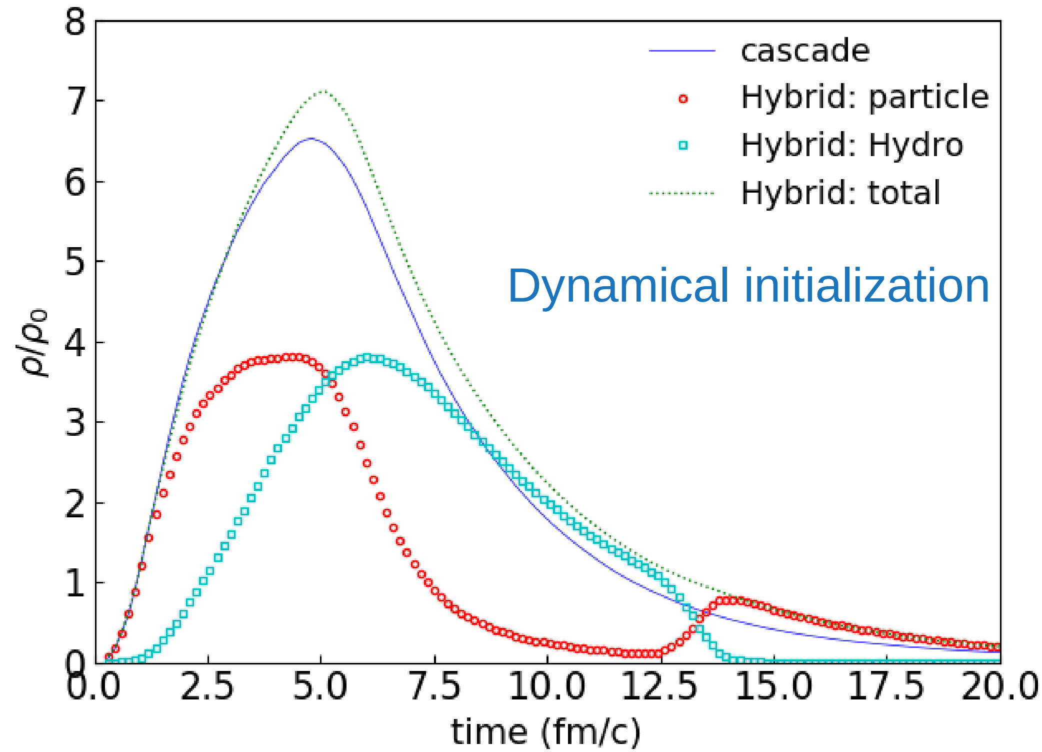
3) equation of state: EOS-Q
first-order phase transition
Bag model B=235MeV^4
hadronic resonances up to 2GeV
baryon density dependent
repulsive potential for baryons



Fraction of fluid energy at central region is about 70% at top SPS energy.

Hybrid model for AGS and SPS energies





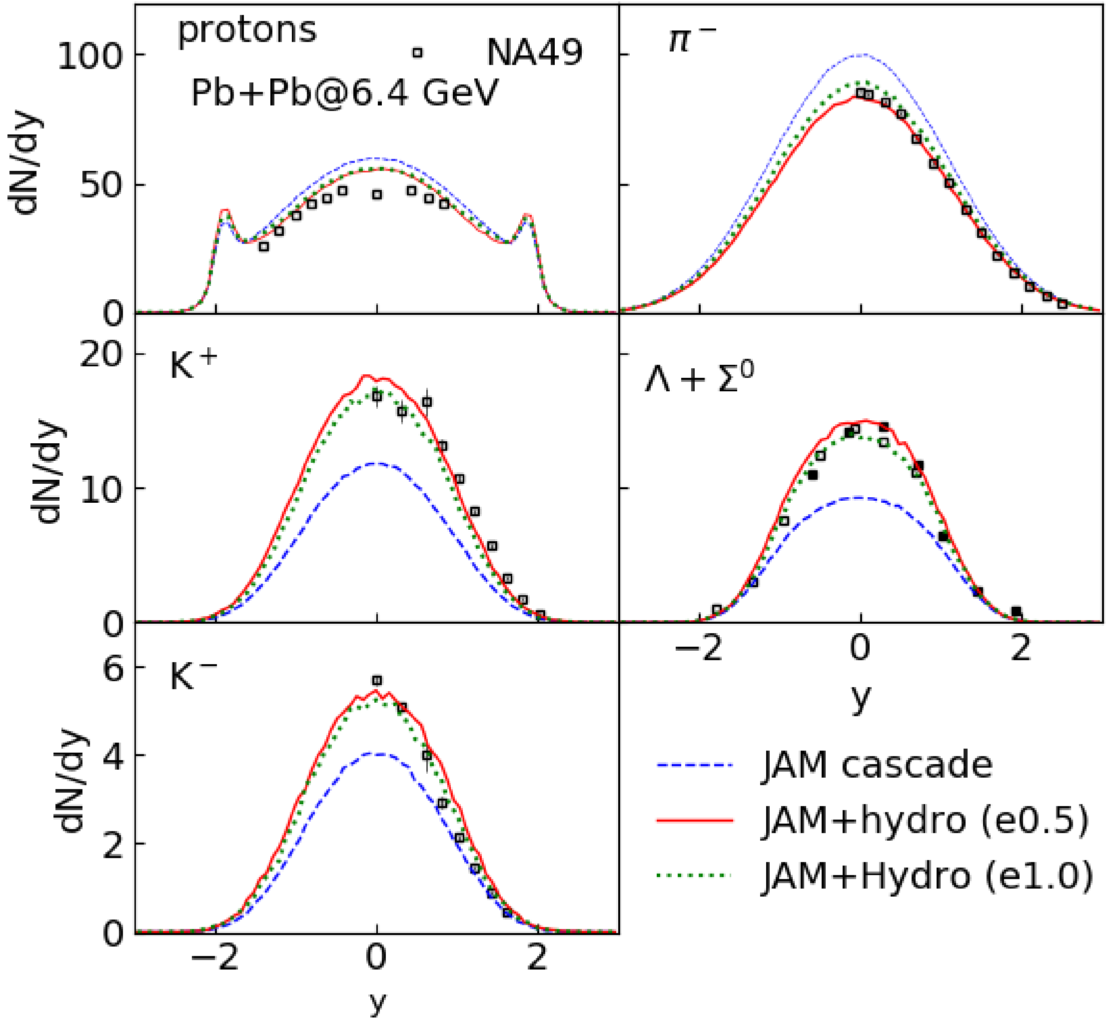
Switch to hydro evolution
after two nuclei pass each other.

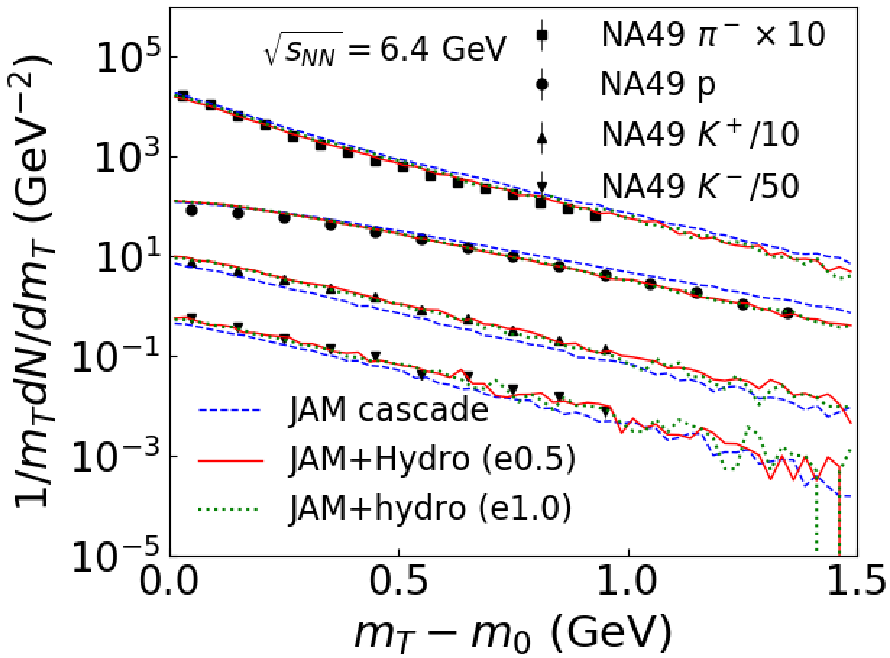
Switch to hadron transport
below a critical energy density.

It is important to take into account potential effect in the Cooper-Fry formula
to ensure smooth transition from fluid to particles.

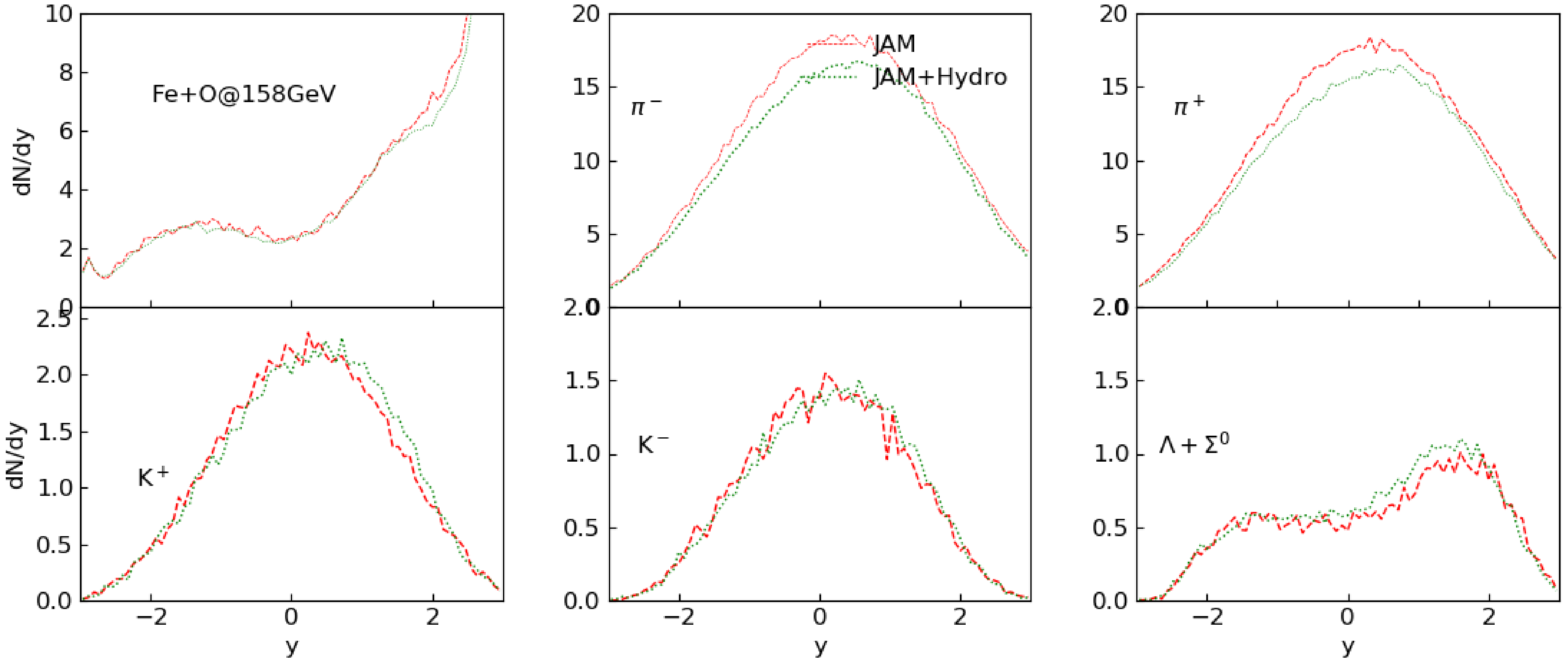
$$\mu = B\mu_B + S\mu_S \to B(\mu_B - V(\rho_B)) + S\mu_S$$

Particle spectra from a new hybrid model in Pb+Pb at Elab=20AGeV

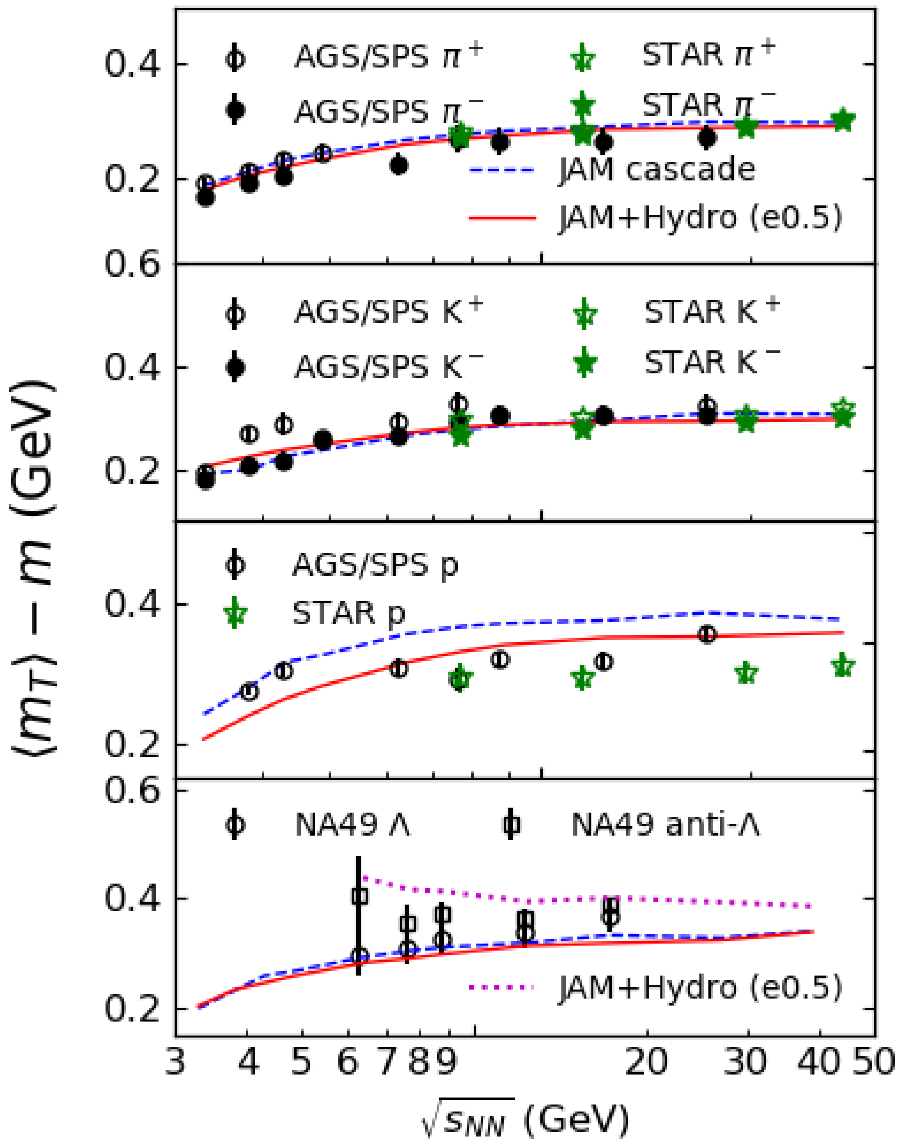


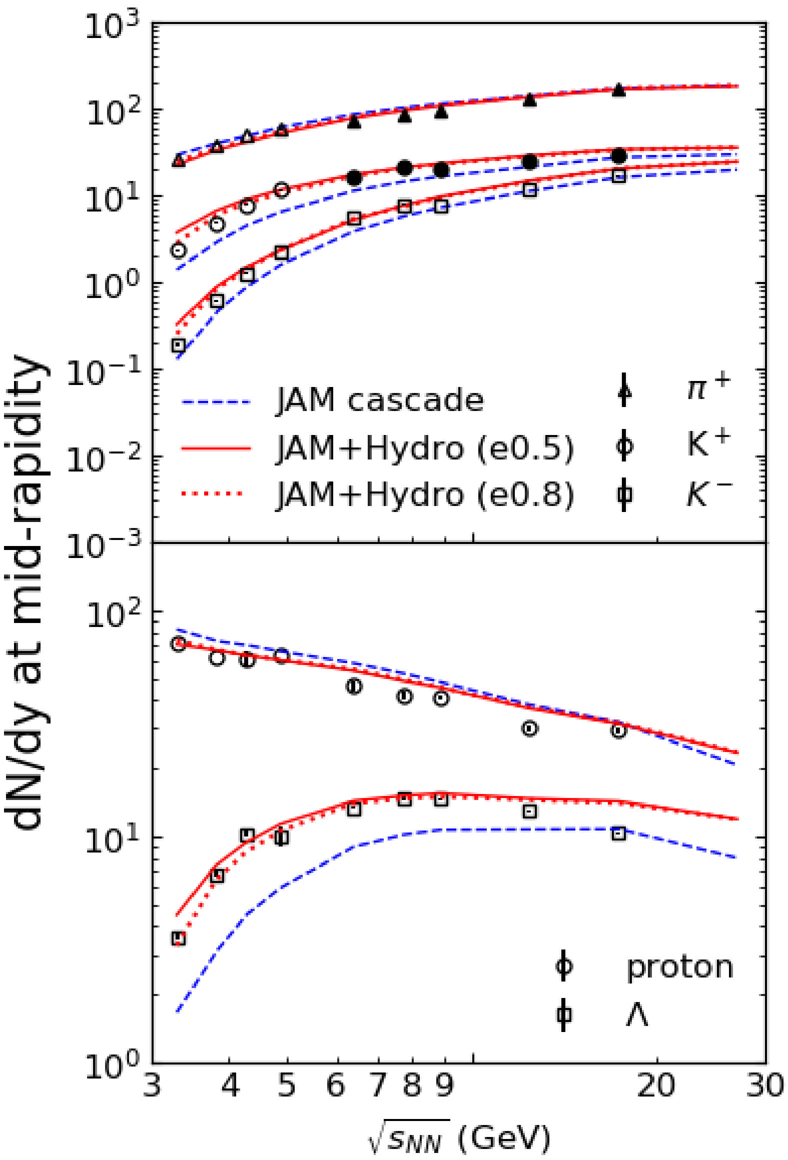


dN/dy from a new hybrid model in Fe+O collisions at Elab=158AGeV

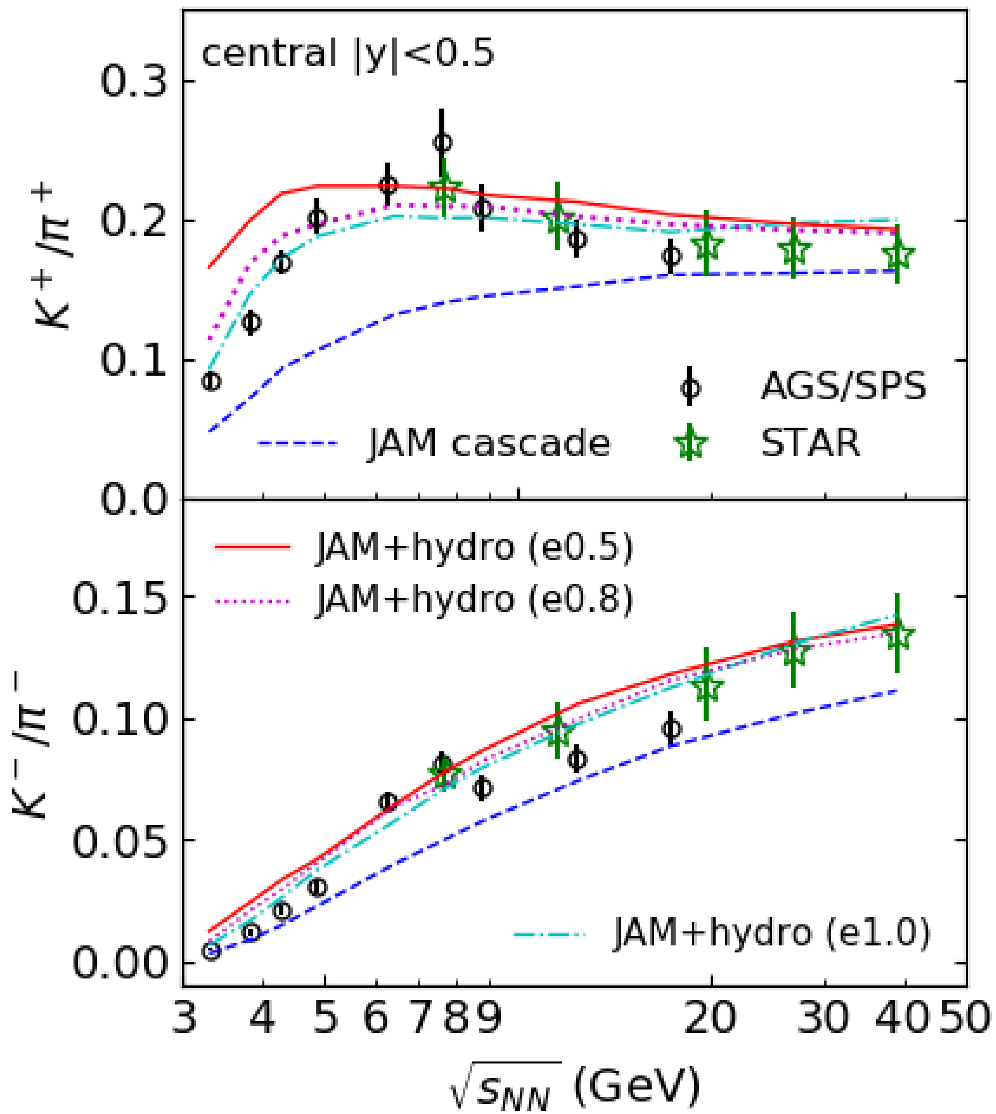


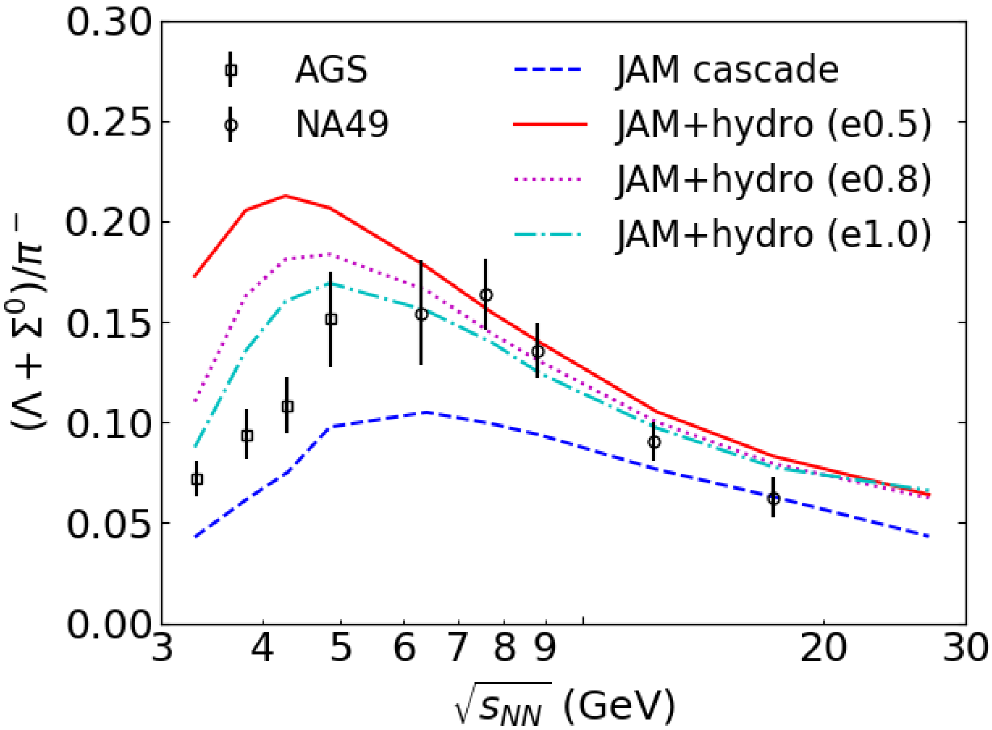
Beam energy dependence of transverse mass and multiplicities from a new hybrid model.





Beam energy dependence of particle ratios from a new hybrid model.





Y. N., H. Niemi, J. Steinheimer, H. Stoecker, PLB769 (2017)

EOS modified collision term

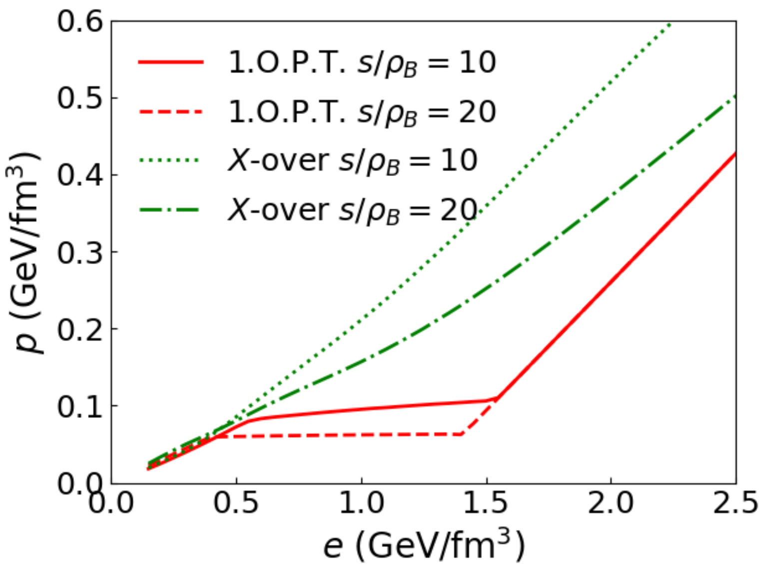
H. Sorge, Phys. Rev. Lett. 82,2048 (1999)   Virial Theorem for two body collisions

$$P = P_{free} + \frac{1}{3TV}\sum_{(i,j)}[(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot \boldsymbol{r}_i + (\boldsymbol{p}_j' - \boldsymbol{p}_j)\cdot \boldsymbol{r}_j]$$

The momentum change is constrained by

$$(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot(\boldsymbol{r}_i - \boldsymbol{r}_j) = 3\frac{(P - P_{free})}{\rho}(\Delta t_i + \Delta t_j)$$

When P < Pfree: attractive orbit in the collision.



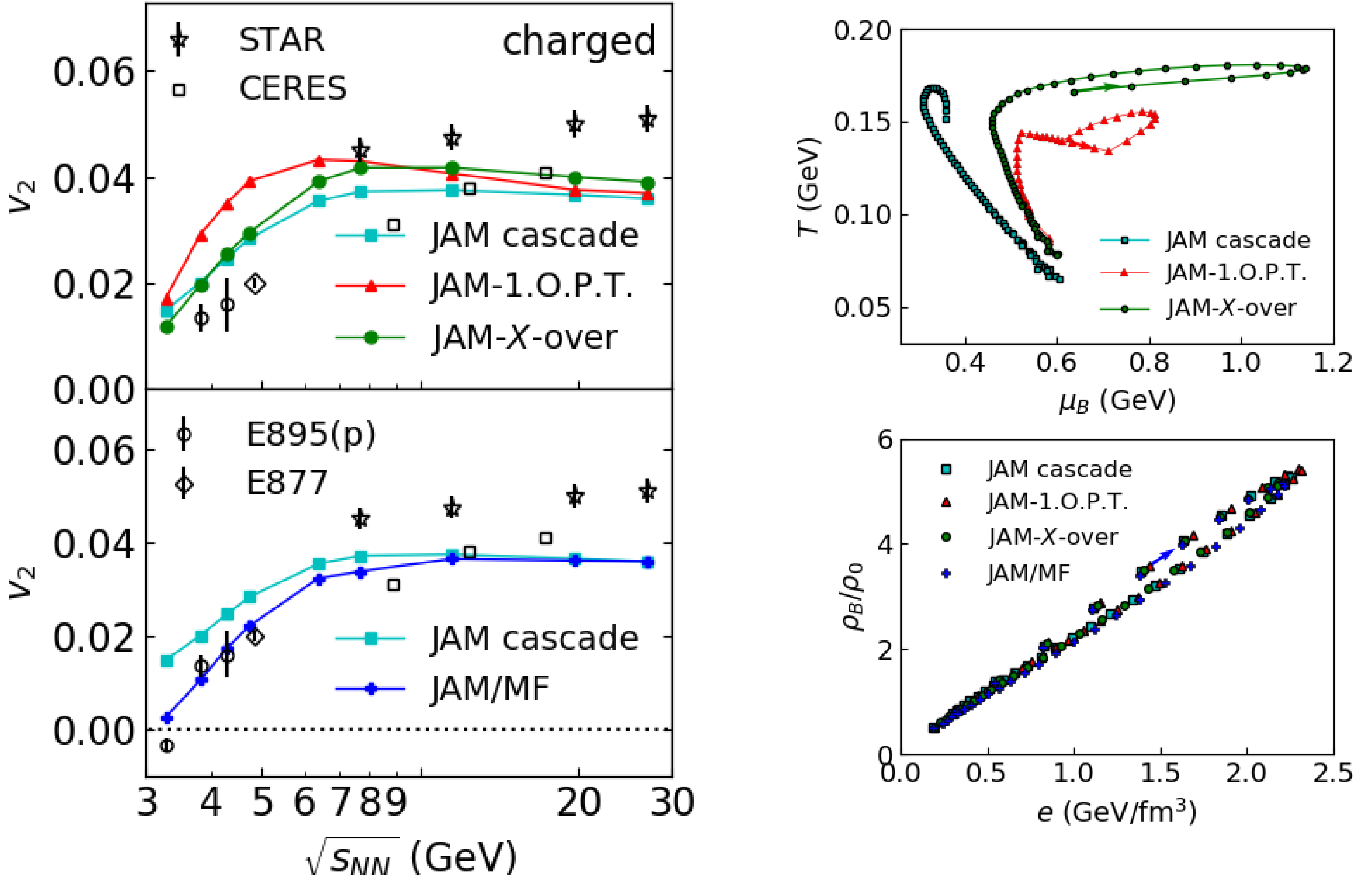
Fully baryon density dependent EoSs are implemented.
Cross-over EOS: J. Steinheimer
EOS-Q: Kolb, Sollfrank, Heinz

- Any EoS can be incorporated
- CPU time is as fast as standard cascade simulation
- Fully non-equilibrium transport approach

$$\frac{dN}{dy d^2 p_T} = \frac{d^2 N}{2\pi d p_T dy}(1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + \cdots)$$

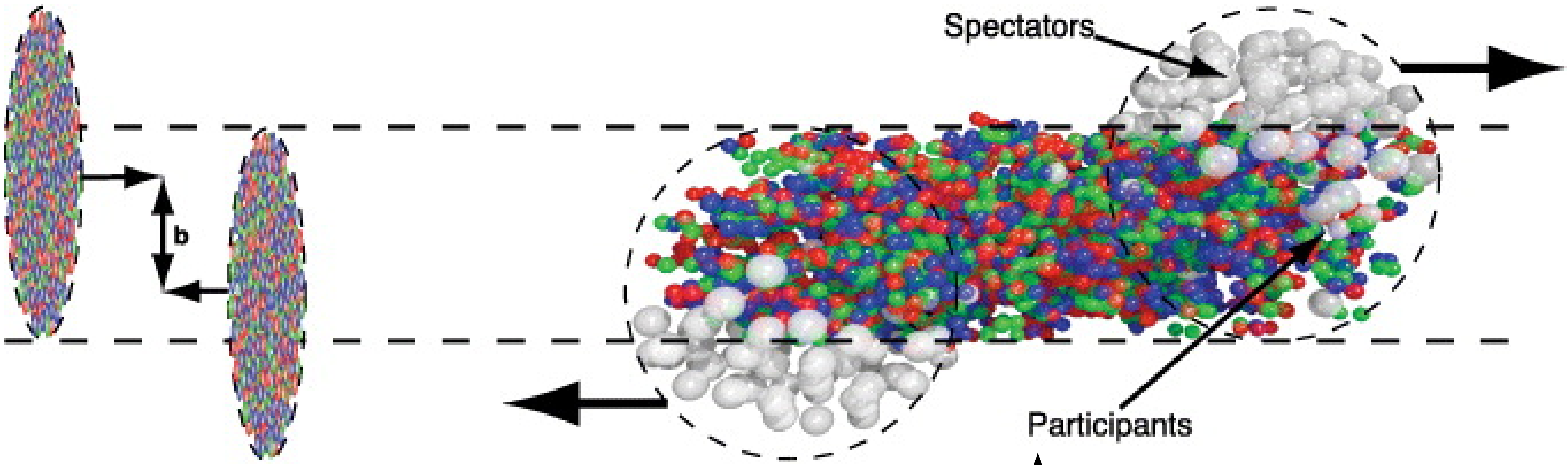
V2 excitation functions

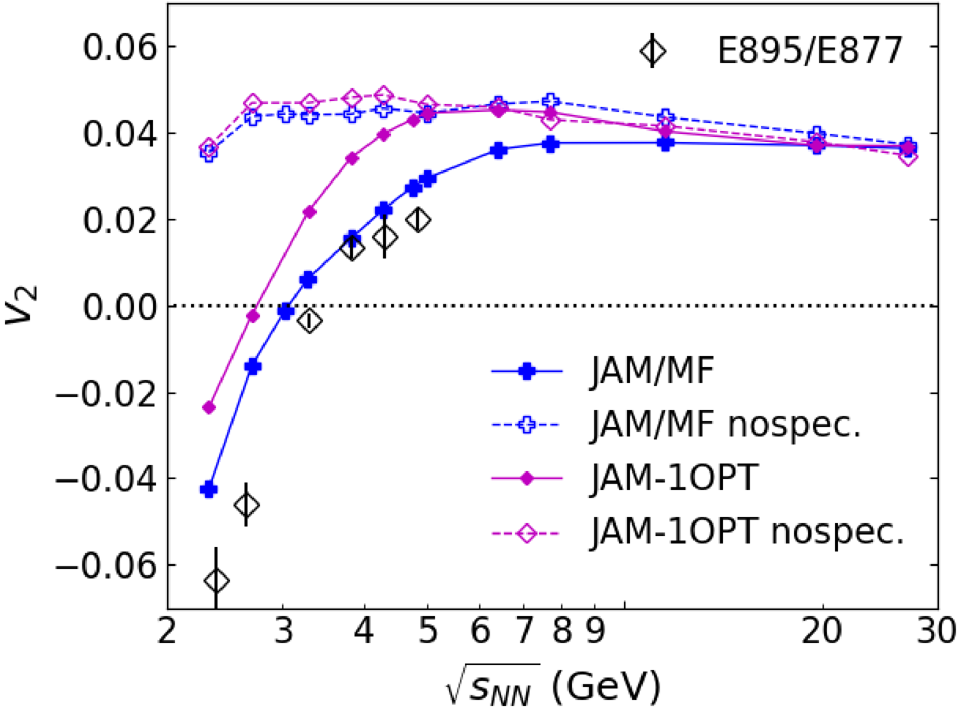
$$v_n = \langle \cos(n\phi) \rangle$$

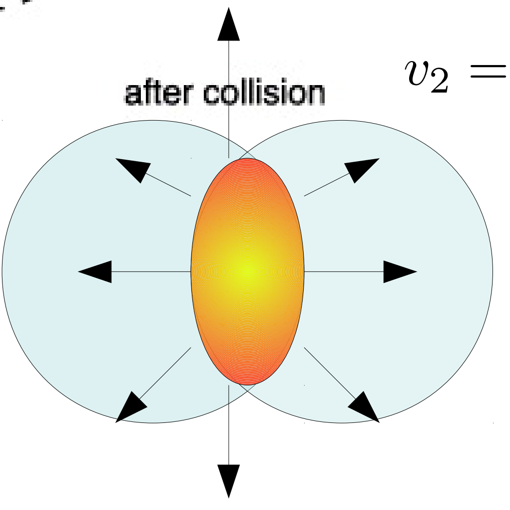


Y. N., H. Niemi, A. Ohnishi, J. Steinheimer, X. Luo, H. Stocker, Eur. Phys. A54 (2018) 18

Effects of interaction with spectator







$v_2 = \langle \cos(2\phi) \rangle < 0$

$v_2 = \langle \cos(2\phi) \rangle > 0$

Comparison of the results without spectator interactions

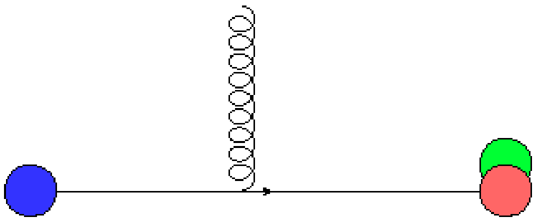
In the case of first-order phase transition, shadowing effects are weak.

Current status for the next version of JAM

How to simulate NN collision

Test two simple methods:

a) Each collision produces strings and hard partons until “nucleons” pass through nucleus.



FRITIOF, HIJING,…

should work for high energies ecm > 20 GeV

Extend Pythia8 to allow collisions of any diffractive states.

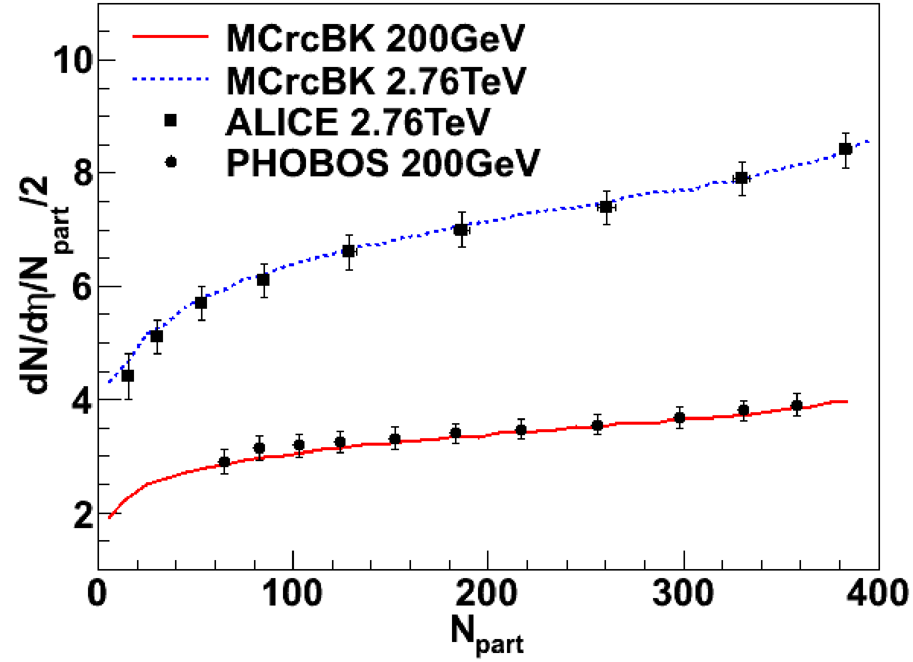
b) Hadronic cascade method: Extend Pythia8 to allow collisions of all hadrons.

At each collision, strings are immediately hadronized, and leading hadrons can interact again.

UrQMD, JAM…

Nuclear effect

Initial state saturation:
CGC (kt-fact.)

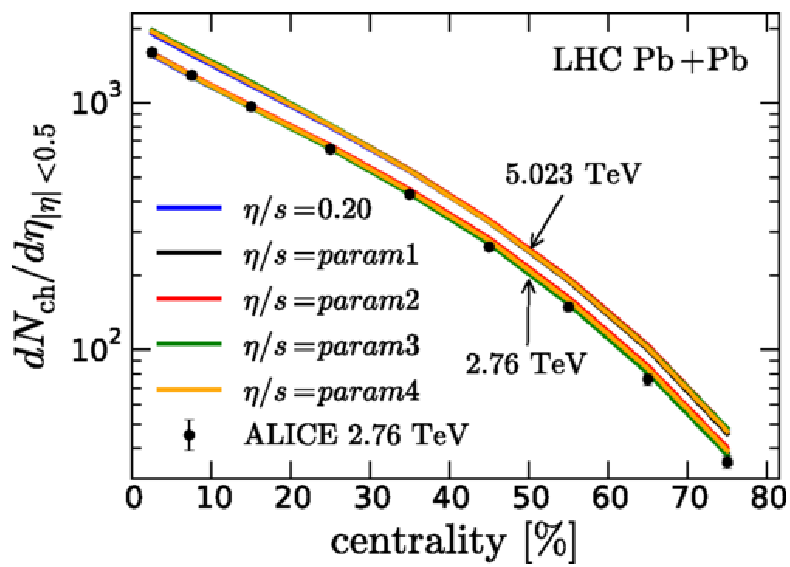


$$\frac{dN_g}{d^2 x_t dy} = \frac{4\pi N_c}{N_c^2 - 1} \int \frac{d^2 p_t}{p_t^2} \int d^2 k_t \alpha_s \phi(x_{1,} k_t^2) \phi(x_{2,} (p_t - k_t)^2)$$

$$\frac{dN}{d^2 \mathbf{x}_\perp dy} \sim \min\{N_{part,1}(\mathbf{x}_\perp), N_{part,2}(\mathbf{x}_\perp)\}$$

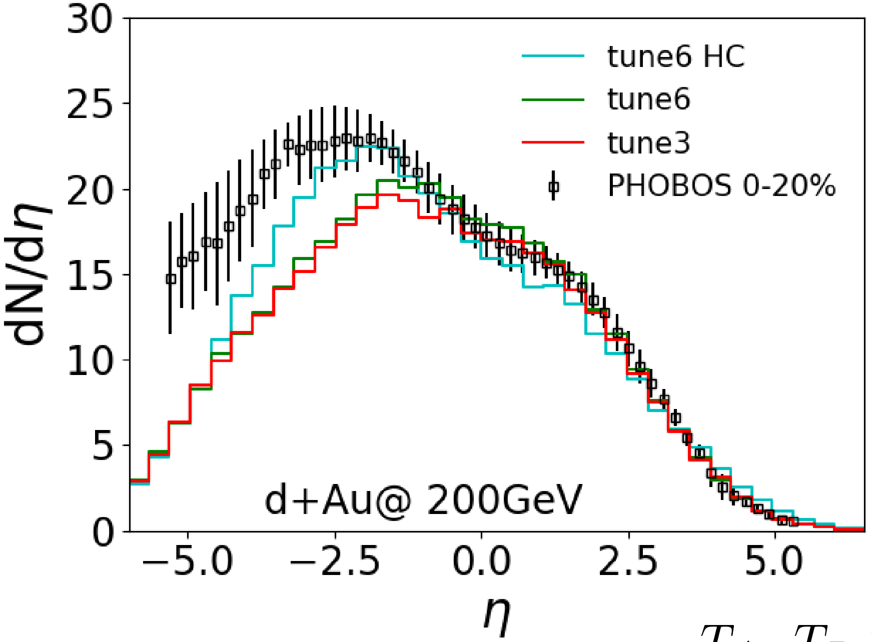
final state saturation
(EKRT: Finland group)

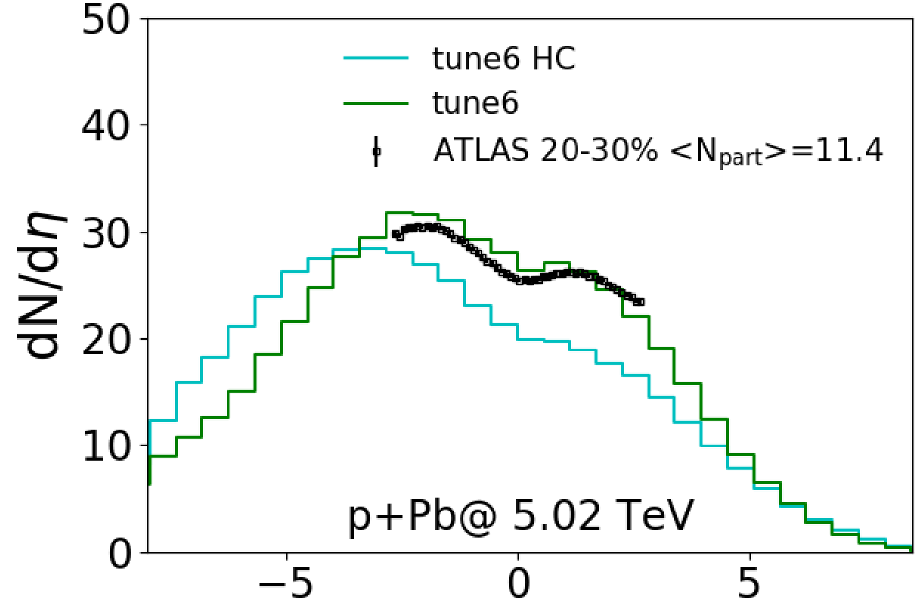
$$N_{AA\,jet} \frac{\pi}{p^2} = \pi R^2$$



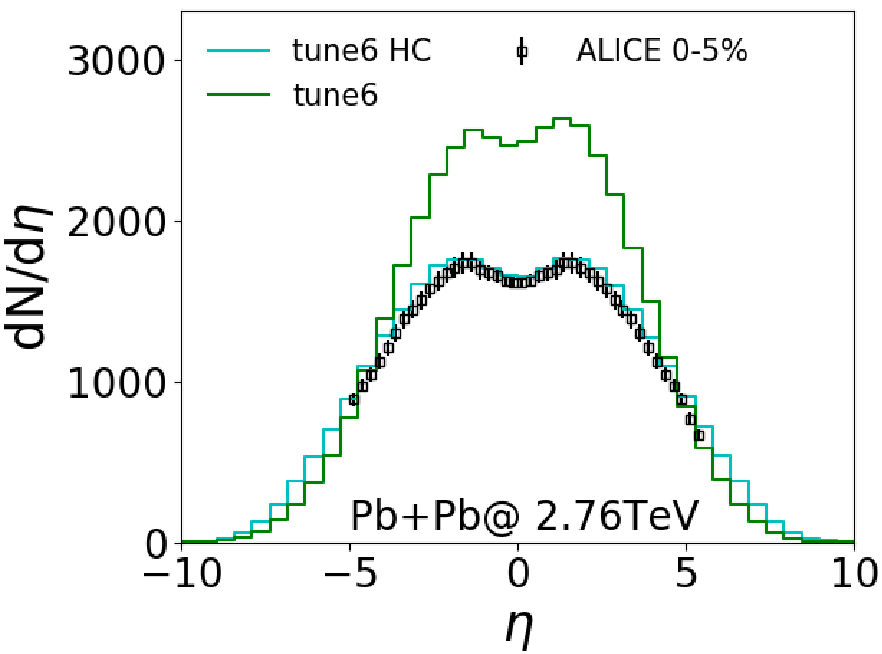
EKRT prediction: PRC93(2016)

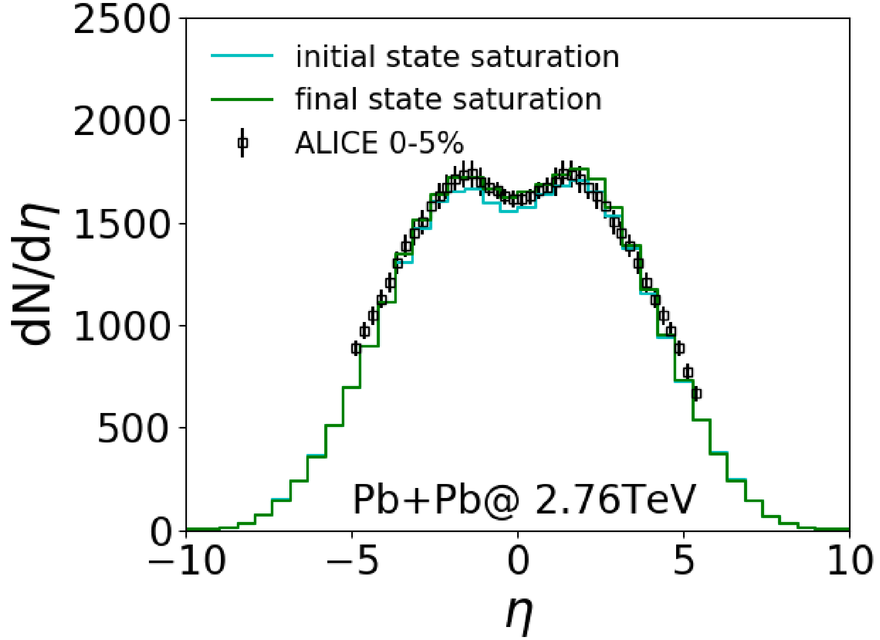
nPythia for d+Au, p+Pb



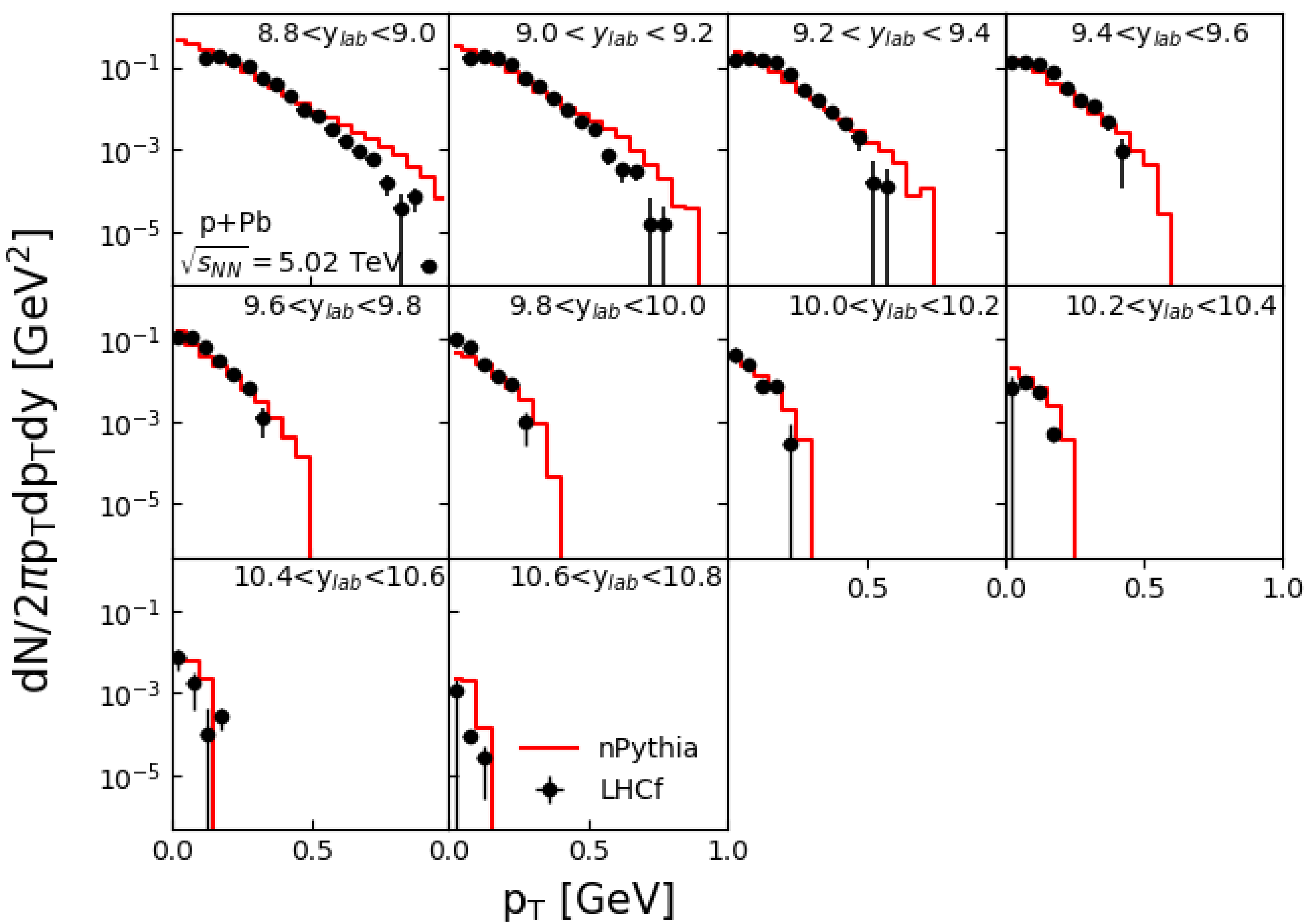


$T_A \cdot T_B > a \rightarrow$ no nondiffractive



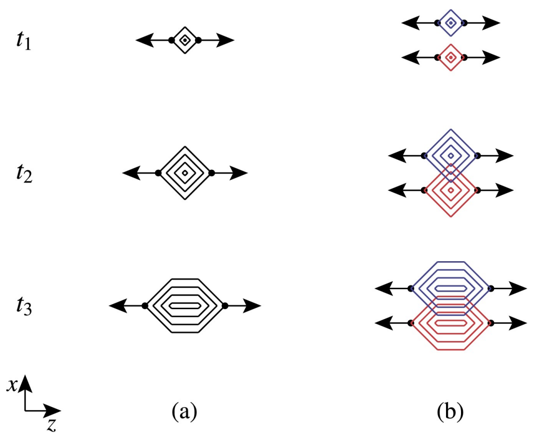


p+Pb at 5.02 GeV



PYTHIA8.230 and Heavy Ion collisions

C.Bierlich, G.Gustafson and L.Lönnblad,
``Diffractive and non-diffractive wounded nucleons and final states in pA collisions,''
JHEP 1610, 139 (2016)



- Heavy-ion collision available
- Rope hadronization C. Bierlich axXiv:1710.04464

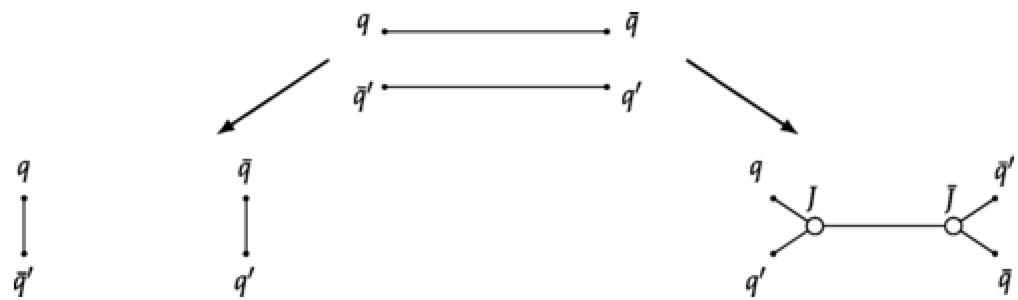
  Strangeness enhancement

- String shoving C. Bierlich et.al axZXiv :1612.05132

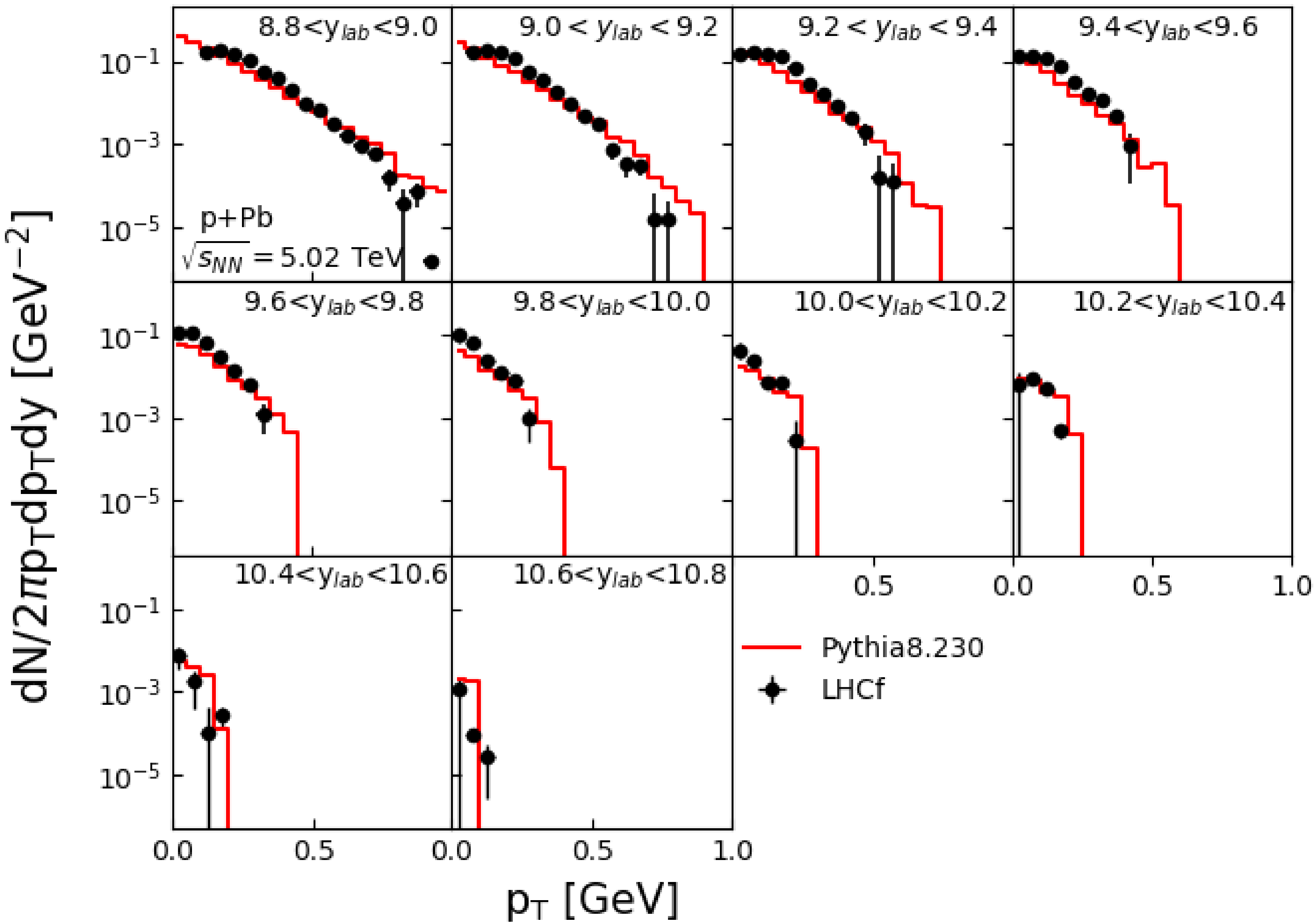
  generate flow

- Color re-connections

  C.Bierlich Phys.Rev.D92(2015)



PYTHIA8.230 result at forward rapidity



Summary

- JAM is a microscopic transport model for high energy nuclear collisions based on strings and hadronic resonances.

- EoS modified collision term can simulate effectively the effects of EoS.

- We have developed a new hybrid approach by dynamical initialization of hydrodynamics which takes into account time dependent core-corona picture in order to simulate heavy ion collision at high baryon energy region.

- As a future update, it is planed to use pythia8 in JAM.