Centrality Dependence of Observables more than a Core-Corona Effect?

A simple model to study the centrality dependence of
observables from SPS to RHIC energies

inspired by the first CuCu results
to extract the physics of EPOS simulations
Precursors: droplet model, Manninen + Becattini, …

The model

Statistical observables (hadron multiplicies M^i)

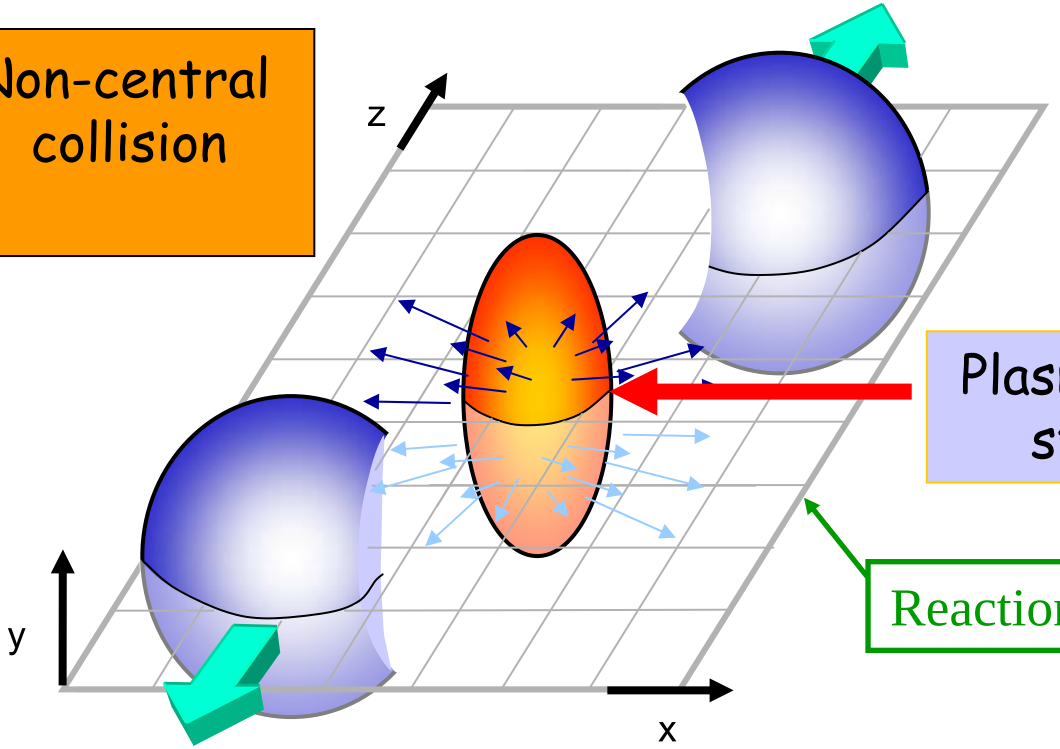
Dynamical variables ($\langle p^i_t \rangle$),elliptic flow v_2)

Spectra of identified particles

in collaboration with C. Schreiber and K. Werner

Geometry of a Heavy-Ion Collision

Non-central collision



Plasma to be studied

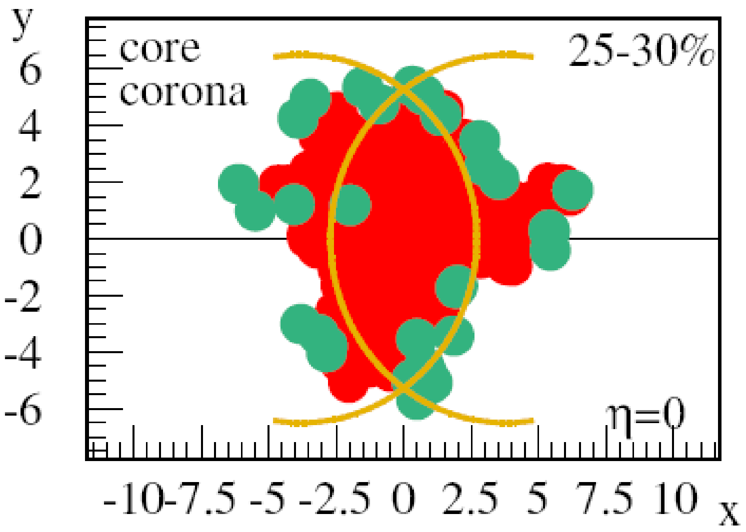
Reaction plane

Number of participants (Npart): number of incoming nucleons (participants) in the overlap region

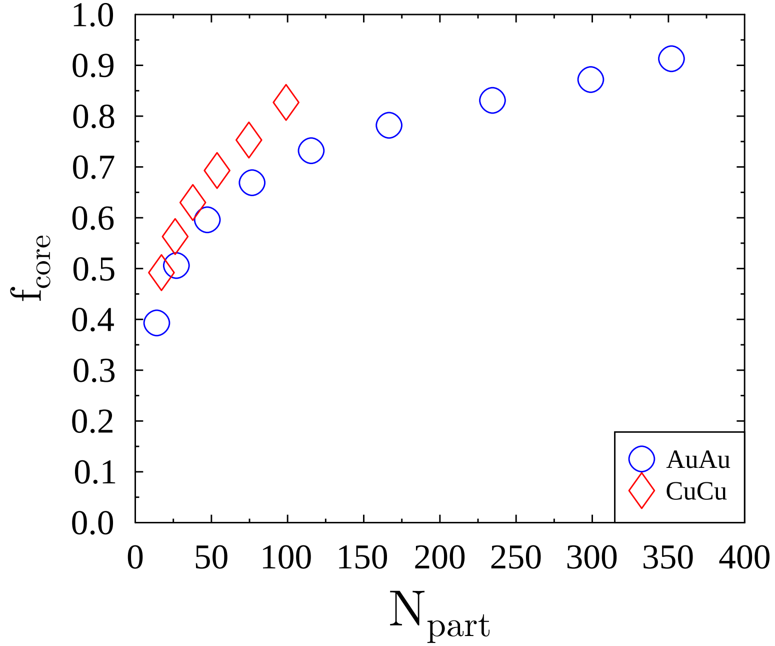
In equilibrium:

Multipl / Npart =const,
independent of b and hadrons species
Experimentally not seen

Centrality Dependence of Hadron Multiplicities



AuAu/CuCu 200 AGeV



In reality more complicated (EPOS)
-finite particle number
-some of the participants scatter only once
 (cannot equilibrate)
→separation of core ● and corona ●

Core – corona model

Assumption:
Nucleons with 1 initial coll: corona
Nucleons with more: core

Calculated in Glauber Model

M^i (Npart) follows a very simple law:

Phys.Rev.C79:064907

$$M^i(N_{\rm part}) = N_{\rm part}\left[f(N_{\rm core})\cdot M^i_{\rm core} + (1-f(N_{\rm core}))\cdot M^i_{\rm corona}\right]$$

$$M^i_{\rm corona} = \frac{1}{2}\frac{dn^i}{dy}\Big|^{pp}_{y=0}$$

$$M^i_{\rm core} = \frac{1}{N_{\rm part}}\frac{dn^i}{dy}\Big|_{y=0} \text{ from stat. model or most central HI collision}$$

$$1-f(N_{\rm core}) = \text{fraction of nucleons which have scattered only once}$$

$$(\to \text{Glauber})$$

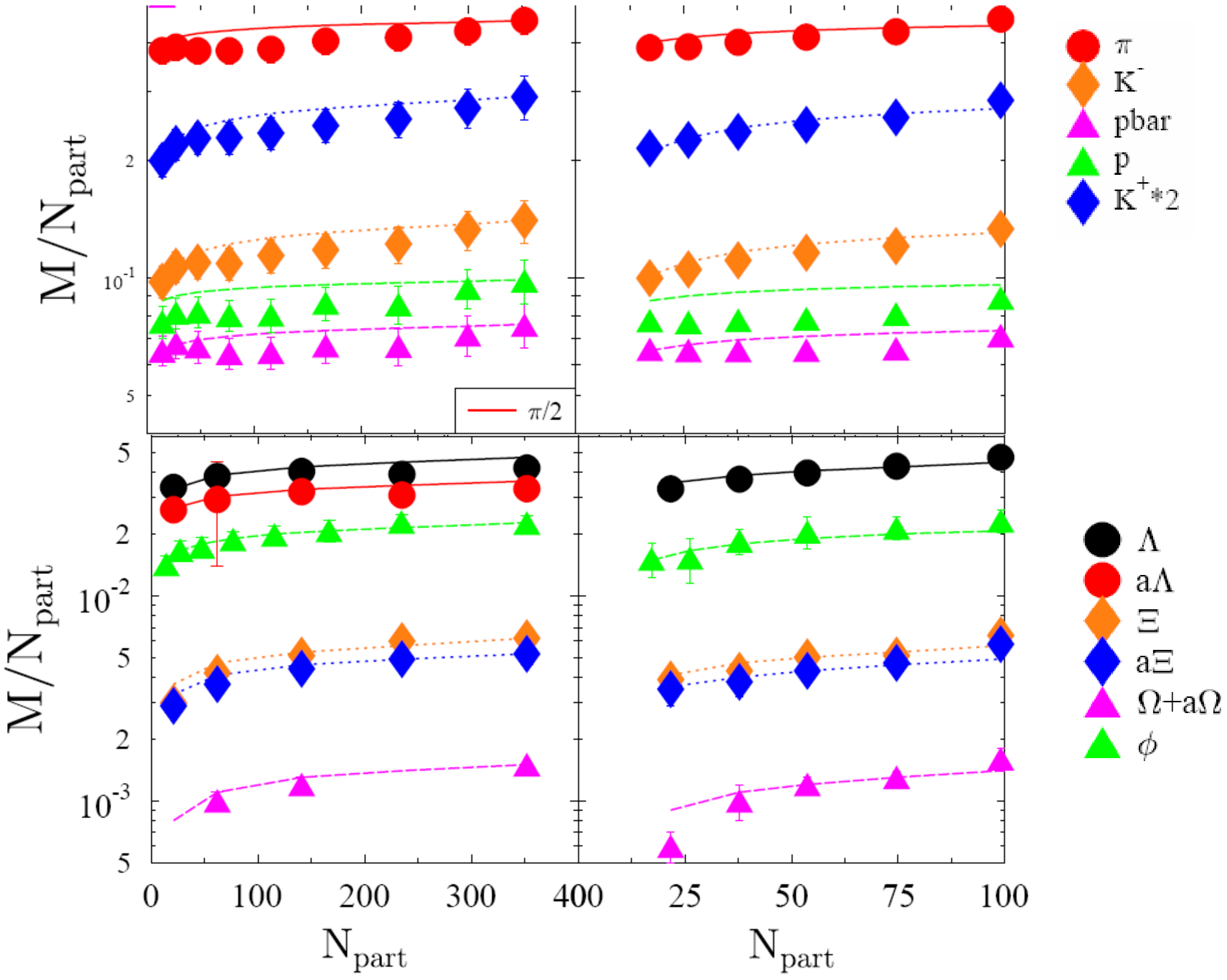
Calculation of the Cu+Cu results without any further input

works for
non strange
and for
strange
hadrons
at 200
(and 62) AGeV

200 AGeV

Theory=lines

Au+Au Cu+Cu

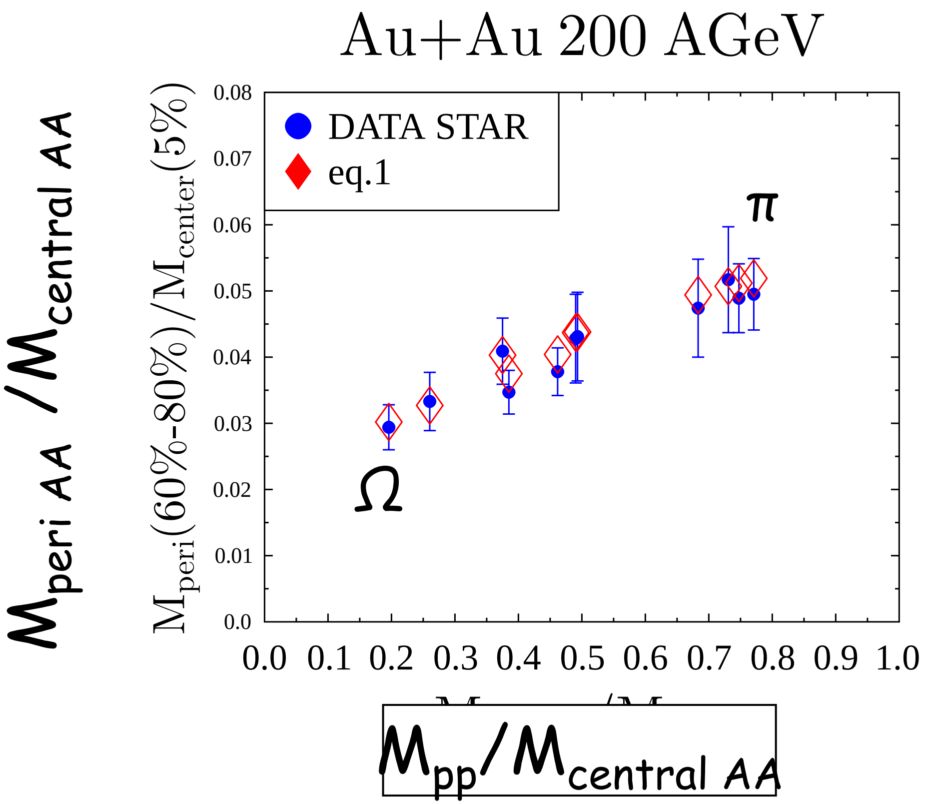


Cu+Cu: completely predicted from Au+Au and pp

Further confirmation of the core-corona effect

strong correlation between
peripheral to central and pp to central collisions
for all hadrons (strange and non-strange)

Such a correlation is neither expected in statistical
nor in hydro models

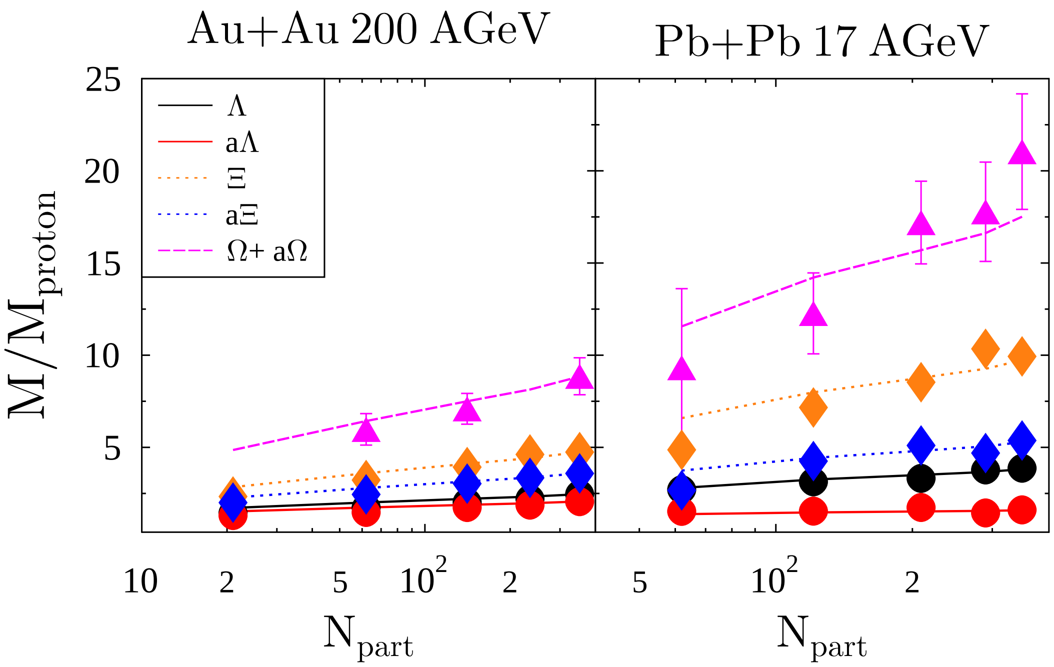


Core-Corona Model
reproduces
quantitatively
this correlation

This model explains

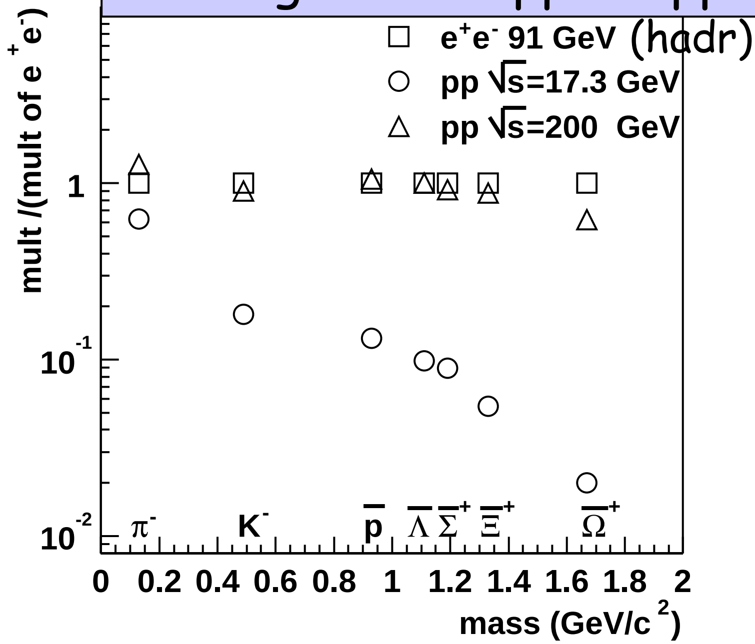
STRANGENESS ENHANCEMENT

especially that the enhancement at SPS is larger than at RHIC

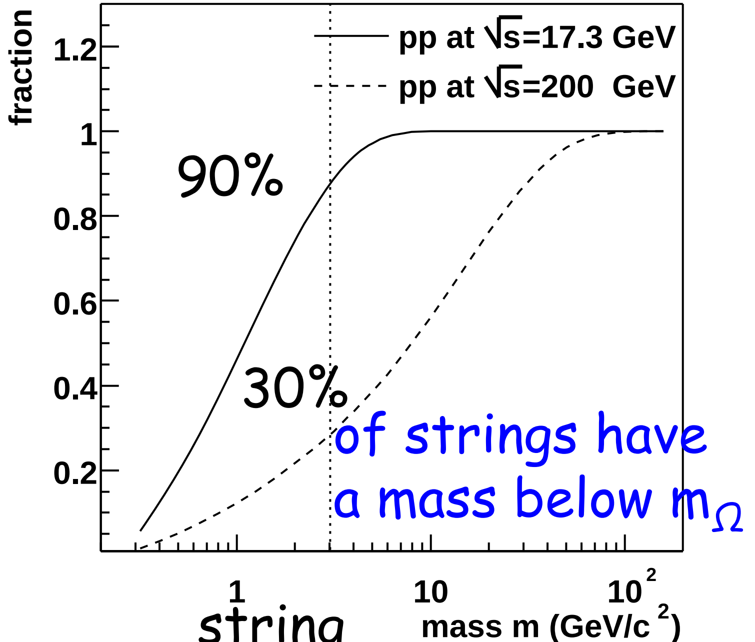


Strangeness enhancement in HI is in reality Strangeness suppression in pp

Strangeness suppr in pp



PRD 65, 057501 (2002)



of strings have a mass below m_Ω

- Central M^i / N_{part} same in Cu+Cu and Au+Au (pure core)
- very peripheral same in Cu+Cu and Au+Au (pp)

  → increase with N_{part} stronger in Cu+Cu

- all particle species follow the same law

  → Φ is nothing special (the strangeness content is not considered in this model)

  → Strangeness enhancement is in reality strangeness suppression in pp (core follows stat model predictions)

- works for very peripheral reactions (N_{core} =25). The formation of a possible new state is not size dependent

Light hadrons insensitive to phase of matter prior to freeze out (v_2 or other collective variables?)

Other Dynamical Variables

Can we go further and investigate also kinematical variables like $<p_T(N_{part})>$, $v_2(N_{part})$ or even single particle spectra ?

Yes, if we make an additional (strong) assumption:

Core and corona particles do not have many interactions among themselves (otherwise the different particles species change their $<p_T>$ which they had at creation and $<p^i_T>$ would not follow the core-corona predictions).

If core and corona particles do not interact among themselves it is improbable that core hadrons interact with corona hadrons

EPOS gives evidence that this is indeed the scenario.
absorption by core possible if there is only one type of part:

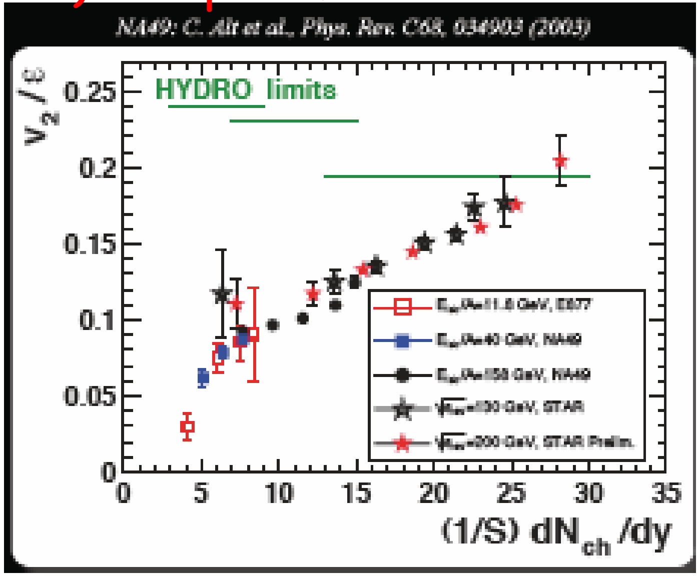
v_2 as a function of centrality has a long history

$$v_2 =< cos2(\phi - \phi_{reaction\ plane}) >$$

v_2/ε ($\epsilon = \frac{x^2-y^2}{x^2+y^2}$ eccentricity in coordinate space) is independent of the geometry if v_2 is caused by ε
1/S dN/dy = measures the particle density

a) All RHIC and SPS data points (for heavy systems) fall on a common line if plotted as: v_2/ε as a fct of 1/SdN/dy

b) Experiments and ideal hydro results do not agree


NA49: C. Alt et al., Phys. Rev. C68, 034903 (2003)

Snellings QM09

Hydrodynamics describes many features in central collisions

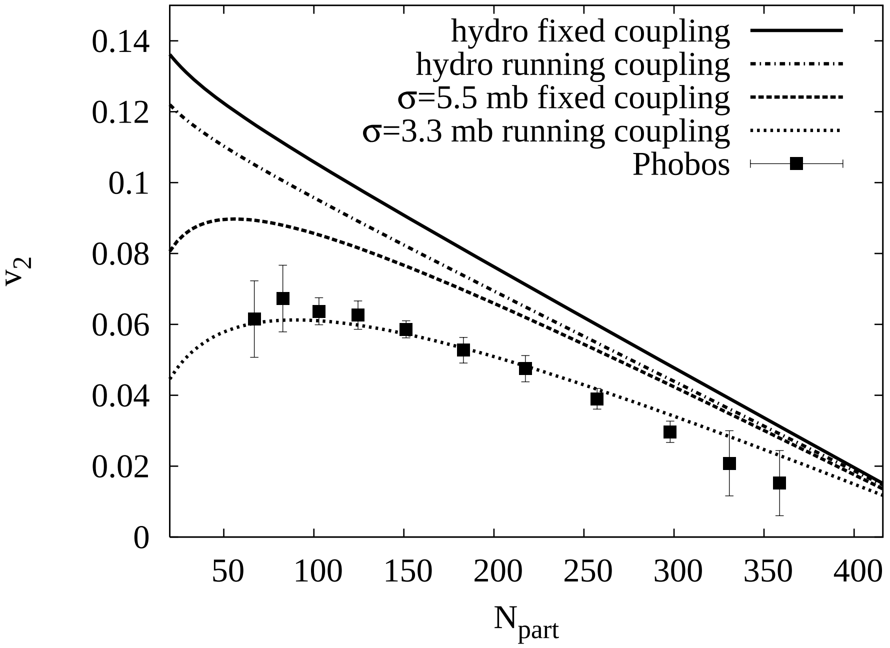
therefore

Centrality dependence points towards the need of viscous hydro (which in the limit of large dN/dy agrees with ideal hydrodynamics)

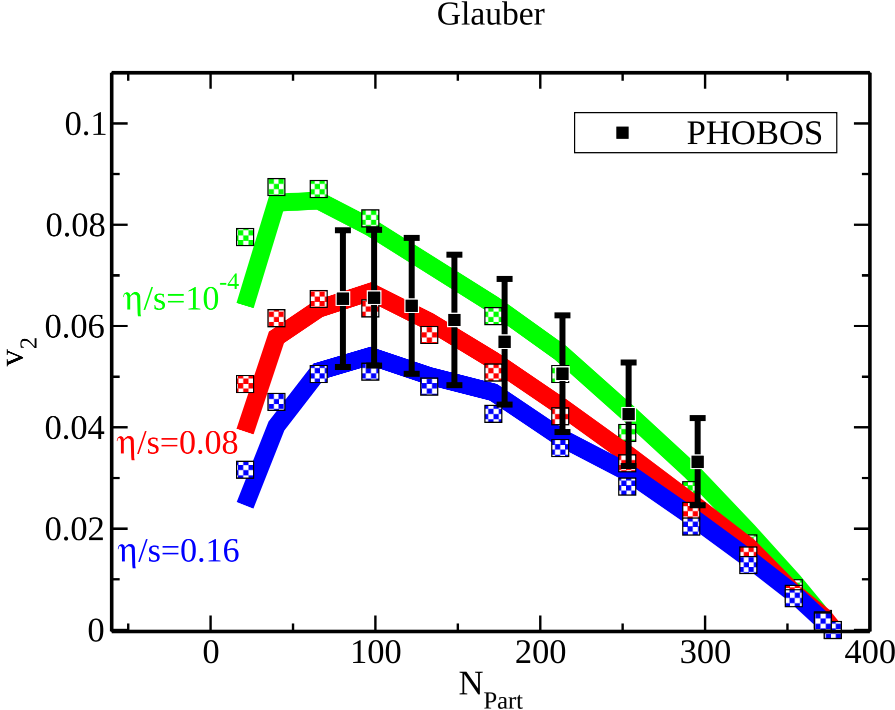
Viscous Hydro fits the viscosity to the centrality dependence of v_2

Other way around: Centrality dependence allows for the determination of the viscosity

Drescher et al. PRC76,024905



Luzum et al. PRC78,034915

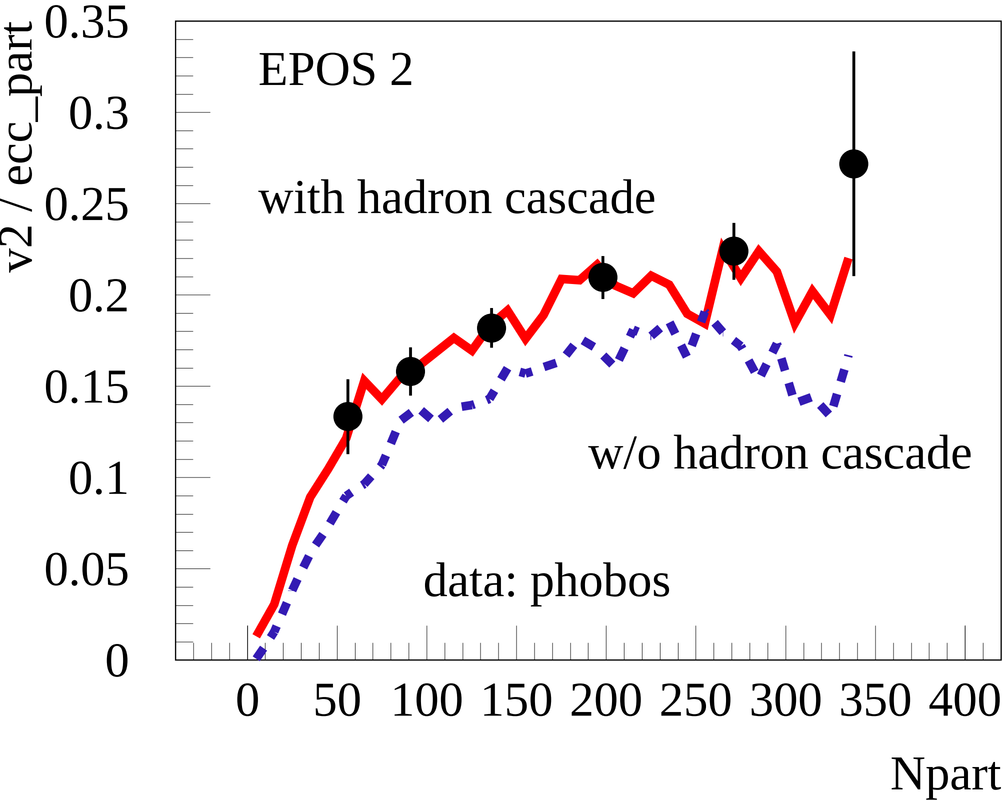


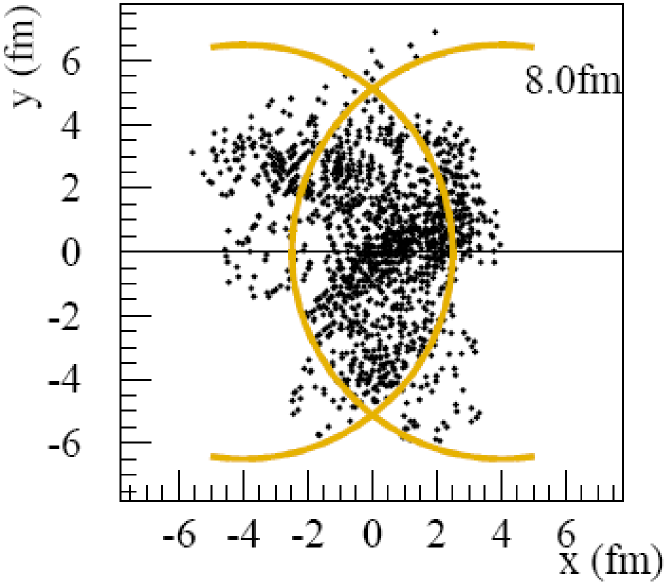
EPOS: Ideal hydro describes the data if

- core- corona
- fluctuating initial conditions (event-by-event hydro)

are applied

arXiv:1004.0805



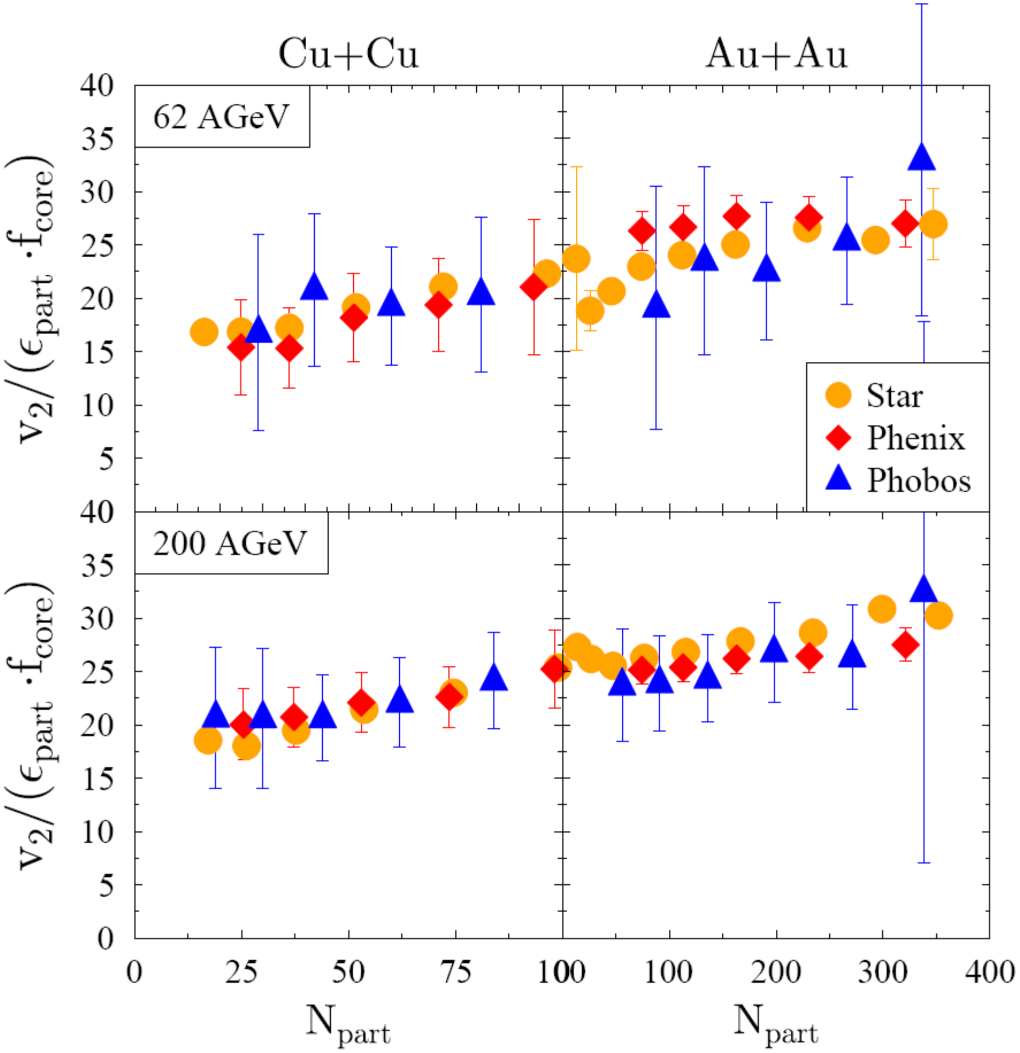


Position of NN scatterings

No need for viscous hydro dynamics

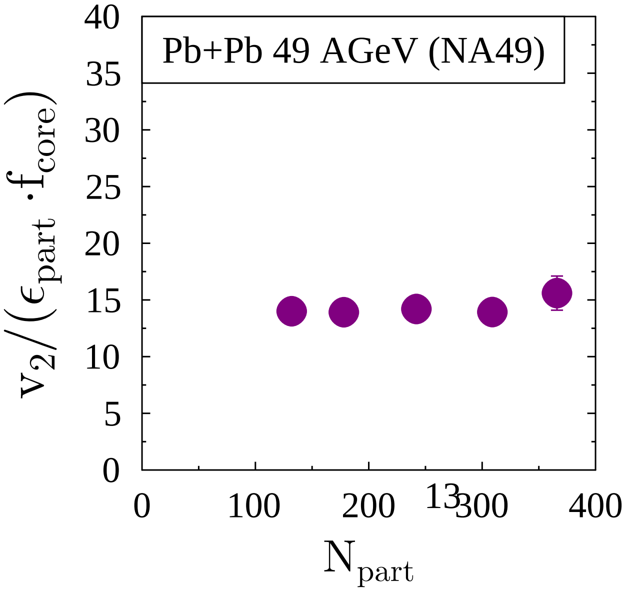
Core-corona model: Only core particles develop elliptic flow (corona part. fragment like pp)

$$v_2/\varepsilon(N_{part}) = (v_2/\varepsilon)^{ideal\ hydro}\ f_{core}(N_{part})$$



All data compatible with a straight line and hence with the core corona assumption

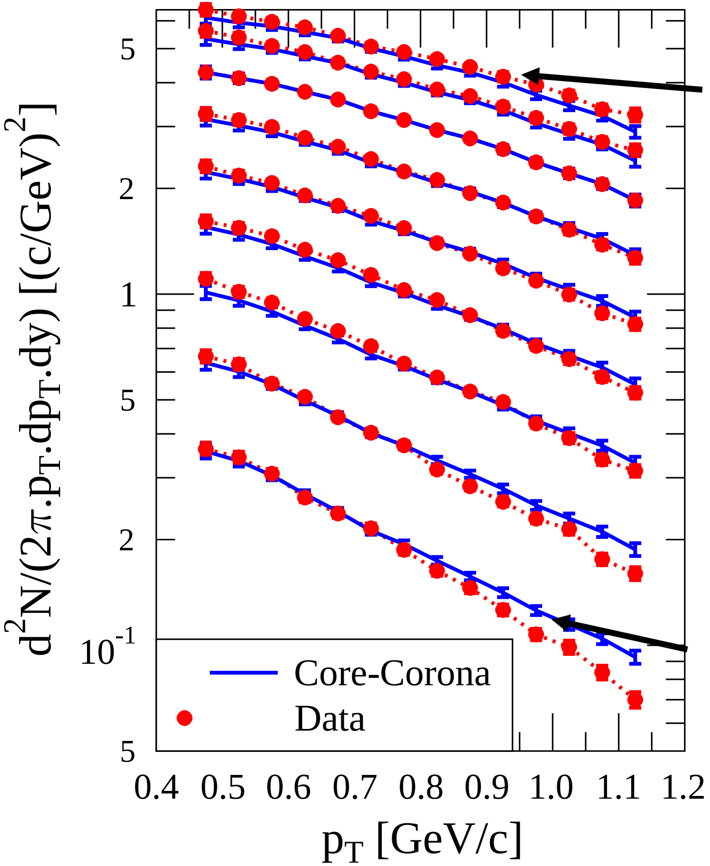
No free parameter



Single particle spectra (protons)

$$\frac{d^2N}{p_t dp_t dy}(N_{part}) = f_{core}(N_{part})\frac{d^2N}{p_t dp_t dy}|_{core} + (1-f_{core})\frac{d^2N}{p_t dp_t dy}|_{pp}$$

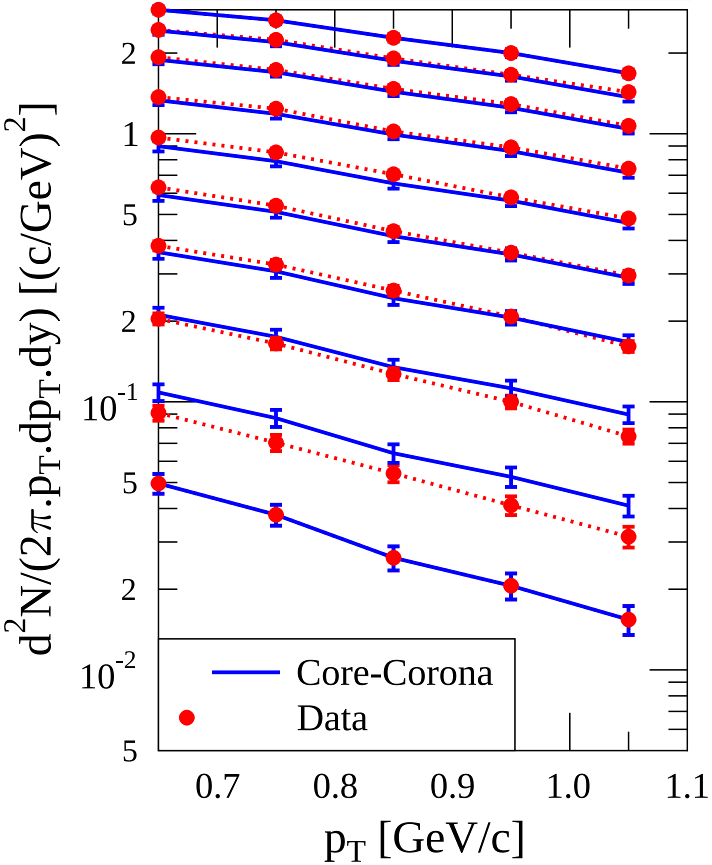
STAR



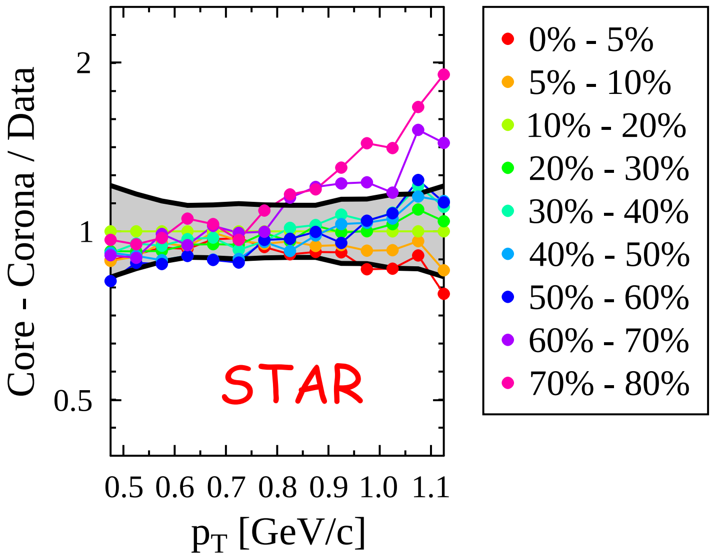
[0,5%]

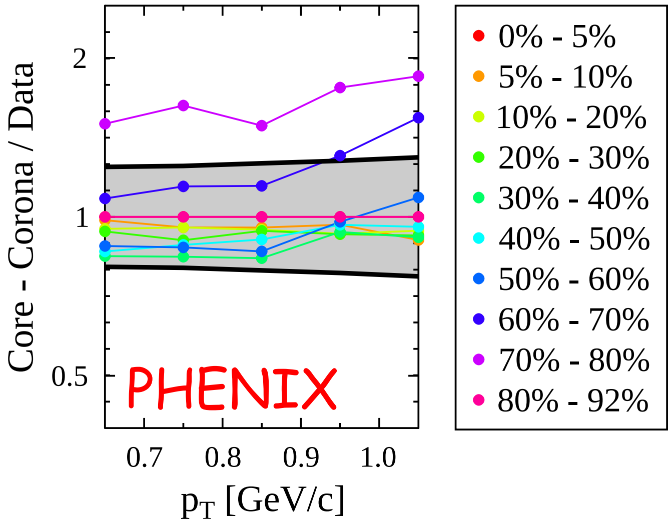
[70-80%]

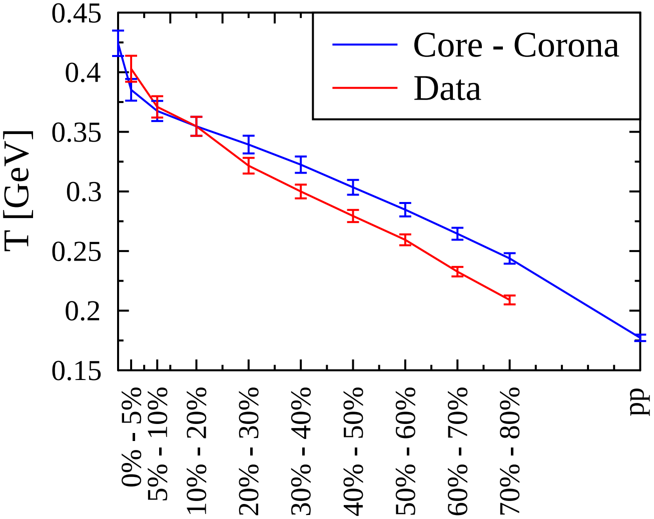
PHENIX

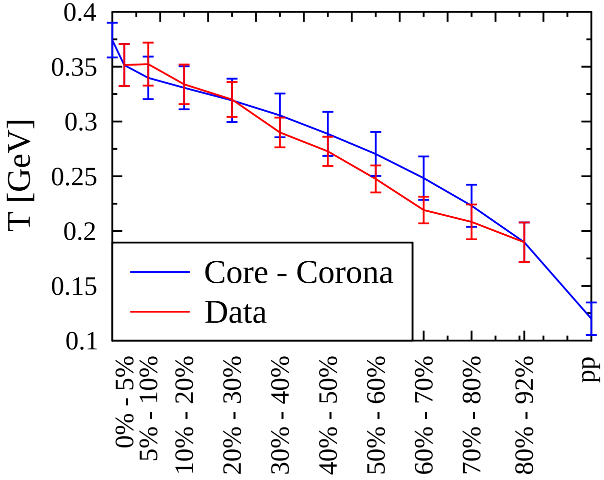


Core-corona agrees almost within errorbars with exp spectra


p spectra comparison

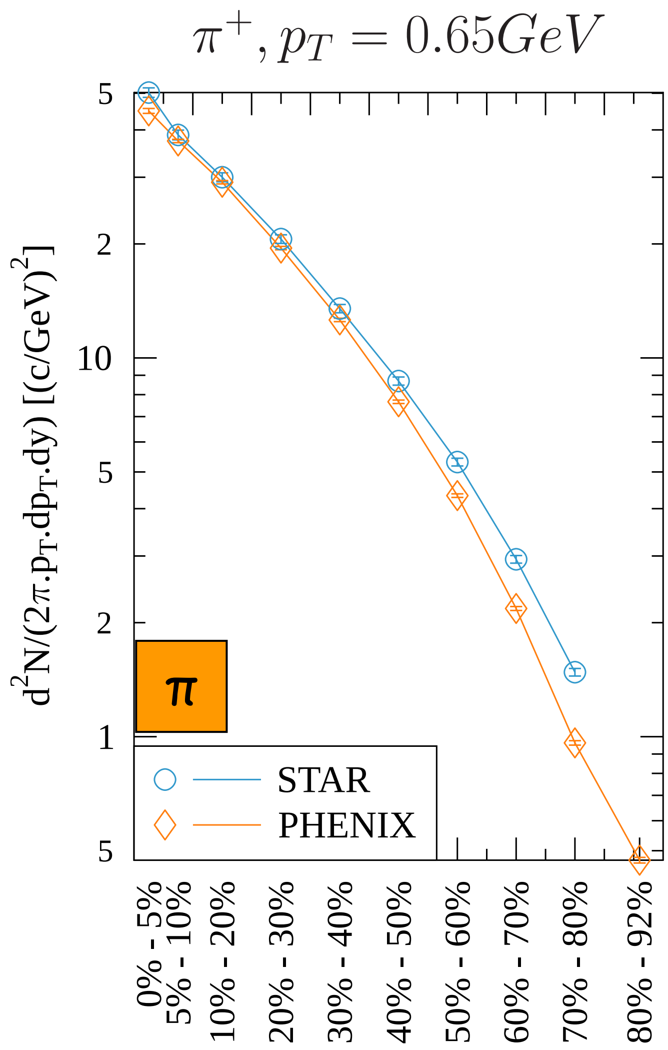

p spectra comparison

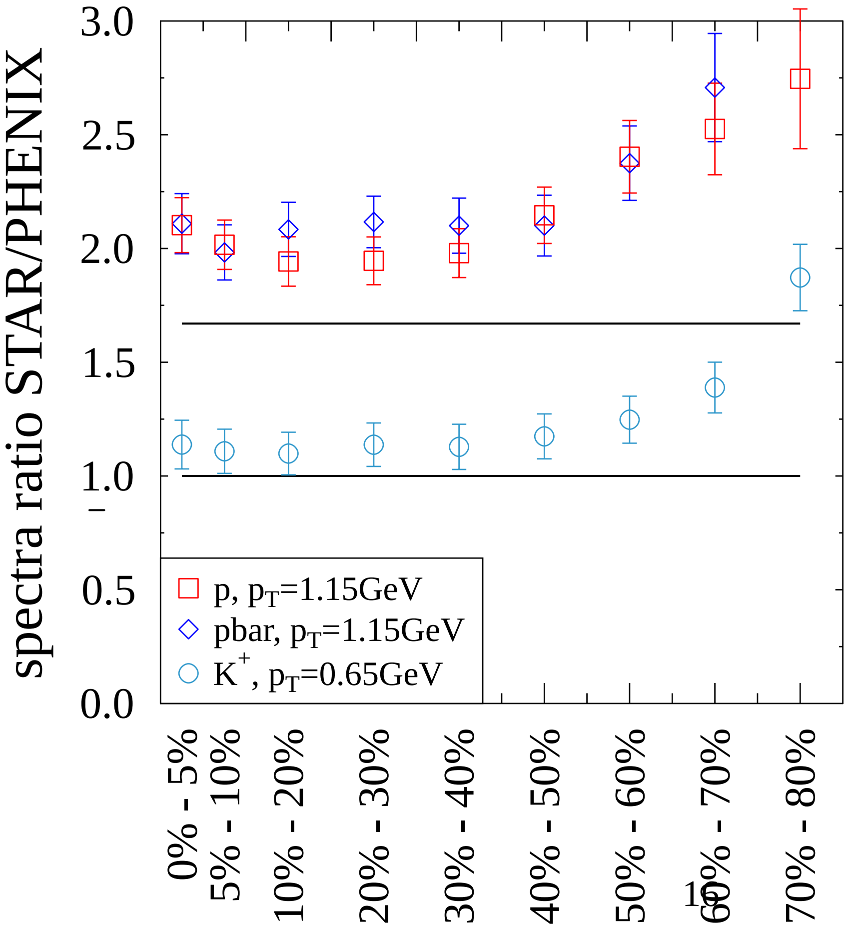

p inverse slope parameter


p inverse slope parameter

Not at all trivial: slope chance by a factor of 2 from central -> peripheral

STAR and PHENIX data do not agree
Therefore the core and corona parameters are different





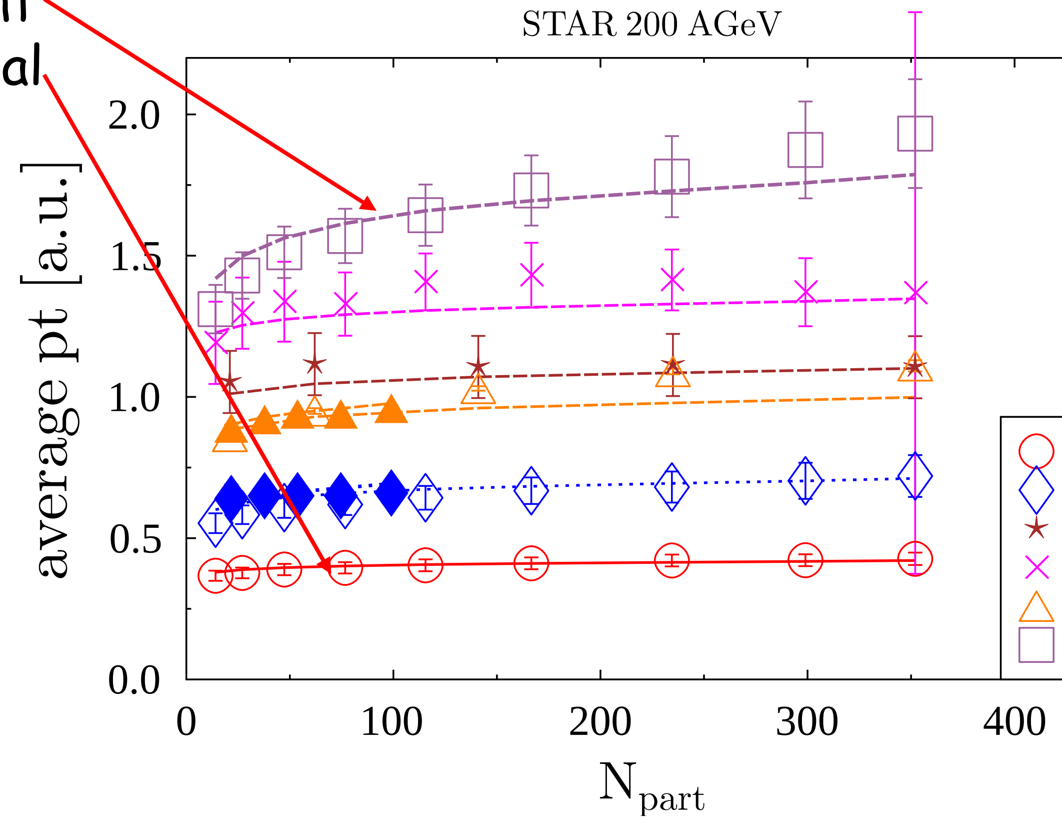
Fortunatelly the mean values <p_t> suffer little from spectral form

$$\langle p_T \rangle = f_{core}(Npart)\langle p_T \rangle_{core} + (1-f_{core}(Npart))\langle p_T \rangle_{corona}$$

Strong dependence

For p $\langle p_T \rangle_{pp}$ and $\langle p_T \rangle_{central}$ different
For π <pT>pp similar to <pT>central
K^+ in between

$\langle p_t \rangle_{exp}$ reproduced by core-corona



Centrality dep. of
$\langle p_t(\Lambda) \rangle$ and $\langle p_t(p) \rangle$ very different:

Centrality dep. of
$\langle p_t \rangle$ due to core-corona and
not necessarily due to
collective flow

Conclusions

Core – corona model inspired by first CuCu result, checked against EPOS and developed to make this physics more transparent

v2,M^i,<p^i_T > in central collisions and pp is the only input

Predicts quantitatively all experimental results on centrality dependence at midrapidity:

-M^i (Npart) of all hadrons i from SPS to RHIC (strangeness enhancement
-v_2/ε (Npart) of charged particles from SPS to RHIC
-<p^i_T> (Npart) of hadrons i from SPS to RHIC
-single particle spectra
-the experimental observation of correlations
  between peri/central and pp/central for multiplicities and <p_T>
  alien to hydro -> is centrality dependence of v_2 really a consequence of the viscosity?

This is much more than we expected in view of its simplicity (improvement difficult due to large experimental error bars)

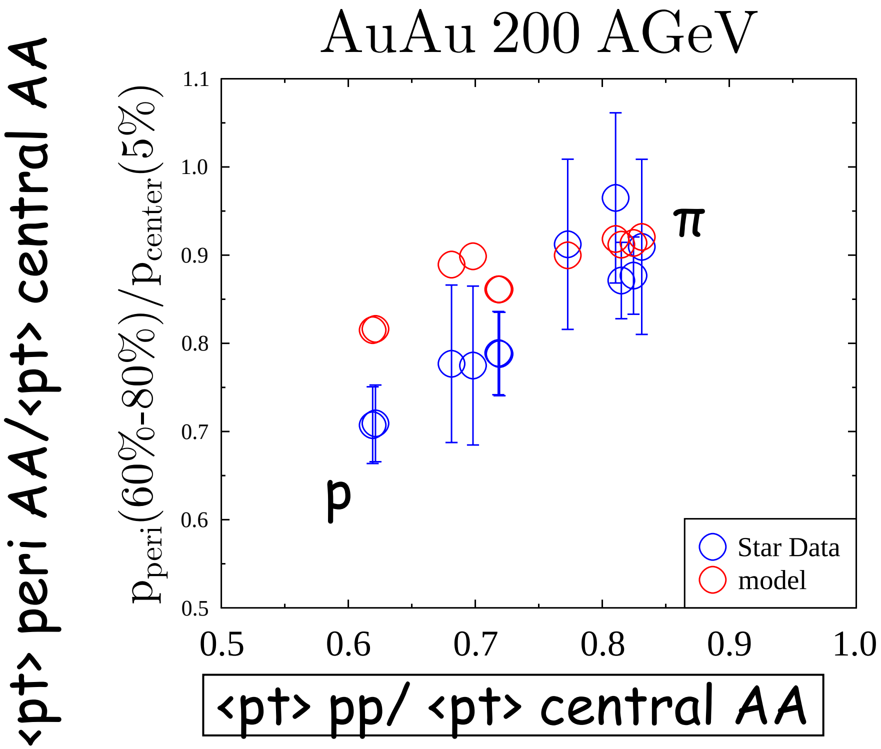
Conclusion on the Physics

The fact that the centrality dependence of all observables is described by this simple model may suggest that it describes the essential features of the reaction.
If this were the case:

What we see in the detector is a superposition of two independent contributions:
A corona contribution with properties identical to pp
A core contribution whose properties are independent of N_{part} even for very small N_{part} (≈20)
The observed centrality dependence is due to the N_{part} dependence of the ratio of both contributions
During the expansion
the average $\langle p_T \rangle$ of each hadron species does not change
The spectra remain a superposition

-> very little final state interaction after hadron formation

Correlation between peripheral AA and pp collisions



Data as core – corona model:

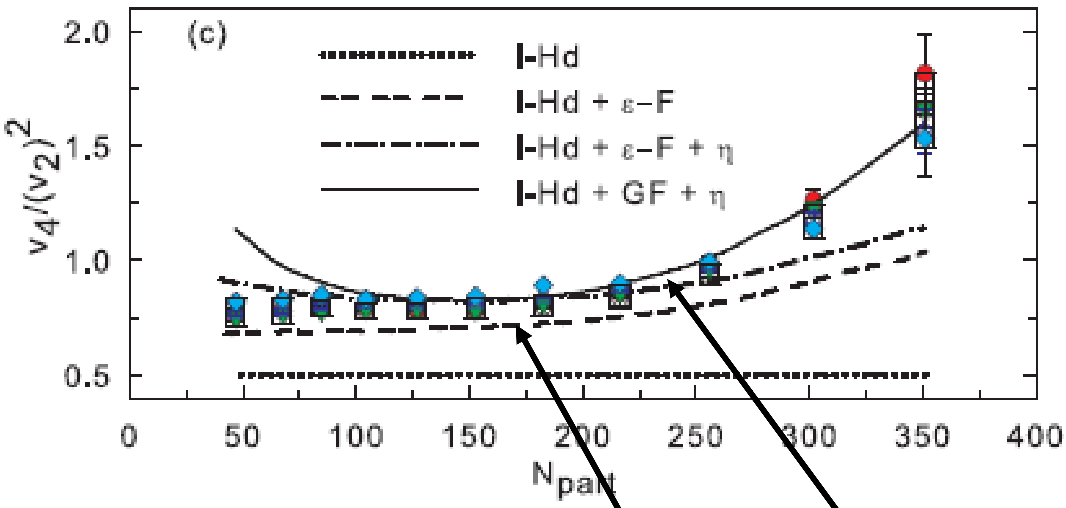
$$\frac{<p_t(AA\ peri)>}{<p_t(AA\ centr)>} \propto \frac{<p_t(pp)>}{<p_t(AA\ centr)>}$$

Such a correlation is unknown in hydro

Problem: pp data are not very precise

Can v_4 help?

Phenix, arXiv:1003:5586

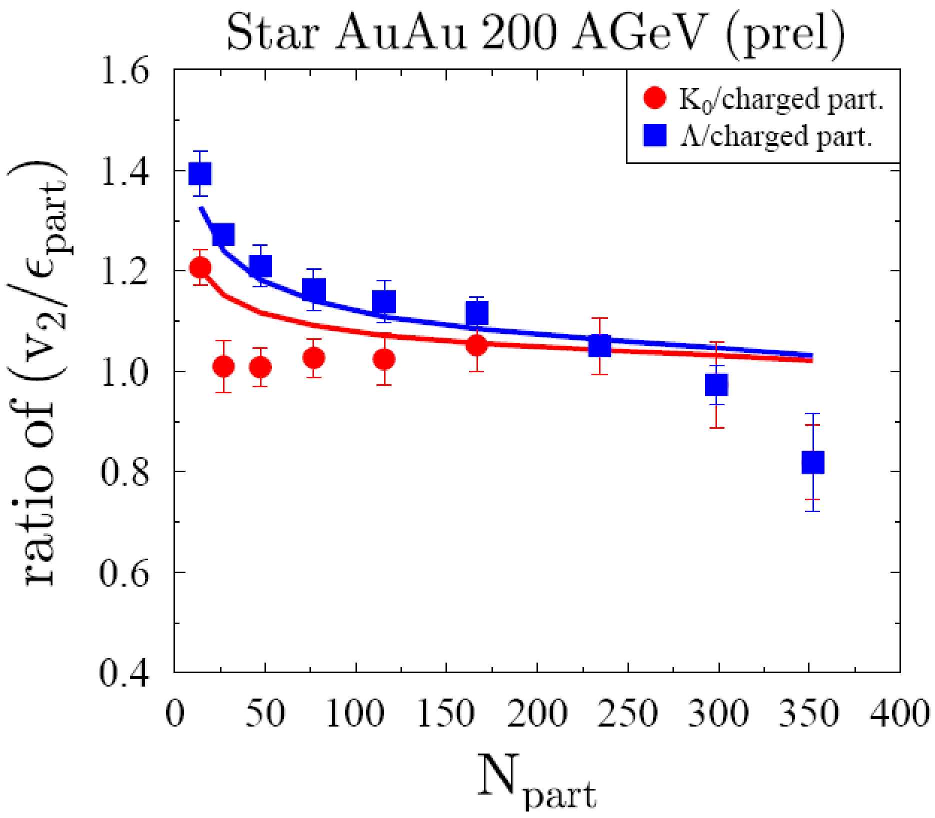


Determined mostly by ε fluctuations
Little difference between ideal and viscous hydro

Possibility to distiguish between hydro and core-corona?

v_2 of identified particles:
core corona fraction is dependent on the species

Less corona particles -> v_2 larger



Good agreement for Λ
less good for K_0

Deviation at central collision
not understood

more data needed

What is the difference between

Viscous hydro

core-corona

no surface effects

Time evolution of all particles identical with finite viscosity

v_2/ε depends on centrality via (Drescher&Ollitrault PRC76, 024905)

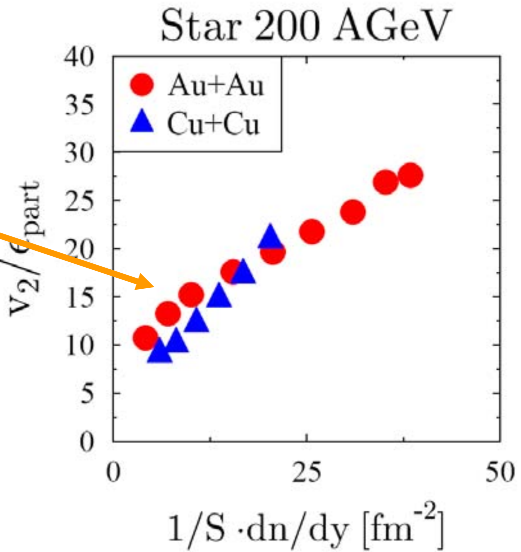
$$\frac{v_2}{\epsilon}(N_{part}) = \frac{v_2^{hydro}}{\epsilon}\frac{1}{1+\frac{K(N_{part})}{K_0}}$$

$$\frac{1}{K} = \frac{\sigma}{S}\frac{dN}{dy}c_s(E_{beam})$$

Parameters:
$(v_2/\varepsilon)^{hydro}$
K_0
c_s (E_{beam})

Distinction between surface and core (critical energy dens.)
core = ideal hydro (visc = 0)
corona = pp

$$\frac{v_2}{\epsilon}(N_{part}) = f_{core}\frac{v_2^{hydro}}{\epsilon}$$



Parameters:
$(v_2/\varepsilon)^{hydro}$
(f_{core} determined from multiplicities or $\langle p_t \rangle$)