A unified description of the reaction dynamics from pp to AA collisions

Comparing pPb and PbPb collisions

(pp: work in progress, problem of statistics)

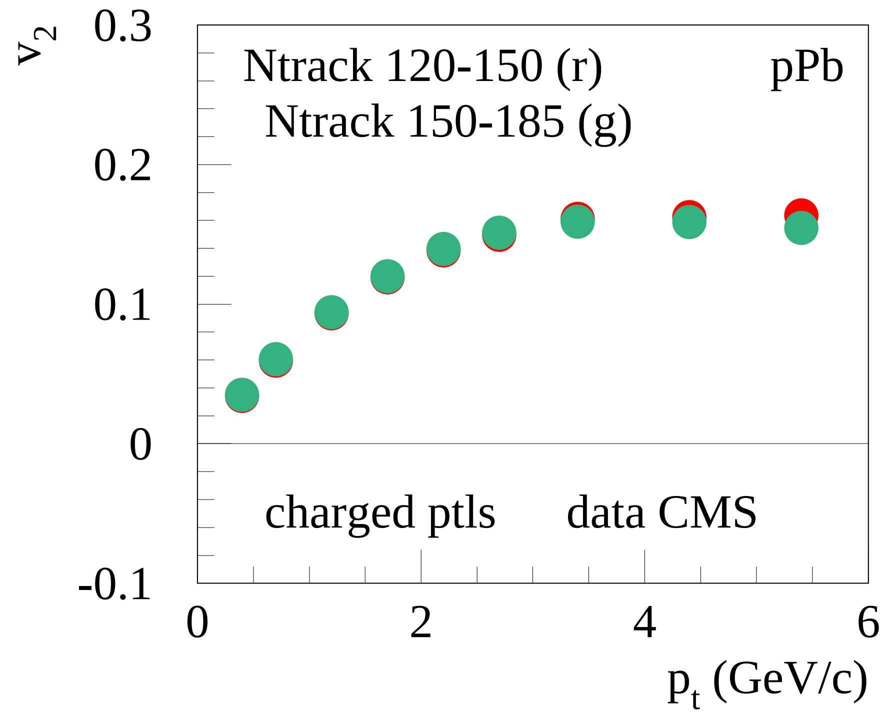
K.W. in collaboration with

B. Guiot, Iu. Karpenko, T. Pierog

Motivation :

Similarities in pPb and PbPb data

CMS: Centrality dependence of v_2



v_2 vs p_t in pPb and PbPb

pPb :

* Little change with multiplicity

* Large v_2 at large p_t

CMS: Centrality dependence of v_2

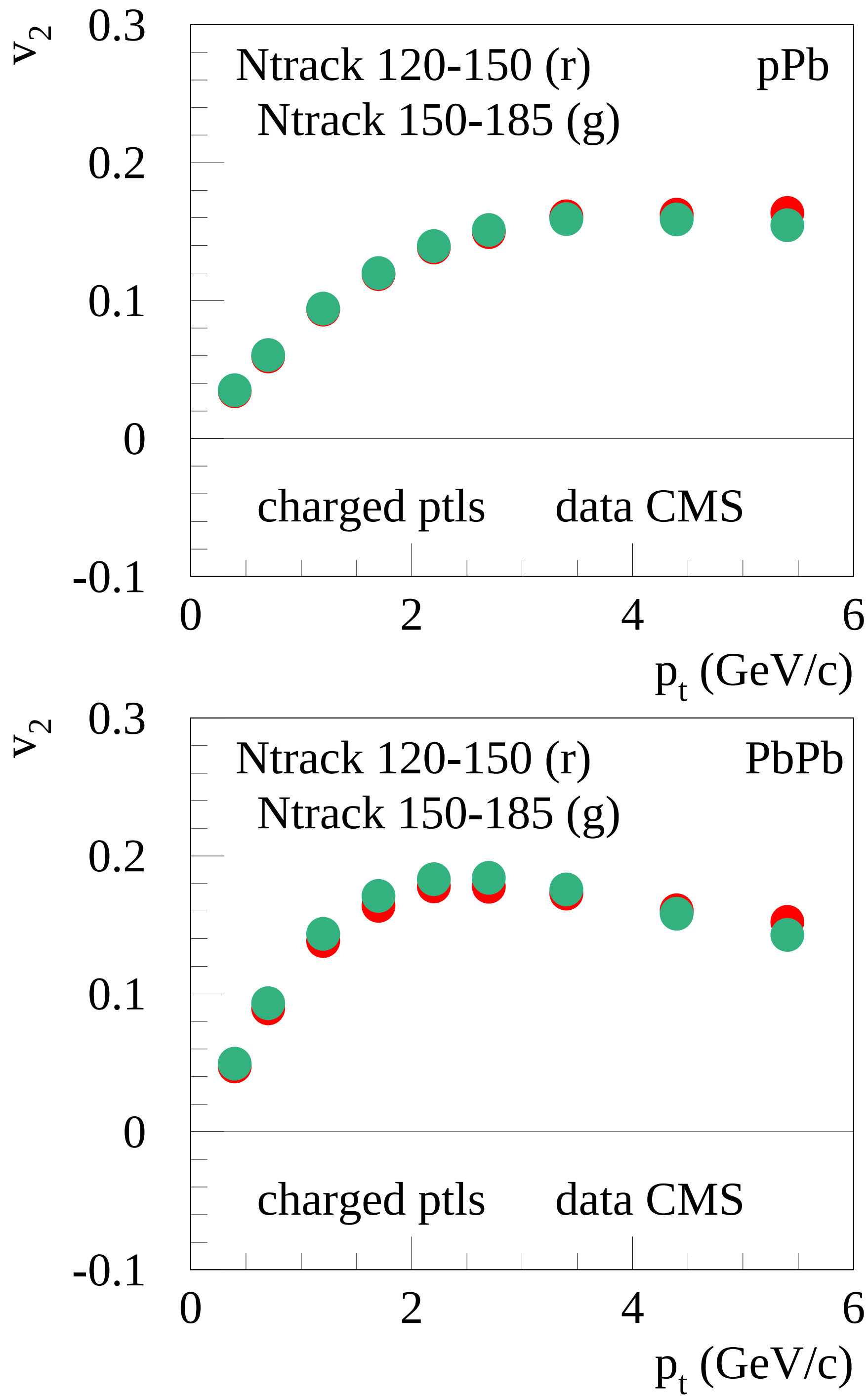
v_2 vs p_t in pPb and PbPb

pPb :

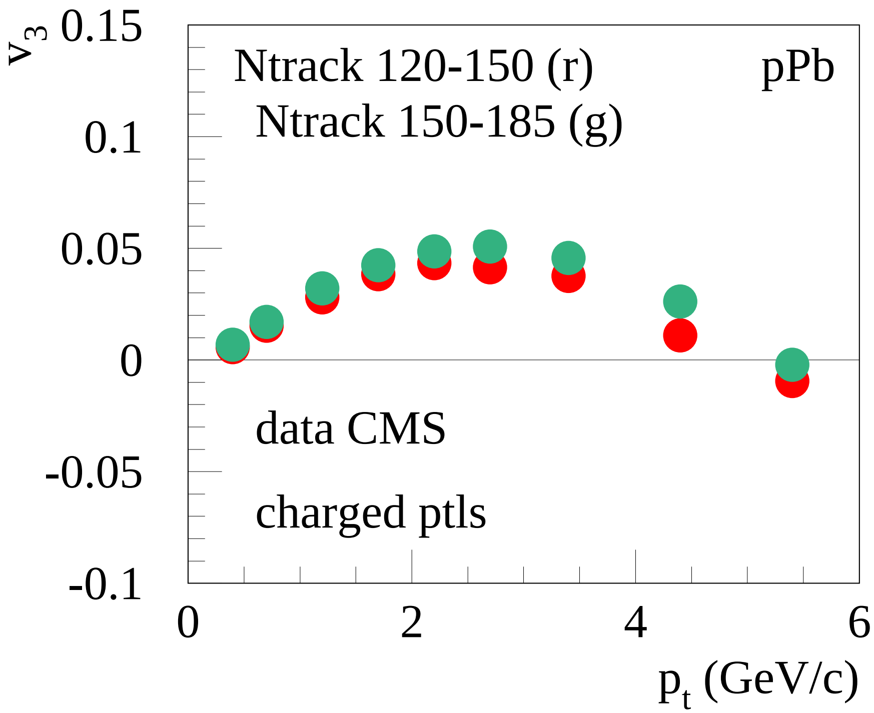
* Little change with multiplicity

* Large v_2 at large p_t

PbPb : similar behavior (but different shape)



CMS: Centrality dependence of v_3



v_3 vs p_t in pPb and PbPb

pPb :

v_3 increases slighly with Ntrack

v_3 becomes small at large p_t

CMS: Centrality dependence of v_3

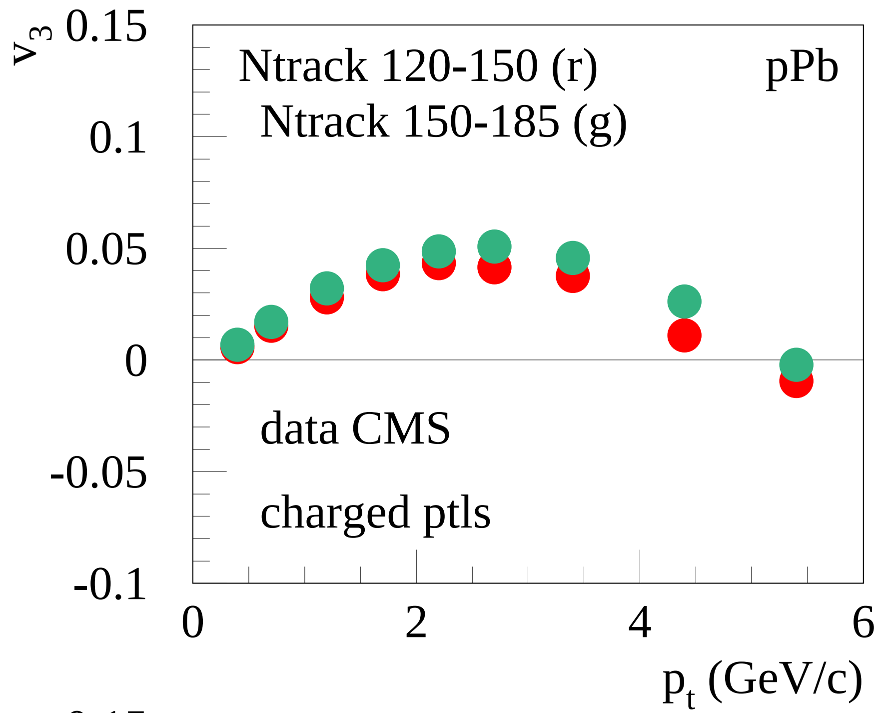
v_3 vs p_t in pPb and PbPb

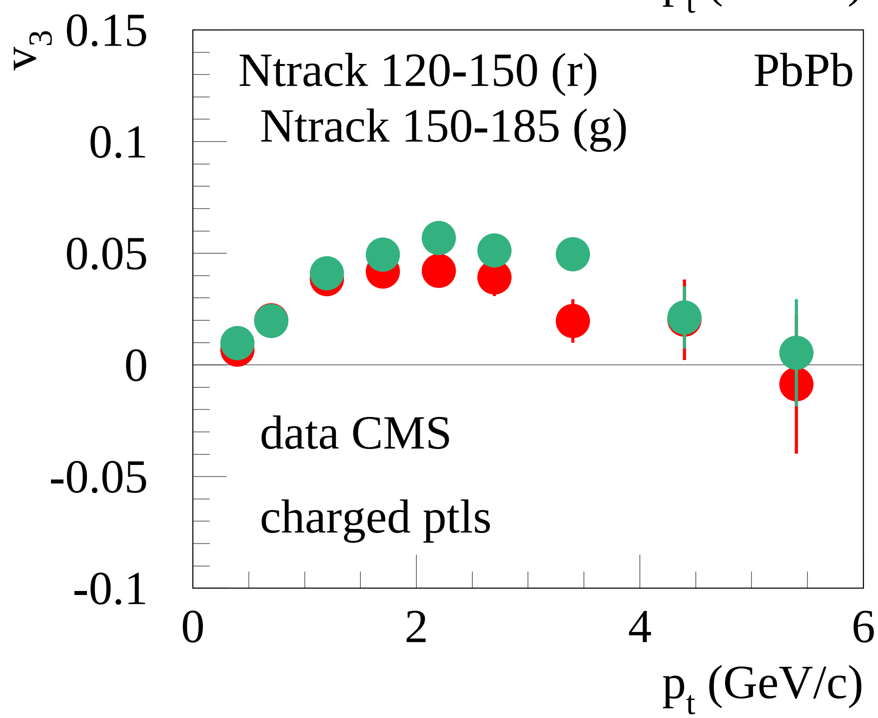
pPb :

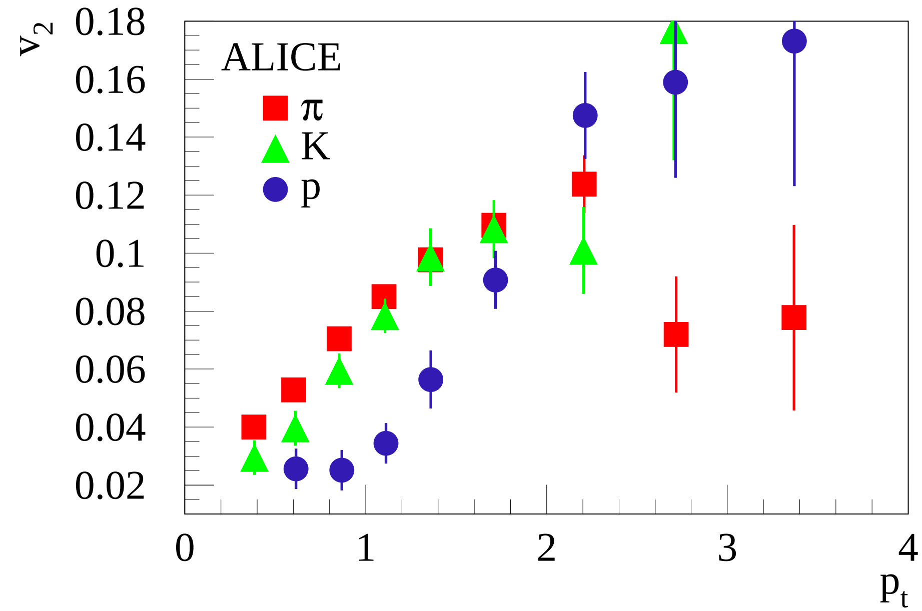
v_3 increases slighly with Ntrack

v_3 becomes small at large p_t

PbPb : same behavior



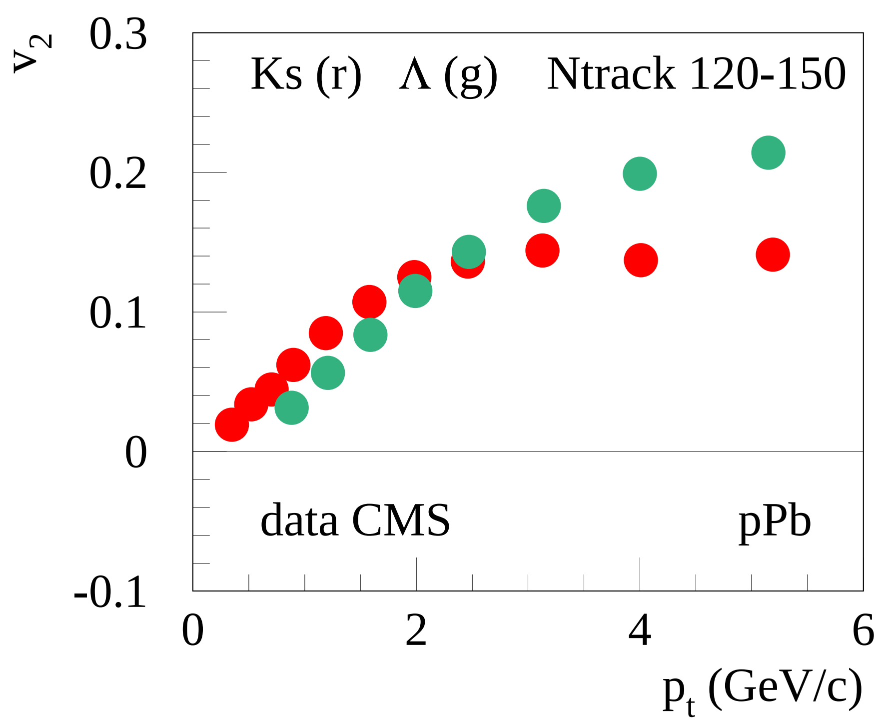




Mass splitting

v_2 vs p_t for identified particles

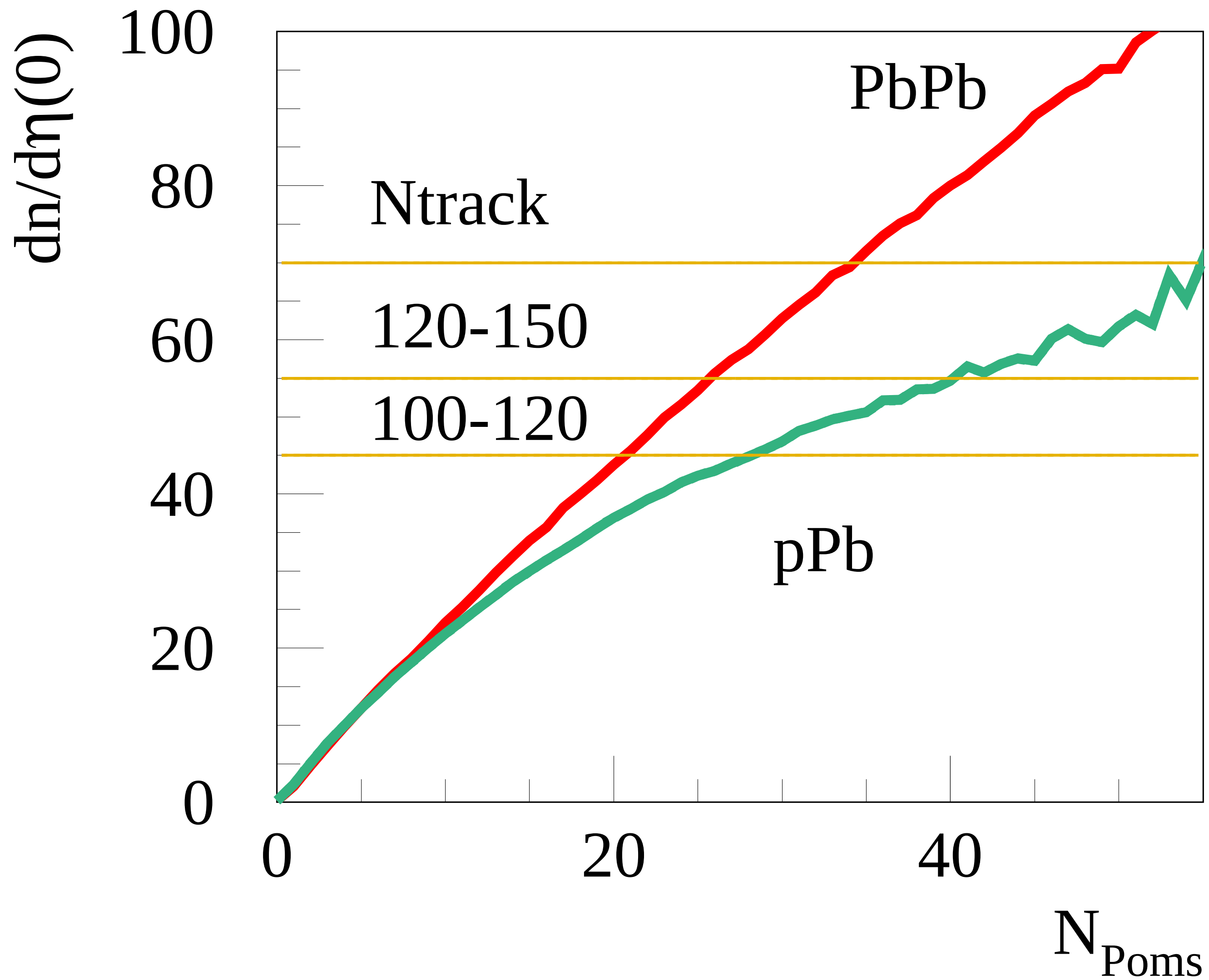
- □ splitting of π, K, p (ALICE)
- □ splitting of K_s, Λ (CMS) (increases with Ntrack)



Comparing pPb and PbPb simulations (EPOS)

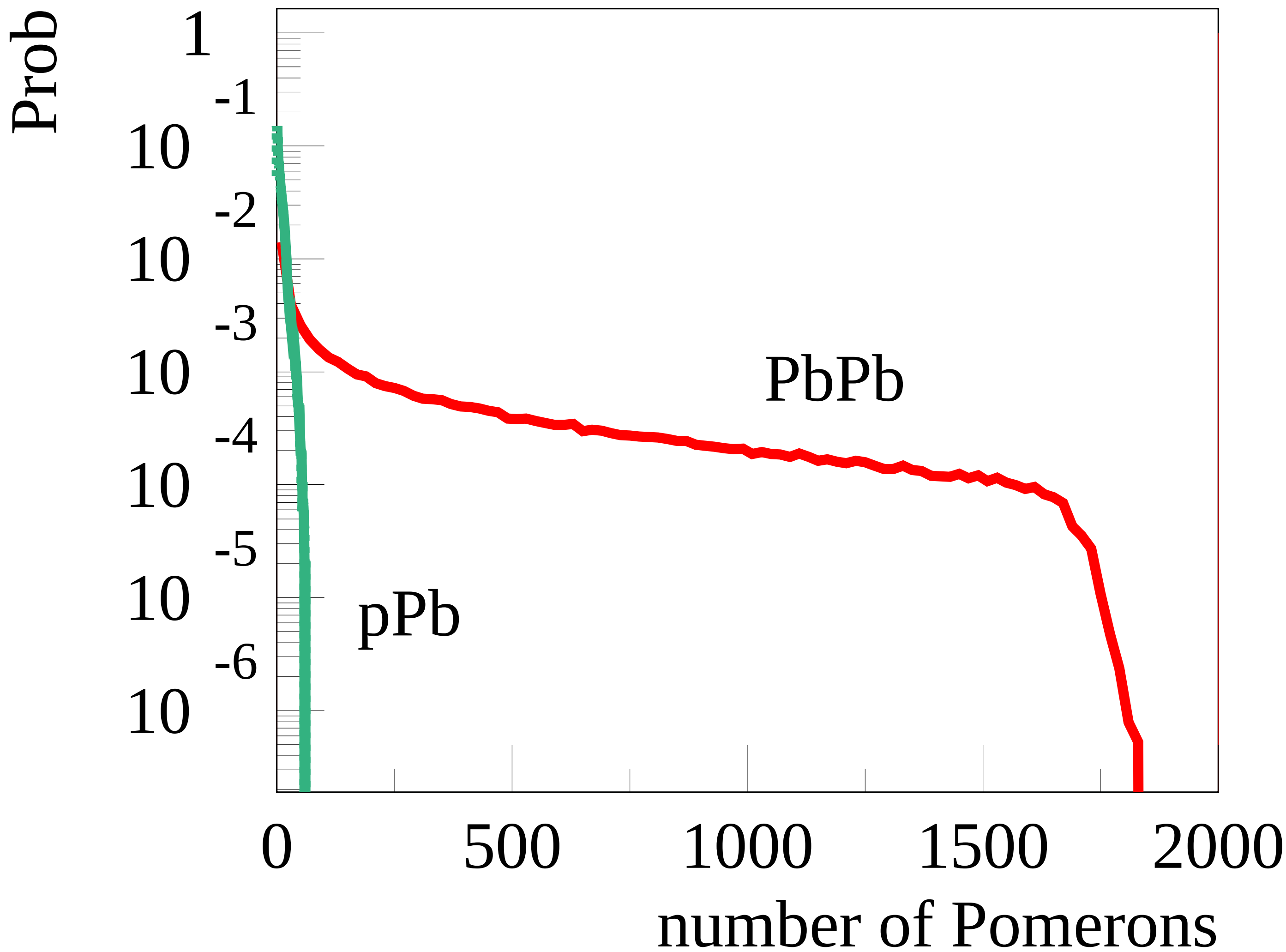
Basic quantity to characterize the geometry: The number N_{Pom} of Pomerons

N_{Pom} strongly correlated with multiplicity



$N_{\rm Pom}$ distributions in pPb and PbPb

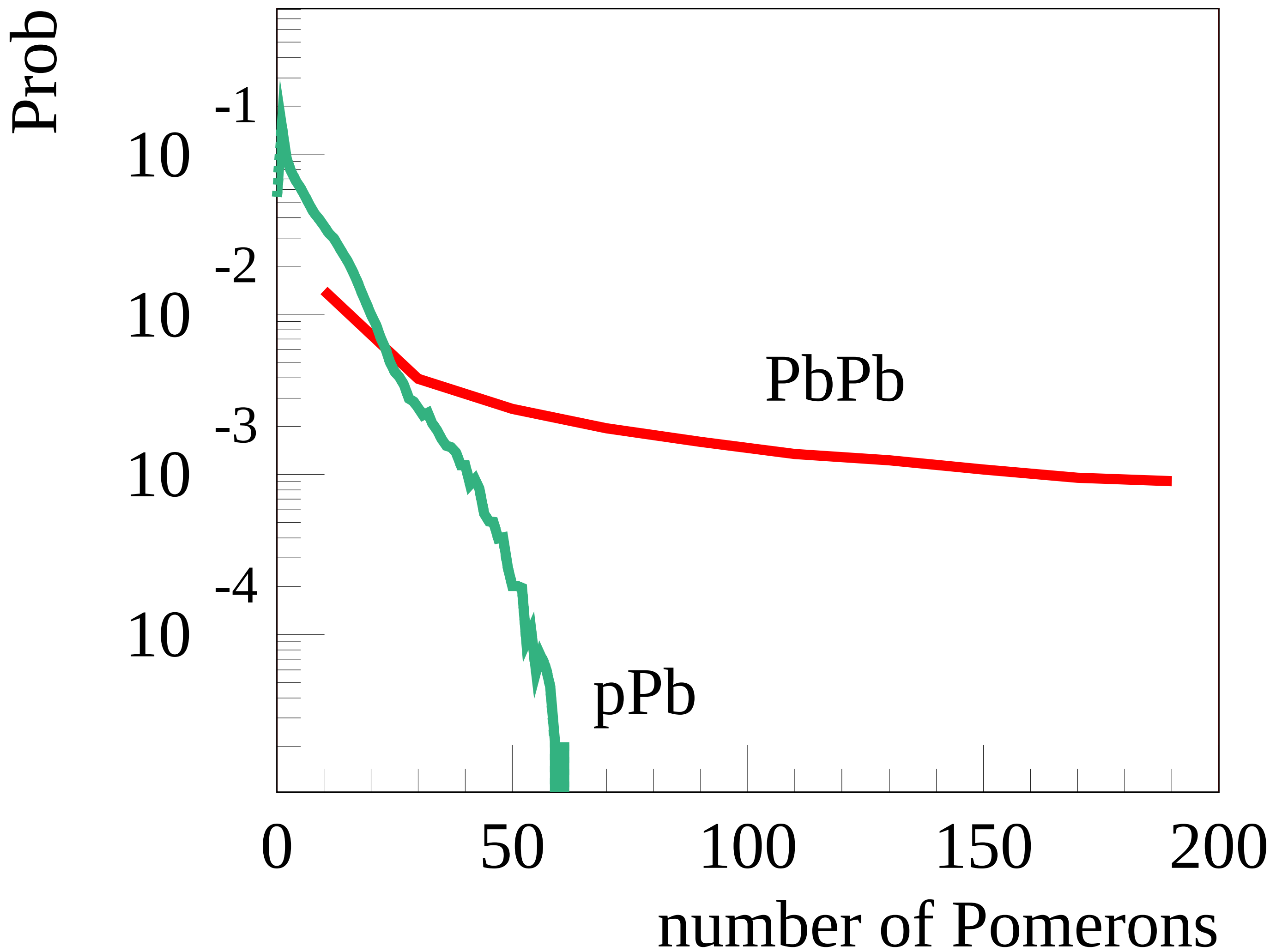
Quite different!



Only peripheral PbPb has overlap w. pPb

pPb:

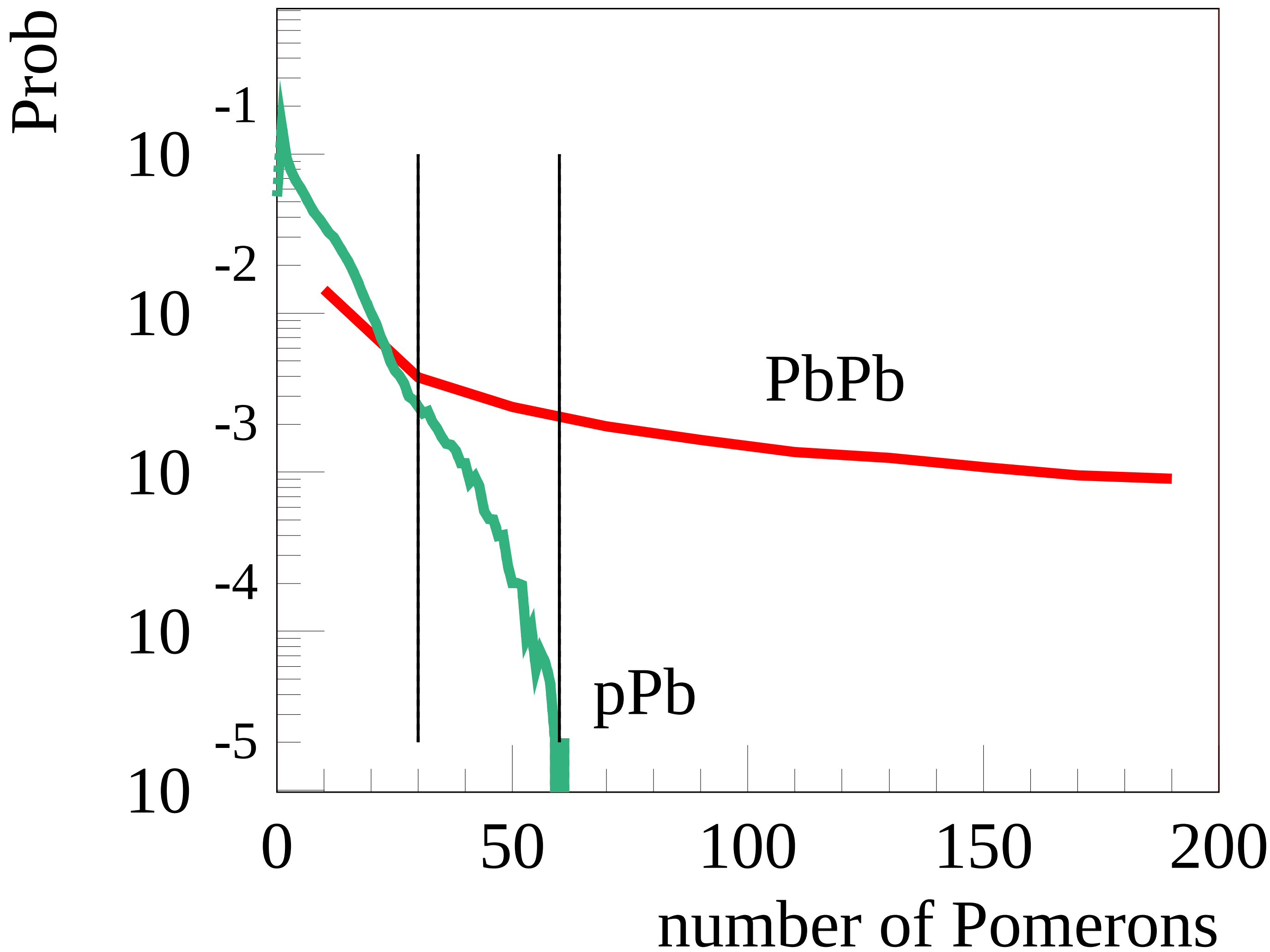
$N_{Pom} < 100$



Only peripheral PbPb has overlap w. pPb

our study :

$N_{Pom} \approx$ **30-60**

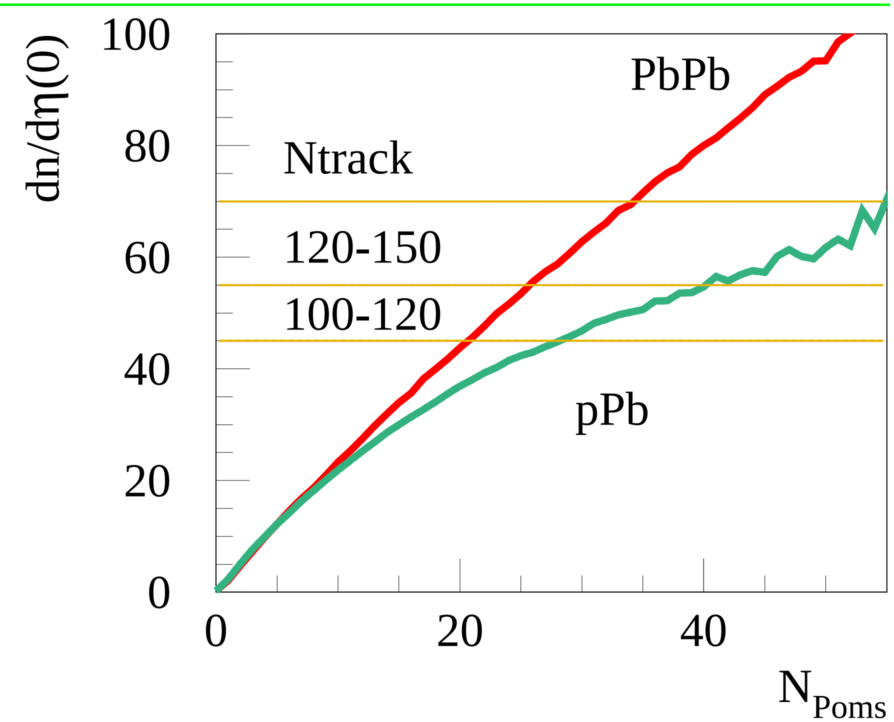


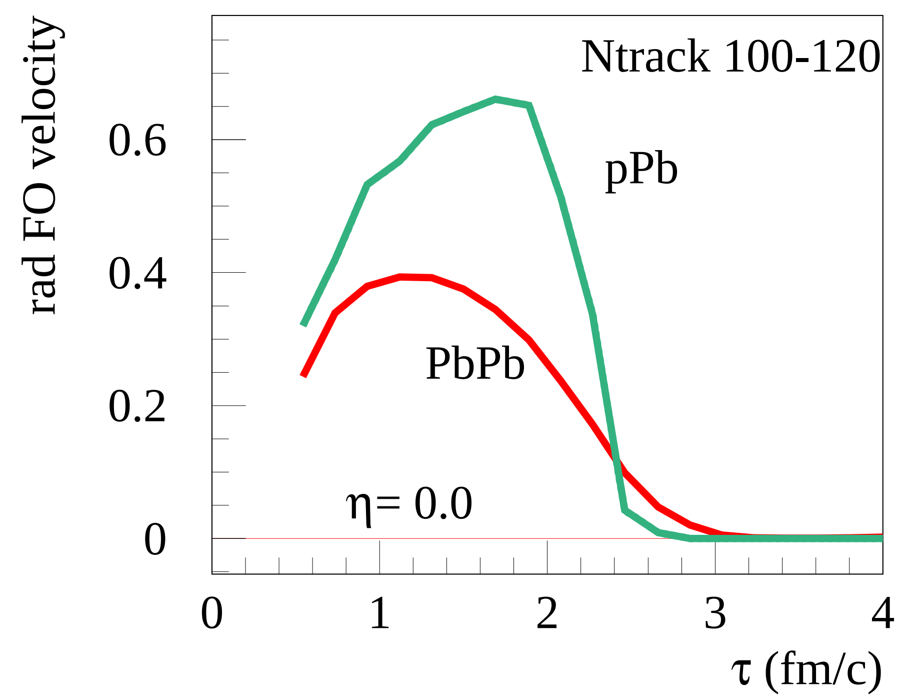
pPb - PbPb same Ntrack

Differences :

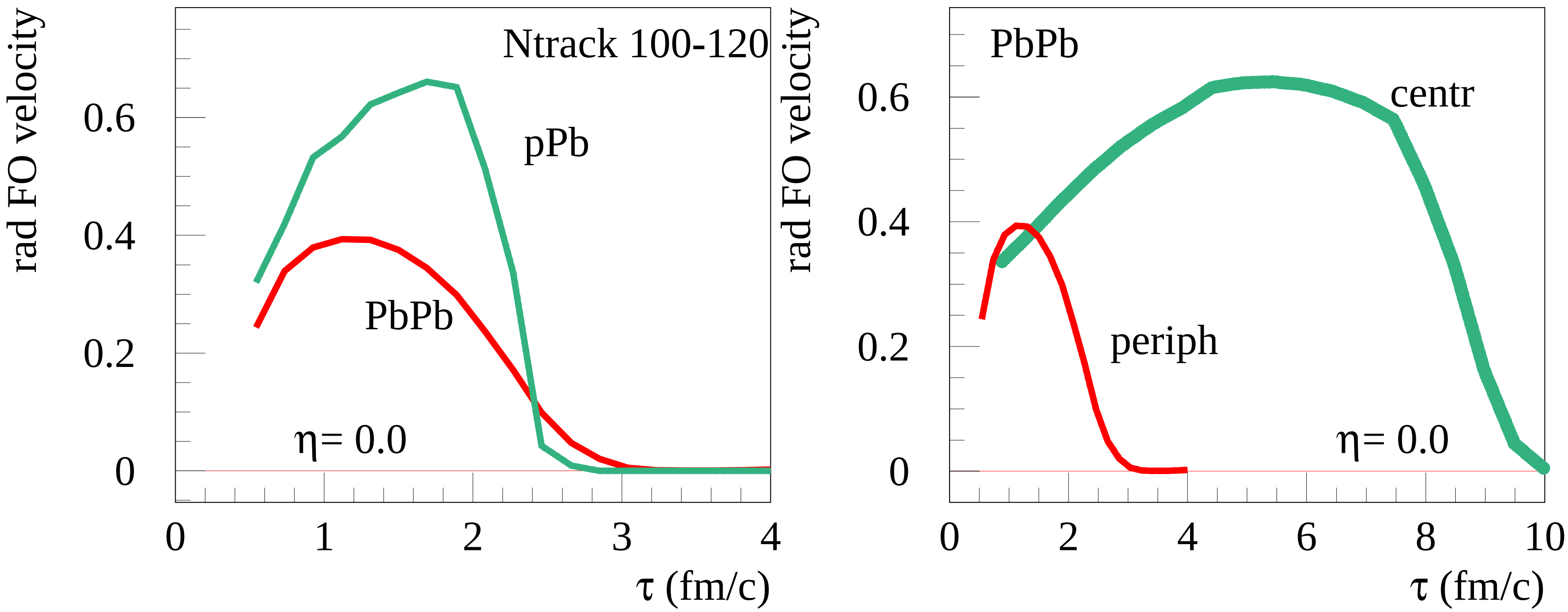
- Relation multiplicity - N_{Pom}

- Radial flow





pPb comparable with central PbPb!



Universal approach: pp, pA, AA

For ALL reactions: Same procedure, several stages

- ☐ Initial conditions:
  Gribov-Regge multiple scattering approach,
  elementary object = Pomeron = parton ladder,
  using saturation scale $Q_s \propto N_{part}\, \hat{s}^{\lambda}$ (CGC)
- ☐ Core-corona approach
  to separate fluid and jet hadrons
- ☐ Viscous hydrodynamic expansion, $\eta/s = 0.08$
- ☐ Statistical hadronization, final state hadronic cascade

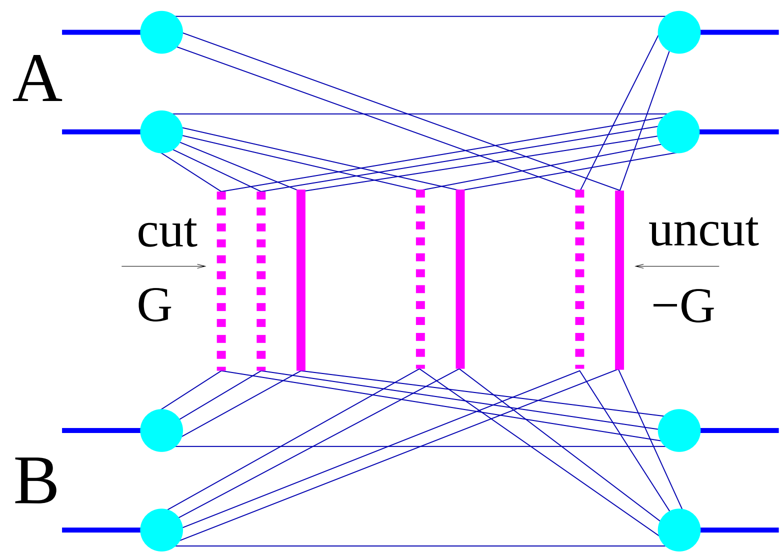
Realization: EPOS3, arXiv:1312.1233 , arXix:1307.4379,
B. Guiot, Y. Karpenko, T. Pierog, M. Bleicher, K. W.

Initial conditions: Marriage pQCD+GRT+energy sharing

(Drescher, Hladik, Ostapchenko, Pierog, and Werner, Phys. Rept. 350, 2001)

For pp, pA, AA:

$$\sigma^{\mathrm{tot}} = \sum_{\mathrm{cut\,P}} \int \sum_{\mathrm{uncut\,P}} \int$$



$$\underbrace{\qquad\qquad\qquad}_{d\sigma_{\mathrm{exclusive}}}$$

$$\mathrm{cut\,Pom} : G = \frac{1}{2\hat{s}} 2\mathrm{Im}\,\{\mathcal{FT}\{T\}\}(\hat{s}, b),\ T = i\hat{s}\,\sigma_{hard}(\hat{s})\,\exp(R^2_{\mathrm{hard}} t)$$

Nonlinear effects considered via saturation scale $Q_s \propto N_{part}\,\hat{s}^{\lambda}$

$$\sigma^{\mathrm{tot}} = \int d^2b \int \prod_{i=1}^{A} d^2b_i^A\, dz_i^A\, \rho_A\Big(\sqrt{(b_i^A)^2 + (z_i^A)^2}\Big)$$

$$\prod_{j=1}^{B} d^2b_j^B\, dz_j^B\, \rho_B\Big(\sqrt{(b_j^B)^2 + (z_j^B)^2}\Big)$$

$$\sum_{m_1 l_1} \dots \sum_{m_{AB} l_{AB}} (1-\delta_{0\Sigma m_k}) \int \prod_{k=1}^{AB} \Bigg(\prod_{\mu=1}^{m_k} dx_{k,\mu}^{+} dx_{k,\mu}^{-} \prod_{\lambda=1}^{l_k} d\tilde{x}_{k,\lambda}^{+} d\tilde{x}_{k,\lambda}^{-} \Bigg) \Bigg\{$$

$$\prod_{k=1}^{AB} \Bigg(\frac{1}{m_k!} \frac{1}{l_k!} \prod_{\mu=1}^{m_k} G(x_{k,\mu}^{+}, x_{k,\mu}^{-}, s, |\vec{b} + \vec{b}_{\pi(k)}^{A} - \vec{b}_{\tau(k)}^{B}|)$$

$$\prod_{\lambda=1}^{l_k} -G(\tilde{x}_{k,\lambda}^{+}, \tilde{x}_{k,\lambda}^{-}, s, |\vec{b} + \vec{b}_{\pi(k)}^{A} - \vec{b}_{\tau(k)}^{B}|) \Bigg)$$

$$\prod_{i=1}^{A} \Bigg(1 - \sum_{\pi(k)=i} x_{k,\mu,}^{+} - \sum_{\pi(k)=i} \tilde{x}_{k,\lambda}^{+} \Bigg)^{\alpha} \prod_{j=1}^{B} \Bigg(1 - \sum_{\tau(k)=j} x_{k,\mu}^{-} - \sum_{\tau(k)=j} \tilde{x}_{k,\lambda}^{-} \Bigg)^{\alpha} \Bigg\}$$

Remark

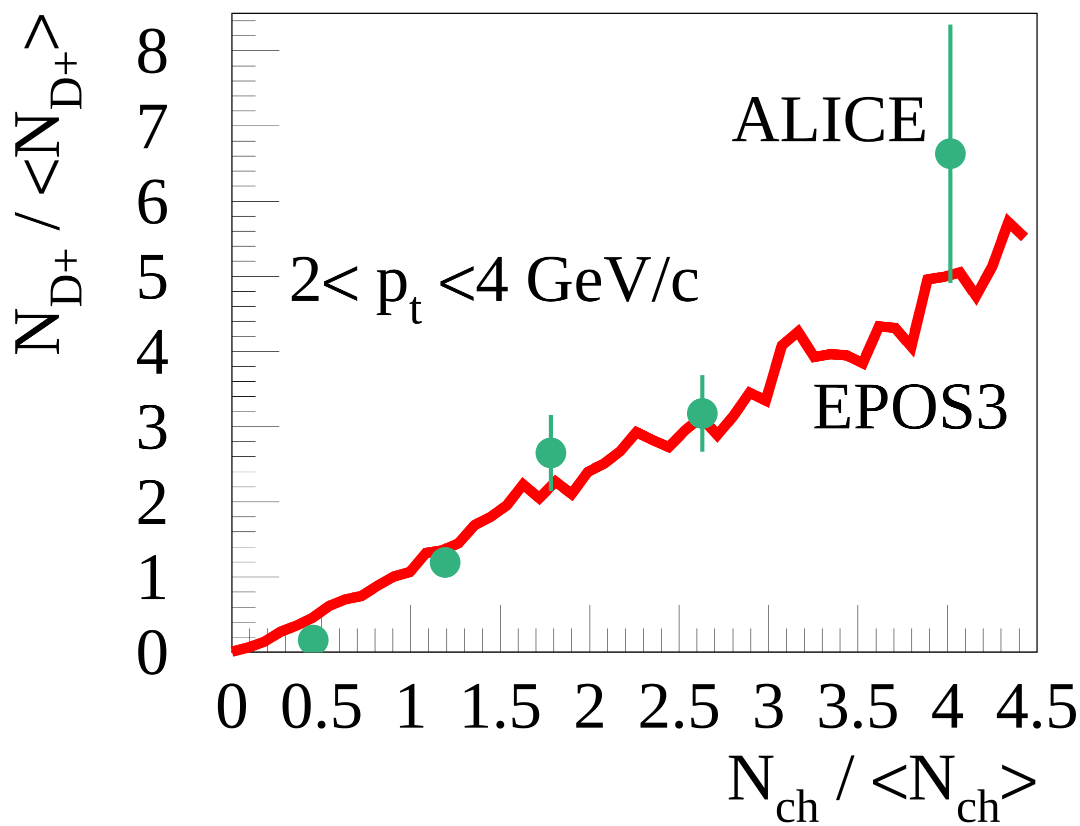
GR multiple scattering gives (automatically)

$$N_{\rm hard} \propto N_{\rm charged} \propto N_{\rm Poms}$$

$N_{\rm hard}$ stands for multiplicity of "hard" particle production.

Example: D^+ mesons

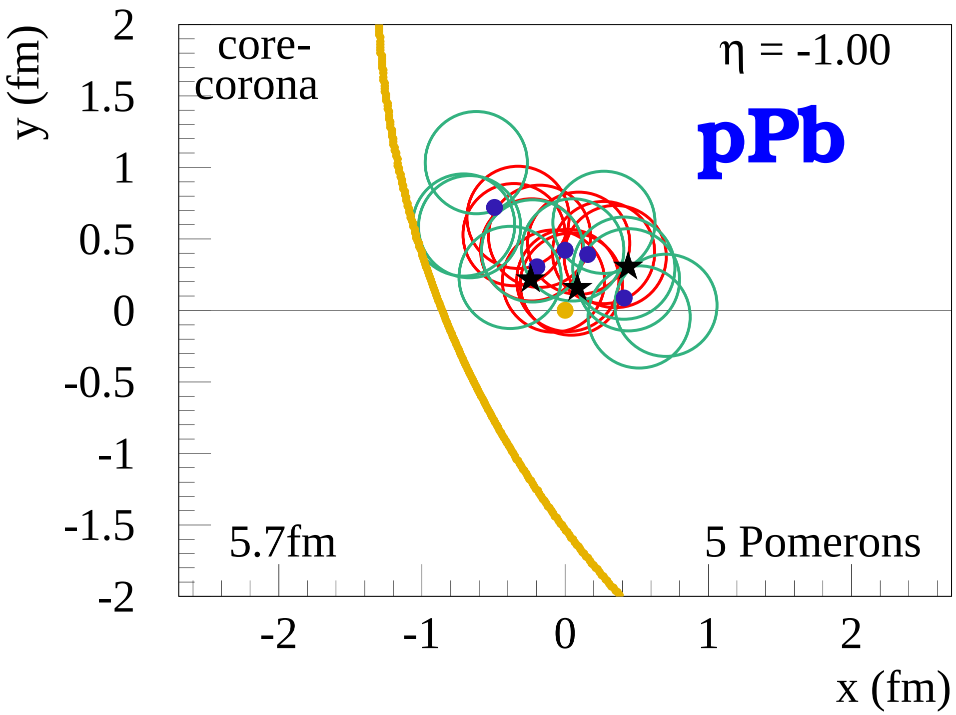
Plot from B. Guiot

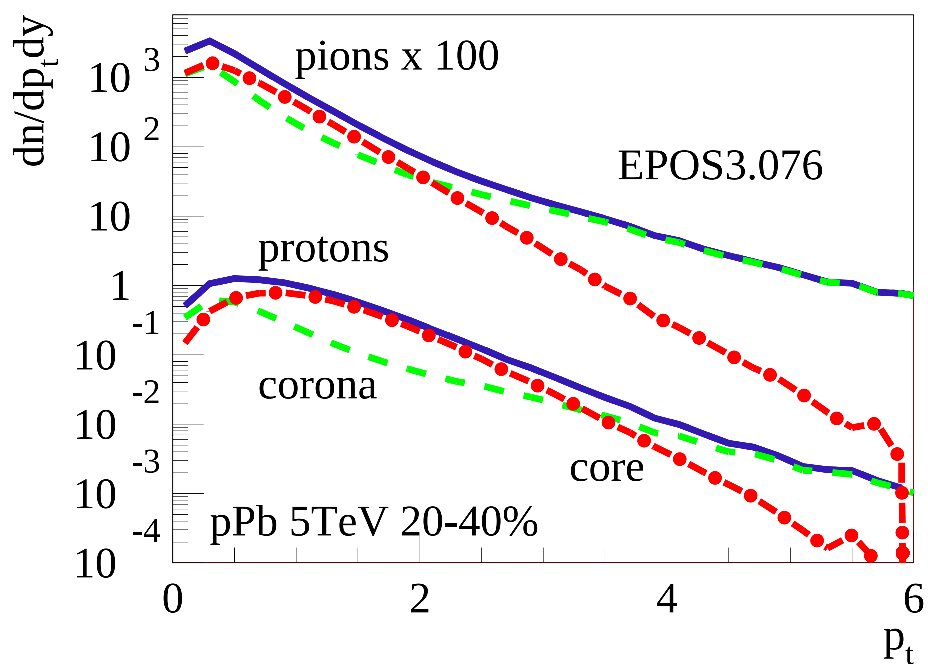


Core-corona procedure (for pp, pA, AA):

Pomeron => parton ladder => flux tube (kinky string)

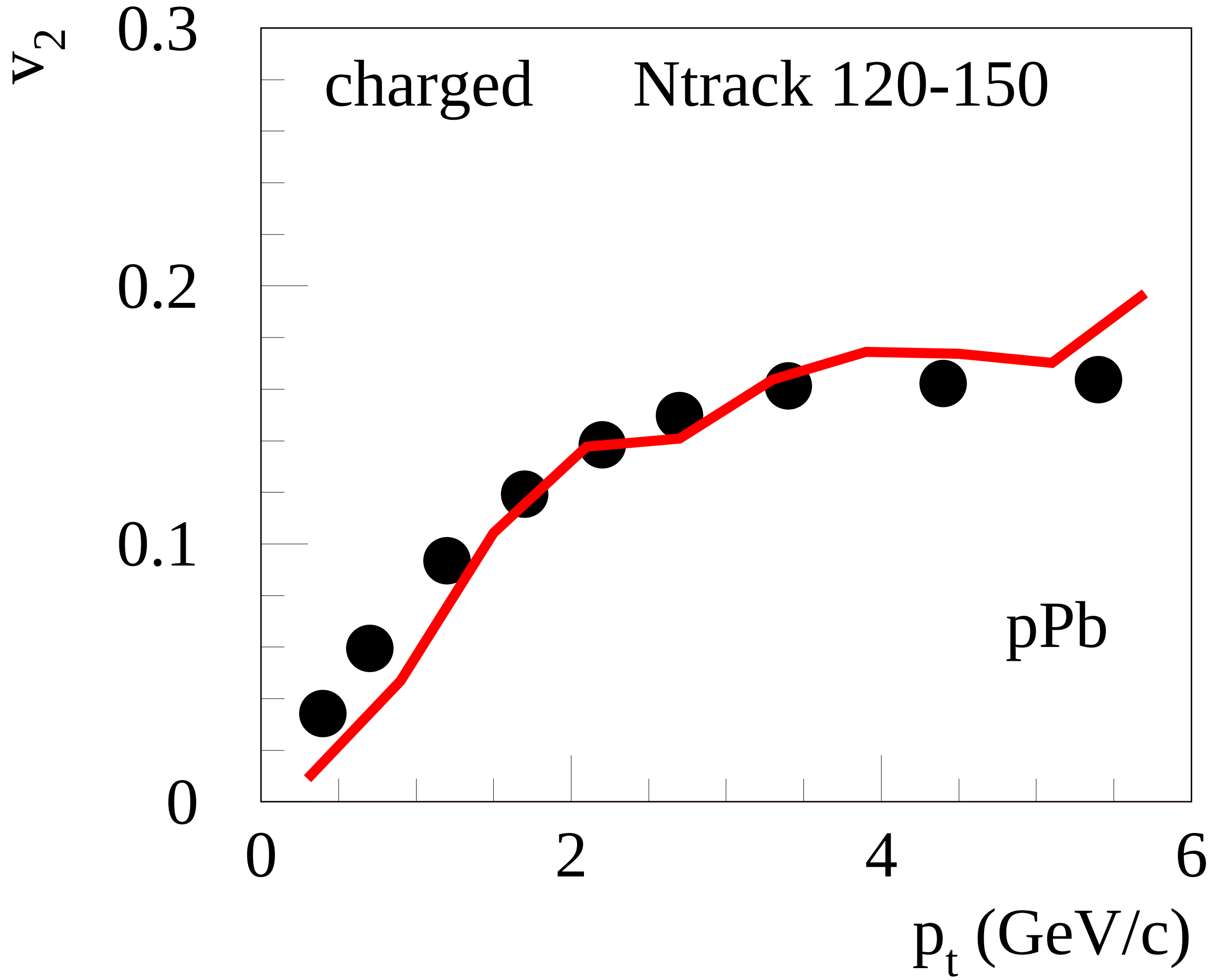
String segments with high pt escape => **corona**,
the others form the **core** = initial condition for hydro
depending on the local string density





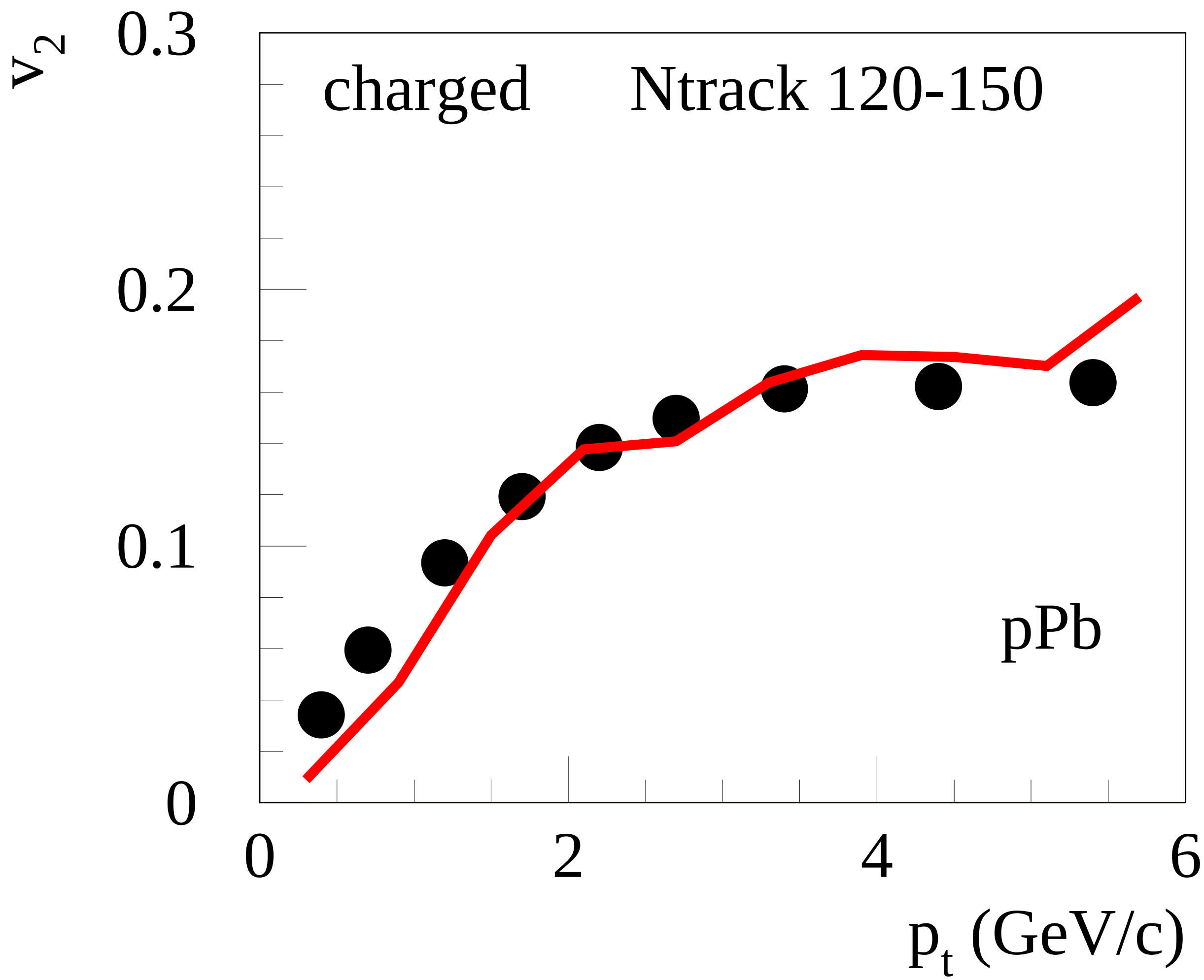
Back to the centrality dependence of $\mathbf{v}_n$

v_2 in pPb



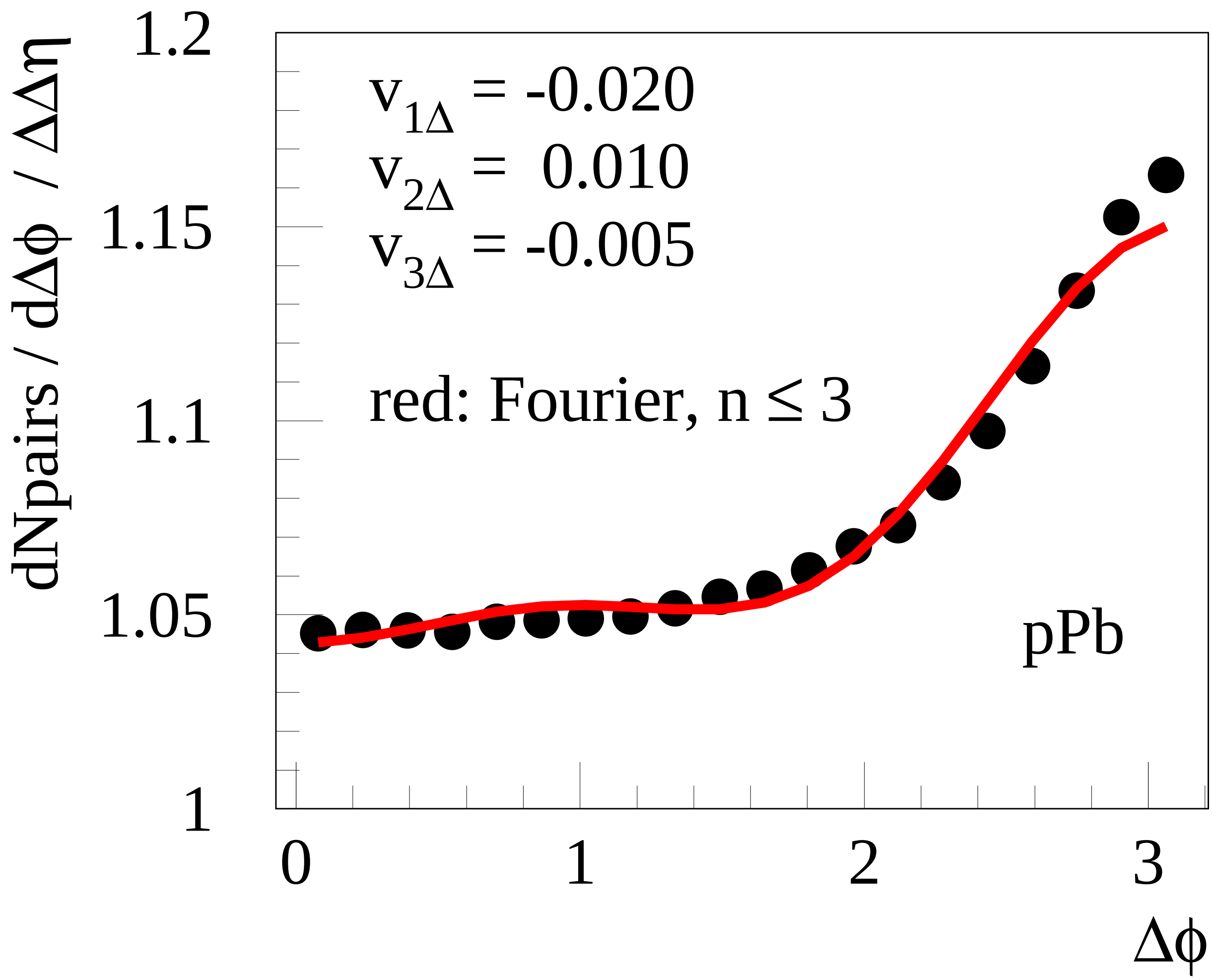
red curve EPOS   points data CMS

v_2 in pPb without hydro



red curve EPOS points data CMS

... better check the correlation function

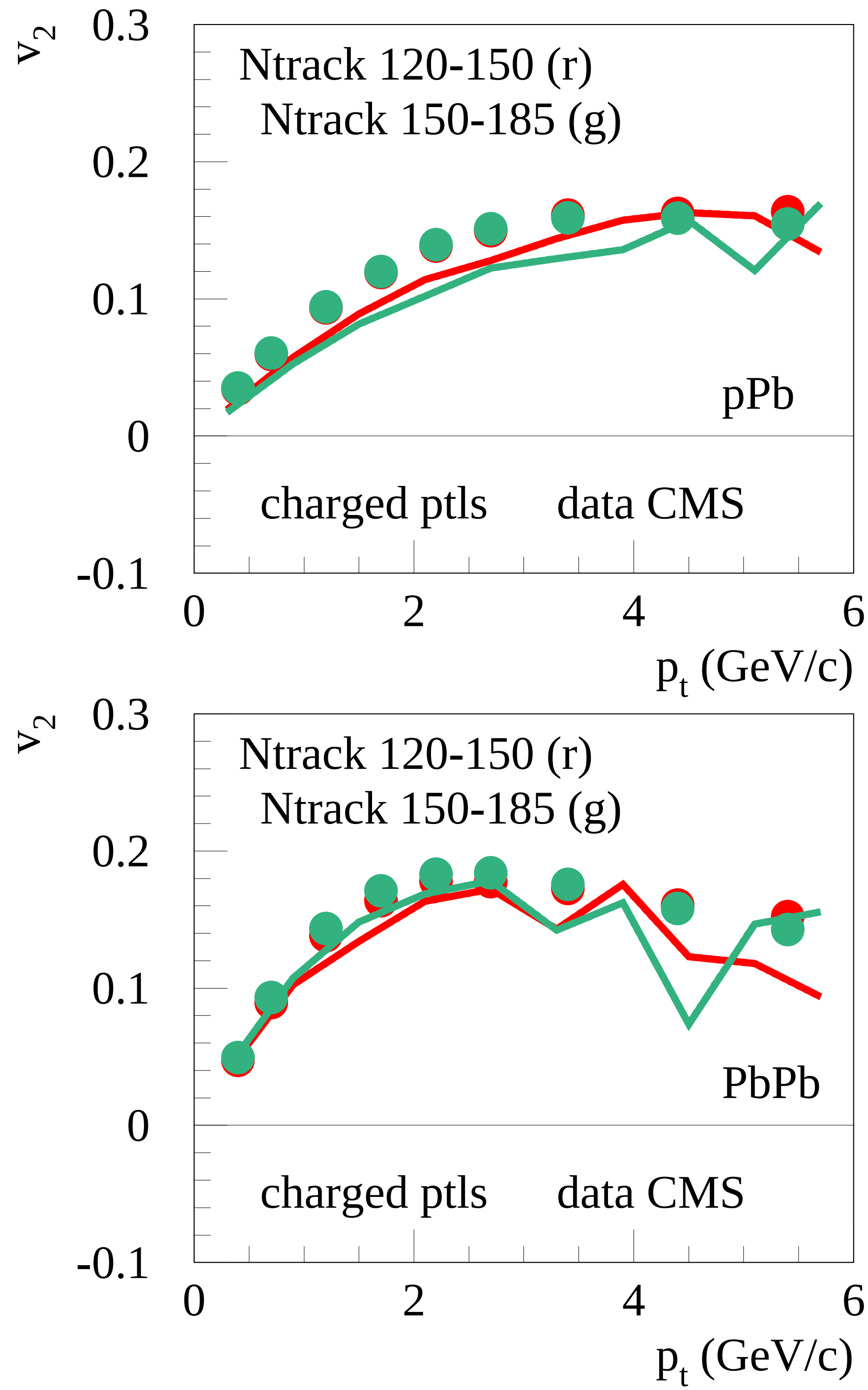


$1 < p_t < 2$ GeV, long-range ($\Delta\eta > 2$)

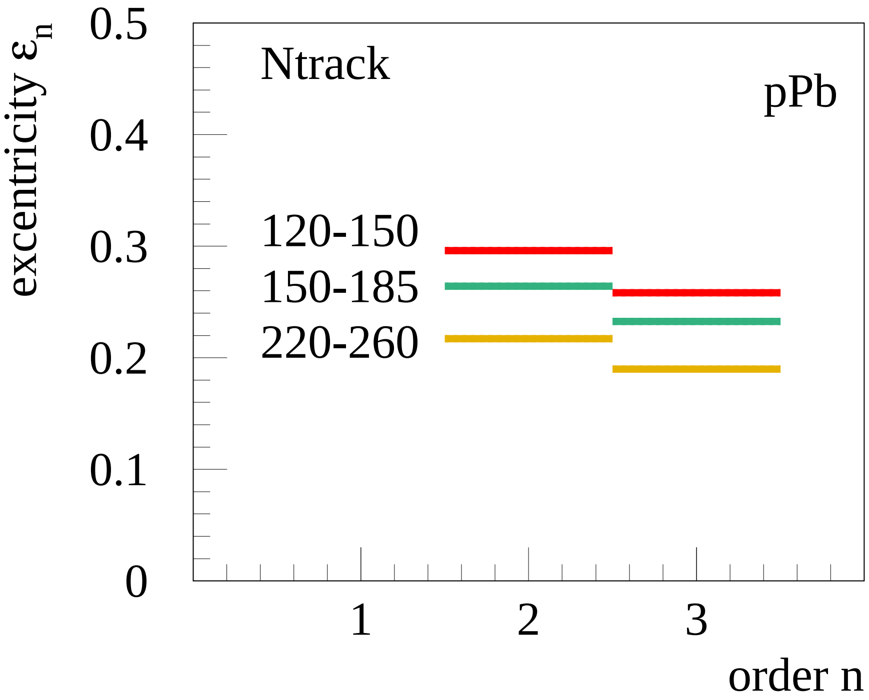
EPOS with hydro

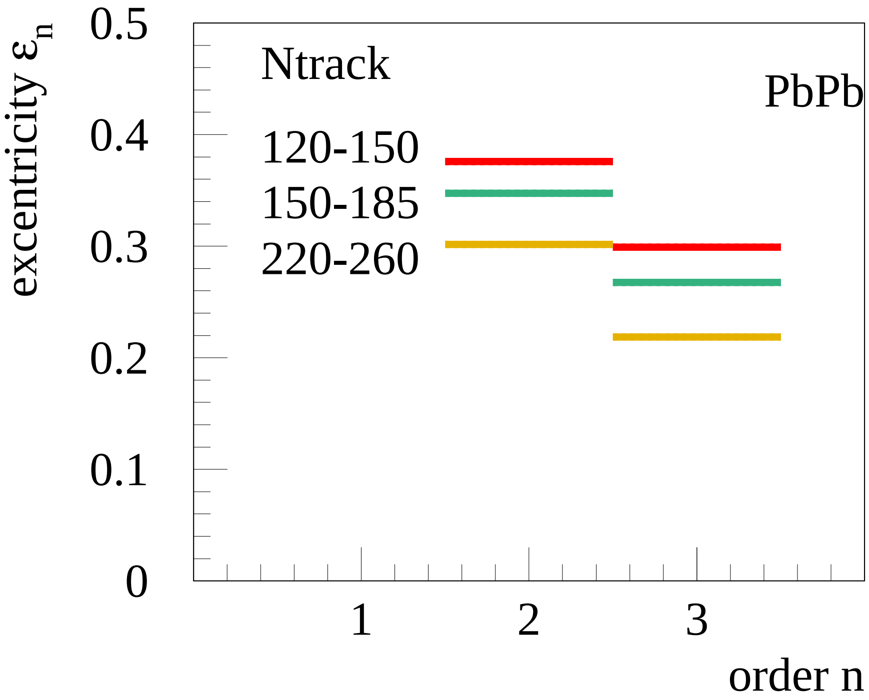
v_2 vs p_t in pPb and PbPb

- Little change with multiplicity
- Large v_2 at large p_t
- **Similar magnitude**
- **Different shape**



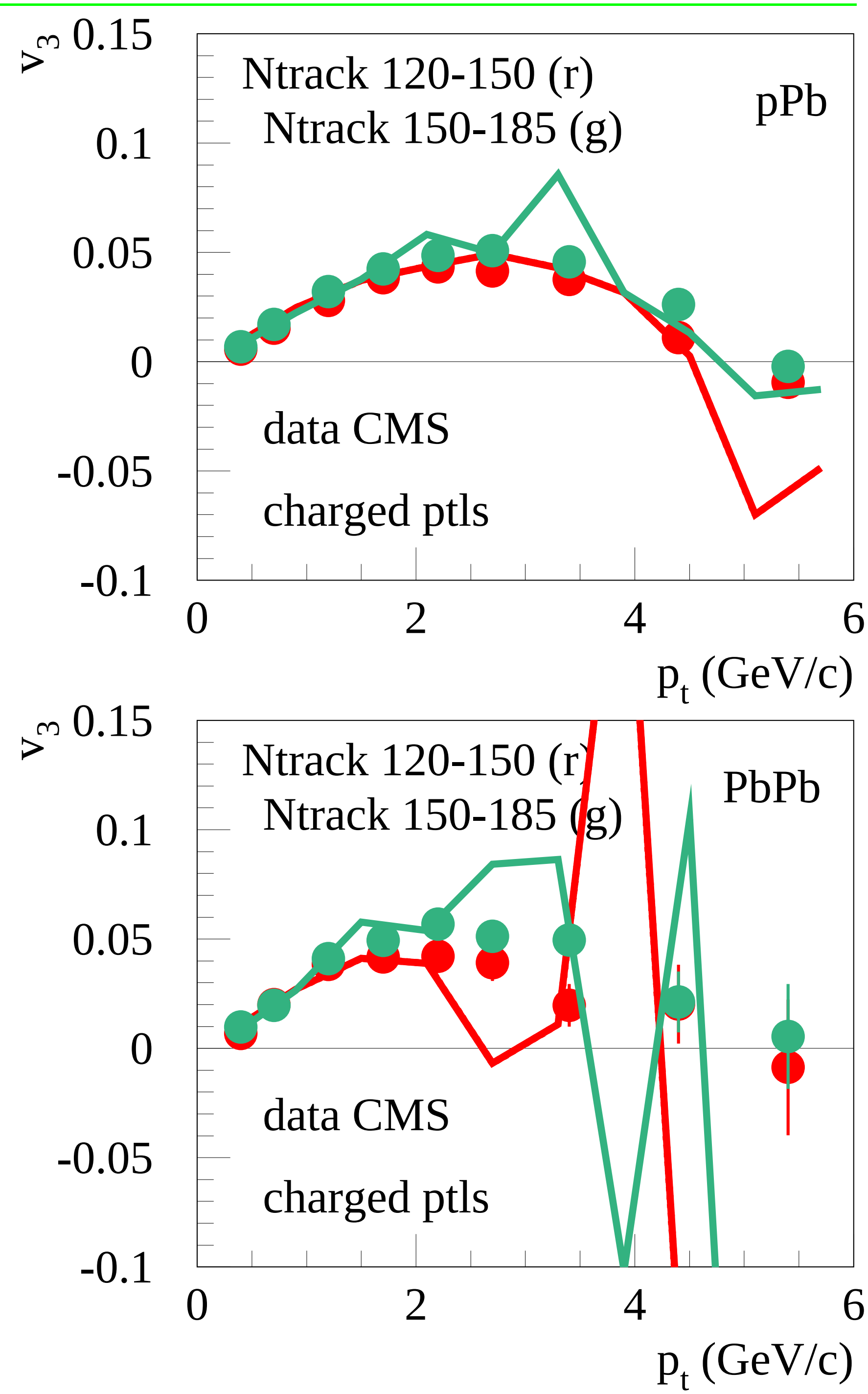
Similar magnitude:
Smaller flow in PbPb
compensated by bigger excentricities



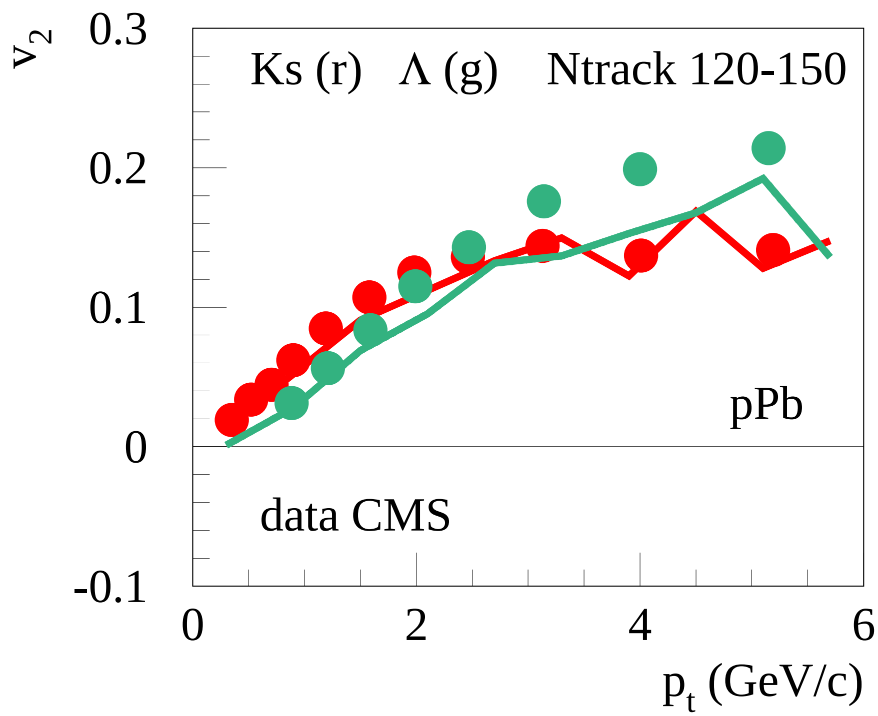


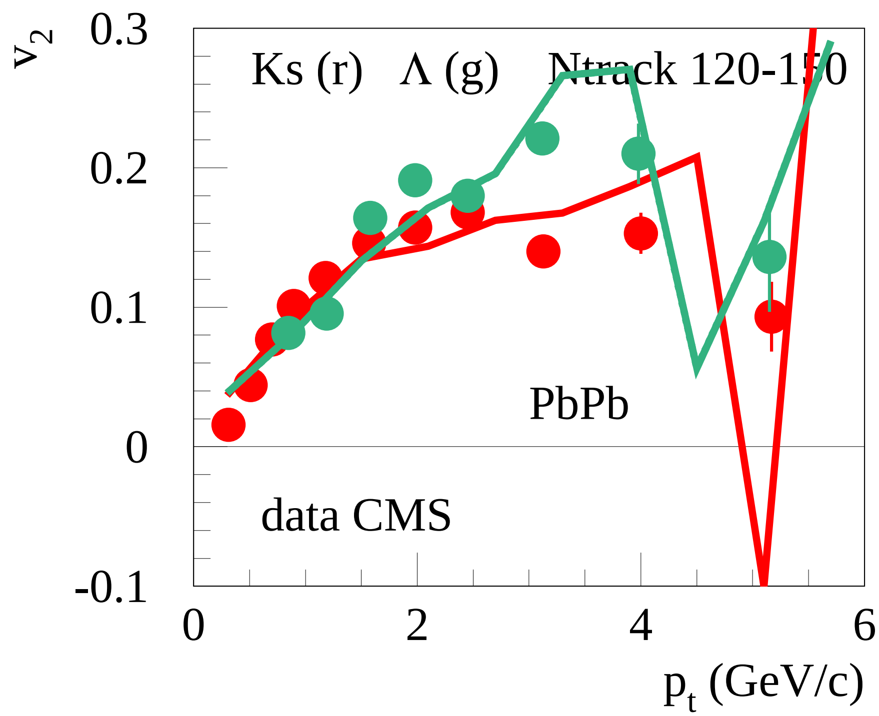
v_3 vs p_t in pPb and PbPb

- Little change with multiplicity
- $v_3 \to 0$ at large p_t
- **Similar magnitude**
- **Similar shape**



Mass splitting





in pPb bigger than in PbPb

Summary

Comparing pPb and PbPb, for the same multiplicities, using EPOS 3.111 (optimized to get pt spectra) :

- ☐ **v2, v3 are quite similar (as in the data)**

- ☐ **Microscopic properties are different:**
  - **more flow in pPb**
  - **bigger excentricities in PbPb**

Plans : Better statistics, pp

Hydro (Yuri Karpenko)

Israel-Stewart formulation, $\eta - \tau$ coordinates, $\eta/S = 0.08$, $\zeta/S = 0$

$$\partial_{;\nu} T^{\mu\nu} = \partial_\nu T^{\mu\nu} + \Gamma^{\mu}_{\nu\lambda} T^{\nu\lambda} + \Gamma^{\nu}_{\nu\lambda} T^{\mu\lambda} = 0$$

$$\gamma\left(\partial_t + v_i \partial_i\right) \pi^{\mu\nu} = -\frac{\pi^{\mu\nu} - \pi^{\mu\nu}_{\mathrm{NS}}}{\tau_\pi} + I^{\mu\nu}_\pi \qquad \gamma\left(\partial_t + v_i \partial_i\right) \Pi = -\frac{\Pi - \Pi_{\mathrm{NS}}}{\tau_\Pi} + I_\Pi$$

- ☐ $T^{\mu\nu} = \epsilon u^\mu u^\nu - (p + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu}$,
- ☐ $\partial_{;\nu}$ denotes a covariant derivative,
- ☐ $\Delta^{\mu\nu} = g^{\mu\nu} - u^\mu u^\nu$ is the projector orthogonal to u^μ,
- ☐ $\pi^{\mu\nu}$, Π shear stress tensor, bulk pressure
- ☐ $\pi^{\mu\nu}_{\mathrm{NS}} = \eta(\Delta^{\mu\lambda}\partial_{;\lambda} u^\nu + \Delta\nu\lambda\partial_{;\lambda} u^\mu) - \frac{2}{3}\eta\Delta^{\mu\nu}\partial_{;\lambda} u^\lambda$
- ☐ $\Pi_{\mathrm{NS}} = -\zeta \partial_{;\lambda} u^\lambda$
- ☐ $I^{\mu\nu}_\pi = -\frac{4}{3}\pi^{\mu\nu}\partial_{;\gamma} u^\gamma - [u^\nu \pi^{\mu\beta} + u^\mu \pi^{\nu\beta}] u^\lambda \partial_{;\lambda} u_\beta$
- ☐ $I_\Pi = -\frac{4}{3}\Pi \partial_{;\gamma} u^\gamma$

Freeze out: at 164 MeV, Cooper-Frye, equilibrium distr

Hadronic afterburner: UrQMD

Marcus Bleicher

Jan Steinheimer : implementing new update (Ω)