EPOS: A unified description of pp, pA, AA collisions

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EPOS3

Motivated by recent interesting and unexpected pPb (and pp) results at the LHC

(Ridges, v2, v3 etc) **:**

Apply unified approach (same formalism: pp,pA,AA)

- **to understand similarities and differences**

in pA (pp) and AA

(spectra and correlations)

at the moment: pPb

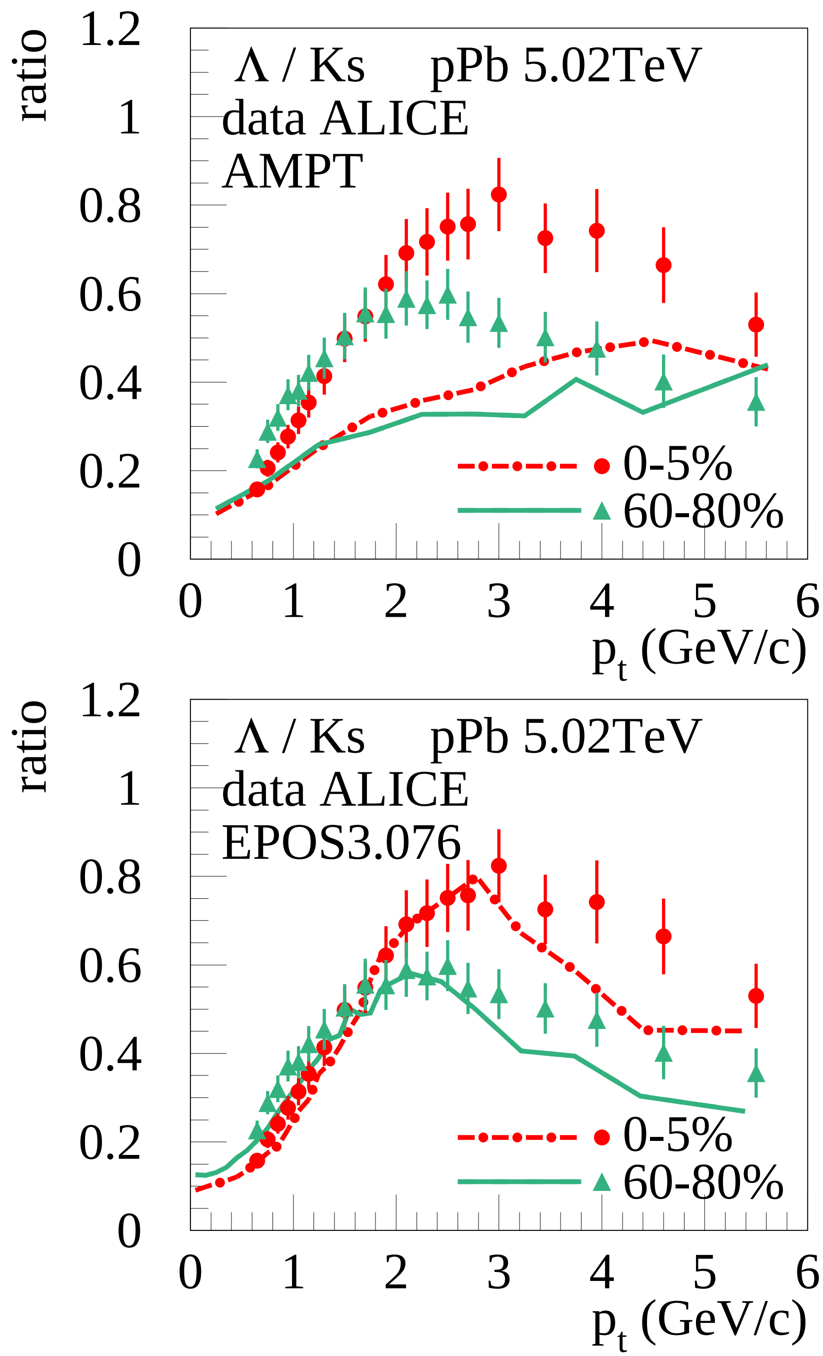
Published EPOS pPb results

Spectra or ratios

(π, K, p, Λ ...)

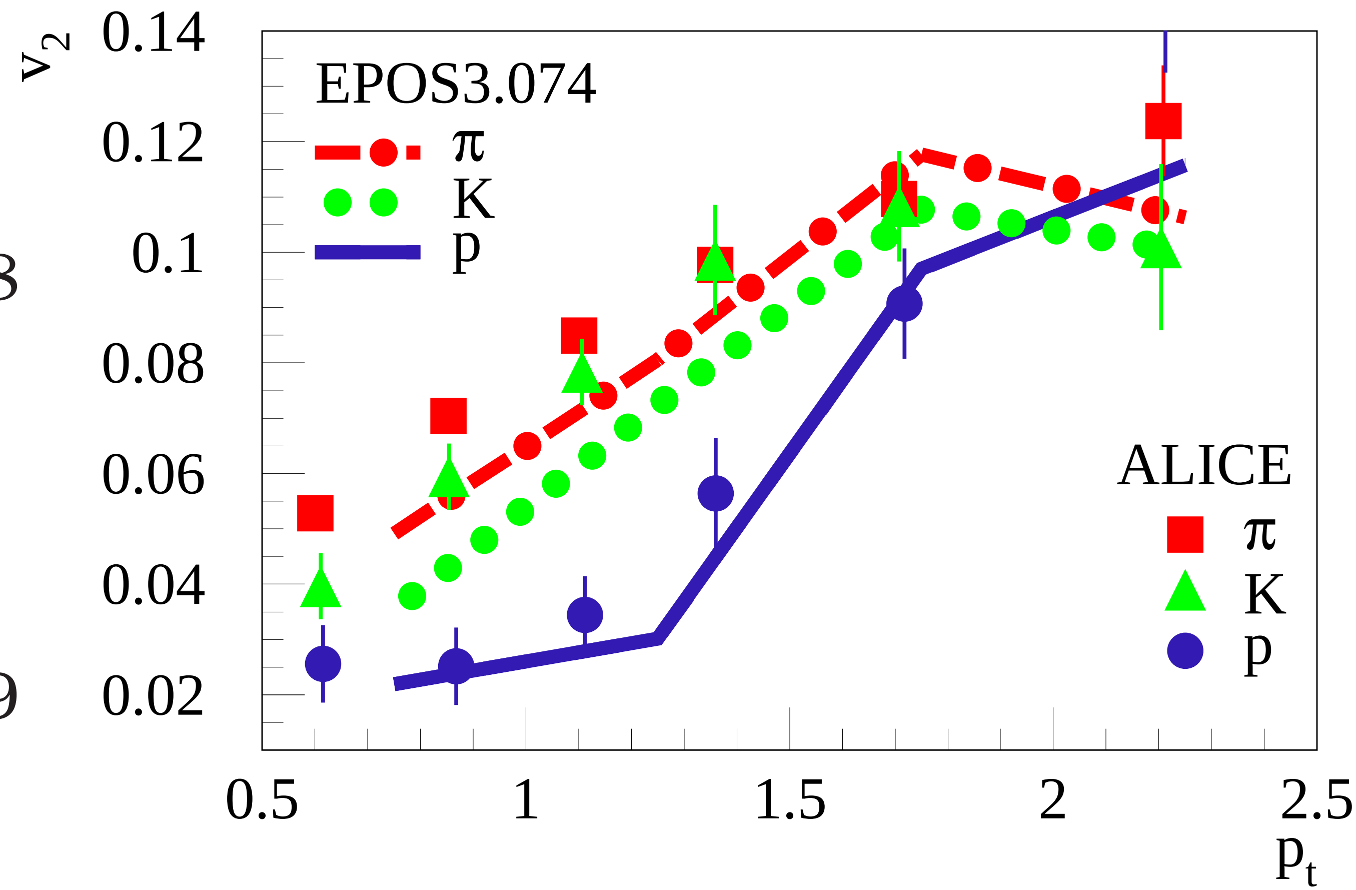
- ☐ QM2014 proceedings arXiv:1411.1048
- ☐ PRC89 (2014) 064903 arXiv:1312.1233

compared to **data** and **other models**



Dihadron correlations **v2 mass splitting**

- ☐ QM2014 proceedings arXiv:1411.1048
- ☐ PRL 112 (2014) 232301 arXiv:1307.4379

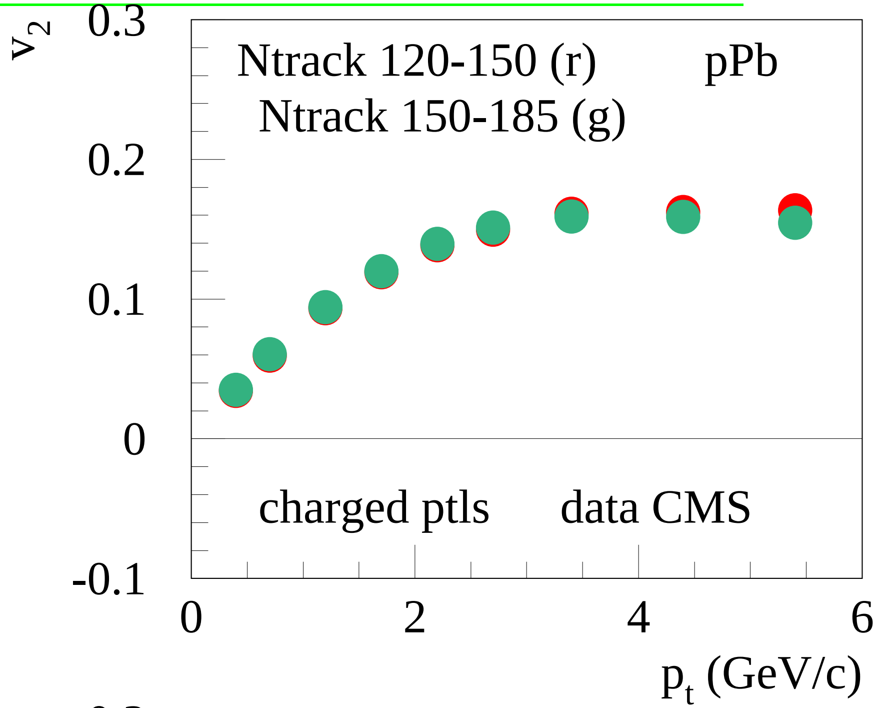


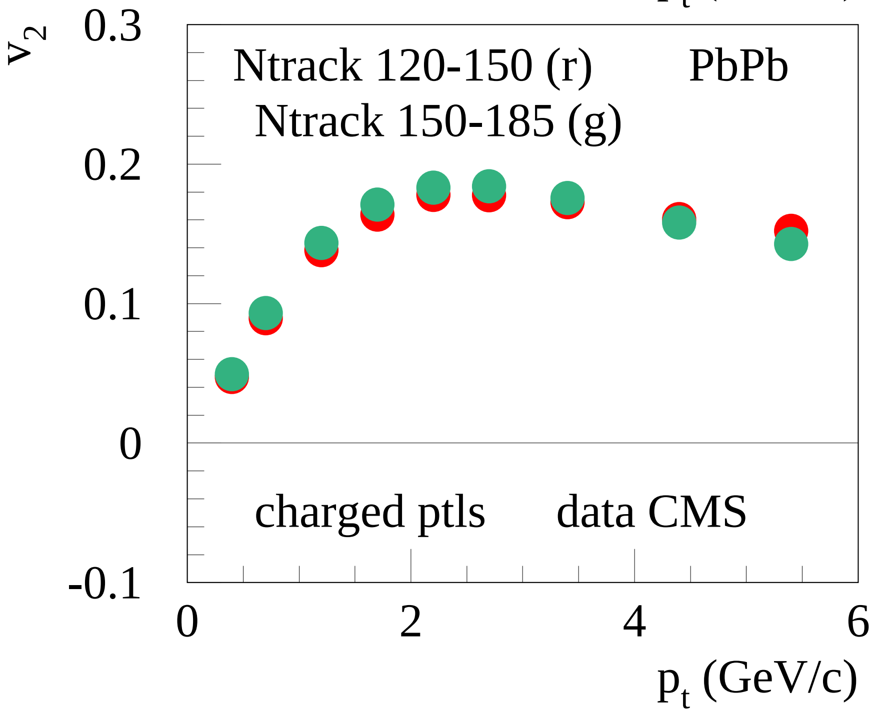
Low multiplicity subtracted

Other challenges: Centrality dependence of v_2

v_2 vs p_t in pPb and PbPb

- pPb : Little change beyond Ntrack = 120 (up to 260)
- PbPb, little change in this range
- Large v_2 at large p_t in both pPb and PbPb

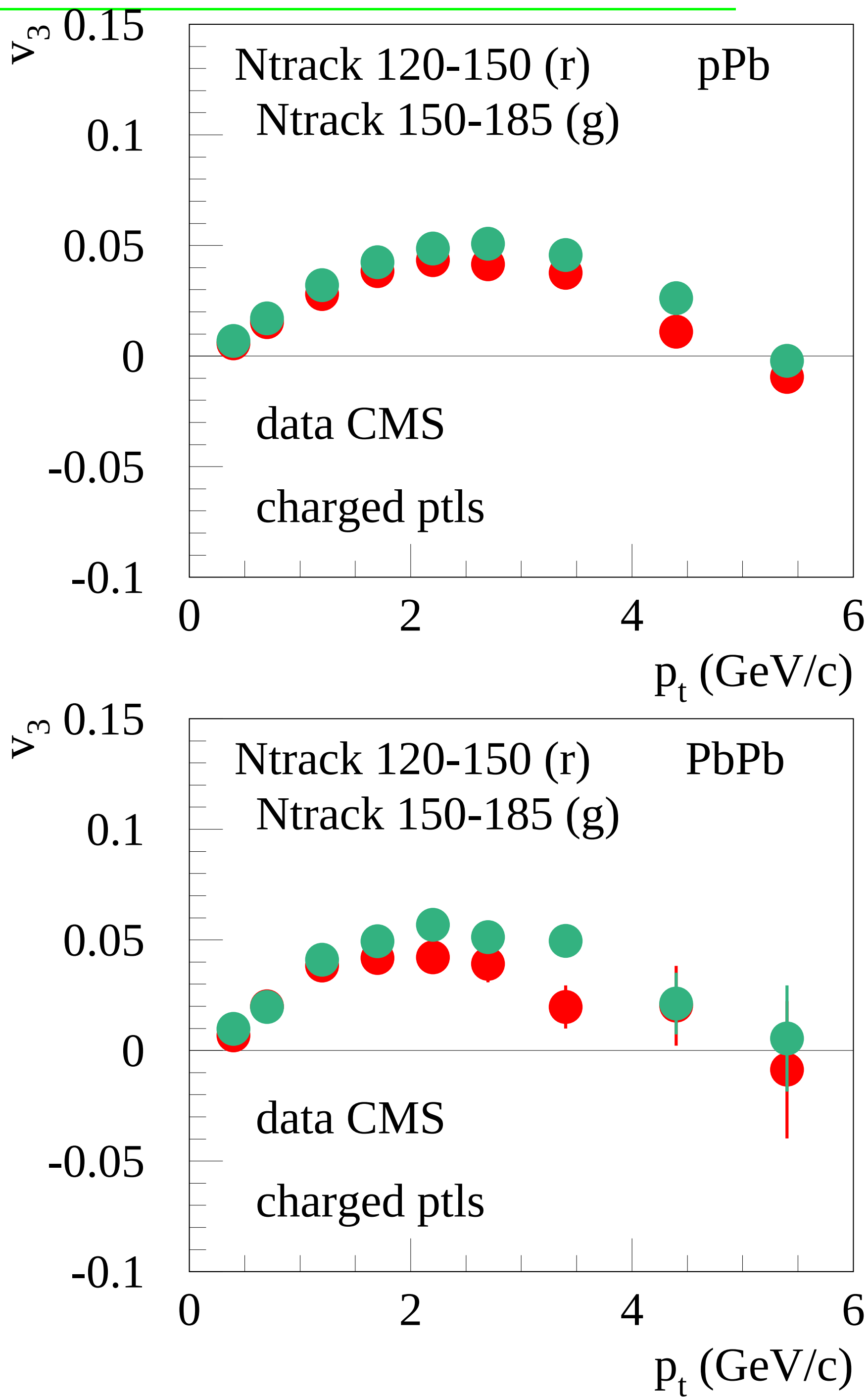




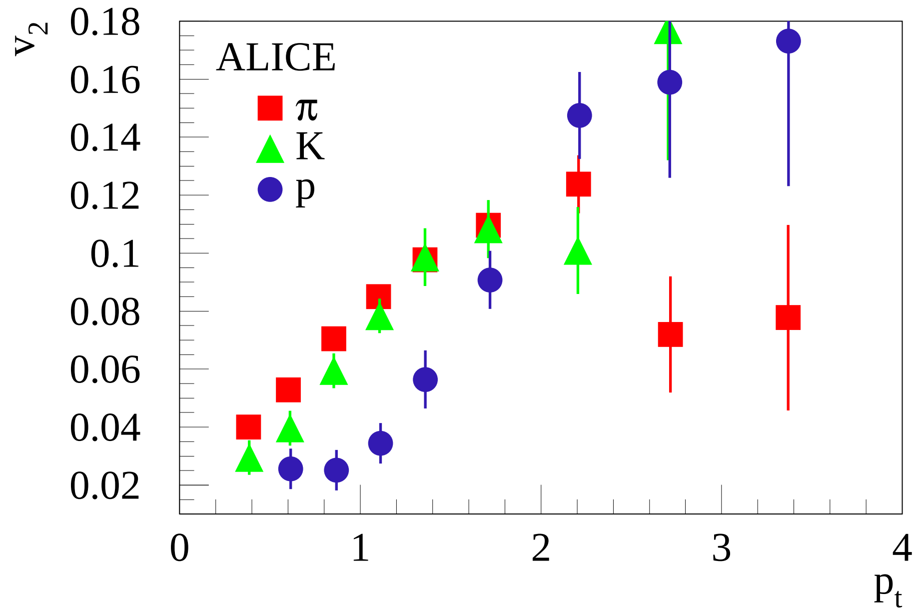
Centrality dependence of v_3

v_3 vs p_t in pPb and PbPb

- pPb and PbPb: Increase with Ntrack
- v_2 small at large p_t in both pPb and PbPb

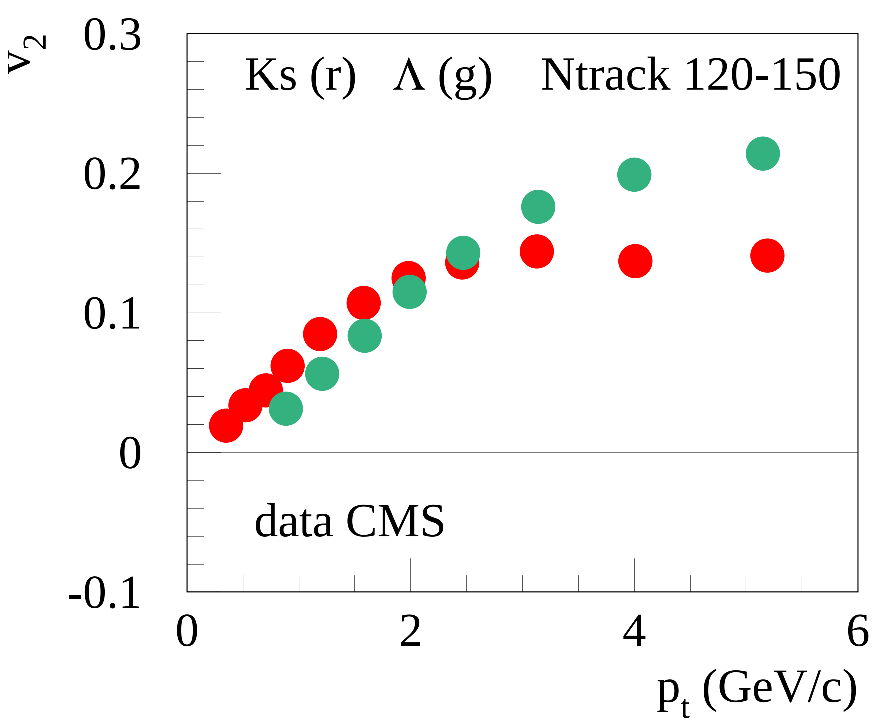


Mass splitting



v_2 vs p_t for identified particles

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



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

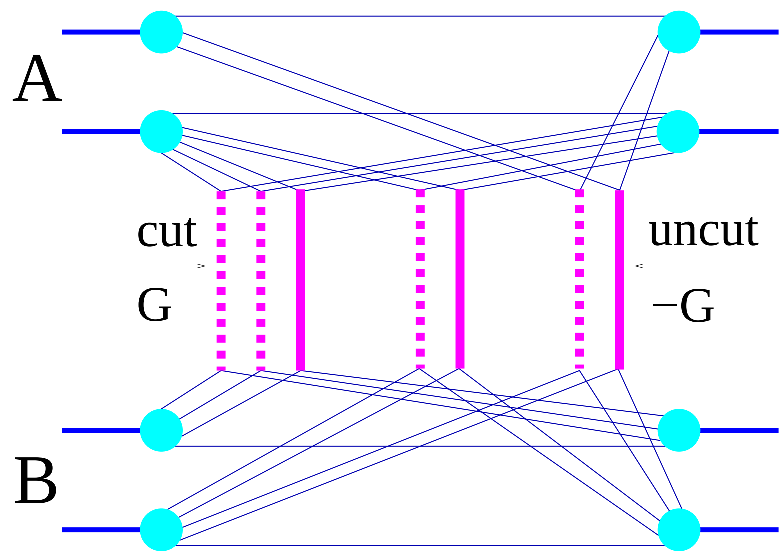
Realization: EPOS3, arXiv:1312.1233 , arXix:1307.4379,
B. Guiot, Y. Karpenko, T. Pierog, M. Bleicher, K. W.

Initial conditions: Marriage pQCD+GRT+energy sharing

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

For pp, pA, AA:

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



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

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

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

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

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

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

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

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

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

Remark 1

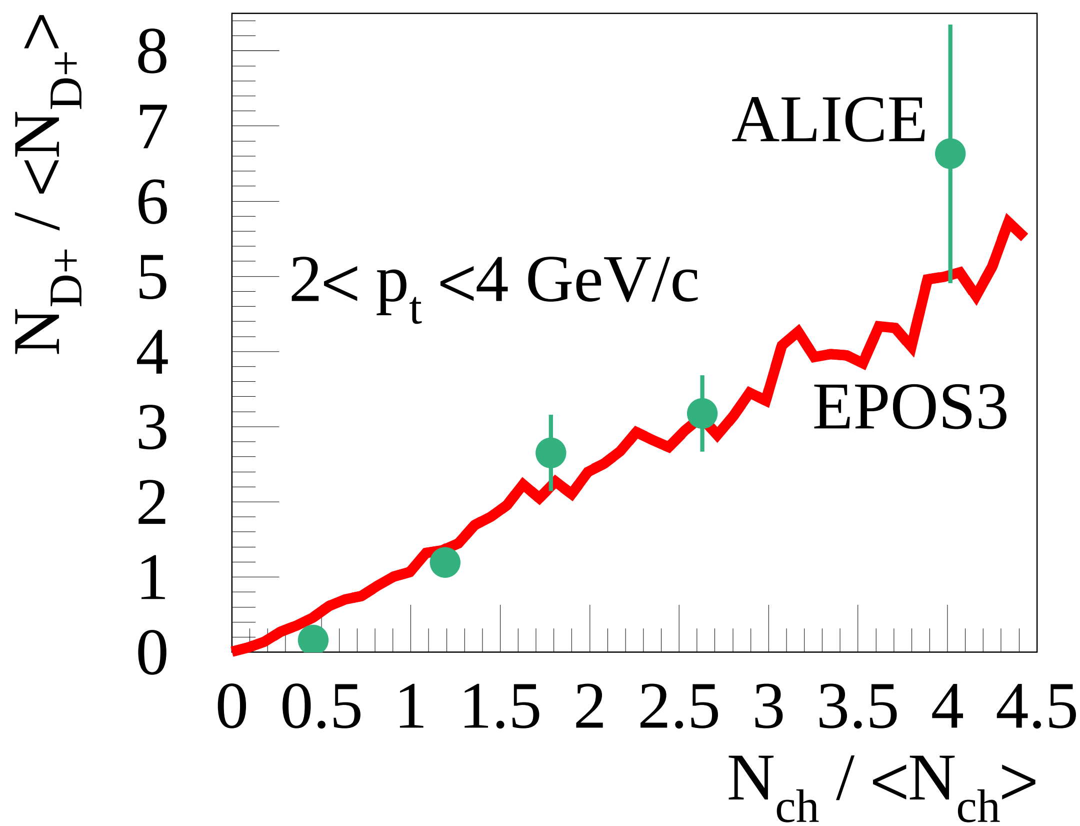
GR multiple scattering gives (automatically)

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

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

Example: D^+ mesons

Plot from B. Guiot



Remark 2

Frequently asked question:

Do we see hydro or CGC in pA?

Obvious answer:

Both !!

Without hydro :

impossible to fit the p_t spectra, get v_2 mass splitting ...

Without saturation:

σ_{tot}^{pp} and $dn/d\eta(0)$ will explode at high energy, ...

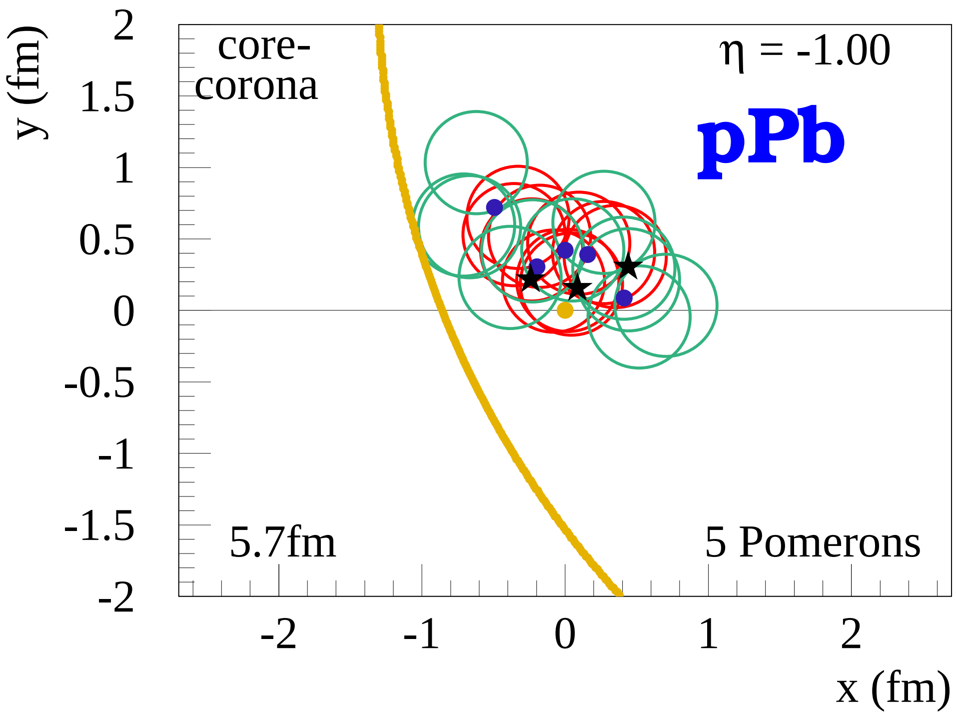
Correct question:

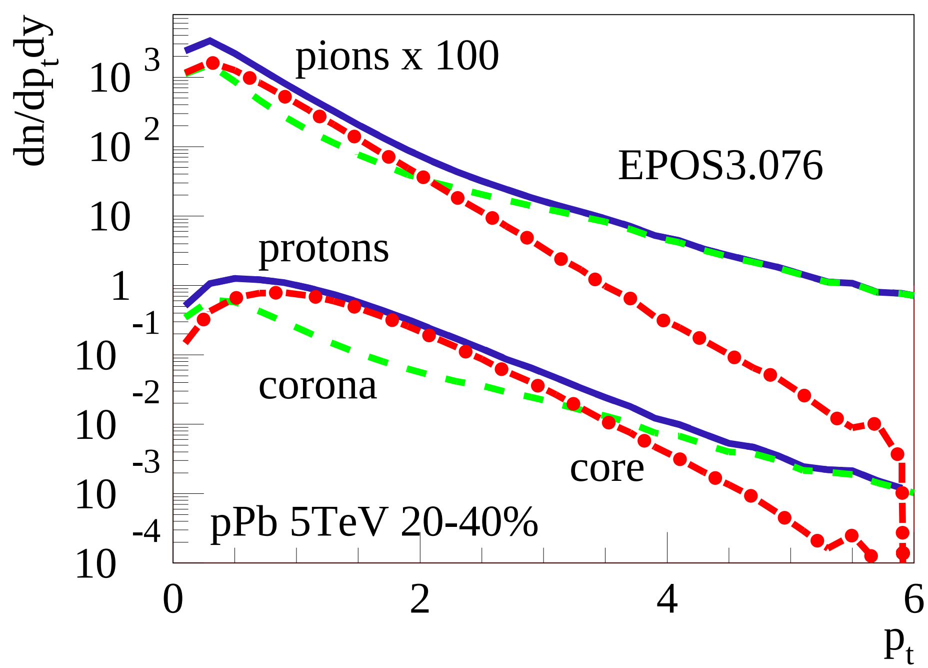
How to implement flow and saturation properly?

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





Hydro (Yuri Karpenko)

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

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

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

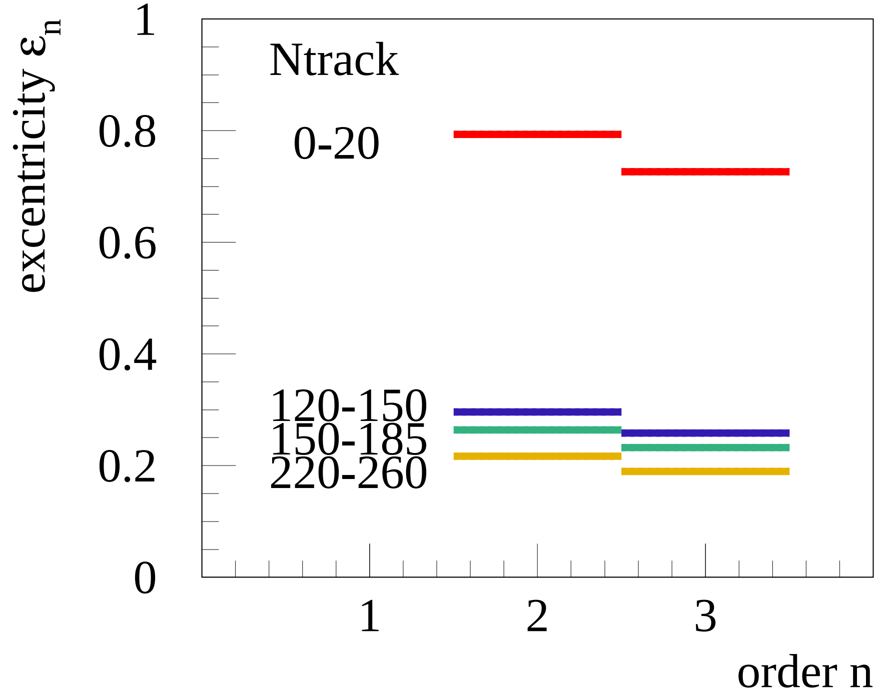
- $T^{\mu\nu} = \epsilon u^\mu u^\nu - (p + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu}$,
- $\partial_{;\nu}$ denotes a covariant derivative,
- $\Delta^{\mu\nu} = g^{\mu\nu} - u^\mu u^\nu$ is the projector orthogonal to u^μ,
- $\pi^{\mu\nu}$, Π shear stress tensor, bulk pressure
- $\pi^{\mu\nu}_{\mathrm{NS}}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

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

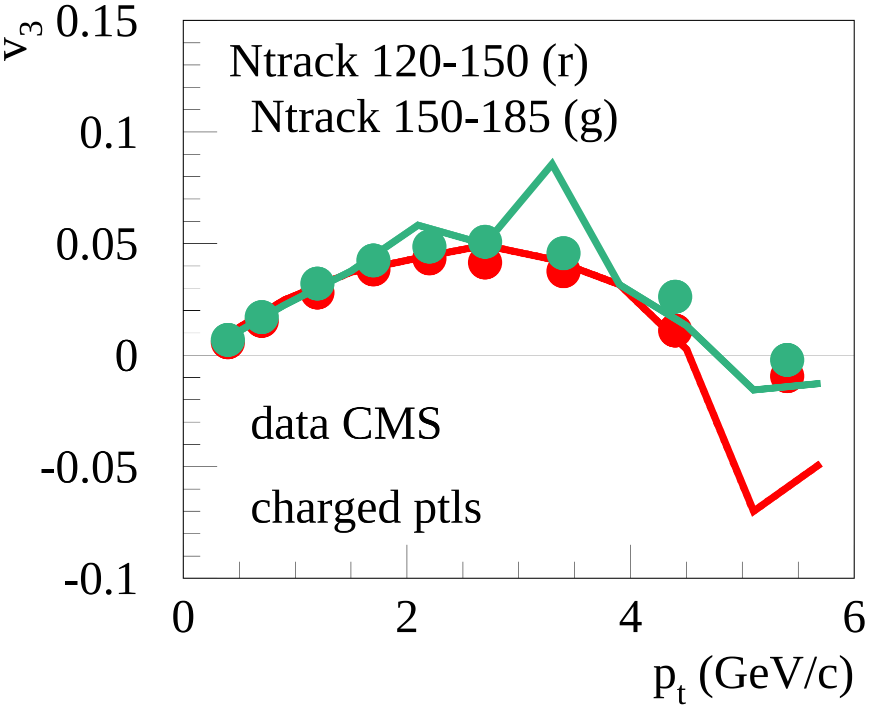
Hadronic afterburner: UrQMD

Marcus Bleicher
Jan Steinheimer : implementing new update (Ω)

Back to centrality dependence of v_n (pPb)

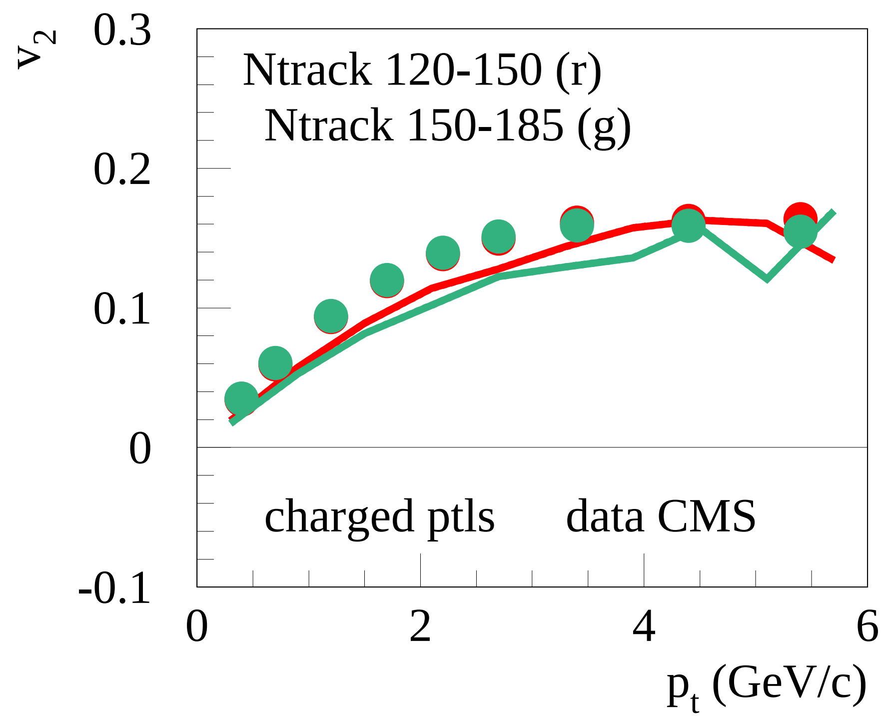


v_3 vs p_t in EPOS:



- Excentricities decrease with Ntrack
- But v_3 increases (compensated by flow) results extremely stable

Centrality dependence of v_2 vs p_t (pPb)



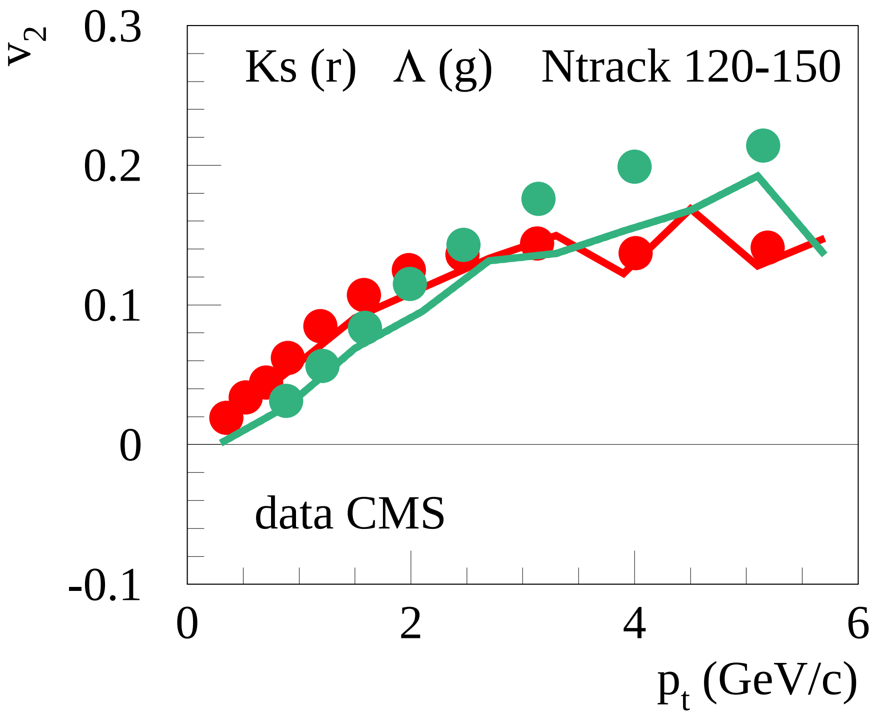
EPOS:

- ☐ Large v_2 at high p_t (jets)
- ☐ v_2 decreases slightly !!
- ☐ too low

Mass splitting (pPb)

EPOS:

- ☐ Magnitude correct
- ☐ But as for charged ptls: too low



Summary

Unified approach (pp,pA,AA) based on

- ☐ **Gribov-Regge** (Pomeron = parton ladder, energy sharing, saturation)
- ☐ **Core-corona** (separate bulk / jets)
- ☐ **Hydro, flow**

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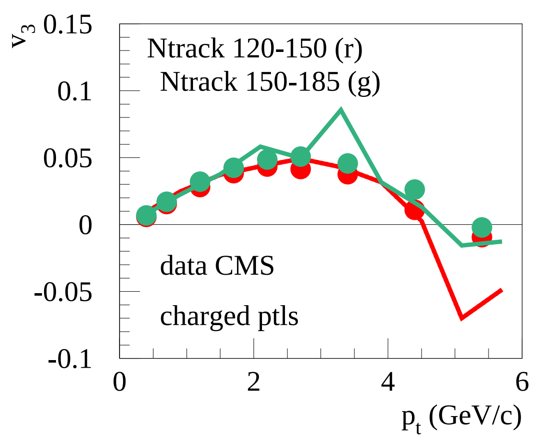
- **Hydro, flow**

Works too well to be an accident



Not good enough to be done