Strange particle production in Monte Carlo generators

in pp and pPb collisions at the LHC

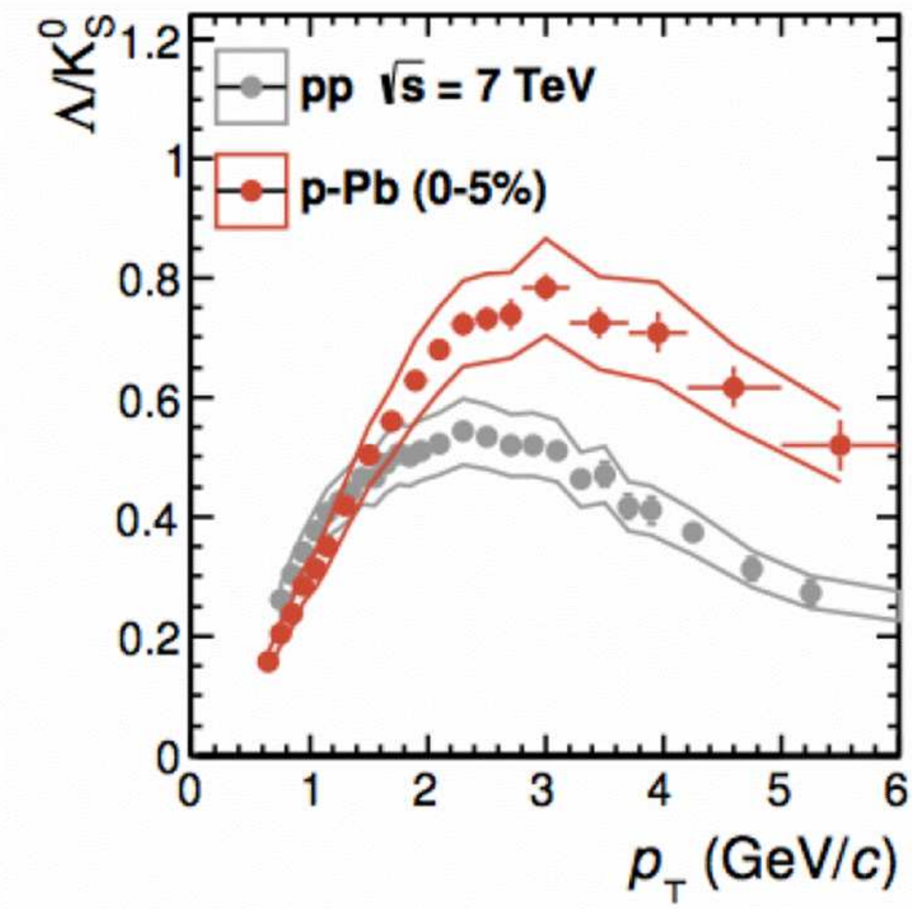
pp: many simulation results from various generators

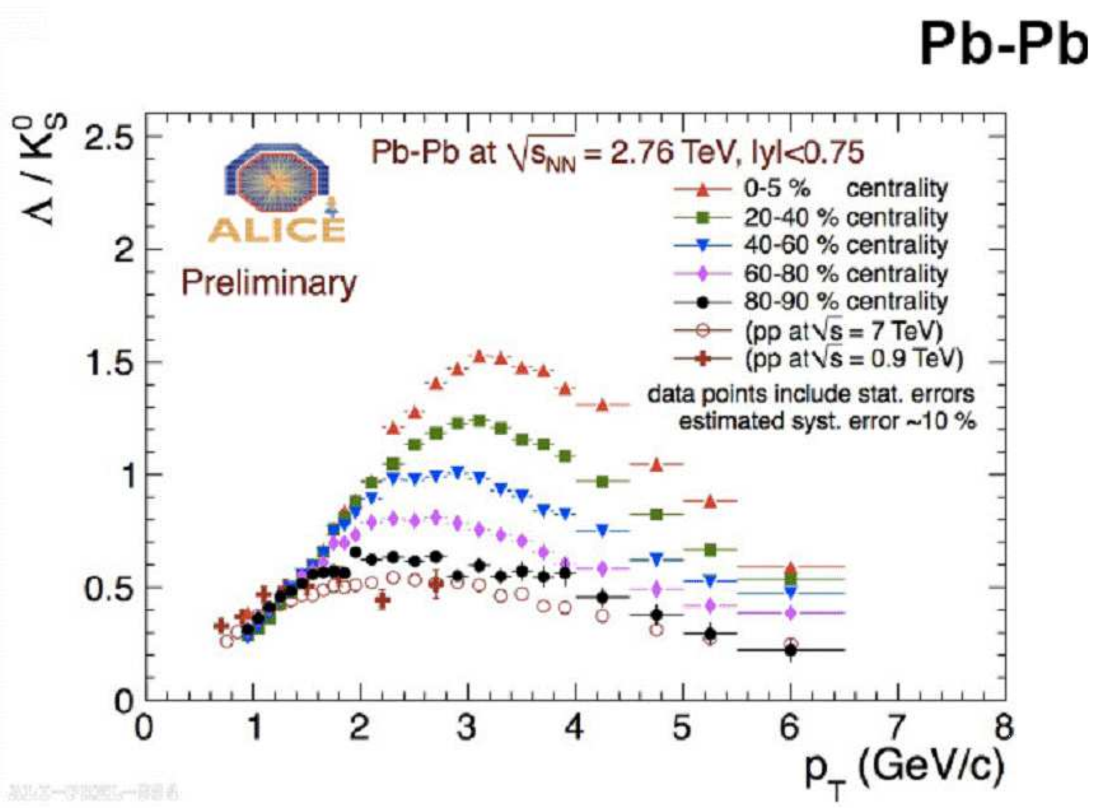
pPb: much less simulated so far,

**amazing experimental results,
only very recently also
on identified particles**

pPb at 5TeV

From R. Preghenella, ALICE, talk Trento workshop 2013



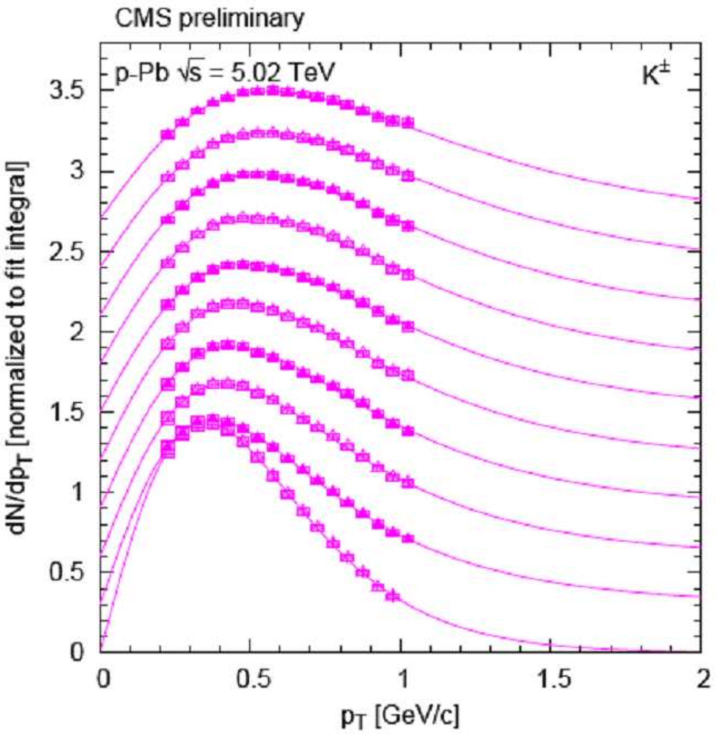


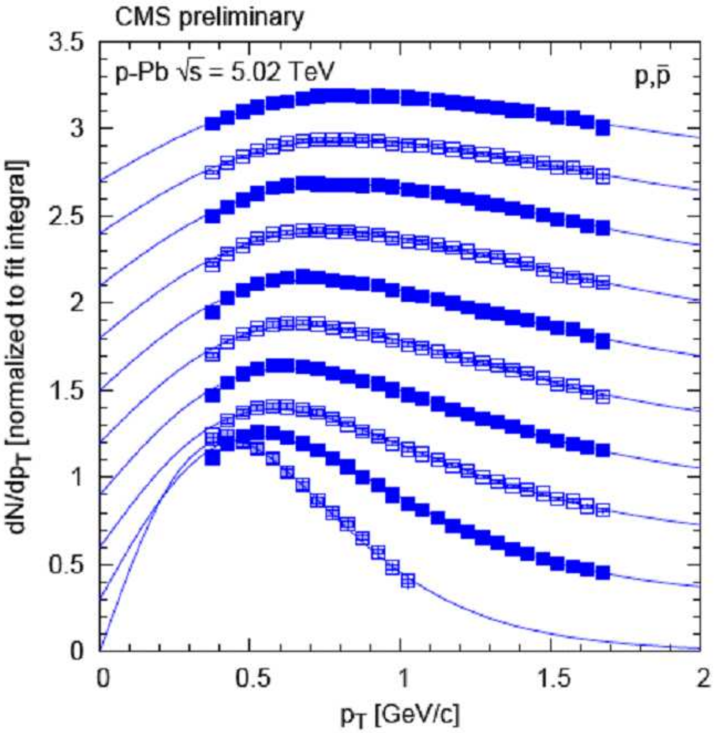
Lambda/Kshort: similar behavior as in PbPb

=> flow?

pPb at 5TeV

CMS, arXiv:1307.3442

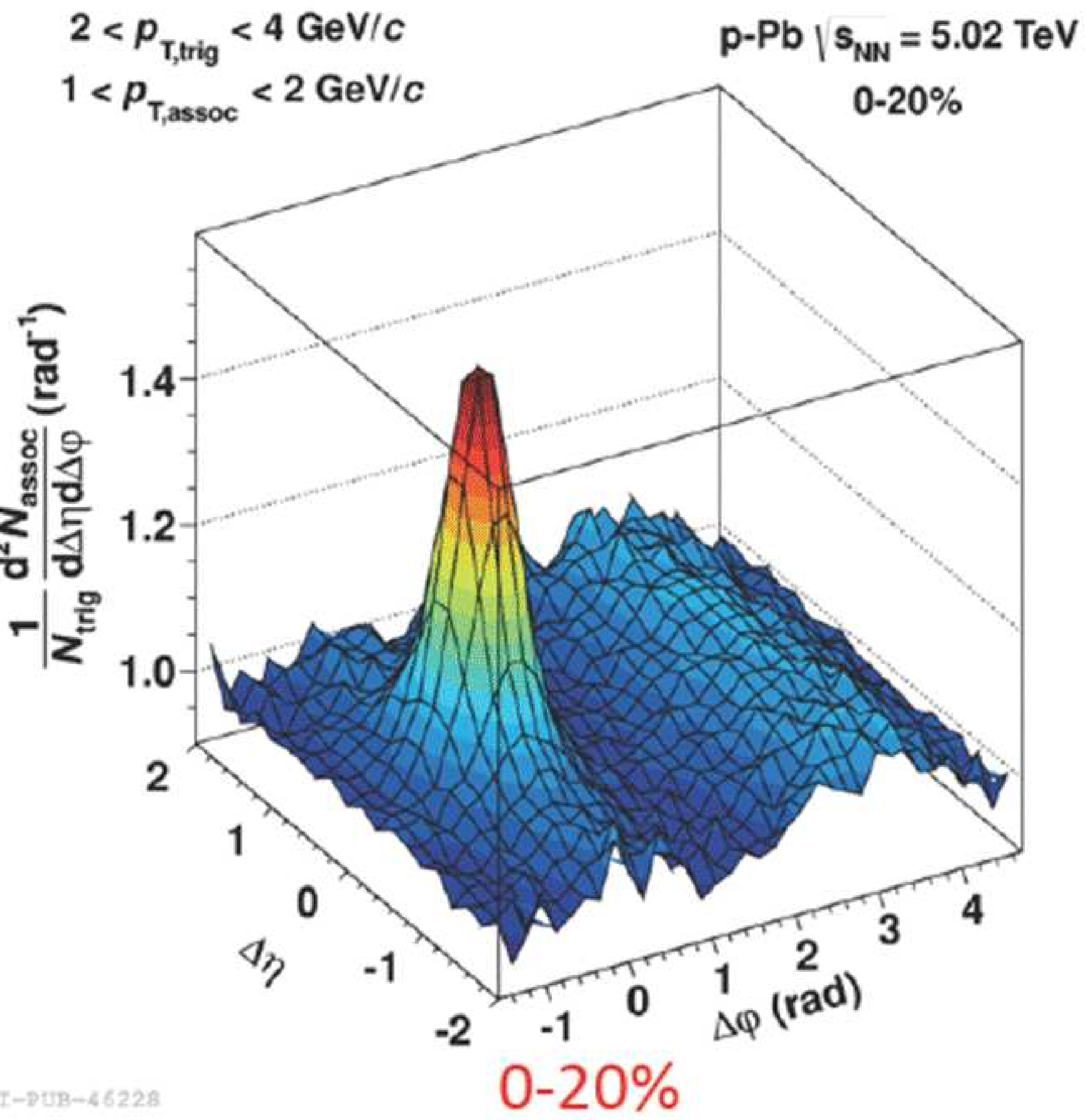




Strong variation of shape with multiplicity

for kaon and even more for proton pt spectra

(flow like)



pPb at 5TeV

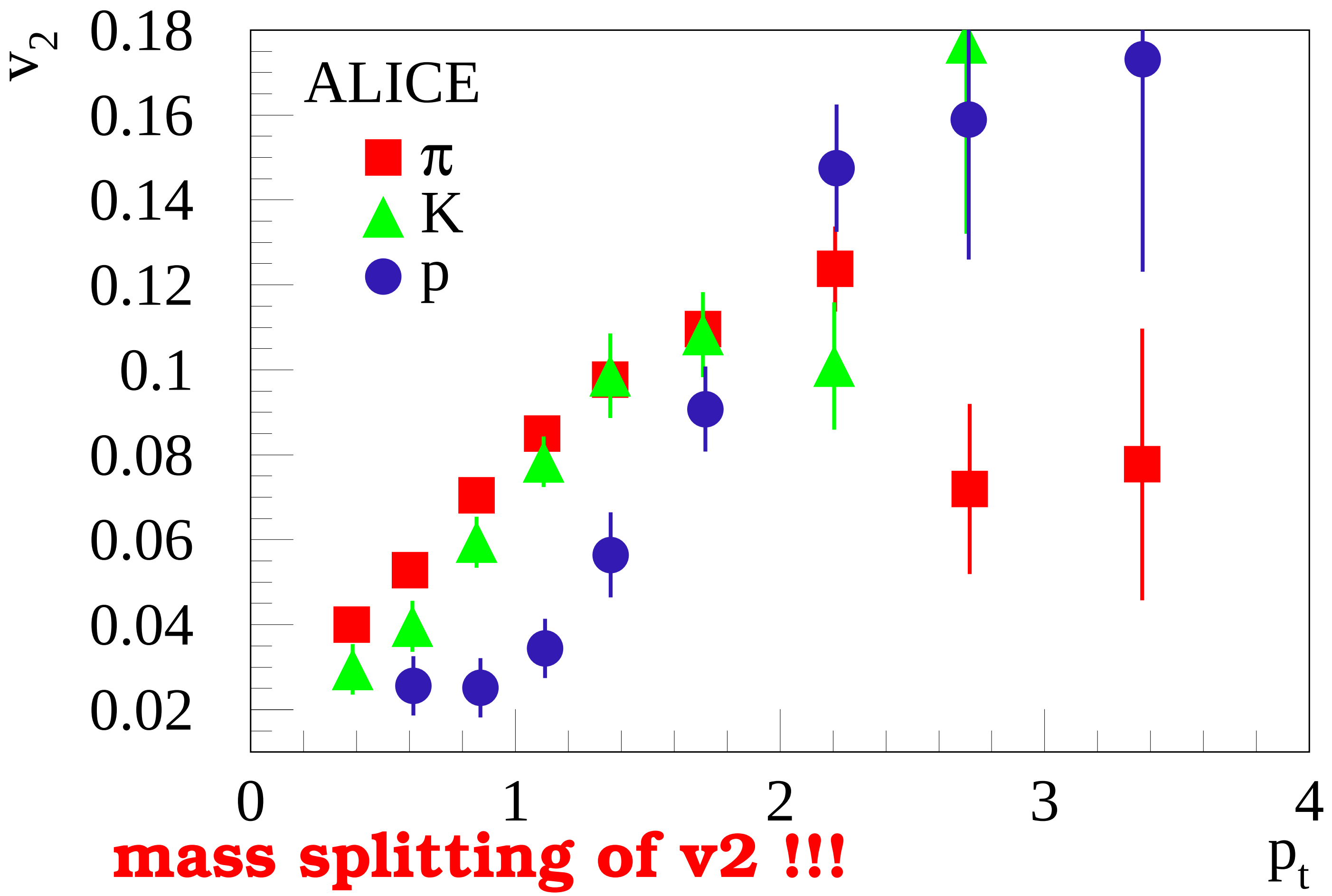
ALICE, Phys.Lett. B719 (2013) 29, arXiv:1212.2001

ridge
& significant v2

as in in PbPb ...

pPb at 5TeV

ALICE, arXiv:1307.3237



mass splitting of v2 !!!

one of the highlights in heavy ion collisions ...

pPb TeV looks very interesting!

But even in pp some of these “flow features” have been observed...

=> closer look at pp first, then pPb.

What do the MC’s predict, concerning identified (strange) particle production?

Models based on factorization

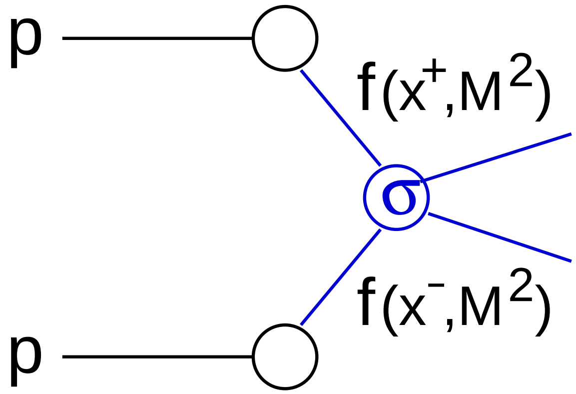
Pythia6
Pythia8
Herwig++
Sherpa

Phys.Rept. 504 (2011) 145-233

see also mcplots.cern.ch/

Starting point:
Factorization formula
+ ISR + FSR

$\sigma_{\text{inclusive}}$:



Multiple scattering
in a second step

Models based on Gribov Regge Theory

Epos3, Epos LHC
Qgsjet, Sybill, Phojet

EPOS3: K. Werner et al., arXiv:1307.4379
EPOS LHC: T. Pierog et al, arXiv:1306.5413
QGSJET: S. Ostapchenko, Phys. Rev. D74 (2006) 014026
SYBILL: E.-J. Ahn et al, Phys. Rev. D 80 (2009) 094003
PHOJET: R. Engel and J. Ranft, Phys. Rev. D54 (1996) 4244
Simulations of SYBILL, QGSJET, EPOS LHC by T. Pierog

Starting point:
Gribov Regge
multiple scattering

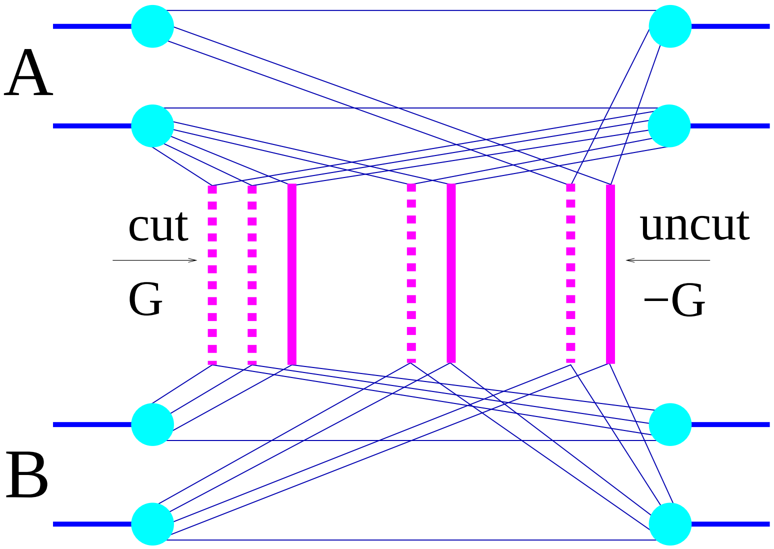
pQCD added

Treats exclusive
and
inclusive quantities

EPOS: Marriage pQCD+GRT+energy sharing

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

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



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

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

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

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

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

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

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

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

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

Other models

AMPT

Z.-W. Lin, C. M. Ko, B.-A. Li, B. Zhang and S. Pal, Phys. Rev. C 72, 064901 (2005).
J. L. Albacete, N. Armesto, R. Baier, et al., Int. J. Mod. Phys. E 22, 1330007 (2013).
Simulations provided by Ziwei Lin

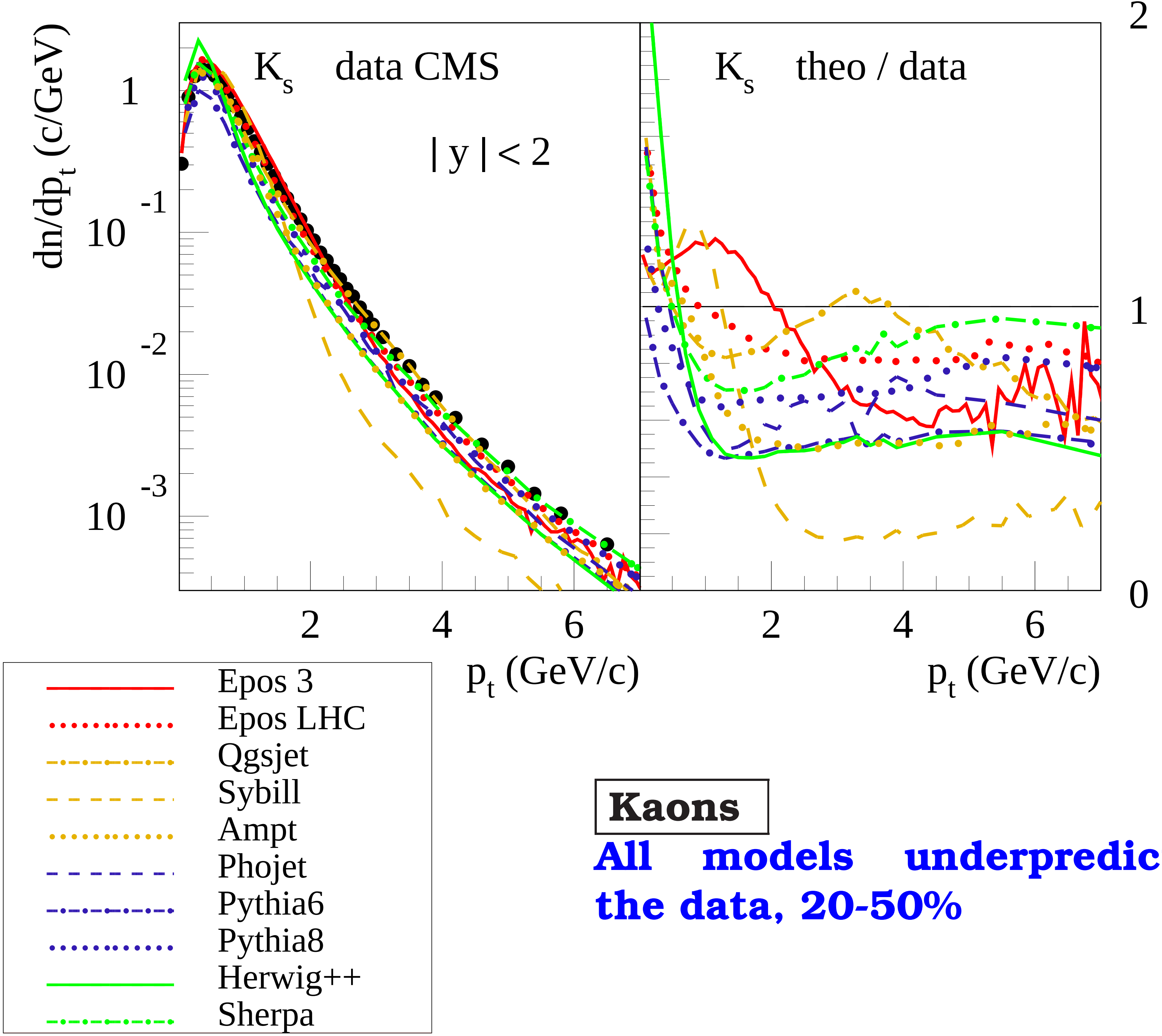
Model not optimized for LHC

Initial condition:
minijets from HIJING 1.0

Minijet partons rescatter in the partonic stage

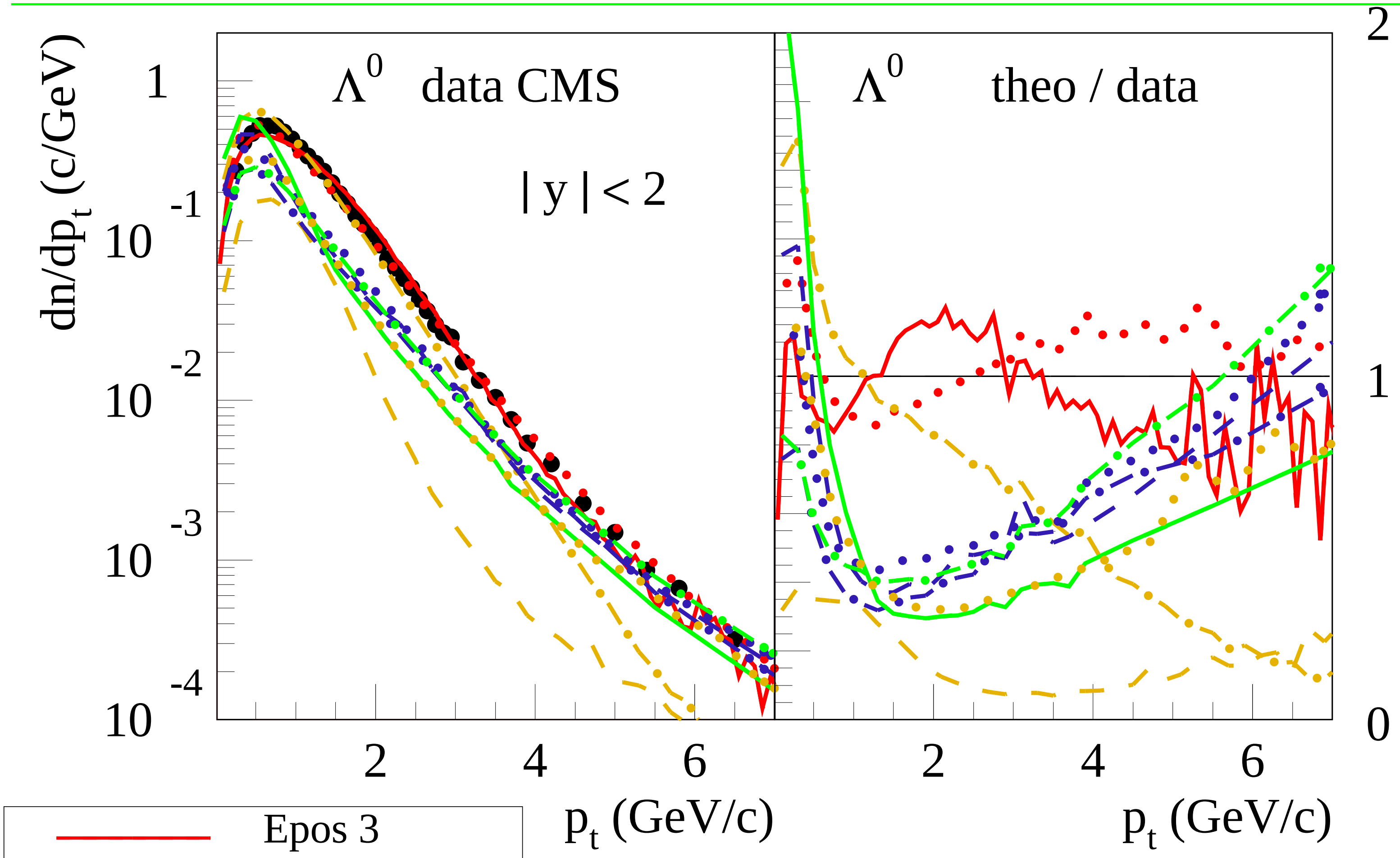
Hadonization via Lund string fragmentation

Final state hadronic cascade



Kaons

All models underpredict the data, 20-50%

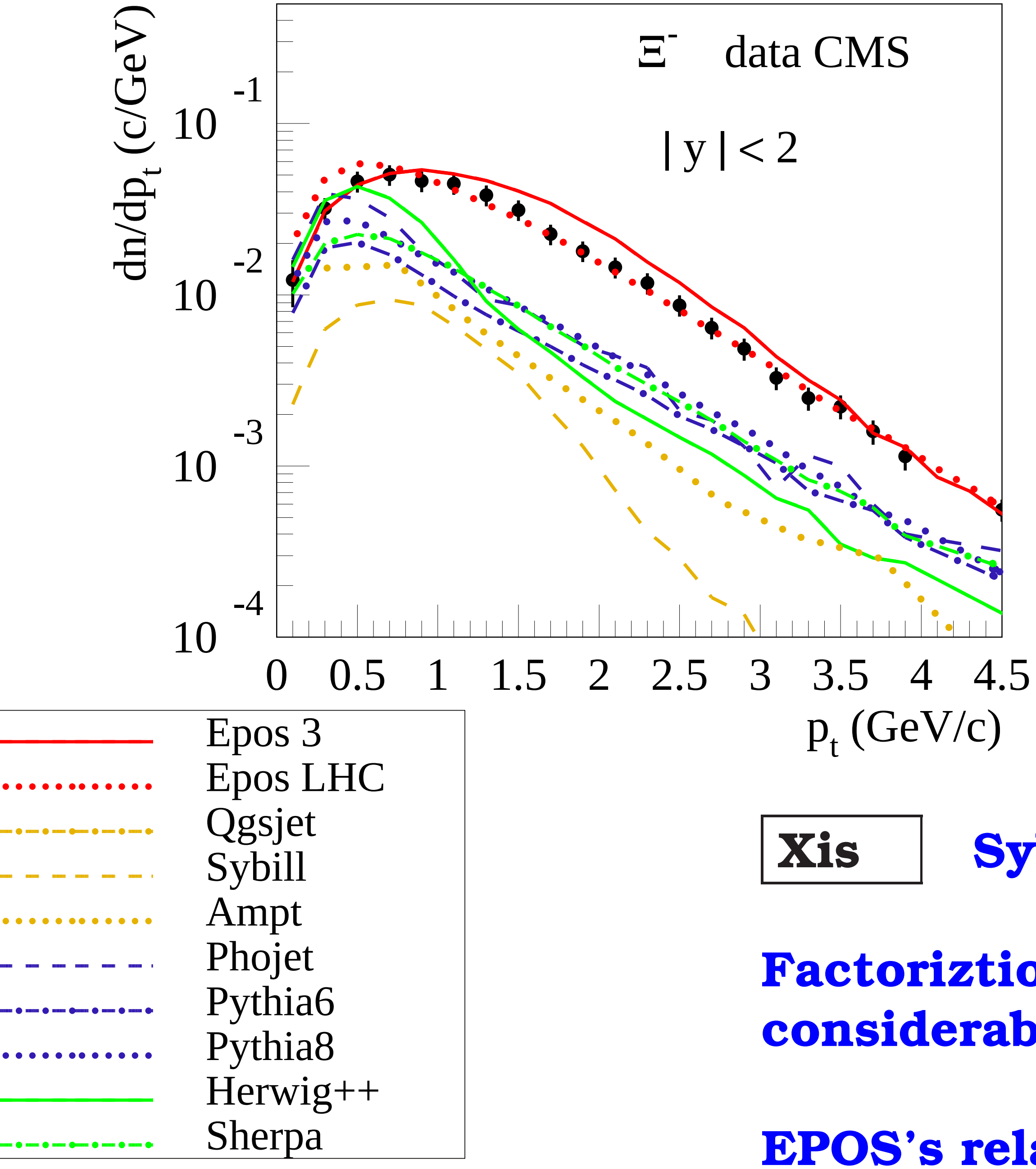


Lambdas

Sybill, Qgsjet drop out

Factoriztion models: profound “hole”

EPOS’s ~20%



Xis

Sybill, Qgsjet (no Xis)**drop out**

Factoriztion models:
considerably below the data

EPOS's relatively close

EPOS3 and EPOS LHC:
collective flow, statistical hadronization

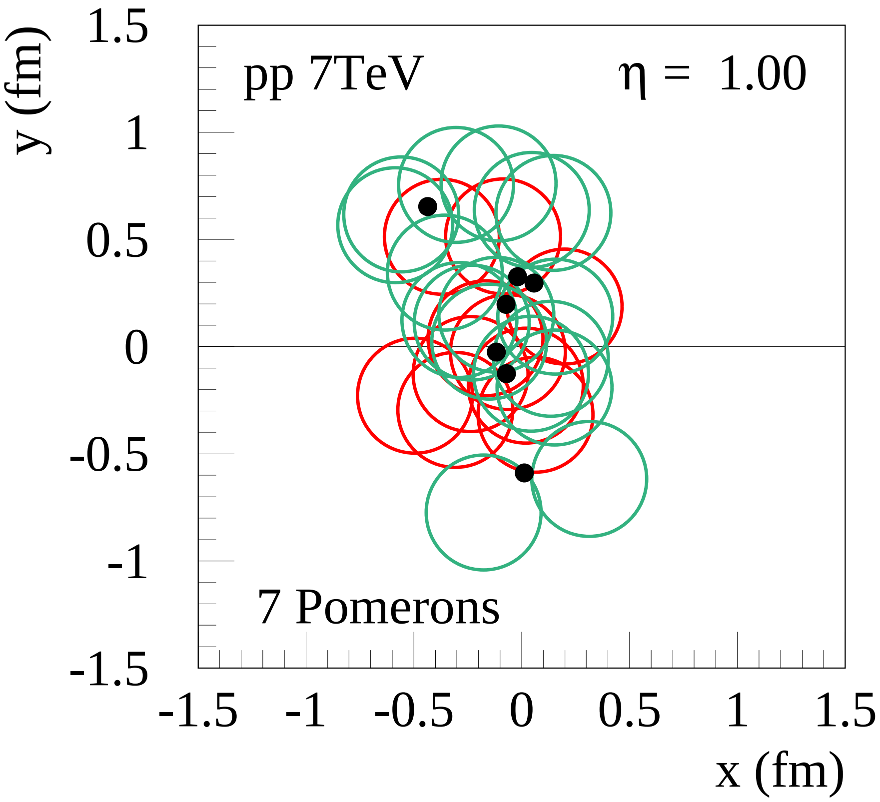
- ☐ **EPOS3: Gribov Regge (GT) approach provides the initial condition for subsequent hydro evolution & hadronization in pp, pA, AA**

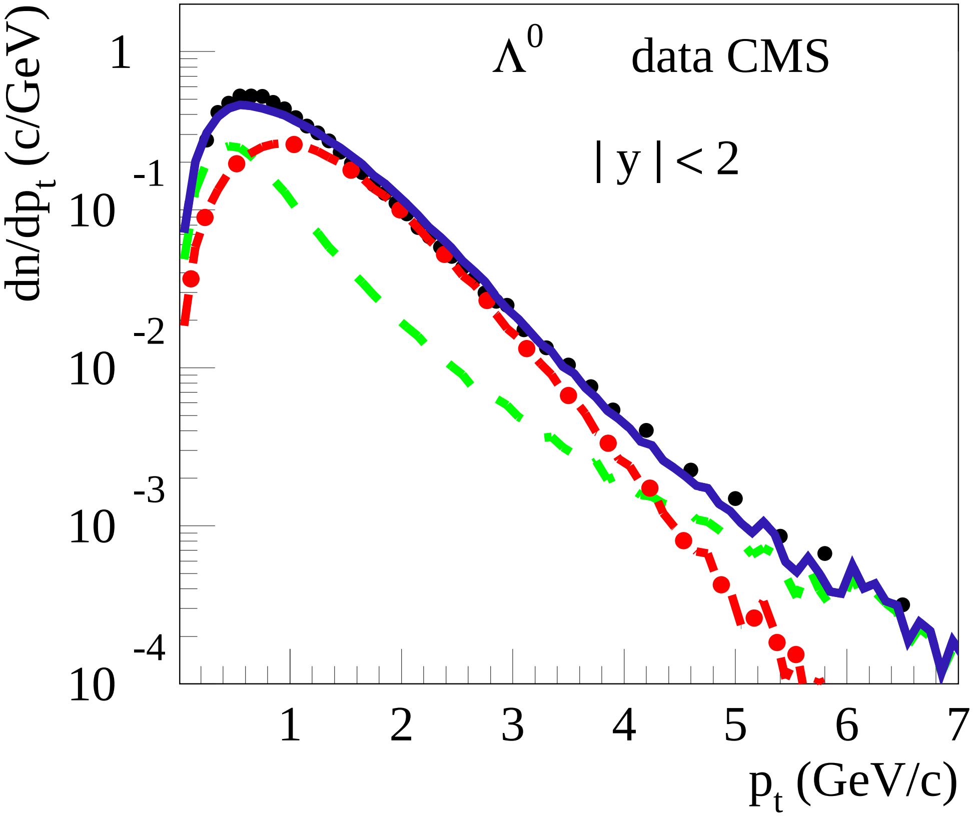
  EbE viscous 3D+1 dim hydro => Y. Karpenko

- ☐ **EPOS LHC (= LHC tune of EPOS1.99, T. Pierog): same GR, but uses parameterized flow**

EPOS3: Pomeron => parton ladder => flux tubes (kinky strings)

String segments with high pt escape (corona),
the others form the “core” = initial condition for hydro

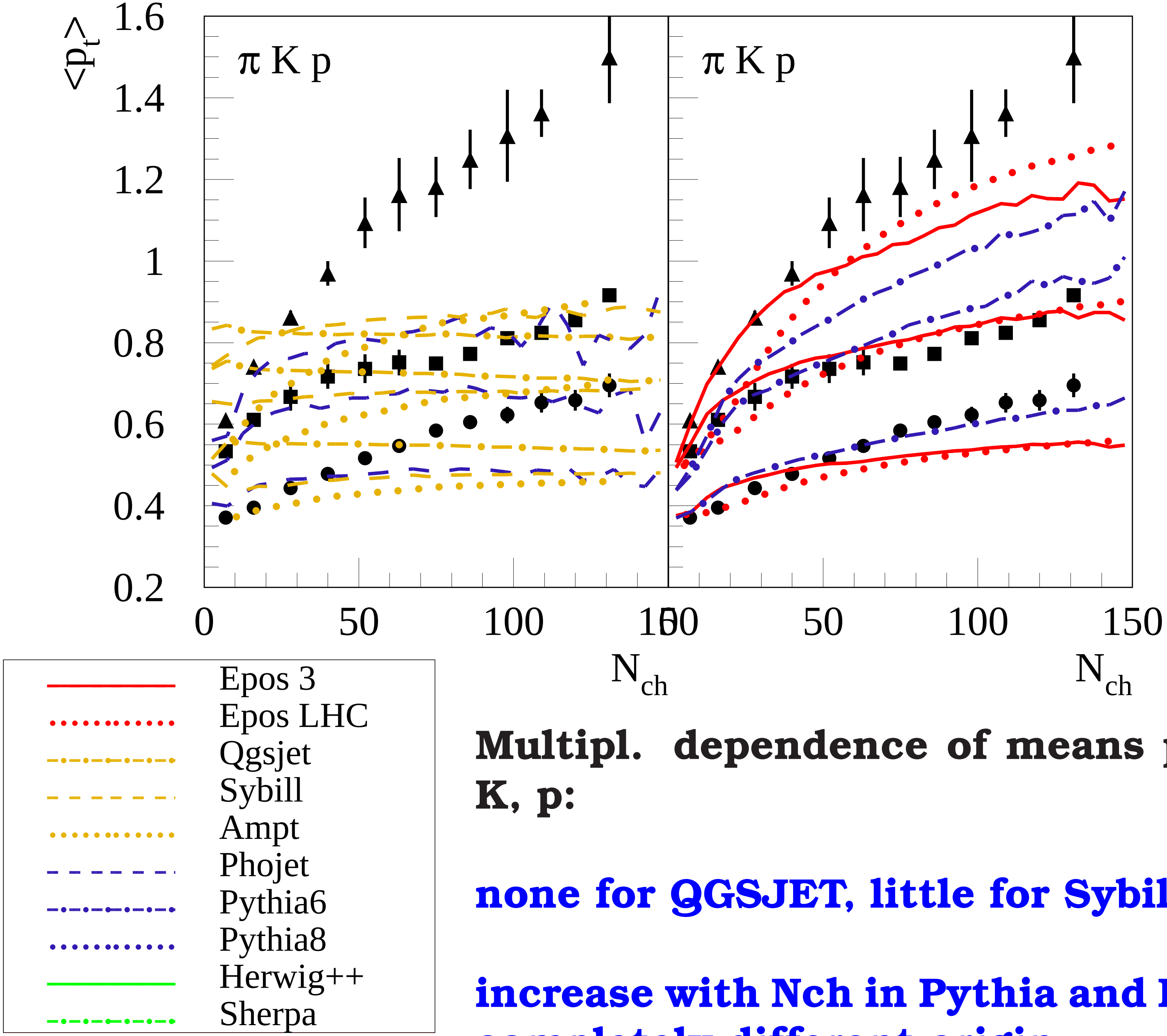




The hydrodynamic equations (Israel-Stewart formulation) in arbitrary coordinate system (implemented/solved by Yuri Karpenko), always $\eta/S = 0.08$, $\zeta/S = 0$

$$\begin{aligned}
\partial_{;\nu} T^{\mu\nu} &= \partial_\nu T^{\mu\nu} + \Gamma^{\mu}_{\nu\lambda} T^{\nu\lambda} + \Gamma^{\nu}_{\nu\lambda} T^{\mu\lambda} = 0 \\
\gamma\left(\partial_t + v_i \partial_i\right) \pi^{\mu\nu} &= -\frac{\pi^{\mu\nu} - \pi^{\mu\nu}_{\mathrm{NS}}}{\tau_\pi} + I^{\mu\nu}_{\pi} \\
\gamma\left(\partial_t + v_i \partial_i\right) \Pi &= -\frac{\Pi - \Pi_{\mathrm{NS}}}{\tau_\Pi} + I_\Pi
\end{aligned}$$

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



Multipl. dependence of means pt for pi, K, p:

none for QGSJET, little for Sybill, Phojet

increase with Nch in Pythia and EPOS has completely different origin

Models for pPb

Epos3
Epos LHC
Qgsjet
AMPT

"QCD generators"
Pythia, Herwig,...
do only pp

Piotr Bozek et al (arXiv:1304.3044): hydrodynamical evolution based on Glauber initial conditions

Results shown later at this conference

CGC / saturation / glasma

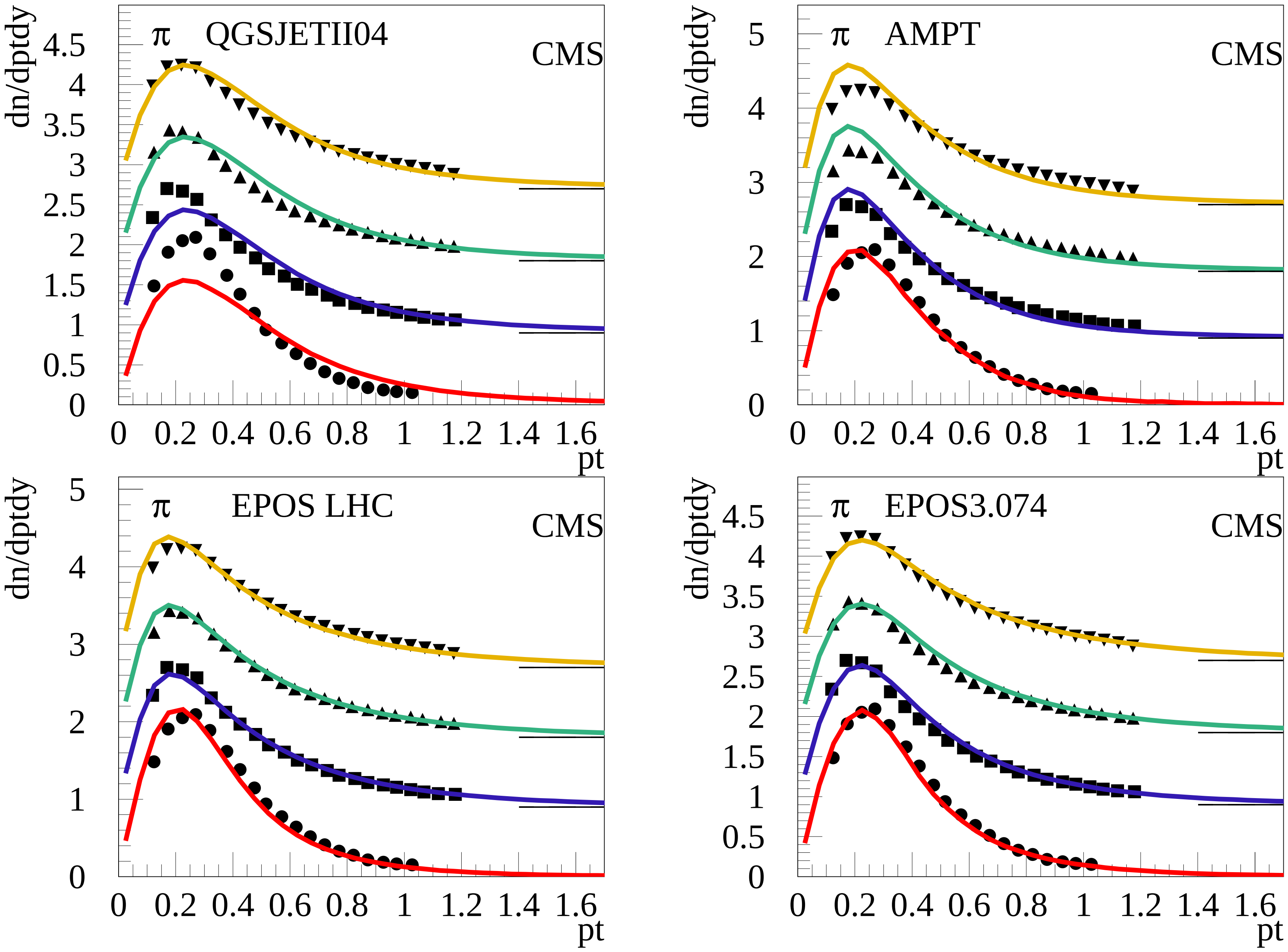
No particular flavor dependencies for u,d,s

CMS: Multiplicity dependence of pion, kaon, proton pt spectra

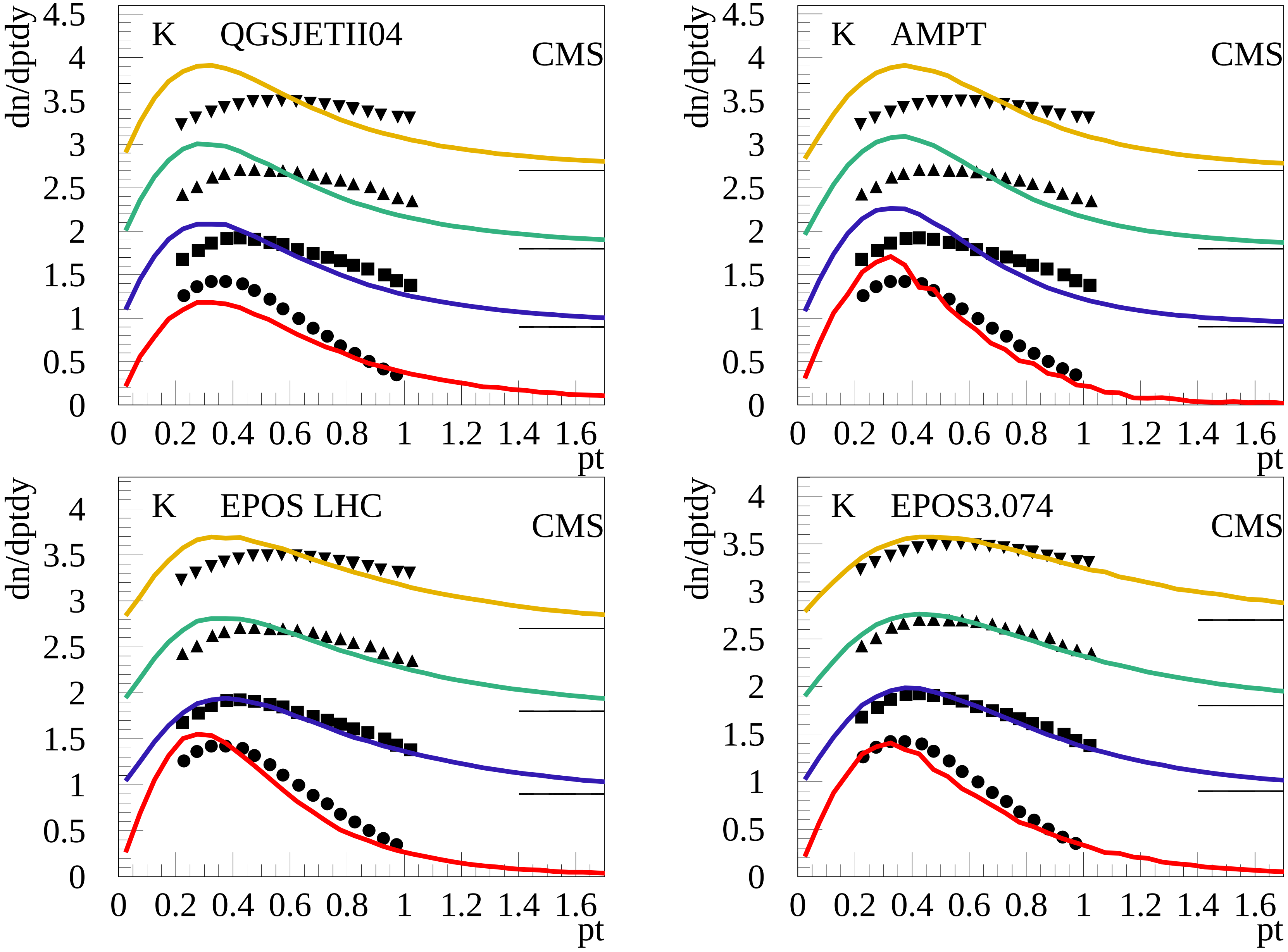
CMS, arXiv:1307.3442

We plot 4 centrality classes:
<N_tracks> = 8, 84, 160, 235 (in $|\eta| < 2.4$)

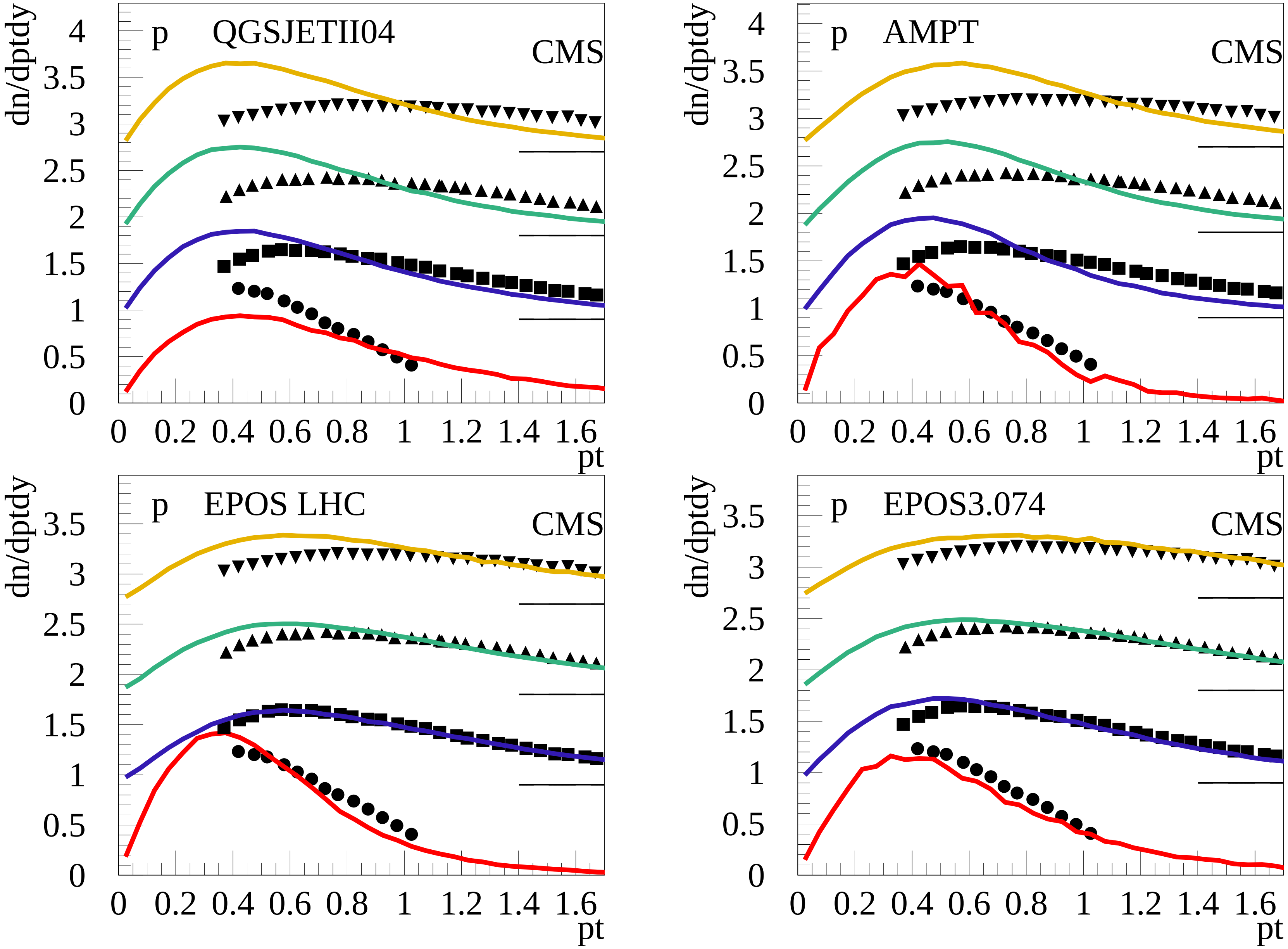
Multiplicity = centrality measure



Little change with <N_tracks> for pions



Kaon spectra change with <N_tracks>

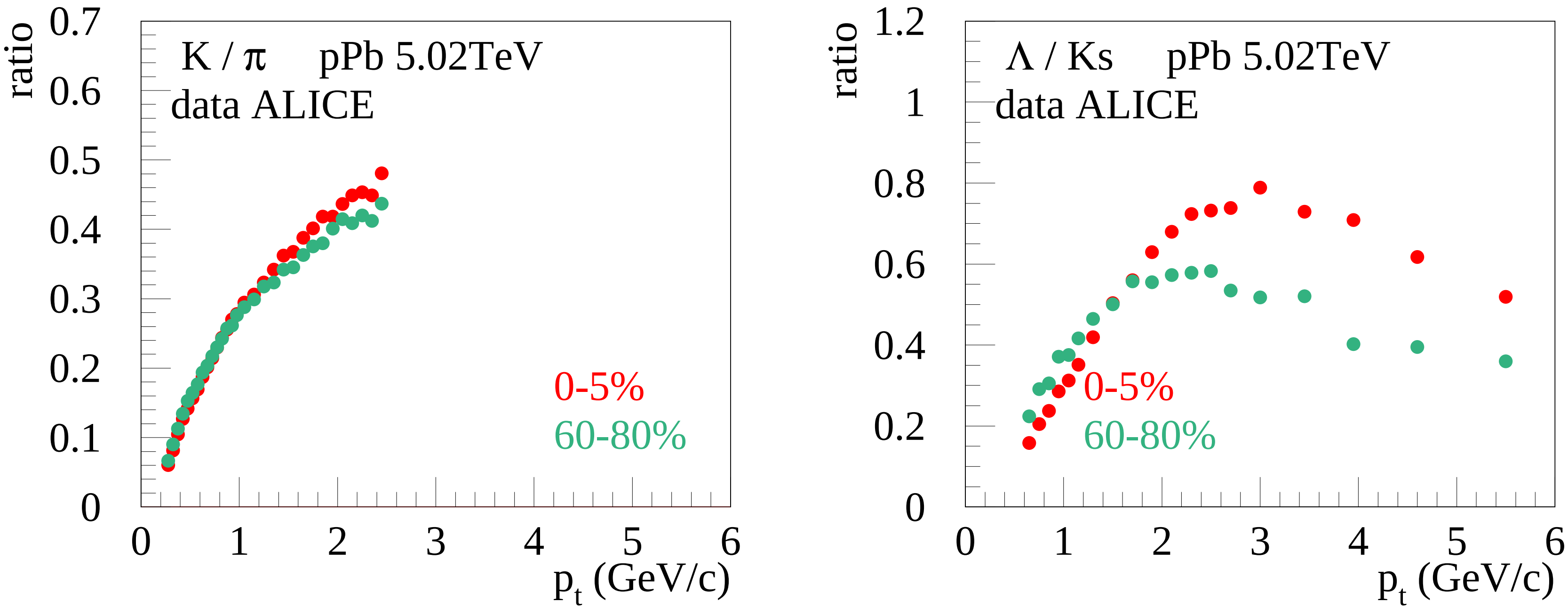


Strong variation of proton spectra => flow helps

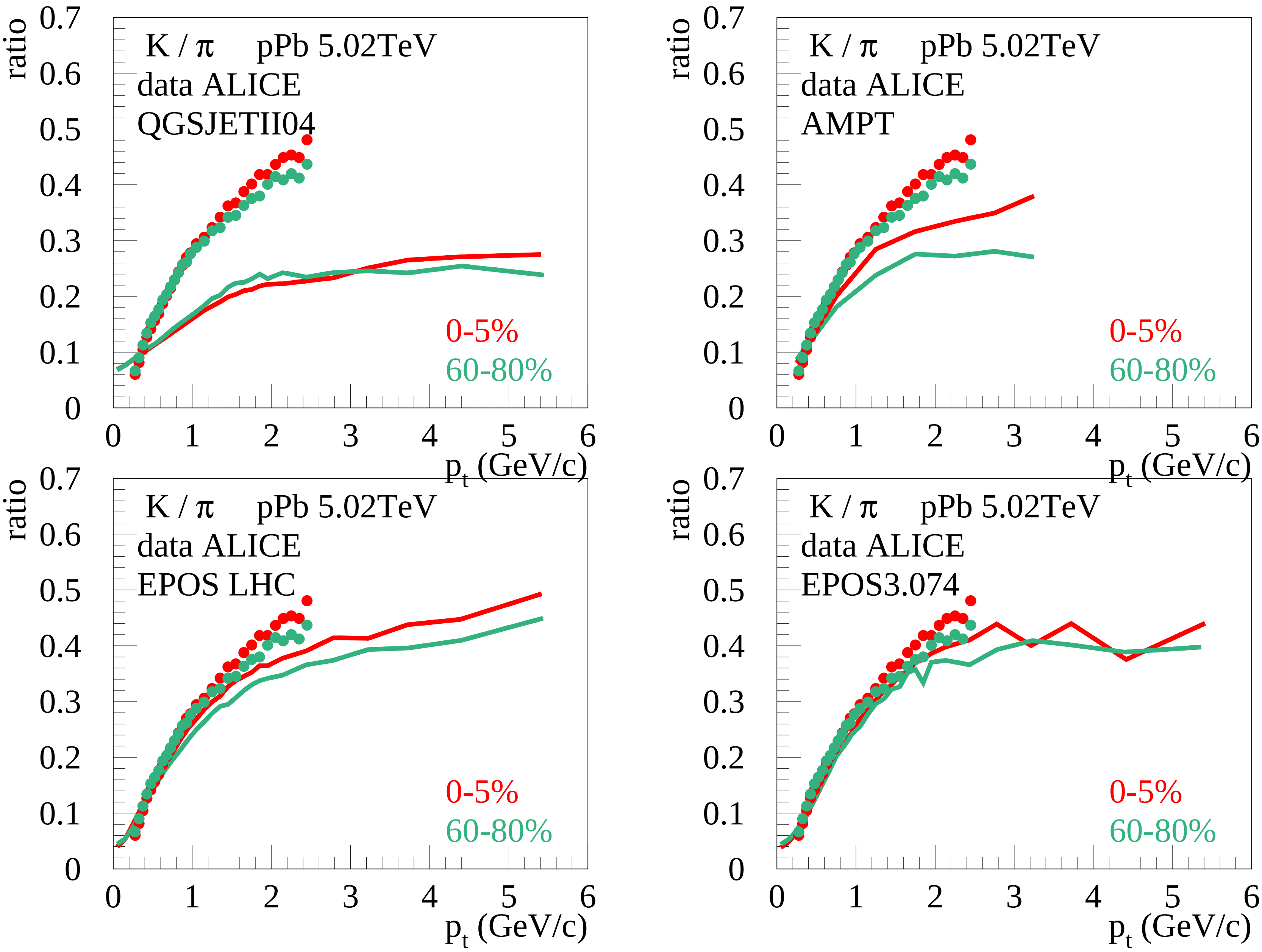
ALICE: compare pt spectra for identified particles in different multiplicity classes: 0-5%,...,60-80%

(in $2.8 < \eta_{\mathrm{lab}} < 5.1$) From R. Preghenella, ALICE, talk Trento workshop 2013

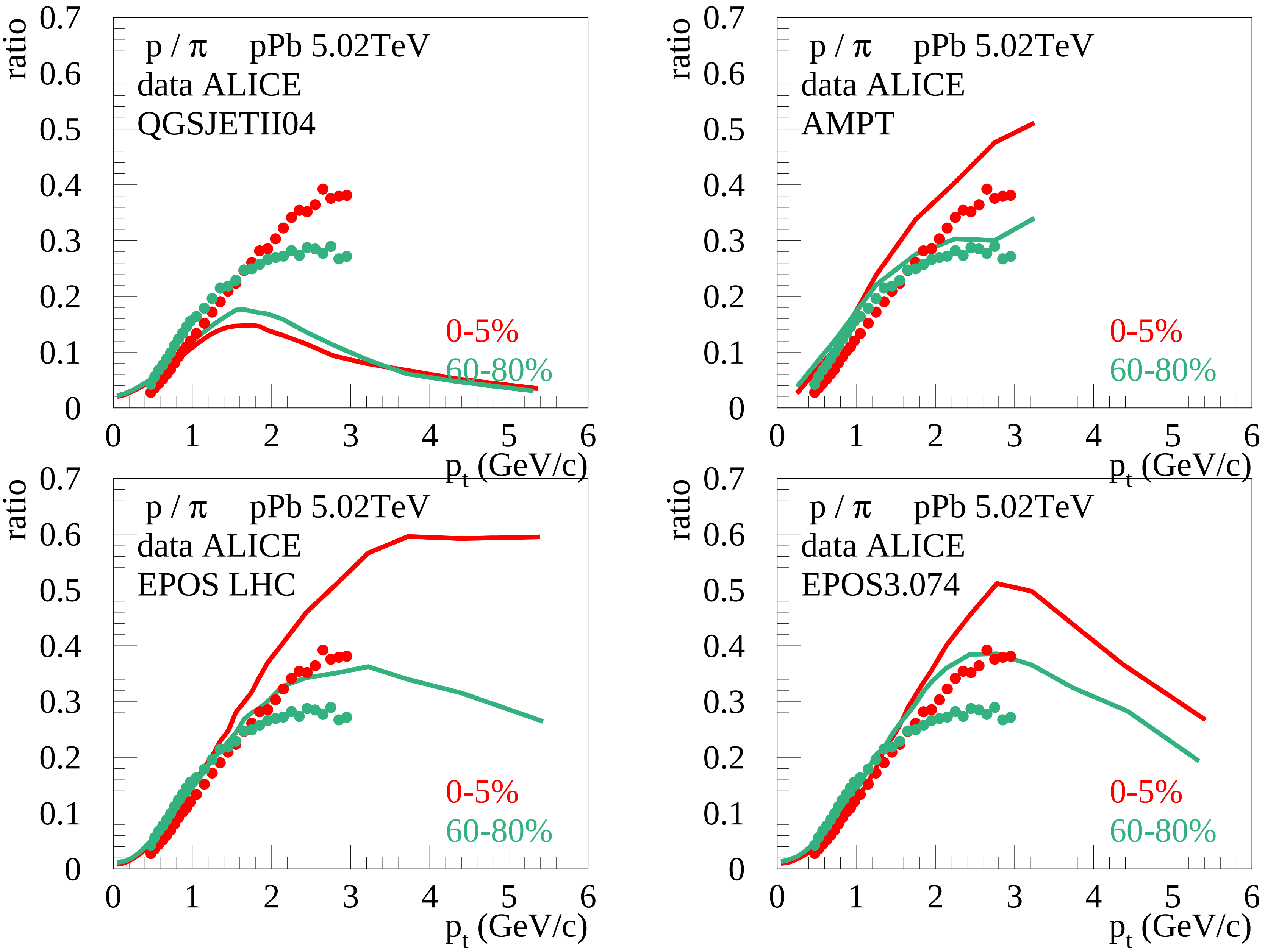
Useful : ratios (K/pi, p/pi...)



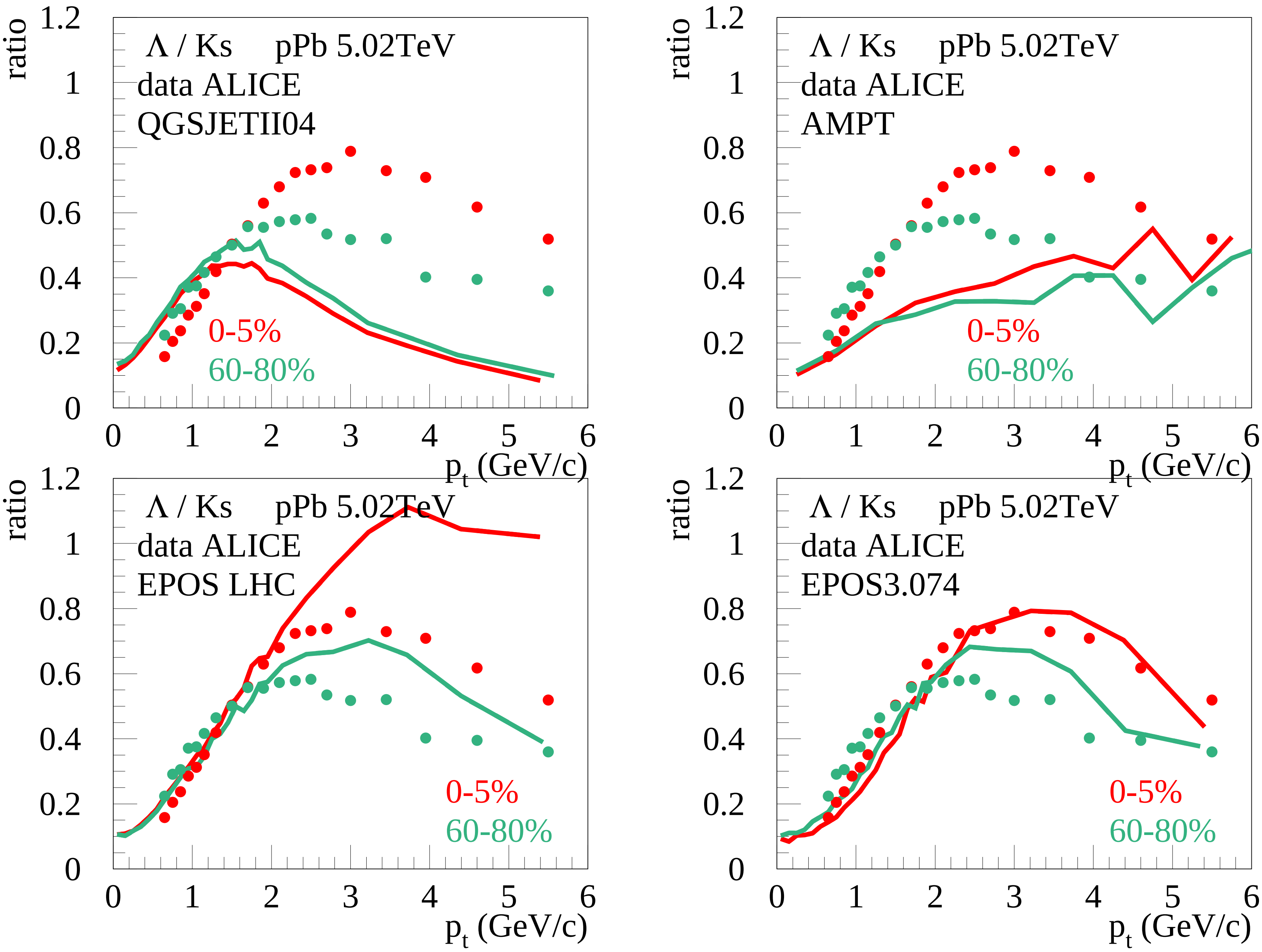
Significant variation of lambda/K – like in PbPb



No multiplicity dependence (not trivial to get the peripheral right)

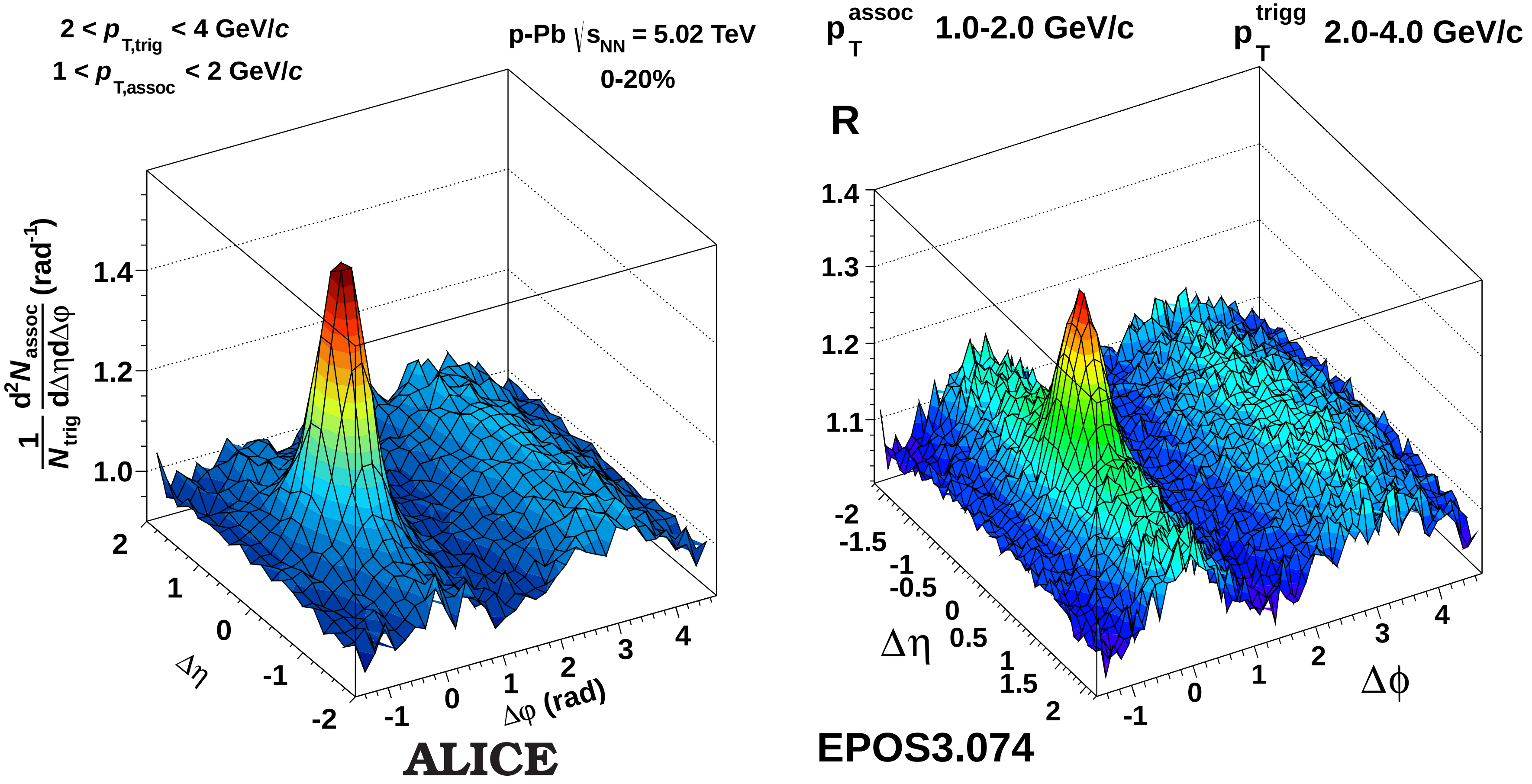


Significant multiplicity dependence



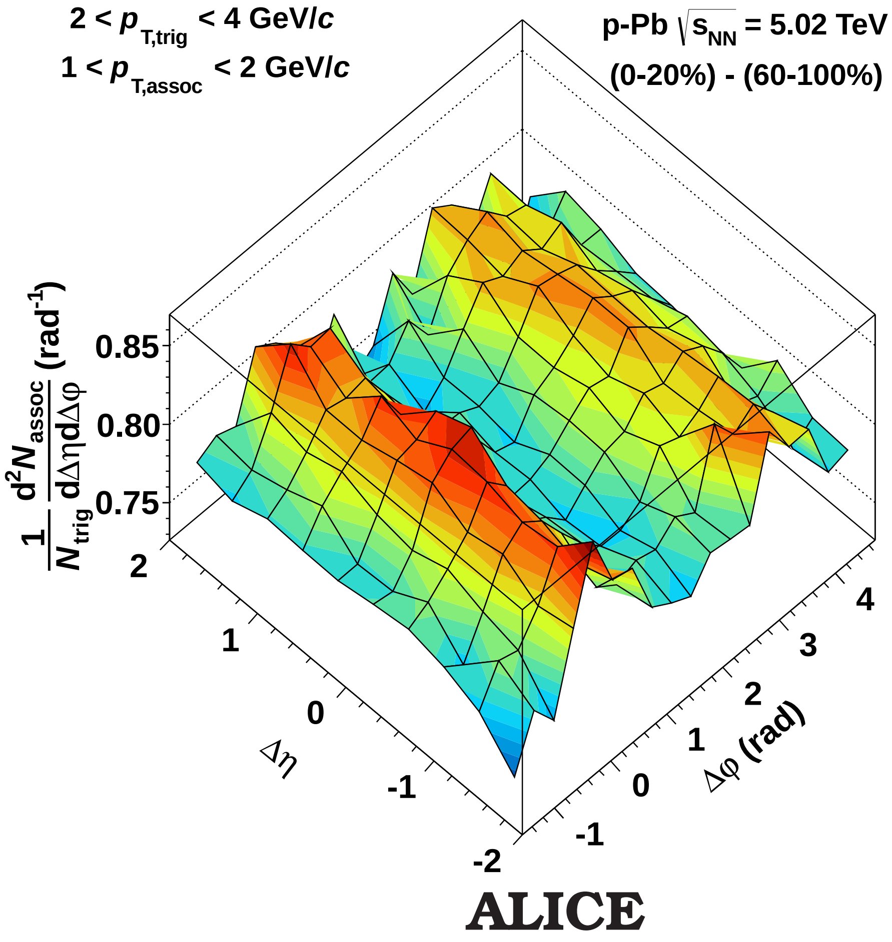
Significant multiplicity dependence **=> flow peak**

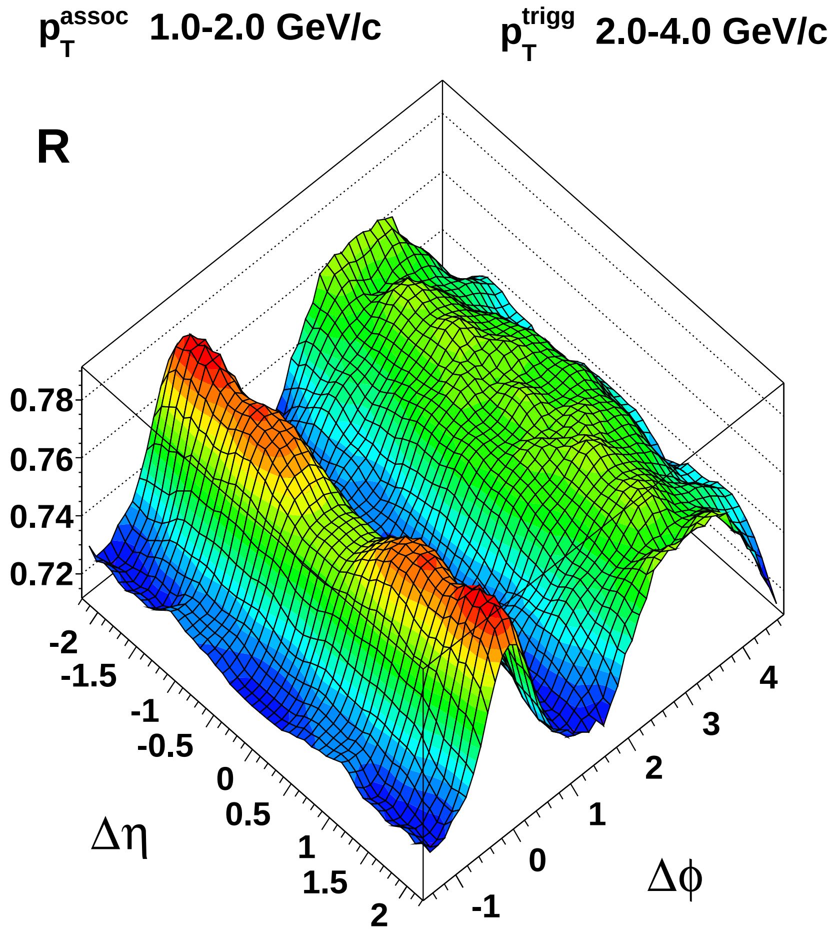
“Ridges” in pA (EPOS3, arXiv:1307.4379)



ALICE, Phys.Lett. B719 (2013) 29, arXiv:1212.2001

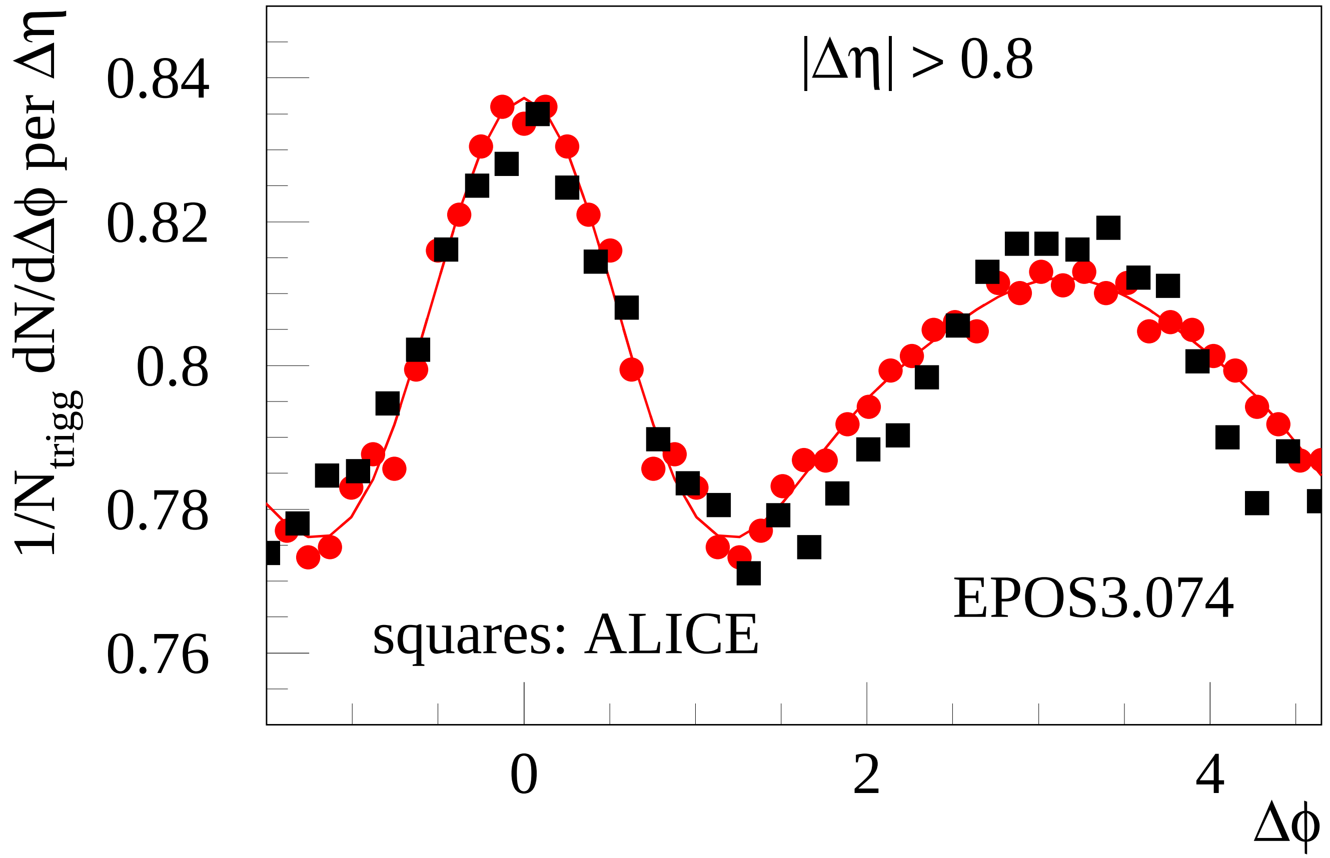
Central - peripheral (to get rid of jets)





EPOS3.074

Projection

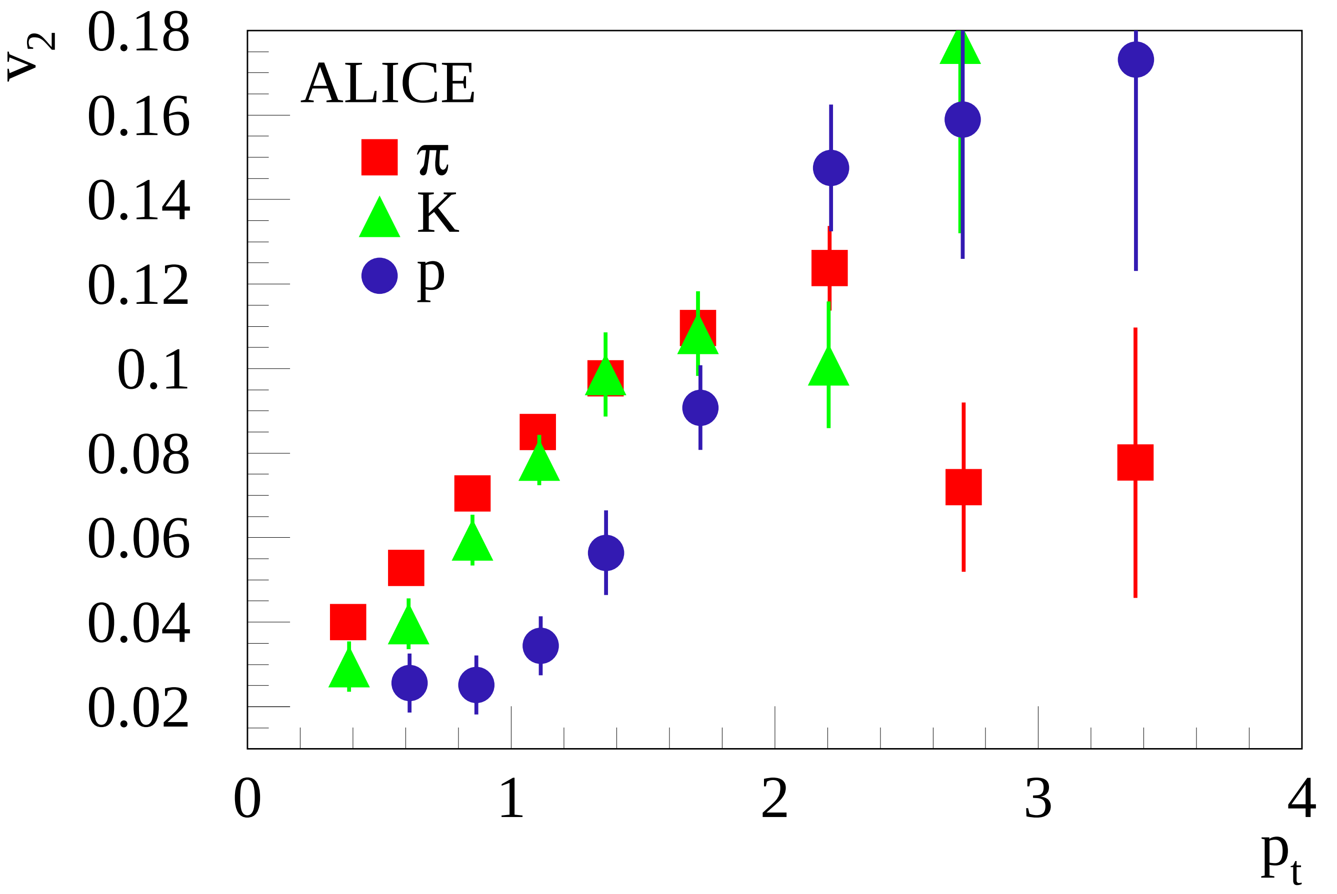


$$\text{red line}: \sum 2a_i \cos(i\Delta\phi);$$

$$\Longrightarrow \qquad v_n = \sqrt{\frac{a_n}{b}}$$

Identified particle v2

ALICE, arXiv:1307.3237

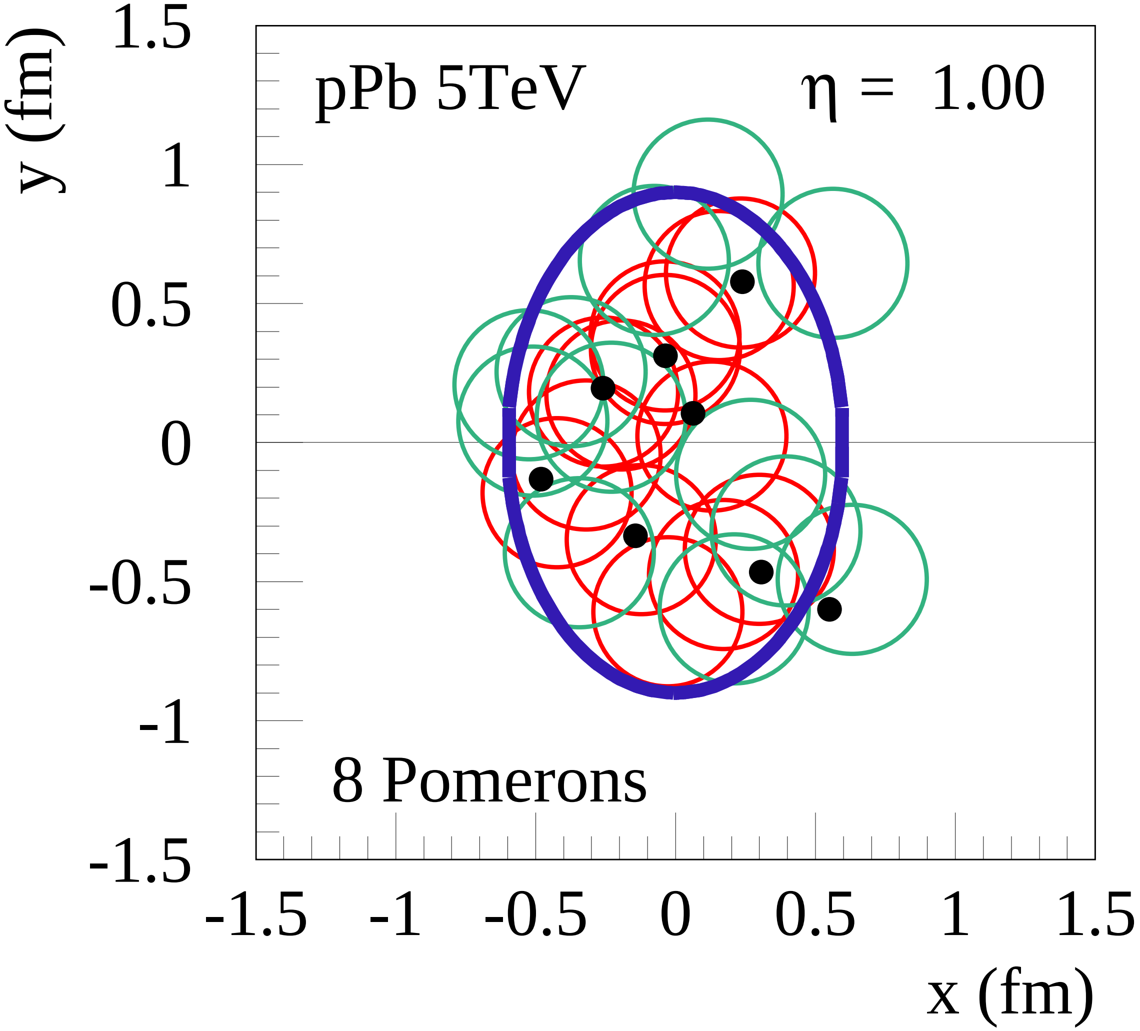


mass splitting, as in PbPb !!!

pPb in EPOS3

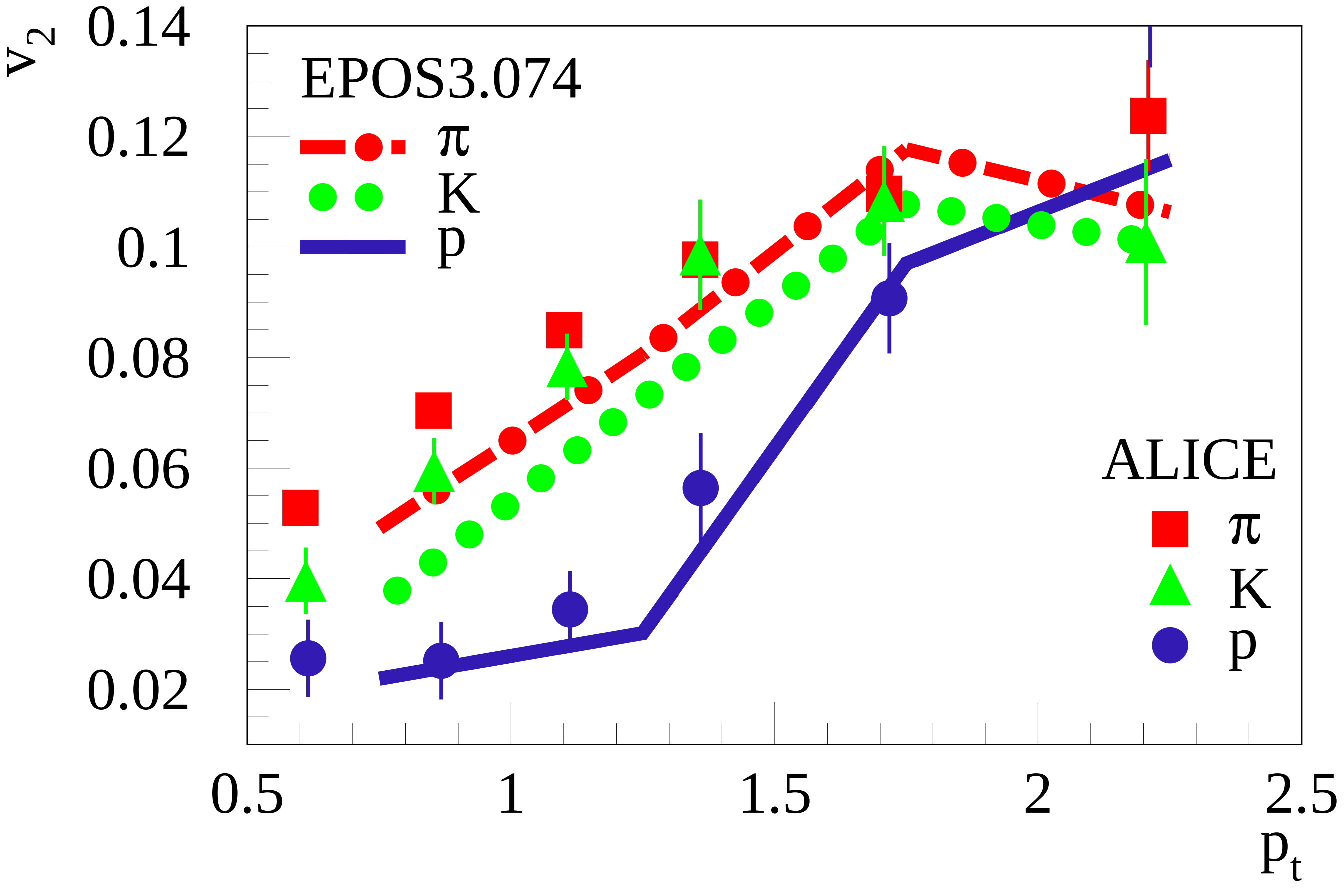
Pomerons (number and positions) characterize geometry **(P. number $\propto$ multiplicity)**

random azimuthal asymmetry => asymmetric flow seen at higher pt for heavier ptls



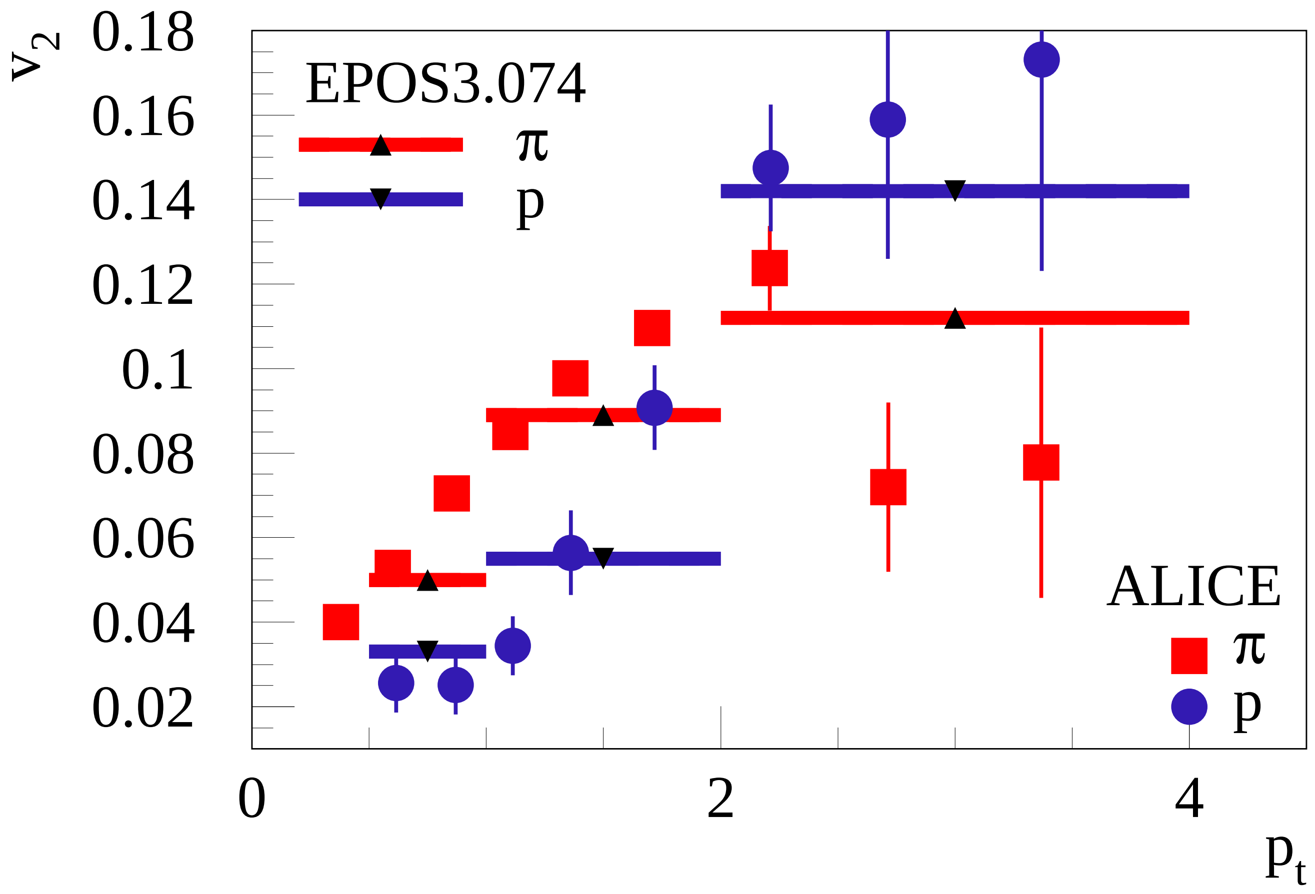
Robust results

v2 for π, K, p clearly differ



mass splitting, due to flow

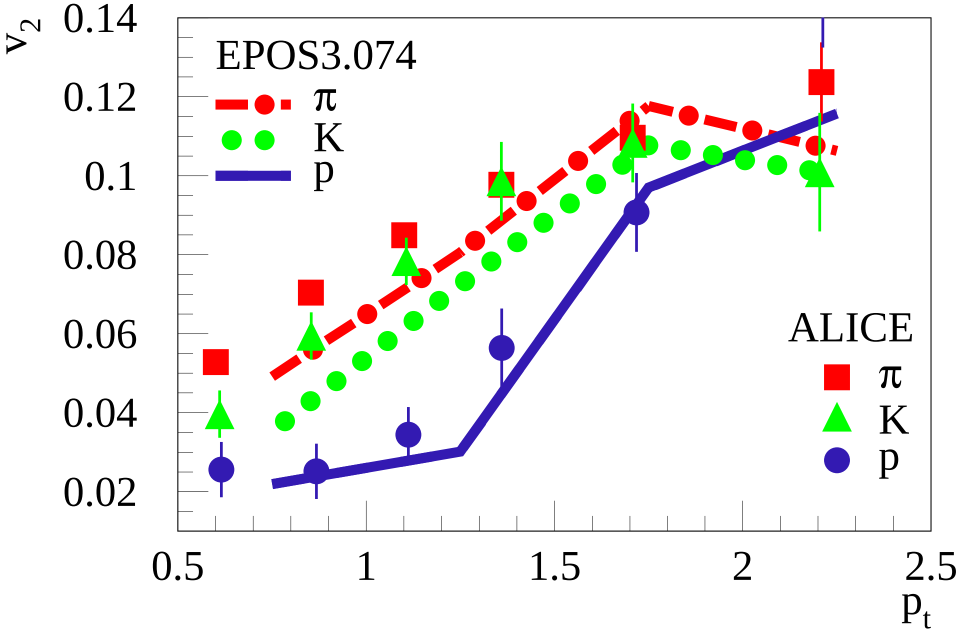
different binning:

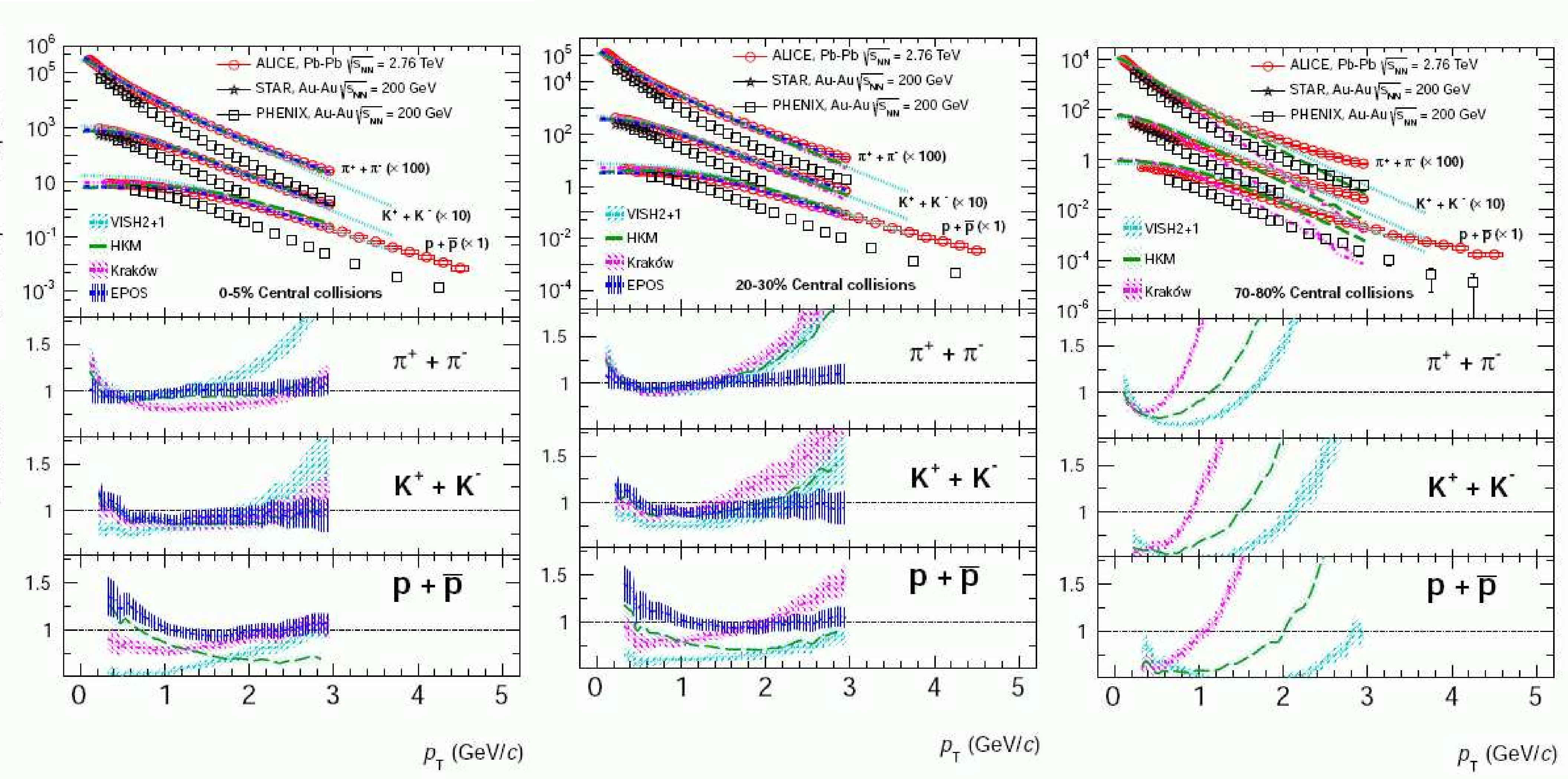


v2(protons) > v2(pions) beyond 2GeV

Summary

- ☐ **Traditional Monte Carlos have difficulties to describe strange particle production in pp.**
  Hydrodynamical picture helps.
- ☐ **pPb looks very much like**
  a hydrodynamically expanding system
  (more clean than PbPb, where hydro and minijets heavily interact, as well as the final hadrons among themselves)





ALICE arXiv:1303.0737