

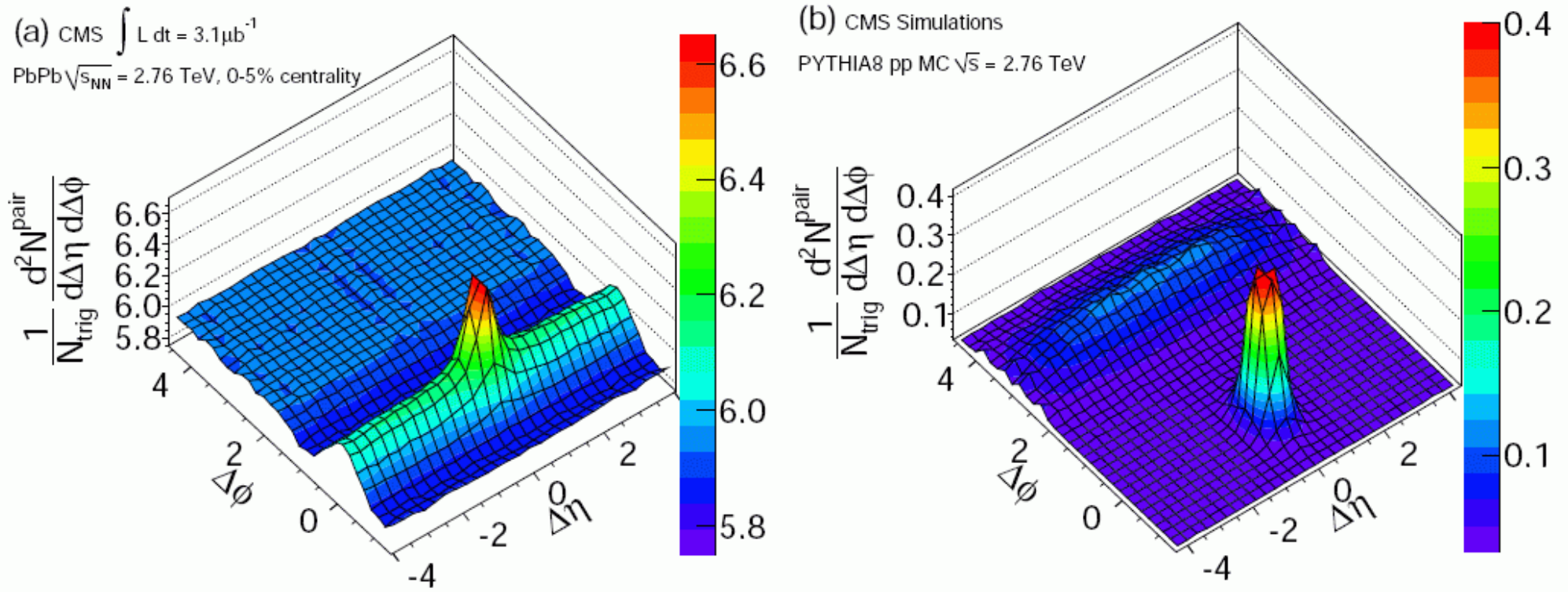
Jets, Bulk Matter, and their Interaction in Heavy Ion Collisions at Several TeV

Klaus Werner <werner@subatech.in2p3.fr>

in collaboration with

Iu. Karpenko, T. Pierog, S. Porteboeuf,
M. Bleicher, K. Mikhailov

Motivation: Dihadron correlations: PbPb 2.76 TeV
 (CMS: CERN-PH-EP/2011-056 2011/05/13)



$$4 < p_t^{\text{trigg}} < 6 \text{ GeV}/c, \quad 2 < p_t^{\text{assoc}} < 4 \text{ GeV}/c$$

Ridge for small trigger pt:

- irregular initial energy density in transverse plane
- + little variation longitudinally (flux tubes)
- translates into long range flow correlation

Ridge at higher pt ???

- One observes “factorization” of $v_n(p_t^t, p_t^a)$ in certain cases,
- which does not explain the phenomenon.

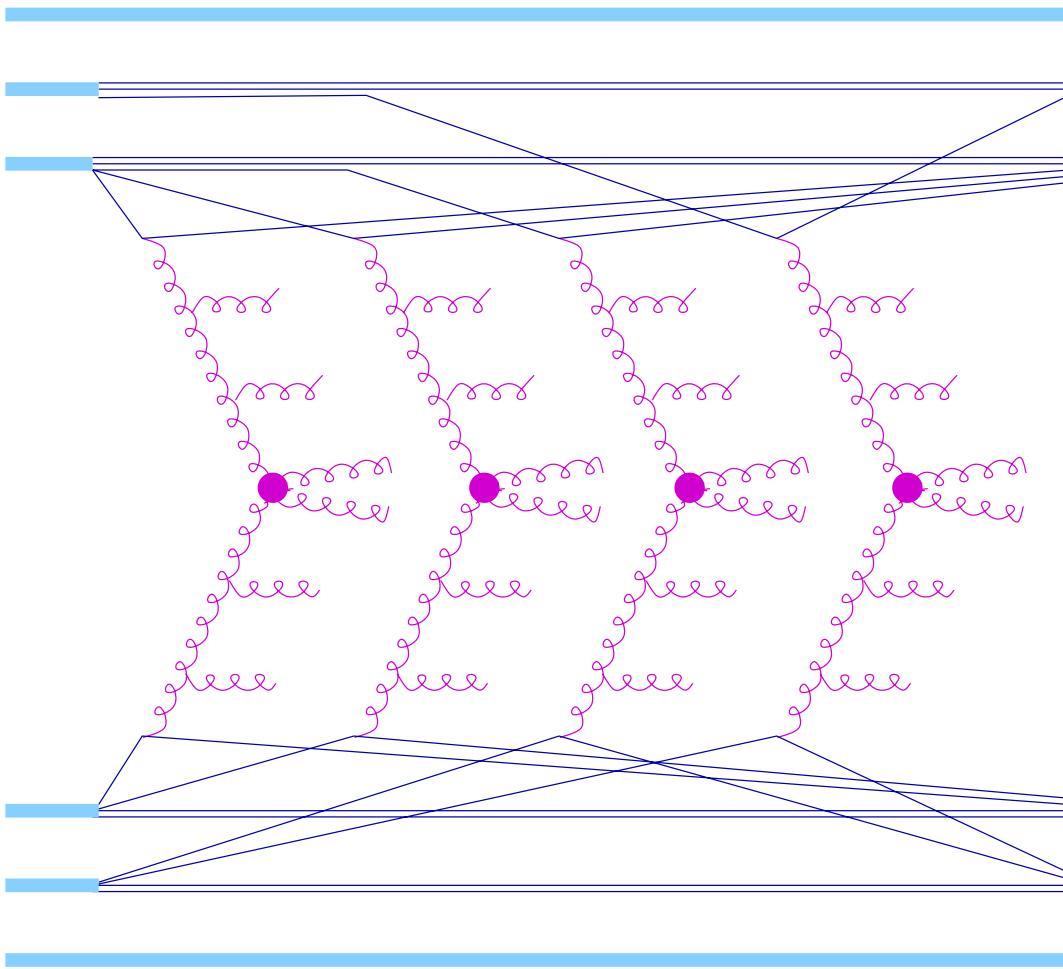
=> some new ideas about bulk, jets, and their interaction

arXiv:1203.5704, Jets, Bulk Matter, and their Interaction in HIC at Several TeV

arXiv:1204.1394, Lambda over Kaon Enhancement in HIC at Several TeV

arXiv:1205.3379, V2 Scaling in PbPb Collisions at 2.76 TeV

Basis: Multiple scattering approach (EPOS): marriage of pQCD and Gribov-Regge, with energy sharing



Many collisions in parallel

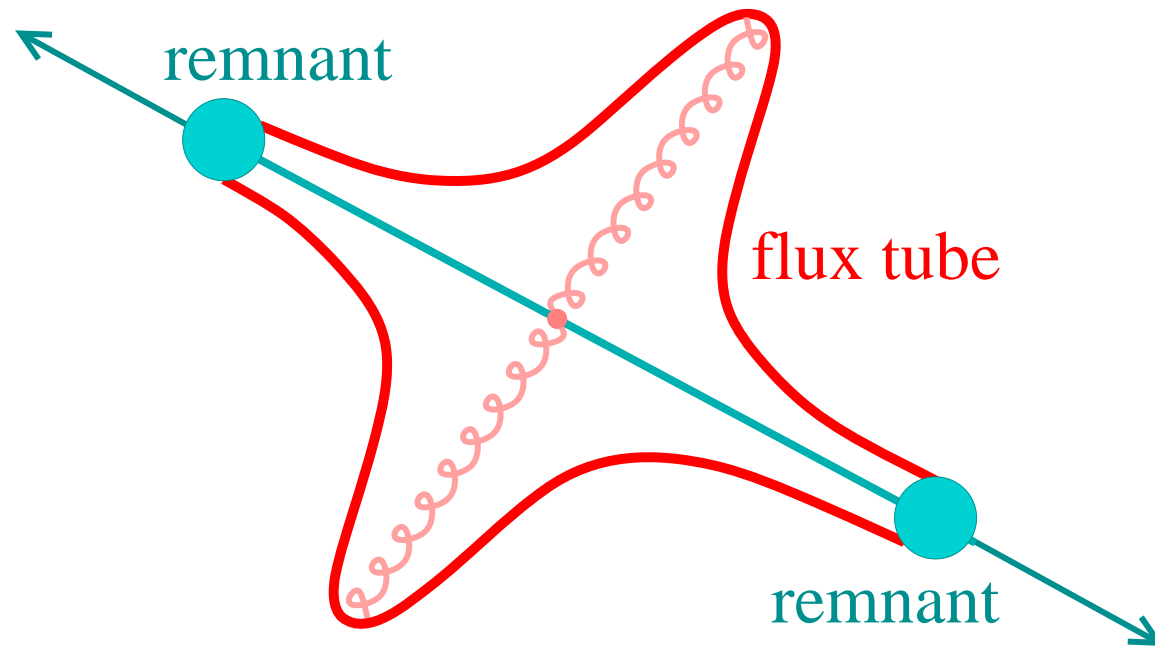
Single scattering

= hard elementary scattering including IS + FS radiation

= parton ladder

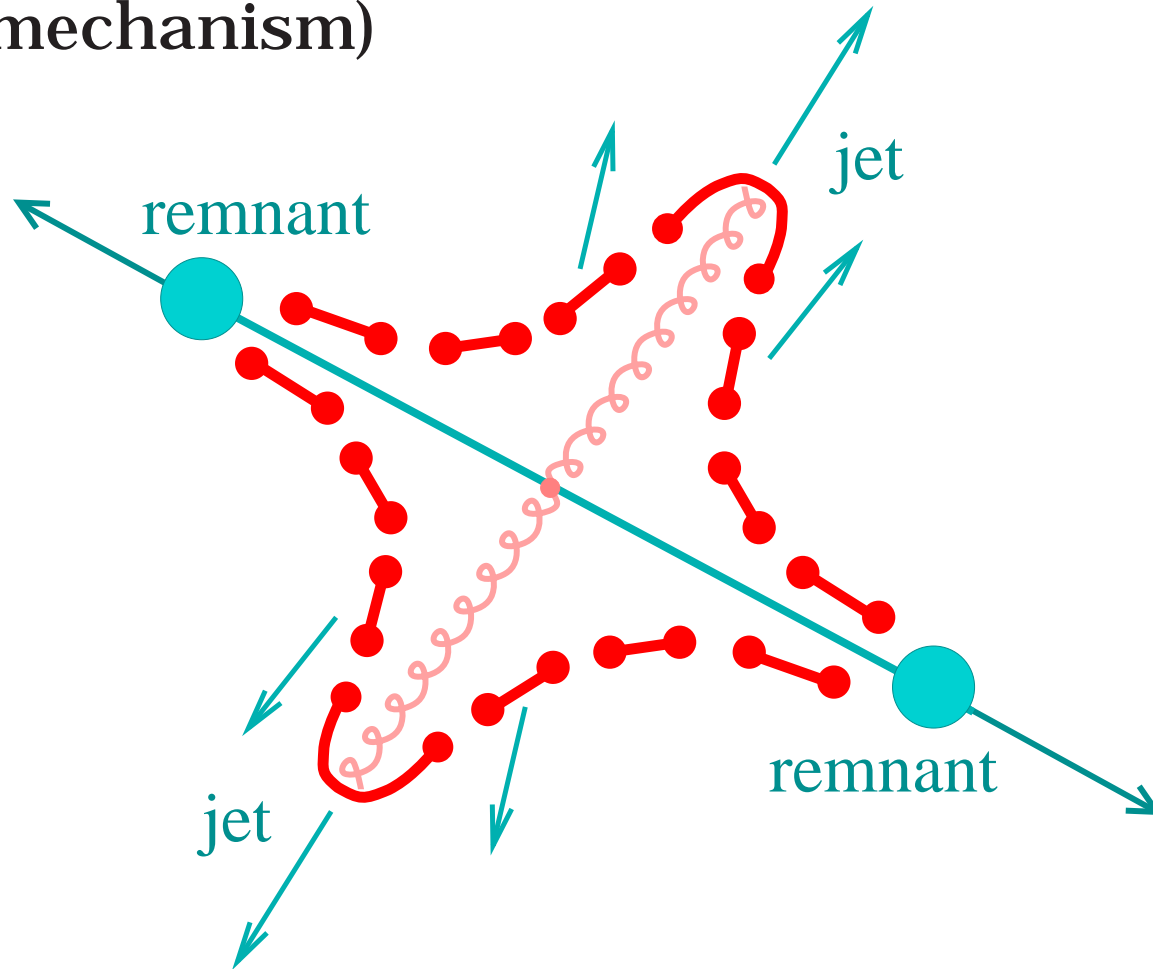
= color flux tubes

parton ladder = color flux tubes = kinky strings



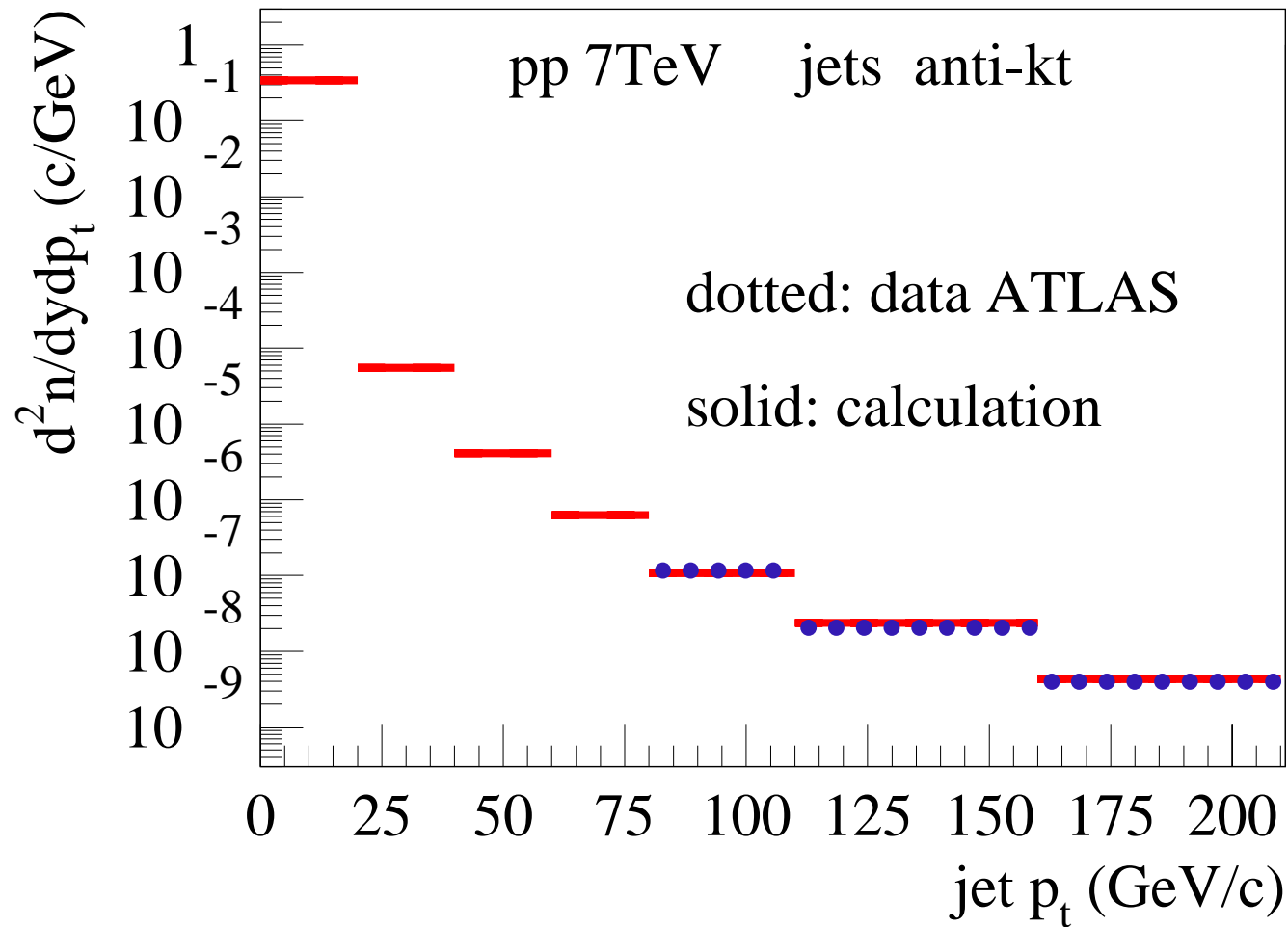
here no IS radiation, only hard process producing two gluons

which expand and break
via the production of quark-antiquark pairs
(Schwinger mechanism)

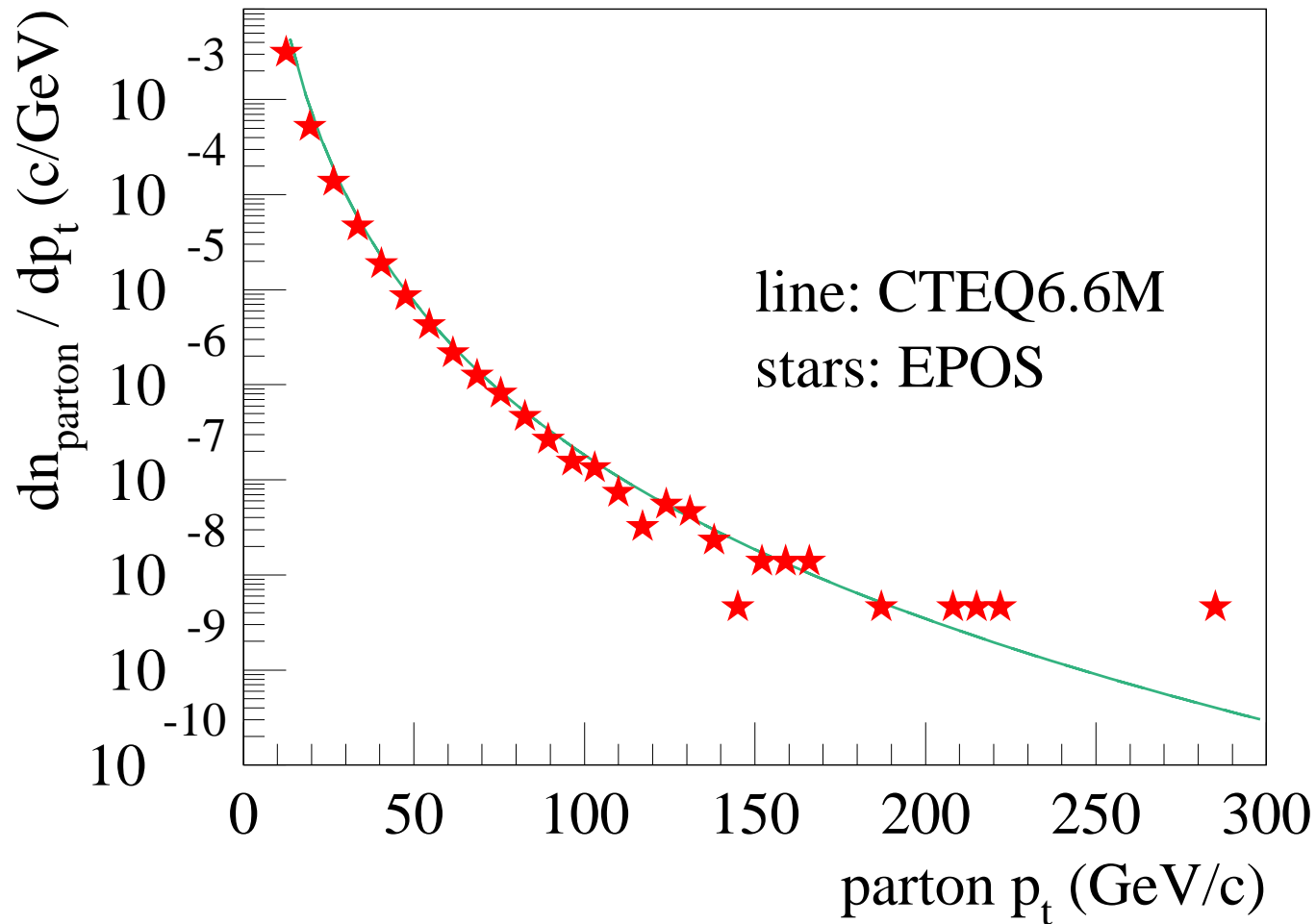


String segment = hadron. Close to “kink”: jets

Check: jet production in pp at 7 TeV



Comparison with parton model calculation using CTEQ PDFs for pp at 7 TeV



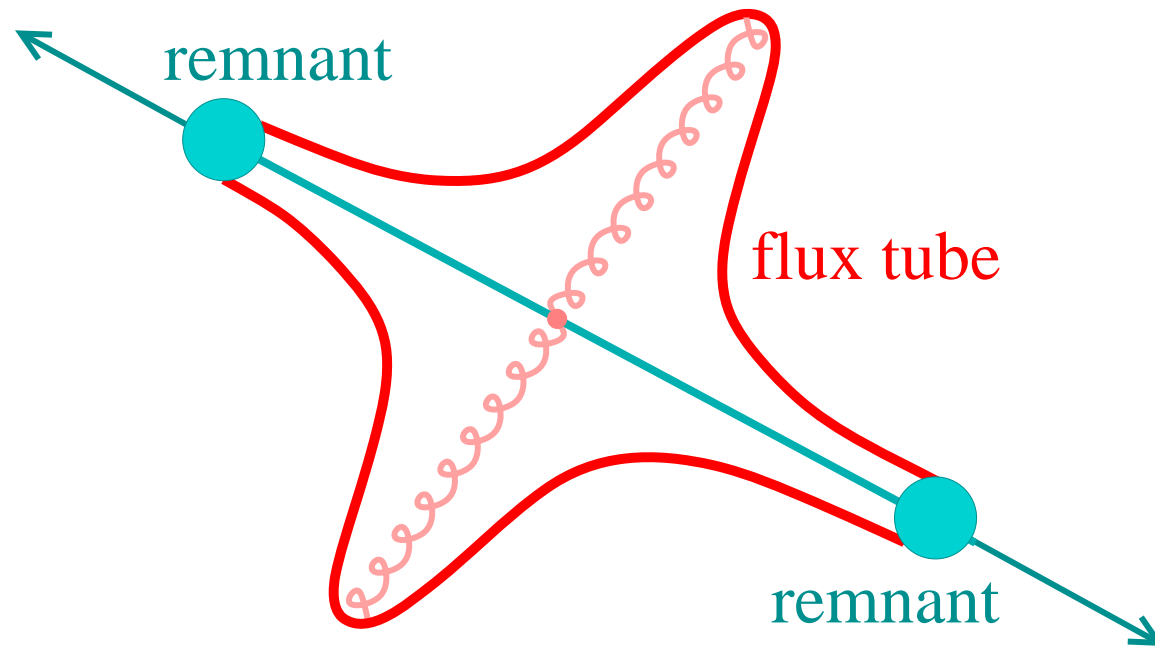
Heavy ion collisions or high energy & high multiplicity pp events:

- the usual procedure has to be modified, since the density of strings will be so high that they cannot possibly decay independently

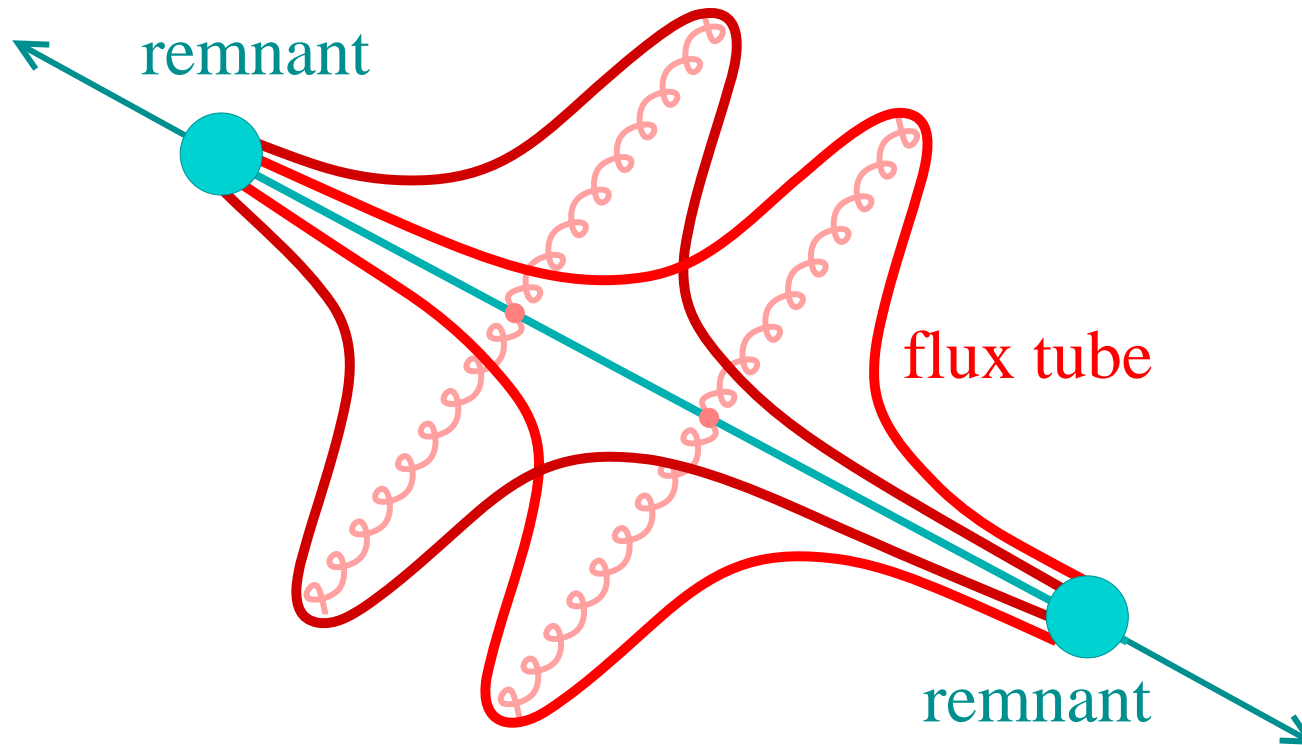
**Some string pieces will constitute bulk matter,
others show up as jets
(jet-bulk separation)**

These are the same strings (all originating from hard processes at LHC) which constitute BOTH jets and bulk !!

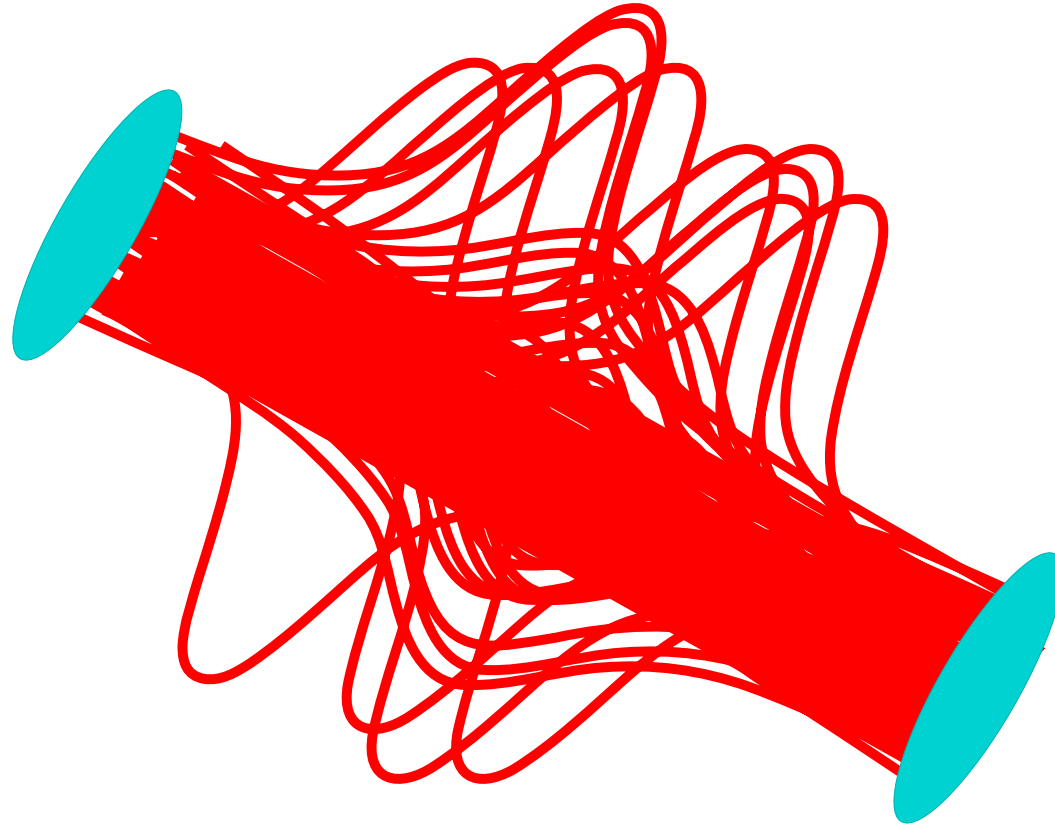
again: single scattering => 2 color flux tubes



... two scatterings => 4 color flux tubes



... many scatterings (AA) => many color flux tubes



=> matter + escaping pieces (jets)

Consider one flux tube in “matter”

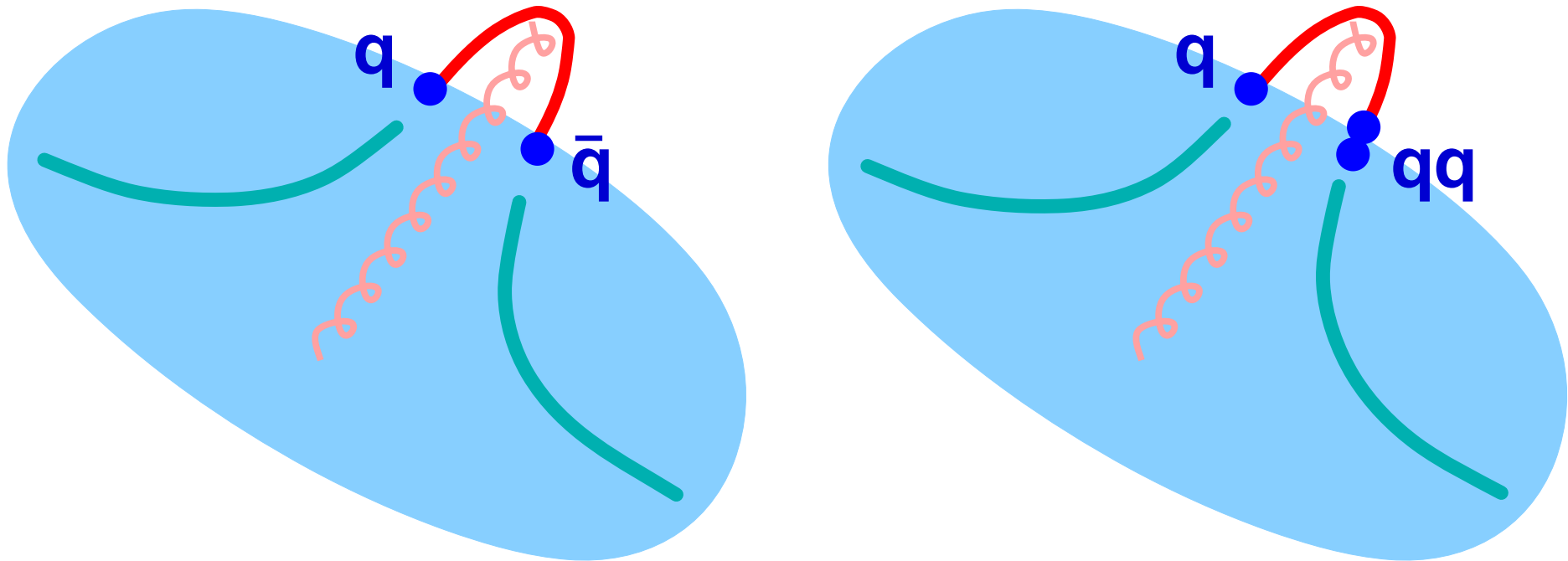
(= high density of other flux tubes, which then thermalize)

Three possibilities:

- (A) String segments which have not sufficient energy to escape will constitute matter ($\Delta E > E$).
They lose their character as individual strings. This matter will evolve hydrodynamically and hadronize; hadrons still interact (“soft hadrons”).
- (B) String segments having sufficient energy to escape and being formed outside the matter, constitute jets (“jet-hadrons”).
- (C) String segments produced inside matter or at the surface, but having enough energy to escape and show up as jets (“jet-hadrons”).
They are affected by the flowing matter (“fluid-jet interaction”).

Jet-hadrons produced inside matter or at the surface

(Type C)



End point partons from fluid, instead of Schwinger

=> adds flow, changes chemistry

Technical realization in two steps

Estimate initially which segments constitute the bulk (= initial condition for hydro), from

$$\Delta E > E$$

E =energy of the segment,

ΔE = energy loss along trajectory, with $dE \propto \rho^{3/8} \max(1, \sqrt{E/E_0}) dL$ ¹⁾

¹⁾ inspired by BDMPS, Peigne arXiv0806.0242

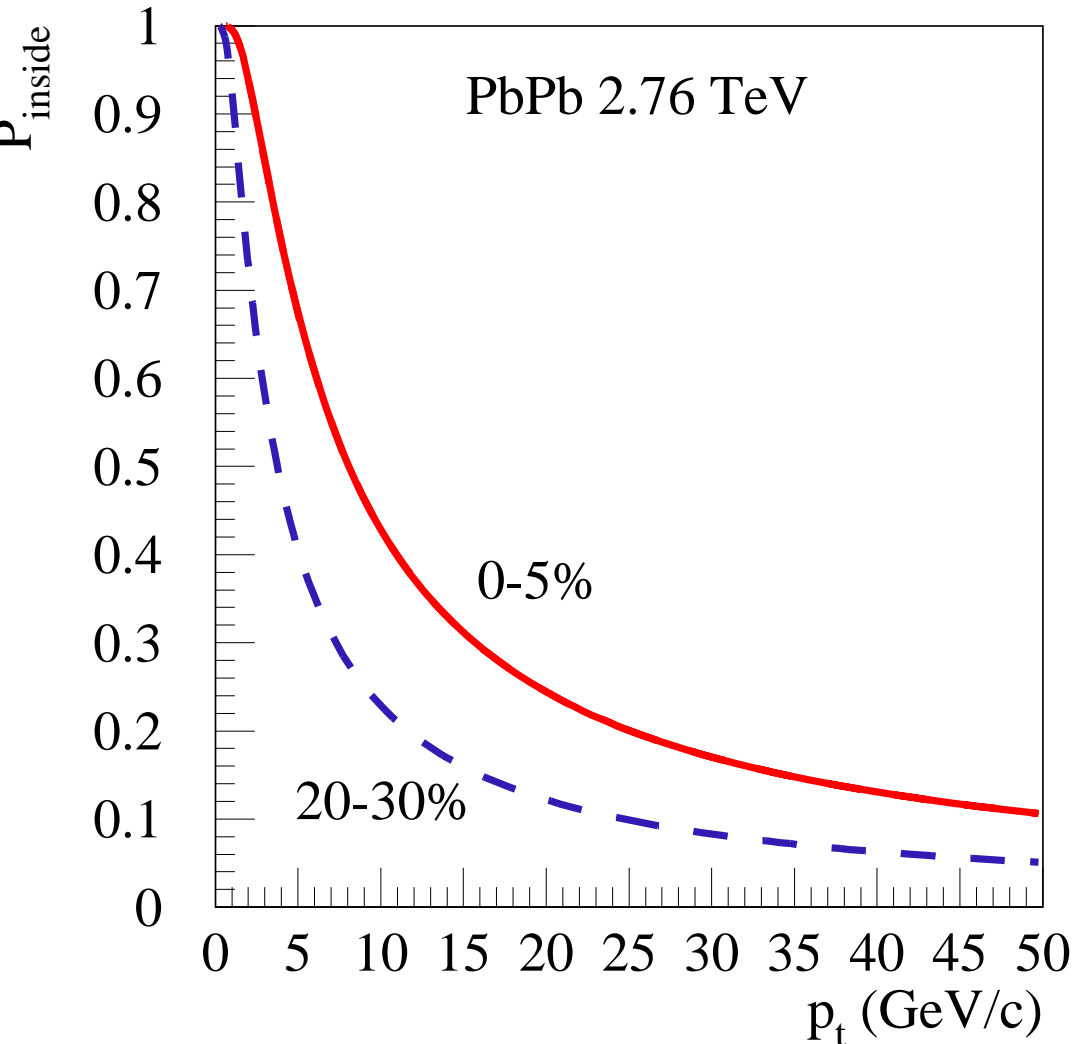
After hydro evolution:

Reconstruct for the "jet segments" produced inside the matter (formation time) their escape points (t, \vec{x}) ,

replace Schwinger q/\bar{q} by thermal ones, "flowing" with $\vec{v}(t, \vec{x})$.

Crucial: formation time !

Probability to form a hadron inside matter:



Simple estimate (ptl moving $\parallel \vec{b}$)

$$P_{\text{inside}} = 1 - \exp\left(-\frac{(r_{\text{Pb}} - b/2) m}{p_t \tau_{\text{form}}}\right).$$

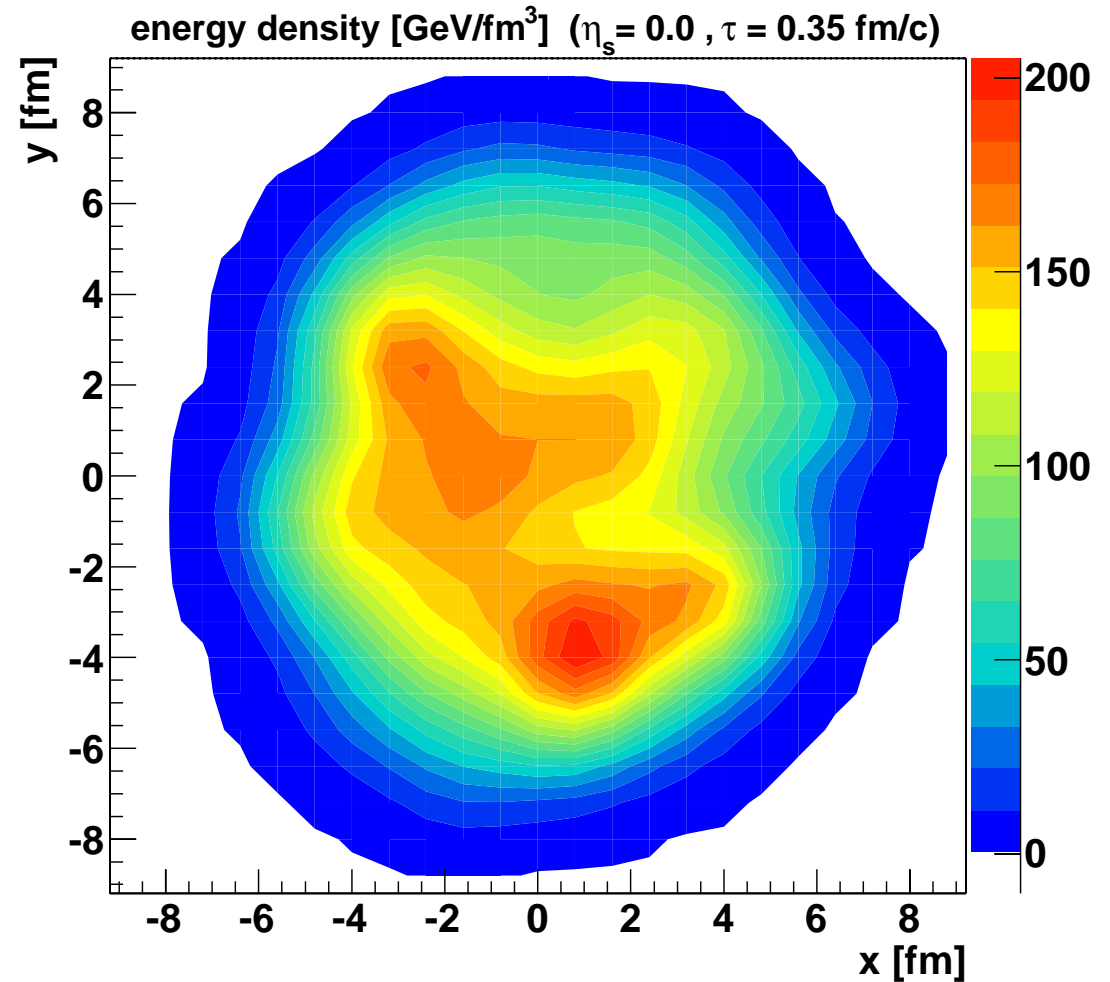
with $c\tau_{\text{form}} = 1 \text{ fm}$, $mc^2 = 1 \text{ GeV}$,

**Using ideal hydro
v2 20-30% too big**

**(standard param setting:
flux tube radii 0.2 fm)**

**mimic viscous effects
by taking artificially large val-
ues of the flux tube radii
(we take 1 fm),**

**=> smoother initial condi-
tions.**



- The heavy ion results shown are based on 2000000 events simulated with EPOS2.17v3.
- A central (0-5%) PbPb event takes on the average around 2 HS06 hours CPU time (15 minutes on the machines of our computing farm).
- Difficult to make “tuning”, results are based on a “good guess of parameters” ...

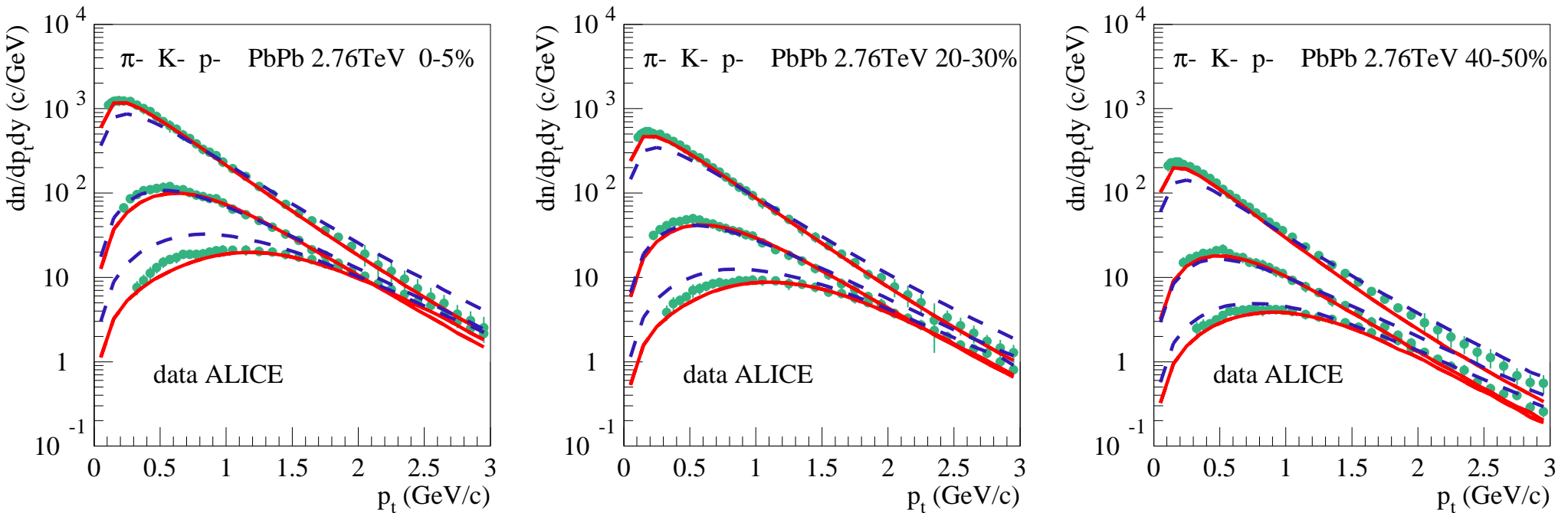
Transverse momentum dependence of particle yields

Pion, kaons, protons vs p_t , in PbPb 2.76 GeV:

0-5%

20-30%

40-50%



blue dashed lines: calculation without hadronic cascade,

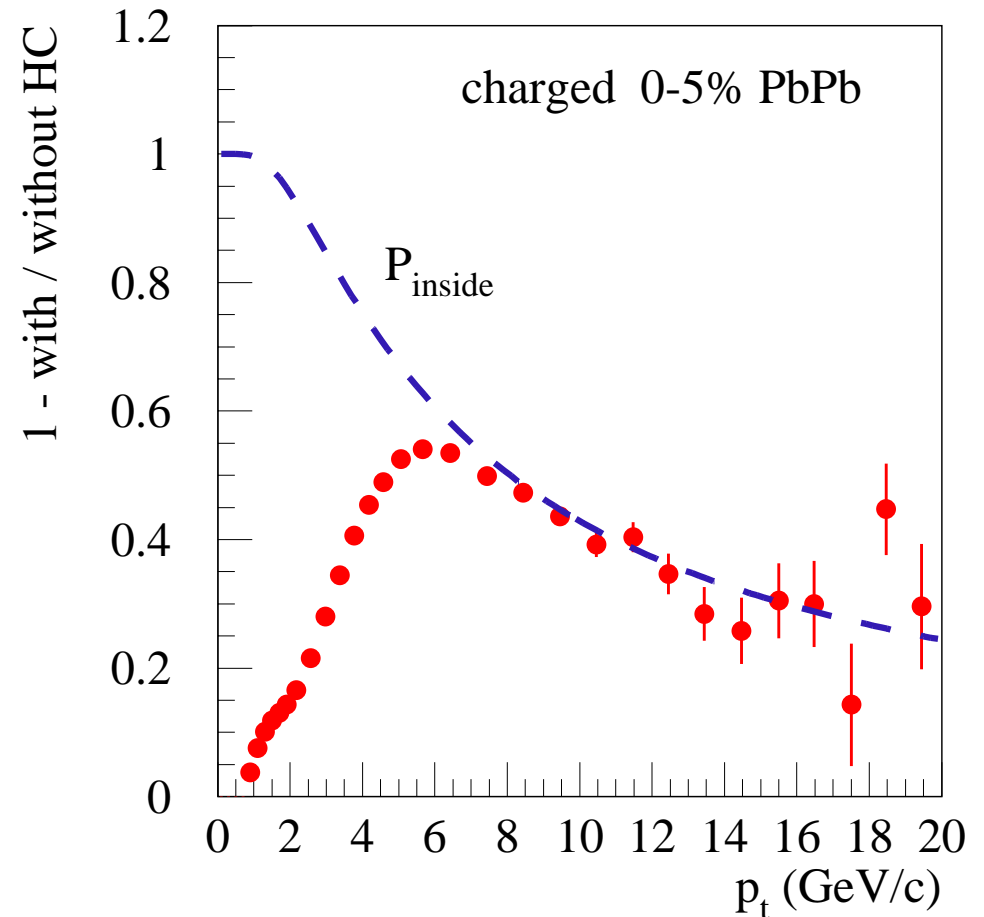
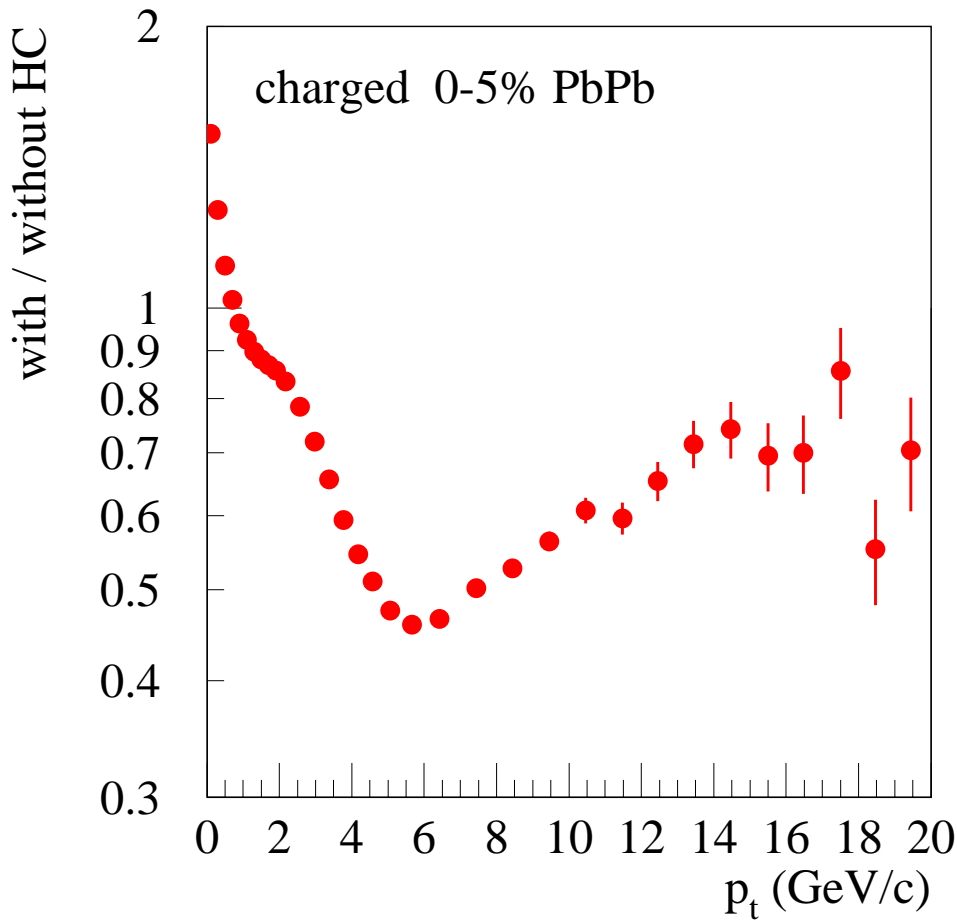
red solid lines: full calculation

green points: data ALICE

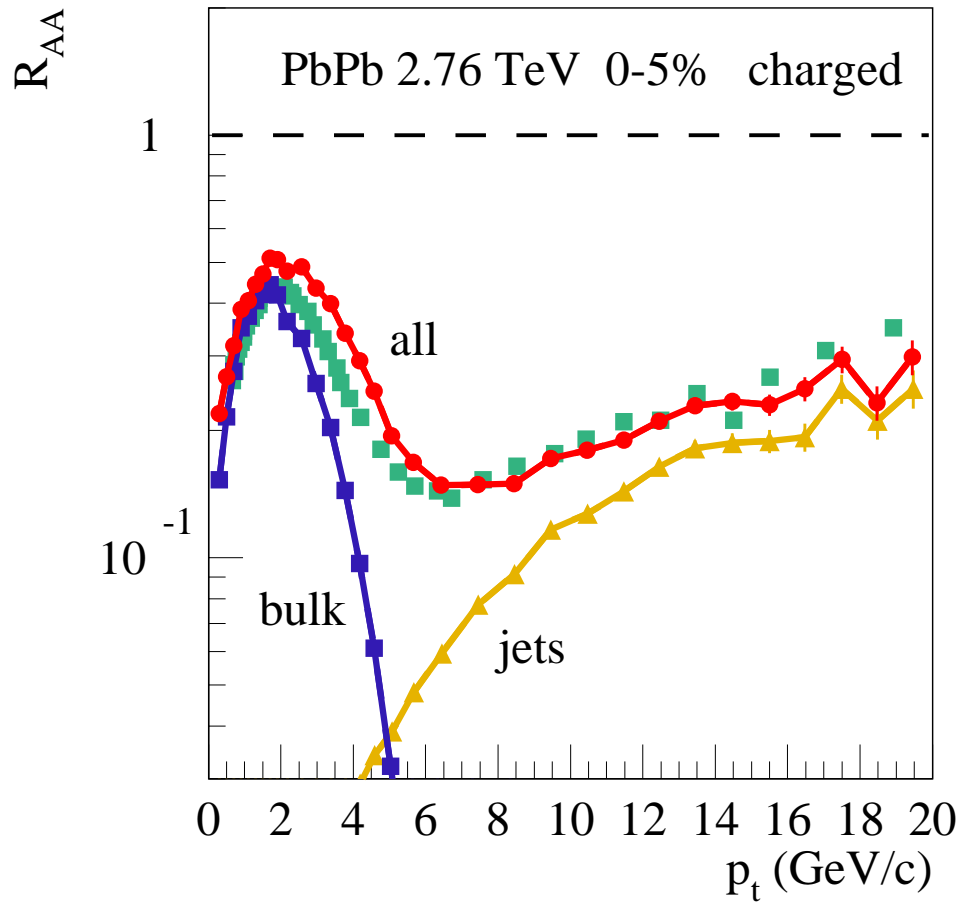
Hadronic cascade important ! HC=UrQMD

**Ratio of charged particle spectra:
full model / calculation without HC**

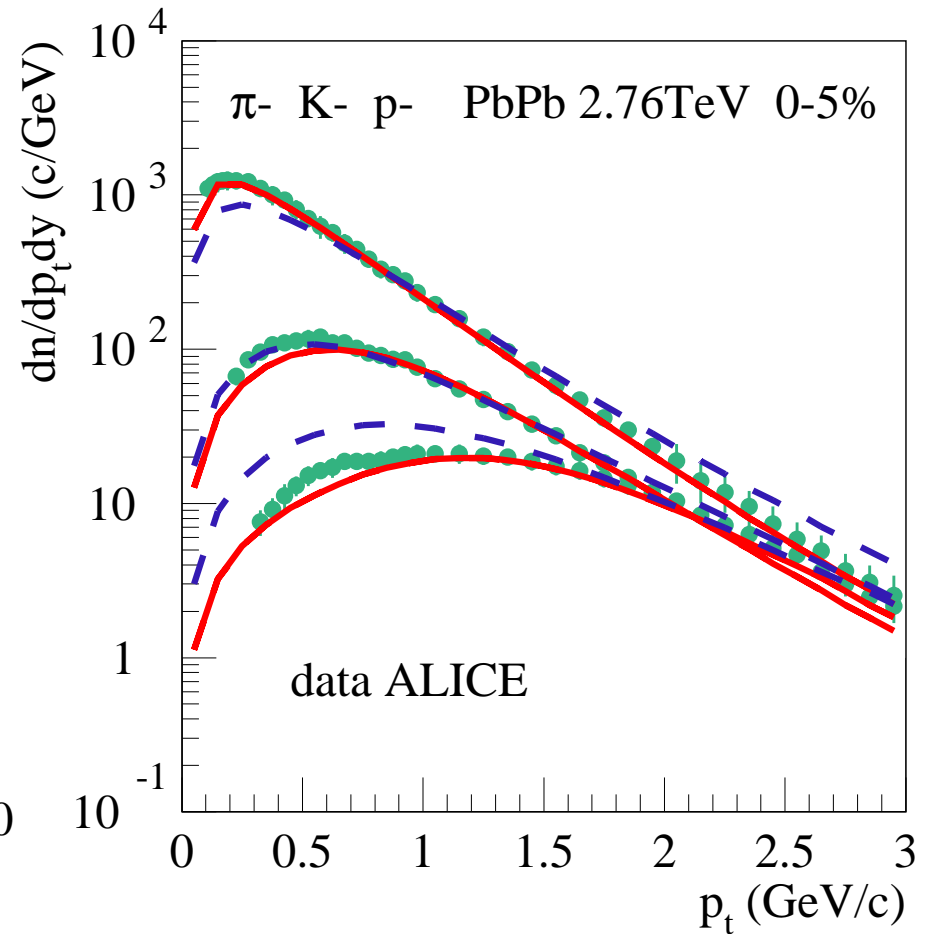
**“1 - ratio”
compared to P_{inside}**

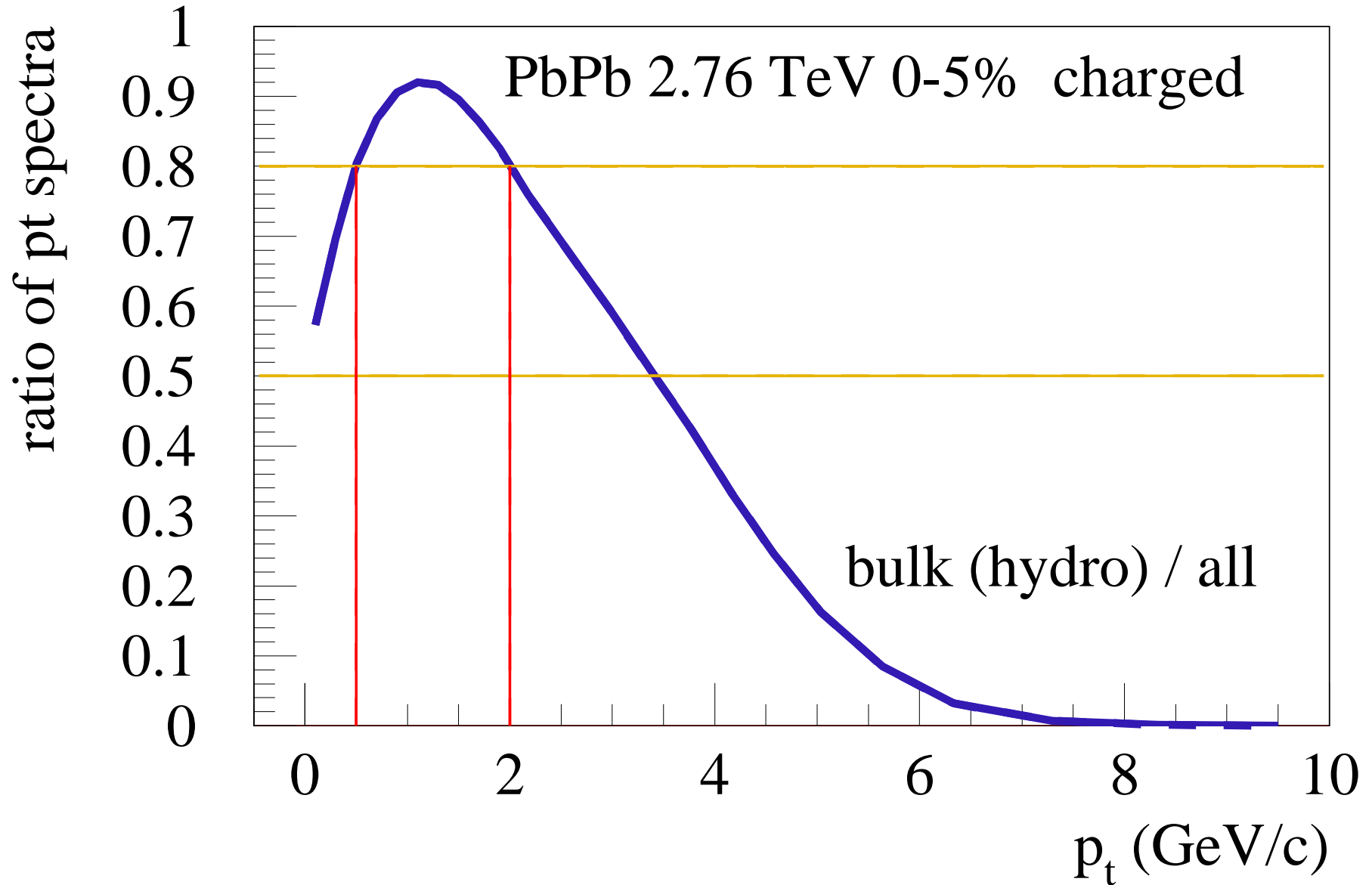


Charged particle R_{AA}

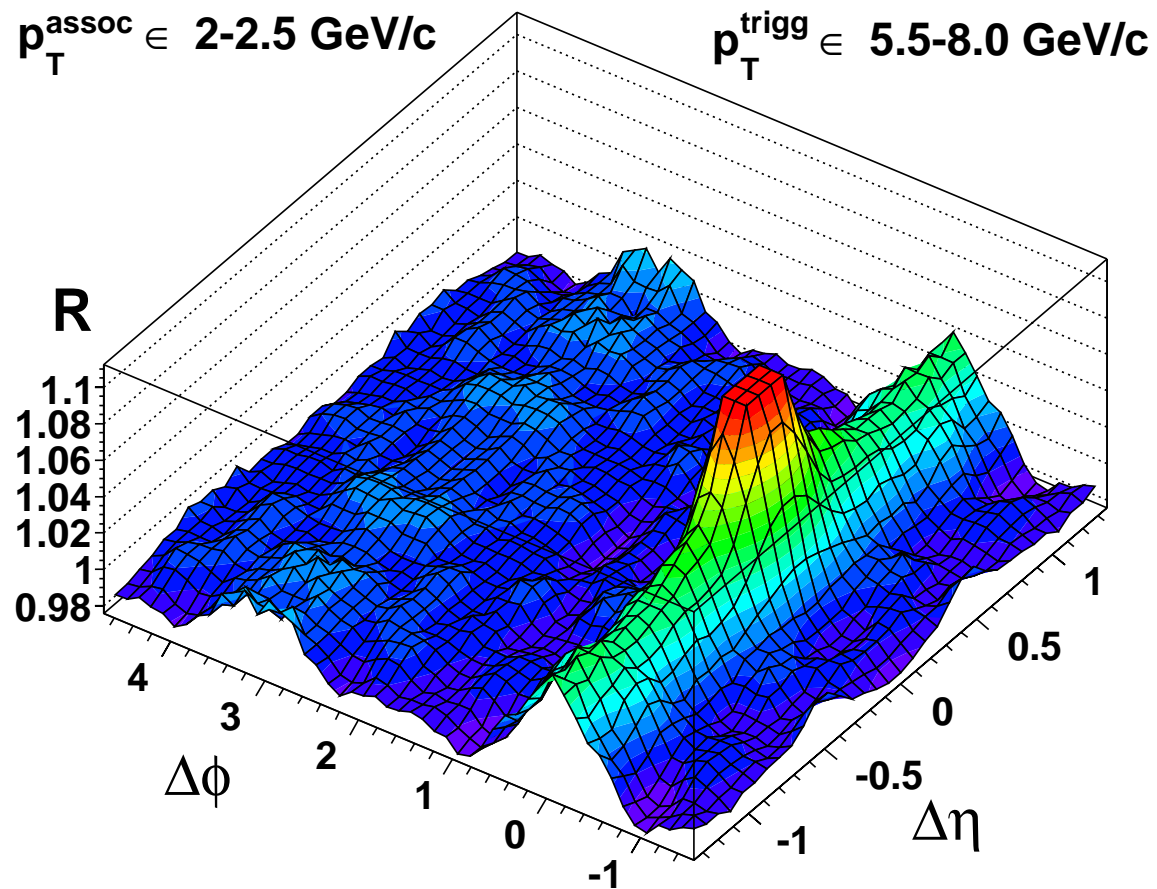


incompatible with PID results

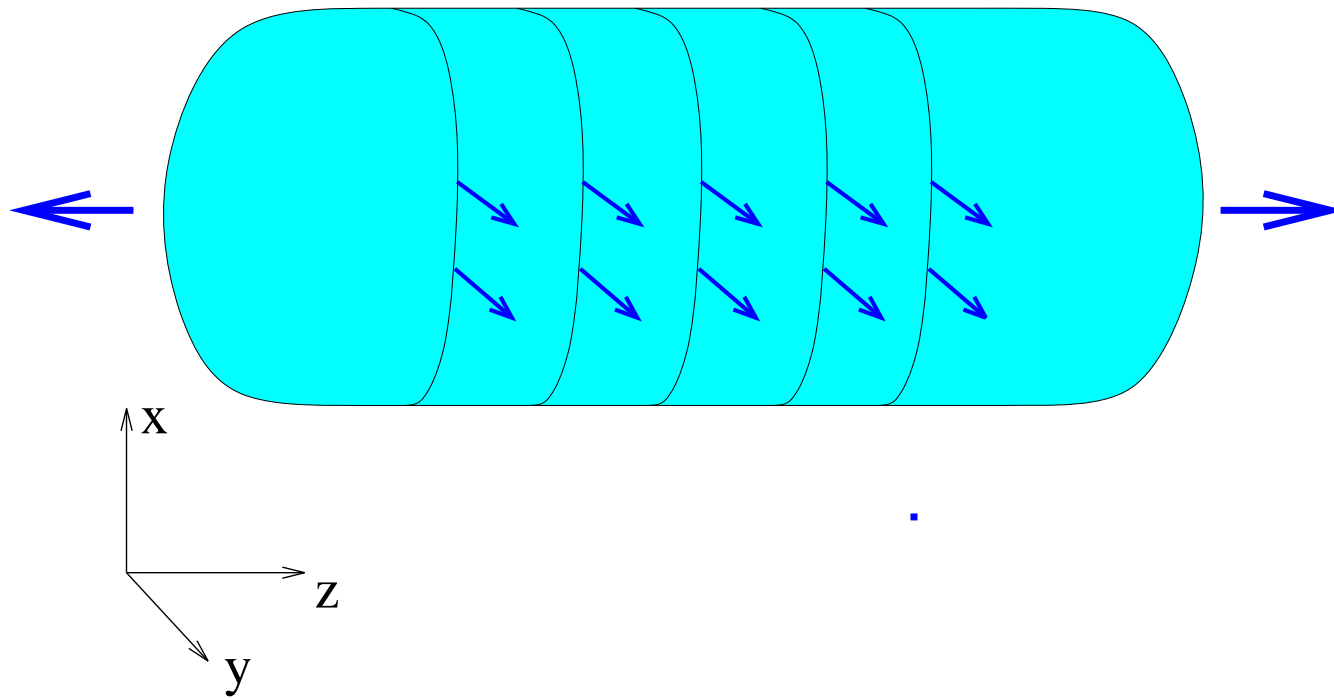




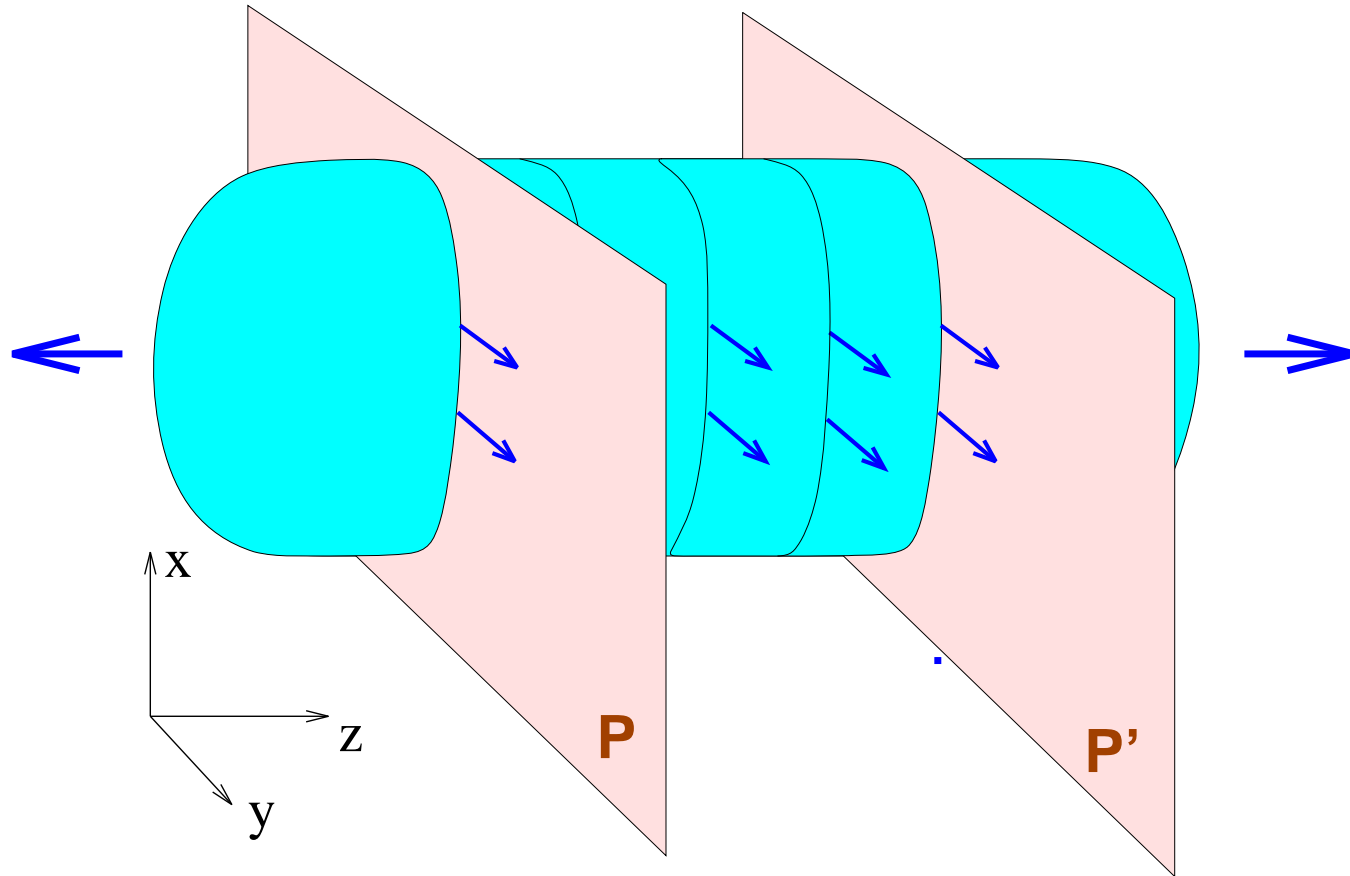
Dihadron correlations : ridges at high pt
(0-5% PbPb)



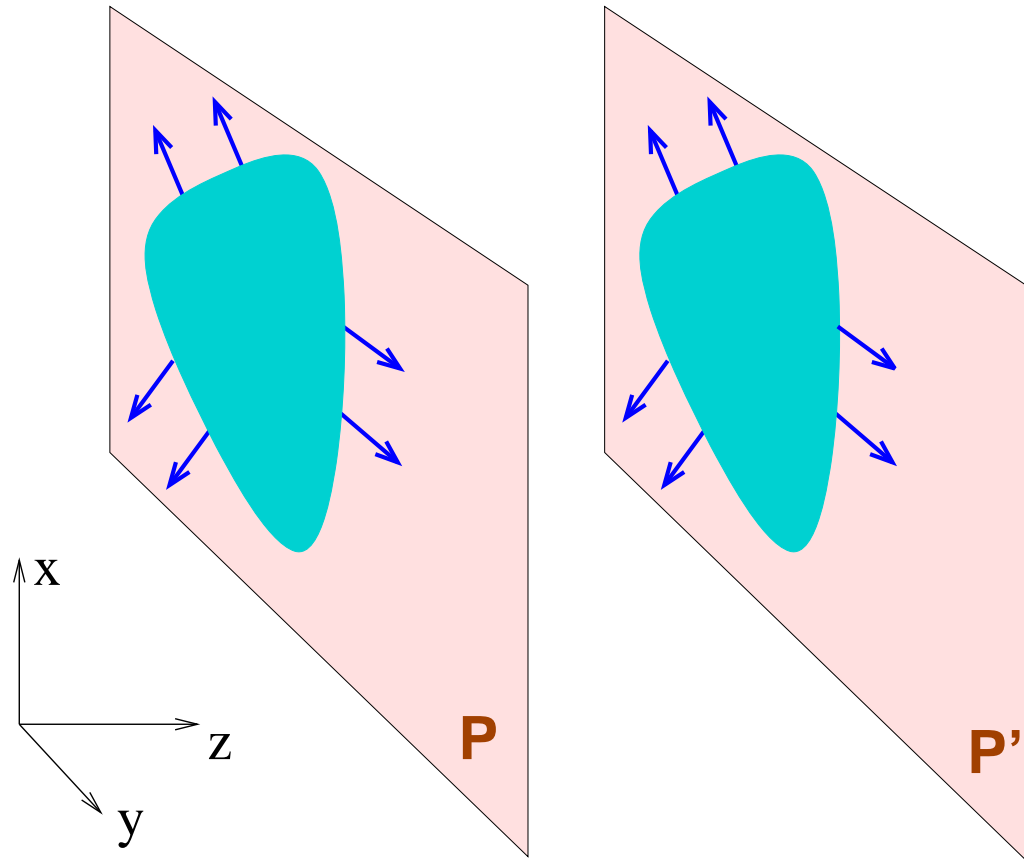
Freeze-out surface of fluid



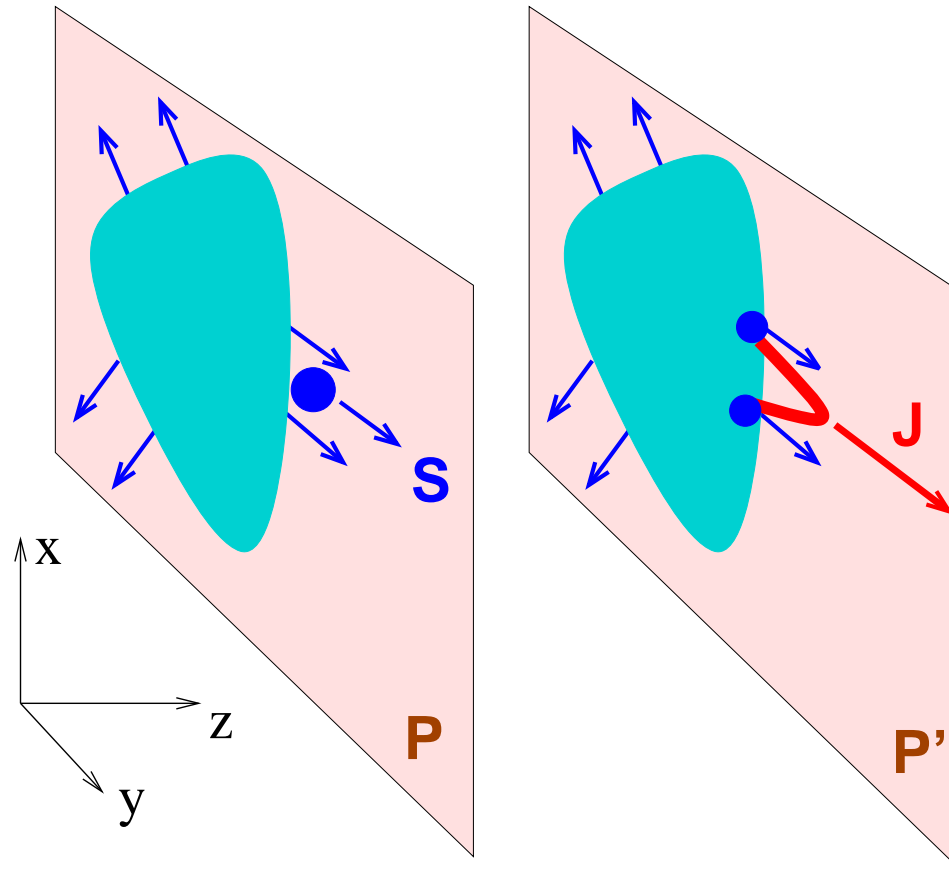
Cuts at two different z-values (P and P')



Same triangular shape and flow on P and P'

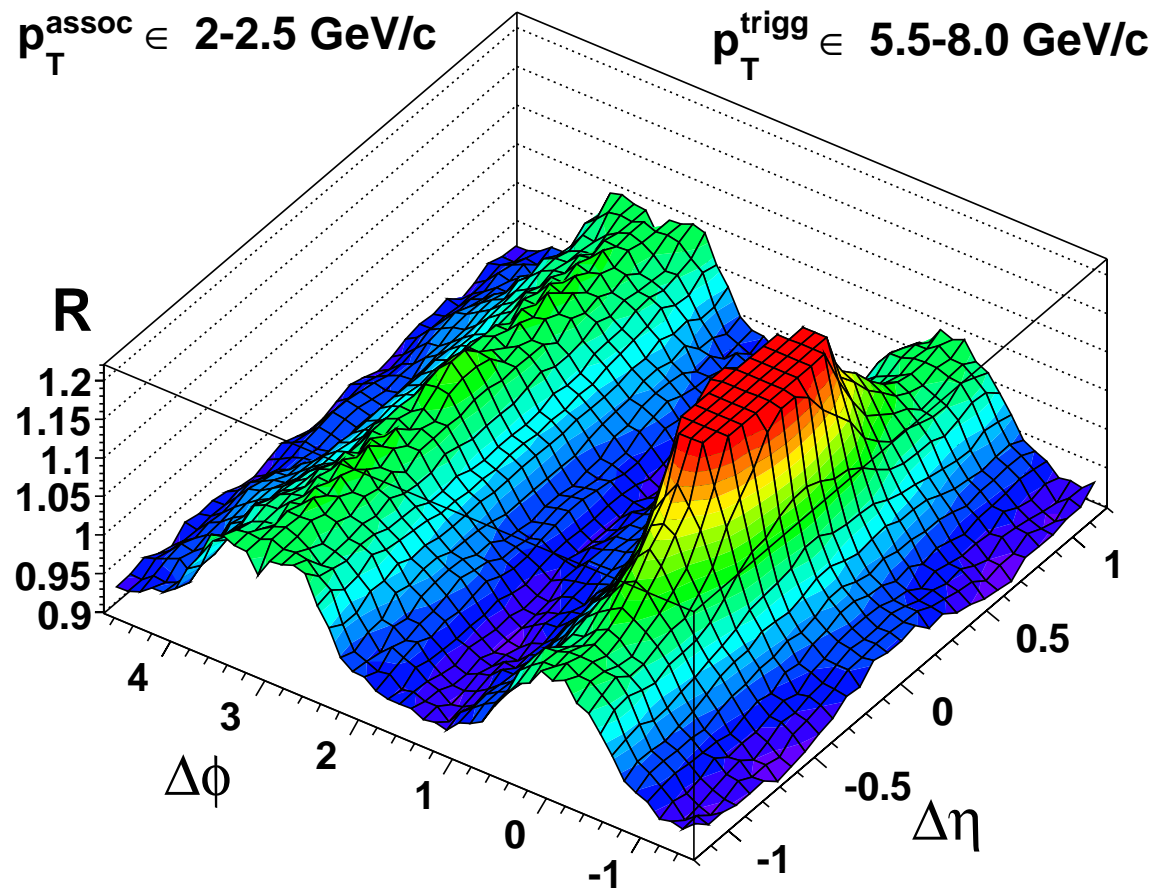


gives soft-jet correlation



also strong jet-soft correlation for peripheral events

(40-50% PbPb)



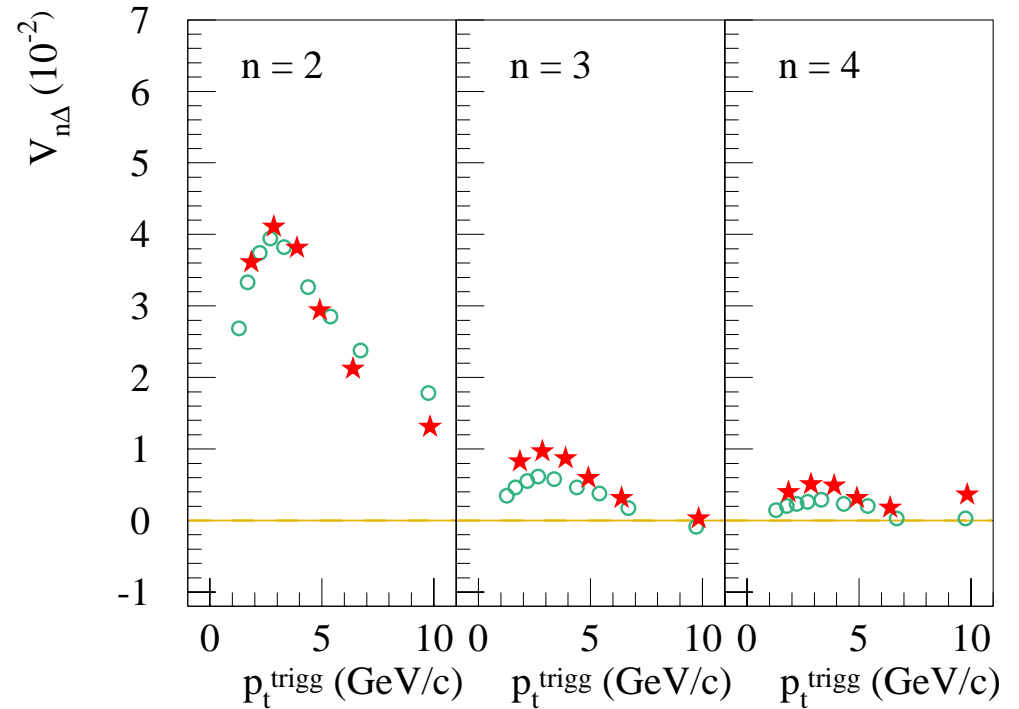
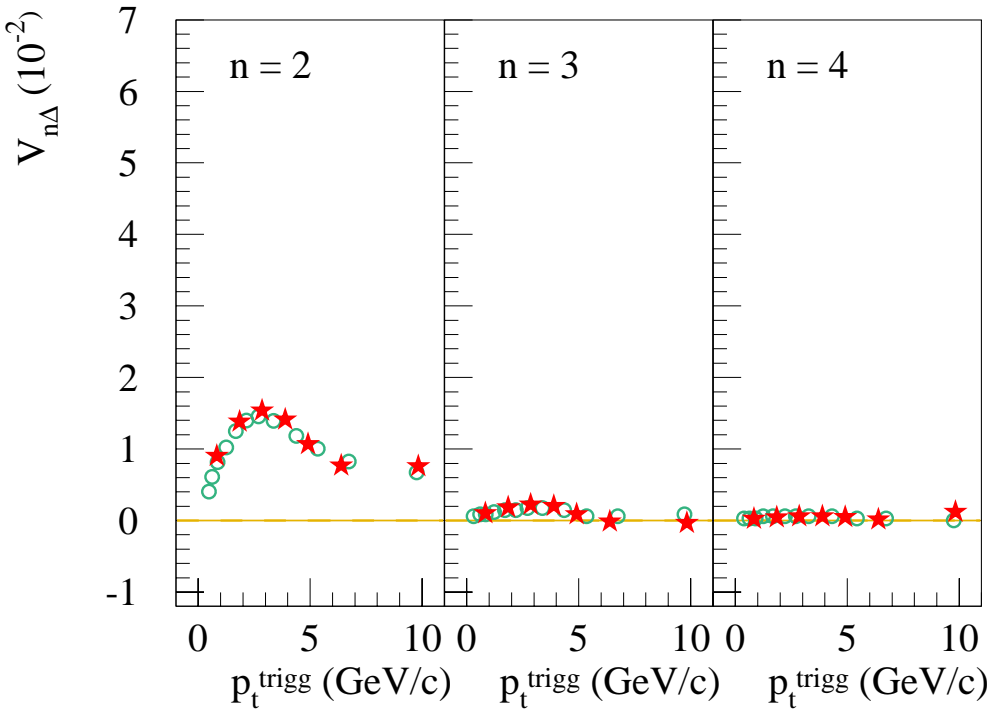
$$R(\Delta\phi) = \frac{1}{2(B - A)} \int_{A < |\Delta\eta| < B} R(\Delta\eta, \Delta\phi) d\Delta\eta$$

$$R(\Delta\phi) = 1 + \sum_{n=1}^5 2V_{n\Delta} \cos(n\Delta\phi)$$

40-50% PbPb

$p_t^{\text{assoc}} \in 0.25-0.5 \text{ GeV}/c$

$p_t^{\text{assoc}} \in 1.0-1.5 \text{ GeV}/c$

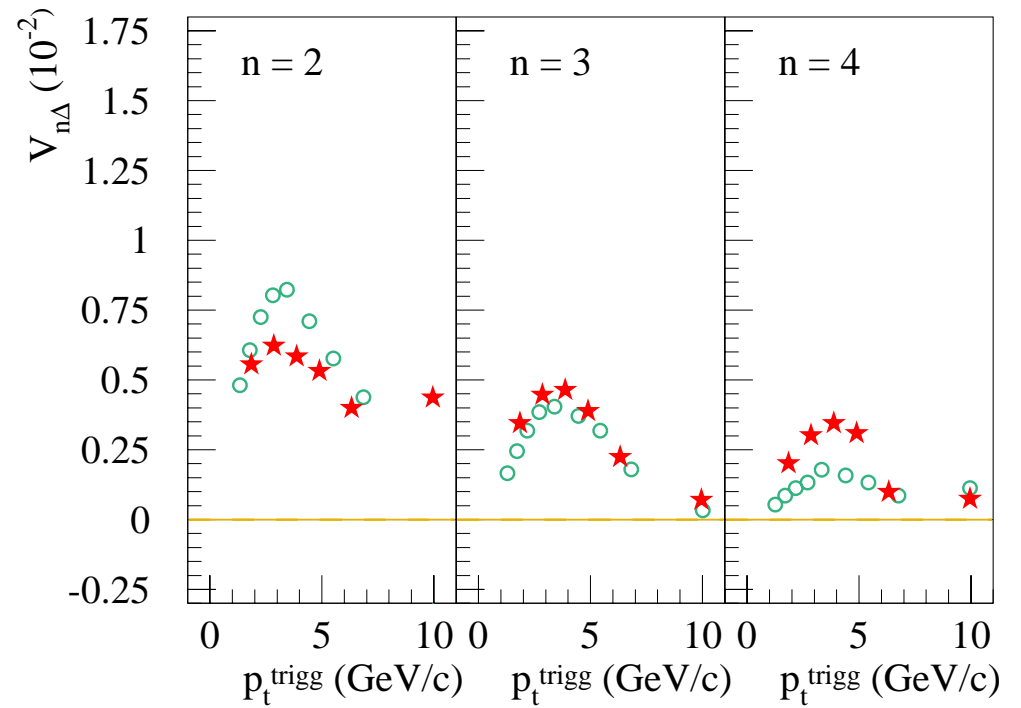
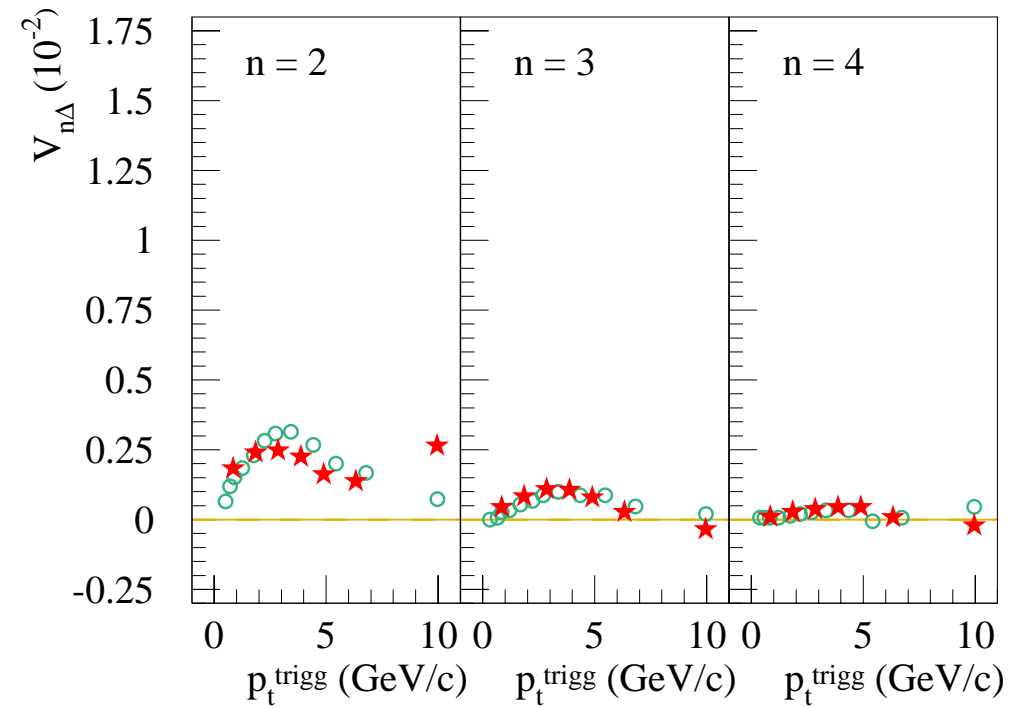


around 3 GeV/c : transition from soft-soft to soft-jet correlation

0-10% PbPb

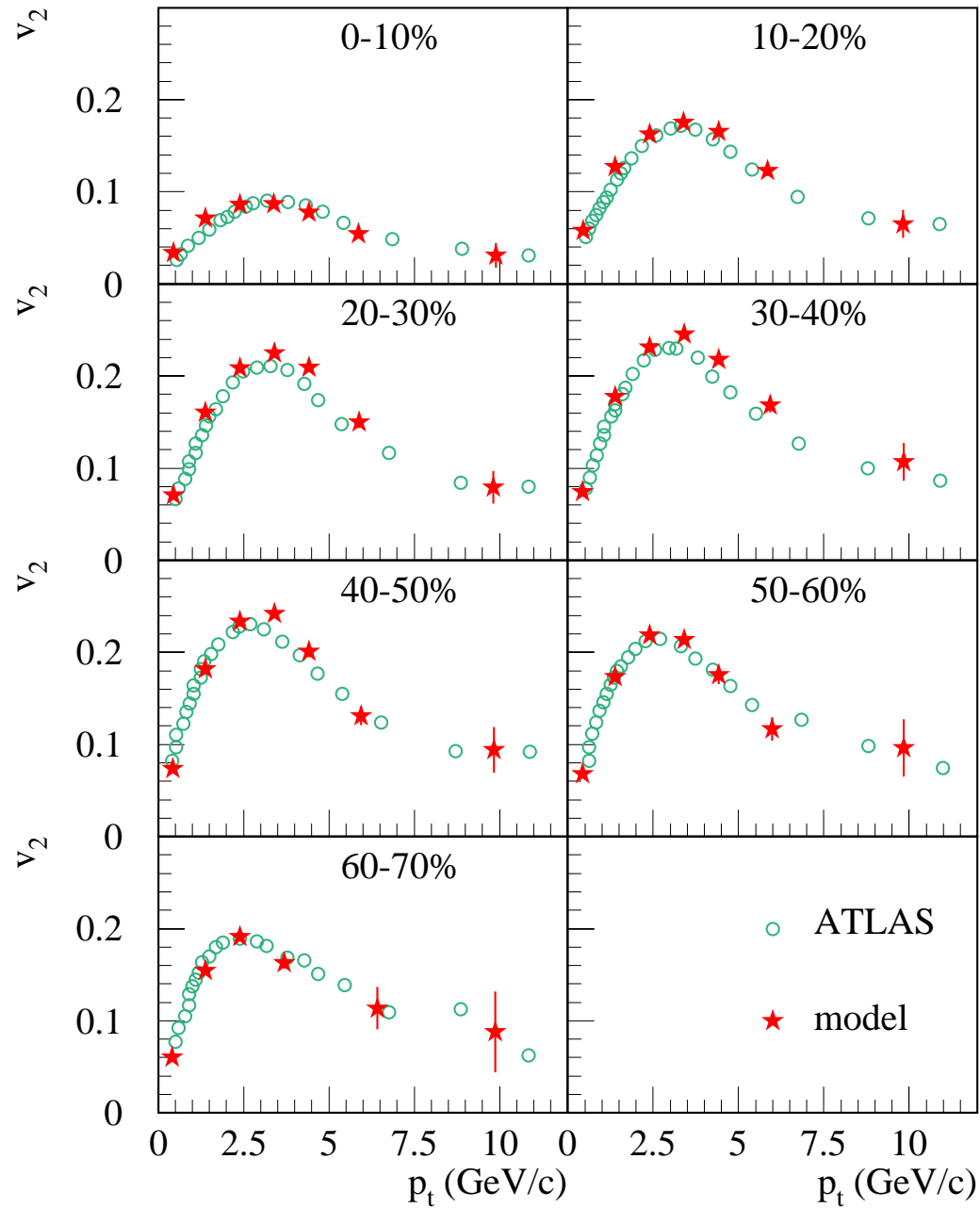
$p_t^{\text{assoc}} \in 0.25-0.5 \text{ GeV}/c$

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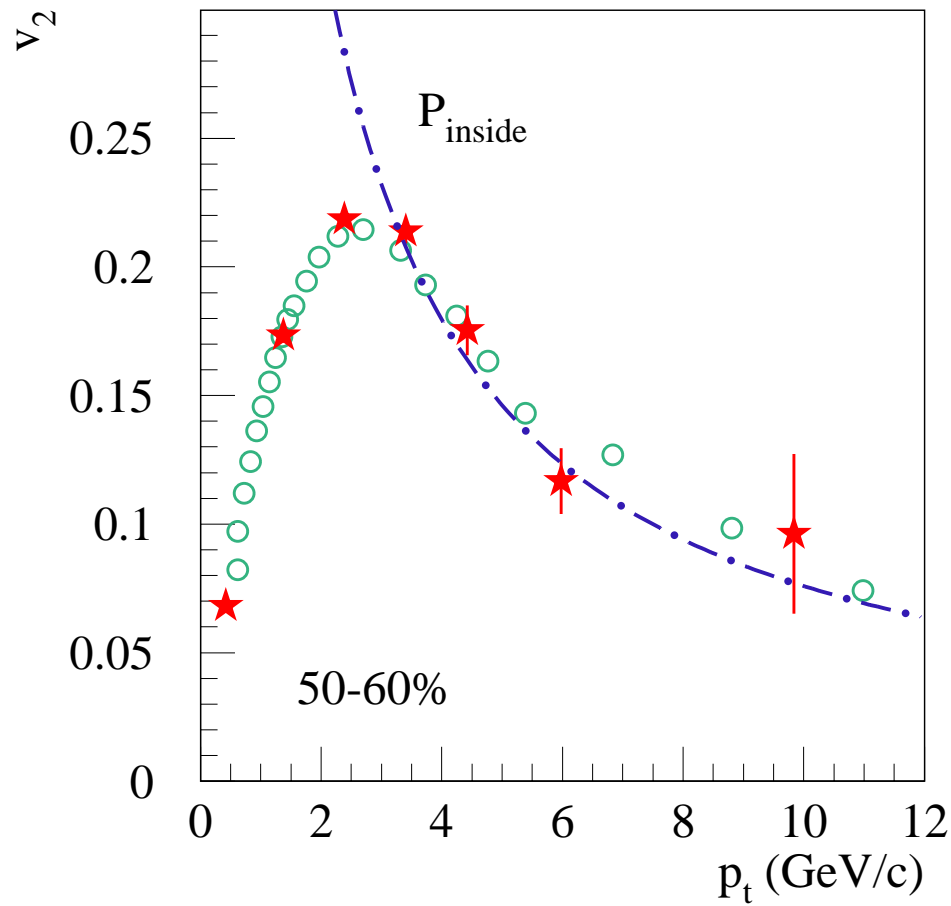


$$v_2 = \langle \cos[2(\phi - \phi_{\text{Ref}})] \rangle$$

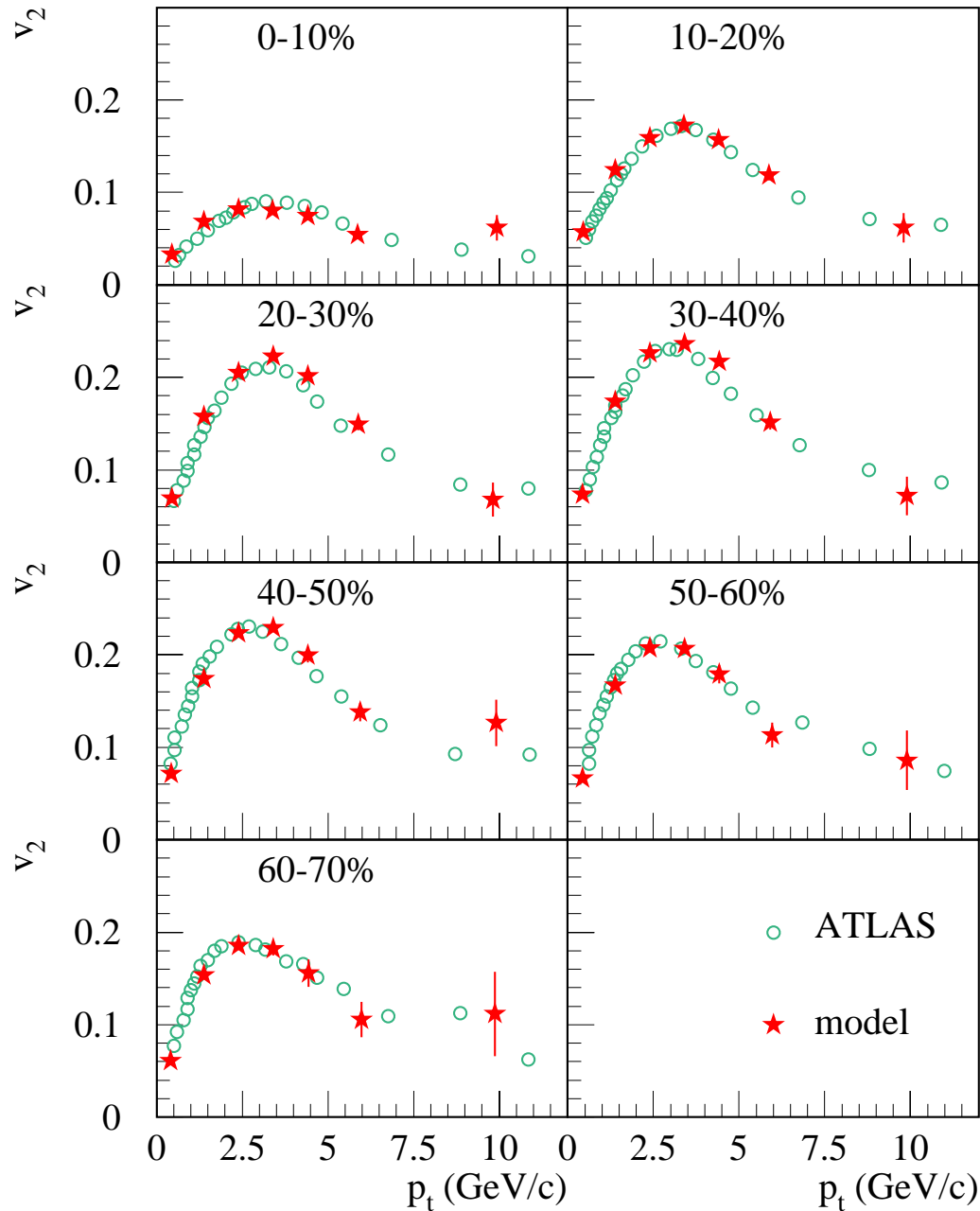
$$\phi_{\text{Ref}} = \phi_{\text{opposite hemisphere}} = \frac{1}{2} \tan^{-1} \frac{\langle \sin 2\phi \rangle}{\langle \cos 2\phi \rangle}$$



Tails again formation time driven:

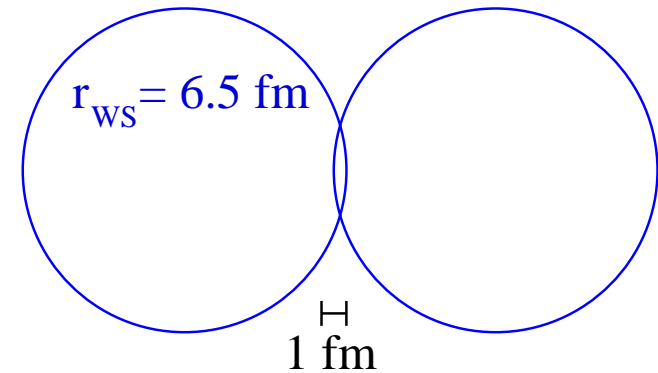


VERY long tails



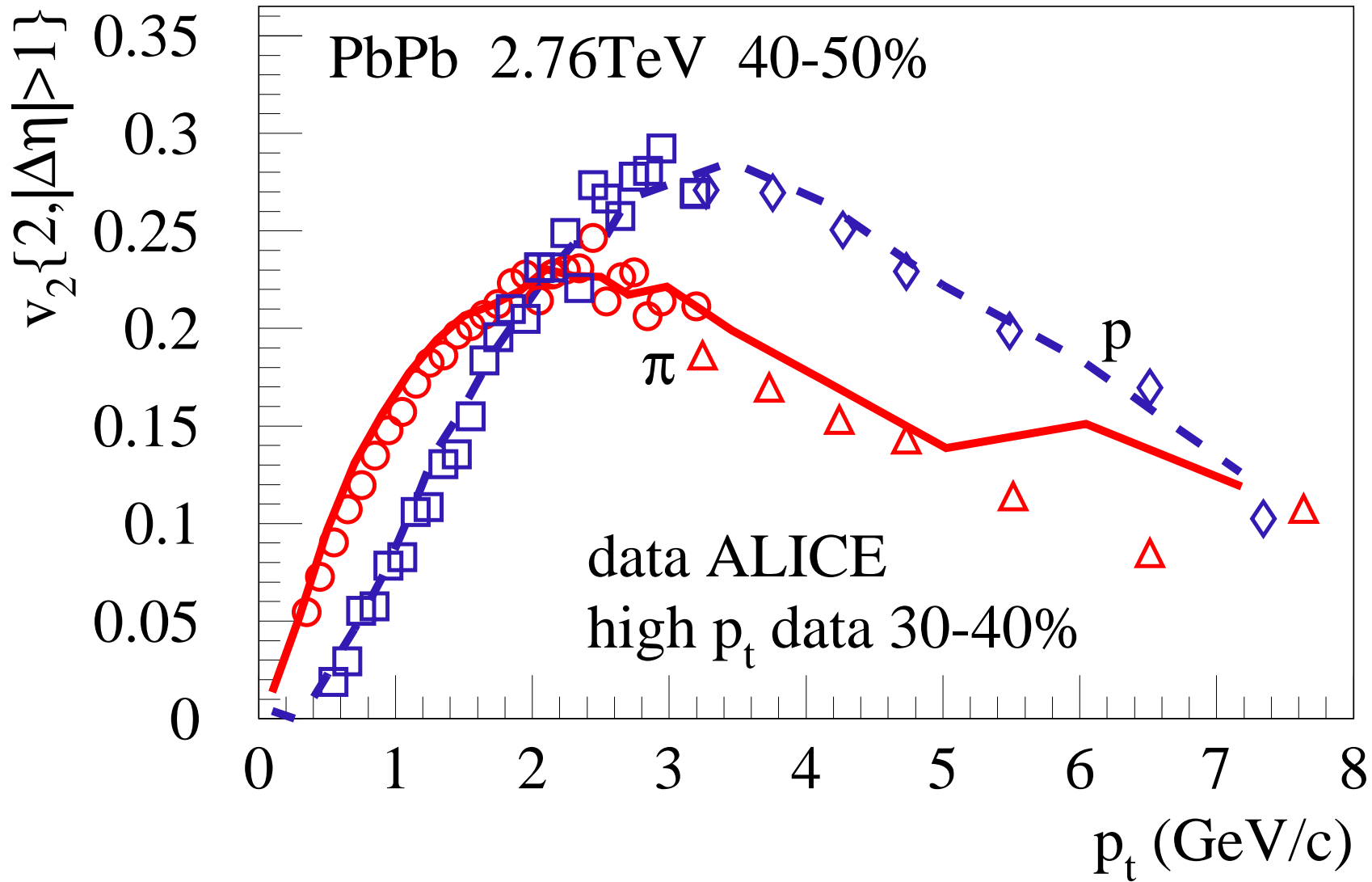
Interesting: Picture works up to peripheral collisions

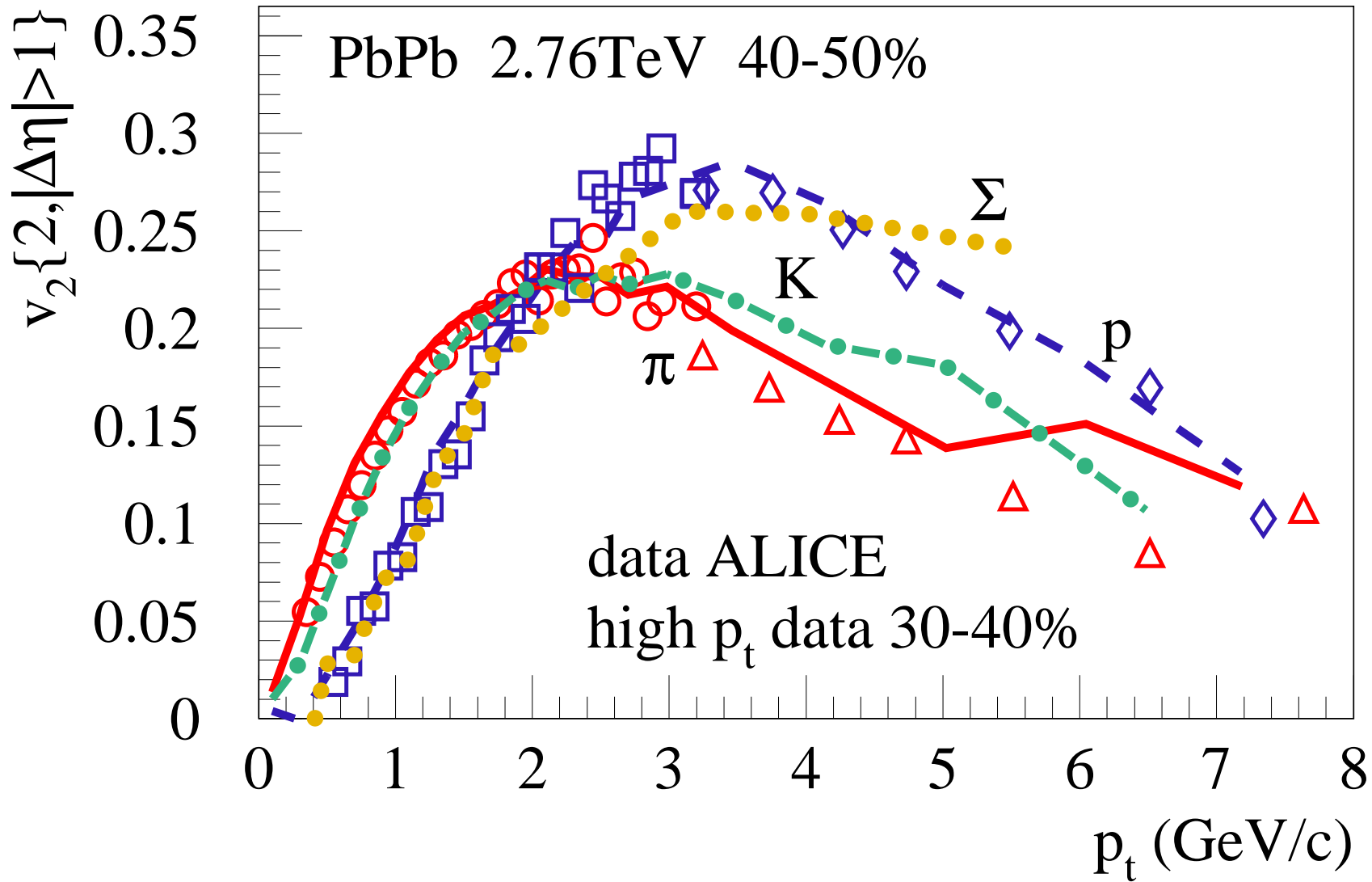
60-70% : $\langle b \rangle = 12.5$ fm

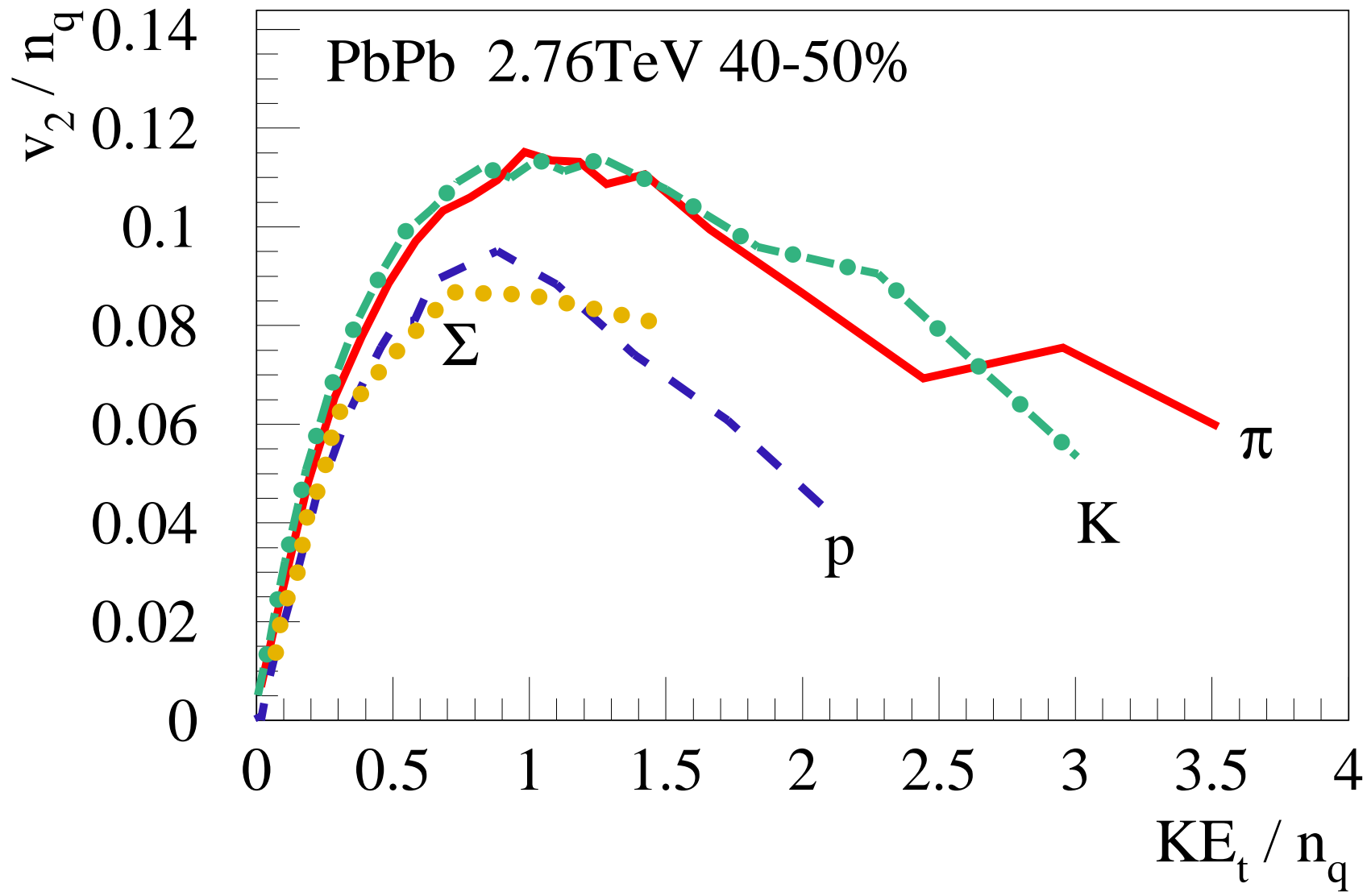


overlap like in pp!!

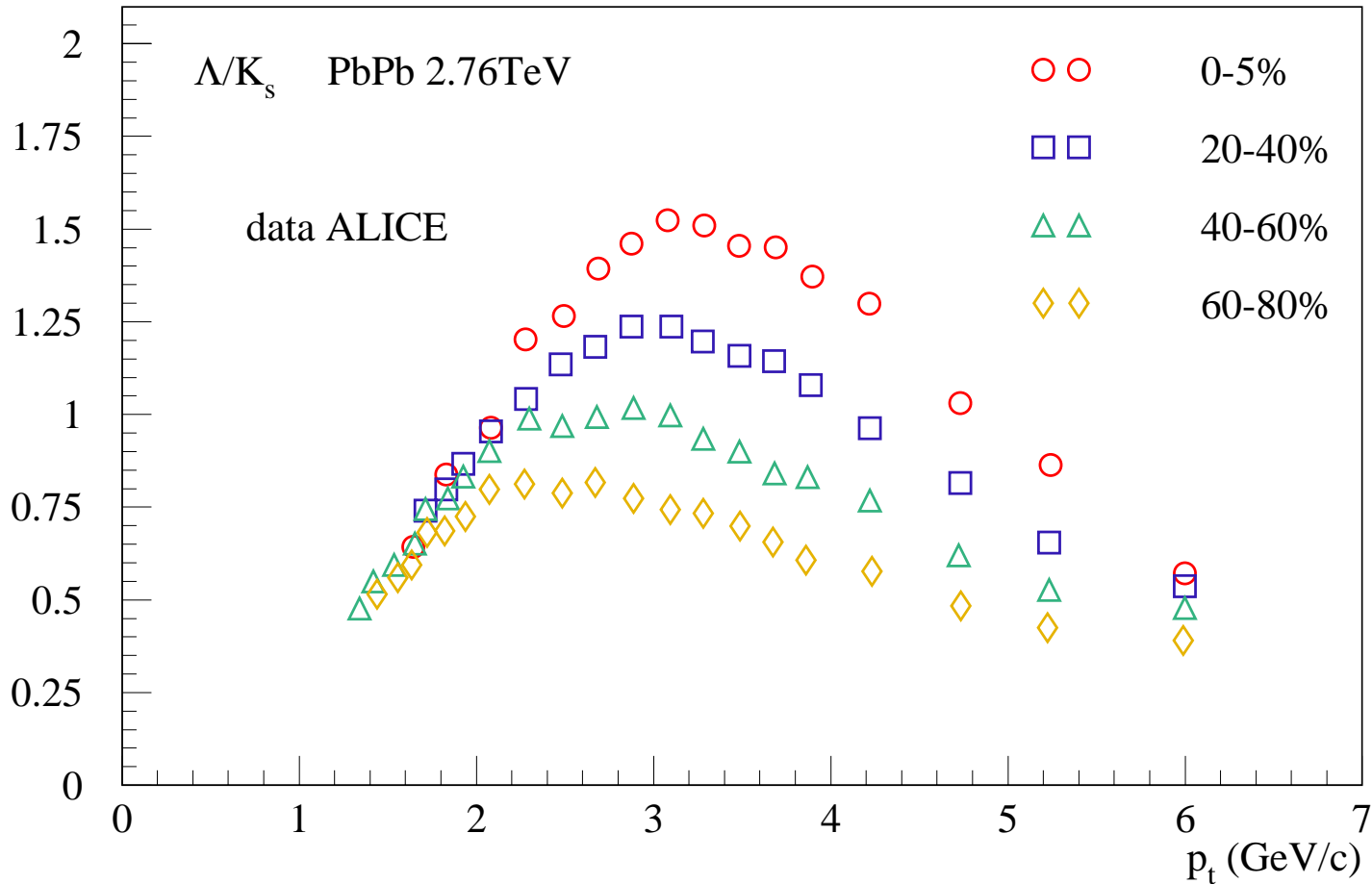
v2 scaling ???





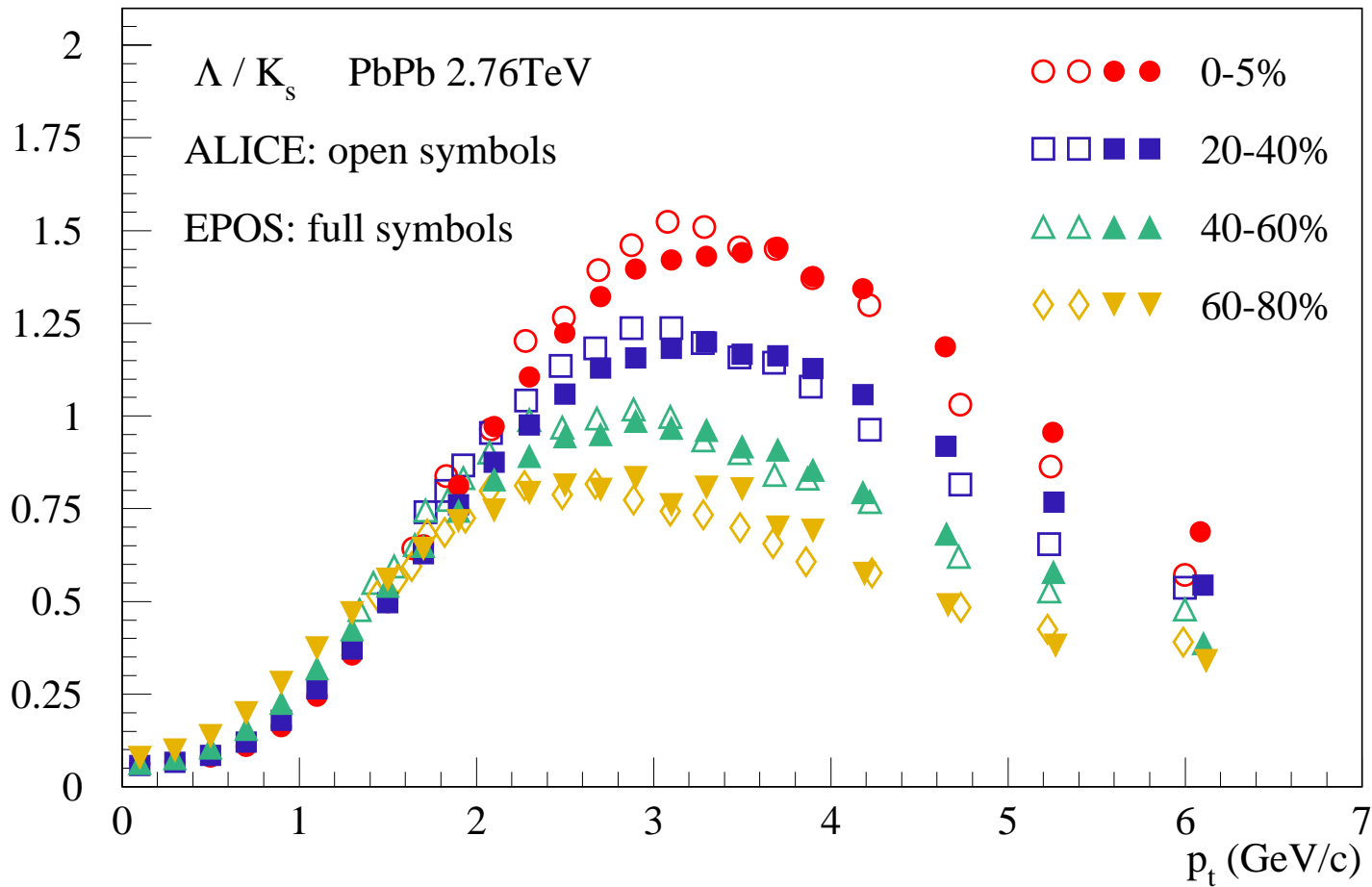


What about Lambda / kaon ratio??



One of the key observables at intermediate p_t

**We get for free:
Lambda/kaon ratio, PbPb at 2.76 TeV**



**size - formation
time effect**

**intermediate pt par-
ticles are produced
in the fluid**

**and carry plasma
properties like
flow, increased
strangeness and
diquark rate**

Summary

- **We present a framework for treating bulk, jets, and their interaction.**
- **Jet-soft and fluid-jet interactions (jet = hadrons) affect particle productions VERY STRONGLY between 0 and 20 GeV/c (even up to 50 GeV/c). Parton energy loss dominant beyond.**
- **Reasonable quantitative description of yields, flow harmonics, dihadron correlations with small and large trigger pt, pion,proton v_2 , lambda/K ratio**

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Thank you !!