Revealing the Source of the Radial Flow Patterns in Proton-Proton Collisions using Hard Probes

https://arxiv.org/abs/1608.04784

Gyula Bencedi [1,2]

in collaboration with A. Ortiz [2], H. Bello [3]

1 Wigner Research Centre for Physics of the HAS, Budapest, Hungary

2 Instituto de Ciencias Nucleares, UNAM, Mexico City, Mexico

3 Facultad de Ciencias Fsico Matematicas, BUAP, Puebla, Mexico

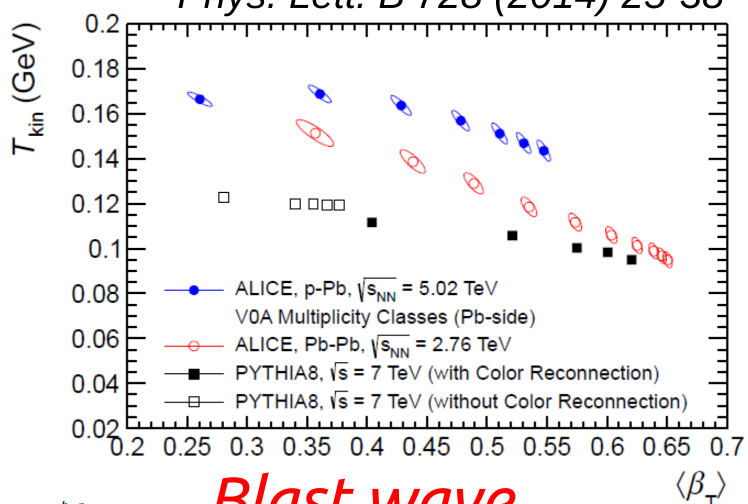
28.11.2016

Motivation

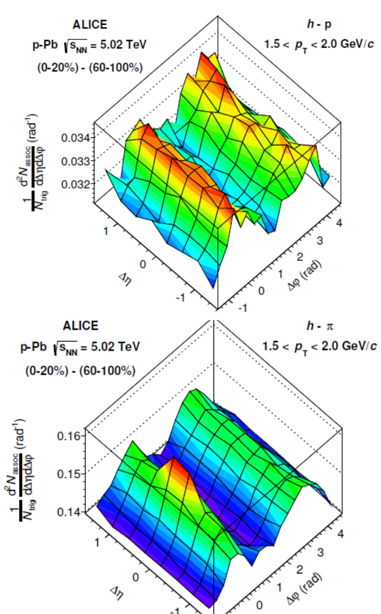
1) Collective-like effects (in high multiplicity events) **in small collision systems**:
(i) radial fow signals, **(ii)** long-range angular correlations, **(iii)** strangeness enh.

Phys. Lett. B 728 (2014) 25-38

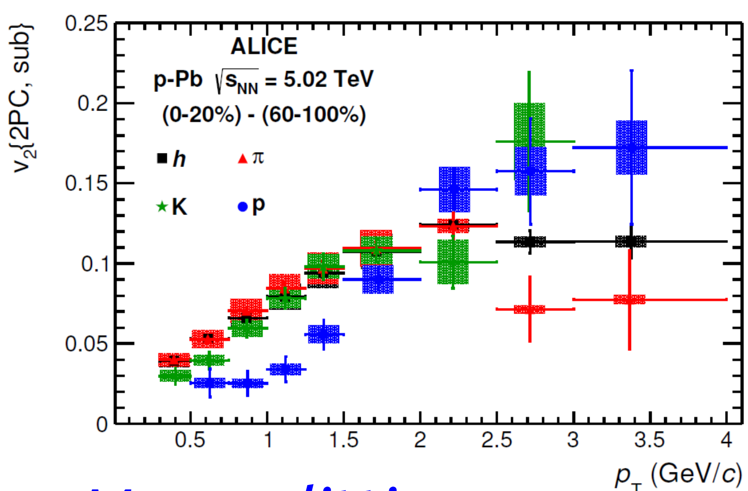
(i)



Blast wave

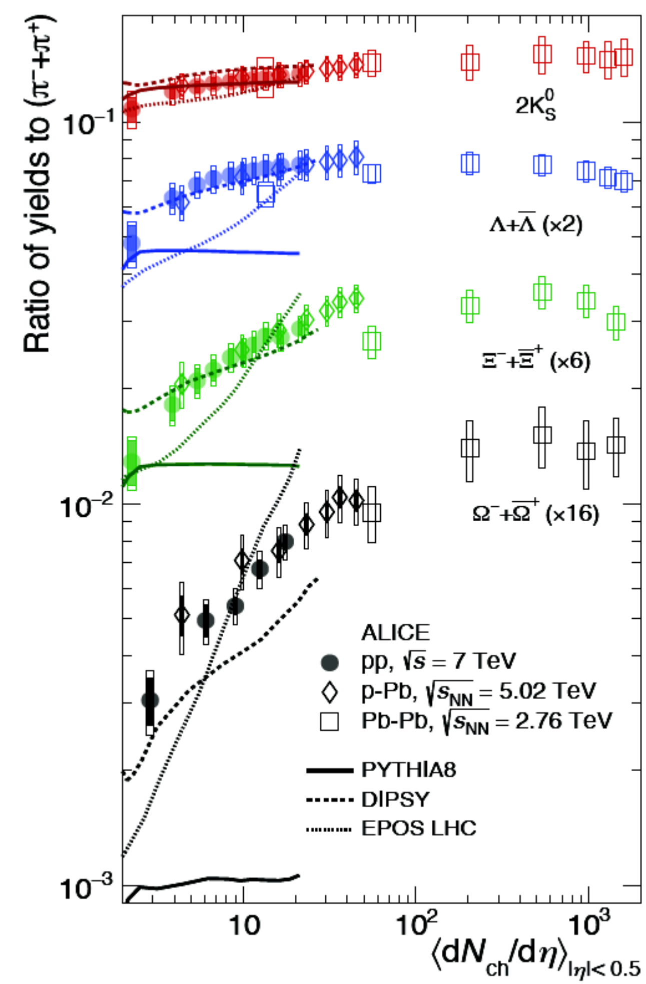


(ii)



Mass splitting

(iii)



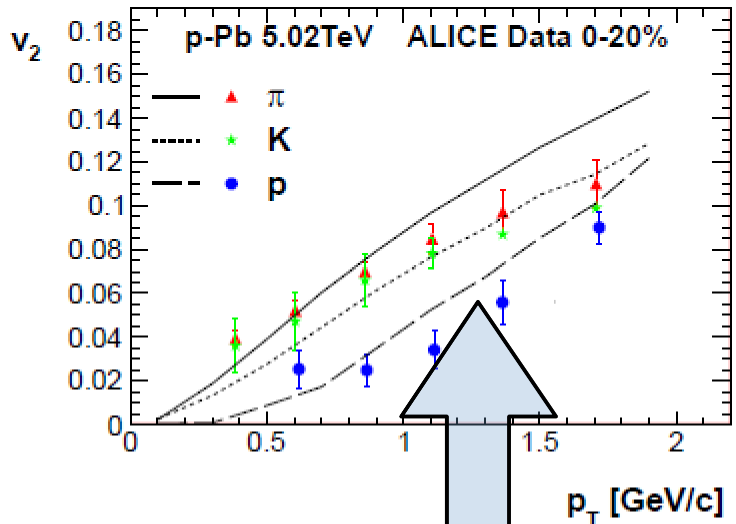
Strangeness enhancement

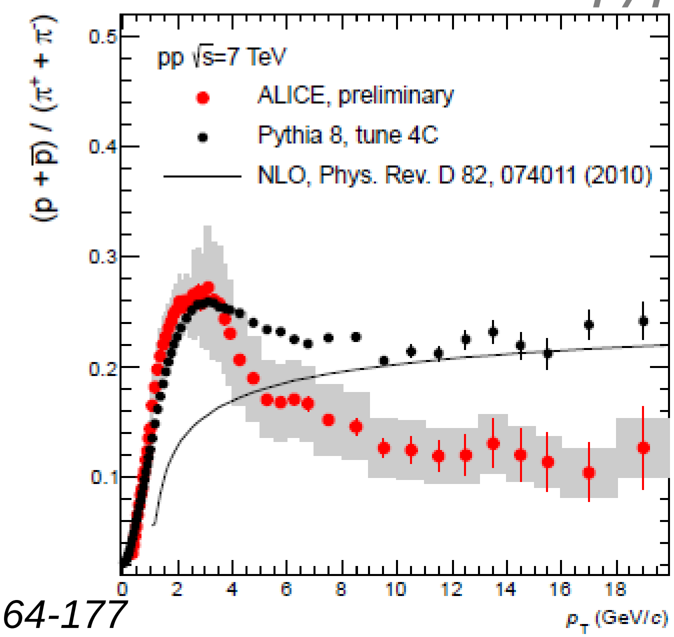
Motivation

2) Hydro and CR reproduces collective-like effects

CR and p/pi ratio

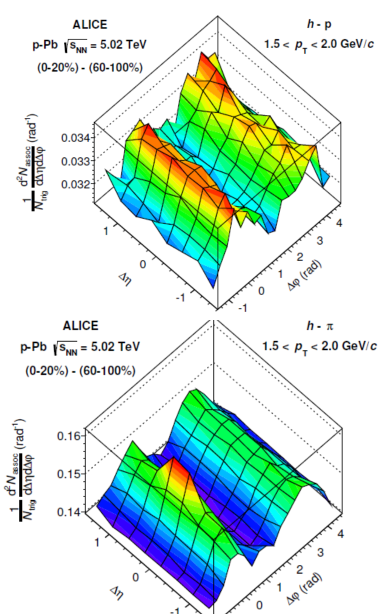
Bozek et. al, Phys. Rev. Lett. 111, 172303 (2013)

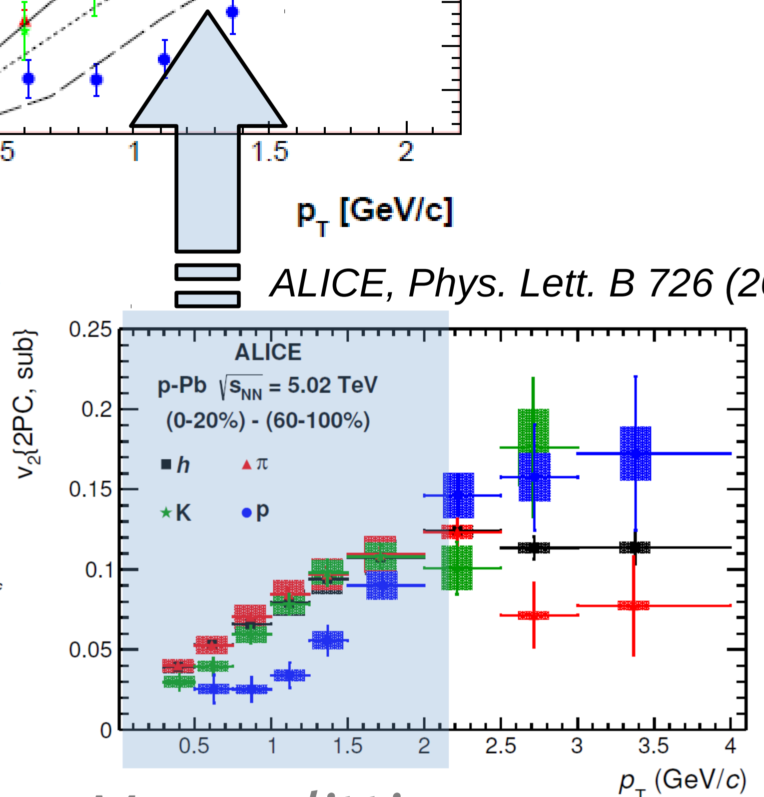


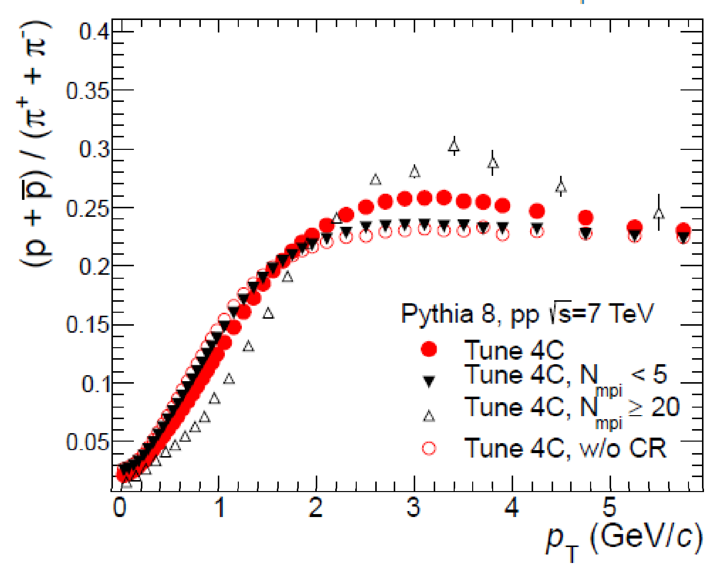


Phys. Rev. Lett. 111, 042001 (2013)

ALICE, Phys. Lett. B 726 (2013) 164-177





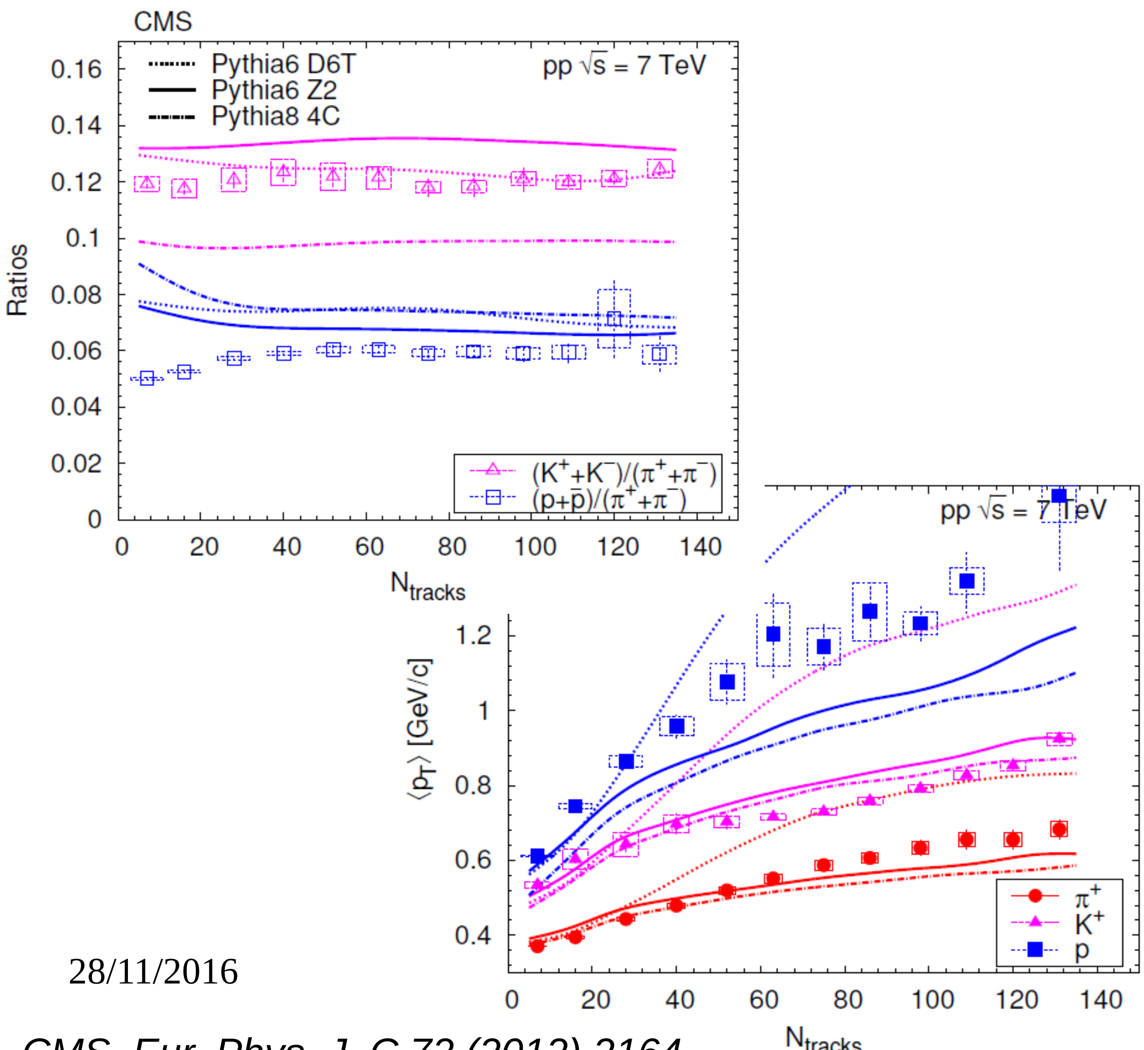


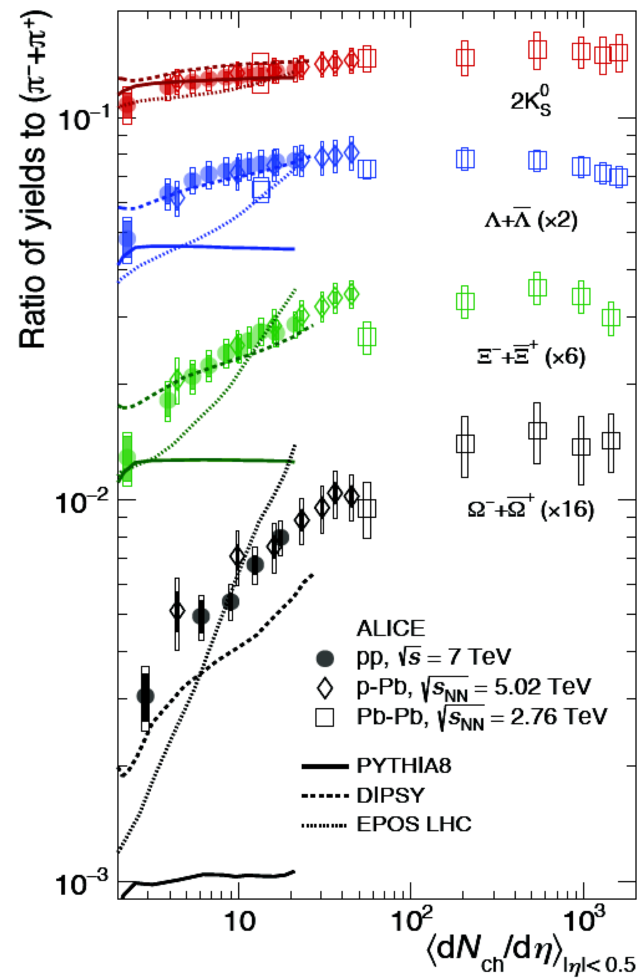
Mass splitting

Motivation

3) Models fail to describe p_T spectra vs N_{ch}

→ No final conclusions for explanation of radial flow





CMS, Eur. Phys. J. C 72 (2012) 2164

ALICE, arXiv:1606.07424v1 [nucl-ex]

Motivation

1) Collectivity in small systems → radial fow signals, long-range angular correlations, and the strangeness enhancement
2) Hydro and CR reproduces collective-like effects (and many others, like AMPT, DIPSY, CGC)
3) Models fail to describe p_T spectra vs N_{ch} → No final conclusions for explanation of radial flow

- ***Propose to study how jets modify the low-p_T region***
- In CR models: strong correlation of soft and hard components
  → correlation between radial flow-like and hard component
- In a hydro-driven scenario: jets are not expected to strongly modify the radial fow patterns
- by exploiting such a fundamental difference between both models, one might say whether or not the observed effects are driven by hydrodynamics

Goal: analyze mid-rapidity inclusive identified charged-hadron production as a function of $N_{ch,|y|<1}$ and $p_{T,jet}$ of the jet found within the same acceptance

Observables and kinematic sets

- The *relevant observable* to study the radial flow is the transverse momenta of the particles produced in the collisions

- The invariant pt distribution depends of the temperature at freeze out, the particle mass and the velocity profile

- Minimum bias inclusive measurements of charged pion, kaon and proton at mid-rapidity $|y|<1$

1) $1/2\pi p_T \, d^2N/dy dp_T$ invariant yield for pion, kaon, protons
   → obtian particle ratios
   → Blast wave model fits

2) $z = dN/deta \,/\, \langle dN/deta \rangle$
   → study observables for different values of z (low and high)

3) Jet finder: FastJet 3 – p_T^{jet}: selection of samples based on cuts on the p_T of a jet

4) Sample: 100M min.bias events (which were subsequently split into z classes)

5) Pythia 8.212 (Monash-2013) and EPOS 3.117: → w/ and w/o CR/Hydro

Applied tools

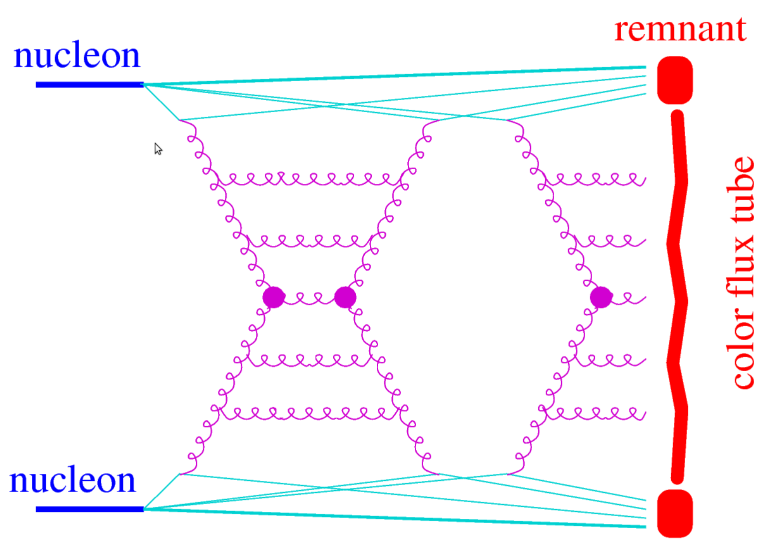
—

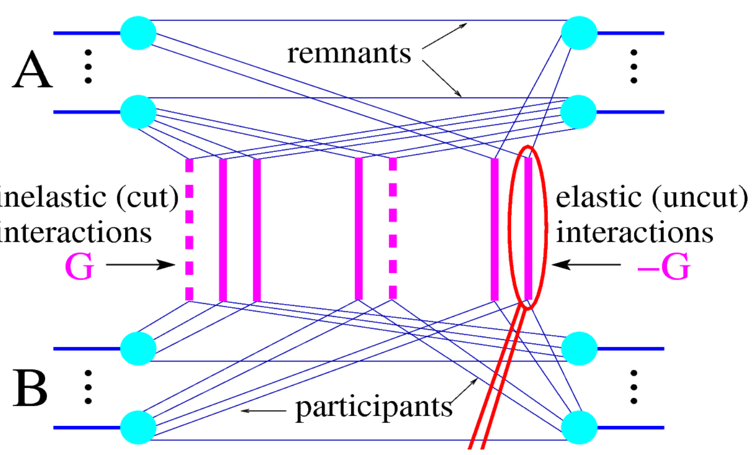
Monte Carlo event generators: Pythia 8 and EPOS 3

and

Jet Finder: FastJet 3

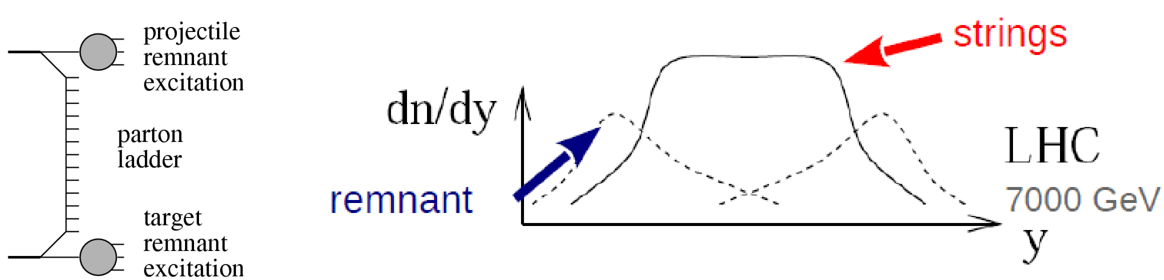
EPOS 3
hydrodynamic core hadronisation





1) EPOS is designed to be used for particle physics experiments (SPS,RHIC, LHC) for pp and heavy ions

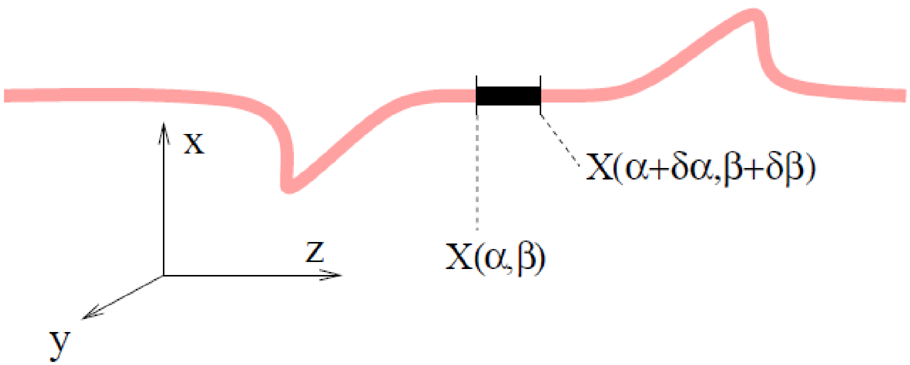
2) EPOS is a parton based (Gribov Regge theory) model where the partons initially undergo multiple scatterings:
   - each scattering is composed of hard elementary scattering with initial and final state linear parton emission forming parton ladder or "pomeron"
   - Parton ladder may be considered as a quasi-longitudinal color field, a so-called "flux tube", conveniently treated as a relativistic string

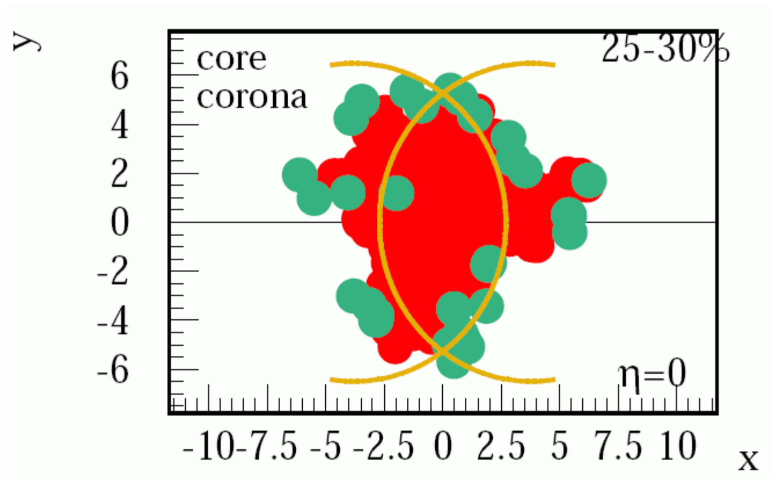


EPOS 3 basically contains a *hydrodynamical approach* based on flux tube initial conditions

This *flux tube* decays via the production of quark-antiquark pairs, creating in this way fragments which are identified with hadrons

EPOS 3
hydrodynamic core hadronisation





String hadronisation

- based on the local density of string segments per unit volume with respect to a critical-density parameter
- Each string splitted into a sequence of string segments, corresponding to widths δα and δβ in the string parameter space
- Each string is classified as being in either
  - a **low density coronal** region
  - or in a **high density core** region
- ***Corona*** hadronisation: via unmodified string fragmentation
- ***Core*** is subjected to a *hydrodynamic evolution*; i.e. it is hadronised including additional contributions from longitudinal and radial flow effects

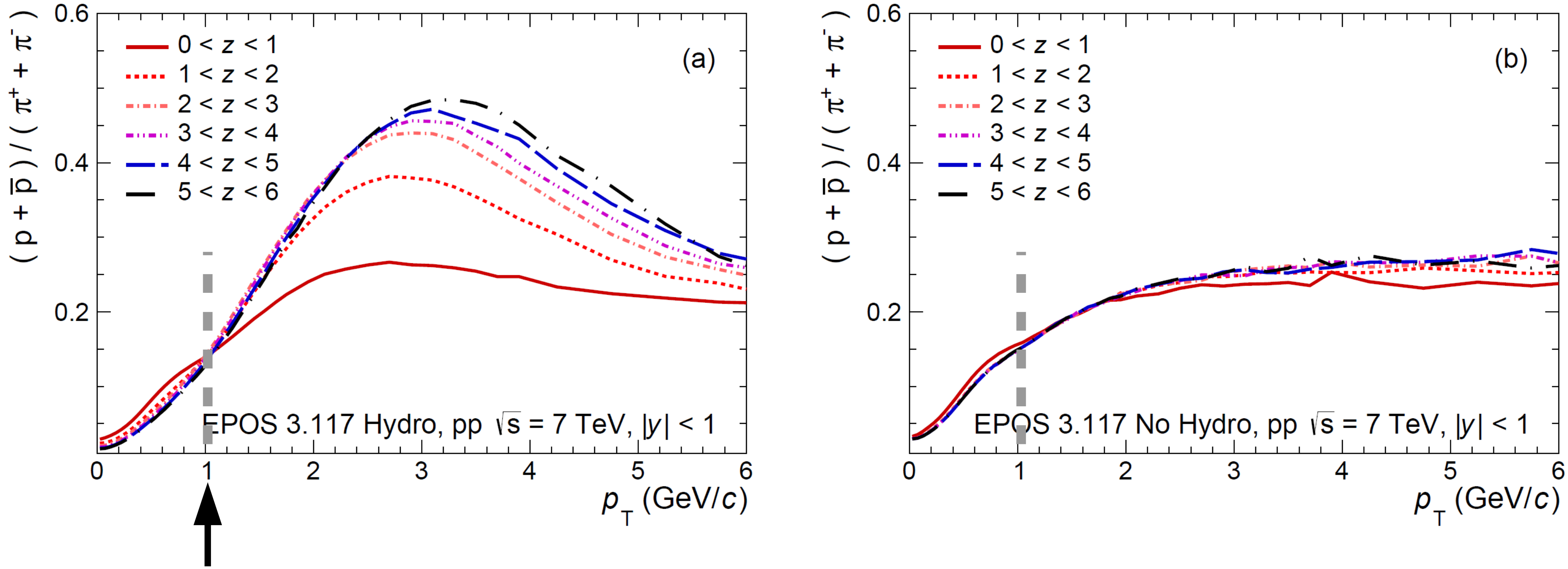
- Core conditions are easily satisfied in ion collisions
- Average pp collision (N_{ch}=30,|η|<2.4) at $\sqrt{s}$=7TeV, ~30 % of central particle production arises from the core region. This rises to 75 % for N_{ch}=100

EPOS 3 – testing flow observable: p/pi ratio

Results are shown

– for different multiplicity event classes in z

– for cases w/ and w/o hydro options



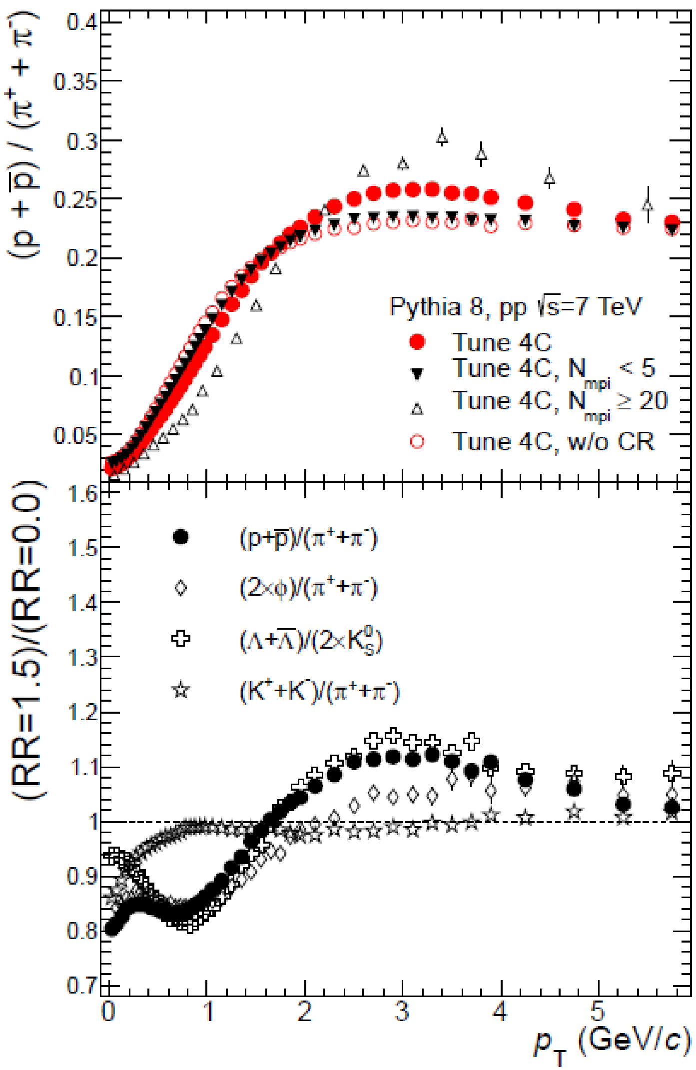
Depletion (increase) for p_T < 1 GeV/c (1 < p_T < 6 GeV/c)

→ can be attributed to radial flow (which modifies the spectral shape of the p_T distributions, depending on the hadron masses)

*Without hydro*dinamical component *no modification* observed as a function of z

Pythia 8

Color reconnection and flow-like effects



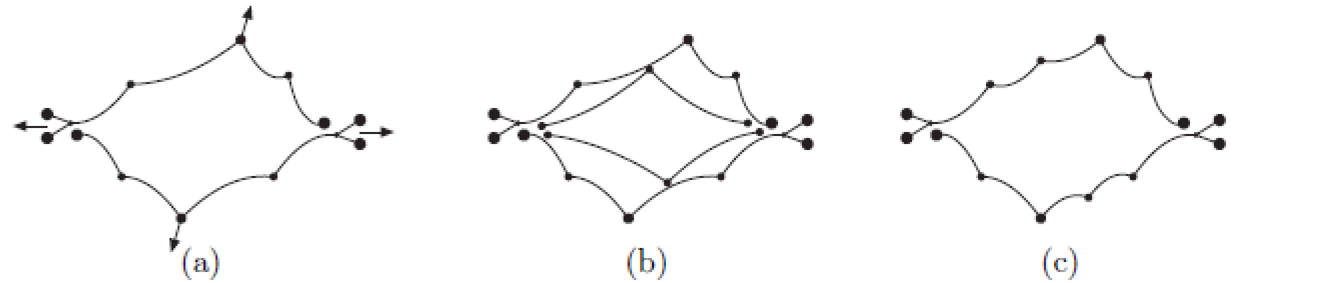


Fig. 2. (a) In a hard gluon-gluon subcollision the outgoing gluons will be colour-connected to the projectile and target remnants. Initial state radiation may give extra gluon kinks, which are ordered in rapidity. (b) A second hard scattering would naively be expected to give two new strings connected to the remnants. (c) In the fits to data the gluons are colour reconnected, so that the total string length becomes as short as possible.

- ***Description of soft-inclusive physics***:
  - *by multiple perturbative parton–parton interactions (MPI) + p⊥-ordered parton showers*

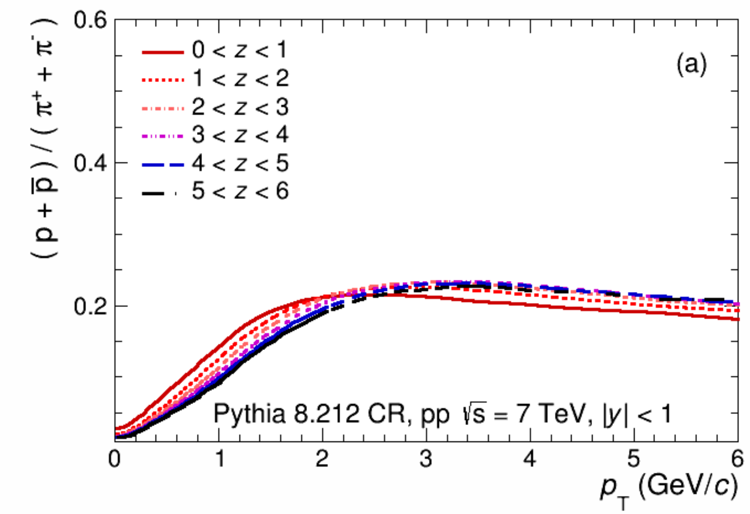
- Pythia 8.185 Monash 2013 (Tune:ee=7; Tune:pp = 14)
  → CR MPI-based by default: allows partons to interact with probability of

$$\mathcal{P}(p_{\mathrm{T}}) = \frac{(R \times p_{\mathrm{T0}})^2}{(R \times p_{\mathrm{T0}})^2 + p_{\mathrm{T}}^2}$$

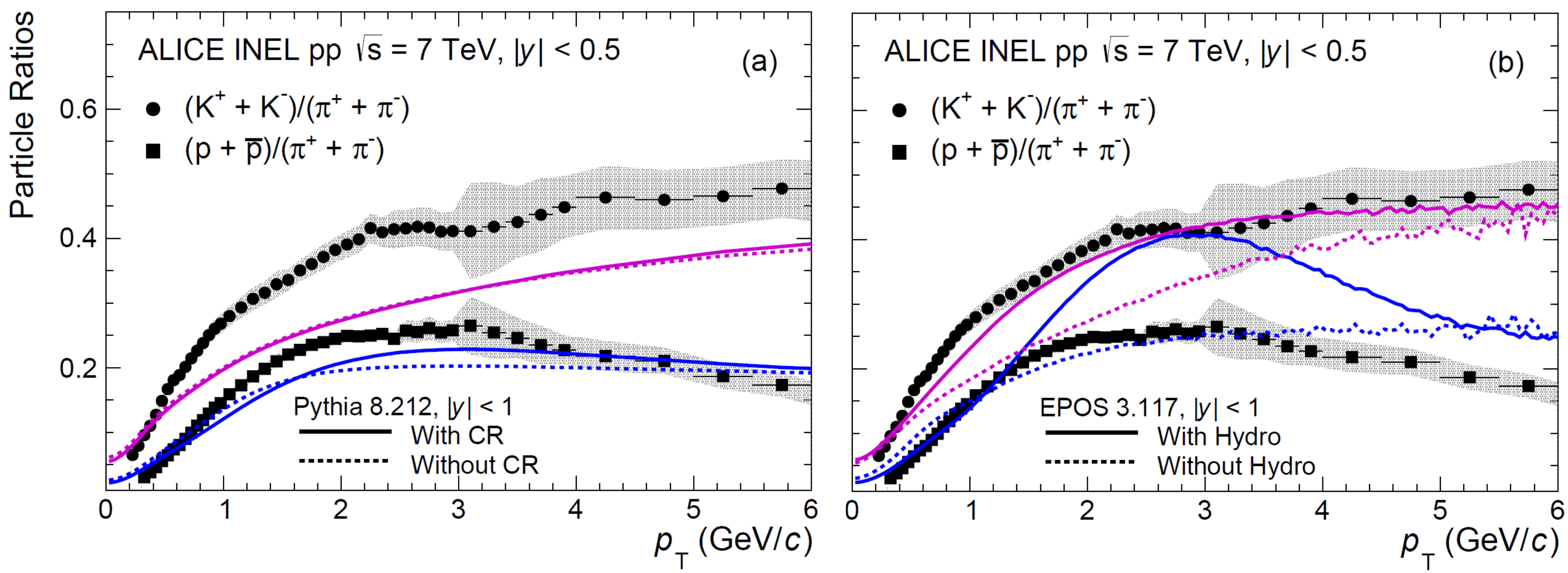
- Reconnection range, RR, which enters in the probability to merge a hard scale p_T system with one of a harder scale

- There is no a priori basis for guessing precisely what reconnection probability to choose, nor whether it should be constant at all CM energies

Pythia 8 – testing description of data



- Flow-like effects observed in pp are potentially connected to CR
- Qualitatively similar effect seen in the model as in heavy ion coll



In general both Pythia 8 and EPOS 3 describe the data qualitatively, whereas they fail to do so quantitatively

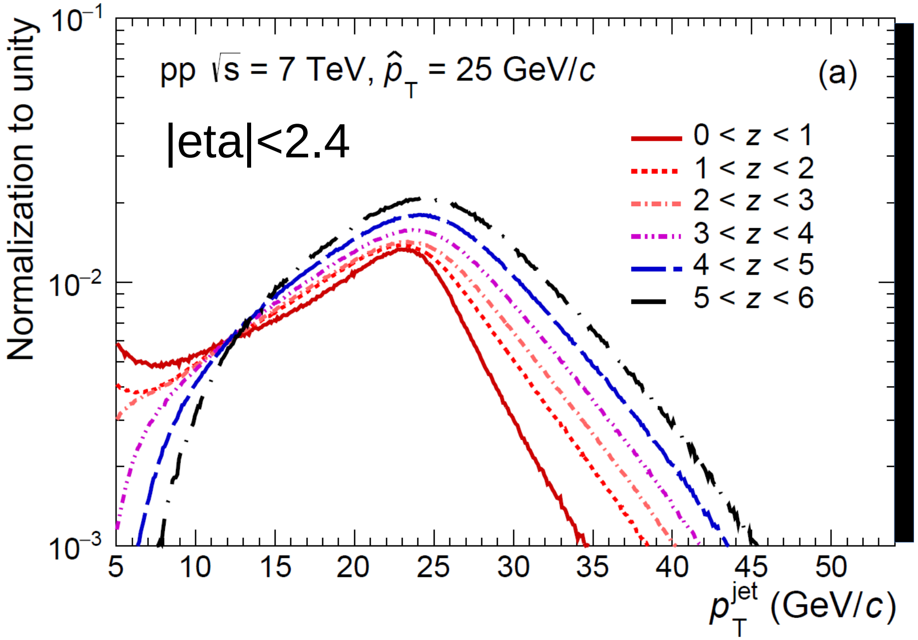
FASTJET 3.1.3 – hardness of the event: selection of jets

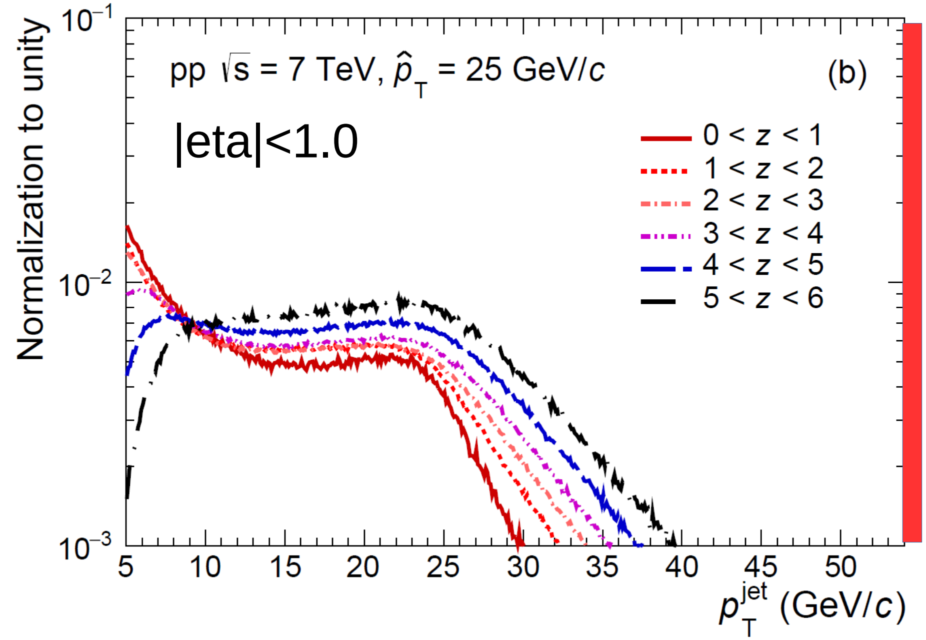
Multiplicity dependence of the leading jet p_T

Anti-k_T algorithm is used by requiring

– R=0.4 cone radius for jet searching

– $p_{T,min}$ = 5 GeV/*c* *(by ensuring the selection of semi-hard/hard events)*





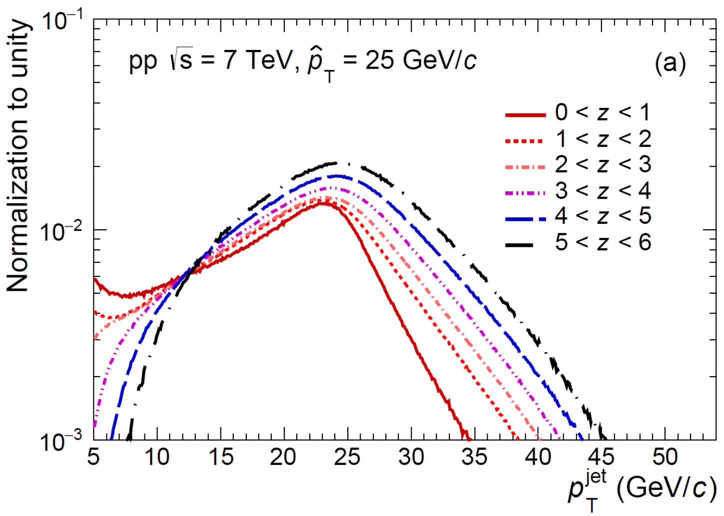
Testing the performance in high-mult events → Samples generated by Pythia8 by fixing the min and max invariant pT of the jet: p_T = 25-26 GeV/c

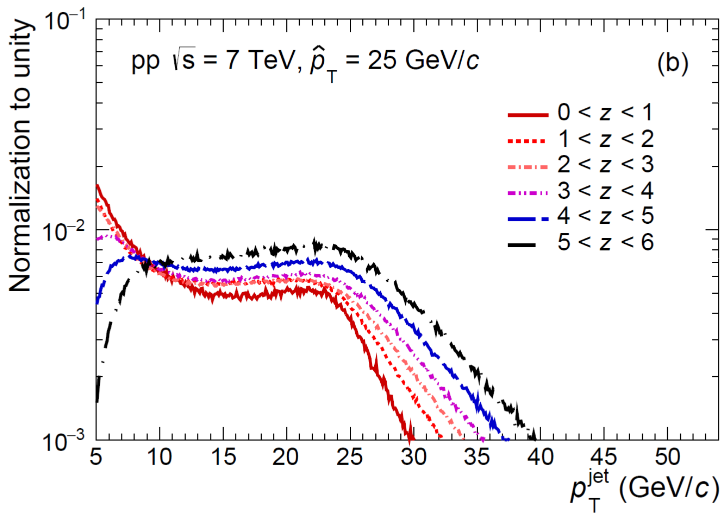
Left: clear peak around the expected pT is seen;
jets w/ pT = 5 GeV/c increases for low-mult case

Right: case corresponds to R=+-0.4; peak around 24 Gev/c;
higher probability of selection non-leading jets in the acceptance

FASTJET 3.1.3 – hardness of the event: selection of jets

Multiplicity dependence of the leading jet p_T





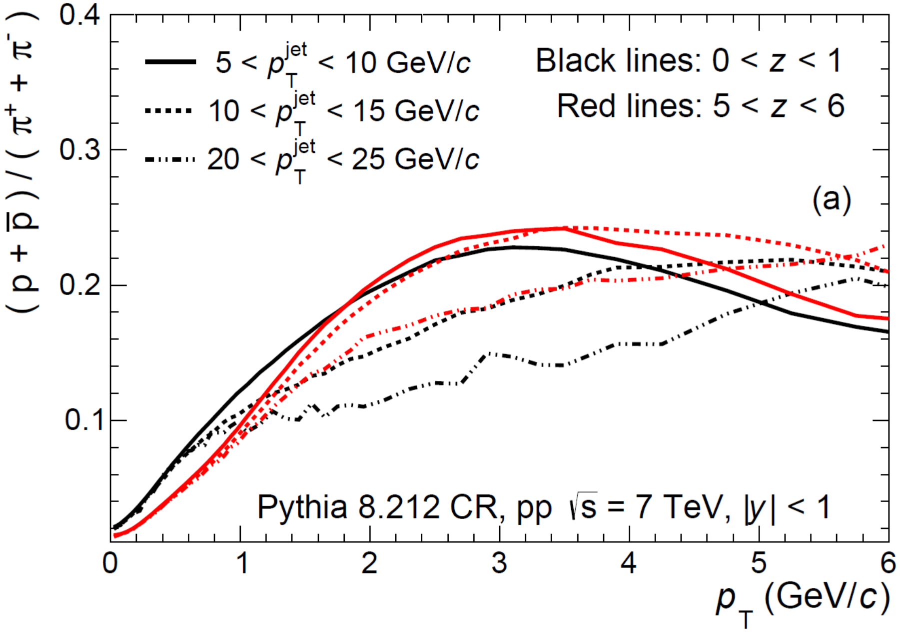
$\left\langle \frac{dN_{ch}}{d\eta} \right\rangle_{\|\eta\|<1}$	$\langle p_T^{jet} \rangle_{\|\eta\|<1}$ (GeV/c)	% of events with $p_T^{jet} > 5\,\mathrm{GeV}/c$
2.12	7.09	1.03
8.12	7.49	13.1
13.6	7.83	37.3
19.0	8.48	63.7
24.4	9.56	83.2
29.8	11.1	93.9
35.2	13.2	98.2
40.6	16.1	99.5
46.1	19.7	99.8

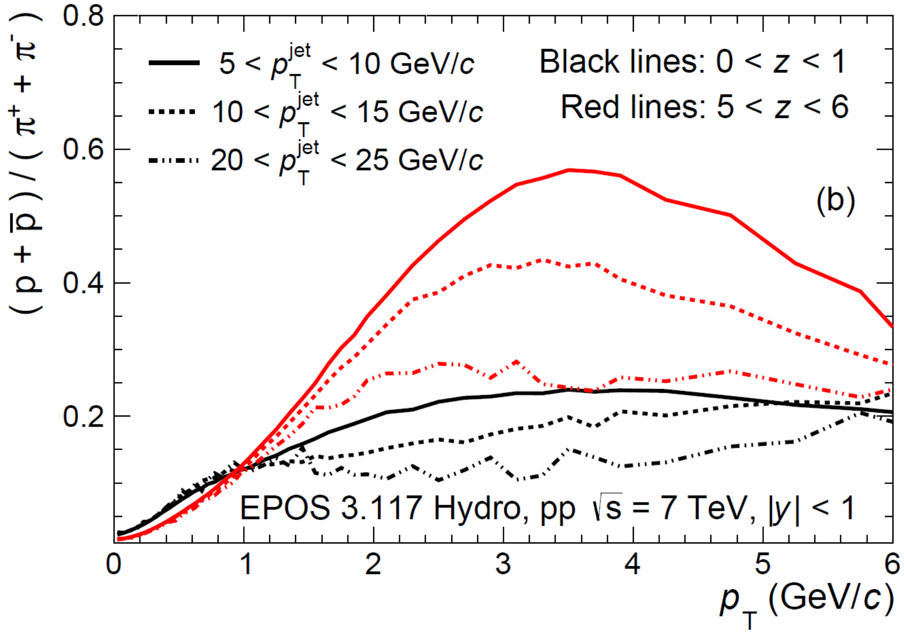
- The higher the multiplicity the larger average $p_{T,jet}$
- The higher the multiplicity the larger the # N_{MPI}
  → prob (hard parton-parton scattering) is larger
- Fraction (%) of events increases having jets within the acceptance

Results

– Proton-to-pion ratio vs multiplicity and $p_{T,jet}$
– Blast-wave model fits vs multiplicity and $p_{T,jet}$

Proton-to-pion ratio vs multiplicity and $p_{T,jet}$





Low-z case:

– increasing $p_{T,jet}$ → peak shifted towards higher p_T

→ not an exclusive effect of radial flow, but rather the effect of fragmentation

→ Ref. ALICE jet hadrochem *[1]*

High-z case:

– maximum of bump increasing w/ multiplicity

High-z case:

– enhancement w.r.t. inlcusive case (w/o selection on $p_{T,jet}$)

– higher $p_{T,jet}$: peak shifted to lower p_T

→ size of peak smaller than inclusive

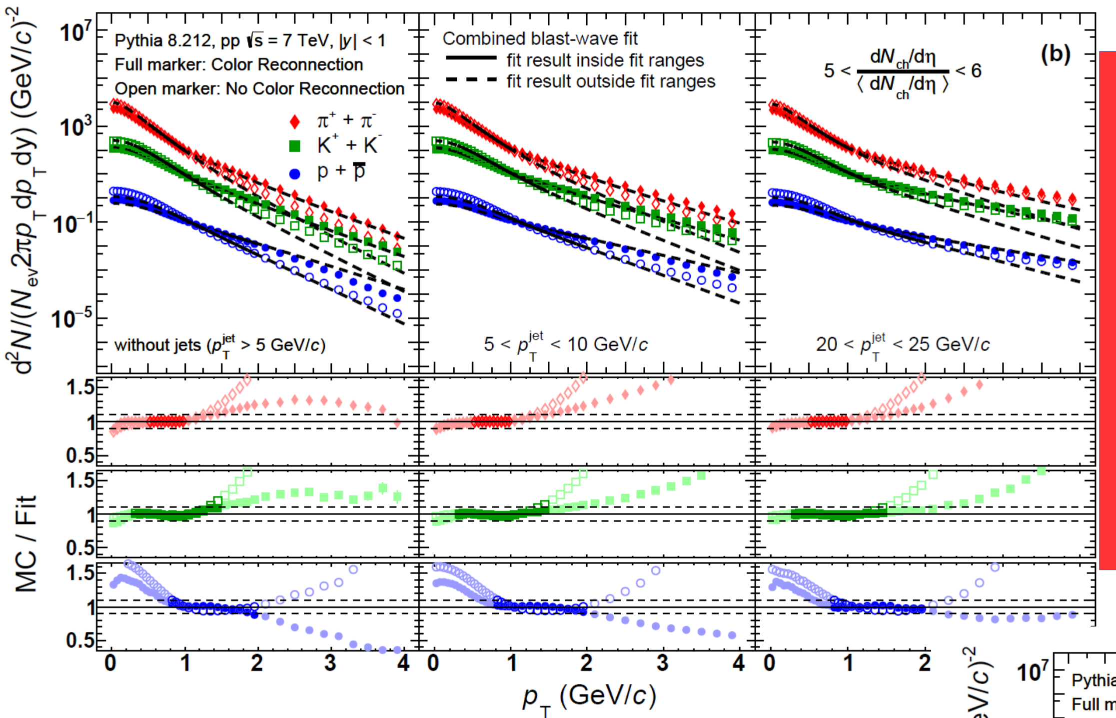
Effect of peak ordering w/ $p_{T,jet}$ disappears w/o hydro

→ consequence of core-corona separation (low-p_T partons likely form the "core")

→ Difference between event classes can be attributed to difference between hadro-chemistry of "jet" and "bulk"

[1] arXiv:1407.8385 [hep-ex]

Blast-wave model fits – *Pythia 8*



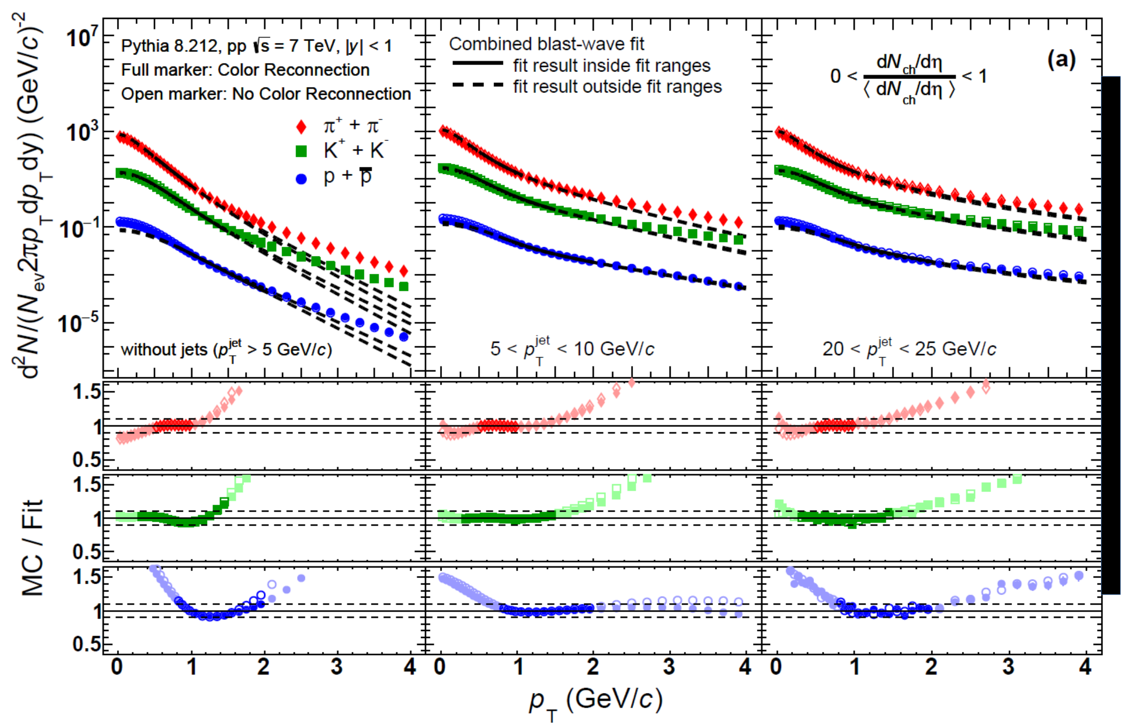
High-z case:

– w/o CR: BW fails to describe the spectra
→ even if a jet is present
– w/ CR: the agreement imporves w/ increasing pT,jet

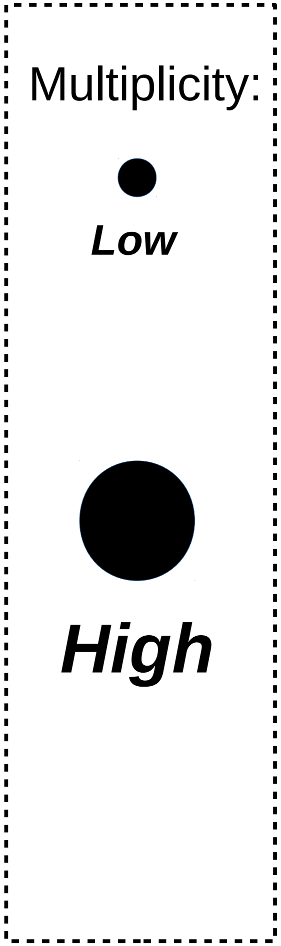
→ Reflects that interaction between jets and underlying event is crucial in describing collective effects

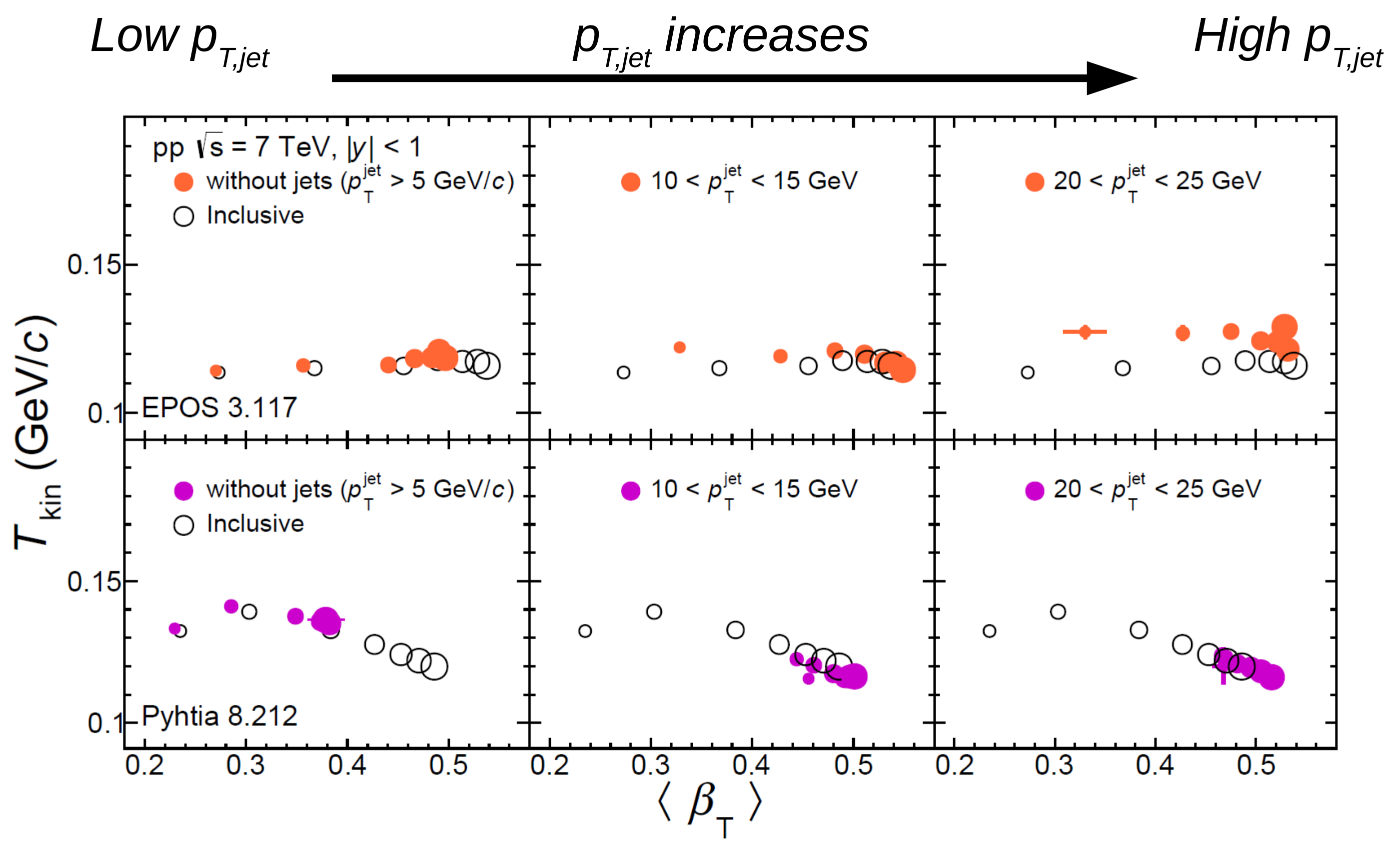
Low-z case:

– CR effects are negligible
→ it is possible to find an event class where radial flow effects pop up
→ events w/ jets pT,jet > 5 GeV/c



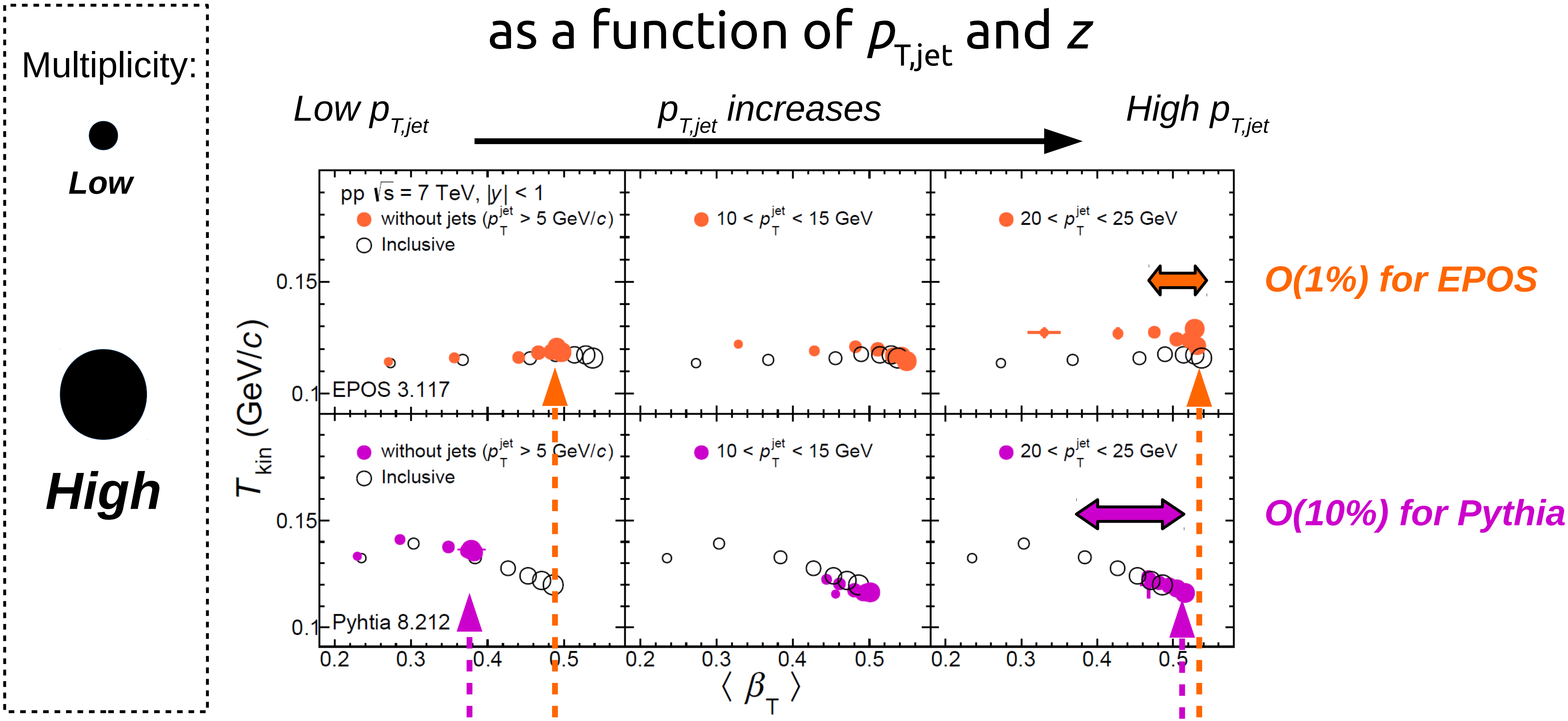
Blast-wave model parameters and their correlation as a function of $p_{T,jet}$ and z





1) The jet contribution is less important for EPOS 3 than for Pythia 8

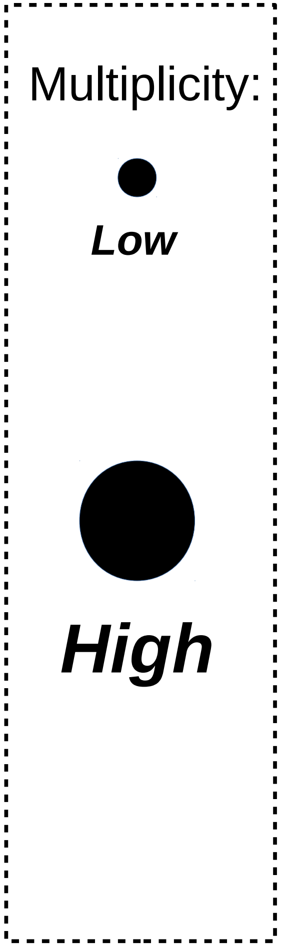
Blast-wave model parameters and their correlation as a function of $p_{T,jet}$ and z

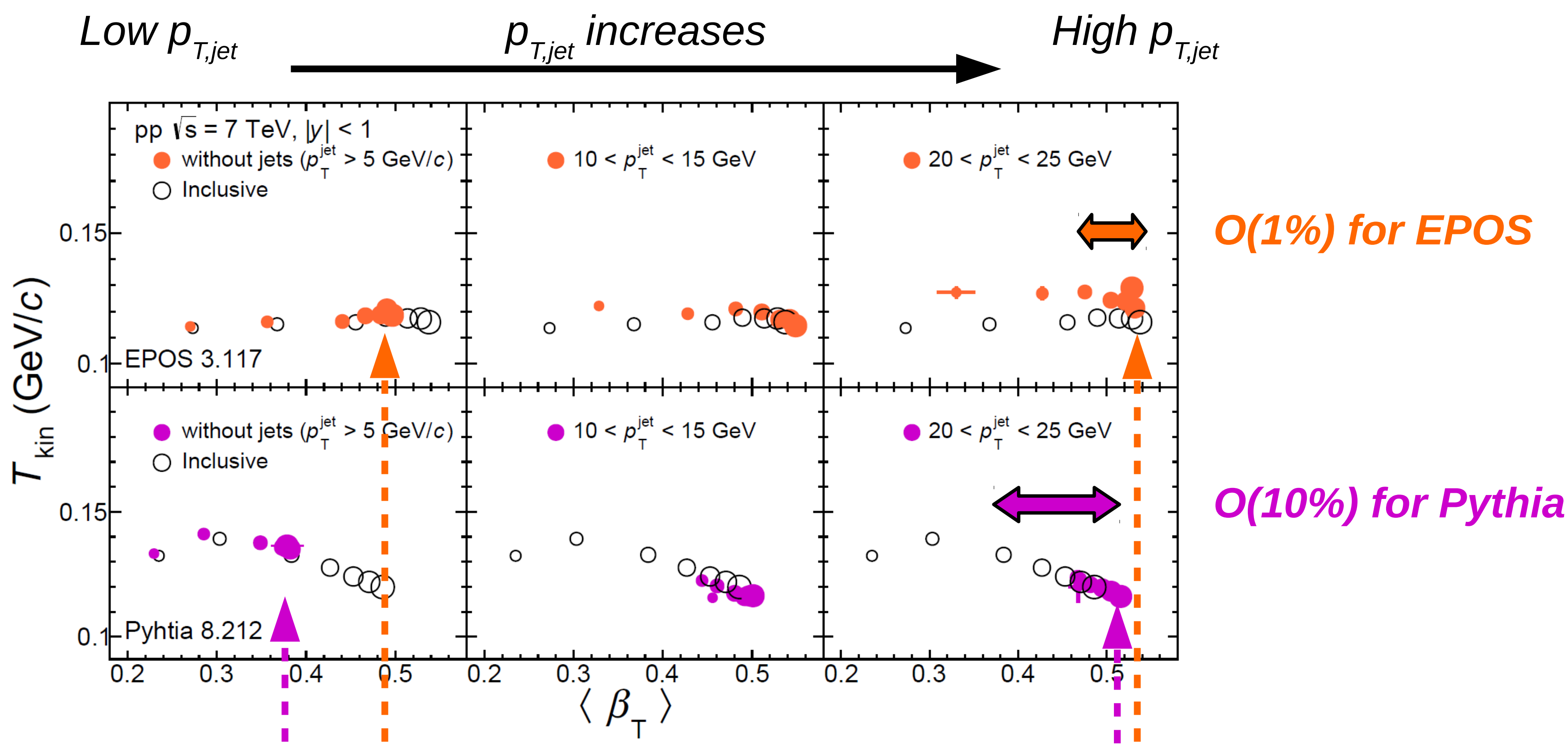


1) The jet contribution is less important for **EPOS 3** than for **Pythia 8**

2) Events w/ jets for fixed multiplicity class (same marker size):
$\langle \beta_T \rangle$ ***increases with respect to inclusive case***

Blast-wave model parameters and their correlation as a function of $p_{\mathrm{T,jet}}$ and z





1) The jet contribution is less important for EPOS 3 than for Pythia 8

2) Events w/ jets for fixed multiplicity class (same marker size): $\langle \beta_T \rangle$ increases with respect to inclusive case

3) Events w/o jets the multiplicity dependence is weaker in EPOS 3 than in Pythia 8 (compared to the one w/ jets)

Summary and Conclusions

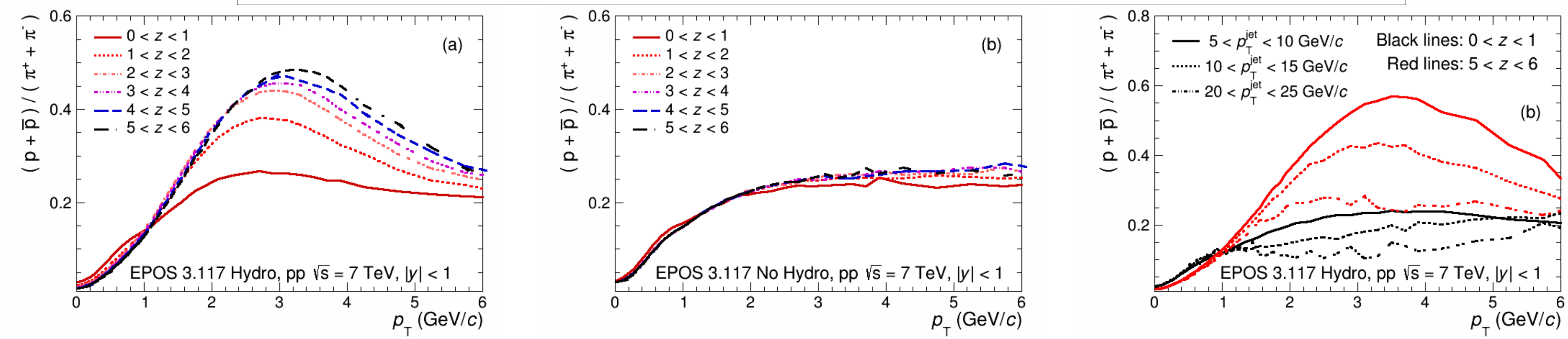
1) The sensitivity of EPOS 3 and Pythia 8 to observables are different in terms of multiplicity and hardness of the events
   → Pythia: strong correlation of soft and hard components
   → EPOS: weak correlation of soft and hard components

Summary and Conclusions

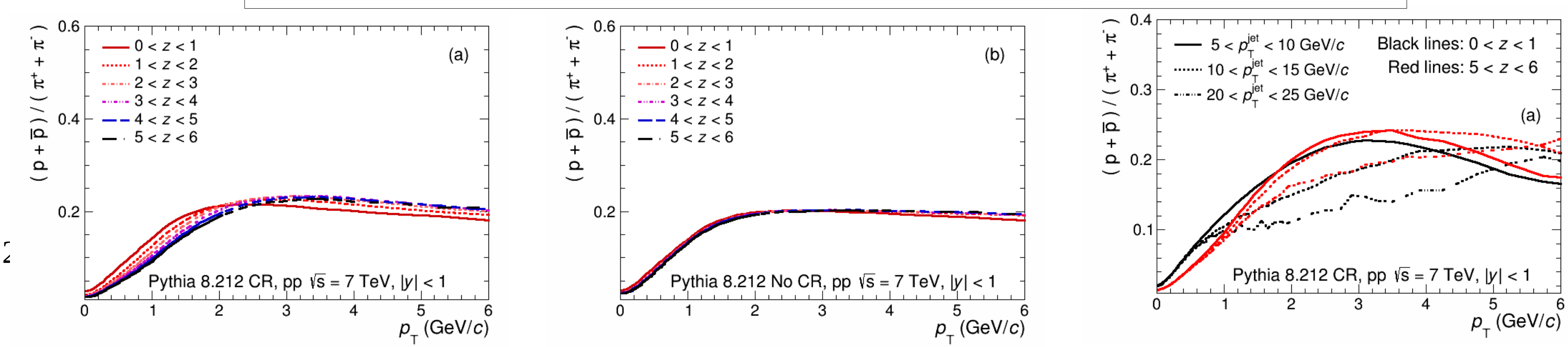
1) The sensitivity of EPOS 3 and Pythia 8 to observables are different in terms of multiplicity and hardness of the events
   → Pythia: strong correlation of soft and hard components
   → EPOS: weak correlation of soft and hard components

2) In <u>low multipicity</u> events (where hydro not valid and color reconnection is weak)

→ *EPOS shows weak or no response to the presence of jets*



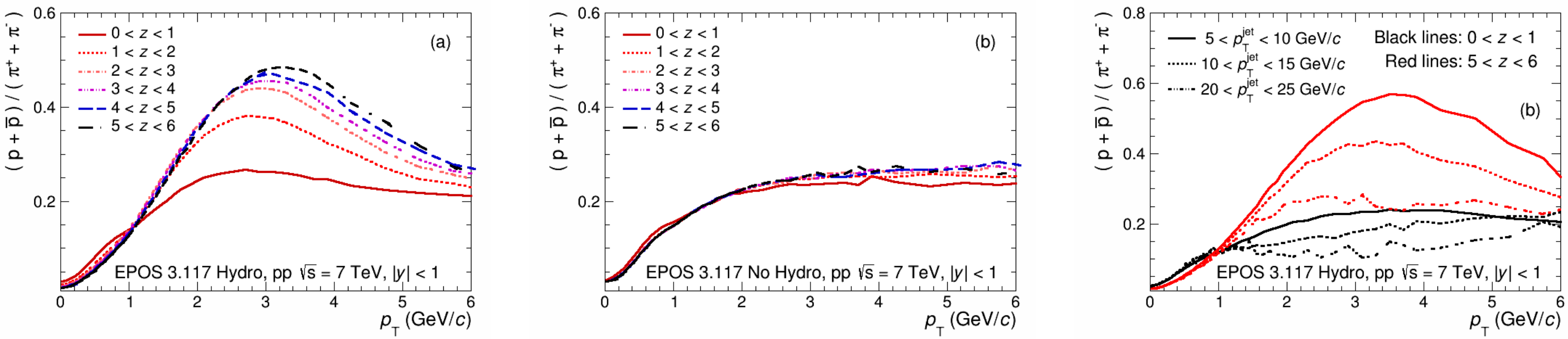
→ Pythia *shows radial flow-like signature to the presence of jets*



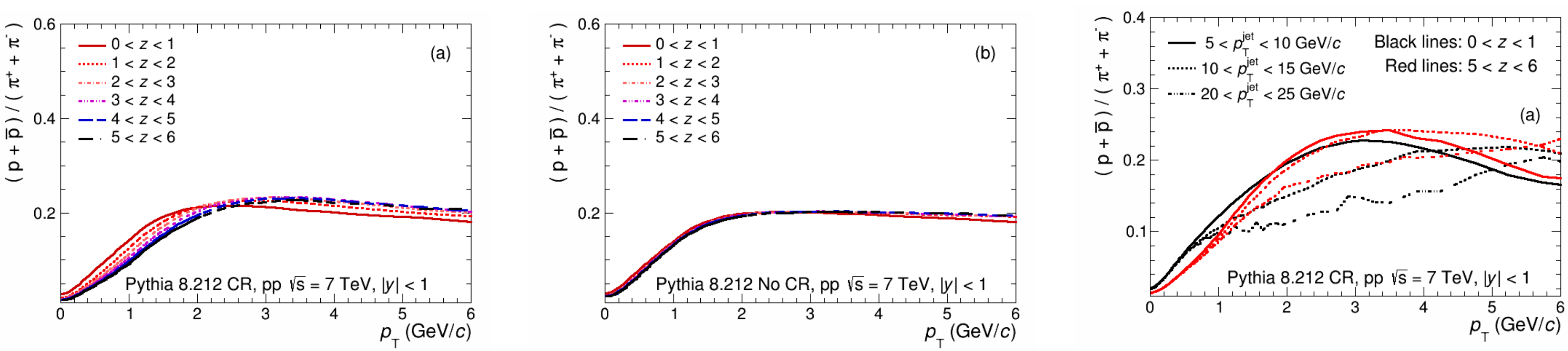
Summary and Conclusions

3) In high multiplicity events

→ *EPOS: magnitude changes of p/pi: decreasing with increasing $p_{T,jet}$*
position of of p/pi *does not* *change*



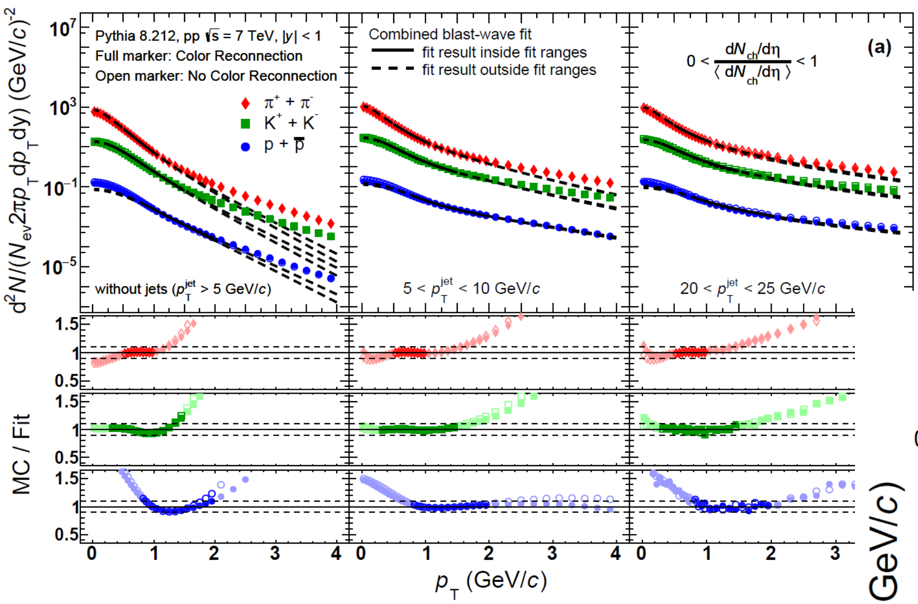
→ Pythia*: magnitude* *does not* *change of p/pi*
position is shifted with increasing $p_{T,jet}$



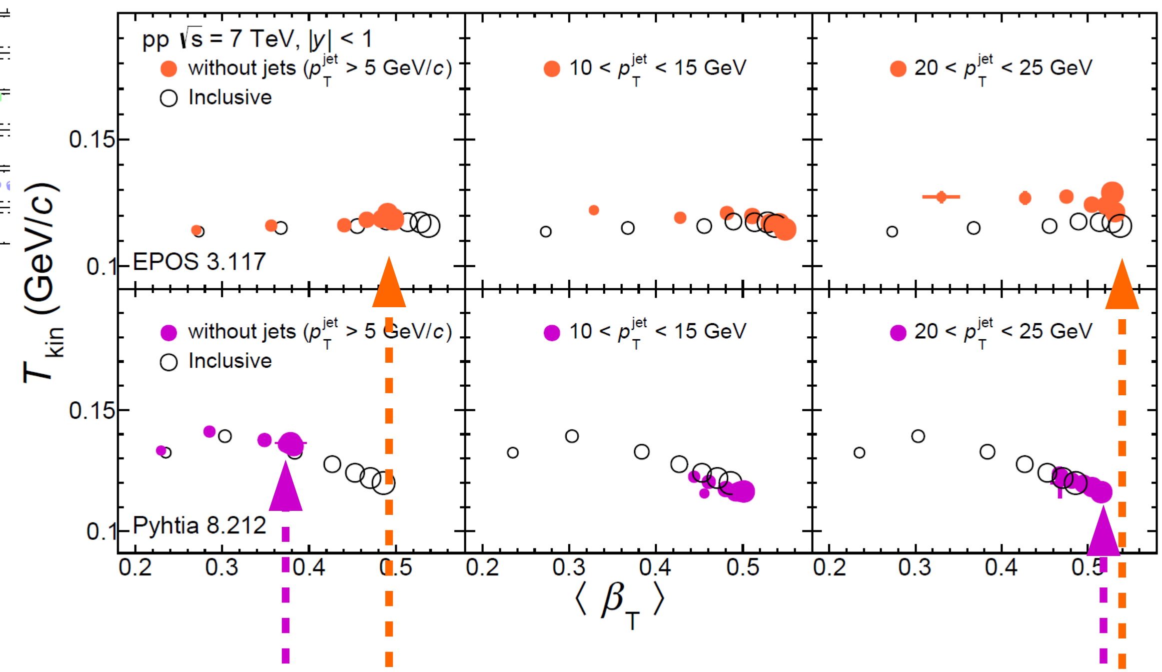
Summary and Conclusions

4) Blast wave model fits:

→ *Blast-wave model fits show better agreement with data in case of jets and the description improves with increasing $p_{T,jet}$*



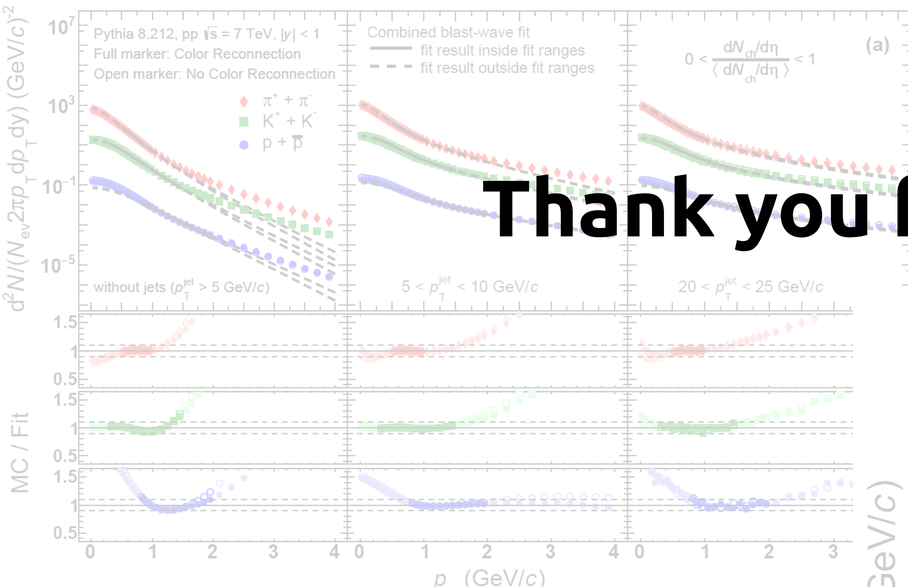
→ *Multiplicity dependence of $\langle \beta_T \rangle$ is more affected by jets in Pythia than in EPOS*



Summary and Conclusions

4) Blast wave model fits:

→ *Blast-wave model fits show better agreement with data in case of jets and the description improves with increasing $p_{T,jet}$*



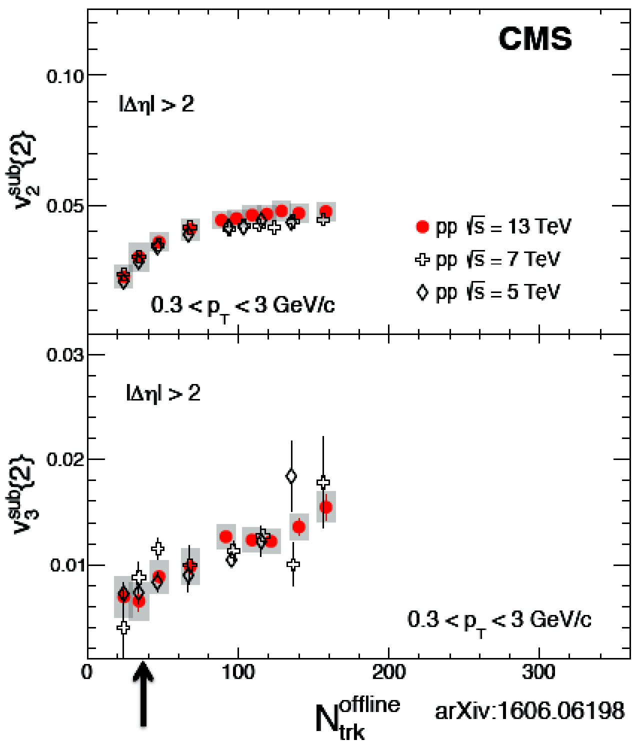
→ *Multiplicity dependence of $\langle \beta_T \rangle$ is more affected by jets in Pythia than in EPOS*

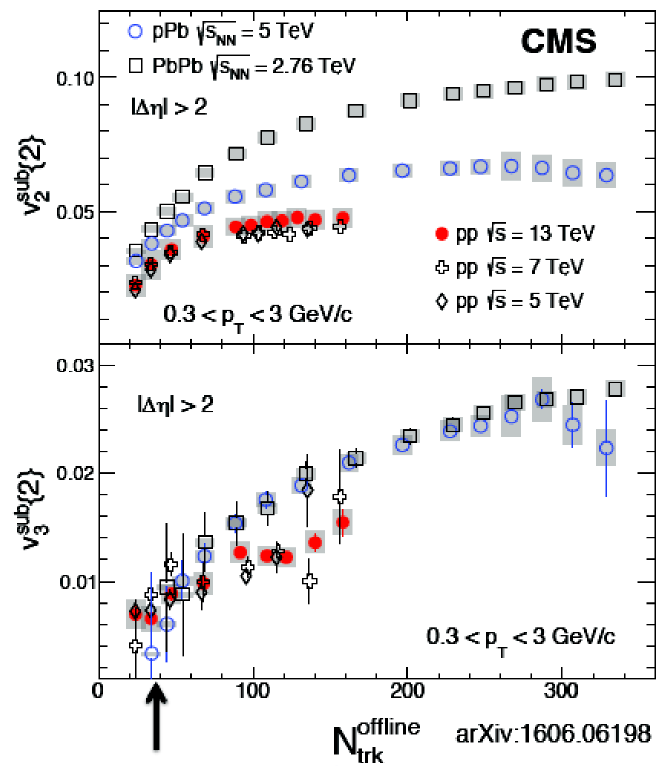
Thank you for your attention!

Backup slides

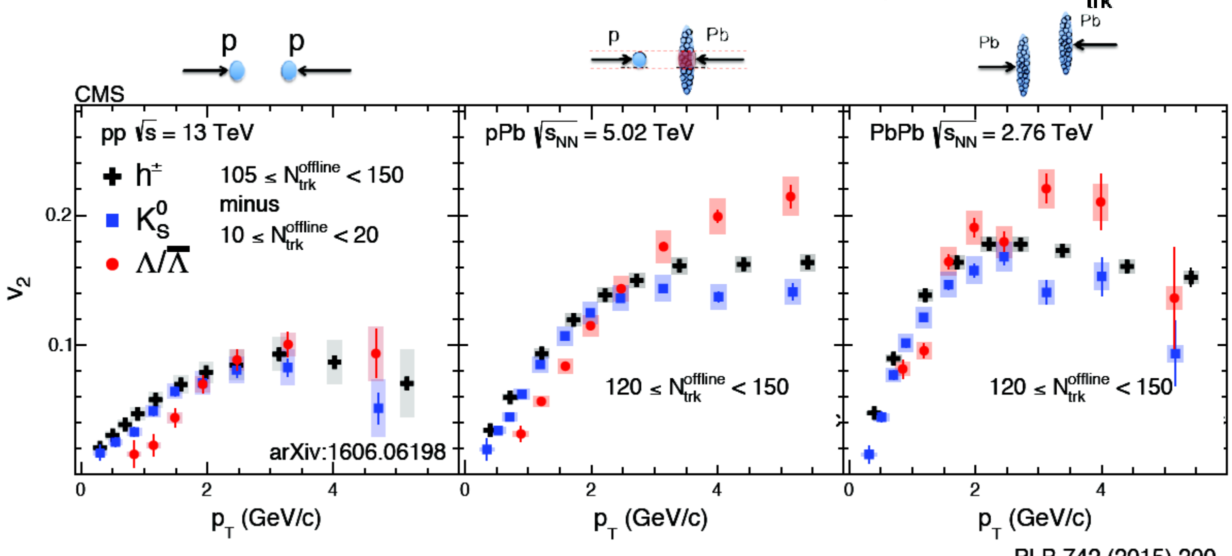
Collectivity in small systems

Flow signatures in small systems





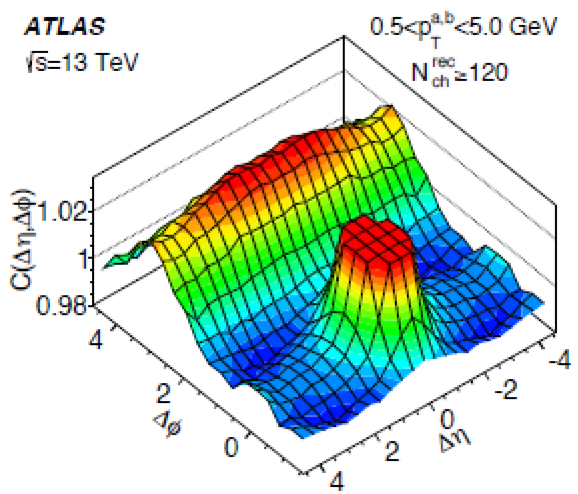
- Both v_2 and v_3 arise from low to high N_{trk}
- Similar behaviors across all 3 systems



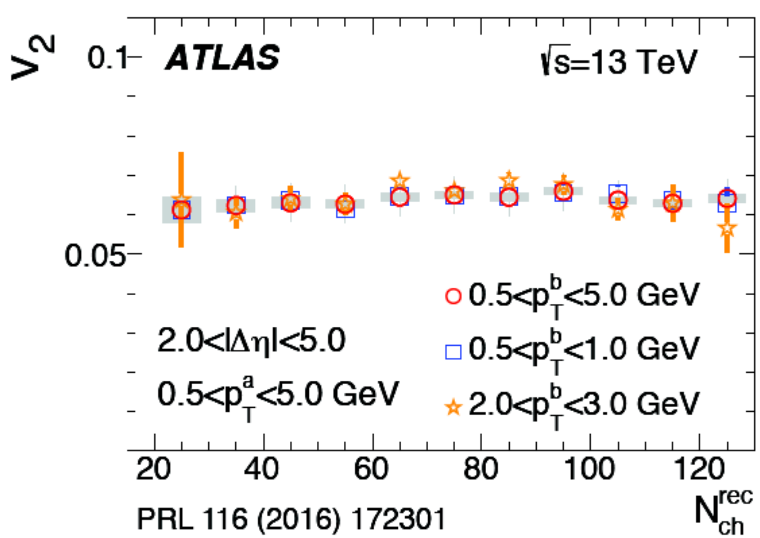
- Mass splitting of v_2
  → Collective expanding source
- larger splitting in pp/p-Pb
  → smaller system is more explosive at fixed N_{trk}

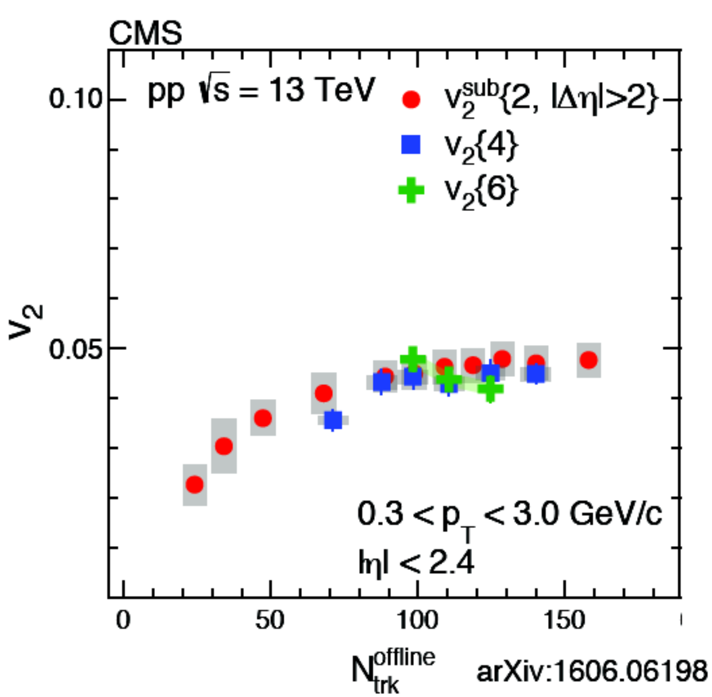
Collectivity in small systems

Long-range correlations – evidence of collectivity

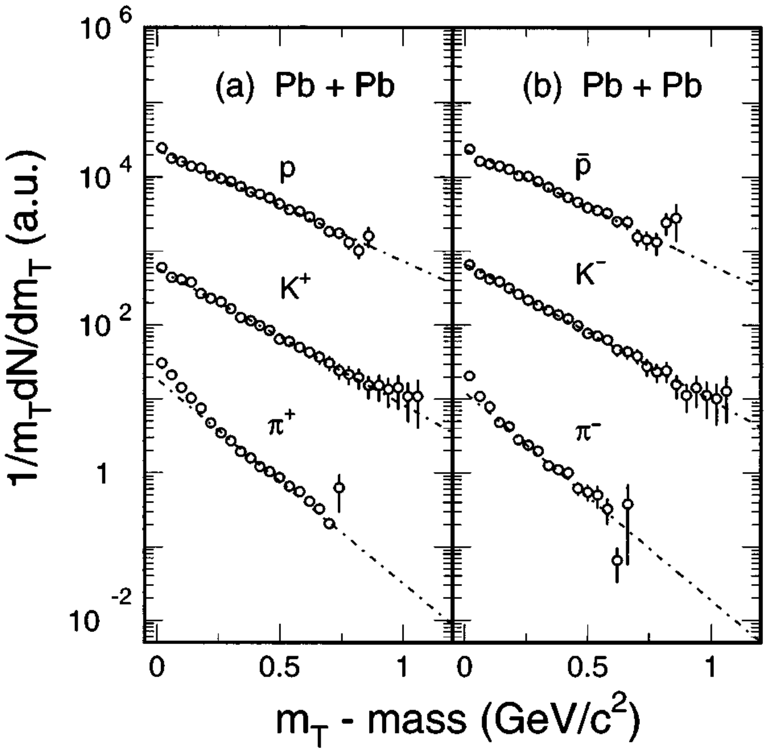


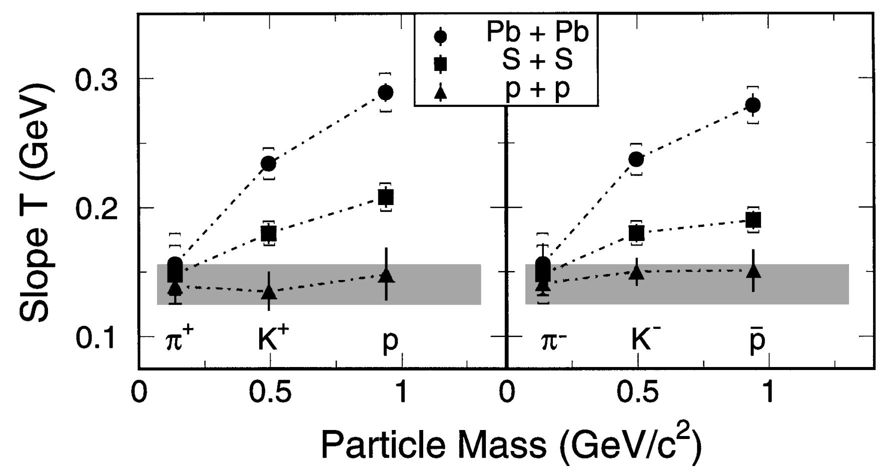
- v_2 *(or collectivity) constant or decreases as system becomes dilute (N_{trk} → 0)*
- *No strong radial flow or mass ordering at low N_{trk}*



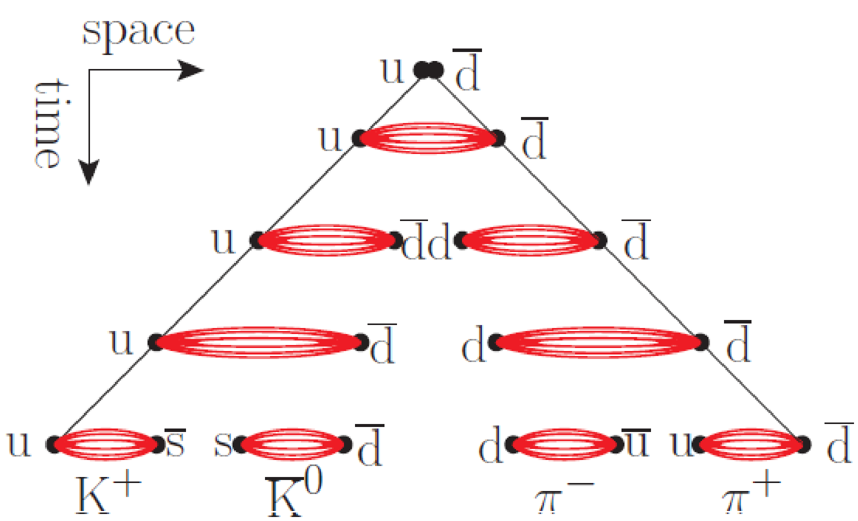


Collective phenomena in heavy ion collisions

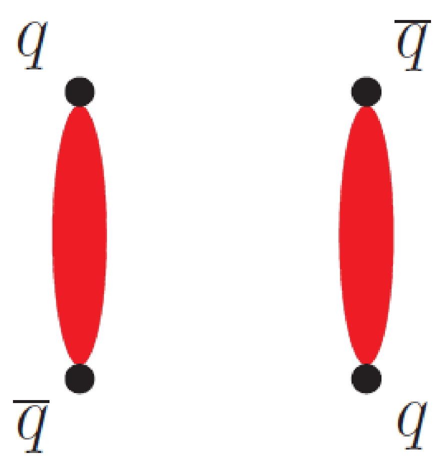


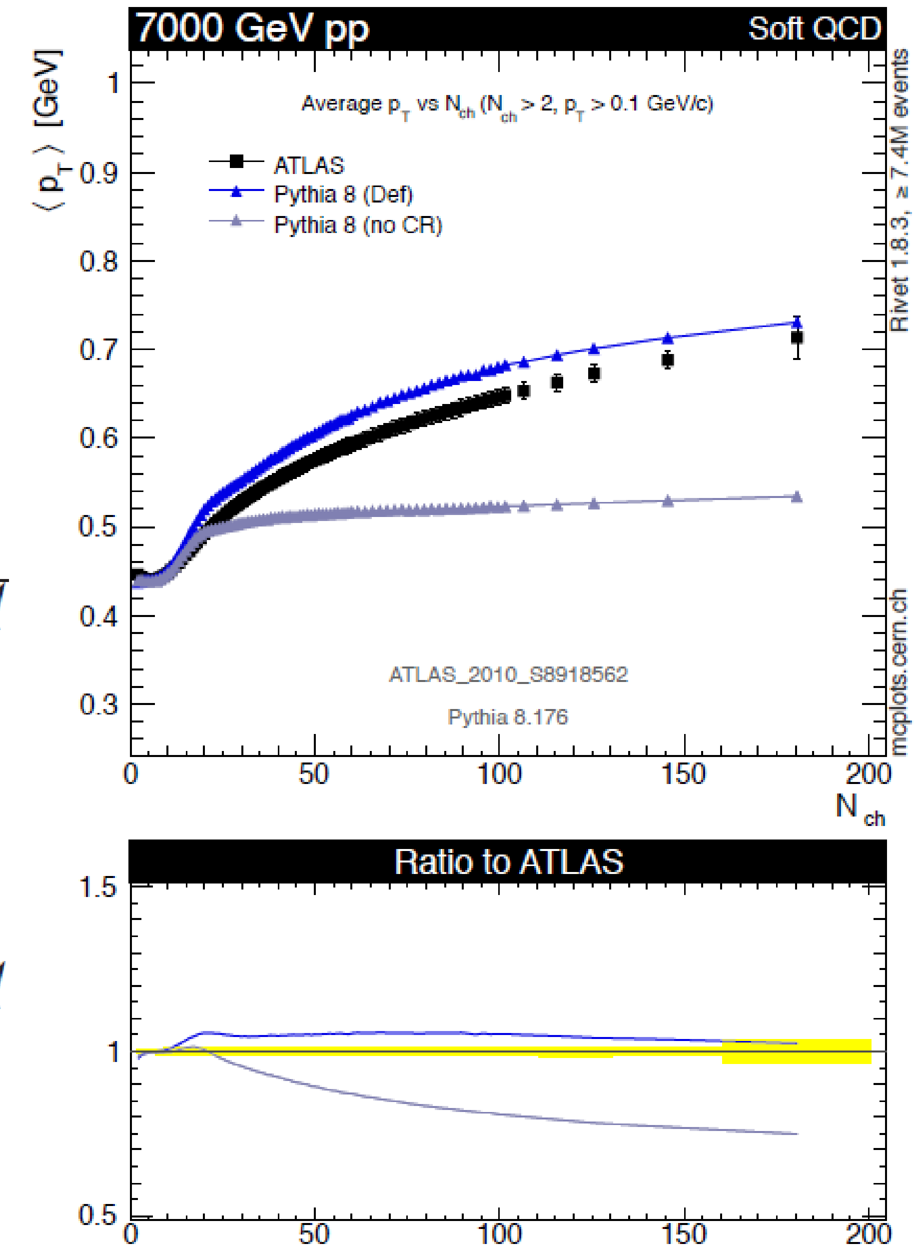


Pythia 8 – Hadronization and Color Reconnection



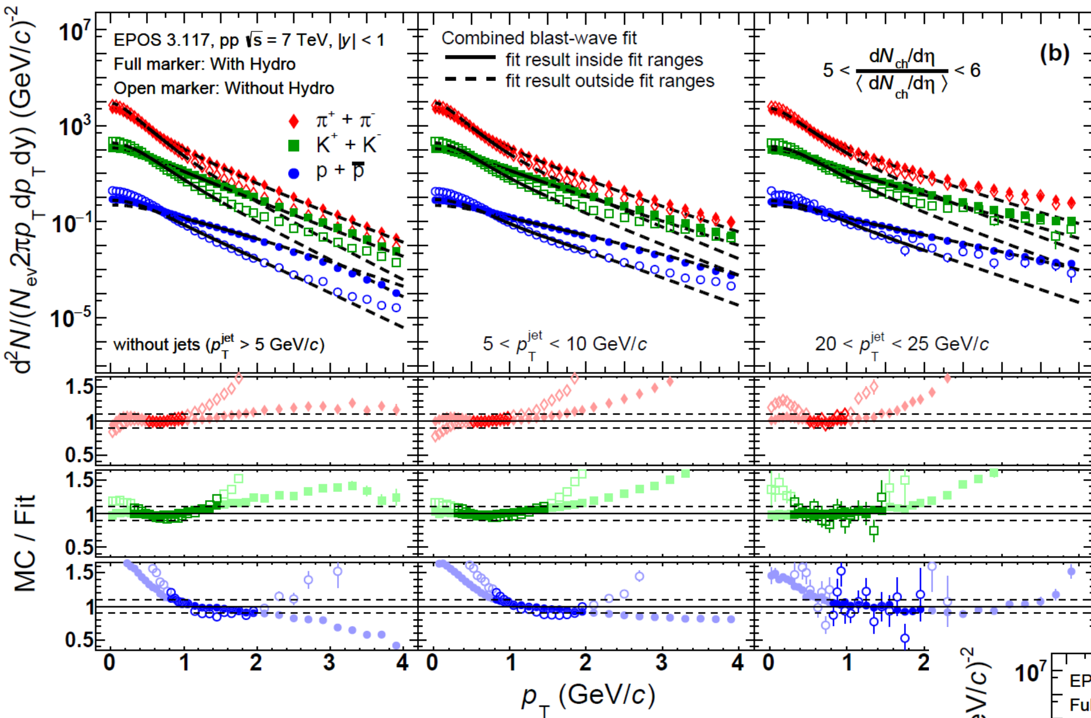
- What happens for multiple strings?
  - QCD quadropole? We have no idea how to hadronize this
  - Instead use several dipoles!
  - Multiple possible pairings $\Rightarrow$ Colour reconnection!



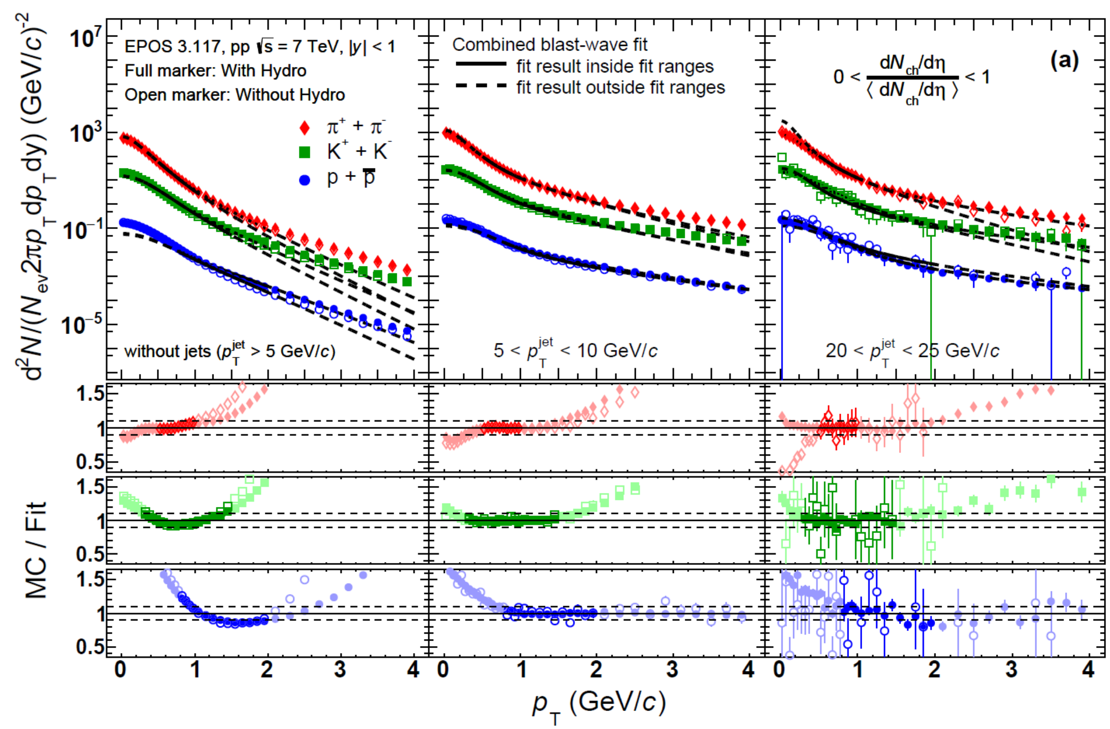


Results – Blast-wave model fits

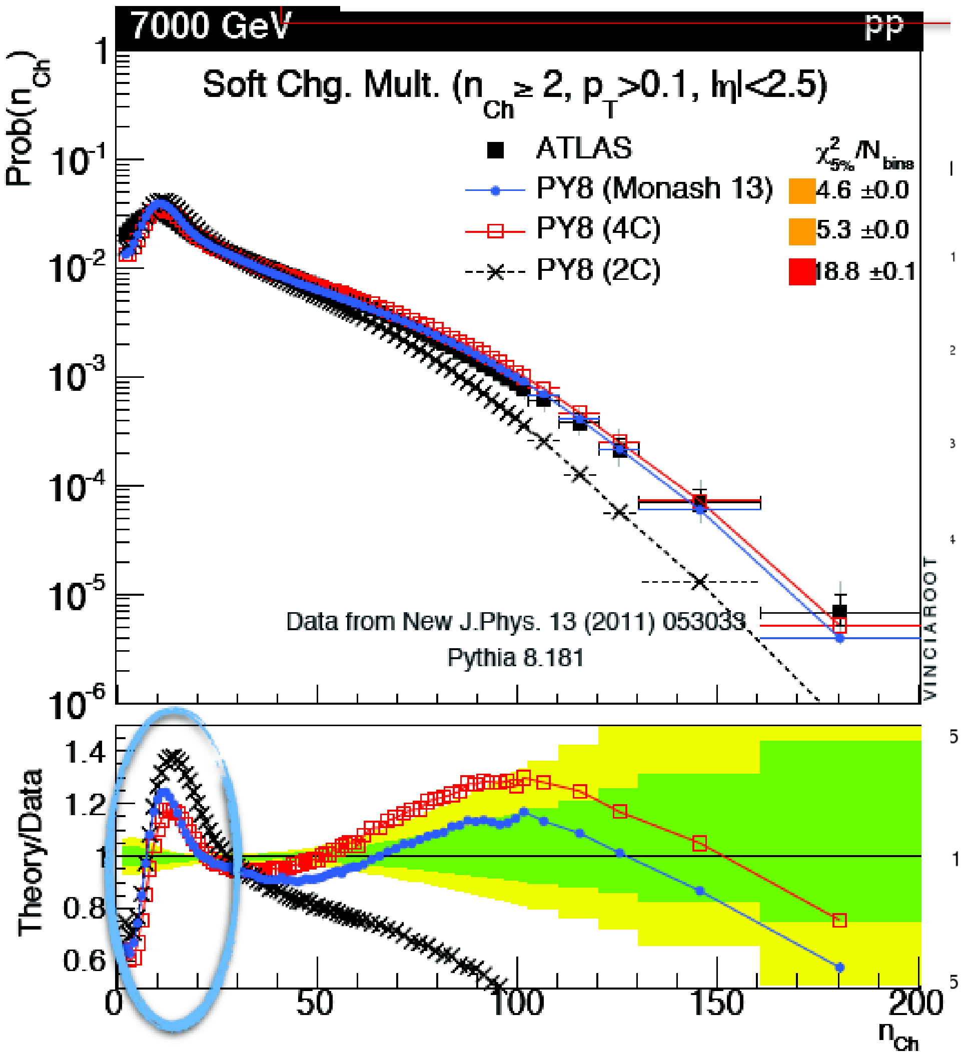
EPOS 3

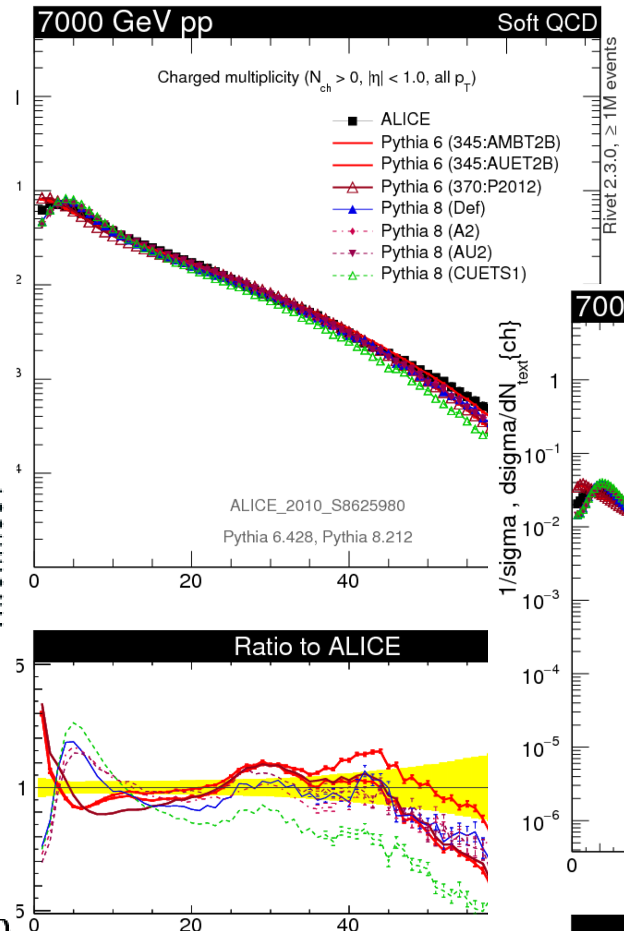


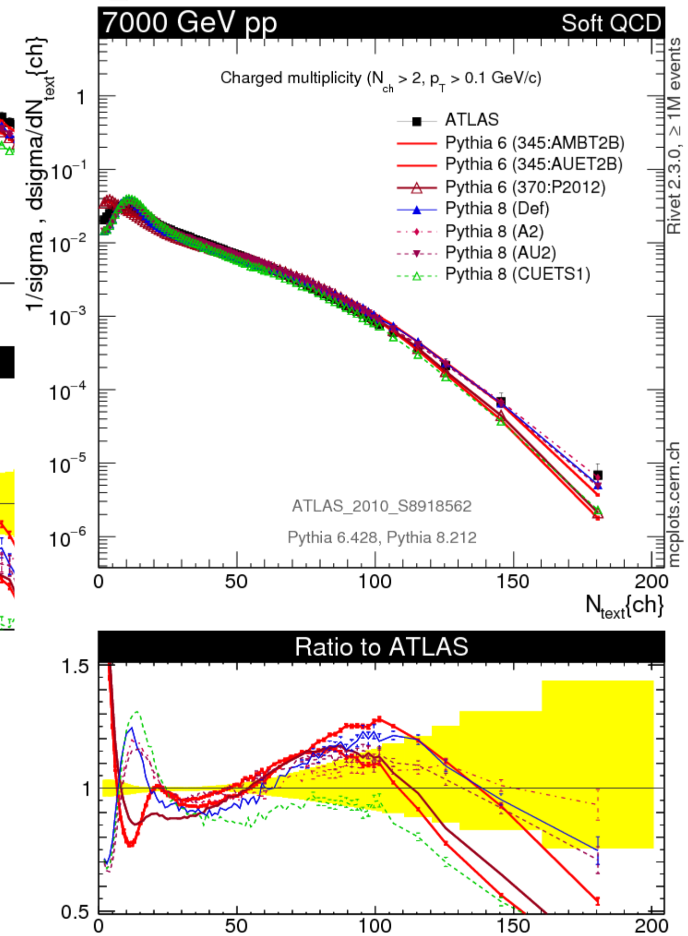
The jet contribution is less important for EPOS 3 than for Pythia 8



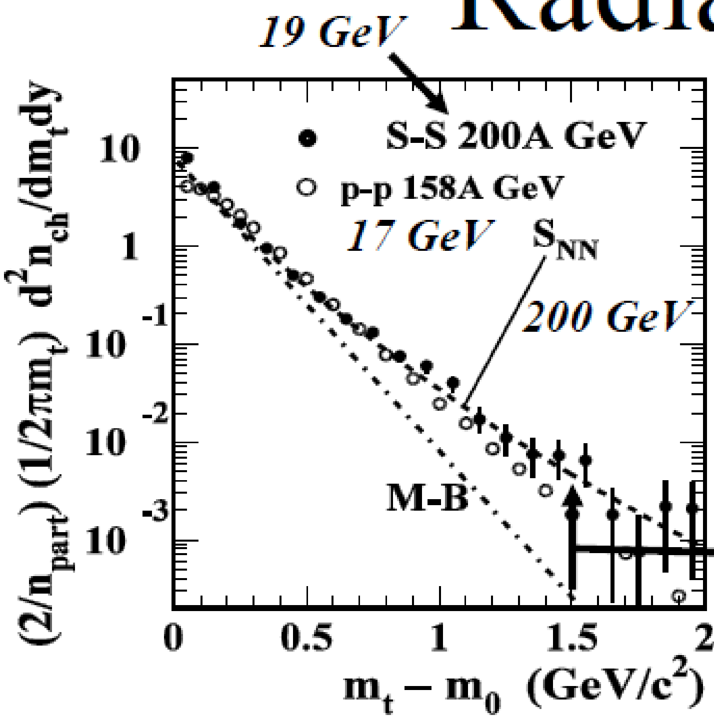
Pythia 8 – Charged-Particle Multiplicities
Tunes: Monash vs 4C

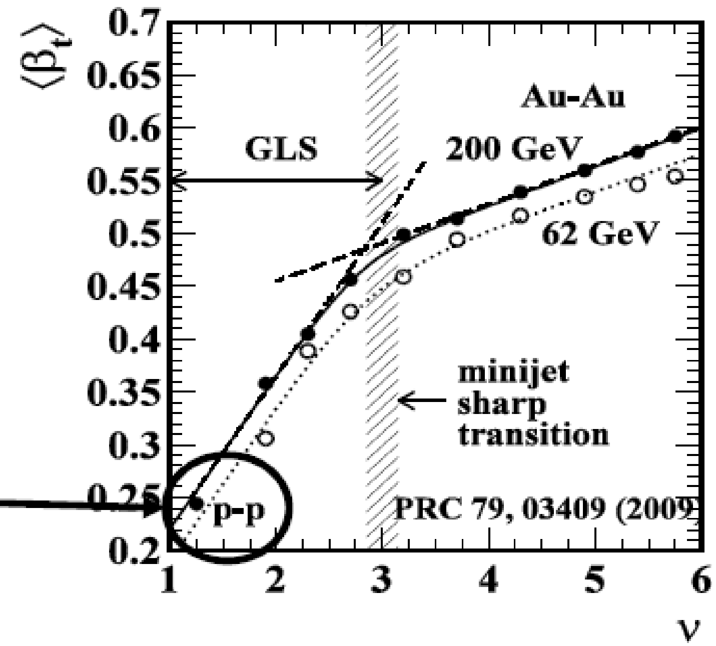






Radial Flow vs Jets

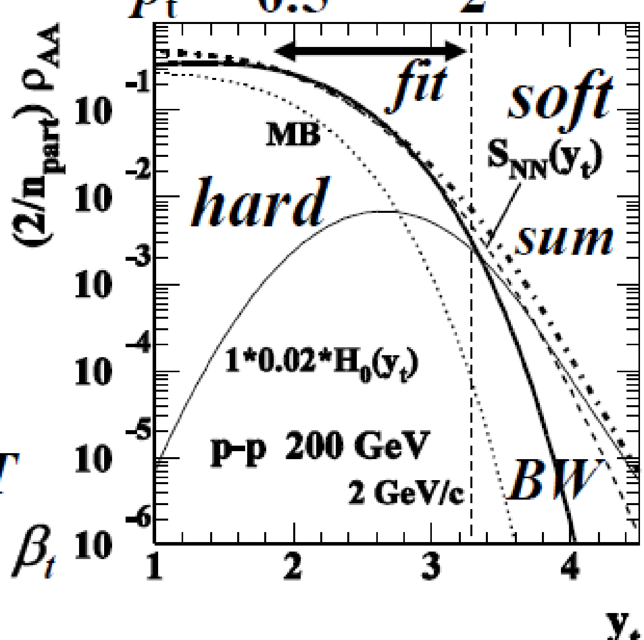


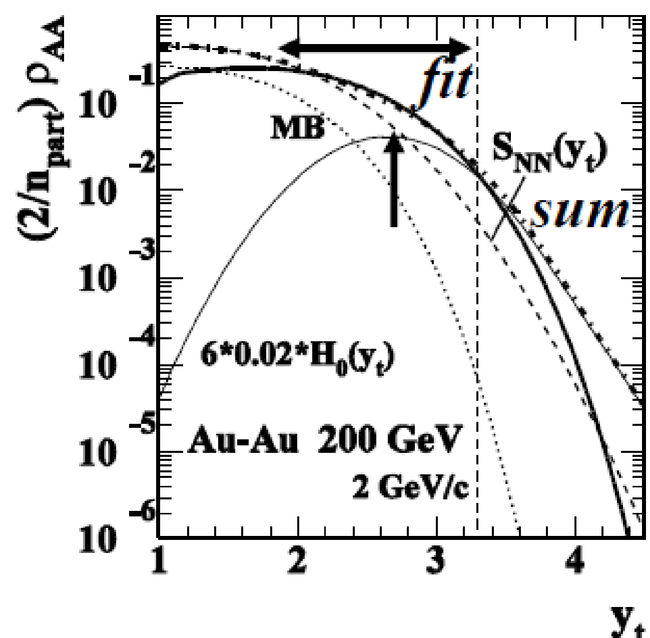


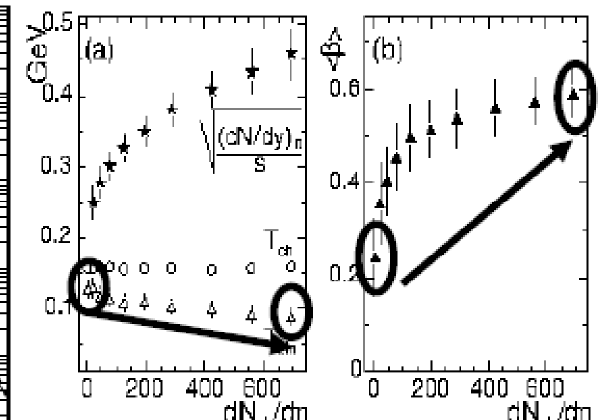
slope break is jet effect

J Phys G 37, 085004 (2010); arXiv:0906.1229

$p_t = 0.5 \quad 2$







larger T
smaller β_t

smaller T
larger β_t

blast-wave BW fits accommodate hard component – jets