Multiplicity dependence of the jet structure in small systems at LHC energies

Wigner Seminar

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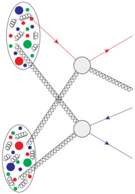
Motivation

- "Traditional" picture after the RHIC results: QGP signatures in A+A collisions.
  - Jet quenching; strongly interacting matter modifies jets.
  - Elliptic flow (v_2): strongly coupled QGP develops hydrodynamical behaviour.
- Suprise at LHC energies: v_2 and long-range correlations in high-multiplicity p+p events;
  - v_n generally governed by multiplicity. Interpretation is problematic.
  - Flow patterns can be (partly) understood by pure QCD rather than hydro.
  - HF multiplicity vs. event activity shows that p+p events are not trivial. This suggests that the role of MPI can be important.

Our motivation

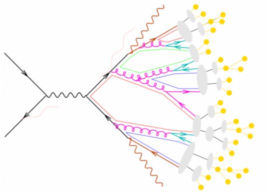
- Recent findings of heavy ion-like phenomena in high-multiplicity p+p collisions.
- The QCD effects in high-multiplicity p-p such as MPI may cause experimentally accessible modification of jet shapes.

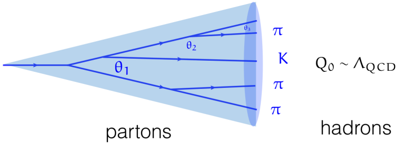


- **We are looking for non-trivial jet shape dependence on event multiplicity.**
- We provide means to validate simulations and help setting the baseline for jet modifications in heavy ions.

Introduction

- We are simulating p+p collisions at $\sqrt{s} = 7$ TeV.
- Monte Carlo event generator: PYTHIA 8.2 with default PDF sets.
- Jet reconstruction: Fastjet software package with anti-k_t algorithm.
- Full jet reconstruction with $R = 0.7$. $(R^2 = \Delta\phi^2 + \Delta\eta^2)$



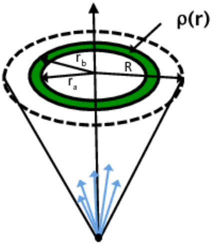


Different tunes and settings

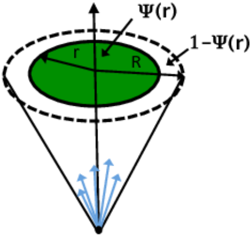
- Tunes: Monash, Monash*, 4C.
- Multi parton interactions (MPI).
- Colour reconnection (CR): In PYTHIA this is an in-built mechanism that allows interactions between partons originating in MPI and initial/final state radiations, by minimizing color string lengths.
  - 0: MPI-based scheme,
  - 1: QCD-based string length minimisation scheme,
  - 2: gluon-move scheme.
  - off: we don't use it.

Differential and integral jet shapes

Differential jet shape:



Integral jet shape:

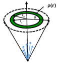


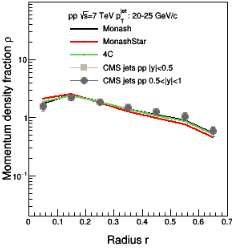
$$\rho(r) = \frac{1}{\delta r}\frac{\sum_{r_a<r_i<r_b} p_t^{(i)}}{p_t^{jet}}.$$

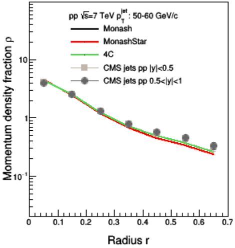
$$\psi(r) = \frac{\sum_{r_i<r} p_t^{(i)}}{p_t^{jet}}.$$

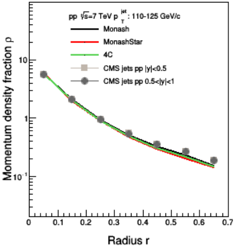
$$\psi(R) = \int_0^R \rho(r')dr' = 1.$$

A reality check: Comparison with CMS for $\rho(r)$



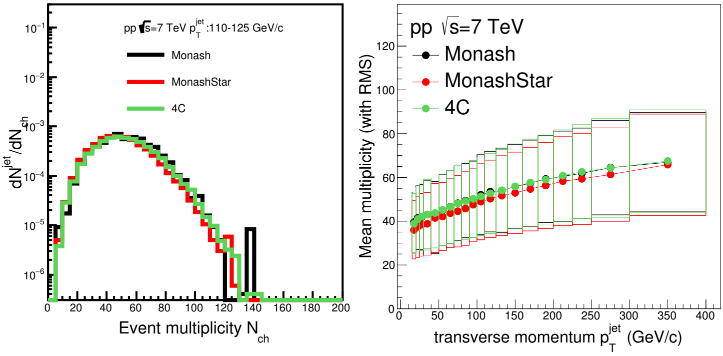






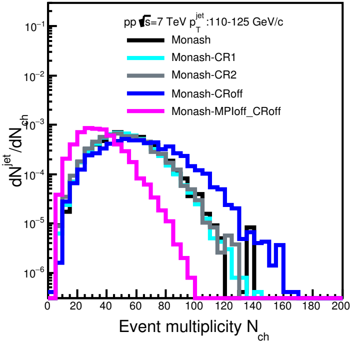
- Different tunes reproduce CMS data within uncertainty.
- We investigated different p_t^{jet} windows between $(15-400)$ GeV.

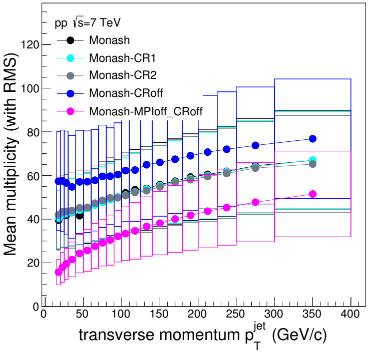
Event Nch multiplicity distribution for the tunes



- All tunes show similar event Nch distributions.

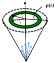
Event Nch multiplicity distribution for the settings

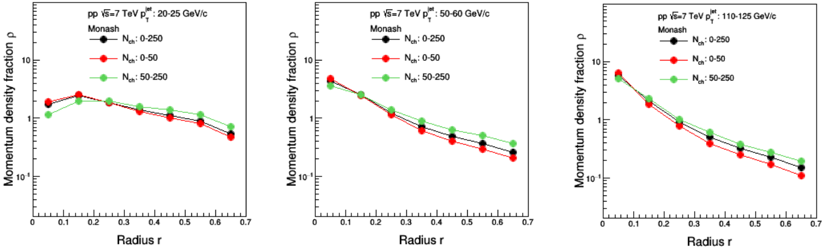




- All tunes show similar event Nch distributions.
- But huge differences between different settings!
- Colour reconnection schemes do not differ much.

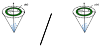
$\rho(r)$ distribution for different tunes

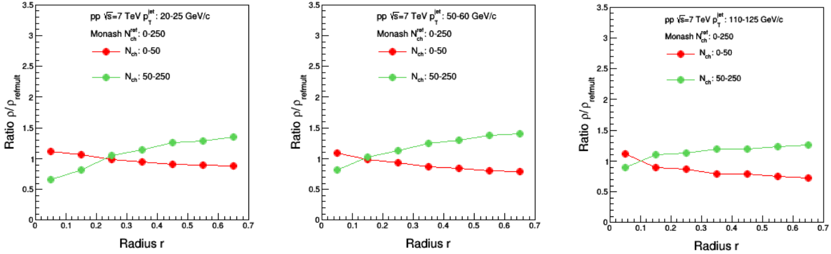




- We see a multiplicity dependence in the jet shapes,
- but it is the trivial multiplicity dependence we expected.

An intersection

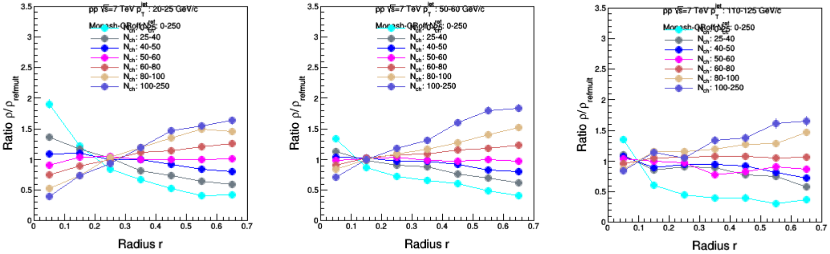

MB



- The two low- and high-multiplicity curves intersect each other at unity.
- The interception point depends on the p_t^{jet}.
- What happens for different multiplicities?

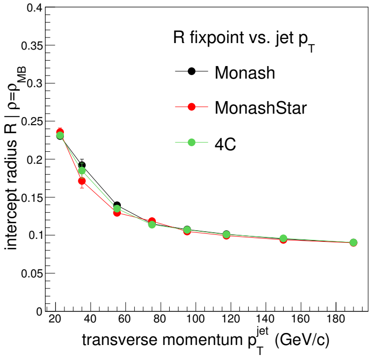
A characteristic jet size measure?

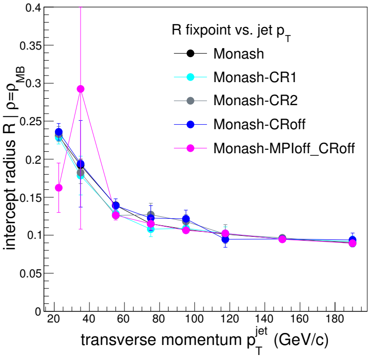
 /  MB



- The intersection does not depend on our bin choice.
- Our finding: it is also independent from tunes and settings!
- Could this r be a characteristic jet size?

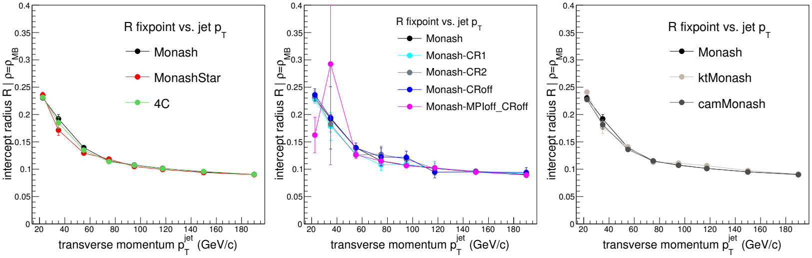
The p_t^{jet} dependence of the r "fix point"





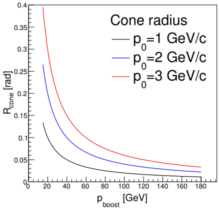
- Good agreement between tunes and settings.
- It is a characteristic jet size at a given p_t^{jet}. Or is it some trivial effect?
- Is it an artefact of our jet reconstruction algorithm?

The p_t^{jet} dependence of the r "fix point"



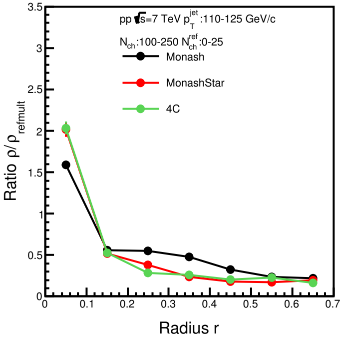
- Good agreement between tunes and settings.
- This "characteristic jet size" is independent of the three jet reconstruction algorithms.

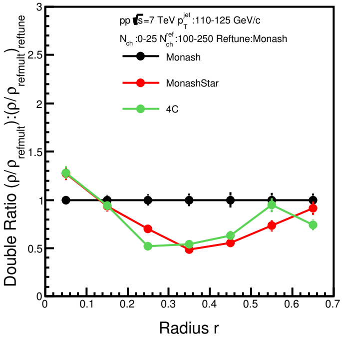
A toy model



- Jet consisting of particles with equal momentum p_0.
- We boost with a certain momentum p_{boost} towards the jet axis.
- High-p_T: qualitatively similar behaviour of the characteristic jet size with respect to p_{boost}.
- Low-p_T: blow-up is not expected in data because jet rec. is limited in R and because of angular cut-off in splitting.

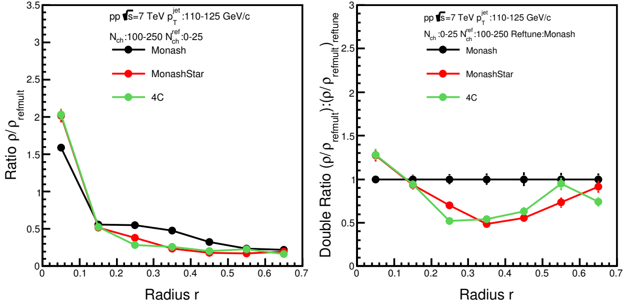
Applying a double ratio for $\rho(r)$





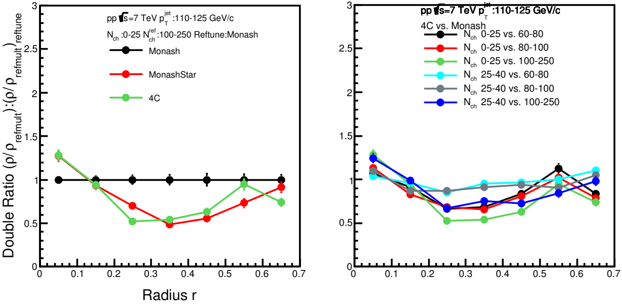
$$\text{Double ratio: } DR(r) = \frac{(\rho_{low}/\rho_{high})}{(\rho_{low}/\rho_{high})_{ref.tune}}.$$

Applying a double ratio for $\rho(r)$



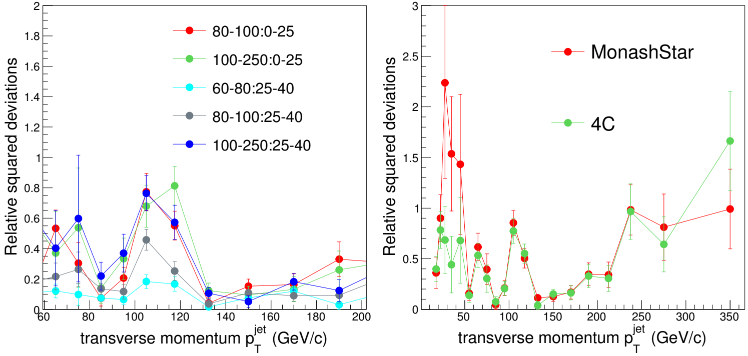
- Trivial multiplicity bias cancelled out.
- We find a significant effect at a given p_t^{jet} windows.
- Non-trivial dependence on p_t^{jet}, origin of the effect needs further investigation.

Double ratio for different multiplicity bins



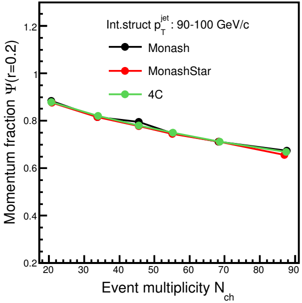
- Same calculations for several different multiplicity bins.
- The effect is larger as the separation in multiplicity is larger.
- Statistically independent samples → not fluctuations.

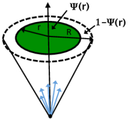
Relative squared deviations

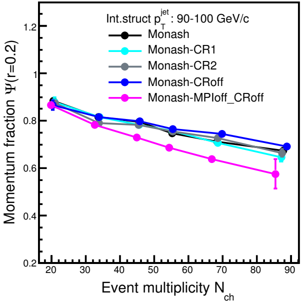


- $RSD = \sqrt{\sum_{0<r_i<R} (DR(r_i) - 1)^2}$
- The nature of the p_T^{jet} dependence is independent of the chosen multiplicity bin.

$\psi(r = 0.2)$ dependence on multiplicity







- No observable effect in integral structure between different tunes.
- Turning off MPI causes significant differences within the same multiplicity class,
- which suggests MPI has an influence on jet structure.

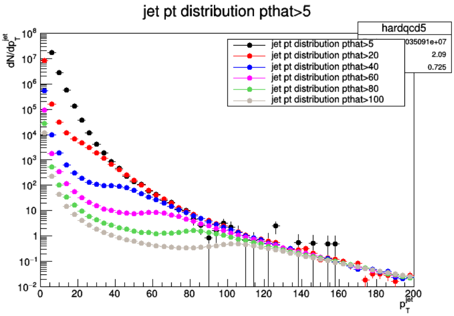
Summary

- We computed several jet structure observables in $\sqrt{s} = 7$ TeV p+p collisions using PYTHIA 8.
- Jet structures measured by CMS are reproduced by our simulations.
- Predictions for multiplicity-dependent jet structures are given.
- We suggest a multiplicity-independent jet size measure.
- Multiplicity-dependent experimental jet-structure analyses could differentiate between otherwise well-performing models.
- Studies concerning heavy-flavour-tagged jets are under way.

Thank you for your attention!

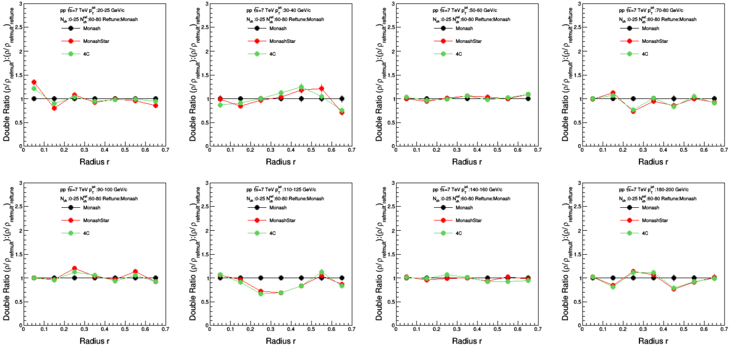
Backup

p_t^{jet} distributions for different $\hat{p}_t$

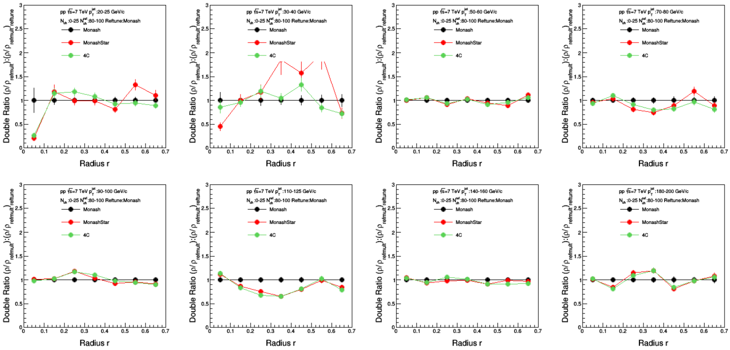


p_t^{jet}	$\hat{p}_t$
20 - 25	5 $\leq$
30 - 40	5 $\leq$
50 - 60	20 $\leq$
70 - 80	20 $\leq$
90 - 100	40 $\leq$
110 - 125	40 $\leq$
140 - 160	80 $\leq$
180 - 200	80 $\leq$
225 - 250	80 $\leq$

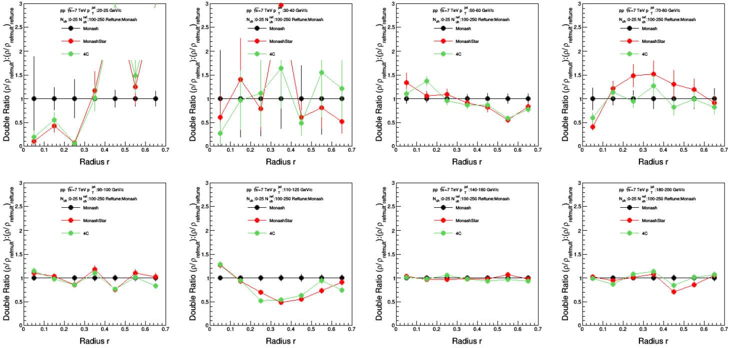
$\rho(r)$ double ratio figure: 1/6



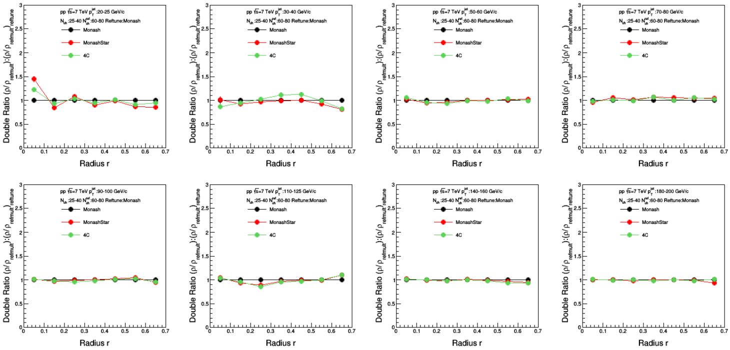
$\rho(r)$ double ratio figure: 2/6



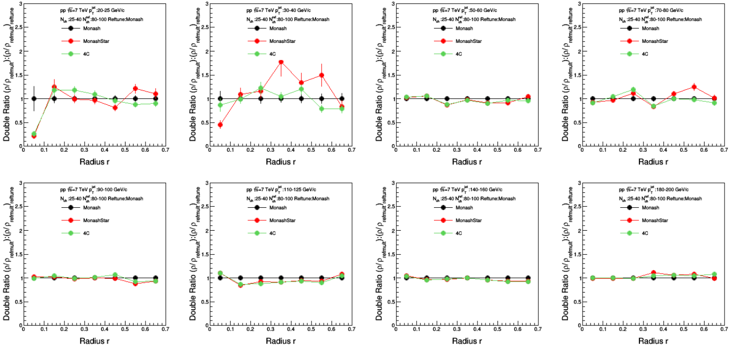
$\rho(r)$ double ratio figure: 3/6



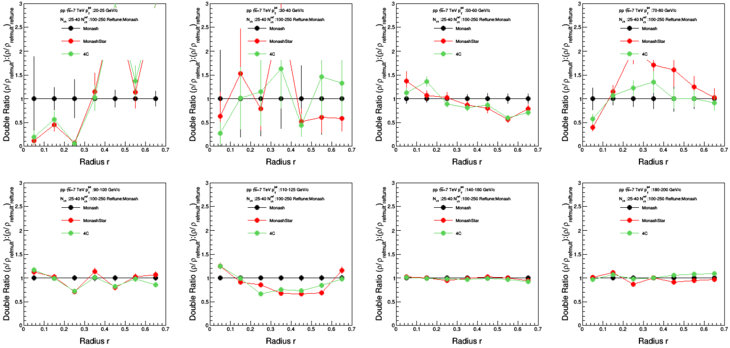
$\rho(r)$ double ratio figure: 4/6



$\rho(r)$ double ratio figure: 5/6



$\rho(r)$ double ratio figure: 6/6



Significant difference between MPIoff-CRoff and CRoff