Investigating jet modification in absence of QGP-medium

Prottoy Das

University Of Illinois Chicago

Hot Jets: Advancing the Understanding of High Temperature QCD with Jets

University of Illinois Urbana-Champaign

Jan 08-10, 2025

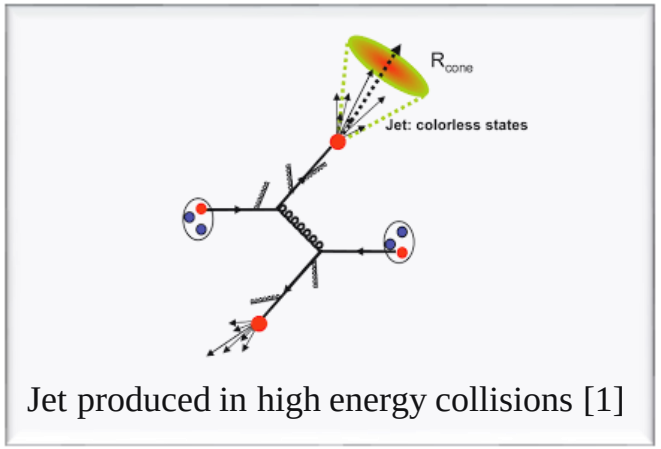
Jets and their importance

Jets

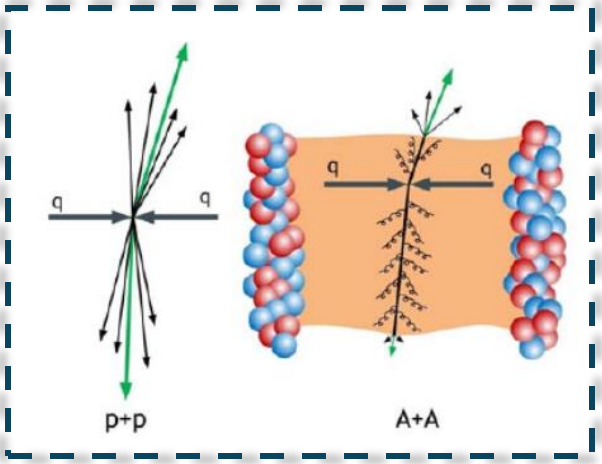
- Collimated showers of particles produced from the fragmentation and hadronization of hard-scattered partons
- Proxy to the initial hard-scattered partons

Importance of jet study

- *In heavy-ion (AA) collisions*
  - Serve as calibrated probes for modification in QGP medium through jet-medium interaction and partonic energy loss (**jet quenching**)
- *In proton-nucleus (pA) collisions*
  - Test the impact of Cold Nuclear Matter (CNM) effects
- *In proton-proton (pp) collisions*
  - Test perturbative QCD (pQCD) calculations
  - Provide reference measurements for pA and AA collisions
  - Help to tune Monte Carlo (MC) event generators



Jet produced in high energy collisions [1]



Jets in pp and AA collisions [2]

Jet quenching in AA

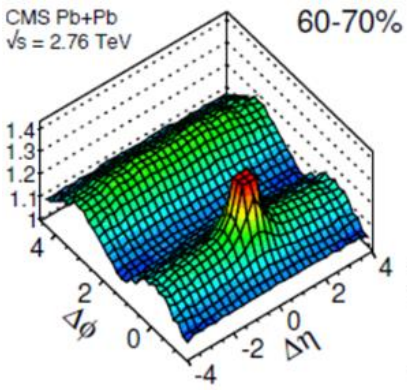
- Suppression of jet production
- Modification of internal jet structure

[1] https://indico.cern.ch/event/748623/contributions/3099340

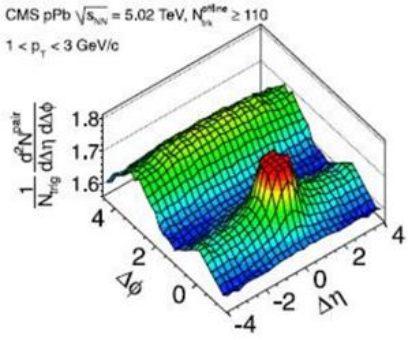
[2] https://indico.fnal.gov/event/10528/contributions/3304

Small collision system puzzle

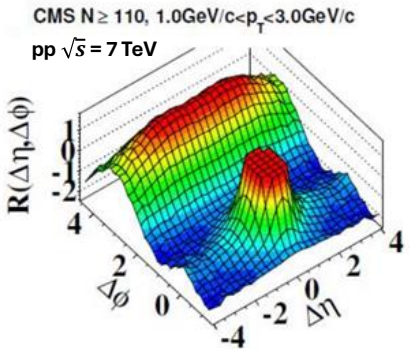
Pb-Pb and **small systems** behave **similarly**



CMS, Eur. Phys. J. C72, 2012 (2012)

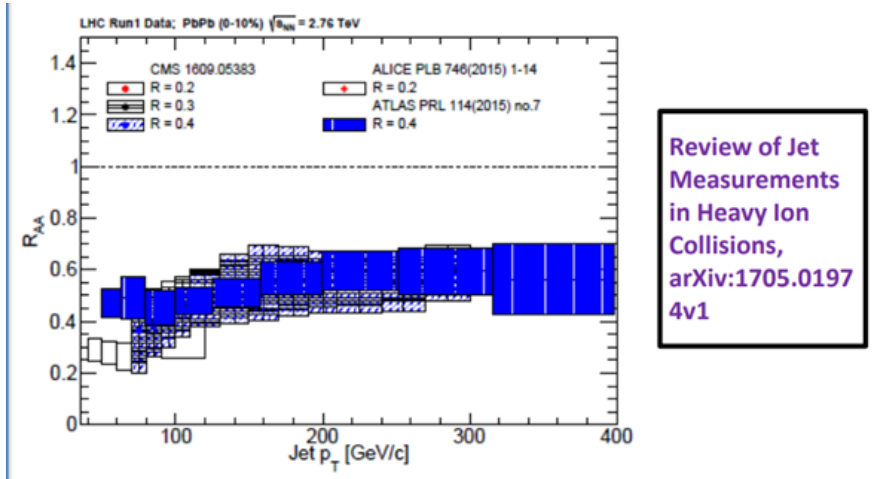


CMS, Phys.Lett. B718, 795 (2013)

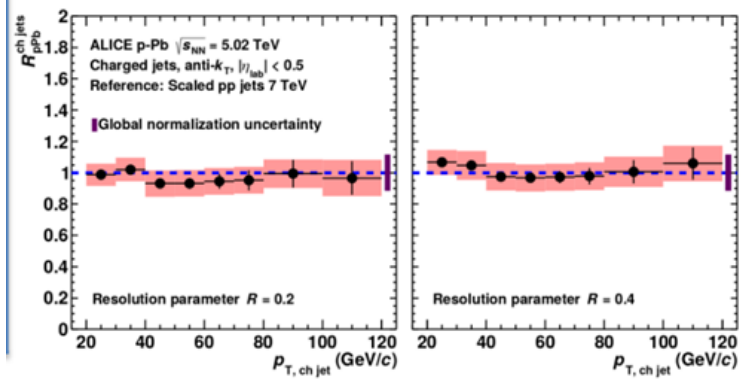


JHEP 09 (2010) 091

Pb-Pb and **small systems** behave **differently**



Review of Jet Measurements in Heavy Ion Collisions, arXiv:1705.01974v1



ALICE, Phys. Lett. B 749 (2015) 68-81

Open questions

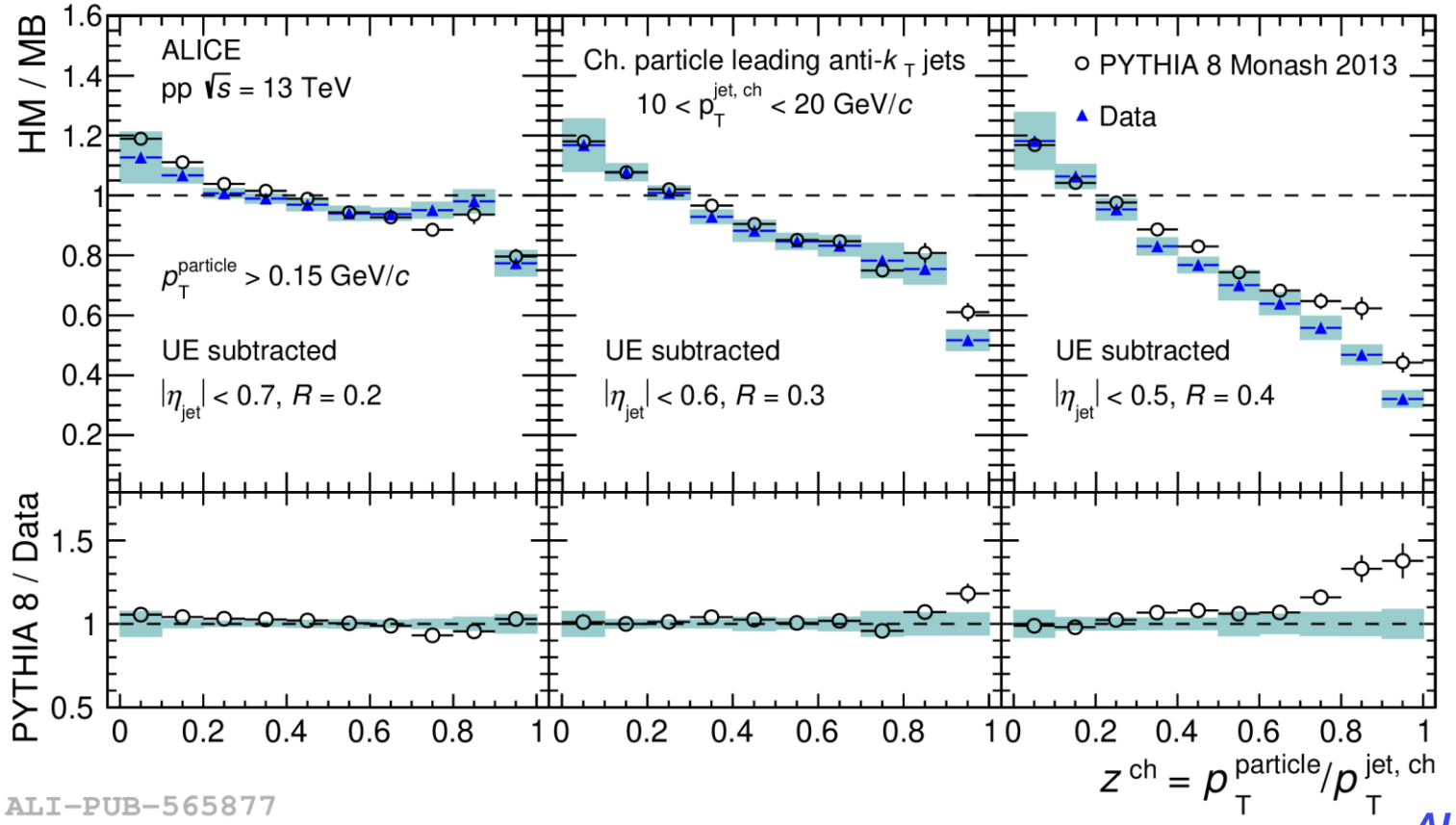
Medium formation in **small systems**? Or some **other source(s)** playing a role here?

Investigation required

Intra-jet properties > **inclusive jet spectra**

More sensitive to the details of parton shower and hadronization processes

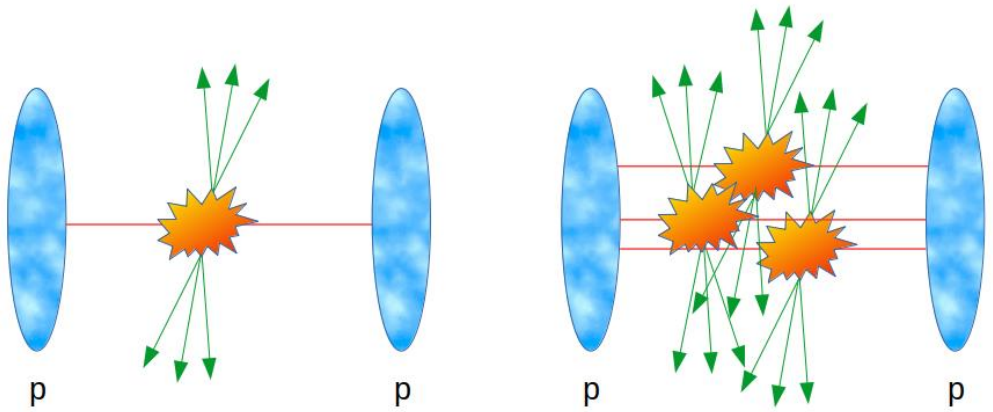
Observation of jet modification in high-multiplicity pp collisions



ALICE, Eur. Phys. J. C 84 (2024) 1079

- Recent multiplicity-dependent measurement of jet properties in pp collisions by ALICE shows modification of jet fragmentation at high multiplicity
- PYTHIA 8, without the implementation of jet quenching effects, show similar pattern as data

Jet modification in PYTHIA?



- **Multiparton interaction (MPI):** multiple partonic hard scatterings occurring in a single event (proton-proton collision)

- **Color reconnection (CR):** final outgoing partons from MPIs are connected via color strings so as to minimize the total length of the strings

- MPI and CR mechanisms in PYTHIA 8 can explain some of the collective behaviors observed in high-multiplicity pp collisions

In this work, we investigate the effects of MPI and CR on jet modification in high-multiplicity pp collisions using PYTHIA 8 simulation

Chinese Phys. C 48 (2024) 1, 013105

Analysis details and observables

Data generation

- Collision system: pp
- Center-of-mass energy ($\sqrt{s}$): 13 TeV
- PYTHIA 8.219 Monash 2013
- 3 Configurations (500 M events each):
  1. MPI: OFF, CR: OFF
  2. MPI: ON, CR: OFF
  3. MPI: ON, CR: ON

Event classes

- Minimum bias (MB)
- High-multiplicity (HM): 0-5% highest multiplicity events

Particle selection

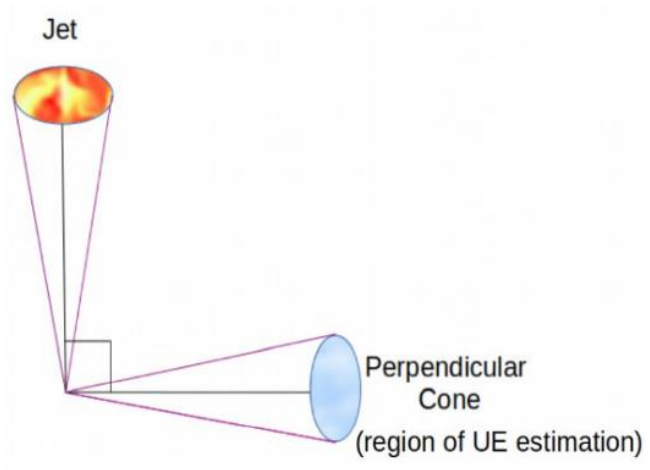
- $p_{\mathrm{T}}^{\mathrm{particle}} > 0.15$ GeV/c
- $|\eta_{\mathrm{particle}}| < 0.9$
- Charged particles

Jet reconstruction

- FastJet anti-k_{T} algorithm
- Jet resolution parameter, $R = 0.4$
- $p_{\mathrm{T}}^{\mathrm{jet,ch}}$ = 10-100 GeV/c
- $|\eta_{\mathrm{jet}}| < 0.5$

Underlying event estimation

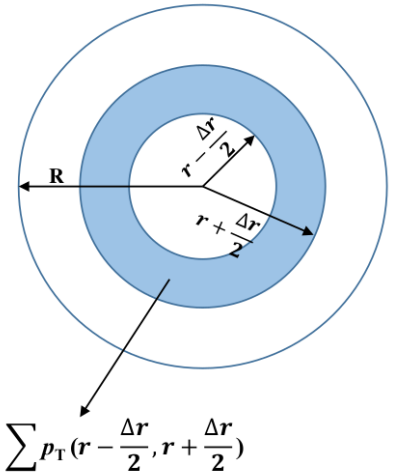
perpendicular cone method



- **Jet shape**: radial distribution of jet transverse momentum density inside the jet cone about the jet axis

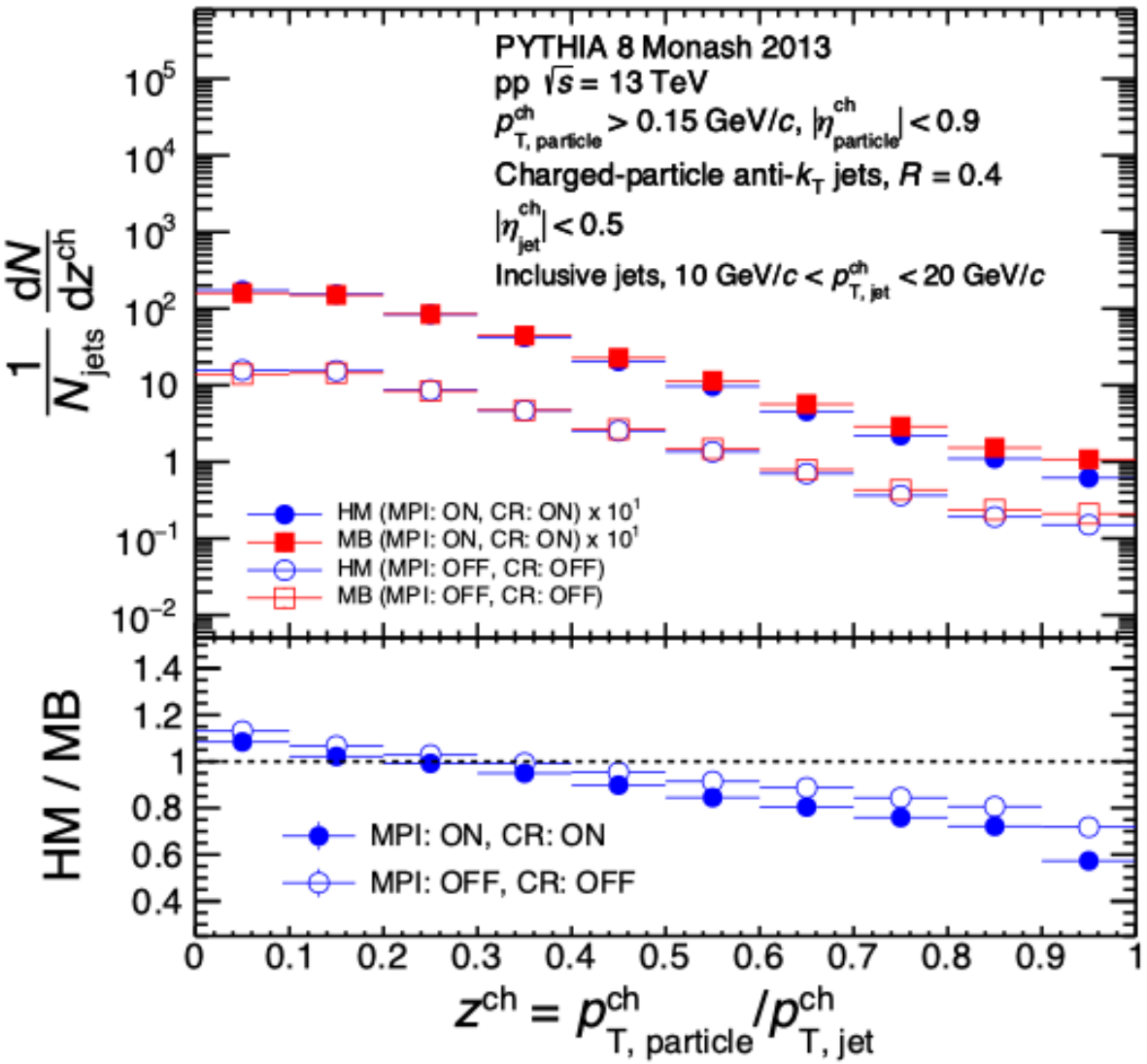
$$\rho(r) = \frac{1}{\Delta r}\frac{1}{N_{\mathrm{jets}}}\sum_{i=1}^{N_{\mathrm{jets}}} p_{\mathrm{T}}{}^{i}\,(r-\frac{\Delta r}{2}, r+\frac{\Delta r}{2})/p_{\mathrm{T}}^{\mathrm{jet,ch}}$$

- **Jet fragmentation function** $(z^{\mathrm{ch}}) = \frac{p_{\mathrm{T}}^{\mathrm{particle}}}{p_{\mathrm{T}}^{\mathrm{jet,ch}}}$



Chinese Phys. C 48 (2024) 1, 013105

Jet fragmentation (z^{ch})



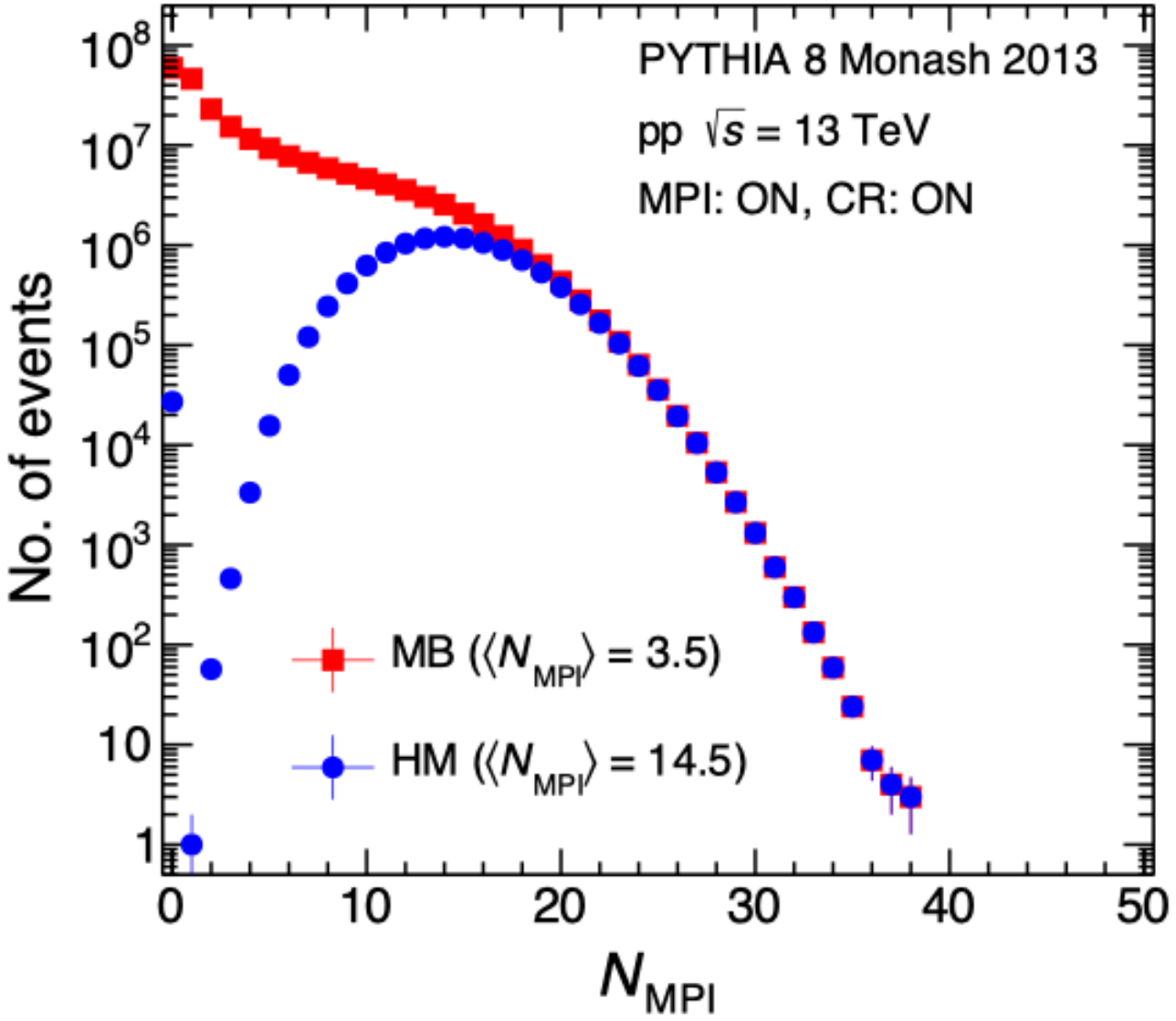
Chinese Phys. C 48 (2024) 1, 013105

- Significant modification of z^{ch} distributions observed in HM events compared to MB
  - ✓ Production of high- z^{ch} particles is substantially suppressed in HM events
  - ✓ Modification is more prominent in presence of MPI and CR effects
  - ✓ Modification is reduced when MPI and CR are switched OFF

Claim: ***MPI*** *and* ***CR*** *are partly responsible for the observed jet modification*

Source(s) of residual modification??

Distribution of no. of multiparton interactions



Chinese Phys. C 48 (2024) 1, 013105

Average no. of MPIs:

$$\langle N_{\mathrm{MPI}} \rangle = \frac{1}{N_{\mathrm{events}}} \sum_{i=1}^{N_{\mathrm{events}}} N_{\mathrm{MPI}}^{i}$$

Where N_{MPI} : no. of multiparton interactions

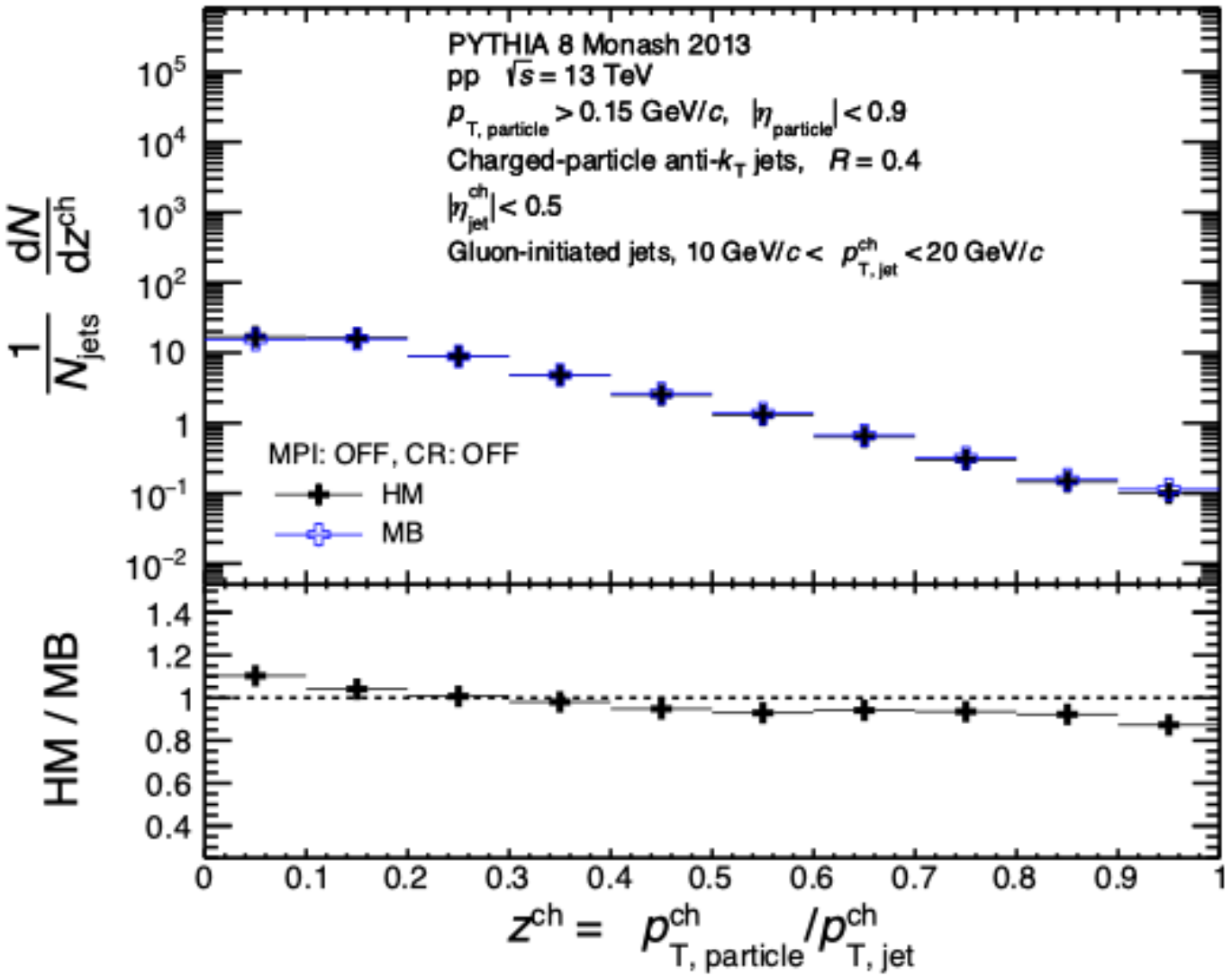
Event class	$\langle N_{\mathrm{MPI}} \rangle$
MB	3.5
HM	14.5

Gluonic contribution to jets

- Gluon-initiated jets are expected to be softer and broader compared to quark-initiated jets
- Gluonic contribution $= \frac{no.\,of\ gluon{-}initiated\ jets}{no.\,of\ inclusive\ matched\ jets}$
- 1-to-1 geometrical matching between initial hard-scattered partons and reconstructed jets is performed
- HM events have larger gluonic contribution (86%) compared to MB events (75%)
  - Expected to contribute to the modification of jet observable

Chinese Phys. C 48 (2024) 1, 013105

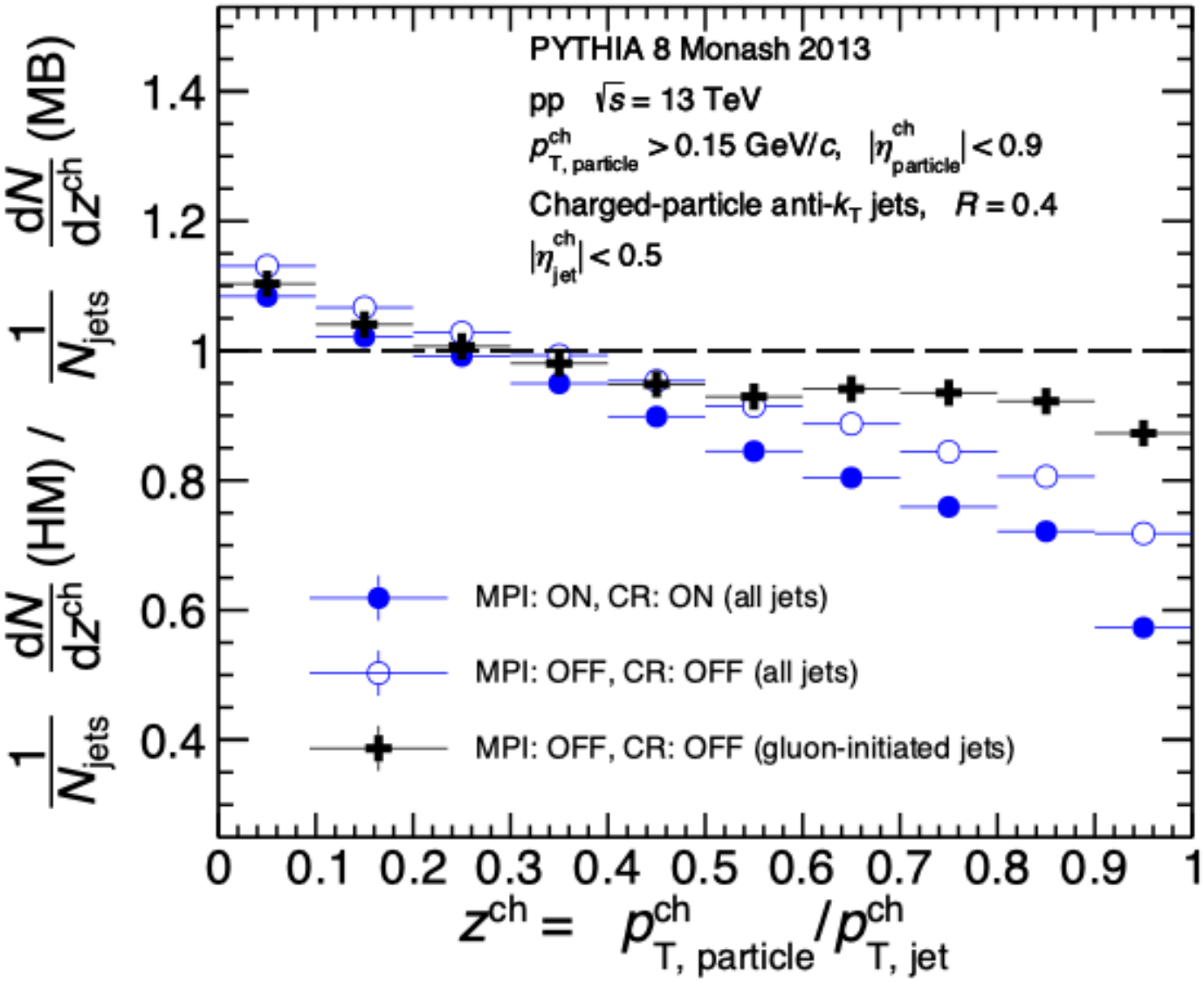
Jet fragmentation (z^{ch})



- Modification is further reduced for gluon-initiated jets in absence of MPI and CR effects

Chinese Phys. C 48 (2024) 1, 013105

Jet fragmentation (z^{ch})

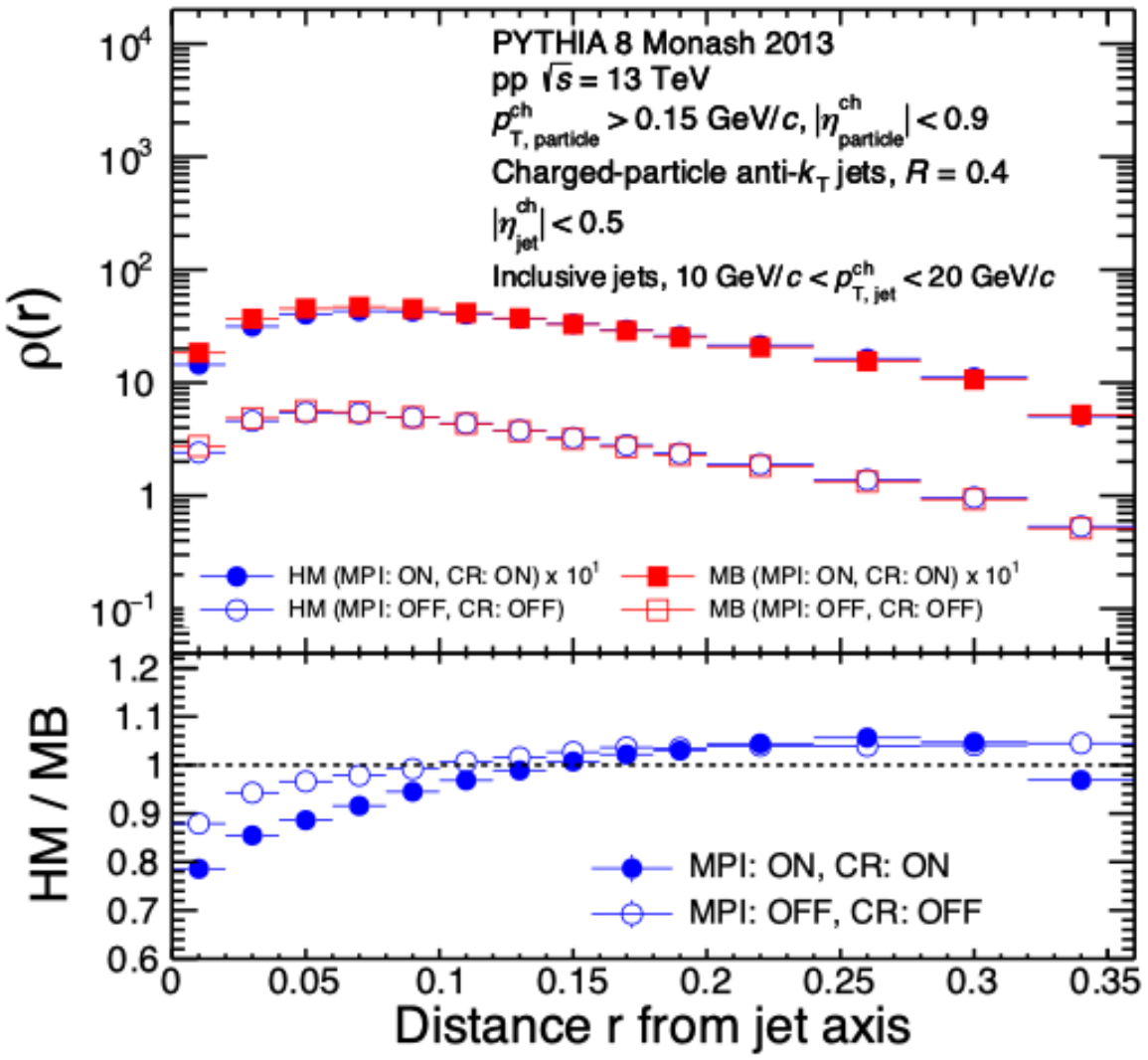


- Modification is further reduced for gluon-initiated jets in absence of MPI and CR effects

MPI, **CR** and **change in gluonic contribution** are some of the major sources responsible for the observed modification of z^{ch} in HM events

Chinese Phys. C 48 (2024) 1, 013105

Jet shape $\rho(r)$



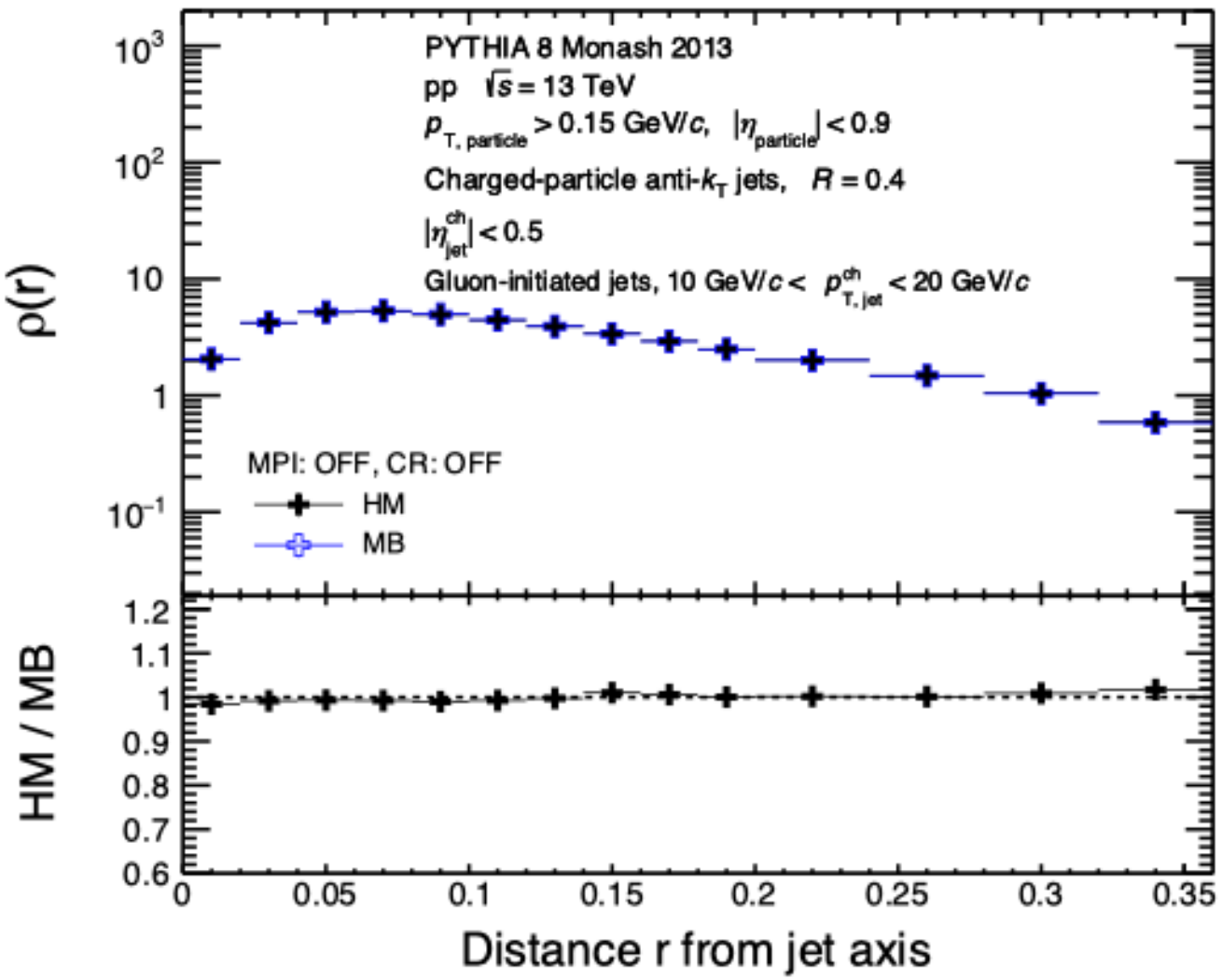
Chinese Phys. C 48 (2024) 1, 013105

- Significant modification of $\rho(r)$ distributions observed in HM events compared to MB
  - ✓ Jet core in HM events is depleted and the energy is redistributed away from the jet axis
  - ✓ Modification is more prominent in presence of MPI and CR effects
  - ✓ Modification is reduced when MPI and CR are switched OFF

Claim: ***MPI*** *and* ***CR*** *are partly responsible for the observed jet modification*

Source(s) of residual modification??

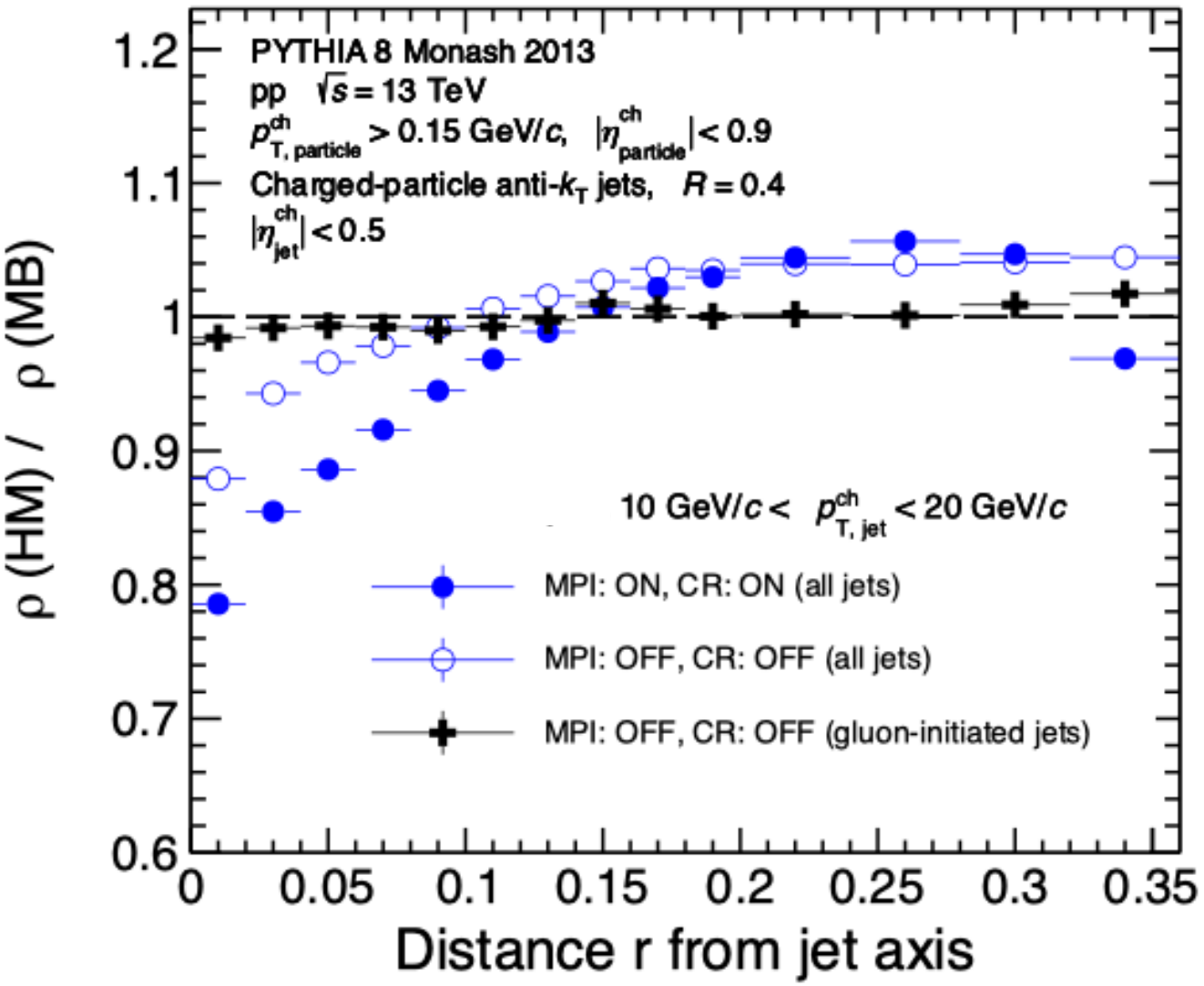
Jet shape $\rho(r)$



- Almost no modification for gluon-initiated jets in absence of MPI and CR effects

Chinese Phys. C 48 (2024) 1, 013105

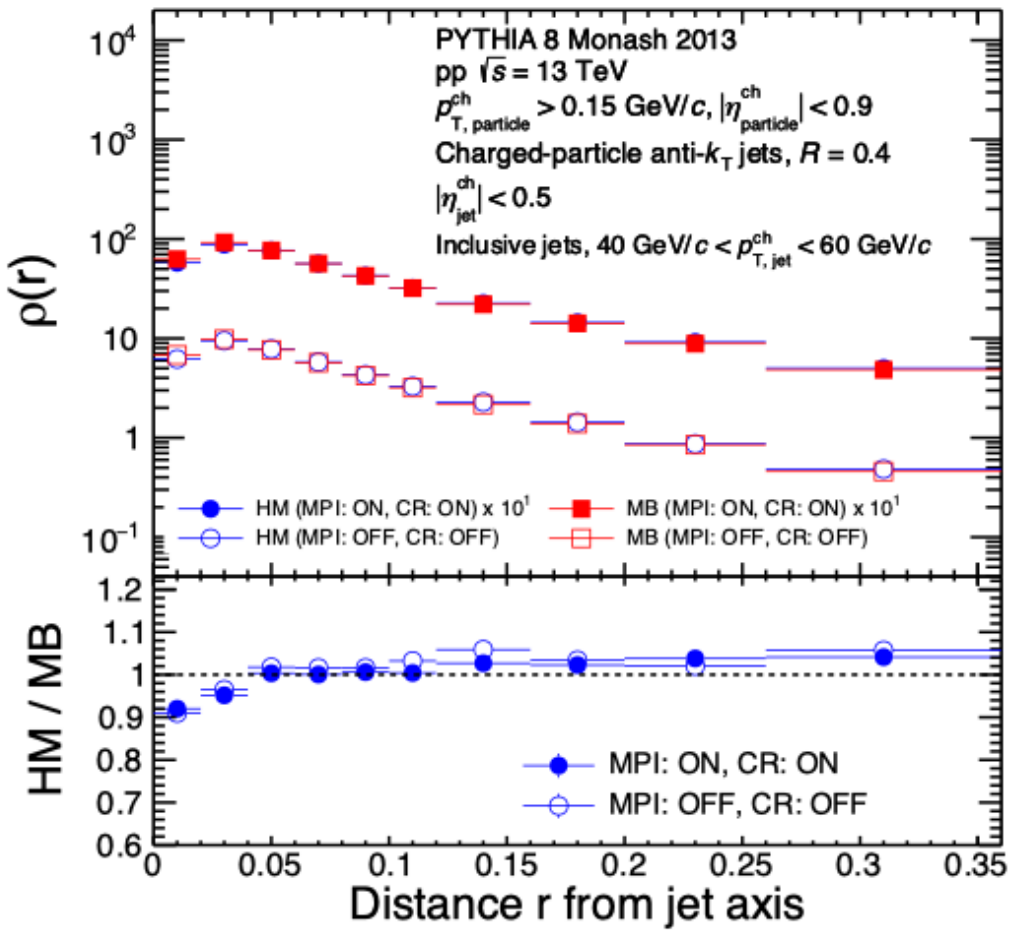
Jet shape $\rho(r)$

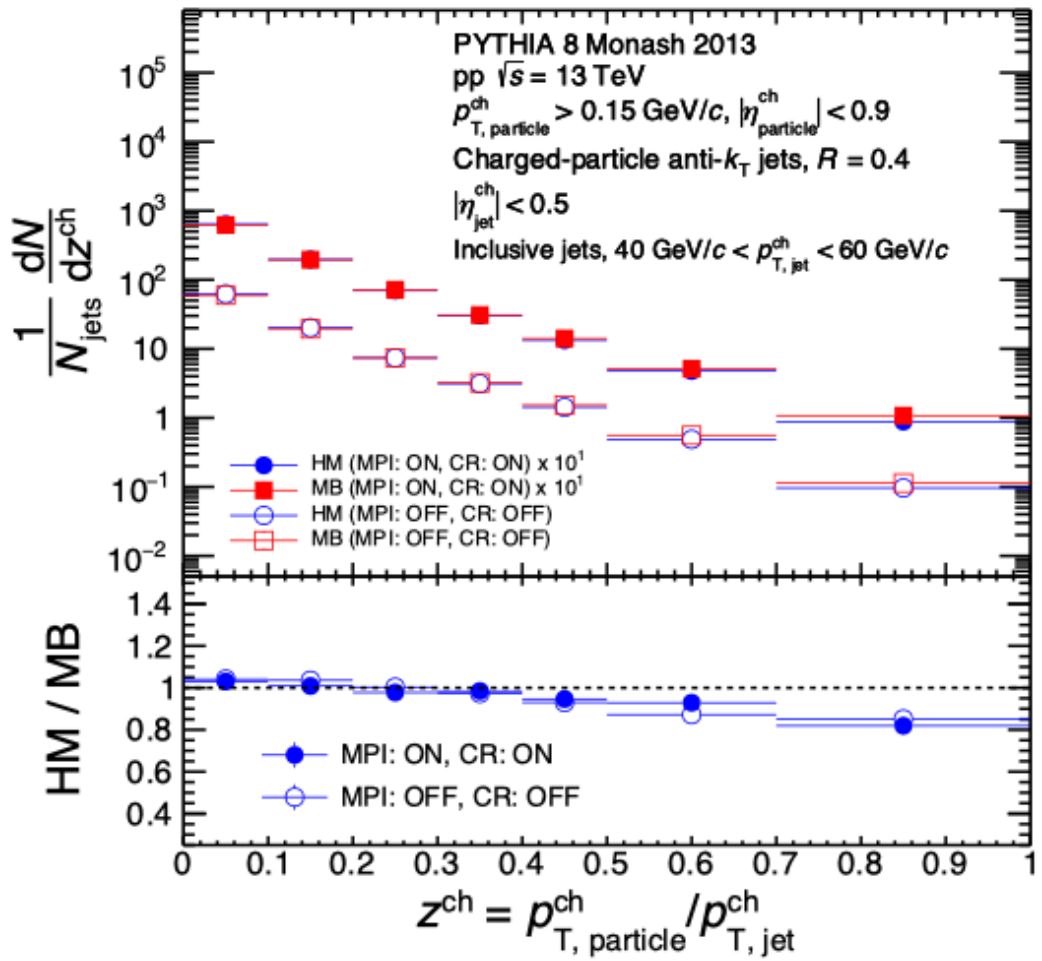


- Almost no modification for gluon-initiated jets in absence of MPI and CR effects

MPI, **CR** and **change in gluonic contribution** are the major sources responsible for the observed modification of $\rho(r)$ in HM events

$\rho(r)$ and z^{ch} at high jet p_T



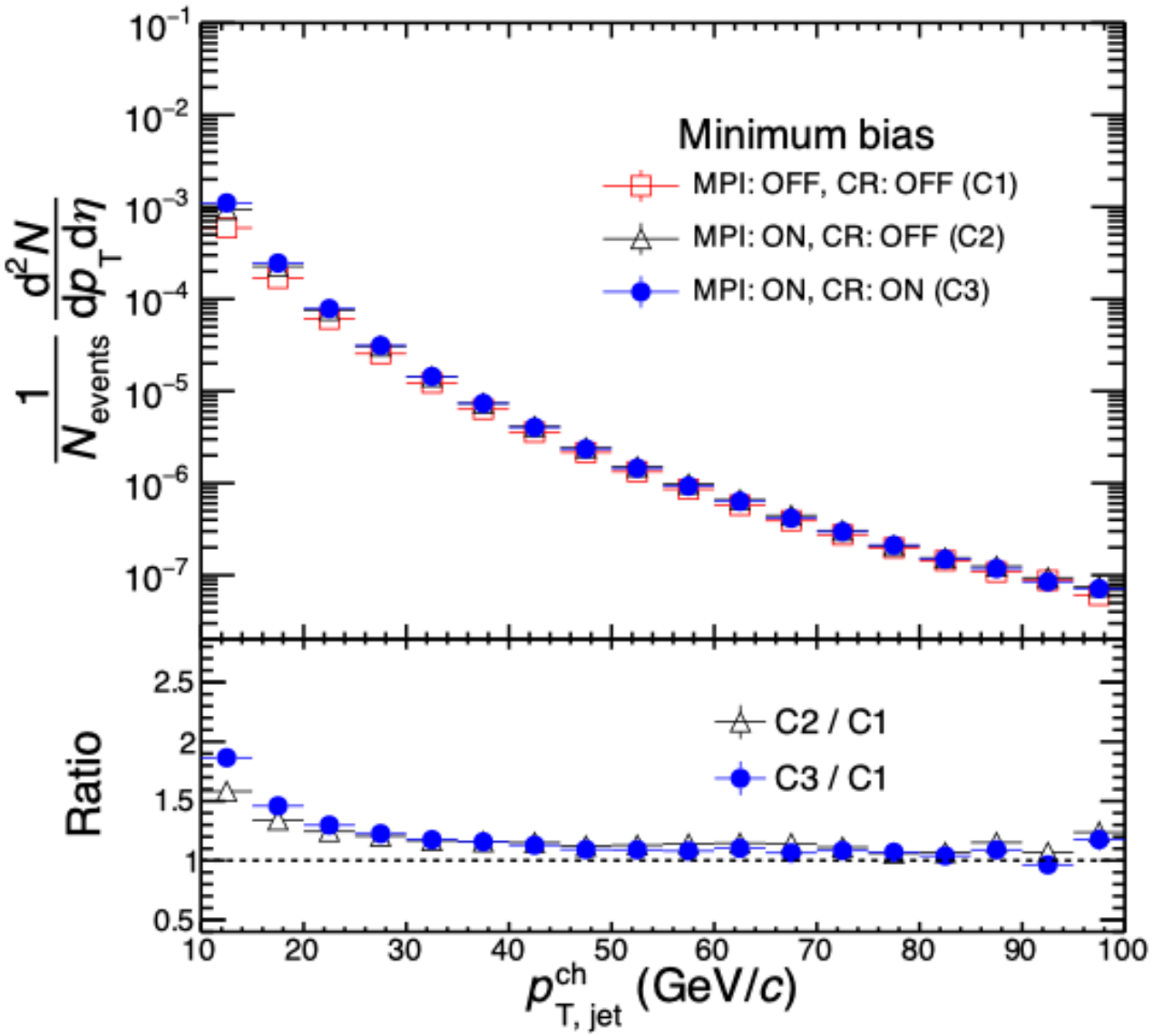


Chinese Phys. C 48 (2024) 1, 013105

❖ Magnitudes of modification of $\rho(r)$ and z^{ch} are significantly reduced at higher jet p_T

➢ Expected as effects of MPI and CR are dominant at low p_T

Jet p_T spectra



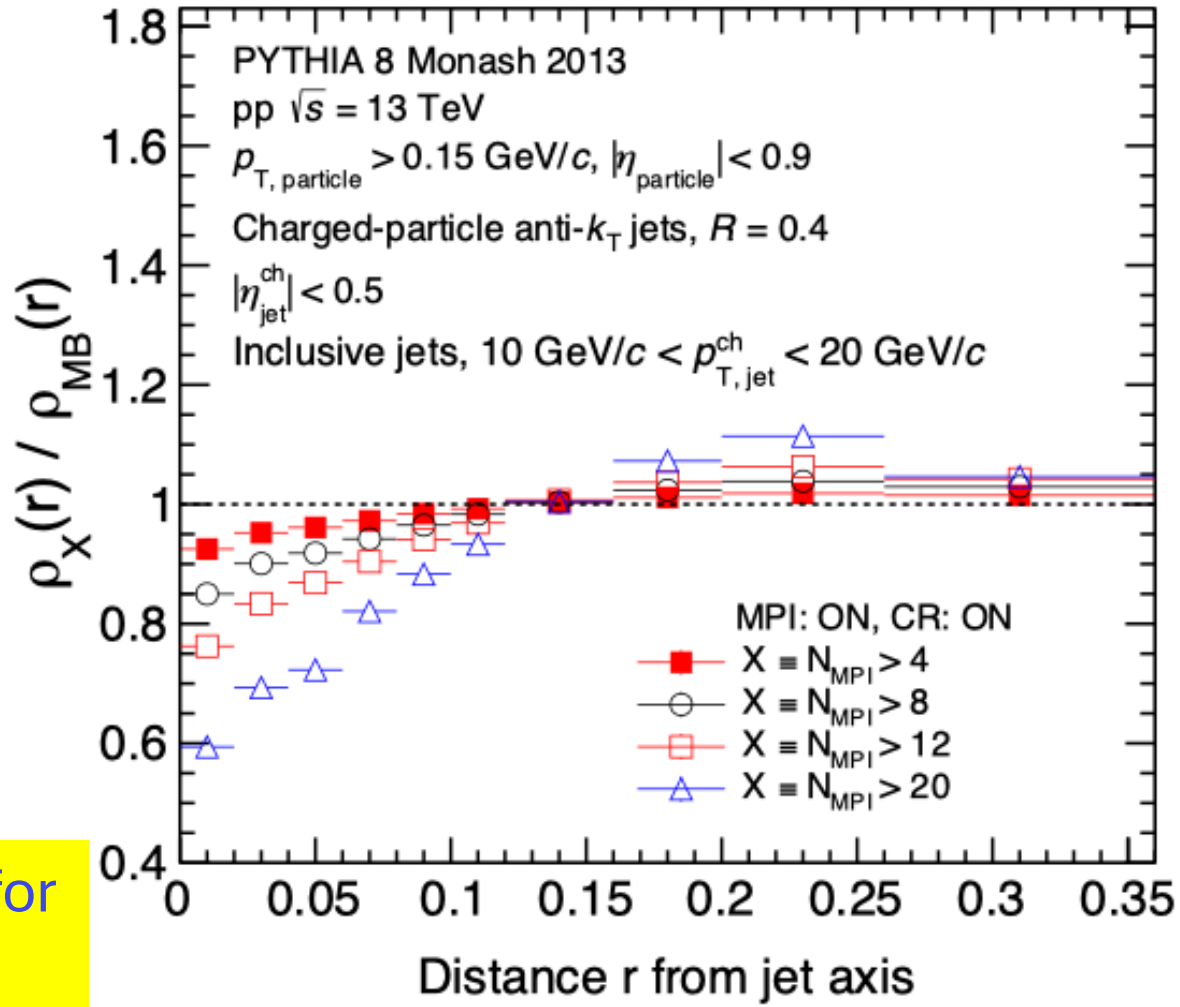
- Rate of jet production increases due to MPIs at low jet p_T
- CR effects further enhances production of low p_T jets
- Indication of multiple jet production due to MPI, as expected to be more prominent at low p_T

Chinese Phys. C 48 (2024) 1, 013105

Effect of MPI and CR on $\rho(r)$

❖ Following event samples are considered based on the N_{MPI}:

Event class	$\langle N_{MPI} \rangle$
MB	3.5
I ($N_{MPI} > 4$)	9.1
II ($N_{MPI} > 8$)	12.4
III ($N_{MPI} > 12$)	15.3
IV ($N_{MPI} > 20$)	22



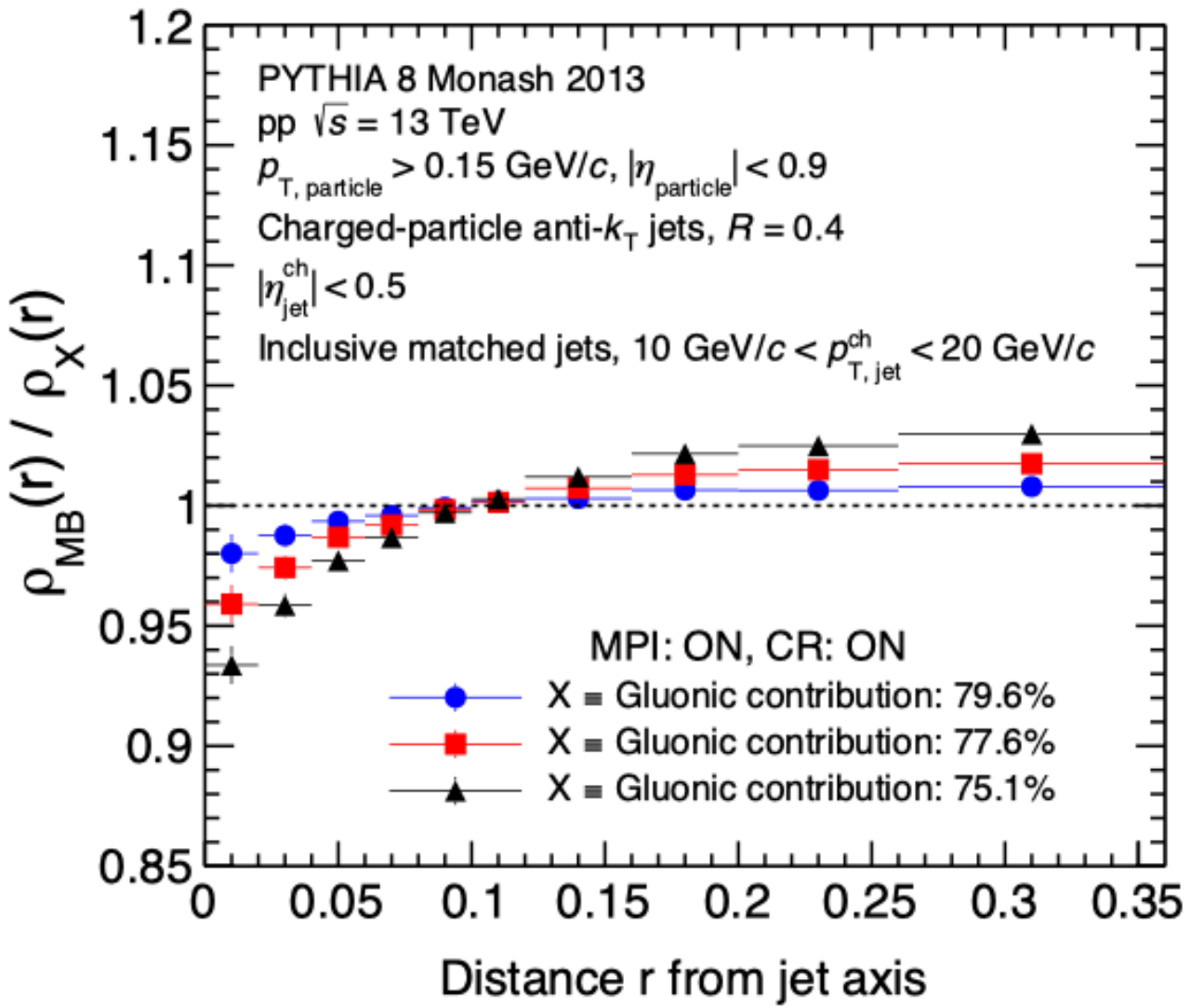
Magnitude of modification in $\rho(r)$ increases for event classes with larger $\langle N_{MPI} \rangle$

Chinese Phys. C 48 (2024) 1, 013105

Effect of change in gluonic contribution on $\rho(r)$

- Different jet samples are considered by randomly discarding 10%, 20% and 30% of gluon-initiated jets from MB jet samples

Magnitude of modification in $\rho(r)$ increases with increasing change in gluonic contribution



Chinese Phys. C 48 (2024) 1, 013105

Summary

- Multiplicity dependence of charged-particle jet properties are studied in pp collisions at 13 TeV with PYTHIA 8 Monash 2013 tune
- PYTHIA 8, without any implementation of jet quenching mechanisms, exhibits modification of jet shape $\rho(r)$ and jet fragmentation function z^{ch} at low jet p_T regime in high-multiplicity events compared to minimum bias ones
- Major possible sources responsible for the observed jet modification in PYTHIA are **MPI, CR** and **change in the number of gluonic contribution in high-multiplicity events**
- The larger the no. of MPIs and/or gluonic contribution, the larger the amount of jet modification

Key takeaways:

- These findings demand very careful study and interpretation of such observables by the experimental community
- Disentangling gluon-initiated jets experimentally is challenging; still studying multiplicity dependence of these observables for pure gluonic jets would be worth pursuing!

Thank you

Backup