

Disentangling the gluon Bremsstrahlung effects from the underlying event in high-multiplicity pp collisions

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Motivation

2

1. **High-multiplicity proton-proton collisions show collective behavior**

$$\frac{dn}{d\phi} \propto 1 + \sum_n 2v_n(p_T) \cos[n(\phi - \Psi_n)]$$

2. **Good agreement with relativistic viscous hydrodynamic calculations**

Figure: Elliptic (v_2), triangular (v_3) and quadrupolar (v_4) flow coefficients, PLB 774 (2017) 351-356

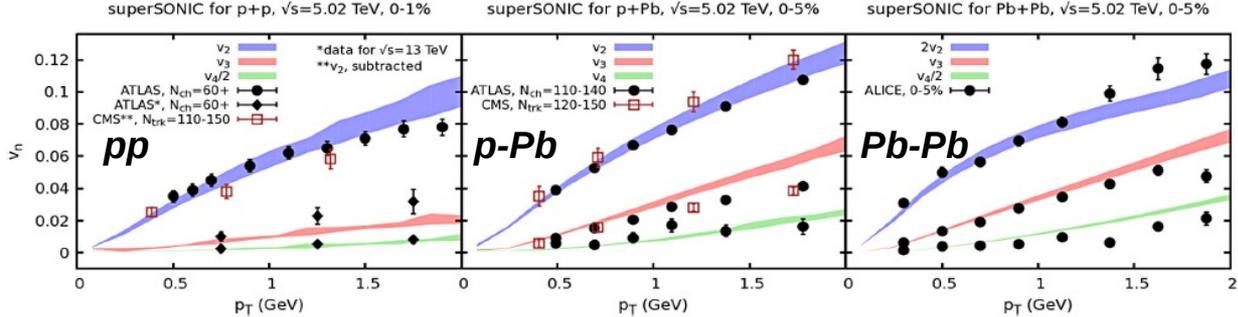
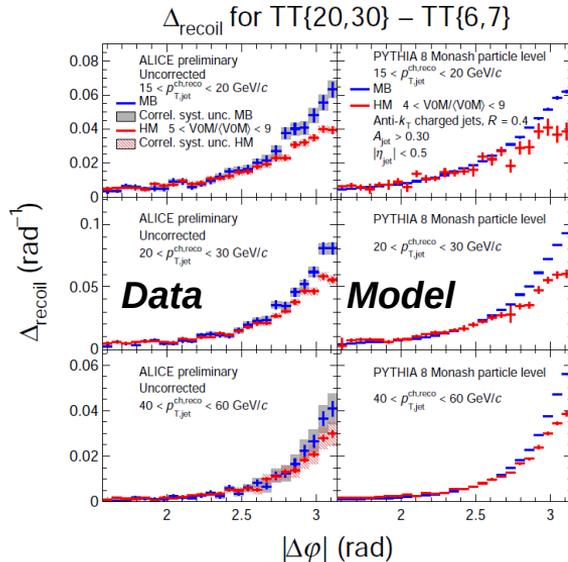


Figure: Uncorrected acoplanarity distributions for ALICE data (left) and PYTHIA 8 Monash (right), Nucl.Phys.A 1005 (2021) 121924

No jet quenching found so far → searches warranted: **first measurement from ALICE collaboration**: Search for jet quenching effects in high multiplicity pp collisions at 13 TeV (Nucl.Phys.A 1005 2021, 121924, QM'19)

- Event activity classes based on average multiplicities
- broadening of recoil jet acoplanarity → characteristic of jet quenching
- similar effect observed in the PYTHIA model (which lacks the mechanism of jet-quenching)

Goal: Study high-multiplicity pp events in models to understand biases



Methods - Observables and Event activity classifier R_T

3

Standard two-particle azimuthal correlation analysis to study jet-quenching effects

I_{AA} : ratio of jet-like yield from AA to the one from pp collisions

- > interplay between the parton production spectrum and energy loss in the medium
- > Towards (away) region: enhancement (suppression)

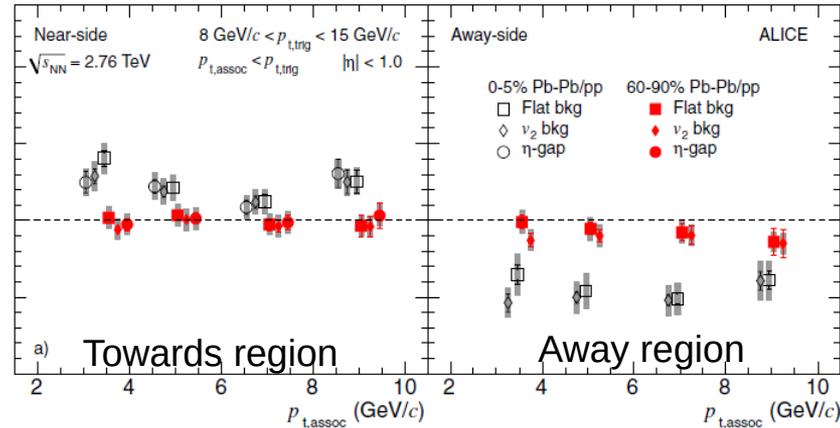


Figure:

I_{AA} for central (black) and peripheral (red) collisions, PRL 108, 092301 (2012)

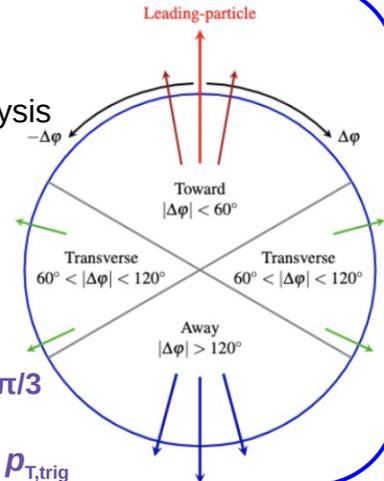
- > **PYTHIA 8 model**: 2->2 process + parton shower (Initial- and Final state radiation), Color Reconnection, MPI
- > primary charged particles in $|\eta| < 0.8$, $\sqrt{s} = 5.02$ TeV
- > trigger particle: $8 \text{ GeV}/c < p_T < 15 \text{ GeV}/c$
- > Study Underlying Event activity (semi-hard and multi-parton interactions)
- > Use **relative transverse activity classifier R_T**

$$R_T = \frac{N_{ch}^{trans.}}{\langle N_{ch}^{trans.} \rangle}$$

=> **Goal: study how event selection based on R_T biases towards and away regions**

R_T : defined in the 'transverse region', adopted in the Underlying Event analysis

- > Towards region: $|\Delta\phi| < \pi/3$
- > Away region: $|\Delta\phi| > 2\pi/3$
Sensitive to string fragmentation
- > **Transverse region: $\pi/3 < |\Delta\phi| < 2\pi/3$**
- Sensitive to Underlying Event
- Used to build R_T ; insensitive to $p_{T,trig}$



Methods - jet-like signal $C(\Delta\eta\Delta\phi)$ extraction

-> **Correlations at partonic level** (due to gluon radiation or colour reconnection) are turned **on and off**: Initial- and Final state radiation, CR

-> **Monash tune**: above given R_T value $\langle N_{\text{MPI}} \rangle$ saturates -> towards region “picks up” particles from jet fragments -> **activity biased**

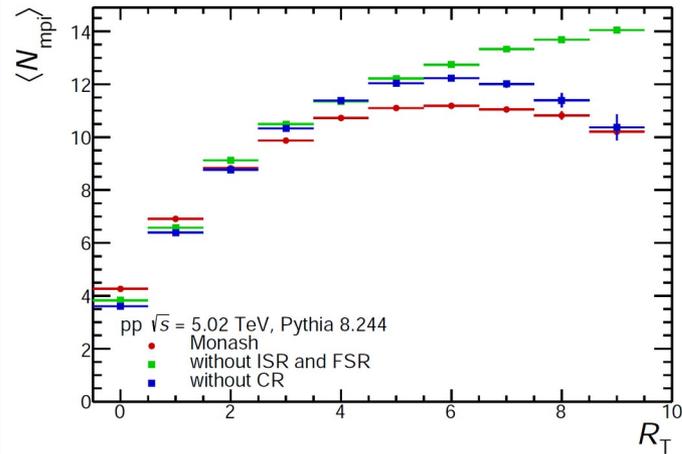


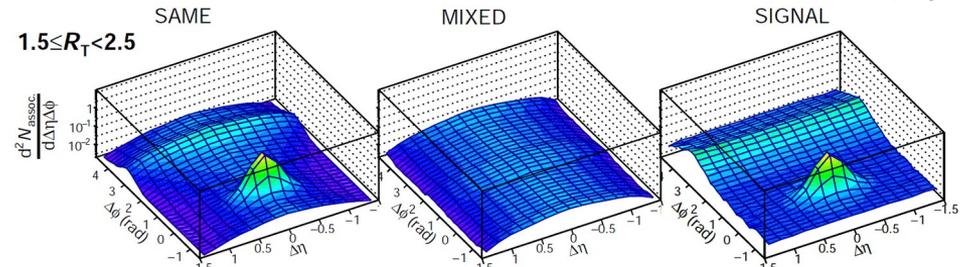
Figure. Average number of multi-parton interactions as a function of R_T

-> Selection on R_T , **a third structure in the transverse region** ($\pi/3 < |\Delta\phi| < 2\pi/3$): associated yield increases with R_T

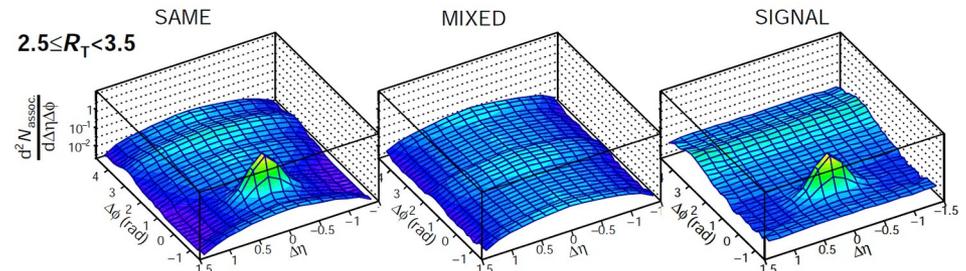
-> **Contribution** to the towards and the away regions has to be **removed: using mixed event technique**

-> Underlying event subtracted using Zero Yield at Minimum method

-> **Evolution of jet signal with R_T is studied** $C(\Delta\eta, \Delta\phi) = B(0, 0) \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$



pp $\sqrt{s} = 5.02$ TeV Pythia 8.244 (Monash), $8 \leq p_T^{\text{leading}} < 15$ GeV/c, $4.0 \leq p_T^{\text{assoc}} < 6.0$ GeV/c

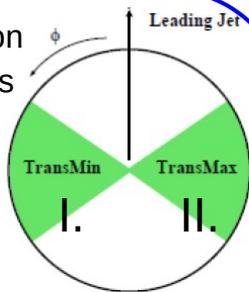


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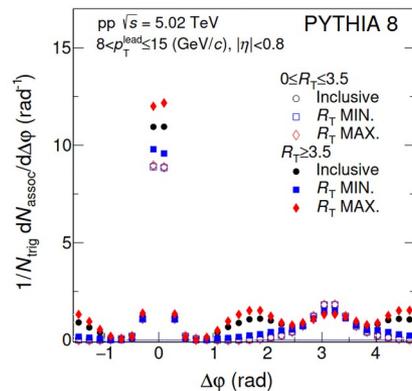
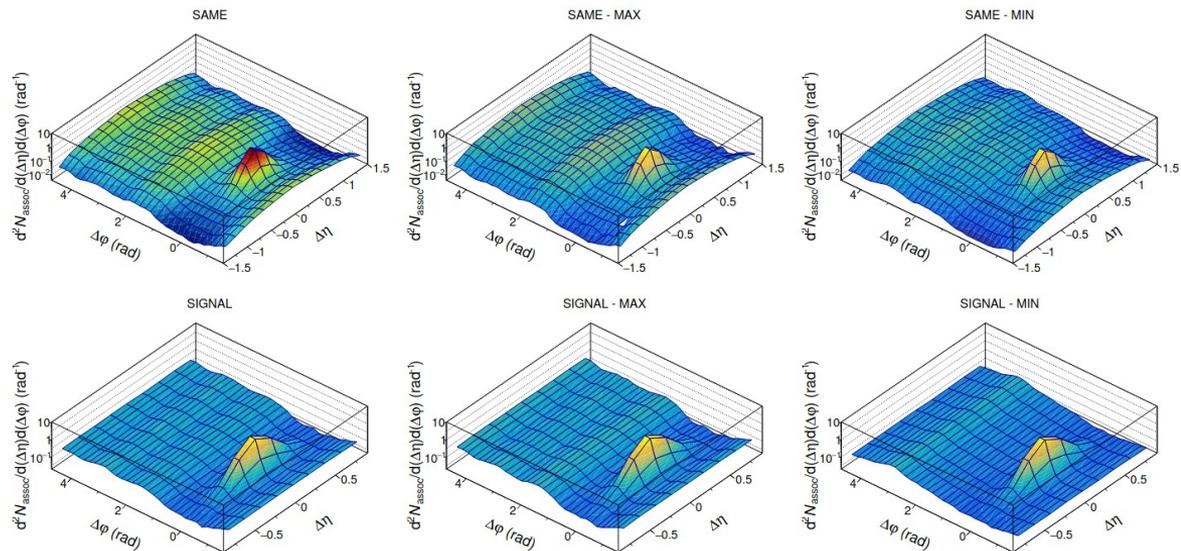
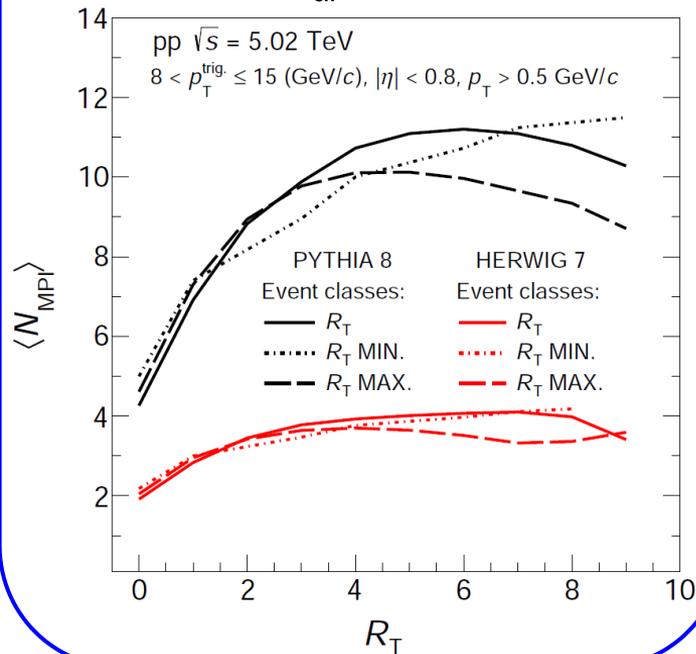
Results – Dihadron correlation vs. UE activity

New selection of R_T based on charged-particle multiplicities

$N_{ch}^{trans,max}$ and $N_{ch}^{trans,min}$



Trans-max (trans-min) = trans. region (I. or II.) with largest (smallest) N_{ch}



Di-hadron correlation as a function of UE activity

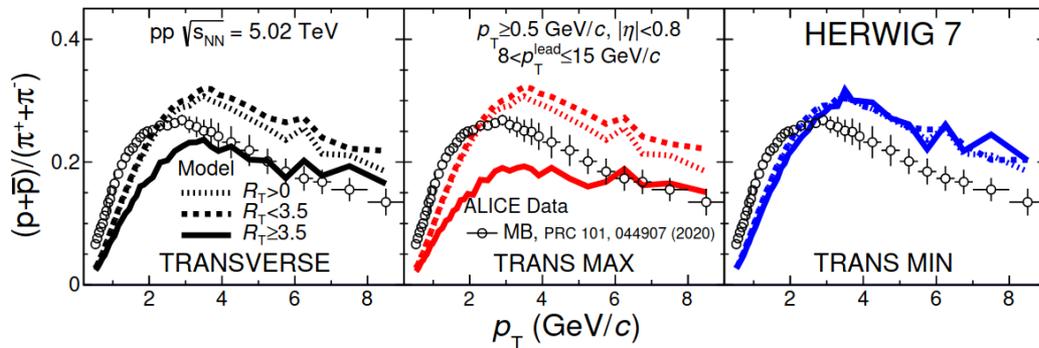
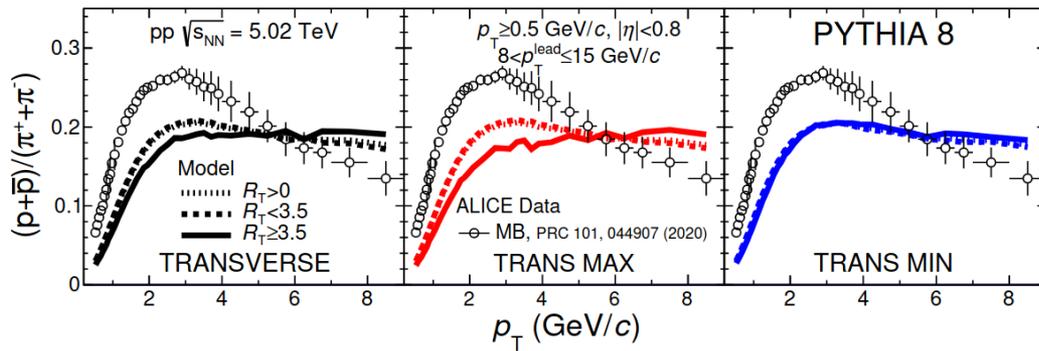
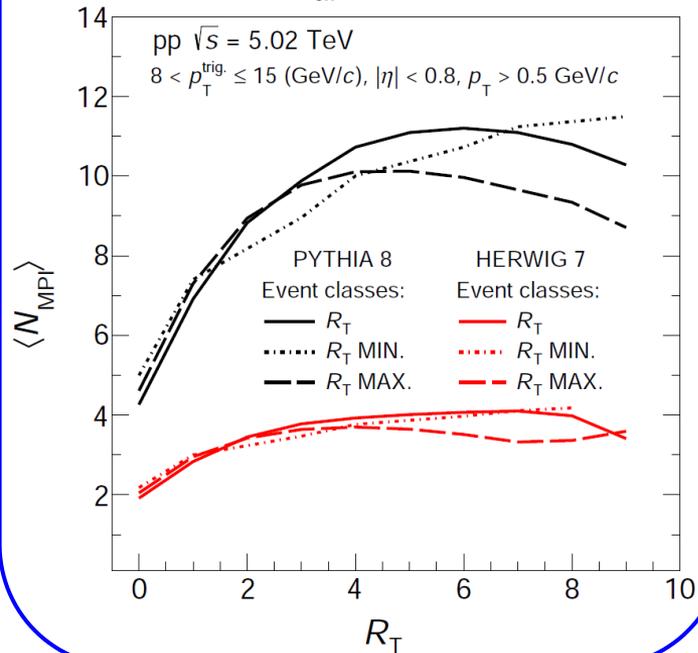
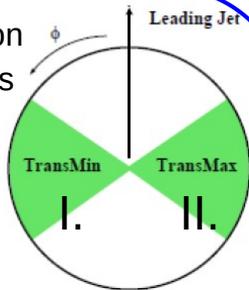
- presence of more ISR and FSR in events with large $R_{T,max}$
- $R_{T,min}$ better suited as event activity estimator (reduced bias)

Results – Baryon-to-meson ratio vs. UE activity

New selection of R_T based on charged-particle multiplicities

$N_{ch}^{trans,max}$ and $N_{ch}^{trans,min}$

Trans-max (trans-min) = trans. region (I. or II.) with largest (smallest) N_{ch}



**Barion-to-meson ratios
 as a function of UE activity**

$R_{T,max}$: depletion consistent with the presence of jets in the trans. region
 $R_{T,min}$: enhancement with increasing $R_{T,min}$
 → expected in events with large avg. N_{MPI}

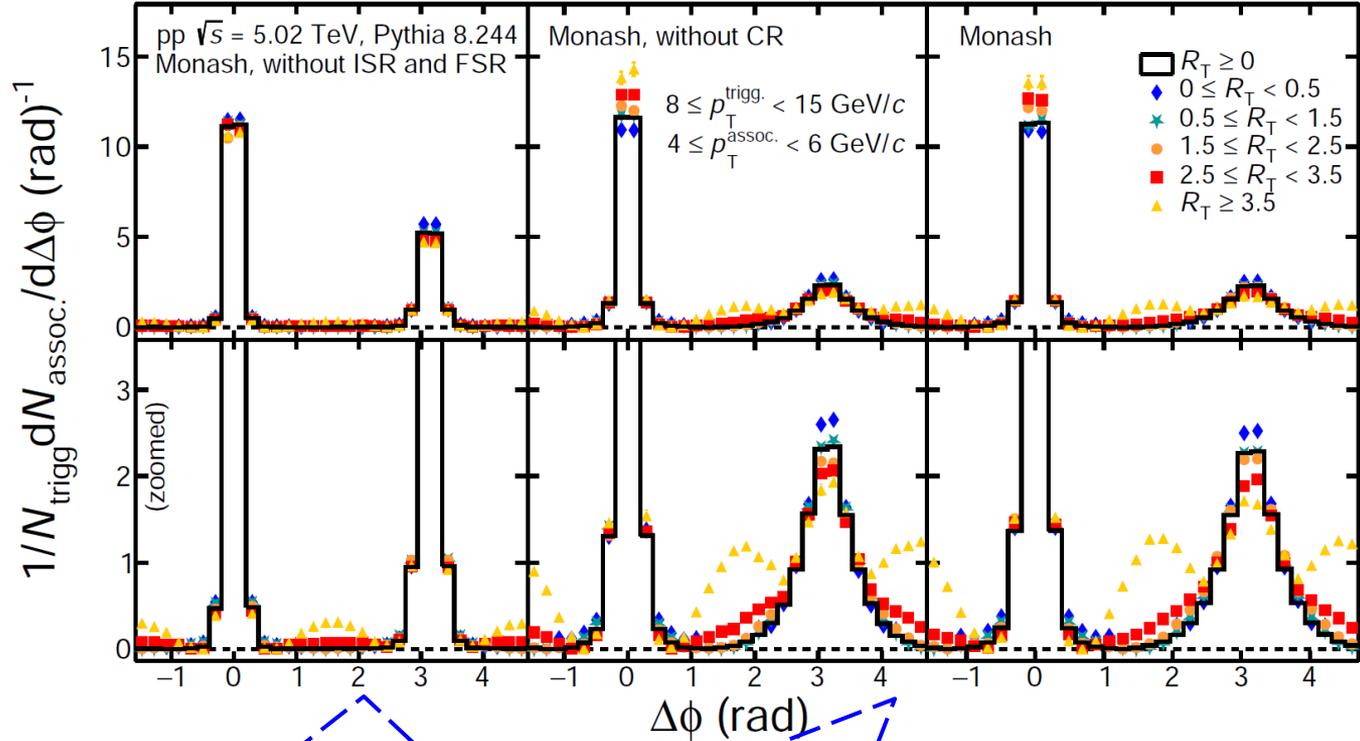
Backup I.

$R_T > 2.5$: distributions have peak at $\Delta\phi \sim 2$ rad
 -> region where NMPI saturates: presence of a third jet -> selection bias

-> experimentally also observed [ArXiv 1910.04457](#): particle production strong increase with R_T

-> Quantify the effect: calculate the ratio of yields from different R_T classes to the R_T -integrated one -> I_{pp}

Figure. Charged particle yield as a function of $\Delta\phi$. R_T -integrated distributions are compared to those from different R_T classes. The lower panels are zoomed versions of the upper panels.



-> different $\Delta\phi$ regions show no dependence on R_T for $0 < R_T < 2.5$
 -> shape of the jet peaks are independent of R_T

-> away region exhibits a broadening with R_T
 -> yield in the towards region increases with R_T

Backup II.

-> $I_{pp} = 1$: in the absence of selection bias

-> Selection bias reduced: integrate the $\Delta\phi$ distribution around the towards/away regions

-> $I_{pp} = 1$ w/o radiations

-> negl. difference w/ UE subtraction

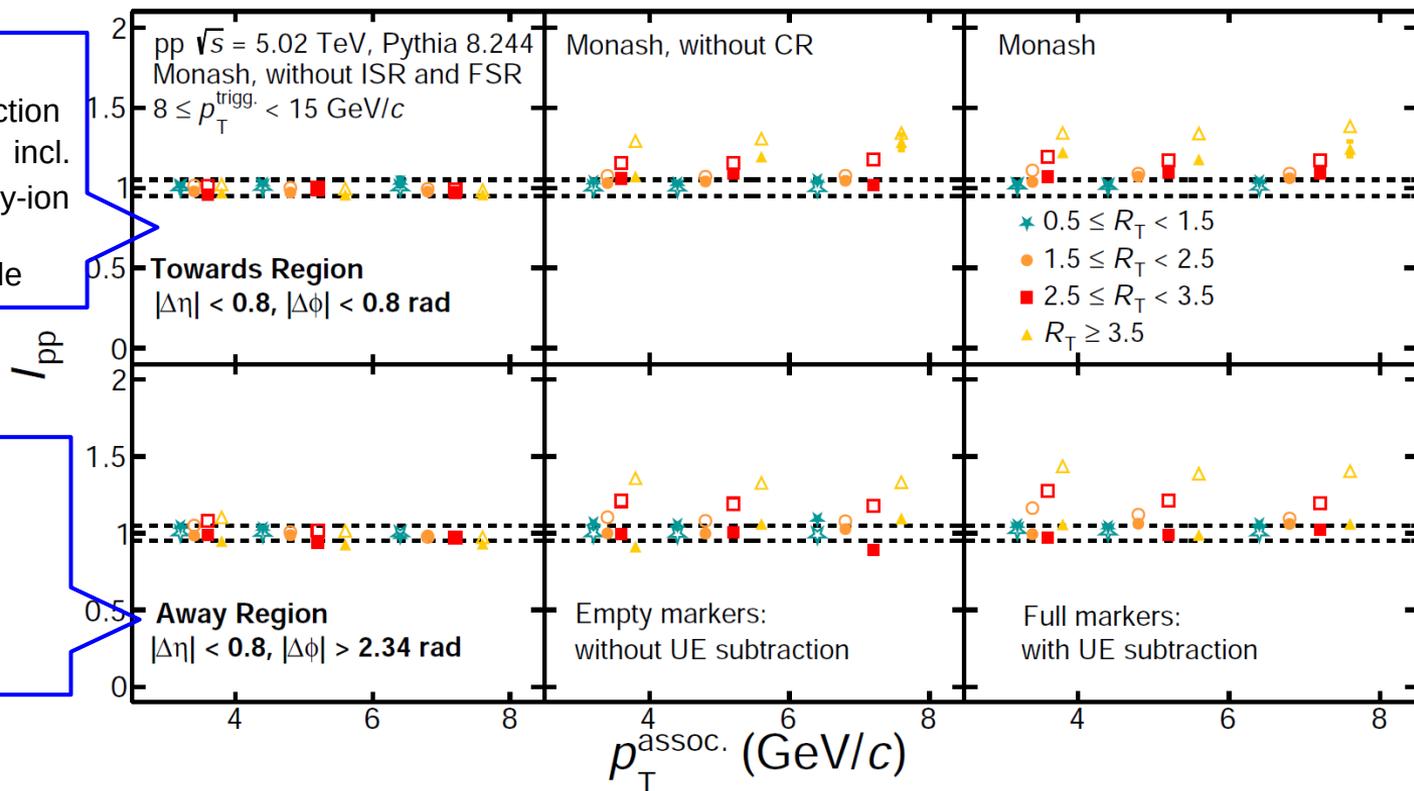
-> I_{pp} increase with R_T incl. radiations: similar to heavy-ion results

=> Radiation plays significant role

-> $I_{pp} = 1$ w/o radiations

-> w/ UE subtraction: different behavior w.r.t. towards region

-> $I_{pp} = 1$ after UE subtraction: event selection bias negligible



Takeaway message

High-multiplicity pp events can be made bias-free using event classification based on R_T and study observables in the away region