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

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Based on

J.Phys.G 48 (2020) 1, 015007
Phys.Rev.D 104 (2021) 1, 016017
Eur.Phys.J A (2021) 57, 301

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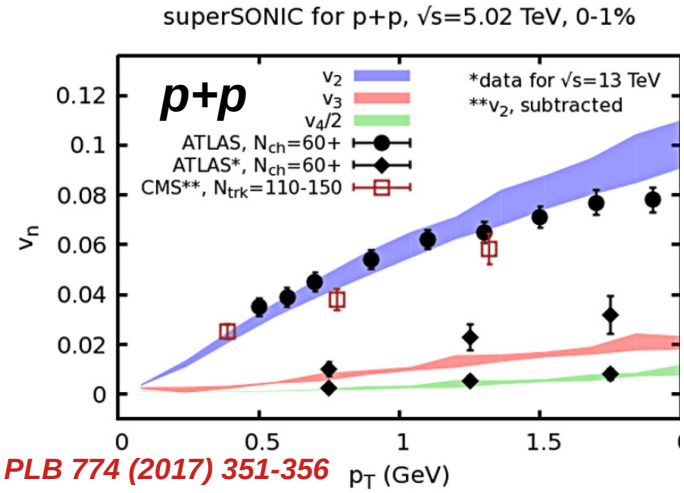
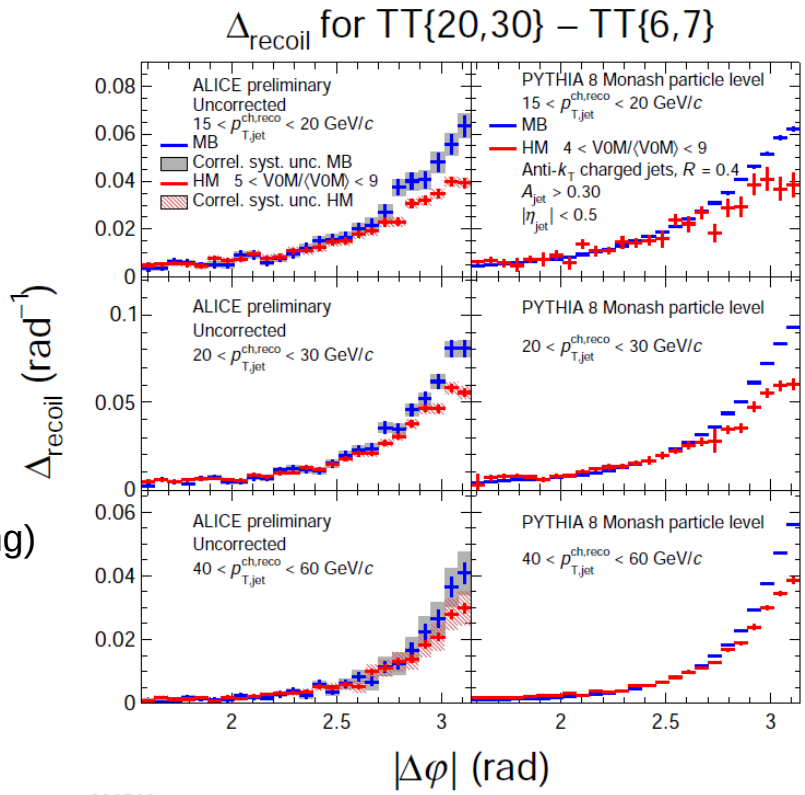
Motivation – collectivity in small systems but ...



PLB 774 (2017) 351-356

-> High-multiplicity proton-proton collisions show collective behavior



… no effect of jet quenching found so far

-> Broadening of recoil jet acoplanarity -> not conclusive

-> Similar effect observed in the PYTHIA model (no jet-quenching)

-> Alternative: vacuum QCD effects produce collective behavior

Goal: *Study high-multiplicity pp events in the* ***PYTHIA model*** *to* ***understand*** *event* ***selection biases***

ALI-PREL-339740

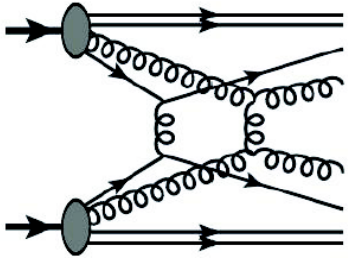
ALICE: *NPA 1005 2021, 121924, QM'19*

Methods – PYTHIA 8 model

PYTHIA MC event generator: standard "tool" in HE physics for modeling pp collisions:
***LO* 2->2 process + parton shower (Initial- and Final state radiation), Color Reconnection, MPI**

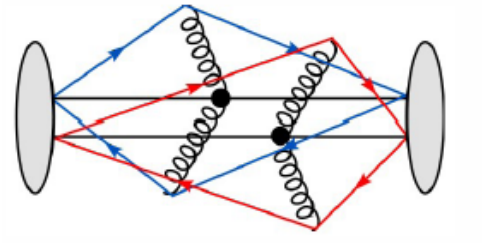
Multiparton interactions:
-> more than one hard parton scattering in a pp collision
-> *explain increased activity in the UE in a hard scattering*

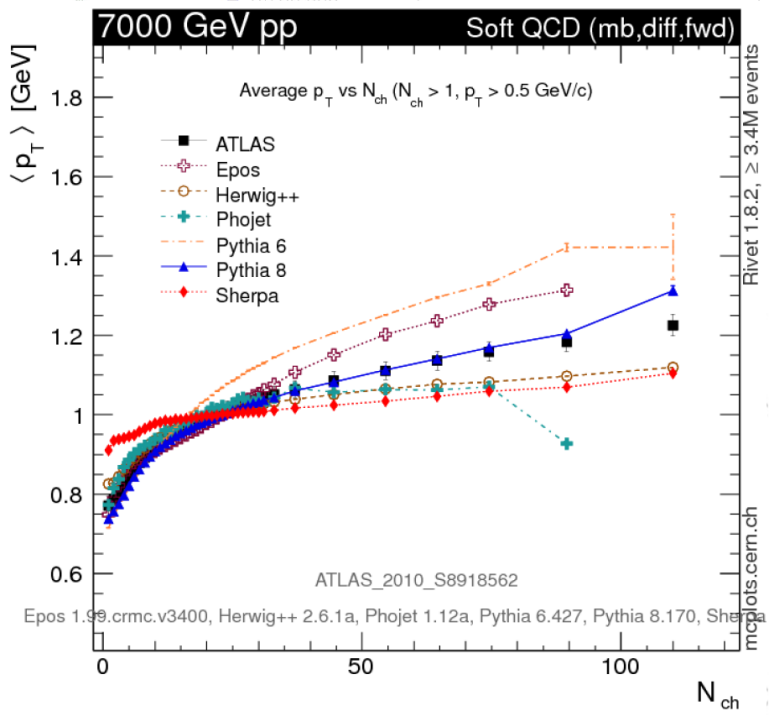
See e.g.: *EPJC 74, 3024 (2014)*



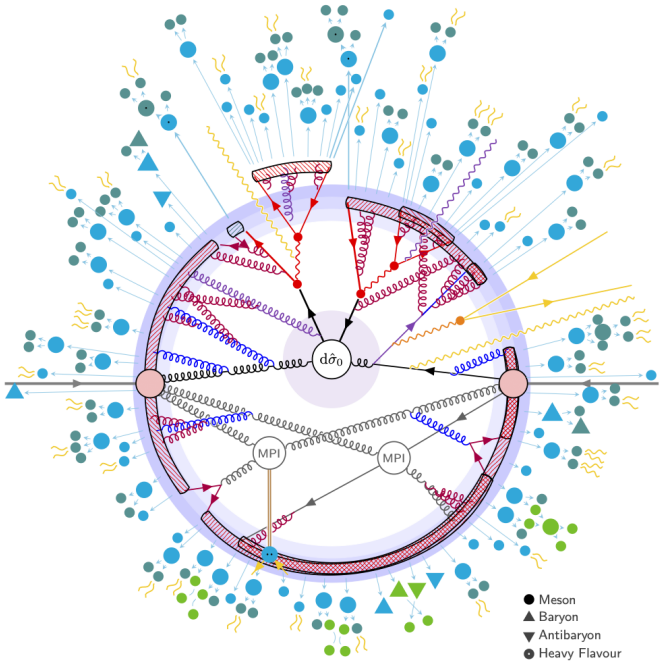
Color reconnection:
-> reconnect color strings before hadronization
-> *explain experimental data: average p_T, flow -> causing collective behavior*

See e.g.: *PRL 111, 042001 (2013)*



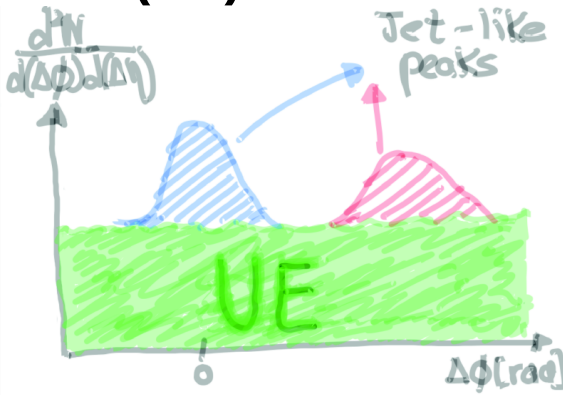


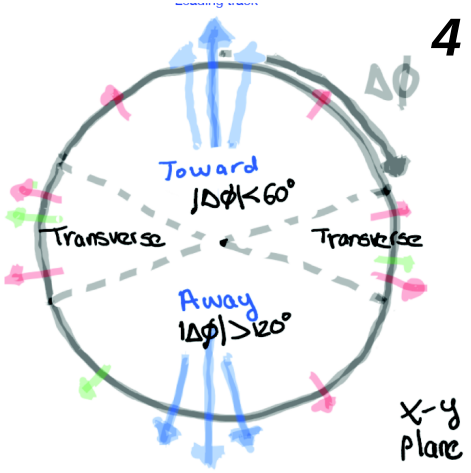
Methods – The underlying event (UE)

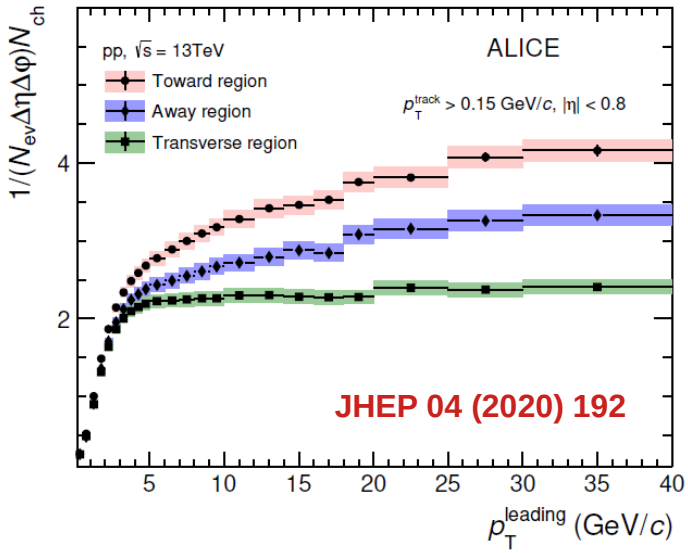


- Hard Interaction
- Resonance Decays
- Matrix Elements
- Final-State Radiation
- Initial-State Radiation
- QED Radiation
- Weak Showers
- Hard Onium
- Multiparton Interactions
- Beam Remnants*
- Strings
- Ministrings / Clusters
- Colour Reconnections
- String Interactions
- Bose-Einstein & Fermi-Dirac
- Primary Hadrons
- Secondary Hadrons
- Hadronic Reinteractions

(: incoming lines are crossed)*







-> **Underlying event:** unavoidable background; everything but hard scattered partons (MPI, ISR/FSR)

-> Measurable in experiment: charged particle number densities, self-normalized quantities, ...etc.

-> Transverse region ***(π/3 < \|Δφ\| < 2π/3):***
sensitive to UE, **insensitive to** $p_{T,trig}$

Methods – The event activity classifier R_T

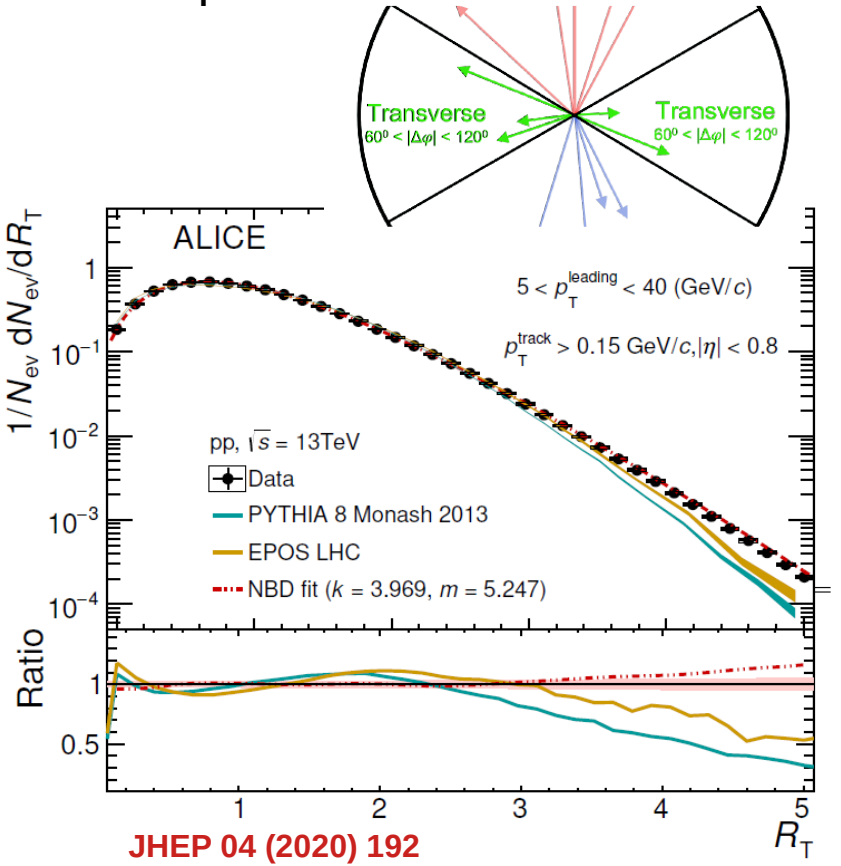
-> New set of observable to probe
the structure of the UE **(EPJ C (2016) 76, 299)**
-> ***relative transverse activity classifier R_T***

$$R_{\mathrm{T}} = \frac{N_{\mathrm{ch}}^{\mathrm{trans.}}}{\langle N_{\mathrm{ch}}^{\mathrm{trans.}} \rangle}$$

-> ***R_T***: defined in the Transverse region,
adopted in the Underlying Event analysis

=> ***Goal:***

- ***study how event selection based on R_T biases towards and away regions***
- ***study observable more suitable for jet quenching searches in small systems***



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Methods – The "I_{pp}"

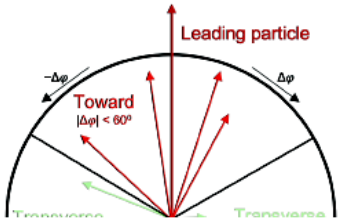
I_{AA}: ratio of jet-like yield from AA to the one from pp collisions

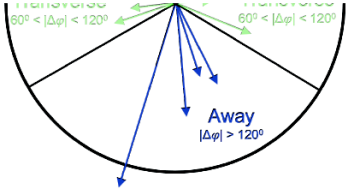
-> interplay between the parton production spectrum and energy loss in the medium

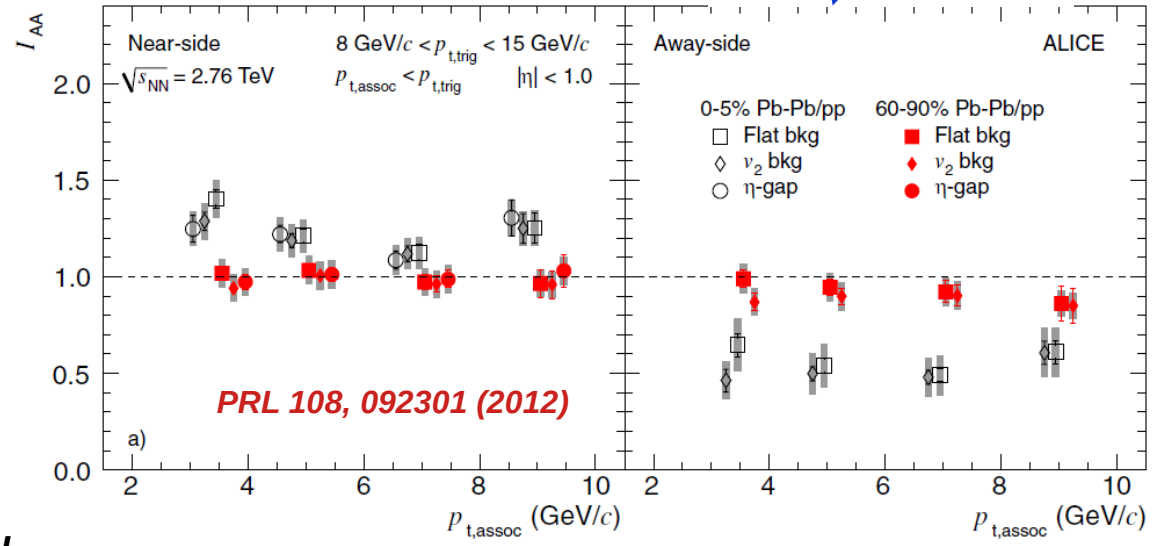
-> Similar observation by CMS (CMS-PAS-HIN-12-010)

I_{pp}: $(dN/dp_T)_{RT\ class}$ to $(dN/dp_T)_{RT>0}$

ALICE coll. *arXiv:2204.10157v1*



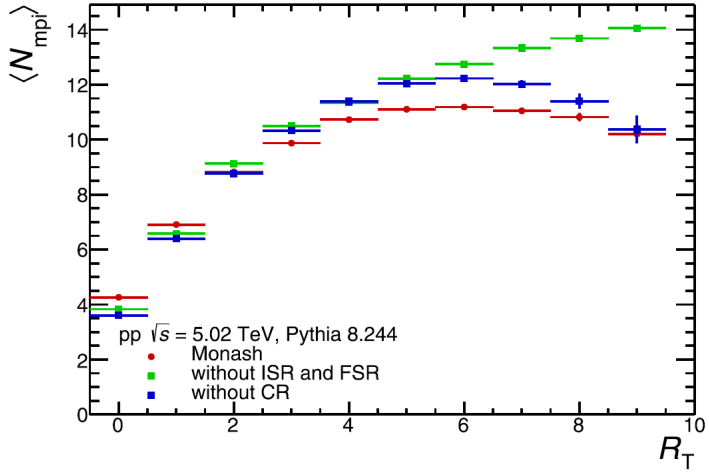


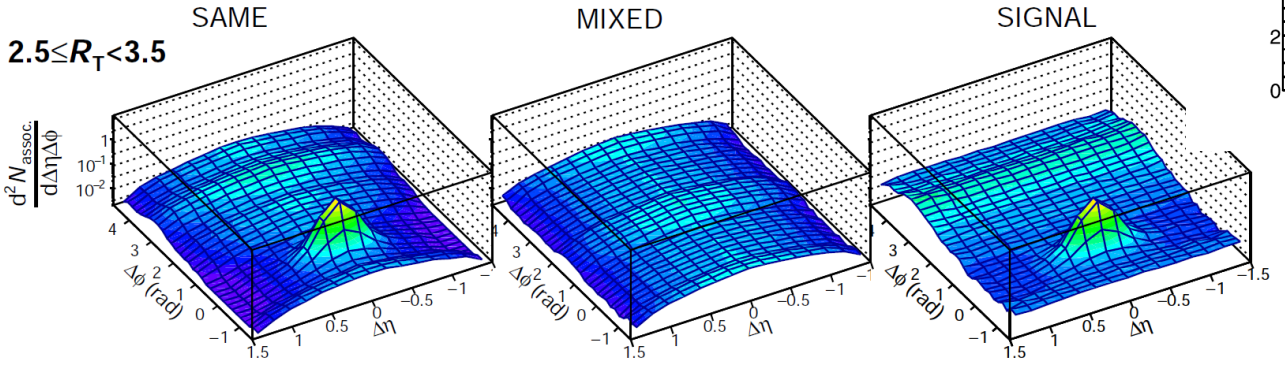


=> Goal:
Perform standard two-particle azimuthal correlation analysis to study jet-quenching effects

Methods - jet-like signal $C(\Delta\eta\Delta\phi)$ extraction (J.Phys.G 48 (2020) 1, 015007)

-> **Correlations at partonic level** turned **on/off:**
Initial- and Final state radiation, CR
-> **Monash tune:** $\langle N_{MPI} \rangle$ saturates
"picks up" particles from jet fragments -> **activity biased**





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

-> ***structure observed in the Transverse region*** ($\pi/3 < |\Delta\varphi| < 2\pi/3$): associated yield increases with R_T
-> **Contribution** to the Towards/Away regions ***removed with mixed event technique***
-> Underlying event subtracted using Zero Yield at Minimum method
-> **Evolution of jet signal with R_T is studied**

Results: *Charged particle yield as a function of Δφ* (J.Phys.G 48 (2020) 1, 015007)

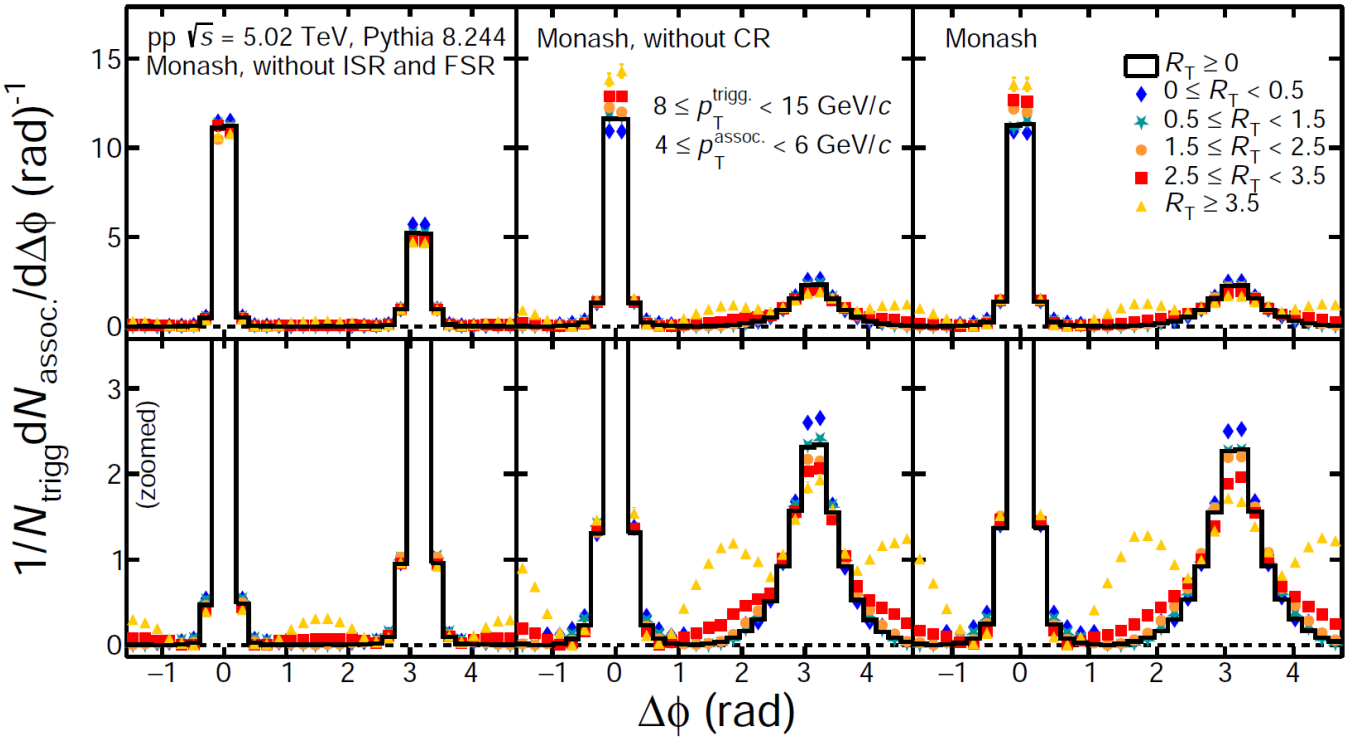
R_T>2.5: peak at Δφ~2 rad
-> region where avg. MPI saturates: presence of a third jet -> selection bias

->Experimentally observed: increase of particle yield with R_T
ALICEColl. ***arXiv:1910.04457v2***

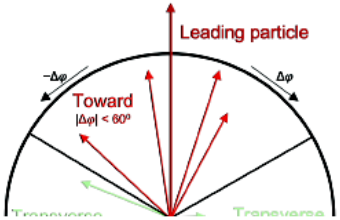
-> Toward region: yield increases with R_T
-> Away region: broadening with R_T

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

w/o ISR/FSR ***w/ ISR/FSR***

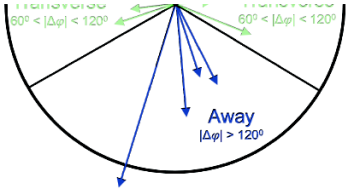


Results: Ratio of yields in R_T event classes = I_{pp} (J.Phys.G 48 (2020) 1, 015007)

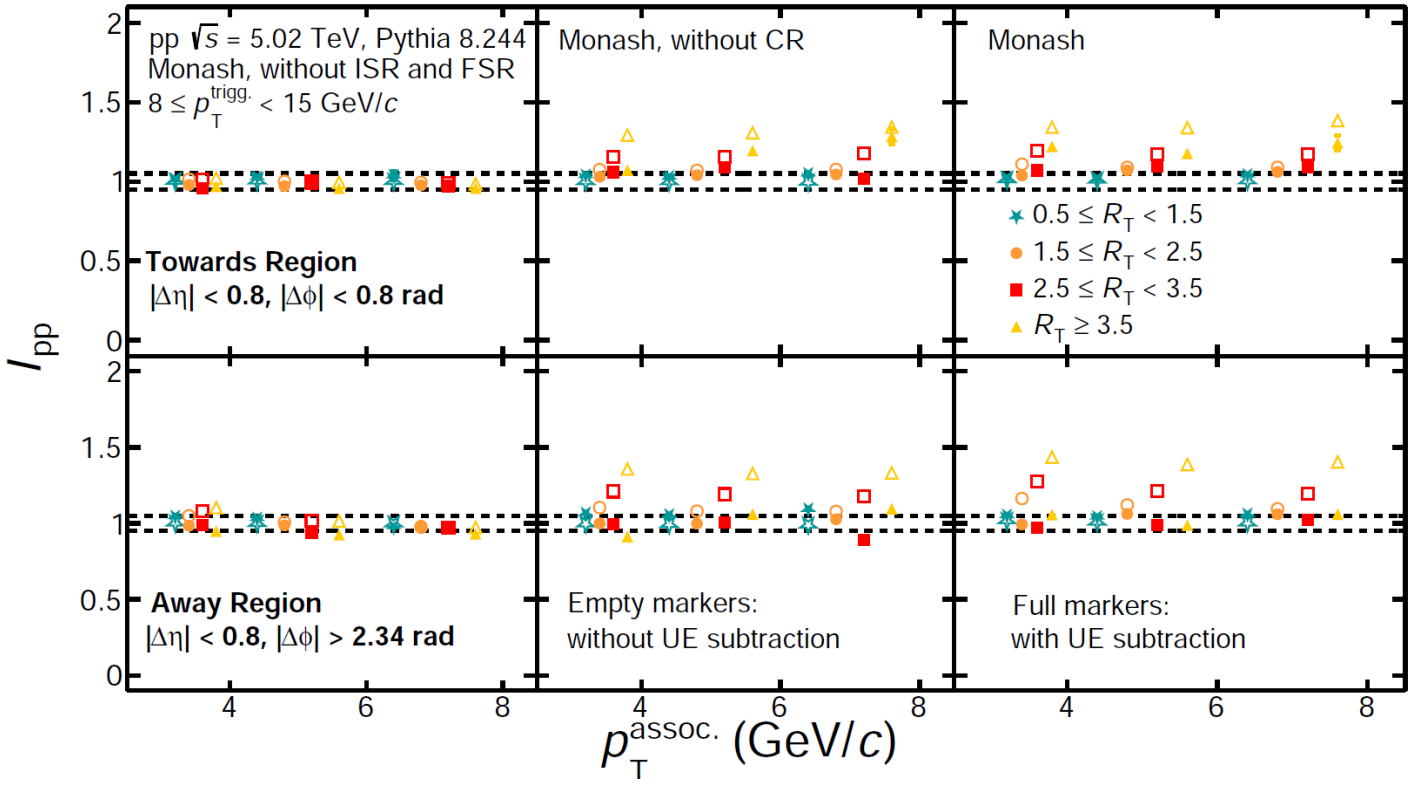


-> I_{pp} = 1 no selection bias and/or w/o radiations

→ISR/FSR: I_{pp} increase w/ R_T similar to heavy-ion



UE subtraction:
-> different behavior
-> I_{pp} = 1 UE subtraction: event selection bias negligible

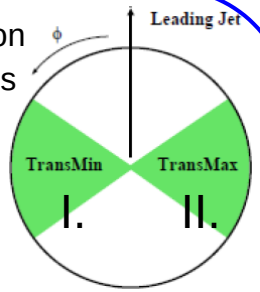


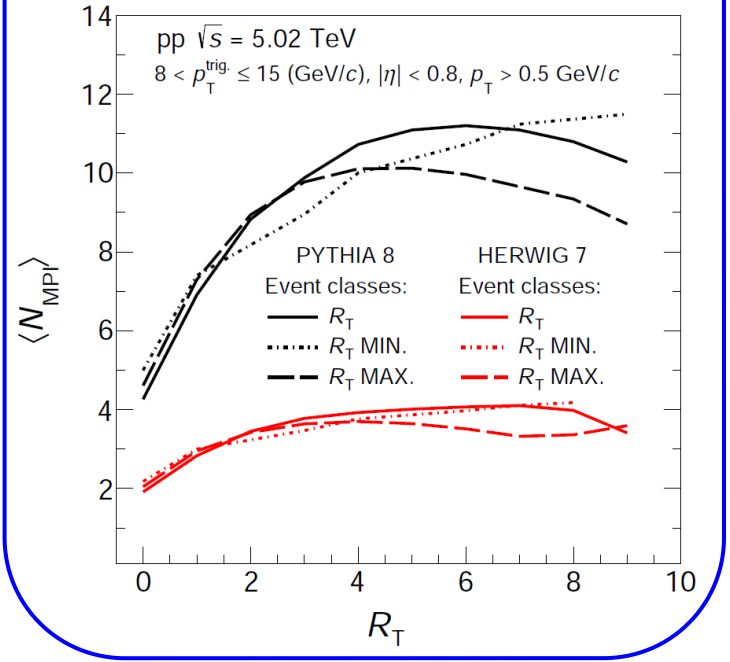
High-multiplcity pp events can be made bias-free using event classification (R_T) and study observables in the Away region

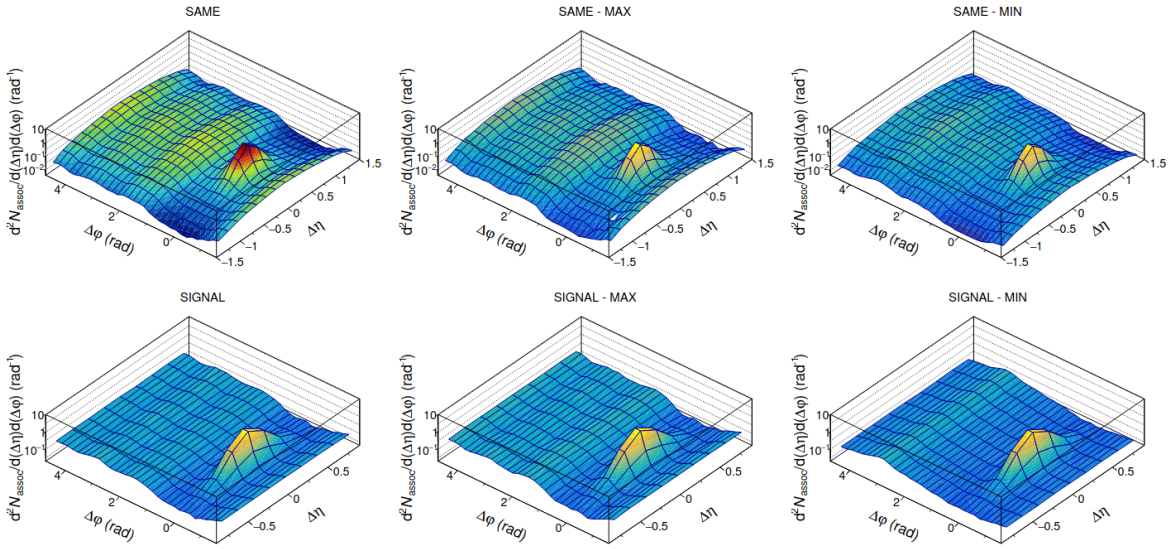
Results – Dihadron correlation vs. UE activity (PRD 104 (2021) 1, 016017)

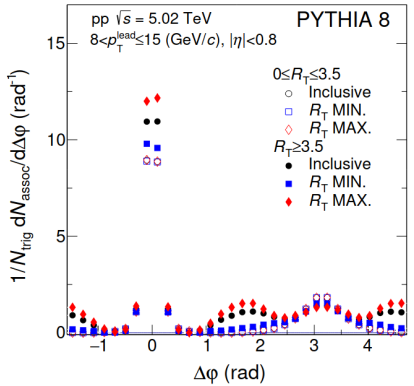
New selection of R_T based on charged-particle multiplicities $N_{ch}^{trans.max}$ and $N_{ch}^{trans.min}$

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 (PRD 104 (2021) 1, 016017)

New selection of R_T based on charged-particle multiplicities $N_{ch}^{trans.max}$ and $N_{ch}^{trans.min}$

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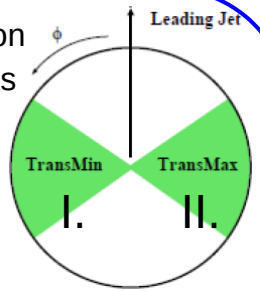

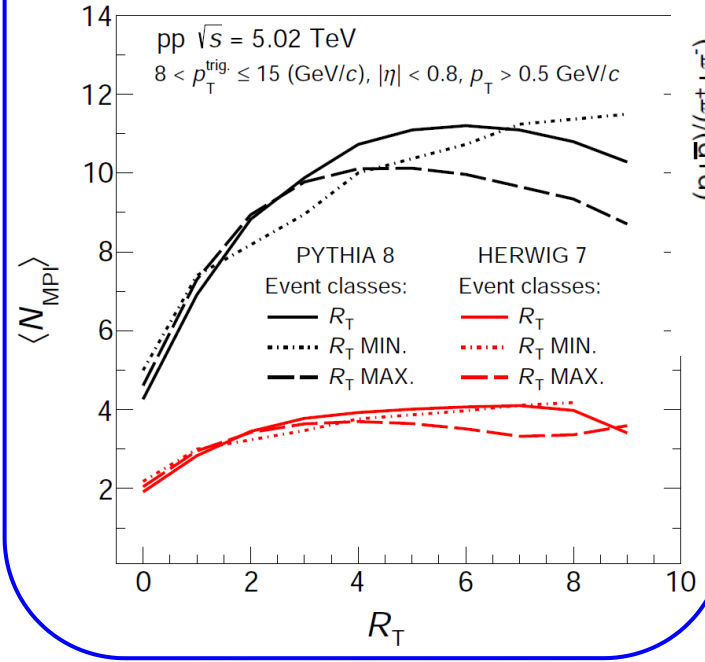

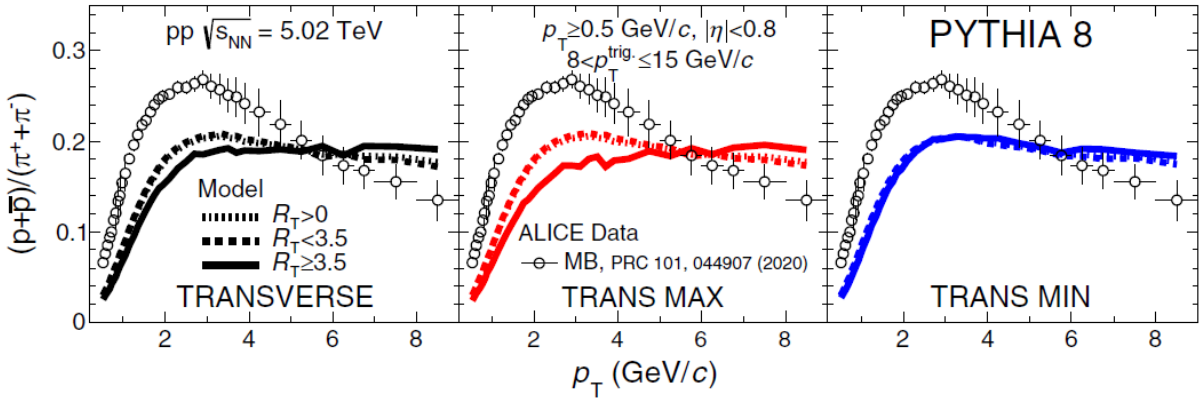

Barion-to-meson ratios as a function of UE activity

$R_{T,max}$: 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}

Interaction of UE and q/g using heavy flavors

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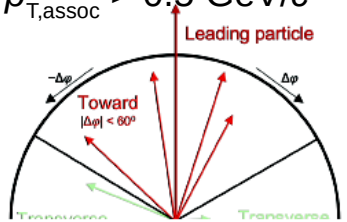
D, B, charged pions
$p_{T,trigger}$ > 0.5 GeV/c
$p_{T,assoc}$ > 0.5 GeV/c



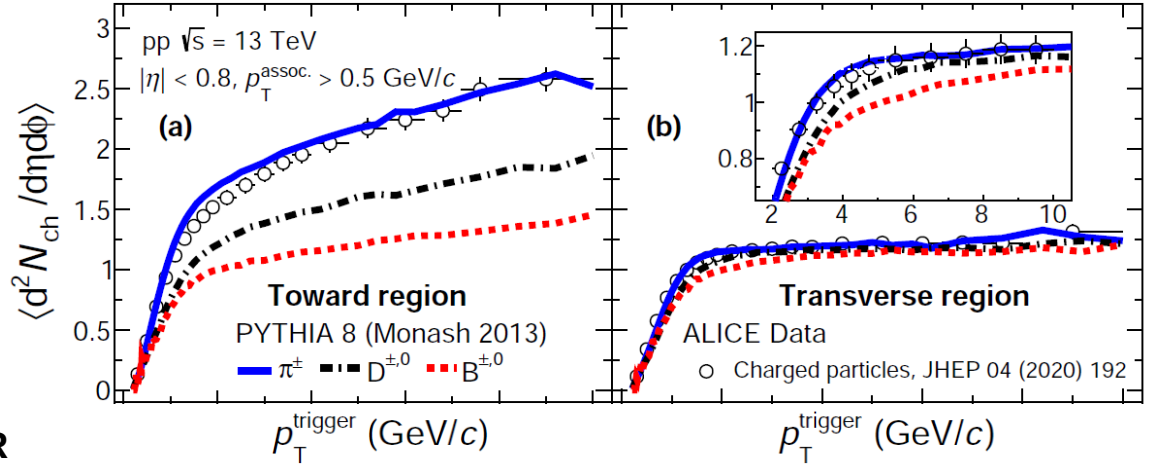
-> Study UE event activity with light- and heavy flavor triggers
-> Light (heavy) flavors initiated by q/g (q) => color charge difference
-> Flavor-dependent fragmentation functions

Observation: heavy flavor hierarchy is due to CR and not hadron mass
(light fl., PRD 99(3), 034027 (2019))

PYTHIA string fragmentation bias:
g (q) are connected to two (one) string pieces
→ pion sample biased with enhanced gluons
→ pion trigger larger CR effect expected

Selection of q/g initiating partons
B-jets / pions proxies for q/g jets
misidentification rates: 5–10% / 10-25%

Goal: Test flavor hierarchy in UE with CR



Results – flavor separation with different CR strenghts (measures UE activity)

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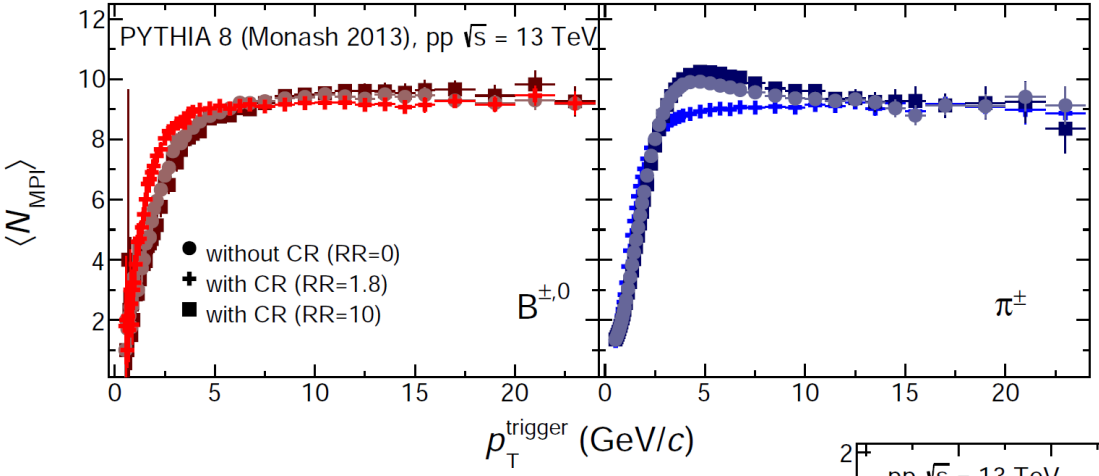
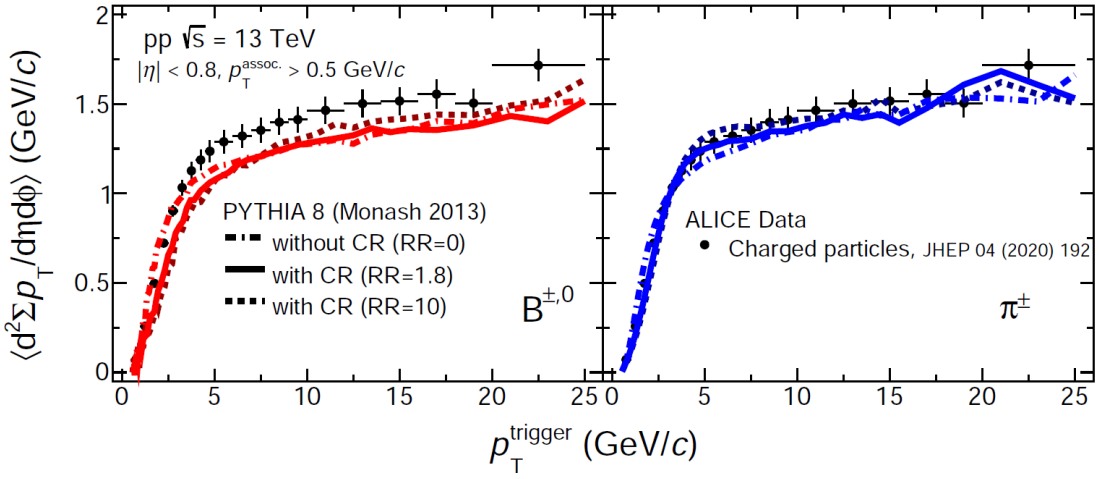


2 GeVc < p_T < 8 GeV/c:

-> UE activity $_{\text{HEAVY trigger}}$ < UE activity $_{\text{LIGHT trigger}}$

-> Leading hard process is connected to the UE via color reconnection

-> Flavor dependence is driven by the color composition of the initiating parton



Summary

- *High-multiplcity pp events can be made bias-free using event classification based on R_T and study observables in the Away region*
  (J.Phys.G 48 (2020) 1, 015007)

- Minimum activity Transverse region ($R_{T,min}$) reduces selection bias due to gluon radiation
  (PRD 104 (2021) 1, 016017)

- Flavor of the leading process affects the UE
  (EPJ A (2021) 57, 301)