Investigation of the underlying event with heavy quarks

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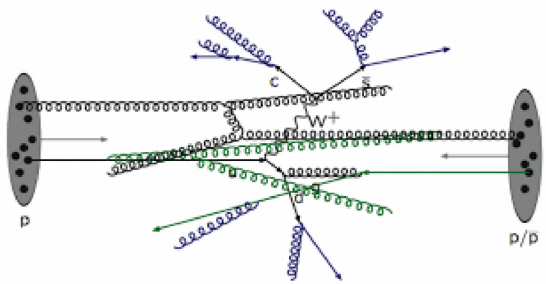
Motivation

- High-multiplicity p+p at LHC energies:
  - unexpected findings
  - substantial v_n in high-multiplicity pp events
- Current understanding:
  - Collectivity can arise from features other than QGP
  - Pure QCD can generate it at the soft-hard boundary

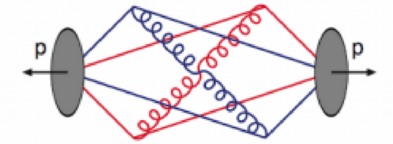
Concepts and definition



- Multi-Parton Interaction (MPI):

 - more partons interact

 - multistep process

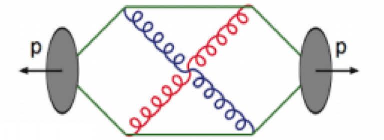


- Color-Reconnection (CR):

 - striving for energy minimum (analogy)

 - has a major role in the interaction of particles

 - CR leads to radial flow (Ortiz-Bencédi-Bello,J.Phys. G44 (2017), 065001)



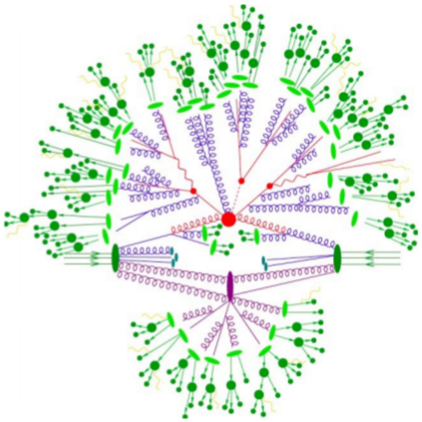
- Underlying Event (UE)

 - presence of UE from non-hard processes

 → significantly influenced by MPI and CR

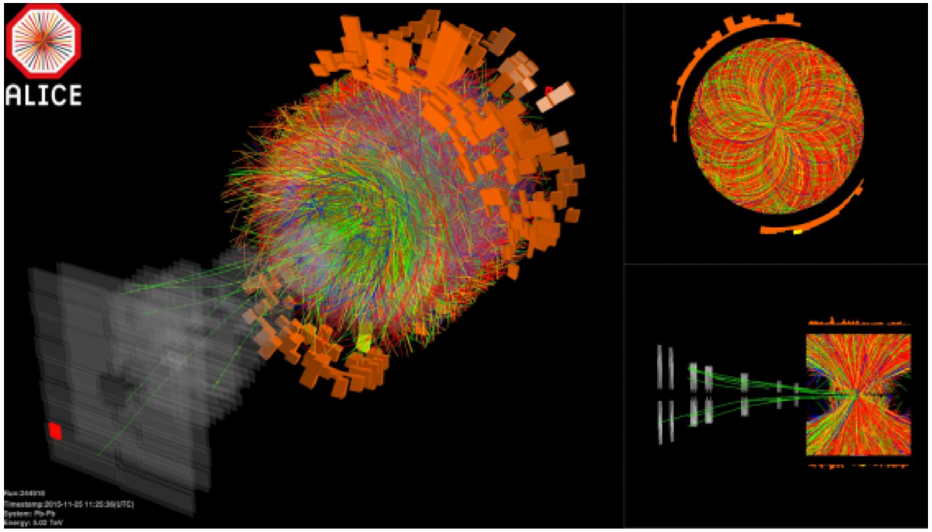
 - Goal: examining the hard processes without UE

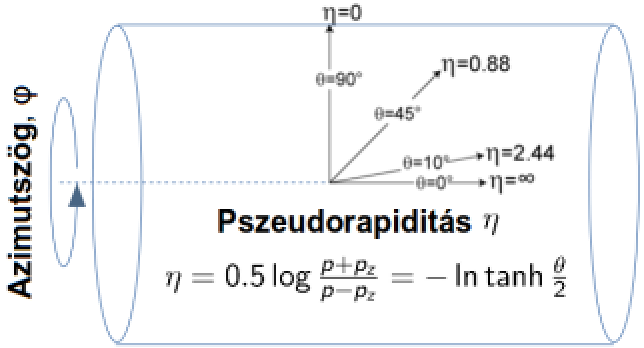
 - interplay between UE and hard processes



ALICE experiment

- Large Hadron Collider: ALICE (A Large Ion Colliding Experiment)
- More than 1,800 physicists and engineers from several countries are working together on the ALICE project
- Goal:
  - understanding of the early stages of the universe with QGP





Pythia 8.1

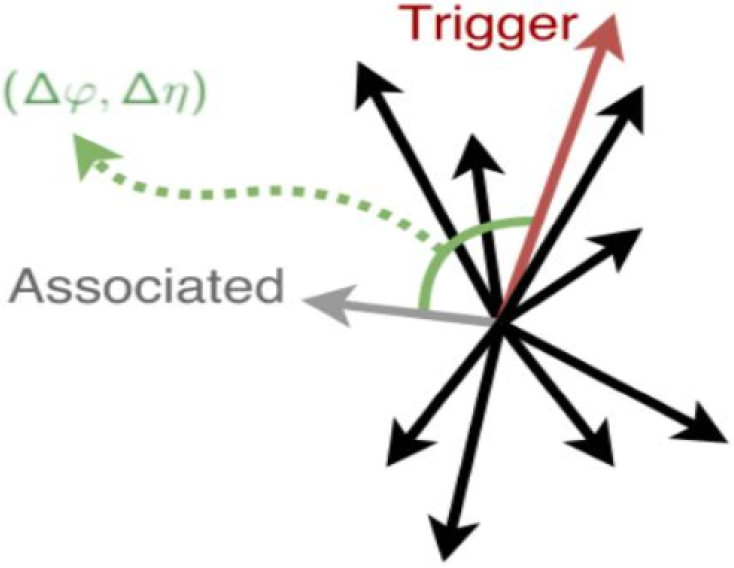
1) Modeling a basic “hard” QCD process
    - with leading order perturbation calculation
2) Parton level processes: initial and final- state radiation and MPI
    - perturbative calculation, phenomenological considerations
3) Generation of the hadronic state with Lund string fragmentation model
4) Secondary decay, and rescattering between hadrons

Simulation settings

- simulations with Pythia 8.1 Monash tune
- Proton-proton
- minimum bias events, SoftQCD:All
- $\sqrt{s}$ = 7 TeV
- 25 million events with each settings:
  - Physics case
  - CR off
  - MPI off and CRoff

Identification of trigger particles

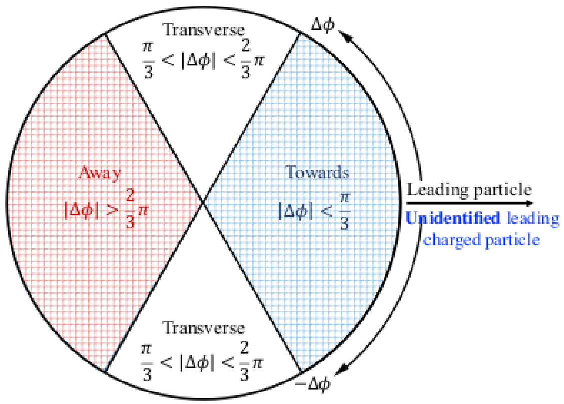
- The highest pT „trigger” particle is selected from each event
- $|\eta| < 0.8$
- pion: only charged
- proton: proton and anti-protons included
- D meson: D^+, D^-, D^0, anti-D^0-meson
- B meson: B^+, B^-, B^0, anti-B^0-meson
- I have prevented their decay

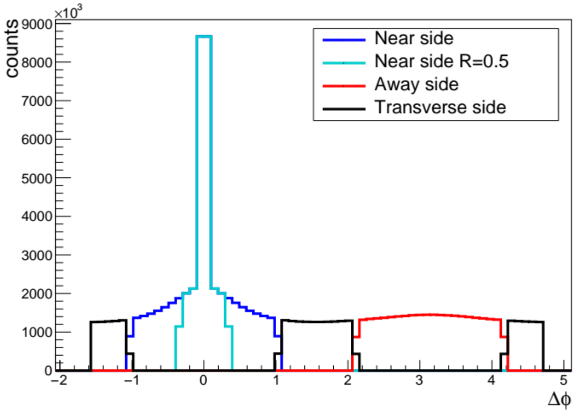


Selection of associated particles

$$n(p_T^{leading}) = \frac{1}{N_{ev}} \frac{\partial^3 N_{ch}}{\partial\phi \cdot \partial\eta \cdot \partial p_T^{leading}}$$

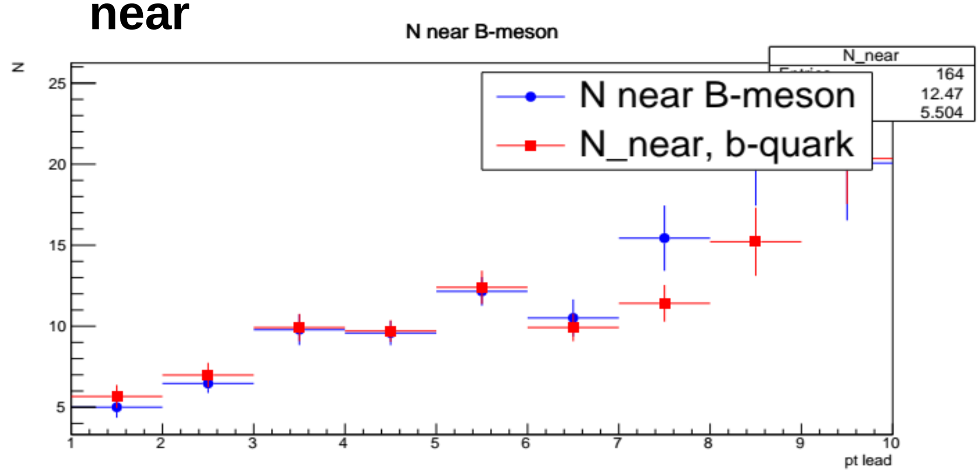
- p_T > 0.5 GeV/c
- only charged particles
- spatial division based on angle between trigger and associated particle:
  - – Near side: leading jet
    - Near side range restricted to $R < 0.5$ around the trigger particle
  - – Away side: recoild jet
  - – Transverse side: UE



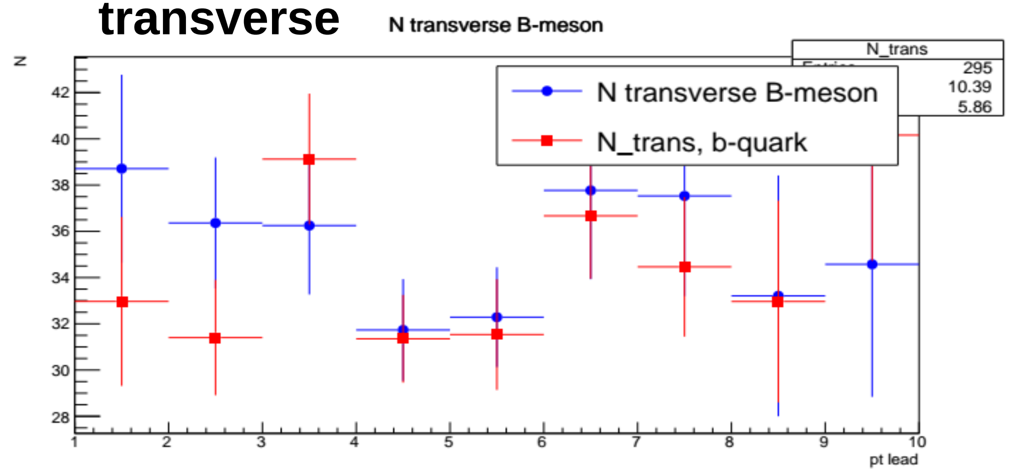


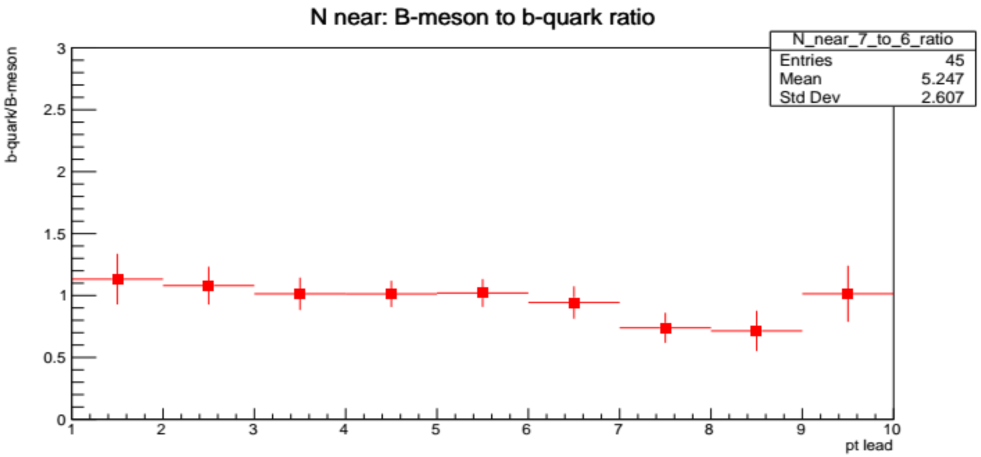
b quark compared to B-meson

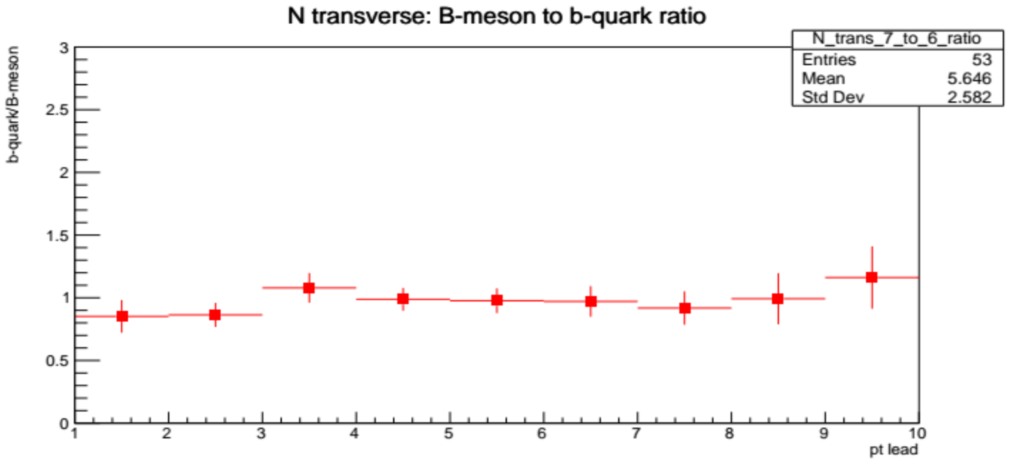
near



transverse



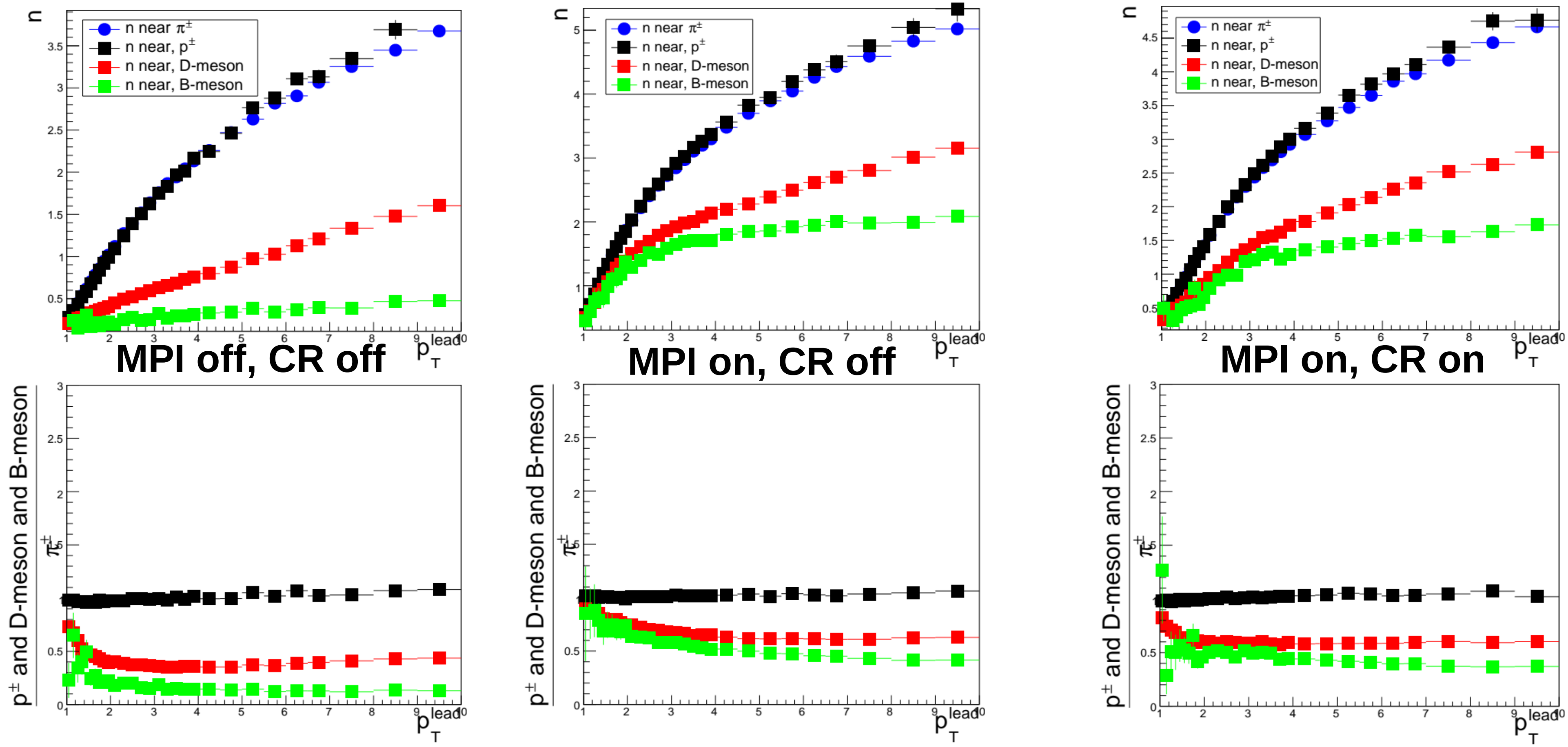




- No significant difference (B-meson is a good proxy for b quark)
- Not necessary the jet reconstruction
- Near side: the fragmentation peak is slightly different

B-meson
b quark

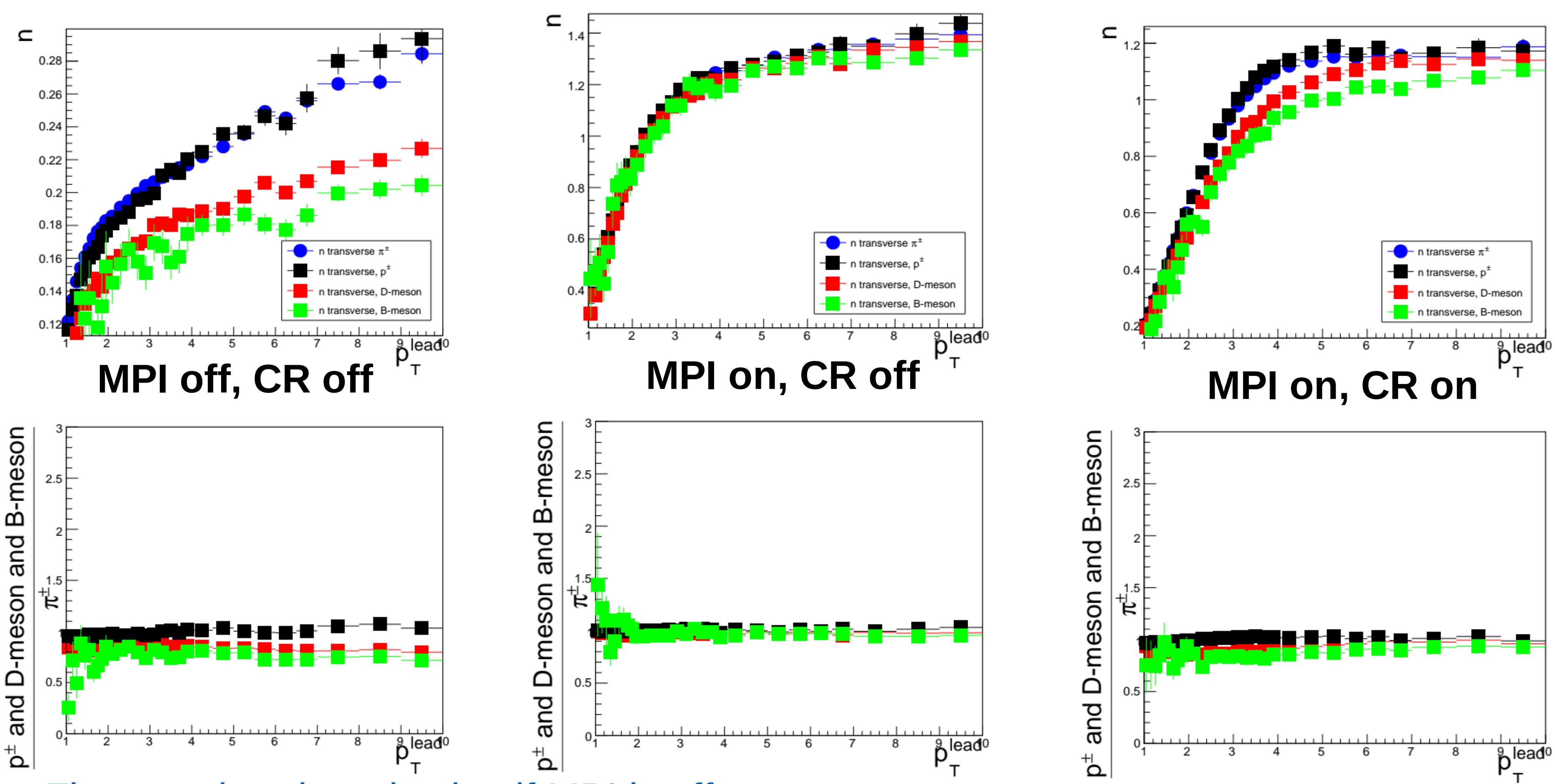
Pion compared to proton, D- and B-meson particle count (near side)



- Ordering by flavor
- Strongest if MPI is off, weakest is CR is off
  - Looks like a multiplicity effect ($n_{MPIoff} < n_{CRonMPIon} < n_{CRoff}$)
  - Underlying event descreases ordering

Pion
Proton
D-meson
B-meson

Pion compared to proton, D- and B-meson particle count (transverse side)

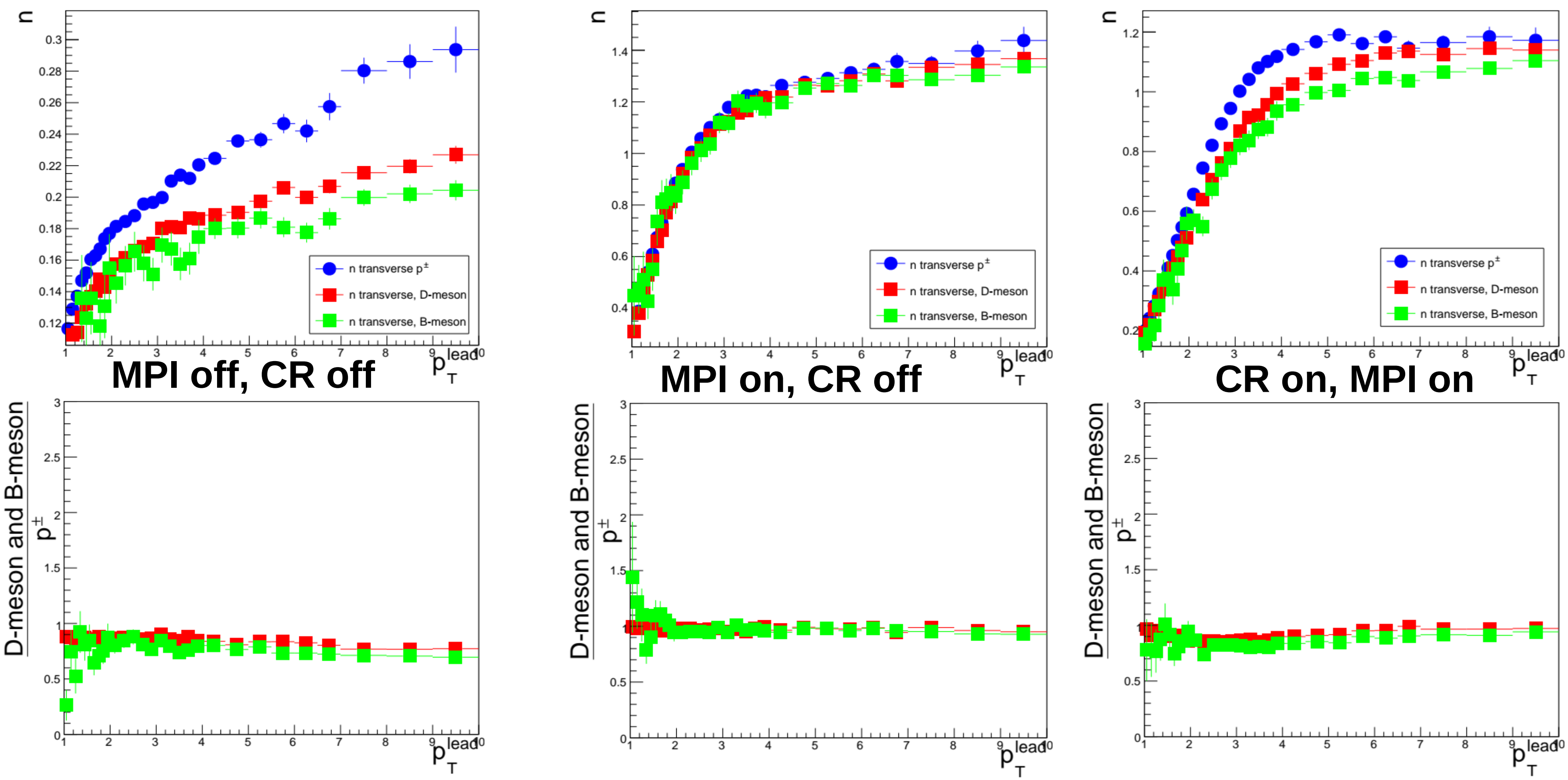


- Flavor-ordered production if MPI is off
- MPI levels any ordering
- CR re-introduces ordering at lower pT, similarly to observations with light and strange particles

Pion
Proton
D-meson
B-meson

(*Ref:* A. Ortiz and L. Valencia Palomo, „Probing color reconnection with underlying event observables at the LHC energies," Phys. Rev. D 99 (2019) no.3, 034027 [arXiv:1809.01744 [hep-ex]].)

D and B meson comparison

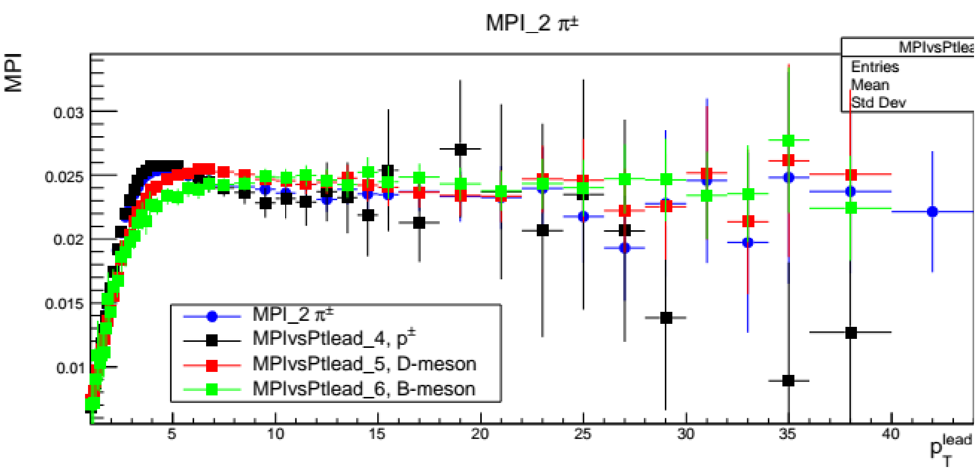


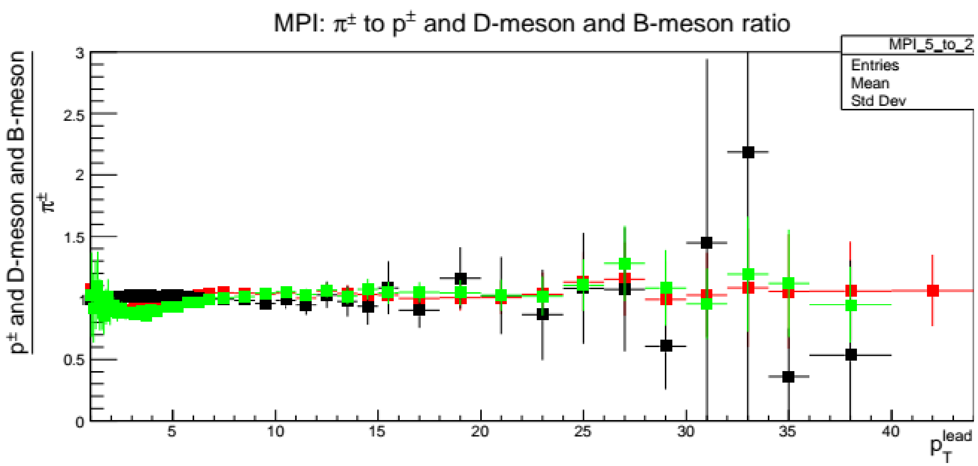
Proton
D-meson
B-meson

- Mass-ordering at higher pT in the physical case

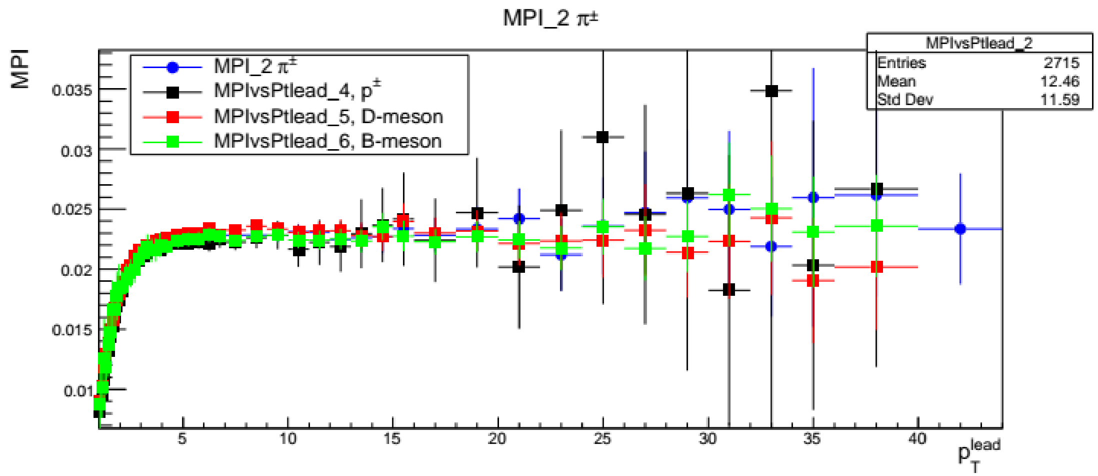
Number of MPI in an event

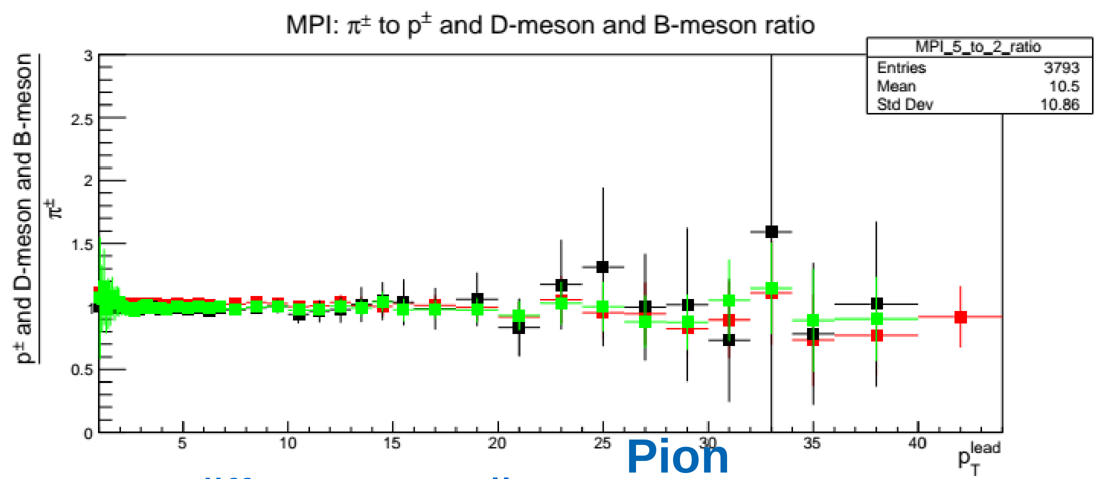
MPI on, CR on





MPI on, CR off





- The difference between p, D and B meson:
  → MPI processes → flavour difference
- No difference between pion and proton
- Significant difference between flavor: effect of CR

- No difference at all

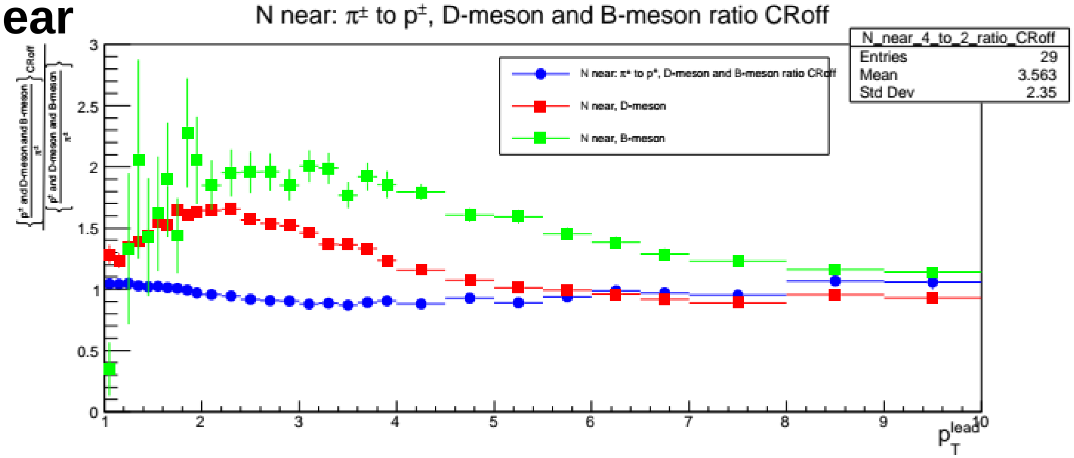
Pion
Proton
D-meson
B-meson

CR effect particle count - double ratio

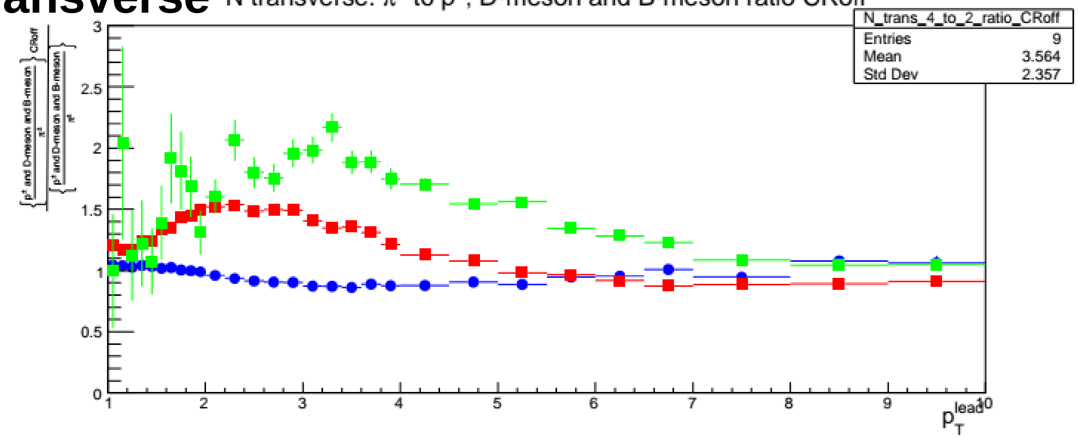
$$\frac{\text{MPI on, CR off}}{\text{MPI on, CR on}}$$

Proton
D-meson
B-meson

near



transverse



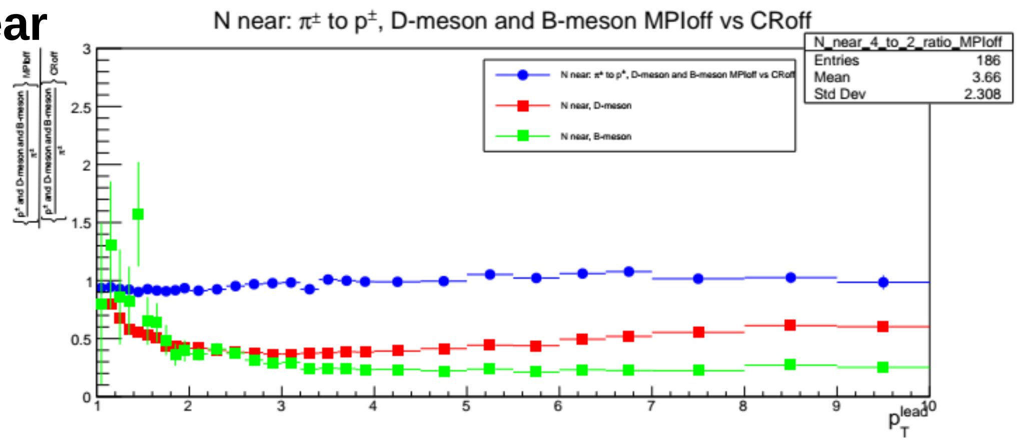
- CR causes separation of c, b and light flavors at lower pT
- Separation of b persists up to higher pT – mass effect?
- Relative change same at near and transverse side

MPI effect particle count - double ratio

MPI off, CR off
―――――――――――
MPI on, CR off

Proton
D-meson
B-meson

near



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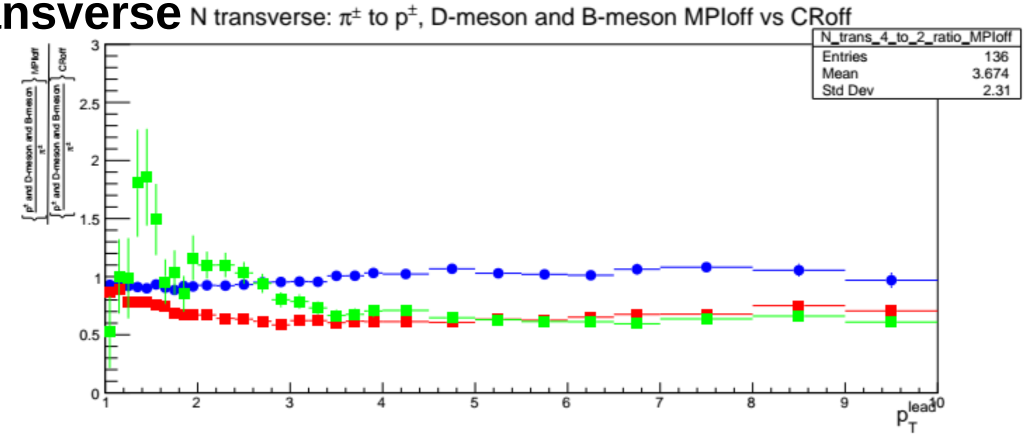
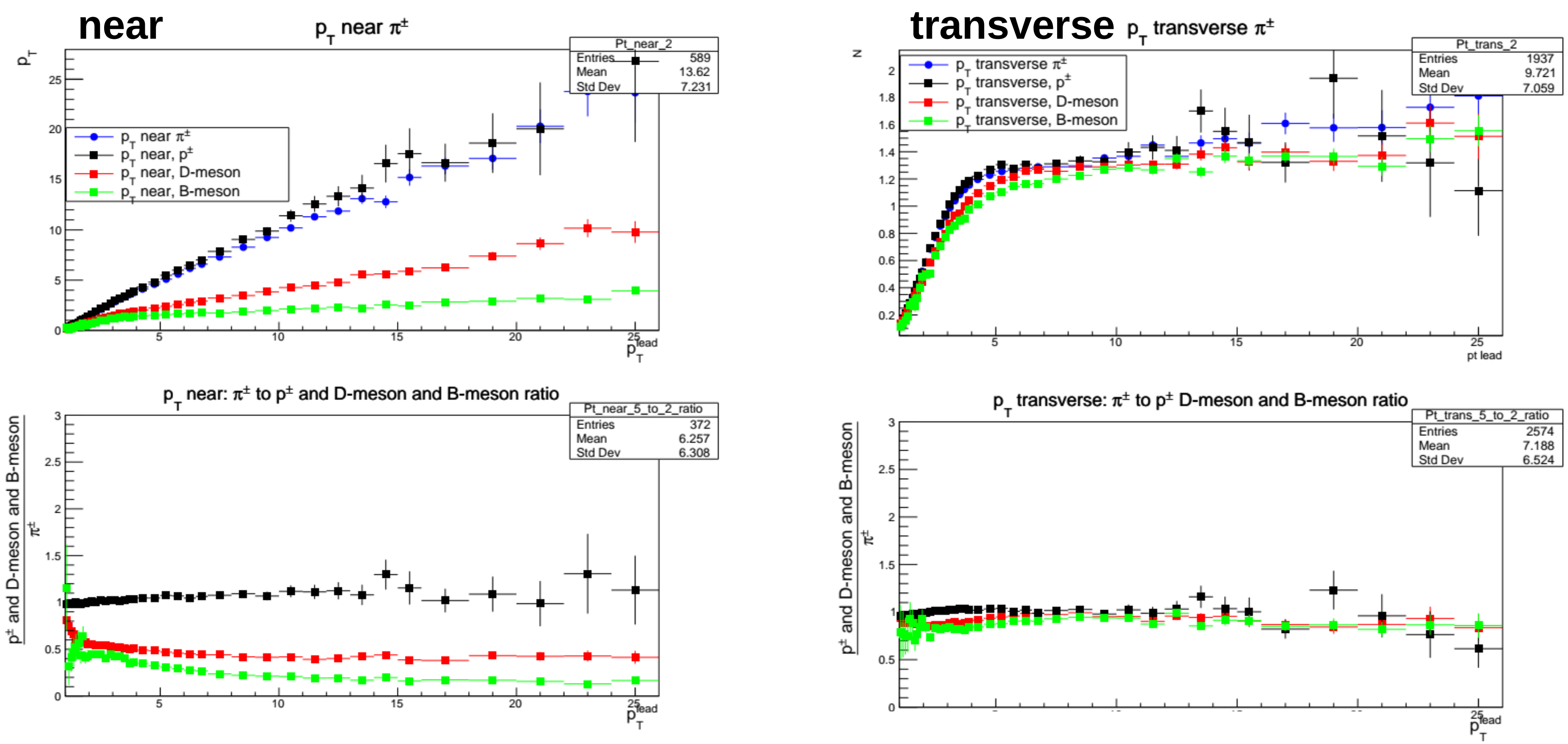


- MPI causes a flavor-ordered difference on the near side. Flavor-dependent parton shower and fragmentation?
- Difference between light and heavy only on the transverse side. Dependence of MPI on color-charge (quark vs gluon jets?)

Momentum distribution (near and transverse side)



- Momentum instead of particle count

→ we get the same physical message

- Considering momentum density: particles from the hard process have larger weight

$$\rho_T(p_T^{leading}) = \frac{1}{N_{ev}} \frac{\partial^3(\sum_i p_{T,i})}{\partial\phi \cdot \partial\eta \cdot \partial p_T^{leading}}$$

Pion
Proton
D-meson
B-meson

Summary

- Jet development is ordered by flavor, UE descreases the effect
- Particle yield in the transverse side: strong flavor difference

  - MPI levels the difference

  - CR low pT: re-introduction
- Particle yield in the near side: flavor ordering connected to multiplicity
- CR effect: relative effect is same on the near and transverse side
- MPI color-charge effect on the transverse side
- Momentum instead of particle count: same physical message
  - just particles from the hard process have larger weight
- B-meson is a good proxy for b quark
  - no significant difference → not necessary the jet reconstruction

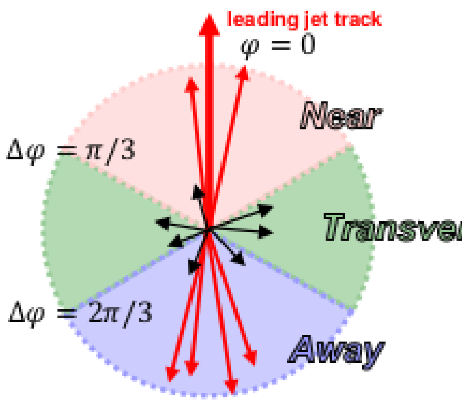
Future

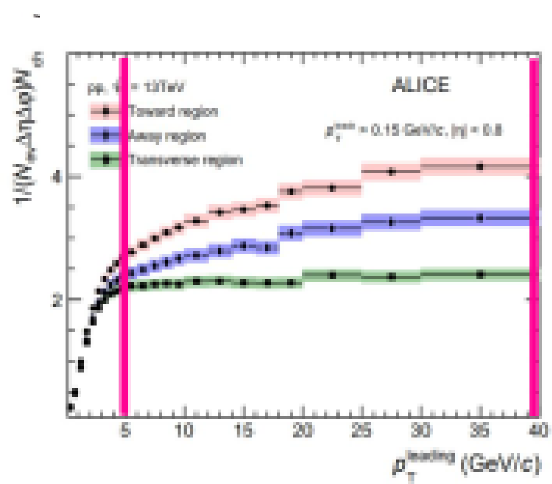
Ref: T. Martin, P. Skands and S. Farrington, „Probing Collective Effects in Hadronisation with the Extremes of the Underlying Event," Eur. Phys. J. C 76 (2016) no.5, 299 [arXiv:1603.05298 [hep-ph]].

- *R_T*:

- UE activity
- MPI is not measurable, but the R_T is correlation of number of MPI
- self-normalised charged particle density
- in the transverse region
- is almost independent on the initial hard scattering
- discriminate between soft, UE dominated, and hard, jet dominated, events
- goal: examine heavy quark yield in different R_T classes

$$R_T = \frac{N_{\mathrm{ch}}^{\mathrm{trans}}}{<N_{\mathrm{ch}}^{\mathrm{trans}}>}$$

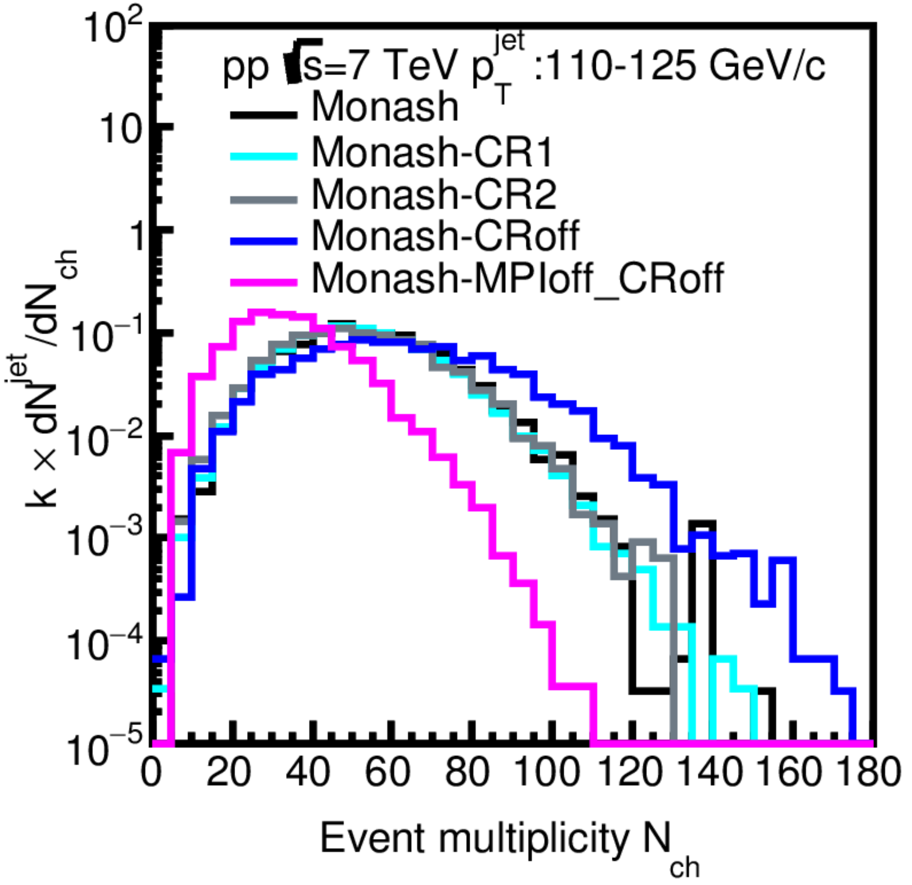




Thank you for your attention

JetStruct - Event charged multiplicity

- The three different "stock" tunes show similar multiplicity dependences (all tuned to describe data)
- Different CR-schemes also yield similar N_{ch} distributions
- MPI:off - yields less multiplicity on the average
- MPI:on, CR:off - more multiplicity on the average

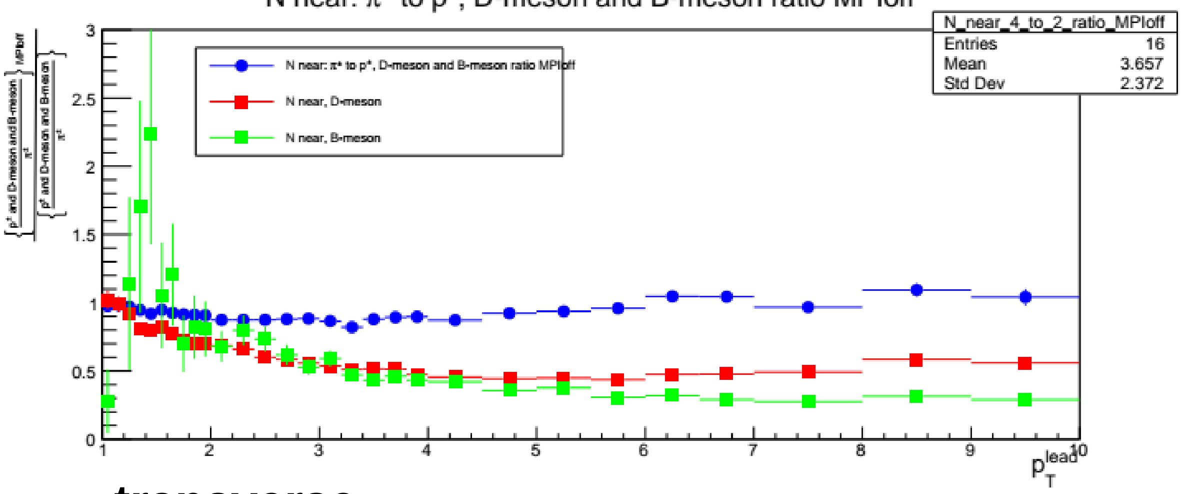


MPI effect particle count - double ratio

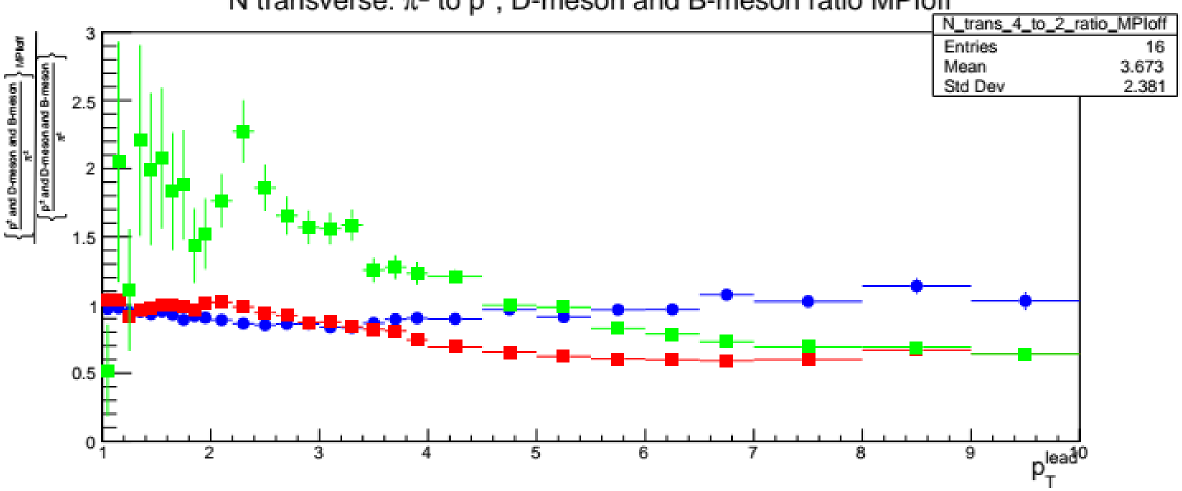
$$\frac{\text{MPI off, CR on}}{\text{MPI on, CR off}}$$

Ordering with mass p~D,B meson

near



transverse



Proton
D-meson
B-meson