Investigation of the underlying event with heavy quarks

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MŰEGYETEM 1782

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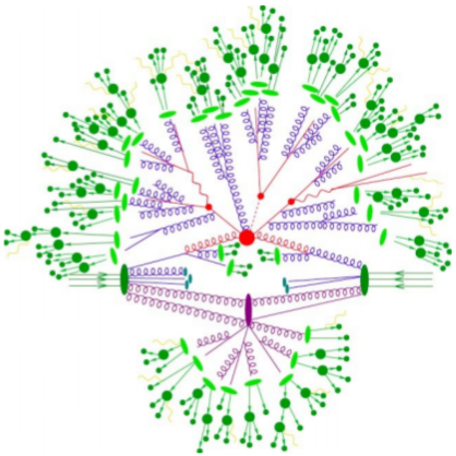
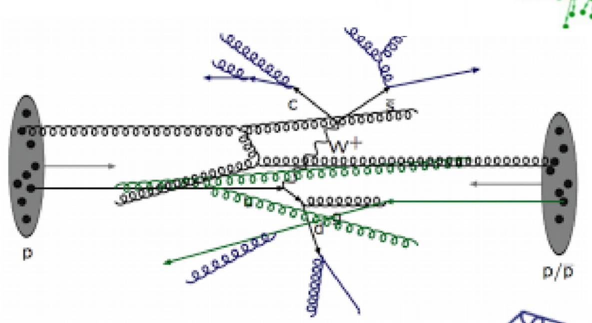
Motivation

- High-multiplicity p+p at LHC energies:
  - unexpected findings
  - substantial azimuthal anisotropy (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

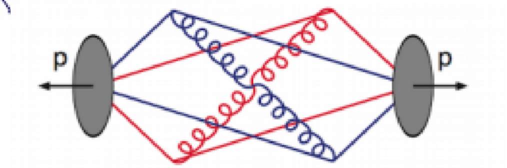
Concepts and definitions

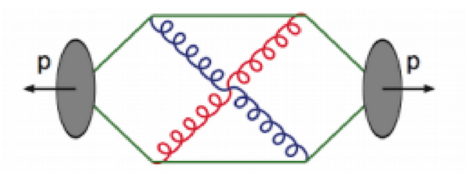


- Underlying Event (UE)
  - presence of UE from non-hard processes
  - Goal: examining the hard processes without UE
  - interplay between UE and hard processes
  - significantly influenced by MPI and CR



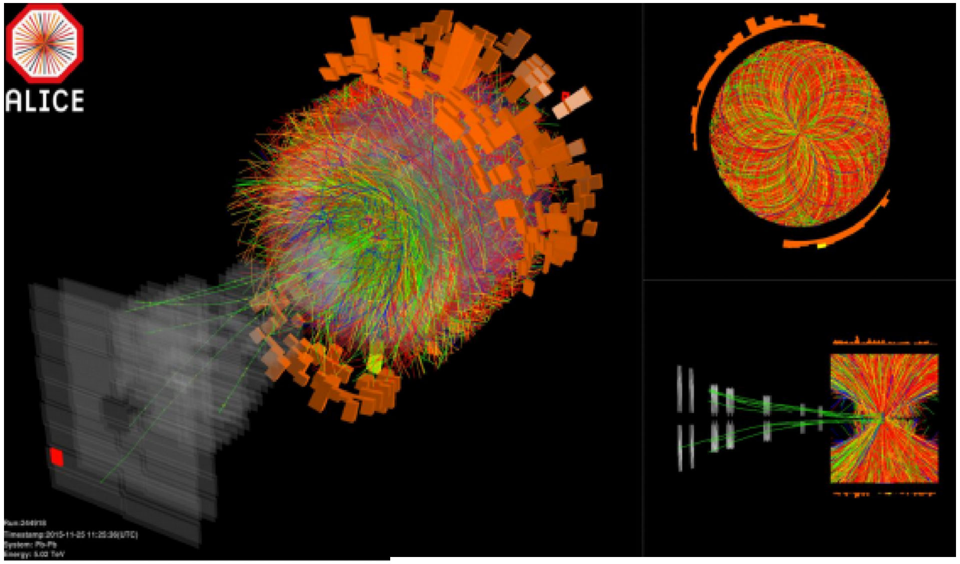
- Multi-Parton Interaction (MPI):
  - more partons interact
  - multistep process
- Color-Reconnection (CR):
  - striving for energy minimum (analogy)
  - CR leads to radial flow (Ortiz-Bencédi-Bello,J.Phys. G44 (2017), 065001)

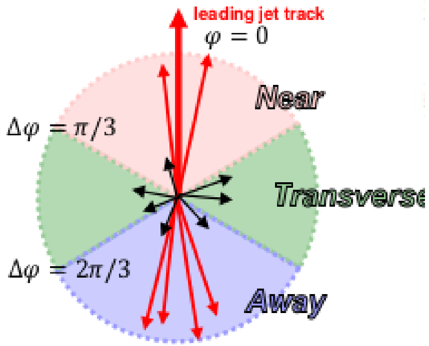


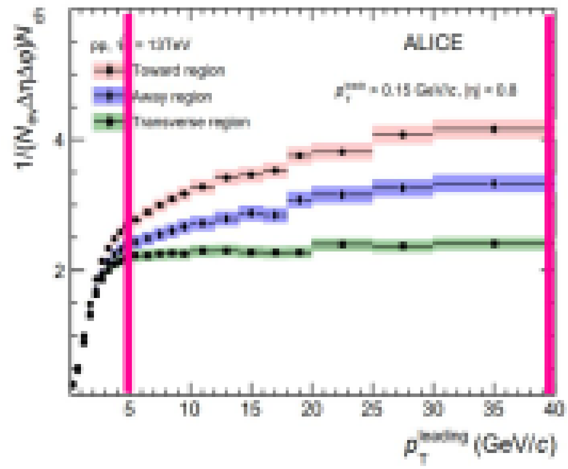


Experimental setup

- Large Hadron Collider: ALICE (A Large Ion Colliding Experiment)
- Tool: study of hadron production in jets and UE
- Heavy flavor:
  - penetrating probe
  - Understand mass and flavor dependence of parton shower and fragmentation





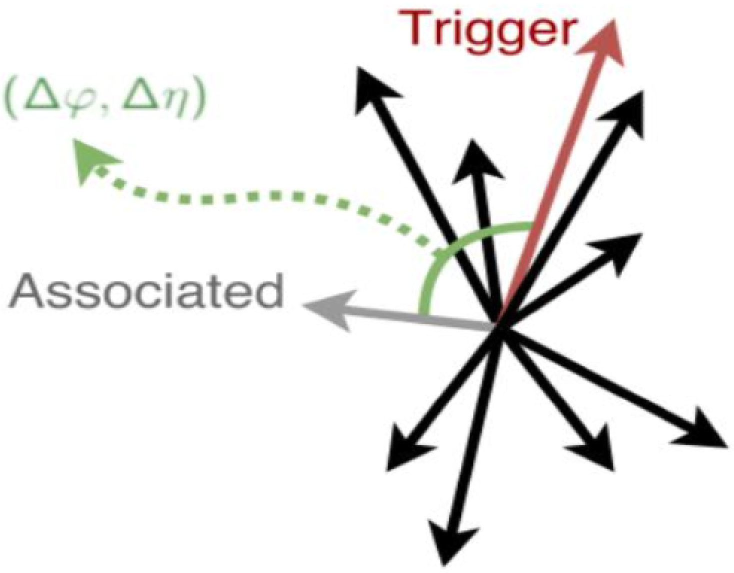


Simulation settings

- simulations with Pythia 8.1 Monash tune
  1) Modeling a basic “hard” QCD process with LO pQCD
  2) Parton level processes: ISR, FSR and MPI with CR
  3) Hadronic state with Lund string fragmentation
  4) Secondary decays and rescattering between hadrons
- proton-proton
- minimum bias events, SoftQCD:All
- $\sqrt{s}$ = 7 TeV
- 25 million events with each settings:
  - A) MPI off and CR off
  - B) MPI on and CR off
  - C) Physics case: MPI on, CR on

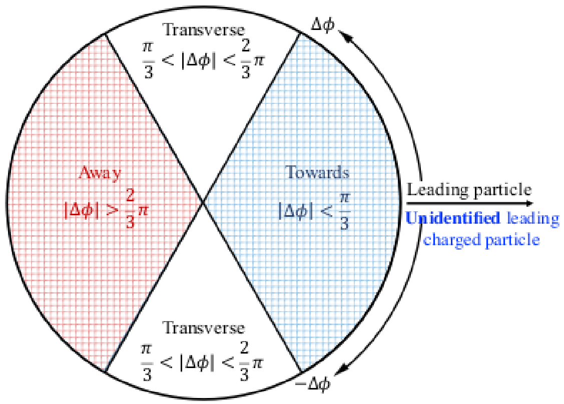
Identification of trigger particles

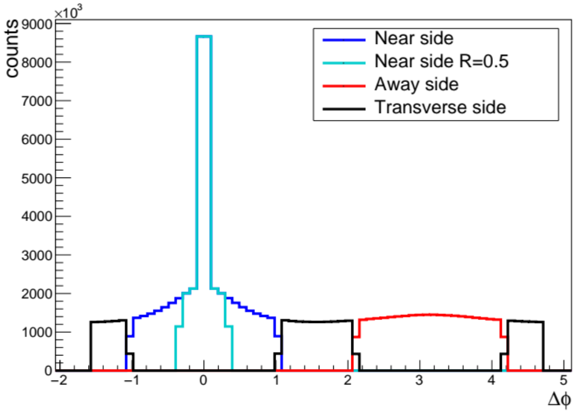
- The highest p_T „trigger” particle is selected from each event
- $|\eta| < 0.8$
- pion: only charged
- proton: proton and anti-protons included
- D meson: D^+, D^-, D^0, anti-D^0 meson
- B meson: B^+, B^-, B^0, anti-B^0 meson
- I have prevented their decay (mayDecay = off)



Selection of associated particles

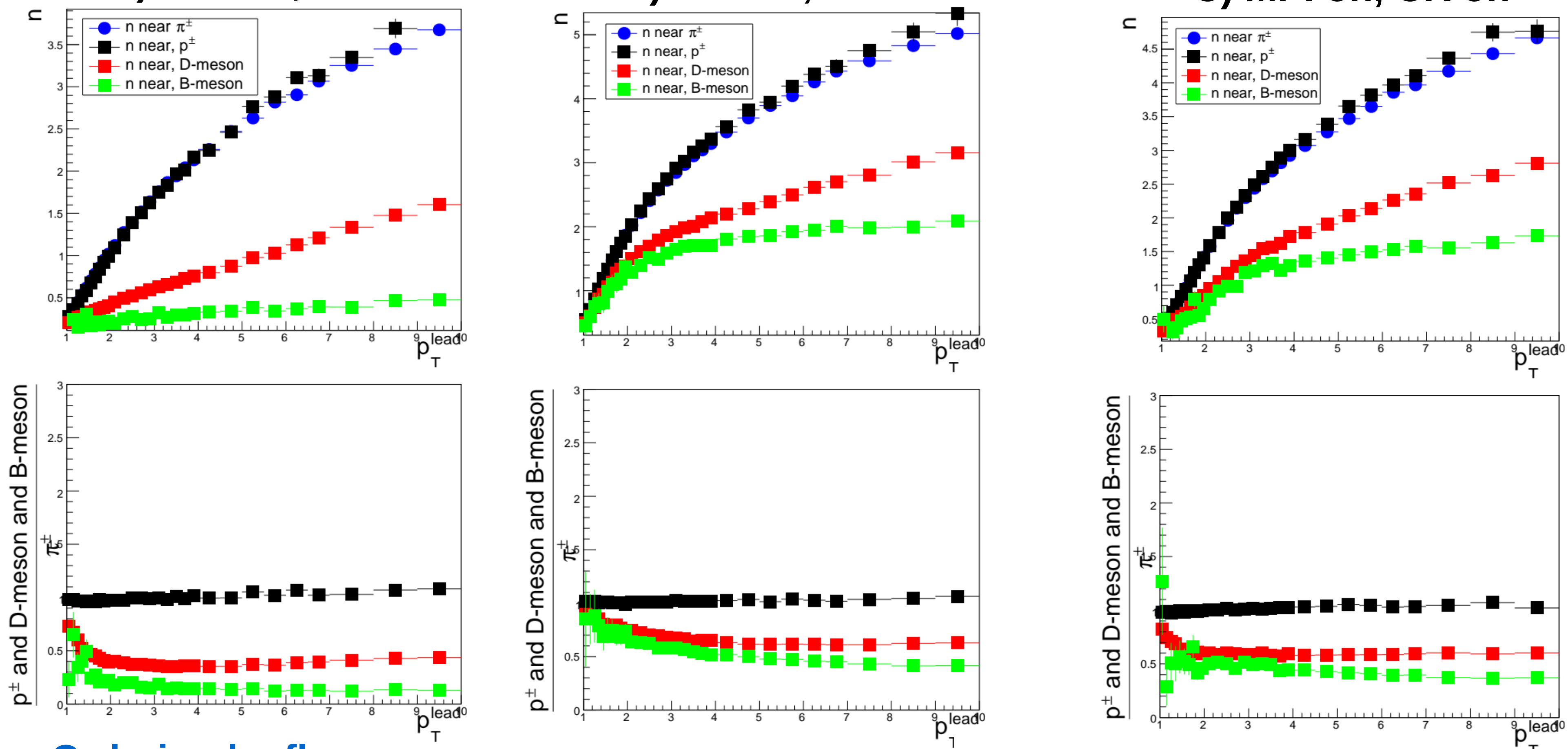
- p_T > 0.5 GeV/c
- only charged particles
- spatial division based on angle between trigger and associated particle:
  - Near side: leading jet
    - Near side range restricted to $R < 0.5$ around the trigger particle
  - Away side: recoild jet
  - Transverse side: UE





π compared to p, D- and B-meson particle count (near side)

A) MPI off, CR off B) MPI on, CR off C) MPI on, CR on

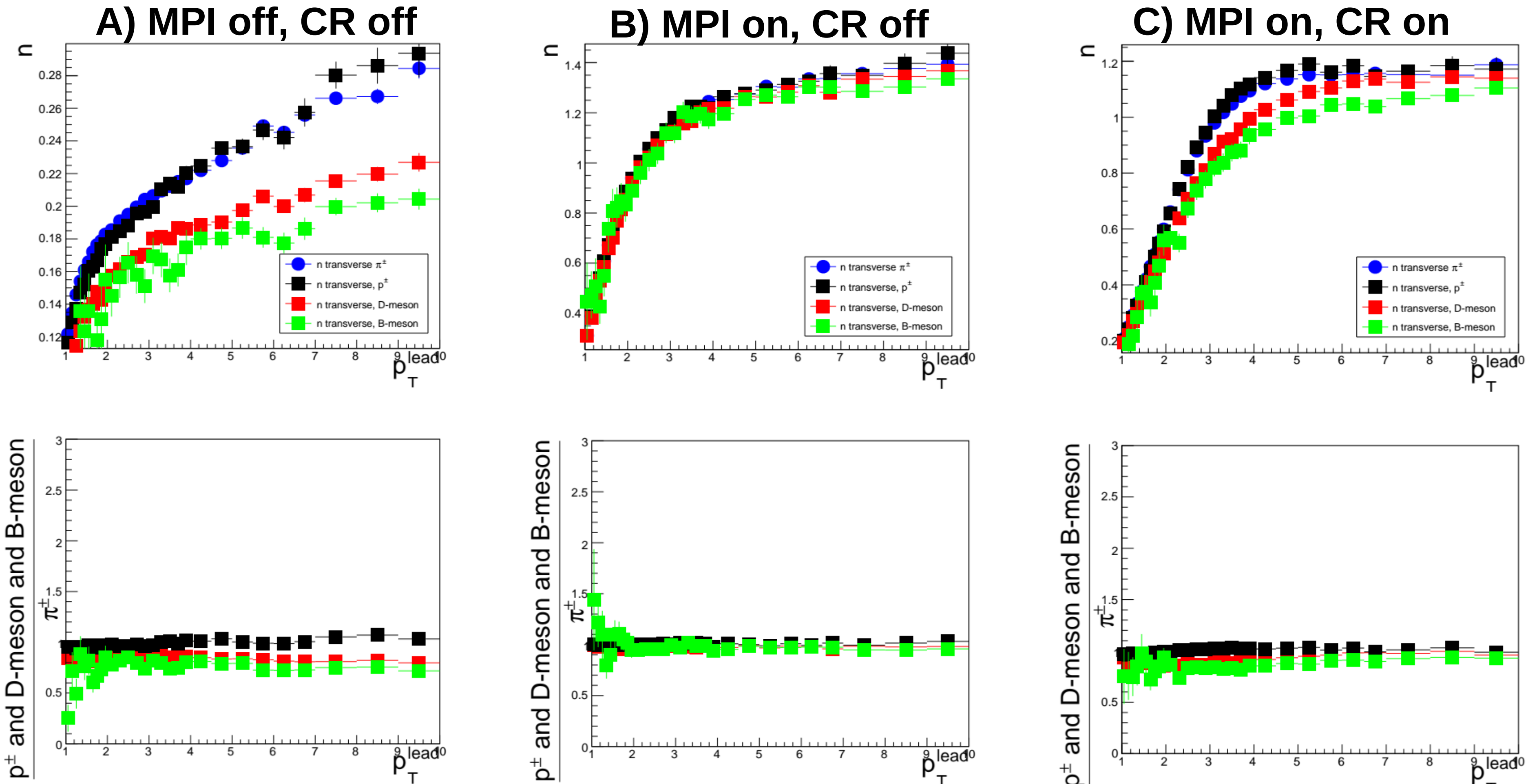


- **Ordering by flavor**
- Strongest if MPI is off, weakest is CR is off
  - Looks like a multiplicity effect ($n_{MPIoff} < n_{CRonMPIon} < n_{CRoff}$)
  - Underlying event in jet region descreases ordering

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

Pion
Proton
D-meson
B-meson

π compared to p, D- and B-meson particle count (transverse side)

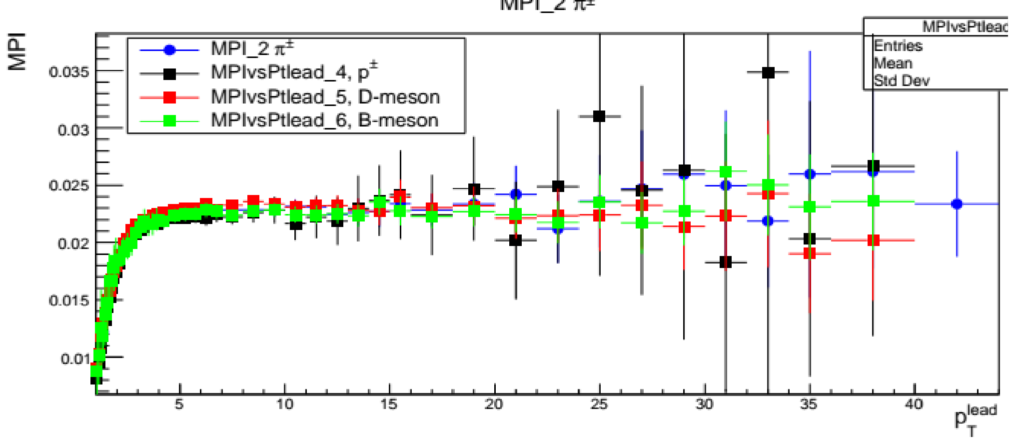


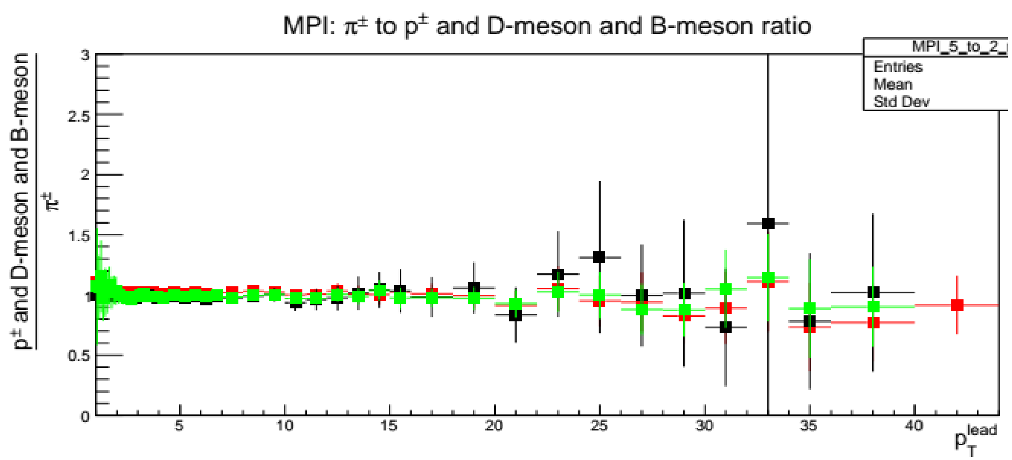
- Flavor-ordered production if MPI is off
- MPI levels any ordering
- CR re-introduces ordering at lower p_T, similarly to observations with light and strange particles (A. Ortiz and L. Valencia Palomo, Phys. Rev. D 99 (2019) no.3, 034027)

Pion
Proton
D-meson
B-meson

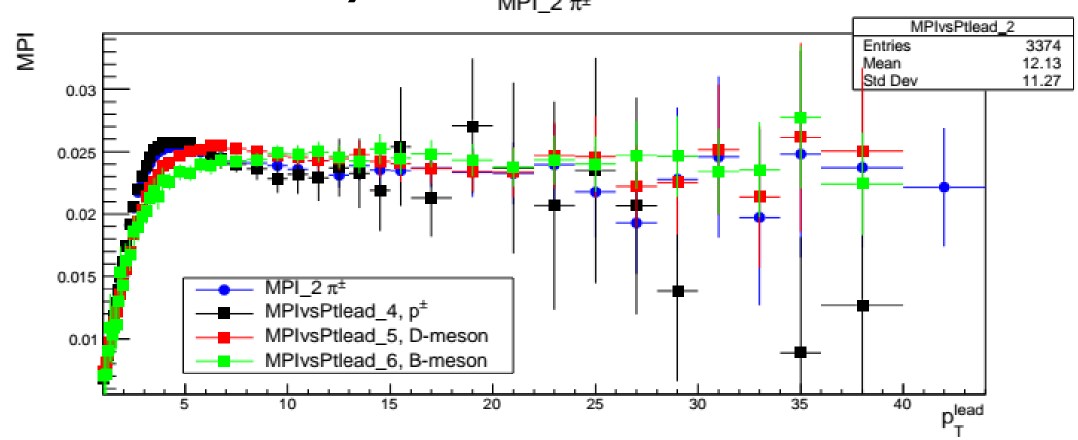
Number of MPI in an event

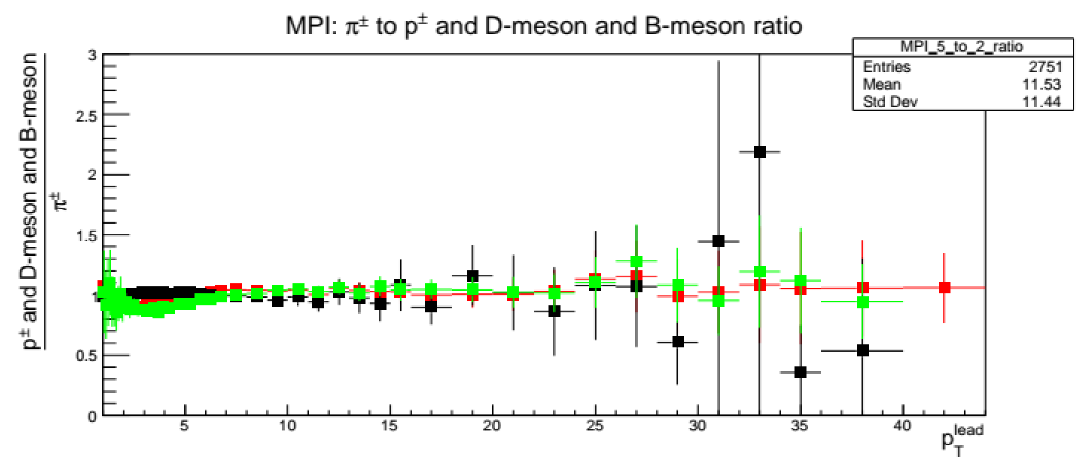
B) MPI on, CR off





C) MPI on, CR on





- No difference at all

Pion
Proton
D-meson
B-meson

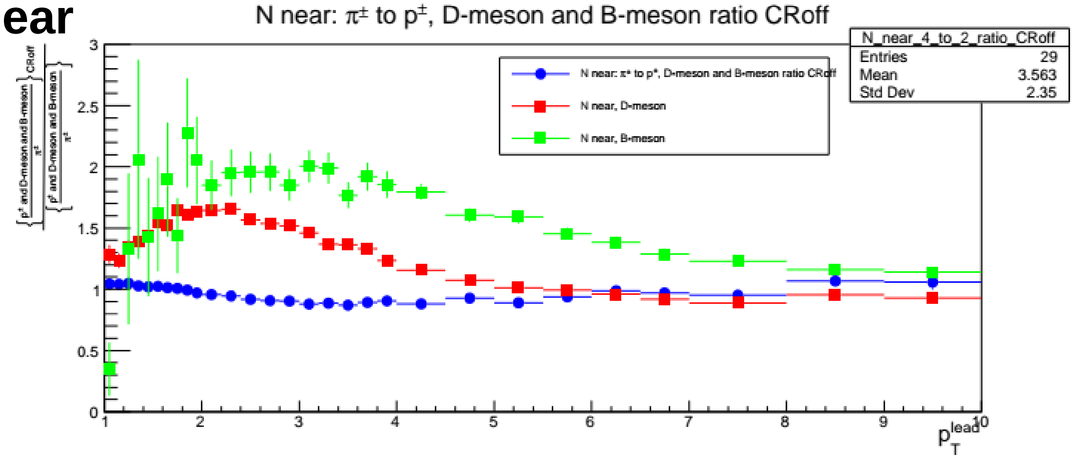
- The difference between p, D and B meson:
  → MPI processes → flavour difference
- No difference between pion and proton
- **Significant difference between flavor: effect of CR**

CR effect particle count - double ratio

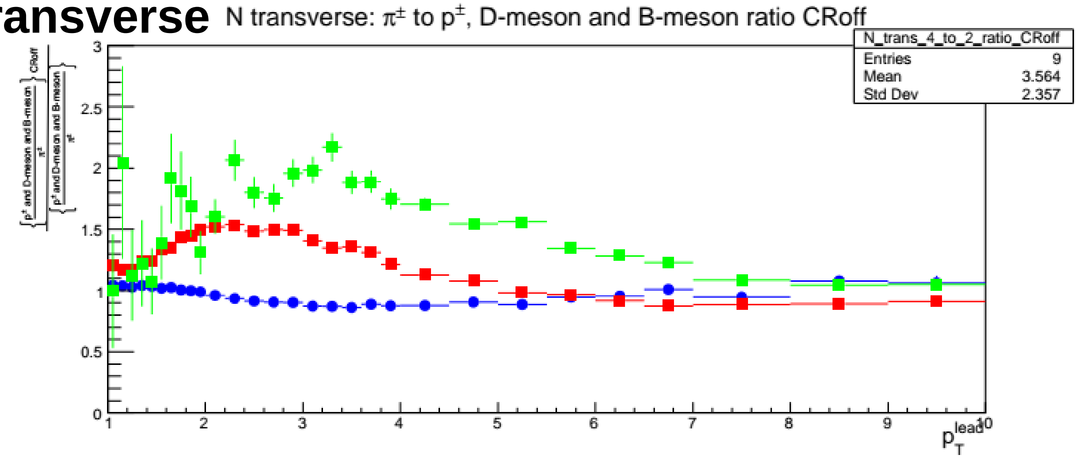
B) MPI on, CR off
C) MPI on, CR on

Proton
D-meson
B-meson

near



transverse



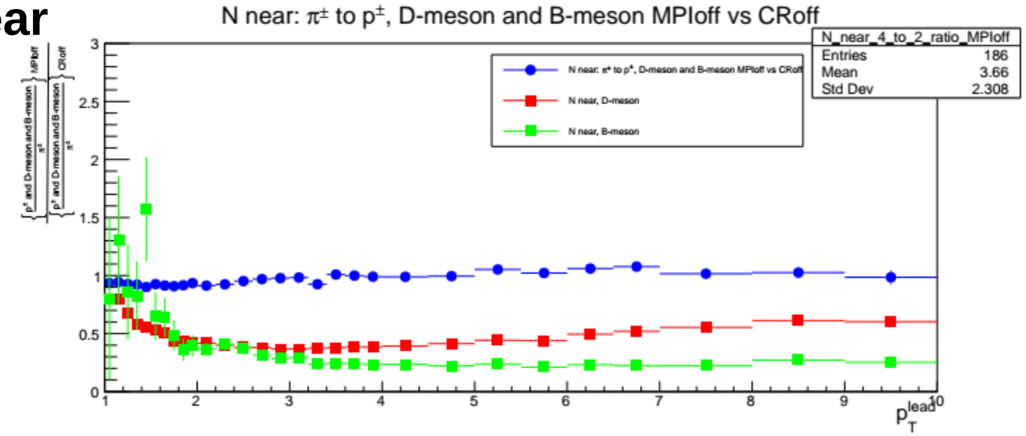
- CR causes separation of c, b and light flavors at lower p_T
- Separation of b persists up to higher p_T – mass effect?
- **Relative change same at near and transverse side**

MPI effect particle count - double ratio

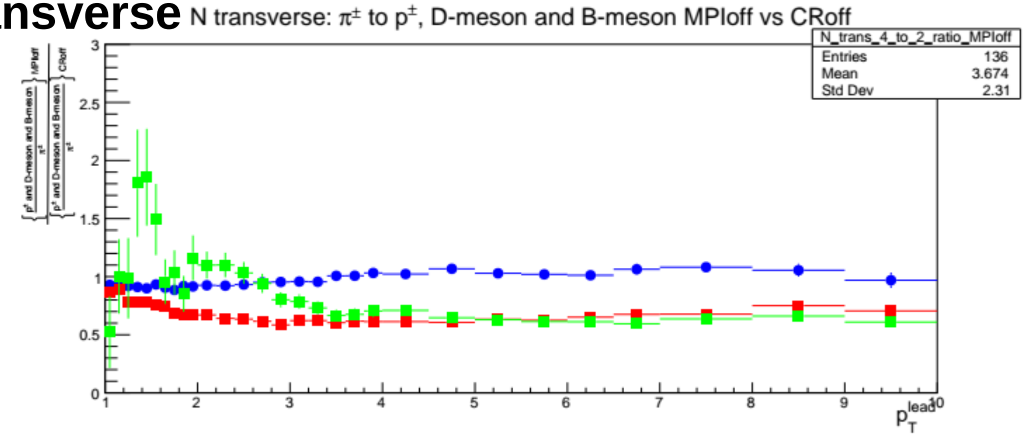
A) MPI off, CR off
B) MPI on, CR off

Proton
D-meson
B-meson

near



transverse



- 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)

Summary and outlook

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

  - MPI levels the difference

  - CR low p_T: 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
- Future: R_T – is correlated to number of MPI $$R_T = \frac{N_{\mathrm{ch}}^{\mathrm{trans}}}{<N_{\mathrm{ch}}^{\mathrm{trans}}>}$$
  - Goal: examine heavy quark yield in different R_T classes

Thank you for your attention

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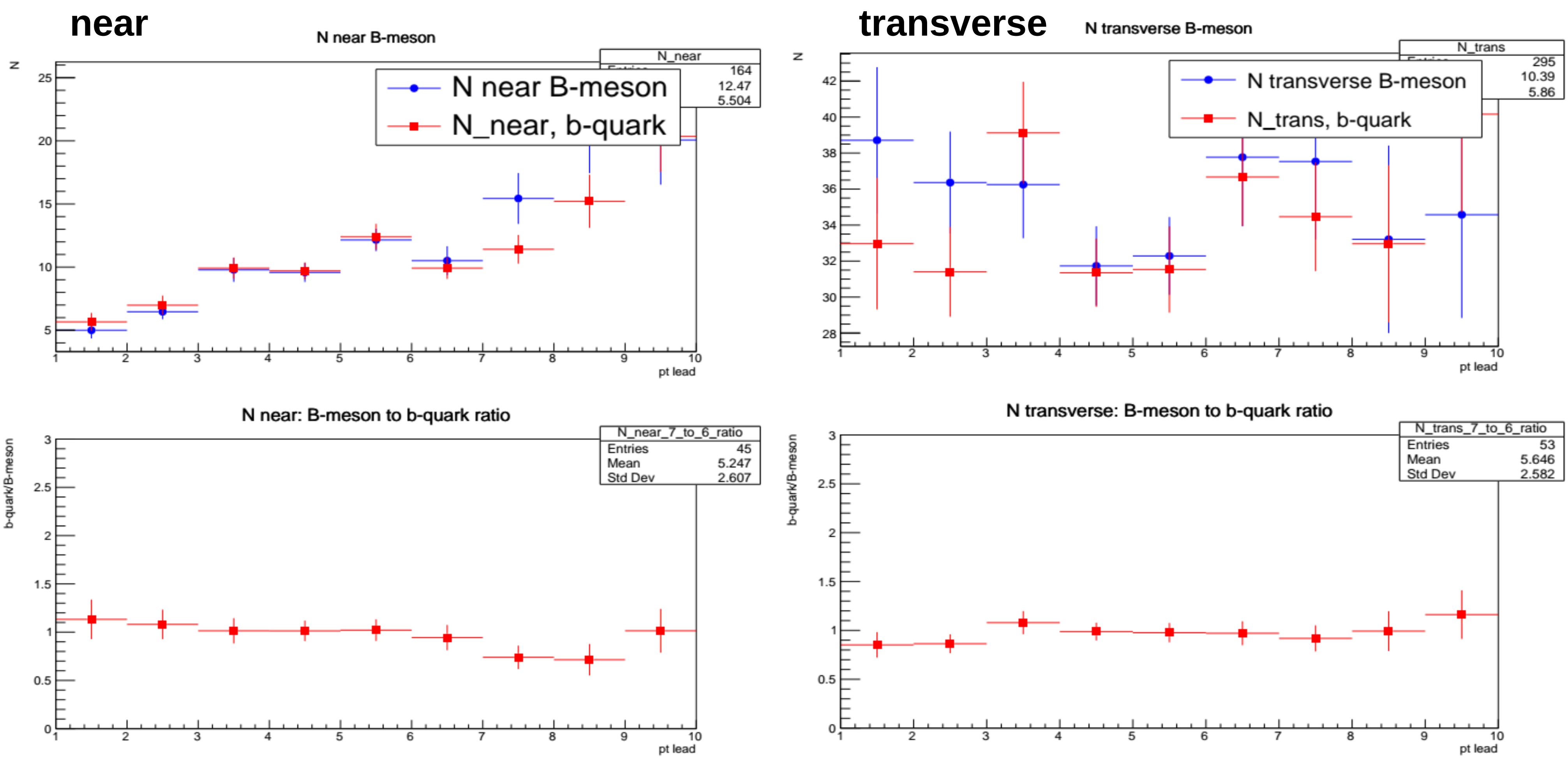
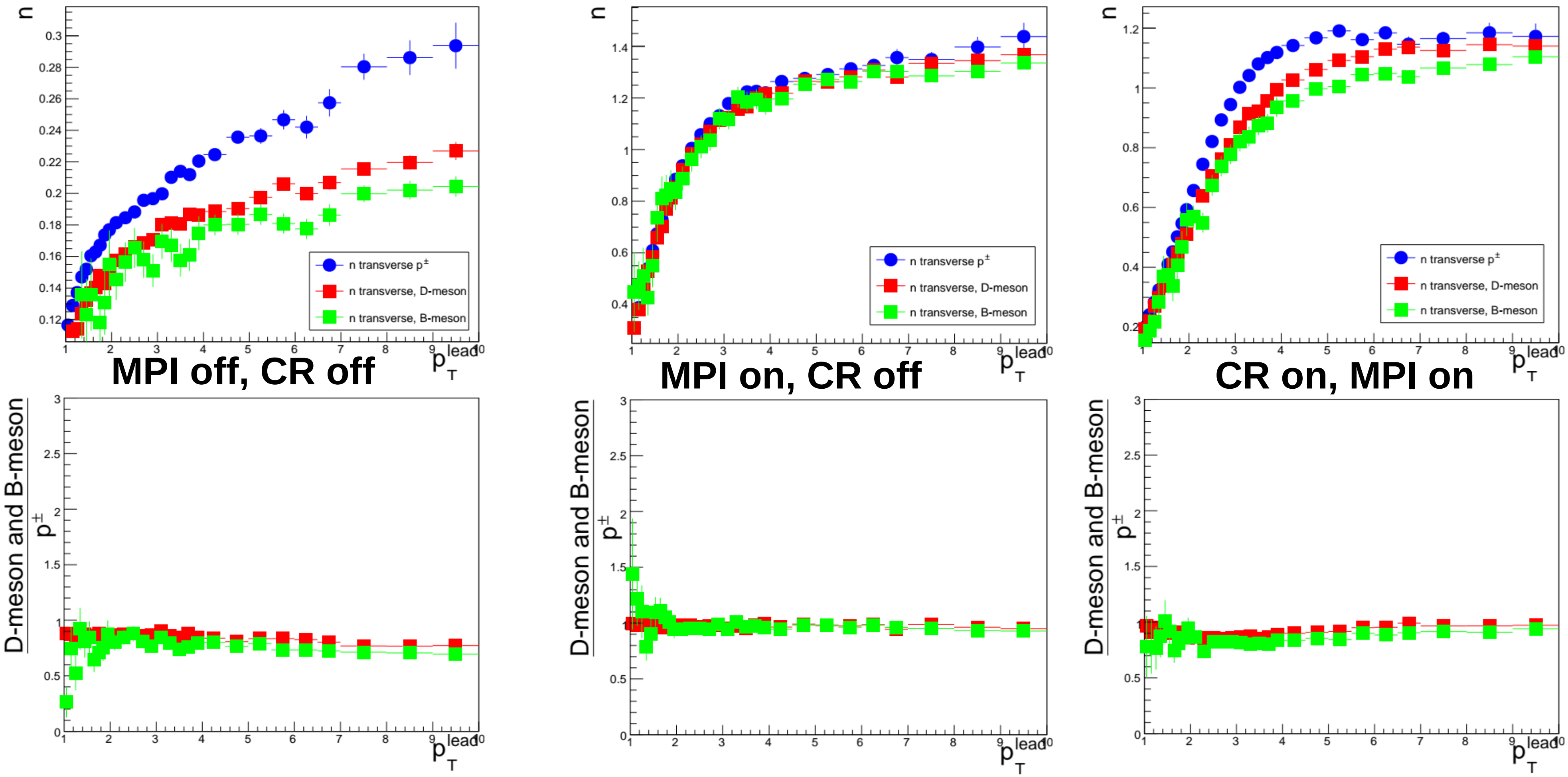
b quark compared to B-meson



- 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

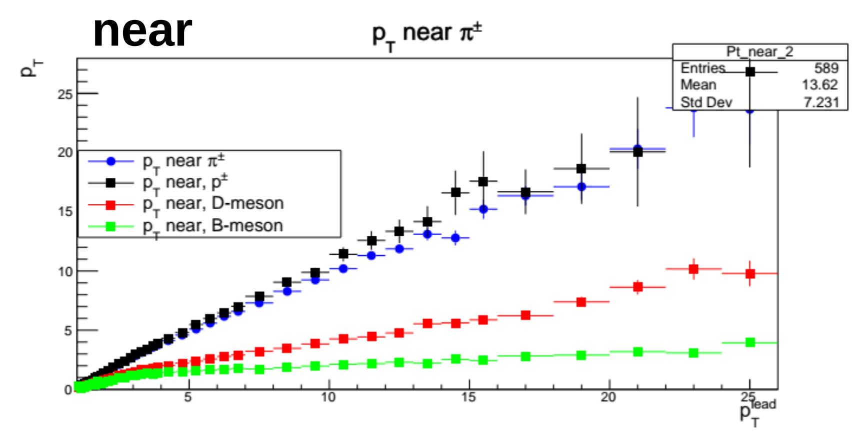
D and B meson comparison

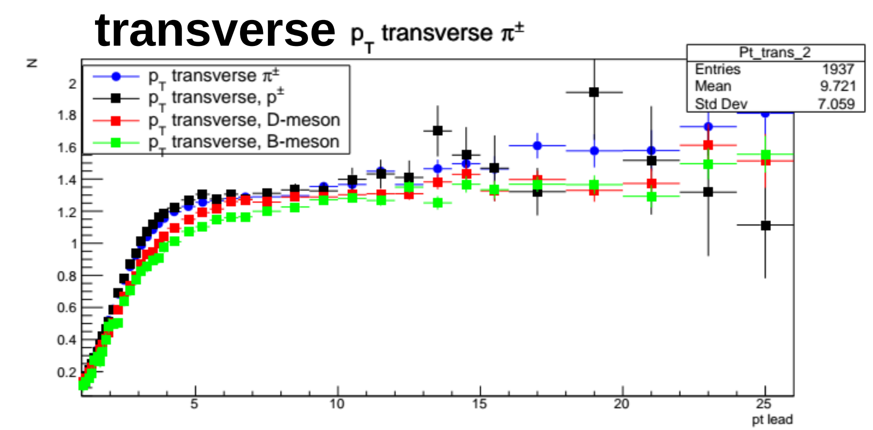


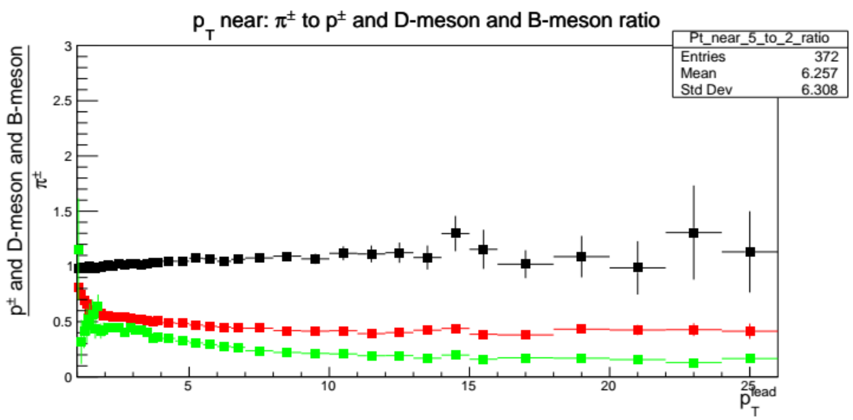
Proton
D-meson
B-meson

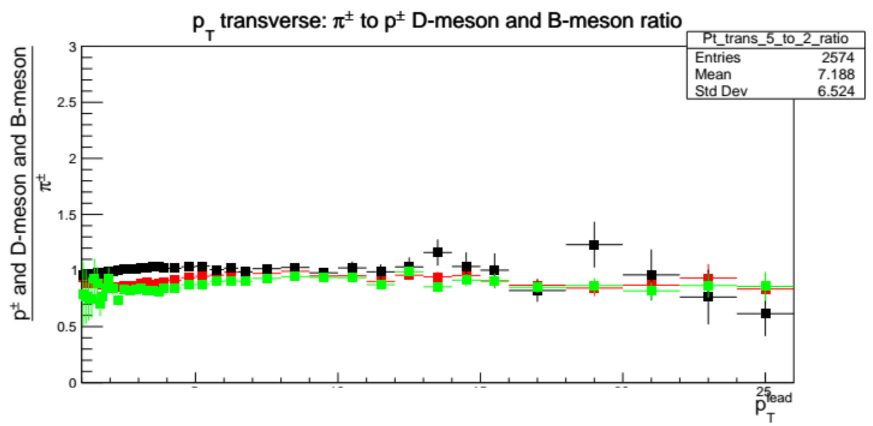
- Mass-ordering at higher p_T in the physical case

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

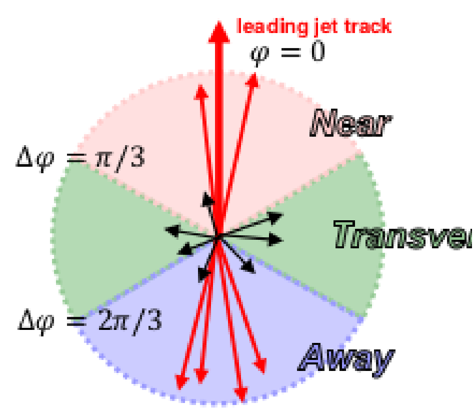
Future

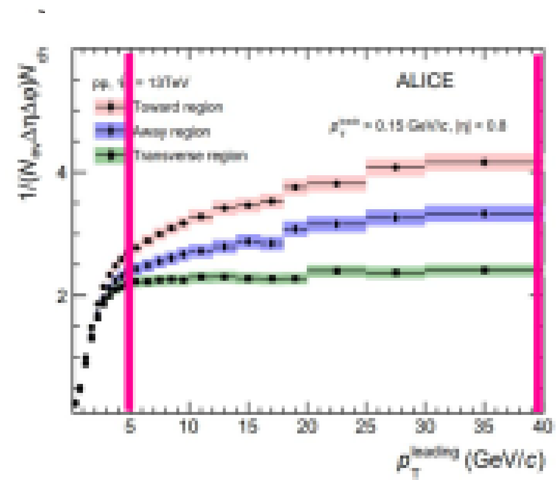
Ref: T. Martin, P. Skands and S. Farrington, „Probing Collective Effects in Hadronisation with the Extremes of the Underlying Event,” Eur. Phys. J. C 76 (2016) no.5, 299 [arXiv:1603.05298 [hep-ph]].

- 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

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





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