



Defining the underlying-event activity in the presence of heavy-flavour processes in proton-proton collisions at LHC energies

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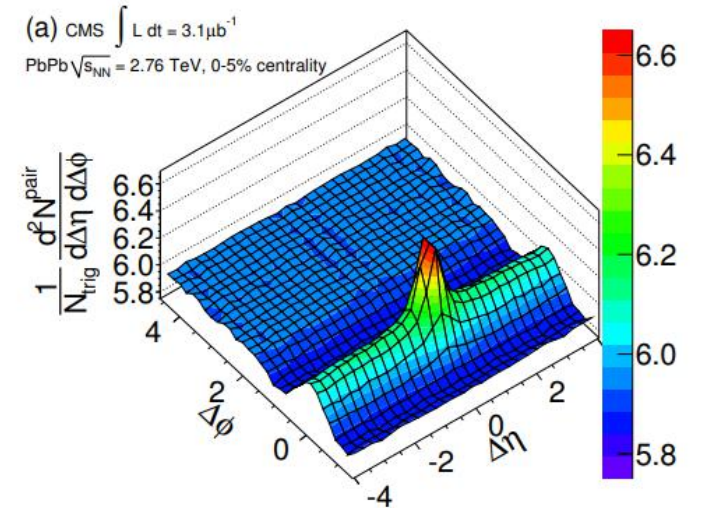
Based on: *L. Gyulai, Sz. Sándor, R. Vértesi,*
Particles **5** (2022) 235

Collectivity in high-energy collisions

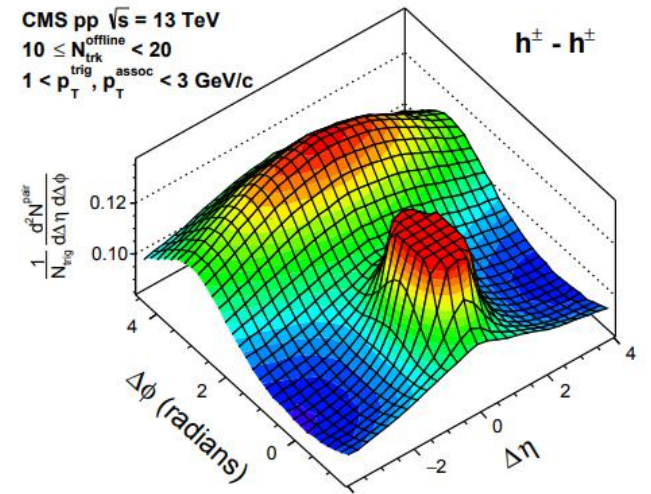
Collective phenomena arise in high-energy heavy-ion collisions. This is due to the Quark-Gluon Plasma (QGP).

Such collective-like behaviour is also observed in small systems (pp, p-Pb) with high final-state multiplicity. Energy densities are insufficient to form QGP in substantial volumes in these collisions.

Another possibility: vacuum-QCD effects such as multiple parton interaction (MPI).



Two-particle correlation in Pb-Pb collisions [JHEP **07**, 076 (2011)]



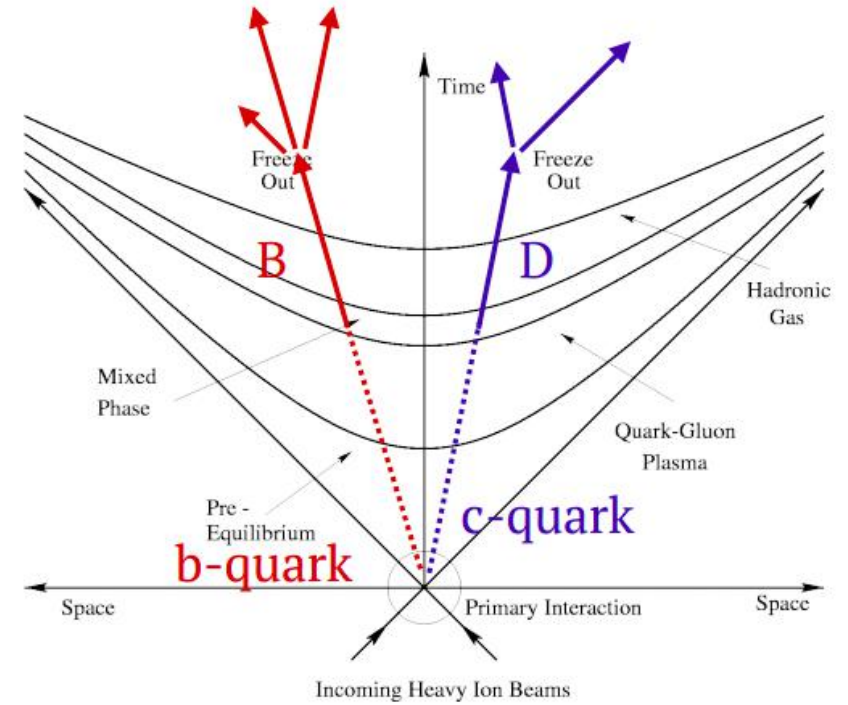
Two-particle correlation in pp collisions [PLB **765**, 193 (2017)]

Heavy-flavour probes

Heavy-flavour (c and b) quarks are mostly produced in the initial hard scattering processes.

The formation time of c and b quarks is shorter than that of the QGP, and they have a lifetime which is longer than the duration of QGP. This allows for probing the QGP in ion-to-ion collisions.

In pp collisions heavy flavour is used for testing the QCD, and provides a baseline for heavy-ion collisions.



Creation of heavy flavour

Transverse activity classifier

Experiments show a saturation of particle production in the transverse region if a high- p_T leading process is present.

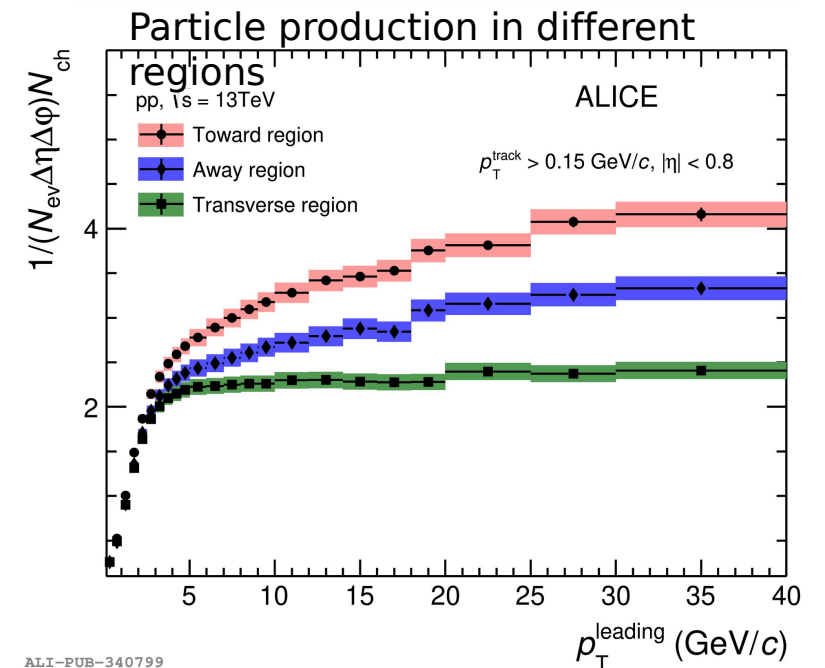
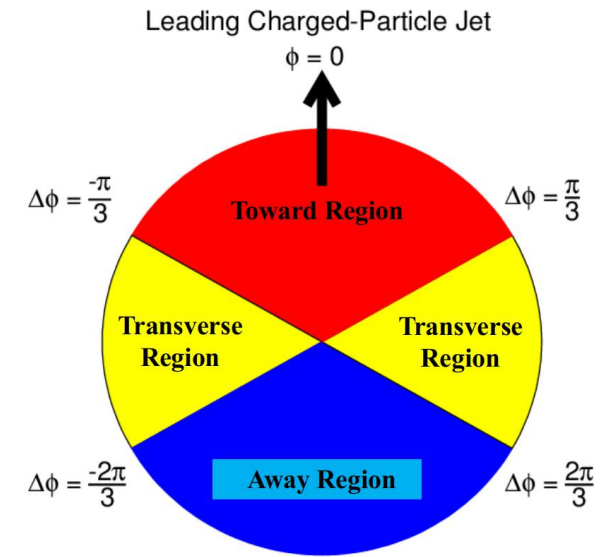
In such events, processes in the transverse region are assumed to be independent of the hard scattering. Particle production there is mainly determined by the underlying event.

To select events with hard processes, we are searching for a final-state charged hadron ("trigger") with $p_T > 5 \text{ GeV}/c$.

To classify the activity of underlying event, the R_T parameter is used:

$$R_T = \frac{N_{\text{ch,transverse}}}{\langle N_{\text{ch,transverse}} \rangle}$$

Simulations show a strong correlation between the R_T and MPI. [EPJC **76** (2016) 5, 299]



Simulation study of heavy flavour production vs R_T

PYTHIA 8 with SoftQCD and MPI-based colour-reconnection.

FastJet for jet reconstruction with anti- k_T algorithm.

Jet-tagging: charm (containing c quark), beauty (containing b quark), and light (containing only light u, d and s quarks or gluons) jets.

Total of 1 billion pp events at $\sqrt{s} = 13$ TeV were generated.

Studied particles:

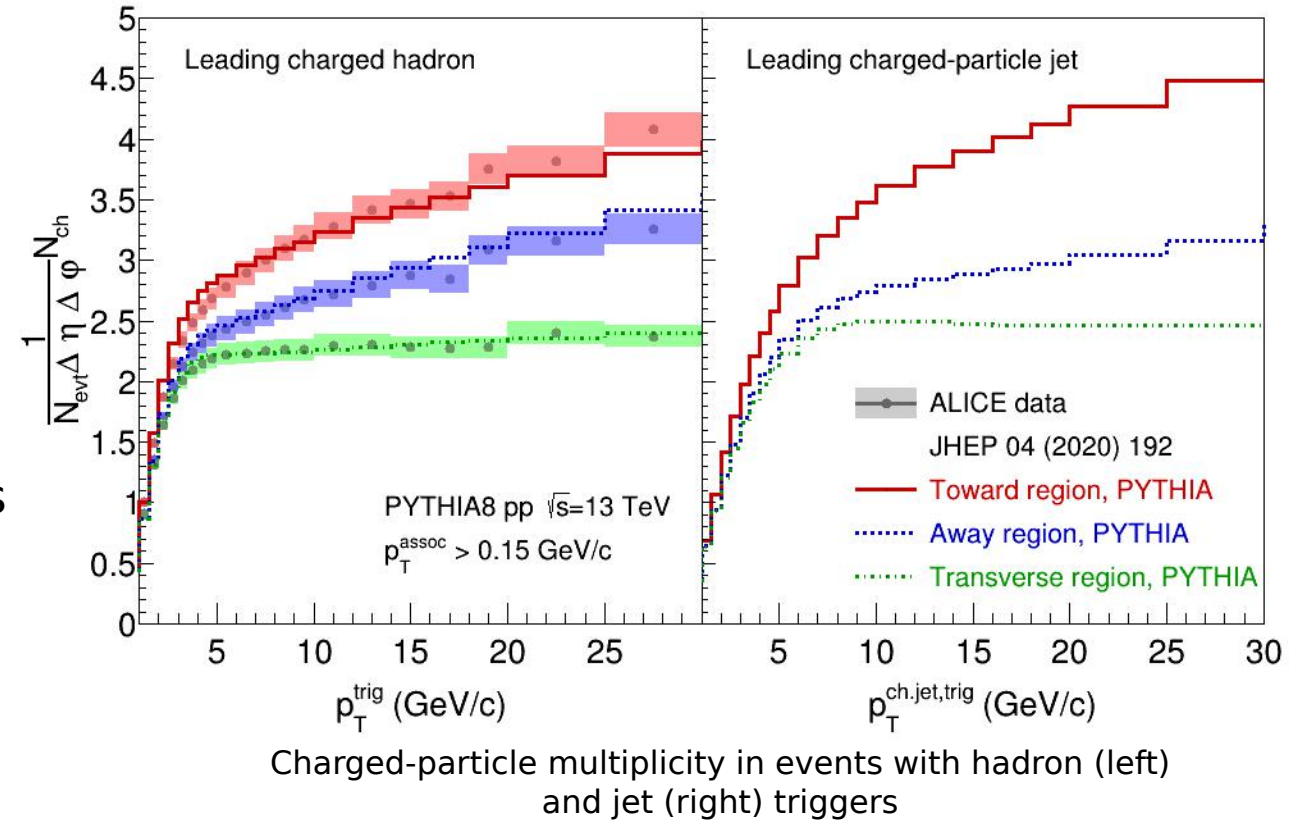
- D mesons (D^0 , D^+ , D^* and their antiparticles);
- B mesons (B^0 , B^+ , B^* and their antiparticles);
- c quarks;
- b quarks.

Charged particle multiplicity in events with hadron and jet triggers

Simulations generally reproduce the data.

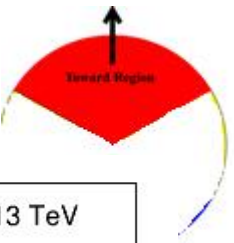
Motivation for jet trigger:

- Jet triggers also result in plateau, but at 10 GeV/c;
- a hadron trigger may come either from fragments of light or heavy-flavour jets;
- the fragmentation functions are different in both cases and heavy-flavour decay kinematics play a role;
- therefore the sensitivity of heavy flavour and light flavour for the trigger will be different.

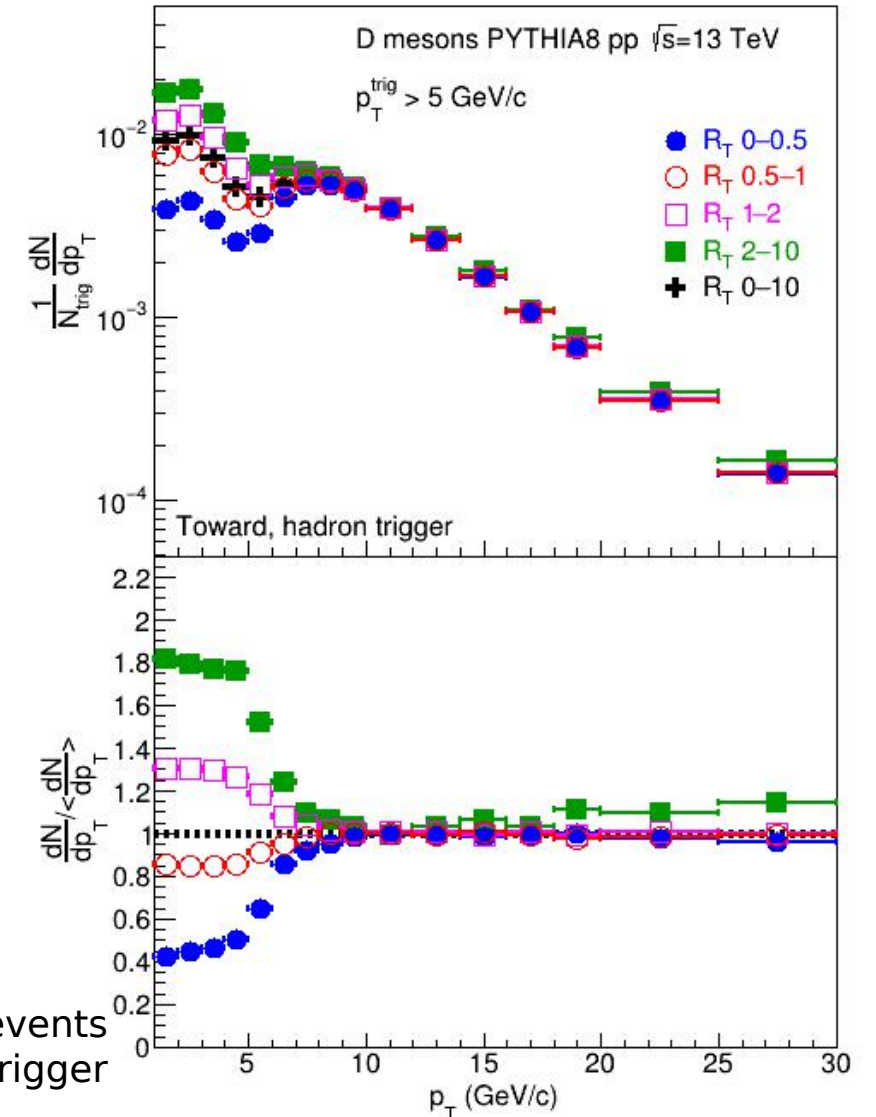


Look separately at events that are triggered with identified heavy-quark and light-flavour jets in order to connect heavy-flavour production to the underlying event.

Production of D mesons in the Toward region, hadron trigger



- Over $p_T \approx 7$ GeV/c D meson production is independent of the transverse activity.
→ Particles are produced mostly in the hard scattering.
- Between $p_T \approx 5$ and $p_T \approx 7$ GeV/c a “trigger turn-on” effect is observed.
- Below $p_T \approx 5$ GeV/c D meson production is heavily dependent on the R_T .
→ These particles come from the underlying event.



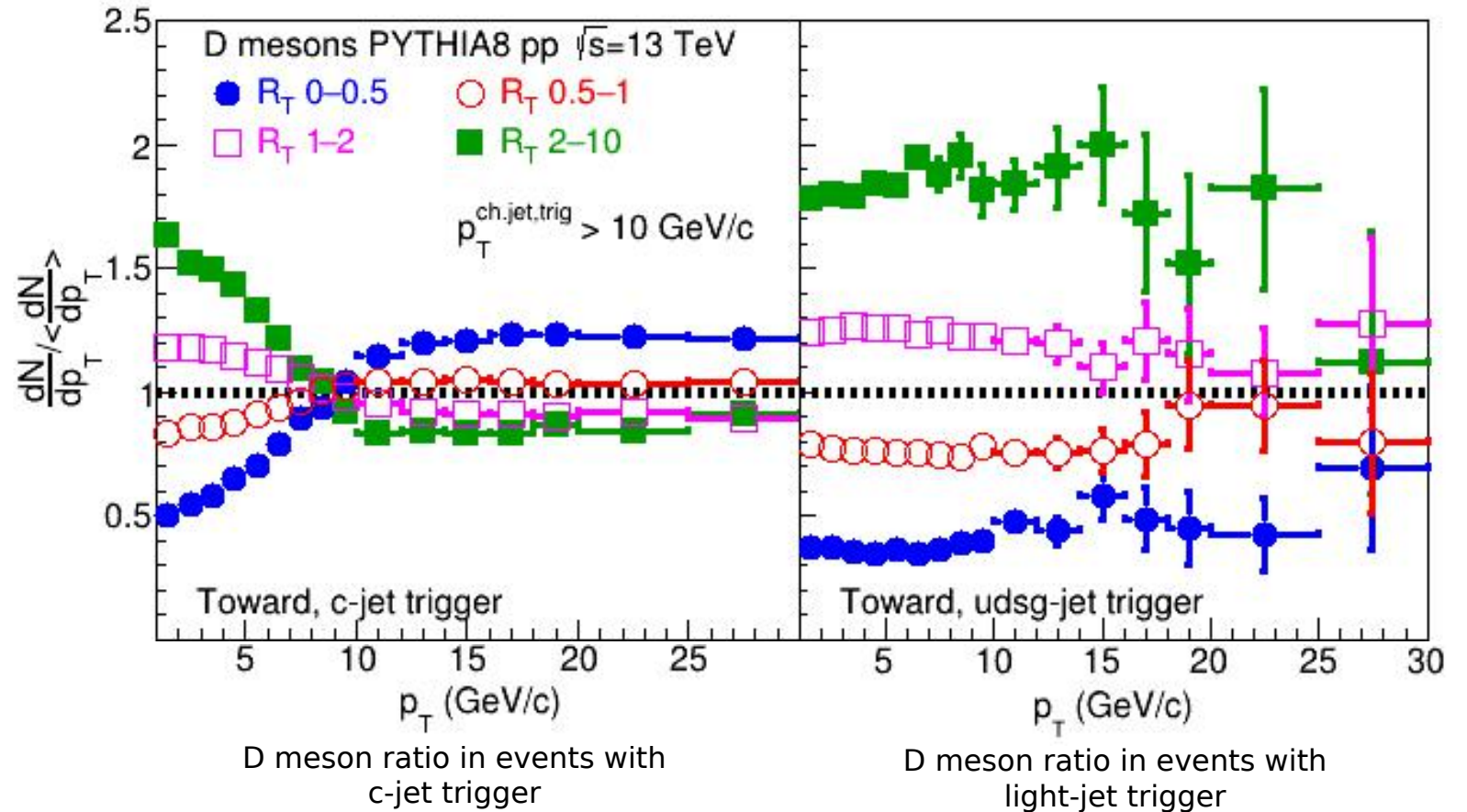
Production of D mesons in the Toward region, tagged jet trigger



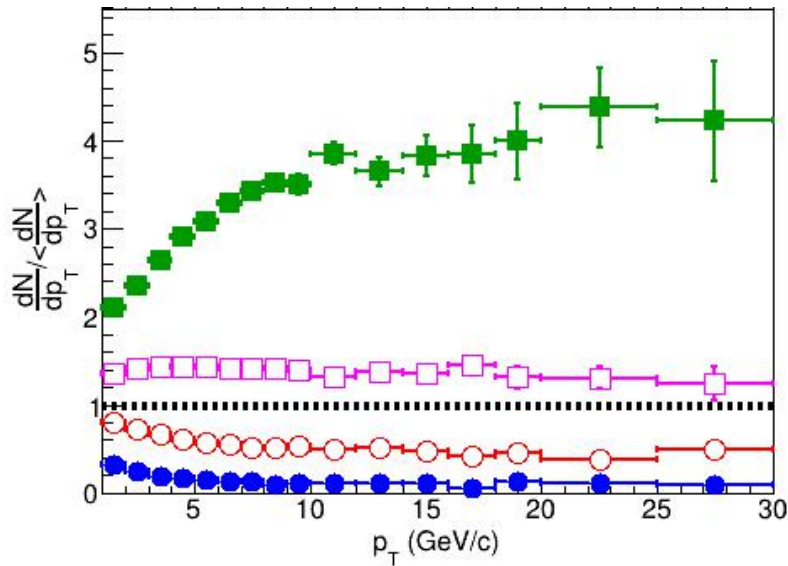
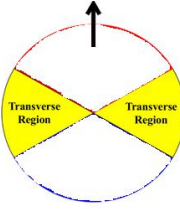
D-meson yields depend on R_T in c-jet triggered events even above the trigger threshold.

This behaviour is probably due to the wide-angle gluon splitting.

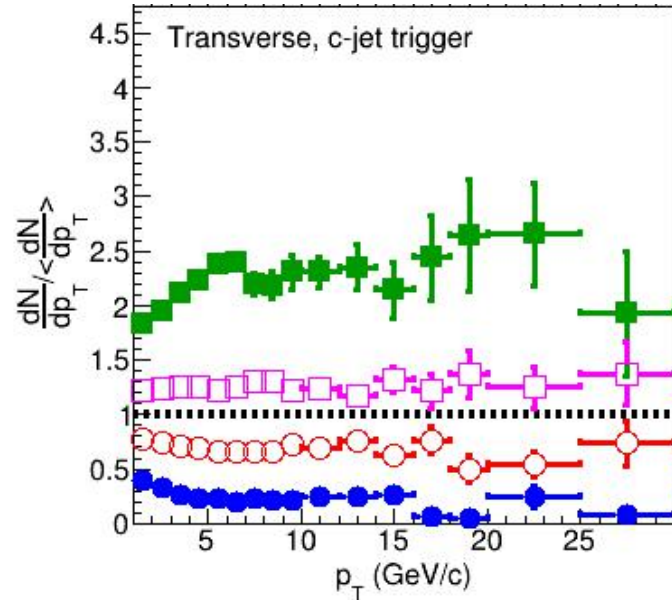
In case of light-jet trigger a strong dependence on the R_T is present in the toward region.



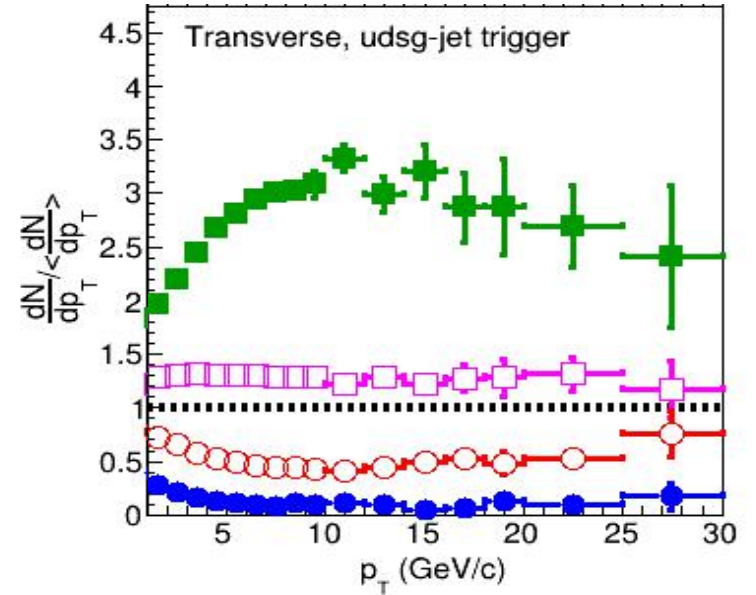
Production of D mesons in the Transverse region



D meson ratio in events with hadron trigger



D meson ratio in events with c-jet trigger



D meson ratio in events with light-jet trigger

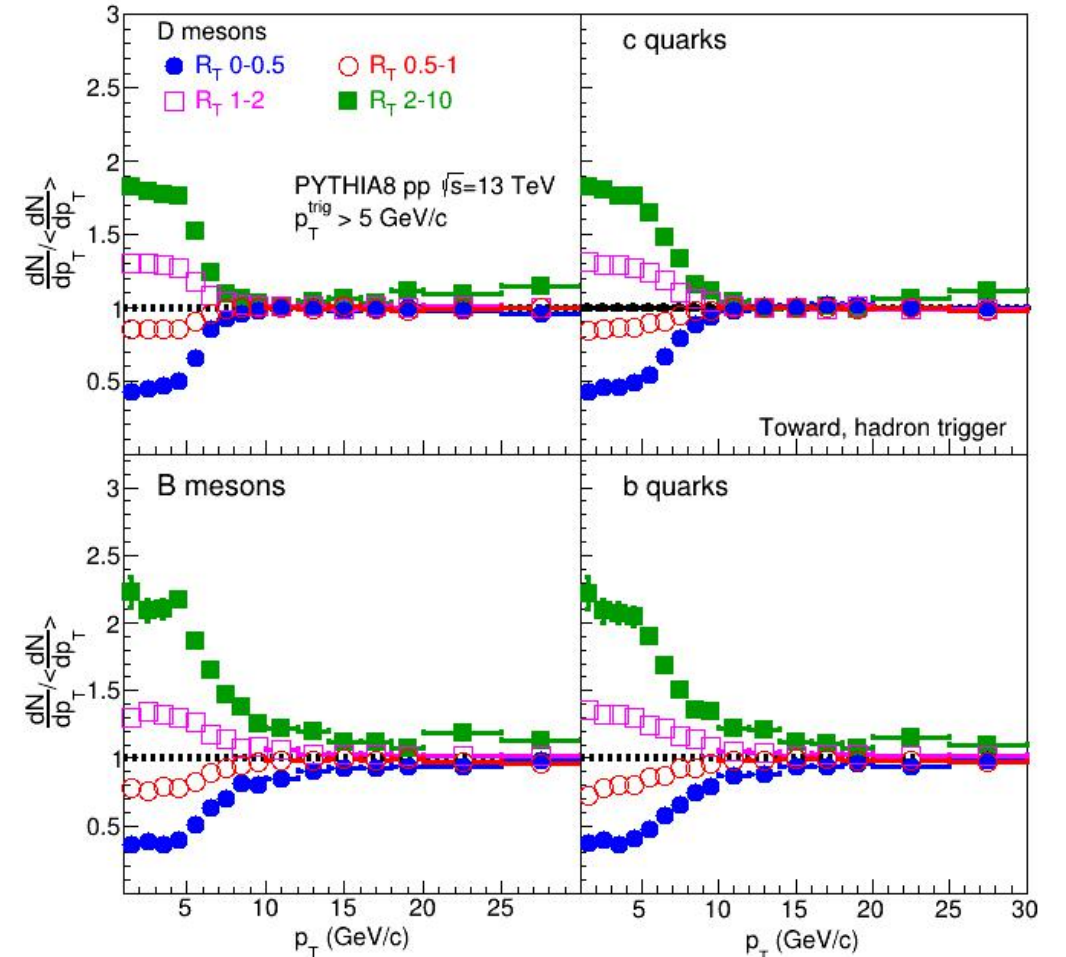
D meson production increases with higher R_T , trends are separated in the whole p_T range.
 → Particles come from the underlying event.

Effect of charm and beauty fragmentation

The transition from the soft to the hard production dominated range of c quarks is at about 40% higher p_T than in the hadronic case.

This is due to the change in momentum scale during the fragmentation of c quarks into D mesons.

Due to the much harder fragmentation of the b quarks, no significant difference in the transition is seen between b quarks and B mesons.



Heavy-flavour particle production in toward region with hadron triggers

Summary

- The production of low-momentum heavy flavour in toward region in the events with hadron trigger is mostly determined by the underlying event.
- In the case of charm-jet triggers, the production of heavy flavour is R_T -dependent over the whole p_T range, which is likely an effect of gluon radiation.
- Light-flavour jet triggers allow for the underlying-event dependent analysis of the connection between two hard processes.
- The impact of fragmentation was investigated. We see a p_T shift caused by fragmentation, that is much smaller for the higher-mass b quarks than for the c quarks.
- Our results provide great opportunity for the detailed verification of calculations for light and heavy-flavour production in the jet and the underlying event, and set the base for further model development.

Thank you for attention!

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