Motivation

**Small systems with high-multiplicity (pp collisions)**
- Collectivity of particles observed
- Likely caused by multiple-parton interactions (MPI)

**Heavy quarks:**
- Heavy quarks produced in initial hard processes
- Long lifetime: weak decays into heavy-flavour hadrons ($c\tau \sim 100-400 \mu m$)
- Yield increases strongly with multiplicity: effect of MPI

We can study the relationship between the hard process and the underlying event in high-multiplicity pp collisions.
Definitions

Multi-Parton Interaction (MPI)
- Semi-soft QCD multi-step processes involving several partons
- Increasing with event activity

Leading process
- The parton scattering with the highest momentum exchange

Underlying Event (UE)
- Everything else: secondary hard processes, beam remnants, soft particles from MPI
- Generally considered independent from leading process

Is there connection between the leading process and the UE through MPI?
ALICE: yield of charged particles in pp collisions

Categorize the events by UE activity $\sim$ MPI: $R_T = N_{\text{trans}} / \langle N_{\text{trans}} \rangle$

The yield of charged particles depends a lot of multiplicity: low $p_T$ on Near Side (NS), high $p_T$ on Transverse Side (TS).

The dependence of multiplicity in high $p_T$ on NS shows the connection between the hard process and UE.
Yield of charged pions (hadron trigger)

Simulations settings:
- Pythia 8 SoftQCD (MinBias)
- pp collisions at $\sqrt{s} = 13$ TeV,
- 100 million events
- Trigger particle: $\pi^+, K^+, p/p\bar{p}$, 
  $|\eta| < 0.5$, $p_T^{\text{trigger}} > 5$ GeV/c
- Associated particles: $|\eta| > 0.8$, $p_T > 0.5$ GeV/c

ALICE results qualitatively reproduced.
Yield of D-mesons (hadron trigger)

- The c quark decays to $D^+, D^0, D^{0\bar{b}ar}$

- The yield of D-mesons independent of the activity of UE at high $p_T$.

- D-mesons from low $p_T$ came from UE, because the $p_{T,\text{trigger}} > 5$ GeV/c

The production of D-mesons in leading processes are independent of UE at high $p_T$. 

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Yield of heavy charm particles (hadron-trigger)

The c quark hadronises mostly to D-mesons

- The difference between distribution of c quark and D-meson is 20-25%

<table>
<thead>
<tr>
<th></th>
<th>Average (NS)</th>
<th>St Deviation (NS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>c-quark</td>
<td>9.086</td>
<td>5.94</td>
</tr>
<tr>
<td>D-meson</td>
<td>7.173</td>
<td>4.485</td>
</tr>
</tbody>
</table>

The difference between charm particles is not negligible based on my simulations.
Yield of heavy beauty particles (hadron-trigger)

<table>
<thead>
<tr>
<th></th>
<th>Average (NS)</th>
<th>St Deviation (NS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b-quark</td>
<td>13.00</td>
<td>5.457</td>
</tr>
<tr>
<td>B-meson</td>
<td>12.55</td>
<td>5.318</td>
</tr>
</tbody>
</table>

- The b quark hadronises mostly to B-mesons
- The difference between distribution of b quark and B-meson is 2-4%

The difference between beauty particles is negligible, so we can focus on B-mesons.
Yield of beauty quarks (inclusive trigger)

- Using **parton trigger**: represents the momentum and angle of the jets more precisely than leading hadrons.

- Identifying **jet types** can select particular hard processes.

- On TS the formation of heavy-flavour shows the connection between the hard processes.

The jet-trigger method is suitable for studying the secondary processes, like gluon-splitting.
Yield of beauty quarks (p,q trigger vs b trigger vs u,d,s trigger)

Beauty jet-triggers ensure that b in the TS is from secondary processes:
- It is either an independent, softer b-bbar pair
- Or part of leading b-bbar process in a higher-order 3-jet event

Light jet isolates higher-order b-bbar production from eg gluon-splitting (statistics is a problem here though)

Identified full-jet triggers can isolate soft b-bbar (eg. Gluon-splitting) contribution.
Summary and outlook

- The yield of heavy quarks is independent of UE at high $p_T$
- The yield of reconstructed $B$-mesons are a good proxy for $b$-quarks
- Identified quark-jet triggers reveals the dependence of higher-order heavy-flavor production (eg. gluon splitting) on MPI.

**Future:**

- Looking forward to ALICE Run-3, where statistics will allow for the detailed study of $b$-production w.r.t UE
Thank you for your attention!

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Inclusive trigger

\begin{align*}
\text{b yield NS (parton trigger)} & \\
\text{b yield AS (parton trigger)} & \\
\text{b yield TS (parton trigger)} & \\
\end{align*}

\begin{align*}
\text{b yield NS, Ratio to } R_\text{y-inclusive} & \\
\text{b yield AS, Ratio to } R_\text{y-inclusive} & \\
\text{b yield TS, Ratio to } R_\text{y-inclusive} & \\
\end{align*}
Beauty-quark trigger

$^{\gamma}$ yield NS (beauty quark trigger)

$^{\gamma}$ yield AS (beauty quark trigger)

$^{\gamma}$ yield TS (beauty quark trigger)

$^{\gamma}$ yield NS, Ratio to $R_y$ inclusive

$^{\gamma}$ yield AS, Ratio to $R_y$ inclusive

$^{\gamma}$ yield TS, Ratio to $R_y$ inclusive
Lightquark trigger

b yield NS (light quark trigger)

b yield AS (light quark trigger)

b yield TS (light quark trigger)

b yield NS, Ratio to $R_1$-inclusive
associated b ($b, b'$)

b yield AS, Ratio to $R_1$-inclusive

b yield TS, Ratio to $R_1$-inclusive