Particle production as a function of UE in pp, p-Pb, and Pb-Pb collisions, and search for jet-like modifications

Antonio Ortiz, for the ALICE collaboration
Introduction

- In pp the underlying event (UE) is defined as the set of particles which do not originate from the main parton-parton scattering.

- Three azimuthal regions relative to the particle with the highest transverse momentum ($p_T^{\text{trig}}$) of the event are studied: toward, away, and transverse region.

- Recently, these three regions have been proposed as a tool to investigate the origin of the heavy-ion-like features discovered in small systems:

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This work: results from UE-inspired techniques applied to pp, p-Pb and Pb-Pb collisions are presented.

T. Martin et al., EPJC 76 (2016) 5, 299
A. Ortiz et al., PRD 99 (2019) 3, 034027
S. Weber et al., EPJC 79 (2019) 1, 36
The ALICE detector

Relevant detectors for the present analysis:

**ITS**: primary vertex, pile up rejection, and tracking

**TPC**: tracking

**V0**: triggering, background rejection, and event classification

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### System | $\sqrt{s_{NN}}$ | Statistics (this work)
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pp | 13 TeV | $2 \times 10^8$
pp | 5.02 TeV | $10^8$
p-Pb | 5.02 TeV | $10^8$
Pb-Pb | 5.02 TeV | $10^7$
Analysis as a function of leading transverse momentum ($p_T^{\text{trig}}$)
Average charged-particle density (event activity) as a function of $p_T^{\text{trig}}$:

- $p_T^{\text{trig}} < 5$ GeV/c: in the toward, away, and transverse regions the activity increases by a factor $\sim 10$.

- $p_T^{\text{trig}} > 5$ GeV/c: for the transverse region the activity saturates. For the toward and away regions, still increases.
UE in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

In p-Pb and pp collisions the activity in the transverse region saturates for $p_T^{\text{trig}} > 5$ GeV/c.

However, the relative contribution of the underlying event to the toward and away regions is bigger in p-Pb collisions than in pp collisions.
UE in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

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- This picture is supported by PYTHIA 8 / Angantyr, C. Bierlich et al., JHEP 10 (2018) 134
- EPOS LHC does not reproduce the saturation

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Data/MC, ALICE-PUBLIC-2022-014

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Transverse Region, ALICE Preliminary

ALICE-PUBLIC-2022-014

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QM, 06/04/2022

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Jet-like signals: pp vs p-Pb

The average charged-particle density in the transverse region is subtracted from that in the toward and away regions.
Jet-like signals: pp vs p-Pb

$p_T^{\text{trig}} > 8$ GeV/c: no jet-like modifications are observed

- Within 10%, models describe the data
Jet-like signals: pp vs p-Pb

\[ p_T^{\text{trig}} < 8 \, \text{GeV/c}: \text{the activity is up to 20\% higher in p-Pb than in pp collisions} \]

- PYTHIA 8 shows the opposite behaviour
- EPOS LHC qualitatively describes the data. The effect could be attributed to larger flow in p-Pb relative to pp collisions
UE observables as a function of multiplicity in the transverse region, $N_{ch}^t$
Event properties as a function of $N_{ch}^t$

Based on PYTHIA 8 simulations, in pp collisions with $p_T^{\text{trig}} > 5 \text{ GeV/c}$ the average impact parameter is small

$\langle p_T^{\text{trig}} \rangle$ is independent of $N_{ch}^t$
Event properties as a function of $N_{ch}^t$

Based on PYTHIA 8 simulations, in pp collisions with $p_T^{\text{trig}} > 5$ GeV/c the average impact parameter is small

$\langle p_T^{\text{trig}} \rangle$ is independent of $N_{ch}^t$

But, the UE activity drastically increases with increasing $N_{ch}^t$

We can study the jet-like signals as a function of $N_{ch}^t$ in order to search for any jet-like modification in events with large UE
$N_{\text{ch}}^{t}$ distributions

For pp collisions at $\sqrt{s} = 13$ TeV neither PYTHIA 8 nor EPOS LHC describe the $N_{\text{ch}}^{t}$ distributions
$N^t_{\text{ch}}$ distributions

For pp collisions at $\sqrt{s} = 13$ TeV neither PYTHIA 8 nor EPOS LHC describe the $N^t_{\text{ch}}$ distributions

Observable used $\rightarrow$ self-normalised $N^t_{\text{ch}}$:

$$R_T = \frac{N^t_{\text{ch}}}{\langle N^t_{\text{ch}} \rangle}$$

See Feng Fan’s poster for more details
p/π ratio as a function of \( R_T \)

Transverse region
- \( p_T < 2 \) GeV/c: the ratio exhibits a depletion going from low to high \( R_T \)
- The particle ratios are almost \( R_T \) independent for \( p_T > 2 \) GeV/c
- Qualitatively, PYTHIA 8 reproduces the behaviour of the data
p/π ratio as a function of $R_T$

**Toward Region**

- Low $p_T$: the ratio exhibits a depletion going from low to high $R_T$
- Intermediate $p_T$: the ratio exhibits an enhancement going from low to high $R_T$
- Qualitatively, both PYTHIA 8 and EPOS LHC reproduce the behaviour of the data
Jet-like modifications

The high-$p_T$ yields (4-6 GeV/c) as a function of the activity in the V0 detector were normalised to same quantity measured in minimum-bias pp collisions:

$$I_X = \frac{\frac{dN_{ch}}{dp_T}^{\text{jet-like signal in } X}}{\frac{dN_{ch}}{dp_T}^{\text{jet-like signal in MB pp}}}$$

$X$: multiplicity classes and topological regions in pp, p-Pb and Pb-Pb collisions
Pb-Pb: the $I_X$ values in toward (away) exhibit a suppression (enhancement) relative to MB pp with increasing event activity, similar results were obtained for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV: ALICE, PRL 108 (2012) 092301
Absence of jet-like modifications in pp and p-Pb collisions as a function of the activity in the V0 detector
Conclusions

- The activity in the transverse region as a function of $p_T^{\text{trig}}$ exhibits the same behaviour in pp and p-Pb collisions.

- For $p_T^{\text{trig}} > 8$ GeV/c, the activity in the jet-like signal is the same for pp and p-Pb collisions. For lower $p_T^{\text{trig}}$ values the activity is larger in p-Pb than in pp collisions presumably due to flow. Qualitatively, EPOS LHC describes the data.

- The $I_X$ values, in the toward and away regions, as a function of event multiplicity in the V0 detector, suggest the absence of jet-like modifications in pp and p-Pb collisions. In contrast, Pb-Pb data suggest the presence of jet quenching effects.
Backup
Data analysis

The $p_T$ spectra as a function of either $p_T^{\text{trig}}$ or the particle multiplicity registered in the V0 detector are corrected for detector effects, the relevant corrections are:

- **Tracking efficiency**: this correction considers the real particle composition measured at the LHC energies
- **Contamination from secondary particles**: this correction is estimated using a multi-template model which is fitted to the distance-of-closest approach distributions measured in data
- For the UE analysis a correction which takes into account the leading track misidentification is implemented. This correction is relevant for $p_T^{\text{trig}} < 5 \text{ GeV}/c$

In addition, for the transverse momentum spectra in the toward, away, and transverse regions, as a function of the charged particle multiplicity in the transverse region ($N_{\text{ch}}^t$), a Bayesian unfolding technique is implemented in order to correct for the $N_{\text{ch}}^t$ selection
Particle ratios as a function of $R_T$

**Toward Region**

- $p_T^{leading} \geq 5$ GeV/c
- $2.5 \leq R_T < 5.0$
- $0.0 \leq R_T < 0.5$

**Transverse Region**

- $p_T^{leading} \geq 5$ GeV/c
- $2.5 \leq R_T < 5.0$
- $0.0 \leq R_T < 0.5$

**ALICE Preliminary**

- pp. $\sqrt{s} = 13$ TeV
- $p_T \geq 0.15$ GeV/c, $|\eta| < 0.8$

**Models**

- PYTHIA 8 (Monash 2013)
- EPOS-LHC
Jet-like signals: pp vs p-Pb

Within uncertainties, the average transverse momentum is the same in pp and p-Pb collisions within the full $p_T^{\text{trig}}$ interval.

- Within 20% PYTHIA 8/Angantyr and EPOS LHC describe the data.
- A similar behaviour is seen in both the toward and away regions.
If the fragmentation function is softened in the medium, hadrons carry a smaller fraction of the initial parton momentum in Pb-Pb collisions as compared to pp collisions. Therefore, hadrons with a given $p_T$ originate from a larger average parton momentum which may lead to more associated particles and $I_{AA} > 1$.

ALICE, PRL 108 (2012) 092301
$p_T$ spectra as a function of $R_T$ (pp)

For the toward and away regions, the yields approach to the values measured for the $R_T$-integrated case. This behaviour is reproduced by MC generators. This suggests the absence of jet-like modifications.

$p_T > 4$ GeV/c:
- For the transverse region, the high-$p_T$ yield exhibits a fast increase with increasing $R_T$ due to the selection bias. The effect is reproduced by MC generators.
$p_T$ spectra as a function of $R_T$ ($p$-Pb)

For the toward and away regions, the yields approach to the values measured for the $R_T$-integrated case. This behaviour is reproduced by MC generators. This suggests the absence of jet-like modifications.

A similar behaviour is found for $p$-Pb collisions.

$p_T > 4$ GeV/c:

- For the toward and away regions, the yields approach to the values measured for the $R_T$-integrated case. This behaviour is reproduced by MC generators. This suggests the absence of jet-like modifications.