Particle production as a function of UE activity measured with ALICE at the LHC

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for the ALICE Collaboration
At LHC high collision energies -> significant contributions from hard processes

- pQCD precise calculations

Nevertheless particle production dominated by **soft-QCD** processes $p_T \sim$ few GeV

- non perturbative phenomenology
- modelling
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**Underlying Event**

- Multiple parton interactions (MPI): more than one hard scattering
- semi-hard + soft interactions (ISR/FSR and beam remnants)

Figure adapted from Eur.Phys.J. C62 (2009) 237-242

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Motivation

\( p_T \) spectra versus multiplicity

Midrapidity multiplicity selection \( \rightarrow \) particle production above 0.8 GeV/c increases with increasing multiplicity

\( \frac{d^2 N_{\text{ch}}}{dp_T^2} \frac{dN}{dp_T} \) (GeV/c)^{-1}

Ratio to INEL>0

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ALICE pp

Uncorr. syst. unc.

Stat. unc.

Total syst. unc.
Motivation

\(p_T\) spectra versus multiplicity

Midrapidity multiplicity selection →
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The effect is reduced using a forward multiplicity estimator → but still visible
Motivation

\( p_T \) spectra versus multiplicity

Midrapidity multiplicity selection \( \rightarrow \) particle production above 0.8 GeV/c increases with increasing multiplicity

The effect is reduced using a forward multiplicity estimator \( \rightarrow \) but still visible

- Is it due to the presence of jets which bias the selection?
- Could a jet free multiplicity estimator help to understand the correlation between low and high \( p_T \) particle production?

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Non-linear heavy-flavour and high-$p_T$ particle production increase with multiplicity

- effect of multiplicity saturation?
- interplay between multiplicity fluctuations of individual parton interactions and decrease of MPI?

Motivation

Multiplicity dependence studies

ALICE

JHEP 1509 (2015) 148
arXiv:1905.07208
Motivation

Multiplicity dependence studies

Non-linear heavy-flavour and high-$p_T$ particle production increase with multiplicity

- effect of multiplicity saturation?
- interplay between multiplicity fluctuations of individual parton interactions and decrease of MPI?

Could a jet free multiplicity estimator help to understand soft QCD dynamics?

ALICE, pp

J/ψ → e⁺e⁻, |y|<0.9
ś=13 TeV, Preliminary

J/ψ → e⁺e⁻, |y|<0.9
ś=7 TeV, PLB 712 (2012) 165

D, |y|<0.5, 2<p_T<4 GeV/c
ś=7 TeV, JHEP 1509 (2015) 148

ALICE pp (ś = 13 TeV)
SPD tracklets mult. estimator

Data
PYTHIA 8
EPOS LHC

Stat. unc.
Uncorr. syst. unc.

Ratio

JHEP 1509 (2015) 148
arXiv:1905.07208

ALI-PREL-126584
The ALICE detector
18 different detector systems
- high-momentum resolution
- excellent PID

Trigger and event characterisation detectors

solenoidal magnet: 0.5 T
A Large Ion Collider Experiment

- 18 different detector systems
- high-momentum resolution
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Data-taking detectors

Tracking

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Vertexing

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Data-taking detectors
- Tracking
- Vertexing

PID

solenoidal magnet: 0.5 T

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$\langle \rho_T \rangle$ vs multiplicity
Unfolding of $p_T$ spectra

The correlation between $N_{ch}$ and $p_T$ is experimentally unknown (biased by acceptance and secondaries)
Unfolding of $\rho_T$ spectra

The correlation between $N_{ch}$ and $\rho_T$ is experimentally unknown (biased by acceptance and secondaries)

- high resolution response matrix available from MC
- benefit from unfolding application from Bayes’ theorem

Energy and system–size dependence

Energy dependence of $<p_T>$ versus multiplicity in pp collisions

- $<p_T>$ increases with increasing multiplicity for higher energy

**New Results**

![Graph showing the energy dependence of $<p_T>$ versus multiplicity in pp collisions.](image)
Energy and system–size dependence

Energy dependence of $<p_T>$ versus multiplicity in pp collisions
- $<p_T>$ increases with increasing multiplicity for higher energy

System-size dependence of $<p_T>$ versus multiplicity results
Energy and system–size dependence

Energy dependence of $<p_T>$ versus multiplicity in pp collisions
- $<p_T>$ increases with increasing multiplicity for higher energy

System-size dependence of $<p_T>$ versus multiplicity results
- possibility to reach higher $N_{ch}$ to study the full shape thanks to unfolding

New Results

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$p_T$ spectra vs UE activity
A jet–free multiplicity estimator

What is $R_T$?

We look for a variable that
1. is not influenced by the initial hard parton scattering
2. can discriminate among soft and hard events
A jet–free multiplicity estimator

What is $R_T$?

We look for a variable that
1. is not influenced by the initial hard parton scattering
2. can discriminate among soft and hard events

- define the relative transverse activity classifier $R_T$ in the plateau region (jet pedestal)

$$R_T = \frac{N_{\text{inclusive}}}{\langle N_{\text{inclusive}} \rangle}$$

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$R_T$ is a measure of the relative transverse activity in the plateau region (jet pedestal). It is defined as the ratio of the multiplicity of inclusive events to the average multiplicity of inclusive events. This variable is used to study the balance between soft and hard events in the transverse region of the event.
A jet–free multiplicity estimator

$R_T$ distribution

Selection done in:

- transverse multiplicity
- plateau region $5 < p_T^{\text{leading}} < 40$ GeV/c

New Results
A jet–free multiplicity estimator

$R_T$ distribution

Selection done in:

- transverse multiplicity
- plateau region $5 < p_T^{\text{leading}} < 40$ GeV/c
- several $R_T$ bins to allow to distinguish among low and high UE activity
Transverse $p_T$ distributions

Comparison to inclusive transverse spectra

- clear $p_T$ hardening at high multiplicity in the transverse region $\rightarrow$ same trend observed for the midrapidity-based multiplicity estimator

N.B.: The figure has been updated after the conference to account for a change in the normalisation factor of the $R_T$-integrated $p_T$ spectrum for the transverse region

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Transverse $p_T$ distributions

Comparison to inclusive transverse spectra

- clear $p_T$ hardening at high multiplicity in the transverse region → same trend observed for the midrapidity-based multiplicity estimator

- measurement ($p_T$) and selection (multiplicity) are done in the same pseudorapidity region

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New Results
Comparison to inclusive toward spectra

- If the multiplicity is determined in the transverse region, the spectra in the toward (jet) region clearly show the opposite trend.
Toward $p_T$ spectra distributions

Comparison to inclusive toward spectra

- If the multiplicity is determined in the transverse region, the spectra in the toward (jet) region clearly show the opposite trend

- we observe convergence to the jet:
  - complete separation among soft (UE) and hard (jet) part of the event at high $p_T$
  - correlation effects are significantly reduced
$R_T$ dependence for transverse and toward

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\( R_T \) dependence for transverse and toward

- yield in transverse vs \( R_T \)
- same behavior observed using the midrapidity–based multiplicity estimator

New Results

ALICE preliminary
pp, \( \sqrt{s} = 13 \text{ TeV} \)
\(|\eta| < 0.8, 2 < p_T < 4 \text{ GeV/c} \)
\(5 < p_{T,\text{leading}} < 40 \text{ GeV/c} \)

- Transverse
- Toward

PYTHIA 8 (Monash 2013)

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ALICE
arXiv:1905.07208

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- Transverse
- Toward

PYTHIA 8 (Monash 2013)
$R_T$ dependence for transverse and toward

- yield in toward vs $R_T$
  - does not converge to 0
    - at $R_T = 0$ we can have a jet
    - possibility to study hard object with almost no UE activity!
$R_T$ dependence

for transverse and toward

- yield in toward vs $R_T$
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  - it is linear
    - not the same as heavy flavours!

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- PYTHIA 8 (Monash 2013)
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  - it is linear
    - not the same as heavy flavours!
  - PYTHIA 8.2 reproduces well the observed trends

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- Transverse
- Toward

PYTHIA 8 (Monash 2013)
Summary and outlook

- \( <p_T> \) vs multiplicity:
  - high resolution energy and system-size study capabilities due to unfolding

- Transverse \( p_T \) spectra:
  - hardening at high multiplicity \( \rightarrow \) confirms the trend observed using the midrapidity multiplicity estimator

- Toward \( p_T \) spectra:
  - separation among soft (UE) and hard (jet) part of the event, at high \( p_T \)
  - no \( R_T \) saturation \( \rightarrow \) no autocorrelation effects at play!
  - still possible to have a jet at \( \sim 0 \) UE activity
    \( \rightarrow \) unique opportunity to relate to elementary systems like \( e^+e^- \)
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  - still possible to have a jet at $\sim 0$ UE activity
    $\rightarrow$ unique opportunity to relate to elementary systems like $e^+e^-$
    
    $R_T$ is an effective instrument to disentangle jet and UE components of the spectra

$\rightarrow$ Promising for identified particle yields study, both for light and heavy flavours
Backup slides