Transverse Momentum Spectra of Charged Particles Measured with ALICE

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Interesting in many ways...

- Bulk particle production still challenge for (non-perturbative) QCD
- $pp$ data as reference for heavy ion collisions
- Transverse momentum spectra crucial to understand soft QCD
- Here:
  - different multiplicities
  - as function of energy


CDF

$|n|\leq1$ and $p_T \geq 0.4$ GeV/c

Pythia hadron level:
- TuneA no MPI
- TuneA $\hat{p}_T = 0$
- TuneA $\hat{p}_T = 1.5$
- ATLAS tune
**ALICE – setup**

**Inner Tracking System**

**Time Projection Chamber**

**ITS** and **TPC** detectors used in present analysis of $p_T$ spectra.
Event Selection

- Min Bias Trigger
  - SPD or V0A or V0C
- Beam background rejection
  - SPD and V0
- Event and track selection
  - ITS + TPC

(full tracking, $|\eta| < 0.8$)
$2.67 \times 10^5$ pp events
$\sqrt{s} = 900$ GeV
momentum resolution (from matching of two segments of cosmic track)

- \( \Delta p_t / p_t \approx 7\% \) at 10 GeV/c

ALICE performance work in progress

- present \( p_T \) resolution
- 7\% at 10 GeV/c
- below 1\% at \( p_T < 1 \) GeV/c
- confirmed by \( K^0_s \) measurements
ITS alignment

alignment with cosmic tracks

SPD alignment:
- $\sigma_\phi \approx 14 \, \mu m$
- impact parameter resolution $\sigma \sim 50 \, \mu m$
- misalignment $< 10 \, \mu m$

- close to design values

alignment with pp data ongoing
TPC dE/dx resolution:
5.5% (= design value!)

TPC particle ID used for track propagation through material and $p_T$ reconstruction.
MC corrections rely on detailed knowledge of material budget

- Efficiency correction (particle absorption)
- Contamination correction (γ conversion, protons, ...)
- Energy loss corrections (10% for 0.2 GeV/c pions)

**Agreement between MC and Data within 10%.**
Efficiency and Contamination

Efficiency of the primary track selection

Contamination by secondary tracks

PYTHIA
## Systematic Uncertainties

<table>
<thead>
<tr>
<th>$p_T$ range (GeV/c)</th>
<th>$\frac{1}{N_{\text{evt}} \frac{d^2N_{\text{ch}}}{dy dp_T}}$</th>
<th>$0.5 - 4$</th>
<th>$0.15 - 4$</th>
<th>$0 - 4$ (extrap.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track selection cuts</td>
<td>0.2-4%</td>
<td>negl.</td>
<td>0.3%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Contribution of diffraction (INEL)</td>
<td>0.9-1%</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>Contribution of diffraction (NSD)</td>
<td>2.8-3.9%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Event generator dependence (INEL)</td>
<td>2.5%</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>Event generator dependence (NSD)</td>
<td>0.5%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Particle composition</td>
<td>1-2%</td>
<td>0.1%</td>
<td>negl.</td>
<td>0.1%</td>
</tr>
<tr>
<td>Secondary particle rejection</td>
<td>0.2-1.5%</td>
<td>negl.</td>
<td>0.1%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Detector misalignment</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>ITS efficiency</td>
<td>0-1.6%</td>
<td>negl.</td>
<td>0.3%</td>
<td>0.5%</td>
</tr>
<tr>
<td>TPC efficiency</td>
<td>0.8-4.5%</td>
<td>negl.</td>
<td>0.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>SPD triggering efficiency</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>VZERO triggering efficiency (INEL)</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>VZERO triggering efficiency (NSD)</td>
<td>0.2%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Beam-gas events</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>Pile-up events</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
<td>negl.</td>
</tr>
<tr>
<td>Total (INEL)</td>
<td>3.0-7.1%</td>
<td>0.1%</td>
<td>0.7%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Total (NSD)</td>
<td>3.5-7.2%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>$R$ weighting procedure</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
<td></td>
</tr>
<tr>
<td>Extrapolation to $p_T = 0$</td>
<td>-</td>
<td>-</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3.0%</td>
<td>3.1%</td>
<td>3.3%</td>
<td></td>
</tr>
</tbody>
</table>
p_T Spectra
Fit by modified Hagedorn function
For extrapolation to $p_T=0$

\[
\frac{1}{2\pi p_T} \frac{d^2N_{ch}}{d\eta \, dp_T} \propto \frac{p_T}{m_T} \left(1 + \frac{p_T}{p_{T,0}}\right)^{-b}.
\]

$p_{T,0} = 1.05 \pm 0.01 \, \text{(stat.)} \pm 0.05 \, \text{(syst.)} \, \text{GeV}/c$
$b = 7.92 \pm 0.03 \, \text{(stat.)} \pm 0.02 \, \text{(syst.)}$.

Fit by power law function for $p_T > 3 \, \text{GeV}/c$

\[
\frac{1}{2\pi p_T} \frac{d^2N_{ch}}{d\eta \, dp_T} \propto p_T^{-n},
\]

$n = 6.63 \pm 0.12 \, \text{(stat.)} \pm 0.01 \, \text{(syst.)}$.

\( \frac{dN_{\text{ch}}}{dp_T} \) – comparison to experiments

- good agreement at \( p_T < 1 \text{ GeV/c} \)
- ALICE spectrum harder at higher \( p_T \)
- UA1 sees higher yield at low \( p_T \)
$<p_T>$ - energy dependence

- ALICE sees larger $<p_T>$ than other experiments with larger $\eta$ acceptance at 900 GeV
- similar trend also observed
  - at Tevatron
  - in $\eta$ bins of CMS data
  - in PYTHIA

$$<p_T>_{INEL} = 0.483 \pm 0.001 \text{ (stat.)}$$
$$\pm 0.007 \text{ (syst.) GeV/c.}$$

$$<p_T>_{NSD} = 0.489 \pm 0.001 \text{ (stat.)}$$
$$\pm 0.007 \text{ (syst.) GeV/c.}$$
\( \frac{dN_{\text{ch}}}{dp_T} \) – comparison to MC

- PYTHIA D6T and Perugia0 describe shape reasonably well but fail in the yield
- PHOJET and ATLAS-CSC are off
Multiplicity Dependence
<p><span style="text-align: center;" label="caption">ALICE, pp, INEL</span><br><span style="text-align: center; font-size: smaller;">√s = 900 GeV, |η| < 0.8</span></p>

Fits of $\frac{1}{p_T} \frac{d^2N_{ch}}{dηdp_T} \propto p_T \frac{m_T}{p_T} \left(1 + \frac{p_T}{p_{T,0}}\right)^{-n}$

in bins of multiplicity
$<p_T>$ vs multiplicity

$p_T > 500$ MeV/c:
weighted average over data points $0.5 < p_T < 4$ GeV/c

$p_T > 150$ MeV/c:
weighted average over data points $0.15 < p_T < 4$ GeV/c

$p_T > 0$:
weighted average over data points $0.15 < p_T < 4$ GeV/c, combined with result from fit at $p_T < 0.15$ GeV/c
\[ N_{\text{meas}} \rightarrow N_{\text{true}} \]

- Transition not trivial
- Cross checks:
  - PYTHIA
  - PHOJET
  - Unfolding of matrix
- Edge effects to be considered

\[
\langle p_T \rangle (n_{ch}) = \sum_{n_{acc}} \langle p_T \rangle (n_{acc}) \cdot R(n_{ch}, n_{acc})
\]
$\langle p_T \rangle$ vs multiplicity

from measured to true multiplicity (employing MC)
\(<p_T> vs \text{ multiplicity} – \text{ comparison to MC}\)

- \(p_T>500 \text{ MeV/c}:
  - PYTHIA Perugia0 gives good description of the data

- \(p_T>150 \text{ MeV/c}:
  - all models fail
  - (Perugia0 is still best)
Reminder: $dN_{ch}/d\eta$

- PYTHIA D6T and Perugia-0 don’t match at any energy.
- Pythia ATLAS-CSC and PHOJET reasonably close at 0.9 and 2.36 TeV.
- only ATLAS-CSC close at 7 TeV.
Monte Carlo

PYTHIA D6T and Perugia0

None of the MC’s do really well

ATLAS-CSC and PHOJET
Summary

• Primary charged particle transverse momentum spectrum
• Mean transverse momentum for pp collisions at $\sqrt{s} = 900$ GeV

• Good agreement with previous results from LHC up to $p_T = 1$ GeV/c
• At higher $p_T$, harder momentum spectrum than other measurements at same energy -> different pseudorapidity intervals

• None of models and tunes describe $p_T$ spectrum and correlation between $<p_T>$ and $n_{ch}$

• In low $p_T$ region, where the bulk of the particles are produced, the models require further tuning
Outlook and Questions

- Data will be used as baseline for heavy ion measurements
- Need for good energy scaling
- What do we learn on soft QCD rather than only modifying parameters?
- What are the implications on HI predictions?