Measurements of Particle Production in pp-Collisions in the Forward Region at the LHC

Introduction

Particle Multiplicities
  Preliminary results New!

Particle Production
  Final results

Summary
Particle multiplicities and particle production measurements are important input for tuning of event generators and modelling of the underlying event. Good understanding of soft QCD processes is required for extracting many important measurements at the LHC.

The LHCb detector has a unique forward coverage in the pseudorapidity range of $2<\eta<5$.

The LHCb measurements are compared to different event generators and tunings.
The LHCb Detector

- Single arm forward spectrometer made for high precision measurements of CP violation and rare decays in the beauty and charm sector
- Excellent tracking and vertexing
  - VELO, 8mm distance to beam, impact parameter resolution ~15\(\mu\)m (high \(p_T\))
- Unique Hadron PID
  - Two Rich detectors exploiting 3 radiators

Data: from early 2010, low luminosity running of LHC
- low pile-up
- low trigger thresholds (at least one track reconstructed in the event)  
  \(\Rightarrow\) no or small corrections
Particles are counted by reconstructing tracks in the VELO

- high and uniform efficiency, closest to interaction point (minimal material), partial backward coverage
- outside main magnetic field, no momentum measurement

Measurement of Particle Multiplicities
Particles are counted by reconstructing tracks in the VELO

- high and uniform efficiency, closest to interaction point (minimal material), partial backward coverage
- outside main magnetic field, no momentum measurement
Definition of prompt charged particles at generator level:

- \((e, \mu, \pi, K, p)\) excluding particles from \(K_s\) or hyperon decays.
- Proper lifetimes of all mother particles \(\sum \tau < 10\)ps

Tracks are required to originate from luminous region.

- Correction for remaining non-prompt particle contamination, (5-10)\%, mainly tracks from converted photons is taken from MC. Assume scaling with charged particle multiplicity, sys. error: 1%.

No explicit momentum cut

- Due to residual magnetic field and multiple scattering, efficiency drops towards very low momentum \(\Rightarrow\)
- Using predictions of different event generators, about \(~1\)% of particles are lost. Contained in the efficiency correction

Distributions need to be corrected for a small pile-up contamination

- \((3.7\pm0.4)\)% of the events have more than one interaction.
Event particle multiplicities are obtained by unfolding migrations due to reconstruction inefficiencies with fits to a sum of binomial distributions:

- Observed distribution: events with \( k \) tracks with probability \( f(k) \):

\[
f(k) = \sum_{i=0}^{\infty} a_i \times \binom{N}{k} (1 - \varepsilon)^{N-k} \varepsilon^k
\]

- Weight \( a_i \) of each binomial distribution corresponds to the probability for the original particle multiplicity to occur. \( \varepsilon \) taken from MC and cross checked with data.

Procedure verified with MC simulations:

- Reconstructed and corrected particle multiplicity distribution reproduces generated distribution

Systematic error:

- Change of \( \varepsilon \) by \( \pm 4\% \)
Results: Charged Particles vs \( \eta \)

Normalized to events with at least one charged particle in the forward acceptance, \( 2.0 < \eta < 4.5 \)

- Data points systematically above generator predictions
  - LHCb Pythia tune comes closest to data
- Monte Carlo Pythia tunes include diffractive processes
Charged Particle per Event Multiplicities

Normalized to number of events with at least one charged particle in the related $\eta$ range

Pythia6 default and Perugia0 are far off from the data points

$\sqrt{s} = 7$ TeV
Charged Particle per Event Multiplicities

Hard interactions: require at least one charged particle with $p_T>1\text{GeV/c}$ in $2.5<\eta<4.5$

Good agreement between Pythia6 (NOCR, AMBT1) tune and data.
Preliminary Results: Charged Particle Multiplicities

Data (hard events) compared to LHCb Pythia tune: Good agreement.

Thomas Ruf, CERN
Forward Particle Production with LHCb
EPS-HEP, Grenoble, 2011
Small $\eta$ intervals fit well with single negative binomial function, full range requires 2 NBD.

$$P(n) = \frac{(n+k-1)!}{n!(k-1)!} p^k (1 - p)^n, \quad p = \frac{k}{k + \text{mean}}$$

- $\eta$: 2.25 – 4.25
- $k$: 1.1 – 1.4
- $\text{mean}$: 3.1 – 2.5
- $k \ast \text{mean} \approx 3.4$
\[ z = \frac{n_{\text{ch}}}{<n_{\text{ch}}>} \], expected to scale with energy. \(<n_{\text{ch}}>\) taken from negative binomial fit.

Clearly shows that distributions in each \( \eta \)-range are self-consistent.

Will be interesting to see these distributions at higher \( E_{\text{cm}} \).
$V^0$ Production Studies
Study of baryon number transport in pp-collisions to final state hadrons and baryon vs. meson suppression in hadronization at two different energies:

\[
\frac{\bar{\Lambda}}{\Lambda} = \frac{\sigma(pp \rightarrow \bar{\Lambda}X)}{\sigma(pp \rightarrow \Lambda X)}
\]

\[
\frac{\bar{\Lambda}}{K_S^0} = \frac{\sigma(pp \rightarrow \bar{\Lambda}X)}{\sigma(pp \rightarrow K_S^0 X)}
\]

\[
\Delta y = y_{\text{beam}} - y
\]

\[
y_{\text{beam}} = 6.9 \text{ at } 0.9 \text{ TeV} \\
8.9 \text{ at } 7 \text{ TeV}
\]
Extreme Perugia NOCR favoured for $\bar{\Lambda}/\Lambda$ at high rapidity

For $\sqrt{s} = 0.9$ TeV:

- LHCb Data
- LHCb MC
- Perugia 0
- Perugia NOCR

For $\sqrt{s} = 7$ TeV:

- LHCb Data
- LHCb MC
- Perugia 0
- Perugia NOCR

Rapidity
Inclusive $\phi$ Production
Inclusive $\phi$ Production

Underestimated by Pythia Perugia 0 and LHCb tune

Integrated cross section for $(0.6 \text{ GeV/c} < p_T < 5.0 \text{ GeV/c})$ and $(2.44 < y < 4.06)$:

$$\sigma(pp \rightarrow \Phi X) = 1758 \pm 19_{\text{stat}}^{+43}_{-14_{\text{syst}}} \pm 182_{\text{syst}} \mu b$$

Mean $p_T$: 1.24 $\pm$ 0.01 GeV/c (*data*) ; 1.238 $\pm$ 0.002 GeV/c (*Perugia 0 MC*)
Particle multiplicities and particle production in the forward region are studied with the LHCb detector

- Charged particle production is underestimated in most generator tunings
  - The LHCb Pythia tune describes the observed particle multiplicities best
  - Differences become smaller for hard interactions
- The ratio $\bar{\Lambda}/\Lambda$, measuring baryon number transport, is smaller in data than predicted in simulation, particularly at high rapidity.
- The ratio $\bar{\Lambda}/K_S$, measuring baryon-to-meson suppression, is significantly larger than predicted at $\sqrt{S} = 0.9$ TeV and $\sqrt{S} = 7$ TeV
- $\phi$ production is largely underestimated by the event generators
Non default {PYTHIA} parameters in the LHCb simulation software

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Perugia0 corresponding {PYTHIA} parameters

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{PARP}(82): UE IR cutoff at reference ecm, {Pythia} 0: 3.4  {Pythia} NOCR: 3.19
{PARP}(89): Reference ecm
{PARp}(90): UE IR cutoff ecm scaling power