Inclusive particle production at LHCb

Markward Britsch for the LHCb Collaboration

Max-Planck-Institut für Kernphysik, Heidelberg

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Outline

1. Introduction
2. Charged particle multiplicity
3. Hadron production ratios
4. Strange particle production
5. Summary
The LHCb detector is optimized for \( b \)-physics and excellent also for charm and light flavor physics. Its unique kinematic range is \( 2 < \eta < 5 \), down to \( p_T \approx 0 \).

- Excellent vertex resolution (VELO)
- Particle identification (RICH: \( \pi/K/p \), ECAL: \( e/\gamma \), MUON)
- Trigger used in analyses in this talk: trigger with minimal bias

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Inclusive particle production

2012-3-28 3 / 23
Inclusive particle production

Important input to models:
- tuning of event generators
- modeling of underlying event
- forward region especially interesting
- test of particle production
- test hadronization
- baryon number transport

Not covered here:
Heavy flavors, energy flow, electro-weak

Charged particle multiplicities, overview

- **primary charged particles:**
  directly produced in $pp$-collision, or from short lived decays

- **use VELO** (Silicon Vertex Detector)
  - uniform acceptance and high efficiency coverage:
    \[ 2 < \eta < 4.5 \quad \text{(forward)} \]
    \[ -2.5 < \eta < -2 \quad \text{(backward)} \]
  - no magnetic field
    - tracks are straight lines
    - no explicit momentum cut
    - but no momentum measurement

- **low material budget**

- **dataset:**
  - low luminosity running phase in 2010 \( \rightarrow \) low pile up (3.7 %)
  - $1.5 \cdot 10^6$ $pp$ events of each magnet polarity at $\sqrt{s} = 7$ TeV
Charged particle multiplicities, method

- to select **primary particles** from \( pp \)-collision:
  - cut on minimal track distance to beam line
  - particles from "luminous region" in beam line direction

- suppress fake tracks (ghosts & clone tracks) by track quality cuts

- corrections applied to data:
  - **per event background correction**:
    - remaining fake tracks (linear dependency on occupancy)
    - remaining non-prompt particles (gamma conversions, \( V^0 \)s)
  - **efficiency correction** for particle multiplicity:
    - unfolding to correct for migrations due to reconstruction efficiency
  - correct for the small pile up

- main systematics: tracking efficiencies (4 %)
  - obtained by combining data and MC driven methods
Particle multiplicities

Multiplicity distribution in forward range \((2 < \eta < 4.5)\)

Only events with at least one track in forward range accepted

- all generators underestimate charged particle multiplicity
- excluding diffractive processes in PYTHIA improves result

LHCb-PAPER-2011-011
Particle densities $\rho$ per event versus pseudorapidity

Only events with $\geq 1$ tracks in forward direction accepted ($2 < \eta < 4.5$) (in data and MC)

- charged particle density larger than in standard MC prediction
- models without diffractive processes: better quantitative description but shape not well reproduced
Particle multiplicities – hard interactions

Multiplicity distribution in forward range ($2 < \eta < 4.5$) for hard events

**l.e.,** at least one high $p_T$-track w/ $p_T > 1$ GeV in forward range

- hard events **better described** by MC
- best agreement with **PYTHIA** in LHCb & NOCR tuning

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Prompt hadron production ratios, method

Ratios like: $\frac{\bar{p}}{p}$, $\frac{K^-}{K^+}$, $\frac{\bar{p} + p}{K^- + K^+}$, $\frac{K^- + K^+}{\pi^- + \pi^+}$, ...

- probes baryon transport where protons are involved
- measurements performed at $\sqrt{s} = 900$ GeV (0.3 nb$^{-1}$) and $\sqrt{s} = 7$ TeV (1.8 nb$^{-1}$)
- prompt particles with $p > 5$ GeV selected with PID requirements
- largest systematic error: PID efficiencies
- efficiency and purity of PID evaluated on data using tag and probe method on: $\phi \rightarrow K^+ K^-$, $K_s^0 \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow \pi p$

Measurements are done in 3 bins of $p_T$ (0; 0.8; 1.2 GeV) and 4 equally sized bins of $\eta$ in $2.5 < \eta < 4.5$ ($p_T < 0.8$: $3 < \eta < 4.5$)
cross contamination effect due to PID misidentification
  - taken from calibration sample
  - in bins of $p_T$, $\eta$
  - for each magnet polarity and particle/anti-particle separately

PID efficiency reweighted according to track multiplicity

- e.g., for $p_T > 1.2$ GeV, $\eta > 3$:
  - protons: purities > 90%, efficiencies > 95%
  - kaons: purities > 90%, efficiencies > 80%

correction of particle losses due to interaction with material
  - extracted from MC
  - in bins of $p_T$, $\eta$
  - for each magnet polarity and particle/anti-particle separately
Prompt hadron production ratios

\( \frac{\bar{p}}{p} \), \( \sqrt{s} = 900 \text{ GeV} \)

\( \frac{\bar{p}}{p} \), \( \sqrt{s} = 7 \text{ TeV} \)

LHCb-PAPER-2011-037 (in preparation)
rapidity loss $\Delta y = y_{\text{beam}} - y$, to compare data from different $\sqrt{s}$
no evidence of significant $p_T$ or $\sqrt{s}$ dependency
consistent w/ previous experiments, significantly more precise
Prompt hadron production ratios

$LHCb$ Preliminary = 0.9 TeVs
$< 0.8 \text{ GeV/c}$
$p_T \leq 0.0$

$LHCb$ Preliminary = 7 TeVs
$< 0.8 \text{ GeV/c}$
$p_T \leq 0.0$

$LHCb$ Preliminary

\[ \frac{K^-}{K^+}, \; \sqrt{s} = 900 \text{ GeV} \]

\[ \frac{K^-}{K^+}, \; \sqrt{s} = 7 \text{ TeV} \]

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Prompt hadron production ratios

$\frac{\pi^-}{\pi^+}$, $\sqrt{s} = 900$ GeV

$\frac{\pi^-}{\pi^+}$, $\sqrt{s} = 7$ TeV

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Prompt hadron production ratios

\[ \frac{\bar{p} + p}{K^- + K^+}, \sqrt{s} = 900 \text{ GeV} \]

\[ \sqrt{s} = 7 \text{ TeV} \]

\[ 0.0 \leq p_T < 0.8 \text{ GeV} \]
\[ 0.8 \leq p_T < 1.2 \text{ GeV} \]
\[ p_T \geq 1.2 \text{ GeV} \]

LHCb-PAPER-2011-037 (in preparation)
Prompt hadron production ratios

\( \frac{p+p}{\pi^- + \pi^+} \), \( \sqrt{s} = 900 \text{ GeV} \)

\( \frac{p+p}{\pi^- + \pi^+} \), \( \sqrt{s} = 7 \text{ TeV} \)

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Inclusive particle production
Prompt hadron production ratios

$K^- + K^+ \over \pi^- + \pi^+ , \sqrt{s} = 900 \text{ GeV}$

$K^- + K^+ \over \pi^- + \pi^+ , \sqrt{s} = 7 \text{ TeV}$
Strangeness – production ratios

- testing baryon number transport from \( pp \) to final state
- same data used as in previous analysis
- no PID used
- largest systematic uncertainty: interaction with material

Graph by Peter Skands

\[
\begin{align*}
\chi^2/\text{ndf} &= 3.4/9.0 \\
P &= 0.9462
\end{align*}
\]

LHCb
\( \sqrt{s} = 0.9 \, \text{TeV} \)

\( (\Lambda/\bar{\Lambda})_{\text{Data}} / (\Lambda/\bar{\Lambda})_{\text{MC}} \)

Material traversed \([X_0]\)
Strangeness – production ratio $\frac{\Lambda}{\bar{\Lambda}} = \frac{\sigma(pp\rightarrow\Lambda X)}{\sigma(pp\rightarrow\bar{\Lambda} X)}$

- PV requirement results in small diffractive contribution in data
- only agreement with Monte Carlo at low rapidity
- larger rapidities: extreme baryon transport (NOCR) favored

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Inclusive particle production

Strangeness – production ratio \( \frac{\Lambda}{K_s} = \frac{\sigma(pp \rightarrow \Lambda X)}{\sigma(pp \rightarrow K_s^0 X)} \)

Baryon-to-meson suppression in strange quark hadronization

- both energies: production ratio much larger than in MC
- similar size of the effect in both energies

\( \Rightarrow \) baryon/meson suppression lower than expected

\( \sqrt{s} = 900 \text{ GeV} \)

\( \sqrt{s} = 7 \text{ TeV} \)
Inclusive $\phi$ production

- measure $\phi$ meson cross-section in $pp$ collisions at $\sqrt{s} = 7$ TeV
- dataset: 14.7 nb$^{-1}$ collected
- $\phi \rightarrow K^+ K^-$ mass window: $995 \text{ MeV} < m_\phi < 1045 \text{ MeV}$

$\Rightarrow$ simulations underestimate $\phi$ production in measured range
inclusive cross-section ($0.6 \text{ GeV} < p_T < 5.0 \text{ GeV}, 2.44 < y < 4.06$):

$$\sigma_{pp\rightarrow\phi X} = 1758 \pm 19\text{(stat)}^{+43}_{-14}\text{(syst)} \pm 182\text{(scale)} \mu\text{b}$$
Summary and outlook

- **LHCb** is an excellent environment for particle production measurements in forward region.
- Charged particle multiplicities underestimated by MC generators, better description of hard events (esp. NOCR and LHCb tunes).
- Particle production ratios not well described by simulations.
  - Light flavor hadron ratios need MC-tuning: best described by NOCR and LHCb tunes.
  - Models underestimate baryon number transport, esp. at 900 GeV:
    - Low $\eta$: standard tunes agree with data, high $\eta$: NOCR fits data better.
    - Baryon/meson suppression is much lower than expected.
- $\phi$ meson production largely underestimated by models.

Outlook:

- $\sqrt{s} = 2.76$ TeV data on disk.
- $\sqrt{s} = 8$ TeV data to be taken soon.
Start backup slides

Backup
Non default **Pythia** parameters in the LHCb simulation software

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Perugia0 corresponding **Pythia** parameters

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Particle multiplicities: unfolding

Correct migrations due to reconstruction efficiency $\varepsilon$:

$$ P_{\text{obs}}(n_{\text{obs}}) = \sum_{n_{\text{true}}=0}^{\infty} P_{\text{true}}(n_{\text{true}}) \cdot f_{\text{binomial}}(n_{\text{obs}}; n_{\text{true}}, \varepsilon) $$

unfold true particle multiplicity by fitting to observed multiplicity