Soft-QCD measurements at LHCb

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University of Oxford
On behalf of the LHCb collaboration

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- $\bar{\Lambda}/\Lambda \bar{\Lambda}/K_S$ production ratios
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The LHCb Experiment

Single arm spectrometer (2<\eta<5) for precision measurements of CP violation and rare B decays

Data taken with minimum bias triggers:
2009: Calo (7\mu b^{-1})
2010: 1 or more reconstructed tracks (14nb^{-1})

Provides measurements in a region of phase space complementary to GP detectors
Tracking system

VELO was partially opened at $\sqrt{s}=0.9$ TeV due to beam size and extreme crossing angle at low energy.

$\delta p/p \sim 0.5\%$ - reconstruction efficiency $\sim 95\%$

Resolution for primary(secondary) vertices is $\sigma_z \sim 50(150) \mu m$
2 Ring Imaging CHERENKOV (RICH) detectors provide charged particle identification in a momentum range of 2 - 100 GeV
RICH Detectors & PID

3 Radiators needed
RICH1 (2<p<60 GeV):
- Aerogel,     \( n \approx 1.03 \)
- \( C_4F_{10} \),     \( n \approx 1.0014 \)

RICH2 (p>20 GeV)
- \( CF_4 \),     \( n \approx 1.0005 \)

A ΔLL(x-y)* is constructed to discriminate between \( \rho \), \( K \) and \( \pi \).
PID efficiencies and misID rates vs ΔLL cuts are calculated from data using dedicated calibration samples

**Protons:** \( \Lambda \rightarrow p\pi \)

**Kaons:** \( \Phi \rightarrow KK \),
\( D^* \rightarrow D(K\pi)\pi \)

**Pions:** \( K_s \rightarrow \pi\pi \)

*Delta Log Likelihood between x and y particle hypotheses*
**K_{S} Production Cross Section**

- First measurement for LHCb with 2009 pilot run data
- $K_{S} \rightarrow \pi \pi$ selection based on tracking and impact parameters
- Two selections with long and downstream tracks
- First test for detector calibration

**K_s Production Cross Section**

Good consistency with PYTHIA expectations

$P_T$ spectra slightly harder
$K_S$ Production Cross Section

Comparison with other experiments

Unique measurement at high rapidity and low $P_T$
Motivation:
- Baryon number transport
- Hadronisation
- MC tuning

2 analyses:
- $V^0$ ratios (tracking & vertexing only)
- $\bar{p}/p$ (+ RICH PID)

Use minimum bias data
No need to know absolute $L$

P. Skands http://home.fnal.gov/~skands/
Analysis outline

- Long tracks
- Purely kinematic PID (Armenteros-Podolanski)
  - $K_S \rightarrow \pi\pi$ and $\Lambda \rightarrow p\pi$ selection based on impact parameters
- Systematics partially cancel

Published in: JHEP08(2011)034
V^0 Ratios - \bar{\Lambda}/\Lambda Results

Baryon transport higher than predicted by LHCb MC or Perugia0, especially at 0.9 TeV

7 TeV
**$V^0$ Ratios – $\bar{\Lambda}/K_S$ Results**

Baryon/meson suppression significantly lower than predicted

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0.9 TeV

- LHCB Data
- LHCB MC
- Perugia 0

LHCb
\[ s = 0.9 \text{ TeV} \]

Rapidity

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Transverse Momentum [GeV/c]

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7 TeV

- LHCB Data
- LHCB MC
- Perugia 0

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

Rapidity

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V^0 Ratios – Summary

Rapidity Loss $\Delta y = y_{\text{beam}} - y_{\text{baryon}}$

Good consistency with previous measurement
\( \bar{p}/p \) ratio

- Pure samples of protons, kaons and pions selected with RICH particle ID
- PID efficiencies and misID are extracted from data using calibration samples of \( \Lambda, \Phi, K_s \)

CERN-LHCB-CONF-2010-009

The analysis has been extended to provide further ratios such as \( K^-/K^+ \), \( \pi^-/\pi^+ \), \( p/\pi \), \( K/\pi \), \( p/K \) and results will be public soon.
**p/p ratio - Analysis strategy**

**Contamination correction**

\[
\begin{pmatrix}
P_{Sel} \\
K_{Sel} \\
\pi_{Sel}
\end{pmatrix} =
\begin{pmatrix}
p \rightarrow p \\
p \rightarrow K \\
p \rightarrow \pi
\end{pmatrix}
\begin{pmatrix}
k \rightarrow p \\
k \rightarrow K \\
p \rightarrow K
\end{pmatrix}
\begin{pmatrix}
\pi \rightarrow p \\
\pi \rightarrow \pi \\
\pi \rightarrow \pi
\end{pmatrix}
\begin{pmatrix}
P_{True} \\
K_{True} \\
\pi_{True}
\end{pmatrix}
\]

From data

All corrections are applied independently for each \((P_T, \eta)\) bin and particle charge

Different interaction cross-sections in the material between \(p\) and \(\bar{p}\), particularly at low momentum

Therefore limit analysis to tracks with \(P > 5\) GeV and correct using MC
Baryon transport higher than predictions and consistent with $\bar{\Lambda}/\Lambda$.
$\bar{p}/p$ Ratio – Results 7 TeV

Ratios become flatter as predicted by models

Better agreement with MC
Inclusive $\Phi$ Cross Section

Unique way to study strangeness production
- Discrepancies from MC seen by other major LHC experiments
- Test QCD fragmentation models in $pp$ interactions in LHCb's kinematic region

$\Phi \rightarrow K^+K^-$ candidates selection requires RICH PID information

arXiv:1107.3935, submitted to PLB
Cross section measurement is performed in bins of $P_T$ and $Y$

$$\sigma = \frac{N}{L \cdot B(\Phi \rightarrow KK) \cdot \epsilon_{REC}}$$

Major systematics uncertainties (%)

- Tracking efficiency: 8
- Track Multiplicity: 4
- Reconstruction and PID (bin dependent): 3-7
- Fit systematics: 3
- Luminosity (Normalisation): 4

PID cuts efficiency estimated from data using tag&probe technique.
Inclusive $\Phi$ Cross Section

$\Phi$ production is underestimated in the measured kinematic range by both tunings.
Charged Track Multiplicity

- Sensitive to low-x QCD dynamics and MPI
- Counting reconstructed tracks in VELO detector, high efficiency in the \( \eta \) ranges \([-2.5<\eta<-2]\) and \([2<\eta<4.5]\)
- Magnetic field negligible, no momentum measurement, tracks are straight lines
- The multiplicity distribution is determined using an unfolding technique
- Systematics (efficiency, ghosts, non-prompt and pile-up) are in general \( \sim \) few\%.
Charged Track Multiplicity

Normalised to events with at least one charged particle in the forward acceptance
Charged Track Multiplicity

Normalised to events with at least one track in the forward acceptance having $p_T > 1\text{GeV}$ to enhance hard interactions

Different $\eta$-distributions scaled by factors of 10 to fit in one plot.
Conclusions

LHCb has explored a unique kinematic region at low $p_T$ and high rapidity

- Several analyses investigated hadron production and provide valuable input for QCD models and the LHCb MC retuning
- Proton analysis has been extended and improved to provide further ratios ($K^-/K^+$, $\pi^-/\pi^+$, $p/\pi$, $K/\pi$, $p/K$), results will be ready soon

Results compared to models indicate:
- Higher baryon transport
- Harder $P_T$ spectra
- Underestimated strangeness production
- Underestimated charged particle multiplicity
LHCb MC is based on Pythia v6.418

### Non default Pythia parameters

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### Minimum Bias definition

#### Processes included

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