Preliminary Measurement of the $\bar{p}/p$ ratio in LHCb at $\sqrt{s} = 900$ GeV and 7 TeV

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MPI November 29, 2010
Outline

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Measurement of the $\bar{p}/p$ ratio in LHCb at $\sqrt{s} = 900$ GeV and 7 TeV

The LHCb Collaboration$^1$
Measurement of $\bar{p}/p$ is a probe of Baryon Number Transport.

LHCb can provide information in sparsely-populated regions of the $p_T-\eta$ space.

Measurement benefits from the excellent PID provided by the LHCb RICHes.

Will extend analysis to other ratios: $\frac{K^-}{K^+}$, $\frac{\pi^-}{\pi^+}$, etc. in the final analysis.
The LHC is a pp collider, nominal $\sqrt{s} = 14$ TeV.
Measurement of the $\bar{p}/p$ ratio in LHCb.
Movable device.

Best Velo hit resolution < 5 μm.

Only long tracks used in analysis. (Velo, TT, T1,2,3.)

Excellent tracking efficiency.
Algorithm calculates $-\log L$ for all tracks in an event for all PID hypotheses.

Implicit $p$ cut when using Delta Log Likelihood (DLL) cuts.
Example Event

Measurement of the $\bar{p}/p$ ratio in LHCb.

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LHCb Preliminary
EVT: 49700980
RUN: 70684
Approximately 38 $pb^{-1}$ recorded at LHCb so far.

These preliminary measurements use only $\sim 0.5 nb^{-1}$. 
Both data and calibration samples taken during 2010.

Trigger conditions (MicroBias):
- One track in the Velo or Tracking stations downstream of the magnet
- Very high efficiency trigger.

Collisions recorded at $\sqrt{s} = 900$ GeV and 7 TeV.

During 900 GeV running, each Velo half was retracted by 10 mm from the nominal closed position.
Data Sample

- 0.3 $nb^{-1}$ at $\sqrt{s} = 900$ GeV.
- 0.2 $nb^{-1}$ at $\sqrt{s} = 7$ TeV.
- Magnetic field inverted every 1-2 weeks of data taking.
- Data divided approximately equally between the two polarities at each energy.

Simulation Sample

- Monte Carlo events simulated using GEANT4.
- Simulation samples approximately three times larger than the data samples.
Offline Processing

Track and Vertex Reconstruction

- Tracks reconstructed and search performed for the Primary Vertexes (PV) in the event.
- A primary vertex consists of at least three tracks observed in the Velo.

Particle Identification

- A pattern recognition and particle identification algorithm constructs a negative log likelihood using all photodetector and track information.
- After minimisation, the change in log likelihood (DLL) is recorded for each track when the particle hypothesis is altered.
- This DLL is used to discriminate between hadron species.
Sample Selection

Primary Vertex Position and Impact Parameter Significance

- Events selected which contain at least one reconstructed PV within ±20 cm of the nominal interaction point.
- Background from non-prompt particles is suppressed by imposing a cut on the impact parameter significance with respect to the nearest reconstructed PV.
- Cut value chosen to obtain 95% purity of true prompt protons in the MC.

Track Quality and Momentum

- Contamination by fake tracks is minimised by requiring good track fit quality.
- Tracks required to possess a momentum of at least 5 GeV/c in order to minimise systematic effects arising due to interaction cross-section differences at low momenta.
Sample Selection: Calibration Samples

- Decays selected from the $\sqrt{s} = 7$ TeV sample due to higher probability of having hits in the Velo.
- $\pi$ and $p$ from $K_S^0 \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$:
  - Kinematical cuts only.
- $K$ from $\phi \rightarrow K^+K^-:
  - One track identified as a $K$ in the RICH.
  - Other track left unbiased.
- PID efficiency calculated in each bin.
Sample Selection: Binning

**Binning**
- Analysis performed in bins of $\eta$ and $p_T$.
- Three irregular $p_T$ bins chosen such that each bin contains similar statistics at $\sqrt{s} = 900$ GeV.
- Eight regular $\eta$ bins from 1 to 5.

**Comments**
- Kinematics of tracks in a bin very similar for both the 900 GeV and 7 TeV data.
- Results only evaluated in bins with sufficiently high statistics in both the analysis and calibration samples.
Sample Selection: PID cuts

- Pure samples of $\pi$, $K$ and $p$ are isolated using RICH information.
- Cuts placed on $DLL(p - K)$ and $DLL(p - \pi)$ to select $p$.
- Cuts placed on $DLL(K - p)$ and $DLL(p - \pi)$ to select $K$.
- Cuts placed on $DLL(\pi - K)$ to select $\pi$. 

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The number of reconstructed particles is given by:

\[
\begin{pmatrix}
N_{p}^{\text{rec}} \\
N_{K}^{\text{rec}} \\
N_{\pi}^{\text{rec}}
\end{pmatrix}
= \begin{pmatrix}
\epsilon_{p \rightarrow p} & \epsilon_{K \rightarrow p} & \epsilon_{\pi \rightarrow p} \\
\epsilon_{p \rightarrow K} & \epsilon_{K \rightarrow K} & \epsilon_{\pi \rightarrow K} \\
\epsilon_{p \rightarrow \pi} & \epsilon_{K \rightarrow \pi} & \epsilon_{\pi \rightarrow \pi}
\end{pmatrix}
\begin{pmatrix}
N_{p}^{\text{true}} \\
N_{K}^{\text{true}} \\
N_{\pi}^{\text{true}}
\end{pmatrix}
\]

where \(\epsilon\) represents the PID efficiency.

In each \(\eta, p_T\) bin, \(\epsilon_{i \rightarrow j}\) is calculated using the calibration samples. Inversion of the efficiency matrix allows the number of true particles to be calculated. Calculation performed for each combination of particle charge, bin and magnet polarisation.

Material Interactions

MC used to calculate survival probability of each particle species.
Systematic Uncertainties

**PID Performance**
- Dominant systematic uncertainty from PID performance:
- Uncertainty typically $< 5\%$ (size of calibration sample).
- Tighter RICH DLL cuts show good stability and no bias.

**Detector Interaction**
- Assume material in the detector modelled to $< 10\%$.
- Hadron-nuclear interactions used in the simulation are in agreement with the available measurements, with a precision of 20\%.
- Together this corresponds to a systematic error of $< 1\%$ in most bins.

**Fake Tracks**
- $\sim 5\%$ fake tracks for $p$, $\bar{p}$ below the RICH threshold.
- $\sim 2.5\%$ fake tracks for $p$, $\bar{p}$ above threshold.
- Uncertainty of $\sim 1\%$ per bin assigned.
The measured $\bar{p}/p$ ratios are compared to the predictions of PYTHIA:

- The LHCb implementation.  
- The Perugia 0 tune [1].

\[^{1}\text{Full LHCb PYTHIA settings in Appendix.}\]
The data shows a significant dependence on $p_T$, $\eta$. Similar behaviour, but general agreement is poor. For low- and middle-$p_T$ bins, data is lower than both predictions.
$ar{p}/p$ rapidity distribution at $\sqrt{s} = 7$ TeV after correction.

Measurements compatible with both the LHCb PYTHIA and Perugia 0 expectations.

Observed ratios more consistent with unity.

Ratios calculated only in bins with sufficient statistics.
Rapidity loss is given by the difference in rapidity between the baryon and the beam:

$$\Delta y = y_{\text{beam}} - y_{\text{baryon}}$$
\( \bar{p}/p \) ratio in terms of Rapidity Loss

Results span an interval of approximately 4 units, up to \( \Delta y = 7 \).

Results appear consistent with a monotonic distribution in a given \( p_T \) bin.

- Results span an interval of approximately 4 units, up to \( \Delta y = 7 \).
- Results appear consistent with a monotonic distribution in a given \( p_T \) bin.
The results appear to have some $p_T$ dependence.

The results are reasonably consistent with other measurements.
Preliminary measurement of the $\bar{p}/p$ ratio have been made in bins of $p_T$ and $\eta$ at $\sqrt{s} = 900$ GeV and 7 TeV.

First measurements in the low-$p_T$ region.

The results are compatible with the predictions of the Perugia 0 Pythia tune, except at 900 GeV for $p_T < 1.2$ GeV/$c$ where the results lie below the generator expectation.

Where comparisons can be made, the results are compatible with previous measurements and indicate some dependence on $p_T$.

Results are still being finalised, and we expect to also measure other ratios $\left( \frac{K^-}{K^+}, \frac{\pi^+}{\pi^-} \right)$ soon.

Final results will benefit from larger calibration sample.

Conversion to Rapidity

$\eta \rightarrow y$

- Useful to display this data in an energy-independent form: $\eta \rightarrow y$.
- The mean rapidity, $\langle y \rangle$ and RMS of the distribution of the tracks in each bin is calculated.

Correction Process for Reconstruction Bias

- Same $\eta \rightarrow y$ process applied to MC events:
  - Tracks passing reconstruction.
  - True particles passing kinematical selection prior to reconstruction.
- Difference between the two MC datasets used to correct for reconstruction bias.
- Reconstructed rapidity similar in both the data and MC.
  - Confirms bin width small compared to the scale of the underlying distributions.
Data shows significant dependence on $p_T$, $\eta$.

Similar behaviour, but general agreement is poor.

For low- and middle-$p_T$ bins, data lower than both predictions.
Measurements compatible with both the LHCb PYTHIA and Perugia 0 expectations.

- Observed ratios more consistent with unity.
- Ratios calculated only in bins with sufficient statistics.
<table>
<thead>
<tr>
<th>Process</th>
<th>Explanation</th>
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<tr>
<td>11</td>
<td>$f_i f_j \rightarrow f_i f_j$</td>
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<tr>
<td>12</td>
<td>$f_i f_i \rightarrow f_k f_k$</td>
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<tr>
<td>13</td>
<td>$f_i f_i \rightarrow gg$</td>
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<tr>
<td>28</td>
<td>$f_i g \rightarrow f_i g$</td>
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<tr>
<td>53</td>
<td>$gg \rightarrow f_k f_k$</td>
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<td>68</td>
<td>$gg \rightarrow gg$</td>
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<tr>
<td>91-95</td>
<td>Soft QCD</td>
</tr>
<tr>
<td>421-439</td>
<td>Closed Heavy Flavour</td>
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<tr>
<td>461-479</td>
<td>Closed Heavy Flavour</td>
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## Backup Slides: LHCb PYTHIA (v6.421) Parameters

<table>
<thead>
<tr>
<th>Block</th>
<th>Parameter</th>
<th>Value</th>
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<td>ckin</td>
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<td>$2^{nd}$ order running $\alpha_s$</td>
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<td>K factor shift in $\alpha_s Q^2$</td>
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<td>Scale of hard QCD scattering.</td>
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<td>Prob. of gg with colour connections to NN in old MI.</td>
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<td>Prob. of gg is in 85 or as closed loop.</td>
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<tr>
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<td>Width of Gaussian $k_T$ distribution.</td>
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<td>Matrix element for charmonium and bottomonium prod.</td>
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<td>Prob. strange meson has spin 1.</td>
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<tr>
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<td>Prob. heavy meson has spin 1.</td>
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<td>Prob. $s=0, l=1, j=1$ meson produced.</td>
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<td>Prob. $s=1, l=1, j=0$ meson produced.</td>
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<td>Prob. $s=1, l=1, j=1$ meson produced.</td>
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<td>Prob. $s=1, l=1, j=2$ meson produced.</td>
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<td>0.4</td>
<td>Parton fragmentation lower cutoff.</td>
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