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

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MPI November 29, 2010

Outline

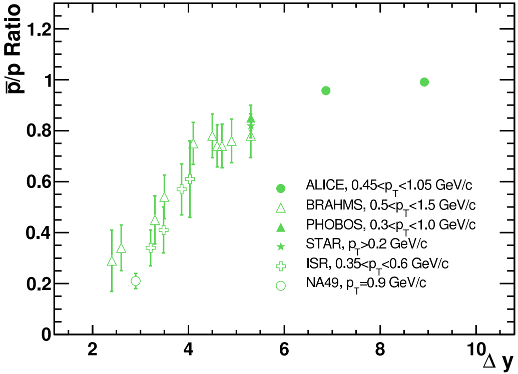
LHCb-CONF-2010-009
26 August 2010

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

The LHCb Collaboration[1]

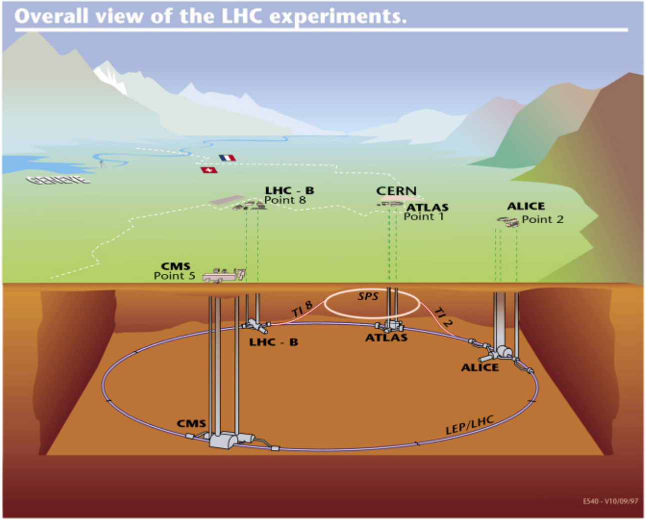
Motivation

- Measurement of $\overline{\mathrm{p}}/\mathrm{p}$ is a probe of Baryon Number Transport.
- LHCb can provide information in sparsely-populated regions of the p_T-η space.



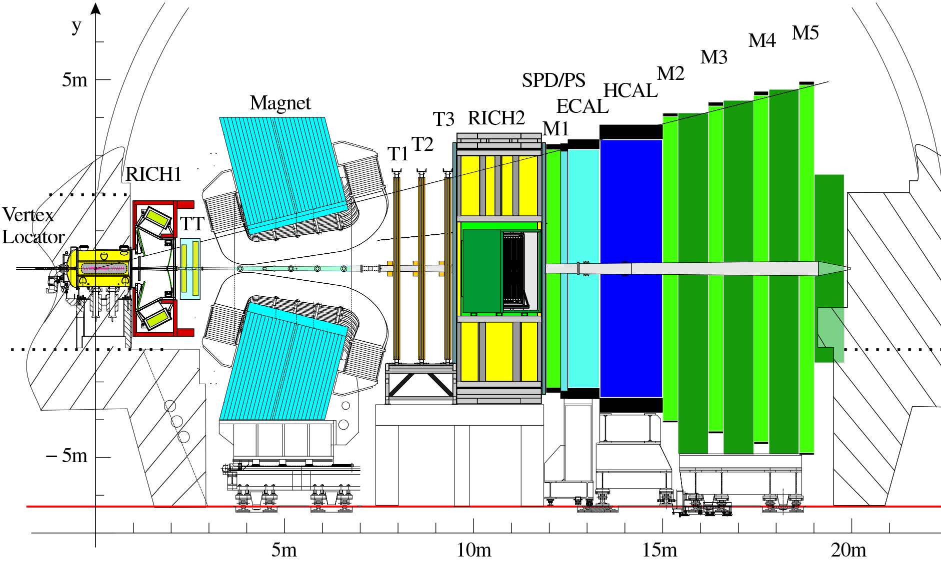
- Measurement benefits from the excellent PID provided by the LHCb RICHes.
- Will extend analysis to other ratios: $\frac{\mathrm{K}^-}{\mathrm{K}^+}$, $\frac{\pi^-}{\pi^+}$, etc. in the final analysis.

The LHC

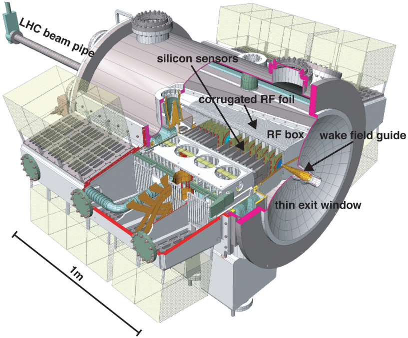


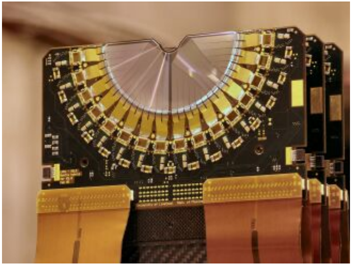
The LHC is a pp collider, nominal $\sqrt{s} = 14\,\text{TeV}$.

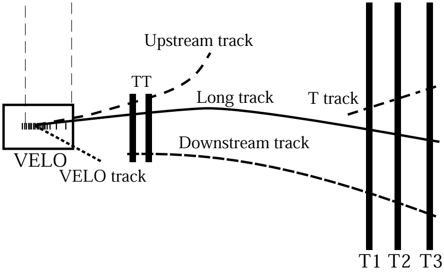
The LHCb Detector



Tracking: VeLo and Tracking Stations

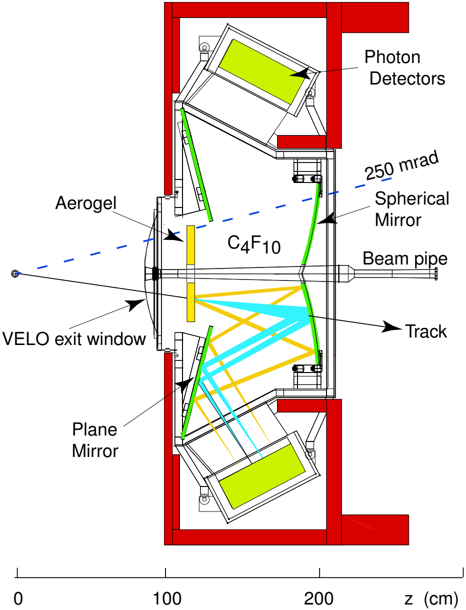


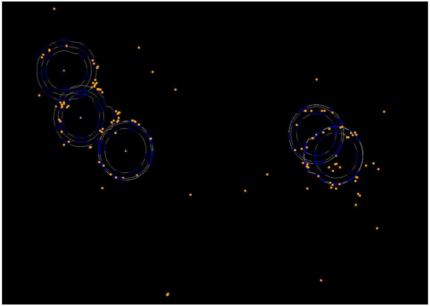




- Movable device.
- Best Velo hit resolution $< 5\,\mu$m.
- Only long tracks used in analysis. (Velo, TT, T1,2,3.)
- Excellent tracking efficiency.

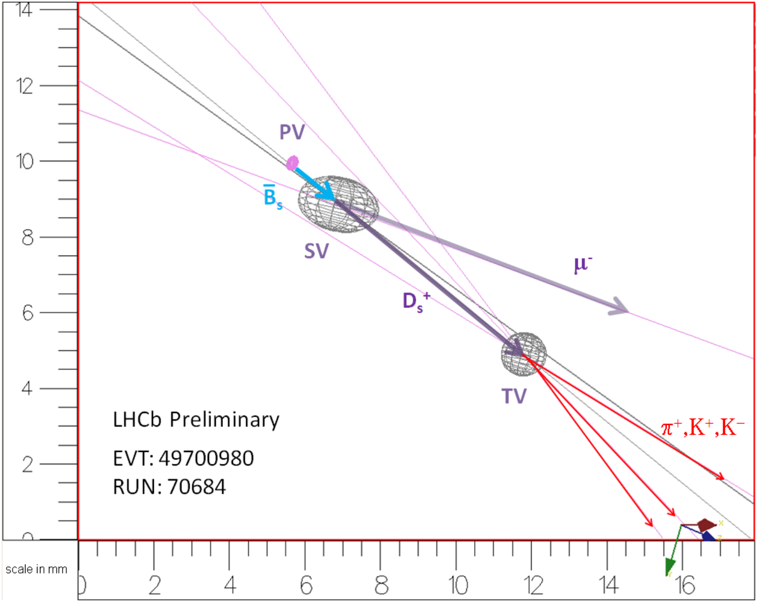
RICH 1



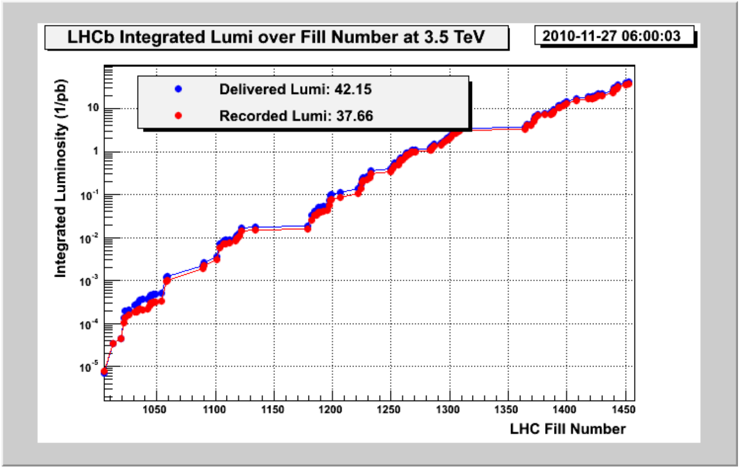


- Algorithm calculates $-\log \mathcal{L}$ for all tracks in an event for all PID hypotheses.
- Implicit p cut when using Delta Log Likelihood (DLL) cuts.

Example Event



Current Integrated Luminosity



- Approximately 38 pb^{-1} recorded at LHCb so far.
- These preliminary measurements use only $\sim 0.5\, nb^{-1}$.

Data Sample

- 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 $\sqrt{s} = 900\,\text{GeV}$ and $7\,\text{TeV}$.
- During 900 GeV running, each Velo half was retracted by 10 mm from the nominal closed position.

Data Sample

Data Sample

- $0.3\, nb^{-1}$ at $\sqrt{s} = 900\,\text{GeV}$.
- $0.2\, nb^{-1}$ at $\sqrt{s} = 7\,\text{TeV}$.
- 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

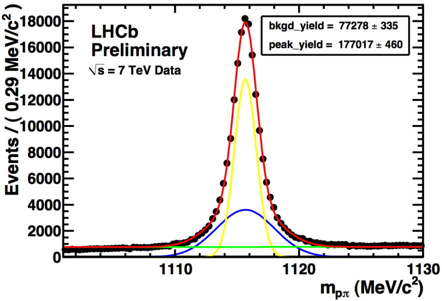
- Events selected which contain at least one reconstructed PV within $\pm 20\,\text{cm}$ of the nominal interaction point.
- Background from non-prompt particles is suppressed by imposing a cut on the impact parameter significance with respect to the nearest reconstructed PV.
- Cut value chosen to obtain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

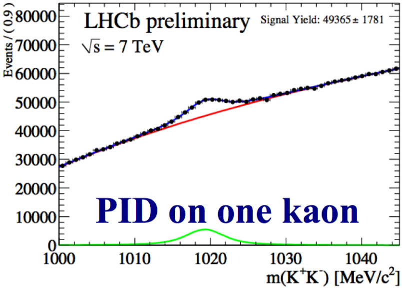
Track Quality and Momentum

- Contamination by fake tracks is minimised by requiring good track fit quality.
- Tracks required to posess 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 $\sqrt{s} = 7\,\text{TeV}$ sample due to higher probability of having hits in the Velo.
- π and p from $\mathrm{K^0_S} \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow \mathrm{p}\pi^-$:
  - Kinematical cuts only.
- K from $\phi \rightarrow \mathrm{K^+K^-}$:
  - One track identified as a K in the RICH.
  - Other track left unbiased.
- PID efficiency calculated in each bin.





Sample Selection: Binning

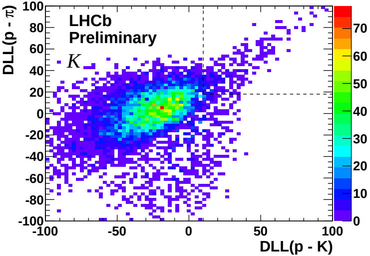
Binning

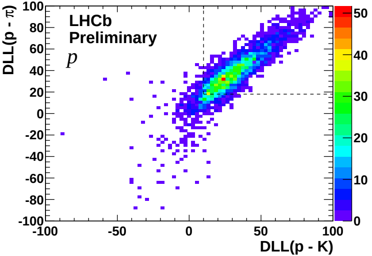
- Analysis performed in bins of η and p_T.
- Three irregular p_T bins chosen such that each bin contains similar statistics at $\sqrt{s} = 900\,\mathrm{GeV}$.
- Eight regular η bins from 1 to 5.

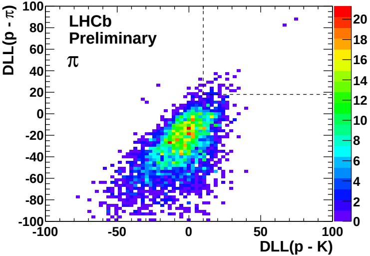
Comments

- 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 π, K and p are isolated using RICH information.
- Cuts placed on $DLL\,(\mathrm{p}-\mathrm{K})$ and $DLL\,(\mathrm{p}-\pi)$ to select p.
- Cuts placed on $DLL\,(\mathrm{K}-\mathrm{p})$ and $DLL\,(\mathrm{p}-\pi)$ to select K.
- Cuts placed on $DLL\,(\pi-\mathrm{K})$ to select π.

Correction for Reconstruction Bias & Acceptance

Hadron Cross-contamination

The number of reconstructed particles is given by:

$$\begin{pmatrix} N_{\mathrm{p}}^{\mathrm{rec}} \\ N_{\mathrm{K}}^{\mathrm{rec}} \\ N_{\pi}^{\mathrm{rec}} \end{pmatrix} = \begin{pmatrix} \epsilon_{\mathrm{p}\to\mathrm{p}} & \epsilon_{\mathrm{K}\to\mathrm{p}} & \epsilon_{\pi\to\mathrm{p}} \\ \epsilon_{\mathrm{p}\to\mathrm{K}} & \epsilon_{\mathrm{K}\to\mathrm{K}} & \epsilon_{\pi\to\mathrm{K}} \\ \epsilon_{\mathrm{p}\to\pi} & \epsilon_{\mathrm{K}\to\pi} & \epsilon_{\pi\to\pi} \end{pmatrix} \cdot \begin{pmatrix} N_{\mathrm{p}}^{\mathrm{true}} \\ N_{\mathrm{K}}^{\mathrm{true}} \\ N_{\pi}^{\mathrm{true}} \end{pmatrix}$$

where ϵ represents the PID efficiency.
In each η, p_T bin, $\epsilon_{i\to j}$ 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

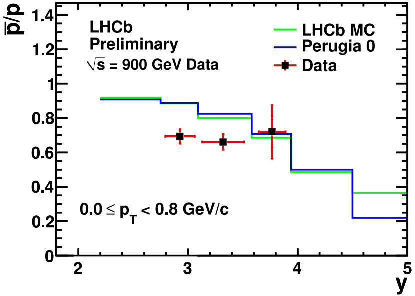
- $\sim 5\%$ fake tracks for p, $\overline{\mathrm{p}}$ below the RICH threshold.
- $\sim 2.5\%$ fake tracks for p, $\overline{\mathrm{p}}$ above threshold.
- Uncertainty of $\sim 1\%$ per bin assigned.

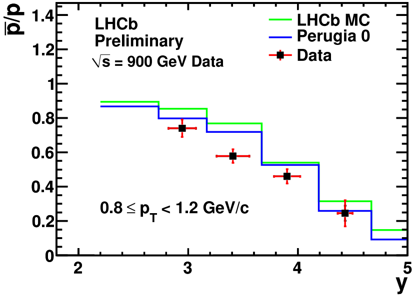
Results

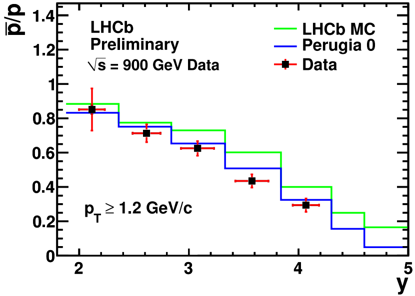
- The measured $\overline{\mathrm{p}}/\mathrm{p}$ ratios are compared to the predictions of PYTHIA:
  - The LHCb implementation. [1]
  - The Perugia 0 tune [1].

[1] Full LHCb PYTHIA settings in Appendix.

$\bar{p}/p$ rapidity distribution at $\sqrt{s} = 900$ GeV after correction.

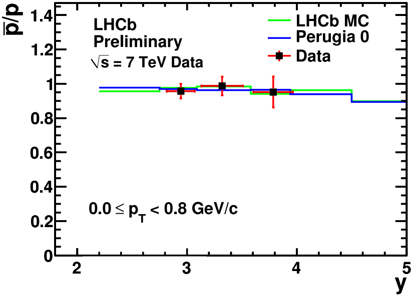


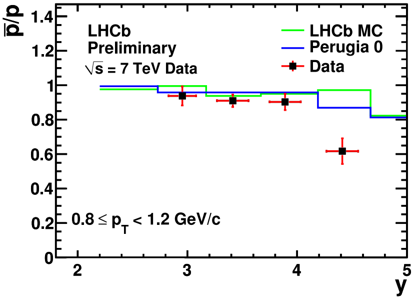


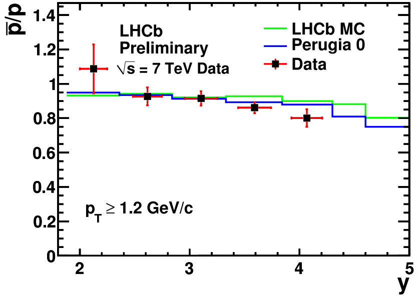


- Data shows significant dependence on p_T, η.
- Similar behaviour, but general agreement is poor.
- For low- and middle-p_T bins, data lower than both predictions.

$\bar{p}/p$ rapidity distribution at $\sqrt{s} = 7\,\text{TeV}$ after correction.







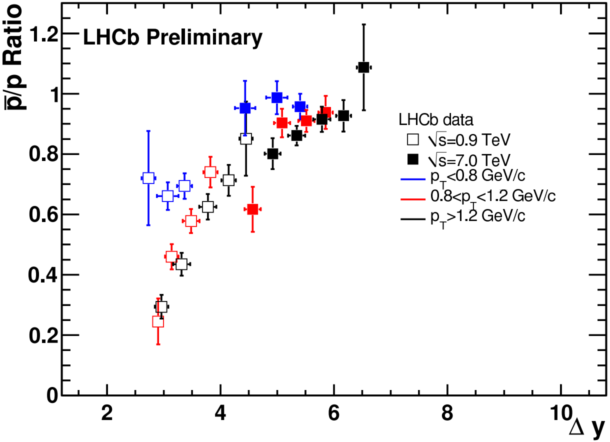
- Measurements compatible with both the LHCb PYTHIA and Perugia 0 expectations.
- Observed ratios more consistent with unity.
- Ratios calculated only in bins with sufficient statistics.

$\overline{\mathrm{p}}/\mathrm{p}$ ratio in terms of Rapidity Loss

- Rapidity loss is given by the difference in rapidity between the baryon and the beam:

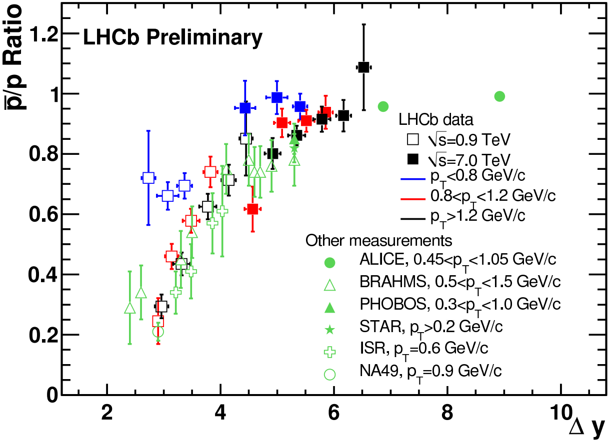
$$\Delta y = y_{\mathrm{beam}} - y_{\mathrm{baryon}}$$

$\overline{p}/p$ 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.

$\bar{p}/p$ ratio in terms of Rapidity Loss



- The results appear to have some p_T dependence.
- The results are reasonably consistent with other measurements.

Summary

- Preliminary measurement of the $\bar{p}/p$ ratio have been made in bins of p_T and η at $\sqrt{s} = 900\,\text{GeV}$ and $7\,\text{TeV}$.
- First measurments 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 resuts 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 $\left(\frac{\mathrm{K}^-}{\mathrm{K}^+}, \frac{\pi^+}{\pi^-}\right)$ soon.
- Final results will benefit from larger calibration sample.

References I

[1] P. Skands, *The Perugia tunes*, arXiv:0905.3418v1 [hep-ph] (2009).

[2] The LHCb Collaboration, *Measurement of the $\bar{p}/p$ ratio in LHCb at $\sqrt{s} = 900$ GeV and 7 TeV*, (2010).

Conversion to Rapidity

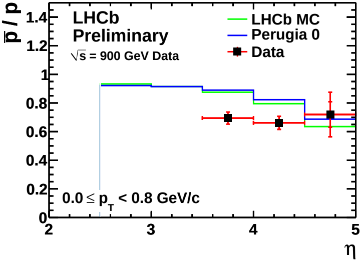
$\eta \longrightarrow y$

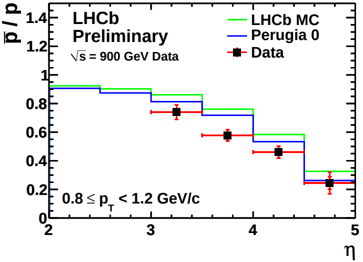
- Useful to display this data in an energy-independent form: $\eta \rightarrow y$.
- The mean rapidity, $\langle y \rangle$ and RMS of the distribution of the tracks in each bin is calculated.

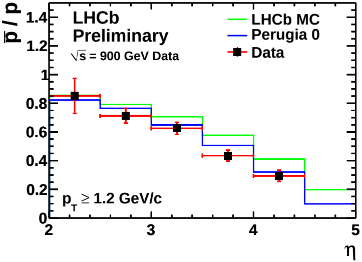
Correction Process for Reconstruction Bias

- 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.

$\bar{\mathrm{p}}/\mathrm{p}$ η distribution at $\sqrt{s} = 900\,\mathrm{GeV}$ after correction.

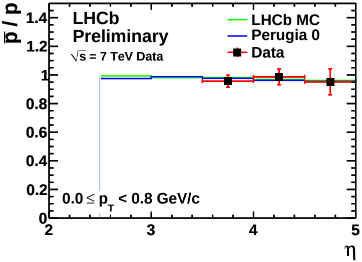


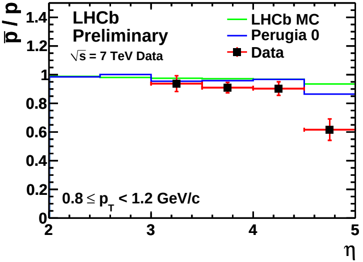


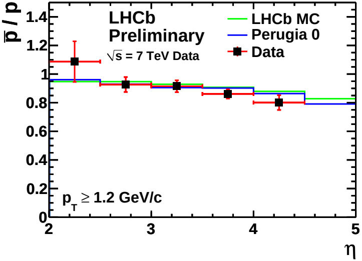


- Data shows significant dependence on p_T, η.
- Similar behaviour, but general agreement is poor.
- For low- and middle-p_T bins, data lower than both predictions.

$\overline{\mathrm{p}}/\mathrm{p}$ η 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.

Backup Slides: LHCb PYTHIA (v6.421) Process Types

Process	Explanation
11	$f_i f_j \longrightarrow f_i f_j$
12	$f_i \bar{f}_i \longrightarrow f_k \bar{f}_k$
13	$\bar{f}_i f_i \longrightarrow gg$
28	$f_i g \longrightarrow f_i g$
53	$gg \longrightarrow f_k \bar{f}_k$
68	$gg \longrightarrow gg$
91-95	Soft QCD
421-439	Closed Heavy Flavour
461-479	Closed Heavy Flavour

Backup Slides: LHCb PYTHIA (v6.421) Parameters

Block	Parameter	Value	Explanation
ckin	41	3.0	Resonance mass range.
mstp	2	2	2^{nd} order running α_s
mstp	33	3	K factor shift in α_s Q^2
mstp	128	2	Event record config for resonances.
mstp	81	1	Multiple interactions on.
mstp	82	3	MI structure.
mstp	52	2	PDFLIB proton pdf library.
mstp	51	10042	Choice of PDF set.
mstj	26	0	No B-$\overline{\mathrm{B}}$ mixing.

Backup Slides: LHCb PYTHIA Parameters 2

Parameter	Block	Value	Explanation
parp	67	1.0	Scale of hard QCD scattering.
parp	82	4.28	Regularisation scale.
parp	89	14000.	Reference energy scale.
parp	90	0.238	Power of energy-rescaling term.
parp	85	0.33	Prob. of gg with colour connections to NN in old MI.
parp	86	0.66	Prob. of gg is in 85 or as closed loop.
parp	91	1.0	Width of Gaussian k_T distribution.
parp	149	0.02	Matrix element for charmonium and bottomonium prod.
parp	150	0.085	Matrix element for charmonium and bottomonium prod.
parj	11	0.5	Prob. light meson has spin 1.
parj	12	0.4	Prob. strange meson has spin 1.
parj	13	0.79	Prob. heavy meson has spin 1.
parj	14	0.0	Prob. $s = 0, l = 1, j = 1$ meson produced.
parj	15	0.018	Prob. $s = 1, l = 1, j = 0$ meson produced.
parj	16	0.054	Prob. $s = 1, l = 1, j = 1$ meson produced.
parj	17	0.131	Prob. $s = 1, l = 1, j = 2$ meson produced.
parj	33	0.4	Parton fragmentation lower cutoff.