QCD studies in the forward region @ LHCb

Hadron Collider Physics Symposium 2011

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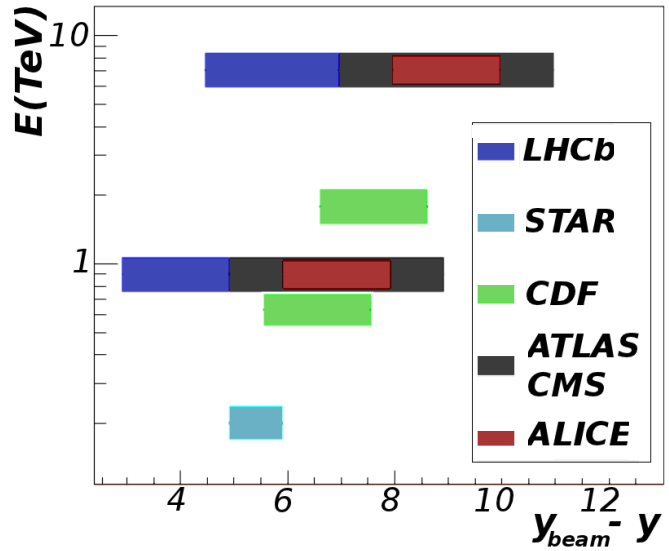
NIKHEF

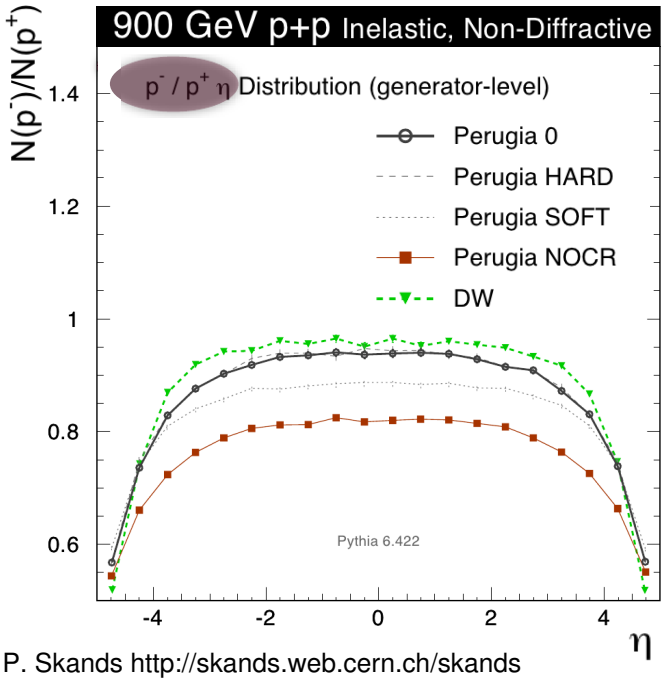
November 14th-18th, 2011

On behalf of the LHCb collaboration

Introduction

- LHCb experiment is fully instrumented over a unique region of pseudo rapidity at LHC ($2 < \eta < 5$).
- Forward region provide an interesting test of particle production, hadronisation and baryon number transport for MC models.
- Several measurements are covered in this talk:
  - Charged particles multiplicity at $\sqrt{s} = 7\ TeV$.
  - Inclusive ϕ cross-section at $\sqrt{s} = 7\ TeV$.
  - V0 production ratio at $\sqrt{s} = 900\ GeV$ and $\sqrt{s} = 7\ TeV$.
  - Light hadron production ratio at $\sqrt{s} = 900\ GeV$ and $\sqrt{s} = 7\ TeV$.
- All these measurements were performed with the 2009/2010 data sample, but some are shown here for the first time.



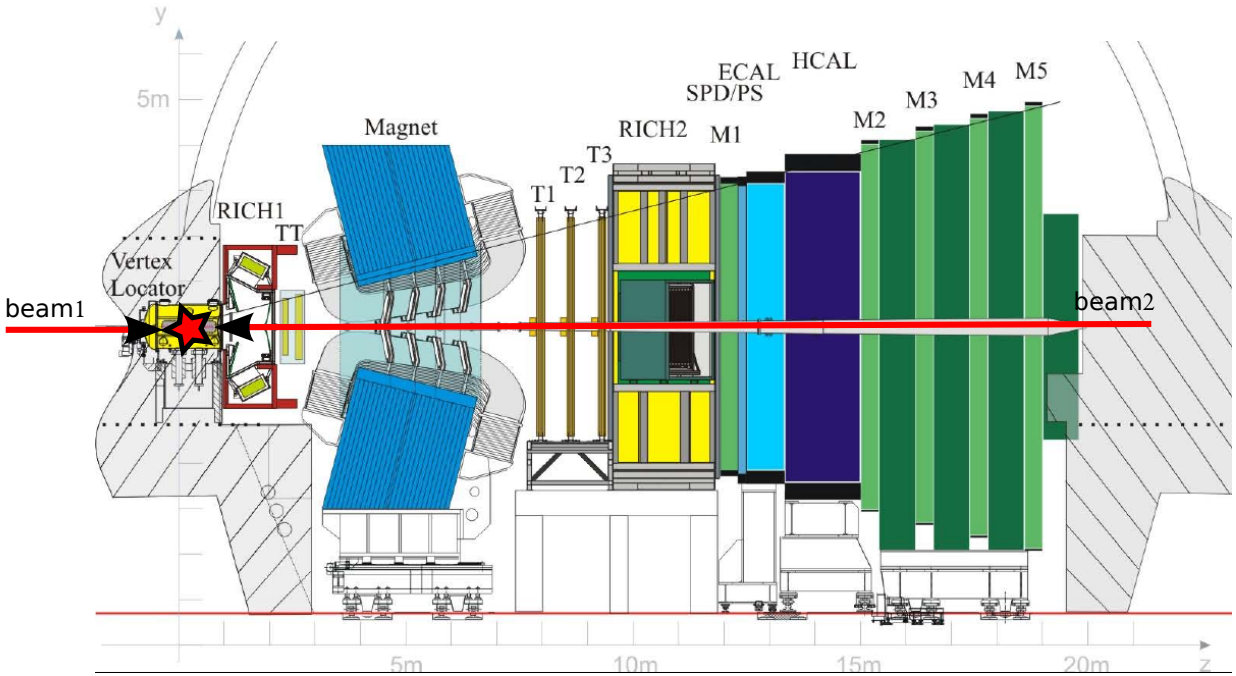


P. Skands http://skands.web.cern.ch/skands

LHCb detector

Focus on Tracking and Hadronic Particle ID

2008 JINST 3 S08005



- Designed for CP violation studies in B decay and rare decays.
- Single arm spectrometer, $\sim 30\%$ of $b\bar{b}$ pairs produce in the acceptance.
- So far $\sim 0.3 nb^{-1}$ recorded at $\sqrt{s} = 900 GeV$ and $\sim 1.1 fb^{-1}$ $\sqrt{s} = 7 TeV$.

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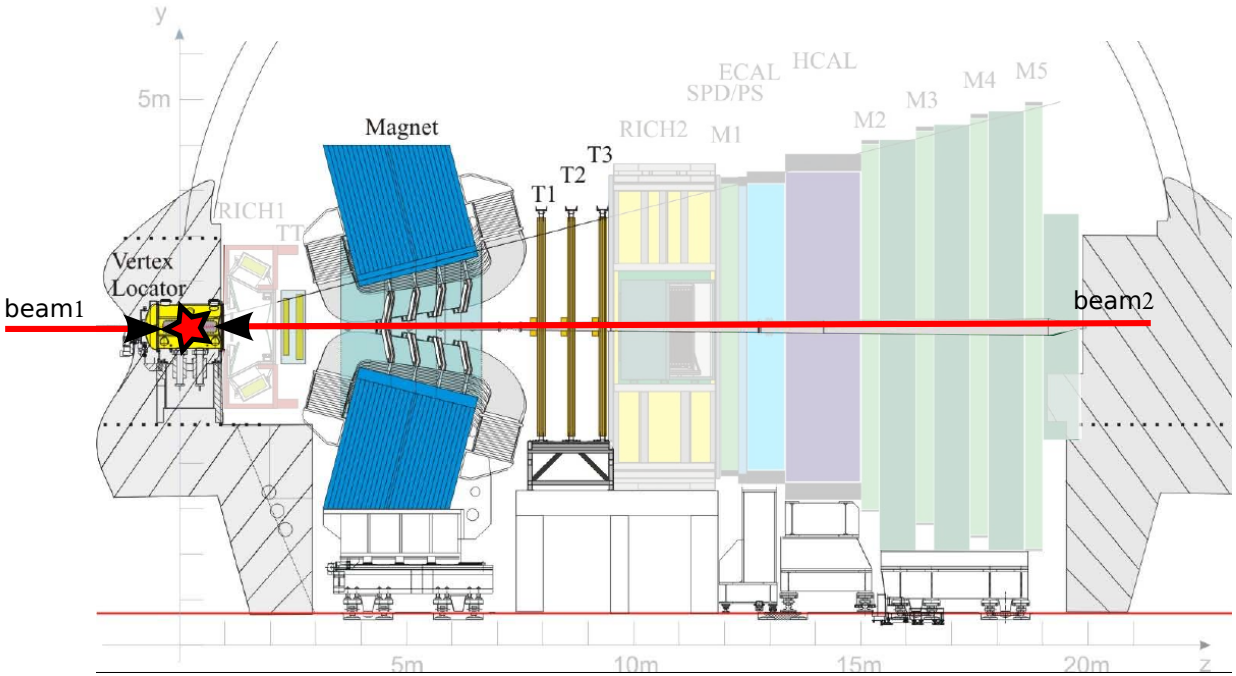
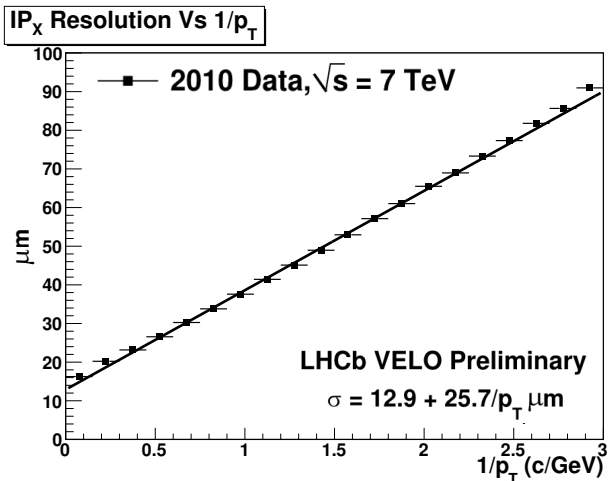


- Tracking efficiency $\sim 95\%$
- $\delta p/p \sim 0.5\%$
- Primary vertex resolution $50\mu m$
- VELO partially open at $\sqrt{s} = 900GeV$



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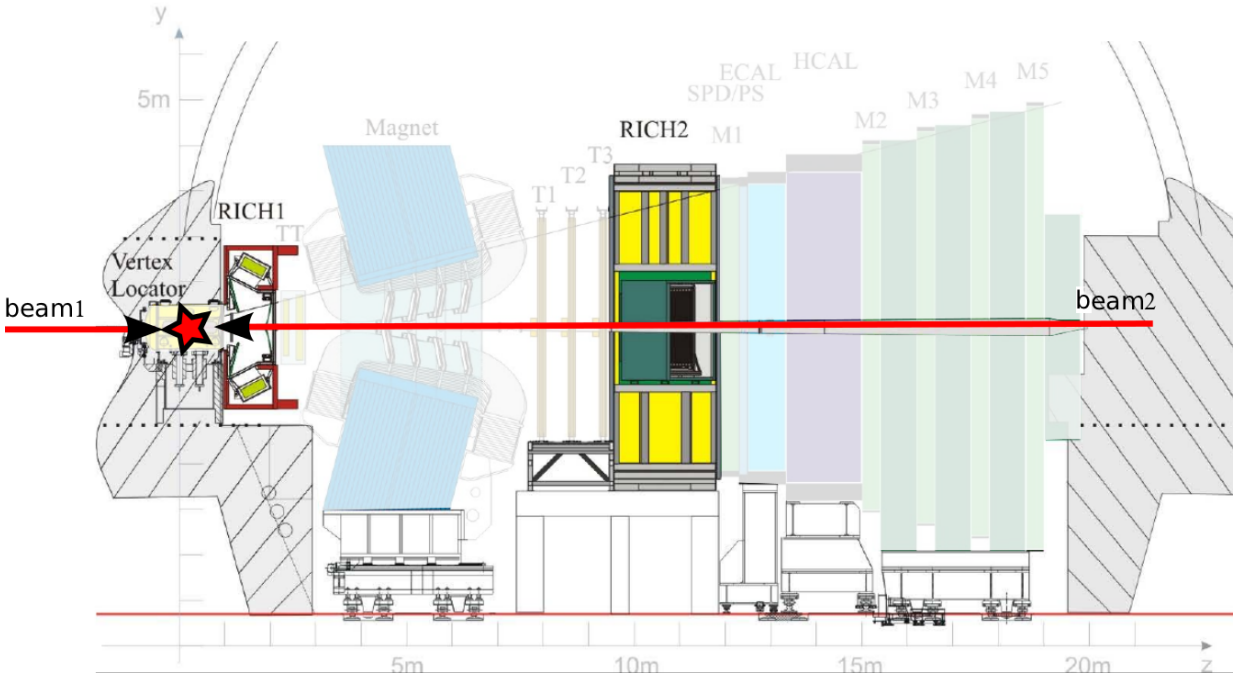
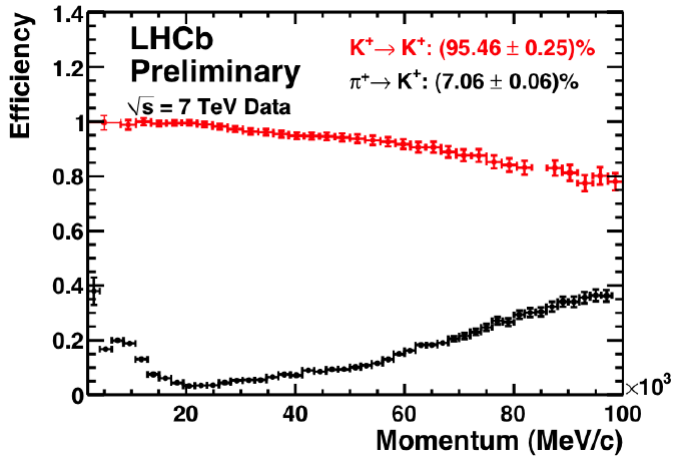


- RICH1 cover momentums from 2 to 60 GeV/c
- RICH2 cover momentums from 20 to 100 GeV/c



- Charged particles are counted by reconstructing tracks in the vertex locator (VELO)

  $\rightarrow$ low material budget, high efficiency, partial backward coverage but no momentum information.

- Only prompt charged particles are considered

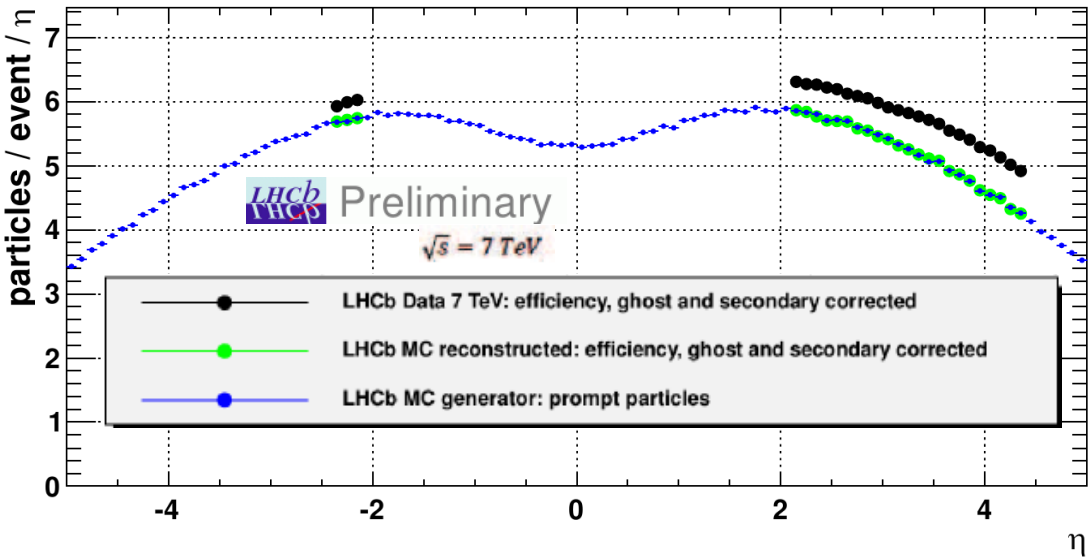
  $\rightarrow$ definition at MC generator level: $\tau_{ancestors} < 10ps$, no K_s^0 and Λ decays.

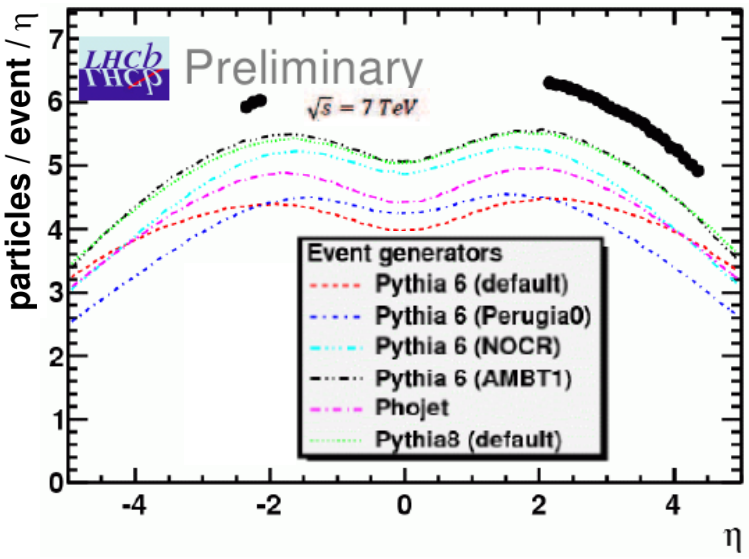
- Loose trigger and selection: one reconstructed track in the VELO.
- 1.5 M events at each polarity with low pile-up dataset ($3.7 \pm 0.4\%$ events with more than one interaction).

Charged particles multiplicity @ $\sqrt{(s)} = 7\,TeV$

Multiplicity vs. pseudo-rapidity

- Event particle multiplicity obtained by unfolding of the migration due to reconstruction inefficiencies.
- Procedure verified with MC simulations, good agreement between the reconstructed and corrected distribution and the generated distribution.
- Distribution as function of η are normalised to events with at least on charged particle in forward acceptance.



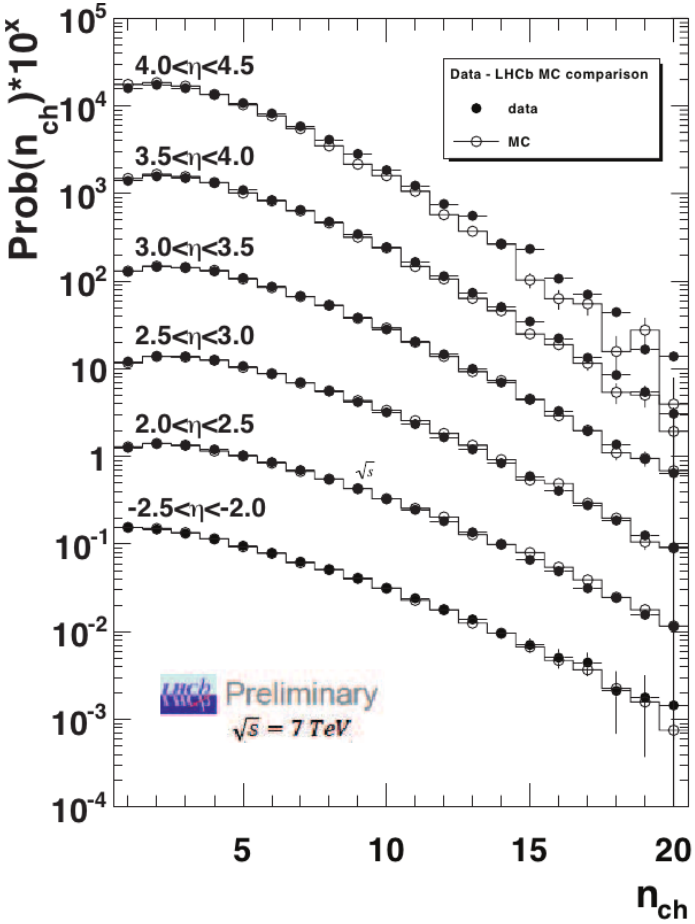


- Multiplicity is larger in data than in any of the tested MC tunes.

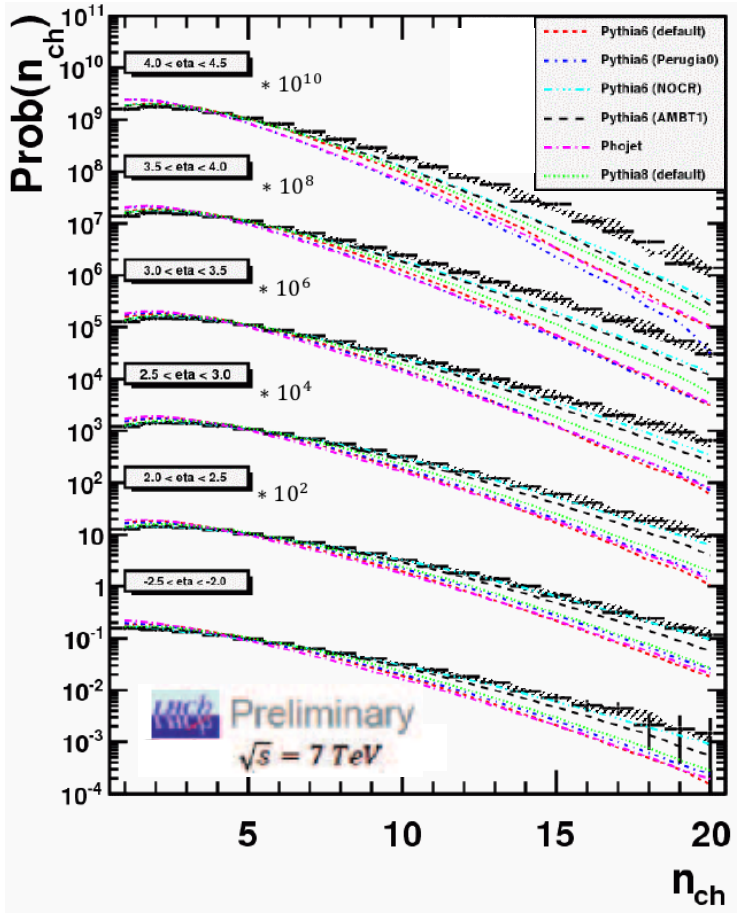
Charged particles multiplicity @ $\sqrt{(s)} = 7\,TeV$

Multiplicity probabilities

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



- Good agreement of unfolded multiplicity between LHCb MC and data



- Good agreement between Pythia 6 NOCR and data.

Inclusive ϕ cross section @ $\sqrt{(s)} = 7\,TeV$

Selection

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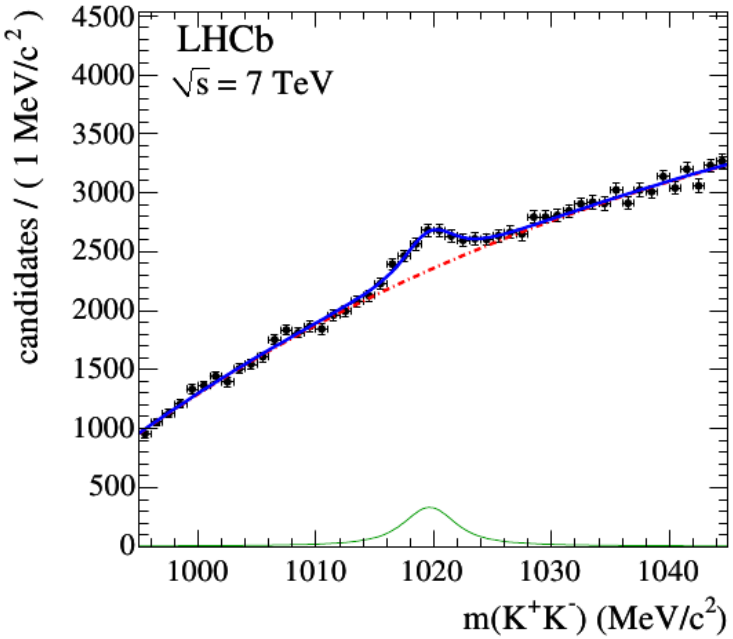
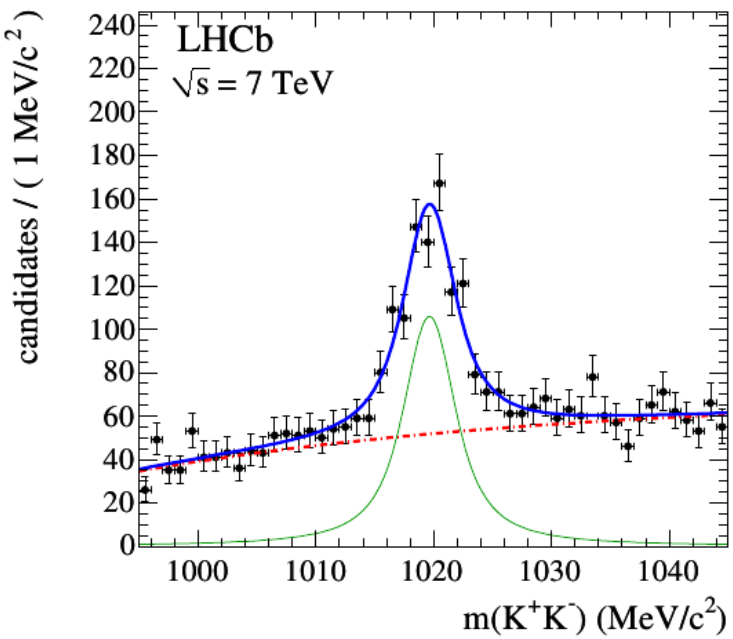
- Probe strangeness production $\rightarrow$ information on fragmentation, tuning of MC models in our pseudorapidity region.
- Measurements performed at $\sqrt{s} = 7\,TeV$ $(14.7 nb^{-1})$ with loose trigger.
- $\phi \rightarrow K^+K^-$ are selected with at least one K PID requirements, $1. < m_{KK} < 1.045\,GeV/c^2$
- Resolution dominated by the natural width of the ϕ





$$\sigma_{pp\to\phi X} = \frac{N_{tag}}{\epsilon_{PID} \times \epsilon_{reco} \times \epsilon_{trigger} \times \epsilon_{PV} \times B(\phi \to KK) \int L}$$

- PID efficiency is extracted from data, per bins of p_T, y ($> 80\%$ in most of the bins).
- Number of ϕ candidates is extracted from the tag and probe mass distributions.
- Trigger efficiency is a known prescale.
- Reconstruction efficiency is extracted from MC per bins of p_T, y.

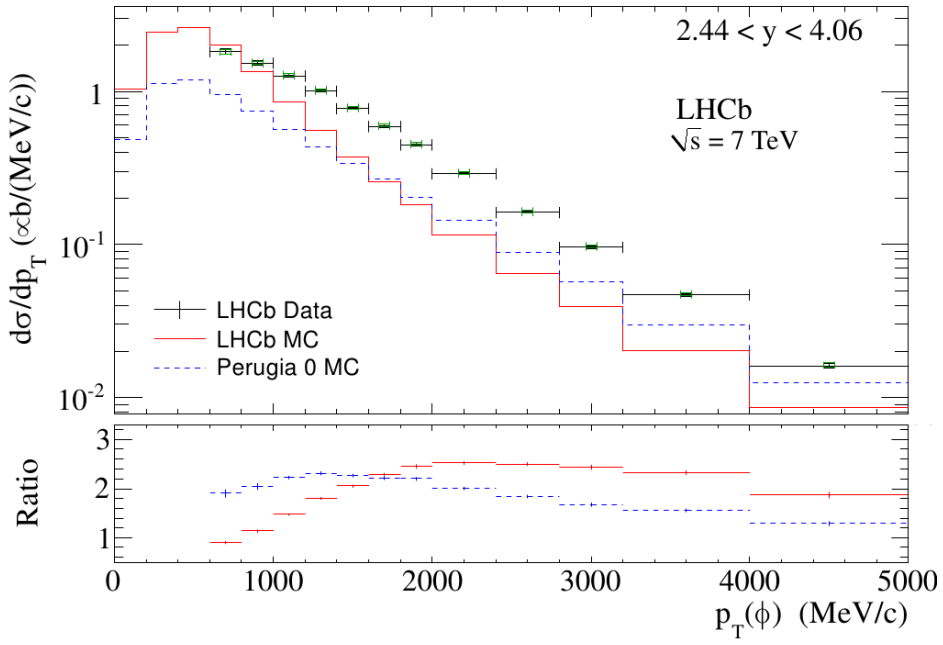
Main systematics

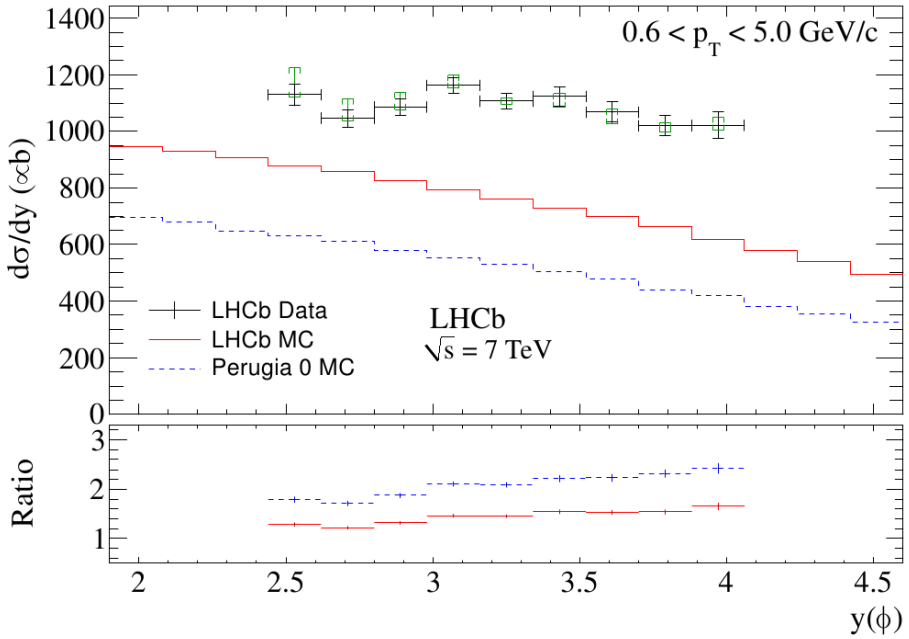
Common to all bin	%
Tracking efficiency	8
Luminosity	4
Track Multiplicity	3
...	
Total correlated	10

Bin dependent	%
Reconstruction efficiency	typically 5%
PID	typically 2%

Inclusive ϕ cross section @ $\sqrt{(s)} = 7\,TeV$

Results





- At $\sqrt{s} = 7\,TeV$, for ϕ with $p_T \in [0.6, 5.\,GeV/c]$ and $y \in [2.44, 4.06]$:

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

- More strange mesons produced forward than expected from MC models.

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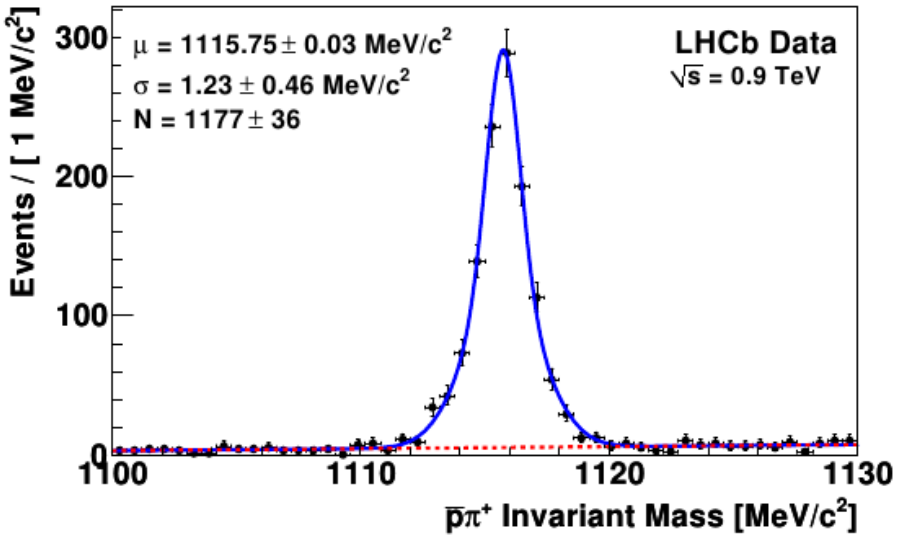
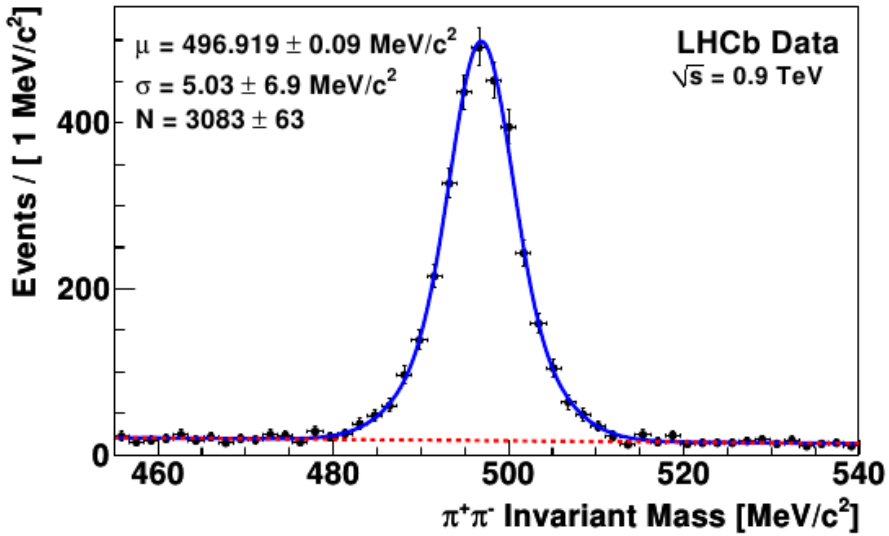
- $\bar{\Lambda}/\Lambda$ probe the baryon transport number. $\bar{\Lambda}/K_s^0$ probe the strange baryon suppression.
- Measurements performed at $\sqrt{s} = 900\,GeV$ $(0.3nb^{-1})$ and $\sqrt{s} = 7\,TeV$ $(1.8nb^{-1})$.
- Very loose trigger: one track seen in downstream tracking.
- A primary vertex is required.
- Prompt K_s^0 and $\Lambda(\bar{\Lambda})$ decaying to $\pi^+\pi^-$ and $p\pi^-(\bar{p}\pi^+)$.
- Cut on IP combination of the Λ and K_s^0 and daughters, to reduce combinatorial background and non-prompt contribution.





- Measurements are done in 6 bins of p_T $(250 < p_T < 2500 MeV/c)$ and 4 bins of rapidity $2 < y < 4$.

Production ratio: $\bar{\Lambda}/\Lambda$, $\bar{\Lambda}/K_s^0$

Systematics

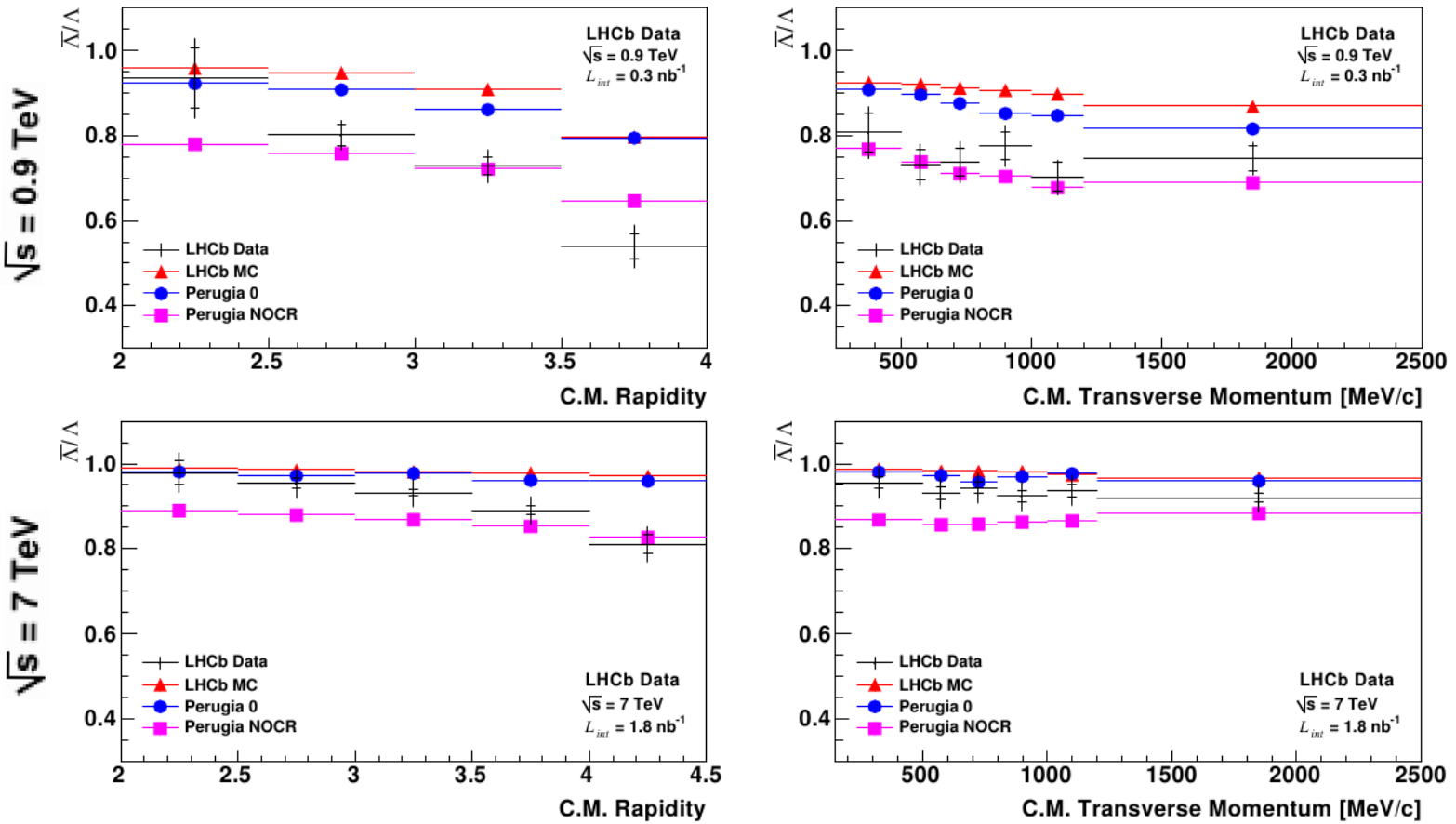
- Efficiency of selection prompt Λ and K_s^0 estimated from MC after reweighing of p_T,y distribution to match data.
- Most systematics cancel through the ratio.

	$\bar{\Lambda}/\Lambda$	$\bar{\Lambda}/K_s^0$
Material interaction (*)	0.02	0.02
Diffractive event fraction(*)	$0.01 - 0.02$	$0.01 - 0.02$
Primary vertex finding (*)	< 0.02	< 0.01
Non prompt fraction (*)	< 0.01	< 0.01
Track finding (*)	negligible	0.01
MC kinematic correction	$0.01 - 0.05$	< 0.03
Signal extraction	0.001	0.001
Total	$0.02 - 0.06$	$0.02 - 0.03$

After corrections, the two magnet polarity sample are in good agreement $\rightarrow$ combined in the results, taking (*) into account.

Baryon Number transport: $\bar{\Lambda}/\Lambda$

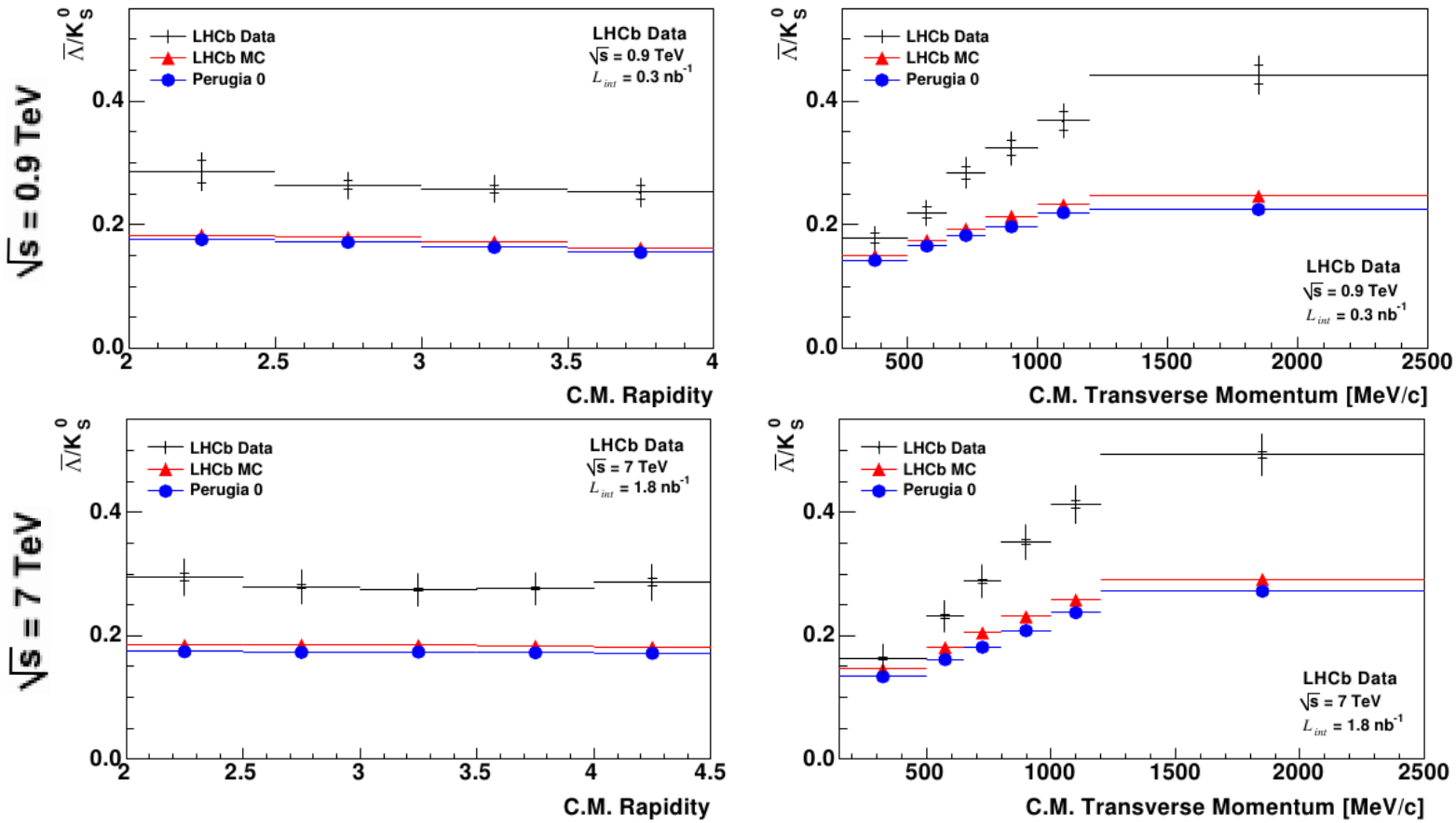
Results



- Good agreement with MC at low rapidity, underestimated at higher rapidity.
- Extreme models of baryon number transport seams to be favoured at high rapidity.

Strange baryon suppression: $\bar{\Lambda}/K_s^0$

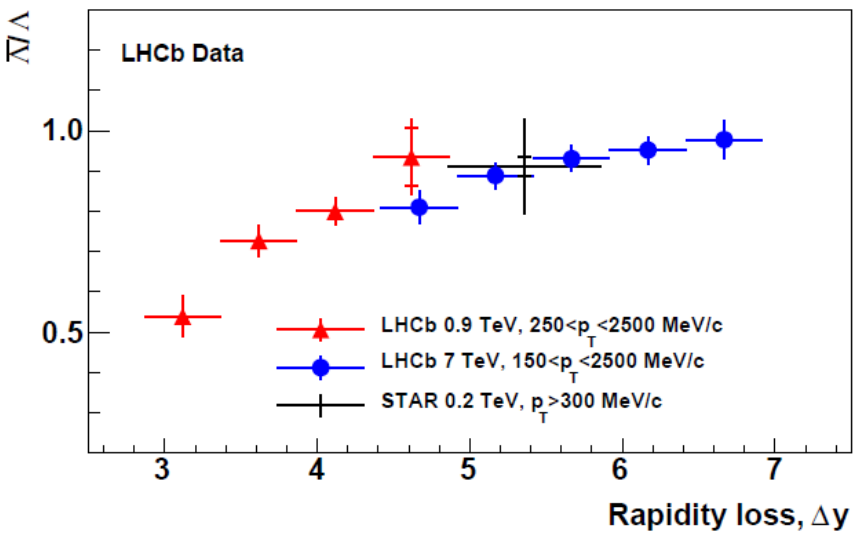
Results

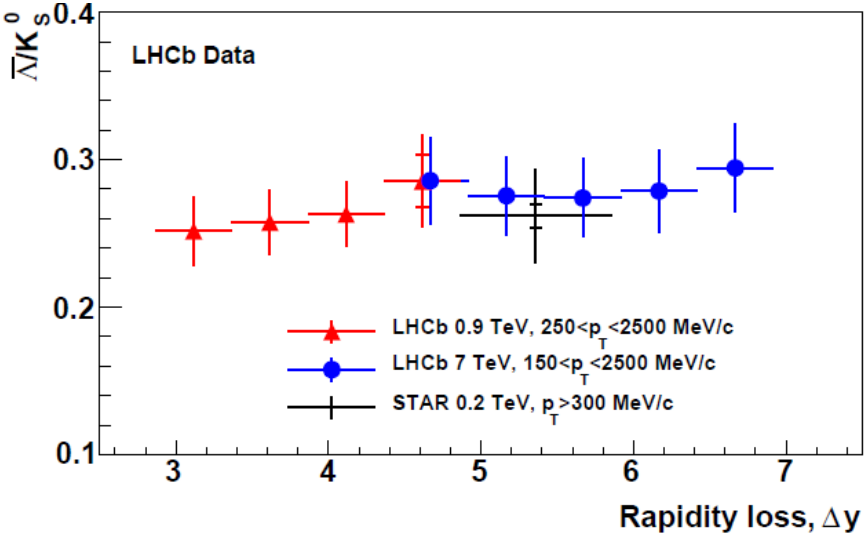


- The ratio Λ/K_s^0, measuring the suppression of strange baryons in hadronisation, is signifcantly larger than expected.

$\bar{\Lambda}/\Lambda$ and $\bar{\Lambda}/K^0_s$ as function of rapidity loss

Results





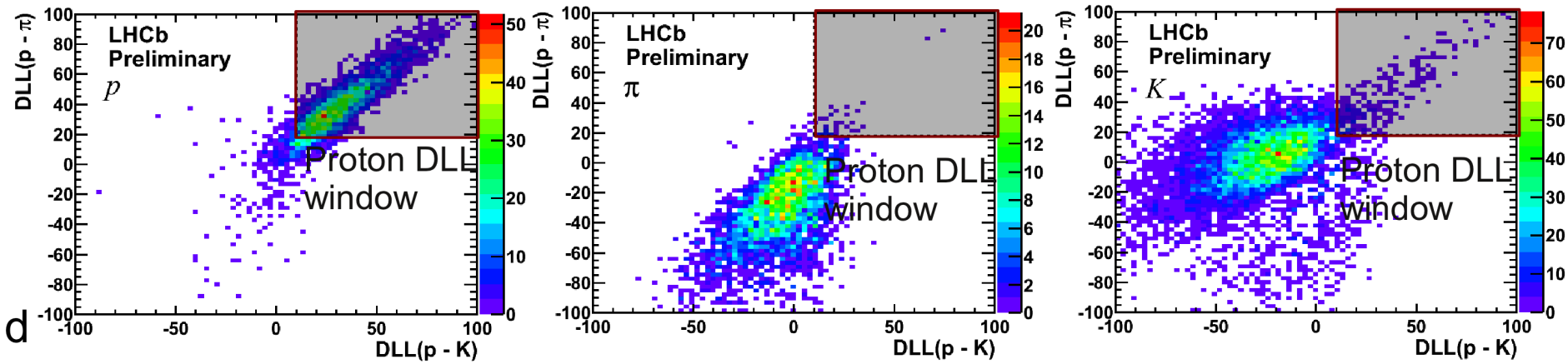
- $\Delta y = y_{beam} - y$
- Agreement with STAR measurment.
- Good agreement between the two energies.

Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

Proton selection

LHCb-CONF-2010-009
Update first shown here

- $\bar{p}/p$ production ratio first presented at ICHEP 2010, since then systematic error treatment have been finalized, and the analysis is extended to K^-/K^+,π^-/π^+, $(\bar{p}+p)/(K^-+K^+)$,$(\bar{p}+p)/(\pi^-+\pi^+)$,$(K^-+K^+)/(\pi^-+\pi^+)$ observables.
- Measurements performed at $\sqrt{s} = 900\,GeV$ $(0.3nb^{-1})$ and $\sqrt{s} = 7\,TeV$ $(1.8nb^{-1})$ with loose trigger.
- Prompt particles with $p > 5\,GeV/c$ are selected with PID requirements.
- Efficiency and purity of the PID evaluated on data using tag and probe method on calibration samples: $\phi \to K^+K^-$, $K_s \to \pi^+\pi^-$ and $\Lambda \to \pi p$.



- Measurements are done in 3 bins of p_T $(0; 0.8; 1.2\,GeV/c)$ and 5 bins of rapidity $2 < y < 4.5$.

Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

Correction for reconstruction bias and systematics

- Cross contamination effect for ID efficiency and misID extracted from calibration sample for each p_T, η bins, magnet polarity and particle/anti particle.
- ID efficiency reweighted according to track multiplicity.
- For p of $p_T > 1.2\,GeV$, purities are $> 90\%$ with efficiencies $> 95\%$ for $\eta > 3$.
- Correction of particle losses through interaction with material extracted from MC for each p_T, η bins, magnet polarity and particle/anti particle.

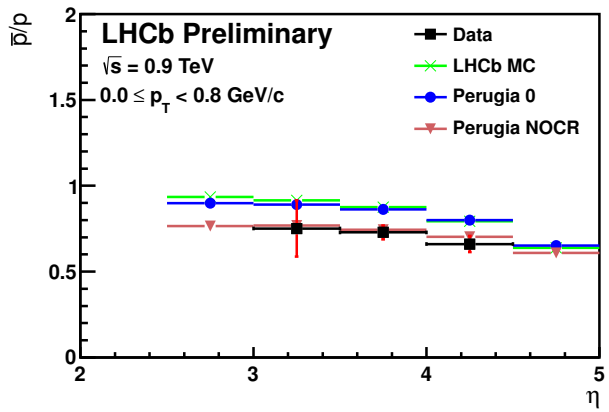
Main systematics
(bin extrema values)

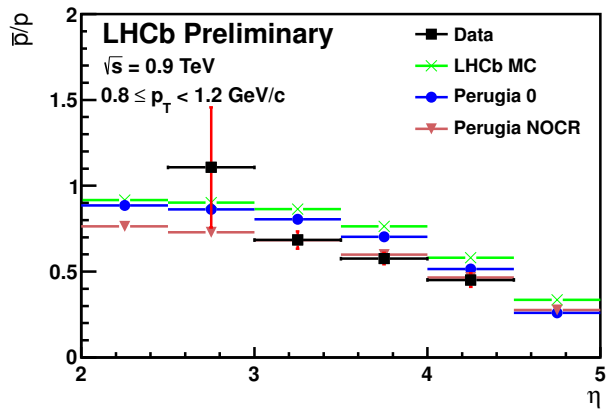
$\pm$ ratios	$\sqrt{s} = 900\,GeV$	$\sqrt{s} = 7\,TeV$
PID contamination (%)	0.8-45	0.5-25.
Material Interaction (%)	0.04-1.5	0.04-1.7
MC Detector description (%)	0.04-1.6	0.04-0.8
Track asymmetry (%)	1.	0.5

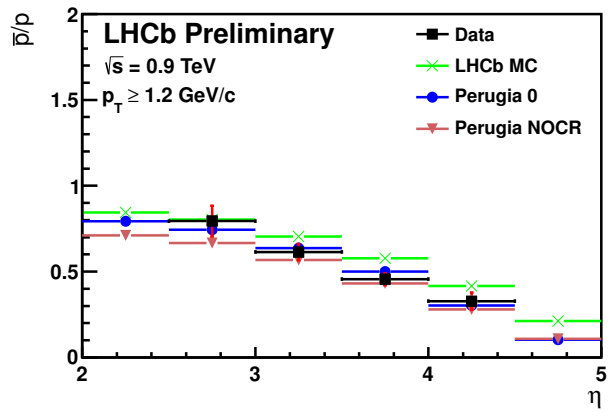
A/B ratios	$\sqrt{s} = 900\,GeV$	$\sqrt{s} = 7\,TeV$
PID contamination (%)	6.-64.	3.7-31.
Material Interaction (%)	0.08-2.4	0.2-2.2
MC Detector description (%)	0.04-1.2	0.1-1.1

Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

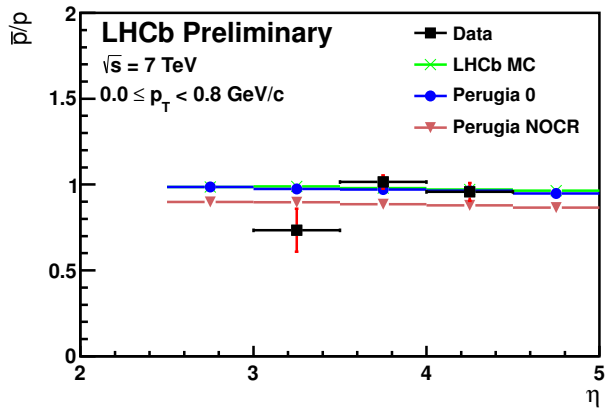
$\bar{p}/p$ @ $\sqrt{s} = 900\,GeV$

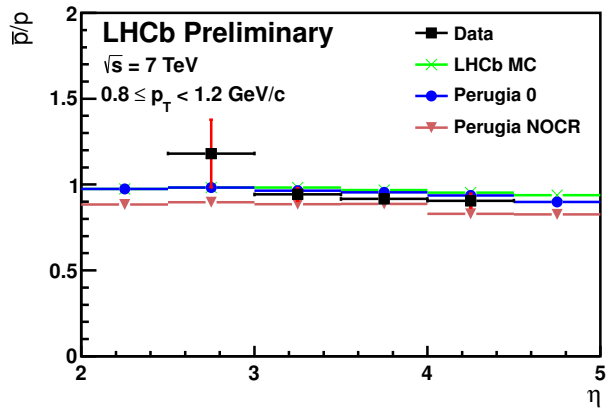


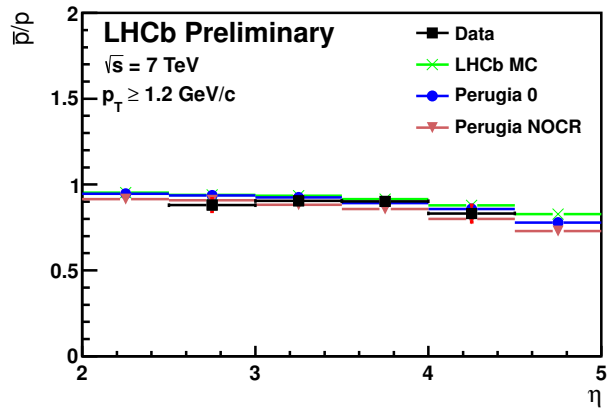




$\bar{p}/p$ @ $\sqrt{s} = 7\,TeV$

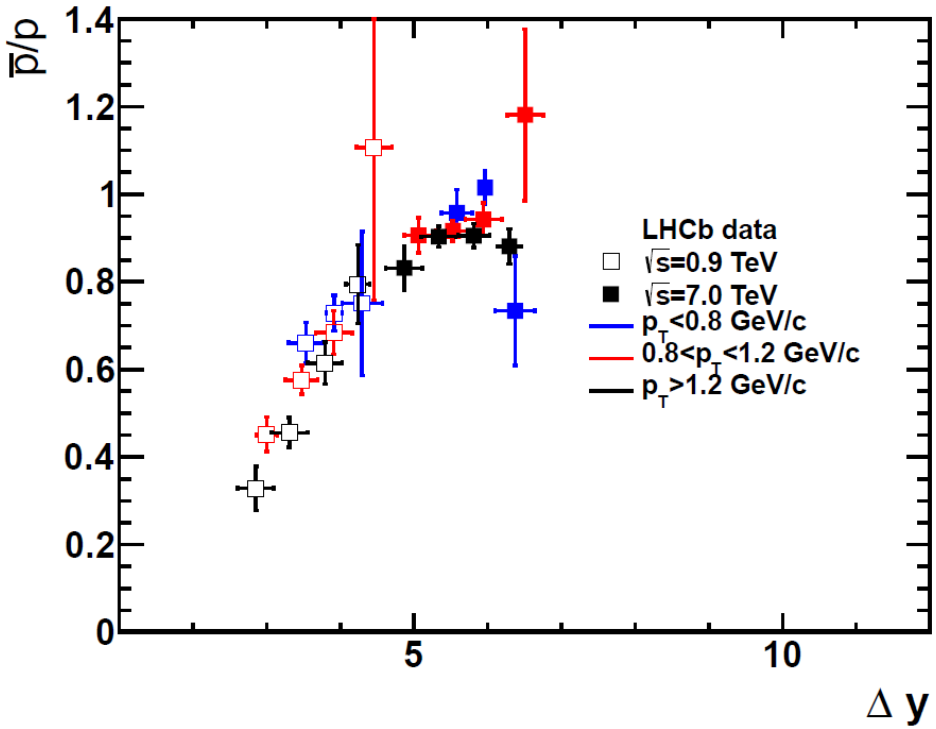


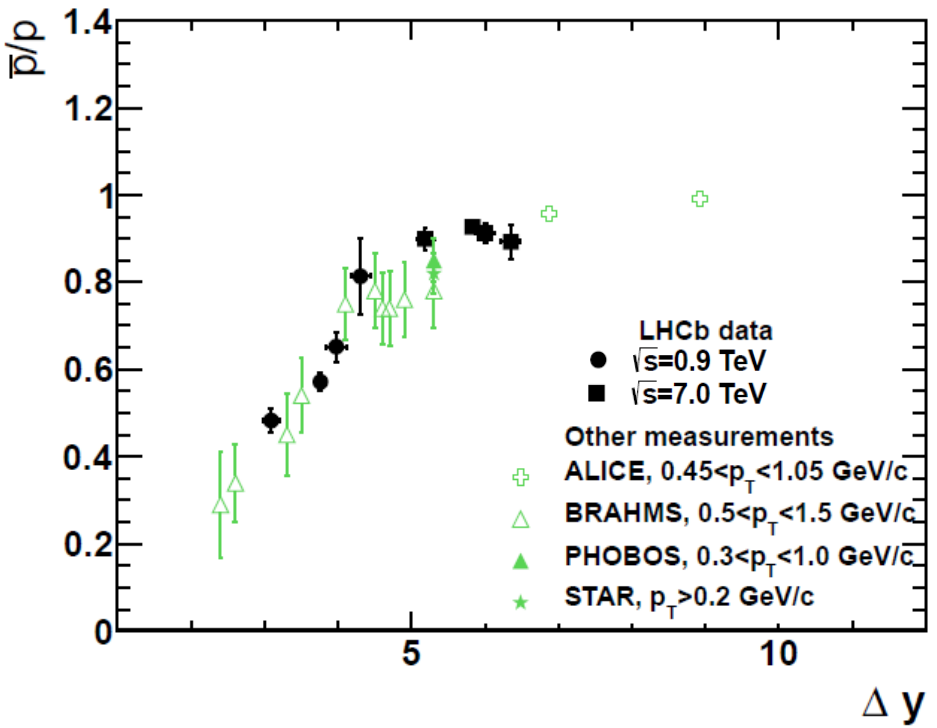




Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

Baryon number transport

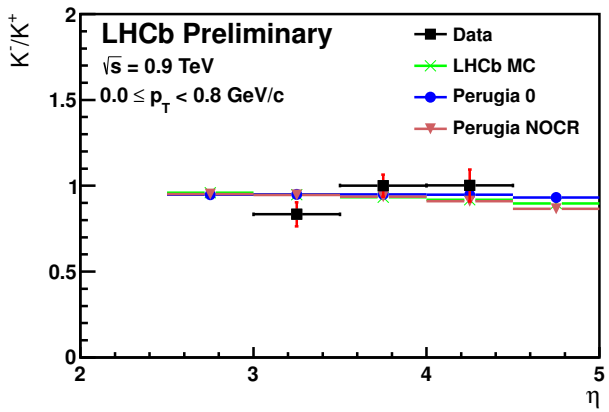


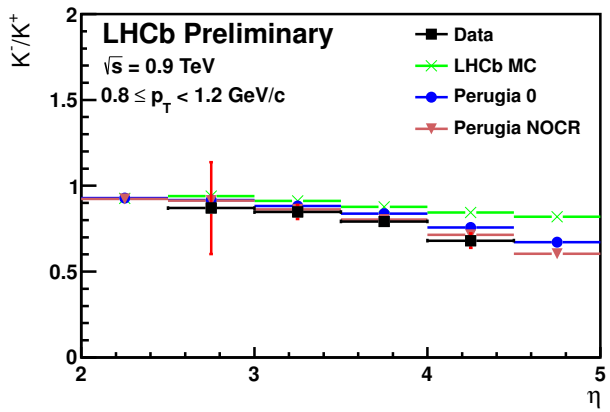


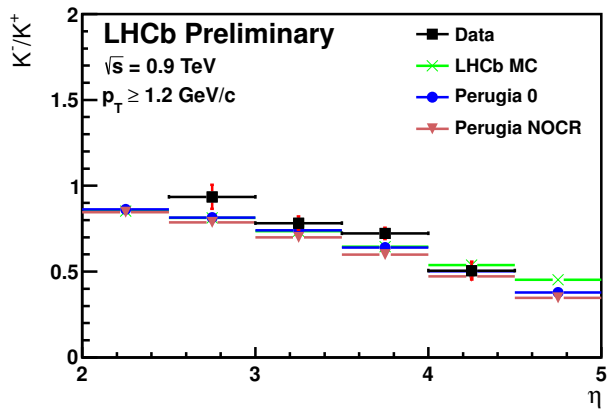
- No evidence of significant p_T dependency.
- Consistent with previous experiments but significantly more precise.

Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

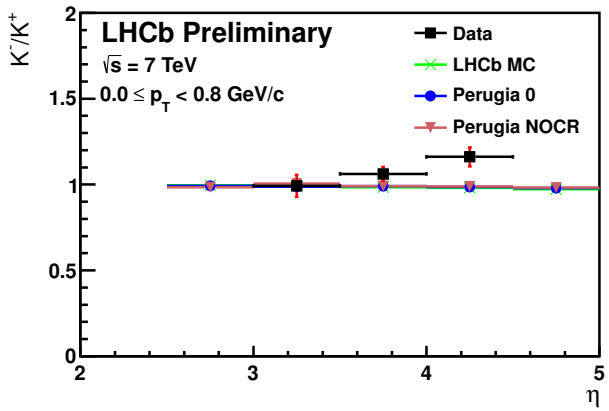
K^-/K^+ @ $\sqrt{s} = 900\,GeV$

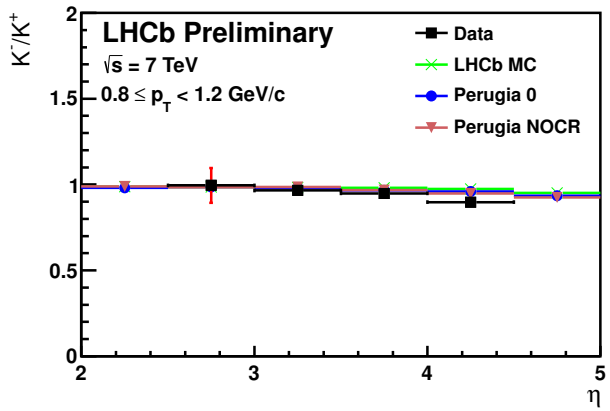


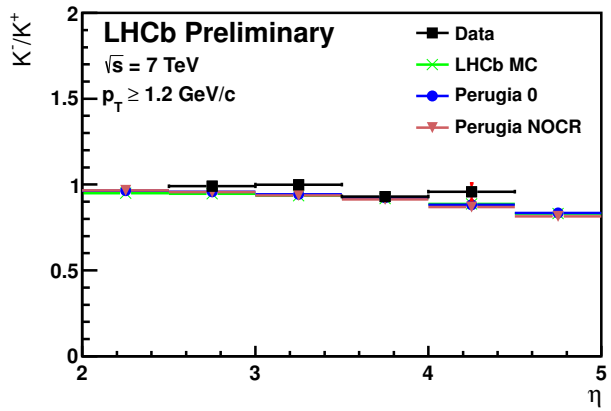




K^-/K^+ @ $\sqrt{s} = 7\,TeV$

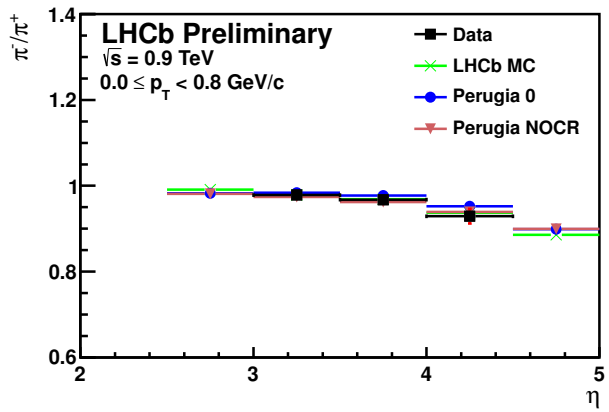


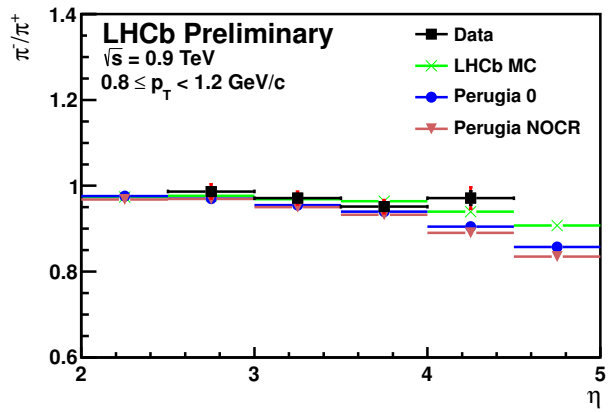


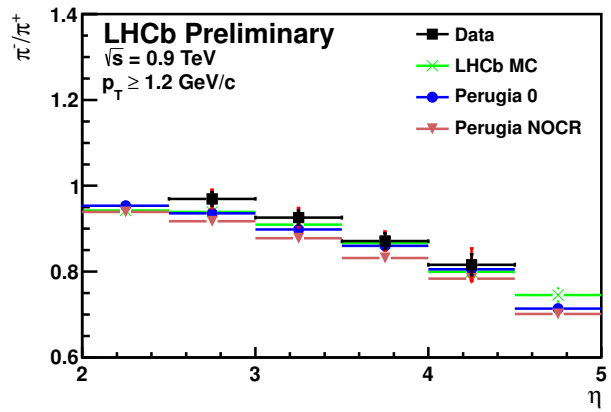


Prompt hadron production ratio at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

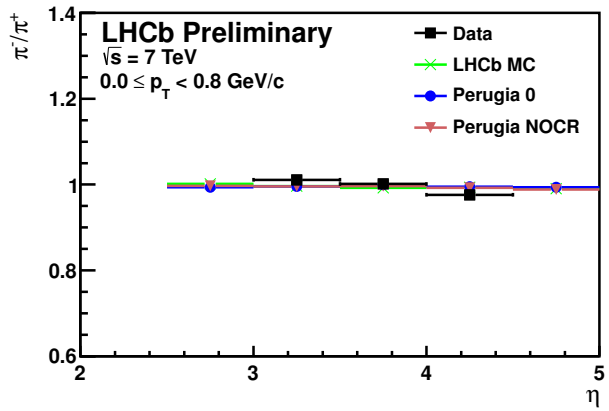
π^-/π^+ @ $\sqrt{s} = 900\,GeV$

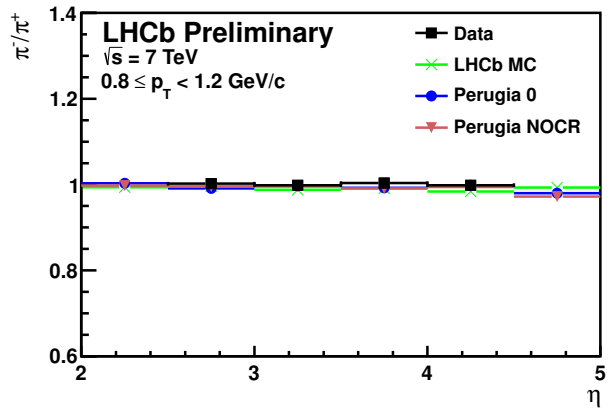


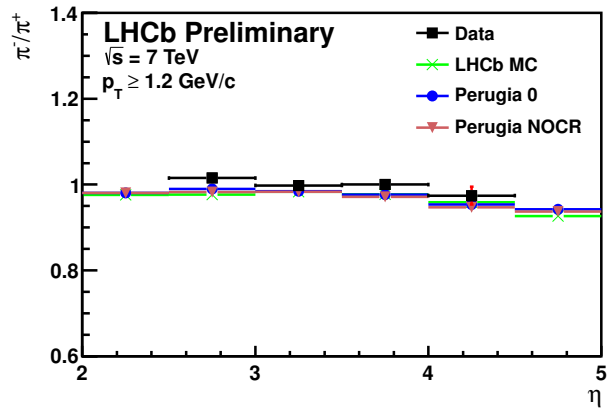




π^-/π^+ @ $\sqrt{s} = 7\,TeV$

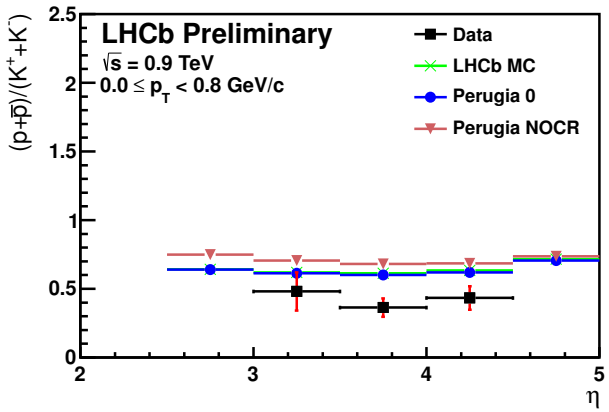


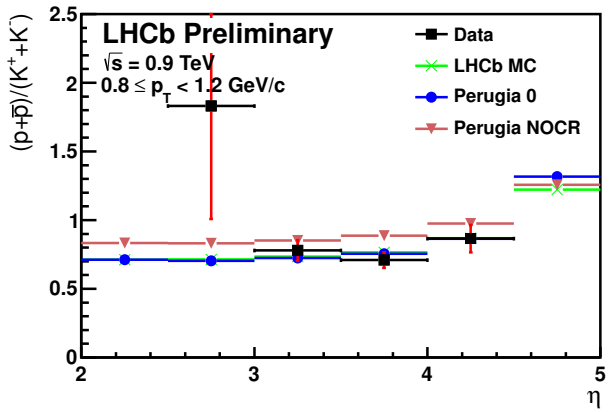


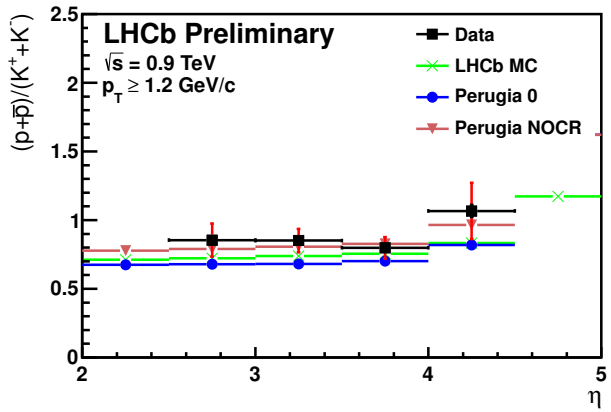


Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

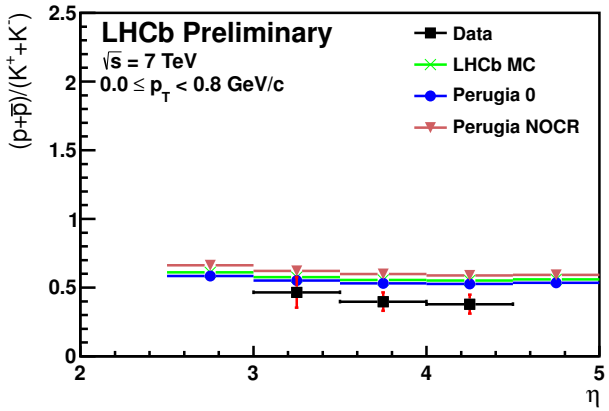
$(\bar{p} + p)/(K^- + K^+)$ @ $\sqrt{s} = 900\,GeV$

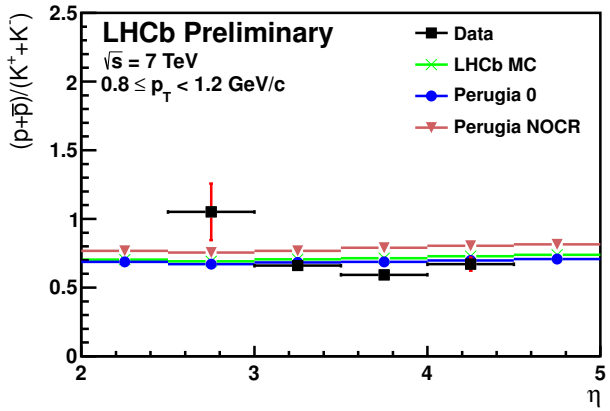


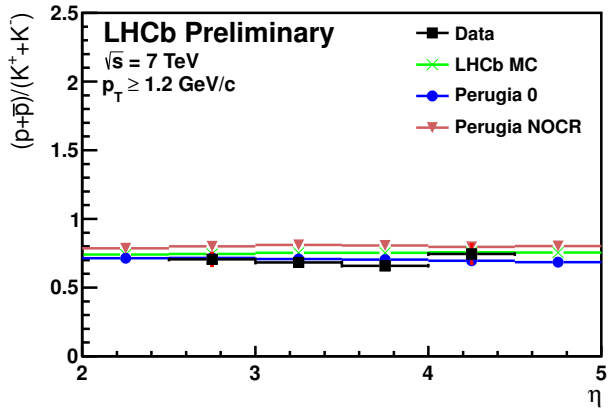




$(\bar{p} + p)/(K^- + K^+)$ @ $\sqrt{s} = 7\,TeV$

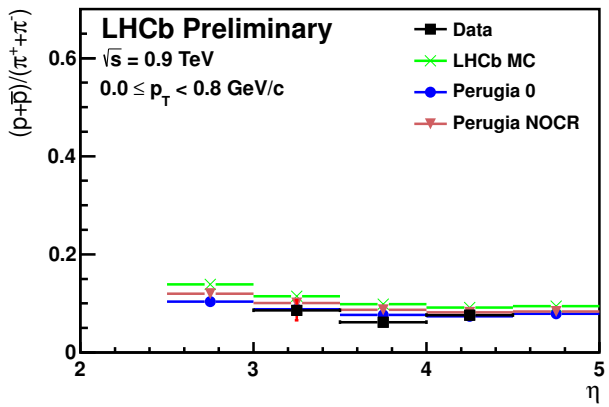


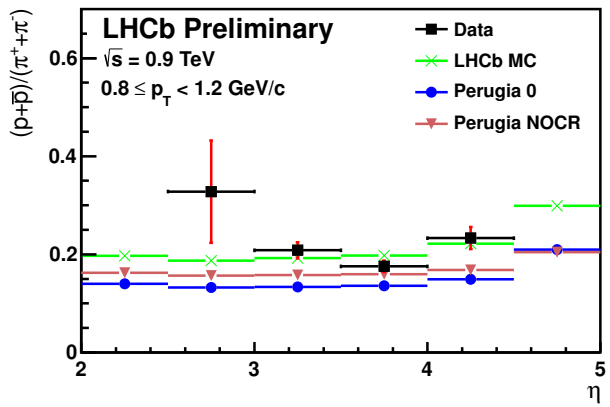


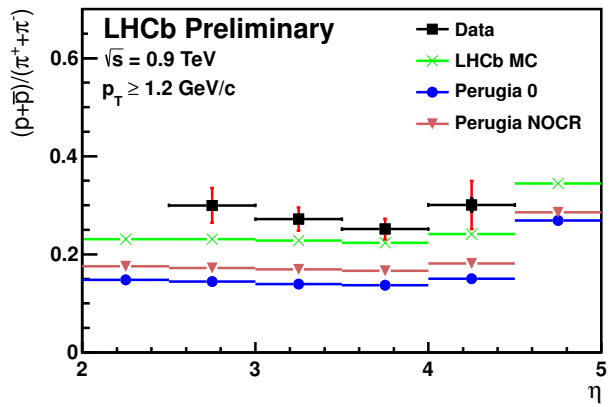


Prompt hadron production ratio at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

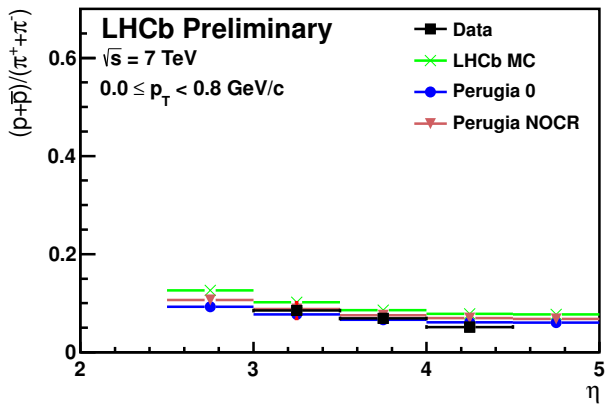
$(\bar{p} + p)/(\pi^- + \pi^+)$ @ $\sqrt{s} = 900\,GeV$

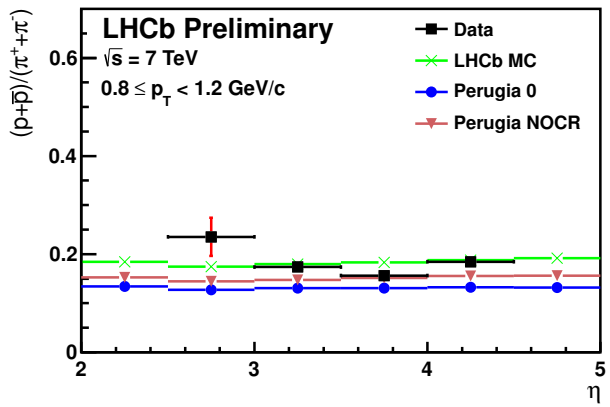


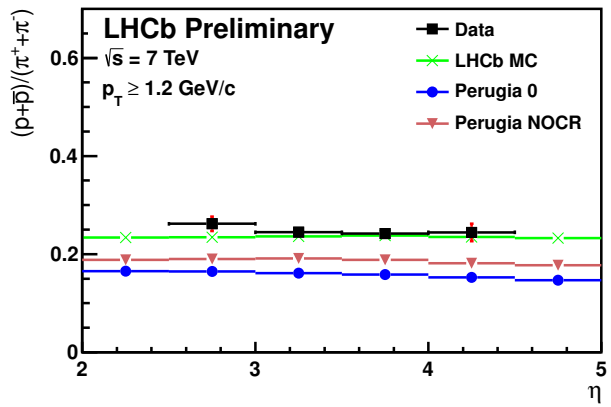




$(\bar{p} + p)/(\pi^- + \pi^+)$ @ $\sqrt{s} = 7\,TeV$

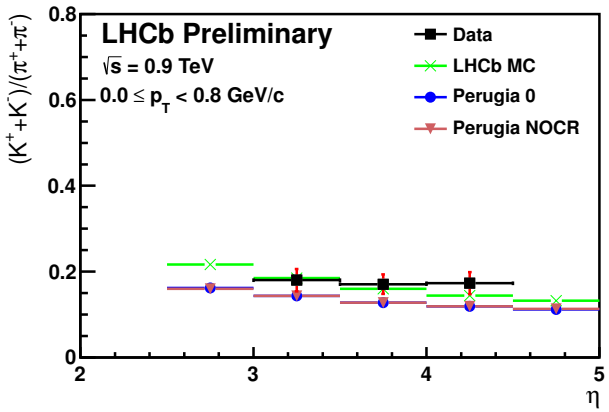


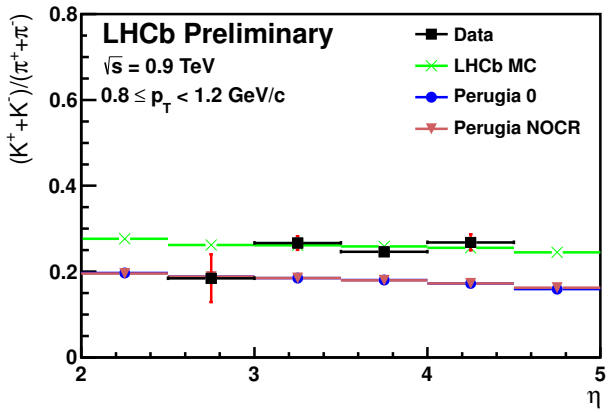


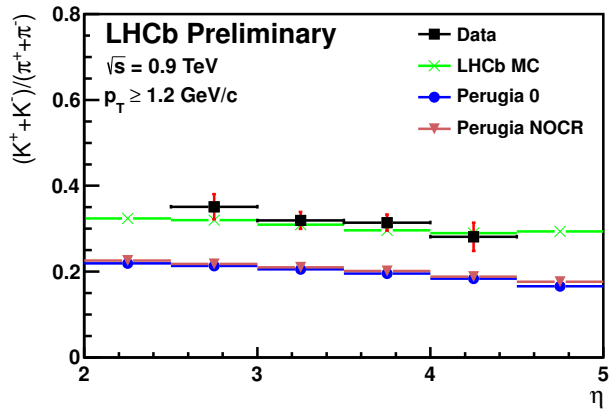


Prompt hadron production ratios at $\sqrt{s} = 900\,GeV$ and $\sqrt{s} = 7\,TeV$

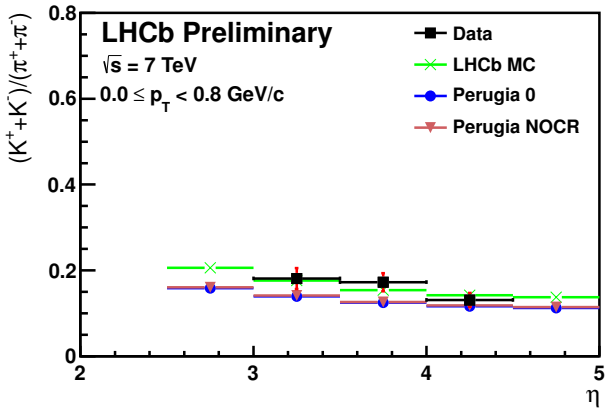
$(K^- + K^+)/(\pi^- + \pi^+)$ @ $\sqrt{s} = 900\,GeV$

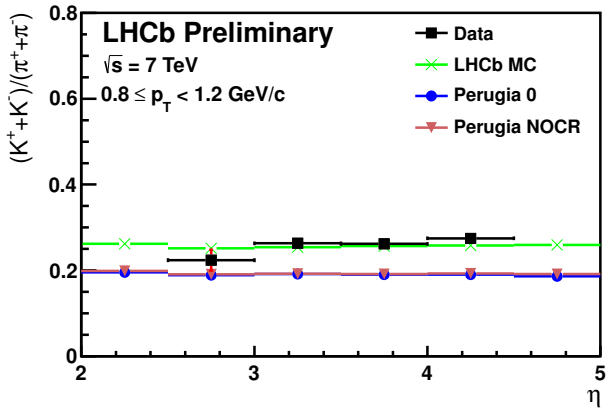


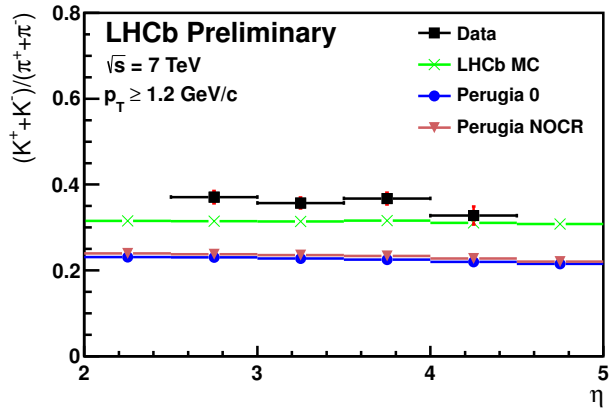




$(K^- + K^+)/(\pi^- + \pi^+)$ @ $\sqrt{s} = 7\,TeV$







Summary

- LHCb experiment provide an excellent environment for particle production studies at high rapidity.
- ϕ production is underestimated in event generators, p_T and y spectra differs from prediction.
- Charged particle production is underestimated in most of the generator tunes for soft events, better agreement for hard interaction.
- $\bar{\Lambda}/K_s^0$ is higher than expected, especially at large p_T.
- Baryon number transport is generally underestimated in MC models, especially at $\sqrt{s} = 900\ GeV$.
- Prompt hadron production ratios measurement also shows there is room for improvement in tuning of MC models in LHCb rapidity region.

Backup

Pythia LHCb MC

Non default PYTHIA parameters in the LHCb simulation software

Parameter	Value	Parameter	Value
CKIN(41)	3.0	PARP(86)	0.66
MSTP(2)	2	PARP(89)	14000
MSTP(33)	3	PARP(90)	0.238
MSTP(81)	21	PARP(91)	1.0
MSTP(82)	3	PARP(149)	0.02
MSTP(52)	2	PARP(150)	0.085
MSTP(51)	10042	PARJ(11)	0.5
MSTP(142)	2	PARJ(12)	0.4
PARP(67)	1	PARJ(13)	0.79
PARP(82)	4.28	PARJ(14)	0.0
PARP(85)	0.33	PARJ(15)	0.018
MSTJ(26)	0	PARJ(16)	0.054
PARJ(33)	0.4	PARJ(17)	0.131

Processes activated in the LHCb simulation software

Process number	Description
11	$f + f' \to f + f'$ (QCD)
12	$f + \overline{f} \to f' + \overline{f'}$
13	$f + \overline{f} \to g + g$
28	$f + g \to f + g$
53	$g + g \to f + \overline{f}$
68	$g + g \to g + g$
91	Elastic scattering
92	Single diffractive ($AB \to XB$)
93	Single diffractive ($AB \to AX$)
94	Double diffractive
95	Low-p_T scattering
421 – 439	Prompt charmonium
461 – 479	Prompt bottomonium

Pythia Perugia Tunes

Phys.Rev. D82 (2010) 074018