Soft QCD measurements in the forward direction with the LHCb experiment

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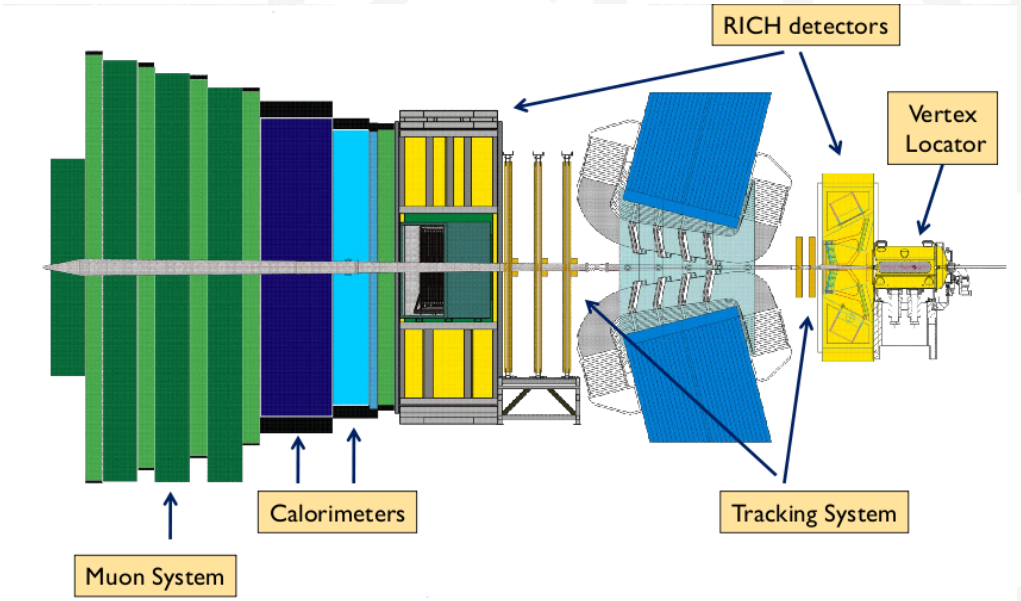
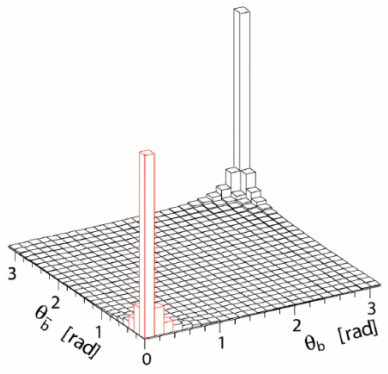
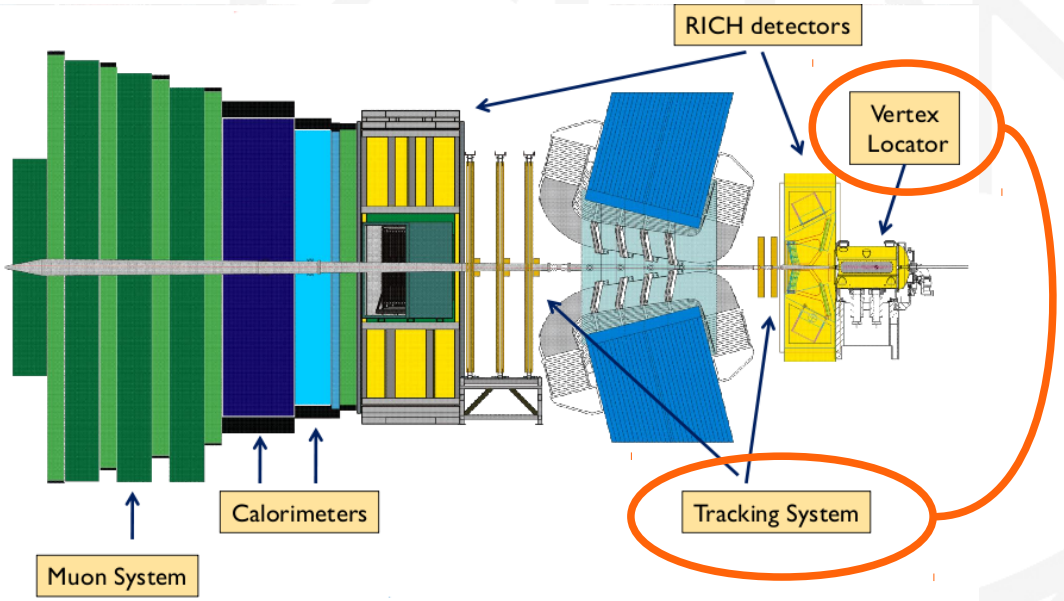
The LHCb experiment



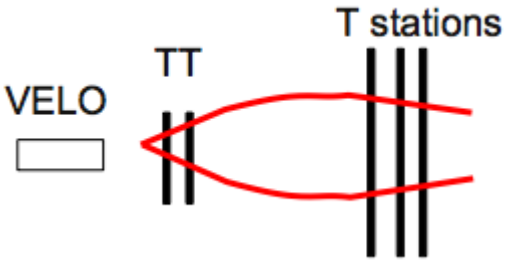


- **Single arm forward spectrometer made for high precision measurements of CP violation and rare decays in the beauty and charm sector**
  - B hadrons at the LHC are predominantly produced at low polar angles in the same forward cone
- **Excellent vertexing**
  - **VELO**, 8 mm distance to beam, impact parameter resolution ~15μm (high p_T)
    - VELO Pile-Up unit
- **Unique Hadron PID**
  - Two **RICH** detectors exploiting 3 radiators

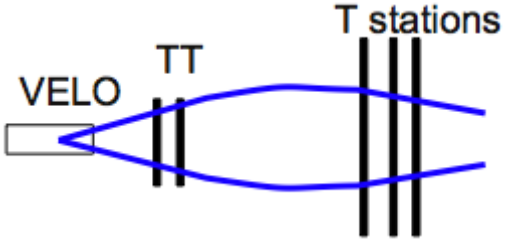
Tracking



- **Excellent tracking performance**
  - Momentum resolution of tracks $\delta p/p \sim 0.3 - 0.5\%$ depending on p
  - Mass resolution ~ 10 – 20 MeV/c^2 depending on the B channel



Downstream tracks



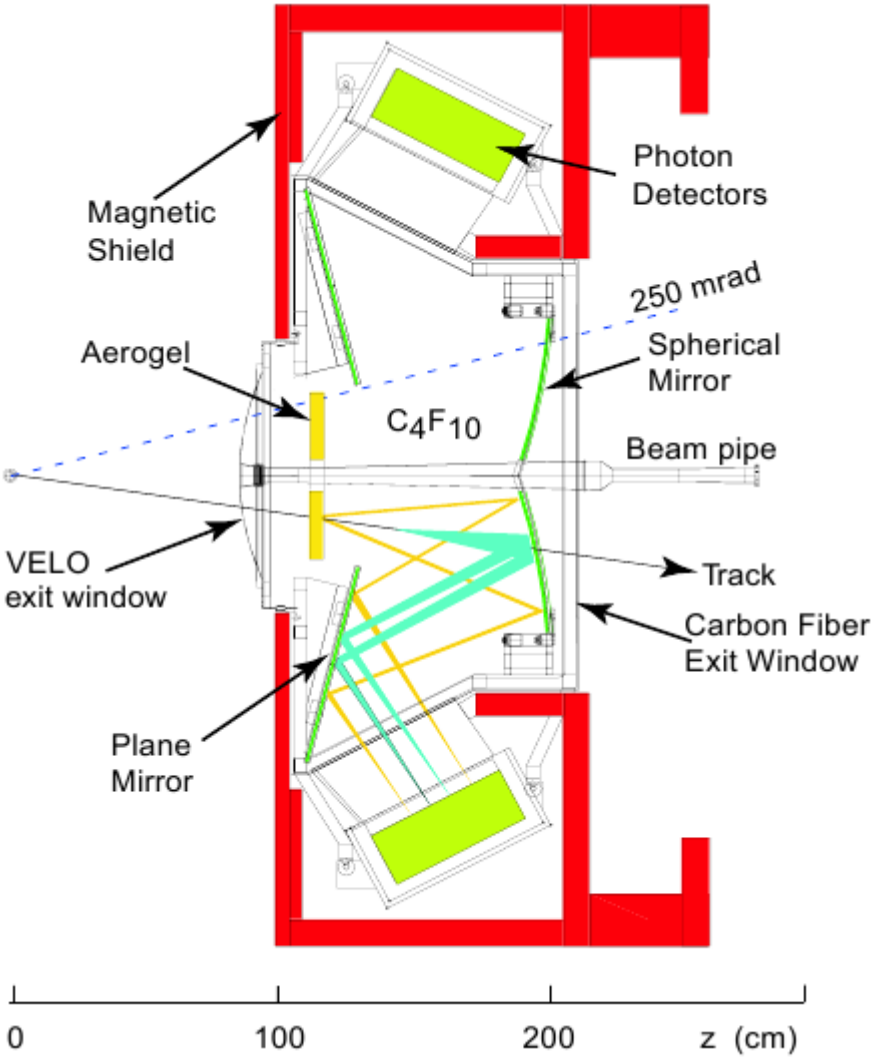
Long tracks

Particle Identification

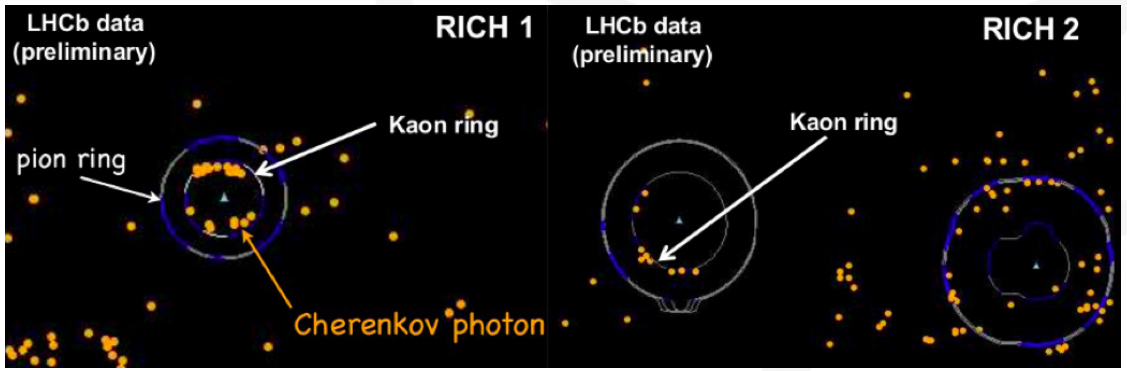
PID over large momentum range thanks to RICH Cherenkov light detectors:

➞ Efficient π/K, p/K separation

- **RICH1**
  - Aerogel p < 10 GeV/c
  - C_4F_{10} p < 60 GeV/c
- **RICH2**
  - CF_4 15 < p < 100 GeV/c



Key feature for $\bar{p}$/p and φ studies

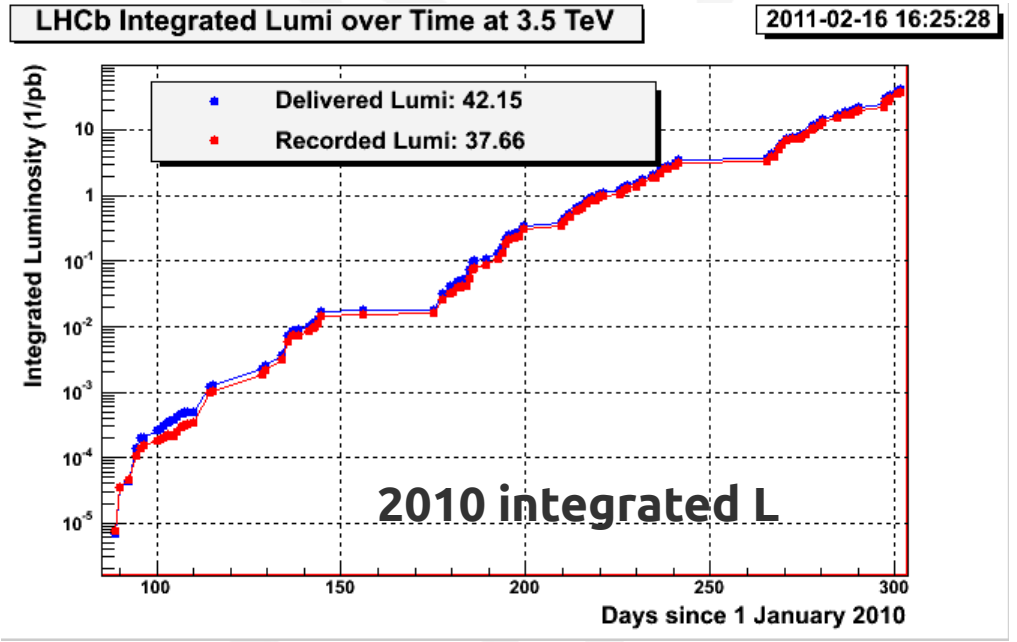


Recorded luminosity

LHCb designed L = $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$
Current L = $3.5 \cdot 10^{32}$ $cm^{-2}s^{-1}$

➡ Large pile-up

✔ Subdetectors performing OK
✔ Good quality of recorded data
✔ High data taking efficiency



year	*luminosity*	*$\sqrt{s}$ (TeV)*
2009	6.8 μb^{-1}	0.9
2010	0.3 nb^{-1}	0.9
2010	37 pb^{-1}	7
2011	> 631 pb^{-1}	7

Results in this talk from here (only a small fraction of 37 pb^{-1} @7 TeV)

1 fb^{-1} expected by the end of 2011

Strangeness production

K^0_s cross-section at 0.9 TeV and ϕ cross-section at 7.0 TeV

PLB 693 (2010) pp. 69-80
arXiv:1008.3105v2

arXiv:1107.3935
(submitted to PLB)

Motivation:

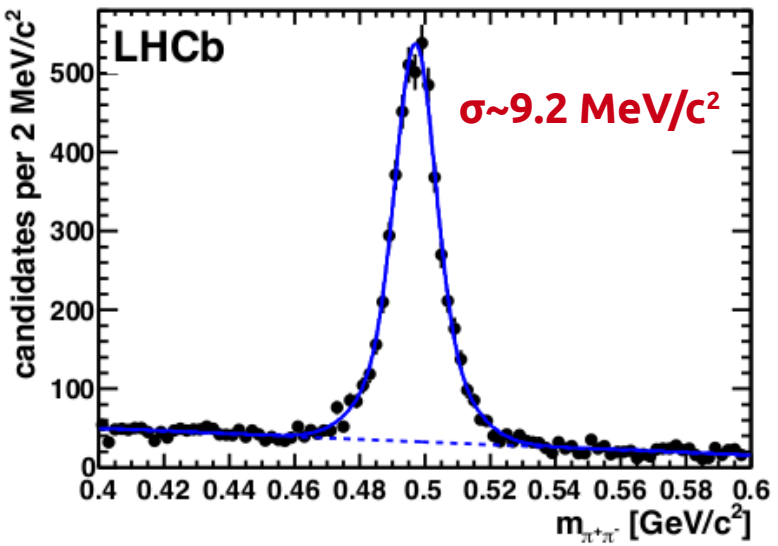
- Sensitive tests of soft hadronic interactions, M_s is of the order of Λ_{QCD}
- QCD predictions in this region have large uncertainties
- Explore uncovered phase space regions
  - LHCb complementary wrt other LHC experiments
  - Current models have been tuned to describe SPS and Tevatron data (central rapidity and $p_T > 0.5$GeV)

K^0_s cross section

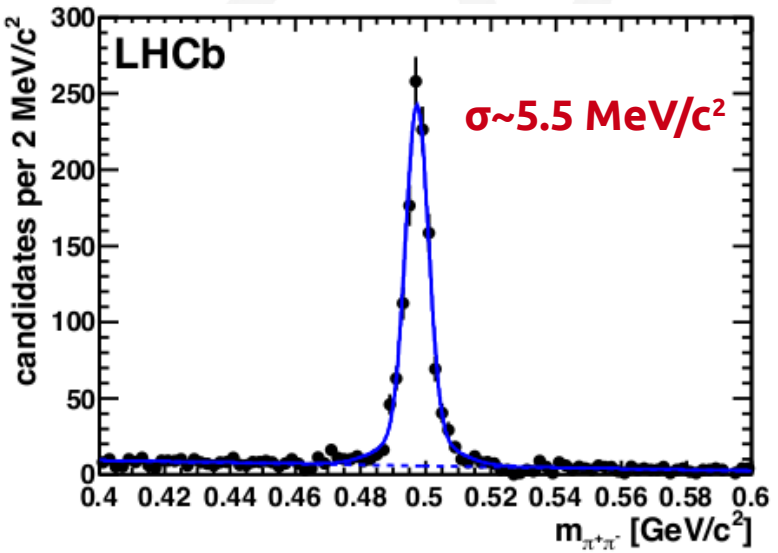
- Prompt K^0_s reconstructed in $K^0_s \rightarrow \pi^+\pi^-$
- Done with first 2009 MB data: 6.8 μb^{-1} @0.9 TeV (calo based MB trigger)
- No PID
- L_{int} estimation: a novel technique based on the beam currents, sizes and positions
- Testing ground for detector understanding/calibration (early alignment and reconstruction)

Long K^0_s lifetime
VELO partially open ➡ **two paths for reconstruction:**

downstream-track selection



long-track selection

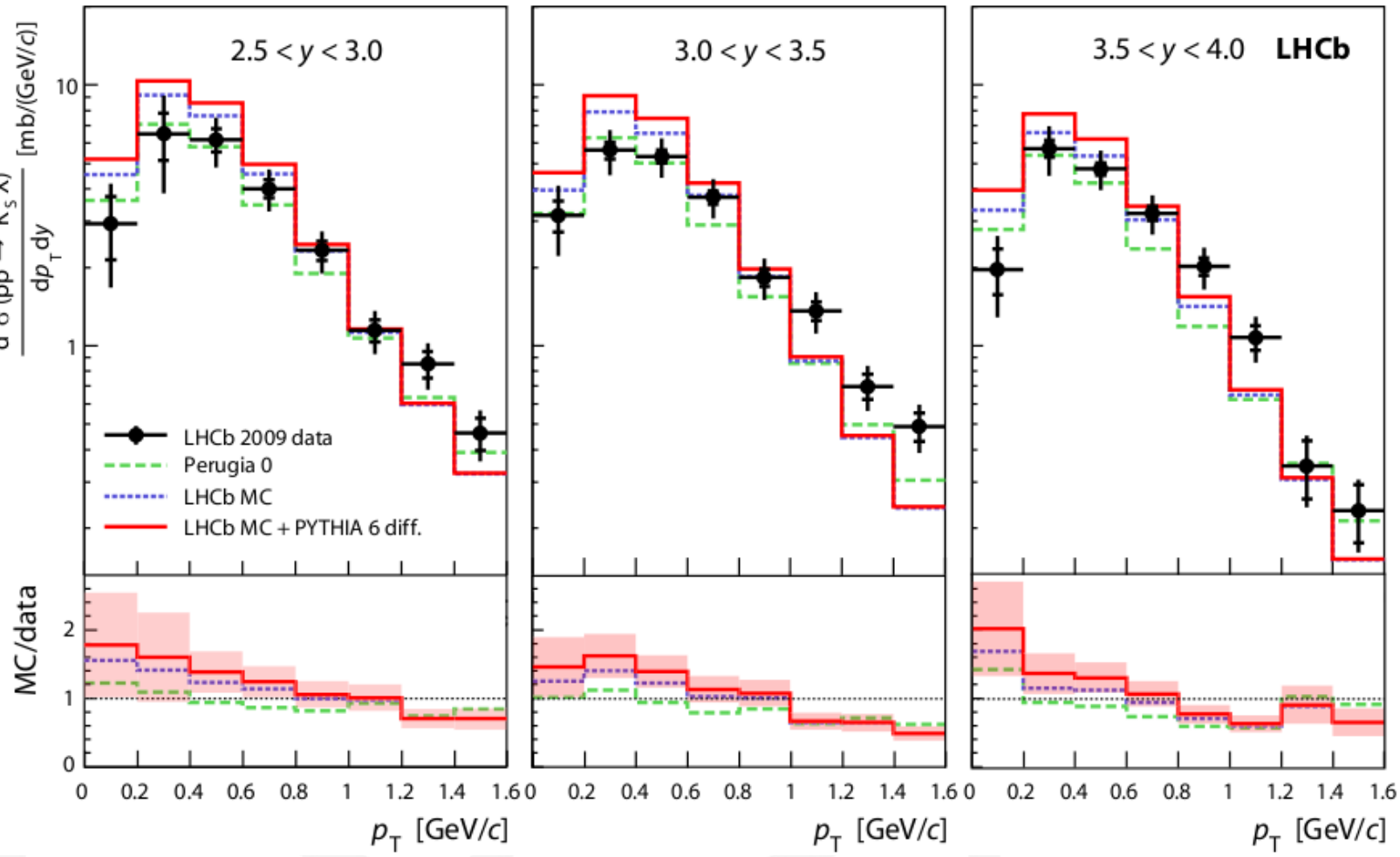


K^0_s cross section

$$\frac{d\sigma^2}{dp_T dy}$$

key systematics:
luminosity 12%
tracking eff. 10%

efficiencies estimated using MC

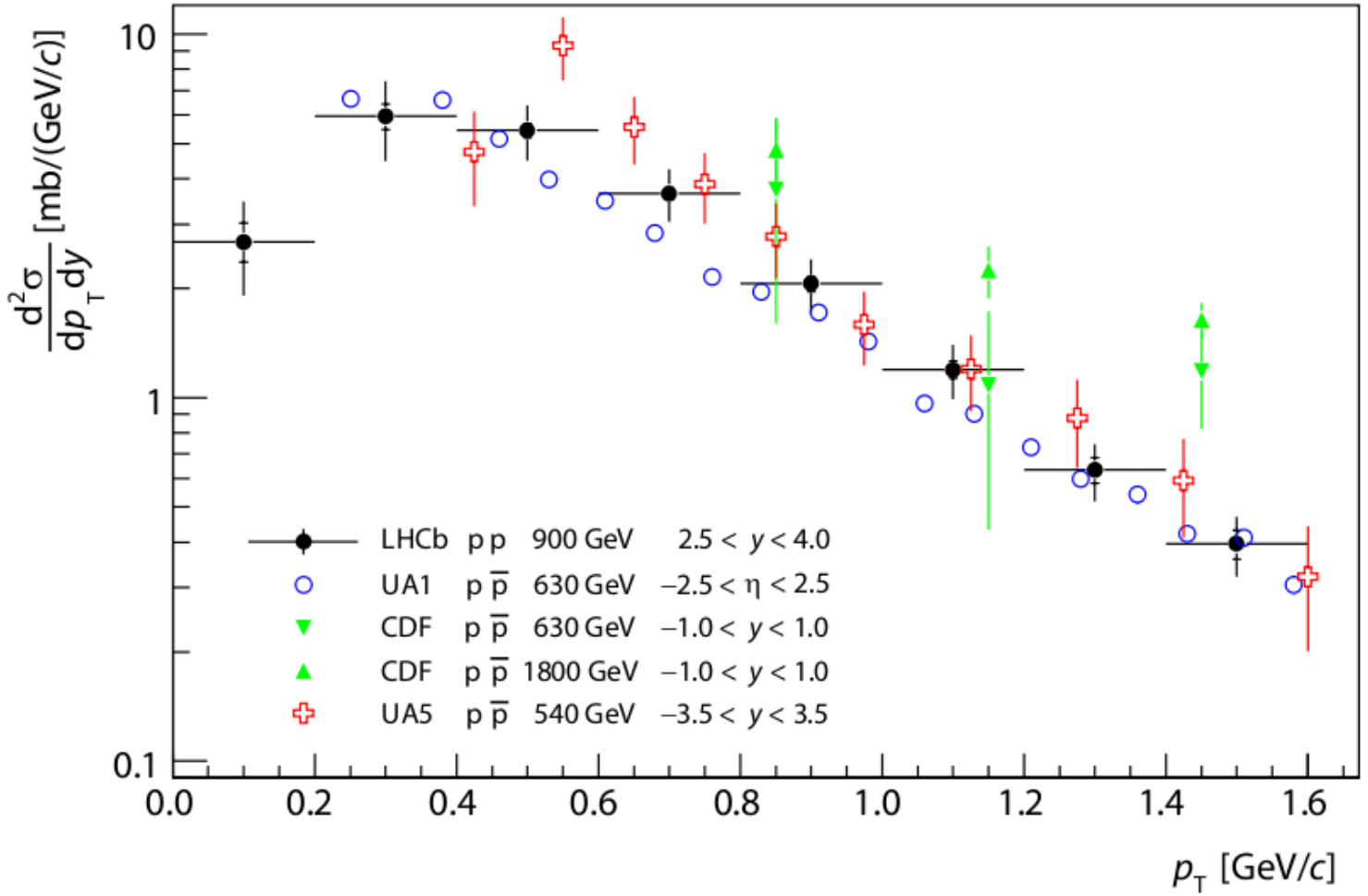


- P_T spectrum is harder in data than in MC
- Best description given by Perugia 0 tune (no diffraction)

[Phys. Rev. D **82** (2010) 074018]

K^0_s cross section

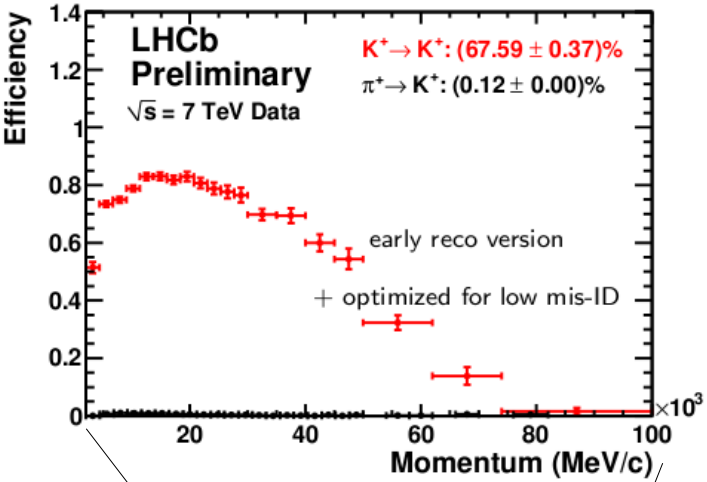
Comparison with other experiments having different collision energies and rapidity coverage:



Rapidity and p_T range extended

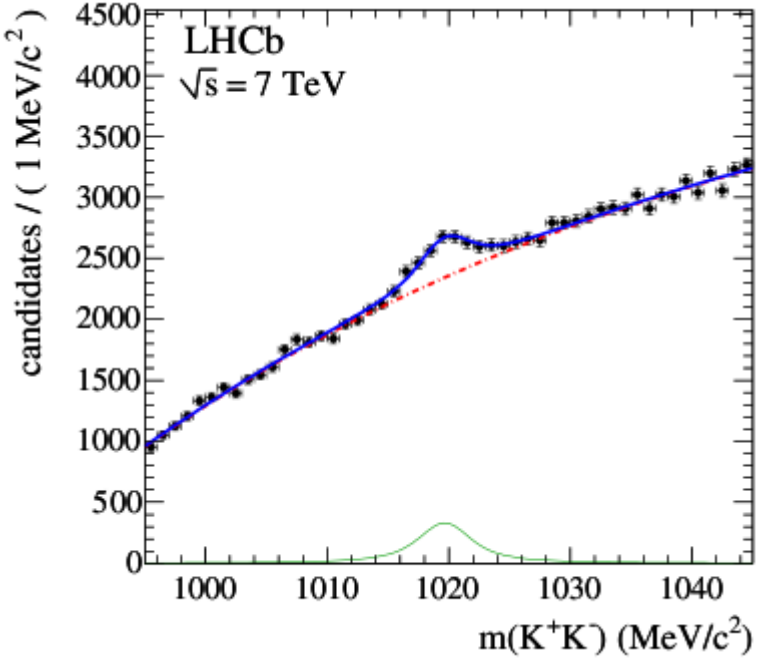
ϕ cross section

- Reconstructed in $\phi \rightarrow K^+K^-$
- Done with 2010 data: 14.7 nb^{-1} @7 TeV (low pile-up)
- Test of RICH PID performance
- Only reconstruction efficiency relies on MC
- RICH PID cut efficiency determined on data

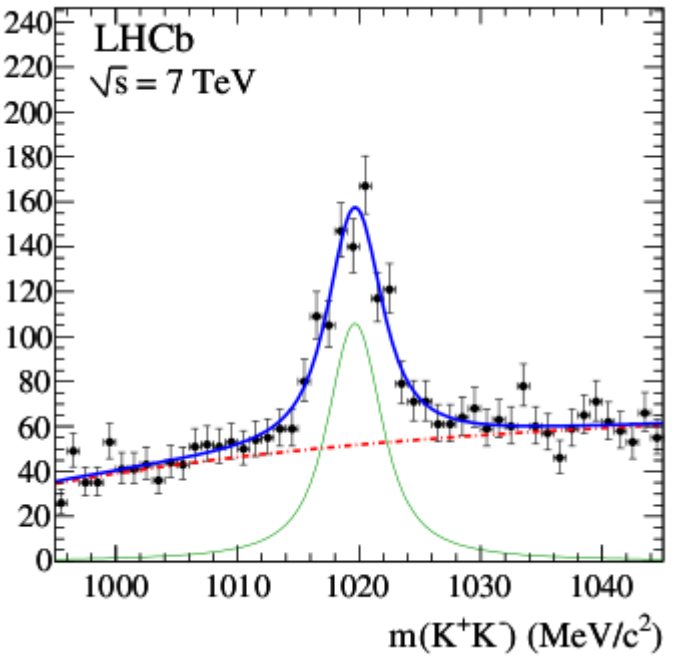


Tag-and-Probe approach

Tight PID cut on **one** kaon (*tag* sample)



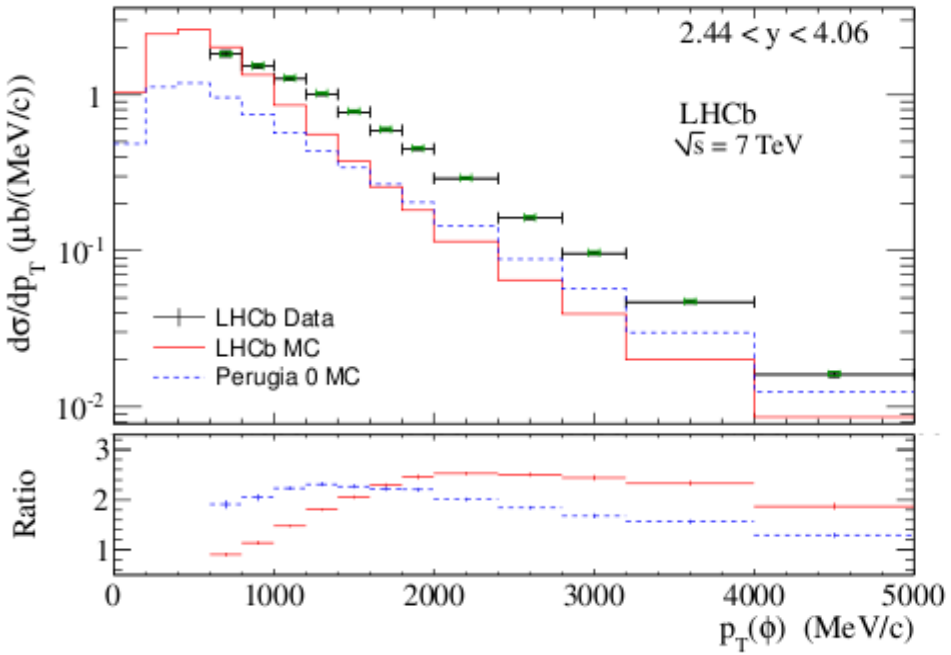
Tight PID cut on **both** kaons (*probe* sample)



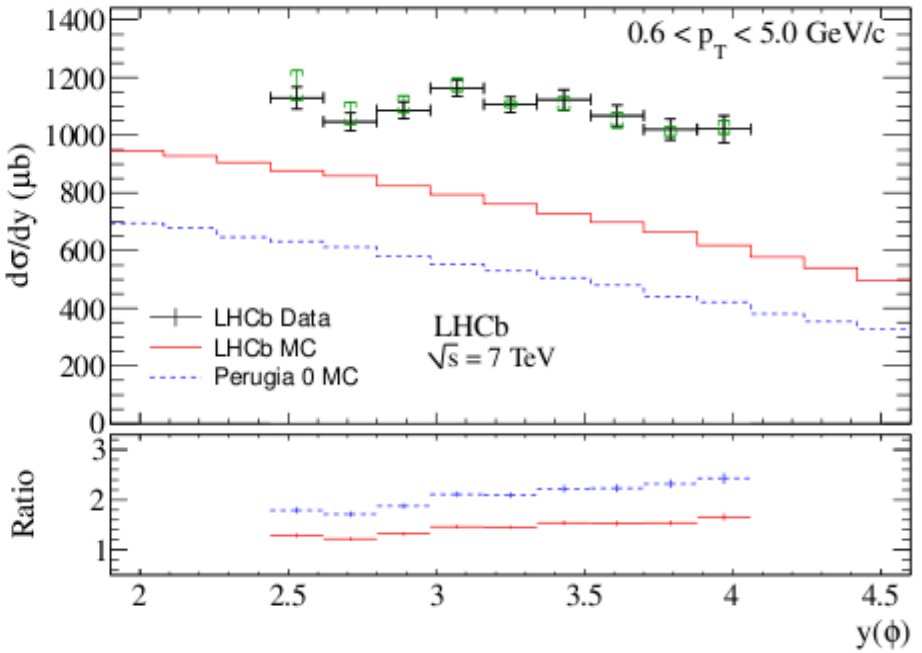
Deduce PID cut efficiency (tag&probe)

ϕ cross section

$$\frac{d\sigma}{dp_T}$$



$$\frac{d\sigma}{dy}$$



- φ production underestimated in the measured kinematic range by both LHCb-MC and Perugia 0
- Harder p_T spectrum as compared to MC

V^0 ratios

$\bar{\Lambda}/\Lambda$ and $\bar{\Lambda}/K^0_s$ production ratios at 0.9 TeV and 7.0 TeV

arXiv:1107.0882v2
(submitted to JHEP)

Motivation:

- $\bar{\Lambda}/\Lambda$: direct measurement of the baryon transport from the beam particles to the fragmented final states.
- $\bar{\Lambda}/K^0_s$: good test of fragmentation models probing baryon-to-meson production suppression
- Production ratios cancel many systematic uncertainties
- Independent from luminosity measurement

Identification:

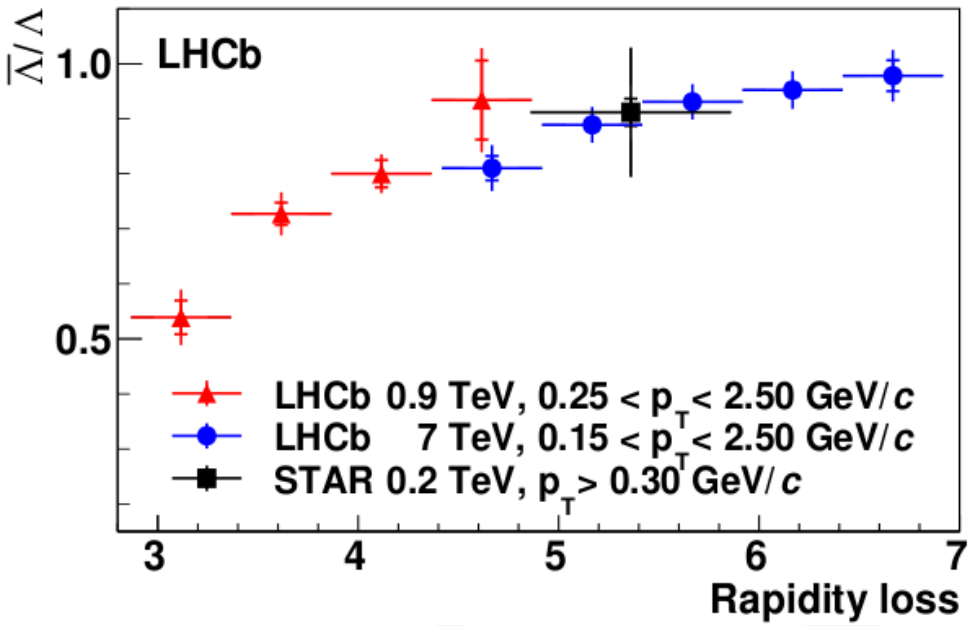
- Long tracks only, cuts on track X^2 to remove fakes
- Λ and Ks selection based on impact parameters
- Reconstructed in $\Lambda \rightarrow p\pi$, $K^0_s \rightarrow \pi\pi$

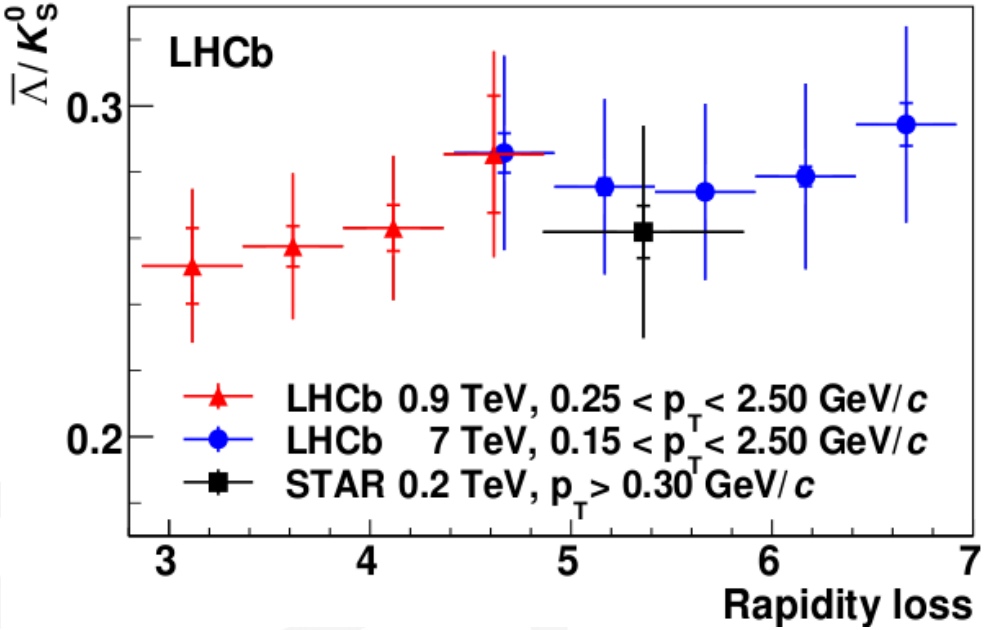
V^0 production ratios

- 0.3 nb^{-1} @0.9 TeV / 1.8 nb^{-1} @7 TeV

$$\frac{\bar{\Lambda}}{\Lambda} = \frac{\sigma(pp \to \bar{\Lambda}X)}{\sigma(pp \to \Lambda X)}$$

$$\frac{\bar{\Lambda}}{K^0_s} = \frac{\sigma(pp \to \bar{\Lambda}X)}{\sigma(pp \to K^0_s X)}$$



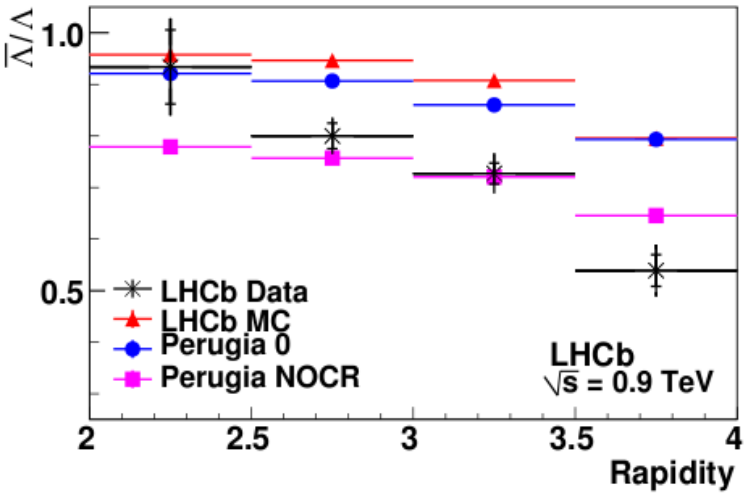


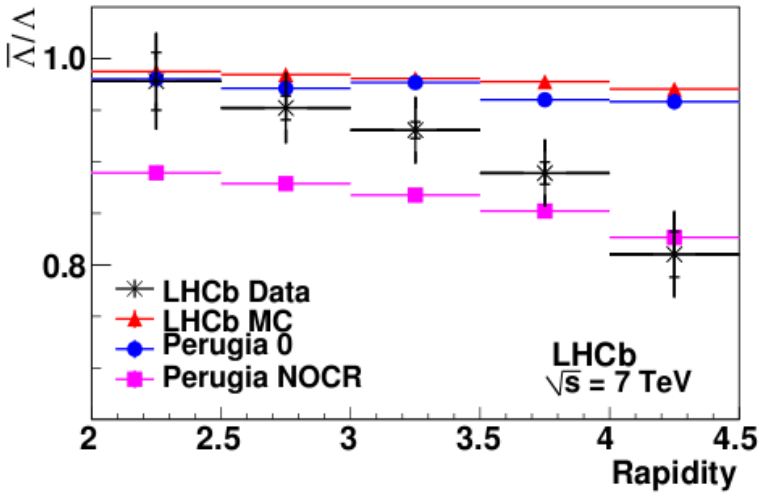
Rapidity loss: $\Delta y = y_{beam} - y$

- Consistency between $\sqrt{s}$ = 0.9 TeV, 7 TeV and previous measurement

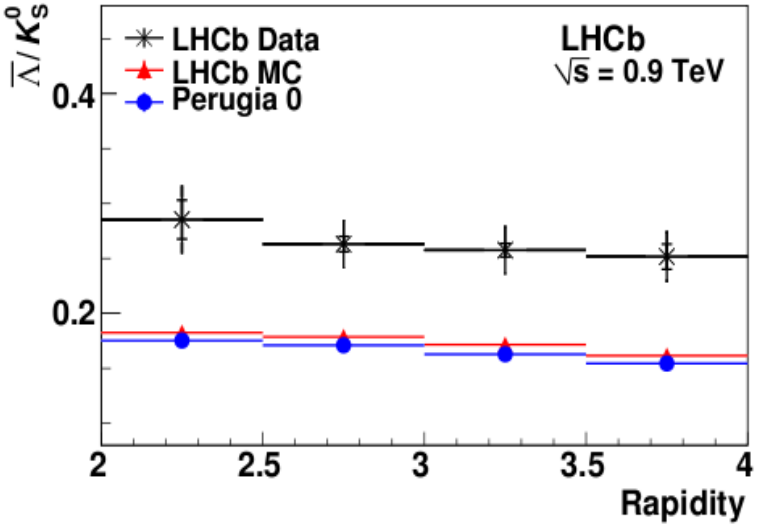
V⁰: comparison with generators

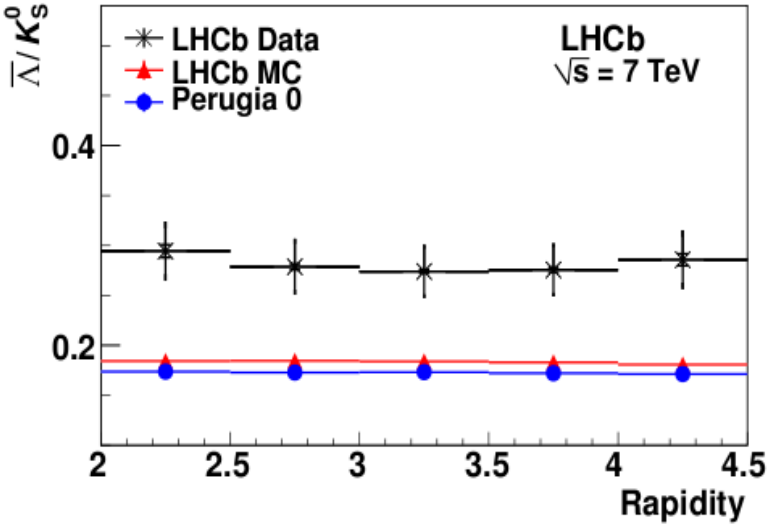
$\overline{\Lambda}/\Lambda$





$\overline{\Lambda}/K^0_s$

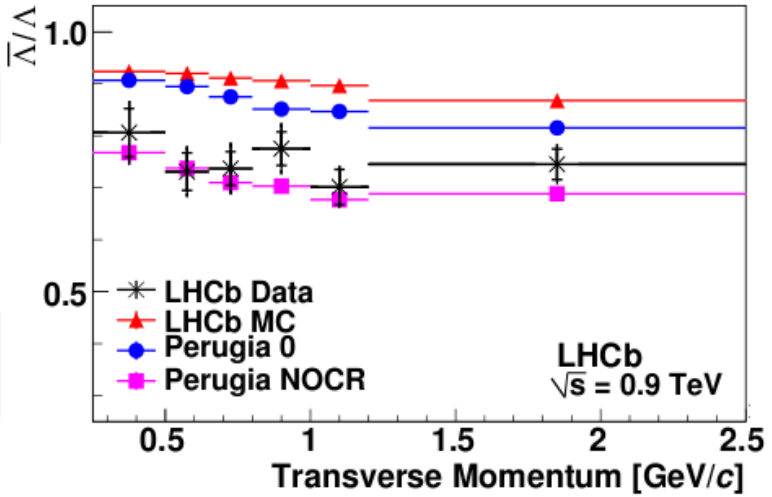


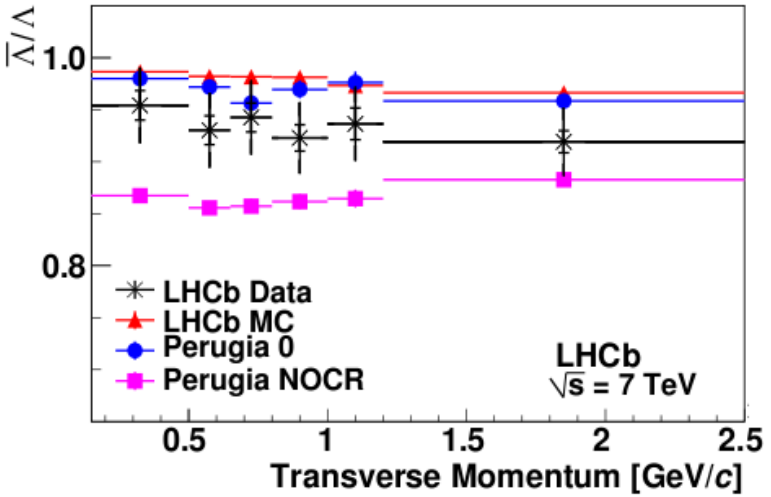


- Energy dependence observed
- Important input for MC tuning
- **$\overline{\Lambda}/\Lambda$:** Perugia NOCR favoured at high rapidity
- **$\overline{\Lambda}/K^0_s$:** underestimated by MC at both beam energies

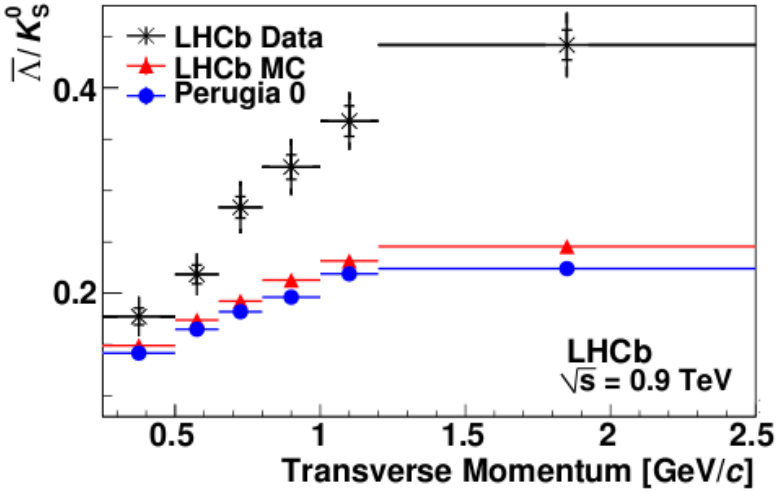
V⁰: comparison with generators

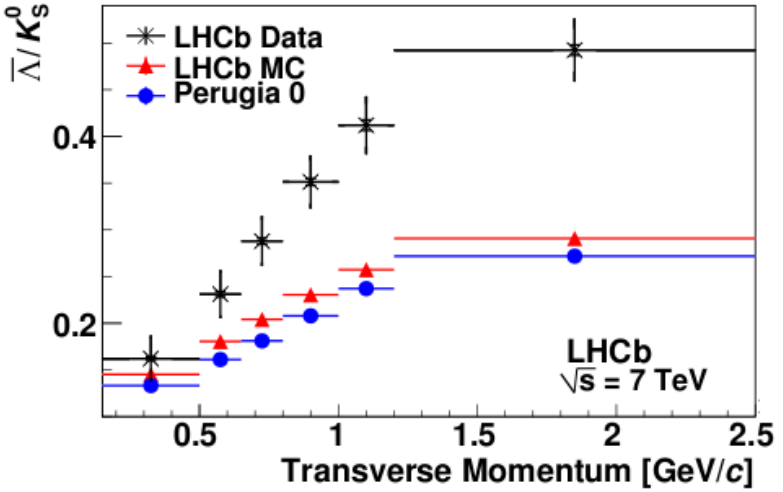
$\bar{\Lambda}/\Lambda$





$\bar{\Lambda}/K^0_s$



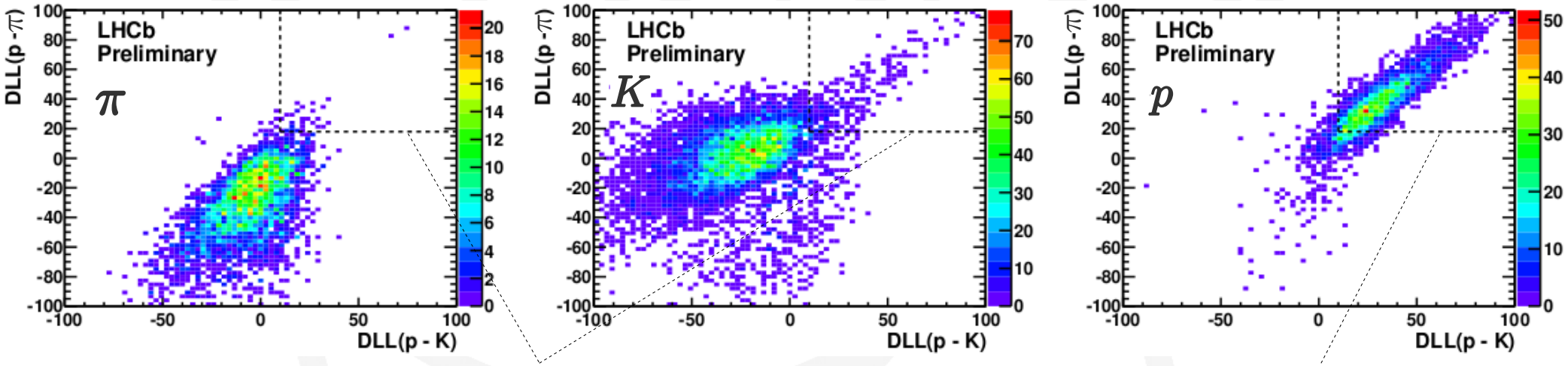


- $\bar{\Lambda}/\Lambda$: Perugia NOCR fits better at 0.9 TeV , Perugia 0 at 7 TeV
- $\bar{\Lambda}/K^0_s$: data is described better by the MC at low p_T

$\bar{p}/p$ ratio

CERN-LHCb-CONF-2010-009 (preliminary)

- Strongly dependent on PID system



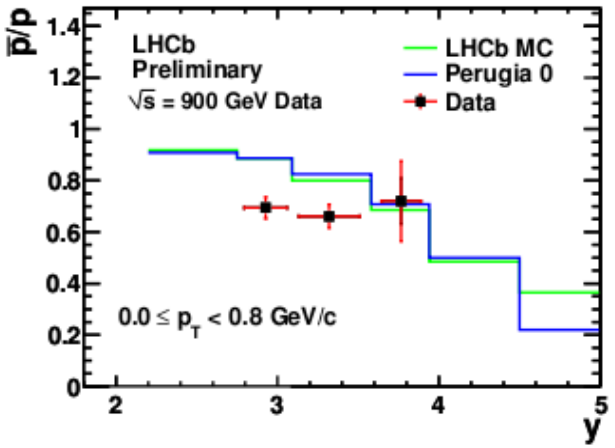
Retained background

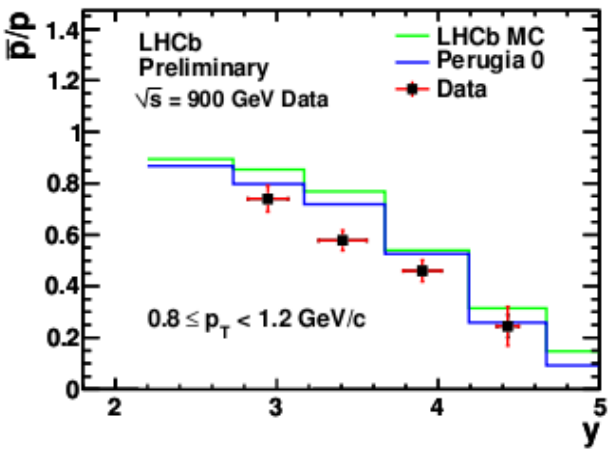
Signal

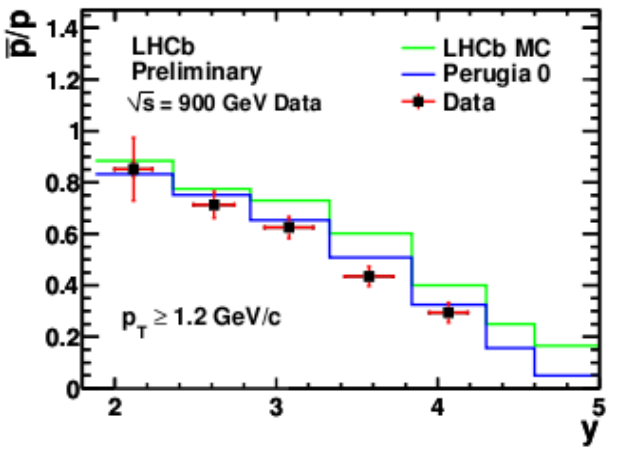
- PID calibrated on data:
  - π and p from $K^0_s \rightarrow \pi\pi$ and $\Lambda \rightarrow p\pi$
  - K from $\varphi \rightarrow KK$

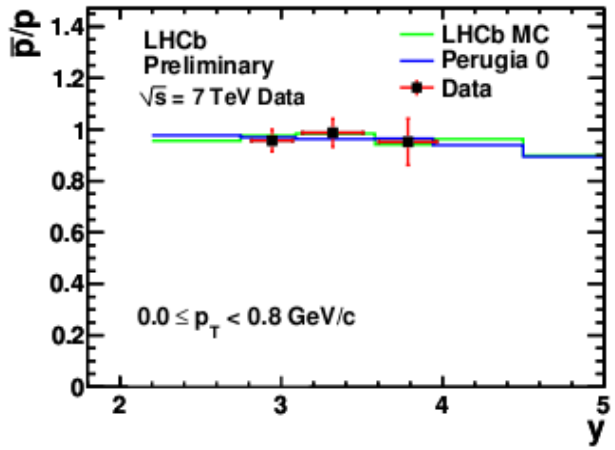
$\bar{p}/p$ ratio

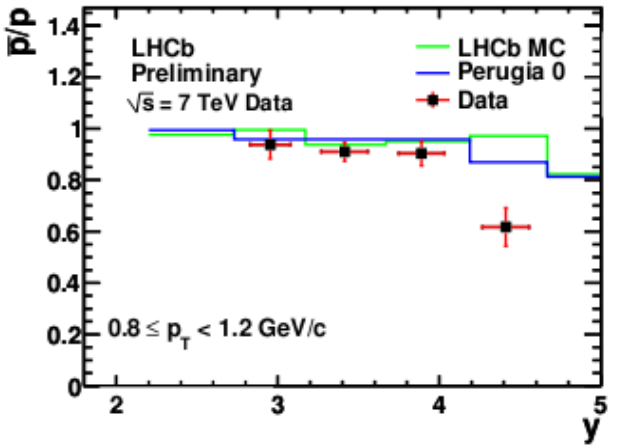
- 0.3 nb^{-1} @0.9 TeV / 0.2 nb^{-1} @7 TeV

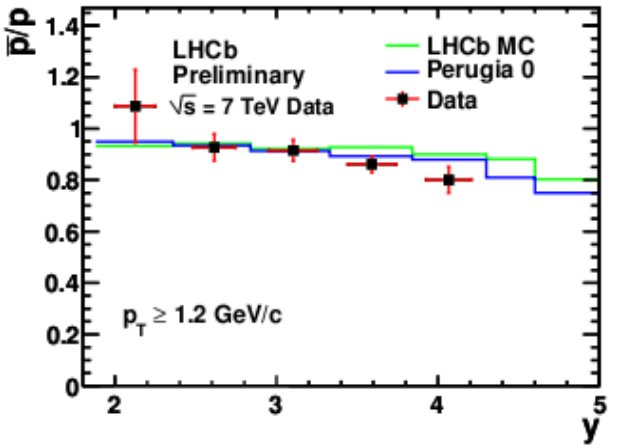






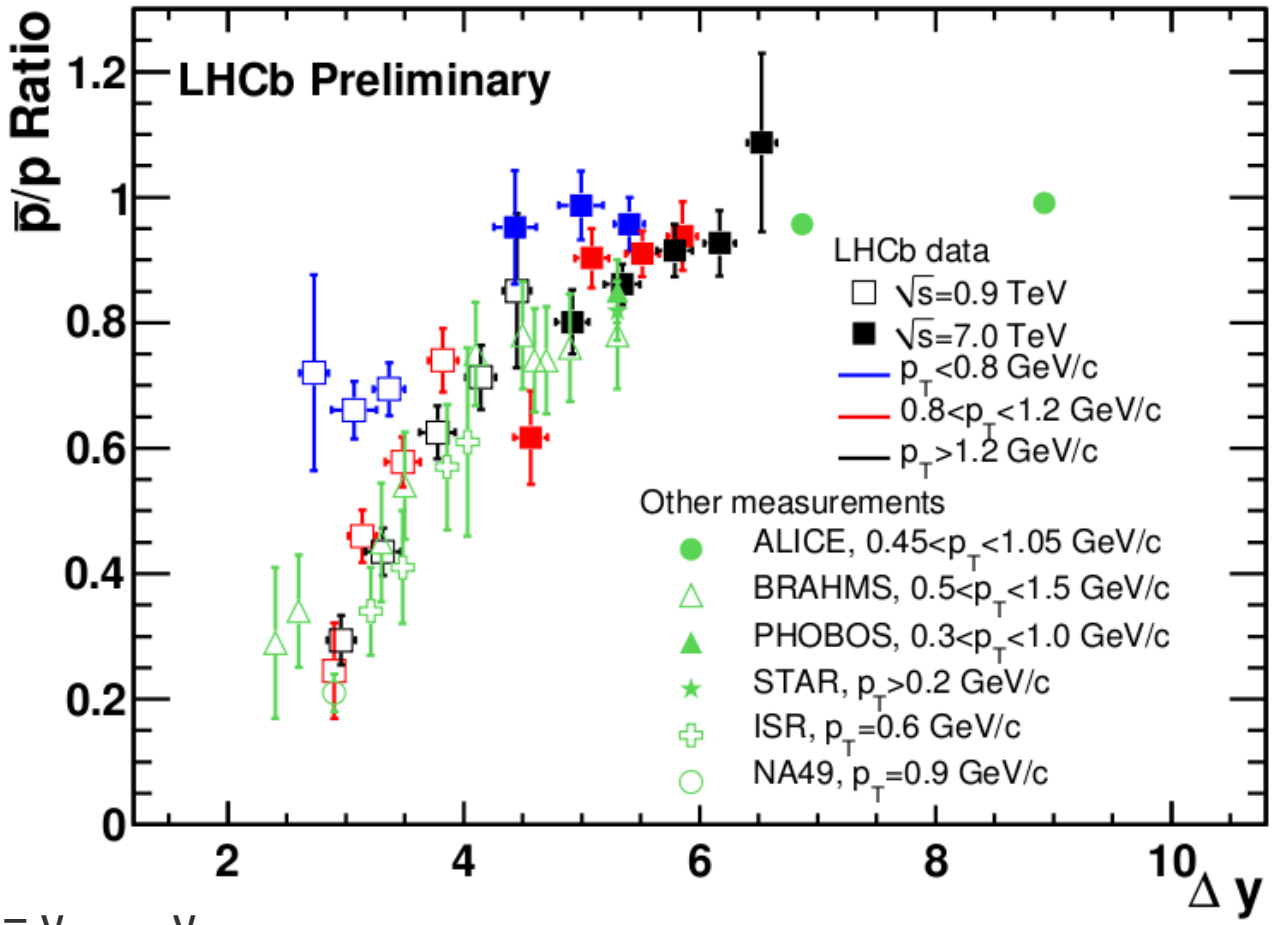






- Ratio overestimated at $\sqrt{s}$ = 0.9 TeV
- Good agreement data-MC at $\sqrt{s}$ = 7 TeV

Baryon transport $\bar{p}/p$



Rapidity loss: $\Delta y = y_{beam} - y_{baryon}$

- Indication of some p_T dependence
- Reasonable consistency with other experiments, mainly at high p_T

Charged track multiplicities

Motivation:

- Important input for tuning of generators and modelling of the underlying event
  - Soft QCD processes required for extracting many important measurements at the LHC

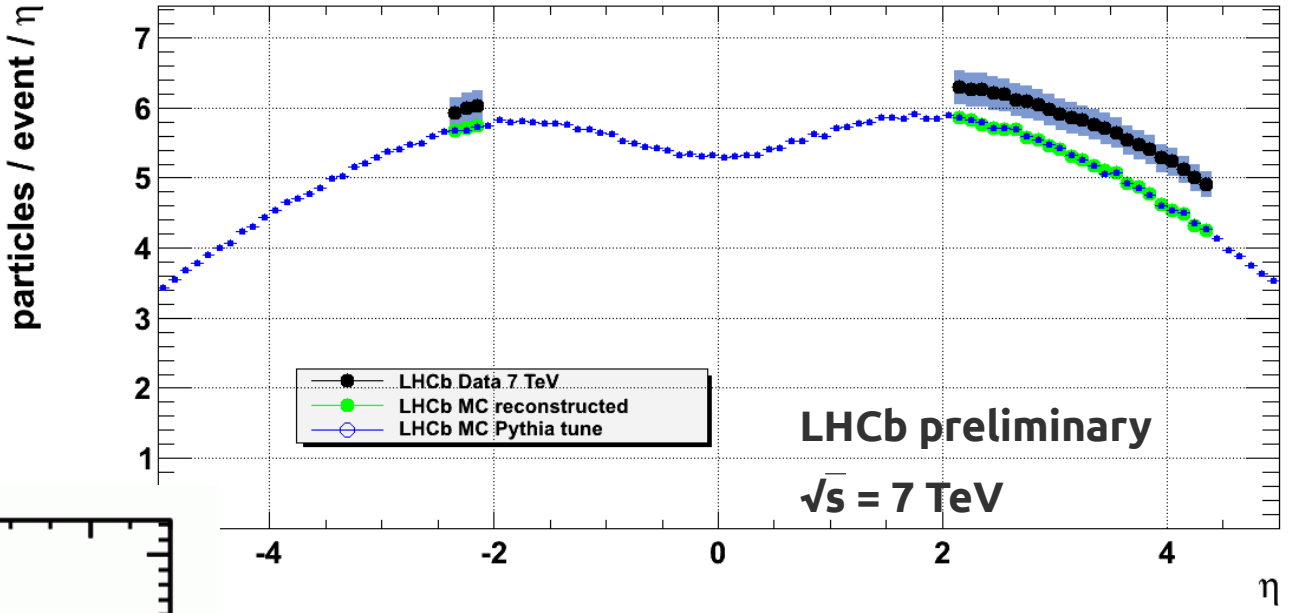
- Data: from early 2010
  - Low pile-up
- Particles are counted by reconstructing tracks in the VELO
  - High and uniform efficiency, closest to interaction point, partial backward coverage
  - No momentum measurement (VELO out of magnetic field)
  - No explicit momentum cut

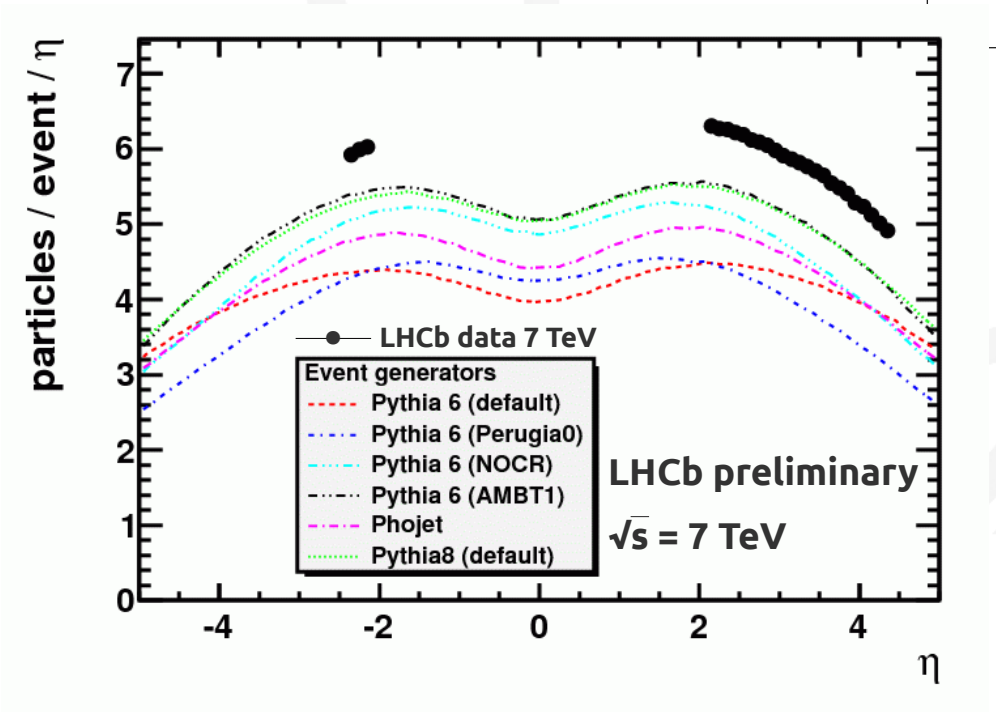
Corrections:

- Non-prompt particle contamination (5-10%), mainly tracks from converted photons, is taken from MC
- Efficiency drops at very low momentum (residual magnetic field and multiple scattering) (~1% particles)
- Correction applied for small pile-up contamination (3.7% events with >1 interactions)

Charged Particles vs η

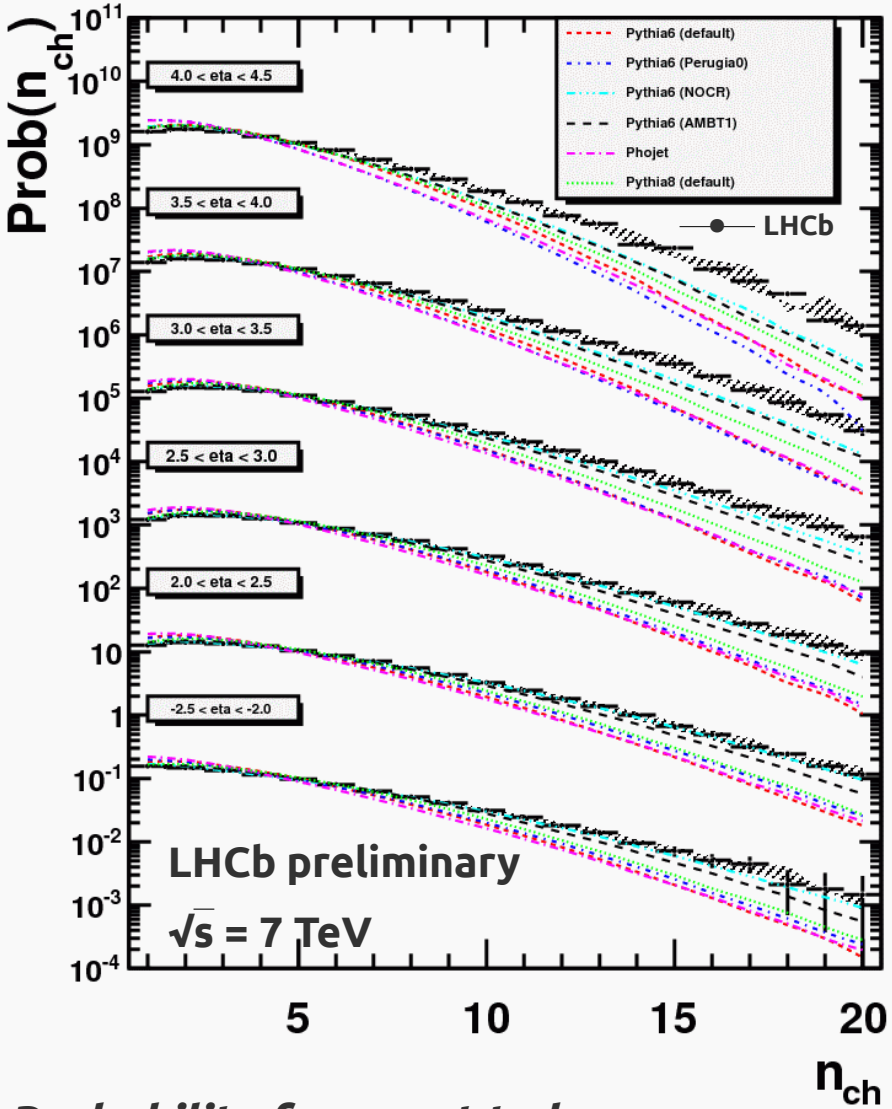
Normalized to events with at least one charged particle in the forward acceptance



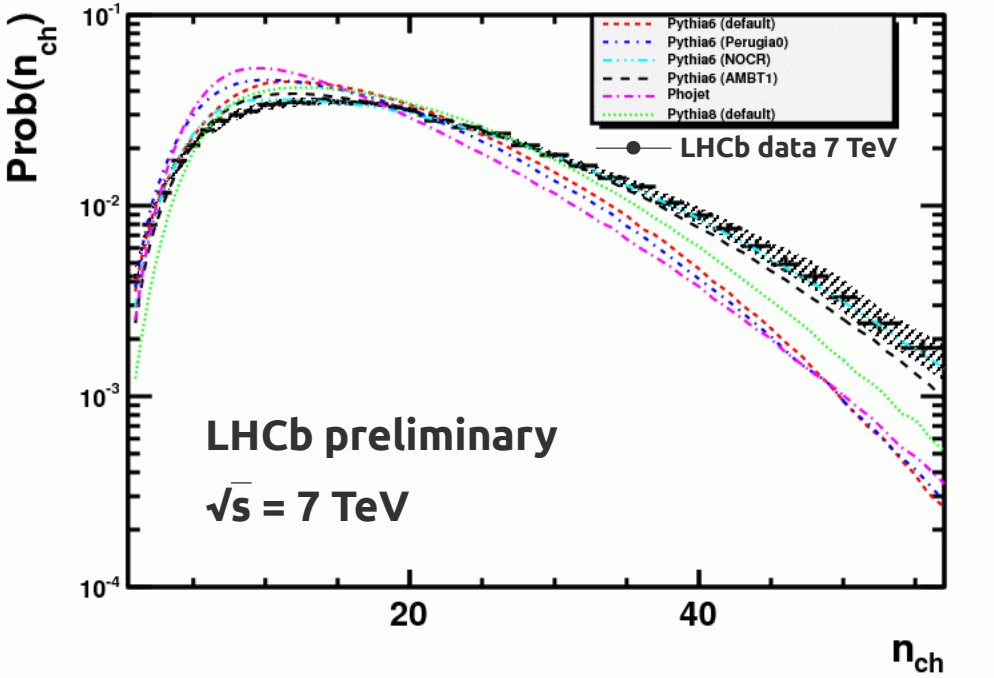


- Data points systematically above generator predictions
  - Data and MC show same behaviour with η
  - LHCb Pythia tune comes closest to data

Charged track multiplicities



Probability for event to have n_{ch}



Hard interactions: require at least one charged particle with pT>1GeV/c

Good agreement between Pythia6 (NOCR) tune and data

Conclusions

- First soft QCD results in the high-η(y) region from LHCb deliver much input to the theory
- **Strangeness production**
  - K^0_s at $\sqrt{s}$ = 0.9 TeV: harder p_T spectrum as compared to MC
  - φ at $\sqrt{s}$ = 7 TeV: largely underestimated by the event generators
- **V^0 ratios** at 0.9 and 7 TeV
  - $\bar{\Lambda}/\Lambda$ ratio is smaller in data than predicted in simulation, particularly at high rapidity
  - $\bar{\Lambda}/K^0_s$ significantly larger than predicted at both collision energies
- **$\bar{p}/p$ ratio** slightly lower than Perugia 0 at $\sqrt{s}$ = 0.9 TeV, good agreement data-MC at $\sqrt{s}$ = 7 TeV
- **Charged particle production** at $\sqrt{s}$ = 7 TeV is underestimated in most generator tunes
  - Differences become smaller for hard events