Studies of soft QCD at LHCb

Raluca Muresan
Horia Hulubei National Institute of Physics and Nuclear Engineering
On behalf of LHCb collaboration

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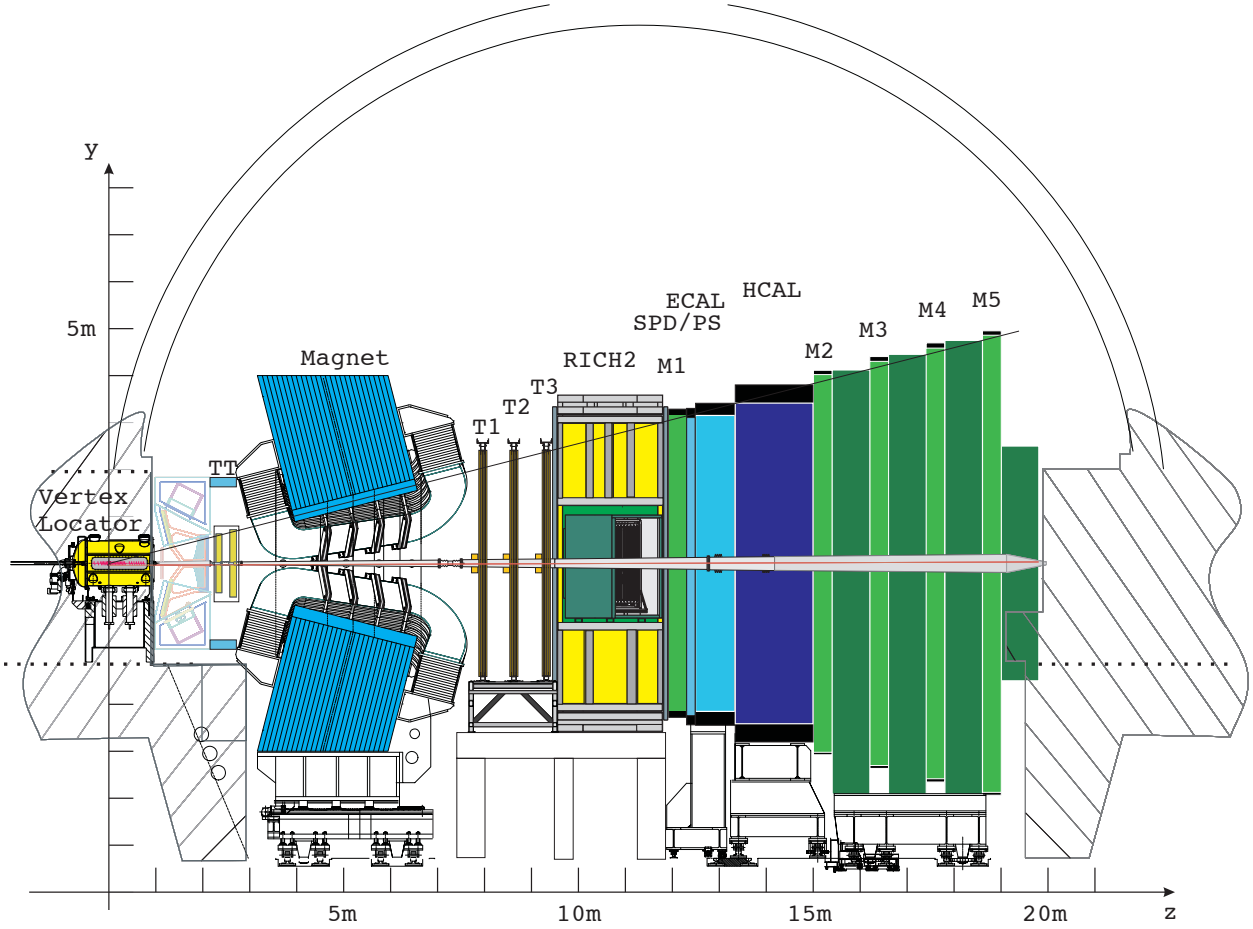
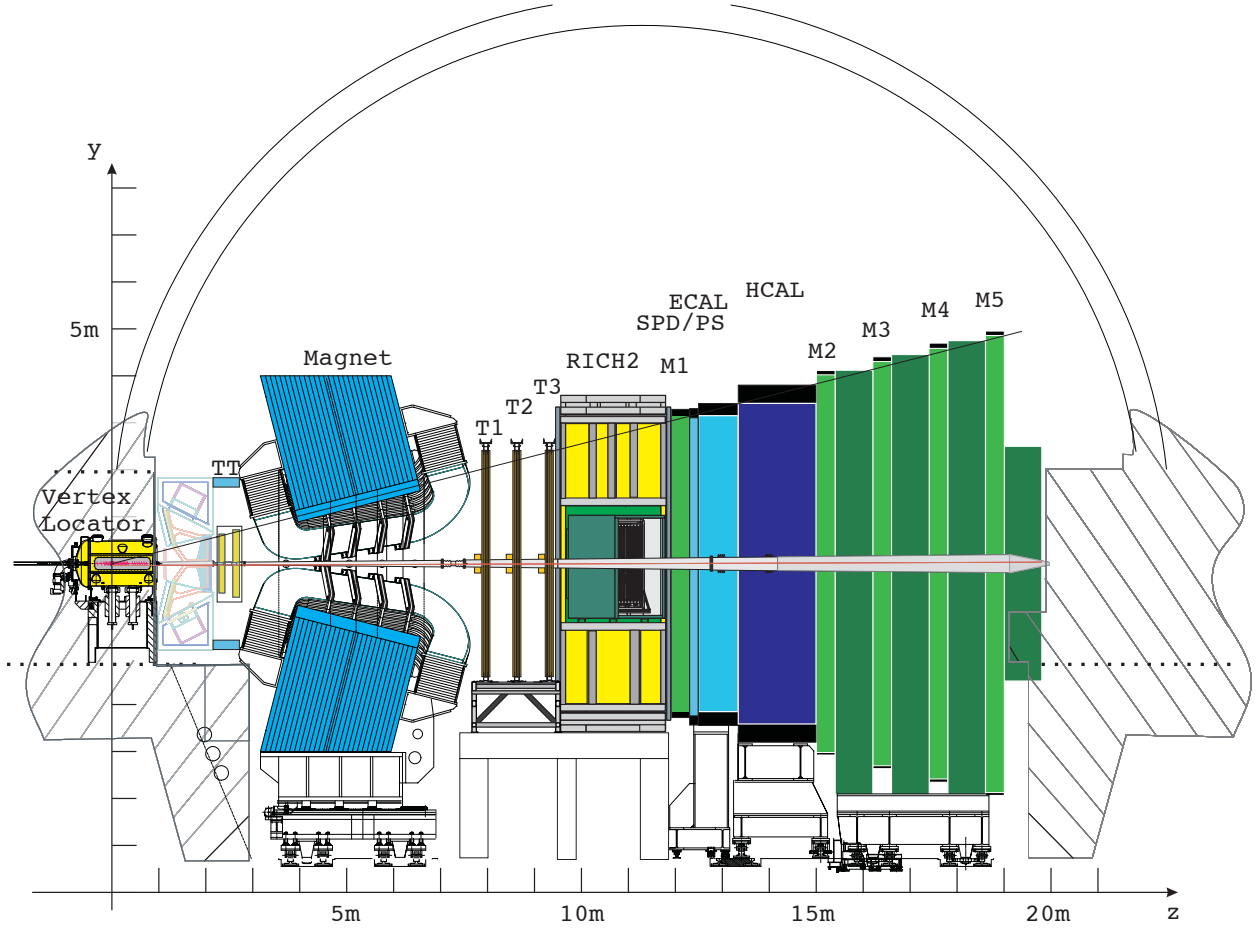
LHCb detector



Designed to look for physics beyond the SM by studies of CP violation and rare decays using b & c hadrons

JINST 3 (2008) S08005.

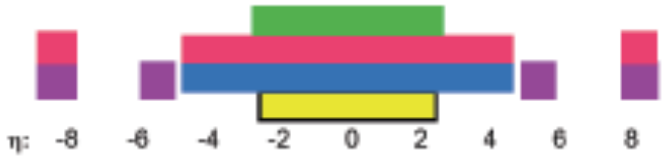
LHCb detector



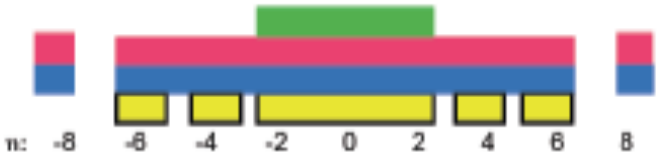
Forward coverage 15-300(250) mrad, high precision tracking and vertexing, excellent PID
→ Perfect tool for particle production studies in the forward region

Phase space coverage

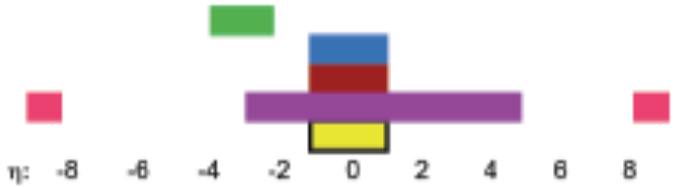
Soft QCD physics results very interesting due to the unique phase space coverage in η, LHCb fully instrumented in an η range from 2 to 5.



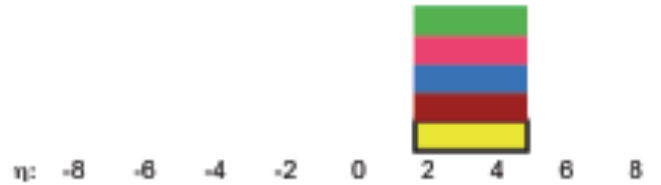
ATLAS



CMS&TOTEM



ALICE



LHCb

tracking, ECAL, HCAL, counters lumi, muon, hadron PID

LHCb Soft-QCD results

2010:

- **K_S^0 x-section @ 0.9 TeV, Phys. Lett. B 693 (2010) 69-80;**

2011:

- **V^0 ratios: baryon vs. meson suppression & baryon number transport at @ 0.9 TeV and 7 TeV; JHEP 1108 (2011) 034.**
- **φ cross-section @ 7 TeV; Phys.Lett. B703 (2011) 267-273.**
- **Charged particle multiplicities @ 7 TeV; Eur. Phys. J. C 72 (2012) 1947.**

2012:

Measurement of forward energy flow LHCb-CONF-2012-012 @ 7 TeV

Particle ratios at 0.9 & 7 TeV, arXiv:1206.5160.

Forward energy flow

- **Energy flow (EF) @ high η - directly sensitive to the amount of parton radiation and Multiple Parton Interaction (MPI).**
- **EF measurements results useful both for the collision physics and for the ultra-high energy cosmic-ray interaction models.**
- **EF defined as:**

$$\frac{1}{N_{\text{int}}}\frac{dE_{tot}}{d\eta}$$

dE_{tot} is the total energy of stable particles in the η bin
N_{int} number of inelastic *pp* interactions

Experimentally determined for a Δη bin:

$$\frac{1}{\Delta\eta}\left(\frac{1}{N_{int}}\sum_{i=1}^{N_{part},\eta}E_{i,\eta}\right)$$

$E_{i,\eta}$ energy of an individual particle

Data and event sample

- ✓ 0.1 nb^{-1} low luminosity LHC run @7 TeV
- ✓ Events with at least one track segment.

➢ Inclusive MB

at least one well reconstructed track p_T>2 GeV/*c*

➢ Hard scattering

at least one well reconstructed track p_T > 3 GeV/*c*

➢ Diffractive enriched

inclusive MB with no tracks in $-3.5<\eta<-1.5$

➢ Non-diffractive enriched

inclusive MB with at least one track in $-3.5<\eta<-1.5$

Charged EF → the energy flow carried by the charged particles, based on p measurement

Total EF → data constrained MC estimate of neutral component

Correction for detector effects - bin-by-bin from simulation

Systematic uncertainties:

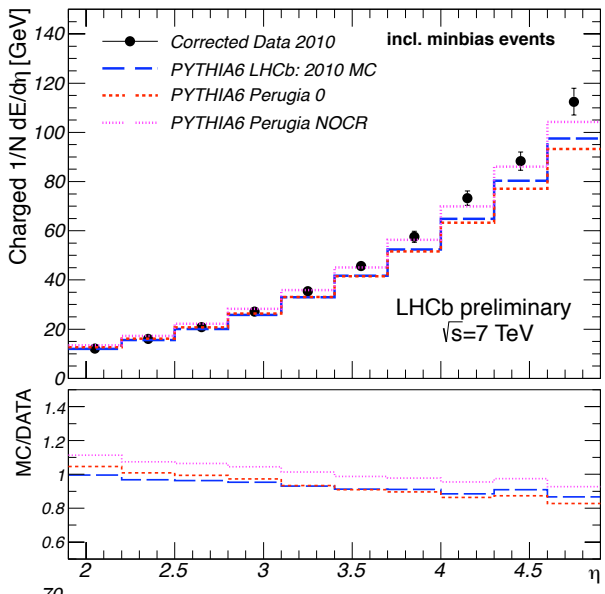
- ✓ **tracking**
- ✓ **multiple interaction events (5% of events)**
- ✓ **simulation model**

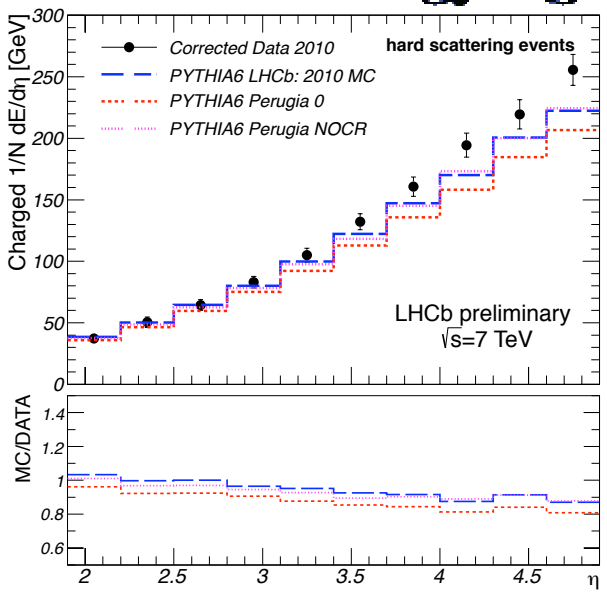
Forward charged energy flow

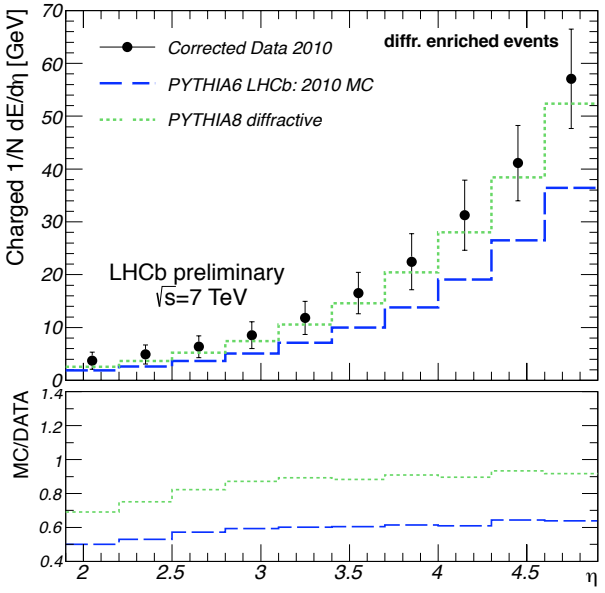
Corrected charged energy flow compared with PYTHIA generator predictions.

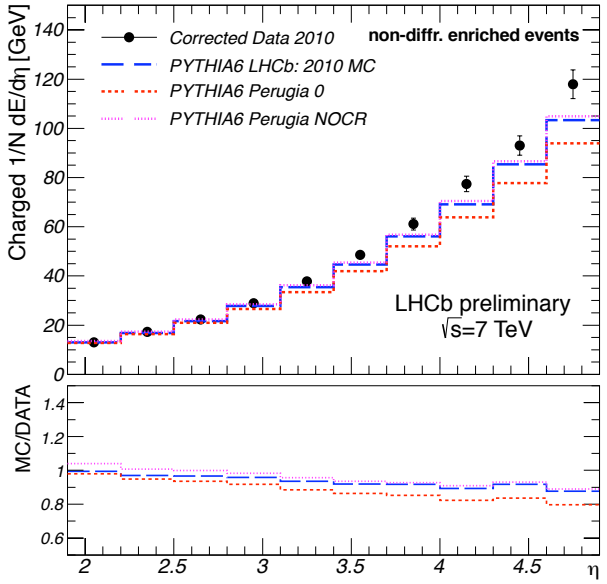
All PYTHIA 6 tunes used underestimate the charged EF at high η for all the type of events studied.

PYTHIA 8 describes the best the charged EF for diffractive enriched events. ***LHCb-CONF-2012-012***









Forward charged energy flow

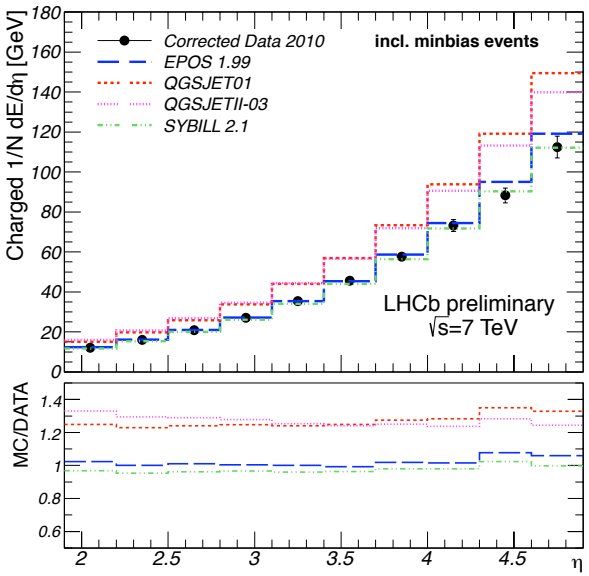
Corrected charged EF vs. cosmic ray generators predictions.

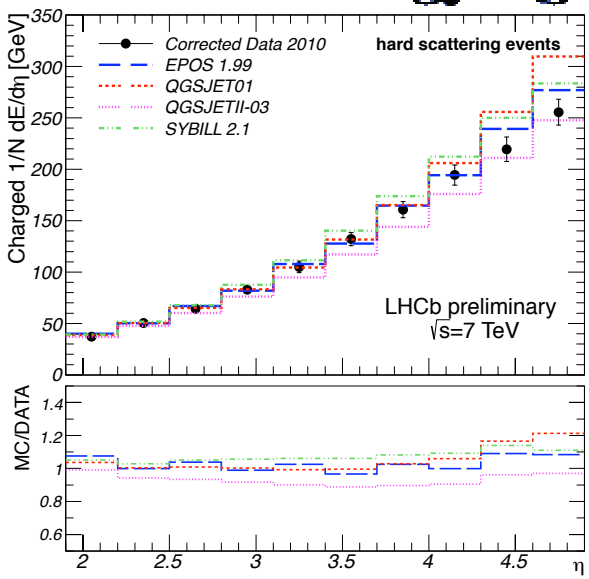
Cosmic-ray models overestimate the charged EF.

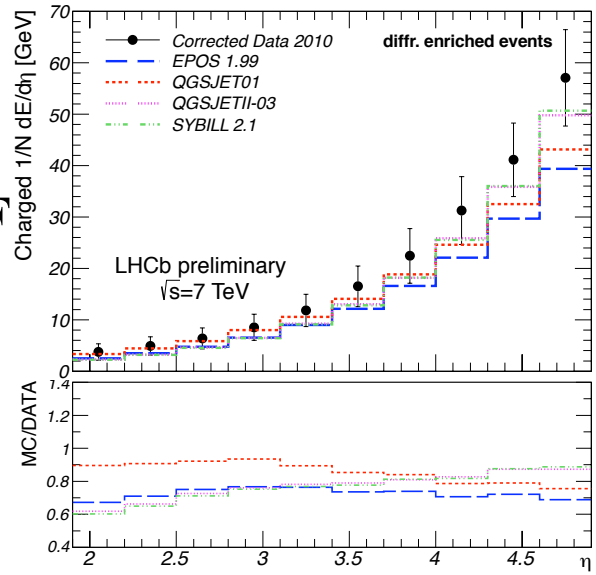
SYBILL/EPOS best description of the inclusive MB charged EF.

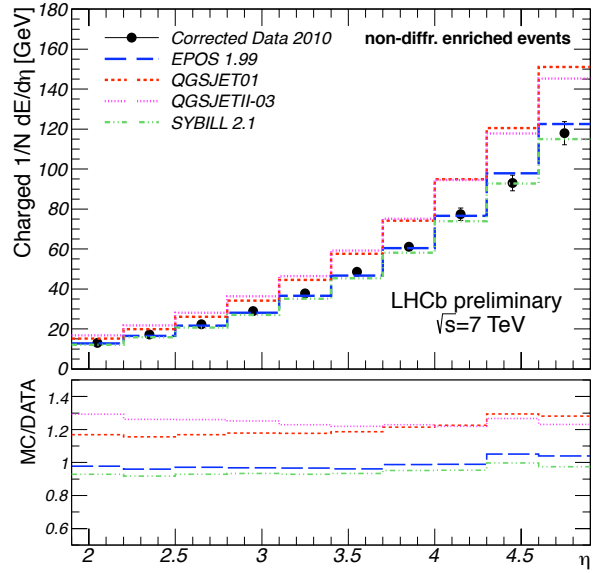
QGSJETII-03 reasonable description of the charged EF in hard scattering.

Diffractive charged EF is underestimated by the cosmic-ray models









LHCb-CONF-2012-012

Total forward energy flow

Corrected total EF compared with PYTHIA generator predictions.

Total EF underestimated at high η by all the PYTHIA6 tunes used and for all event categories studied.

PYTHIA 8 describes well the total EF for diffractive enriched events.

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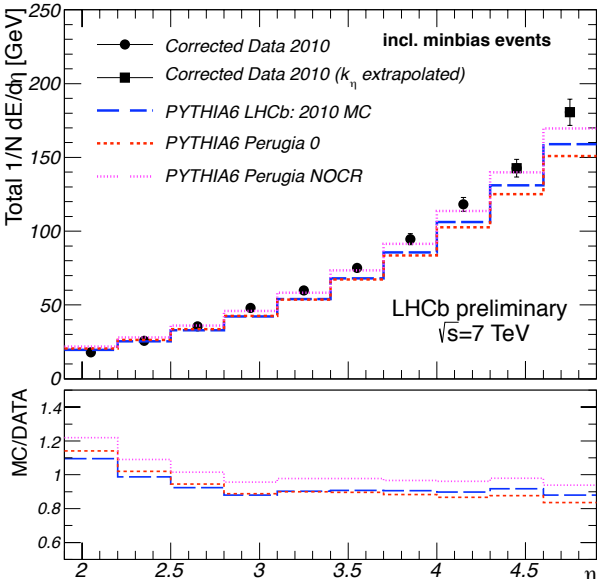

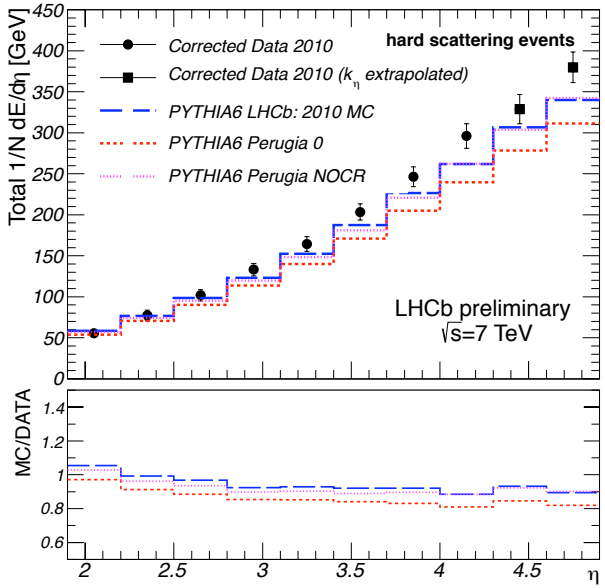

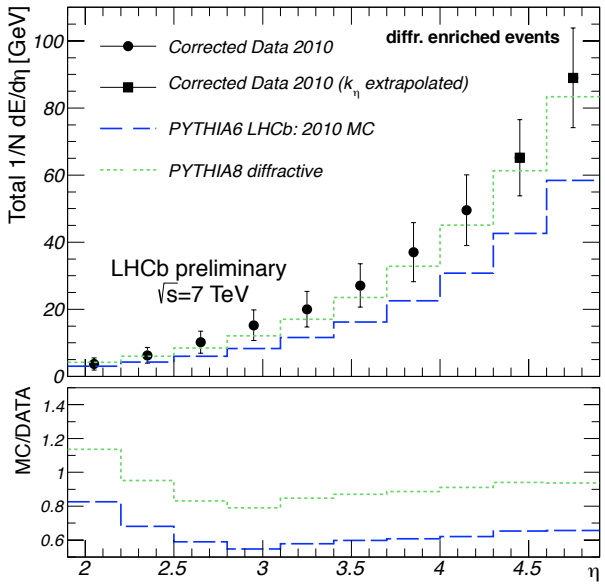

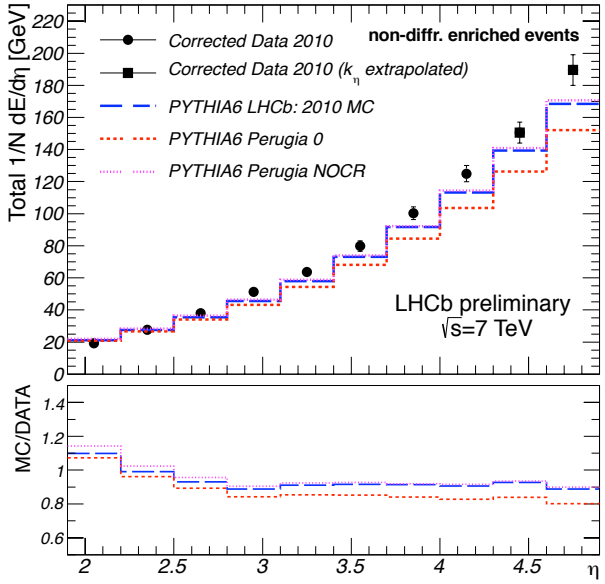

Total forward energy flow

LHCb-CONF-2012-012

Corrected total EF compared with cosmic ray generators predictions.

Cosmic-ray models overestimate the total EF.

SYBILL/EPOS the best description of the total EF for inclusive MB events.

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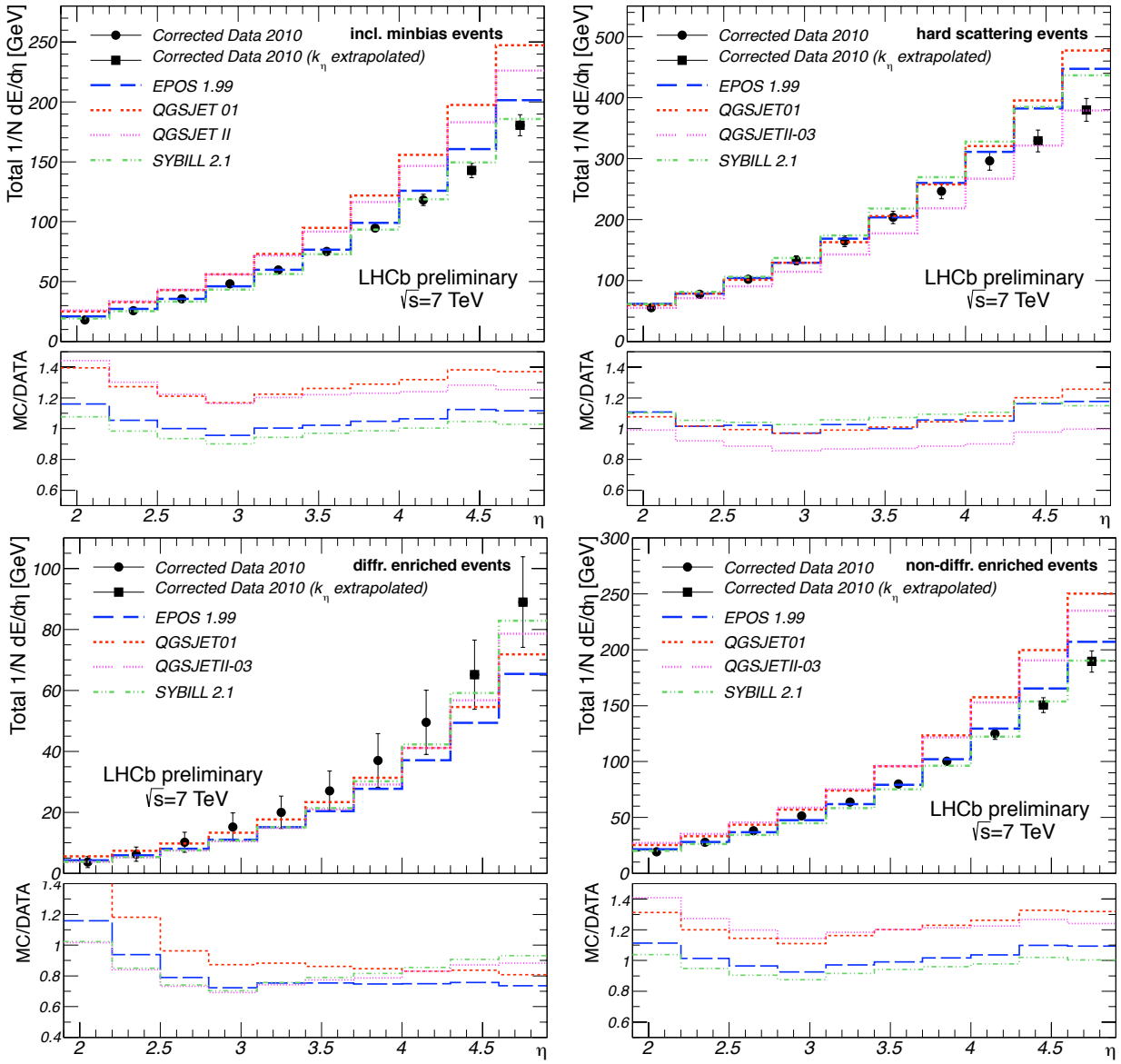


Prompt hadron production ratios

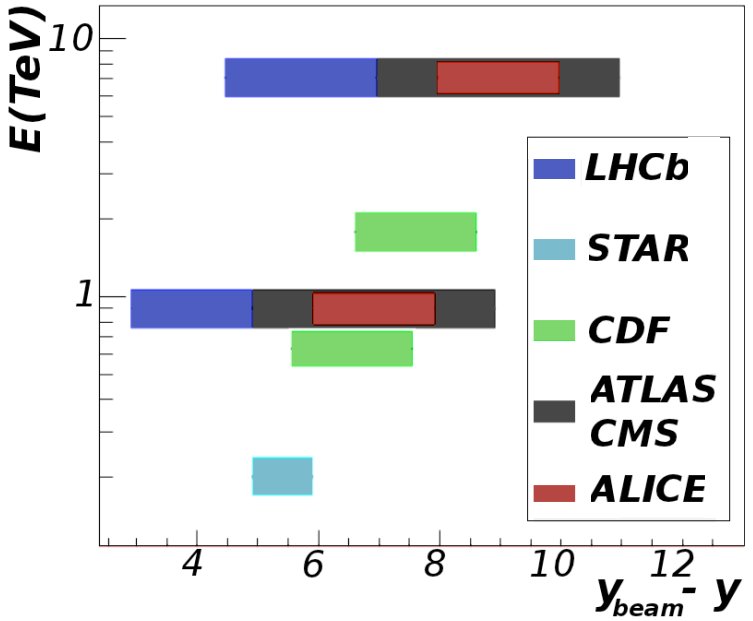
- **Charged particle production ratios:**

$$\frac{\bar{p}}{p}, \frac{K^-}{K^+}, \frac{\pi^-}{\pi^+}, \frac{p+\bar{p}}{\pi^+ + \pi^-}, \frac{K^+ + K^-}{\pi^+ + \pi^-}, \frac{p+\bar{p}}{K^+ + K^-}$$

- **0.3 nb^{-1} of data @0.9 TeV and 1.8 nb^{-1} low luminosity LHC run.**
- **Important input for model building and generator tuning.**

0.9 TeV farther from the beam in y compared with other measurements;

7 TeV, overlap in rapidity loss with previous measurements, probing energy scale violation.



Prompt hadron production ratios

- Simulated events used to calculate efficiencies and estimate systematic uncertainties.
- PID calibration using data samples of

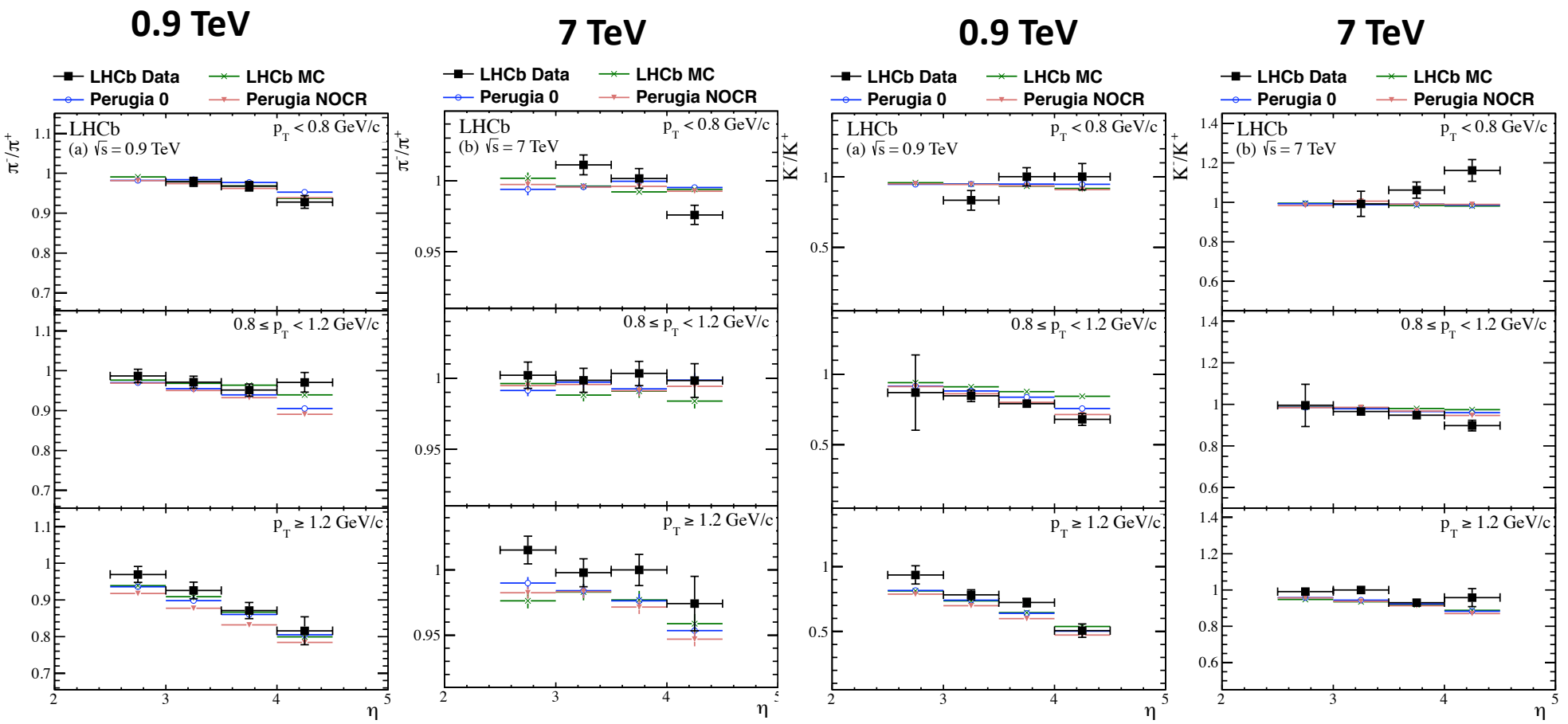
$$K_S^0 \to \pi^+\pi^- \,, \Lambda \to p\pi^- \,, \phi \to K^+K^-$$

- Corrections applied for:
  - ✓ effects of non-prompt contamination,
  - ✓ geometrical acceptance losses,
  - ✓ track finding inefficiency.

- Systematic uncertainties:
  - ✓ PID (most important – size of calibration sample) ,
  - ✓ interaction x-section & amount of material,
  - ✓ tracking & non-prompt contamination.

Same particle ratios

LHCb-PAPER-2011-037 (arXiv:1206.5160)

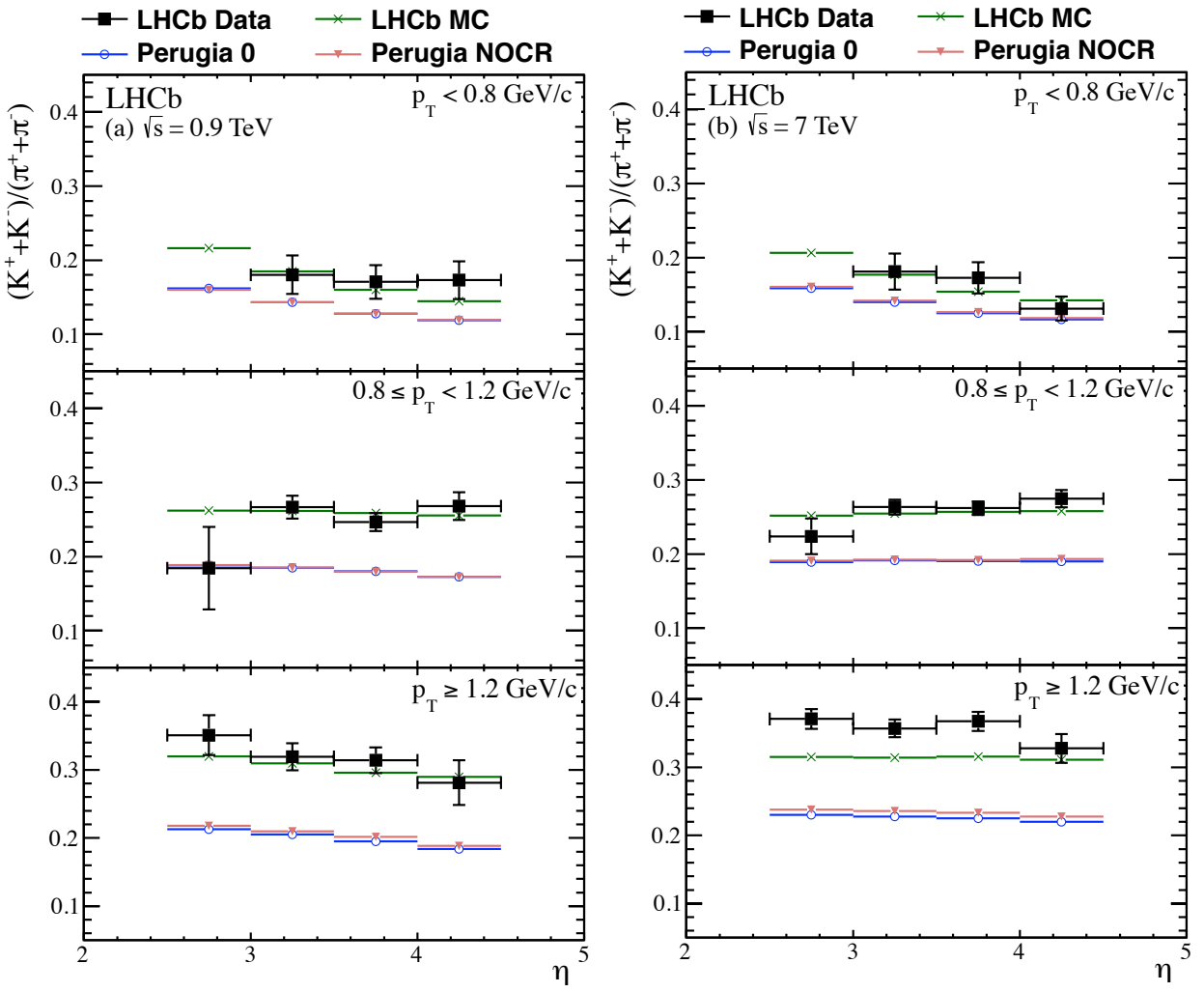


The ratios differ from unity especially at high p_T and high η.
The behaviour is well described by all the generator tunes.

Strange vs. up/down particles

LHCb-PAPER-2011-037 (arXiv:1206.5160)

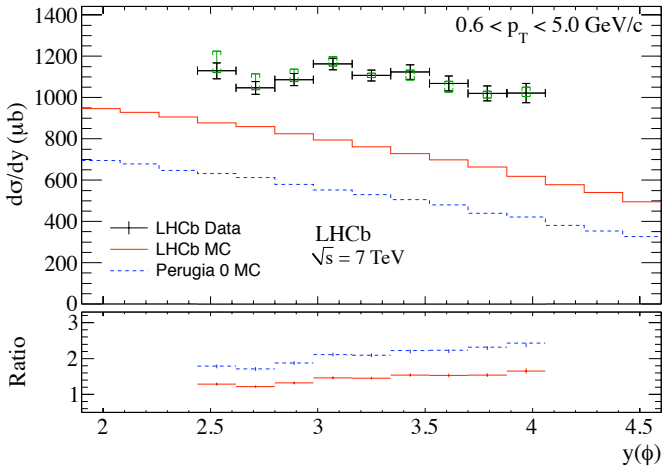
Tendency for data to lie significantly higher than Perugia 0 and Perugia NOCR PYTHIA 6 tunes, excess strangeness being produced compared to some MC predictions.

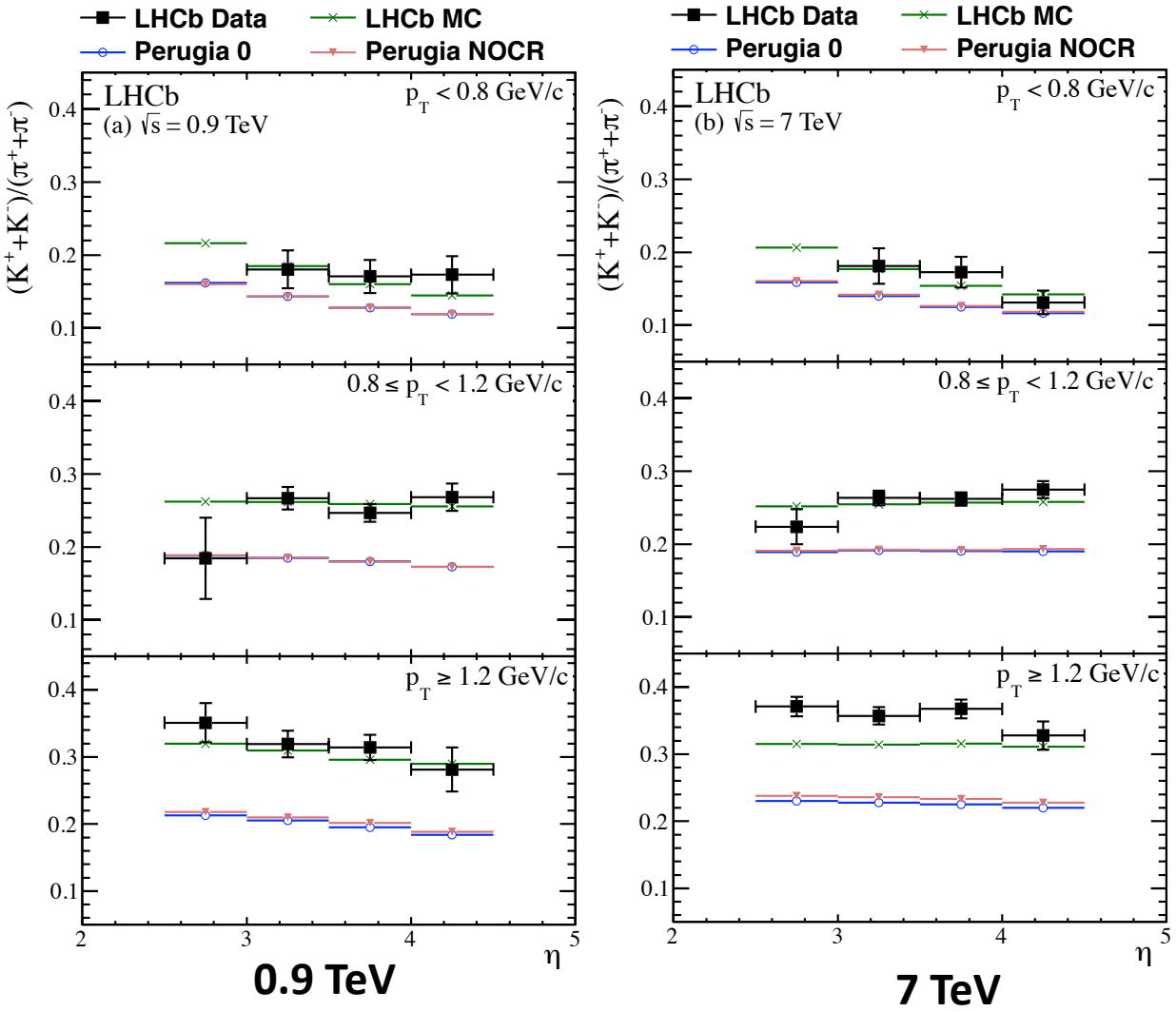


Strange vs. up/down particles

LHCb-PAPER-2011-037(arXiv:1206.5160)

Tendency for measurements to lie significantly higher than Perugia 0 and Perugia NOCR tune, excess strangeness seems to be produced compared to some MC predictions.



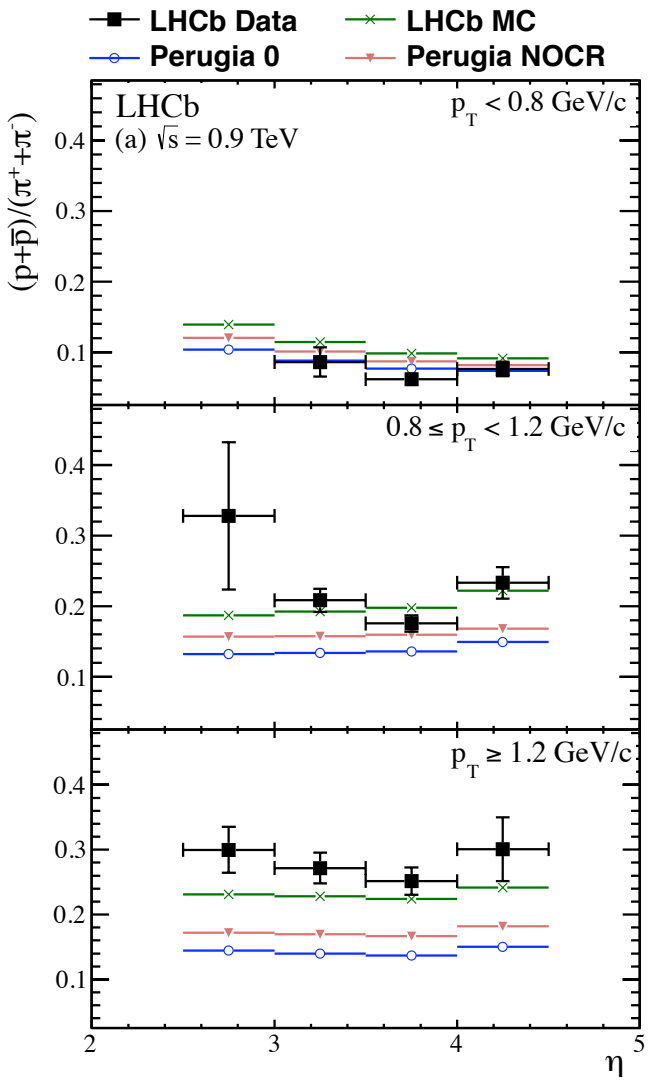


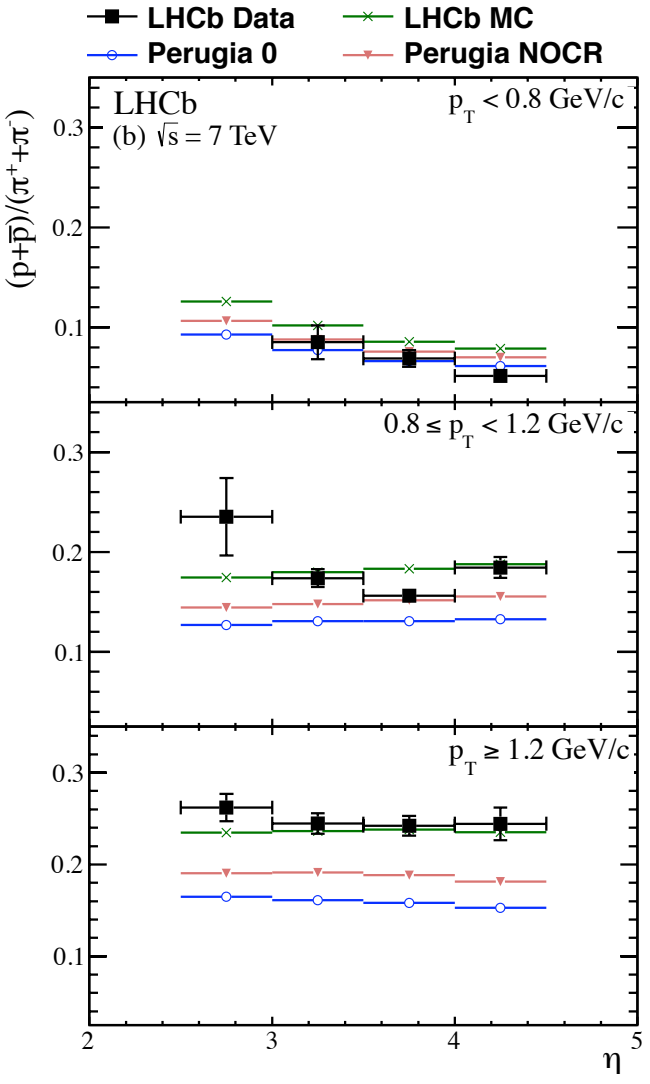
φ cross-section measurement Phys.Lett. B703 (2011).

Baryon suppression

LHCb-PAPER-2011-037 (arXiv:1206.5160)

Data lie in most cases significantly higher than predictions – especially at high p_T and high η.





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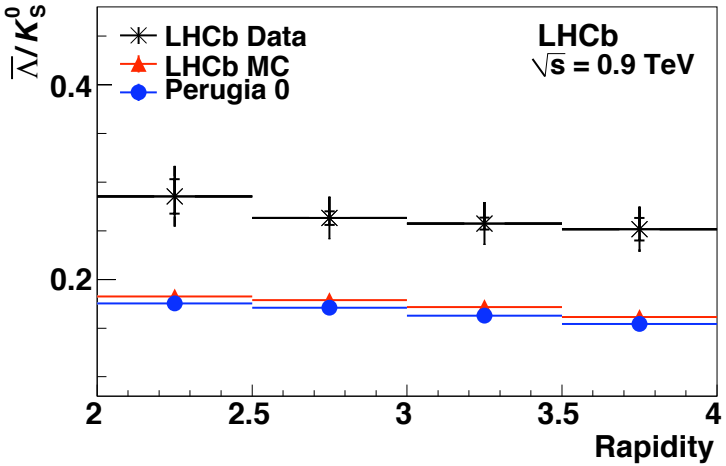
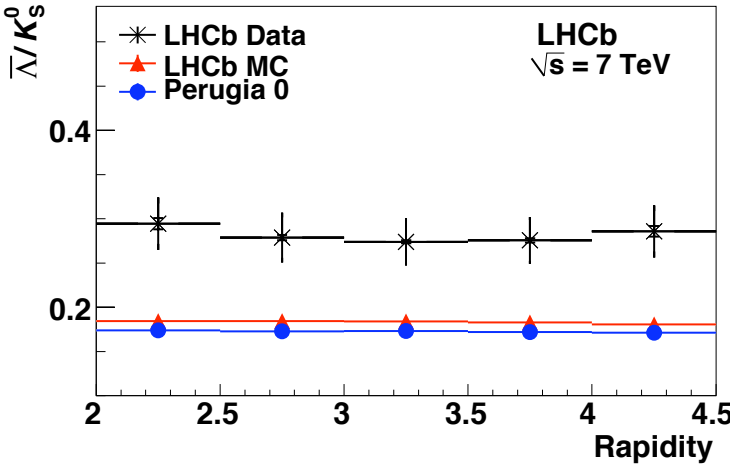
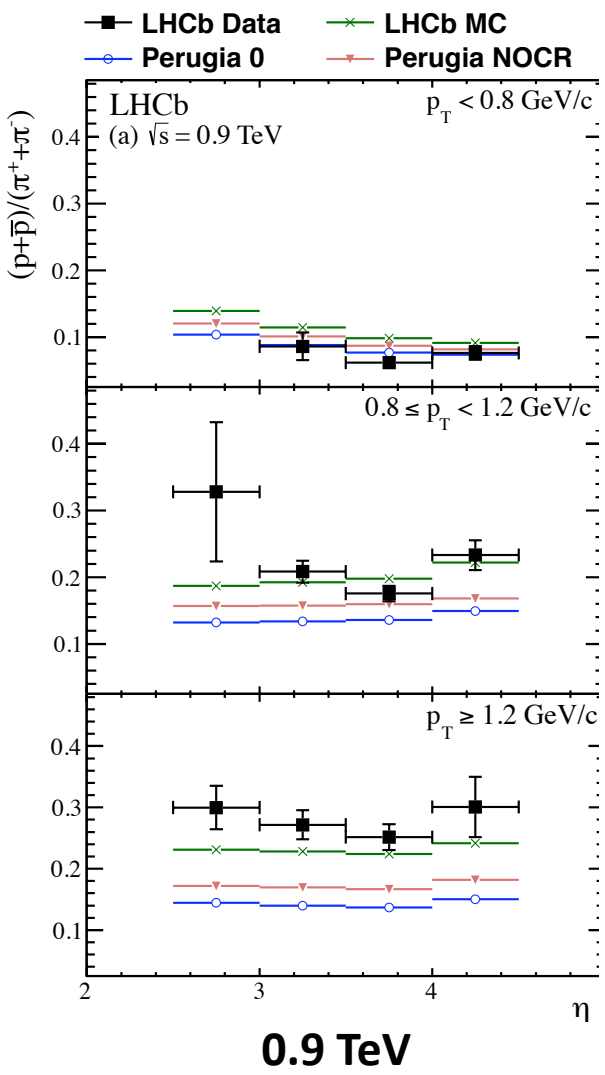
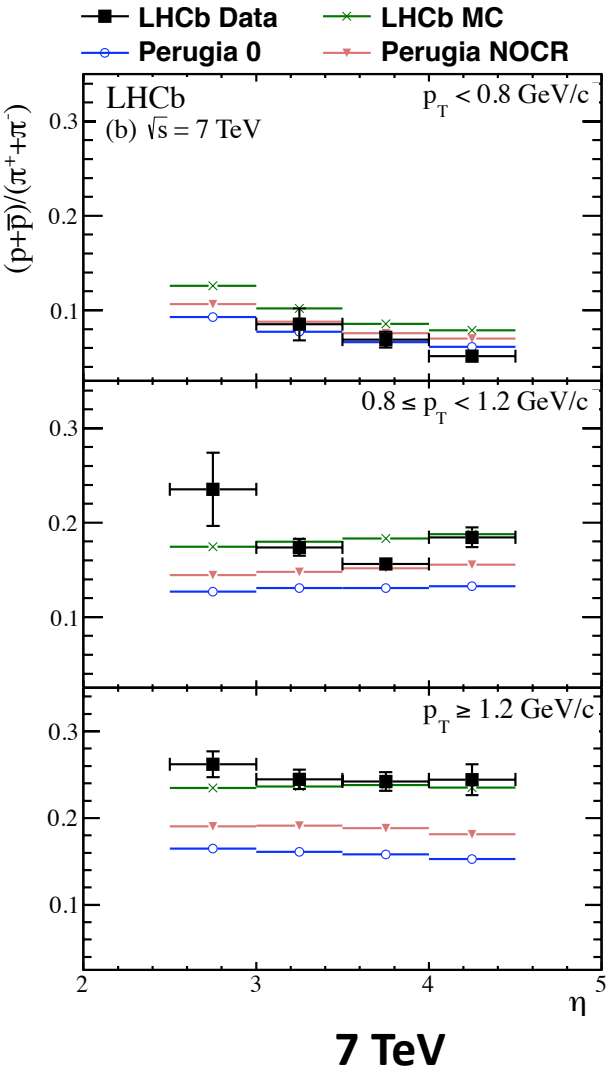




JHEP 1108 (2011) 034



0.9 TeV

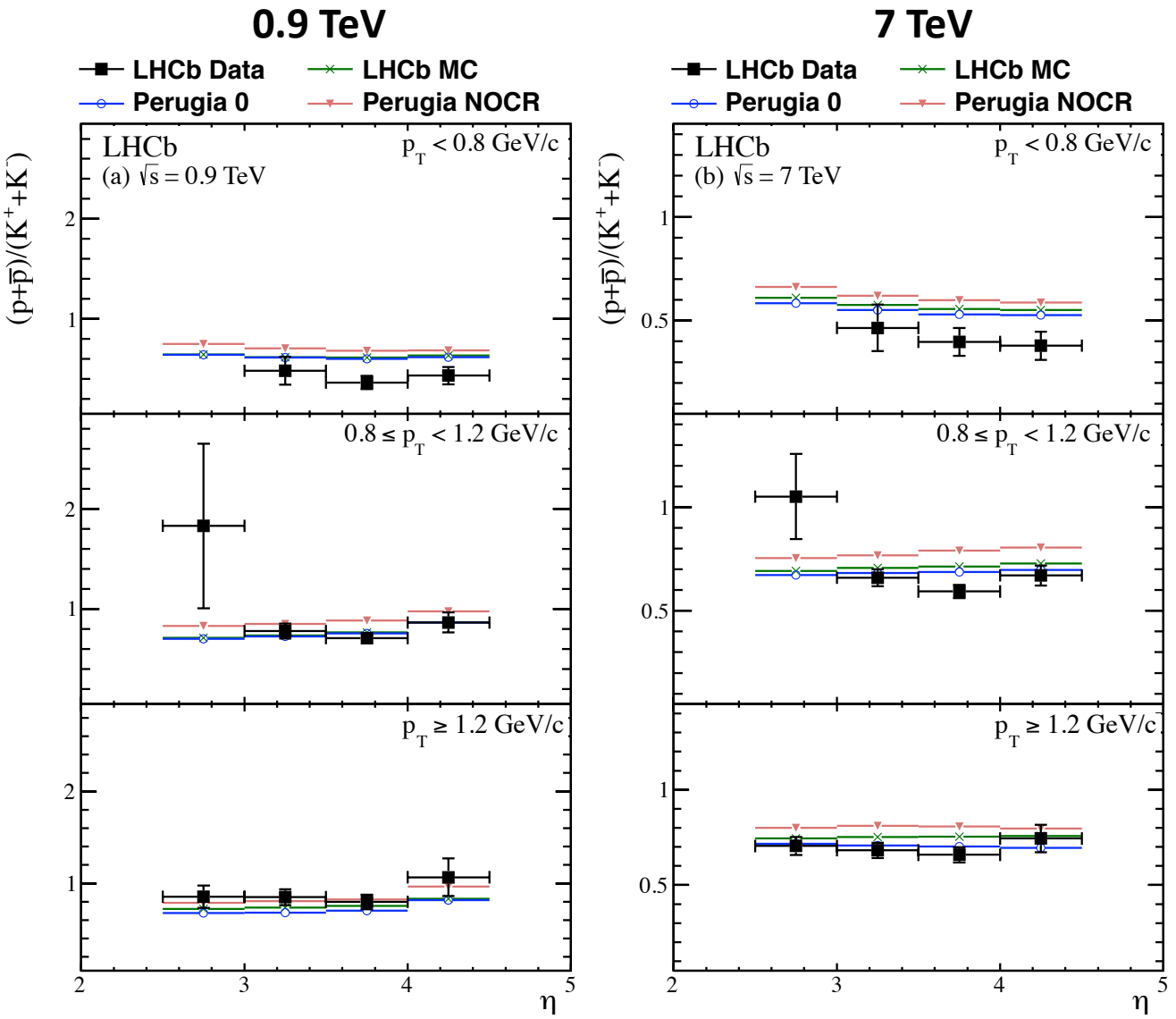


7 TeV

Protons vs. kaons

LHCb-PAPER-2011-037 *(arXiv:1206.5160)*

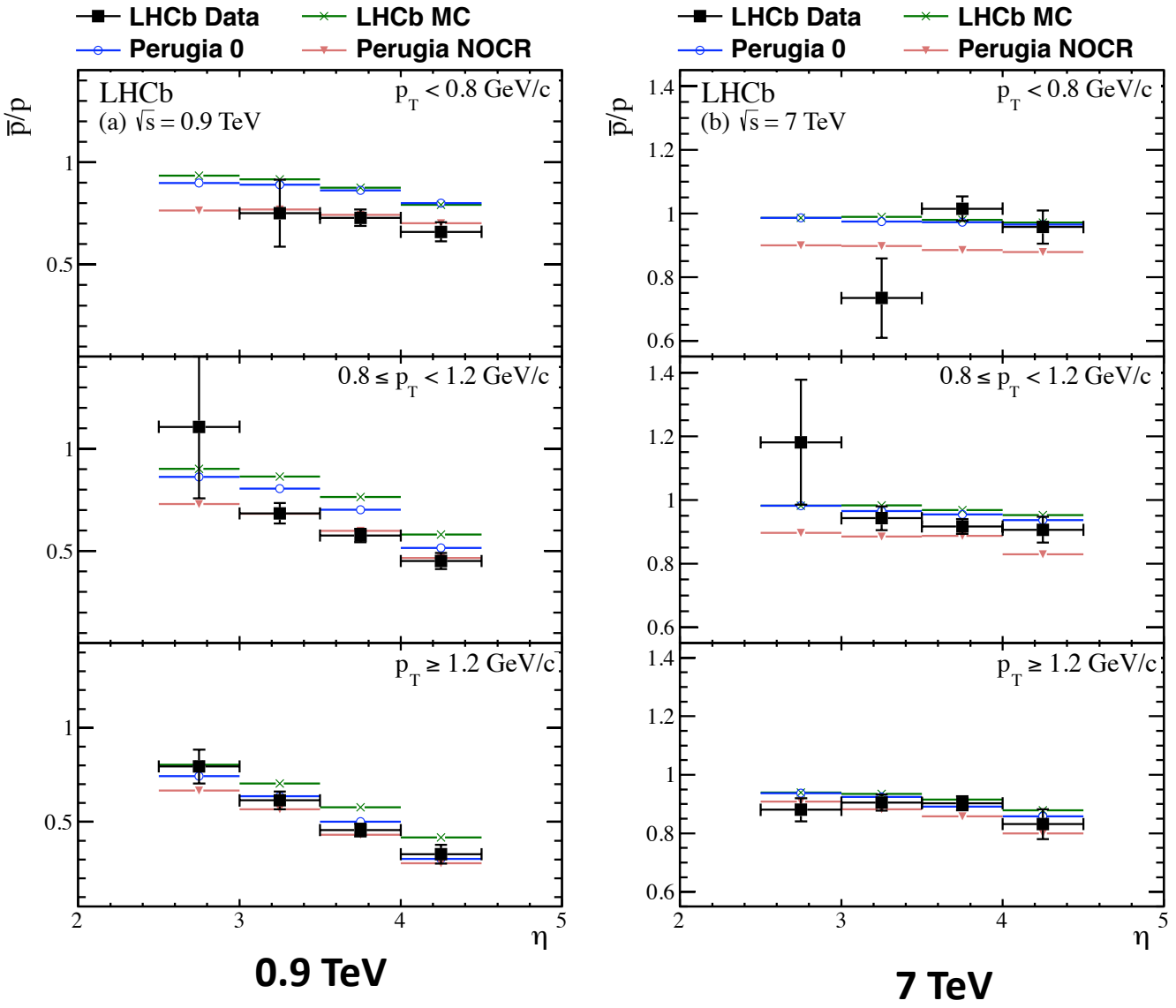
Agreement with simulation generally good, but results hard to interpret.



Baryon transport

LHCb-PAPER-2011-037 (arXiv:1206.5160)

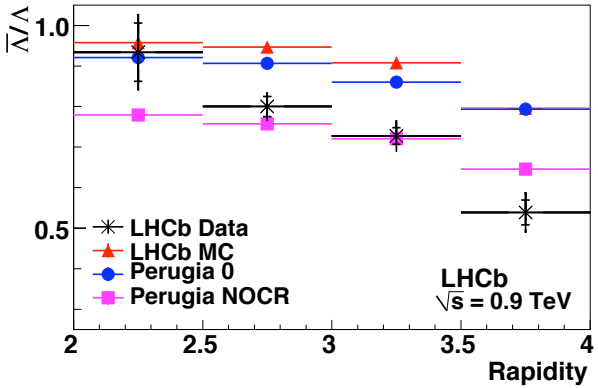
At 0.9 TeV the $\bar{p}/p$ ratio ↘ from 0.8 to 0.4 in the highest p_T and η bin. Data usually below LHCb MC and Perugia 0 predictions closer to Perugia NOCR PYTHIA 6 tunes

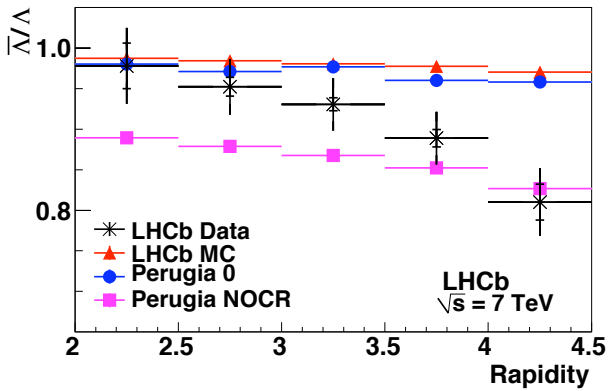


Baryon transport

LHCb-PAPER-2011-037 (arXiv:1206.5160)

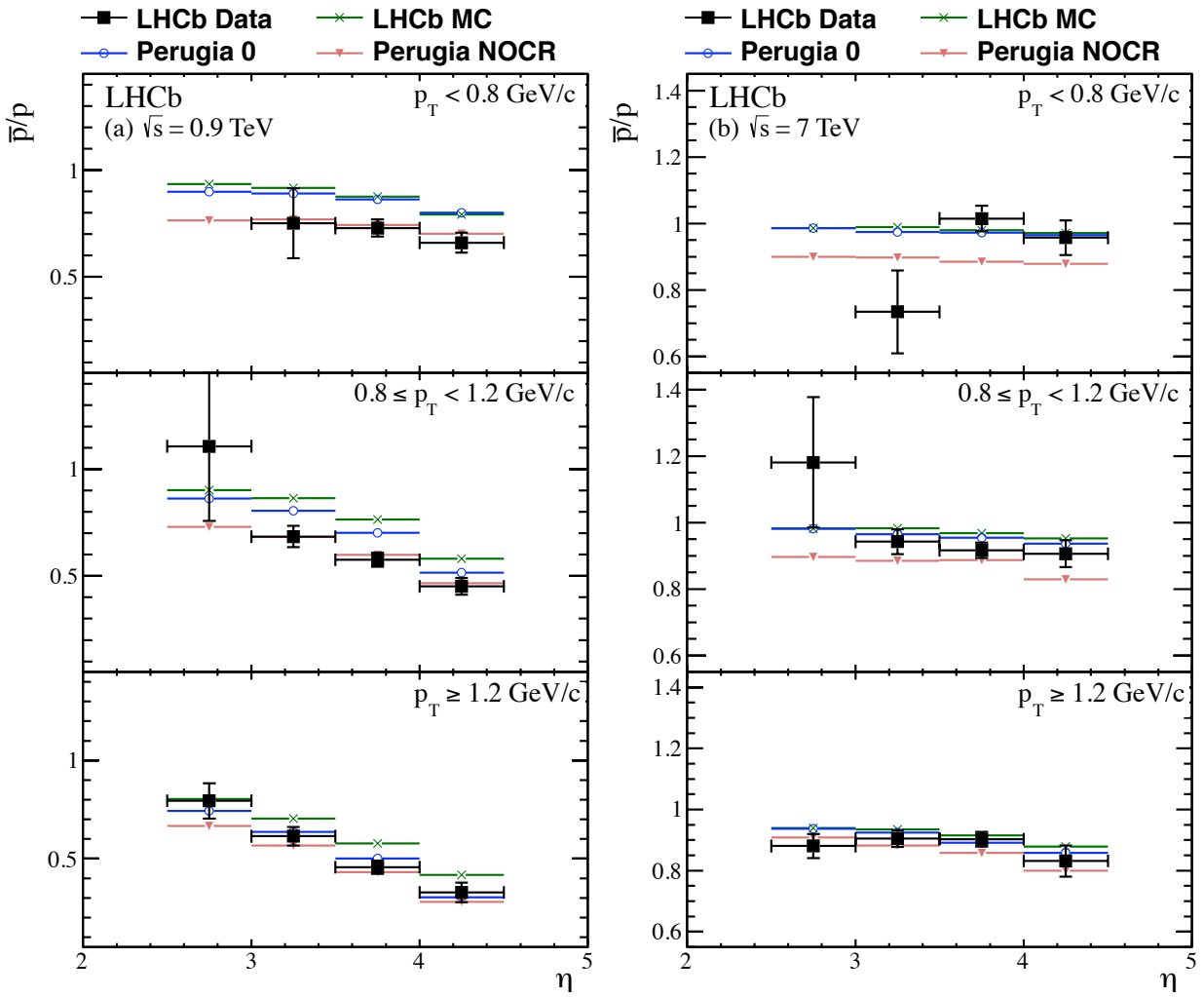
At 0.9 TeV the $\bar{p}/p$ ratio ↘ from around 0.8 to around 0.4 in the highest p_T and η bin. Data below LHCb MC and Perugia 0 predictions closer to Perugia NOCR





0.9 TeV

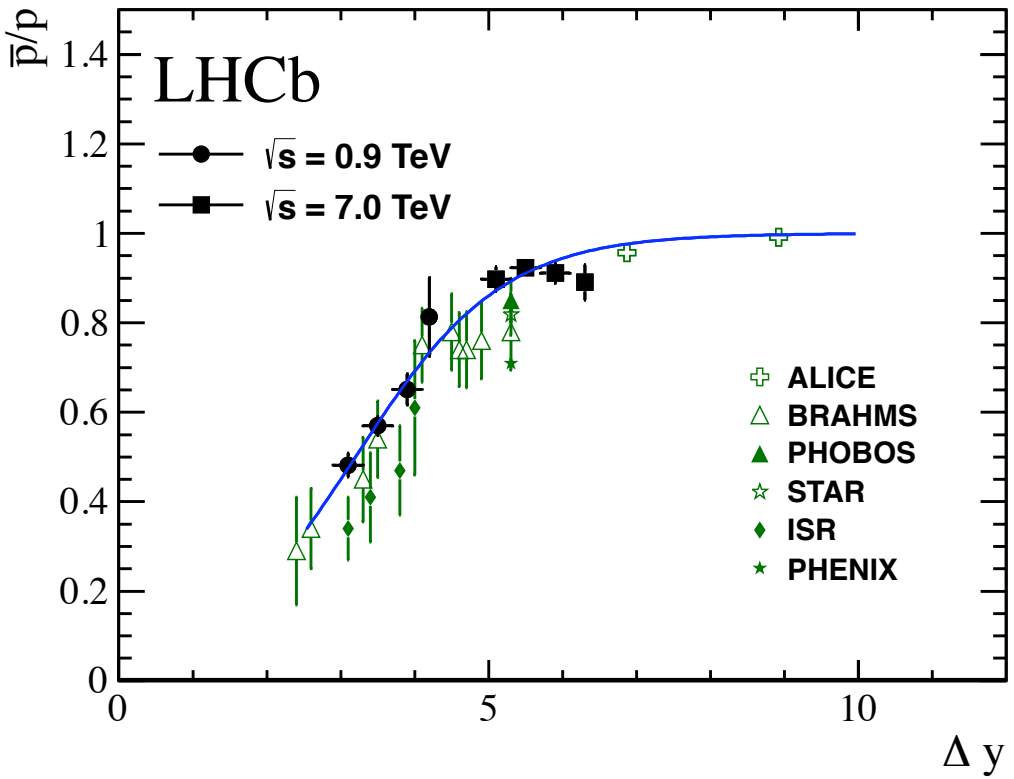
7 TeV



JHEP 1108 (2011) 034.

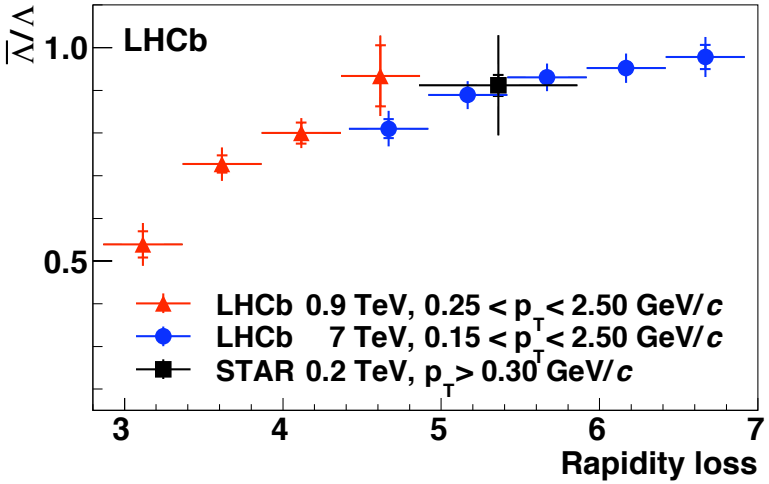
Baryon transport vs. rapidity loss

LHCb-PAPER-2011-037 (arXiv:1206.5160)



JHEP 1108 (2011) 034.

LHCb results cover a larger rapidity loss than any other single experiment and significantly improve the measurement precision in the region $\Delta y = y_b - y < 6.5$.



Summary

Pythia 6 tunes underestimate the energy flow at high η while most of the cosmic ray generators overestimate them. None of the generators investigated describe the energy flow correctly for all the classes of events studied -> results input for model tuning.

Measurements of : $\frac{\bar{p}}{p}, \frac{K^-}{K^+}, \frac{\pi^-}{\pi^+}, \frac{p+\bar{p}}{\pi^+ + \pi^-}, \frac{K^+ + K^-}{\pi^+ + \pi^-}, \frac{p+\bar{p}}{K^+ + K^-}$

were presented @ 0.9 and 7 TeV (first such studies at this energy). No single tune is able to describe well all the observables, largest discrepancies for $\frac{p+\bar{p}}{\pi^+ + \pi^-}, \frac{K^+ + K^-}{\pi^+ + \pi^-}$

$\frac{\bar{p}}{p}$ **has been studied as function of rapidity loss over a range from 3.1 to 6.3, more precise results than previous measurements.**

LHCb is not only a b&c-physics experiment but provides also an excellent environment for soft-QCD studies at high rapidities/pseudorapidities.

Stay tuned ! for our future soft-QCD studies exploiting also the data @ 2.76 and 8 TeV