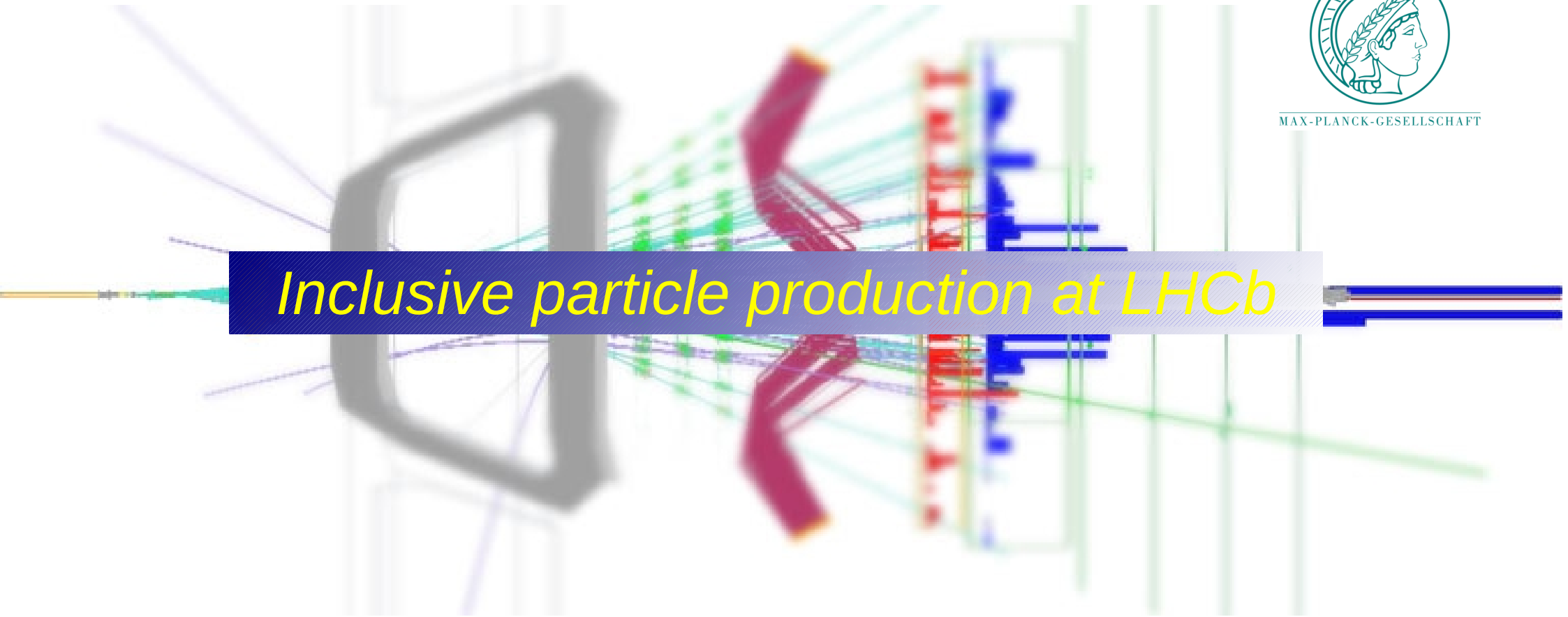


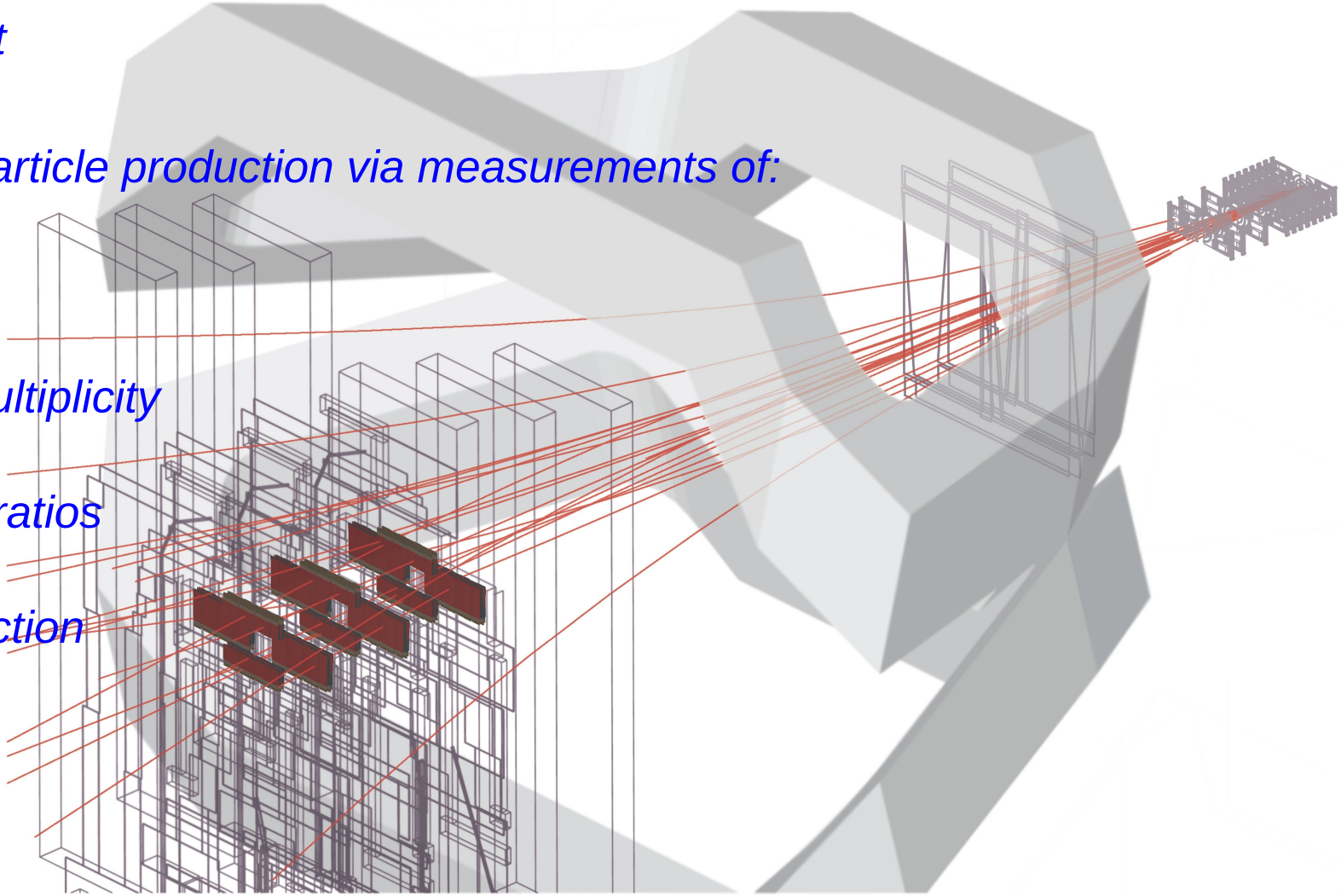
Inclusive particle production at LHCb

Dmytro Volyanskyy
Max-Planck-Institut für Kernphysik (Heidelberg, Germany)
on behalf of the LHCb collaboration

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2013), April 22-26th, 2013, Marseille, France

Outline

- *The LHCb experiment*
- *Studies of inclusive particle production via measurements of:*
  - → *Energy flow*
  - → *Charged particle multiplicity*
  - → *Hadron production ratios*
  - → *Strangeness production*
- *Summary*



LHCb presentations at DIS2013

- *Good assortment for all tastes :-)*

- *See conference program for more details*

- *Charm and beauty production at LHCb (by A. Kozlinskiy on 23.04.2013)*
- *Inclusive particle production at LHCb (by D. Volyanskyy on 23.04.2013)*
- *Limits on neutral Higgs production in the forward region in pp collisions at 7 TeV (by P. Ilten on 23.04.2013)*
- *Properties and decays of the Bc meson and b baryons (by Y. Xunao on 23.04.2013)*
- *Quarkonia and quarkonia-like spectroscopy at LHCb (by C. Fitzpatrick on 23.04.2013)*
- *Studies of excited charm and beauty mesons at LHCb (by V. Gligorov on 23.04.2013)*
- *Studies of quarkonia production and polarisation at LHCb (by M. Frosini on 23.04.2013)*
- *Electroweak boson production at LHCb (by S. Tourneur on 24.04.2013)*
- *Exclusive J/psi and psi(2S) production in pp collisions at 7 TeV (by R. MCnulty on 24.04.2013)*
- *The LHCb upgrade (by U. Marconi on 24.04.2013)*

The LHCb experiment

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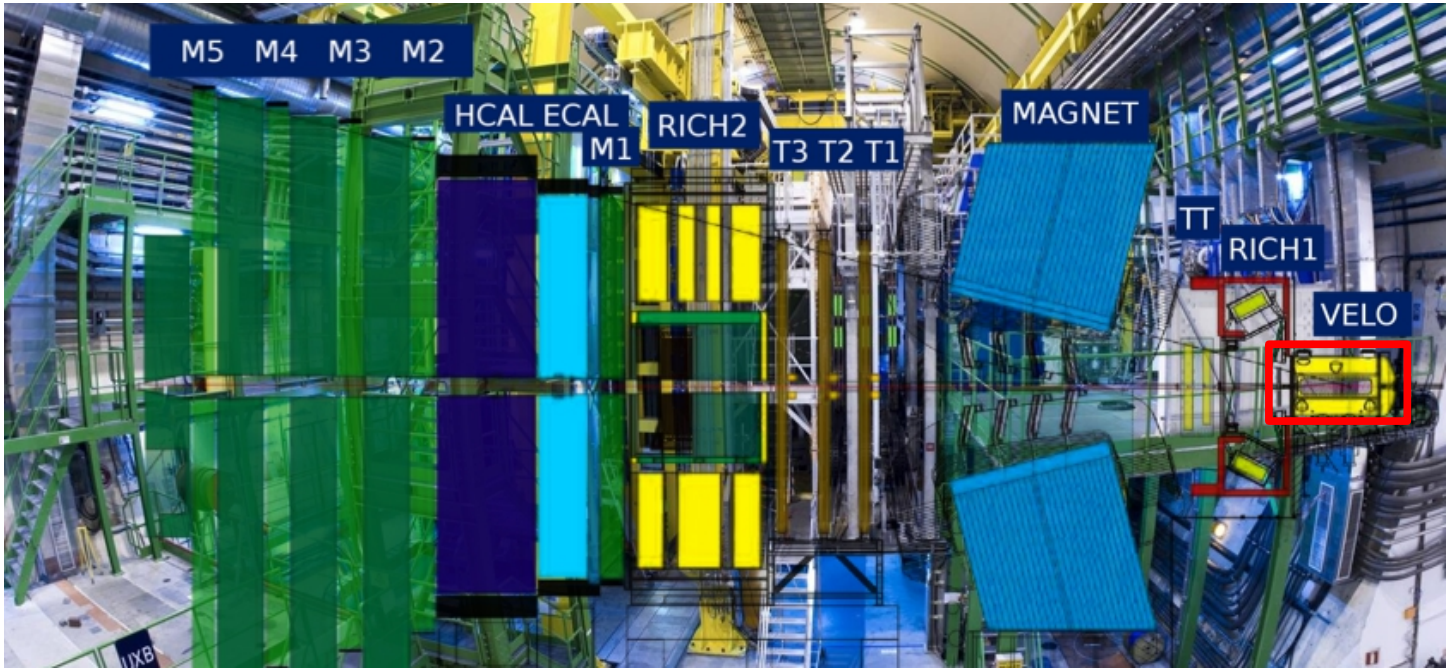
- *Major physics goal: CP violation, rare decays and New Physics searches*

- *Forward spectrometer with planar detectors:*

→ *angular coverage: $1.9 < \eta < 4.9$*

→ *combination of PID and tracking detectors covering the full acceptance: unique @ LHC*

→ *ability to explore low-p_T processes at large η*



- *Excellent tracking performance:*

→ *momentum resolution of tracks traversing the full tracking setup $\delta p/p \sim 0.4$–0.6%*

→ *great invariant mass resolution and precise vertex reconstruction achieved*

- *High quality particle identification:*

→ *RICH system: efficient hadron ID over the wide momentum range – unique@LHC*

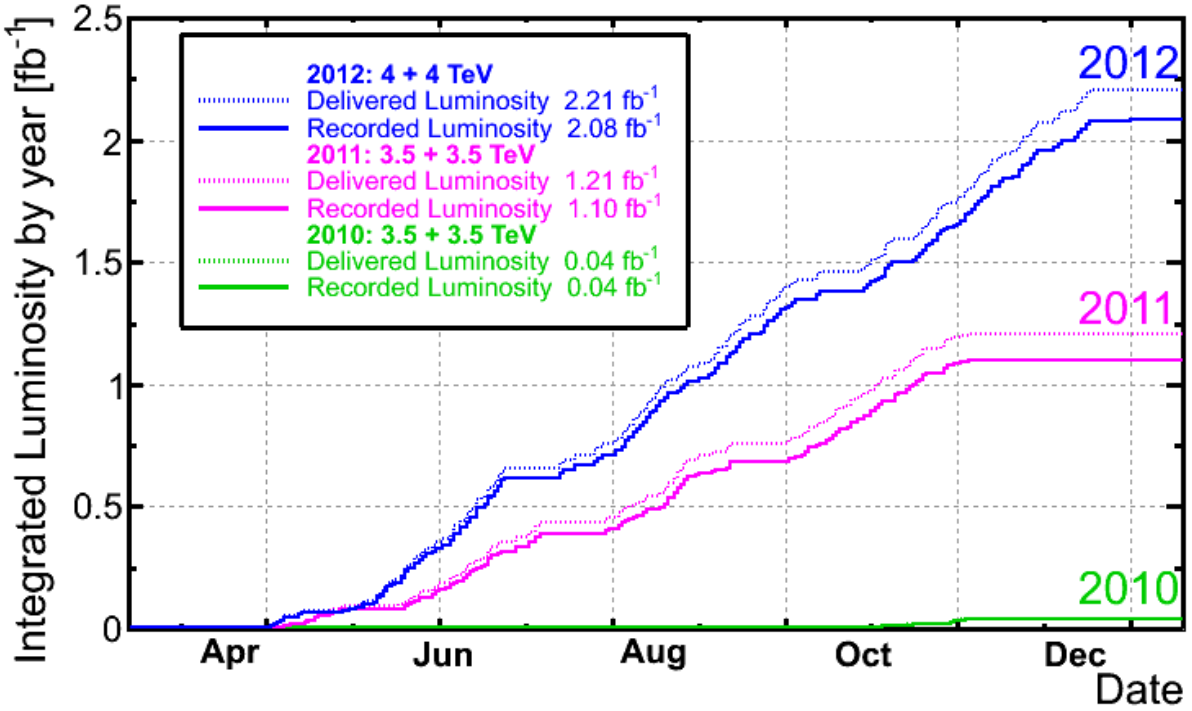
→ *Calorimeter and Muon Systems: robust e, γ, muon, hadron separation + trigger*

- *Selective and flexible trigger system*

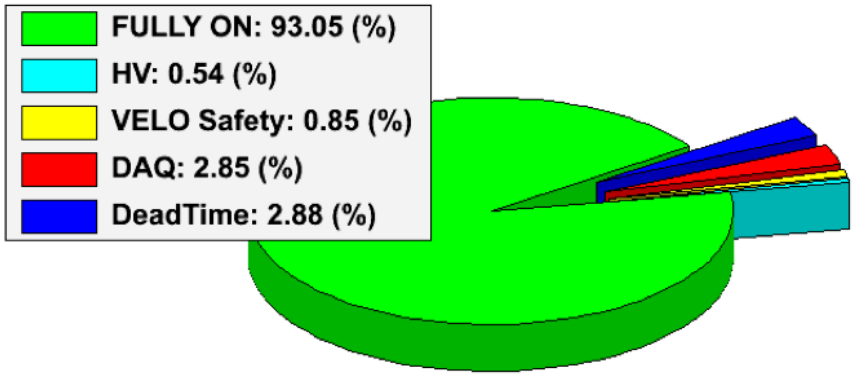
JINST 3 (2008) S08005

Data taking

year	luminosity	energy (TeV)
2009	6.8 μb^{-1}	0.9
2010	0.3 nb^{-1}	0.9
2010	37 pb^{-1}	7
2011	0.1 pb^{-1}	2.76
2011	1.0 fb^{-1}	7
2012	2.0 fb^{-1}	8
2011	3.7 pb^{-1}	2.76
2012	2.0 nb^{-1}	5.02(pPb/Pbp)



LHCb Efficiency breakdown pp collisions 2010-2012



Results shown here were obtained with low pile-up data and microbias trigger

- *~93 % data taking efficiency*
- *~99% r/o channels operational*
- *~99% of accumulated data are useful for physics analysis*
- *Luminosity leveling to moderate interaction rate*
- *In 2011&2012, high luminosity (up to 4.0× 10^{32} cm^{-2} s^{-1}) running*
- *LHCb design luminosity: 2.0 × 10^{32} cm^{-2} s^{-1}*
- *Smooth data taking by LHCb despite strong challenge for the trigger and offline data processing*

Forward Energy Flow: outline

- *Energy Flow (EF) :*
  → average energy created in a particular η interval per inelastic pp interaction

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

- *EF is sensitive to the amount of parton radiation and multi-parton interactions (MPI)*
  - *→ strongly needed for a precise description of the UE*
  - *→ possibility to discriminate between MPI models*
  - *→ great input for MC tuning*
- *improve the existing constraints on ultra high energy cosmic-ray interaction models:*
  - *→ LHC provides first possibility to compare cosmic-ray showering models at E_{lab} of up to ~10^{17}eV*

- *EF is measured for the following event classes:*
  - *→ inclusive MB: at least 1 track in 1.9<η<4.9 with p > 2 GeV*
  - *→ hard scattering: at least 1 track in 1.9<η<4.9 with p_T > 3 GeV*
  - *→ diffractive enriched: inclusive MB with no backward tracks in −3.5<η<−1.5*
  - *→ non-diffractive enriched: inclusive MB with at least 1 backward track in −3.5<η<−1.5*
- *Charged EF: tracks traversing the full setup*
  Neutral EF: data-constrained MC estimate
- *Data corrected for detector effects & compared to PYTHIA-based+cosmic-ray models*
- *Systematic effects decrease towards large η*

arXiv:1212.4755 [hep-ex]
accepted by EPJC

Forward Energy Flow: results (1)

- *EF increases with the momentum transfer in an underlying pp process:*

$$EF_{\text{hard}} > EF_{\text{non-diffr}} > EF_{\text{incl}} > EF_{\text{diffr}}$$

- *PYTHIA6-based models underestimate EF at large η and overestimate it at low η in case of all event classes*

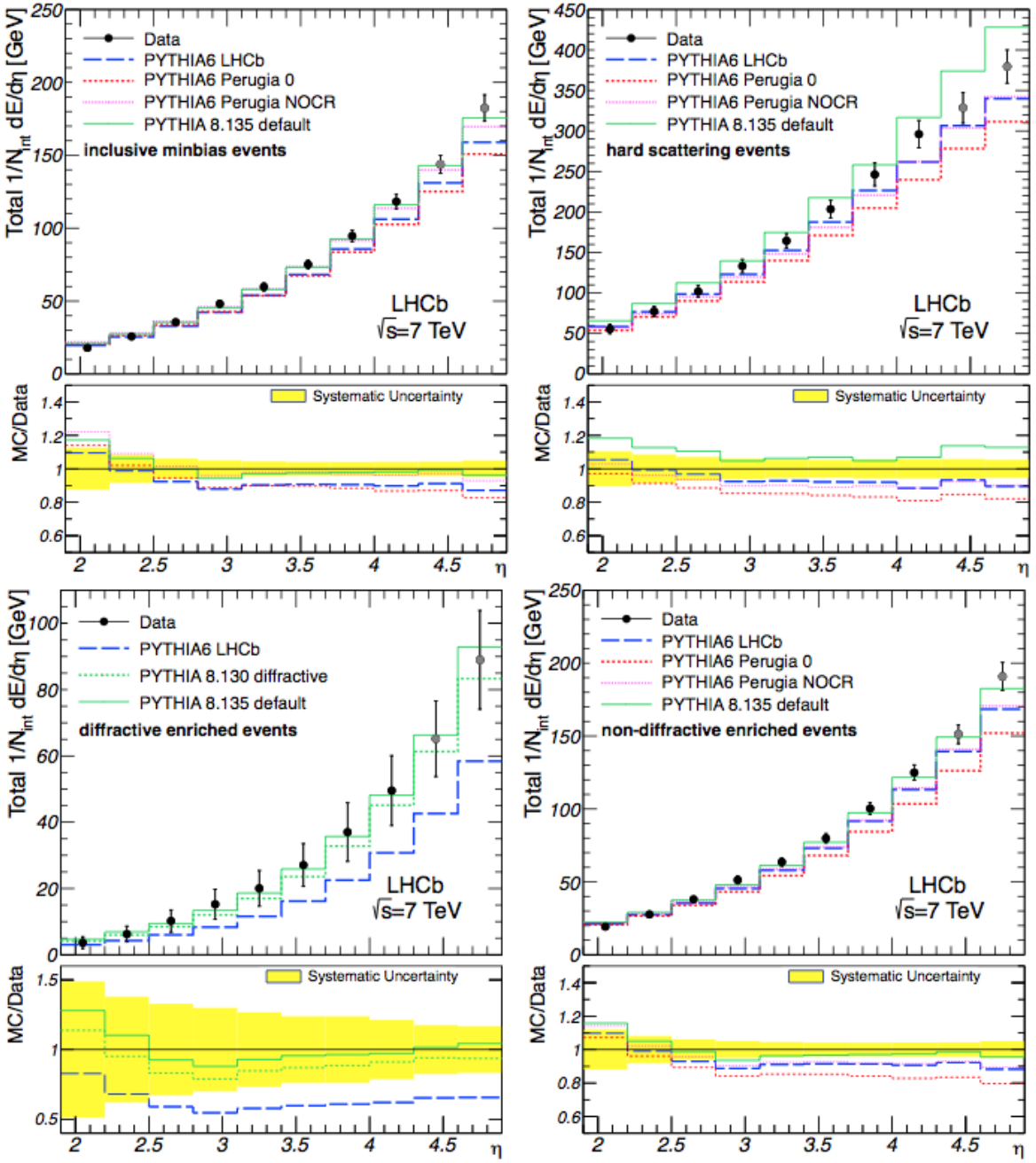
- *PYTHIA8 gives excellent description of the inclusive, diffractive and non-diffractive enriched EF at large η*

J. of Phys. : Conf. Ser. 331 (2011) 032023.

Phys. Rev. D82 (2010) 074018, arXiv:1005.3457

Comput. Phys. Commun. 178 (2008) 852, arXiv:0710.3820

arXiv:1212.4755 [hep-ex]
accepted by EPJC



Forward Energy Flow: results (2)

- *EPOS 1.99, SYBILL 2.1, QGSJET01, QGSJETII cosmic ray interaction models*
  - → *soft processes via Pomeron exchanges (Gribov's Reggeon Field Theory)*
  - → *hard processes: pQCD or exchanges of semi-hard Pomerons*
  - → *models are not tuned to LHC data*
  - → *thanks to Ralf Ulrich and Colin Baus from KIT for providing these predictions*

Astropart. Phys. 35 (2011) 98, arXiv:1101.5596.

J. Phys. : Conf. Ser. 60 (2007) 167, arXiv:astro-ph/0610788.

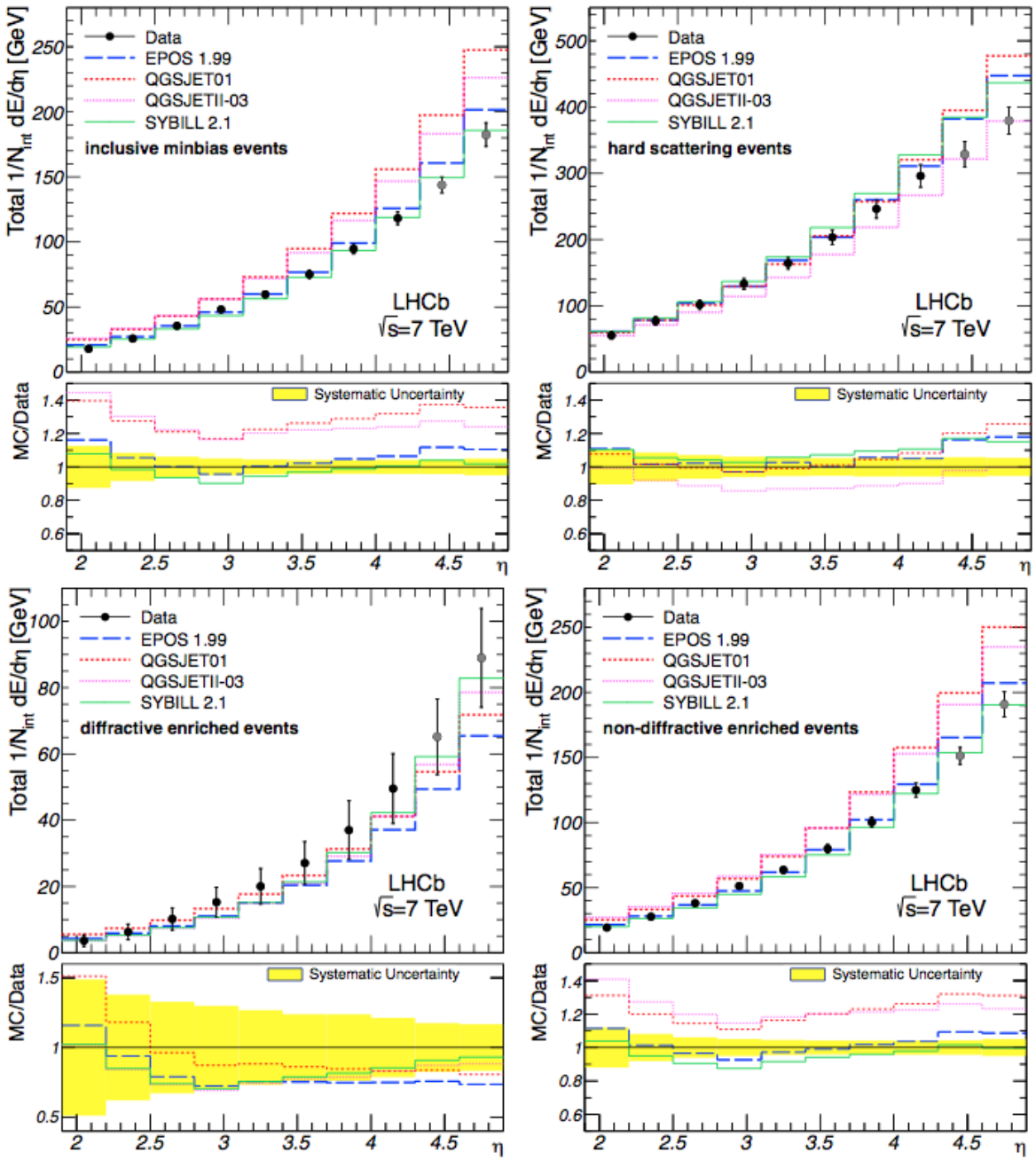
AIP Conf. Proc. 928 (2007) 118.

Nucl. Phys.Proc. Suppl. 196 (2009) 102, arXiv:0905.1198.

Phys. Rev.D80 (2009) 094003, arXiv:0906.4113.

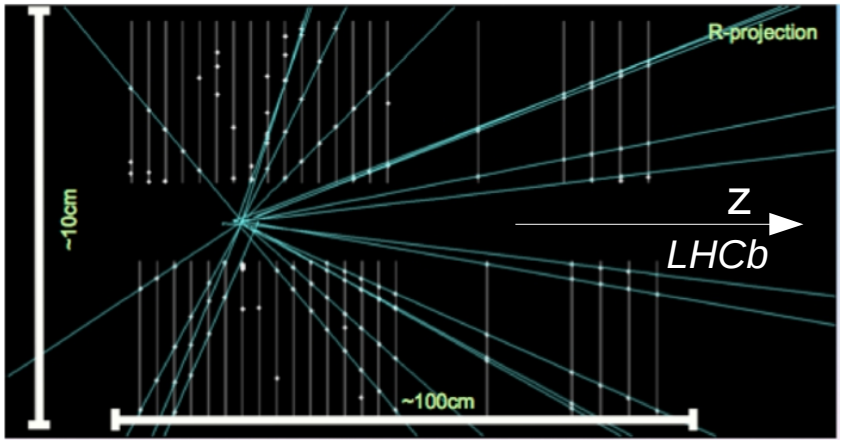
- *SYBILL 2.1 gives the best description of the inclusive and non-diffractive EF*
- *None of the models are able to describe the EF measurements for all event classes:*
  - → *valuable input for MC tuning and MPI/UE models*

arXiv:1212.4755 [hep-ex]
accepted by EPJC

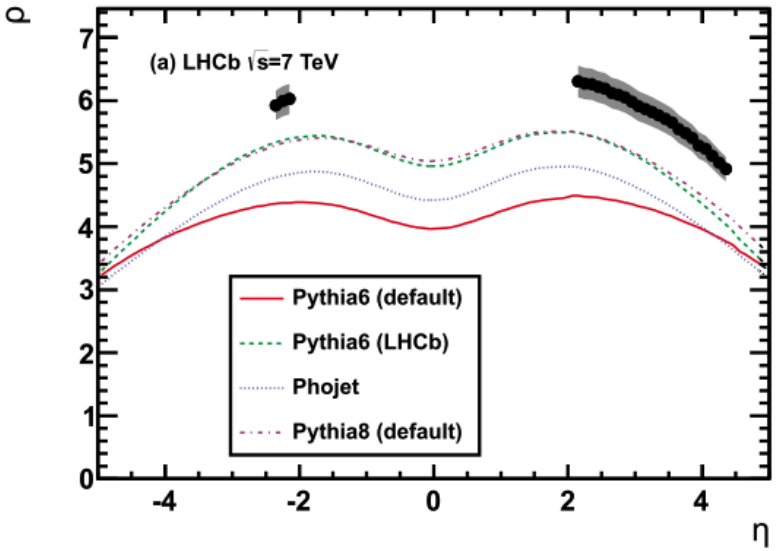


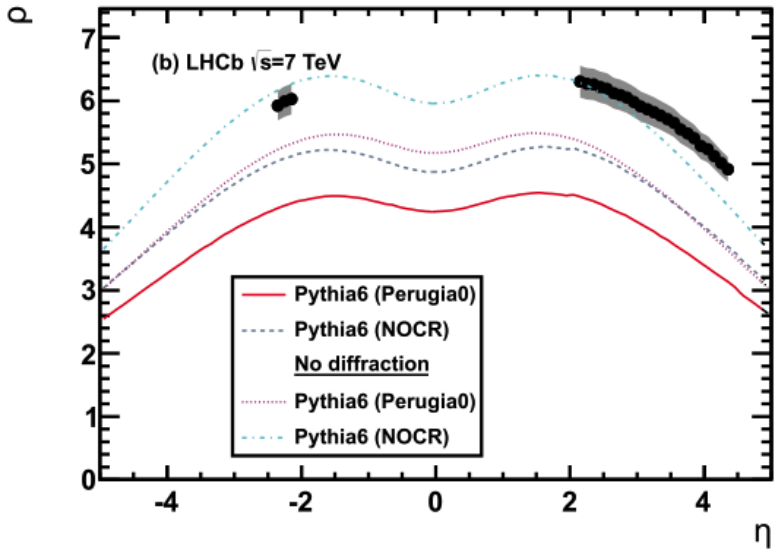
Charged Particle Multiplicities (1)

- *Measurement of the charged particle multiplicities :*
  - → *sensitivity to the underlying QCD dynamics*
  - → *charged particles counted using reconstructed tracks in the VELO (no magnetic field – tracks are straight lines)*
  - → *measurements with minimum bias and hard interaction (at least 1 long track with p_T>1 GeV) events*



- *Charged particle density per event vs η for the data and models:*
  - → *normalized to events with at least 1 charged particle in the forward acceptance*



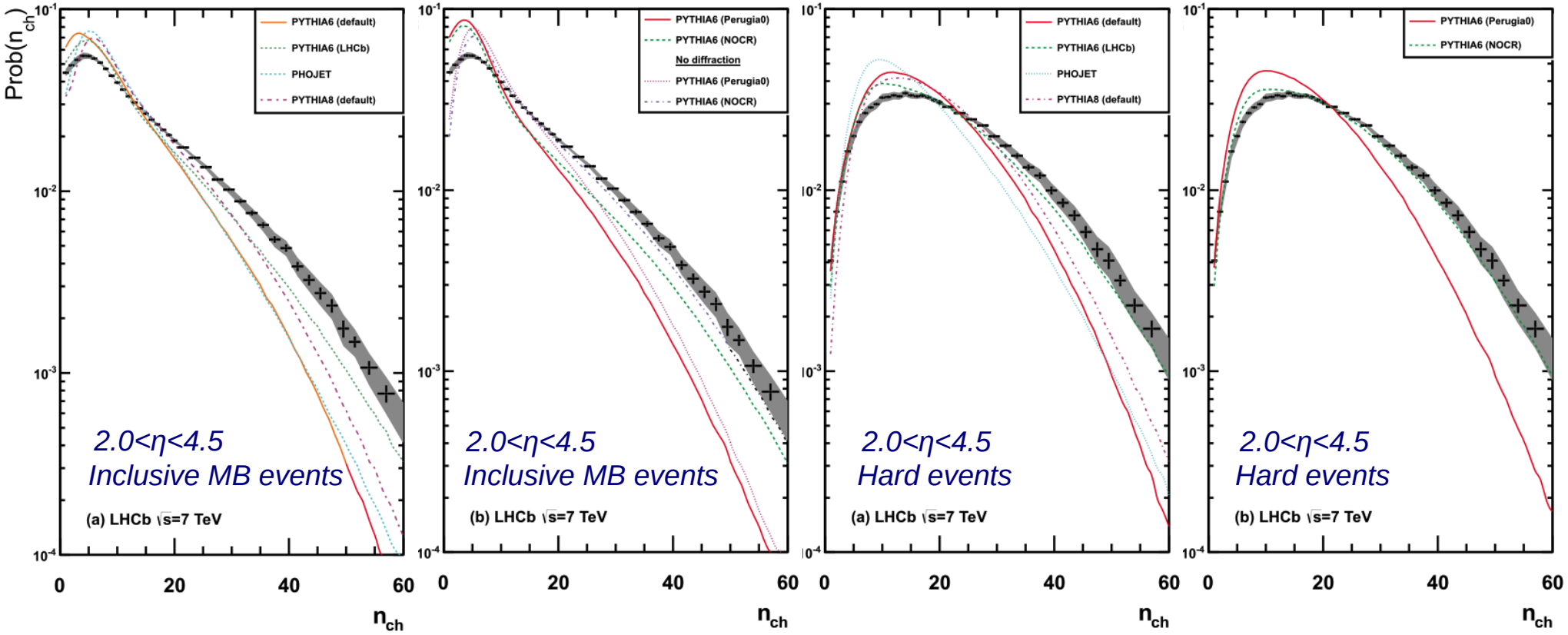


→ *large discrepancy between the data and model predictions: Perugia NOCR without diffraction gives the best description of the measurements*

Eur. Phys. J. C 72 (2012) 1947

Charged Particle Multiplicities (2)

- *multiplicity distributions for inclusive MB and hard events vs generator level predictions:*



- *none of the generators are fully able to describe the multiplicity distributions or the charged density distribution as a function of η in the LHCb acceptance*

- *models underestimate the charged particle production in the forward region*
  → valuable input for MC tuning and UE models

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Hadron Production Ratios (1)

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- *Ratios of prompt hadrons at 0.9 TeV and 7 TeV*

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

as a function of pseudorapidity and transverse momentum:

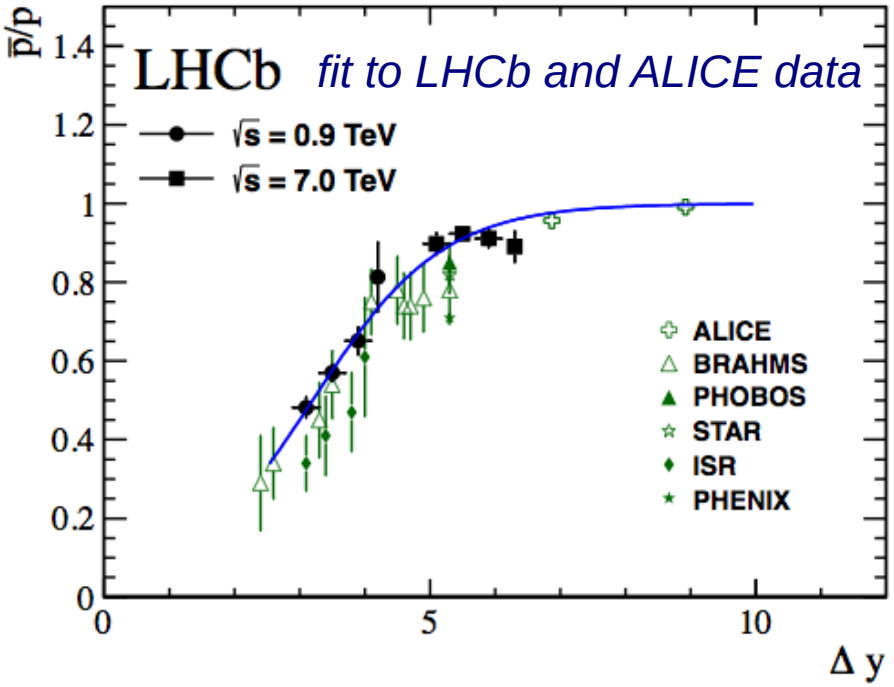
→ *sensitive test of hadronisation and baryon number transport*

→ *very important measurements for MC tuning*

→ *RICH-based analysis: π/K/p separation over a wide momentum range*

→ *PID efficiency and purity estimated from data using tag and probe method on:*

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



- *Ratio* $\bar{p}/p$ *is also measured as a function of rapidity loss*

$$\Delta y = y_{\text{beam}} - y_{\text{particle}}, \; y_{\text{beam}} = 8.9\,(6.9) \text{ at } \sqrt{s} = 7\,(0.9)\,\text{TeV}$$

→ *consistency with previous measurements, much better accuracy*

→ *no significant dependence on pT and* $\sqrt{s}$

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Hadron Production Ratios (2)

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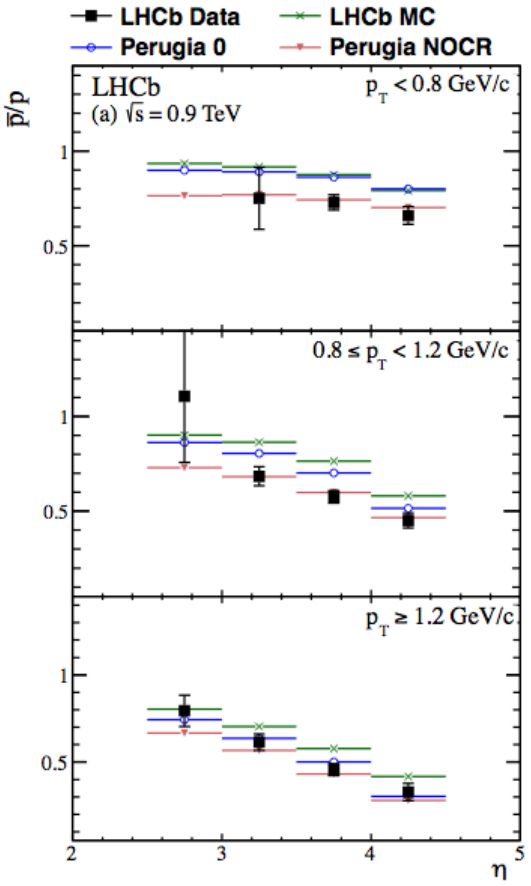
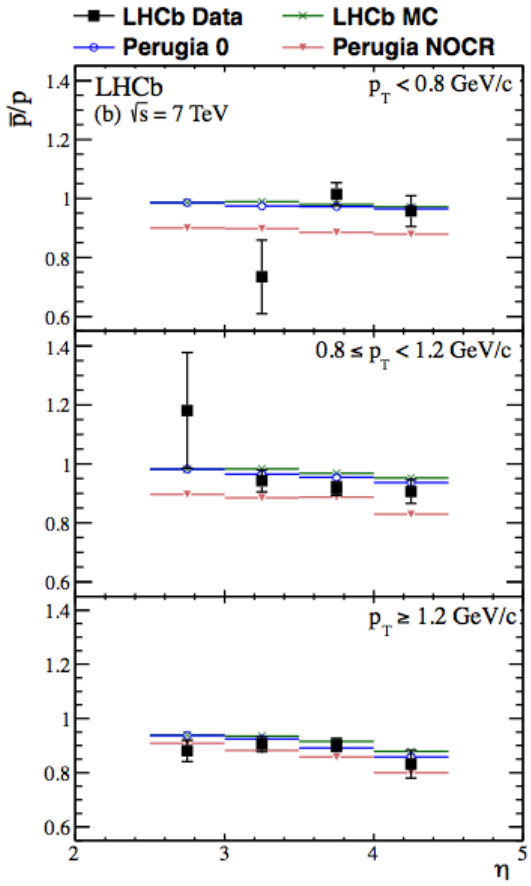
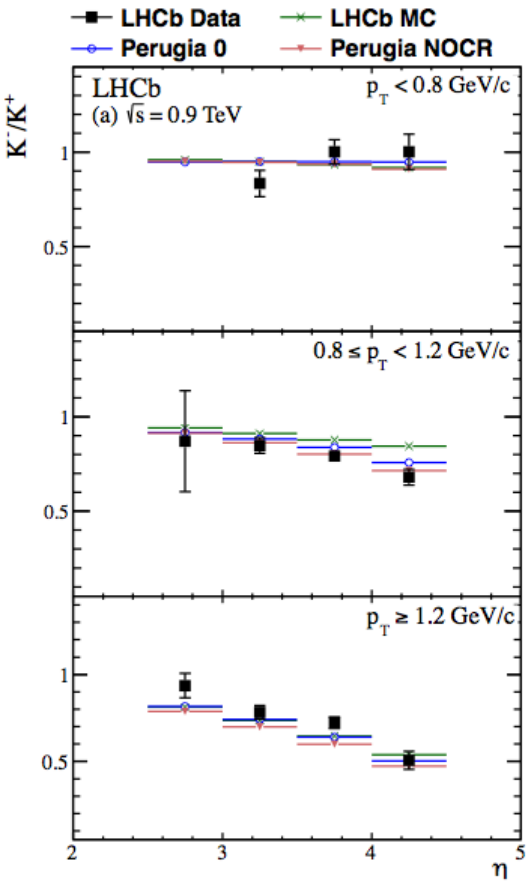
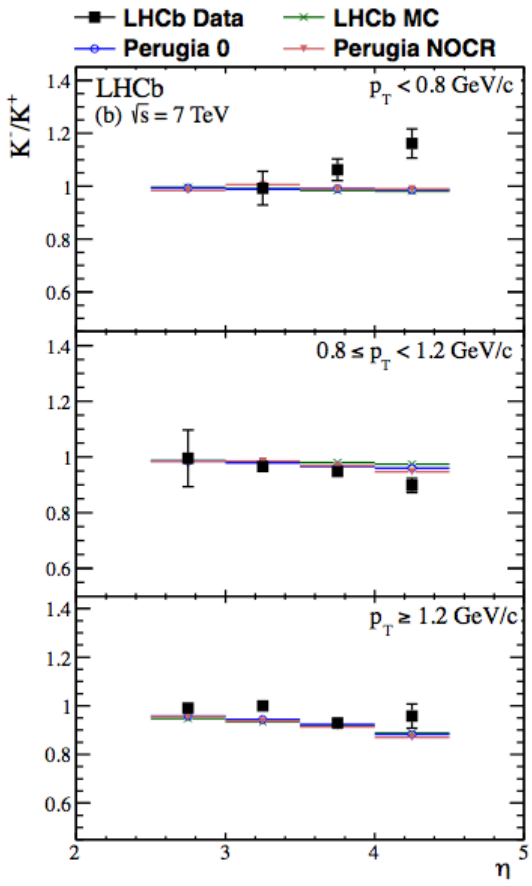
$\bar{p}/p$





K^-/K^+





→ *largest uncertainty at low pT and η*

→ *data is compared to predictions given by various PYTHIA6-based models*

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Hadron Production Ratios (3)

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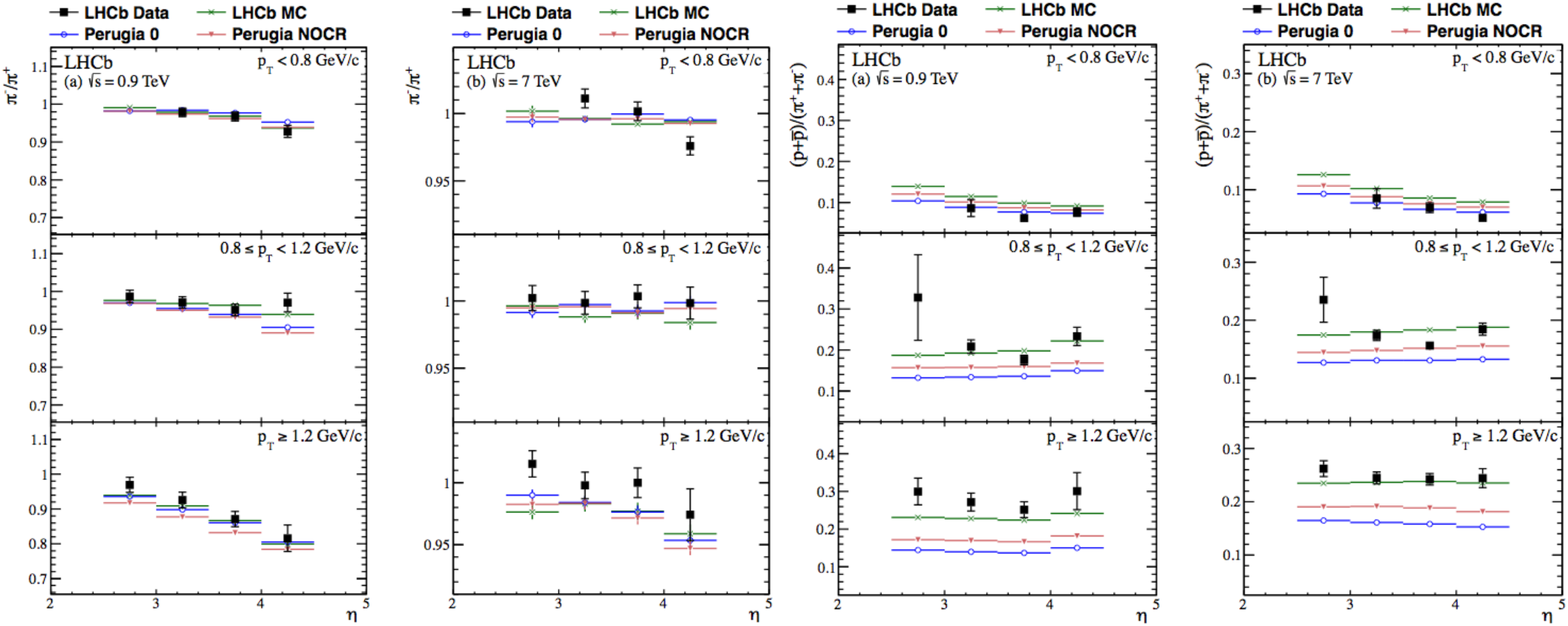
π^-/π^+

$(p+\bar{p})/(\pi^+ + \pi^-)$



→ *discrepancy between data and MC is observed in the majority of bins*

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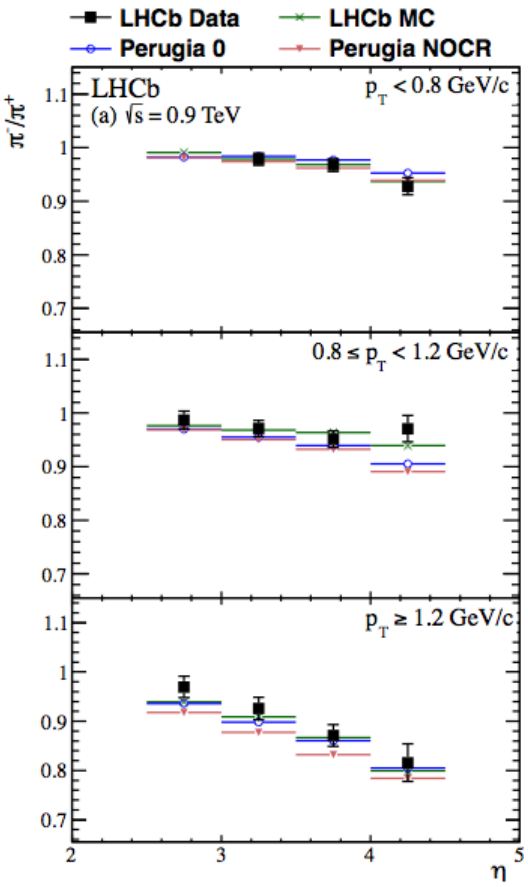
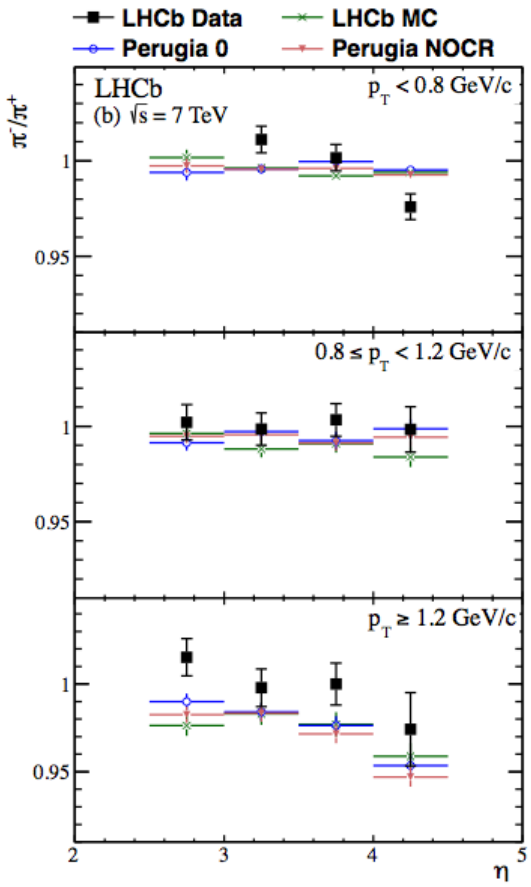
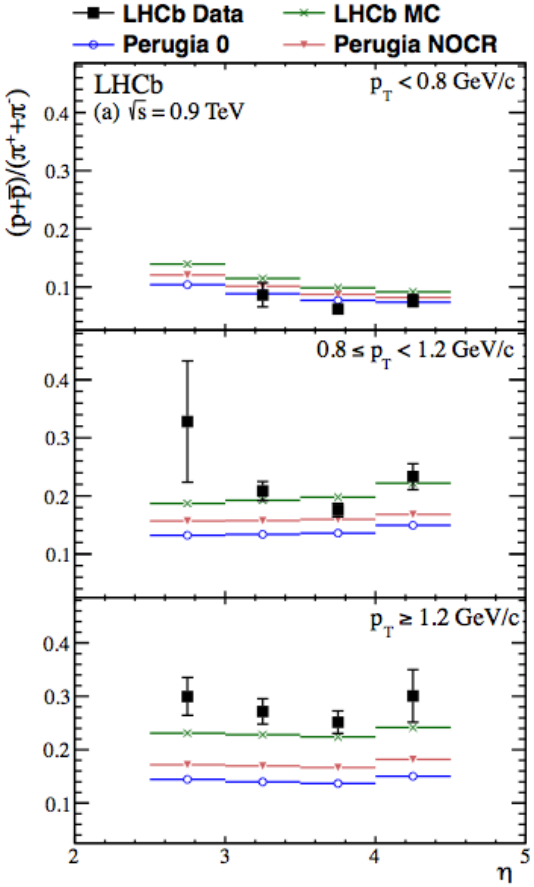
Hadron Production Ratios (4)

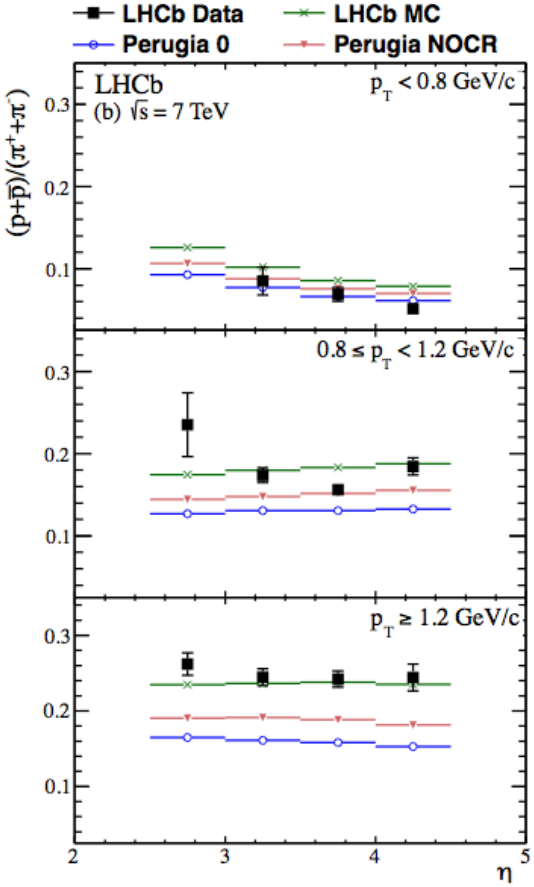
$(K^+ + K^-)/(\pi^+ + \pi^-)$





$(p + \bar{p})/(K^+ + K^-)$





→ *none of the models are able to describe the measurements for all phase space bins: valuable input for MC tuning*

Eur. Phys. J. C 72 (2012) 2168

Strangeness Production (1)

- *V^0 production ratios at 0.9 TeV and 7 TeV:*

JHEP 08 (2011) 034

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

as a function of rapidity and transverse momentum:

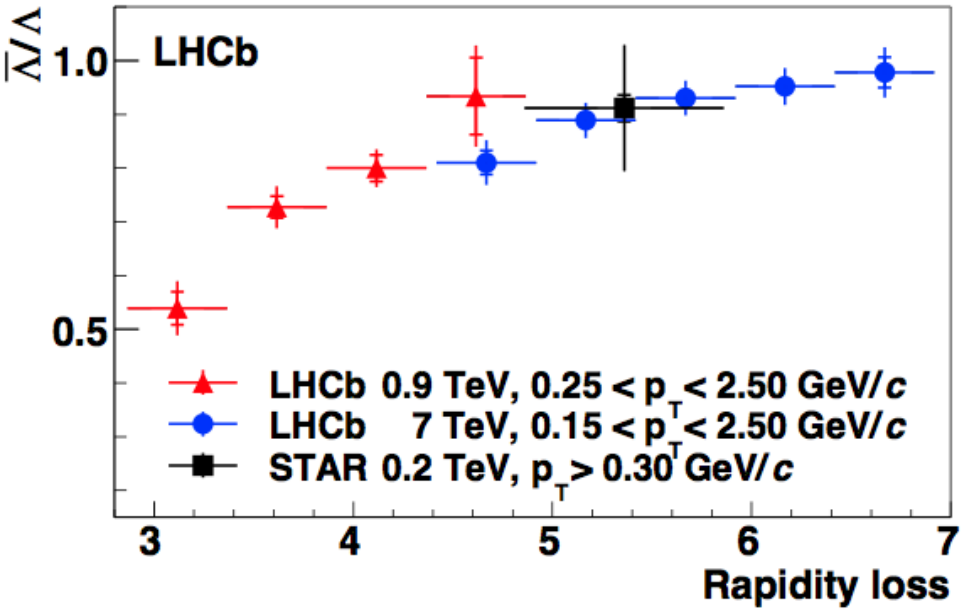
→ *Baryon Number Transport and Baryon/Meson suppression: sensitive test of hadronisation models*

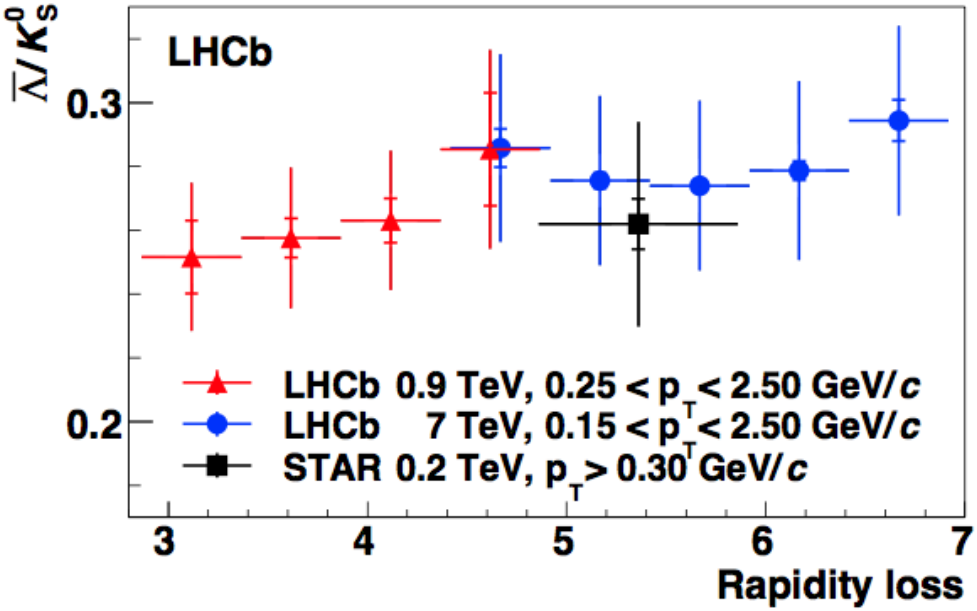
→ $K^0_S \to \pi^+\pi^-$, $\Lambda \to p\,\pi^-$, $\bar{\Lambda} \to \bar{p}\,\pi^+$ *: decays for reconstruction*

→ *reduced systematic uncertainties due to the ratios*

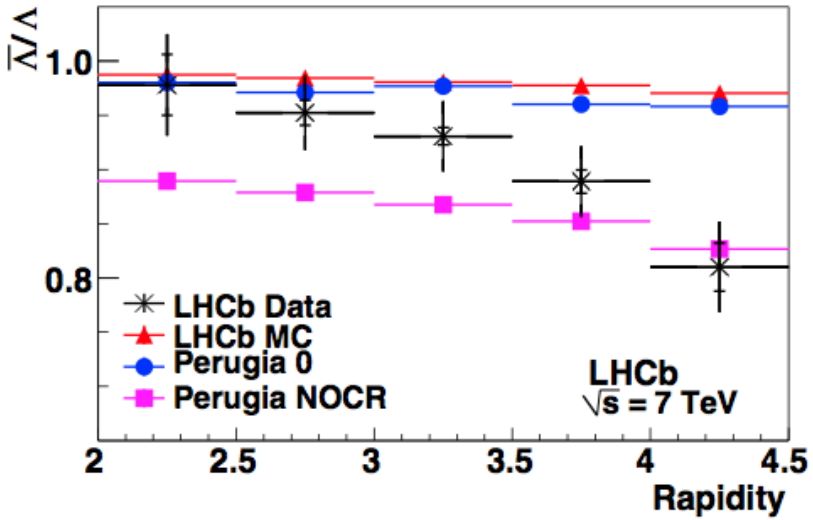
- *Ratios are also measured as a function of rapidity loss:*

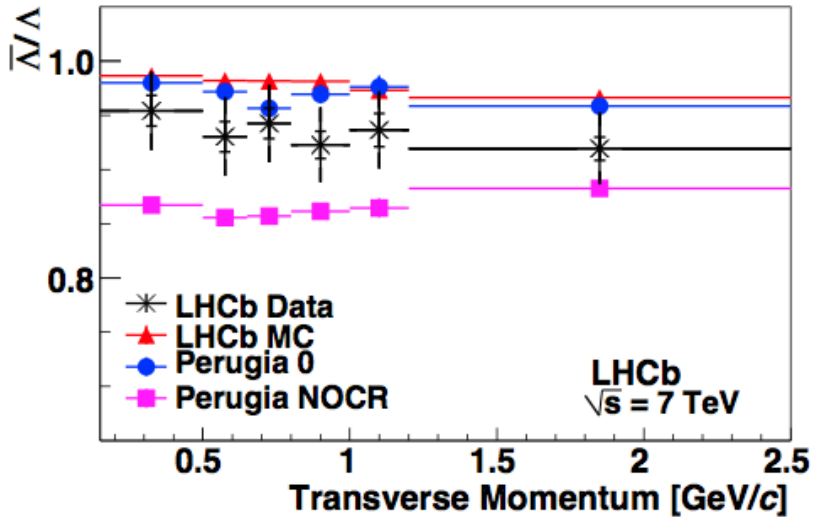
→ *good agreement between 0.9 and 7 TeV data and the STAR measurement*

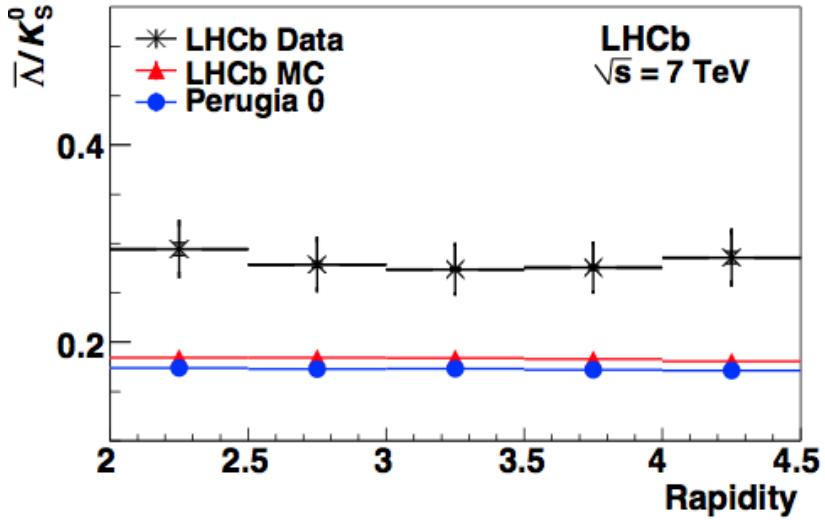


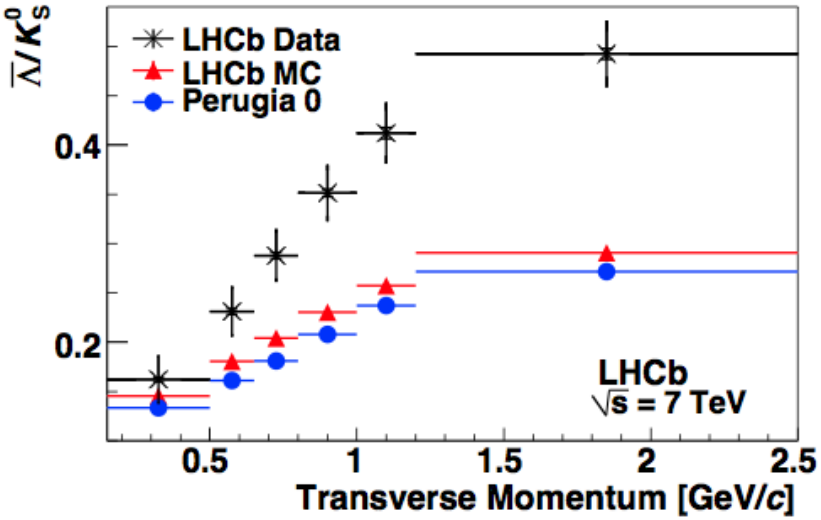


Strangeness Production (2)









→ *Baryon Number Transport is underestimated by PYTHIA6-based models (except for NOCR model), while Baryon/Meson suppression is overestimated: valuable input for MC tuning*

→ *similar behavior at 0.9 TeV*

JHEP 08 (2011) 034

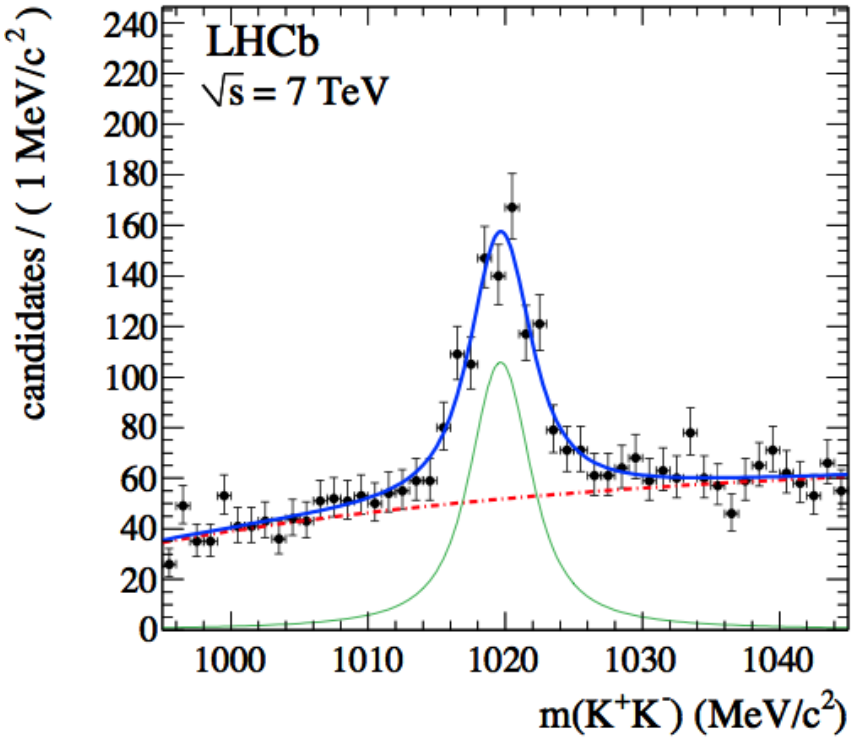
Strangeness Production (3)

- *Inclusive ϕ differential production cross-section:*

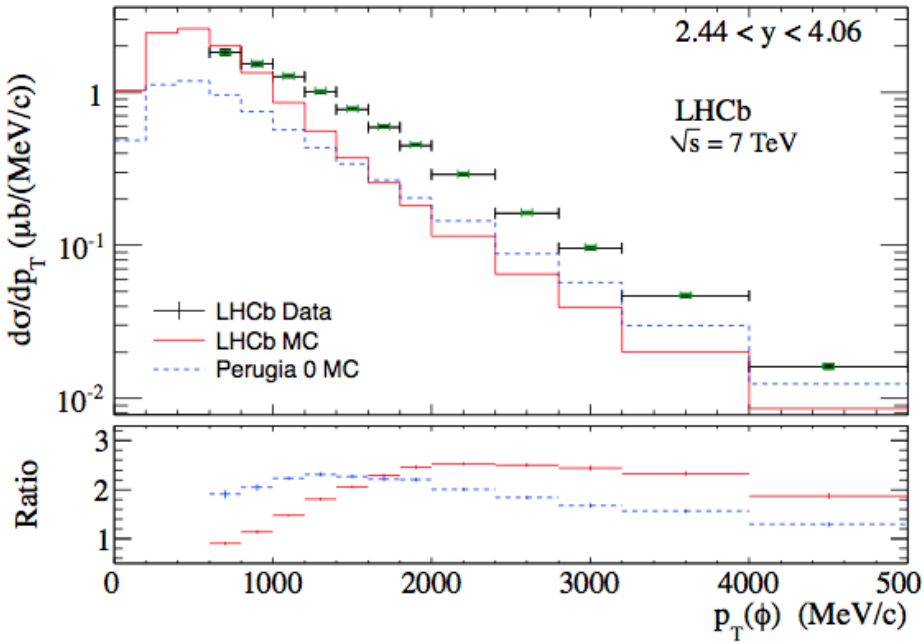
  → *PYTHIA6-based models significantly underestimate the measured cross-section*

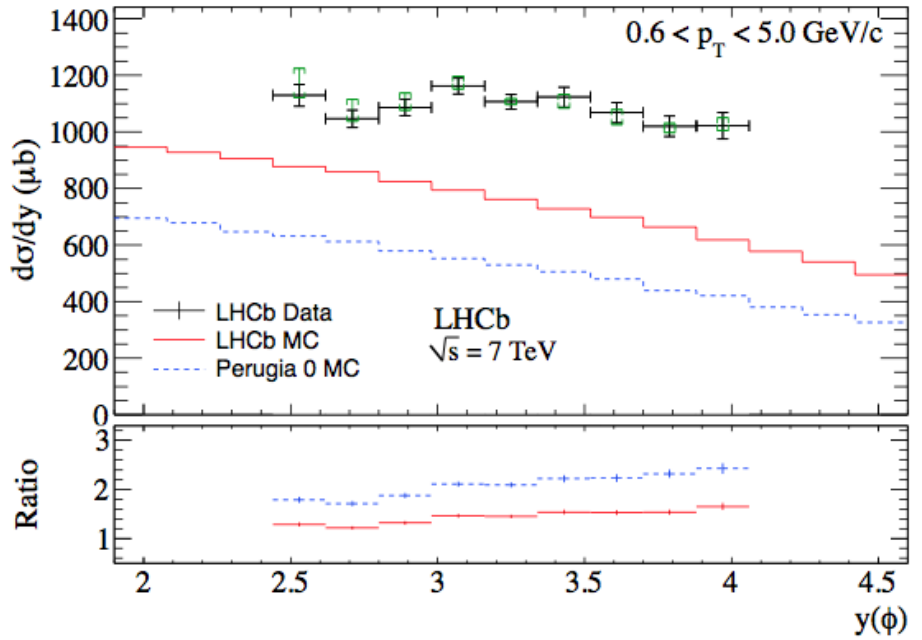
$$2.44 < y(\phi) < 4.06, 0.6 < p_T < 5\,\text{GeV/c}$$

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



Phys. Lett. B 703 (2011) 267-273





Summary

- *LHCb instrumentation permits high-precision studies of particle production in a unique, previously unexplored kinematic range:*
  - → *smooth running of the detector over 2009-2013*
  - → *3 fb^{-1} of high quality data is accumulated*
  - → *possibility to perform analyses using pp collisions at* $\sqrt{s} = 0.9, 2.76, 7.0, 8.0\,\text{TeV}$ *and in pPb and Pbp interactions at* $\sqrt{s_{\text{NN}}} = 5.02\,\text{TeV}$
- *Different inclusive particle production measurements are performed for pp collisions at* $\sqrt{s} = 0.9, 7.0\,\text{TeV}$
- *Great input to theory is delivered by the forward energy flow, charged particle multiplicity, hadron and strangeness production measurements*
- *Analyses at other collision energies are currently ongoing*

Stay tuned for further results !