Soft QCD measurements at LHCb

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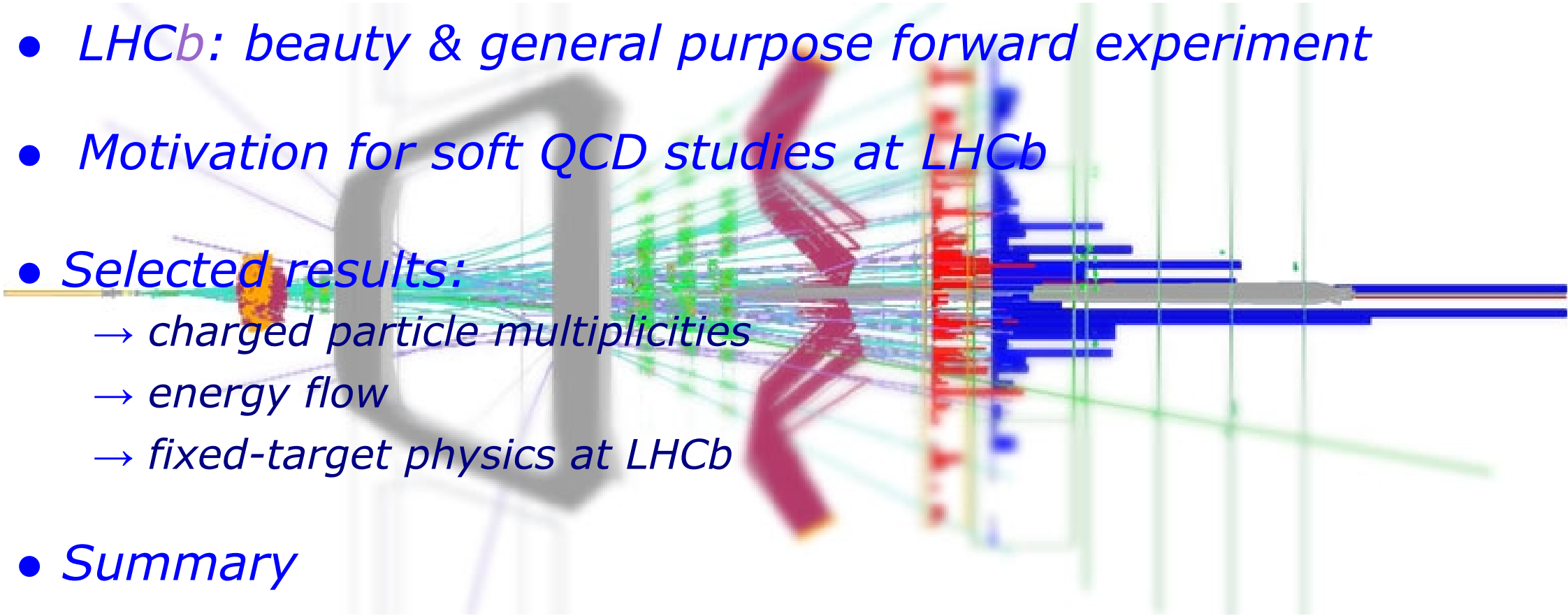
on behalf of the LHCb collaboration

XXVII International Conference on High Energy Physics (ICHEP 2014)

Valencia, Spain, July 2-9th, 2014

Outline



- *LHCb: beauty & general purpose forward experiment*
- *Motivation for soft QCD studies at LHCb*
- *Selected results:*
  - → *charged particle multiplicities*
  - → *energy flow*
  - → *fixed-target physics at LHCb*
- *Summary*

LHCb experiment at the LHC

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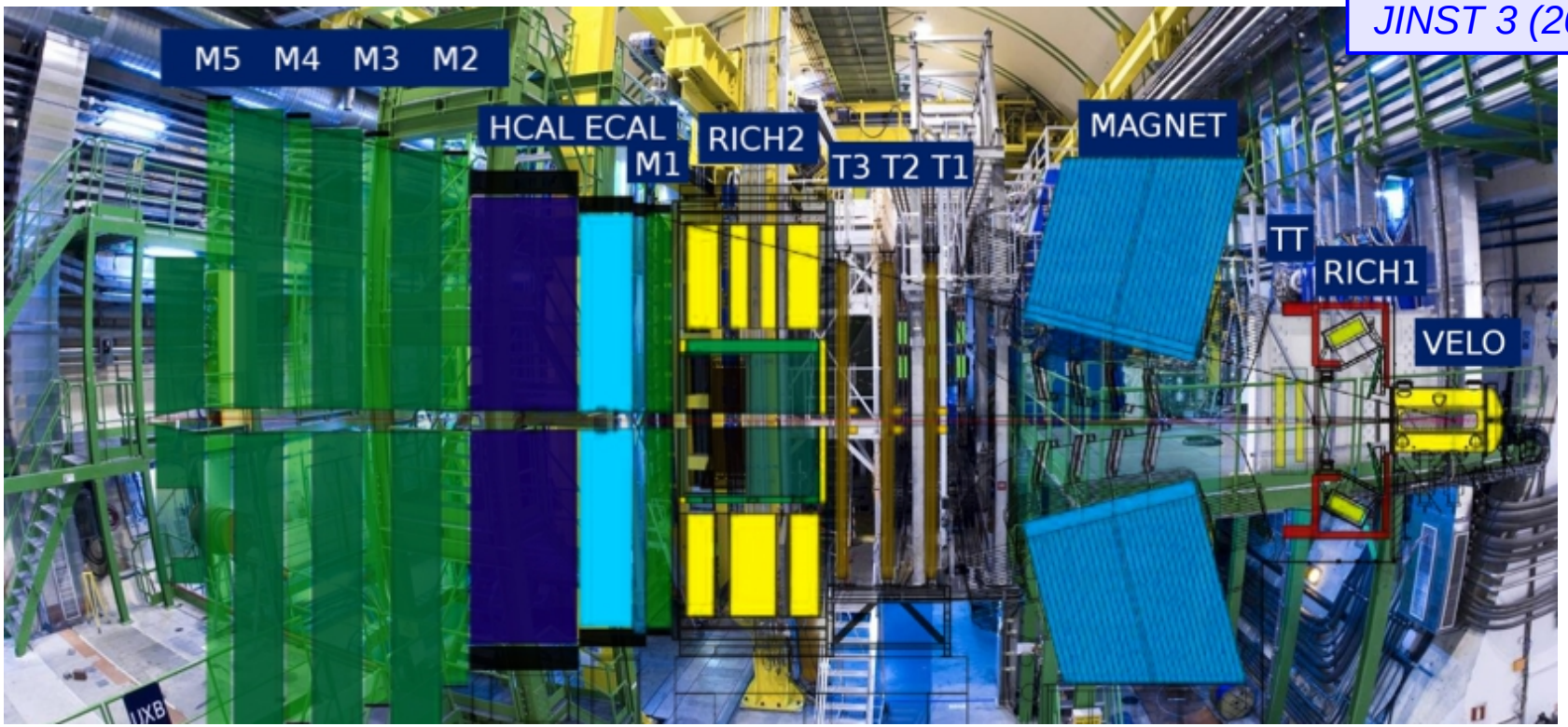
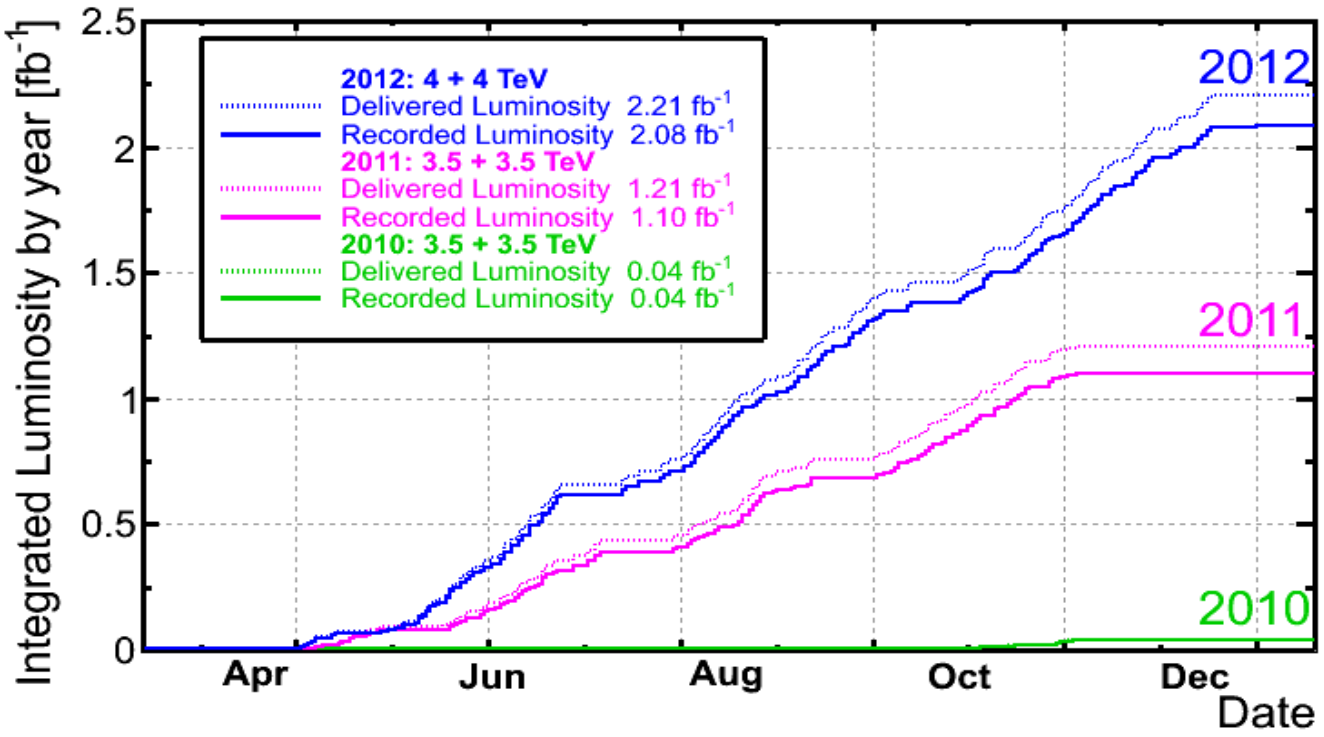
JINST 3 (2008) S08005



- *LHCb uniqueness:*
  - → *tracking, RICH, CALO, MUON cover the full detector acceptance (2.0<η<5.0); also backward tracking (-4.0<η<-1.5)*
  - → *unique kinematic coverage: ability to study low-p_T processes at large η*
  - → *covers just ~4% of the solid angle but captures ~25% of heavy quark pairs produced at the LHC*
- *Excellent tracking performance for charged particles with 2<p<1000 GeV*
- *High quality particle identification:*
  - → *robust hadron ID & lepton/γ/hadron separation over a wide p range*
- *Selective & flexible trigger*

LHCb in the LHC Run I



- *Excellent detector performance:*
  - → *~93 % data taking efficiency*
  - → *~99% r/o channels operational*
  - → *~99% of accumulated data are useful for physics analyses*

- *Smooth data taking in 2011-2012 regardless of high luminosity running:*
  - → *twice the design instantaneous luminosity at double nominal bunch spacing*

- *About 2 × 10^{14} visible pp interactions over the years 2010-2012*

- *Ability to conduct different measurements with 0.9, 2.76, 7 and 8 TeV pp collision data and with 5 TeV pPb collision data plus pNe at and PbNe samples*

LHCb: more than beauty

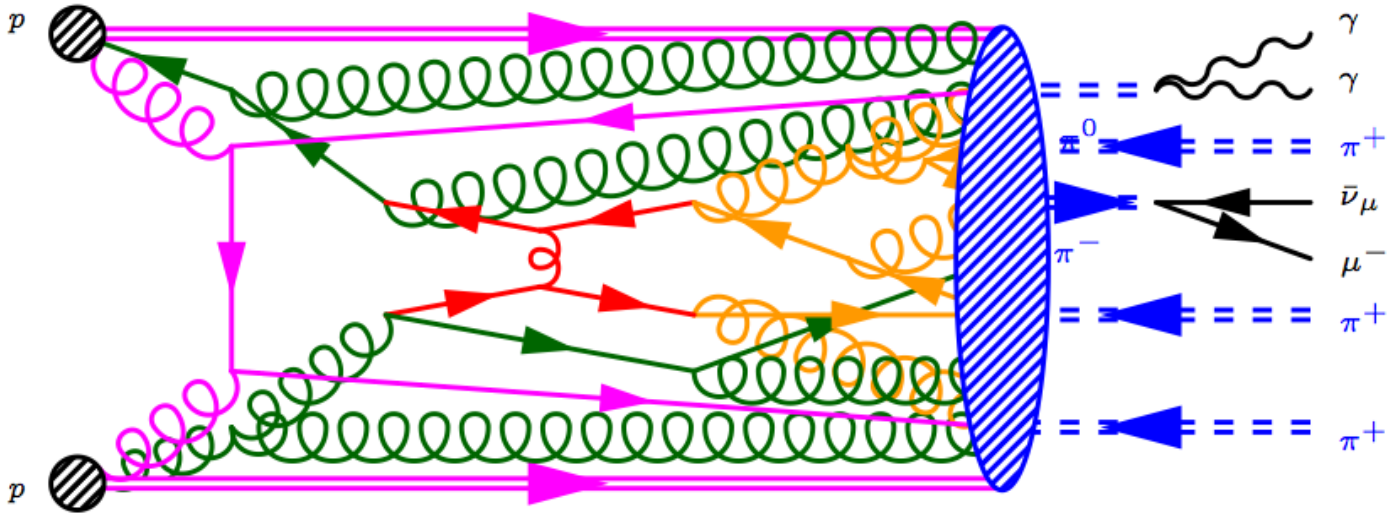
LHCb: General Purpose Forward Detector

- *LHCb's major physics goals:*

→ *measure processes in the heavy quark sector strongly suppressed in SM and search for any deviations from SM predictions (hints of the New Physics)*

→ *explore particle production at different collision energies in a unique kinematic range providing valuable insight into electroweak and QCD processes*

Why soft QCD at LHCb

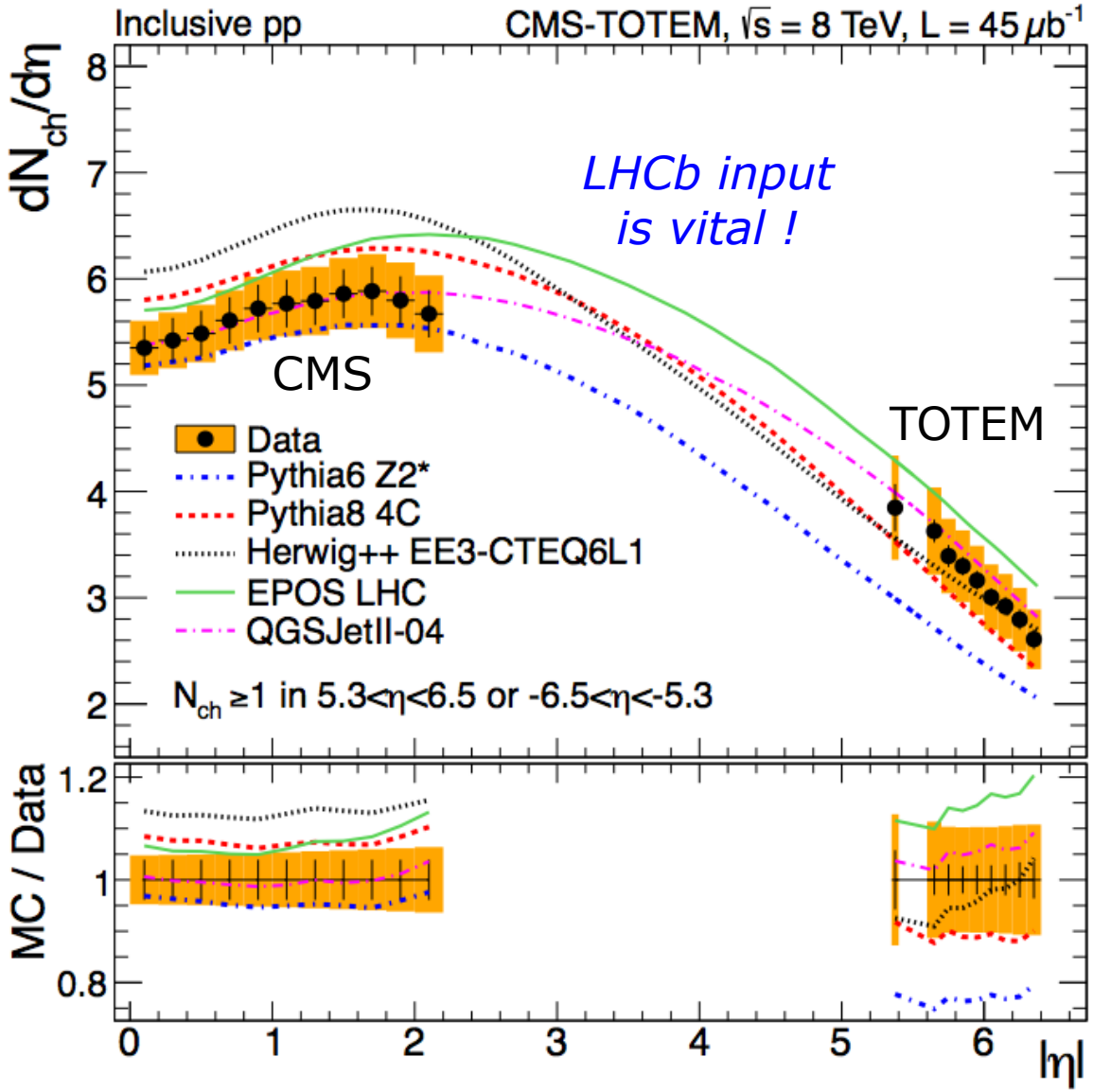


- *Important probes of non-perturbative regimes of QCD*
- *Exploration of the underlying event (UE) activity and structure*
- *Insight into the hadronisation processes*

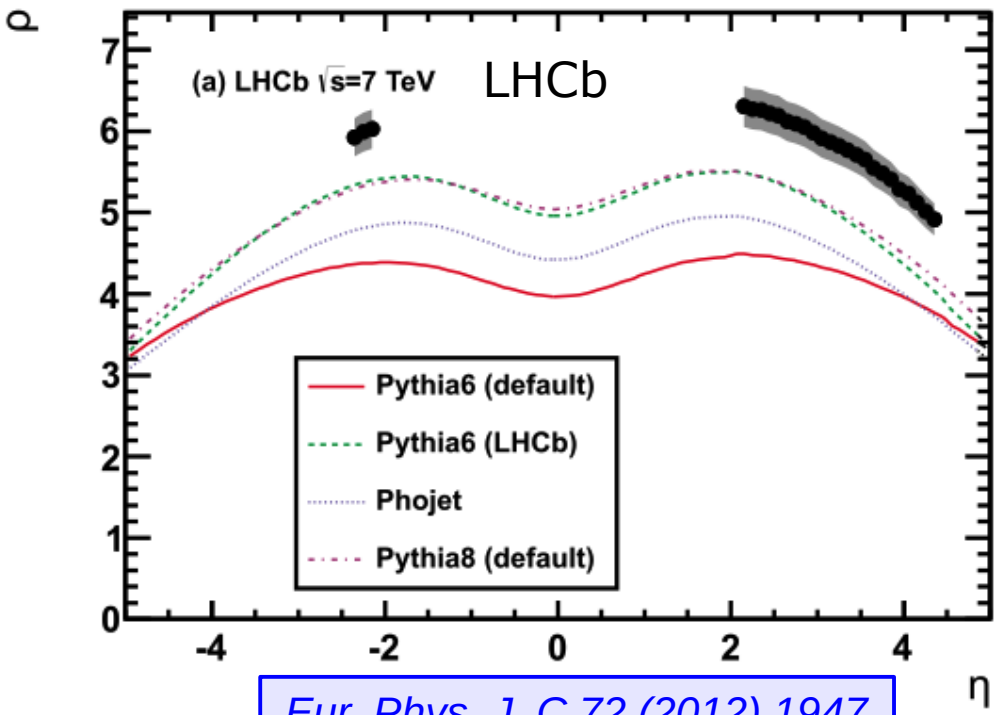
... in a unique kinematic range (at high η and p_T down to 50 MeV) where current models have large uncertainties !

LHCb unique role

- *Combined CMS and TOTEM results on particle multiplicities:*



- *LHCb measurements are essential for exploring forward particle production at the Terascale !*



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

arXiv:1405.0722 [hep-ex]

Charged particle multiplicities

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- *Study of charged particle multiplicity as a function of p_T and η*

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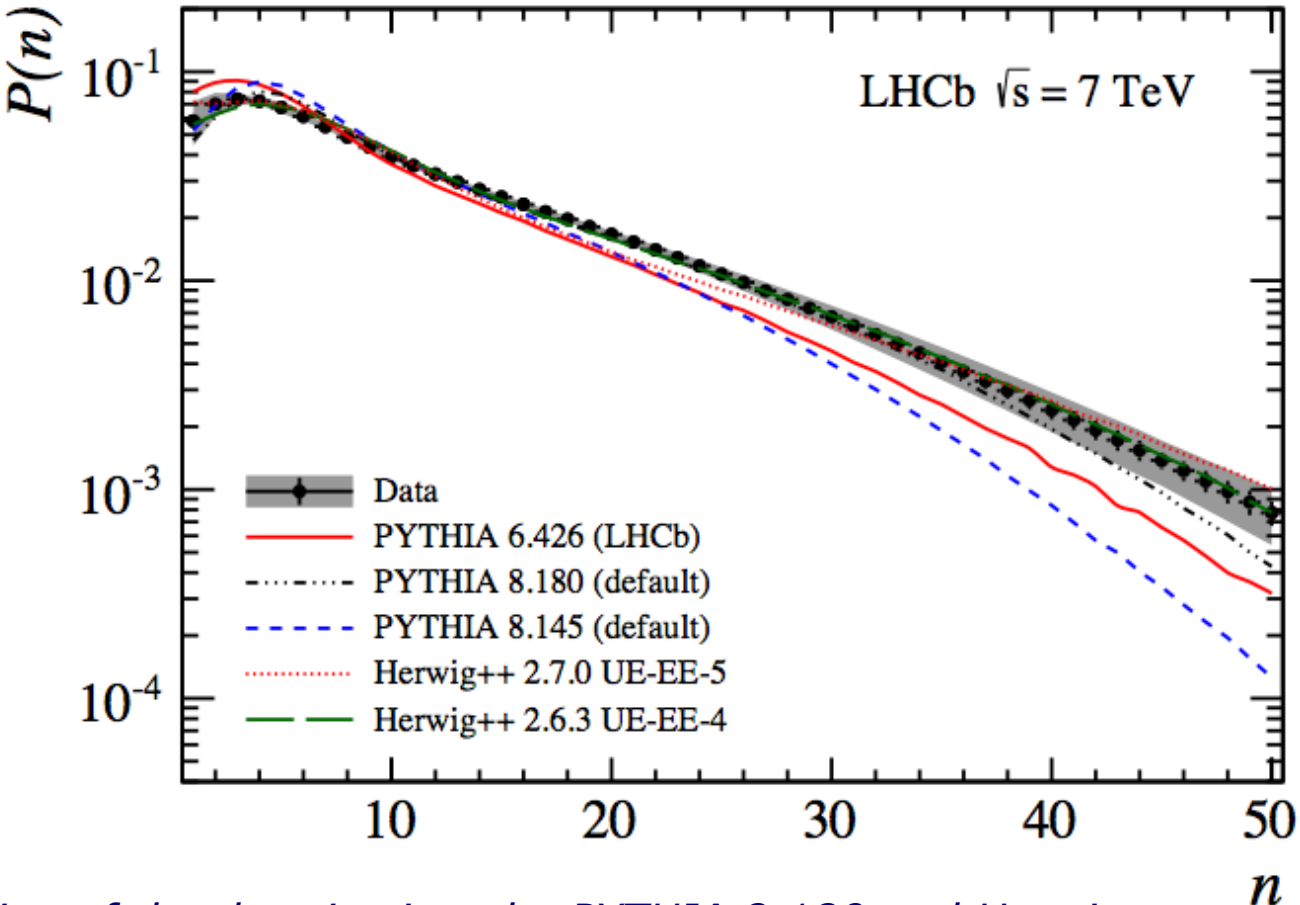
→ *essential for understanding of UE and phenomenology of soft QCD processes*
→ *complements Eur. Phys. J. C72 (2012) 1947 including p dependent measurements*
→ *inclusive pp events ; kinematic region : p_T>0.2 GeV, p>2 GeV, 2.0<η<4.8*
→ *dominant systematic contribution from inactive detector material*



→ *Good description of the data is given by PYTHIA 8.180 and Herwig++ tuned to the LHC data in the central region*

Charged particle multiplicities

- *Charged particle density per event as a function of η and p_T*

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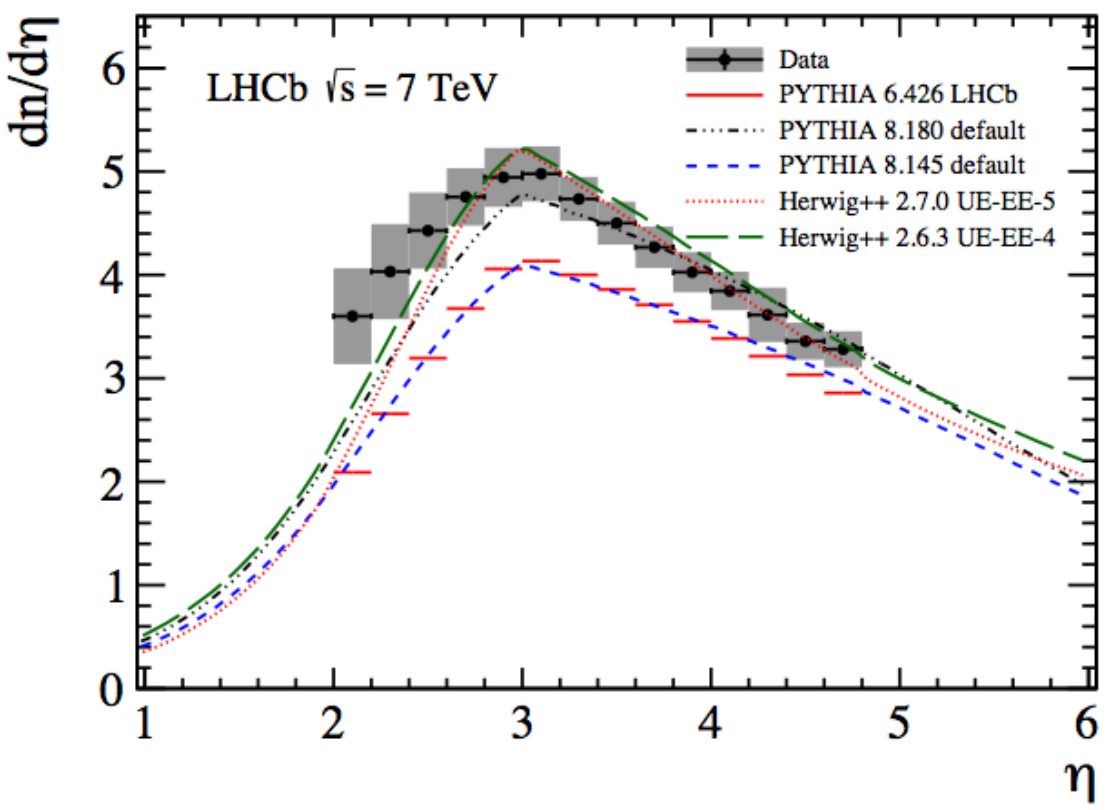
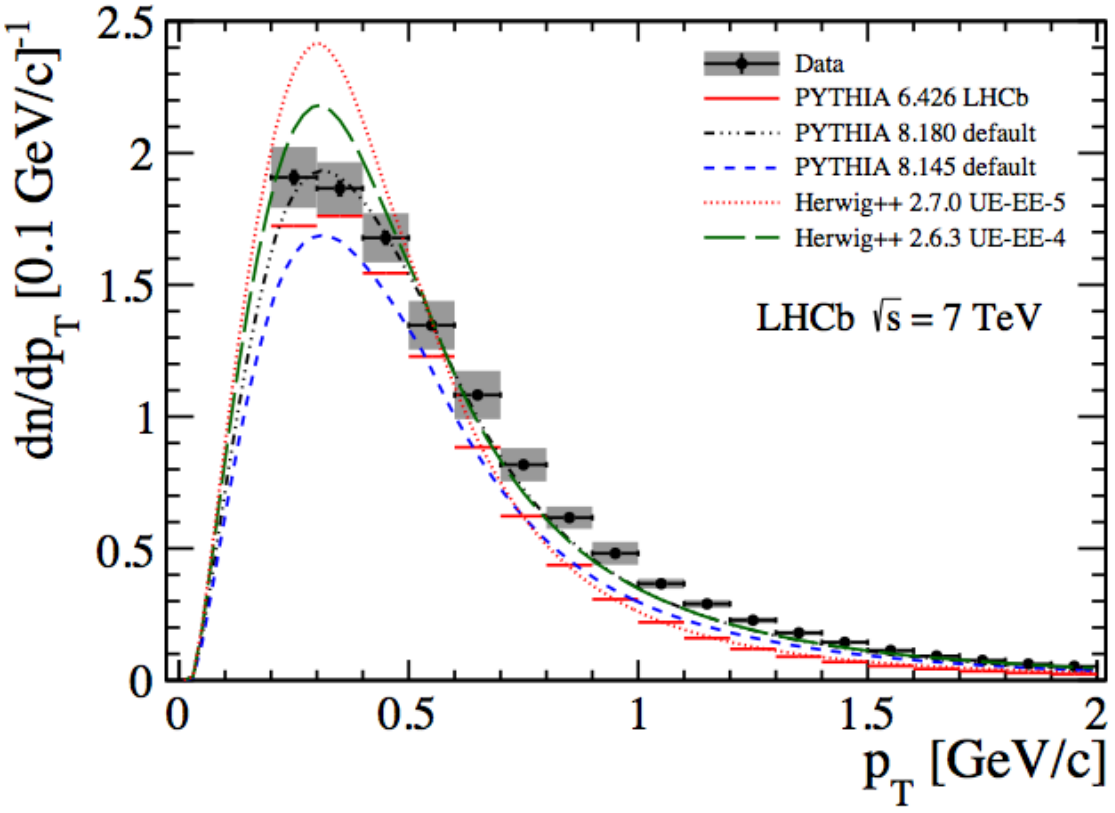
→ *kinematic region: p_T>0.2 GeV, p>2 GeV, 2.0<η<4.8*





→ *all considered models fail to describe both dependencies...*

Charged particle multiplicities

- *Results for lowest and highest η bins:*

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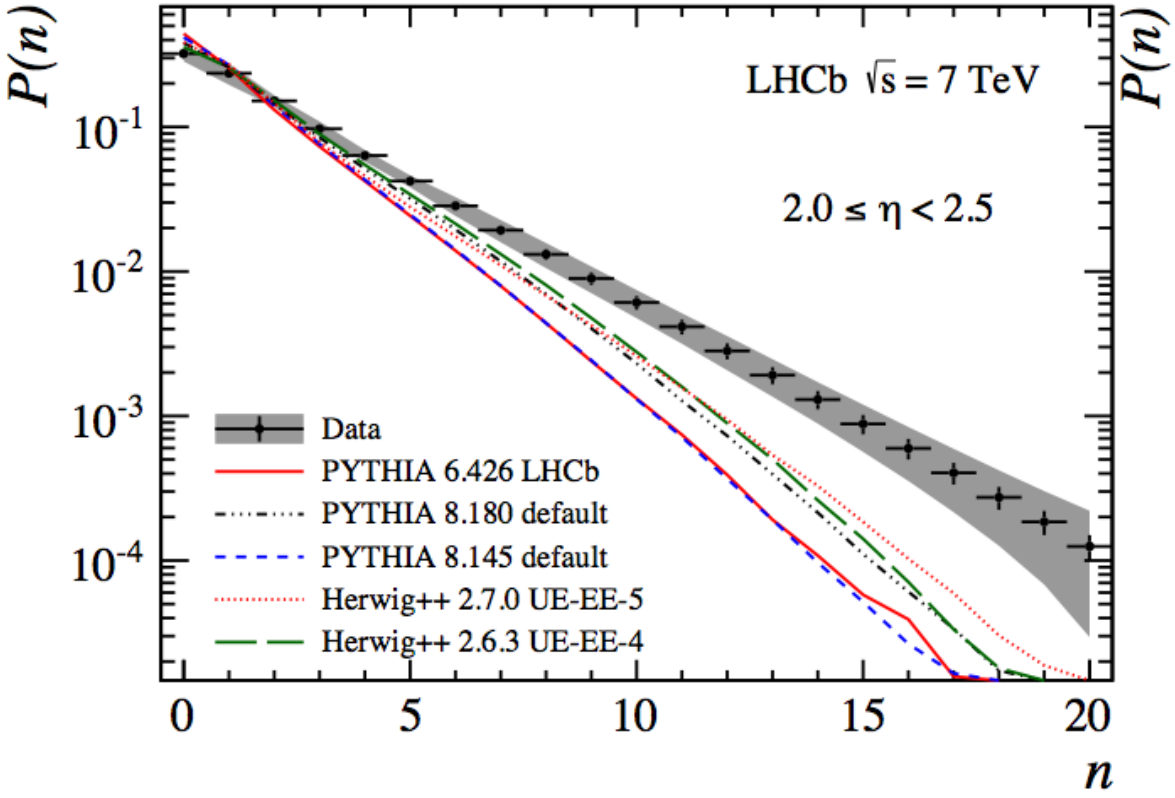

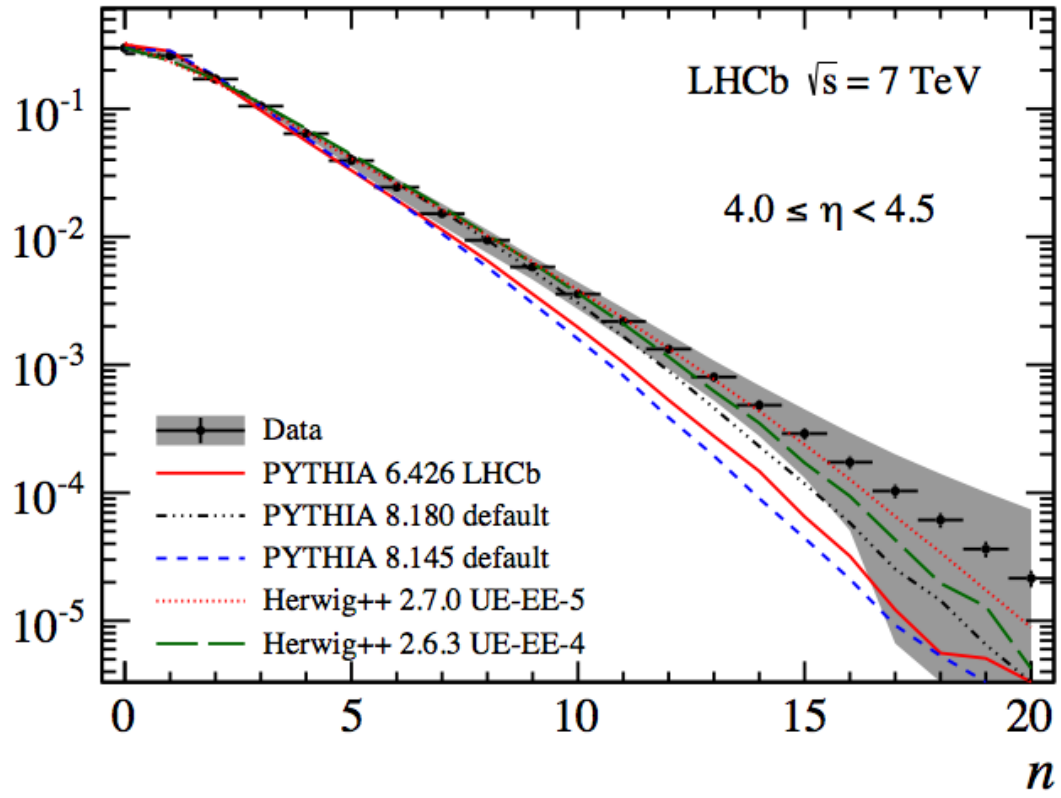

→ *all considered models underestimate charged particle production at low η*

Charged particle multiplicities

- *Results for the lowest and highest p_T bins:*

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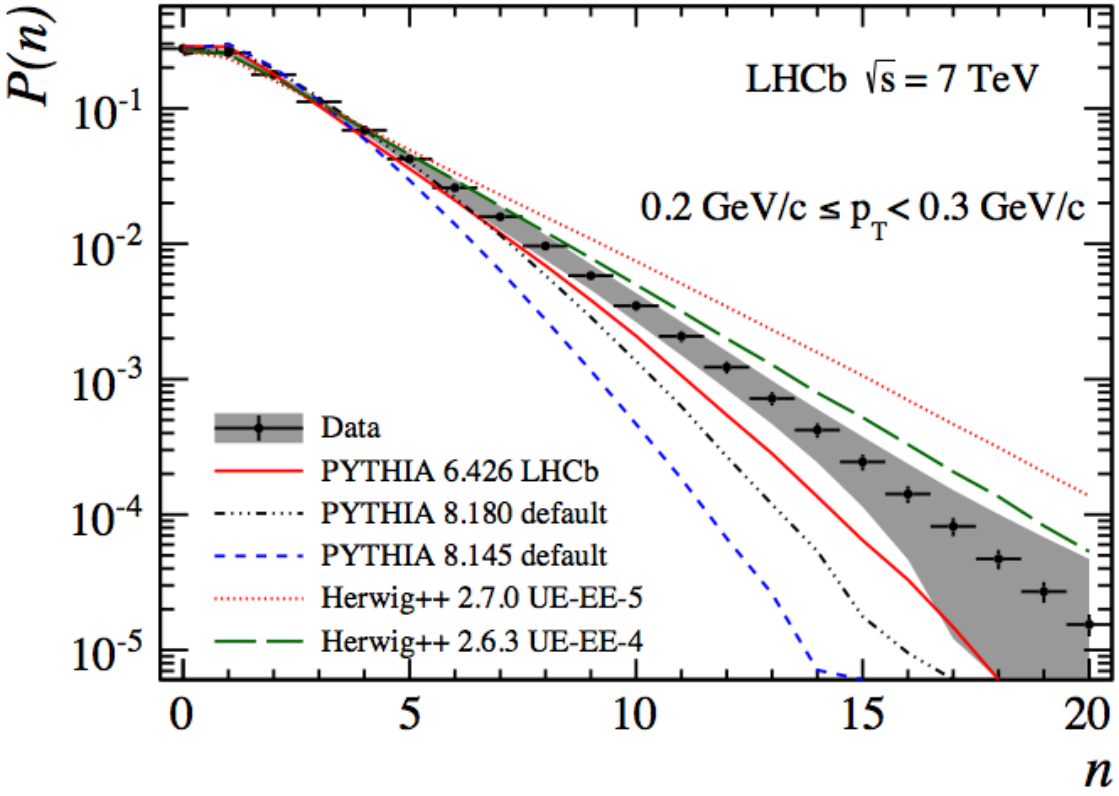

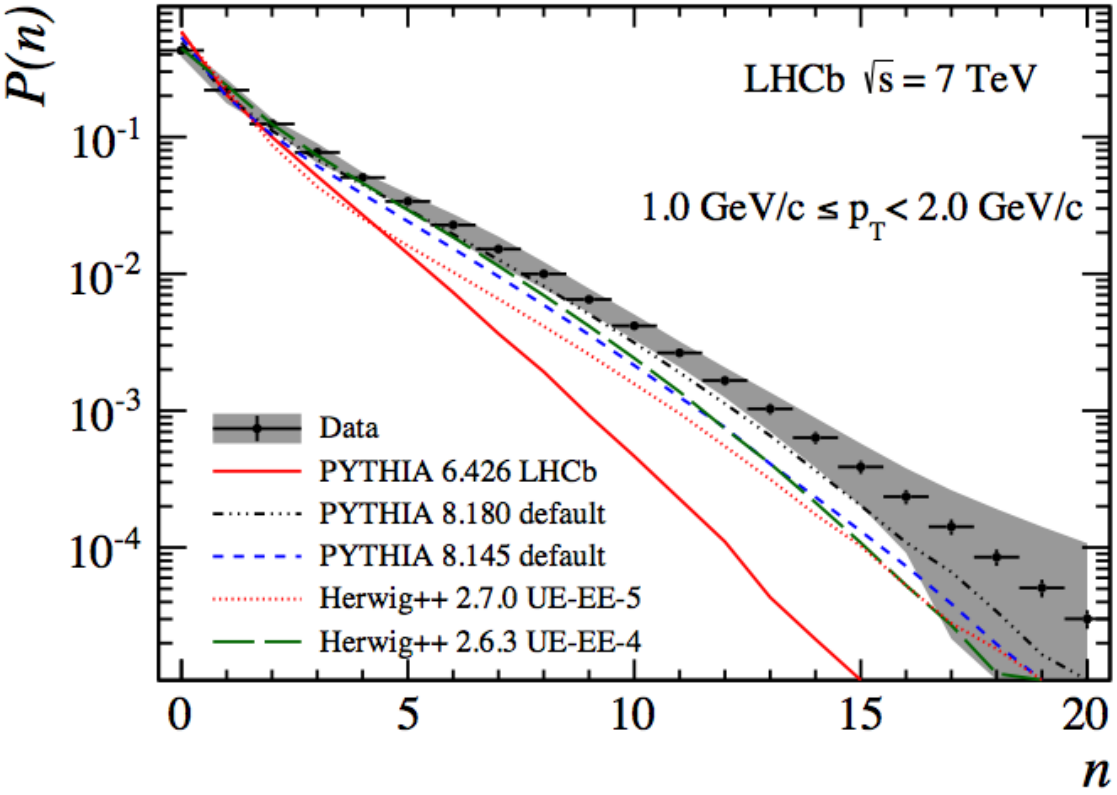

→ *all considered models tend to underestimate charged particle production at high p_T*

- *None of the models are able to describe the data over the full kinematic region:*

→ *valuable input for UE models*

Forward Energy Flow

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

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

- *Direct sensitivity to the amount of parton radiation & multi-parton interactions (MPI)*
  - → *needed for a precise description of the UE*
  - → *discrimination between MPI models*
  - → *strong constraints on the existing ultra high energy cosmic-ray interaction models*

- *Measurements 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 (Large Rapidity Gap)*
  - → *non-diffractive enriched: inclusive MB with at least 1 backward track in −3.5<η<−1.5*

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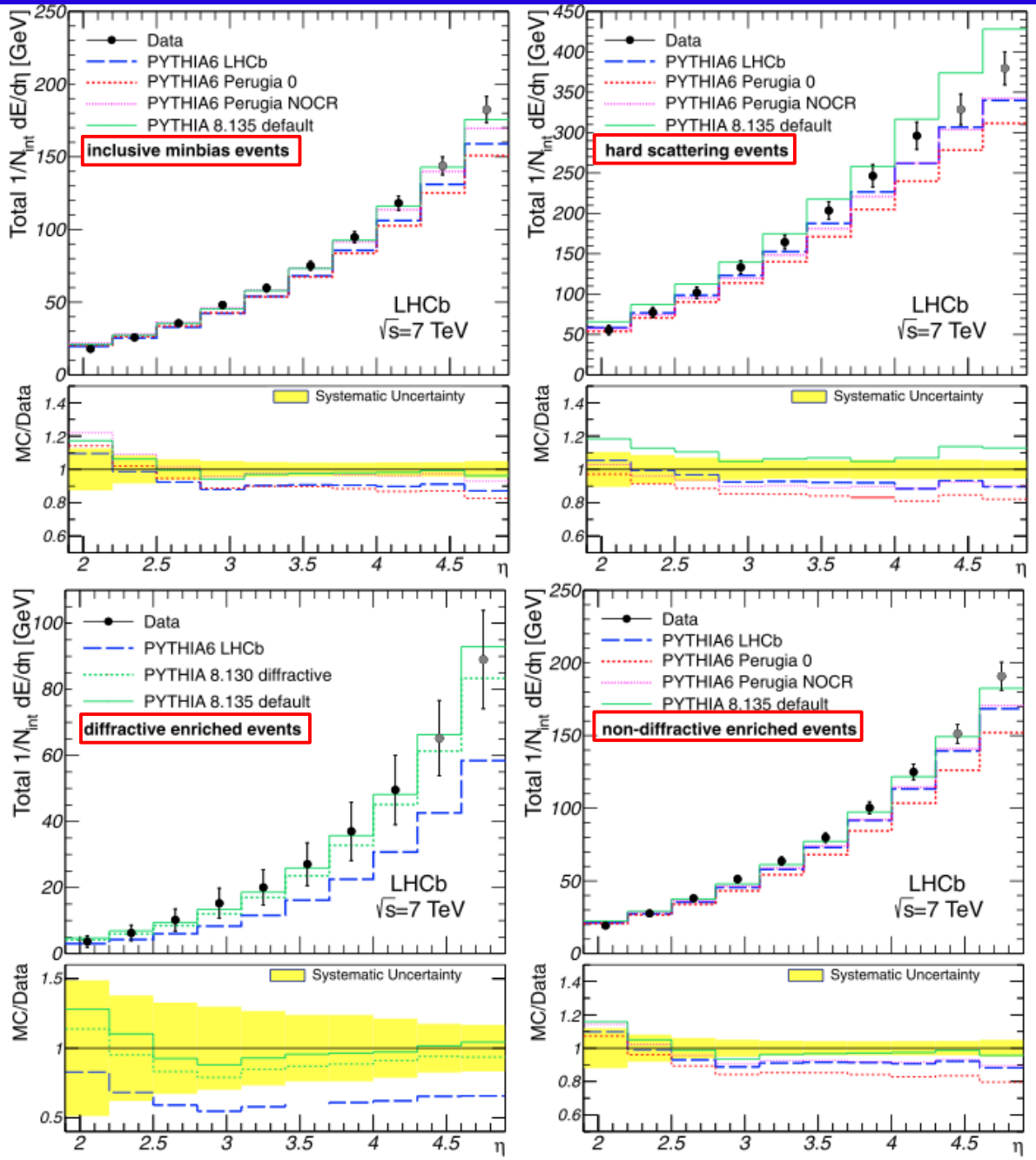
Forward Energy Flow



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

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

- *Systematic uncertainties decrease towards large η (detection inefficiency for low p_T tracks at low η)*
- *PYTHIA6 tunes underestimate EF at large η and overestimate it at low η for all event classes*
- *PYTHIA8.135 with default parameters gives excellent description of the data at large η except for hard scattering events*

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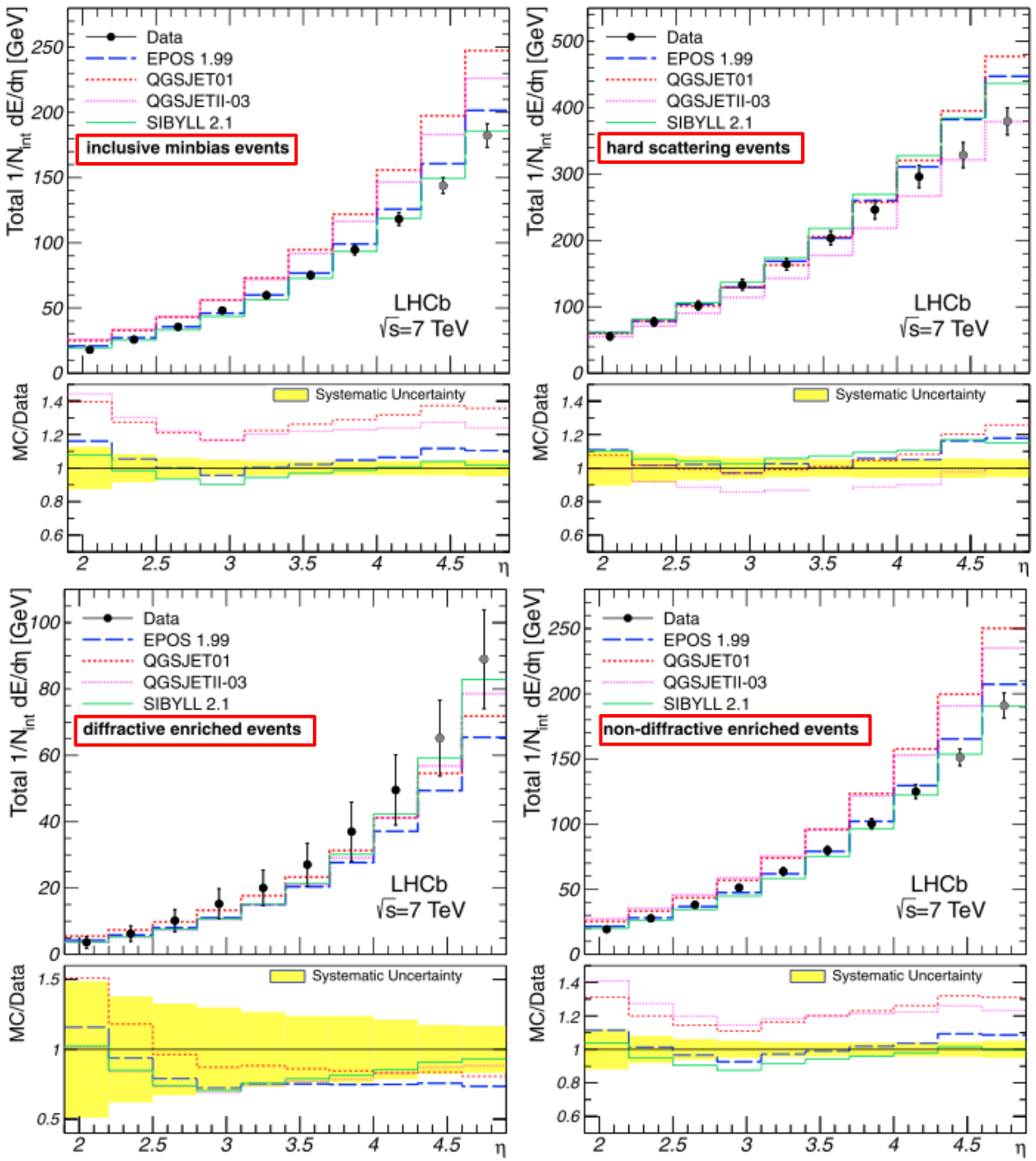
Forward Energy Flow



- *Results are also compared with cosmic-ray interaction models not tuned to the LHC data: EPOS 1.99, SIBYLL 2.1, QGSJET01, QGSJETII*
  - → *soft processes via Pomeron exchanges (Gribov's Reggeon Field Theory)*
  - → *hard processes: pQCD or exchanges of semi-hard Pomerons*
- *SIBYLL 2.1 gives the best description for inclusive & non-diffractive events at large η*
- *None of the models are able to describe the EF measurements for all event classes:*
  - → *valuable input for MPI/UE/cosmic-ray interaction models*

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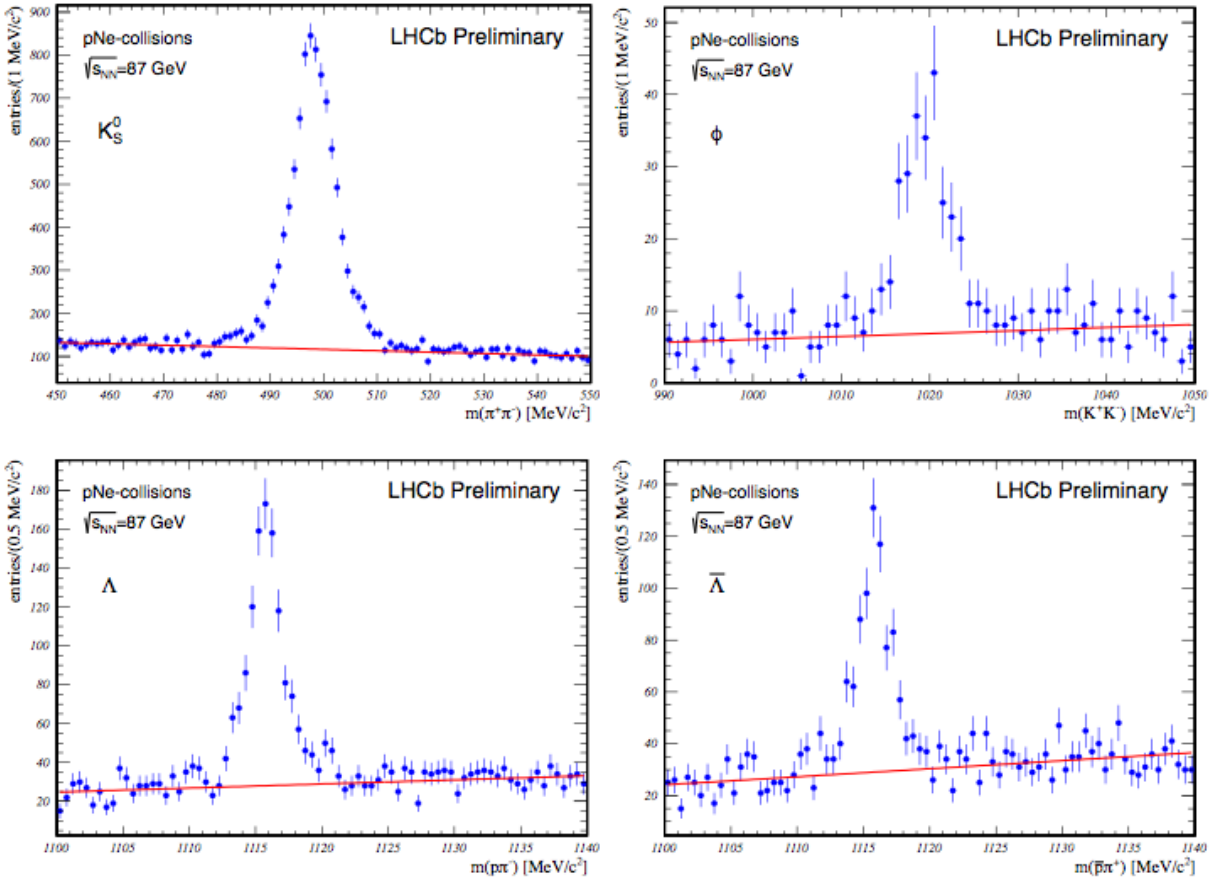
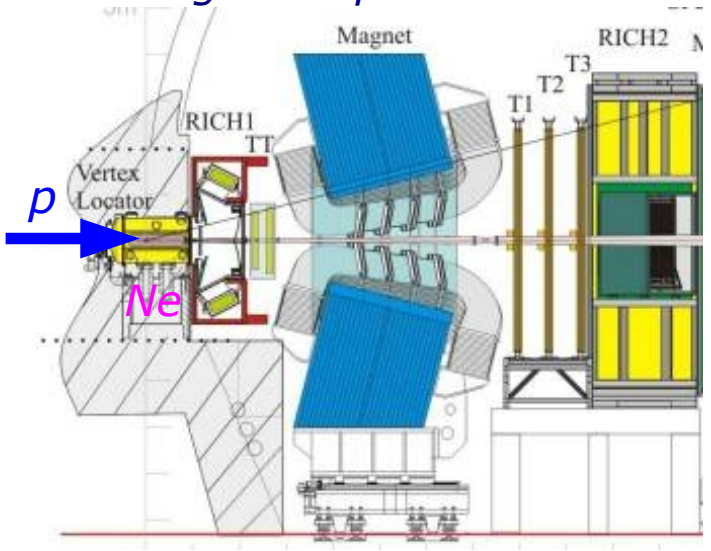
Fixed target physics at LHCb

- *p-nucleus physics with LHCb: exciting research field !*
  → *2 papers on heavy quarkonia production in pPb collisions; studies of cold nuclear matter effects in a unique kinematic range (see G. Manca's talk this afternoon)*
- *Sizeable samples of pNe and NePb collisions are recorded: unique at the LHC*
  → *injecting Ne-gas into the VELO using the LHCb SMOG system*
  → *rate of pNe interactions is sufficient to measure light quark & strangeness production*





LHCb-CONF-2012-034

→ *ideal conditions for testing cosmic-ray interaction models: studies are ongoing!*

Summary and Outlook

- *LHCb is a successful general purpose forward experiment at the LHC:*

→ *excellent detector performance during the LHC Run 1*

→ *world's best measurements of different physics parameters in the heavy flavor sector*

→ *very rich QCD/electroweak/proton-nucleus physics program*

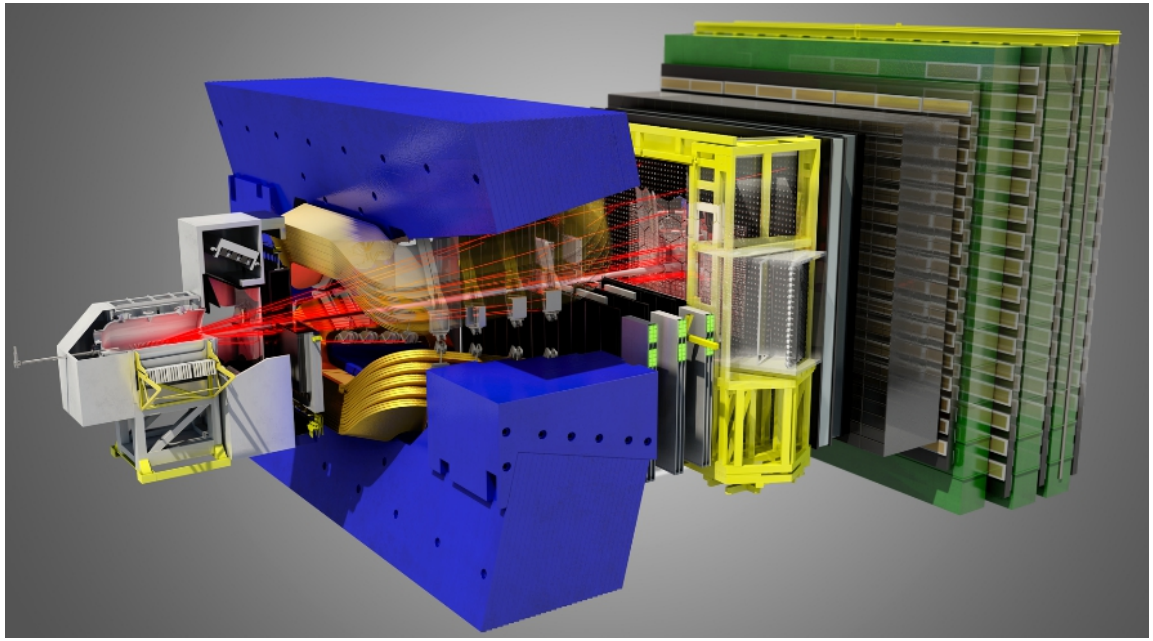
- *Soft QCD measurements in the LHCb acceptance:*

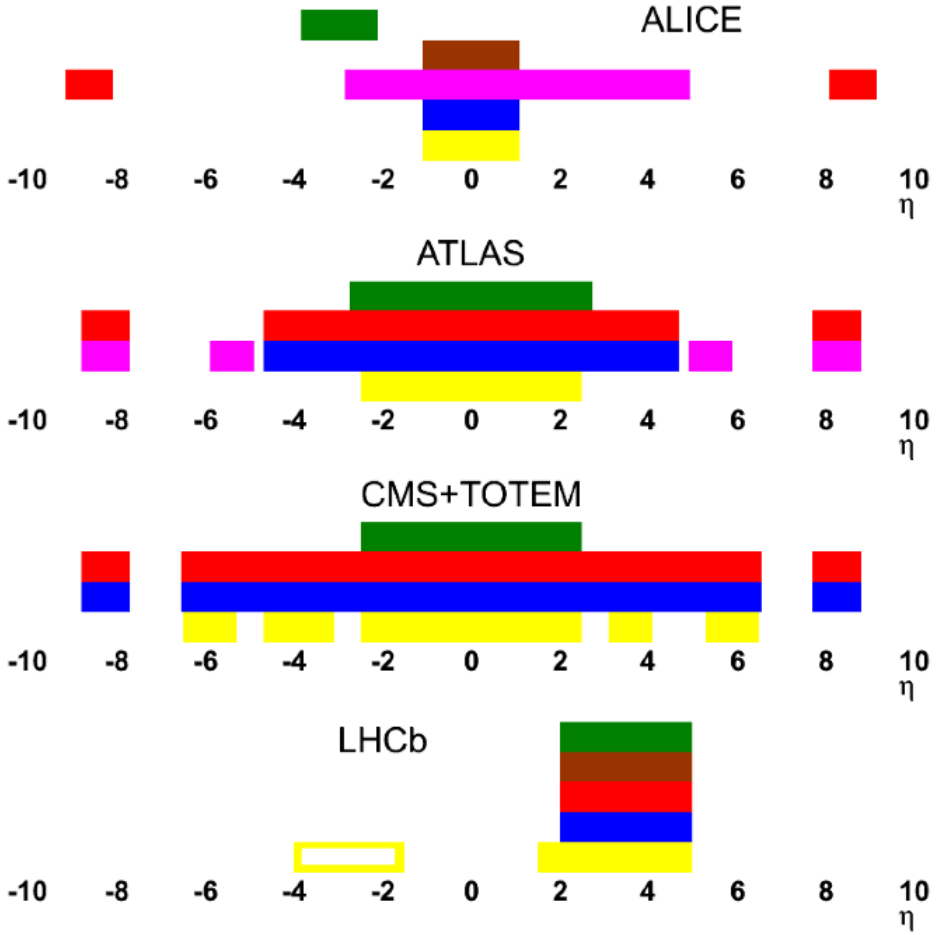
→ *important probes of non-perturbative regimes of QCD and insight into hadronisation processes plus underlying event in a unique kinematic range*

→ *various inclusive light quark production measurements are performed - none of the models are able to describe fully our data !*

- *High Rapidity Shower Counters will be installed downstream and upstream of the LHCb detector for the LHC RunII, and will significantly enhance LHCb's ability to study soft QCD processes (in particular, diffractive and exclusive events).*

Backup




ALICE
-10 -8 -6 -4 -2 0 2 4 6 8 10
η
ATLAS
-10 -8 -6 -4 -2 0 2 4 6 8 10
η
CMS+TOTEM
-10 -8 -6 -4 -2 0 2 4 6 8 10
η
LHCb
-10 -8 -6 -4 -2 0 2 4 6 8 10
η
hadron PID
muon system
lumi counters
HCAL
ECAL
tracking