Recent LHCb results on QCD processes in pp and pPb collisions

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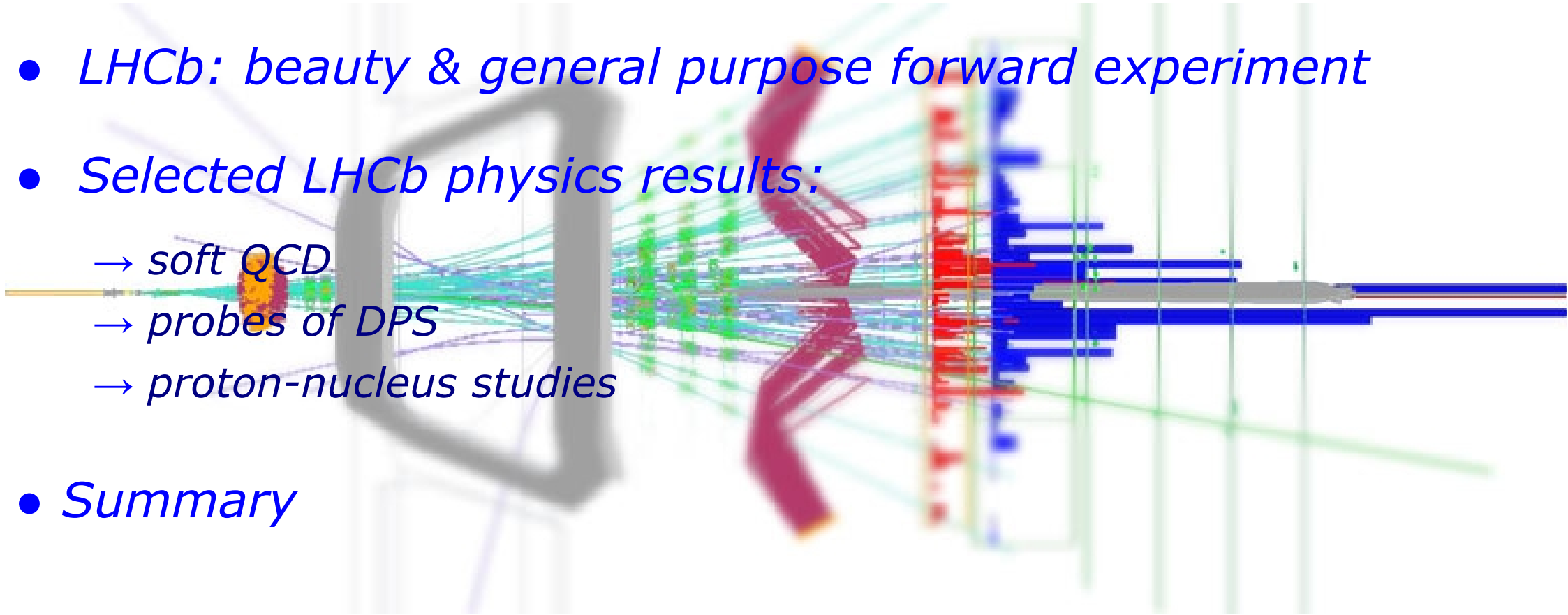
on behalf of the LHCb collaboration

Invited talk at the Workshop on QCD and Forward Physics at the LHC
Trento, Italy, April 14-18th, 2014

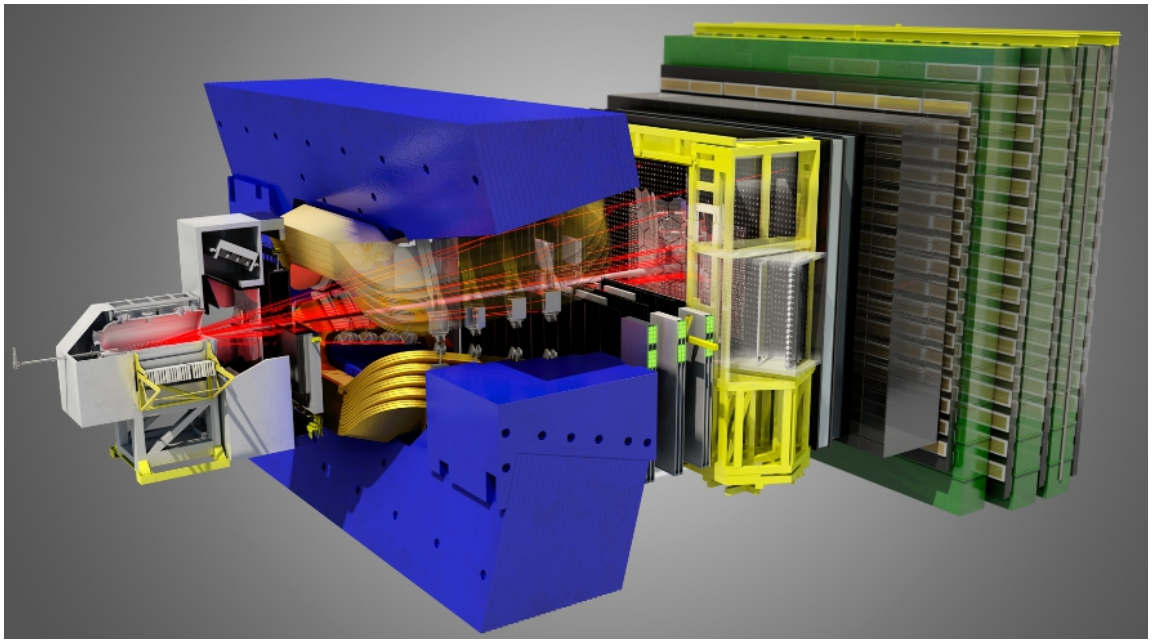
Outline

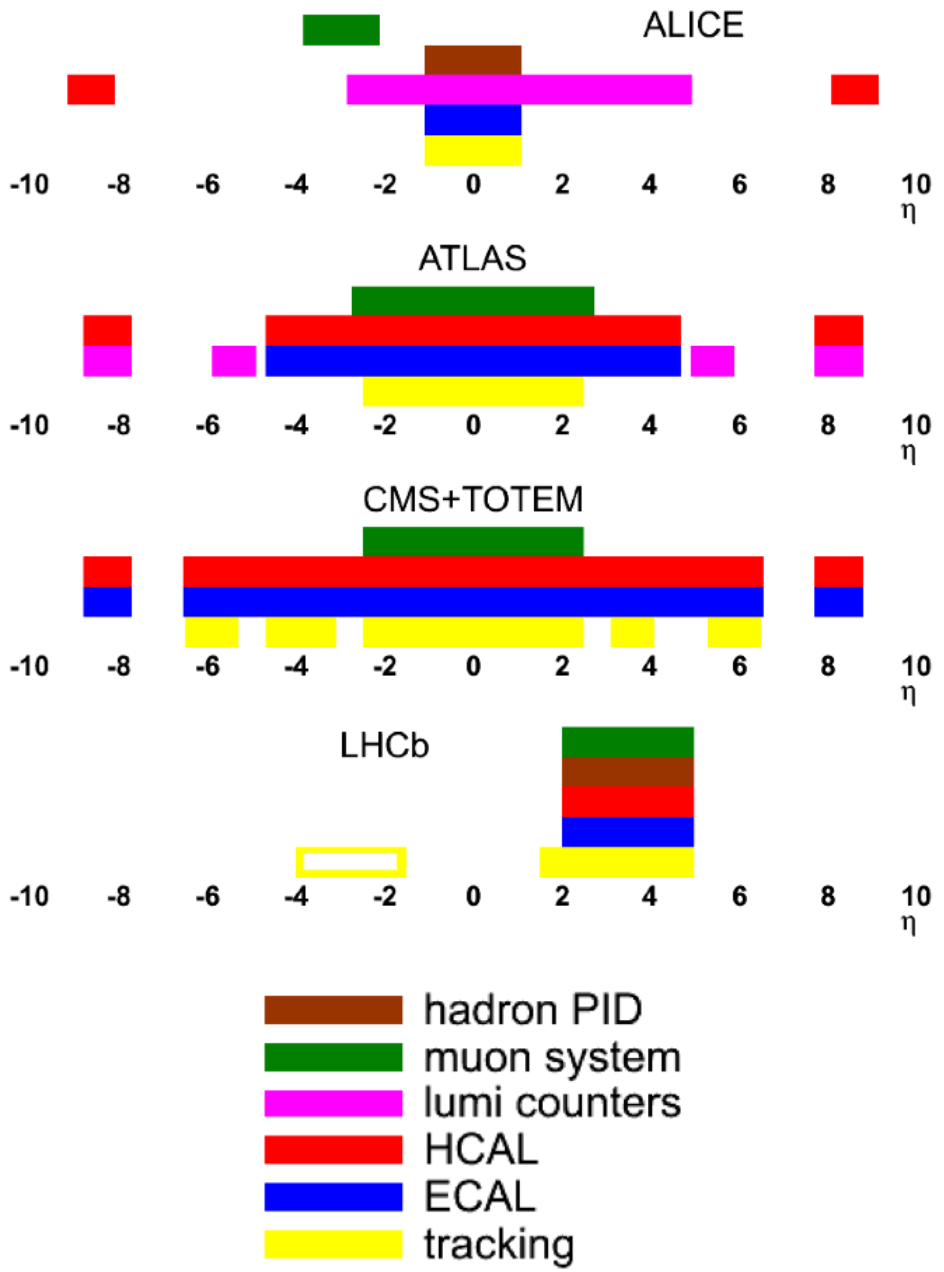


- *LHCb: beauty & general purpose forward experiment*
- *Selected LHCb physics results:*
  - → *soft QCD*
  - → *probes of DPS*
  - → *proton-nucleus studies*
- *Summary*

LHCb experiment

- *Forward spectrometer with planar detectors*





- *LHCb uniqueness:*

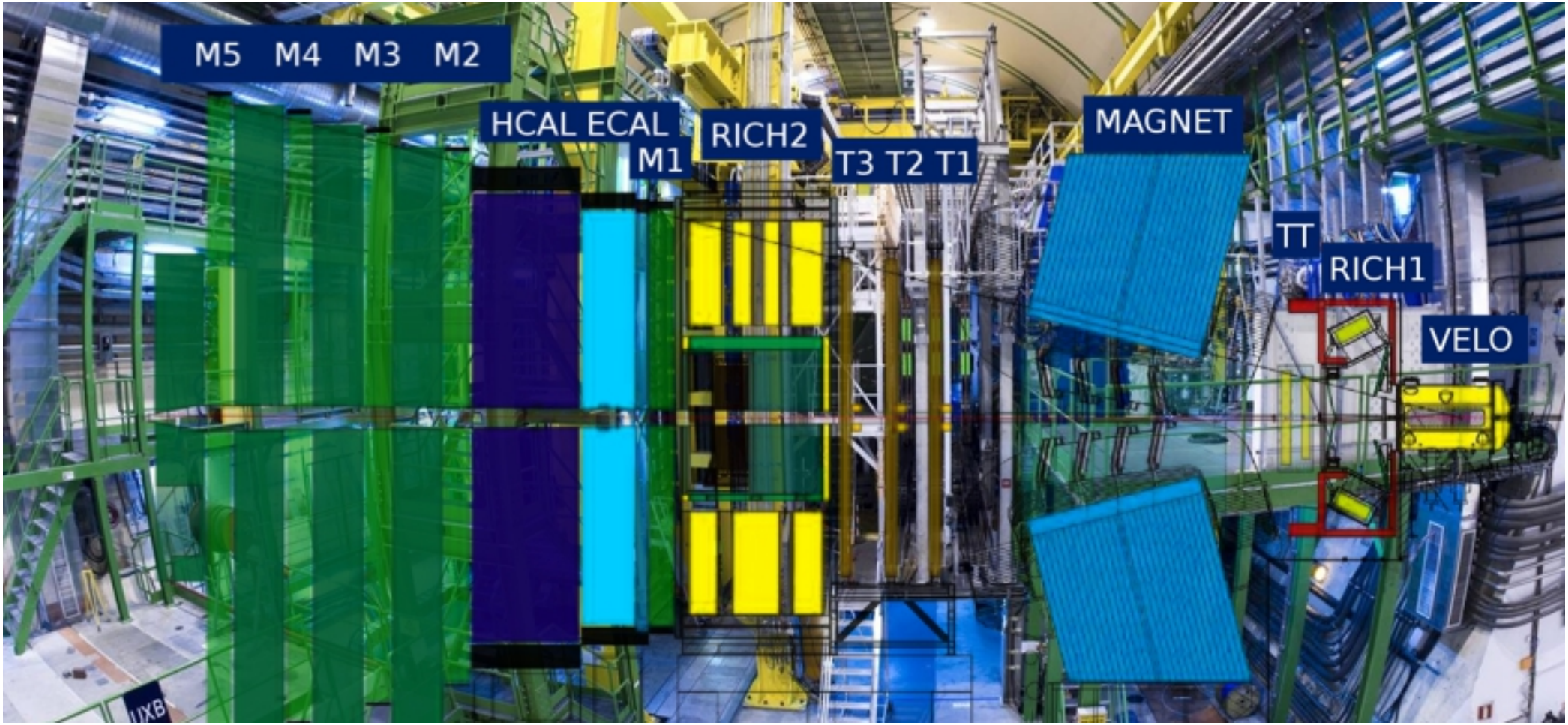
  → *tracking, RICH & calorimeters cover the full detector acceptance (2.0<η<5.0); tracking also in the backward region (-4.0<η<-1.5)*

  → *covers just ~4% of the solid angle but captures ~25% of heavy quark pairs produced at the LHC*

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

  → *ideally suited for forward physics studies*

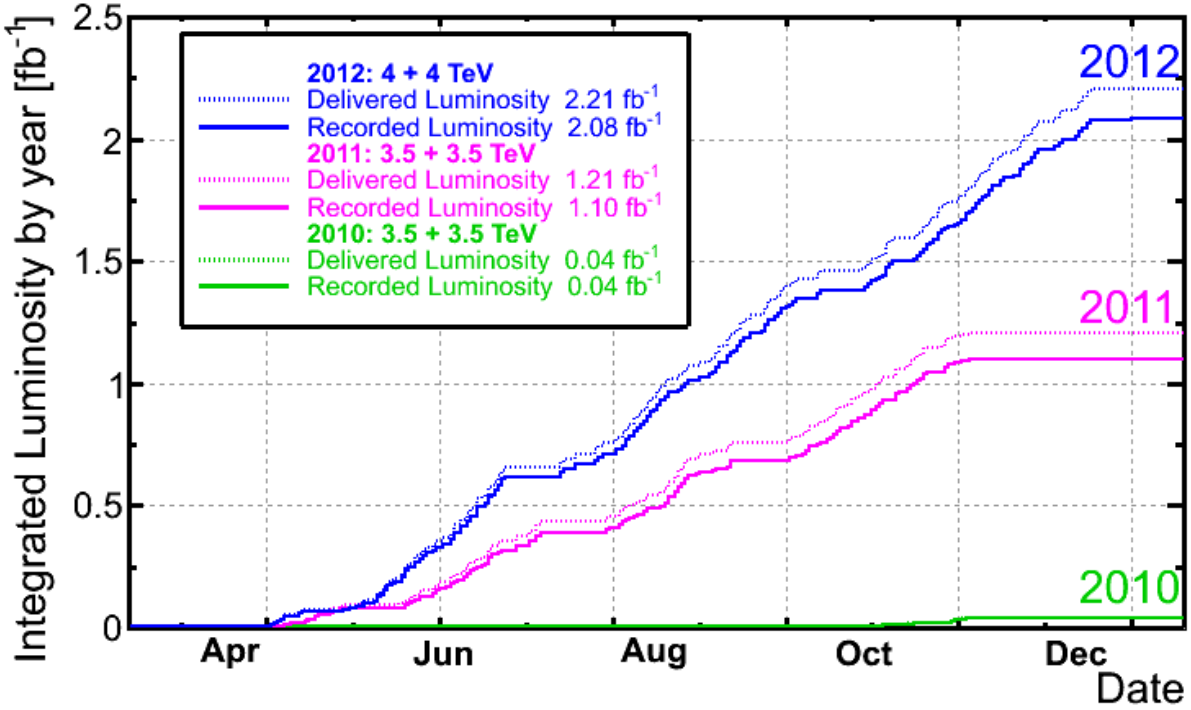
LHCb detector



- *Excellent tracking performance for charged particles with momenta up to 1 TeV*
- *High quality particle identification: robust hadron ID & lepton/photon/hadron separation*
- *Selective and flexible trigger system*

JINST 3 (2008) S08005

LHCb data taking



- *In the years 2010-2012:*

  → *2 × 10^{14} visible pp interactions*

  → *6 × 10^{12} visible $\bar{c}\,c$ quark pairs*

  → *3 × 10^{11} visible $\bar{b}\,b$ quark pairs*

were produced in the LHCb acceptance

- *~93 % data taking efficiency*
- *~99% read-out channels operational*
- *~99% of accumulated data are useful for physics analyses*
- *Luminosity leveling: constant and moderate interaction rate throughout the data taking periods*
- *Smooth data taking in 2011-2012 regardless high luminosity running*

Ability to perform different measurements with pp collisions at 2.76 TeV, 7 TeV and 8 TeV and with pPb collisions at 5 TeV

LHCb: more than just beauty

LHCb: General Purpose Forward Detector

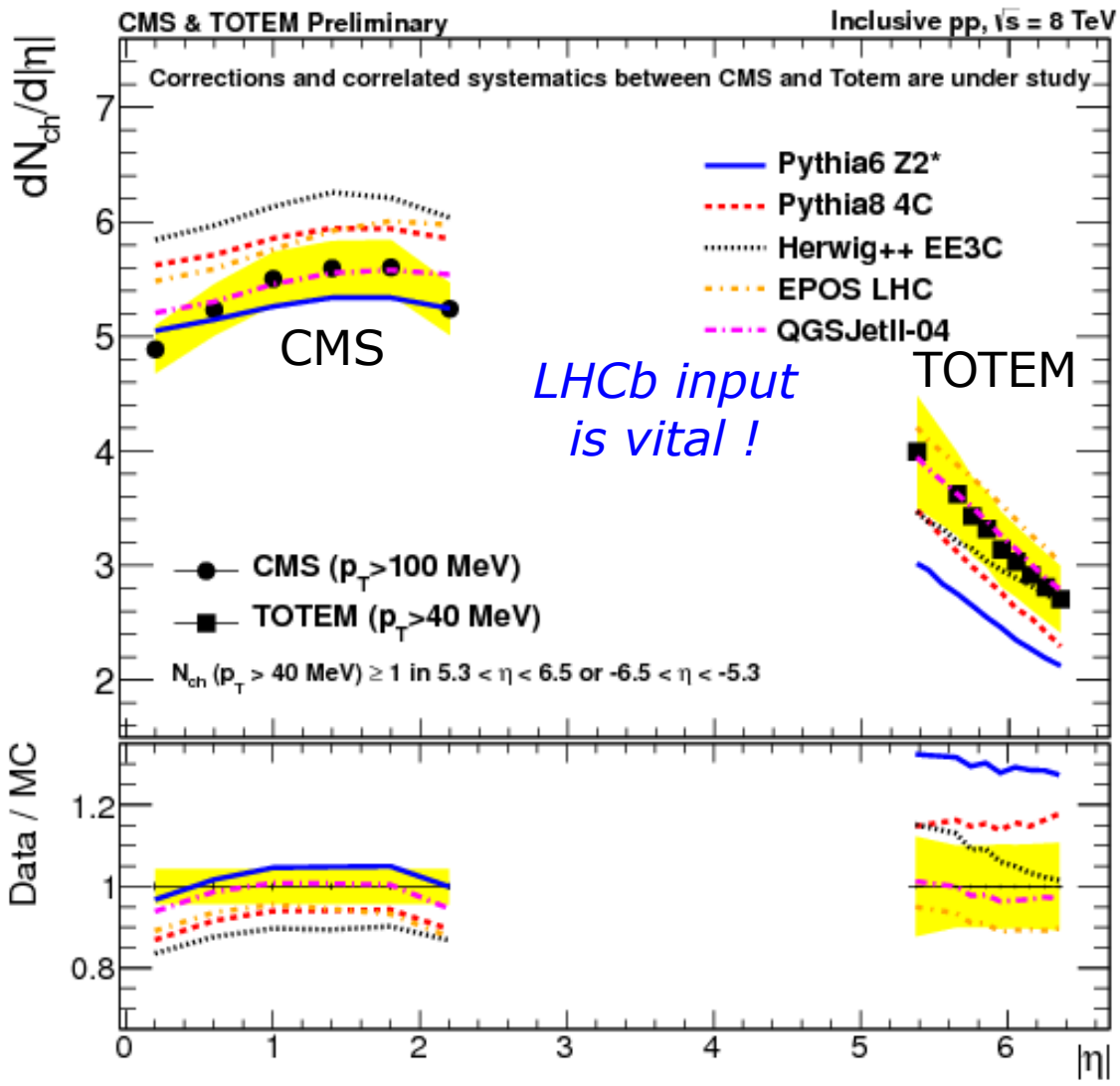
- *LHCb's major physics goals:*

→ *measure processes in the heavy quark sector strongly suppressed in SM and search for 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*

LHCb unique role

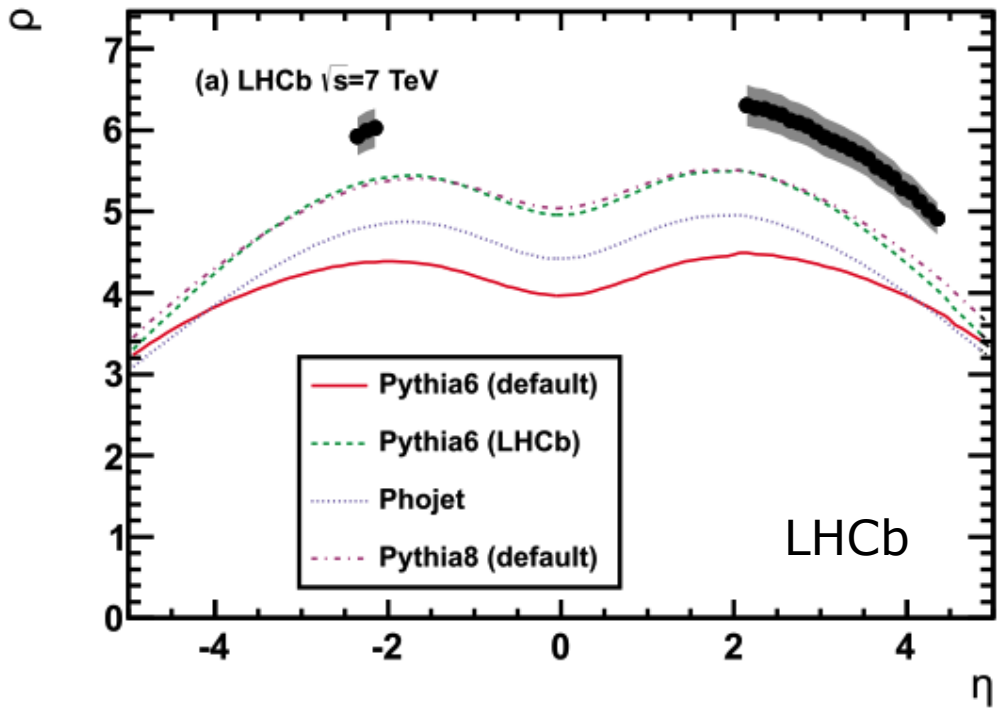
- *First combined CMS and TOTEM results on particle multiplicities:*



LHCb input is vital !

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

  → *current models have large deviations in this region of phase space*



CMS-PAS-FSQ-12-026

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

Updated particle multiplicities

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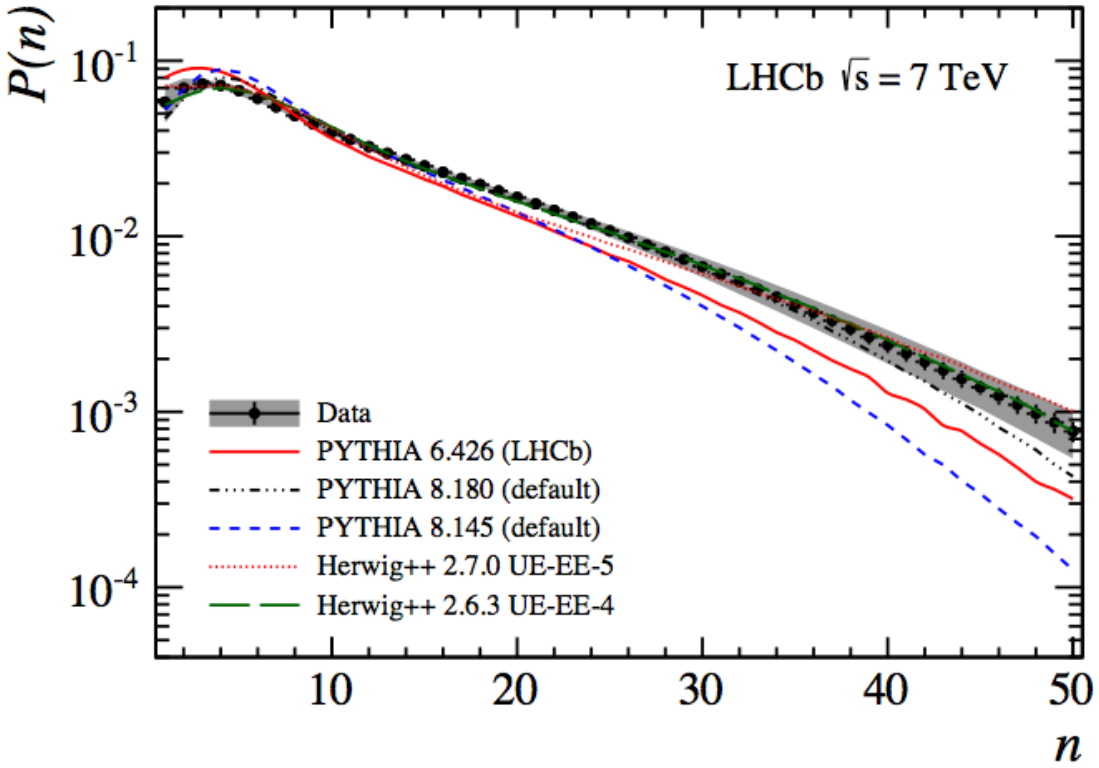
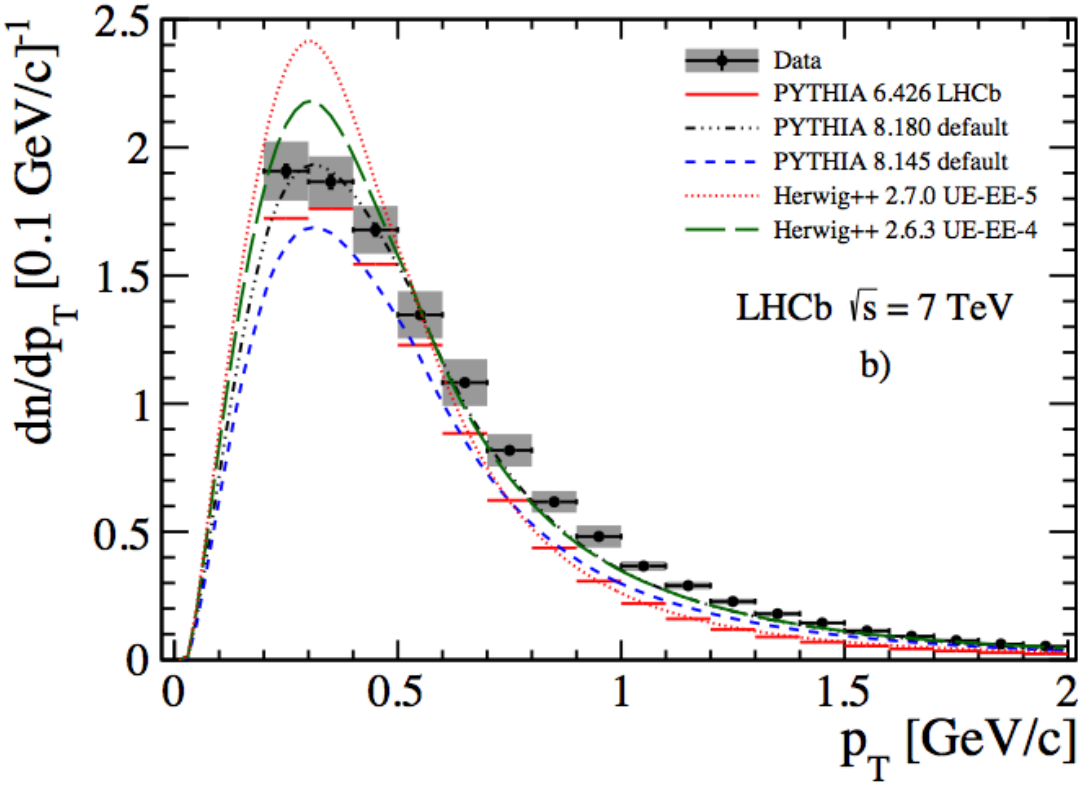
- *Studies of particle multiplicities as a function of p_T and η*

→ *supersedes Eur. Phys. J. C 72 (2012) 1947*
→ *performed with tracks having p_T>0.2 GeV, p>2 GeV, 2.0<η<4.8*
→ *results for the full kinematic region:*

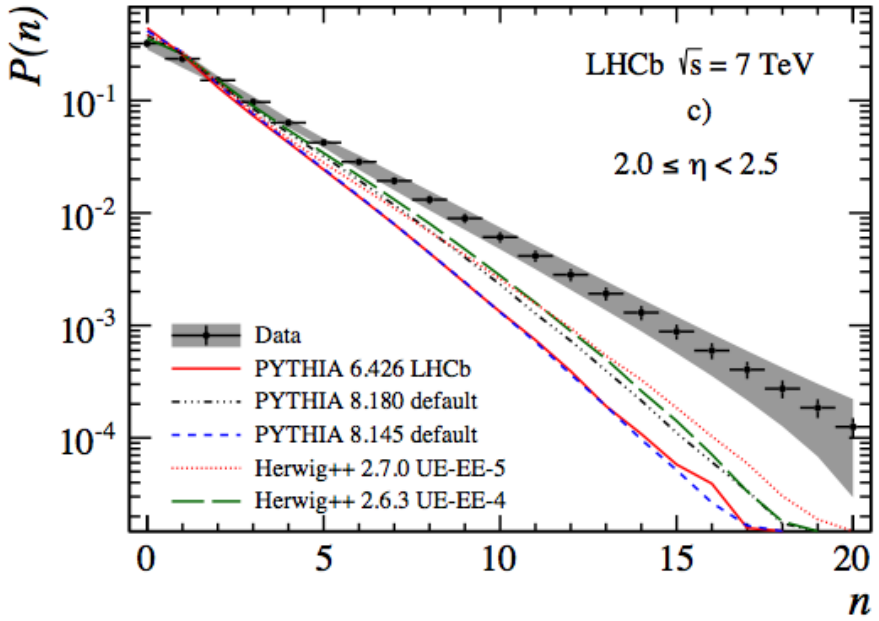


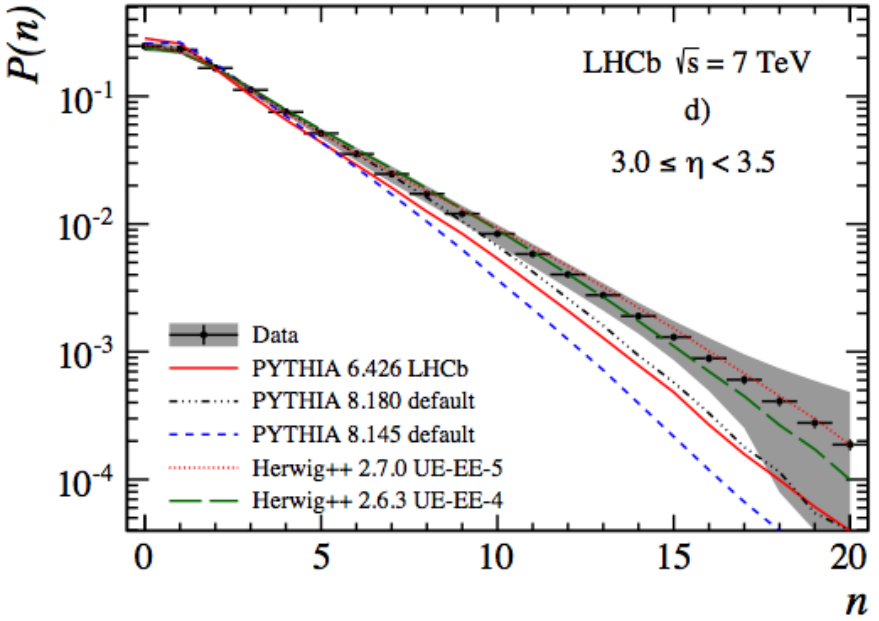


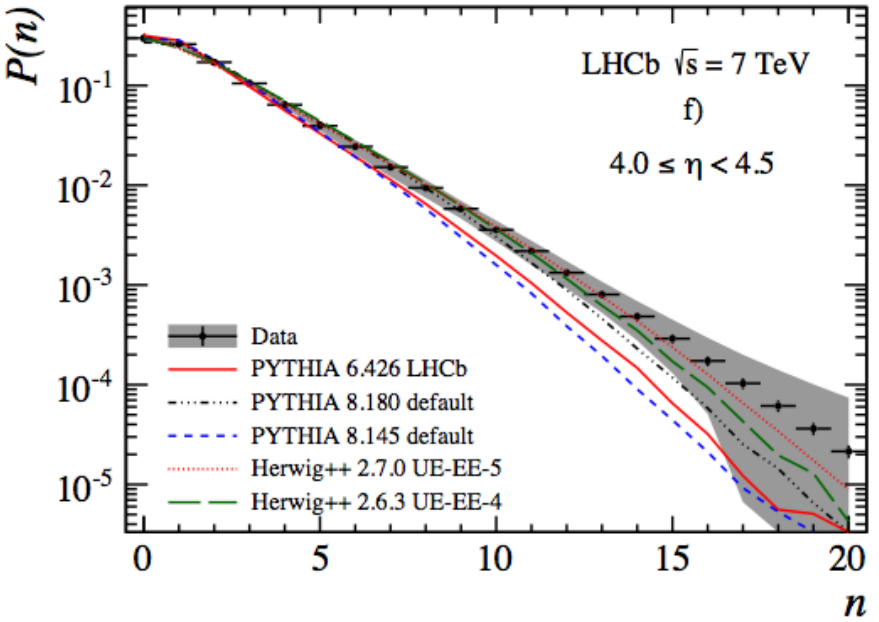
arXiv:1402.4430 [hep-ex]

Updated particle multiplicities

- *Results for selected η bins:*







→ *models underestimate charged particle production at low η*

→ *recent generators, tuned to LHC data in the central region, are in better agreement with data than predictions from older models*

arXiv:1402.4430 [hep-ex]

Updated particle multiplicities

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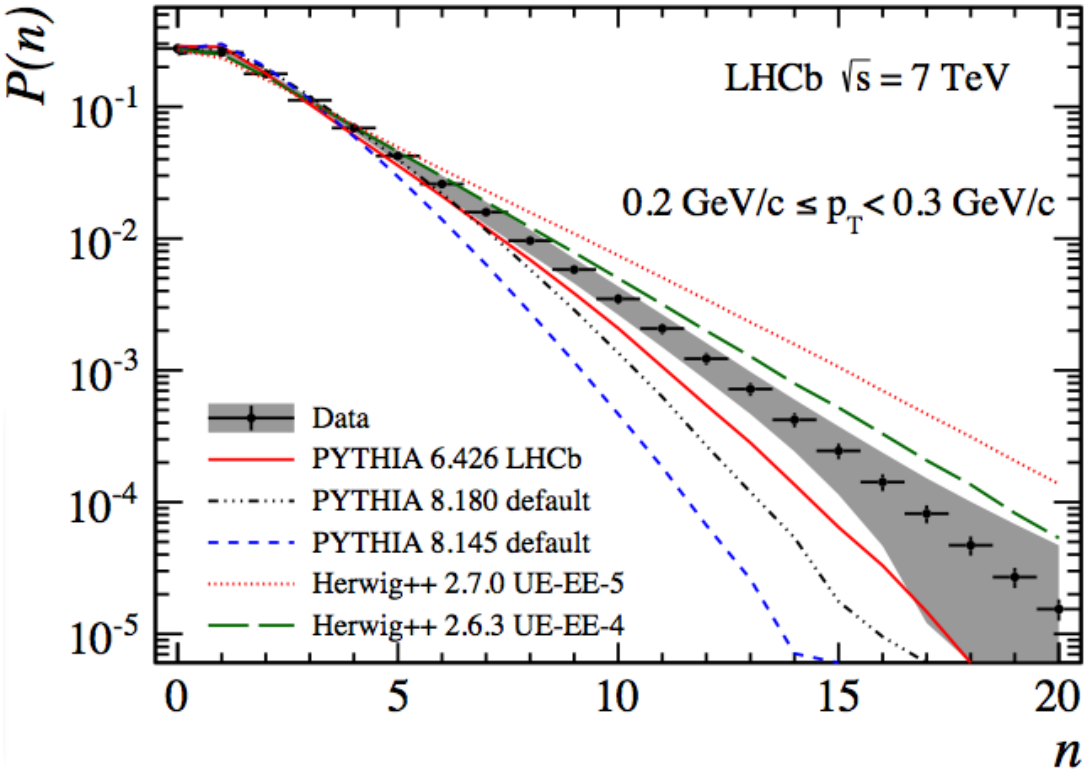
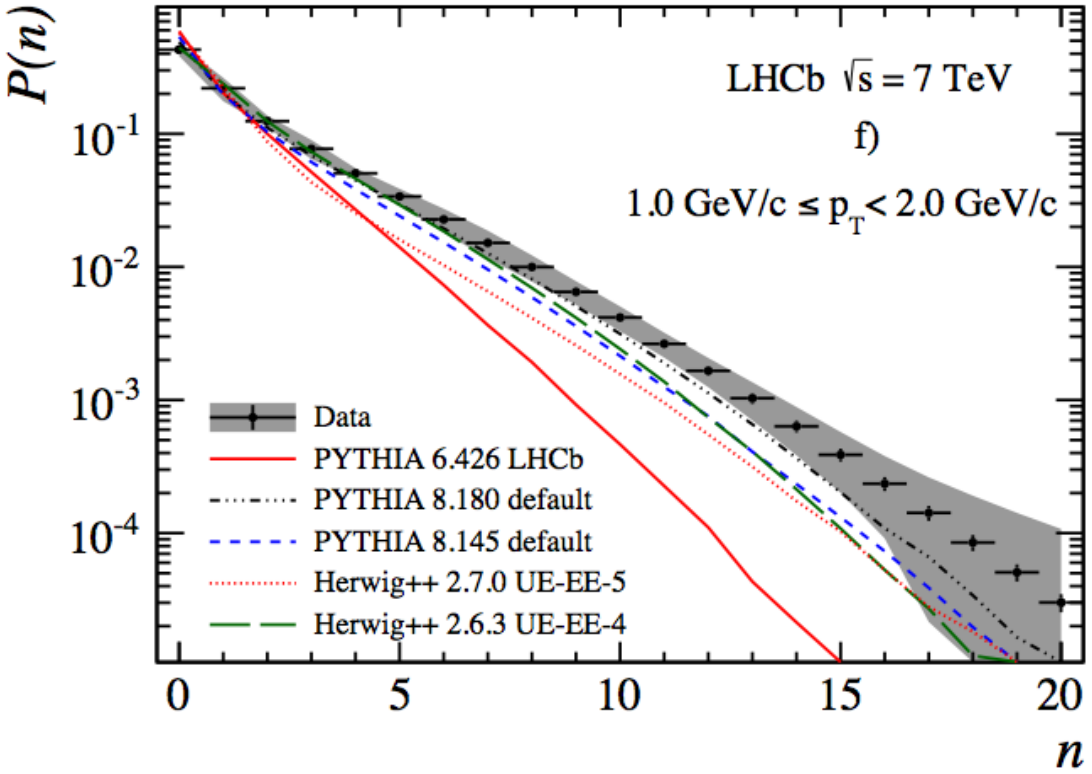
CERN YR: Chapter 7

- *Results for selected p_T bins:*

→ *models underestimate charged particle production at high p_T*





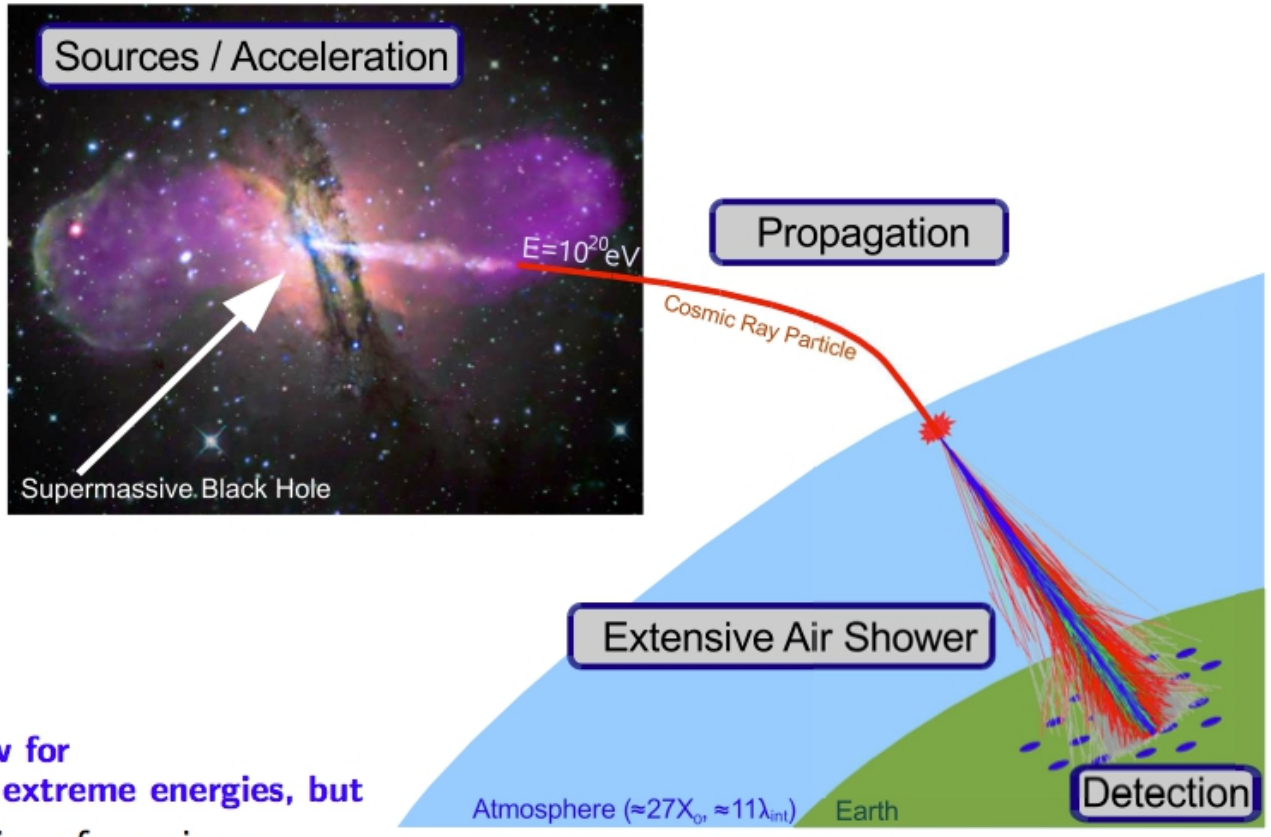
- *None of the models are able to describe the data over the full kinematic region*

arXiv:1402.4430 [hep-ex]

Input to cosmic-ray physics

- *LHC provides first possibility to test cosmic-ray showering models at E_{lab} of up to 10^{17}eV*

- *Valuable input to various cosmic-ray models & other High Energy Physics MC generators*



Observational window for astrophysics at most extreme energies, but

- No direct detection of cosmic rays
- Extensive Air Showers (EAS)
- Need to understand ground based EAS observables
- **Very good EAS models required!**

⇒ **Interactions up to $\sqrt{s}$ ~500 TeV**

by Ralf Ulrich

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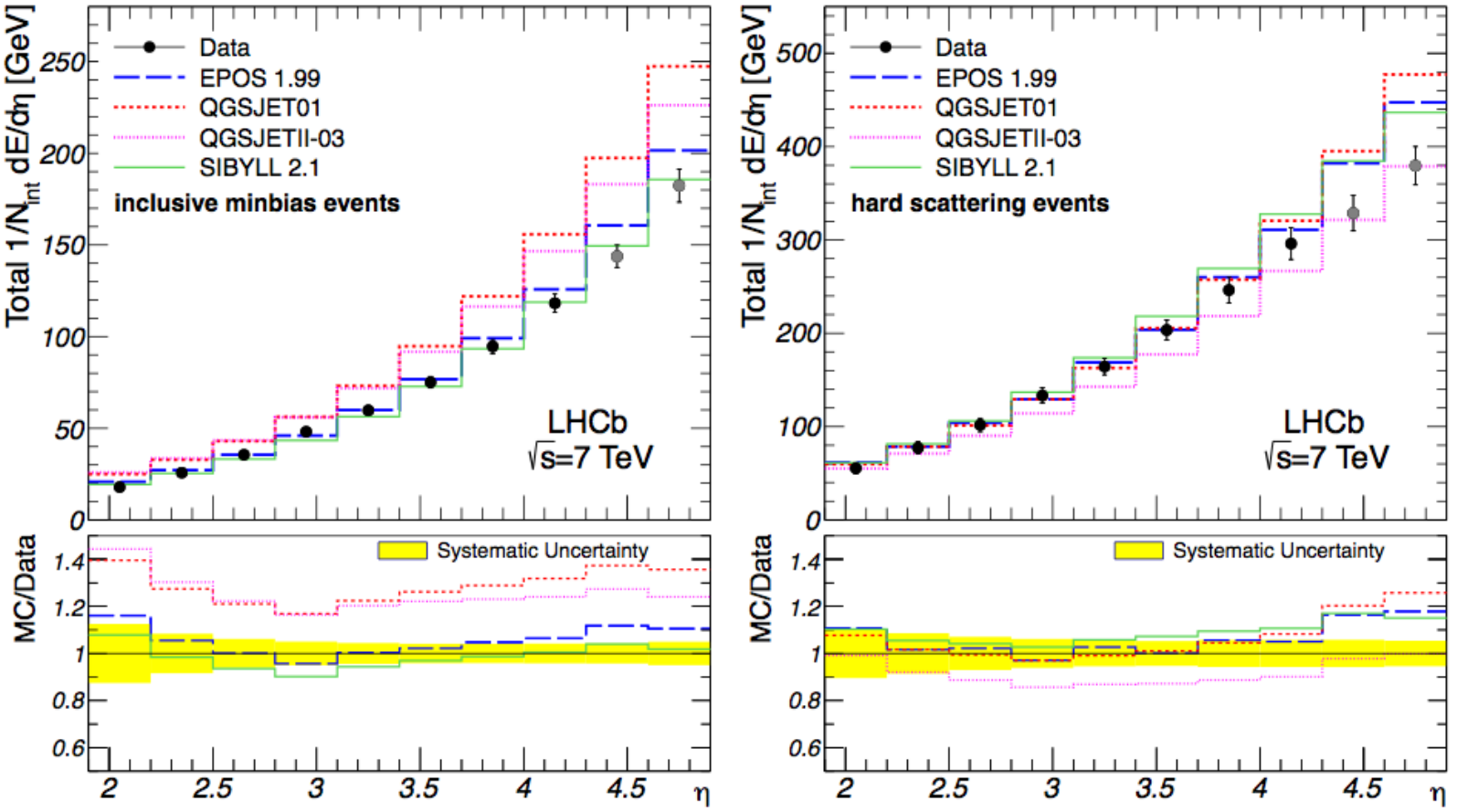
Forward Energy Flow

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

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

- *Sensitivity to the amount of multi-parton interactions*
  - → *essential for precise UE description & MC tuning*
  - → *constraints on cosmic-ray models*
- *Measurements for different event classes*

CERN YR: Chapter 7



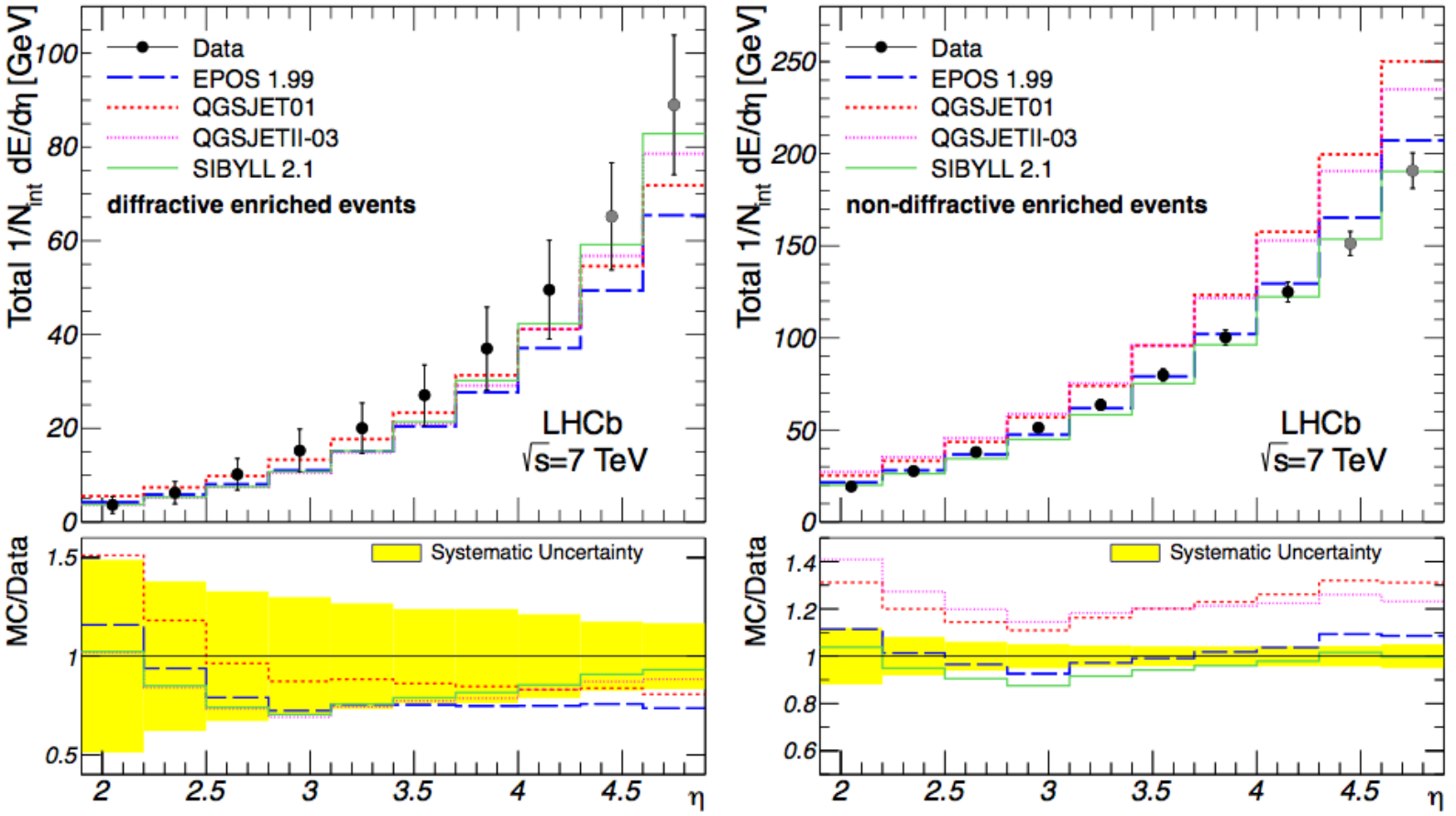
- *First LHCb analysis where the data are compared with cosmic-ray interaction models*

Eur. Phys. J. C 73 (2013) 2421

Forward Energy Flow

- *First LHCb analysis where the data are compared with cosmic-ray interaction models*

  → *SIBYLL2.1 gives the best description for inclusive minbias & non-diffractive enriched events*



- *None of the models are able to describe the measurements for all event classes:*

  → *valuable input to UE/cosmic-ray models*

Eur. Phys. J. C 73 (2013) 2421

Future soft QCD studies

- *For future soft QCD analyses on:*

→ *charged particle multiplicities (for different event classes)*
→ *energy flow (for different event classes)*
→ *hadron ratios (for different event classes)*
→ *inclusive charged particle cross-sections*
→ *correlations*
→ *strangeness production*
→ …

a sample of at least 10 nb^{-1} minimum bias data is required !

→ *2 LHC fills each at least 5 nb^{-1} with different magnet polarities*
→ *average number of visible pp interactions per BX: $\mu < 0.10$ => pile-up < 1.05*
→ *bunch spacing 50 ns*

Future soft diffractive studies

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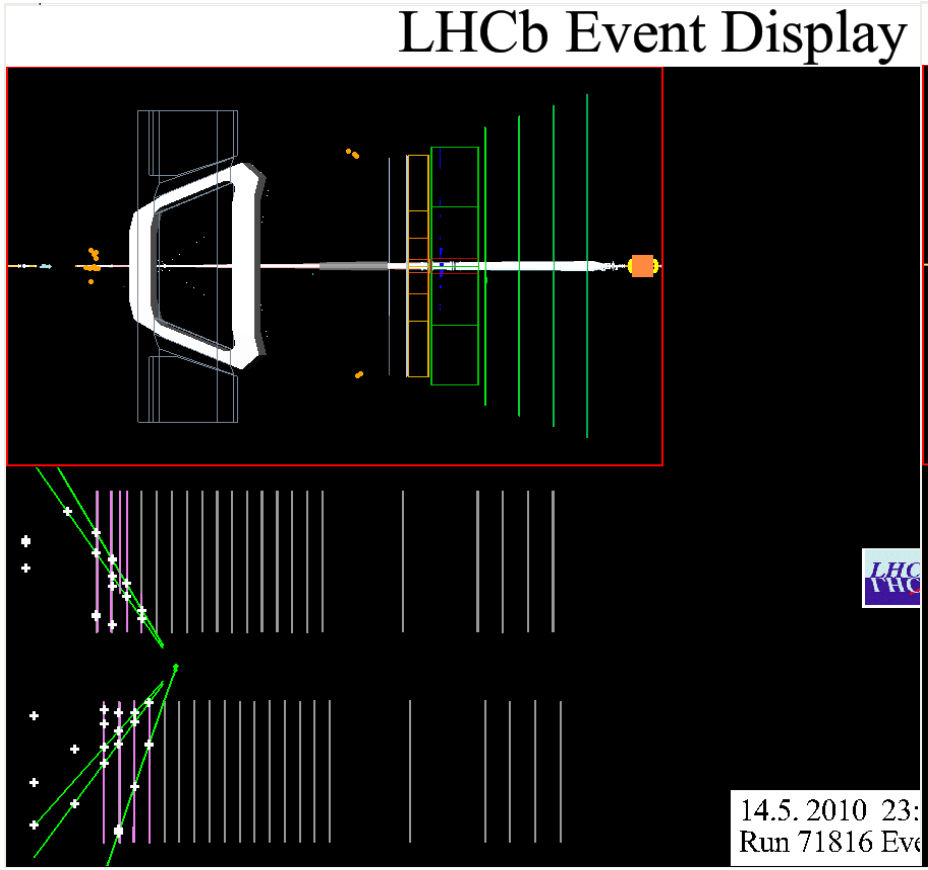
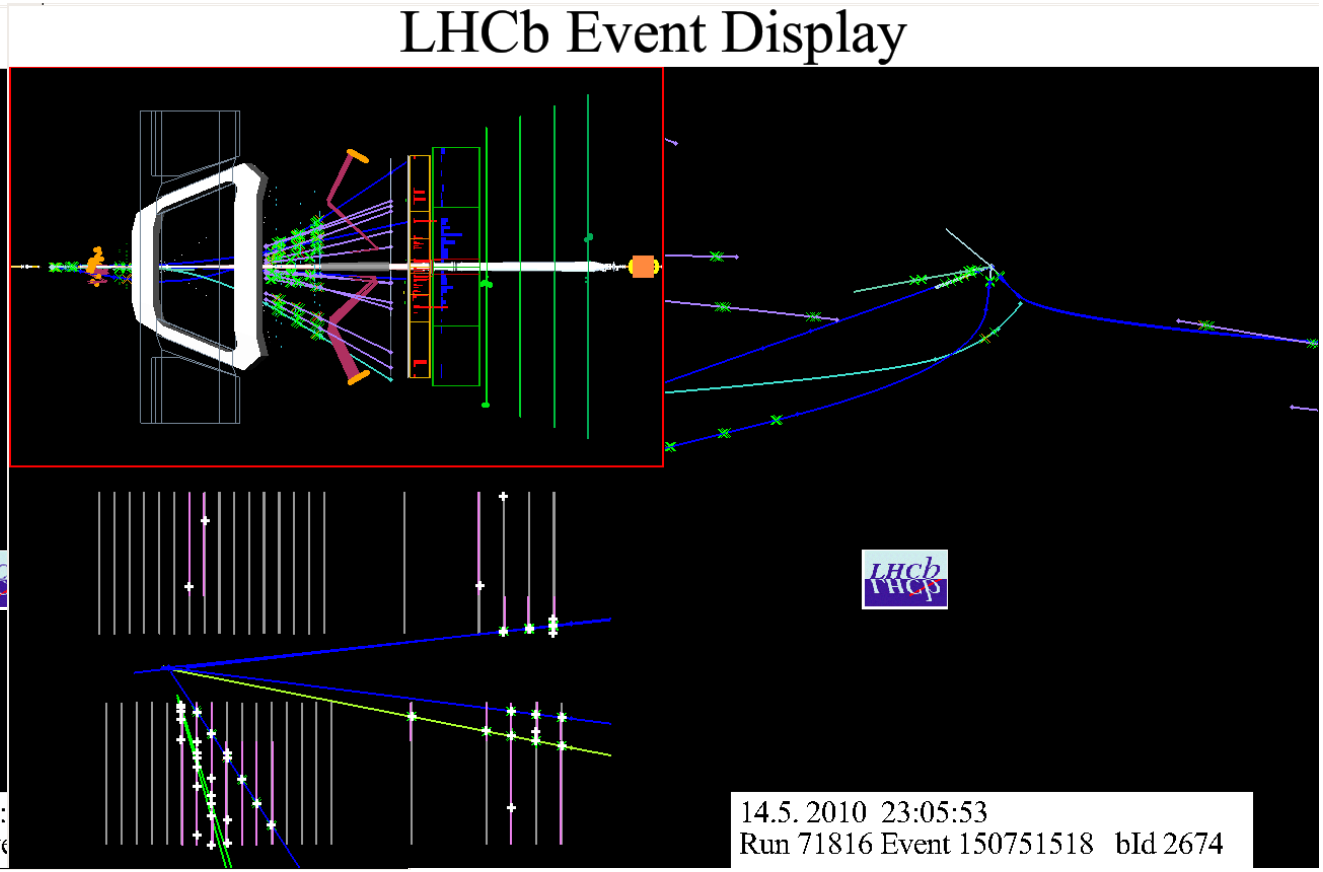
- *Measurements of single-diffractive processes are possible with LHCb*
  - *→ VELO provides forward (1.5<η<5.0) and backward (-4.0<η<-1.5) coverage*
  - *→ selection of SD enriched event samples: LRG over ~2 units of η in the backward region*



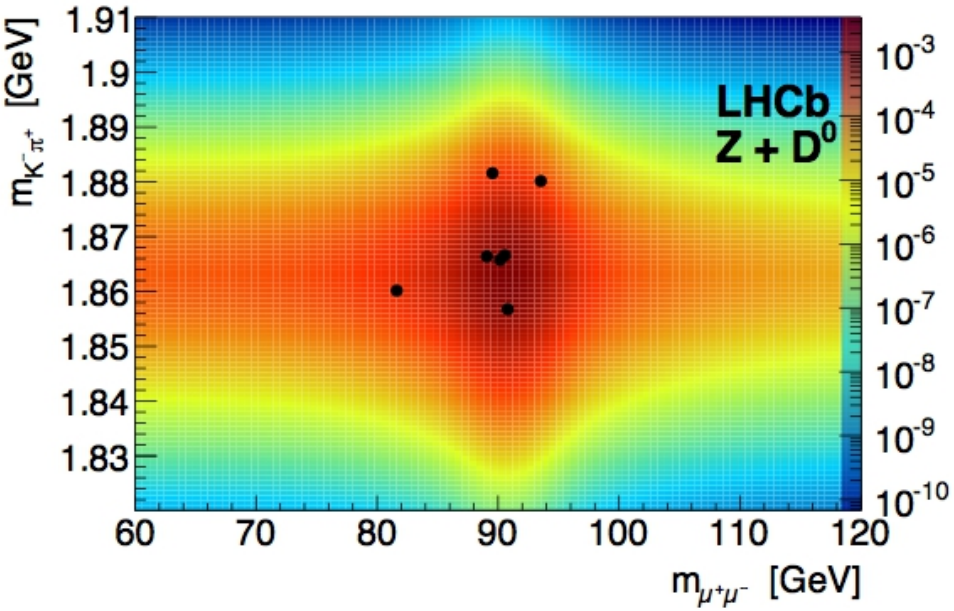


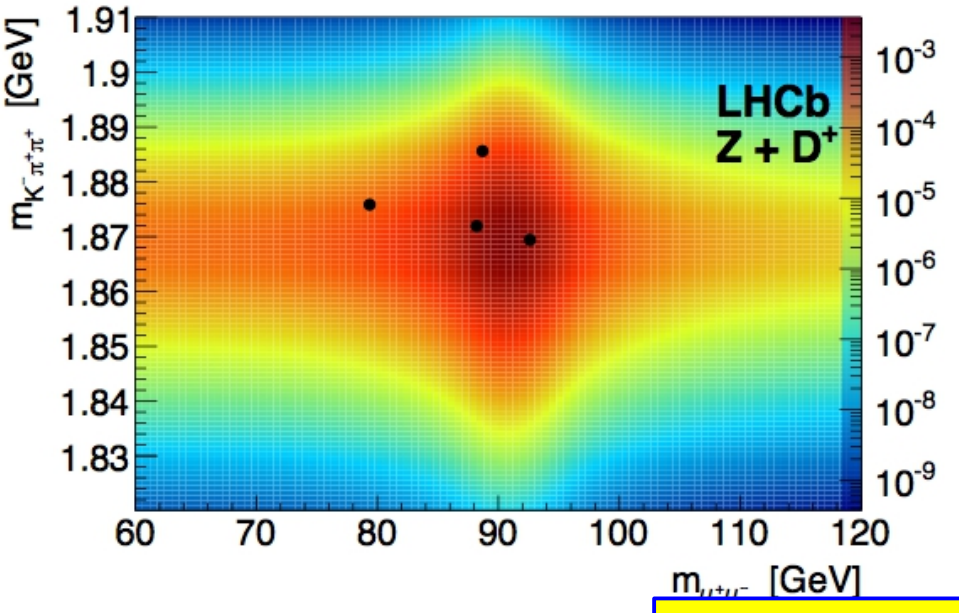
- *→ to study various properties of SD events, at least 1 pb^{-1} of low pile-up data is desirable*
- *HERSCHEL should drastically improve LHCb's ability to study SD events*

Recent probes of DPS

arXiv:1401.3245 [hep-ex]

- *Associated production of Z+D mesons - unique insight into:*
  - → *double parton scattering (DPS)*
  - → *charm production mechanism and charm parton distribution inside the proton*
- *Performed with 1 fb^{-1} of 7 TeV pp data:*
  - → *kinematic range: $60<M(\mu^+\mu^-)<120$ GeV; $p_T(\mu)>20$ GeV; $2.0<\eta(\mu)<4.5$; $2<p_T(D)<12$ GeV; $2.0<y(D)<4.0$*
  - → *$Z\to\mu^+\mu^-$; $D^0\to\pi^+K^-$; $D^+\to\pi^+\pi^+K^-$ decay modes*
  - → *$Z+D^0$: 7 reconstructed candidates ; $Z+D^+$: 4 reconstructed candidates*
  - → *5.1σ combined significance: first observation*
  - → *background contamination mainly due to Z+b(D) feed down contribution (taken as systematics)*





→ *color scale shows the PDF value at any given point*

CERN YR: Chapter 6

Recent probes of DPS

arXiv:1401.3245 [hep-ex]

- *Z+D cross-section (in pb): data vs theory*

→ *contribution from SPS and DPS production mechanisms*

→ *SPS: NLO parton-level integrator, MCFM*

→ *DPS: factorisation approximation* $\sigma^{DPS}_{Z\to\mu^+\mu^-,D} = \frac{\sigma_{Z\to\mu^+\mu^-}\,\sigma_D}{\sigma_{eff}}$

Nucl. Phys.Proc. Suppl. 205-206 (2010) 10

	measured	MCFM massless	MCFM massive	DPS
$Z + D^0$	$2.50 \pm 1.12 \pm 0.22$	$0.85^{+0.12}_{-0.07}\,{}^{+0.11}_{-0.17} \pm 0.05$	$0.64^{+0.01}_{-0.01}\,{}^{+0.08}_{-0.13} \pm 0.04$	$3.28^{+0.68}_{-0.58}$
$Z + D^+$	$0.44 \pm 0.23 \pm 0.03$	$0.37^{+0.05}_{-0.03}\,{}^{+0.05}_{-0.07} \pm 0.03$	$0.28^{+0.01}_{-0.01}\,{}^{+0.04}_{-0.06} \pm 0.02$	$1.29^{+0.27}_{-0.23}$

→ *MCFM underestimates $Z(\mu^+\mu^-)+D^0$ and provides good description for $Z(\mu^+\mu^-)+D^+$*

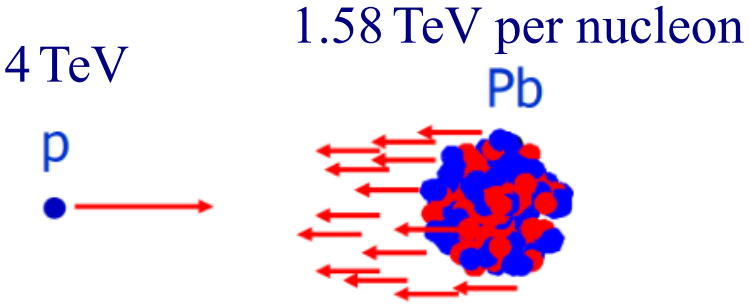
→ *DPS provides reasonable description for $Z(\mu^+\mu^-)+D^0$ and overestimates $Z(\mu^+\mu^-)+D^+$*

CERN YR: Chapter 6

p-nucleus program at LHCb

- *LHC provides a unique opportunity to explore pPb & PbPb interactions at the Terascale*
  - → *studies of PbPb collisions are not really feasible with LHCb due to high occupancy*
  - → *first studies of pPb collisions are performed with LHCb at* $\sqrt{s_{NN}} = 5\,\mathrm{TeV}$

Why study this ?

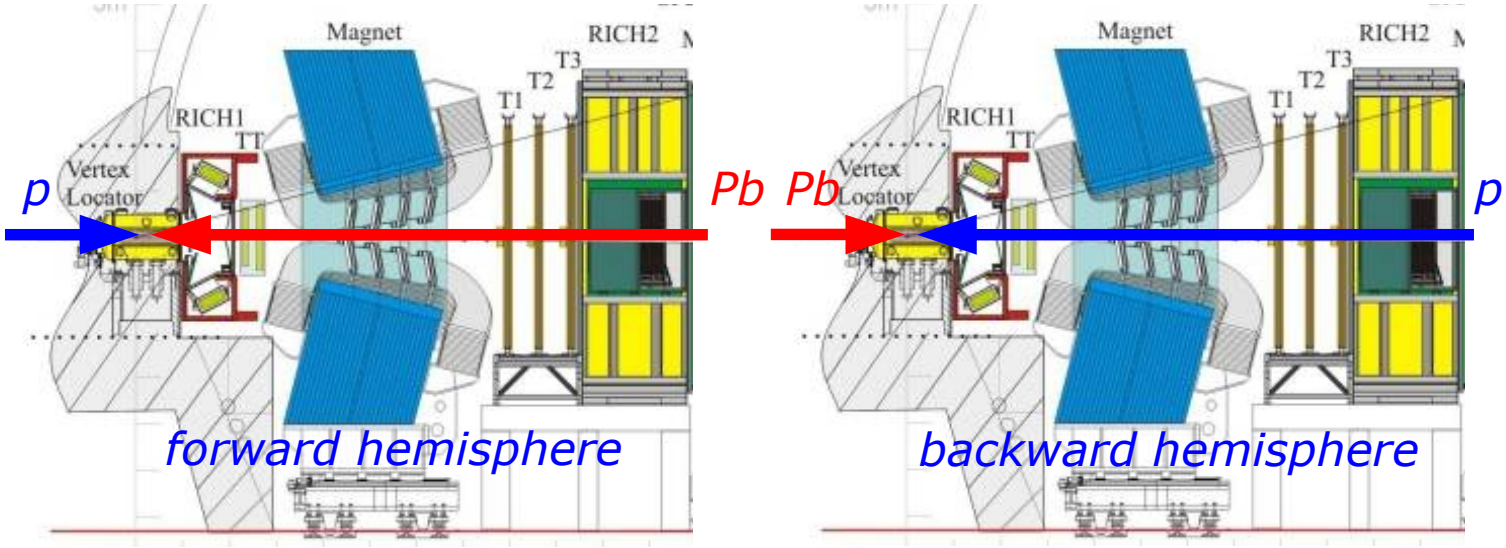


- *Quark-Gluon Plasma (QGP) can be created in PbPb but not in pPb collisions*
- *Only cold nuclear matter effects can occur in p*Pb *collisions*
- *pPb measurements are essential to disentangle QGP signatures from the cold nuclear matter effects*
- *pPb studies provide a unique opportunity to constrain nuclear PDFs*
- *Measurements of soft QCD & hadron spectroscopy with pPb data provide valuable input to Heavy Ion Physics & allow constraining of cosmic-ray models*

CERN YR: Chapter 8

First *pPb* results

- *Both pPb & Pbp interactions are recorded:*



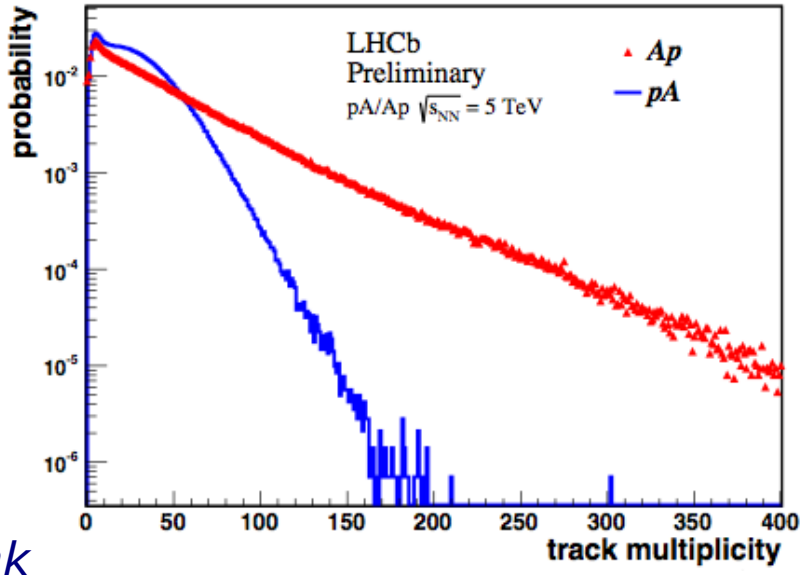
→ *studies of the forward & backward hemispheres of pPb interactions*

→ *4×10^9 pPb / Pbp collisions are recorded (~ 2 nb^{-1})*

→ *single pPb interactions per bunch crossing*

- *In 2015, about 10 times more pPb data is expected to be recorded by LHCb*

→ *high-precision measurements of different QCD/electroweak processes will be possible*



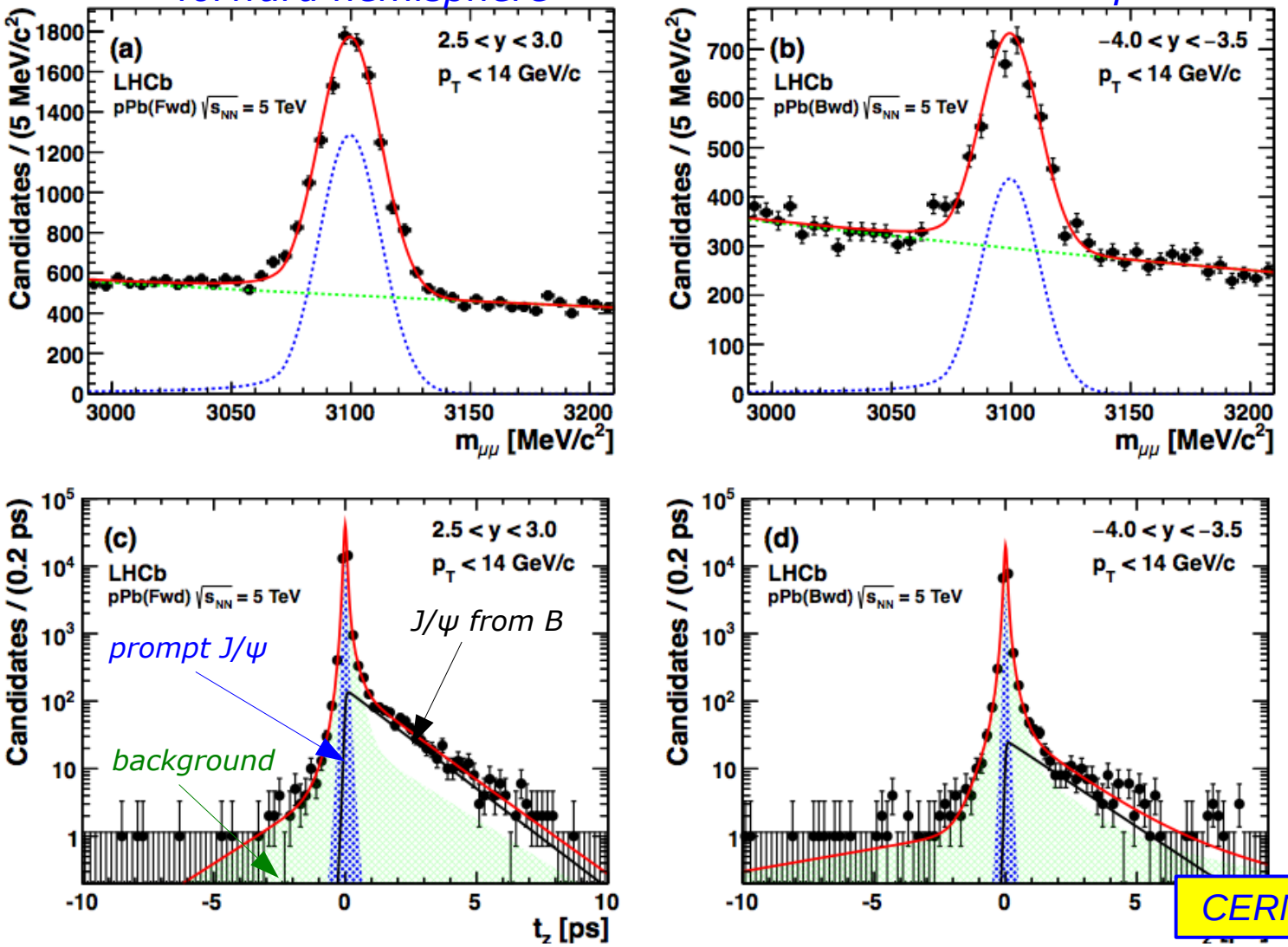
CERN YR: Chapter 8

First *pPb* results

- *heavy quarkonia production is suppressed in pPb w.r.t. pp*
  → *use J/ψ mesons to probe nuclear environment; distinguish between prompt J/ψ and J/ψ from B decays using proper time (helpful to disentangle between different nuclear effects)*

JHEP 02 (2014) 072

forward hemisphere *backward hemisphere*



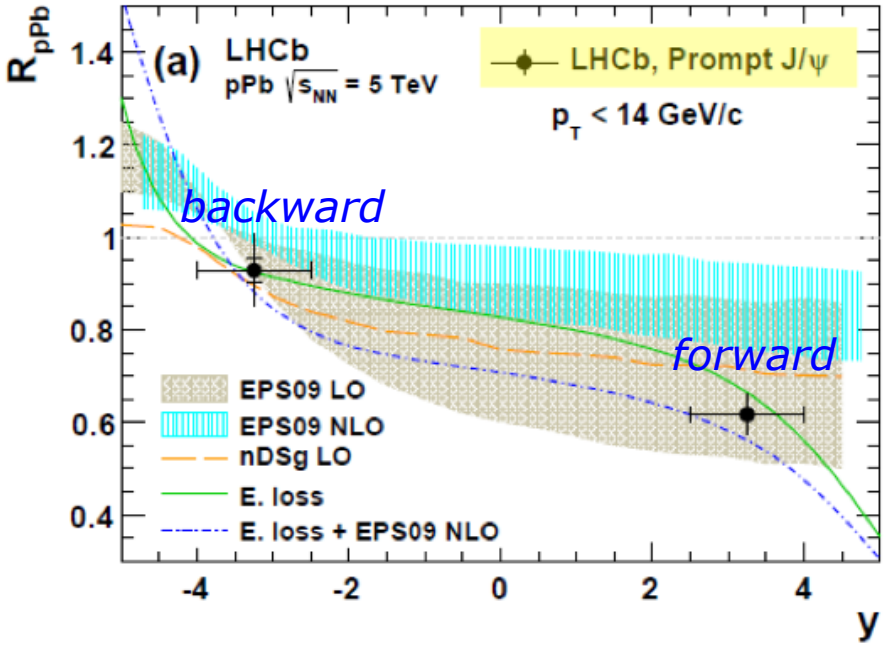
CERN YR: Chapter 8

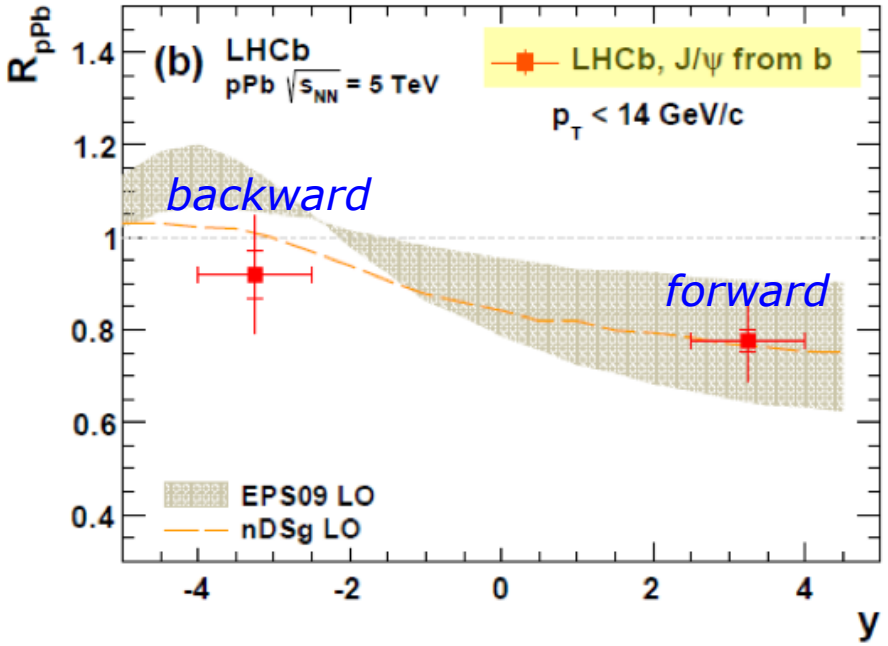
First *pPb* results

- *Probing nuclear effects with Nuclear Modification Factor*

JHEP 02 (2014) 072

$$R_{pA}(y,\sqrt{s_{NN}}) \equiv \frac{1}{A}\frac{d\sigma_{pA}(y,\sqrt{s_{NN}})/dy}{d\sigma_{pp}(y,\sqrt{s_{NN}})/dy}$$





→ *factor≠1 nucleons are bounded within the nucleus as known*

→ *suppression of about 40% at forward rapidity for prompt J/ψ, while B hadrons are less affected by nuclear effects- first indication. Mass dependence is being checked with Y mesons*

→ *large uncertainty of theoretical predictions*

→ *adding energy loss nuclear effect seems to be important*

CERN YR: Chapter 8

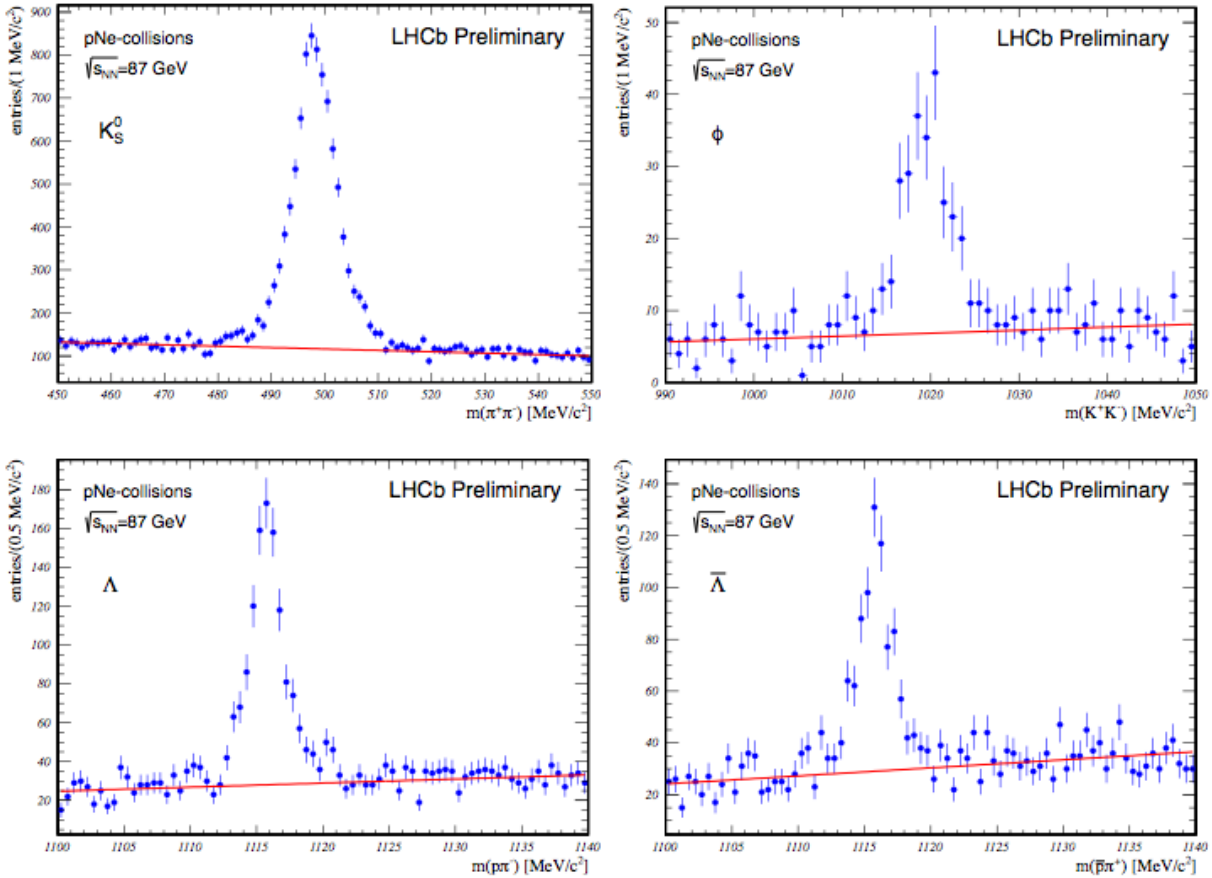
Fixed target physics at LHCb

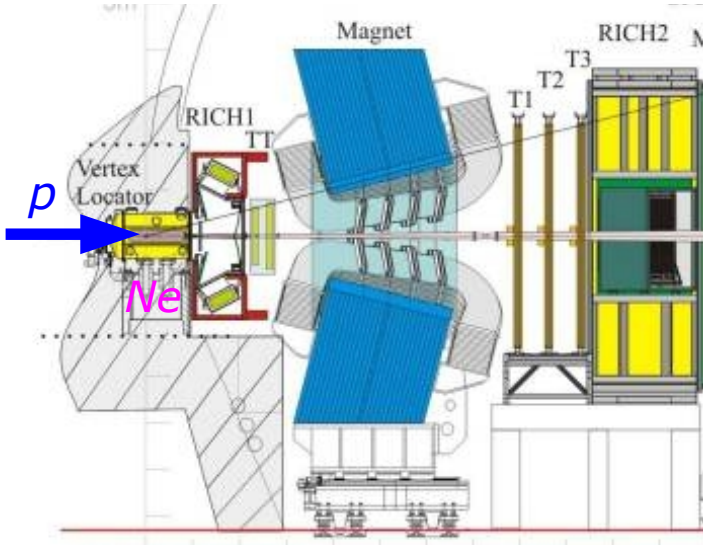
- *pNe collisions at LHCb: unique at the LHC*

  → *injecting Ne-gas into the VELO*

  → *rate of pNe interactions is sufficient to measure light quark & strangeness production*

LHCb-CONF-2012-034





→ *ideal conditions for testing cosmic-ray interaction models*

CERN YR: Chapter 7/8

Summary

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

→ *excellent detector performance since the data taking start*

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

→ *high-precision studies of QCD and electroweak processes in a unique kinematic range at different collision energies*

→ *extensive QCD/electroweak/proton-nucleus physics program*

→ *possibility to explore cold nuclear matter effects and carry out fixed target physics studies*

→ *HERSCHEL will significantly enhance LHCb's ability to study soft and hard diffractive processes*

- *Rich input to the CERN Yellow Report (see also Ronan's talk)*