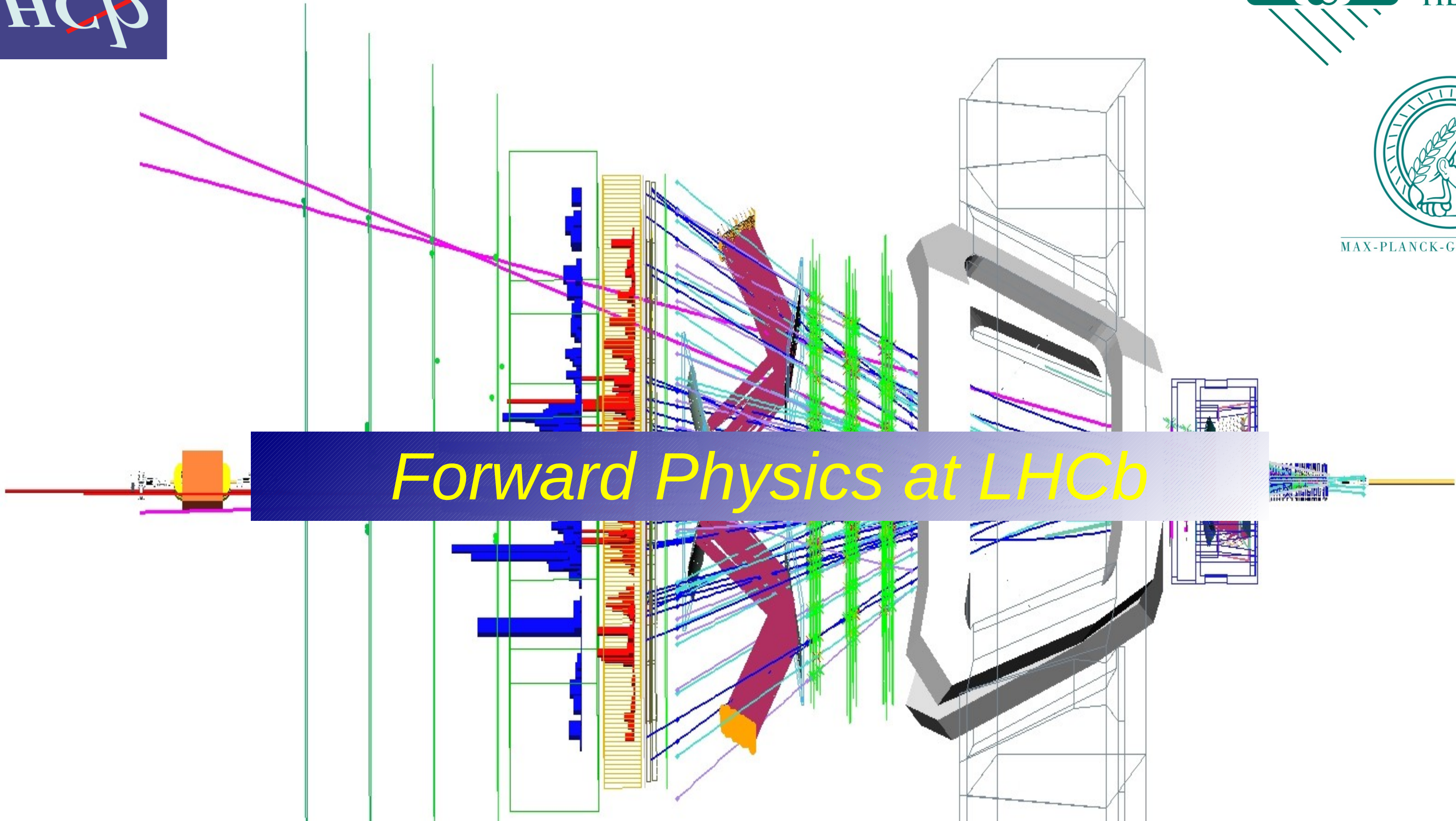

Forward Physics at LHCb

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on behalf of the LHCb collaboration

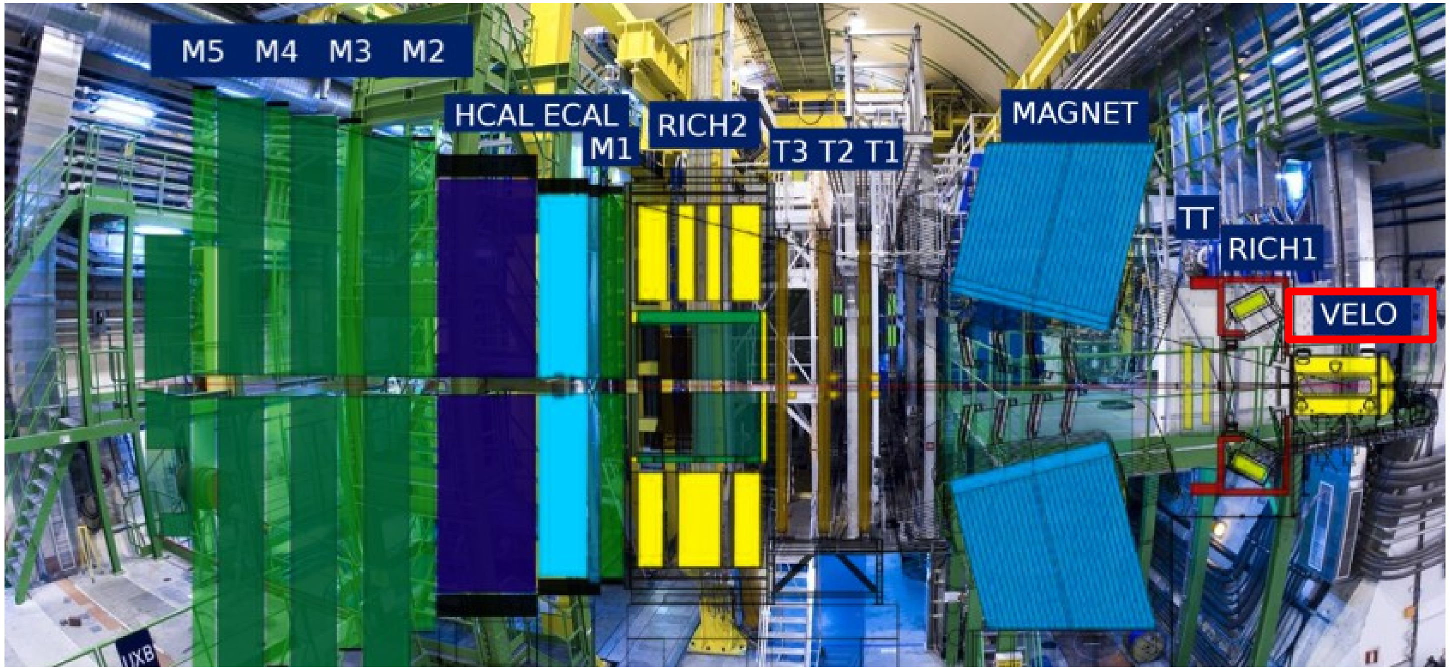
7th International Workshop on Diffraction in High Energy Physics
10–15 September 2012, Puerto del Carmen, Lanzarote, Spain

LHCb menu at Lanzarote

- *LHCb and its current status*
- *Electroweak boson production*
- *Drell-Yan cross-section*
- *Diffractive studies and energy flow measurements*
- *Exclusive dimuon production*
- *Summary*

LHCb experiment

- *One of the 4 main detectors at the LHC: CP violation, rare decays, New Physics searches*



- *Forward spectrometer with planar detectors:*

→ *B hadrons at the LHC are mainly produced at low polar angles*

→ *angular coverage: $2 < \eta < 5$*

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

- *Excellent tracking performance:*

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

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

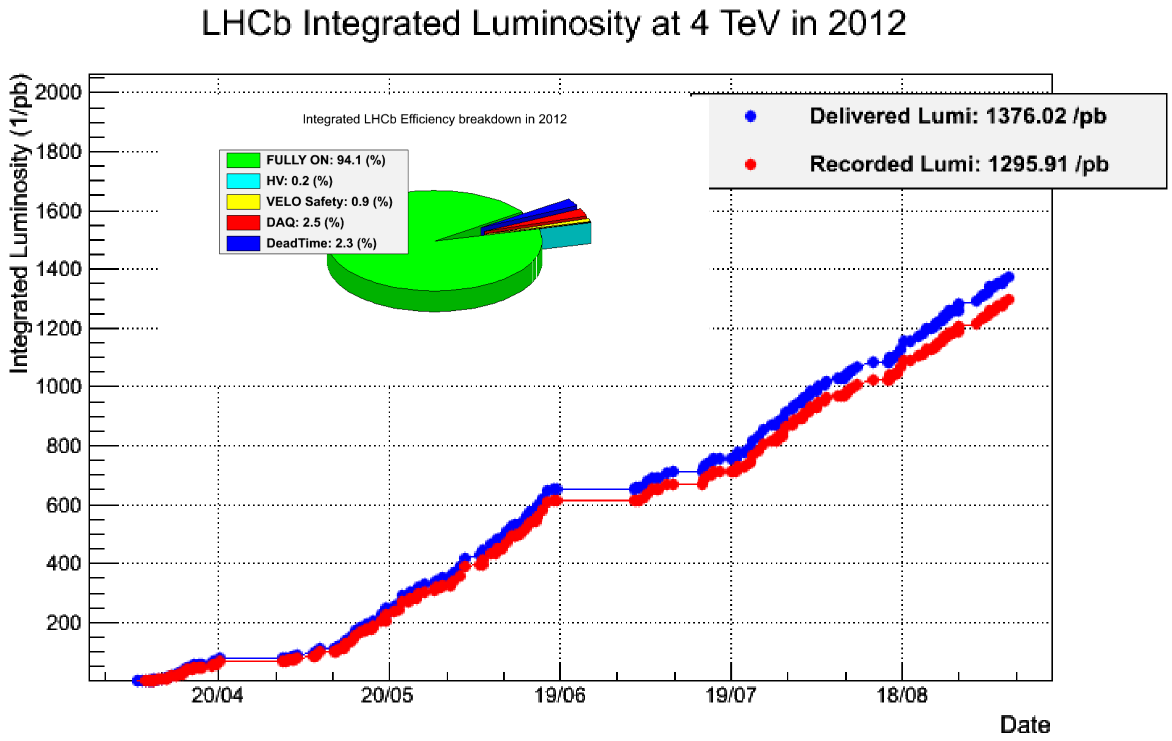
- *High quality particle identification:*

→ *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*

Data taking: 2009-2012



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	2.2 fb^{-1} (exp.)	8

- *~95 % data taking efficiency*
- *~99% r/o channels operational*
- *~99% of accumulated data is useful for physics analysis*

Running challenges:

- *In 2011 and 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, offline reconstruction and data processing*

LHCb potential

- *LHCb, due to its rapidity coverage, explores particle production in an unique kinematic range:*

  → probes of PDFs at very low and at high values of x and low-Q^2 : collision between parton at high (known) and low-x (unexplored). For ATLAS/CMS: collisions of two partons with similar x

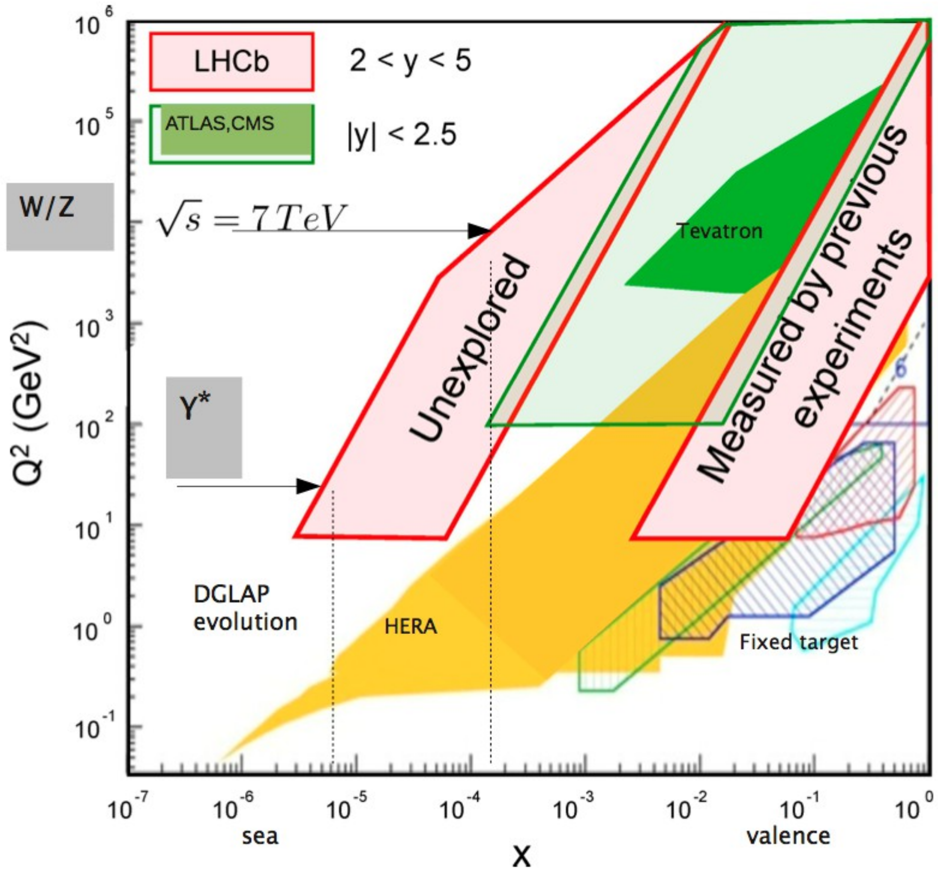
  → PDF uncertainty increases towards large η

  → low-mass Drell-Yan and W/Z cross-section measurements: probe x values down to ~10^{-6} and 10^{-4}, respectively

- *Ability to study low-p_T region (<0.5 GeV/c) at large η(>4)*

  → the only LHC experiment that can investigate this region of the phase space

  → great potential to study soft QCD processes



Electroweak Boson Production (1)

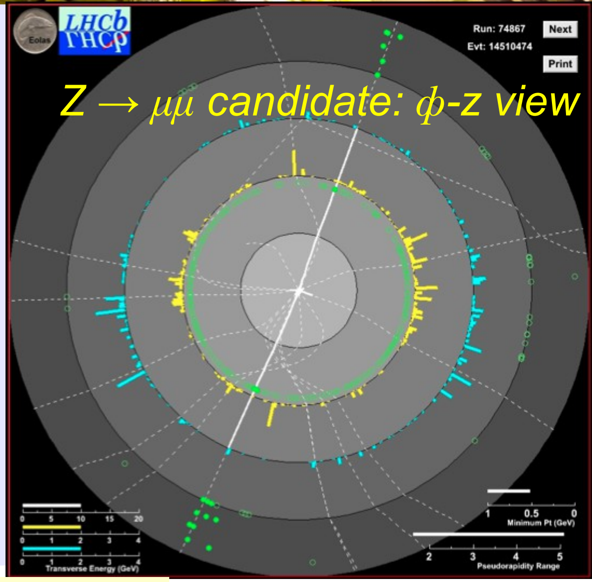
- *Z production studied with 4 decay modes:*

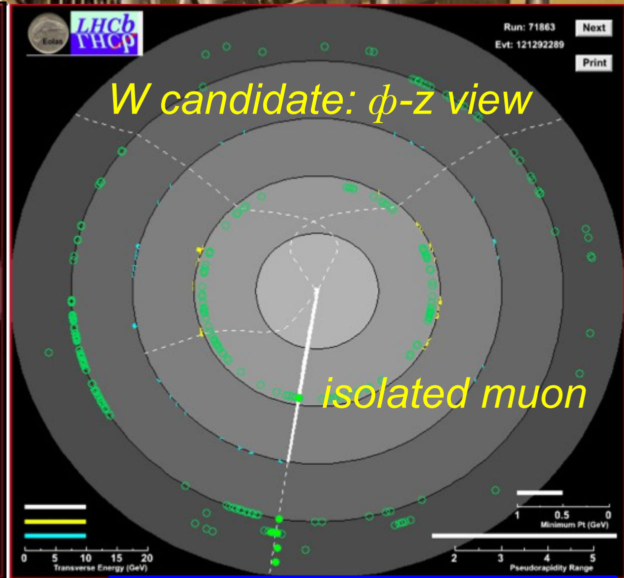
  1) $Z \to \mu\mu$:
  $\to$ 37 pb^{-1}, LHCb-PAPER-2012-008

  2) $Z \to ee$
  $\to$ 1 fb^{-1}, LHCb-CONF-2012-011

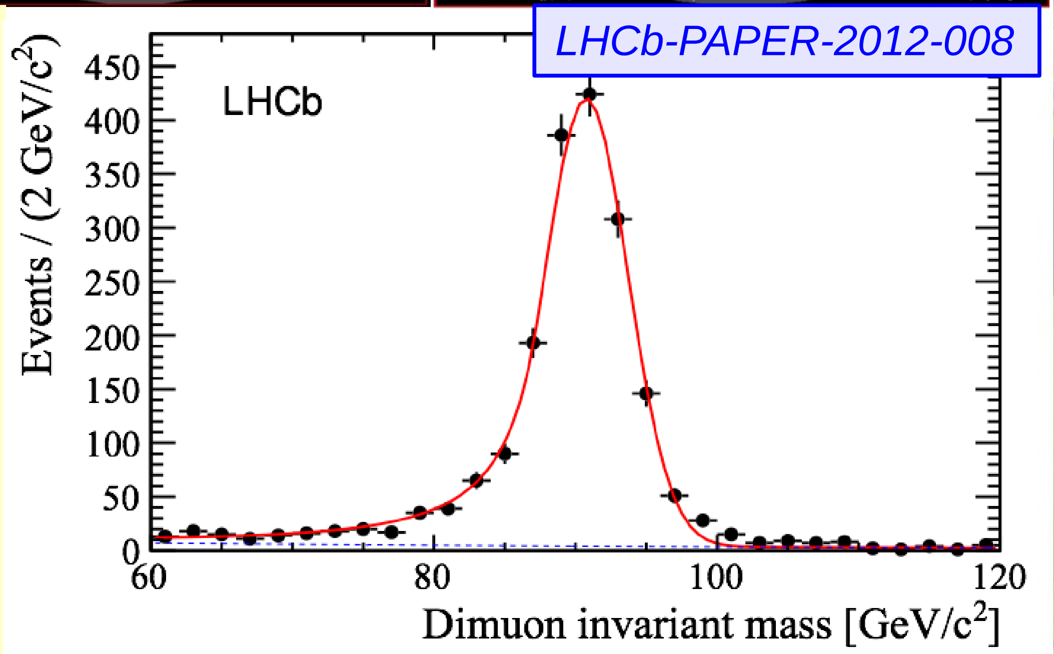
  3,4) $Z \to \tau(\mu\upsilon\upsilon)\tau(\mu\upsilon\upsilon)$, $Z \to \tau(\mu\upsilon\upsilon)\tau(e\upsilon\upsilon)$
  $\to$ 0.25 fb^{-1}, LHCb-CONF-2011-041

- *Z selection: muons/electrons with high p_T*

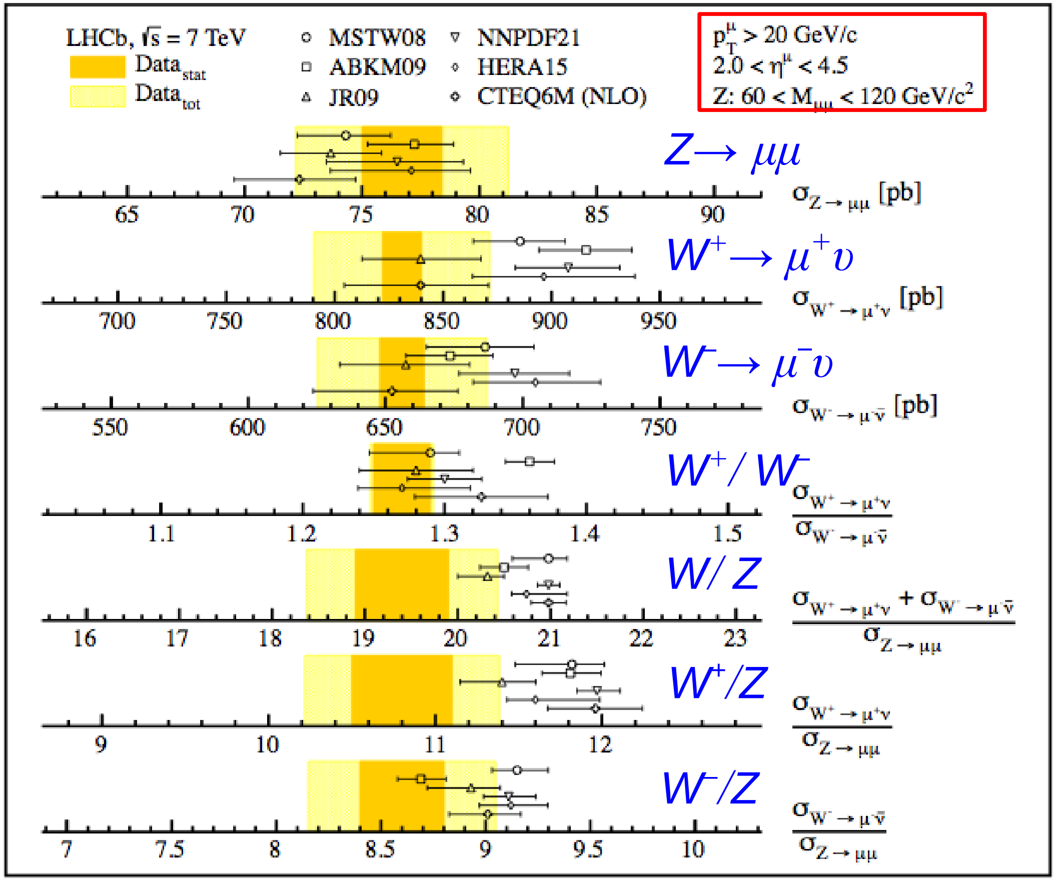




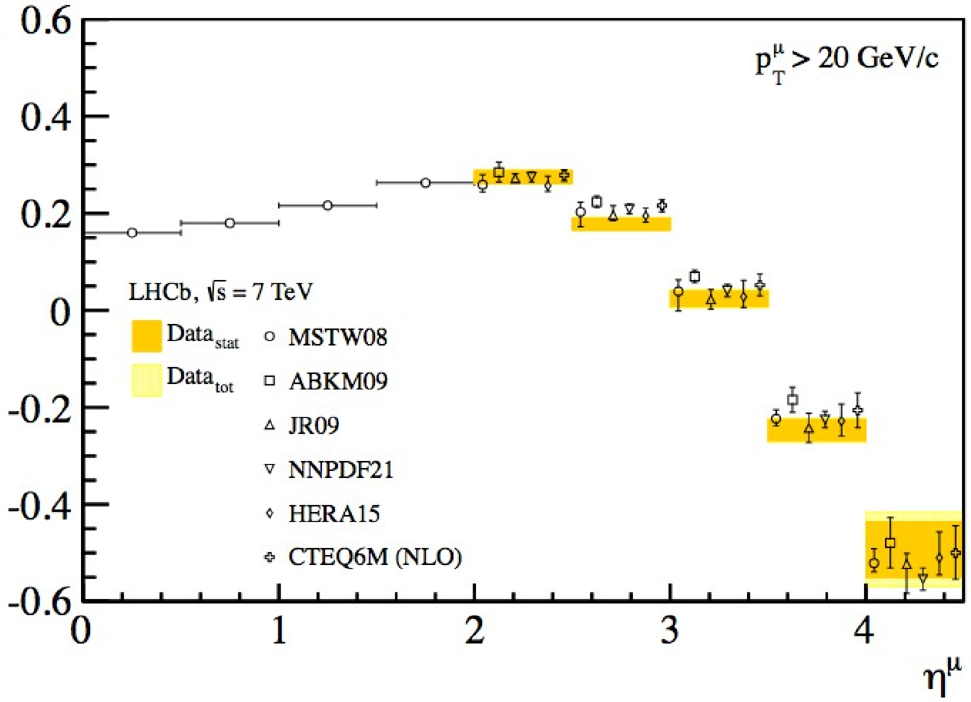
- *$W^{\pm} \to \mu^{\pm}\upsilon$ selection: high p_T and isolated muons ($W^{\pm}$purity : 78%)*
- *Lepton charge asymmetries are investigated*
- *Signal yield is estimated by fitting the p_T spectra of positive and negative muons in data to templates for signal and backgrounds*
  - *$\to$ Signal+Z-related background templates taken from MC, heavy flavor background from data*
- *W,Z selection efficiencies derived from data*
- *All results corrected for final state radiation*



LHCb-PAPER-2012-008



- *Lepton charge asymmetry vs muon pseudorapidity:*



$$A_\mu = (\sigma_{W^+\to\mu^+\nu} - \sigma_{W^-\to\mu^-\bar{\nu}})/(\sigma_{W^+\to\mu^+\nu} + \sigma_{W^-\to\mu^-\bar{\nu}})$$

MSTW08 arXiv:0901.0002
ABKM09 arXiv:0908.2766
JR09 arXiv:0810.4274
NNPDF arXiv:1002.4407
HERA15 arXiv:0911.0884
CTEQ6M arXiv:0802.0007

- *general agreement with the predictions, though some PDFs overestimate the ratios of the cross-sections*
- *errors include PDF and scale uncertainties*
- *accuracy of the results will be improved with more data*

Drell-Yan Production (1)

- $qq \rightarrow \gamma^* \rightarrow \mu\mu$ process studied with 37 pb^{-1}
- selection: high p_T identified muons with $5 < M_{\mu\mu} < 120$ GeV
- Signal extraction using the muon isolation:

$$z = p_T^{\mu} / p_T^{Jet}$$

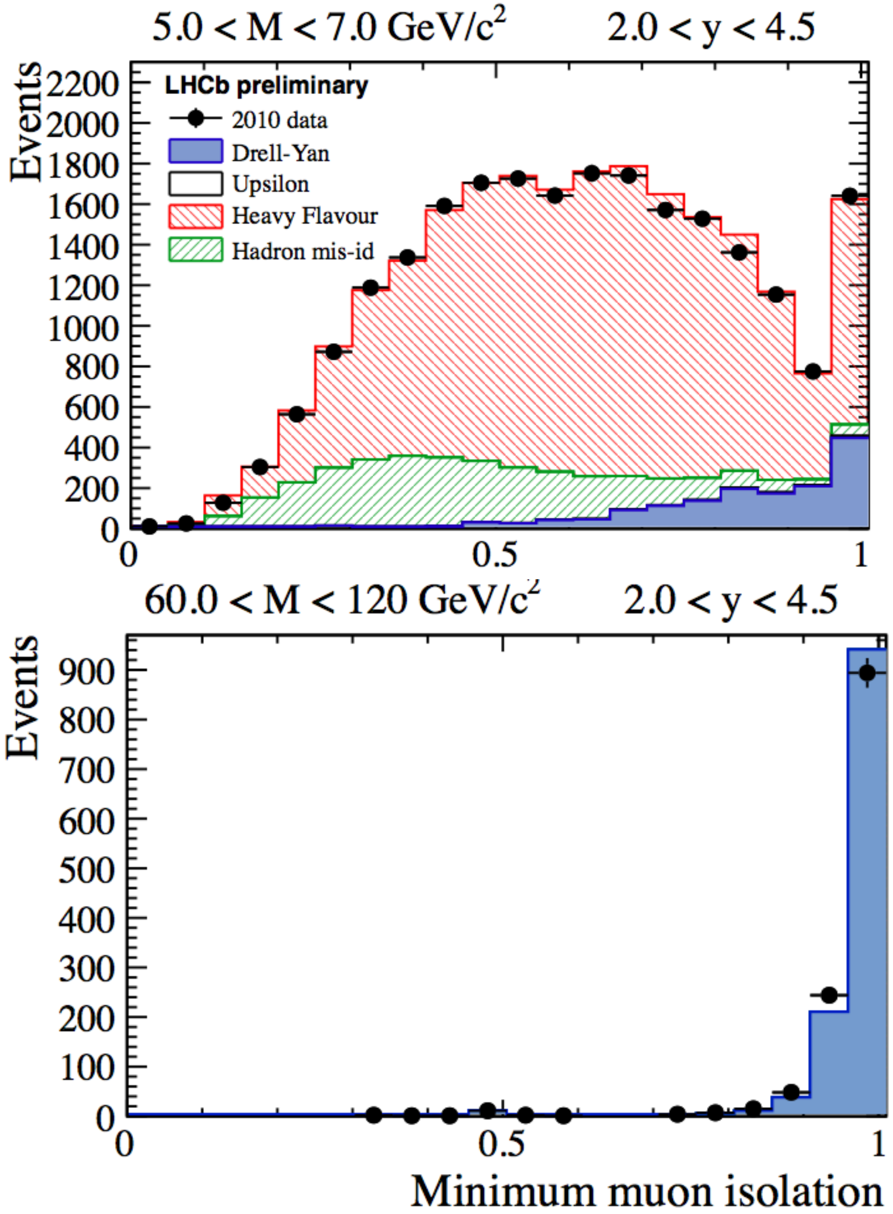
→ for signal $z \rightarrow 1$: checked with Υ and Z data
for background $z < 1$: usually produced in the same direction as the other collision products

→ minimum muon isolation of two muons is used

- Signal yield extraction using a fit to the Minimum Muon Isolation distribution of two muons in data to templates for the signal and background.

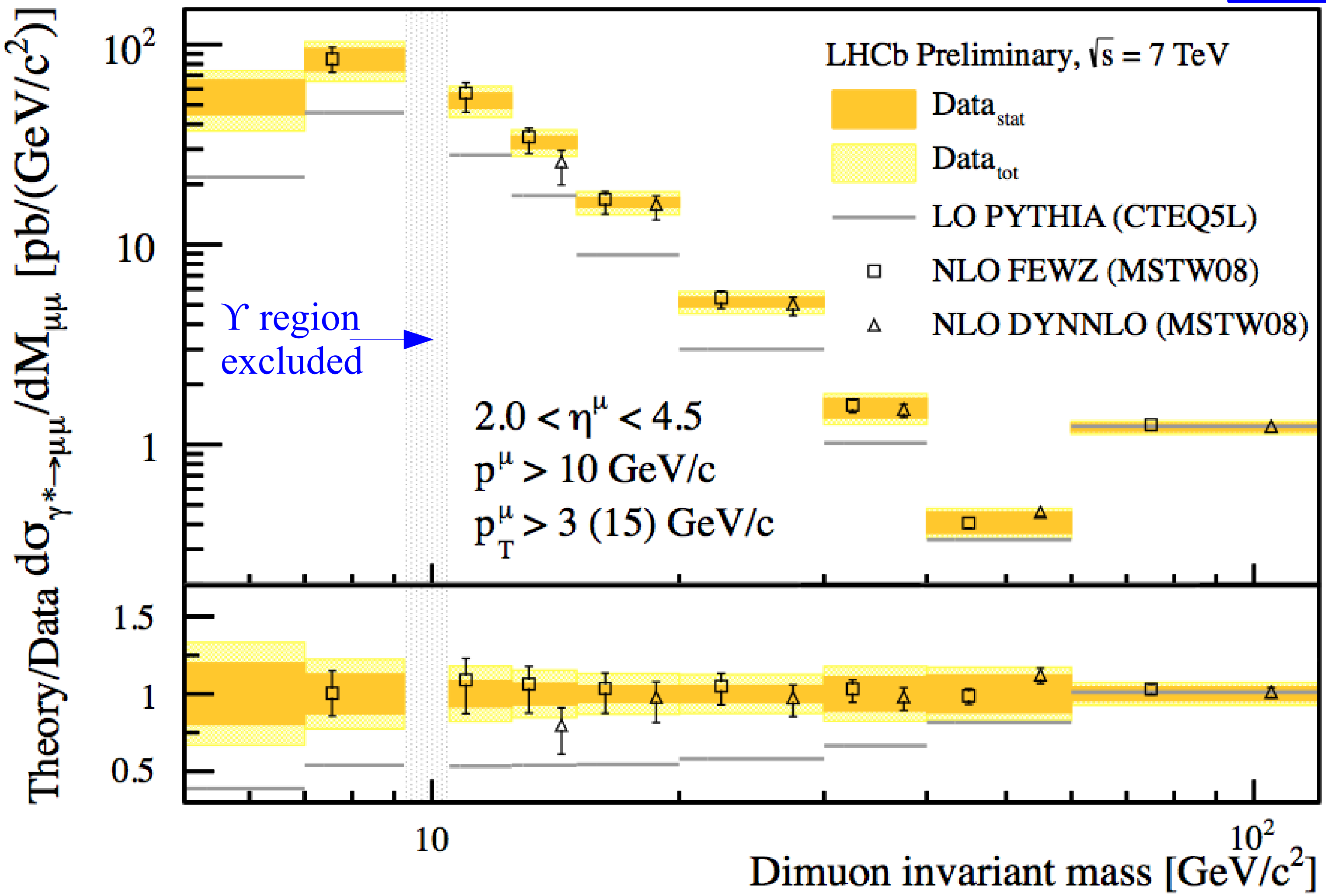
→ signal template is taken from PYTHIA, while background templates are mainly taken from data

LHCb-CONF-2012-013



Drell-Yan Production (2)

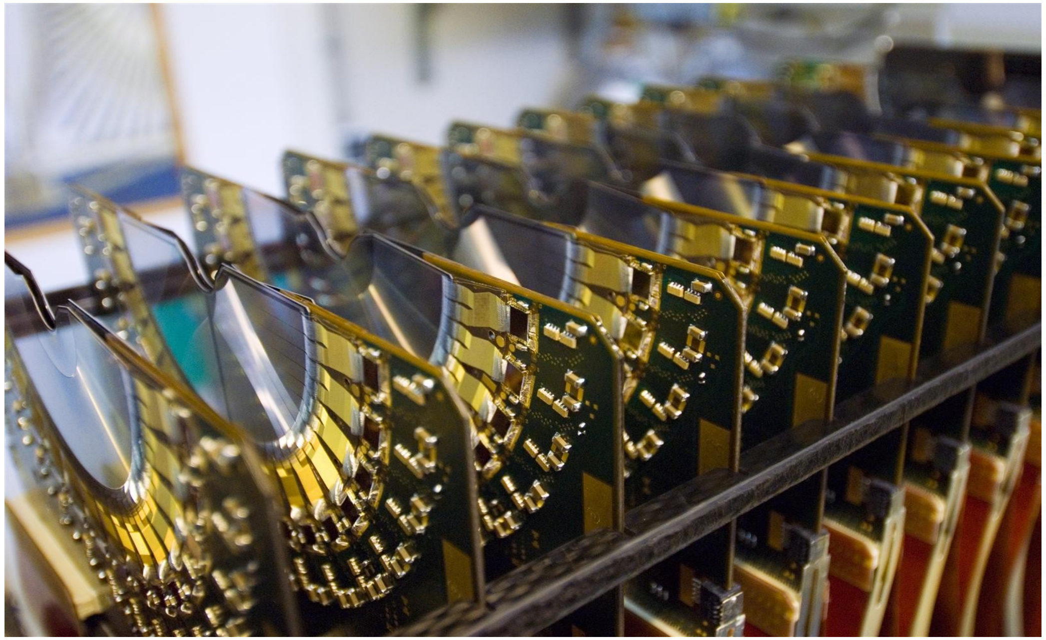
LHCb-CONF-2012-013



- *NLO predictions provide good description of the data*
- *NNLO predictions are about 10-20% higher than NLO at low masses*

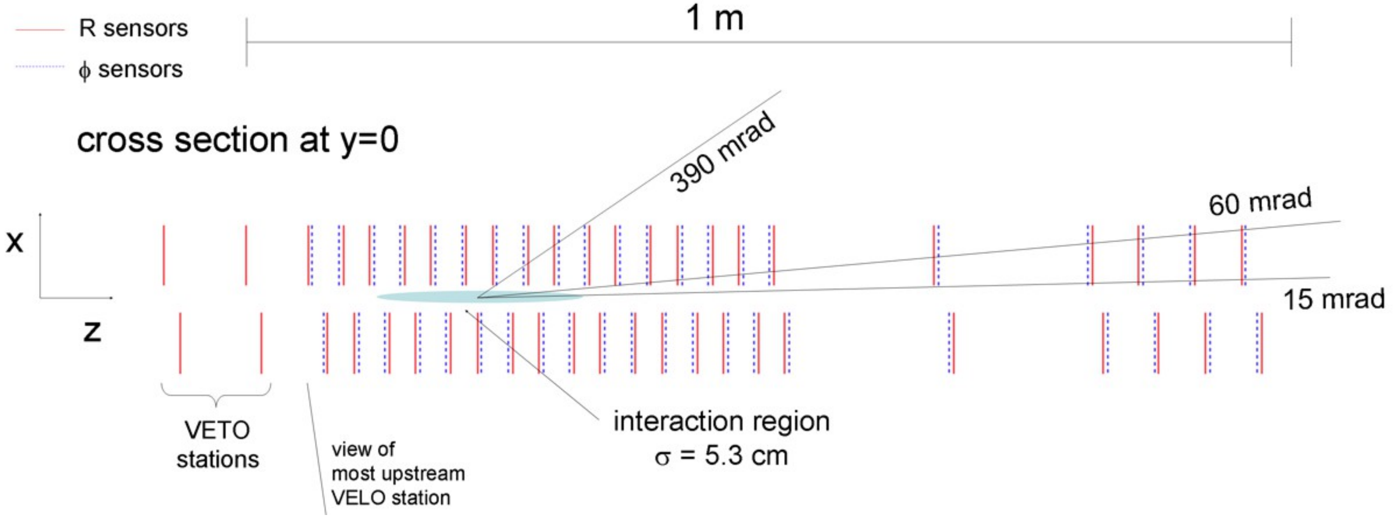
Detection of diffractive events

- *LHCb Vertex Locator (VELO) allows to measure diffractive processes by detecting events with Large Rapidity Gaps (LRG)*
- *23 SiStrip stations surrounding the Collision Point being outside magnetic field, just 8 mm away from the beam line*
- *largest angular coverage among LHCb subsystems*
- *detection coverage: $1.5<\eta<5.0$, $-4<\eta<-1.5$*
- *reconstruction of the primary and decay vertices, track seeds + info for the trigger*
- *excellent performance during data taking*

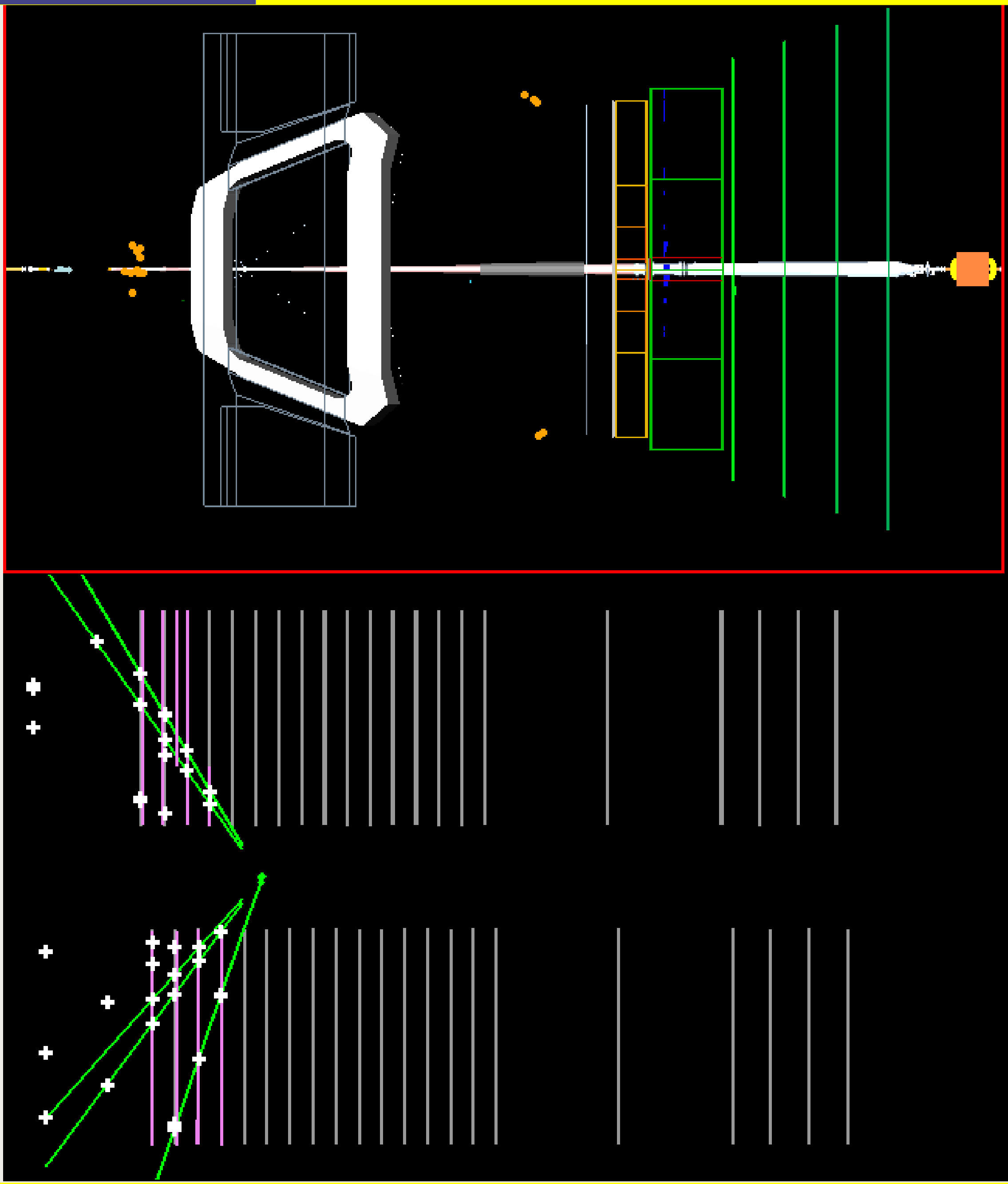


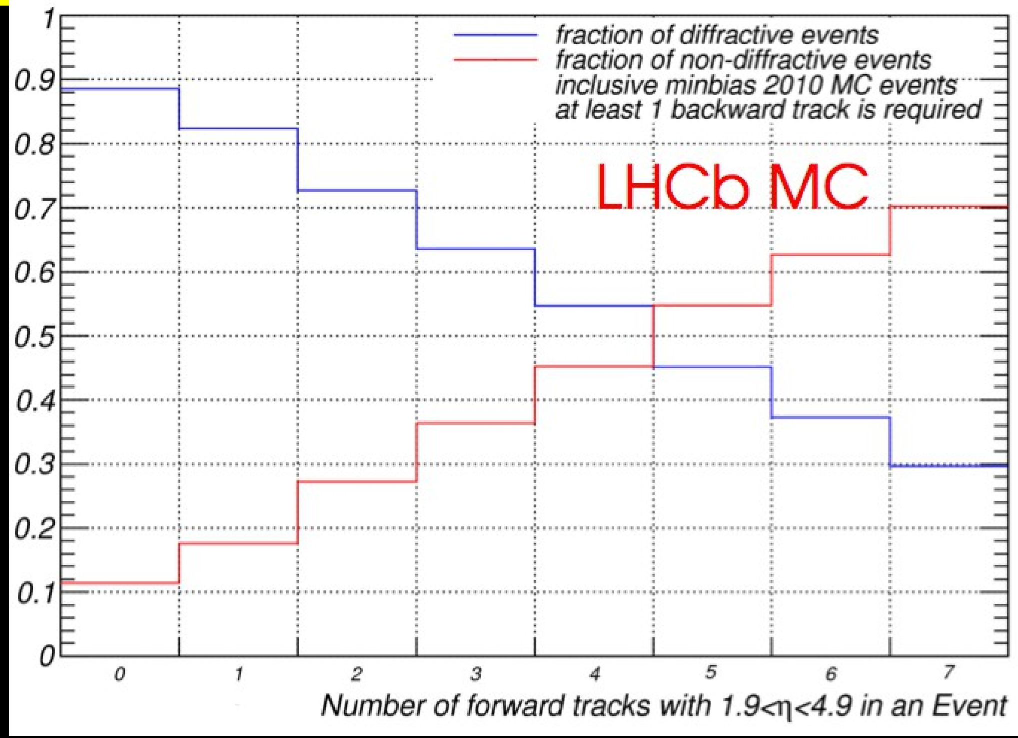
- *High detection efficiency for events with LRG over:*

  $-3.5 < \eta < -1.5$
  $2.0 < \eta < 5.0$



Upstream Diffractive Candidate

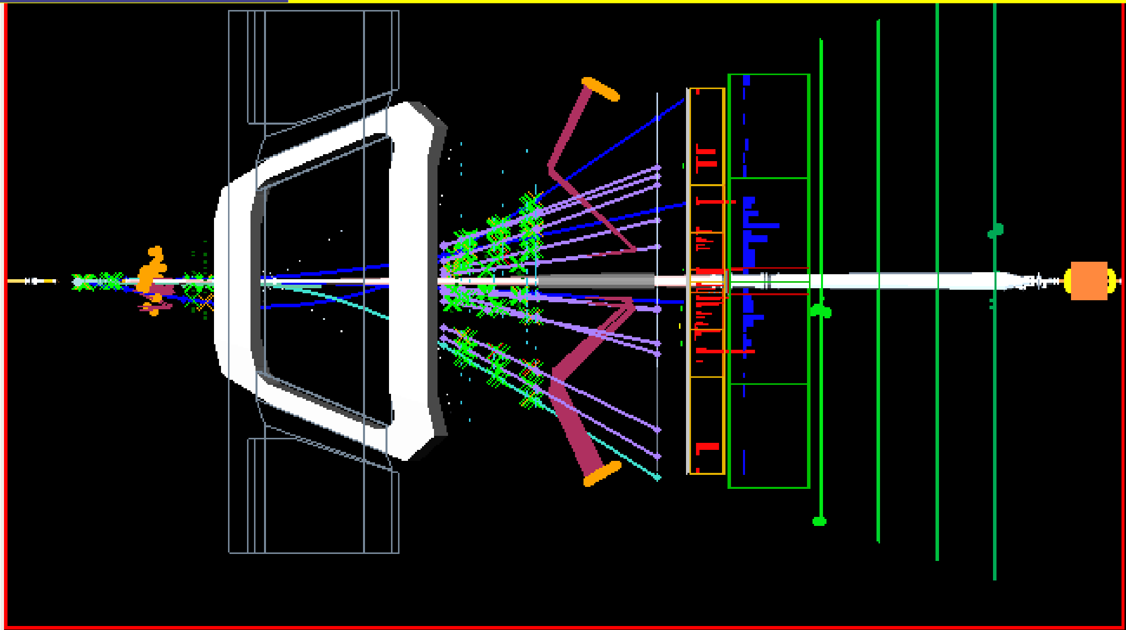


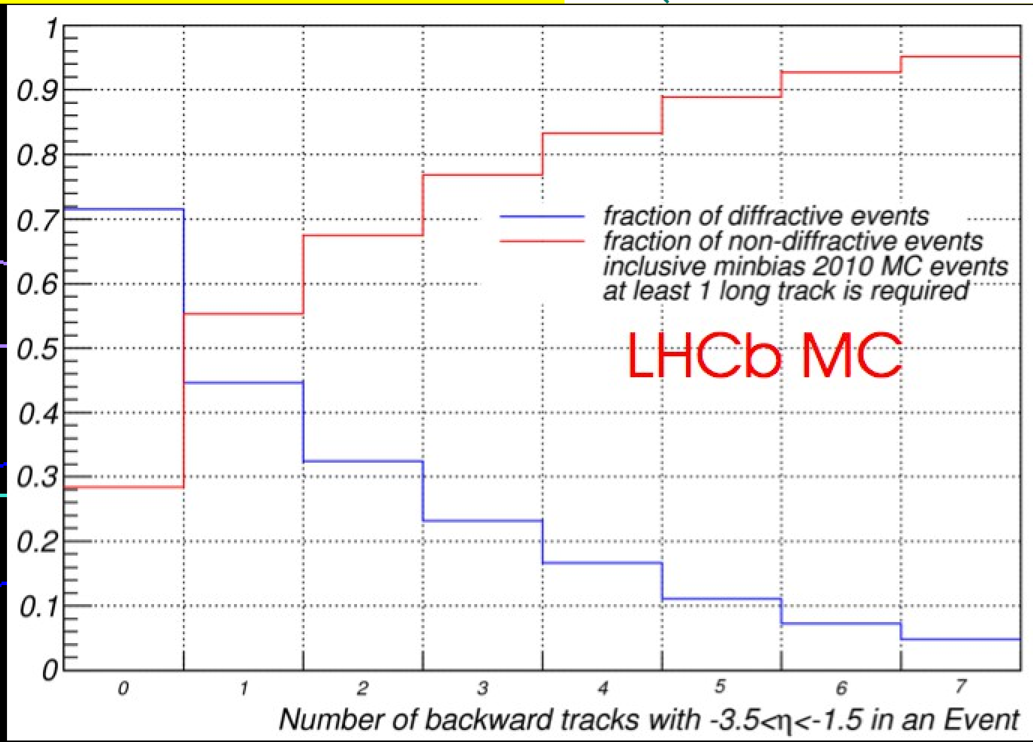


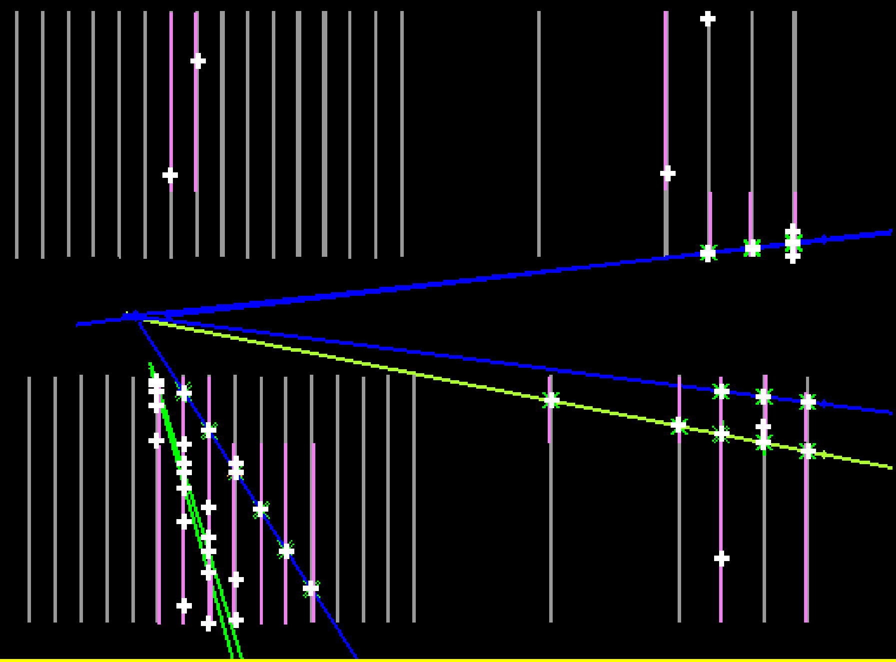
- *quite a few backward tracks reconstructed*
- *no activity in the main detector acceptance*
  → LRG extends over ~3 units of η

14.5. 2010 23:05:53
Run 71816 Event 150752285 bId 2674

Downstream Diffractive Candidate







- *>5 forward tracks reconstructed*
- *no activity in the backward region*
  → LRG extends over ~2 units of η

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Run 71816 Event 150751518 bId 2674

Forward Energy Flow: outline

- *Energy Flow (EF) :*

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

LHCb-CONF-2012-012

average energy created in a particular η interval per inelastic pp interaction and normalized to the η bin size

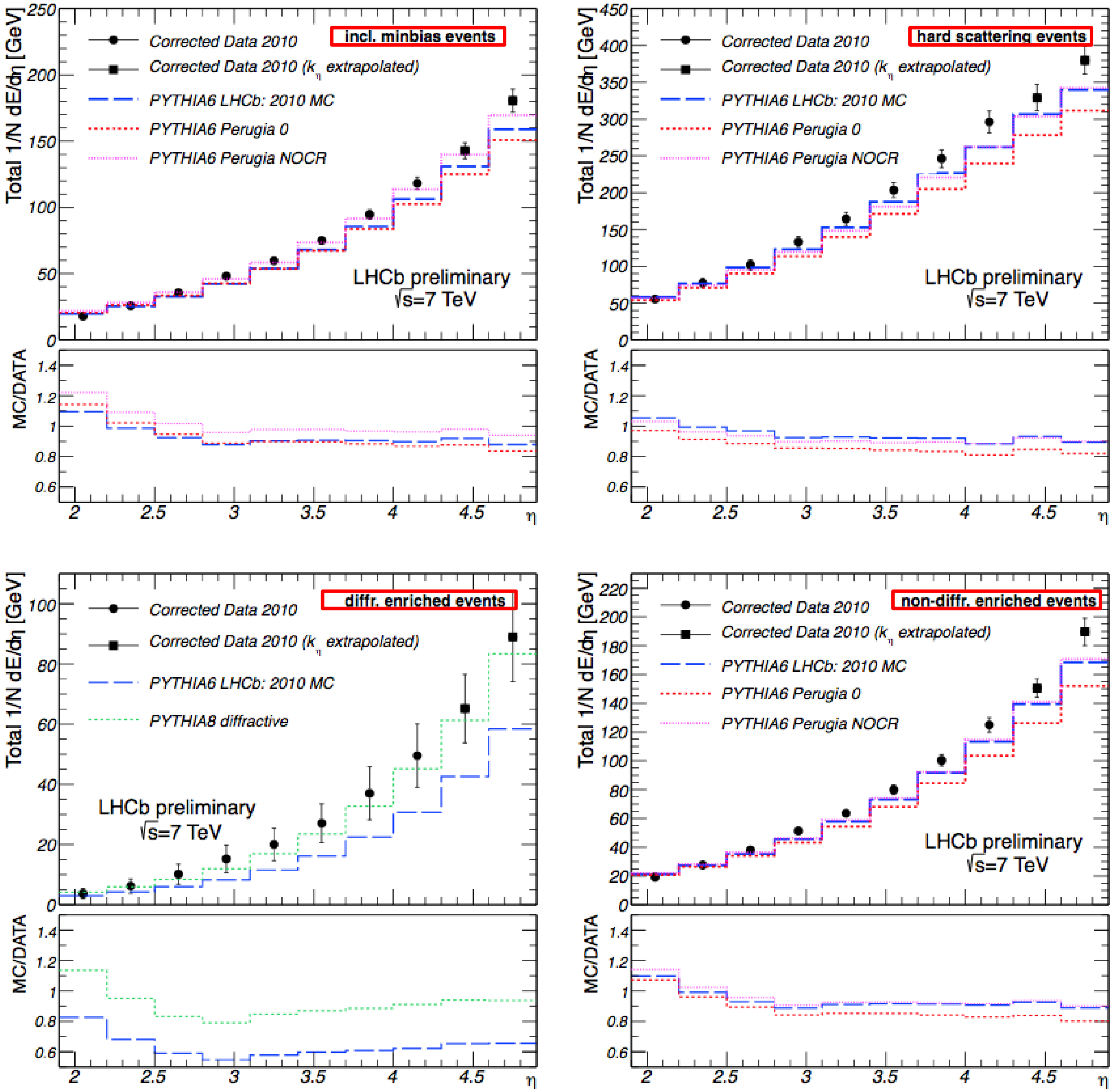
- *EF directly sensitive to the amount of parton radiation and multi-parton interactions (MPI) at large η*
  - → *MPI features are still not well known: strongly needed for a precise description of the UE*
  - → *possibility to discriminate between MPI models and determine important parameters*
  - → *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*
- *it has never been measured at a hadron collider in the pre-LHC era*

- *EF is measured in 1.9<η<4.9 with low pile-up pp MB data at 7 TeV for the following event classes:*
  - → *inclusive MB: at least 1 long track in 1.9<η<4.9 with p > 2 GeV/c*
  - → *hard scattering: at least 1 long track in 1.9<η<4.9 with p_T > 3 GeV/c*
  - → *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*
- *Data corrected for detector effects & compared to the generator level predictions (PYTHIA-based and cosmic-ray models)*
- *Systematic effects: tracking related factors, model dependency, pile-up contamination*

Total EF vs PYTHIA tunes

- *EF increases with the momentum transfer in an underlying pp process:*
  $EF_{hard} > EF_{non\text{-}diffr} > EF_{incl} > EF_{diffr}$
- *PYTHIA-based models underestimate EF at large η and overestimate it at low η in case of all event classes*
- *PYTHIA LHCb tune and Perugia NOCR predictions for the selected inclusive and non-diffractive enriched events are similar*
- *Perugia 0 significantly underestimates EF at large η in case of all event classes*
- *PYTHIA8 describes the diffractive enriched EF much better than PYTHIA6*

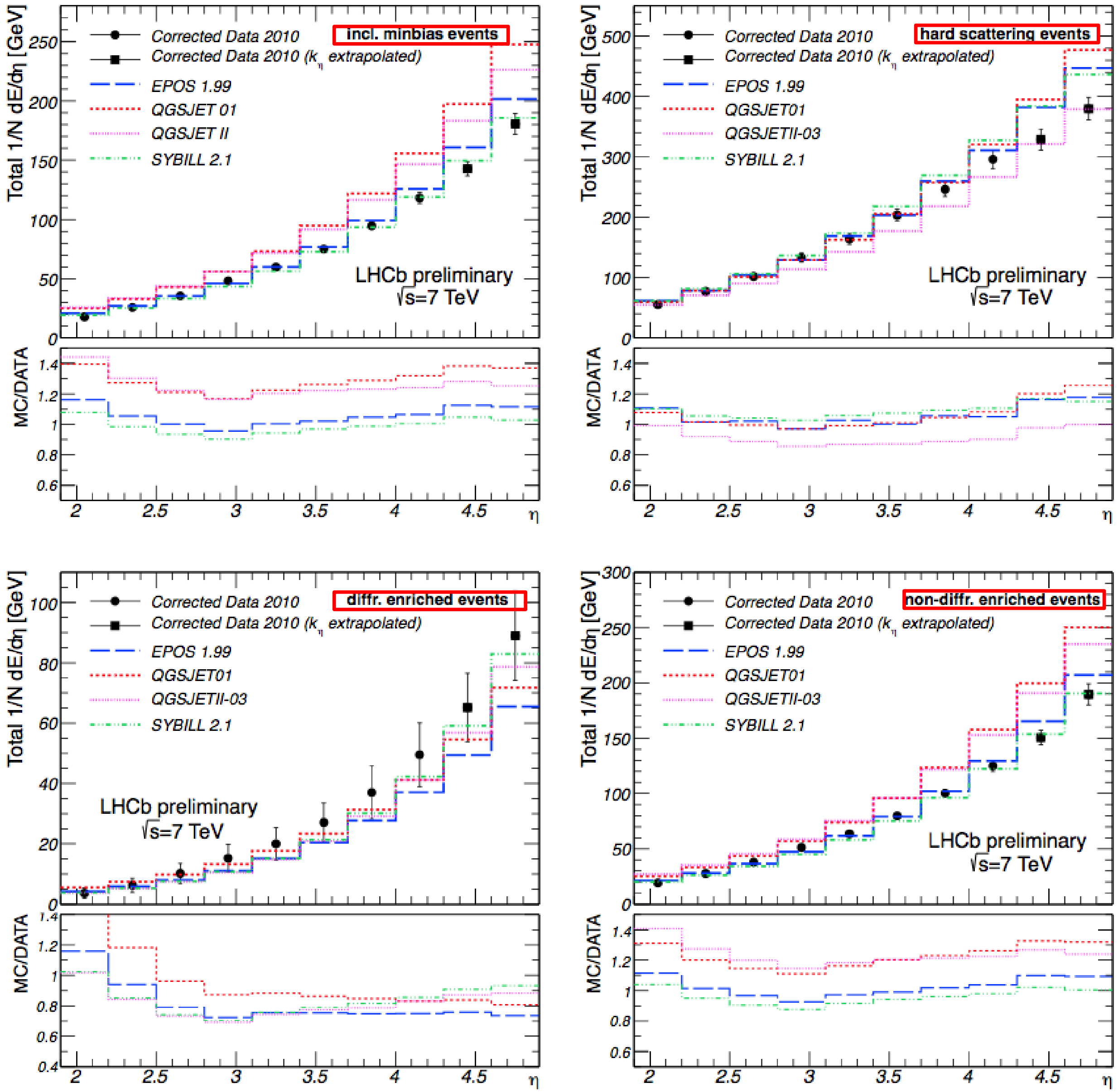
LHCb-CONF-2012-012



Total EF vs cosmic-ray models

- *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*
- *Good agreement between the data and QGSJETII prediction for the hard scattering EF at large η*
- *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*

LHCb-CONF-2012-012



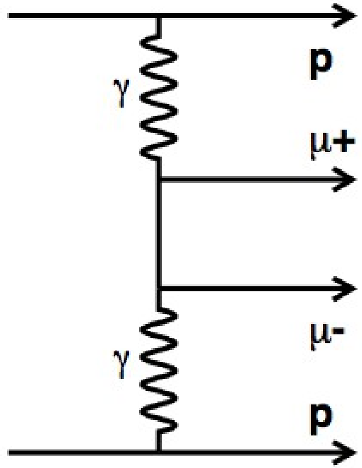
Exclusive Dimuon Production (1)

- *Elastic pp → p ($\mu\mu$) p process: protons remain intact*
- *Experimental signature: completely empty event except for two muons (and possibly γ)*

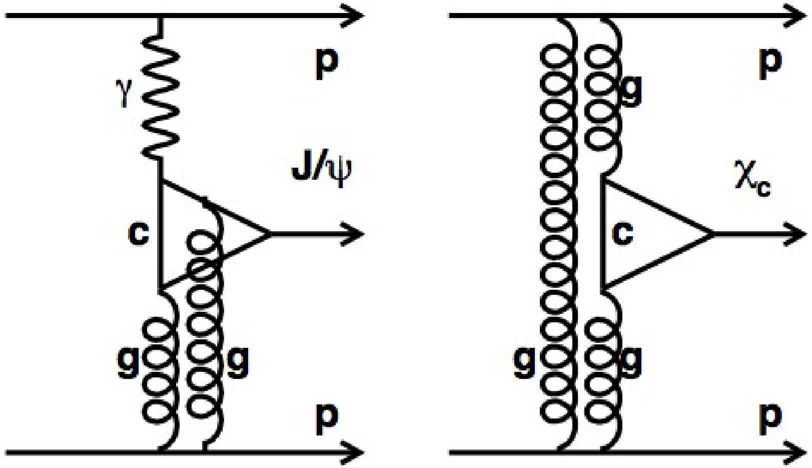
→ protons are undetected as they escape through the beam pipe

- *Selection: no backward tracks in an event (LRG over 2 units), exactly two reconstructed tracks with 2.0<η<4.5 and $p_T(\mu\mu)$< 0.9 GeV*
- *Contamination from non-elastic events, where the other particles travel outside the acceptance*
- *Signal purity ~70%*
- *Analysis performed with 3 pb^{-1} of low pile-up data @ 7TeV*

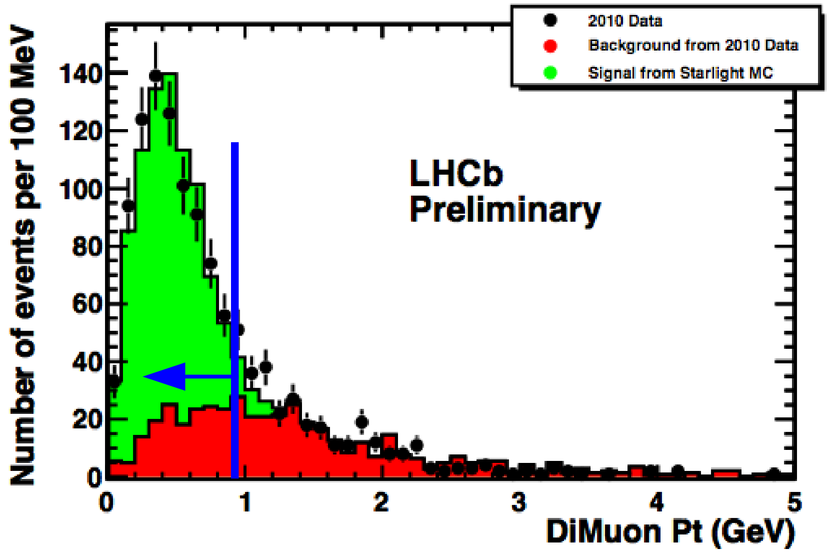
LHCb-CONF-2011-022



Pure QED process: potential for luminosity measurements



Study of Pomeron and Odderon states. Probe of gluon density at low x



Exclusive Dimuon Production (2)

- *Forward track multiplicity for events with LRG over the backward region:*

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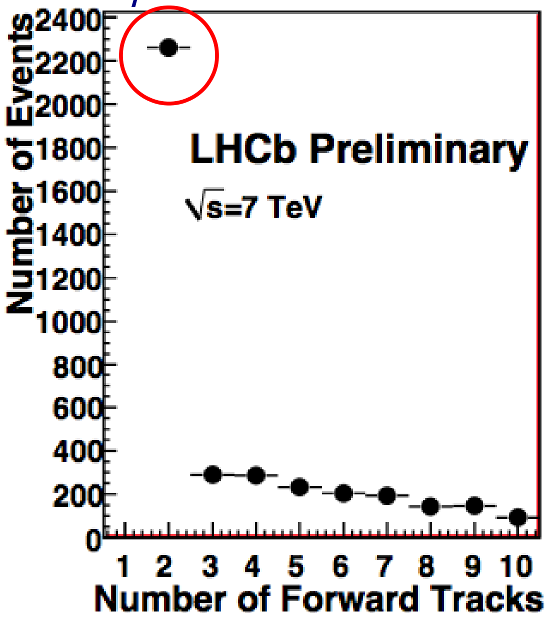
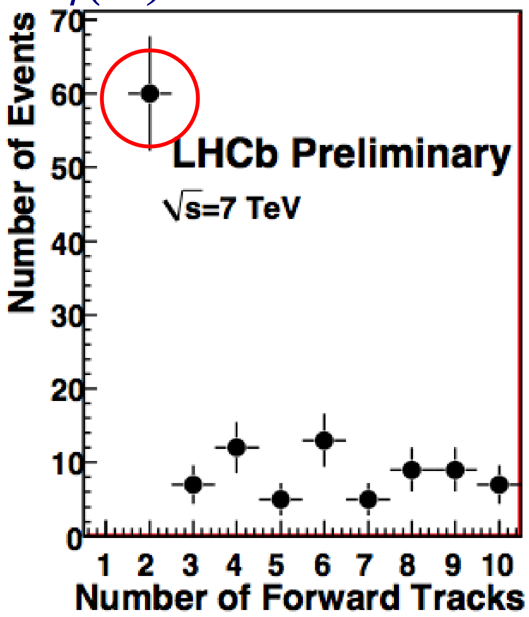
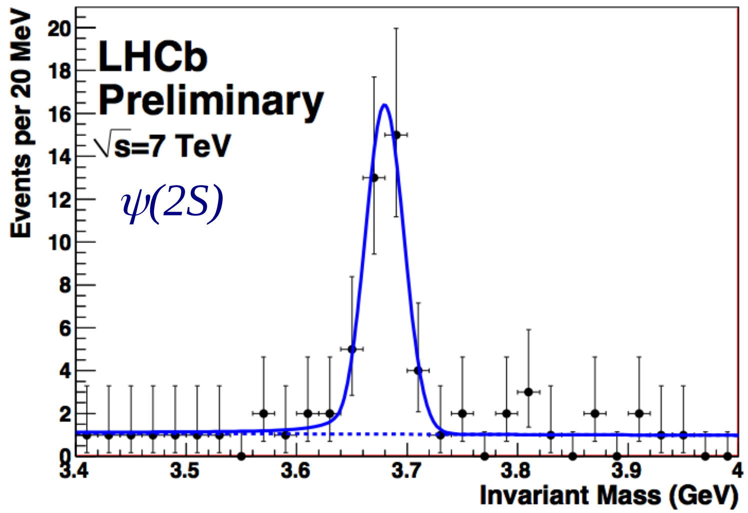
J/ψ exclusive candidates

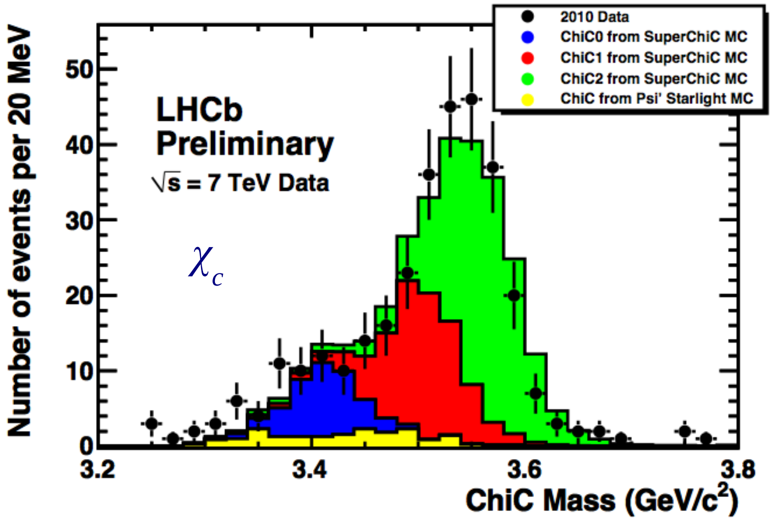


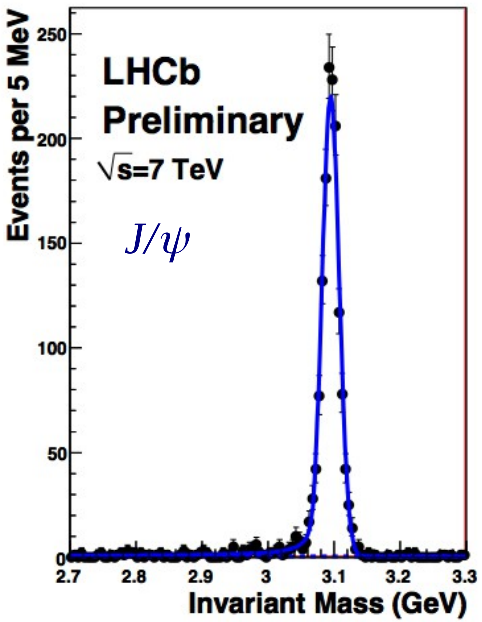
$\psi(2S)$ exclusive candidates





- *χ_c exclusive candidates: J/ψ candidates combined with γ*
- *fractions of χ_{c0}, χ_{c1}, χ_{c2} obtained performing a fit to the data using template shapes provided by MC*





Exclusive Dimuon Production (3)

- *Preliminary results on the cross-sections of different exclusive dimuon processes:*

$$\sigma_{J/\psi\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 474 \pm 12 \pm 51 \pm 92 \text{ pb}$$

$$\sigma_{\psi(2S)\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 12.2 \pm 1.8 \pm 1.3 \pm 2.4 \text{ pb}$$

$$\sigma_{\chi_{c0}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb}$$

$$\sigma_{\chi_{c1}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb}$$

$$\sigma_{\chi_{c2}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb}$$

$$\sigma_{pp\to p\mu^+\mu^-p}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5; m_{\mu+\mu-} > 2.5 \text{ GeV}/\text{c}^2) = 67 \pm 10 \pm 7 \pm 15 \text{ pb}$$

→ *statical+systematical+luminosity uncertainties are listed*

→ *efficiencies are estimated from simulation*

- *all measured cross sections are consistent with theoretical predictions which have large uncertainties*

L. Motyka, G. Watt,, Phys. Rev. D 78, 014023 (2008).

W. Schäfer, A. Szczurek, Phys.Rev. D76:094014,2007. arXiv:0811.2488

SuperCHIC and Starlight generators

LHCb-CONF-2011-022

Summary

- *LHCb is much more than just a beauty experiment :-) allowing in particular to perform electroweak and QCD measurements in an unique, previously unexplored kinematic range.*
- *Electroweak results are in reasonable agreement with theoretical predictions. Good input for PDF constraining.*
- *First diffractive related measurements are performed. Diffractive enriched forward energy flow is well described by the PYTHIA8 generator.*
- *None of the models used are able to describe the forward energy flow measurements for all event classes.*
- *Preliminary results on the exclusive dimuon production are encouraging. Accuracy of the measurements is expected to be significantly improved.*

Stay tuned for further results !

Backup: various Z modes