Measurements with electroweak bosons at LHCb

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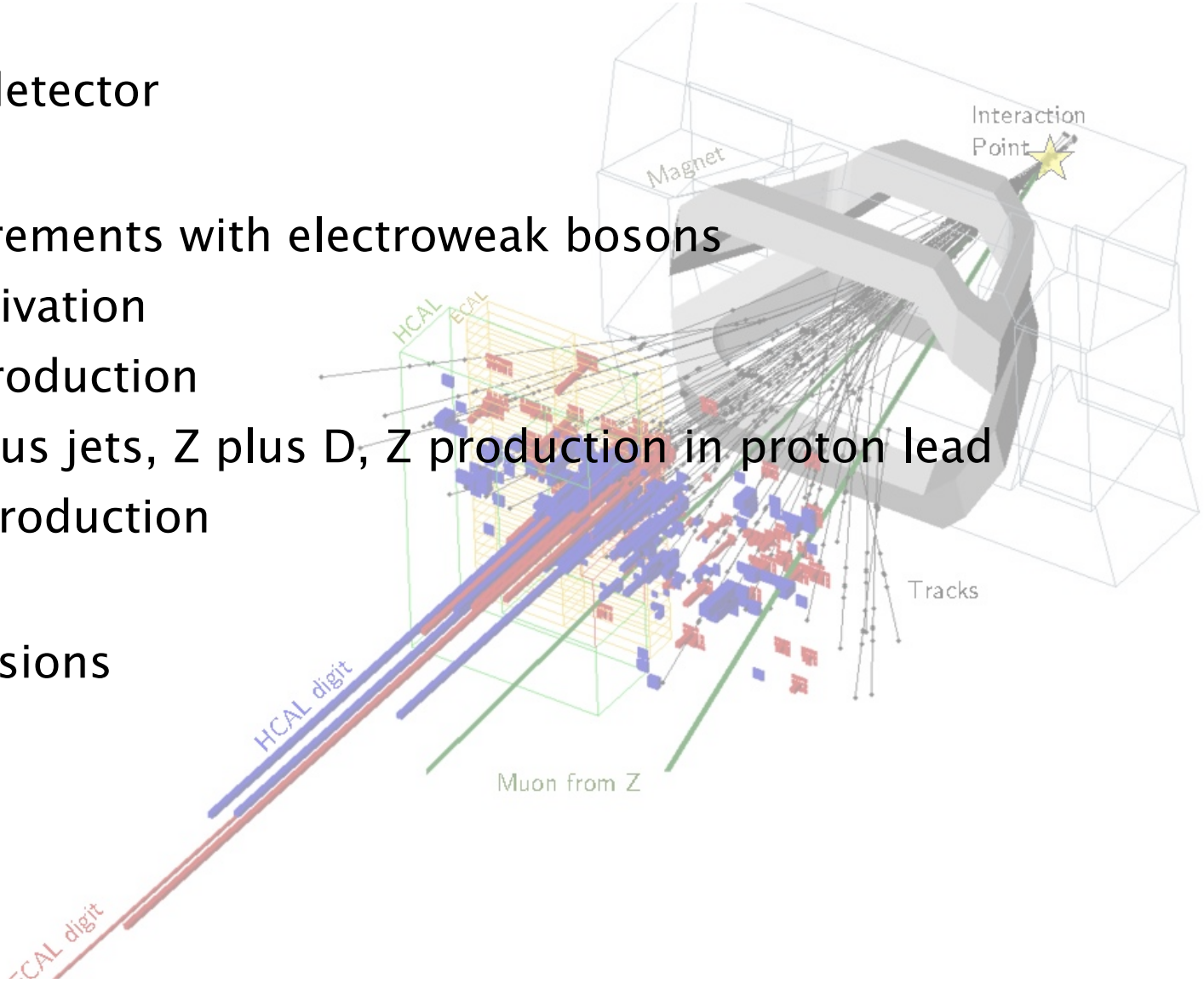
Katharina Müller

on behalf of the LHCb collaboration

University of Zurich[UZH]

Outline

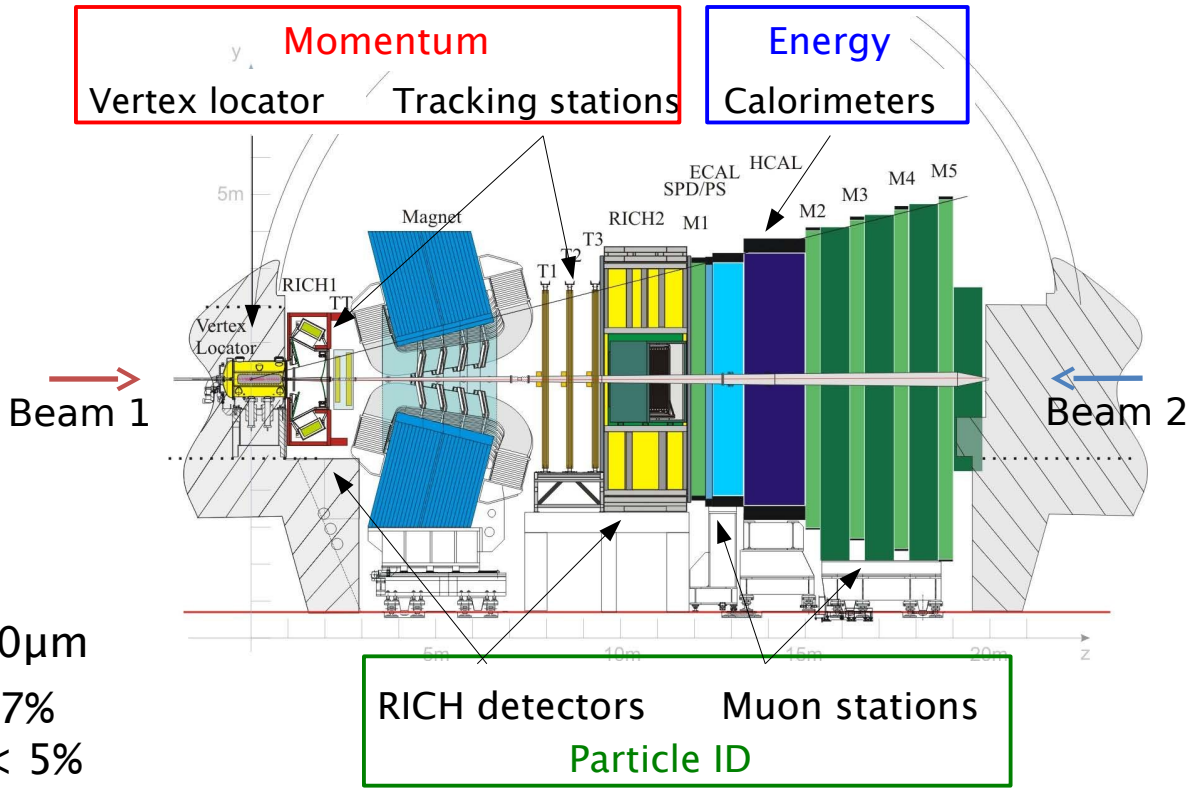
- LHCb detector
- Measurements with electroweak bosons
  - Motivation
  - Z production
  - Z plus jets, Z plus D, Z production in proton lead
  - W production
- Conclusions



LHCb Detector

JINST3 (2008) S08005

Fully instrumented in the forward region ($2 < \eta < 5$)
some detection capability in backward region ($-3.5 < \eta < -1.5$)

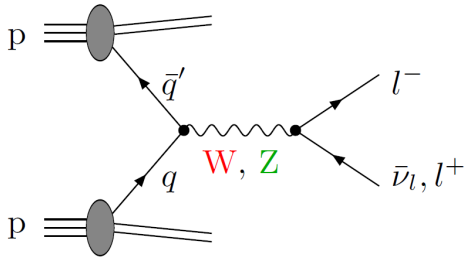


- Tracking: $\sigma_p/p \sim 0.4$–0.6%
- Vertex resolution:
  $\sigma_{xy} \sim 15\mu m$, $\sigma_z \sim 80\mu m$
- Muon ID $\epsilon = 97\%$; mis-id: 0.7%
- Kaon ID $\epsilon = 90\%$; π mis-id $< 5\%$

- Analyses based on
  - 2011 1 fb^{-1} @ 7 TeV: Z plus jet, Z plus D, W production
  - 2013 proton-lead runs 2 nb^{-1} @ 5 TeV: Z in proton lead

Measurements with electroweak bosons

LHCb probes two distinct regions in x–Q^2: $x_{1,2} = (Q/\sqrt{s})\, e^{\pm y}$



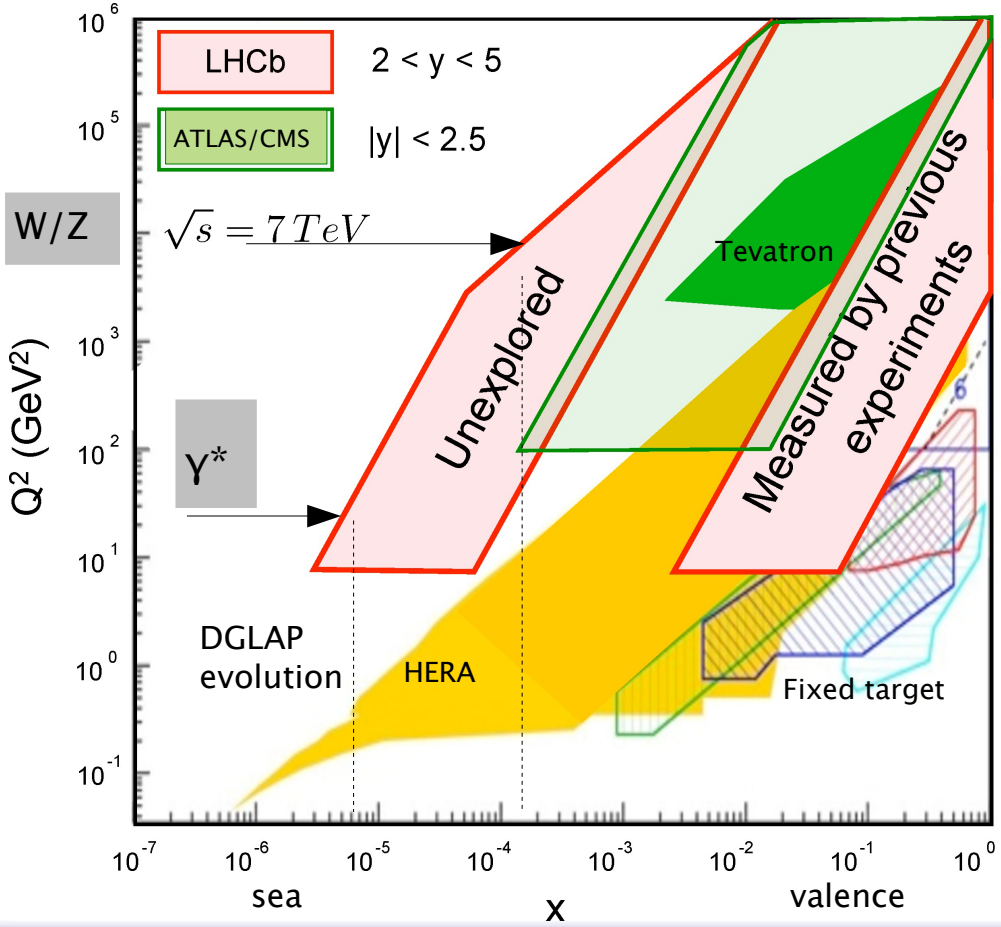
Forward kinematics:

@ first order, collision of a sea and a valence quark

- asymmetry in production rate for W^+ and W^-
- sensitivity to parton distribution functions (PDF)

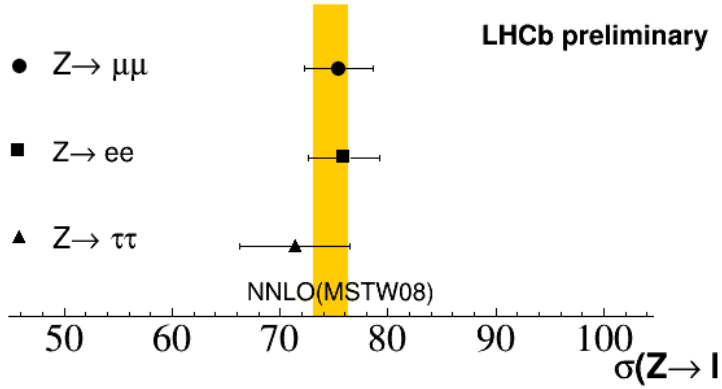
Unique region at low x

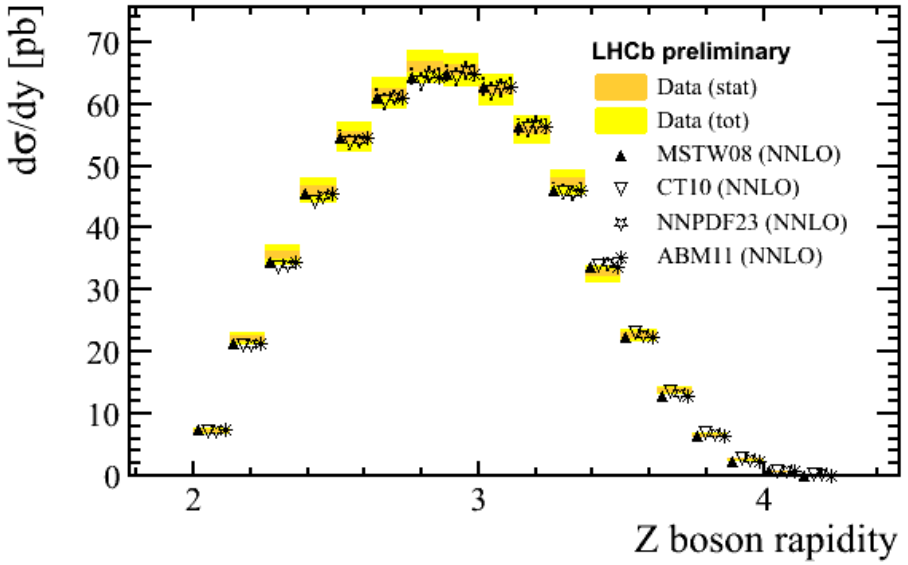
- W, Z production: $x = 1.7 \cdot 10^{-4}$
- complementary to ATLAS/CMS
- input to PDF fits in previously unprobed region



Inclusive Z measurements

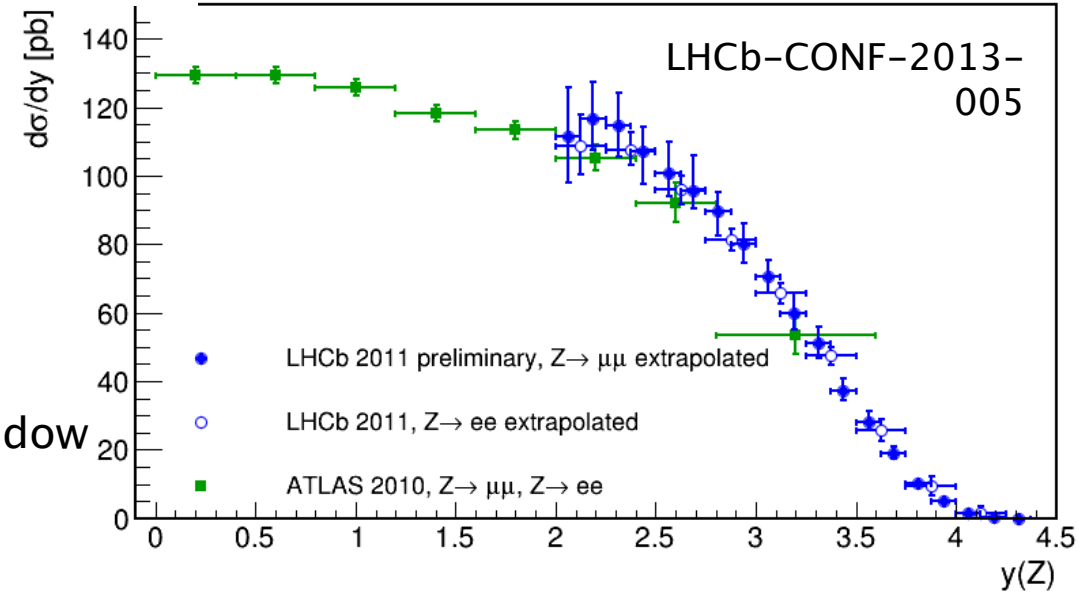
Fiducial volume:
$2<\eta<4.5$, $p_T>20$ GeV
$60<M_{ll}<120$ GeV^2



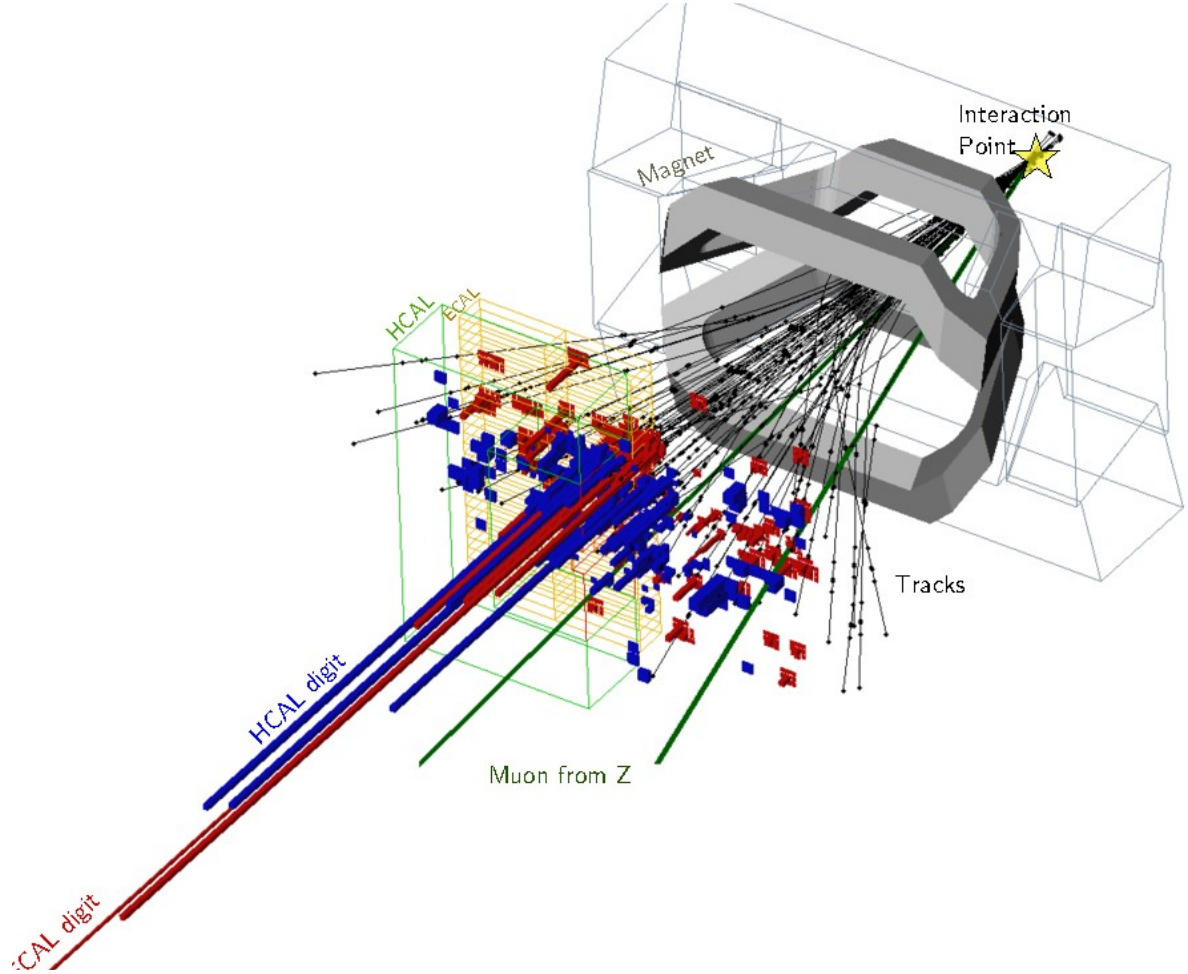


Good agreement
- between different channels
- with NNLO predictions
- with ATLAS in overlap region

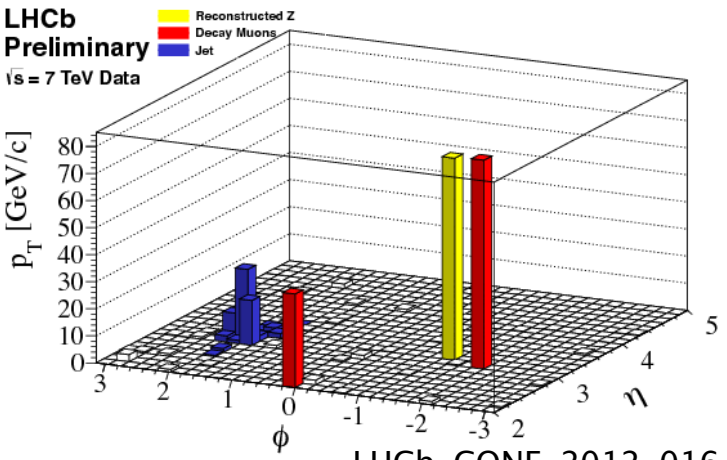
extrapolation to ATLAS:
accounts for acceptance of
the leptons and a different mass window



Z plus jet production



Sensitivity to gluon content of proton
Test of pQCD



LHCb-CONF-2012-016

Z plus jet

Jet reconstruction

- anti-k_T algorithm(R=0.5)
- particle-flow objects:
  charged tracks and neutral clusters

Z plus jet selection

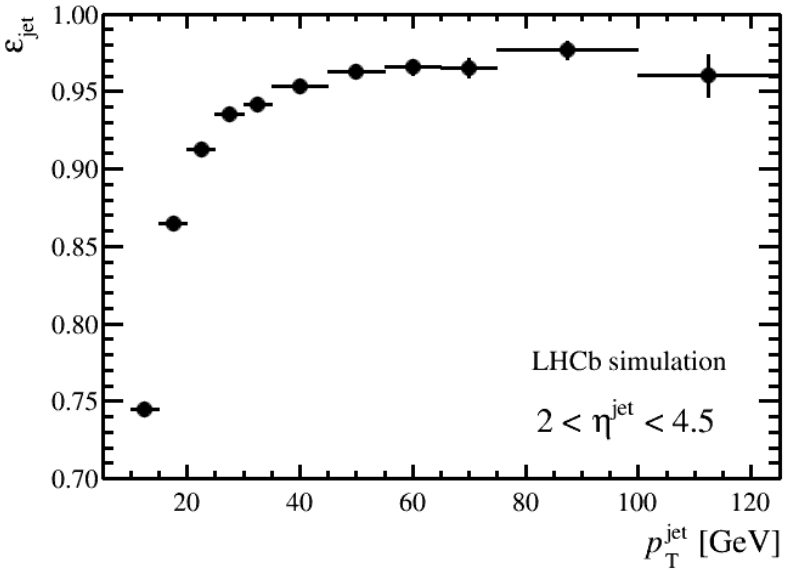
- standard selection for the Z
- jet $2<\eta<4.5$, $p_T>10$ (20 GeV)
- jet-muon separation: $\Delta r(\text{jet},\mu)>0.4$

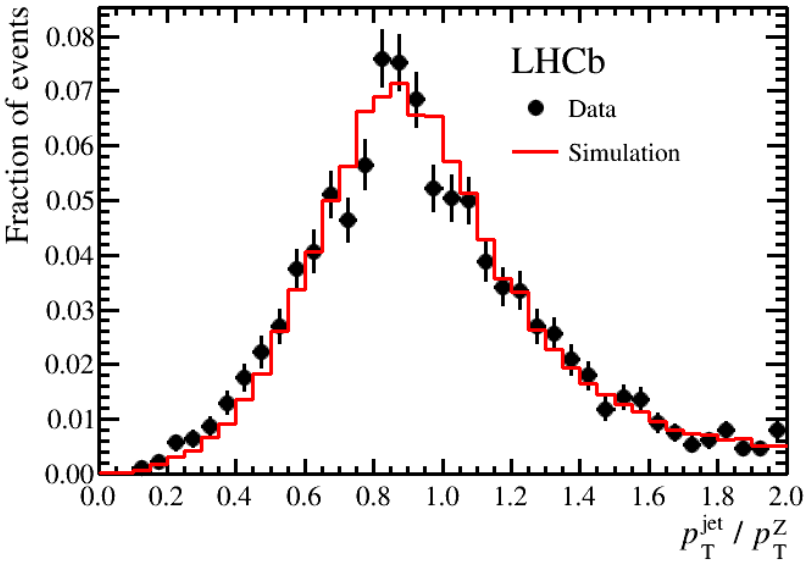
Jet energy correction

- from simulation: 0.9-1.1
- validated in data: Z plus 1 jet events
- simulation describes data well

Dominant systematic uncertainties

- jet energy scale and resolution
- jet reconstruction efficiency



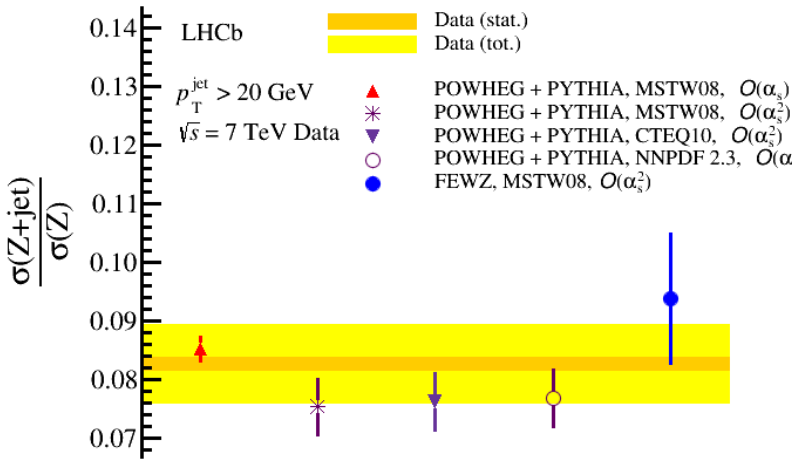


Z plus jet production

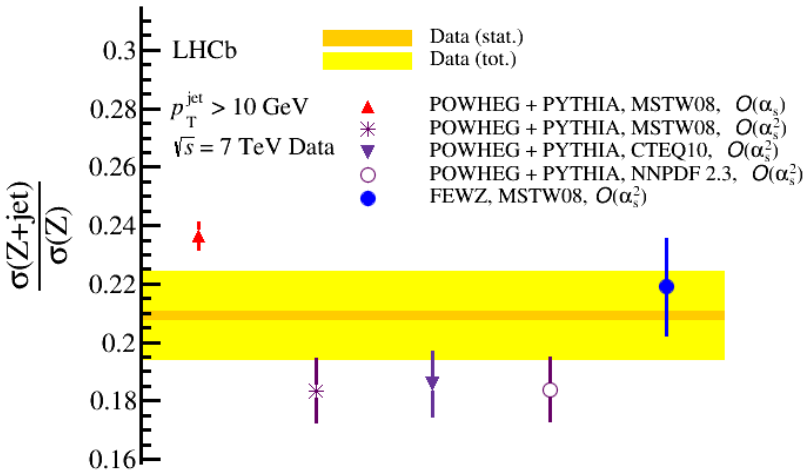
$p_{T(jet)}$>10 GeV: σ = 16.0 ± 0.2(stat) ± 1.2(syst) ± 0.6(lumi) pb

$p_{T(jet)}$>20 GeV: σ = 6.3 ± 0.1(stat) ± 0.5(syst) ± 0.2(lumi) pb

$p_{T(jet)}$>20 GeV



$p_{T(jet)}$>10 GeV



Predictions:

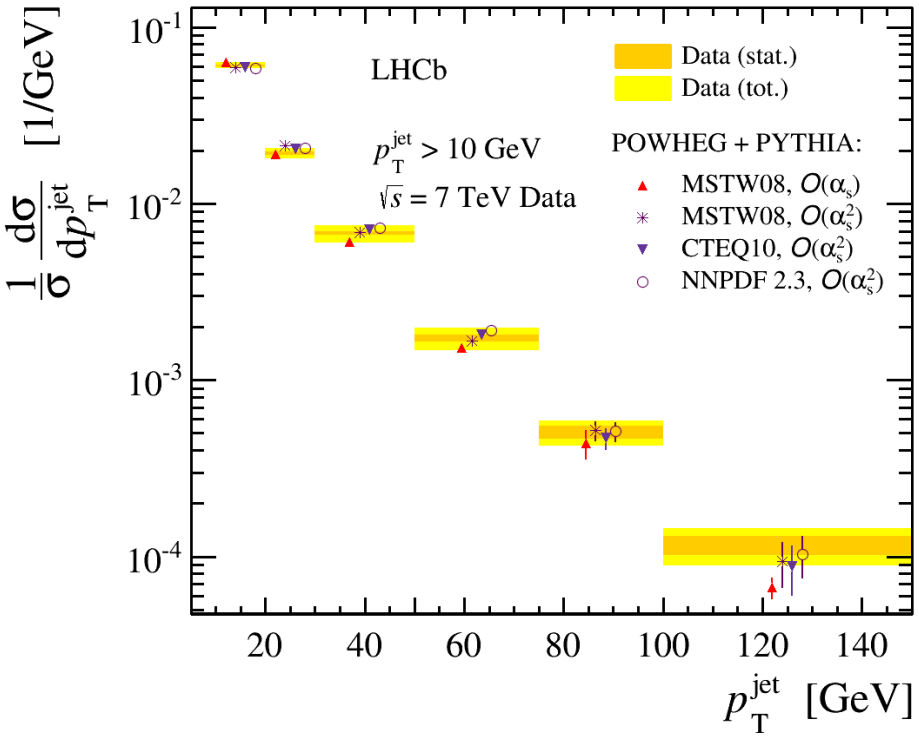
POWHEG+PYTHIA at $O(\alpha_s)$ and $O(\alpha_s^2)$ and different PDF sets

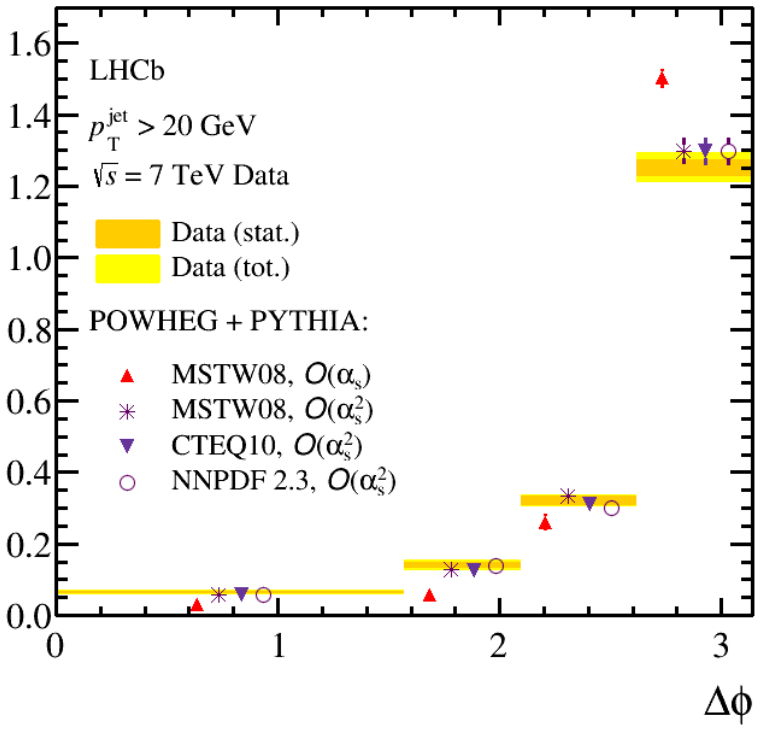
FEWZ $O(\alpha_s^2)$ not corrected for hadronisation and underlying event

FEWZ: Y. Li and F. Petriello, Phys. Rev. D86 (2012) 094034,
POWHEG: JHEP 01 (2011) 095
PYTHIA: JHEP05 (2006) 026

Z plus jet: differential cross sections

JHEP01 (2014) 033





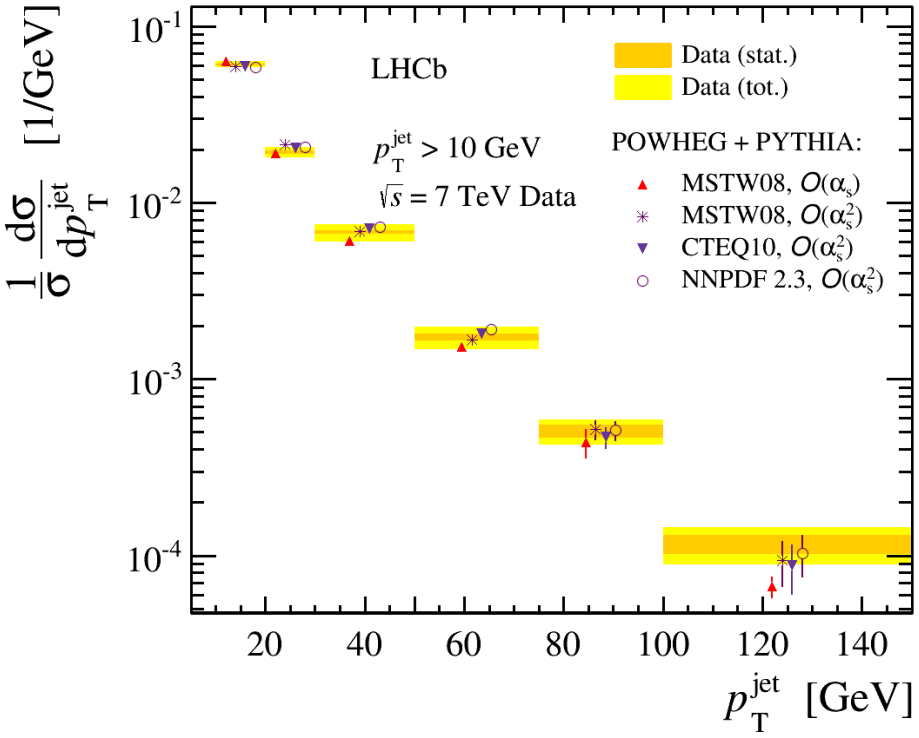
Results not corrected for FSR

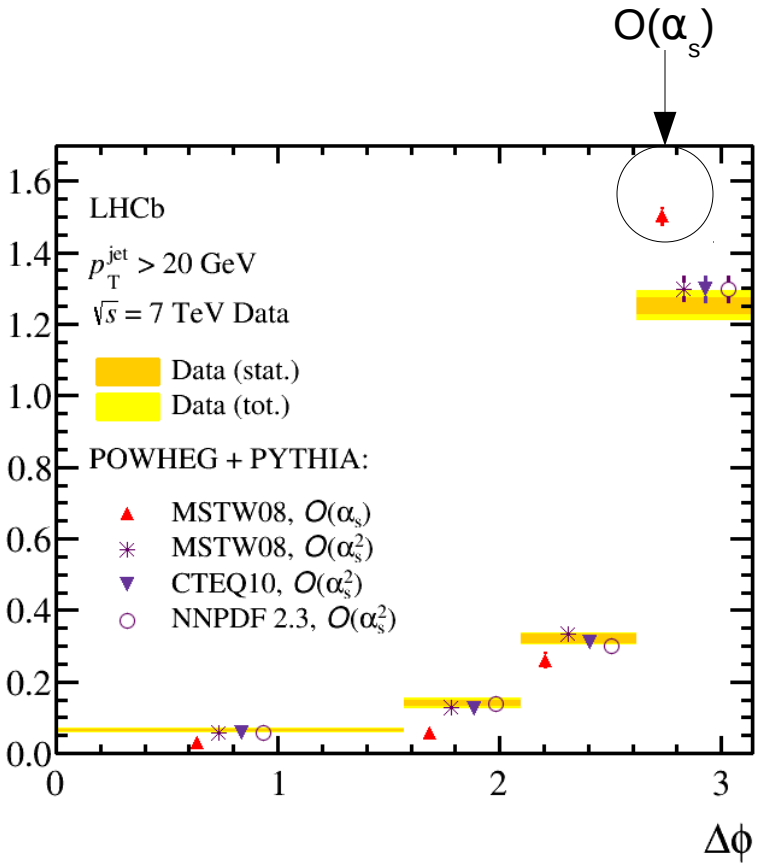
Shapes well described by NLO predictions

LO fails to describe Δφ(Z,jet)

Z plus jet: differential cross sections

JHEP01 (2014) 033





Results not corrected for FSR

Shapes well described by NLO predictions

LO fails to describe Δφ(Z,jet)

Z plus D

Yields information on charm PDF and charm production mechanisms
Contribution from single-(SPS) and double-parton scattering (DPS)

Selection

standard Z selection
$D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+\pi^+$
$2 < p_T^D < 12$ GeV, $2 < \eta^D < 4$

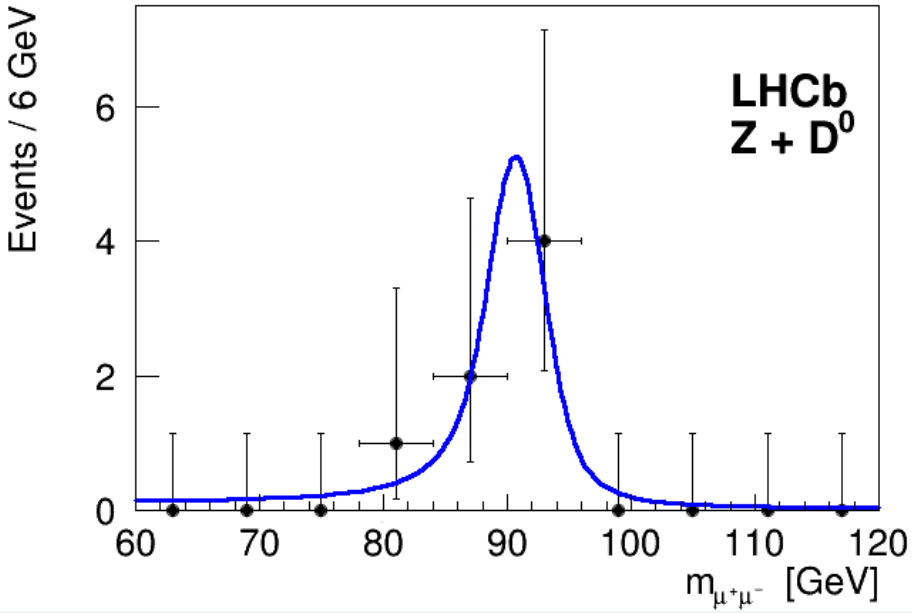
Z and D from same vertex

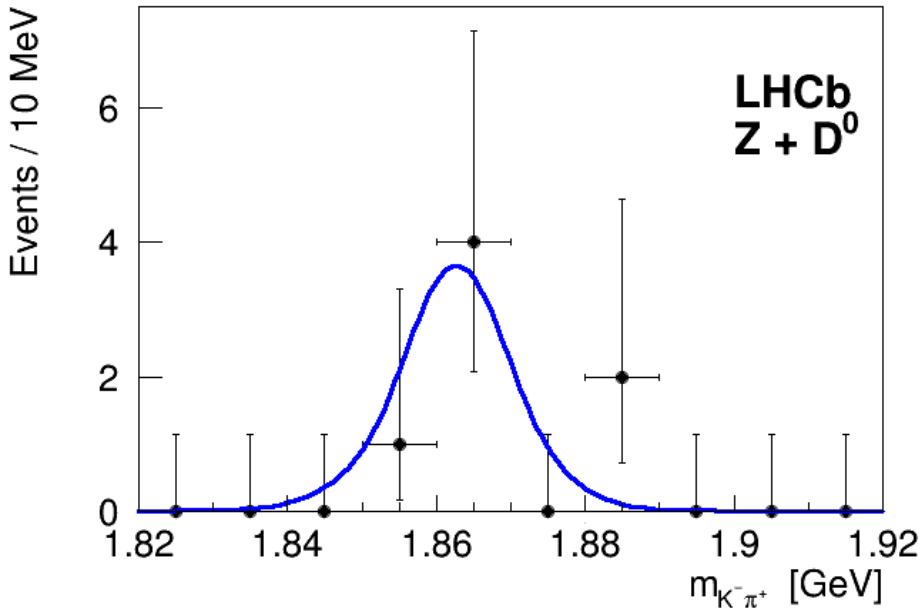
Background: purity>95%

charmed hadrons from B-decays (dominant)
real Z and D from different vertices
combinatorial background

7 Z plus D^0 and 4 Z plus D^+ candidates

no $\Lambda_c^+ \to pK\pi$, $D_s^+ \to \Phi\pi^+$





Z plus D: Results

$\sigma(Z\rightarrow\mu\mu,D^0) = 2.50 \pm 1.12(stat) \pm 0.22(syst)$ pb

$\sigma(Z\rightarrow\mu\mu,D^+) = 0.44 \pm 0.23(stat) \pm 0.03(syst)$ pb

Predictions

Single parton scattering (SPS) from MCFM

Double parton scattering (DPS):

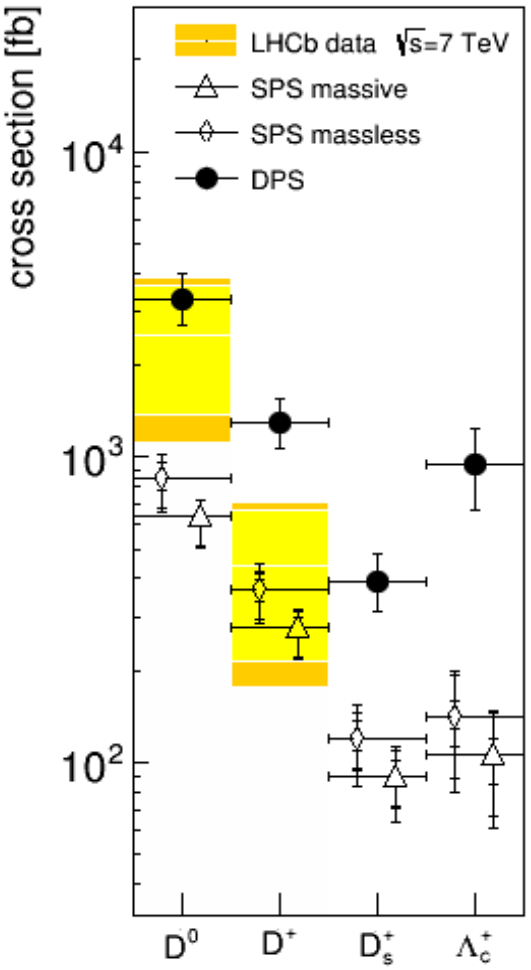
$$\sigma(DPS)=(\sigma(Z\rightarrow\mu\mu)\ \sigma(D))/\sigma_{eff}$$

$$\sigma_{eff} = 14.5 \pm 1.7\ ^{+1.7}_{-2.5}\ \text{mb}\quad (CDF)$$

Sum of SPS and DPS expected to describe signal

- consistent for Z plus D^0
- Z plus D^+ below expectation

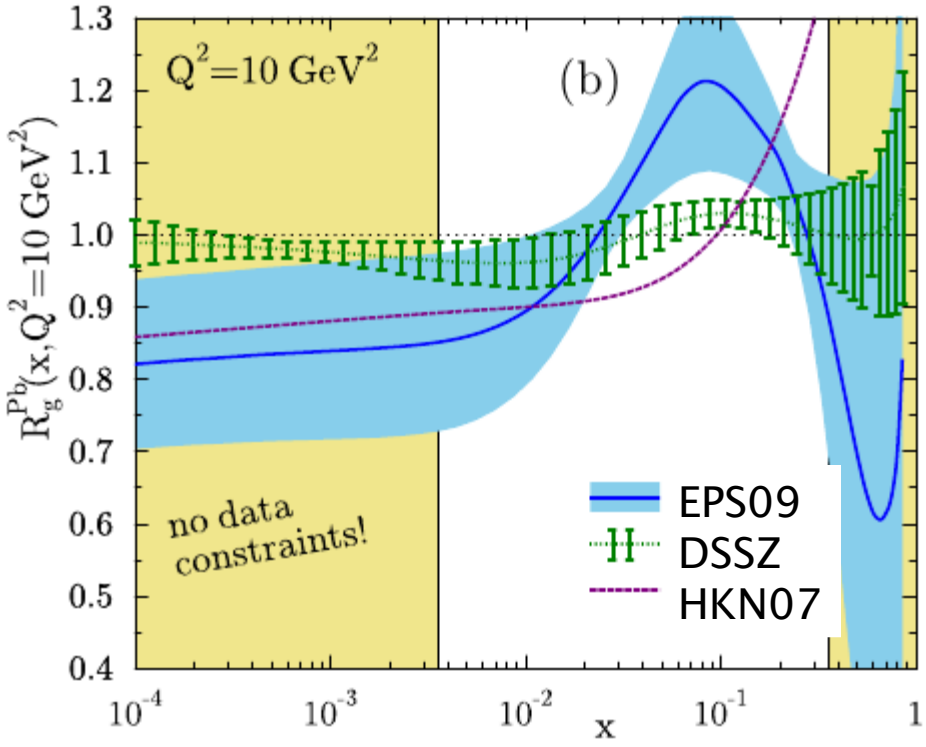
→ differential measurements with high statistics will allow to disentangle SPS and DPS contributions

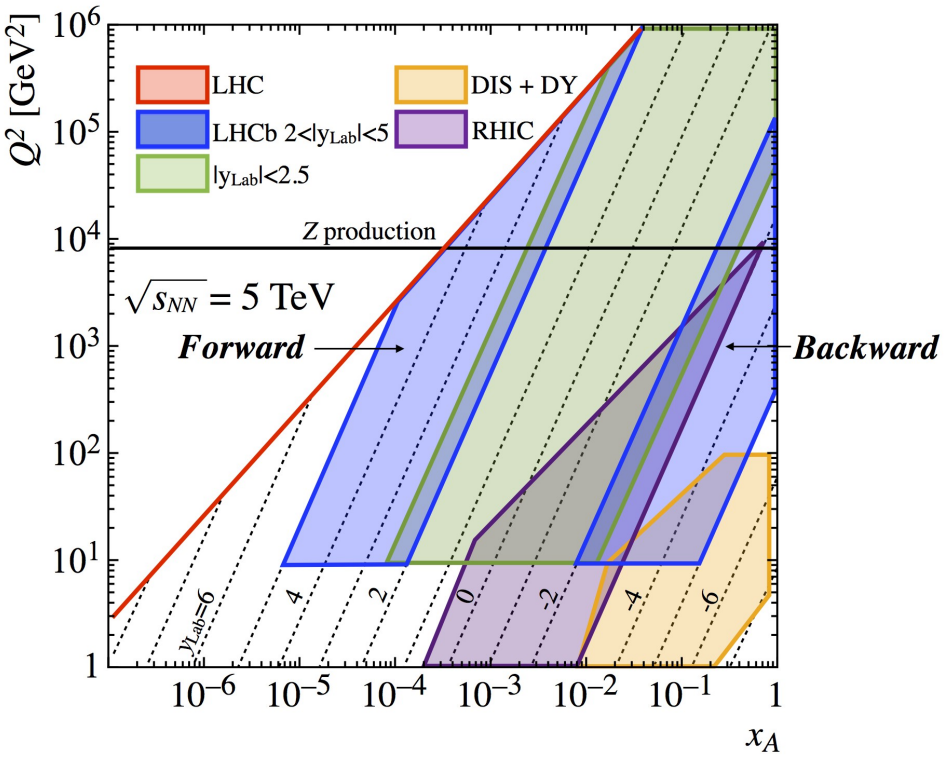


MCFM- Monte Carlo for Femtobarn processes: J. M. Campbell and R. K. Ellis, Nucl. Phys. Proc. Suppl. 205-206 (2010) 10, arXiv:1007.3492.

Z production in pA

Ratio of nuclear PDF (gluon) for Pb to bare proton PDF [arXiv:1401.2345]





Nuclear PDF (nPDF) poorly constrained at high and low x_A, where measurements at LHCb have a good sensitivity.

x_A:momentum fraction of a parton inside the nucleon

Forward: proton beam in LHCb direction, backward: lead beam in LHCb direction

EPS09: JHEP 04 (2009) 065, DSSZ : Phys. Rev. D 85 (2012),HKN07: Phys. Rev. C 76 (2007) 065207

Z production in proton-lead

arXiv:1406.2885, accepted by JHEP

Forward: pA collisions

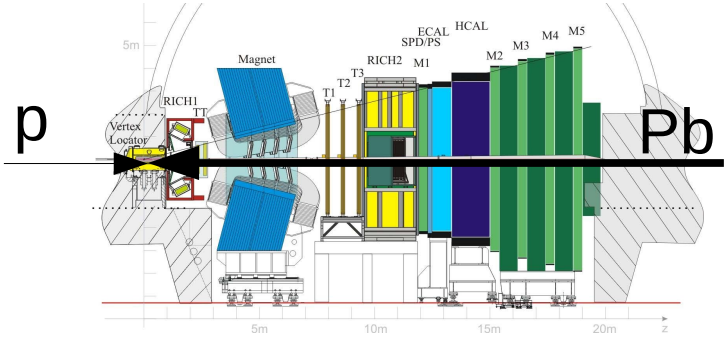
Proton beam: $E_p = 4$ TeV

$^{208}_{82}$Pb beam: $E_N = Z\,E_p \approx 1.58$ TeV

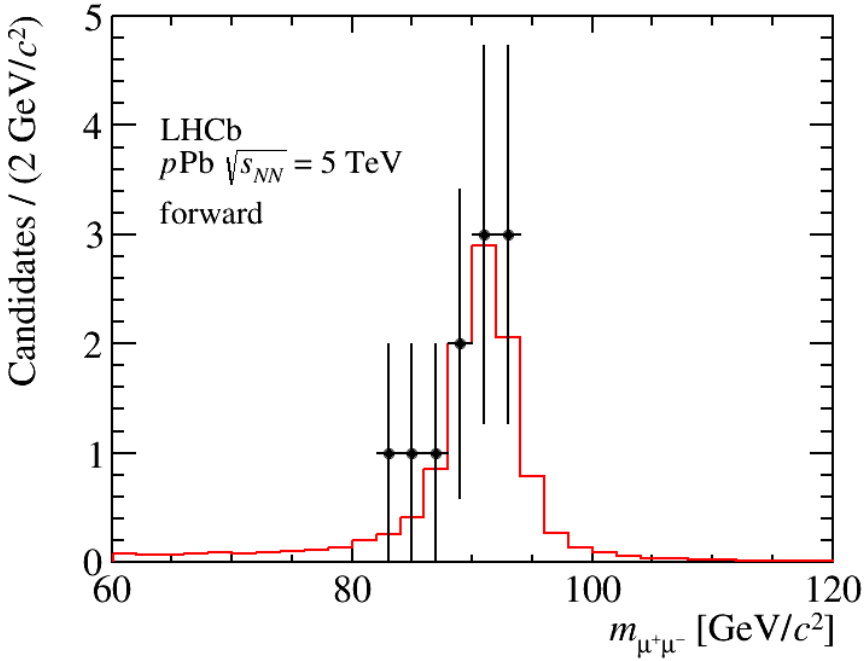
cms energy: $\sqrt{s}_{pN} \approx 5.02$ TeV

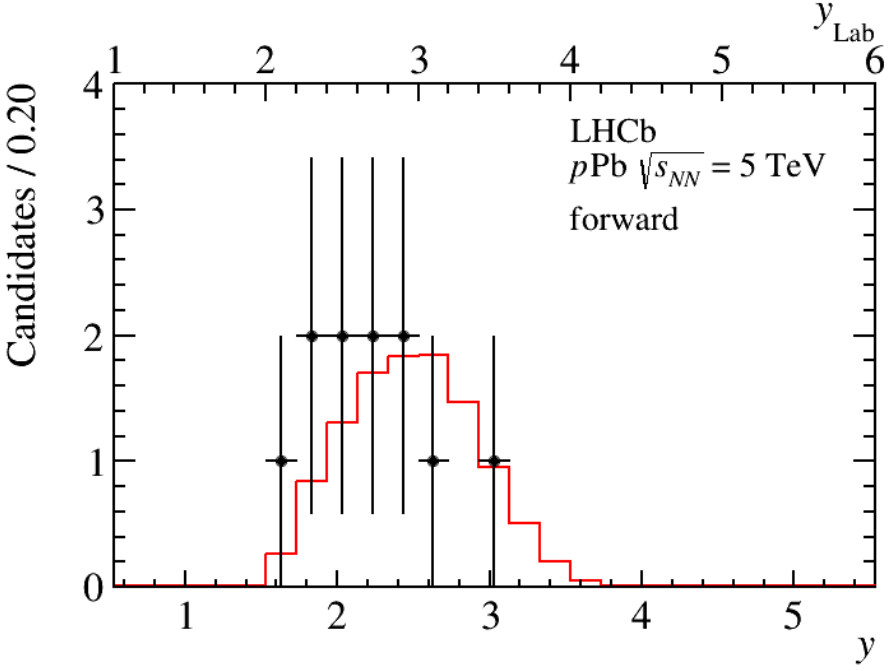
Shift in rapidity: $\Delta y = -1/2 \ln Z/A \approx 0.47$

Luminosity: 1.099 ± 0.021 nb^{-1}



11 candidates





Z production in proton-lead

arXiv:1406.2885, accepted by JHEP

Backward: Ap collisions

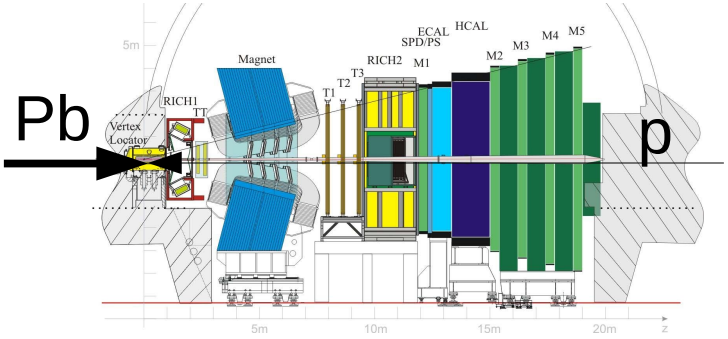
Proton beam: $E_p = 4$ TeV

$^{208}_{82}$Pb beam: $E_N = Z\,E_p \approx 1.58$ TeV

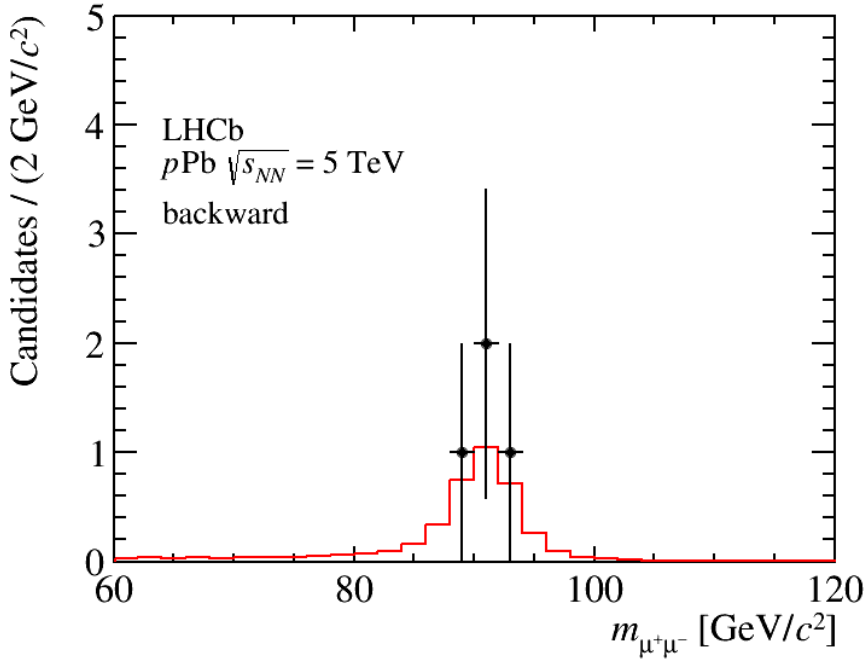
cms energy: $\sqrt{s}_{pN} \approx 5.02$ TeV

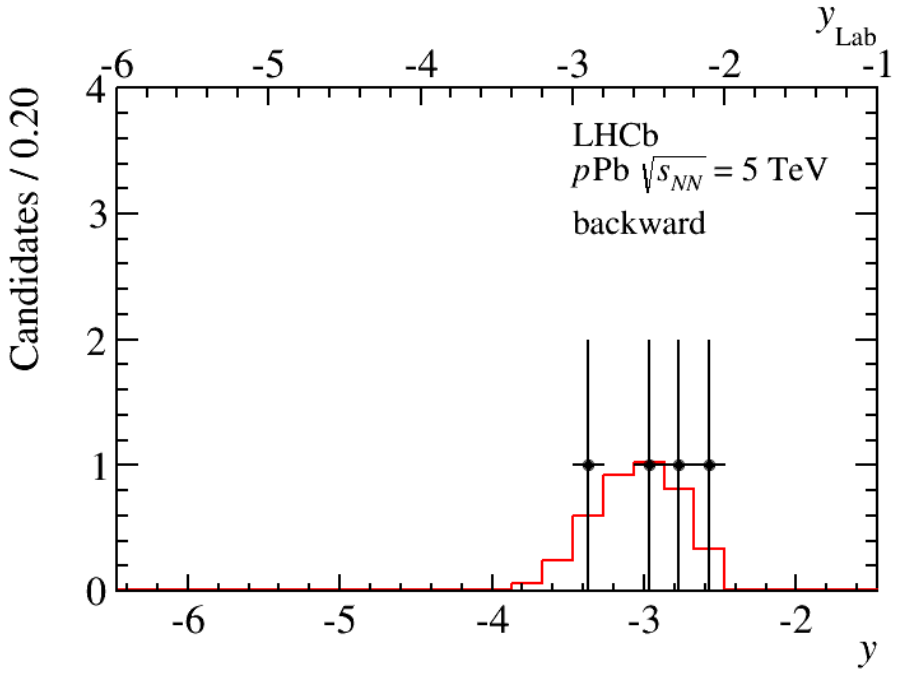
Shift in rapidity: $\Delta y = -1/2 \ln Z/A \approx 0.47$

Luminosity: 0.521 ± 0.011 nb^{-1}



4 candidates





Z production in proton-lead

arXiv:1406.2885, accepted by JHEP

Efficiencies, purity from data (purity >0.995)
Cross sections:

forward:

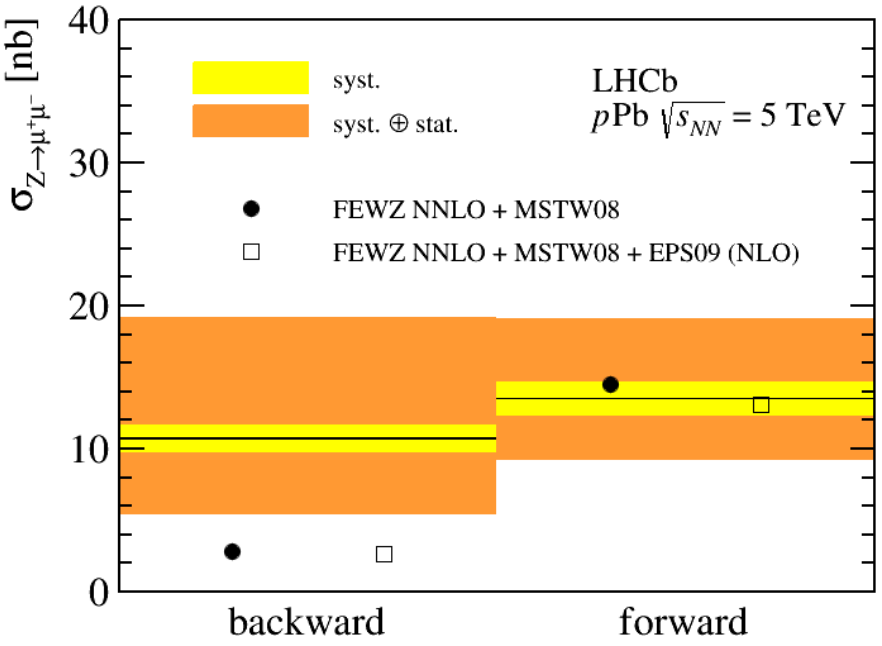
$\sigma_{Z(\to\mu+\,\mu-)} = 13.5^{+5.4}_{-4.0}$ (stat.) ± 1.2(syst.) nb

backward:

$\sigma_{Z(\to\mu+\mu-)} = 10.7^{+8.4}_{-5.1}$ (stat.) ± 1.0(syst.) nb

Theoretical predictions:
NNLO calculations (FEWZ)
nuclear modification: EPS09(NLO)

→ future higher statistics measurements will provide important information on nuclear PDFs

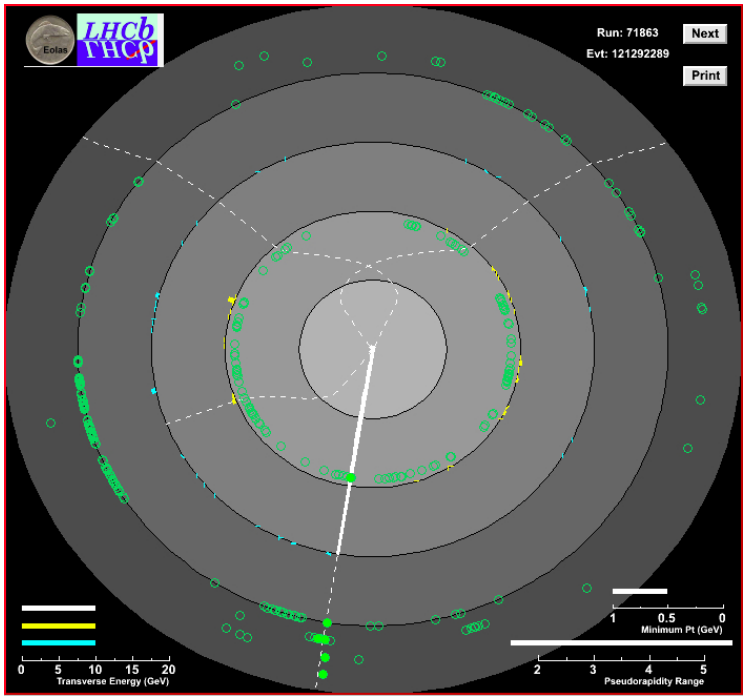


Fiducial volume
muons: p_T>20 GeV, 2<η<4.5
mass: 60<M(μμ)<120 GeV^2

FEWZ: Y. Li and F. Petriello, Phys. Rev. D86 (2012) 094034, arXiv:1208.5967.

EPS09: K. Eskola, H. Paukkunen, and C. Salgado, JHEP 04 (2009) 065, arXiv:0902.4154.

W production in pp @ 7 TeV



W selection: one (isolated) muon

Muon: one muon
$20 < p_T < 70$ GeV/c, $2.0 < \eta_\mu < 4.5$

Isolation $E_T^{cone} < 2$ GeV
$p_T^{cone} < 2$ GeV/c

Cuts against background:

- from semi-leptonic decays of heavy flavour
  Impact parameter < 40 μm
- γ*/Z: No other muon with $p_T > 2$GeV
- K/π punch through
  E(Calorimeter)/p<0.04

Main background:
kaon, pion decay in flight
γ*/Z→μμ, one muon in acceptance

W production

arXiv 1408.4354

Purity from fit to p_T distribution

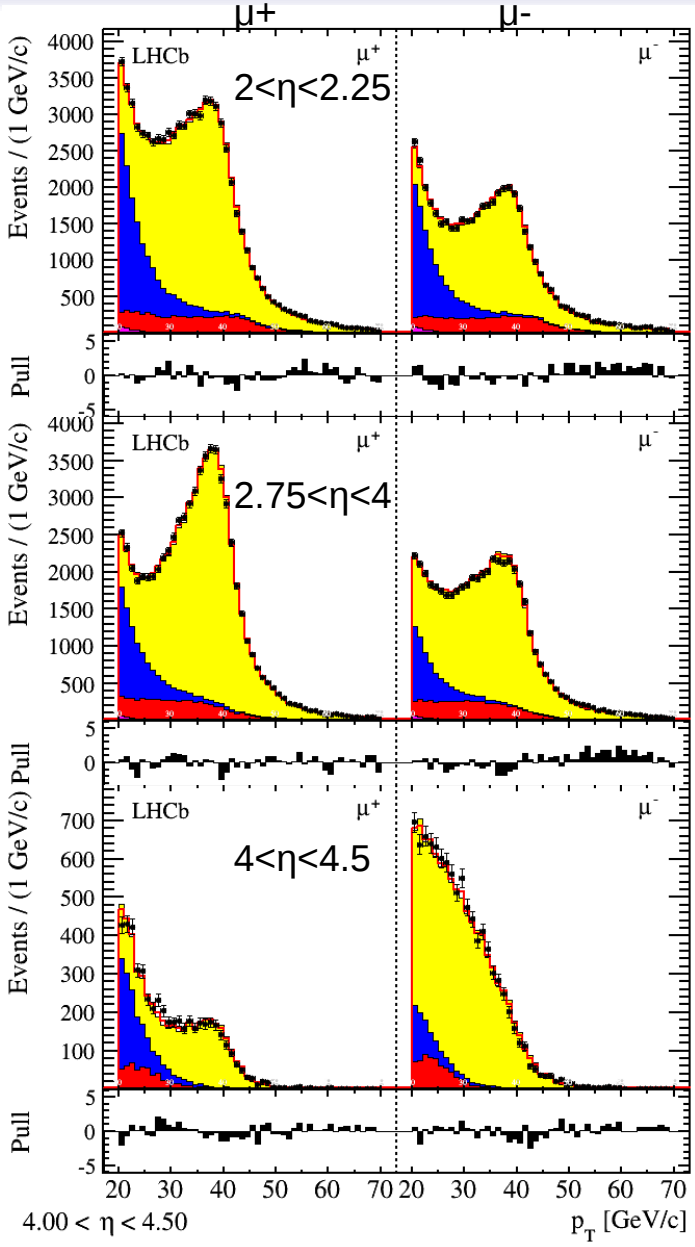
simultaneously in 8 η bins and both charges

	Shape	Norm.
W →μν	simulation	fit
K/π decay in flight	data	fit
γ*/Z→μμ	simulation	fixed
W→τν , Z→ττ	simulation	fixed
Heavy Flavour	data	fixed

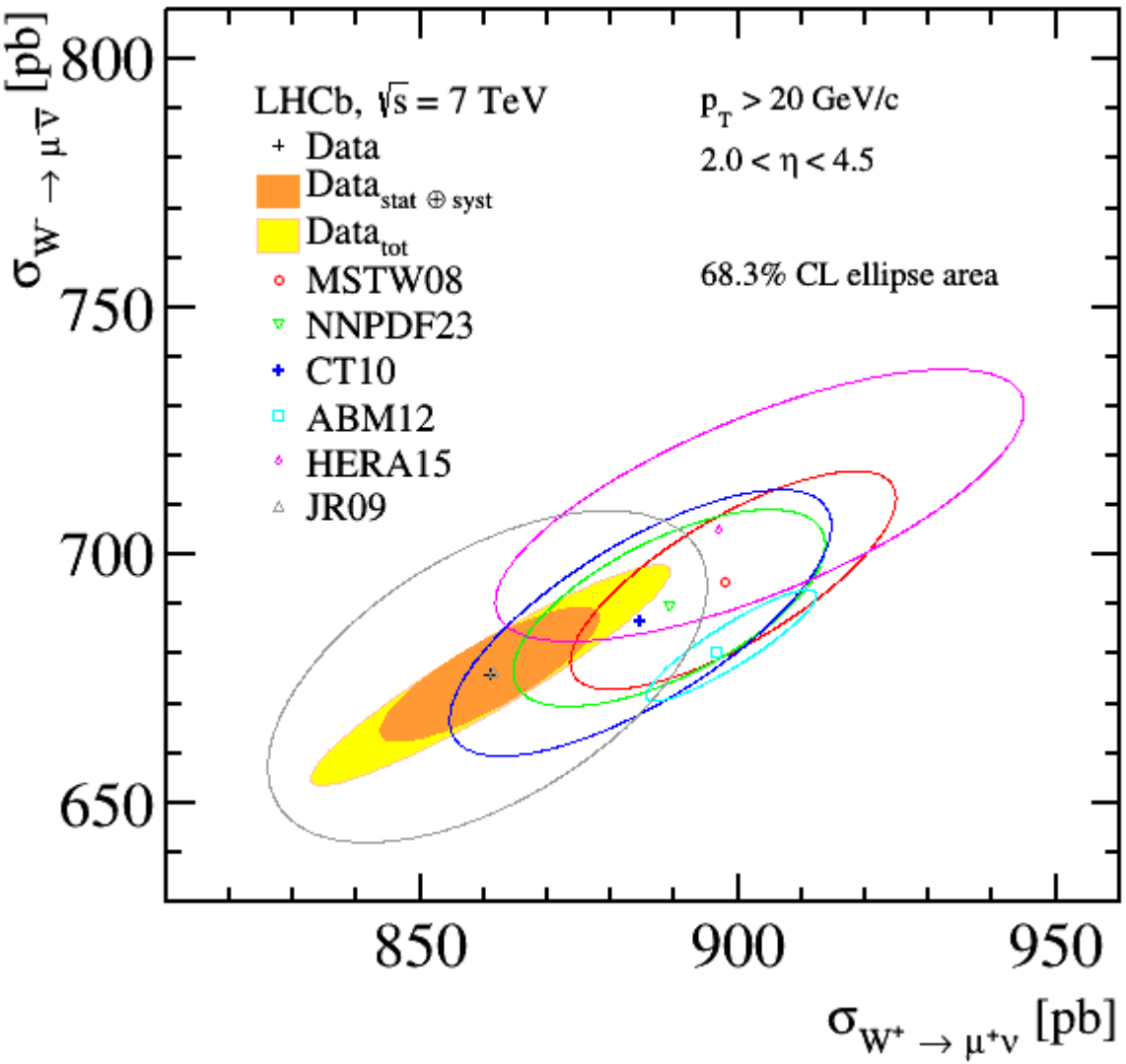
Normalisation
- signal and decay in flight: fitted
- others : fixed from data

Purity: (77.17 ± 0.19)% for W^+

(77.40 ± 0.23)% for W^-

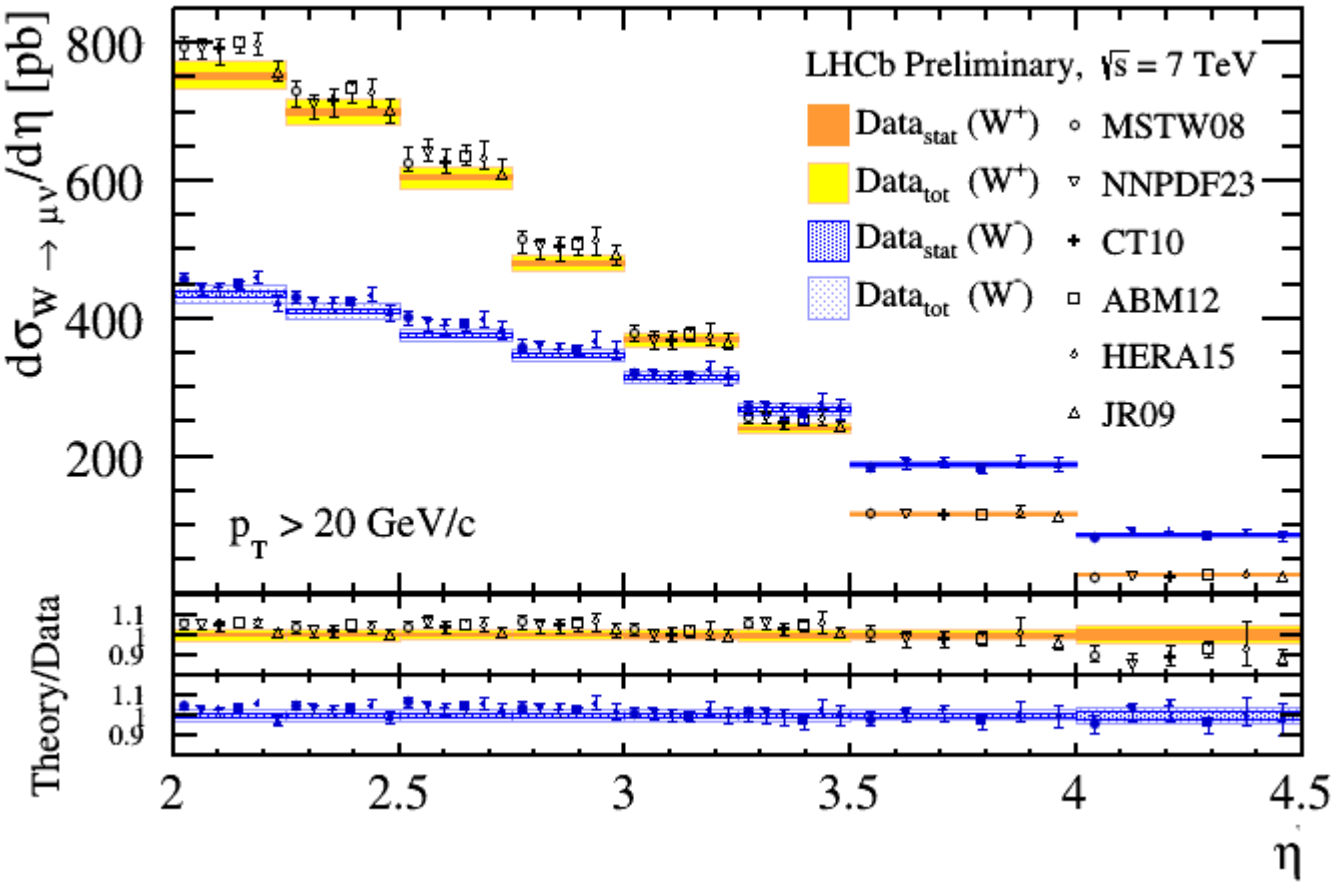


arXiv 1408.4354



W cross section

arXiv 1408.4354

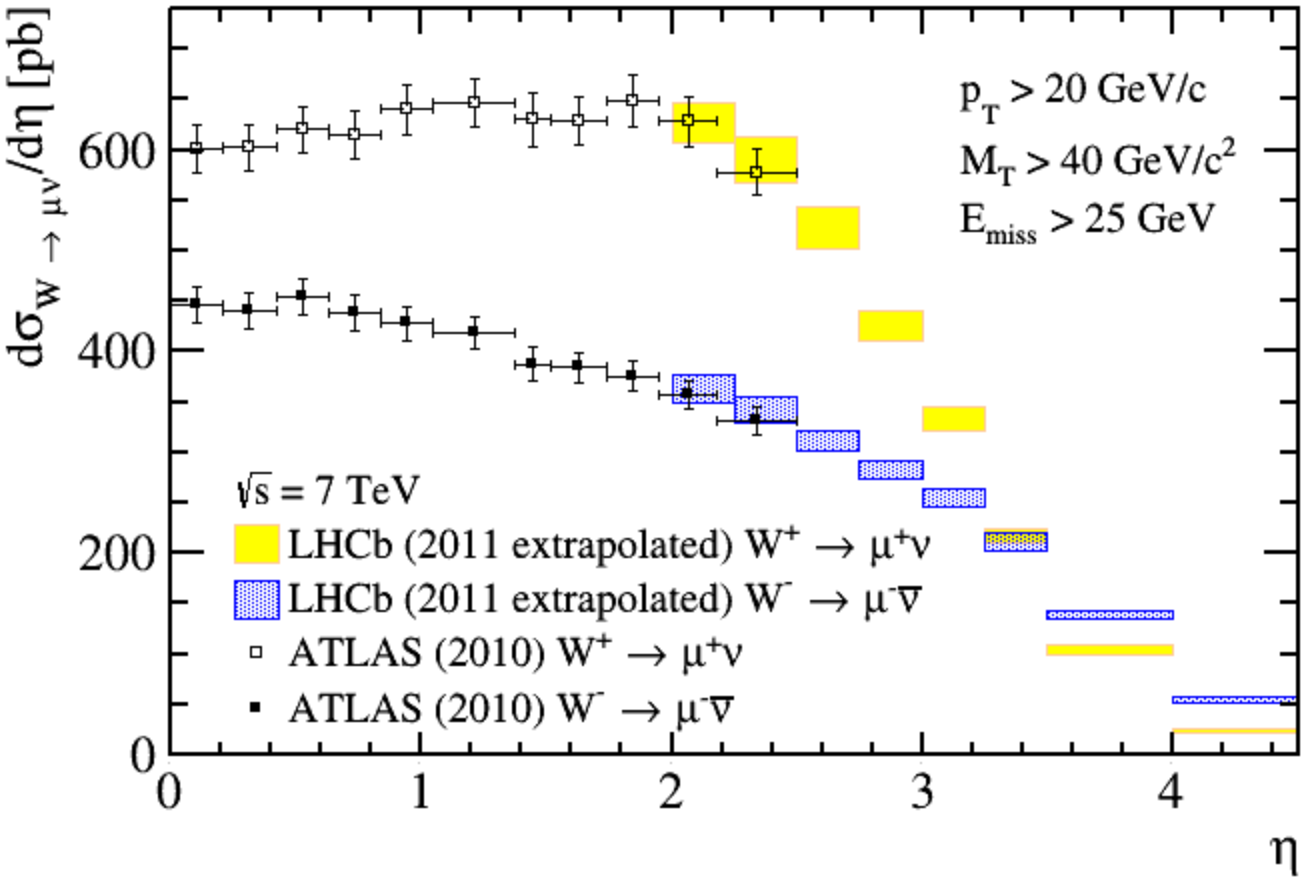


Comparison to NNLO predictions with six different PDF sets

W cross section – comparison to ATLAS

LHCb-PAPER-2014-022

supplementary material, not on arXiv

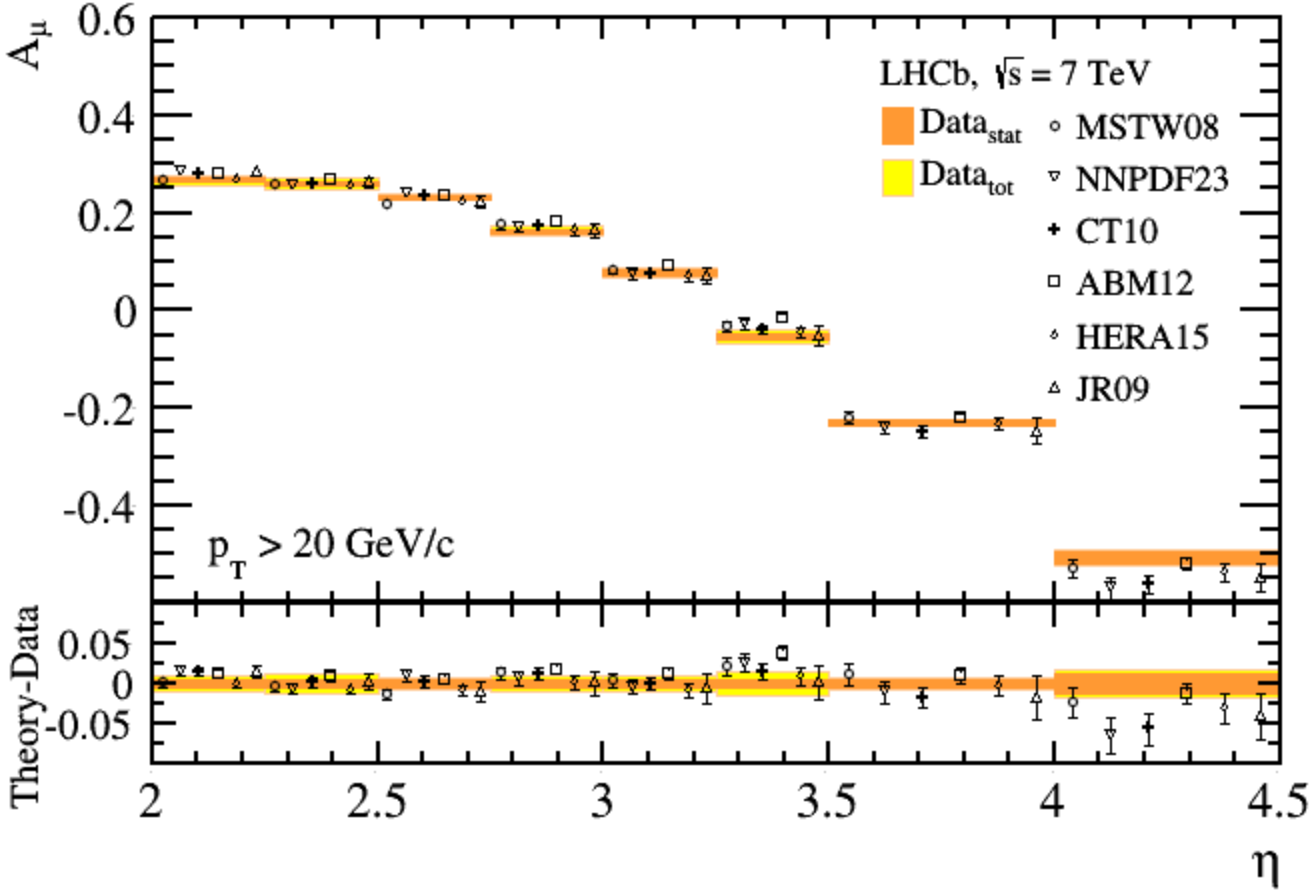


Comparison to ATLAS: LHCb measurements corrected to account for the additional cuts: E_{Tmiss}>25 GeV, M_T>40 GeV

→ good agreement in overlap region

W: lepton charge asymmetry

arXiv 1408.4354

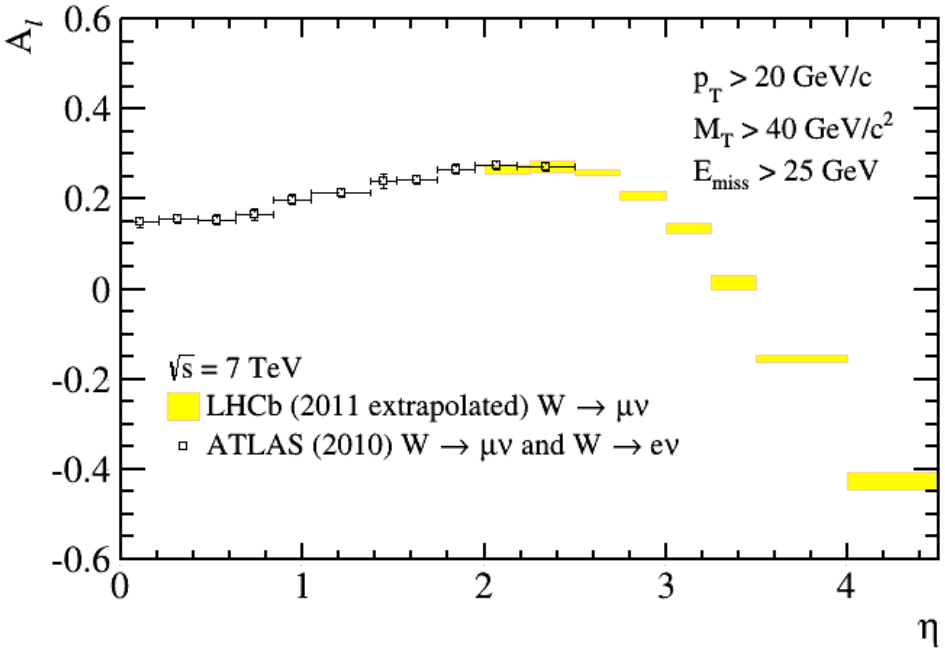


W: lepton charge asymmetry

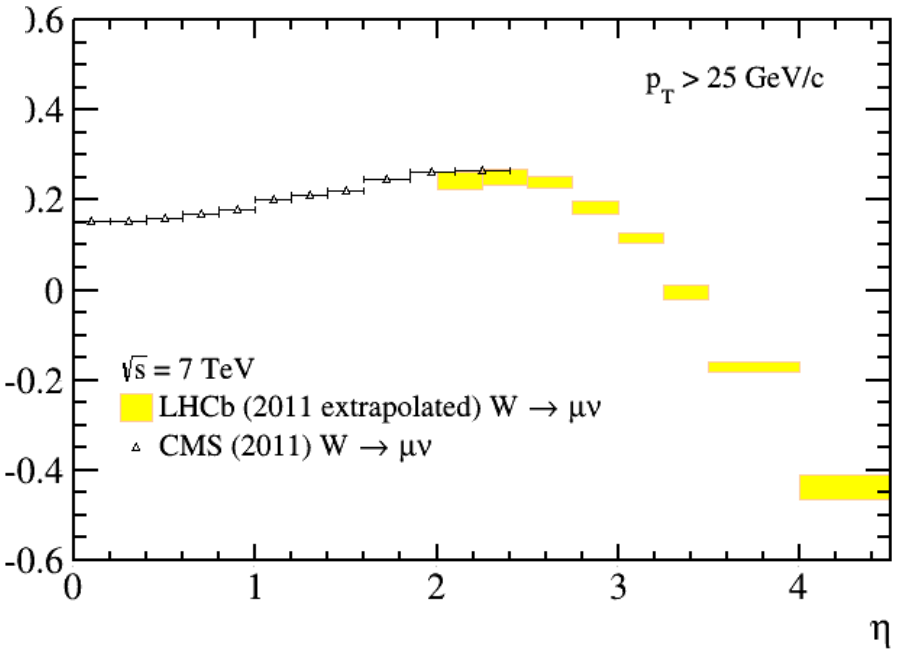
supplementary material, not on arXiv

Comparison to ATLAS for p_T>20 GeV

corrected for cut on M_T>40 GeV and $E_{T,miss}$>25 GeV



Comparison to CMS for p_T>25 GeV



Conclusions

Z production

Z plus jet: first LHCb measurement with jets

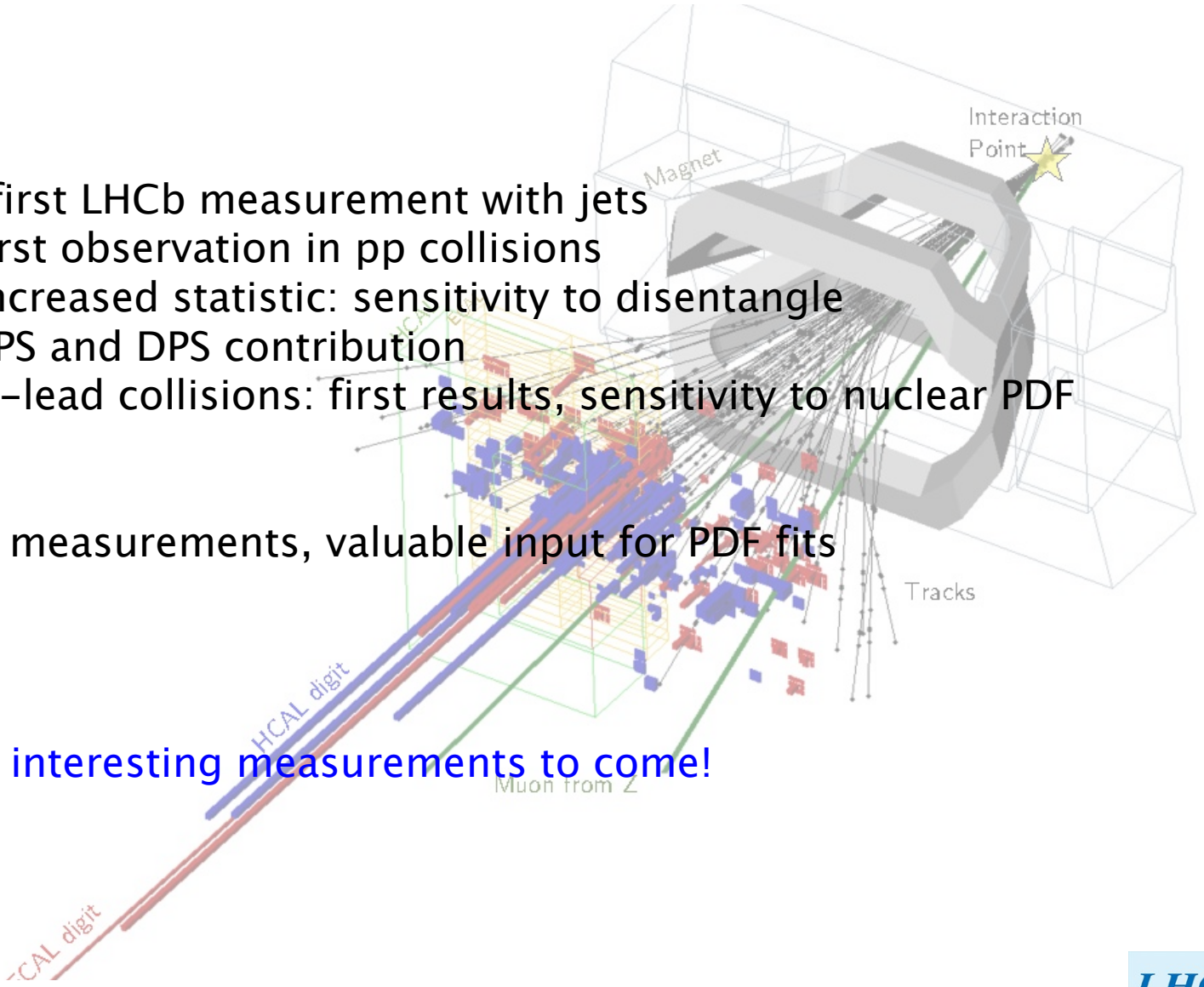
Z plus D: first observation in pp collisions
increased statistic: sensitivity to disentangle SPS and DPS contribution

Z in proton-lead collisions: first results, sensitivity to nuclear PDF

W production

Precise new measurements, valuable input for PDF fits

→ Many more interesting measurements to come!



Backup slides

LHCb running

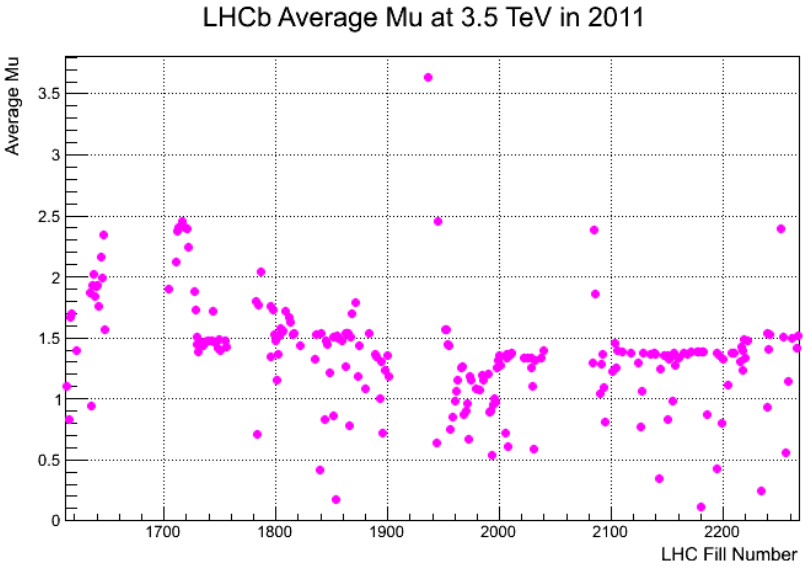
2010 36 pb^{-1}@ 7 TeV

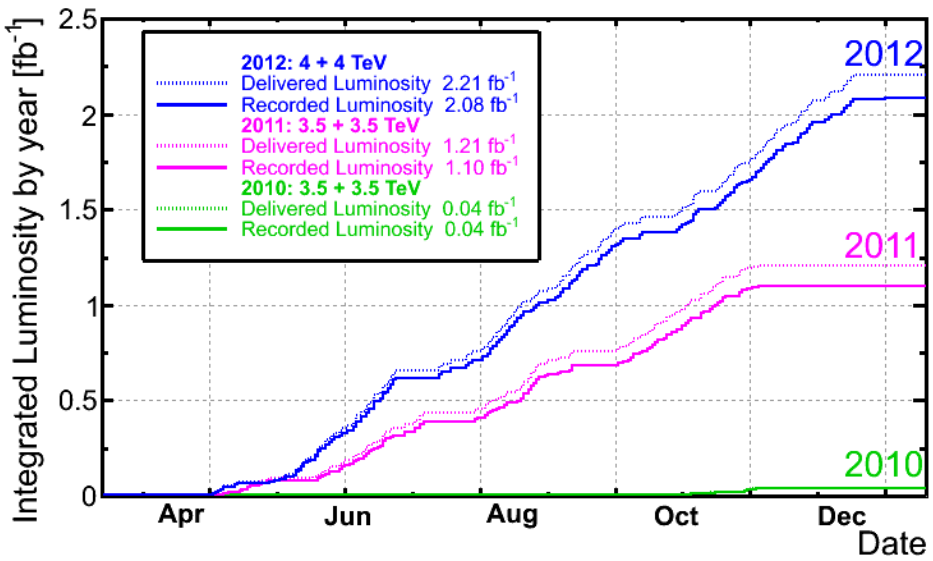
2011 1 fb^{-1} @ 7 TeV

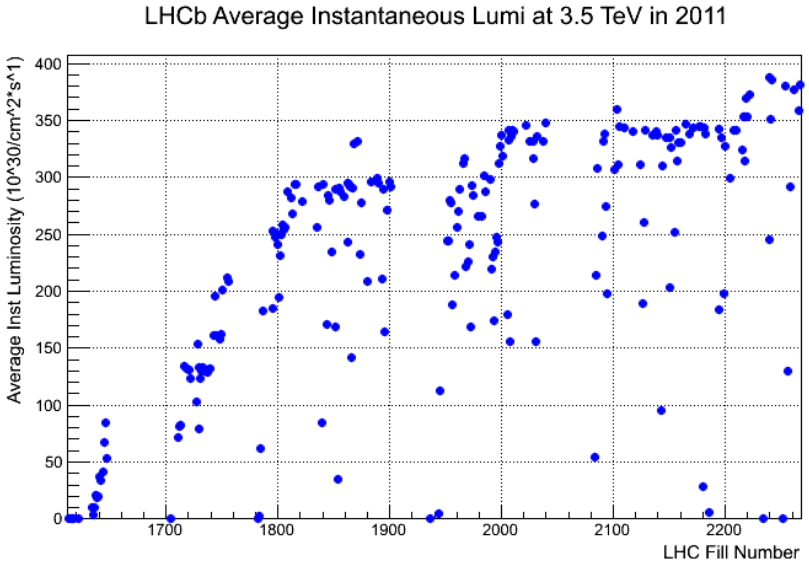
2012 2 fb^{-1} @ 8 TeV

2013 2 nb^{-1} @ 5 TeV proton-lead

Since 2011: Luminosity levelling:
Continuous adjusting of beam overlap
→ roughly constant luminosity
→ stable running conditions
High data taking efficiency:>90%





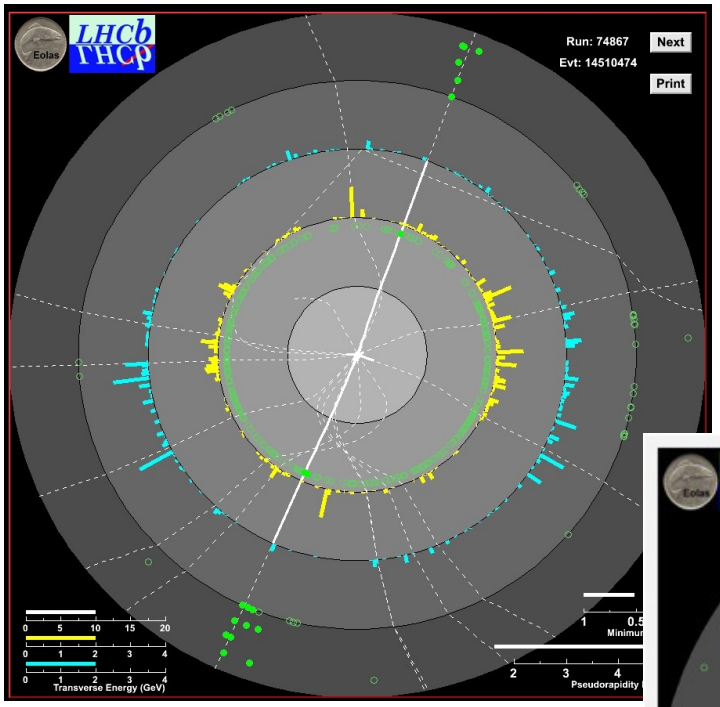


Systematic uncertainties for W measurement

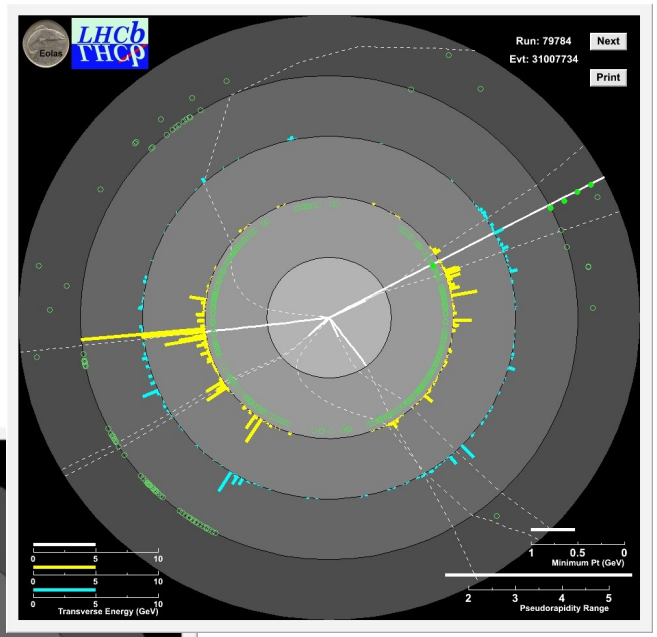
Source	$\Delta\sigma_{W^+\to\mu^+\nu}$ [%]	$\Delta\sigma_{W^-\to\mu^-\overline{\nu}}$ [%]	ΔR_W [%]
Template shape	0.28	0.39	0.59
Template normalisation	0.10	0.10	0.06
Reconstruction efficiency	1.21	1.20	0.12
Selection efficiency	0.33	0.32	0.18
Acceptance and FSR	0.18	0.12	0.21
Luminosity	1.71	1.71	—

Inclusive Z measurements

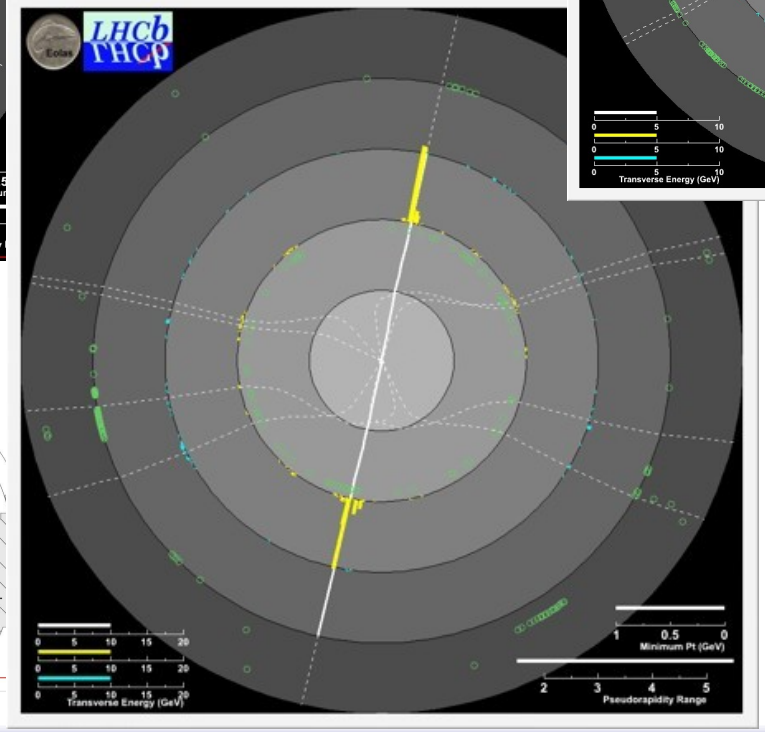
Z → μμ



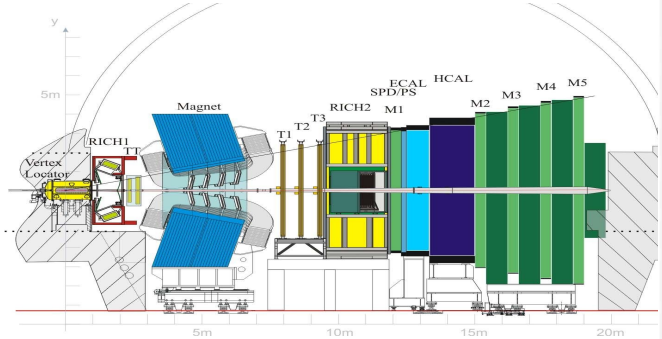
Z→ττ → eμ



Z→ee



φ–z view (Radius=z)



Z plus D: backgrounds

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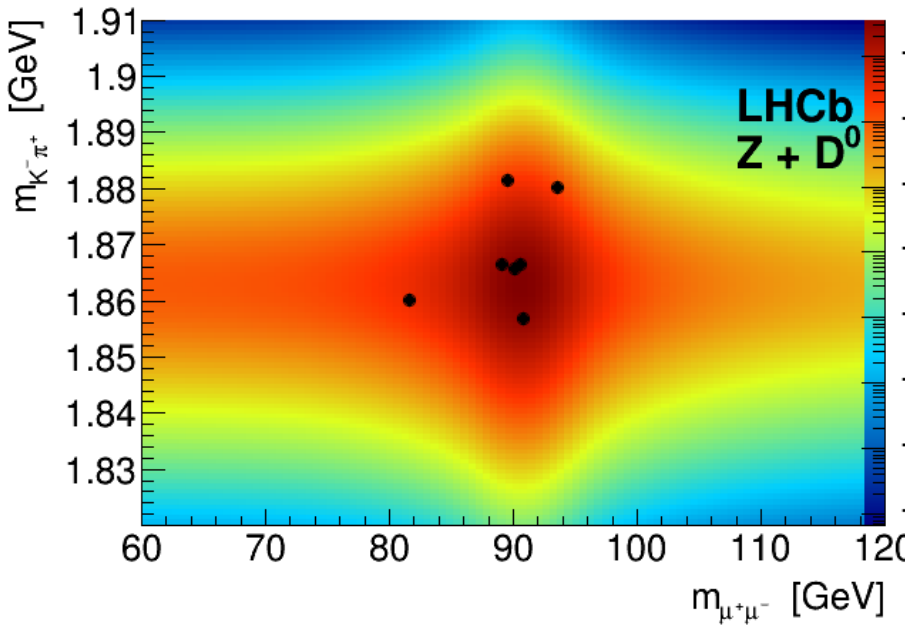
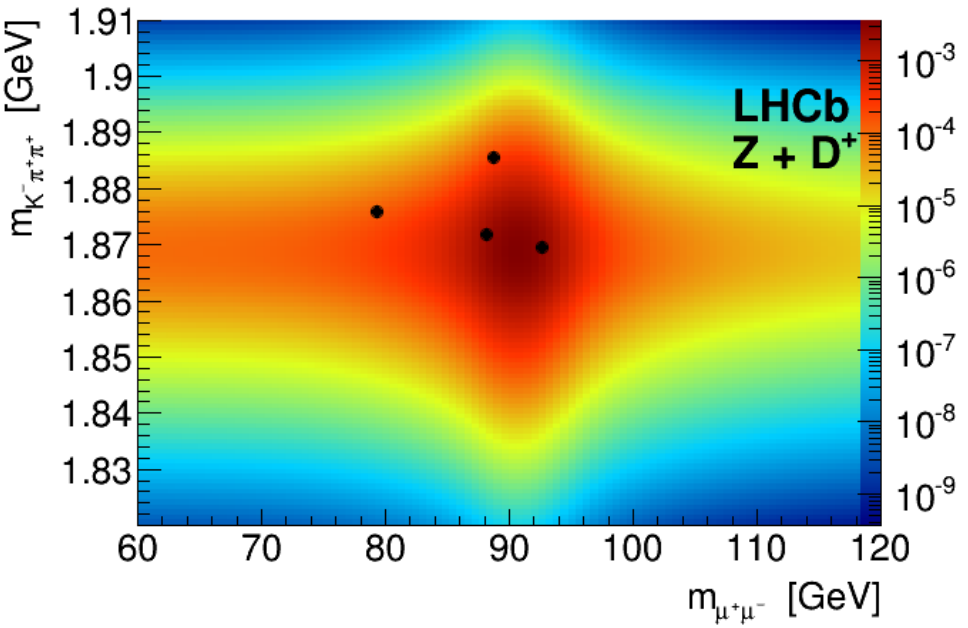
- charmed hadrons from B-decays (dominant)
- real Z and D from different vertices
- combinatorial background: from 2d fit to mass distributions

2D mass distribution with PDF for signal and background





- purity is high about 95%

Inclusive Z measurements at 7 TeV

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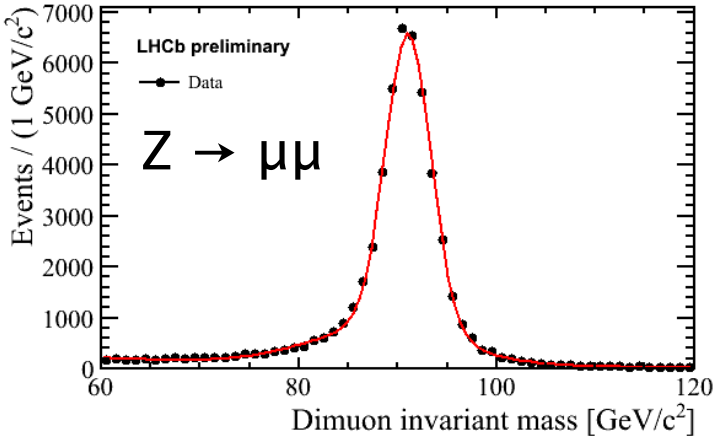

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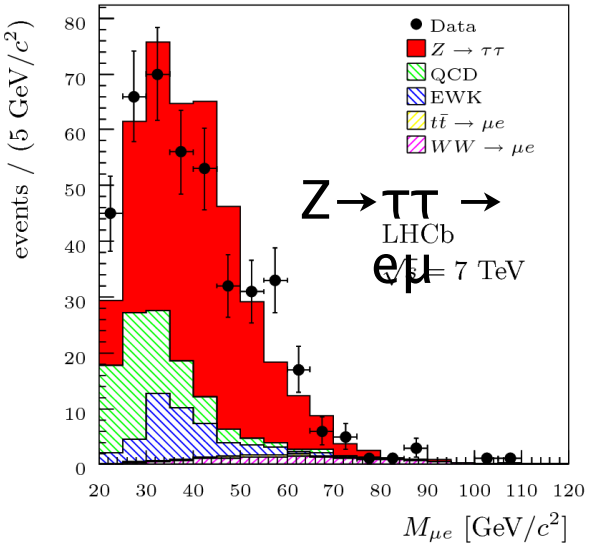

Fiducial volume

leptons: p_T>20 GeV, 2<η<4.5

mass: 60<M_{ll}<120 GeV^2

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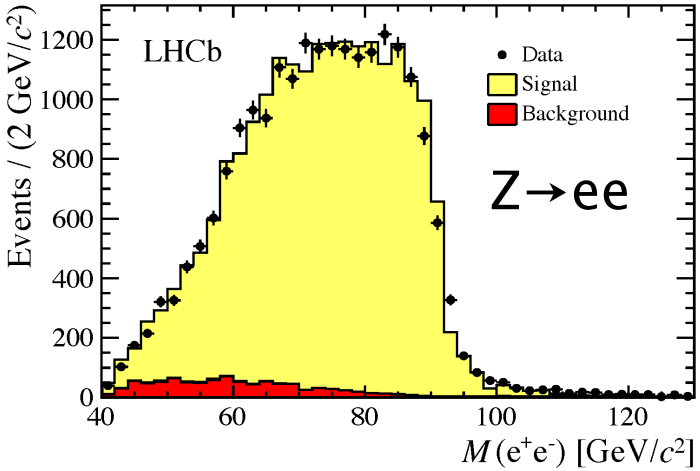

Background

muon < 0.3%

electron ~ 4.5%

tau 28-37

→ the following analyses are all based on the di-muon final state
backgrounds:semileptonic decays of heavy quarks, misidentified hadrons