QCD / EW Measurements at LHCb

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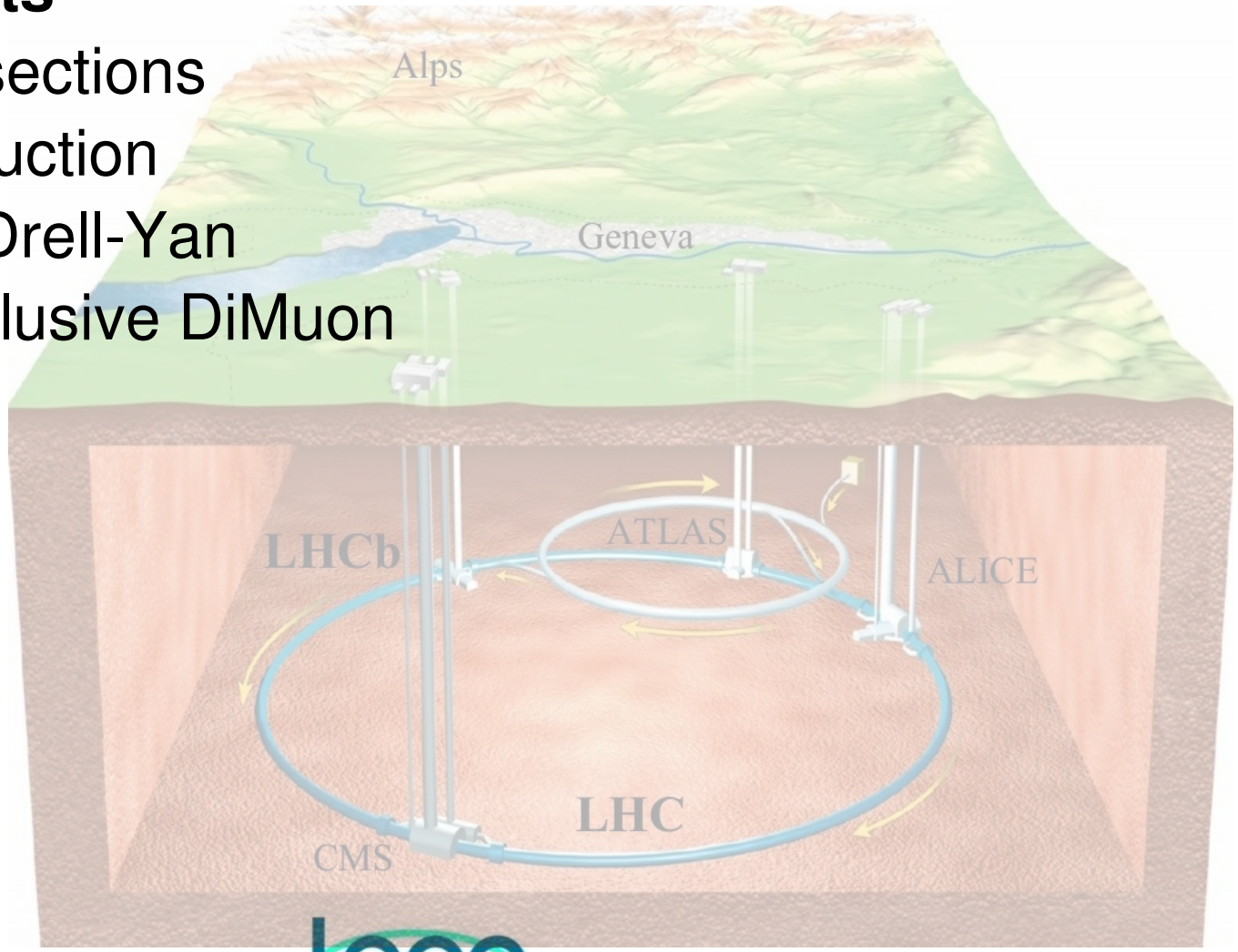
on behalf of the LHCb Collaboration

Outline

→ **LHCb Experiment**

→ **Measurements**
- W/Z cross sections
- Z+jets production
- Low mass Drell-Yan
- Central Exclusive DiMuon

→ **Summary**



LHCb Experiment

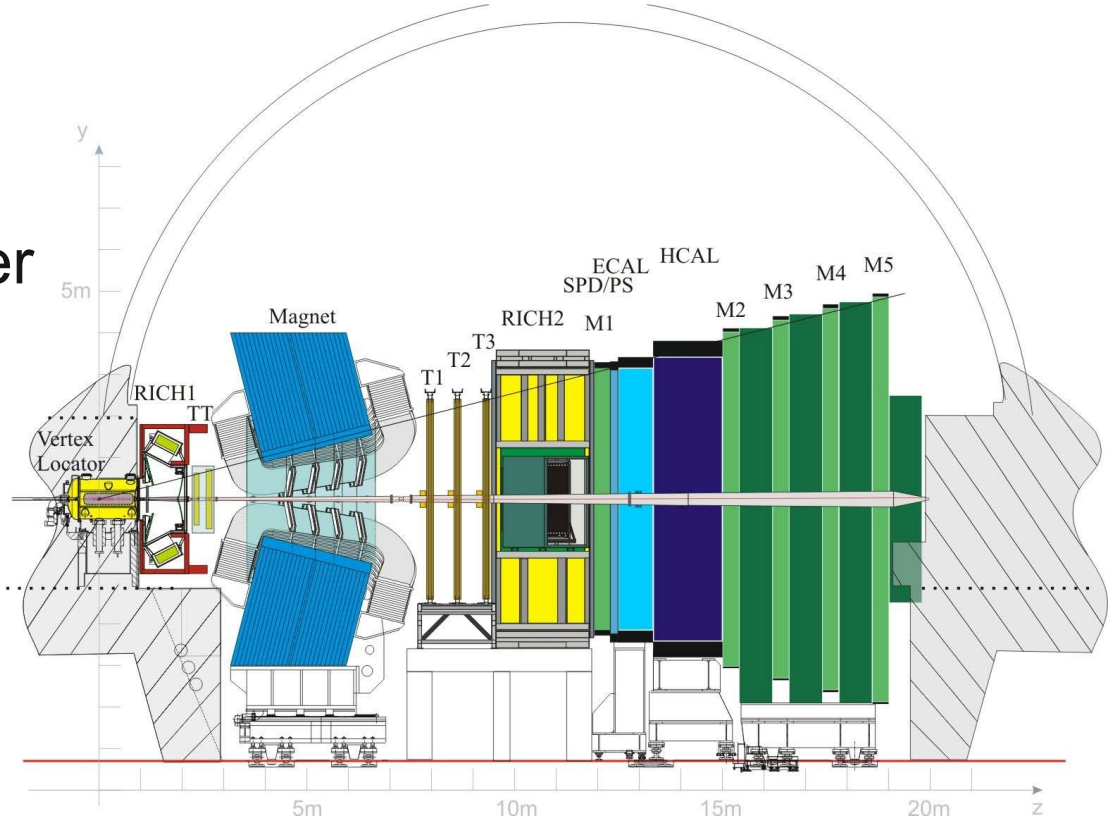
The detector is a single arm spectrometer fully instrumented in the forward region ($2.0 < \eta < 5.0$) → Unique coverage at LHC

Excellent Vertex Resolution and Tracking
→ Vertex Locator
→ Tracking Stations

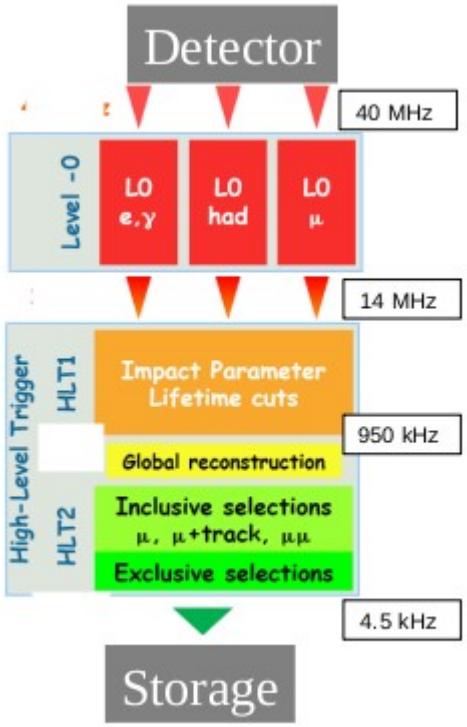
Energy Measurements
→ EM and Hadronic Calorimeter

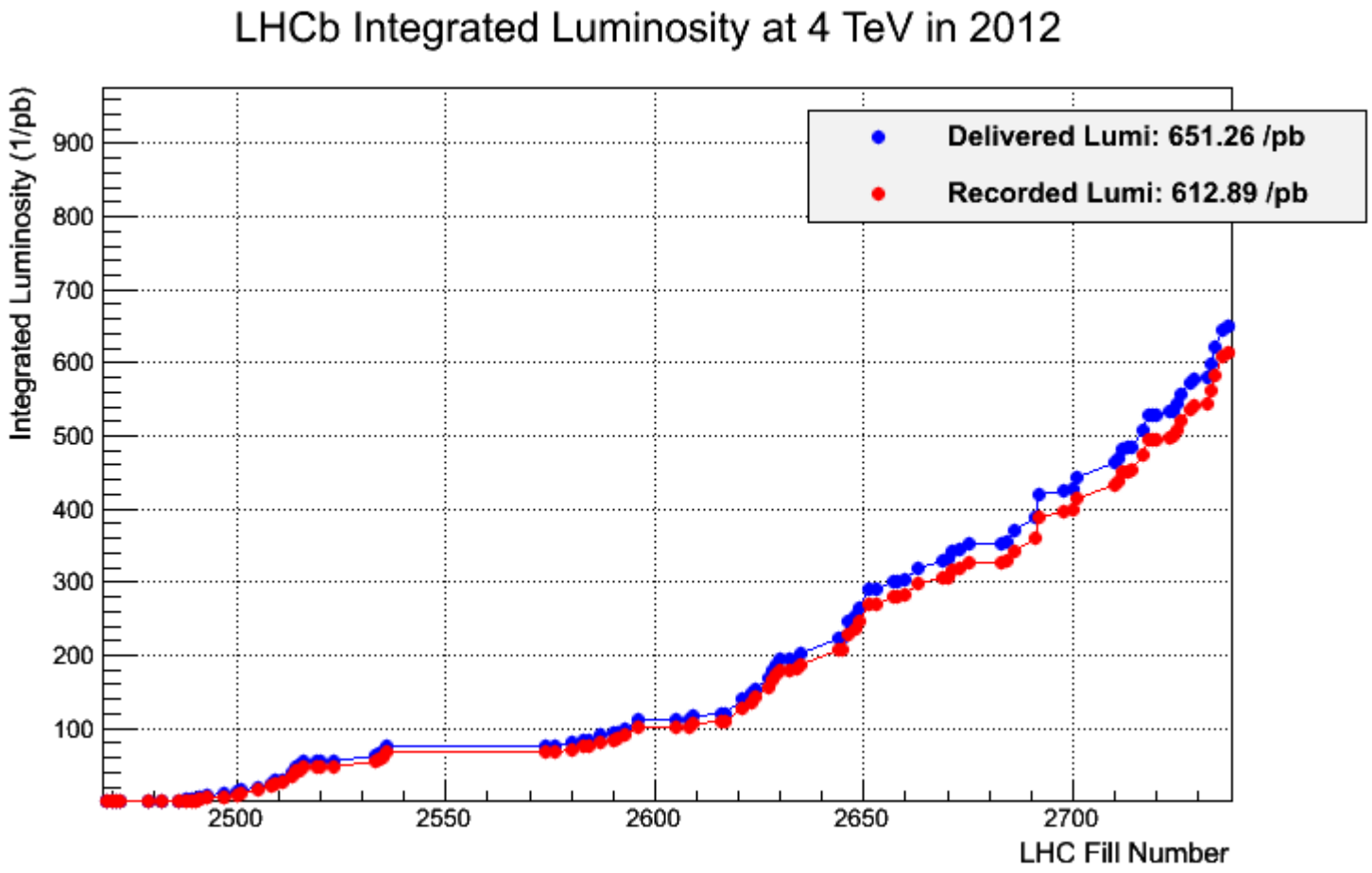
Particle Identification
→ Rich detectors
→ Muon Stations

Trigger
→ Ability to go low in muon p_T



LHCb Data





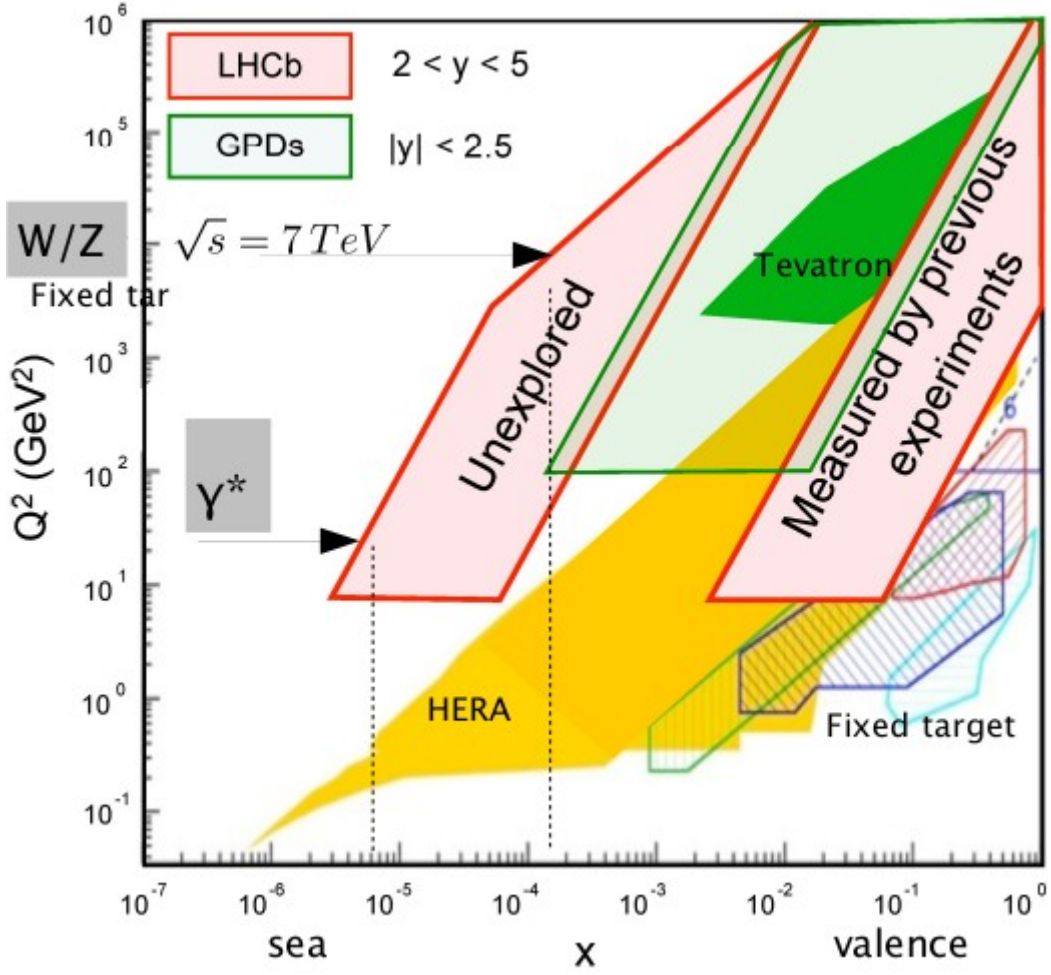
>90% data taking efficiency
2010 → 37/pb at √s = 7 TeV
2011 → 1/fb at at √s = 7 TeV
Thanks to LHC team!

Cross sections

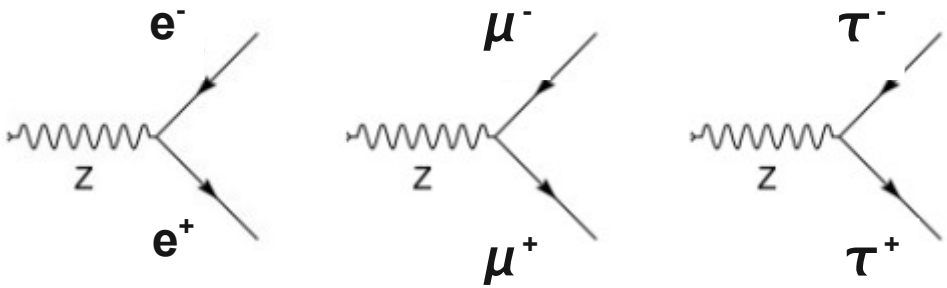
$$\underbrace{\sigma(x,Q^2)}_{hadronic\ x-sec.} = \sum_{a,b} \int_0^1 dx_1\, dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{PDFs\ 2-8\%} \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{partonic\ x-sec.:\ NNLO\ 1\%}$$

LHCb is sensitive to low-x and a high-x parton collisions.

Two different regions are probed
→ inputs for PDF fits



Inclusive Z production



Data

→ 2010/2011

→ Single muon/electron trigger

Event Selection ($Z \rightarrow \mu^+\mu^-$ / $Z \rightarrow e^+e^-$)

→ Two muons/electrons - p_T > 20 GeV and 2.0 < η < 4.5

→ 60 < $M_{\mu\mu}$ < 120 GeV / M_{ee} > 40 GeV

Event Selection ($Z \rightarrow \tau^+\tau^-$)

→ Decays - $\mu\mu\nu\nu$ / $\mu e\nu\nu$

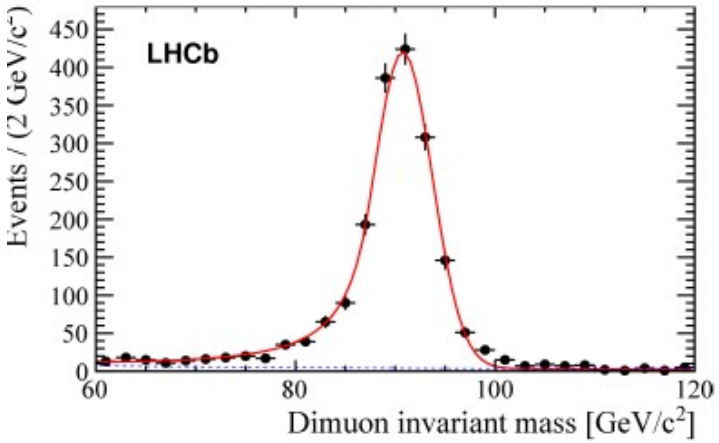
→ One muon with p_T > 20 GeV and second lepton with p_T > 5 GeV

→ Isolated leptons

→ $\Delta\varphi$>2.7 and not p_T balanced for $\mu\mu\nu\nu$

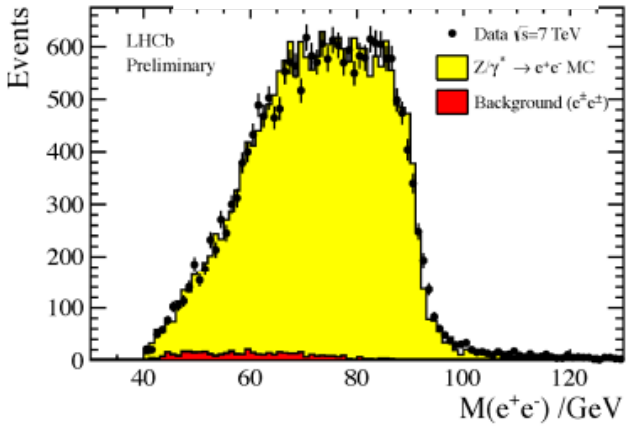
Inclusive Z production

JHEP06(2012)058



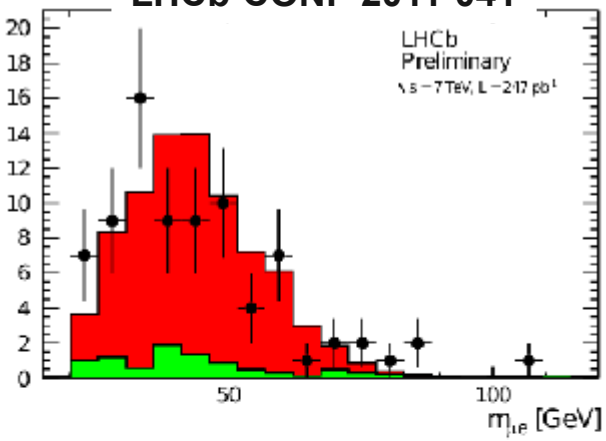
Candidates:	1966
Background:	4.8±1.0
Purity:	99.7%

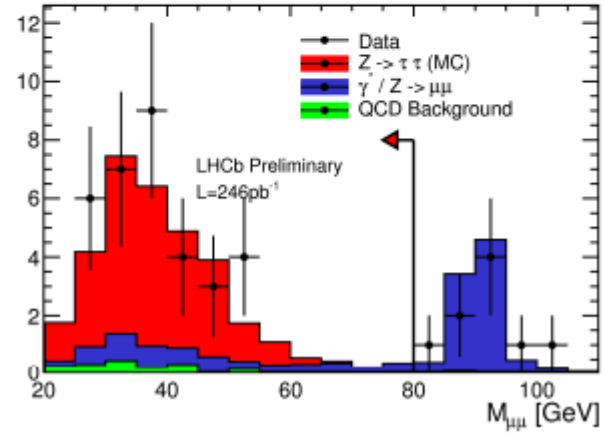
LHCb-CONF-2012-011



Candidates:	21535
Background:	473
Purity:	97.8%

LHCb-CONF-2011-041

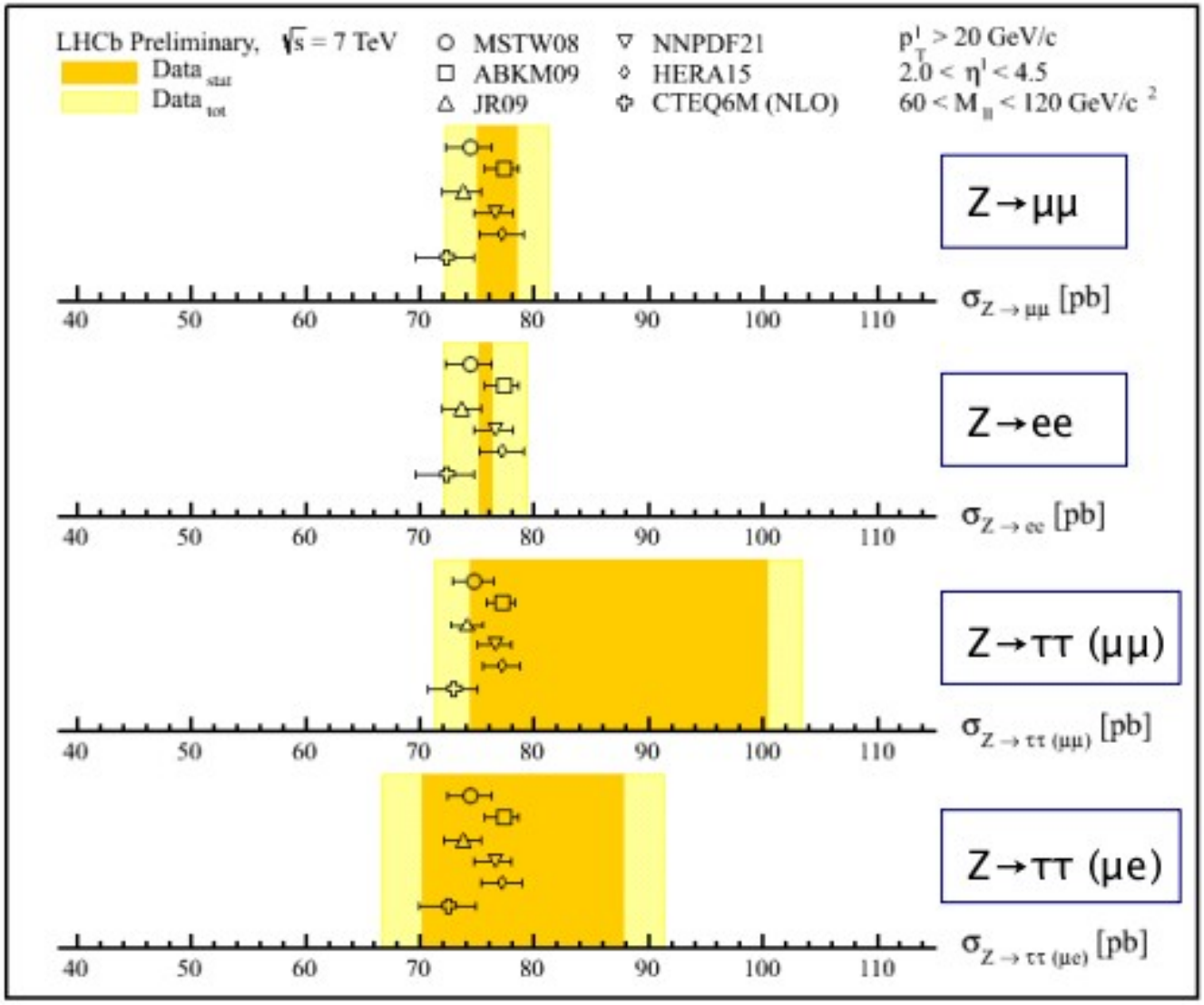




	μe	μμ
Candidates:	81	33
Background:	12.4±2.7	7.1±2.0
Purity:	85%	78%

Precision:	Z→ μμ	Z→ ee	Z→ ττ μe	Z→ ττ μμ
Statistical [%]	2.2	0.7	17	12
Luminosity[%]	3.5	3.5	5.1	
Systematic[%]	4.3	3.1	16	10
Luminosity[pb]	37.5	945	247	

Inclusive Z production



NNLO (DYNNLO) PDF uncertainties at 68% CL

JHEP06(2012)058

LHCb-CONF-2012-011

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LHCb-CONF-2011-041

W measurements

Data

→ 2010 - 37/pb

→ trigger on single muon (p_T > 10 GeV)

Event Selection

→ Isolated muon p_T > 20 GeV

+ cone 0.5 p_T < 2 GeV

→ Impact Parameter of muon < 40 μm

→ 2nd muon veto p_T > 2 GeV

→ E(calorimeter)/pc < 0.04

→ Purity from template fit

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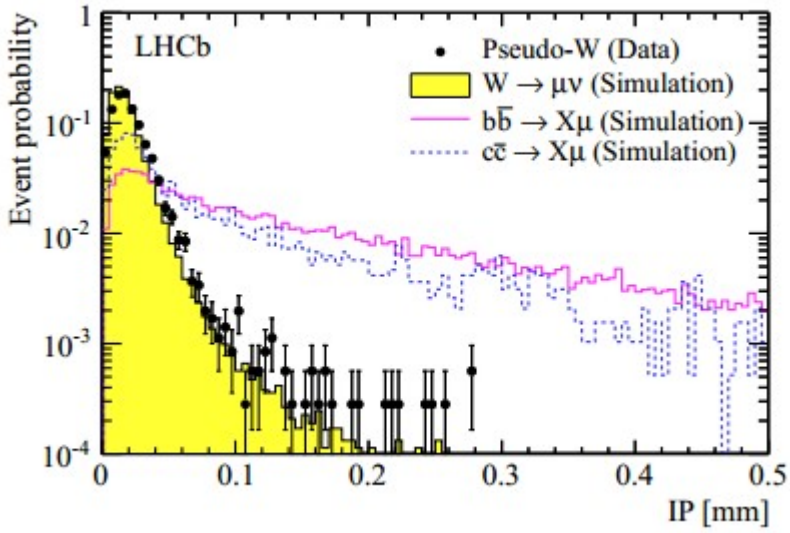

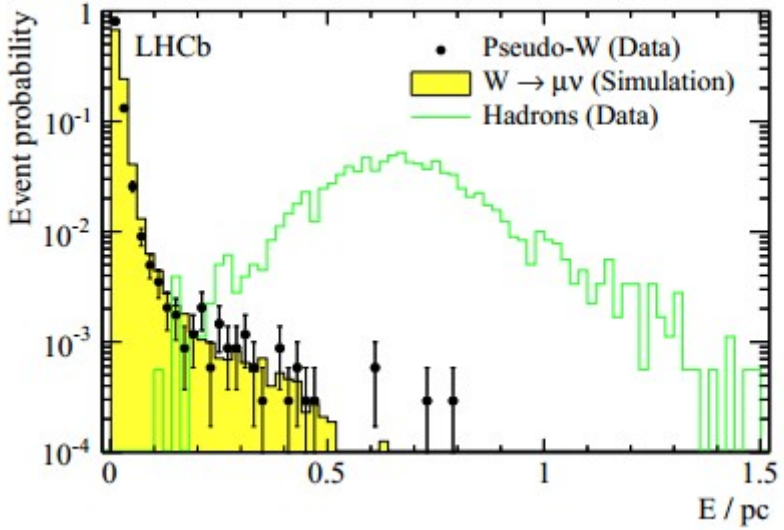

Results

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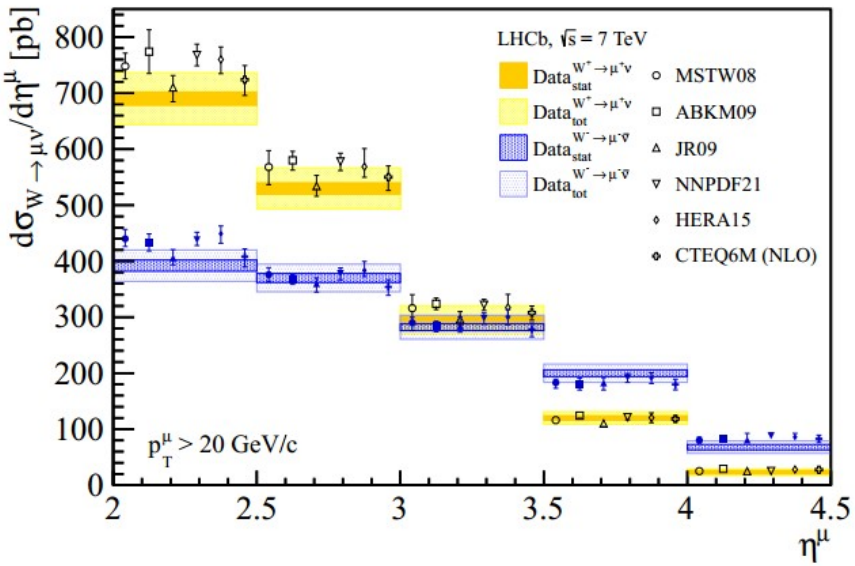

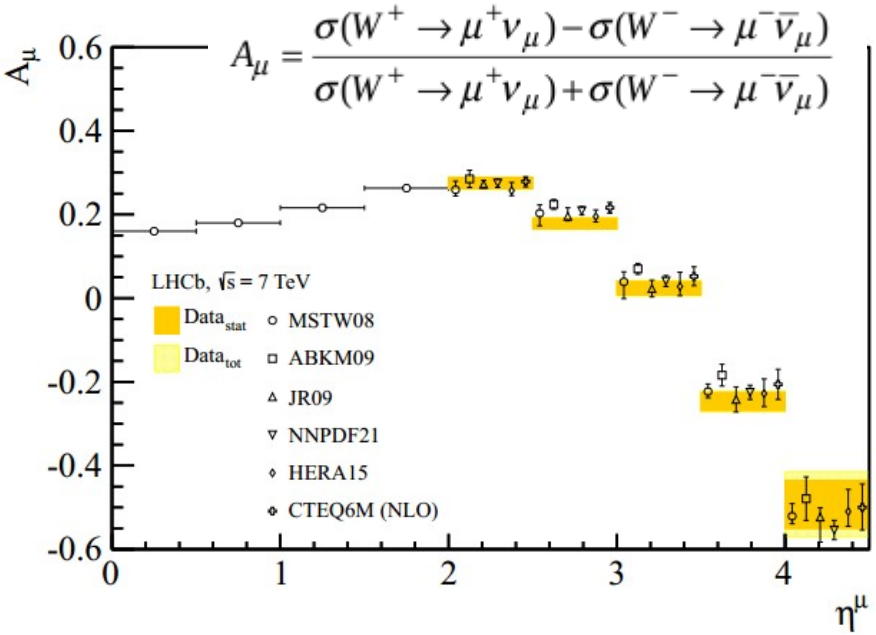

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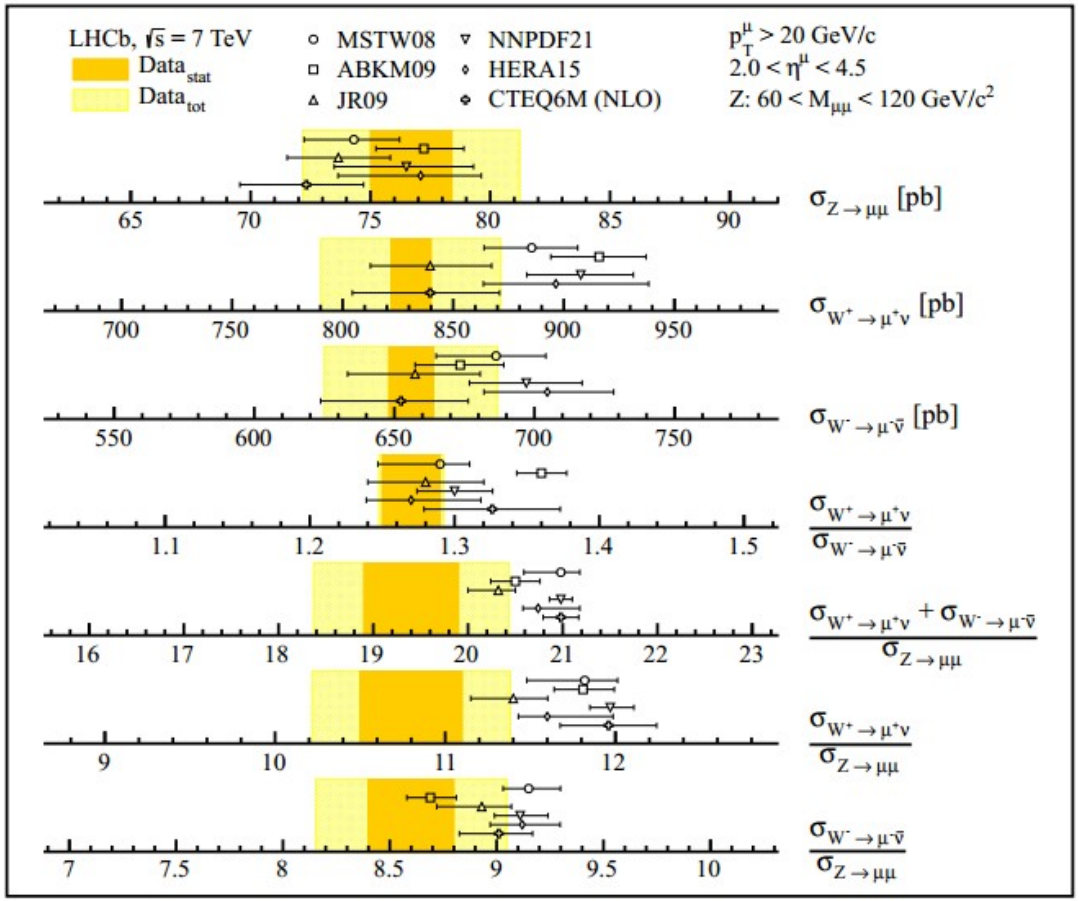


$Z(\mu^+\mu^-)$+jets

Data

→ 2011 - 1/fb

→ same trigger and event selection for ($Z \rightarrow \mu^+\mu^-$)

Jet Selection

→ Particle Flow method

- tracks, γ, calorimeter clusters, V0s

→ anti-kt (R=0.5) reconstruction

→ Jet Identification cuts

→ Jet Energy Correction (MC)

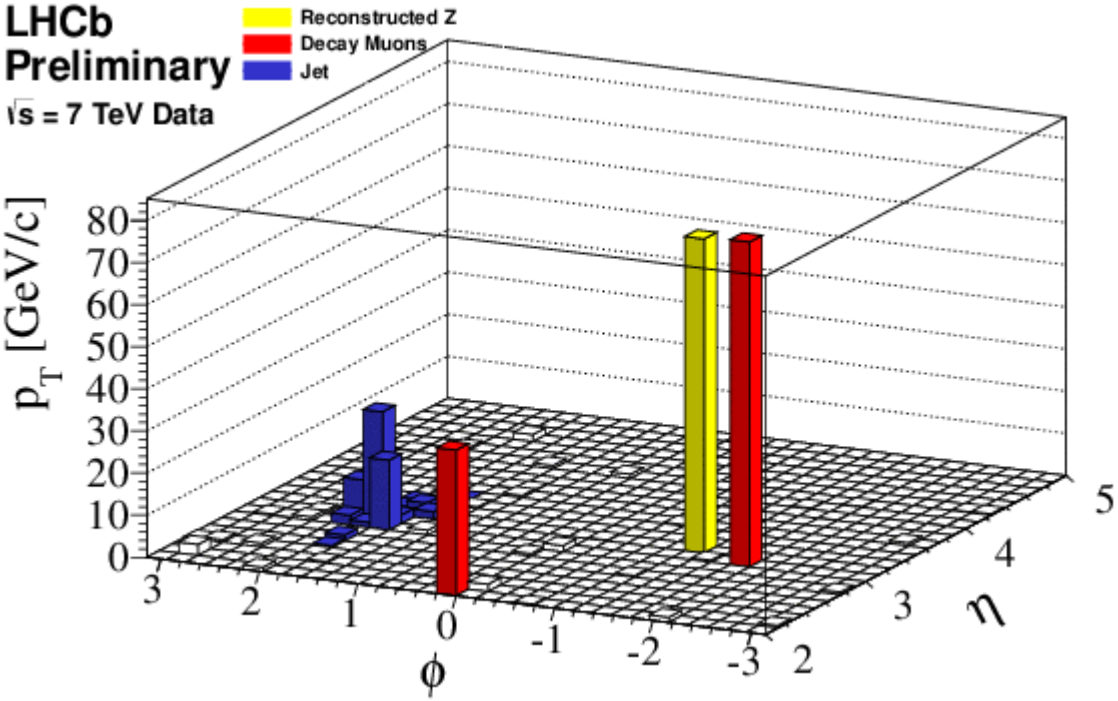
→ p_T > 10 GeV and 2.0 < η < 4.5

→ DR(jet,μ)>0.4

Measurements

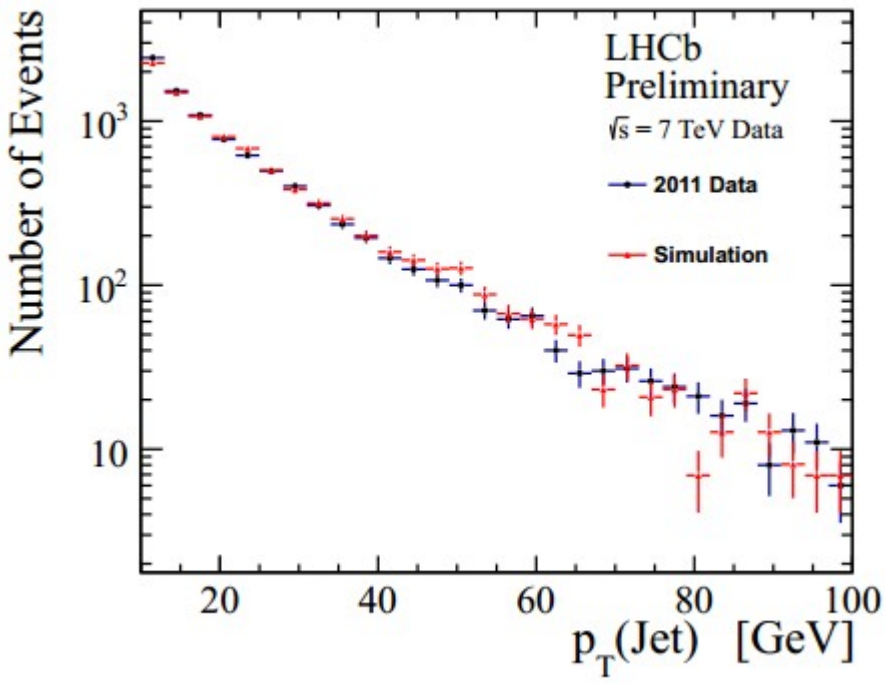
→ Differential Cross Section

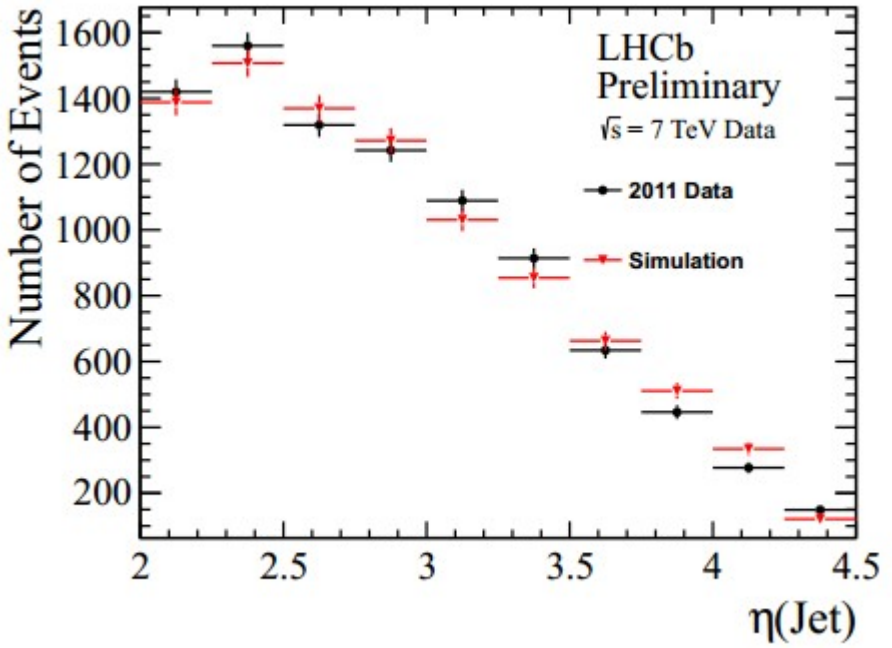
→ Jet Multiplicity

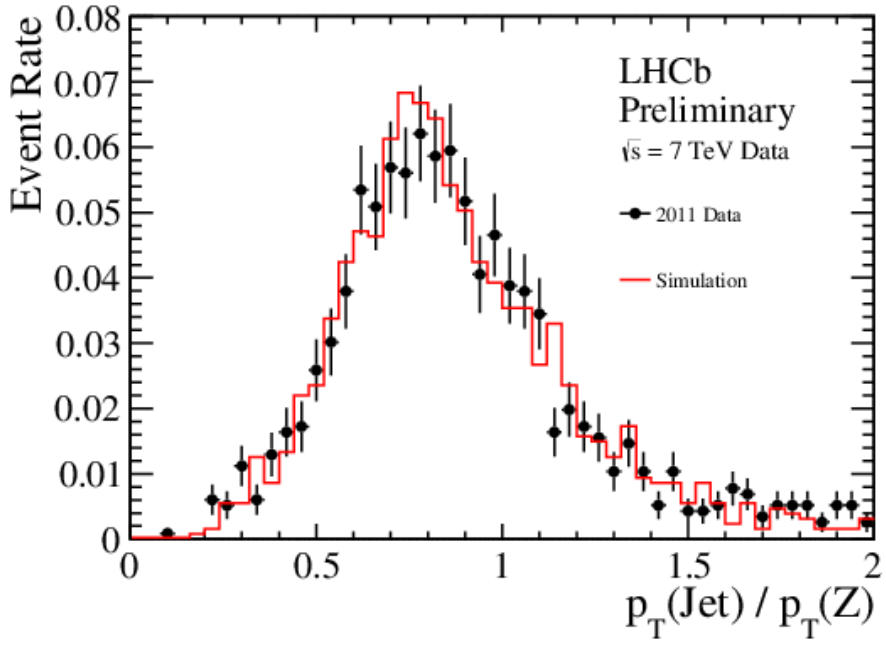


Control Plots

LHCb-CONF-2012-016



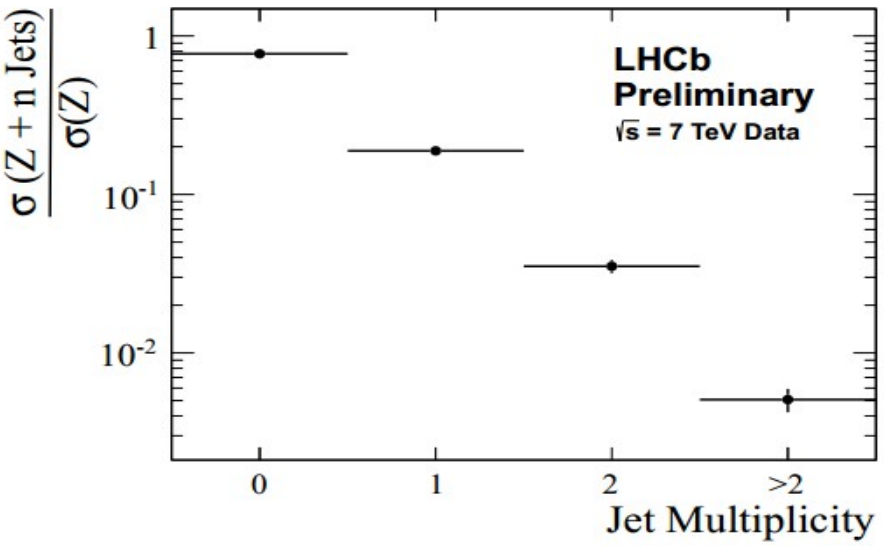


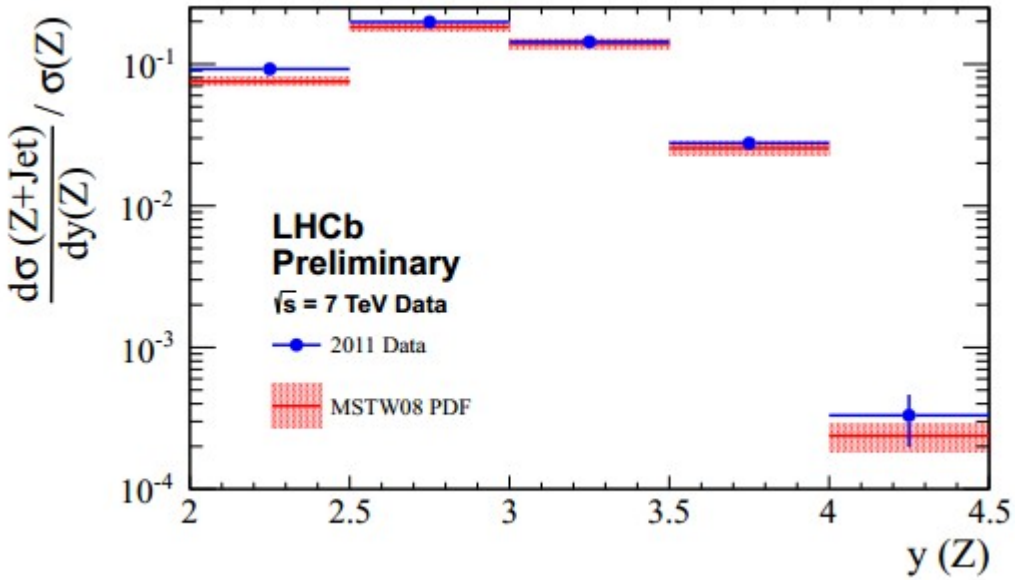


- Simulation and data agrees well at detector level
- JEC is validated in data
- 1st step for jet measurements at LHCb

Results

LHCb-CONF-2012-016

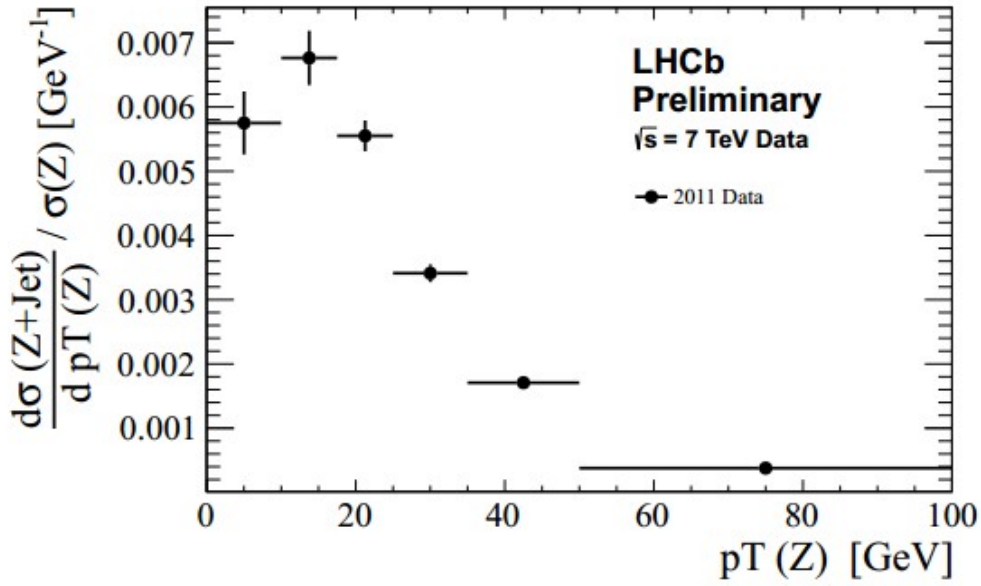




Fraction of events with at least one jet:

LHCb preliminary:
0.229 ±0.006(stat) ±0.009(syst)

NLO: FEWZ with MSTW0 (parton level)
$0.212\ ^{+0.006}_{-0.009}$ (PDF) ±0.016 (scale)



Low Mass Drell-Yan Production

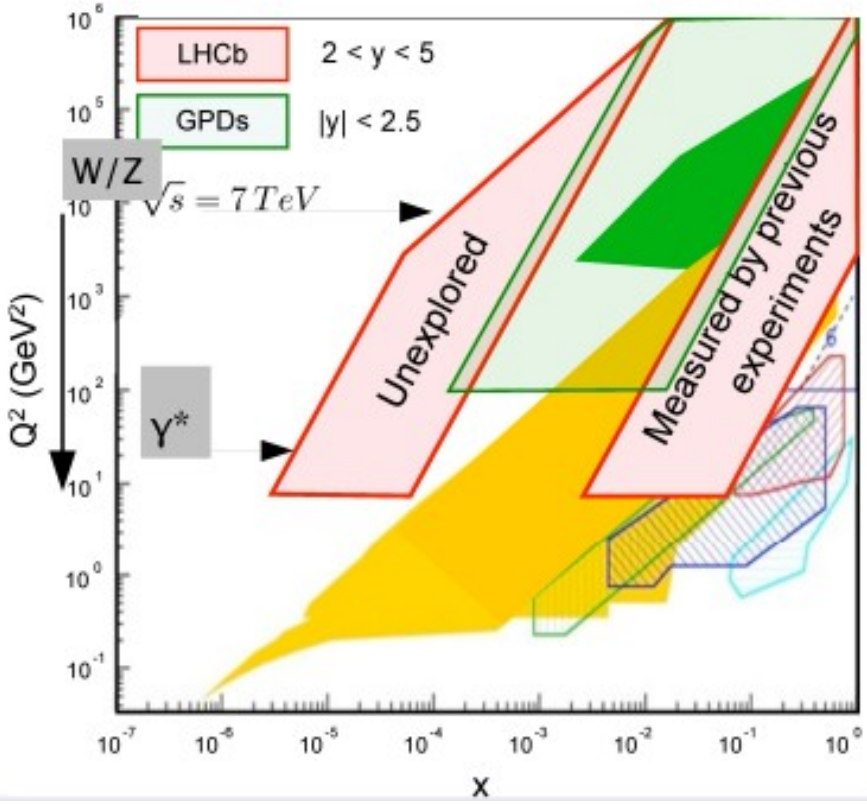
LHCb-CONF-2012-013

- W/Z measurements probe

  $Q^2 = 10'000\ GeV^2$, $x = 1.7 \cdot 10^{-4}$

- Low mass Drell-Yan (γ^*)

  $Q^2 = 25\ GeV^2$, $x = 8 \cdot 10^{-6}$



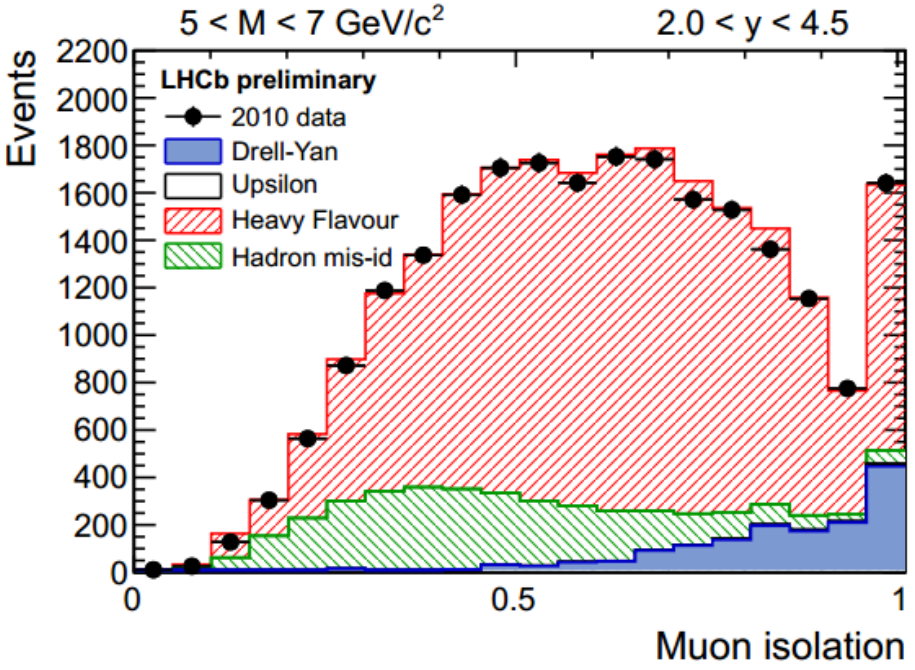
Data

→ 2010 – 37/pb

→ di-muon trigger $p_T > 2.5$ GeV

Selection

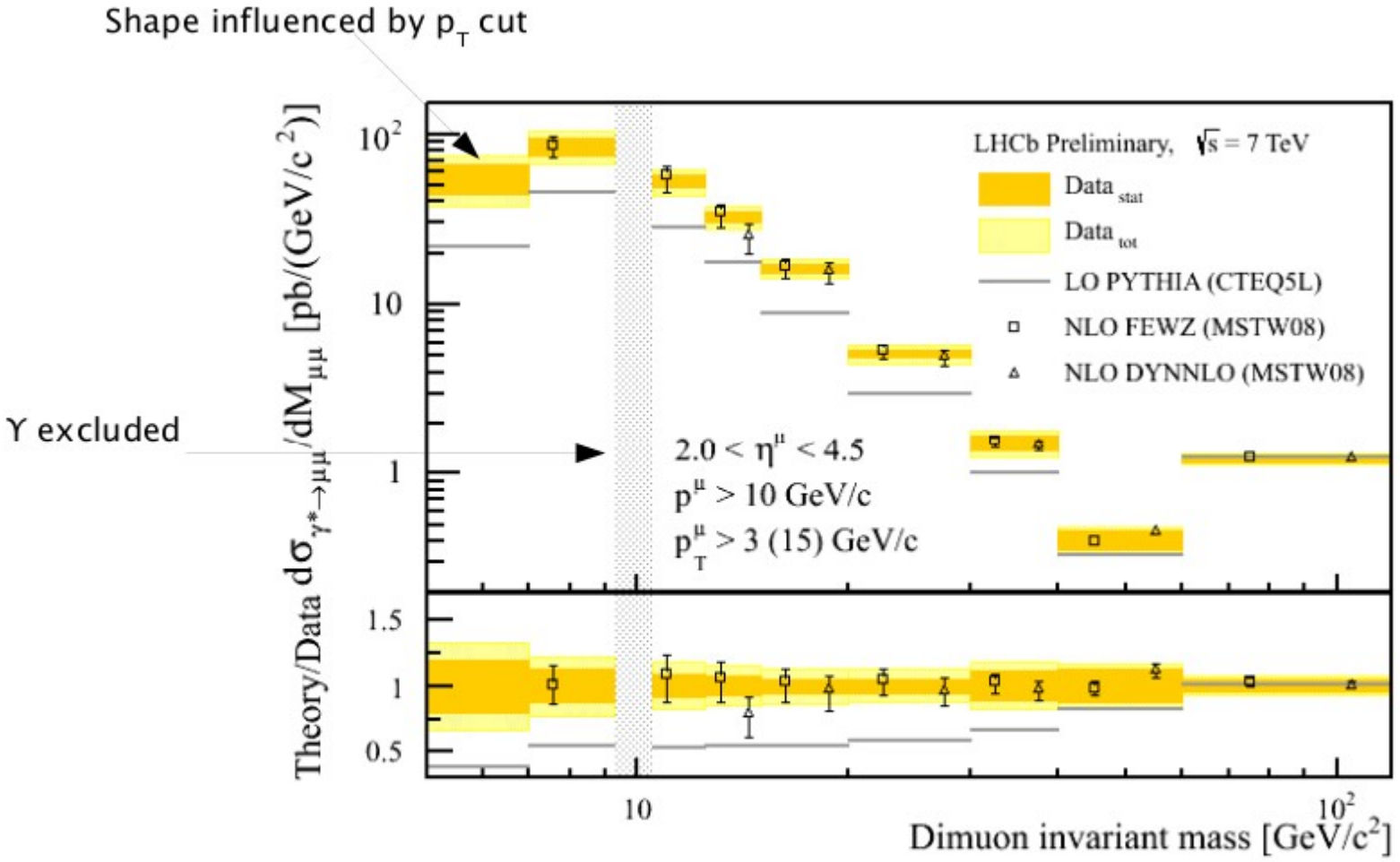
→ 2 muons - $5 < M_{\mu\mu} < 120$ GeV



- Signal extracted from template fits
- **9** mass bins
- **5** η bins in **2** mass regions

Low Mass Drell-Yan Production

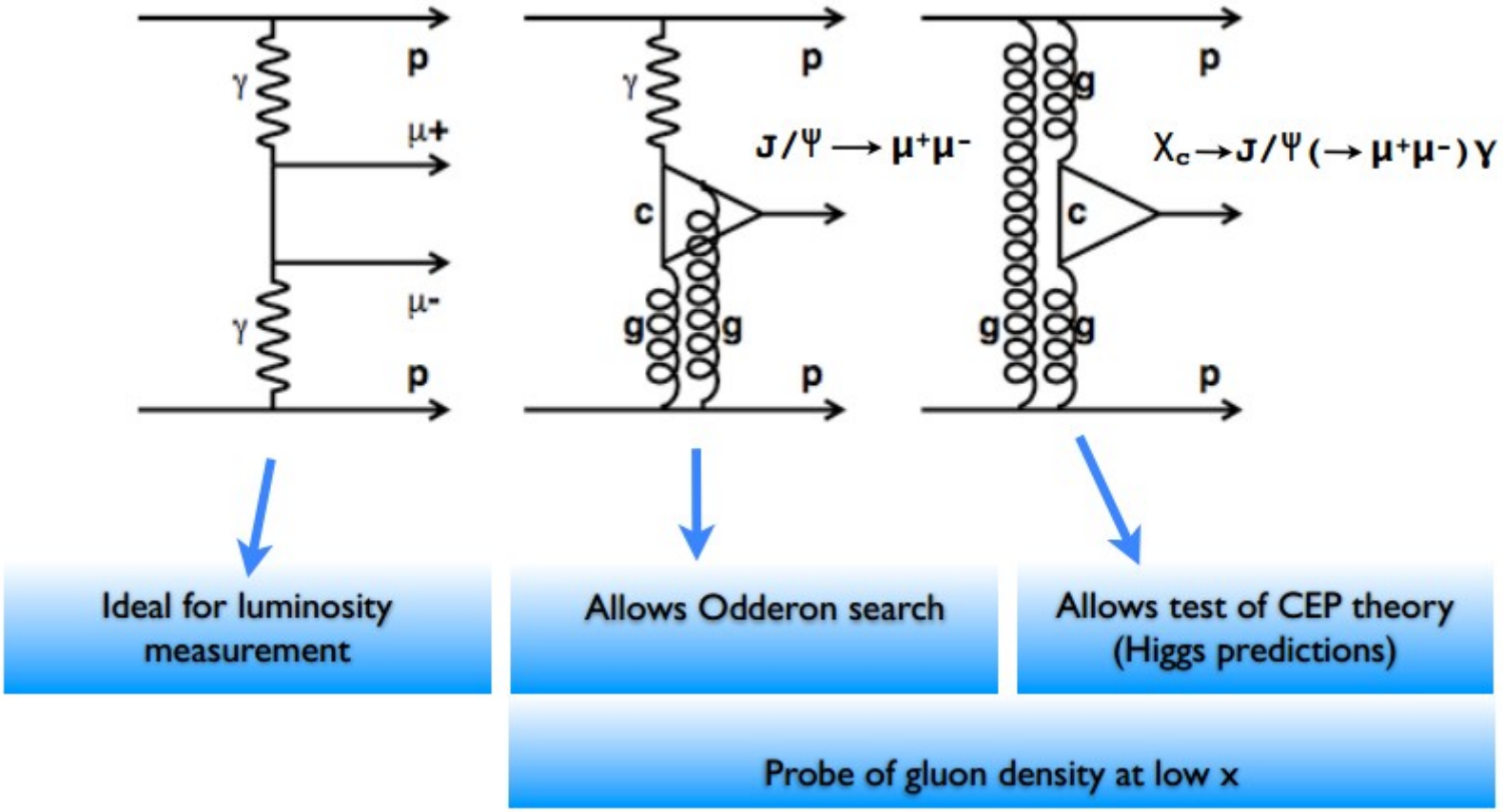
LHCb-CONF-2012-013



Compared to NLO predictions (FEWZ and DYNNLO) and PYTHIA
FEWZ predictions above 7 GeV/c^2, DYNNLO above 12.5 GeV/c^2

Central Exclusive DiMuon

LHCb-CONF-2011-022



Data

→ 2010 – 37/pb

→ di-muon + low multiplicity

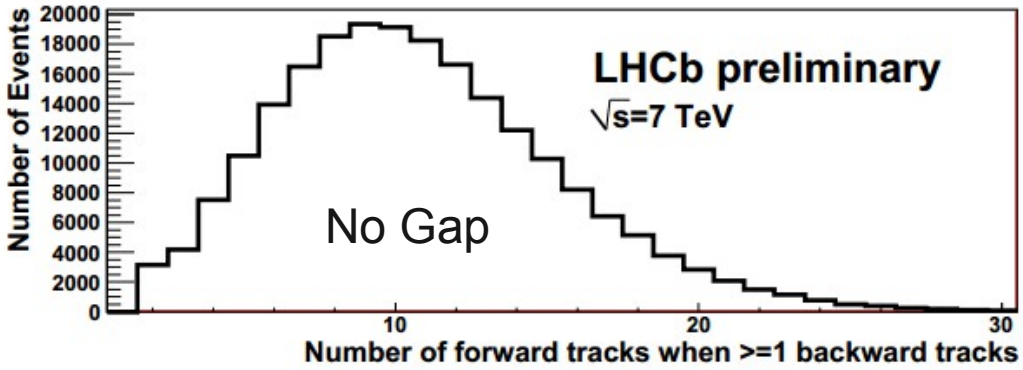
Selection

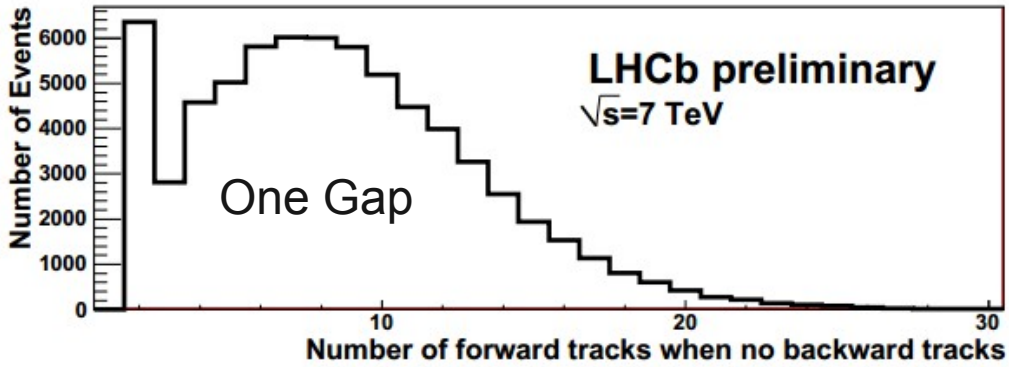
→ Rapidity Gap

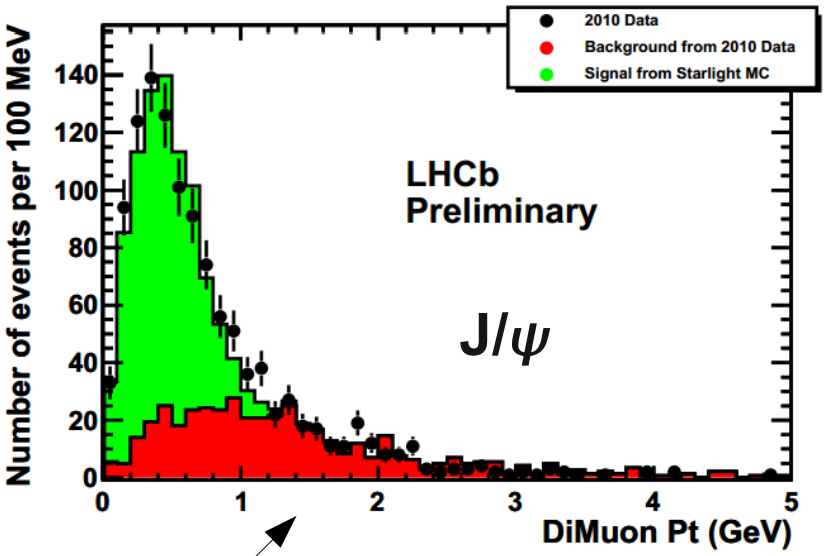
→ $M_{\mu\mu} > 2.9$ GeV or $p_{T\mu\mu} < 900$ MeV

Central Exclusive DiMuon

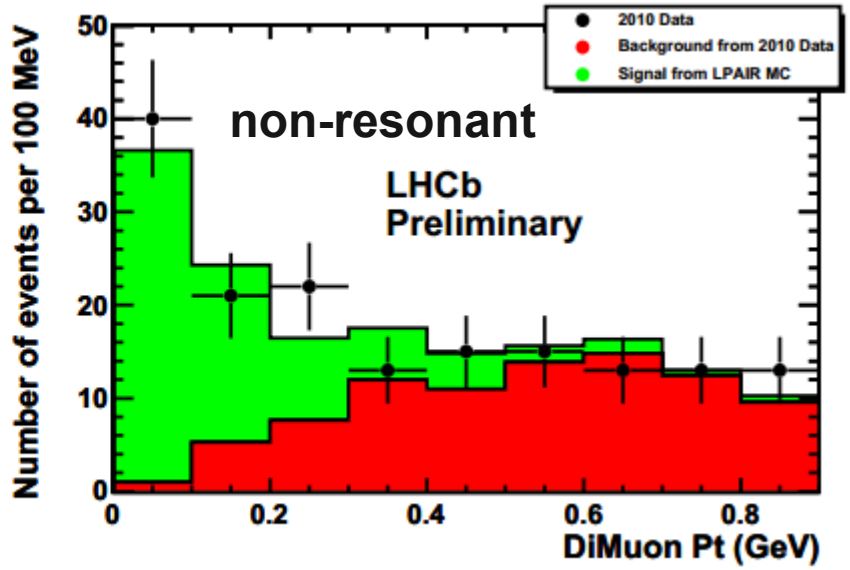
LHCb-CONF-2011-022



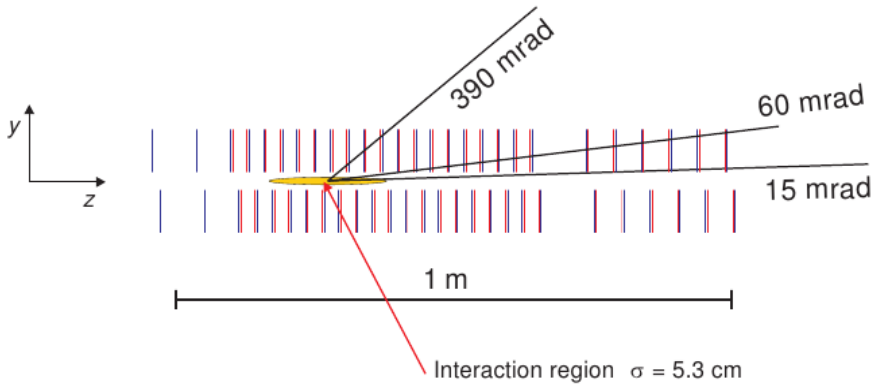




Requiring only 2 tracks

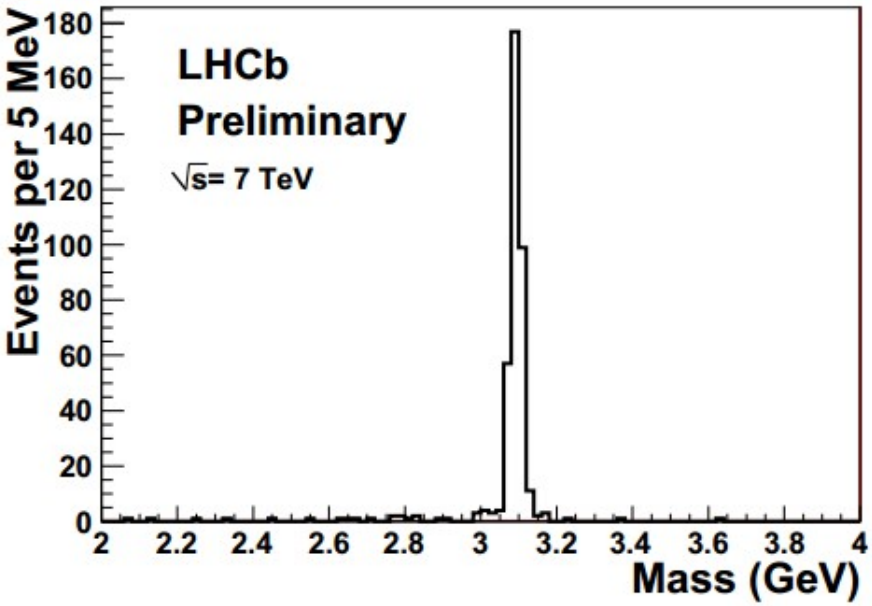


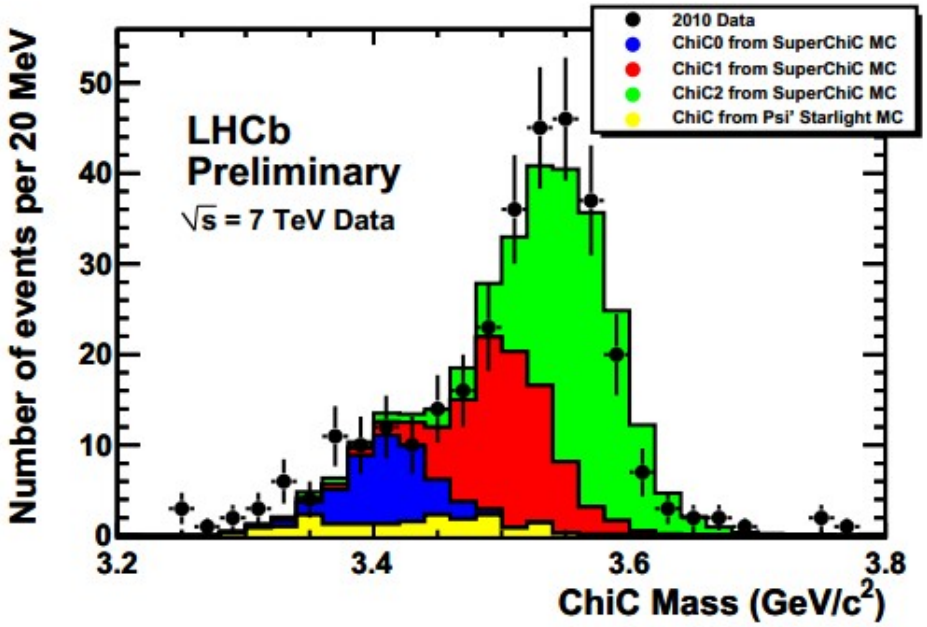
cross section at x=0:



LHCb-CONF-2011-022

.. and requiring 2 tracks and 1 photon





Preliminary Results

$\sigma_{J/\psi\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5) = 474\pm12\pm51\pm92$ pb

$\sigma_{\psi(2S)\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5) = 12.2\pm1.8\pm1.3\pm2.4$ pb

$\sigma_{\chi_c^0\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 9.3\pm2.2\pm3.5\pm1.8$ pb

$\sigma_{\chi_c^1\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 16.4\pm5.3\pm5.8\pm3.2$ pb

$\sigma_{\chi_c^2\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 28.0\pm5.4\pm9.7\pm5.4$ pb

$\sigma_{\gamma\gamma\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5;\ m_{\mu+\mu-}>2.5\ \text{GeV}/c^2) = 67\pm10\pm7\pm15$ pb

+/- Stat +/- Sys +/- Lumi

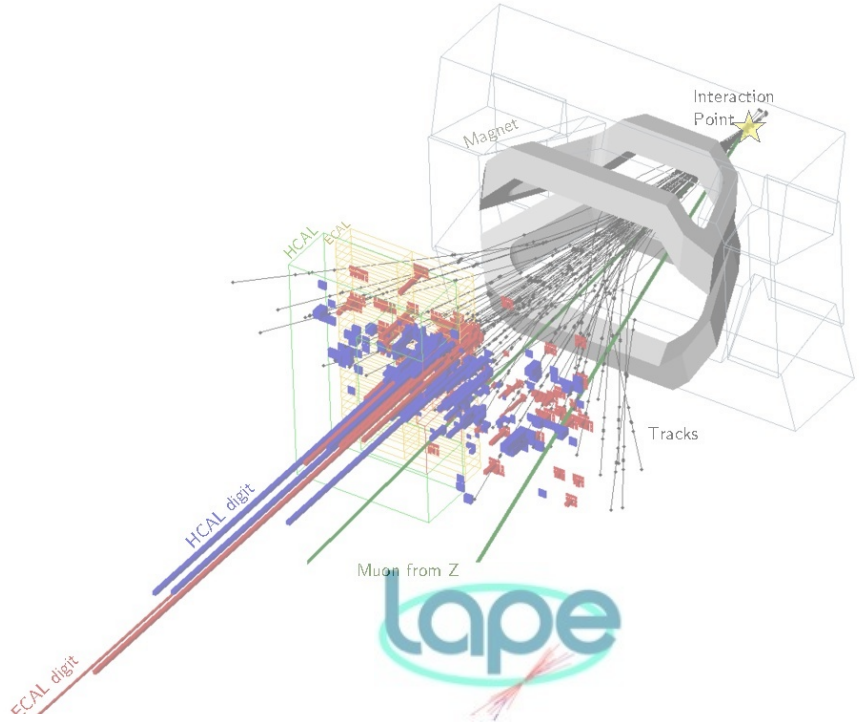
Summary

→ LHCb probes an unique range down to $x=8\times10^{-6}$

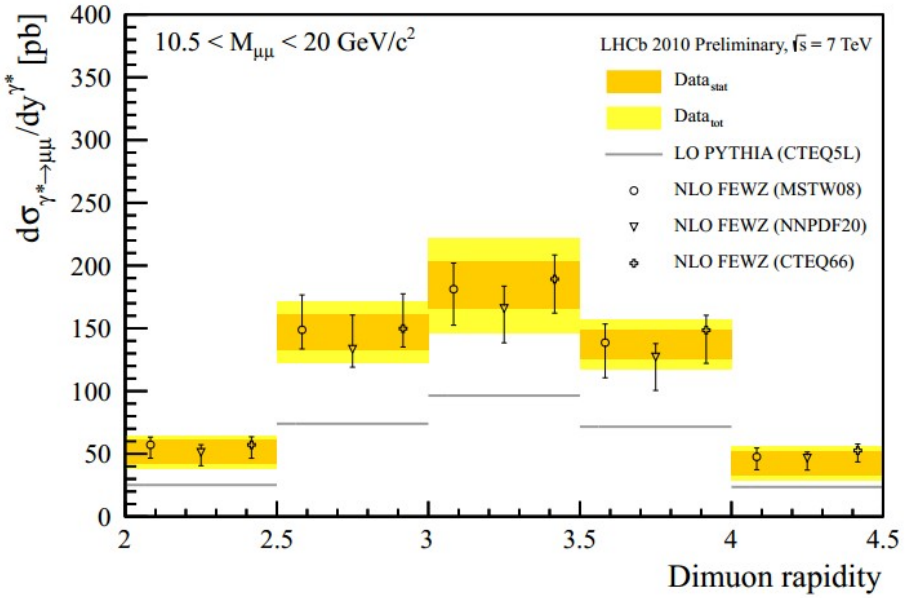
→ Measurements are in agreement with theoretical predictions and few of them already have precision comparable with theoretical uncertainties

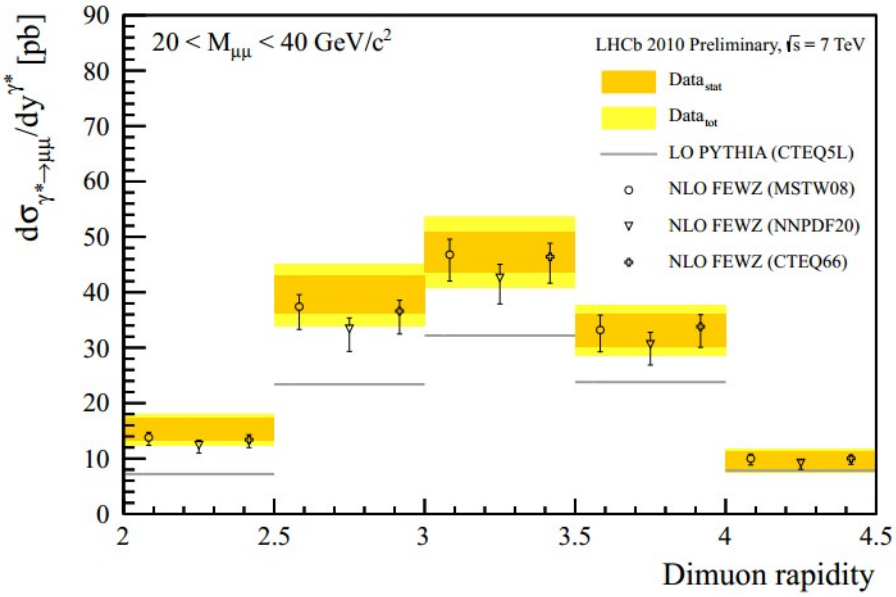
→ Many other measurements not covered in this talk are available here: LHCb Results (Energy Flow / Multiplicities / Flavor Production / ...)

→ Update with **2011 (7 TeV) / 2012 (8 TeV)** data will improve experimental precisions and will allow other studies



Low Mass Drell-Yan Production - Backup

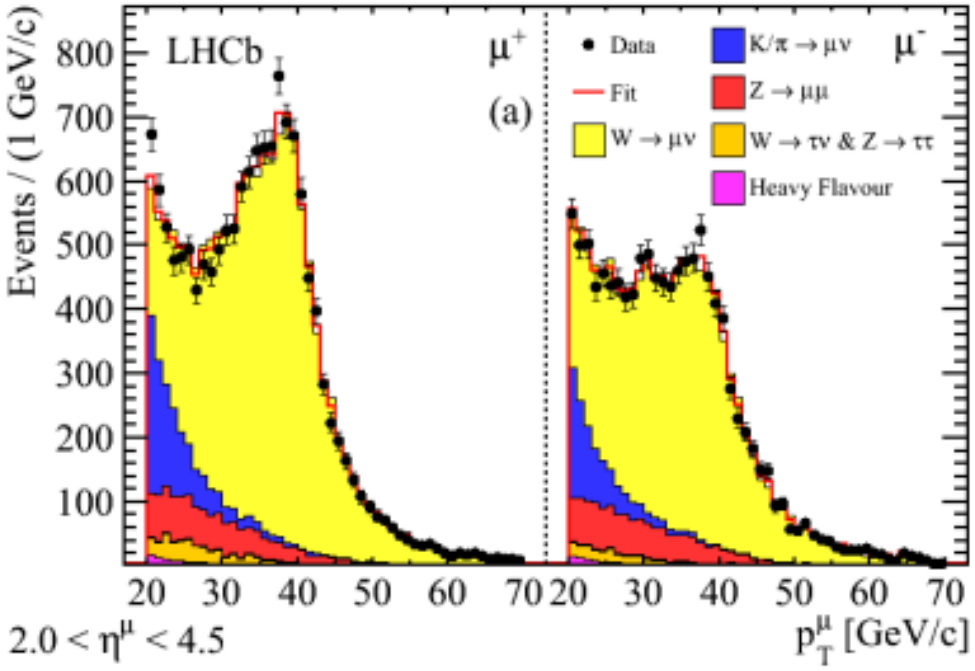




Normalization - BACKUP

	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



Inclusive Z production - BACKUP

Results compared to NNLO predictions (DYNNLO)with 6 recent PDF sets

- MSTW08. A. Martin, W. Stirling, R. Thorne and G. Watt
  arXiv:0901.0002
- ABKM09: S. Alekhin, J. Blumlein, S. Klein and S. Moch
  arXiv:0908.2766
- JR09: P. Jimenez-Delgado and E. Reya
  arXiv:0810.4274
- NNPDF D. Ball et al.
  arXiv:1002.4407
- HERA15 H1 and ZEUS collaboration
  arXiv: 0911.0884
- CTEQ6M P. M. Nadolsky et al. (NLO)
  arXiv:0802.0007

Inclusive Z production - BACKUP

Precision:	Z→ μμ	Z→ ee	Z→ ττ μe μμ
Statistical [%]	2.2	0.7	17 12
Luminosity[%]	3.5	3.5	5.1
Systematic[%]	4.3	3.1	16 10
Luminosity[pb]	37.5	945	247

Systematic uncertainties will reduce with more statistics

Dominant systematic uncertainties:
- Efficiencies 4.3%
- Purity 0.1%
- FSR corr. 0.02%

- Z→ ττ : limited by statistics
- Z→ μμ : limited by efficiency uncertainty (statistical)
- Z→ ee : luminosity uncertainty

Inclusive Z production - BACKUP

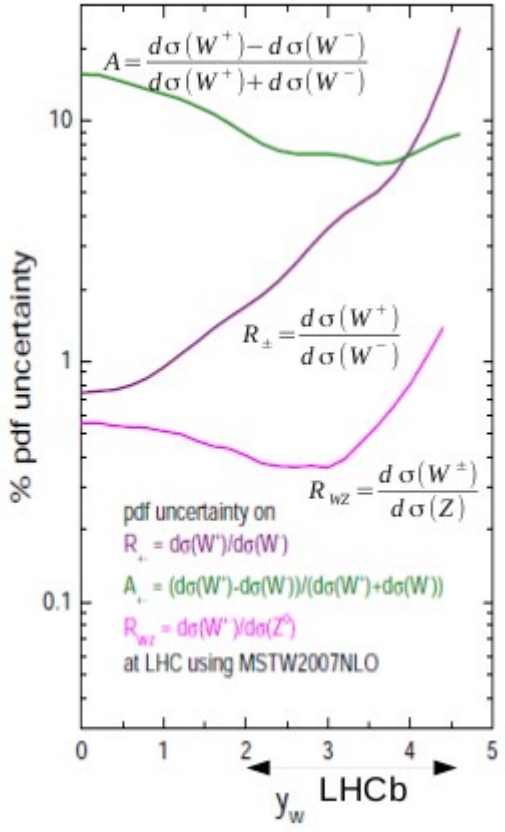
Cancel or highlight PDF uncertainties with ratios

- Many systematic uncertainties cancel
- Theoretical uncertainties partially cancel
- $A_W = (d\sigma(W^+) - d\sigma(W^-))/(d\sigma(W) + d\sigma(W^-))$

  tests valence quarks: difference btw. u_V and d_V
- $R_{+-} = d\sigma(W^+)/d\sigma(W^-)$

  tests valence quarks: u_V/d_V ratio
- $R_{WZ} = d\sigma(W^{+-})/d\sigma(Z)$

  almost insensitive to PDFs
  precise test of SM



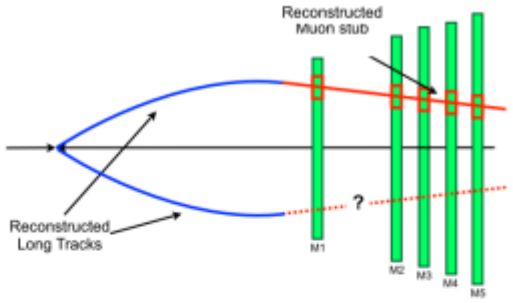
Plot from Thorne et al. (arXiv:0808.1847)

Inclusive Z production - BACKUP

$$\sigma = \frac{\rho N}{A L \epsilon} f_{FSR}$$

ρ: purity
A: acceptance
L: luminosity
ϵ: efficiency
N: candidates
f_{FSR}: final state radiation

Muon identification



Efficiencies mostly from data
tracking, identification and trigger: tag and probe in Z sample

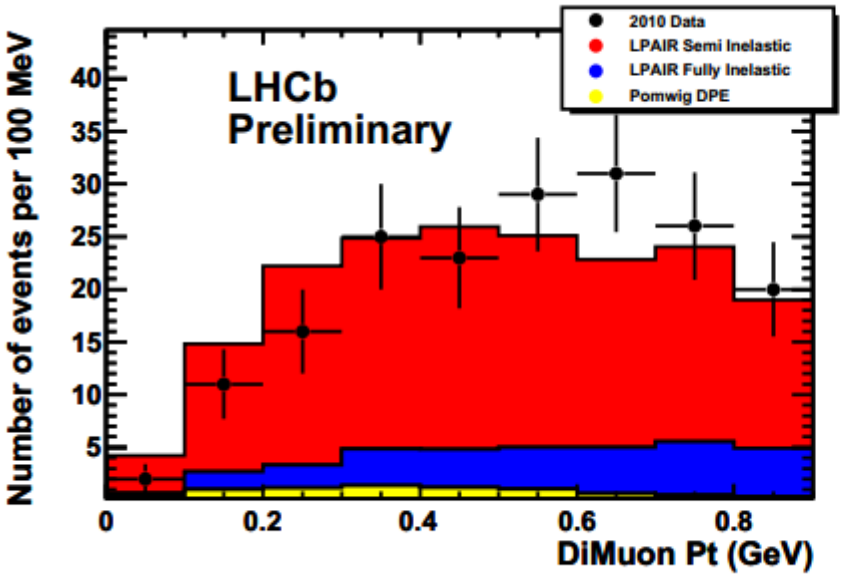
Tag:
well identified, triggered muon/electron
Probe:
Identification: fully reconstructed track
Tracking: muon-stub -TT hits
Trigger: identified muon/electron
Electron tracking from MC
Selection ($Z \to \tau\tau$) from MC
$\mu\mu$: $\epsilon_{sel} = 0.172 \pm 0.014$
μe: $\epsilon_{sel} = 0.46 \pm 0.03$
Acceptance:
Result within fiducial range of measurement

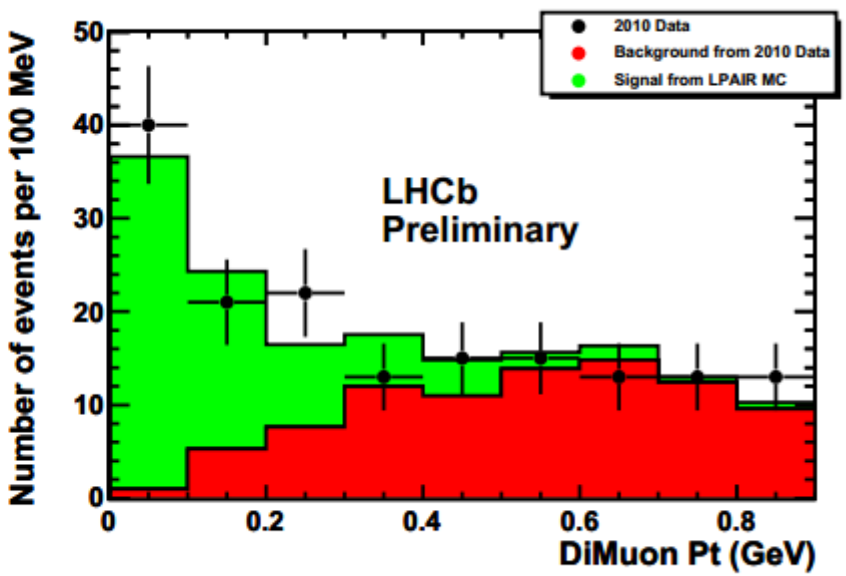
$Z \to \mu\mu$:	>0.99
$Z \to ee$:	0.4-0.6
$Z \to \tau\tau$:	0.25 (μe), 0.39 ($\mu\mu$)

Typical efficiencies
Tracking: 90%
Muon identification: >99%
Electron identification: 95%
Muon Trigger: 88%
Electron Trigger: 85%

Corrected event-wise as function of η_μ
Checked for charge bias

CEP - BACKUP

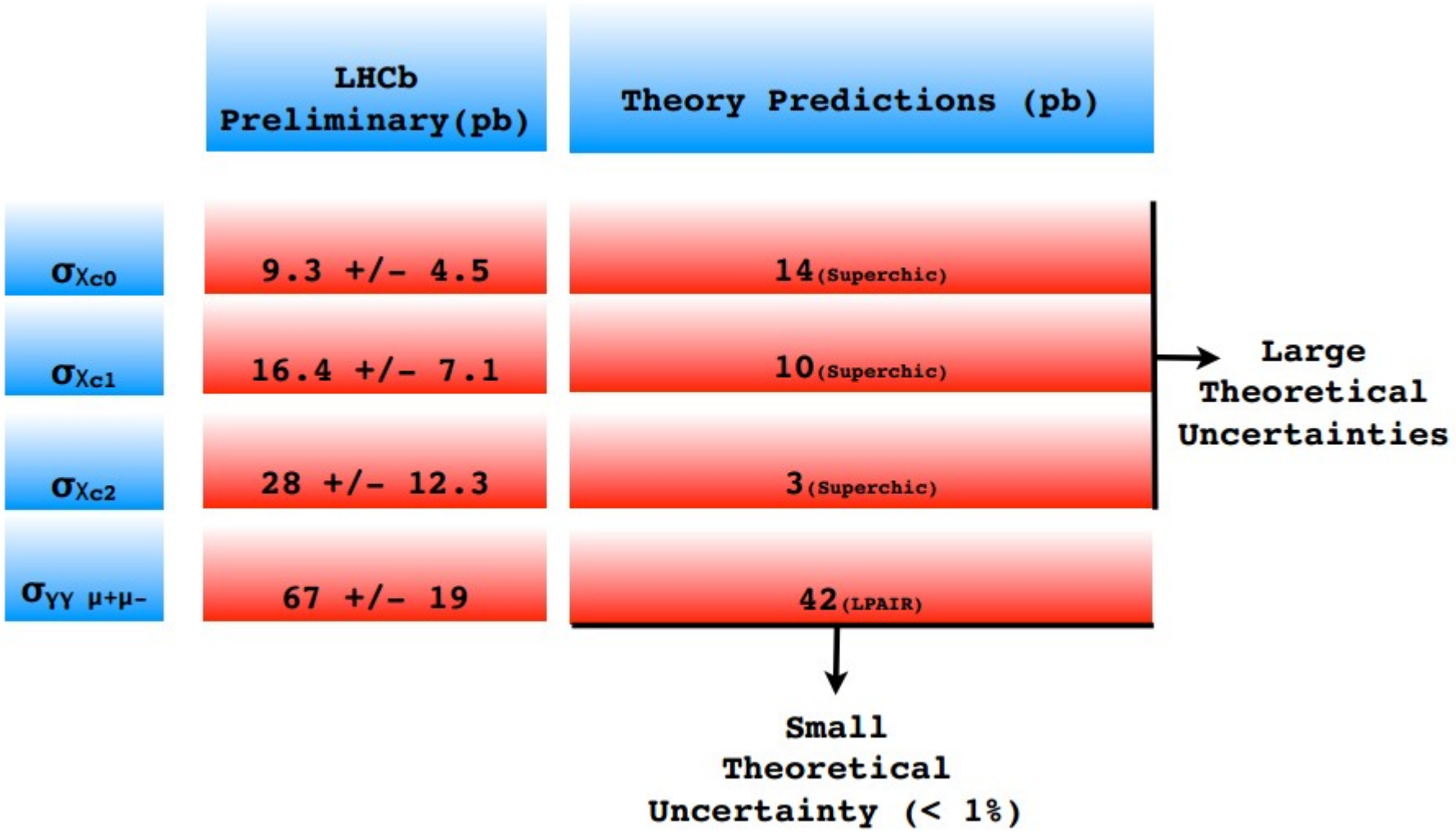

2010 Data
LPAIR Semi Inelastic
LPAIR Fully Inelastic
Pomwig DPE
LHCb
Preliminary
Number of events per 100 MeV
DiMuon Pt (GeV)


2010 Data
Background from 2010 Data
Signal from LPAIR MC
LHCb
Preliminary
Number of events per 100 MeV
DiMuon Pt (GeV)

	LHCb Preliminary(pb)	Theory Predictions (pb)
$\sigma_{J/\Psi}$	474 +/- 106	292 (Starlight) 330 (Superchic) 430 (Motyka&Watt)[5] 710 (Schafer&Szczurek)[6]
$\sigma_{\Psi(2S)}$	12.2 +/- 3.2	6.1 (Starlight) 17 (Schafer&Szczurek)
$J/\Psi/\Psi(2S)$	0.2 +/- 0.03	0.16 (Starlight) 0.2 (Schafer&Szczurek)

Also Measured at CDF: 0.14 +/-.05
and Hera: 0.17 +/-.01

[5]L. Motyka, G. Watt,, Phys. Rev. D 78, 014023 (2008).
[6]W. Schäfer, A. Szczurek, Phys.Rev. D76:094014,2007. arXiv:0811.2488.


LHCb Preliminary(pb)
Theory Predictions (pb)
σ_{Xc0}
9.3 +/- 4.5
14 (Superchic)
σ_{Xc1}
16.4 +/- 7.1
10 (Superchic)
σ_{Xc2}
28 +/- 12.3
3 (Superchic)
$\sigma_{\gamma\gamma\ \mu+\mu-}$
67 +/- 19
42 (LPAIR)
Large Theoretical Uncertainties
Small Theoretical Uncertainty (< 1%)

Energy Flow - BACKUP