“Fisica elettrodebole nella regione in avanti e ricerca di risonanze $b\bar{b}$ a LHCb”

Lorenzo Sestini (Università di Padova e INFN),
on behalf of the LHCb collaboration

IFAE, Università di Roma Tor Vergata, 9-4-2015

Motivation

- **LHCb** offers a **complementary phase space region** for electroweak and jets measurements respect to ATLAS and CMS.

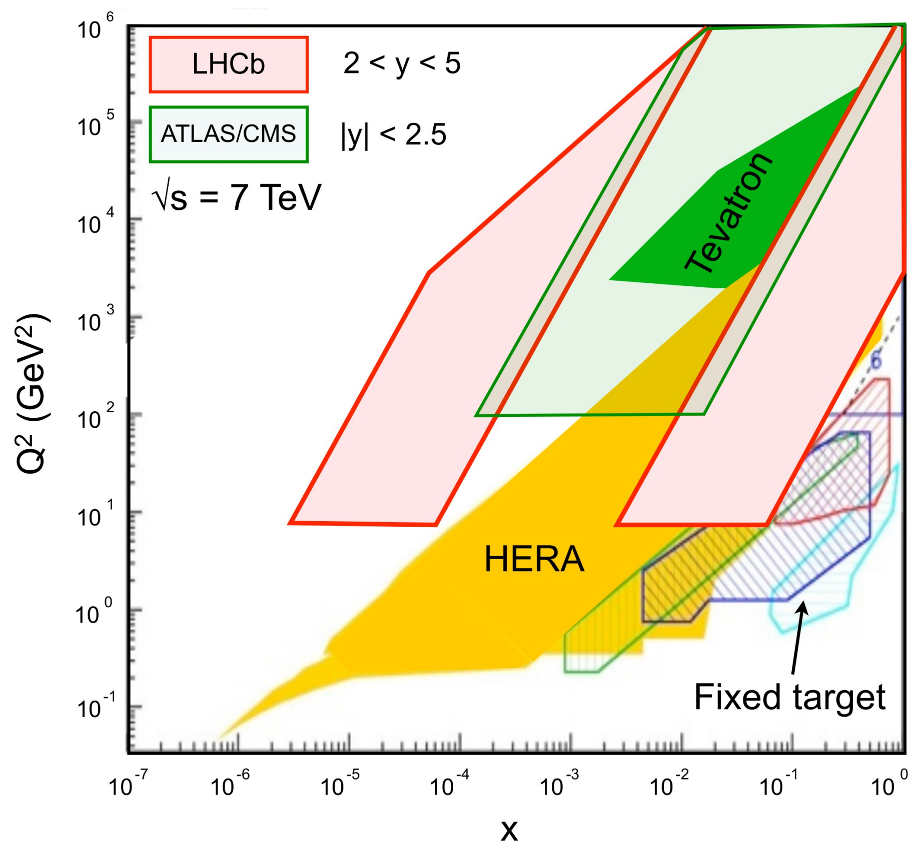
- It relies on **several specific features**:
  - **Unique acceptance**: $2 < \eta < 5$
  - **Cleanest LHC events**: <Pile-Up> ~ 2
  - **Very large bandwith trigger** for events with b jets and displaced vertices, efficient even at very low p_T.

- If **New Physics** produces events with no high p_T leptons but only events with low p_T jets, **only LHCb could fill this gap**!

- **Examples of New Physics searches:**
  - **$b\bar{b}$ resonances**.
  - 4 b final states.

Motivation

- Within the **Standard Model** there are measurements unique to **LHCb**:
  - **Precision measurements of $\sigma_{W(Z)}$** in the forward region are important tests of perturbative QCD and EWK theory.
  - **$b\bar{b}$ cross section** and multiple b cross section in the forward region.
  - **$b\bar{b}$ correlations and asymmetries**.
  - Measurement in the forward region **provide unique access to PDFs (x,Q^2)**. **Two different region are available**: one well understood and the other **unexplored** (at low x and large Q^2).



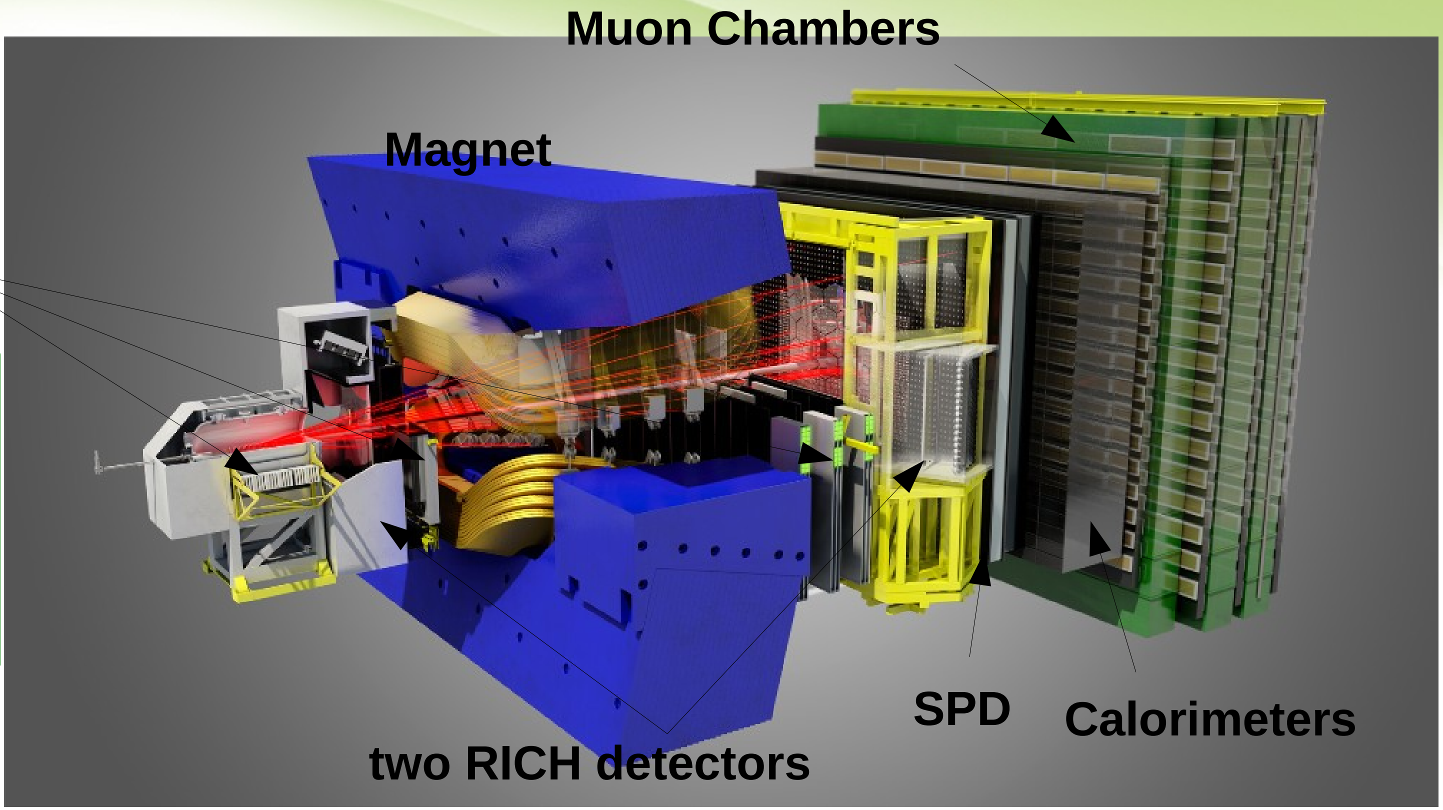
$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$

LHCb detector

Vertex Locator and tracking system: B and D vertex position and track momenta

IP resolution: 20 μm

$\Delta p / p = 0.4\,\%$ at 5 GeV/c to 0.6 % at 100 GeV/c



Particle ID performances

kaon ID efficiency:
~ 95 % for ~ 5 % $\pi \to K$ mis-id probability
muon ID efficiency:
~ 97 % for 1-3 % $\pi \to \mu$ mis-id probability

Calorimeters performances

ECAL resolution:
$1\,\% + 10\,\% / \sqrt{E[\mathrm{GeV}]}$
HCAL resolution:
$9\,\% + 69\,\% / \sqrt{E[\mathrm{GeV}]}$

Not the best for jets physics...

Forward W production at 7 TeV

JHEP (1412) 2014 079

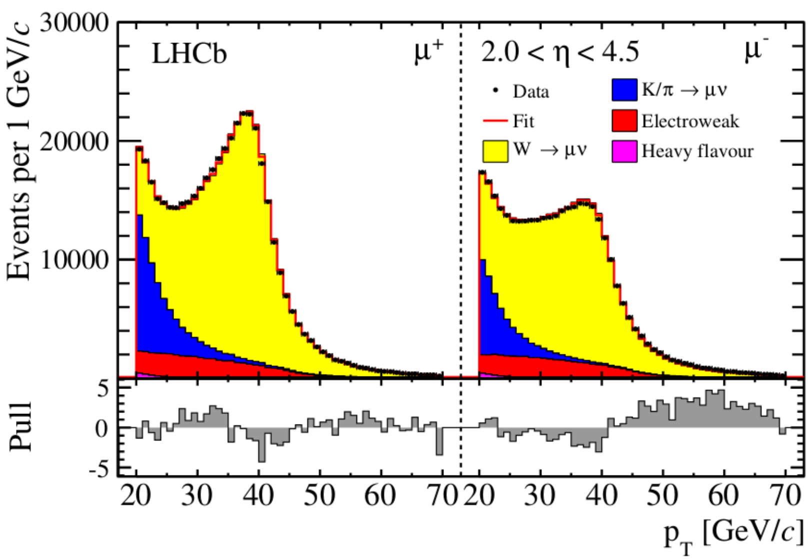
Forward W production at 7 TeV

- **Measurement**: **inclusive W → μν production cross section**
- **Motivations:** Test theoretical predictions at low Bjorken-x values, where the uncertainties of PDFs are large.
- **Data**: 1 fb^{-1} from pp collisions at 7 TeV
- **Muon final state**: $p_T > 20$ GeV, $2 < \eta < 5$
- **Selection requirements**:
  - Muon isolation from jets
  - Second high p_T muon vetoed (pT > 2 GeV)
  - muon IP < 40 μm, to reduce μ from τ decay or from heavy flavour semileptonic decay
  - Remove hadronic punch through: $E_{calo}/p < 0.4\%$
- **Yield extraction**: $p_T(\mu)$ distribution fit

Backgrounds and signal templates:

- $W \rightarrow \mu\nu$ signal: Pythia+ResBos
- K/π decay on flight: data
- $Z \rightarrow \mu\mu$, $W \rightarrow \tau\nu$, $Z \rightarrow \tau\tau$: simulation
- Heavy flavour decays: data

Number of candidates: 806,094



Forward W production at 7 TeV

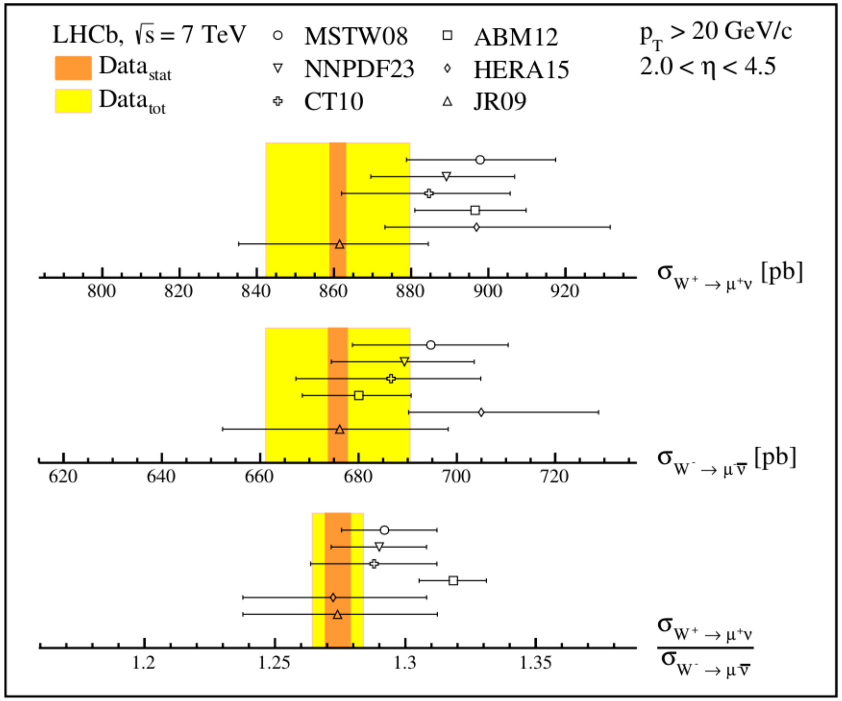
- The **integrated cross section** ($p_T(\mu) > 20$ GeV, $2 < \eta < 5$) is:

$$\sigma_{W^+\to\mu^+\nu} = 861.0 \pm 2.0 \pm 11.2 \pm 14.7\,\text{pb},$$
$$\sigma_{W^-\to\mu^-\overline{\nu}} = 675.8 \pm 1.9 \pm 8.8 \pm 11.6\,\text{pb},$$

$$R_W = \frac{\sigma_{W^+\to\mu^+\nu}}{\sigma_{W^-\to\mu^-\overline{\nu}}} = 1.274 \pm 0.005 \pm 0.009,$$

where the first error is statistical, the second systematic and the third is due to the luminosity determination.

- The **systematic uncertainty** is dominated by the limited knowledge of the reconstruction efficiency.
- The measurements **agree well with the SM predictions**, calculated at NNLO in perturbative QCD. Several parametrizations of PDFs are used.



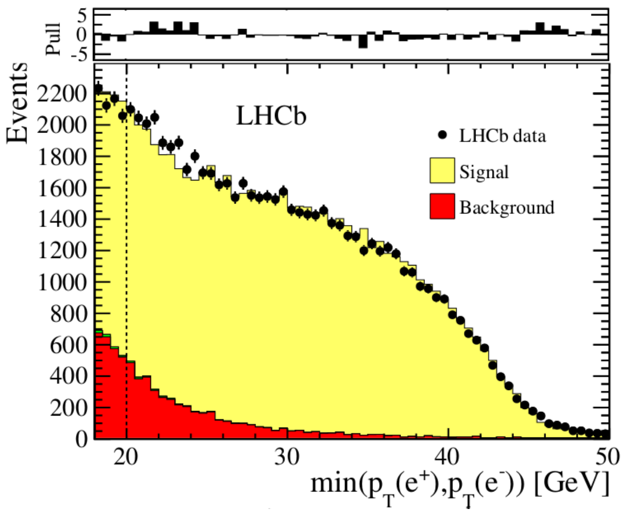
Forward $Z \rightarrow e^+e^-$ production at 8 TeV

arXiv: 1503.00963

Forward Z $\rightarrow$ e^+e^- production at 8 TeV

- **Measurement**: **inclusive Z $\rightarrow$ e^+e^- production cross section**
- **Motivations:** Measurement sensitive to knowledge of PDFs at very low Bjorken-x.
- **Data**: 2 fb^{-1} from pp collisions at 8 TeV
- **Acceptance**: electrons with $p_T > 20$ GeV, $2 < \eta < 5$
- **Electrons pass through a significant amount of material**:
  - Large amount of **bremsstrahlung** before magnet.
  - This effect is partially recovered using calorimeter.
  - Momenta degraded by ~ 25%, but well known direction
- **Selection**:
  - Momentum uncertainties < 10%
  - Significative HCAL and ECAL deposits
  - $60 < M_{ee} < 120$ GeV
- **Background contributions**:
  - hadron mis-ID: subtract $e^{\pm}e^{\pm}$ from data.
  - 0.2% contribution from $Z \rightarrow \tau\tau$ evaluated in MC.

65,552 candidates



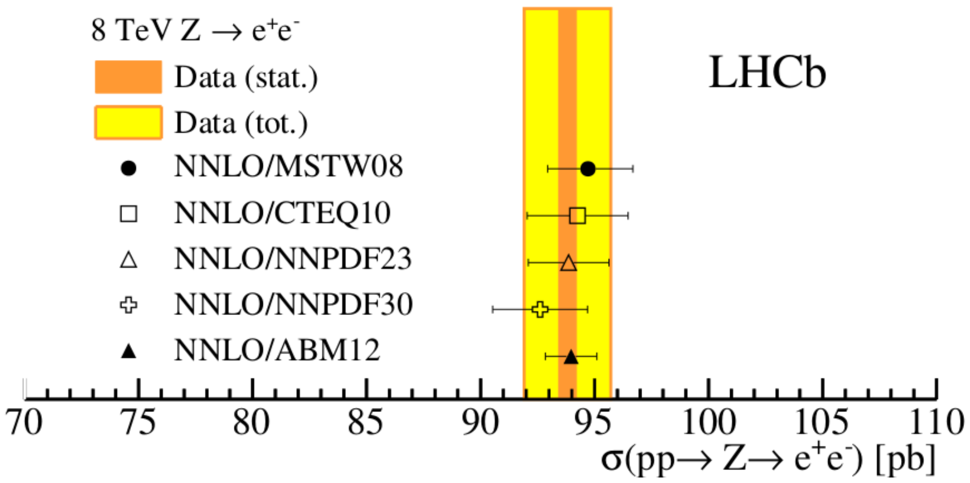
Forward Z → e^+e^- production at 8 TeV

- The main source of **systematic uncertainty** is in the evaluation of the tracking efficiency (1.0 %).

- **Integrated cross section**:

$$\sigma(\mathrm{pp} \to \mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-) = 93.81 \pm 0.41(\mathrm{stat}) \pm 1.48(\mathrm{syst}) \pm 1.14(\mathrm{lumi})\ \mathrm{pb}$$

- **Results are compared to NNLO QCD predictions using different PDFs.**



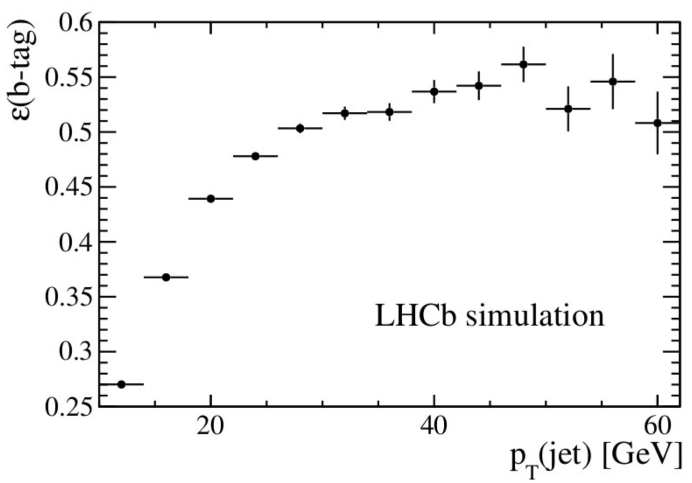
- Predictions agree well with data down to x = 10^{-6}.

Forward Z + b-jet production at 7 TeV

JHEP 1501 (2015) 064

Forward Z + b-jet production at 7 TeV

- **Measurement**: **Z (→ μμ) production cross section in association with a bottom quark**.
- **Motivations**: Test perturbative QCD predictions. Probe the capability of LHCb to jets physics.
- **Data**: 1 fb^{-1} from pp collisions at 7 TeV.
- **Fiducial region**:
  - muons and jet with $2 < \eta < 4.5$
  - muon $P_T > 20$ GeV
  - two different jet energy thresholds are considered: 10 and 20 GeV
- **Benchmark measurement**:
  - Sensitive to **proton PDF**.
  - Constraints **SM Higgs and BSM background**.
  - **Complementary with ATLAS and CMS measurements** (jet $P_T > 25$ GeV, $|\eta|<2.1$).
- **Jet reconstruction and tagging**:
  - **Particle flow**: charged track and calo clusters.
  - **Anti – K_t** clustering algorithm, R = 0.5.
  - Jet isolated from muons: $\Delta R(\text{jet},\mu) > 0.4$.
  - **b-tagging**: secondary vertices using 2,3,4 tracks in the jet.



b-tag efficiency obtained from simulation

Forward Z + b-jet production at 7 TeV

- **Fit strategy**:
  - Fit to the **corrected SV mass**:

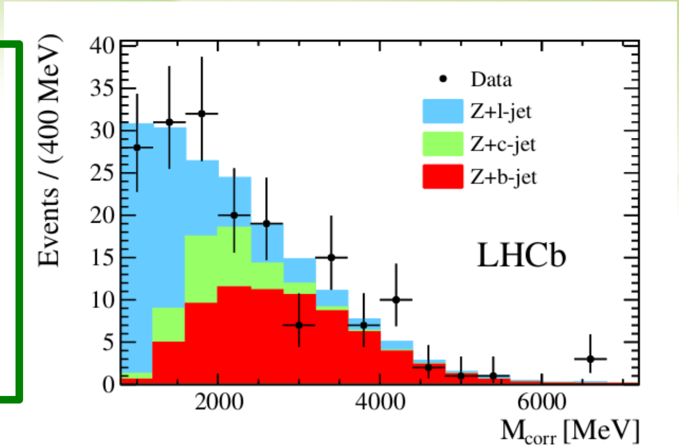
$$M_{\rm corr} \equiv \sqrt{M^2 + p^2 \sin^2\theta} + p \sin\theta$$

  - Background templates taken from MC.

P_T(jet) > 10 GeV:

179 candidates

75 ± 15 b-jet fitted events



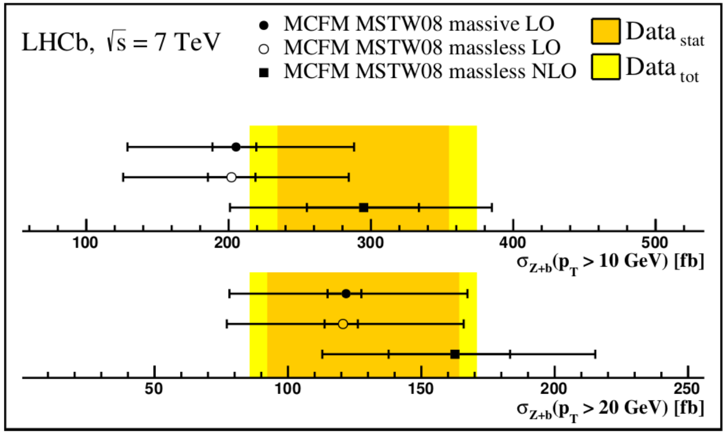
- **Systematic uncertainties** dominated by b-tag efficiency and purity determination (15%).

- **Results**:
  - p_T(jet) > 10 GeV:

$$\sigma(Z/\gamma^*(\mu^+\mu^-)\text{+b-jet}) = 295 \pm 60\ (\text{stat}) \pm 51\ (\text{syst}) \pm 10\ (\text{lumi})\ \text{fb}$$

  - p_T(jet) > 20 GeV:

$$\sigma(Z/\gamma^*(\mu^+\mu^-)\text{+b-jet}) = 128 \pm 36\ (\text{stat}) \pm 22\ (\text{syst}) \pm 5\ (\text{lumi})\ \text{fb}$$



- Results are compared to MCFM calculation with massless (LO, NLO) or massive (LO) b-quarks. Predictions are corrected for hadronization and fragmentation using Pythia 8. **Results are consistent with the predictions**.

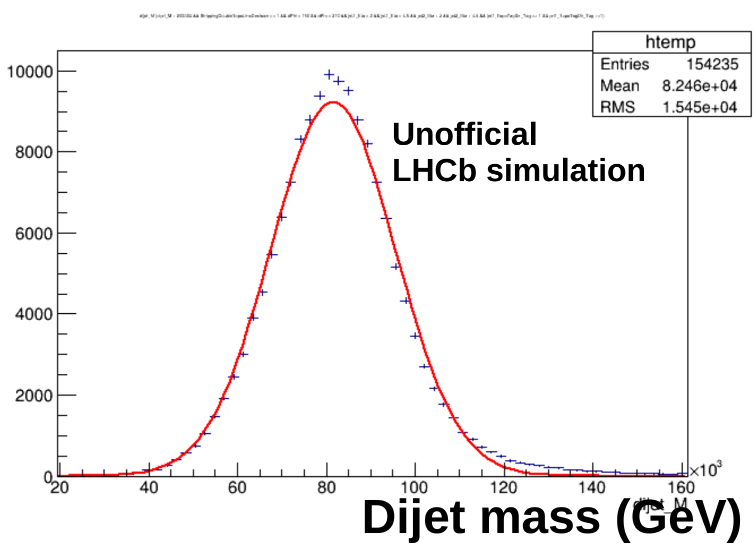
Moving on: search for $b\bar{b}$ resonances

- **Jet-capability** at LHCb demostrated: **Z + b-jets**, **forward-central $b\bar{b}$ asymmetry** (LHCb-CONF-2012-014), **$b\bar{b}$ cross section** (LHCb-CONF-2013-002).
- **H → $b\bar{b}$** decay not yet “discovered” at ATLAS and CMS (significance < 3 σ)
- We can search for the **H → $b\bar{b}$ production in the forward region**:
  - **Higgs production associated to a vector boson** in order to reduce the background
- **Backgrounds study needed**:
  - $W^{\pm} b\bar{b}$
  - $Z b\bar{b}$
  - QCD combinatorial
- **Hadronic trigger lines** for these analysis are currently under studying.
- Several **New Physics searches** will be possibile:
  - $b\bar{b}$ resonances
  - 4 b final states

Dijets resonances: $Z \rightarrow b\,\bar{b}$

- If we want to understand our data samples to look for **New Physics**, we have to start with something we already know it exists.
- The purpose of this study is to understand if we can reconstruct and identify the $\mathbf{Z \rightarrow b\,\bar{b}}$ decay. In this way we can:
  - Measure the $Z \rightarrow b\,\bar{b}$ cross section.
  - Determine the best R parameter for the jet cone.
  - Test and validate **the background modeling**.
  - Validate the jet energy scale and improve if necessary.

- **Peak resolution** estimated on LHCb simulation (≃ 14 GeV with R=0.7 and both jets b-tagged).
- S/B estimated using selection efficiencies (not optimized) and $Z \rightarrow b\,\bar{b}$ NNLO cross section: **S/B ≃ 0.03**
- We are using the **tag-and-probe** technique to evaluate the jet tagging probability, in order to modeling the background.



Conclusions

- LHCb is continuing with success its **electroweak program**.
- LHCb is able to **complement with ATLAS and CMS** for EW and QCD measurements.
- We are successfully branching into **jets physics**.
- In the next months several preliminary measurements needed for **$b\bar{b}$ resonances searches** are expected.

Backup Slides

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	—

		Fractional uncertainty	
	Average value	Uncorrelated	Correlated
ϵ_{track}	0.912	0.001	0.010
ϵ_{kin}	0.507	0.002	0.006
ϵ_{PID}	0.838	0.001	0.007
ϵ_{GEC}	0.916	—	0.006
ϵ_{trig}	0.892	0.001	—
ϵ	0.319	0.002	0.016
f_{MZ}	0.969	0.001	—
Background estimation	—	—	0.004
$\int \mathcal{L}\mathrm{d}t$ / pb^{-1}	1976	—	0.012

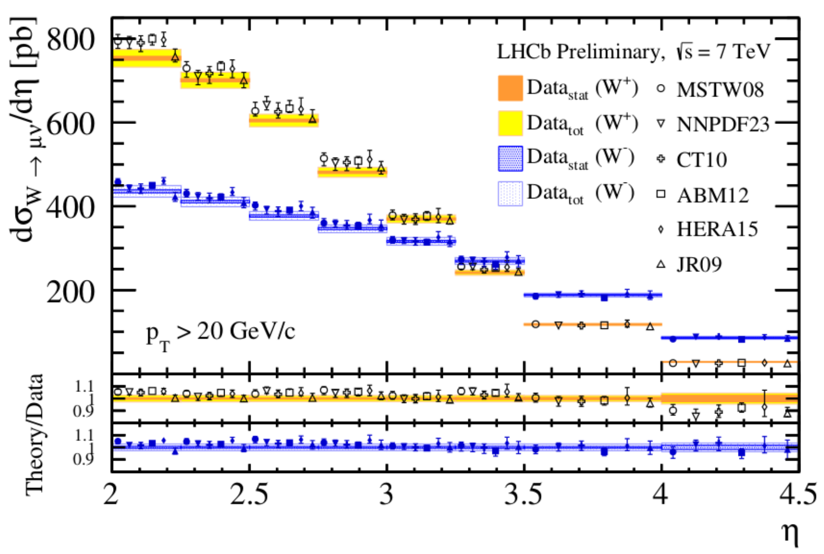
Source of systematic uncertainty	Relative uncertainty (%)
Z boson reconstruction	3.5
Unfolding	1.5
Jet-energy scale, resolution and reconstruction	7.8
Final-state radiation	0.2
Luminosity	3.5
M_{corr} template and b-tagging	15.0
Jet reconstruction flavour dependence	2.0
Total	17.8

Forward W production at 7 TeV

- Cross section measured in 8 bin of η:

$$\sigma_{W^\pm\to\mu^\pm\nu}(\eta_i) = \frac{1}{\mathcal{L}}\cdot\frac{N_W\cdot\rho^\pm(\eta_i)}{\mathcal{A}^\pm(\eta_i)\cdot\varepsilon_{\rm rec}(\eta_i)\cdot\varepsilon_{\rm sel}(\eta_i)}\cdot\frac{1}{1-f^\pm_{\rm FSR}(\eta_i)},$$

  - **Acceptance *$A^\pm$*** for reduced p_T range obtained from MC (>99%)
  - **ε_{rec}** evaluated in Z → μμ data via tag-and-probe (60-75%)
  - **ε_{sel}** evaluated in Z → μμ and corrected for harder pT (30-70%)
  - ***f_{FSR}*** final state radiation correction evaluated from MC (1-2%)



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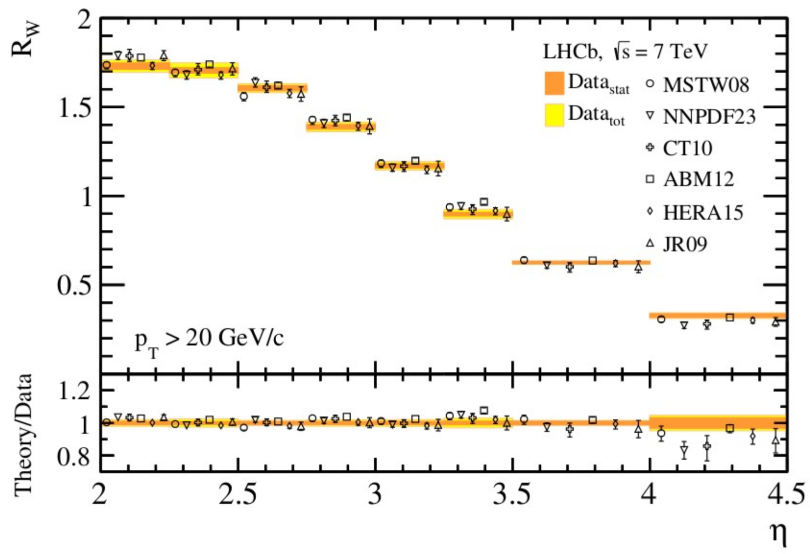

Forward Z $\rightarrow$ e^+e^- production at 8 TeV

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- **Motivations:** Measurement sensitive to knowledge of PDFs at very low Bjorken-x.
- **Data**: 2 fb^{-1} from pp collisions at 8 TeV
- **Acceptance**: electrons with $p_T > 20$ GeV, $2 < \eta < 5$
- **Electrons pass through a significant amount of material**:
  - Large amount of **bremsstrahlung** before magnet.
  - This effect is partially recovered using calorimeter.
  - Momenta degraded by ~ 25%, but well known direction
- **Cross section measured in**:
  - bins of y_Z
  - bins of Φ*:

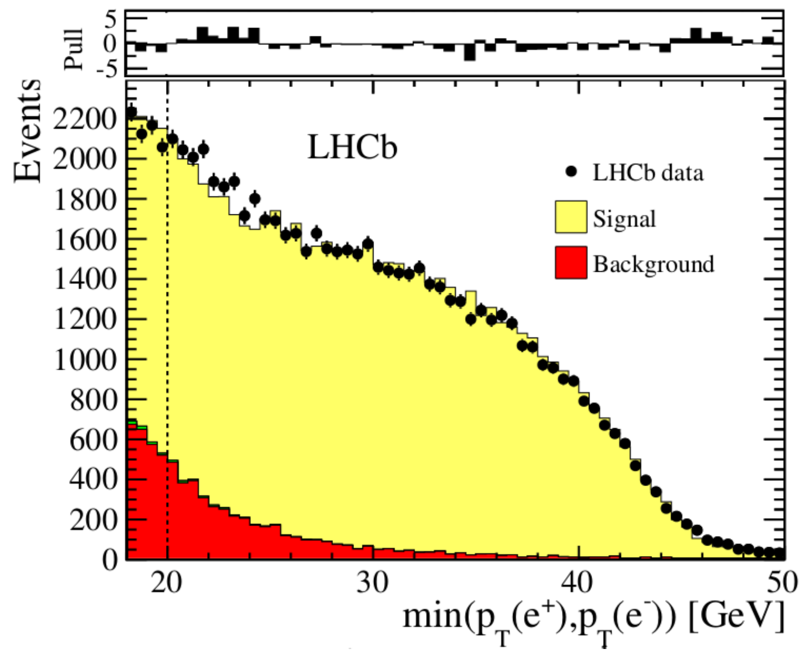
$$\phi^* \equiv \frac{\tan(\phi_{\rm acop}/2)}{\cosh(\Delta\eta/2)} \approx \frac{p_{\rm T}}{M}$$

- **Selection**:
  - Momentum uncertainties < 10%
  - Significative HCAL and ECAL deposits
  - $60 < M_{ee} < 120$ GeV

→ **65,552 candidates**

Forward Z → e^+e^- production at 8 TeV

- **Background contributions**:
  - hadron mis-ID: subtract $e^{\pm}e^{\pm}$ from data.
  - 0.2% contribution from Z → τ τ evaluated in MC.



- **Cross section**:

$$\sigma = \frac{N(e^+e^-) - N(e^{\pm}e^{\pm}) - N_{bg}}{\epsilon \cdot \int \mathcal{L}dt} \cdot f_{MZ}$$

- **The efficiency ε** takes into account:
  - inefficiency due to bremsstrahlung causing failure of kinematic requirements (51%).
  - Tracking (94%), PID (84%) and trigger (89%) efficiencies evaluated in simulation and validated on data.

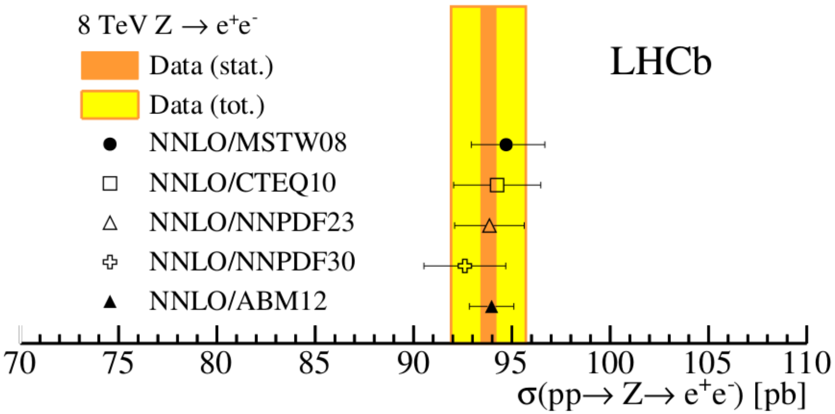
- **The factor f_{MZ}** takes into account of the limited invariant mass range (97%).

- The main source of **systematic uncertainty** is in the evaluation of the tracking efficiency (1.0 %).

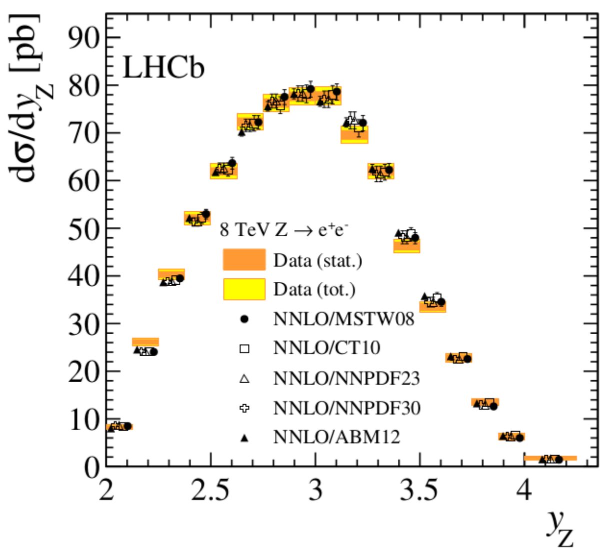
Forward Z → e⁺e⁻ production at 8 TeV

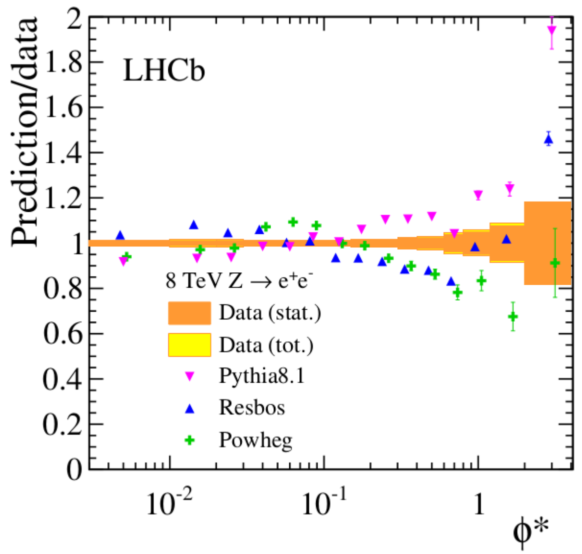
- **Integrated cross section**:

$$\sigma(pp \to Z \to e^+e^-) = 93.81 \pm 0.41(\mathrm{stat}) \pm 1.48(\mathrm{syst}) \pm 1.14(\mathrm{lumi})\ \mathrm{pb}$$



- **Results are compared to NNLO QCD predictions using different PDFs.**





- Predictions agree well with data down to x = 10^{-6}.