Associated Boson Production
MPI@LHC 2014

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on behalf of the LHCb collaboration

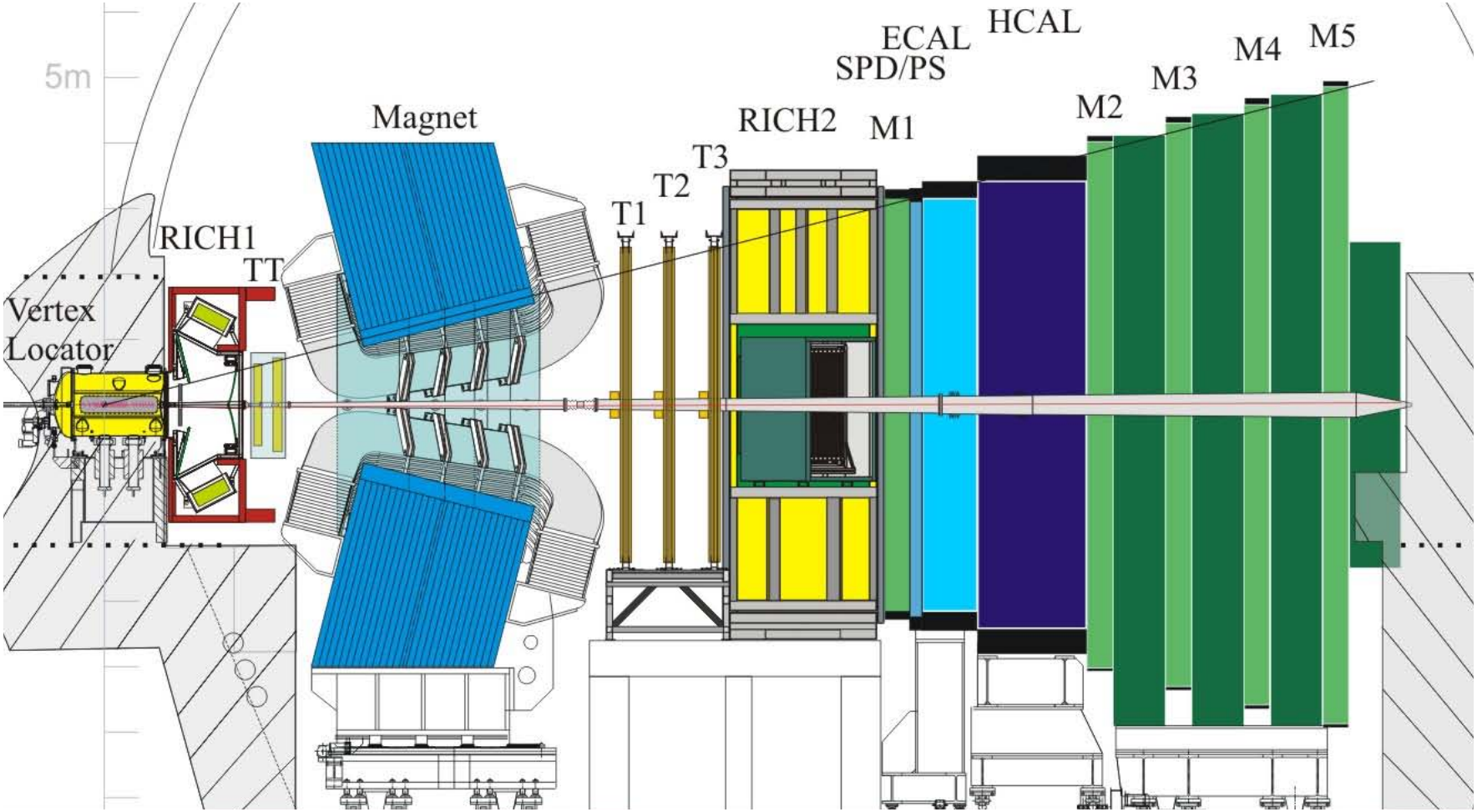
University of Zurich

Tuesday November 4th, 2014

University of Zurich[UZH]

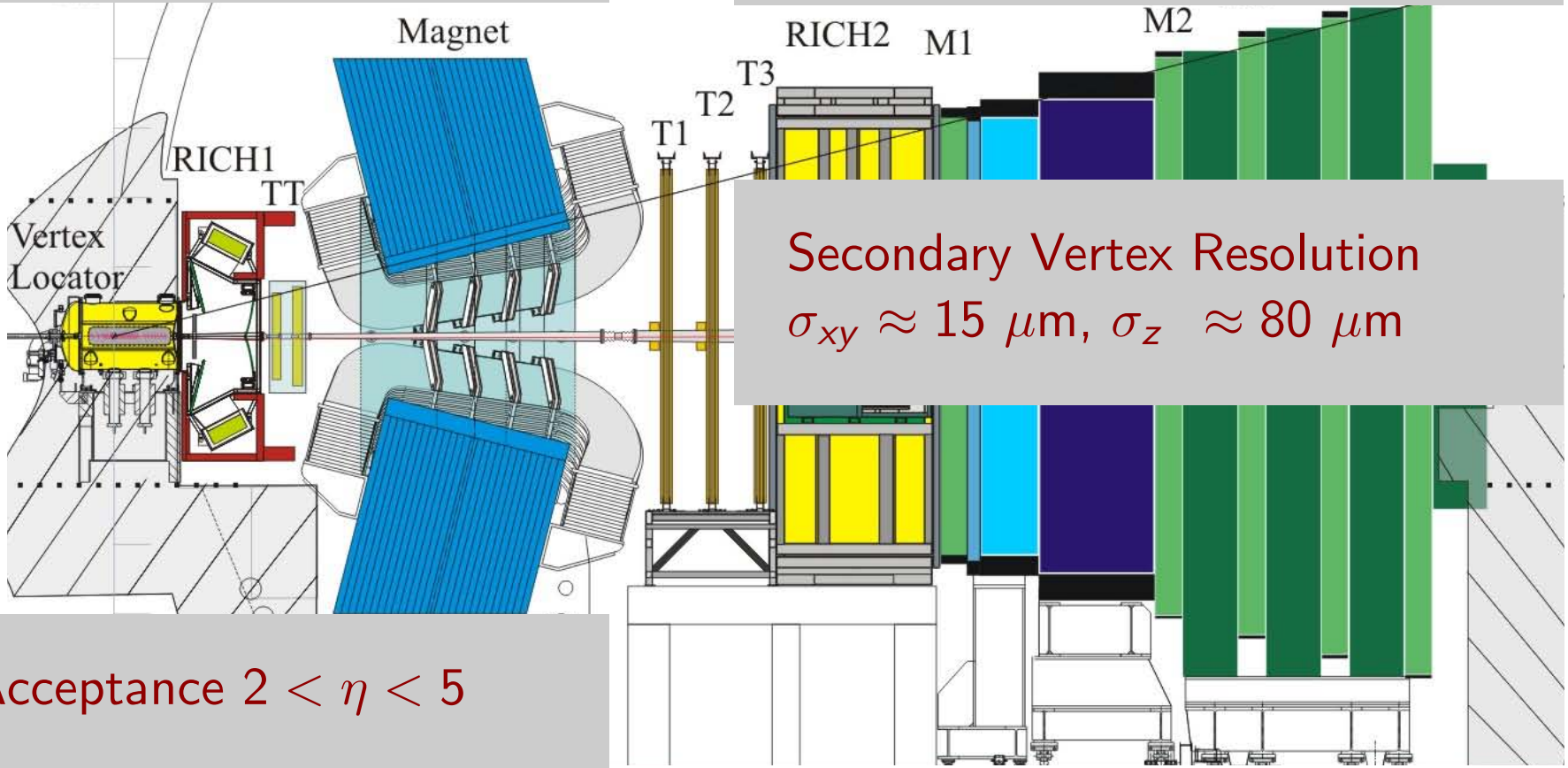
Outline

LHCb Experiment



Kaon Identification
$\varepsilon \approx 90\%$, mis-ID$< 5\%$

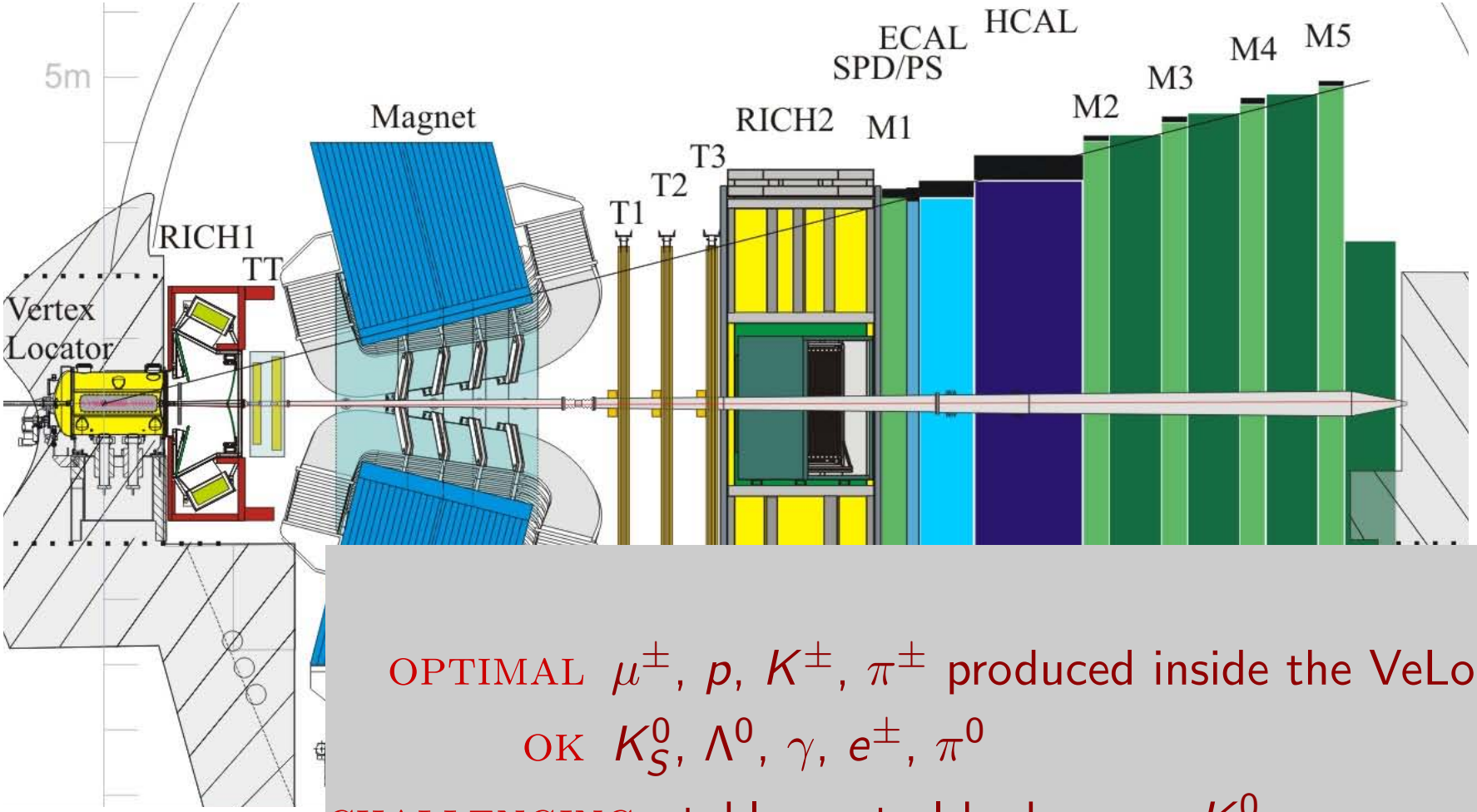
Muon Identification $\varepsilon \approx 97\%$,
mis-ID$\approx 0.7\%$ at high p_T



Secondary Vertex Resolution
$\sigma_{xy} \approx 15\ \mu$m, $\sigma_z \approx 80\ \mu$m

Acceptance $2 < \eta < 5$

LHCb Experiment

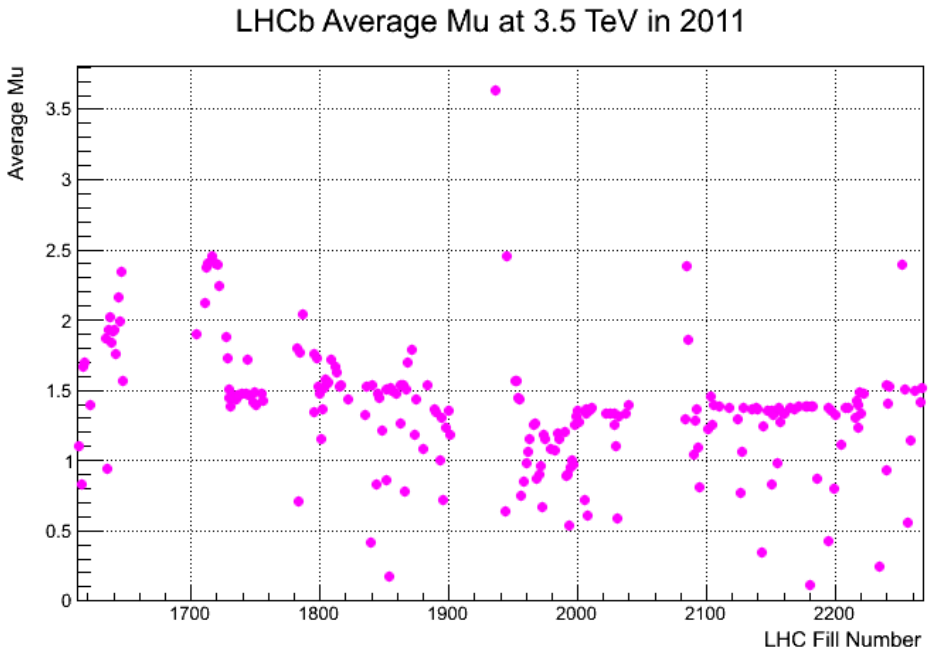


OPTIMAL $\mu^{\pm}$, p, $K^{\pm}$, $\pi^{\pm}$ produced inside the VeLo

OK K^0_S, Λ^0, γ, $e^{\pm}$, π^0

CHALLENGING stable neutral hadrons n, K^0_L

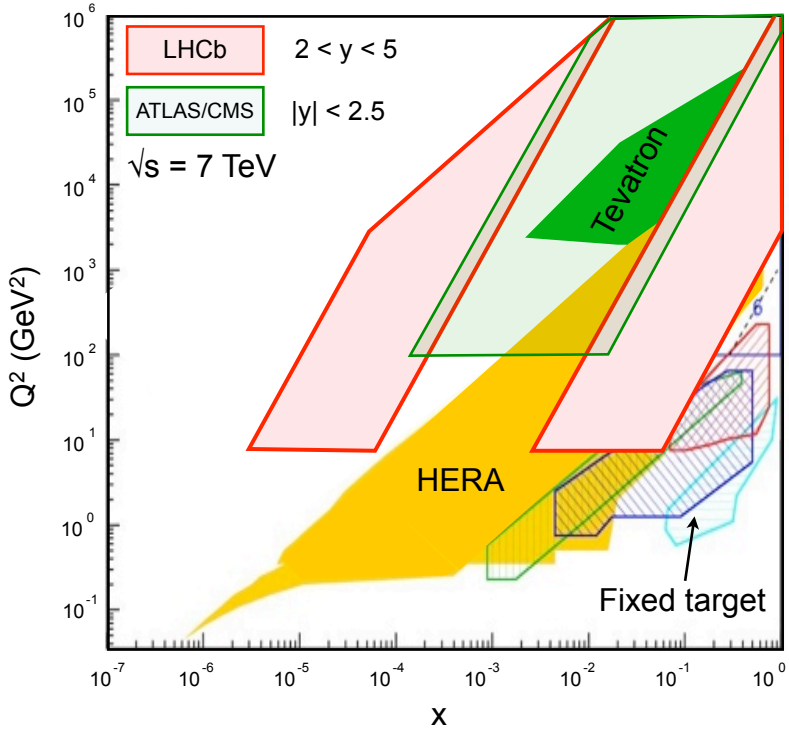
Data Taking in LHCb in 2011



- High pileup $\mu \leq 2$.
- Since 2011 the luminosity is *levelled* leading to stable conditions for the full year.

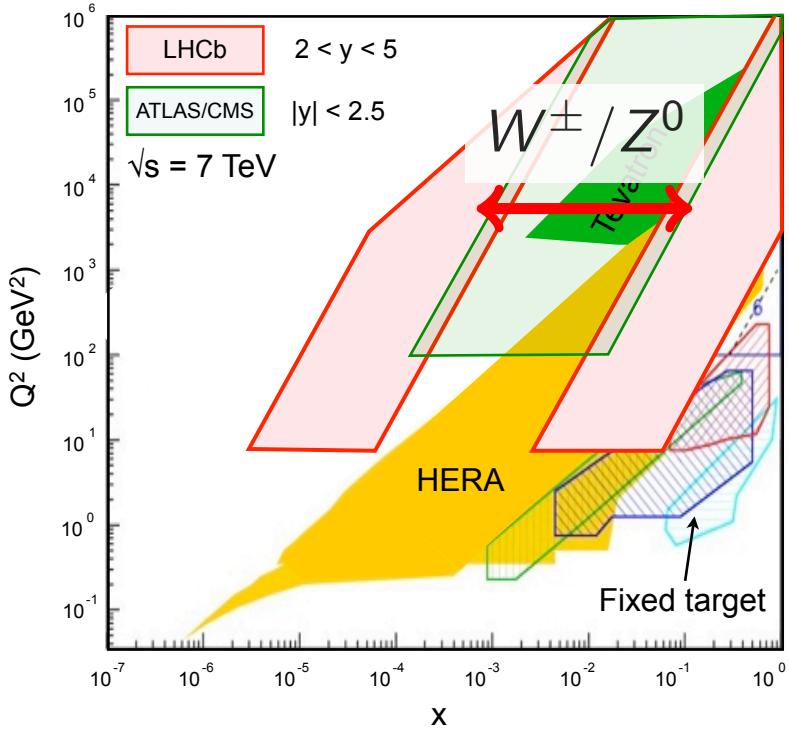
LHCb Sensitivity to Parton density functions

- unique kinematic acceptance
- $Q^2 = M^2$, $x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$
- combination of KNOWN high-x with UNEXPLORED low-x partons



LHCb Sensitivity to Parton density functions

- unique kinematic acceptance
- $Q^2 = M^2$, $x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$
- combination of KNOWN high-x with UNEXPLORED low-x partons
- For Z^0, $W^{\pm}$
  - $Q^2 \approx 10000$ GeV^2
  - x_2 down to $1.7 \cdot 10^{-4}$.



Theory Codes and Parton Distribution Functions

- Fixed order in the pertubation series in α_s:

$\mathcal{O}(\alpha_s)$ MCFM
$\mathcal{O}(\alpha_s^2)$ FEWZ

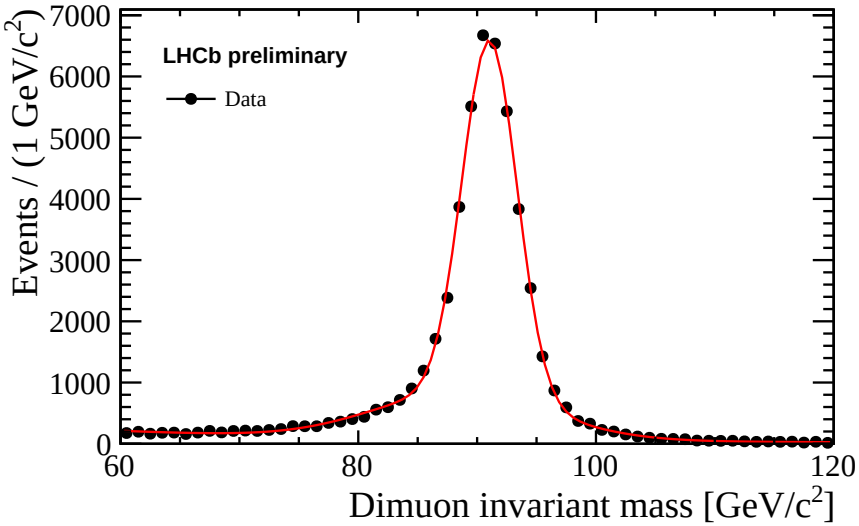
- Leading Logarithm
  - PowHEG with parton shower from PYTHIA
  - PYTHIA
- Resum all logarithms
  - ResBos

References are links behind the names.

- Before LHC
  - MSTW08
  - CT10
  - JR09
- After the start of LHC
  - NNPDF 2.3
  - ABM12

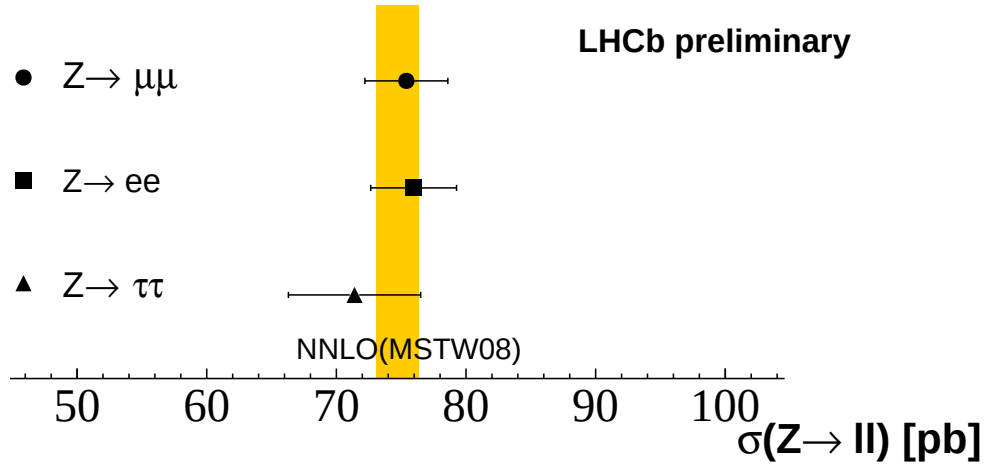
Those include results from LHCb-PAPER-2012-008

Inclusive Z Production at $\sqrt{s} = 7$ TeV



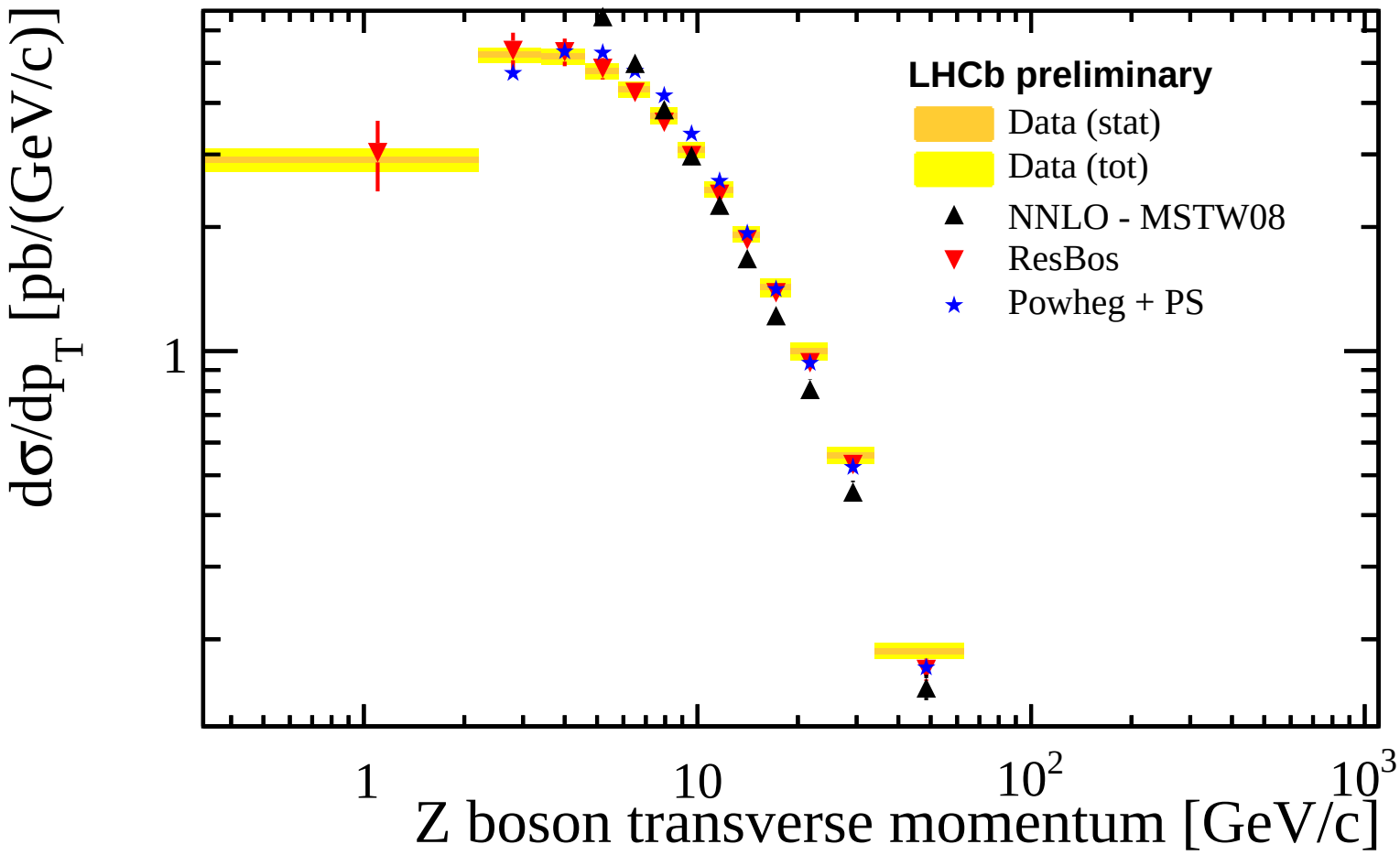
$$\sigma_{Z\to\mu\mu} = 75.4 \pm 0.3 \pm 1.9 \pm 2.6\text{pb}$$
$$\approx 53000 \text{ events}$$

- $q\bar{q}$ initial state
- $2 < \eta_\mu < 4.5$
- $p_{T,\mu} > 20\,\text{GeV}$
- $60 < m_{\mu\mu} < 120\,\text{GeV}$
- Measurements with all charged leptons in the final state



$\sqrt{s} = 7$ TeV LHCb preliminary LHCb-CONF-2013-007

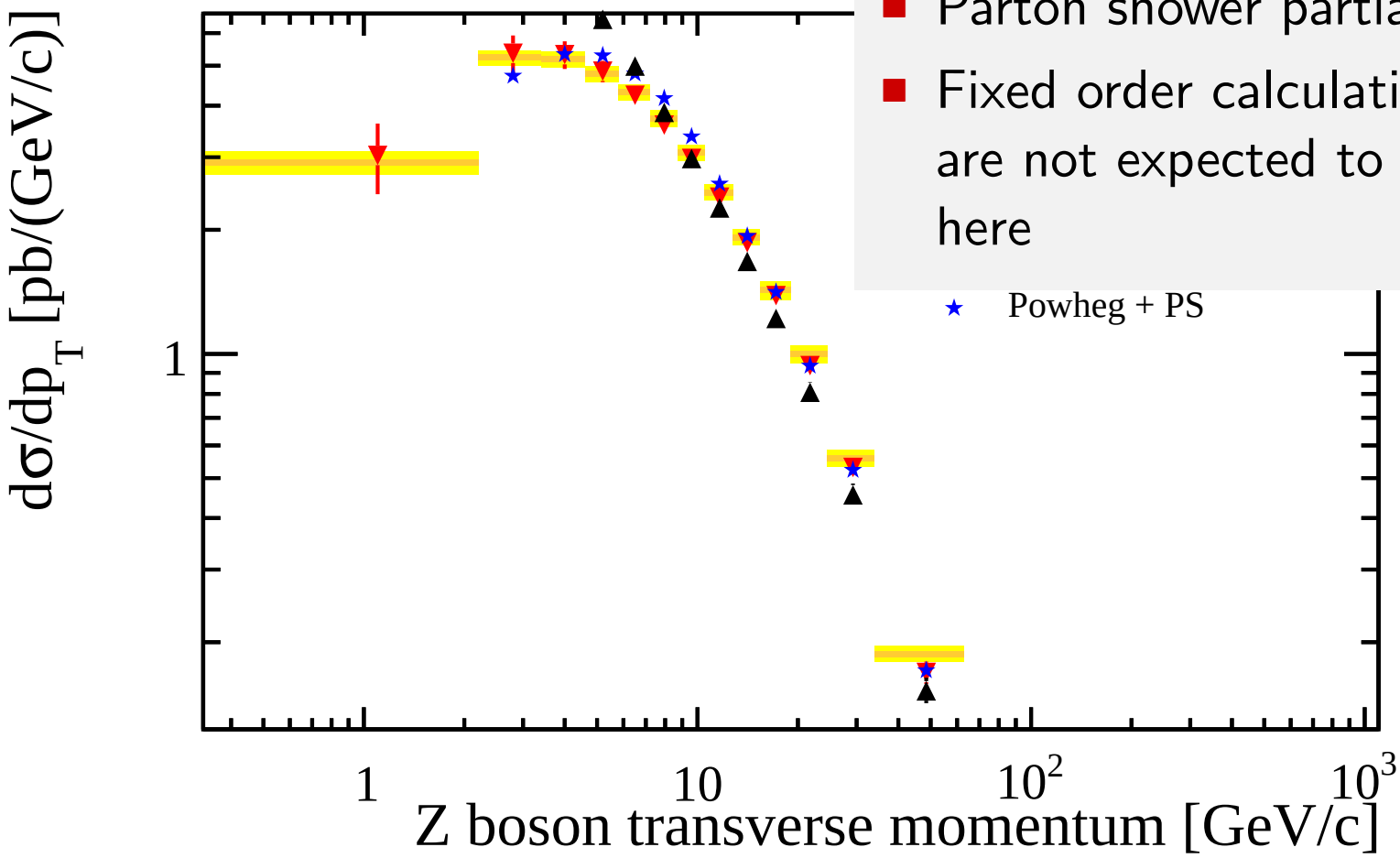
Z: Probe pQCD with Z p_T



$\sqrt{s} = 7$ TeV LHCb-CONF-2013-007

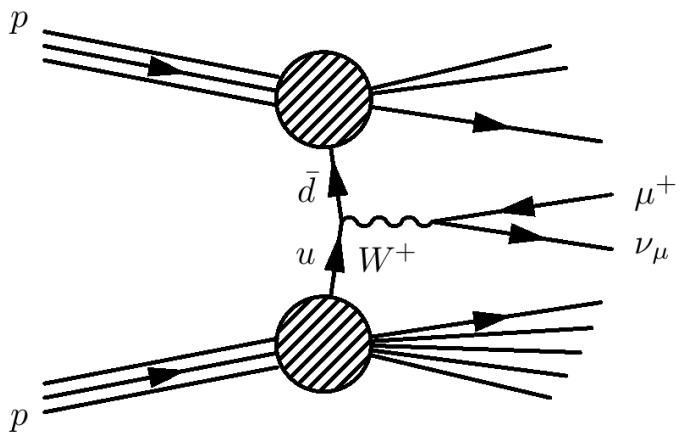
Z: Probe pQCD with Z p_T

- ResBos describes the data
- Parton shower partially
- Fixed order calculations are not expected to work here



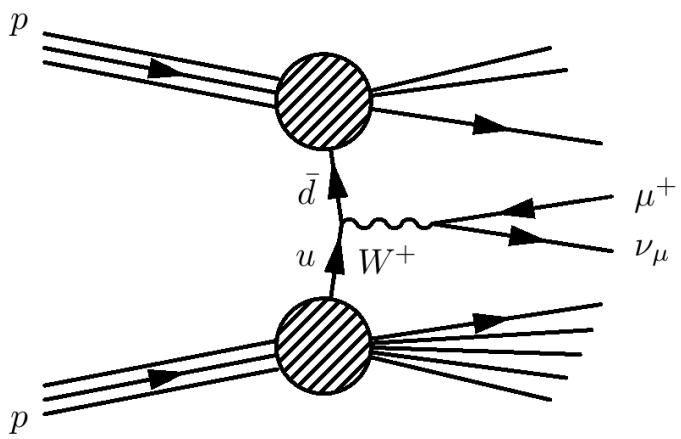
$\sqrt{s} = 7$ TeV LHCb-CONF-2013-007

$W^{\pm} \to \mu^{\pm}\nu$–Selection



$W^{\pm} \to \mu^{\pm}\nu$–Selection

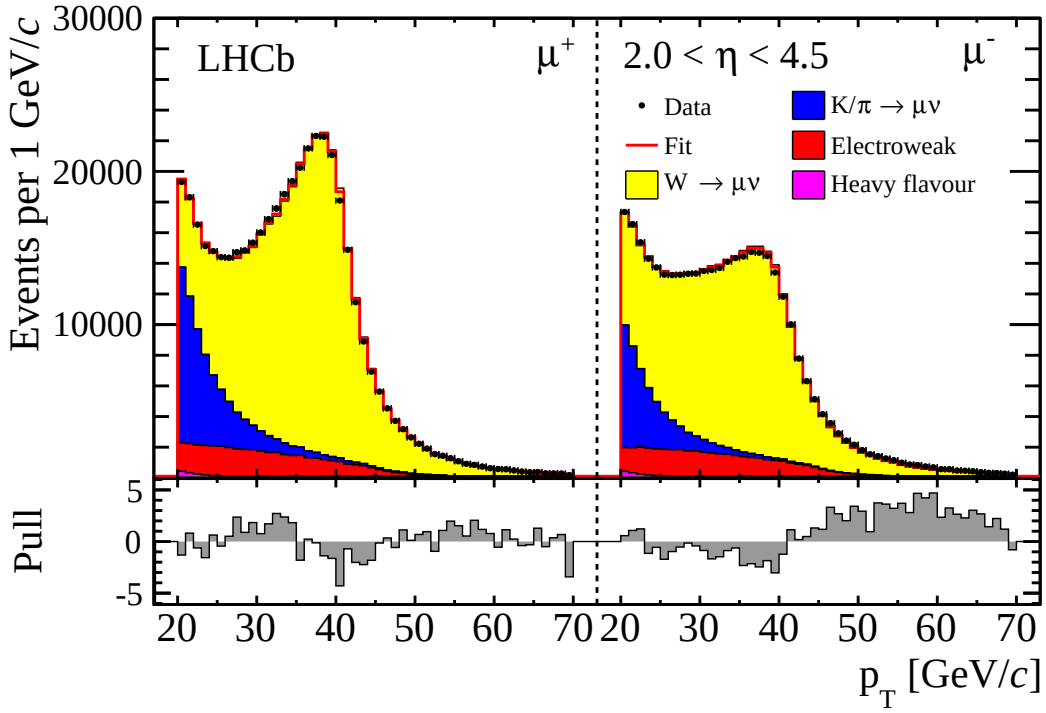
- 2011 dataset, 975 ± 17 pb^{-1} at 7 TeV
- Isolated muons $\sum_{\Delta R<0.5} p_T < 2$ GeV
- $20 < p_T^{\mu} < 70$ GeV
- Veto second muon in the event
- $\frac{E_{\text{Calo}}}{p_{\mu}} < 4\%$
- Impact Parameter less than 40 μm



  - This leads to a purity of 77%
  - Needs to be determined precisely

$W^{\pm} \to \mu^{\pm}\nu$–Purity

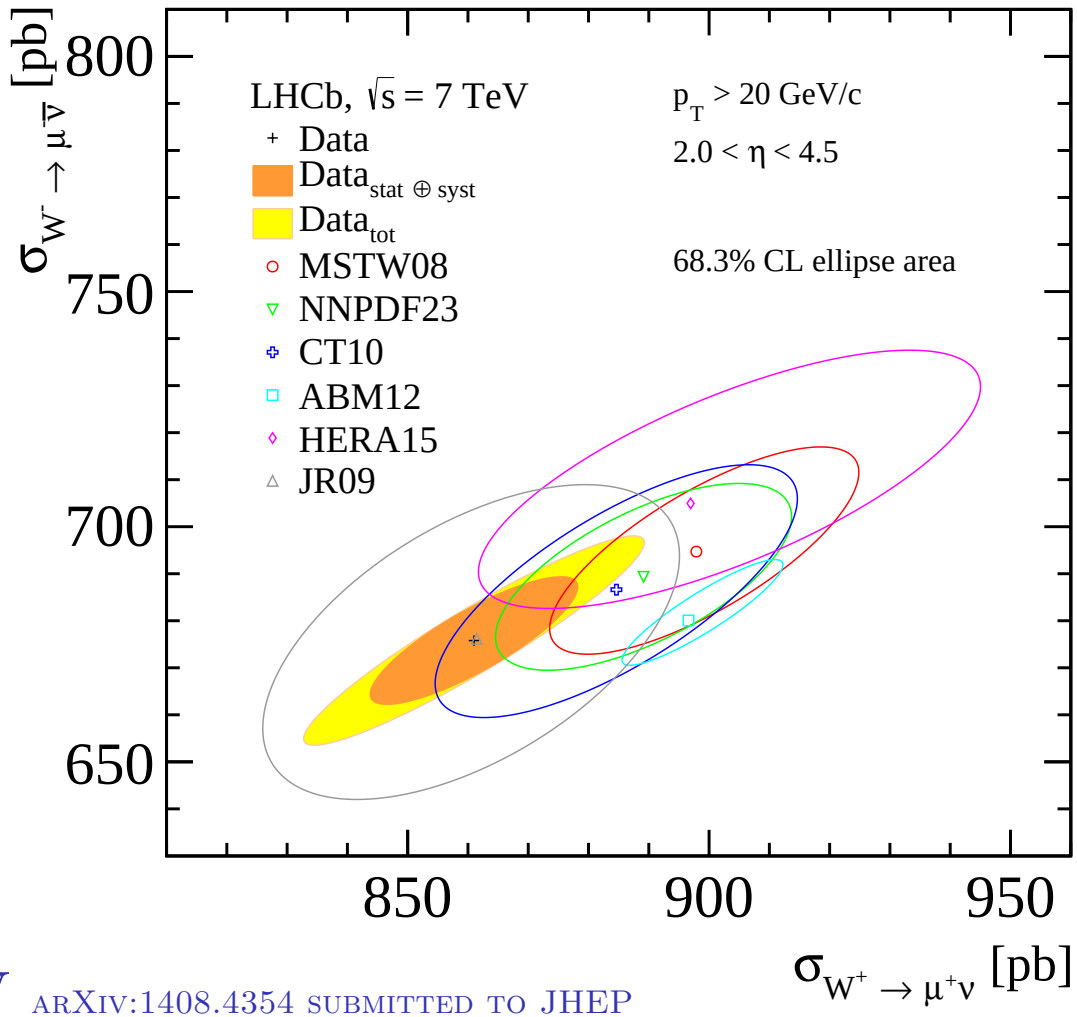
Fit in p_T^{μ}



- Signal Template from Simulation (Pythia corrected to ResBos).
- $W^{\pm} \to \tau\nu$ from Pythia, normalised to W cross section.
- $Z^0 \to \tau\tau$ from Pythia, normalised to Z cross section.
- $Z^0 \to \mu\mu$ from Pythia corrected to ResBos and normalised to Z.
- $K^{\pm}, \pi^{\pm}$ decay in flight shape from data and normalisation from fit.

$\sqrt{s} = 7$ TeV arXiv:1408.4354 submitted to JHEP

Total Cross Section



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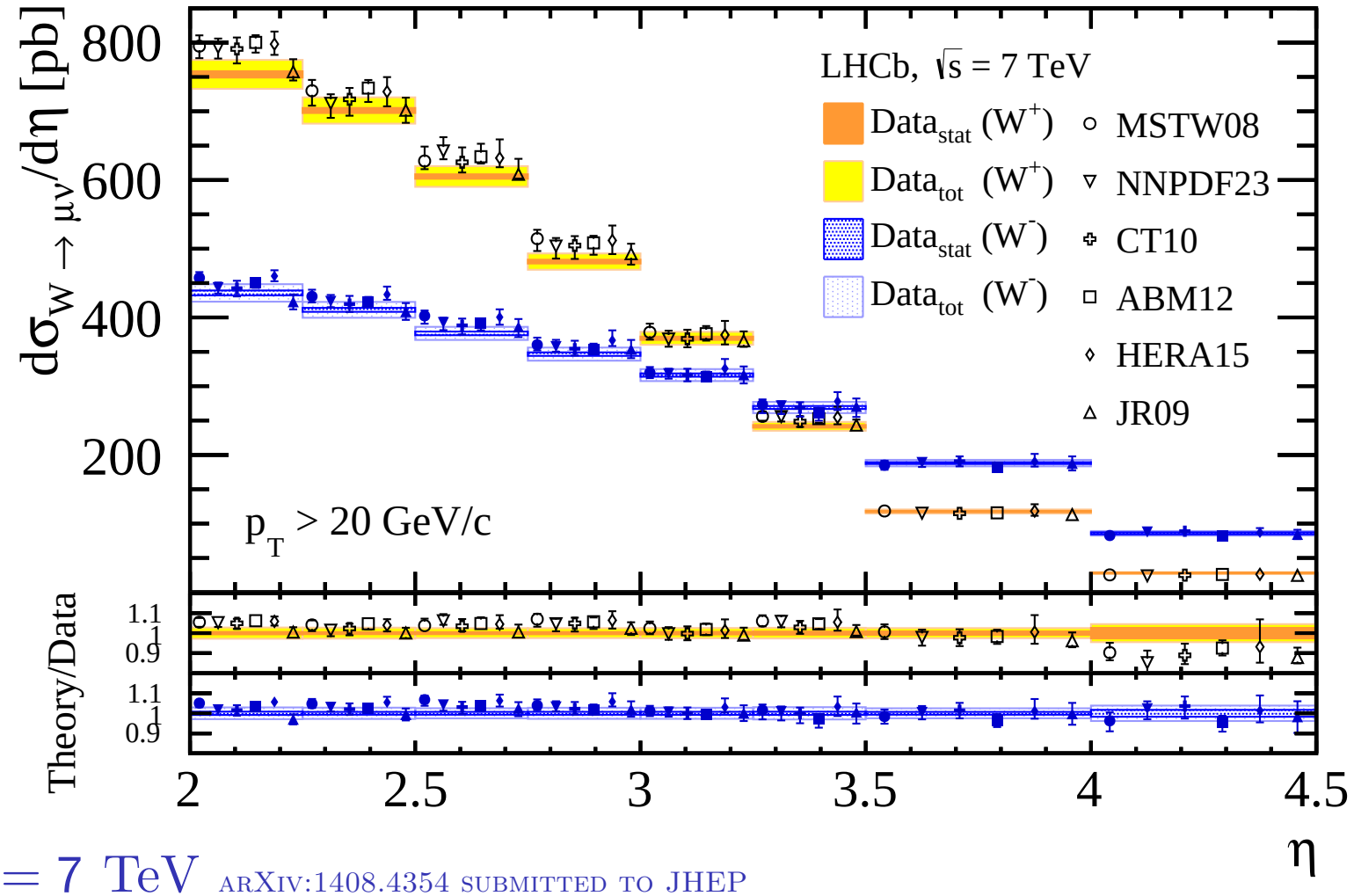
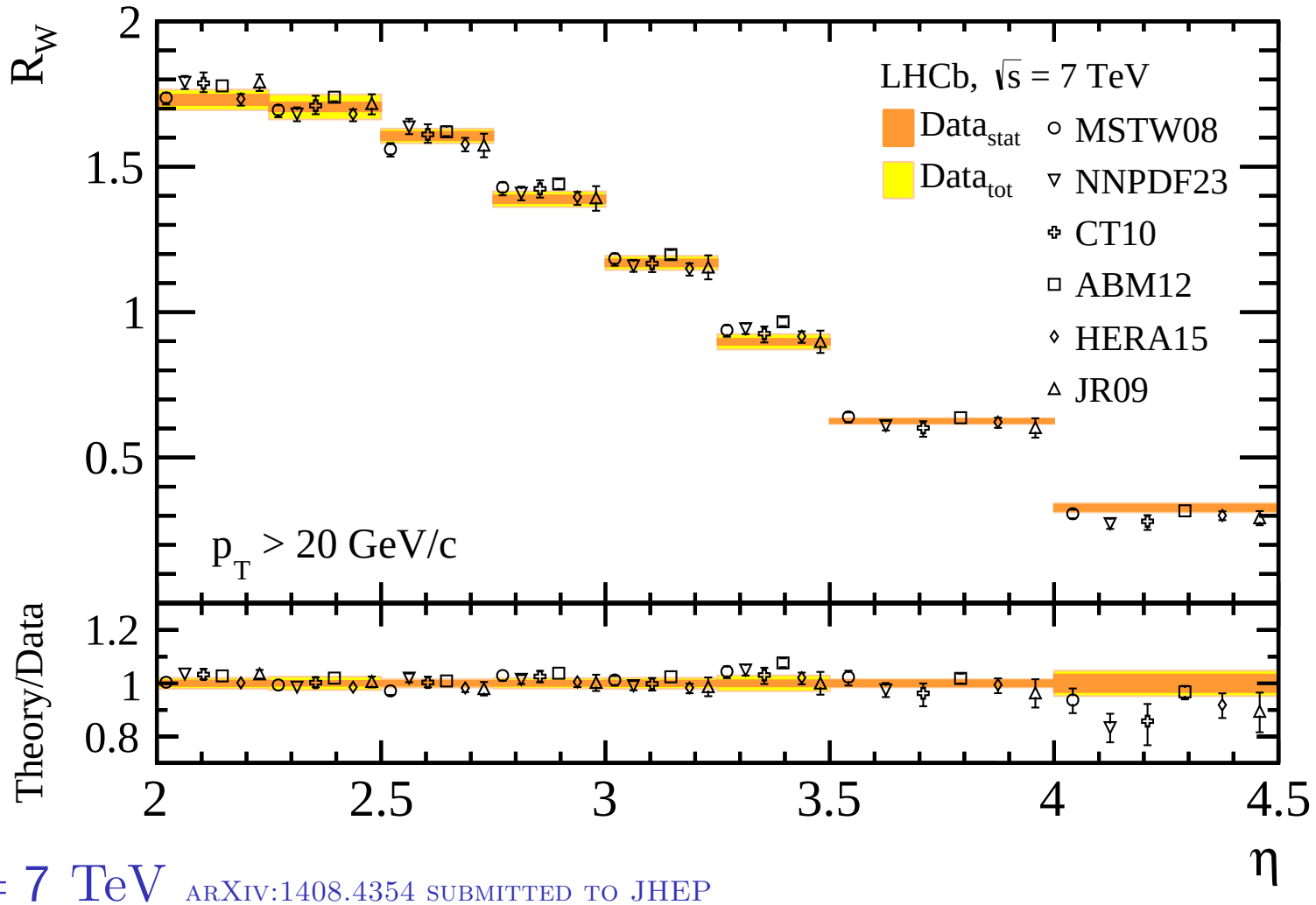
Differential Cross Section



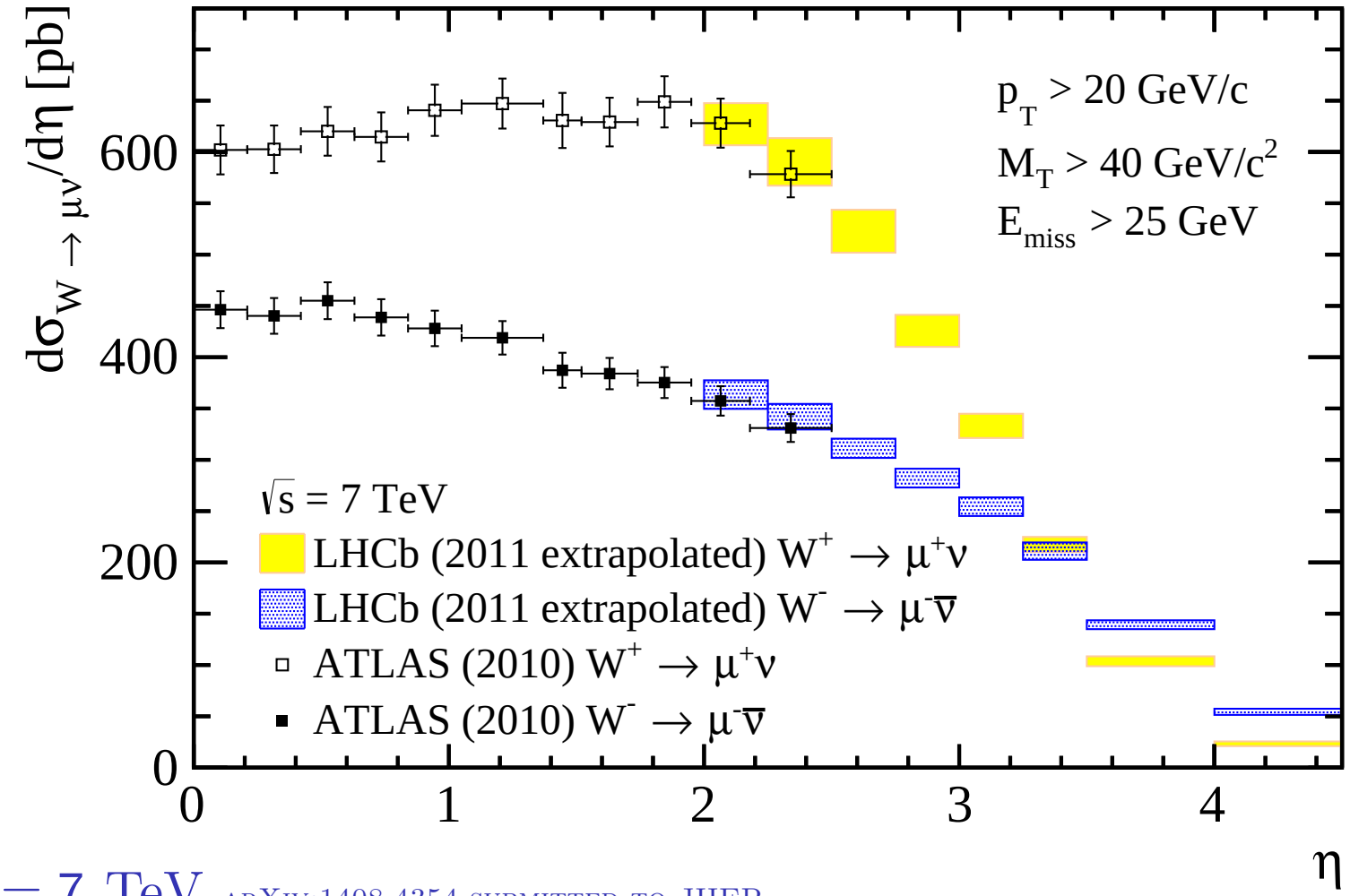
$\sqrt{s} = 7$ TeV arXiv:1408.4354 submitted to JHEP

Differential Cross Section Ratio



$\sqrt{s} = 7$ TeV arXiv:1408.4354 submitted to JHEP

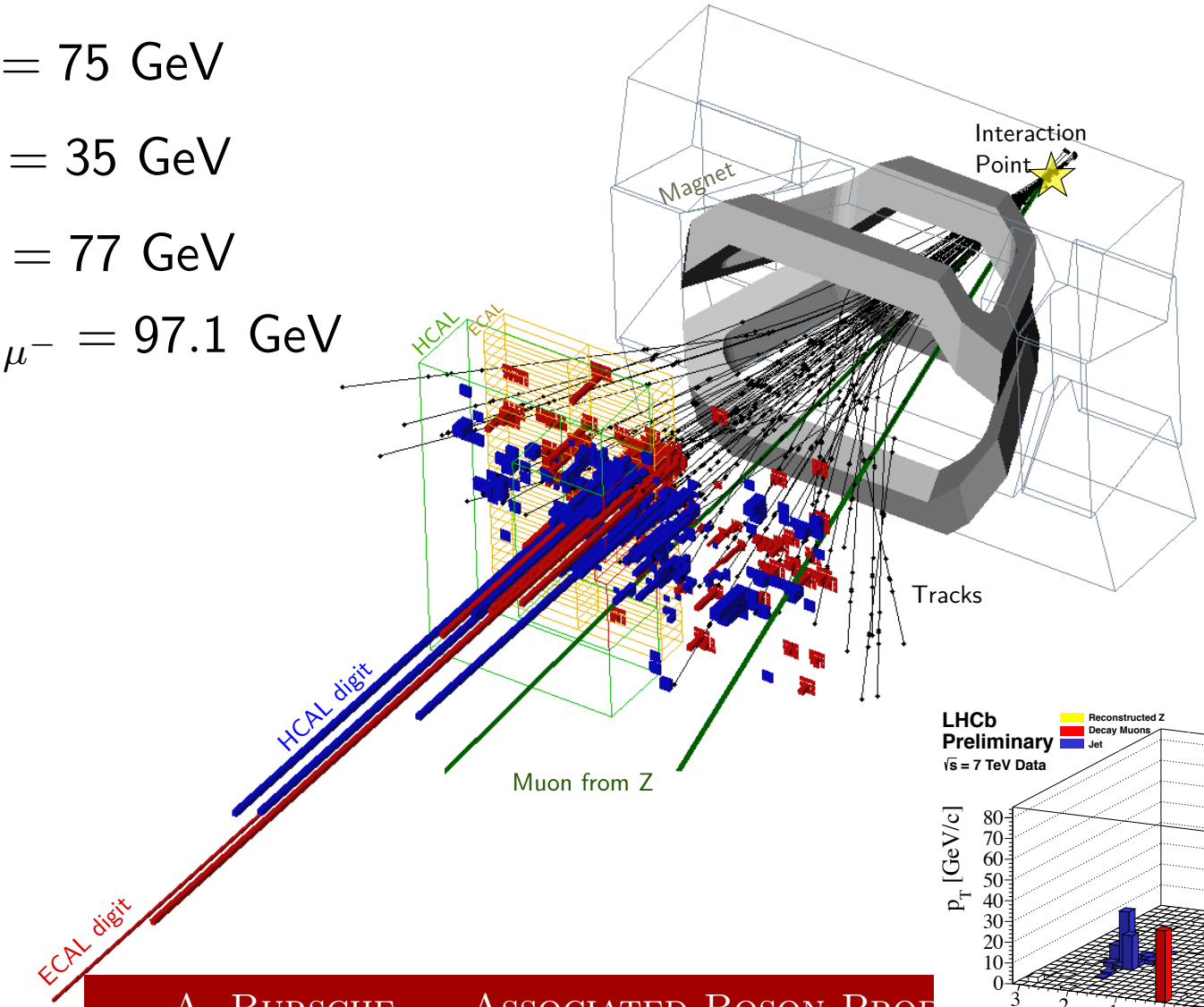
Extrapolation to Atlas

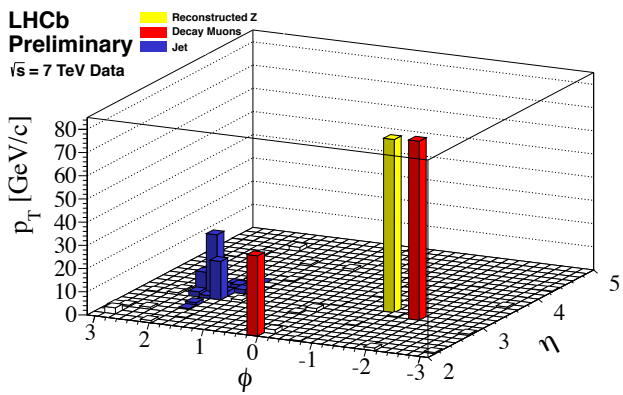


$\sqrt{s} = 7$ TeV arXiv:1408.4354 submitted to JHEP

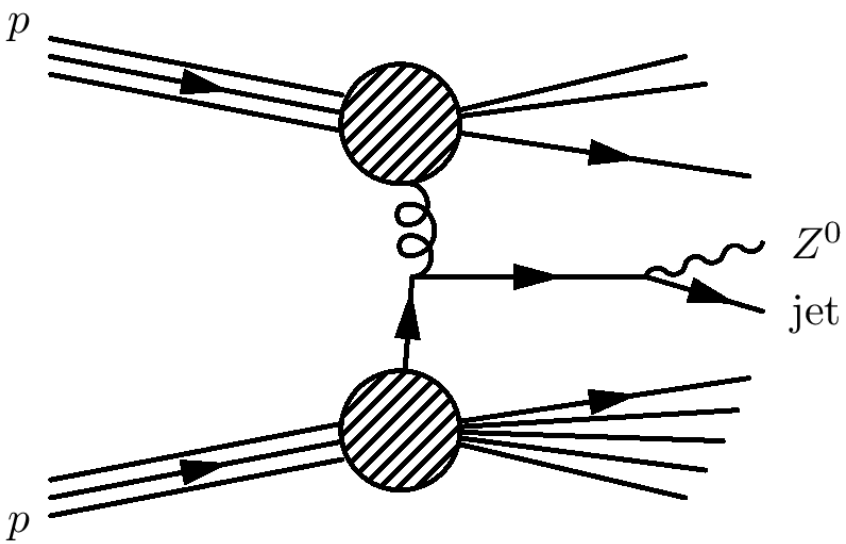
$Z^0 \to \mu\mu$ plus Jet Event

- $p_T^{\text{jet}} = 75$ GeV
- $p_T^{\mu^+} = 35$ GeV
- $p_T^{\mu^-} = 77$ GeV
- $m_{\mu^+\mu^-} = 97.1$ GeV





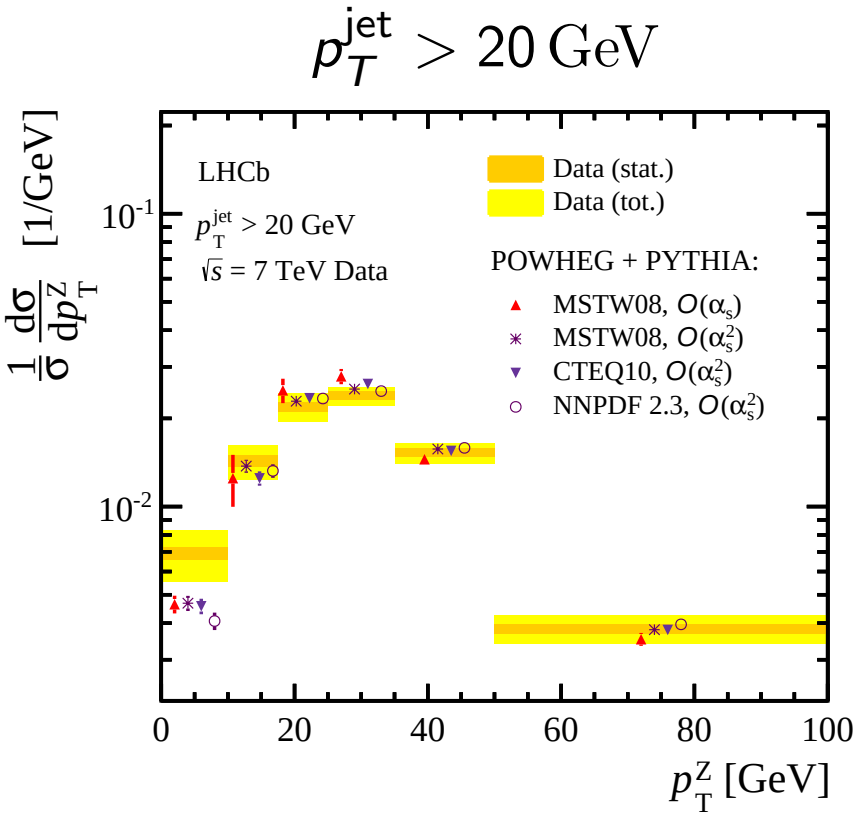
Z plus Jets at $\sqrt{s} = 7$ TeV

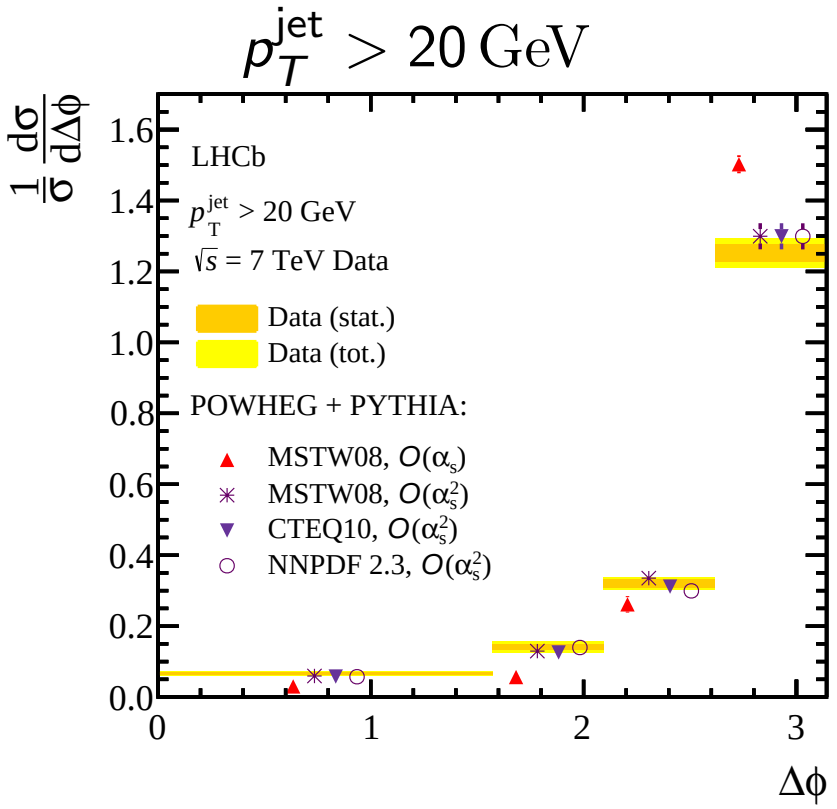


- Measurements only in $Z \to \mu\mu$ final state
- Jet Algorithm $\overline{k}_T$ (R=0.5)
- Use tracks and neutral clusters
- $2 < \eta^{\text{Jet}} < 4.5$
- $\Delta R_{\text{jet},\mu} > 0.4$
- Largest uncertainty from JES

$\sqrt{s} = 7$ TeV JHEP 01 (2014) 033

Z +JETS: Z p_T AND $\Delta\Phi$

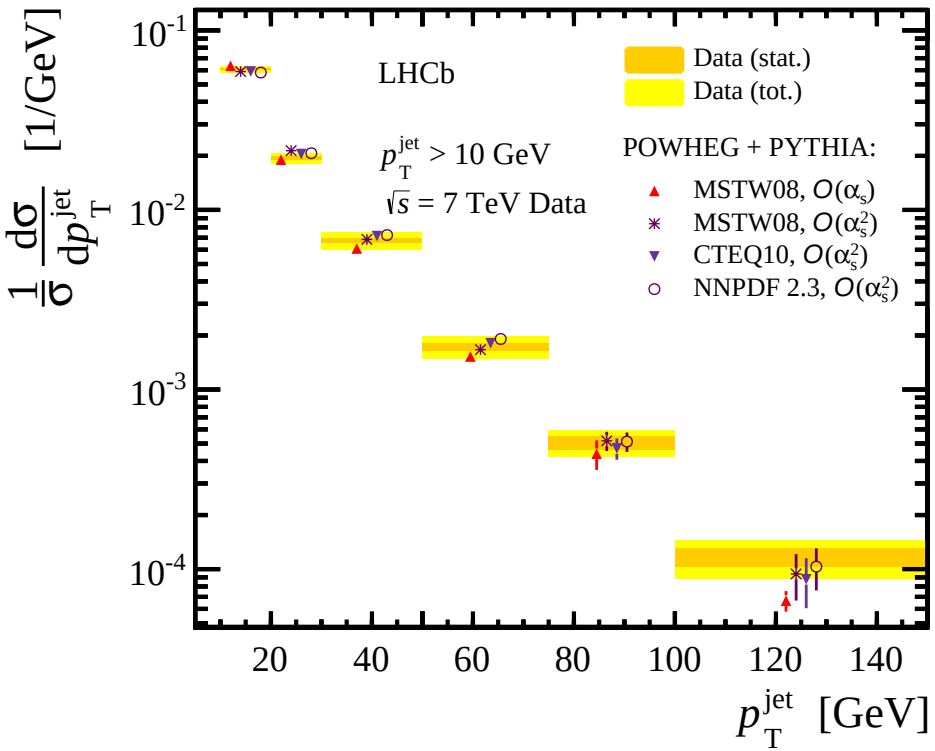




This is also measured for the $p_T > 10$ GeV threshold.

$\sqrt{s} = 7$ TeV JHEP 01 (2014) 033

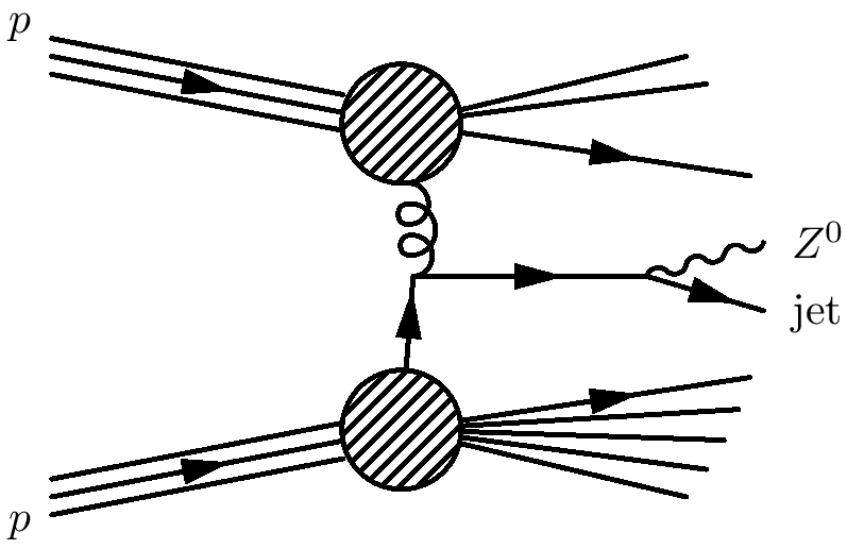
Z +jets: Jet p_T



- Compared to Powheg
- Parton Shower with Pythia

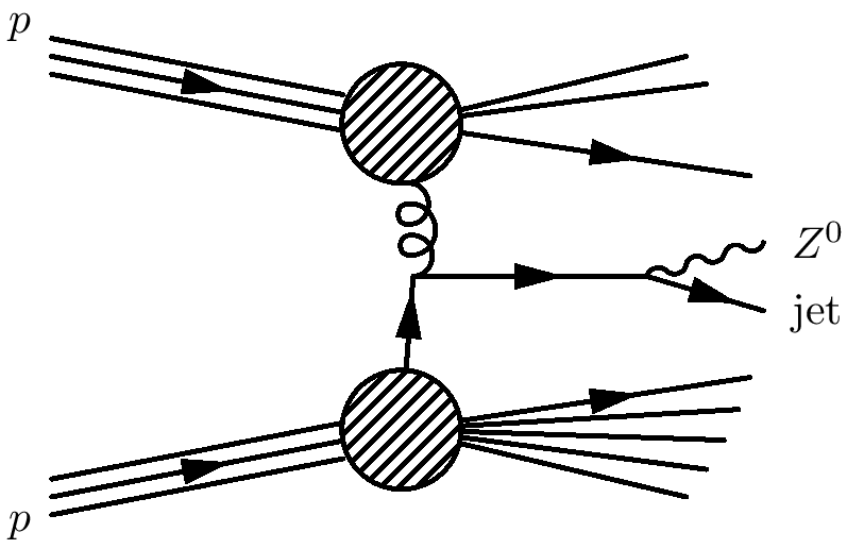
$\sqrt{s} = 7$ TeV JHEP 01 (2014) 033

Z plus b-jets



$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Z plus b-jets

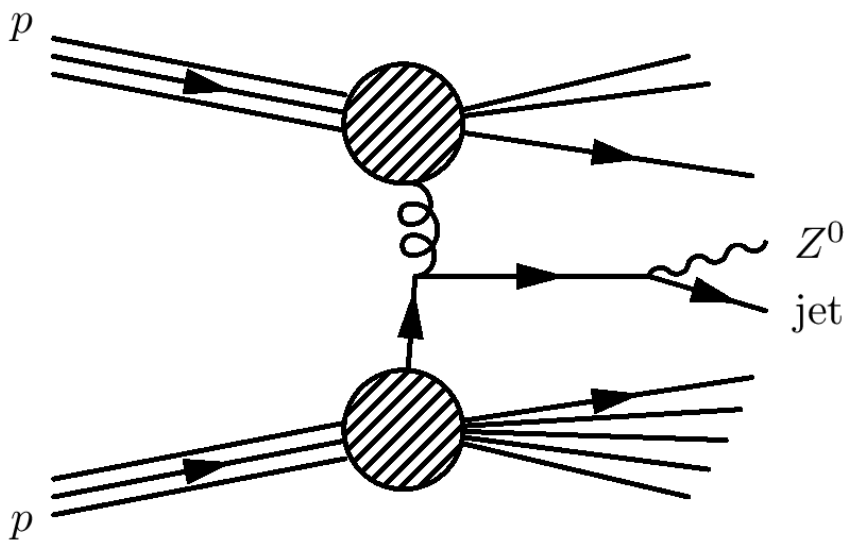


Overview

- $Z \to \mu^+\mu^-$ as before
- jets as before
- again with two p_T thresholds
- add b-tag from secondary vertex to leading jet

$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Z plus b-jets



Overview

- $Z \to \mu^+\mu^-$ as before
- jets as before
- again with two p_T thresholds
- add b-tag from secondary vertex to leading jet

Background

- light jets
- charm jets

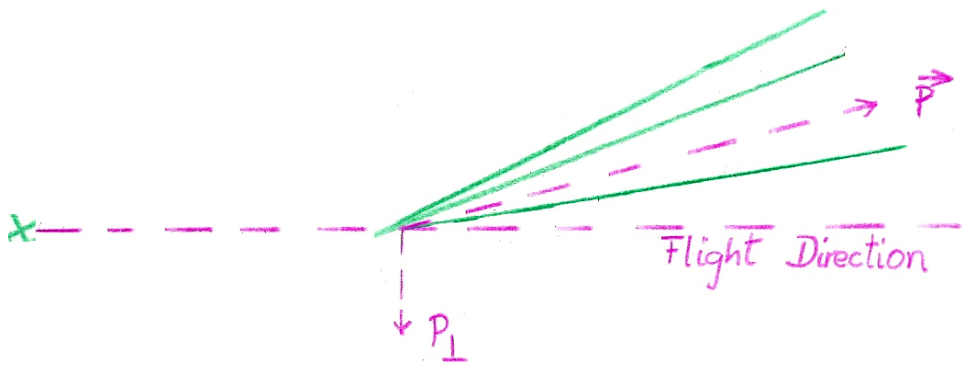
$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Tagging b-jets

- Use the strategy already in place in the incl. b trigger
- Form secondary vertices from two, three, and four particles
- Look at corrected mass

$$m_{\text{corr}} = \sqrt{m^2 + p_\perp^2} + p_\perp$$

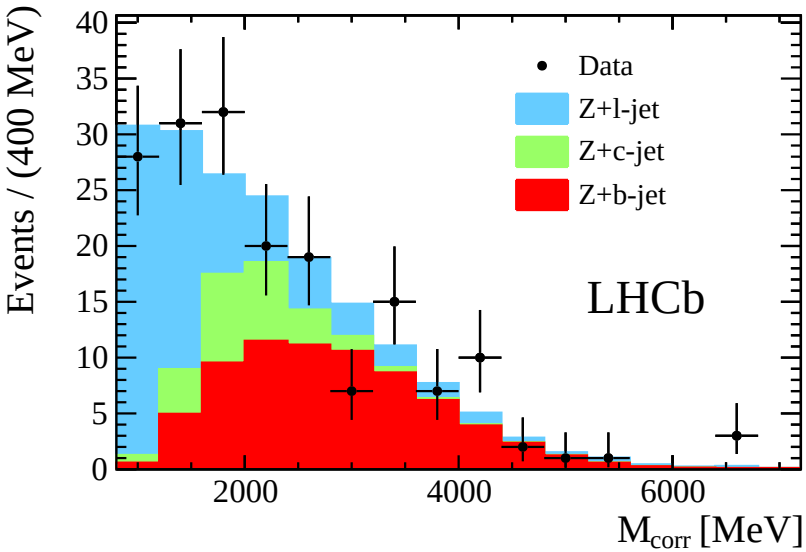
where $p_\perp$ it measured with respect to the geometrical flight direction of the secondary vertex.

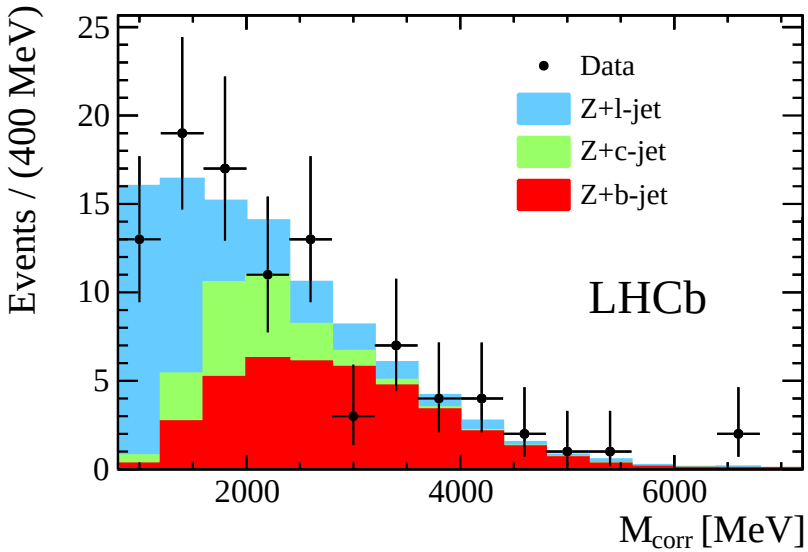


$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Purity Determination

Use templates from simulation for light, beauty and charm jets.

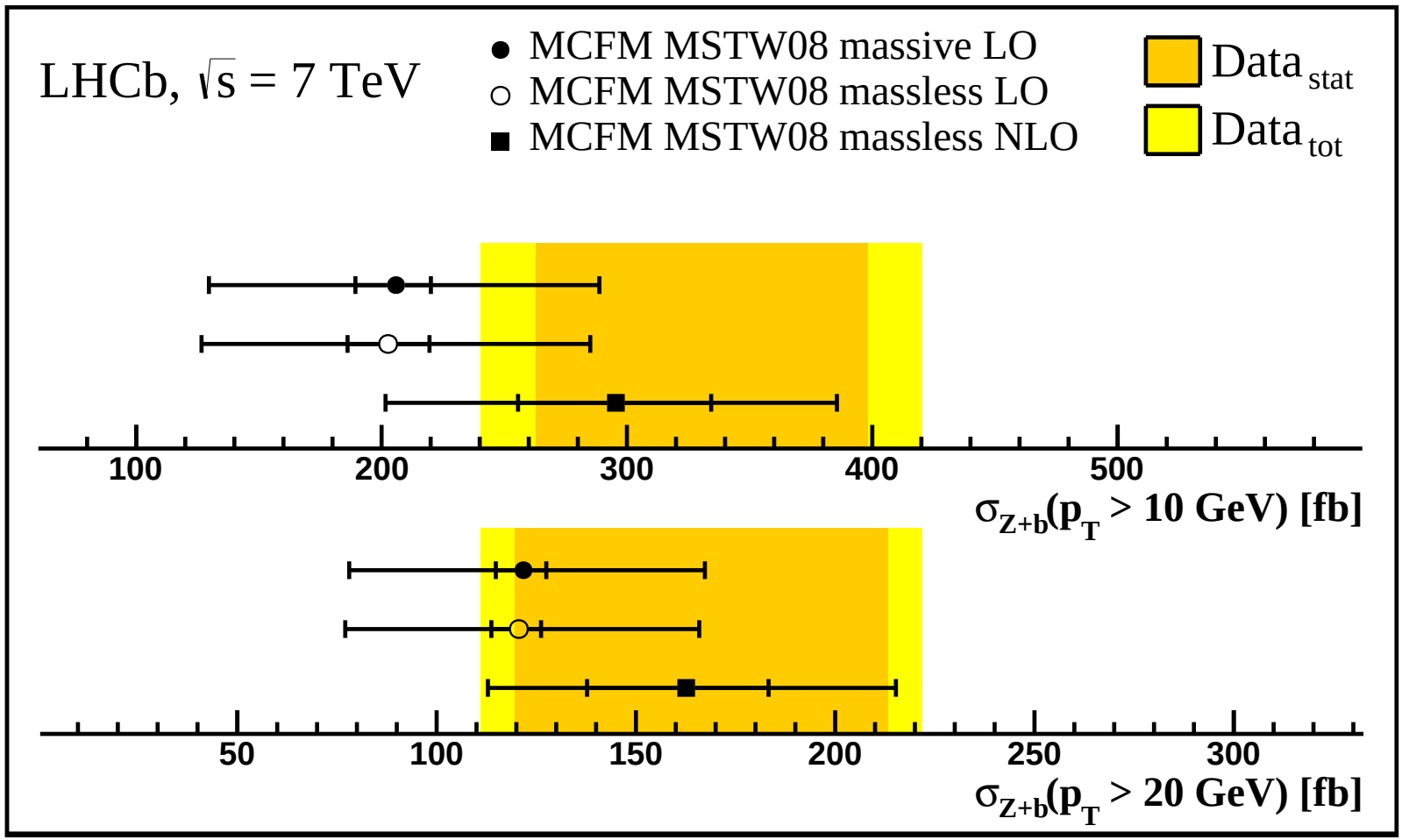




Jets thresholds of $p_T > 10$ GeV and 20 GeV.

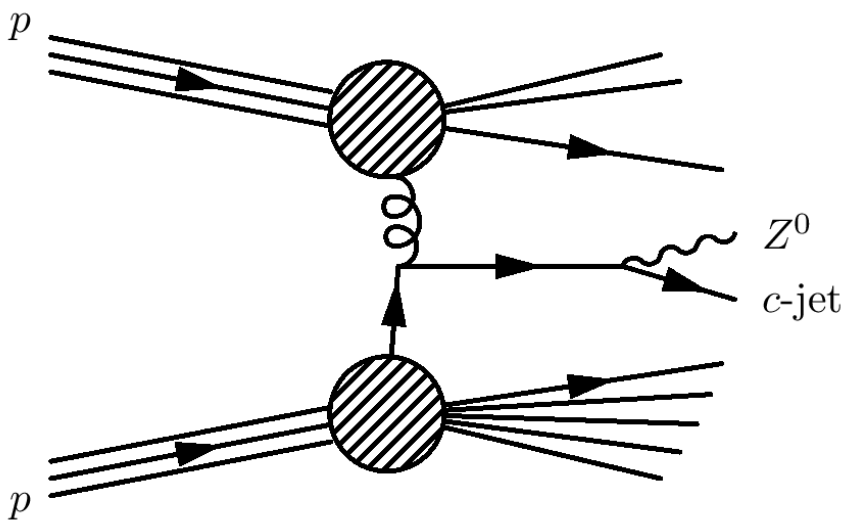
$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Z + b-jet Cross Section



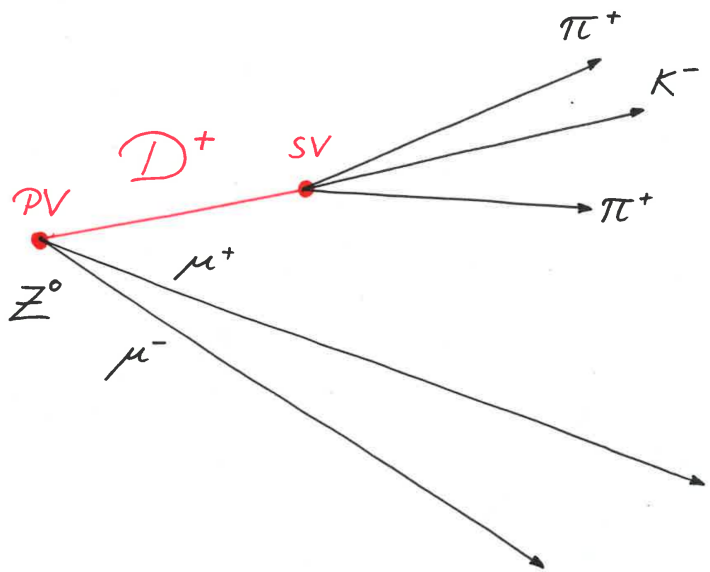
$\sqrt{s} = 7$ TeV LHCb preliminary (LHCB-PAPER-2014-055 to be submitted to JHEP)

Z plus D



$\sqrt{s} = 7$ TeV JHEP 04 (2014) 091

Z plus D



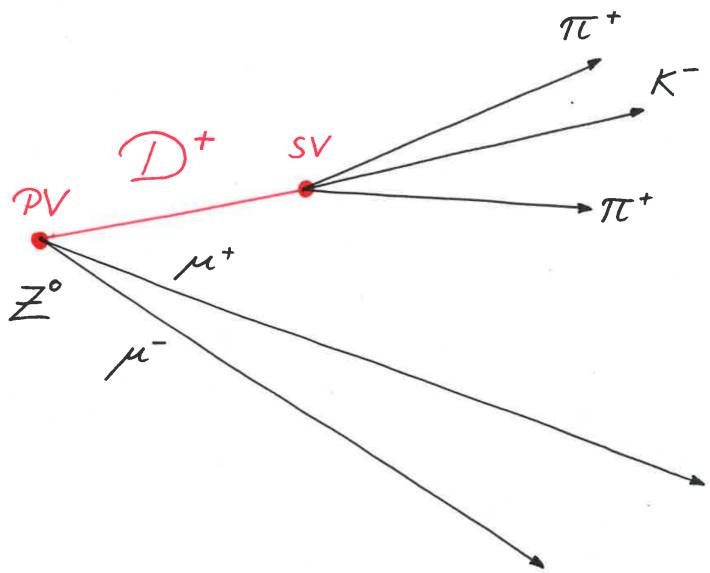
- Z from PV with zero lifetime
- D from secondary vertex but associated to the same PV as the Z

Overview

- $Z \to \mu^+\mu^-$ as before
- $2 < p_{T,D} < 12\,\mathrm{GeV}$
- $D^0 \to K^-\pi^+$ $(3.89 \pm 0.05\%)$
- $D^+ \to K^-\pi^+\pi^+$ $(9.22 \pm 0.21\%)$

$\sqrt{s} = 7$ TeV JHEP 04 (2014) 091

Z plus D



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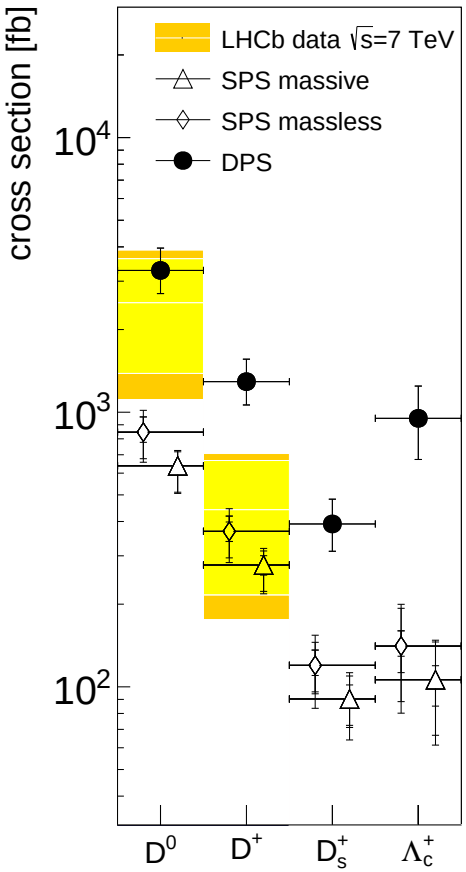
Background

- Feed Down, Pile Up, Combinatorial
- Purity 95%

$\sqrt{s} = 7$ TeV JHEP 04 (2014) 091

Results



- $\sigma_{Z\to\mu^+\mu^-,D^0}\mathcal{B}_{Z\to\mu^+\mu^-} = 2.50 \pm 1.12 \pm 0.22\,\mathrm{pb}$
- $\sigma_{Z\to\mu^+\mu^-,D^+}\mathcal{B}_{Z\to\mu^+\mu^-} = 0.44 \pm 0.23 \pm 0.03\,\mathrm{pb}$
- Comparison to single parton and double parton scattering predictions
- The measured cross-section is expected to be composed of both.

DPS Formula: $\sigma_{DPS} = \dfrac{\sigma_Z \sigma_D}{\sigma_{\mathrm{eff}}}$

$\sigma_{\mathrm{eff}} = 14.5 \pm 1.7^{+1.7}_{-2.3}$ mb [CDF]

$\sqrt{s} = 7$ TeV JHEP 04 (2014) 091

Conclusion

- Many different QCD results available relevant for
  - QCD Models
  - PDFs
- There are more already published ($Z \to ee$@7 TeV ...)
- Even more in preparation ($W^{\pm} + b/c$, $Z \to ee$@8 TeV ...)

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Thank You!