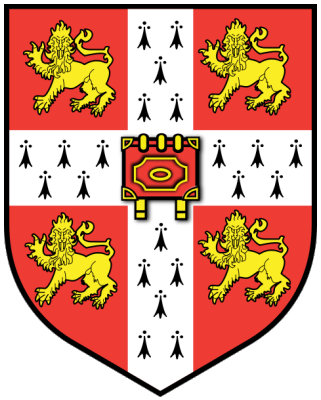

Electroweak Gauge Boson and Associated Jet Production at LHCb

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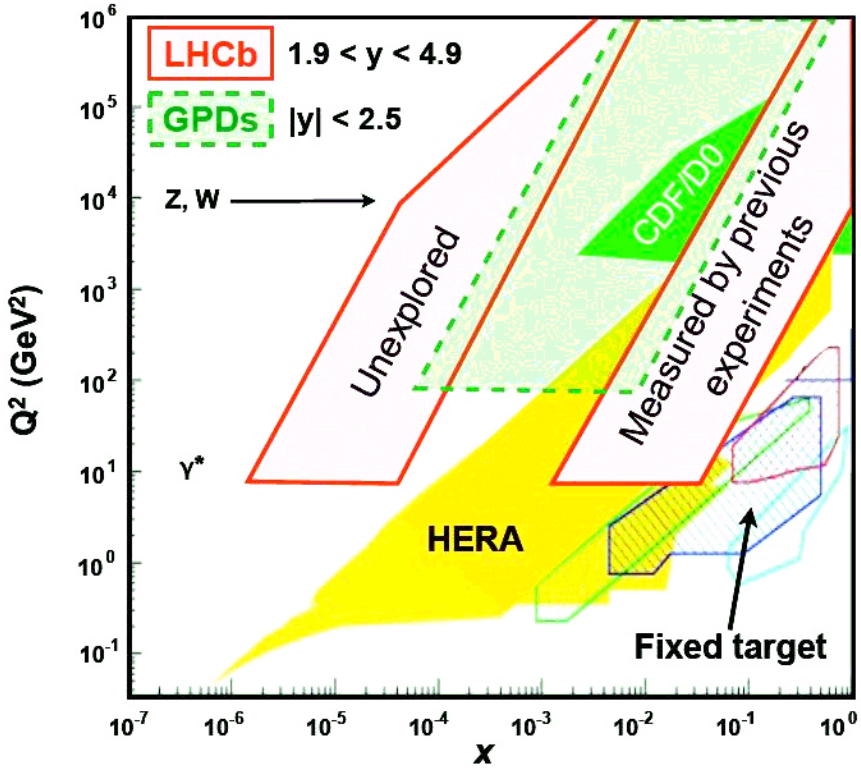
University of Cambridge

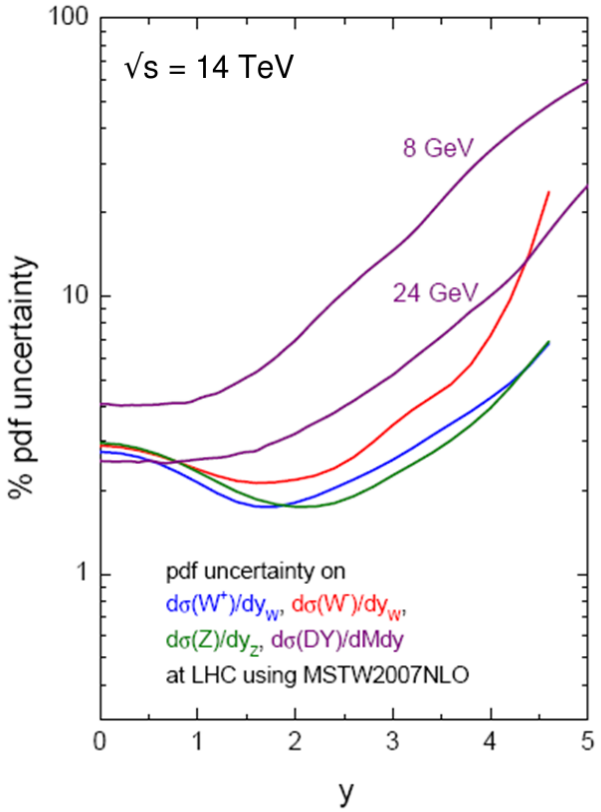
9th April 2013

Motivation - LHCb Detector - Jet Reconstruction at LHCb
Selection of Z+Jet events - Kinematic Distributions and Cross-sections
Conclusions

Motivation

- Studies of Z$\rightarrow \mu\mu$ + jet production at LHCb:
  - test MC predictions in the forward region - where they are not tuned. This is especially interesting at low p_T.
  - probe previously unexplored regions of phase space (low x, high Q^2).
  - allow us to probe PDFs in a previously unexplored kinematic region.

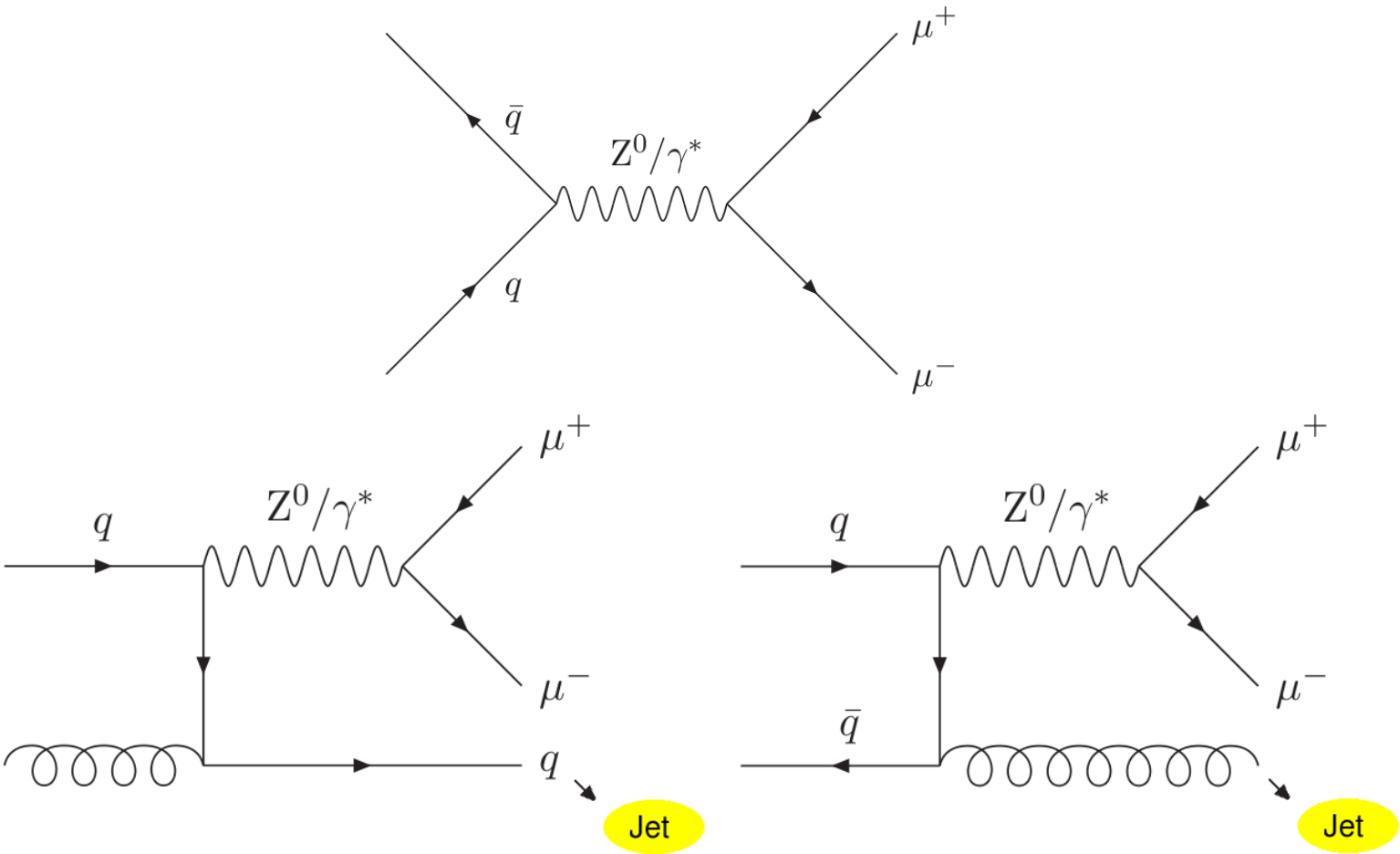




Right hand plot from Thorne et al. (arXiv:0808.1847).

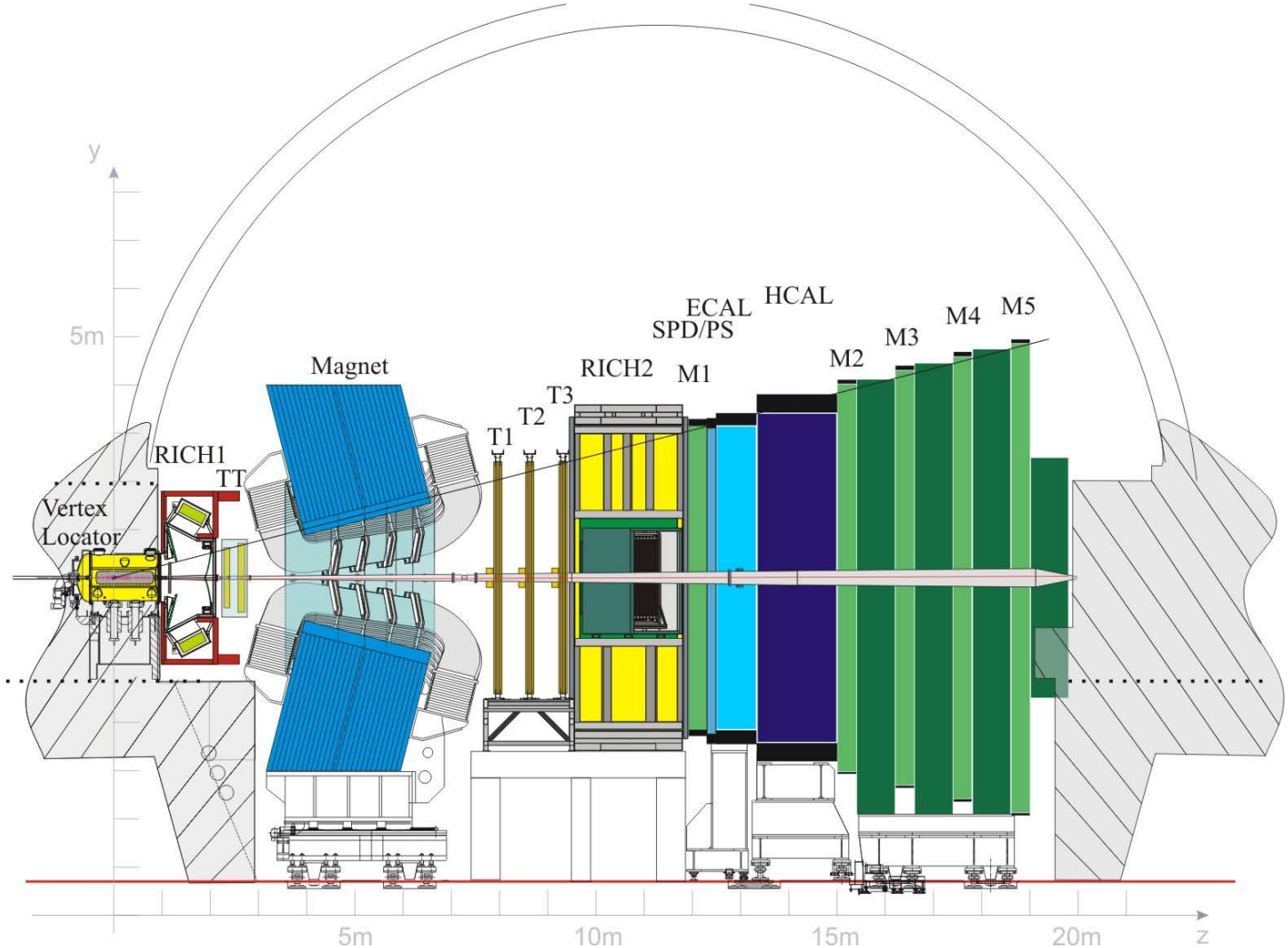
Motivation

- The jet measurements are particularly sensitive to the gluon PDF at low x.



The LHCb Detector

Coverage between: $\sim 2 < \eta < 5$.

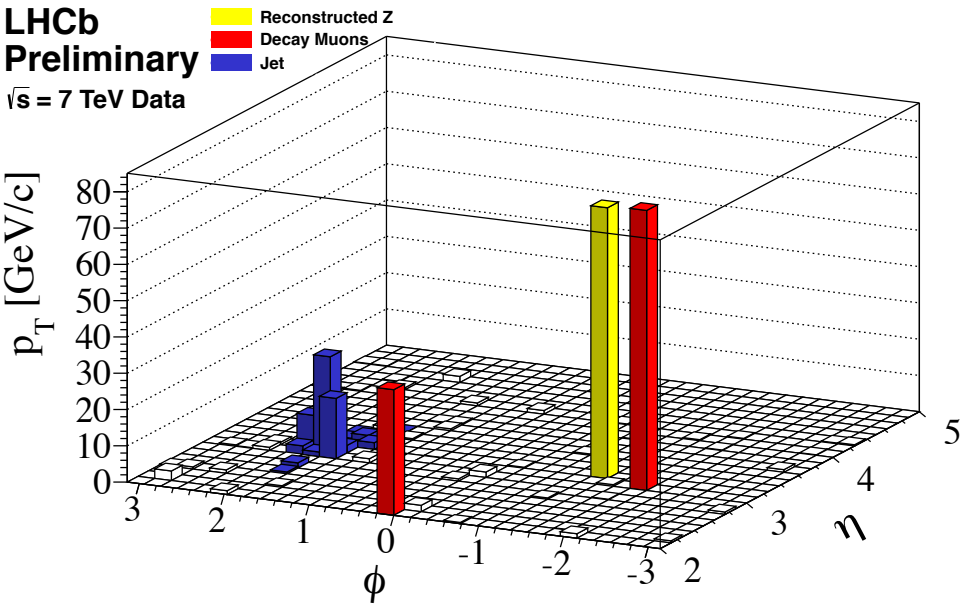


Jet Reconstruction at LHCb

- In order to find jets, particles in the event must be passed to a jet finding algorithm. We take a particle flow approach for this. We consider:
  - Charged Particles - taken from well reconstructed tracks, from the same PV as the interaction of interest,
  - Photons - taken from clusters in the ECAL that do not match tracks.
  - V0s - mainly K_s^0 and Λ^0.
  - Other Neutral Hadronic Particles - taken from clusters in the HCAL that do not match tracks.
- A fully calorimeter based approach is not possible at LHCb as the ECAL saturates for $E_T > 10$ GeV - the LHCb calorimeters are optimised for B physics and are mainly used to trigger on events.

Jet Reconstruction at LHCb

- The particles are passed to the FASTJET jet finding program.
- The jets are then reconstructed using the anti-kT algorithm, using $R = 0.5$ - particles within a radius of 0.5 in $\eta - \phi$ space tend to be clustered.



$p_T(Z) = 74.6$ GeV
$p_T(\text{jet}) = 64.0$ GeV

- Jets are required to pass quality requirements, and to be in the LHCb acceptance ($2.0 < \eta < 4.5$). We determine the efficiency ($\gtrsim 90\%$) of the quality cuts to an accuracy of $\sim 1\%$.

Jet Energy Correction (JEC) and Resolution

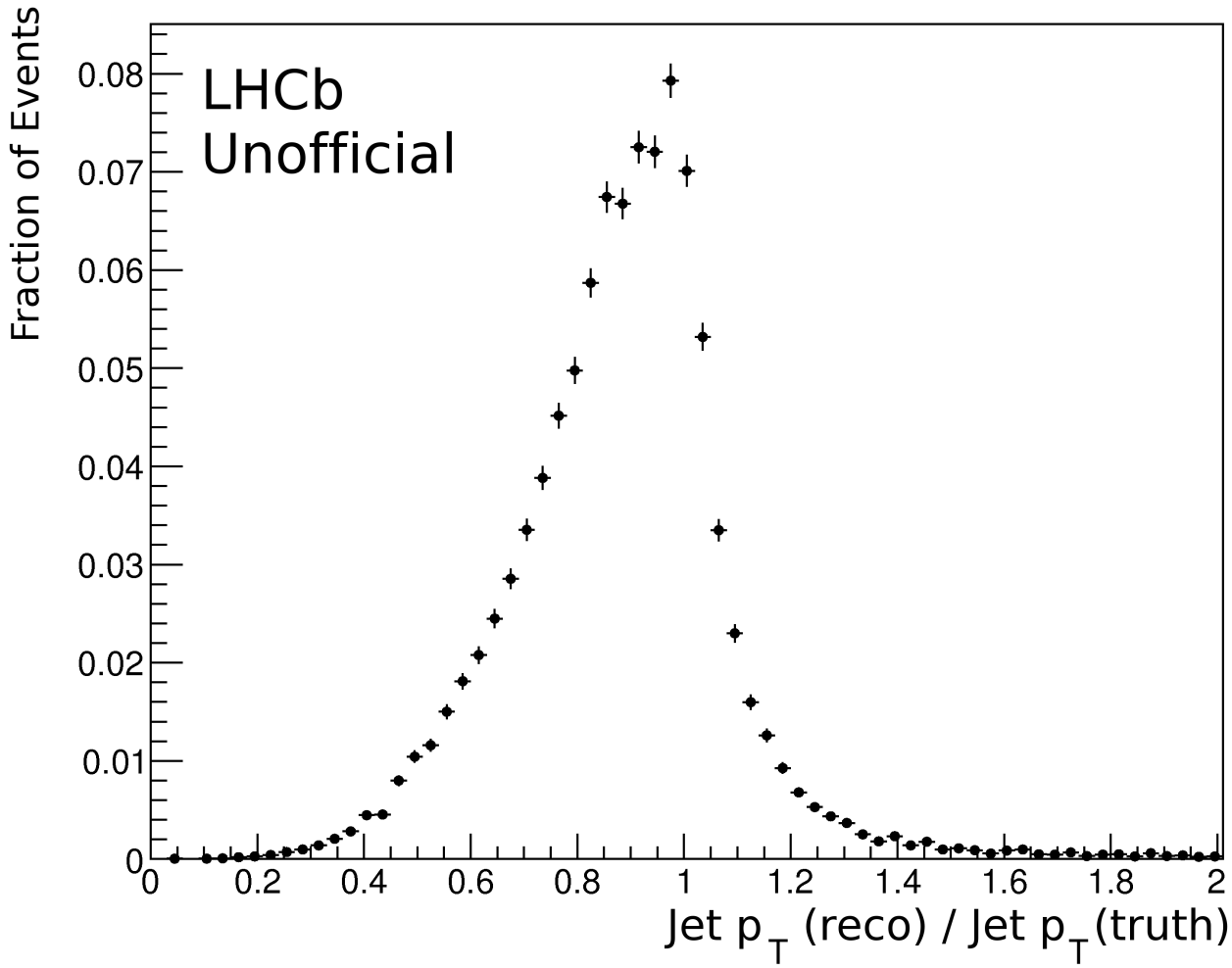
- We correct the measured jet energy by a scaling factor, to give a best estimate of the true jet energy:

$$p_{\mathrm{T}}(\text{reco jet}) = k(\text{nPV}, p_{\mathrm{T}}, \eta) \cdot p_{\mathrm{T}}(\text{clustered jet})$$

- This correction is found by comparing jets reconstructed at the MC truth (hadron) level to reconstructed jets in MC events.
- k typically takes values between 0.95 & 1.05.

- Comparison between data and MC of the p_{T} balance of Z and jet (when they are emitted back to back) shows that we can trust the MC JEC to an accuracy of $\sim 3\%$ (checked as a function of p_{T}, η).

Jet Energy Correction (JEC) and Resolution



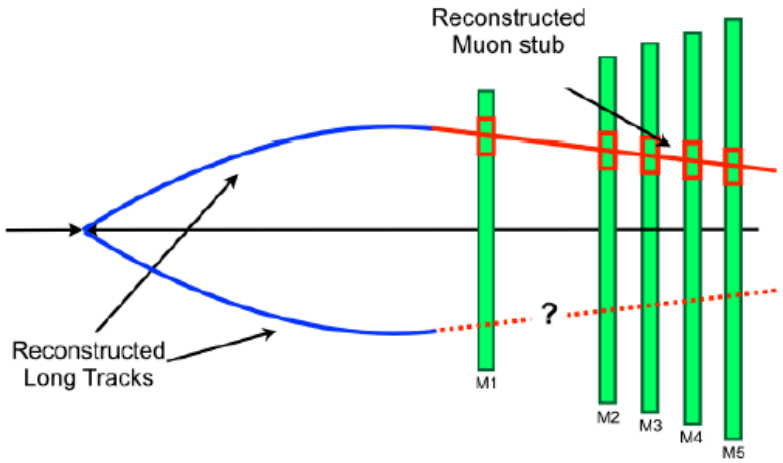
- Resolution of jet p_{T} is $\sim 15\%$ (1/2 FWHM). This is relatively flat (for $10 < p_{\mathrm{T}} < 100$ GeV).
- Resolve Jet Direction (in $\eta - \phi$) with $\Delta R(\text{truth, reco}) < 0.1$ for $\sim 90\%$ of jets.

Selection of Z+Jet events

- Trigger on single muons with $p_T(\mu) > 10$ GeV.
- LHCb $Z \rightarrow \mu\mu$ fiducial acceptance: J. High Energy Phys. 06 (2012) 058
  - $p_T(\mu) > 20$ GeV, $2.0 < \eta(\mu) < 4.5$,
  - $60 < M(\mu\mu) < 120$ GeV.
- Reconstruct ~ 50000 $Z \rightarrow \mu\mu$ events in $\int \mathcal{L} dt \sim 1$ fb^{-1} of $\sqrt{s} = 7$ TeV data collected in 2011.
- In the Z+jet analysis, we use the same acceptance and require at least one jet with:
  - $p_T(\text{jet}) > 10(20)$ GeV,
  - $2.0 < \eta(\text{jet}) < 4.5$,
  - and $\Delta R(\mu,\ \text{jet}) > 0.4$.
- Reconstruct $\sim$ 10000(4000) events in 2011 data.
- Background level not significantly different between Z and Z + jet events $\sim 0.3\%$.

Z Detection Efficiencies

- Determine Z detection efficiencies using data driven approach.
- Measure using tag and probe methods:
  - Muon ID efficiency ($\sim 99\%$),
  - Muon Track reconstruction efficiency ($\sim 90\%$ to reconstruct a muon track passing quality requirements - strong η dependence),
  - Muon Trigger efficiency ($\sim 91\%$ to trigger on either muon).

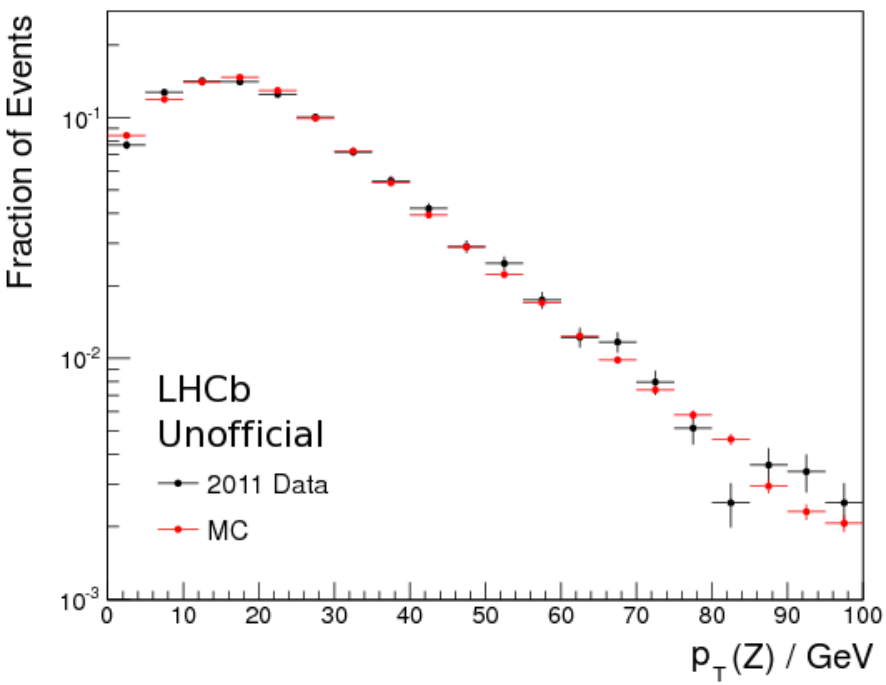


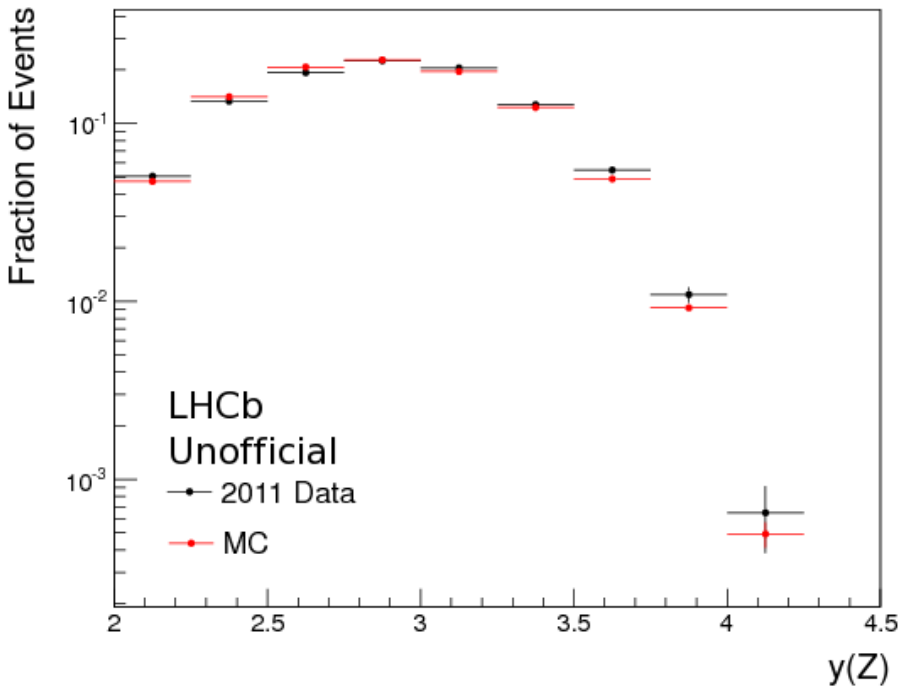
- Select $\sim 70\%$ of $Z \rightarrow \mu\mu$ decays in acceptance.

Kinematic Distributions of Z+Jet events

- We see very good agreement between the LHCb PYTHIA Monte Carlo Simulation (MC) and the 2011 LHCb Data.
- Plots not corrected for detection efficiencies, and are normalised to unit integral.

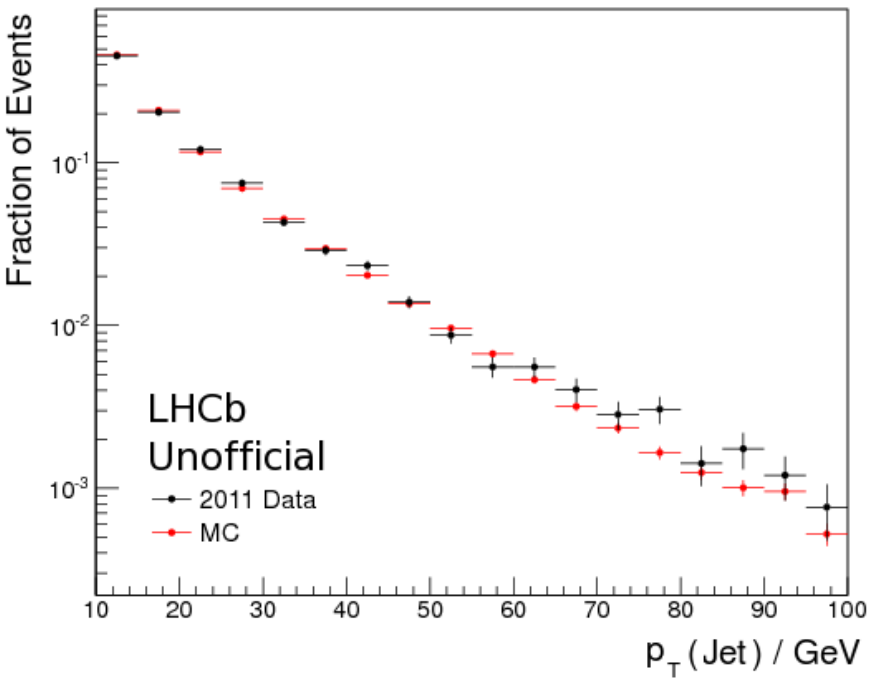
Z p_T and Rapidity Distributions

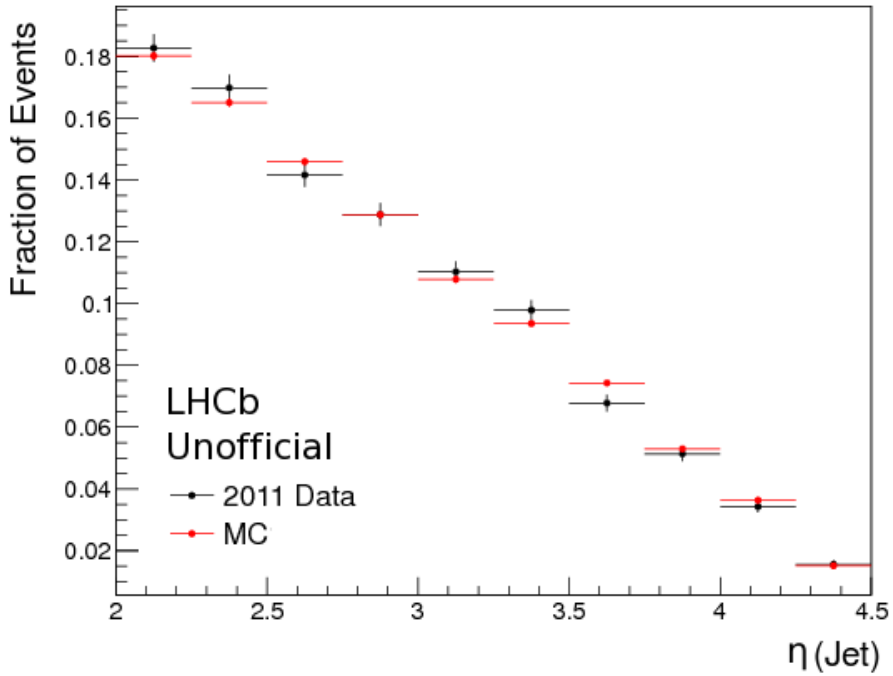




Kinematic Distributions of Z+Jet events

Jet p_T and Pseudorapidity Distributions





- p_T distributions encode information about higher orders in pQCD, whereas (pseudo)rapidity distributions are related to the PDFs.
- To probe this physics, we need to measure the cross-section.

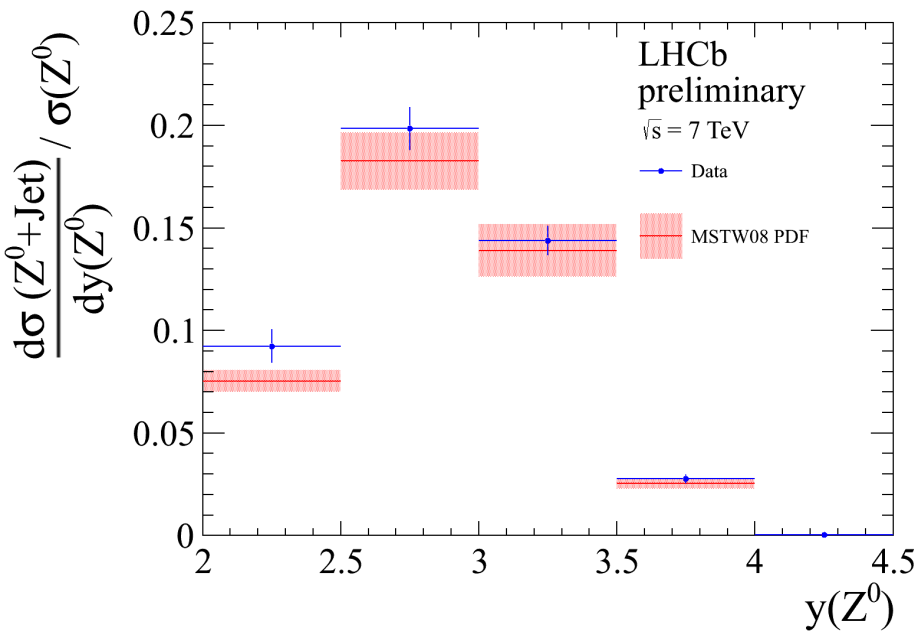
Cross-section Measurement

- We correct for the Z detection efficiencies and unfold the data to correct for the jet energy resolution and jet detection efficiencies.
- The agreement between data and MC gives us confidence in the MC based corrections (with systematic uncertainties assigned from compatibility of MC with data).

- e.g. The dominant systematic uncertainty is from the validation of the MC based Jet Energy Correction on data.
- We also consider systematic uncertainties from the unfolding process, the Z detection efficiency, and the validation of the Jet Detection Efficiency and the Jet Energy Resolution on data.

Cross-section Measurement

$$\sigma(Z + \text{Jet})/\sigma(Z) = 0.229 \pm 0.006(\textit{stat.}) \pm 0.009(\textit{syst.}) \text{ (LHCb prelim.)}$$
$$0.212\ ^{+\,0.006}_{-\,0.009}(\textit{PDF}) \pm 0.016(\textit{scale}) \text{ (Theory)}$$



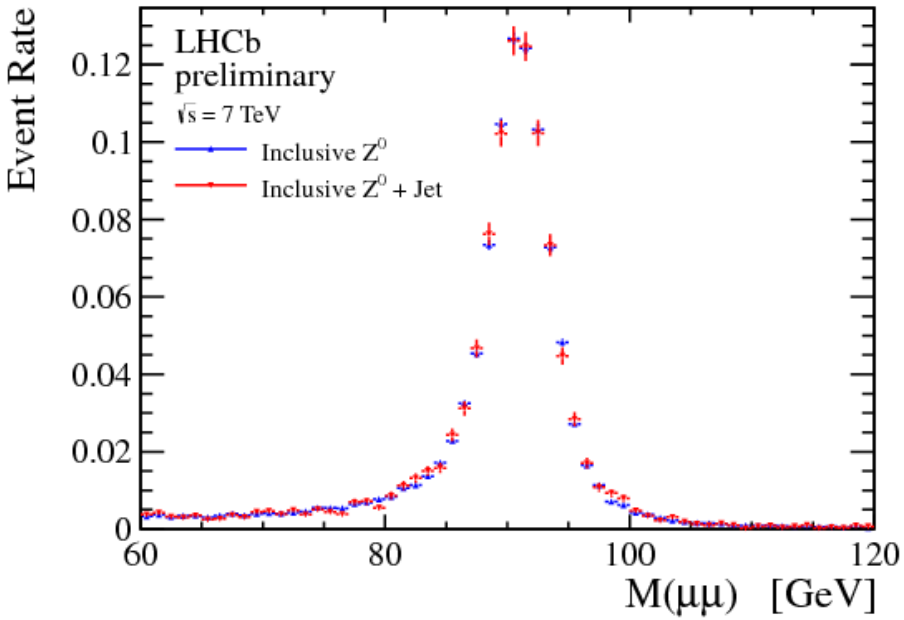
- Also in LHCb-CONF-2012-016:
  - Jet multiplicity distribution,
  - Z rapidity, p_T distributions in Z+Jet events,
  - Jet detection efficiencies,
  - Jet reconstruction performance.
- More distributions to follow soon.

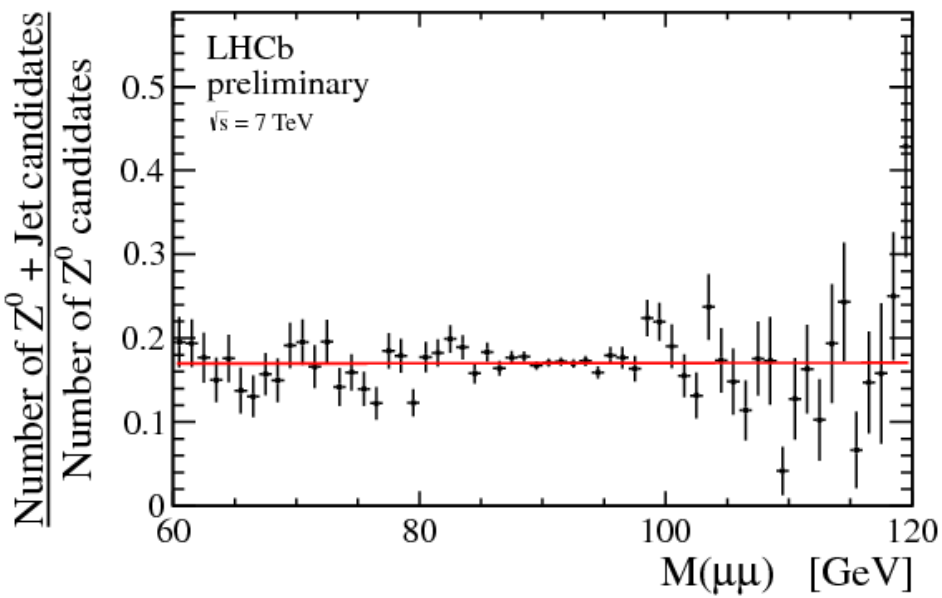
Conclusions

- Measurements of Z+jet production at LHCb provide tests of:
  - QCD - especially its treatment in different Monte Carlo programs,
  - parton distribution functions - LHCb probes a previously unexplored region of phase space.
- We see good agreement in the kinematic distributions of Z+Jet events between data and Monte Carlo.
- Our measurement of the Z+Jet cross-section is consistent with SM predictions.

BACKUP SLIDES

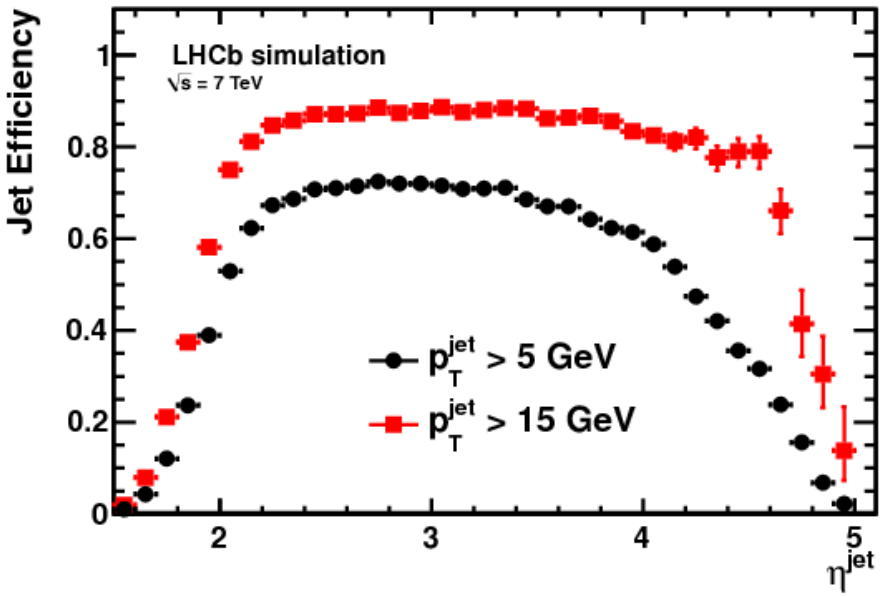
Background Studies

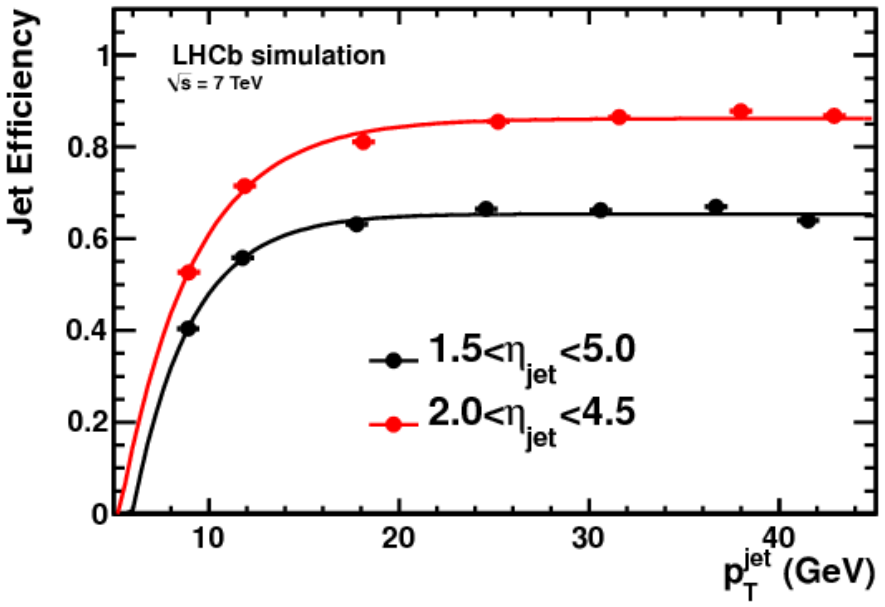




- Background level in Z and Z+Jet events is consistent.
- Confirmed by direct estimate of number of background events: studied in data (mis-ID, heavy flavour background), and MC ($Z \rightarrow \tau\tau$, top pair production.)

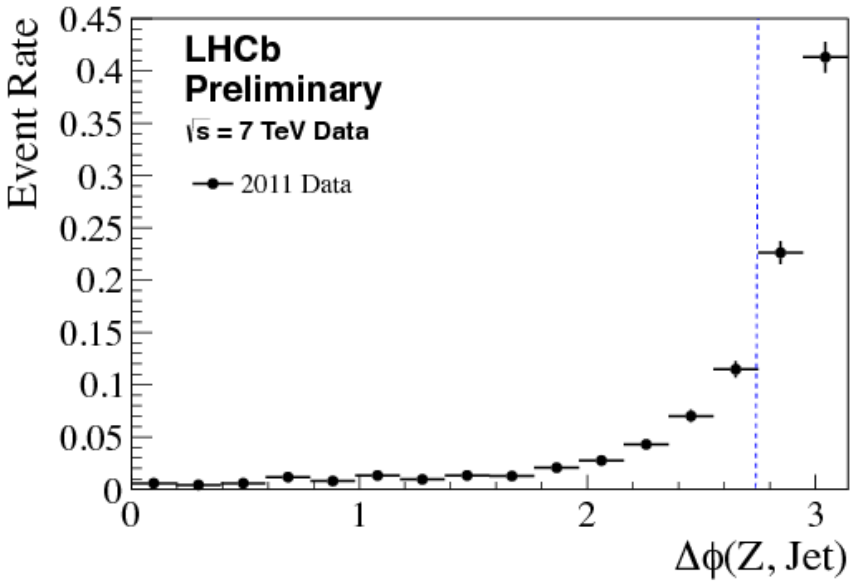
Jet Detection Efficiency

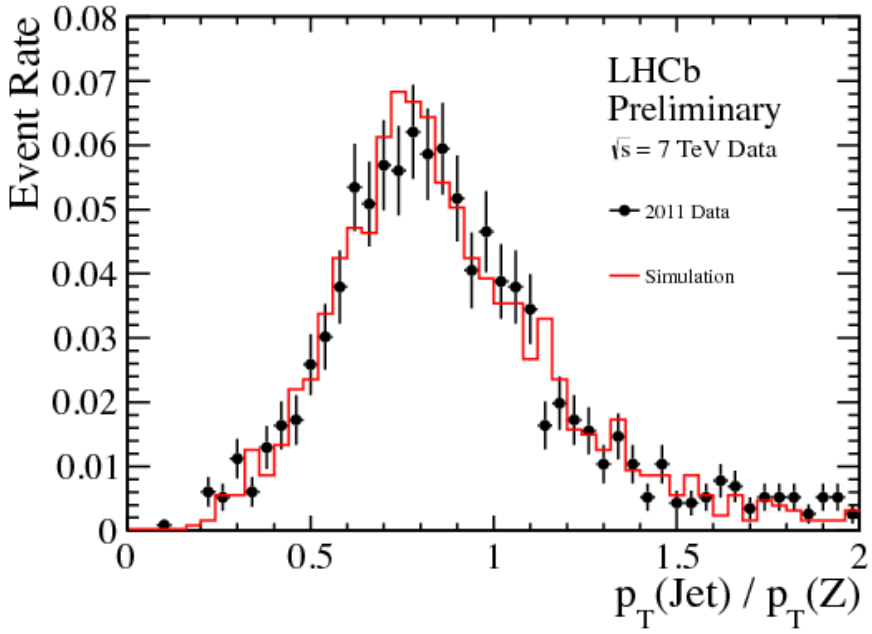




- Plots shown here have tighter jet ID requirements than those now used.

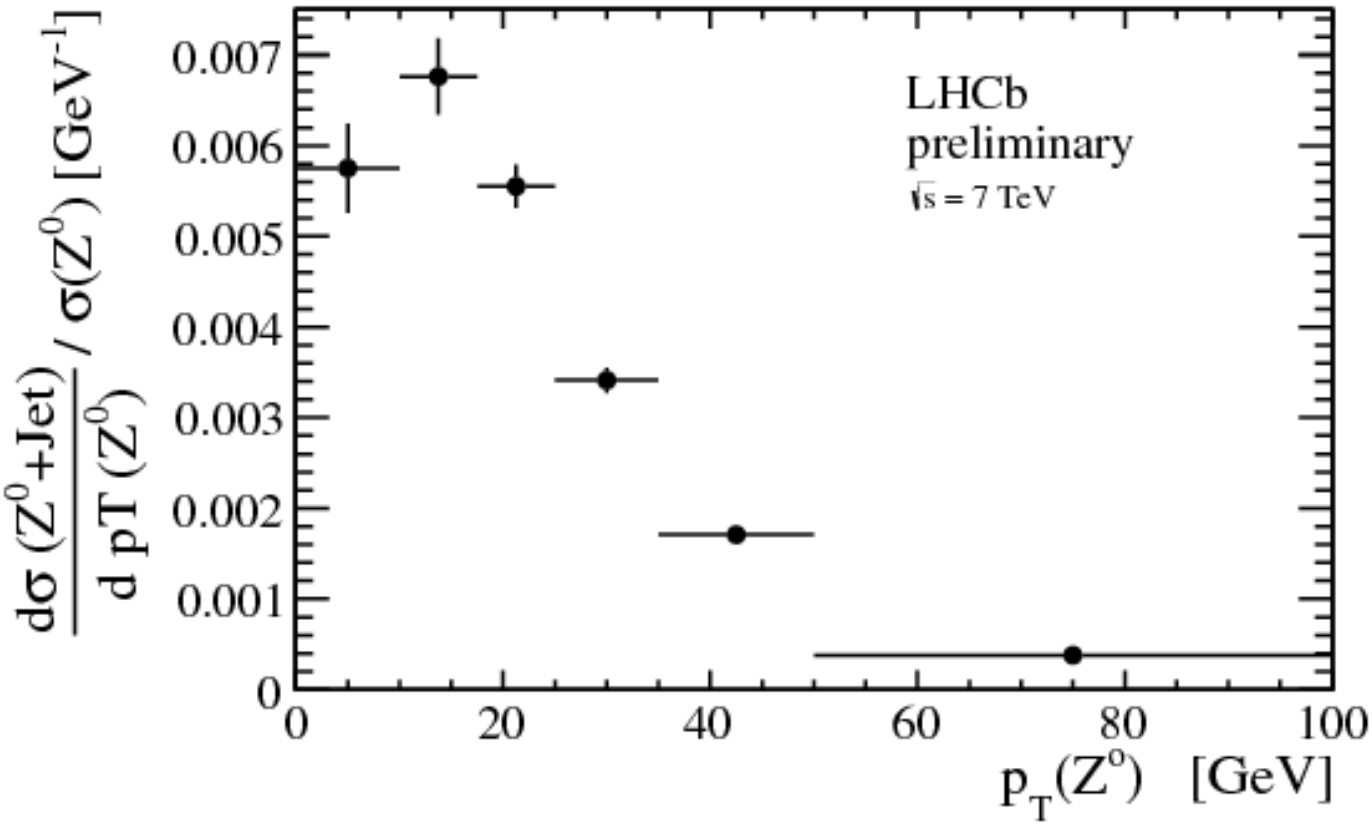
Jet Energy Scale Validation





- In events where the Z and jet are produced back to back, the p_{T} balance in data and MC agrees well.
- Study of this data/MC compatibility as a function of jet p_{T} and η sets a systematic uncertainty on the jet energy scale of $\sim 3\%$.

Z p_T Distribution in Z+Jet events



- LHCb result from LHCb-CONF-2012-016.