Jet measurements in LHCb and their relevance for PDF's

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Standard Model @ LHC

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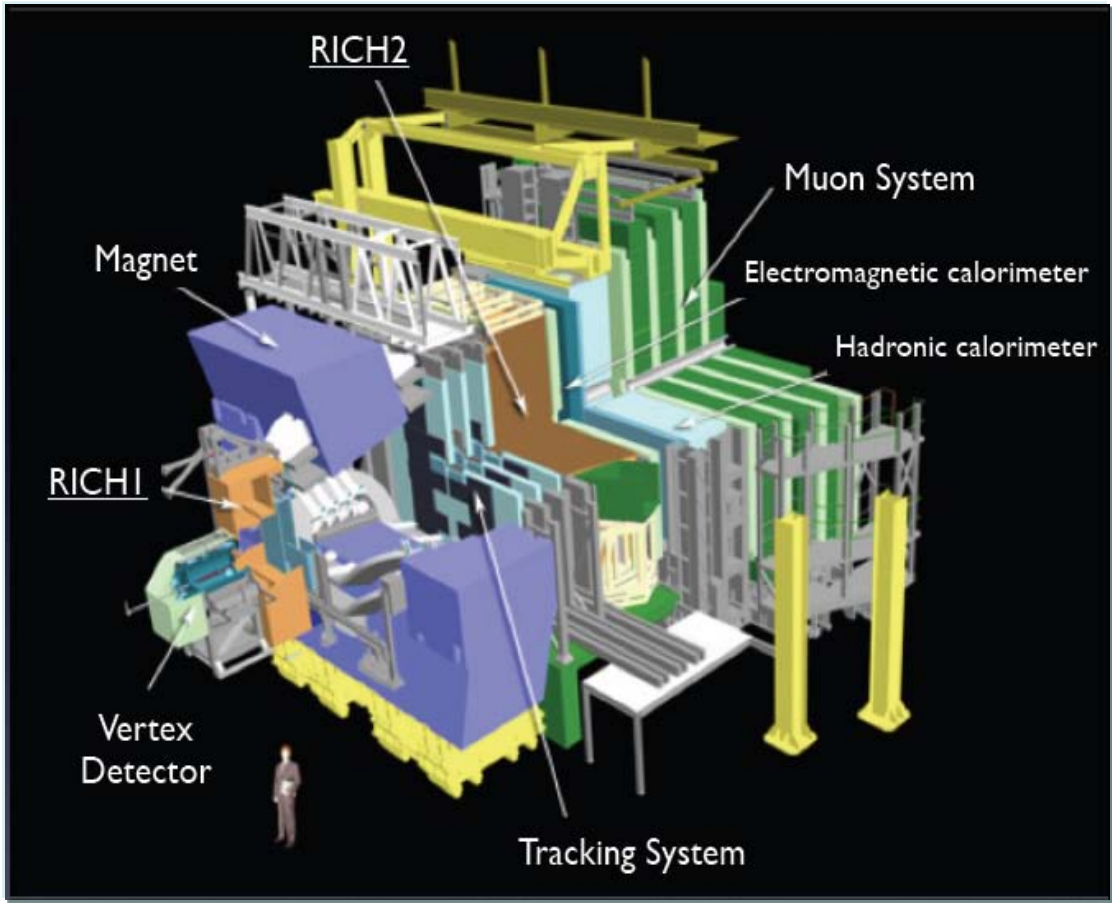
LHCb overview

LHCb is an experiment dedicated to B physics measurements at LHC pp collider

Single arm spectrometer

- designed for CP violation & rare decays of heavy mesons
- correlated production of $b\bar{b}$ pairs *(~40% in acceptance)*
- excellent vertex resolution
- very good momentum resolution and PID
- calorimeters and muon detectors
- efficient multi-level trigger *(hardware & software)*
- $\int L$: 37.6 pb^{-1} (2010)
  1.0 fb^{-1} (2011)



LHCb forward

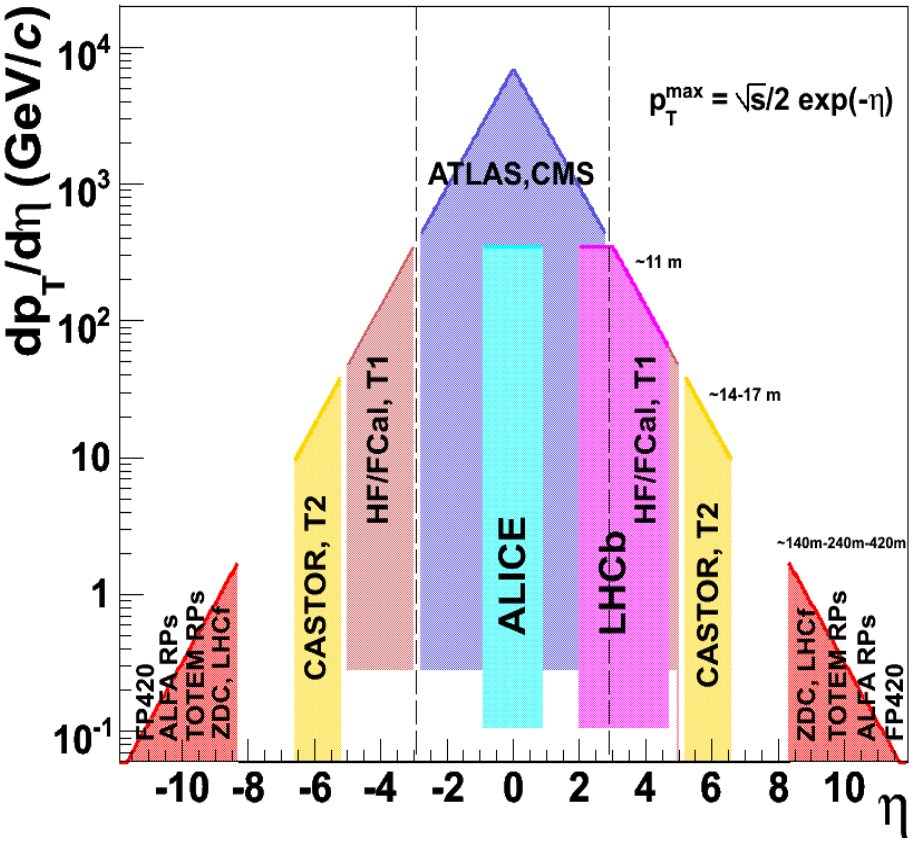
Unique kinematic region among LHC experiments

- η coverage in the forward region (2-5)
  - *able to access low p_T*
- precise tracking and vertexing in η ∈ (2-5)
  - *tracking efficiency ~ 95%*
  - *$\delta p/p = 0.35\text{-}0.55\%$ for $p \in (0.2\text{-}140)$ GeV*
- very good PID using two RICH detectors *(2-100 GeV/c)*
- good separation charged/neutral in calorimeters
  - *designed ECAL resolution:*

    $\sigma E/E = 10\%\sqrt{E} + 1\%$ *(in GeV)*
  - *HCAL resolution from test-beam data:*

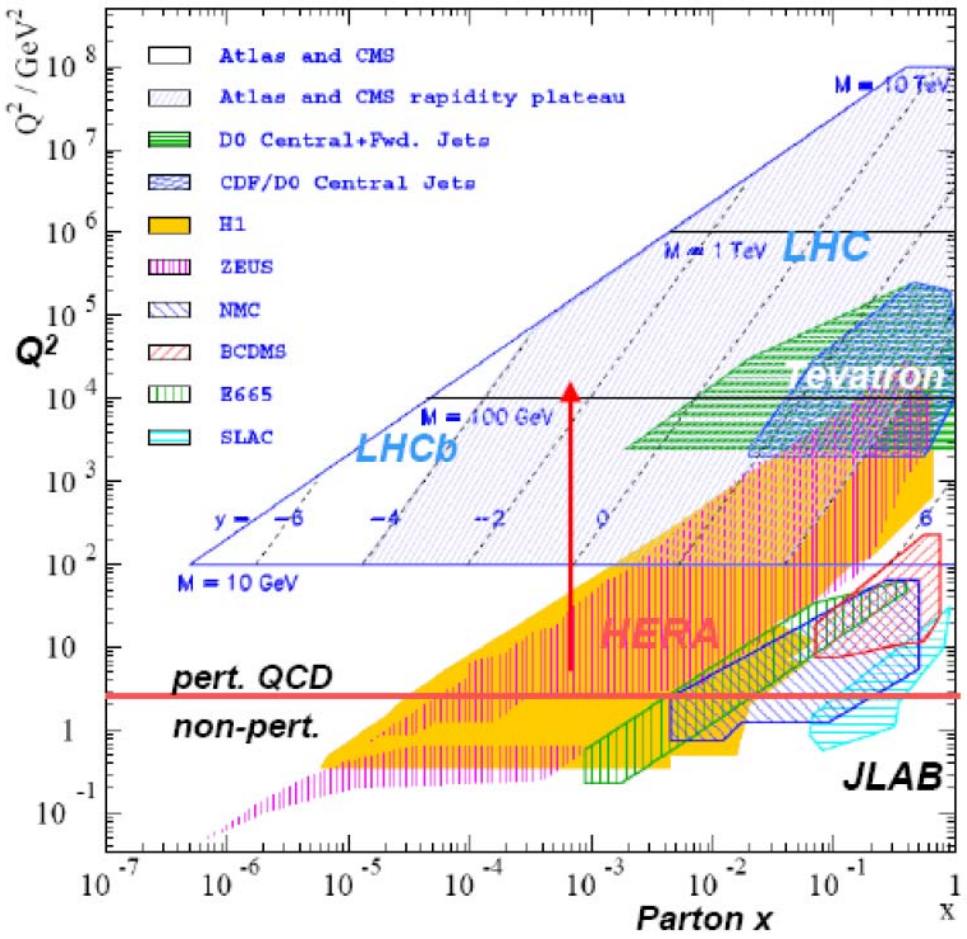
    $\sigma E/E = (69\pm5)\%\sqrt{E} + (9\pm2)\%$ *(in GeV)*

arXiv:0806.0883



LHCb extends coverage to $3 \leq \eta \leq 5$
overlaps with ATLAS/CMS at η ∈ (2-3)

QCD studies in the forward region



Forward jet production

- forward jets: *unusual mixture of high-x PDF's on low-x PDF's*
- probe of perturbative QCD
- understand underlying parton structure and its dynamical evolution
- provides information on the gluon density in a regime of low mom. fraction

(*standard deep inelastic e-p data can only indirectly constrain its value*)

→ **inclusive jets distributions**

→ **tagged jets** ***(not only b,c)***

→ **fully reconstructed dijets**

→ **multiple jets**

→ **jet + Z / W**

→ **underlying events**

Inclusive dijets *(2010 data)*

Preliminary stage of analysis

→ check feasibility of jet reconstruction in LHCb

→ establish a benchmark with low constraints

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2010 data sample

- ~1.0 pb^{-1} pp collisions at 7 TeV
- very low pileup
- very loose trigger cuts
  - low L0 trigger cuts
  - no HLT trigger

→ **50 nb^{-1}**

very loose trigger cuts,

jet rec. eff. (MC): 99.8%

→ **0.97 pb^{-1}**

slightly tighter trigger,

jet rec. eff. (MC): 74.2%

1 PV events

good sample to be considered as a reference

Event selection

Event cuts

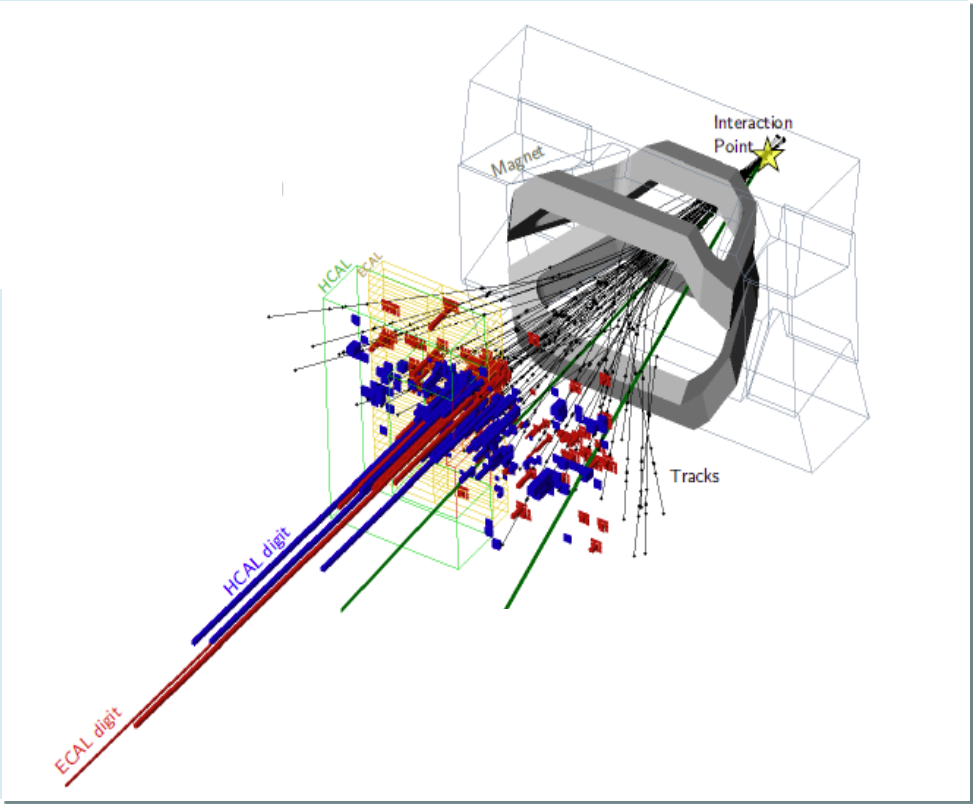
- L0 minimum bias trigger
- exactly *1* reconstructed primary vertex
- at least *5* charged tracks

Charged tracks

- good quality tracks from PV
- tracking system used *(+ calo)*

Neutrals

- π^0's with $p_T > 2$ *GeV/c*
  (max. efficiency > 50%)



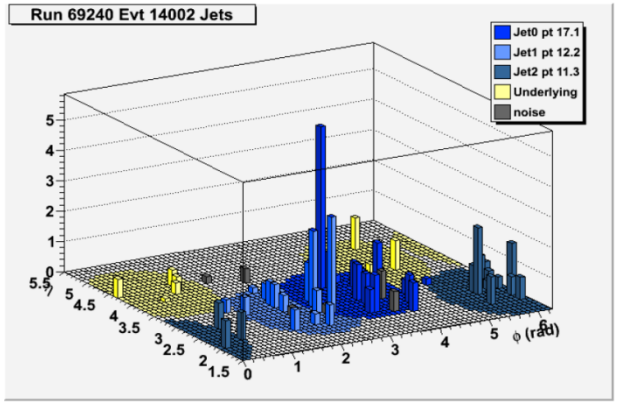
Jet reconstruction

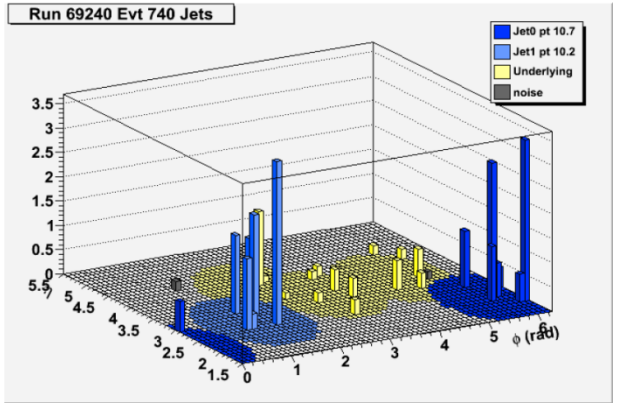
- charged tracks and rec. π^0's $\rightarrow$ ***Particle Flow Jet***
- k_T algotithm *(E-recombination scheme, R=0.7)*
- at least 1 jet with $p_T > 10$ GeV/c

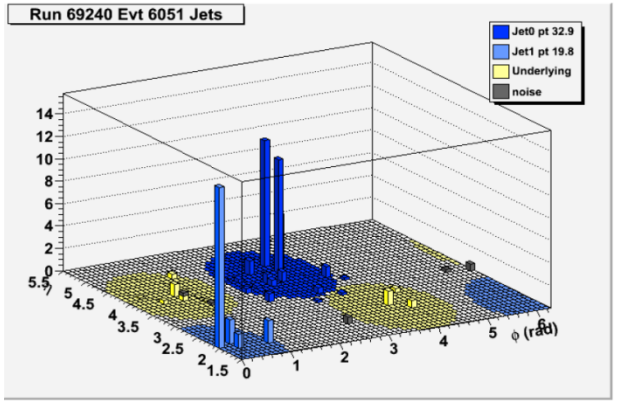
'RAW' jets:
uncorrected for acceptance, energy scale and resolution

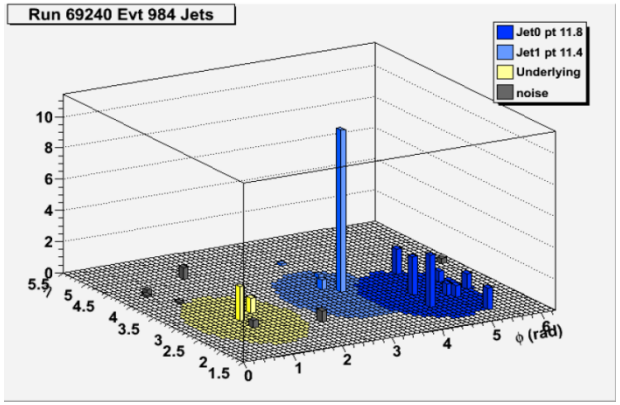
Examples of jets in LHCb

Some illustrative LHCb events with the leading jet p_T >10 GeV from very early runs at 7 TeV









- k_T algorithm;
- E-recombination scheme;
- cone size R = 1.0;
- leading jet p_T > 10 GeV *(no jet energy correction)*

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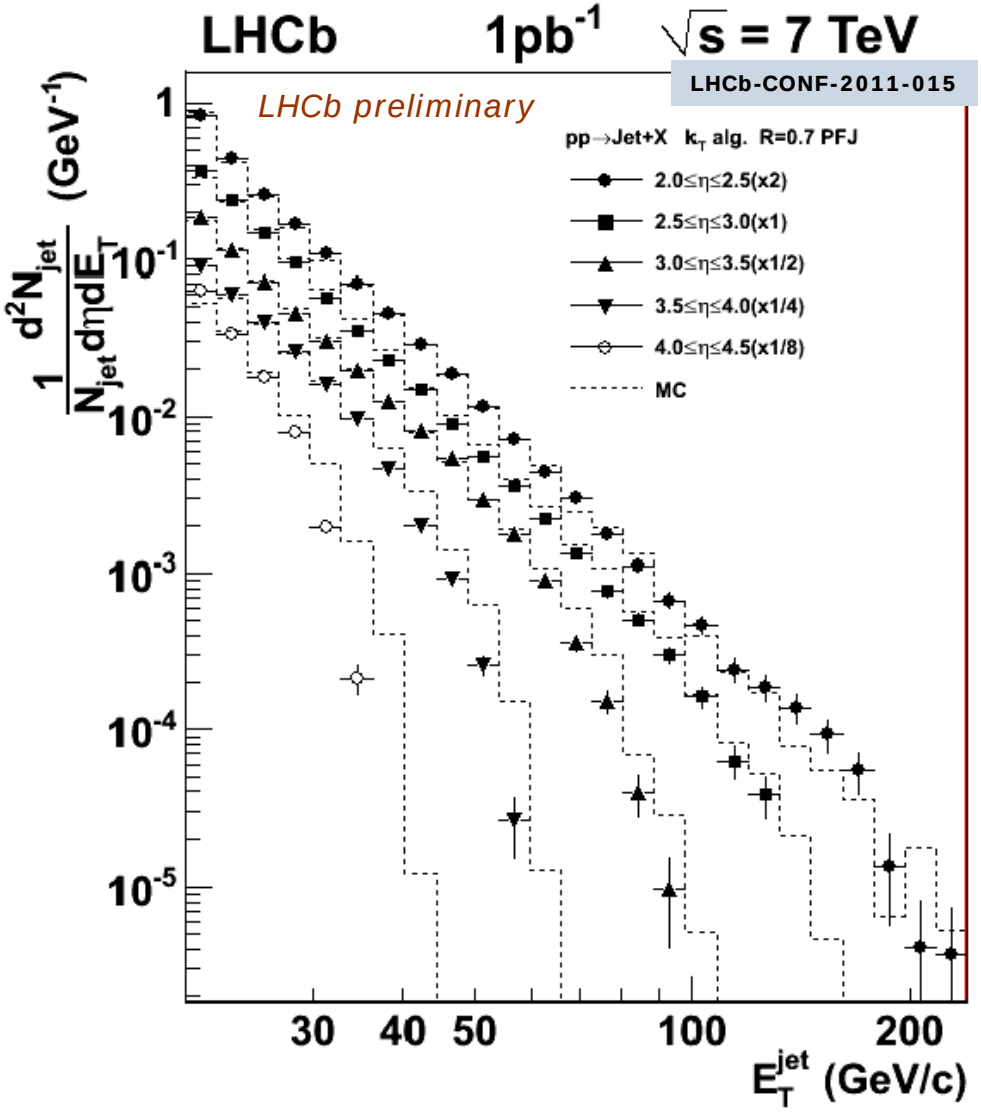
Inclusive jets spectra

Inclusive jet spectrum

- jet transverse energy in E-recombination scheme
- uncorrected for acceptance, jet energy scale and resolution
- figures denote real data
- dashed lines are for MC using Pythia 6.4 generator with PDF CTEQ6 LO where the best LHCb detector was employed

$$E_T^{RAW} = \frac{\sum E_j}{\cosh \eta_{jet}}$$



Signal of partonic dijets

Signal of back-to-back dijet events

- **azimuthal angle difference**:

$$\Delta\phi = \phi_{jet_1} - \phi_{jet_2}$$

for two leading jets

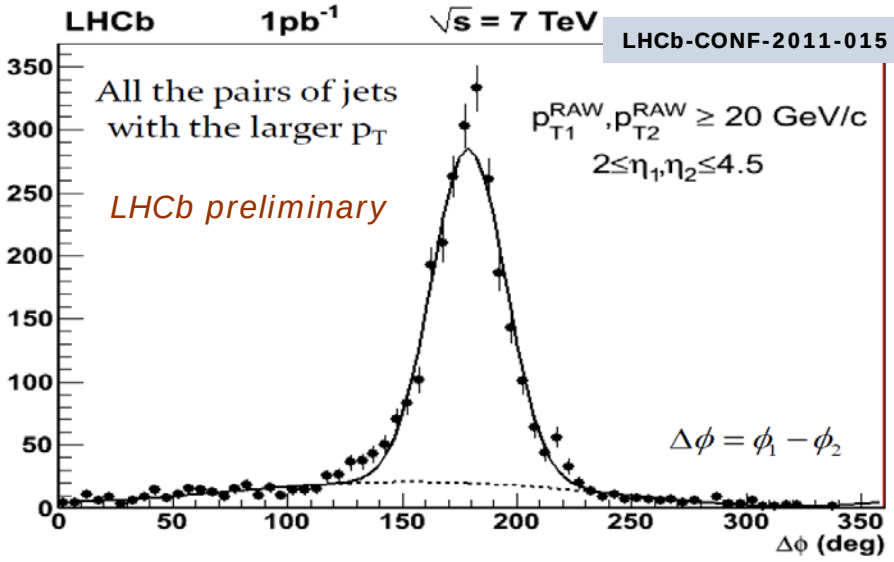
- **asymmetry parameter**:

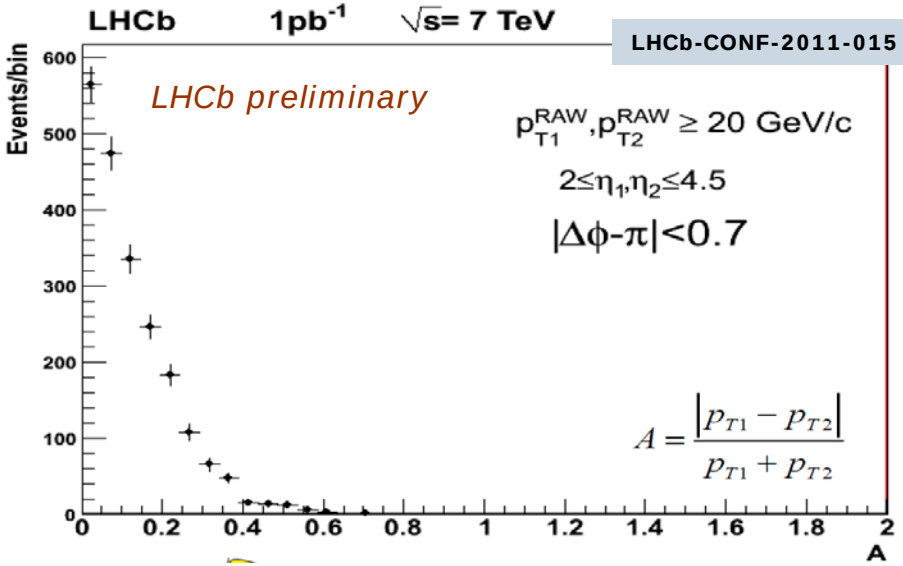
$$A = \frac{|p_{T1}^{RAW} - p_{T2}^{RAW}|}{p_{T1}^{RAW} + p_{T2}^{RAW}}$$

for events with two jets where $|\Delta\varphi - \pi| < 0.7$

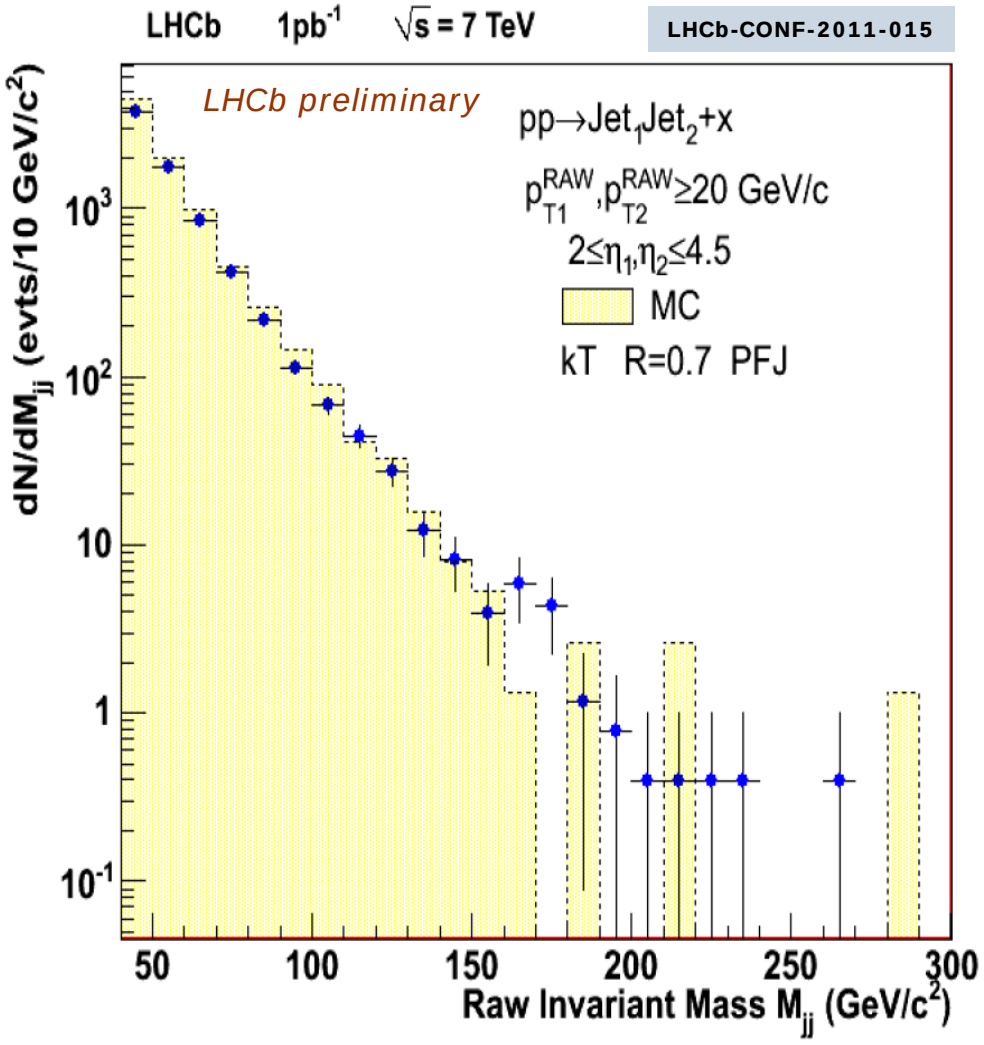
Asymmetry spread: long range QCD effects

- initial & final state radiation
- multiple partonic interactions





Dijet invariant mass



- dijet invariant mass reconstructed from the sum of 4-vectors of two jets
  - no corrections applied
  - MC: Pythia 6.4 CTEQ6LO generator with LHCb detector description

Dijet selection

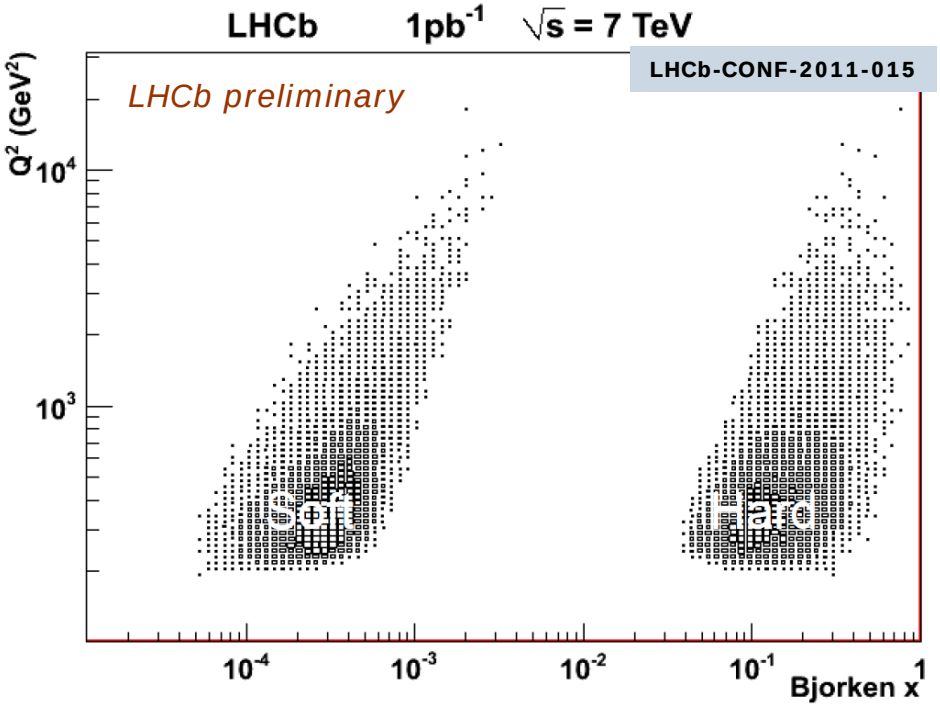
jet $p_T > 20$ GeV

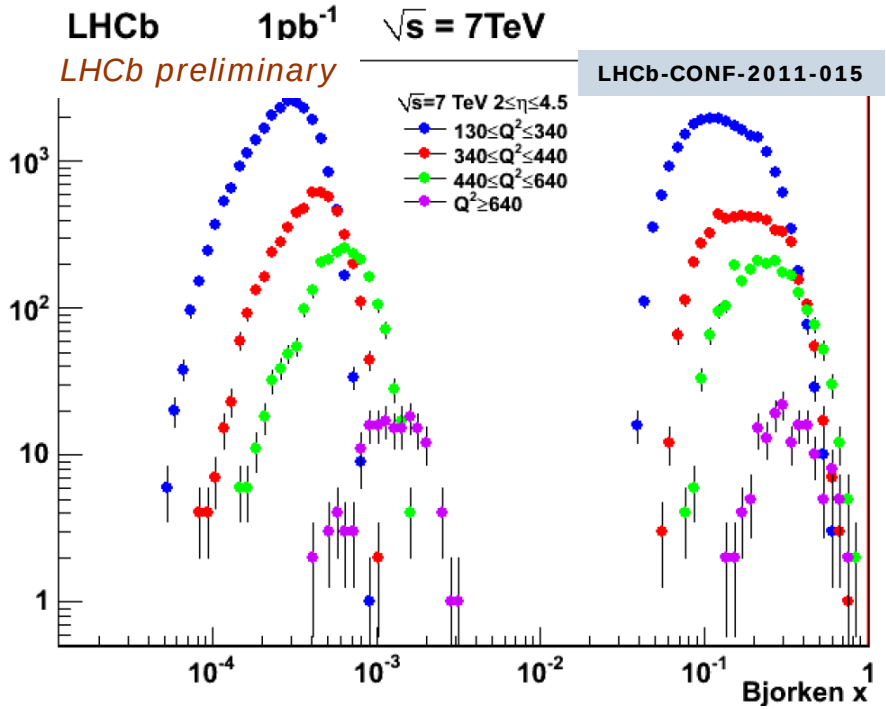
$||\varphi - \varphi| - \pi| < 0.7$

$A < 0.2$

QCD with dijets

Plots showing experimentally the range accessible to LHCb





Measurements employing relations:

$$\tilde{x}_{1,2} = \frac{2p_{T1,2}^{RAW}}{\sqrt{s}} e^{\pm\bar{\eta}} \cosh\frac{\Delta\eta}{2}, \qquad \tilde{Q}^2 = p_{T1}^{RAW} p_{T2}^{RAW}$$

$$\bar{\eta} = \frac{1}{2}(\eta_1 + \eta_2)$$
$$\Delta\eta = \eta_1 - \eta_2$$

are used to determine kinematics of 2 partons

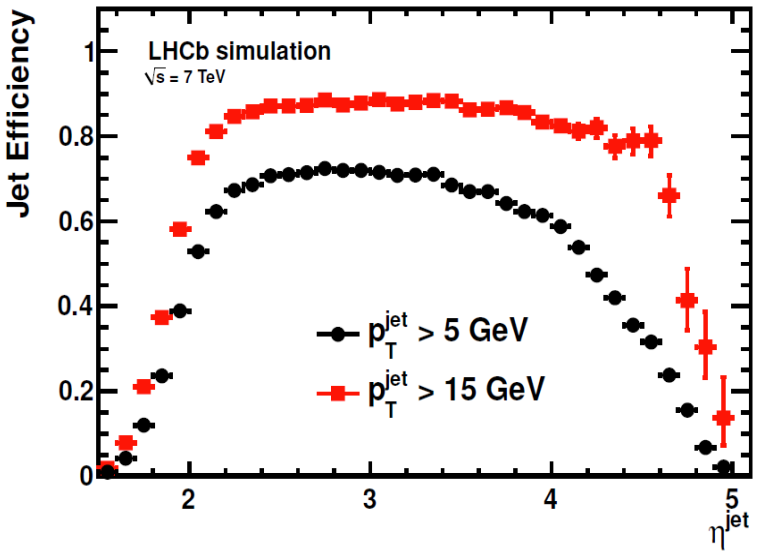
Z + jet analysis *(2011 data)*

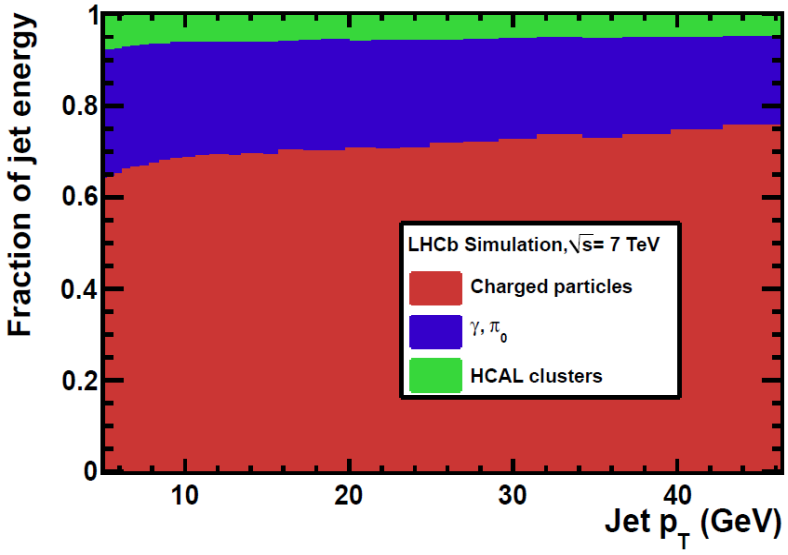
Input

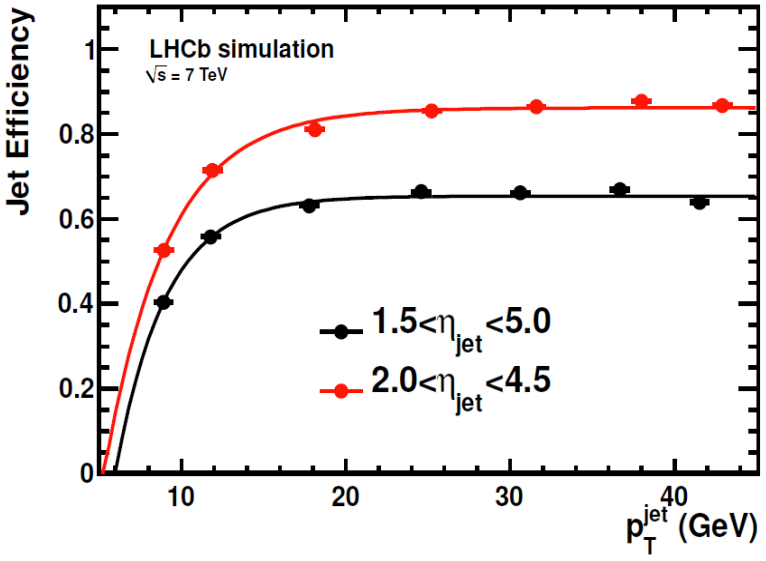
- charged particles
- reconstructed neutral resonances (K^0_S,Λ^0)
- photons and π^0's from ECAL
- neutral hadrons from HCAL

Jets

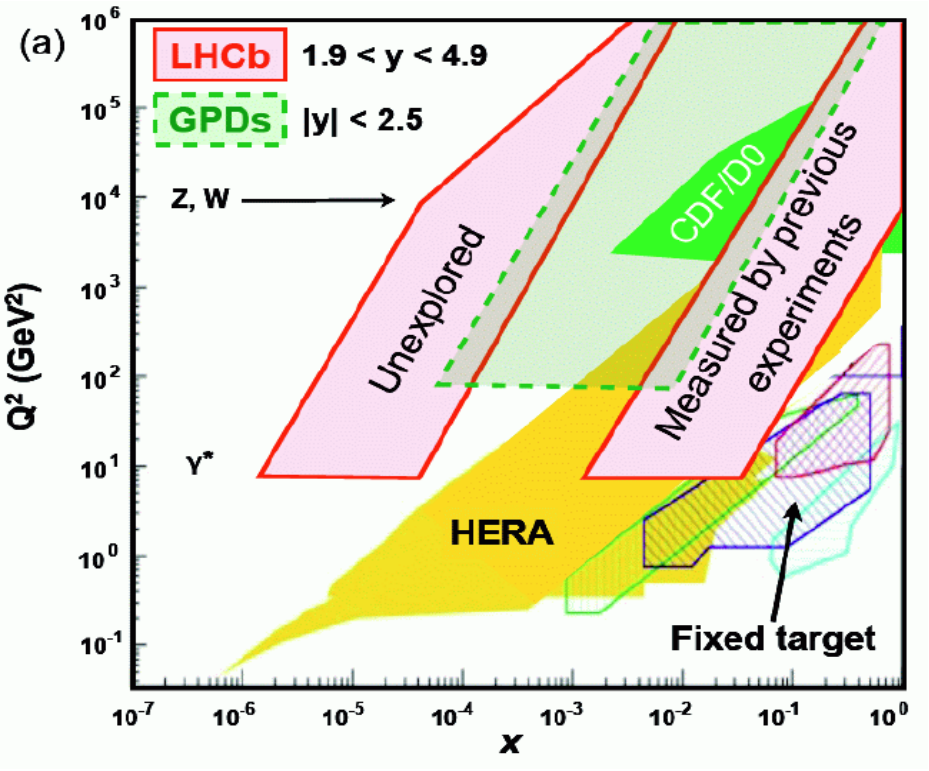
- anti-kt, E combination scheme, R=0.5, p_T > 5GeV
- jets are reconstructed for every primary vertex
- no jets dominated by one track.
- 90% of the energy shared by ≥ 4 particles





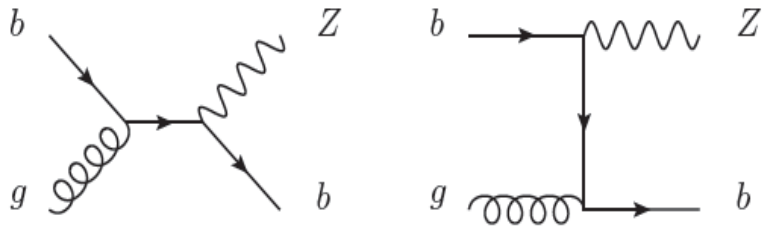


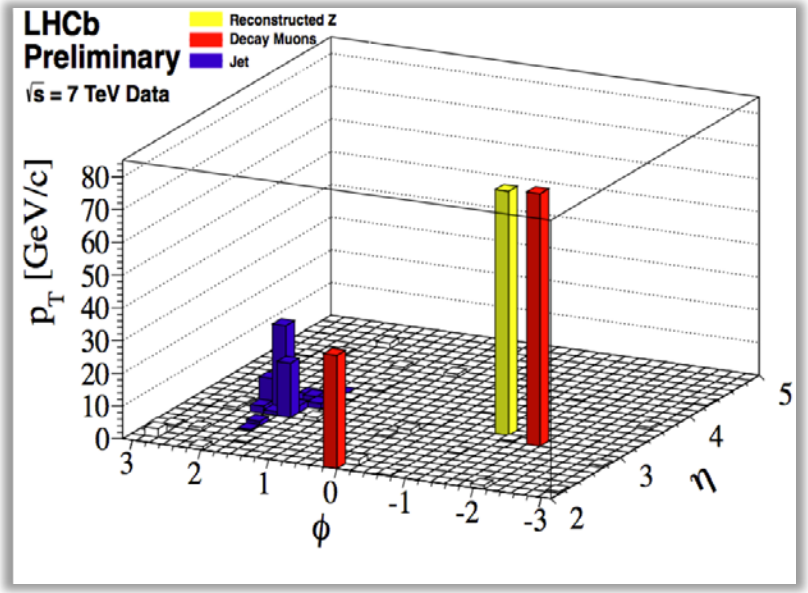
Z + jet



Q^2–$x_{1,2}$ kinematic range

- **direct access to the b content in the proton**
- **useful measurement to constrain PDF's**





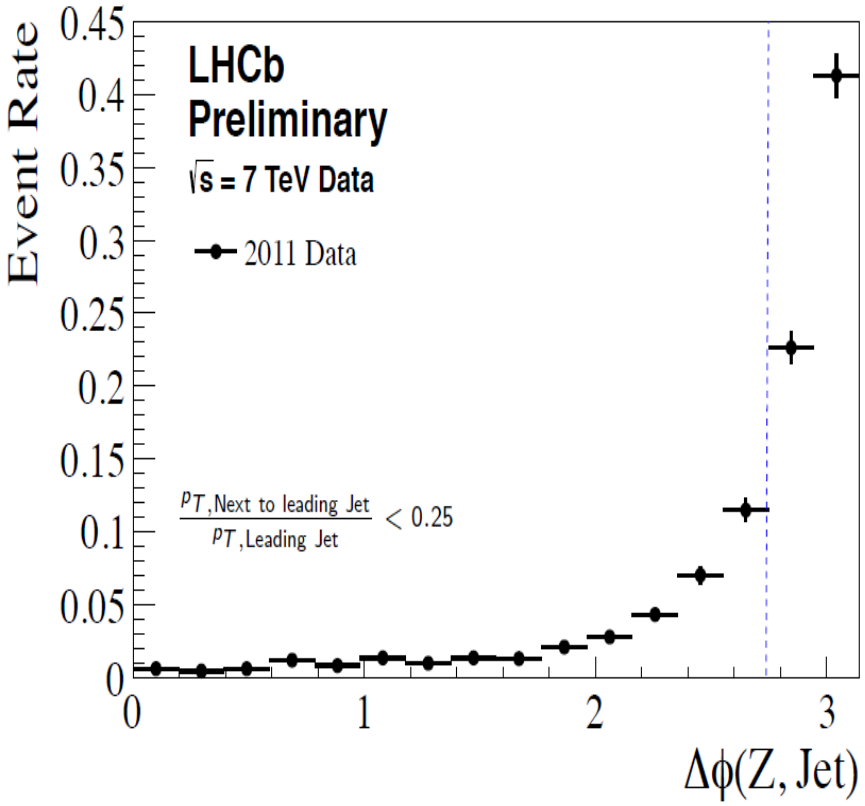
- $p_{T,jet}$ = 75 GeV
- $p_{T,\mu+}$ = 35 GeV
- $p_{T,\mu-}$ = 77GeV
- $m_{\mu+\mu-}$ = 97.1 GeV

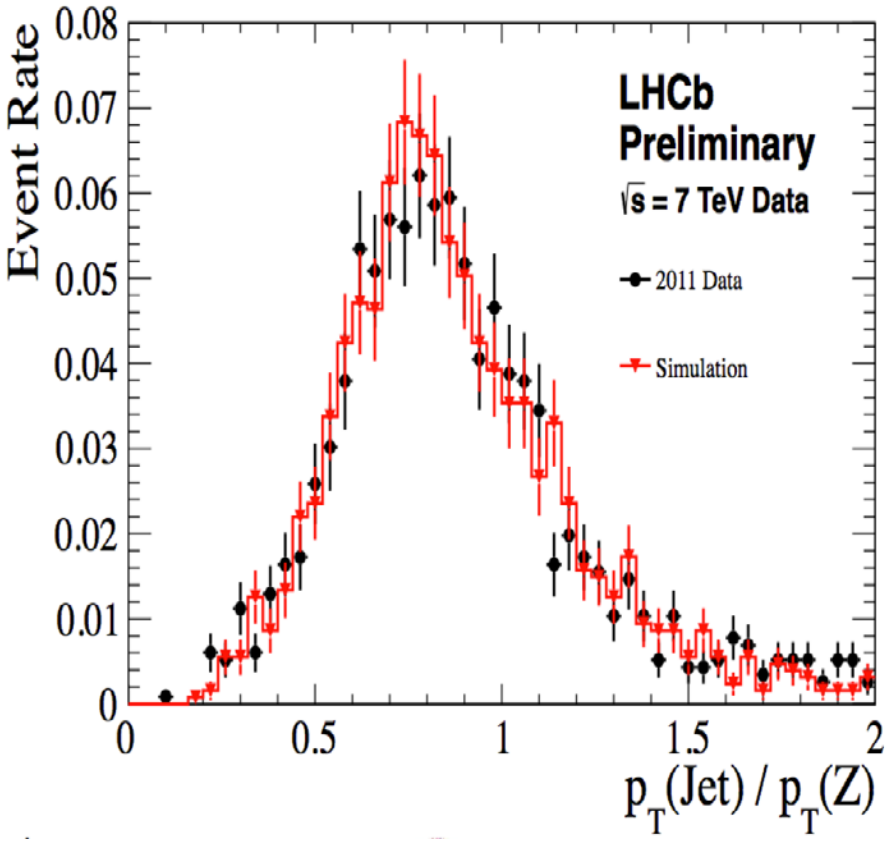
Angular distribution and p_T balance

$$\frac{p_T,\text{Next to leading Jet}}{p_T,\text{Leading Jet}} < 0.25$$

$$p_T,\text{Leading Jet} > 10\ \text{GeV}$$

$$|\Delta_\phi(Z, \text{Leading Jet})| < \frac{7\pi}{8} \quad \rightarrow \textit{ right plot only}$$





Conclusions

- Ongoing analyses
  - inclusive dijets
  - Z + jet
- Preliminary results for dijets show the feasibility of jet rec. in LHCb
  - 1 pb^{-1} sample from at 7 TeV analysed
  - analysis of full available sample ongoing
- It may be seen that LHCb has a potential to measure inclusive jets and dijets parameters within the $\eta \in (2 - 5)$
- Large statistics already collected in 2010 and 2011
  - interesting results on perturbative QCD expected at low momentum fraction $x \leq 10^{-3}$
- LHCb also very useful for jet analyses