Jets and QCD measurements in LHCb

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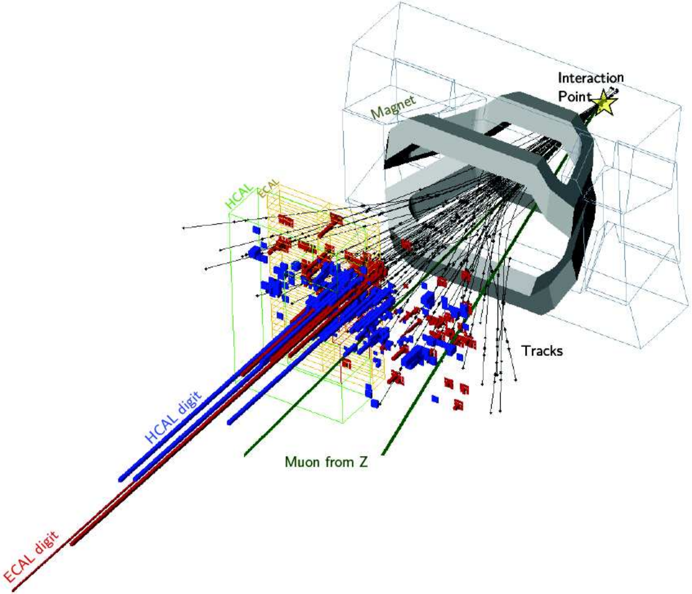
on behalf of the LHCb Colaboration

LHCb workshop on quantum interference effects, QCD measurements and generator tuning

CERN, October 20th 2014

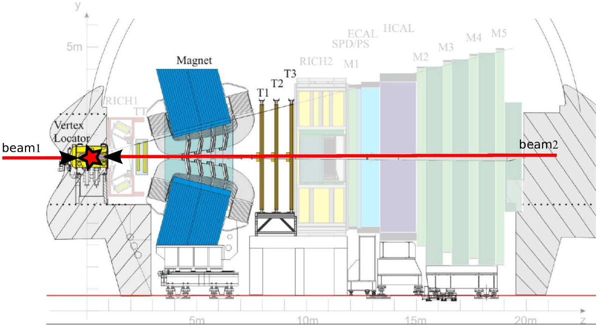

Interaction
Point
Magnet
HCAL
ECAL
Tracks
HCAL digit
Muon from Z
ECAL digit

- LHCb detector is a forward spectrometer designed for precise measurements of B and D hadron decays
- Unique η coverage among LHC experiments ($2 < \eta < 5$)
- Low pileup condition ($< \mu > \sim 2$)
- recent effort to define a jet reconstruction for LHCb

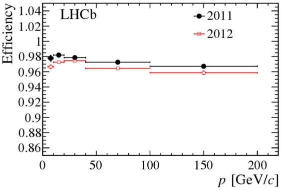
Outline

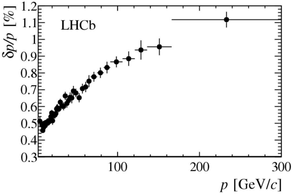
- LHCb detector
- Jet Reconstruction:
  - Particle Flow
  - Jet Identification
  - Jet Energy Correction
  - b tagging
- Analysis with Jet(s):
  - Z+jet
  - Z+b-jet
  - $A_C^{b\bar{b}}$

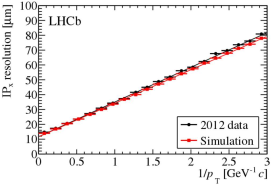
2008 JINST 3 S08005



- Excellent tracking performances.







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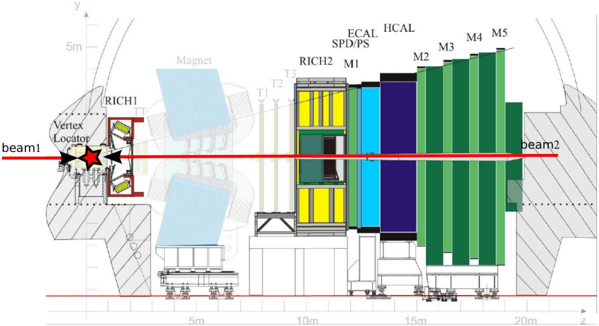
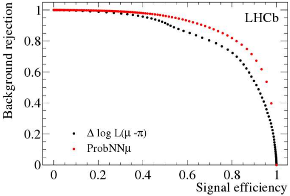
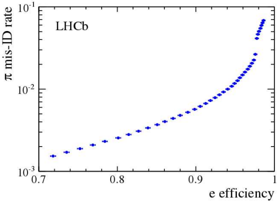


- Good lepton vs. hadron separation.





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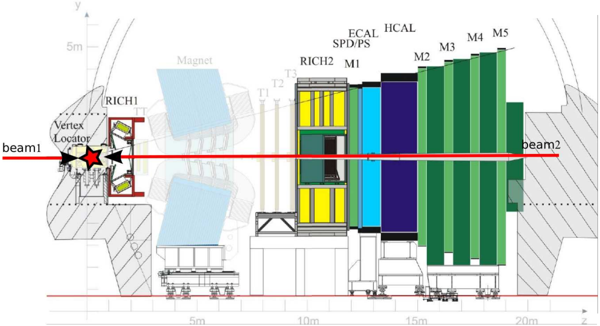
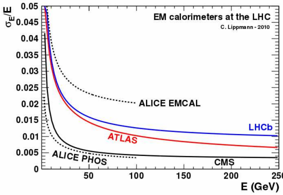
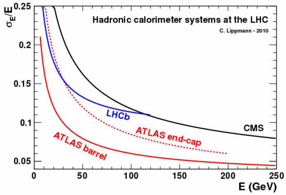


- Calorimeter not optimised for calo based jet reconstruction.



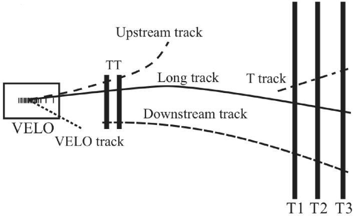


Particle Flow approach to jet reconstruction.

- **Charged Particles**:
  quality cuts to reduce fake contributions. Flagging all ECAL and HCAL clusters that match those tracks
- **Reconstructed V0s**:
  using K_s^0 and Λ^0 and removing their tracks from the charged particles.
- **Isolated Neutrals**:
  from not "used" CALO clusters (π^0, photon, neutral hadrons)
- **Non Isolated Neutrals** ("used" clusters):
  removing charged particle contributions.
  - Contribution from charged particles is substracted from coresponding calorimeter clusters
  - Charged hadron, muon and electrons <Ecalo/ptrack> taken from isolated track sample in data
  - If significant amount of energy is left, create neutral particle out of it

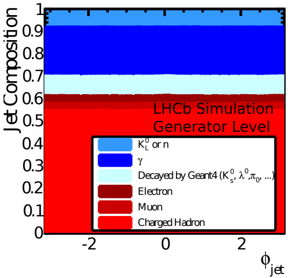
Excellent IP resolution for charged particles: reconstruct jets per PV.
Different set of input for each PV in the event.

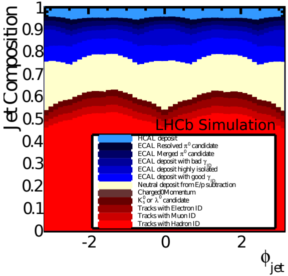
- Object with pointing infromation: used only for the corresponding PV.
  - Charged Particles - from Long and Upstream tracks pointing to the PV of interest.
  - Reconstructed V0s which point to the PV of interest.



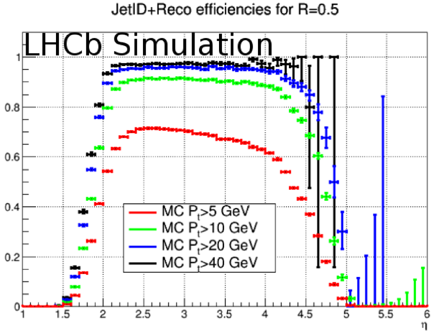
- Object without pointing information: used for all PVs
  - Charged Particles - from Downstream tracks.
  - Isolated Neutral Particles
  - Non Isolated Particles

- anti-k$_T$ jet with $R = 0.5$.
- Top: Generator Level; Right: Reconstruction in MC Simulation.
- Red colors: charged particles; Blue: neutral; Cream: Non Isolated Neutrals
- Good agrement in particle fractions.
- Generator Level Jet: Stable Particles without neutrino clustered with the same jet algo.

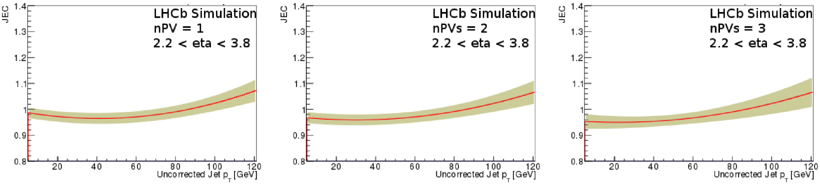




- quality cuts are applied in order to remove leptonic jets and noise.
- variable used: maximum PT fraction that only one particle carries (mtf), highest pt particle (mpt) and number of track pointing to PV (nPVTrks).
- cuts: mtf < 0.75, mpt > 1.8, nPVTrks > 1



- Derived from Simulation
- JEC is determined from the measured jet p_T/true jet p_T distribution. The correction is binned in η, cpf (charged particle energy fraction), number of PV and in p_T.
- Not correcting for missing energy (neutrino), only for detector and reconstruction effects.



- Correction of the order of 0.9 to 1.1
- Uncertainty band accounting for: closure test, flavour dependence, stat.
- Flavour dependence uncertainty (HF vs light): 2 %
- Syst. uncertainty analysis per anaylsis
- Working on more generic evaluation.

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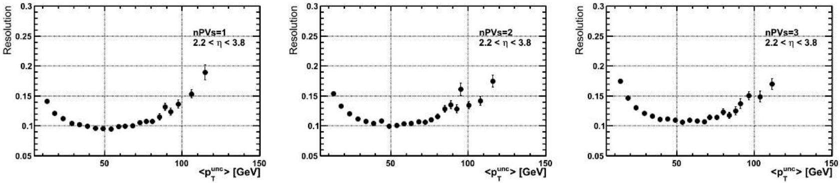


- Resolution between 10-15 % up to 100 GeV
- Syst. uncertainty analysis per anaylsis
- Working on more generic evaluation.

run I:

- most of the triggers are optimised for B and D decays (low p_T, high displacement)
- inclusive muons triggers down to low mass and p_T

	prompt	Detached
single-μ	$\mathbf{p_T > 10}$ **GeV**	$\mathbf{p_T > 1.3}$ **GeV** $(IP > 0.5\ mm, IP\chi^2 > 200)$
double-μ	$\mathbf{m_{\mu\mu} > 4.8}$ **GeV**	$\mathbf{m_{\mu\mu} > 2.95}$ **GeV** $(DLS > 5)$

- no jet-based trigger, BUT an inclusive B hadron trigger (TOPO)
- 2, 3 or 4 displaced tracks vertex compatible with a B + MVA selection

$\rightarrow$ **Act as a b-jet trigger.** $\epsilon_{b-jet} \sim 30 - 45\%$ **for** $p_T > 15\ GeV$
c-jet $\sim 1 - 8\%$**, l-jet** $\sim 0.1 - 1\%$

run II:

- online detector calibration mechanism after first stage of triggering

$\rightarrow$ **Offline-like reconstruction available (PID, tracking)**

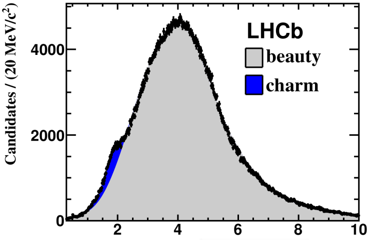
- b-jet trigger under investigation.
- more flexibility $\rightarrow$ more complex signature.
- storage rate: 5 kHz (Run I)$\rightarrow$ 12.5 kHz (Run II).

In $A_C^{b\bar{b}}$ and Z+b-jets

TOPO based tagging:

$a_c^{b\bar{b}}$ PRL 113 (2014) 082003:

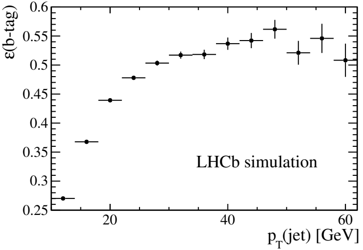
- trigger on muon of one of the B → looser version of the TOPO
- b-jet containing a μ: $\epsilon_{b-tag} \sim 60\%$
- second b-jet: $\epsilon_{b-tag} \sim 50\%$
- non-$b\bar{b}$ contamination in final sample $3.6 \pm 1.2\%$



$$M_{\rm corr} = \sqrt{M^2 + \left(\frac{p}{c}\right)^2 \sin^2\theta} + \frac{p}{c}\sin\theta$$

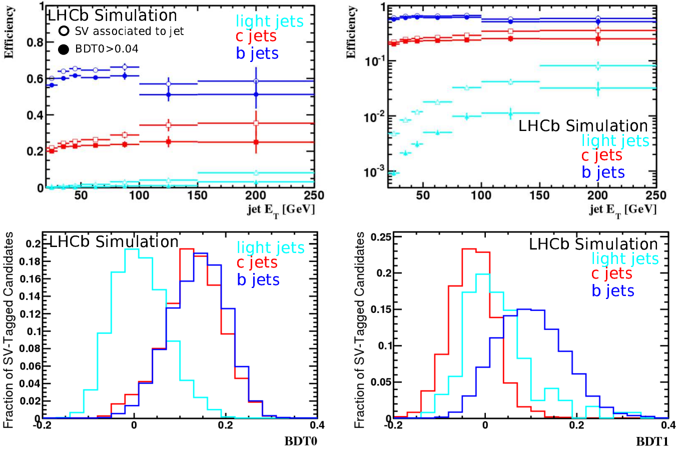
z+b-jet cross section, PAPER-2014-055:

- trigger on the Z → looser version of the TOPO
- ℓ, c-jet contribution from template fit to M_{corr}



New development

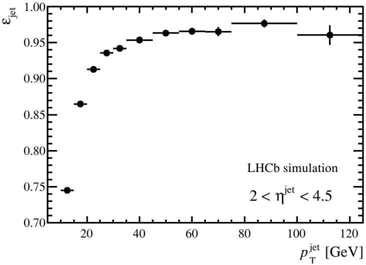
- inclusive secondary vertex reconstruction from good quality displaced tracks.
- SV based and jet based variables are inputs of 2 BDTs (ℓ vs. b, c and c vs. b):

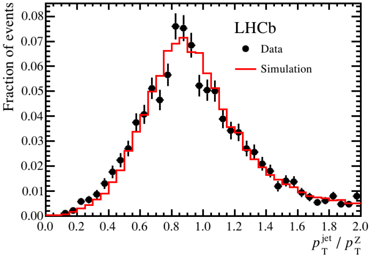


- HF jet tagging paper in review and used in $W + (b, c, \ell) - jets$ analysis also in review.

first measurement with jets at LHCb, JHEP01 (2014) 033

- fiduciual volume of the measurement:
  - $2 < \eta_{jet} < 4.5$, $p_{T\ jet} > 10(20)\ GeV$
  - $60 < m_{\mu\mu} < 120\ GeV$
  - $\Delta R(\mu, jet) > 0.4$
- dominant uncertainties are jet related 7.8 %:
  - energy scale uncertainty (2 % from method and 3 % from DATA/MC)
  - resolution uncertainty(10 % DATA/MC agreement)
  - reconstruction efficiency uncertainty (3 %)
  - work on-going to improve these points.





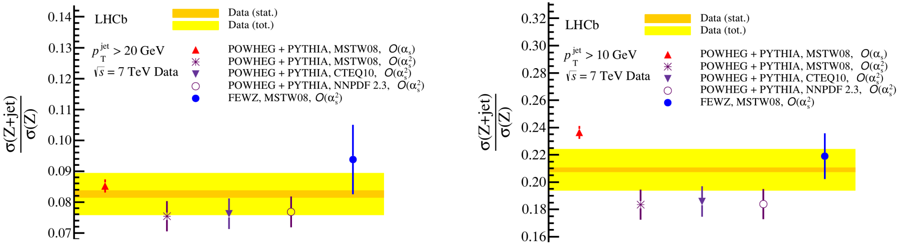
Result

- measured at the Born level

$$p_T^{jet} > 10 \text{ GeV} \qquad \frac{\sigma(Z+jet)}{\sigma(Z)} = 0.209 \pm 0.002\,(\text{stat.}) \pm 0.015\,(\text{syst.})$$

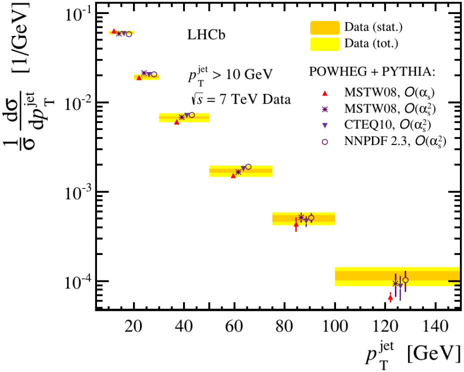
$$p_T^{jet} > 20 \text{ GeV} \qquad \frac{\sigma(Z+jet)}{\sigma(Z)} = 0.083 \pm 0.001\,(\text{stat.}) \pm 0.007\,(\text{syst.})$$

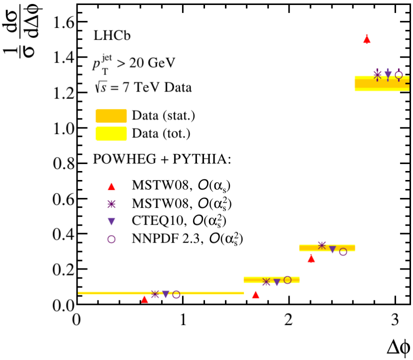
- predictions from POWHEG+PYTHIA at $O(\alpha_s)$ and $O(\alpha_s^2)$ with different PDF sets.
- predictions from FEWZ at $O(\alpha_s^2)$ not corrected for hadronisation and underlying event.



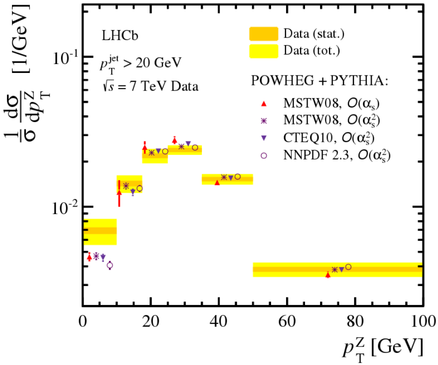
Result

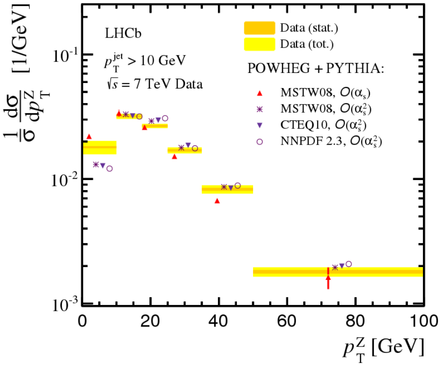
- not corrected for FSR
- shapes in good agreement with NLO





Result

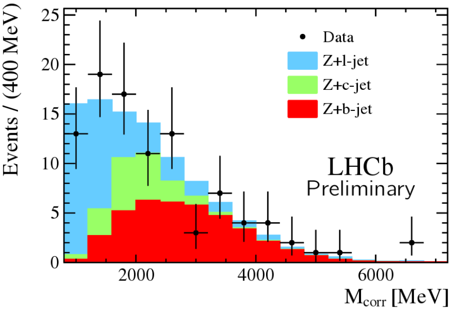




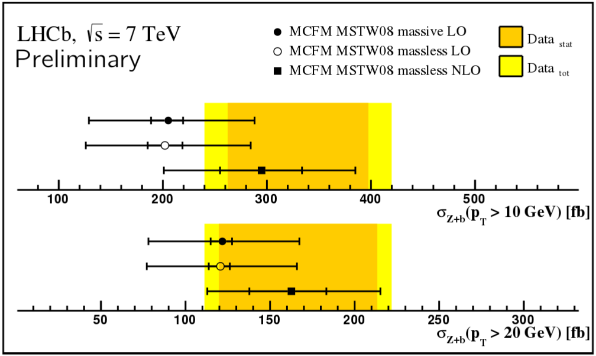
- good agreement with NLO
- slight undershot at low pt Z

- Z+jet measurement extended by requesting a b-tagged jet (see previous slide).
- b-tagging efficiency up to $\sim 50-55\%$.
- purity of the sample from template fit of the M_{corr} variable.
- templates taken from simulation
- templates controled on exclusive (B and D) decay samples

LHCb-PAPER-2014-055 (Preliminary)



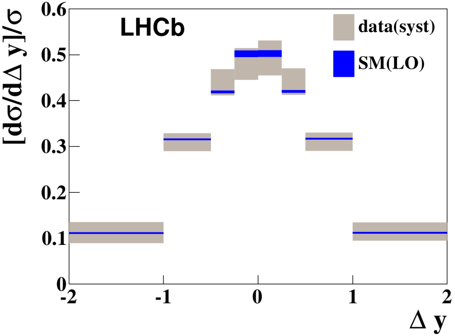
LHCb-PAPER-2014-055 (Preliminary)



- statistical uncertainty $\sim 20\%(\sim 28\%)$ for $p_T > 10$ GeV($p_T > 20$ GeV).
- systematic uncertainty dominated by b-tagging and purity determination ($\sim 15\%$).
- MCFM predictions corrected for fragmentation and hadronization using Pythia 8.
- good agreement with predictions.

PRL 113 (2014) 082003

- back to back b-tagged di-jets.
- one jet is charged tagged by a muon.
- $70.3 \pm 0.3\%$ purity of the charge tag.



$a_{fc}^{b\bar{b}} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$,
$\Delta y = |y_b| - |y_{\bar{b}}|$
in different m_{bb} bins:

- $A_{FC}^{b\bar{b}}(40,75) = 0.4 \pm 0.4 \pm 0.3$ %
- $A_{FC}^{b\bar{b}}(75,105) = 2.0 \pm 0.9 \pm 0.6$ %
- $A_{FC}^{b\bar{b}}(> 105) = 1.6 \pm 1.7 \pm 0.6$ %

- no deviation from expectation with available statistics.
- result with 1 fb^{-1}, still 2 fb^{-1} of the Run I data to be analysed.

- Jet tools ready and already used for LHCb analysis
- 2 papers published, 1 about to be and others in the pipeline.
- Working on:
  - reducing uncertainties
  - new methods to evaluate JES (using CPF) and resolution (balanced dijets) from DATA
  - pileup substraction from DATA