Jety s vysokou příčnou hybností v RunII experimentu ATLAS

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Obhajoba diplomové práce

June 4, 2015

Úvod

Cíl práce

Cílem diplomové práce bylo připravit analýzu inkluzivního účinného průřezu produkce jetů a porovnat data s předpovědí next-to-leading order QCD v rámci Standard Model skupiny experimentu ATLAS pro použití po spuštění urychlovače s těžišťovou energií 13 TeV.

Osnova prezentace

- **Úvod**
  Jet, Inkluzivní jet, K čemu?
- **Analýza dat**
  Charakteristika dat, Rekonstrukce jetů, Unfolding.
- **Porovnání dat s předpovědí NLO QCD**
  Neurčitosti v předpovědích QCD, LO vs. NLO QCD.
- **Závěr**

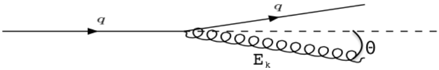
Why Do We Need Jets?

Gluon radiation cross section:

$$\sigma_{q\to qg} \sim \frac{d\theta}{|\sin\theta|}\frac{dE_k}{E_k}$$

Divergences:

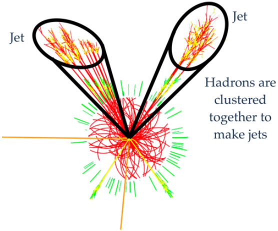
- *Infrared* ($E_k = 0$)
- *Collinear* ($\theta = 0$)



Jet: A group of collimated particles

Jet algorithm: A prescription, how particles (or other objects) are clustered into separate jets. It should fulfill

- *Infrared safety:* The presence of an additional soft particle should not affect the recombination of particles into a jet
- *Collinear safety:* Jet reconstruction should not depend on the fact, if the energy is carried by one particle, of if the particle is split into more collinear particles



q or g CANNOT be directly observed. Jets CAN

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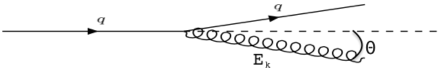

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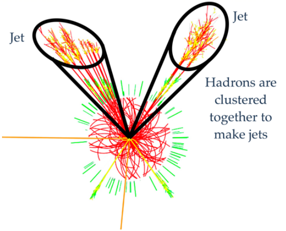

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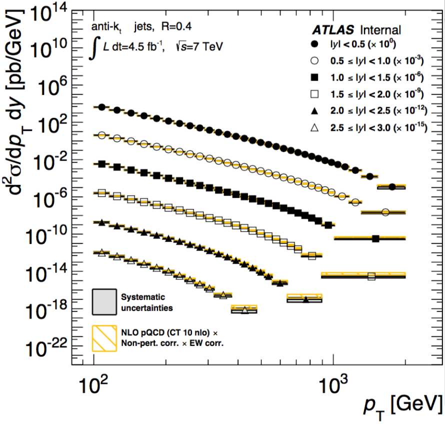
Inclusive Jets

Inclusive jet double differential cross section in p_T and rapidity y (inclusive means $pp \rightarrow$ jet + "anything") in Run II of the ATLAS Experiment ($\sqrt{s} = 13\,\text{TeV}$). 2012 Analysis[1]:



Why Inclusive Jets?

- They Cover a *wide range of momentum transfers* ($\sim 1\,\text{GeV} - 1\,\text{TeV}$ on the LHC) $\rightarrow$ predictions sensitive to the properties of the running coupling constant α_S
- They probe the structure of proton at *small distance scales*

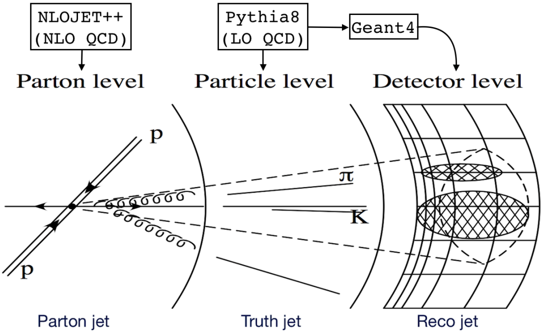
$$\lambda \sim 1/p_T \sim \text{TeV}^{-1} \sim 10^{-19}\,\text{m}$$

- They contribute to our understanding of PDFs
- They *appreciate the increase in the center-of-mass energy* as no other physics process observed on hadron colliders

[1] Georges Aad et al. "Measurement of inclusive jet and dijet production in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector". In: *Phys.Rev.* D86 (2012), p. 014022. DOI: 10.1103/PhysRevD.86.014022. arXiv: 1112.6297 [hep-ex].

Three Different Levels of Collision

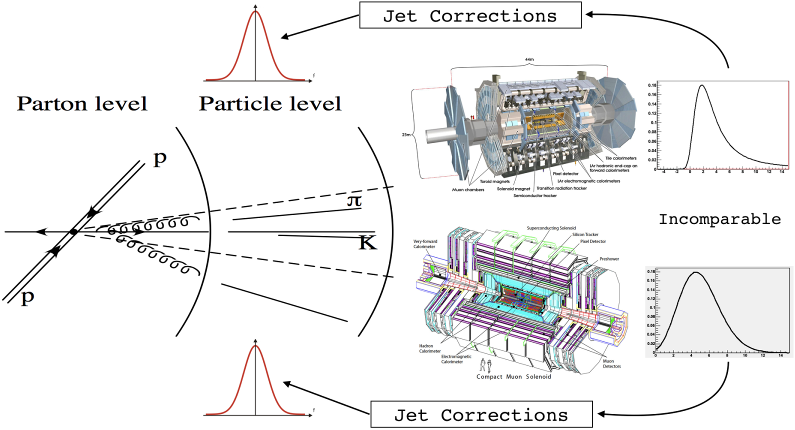
- **Parton level** - particles $(q, g, \ldots)$ created just after the collision
  NLOJET++ (*NLO QCD*)
- **Particle level** - particles created by the hadronization
  Events generated by PYTHIA8 (*LO QCD*)
- **Detector level** - recorded signal
  Detector response obtained by GEANT4 full detector simulation



Detector causes *distortion of observables*

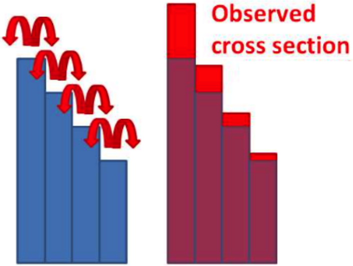
Jet Corrections

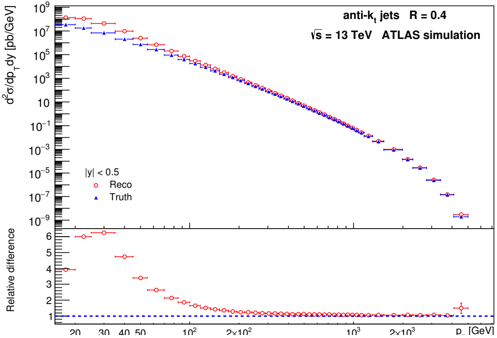
- Correct observables derived from detector to particle level by removing the detector effects
- Two main procedures - *Calibration* and *Unfolding*



Unfolding

- Final step of jet corrections
- Tries to minimize the effects of detector *finite resolution*
- *Analysis dependent*





Unfolding - Mathematical Formulation

- **I want:** $f(p_T)$ (distribution of inclusive jet p_T for $p_T \in \langle a, b \rangle$)
- From detector, **I get:** $g(x)$ (distribution of unphysical variable x)

$$g(x) = \int_a^b A(x, p_T) f(p_T) dp_T$$

- Detector smearing described by $A(x, p_T)$
- Complicated *integral equation* for $f(p_T)$
- Luckily $g(x)$ and $f(p_T)$ are for practical purpose discretized and in analysis, I assume $x \in \langle a, b \rangle$, $N(i) \subset \langle a, b \rangle$

$$g_i = \int_{N(i)} g(x) dx \quad , \quad f_i = \int_{N(i)} f(p_T) dp_T$$

- So the response of the detector is described by a "simple" *matrix equation*, with A being called *Transfer Matrix*

$$g = Af$$

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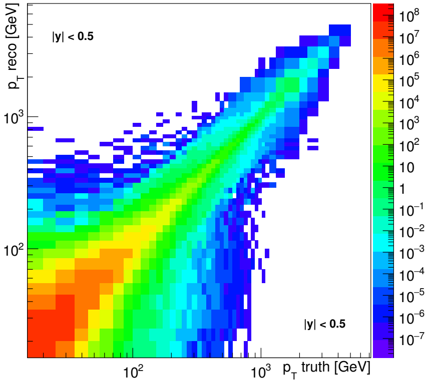
Unfolding

- Unfolding(detector spectrum) $\approx$ particle spectrum
- **Transfer matrix** A_{ij} - containing the number of jets which enterd detector in bin i but were reconstructed in bin j
- I test two approaches to the unfolding, allowing a dealing with the double binning (in p_T and y)

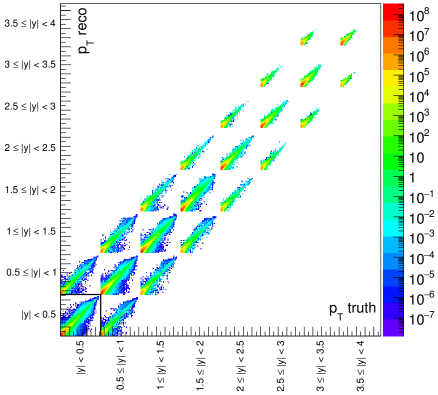
1. **Simple unfolding**
   If reconstructed jet migrates to different rapidity bin, it is ignored. There are 8 independent 46x46 transfer matrices, one for each rapidity bin ($46 =$ number of p_T bins)
2. **2D unfolding**
   Migration to different rapidity bins allowed. Only one 368x368 transfer matrix ($368 = 8 \times 46$)

Transfer Matrices

Simple unfolding

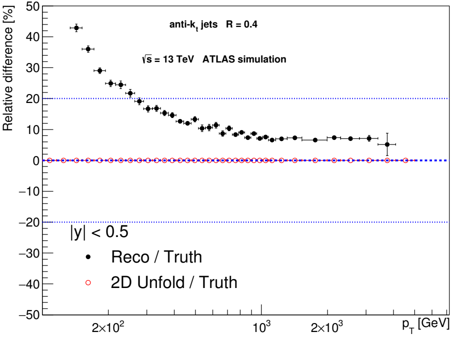


2D unfolding



Unfolding Results

Reco and Unfolded vs. Truth Spectrum



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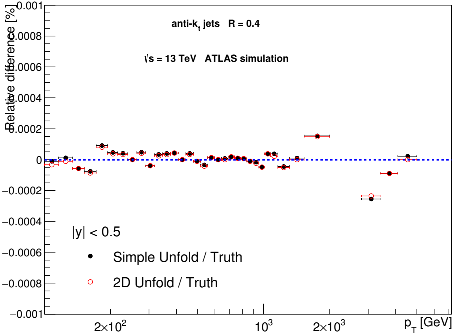

NLO QCD Prediction

- NLO QCD predictions on parton level for $\sqrt{s} = 8\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$
- *Theoretical uncertainties* which are taken into account
  - **Scale uncertainty**
    Choice of renormalization and factorization scales, including neglecting the higher order terms beyond the NLO
  - α_S **uncertainty**
    Because of experimental measurements of α_S
  - **PDF uncertainty**
    Prediction depends on the concrete choice of a PDF
- *Other corrections* (not so significant[2])
  - **Nonperturbative corrections**
    Hadronization and Underlying Event corrections
  - **Electroweak corrections**
    Next to the QCD processes, the electroweak processes should be assumed

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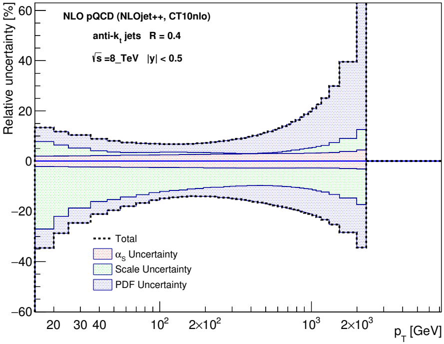
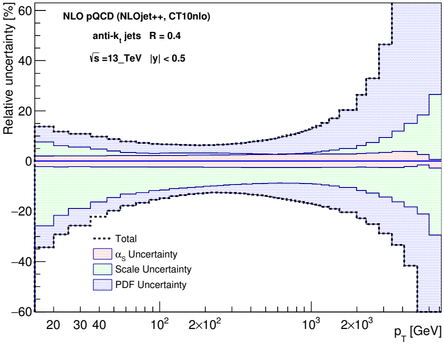
NLO Systematic Errors

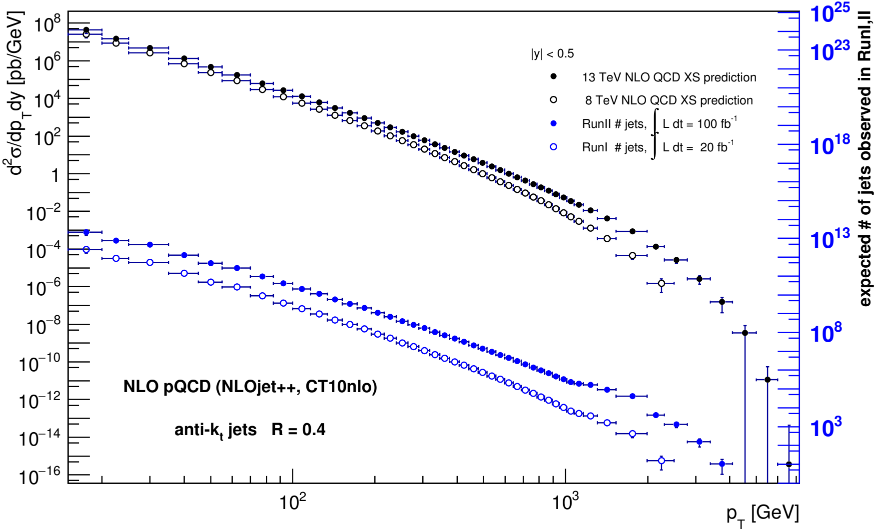
$\sqrt{s} = 8\,\text{TeV}$



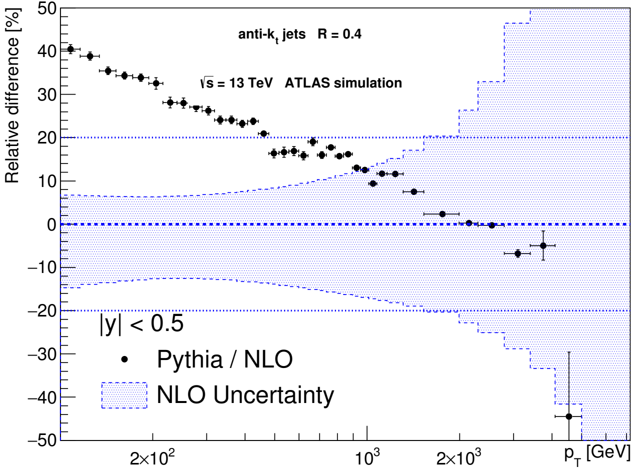
$\sqrt{s} = 13\,\text{TeV}$



Comparison of NLO QCD Predictions



Comparison of LO and NLO QCD



Thesis Conclusions

Unfolding

- Two approaches were probed
- No significant differences between these two approaches imply, for the real analysis, the Simple Unfolding approach should be used for its simpler implementation
- Agreement of the unfolded p_T spectra with the truth p_T spectra up to systematic error $< 10^{-3}\,\%$

LO and NLO QCD

- Significant differences showing the influence of the NLO QCD processes on physical observables