Jety s vysokou příčnou hybností v RunII experimentu ATLAS

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Obhajoba diplomové práce

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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**

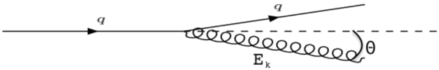
Why Do We Need Jets?

Gluon radiation cross section:

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

Divergences:

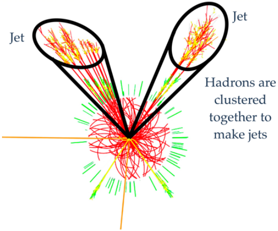
- *Infrared* $(E_k = 0)$
- *Collinear* $(\theta = 0)$



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 observed. Jets CAN.

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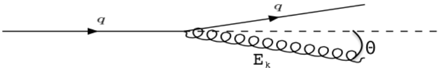

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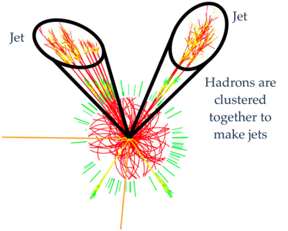

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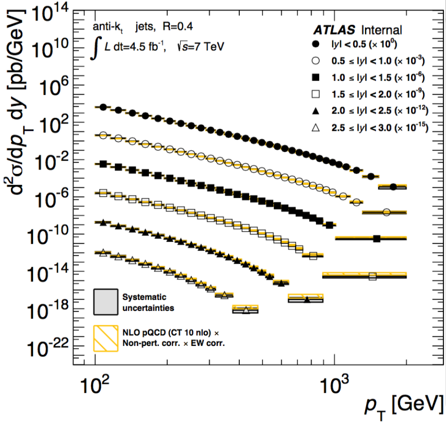
Inclusive Jets

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 ($\sqrt{s} = 13\,\text{TeV}$). 2013 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*

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

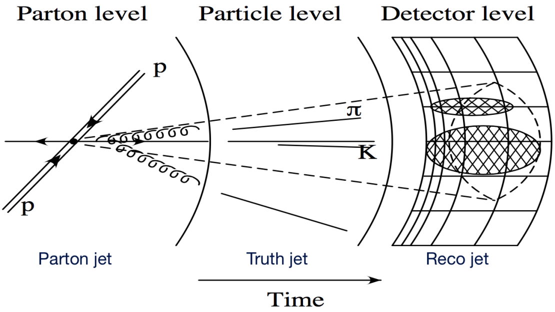
- They contribute to our understanding of PDFs
- They *appreciate the increase in the center-of-mass energy* as no other physics process observed on hadron colliders

[1] T Carli et al. *Measurement of inclusive jet production in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector (Supporting Documentation)*. Tech. rep. ATL-COM-PHYS-2013-1390. Geneva: CERN, Oct. 2013.

Jet Reconstruction

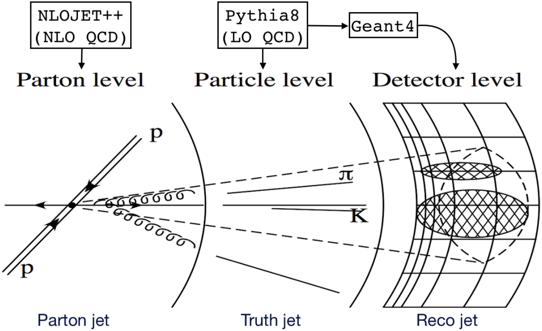
Jet can be defined on a *three different levels of collision*:

- **Parton level** - quarks, gluons and other particles created just after the collision. Directly connected to the QCD processes.
- **Particle level** - particles created by the hadronization.
- **Detector level** - recorded signal. Detector imperfections cause a *distortion of observables*.



Data Characteristics

- *pp* collisions at $\sqrt{s} = 13\,\text{TeV}$, anti-$k_t$ jet algorithm with $R = 0.4$, CT10 PDFs, AU2
- Measuring of inclusive jet double differential cross section in p_T and rapidity y

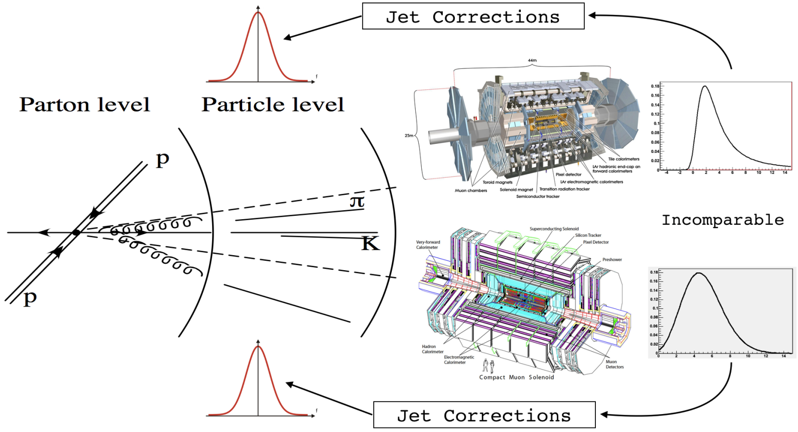


- **Parton level** - cross section prediction calculated with NLOJET++ program (*NLO QCD*).
- **Particle level** - events generated by Pythia8 (*LO QCD*).
- **Detector level** - detector response on Pythia8 events obtained by Geant4 full detector simulation.

Jet Matching - for each truth jet, corresponding reco jet is found.

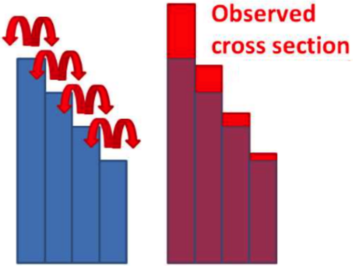
Jet Corrections

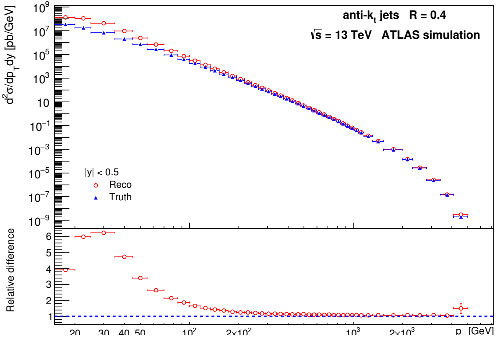
- Correct observables derived from detector to particle level by removing the detector effects
- Two main procedures - *Calibration* and *Unfolding*



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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Inputs for Unfolding

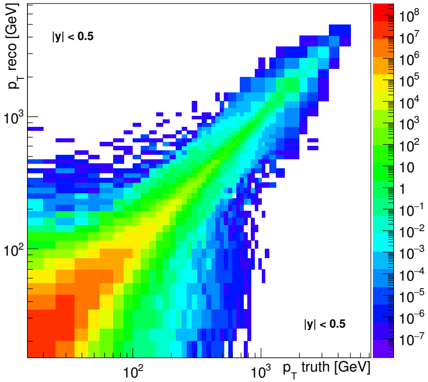
Unfolding(calibrated reco spectrum) $\approx$ truth spectrum

- Inputs for unfolding procedure
  - **Matching efficiencies** - describing the ratio of matched jets to all jets
  - **Transfer matrix** A_{ij} - containing the number of reco jets in bin i with a matched truth jets generated in bin j
- I test two approaches to the unfolding, allowing a dealing with the double binning (in p_T and y)

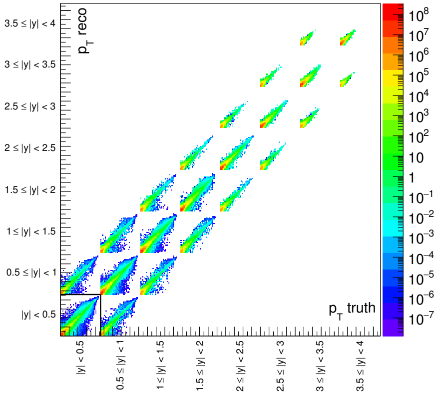
1. **Simple unfolding**
   Matching jets within different rapidity bins is not allowed. There are 8 independent 46x46 transfer matrices, one for each rapidity bin ($46 =$ number of p_T bins)
2. **2D unfolding**
   Matching within different rapidity bins allowed. Only one 368x368 transfer matrix ($368 = 8 \times 48$)

Transfer Matrices

Simple unfolding

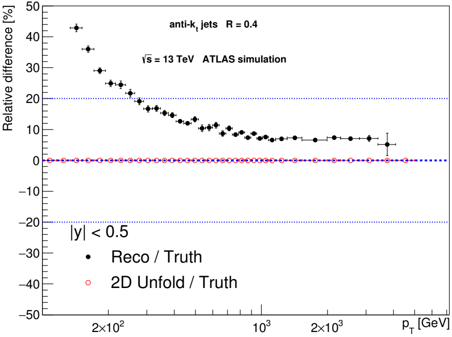


2D unfolding



Unfolding Results

Reco and Unfolded vs. Truth Spectrum



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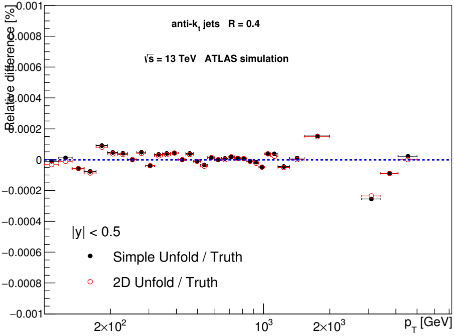

NLO QCD Prediction

- 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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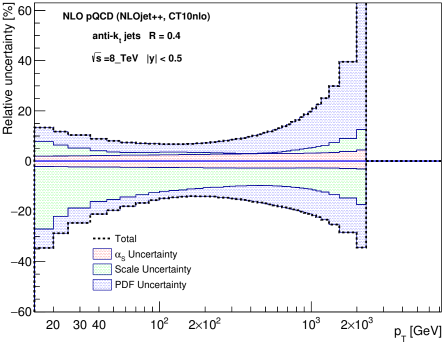
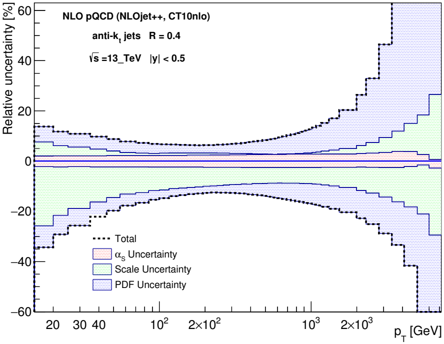
NLO Systematic Errors

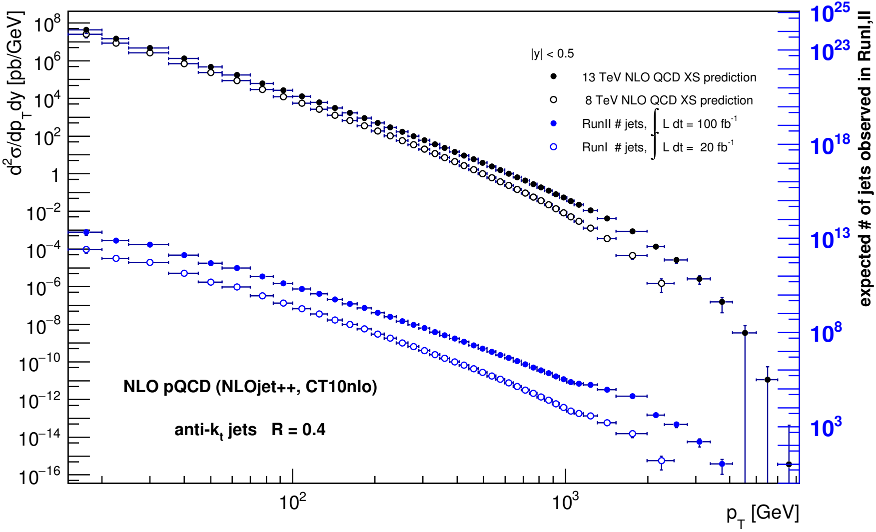
$\sqrt{s} = 8\,\mathrm{TeV}$



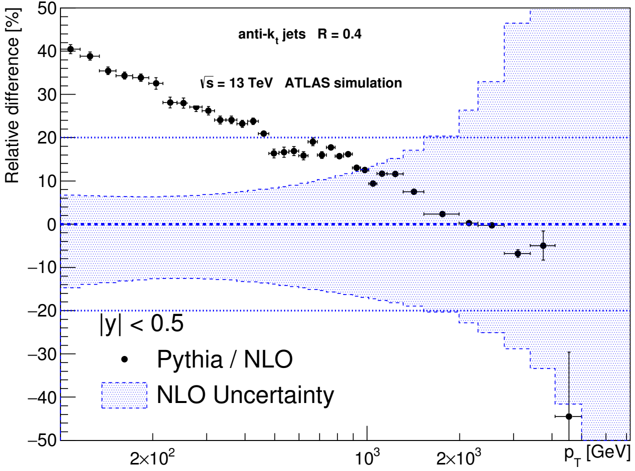
$\sqrt{s} = 13\,\mathrm{TeV}$



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.