α_s Determination via the Differential 2-Jet-Rate with ATLAS

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DFG Deutsche Forschungsgemeinschaft

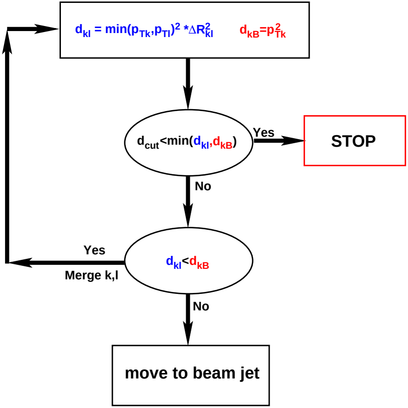
Outline

- Jet-Algorithm
- α_s and NLOJET++
- Real Data Analysis
  - Separation from 4-Jet-Events
  - Comparison to Simulation
- Corrections
  - Jet-Energy-Scale
  - Hadronization
  - Underlying Event
- α_s-Fit and Systematic Unc.
- Summary

Jets

- Jets very important for many physics analysis: QCD, Top-Quark, Higgs, SUSY, etc.
- large statistics
  $\rightarrow$ first data analysis
  e.g. α_s determination
- several different Jet-Algorithms available (different physical and theoretical motivations)
- two big groups: Cone- and $\mathrm{k_T}$-Jets

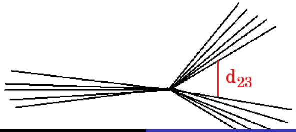
Exclusive $\mathrm{k_T}$-Algorithm, ΔR-scheme



- d_{min}: smallest value among d_{kB} and d_{kl}
- $\mathrm{d_{Cut}}$: cut-off parameter until jets are merged
- $\mathrm{d_{min}} > \mathrm{d_{Cut}}$: all remaining objects are classified as jets
- if d_{kl} is smallest, k and l are combined
- if d_{kB} is smallest, k is included in beam jet
- jet-size is dynamic, no overlapping jets

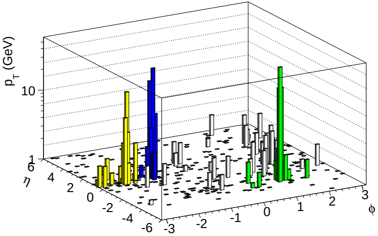
Exclusive $\mathrm{k_T}$-Algorithm, ΔR-scheme

- infrared- and collinearsafe
- clusters objects close in momentum space:
  $d_{min} = \min\ [d_{kl} = min(p_{Tk}^2, p_{Tl}^2) * R^2$ and $d_{kB} = p_{Tk}^2]$
  (with $R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$)
  $\rightarrow$ objects clustered to jets until $d_{min} \geq d_{cut}$
  $\rightarrow$ number of jets in final state depends on d_{cut}
- here (other way round): interested in d_{cut} for specific jetmultiplicity
  $\rightarrow \mathrm{d}_{23}$: d_{cut}-value where jetmultiplicity flips from 3 to 2
  $\rightarrow \mathrm{d}_{34}$: d_{cut}-value where jetmultiplicity flips from 4 to 3

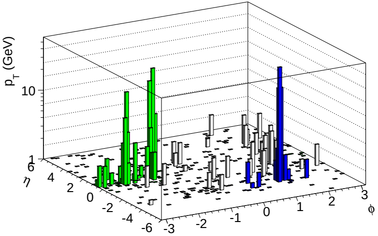


Exclusive $\mathrm{k_T}$-Algorithm, ΔR-scheme

3 jets



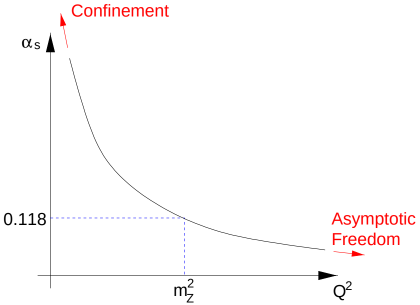
2 jets



green: leading jet

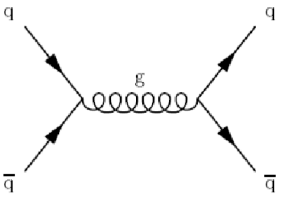
(plots from C. Schmitt)

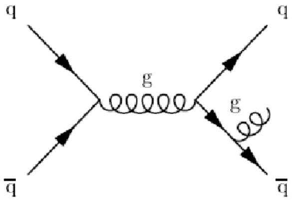
Strong coupling constant α_s



- $\alpha_s = \frac{g_s^2}{4\pi}$ with color charge g_s
- processes with gluons needed to evaluate α_s (strength of gluon-coupling on colored particles $= \alpha_s$)

α_s and Jets in hadron collisions



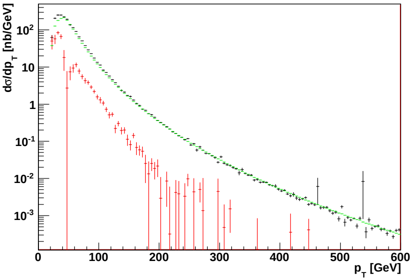


- $\sigma \sim \alpha_s^2$
- no emission of additional parton

- $\sigma \sim \alpha_s^3$
- emission of additional parton
- in theory: infrared and collinear divergences
  $\rightarrow$ need infrared- and collinearsafe observables, e.g. $\mathrm{k_T}$-Jets

NLOJET++

- NLOJET++ (version 4.1.3)
- by Zoltan Nagy
- used to generate inclusive 3 parton production @ NLO (**N**ext-to-**l**eading-**o**rder)
- e.g. Jet-p_T-distributions for born, nlo and full (born+nlo)



3-Jet-Rate

- $$\frac{number\ of\ events\ with\ 3\ Jets\ in\ final\ state}{number\ of\ events}$$

$$R_3 = \frac{\sigma_{3Jets}}{\sigma_{2Jets} + \sigma_{3Jets}}$$

- in LO proportional to α_s
- for more exact determination: NLO calculations
  $R_3(d_{23}) = A(d_{23}) * \alpha_s + B(d_{23}) * \alpha_s^2$
- entries in R_3-distribution are correlated
  $\rightarrow$ slope of R_3-distribution is uncorrelated

$R_2 = 1 - R_3(-R_4)$
$\rightarrow$ in experiment: measure regions where R_4 is negligible

Differential 2-Jet-Rate

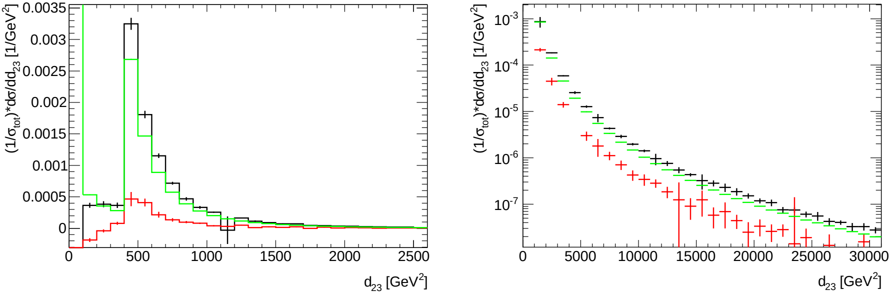
$$D_{23} = \frac{\Delta R_2}{\Delta d_{23}} = -\frac{\Delta R_3}{\Delta d_{23}} =$$

$$\frac{\Delta A(d_{23})}{\Delta d_{23}} * \alpha_s + \frac{\Delta B(d_{23})}{\Delta d_{23}} * \alpha_s^2$$

$$= \frac{1}{N} * \frac{\Delta N}{\Delta d_{23}}$$

D_{23} (NLOJet++)

D_{23} distribution of born, nlo and full, N=3

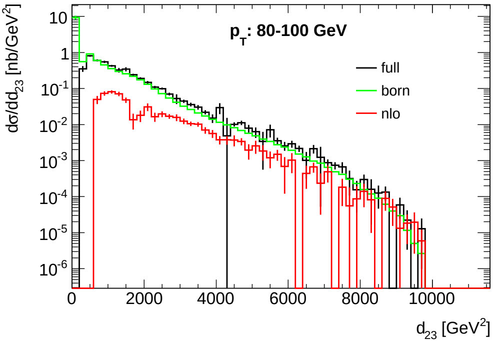


(many different values of Q)

Principle of α_s measurement

- α_s depends on Q
- $Q \cong \mathrm{p_{T,leading\ Jet}}$

d_{23} distribution ($p_{T,leading\ \ Jet}$: $80 - 100 GeV$)



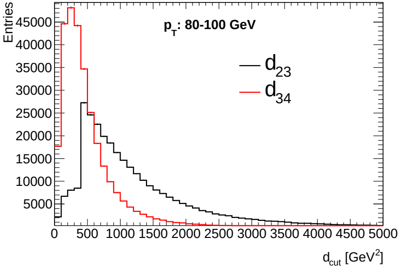
Principle of α_s measurement

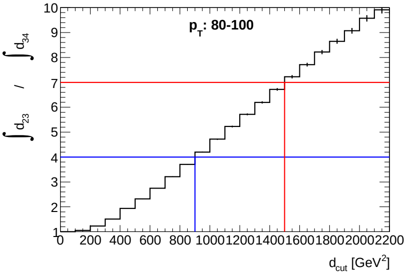
- $$D_{23} = \frac{1}{N} * \frac{\Delta N(Q)}{\Delta d_{23}} =$$
  $$\frac{\Delta A(d_{23}, Q)}{\Delta d_{23}} * \alpha_s(Q) + \frac{\Delta B(d_{23}, Q)}{\Delta d_{23}} * \alpha_s^2(Q)$$
- get $\frac{1}{N} * \frac{\Delta N(Q)}{\Delta d_{23}}$ from measured data
- obtain $\frac{\Delta A(d_{23},Q)}{\Delta d_{23}}$ (=born) and $\frac{\Delta B(d_{23},Q)}{\Delta d_{23}}$ (=nlo) from NLOJET++

  $\rightarrow$ evaluate α_s from fits on D_{23}-distribution

Separation from 4-Jet-Events

$\mathcal{L}$=700/nb



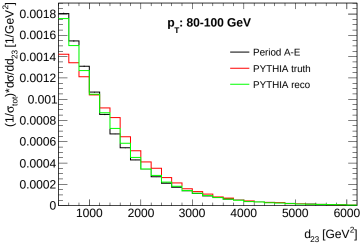


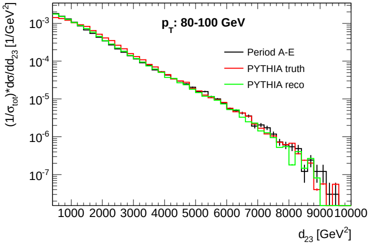
blue line: impurity of 20%

red line: impurity of 12.5%

Comparison to simulation

- PYTHIA dijet samples with truth and reco jets
- cuts: $p_T(jets) > 20\ GeV$, $|\eta| < 2.6$, $d_{23} > 400\ \mathrm{GeV}^2$



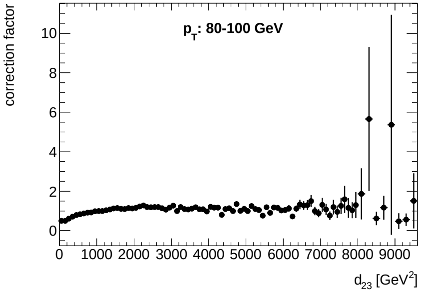


good match between simulation and data!

Jet-Energy-Scale

Correction factor

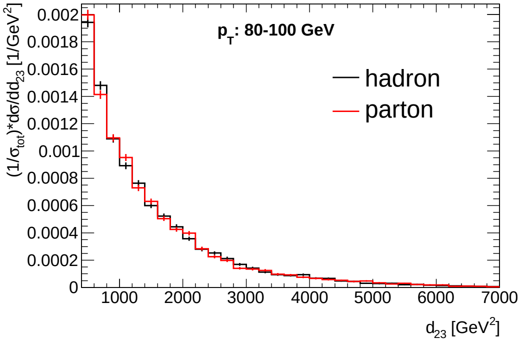
$$H^i_{JES}(d_{23}) = \frac{d^i_{23,truth}}{d^i_{23,reco}}$$



$$\rightarrow d_{23,data(JES\ \ corrected)} = H^i_{JES}(d_{23}) \times d_{23,data}$$

Hadronization

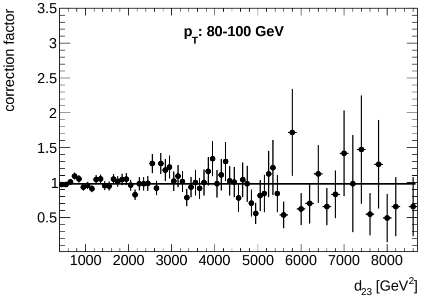
Simulation with PYTHIA (version 6.4.24)



Hadronization

Correction factor

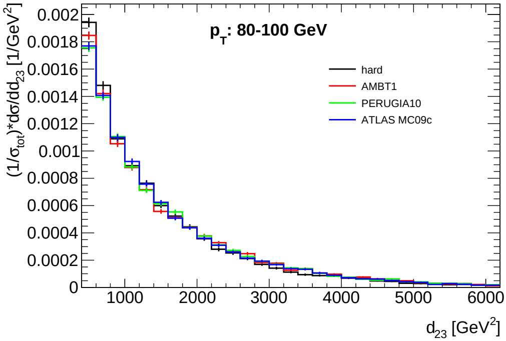
$$H^i_{hadr}(d_{23}) = \frac{d^i_{23,hadr}}{d^i_{23,part}}$$



$$\rightarrow d_{23,NLOJET++(hadr)} = H^i_{hadr}(d_{23}) \times d_{23,NLOJET++}$$

Underlying Event

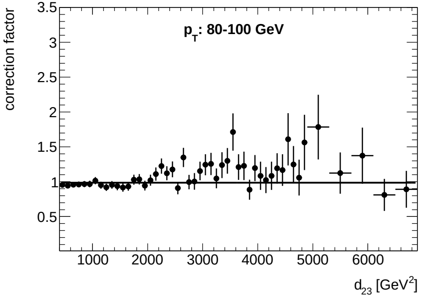
Simulation with PYTHIA (version 6.4.24)



Underlying Event

Correction factor (here: AMBT1)

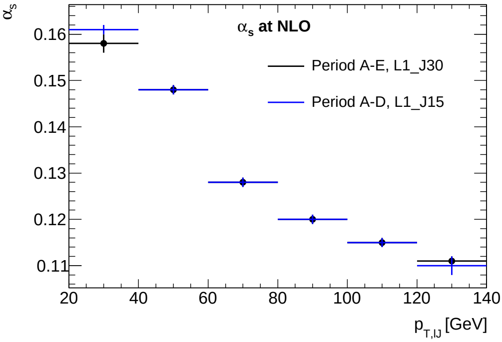
$$H^i_{UE}(d_{23}) = \frac{d^i_{23,UE}}{d^i_{23,hadr}}$$



$$\rightarrow d_{23,NLOJET++(UE)} = H^i_{UE}(d_{23}) \times d_{23,NLOJET++(hadr)}$$

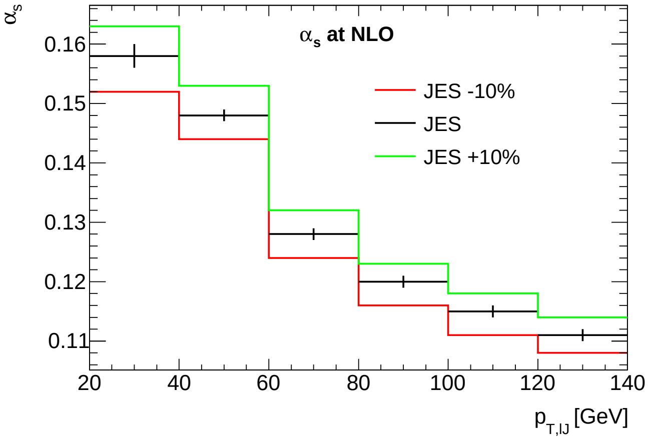
Determination of α_s

χ^2-Fit on data:



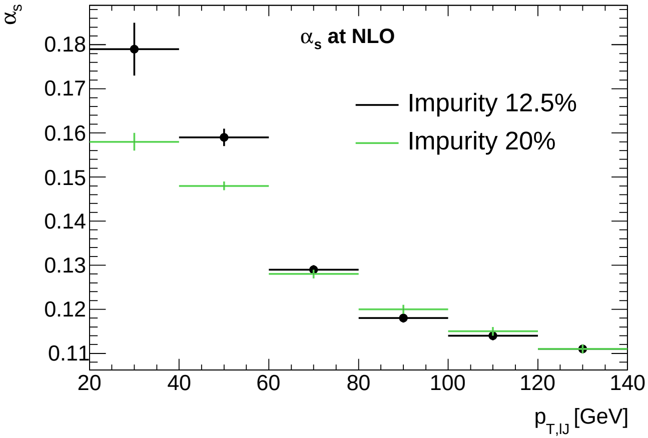
$$\alpha_s(M_Z) = 0.120 \pm 0.001(stat.)$$

JES Uncertainty



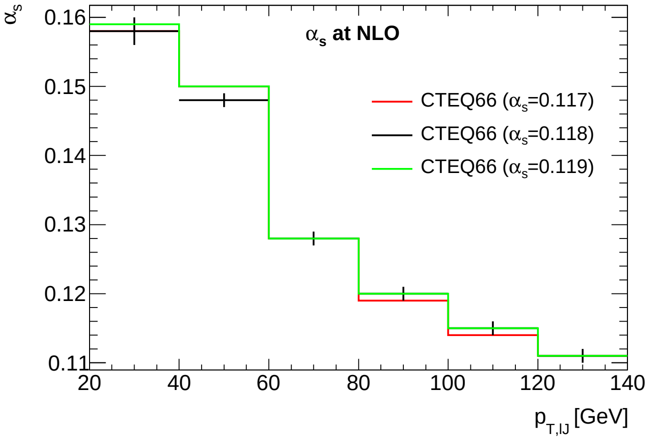
$$\Delta\alpha_s^{sys.}(M_Z)[JES] = \pm 0.004$$

Impurity due to 4-Jet-Events



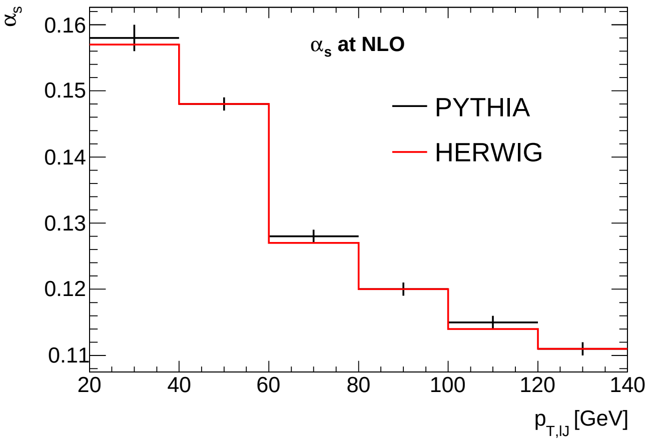
$$\Delta\alpha_s^{sys.}(M_Z)[4jet] = \pm 0.002$$

PDF Uncertainty



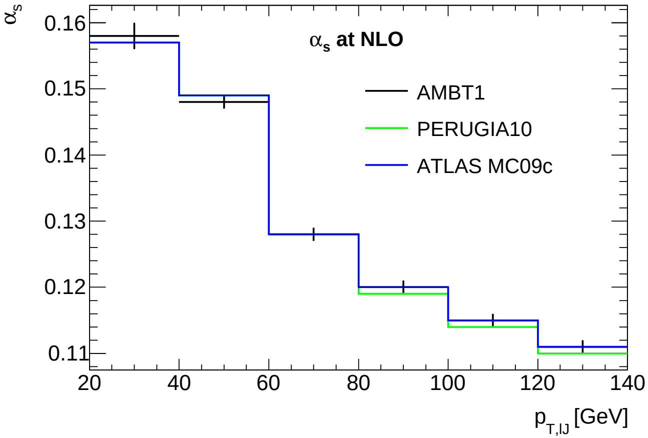
$$\Delta\alpha_s^{sys.}(M_Z)[PDF] = \pm 0.001$$

Hadronization Uncertainty



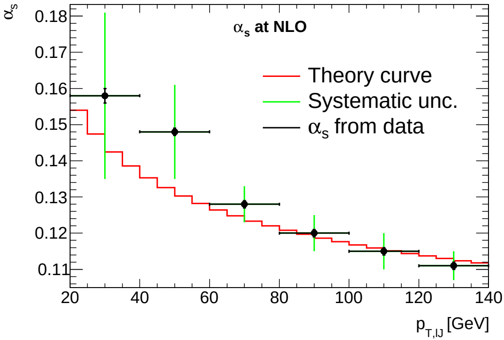
$$\Delta\alpha_s^{sys.}(M_Z)[hadr.] = \pm 0.001$$

Underlying Event Uncertainty



$$\Delta\alpha_s^{sys.}(M_Z)[UE] = \pm 0.001$$

Comparison to Theory Curve



(theory curve defined @ $\alpha_s(M_Z) = 0.1184 \pm 0.0007$)

determination of α_s with ATLAS at LHC:

$\alpha_s(M_Z) = 0.120 \pm 0.001(stat.) \pm 0.005(syst.)$

$\rightarrow$ good agreement with current world average!

Summary

- NLOJET++ useful for NLO calculations
- Real Data Analysis
  - good match between simulation and data
  - D_{23} (differential 2-Jet-Rate) can be used to determine α_s
  - corrections applied: JES, hadronization, UE
  - determination of α_s with ATLAS at LHC:
    $\alpha_s(M_Z) = 0.120 \pm 0.001(stat.) \pm 0.005(syst.)$
- outlook: go on vacation!