α_s Determination via the Differential 2-Jet-Rate at LHC

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Outline

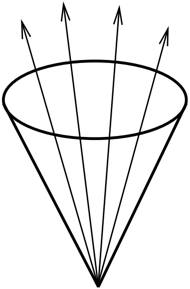
- Jet-Algorithms
- α_s and NLOJet++
- Influence of the Underlying Event
- Summary

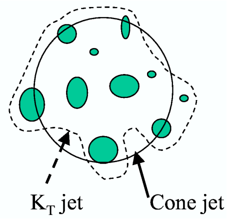
Jets

- 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

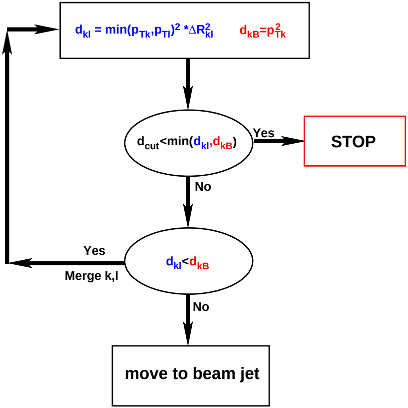
Cone-Jet Algorithms

- geometrical Jet-Definition
  $\rightarrow$ objetcs inside cone with $R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$
- not infrared- and collinearsafe in all variants





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

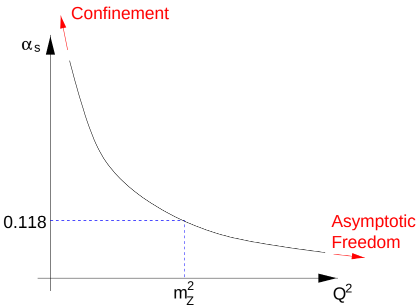


- d_{min}: smallest value among d_{kB} and d_{kl}
- $\mathrm{d_{Cut}}$: cut-off parameter until jets are merged
- $\mathrm{d_{min}} > \mathrm{d_{Cut}}$: all remaining objects are classified as jets
- if d_{kl} is smallest, k and l are combined
- if d_{kB} is smallest, k is included in beam jet
- jet-size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

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

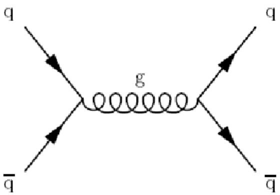
- infrared- and collinearsafe
- clusters objects close in momentum space
- distance between objects $d_{kl} = min(p_{Tk}^2, p_{Tl}^2) * R^2$ (with $R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$)
  $\longrightarrow$ objects clustered to Jets until $d_{kl} \geq d_{cut}$
  $\longrightarrow$ number of Jets in final state depends on d_{cut}
- here (other way round): interested in d_{cut} for specific Jetmultiplicity
  $\longrightarrow$ d_{23}: d_{cut}-value where Jetmultiplicity flips from 3 to 2

Strong coupling constant α_s

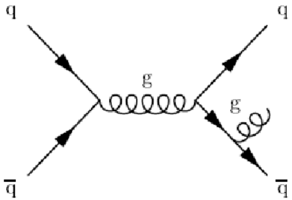


- $\alpha_s = \frac{g_s^2}{4\pi}$ with color charge g_s
- processes with gluons needed to evaluate α_s
  (strength of gluon-coupling on colored particles $= \alpha_s$)

α_s and Jets in hadron collisions



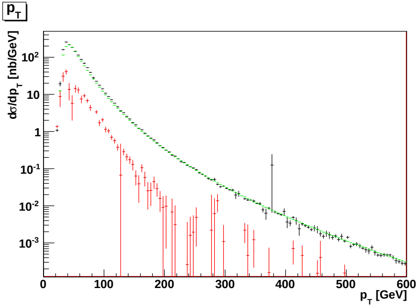
- $\sigma \sim \alpha_s^2$
- no emission of additional parton



- $\sigma \sim \alpha_s^3$
- 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-$\mathrm{p_T}$-distributions for born, nlo and full ($\mathrm{p}_T > 20\ GeV, p_{T,SUM} > 80\ GeV$)



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

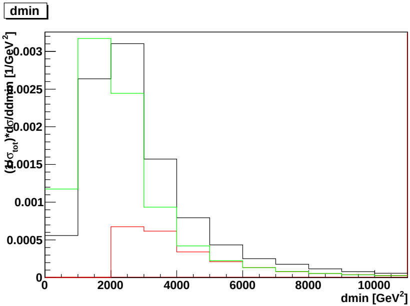
$$D_{23} = \frac{\Delta R_2}{\Delta d_{23}} = -\frac{\Delta R_3}{\Delta d_{23}} =$$

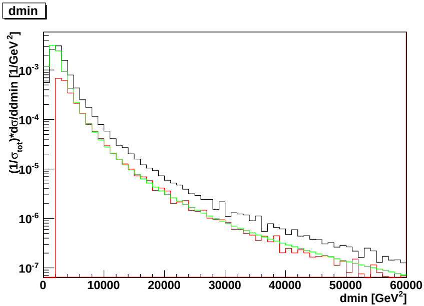
$$\frac{\Delta A(d_{23})}{\Delta d_{23}} * \alpha_s + \frac{\Delta B(d_{23})}{\Delta d_{23}} * \alpha_s^2$$

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

D_{23}

D_{23} distribution of born, nlo and full





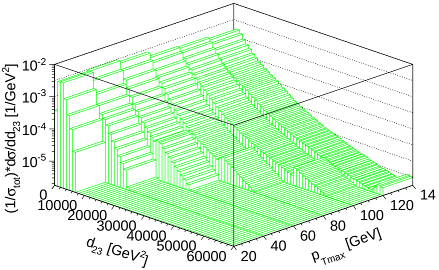
(many different values of Q^2)

Q^2 dependancy of α_s

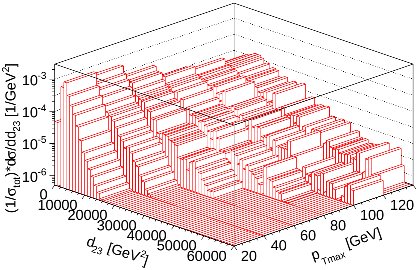
- α_s depends on Q^2
- $\mathrm{Q}^2 \cong \mathrm{p}^2_{\mathrm{T,leading\ Jet}}$

D_{23} distribution vs. $\mathrm{p_T}$(leading Jet)

born



nlo



born and nlo distributions differ in shape!

Principle of α_s measurement

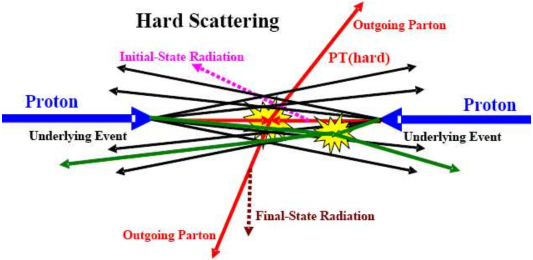
- $$D_{23} = \frac{1}{N} * \frac{\Delta N(Q^2)}{\Delta d_{23}} =$$
$$\frac{\Delta A(d_{23}, Q^2)}{\Delta d_{23}} * \alpha_s(Q^2) + \frac{\Delta B(d_{23}, Q^2)}{\Delta d_{23}} * \alpha_s^2(Q^2)$$

- get $\frac{1}{N} * \frac{\Delta N(Q^2)}{\Delta d_{23}}$ from measured data

- obtain $\frac{\Delta A(d_{23}, Q^2)}{\Delta d_{23}}$ (=born) and $\frac{\Delta B(d_{23}, Q^2)}{\Delta d_{23}}$ (=nlo) from NLOJET++

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

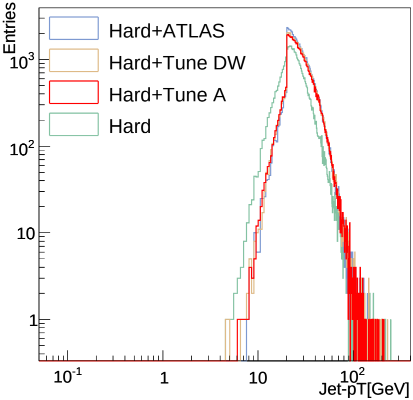
Underlying Event



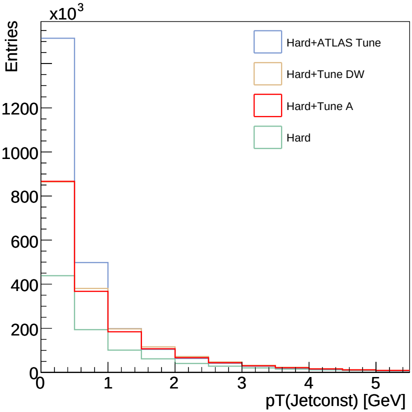
- particles from hard 2 *Parton* $\rightarrow$ 2 *Parton* collision
- Initial and Final State Radiation
- additional, soft contributions - the **Underlying Event** (UE)
  - Beam remnants
  - Multiple Interactions
- perturbation theory can't be applied at low $\mathrm{p_T}$

p_T-distribution (PYTHIA, $p_{T\min} = 20$ GeV)

k_T-jets



jet constituents

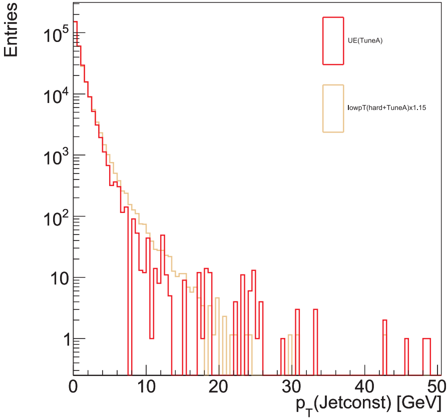


UE leads to higher p_T(jets)

Subtraction of UE: low-p_T-method

- (Hard+Tune A) – Hard approximates the fraction of UE in a hard process
- How to describe the UE in a real event, when no possibility to get solely particles from hard scattering (without contribution of UE)?
- idea: UE $\approx$ soft collision $\longrightarrow$ low-$\mathrm{p_T}$ jets
- select low-$\mathrm{p_T}$ jets in hard collision (3rd jet)

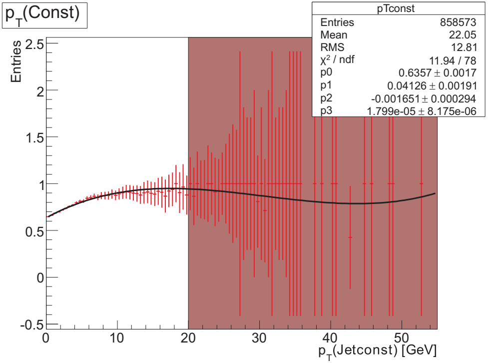
comparison: "low-$\mathrm{p_T}$ jets" to "UE $\approx$ (Hard+Tune A) – Hard"
scalefactor needed: low-$\mathrm{p_T}$ $\times$ 1.15



UE can be approximated by low-$\mathrm{p_T}$-jet!

How to correct k_T jets for UE ?

- weight each particle ($p_T < 20$ *GeV*) in jet by probability not to come from UE
- weighing-factors from [(Hard+Tune A)–(1.15×low-p_T)]/(Hard+Tune A)

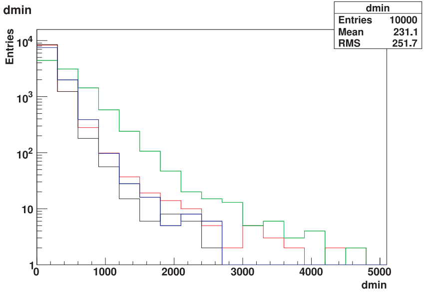


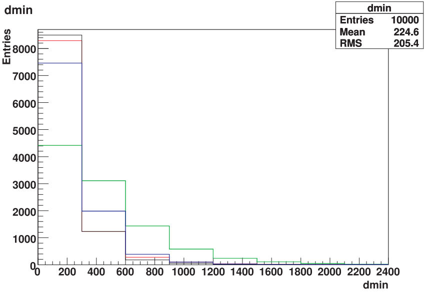
How to correct d_{23} for UE ?

- weight each particle ($p_T < 20\ GeV$) in jet by probability not to come from UE
- sum up corrected particles to new jets with corrected p_T
- calculate new d_{23} with new jet-p_T and original R:
  min of:
  - $d_{kl} = min(p_{Tk}^2, p_{Tl}^2) * R^2$ and
  - $d_{kB} = p_{Tk}^2$

d_{23}-distribution

hard, hard+UE,hard+UE(cor,N=3),
hard+UE(cor,$\mathrm{d_{cut}} = 400 \; GeV^2$)

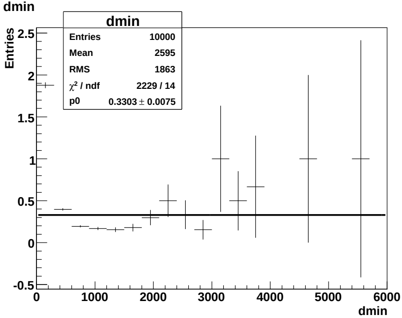




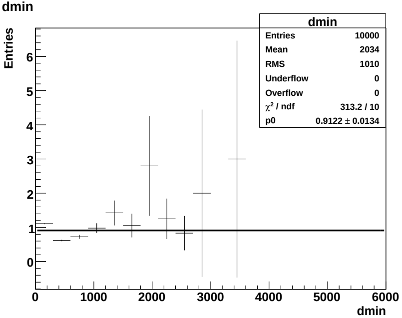
hard scattering of $\mathrm{p_{Tmin}} = 20$ GeV

$\mathrm{d}_{23}(\mathrm{hard})/\mathrm{d}_{23}(\mathrm{hard} + \mathrm{UE})$

$$\frac{\mathrm{d}_{23}(\mathrm{hard})}{\mathrm{d}_{23}(\mathrm{hard{+}UE})}$$



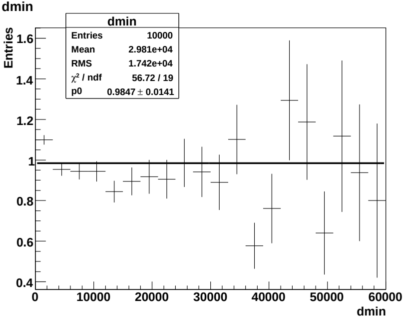
$$\frac{\mathrm{d}_{23}(\mathrm{hard})}{\mathrm{d}_{23}(\mathrm{hard{+}UE(cor)})}$$



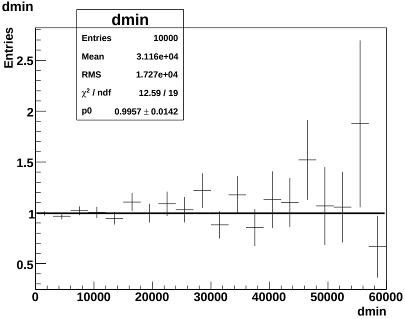
hard scattering of $\mathrm{p_{Tmin}} = 20$ GeV

...same for $p_{Tmin} = 200$ GeV

$$\frac{d_{23}(\text{hard})}{d_{23}(\text{hard+UE})}$$



$$\frac{d_{23}(\text{hard})}{d_{23}(\text{hard+UE(cor)})}$$



hard scattering of $p_{Tmin} = 200$ GeV

$\rightarrow$ small influence of the UE!

$\rightarrow$ influence of the UE decreases with higher p_{Tmin}

Summary

- NLOJet++
  - useful for NLO calculations
  - born and nlo distributions differ in shape
  - D_{23} (differential 2-Jet-Rate) can be used to determine α_s
- Influence of the Underlying Event
  - correction method for small p_Tmin
  - UE seems to have small influence at high p_Tmin