Determination of the strong coupling constant from inclusive jet cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Lars Sonnenschein

on behalf of the DØ collaboration

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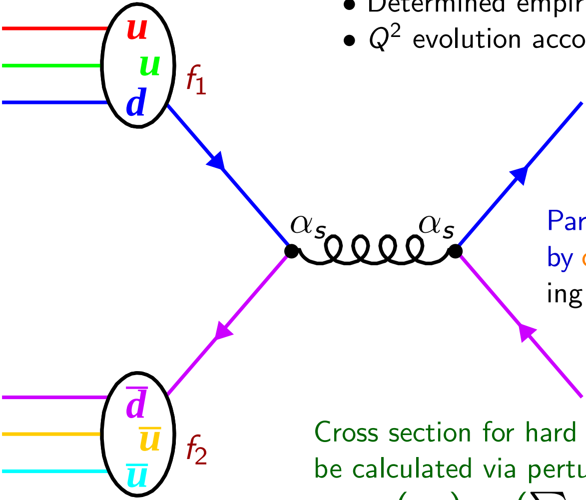
RWTH AACHEN

- Introduction
- Extraction of α_s from inclusive jets
- Use of PDF's and correlations with data
- Determination of α_s
- Summary

Tevatron: $p\bar{p}$ collisions ($\sqrt{s} = 1.96$ TeV)

- Intial state given by non-perturbative PDF's.
- Determined empirically.
- Q^2 evolution according to QCD theory

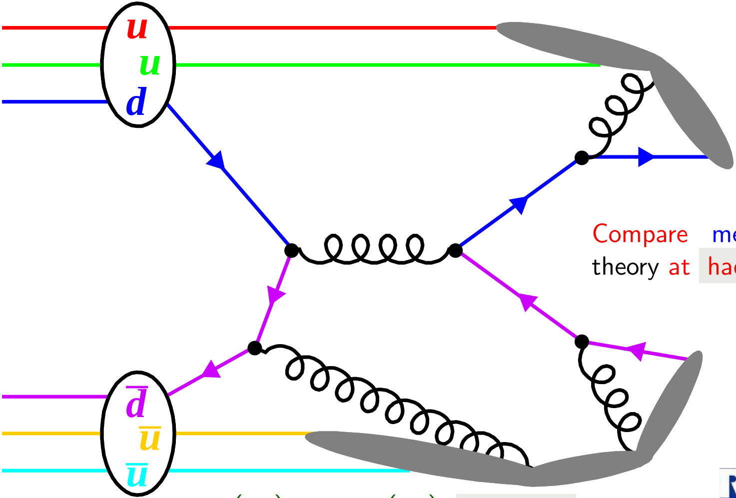


Partonic final state determined by convolution of pQCD scattering amplitudes and PDF's

Cross section for hard scattering of partons can be calculated via perturbative expansion in QCD:
$\sigma_{\text{pert.}}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1 \otimes f_2$

Tevatron: $p\bar{p}$ collisions ($\sqrt{s} = 1.96$ TeV)

pQCD calculations are corrected for non-perturbative effects of hadronisation and underlying event



Measurements are corrected for detector effects

Compare measurements and theory at hadronic final state

$\sigma_{\text{theory}}(\alpha_s) = \sigma_{\text{pert.}}(\alpha_s) \cdot c_{\text{non-pert.}}$

Strong coupling α_s in QCD

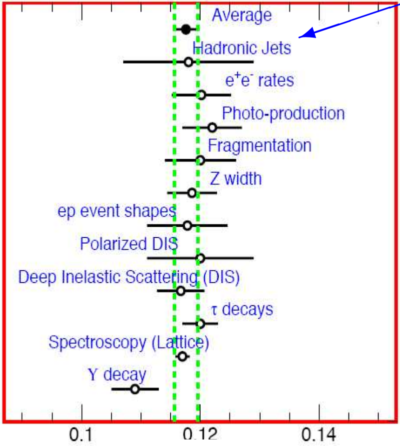
- The coupling strength α_s is scale dependent, $\alpha_s(\mu_R)$
- Its numerical value is not predicted by theory (QCD)
- **R**enormalisation **G**roup **E**quation (RGE) predicts μ_R-dependence
- Measure values in experiment and test RGE compatibility
  - For jet production take $\mu_R =$ jet p_T
  - Values of $\alpha_S(\mu_R)$ can be compared at common scale (typically $\alpha_S(M_Z)$) using RGE, e.g. for 2-loop solution to RGE:

$$\alpha_s(M_Z) = \frac{\alpha_s(\mu_R)}{1 + \alpha_s(\mu_R)(b_0 + b_1\alpha_s(\mu_R)\ln(\mu_R/M_Z))}$$

(3-loop solution used in this analysis for NLO calculations + 2-loop threshold corrections)

Previous status (2008) of α_s measurements

2008 Review of Particle Physics



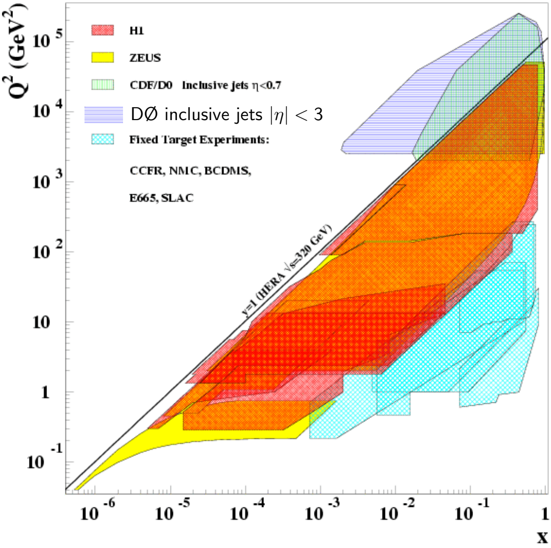
$\alpha_s(M_Z)$

(error band includes theoretical uncertainties)

- Large uncertainties associated with "hadronic jets"
- Previously not very competetive with other determinations
- Have now the tools to substantially improve this result
  - More and better data
  - More precise theory calculations

Hadron momentum fraction x and scale Q^2

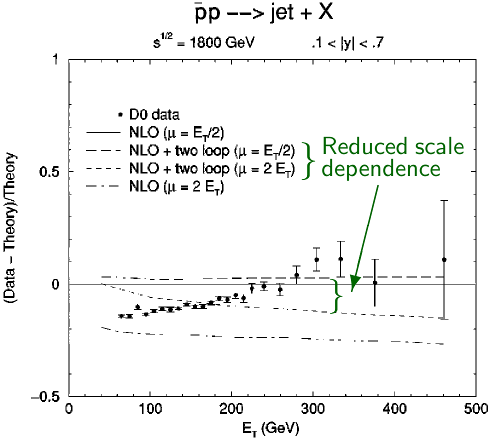
Kinematic plane: Q^2 vs. x



- Tevatron jet measurements cover a wide kinematic range
- Covers unique regions of phase space and also overlaps with other measurements from *ep* collisions
- Data allow precision tests of pQCD and also an independent extraction of alpha strong

More precise theory: 2-loop threshold corrections

Kidonakis, Owens, Phys. Rev. D 63, 054019 (2001)

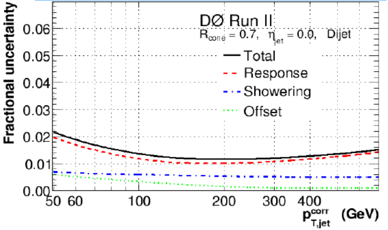


- Threshold corrections calculation is rather old
- Has been ignored for a long time
- Has only become popular (and accessible) since included in *fastNLO* (arXiv:hep-ph/0609285), based on *NLOJET++*, provides fast recalculations for arbitrary PDF's

NLO and NLO + NNLO calculations for inclusive jet production at the Tevatron compared to DØ data

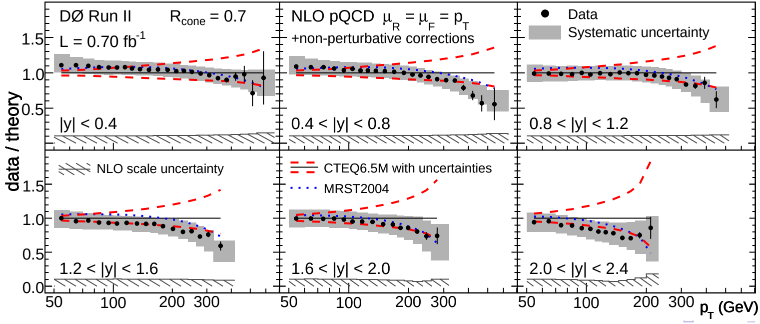
Extraction of α_s from inclusive jets

Energy scale uncertainty: 1-2% !



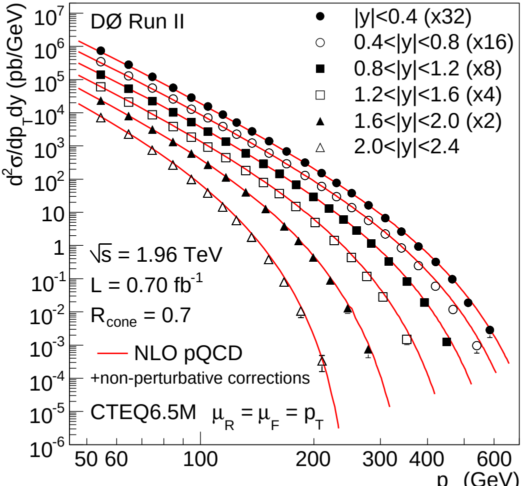
Uncertainties significantly reduced compared to previous results due to hard work on jet energy scale

- Each data point sensitive to $\alpha_s(p_T)$ $\Rightarrow$ can verify running
- Use combined fit of selected data points to determine $\alpha_s(M_Z)$



Most precise measurement of inclusive jet production

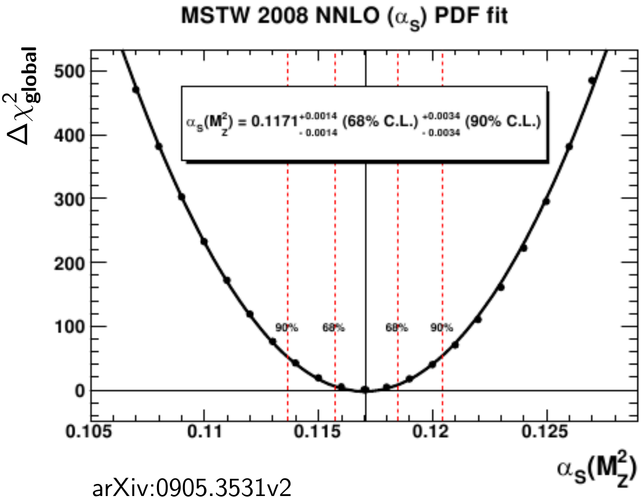
$$\sigma_{\text{pert.}}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$



Phys. Rev. Lett. 101, 062001 (2008)

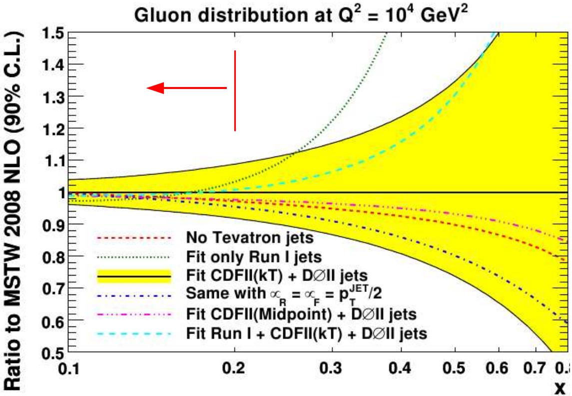
- RGE uniquely relates $\alpha_s(\mu_R)$ for arbitrary scale μ_R to $\alpha_s(M_Z)$
- Express theoretical prediction as $\sigma_{\text{theory}}(\alpha_s(M_Z)) = \sigma_{\text{pert.}}(\alpha_s(M_Z)) \cdot c_{\text{non-pert.}}$
- Contains α_s dependence in ME and implicit α_s dependence in PDF's

Choice of PDF models



arXiv:0905.3531v2
Eur.Phys.J.C64:653-680 (2009)

- MSTW2008 provides PDF fits in fine binning of α_s
- Allow for smooth interpolation of results to arbitrary $\alpha_s(M_Z)$ values
- NNLO accuracy



- Precision Tevatron jet data currently dominate models for gluon densities at high momentum fraction x
- Minimising unknown correlations between data and PDF's by restricting analysis to kinematic phase space where Tevatron data do not dominate PDF determination

Restricting hadron momentum fraction x

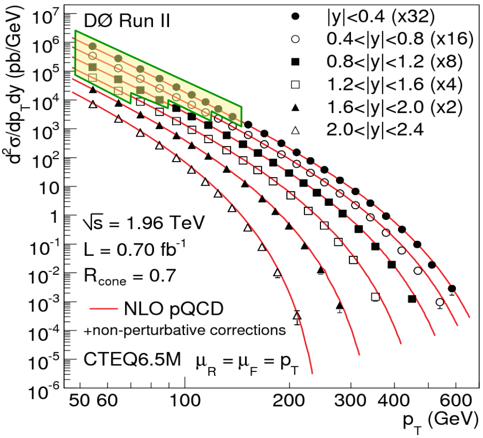
- At leading order, di-jet events access x-values of:
  $x_a = x_T \frac{e^{y_1}+e^{y_2}}{2}$ and $x_b = x_T \frac{e^{-y_1}+e^{-y_2}}{2}$ with $x_T = \frac{2p_T}{\sqrt{s}}$

- Mapping is less clear in inclusive cross section data
  x-value not fully constrained given a measured bin of p_T, $|y|$
  Full kinematics unknown since intergated over number of jets

- Constrain momentum fraction (approximately),
  treating subleading jets as central $|y| = 0$:
  $\tilde{x} = x_T \cdot (e^{|y|} + 1)/2$

- Cut on $\tilde{x}$ to ristrict accessible x-range
  Systematics based on variations of cut value

Minimising correlations between data and PDF's



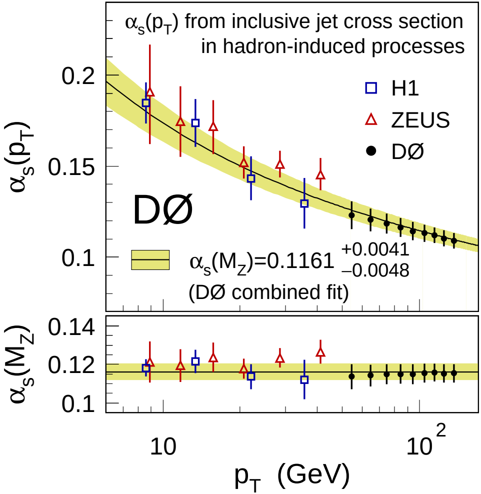
22 (out of) 110 data points

$50 < p_T < 145$ GeV

- Select points from inclusive cross section using approximate mapping having strong correlation with maximum momentum fraction x in a 2-hadron collision
- $\tilde{x} = x_T(e^{|y|} + 1)/2$
- $x_T = 2p_T/\sqrt{s}$
- Require $\tilde{x} < 0.15$
  $\Rightarrow x_{max} \sim 0.25$

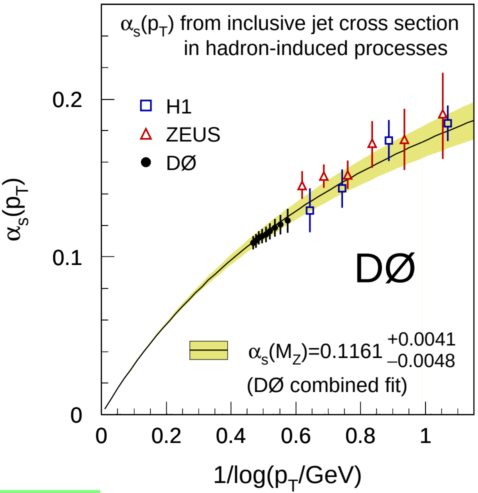
Determination of α_s

- NLO matrix elements for five flavours
  + additional 2-loop threshold corrections (reduced renormalisation/factorisation scale dependence)
- MSTW2008 NNLO PDF's (alternatively NLO)
- Extends results from HERA to higher p_T
- Highest p_T measurements of running α_s to date



Determination of α_s

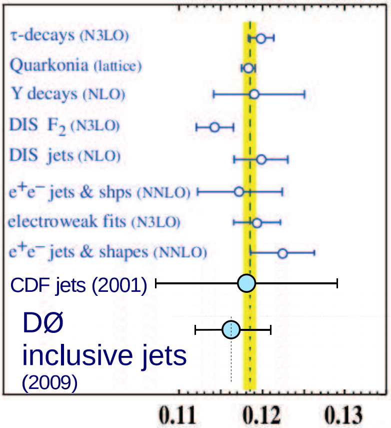
$\alpha_s(M_Z) = 0.1161$	$^{+0.0041}_{-0.0048}$
exp. uncorr.	± 0.0001
exp. corr.	$^{+0.0034}_{-0.0029}$
non perturb. correction	± 0.0010
PDF uncertainty	$^{+0.0012}_{-0.0011}$
$\mu(r, f)$ variation	$^{+0.0021}_{-0.0029}$



Consistent with asymptotic freedom

Summary

- α_s determined from DØ inclusive jet cross section
- Using theory at NLO plus 2-loop threshold corrections
- Measured $\alpha_s(p_T)$ supports energy dependence predicted by RGE
- This is the most precise determination of the strong coupling constant from a hadron collider
  - comparable to $ep \to$jets



Modified from arXiv:0908.1135
Eur.Phys.J.C64: 689-703.2009

$$\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}$$

Phys. Rev. D 80, 111107 (2009)

$$\alpha_s(M_Z) = 0.1189 \pm 0.0032$$

HERA jet data combined

Backup slide

- MSTW NLO PDF's (21 α_s values)
  (NLO pQCD + 2-loop RGE):
  $\alpha_s = 0.1202^{+0.0072}_{-0.0059}$
- MSTW NNLO PDF's (21 α_s values)
  (NLO pQCD + 2-loop threshold corrections + 3-loop RGE):
  $\alpha_s = 0.1161^{+0.0041}_{-0.0048}$
- CTEQ 6.6 NLO PDF's (5 α_s values)
  (NLO pQCD + 2-loop RGE):
  Central result changes by only $+0.5\%$