(Multi-) Jet Production and Determination of the Strong Coupling Constant

Markus Wobisch

Louisiana Tech University

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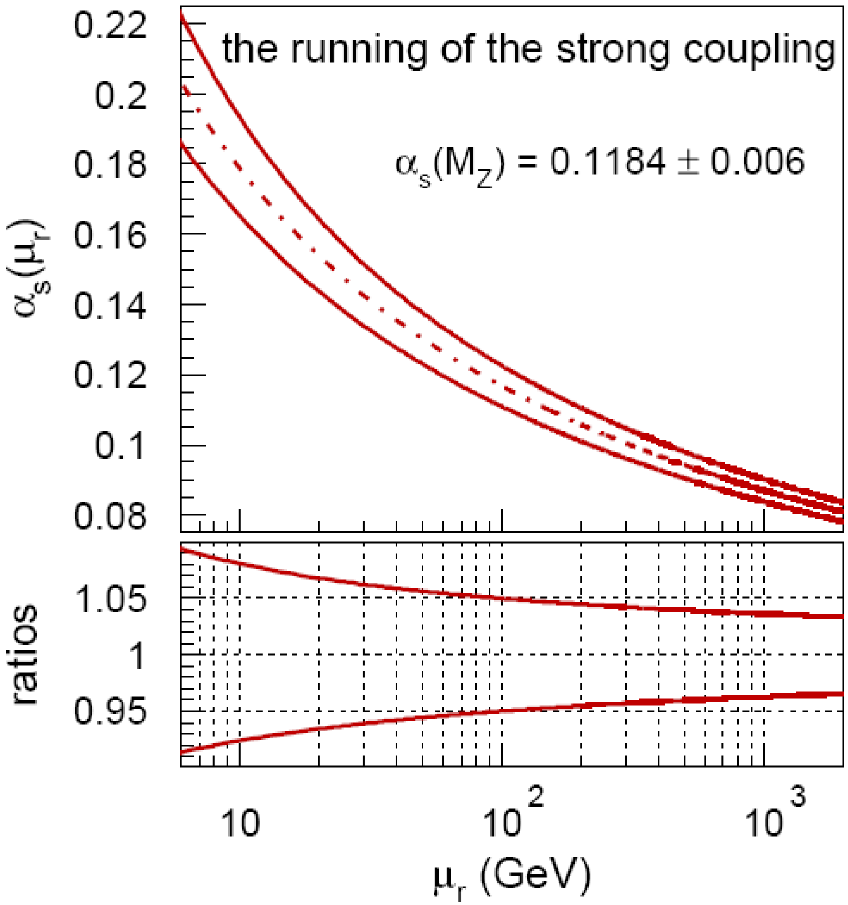
α_s and the RGE



- $\alpha_s(\mu_R)$: depends on renormalization scale
  → predicted by "RGE"

- Values $\alpha_s(\mu_R)$ are not predicted

- if we know value at one scale, $\alpha_s(\mu_0)$, we know the value at any scale $\alpha_s(\mu_R)$

- Agreement: compare $\alpha_s(M_Z)$

QCD test:

- Determine $\alpha_s(M_Z)$
  → check process independence
- Test predicted running $\alpha_s(\mu_R)$

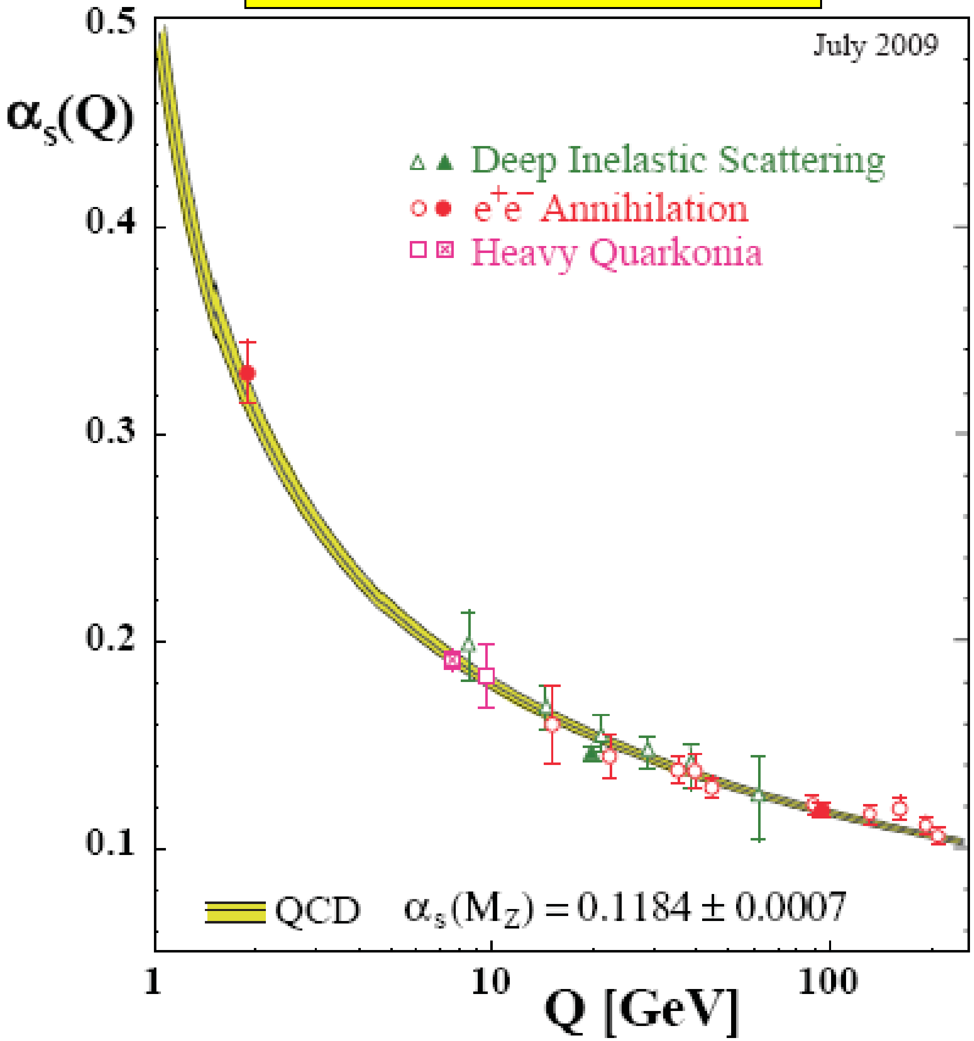
RGE:

$$Q^2 \frac{\partial \alpha_s(Q^2)}{\partial Q^2} = \beta\left(\alpha_s(Q^2)\right)$$

$$\beta(\alpha_s(Q^2)) = -\beta_0 \alpha_s^2(Q^2) - \beta_1 \alpha_s^3(Q^2) - \beta_2 \alpha_s^4(Q^2) - \beta_3 \alpha_s^5(Q^2) + \mathcal{O}(\alpha_s^6)$$

Knowledge of α_s

S. Bethke, arXiv:0908.1135

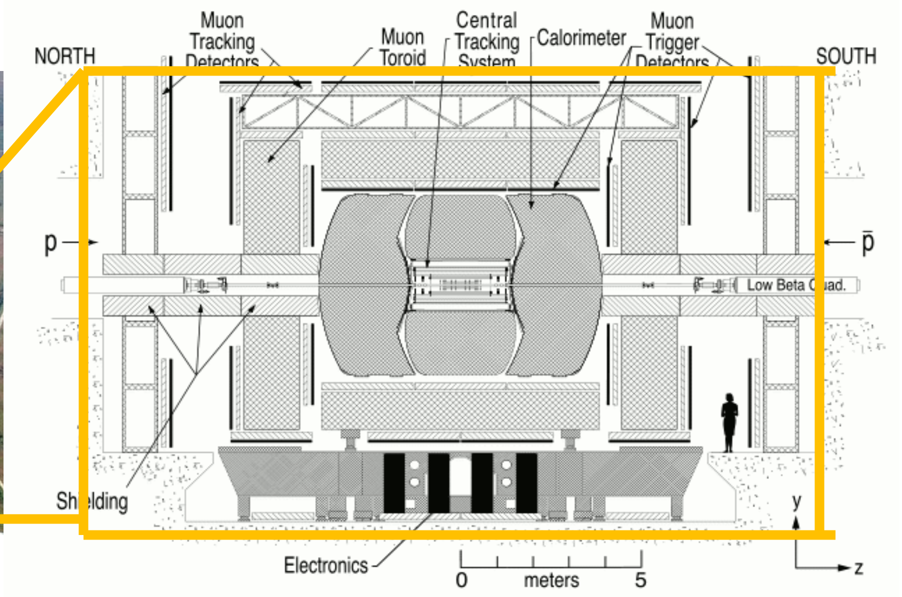


Renormalization Group Equation has been tested for momenta up to 209 GeV

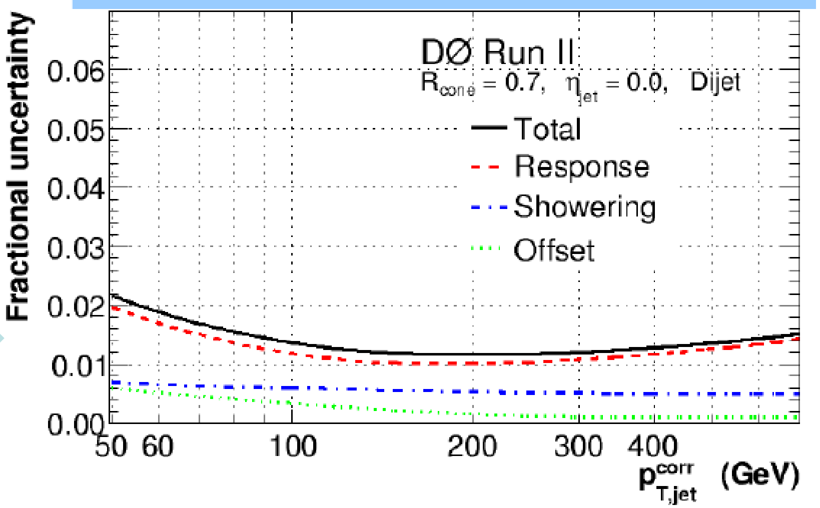
(LEP e^+e^- data)

→ But not yet for larger scales

Fermilab Tevatron and DØ

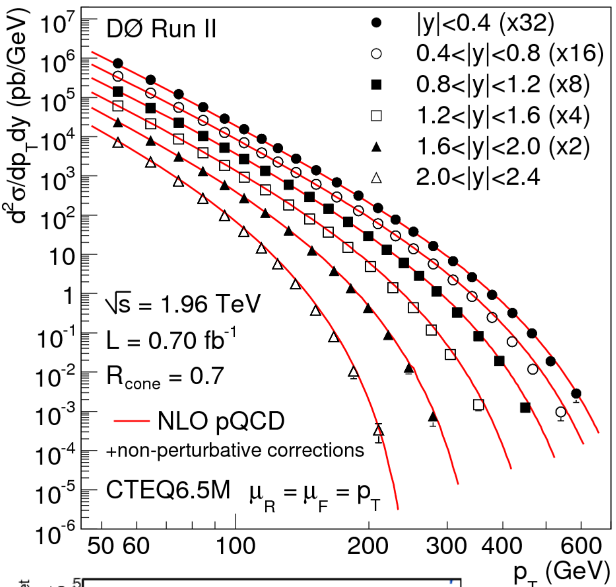


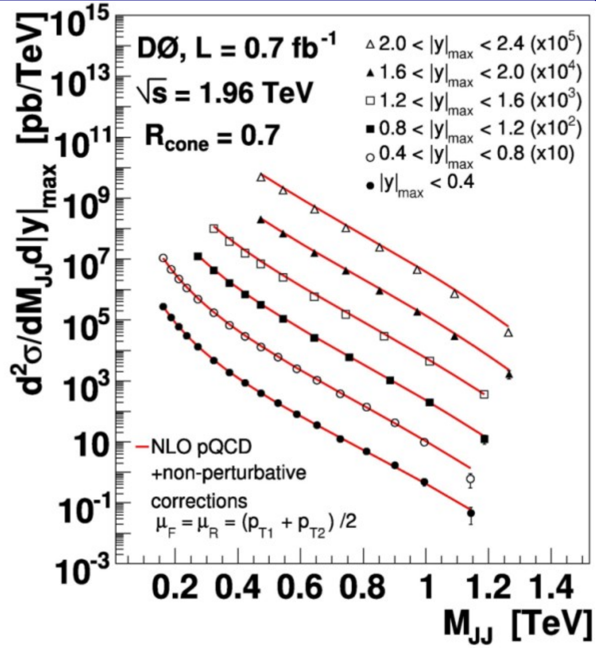
Energy scale uncertainty: 1-2% !

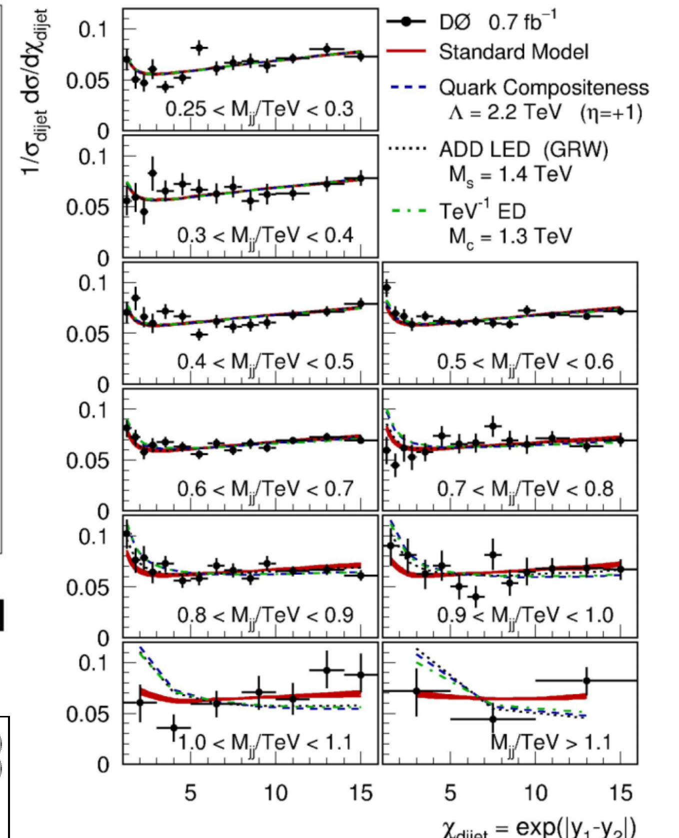


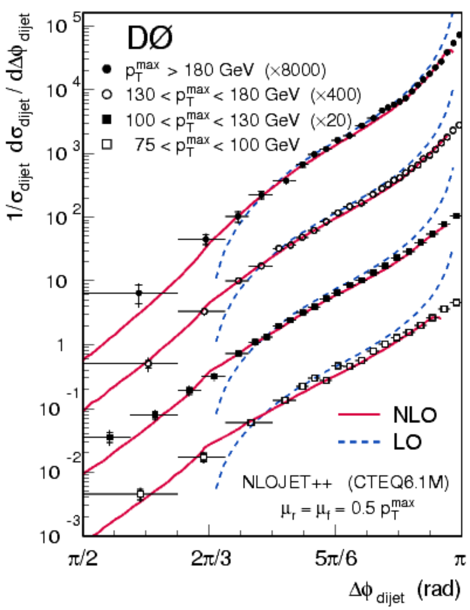
Most precise jet energy calibration at a hadron collider!

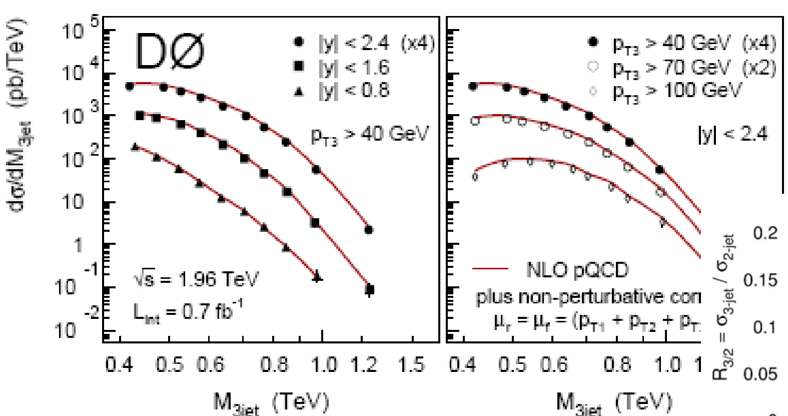
D0 Run II Jet Results

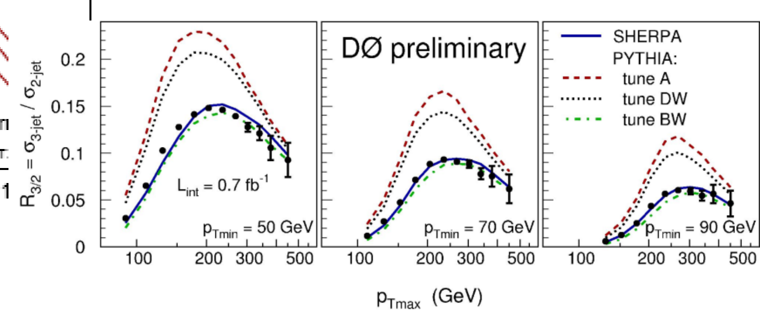








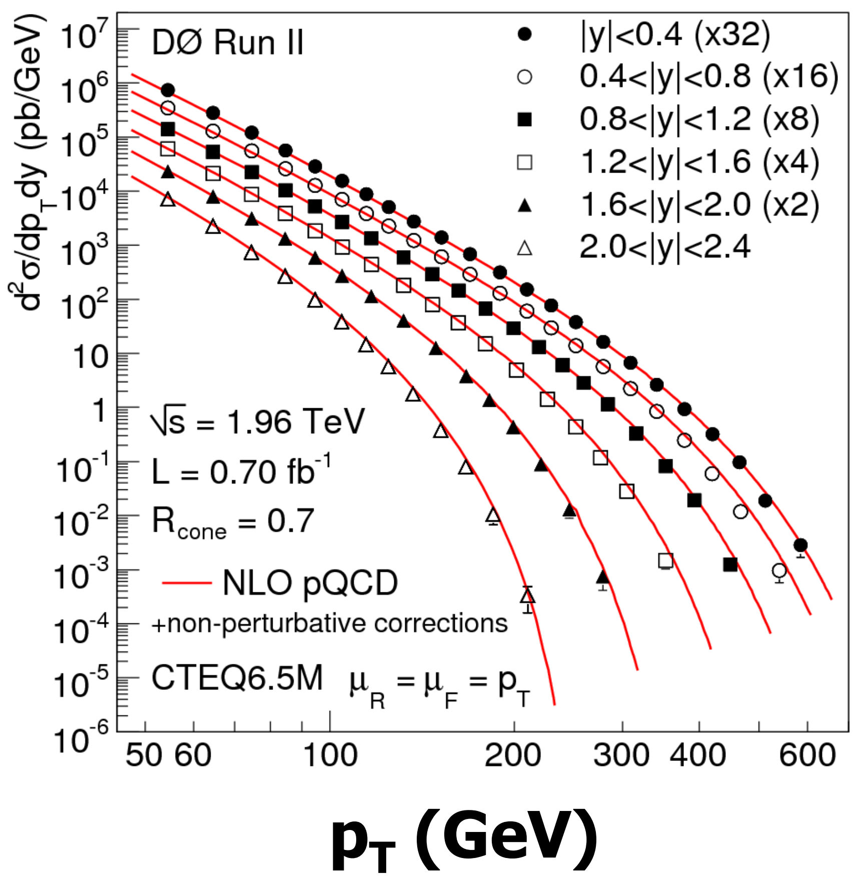


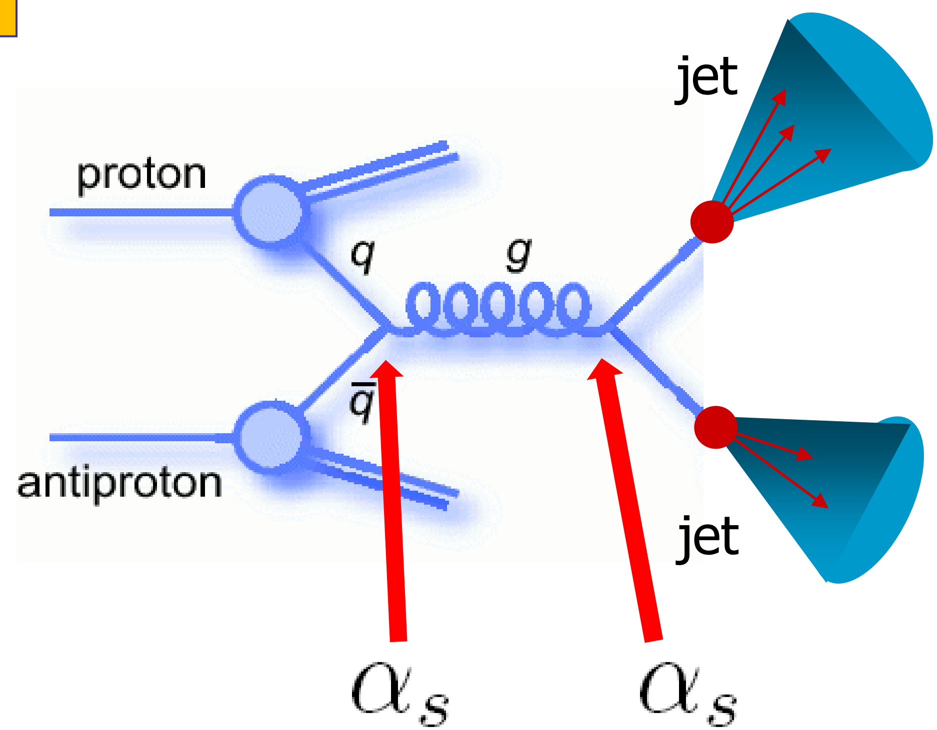


Inclusive Jet Cross Section

Very precise: benefit from hard work on jet energy calibration

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





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

Basic principle

Perturbative cross section formula:

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

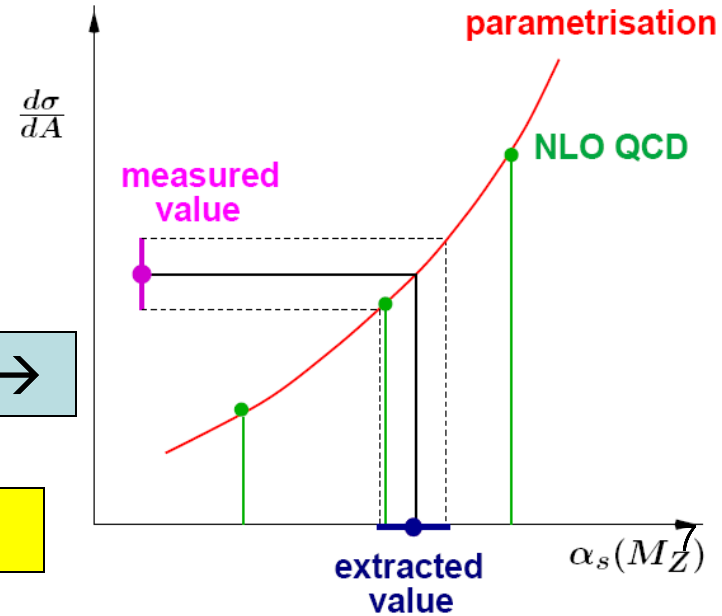
- pQCD matrix elements: explicit α_s dependence
- f_1, f_2 (PDFs): implicit α_s dependence

Determine α_s from data:

- Vary α_s until sigma-theory agrees with sigma-experiment

→ chi2 minimization

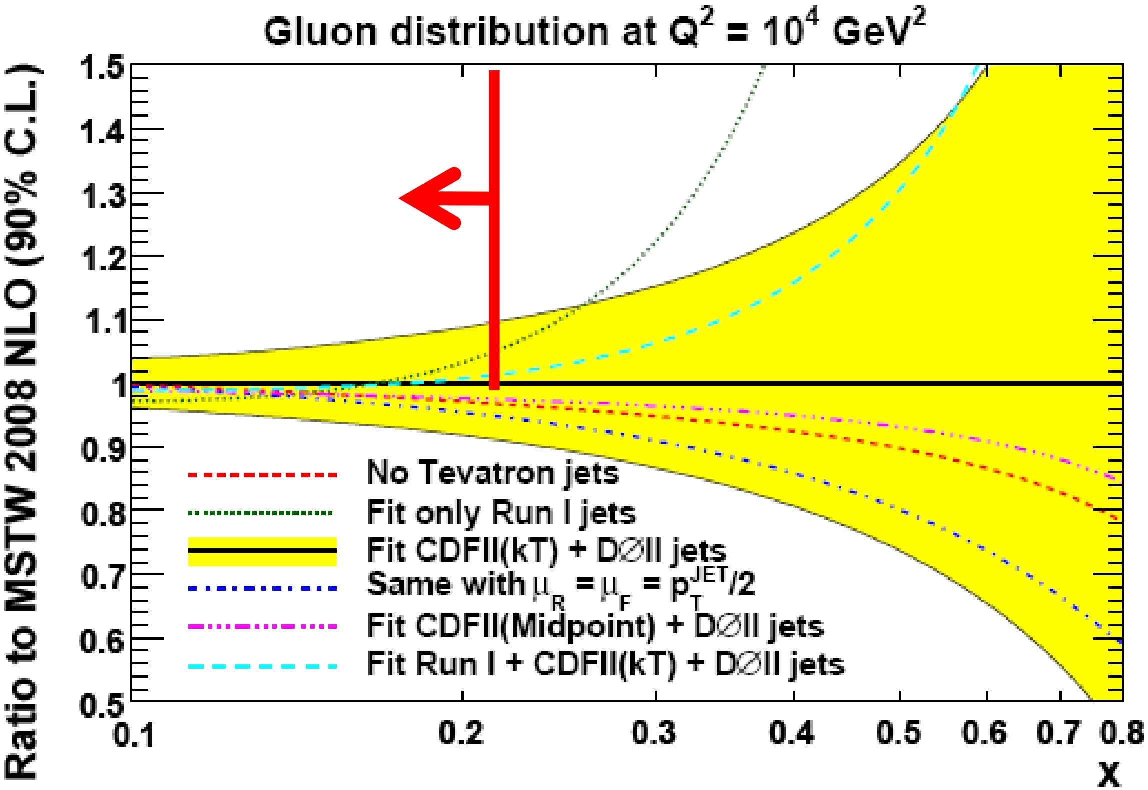
For a single bin →



→ Procedure requires PDFs as external input

PDFs and input data

MSTW2008 paper (Fig 52. / see also Figs. 51, 53)



Currently:
Main constraints on high-x gluon density come from Tevatron jet data

Goal:
Minimize correlations between data and PDF uncertainties

→ Restrict α_s analysis to kinematic regions where impact of Tevatron data for PDFs is small.

→ Tevatron jet data don't affect gluon for x < 0.2 – 0.3

Incl. Jets: x-sensitivity

Jet cross section has access to x-values of: (in LO kinematics)

$$x_a = x_T \frac{e^{y_1} + e^{y_2}}{2}, \quad x_b = x_T \frac{e^{-y_1} + e^{-y_2}}{2} \quad \text{with} \quad x_T = \frac{2\, p_T}{\sqrt{s}}$$

What is the x-value for a given incl. jet data point @(p_T, |y|) ?

→ Not completely constrained – unknown kinematics since we integrate over other jet(s)

→ Construct "test-variable" (treat as if other jet was at y=0):

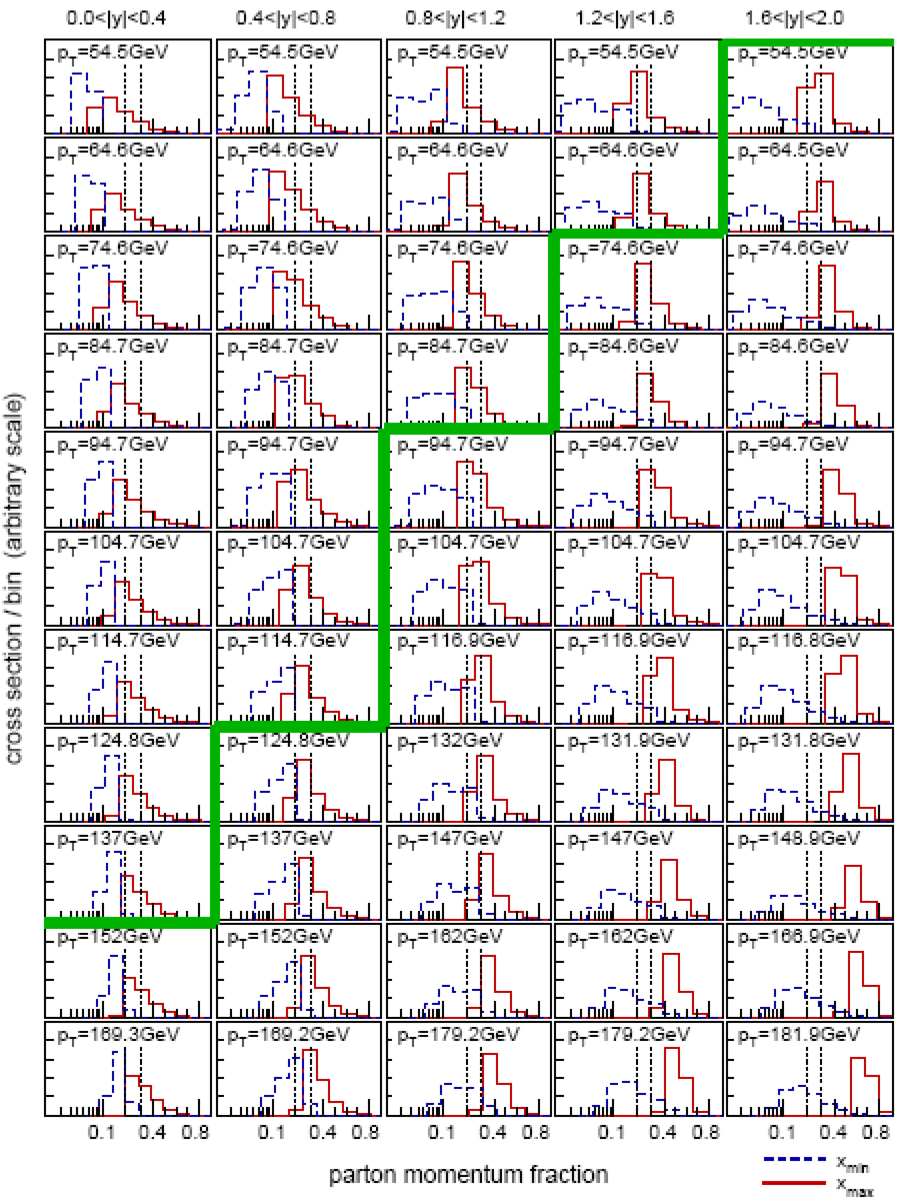
$$x = x_T \cdot (e^{|y|} + 1)/2$$

→ Apply cut on this test-variable to restrict accessible x-range

→ Find: requirement x-test < 0.15
removes most of the contributions with x > 0.2 – 0.3

→ 22 (of 110) data points remaining at 50 < p_T < 145 GeV

x_{min} / x_{max} distributions



Every analysis bin → one plot

Each plot: x-min/x-max distributions

Cut on test-variable x-test < 0.15
→ 22 (of 110) data points remain

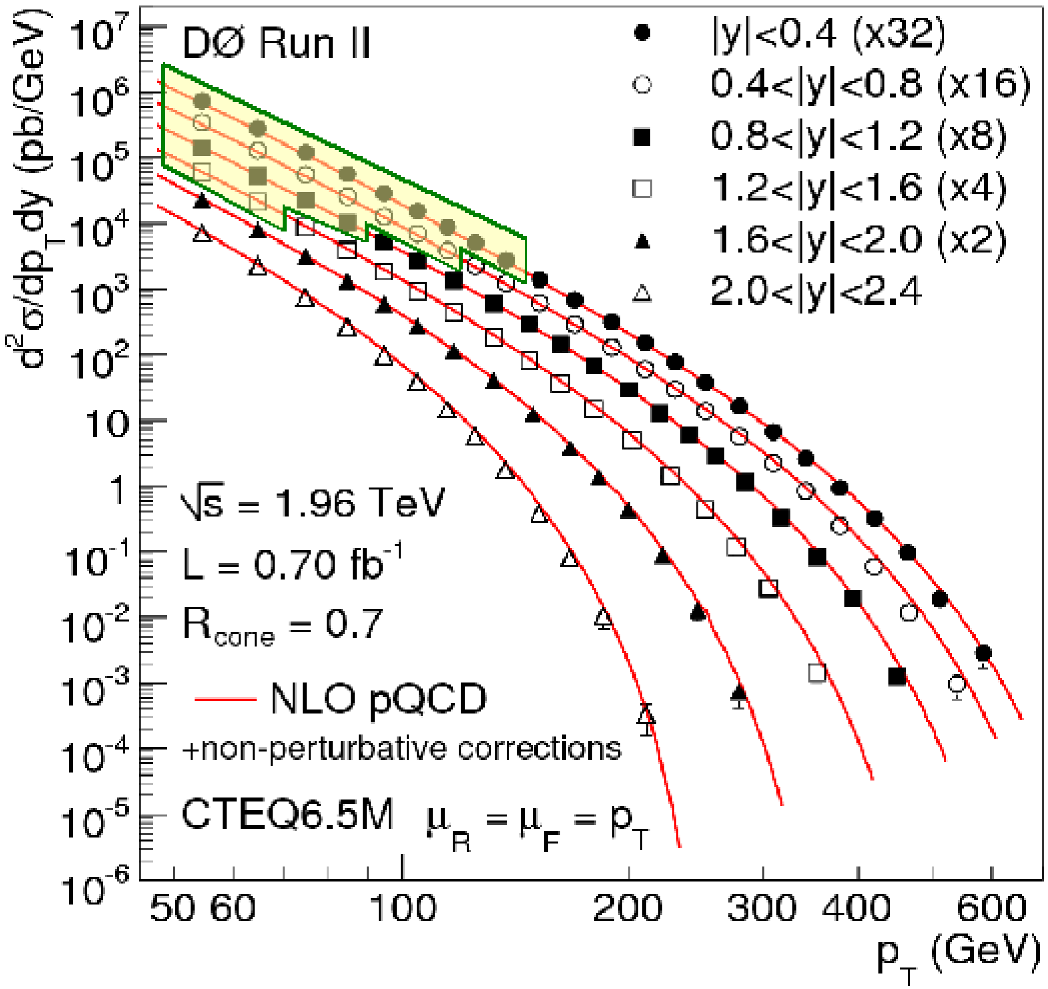
These have small contributions from
x > 0.2 – 0.3

← Only data points above green line are used

x_{min}

x_{max}

Data Sample



22(out of 110) inclusive jet cross section data points at $50 < p_T < 145$ GeV

→ Input in α_s analysis

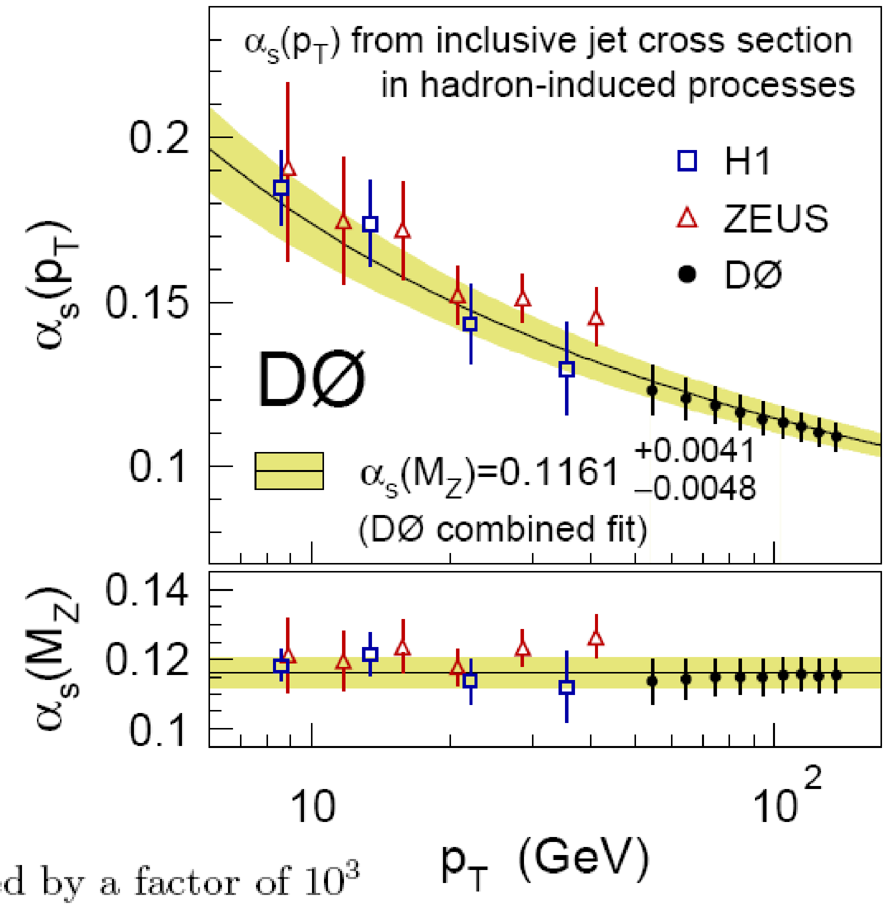
Strong Coupling Const.

→ Use best theory prediction:
NLO + 2-loop threshold corrections
(Kidonakis/Owens)
with MSTW2008NNLO PDFs

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

→ Most precise result
from a hadron collider

→ Consistent with HERA results
and world average



All uncertainties are multiplied by a factor of 10^3

	Total uncertainty	Experimental uncorrelated	Experimental correlated	Nonperturb. correction	PDF uncertainty	$\mu_{r,f}$ variation
0.1161	$^{+4.1}_{-4.8}$	± 0.1	$^{+3.4}_{-3.3}$	$^{+1.0}_{-1.6}$	$^{+1.1}_{-1.2}$	$^{+2.5}_{-2.9}$

Theoretical Precision

Main result: use best theory predictions
NLO + 2-loop threshold corrections (Kidonakis/Owens)
with MSTW2008NNLO PDFs

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

Use only NLO
with MSTW2008NLO PDFs

$$0.1202^{+0.0072}_{-0.0059}$$

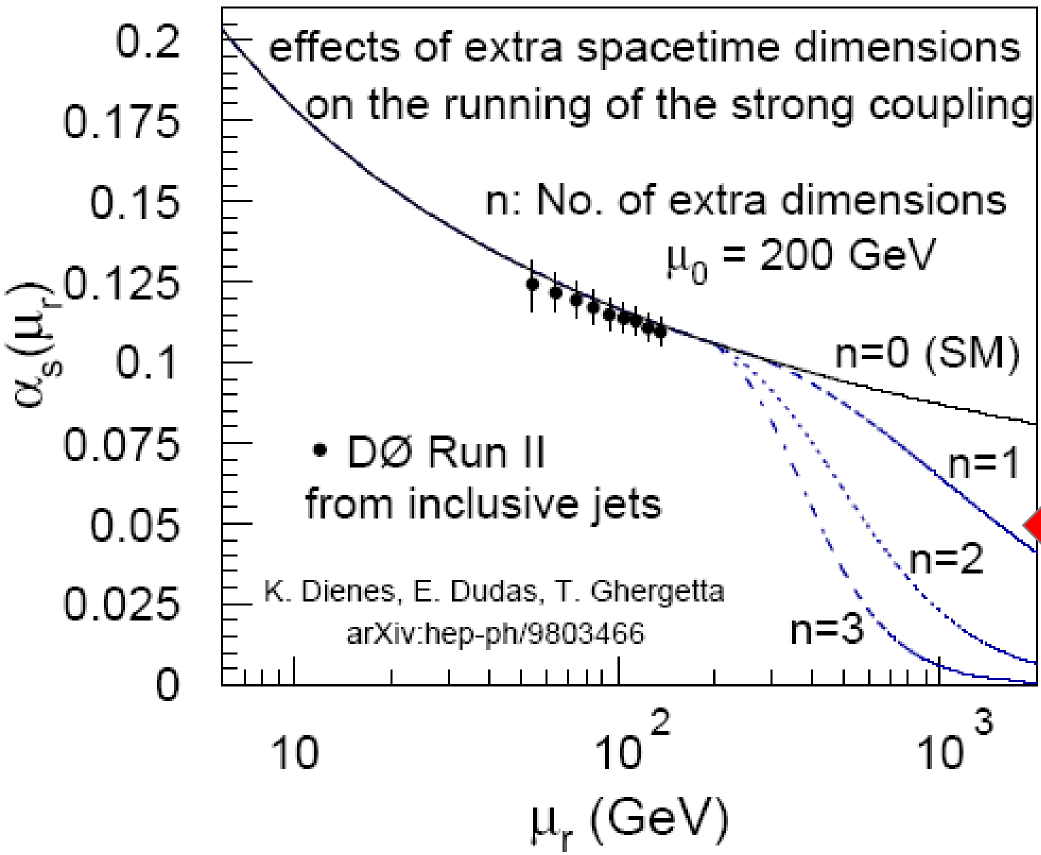
- Larger value of "NLO-only" result:
  → due to missing $O(\alpha_s^4)$ contributions
- Larger uncertainty of "NLO-only" result:
  → due to increased scale dependence (main effect)
  → and increased PDF uncertainty (minor effect)

All uncertainties are multiplied by a factor of 10^3

	Total uncertainty	Experimental uncorrelated	Experimental correlated	Nonperturb. correction	PDF uncertainty	$\mu_{r,f}$ variation
0.1161	$^{+4.1}_{-4.8}$	± 0.1	$^{+3.4}_{-3.3}$	$^{+1.0}_{-1.6}$	$^{+1.1}_{-1.2}$	$^{+2.5}_{-2.9}$

α_s extraction at large p_T requires high (experimental & theory) precision

Running of α_s (?)



→ so far tested
up to μ_r = 209 GeV (LEP)

Could be modified
for scales $\mu_r > \mu_0$
e.g. by extra dimensions

here: μ_0 = 200 GeV
and n=1,2,3 extra dim.
(n=0 → Standard Model)

But: α_s extraction from inclusive jets uses PDFs which were derived assuming the RGE

→ We cannot use the inclusive jets to test the RGE in yet untested region

Going further …

… towards testing in the RGE
in novel energy regimes

→ Cannot rely on PDF information
(PDF parametrizations already assume
RGE in DGLAP evolution)

Cancelling PDFs: Ratios

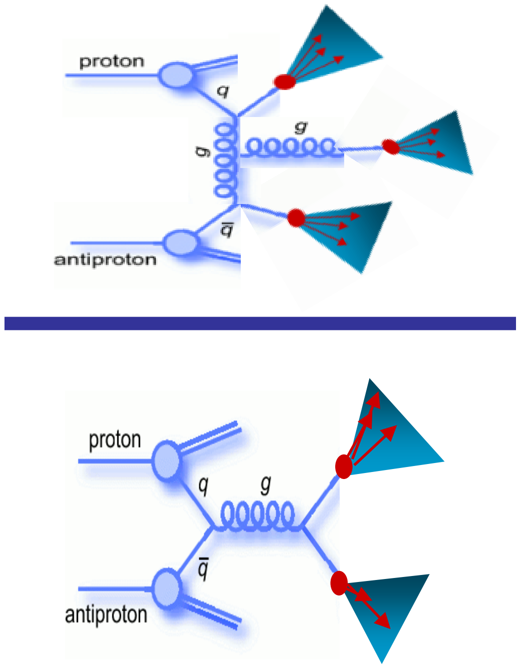
Goal: test pQCD (and α_s) **independent** of PDFs

Conditional probability:

$R_{3/2}$

$= P(3^{rd} \text{ jet} \mid 2 \text{ jets})$

$= \sigma_{3\text{-}jet} / \sigma_{2\text{-}jet}$



$\Leftrightarrow \alpha_s$

- Probability to find a third jet in an inclusive dijet event
- Sensitive to α_s (3-jets: α_s^3 / 2-jets: α_s^2)
- (almost) independent of PDFs

$R_{3/2} = \sigma_{3\text{-}jet} / \sigma_{2\text{-}jet}$

Measure as a function of two momentum scales:

- p_{Tmax} : common scale for both $\sigma_{2\text{-}jet}$ and $\sigma_{3\text{-}jet}$
- p_{Tmin} : scale at which 3rd jet is resolved ($\sigma_{3\text{-}jet}$ only)

Sensitive to α_s at the scale p_{Tmax} → probe running of $\alpha_s(p_{Tmax})$

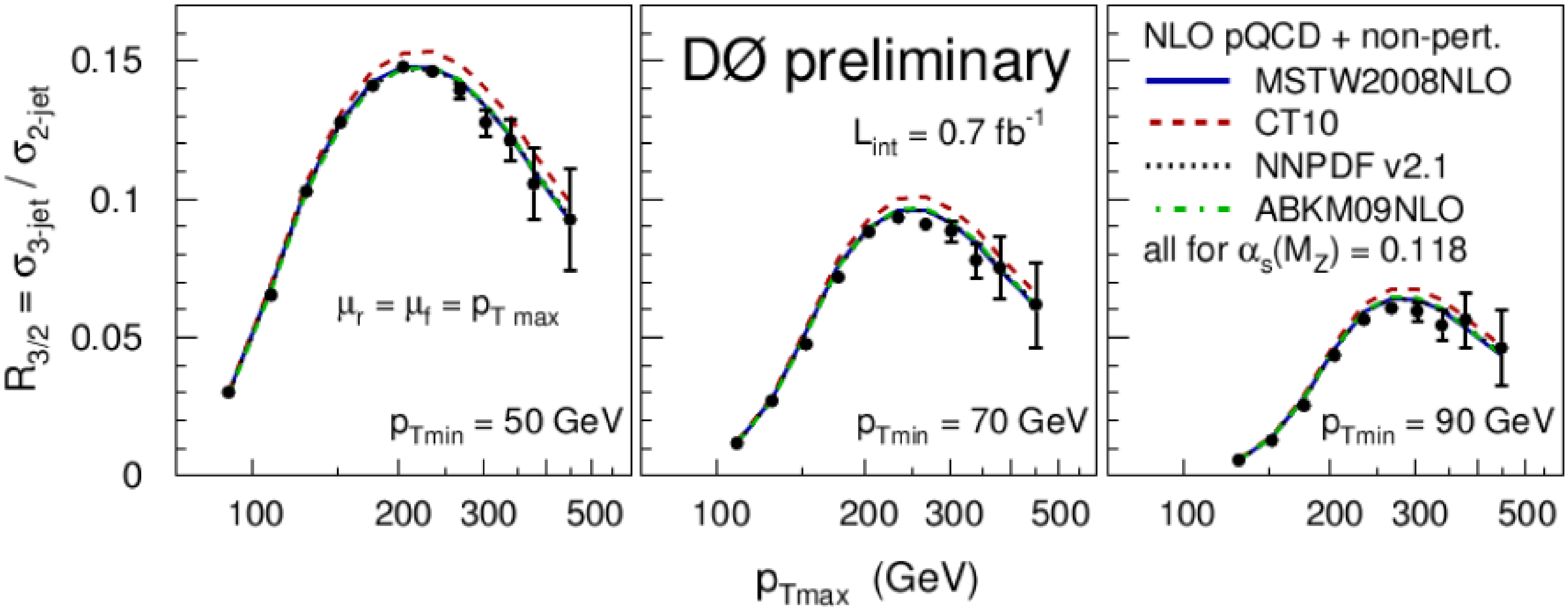
Details:

- inclusive *n*-jet samples (*n*=3,2) with *n* (or more) jets above p_{Tmin}
- $|y| < 2.4$ for all *n* leading p_T jets
- $\Delta R_{jet,jet} > 1.4$ (insensitive to overlapping jet cones)
- study p_{Tmax} dependence for different p_{Tmin} of 50, 70, 90 GeV

→ Measurement of $R_{3/2}(p_{Tmax}\,;\,p_{Tmin})$

$R_{3/2}$ vs. NLO pQCD

Using $R_{3/2}$ to test NLO matrix elements



For a given $\alpha_s(M_Z) = 0.118$:

→ NLO results for MSTW2008NLO, NNPDF v2.1, ABKM09NLO agree

→ CT10 slightly higher at high p_T

Summary

α_s from inclusive jet cross section:
detailed analysis to avoid inconsistencies (or circular arguments) related to
- correlations between experimental and PDF uncertainties
- assumptions of RGE in DGLAP evolution of PDFs

→most precise result from a hadron collider → see consistency

α_s determinations from cross section (assuming PDFs) can not be used to test running in novel energy regimes

→ Need observables which are insensitive to PDFs

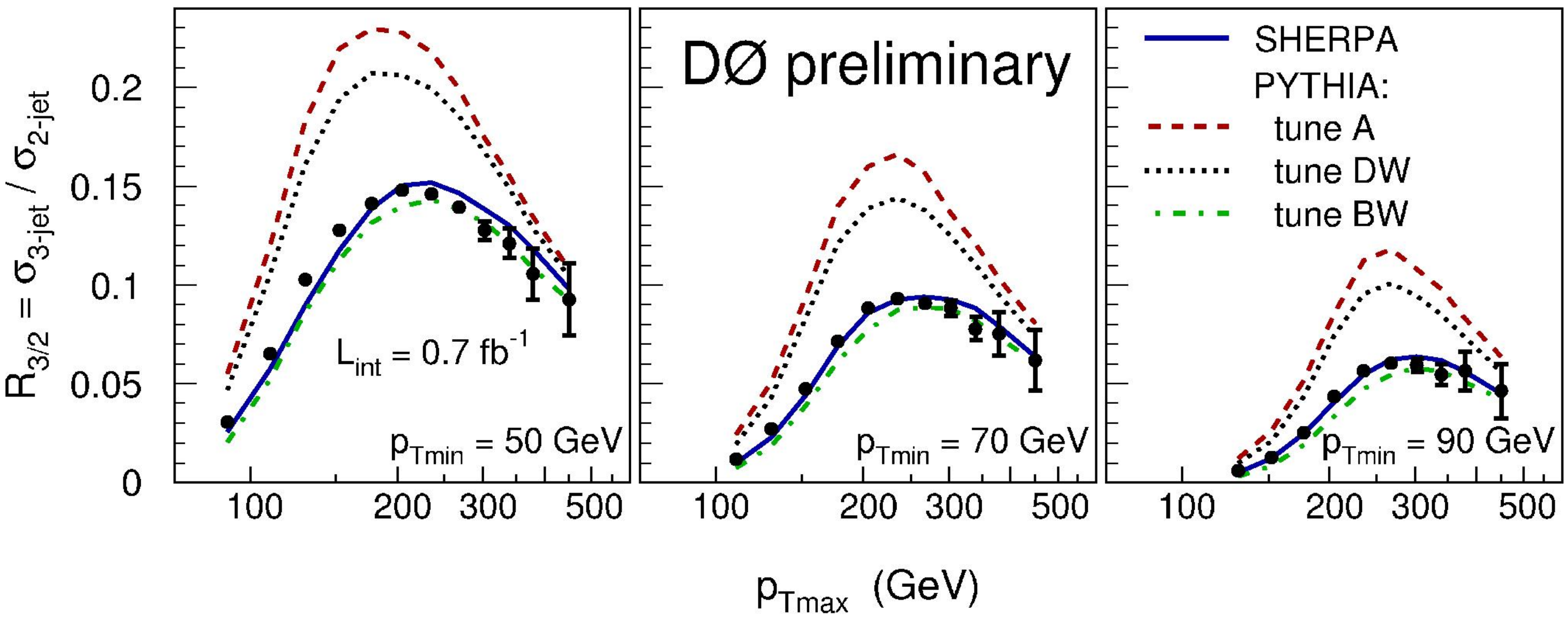
$R_{3/2}$ precision data:
- well described by NLO pQCD

→ basis to extend knowledge of α_s to novel energy regime

Backup Slides

$R_{3/2}$ vs. MC models

Testing Monte Carlos and MC tunes



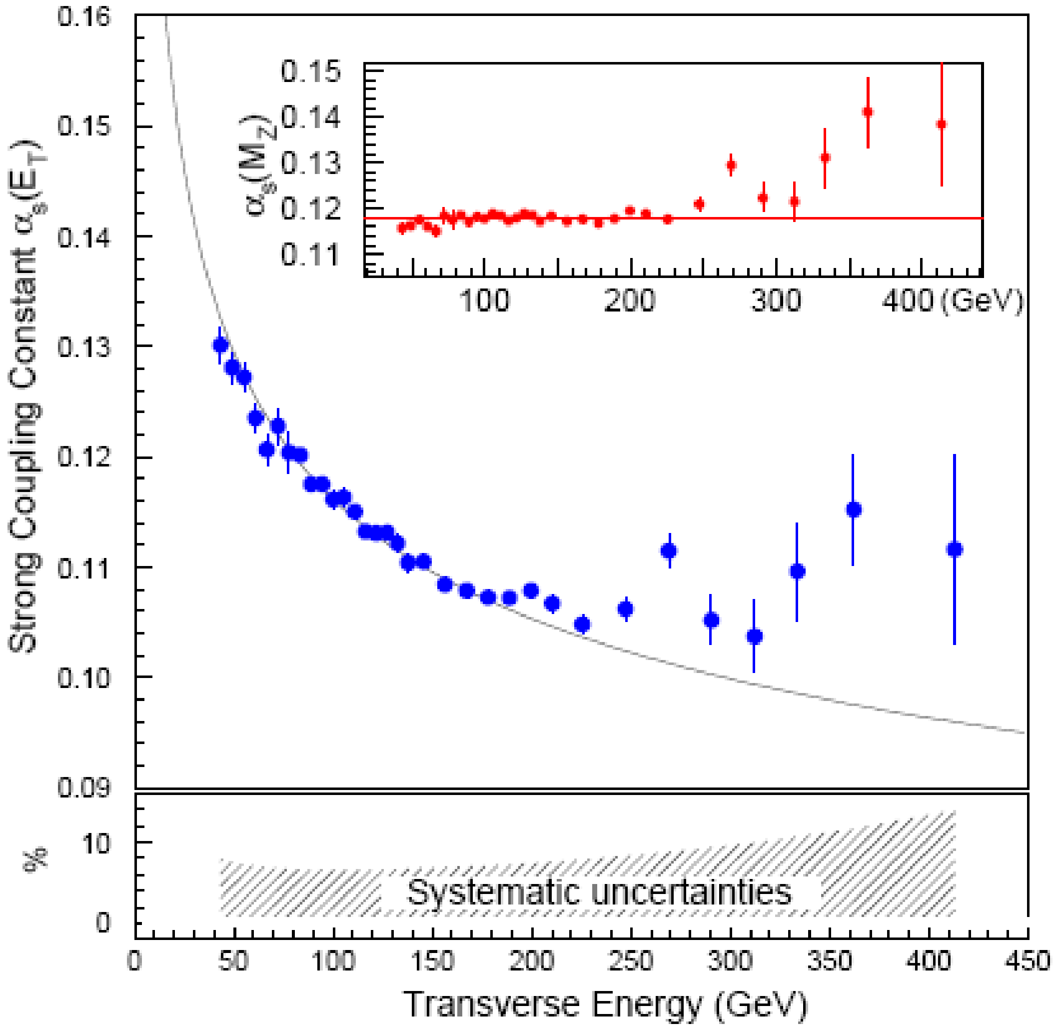
SHERPA (out of the box) describes data

PYTHIA tune DW (tuned to D0 dijet azimuthal decorrelations) fails

→ "softer" tune BW describes the data

CDF Run I result

CDF Collaboration, T. Affolder et al., Phys. Rev. Lett. 88, 042001 (2002)



Claim:

"Test running over 40 < ET < 440 GeV"

→ Not really!!
because analysis uses PDFs for which DGLAP evolution is already done under assumption of running according to RGE

→ RGE was already assumed

→ No independent test

→ Avoided in the D0 analyses