Determination of the strong coupling constant using the inclusive jet cross section in $p\bar{p}$ collisions

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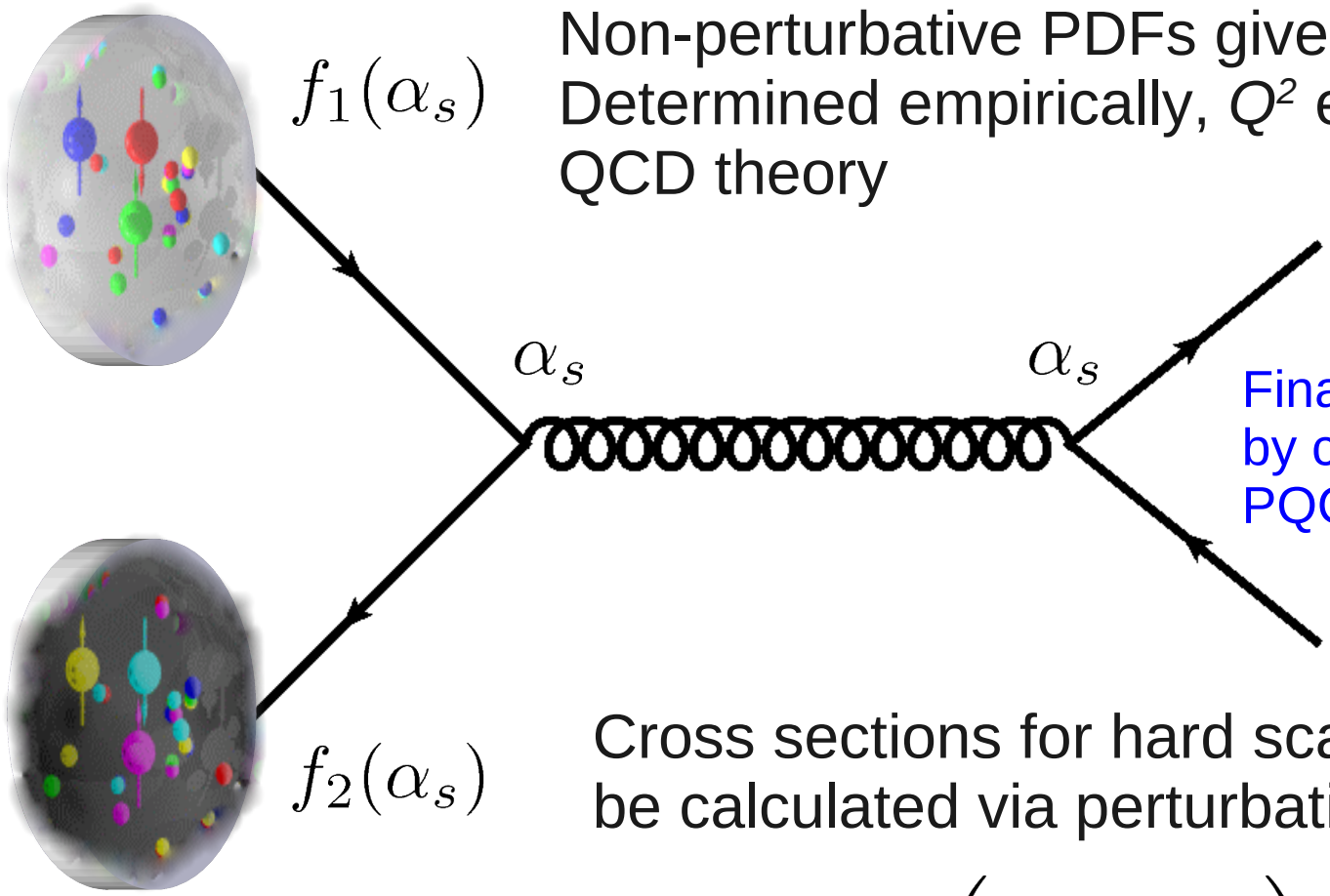
$P\bar{P}$ collisions



Non-perturbative PDFs give initial parton states. Determined empirically, Q^2 evolution according to QCD theory

Final partonic states determined by convolution of PDFs and PQCD scattering amplitudes

Cross sections for hard scattering of partons may be calculated via perturbative expansion in QCD

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

α_s in QCD

The coupling strength, α_s is scale dependent, $\alpha_s(\mu_R)$

- Its numerical value is not predicted in QCD
- But **R**enormalization **G**roup **E**quation (RGE), predicts μ_R-dependence

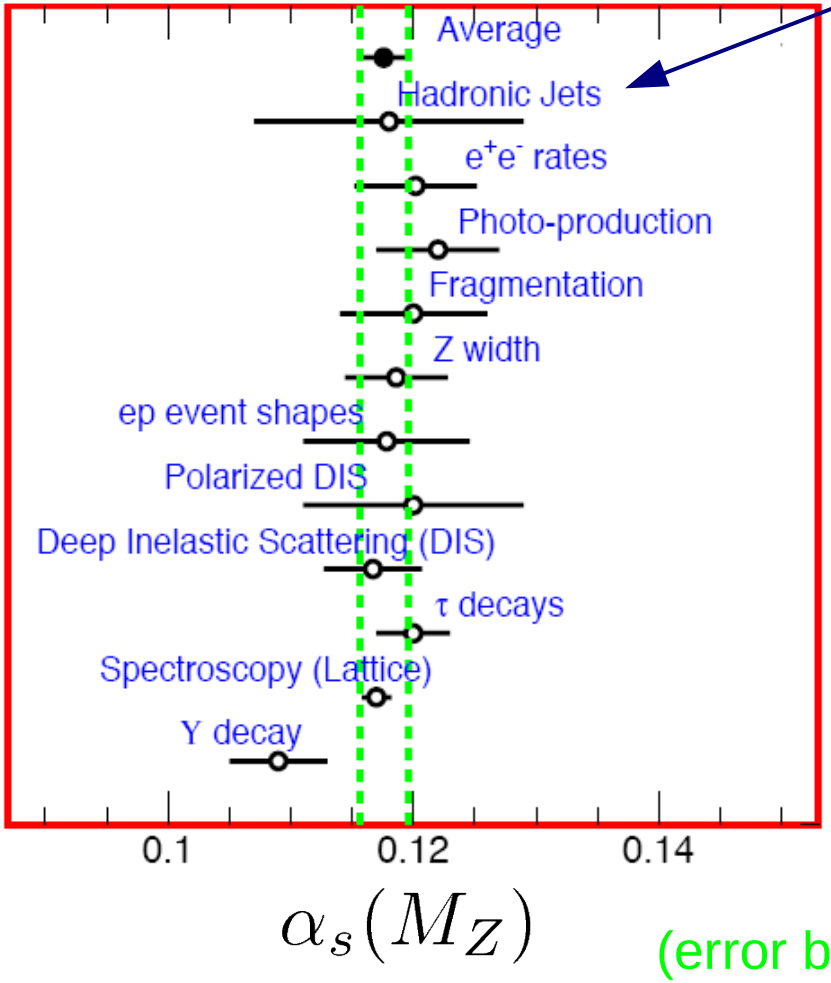
- Measure values in experiment and test RGE compatibility
  - For jet production take μ_R = jet p_T
  - Values of $\alpha_s(\mu_R)$ can be compared at a common scale, typically $\alpha_s(M_Z)$, by using RGE

e.g. for two loop solution to RGE

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

Recent past status of α_s measurements

2008 Review of Particle Physics



(error band includes theory)

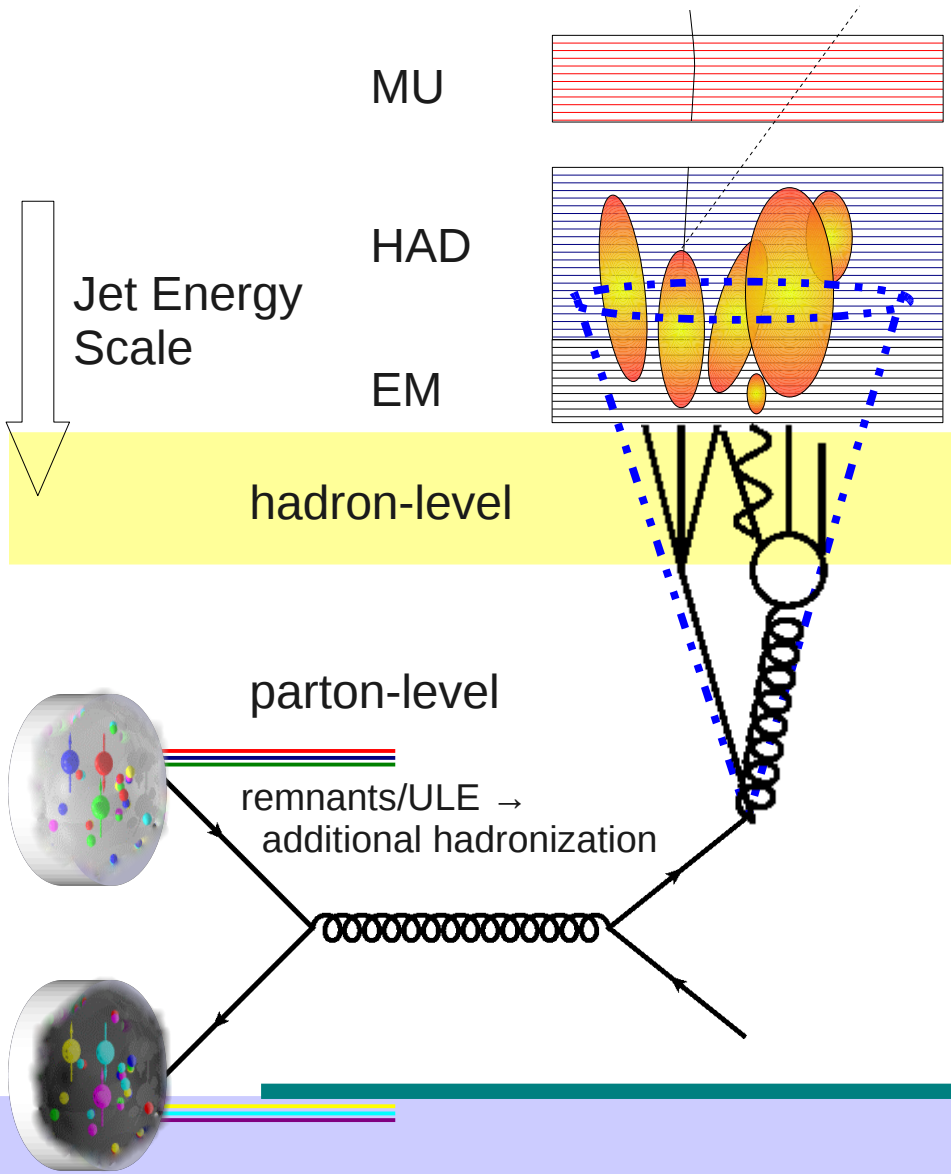
Large uncertainty associated with "Hadronic Jets"

Previously not very competitive with other determinations

Now have the tools to substantially improve this result.

- More and better data
- More precise theory calculations

Canonical picture of jet observables

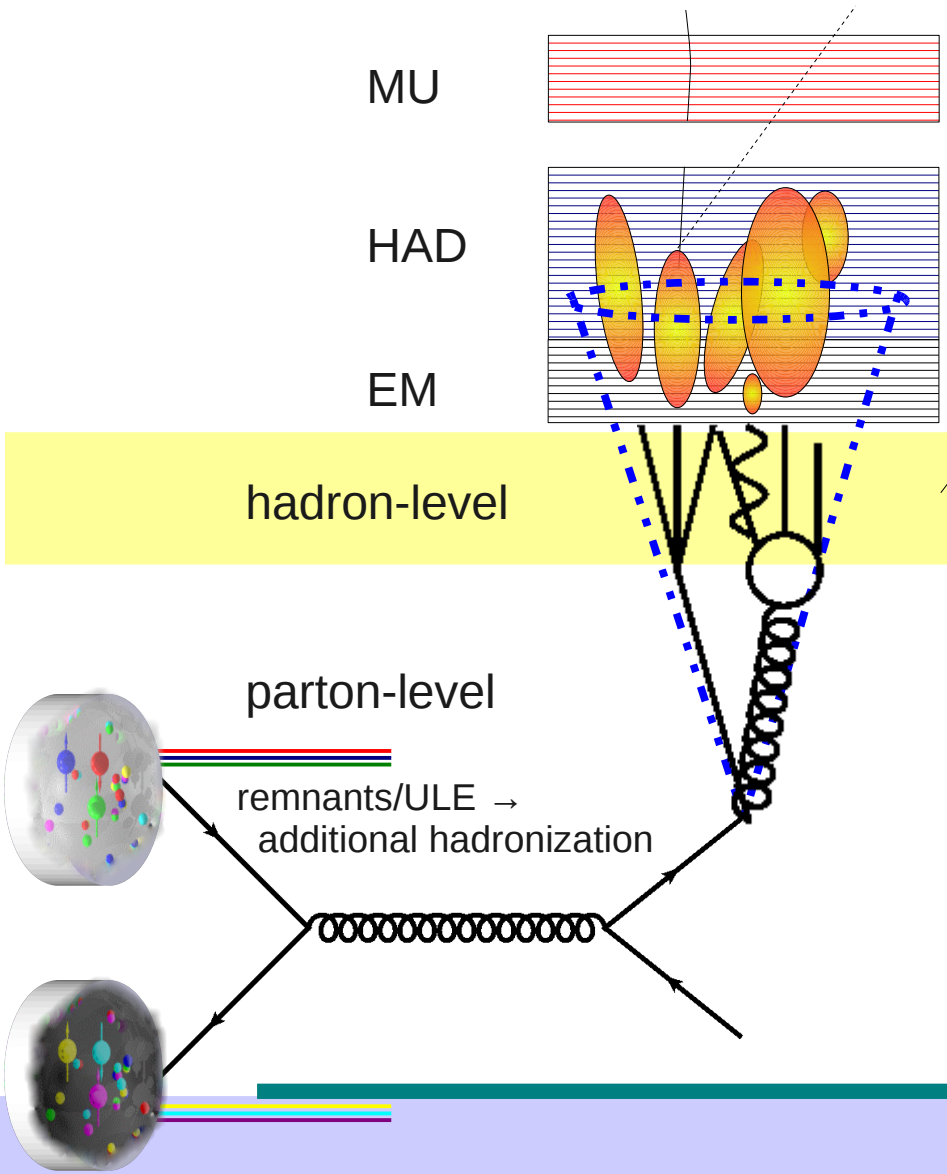


Clustering algorithm chosen to accurately define jets at detector particle, parton levels

Observed energies corrected to particle(hadron)-level expectations

PQCD calculations are corrected for non-perturbative effects of hadronization and underlying event

Canonical picture of jet observables



Clustering algorithm chosen to accurately define jets at detector particle, parton levels

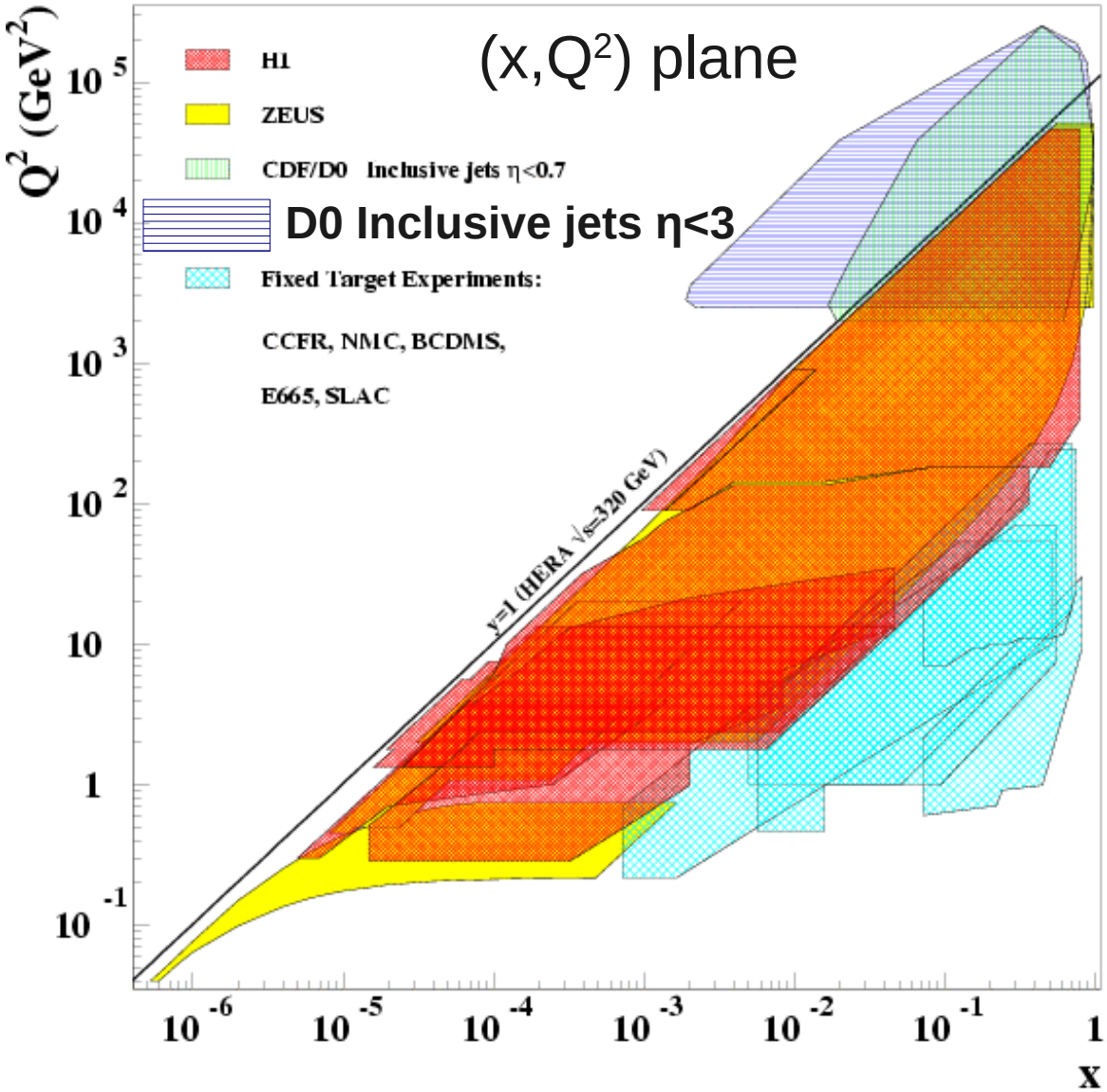
Compare data/MC here

Observed energies corrected to particle(hadron)-level expectations

PQCD calculations are corrected for non-perturbative effects of hadronization and underlying event

Theory/experiment typically compared at particle-level

Parton *x* and momentum scales Q^2



Tevatron jet measurements access a wide kinematic range

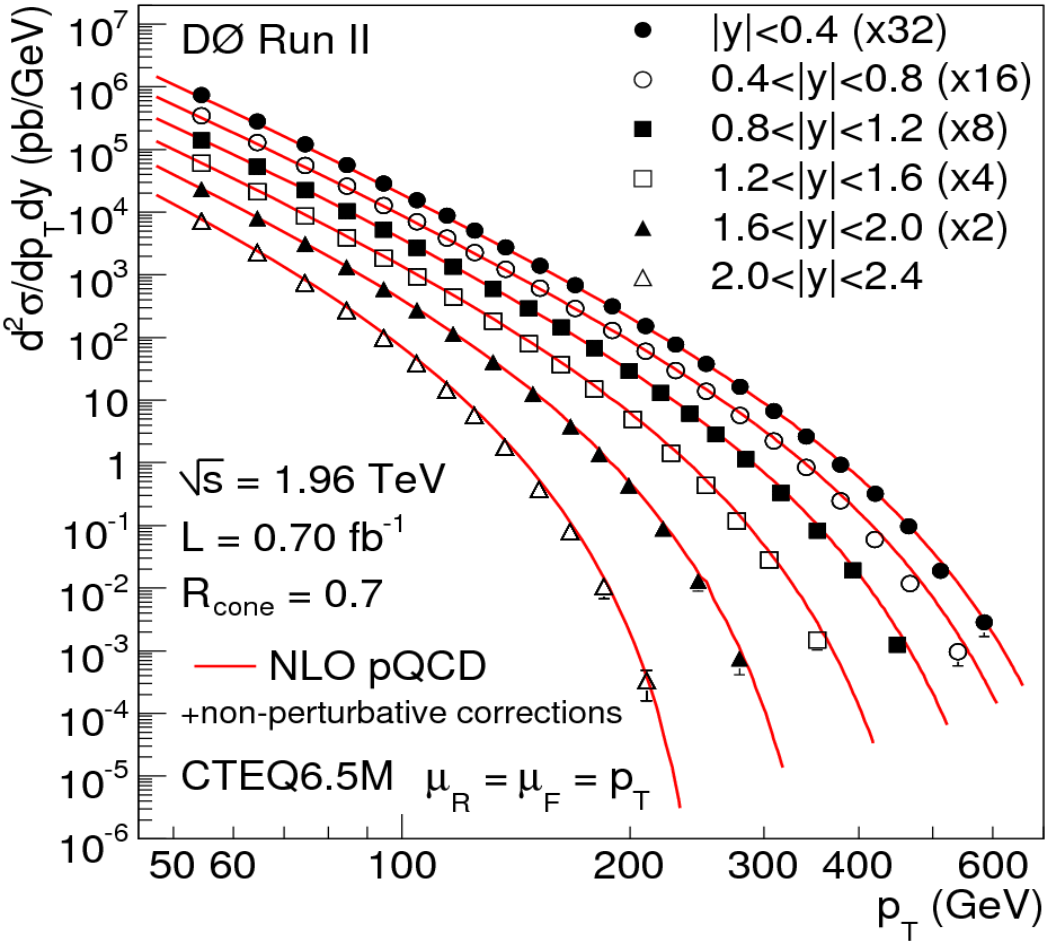
Covers unique regions of phase space and also overlap with other measurements from e-p

Data allow precision tests of PQCD and also an independent extraction of alpha strong

Extraction of α_s from inclusive jet CS

Most precise measure of inclusive jet production

$$\sigma^{jet}_{pert}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$



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

Renormalization Group Eqn uniquely relates $\alpha_s(\mu_R)$, for arbitrary scale μ_r to $\alpha_s(M_Z)$

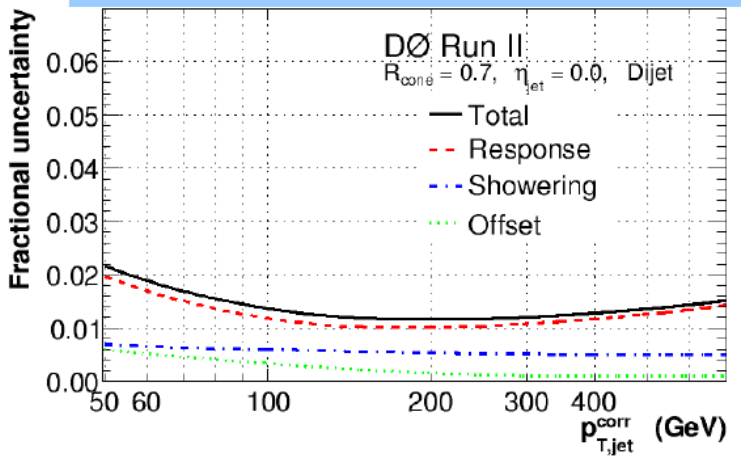
Express theoretical prediction as:

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

Contains α_s dependence in ME as well as implicit α_s dependence in the PDFs

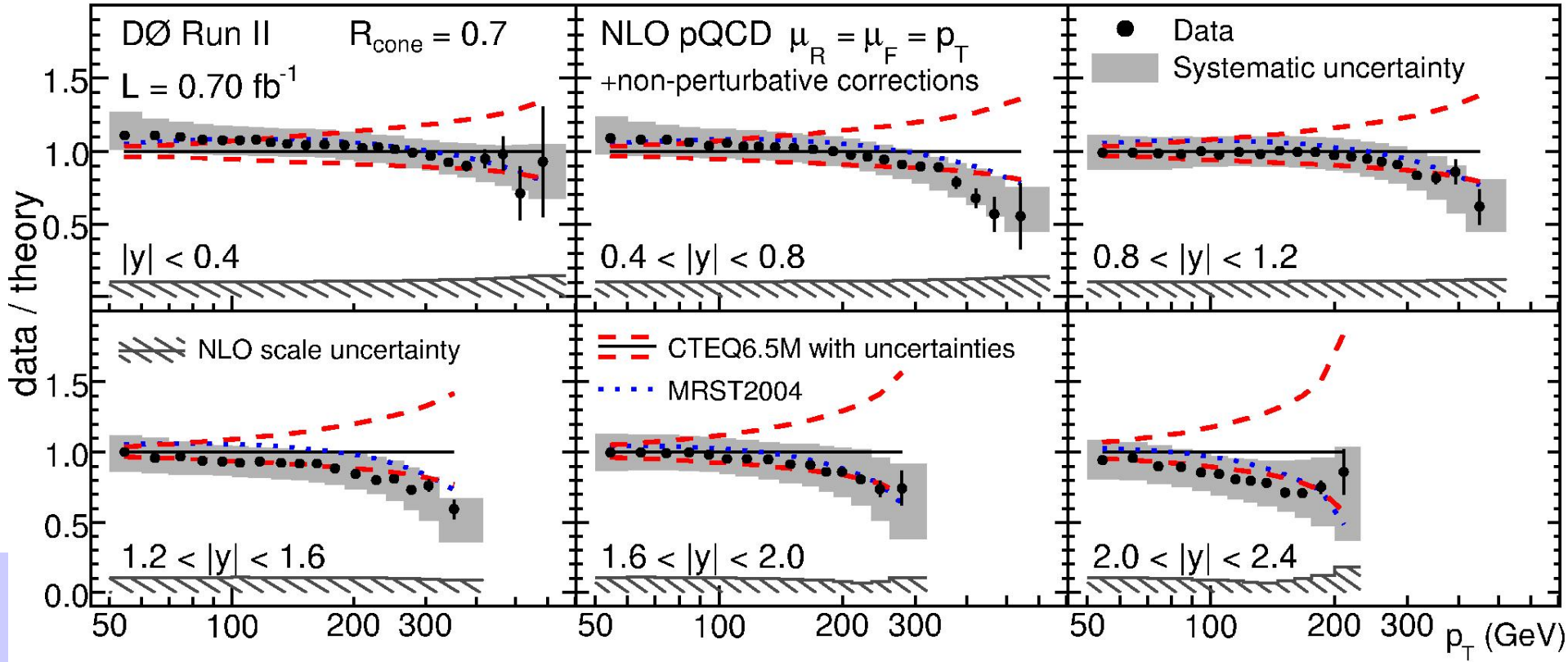
DØ inclusive iets measurement

Energy scale uncertainty: 1-2% !



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

- Each data point sensitive to $\alpha_s(p_T)$ => *running*
- Use combined fit of selected data points to determine $\alpha_s(M_Z)$



Extraction of α_s from inclusive jet CS

Strategy: Determine best fit to data using χ^2 function

$$\chi^2(\xi,\vec{\epsilon},\vec{\alpha}) = \sum_{i=1}^{npoints} \frac{\left[d_i - t_i(\xi,\vec{\alpha})\left(1+\sum_j \delta_{ij}(\epsilon_j)\right)\right]^2}{\sigma^2_{i,stat}+\sigma^2_{i,uncorr.}} + \sum_j \epsilon_j^2 + \sum_k \alpha_k^2$$

ξ : fit parameter, $\alpha_s(M_Z)$
$\bar{\alpha}$: systematic parameters for calculation (PDFs, non-pert. corrs)
$\bar{\epsilon}$: systematic parameters on measurement (luminosity, jet E scale, etc.)

Minimize χ^2 wrt variable nuisance parameters ($\bar{\epsilon}$,$\bar{\alpha}$). These vary, but not freely, due to constraints from prior knowledge of systematics.

Uncertainties due to renormalization and factorization scales can not be treated as normal distributions. Instead repeat fit with $\mu_{r,f} = 0.5p_T$, $2.0p_T$ and use difference with central result, $\mu_{r,f} = p_T$.

Extraction of α_s from inclusive jet CS

Strategy: Determine best fit to data using χ^2 function

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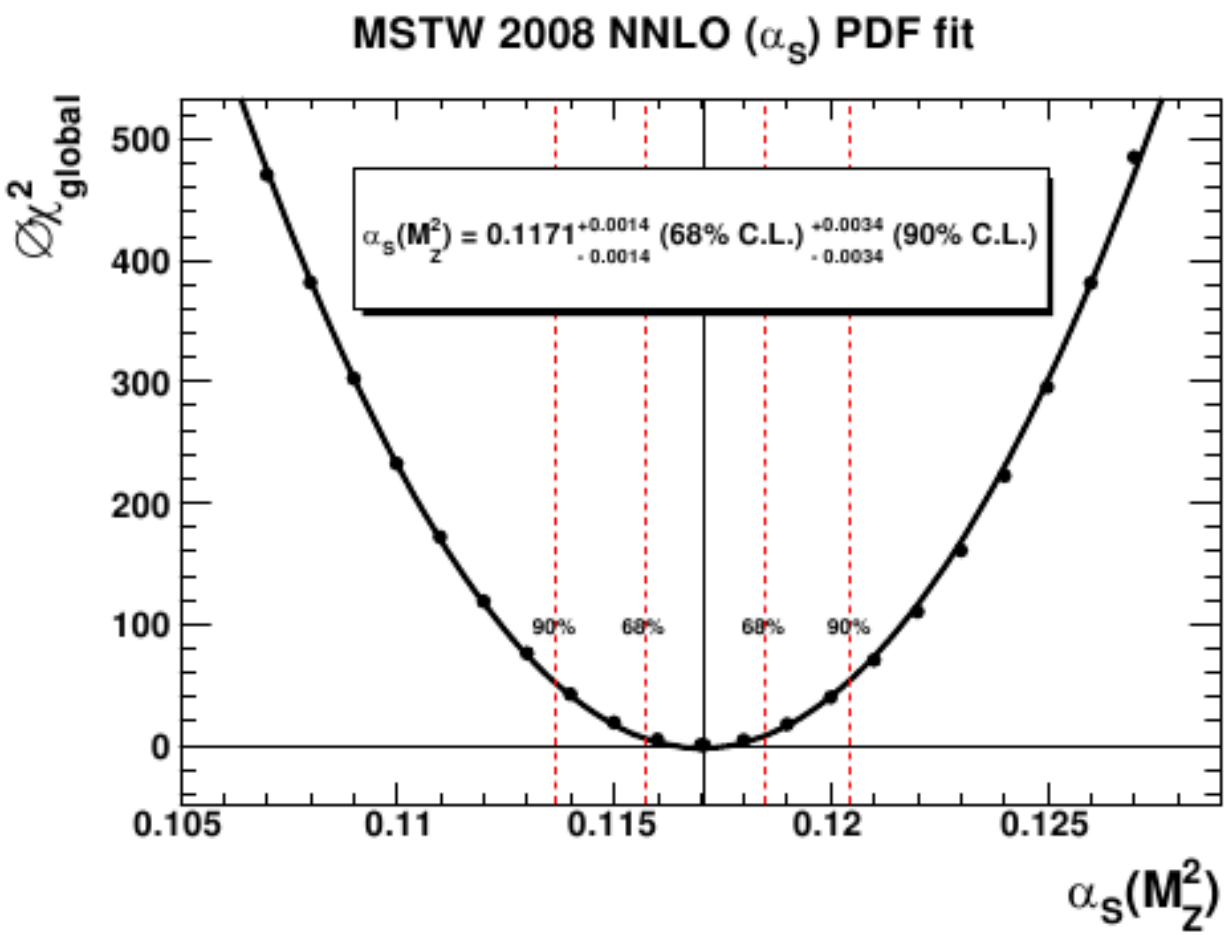
Contains ME and PDFs. Minimizing for $\xi = \alpha_s(M_Z)$ requires knowledge of PDF sets including α_s dependence. Use MSTW2008, provides fits for 21 values of $\alpha_s(M_Z)$ in range 0.110--0.130

$\underline{\xi}$: fit parameter, $\alpha_s(M_Z)$
$\underline{\alpha}$: systematic parameters for calculation (PDFs, non-pert. corrs)
ϵ : systematic parameters on measurement (luminosity, jet E scale, etc.)

Choice of PDF models



MSTW2008 provides PDF fits in fine binning of alpha strong.

Allow for smooth interpolation of results to arbitrary $\alpha_s(M_Z)$ in range

NNLO accuracy.

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

Theory

PQCD (two alternatives):

- NLO + added 2-loop threshold corrections (from Kidonakis/Owens)
  'NLO + 2-loop'
- NLO as cross check

Uncertainties due to scale dependence: $\mu_{r,f} = p_T$ (+ x0.5, x2.0)

Matched to appropriate PDF models

- MSTW2008NNLO for NLO + 2-loop
- MSTW2008NLO for NLO

NLO calculations performed using fastNLO (arXiv:hep-ph/0609285)

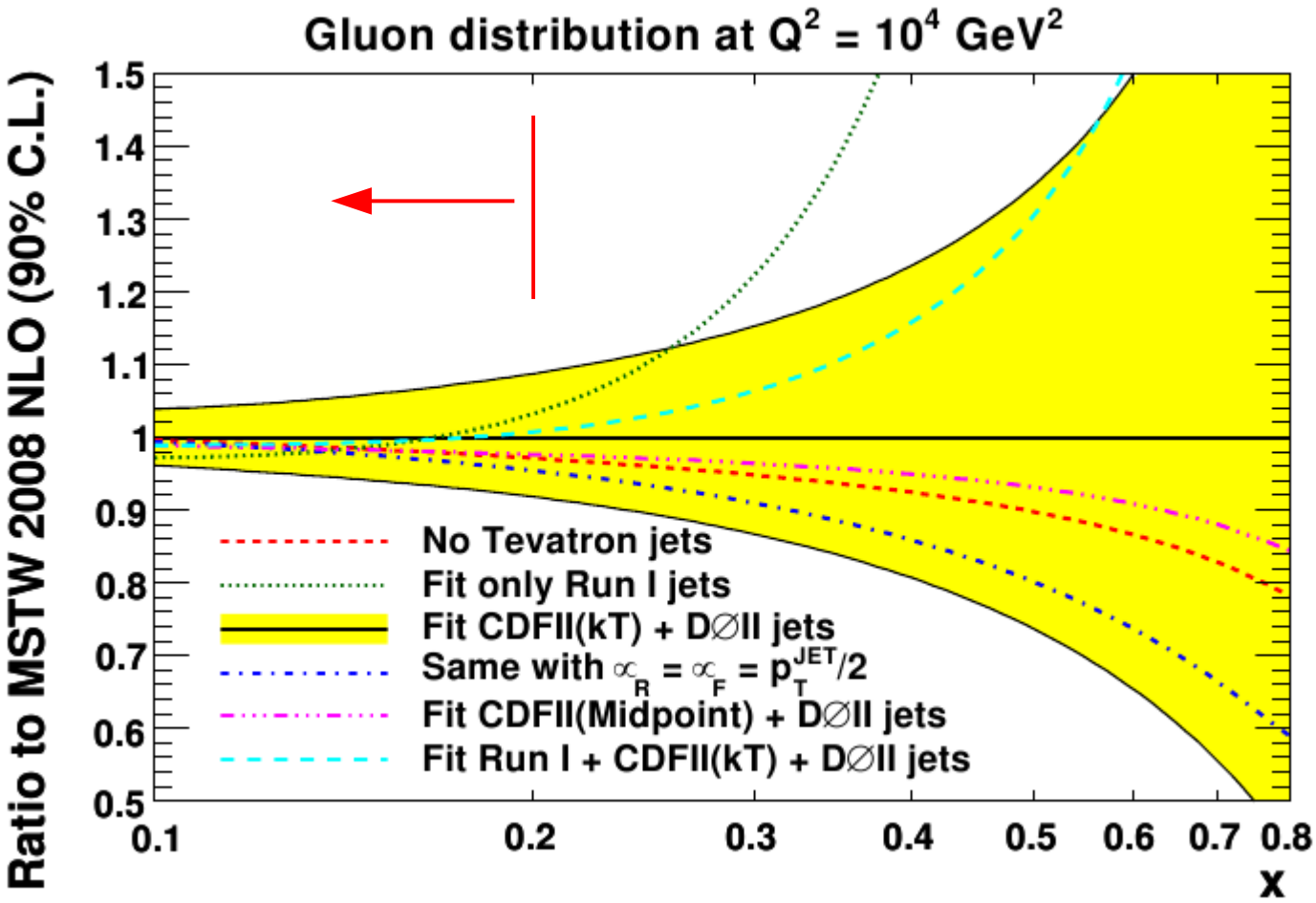
- Based on NLOJET++, provides fast recalculations wrt arbitrary PDFs

Non perturbative corrections (hadronization/underlying event)

- From PYTHIA (as with Inclusive Jets analysis)

Uncertainties: - 50% of correction, separately for each component

Minimizing correlations for data, PDFs



Precision Tevatron jet data currently dominate models for gluon densities at high-x

Minimize correlations between data and PDFs by restricting analysis to kinematic regions where impact of Tevatron data do not dominate PDF determination.

Parton-x sensitivity

At leading order, di-jet events access x-values of:

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

Mapping is less clear in inclusive cross section data
x-value not fully constrained given a measurement bin of p_T, |y|

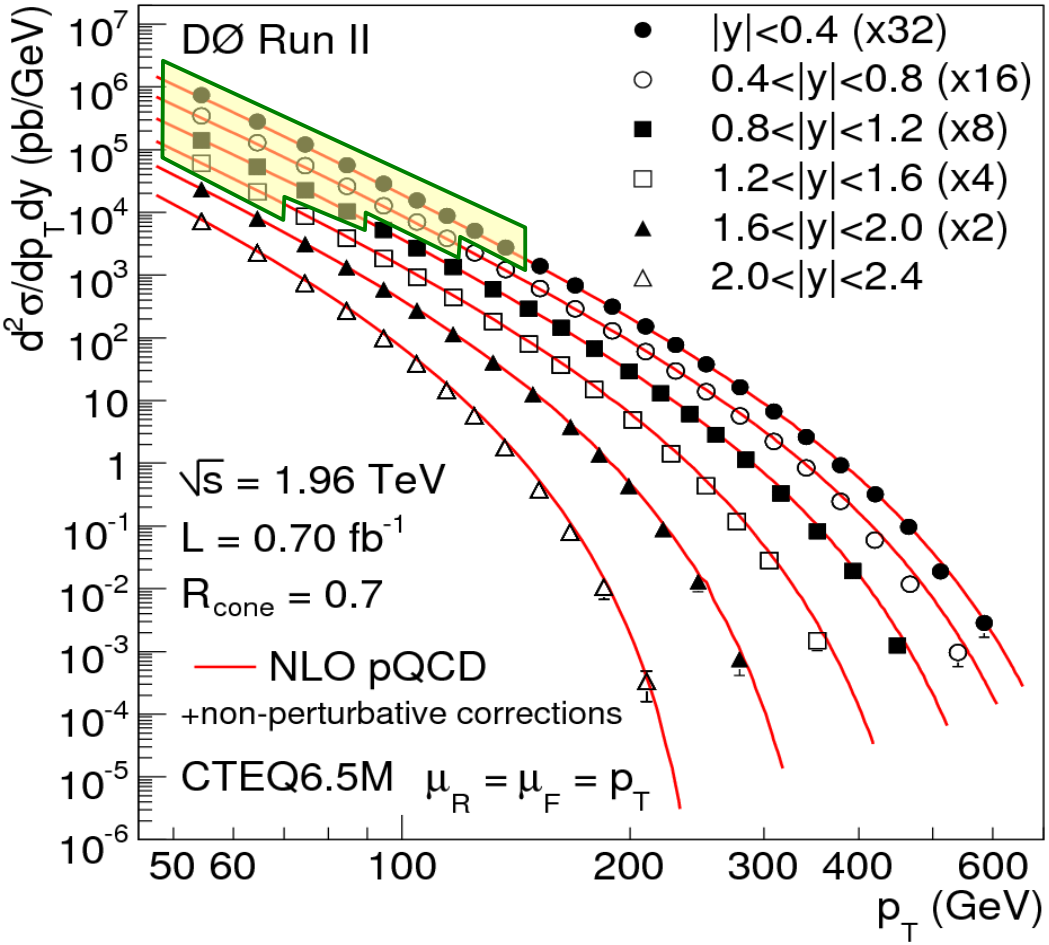
Full kinematics unknown, since we integrate over other jets

Construct 'test-variable' treating subleading jet(s) as a jet at |y|=0

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

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

Minimizing correlations for data, PDFs



Select points from inclusive cross section using approximate mapping having strong correlation with maximum parton-x in a 2-body collision

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

$$x_T = 2P_T/\sqrt{s}$$

Require $\tilde{x} < 0.15$

22 (of 110) data points $50<p_T<145$ GeV

corresponds to x_{max}~0.25

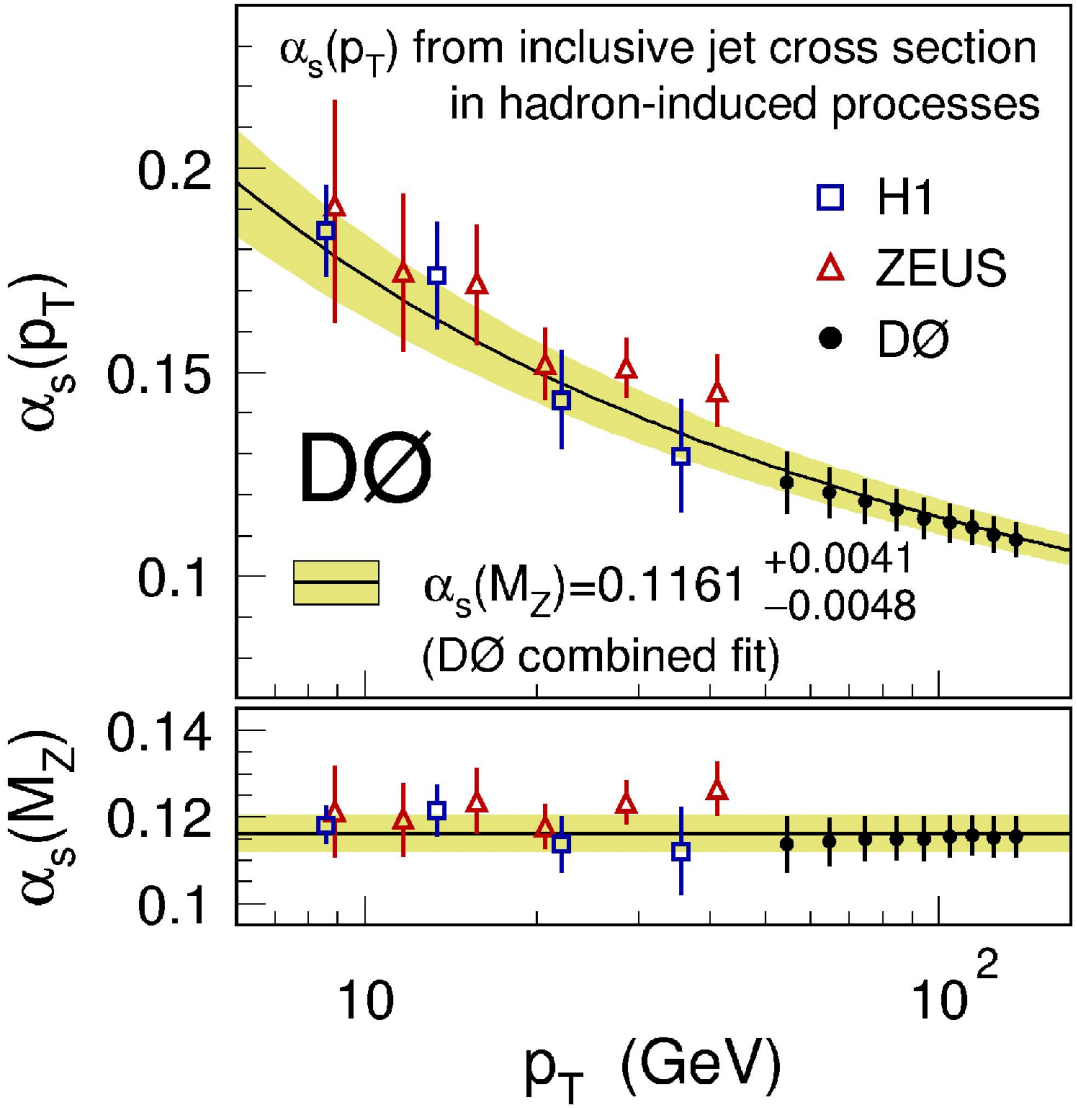
Results

- NLO Matrix Elements for five flavors, + additional 2-loop threshold corrections (reducing renormalization/ factorization scale dependence)

- MSTW2008 NNLO PDFs

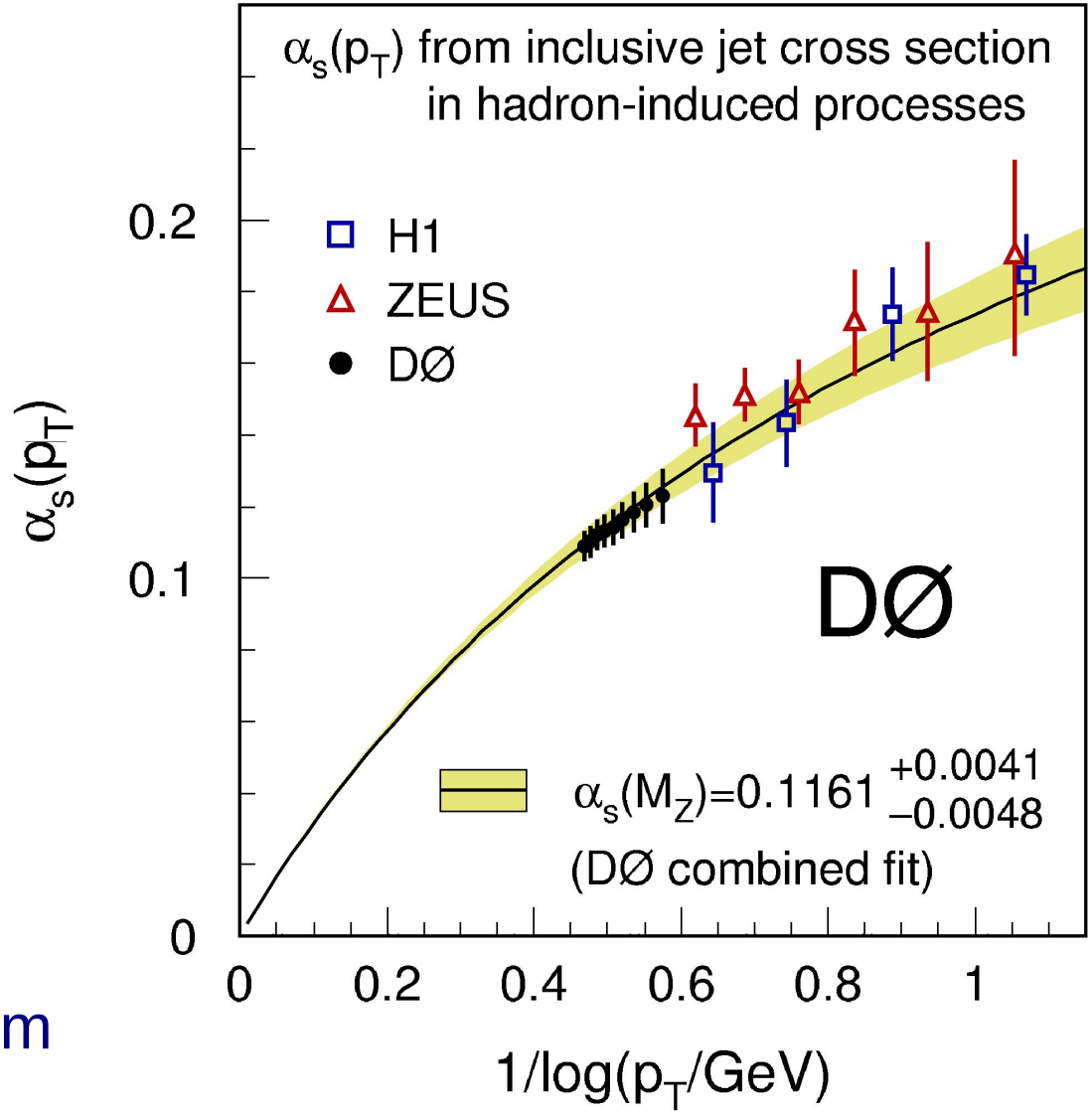
- Extends results from HERA to higher p_T

- **Highest P_T measurements of running α_s to date**



Results

$\alpha_s(M_Z)$	**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
μ(r,f) variation	+ 0.0021 - 0.0029



Consistent with asymptotic freedom

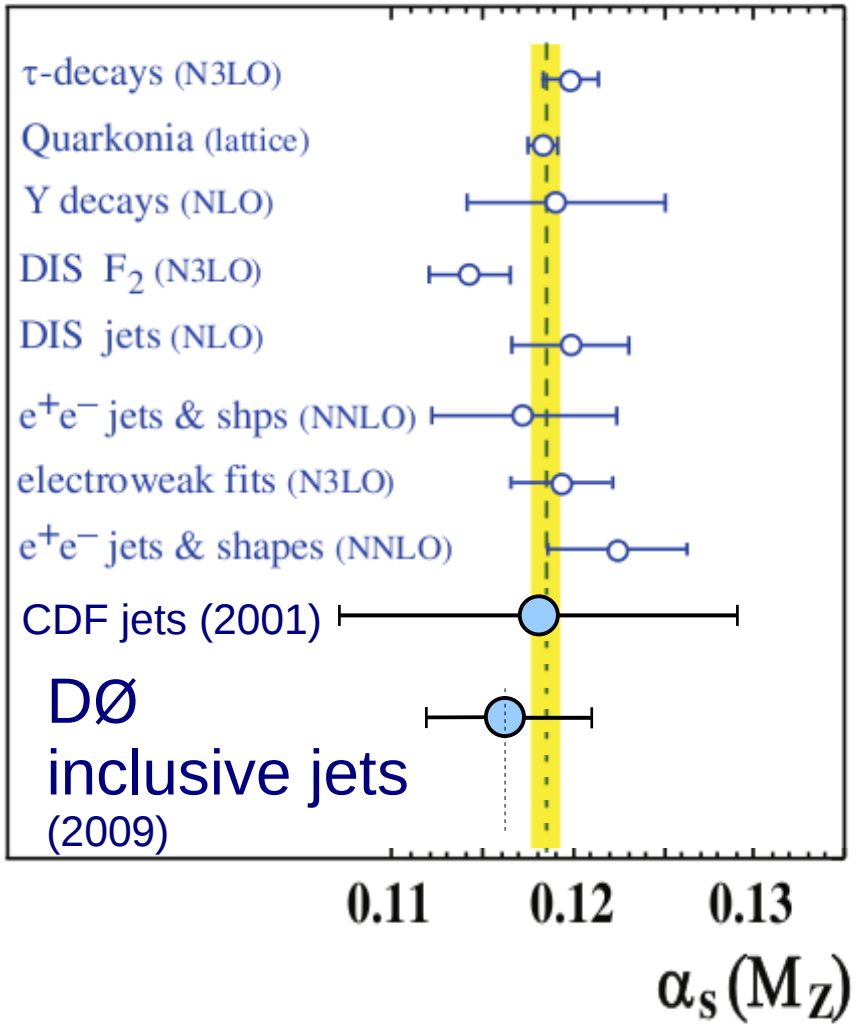
Conclusion

We have determined *alpha strong* from the DØ inclusive jet cross section

using theory at NLO plus 2-loop threshold corrections.

The measured $\alpha_s(p_T)$ supports the energy dependence predicted by the RGE.

This is the most precise determination of the strong coupling constant from a hadron collider, comparible to ep → jets.



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

Phys. Rev. D 80, 111107 (2009)

Modifed from: arXiv:0908.1135
Eur.Phys.J.C64:689-703,2009