# Measurements of differential W+jets production and $\alpha_s$ from multijet production


**Mike Strauss**

**The University of Oklahoma**

**The Oklahoma Center for High Energy Physics**

**for the**

**DØ Collaboration**


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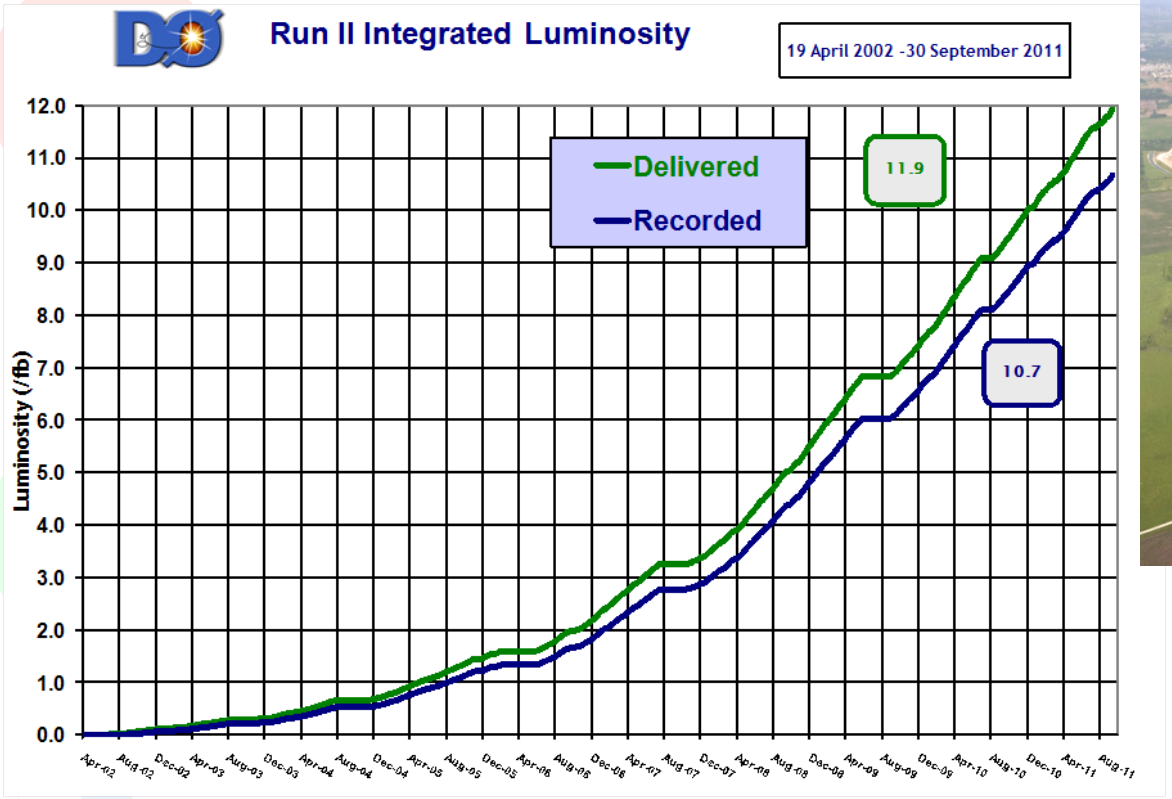
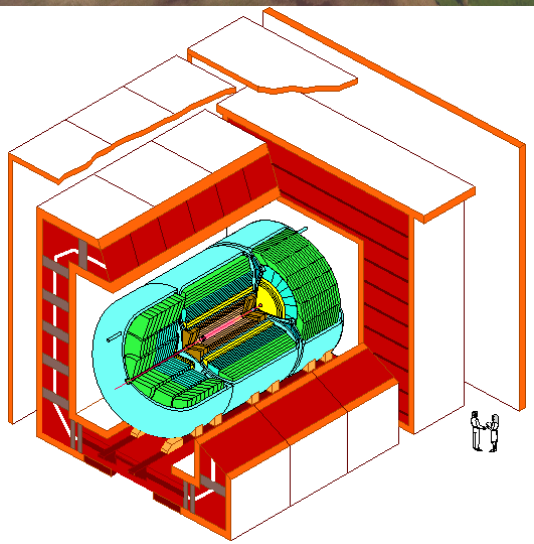
**Melbourne, Australia**

# DØ and the Tevatron



$p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV

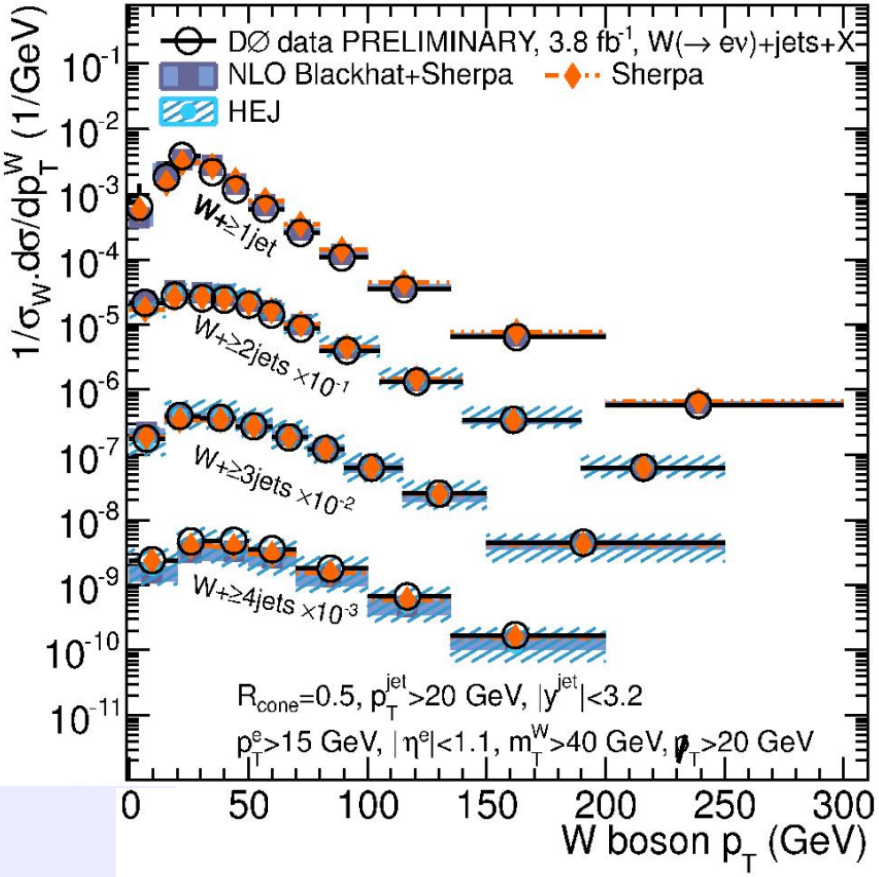
$\int L dt$ = 10.7 fb$^{-1}$

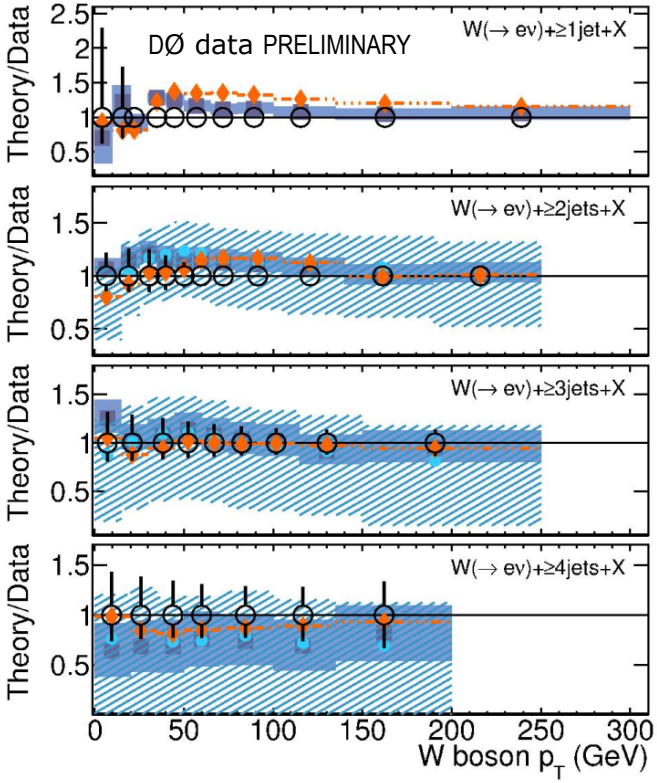
# W + jets Introduction

- Motivation
  - Tests of pQCD
  - A dominant background in SM process like $t\bar{t}$ production, Higgs
  - Background in non-SM processes
- Use $W \rightarrow e\nu$ channel. Same dataset as PLB 705, 200 (2011)
- Selection Criteria
  - Global: $|z_{vtx}| < 60$ cm
  - Electron: $p_T > 15$ GeV, $|\eta| < 1.1$, $\Delta R$(between e and jet) $> 0.5$
  - Jet: $\geq 1$ jet, $E_T > 20$ GeV, $|y| < 3.2$
  - W: $\not{E}_T > 20$ GeV, $m_T(W) > 40$ GeV
- Backgrounds Considered: Z+jets, $t\bar{t}$, single top, diboson, multijet
- Theoretical Predictions:
  - Sherpa (ME matched to parton shower)
  - HEJ (all order resummation)
  - Blackhat (+Sherpa) NLO
- Data and theory compared at particle level

# W+jets cross section, $p_T(W)$

## Cross section as a function of W boson $p_T$




≥1 Jet

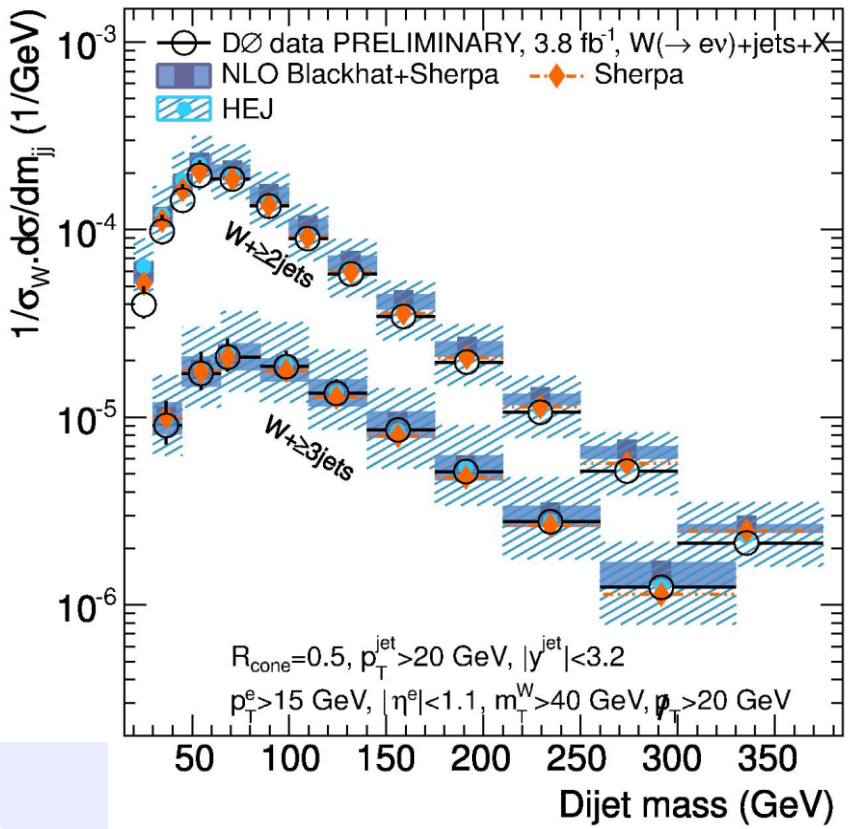
≥2 Jets

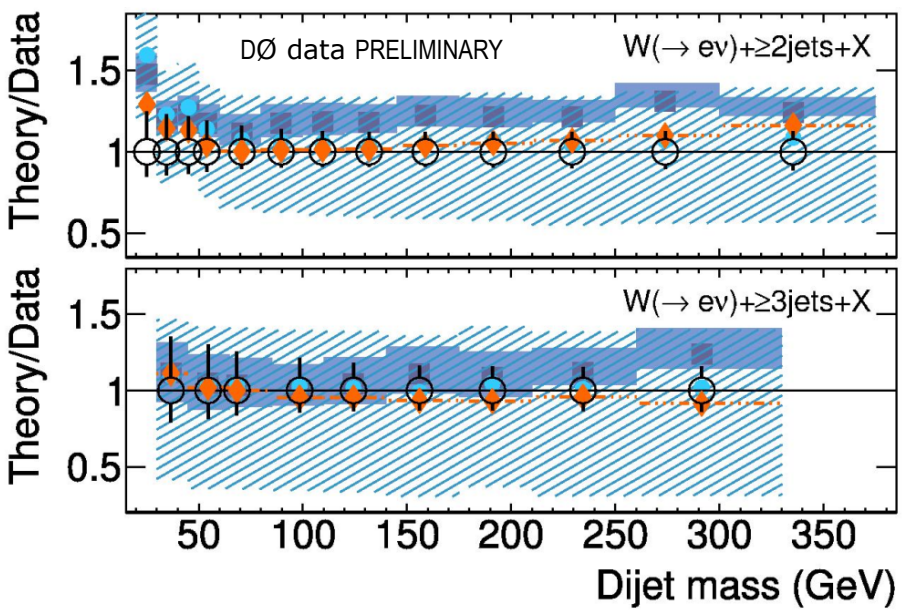
≥3 Jets

≥4 Jets

# W+jets cross section, $m_{jj}$

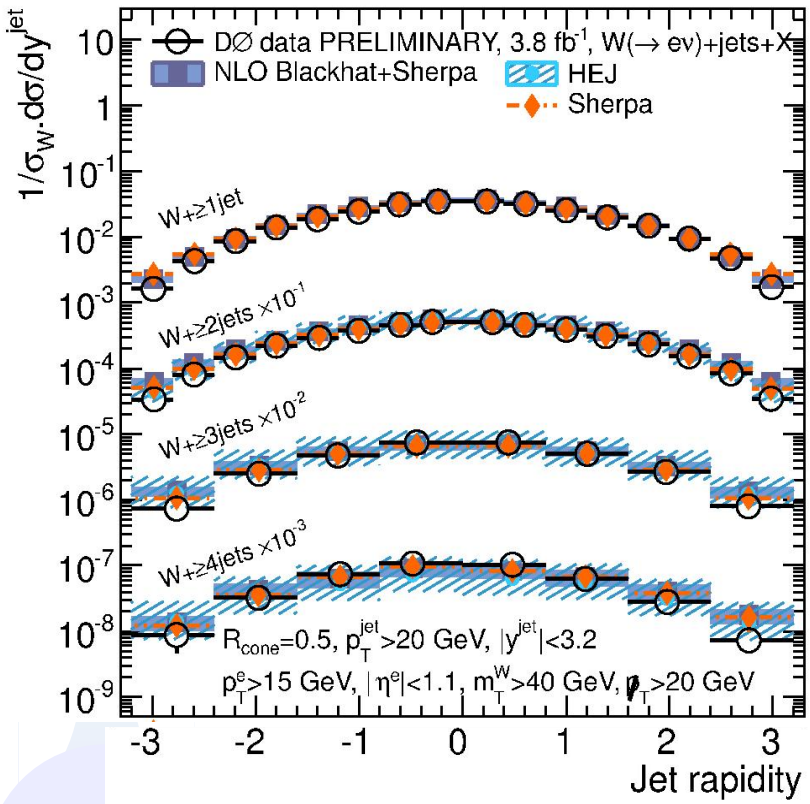
Cross section as a function of dijet mass for two highest $p_T$ jets for W+2 jet and W+3 jet

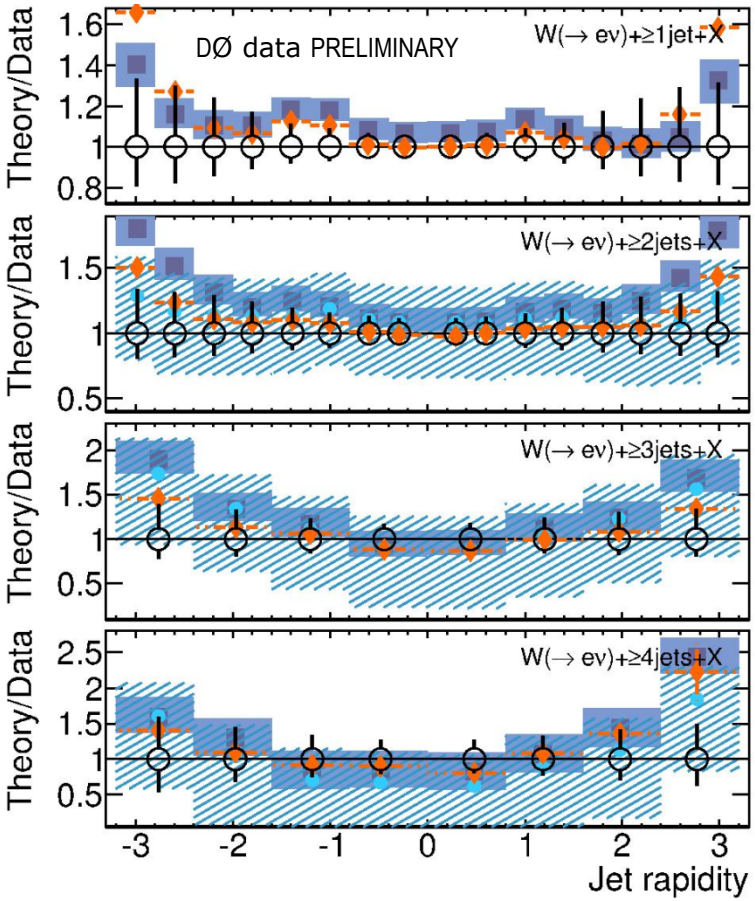


# W+jets cross section, η

Cross section as a function of $n^{th}$ jet rapidity.




≥1 Jet

≥2 Jets

≥3 Jets

≥4 Jets

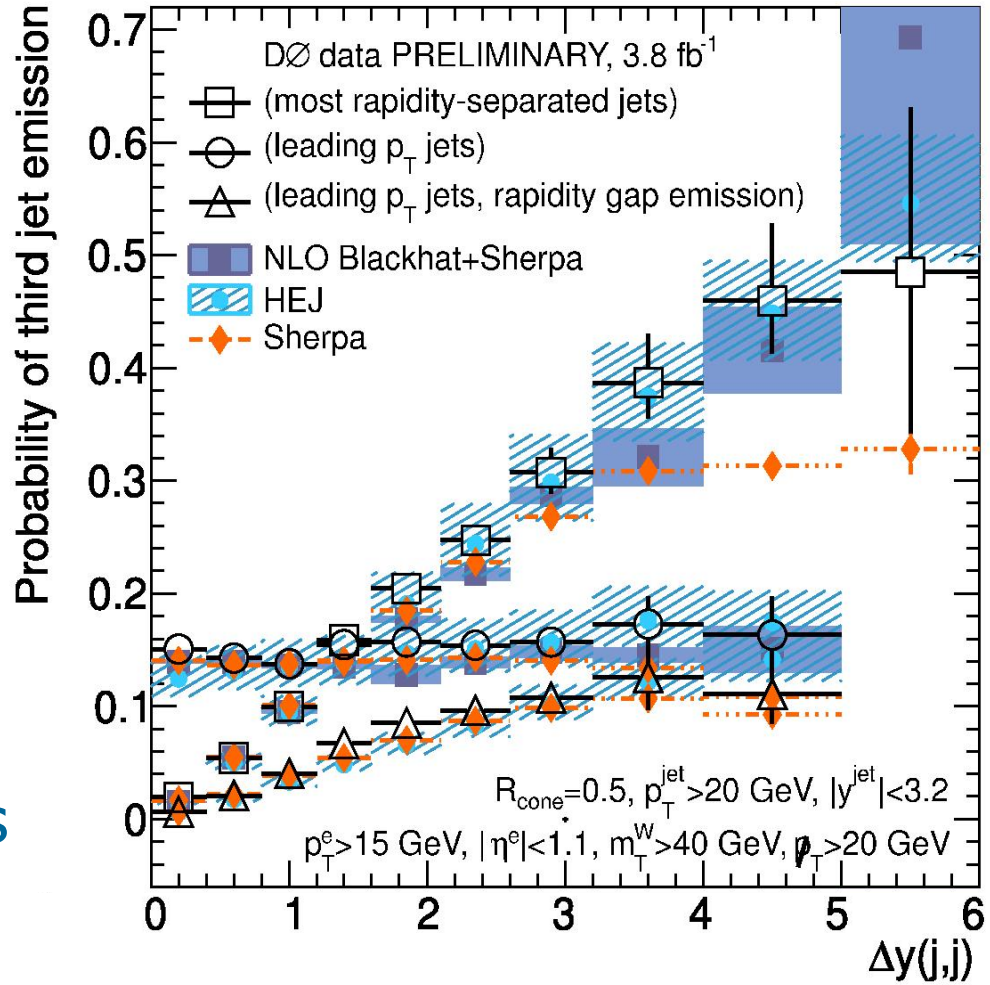
Some problems in high η regions

# W+jets, 3rd jet emission

Probability of emission of a 3rd jet in W+≥2 jet events as a function of rapidity separation

Three selection choices

- □ Two jets with the largest gap in rapidity
- ○ Two leading $p_T$ jets
- △ Two leading $p_T$ jets with 3rd jet in rapidity gap between them

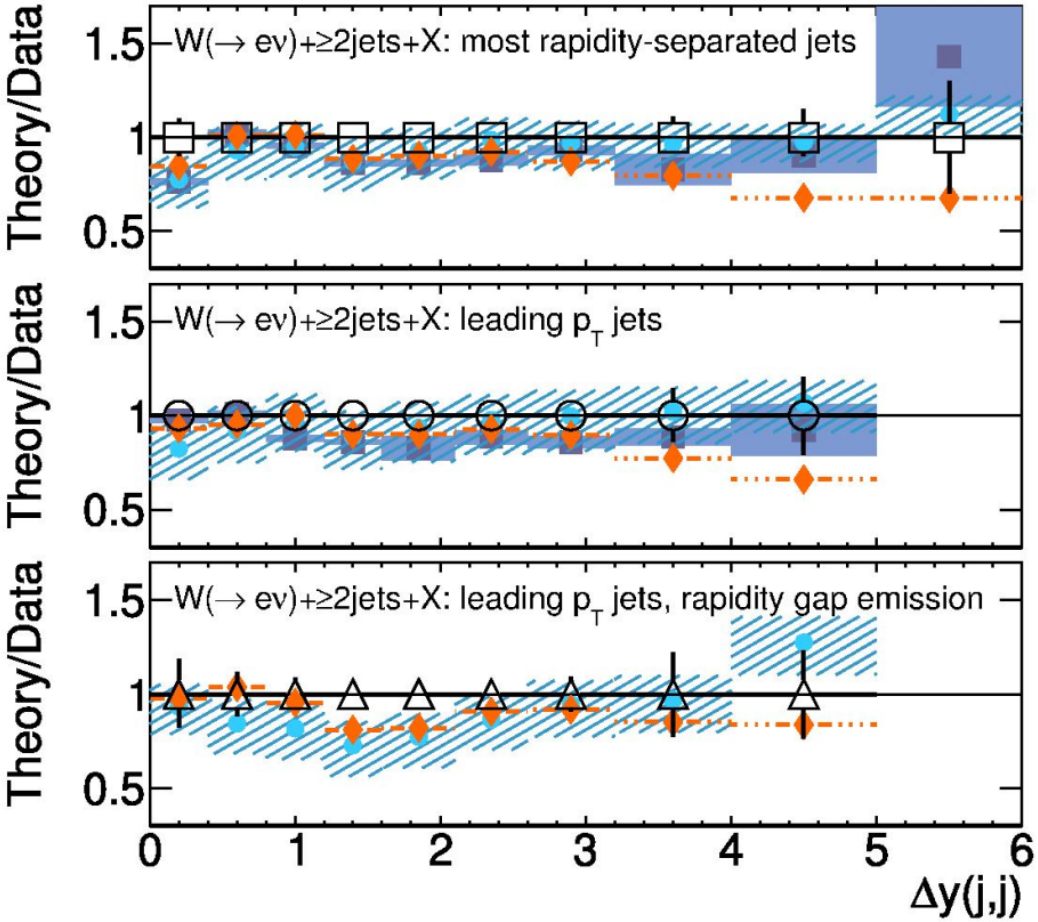



Emission probability grows with gap size as expected.

# W+jets, 3rd jet emission

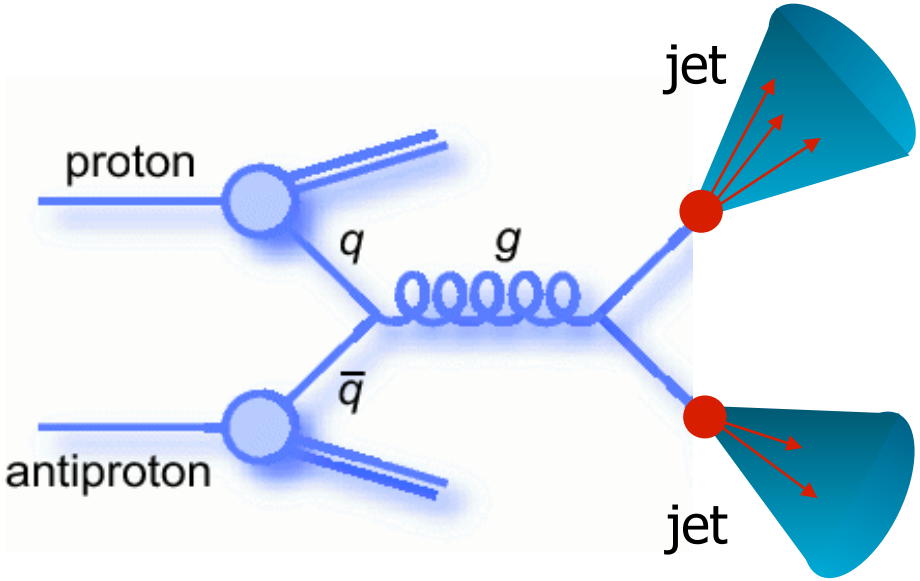
Probability of emission of a 3rd jet in W+2 ≥ jet events as a function of rapidity separation

- Blackhat+Sherpa gives marginally the best fit.
- Some discrepancies in leading $p_T$ gap emission.



# Measuring $\alpha_s$ from multijet events

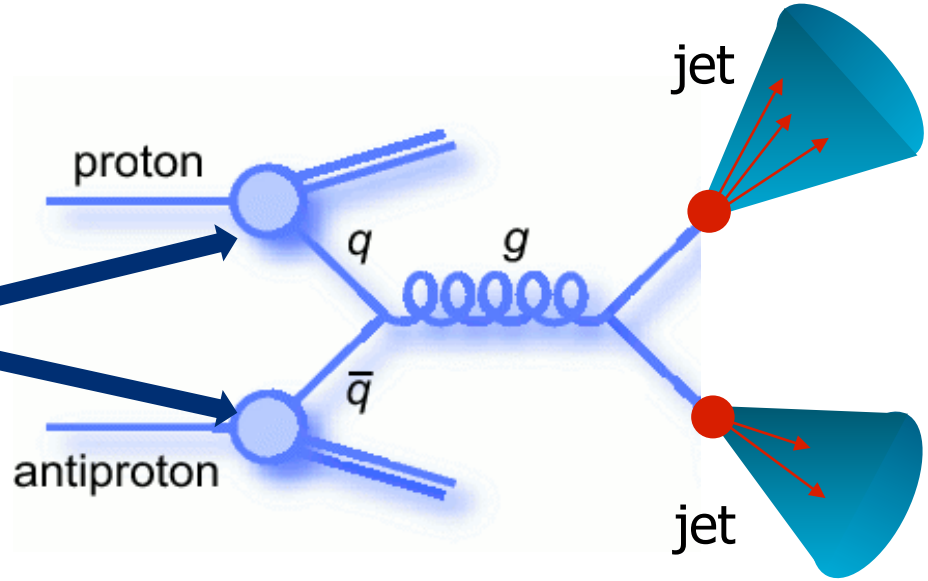
## Jet production in hadron collisions



# Measuring $\alpha_s$ from multijet events

## Jet production in hadron collisions

Parton distribution functions (PDFs) of the hadrons



# Measuring $\alpha_s$ from multijet events

## Jet production in hadron collisions

pQCD matrix elements

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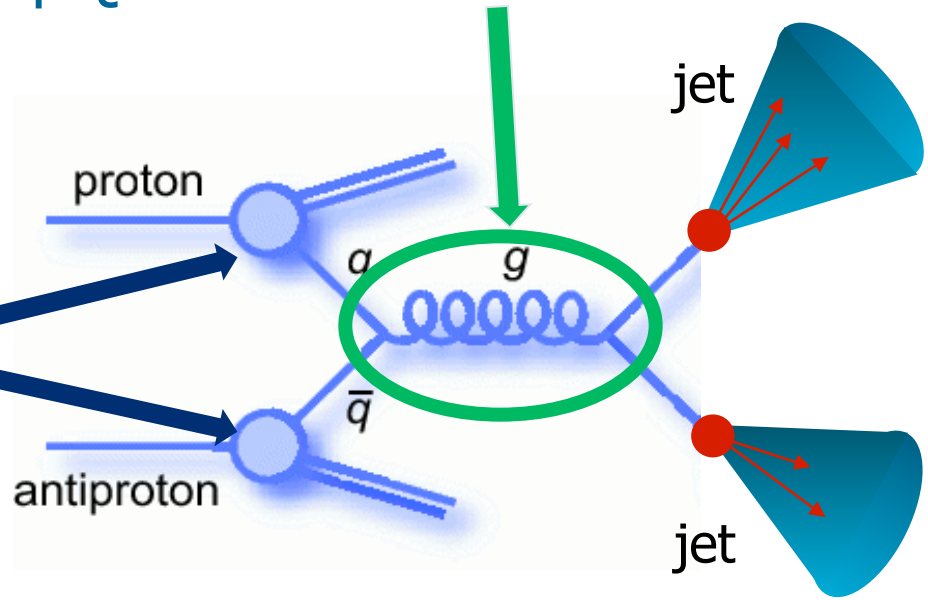

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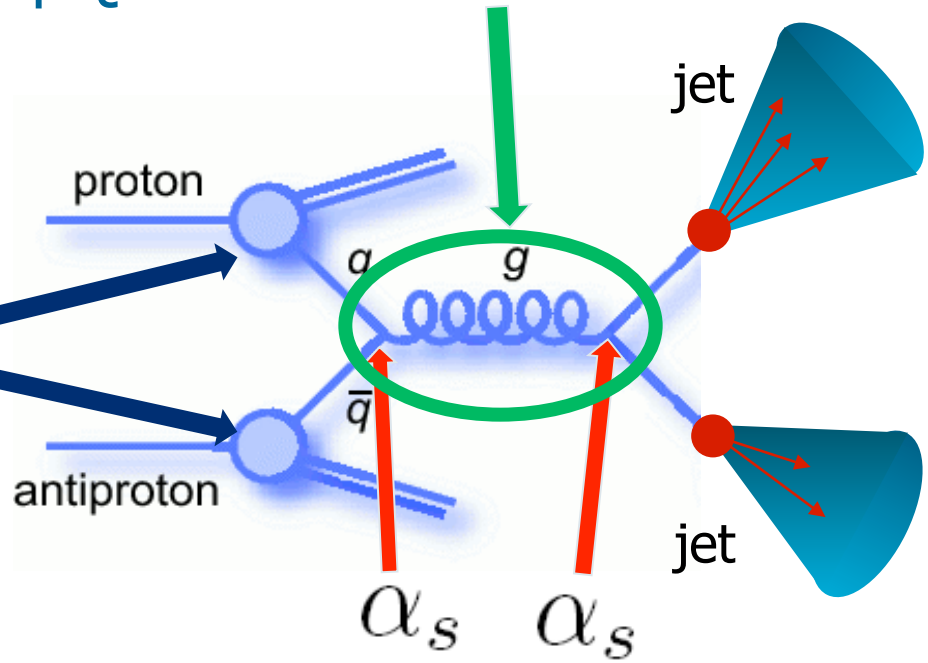
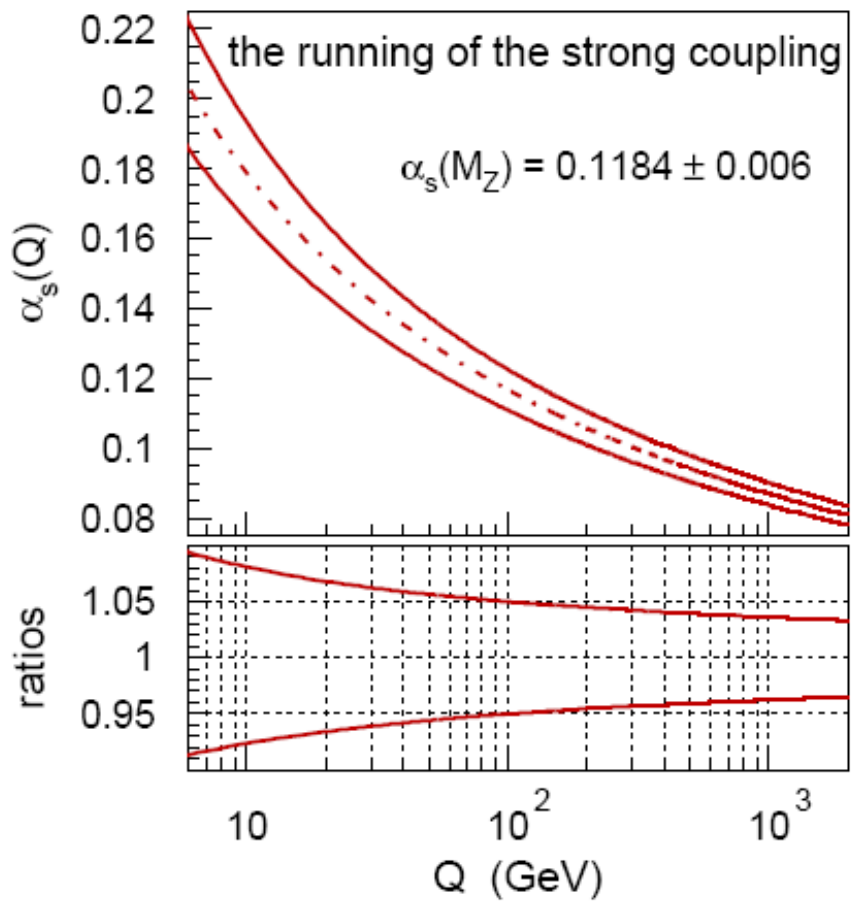



Strong coupling constant

# $\alpha_s$ and the RGE

- $\alpha_s(\mu_R)$: depends on $\mu_R$ the renormalization scale
- Observables must be independent of $\mu_R$
- Renormalization Group Equation (RGE) relates $\alpha_s(Q_0)$ at one scale $Q_0$ to $\alpha_s(Q)$ at any other scale Q
- RGE predicts all $\alpha_s(Q)$ curves which are possible



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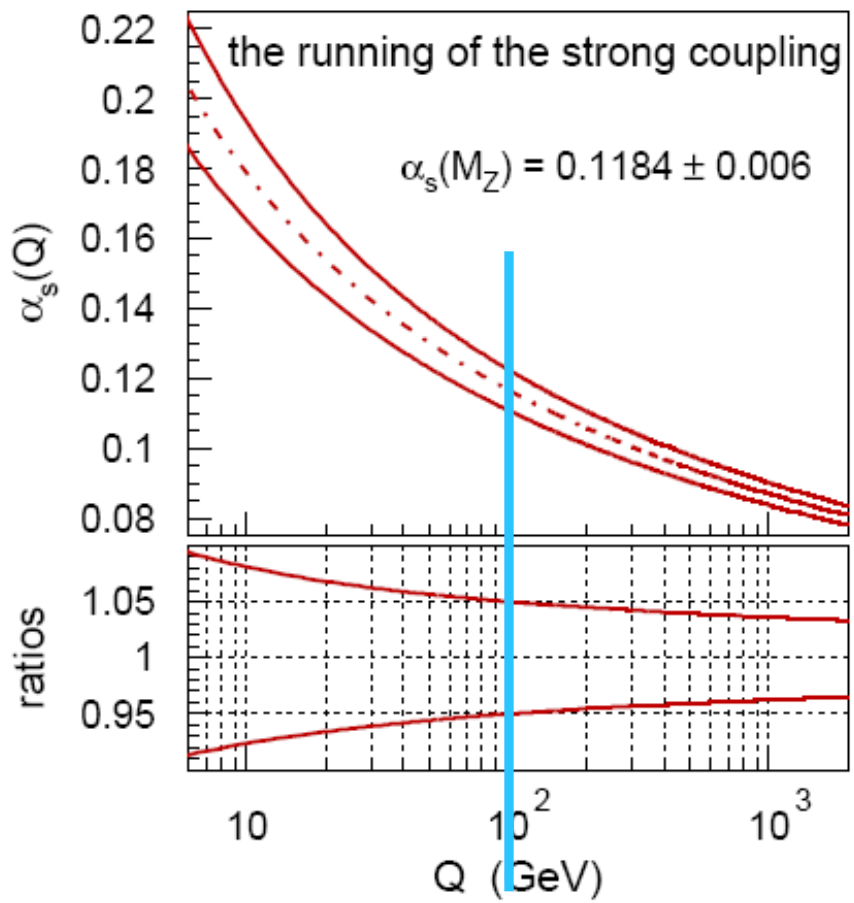
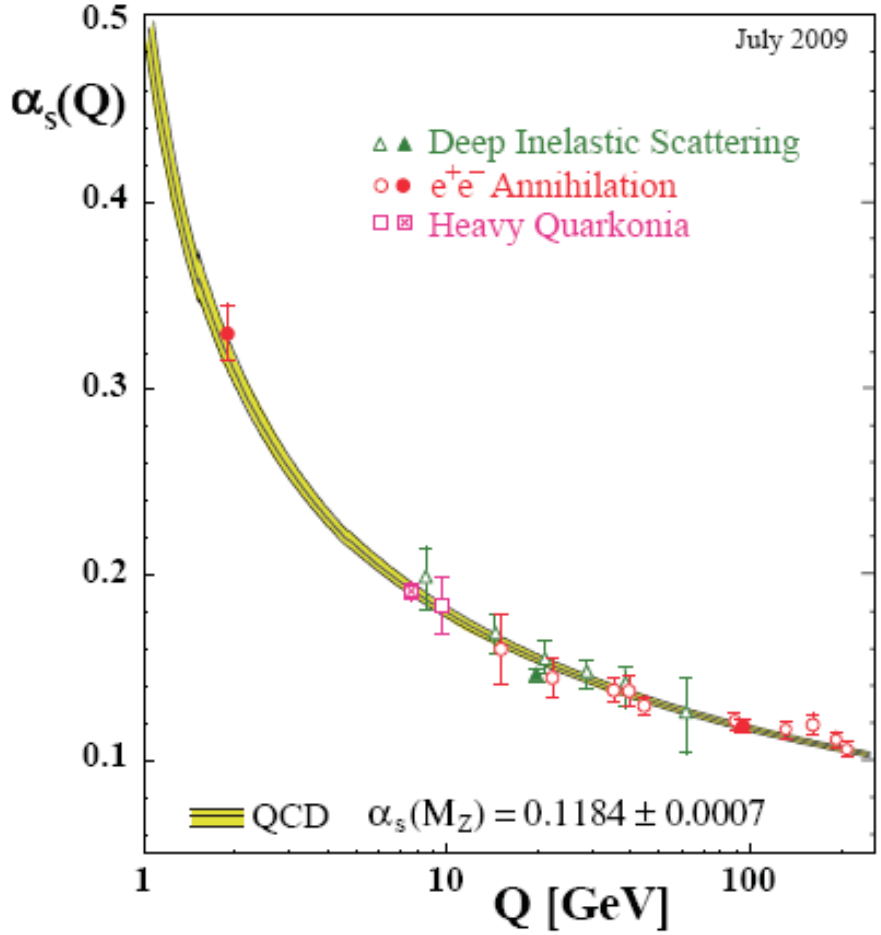
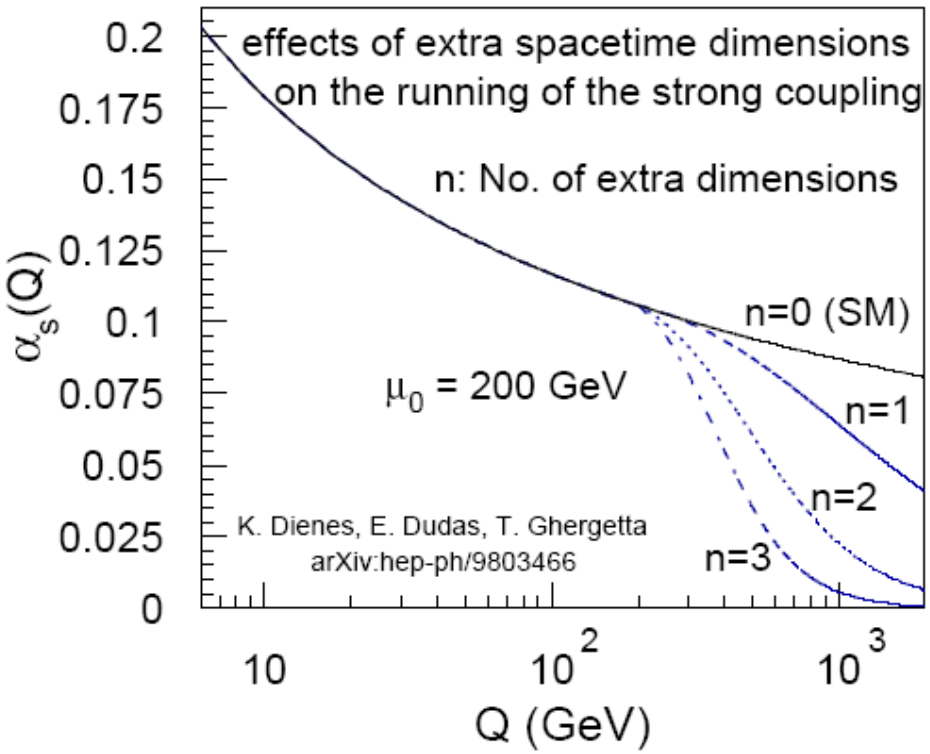



Agreement: label curves by $\alpha_s(\mu_R=M_Z)$

# Strong Coupling $\alpha_s$

S. Bethke, arXiv:0908.1135

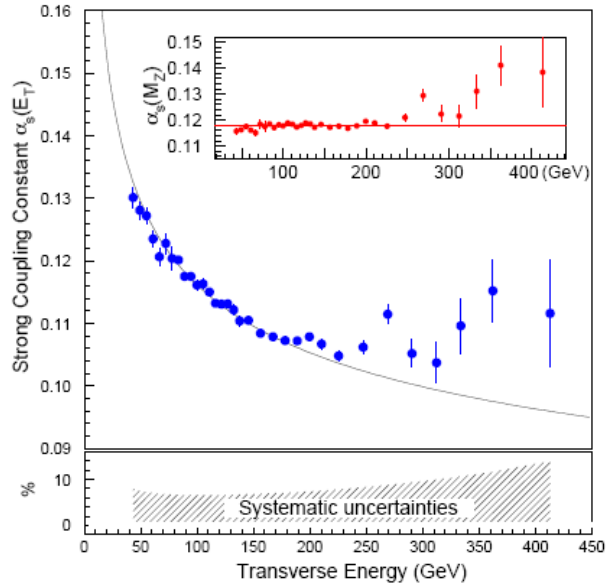



Not yet at scales > 208 GeV

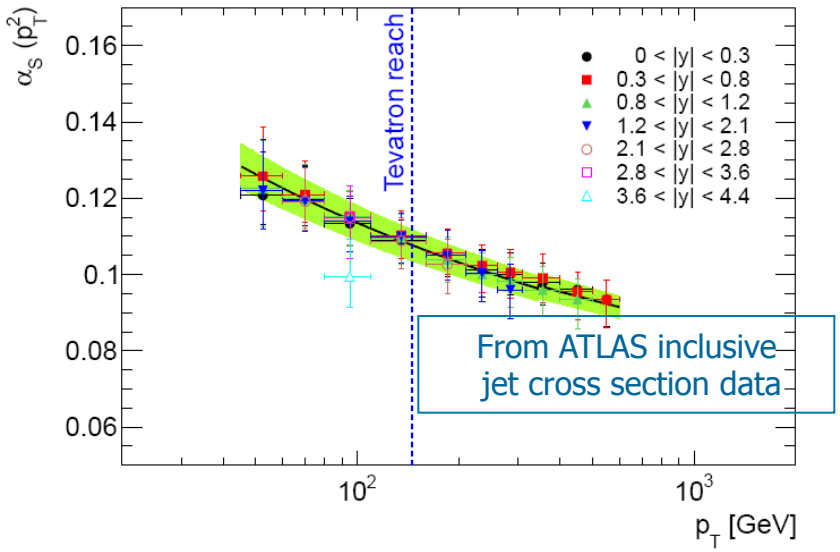
# $\alpha_s$ from inclusive jet cross section

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




"Test running over 40 < $E_T$ < 440 GeV"

B. Malaescu, P. Starovoitov, arXiv:1203.5416




"Test running up to $p_T$ → 600 GeV"

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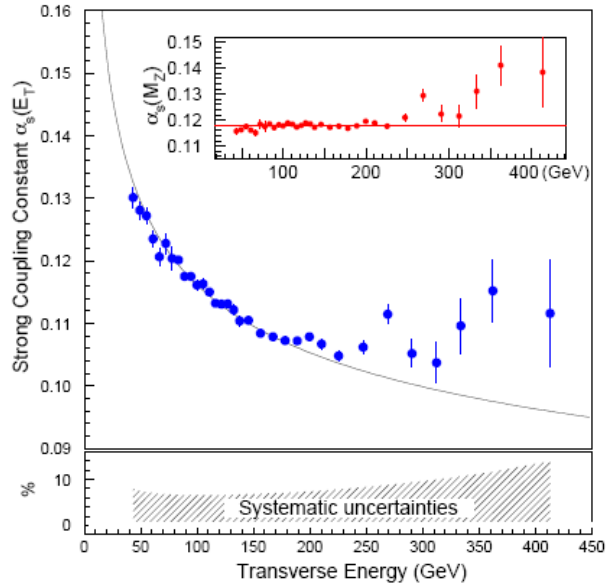
CDF Collaboration, T. Affolder et al., Phys. Rev. Lett. 88, 042001 (2002)

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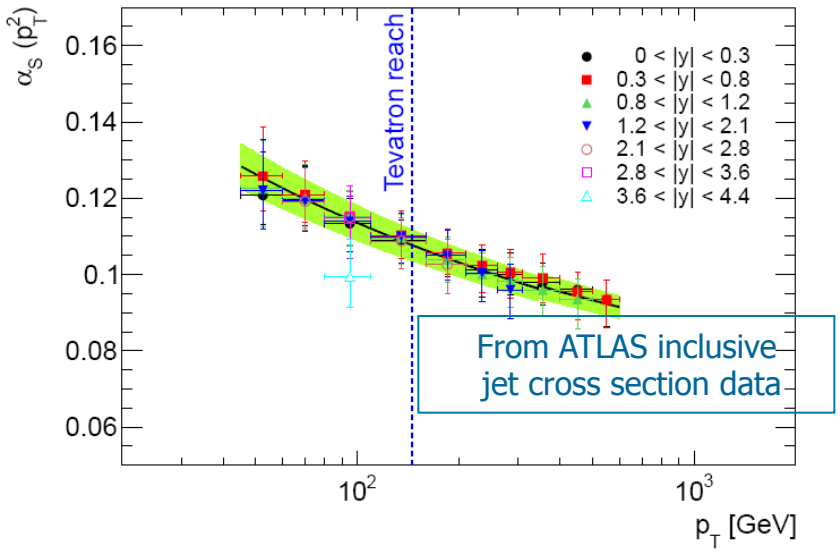



"Test running over 40 < $E_T$ < 440 GeV"

"Test running up to $p_T$ = 600 GeV"

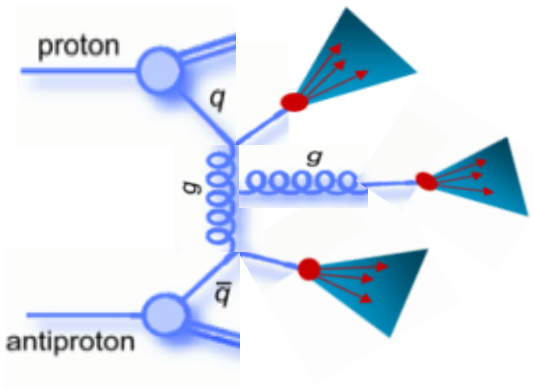
But analyses use PDFs for which DGLAP evolution is already done under assumption of running $\alpha_s(Q)$ according to the RGE

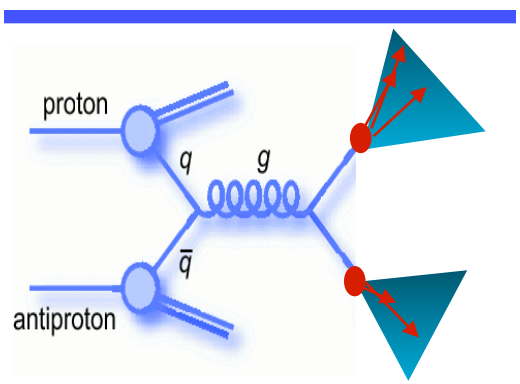
- RGE was already assumed
- Not an independent test

DGLAP: Dokshitzer–Gribov–Lipatov–Altarelli–Parisi

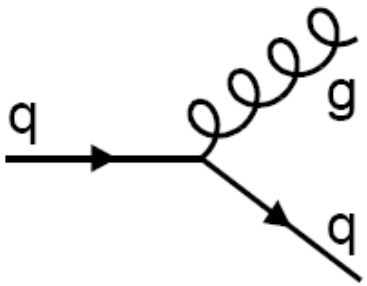
# Multijet Production and $\alpha_s$

$R_{\Delta R}$
average number of neighboring jets for jets from an inclusive jets sample




$\alpha_s$




Depends on 3 variables:

- inclusive jet $p_T$
- distance $\Delta R$ to neighbor jet in $(\Delta\phi, \Delta y)$
- neighbor jet $p_{T\text{-nbr}}$ requirement

# $R_{\Delta R}$ Observable

1. Start with central inclusive jet sample ($|y|<1$)
2. Loop over all inclusive jets
   For each inclusive jet: count No. of neighboring jets
   - in distance $\Delta R$ in ($\Delta\phi$, $\Delta y$)
   - with $p_{Tnbr} > p_T^{min}{}_{nbr}$
3. Ratio: sum of all neighboring jets /total number of inclusive jets
   - average number of neighboring jets:

$$R_{\Delta R}(p_T, \Delta R, p_T^{min}{}_{nbr})$$

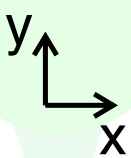
- For $\Delta R < \pi$ only contributions from (at least) 3-jet events
- Inclusive measurement using all jets
- RGE dependence and systematic uncertainties mostly cancel out in the ratio

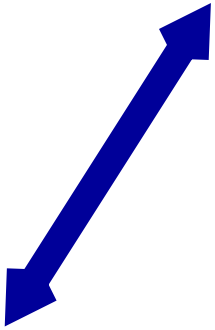
# $R_{\Delta R}$ : examples

$R_{\Delta R}$ = average number of neighboring jets per jet

here: for $\Delta R < \pi/2$

in this example all jets have same ($p_T$, y)

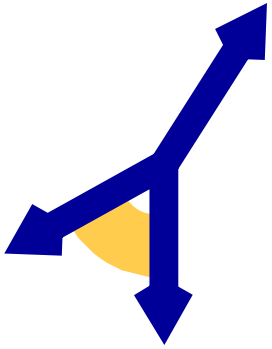


2 jets

no neighbors within $\Delta R$:

0 neighbors



3 jets

two jets have one neighbor each:

2 neighbors

4 jets

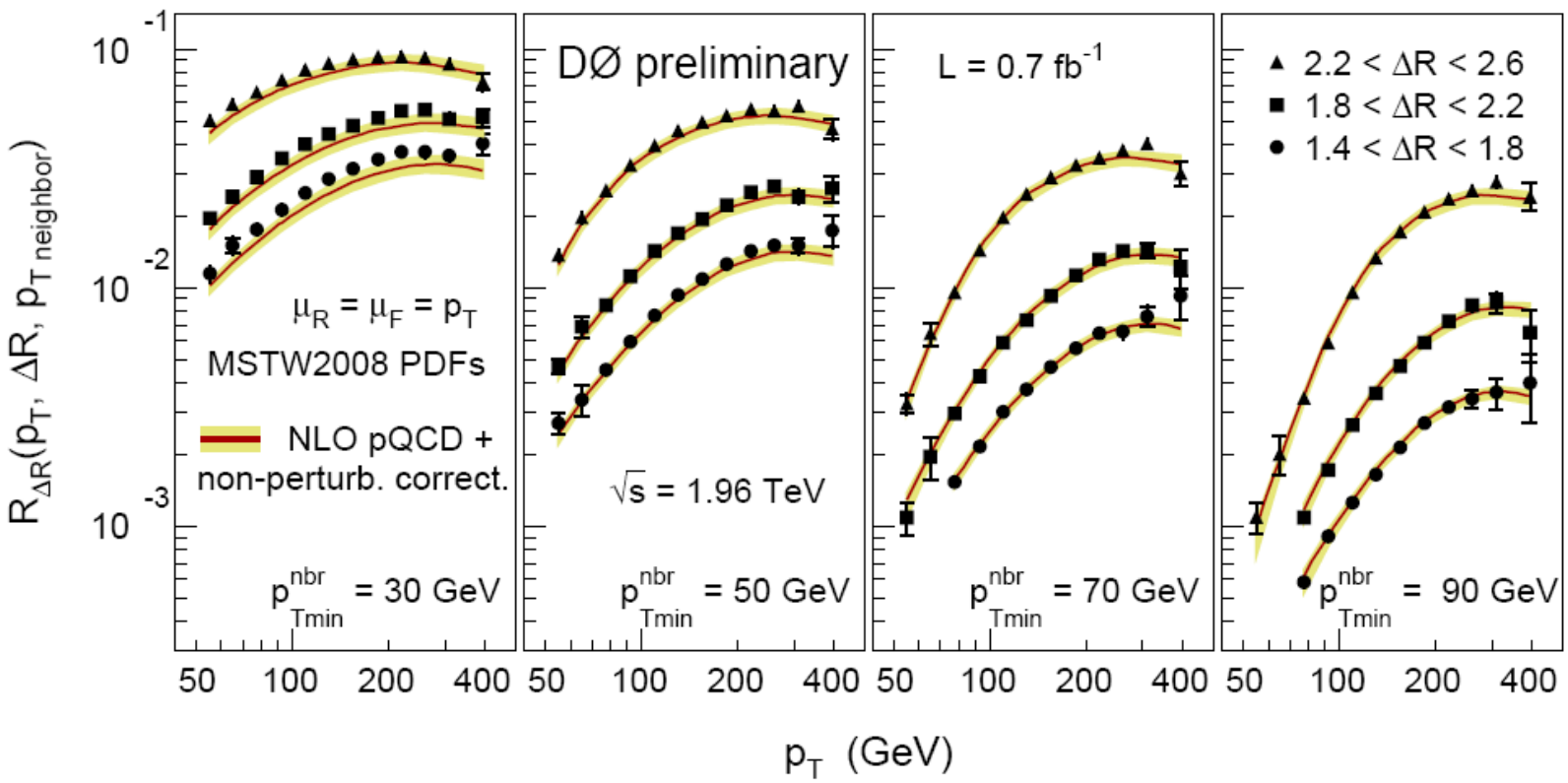
each of the four jets has one neighbor:

4 neighbors

| | | | |
|---|---|---|---|
| if all events were like this | $R_{\Delta R} = 0$ | $R_{\Delta R} = 2/3$ | $R_{\Delta R} = 1$ |

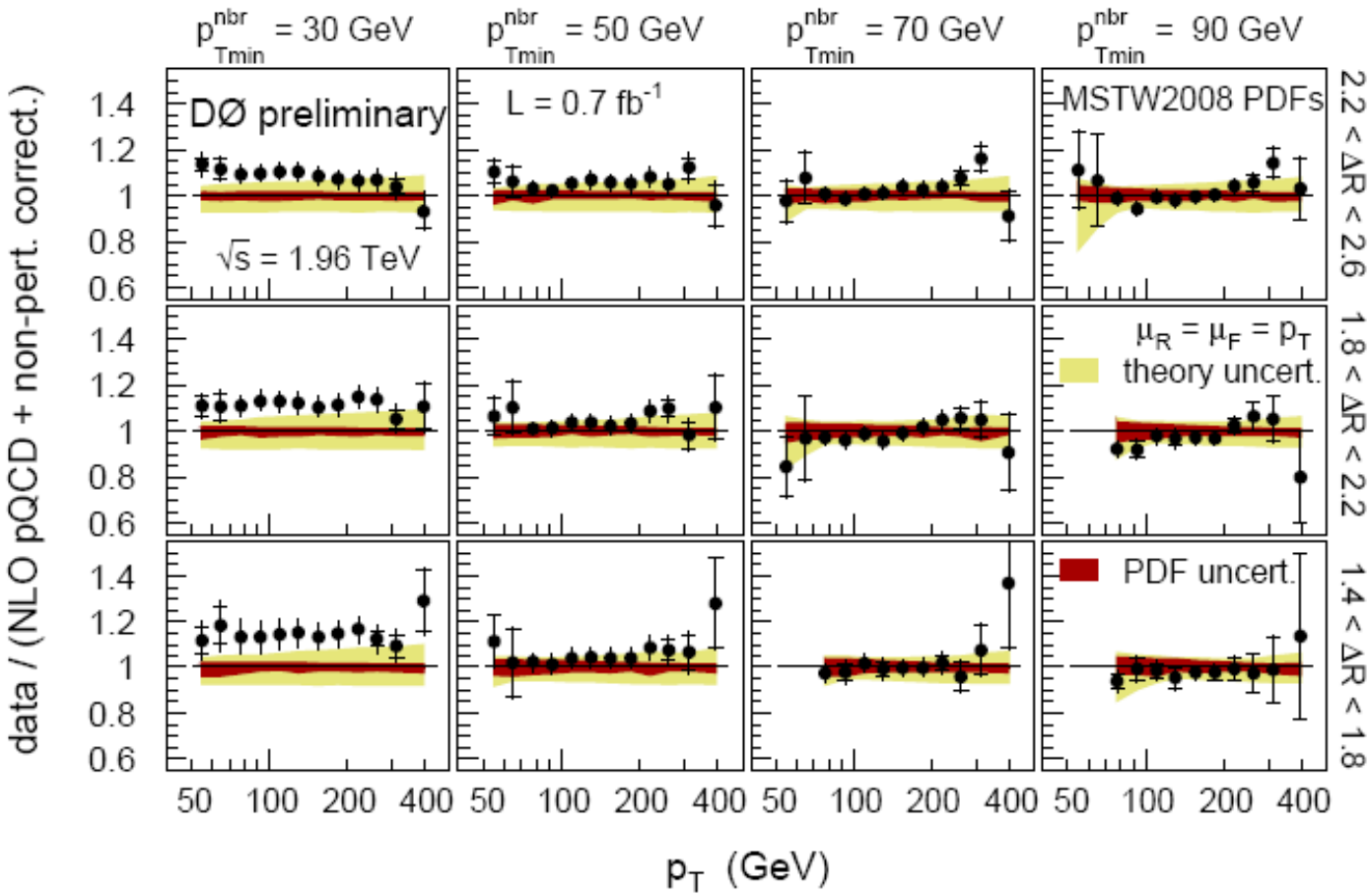
# $R_{\Delta R}$ results

- Average number of neighbor jets within ΔR of an inclusive jet
- $|y|<1$, $50<p_T<450$ GeV
- 4 different $p_{T\text{-nbr-min}}$ requirements in 3 ΔR regions




Dependence of $R_{\Delta R}$ on ($p_T$ , $p_{T\text{-nbr}}$ , ΔR) described by pQCD

# $R_{\Delta R}$ data/theory



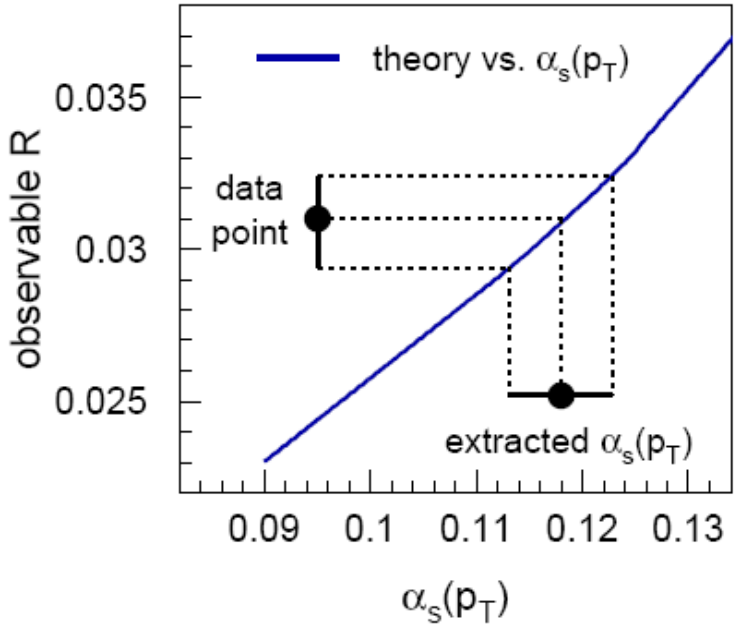

- Good agreement for $p_{T\text{-nbr-min}}$ = 50 GeV and higher
- Not so good for requirement $p_{T\text{-nbr-min}}$ = 30 GeV (low $p_T$ physics?)

# $\alpha_s$ from $R_{\Delta R}$

Single data point:
Determine $\alpha_s$ from projection

Groups of data points:
Determine $\alpha_s$ by minimizing $\chi^2$ function

Both require a parameterization of the theory result vs. $\alpha_s$.




**Perturbative:**

- NLOJET++/fastNLO for 2-jet and 3-jet NLO calculation
- PDFs: MSTW2008NLO
- PDF uncertainty: MSTW 68% C.L. PDFs / CT10, NNPDFv2.1
- Central scale $\mu_R = \mu_F = \mu_0 = p_T$
- Scale uncertainty varying: $\mu_R$, $\mu_F$ in $(0.5, 2)\mu_0$ with $0.5<(\mu_R/\mu_F)<2$

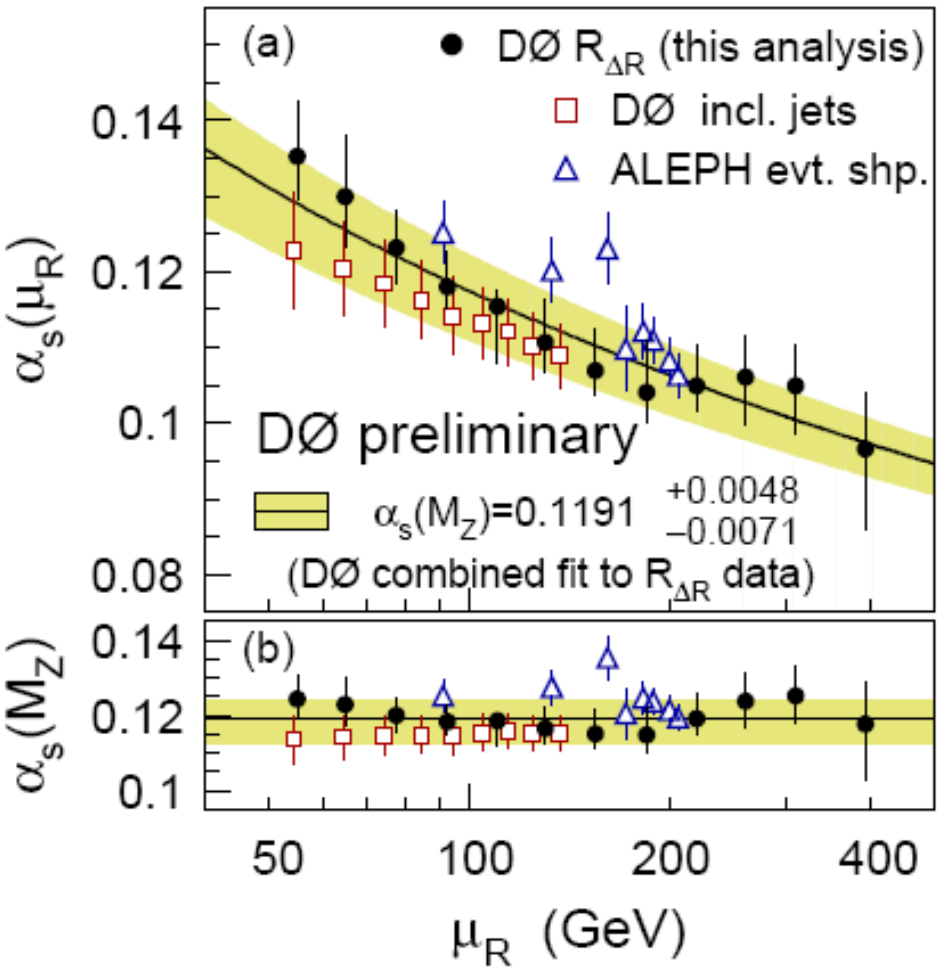
**Non-Perturbative Corrections:** PYTHIA with different tunes

# $\alpha_s(p_T)$ results

- Use $p_{Tnbr}$ > 50, 70, 90 GeV (138 data points total)
- At each $p_T$, combine all data points with different $p_{Tnbr}$ and $\Delta R$ requirements
- Determine results for $\alpha_s(p_T)$ at 12 $p_T$ values

→ $\alpha(p_T)$ results up to 400 GeV
→ $\alpha_s(p_T)$ decreases with $p_T$ as predicted by the RGE

Results agree with results from
→ ALEPH event shape data
→ Previous DØ results from inclusive jets



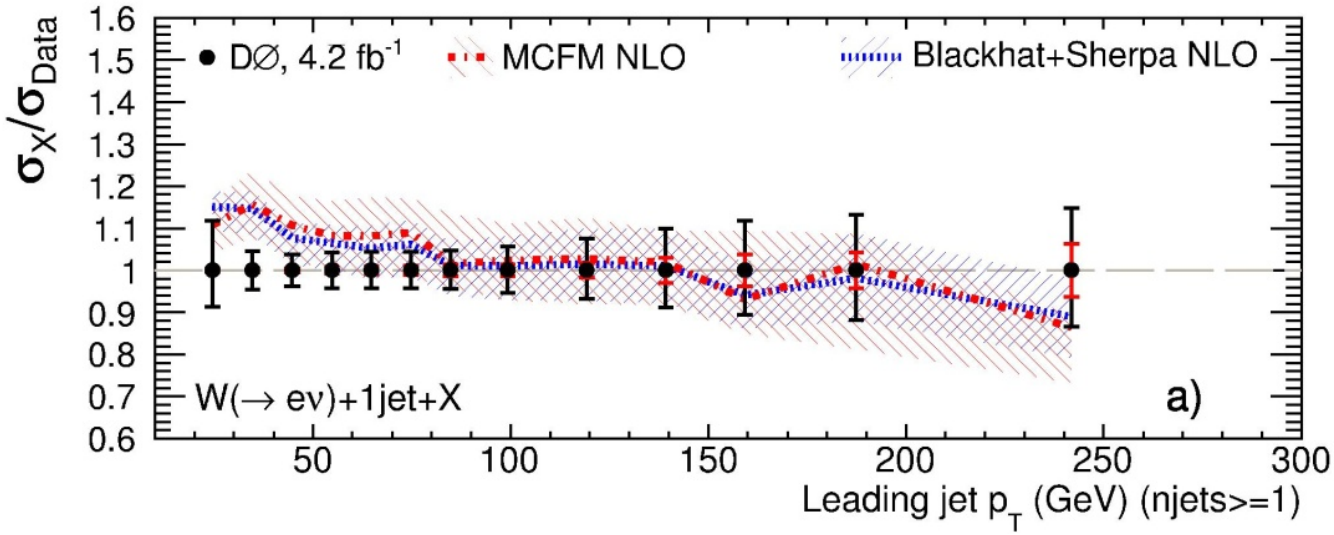

$$\alpha_s(M_Z) = 0.1191^{+0.0048}_{-0.0071}$$

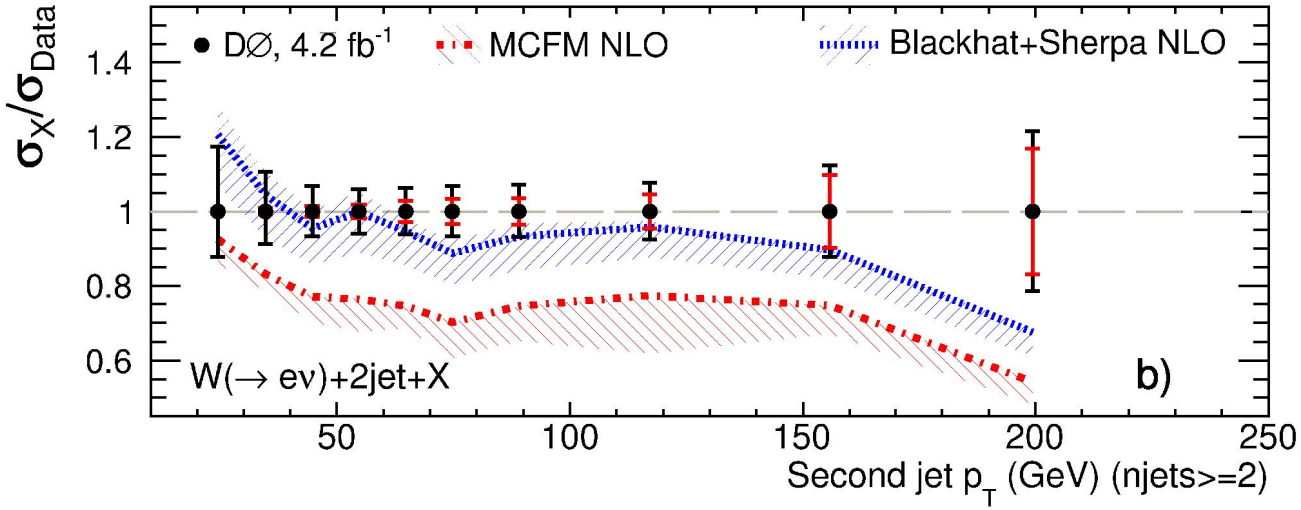
# Summary

- DØ continues to produce important QCD results
- W+jet distributions measured and compared with theory. Agreement is reasonable
- A new inclusive variable defined ($R_{\Delta R}$) for measuring $\alpha_s$ from multi-jet events
- $\alpha_s(M_Z) = 0.1191^{+0.0048}_{-0.0071}$
- Demonstrates running of $\alpha_s$ to 400 GeV

# Backup

# Published W+jets



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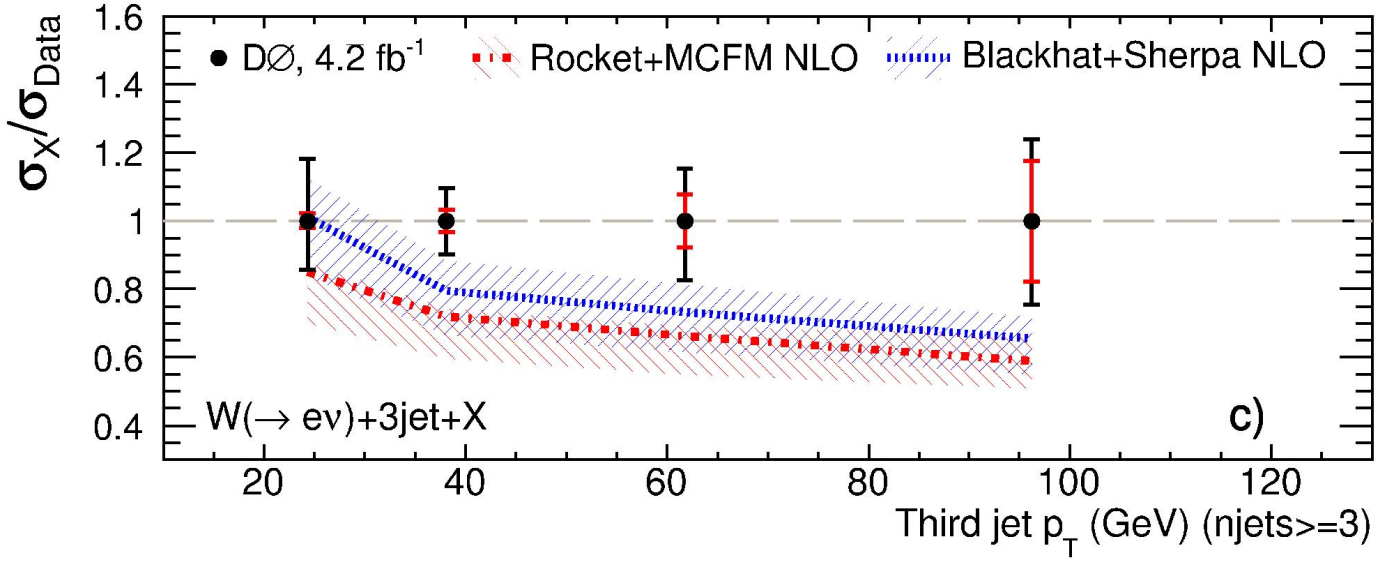
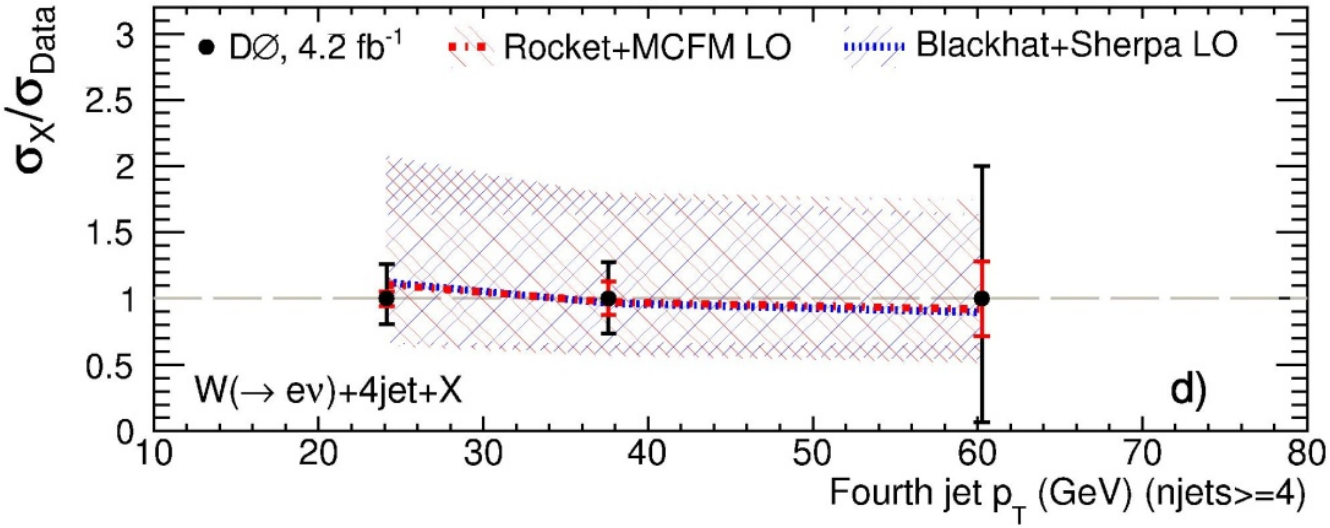
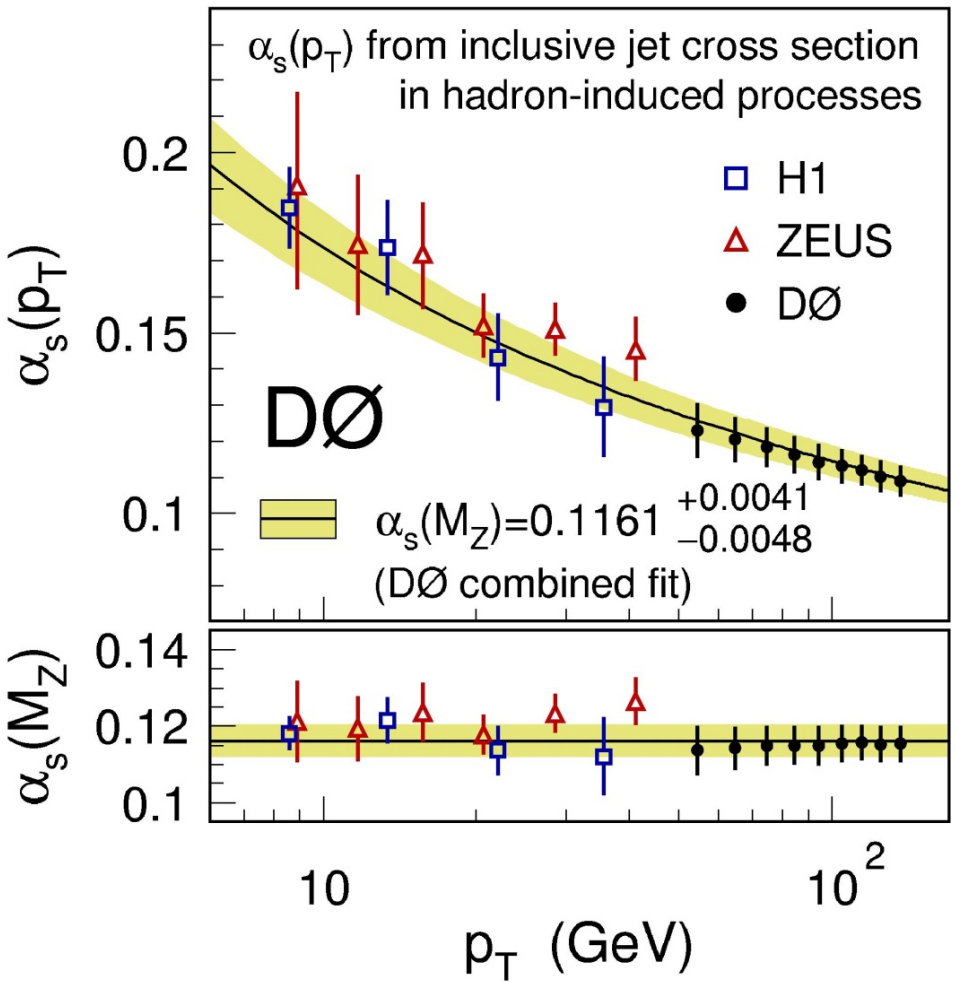


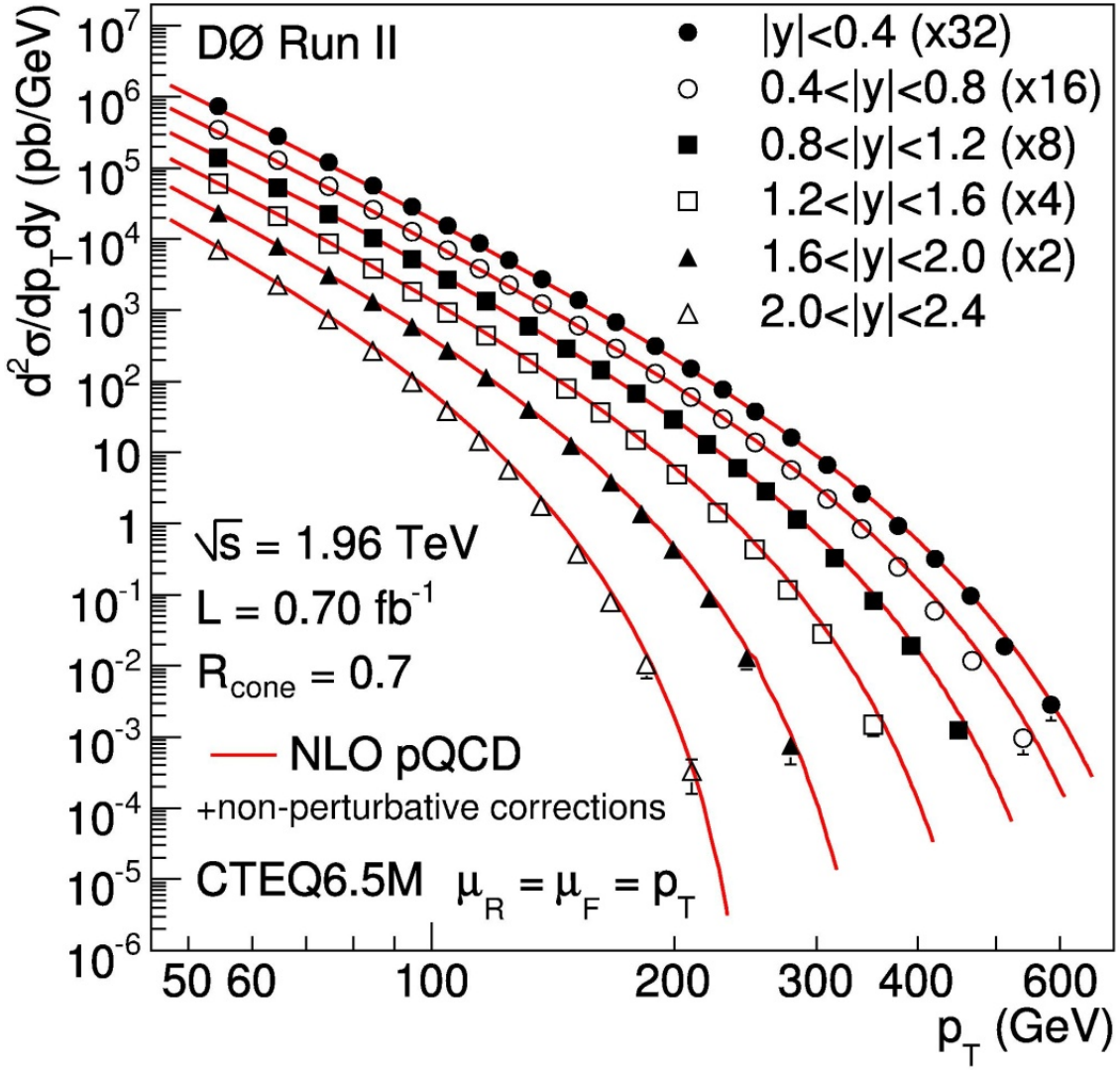



# $\alpha_s$ from inclusive jets




Phys. Rev. D **80**, 111107 (2009),

# Inclusive Jet Cross Section




Phys. Lett. B **669**, 278 (2008),

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