QCD results from DØ

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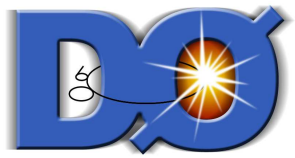
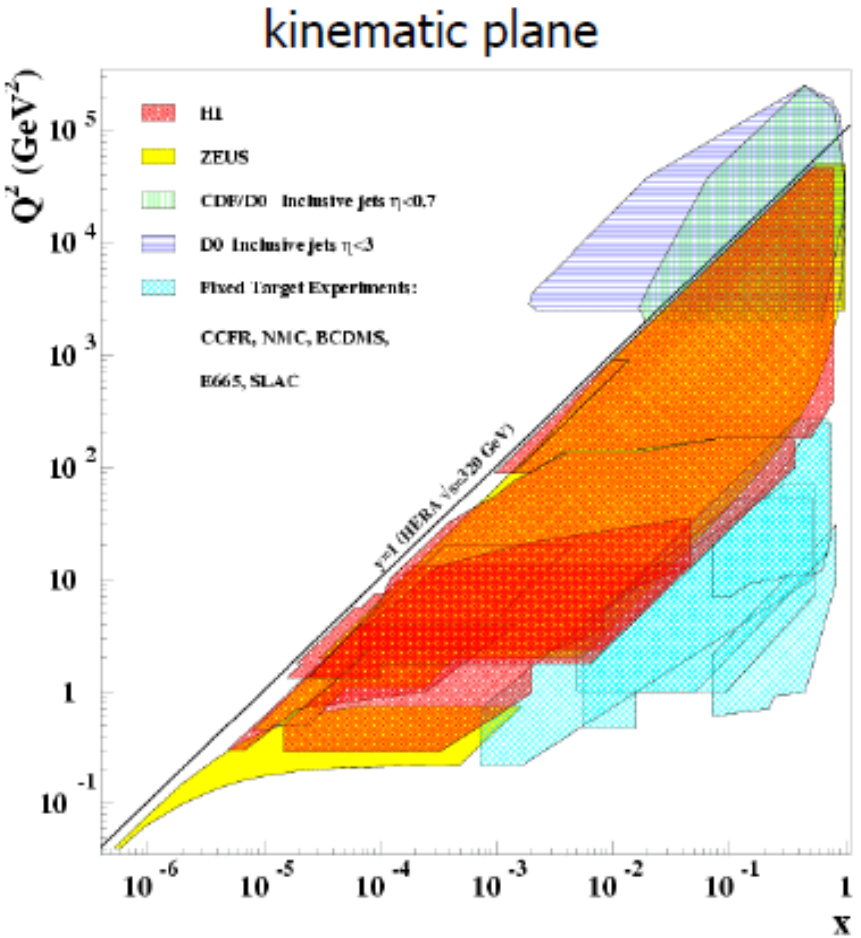


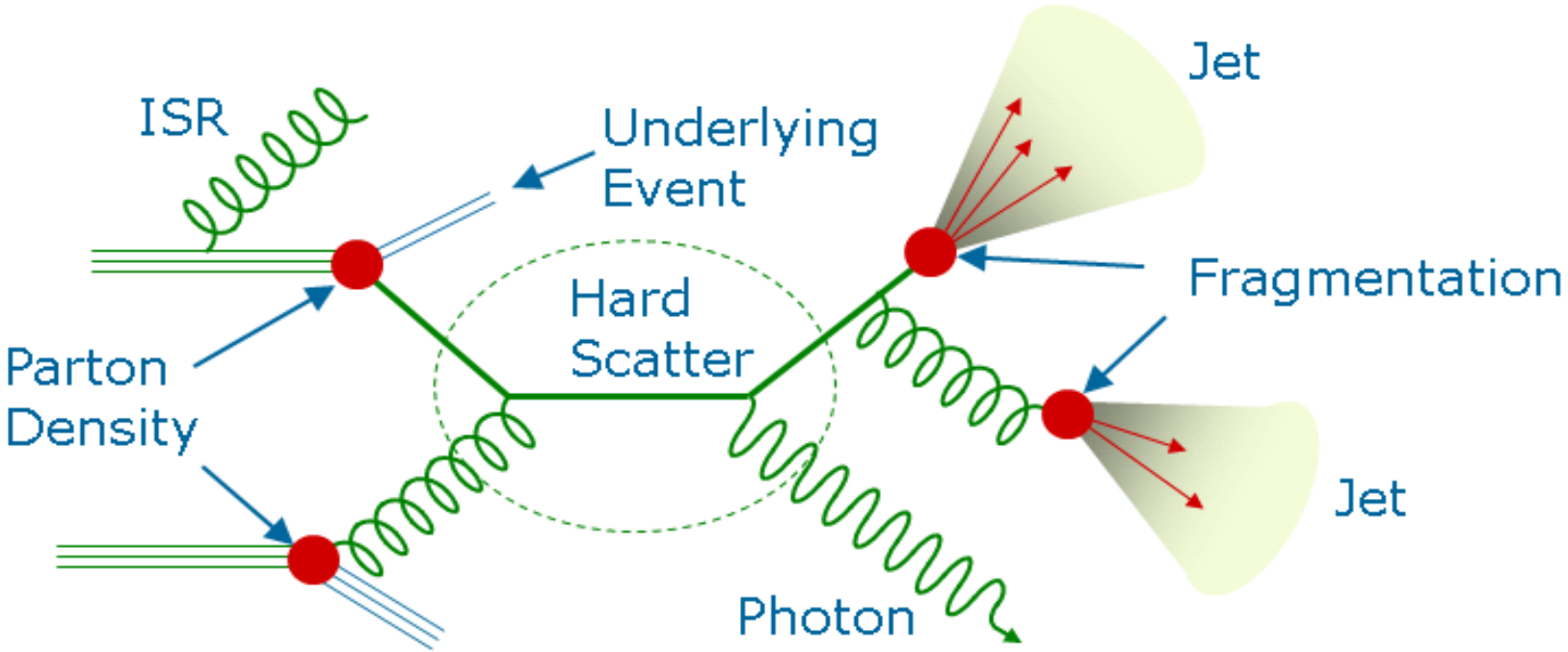
Outline

- **Motivation**
- **DØ Experiment**
- **DØ QCD Measurements**
- **Summary**

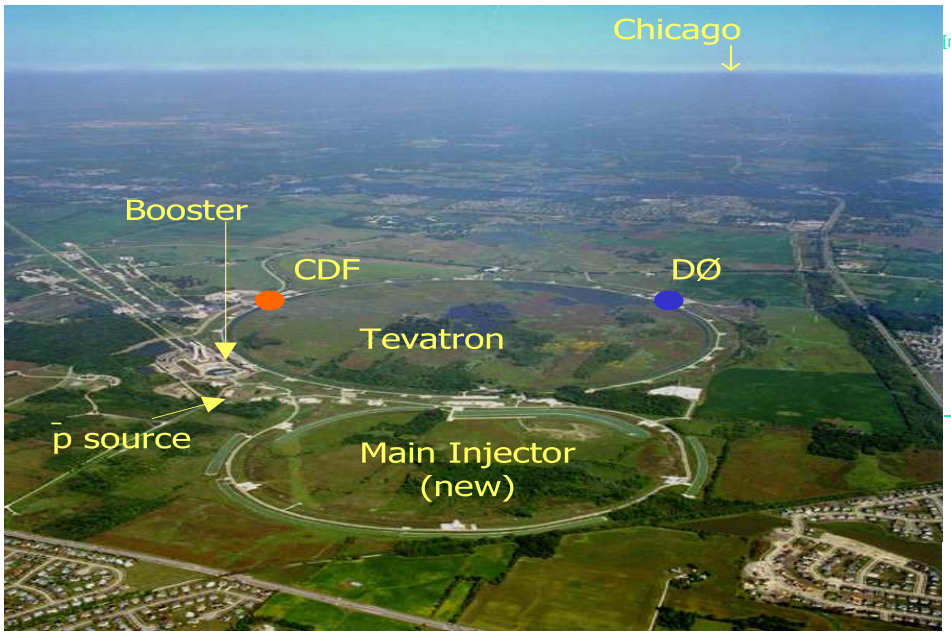


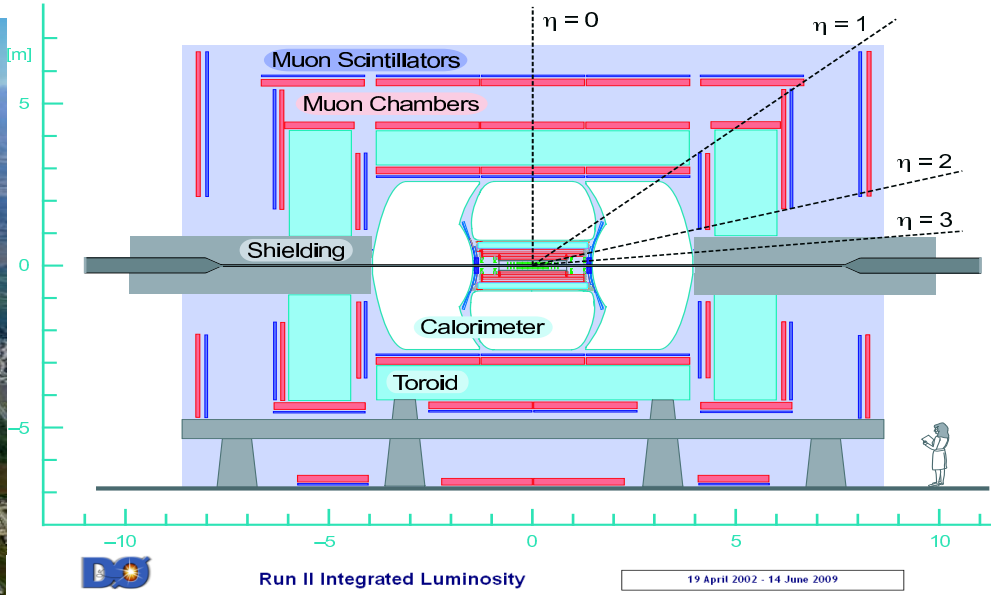
Motivation - large p_T processes in $p\bar{p}$ collisions

- Test of perturbative QCD (LO/NLO calculations, PDFs, α_S)
- Constrain of PDFs (high Q^2, medium to high x)
- Background to other SM processes (top quark, Higgs) or to new physics (SUSY, 4^{th} generation, extra dimensions, . . .)

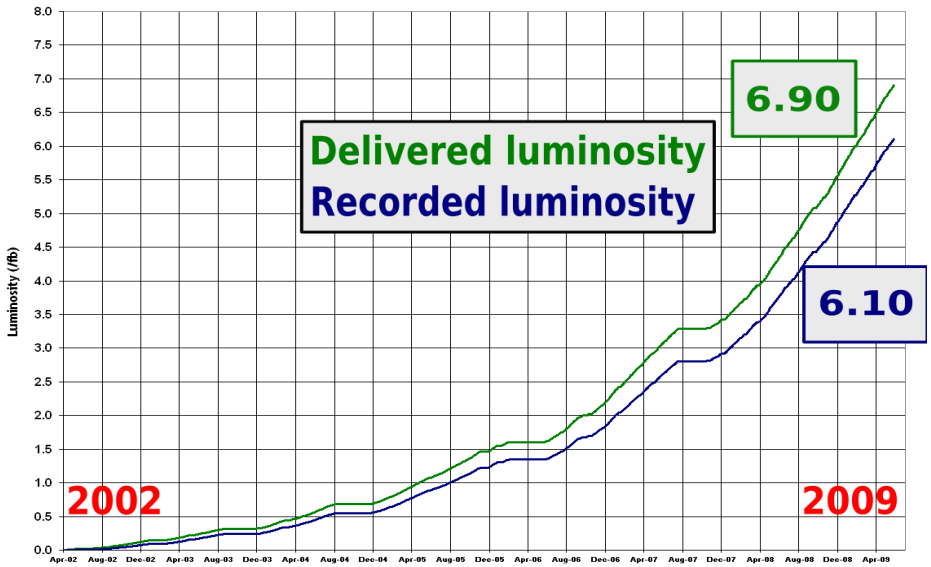


Tevatron and DØ Experiment Overview

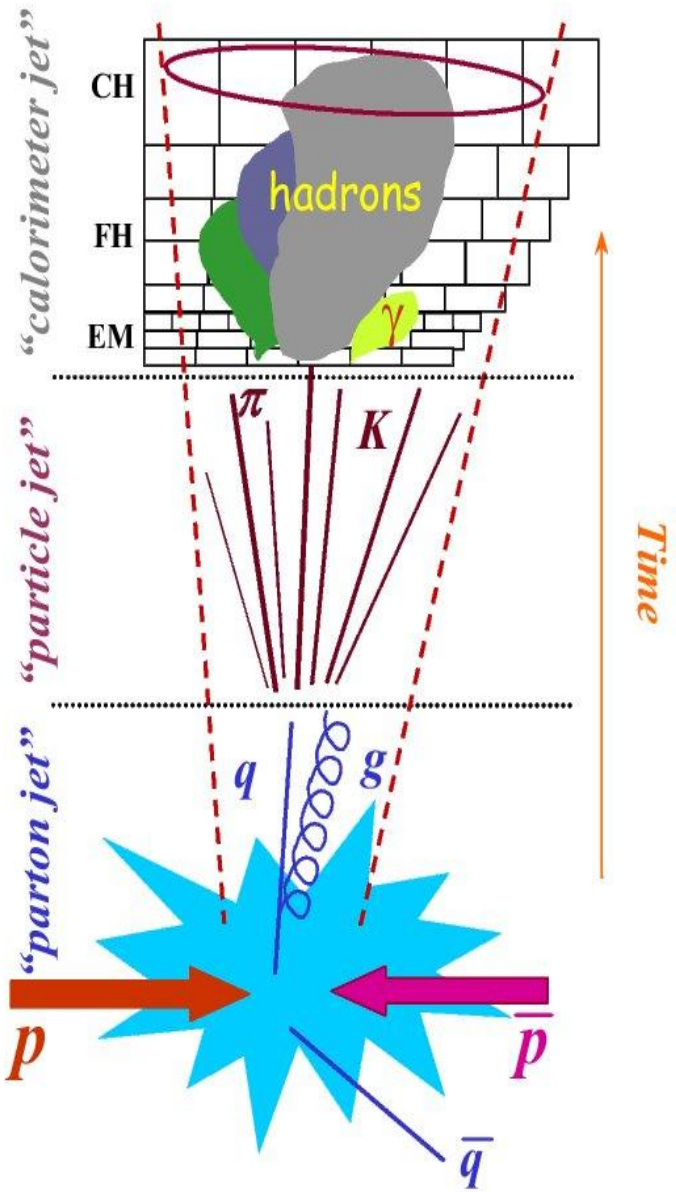




- $\sqrt{s} = 1.96\mathrm{TeV}$
- Peak luminosity
  $3.5 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Integrated luminosity $\sim 7\mathrm{fb}^{-1}$



Jets

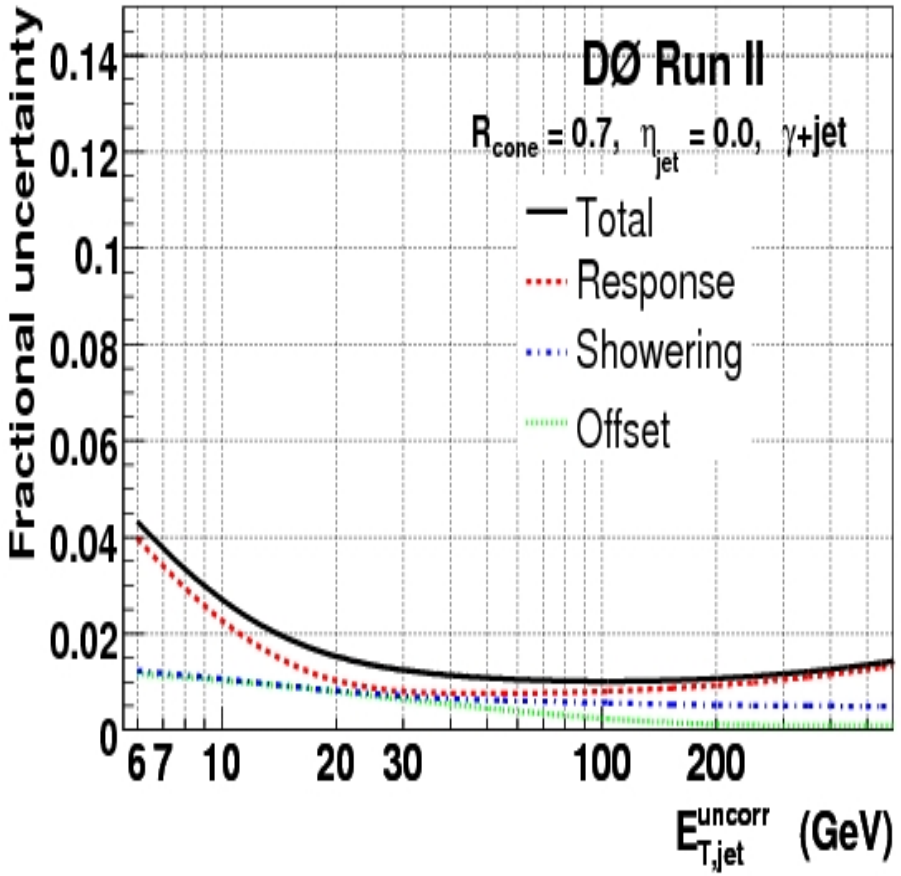


- Calorimeter jet
  - interaction of hadrons with calorimeter
  - collection of calorimeter cell energies
- Particle jet
  - after hadronization and fragmentation
  - effect of hadronization is soft $\Rightarrow$ allows comparison between particle and parton jets
- Parton jet
  - hard scattering
  - additional showers

Jet Energy Calibration

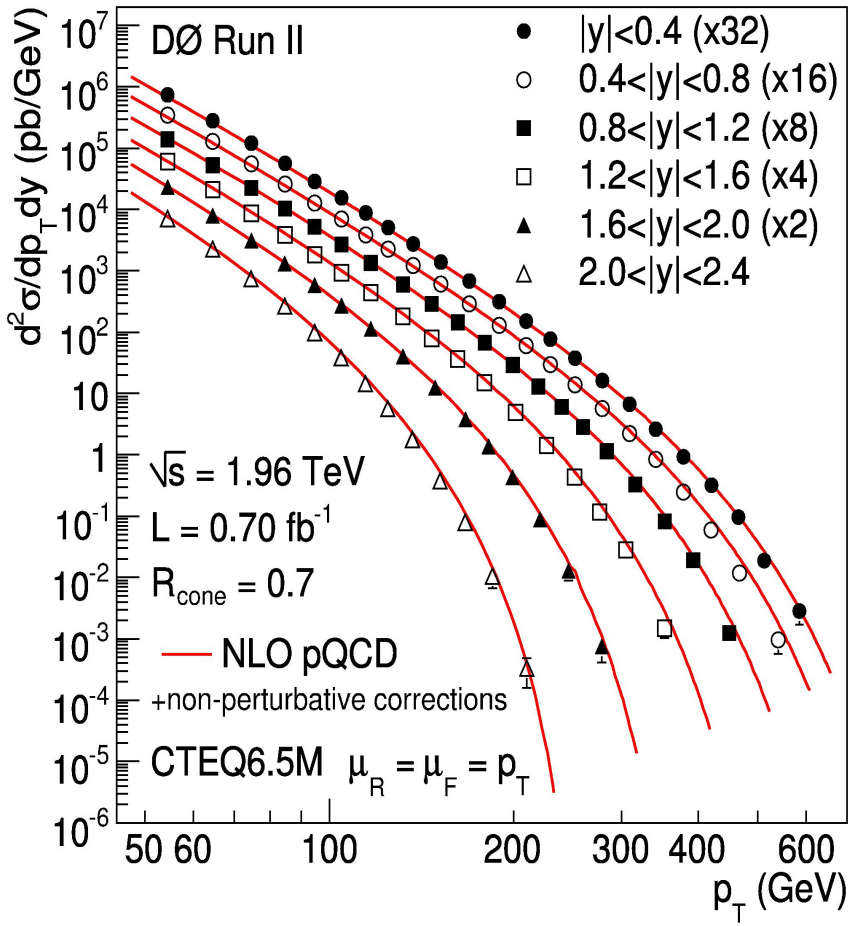
$$E_{\text{jet}}^{\text{corrected}} = \frac{E_{\text{jet}}^{\text{calorimeter}} - O}{R \cdot S}$$

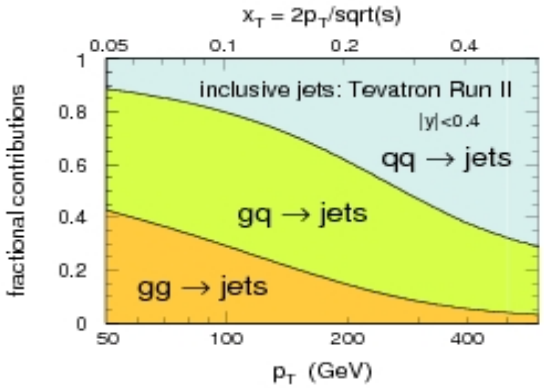
- Offset (O) coming from calorimeter noise, underlying event, multiple interactions and pile-up
- Response (R) of the calorimeter to jets
- Showering (S) is a fraction of energy deposited outside the jet cone

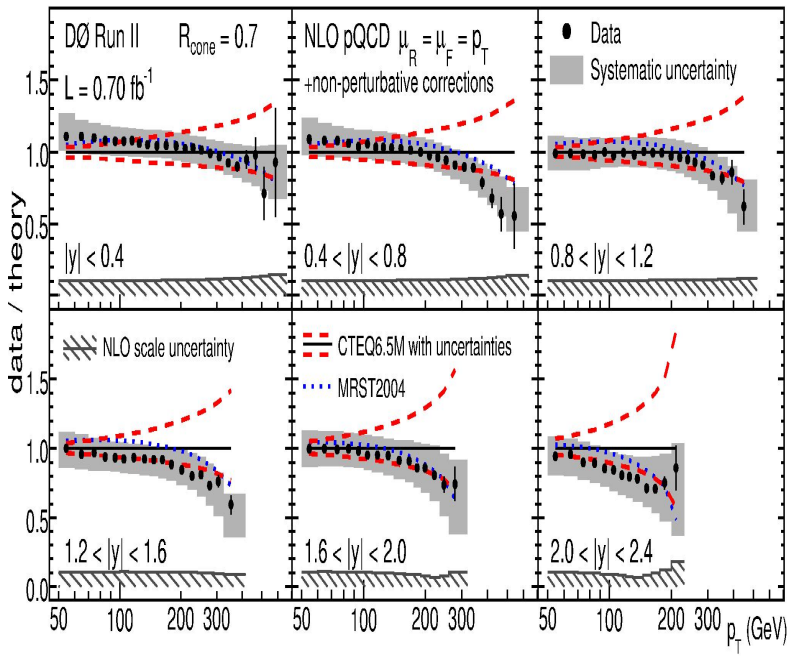


Inclusive Jet Cross Section

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





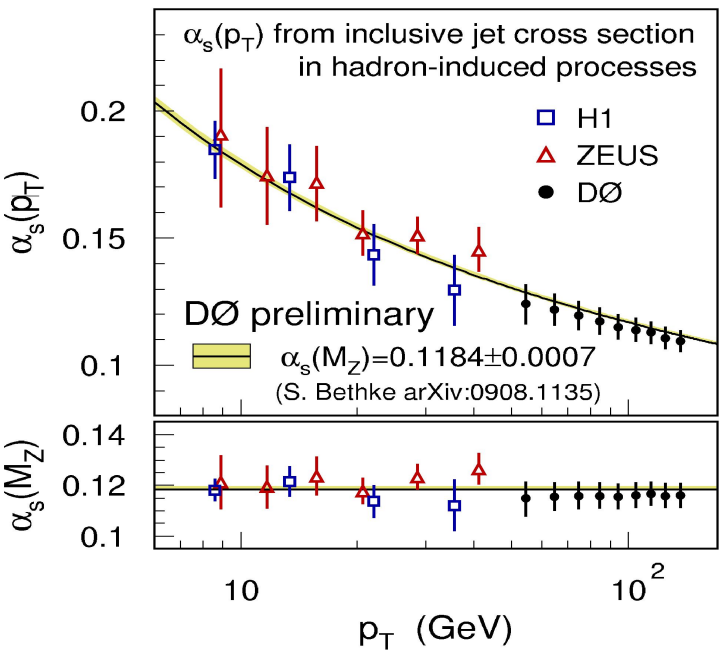


Data favor lower edge of PDF uncertainties $\Rightarrow$ used for newer MSTW2008 PDF sets

Strong Coupling Constant α_S

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

Use new MSTW2008 set which provides PDFs for several different α_S values, select kinematic range where PDFs are not heavily influenced by Tevatron data ($x < 0.2 - 0.3$, $50 < p_T < 145\,\text{GeV}$).



- NLO+$O(\alpha_S^4)$ contributions from 2-loop threshold corrections
- The most precise determination of the strong coupling constant from hadron collider
- $\alpha_S(M_Z) = 0.1173^{+0.0041}_{-0.0049}$

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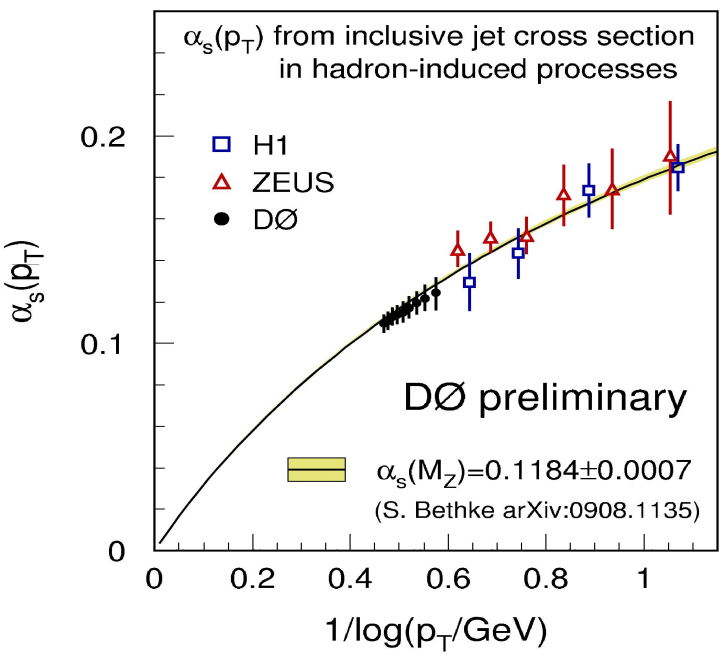
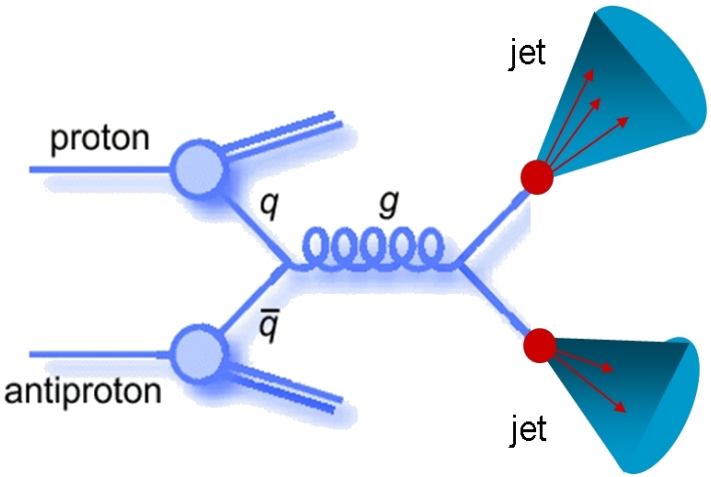
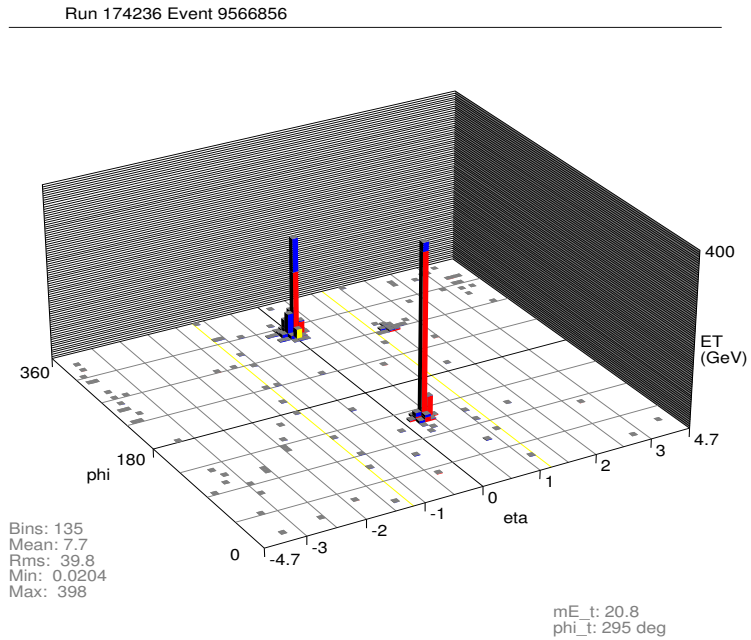


- NLO+$O(\alpha_S^4)$ contributions from 2-loop threshold corrections
- The most precise determination of the strong coupling constant from hadron collider
- $\alpha_S(M_Z) = 0.1173^{+0.0041}_{-0.0049}$
- Consistent with asymptotic freedom

Dijet System

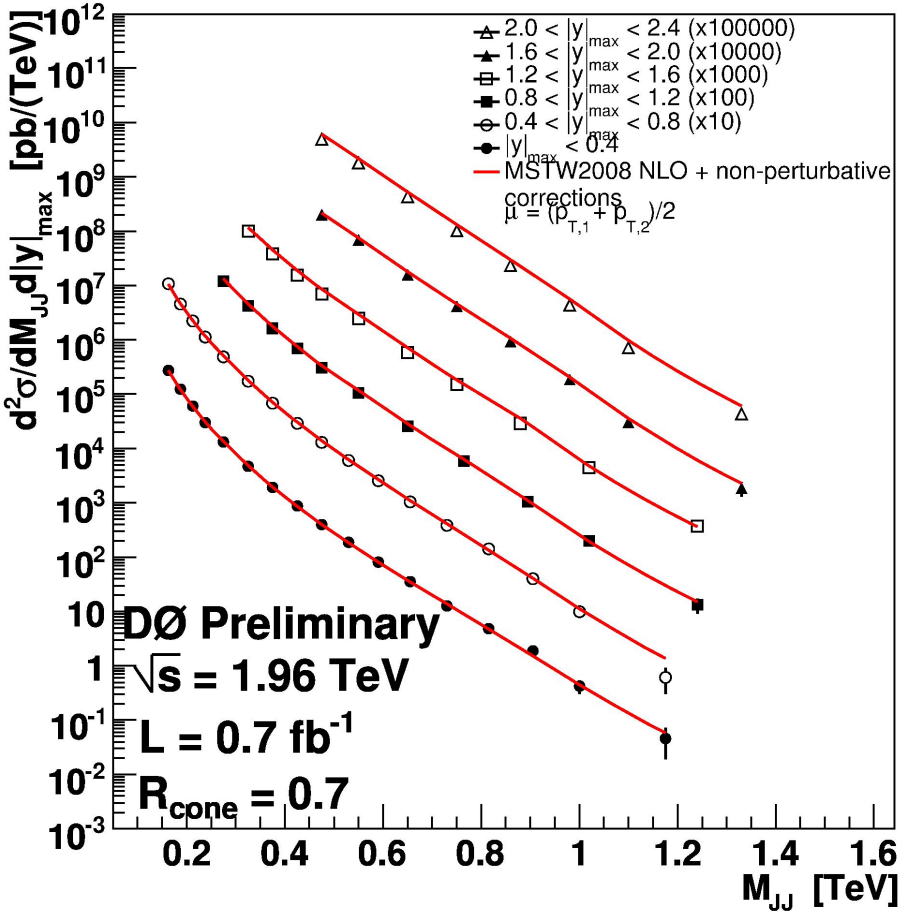


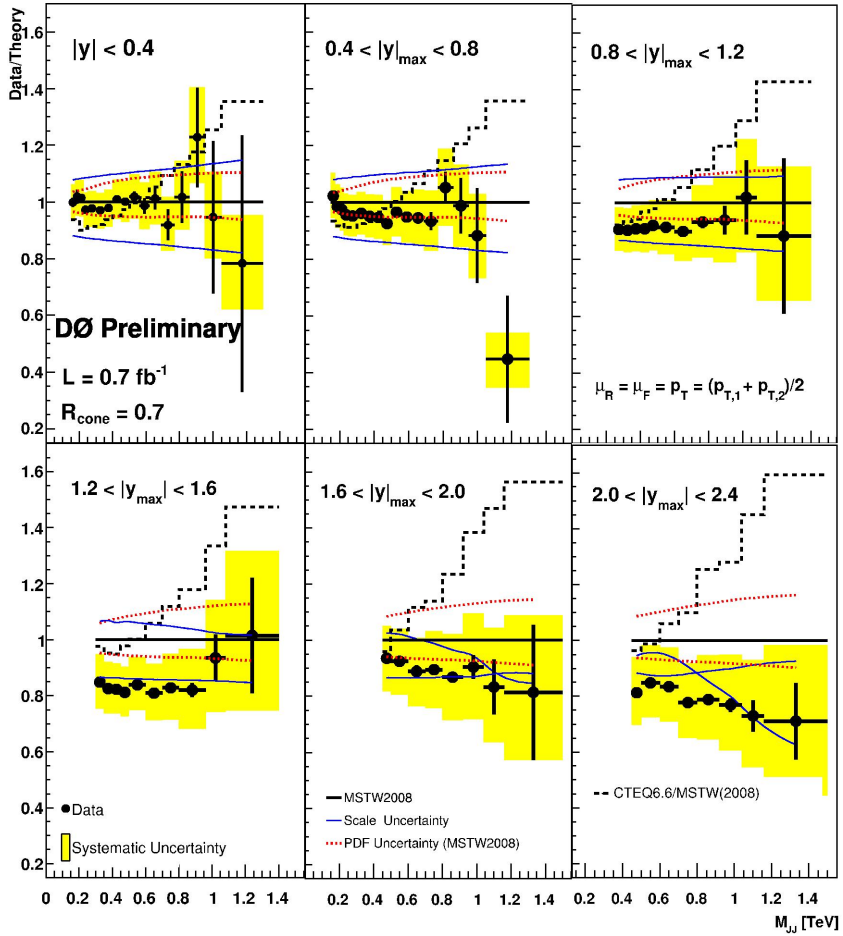


A few variables of interest:

- Dijet $\Delta\phi$ - Phys. Rev. Lett. 94 , 221801 (2005)
- Dijet invariant mass
- Dijet $\chi = \exp(|y_1 - y_2|), y = 1/2 \ln[(E + p_L)/(E - p_L)]$

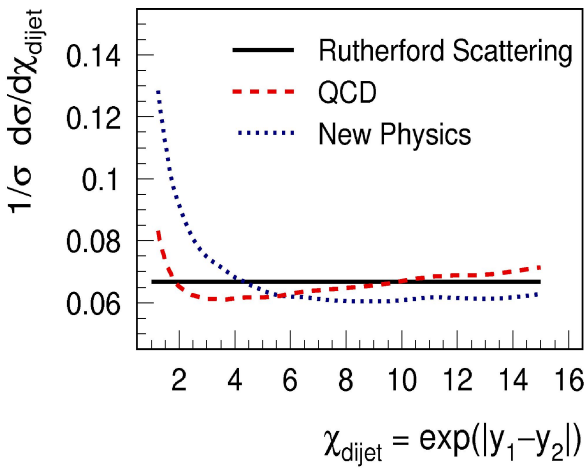
Dijet Mass Cross Section





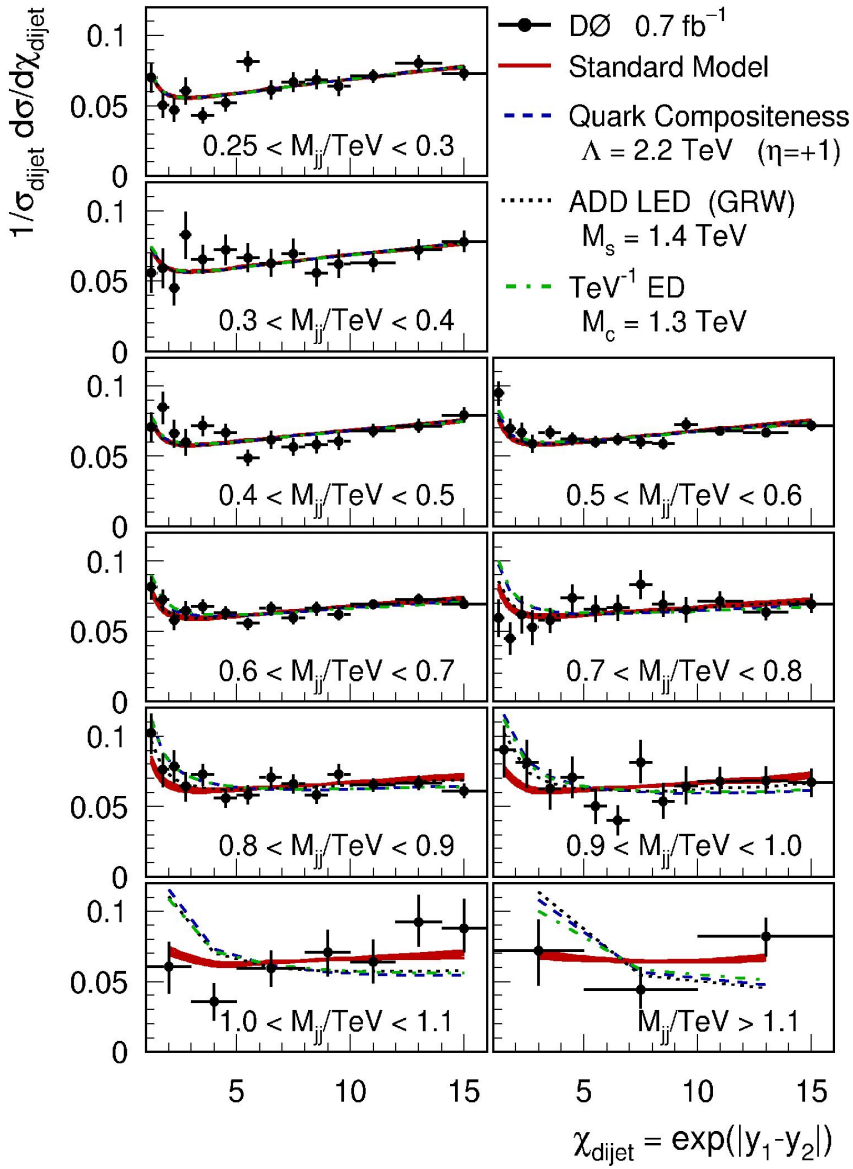
- Uses new MSTW2008 NLO PDFs

Dijet Angular Distribution ($\chi = \exp(|y_1 - y_2|)$)

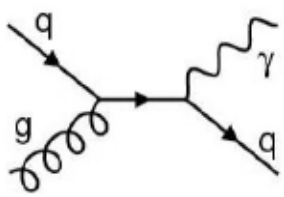


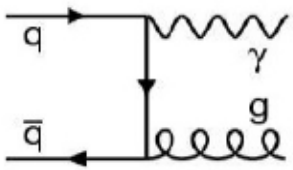
Best limits on new physics:

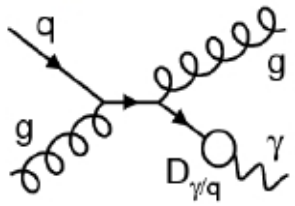
- Quark compositeness
- ADD Large extra dimensions
- TeV^{-1} extra dimensions



Photon and Jets



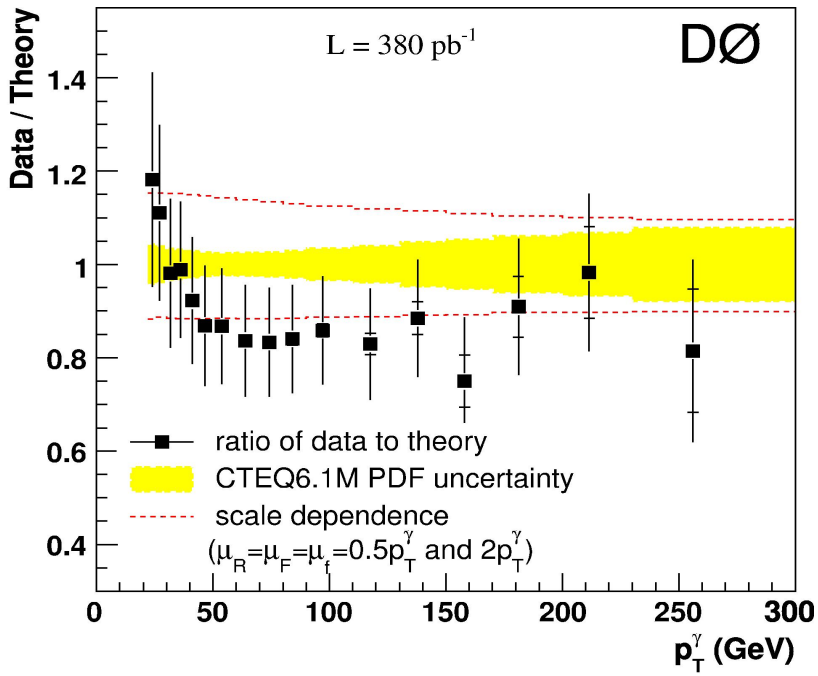




Direct photons emerge unaltered from the scattering process $\longrightarrow$ direct probe of hard scattering dynamics + potential sensitivity to PDFs

DØ published several measurements:

- Isolated photon cross section



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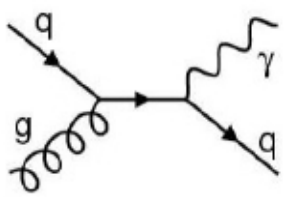
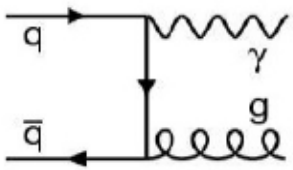
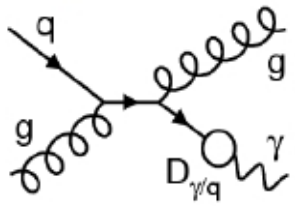


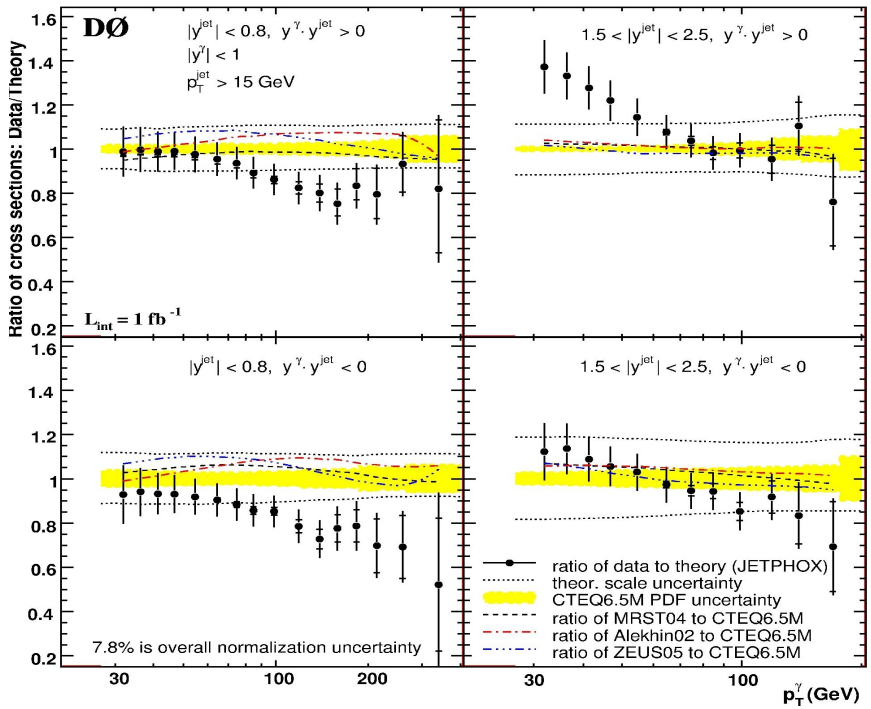




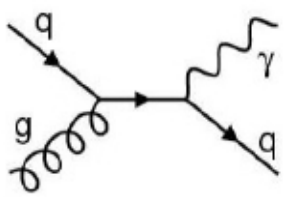
Direct photons emerge unaltered from the scattering process $\longrightarrow$ direct probe of hard scattering dynamics + potential sensitivity to PDFs

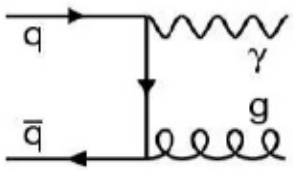
DØ published several measurements:

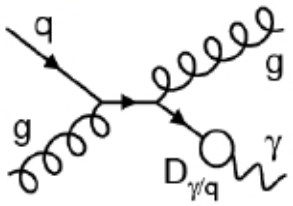
- Isolated photon cross section
- Photon+jet



Photon and Jets



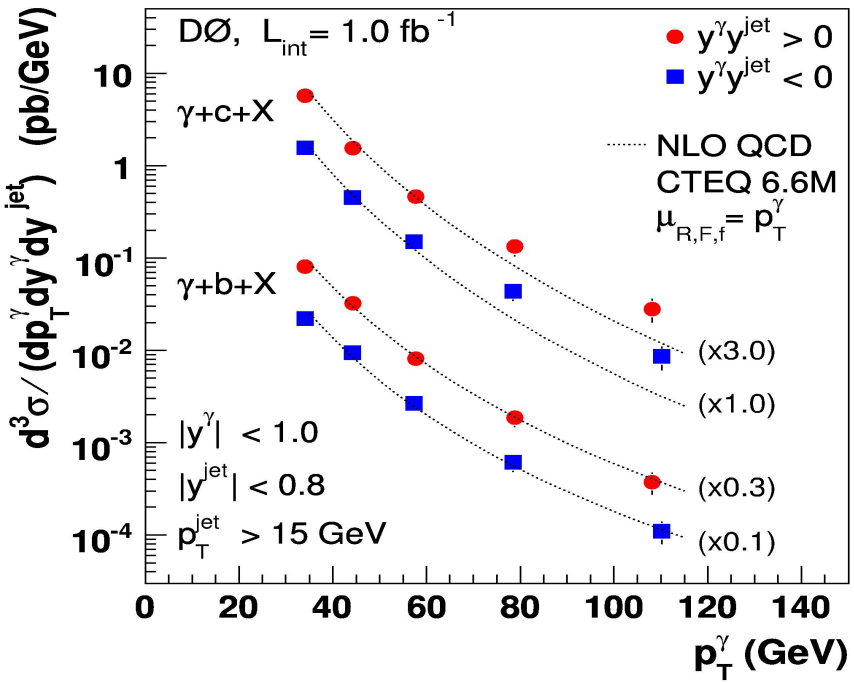




Direct photons emerge unaltered from the scattering process $\longrightarrow$ direct probe of hard scattering dynamics + potential sensitivity to PDFs

DØ published several measurements:

- Isolated photon cross section
- Photon+jet
- Photon+heavy flavor jet



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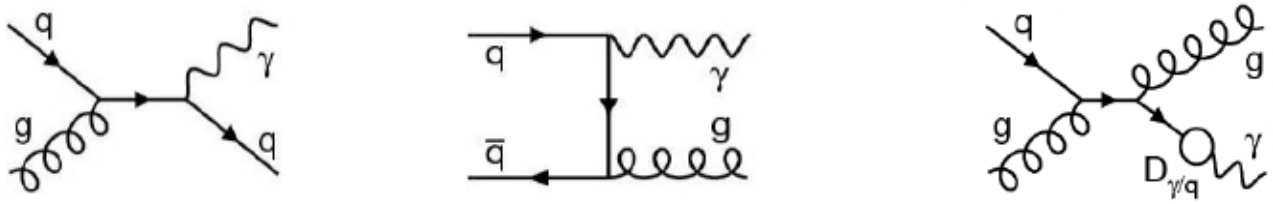
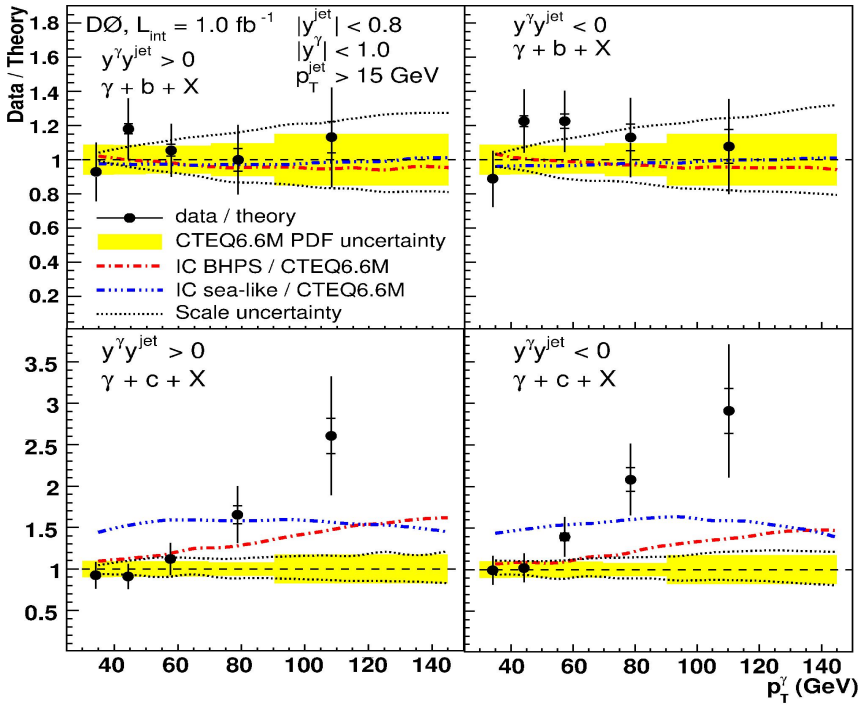


Direct photons emerge unaltered from the scattering process $\longrightarrow$ direct probe of hard scattering dynamics + potential sensitivity to PDFs

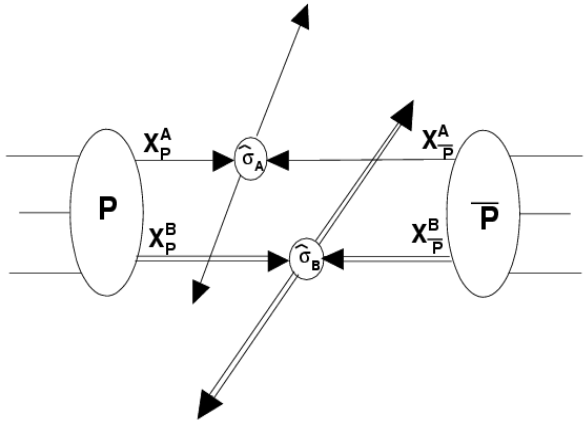
DØ published several measurements:

- Isolated photon cross section
- Photon+jet
- Photon+heavy flavor jet
- All with data/theory discrepancies - missing theory piece?

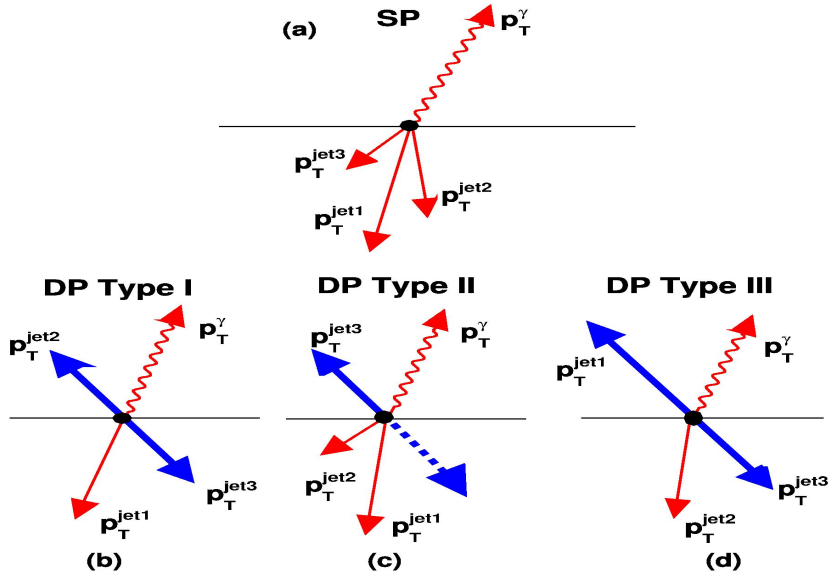


Double Parton Interaction in Photon + 3 Jets Events

Events with photon and 3 jets can originate from double parton (DP) interaction $\sigma_{\mathrm{DP}} = \sigma_{\gamma \mathrm{j}} \sigma_{\mathrm{jj}} / \sigma_{\mathrm{eff}}$, where σ_{eff} is related to spatial distribution of partons in hadrons



Example topology of background (SP) and signal (DP) events



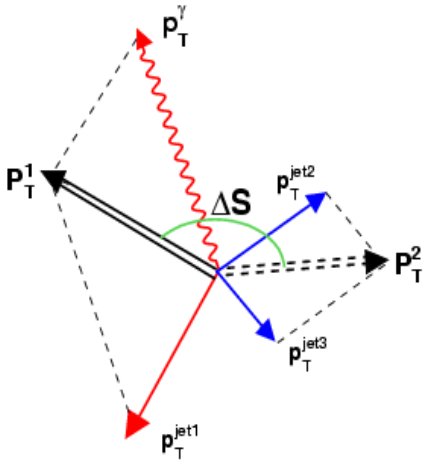
Extracting Double Parton Fraction

Class of S variables to distinguish double parton interactions:

$$S_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{p}_T(\gamma,i)|}{\delta p_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{p}_T(j,k)|}{\delta p_T(j,k)}\right)^2}$$

$$S_{p'_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{p}_T(\gamma,i)|}{|\vec{p}_T^{\,\gamma}| + |\vec{p}_T^{\,i}|}\right)^2 + \left(\frac{|\vec{p}_T(j,k)|}{|\vec{p}_T^{\,j}| + |\vec{p}_T^{\,k}|}\right)^2}$$

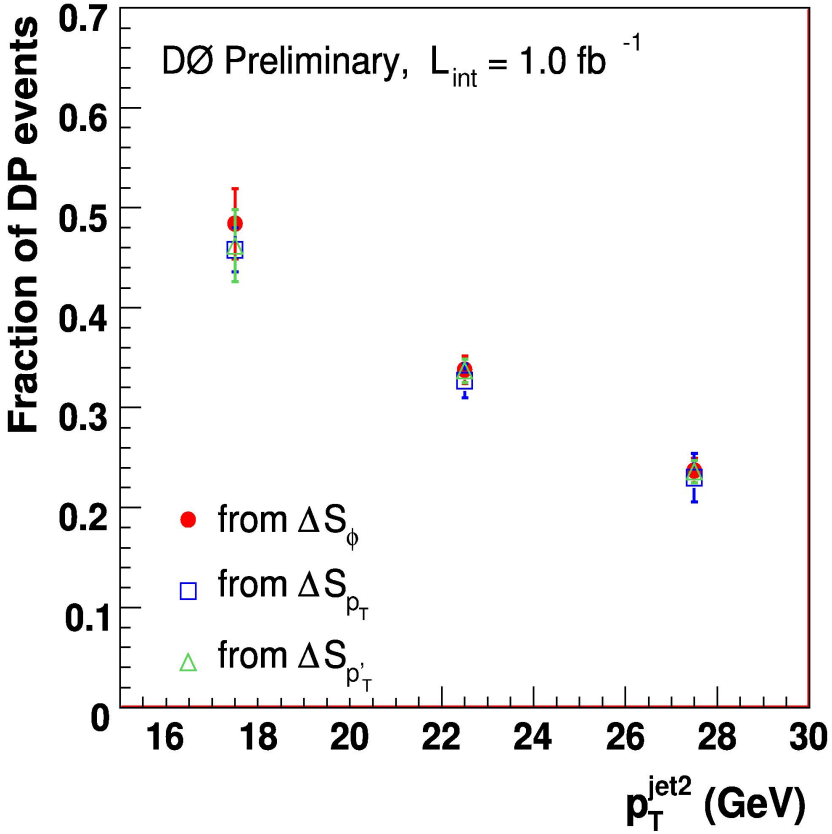
$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

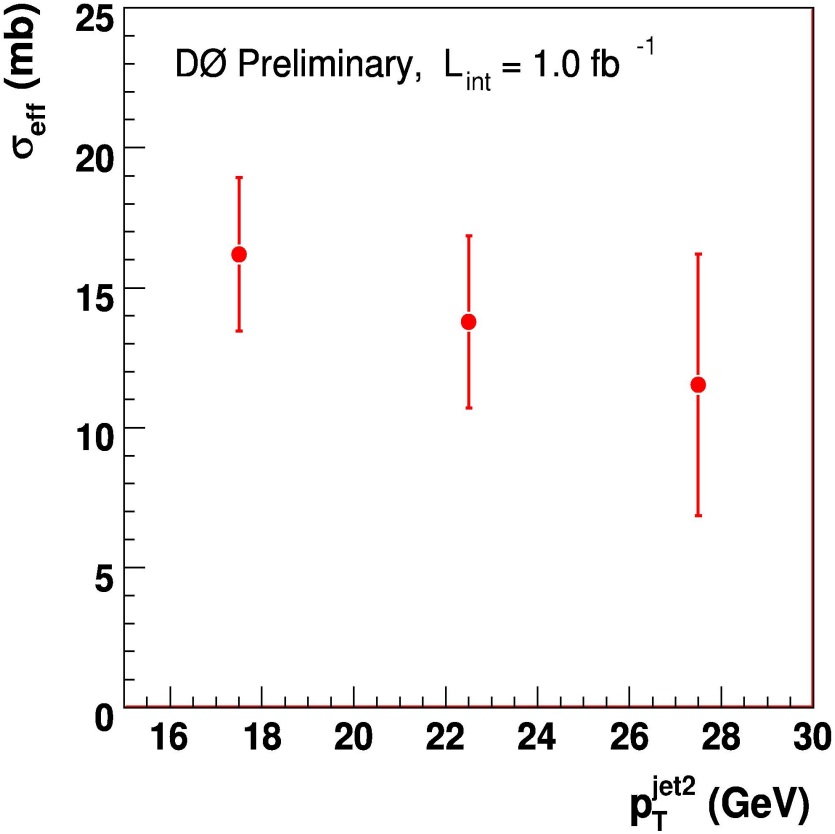


Two pairs with best balanced S are used to calculate ΔS ($\Delta S_\phi = \Delta\phi(\mathbf{p}_T(\gamma,i), \mathbf{p}_T(j,k))$) which can be expressed as a sum of signal and background distributions + examining the distribution in two DP-enriched and DP-depleted data intervals (dependent on p_T^{jet2}) allows extraction of the DP fraction using χ^2 minimization.

Double Parton Fraction

Measured in 3 bins of 2^{nd} jet p_T:

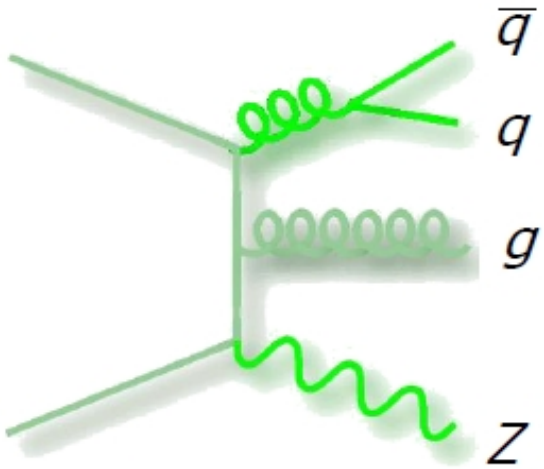




Double parton fraction drop from 0.47 ± 0.04 to 0.23 ± 0.03,
average $\sigma_{\text{eff}} = 15.1 \pm 1.9\,\text{mb}$ (in agreement with CDF Run I result)

Z Boson + Jets

- Use W/Z bosons as a probe of QCD.
- Concentrate on high p_T final states = domain of pQCD
- These final states are backgrounds to many SM and BSM processes



Current status:

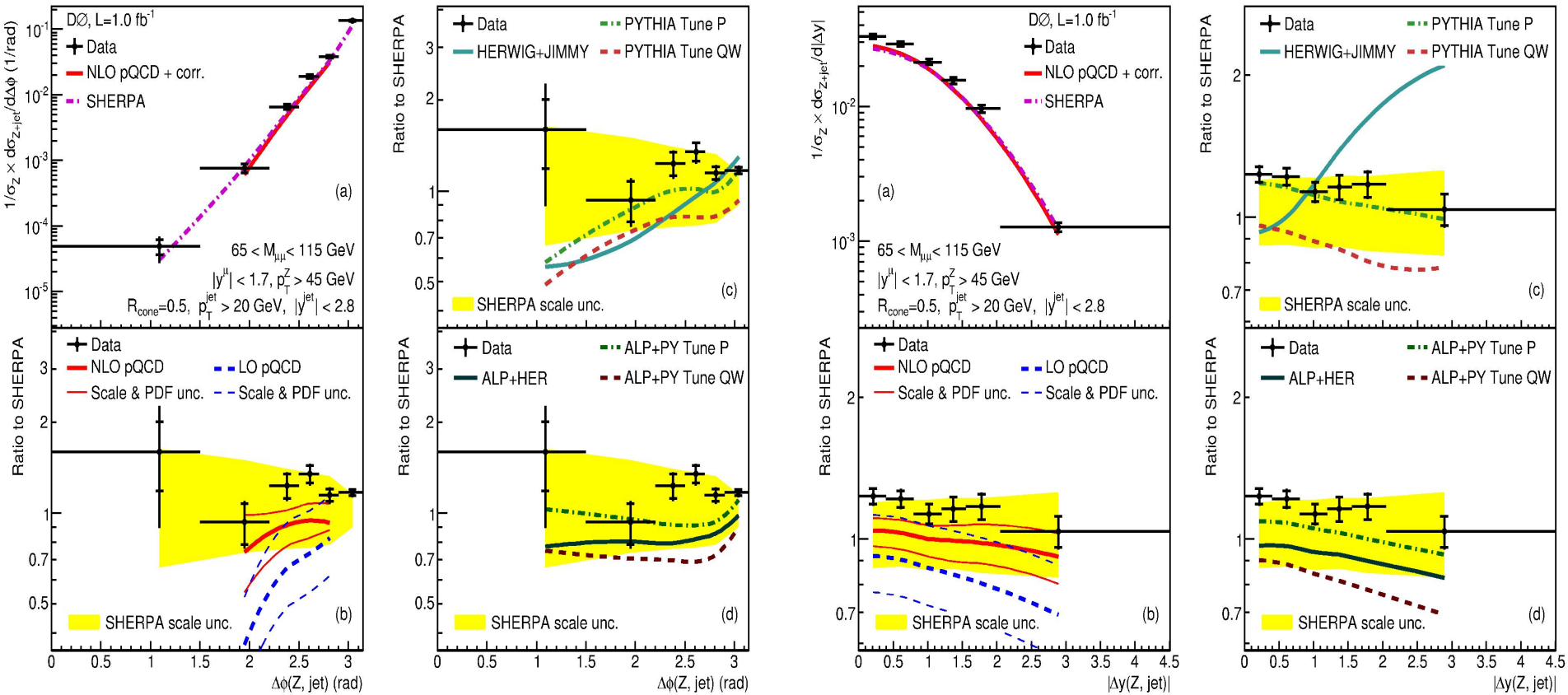
- pQCD
  - LO - $W/Z+$ 1-6 partons
  - NLO - W/Z + 1-2 partons
  - new NLO $W + 3$ partons
- Monte Carlo generators
  - LO $2 \to 1, 2$ + PS (Pythia, Herwig)
  - LO $2 \to 1 - 6$ ME + PS (Alpgen, Sherpa)

$\to Z$ + jets final state used for testing perturbative QCD and for tuning Monte Carlo generators

Z+jets Angular Distributions

Already published Z+jets for 1-3 jets with jet p_T (PLB 669, 278 (2008), PLB 678, 45 (2009)), now look at angular distributions $(\Delta\phi(Z, \text{jet}), \Delta y(Z, \text{jet}), \ldots)$.

Good description by NLO and Pythia "tune **P**erugia"



Summary and Conclusions

- First jet measurements in the TeV regime
  - Improvements in PDFs at high x
  - Best limits in some NP models
- Photon production - something still missing - need to improve theory
  - $\gamma + c$ jet disagreement for $p_T^\gamma > 70\,\mathrm{GeV}$
- Model tuning - multiple parton interactions, W/Z+jets modeling - important for LHC
  - Z+jet angular distributions - good agreement in shape by SHERPA, "tune P" gives best description of various PYTHIA tunes
- Many new results still to come from larger dataset

Backup

References

`http://www-d0.fnal.gov/Run2Physics/WWW/results/qcd.htm`

- Inclusive jets, dijets
  - Inclusive jets: Phys. Rev. Lett. 101, 062001 (2008)
  - Dijet $\Delta\phi$: Phys. Rev. Lett. 94, 221801 (2005)
- Photon measurements
  - Isolated photon cross section Phys. Lett. B 639, 151 (2006), Erratum Phys. Lett. B 658, 285 (2008)
  - Photon+jet cross section Phys. Lett. B 666, 2435 (2008)
  - Photon+heavy flavor jet cross section Phys. Rev. Lett. 102, 192002 (2009)
- Z+jets
  - $(Z \to \mu\mu)$+jet Phys. Lett. B 669, 278 (2008)
  - $(Z \to ee)$+jets Phys. Lett. B 678, 45 (2009)

New Physics Limits in Dijet χ Measurement

TABLE I: Expected and observed 95% C.L. limits in units of TeV on various new physics (NP) models for different Bayesian priors, and for the $\Delta\chi^2$ criterion.

	Prior flat in NP Lagrang.		Prior flat in NP x-section		$\Delta\chi^2 = 3.84$ criterion	
Model (parameter)	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
Quark comp. (Λ)						
$\eta = +1$	2.91	3.06	2.76	2.84	2.80	2.92
$\eta = -1$	2.97	3.06	2.75	2.82	2.82	2.96
TeV^{-1} ED (M_C)	1.73	1.67	1.60	1.55	1.66	1.59
ADD LED (M_S)						
GRW	1.53	1.67	1.47	1.59	1.49	1.66
HLZ $n = 3$	1.81	1.98	1.75	1.89	1.77	1.97
HLZ $n = 4$	1.53	1.67	1.47	1.59	1.49	1.66
HLZ $n = 5$	1.38	1.51	1.33	1.43	1.35	1.50
HLZ $n = 6$	1.28	1.40	1.24	1.34	1.25	1.39
HLZ $n = 7$	1.21	1.33	1.17	1.26	1.19	1.32