Recent QCD physics results from DØ

PLHC 2012

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on behalf of the DØ collaboration

Outline

Elastic scattering in $p\bar{p}$ collisions

- Measurement of the elastic scattering differential cross-section

Multijet production

- Measurement of angular correlations
- Extraction of the strong coupling constant

W+jets production

- W boson p_T cross-section
- Jet rapidity cross-sections (n_{jet}=1—4)
- Dijet mass (n_{jet}=2,3)
- Jet emission probability / gap fraction versus jet angular separation

Associated Z+b-jet production

- Cross-section measurement

Associated photon+b-jet production

- Differential production cross-sections

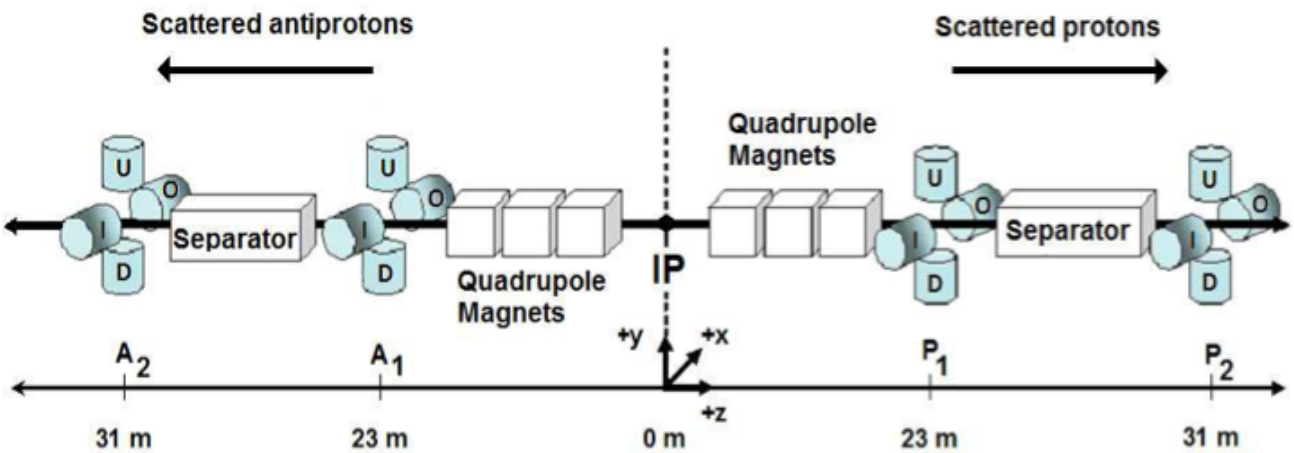
Elastic scattering

Elastic scattering cross-section $p\bar{p} \rightarrow p\bar{p}$ measured differentially as function of four-momentum transfer squared, t.

Sensitive to proton structure / npQCD aspects of hadron-hadron interactions

Measured in |t| range $0.26<|t|<1.2$ GeV^2 using forward proton detectors (FPD)

Two(x2) quadrapole spectrometers on proton/anti-proton sides of interaction point:



Pseudorapidity range covered by detectors: $7.3<|eta|<8.6$

(placement within a few mm of the beam)

Elastic scattering

Use of forward proton detectors requires special run conditions:

- Tevatron β^*=1.6m (0.35 m nominal)
- Only 1 proton/anti-proton bunch colliding
  (0.8 mean interactions per bunch crossing)
- Heavy beam halo scraping
  (primary source of background in analysis)

Luminosity of combined runs ~31 nb^{-1}

Integrated luminosity for this special data-taking period calculated by comparing number of inclusive jet events to that obtained in standard run with identical selection criteria.

Results in overall normalisation uncertainty of 14.4%
(6.1% from standard luminosity uncertainty, 13% from jet analysis).

Elastic scattering

Corrected for detector efficiency, acceptance and resolution effects measure cross-section over $0.26<|t|<1.2$ GeV^2

Exponential dependence observed at low |t|, slope: $16.86\pm0.10_{stat}\pm0.20_{syst}$

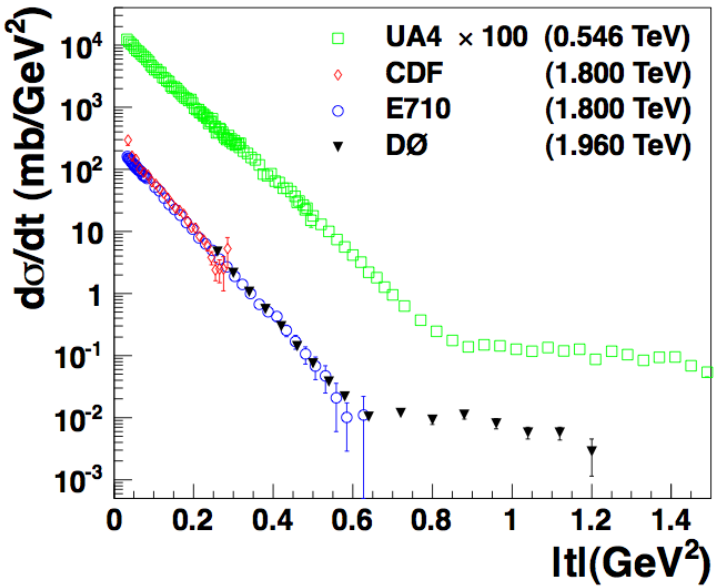
consistent with prior measurements at CDF/E710 (1.8 TeV)

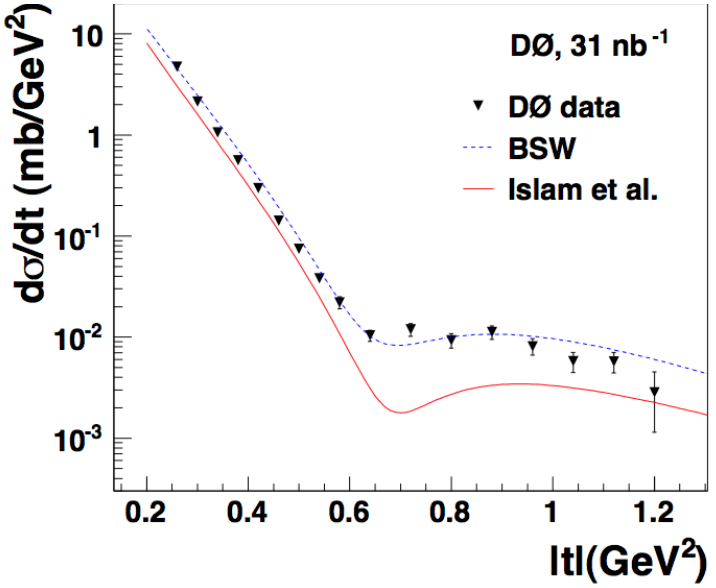
Complementary to TOTEM results from LHC also discussed at this meeting:

- Change in slope occurs at 0.6 GeV^2, moving to lower |t| at increasing centre of mass energy
- Local diffraction minimum seen in pp results much more distinct than in proton-antiproton

Data able to differentiate between and provide input to phenomenological models

ARXIV: 1206.0687, SUBMITTED TO PHYS. REV. D

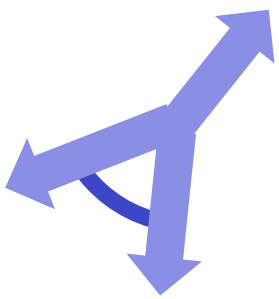




Angular jet correlations

New observable $R_{\Delta R}$: average number of neighbouring jets within given ΔR interval above some p_T threshold

$$R_{\Delta R}(p_T, \Delta R, p_{T\min}^{\mathrm{nbr}}) = \frac{\sum_{i=1}^{N_{\mathrm{j}}(p_T)} N_{\mathrm{nbr}}^{(i)}(\Delta R, p_{T\min}^{\mathrm{nbr}})}{N_{\mathrm{j}}(p_T)}$$



Example:

Choose interval $\Delta R<2\pi/3$

This is an inclusive 3-jet event, has denominator 3

Two of these jets have neighbour in ΔR interval, numerator 2

For this event, $\Delta R=2/3$

Angular jet correlations

New observable $R_{\Delta R}$: average number of neighbouring jets within given ΔR interval above some p_T threshold

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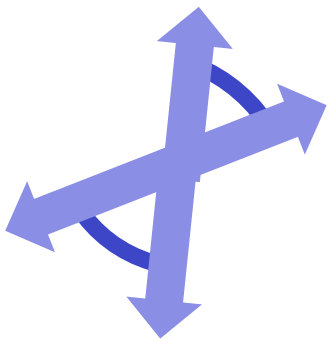


Example:

Choose interval $\Delta R<2\pi/3$

This is an inclusive 4-jet event, has denominator 4

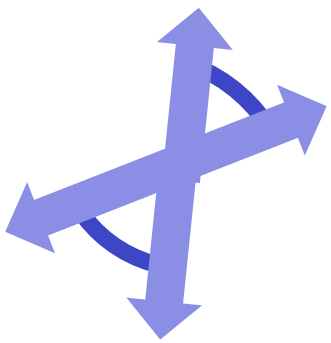
All of these jets have neighbour in ΔR interval, numerator 4

For this event, $\Delta R=1$

Angular jet correlations

New observable $R_{\Delta R}$: average number of neighbouring jets within given ΔR interval above some p_T threshold

$$R_{\Delta R}(p_T, \Delta R, p_{T\min}^{\mathrm{nbr}}) = \frac{\sum_{i=1}^{N_{\mathrm{j}}(p_T)} N_{\mathrm{nbr}}^{(i)}(\Delta R, p_{T\min}^{\mathrm{nbr}})}{N_{\mathrm{j}}(p_T)}$$



Example:

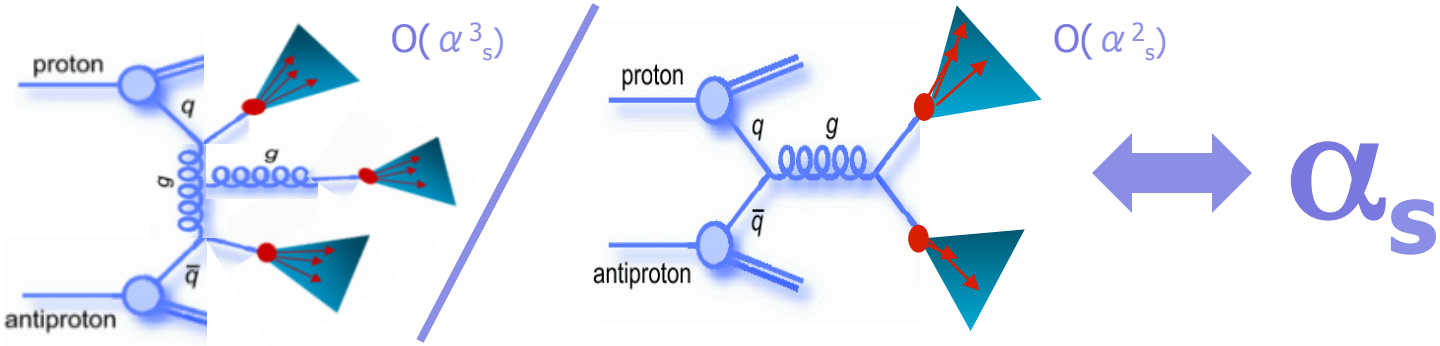
Choose interval $\Delta R<2\pi/3$

This is an inclusive 4-jet event, has denominator 4

All of these jets have neighbour in ΔR interval, numerator 4

For this event, $\Delta R=1$

Benefits: sensitive to strong coupling constant, weakly sensitive to PDF

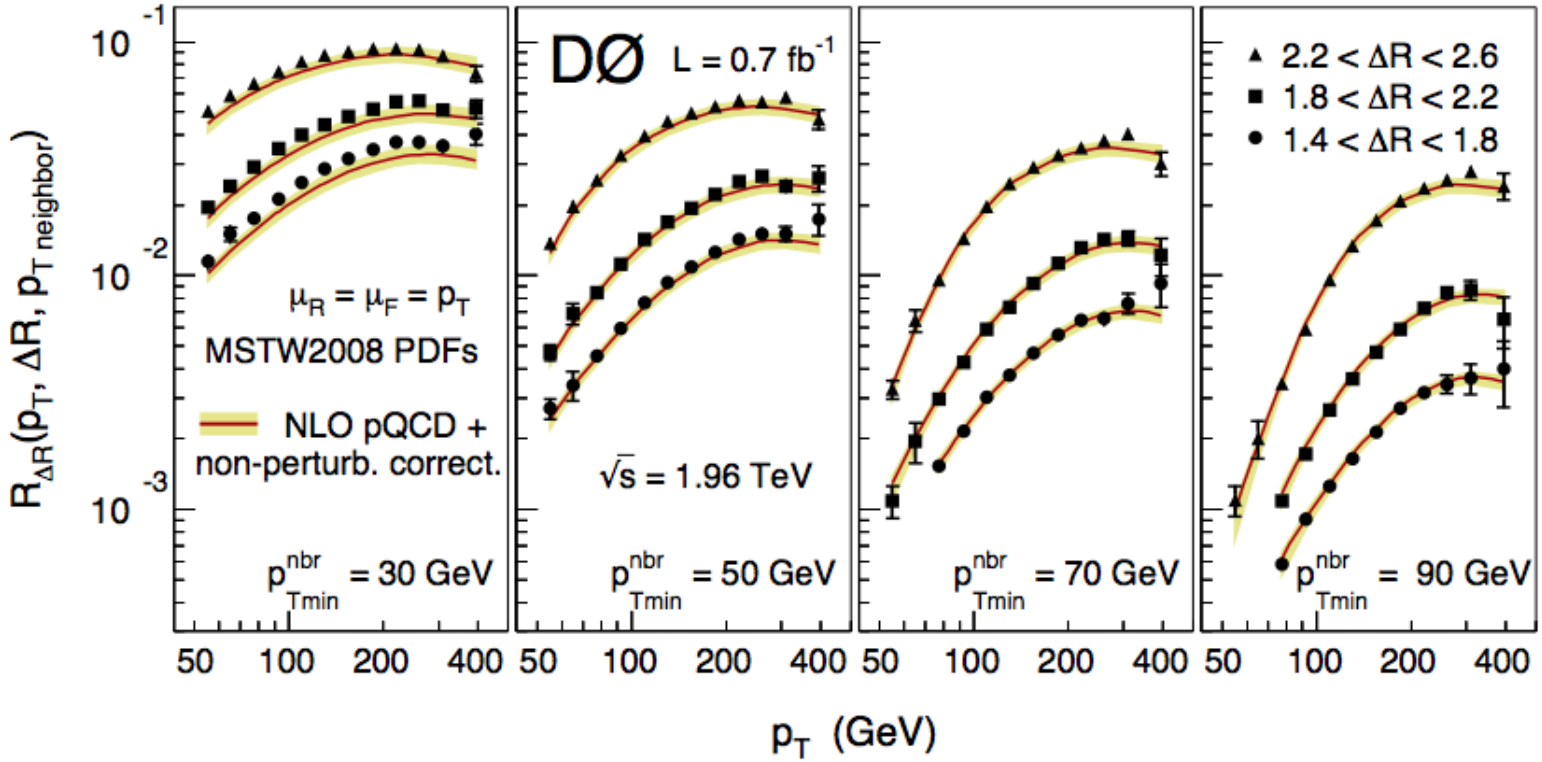


Angular jet correlations

Jet selection:

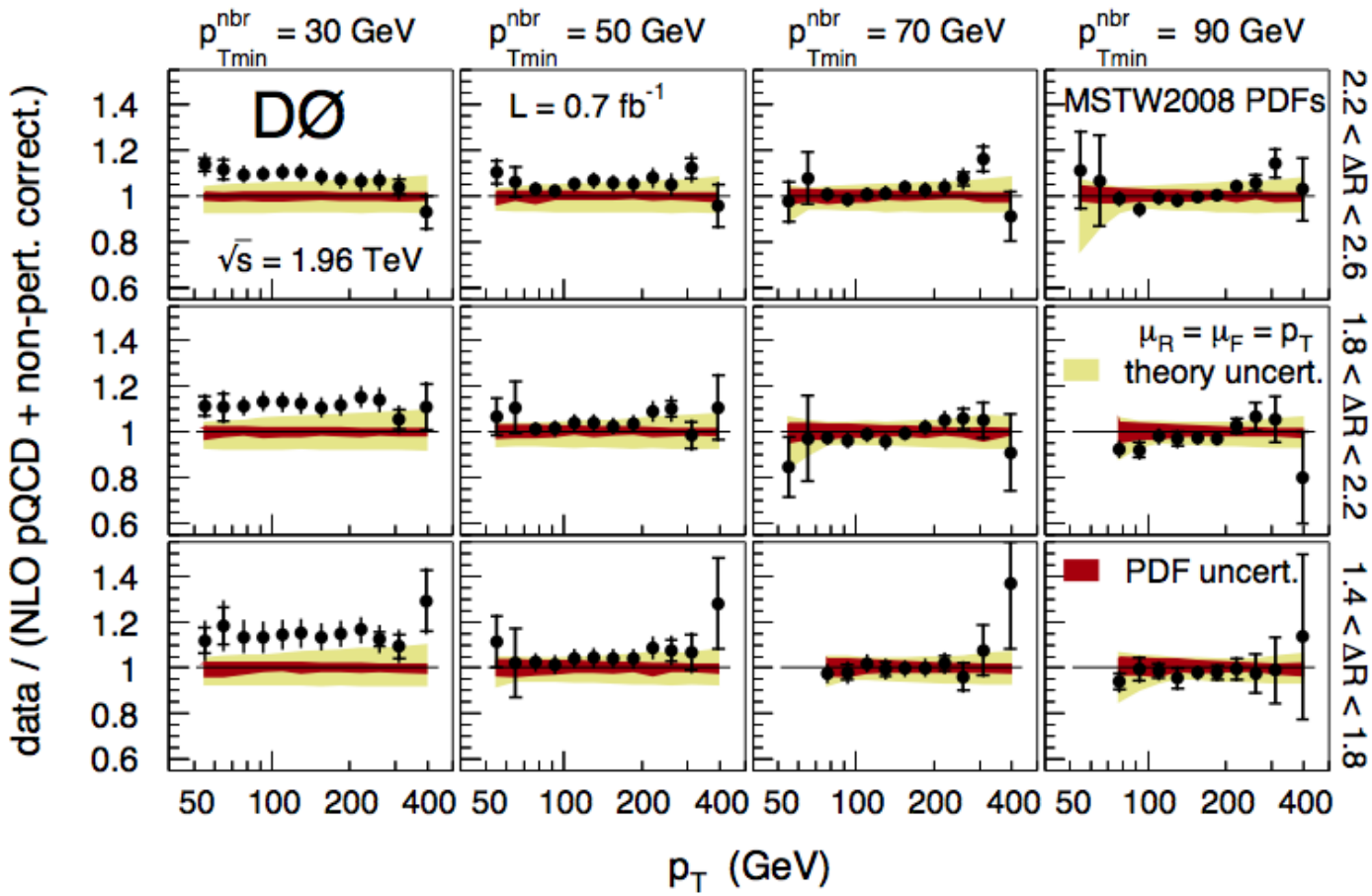
|y|<1.0 (midpoint cone algorithm R=0.7), $50<p_T<450$ GeV

Three ΔR ranges, four neighbouring jet p_T thresholds



Dominant measurement uncertainties from jet energy calibration (2-5%), model-dependence of data correction factors (2-3%)

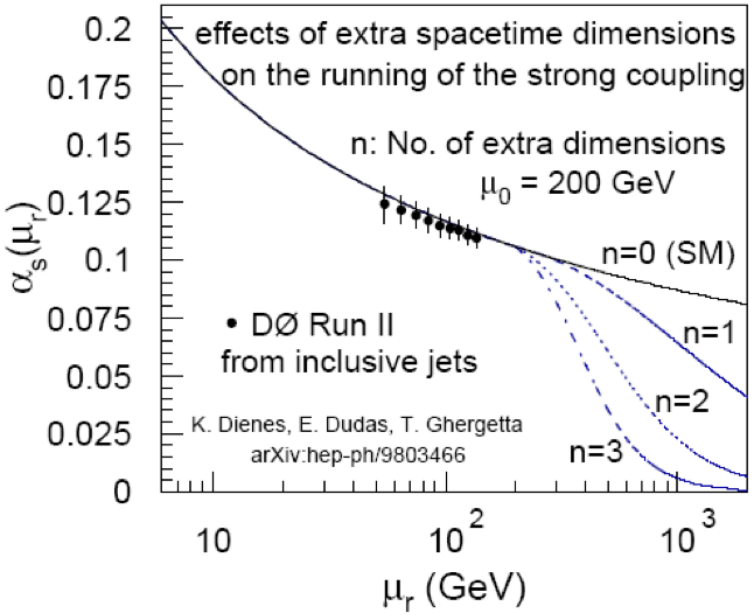
Angular jet correlations



NLO predictions from FastNLO (based on NLOJet++), non-perturbative corrections from Pythia, and MSTW2008NLO PDFs

Good agreement for neighbour p_T > 50 GeV, some problems at 30 GeV

Measurement of strong coupling



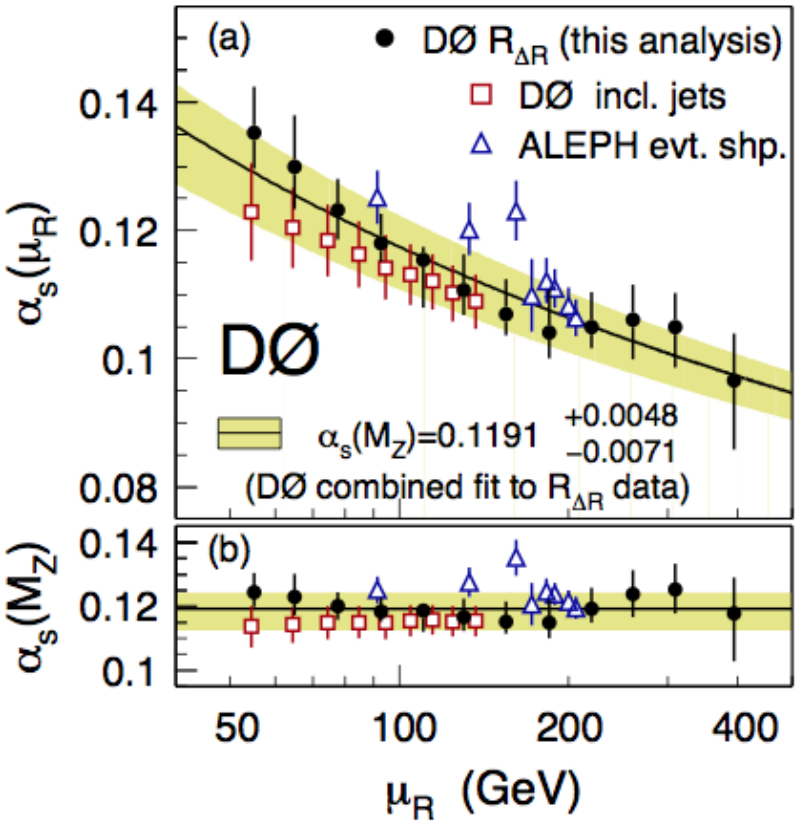
Strong coupling tested up to scale of 208 GeV.
Modification of running at higher scales could occur due to New Physics e.g. extra dimensions

In each analysis region, determine combined $\alpha_s(M_Z)$ and fit quality

Use $R_{\Delta R}$ data for neighbour $p_T > 50, 70, 90$ GeV and at each jet p_T combine all neighbour $p_T / \Delta R$

New $\alpha_s(p_T)$ results up to scale of 400 GeV
Decrease in $\alpha_s(p_T)$ with p_T as predicted by RGE

World average $\alpha_s(M_Z) = 0.1184 \pm 0.004$



W+jets production

W+jets production an important background for precision measurement and searches for new physics

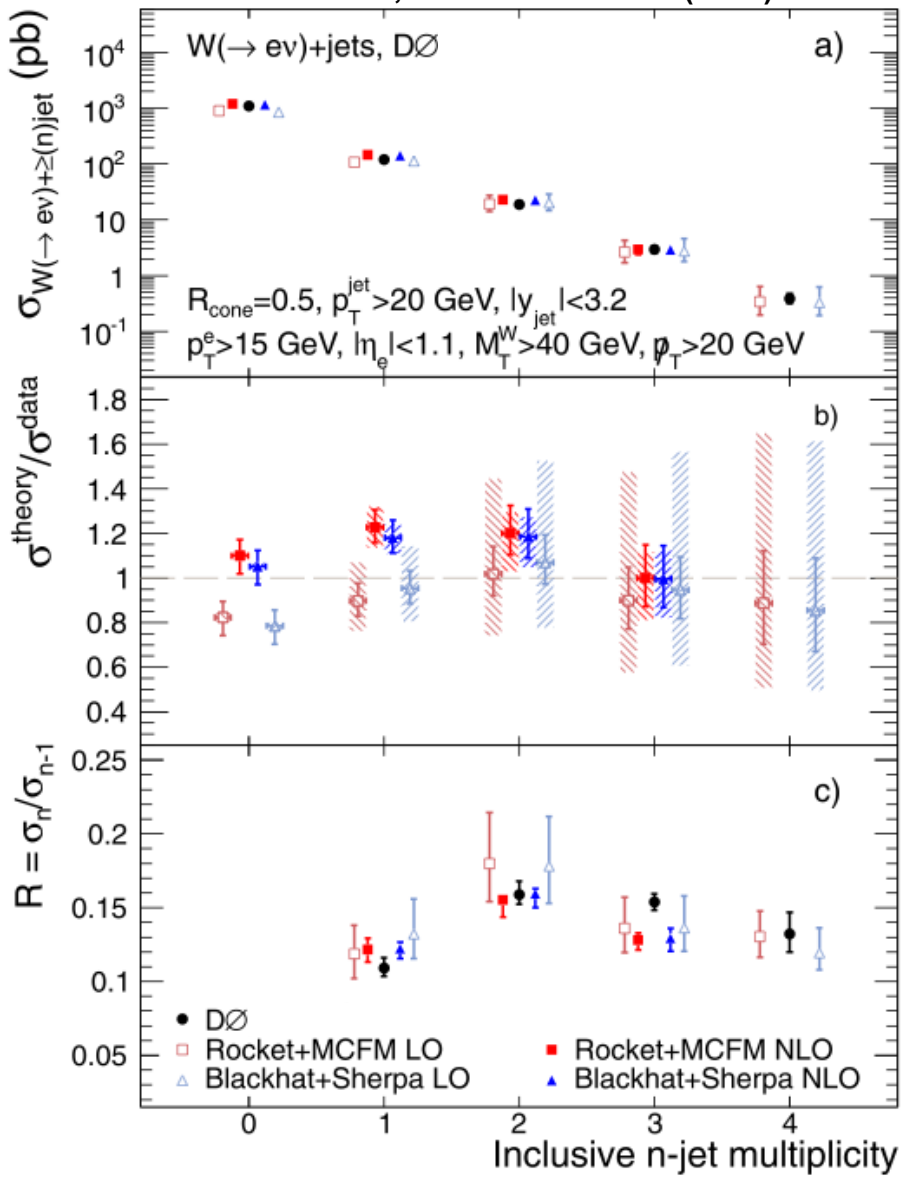
Previously measured inclusive production cross-sections (example to right) and jet p_T at DØ for up to four jets

Unfold to particle-level for comparison to theoretical predictions using Singular Value Decomposition technique (GURU)

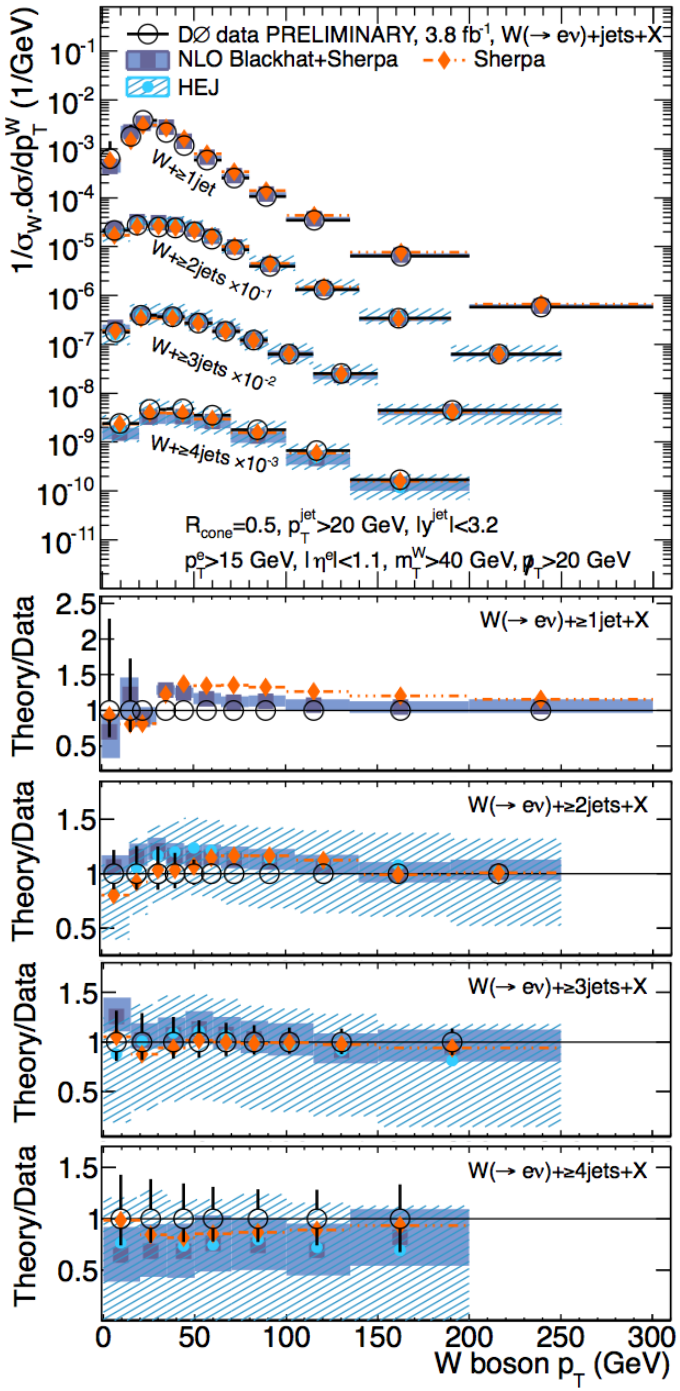
- Proper handling of bin migrations
- Reduced Monte Carlo dependence

New measurements of W+jets from DØ now available…

ARXIV: 1106.1457, PHYS. LETT. B 705 (2011) 200-207



W+jets: W boson p_T



W+(n)jets differential cross-section measured as a function of W boson transverse momentum for inclusive one to four jet events

Comparisons made to three theory predictions:

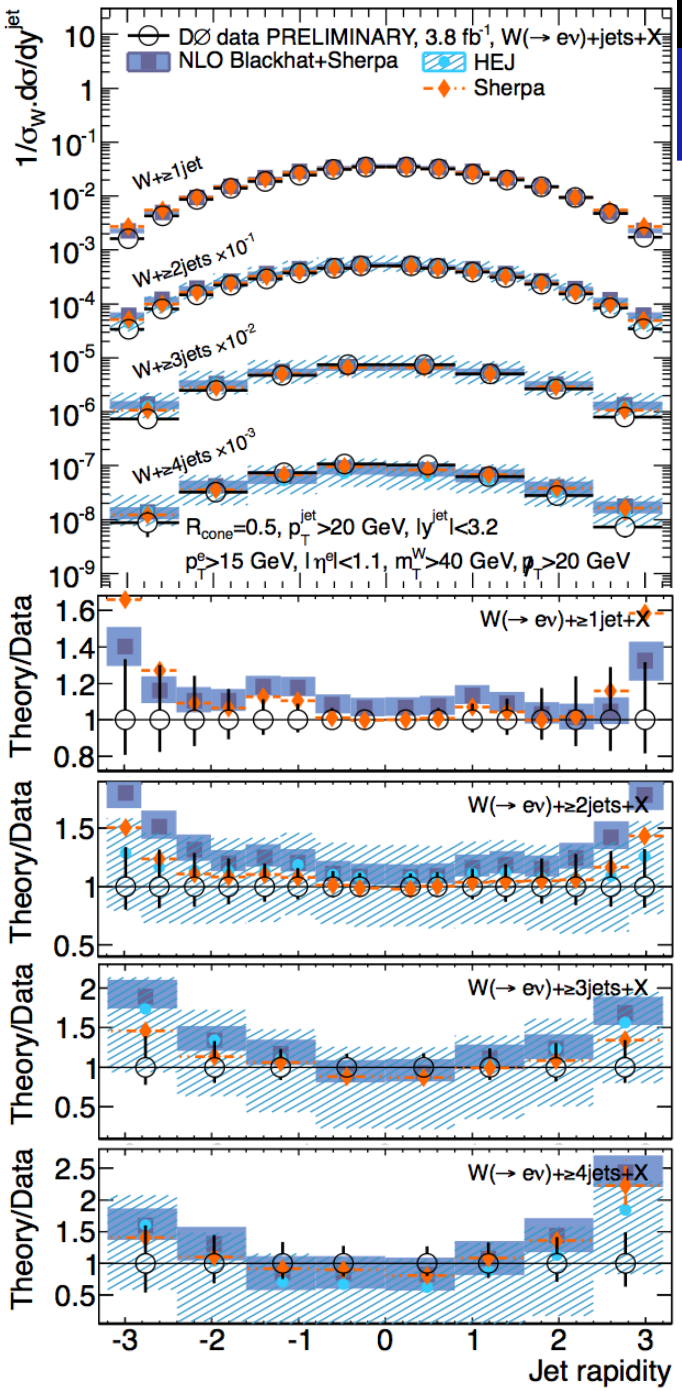
- Sherpa (MEPS event generator)
- NLO Blackhat+Sherpa
- High Energy Jets (HEJ – all-order resummation)

All approaches show good agreement on this basic observable

Some breakdown of NLO expected when W $p_T \approx$ jet p_T threshold (20 GeV)

Uncertainties on data smaller or equal in magnitude to uncertainties on theory predictions

W+jets: jet rapidities



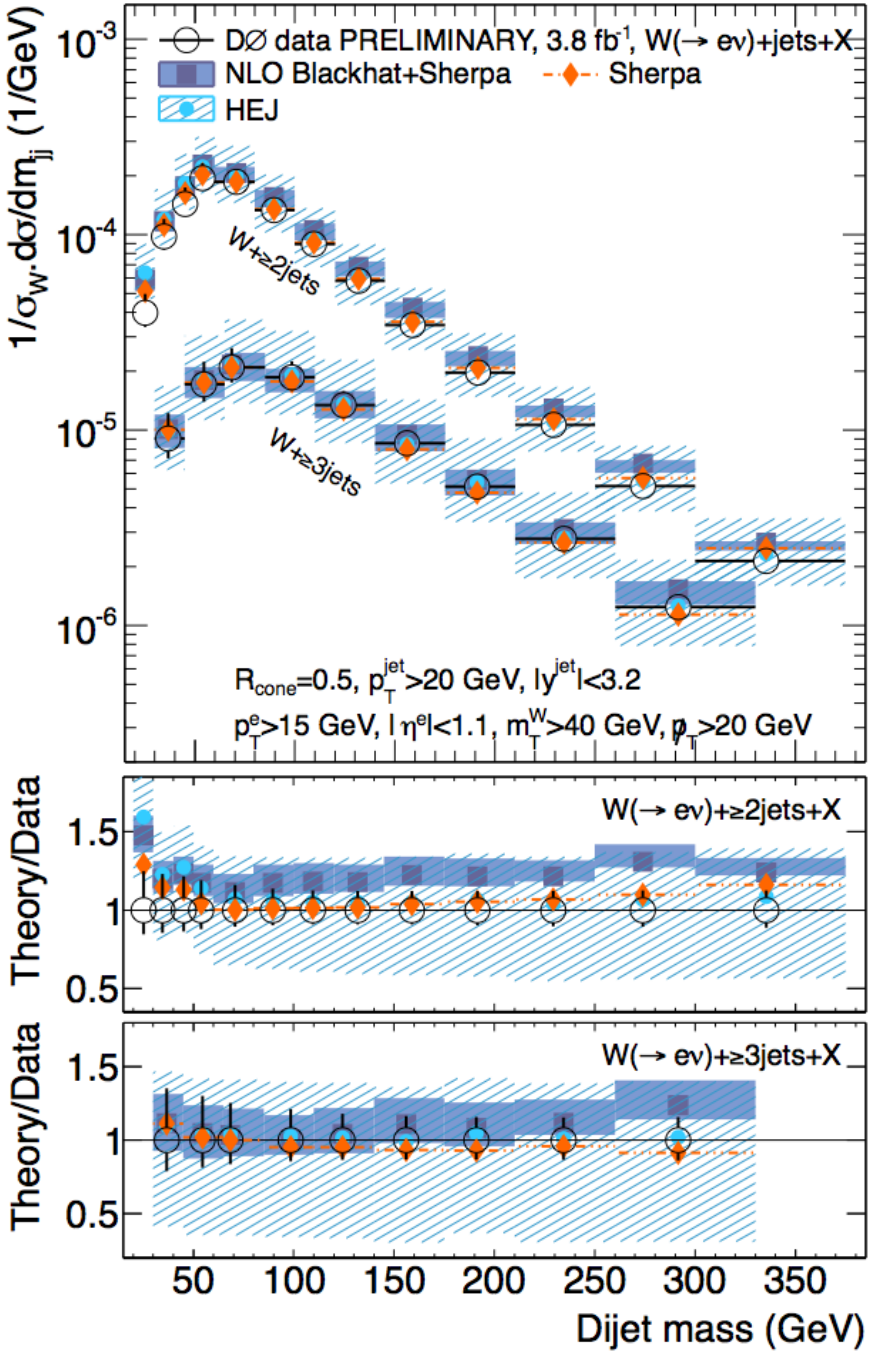
W+(n)jets differential cross-section measured as a function of nth jet rapidity in inclusive n-jet events (for n=1—4)

Good agreement between data and theory at central rapidities, with small uncertainties

Theory predictions tend to overestimate cross-section in forward region: dominated by low p_T jets

Many DØ analyses are sensitive to discrepancies in jet rapidity modelling

W+jets: dijet mass



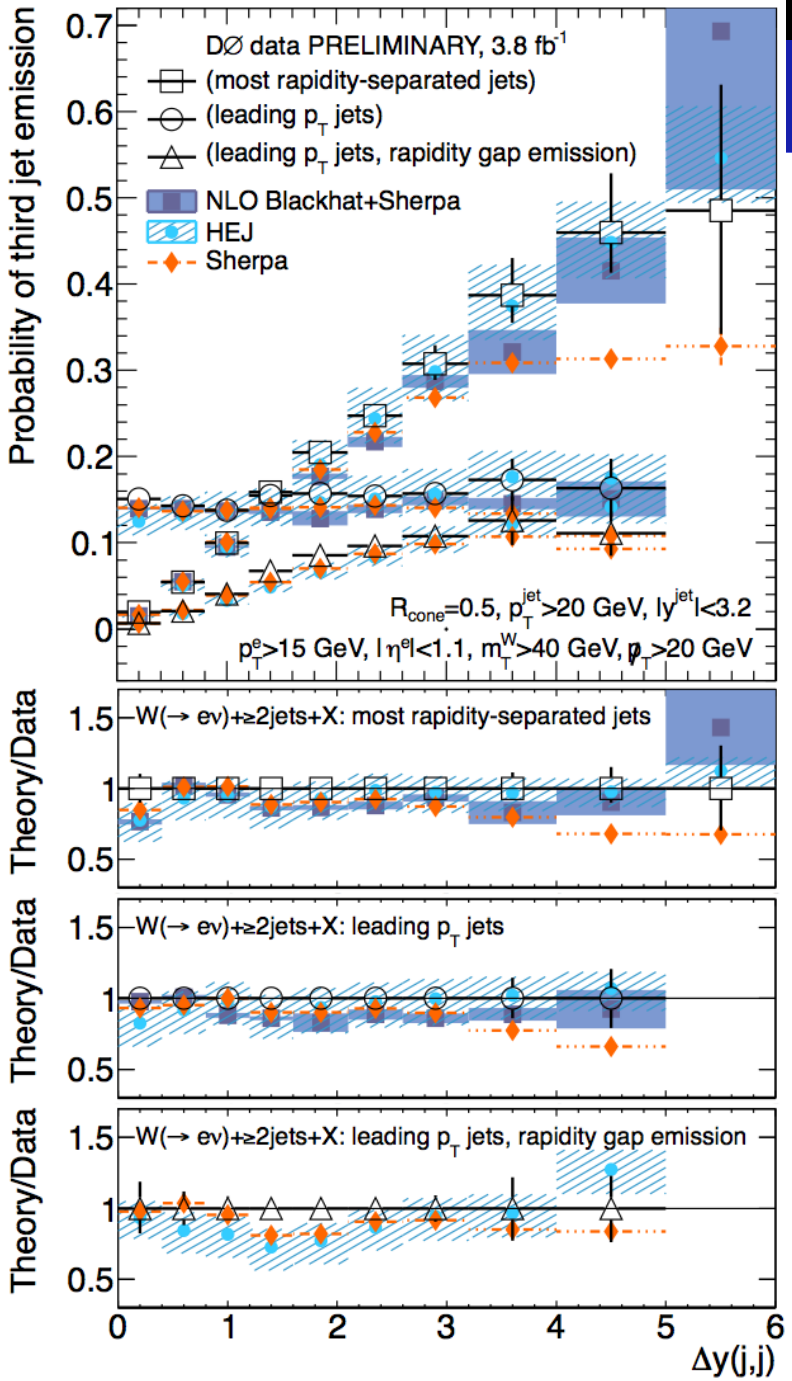
W+(n)jets differential cross-section measured as a function dijet mass
(in inclusive two and three jet multiplicity bins)

Good agreement between data and theory predictions

NLO Blackhat+Sherpa tends to predict slightly higher 2-jet rate than seen in data

Jet Energy Scale and Jet Energy Resolution systematic uncertainties dominant over range of measurement

W+jets: jet emission



Probability of third jet emission in inclusive W+dijet events, as a function of dijet rapidity separation(s).

Encouraging agreement between theoretical approaches and data in all jet configurations, even at highest rapidity spans

Notable differences in jet emission into the rapidity gap for p_T and rapidity ordered jets

For rapidity-ordered jets:

- HEJ in particular performs well with small uncertainties at wide angle
- Sherpa behaves like most MEPS (or PS) MC's with insufficient radiation at wide angle

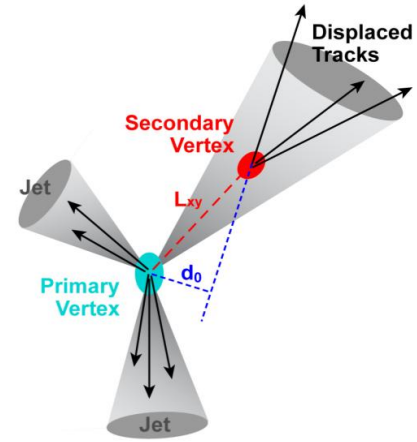
Data can be reinterpreted as a measure of the gap fraction (with a jet veto scale of 20 GeV), relevant for processes like Vector Boson Fusion

σ(Z+b)/σ(Z+jets) measurement

Ratio of inclusive Z+b to Z+jets cross-sections

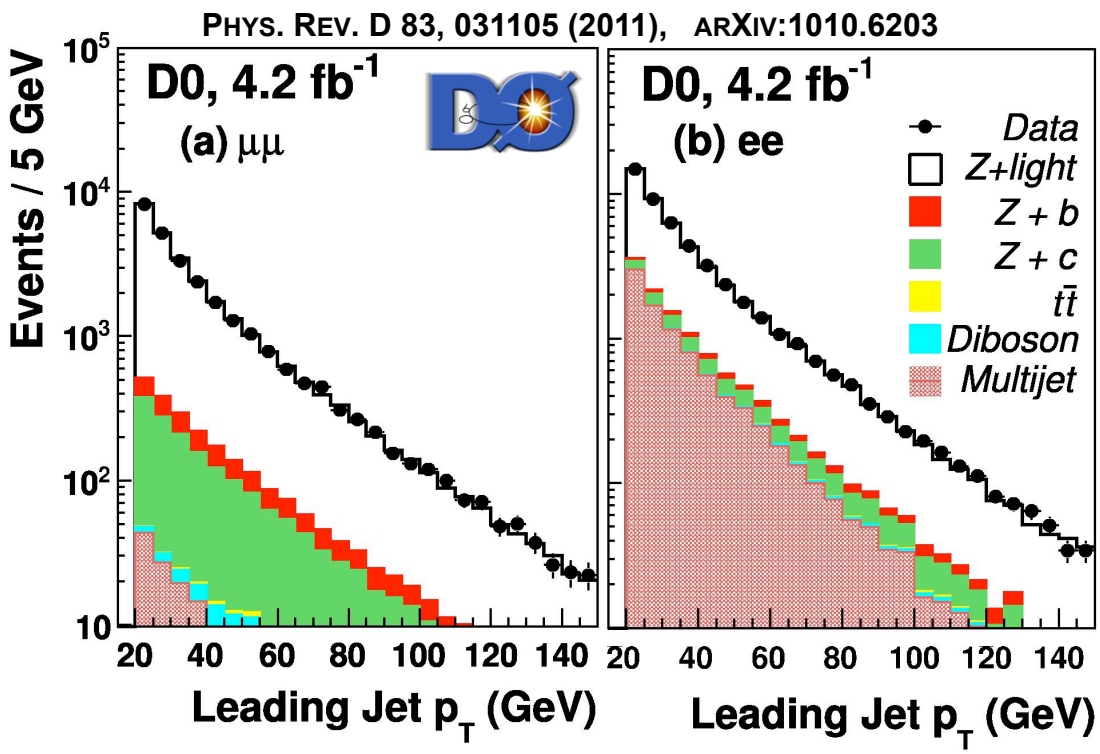
Test of pQCD calculations and b-quark fragmentation, b-quark PDF

Z+b important background to single-top, ZH, new phenomena



Study both di-electron and di-muon channels and combine:

Lepton p_T>15 GeV, jet p_T>20{15} GeV, jet |η|<2.5



Measurement uses neural network based b-tagging algorithm.

Inputs include: B-lifetime, secondary vertices, vertex mass, & decay length significance…

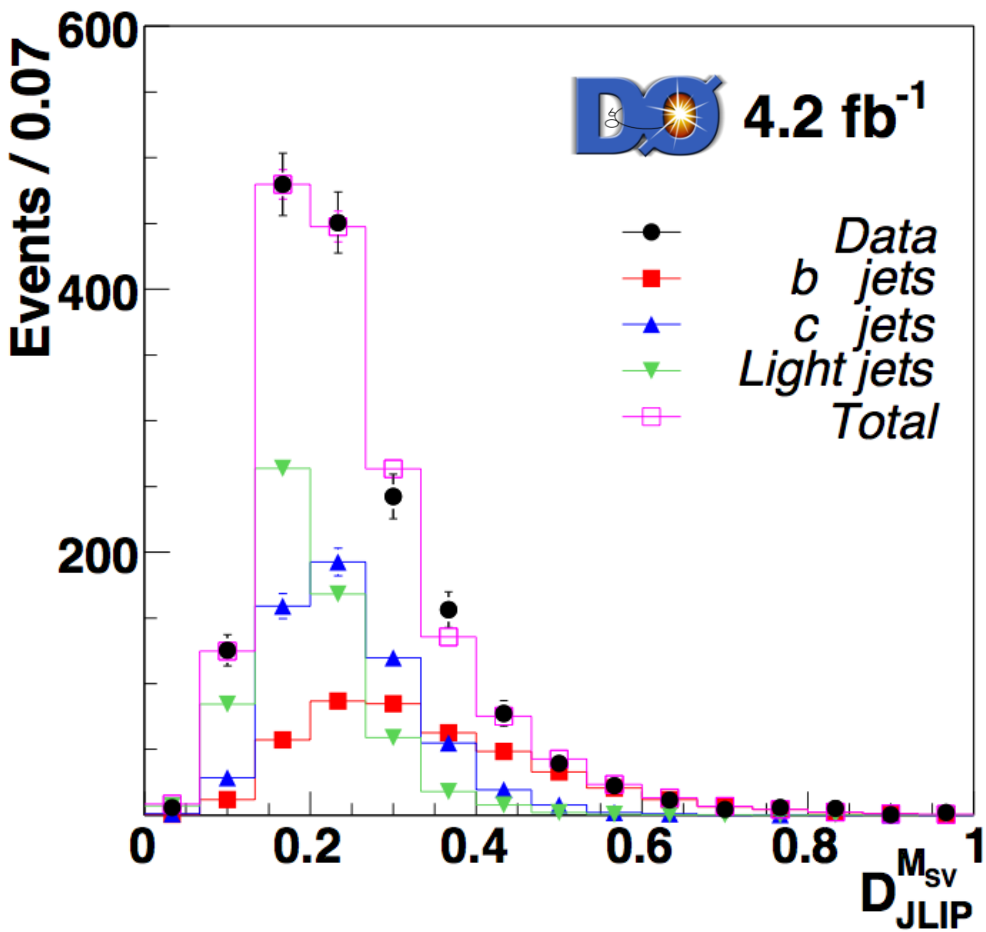
Tag efficiency: 58%, mis-tag rate: 2%

σ(Z+b)/σ(Z+jets) measurement

Jet flavour fractions measured in both di-electron and di-muon channels

Consistent results in both channels, so combine and re-measure with independent fit

PHYS. REV. D 83, 031105 (2011), ARXIV:1010.6203



Largest systematics come from discriminant template shape (4.2%) and efficiency uncertainties (3.7%)

Measured (Z+b)/(Z+jet) = $0.0192 \pm 0.0022_{stat} \pm 0.0015_{syst}$

Consistent with NLO MCFM = 0.0185±0.0022

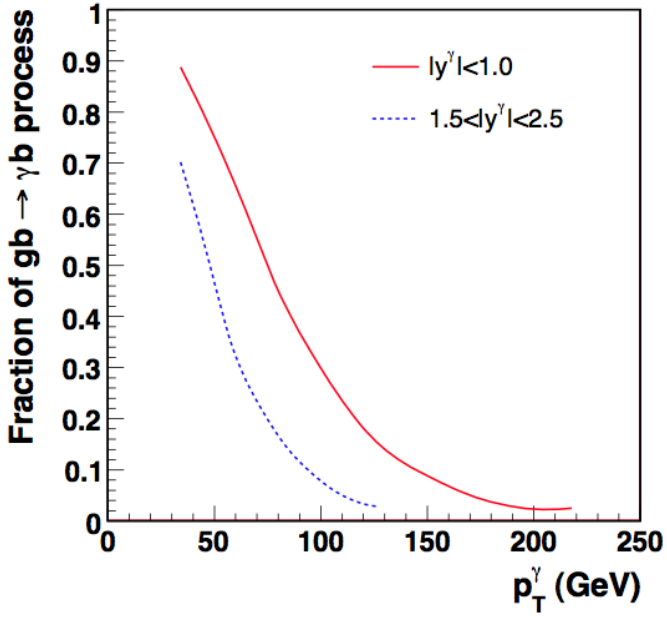
Further measurements on an extended dataset coming soon…

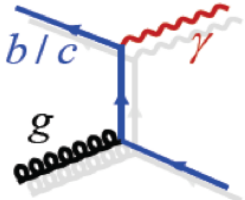
Isolated photon + b-jet production

Prompt photons emerge unaltered from hard scatter: probe QCD dynamics and quark and gluon PDFs

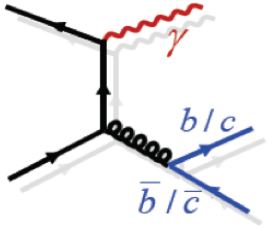
Measure production cross-section of photon +b-jet production as a function of photon p_T and rapidity

$\|y\|<1.0$	$(30 < p_T < 300$ GeV)
$1.5<\|y\|<2.5$	$(30 < p_T < 200$ GeV)





Compton scattering processes dominate at low photon p_T
b-quark comes from colliding hadrons, acts as a probe of b-quark PDF

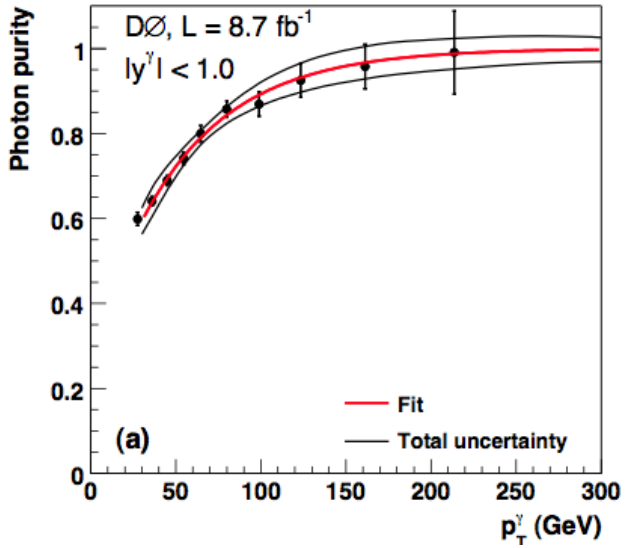


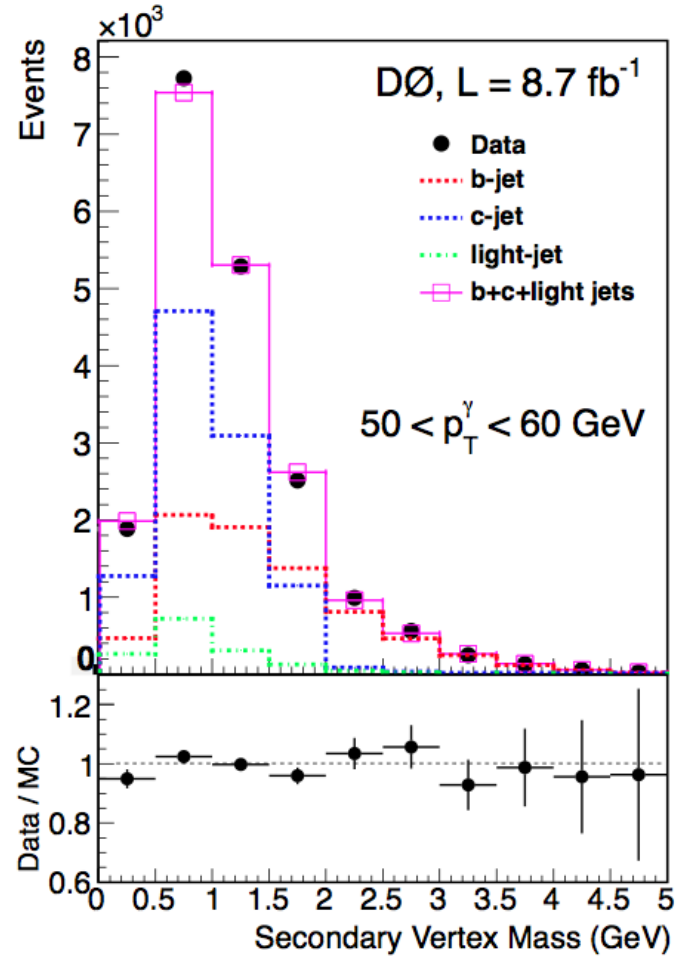
Quark-antiquark annihilation playing an increasing role as p_T increases
b-quark comes from gluon splitting and thus acts as a probe of gluon PDF

Require photon to be isolated to suppress contribution from fragmentation

Isolated photon + b-jet production

Significant backgrounds from multi-jet events where jet fakes a photon.
Photon neural net output template fits used to determine photon purity.



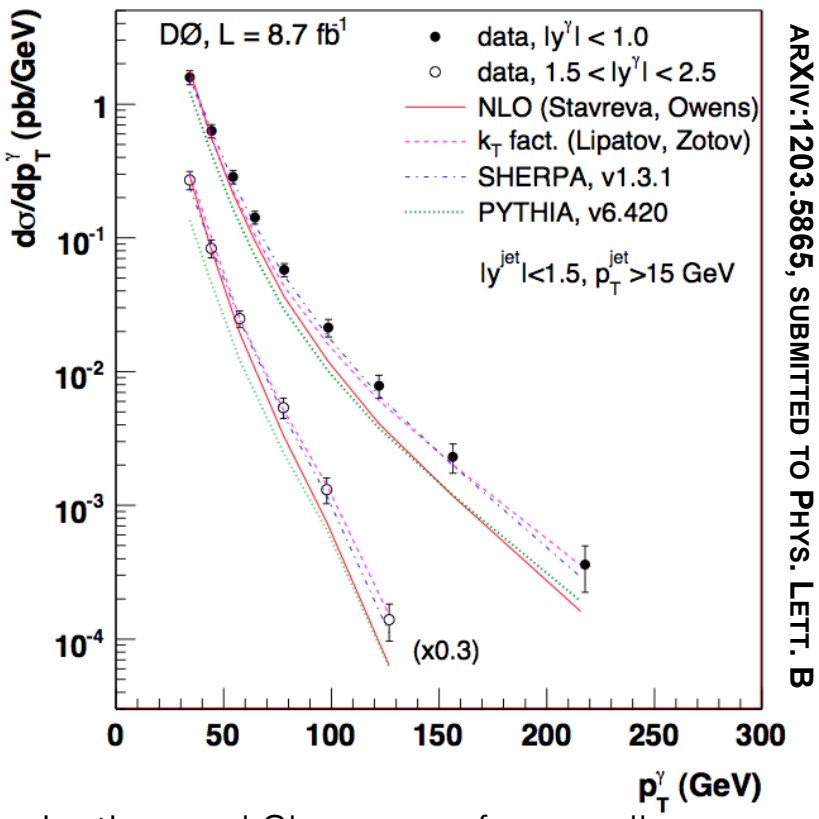


As for Z+b, use discriminator templates to isolate b-jets from charm and light flavour
(secondary vertex mass, number of secondary vertices, decay length and impact parameter significances)

Efficiency 40-52%, mistag rate 0.2-0.4%

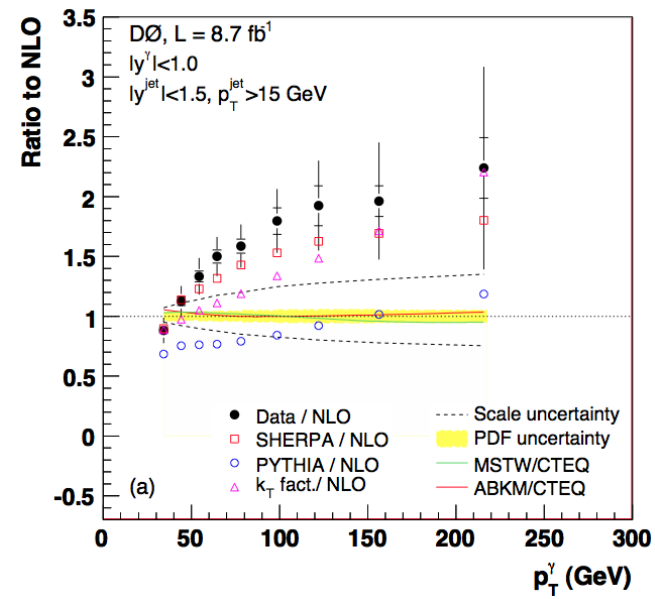
Isolated photon + b-jet production

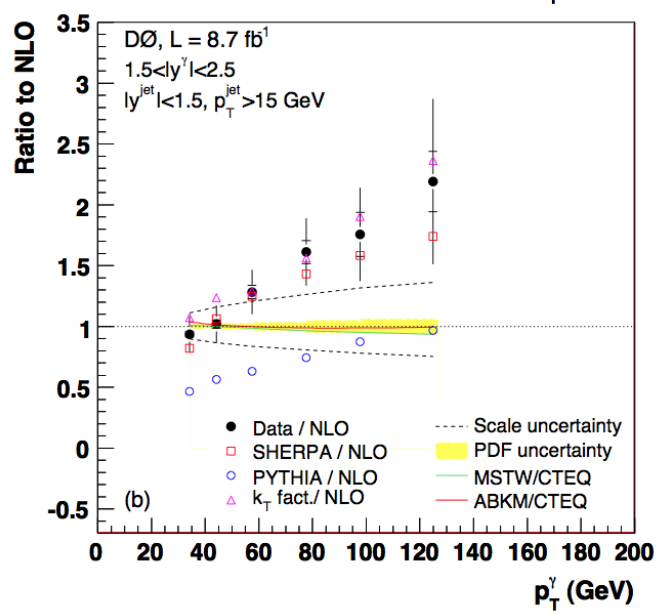
NLO describes data at low p_T (<70 GeV), significant discrepancies at high p_T



k_T-factorisation and Sherpa perform well.

Higher order corrections needed in high p_T region dominated by annihilation processes





Summary

There is a rich and active QCD physics program at DØ!
Wide range of measurements, with many more still to come

- Measurements of elastic scattering at 1.96 TeV in ppbar collisions as a probe of the (anti-)proton
- Novel observables in inclusive jet production to study QCD dynamics, extract the strong coupling and test predictions of the renormalisation group equation over a range of momentum transfers of up to 400 GeV
- Studies of W+jets production dynamics, jet emission, wide angle modelling
- Z+b-jet cross-section measurement
- Photon+b-jet differential cross-sections

Results overall show good agreement with theory predictions
Some discrepancies observed where modelling should be improved