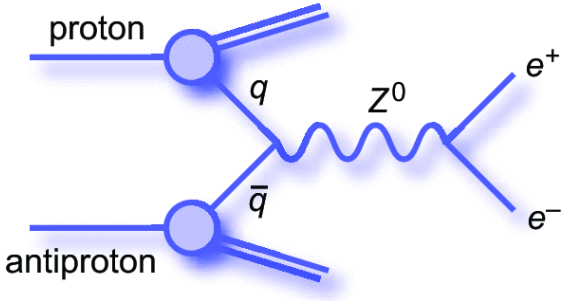
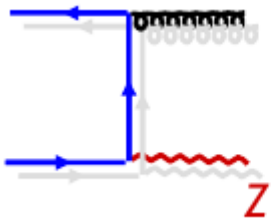
W/Z + jets measurements at D0

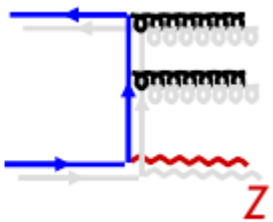
N.Skachkov (JINR, Dubna)

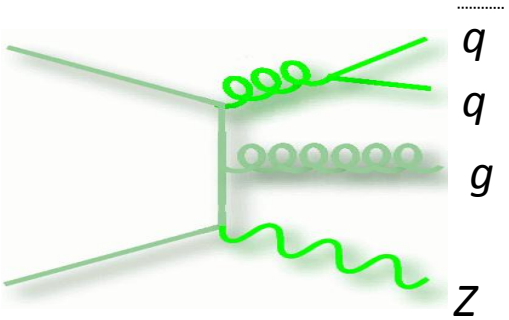
On behalf of the DØ Collaboration

Vector Boson + Jets (N_{jet} =1, 2, 3 …)









- relevant to other high-multiplicity processes
- background to Higgs

Provide detailed measurements of p_T and angular distributions of vector boson and jet

→ test perturbative QCD calculations

→ testing and tuning of phenomenological models

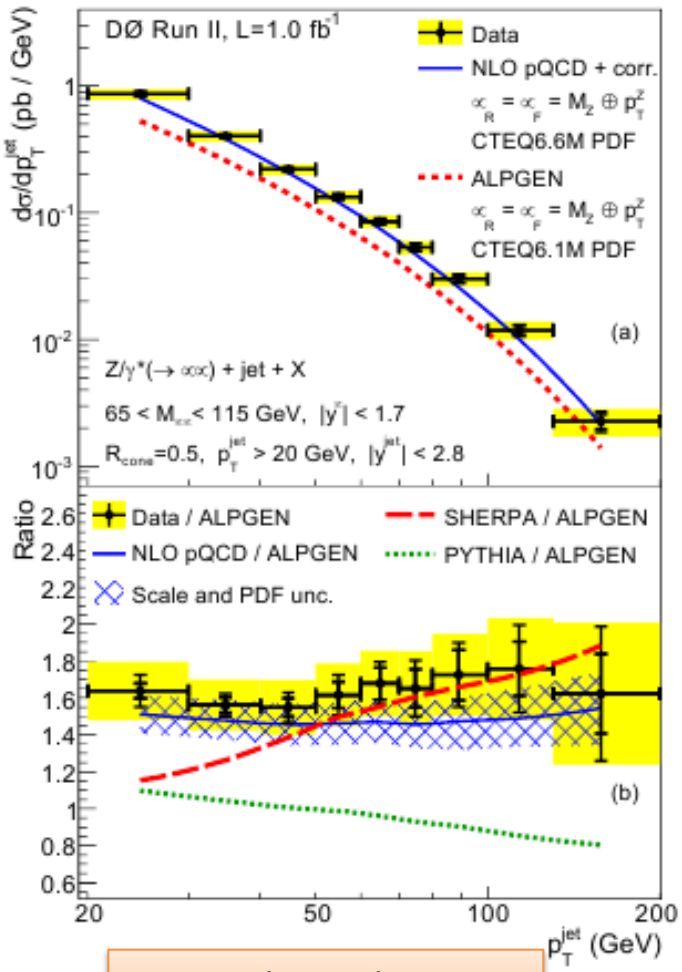
Differential Z/gamma + 1jet+ X cross section , **D0**

$Z/\gamma^*(\rightarrow \mu^+\mu^-)$

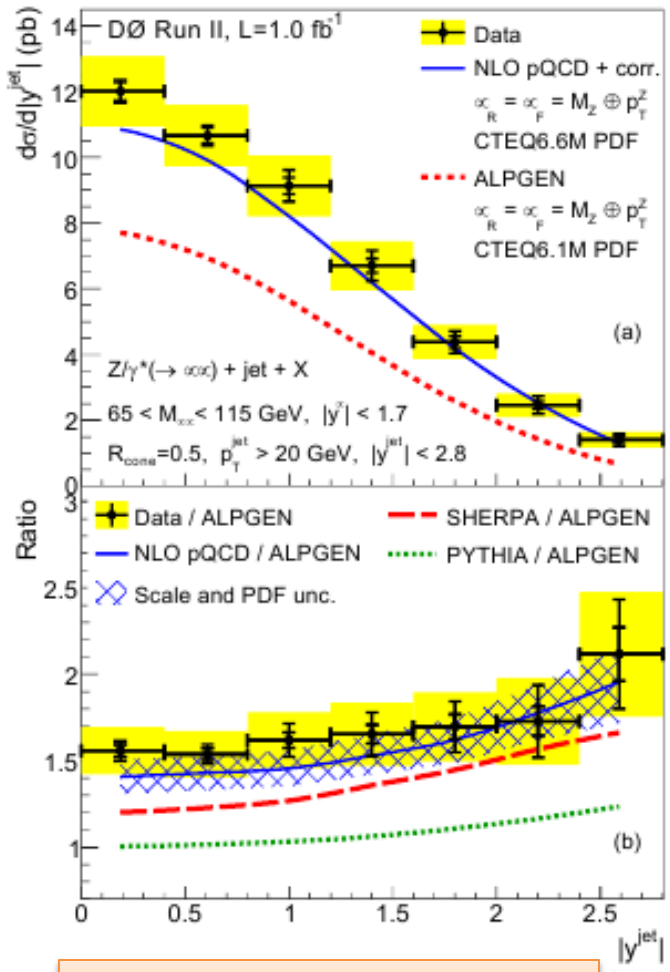
L= 1 fb-1

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

$65 < M_{\mu\mu} < 115$ GeV, $|y_\mu| < 1.7$, $p_T^{jet}(R=0.5) > 20$ GeV, $|y_{jet}| < 2.8$



Pt- jet dependence



Jet- rapidity dependence

NLO pQCD: MCFM v5.4
PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = M_Z^2 + p_{T,Z}^2$

PYTHIA 6.323,
ALPGEN 2.05,
SHERPA 1.1.1,
PDF: CTEQ6.1M

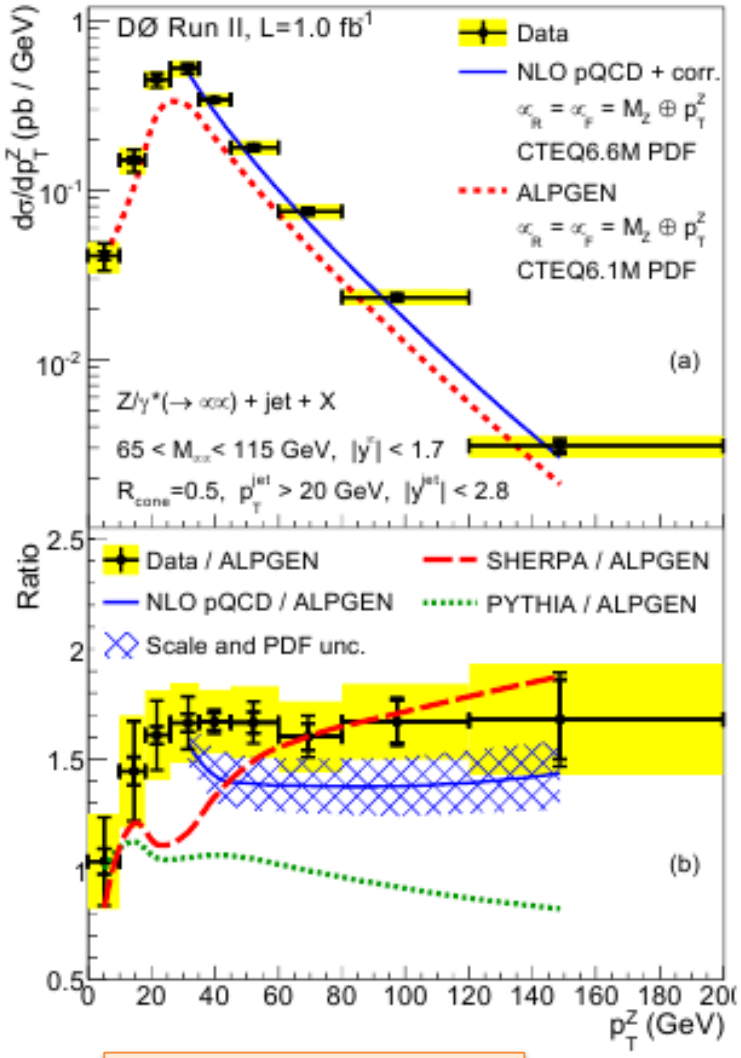
NLO pQCD prediction 5% below measured cross section.

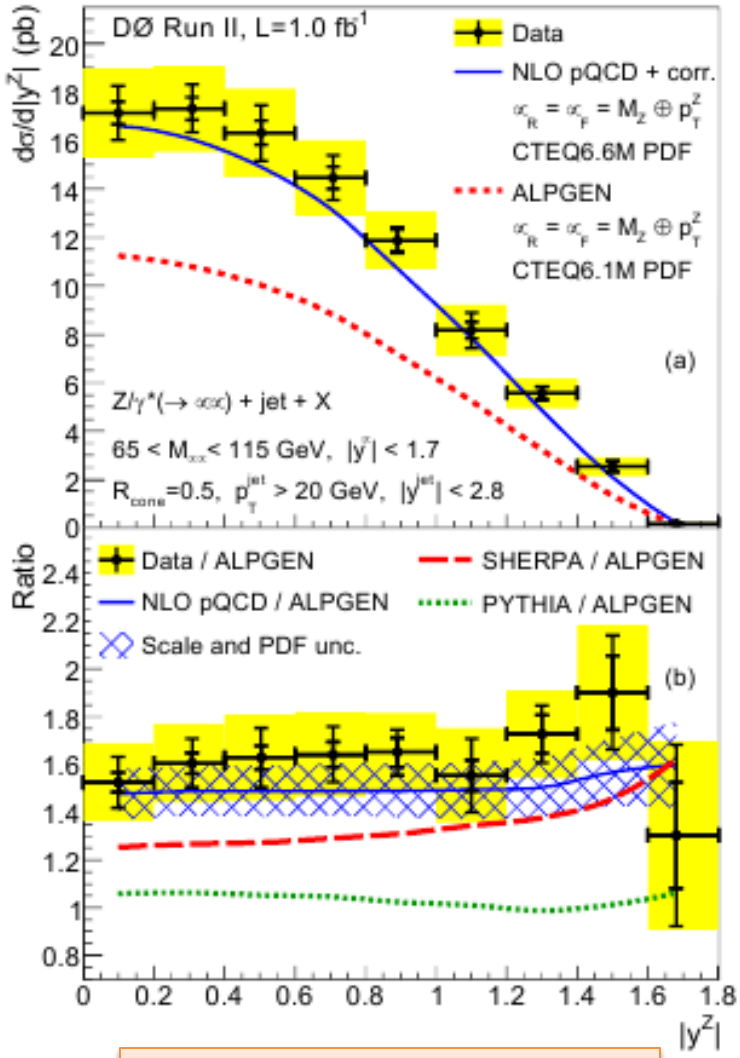
For $p_T(Z) < 30$ GeV prediction sensitive to underlying event

Total cross section prediction of ALPGEN and PYTHIA significantly below data

Differential Z/gamma + 1jet+ X cross section , **D0**

$$\sigma(z/\gamma^*(\rightarrow \mu\mu)+\text{jet}+X) = 18.7 \pm 0.2(\text{stat.}) \pm 0.8(\text{syst.}) \pm 0.9(\text{muon}) \pm 1.1(\text{lumi.})\ \text{pb}$$





1.The shapes are well described by NLOpQCD

2.Cross section at lower Pt-Z is dominated by non -perturbative process.

Pt- Z dependence

Z- rapidity dependence

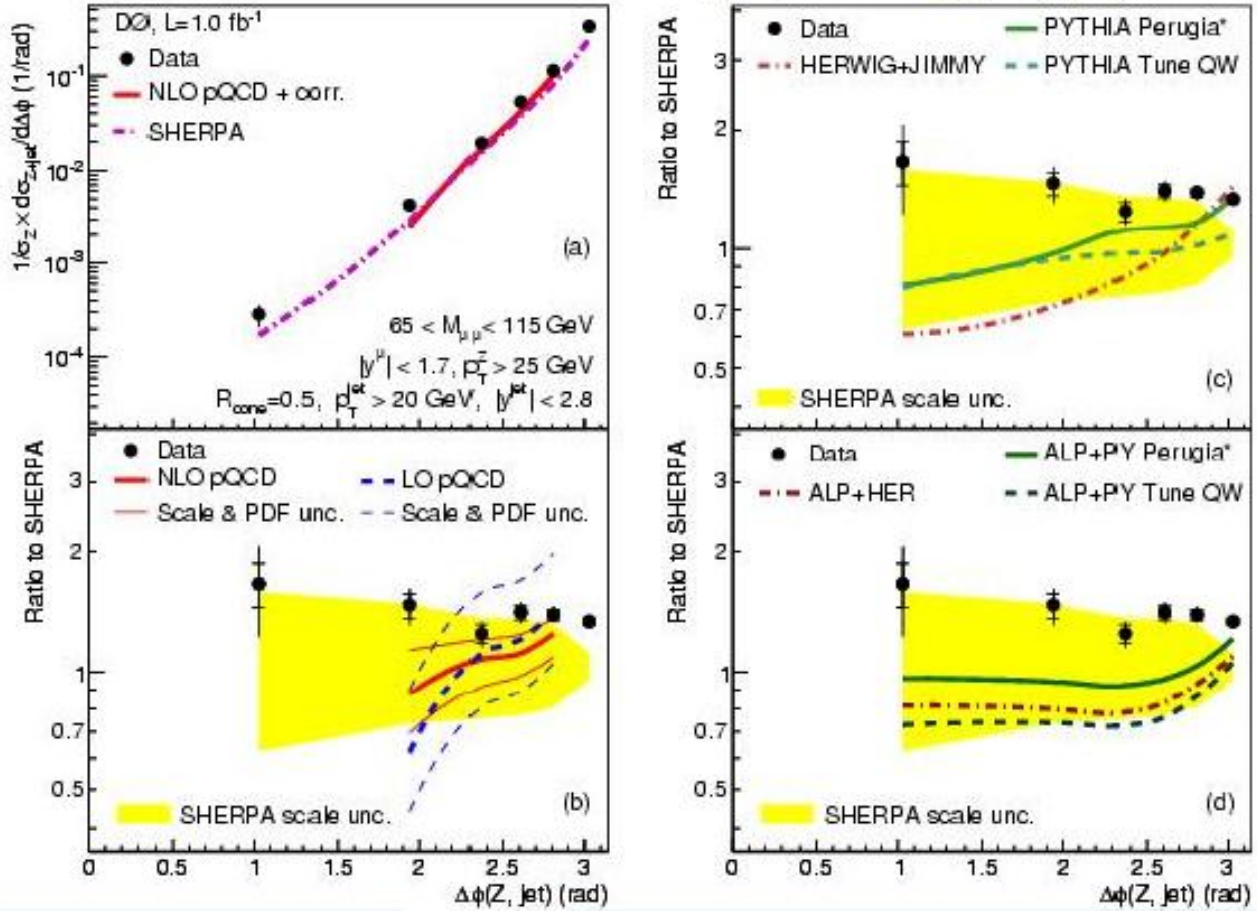
Differential Z/gamma + 1jet+ X angular distributions, D0

L= 1 fb-1

Phys.Lett. B, **682,** 370 (2010)

$Z/\gamma^*(\rightarrow\mu^+\mu^-)$ + jets: angular correlations

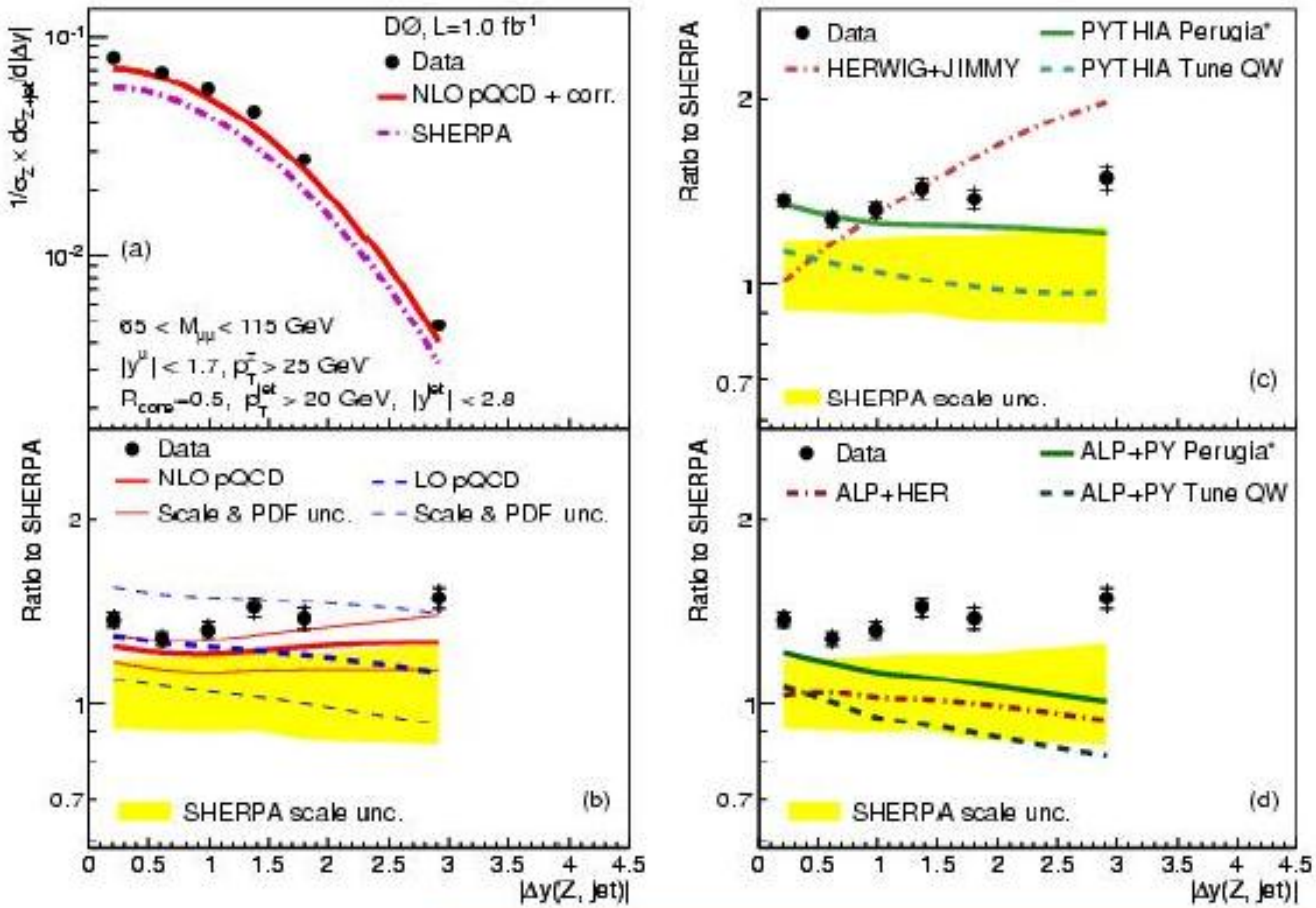
- Normalized diff. cross section in $\Delta\phi$(Z,leading jet), $p_T^Z > 25$ GeV



SHERPA is preferred by data

$Z/\gamma^*(\rightarrow\mu^+\mu^-)$ + jets: rapidity correlations

- Normalized diff. cross section in Δy(Z,leading jet) , $p_T^Z > 25$ GeV



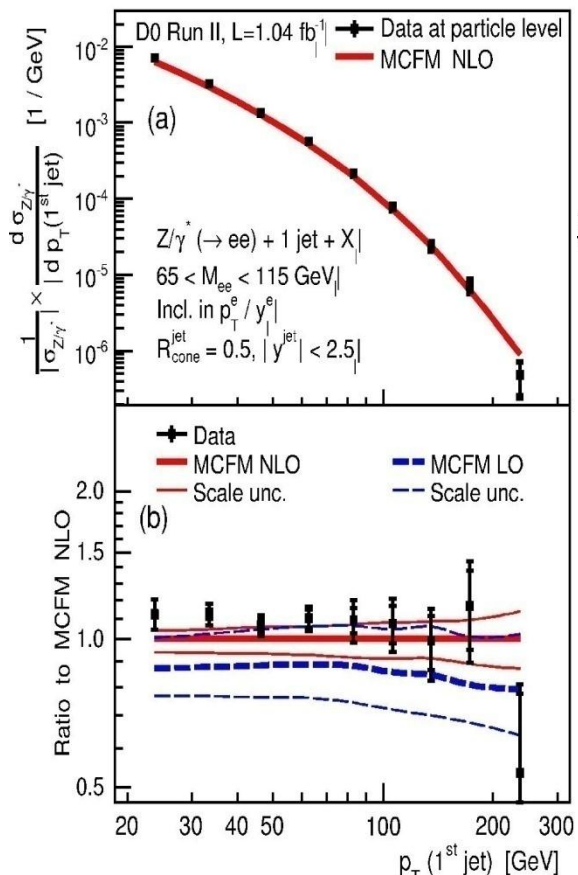
- NLO pQCD is preferred by data

Cross Section for Z/gamma + jets (1,2,3) + X, **D0**

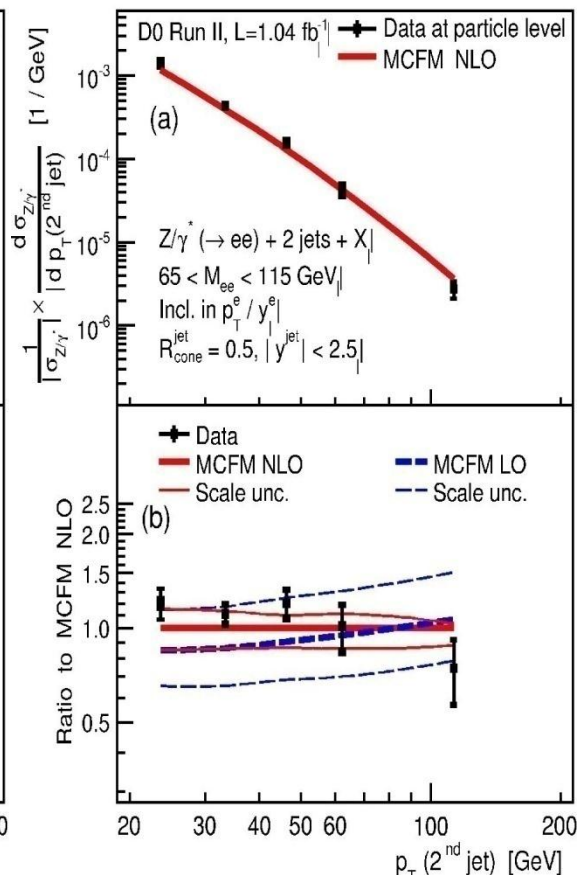
Measurement of 1st, 2nd and 3rd jet p_T in Z events:
→normalize to inclusive Z production (cancel some uncertainties)
compare to pQCD @ LO / NLO

FERMILAB-PUB-09-066-E
arXiv:0903.1748v2 [hep-ex]
4Aug 2009

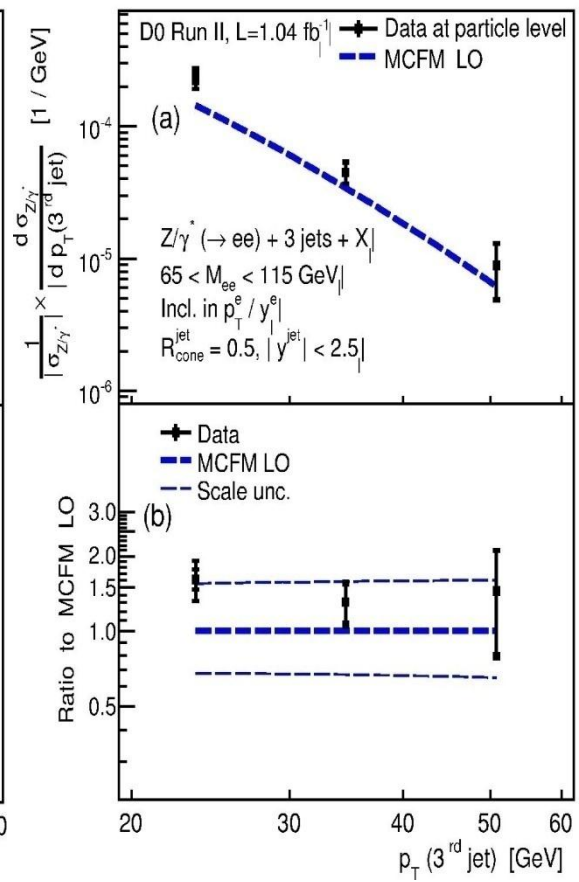
Leading jet in Z + jet + X



Second jet in Z + 2jet + X



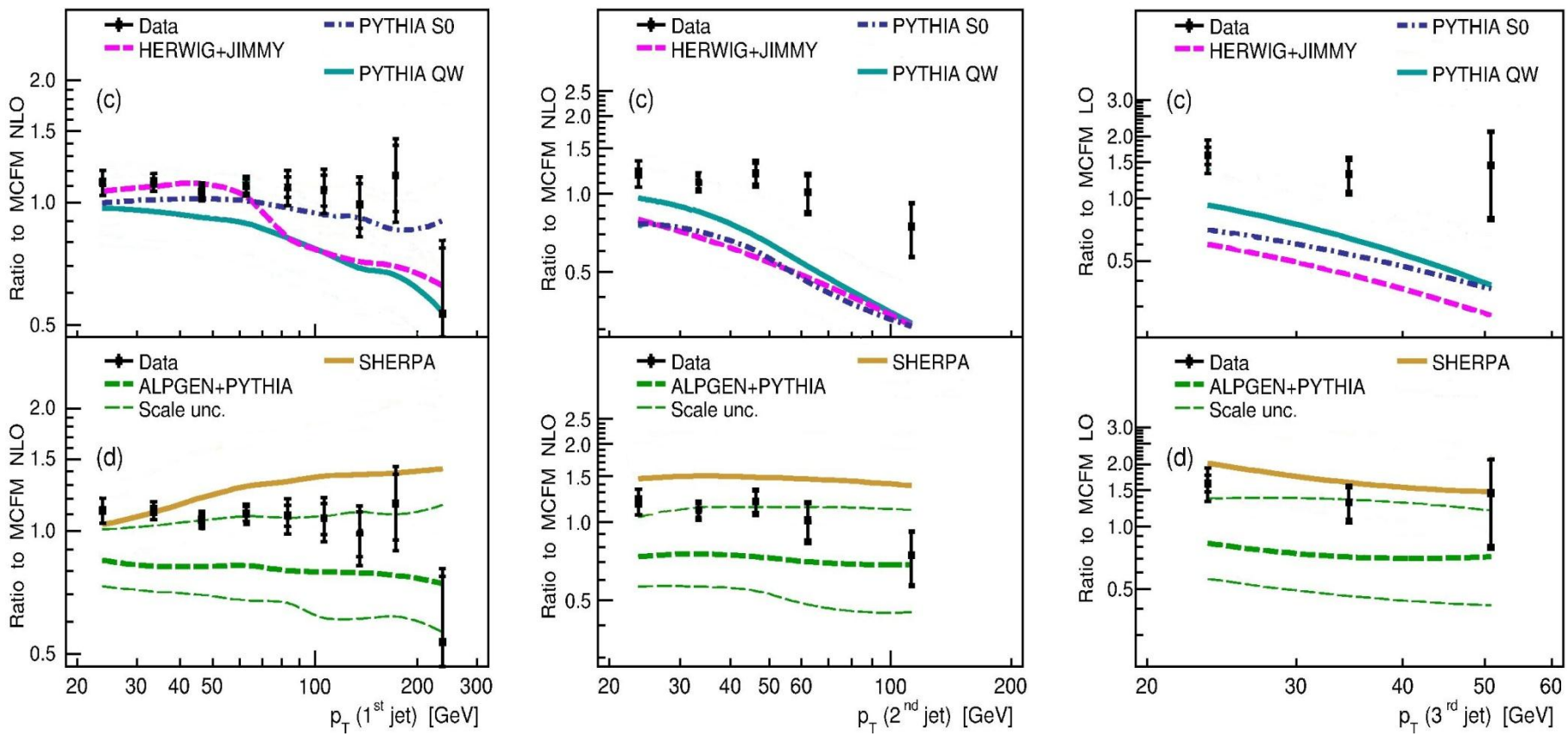
Third jet in Z + 3jet + X



Cross Section for Z/gamma + jets (1,2,3) + X, **D0**

Ratios of data and different MC generators → favor ALPGEN +PYTHIA w/ low scale
For "ALPGEN + PYTHA" (- - -) scales (factoriz. and renorm.) can be chosen so that a good, simultaneous agreement with data is achieved for all three leading jets .

Leading jet in Z + jet + X | **Second jet in Z + 2jet + X** | **Third jet in Z + 3jet + X**



Ratio of Cross Sections Z + b-jet/Z+jet , D0

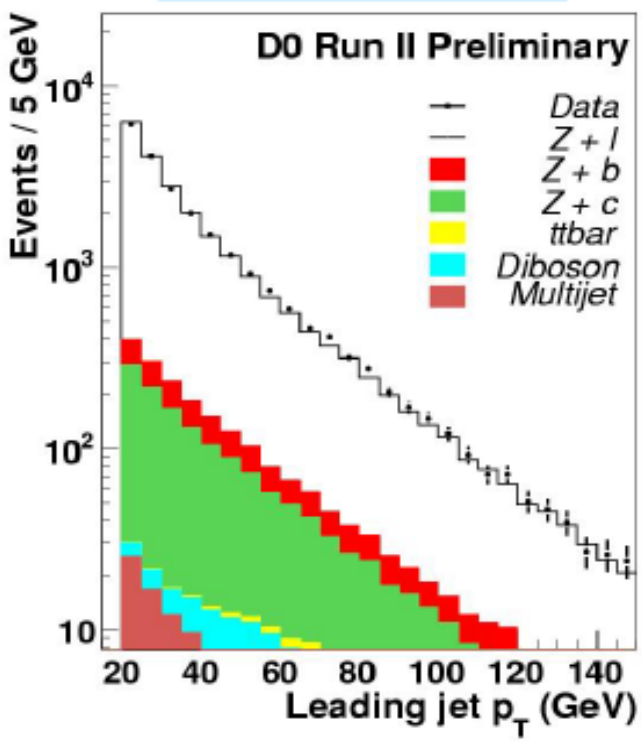
L= 4.2 fb-1

D0 Note 6053--CONF (2010)

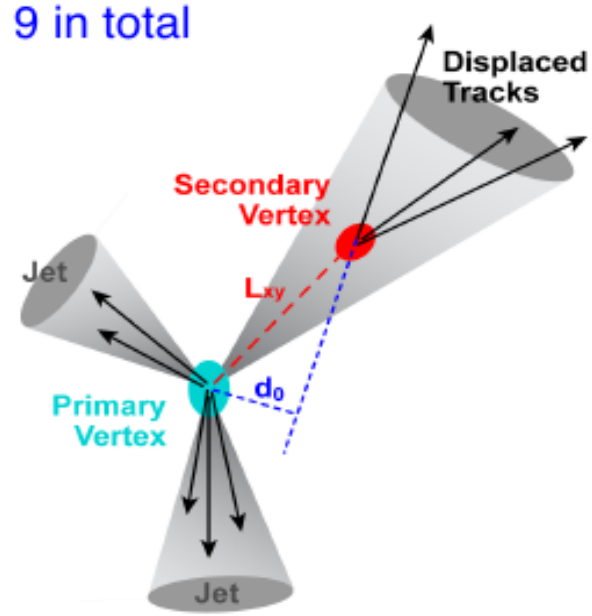
σ(Z+b)/σ(Z+jet) ratio measurement

- Event Selection
  - Dilepton mass 70≤M≤110 GeV
  - ≥ 1 jet: p_T> 20 GeV, |η|<1.1

Before tagging



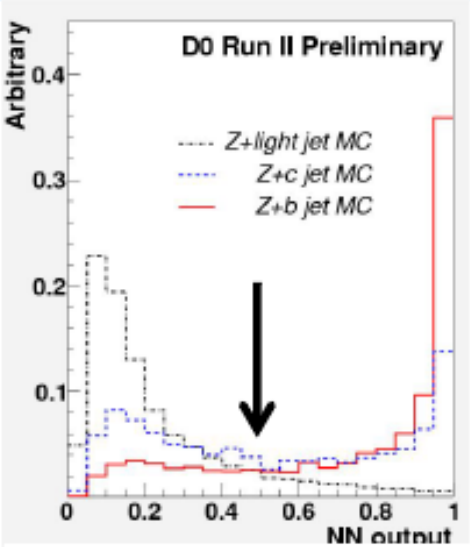
- Inputs for NN tagging algorithm
  - Decay length significance of sec. vtx
  - No. of tracks associated to sec. vtx.
  - Mass of the sec. vertex
  - (reduced) Jet Lifetime Probability, rJLIP: confidence level that all tracks in a jet originate from primary vertex
  - etc., 9 in total

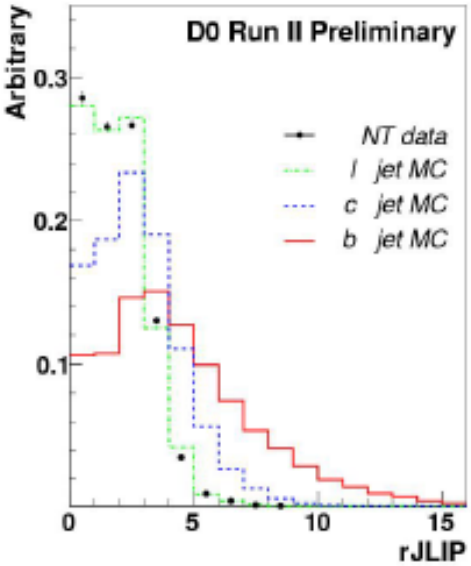


Ratio of Cross Sections Z + b-jet/Z+jet , **D0**

Separation of light, c and b jets

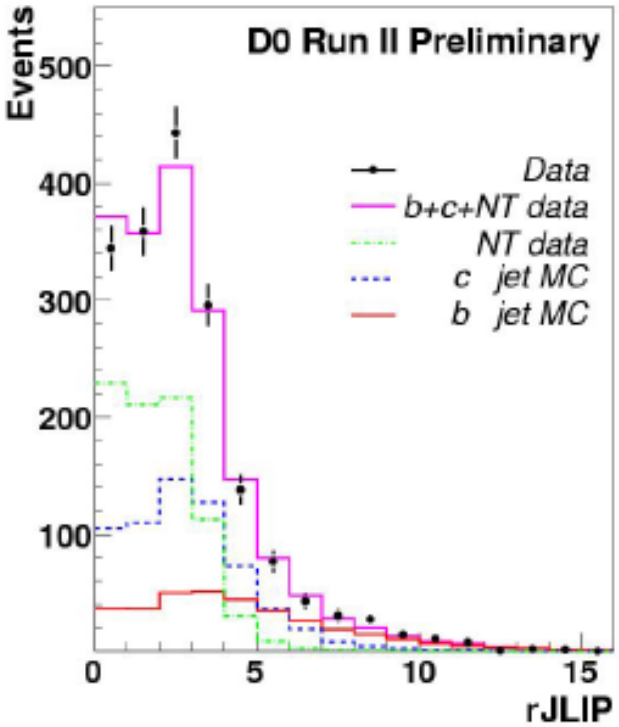
- Apply Neural Network tagging algorithm on jets to enrich b content
- Use rJLIP variable to discriminate between light, c and b jets
- Light jet template is derived from "Negatively Tagged" (NT) data
  - Jets are formed from tracks that have negative values for some of the inputs for the NN algorithm
- Use Alpgen+Pythia for b and c jet templates
- Use log likelihood fit to extract Z+b fraction from the preselected sample

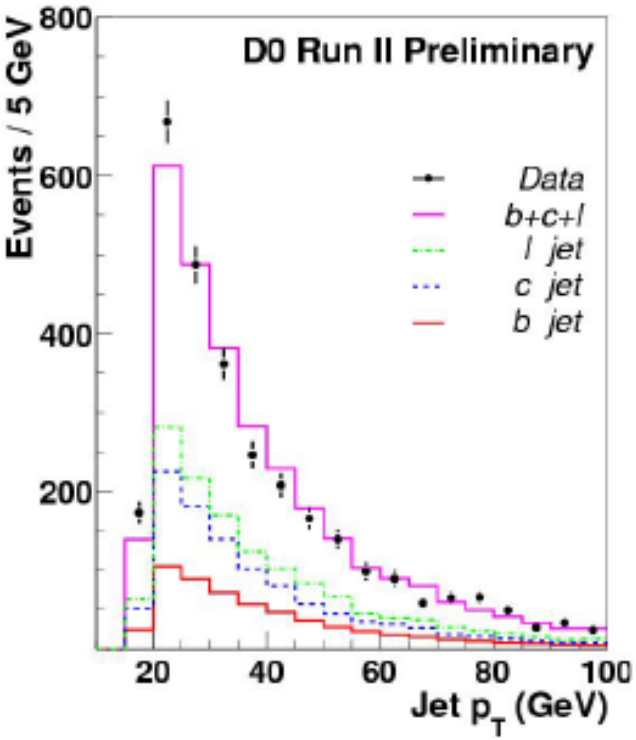




Ratio of Cross Sections Z + b-jet/Z+jet , **D0**

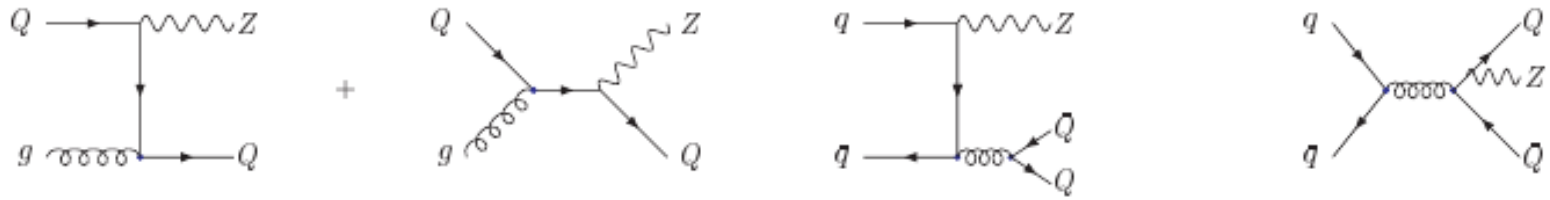
σ(Z+b)/σ(Z+jet): preliminary results





Z+b fraction	**0.191 ± 0.030**
Z+c fraction	0.384 ± 0.072
Z+light jet fraction	0.424 ± 0.054
σ(Z+b)/σ(Z+jet) NLO/MCFM	**0.0176 ± 0.0024 (stat) ± 0.0023 (syst)** 0.0184 ± 0.0022

Ratio of Cross Sections Z + b-jet/Z+jet , D0



σ (Z + b-jet) / σ (Z +jet) = 0.021 $\pm$ 0.005

D0:
Phys. Rev. Lett.,
94, 161801 (2005)

L= 180 pb-1

σ (Z + b-jet) / σ (Z +jet) = 0.0208 $\pm$ 0.0033(stat.) $\pm$ 0.0034(syst.)

CDF : Phys. Rev., D,
79, 052008 (2009)

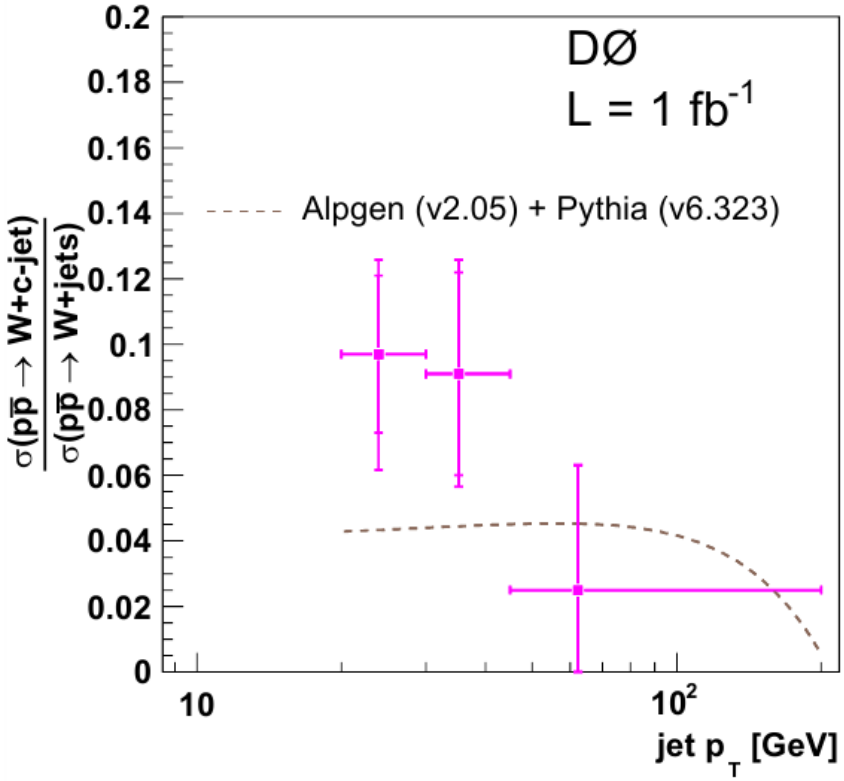
L= 2.0 fb-1

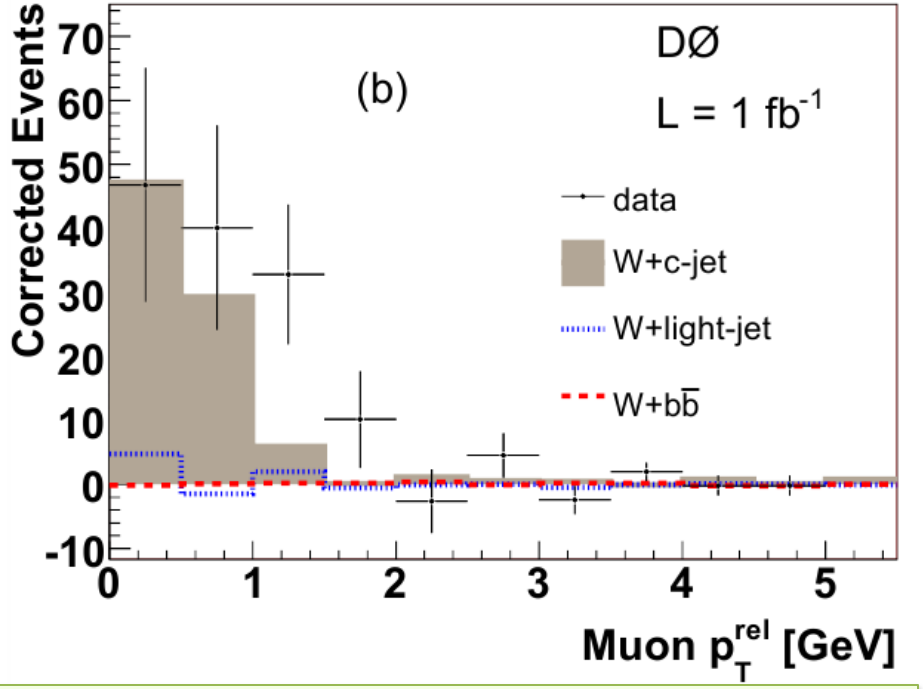
D0: L= 4.2 fb-1

σ(Z+b)/σ(Z+jet) NLO/MCFM	0.0176 ± 0.0024 (stat) ± 0.0023 (syst) 0.0184 ± 0.0022

Ratio of the W+c-jet+X Cross Section to the W +jets+X Cross Section, **D0**

FERMILAB-PUB-08/062-E
arXiv:0803.2259v1 [hep-ex]
14 Mar 2008





Ratio is close to the prediction of
Alpgen + PYTHIA

Relative transverse momentum of the jet-muon with respect to the jet axis, PT^{rel}, shows the consistency between data and the c-jet expectation.

Ratio of the W+c-jet+X Cross Section to the W +jets+X Cross Section, **D0**

The measured $W+c$-jet fractions integrated over $p_T >$ 20 GeV and $|\eta| < 2.5$ are

$$\frac{\sigma\left[W\left(\rightarrow e\nu\right)+c\text{-jet}\right]}{\sigma\left[W\left(\rightarrow e\nu\right)+\text{jets}\right]} = 0.073 \pm 0.023(\text{stat.})^{+0.012}_{-0.014}(\text{syst.}),$$

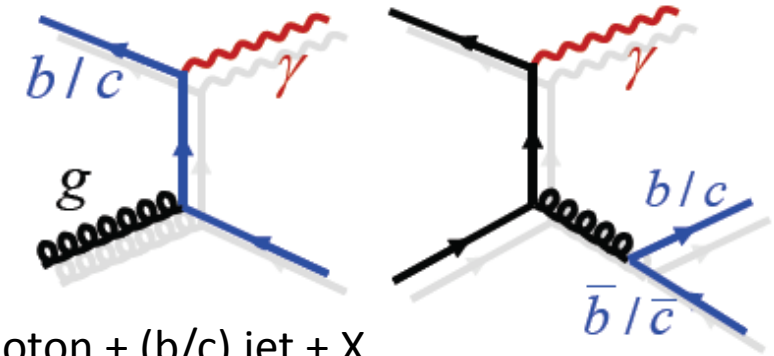
$$\frac{\sigma\left[W\left(\rightarrow \mu\nu\right)+c\text{-jet}\right]}{\sigma\left[W\left(\rightarrow \mu\nu\right)+\text{jets}\right]} = 0.075 \pm 0.031(\text{stat.})^{+0.015}_{-0.017}(\text{syst.}).$$

Since the $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ measurements are consistent with one another, and statistical uncertainties dominate, the two lepton channels are combined to yield

$$\frac{\sigma\left[W+c\text{-jet}\right]}{\sigma\left[W+\text{jets}\right]} = 0.074 \pm 0.019(\text{stat.})^{+0.012}_{-0.014}(\text{syst.}).$$

Isolated Photon + HF Jet

Phys. Rev. Lett. **102**, 192002 (2009)



Photon + (b/c) jet + X

Photon p_T : 30-150 GeV

0.01<x<0.3 → b, c, gluon PDF

→ test gluon splitting contribution

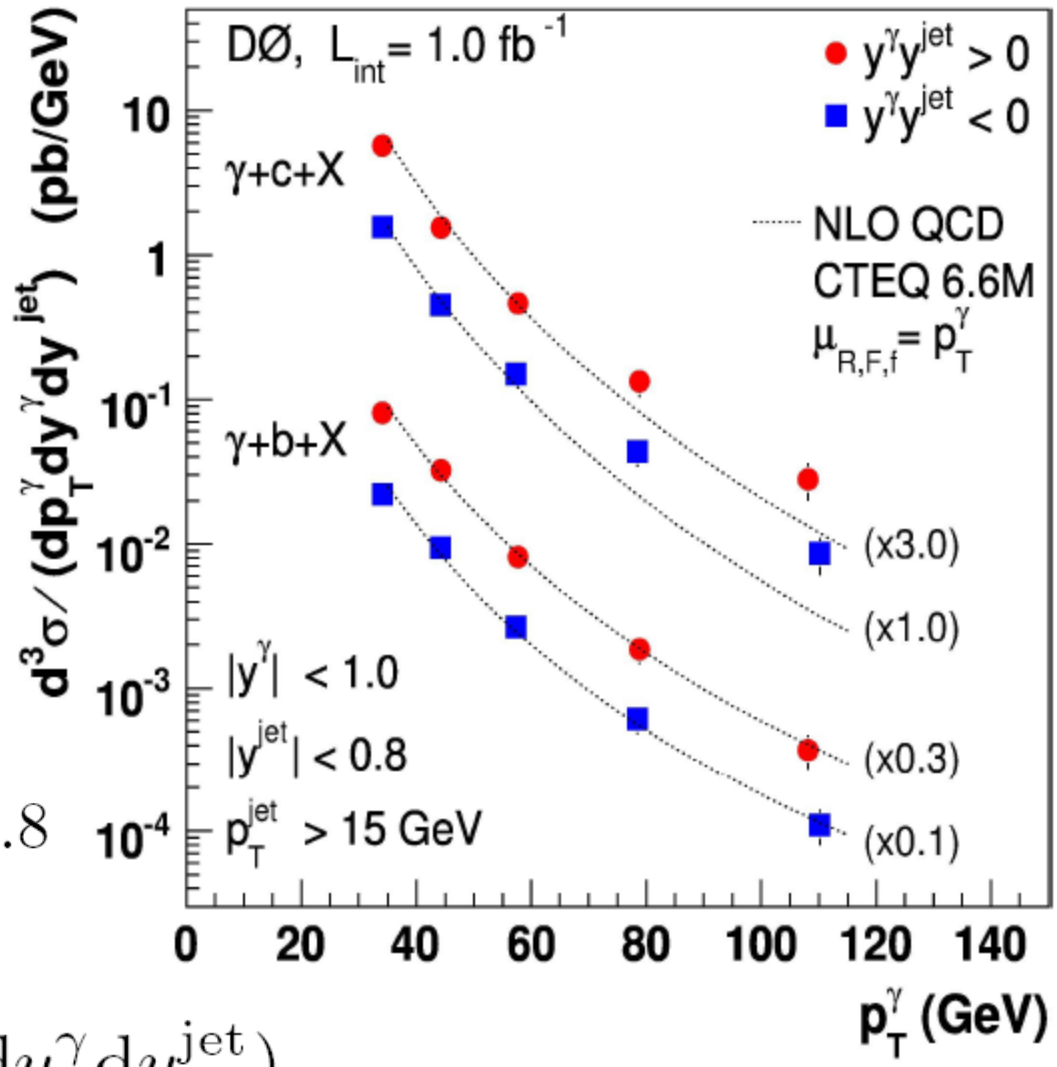
tag **photon and jet**

Rapidities:

$$|y^\gamma| < 1.0 \qquad |y^{\mathrm{jet}}| < 0.8$$

→ triple differential

$$\mathrm{d}^3\sigma/(\mathrm{d}p_T^\gamma \mathrm{d}y^\gamma \mathrm{d}y^{\mathrm{jet}})$$



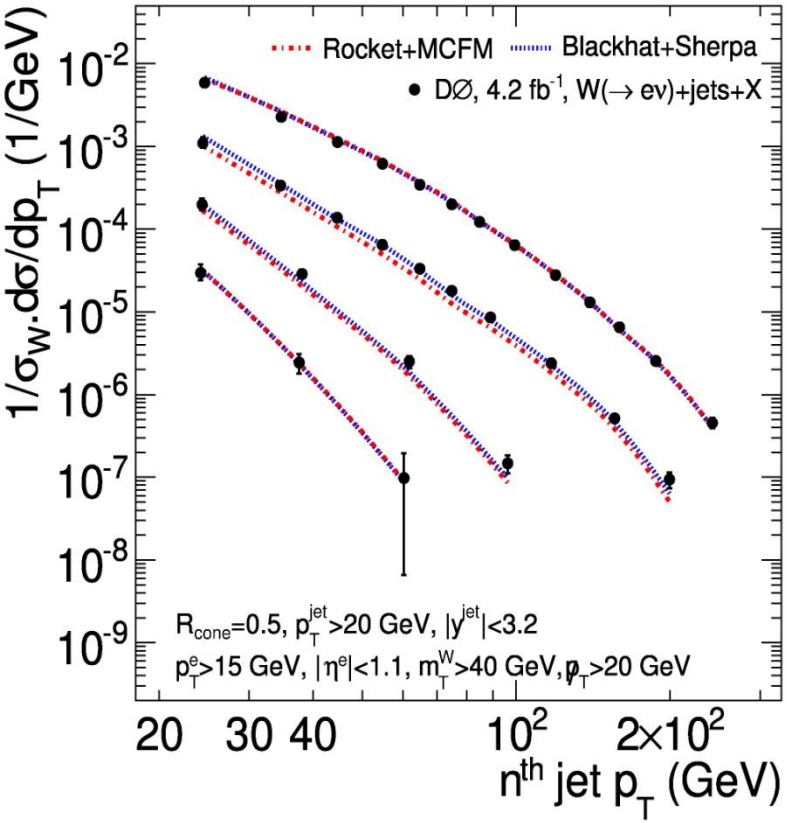
W+jets production D0

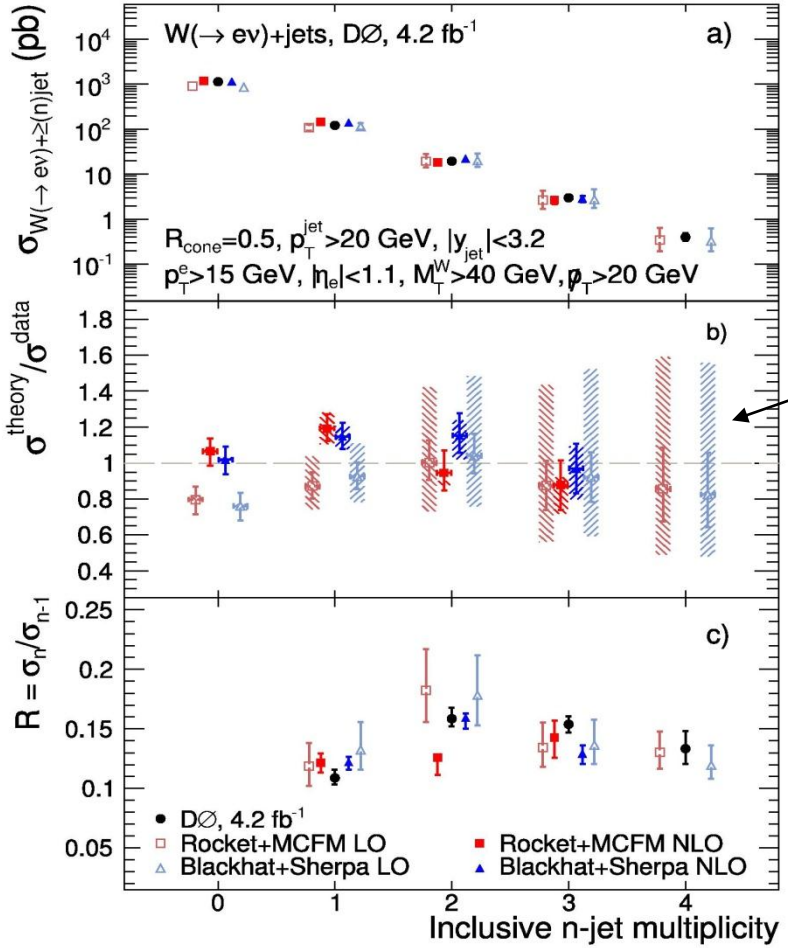
Dominant background to the single top, ttbar, SM Higgs, many BSM searches

4.2 fb^{-1}

- The measurement tests W+n-jet (n=1-4) production cross section vs n-th jet pT
  – Normalized to σ(W)
- Comparison to LO&NLO by Blackhat+Sherpa and Rocket+MCFM

Phys.Lett. B705 200 (2011)





Theor. scale uncertainty

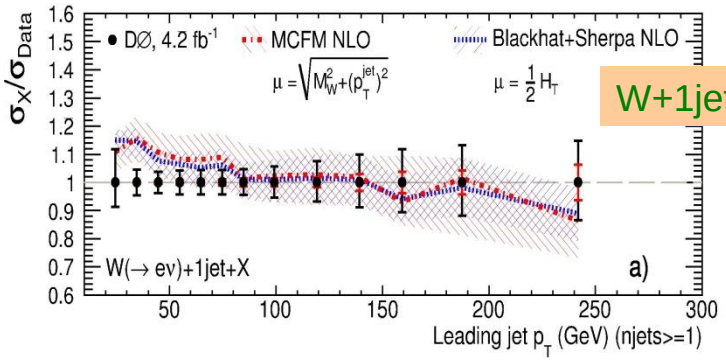
W+jets production D0

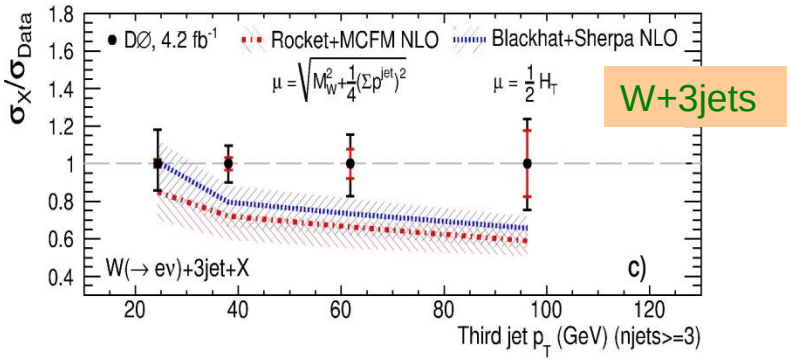
Phys.Lett. B705 200 (2011)

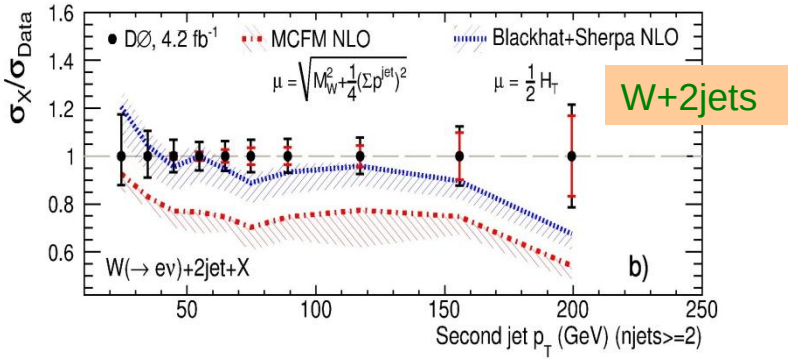
Dominant background to the single top, ttbar, SM Higgs, many BSM searches

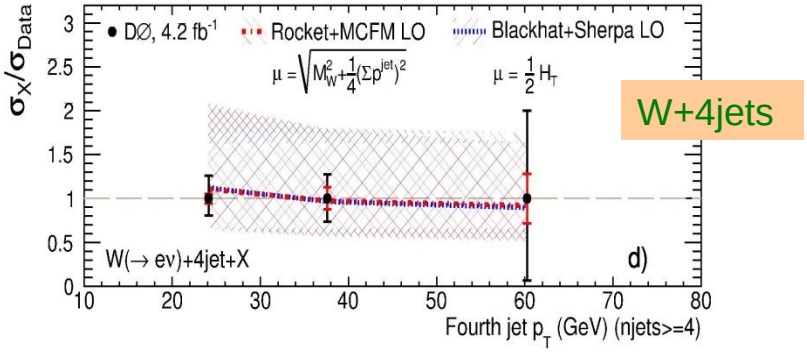
- The measurement tests W+n-jet (n=1-4) production cross section vs n-th jet pT
- Comparison to LO&NLO by Blackhat+Sherpa and Rocket+MCFM (different scales)

Phys.Lett. B705 200 (2011)









- In agreement with QCD NLO in jet pT and #jets
- Experimental uncertainties are lower than theoretical (scale) in many cases
  => tuning the theory
- First W+4jets result (only LO prediction has been available for the Tevatron)

– W+n-jet differential x-section in ~40(!)variables is in a review

Ratio of Cross Sections Z + b-jet/Z+jet , D0

L= 4.2 fb-1

D0 Note 6053--CONF (2010)

σ(Z+b)/σ(Z+jet) ratio measurement

- Event Selection
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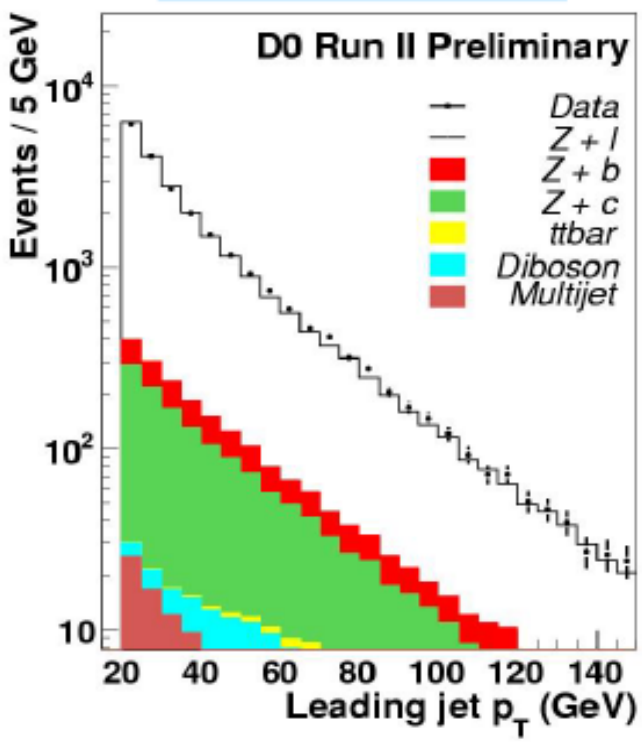

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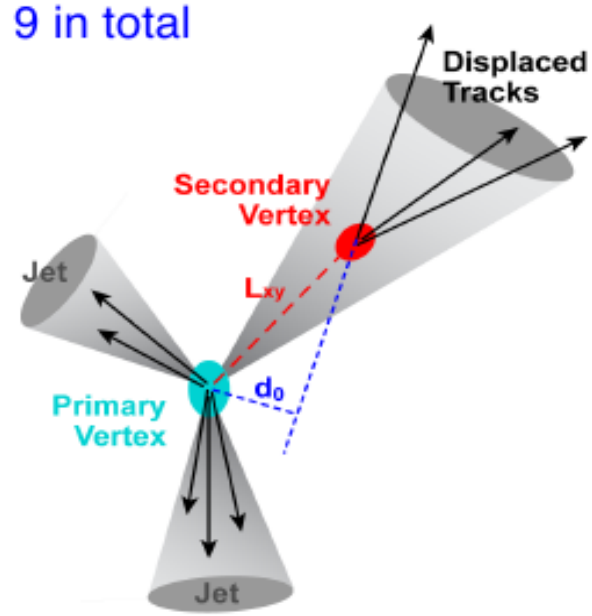
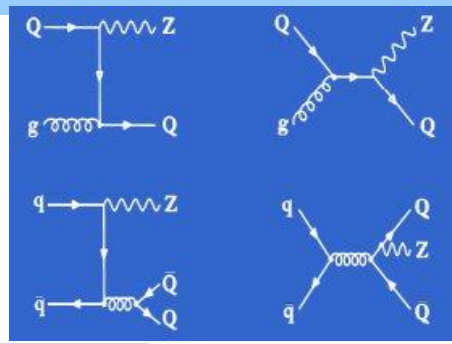
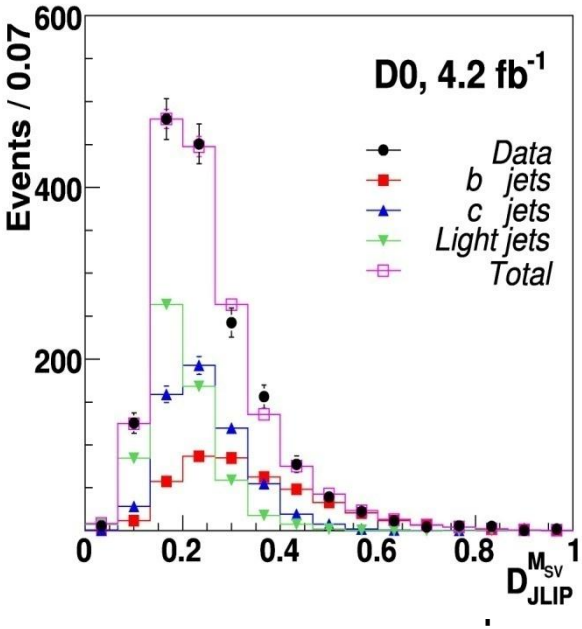


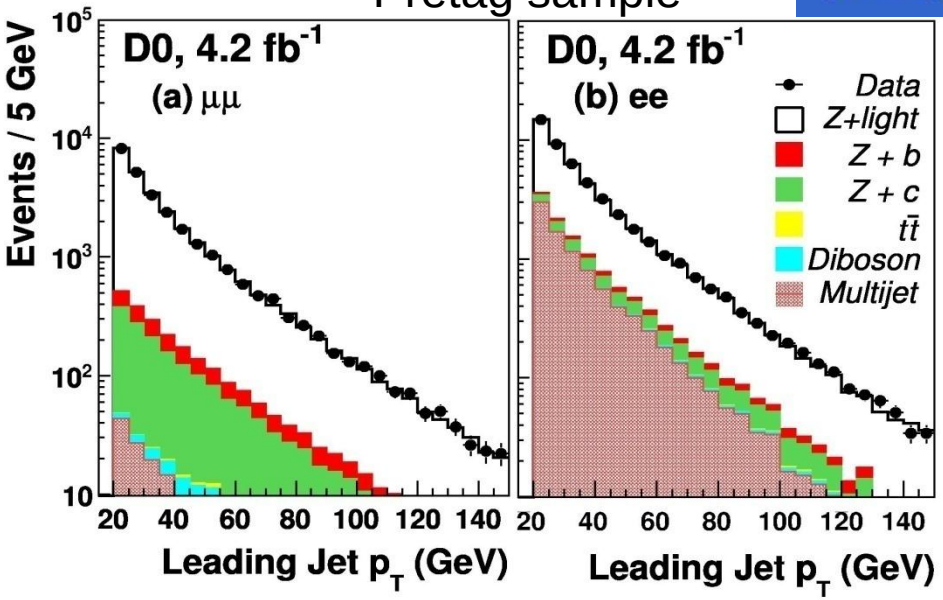
x-section ratio (Z+b) / (Z+jet) PRD83, 031105 (2011)

- Important background to the SM Higgs search in the ZH channel.
- Probe of b-quark PDF, important for gb → Hb & single-top studies
- Measurement of x-section ratio (Z+b) /(Z+j) benefits from cancellation of many systematics => precise comparison with theory





Pretag sample



PRD83, 031105 (2011)

– Measurement: **0.0193 ± 0.0022 (stat)□ 0.0015 (syst)** [~8% syst]
Most precise measurement of 'Z+b' fraction to date!
– Consistent with NLO theory**: 0.0192 +/- 0.0022**
(MCFM, renorm. and factor. scales are at Mz)
– Differential measurement in b-jet pT, (Z,jet) angles in progress

Summary

Tevatron in Vector Boson + jet measurements

=>Crucial for understanding backgrounds to

NP and SM Higgs searches

- Some discrepancies with theory suggest HO corrections and some theory components may need study: tuning of scale choices, PDFs, heavy quark fragmentation, etc

- Understanding of W+b jet x-section is extremely important
- New results on W+n-jets, Z+b and W+b are coming soon.
- Be tuned by looking at

D0: http://www-d0.fnal.gov/Run2Physics/qcd/D0_public_QCD.html

CDF:http://www-cdf.fnal.gov/physics/new/qcd/QCD.html

Backup