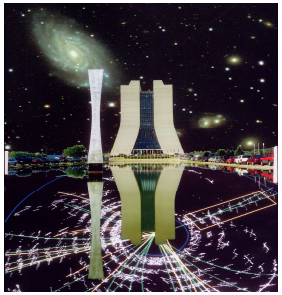
W/Z+Jets and W/Z+Heavy Flavor at the Tevatron



Sebastian Grinstein

ICREA/IFAE-Barcelona

Results from CDF & D0 Collaborations

Moriond QCD

March 13-20, 2010

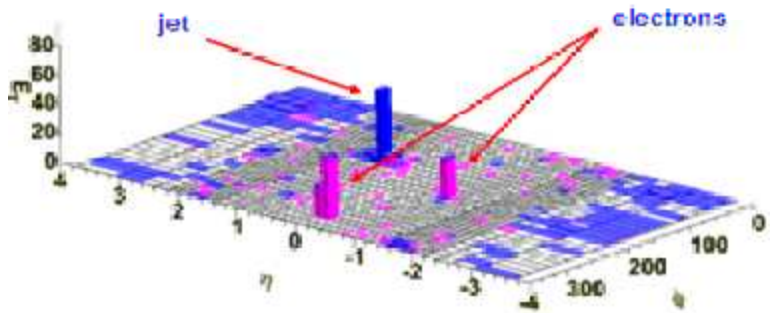
La Thuile, Italy

http://static.panoramio.com/photos/original/8432342.jpg

Vector Boson + Jets

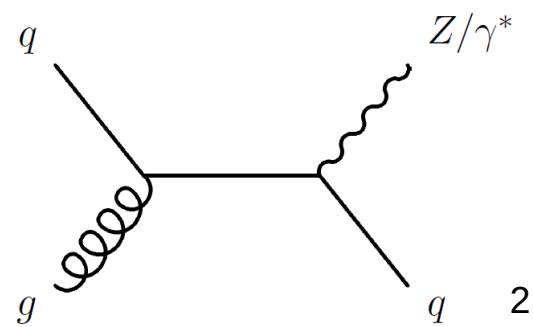
Test of pQCD predictions and Monte Carlo Models

- NLO pQCD predictions available up to 2 (3) jets
- Several Monte Carlo tools available
  - LO + parton shower (eg. Herwig, Pythia)
  - Tree level + parton shower (eg. Alpgen, Sherpa)
- Validate these tools with measurements
- Also background to small cross section processes



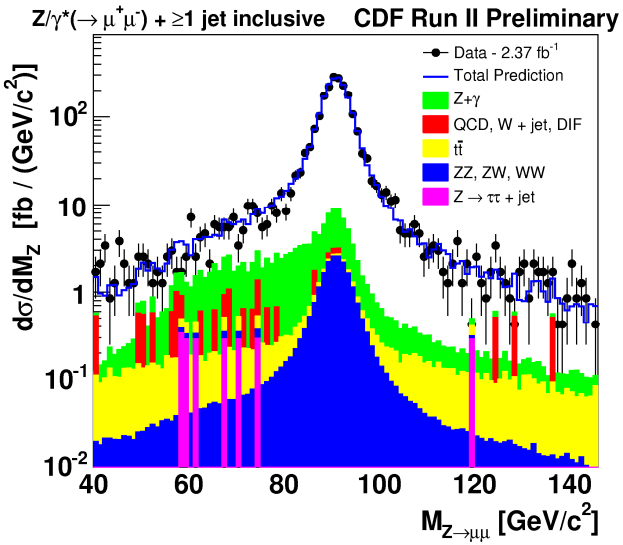
Will present:

- Z(→ μμ) + jets
- Z (→μμ) + jets angular distributions
- Z(→ee) + jets
- W(→eν) + jets

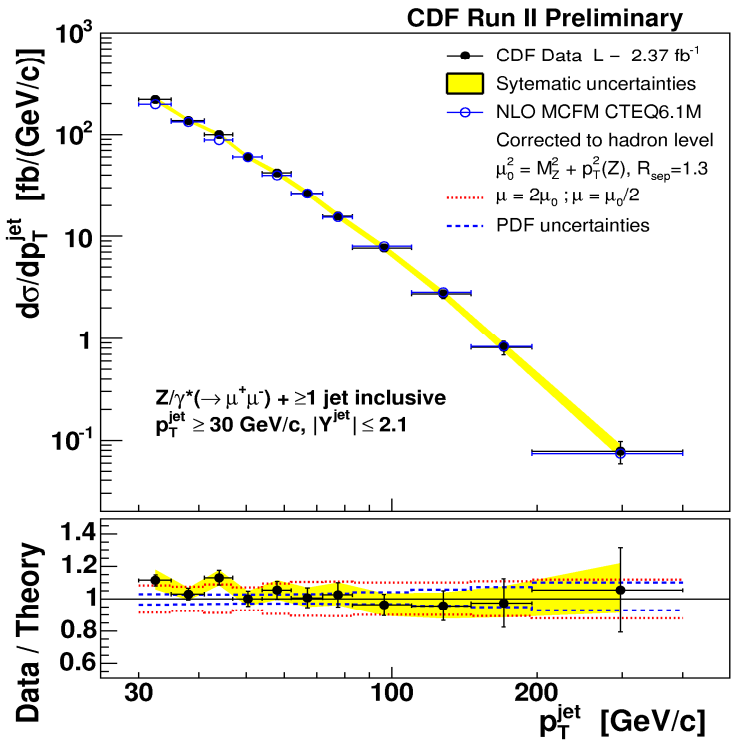


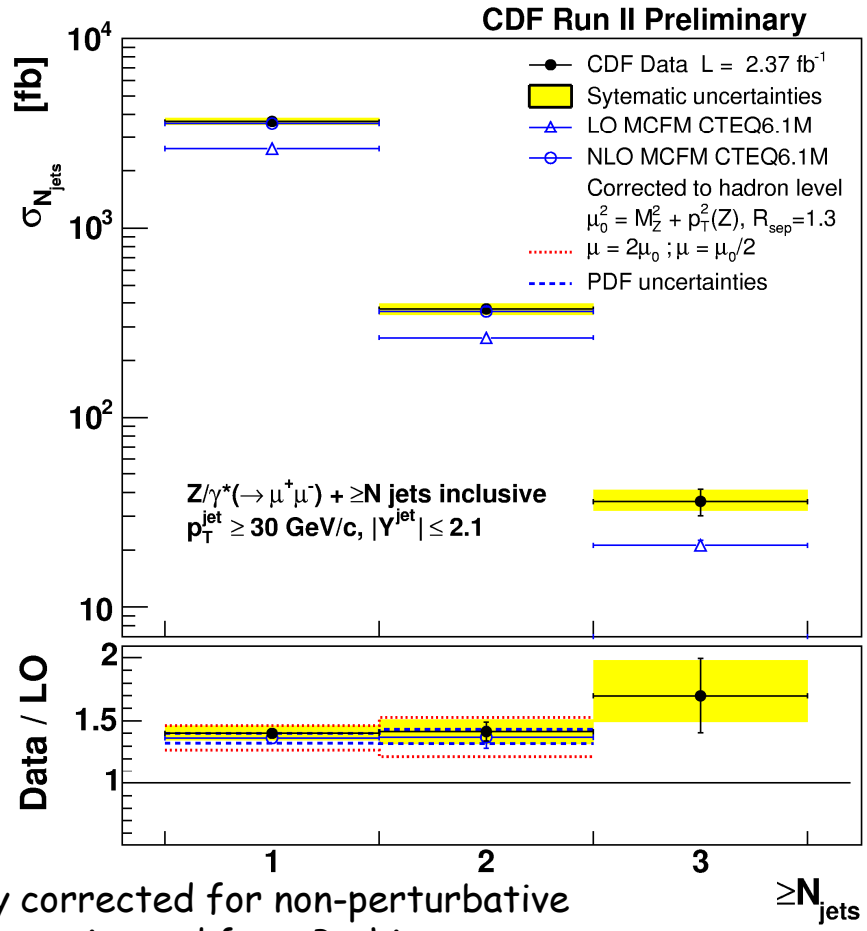
Z/γ*(-> μμ) +jet(s)

Clean and allows to validate Z→νν+jets bkgs.



Same sign tracks and Monte Carlo use to estimate background

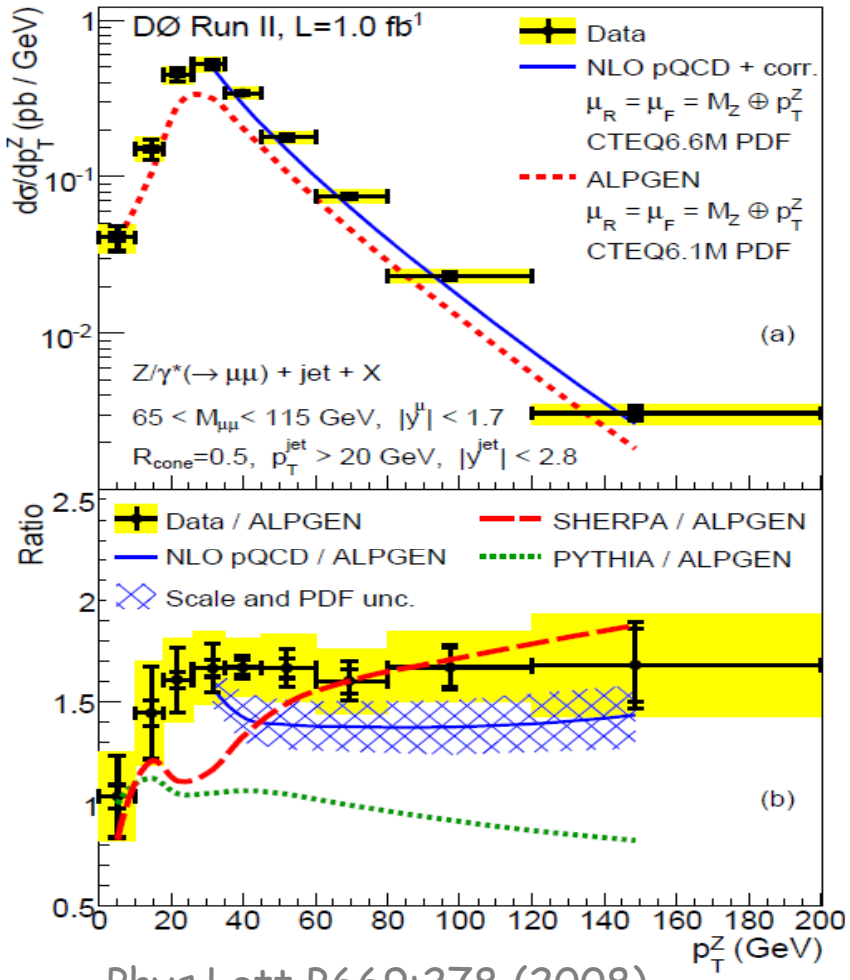




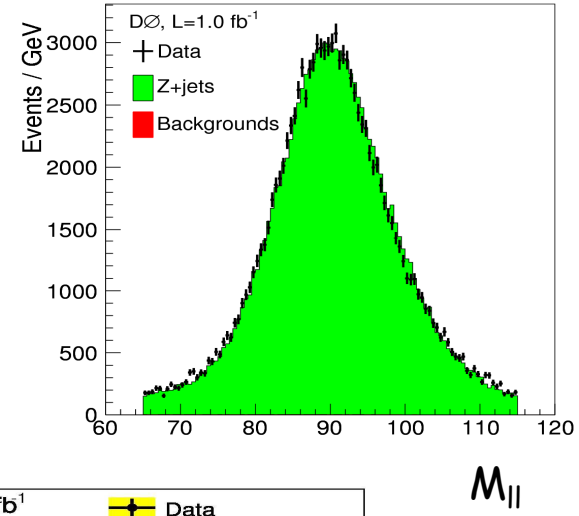
Theory corrected for non-perturbative effects estimated from Pythia

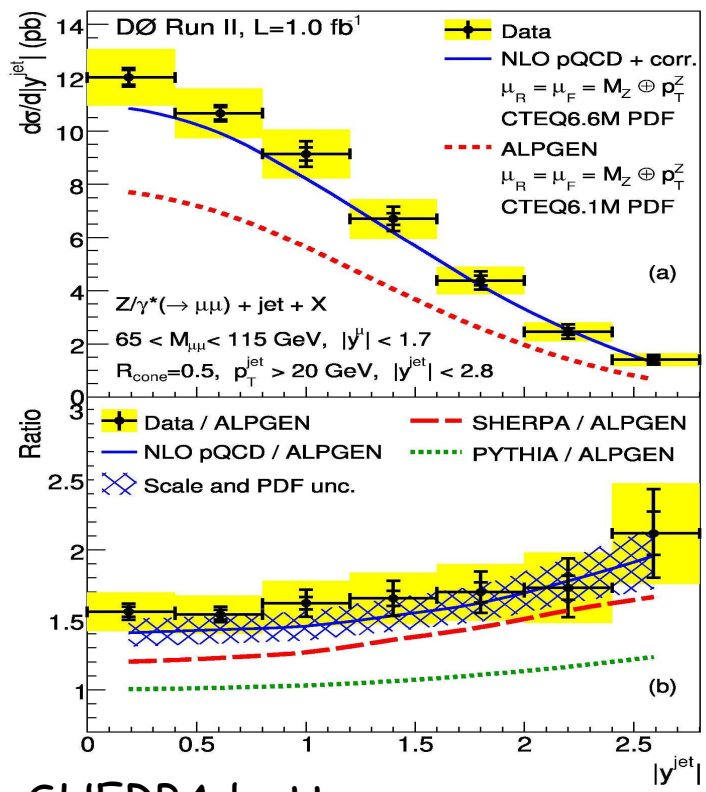
Good agreement between data and NLO

Z/γ*(-> μμ) +jet(s)



Phys.Lett.B669:278 (2008)

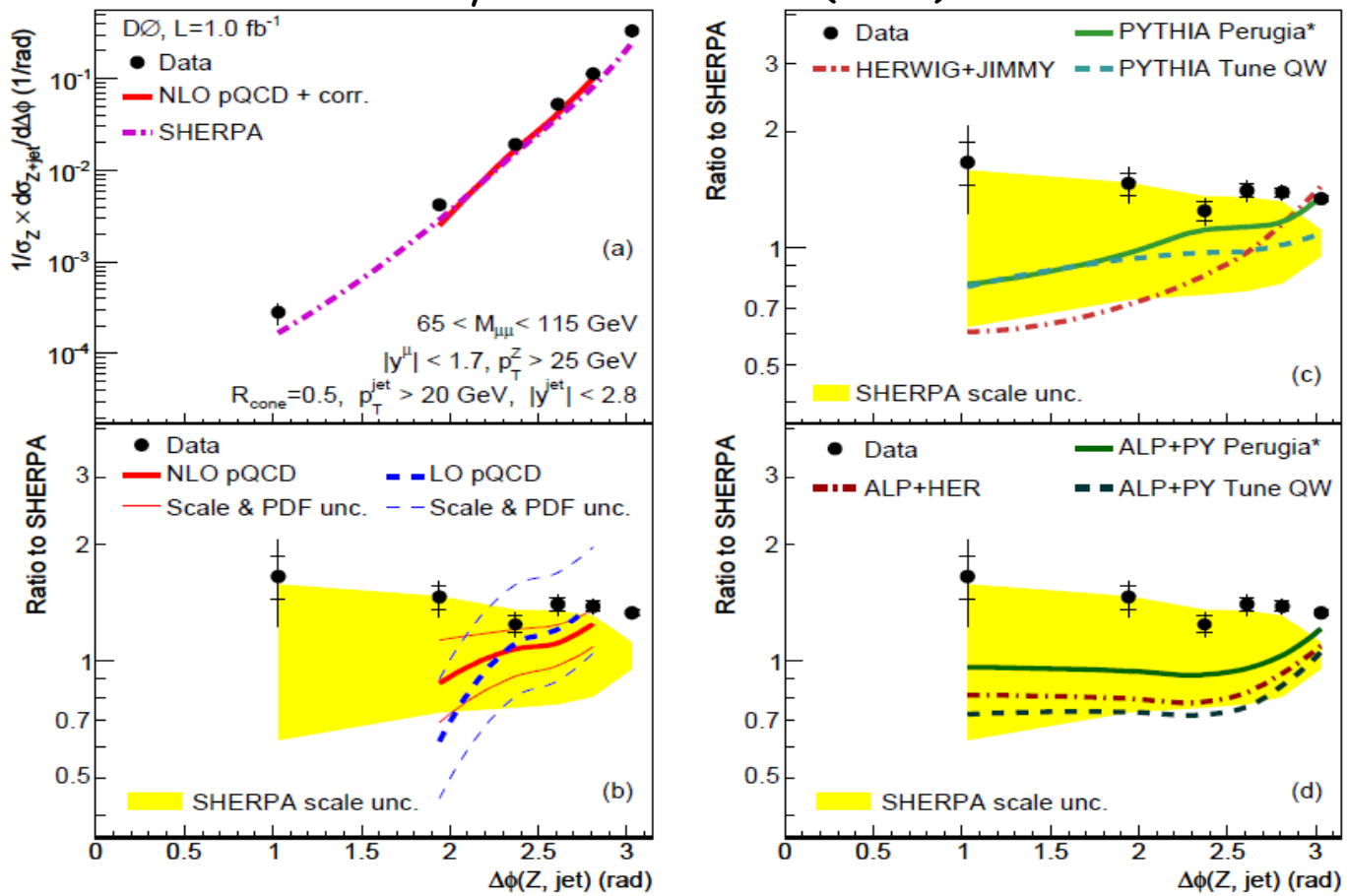




- Data described by NLO pQCD
- PYTHIA and ALPGEN below the data, SHERPA better
- ALPGEN describes shapes well, except at low pT(Z)

$Z/\gamma^*(\to \mu\mu)$ +jet(s) angular distributions

Phys.Lett.B682:370 (2010)



- Avoids systematics of Jet calibrations!

- Reasonable agreement between data and NLO
- Significant improvement of NLO compared to LO

- Event generators tend to have normalization and shape differences
- Alpgen + Pythia (Perugia) improves description
- Sherpa best describes the shape, but not normalization

Z/γ*(-> ee) +jet(s)

- Jets: p_T > 20 GeV, |y|<2.5, R=0.5
- Electrons: E_T > 25 GeV, 65 < Mee < 115 GeV
- Binned in the pT of the n-th jet

Phys.Lett.B678,45 (2009)

P_T (1st Jet), Normalized with $\sigma(Z)^{-1}$

- NLO pQCD large improvement over LO

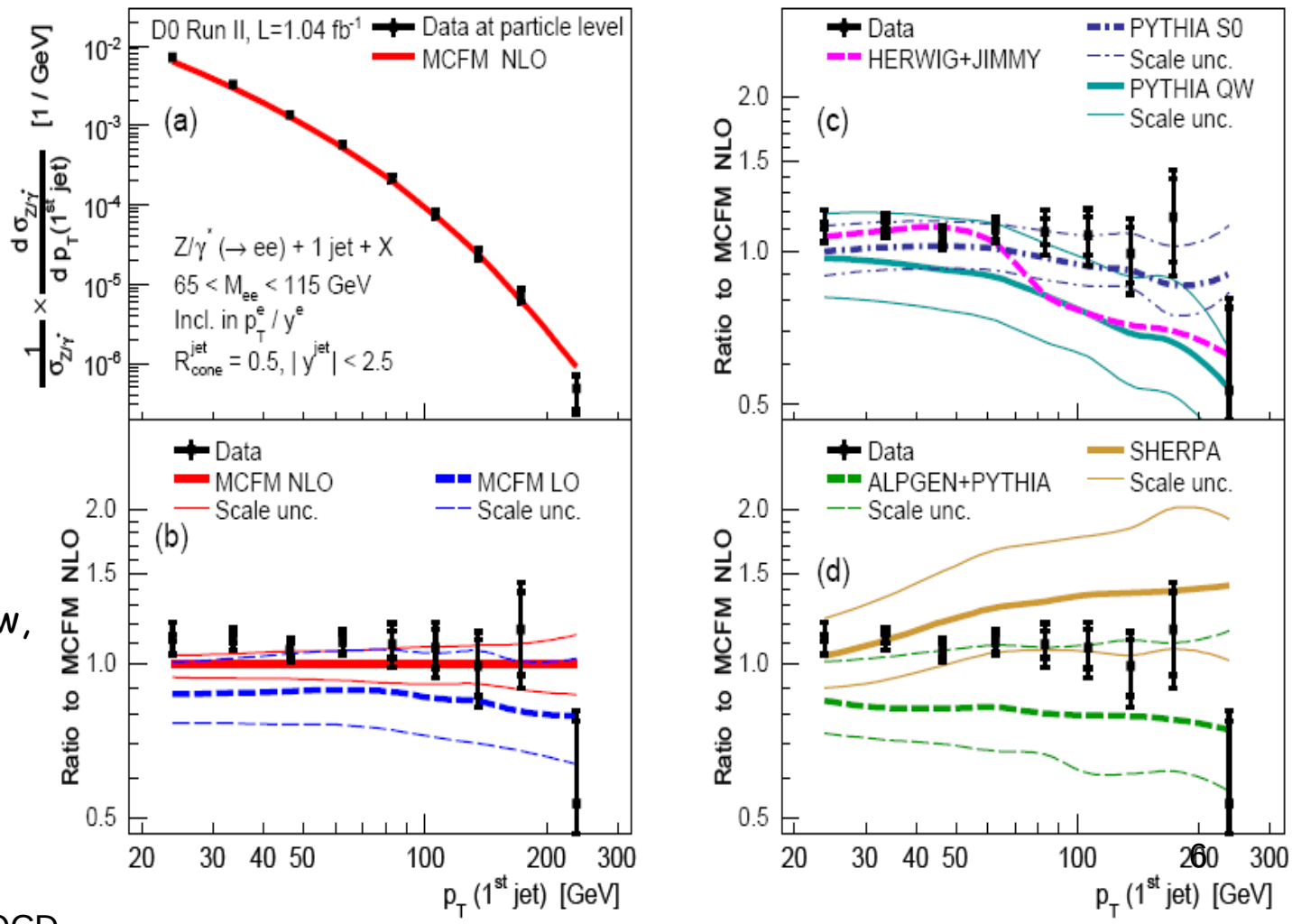
- Event Generators:

  Pythia "pT ordered" better description

  Sherpa: harder than data

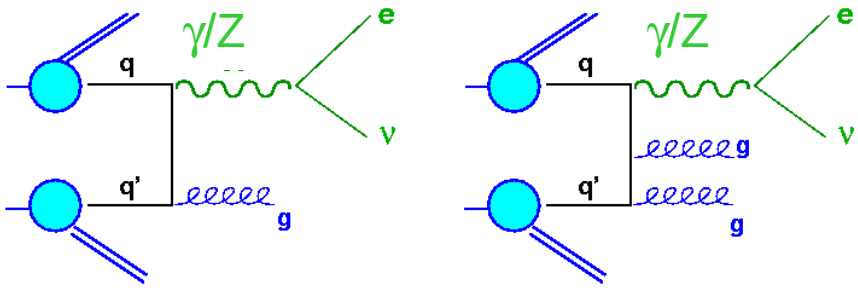
  Alpgen+Pythia: too low, but right shape

  Uncertainties in MC predictions large!

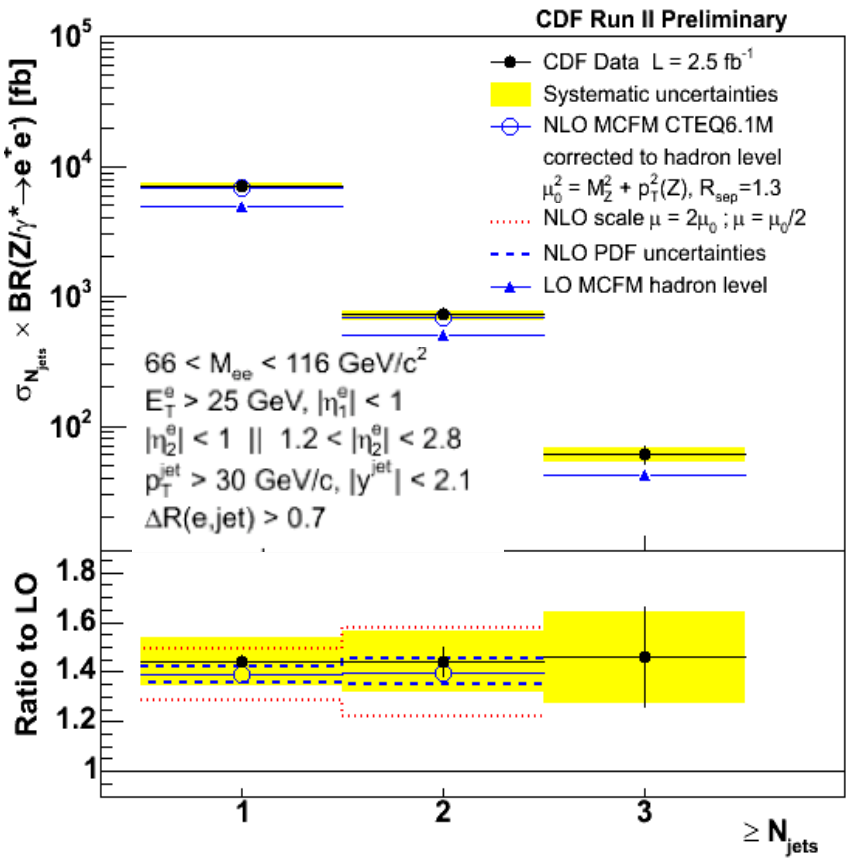


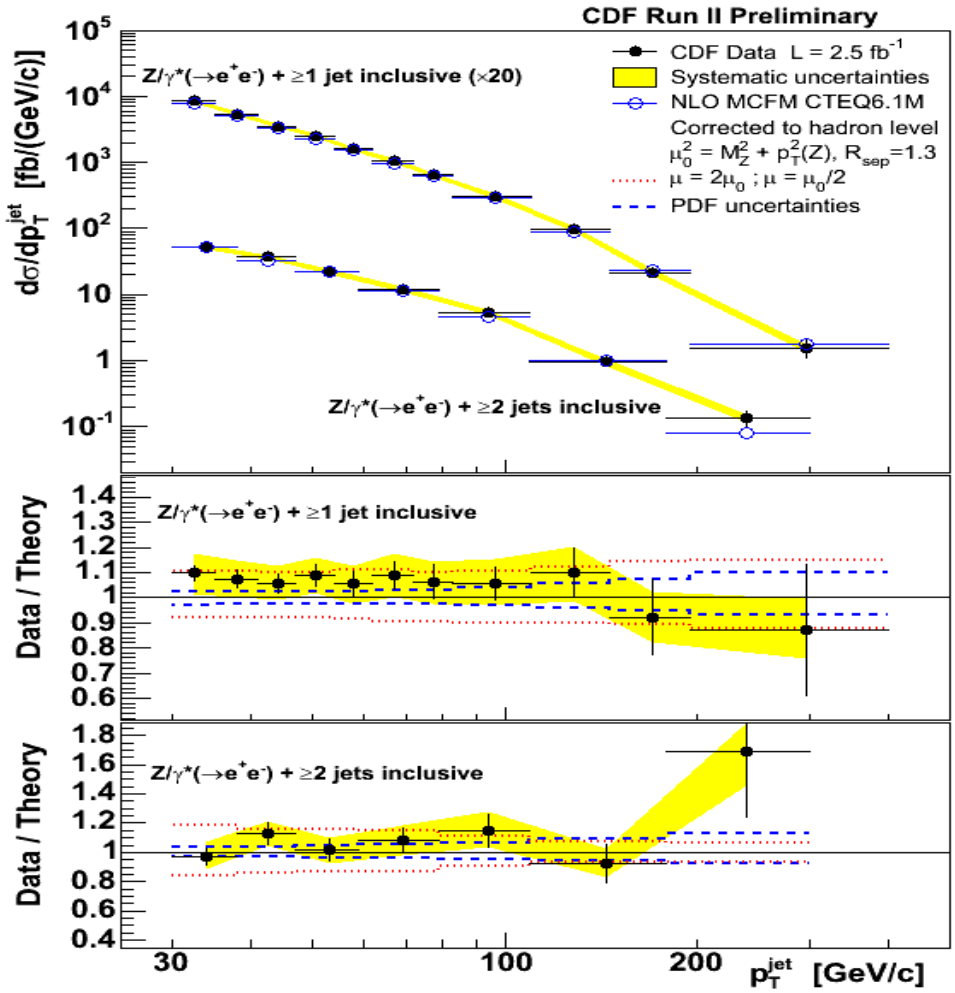
Z/γ*(-> ee) +jet(s)

Phys. Rev. Lett. 100, 102001 (2008)



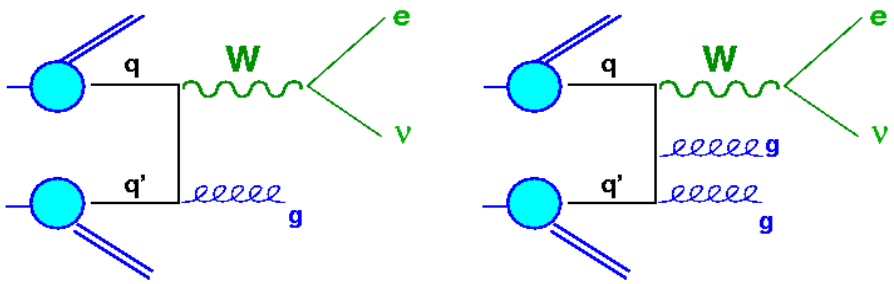
- Measurement corrected for non pQCD effects





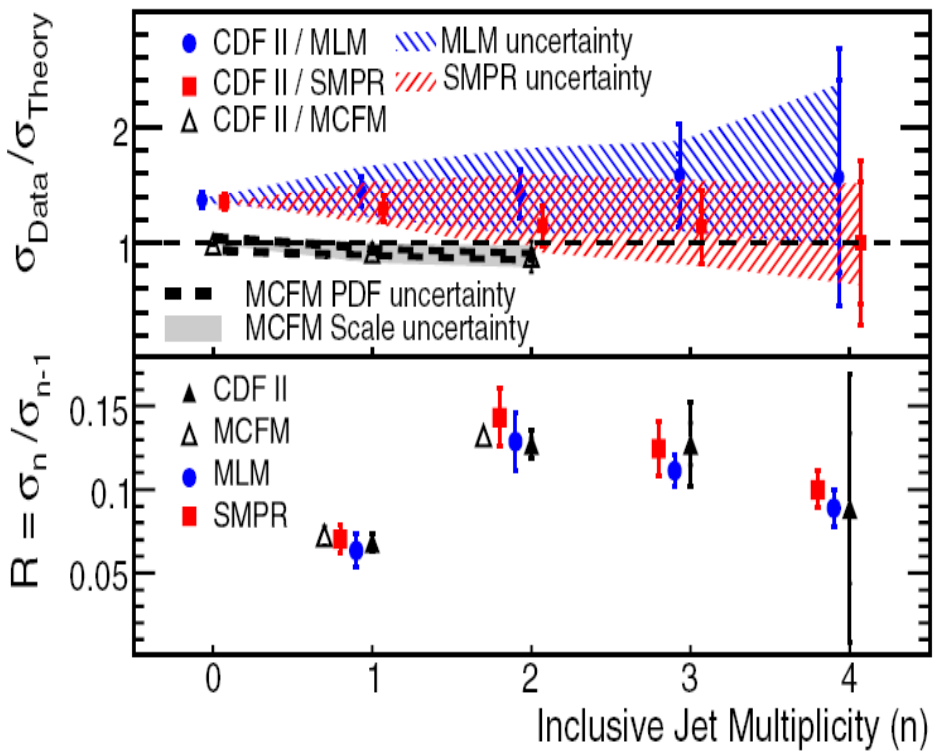
Good agreement with NLO pQCD predictions including non-pQCD corrections

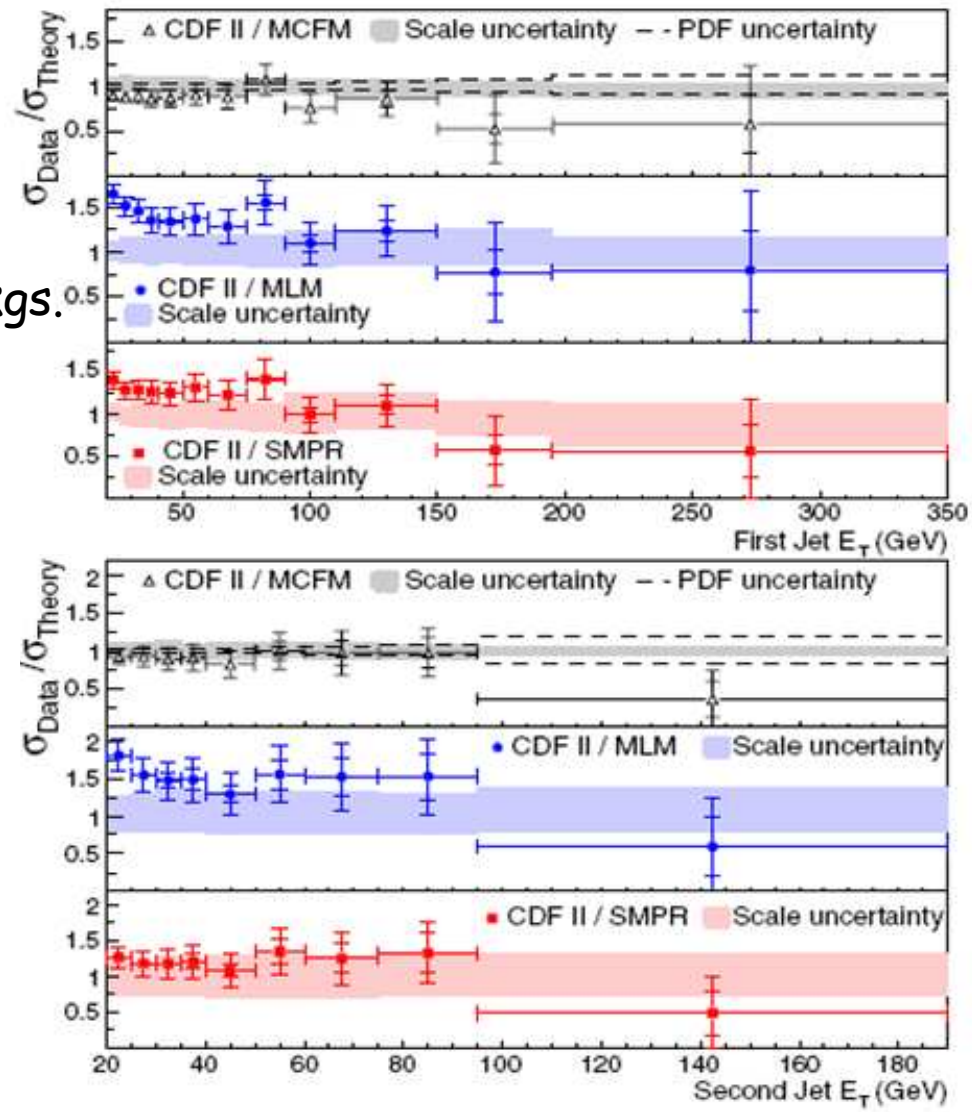
W+jets Production



PRD 77, 011108(R) (2008)

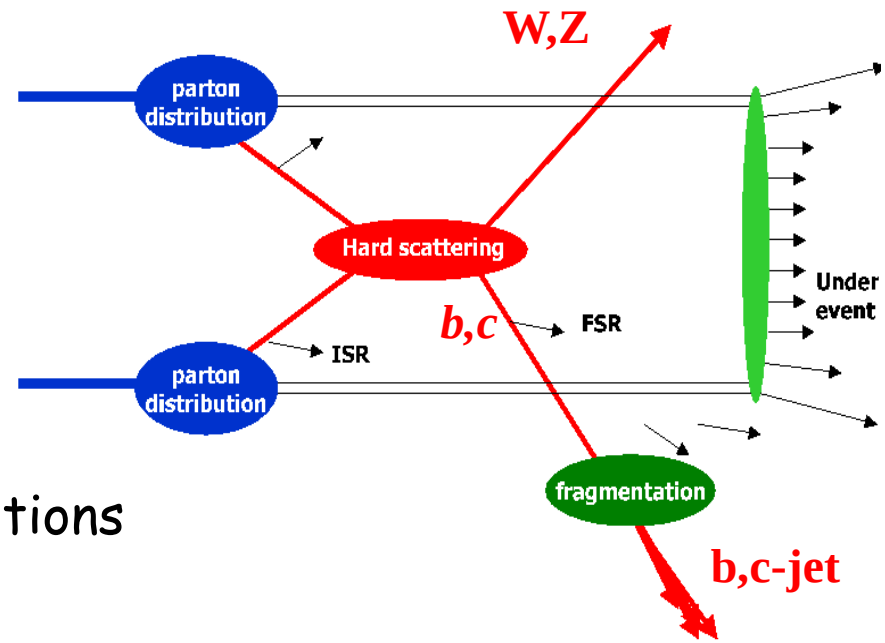
x 10 more cross section than Z+jets
But requires to control QCD and Top bkgs.





Good agreement with pQCD NLO calculation (includes non-pQCD effects)
At low P_T Monte Carlo needs a better modeling of UE (ALPGEN+PYTHIA)

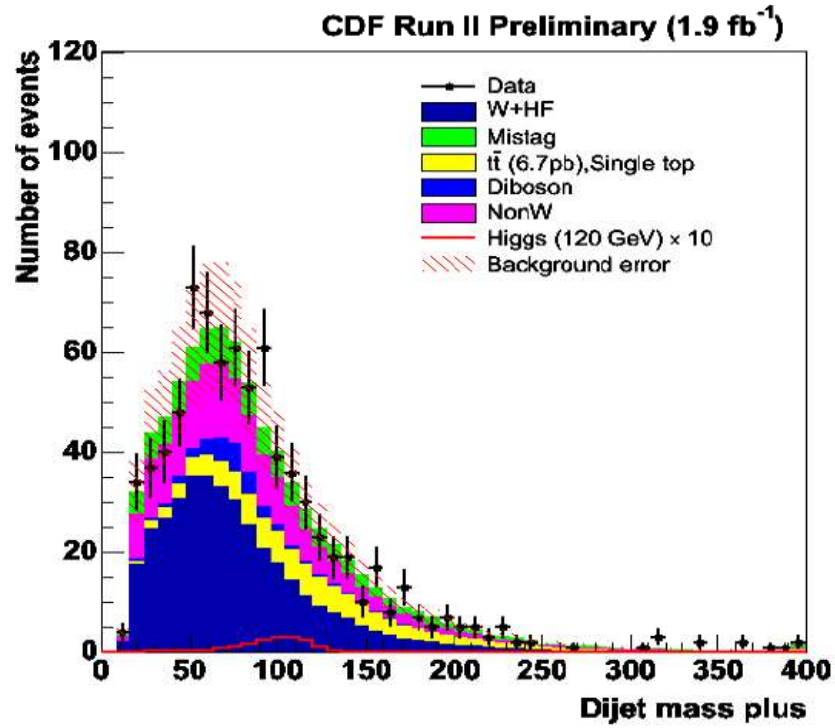
Vector Boson + HF Jets

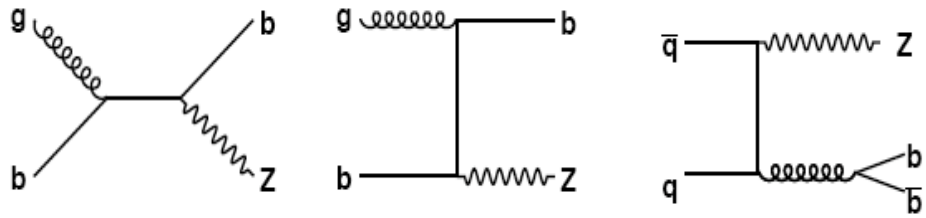


Important for physics program at Tevatron

- For QCD
  - Test perturbative QCD predictions
  - W/Z(γ) direct probe of hard scattering dynamics
  - Sensitive to PDFs HF content

- Understand Background
  - W/Z+HF production is bkgd for: ttbar, single top, and searches like Higgs, SUSY…
  - Challenging to accurately simulate need to validate data



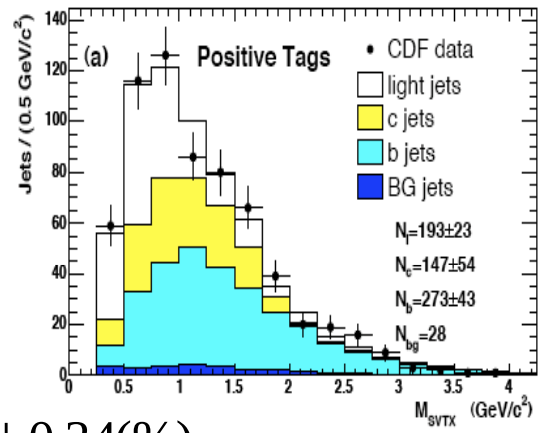


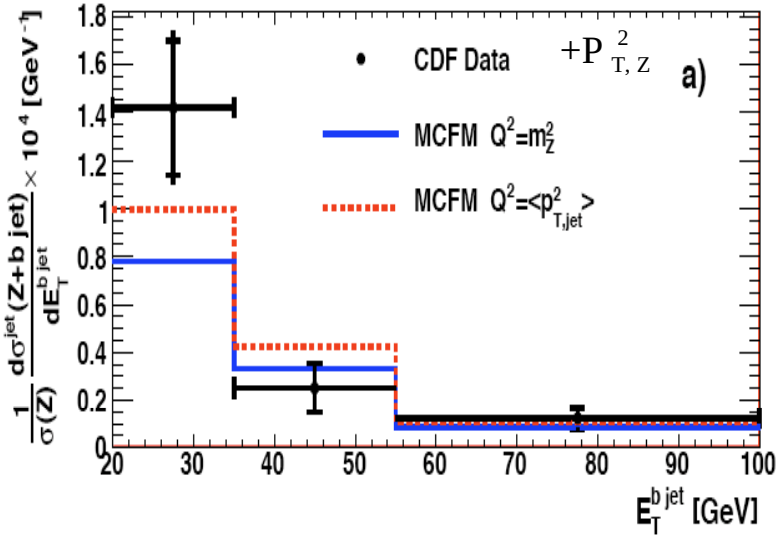
Inclusive Z+b

Test of background for Higgs / SUSY

Considering both electron and muon channels and jets with Et > 20 GeV and |η| < 1.5

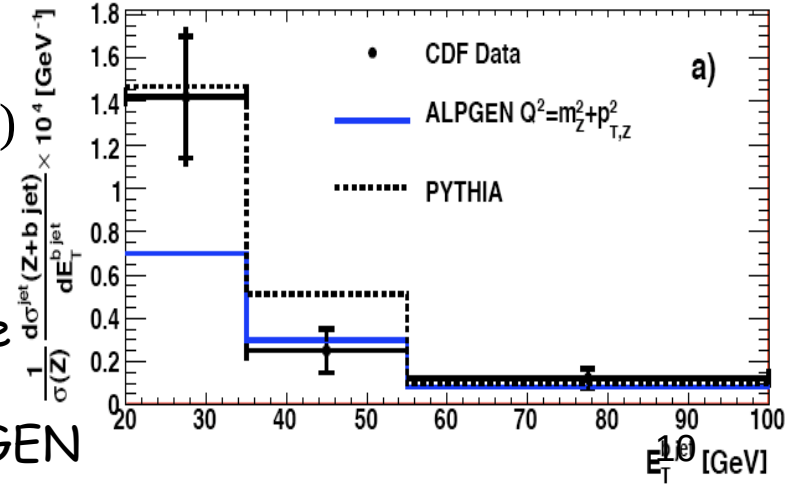
Phys.Rev.D79:052008,2009.





$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34(\%)$$

$$MCFM: 1.8\%\ (Q^2 = M_Z^2 + P^2_{T,Z})\ ;\ 2.2\%\ (Q^2 = <P^2_{T,Jet}>)$$

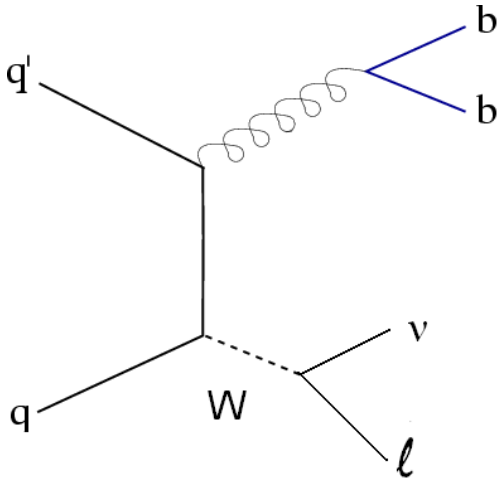


Measurements in agreement with predictions (large uncertainties in both data and theory)

→No complete NLO prediction in the Z+b$\bar{b}$ case translates into a large scale dependence

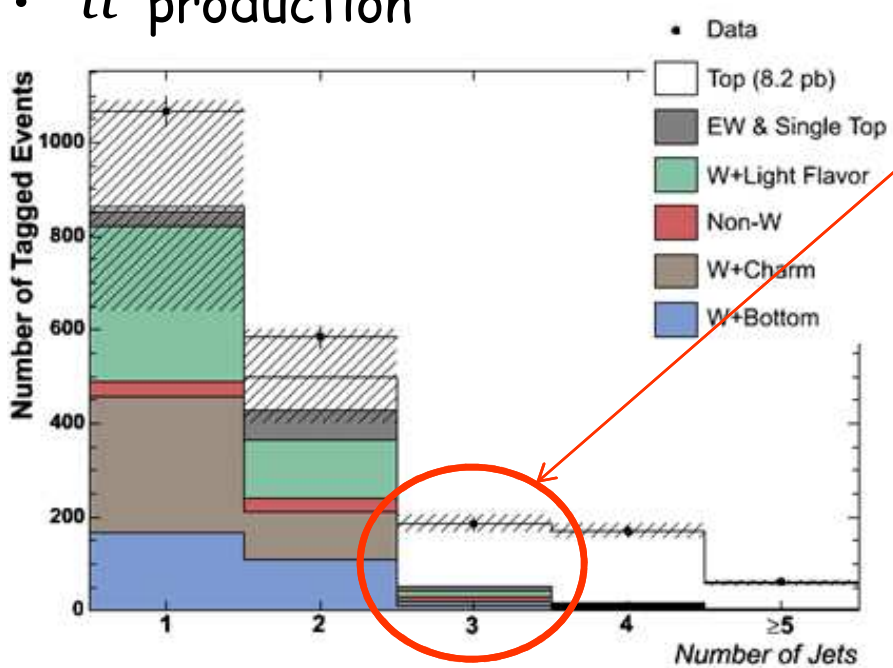
Also large variations between PYTHIA and ALPGEN

W+*b*-jets production



Large background for many analyses

- SM Higgs (WH) production
- Single top quark production
- $t\bar{t}$ production



- ***W*** $\rightarrow$ *l ν (l=e,μ)* **selection:**
  - *e*: E_T > 20 GeV, |η| < 1.1
  - *μ*: p_T > 20 GeV/c, |η| < 1.0
  - ν: Missing E_T, MET > 25 GeV
- **1 or 2 jets in final state**
  (too much top in 3-jet bin)
- **b-Jet selection:**
  - Cone algorithm, R= 0.4
  - E_T > 20 GeV, |η| < 2.0
  - b-identification: "ultratight"
- **W+b-jets cross section:**

$$\sigma_{W+bjets} \cdot Br = \frac{N_{b-tags} \cdot f^{bjets} - N_{bkg}^{bjets}}{L \times A \times \varepsilon}$$

N_{b-tags} : number of b – tags

f^{bjets} : b – jet purity in b - tag sample

N_{bkg}^{bjets} : number of tagged b – jets not from $W + b\bar{b}$

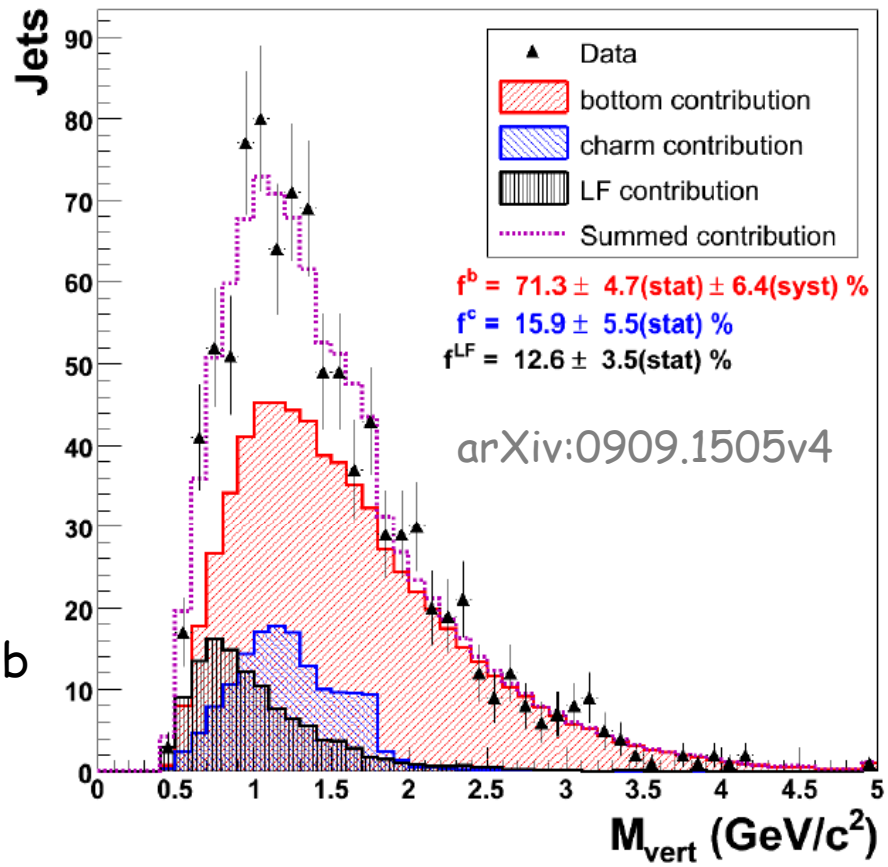
W+*b*-jets production

$$\sigma_{W+bjets} \cdot Br = \frac{N_{b-tags} \cdot f^{bjets} - N_{bkg}^{bjets}}{L \times A \times \varepsilon}$$

- **Major b-jets bkgd. (S/B ~ 3/1):**
  - ttbar (40% of total bkgd)
  - single top (30%)
  - Fake *W* (15%)
  - *WZ* (5%)

- **Measurement:**
  $\sigma \cdot BR$ =2.74 ± 0.27(stat) ± 0.42(syst) pb
  ($p_T^{e\mu}$>20 GeV/c, $|\eta^{e\mu}|$<1.1, p_T^{ν}>25 GeV,
  E_T^{bjet} >20 GeV, $|\eta^{bjet}|$<2.0)

- **Recent NLO prediction:**
  $\sigma \cdot BR$ = 1.22±0.14 pb (J. Campbell, F. Febres Cordero, L. Reina)
  Alpgen (LO) prediction:
  $\sigma \cdot BR$ = 0.78 pb



Measurement higher than Alpgen and NLO predictions (~3σ)

W + Single *c* Production

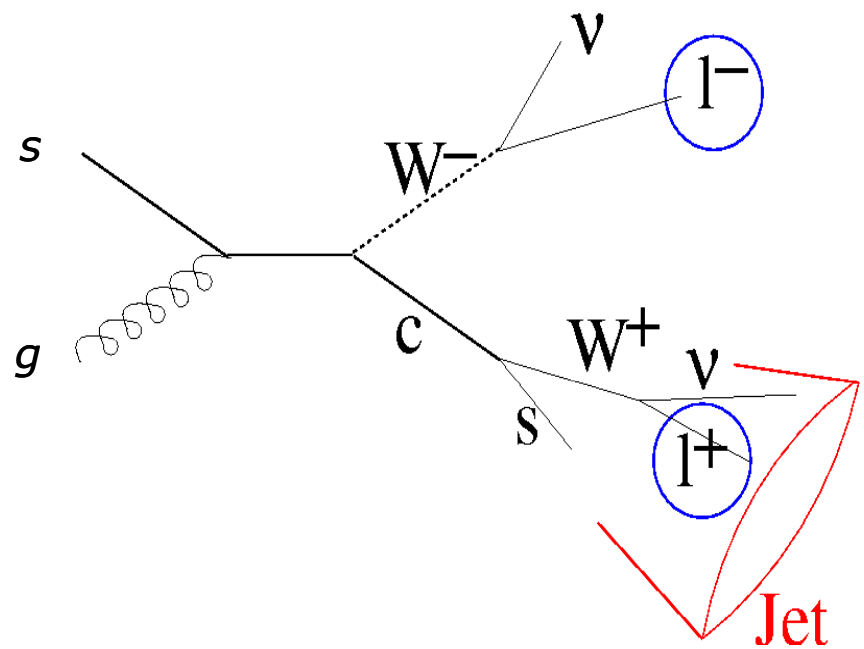
Motivation:

- Probe *s*-content of proton at high Q^2
  - *g+s* ~ 0.9, *g+d* ~ 0.1.
- Important BG for top quark studies, searches for Higgs, stop…
- Handle on charm tagging

Strategy:

- $W \rightarrow l+\nu$ selected by high p_T e,μ + MET
- Charm-jet identified by the soft lepton tagging (SLT) algorithm.
- Utilize charge correlation between W lepton and SLT lepton.
  - W+c production: opposite sign (OS)
  - In W+bb(cc), simetric (SS ~ OS).

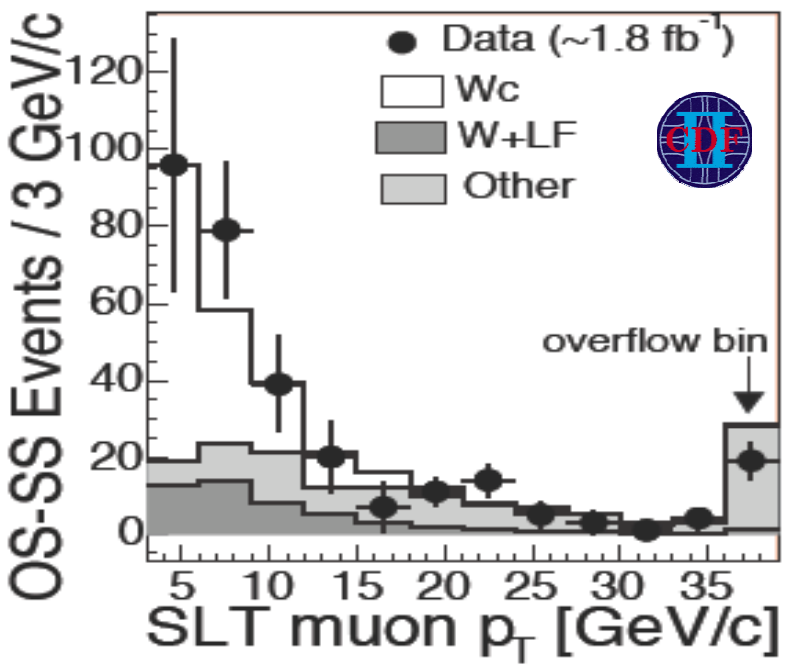
$$\sigma_{W+c} \times Br(W \rightarrow l\nu) = \frac{N_{measured}^{OS-SS} - N_{bkg}^{OS-SS}}{L \times A \times \varepsilon}$$



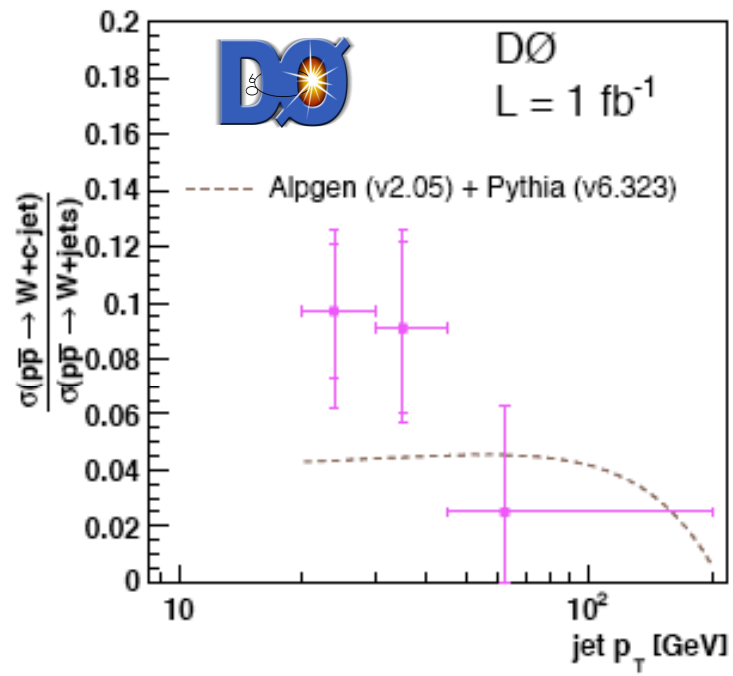
- Main OS-SS backgrounds
  - Fake W
  - W+light jets
  - Drell-Yan

W + Single *c* Production

- D0 uses both e and muon soft leptons For jets with pt > 20 GeV, |η|<2.5
- Measure the ratio σW+c/σW+jets. Many systematic uncertainties cancel.



Phys. Rev. Lett. 100, 091803 (2008)



Phys. Lett. B 666, 23 (2008)

$$\sigma_{Wc}.Br(W \to l\nu) = 9.8 \pm 2.8(stat)^{+1.4}_{-1.6}(syst) \pm 0.6(lum)\,pb$$

$$NLO: 11.0^{+1.4}_{-3.0}\,pb(p_{Tc} > 20GeV/c, |\eta_c| < 1.5)$$

$$\frac{\sigma_{W+c}}{\sigma_{W+jets}} = 0.074 \pm 0.019(stat.)^{+0.012}_{-0.014}(syst.)$$

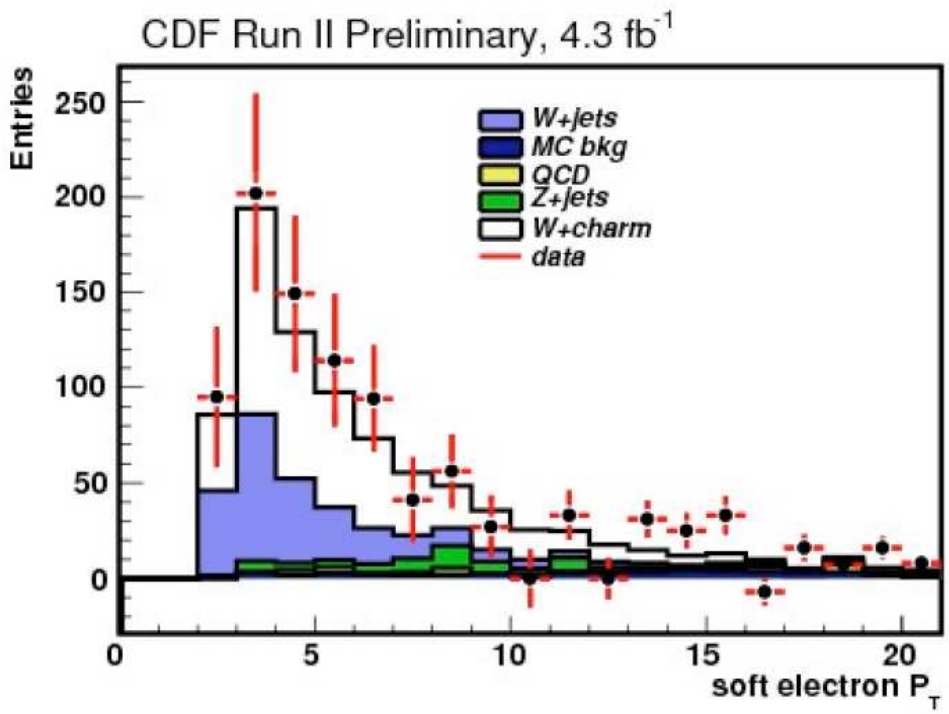
LO (**Alpgen+Pythia**): 0.044 ± 0.003

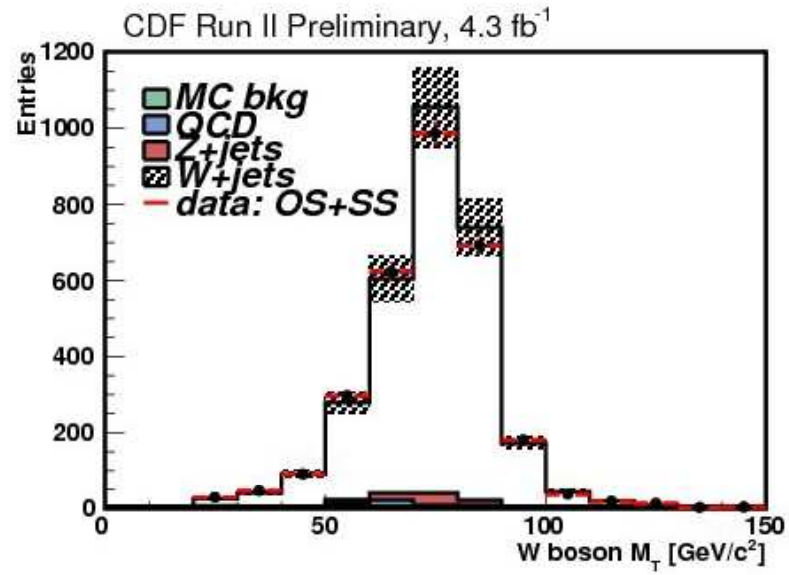
In good agreement

In reasonable agreement

W+ Single c Production

- 4.3/fb result using electrons from the charm decay
- Charm: pt>12 GeV and |η|<1.5





SLT (electron) performance studies

$$\sigma_{Wc} x Br(W \to l\nu) = 33.7 \pm 11.4(stat) \pm 4.7(syst)\, pb$$

$$NLO: 17.8 \pm 1.7\, pb\, (p_{Tc} > 12\, GeV/c, |\eta_c| < 1.5)$$

Plan to combine SLT muon and electron measurements to reduce error.

In reasonable agreement

Final Notes

- Tevatron providing precise QCD measurements
- W/Z+jets and W/Z+HF:
  - Test and tune event generators (critical for Tevatron and LHC programs)
  - Main backgrounds for many processes (Higgs, SUSY..)

✓ W/Z+jets:
  - good agreement with NLO predictions

✓ W/Z+HF:
  - First Z/W+HF measurements start challenging theoretical uncertainties
  - W+charm well described by recent NLO predictions
  - W+bottom does not agree well with predictions

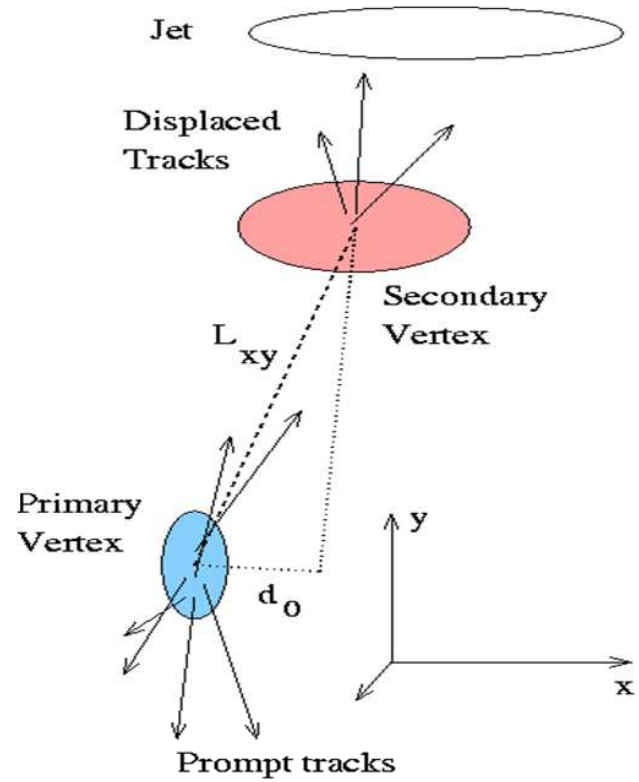
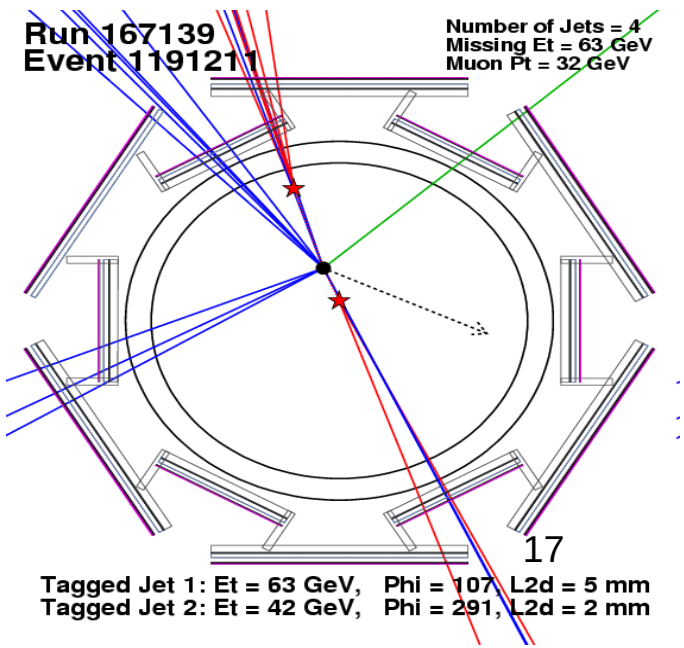
➢ Tevatron: expect 12 fb-1 by 2012
➢ LHC: first QCD measurements this year

HF-Jet Identification

Lifetime taggers:

- Most common b-tagging technique exploits long lifetime of b-hadrons
- Secondary vertex:
  - → Select tracks in jet
  - → Identify displaced tracks (not from primary vertex)
  - → Make secondary vertex with displaced tracks
  - → If large transverse displacement (Lxy) jet is b-tagged

Soft Lepton Taggers:

- Identify soft leptons inside jets (~20% semi-leptonic branching fraction)

Need to characterize tagger: efficiency and mistag rate (light flavor tags)