Vector boson+jets production at DØ

Avto Kharchilava
University of Notre Dame

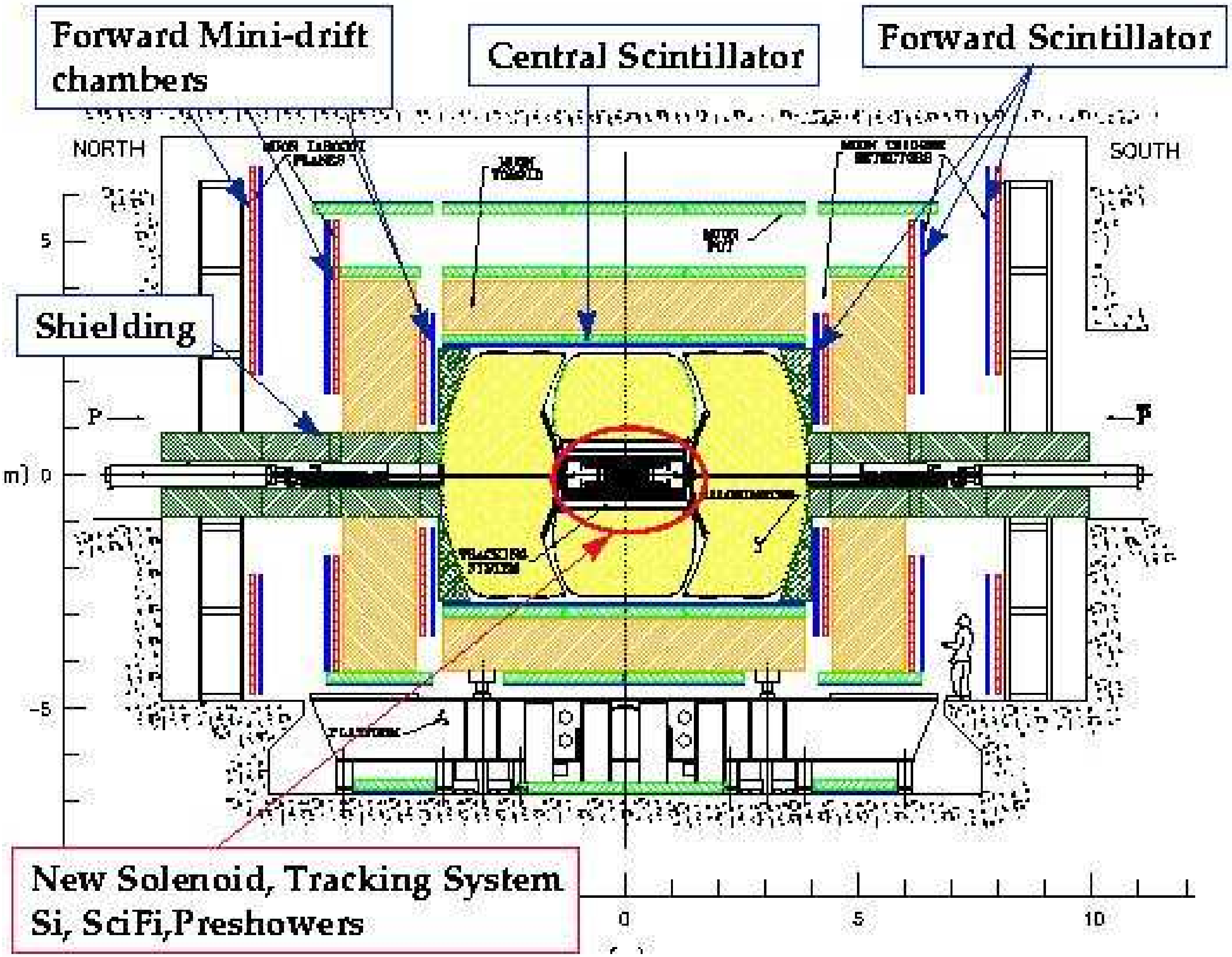
For the DØ Collaboration

TeV4LHC CERN, 29 April 2005

Outline

- Introduction
  - Motivation
  - Jet algorithms
- W + jets production
  - Kinematics properties
  - W + bb
- Z + jets production
  - σ(Z + ≥n jets)/σ(Z)
  - Z + b-jets
    - σ(Z+b)/σ(Z+j) ratio
- Summary

Upgraded DØ detector in Run II of the Tevatron

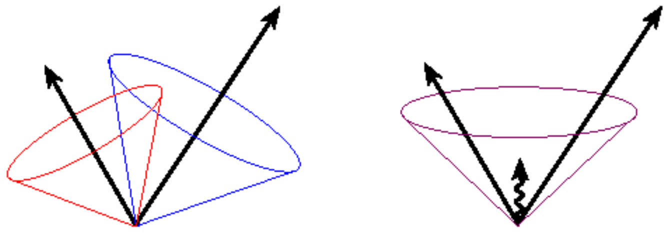


W/Z + jets production

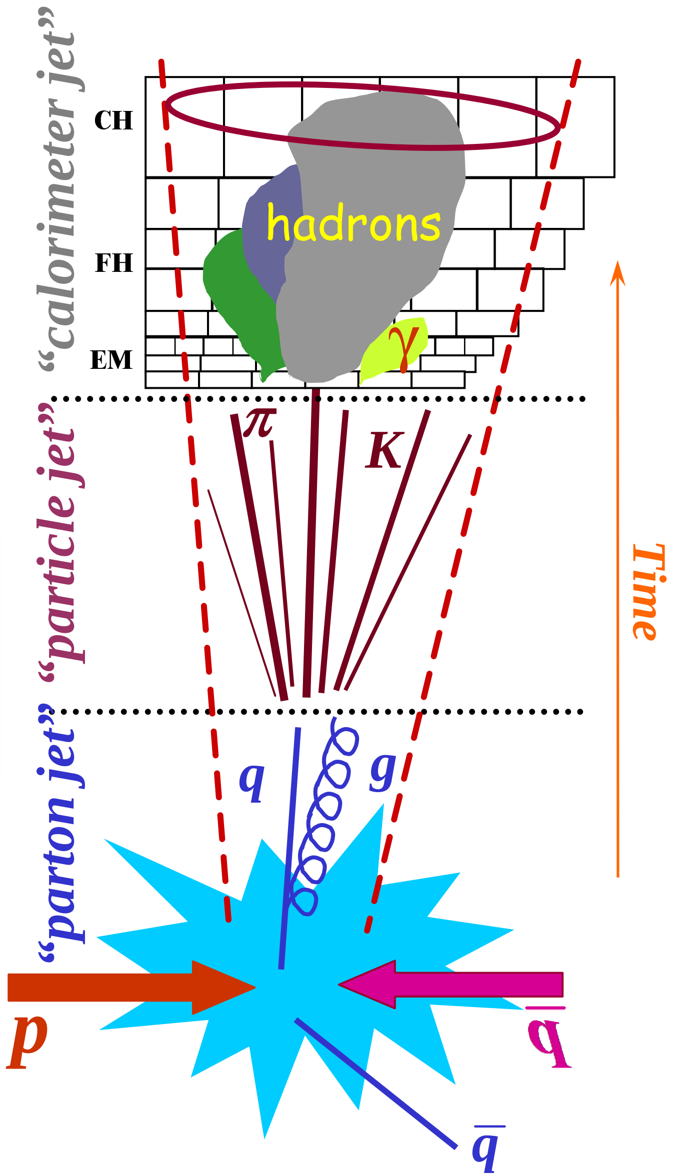
- A laboratory to test QCD predictions
  - W/Z + n jets rate ~ α_s^n in lowest order
  - Perturbation theory should be reliable
    - Heavy boson ↔ large scale
- Important backgrounds for other physics
  - Top, Higgs, New phenomena
- Items to study
  - Rates, differential distributions, flavor composition
- Compare to theory
  - NLO/MCFM calculations available up to 2 jets
  - Variety of multi-parton generators based on LO ME calculations
    - How to combine them with PS generators and avoid “double counting” ?
    - Various prescriptions, MLM, CKKW, SHERPA

Jet definitions in Run II

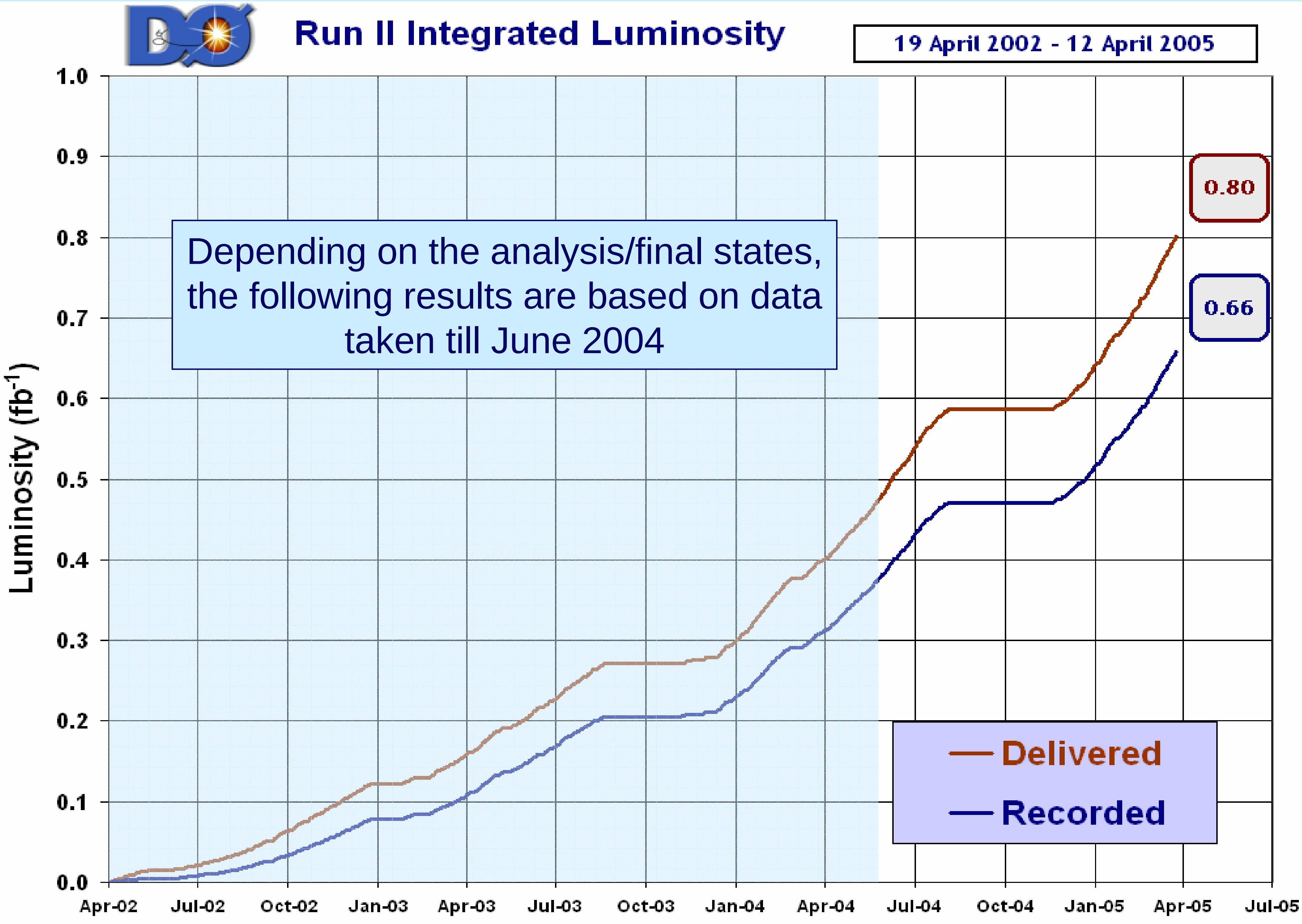
- Run I cone algorithm
  - Add up towers around a "seed"
  - Iterate until stable
  - Jet quantities: E_T, η, ϕ
- Improvements for Run II
  - Use 4-vector scheme, p_T instead of E_T
  - Add midpoints of jets as additional starting seeds
  - Infrared safe



- Correct to particles
  - Underlying event, previous/extra interactions, energy loss out of cone due to showering in the calorimeter, detector response, resolution
- Results in the following are for R_{cone} = 0.5

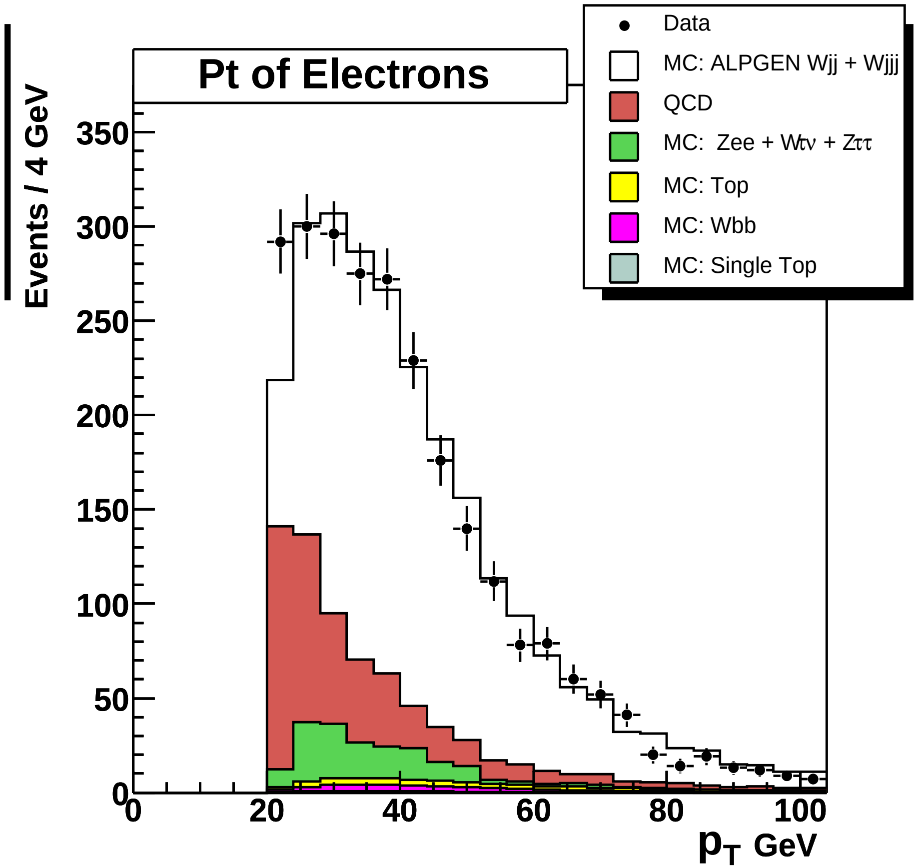


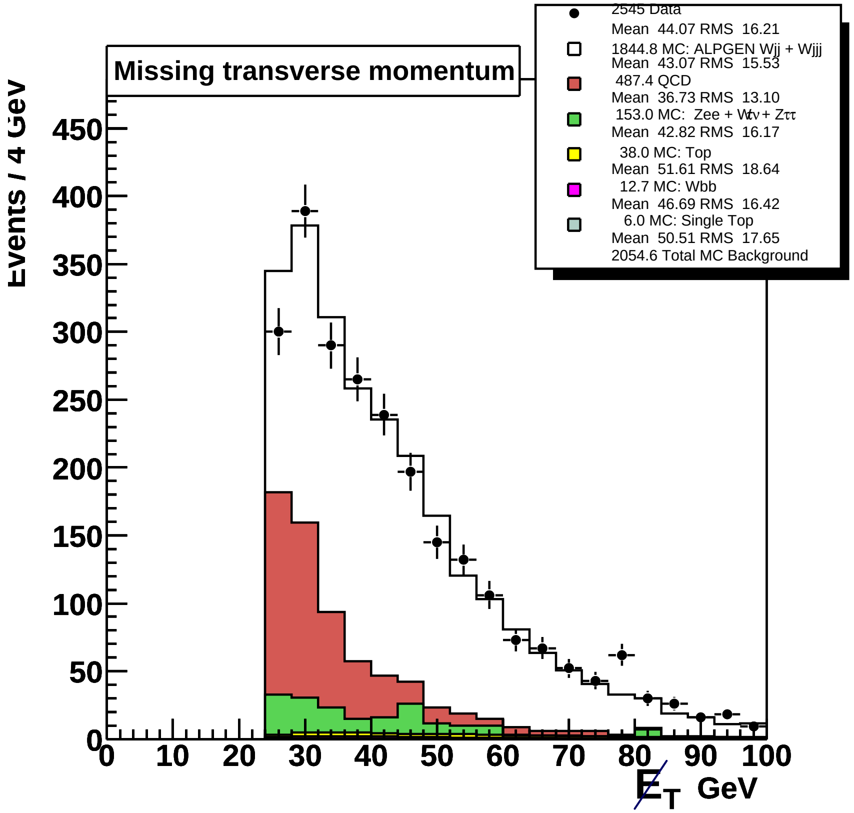
Data sets


Run II Integrated Luminosity
19 April 2002 - 12 April 2005
Depending on the analysis/final states, the following results are based on data taken till June 2004
Luminosity (fb^{-1})
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
0.80
0.66
Delivered
Recorded

W(→eν) + jets production (1)

- Event selection include
  - Isolated e, p_T > 20 GeV, |η| < 1.1
  - Missing E_T > 25 GeV
  - ≥ two jets: E_T > 20 GeV, |η| < 2.5
- 2567 evts (2670 ± 838 expected)





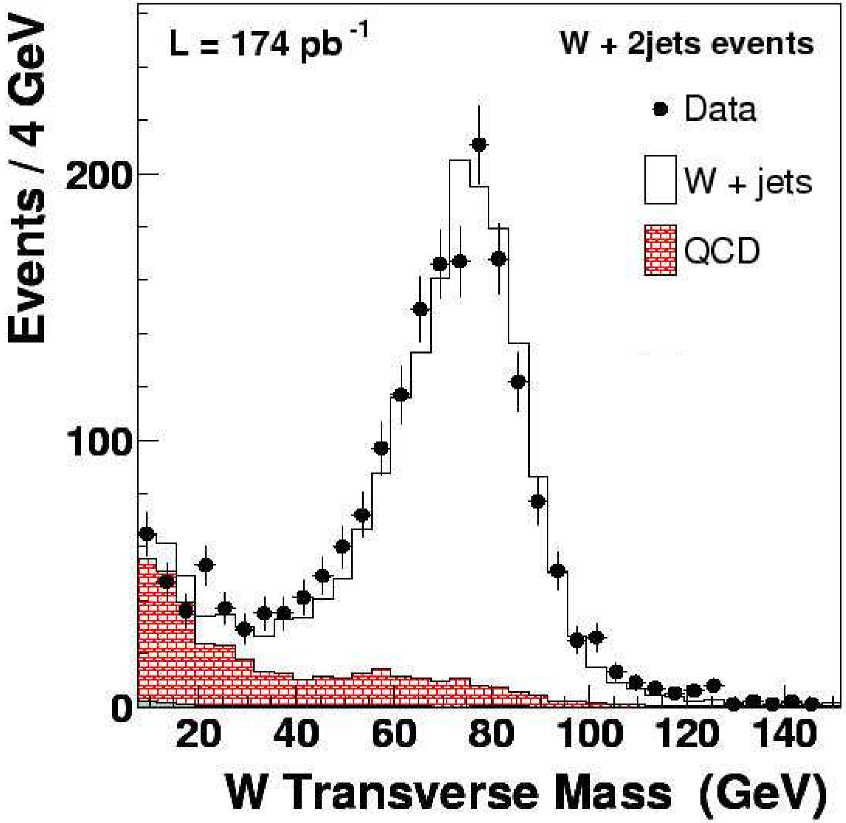
- Simulations with Alpgen plus Pythia through detailed detector response
- Cross sections normalized to MCFM NLO calculations

Good understanding of data

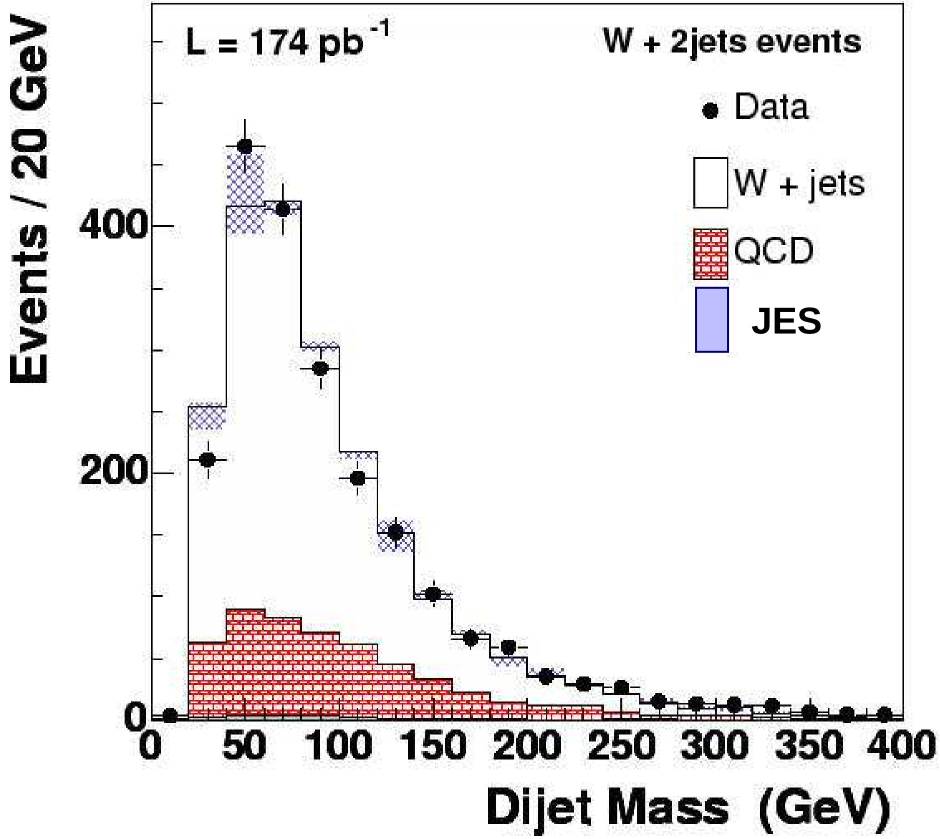
W(→eν) + jets production (2)

- Untagged sample

QCD bkgd. is small



Data and MC agree within JES uncertainties

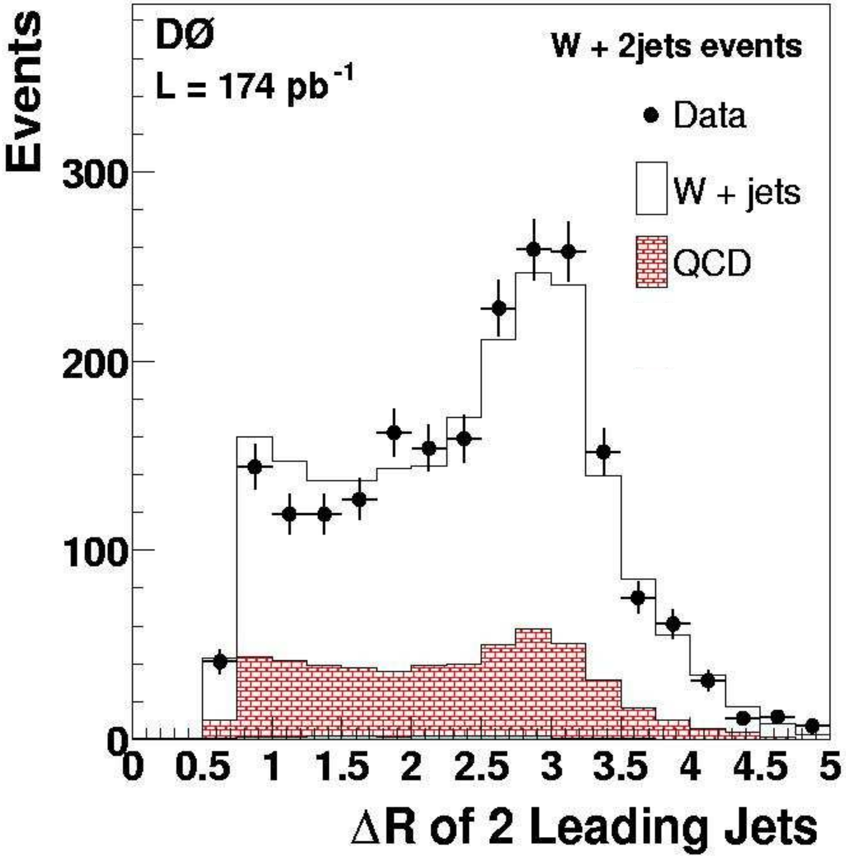


Good overall understanding of data

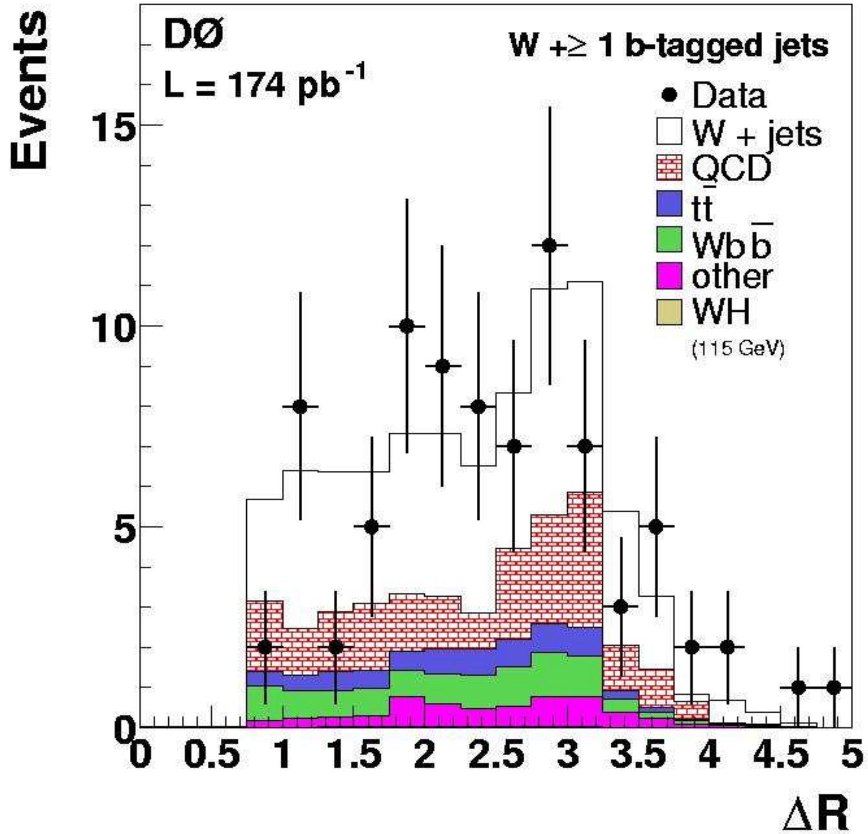
W(→eν) + jets/bb: angular correlations

- Correlations between leading two jets in ΔR – a measure of distance in η–φ space
  - Sensitive to parton radiation processes
  - Reduced sensitivity to jet energy scale

Untagged sample

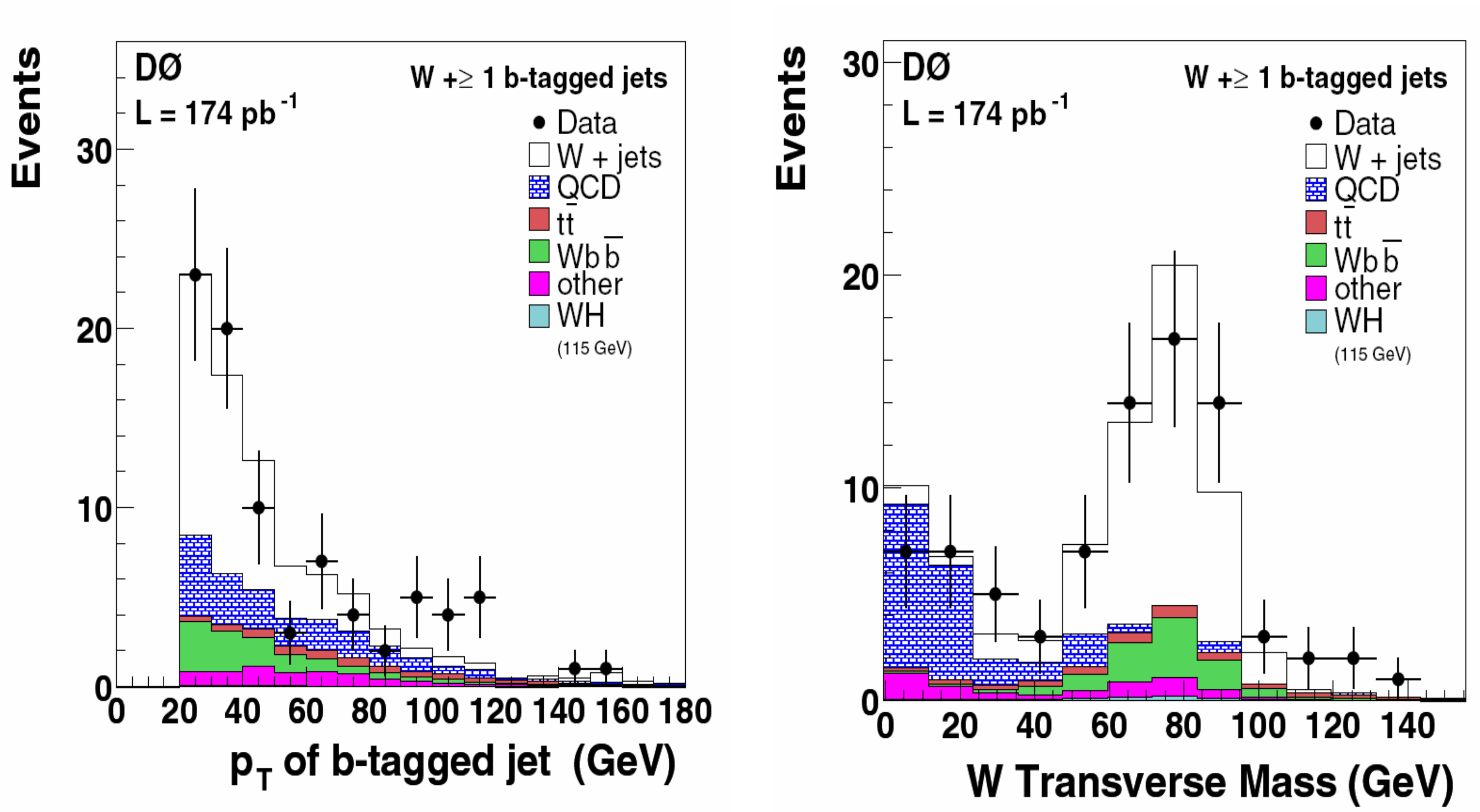


Sample with at least one b-tagged jet



- Several processes "show up"

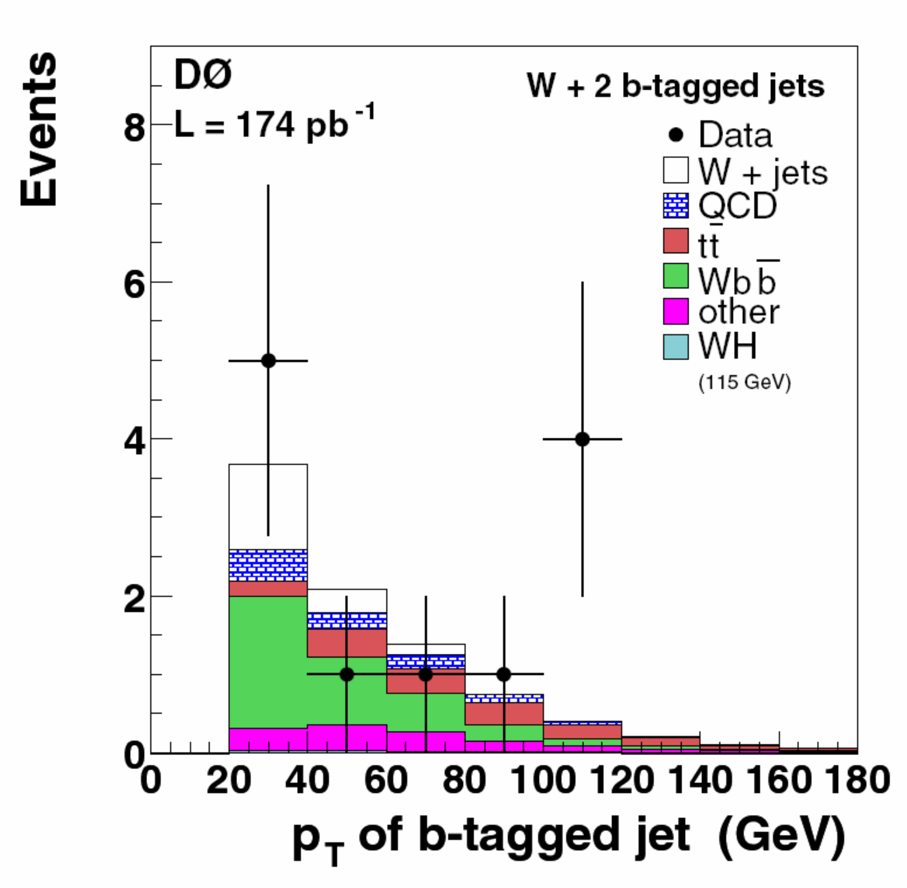
W + ≥1 b-tagged jet

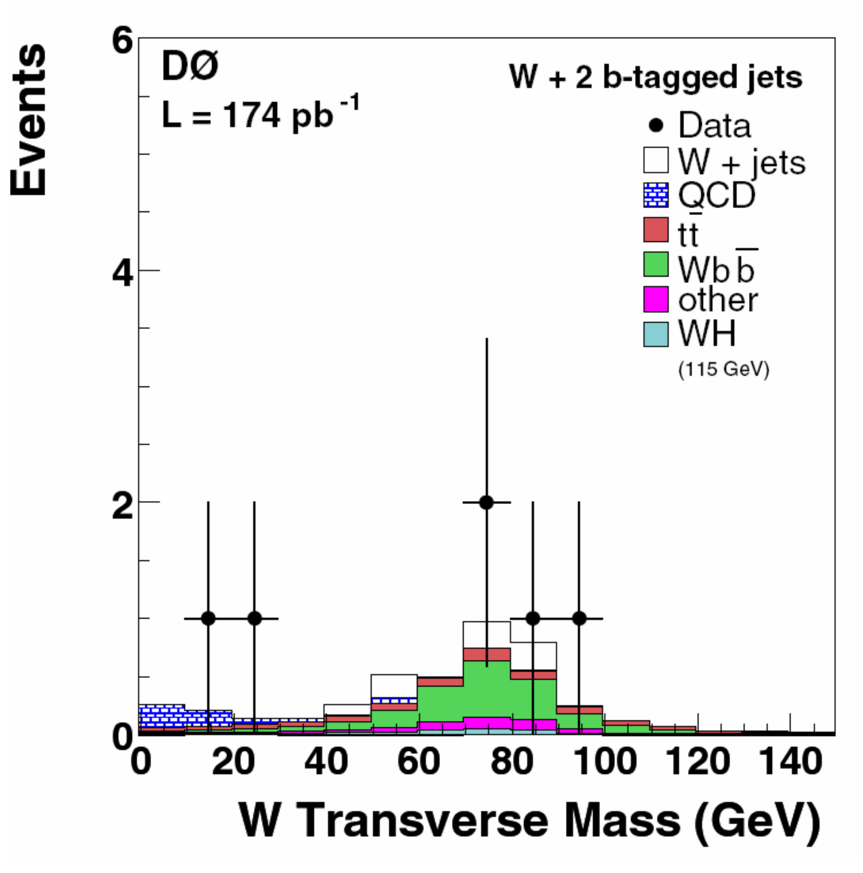


Again, good agreement between data and MC

W + bb cross section limit

- σ(Wbb) < 6.6 pb @ 95% C.L.
  - p_T > 15 GeV, |η| < 2.5 and ΔR(bb) > 0.75
  - Will measure soon
- Observe 6 events
- Expect a total of 4.4 ± 1.2 evts.
  - 1.7 ± 0.4 evts. of Wbb

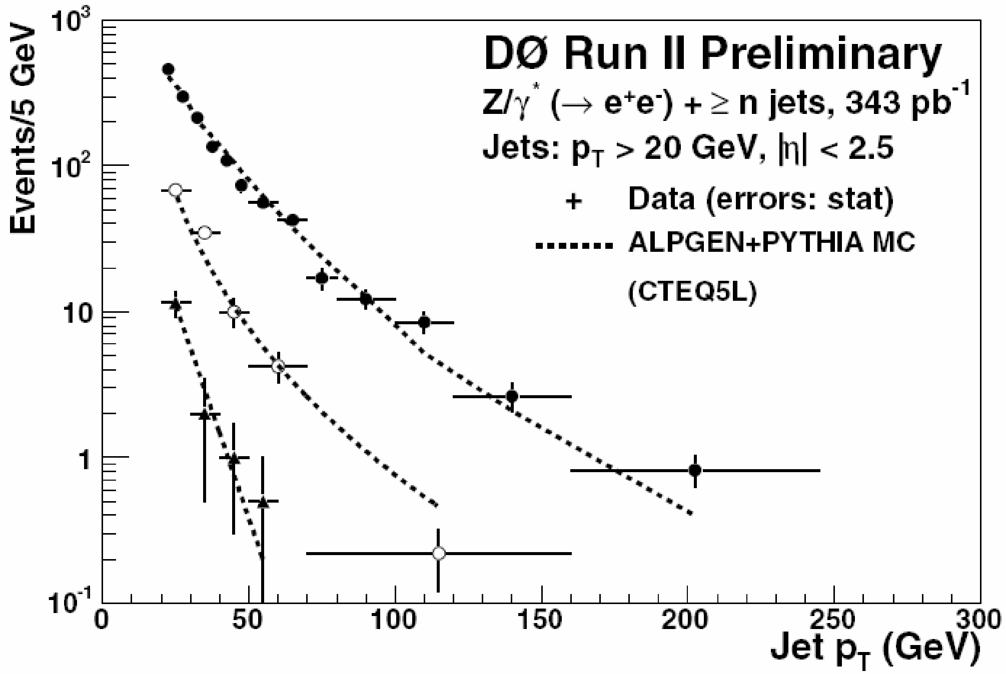




PRL 94, 091802 (2005)

Z/γ* + jets

- Cross section ratio measurement
  - $L_{int} = 343\ pb^{-1}$
  - Electron channel
- Selection
  - Vertex |z| < 60 cm
  - Electrons
    - $p_T > 25$ GeV, $|\eta| < 1.1$
    - Shower shape
    - Isolation
    - At least one track matched
    - $75 < M_{ee} < 105$
  - Jets
    - $p_T > 20$ GeV, $|\eta| < 2.5$
    - JES corrected
  - Electron-jet separation $\Delta R > 0.4$
- 13,893 inclusive Z candidate evts.



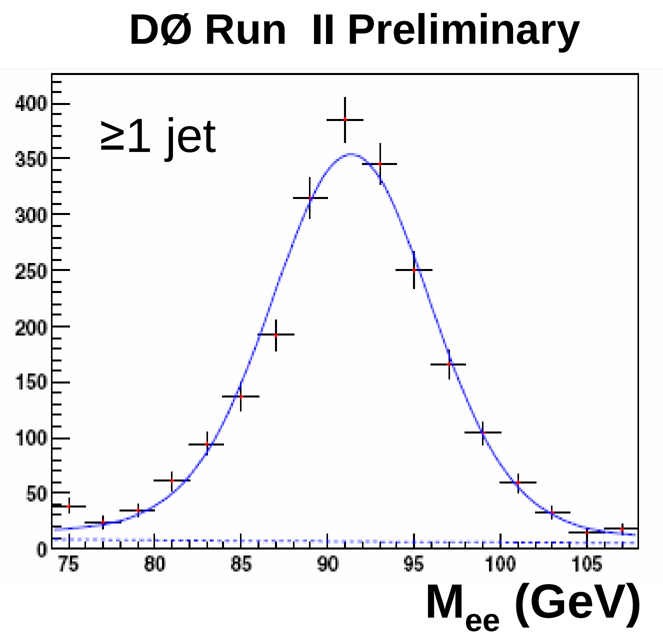
- Comparison with Alpgen plus Pythia showering
  - Generator cuts: parton $p_T > 8$ GeV, $\Delta R > 0.4$
  - No matching
  - Full simulation

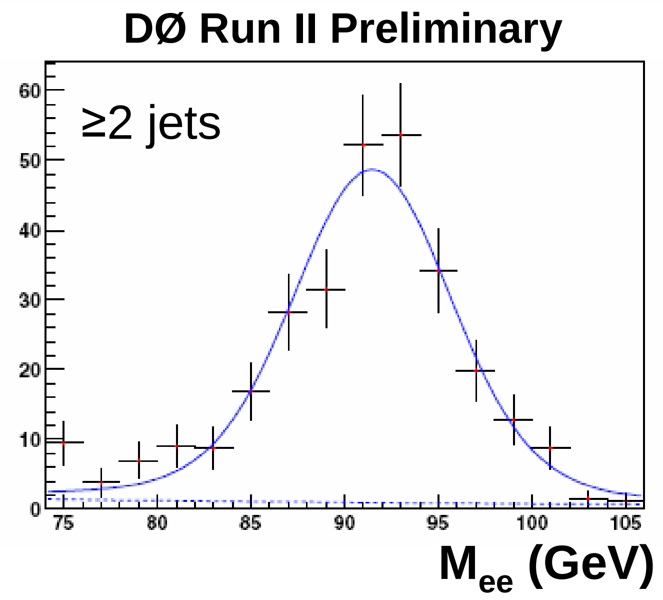
Acceptance and scale factors

- Electron trigger, reconstruction*ID efficiency
  - Use "tag-and-probe" method
- Jet reconstruction*ID efficiency
  - In data, look for jets balancing Z
    - Measure efficiency as function of Z p_T
  - Do the same in MC
  - Derive data vs MC scale factor
- Dependence on jet multiplicity
  - $Z/\gamma^* + \geq 0j$
    - Pythia reweighted to reproduce Z p_T in data
      - Den: Z/γ^* ($75 < M_{ee} < 105$ GeV)
      - Num: those with two electrons $p_T > 25$ GeV, $|\eta| < 1.1$, $|pvz| < 60$ cm
  - $Z/\gamma^* + \geq nj$
    - Alpgen Z + n jets sample.
      - Den: Z/γ^* ($75 < M_{ee} < 105$ GeV) + $\geq$n particle jet ($p_T > 25$ GeV, $|\eta| < 1.1$)
      - Num: those with two electrons $p_T > 25$ GeV, $|\eta| < 1.1$, $|pvz| < 60$ cm
- Acceptance of 21 to 30% depending on jet multiplicity

Background calculation

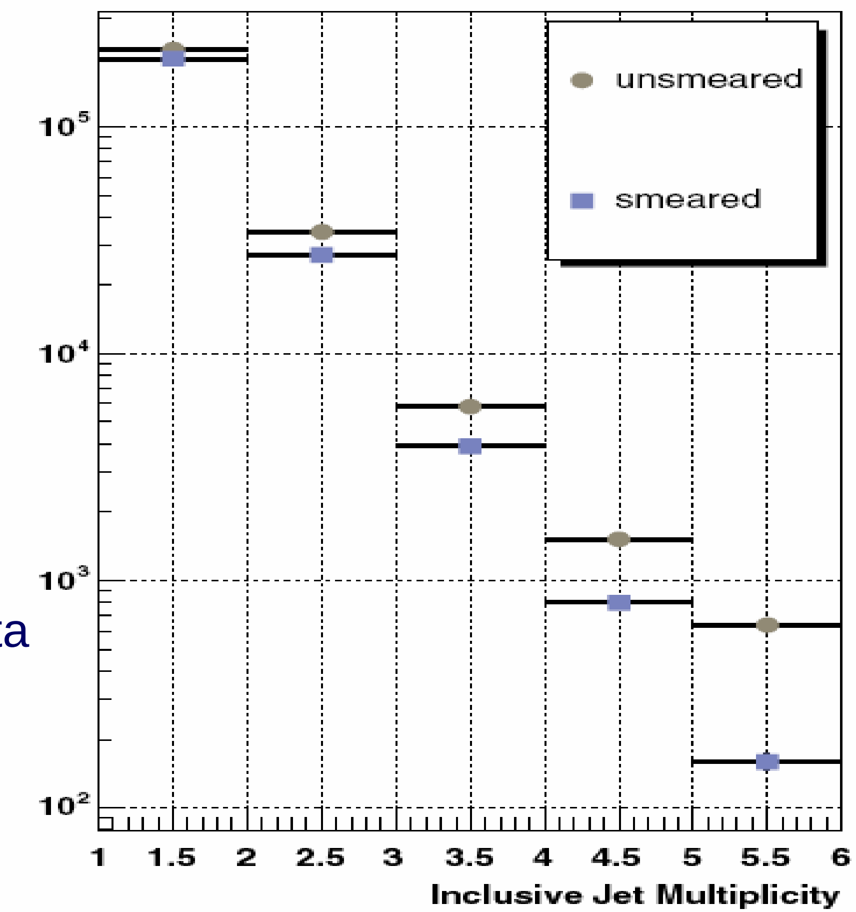
- Estimated from M_{ee} spectrum
  - Relative Drell-Yan continuum contribution from MC
  - Assume flat distribution for the bkgd.
  - Fit by Breit-Wigner convoluted with Gaussian + exponential function
  - For higher jet multiplicities measure from side band
- Background varies from 2 to 5% depending on the jet multiplicity





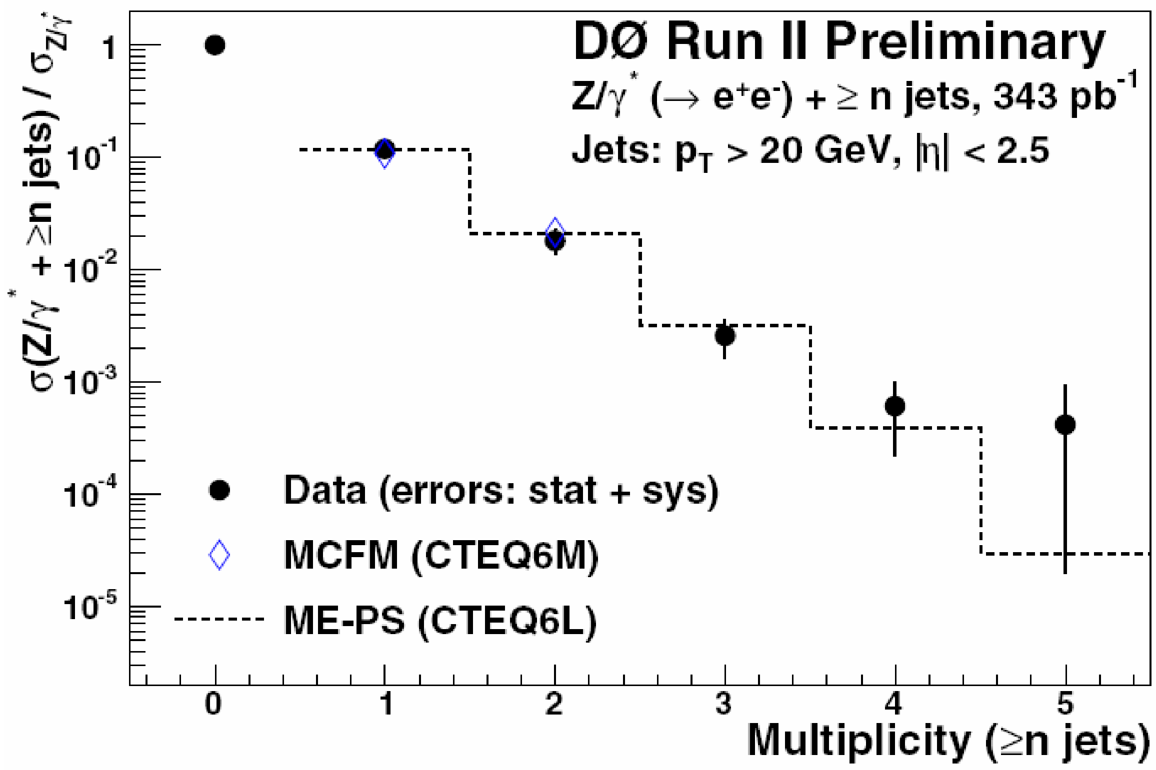
Corrections to inclusive jet multiplicity spectrum

- "Unsmearing" to correct for bin-to-bin migration due to
  - Jet energy resolution
  - Jet reconstruction*ID efficiency
- Derived using Pythia at particle level
  - No detector simulation
    - Apply data resolution smearing and reconstruction*ID efficiency
  - First reweight Pythia events such that smeared MC distribution agrees with data
- Electron-jet overlap correction
  - Accidental overlap between jet and electron must be accounted for
  - 6 to 10% correction depending on nj
- Jet promotion due to multiple interactions
  - Measured in data, effect is small



Ratio applied to "unsmear" data

$\sigma(Z/\gamma^* + \geq n$ jets) / $\sigma(Z/\gamma^*)$ ratio



Z/γ^* inclusive cross section corresponds to
$75 < M_{ee} < 105$ GeV

ME-PS: modified CKKW algo.
normalized to data at ≥ 1j bin

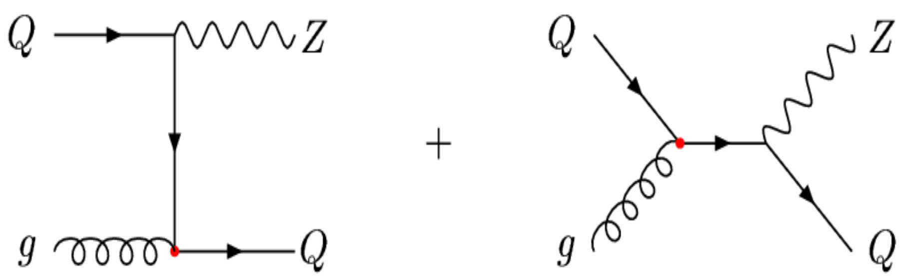
Systematics dominated by uncert. on JES & jet reco*ID eff.

Cross section ratios:

Multiplicity ($\geq$n jets)	$R_n = \frac{\sigma_n}{\sigma_0}$ $[\times 10^{-3}]$	Statistical Uncertainty $[\times 10^{-3}]$	Systematic Uncertainty $[\times 10^{-3}]$
1	119.1	$\pm$3.3	+17.2 / -16.2
2	18.1	$\pm$1.3	+4.5 / -4.3
3	2.6	$\pm$0.52	+0.90 / -0.89
4	0.61	$\pm$0.28	+0.29 / -0.27
5	0.42	$\pm$0.30	+0.42 / -0.24

Z(→ee/μμ)b associated production

- Motivation
  - Benchmark for SUSY Higgs boson production via gb→bh
  - Probes PDF of the b-quark
  - Background to ZH production
- Examples of ZQ (Zj) LO diagrams

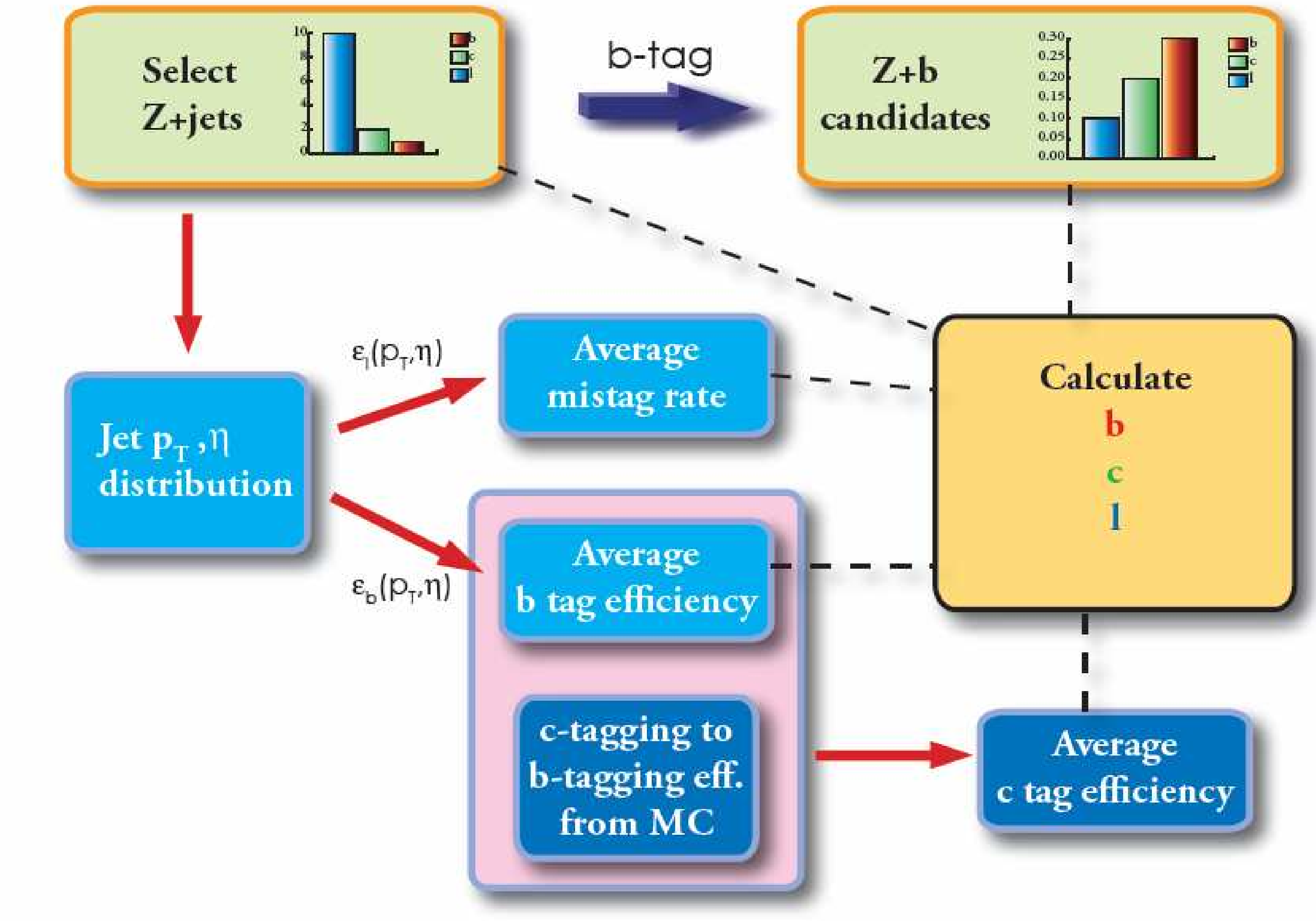


- Measure cross section ratio
  - **σ(Z+b)/σ(Z+j)**
  - Many uncertainties cancel

- Data correspond to integrated lumi. of 184 (ee), 152 (μμ) pb^{-1}
- Event selection include
  - Isolated e/μ: p_T >15/20 GeV
    $|\eta|$ < 2.5/2.0
  - Jet E_T > 20 GeV, $|\eta|$ < 2.5
  - At least one b-tagged jet
  - Z peak for signal, side bands for bkgd. evaluations
- Simulations performed with Pythia or Alpgen plus Pythia passed through detailed detector response
- Cross sections normalized to data
- Relative b- and c-quark content as given by MCFM NLO calculations

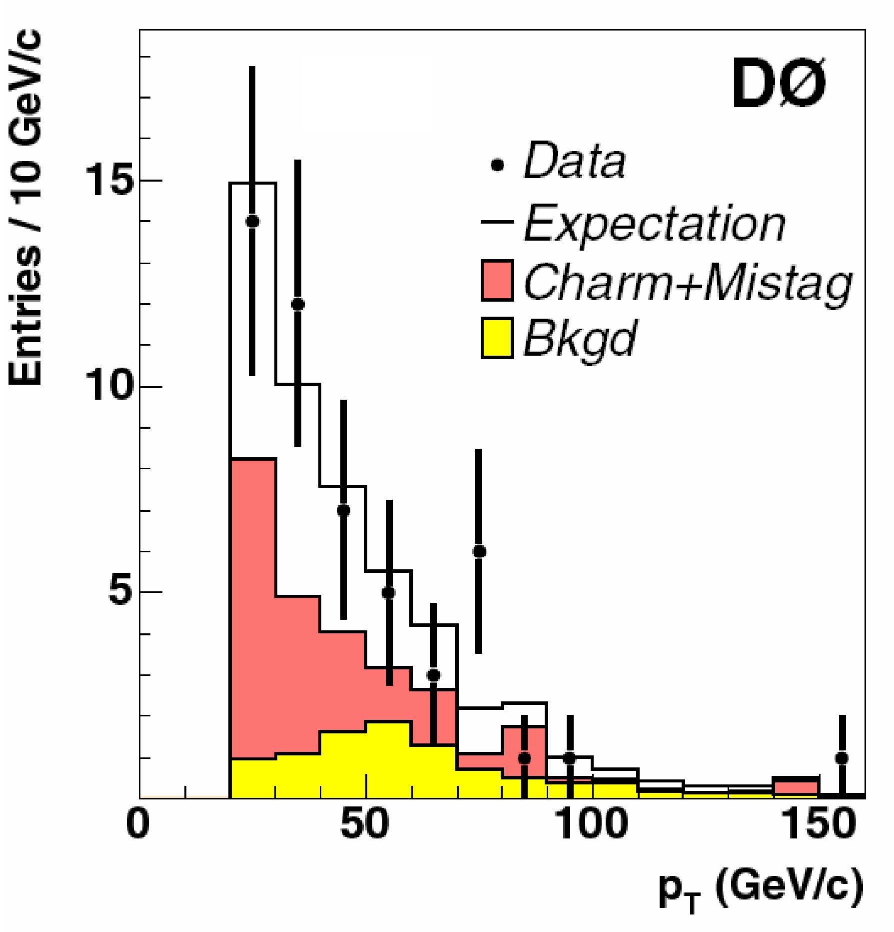
Method

$$N_{\text{before b-tag}} = t'_b N_b + t'_c N_c + t'_\ell N_\ell \qquad N_{\text{b-tagged}} = \bar{\epsilon}_b t'_b N_b + \bar{\epsilon}_c t'_c N_c + \bar{\epsilon}_\ell t'_\ell N_\ell$$



Z + ≥1 b-tagged jet

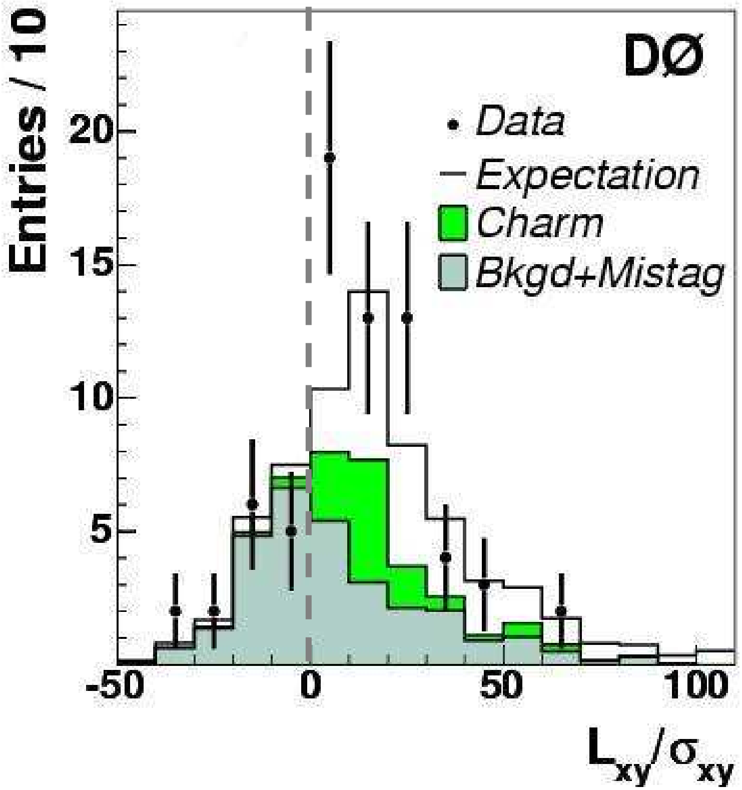
- Apply sec. vertex b-tag
  - 42 events with ≥1 tag
  - 8.3 evts. from QCD bkgd.
    - Estimated from sidebands



- Disentangle light, c, b contributions
  - Use light and b-tagging efficiency from data
  - c-tagging efficiency from MC and scaled for data/MC difference in b-tagging
  - N_c=1.69N_b from theory
- Cross checks with
  - Soft lepton tagging
  - Impact parameter tagging

σ(Z+b)/σ(Z+j) ratio

- Decay length significance of sec. vertices in transverse plane for b-tagged jets



Heavy flavor component in b-tagged candidate events is clearly seen !

- Measure cross section ratio Z+b/Z+j

$$\mathbf{0.021 \pm 0.004\ (stat)\ {}^{+\,0.002}_{-\,0.003}\ (syst)}$$

- Prediction: 0.018±0.004

J.Campbell, R.K.Ellis, F.Maltoni, S.Willenbrock, Phys. Rev. D69 (2004) 074021

- Systematics studies

Source (dominant)	**Uncertainty (%)**
Jet energy scale	+5.8 -6.9
Bkgd. estimation	+5.7 -5.2
Jet tagging	+4.6 -5.1
Z+(QQ) vs Z+QQ	+1.7 -5.4
σ(Z+c)/σ(Z+b)	+2.8 -2.8
Total	**+10.4 -11.8**

PRL 94, 161801 (2005)

Summary

- DØ is taking full advantage of Run II upgrade

- Have first results on W/Z + jets production, including b-jets. Some are unique

- More analyses with W/Z + jets are in the works, including detailed comparisons of event kinematics to various Monte Carlo predictions