Hadron Level Cross-Sections for W + Jets Production at CDF

Ben Cooper

UCL

MICHIGAN STATE UNIVERSITY

MC4LHC

CERN

July 2006

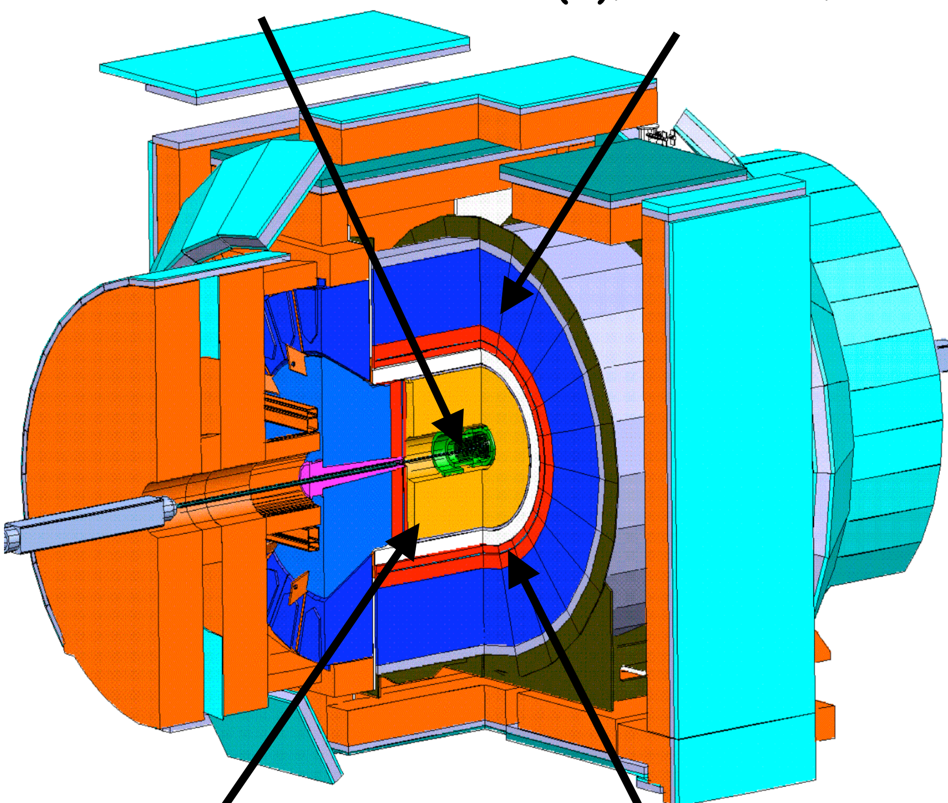
OUTLINE

- Motivations for Study
- Monte Carlo Issues
- Measurement definition
- Correcting to hadron level
- Background estimation
- Results
- Conclusions & plans

CDF and the Tevatron

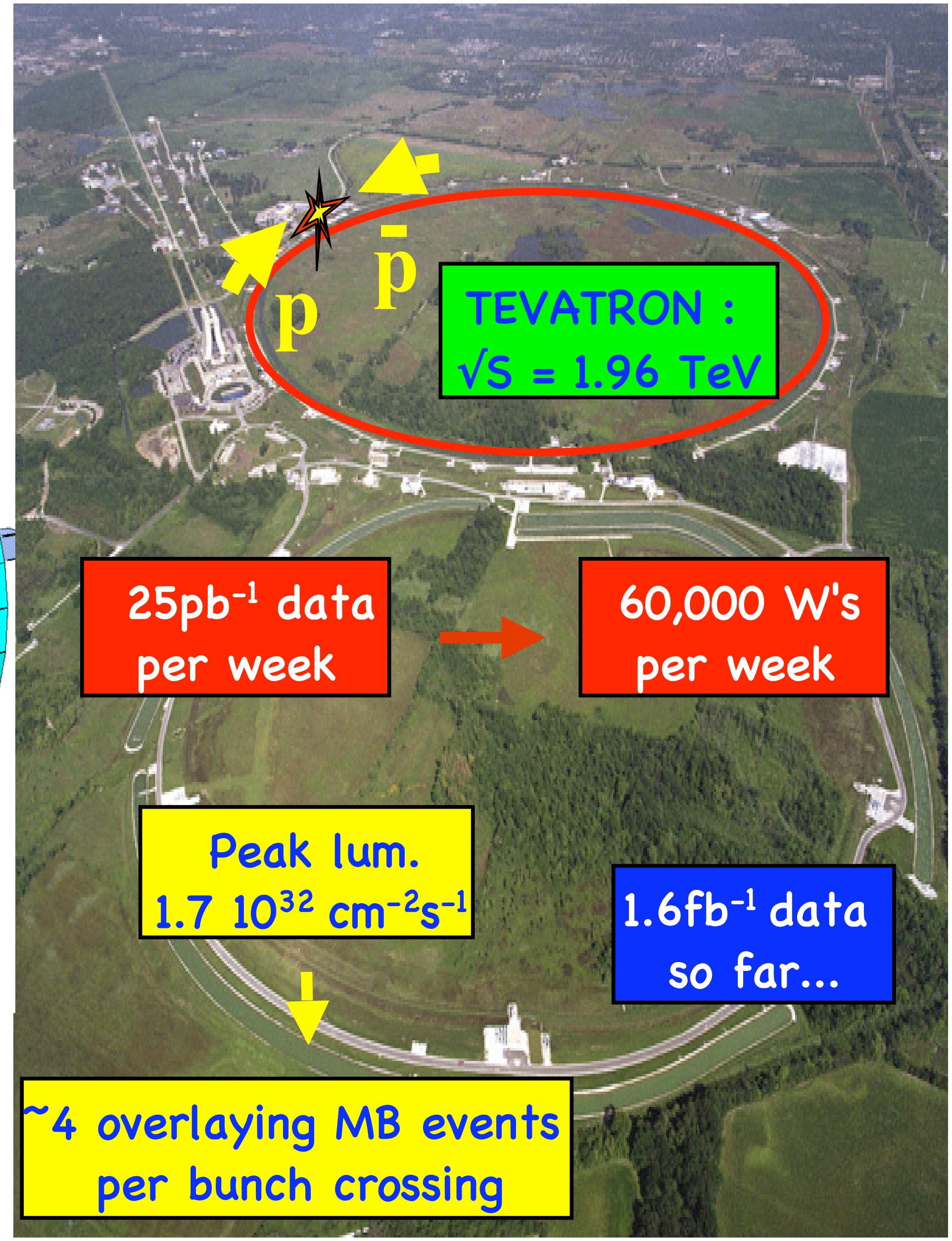
8 layer Silicon Vertex Tracker

Steel HAD CAL
$|\eta| < 3.6$
$\sigma(E)/E \approx 50\%/\sqrt{E}$

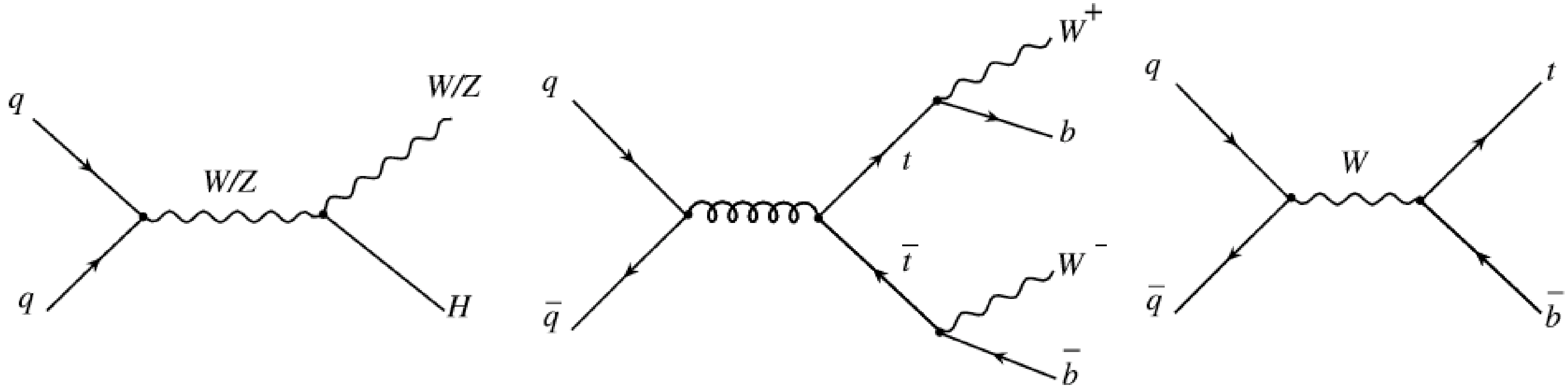


Central Tracker
$|\eta| < 1.0$
$\sigma(P_T)/P_T \approx 0.15\%$

Lead EM CAL
$|\eta| < 3.6$
$\sigma(E)/E \approx 14\%/\sqrt{E}$



Motivation: Understanding a vital background



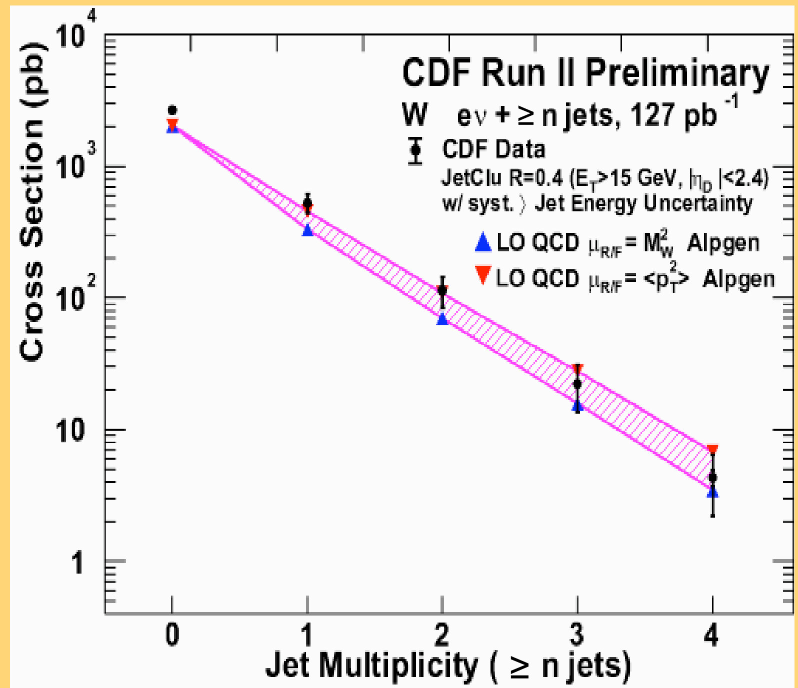
- Boson + jet is the final state for a number of important high p_T physics processes:
  - Top pair & single top production.
  - Higgs boson searches.
  - Searches for super-symmetric particles.
- All these signals are overwhelmed by large QCD production of boson + jets.
- It is crucial to have a good understanding of the boson + jets process.

Motivation: Test of pQCD Predictions

- Testing ground for pQCD in multijet environment
- The presence of a W/Z boson:
  - Ensures high Q^2 - pQCD
  - Large BR into leptons - easy to detect experimentally
- Key sample to test LO and NLO pQCD calculations
  - Pythia, Herwig: parton shower & hadronization, limited ME
  - AlpGen : W + n parton ME, interface to Pythia/Herwig for PS, MLM ME-PS matching scheme
  - Sherpa : W + n parton ME, APACIC showering, CKKW ME-PS matching scheme
  - MCFM: NLO ME W + 1 or 2 partons
  - MC@NLO: W+X (NLO ME + herwig shower)
- Study the underlying event in an alternative topology than inclusive multijets.

W + n Jets LO Predictions

- W + n parton LO ME calculation + parton shower + hadronisation:
  - W + ≥ n jets Cross-section
  - Jet kinematics for ≥ n jets
- Issues:
  - Dependence on Q^2 scale
  - Dependence on parton cuts
  - Phase space overlap when combine n parton samples
- Advances:
  - ME-PS matching - CKKW and MLM prescriptions.
  - NLO predictions.



LO W + ≥ n parton cross-section vs data: good within large Q^2 uncertainties.

Definition of our measurement

- Aim for a definition as much as possible independent of theoretical predictions and detector effects.

$$\frac{d\hat{\sigma}_{W\rightarrow e\nu}}{d(jet)}$$

- Restrict W decay to analysis acceptance.
- $P_T^{ele} > 20$ GeV, $P_T^{\nu} > 30$ GeV
- $WM_T > 30$ GeV/c², $|\eta^{ele}| < 1.1$
- Reduces theoretical dependence of measurement, without comprising usefulness.

- Jets: JETCLU cone 0.4, $E_T > 15$ GeV, $|\eta| < 2.0$.
- Jet energies corrected to hadron level and for multiple interactions - underlying event remains.
- Differential w.r.t. 1st, 2nd, 3rd and 4th jet E_T, 1st-2nd jet invariant mass and ΔR.

- This is not an EWK measurement - W is a clean signal for high Q^2 events within which we can examine jet kinematics.

Making the Measurement

Identify $W \rightarrow e\nu$ candidate events from high E_T electron and large missing E_T.

Reconstruct jets.

In each bin of the jet kinematic variable calculate:

$$\sigma = \frac{N^{cand} - N^{bkgd}}{A \bullet \varepsilon_{ID} \bullet L}$$

Backgrounds:

- QCD multijet
- Top pair
- $Z \rightarrow ee$, $W \rightarrow \tau\nu$
- WW
- Multiple interactons

Dataset luminosity $320 \pm 20 pb^{-1}$

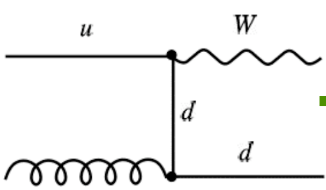
Acceptance and efficiency both estimated using detector simulated LO W + Jets Monte Carlo.

- Theoretical dependence enters the measurement via background and acceptance estimation - covered by systematics.
- Detector dependence removed by jet energy scale corrections and acceptance.

Making a CDF-independent Cross-Section Measurement

The Detector Effects

The "Physics"



High P_T electron

High P_T neutrino

Jets of hadrons

D E T E C T O R

"Electron-like" Cluster of high E_T EM CAL towers + track.

Electron E_T resolution ≈ 5%.

Large Missing E_T – after correction for CAL response to jets.

Missing E_T resolution ≈ 15%.

CAL level jets

CAL granularity (tower size $\Delta\eta = 0.11$, $\Delta\phi = 0.26$)

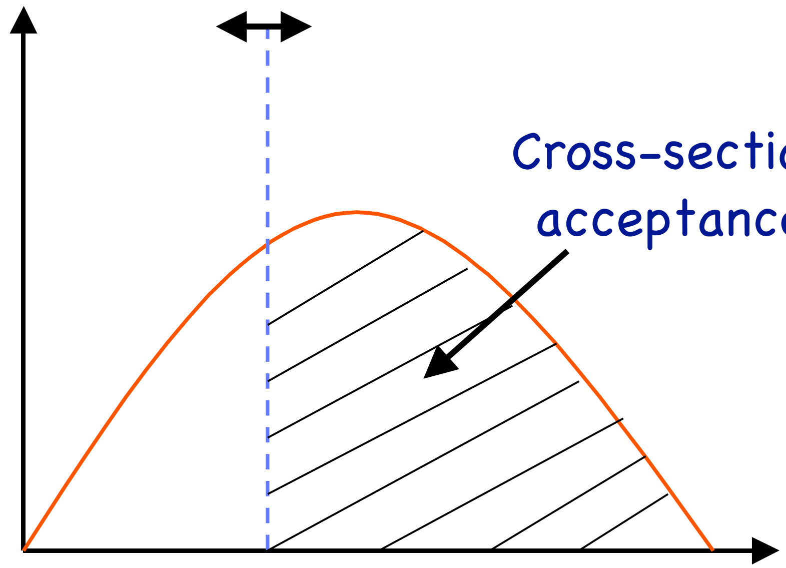
Jet E_T offset ≈ 3%, resolution ≈ 15-20%.

Making a detector independent measurement

- We rely largely on detector simulated Monte Carlo to remove detector effects.
- Affects on W selection accounted for using Monte Carlo derived acceptance and electron ID efficiency corrections.
- Jets corrected back to hadron-level energy:
  - Using generic CDF jet energy scale corrections: on average correction of energies back to hadron-level.
  - On average correction for energy from multiple p-pbar interactions (but no correction for UE here).
  - Additional unfolding of detector resolution effects on jet E_T spectrum.

Acceptance and Efficiency Correction

- W Cross-section phase space same as analysis acceptance.
- Acceptance factor reduced to accounting for detector resolution and local shape around cut.
- Reduces theoretical dependence of measurement.



- Use W MC for acceptance and electron ID efficiency:
  - Systematic on ID efficiency by comparing MC and Z data
  - Estimation of acceptance systematic by comparing different MC models

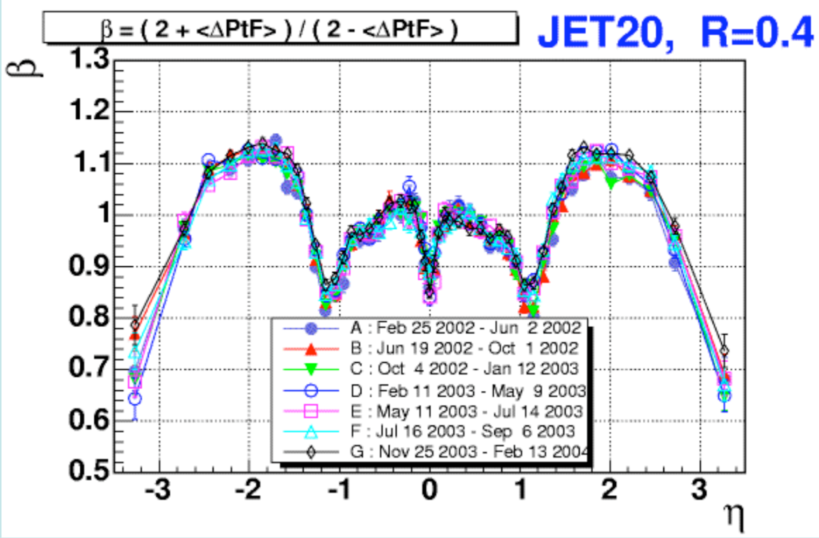
  } 5%

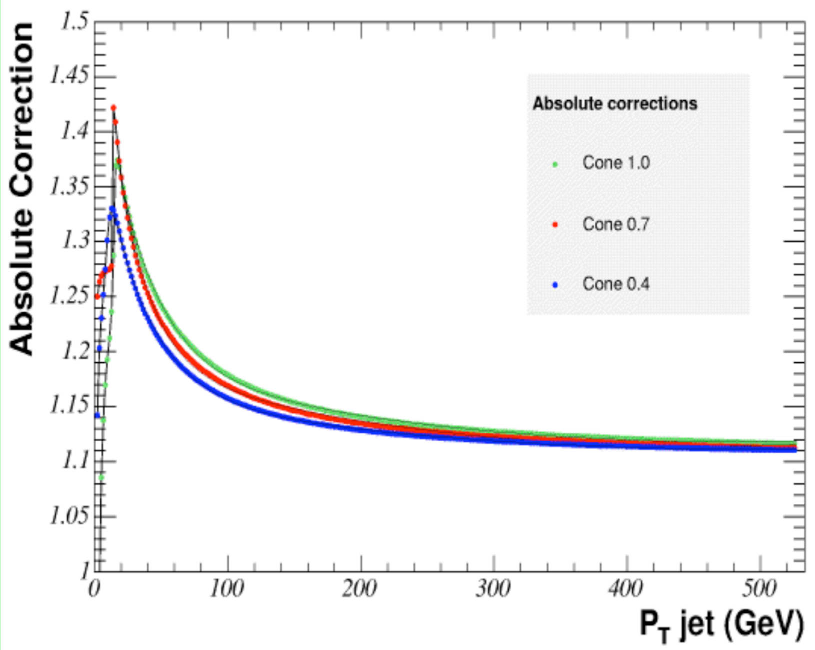
$$A \bullet \varepsilon_{ID} \approx 0.6 \pm 0.03$$

Largely independent of jet kinematics

CDF Jet Energy Scale Corrections

- RELATIVE corrections from "dijet balancing" in data.
- Purpose: Equalise response over all η to that in central CAL.
- Identify QCD 2→2 processes – one central "trigger" and one "probe" jet.
- Probe E_T should on average equal trigger E_T.

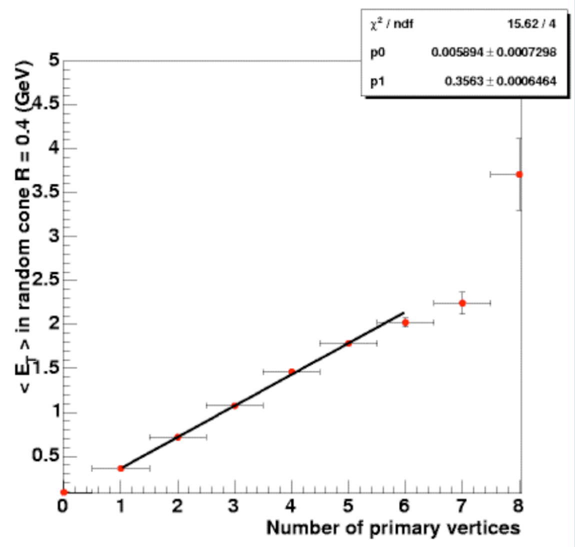




- ABSOLUTE corrections from detector simulated dijet MC.
- Purpose: Correct jets on average from CAL to hadron energy.
- In MC jets clustered at both hadron level and CAL level and "matched".
- Determine most probably HAD E_T for each CAL E_T – defines correction.
- Systematic 2-3%.

Multiple Interactions Correction

- At 1 X $10^{32}cm^{-2}s^{-1}$ most probably no. of interactions is 2 per bunch crossing.
- Additional "soft" interaction deposits energy in jet cone.
- Using minimum bias data - parameterise average energy in random cone as function of number of additional reconstructed vertices.

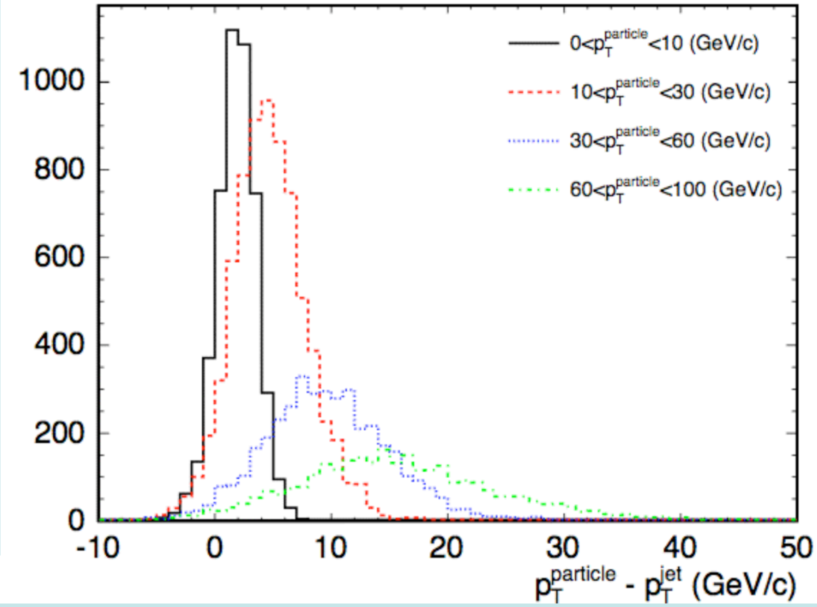


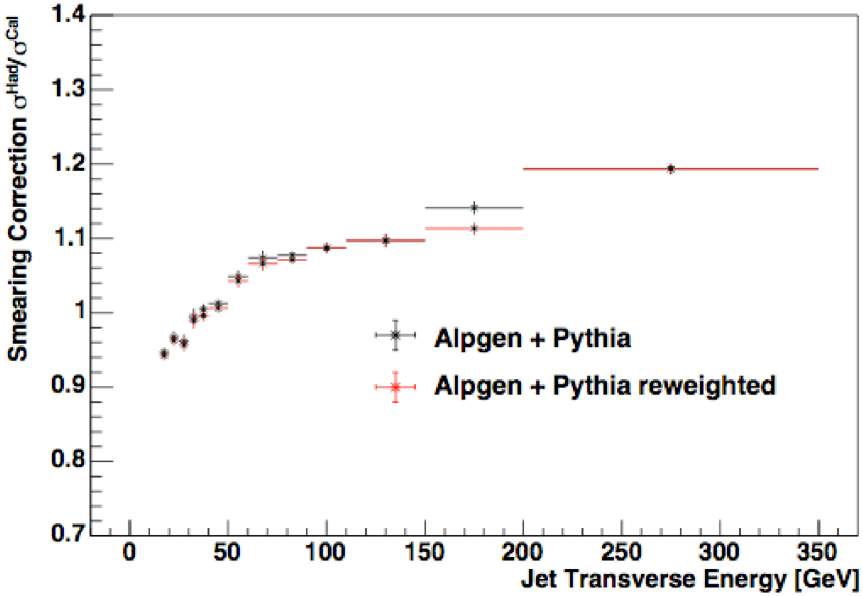
- In addition - rarely MI can result in an extra jet.
- "Promotion bkgd" - causes migration of signal events between jet multiplicity bins.
- Using MB data get extra jet rate per additional vertex.
- W candidate N_{vtx} distbn - normalise MB jet E_T spectra.

njet $\geq$	1	2	3	4
$bkgd_{frac}$ %	2.4	3.6	3.8	3.3

Analysis Specific Unsmearing Correction

- Absolute corrections only correct on average for offset of CAL energy response.
- What about impact of non-zero CAL resolution $\sigma \approx 15\text{-}20\%$.
- Resolution alters shape of measured E_T spectrum – necessitates "unsmearing" correction.



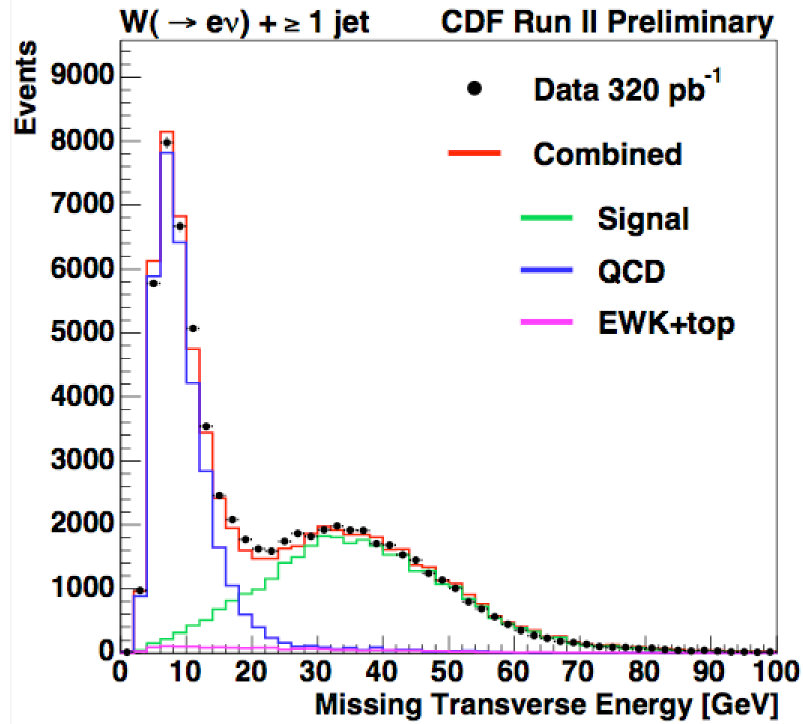


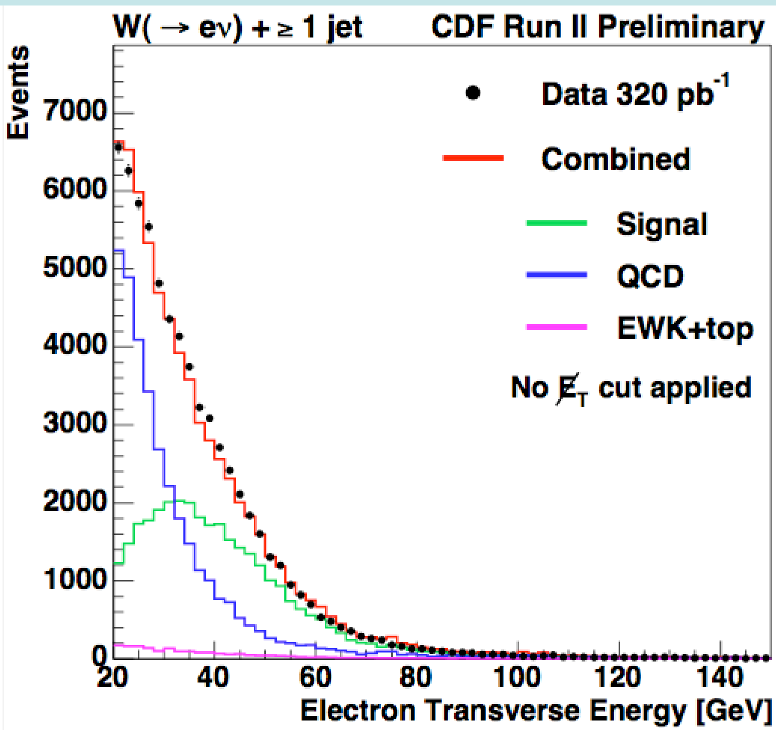
- Use detector simulated W+Jets MC.
- Form jet E_T spectra at HAD level and at (JES corrected) CAL level.
- Define unsmearing factor in each bin as N_{HAD}/N_{CAL}.
- To remove dependance on MC HAD spectrum – use iterative procedure, reweighting until CAL spectrum equal to that observed in data.

Other Elements of the Measurement

Background Estimation

- QCD modelled by fake-electron sample formed from dataset.
- MC for other bkgds and signal
- Background normalisation from fit to data missing E_T distribution.
- Excellent agreement in other kinematic variables.

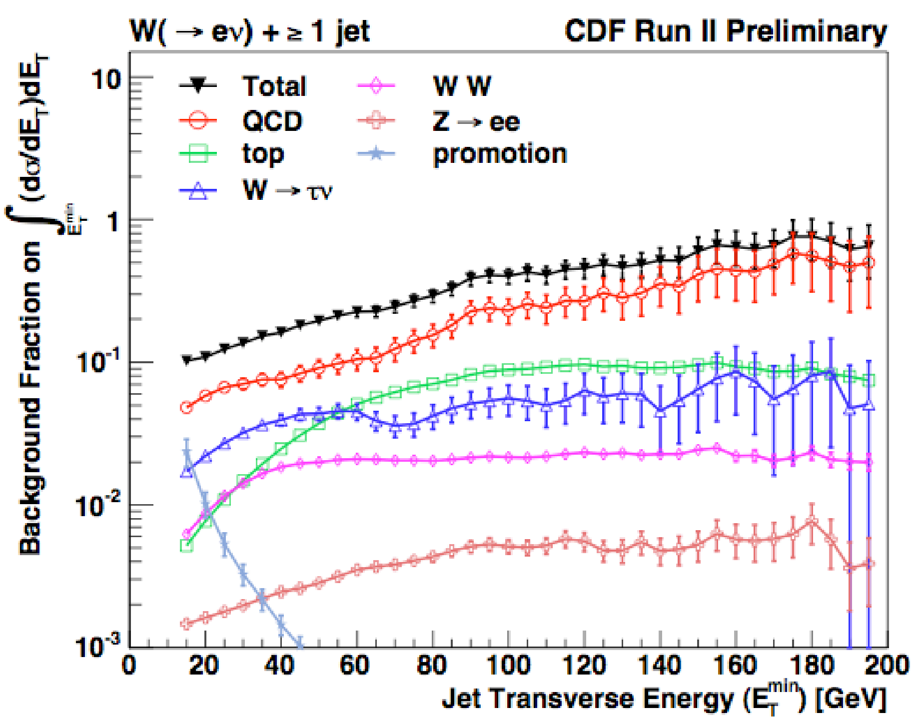


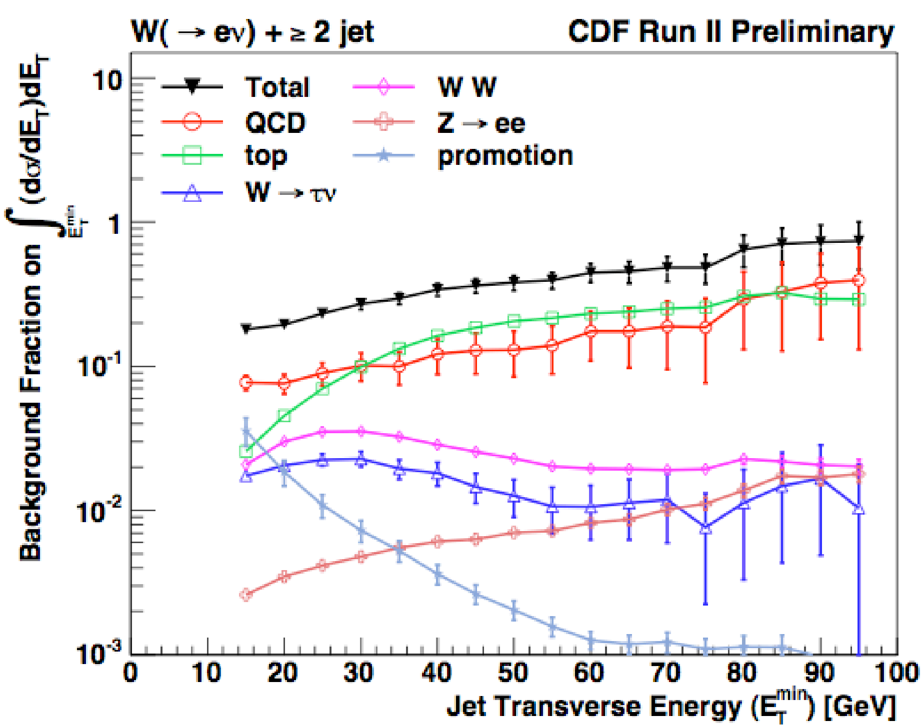


Background Systematics:

- Fake-electron statistics (dominant)
- Fake-electron QCD model (5-20%)
- Top cross-section (10-20%)
- MC model dependence (5%)

Background Fractions





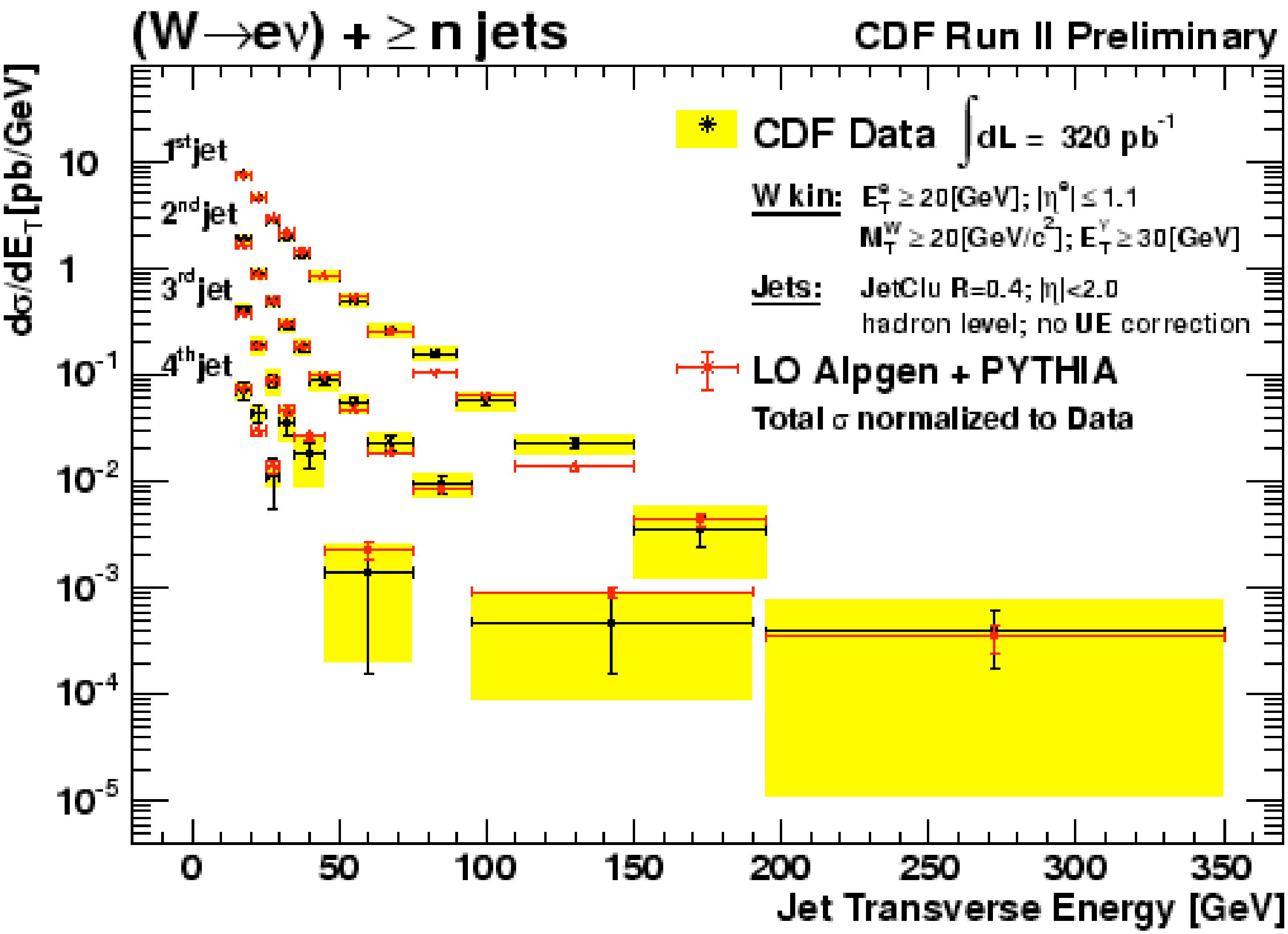
- QCD is a substantial background contribution, dominating at low E_T.
- But in high E_T region Top pair production is dominant.

The Cross-Section Results
(MC comparisons by no means exhaustive)

CDF W+jets Differential Cross-Section

$$\frac{d\hat{\sigma}_{W\rightarrow e\nu}}{dE_T}$$

For 1st, 2nd, 3rd and 4th Jet E_T



MC has been normalized to inclusive data cross section in each jet sample!

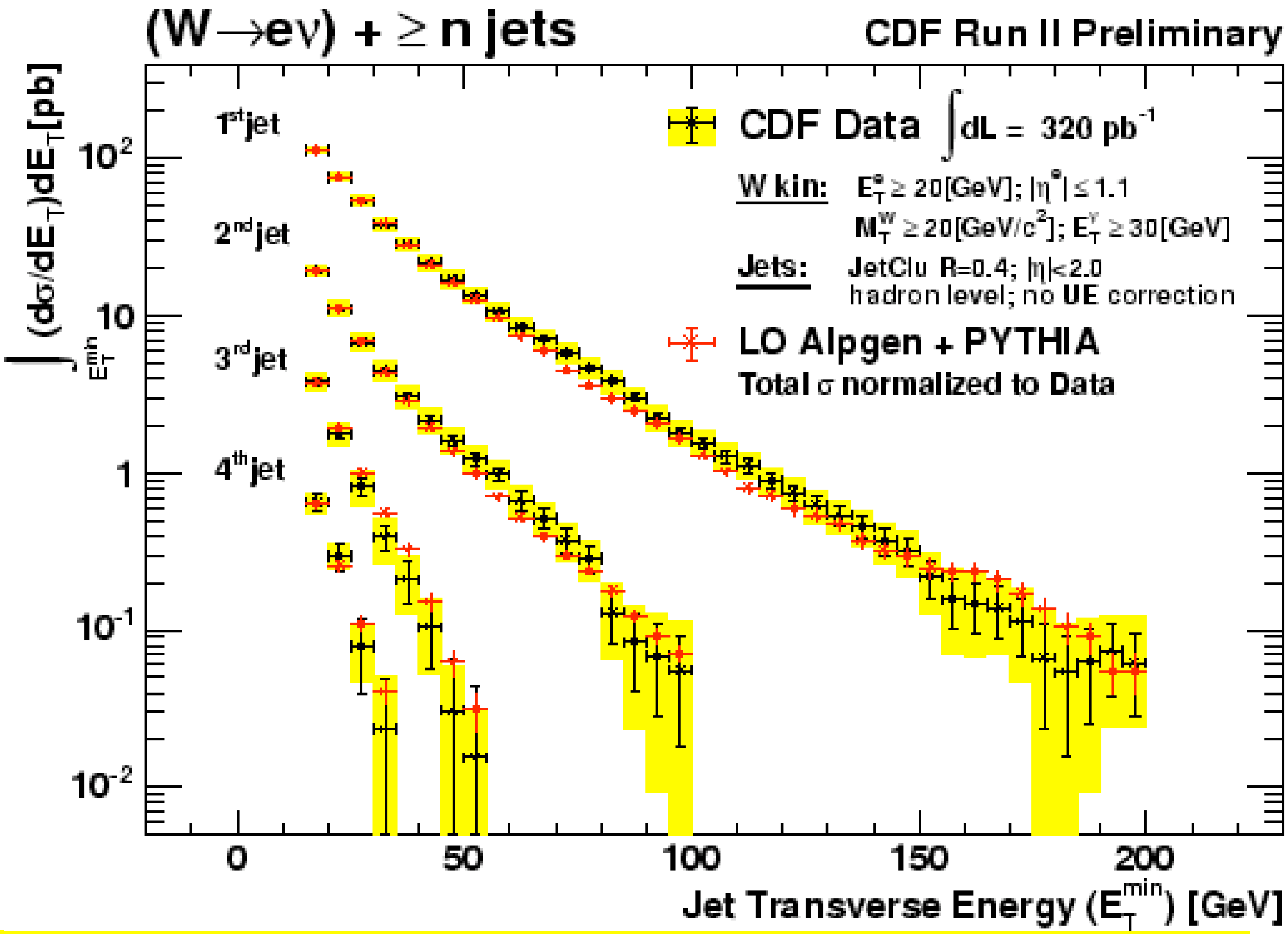
LO W + n parton prediction reproduces shape of $d\sigma/dE_T$ reasonably well.

CDF W+jets Integrated Cross-Section

$$\int_{E_T^{min}} \frac{d\hat{\sigma}_{W\to e\nu}}{dE_T} dE_T$$

For 1st, 2nd, 3rd and 4th Jet E_T

Essentially a measurement of $\sigma(W + \geq n \text{ jets})$ for different jet E_T thresholds.



MC has been normalized to inclusive data cross section in each jet sample!

First bin MC & data is in perfect agreement by construction.

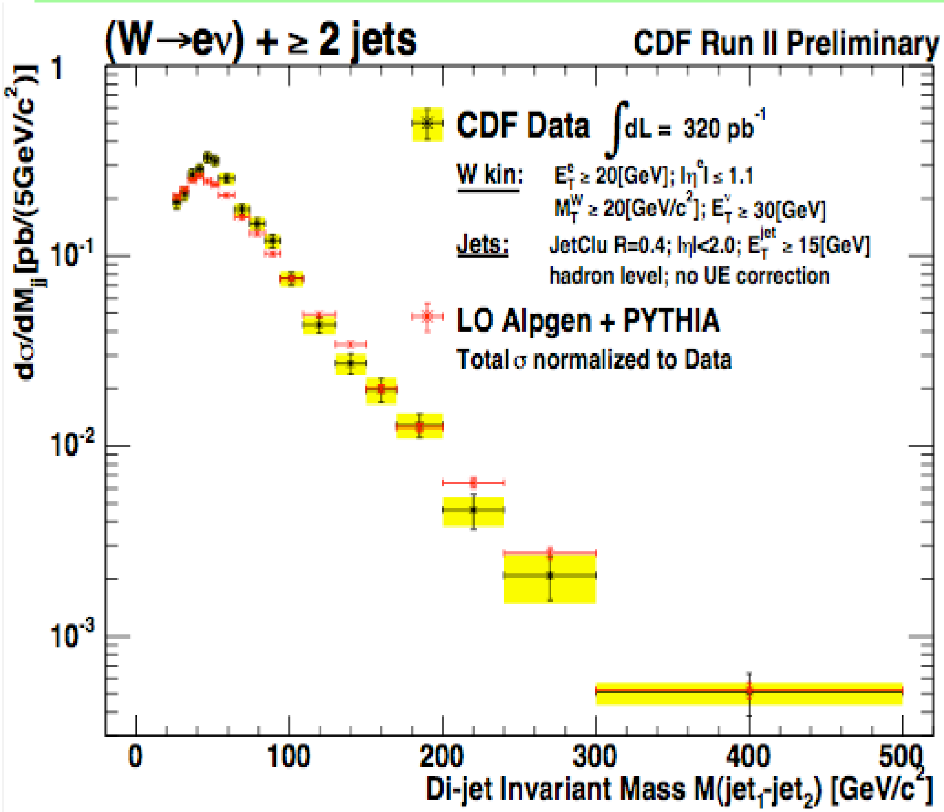
CDF W+jets Differential Cross-Section

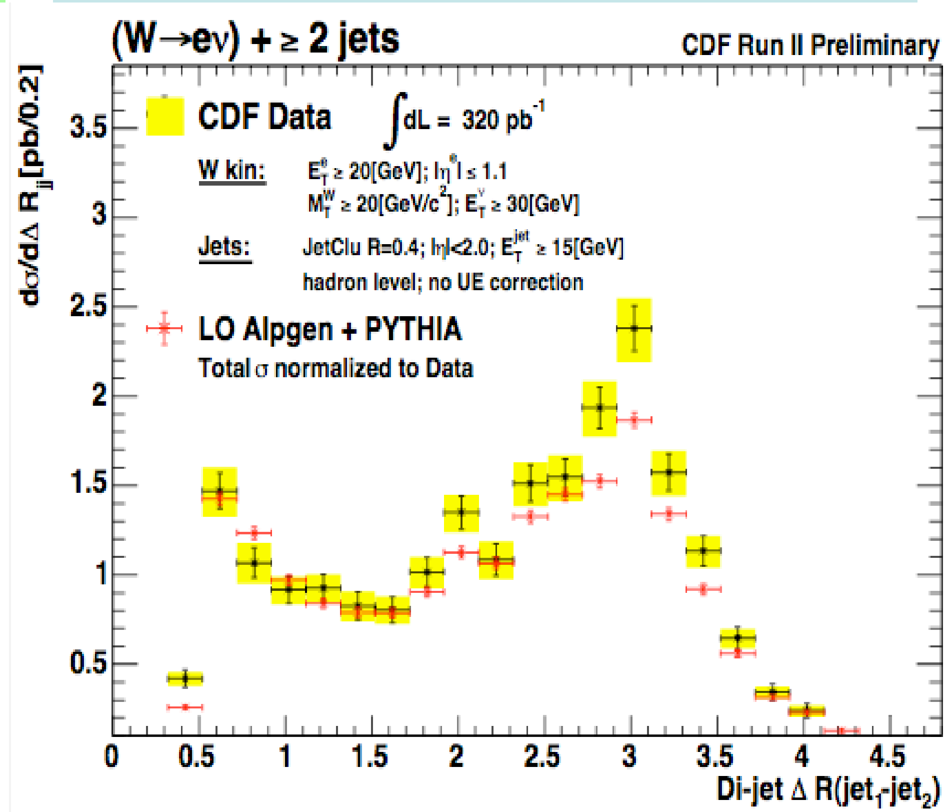
$$\frac{d\hat{\sigma}_{W\rightarrow e\nu}}{dM_{jj}}$$

Differential σ w.r.t 1st-2nd jet invariant mass in the W + ≥ 2 jet sample

$$\frac{d\hat{\sigma}_{W\rightarrow e\nu}}{d\Delta R_{jj}}$$

Differential σ w.r.t 1st-2nd jet ΔR in the W + ≥ 2 jet sample



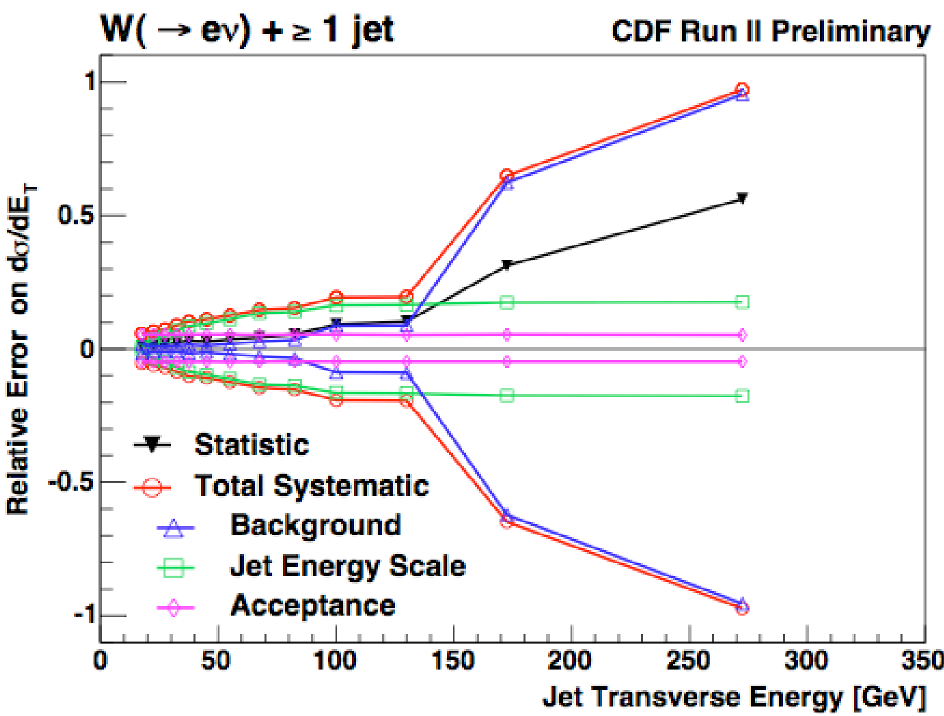


MC has been normalized to measured W+2 jet inclusive cross section!

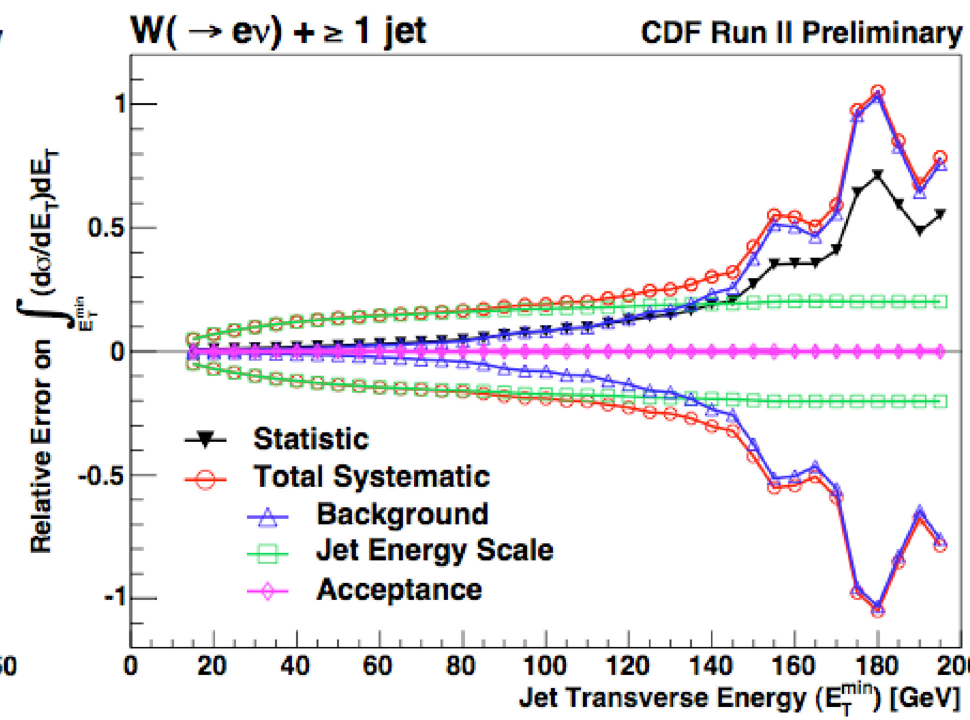
Errors breakdown

Representative of the behavior of errors in the measurements

Relative error on leading jet $d\sigma/dE_T$



Error on leading jet $\int (d\sigma/dET)dET$



- Large statistical uncertainty at large E_T.
- Systematic dominated by jet energy scale at low E_T, and by the (QCD) background subtraction at high E_T.

Work in progress and Plans

- Extend the measurement to use muons and to $1fb^{-1}$:
  - Larger E_T range, more sensitive to the tail of the cross-section.
  - Better control on data driven QCD background subtraction.
- Move to the preferred midpoint algorithm – don't expect big changes.

- Make extensive comparisons to theory, both shape and rate predictions:
  - LO ME-PS matching prescriptions – CKKW and MLM
  - NLO predictions: MCFM (parton level), MC@NLO (hadron level)

- Measure the Z + Jets cross-section:
  - Reduced statistics but backgrounds greatly reduced also.
  - Z + Jet events provide an alternative and cleaner environment for UE studies than multijet events.

Conclusions

- A new measurement of differential σ(W + jets) w.r.t jet kinematics, more suitable for theoretical comparisons:
  - Hadron level measurement: jet detector effects removed.
  - Differential measurement: background, acceptance and efficiency impact on shape accounted for.
  - Restricted W decay cross-section definition: reduced theoretical dependence.

- Any theorist can overlay their hadron-level predictions without need for CDF detector simulation.

- The systematic on many high p_T measurements receives a substantial contribution from boson + jet knowledge.
- Crucial to have a robust simulation of boson + jets to explore for new physics at Tevatron & LHC.