W+jets production at CDF

Andrea Messina

CERN

Berkeley workshop on boson+Jets Production

Berkeley, USA

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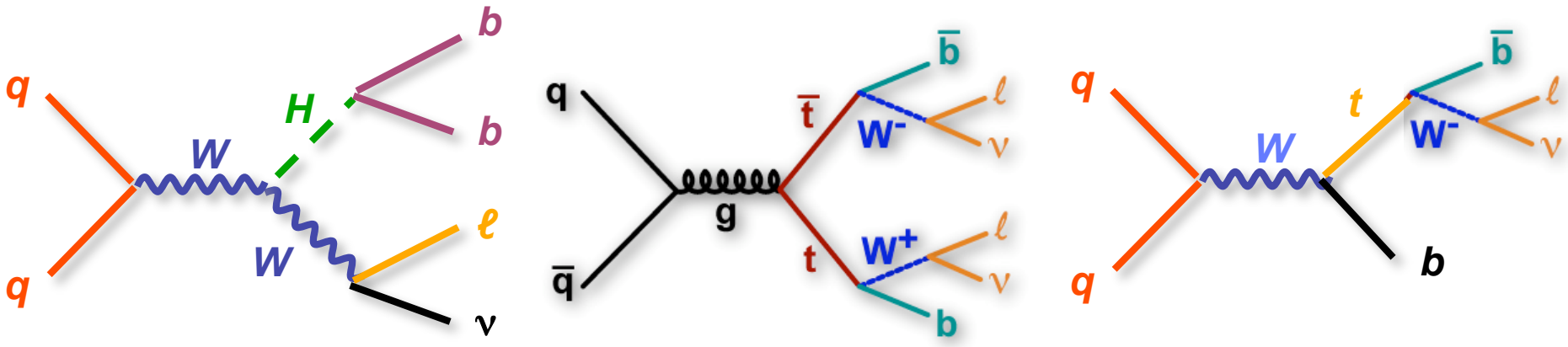
OUTLINE

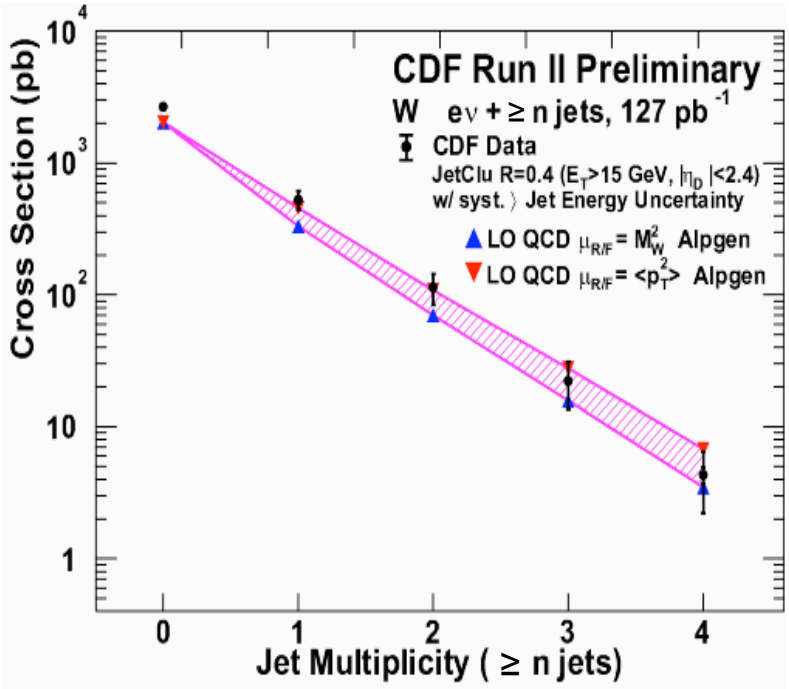
- Why boson+jets
- Experimental environment
- W+jets: a measurement in detail
- Comparison with theory
- conclusions

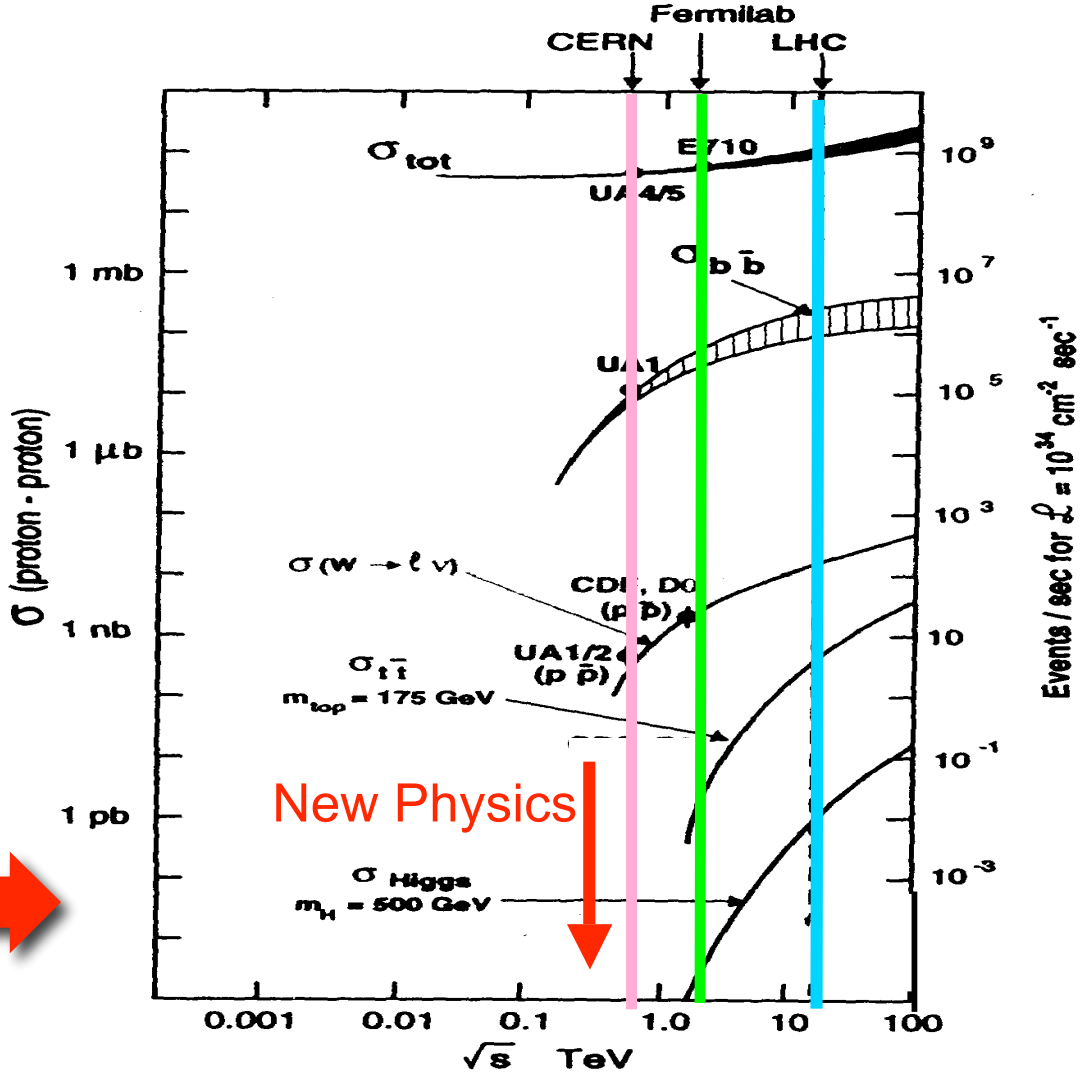
Motivation



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

Some cross sections…



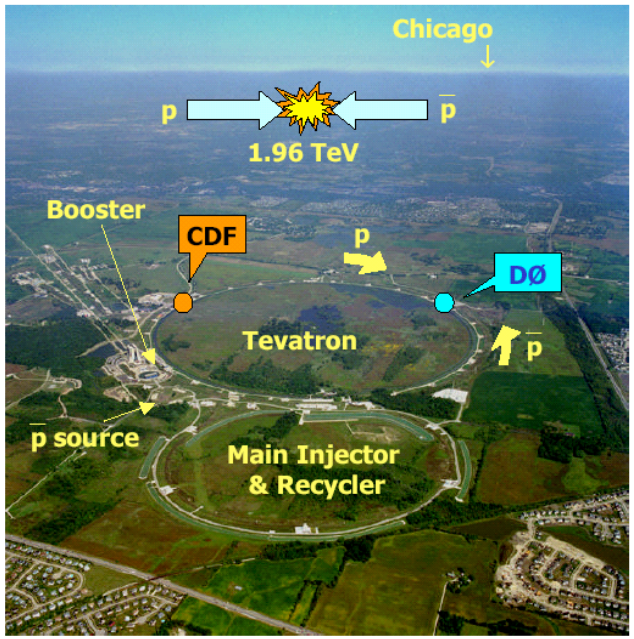


Each additional jet costs a factor of O(10) (α_s)

$\sigma(Z\to ee)/\sigma(W\to e\nu) \approx 0.1$

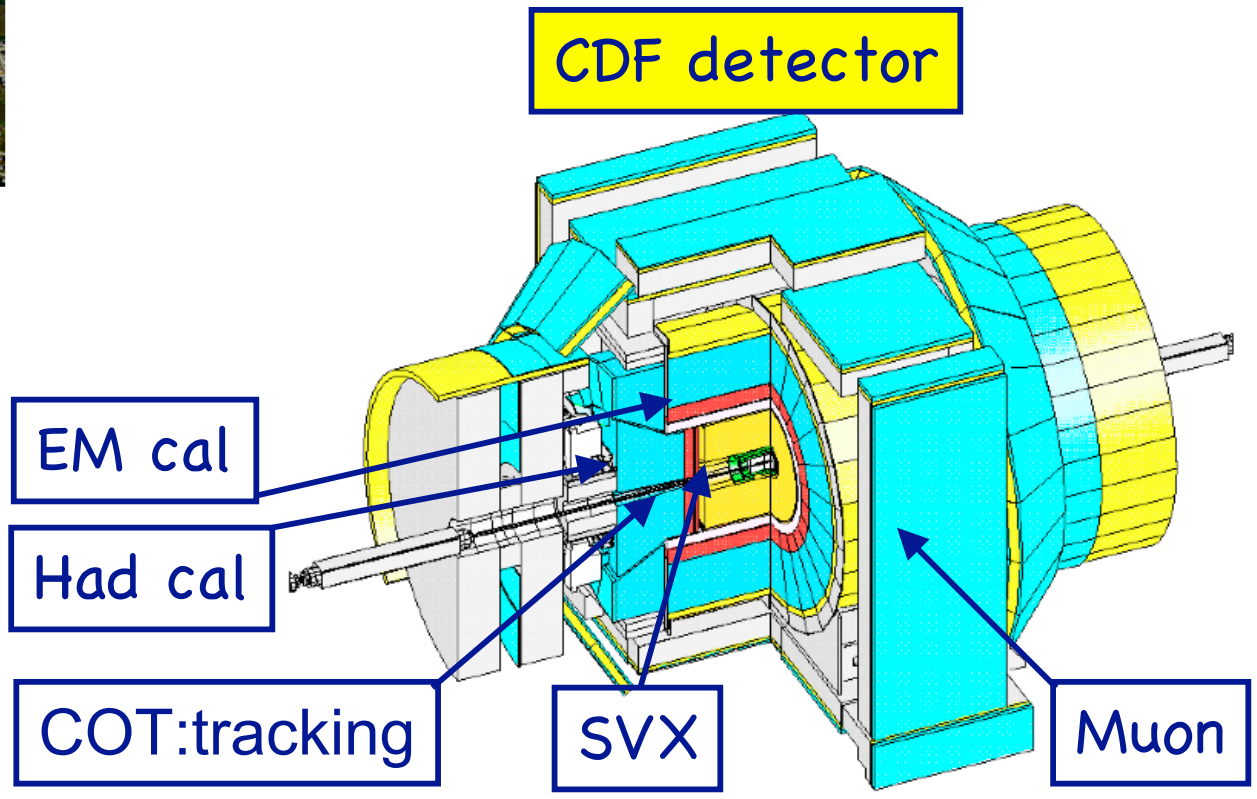
EXPERIMENTAL ENVIROMENT

Experiment apparatus



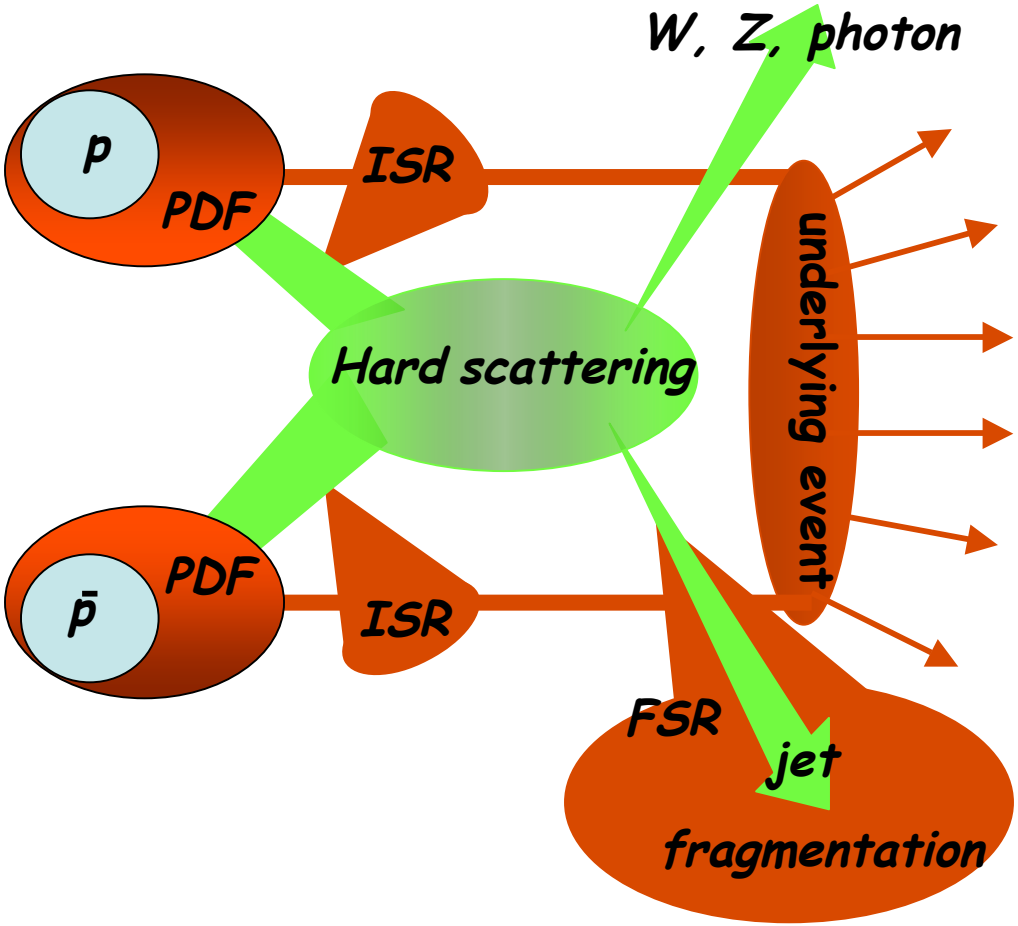
- p-pbar collisions, 36 bunches-396 ns
  $\sqrt{s}$=1.96 TeV
- peak Luminosity 3×10^{32} [$cm^{-2}s^{-1}$]

- Silicon detector (SVX):
  top event b-tag: ~55%
- COT: drift chamber
  Coverage: $|\eta|<1$
  $\sigma_{Pt} / P_T \sim 0.15\% P_T$
- Calorimeters:
  Coverage: $|\eta|<3.6$
  EM: $\sigma_E / E \sim 14\% / \sqrt{E}$
  HAD: $\sigma_E / E \sim 80\% / \sqrt{E}$
- Muon:
  muon ID up-to $|\eta|=1.5$



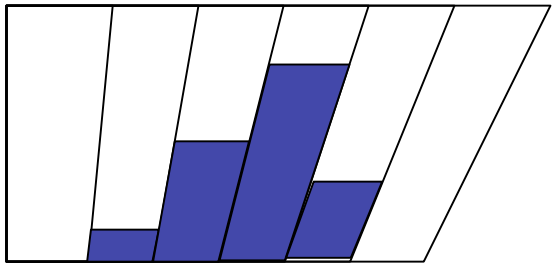
High p_T Physics @ Tevatron

A typical Tevatron event consists of:



- Production QCD related
- Hard scattering:
  - ✓ perturbative regime
- Underlying event & soft physics:
  - ✓ phenomenological models

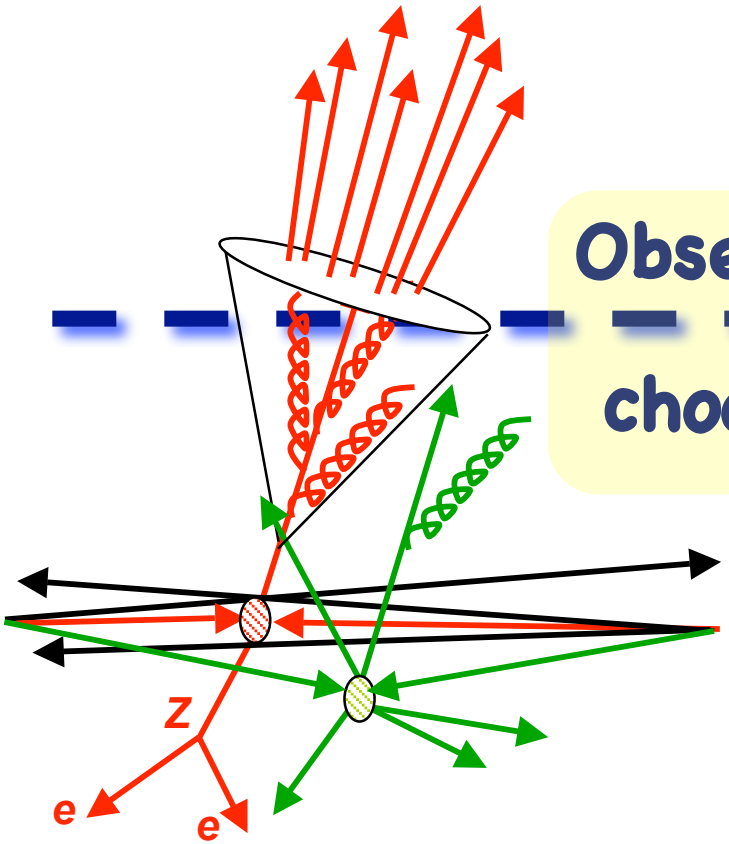
Observable definition



Observable: experimental challenges

Unfold detector effect
- correct for them, assign systematic

Estimate backgrounds



Observable defined at particle level

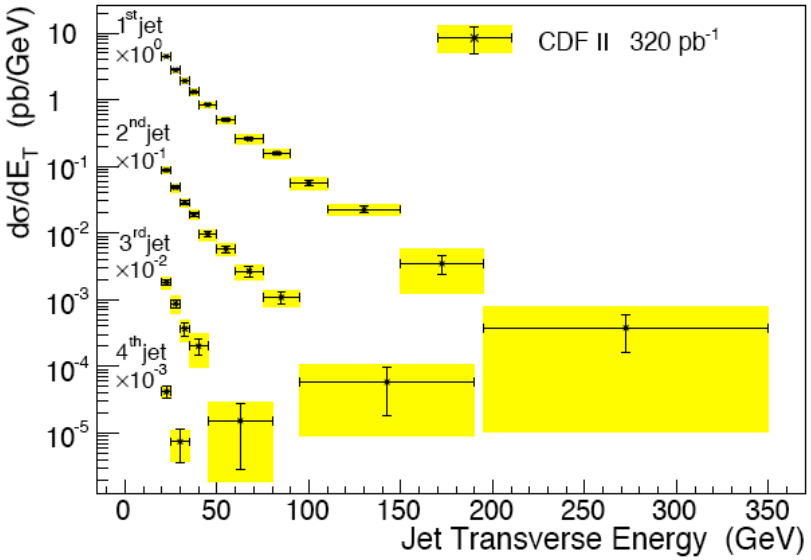
choosing a jet clustering algorithm

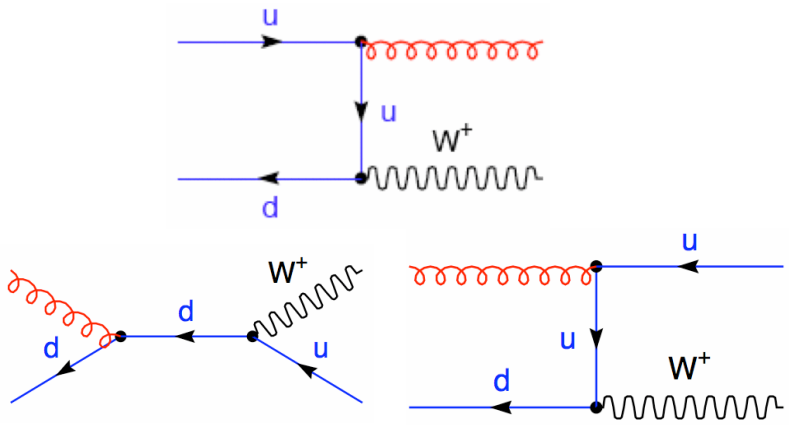
Observable: Theory description

Hard Scattering
(Perturbative-calculable)

Soft contribution
(Model-tuned on data)

Measurement (Phys.Rev.D77:011108,2008)





- ✓ We measure the cross section for W→eν + n jet production
- ✓ Philosophy: Make a measurement that is both detector and model independent:

$$\frac{\delta\sigma\left[\begin{array}{l} P_T^e > 20GeV, M_T > 20GeV \\ P_T^\nu > 30GeV, |\eta^e| < 1.1 \end{array}\right]}{\delta E_T^j}$$

Restrict σ(W) to the measurable phase space

Jets corrected particle level

No UE or had. corrections

JETCLU 0.4

$E_T^{corr} > 20$ GeV; $|\eta| < 2.0$

W + jet measurement definition

High P_T electron trigger ➔

- Identify W:
  - E_t^{ele}>20GeV; Met>30GeV;M_T^W>20GeV
- Reconstruct jets:
  - jetclu R=0.4 $|\eta|$<2 E_t^{jet}>20GeV

✓ In each bin of the jet E_T distribution compute:

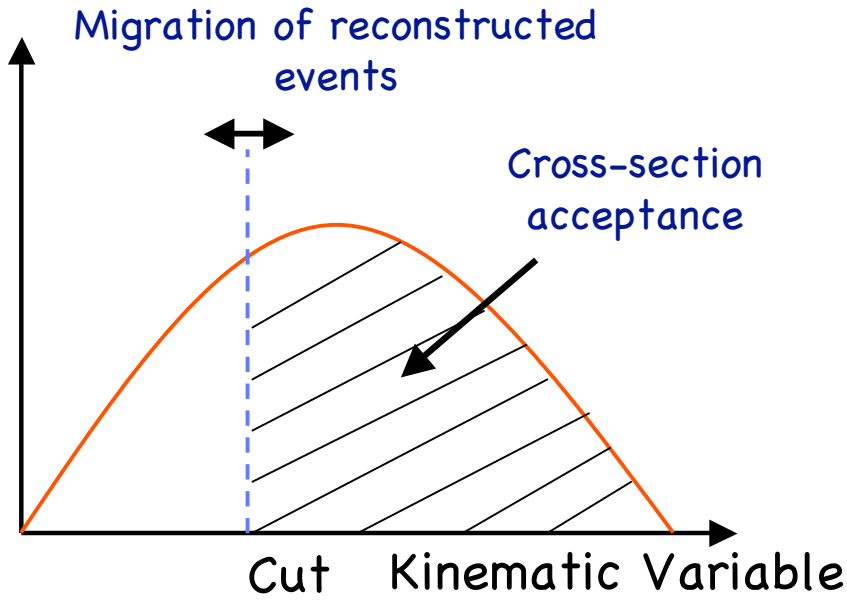
$$\sigma = \frac{N^{cand} - N^{bkgd}}{A \bullet \varepsilon_{ID} \bullet L} \bullet C_{unfold}^{calorimeter}$$

✓ Main backgrounds: QCD, top, W->τν

Acceptance and Efficiency

- ✓ Define cross section phase space as the W detector acceptance

Events migrate across acceptance boundary: convolution of local shape and resolution



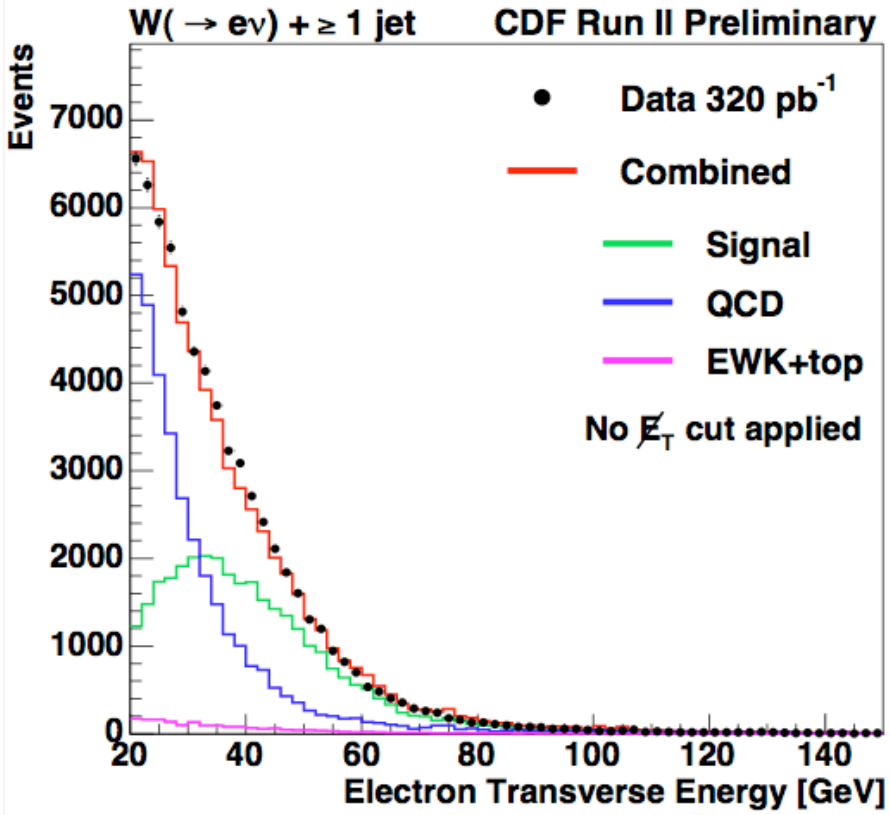
- ✓ Use MC for acceptance and electron ID efficiency
  - Systematic on ID efficiency comparing Z MC and data
  - Systematic on acceptance from different MC models

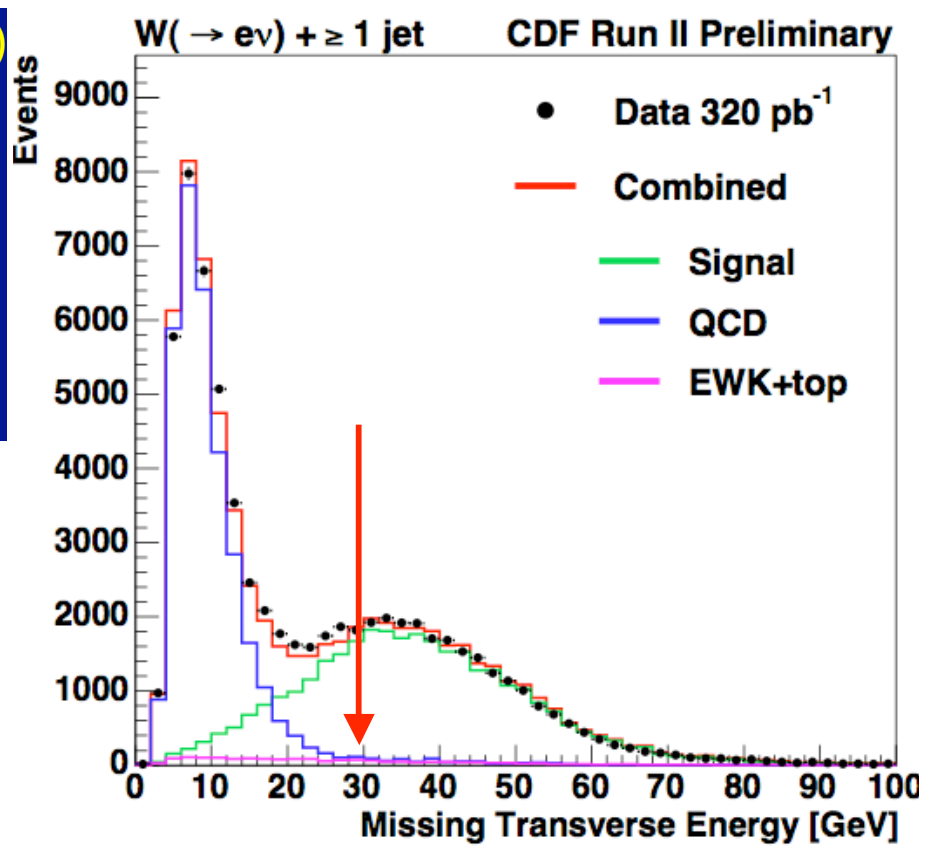
$$A \cdot \varepsilon_{ID} \approx 0.6 \pm 0.03$$

largely flat as function of jet kin

Background

- QCD from fake electron (antielectron)
- Use MC for EWK & top
- Relative normalization from MissE_T fit to data
- Very good agreement with data in other kinematic variables





Systematics:

- antielectron statistic
- antielectron model (5-20%)
- Top cross section (10-20%)
- MC model (5%)

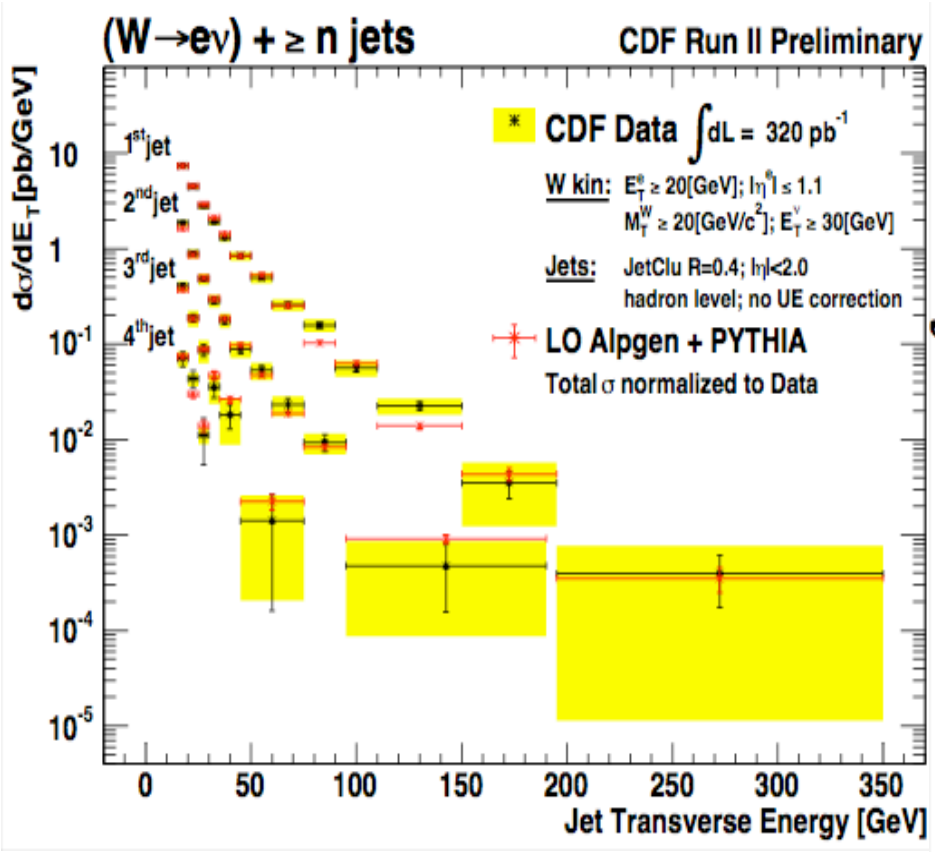
CDF W+jet cross section measurement

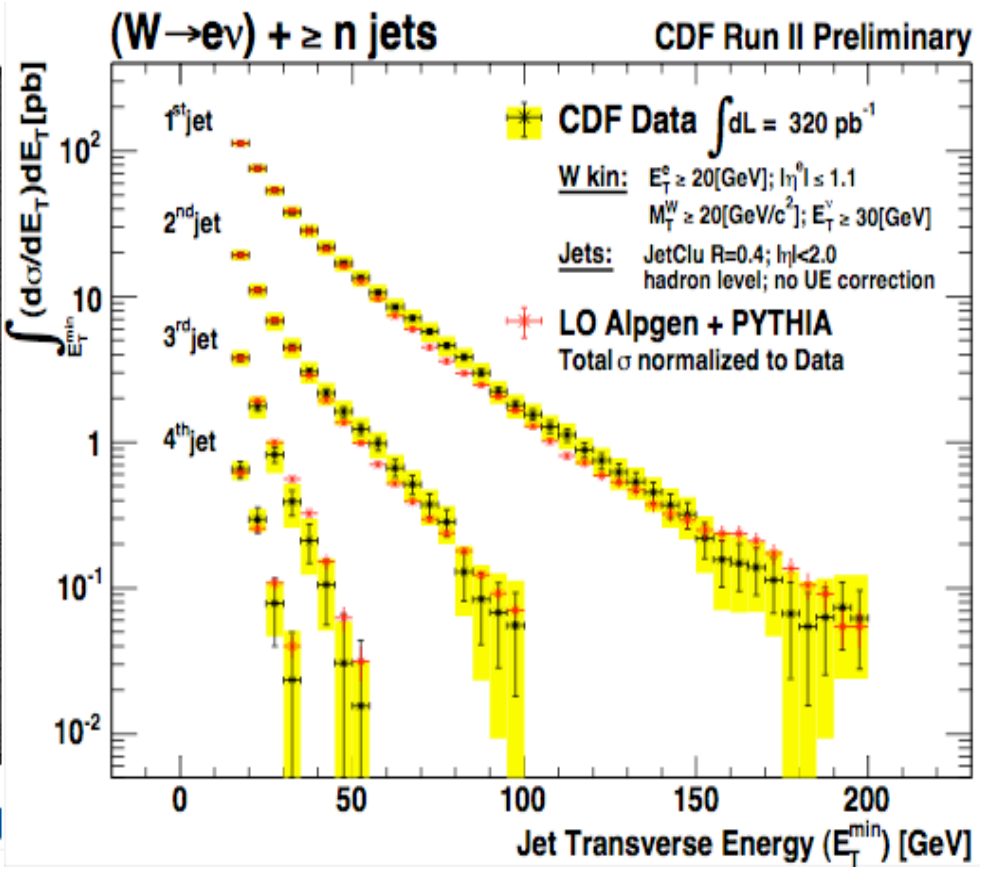
$$\frac{d\sigma_{W\to e\nu}}{dE_T^{n^{th}-Jet}}$$

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

$$\int_{E_T^{\min}}^{\infty} \frac{d\sigma_{W\to e\nu}}{dE_T^{n^{th}-jet}} dE_T^{n^{th}-jet}$$

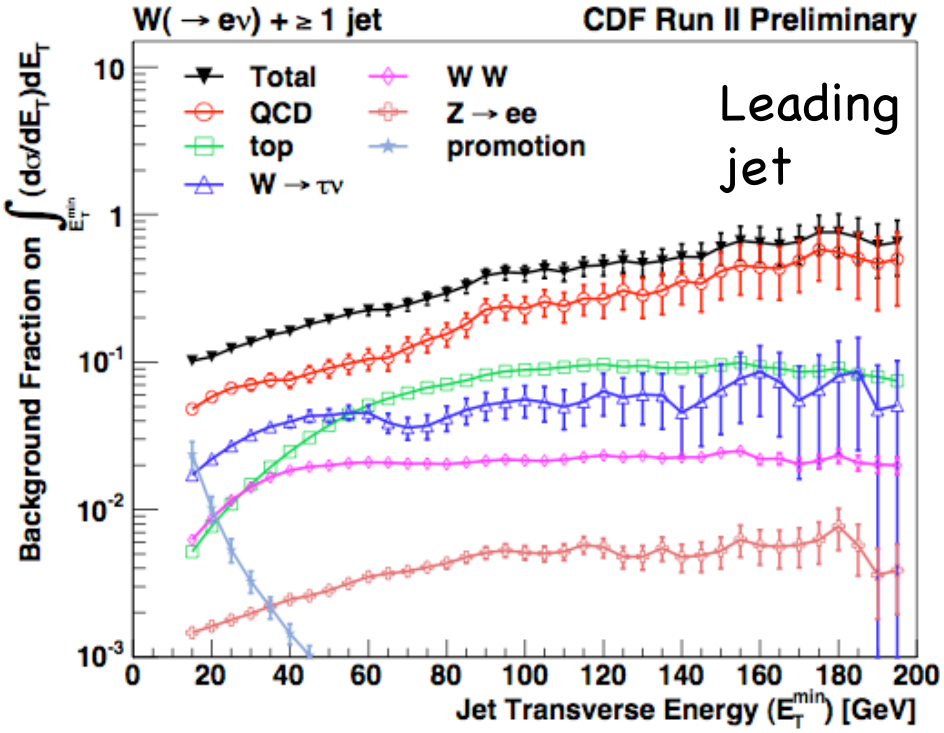
For 1st, 2nd, 3rd and 4th Jet E_T

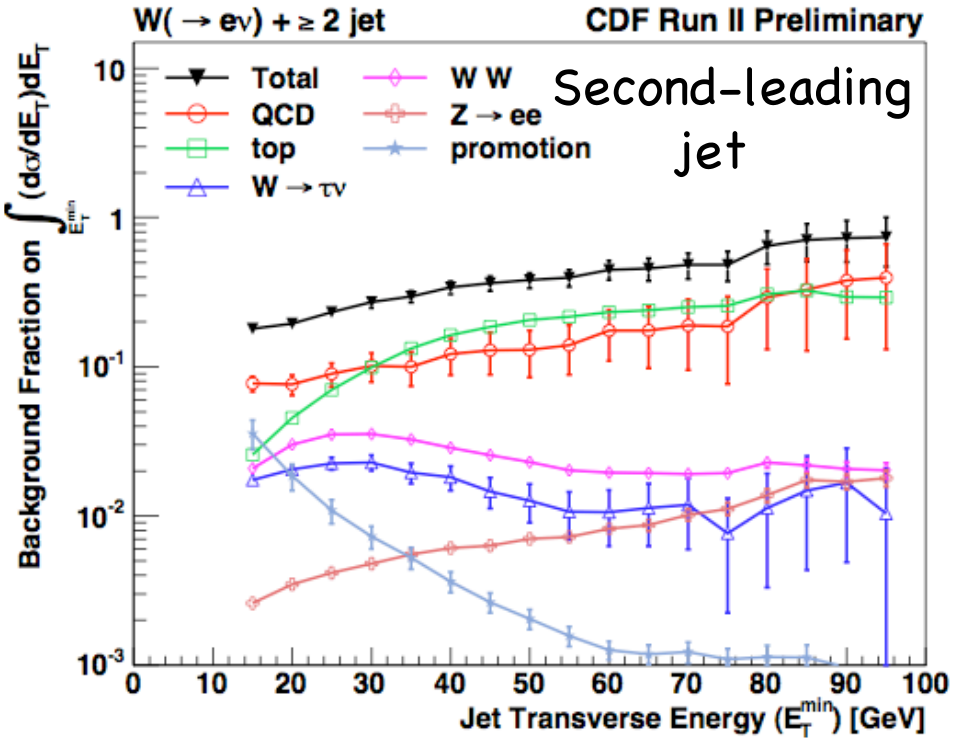




MC have been normalized to inclusive data cross section in each jet sample!

Background breakdown in jet E_T





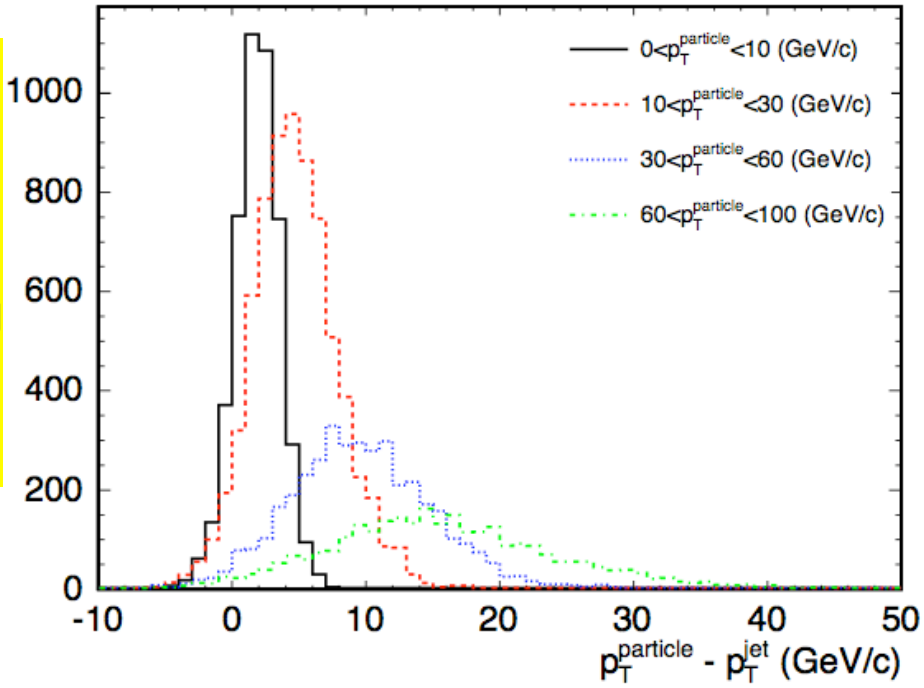
- ✓ QCD gives a substantial contribution to the background fraction
- ✓ In the tail of the distribution (high jet multpl., High E_T) top is dominant

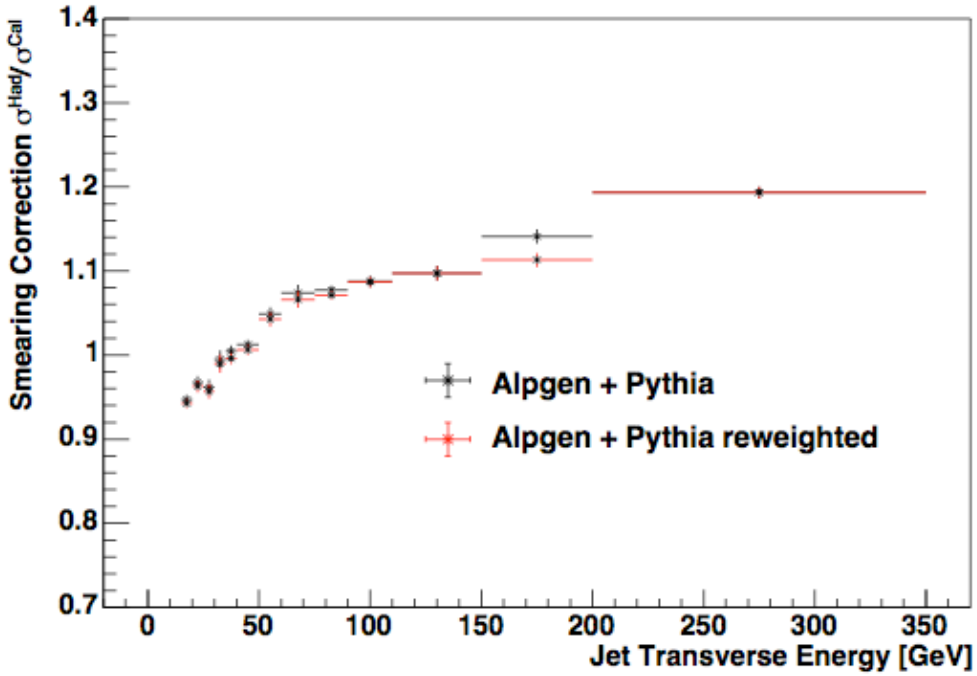
Promotion background (small contribution at low E_T):

- ✓ extra interaction produce jet not associated to the W -> wrong W jet-multipl.
- ✓ Estimate extra jet rate in MB, correct data on average as a function of # vtx

Calorimeter resolution unfolding

- Absolute scale corrects on average for calorimeter response.
- Resolution alters shape of measured E_T spectrum - necessitates unfolding correction.



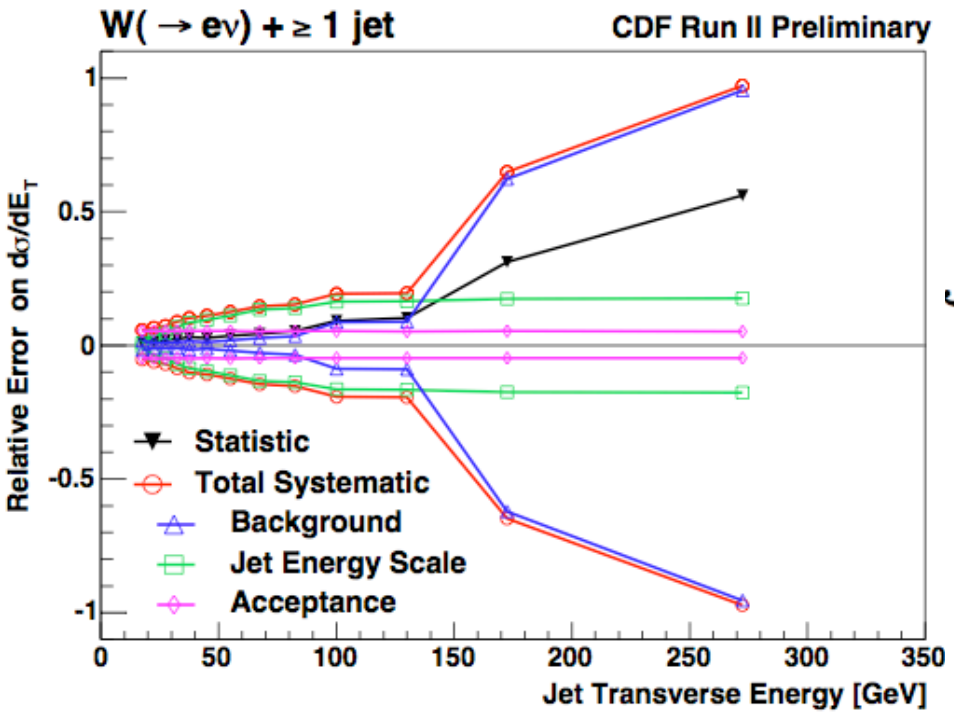


- Use detector simulated W+Jets MC events.
- Form jet E_T spectra at HAD level and at CAL level.
- Define unfolding factor in each bin as N_{HAD}/N_{CAL}.

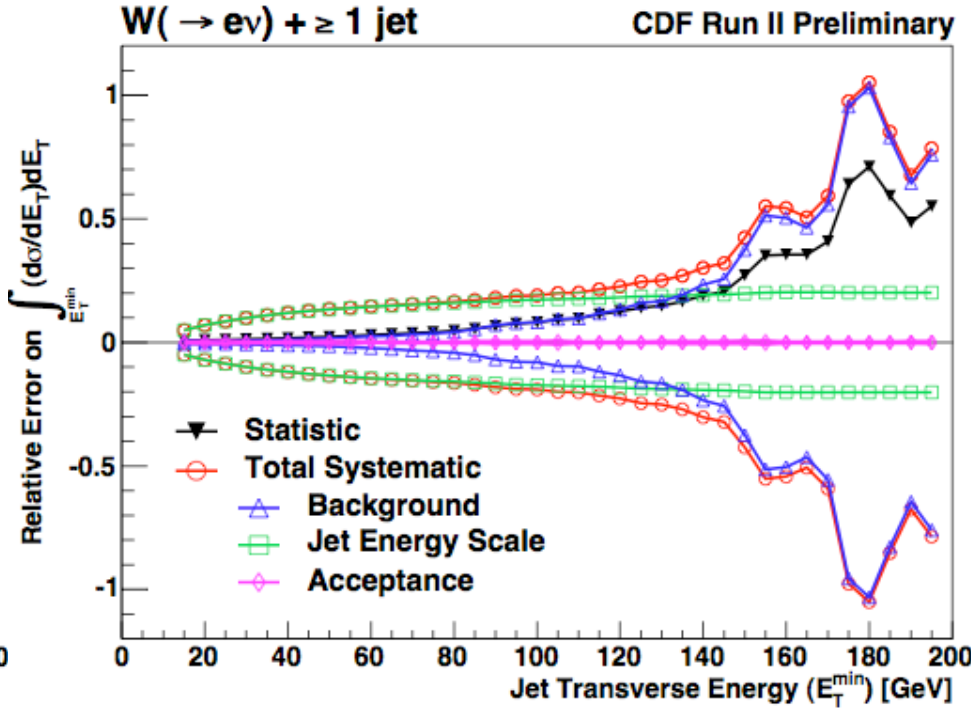
Error breakdown

A representative behavior of the errors in the measurements

Errors on leading jet $d\sigma/dE_T$



Errors on leading jet $\int_{E_T}^{\infty} d\sigma/dE_T$



At high E_T large statistic uncertainty. Systematic dominated by jet energy scale(» 3%) at low E_T, by background subtraction at high E_T.

COMPARISON WITH THEORY

Comparisons with theory

- ✓ Include comparisons with latest W + Jets theory predictions:
  - SMPR: CKKW Madgraph + Pythia ME-PS matched prescriptions.
  - MLM : MLM Alpgenv2 + Herwig ME-PS matched prescriptions.
  - MCFM: NLO predictions for W + 1 and W + 2 jets.
- ✓ First published comparisons to ME-PS matched approach
- ✓ Worked closely with authors of predictions: S. Mrenna, M. Mangano and J. Campbell. They generated predictions and defined systematics.
- ✓ MCFM predictions are at parton level:
  - Data contains UE and hadronization effects.
  - We demonstrated that there is large degree of cancellation to 10% level.
  - We did not make any correction.

Comparisons to Theory

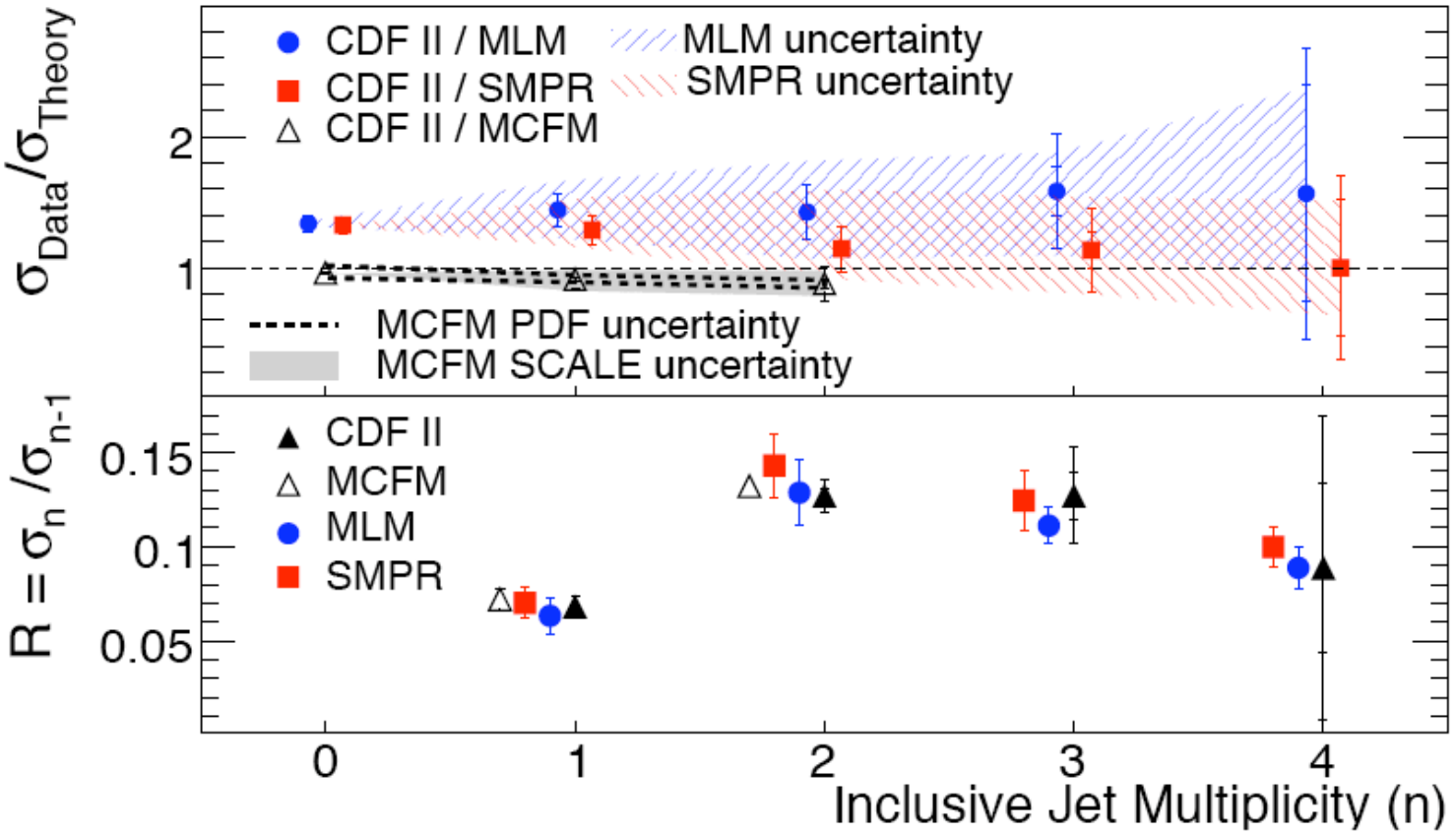


FIG. 2: Top: the ratio of data to theory for the cumulative cross sections $\sigma_n = \sigma(W \rightarrow e\nu + \geq n - \text{jets}; E_T^{nth-jet} > 25$ GeV) as a function of the jet multiplicity n. Bottom: σ_n/σ_{n-1} for data, MLM, SMPR and MCFM. Inner (outer) error bars denote the statistical (total) uncertainties on the measured cross sections.

Comparisons to Theory

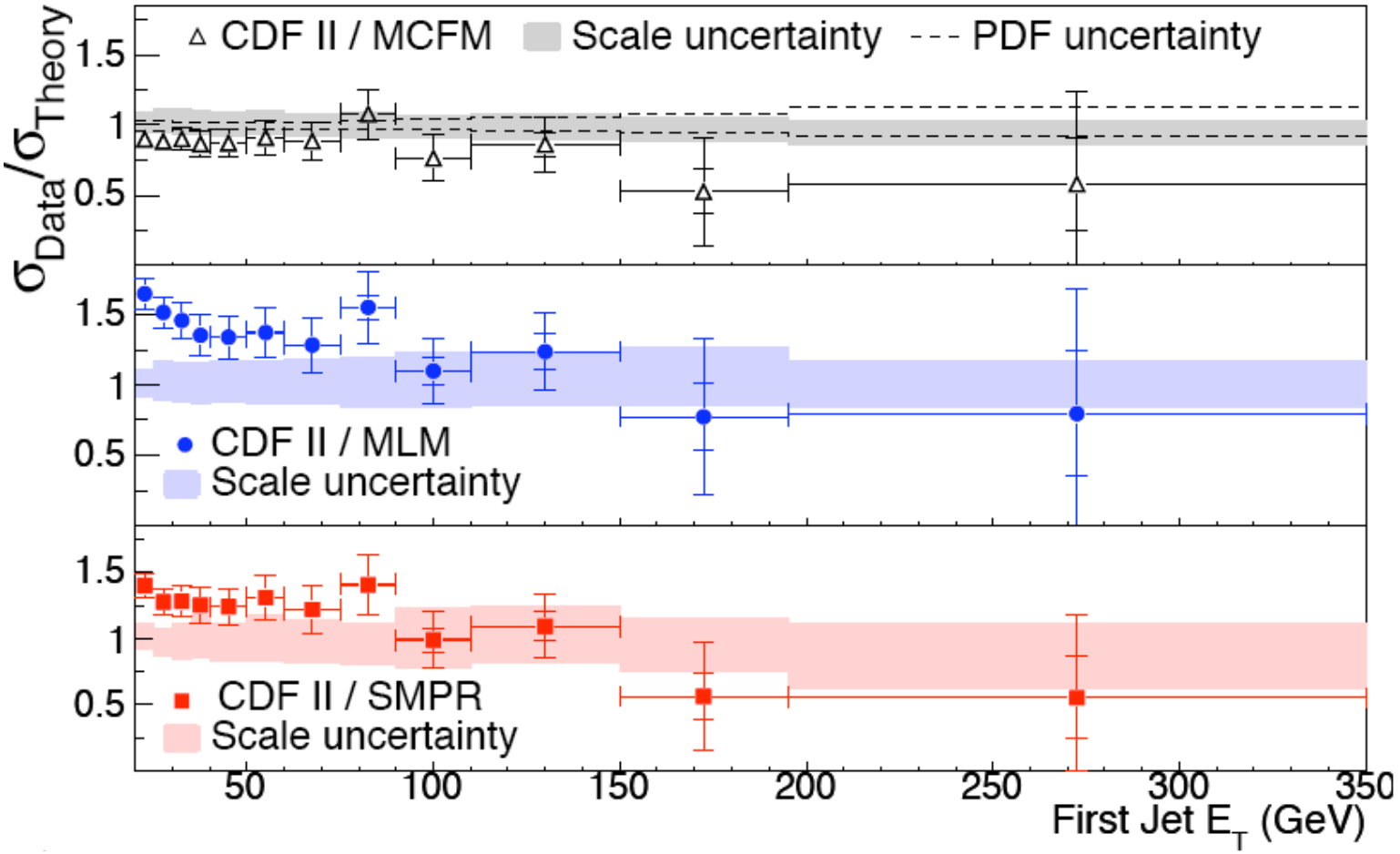
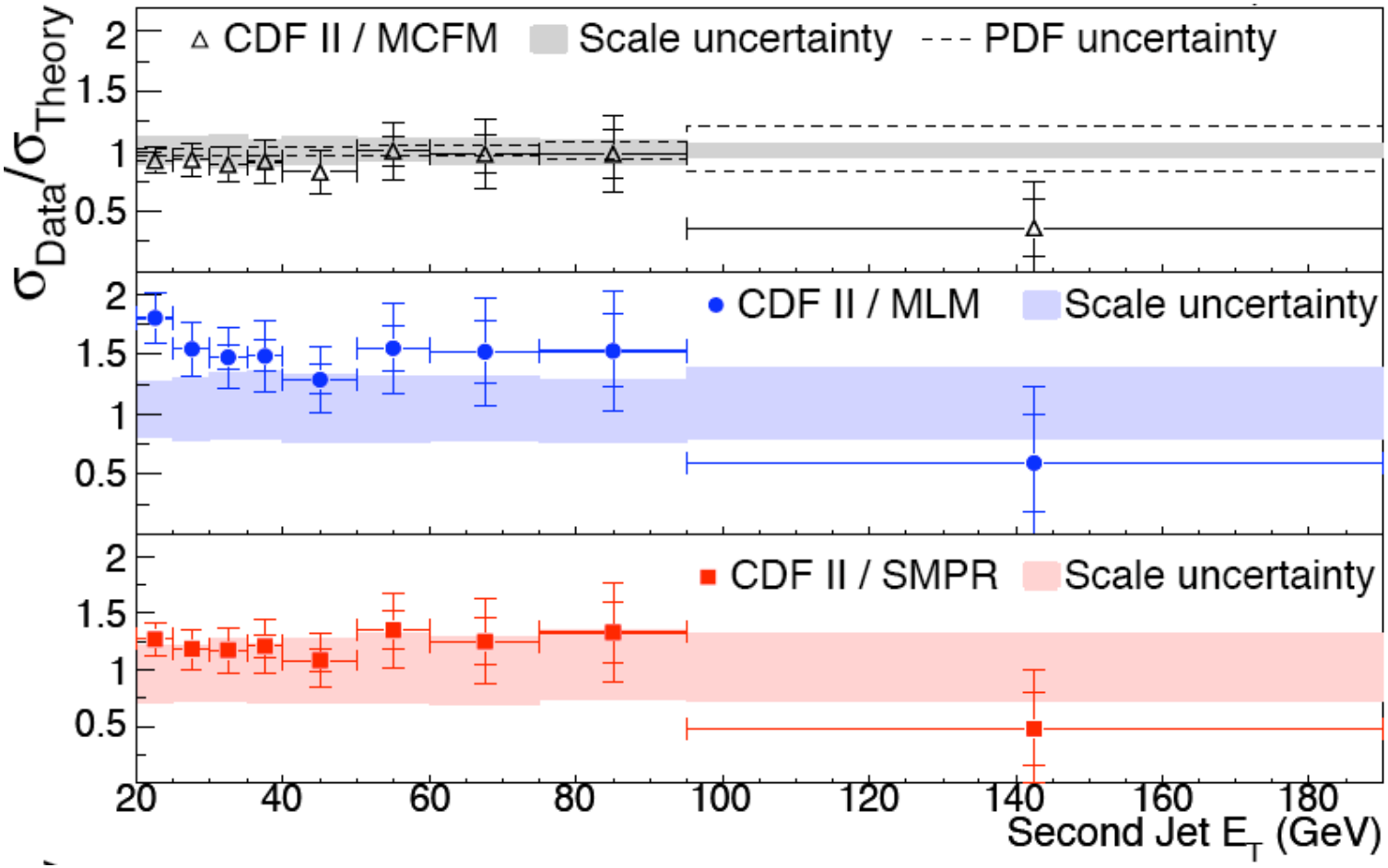


FIG. 3: Ratio of the measured differential cross sections $d\sigma/dE_T^{nth-jet}$ $(n \leq 3)$ to the MLM, SMPR and MCFM predictions. Inner (outer) error bars denote the statistical (total) uncertainties on the measured cross sections.

Comparisons to Theory



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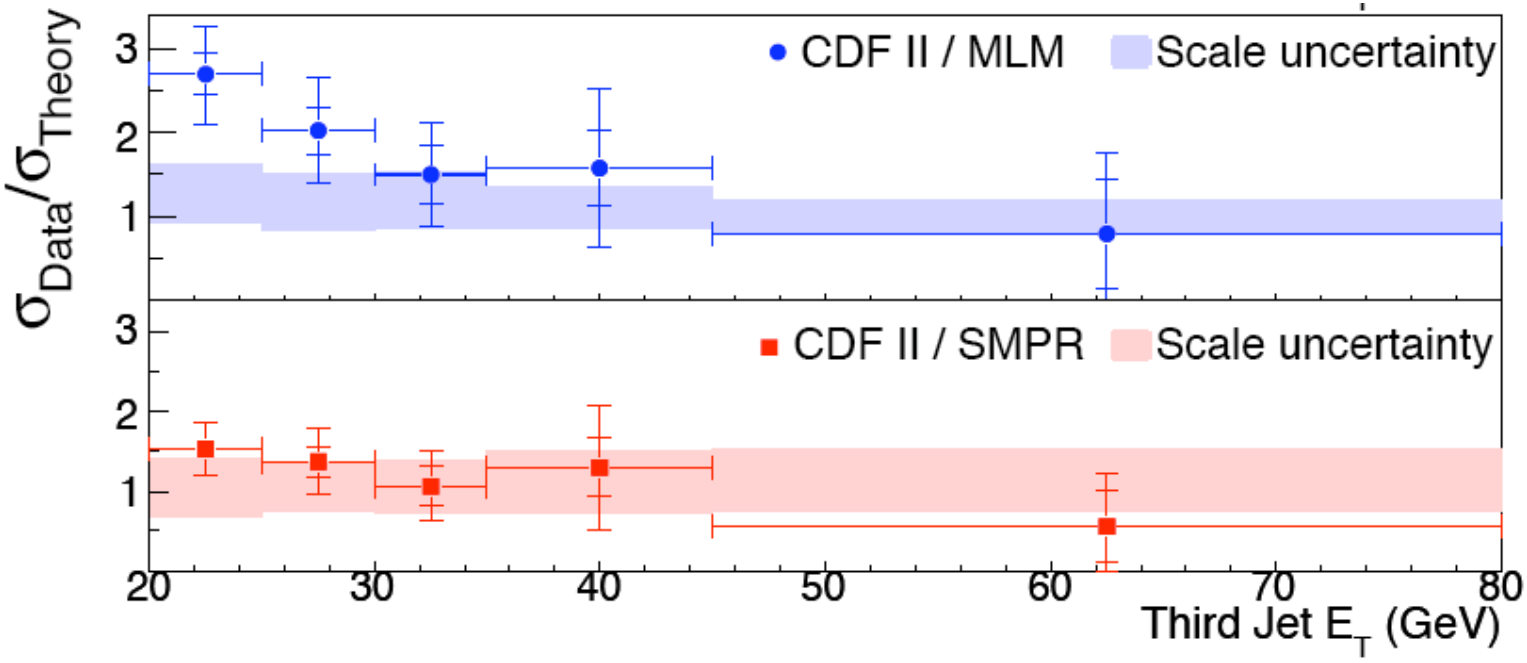

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Conclusions

Boson+jets: conclusion

Make the measurement corrected for all know detector effects.

✓detector unfolding

...reduce as much as possible the model dependence

✓observable as close as possible to what is accessible by detector

more clean and easy comparison against theory.
Critical input to validate Monte Carlo models vastly employed in all kinds of measurements and new physics searches.

✓NLO (when available) gives a good description of data.

✓Matched LO ME gives a good description of the kinematic, k-factor≈1.4.

✓Soft physics important at low E_t^{jet}. Tunings of Pythia give good description, but need always to be checked against data.

Summary

- ✓ We have made the first differential W + jets cross section measurement at the particle level.
- ✓ The measurement has been carefully formulated to be of maximum use and relevance in improving theoretical models of this process.
- ✓ The theoretical comparisons we have made demonstrates that there is room for improvement in the current predictions.
- ✓ This measurement introduces important new methodologies in background and acceptance corrections.

BACKUP SLIDES

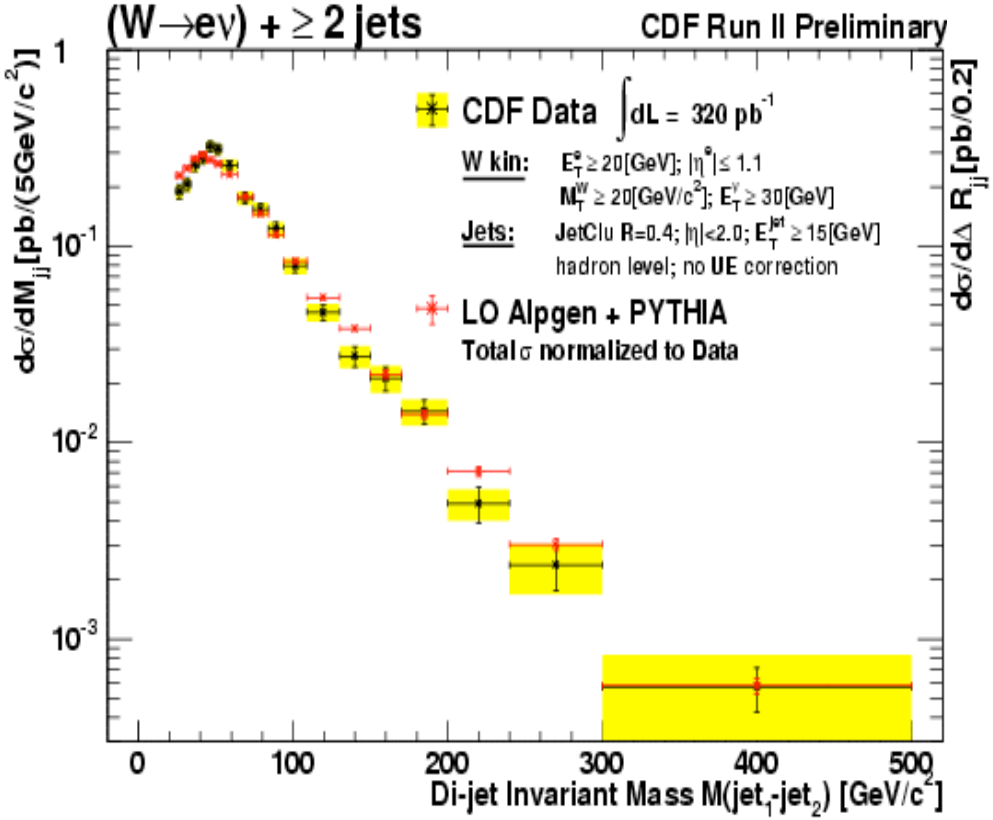
CDF W+jet cross section measurement

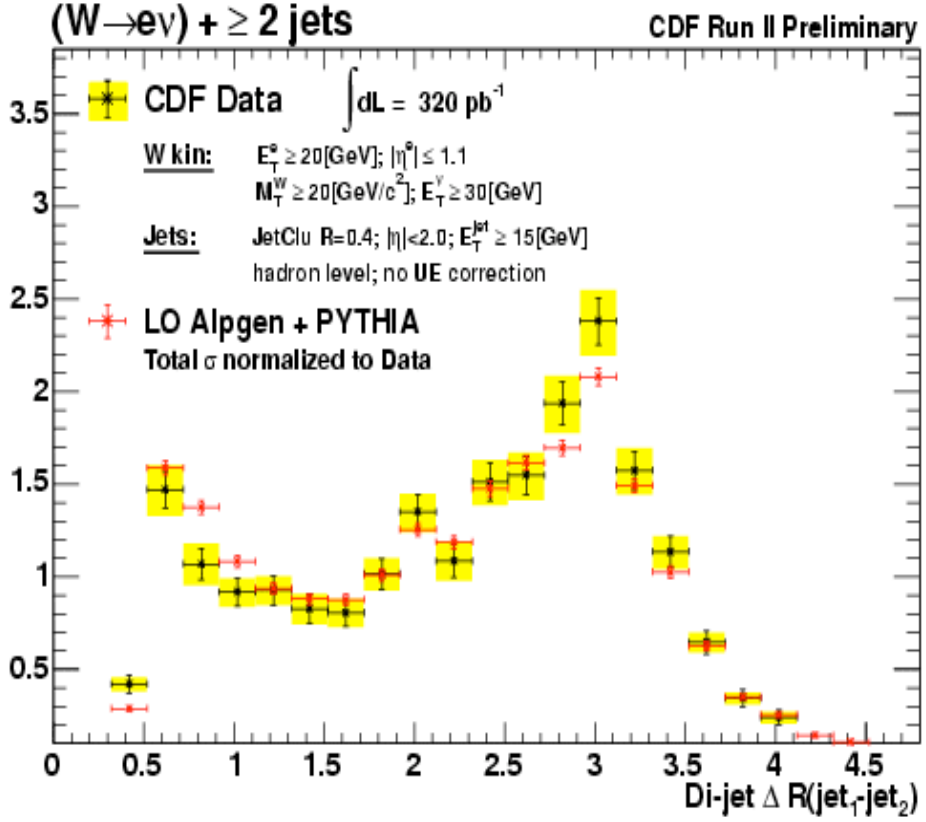
$$\frac{d\sigma_{W\to e\nu}}{dM_{jj}}$$

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

$$\frac{d\sigma_{W\to e\nu}}{d\Delta R_{jj}}$$

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



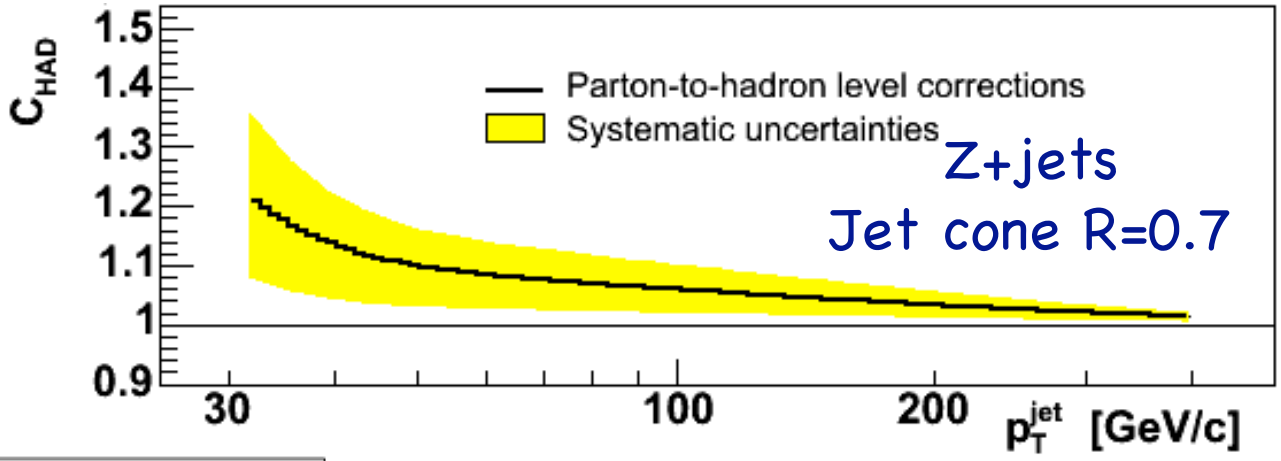


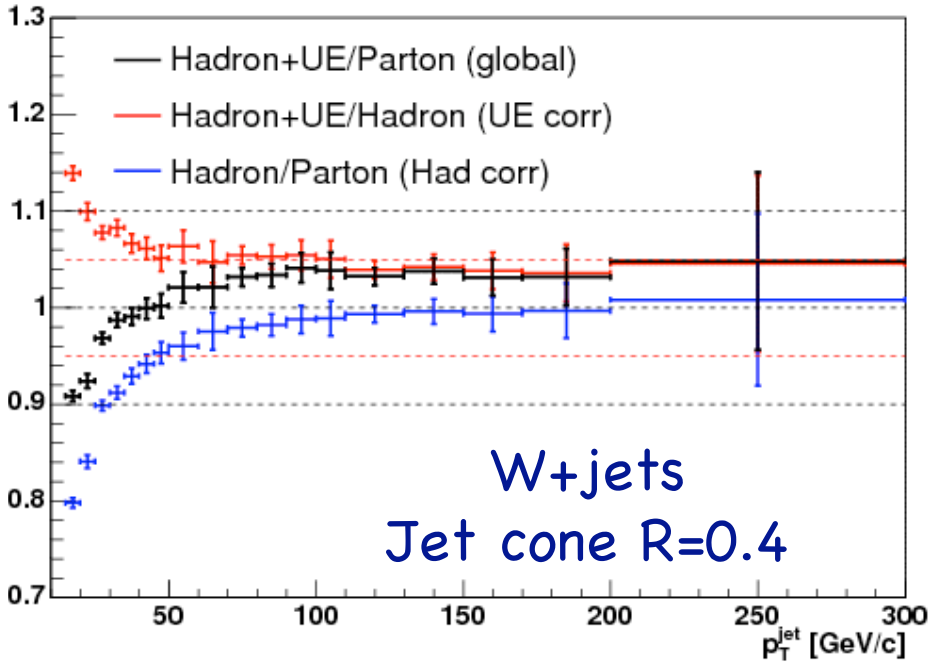
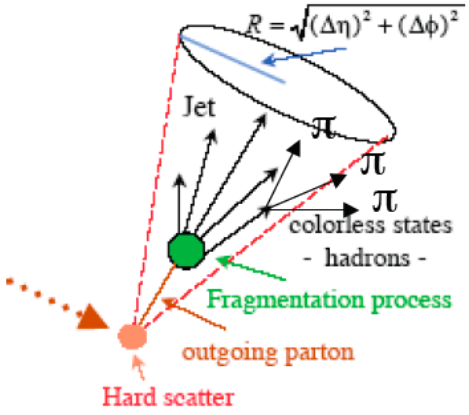
MC has been normalized to measured W+ ≥ 2 jet inclusive cross section!

Non perturbative correction

To compare with data need to estimate non perturbative effects:

1. Hadronization
2. Underlying event





Relying on phenomenological models tuned on data.
Uncertainty estimated from the difference between Pythia Tune A and Tune DW.