Hadronization effects for parton level calculations

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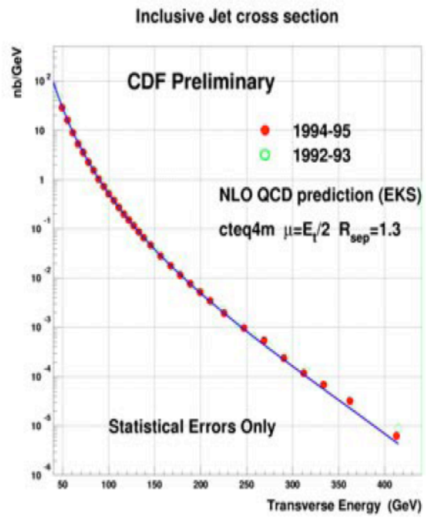
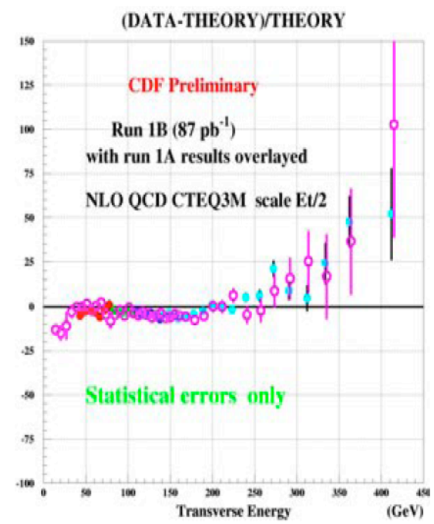
Some notes

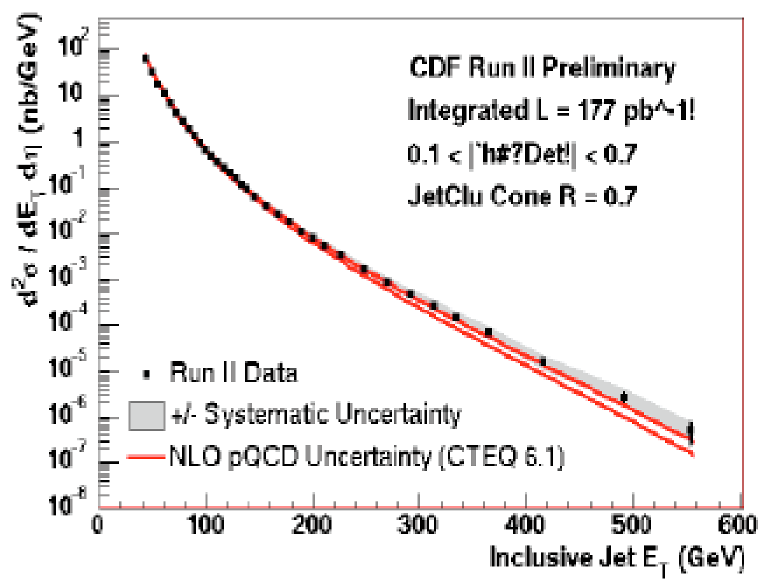
- Come to the Hadron Collider Physics Conference at MSU June 14-18
- Before that come to the special Joint Physics meeting on June 11 dealing with MCatNLO and other MC issues
- The Method 2 at NLO note is on Los Alamos today as hep-ph/0405276

Inclusive jet cross sections in CDF

- The inclusive jet cross sections reported by CDF in both Run 1 and Run 2 have been corrected back to the hadron level and not to the parton level

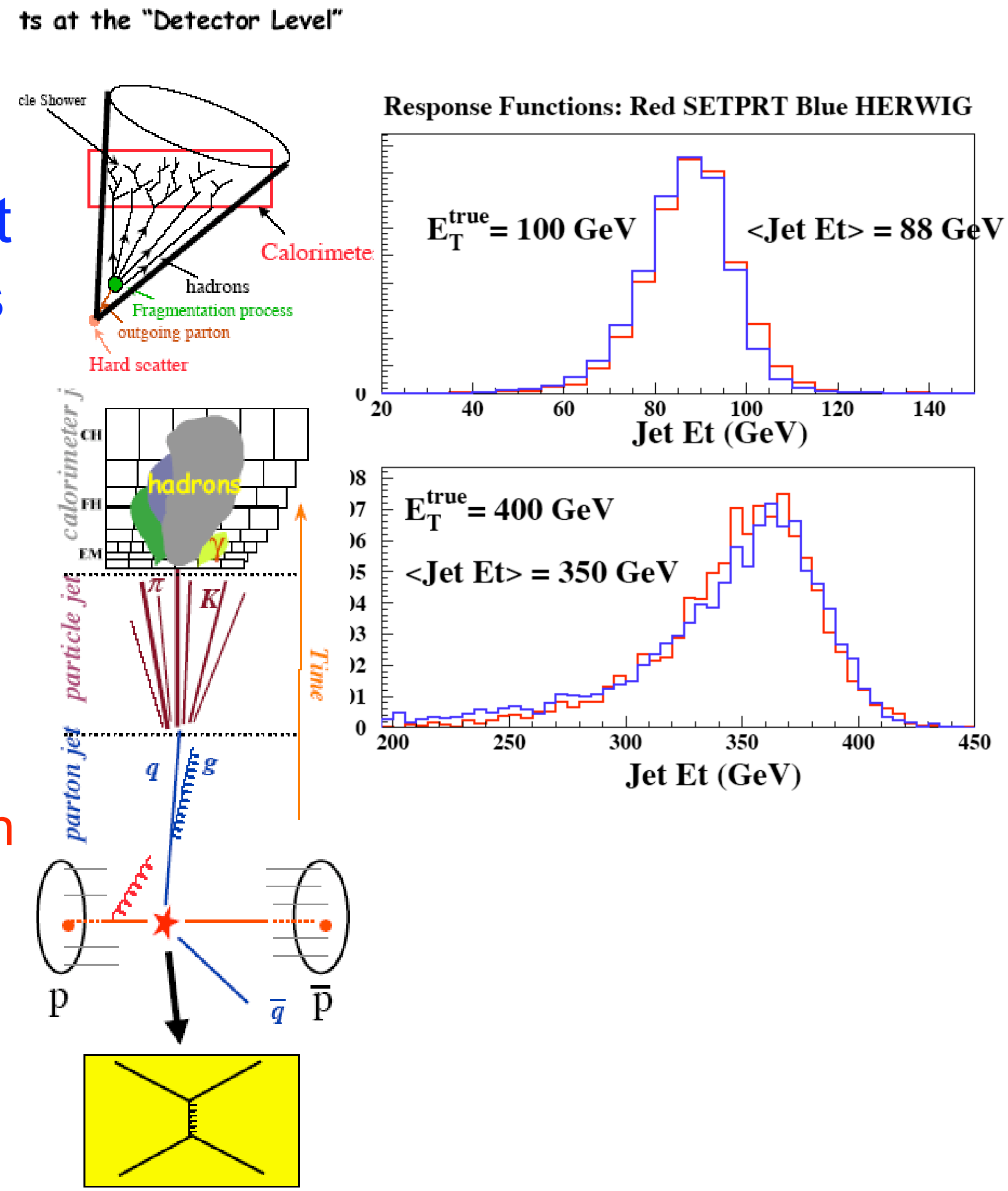






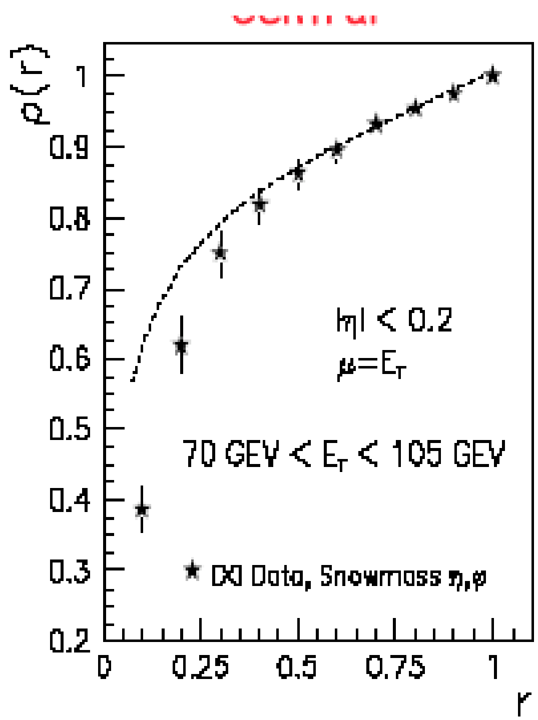
Inclusive jet production

- i.e. the response functions are based on the hadrons inside the jet cone and not the partons
- NLO cross sections are at the parton level
  - EKS, JetRad, MCFM,…
  - either 1 or 2 partons per jet
  - MCatNLO is adding jet production on an ~6 month timescale but for the moment we’re stuck with partons



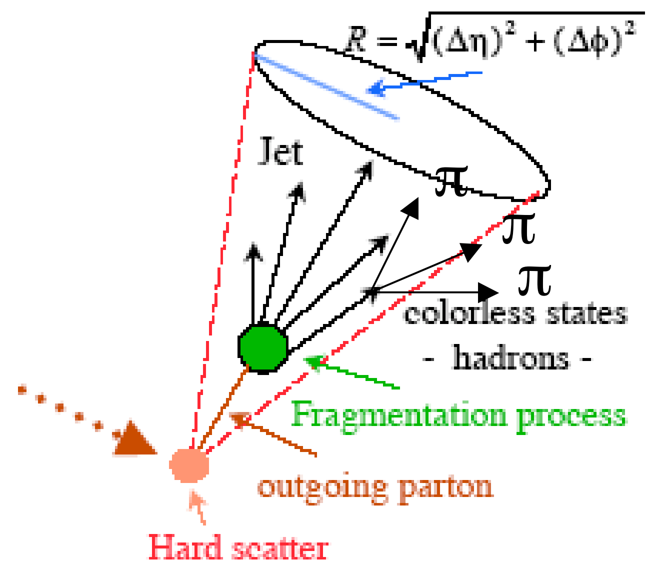
Out-of-cone

- A finite size jet cone will always miss some part of the jet energy
- Out-of-cone corrections (Level 7) take that into account
- We don't want to use Level 7 corrections with NLO calculations
  - most of the out-of-cone corrections are already described by the gluon emission in the NLO calculation
  - to the extent that NLO corrections describe the jet shape, out-of-cone corrections should only be used for comparison to LO predictions and not to NLO



Hadronization corrections

- But still may be useful to provide hadronization corrections
  - correct for hadrons derived from partons inside the jet cone that land outside the jet cone
  - not described by an NLO calculation
  - think of an A_1 decaying into $\pi\pi\pi$ and one or two of the pions are thrown outside



Hadronization corrections

- Can do back of the envelope calculation using a FF-like model
  - find order of 1 GeV/c
- Or can study using parton shower Monte Carlos with hadronization on/off
  - hadronization correction for NLO (2 partons) = hadronization correction for MC (many partons) to the extent that the jet shapes are the same

Consider the hadrons that represent the decay products of a high E_T parton. Let η be the rapidity of the hadrons relative to jet axis. Let $\vec{k}_T$ be the transverse momentum of the particles relative to jet axis. Let the distribution of hadrons be

$$\frac{dN}{d\eta d\vec{k}_T} = \frac{A}{\pi \langle k_T^2 \rangle} \exp\left\{-k_T^2/\langle k_T^2 \rangle\right\}, \tag{10}$$

where A is the number of hadrons per unit rapidity and $\langle k_T^2 \rangle$ is average k_T^2 of the hadrons. Then the E_T lost is approximately

$$E_T^{out} = \int_0^{\eta_1} d\eta \int d\vec{k}_T \, \frac{1}{2} |\vec{k}_T| e^{\eta} \, \frac{dN}{d\eta d\vec{k}_T}, \tag{11}$$

where $\eta_1 = -\ln(\tan(R/2))$. Performing the integral gives

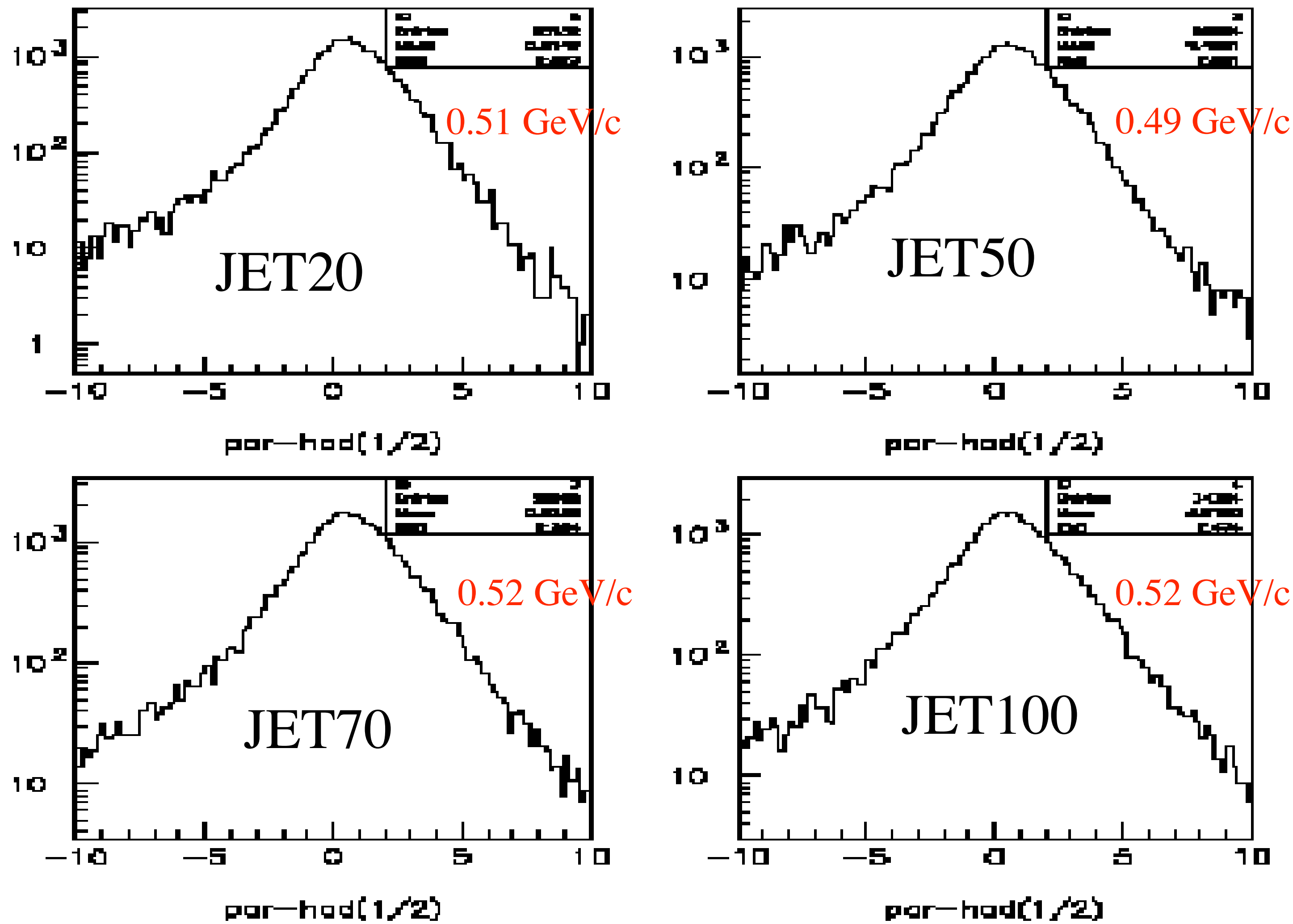
$$E_T^{out} = \frac{\sqrt{\pi}}{4} A \sqrt{\langle k_T^2 \rangle} \left(e^{\eta_1} - 1\right). \tag{12}$$

Taking $\sqrt{\langle k_T^2 \rangle} = 0.3$ GeV and[10] $A = 5$, I find

$$E_T^{out} \approx 1.1 \text{ GeV}. \tag{13}$$

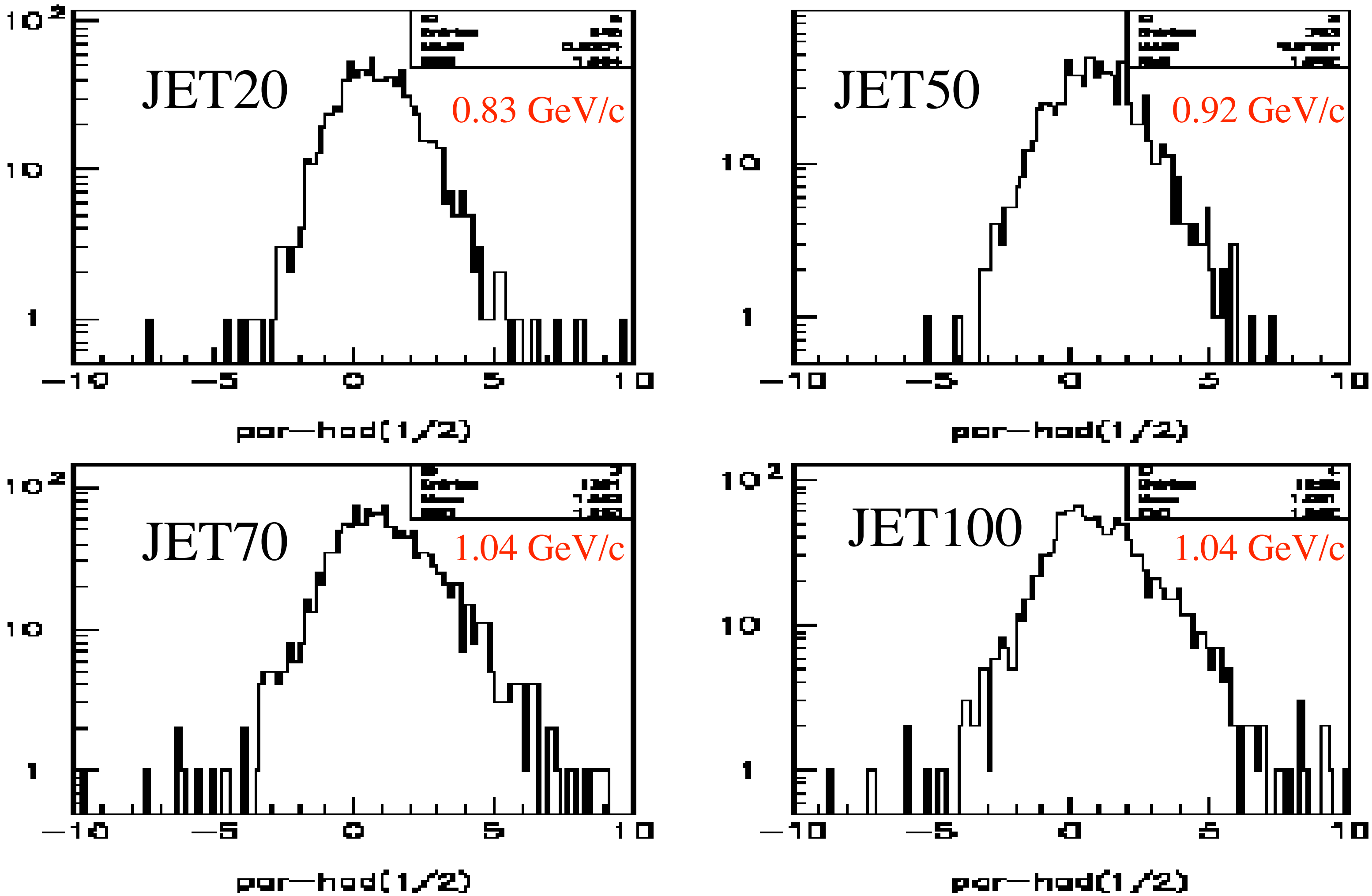
Herwig study: all rapidity

…order of 0.5 GeV/c for whole E_T range



Jets in central rapidity region

…order of 1 GeV/c for whole E_T range



1 GeV/c

- Is it surprising that the splash-out is relatively constant as a function of jet E_T?
- The amount of energy in the outer annulus of a jet doesn't change much as the jet E_T increases
  - more energy in the jet
  - but the jet also becomes more tightly collimated

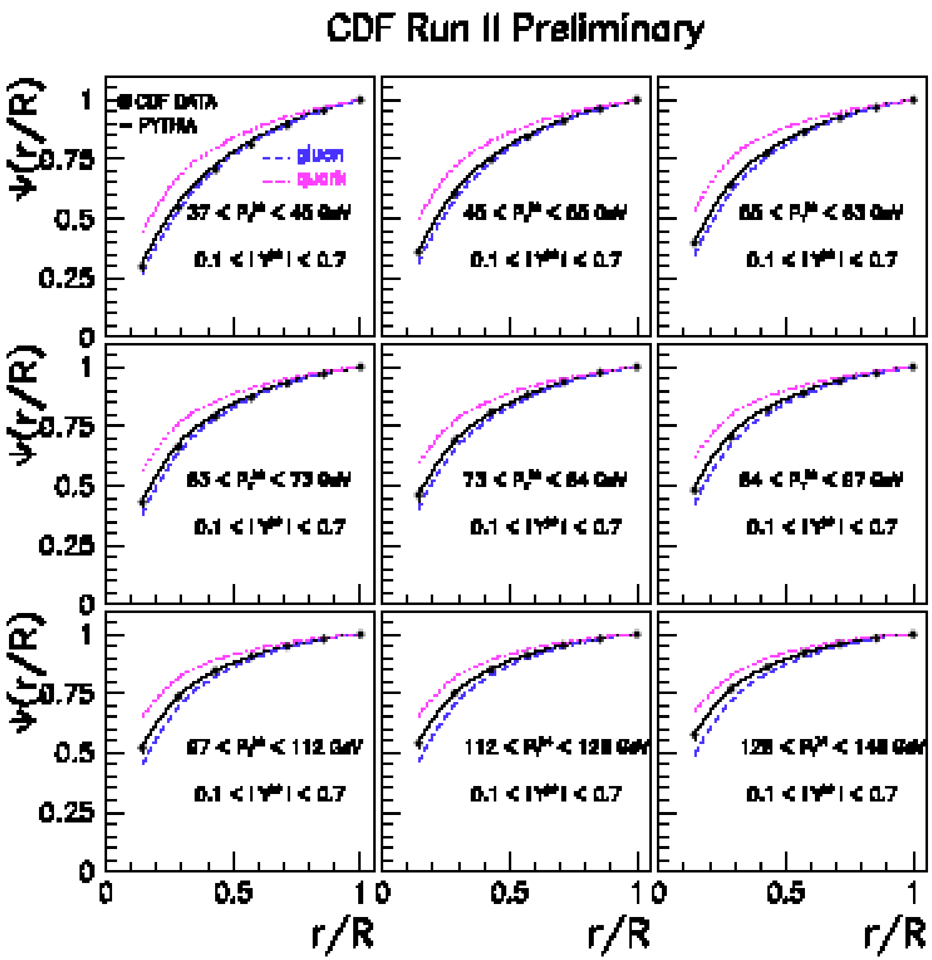
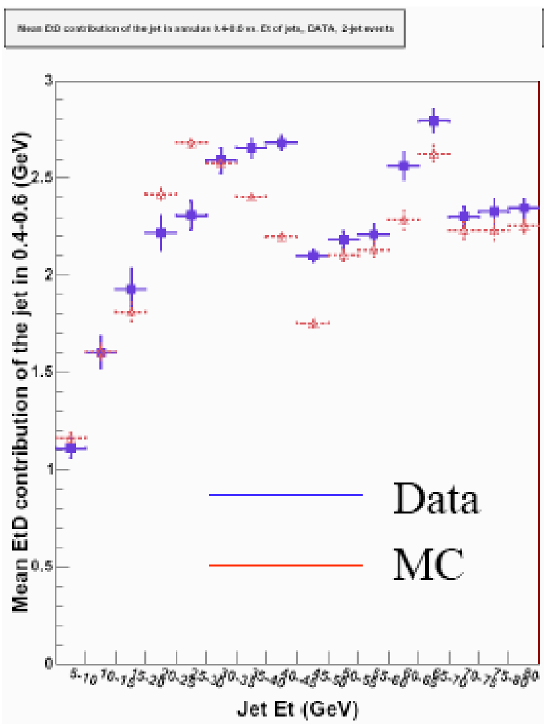


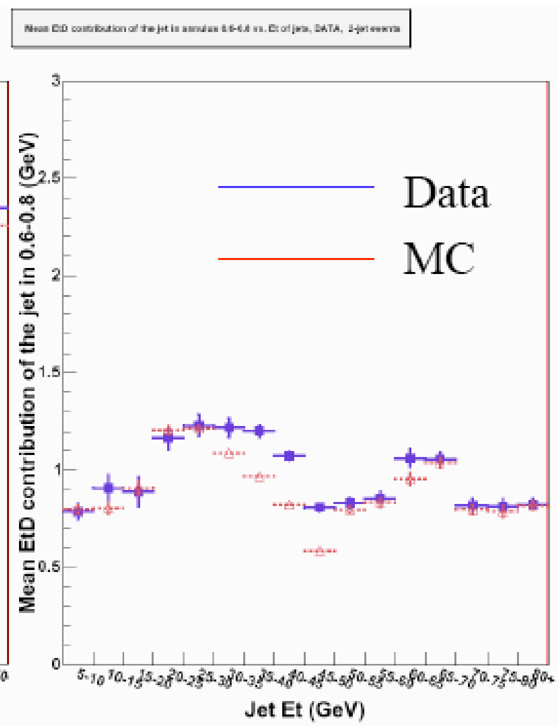
Figure 3: Measured integrated jet shape, $\Psi(r/R)$, in inclusive jet production for jet with $0.1 < |Y^{jet}| < 0.7$ and 37 GeV $< P_T^{jet} <$ 148 GeV, in different P_T^{jet} regions. Error bars indicate the statistical and systematic uncertainties added in quadrature. The predictions of PYTHIA (solid lines) and the separated contributions from quark-initiated jets (dotted lines) and gluon-initiated jets (dashed lines) are shown for comparison.

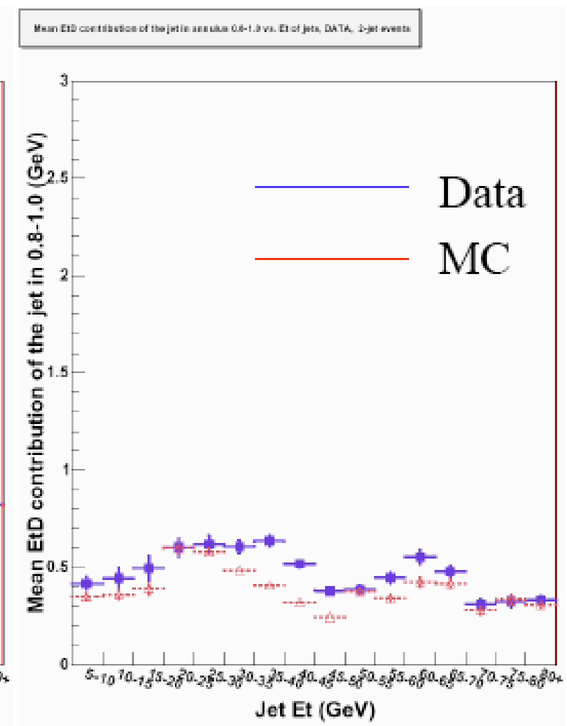
Out-of-cone corrections

Jet Et Contribution to its annuli (using tower info)

0.4 to 0.6	0.6 to 0.8	0.8 to 1.0







1 GeV/c

- How important is 1 GeV/c
- Will cause a noticeable deviation at low E_T
  - see for example the UE systematic error

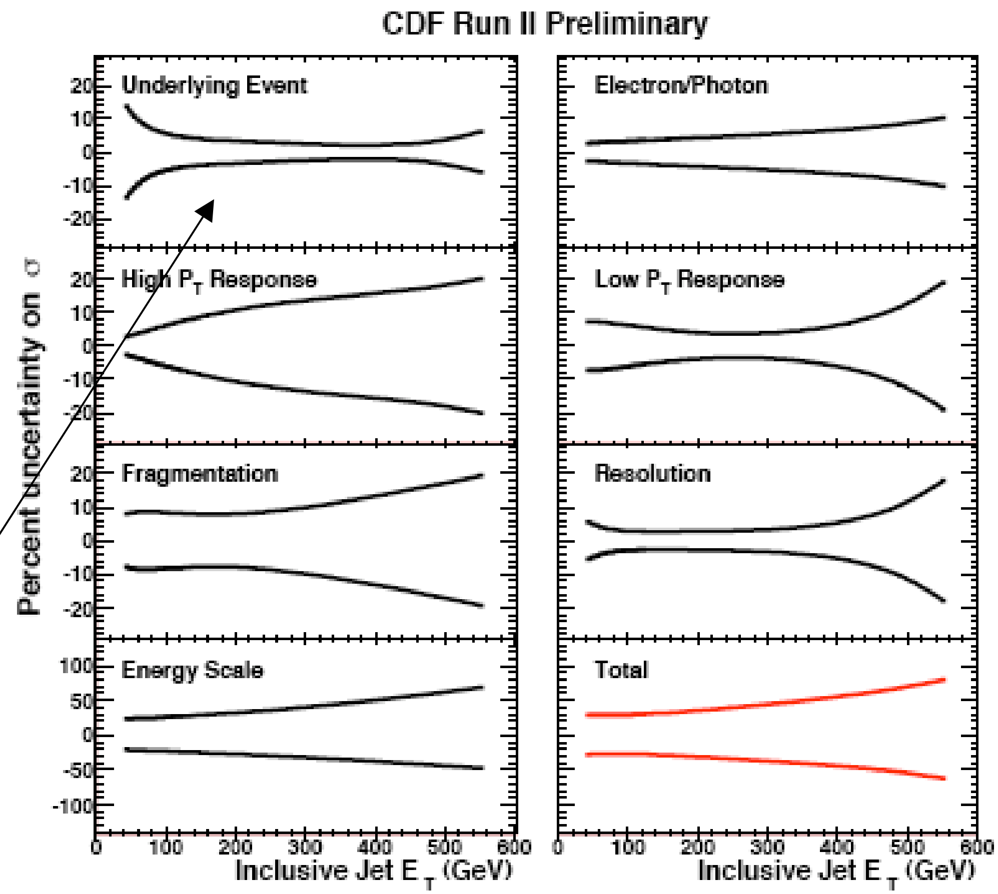
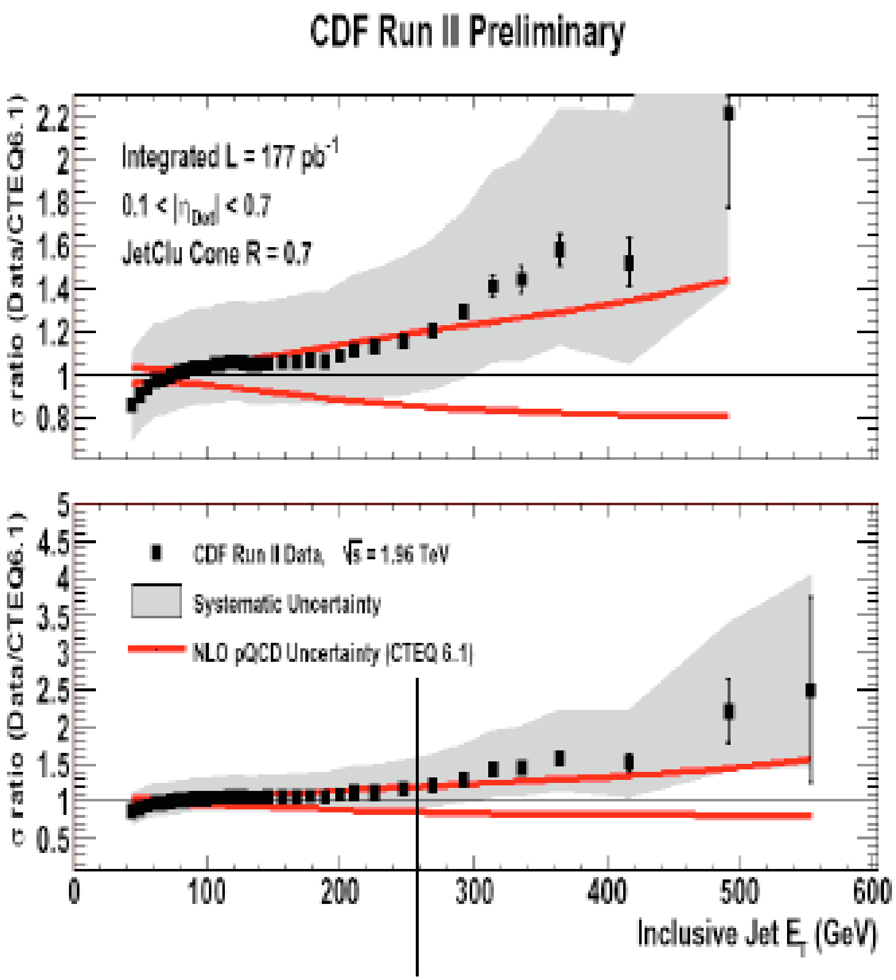


Figure 14: The percentage error on the corrected cross section resulting from the individual contributions to the total systematic error. The dominant uncertainty comes from the shift in energy scale.

Splashout correction for inclusive jets

- Splashout results in a correction to the NLO cross section



$$\frac{d\sigma}{dE_T} \approx \left(\frac{d\sigma}{dE_T}\right)_{\rm NLO} \left\{1 - n \, \frac{\Delta E_T^{in}}{E_T}\right\},$$

$$n(\ln(E_T)) = -\frac{d}{d\ln(E_T)} \ln\left[\left(\frac{d\sigma}{dE_T}\right)_{\rm NLO}\right].$$

where n is the local slope of the jet E_T distribution

n varies from about 5.5 to 13
about a 15% effect at the lowest values of E_T we've measured so far
even more important if we go to lower E_T
effect should die away slightly slower than $1/E_T$

630 GeV

- Is this the problem with the 630 GeV cross section (and the x_T scaling result)?
- It's an effect that's there, but to describe the CDF data, need a much larger splashout
  - maybe other power correction effects due to jet algorithms etc contribute

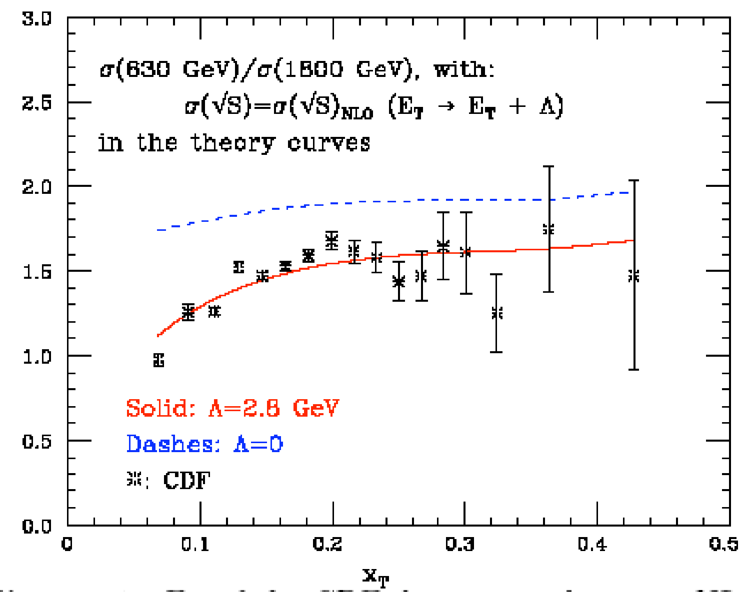
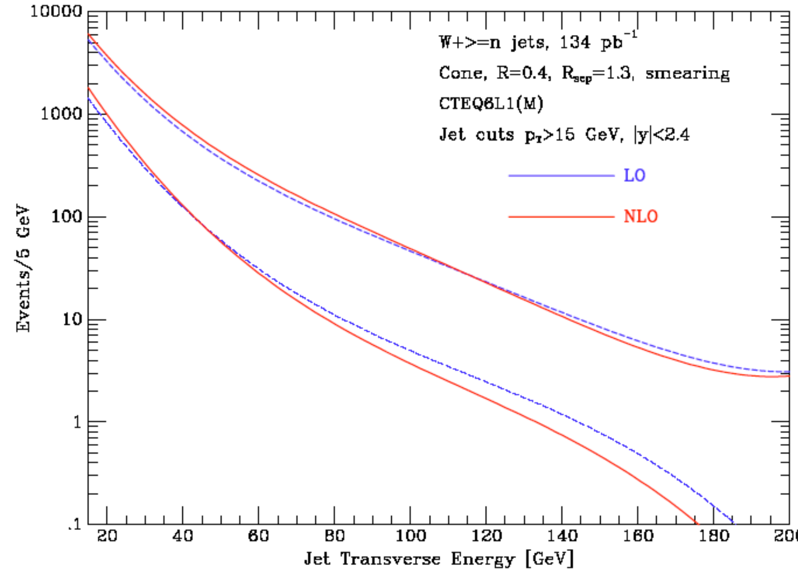
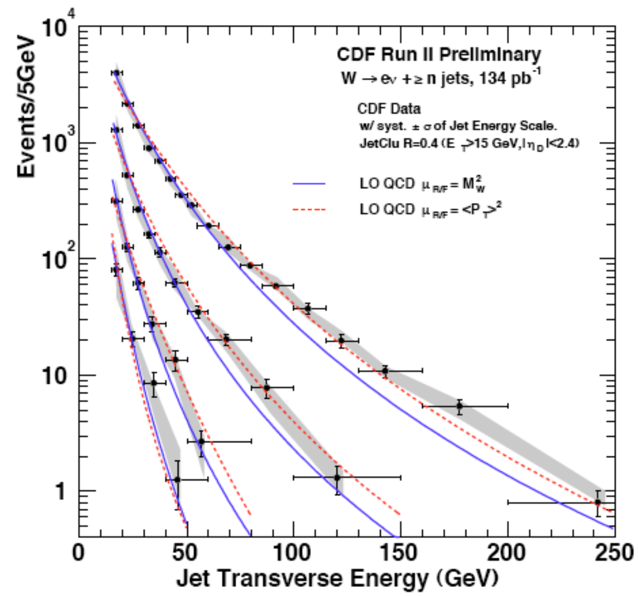


Figure 17. Fit of the CDF data using the exact NLO jet cross-section (CTEQ3M, $\mu = E_T/2$), assuming an E_T-independent shift Λ in the jet energy.

Not just for inclusive cross sections

- We'll need hadronization corrections for precision comparisons of NLO W + 1, 2 jet cross sections to data
  - see my talk at lepton+jets meeting last week
- …or for any other NLO comparison





Summary

- To first order, hadronization corrections are a constant and of order of 1 GeV/c for reasonably high E_T for a cone of 0.7 using Herwig
  - should be checked for other cone sizes, and with other Monte Carlos, i.e. Pythia
  - should be checked for lower values of E_T
  - and we should make a more detailed comparison of parton level jet shape to that from Monte Carlo, data
    - Note: EKS, JetRad give jet shape at LO; NLOJET++ gives jet shape at NLO
- Hadronization corrections come out automatically if bin by bin Monte Carlo-derived corrections are used
  - just refer to partons in the jet cone rather than hadrons
- Is this the whole story?
  - Unfortunately not
    - splash-in; partially taken into account in NLO
    - effects of soft gluon emission in initial state; not taken into account in NLO but vanishing above 25 GeV/c or so

Jet Shapes at parton, hadron and calorimeter levels

- This was a study that Matthias did with Herwig some time ago
  - and I don't remember why the step at $R=R_{cone}$
  - I'll ask Matthias for the details
- Jet shapes at all 3 levels agree for high E_T, but not for low E_T where parton level is narrower