Hadronization and underlying energy effects in comparisons to parton level calculations:

a prompt for some theory/experimental discussions

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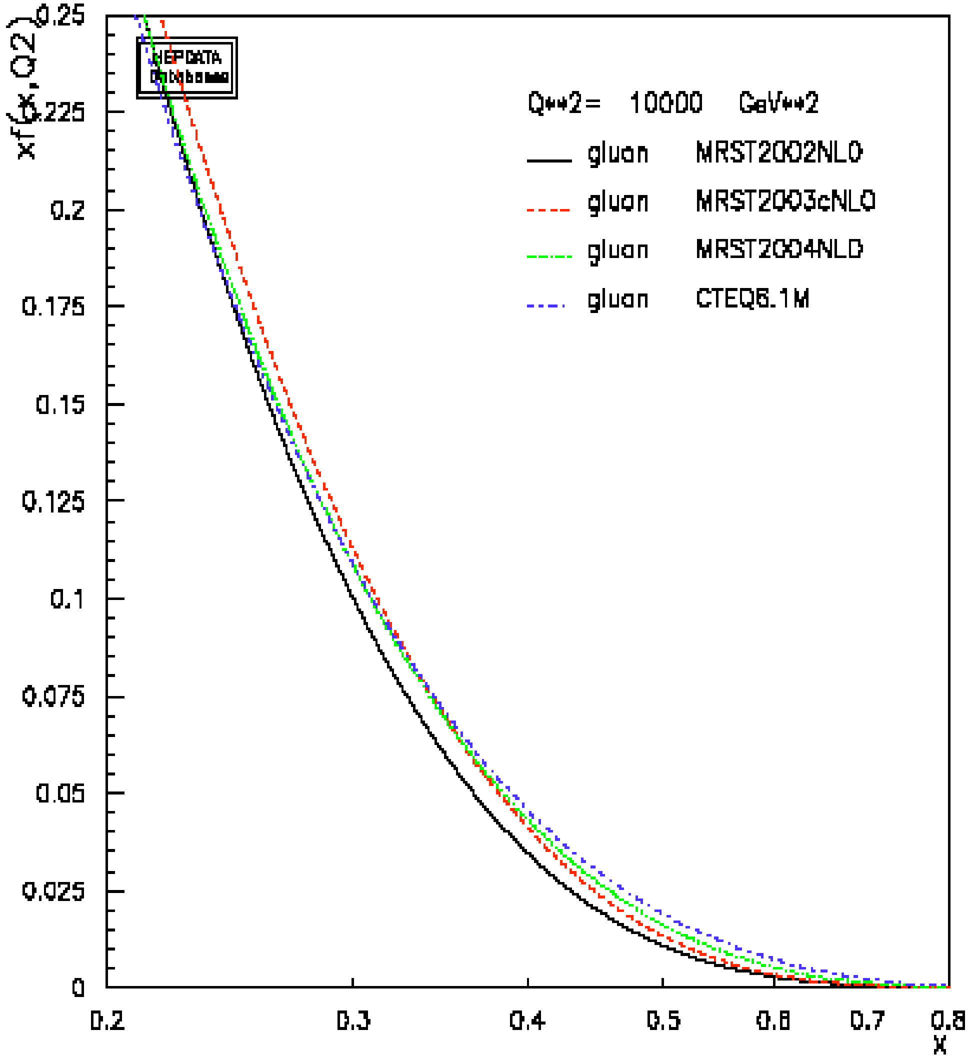
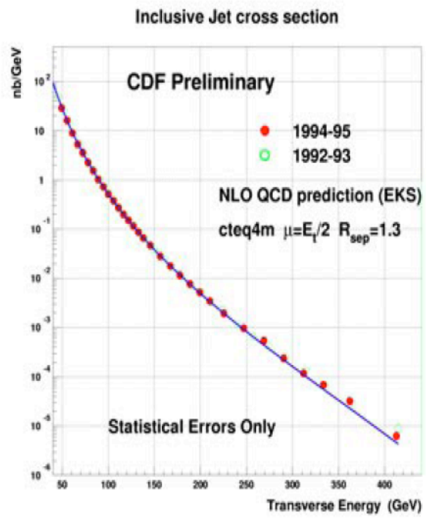
News bulletin

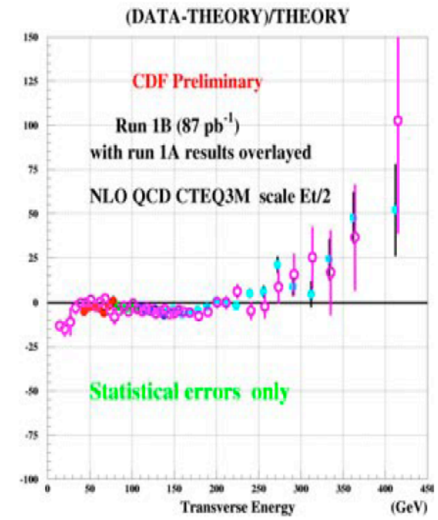
- MRST2004 pdf's have what they term a *physical gluon*
- New MRST2004 pdf's now have a gluon similar to CTEQ6.1 at high x
- And thus similar predictions for jet cross sections at both the Tevatron and LHC

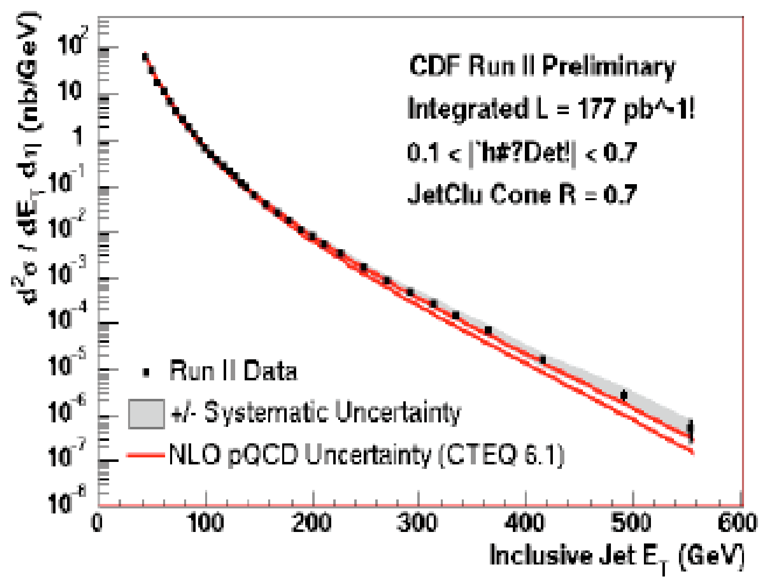


Inclusive jet cross sections in CDF

- 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

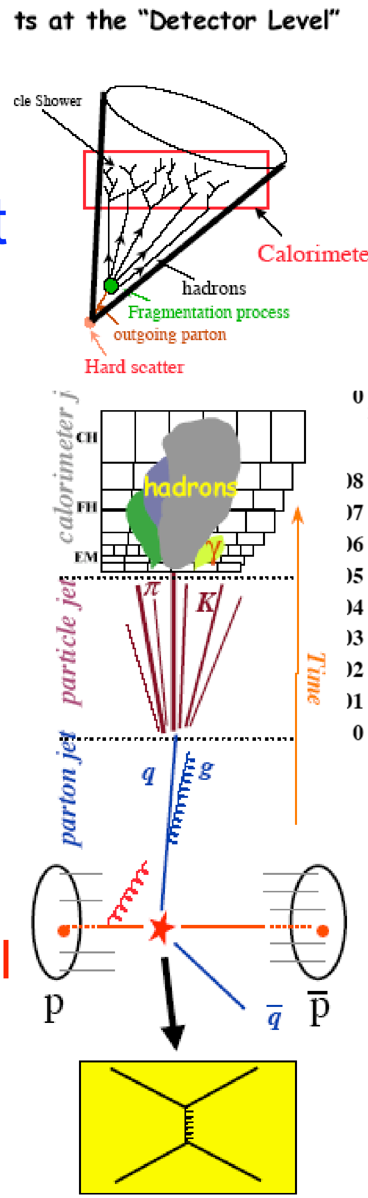


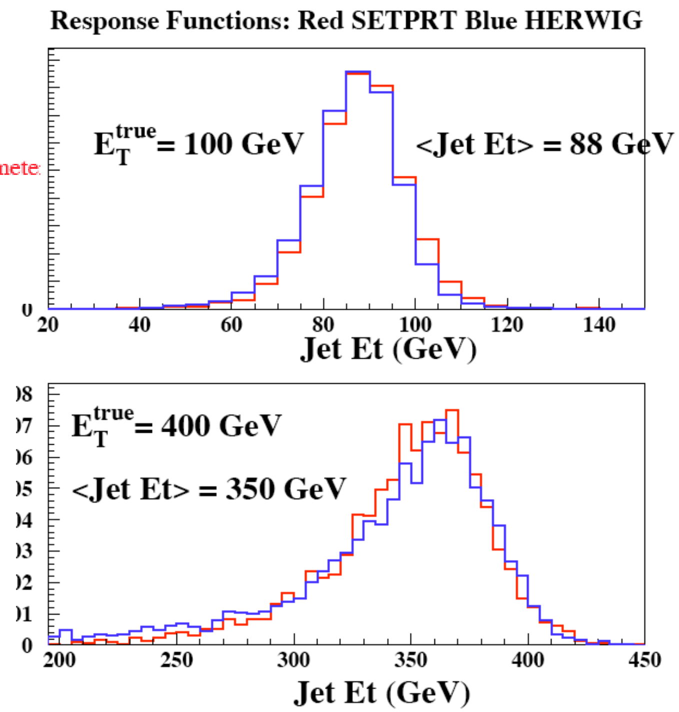




Inclusive jet production

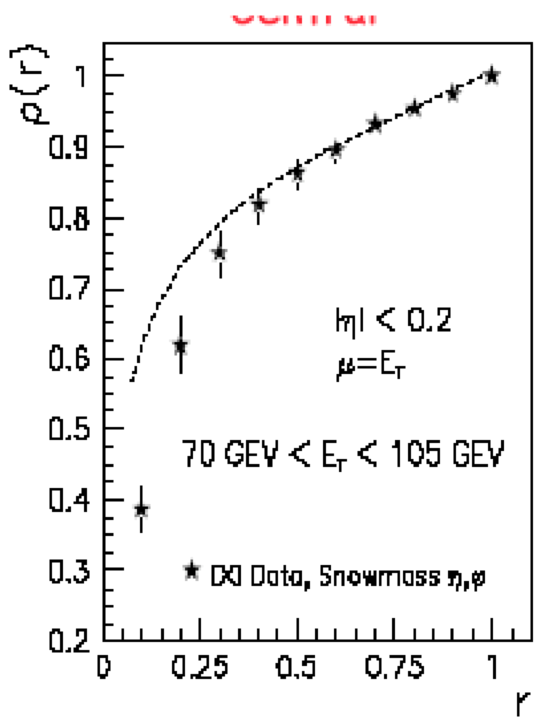
- i.e. the response functions are based on the hadrons inside the jet cone and not the partons
- NLO cross sections are at the parton level
  - EKS, JetRad, MCFM,…
  - either 1 or 2 partons per jet
  - MCatNLO is adding jet production but Steve and Bill haven't done their homework yet so we're still waiting





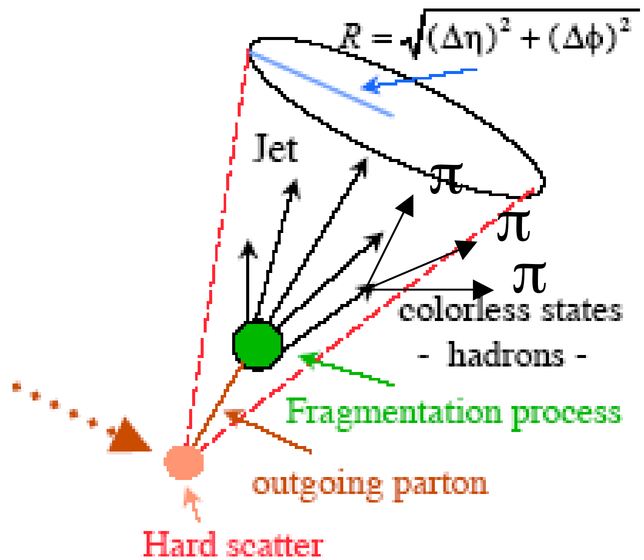
Out-of-cone

- 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

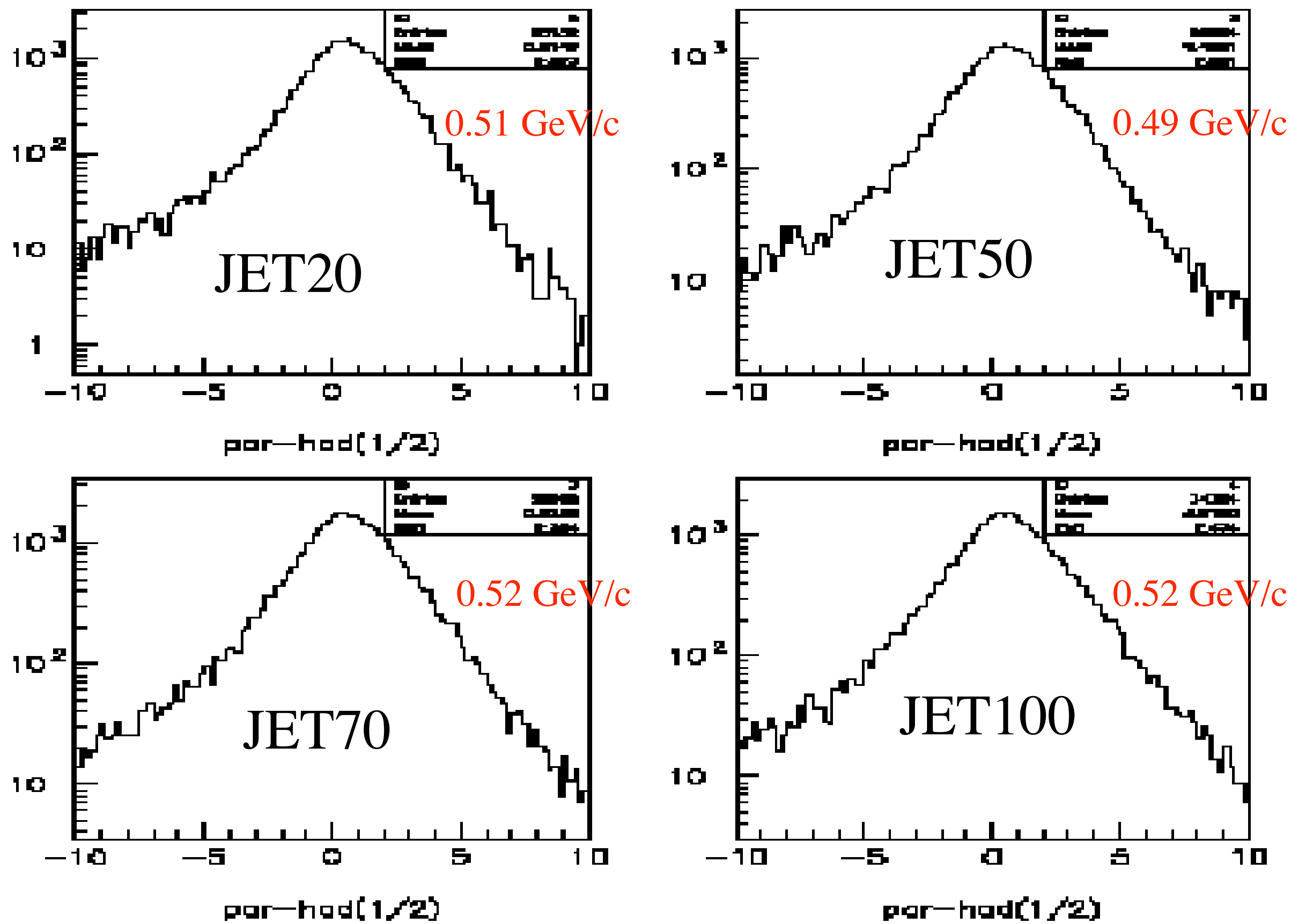
$$E_T^{out} = \frac{\sqrt{\pi}}{4} A \sqrt{\langle k_T^2\rangle} \, (e^{\eta_1} - 1)\,. \tag{12}$$

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

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

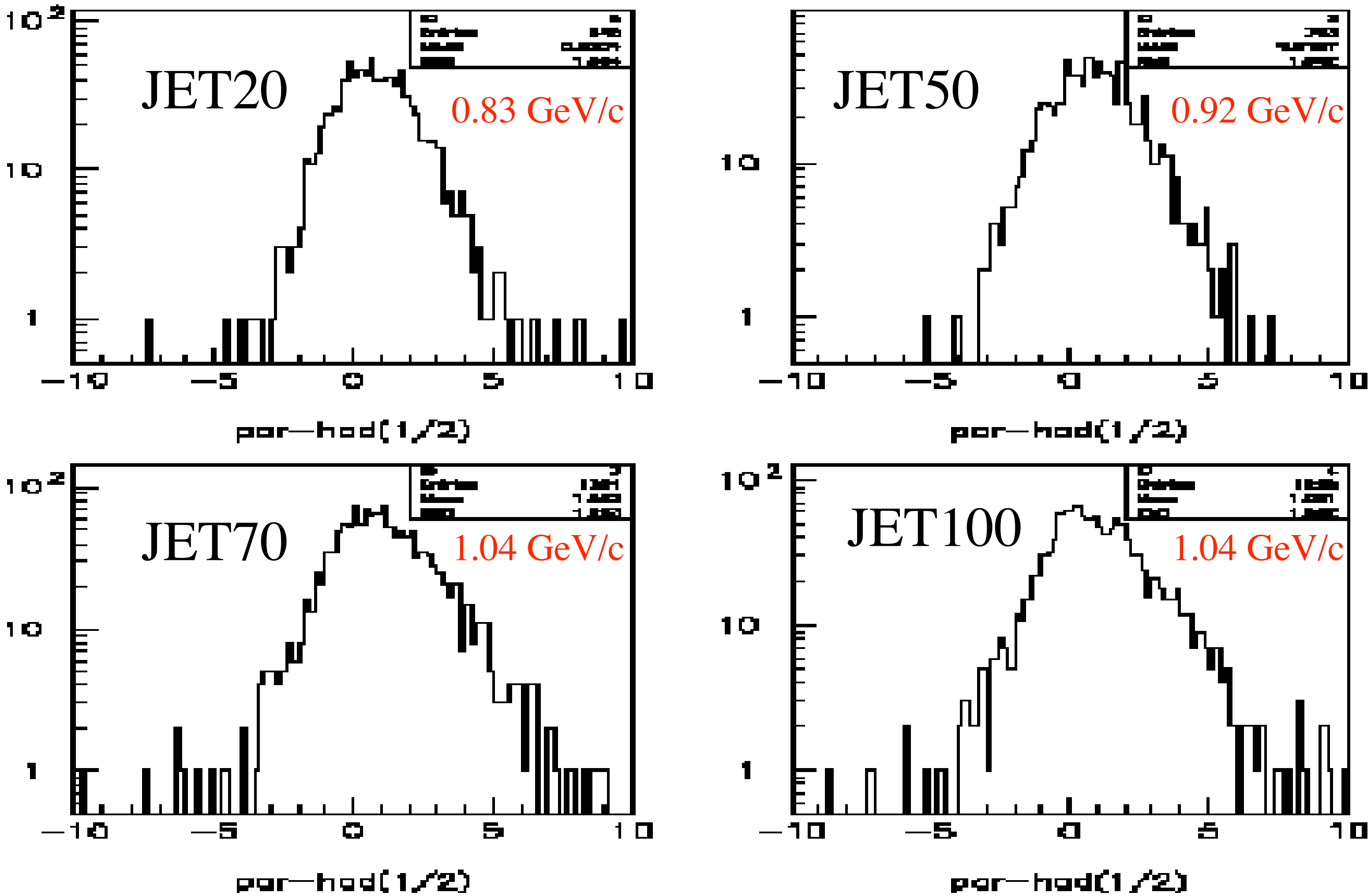
Herwig study: all rapidity, cones of 0.7

…order of 0.5 GeV/c for whole E_T range



Jets in central rapidity region, cones of 0.7

…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

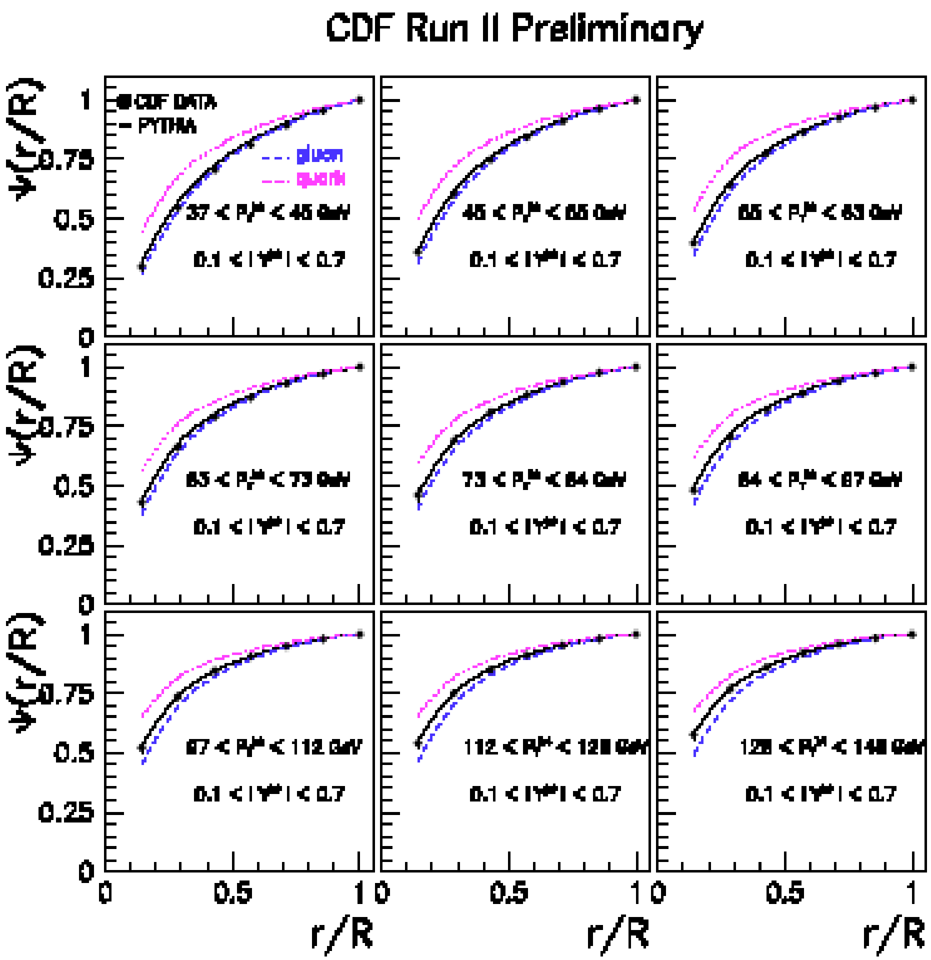
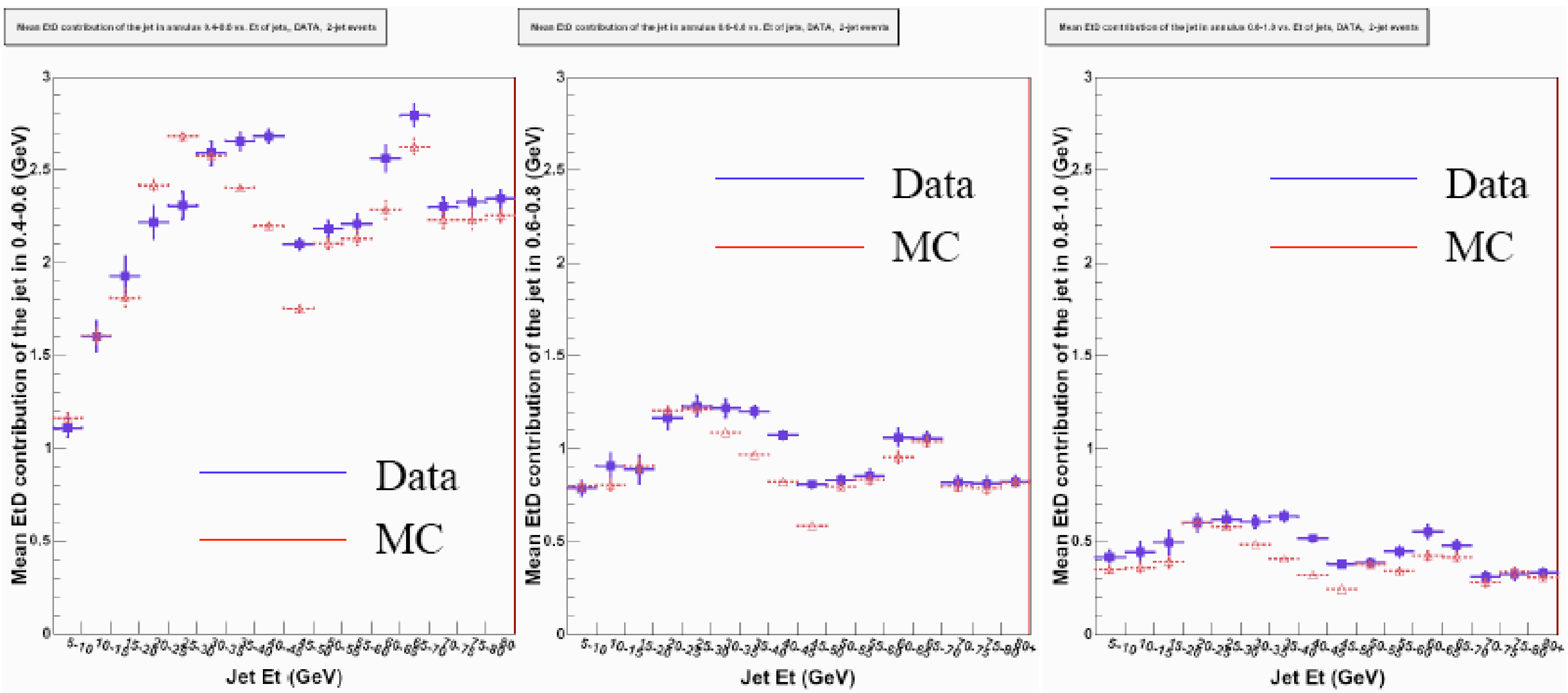


Figure 3: Measured integrated jet shape, $\Psi(r/R)$, in inclusive jet production for jet with $0.1 < |Y^{jet}| < 0.7$ and 37 GeV $< P_T^{jet} <$ 148 GeV, in different P_T^{jet} regions. Error bars indicate the statistical and systematic uncertainties added in quadrature. The predictions of PYTHIA (solid 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

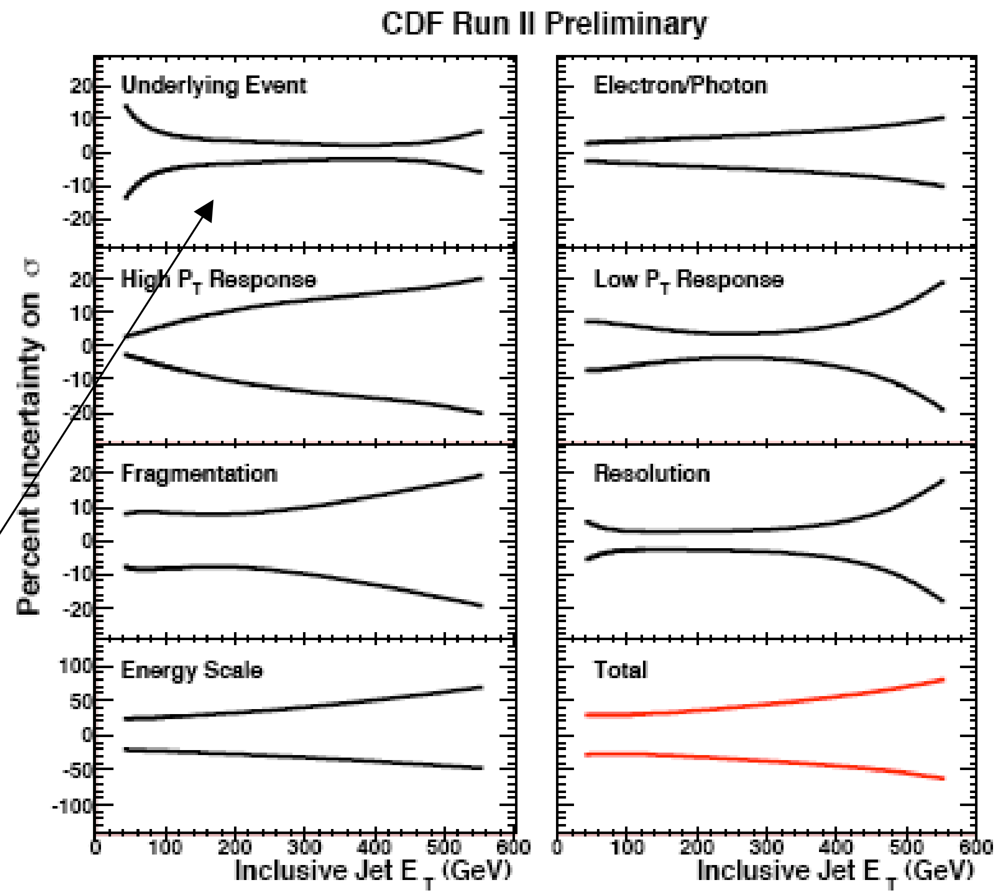
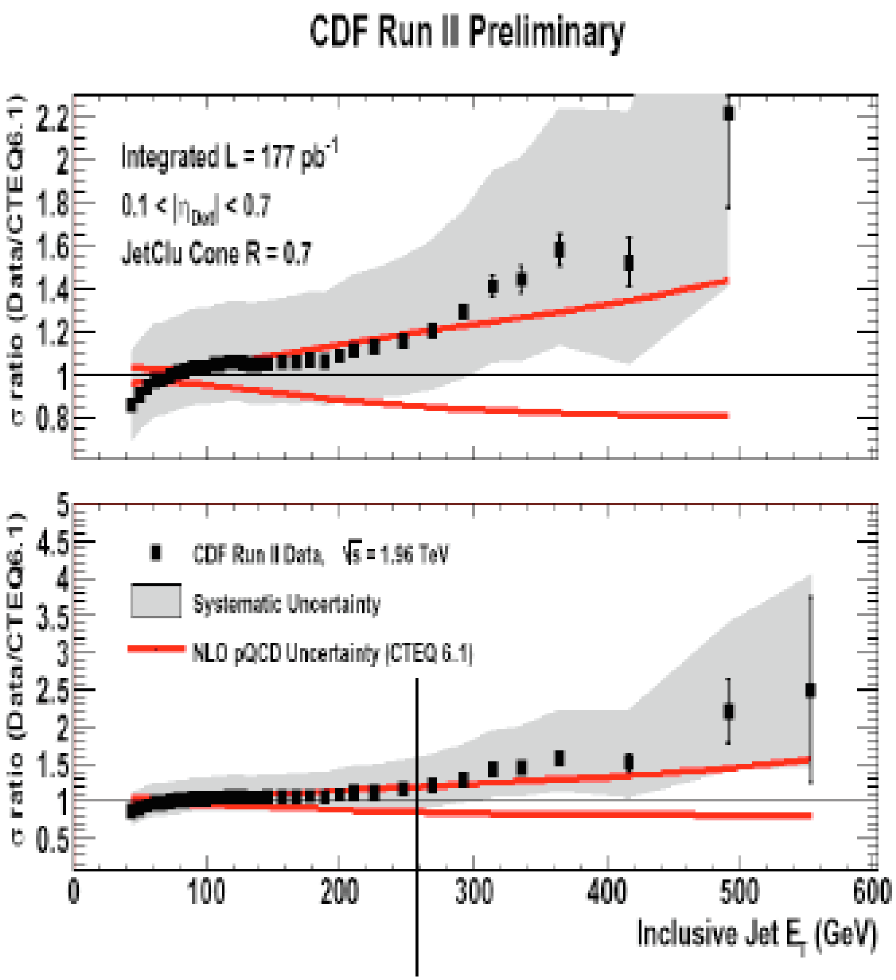


Figure 14: The percentage error on the corrected cross section resulting from the individual contributions to the total systematic error. The dominant uncertainty comes from the shift in energy scale.

Splashout correction for inclusive jets

- Splashout results in a correction to the NLO cross section



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

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

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

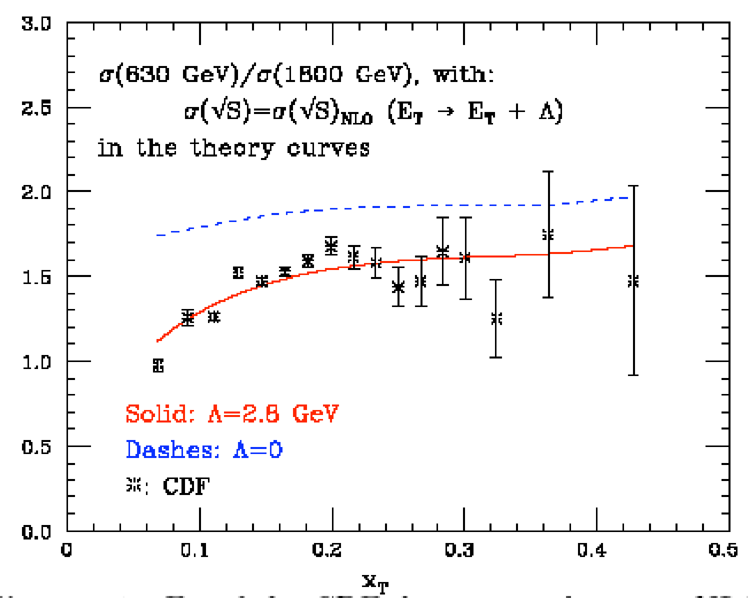
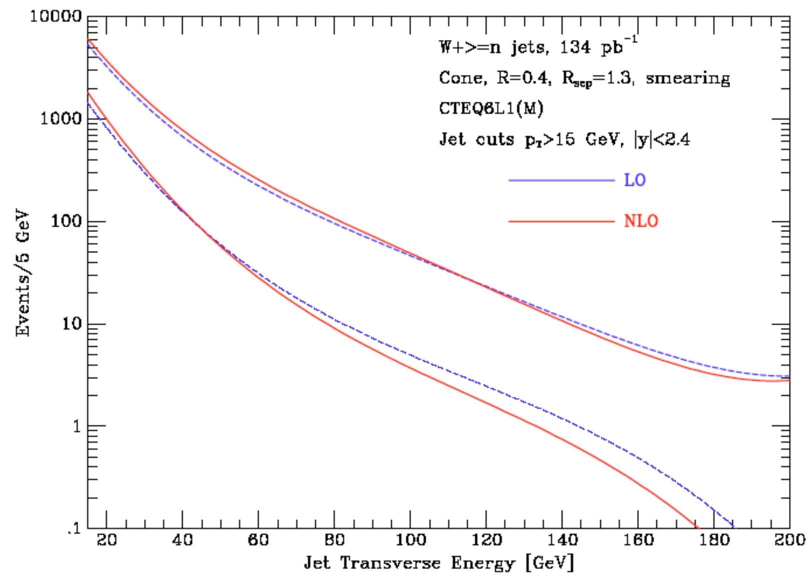
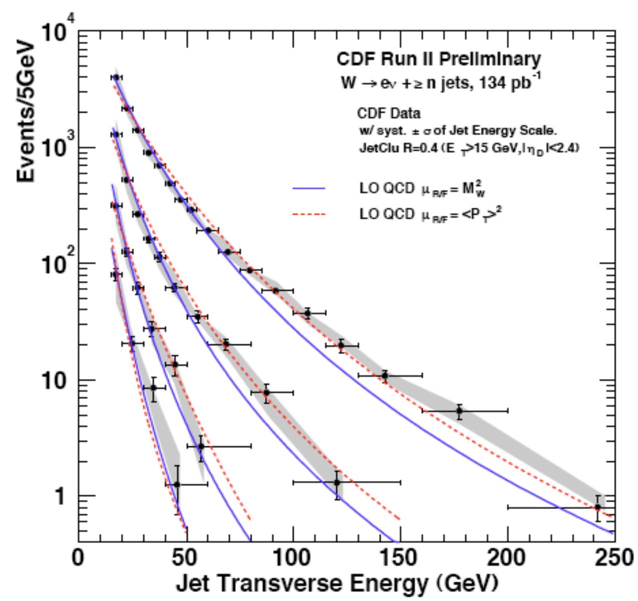


Figure 17. Fit of the CDF data using the exact NLO jet cross-section (CTEQ3M, $\mu = E_T/2$), assuming an E_T-independent shift Λ in the jet energy.

Not just for inclusive cross sections

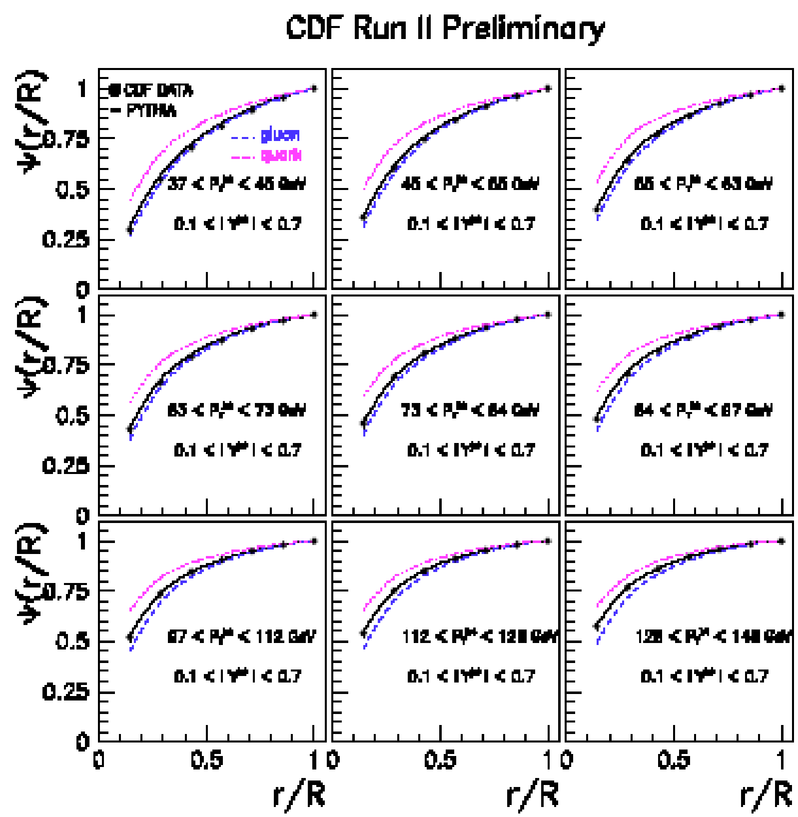
- We'll need hadronization corrections for precision comparisons of NLO W + 1, 2 jet cross sections to data
- …or for any other NLO comparison
- Note that for W + jets, we will need the hadronization study to be repeated for cones of 0.4





Idea

- Currently, we are comparing jet shape to 1 gluon (NLO) or many gluons (Herwig/Pythia)
  - comparisons in progress with NLO 3 jet calculation
- Not really sure how well either describes periphery of jet
  - parton showers are a better description of collinear emission
  - NLO doesn't have hadronization
- What about a CKKW description of jet shape using matrix elements for n hard gluon emissions + parton showers?
  - interfacing to full hadronization



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Underlying event subtraction

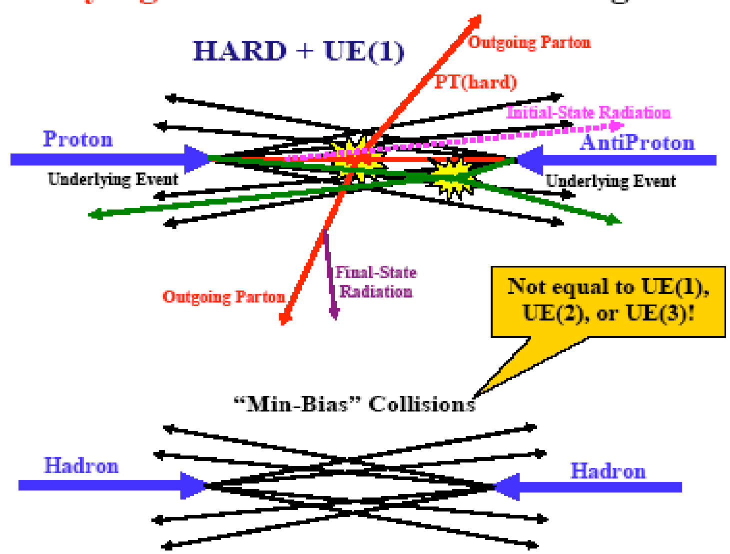
- For comparisons to NLO codes, the underlying event energy not connected to the hard scatttering has to be subtracted from the jet cones

- But the above definition is a very murky beast
- Just what is the appropriate underlying event energy to subtract

The "Underlying Event"

- What is your definition of the "underlying event" in a hard scattering process?

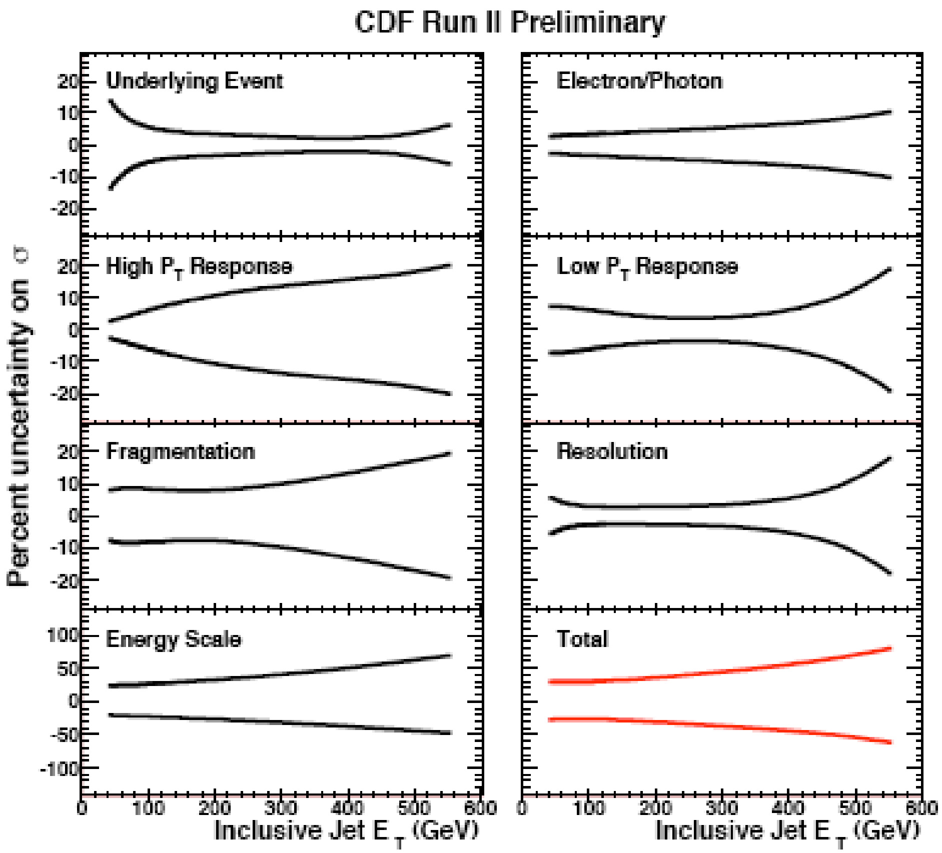
Acronym	Definition
2-to-2	Two outgoing partons
ISR	Initial State radiation
FSR	Final State Radiation
HARD	2-to-2 + ISR + FSR
BBR	Bean-Beam Remnants
MPI	Multiple Parton Interactions
Pile-up	Additional proton-antiproton collisions
MB	"Minimum-Bias" collisions
UE(1)	BBR + MPI
UE(2)	BBR + MPI + ISR
UE(3)	BBR + MPI + ISR + FSR
UE(4)	MB (does not make sense!)



- My definition is UE(1), but for some jet corrections you might want UE(2) or UE(3). No observable directly measures UE(1)!
- The Run 1 "UE" correction was not intended to be UE(1)!

Run 1

- In Run 1, we assumed that the appropriate level of energy to subtract was that contained in active (class 12) minimum bias events
- But we assumed a 30% uncertainty on the amount of energy to subtract, and this ended up being the largest source of uncertainty for jet E_T less than 60 GeV/c
- But this is a different source of error than any other, since it's basically a physics error
- Can we reduce this error for Run 2?



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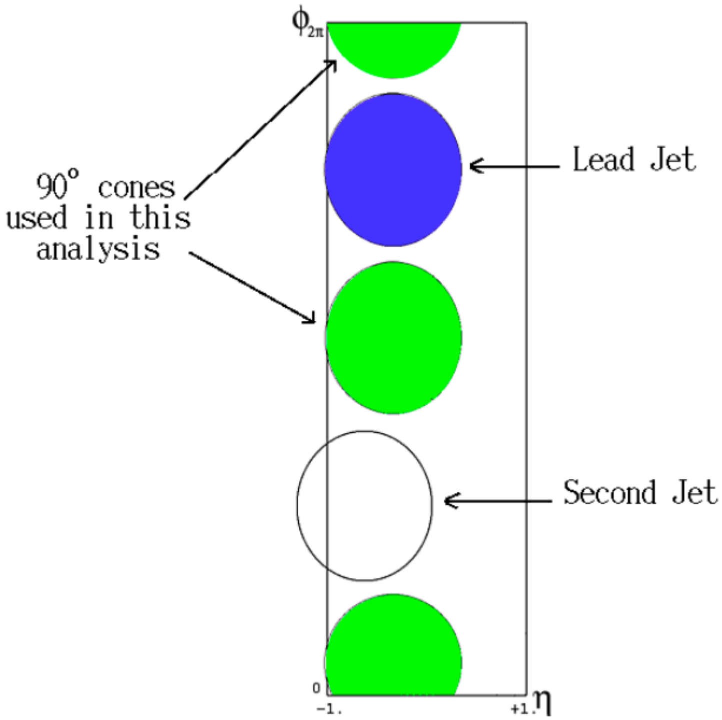
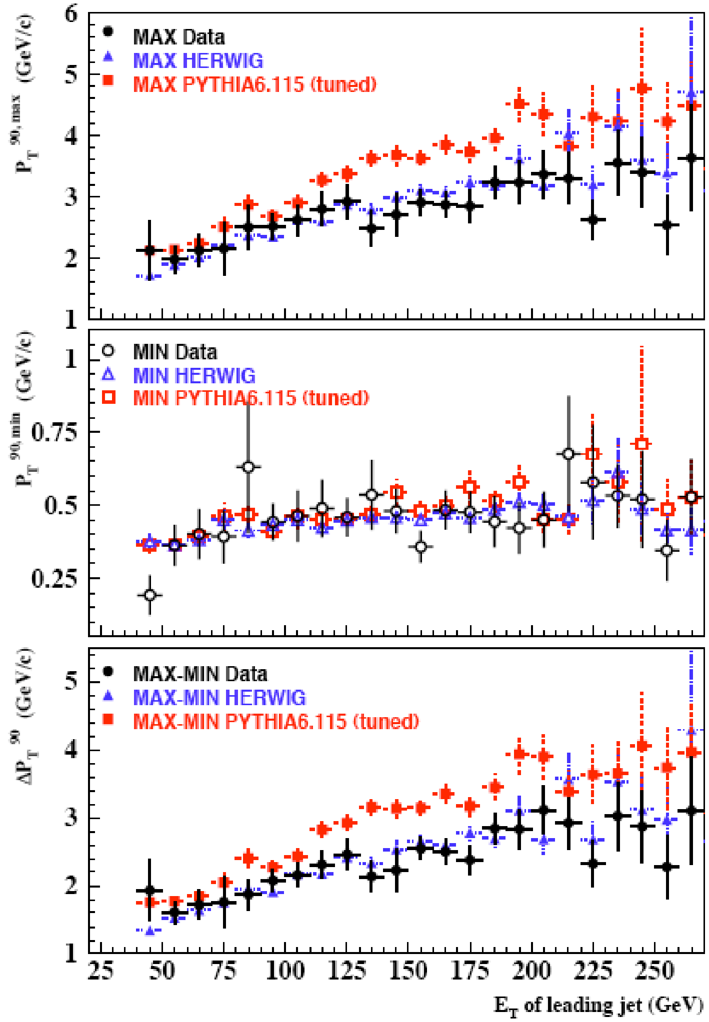
Analysis by Valeria Tano

- She found the min cone energy to be relatively constant as a function of the lead jet E_T and similar to the energy level observed in *active* min bias events

If we continue with that philosophy, what uncertainty should we use?

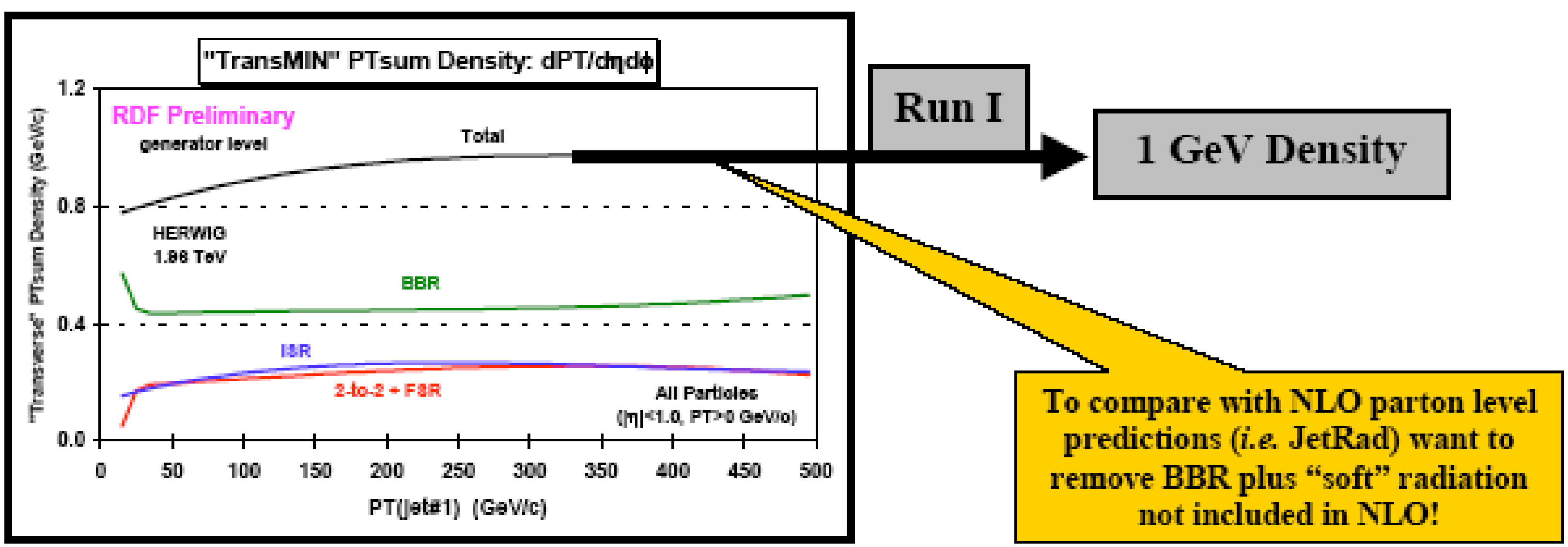




Monte Carlo definitions

As expected, the ISR contributions to min region are suppressed. Would it be useful to define DPS+ISR in which the hardest gluon is removed (an analog of NLO) and examine how much energy is contributed to jets and to max and min regions? Perhaps with the new version of Pythia where DPS+ISR are treated in a more unified manner? Also with the new version of Herwig including Jimmy.

HERWIG: “MIN Transverse” PTsum Density



Helpful magazine

- At first I thought a magazine devoted to ISR might prove helpful
- But then I took a closer look at the title and realized that this is a magazine that Steve Mrenna would never subscribe to

Summary I

- 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 there anything more sophisticated we should be/could be doing? Should we try to do something similar between CDF and D0?

Summary II

- What is best estimate of the appropriate value of underlying event to subtract?
  - active min bias level?
  - tuned Pythia/Herwig prediction for min cone in jet events?
  - tuned Pythia/Herwig prediction for contribution to jet cone from BBR + ISR (with hardest gluon subtracted)?
  - Something better?