Jets: the story so far

- Most of the tools we want to produce/develop in this workshop are QCD-related
  - ME/MC generation
  - NLO
  - jet algorithms
  - pdf's and pdf uncertainties
  - …
  - I don't even know why people are going to the other groups

    -my ed. comment

- Note that there have been a series of previous meetings organized by Steve Mrenna and myself dealing with these types of issues for Run 2
  - cepa.fnal.gov/patriot/mc4run2/index.html

SM Physics

TeV4LHC

Before we publish new physics at the LHC, we need to understand SM physics. A lot of prior knowledge can come from the Tevatron.

Backgrounds – Measuring and Calculating

At present, we rely on MC for signal and background estimates

There are uncertainties in rates from PDF's, higher order QCD

Most of these do no matter at the moment, They will matter once data appears

The MC/theory tools must match the experiments

Don't forget that the LHC will be a precision machine.

Some processes are not well understood: For these we need flexibility in the modeling

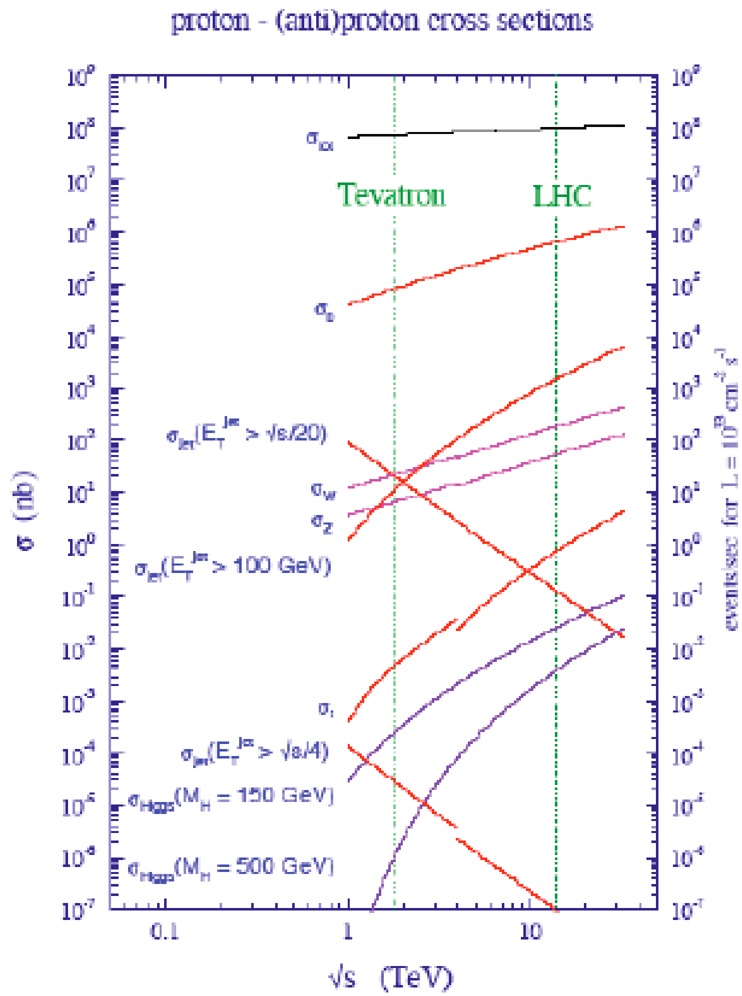
A concern: underlying and min-bias events

Affects process that need forward jet tagging *e.g.* *WW – scattering* or central jet veto *e.g.* extraction of objects produced by EW interaction

Will be measured once data exists and MC will be tuned to agree... But

Speech

Ian Hinchliffe from BNL meeting



Physics group goals

TeV4LHC

- QCD sub-groups
  - pdf's and event classification
    - extraction of pdf's purely at high-momentum transfers
    - establishment of jet contracts between experiments and theorists
    - subtleties and practicalities of jet algorithms
  - hard scattering and hadronization
    - testing of matrix element-parton showering matching
    - underlying event tunes and model development
    - tests of hadronization and tunes/universality of tunes
  - diffraction

- Top and Electroweak
  - top production and decay
  - analysis techniques
  - improved tagging strategies

great deal of overlap

…and that's why much of our time here was spent in joint meetings

Conveners and info

- QCD conveners
  - M. Albrow, F. Chlebana, A. de Roeck, S. Ellis, W. Giele, J. Huston, W. Kilgore, S. Mrenna, W-K. Tung, M. Wobisch, M. Zielinski
- Group website
  - www.pa.msu.edu/~huston/tev4lhc/wg.htm
- Sub-sub-groups
  - PDF's and PDF Uncertainties at the Tevatron and LHC
  - **Jet Algorithms and Event Structure**
  - Matrix element/Monte Carlo/NLO matching
  - **Hadronization Corrections and UE tunes**
  - Diffractive Physics

Jet Projects

1. inclusion of jet production in MC@NLO

   Steve Ellis,Bill Kilgore, Stefano Frixione, Joey Huston

   Stefano was deemed a security risk for this meeting, but hopefully the work will continue at Les Houches.

2. Practicing safe exclusive (jet) final states (jet vetos)

   Steve Ellis

3. jet algorithms at the Tevatron and LHC

   -impact of splitting/merging; understanding the effects of splitting/merging at the parton and hadron level

   -impact on boosted systems, e.g. W->jj in high p_T top

   -understanding differences observed in jet reconstruction between CDF and D0 environments

   -reconstruct sample of MC events that produce problems in the CDF environment using D0 and LHC algorithms

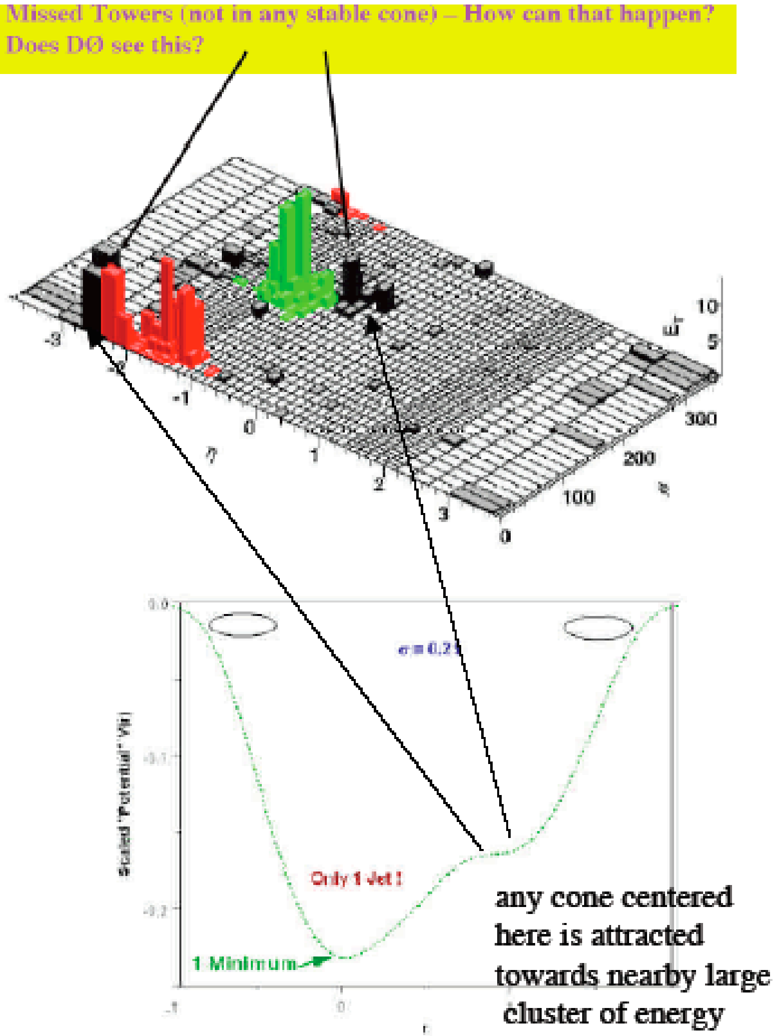
From website

- A stand-alone CDF Fortran/C++ jet clustering routine is available here.
- Some descriptive text from Matthias Tonnesmann is available here.
- The Monte Carlo events that resulted in "dark towers" or "fat jets" in the CDF clustering are available here (along with some descriptive text from Matthias).

Michael Begel, Frank Chlebana, Steve Ellis, Joey Huston, Alison Lister, Matthias Tonnesmann,Markus Wobisch, Marek Zielinski

Jet clustering

- Run II analyses in CDF and D0 use both cone and k_T jet algorithm
- CDF has used both JetClu (Run I) and midpoint (Run II) algorithms; D0 solely midpoint
  - subtle issues (and solutions) regarding use of midpoint algorithm
  - See hep-ph/0111434, S. Ellis, J. Huston, M. Tonnesmann, *On Building Better Cone Jet Algorithms*



Solution: smaller initial search cones ($R_{cone}/2$)

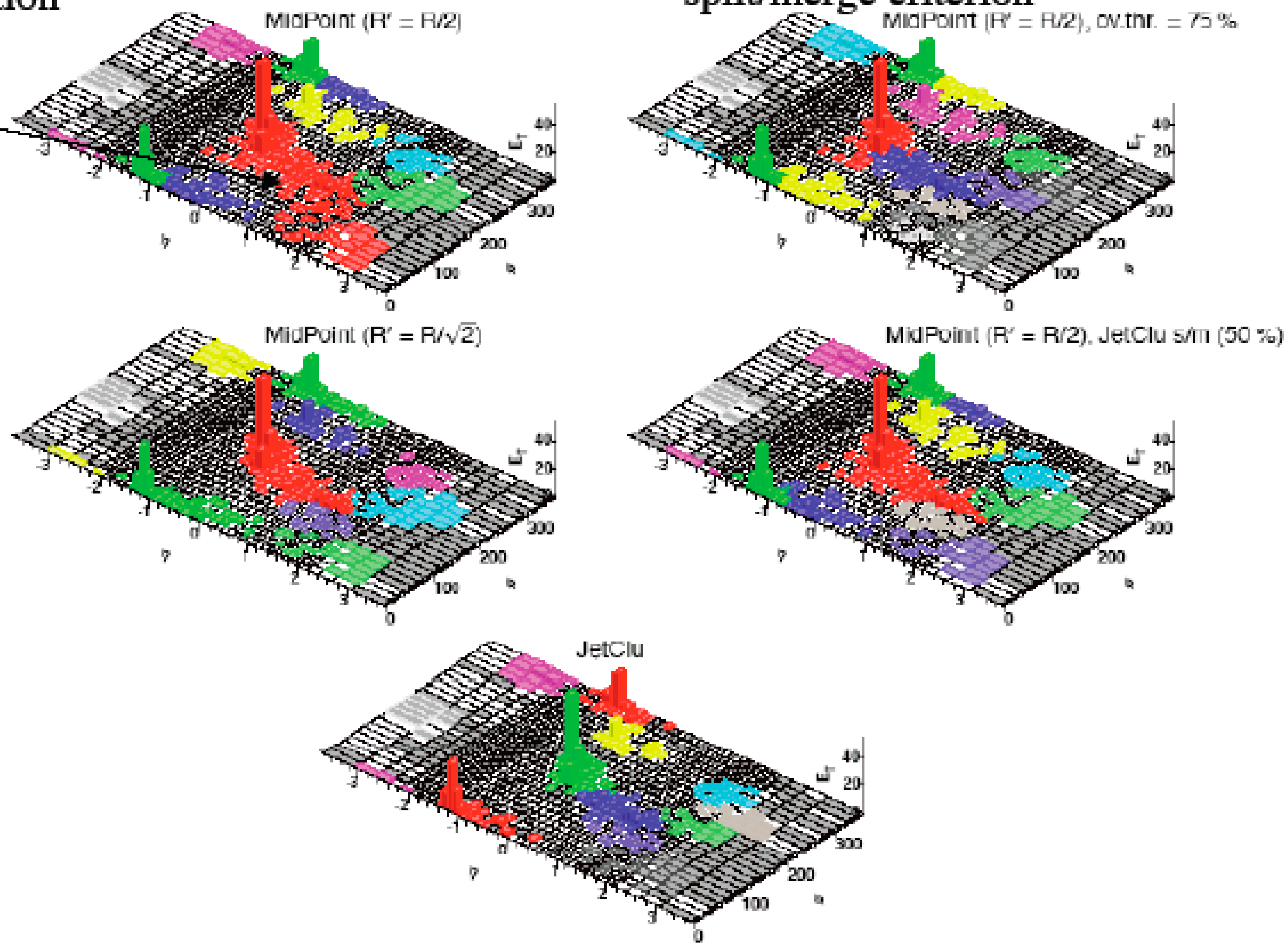
Fat jets

TeV4LHC

- Run / Event: 151843 / 1723497 (Jet100)

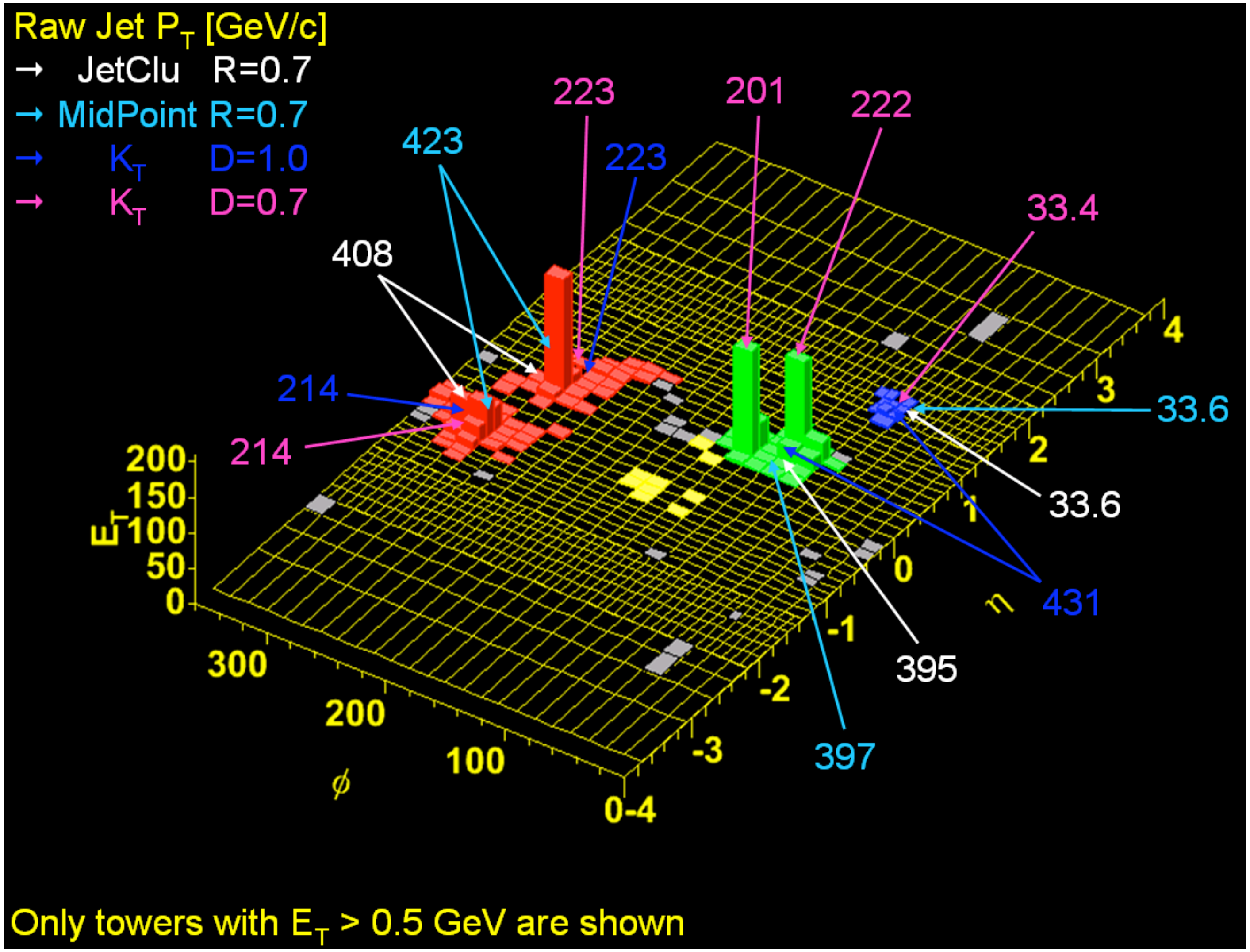
split/merge fraction of 50% can lead to fat jets

…which is greatly reduced with a 75% split/merge criterion



…may be more of a problem in a high luminosity environment

Interesting event to study algorithm differences



Jet Projects

3. UE subtraction

- -definition of UE + uncertainty for comparisons of data to NLO

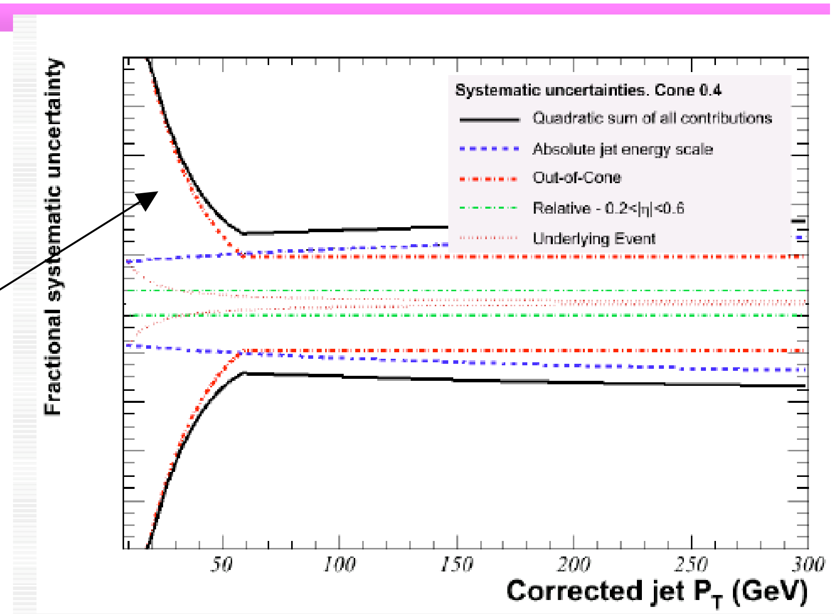
  UE subtraction uncertainty dominant at low E_T

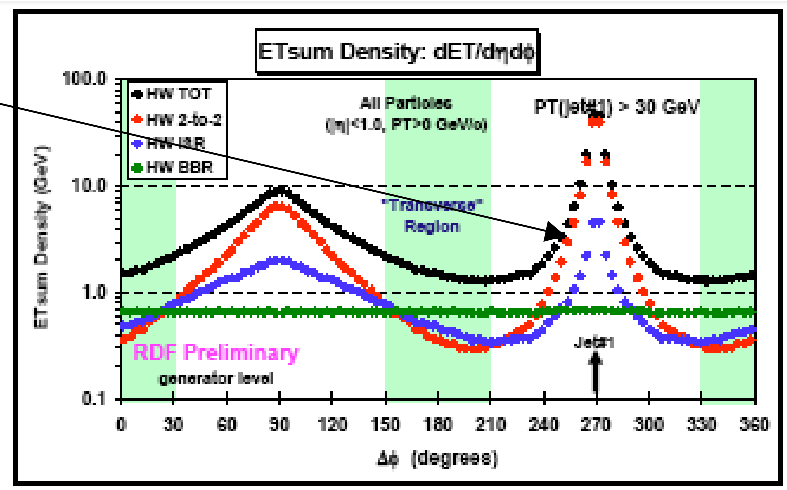
- -impact of ISR on jets and jet predictions

  ->is there an ISR contribution not accounted for by NLO?

- -operation in high multiple interaction environment

Rick Field, Joey Huston, Peter Skands

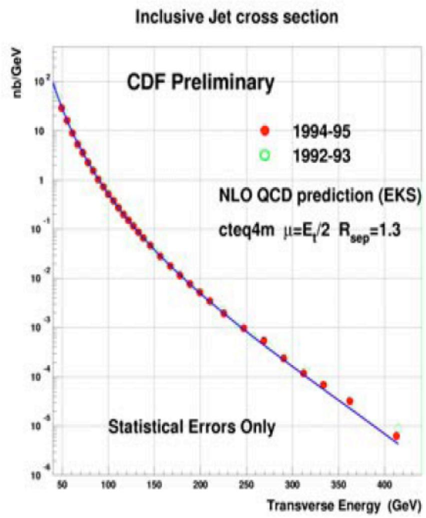


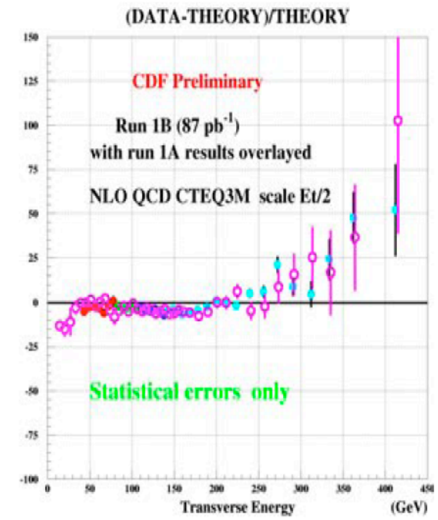


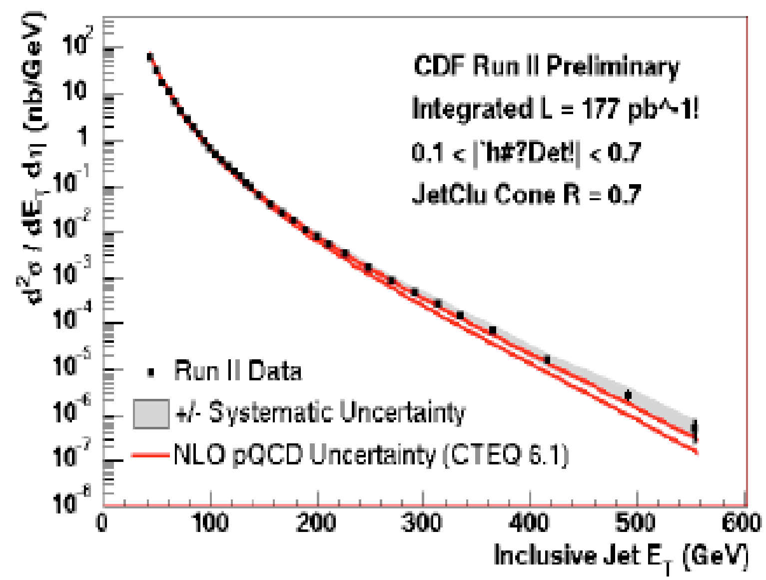
R. Field, TeV4LHC WG meeting in December

Inclusive jet cross sections in CDF

- The inclusive (cone) jet cross sections reported by CDF in both Run 1 and Run 2 (to date) have been corrected back to the hadron level and not to the parton level
- New results to be blessed with the midpoint algorithm will correct back to the parton level

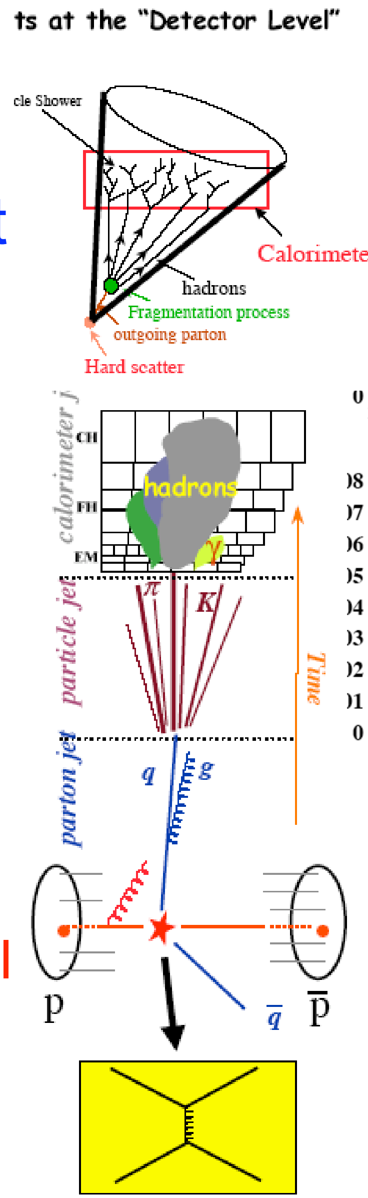


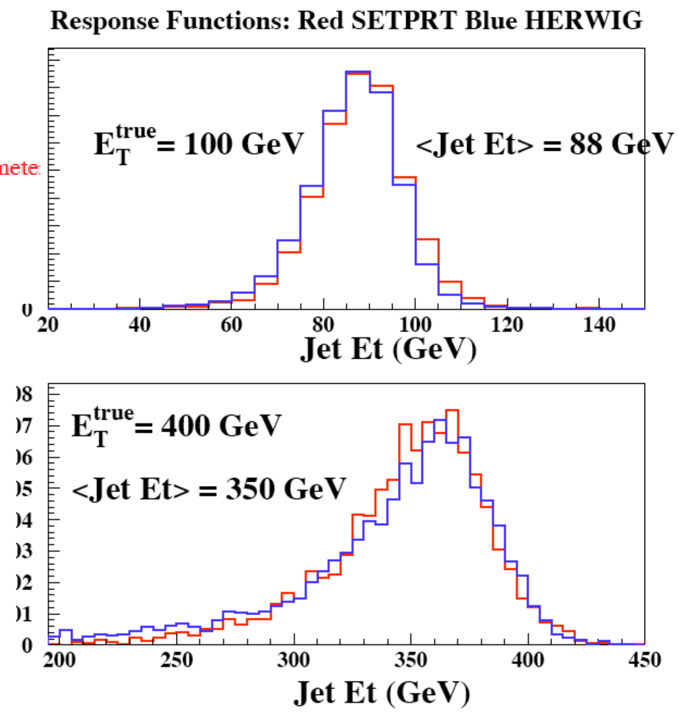




Inclusive jet production

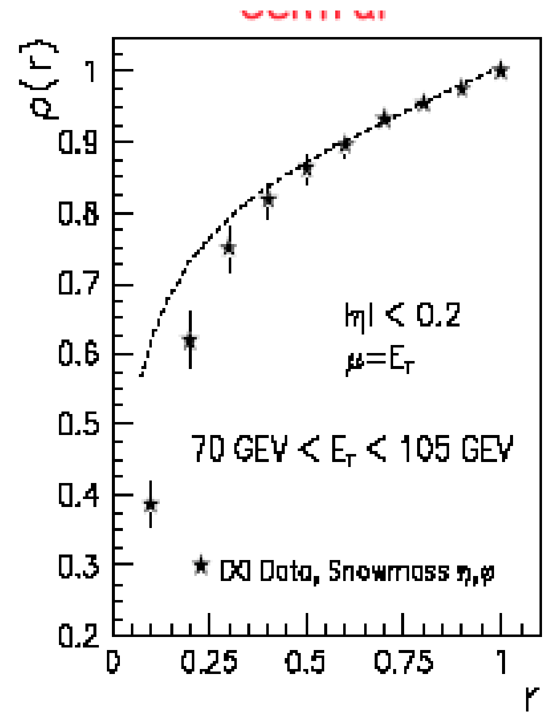
- i.e. the response functions are based on the hadrons inside the jet cone and not the partons
- NLO cross sections are at the parton level
  - EKS, JetRad, MCFM,…
  - either 1 or 2 partons per jet
  - MCatNLO is adding jet production but Steve and Bill haven't done their homework yet so we're still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





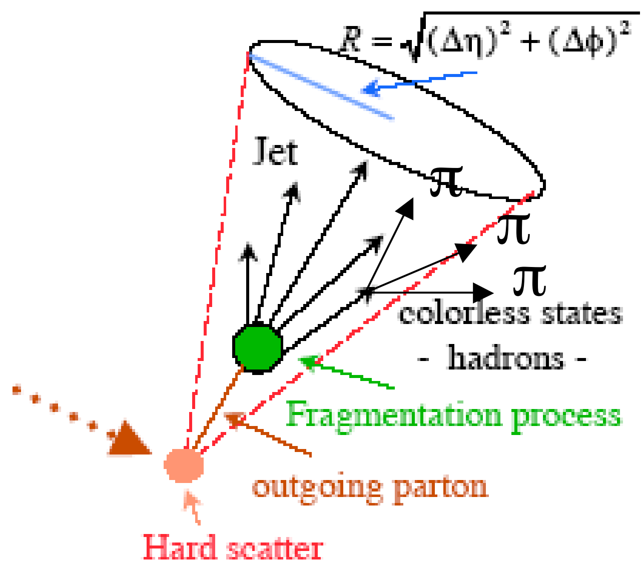
Out-of-cone

- 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

TeV4LHC

- 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

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

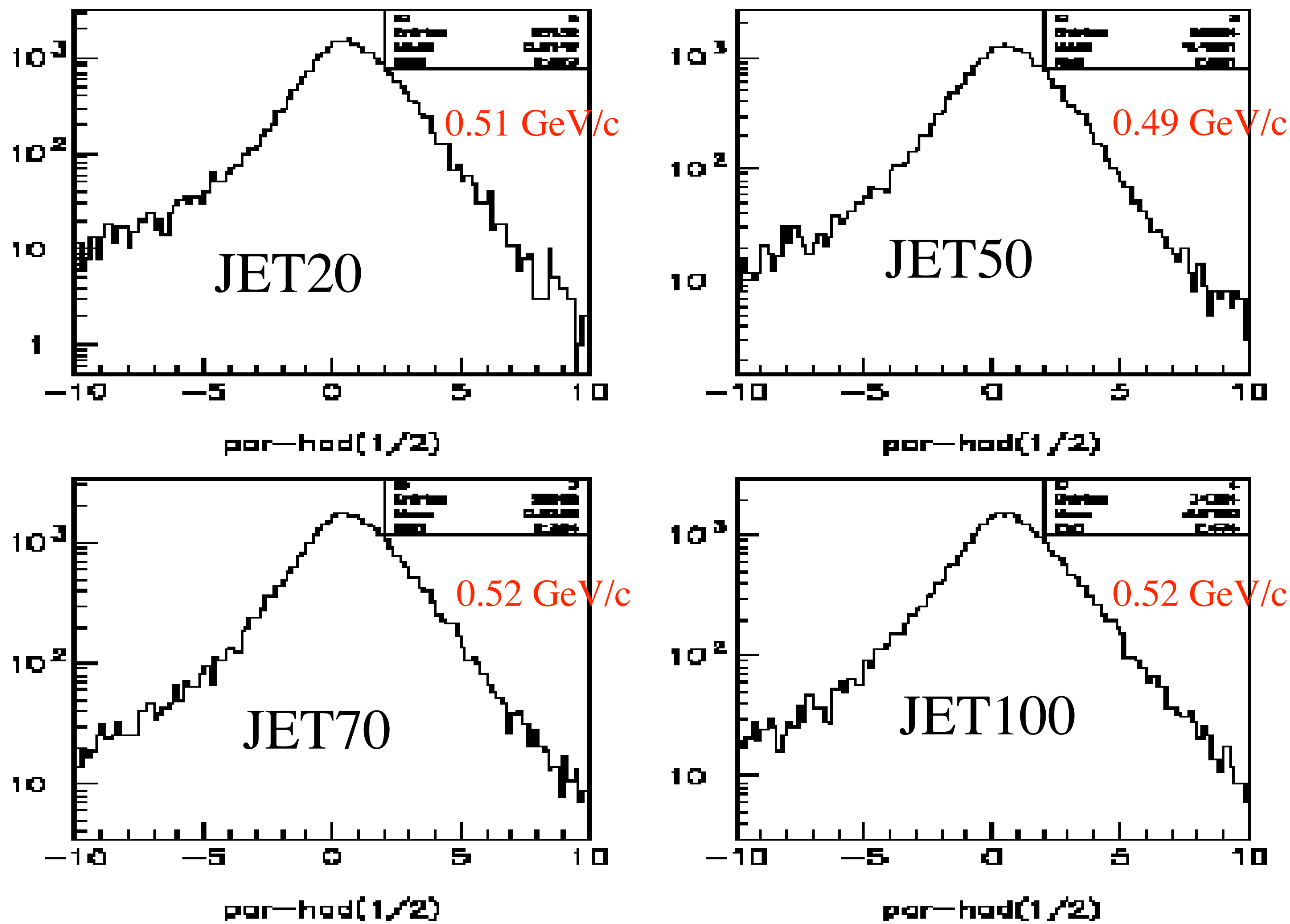
Taking $\sqrt{\langle k_T^2 \rangle} = 0.3$ GeV and[10] $A = 5$, I find

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

Herwig study: all rapidity, cones of 0.7

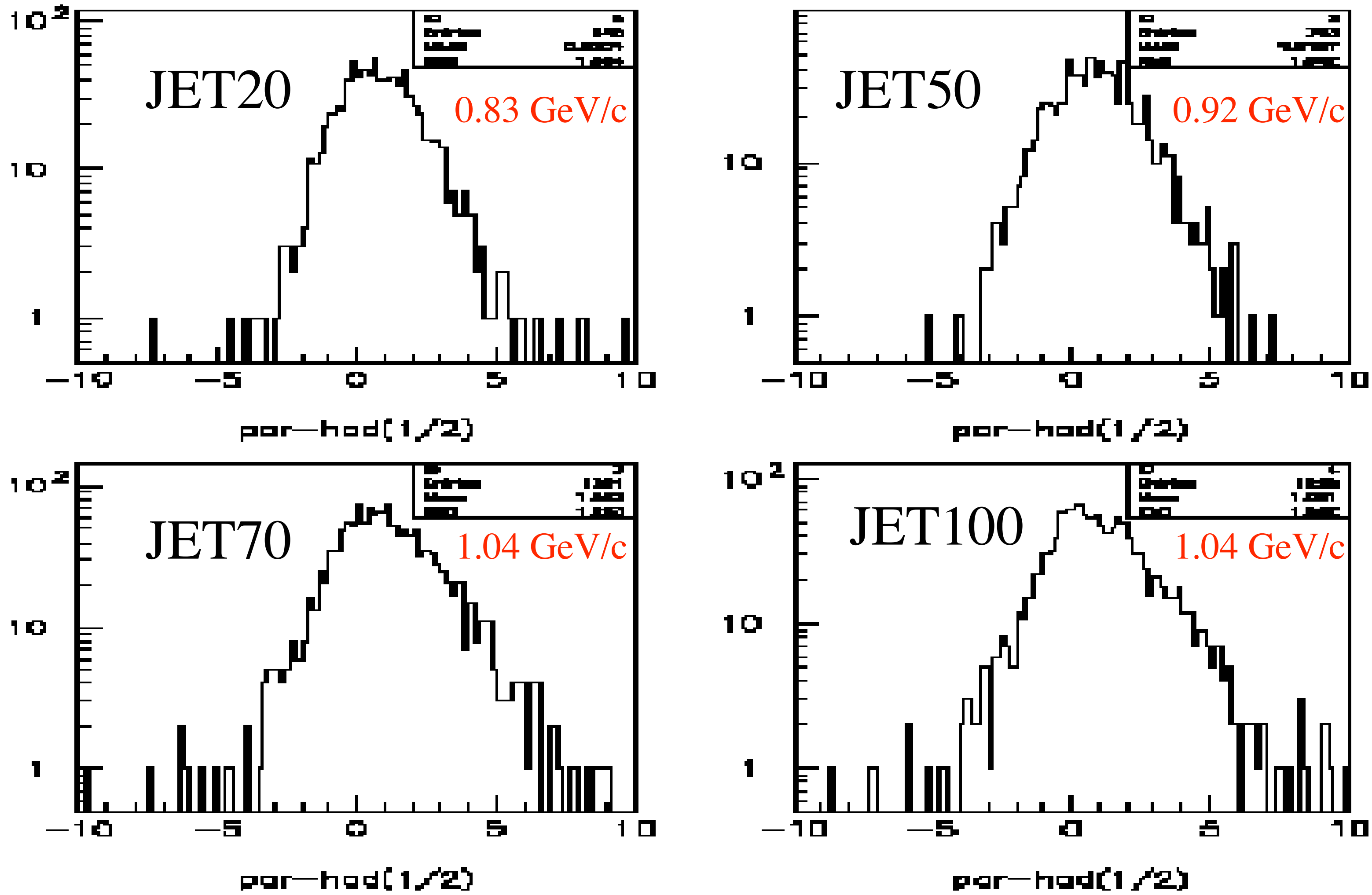
TeV4LHC

…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

TeV4LHC

- 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

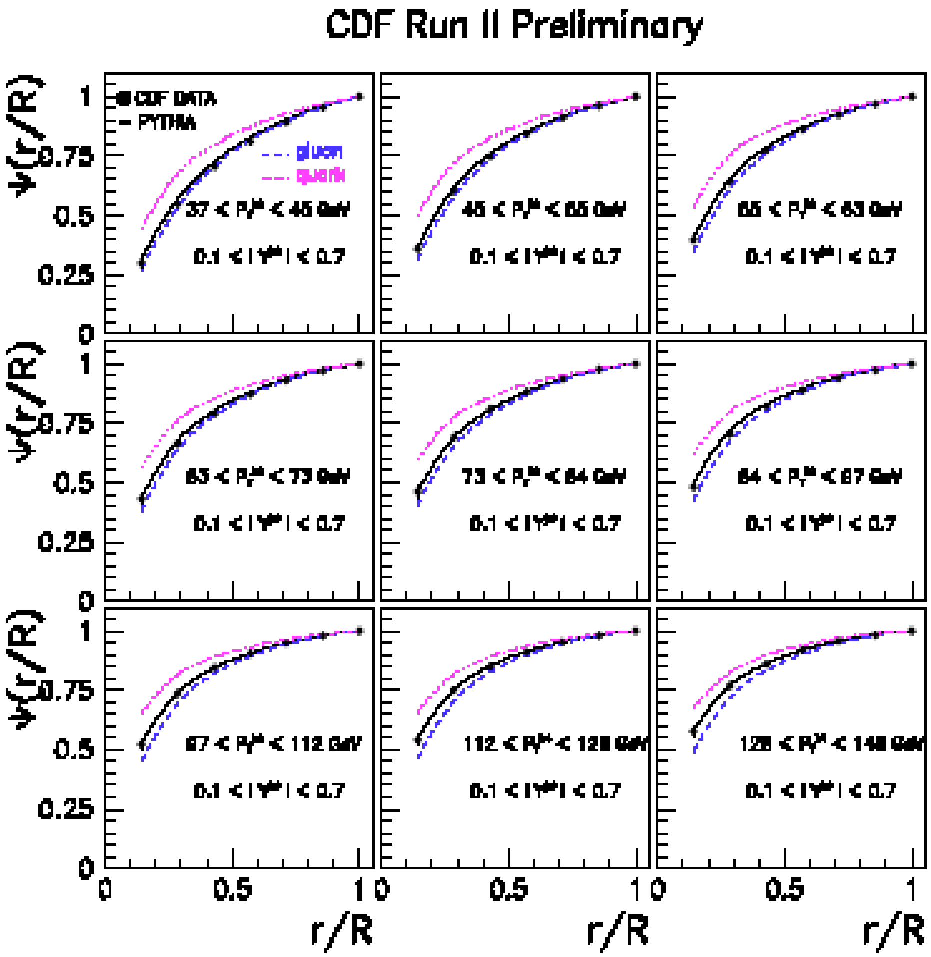
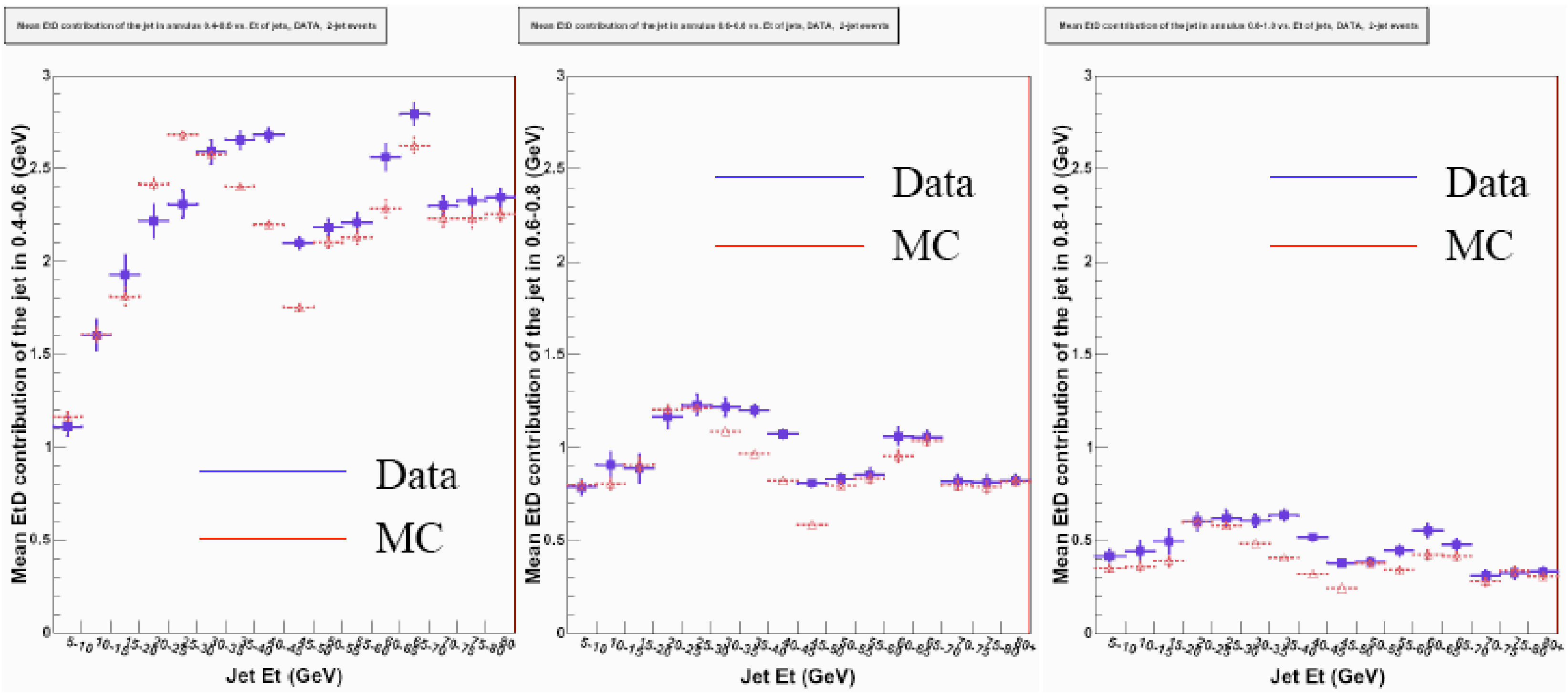


Figure 3: Measured integrated jet shape, $\Psi(r/R)$, in inclusive jet production for jet with $0.1 < |Y^{jet}| < 0.7$ and 37 GeV $< P_T^{jet} <$ 148 GeV, in different P_T^{jet} regions. Error bars indicate the statistical and systematic uncertainties added in quadrature. The predictions of PYTHIA (solid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

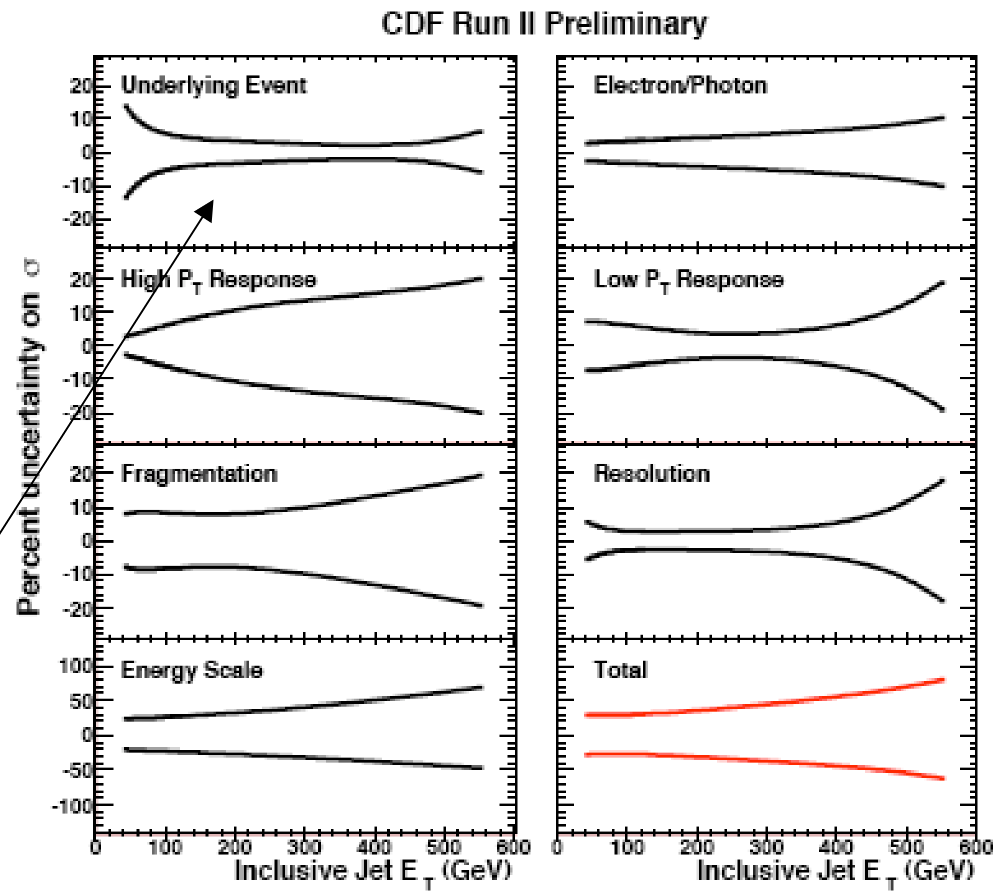
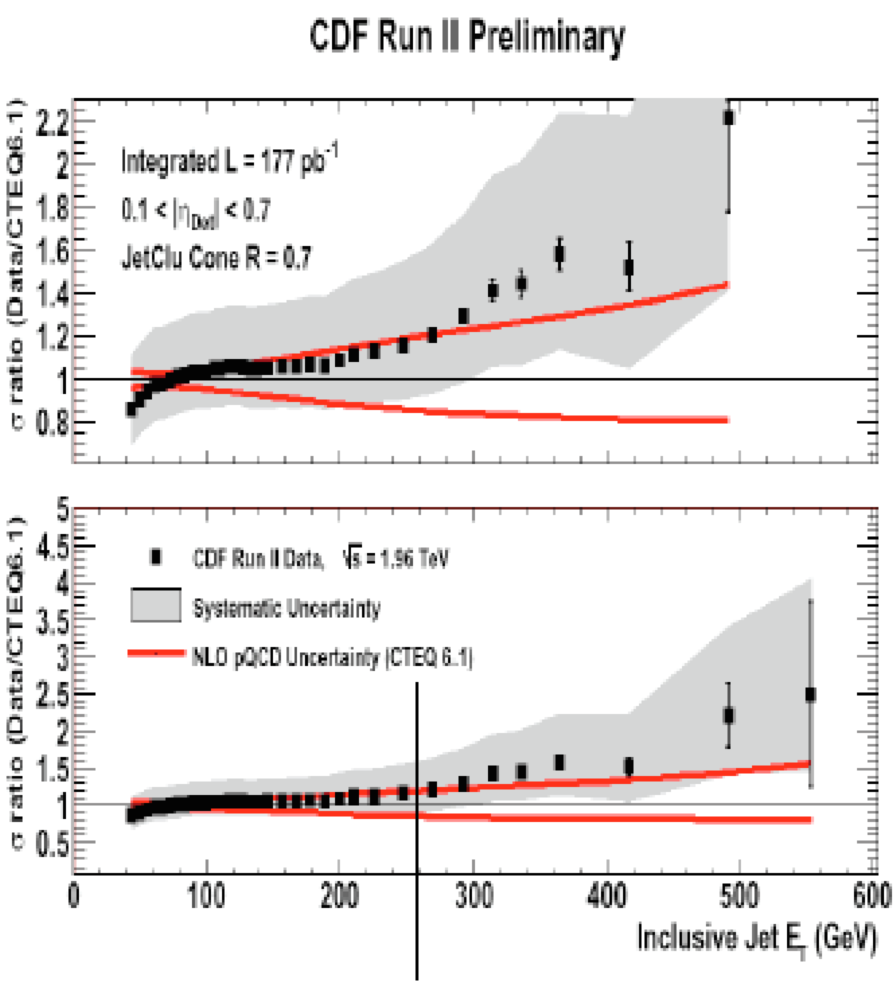


Figure 14: The percentage error on the corrected cross section resulting from the individual contributions to the total systematic error. The dominant uncertainty comes from the shift in energy scale.

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

TeV4LHC

- 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

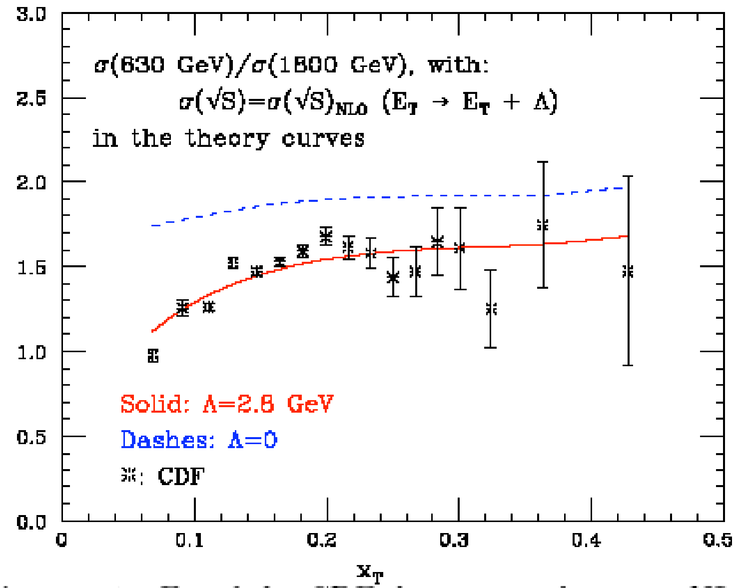
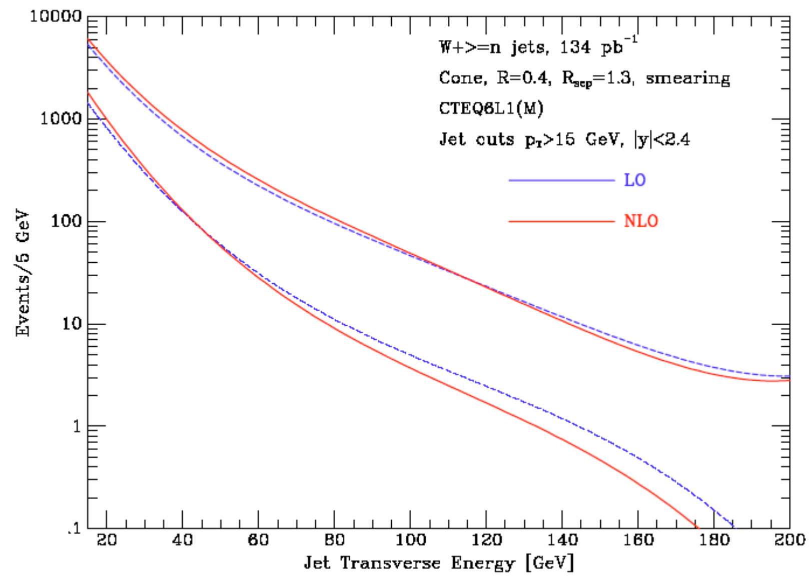


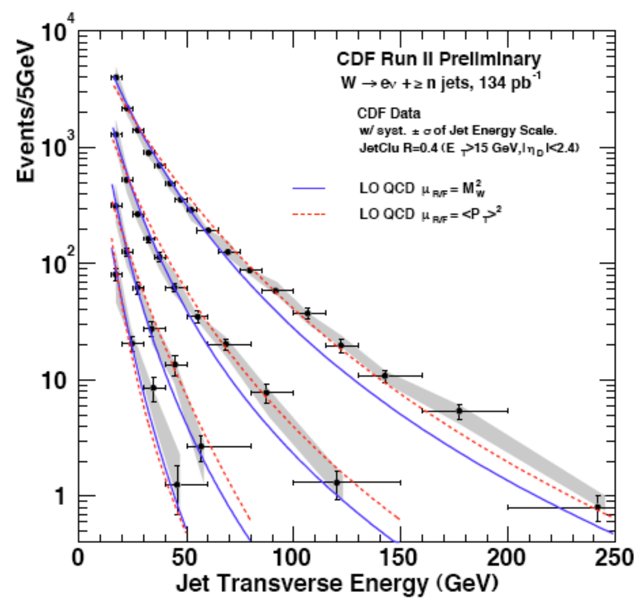
Figure 17. Fit of the CDF data using the exact NLO jet cross-section (CTEQ3M, $\mu = E_T/2$), assuming an E_T-independent shift Λ in the jet energy.

Not just for inclusive cross sections

TeV4LHC

- 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

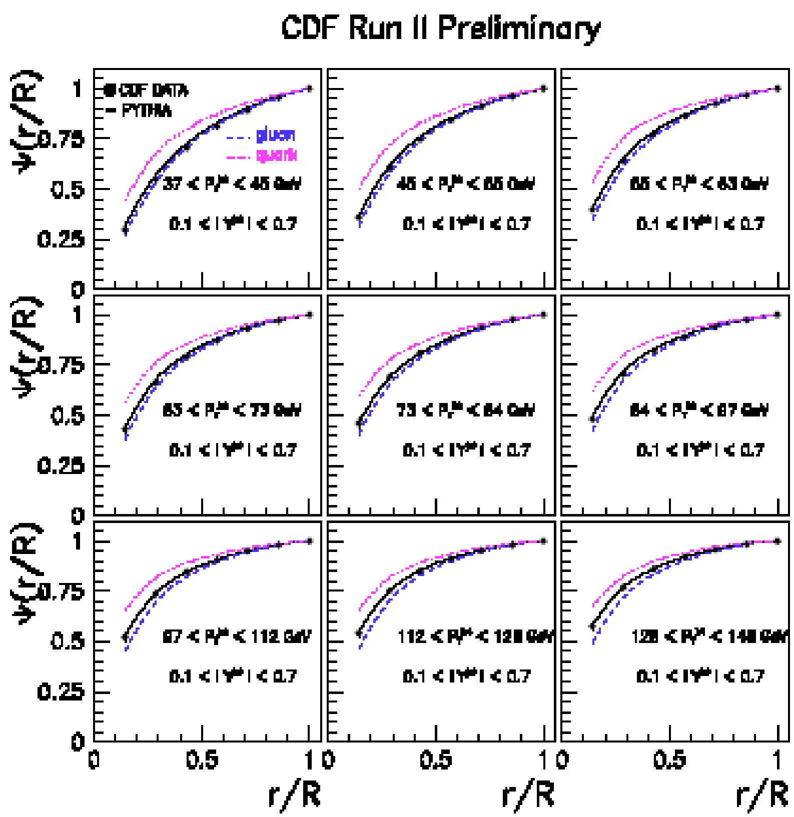


Figure 3: Measured integrated jet shape, $\Psi(r/R)$, in inclusive jet production for jet with $0.1 < |Y^{jet}| < 0.7$ and 37 GeV $< P_T^{jet} < 148$ GeV, in different P_T^{jet} regions. Error bars indicate the statistical and systematic uncertainties added in quadrature. The predictions of PYTHIA (solid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

Underlying event subtraction

TeV4LHC

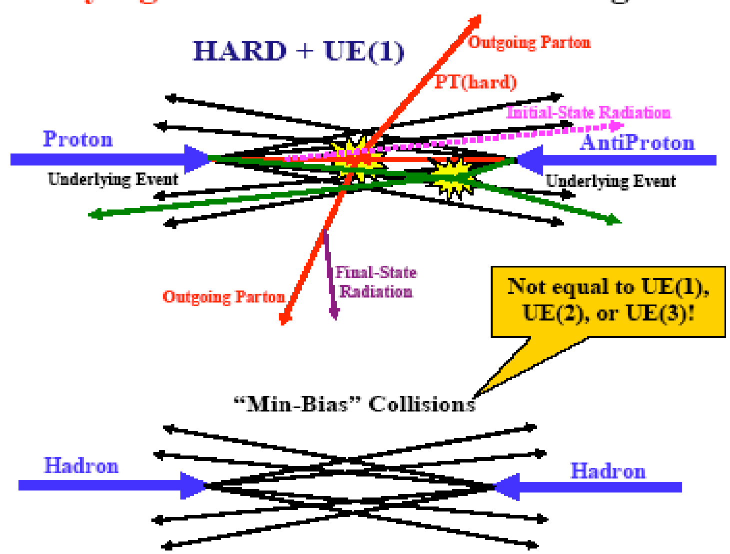
- For comparisons to NLO codes, the underlying event energy not connected to the hard scatttering has to be subtracted from the jet cones
- But the above definition is a very murky beast
- Just what is the appropriate underlying event energy to subtract

Rick Field *November 12, 2004*

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?

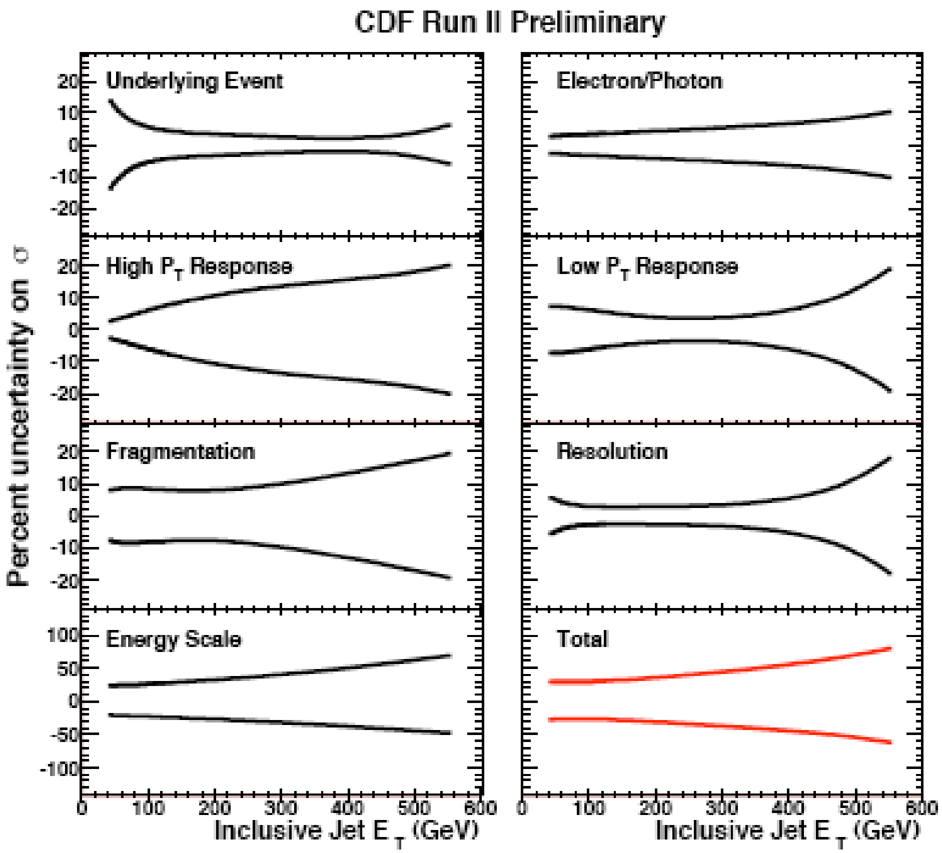
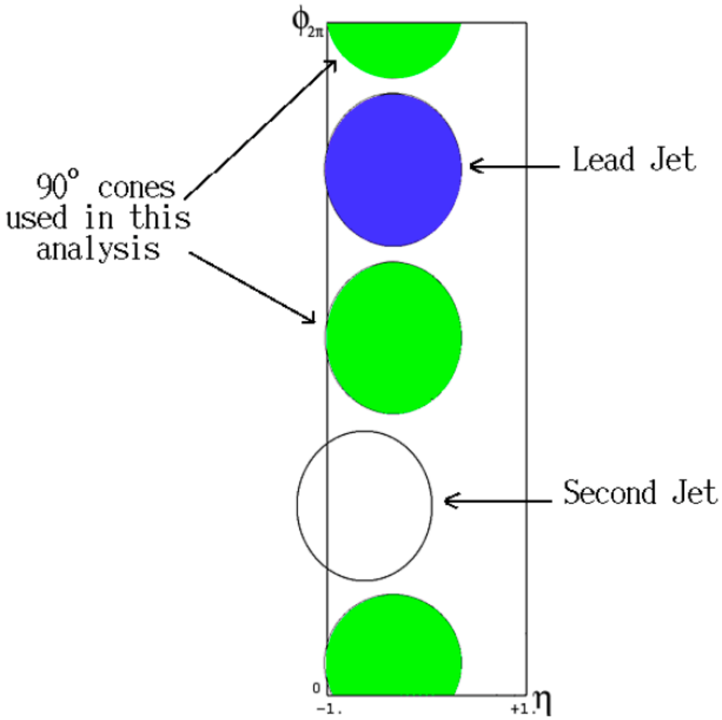


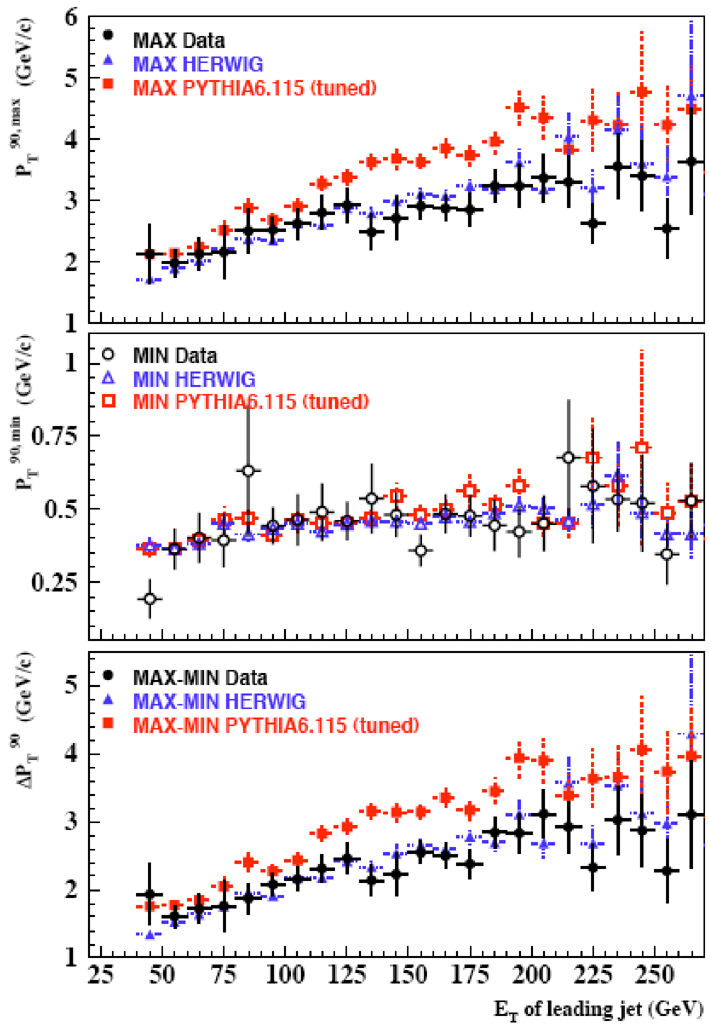
Figure 14: The percentage error on the corrected cross section resulting from the individual contributions to the total systematic error. The dominant uncertainty comes from the shift in energy scale.

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?

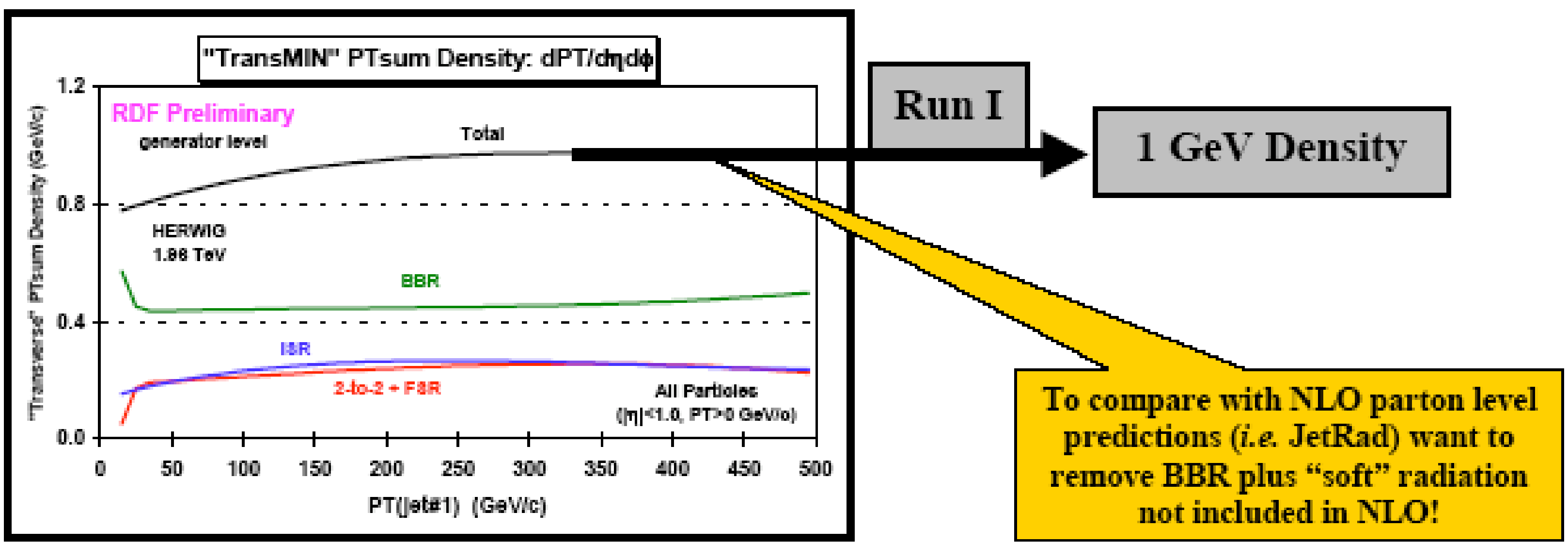




Monte Carlo definitions

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



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?

You’re all wondering, How can I enlist?

- Four listserver mailing groups have been set up:

  <u>tev4lhc-qcd</u>

  tev4lhc-higgs

  tev4lhc-topew

  tev4lhc-landscape

- If you would like to subscribe to the working groups, here are the instructions:
  - To subscribe to a mailing list called MYLIST

    1. Send an e-mail message to listserv@fnal.gov

    2. Leave the subject line blank

    3. Type "SUBSCRIBE MYLIST FIRSTNAME LASTNAME" (without the quotation marks) in the body of your message.