Food For Thought

on Systematic Uncertainties

(remarks from TeV experience)

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The Goal of this talk

- Give an idea of which are the main sources of systematic uncertainty in a typical Tevatron Jet measurement + method to derive them

- Of course this is intimately related to the corrections procedure employed and the experimental device..

- Here I will explain CDF case.. (you should look also D0)

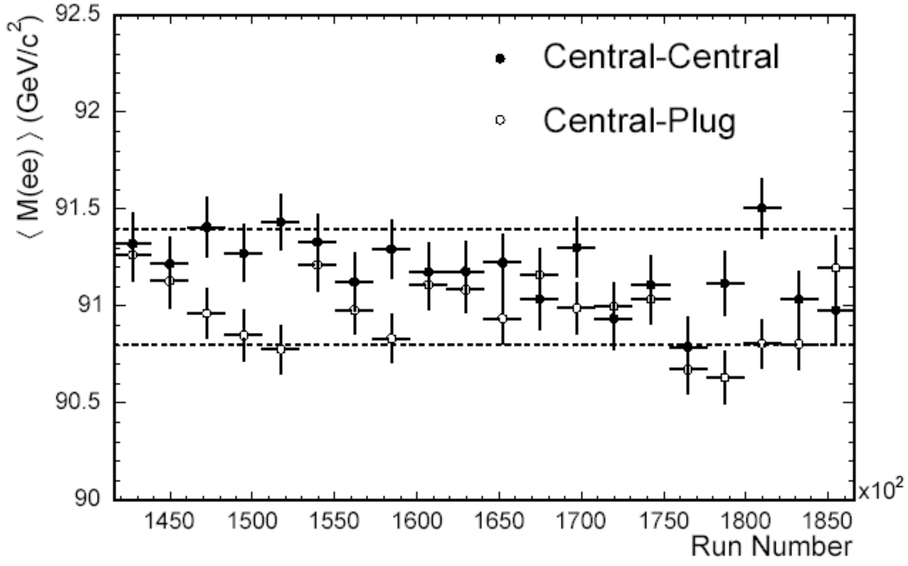
- Not covering top specifics.. (b-jets , W → qq in situ)

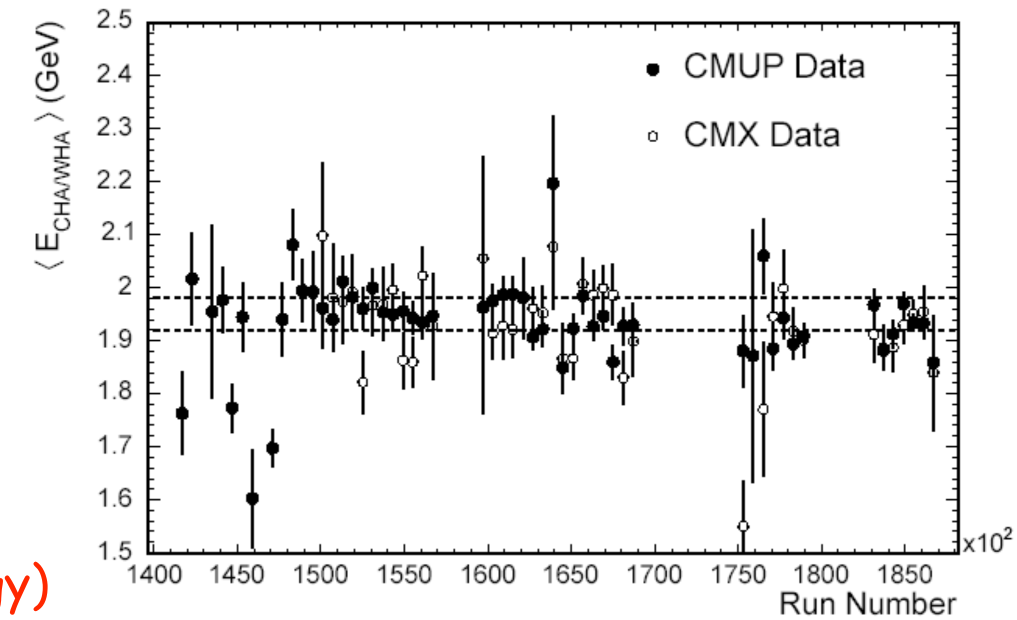
DISCLAIMER: Of course CDF is a "simple" case compared to the level of complication foreseen in ATLAS in terms of input constituents

In situ CAL Calibration vs Time

- Electromagnetic Calorimeter
  - Tower-to-tower relative calibration carried out using e/p for electrons (cluster vs track)
  - Absolute energy scale using Z→e+e- samples (Z-mass peak)
- Hadronic Calorimeter:
  - Using MIPs from W→μ ν and J/Ψ to test stability vs time
- Results
  - 0.3% uncertainty in EM
  - 1.5% uncertainty in HAD

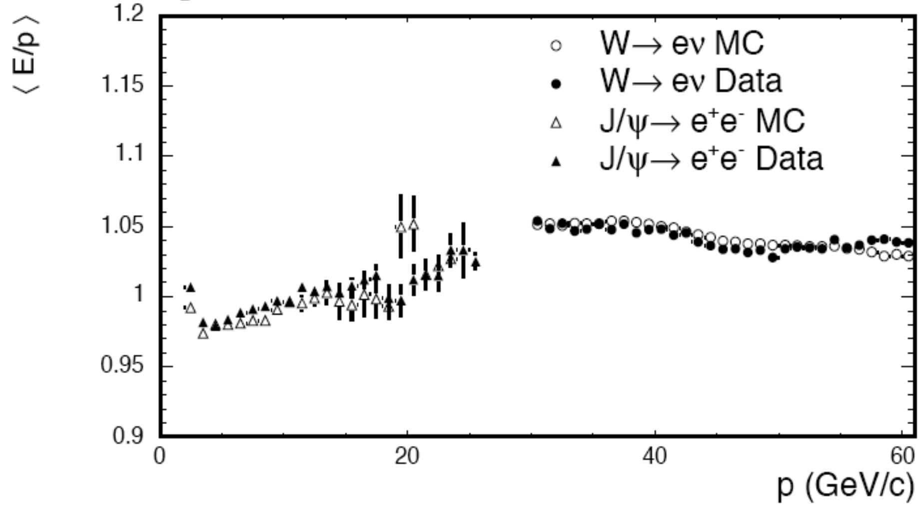
→ 0.5% uncert. on Jet Energy
(assumes 70% EM and 30% HAD energy)



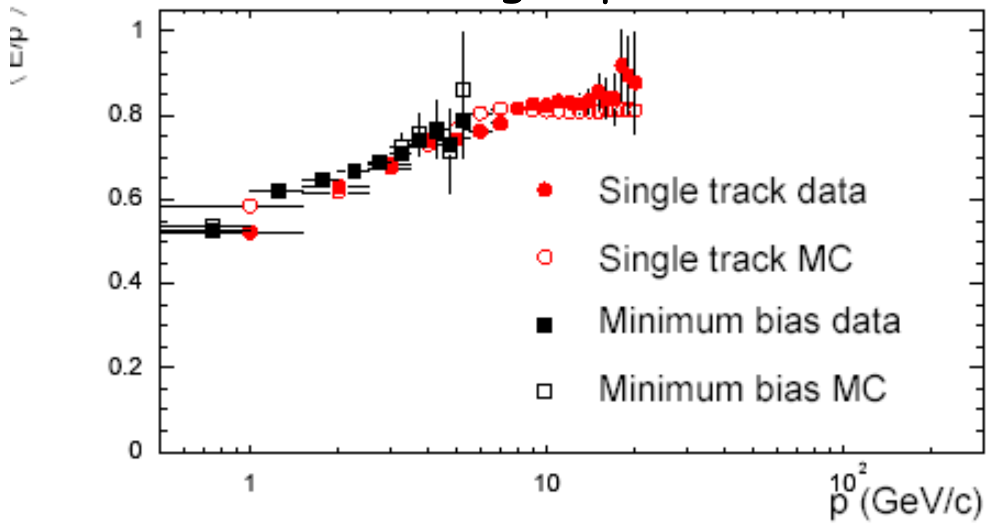


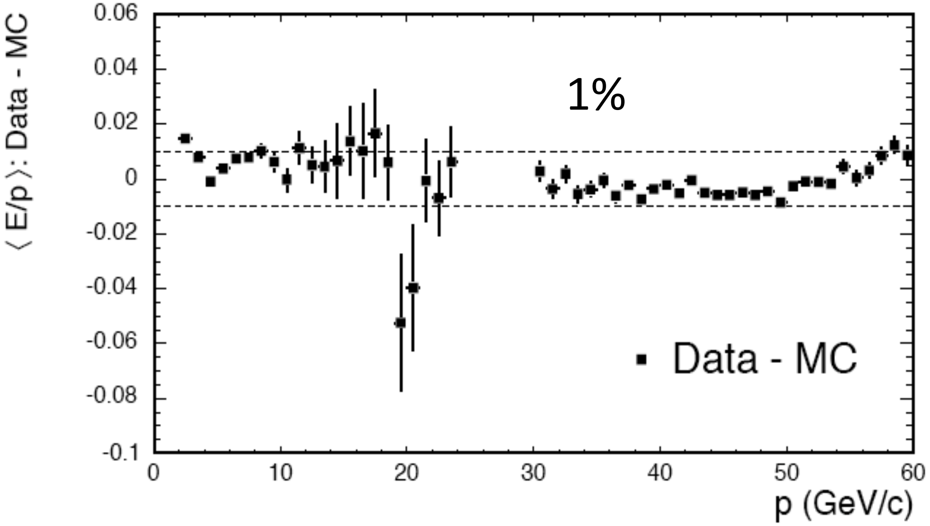
single particle response (e/p)

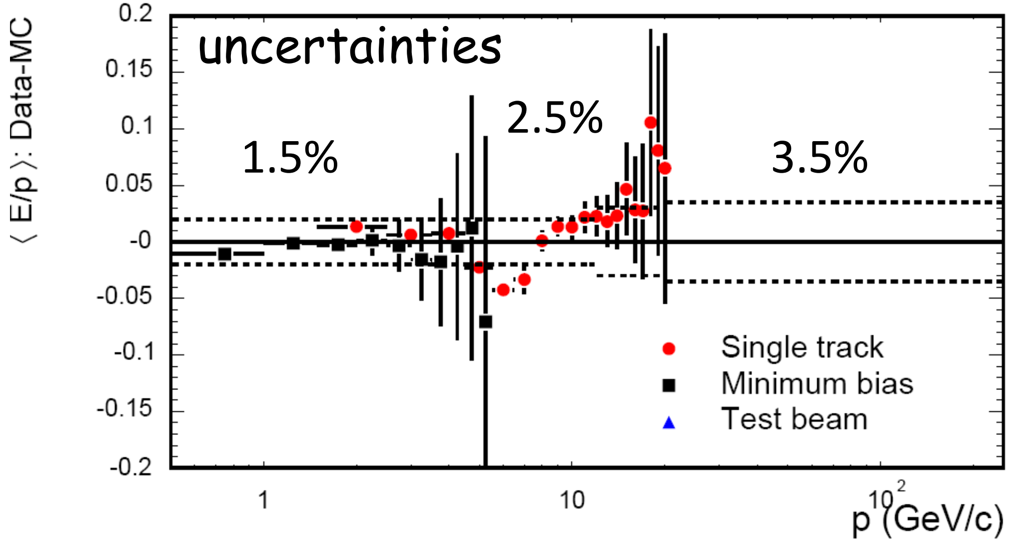
Electrons



Charged particles







1.9% (1.6%) additional uncertainty (data – MC difference) at the phi boundary between towers for HAD (EM) sections

All together (single particle response)

p (GeV/c)	0-12	12-20	>20
$\langle E/p \rangle$ response to hadrons			
Total tower (%)	1.5	2.5	3.5
Near tower ϕ and η-boundaries (%)	1.9	1.9	1.9
Total for hadrons(%)	2.5	3.0	4.0
$\langle E/p \rangle$ response to EM particles			
Total tower (%)	1.0	1.0	1.0
Near tower ϕ-boundary (%)	1.6	1.6	1.6
Total for EM particles(%)	1.7	1.7	1.7

Jet composition:

70 % charged particles

- 10% protons
- 90% pions

30 % neutral pions (→ $\gamma\gamma$)

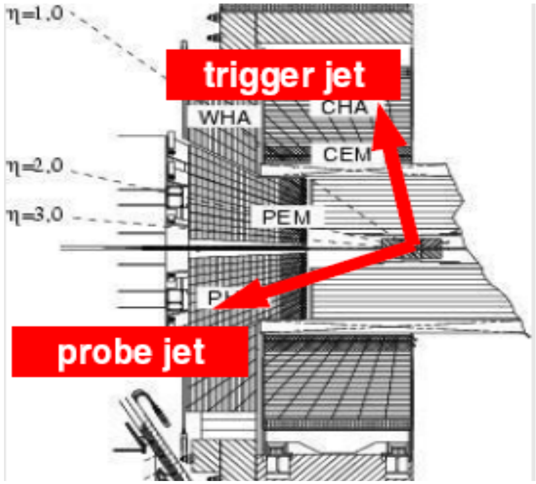
Generic Jet Energy Corrections
(for a cone-based jet algorithm)

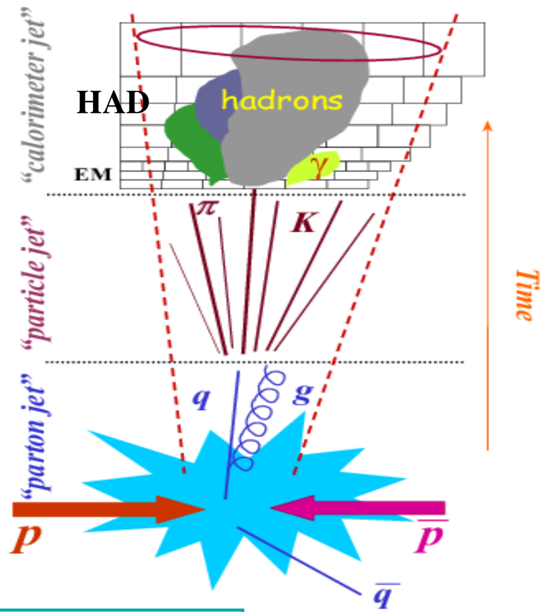
1. Relative Corrections
   - Jet response referred to central region
   - Imposing dijet balance in dijet events
   - Bias on dijet definition (veto on third jets)

2. Pileup
   - Due to multiple pp collisions at high Inst. Lumi
   - Remove a given amount of transverse energy for each additional primary vertex
   - Obtained using MB and random cones in $\eta-\phi$

3. Average correction to hadron level
   - Bring the jet energy back to the hadron level (correct for calorimeter response)
   - Extracted using Monte Carlo samples

4. Corrections "back to the parton level"
   - Physics and MC model dependent
   - Totally rely on Monte Carlo



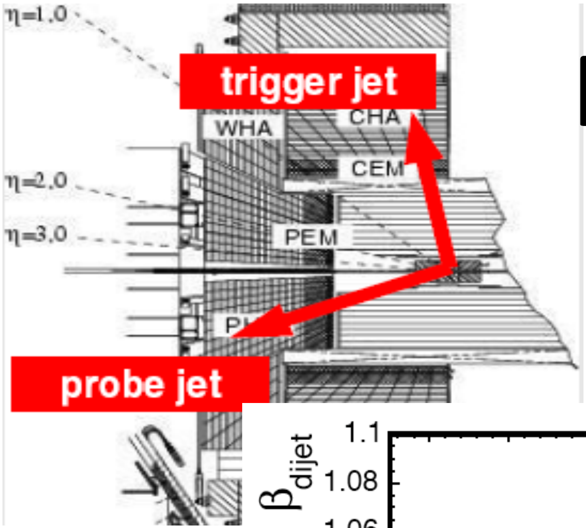


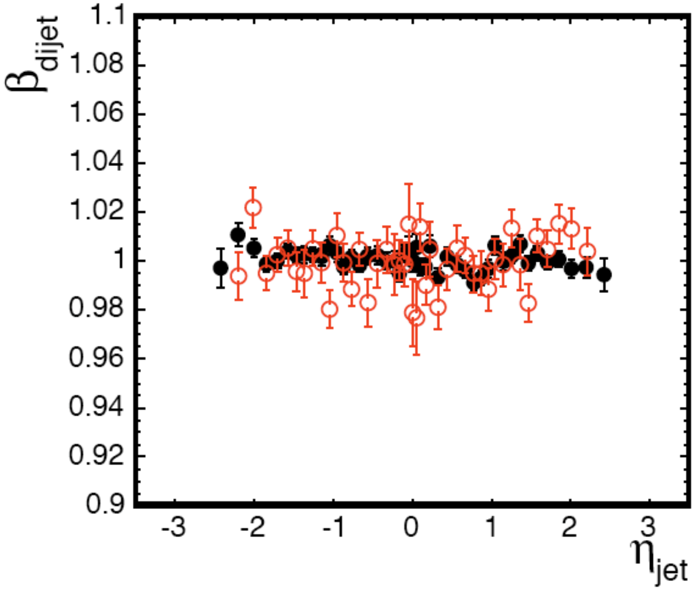
$$P_{T\,jet}(R) = [\, P_{T\,jet}^{raw}(R) \times f_{rel}(R) - MPI(R)] \times f_{abs}(R) - UE(R) + OC(R)$$

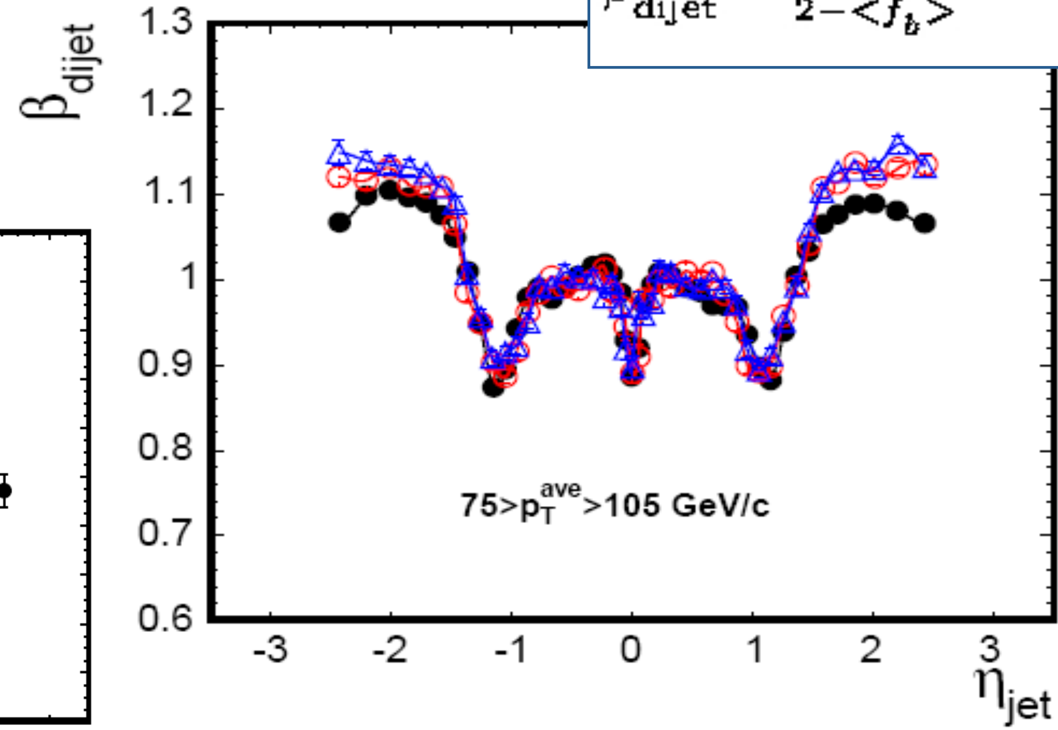
Relative Correction

$$f_b = \frac{P_T^{probe} - P_T^{trig}}{(P_T^{probe} + P_T^{trig})/2}$$

$$\beta_{dijet} = \frac{2 + \langle f_b \rangle}{2 - \langle f_b \rangle}$$





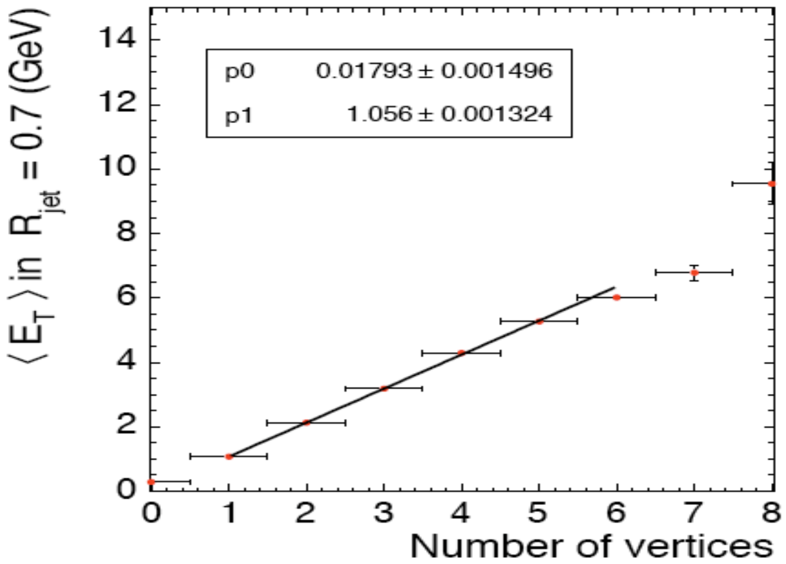


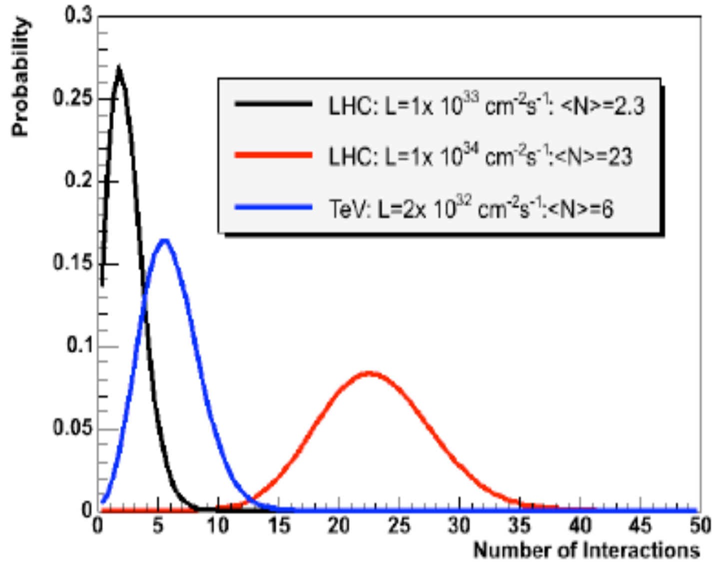
Relative correction: all gets referred to jets in the rapidity region 0.2 – 0.6

→ Remaining differences from 1 and variations with selection cuts in the systematics

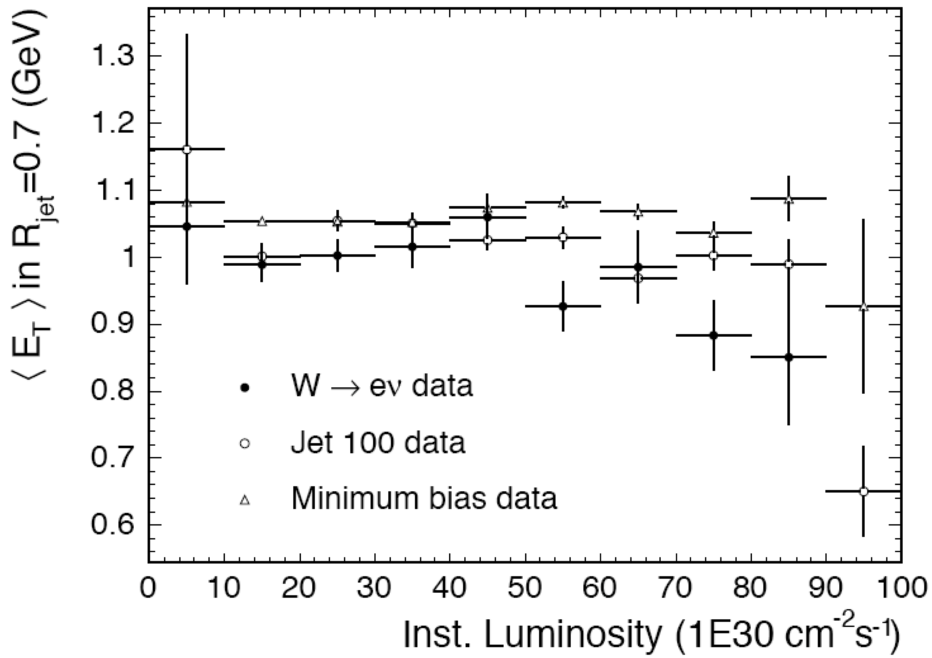
$\lvert\eta\rvert$ range	0.0 – 0.2	0.2 – 0.6	0.6 – 0.9	0.9 – 1.4	1.4 – 2.0	2.0 – 2.6	2.6 – 3.6
$p_T < 12$ GeV/c	1.5 %	0.5 %	1.5 %	2.5 %	1.5 %	5.0 %	7.5 %
$12 \le p_T < 25$ GeV/c	1.5 %	0.5 %	1.5 %	1.5 %	1.5 %	3.0 %	6 %
$25 \le p_T < 55$ GeV/c	1.0 %	0.5 %	1.0 %	1.0 %	0.5 %	1.5 %	6 %
$p_T \ge 55$ GeV/c	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %	1.5 %	6 %

Pile-up correction





For cone R = 0.7, $<E_T>$ = 1.06 GeV



Based on the correlation between Inst. Lumi and average # of primary vertices in the tracker

→Remove an amount of E_T for each additional vertex in the event as determined with random cones places in the CAL in the region (0.2 – 0.6)

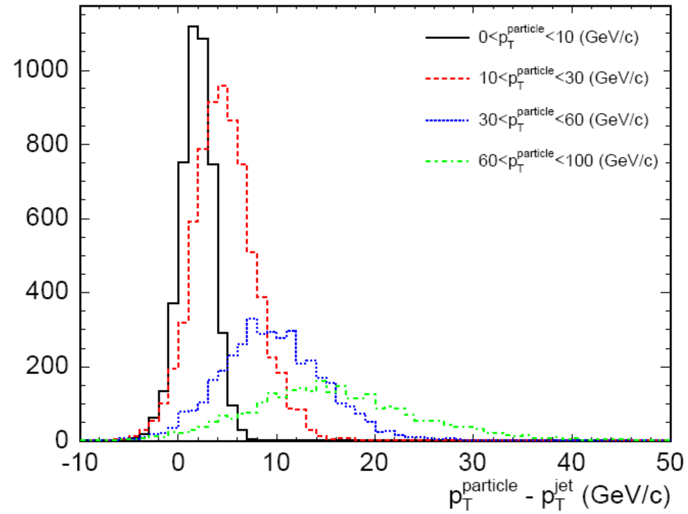
→15% - 30% uncertainty mostly related to the efficiency in finding the vertices vs Inst. Lumi

→Estimated using different Phys samples and covering extrapolation to large #vertices

Absolute (average) Correction

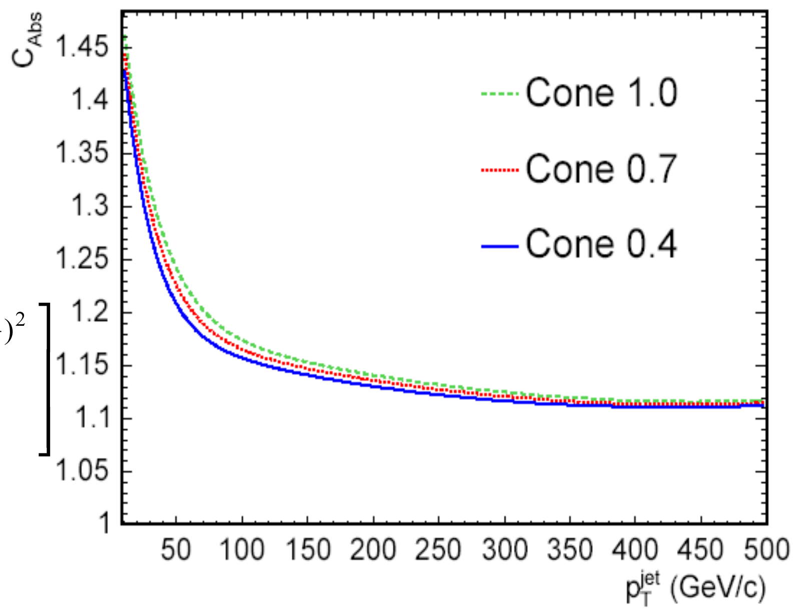
- Taken from Monte Carlo (PYTHIA Dijets) with a UE tune that describes jet fragmentation

- Probability function (given a true Pt what is the most probable value observed in the calorimeter)



$$dP(P_T^{particle}, P_T^{jet}) = f(\Delta P_T)\, dP_T^{particle}\, dP_T^{jet}$$

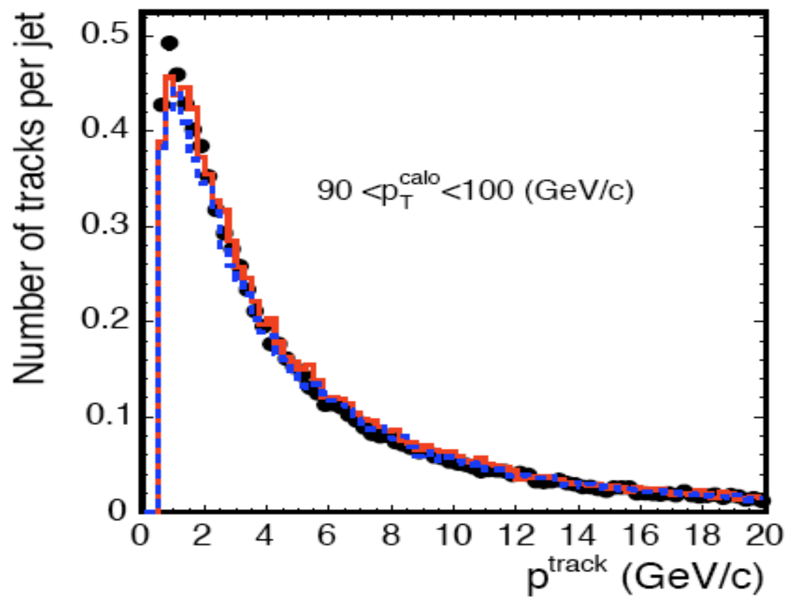
$$f(\Delta P_T) = \frac{1}{\sqrt{2\pi(\sigma_1 + N_2\sigma_2)}}\left[e^{-\frac{1}{2}\left(\frac{(\Delta P_T - \mu_1)}{\sigma_1}\right)^2} + N_2 e^{-\frac{1}{2}\left(\frac{(\Delta P_T - \mu 2)}{\sigma_2}\right)^2} \right]$$



Uncertainty on Absolute correction

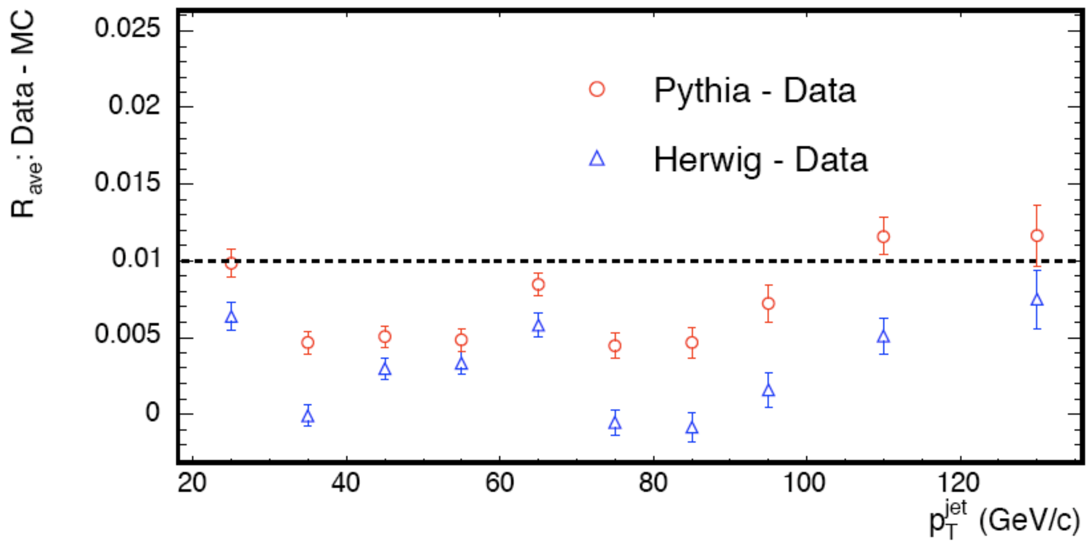
- Convolution of uncertainty on single particle response and fragmentation modeling in the Monte Carlo

- Fragmentation part tested using tracks inside jets (corrected for data/MC diff in tracking efficiency and UE contrib.)

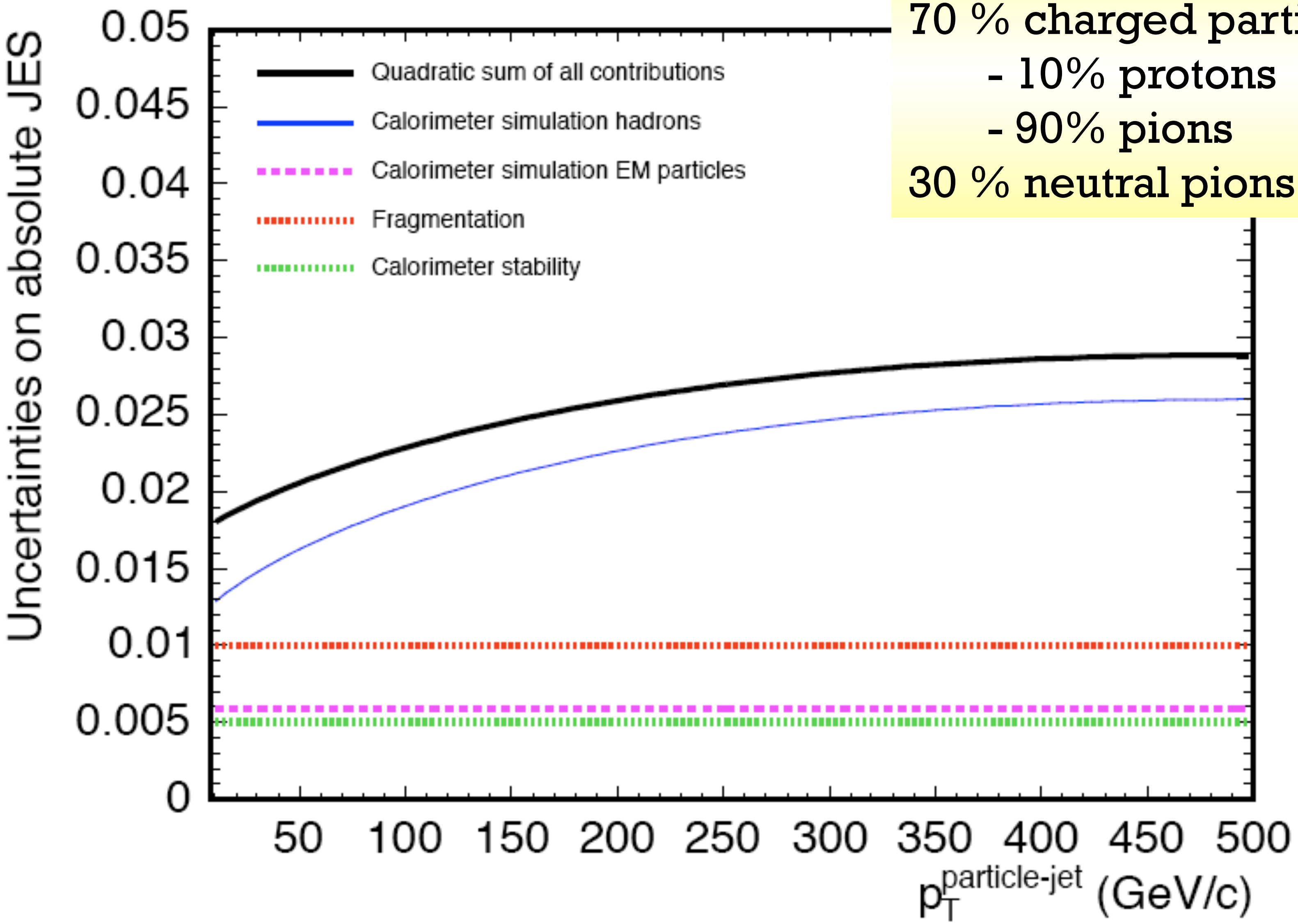


→ Differences in the average response (data vs MC) taken as systematic uncertainty (1%)

$$R_{ave} = \frac{\sum_{i=1}^{N} p_i R(p_i)}{\sum_{i=1}^{N} p_i}$$



All together (Absolute Correction)



Jet composition:

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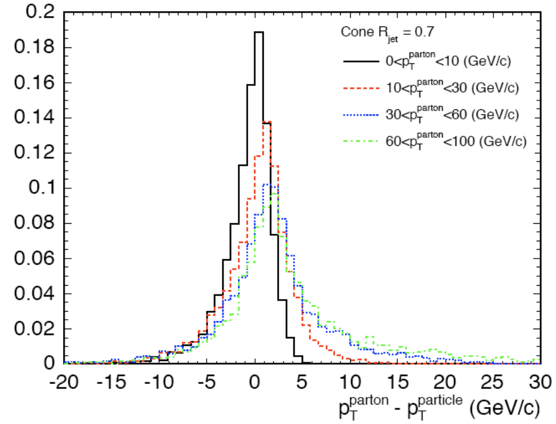
- 90% pions

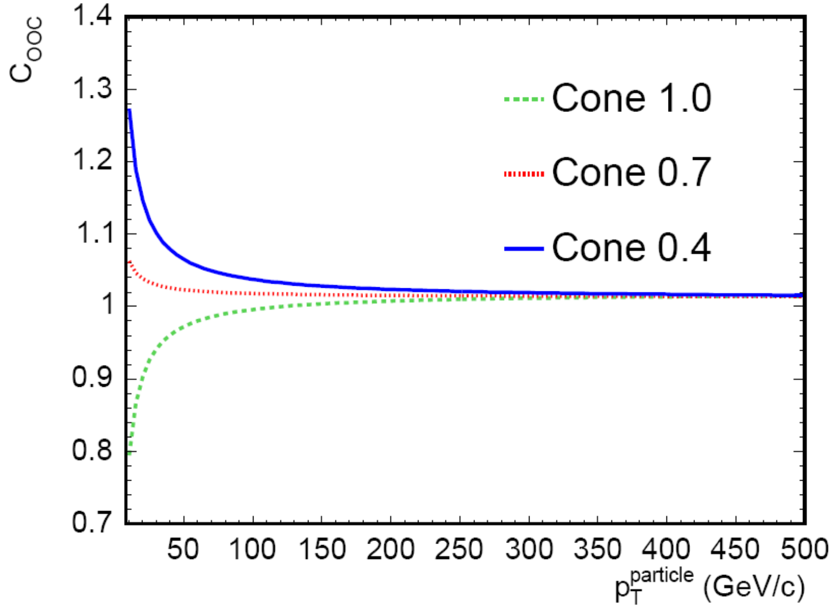
30 % neutral pions (→ γγ)

Correction to parton level

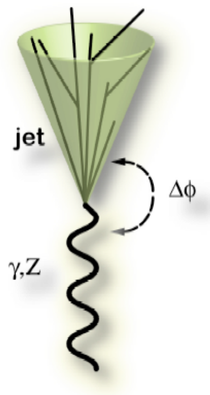


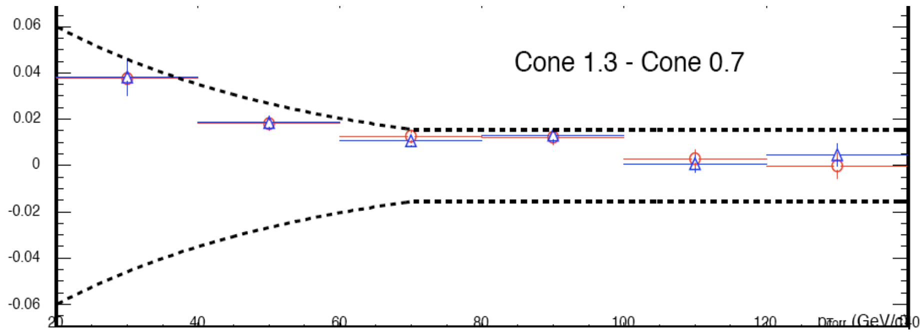
- Not totally well defined and model dependent (suppose to remove UE and OOC contributions)

- Initially taken from Monte Carlo Dijets (as the difference between parton and jet Pts) for parton-jet matched pairs (in eta-phi)



- Uncertainty extracted from γ+jet events in data and MC as the difference between transverse energies observed in an outer annulus around the jet cone and predicted by PYTHIA/HERWIG





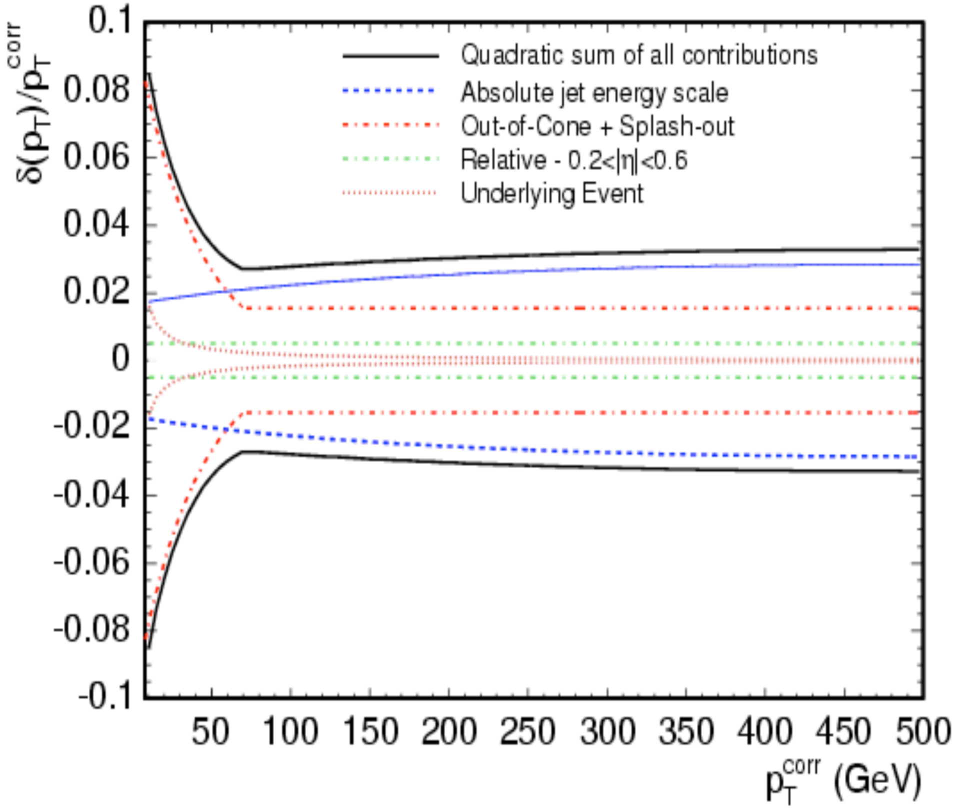
Random (incomplete) notes (only on systematics)

- **What can we learn from the CDF experience ?**
  - No much about clustering in towers… CDF very simple
  - Importance of e/p understanding in MC--- dominant source
  - Importance of early measurements on jet fragmentation/jet shapes

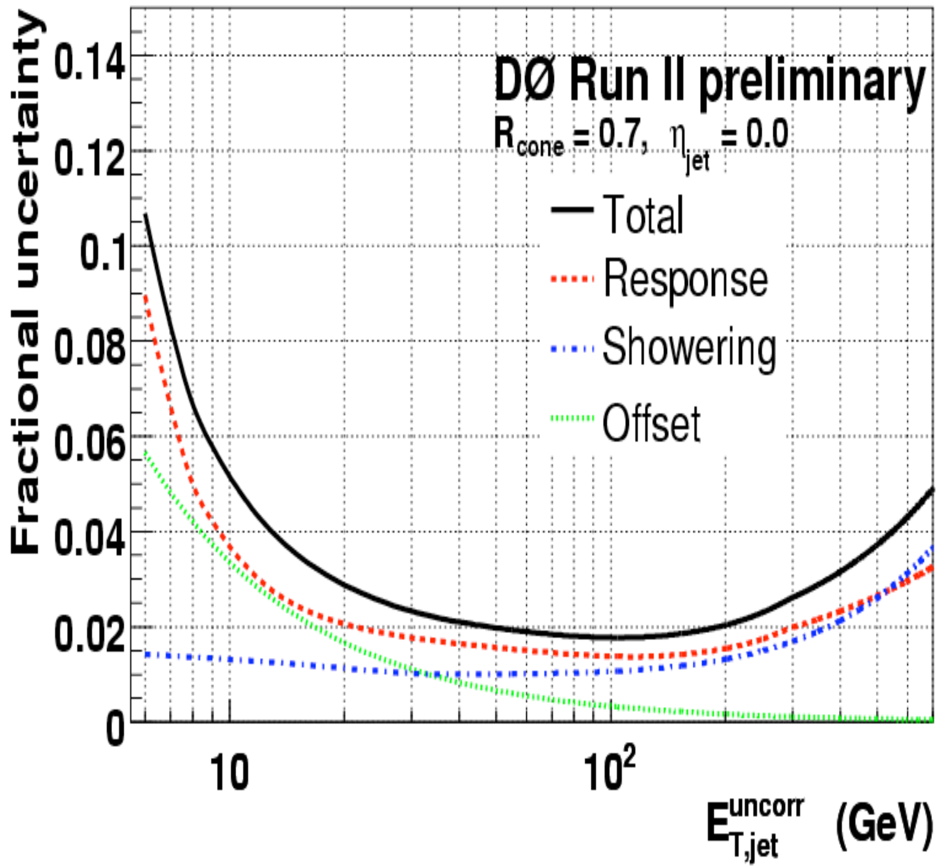
  (hopefully PYTHIA / HERWIG will not miss our ATLAS jet internal structure totally)
  - Pileup subtraction based on cones in the calorimeter works but sensitive to vertex finding efficiency at large Inst. Lumi

  → understanding of track efficiency and vertex finding early in the game..
- **Explore data-driven corrections a la D0 (MPF method) !!! … Of course..**

CDF/D0



0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
$\delta(p_T)/p_T^{corr}$
Quadratic sum of all contributions
Absolute jet energy scale
Out-of-Cone + Splash-out
Relative - 0.2<|η|<0.6
Underlying Event
50 100 150 200 250 300 350 400 450 500
p_T^{corr} (GeV)



Fractional uncertainty
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
DØ Run II preliminary
R_{cone} = 0.7, η_{jet} = 0.0
Total
Response
Showering
Offset
10
10^2
$E_{T,jet}^{uncorr}$ (GeV)