Introduction to Tuning of Simulation and Detector Response Session

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Measuring single particle response

- Claim:
  - *If I can understand single particle response in calorimeter and particle composition of jet I can understand jet response at any energy*
- Requires
  - Response to single particles measured by
    - Test beam (see talks earlier today)
    - In situ measurements of e/γ and charged isolated hadrons
  - Tuning / improving simulation to reflect this
    - Affected by showering model
    - Affected by material understanding
  - Jet fragmentation measurement
    - i.e. the particle momentum spectrum and charged to neutral ratio
    - Typically quite well known thanks to LEP and careful tunings of MC
  - CDF jet calibration was fully based on this
    - First studies during Run 1 (e.g. M. Shapiro *et al.* 1989)
    - Will present here final studies used in Run 2

Method and Challenges

- Select sample of isolated tracks in data
  - Develop selection such that signal is (fully) contained and there is little background
  - Signal will be contaminated by closeby charged and neutral particles (aka “background”)
    - Require isolation against those
    - Subtract remaining background
  - Going to high momentum
    - Difficult due to electron/muon contamination (from W’s and Z’s…)
    - Difficult as background subtraction becomes more challenging
- Use selected sample to
  - Study response and compare to and/or tune simulation
  - Particularly critical in “crack” regions or when there is a lot of material
    - Not probed so well by test beam

Preparing for data/MC disagreements

- What if data and MC disagree in *some* region?
- Do we have the ability to find out what is wrong?
  - Showering models and/or material description
  - How flexible are we to correct/tune MC?
  - Can we determine the material well enough?
    - Which are the best observables?
      - Using single particles: electrons, photons and hadrons
      - Jets are quite sensitive but often it is difficult to narrow down to exact problem in simulation with them
    - Test with CSC MC
  - How to use first data best to make these measurements
    - Specialized trigger and/or dedicated runs

Agenda

- BH:
  - CDF experience
- Daniel Froidevaux:
  - Understanding of electromagnetic scale and material in Inner Detector
- Naoko Kanaya:
  - Sensitivity of single particles to
    - showering model
    - material outside Inner Detector
- Nadia Davidson:
  - track selection
  - triggers and rates
  - background subtraction
- All:
  - discussion

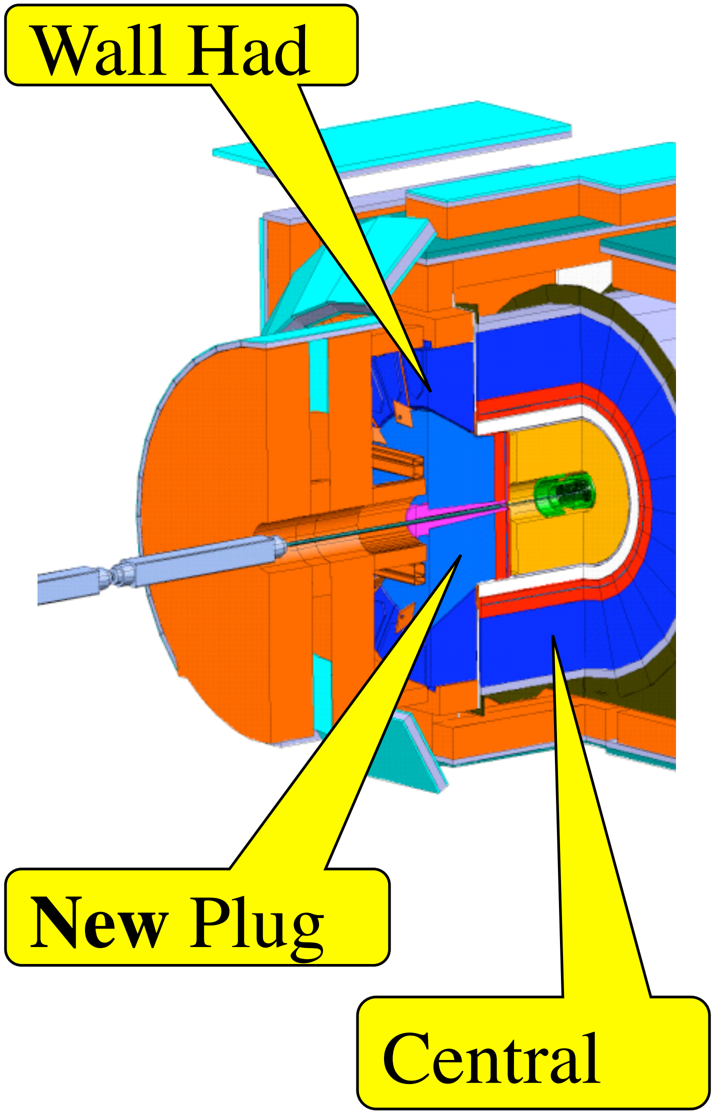
CDF Experience

CDF Experience

- **Very brief overview of generalities**
  - I think most people have seen talks on this
  - See NIM paper on jets:
    - A. Bhatti, F. Canelli, B. Heinemann *et al.*, Nucl. Instrum. Meth. **A566**:375-412,2006, hep-ex/0510047
- **Will discuss in detail the E/p calibration**
  - Got some internal plots approved for this meeting
    - together with Monica d'Onofrio/IFAE Barcelona (thanks!!)
    - Not easy to find all the information in internal notes and talks…
- **Note that this is very detector specific, e.g.**
  - CDF calorimeter much more coarse that ATLAS
  - Electronic noise negligible in CDF
  - Pileup from previous BC's negligible (readout window is 396 ns)
  - Test beam was only available for p>8 GeV

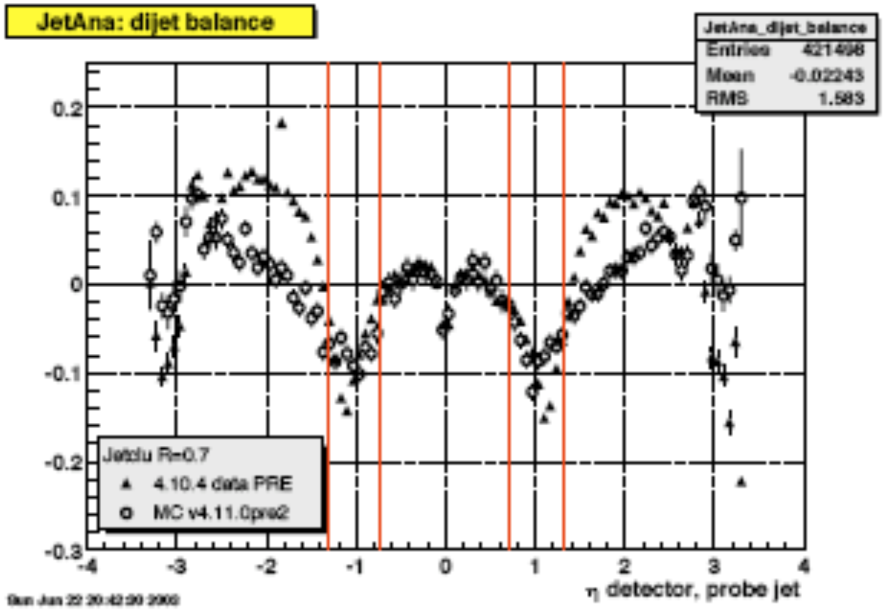
Reminder of CDF calorimeter

- Central and Wall($|\eta|<1.2$):
  - Scintillating tile with lead (iron) as absorber material in EM (HAD) section
  - Coarse granularity:
    - Φ: 24 towers cover 15 degrees in azimuth each
    - η: 10 towers cover 0.1 unit in rapidity each
  - Non-compensating
  - Rather thin: 4.5 interaction lengths
- Plug ($1.2<|\eta|<3.6$):
  - Similar technology to central
  - Differences
    - 48 towers in azimuth
    - More linear response
    - Thicker: 7 interaction lengths
- Compared to ATLAS major differences in strategy arise due to:
  - The coarseness of CDF
  - The lower noise in CDF

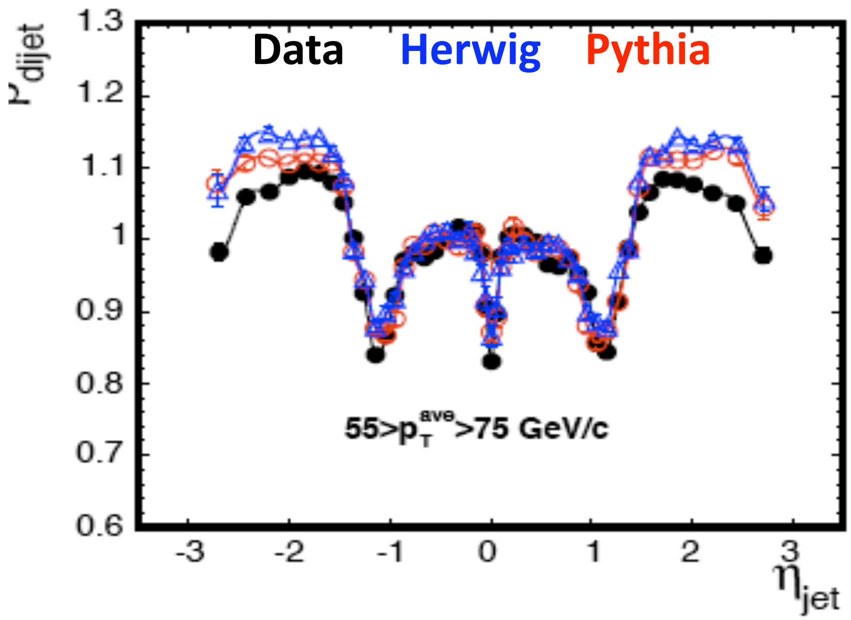


CDF problems in early Run 2

Before E/p tuning

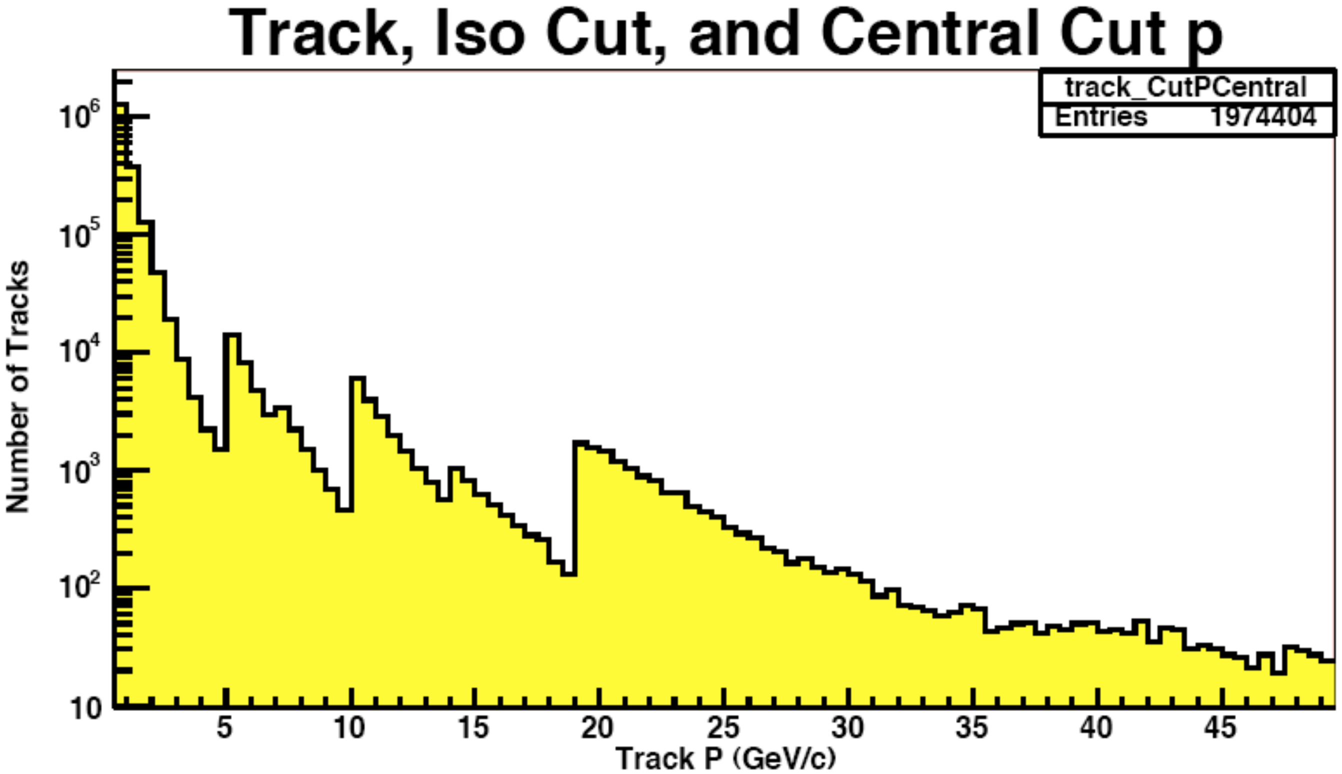


After E/p tuning



- **Major issues in crack region (|η|=1) and plug region early in Run 2**
  - Run 2 had new plug calorimeter (test beam: p>8 GeV)
  - Central response was well known from Run 1
  - Simulation was new: Run 1 was "QFL" and Run 2 was GFLASH
- **Jet task force was put in place to tune simulation**

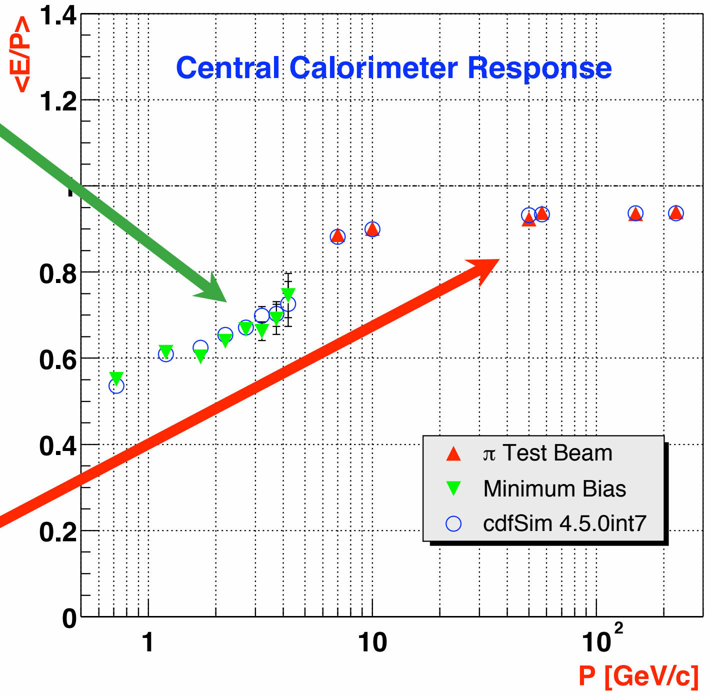
Data Taking and Triggers



- Dedicated triggers with different track momentum thresholds taken
  - Used special runs at the end of store (when luminosity low) mostly
  - Thresholds at 5, 10, 15 and 20 GeV with different prescales

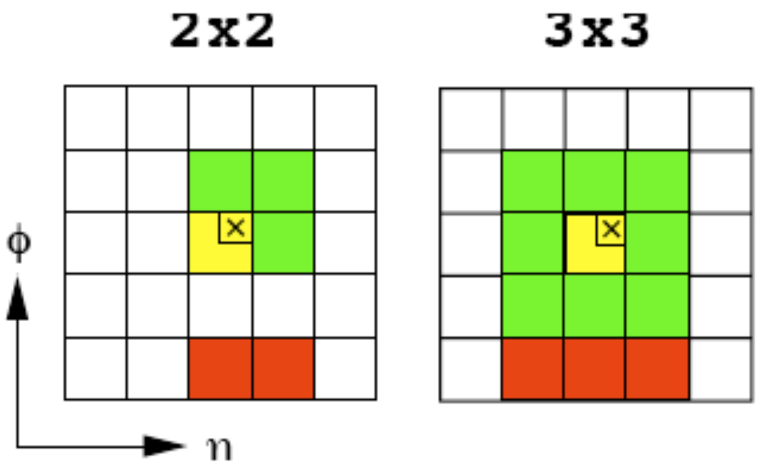
Single Particle Response

- Low Pt (1-10 GeV) in situ calibration:
  - Select “isolated” tracks and measure energy in tower behind them
  - Dedicated trigger
  - Perform average BG subtraction
  - Tune GFlash to describe E/p distributions at each p
    - use π/p/K average mixture in MC
- High Pt (>8 GeV) uses test beam:
  - Later tried using single charged particles up to 40 GeV but results have ultimately not been used
- Non-linear response
  - Drops by 30% between 10 and 1 GeV



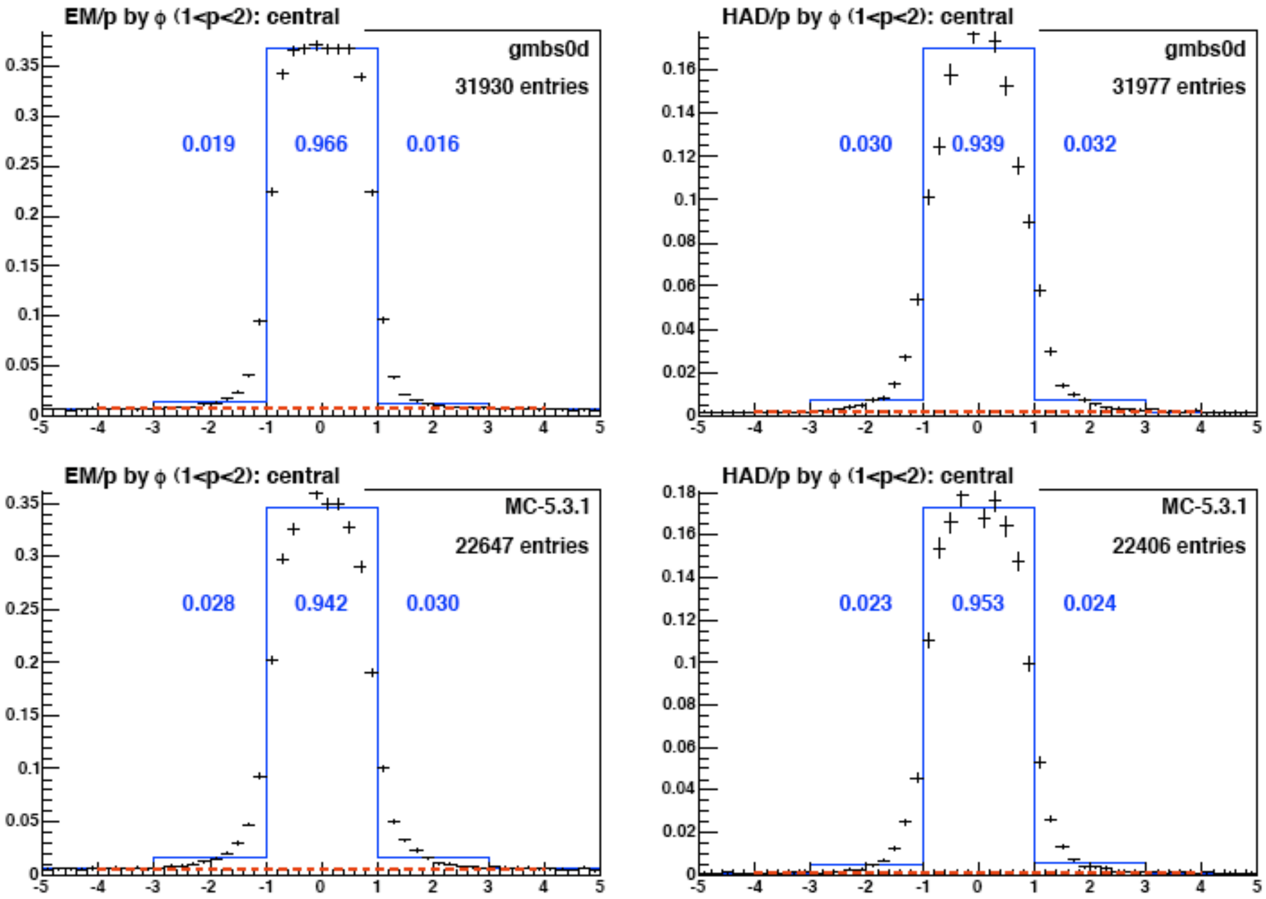
Signal Definition

- Selection:
  - Charged particles >0.4 GeV
    - Some good quality cuts
  - Isolation in surrounding 7x7 block of towers:
    - Against other tracks
    - Against pi0's (using wire/strip chambers)
- Studies of shower containment=> signal definition:
  - EM: 2x2 region
  - HAD: 3x3 region
  - crack: 1x3 region



- **target tower**
  - Track must be in inner 81%
- **Signal region**
  - Sum energy to contain full signal
- **background region**
  - Subtracted from signal event by event

Example Shower profiles: phi

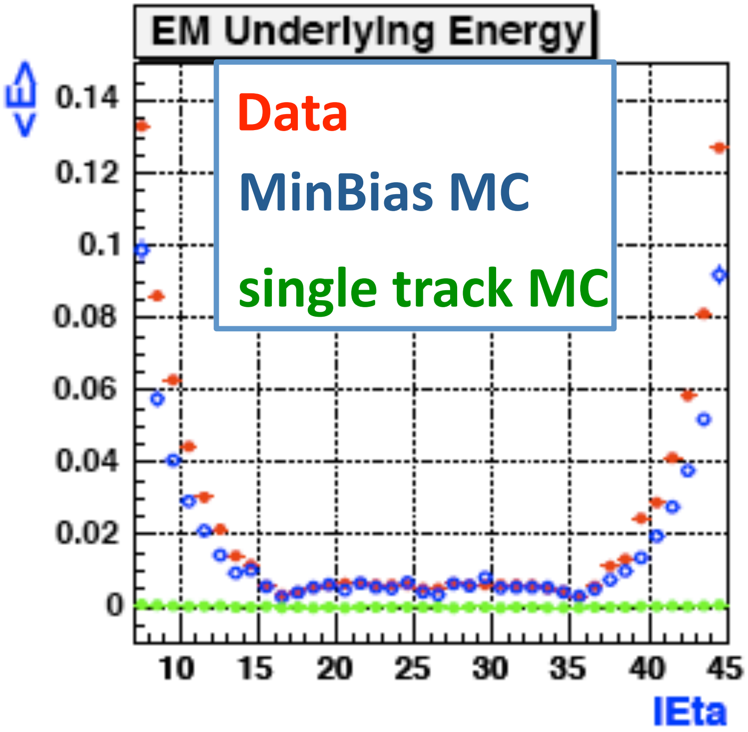


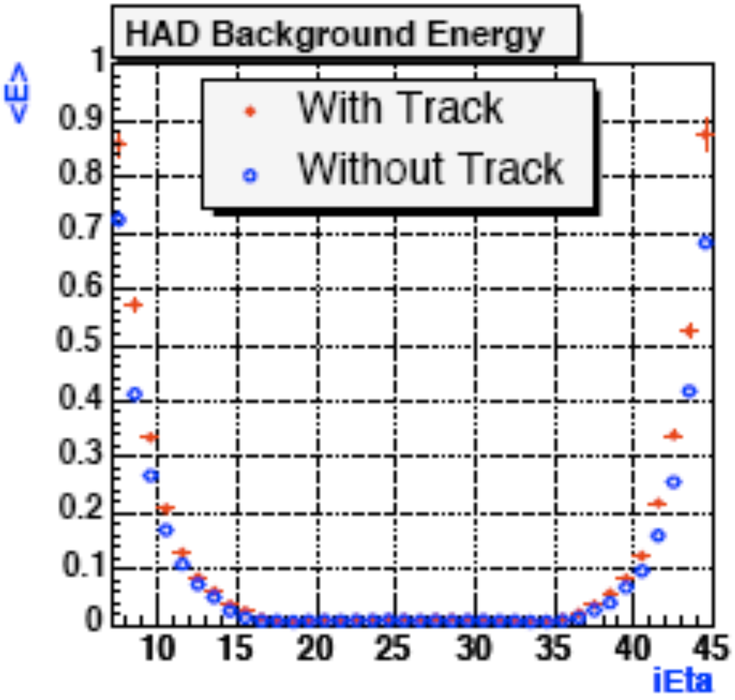
- Fractional energy versus relative phi for EM and HAD compartments for data and minbias MC
  - Important these are modeled well to avoid bias due to selecting subset of signal

Background Subtraction

- Ultimately in done by measuring energy in background towers and subtracting that from signal
  - Taking into account geometry
- Two sources of background were studied:
  - Uncorrelated
    - e.g. from underlying event or noise
  - Correlated
    - Due to other particles (e.g. from same jet) going nearby

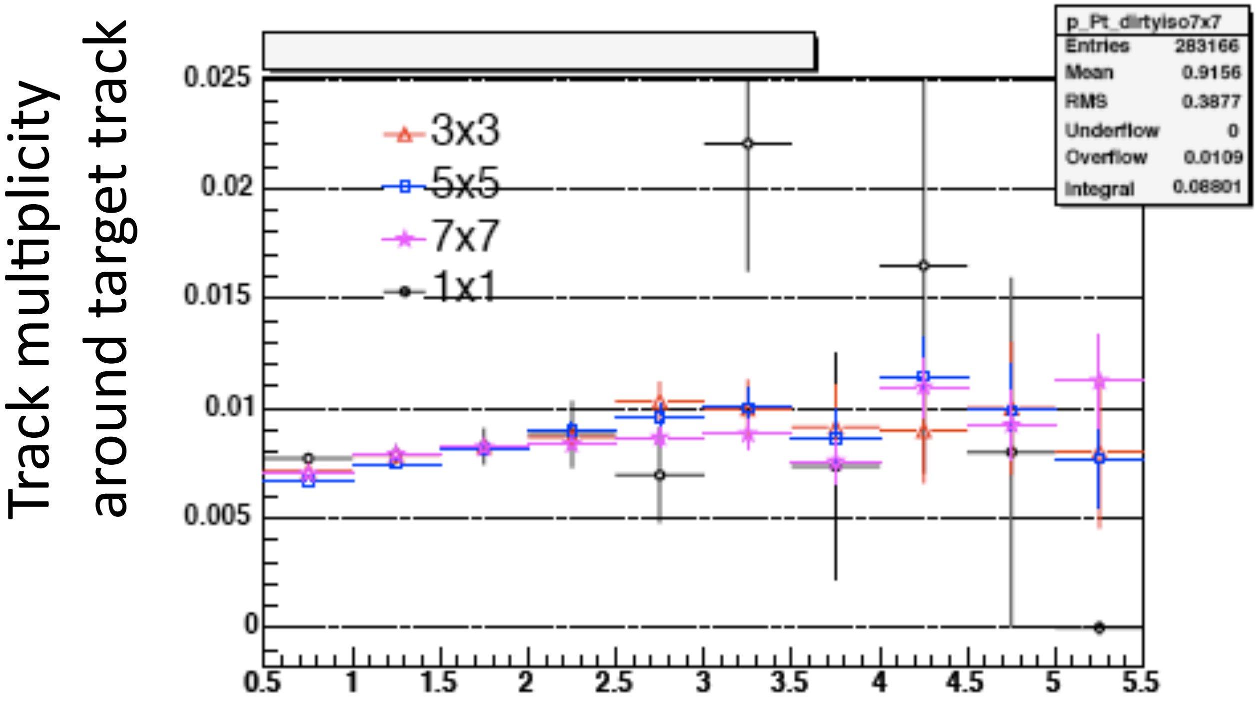
Uncorrelated Background





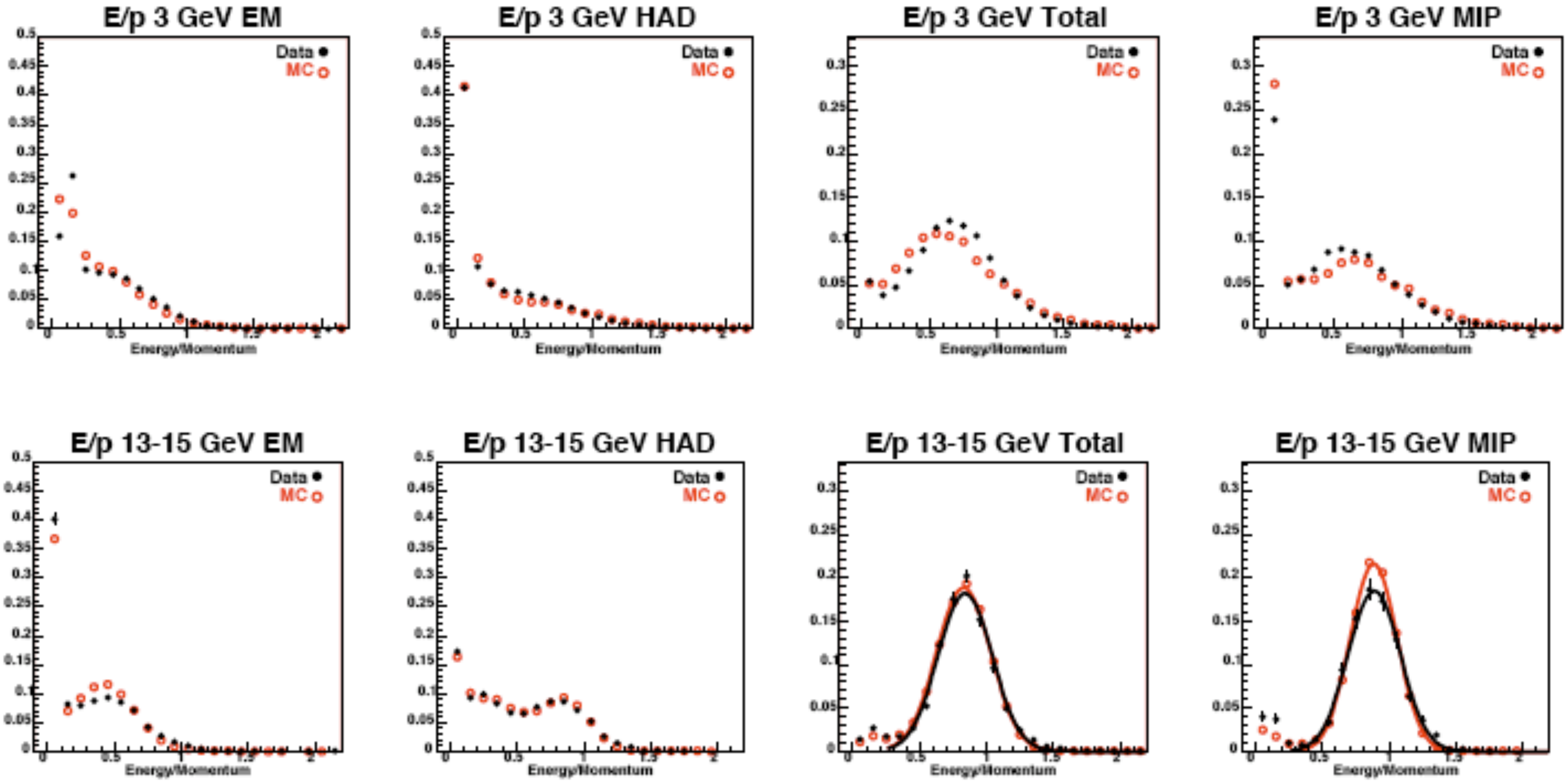
- Checked by looking at
  - 7x7 isolated areas with and without a track inside
- Generally fine up to about |eta|<2.0
  - CDF tracking becomes inefficient there => not used

Correlated background



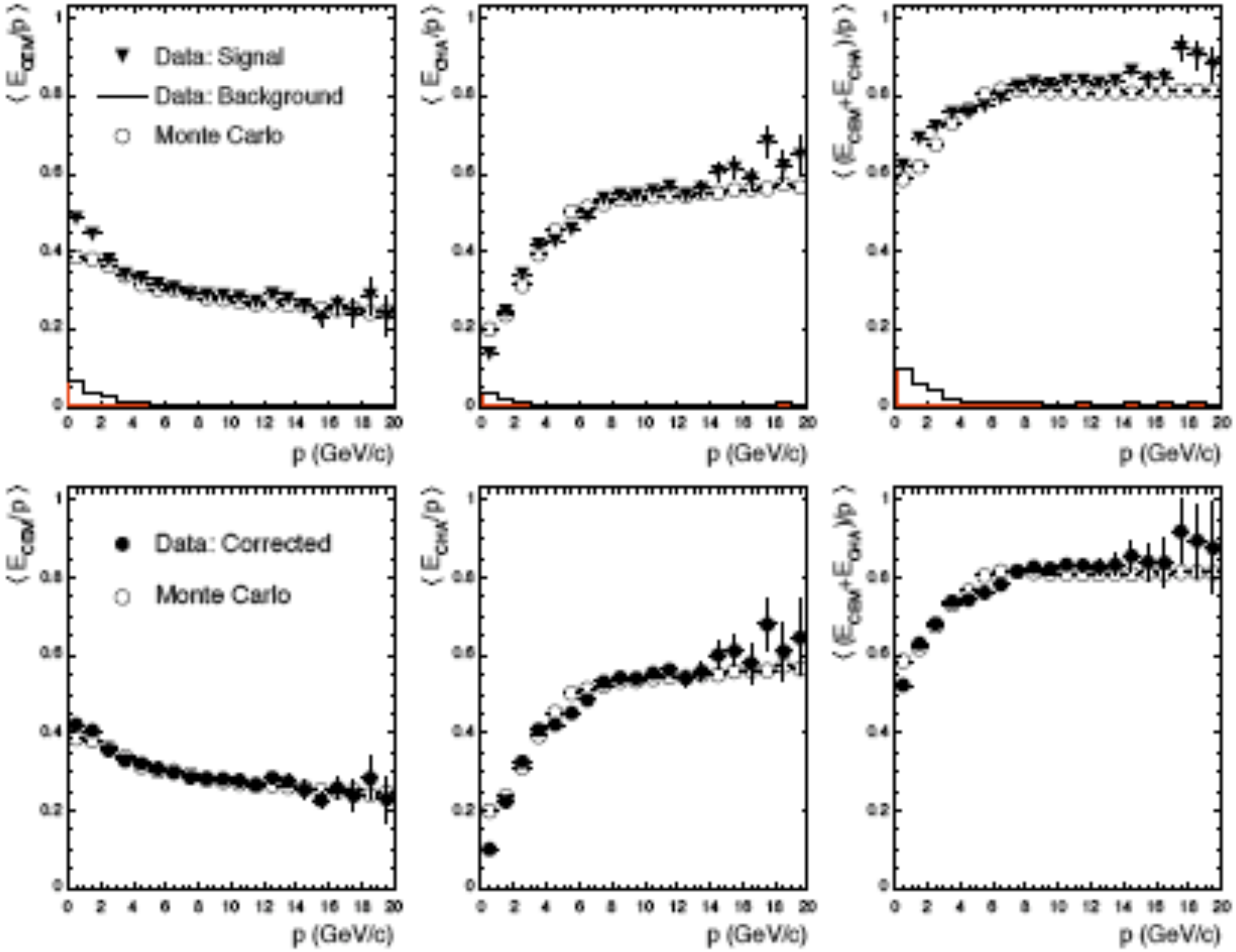
- Background independent of annulus around track up to p_T=5 GeV
  - 5x5 towers used for background subtraction
    - But isolation even requires 7x7 towers to have no tracks or pi0's
  - This will likely break down at higher p_T when environment becomes more and more jetty

Example distributions



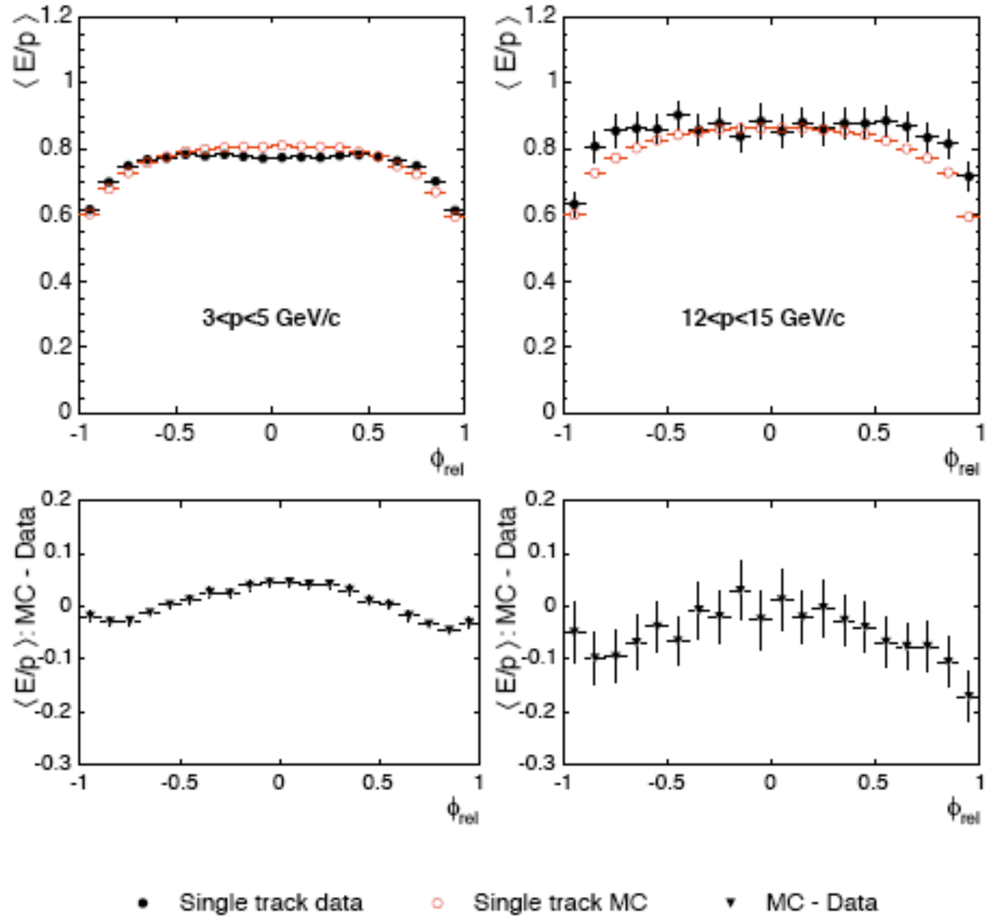
- Measurements of E for EM, HAD and total
  - Data rather well described by tuned GFLASH

Final results on E/p tuning



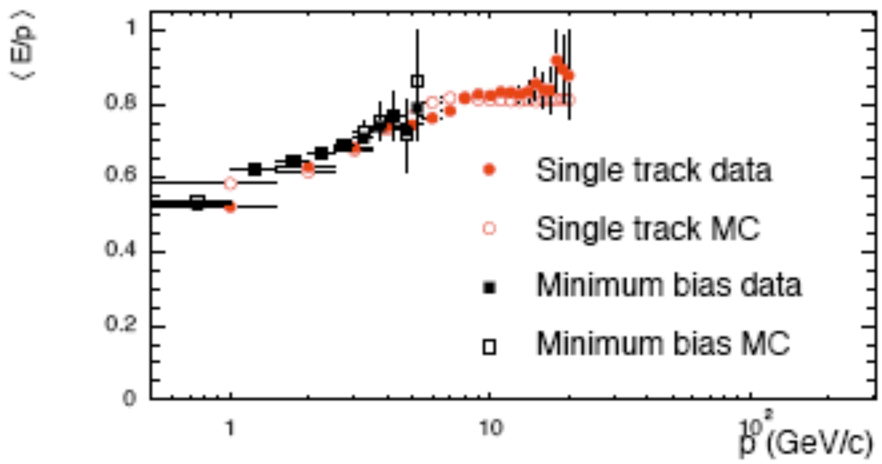
- Good agreement between data and MC
- Background rather small for p>5 GeV

Response variations inside tower



- Response measured using only tracks going to inner 81% of tower
- Response different between data and MC vs position
  - Resulted in additional systematic error

Final systematics

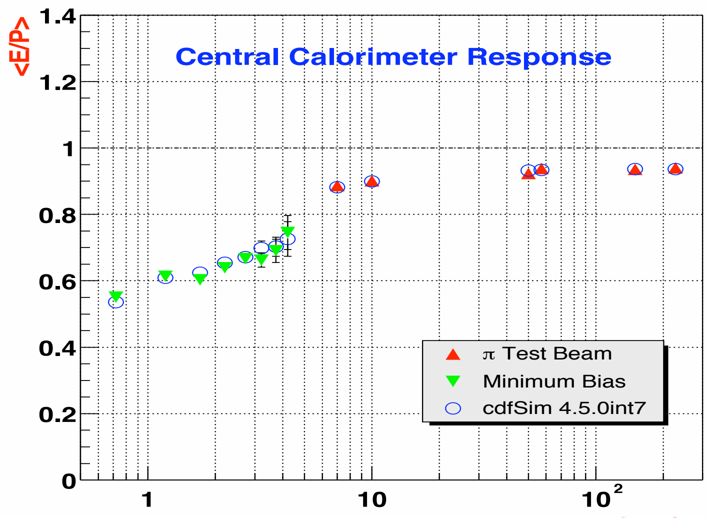


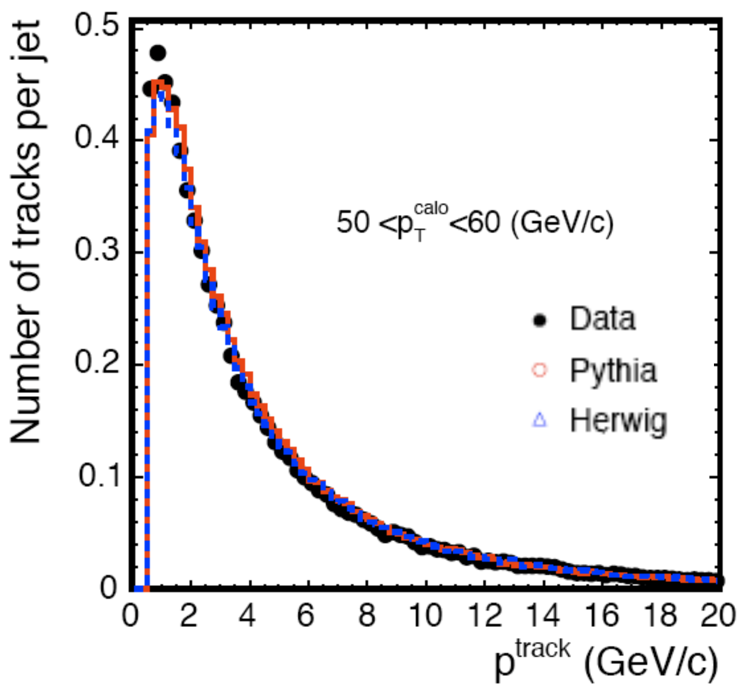
p (GeV/c)	0-12	12-20	>20
$\langle E/p \rangle$ response to hadrons			
Total tower (%)	1.5	2.5	3.5
Near tower ϕ and η-boundaries (%)	1.9	1.9	1.9
Total for hadrons(%)	2.5	3.0	4.0
$\langle E/p \rangle$ response to EM particles			
Total tower (%)	1.0	1.0	1.0
Near tower ϕ-boundary (%)	1.6	1.6	1.6
Total for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

- Uncertainty 2.5%-4.0% for charged hadrons
  - Single track triggers contributed significantly
    - Taken in special runs
  - Allowed measurement up to about 20 GeV
    - Work continued afterwards to improve and to further reduce uncertainty but did ultimately not get used due to CDF’s decision to continue with same simulation for continuity reasons

Fragmentation Measurement

- Due to non-linearity of CDF calorimeter big difference in response between e.g.
  - 1 10 GeV pion
  - 10 1 GeV pions
- Measure multiplicity and P_T spectra of particles in jets at different E_T values as function of track P_T:
  - Requires understanding track efficiency inside jets
  - Ideally done for each particle type (π, p, K)
  - Very good agreement between the probably since they were tuned data and fragmentation functions are universal (enough)



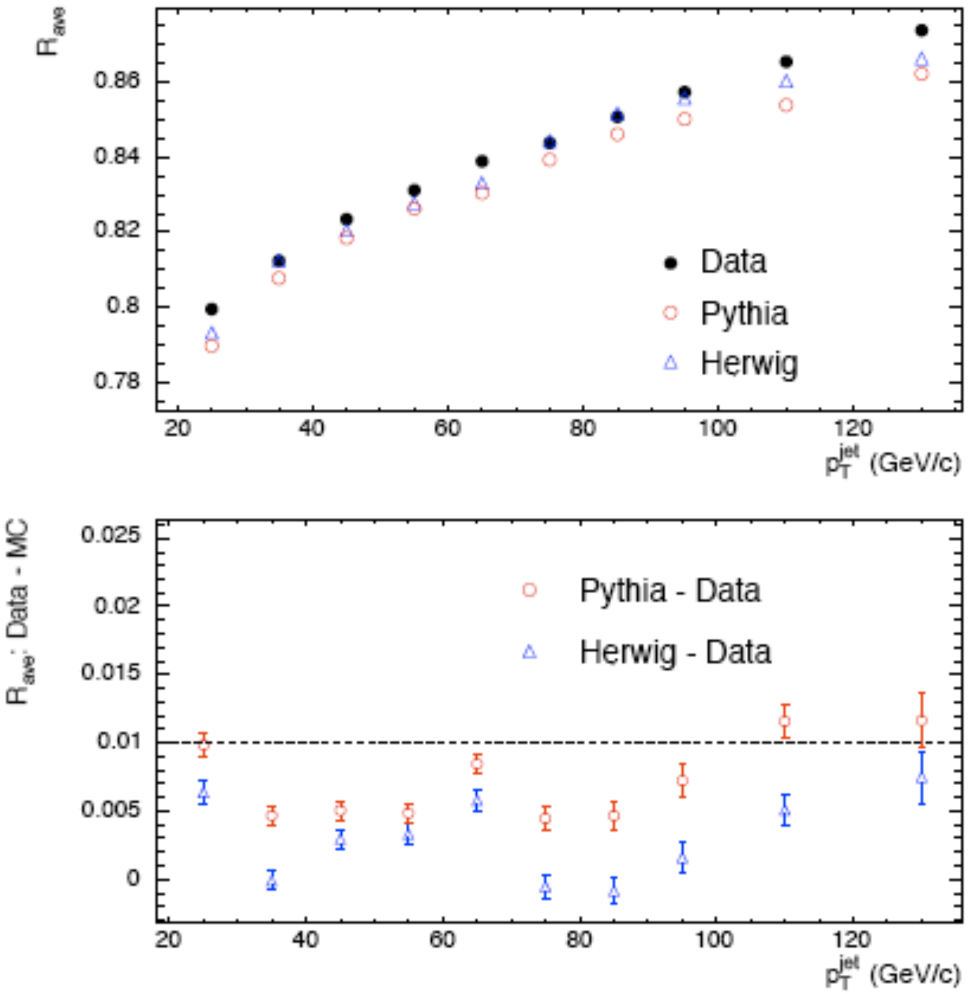


Fragmentation Measurement

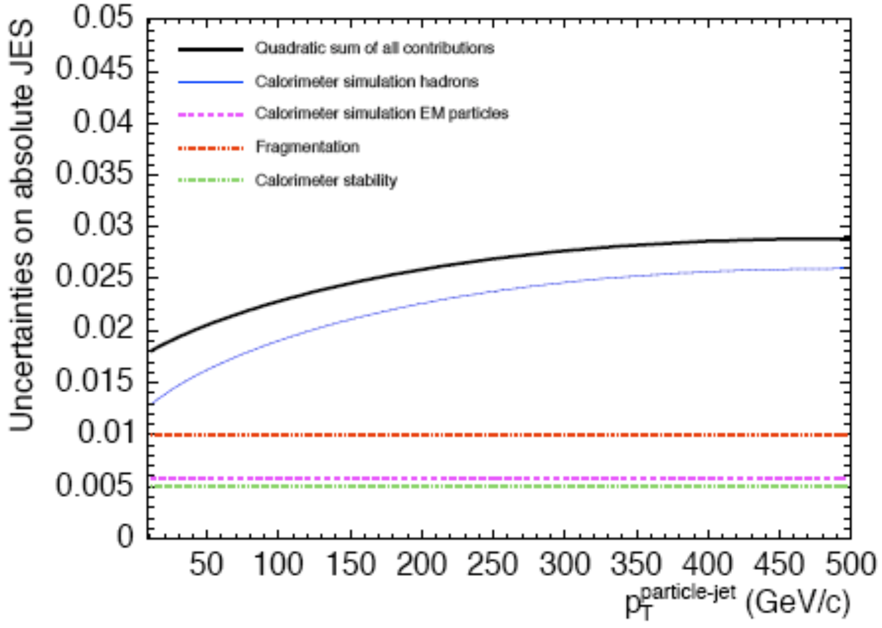
- Impact of fragmentation on response

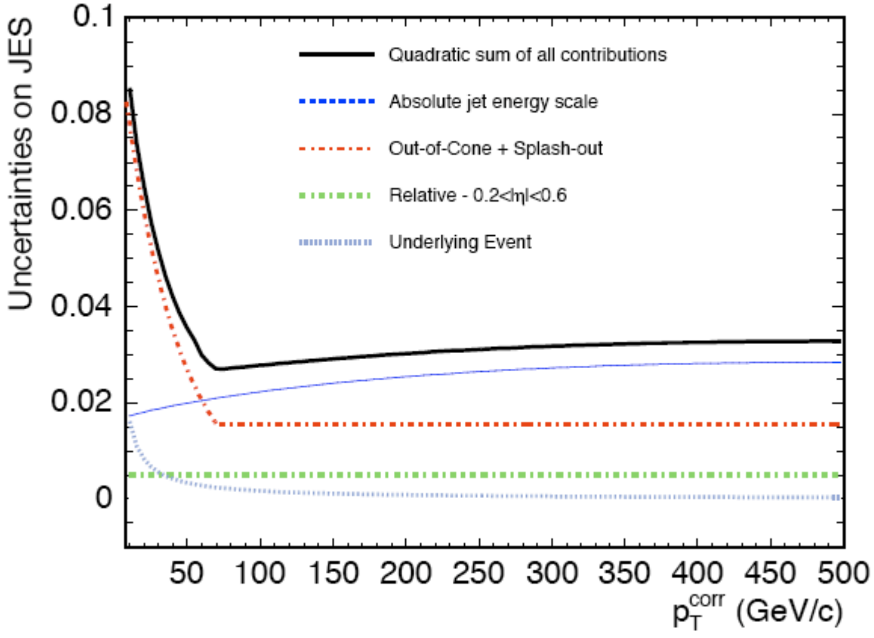
$$R_{ave} = \frac{\sum_{i=1}^{N} p_i R(p_i)}{\sum_{i=1}^{N} p_i}$$

- Turned out to be rather small in comparison:
  - Quote 1% error



Final Jet Uncertainties





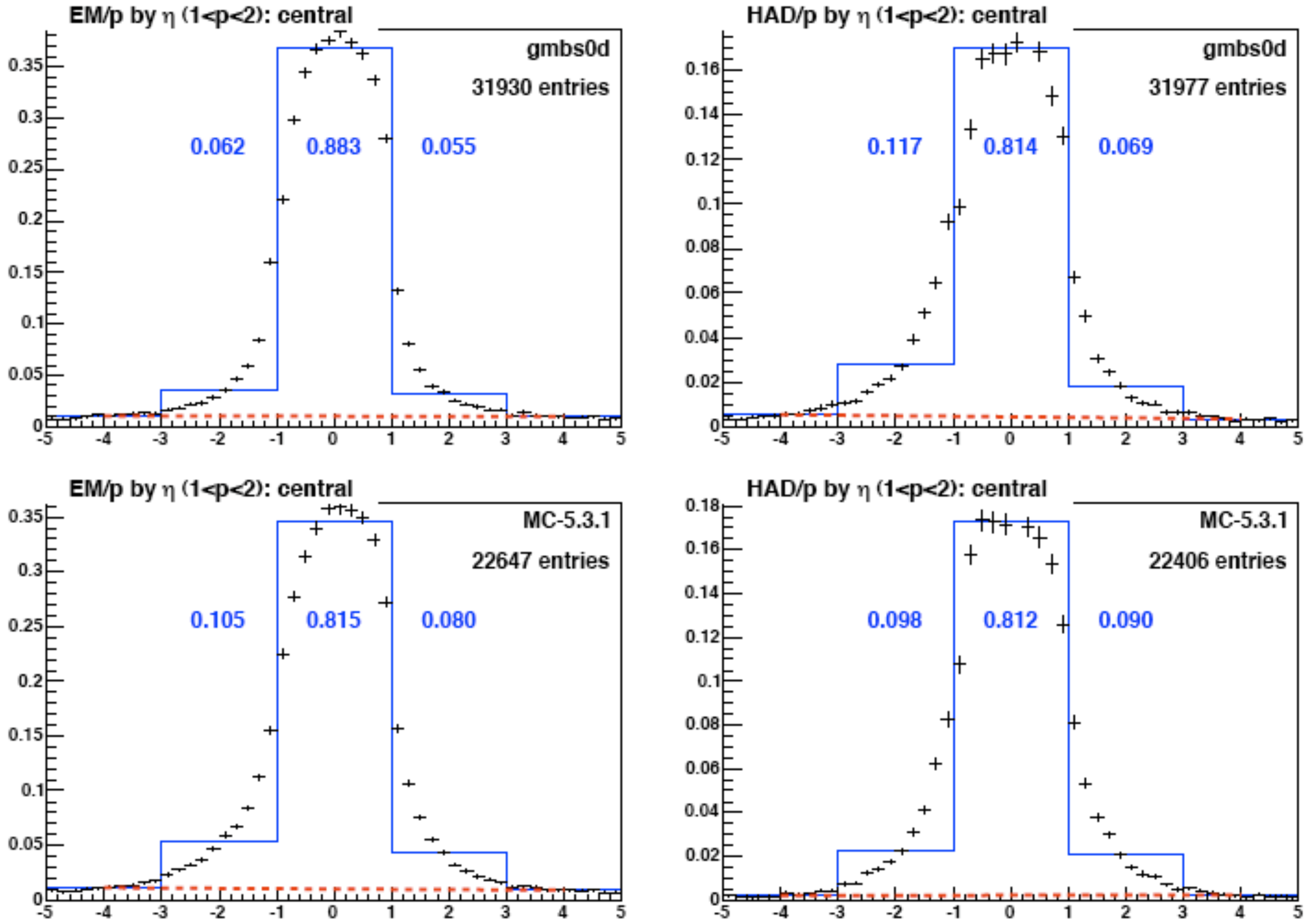
- Single hadron response error dominant at high jet p_T
  - – CDF never tried the 3-jet balancing method
  - – Uncertainty at high p dominated by test beam uncertainty

Conclusions

- **CDF calorimeter response was poorly modeled early in Run 2 in 30^o crack and forward calorimeter**
  - Both were new in run 2 and test beam only available for p>8 GeV
  - Central response also had issues but they were more data related and not simulation related
- **Major program launched to tune GFLASH to describe data**
  - Achieved a reasonable tuning in full calorimeter
- **Important to start this as early as possible since turn-around time and overhead of new simulation is large since**
  - all jet corrections need to be derived again
  - Major disruption to physics analyses

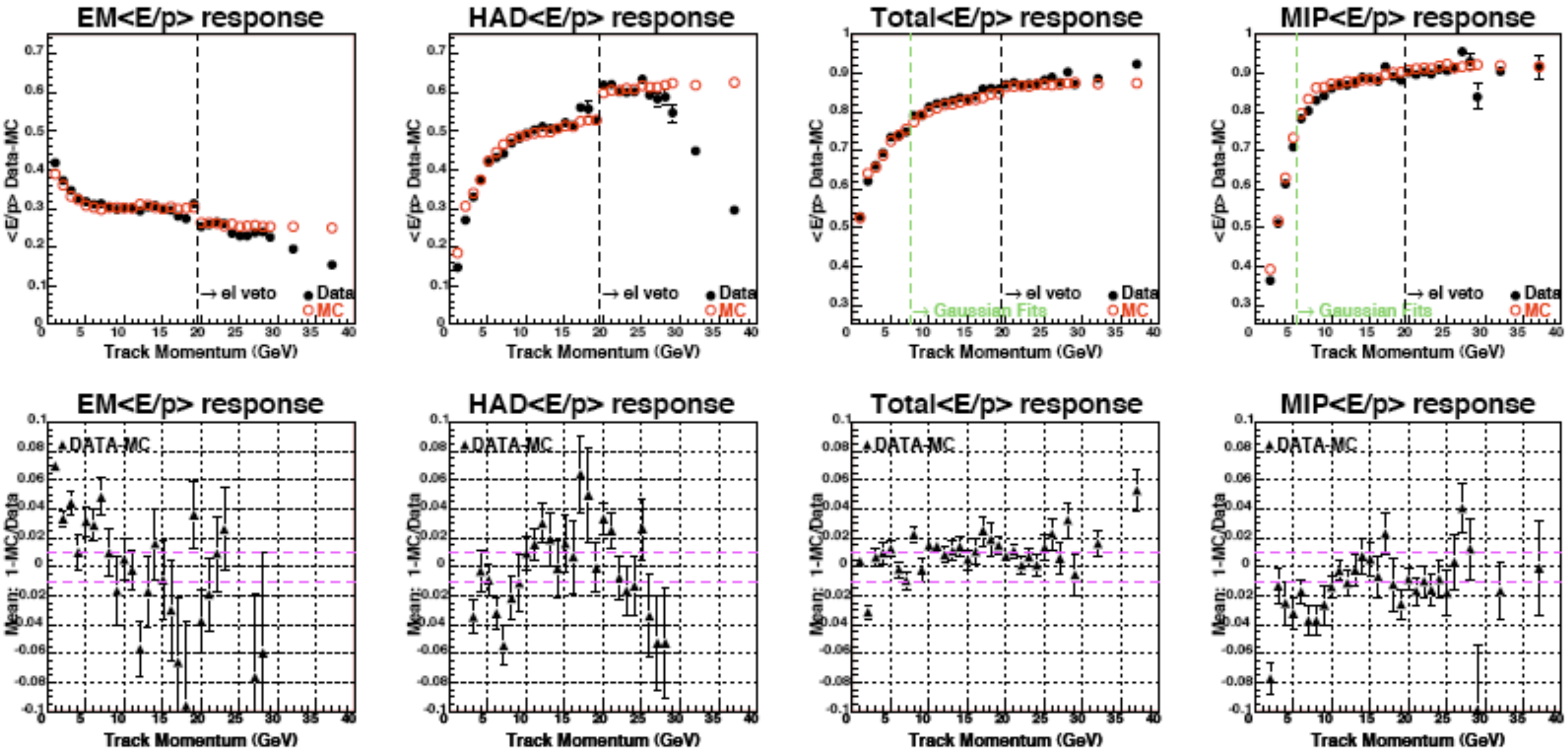
Backup

Example Shower profiles: eta



- Fractional energy versus relative eta for EM and HAD compartments for data and MC
  - This is also quite important for tau identification actually

Since NIM paper: tuning at p>20 GeV



- Looks good but difficulties due to electron/muon contamination for p>30 GeV
  - “eliminated” by using Gaussian fit to peak for total E/p and MIP