CDF Jet Energy Scale Uncertainties

- Status and Improvements -

Pedro A. Movilla Fernández
Lawrence Berkeley National Laboratory

for the Jet Energy and Resolution Group
for the Simulation Group

CDF Top Mass Workshop
Chicago, Aug. 30th 2005

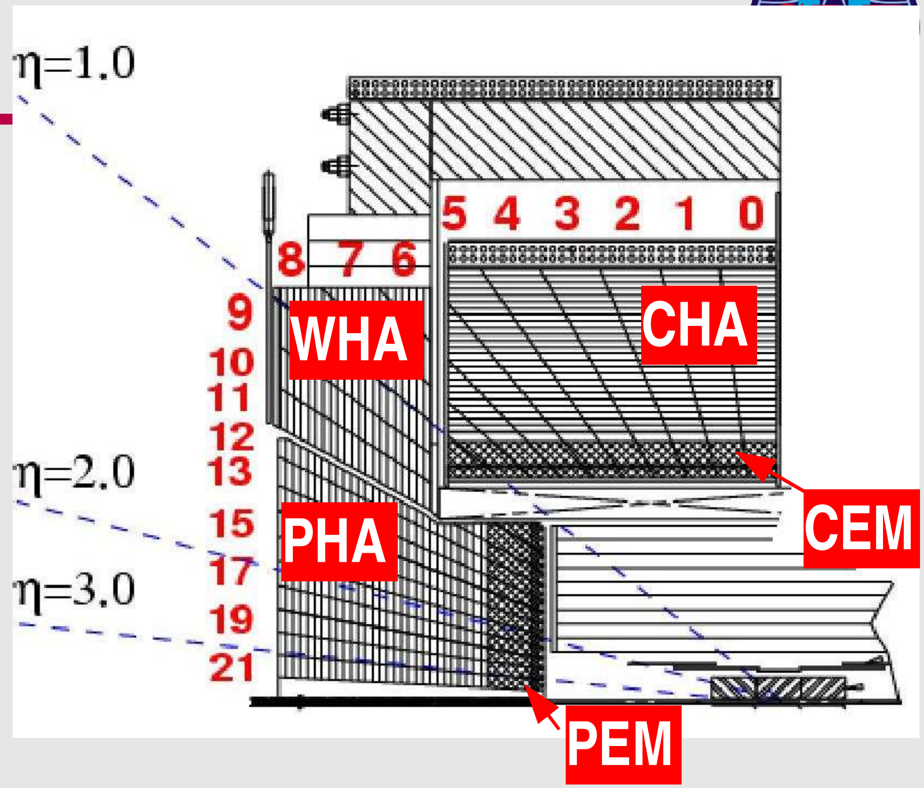
Outline

- Jets at CDF
- Calorimeter Response
- Jet Energy Scale: Status
- Improvements for the Future
  - Tuning of the calorimeter simulation
    - hadronic shower profiles, absolute hadronic responses
    - electron responses
  - Single particle response in the plug
- Conclusions and Outlook

...JES draft to be submitted to NIM very soon...

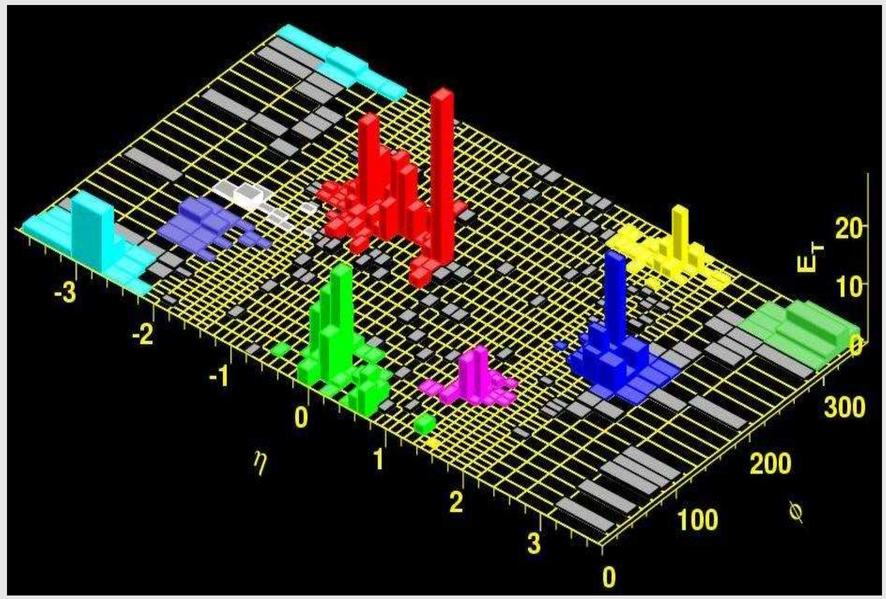
Jets at CDF

- CDF has a sampling calorimeter:
  - scintillating tiles, lead/iron absorbers
  - central: CEM=19X_0 (1λ); CHA=4.7λ; 0.0<|η|<1.0
  - plug: PEM=21X_0 (1λ); PHA=7.0λ; 1.3<|η|<3.6
- σ_E/E (e,γ) ~13.5%/√E (central)
  σ_E/E (e,γ) ~16%/√E (plug)
  σ_E/E (had) ~80%/√E
- Granularity: Δη=0.09...0.6, Δφ=2π/24 (2π/48)

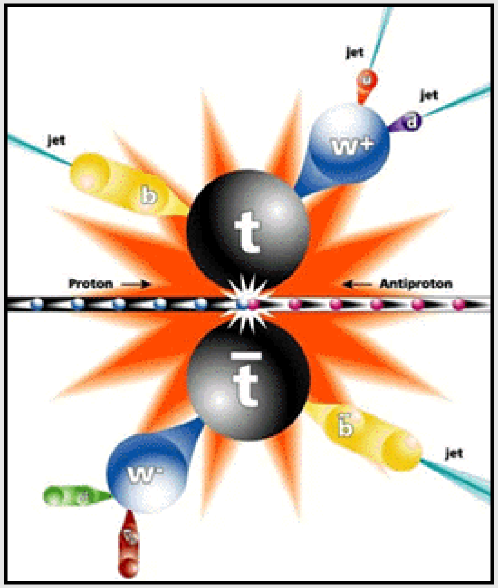


- Clustering of towers: Jet algorithm
  - cone type: JetClu, Midpoint
  - k_T type
- Jet energy corrections are derived for **JetClu** jets with fixed cone radii R = 0.4, 0.7, 1.0

$$R = \sqrt{(\eta - \eta_{jet})^2 + (\phi - \phi_{jet})^2}$$



Top Physics with Jets



- All top production channels have to deal with jets.
- Top analyses mainly based on central jets.
  - Single top: also plug region important.
- Usually small cone sizes.
  - Particles originate from decays of highly boosted /heavy objects.
- Top mass analyses: Need correction to parton level.
- Flavor specific corrections

- JES is still dominant systematic uncertainty of current best CDF top mass measurement based on 318/pb Run-II data:

$$M_{top} = 173.5 \pm 2.7(\text{stat}) \pm \mathbf{2.5(JES)} \pm 1.7(\text{syst})$$

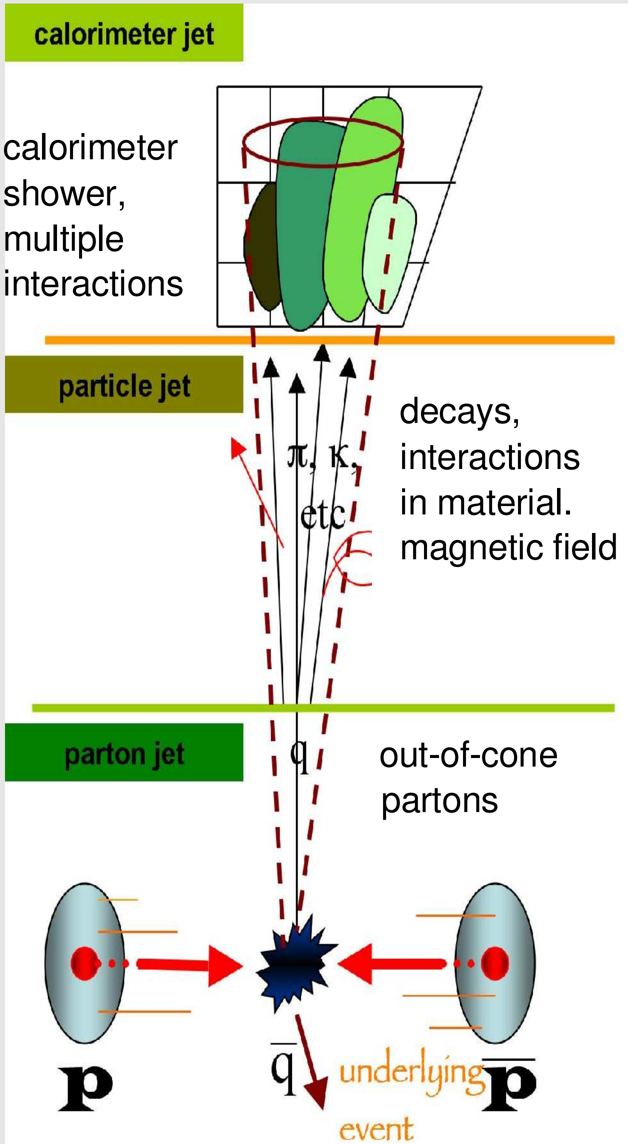
comprises Gen-5 a priori JES uncertainties reduced by in-situ $W \to jj$ calibration

- This talk will focus on “generic” corrections.
- See Tommaso's talk for b-specific corrections.

Jet Energy Scale

Measurement of CDF jet energy scale is a complex task involving:

- Calibration of calorimeter towers:
  - based on test beam / CDF data
- Tuning of the calorimeter simulation:
  - based on test beam / CDF data
- Tuning of physics models
  - based on CDF data (LEP,...)
- Correction procedure
  - detector effects
  - jet clustering effects
  - physics effects
- Validation procedure
  - check of correction factors & uncertainties



Detector effects:

- non-linear energy response
- threshold effects, noise
- un-instrumented regions
- sampling fluctuations
- particle losses due to passive material

Jet algorithm effects:

- energy threshold
- out-of-cone losses

Physics effects:

- hadronization
- spectator partons
- initial and final state gluon radiation
- multiple ppbar interactions
- flavor of parent parton

Jet Energy Correction for Gen-5

$$P_T = \{ P_T^{cal}(R) \times f_{rel} - f_{MI} \} \times f_{abs} - f_{UE} + f_{OOC}$$

$f_{rel}=f_{rel}(R, \eta, P_T^{cal})$:**Relative correction** ← di-jet balance (data, MC)

- makes calorimeter response uniform in η

$f_{MI}=f_{MI}(R)$:**Multiple Interaction Correction** ← MinBias (data)

- subtracts energy from pile-up ppbar interactions

$f_{abs}=f_{abs}(R, P_T)$:**Absolute correction** ← di-jets (MC)

- corrects calorimeter jets to particle jets

$f_{UE}=f_{UE}(R, P_T)$:**Underlying Event Correction** ← MinBias (MC)

- subtracts energy from spectator particles (ISR, beam-beam-remnant)

$f_{OOC}=f_{OOC}(R, P_T)$:**Out-of-Cone Correction** ← di-jets (MC)

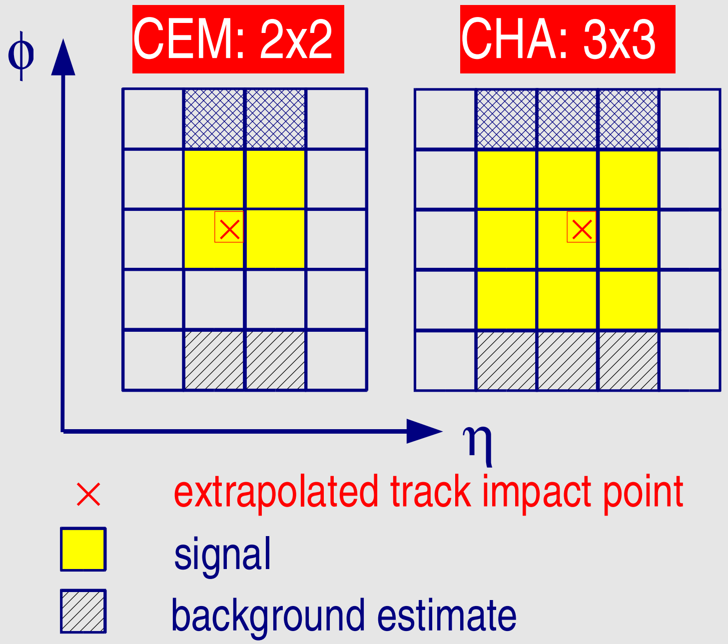
- corrects for particle losses outside the jet cone (FSR, hadronization)

- Various Gen-4 correction levels are not in use anymore:
  - Calorimeter scale time dependence (now absorbed by calibration procedure)
  - Run-I vs. Run-II JES (discrepancies now understood: material effects, ADC gate)
- At each step, systematic uncertainties are estimated by comparing MC and data
- Photon+jets, Z+jets used for validation

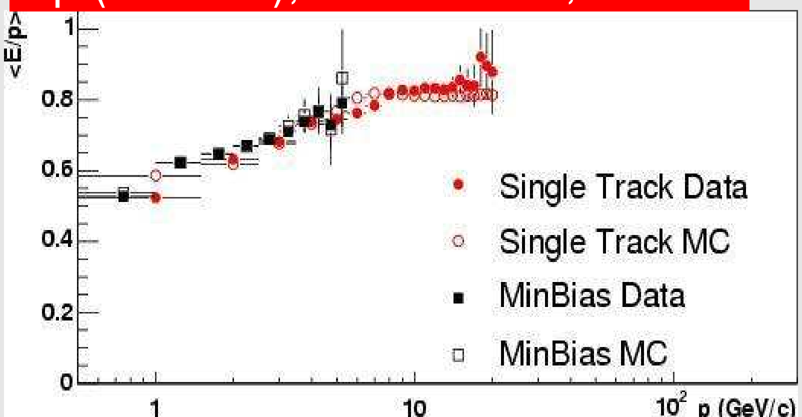
Single Particle Response

In-situ measurement of single particle response:
- calorimeter energy E
- reconstructed track momentum p

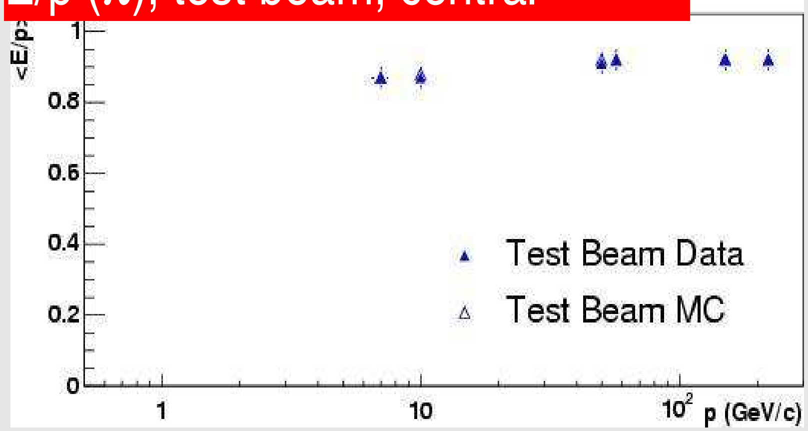
signal definition for hadron response



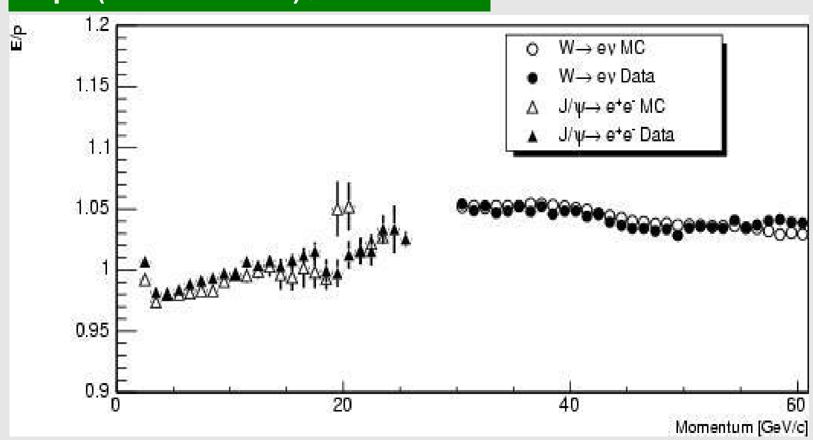
E/p (hadrons), CHA + CEM, central



E/p (π), test beam, central



E/p (electrons), central

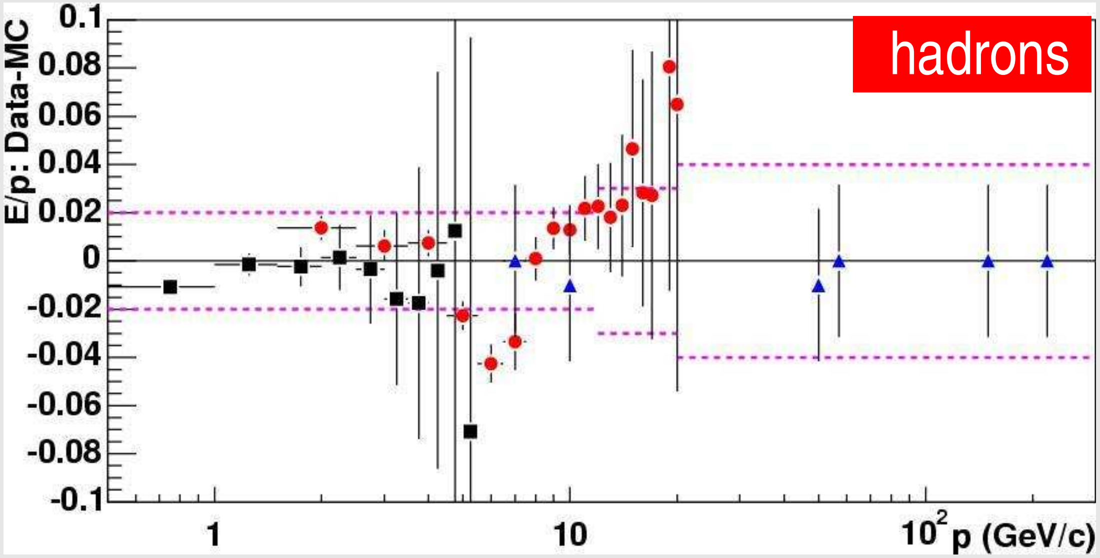


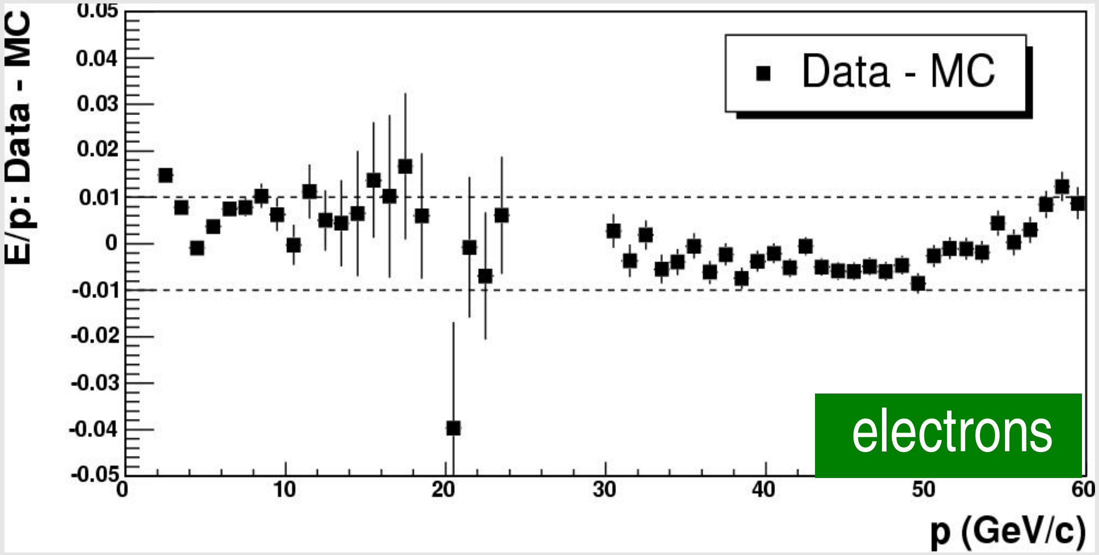
Single Particle Response: Uncertainties

- Evaluated for central region only
- Sources of uncertainty:
  - data vs. MC (low p)
  - statistical precision (medium p)
  - test beam momentum scale (high p)
  - test beam calibration stability
  - tower boundaries in electron response

hadrons:	p< 12 GeV/c: 2% 12 < p < 20 GeV/c: 3% p > 20 GeV/c: 4%
e,γ:	p< 60GeV/c: 1.5%

- These numbers are directly passed to the evaluation of the uncertainties of absolute corrections.

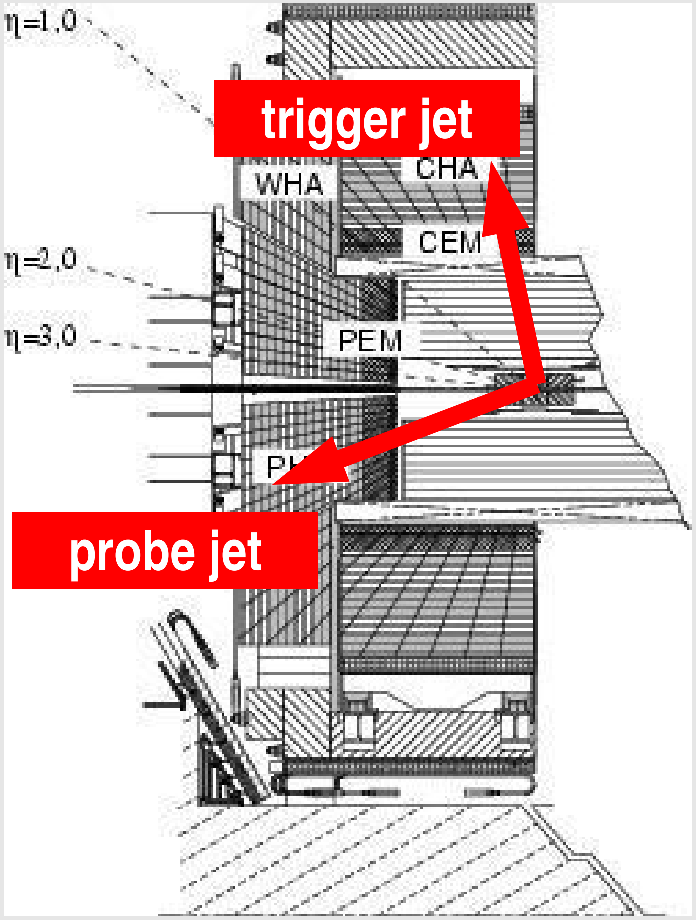




Relative Corrections

We understand the single particle response in the central better that in the plug. Problems in the plug:

- lower track reconstruction efficiency
- poor momentum resolution
- more passive material (COT plate)
- higher background



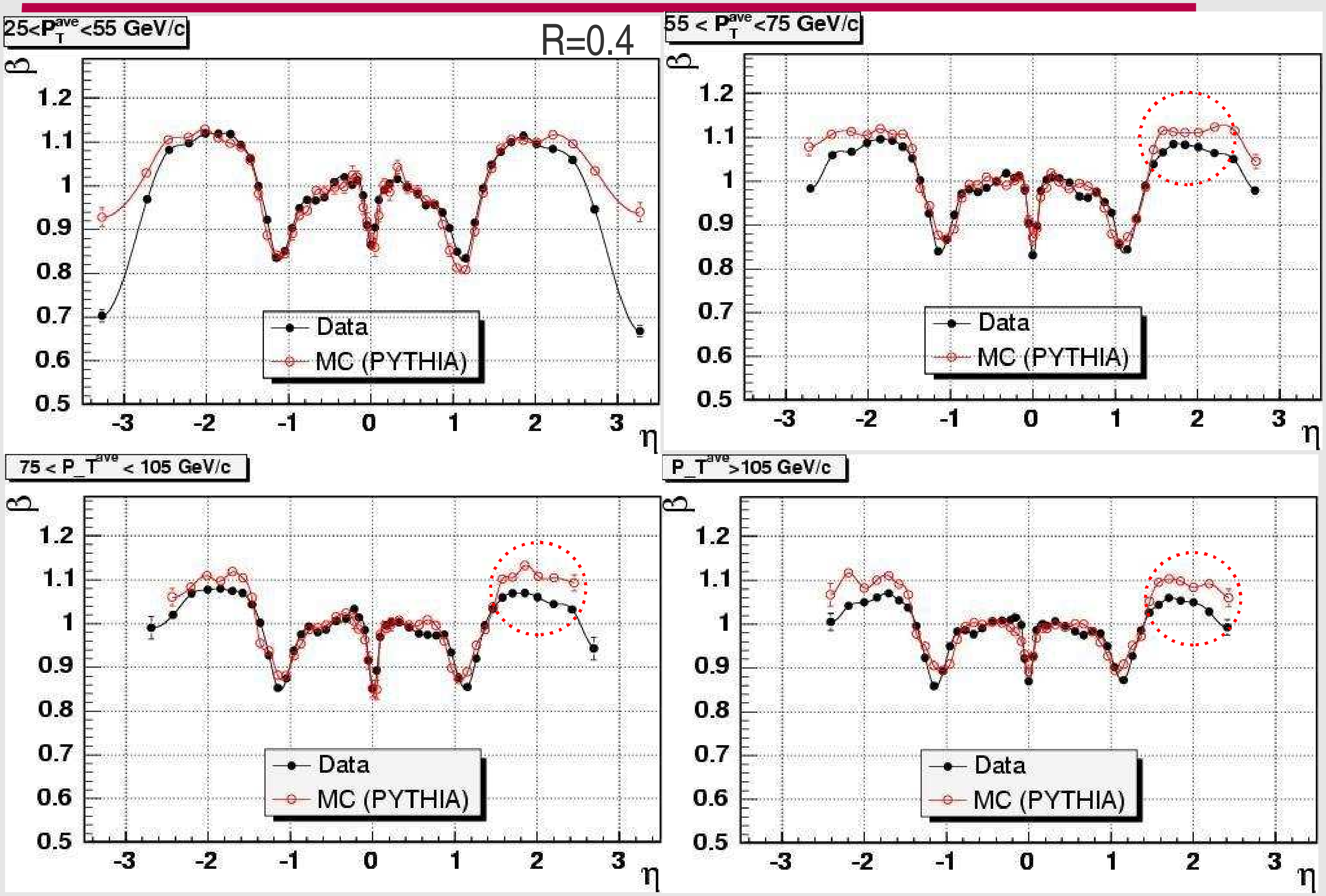
Use di-jet balancing technique: recalibrate energy of non-central jet (“probe jet”) with energy of central jet (“trigger jet”):

- trigger jet: 0.2<|η|<0.6
- **di-jet balance β**

$$f = \frac{p_T^{probe} - p_T^{trigger}}{(p_T^{probe} + p_T^{trigger})/2}$$

$$\beta \equiv \frac{2+f}{2-f} = \frac{p_T^{probe}}{p_T^{trigger}}$$

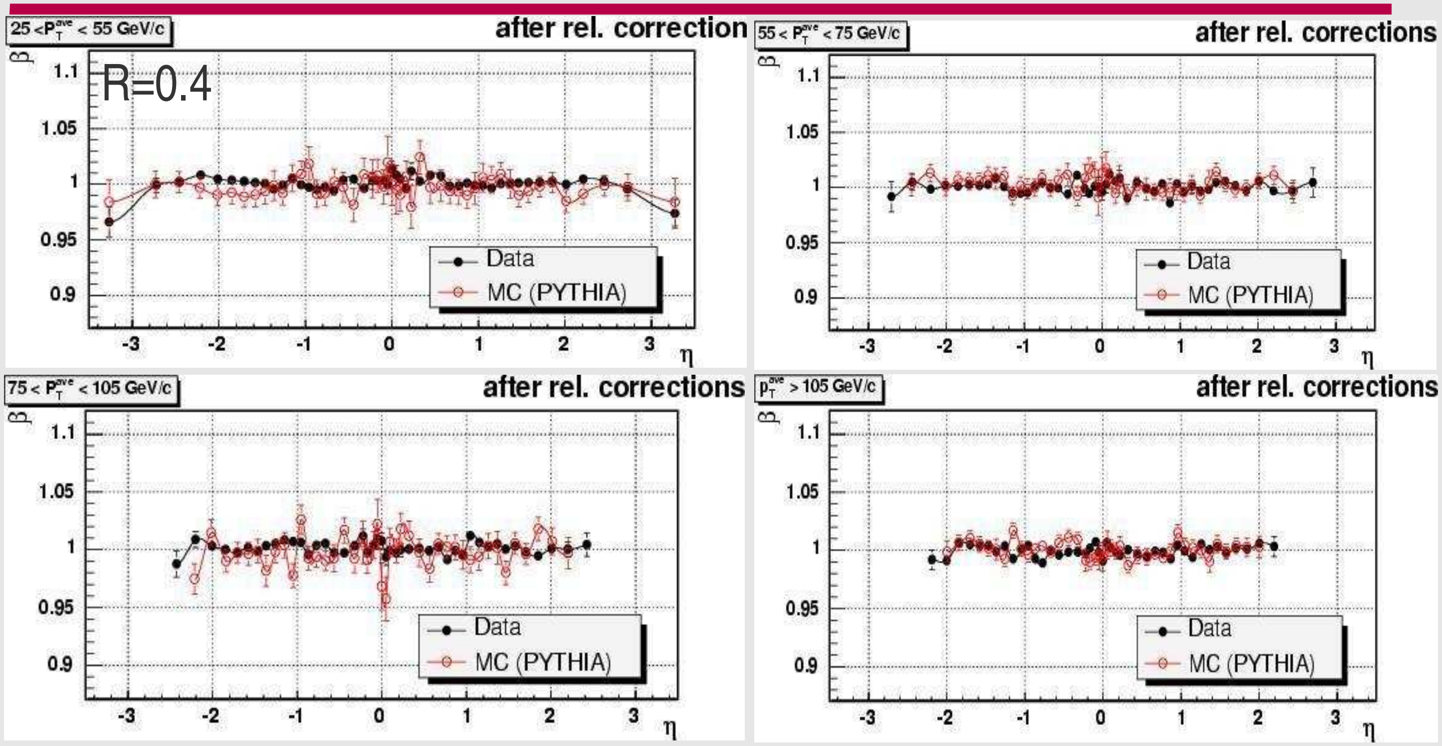
Relative Corrections (2)



suboptimal MC tuning in plug region (?)

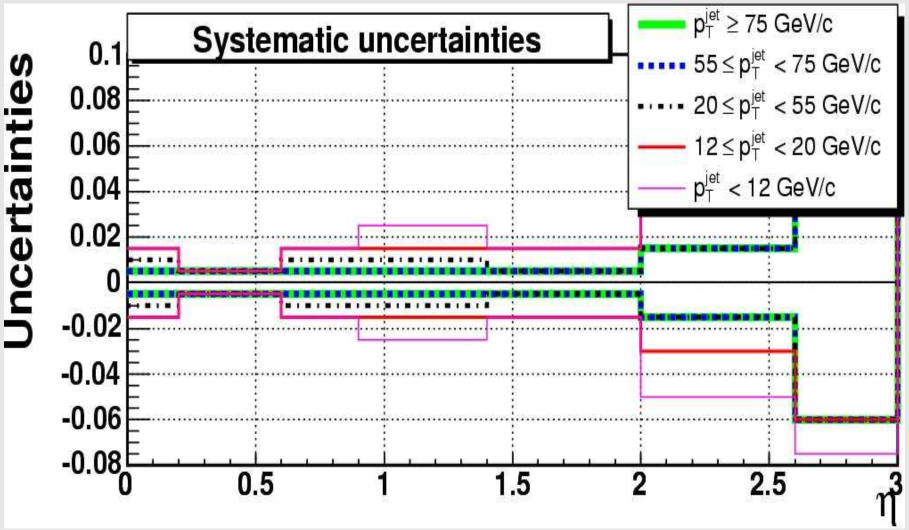
- Discrepancies in the plug increasing with jet p_T .
- Corrections are derived separately for data and MC.
- Primary MC for Gen-5 is PYTHIA Tune A.

Relative Corrections: Uncertainties

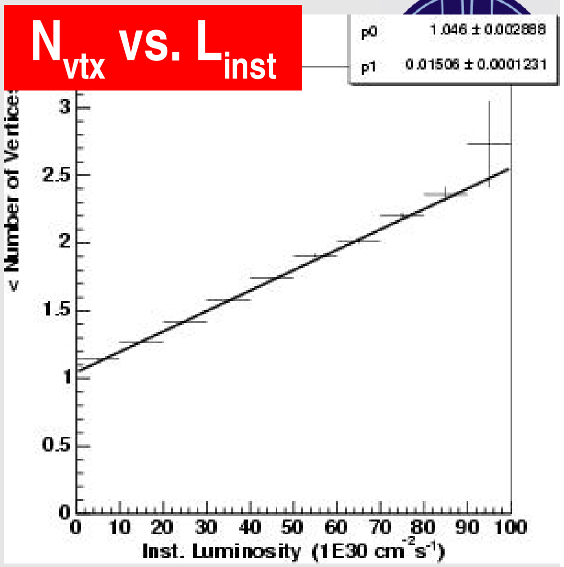


nice flat response after correction

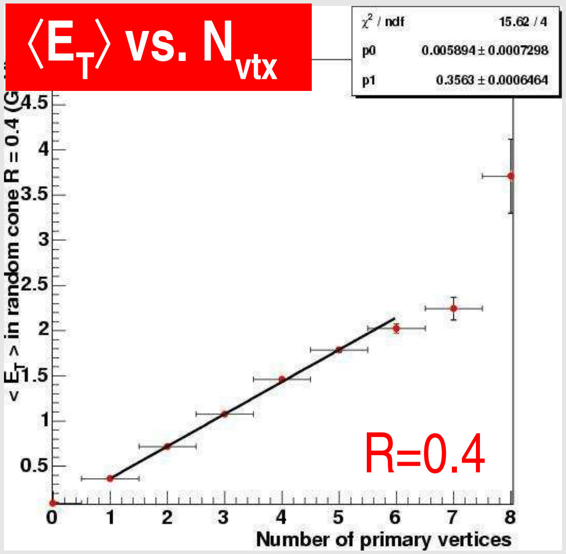
- Uncertainties:
  - deviation of corrected response from unity
  - QCD event selection cuts
  - interpolation procedure
  - difference between data and MC in photon+jets events (certain p_T bins)
  - HERWIG-PYTHIA no longer part of total uncertainties (avoids double counting in various physics analyses)



Multiple $p\bar{p}$ Interactions Correction

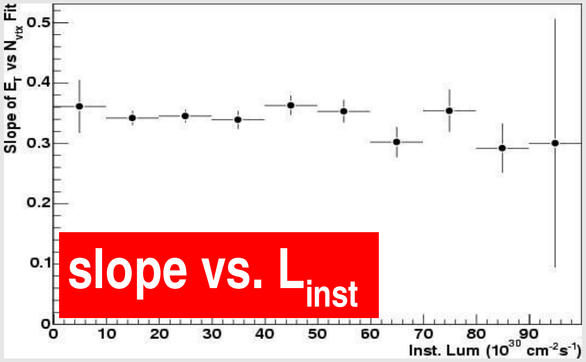


- Multiple $p\bar{p}$ interaction may occur at high instantaneous luminosities
  - 0.1×10^{32} - 1.0×10^{32} cm^{-2} s^{-1} up to Nov. 2004
  - Number of primary vertices is a good estimator for number of extra interactions
- Derive additional pile-up energy using Minbias data
  - measure mean transverse energy vs. number vertices using jet cone with randomly selected seed tower



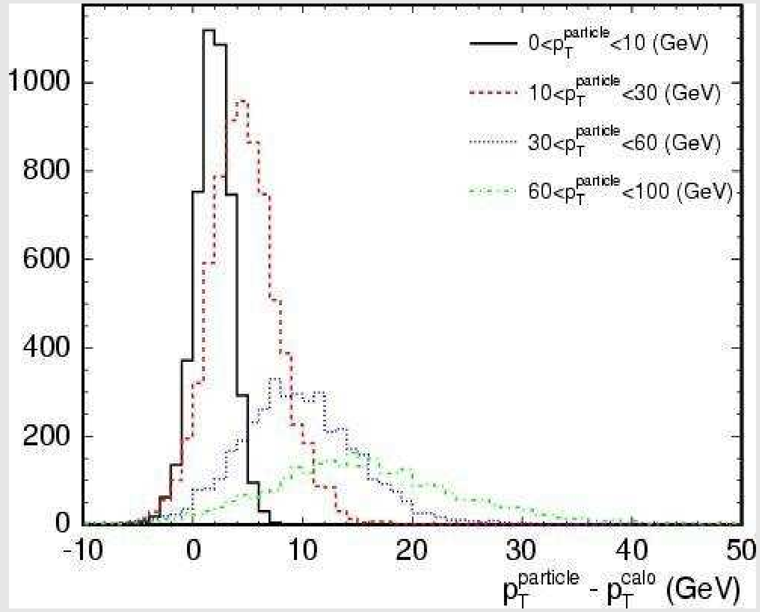
- **Correction procedure:** Count number of vertices and use parametrization to subtract corresponding energy
- **Uncertainties:**
  - Vertex reconstruction efficiencies: depend on event topology: $W\rightarrow e\nu$, $W\rightarrow jj$, Minbias **7.5%**
  - Fake vertex rate: reconstruction might errorneously occur in busy events with large number of extra interactions **10%**

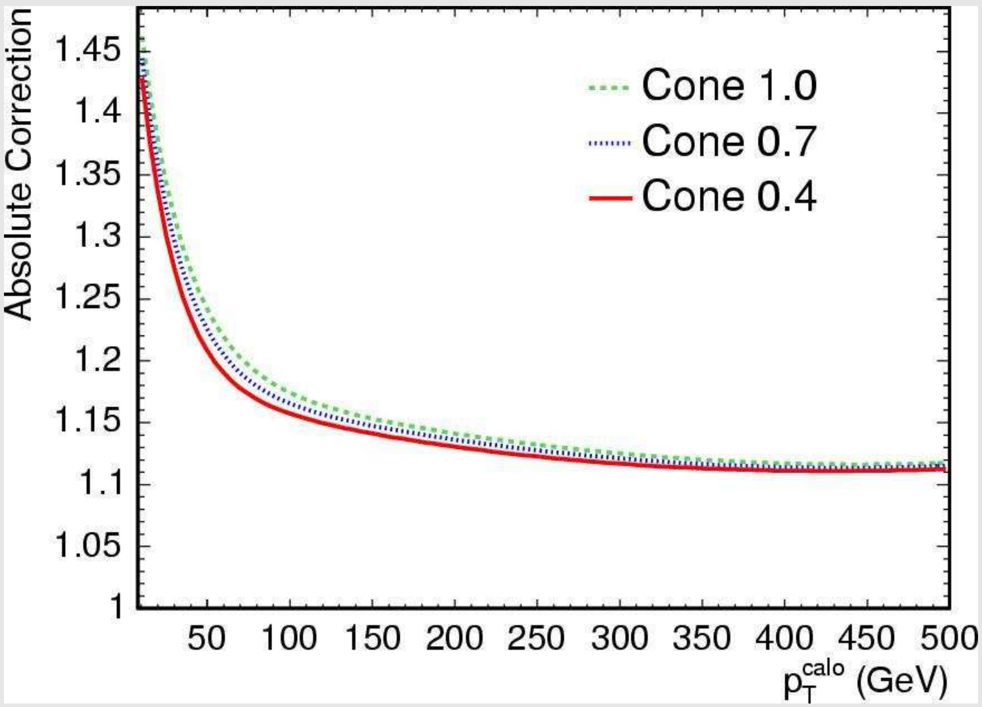
- So far, slope seems to be stable within the range of instantaneous luminosities relevant for Gen-5.
- 15% uncertainties for all cone sizes:
  50MeV (0.4), 150 MeV (0.7), 300 MeV (1.0)



Absolute Corrections

- **Calorimeter-to-particle correction**
- Derived from PYTHIA di-jet samples (Tune A), $P_T^{(min)}$ = 0...600GeV.
- Considers only jets in central region $0.2<|\eta|<0.6$.

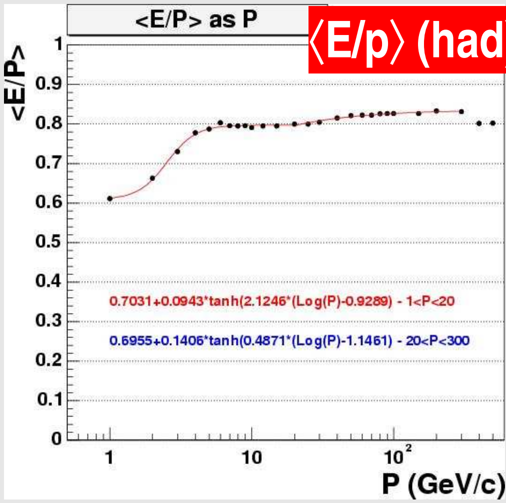




- $\Delta p_T = p_T^{(part)} - p_T^{(calo)}$ parametrized by a double-Gaussian.
- Absolute correction is the most probable value for $\Delta p_T/p_T^{(part)}$ for a given $p_T^{(part)}$.
- Is supposed to remove remaining detector effects. Further corrections deal with pure physics effects.

Absolute Corrections: Uncertainties

- Derived from "first principles", using our full knowledge of the single particle response.
- Reflects performance of shower simulation and tuning of **calorimeter response ⟨E/p⟩**

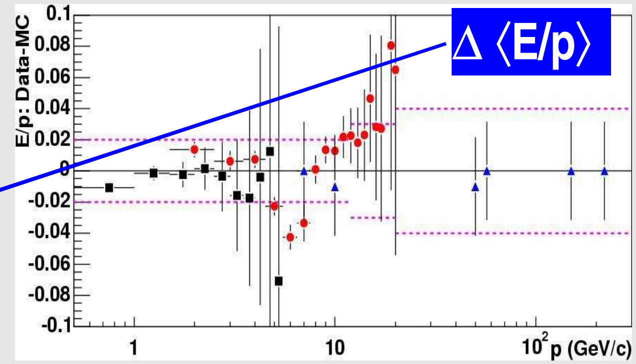


⟨E/p⟩ (had)

⟨E/p⟩(e,γ) = 1

Δ ⟨E/p⟩

$$\frac{\Delta E}{E} = \frac{1}{E}\sum_i p_i \left\langle \frac{E_i}{p_i} \right\rangle \Delta \left\langle \frac{E_i}{p_i} \right\rangle$$

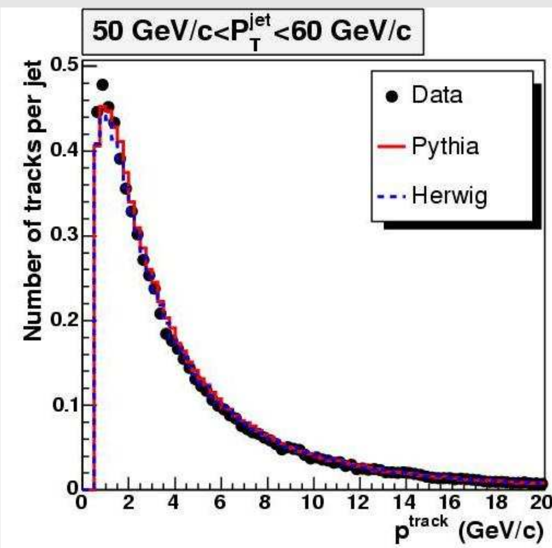


jet electromagnetic fraction: 30%

had: 2...4% × 0.7 → 1.4...2.8%

e,γ: 1.5% × 0.3 → 0.5%

convolution with particle p_T spectrum



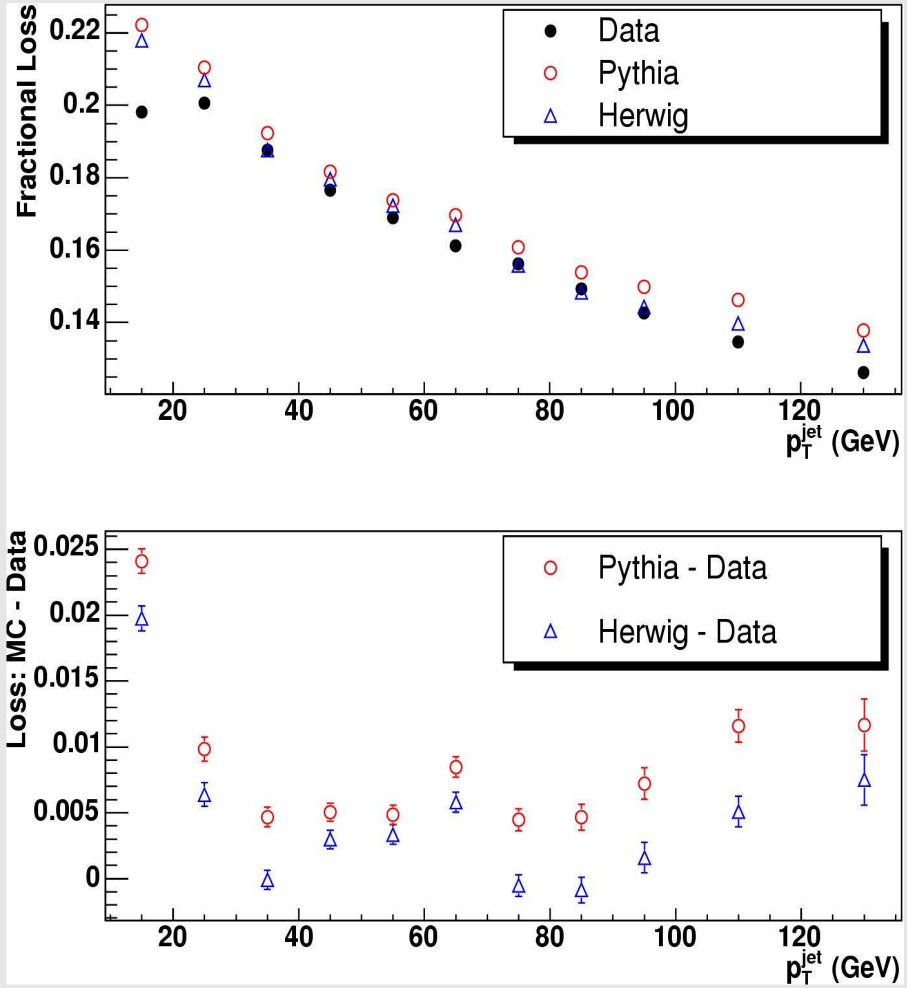
- HERWIG/PYTHIA di-jet used to model spectrum
  - introduces fragmentation uncertainties (next page)
  - spectrum corrected for track inefficiencies and underlying event contribution
- Good agreement between MC and data for all jet p_T bins

Abs. Corr.: Fragmentation Uncertainties

- p_T spectrum of particles inside a jet depends on fragmentation details
- Uncertainty derived from calculating the relative energy loss:

$$\frac{p_T^{loss}}{p_T^{calo}} = \frac{1}{p_T^{calo}} \sum_i p_{T,i} \left(1 - \left\langle \frac{E_i}{p_i} \right\rangle \right)$$

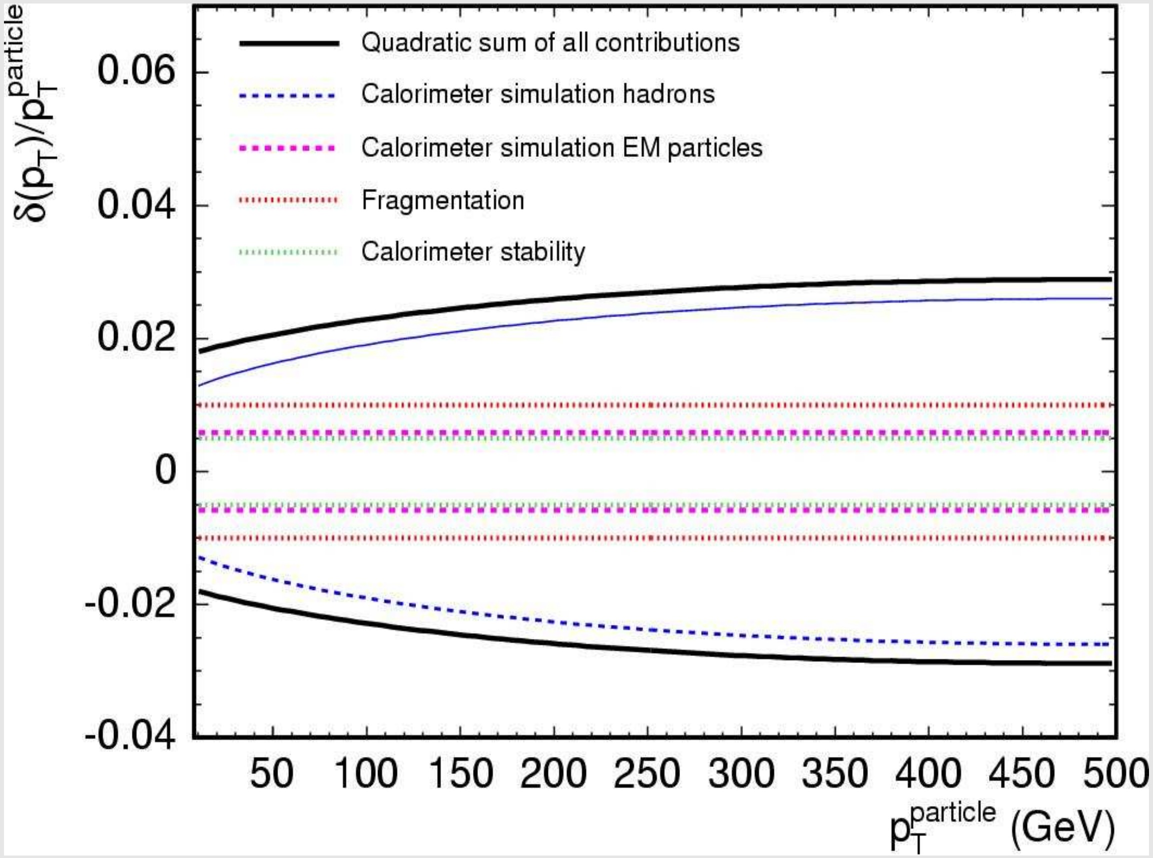
... for data and MC with response ⟨E/p⟩ kept fixed

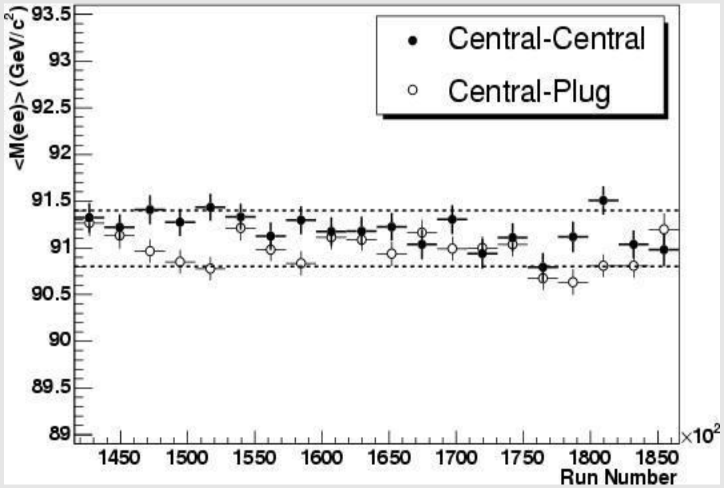


- PYTHIA and data agree within 1% for 20 ... 220 GeV jets - take as uncertainty
- HERWIG and PYTHIA agree to within < 1% - not added to total uncertainty
- HERWIG agrees better with data than PYTHIA (di-jet balance: PYTHIA is better)

Abs. Corr.: Total Uncertainties

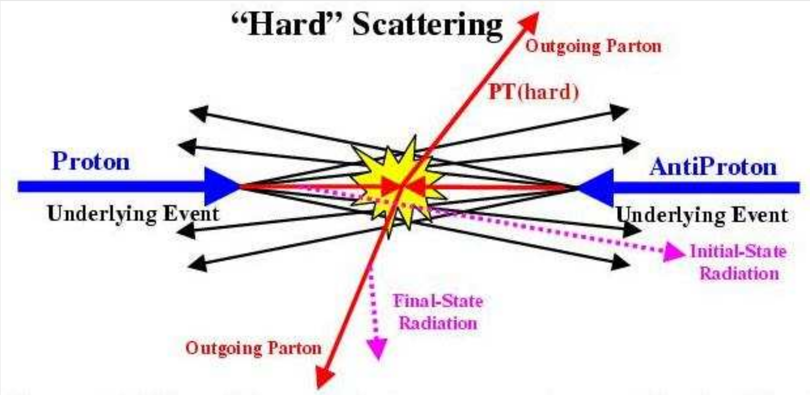
- Calorimeter simulation: **2-3%**
  - reflects our understanding of details of single particle response
- Fragmentation: **1%**
  - reflects our understanding of simulated p_T spectra
- Calorimeter stability: **0.3%**
  - reflects our control over time dependence of calorimeter scale



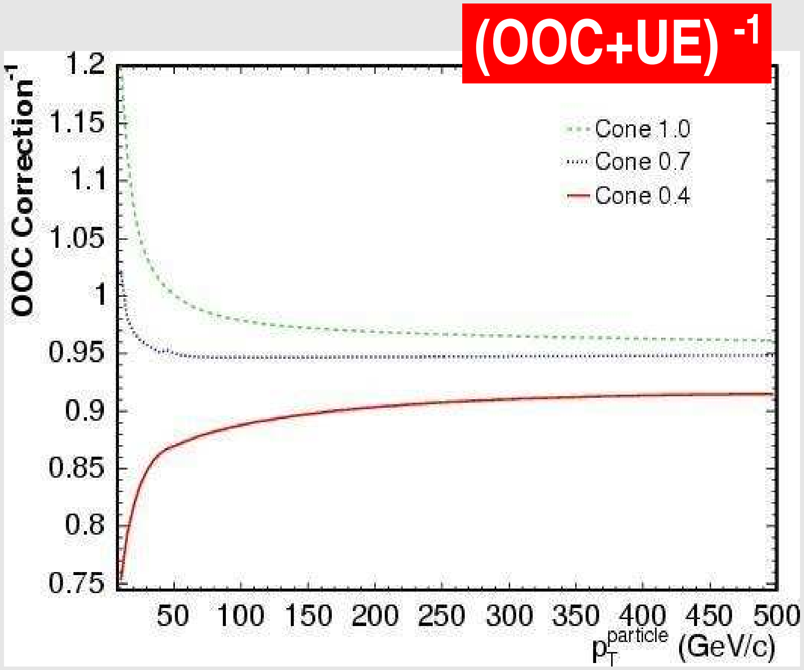


Out-of-Cone & Underlying Event Correction

- **Particle-to-parton correction**
  - relevant for certain analyses (e.g. top mass)
- Simultaneous correction:
  - add energy lost due to FSR, hadronization effects: **OOC**
  - subtract energy contribution from ISR and beam-beam-remnants: **UE**



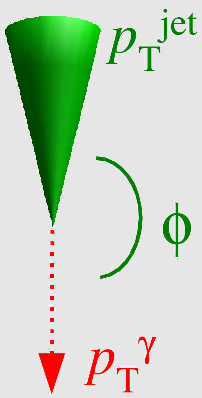
- Derived using two leading jets in PYTHIA samples
  - particle-level and parton-level jets required to match within $\Delta R<0.4$
  - procedure similar to absolute corrections: calculate most probable value for $(p_T^{(particle)}-p_T^{(parton)})/p_T^{(parton)}$



- Pure UE contribution estimated using mean energy in cone R in Minbias events:
  0.2 GeV (R=0.4), 0.5 GeV (R=0.7), 1.2 GeV (R=1.0)

OOC & UE: Uncertainties (1)

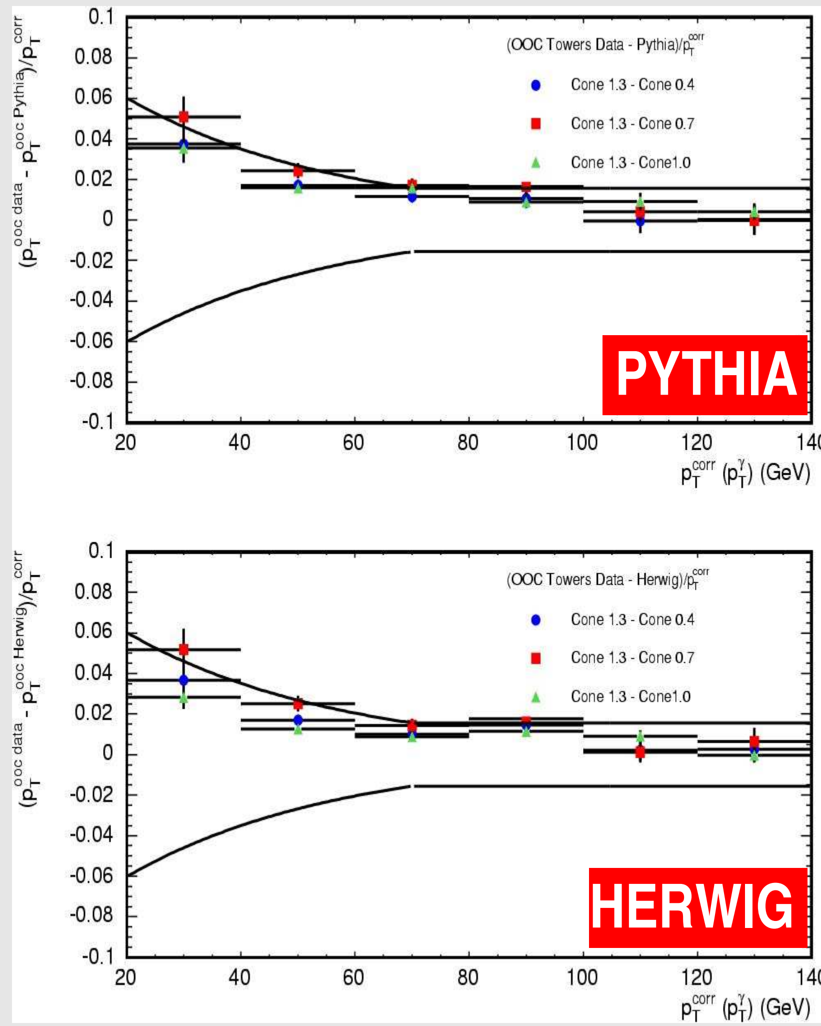
- Compare energy flow in annuli around the cone up to R=1.3 between data and MC in photon + jets events at calorimeter level
- Photon transverse momentum p_T^{γ} is assumed to balance unknown parent parton p_T



$$f_{\gamma} = 1 - \frac{p_T^{jet}}{p_T^{\gamma}}$$

after abs. correction:

$$\delta_{OOC} = f_{\gamma}^{\text{data, cor}} - f_{\gamma}^{\text{MC, cor}}$$

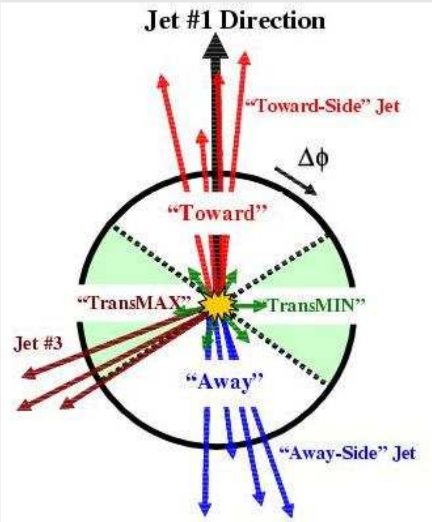


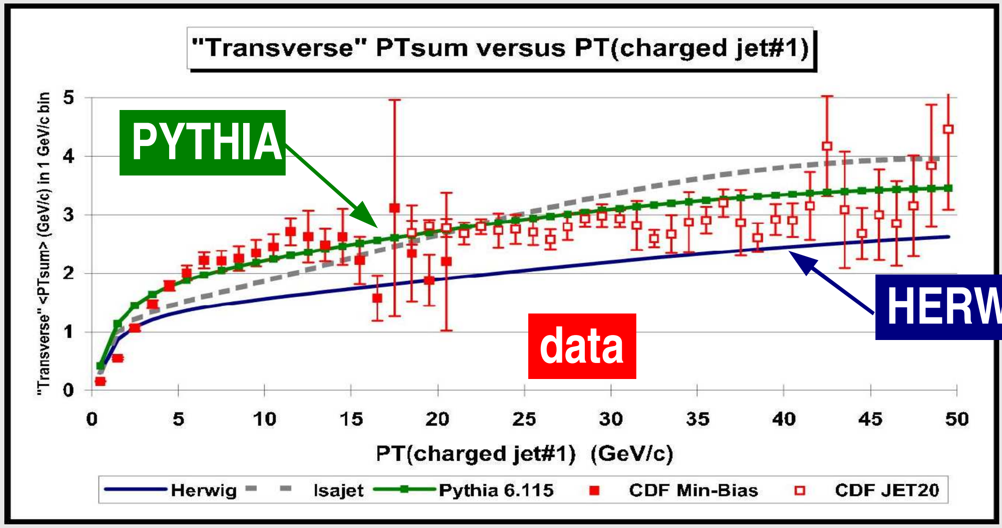
- p_T^{γ} can be measured with high accuracy and is thus used as reference scale p_T^{corr} for jet after absolute correction
- Uncertainty is largest difference between data, PYTHIA and HERWIG, scaled with $f_{abs}(p_T^{\gamma})$

- Additional "Splash-Out" uncertainty accounting for energy flow outside the cone up to R=1.3: ±0.25 GeV

OOC & UE: Uncertainties (2)

- Uncertainties in modeling physics effects not associated with the hard interaction
  - PYTHIA UE model has been tuned to data
  - HERWIG UE model (JIMMY) optimization is in progress
- Quantify by comparing charged particle transverse energy densities in "transverse regions" w.r.t. leading jets in di-jet events between data, PYTHIA and HERWIG

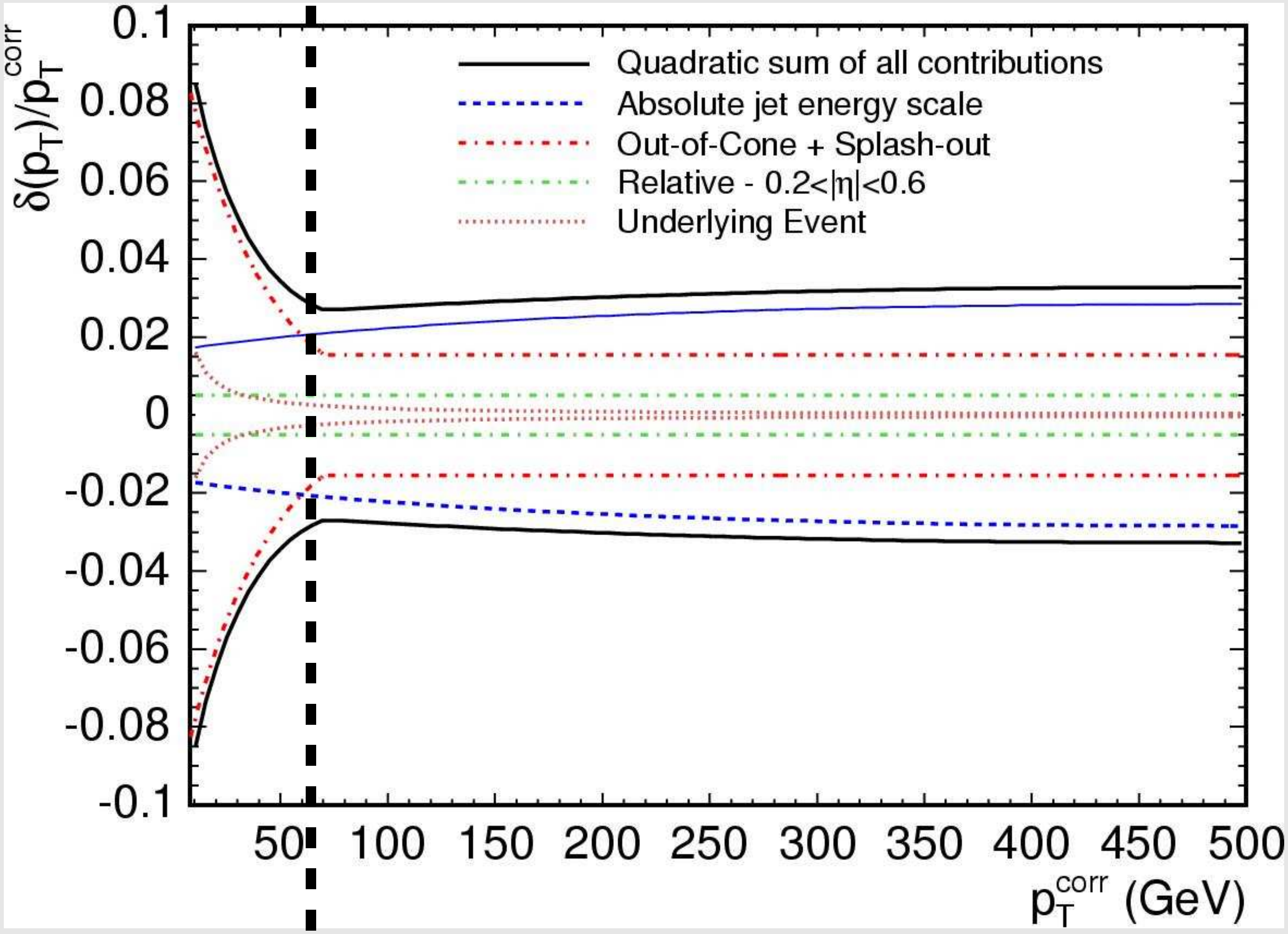




average transverse p_T density

- Agreement between data and MC within 30%: taken as systematic uncertainty for all p_T
- Use Minbias data with N_{vtx}=1 to get absolute numbers:
  0.11 GeV (R=0.4), 0.32 GeV (R=0.7), 0.66 GeV (R=1.0)

Total Uncertainties



dominated by physics model uncertainties

dominated by calorimeter simulation uncertainties

Validation (1)

e.g.: R = 0.4

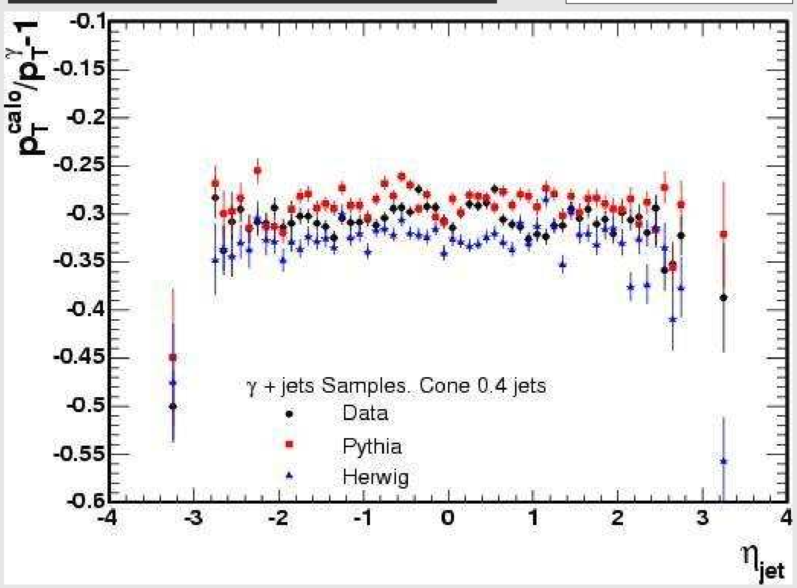
Consistency checks:

- photon+jets events
- Z-jet events
- $t\bar{t}$ events

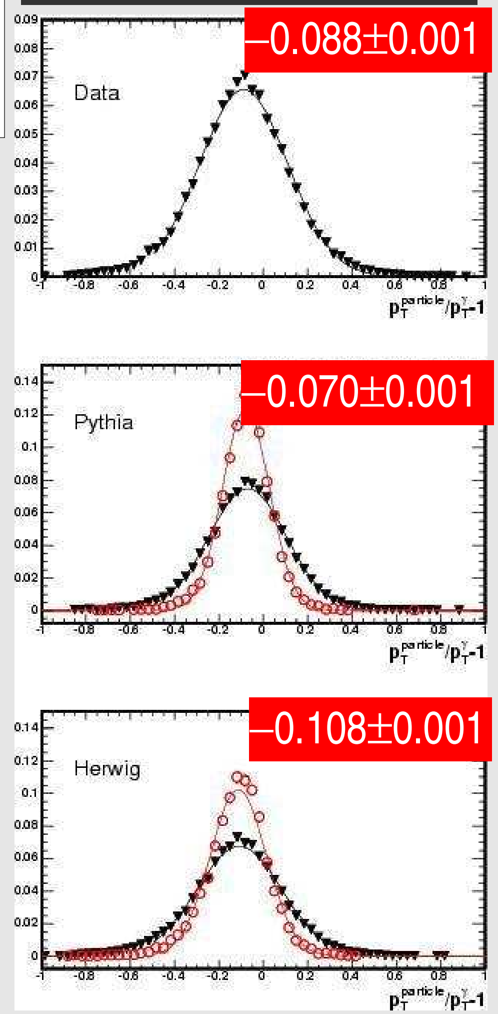
$$\frac{p_T^{corr}}{p_T^{\gamma}} - 1$$

$$\frac{p_T^{calo}}{p_T^{\gamma}} - 1$$

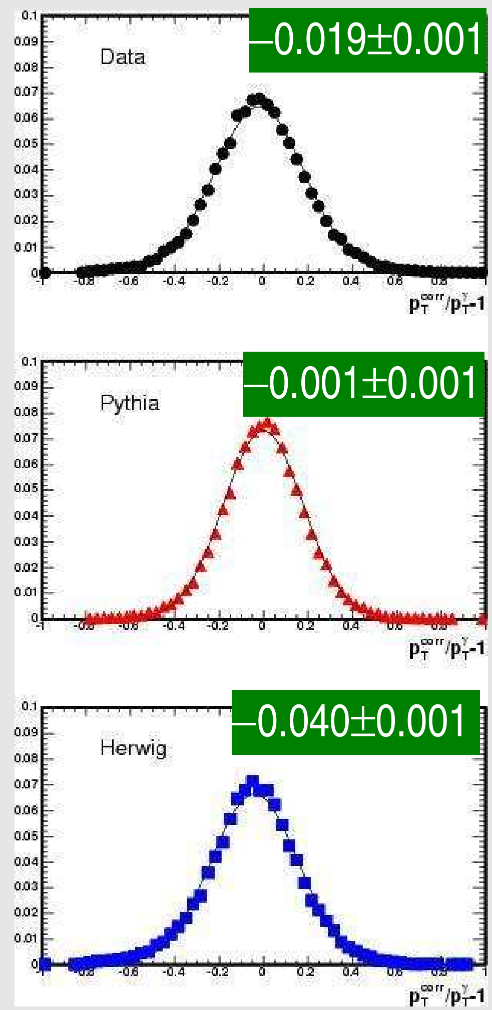
...after relative corrections



...after absolute corrections



...after OOC corrections



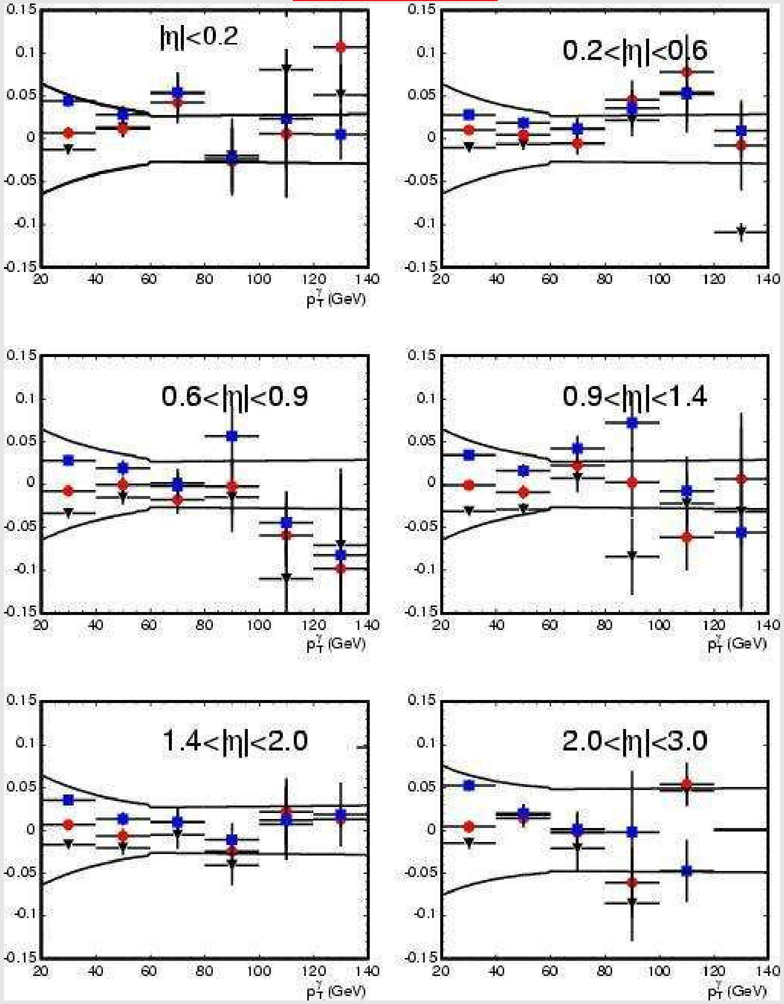
- flat response

- p_T balance should be zero after all corrections applied
- differences between data and MC are well covered by uncertainties

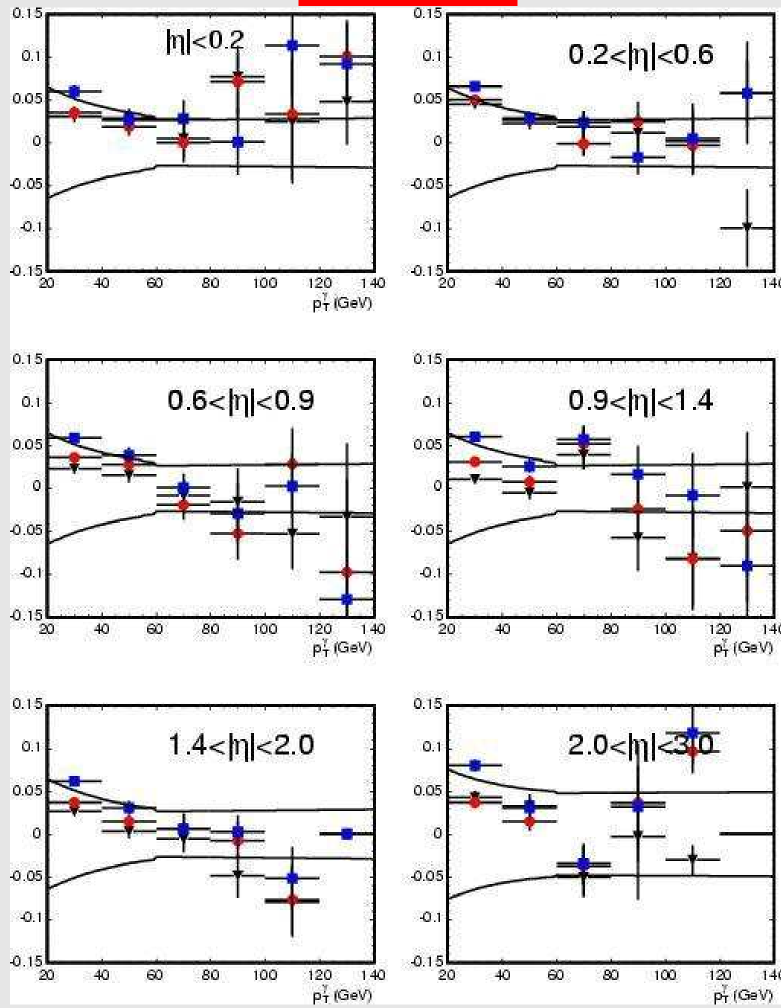
Validation (2)

photon-jet balance

PYTHIA



HERWIG

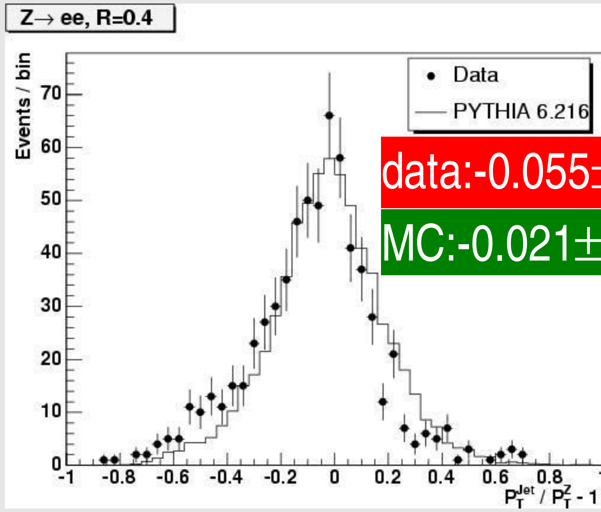


Estimated total uncertainties look reasonable for the three cone sizes and pseudorapidity regions.

Validation (3)

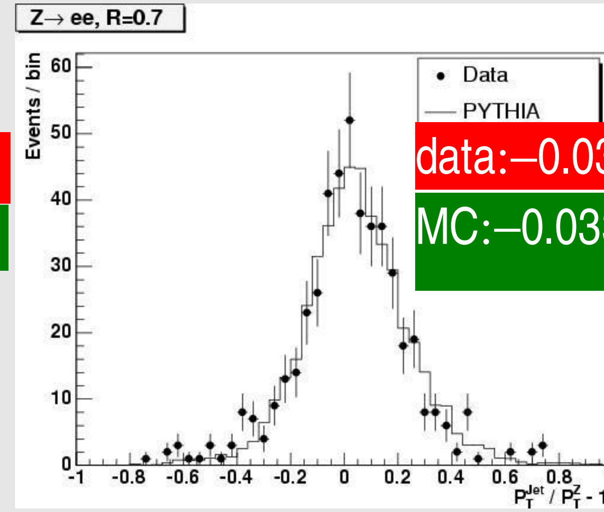
Z-jet balance:

$$\frac{p_T^{corr}}{p_T^{Z}} - 1$$



data:-0.055± 0.010

MC:-0.021± 0.002

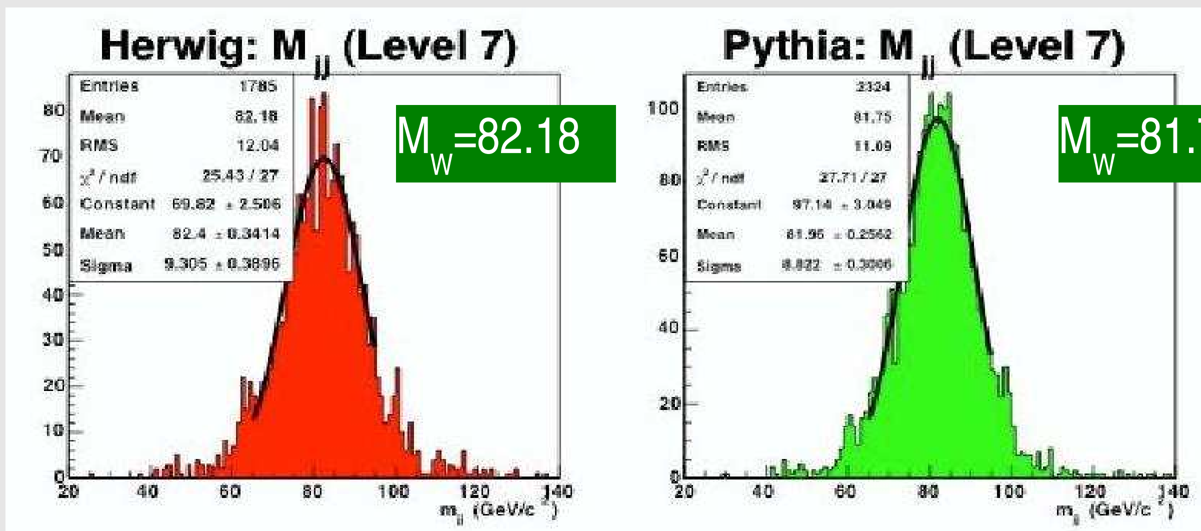


data:–0.034±0.010

MC:–0.033±0.003

- After all corrections: Z-jet balance reasonably close to zero
- Data agree with PYTHIA within 3%

W mass:



M_W=82.18

M_W=81.75

- Reconstructed hadronic W in top decays consistent with nominal W mass

Improvements for the Future

Lots of work was done in the past years to greatly reduce the JES uncertainties:
Data/MC discrepancy in γ+jets, Z+jets, W+jets: **~5% (Gen-4)$\longrightarrow$ ~2% (Gen-5).**

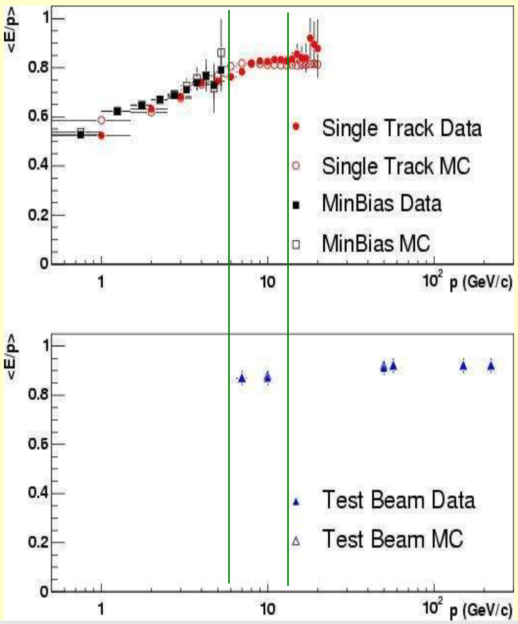
For 1/fb we are aiming at a precision of $\leq$ **1% (Gen-6)**.
How can we accomplish this challenge?

- **Improve calorimeter simulation**
  - statistical precision of single particle response measurement
  - extend tuning consistently using CDF Run II data up to highest possible momenta
- **Improve measurement of single particle response in the plug calorimeter**
  - consistent tuning also here
- **Improve performance of physics generators**
  - better understanding of the underlying event, gluon radiation effects
  - tuning of PYTHIA, HERWIG, JIMMY
- **Improve jet resolution**

Improvements (1)

Simulation (central):

- Post Gen-5 data allows for comparison of measured and simulated single particle response with higher statistical precision and helps to verify/reduce absolute correction uncertainties for p>12 GeV/c.
- With the data already available, the lateral hadronic shower profile can be consistently tuned up to 20 GeV/c. This will improve in particular the OOC correction uncertainties.
- We already can do a refined tuning of the absolute calorimeter response up to ~16GeV/c and thus significantly reduce the absolute correction uncertainties.
- We improved the track trigger to increase the single track statistics up to 20 GeV/c (and beyond).
- We are improving the simulation of the electron response in the ϕ cracks.
- By revalidating the test beam tuning uncertainties using in situ data in the overlap region (requires modified signal definition) we can reduce our conservative error estimate for p> 20GeV/c.



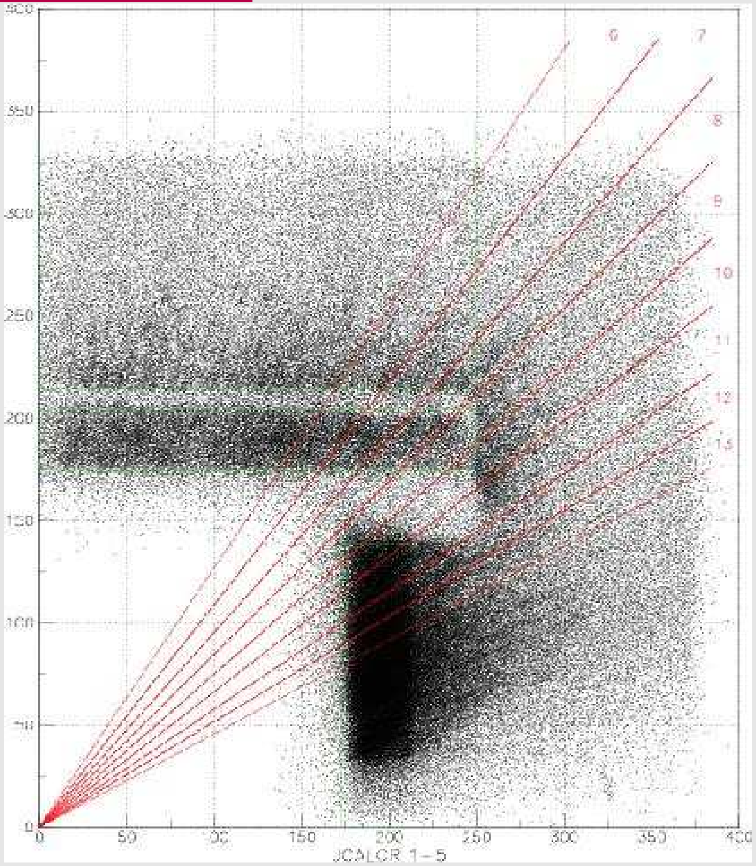
Calorimeter Simulation

CDF Run II simulation is based on GEANT

- encodes detector geometry
- propagates particles up to first inelastic interaction in the calorimeter
- secondary interactions in passive material

Gflash: fast simulation of EM and HAD showers

- parametrization of single particle response
  - energy deposit model
  - detailed shower profile model
- sampling fractions
- leakages due to cracks
- generates energy spots which are summed according to calorimeter geometry



Tuning of hadronic showers in Gflash is based on measured single particle response

- p<5GeV/c: CDF Run II single track data
  - minbias data
  - various Gen-5 tunes restricted to p<2.5GeV/c due to limited statistics
- p>10GeV/c: still use pion test beam data
  - central: 7.0 ≤p≤ 227 GeV/c (1985,1990)
  - plug: 8.6 ≤p≤ 231 GeV/c (1997)

Gflash in a Nutshell

Parametrization of single particle response:

$$\propto a + b \tanh(c \ln E_{\text{inc}} + d)$$

simple model for incident energy dependence

fraction of deposited energy | **relative sampling fractions**

energy deposit

$$dE_{\text{vis}}(\boldsymbol{r}) = E_{\text{inc}}\, f_{\text{dep}}\, \tilde{m}\left[\frac{\tilde{e}}{\tilde{m}} c_{\text{e}} f_{\text{e}}(\boldsymbol{r}) + \frac{\tilde{h}}{\tilde{m}} c_{\text{h}} f_{\text{h}}(\boldsymbol{r})\right] d\boldsymbol{r}$$

shower profile

$$f(\boldsymbol{r}) \propto L(z)\, T(r)$$

z: shower depth

r: radial distance form shower center

longitudinal part:

- photons, electrons: $L(z) = \frac{(\beta z)^{\alpha-1} e^{-\beta z}}{\Gamma(\alpha)}$

2 parameters: α, β

- hadrons: sum of three subprofiles (all Γ functions):

$$L \propto c_{\text{h}} H(x)_{\text{h}} + c_{\text{f}} H_{\text{f}}(y) + c_{1} H_{1}(z)$$

pure hadronic shower

π^0 produced in *first* interaction

π^0 produced in *later* interactions

3×6 parameters: <α>, <β>, σ_α, σ_β, $\langle f_{\text{dep}} \rangle$, $\sigma(f_{\text{dep}})$

mean and widths of 2 shower class fractions

lateral part:

$$T(r) = \frac{2 r R_0^2}{(r^2 + R_0^2)^2}$$

- R_0: log-normal distribution in units of Moliere radius
- photons, electrons: n=2
- hadrons: n=1

$$\langle R_0(E_{\text{inc}}, z)\rangle = \left[R_1 + (R_2 - R_3 \ln E_{\text{inc}}) z\right]^n$$

$$\frac{\sigma_{R_0}(E_{\text{inc}}, z)}{\langle R_0(E_{\text{inc}}, z)\rangle} = \left[(S_1 - S_2 \ln E_{\text{inc}})(S_3 + S_4 z)\right]^2$$

7 parameters: $R_1, R_2, R_3, S_1, S_2, S_3, S_4$

Isolated Track Data

- Minbias (gmbs0d) up to Aug 2004: **21M events**
  - not enough high momentum tracks in the central region
- JET_CALIB (gjtc0d) up to Aug 2004: **16M events**
  - collected mostly with 4 and 7 GeV trigger thresholds

tower number	momentum range (GeV/c) ≥ 2	0.5-2	2-3	3-5	5-8	8-12	12-16	16-24	>24
0	101906	329537	11846	64676	16578	8015	629	116	45
1	109072	345385	12726	68439	17704	9262	754	147	39
2	114259	359959	13951	69419	18595	11170	914	169	41
3	115352	365974	15181	65847	19720	13125	1195	245	37
4	114795	366485	16870	59926	21898	14185	1582	280	52
5	118292	380410	20126	53818	26544	15038	2242	463	61
6	119588	388367	23670	47028	30777	14460	2977	597	76
7	126830	427403	30812	42726	34770	13728	3907	802	85
8	96483	445245	38401	26230	21509	7066	2636	566	72
9	55529	439577	38101	14241	2607	444	90	38	7
10	78510	501283	52699	21349	3754	570	94	32	8
11	121194	552756	78114	34826	6926	1050	195	65	13

suitable for tuning

- Special single track trigger runs 185598 and 185599: **1.3M events**
  - collected with 7 GeV threshold

All in total some 100 events at 20±4 GeV/c in the towers 1-4.

- Tracks statistics sufficient for lateral tuning up to 20 GeV/c.
- Not enough tracks for reasonable tuning of absolute response at p>16 GeV/c.

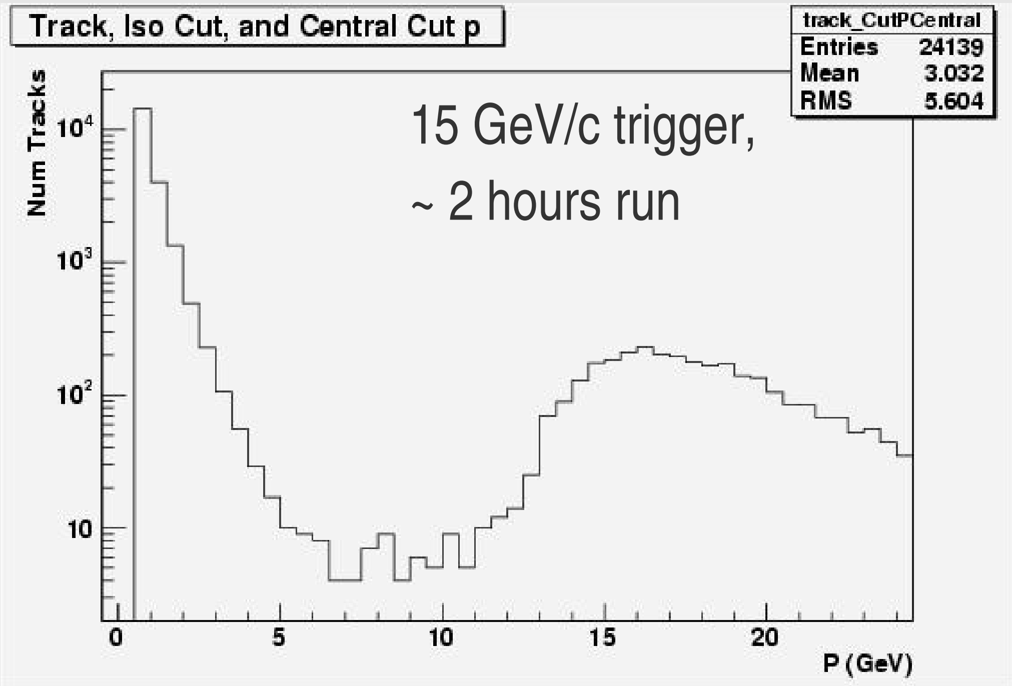
Isolated Track Data (2)

- We requested special track trigger runs with higher p_T thresholds 10, 15 GeV/c.
- Single track trigger now improved and included in regular trigger table:
  - **end-of-store data** collected at instantaneous luminosities < $4\times10^{31}cm^{-2}s^{-1}$, no prescale

- JET_CALIB data accumulated so far after 2004 shutdown:

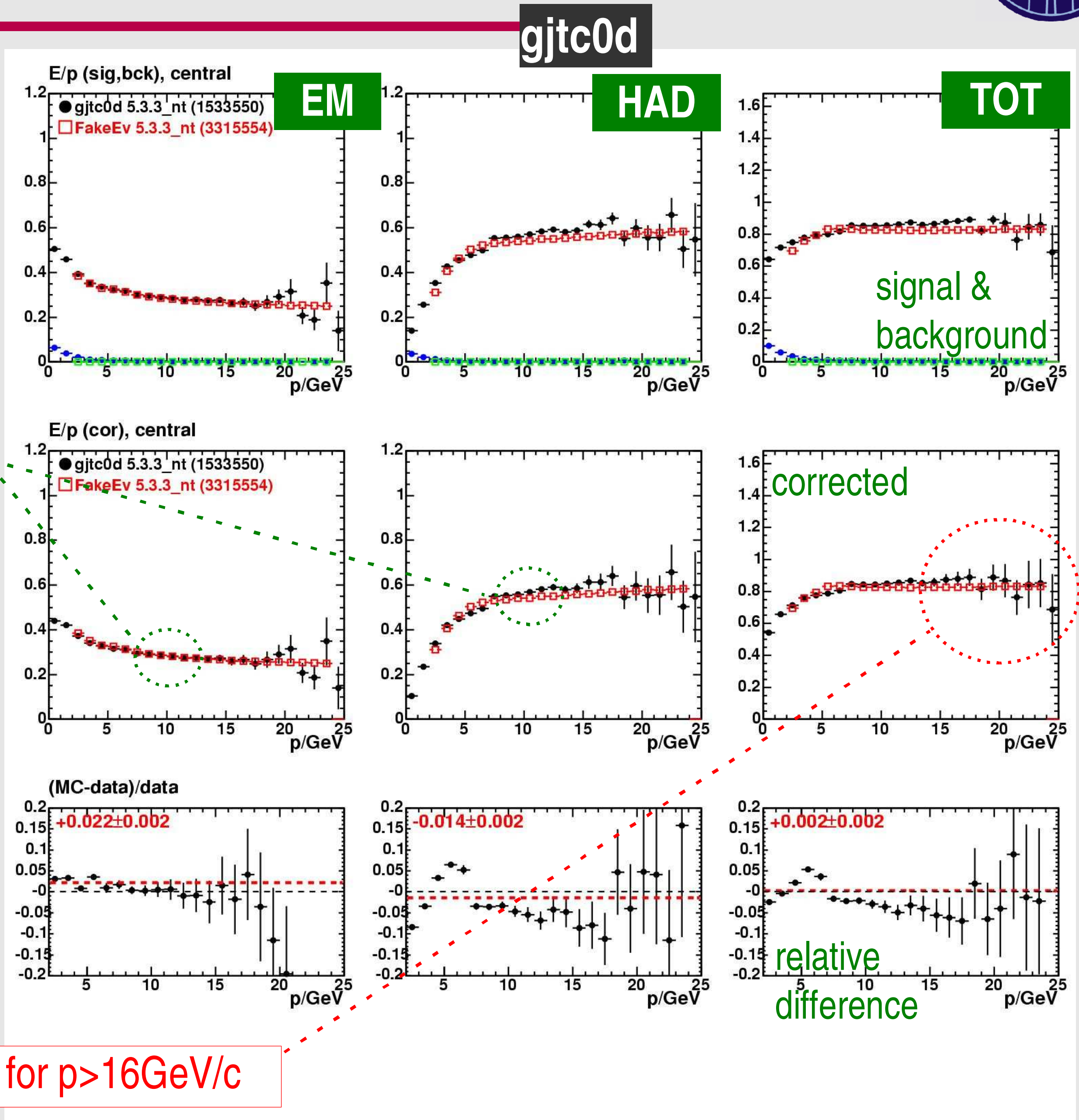
gjtc0e	~3.6M events
gjtcs{1,2}	~1.4M events

- Brand new samples still need better calibration and are not yet included in our response studies.
- We are waiting for more data...



E/p in the Central Part

Single isolated tracks response:
- inner 81% of target tower
- no extra track in 7x7 cluster
- no extra CES cluster
- exclude towers with complicated geometry or cracks.



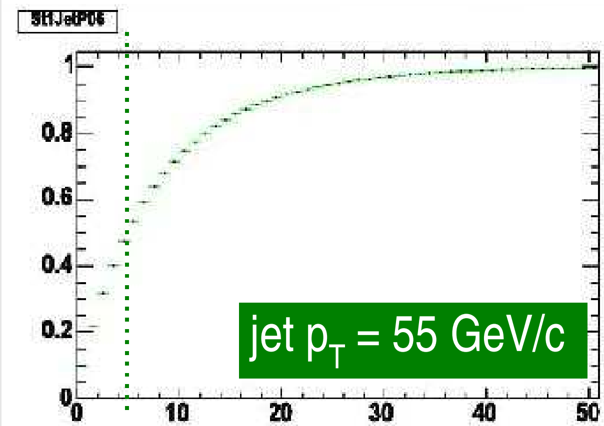
- MC tune (in-situ data <5GeV/c) works "well" up to 20 GeV/c!
  - EM: excellent agreement
  - HAD: reasonable agreement, but MC response too low at high p.
- Refined tuning with in-situ data available should significantly improve the situation at high momenta, with direct impact on absolute correction uncertainties.

- Still need much more data for p>16GeV/c

Hadronic Lateral Shower Profile

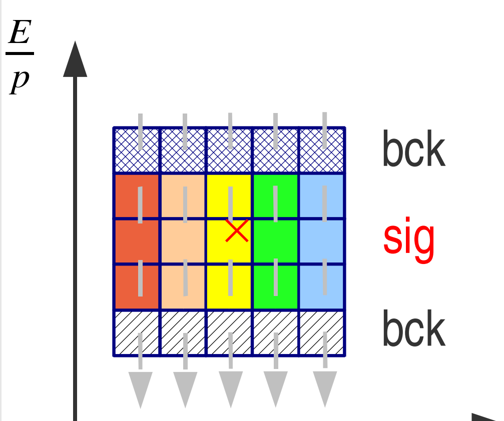
- Gflash hadronic lateral shower profile was tuned in the past using Minbias data up to p=2.5 GeV/c (limitation by statistics)
  - works reasonable up to 5 GeV/c
  - for p>5 GeV/c we still use H1 default
- Currently we have an unreasonable (unphysical) parameter discontinuity at 5 GeV/c
  - transition from wide → very narrow shower cores
- Many physics analyses use jets containing higher momentum tracks
  jet p_T = 55 (255) GeV/c: 50% (75%) of tracks have p_T > 5 GeV/c

fraction of tracks with $p_T < p_T^{max}$(track)

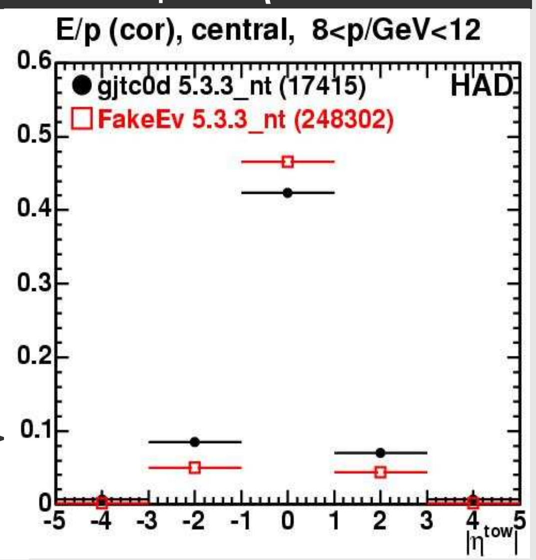


p_T^{max}(track) (GeV/c)

Experimental profile: E/p vs η^{rel}



$$\eta^{rel} = \frac{\eta(\text{track}) - \eta(\text{tower center})}{\eta(\text{tower width})/2}$$

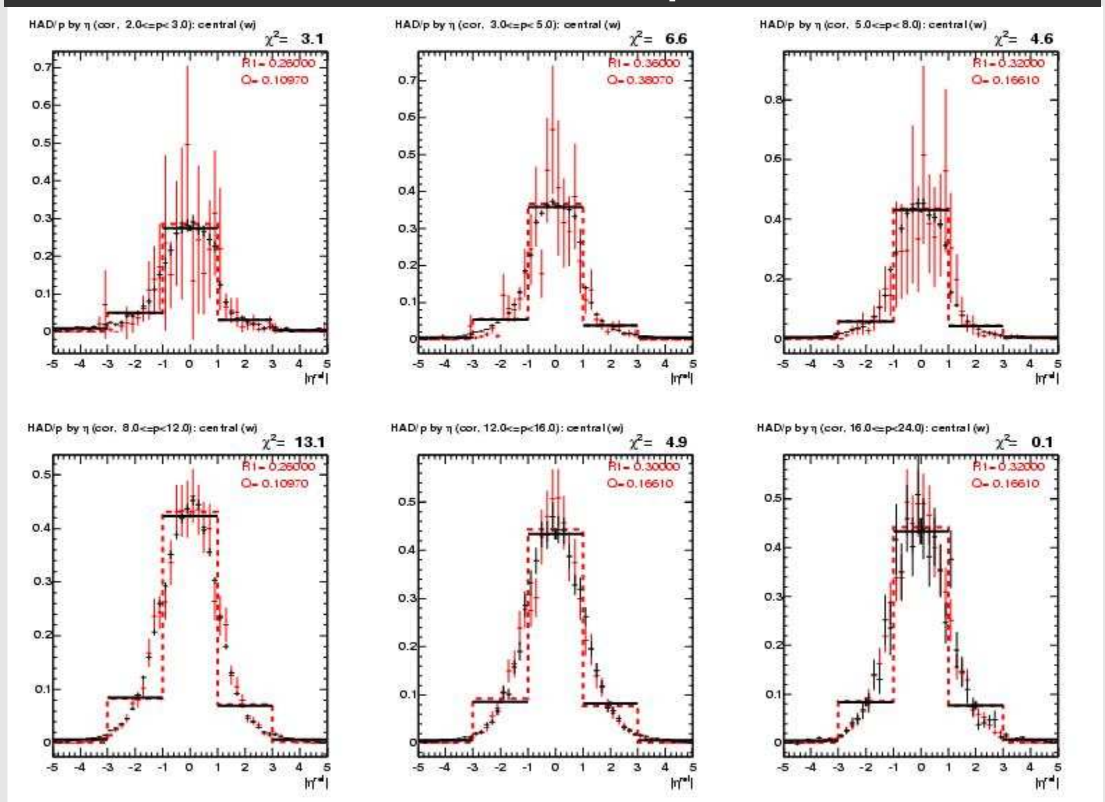


MC profiles at high momenta are too narrow.

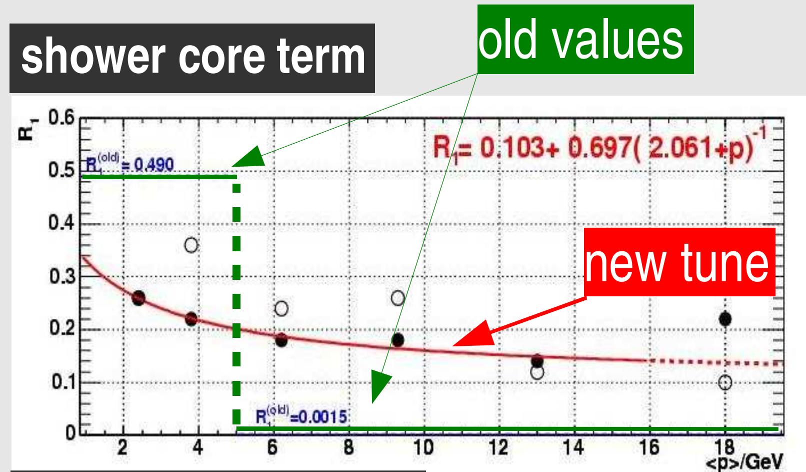
- Overestimate of jet energies: introduces negative bias in absolute corrections (relevant for analyses which do not apply OOC corrections)
- Direct impact on OOC corrections uncertainties: Making profiles wider means decreasing current deficit (δ_{OOC}>0) of energy flow in PYTHIA and HERWIG outside jet cone.

Hadronic Lateral Shower Profile (2)

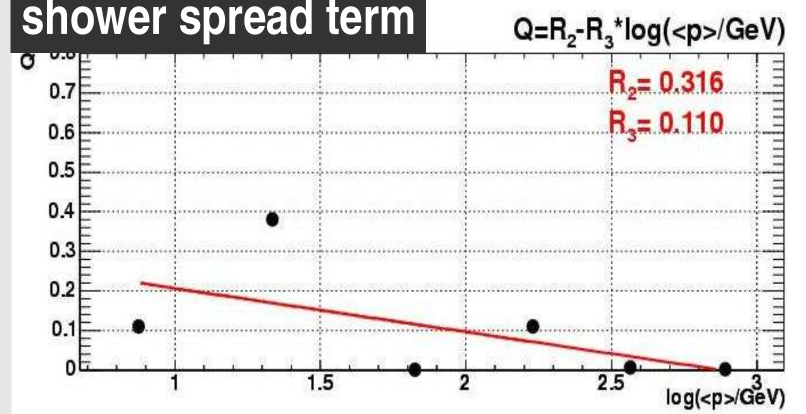
CHA lateral shower profiles:



shower core term



shower spread term

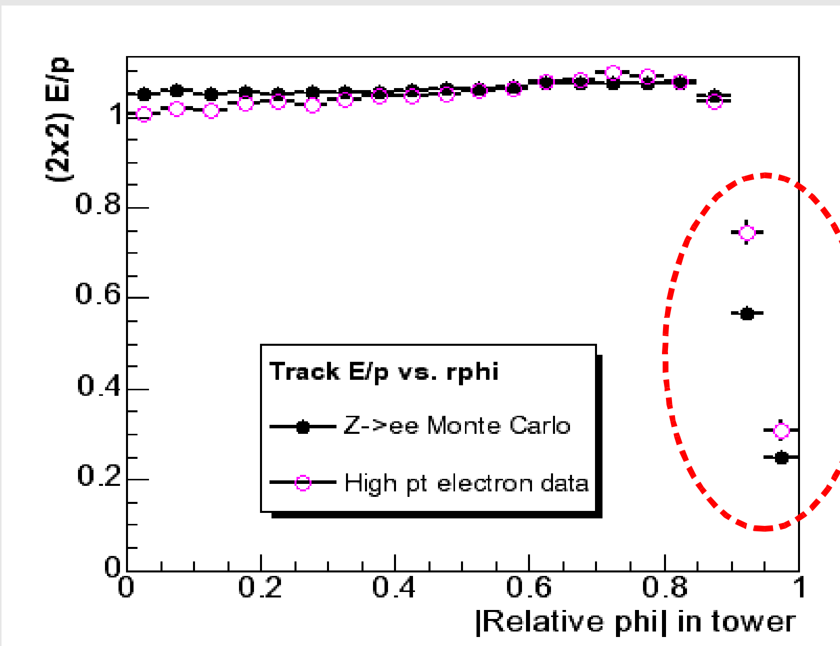


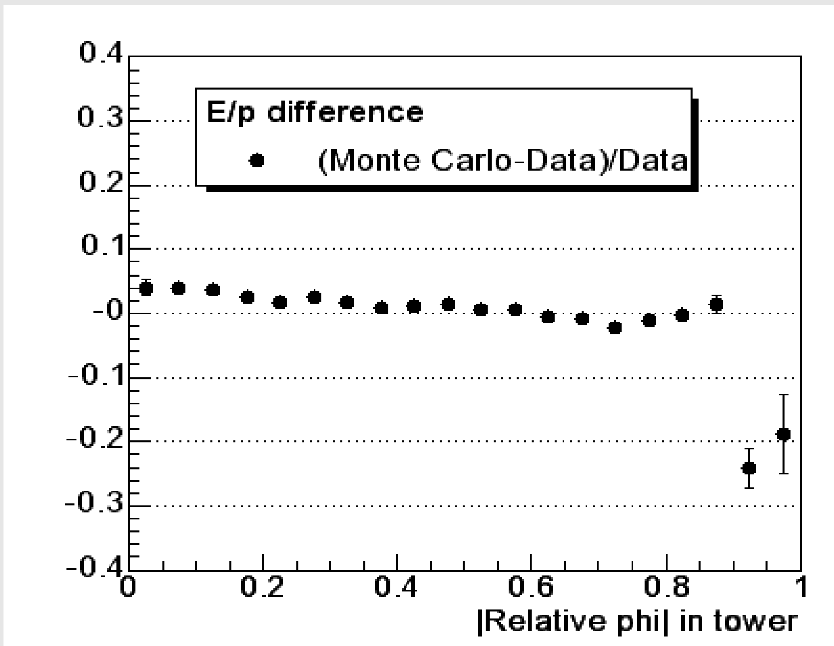
For Gen-6 we have enough isolated tracks to perform a **consistent tuning** up to 20 GeV/c.

...to be completed soon.

Electron Response

- Have to confirm lateral electromagnetic shower profile.
- ϕ cracks:
  - Calorimeter has "blind" cracks between towers due to read-out system.
  - $Z \rightarrow e^+e^-$, "electron+track" analysis, no CES fiducial requirement for one leg





- Crack response underestimated by MC.
- Also relevant for $\pi^0 \rightarrow \gamma\gamma$ component in jets!

Improvements (2)

Plug analysis and simulation:

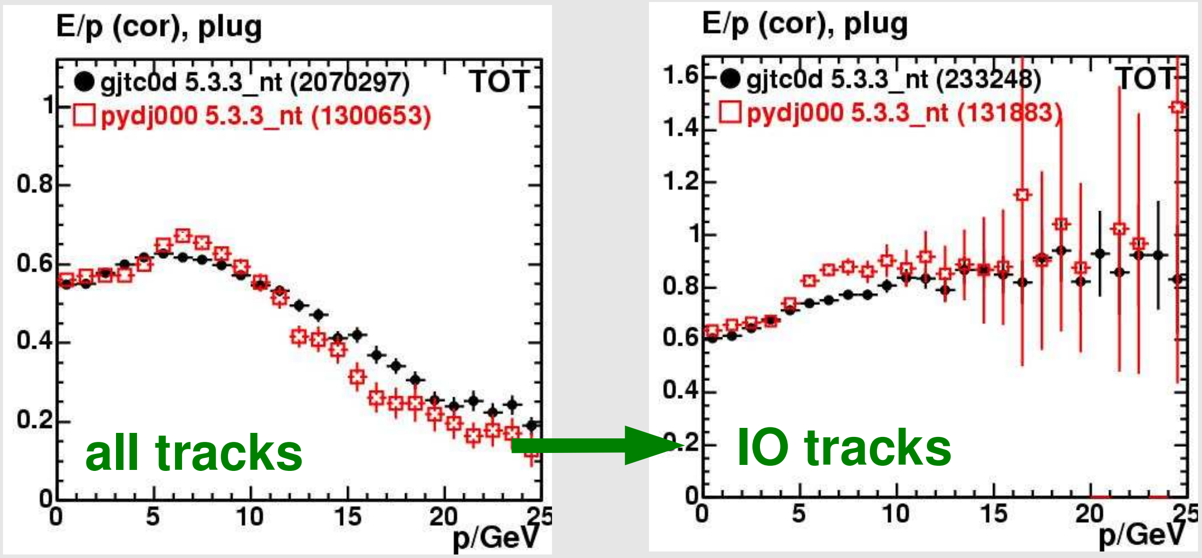
- We are working on optimizing the E/p measurement (background, track resolution)
- Single track data collected so far already allows to explore momentum range 5-10GeV/c for tuning of absolute response. Need much more statistics at higher momenta.
- Lateral profile tuning is feasible up to 20 GeV/c with the data collected so far.
- We want to eliminate any disagreement in di-jet balance between data and MC, thus decreasing the uncertainty of relative corrections and reducing possible biases. We are aiming at a set of relative corrections identical for both data and MC.
- Ideally: Get rid of relative corrections, introduce absolute corrections for plug jets from "first principles"

Single Particle Response in the Plug

Measurement of E/p in the plug is more complicated:

- Energy measurement:
  - background: much higher than in central, towards beam line increasingly non-linear in η
  - more passive material
  - PES useful for background suppression: not used as yet because of biases in the simulation: has recently been improved for Gen-6
- Momentum reconstruction:
  - mostly silicon-stand-alone (SISA) tracks
  - lower reconstruction efficiency, poor momentum resolution

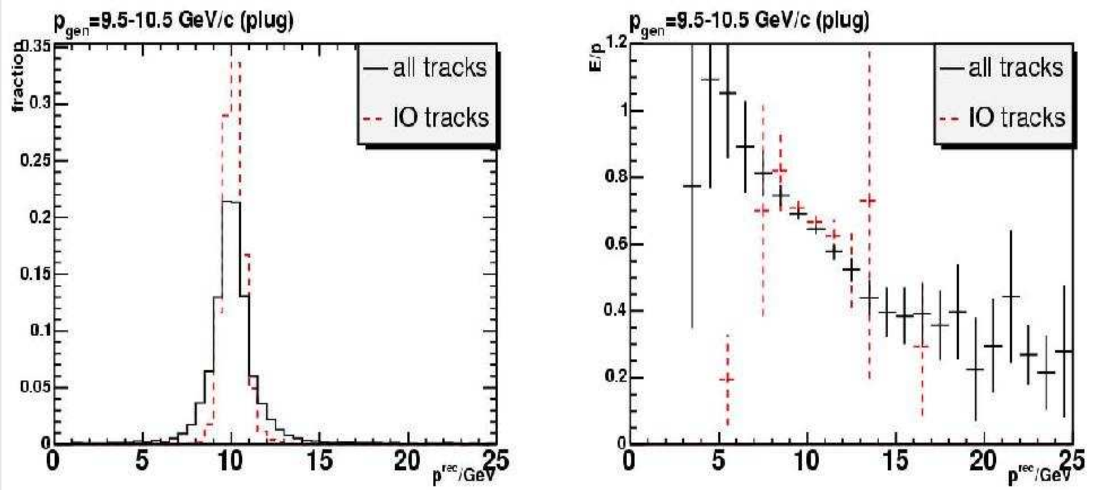
- Resolution effects heavily distort response measurement in both data and MC.

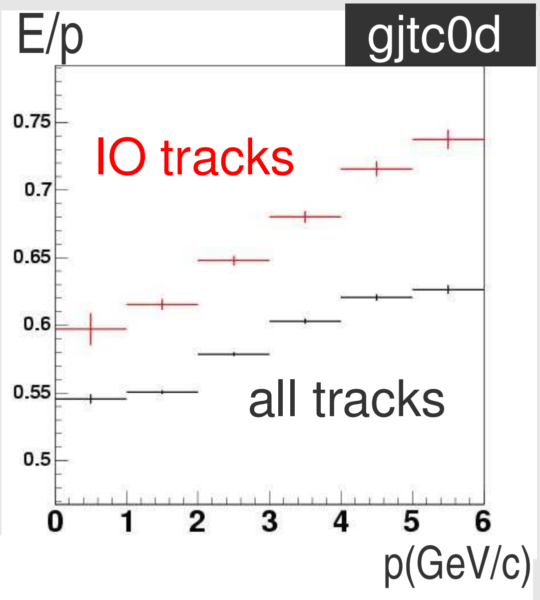


E/p Resolution in the Plug (1)

- Resolution effects convoluted with $1/p^2$ type spectrum: fractional population of fake (too low) E/p values is larger at higher momenta than at lower momenta
  $\rightarrow$ unphysical negative E/p slope at high p

E/p response of generated 10 GeV/c pions (FakeEv)





- Effect not dramatic at low p (hence not noticed as yet) but still a 15% bias for p<5GeV in data and MC.
- Resolution of SISA tracks probably too bad for reasonable plug response analysis.
- What is the impact on past tuning results? What is the impact to relative corrections? (not necessarily a problem if resolution in data and MC agree)
- IO tracks seem to be the remedy.
- Can we also select better quality SISA tracks?

E/p Resolution in the Plug (2)

gjtc0d

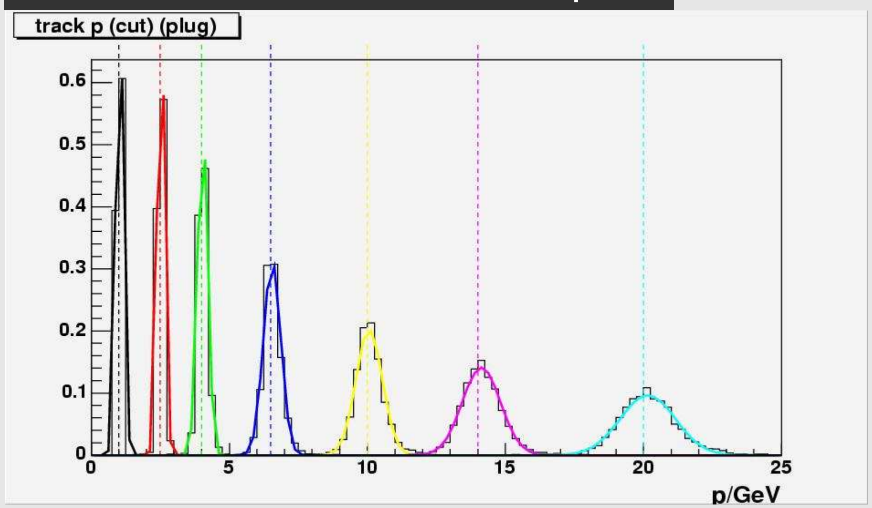
	tower number	≥ 2	0.5-2	2-3	3-5	5-8	8-12	12-16	16-24	>24
IO	12	55123	155289	33863	16738	3703	639	124	43	10
IO	13	60042	69551	29681	21791	6617	1492	307	119	35
IO	14	146406	117826	68410	54821	18081	3916	778	297	97
IO	15	55311	26977	22454	21606	8462	2106	451	191	37
S ISA	16	746687	588297	352425	257514	92407	26494	7335	4645	4579
S ISA	17	673458	280253	282987	234674	99846	32762	9707	6256	5750
S ISA	18	548953	72329	198249	190427	94730	36800	12247	8002	6851
S ISA	19	263477	414	56147	95123	58986	27702	10204	7463	6495
S ISA	20	12478	0	40	4217	3680	2046	910	715	712
S ISA	21	178	0	0	14	46	43	22	20	23

(momentum range (GeV/c))

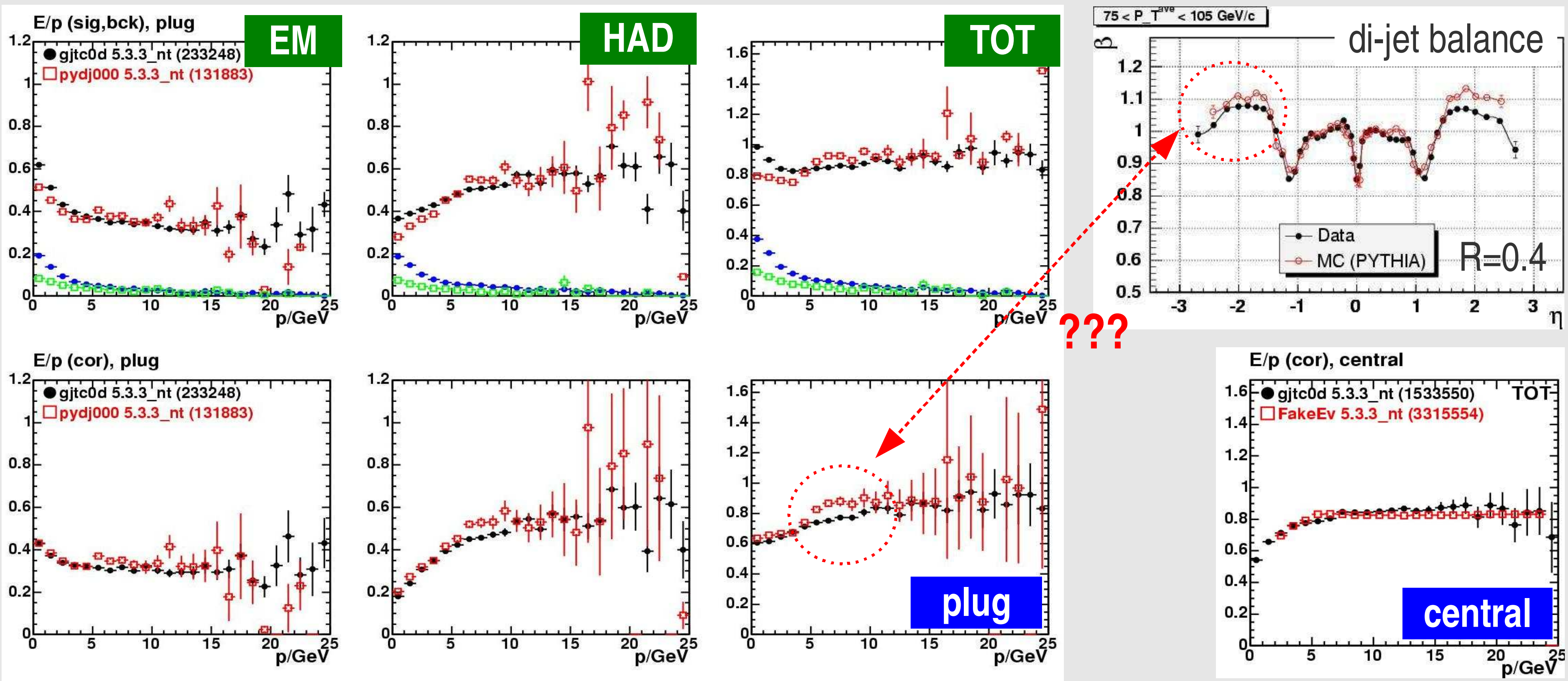
- Tower 13-15 usable for analysis.
- IO track statistics sufficient for lateral profile tuning in the plug up to 20 GeV/c
- Tuning of absolute E/p response:
  - need more data for p>12 GeV/c

- Still sizable migration effects expected for IO tracks.
- Requiries careful choice of bin widths of E/p distributitons in particular in view of aiming at absolute corrections in the plug!
  - Avoid too fine binning, need variable bin widths increasing with p

Resolution of IO tracks vs. p



E/p in the Plug



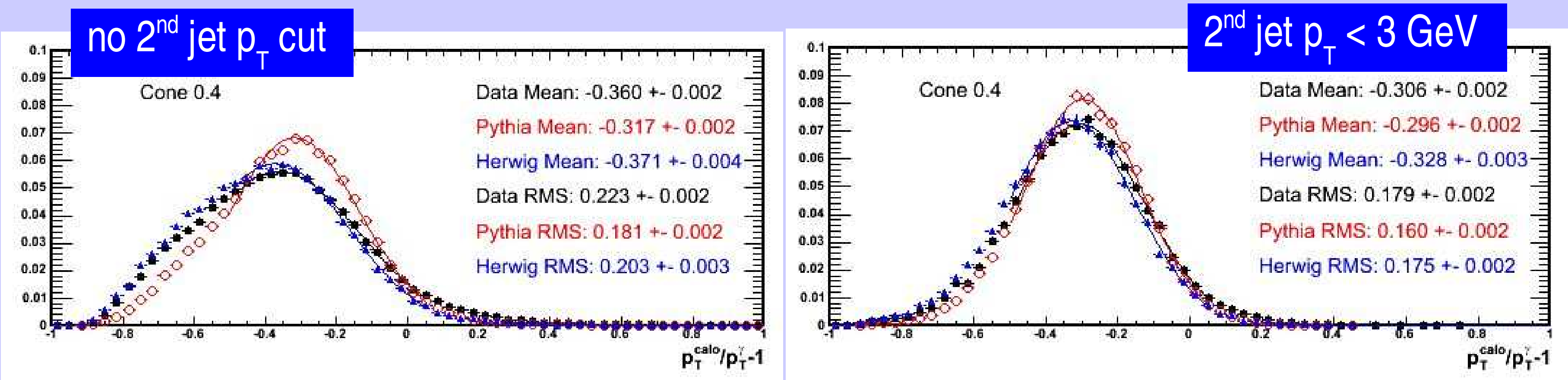
- Plug response using IO tracks is much more consistent with central response.
- Is PYTHIA photon-jet balancing related to wrong E/p tuning (f_{dep}, $\tilde{e}/\tilde{m}$, $\tilde{h}/\tilde{m}$) in plug?

  If so, we have <u>now</u> enough statistics to make better job at 5 - 10GeV/c.
- We are cross checking observation using other generators to exclude physics effects as explanation.
- In leading order, lateral profile tuning is almost decoupled from absolute E/p response problems.

Improvements (3)

Physics effects and generators:

- Data and MC disagree up to 3% in the γ-jet balancing. Agreement depends e.g. on analysis cuts.



→ Better understanding of the physics effects helps to reduce JES uncertainty w/o any tuning of the detector simulation

- Need to understand impact of event topology on di-jet balancing
- UE model for HERWIG fails to describe data, needs improvement (tuning is in progress).

Improvements (4)

Optimization of jet clustering:

- better algorithms?
  impact of gluon radiation on jet finding (JetClu is not infrared safe)
  Midpoint, k_T (more crucial for QCD studies)

Jet energy resolution:

- H1 algorithm:
  - Partially replaces calorimeter tower energies by momenta of associated tracks.
  - Scale dependence of calorimeter response significantly reduced.
  - Studies on improvement of di-jet mass in progress.
- JCOR2K (CDF-I):
  - Tower energies includes track information according to tower classes (track, photon, mixed, not assigned)
  - Improvement in γ-jet events in Run-I: $83\%/\sqrt{p_T} \rightarrow 64\%/\sqrt{p_T}$
  - Is beeing investigated in Run-II.

Improvements (5)

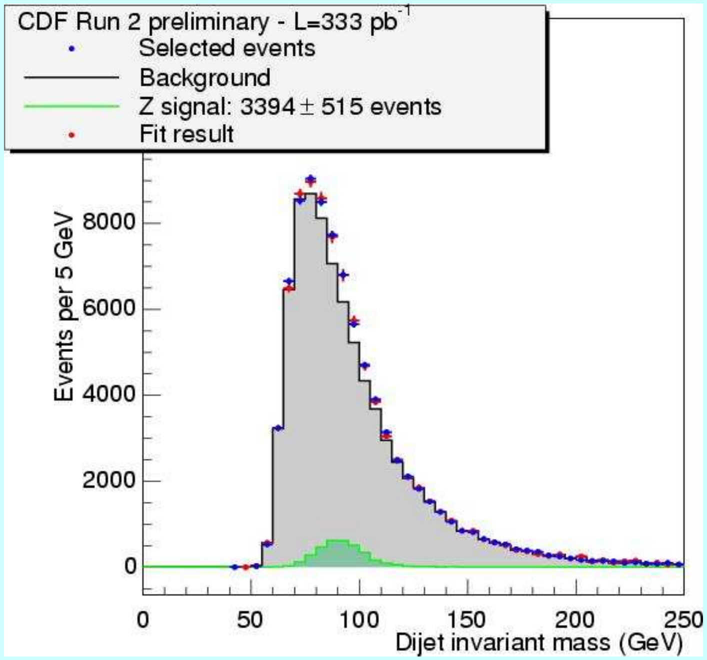
- **b-jet energy corrections and resolution:**

  $Z \rightarrow b\bar{b}$:

  - Z peak might be a chance to formulate **generic corrections** for b jets.
  - Recent studies very promising: Z peak was extracted from data with a statistical precision of <2% .

  Hyperball algorithm:

  - inspired by Higgs Working Group ($H \rightarrow b\bar{b}$)
  - uses correlation between jet E_T and other observables (missing E_T, L_{xy}, ...) to estimate corrected jet E_T.



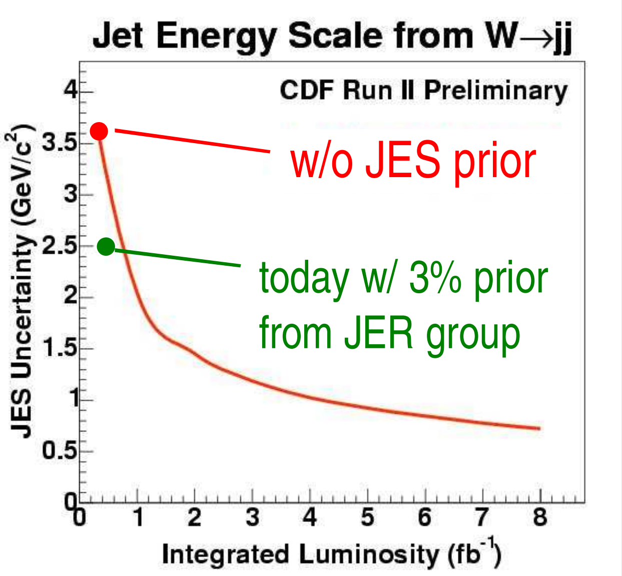
See Tommaso's talk.

Conclusions

- CDF has established jet energy scale corrections that proved to be solid.
- JER group under leadership of Anwar B., Beate H., Florencia C., Ken H., Lina G. (jet corrections) and Tommaso D. (jet resolutions) with the dedicated work of many people greatly reduced the uncertainties:

	20 ... 300 GeV
absolute corrections:	1.8% ... 2.9%
OOC corrections:	6% ... 0.8 %

- Top mass: reduction of JES uncertainties is important for all methods and also contributed to the world's single best measurement (318/fb). Impact on $W \rightarrow jj$ in-situ calibration method still significant for 1/fb analysis but will decrease at higher integrated luminosities.



Outlook

- Many physics working groups are benefiting from better JES determination.
  We need more man power for future improvements.
- Improvement of calorimeter simulation is crucial to further reduce the JES uncertainty.
  Soon J., Yeon-Sei C., Geumbong Y., Shawn K., Ken H., Pedro M.F. are working on it.
- We need to have the improvements included into Gen-6 by end of this year to become effective for Summer 2006 conferences.
- Time scale given by lateral profile tuning (first version for central almost done) and availability of new single track data. Everything should be finished before Dec. 1.
  - Single particle response analysis (high p, high η): Oct. 1 (final data) + 1 month (calib.)
  - Final absolute and lateral response fine tuning & electron response: +1 month
  - Simulation integration: before Dec. 15
- Production/validation: Int. + <3 months (?). We would like the top group to work on validation of JES in γ+jets, Z+jets, W+jets.

JER task list:

http://www-cdf.fnal.gov/internal/physics/joint_physics/tasks/jet_energy_tasklist.html