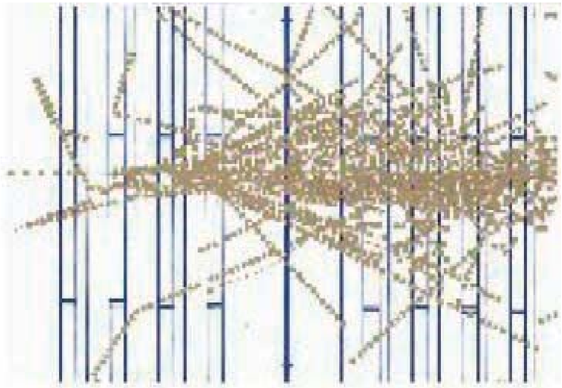


Calor 2008

XIII International Conference on Calorimetry in High Energy Physics

Operation and performance of the CDF calorimeters

Giovanni Pauletta

University of Udine

on behalf of the

collaboration

Outline:

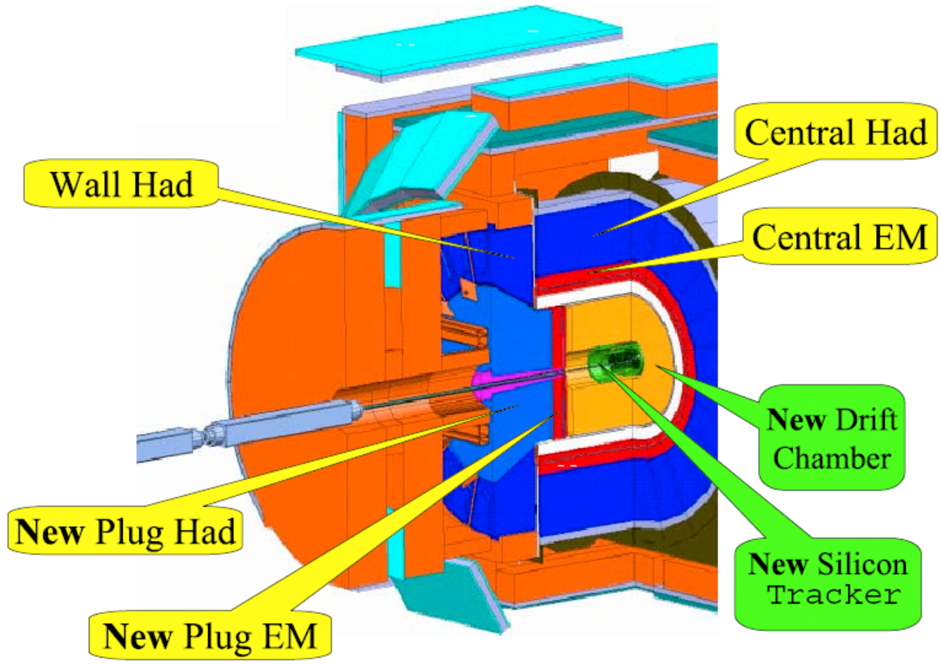
- The CDF calorimeters
- Setting and the calorimeter energy scales
- Keeping the calibrations
- Jet energy scales
- Conclusion

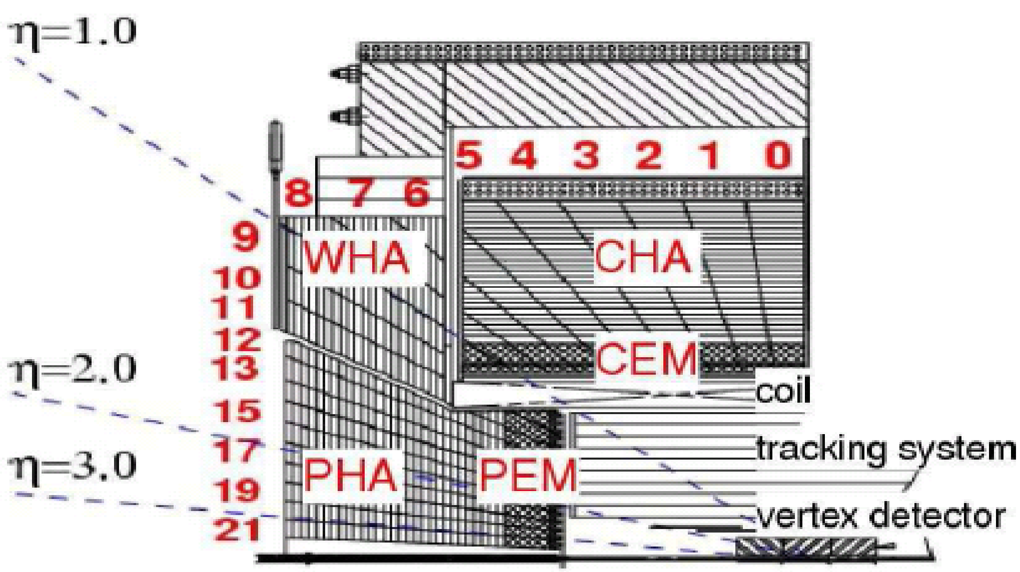
The CDF Calorimeters

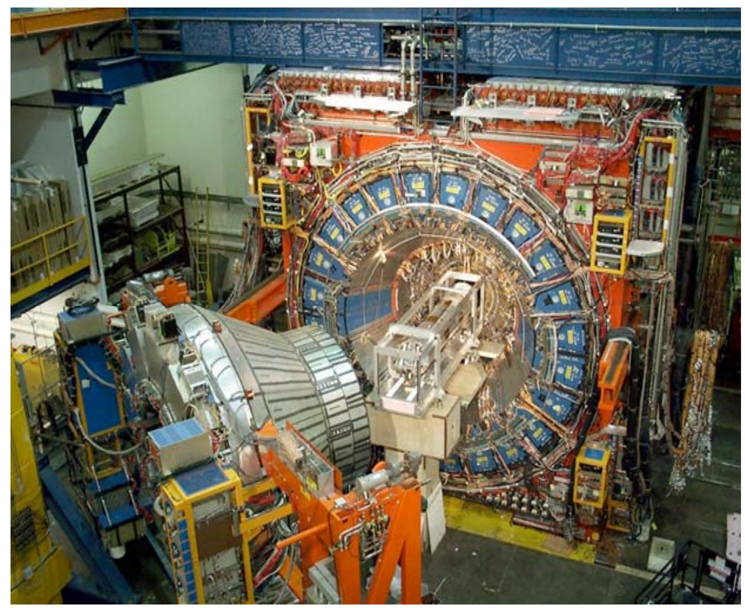
All scintillator-based sampling calorimeters

$\|\eta\|$ Range	$\Delta\phi$	$\Delta\eta$
0. - 1.1 (1.2 h)	15°	~ 0.1
1.1 (1.2 h) - 1.8	7.5°	~ 0.1
1.8 - 2.1	7.5°	~ 0.16
2.1 - 3.64	15°	0.2 - 0.6

Table 1.2: CDF II Calorimeter Segmentation

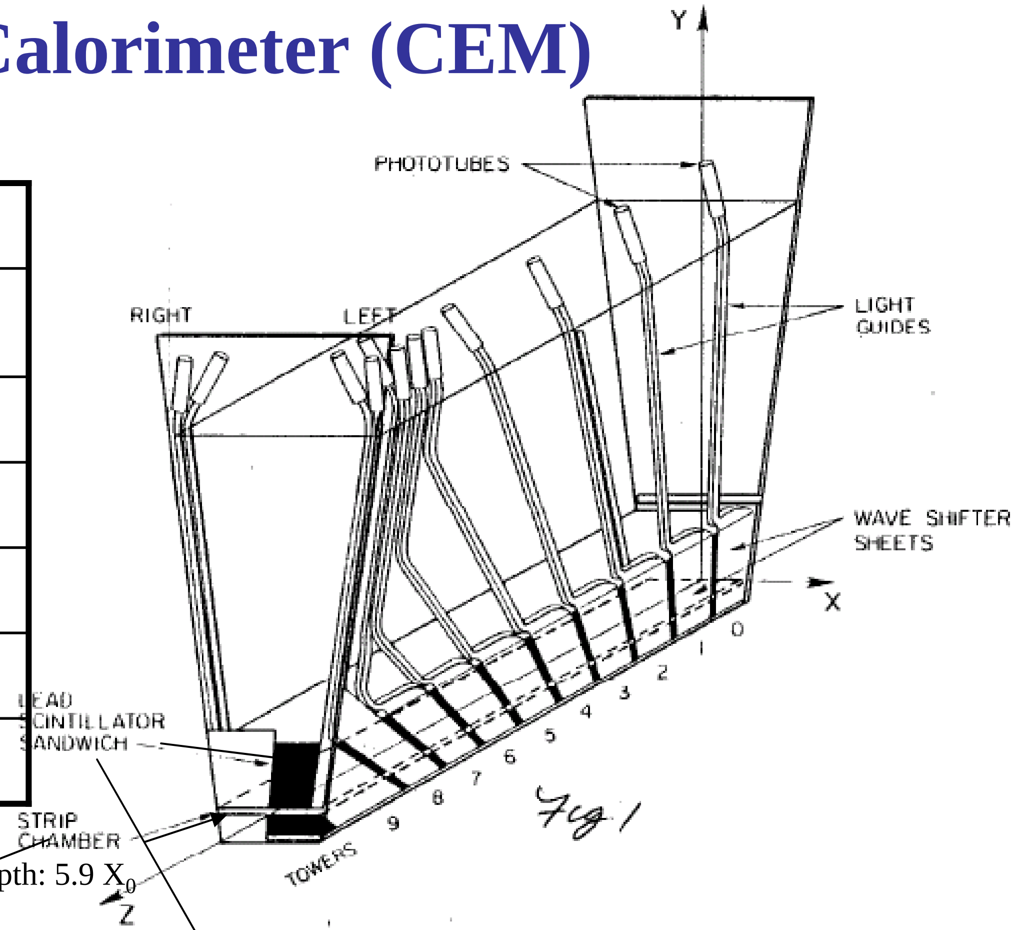






Central Electromagnetic Calorimeter (CEM)

Thickness	**$18X_0$, 1l**
Abs. (pb) layer	**1/8” (4.2 mm,0.6 X_0)**
Scint. layer	**5 mm , polystyrene (SCSN-38)**
w.l.s.	**3mm Y7 acrylic sheet**
PMT	**Ham. R580 (1.5”)**
light yield	**>100 p.e./GeV/pmt**
resolution	$13.5/\sqrt{E_T}$



depth: 5.9 X_0

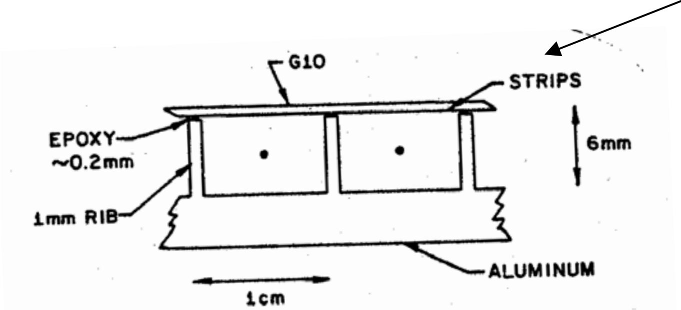
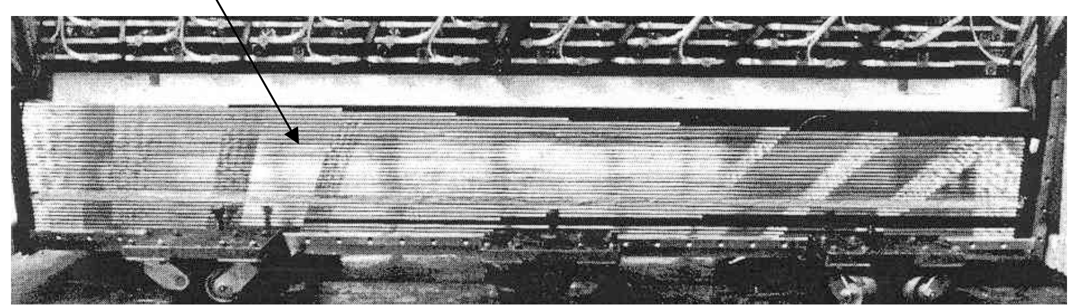
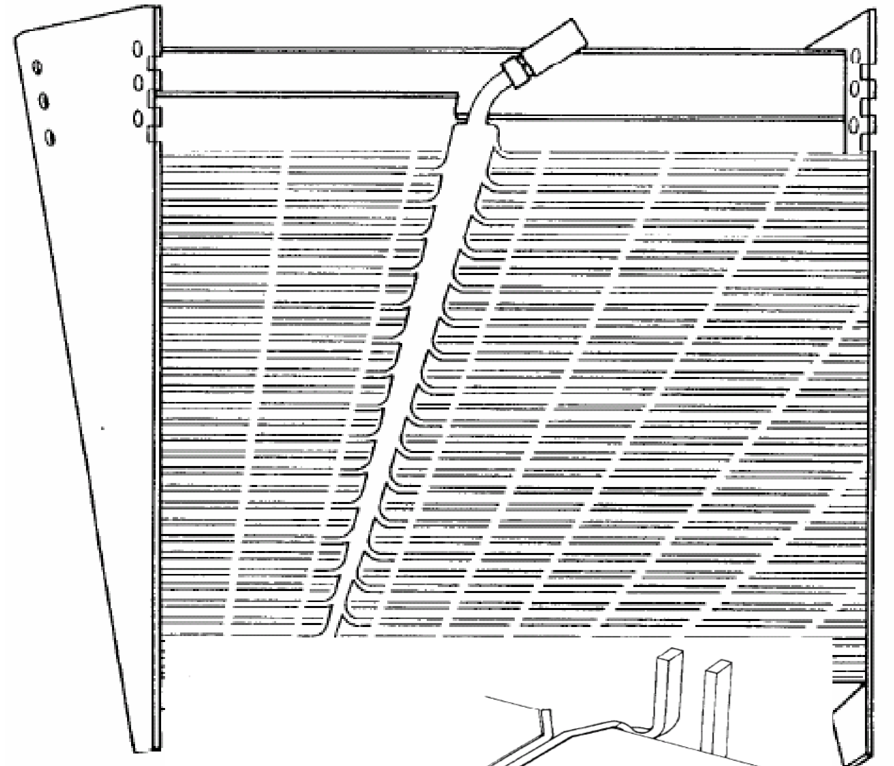


Fig. 3. Prototype strip chamber cross section.



Central Hadronic Calorimeter(CHA)

Thickness (CHA alone)	4.7 λ
Abs. (Fe) layer	**2.5 cm**
Scint. layer	**1 cm-thick , PMMA doped with 8% Naphtalene, 1%Butyl-PBD and .01% POPOP**
w.l.s.	**UVA PMMA doped with 30 mg/l laser dye #481**
PMT	**12-stage THORN-EMI 9954 +dc led**
light yield	**~20 p.e./GeV/pmt (& decreasing)**
resolution	$\sim 50\% / \sqrt{E_T}$



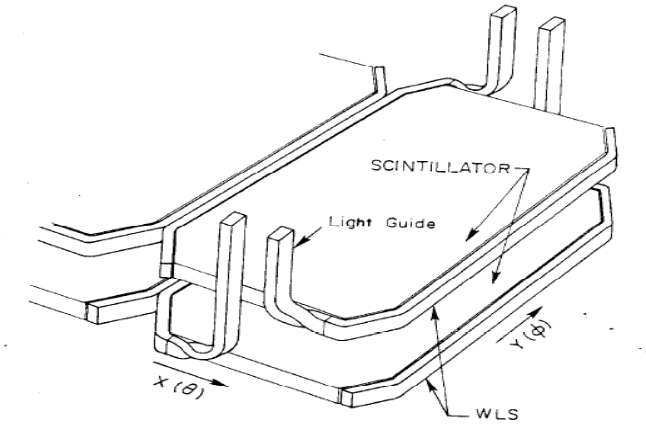


Fig. 4. Two WLS strips collect light from each scintillator layer. In the air gap between WLS and light guide, filters are inserted to ensure light output equalization for different layers of the same tower.

Wall Calorimeter (WHA)

Thickness (WHA alone)	4.5 λ
Abs. (Fe) layer	**5 cm - thick**
Scint. layer	**1 cm-thick , PMMA doped with 8% Naphtalene, 1%Butyl-PBD and .01% POPOP**
w.l.s.	**UVA PMMA doped with 30 mg/l laser dye #481**
PMT	**10-stage THORN-EMI 9954 +dc led**
light yield	**~10 p.e./GeV/pmt (decreasing)**
resolution	$\sim 60\% / \sqrt{E_T}$

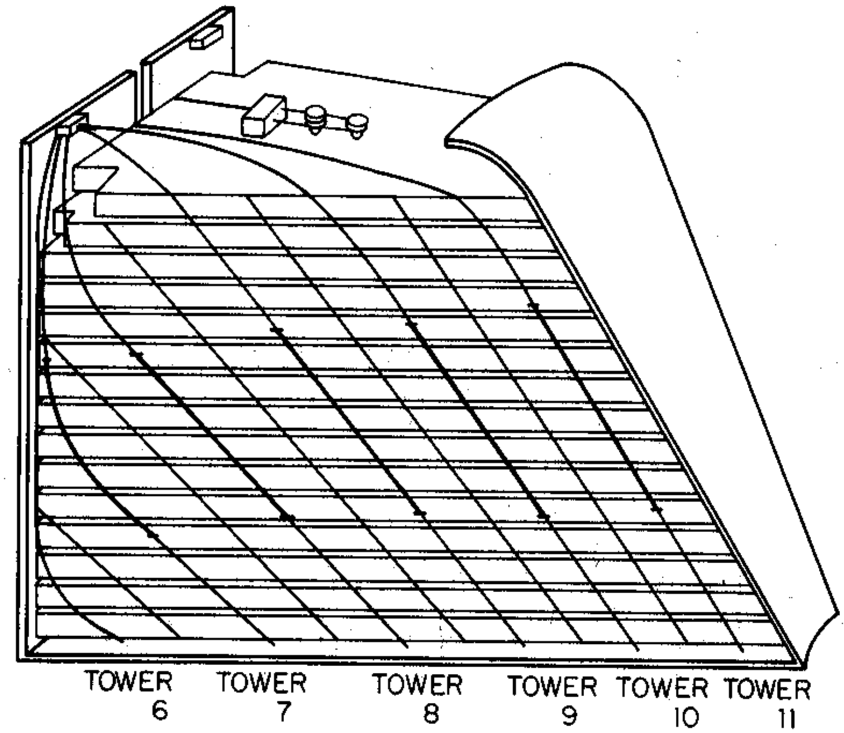
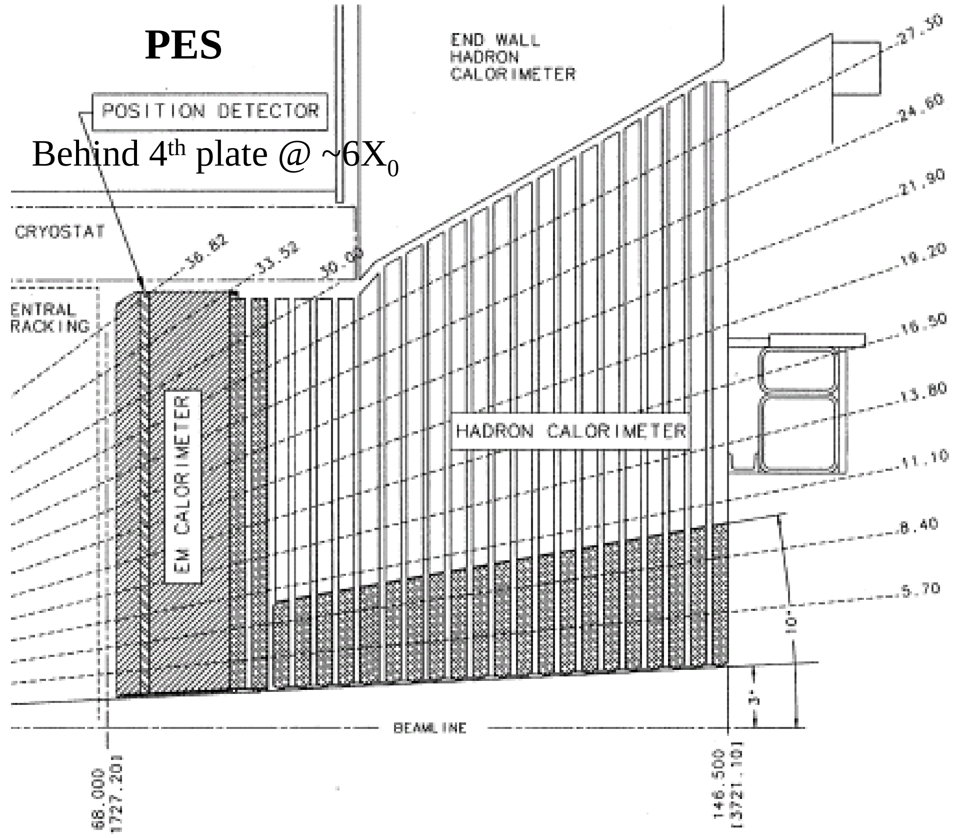


Fig. 2. Endwall calorimeter module. Module side faces are equipped with steel tubes positioned on the center lines of the towers and used for insertion of linear γ sources (section 4.2). The movable point source (section 4.3) is also schematically drawn: the source, moving inside a steel tube, traverses all the towers at a fixed longitudinal depth along scintillator centerlines.

Plug Calorimeters: scintillator – tile sampling calorimeters with w.l.s. fiber readout

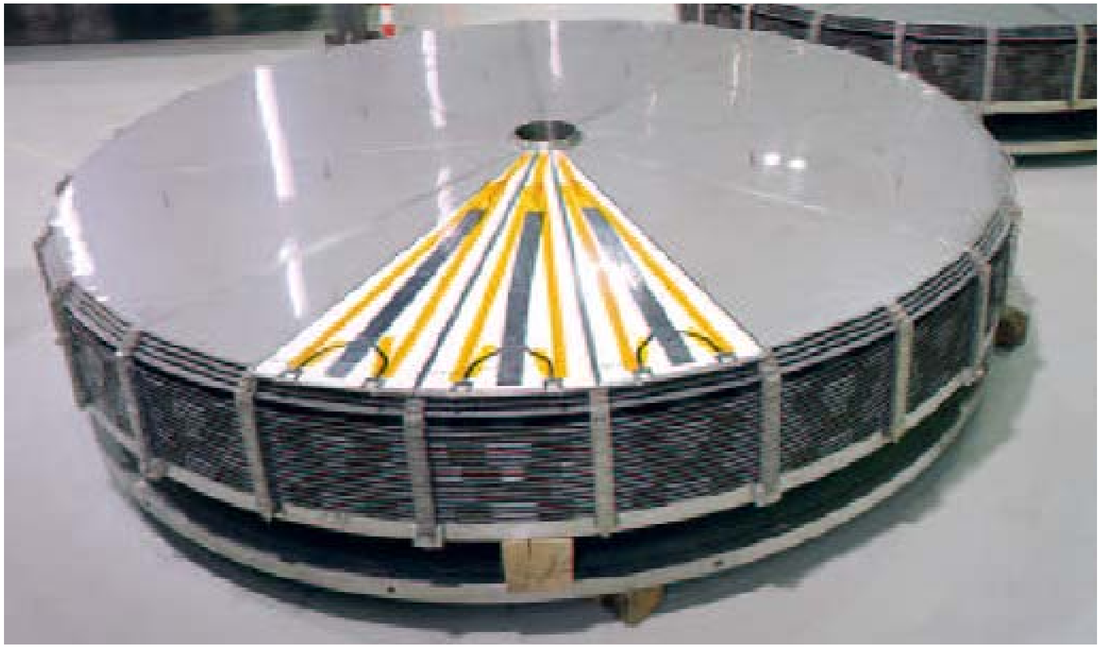
PEM and PHA detail summary

	PEM	PHA
Coverage	$1.1 < \|\eta\| < 3.64$	$1.2 < \|\eta\| < 3.64$
Towers	20 per wedge	18 per wedge
Thickness	$21\ X_0$, $1\ \lambda_I$	$7\ \lambda_I$
Density	$0.36\ \rho_{\mathrm{Pb}}$	$0.75\ \rho_{\mathrm{Fe}}$
Sampling Layers	22 + PPR PPR = Layer 1	10 mm BC408
Scintillator	4mm SCSN38	6mm SCSN38
Absorber	4.5mm Pb with 0.5mm SS covers	5.08cm Fe
Light	5 pe/mip/tile 400 pe/GeV	5 pe/mip/tile 40 pe/GeV
Light x-talk	0.5% per side	1.0% per side
σ/E	$0.16/\sqrt{E} \oplus 0.01$	$0.74/\sqrt{E} \oplus 0.04$
PMTs	Hamamatsu R4125	Hamamatsu R4125

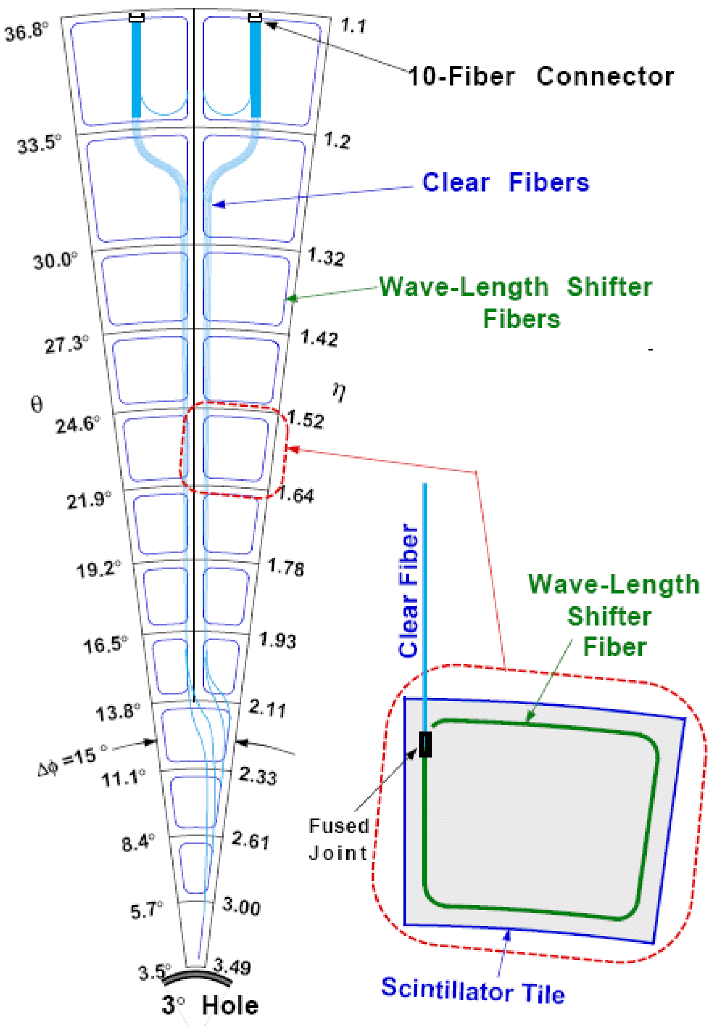


Plug Electromagnetic Calorimeter (PEM)

15º megatiles

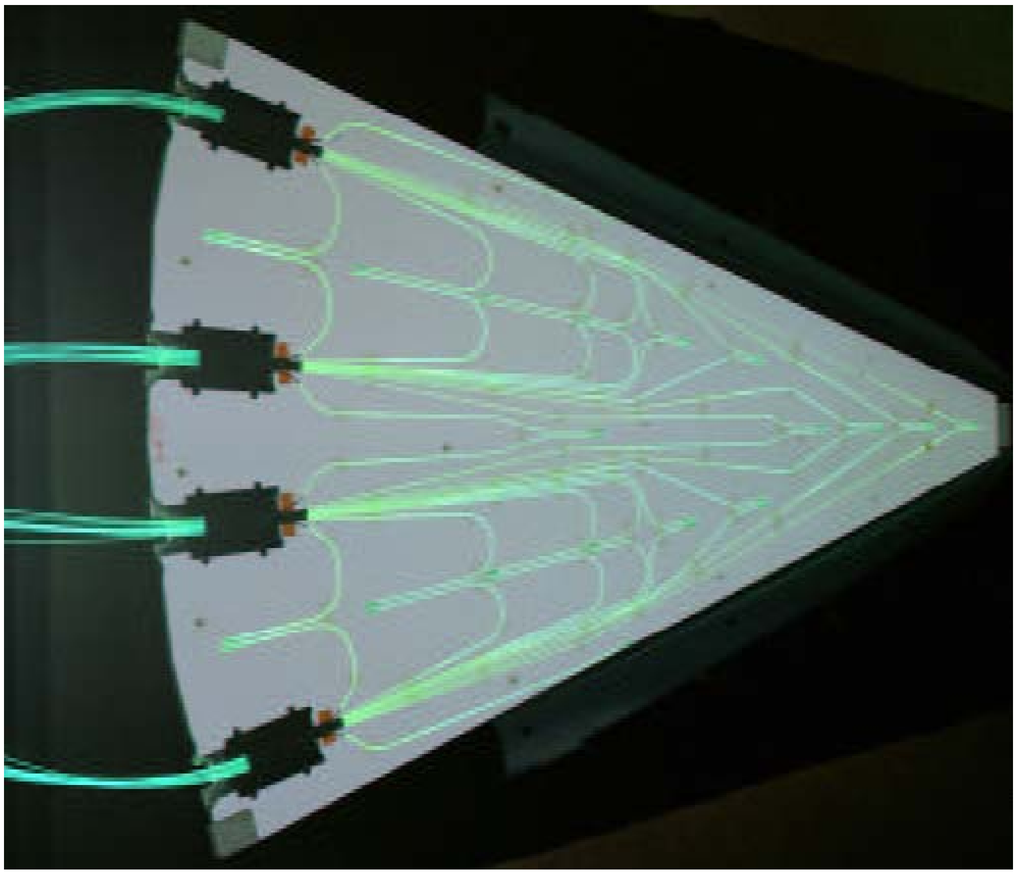


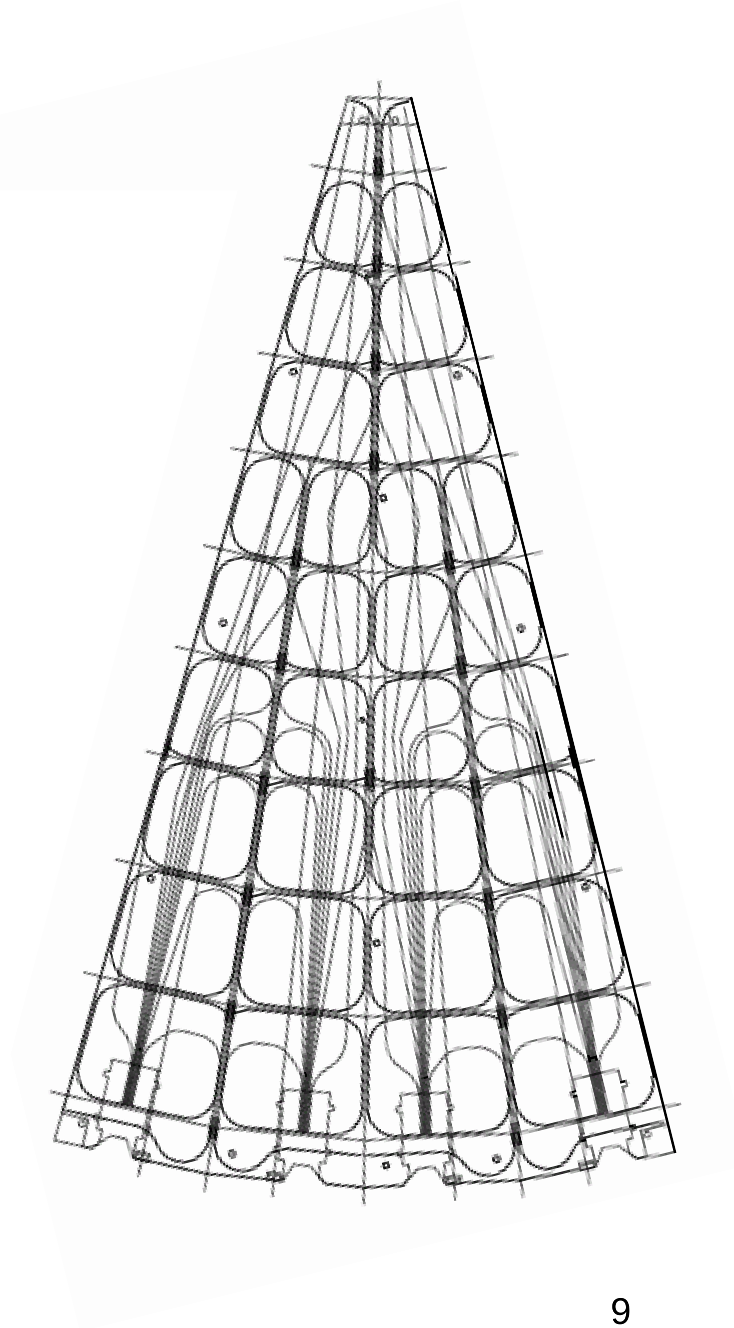
PEM megatile and plug segmentation



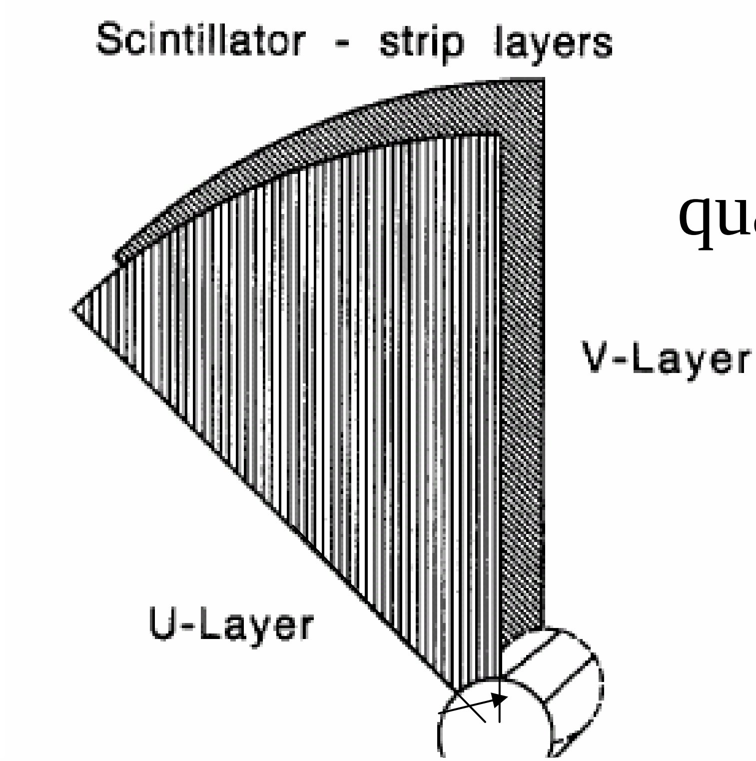
Plug Hadronic Calorimeter (PHA)

30^{o} Megatiles

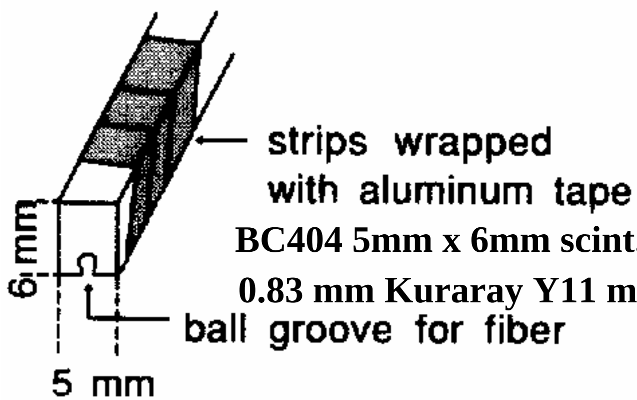




Plug Shower max detector (PES)

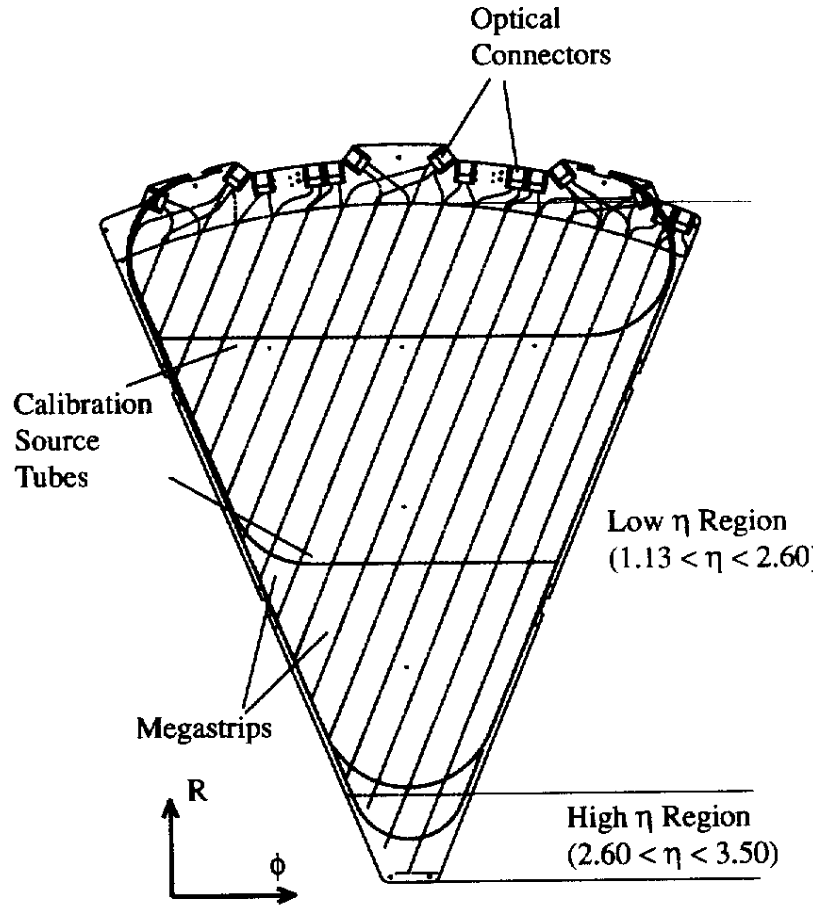


45^{o}
quadrants



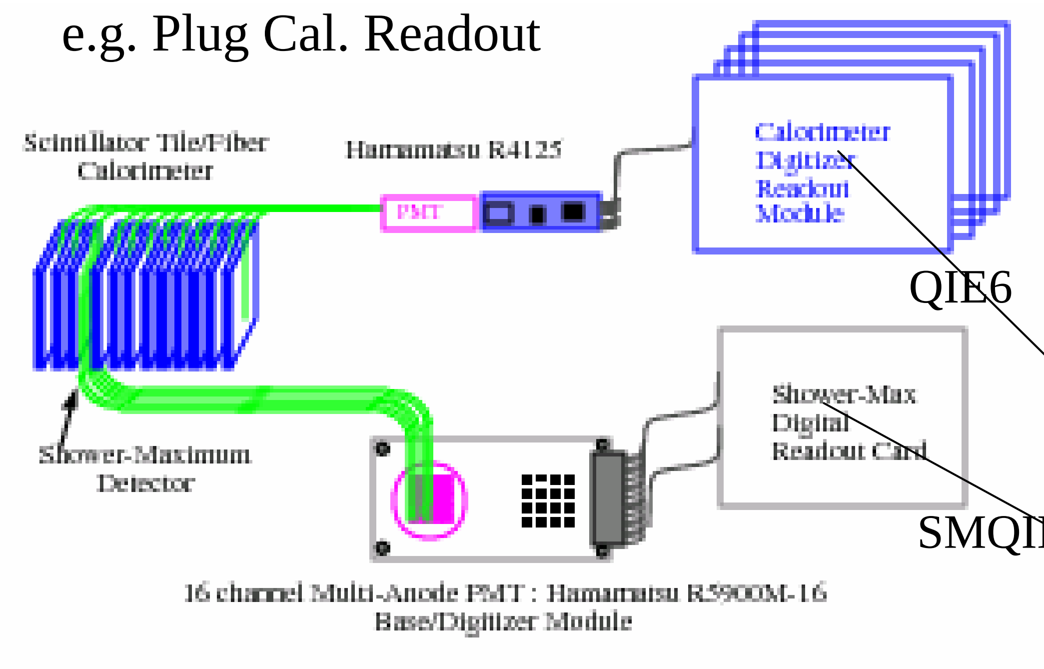
BC404 5mm x 6mm scint. srips

0.83 mm Kuraray Y11 multiclad w.l.s fibers



Calorimeter Readout:

Common design of readout electronics for most calorimeter elements:



Need more (x2) dynamic range for run II so new f.e. readout electronics based on QIE (Q-integrator and encoder): custom-built 8-range (I/2 – I/I256) current splitter / integrator / encoder. Mounted on f.e. (CAFE) card together 10-bit FADC, Q-injection circuit and FRAM

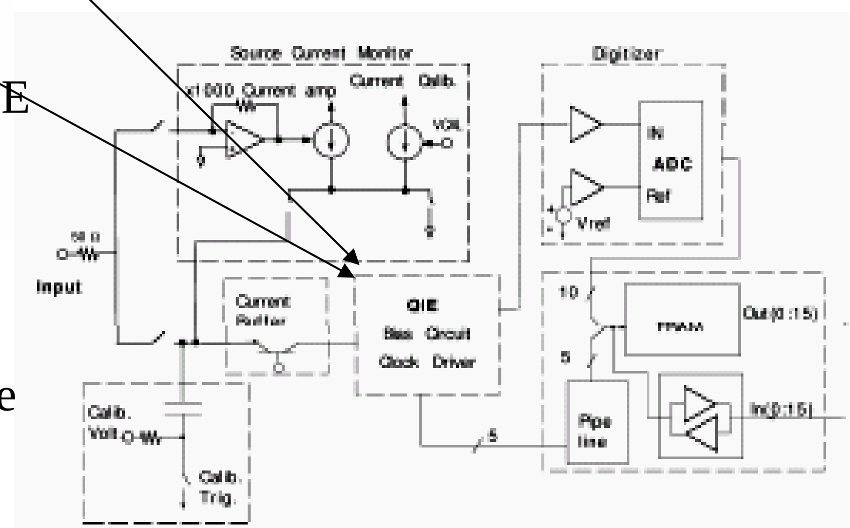


Fig. Simplified schematic of frontend (CAFÉ)card containing QIE and FADC

The CAFÉ cards are in turn mounted onto f.e. VME "ADMEM" (ADC+MEMory) [8] boards. The ADMEMs provide the Level 1 trigger with transverse energy sums using Xilinx FPGA's. They also use a pipelined Level 1 buffer 42 clock-cycles (5.5 s) deep (which provides deadtimeless readout), and four event buers for pre-decision Level 2 storage.

Calibration/Monitoring Instrumentation

Calibration systems are used to transfer calibrations from test beam and monitor stability/functionality

Sub-system	Rad. Sources	Laser /flasher	leds
CEM	Cs^{137} (?)	flasher	yes
CHA	Cs^{137}	laser	
WHA	Cs^{137}	laser	
PEM	Co^{60}	laser	
PHA	Co^{60}	laser	
PES	Co^{60}	laser	
TDC electronics		Laser	
QIE Electronics	Charge injection		

e.g. CEM

CDF Central E-M Calorimeter Calibration Systems

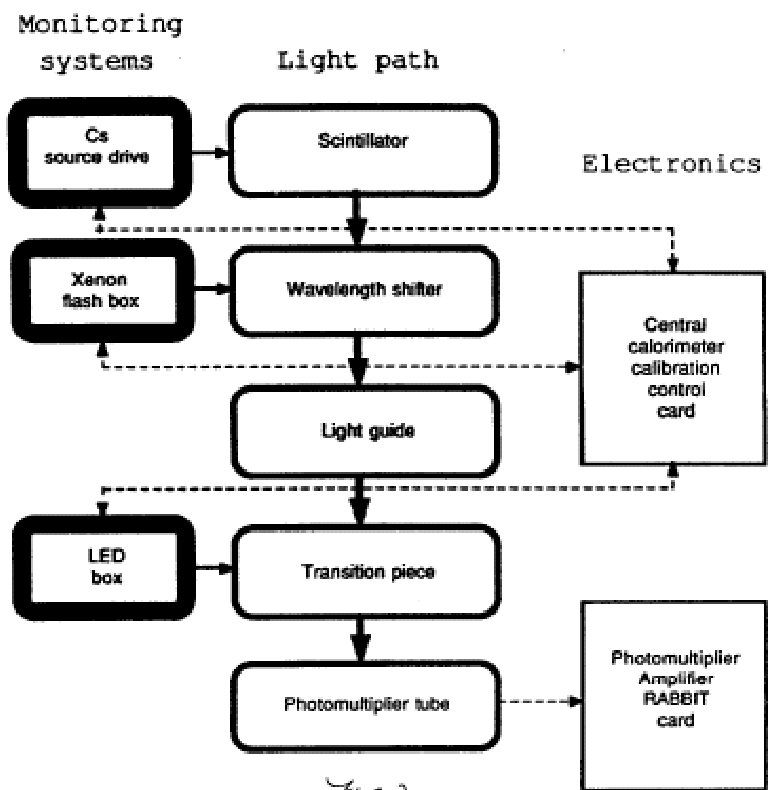


Fig 2

Setting the Calorimeter Energy scales

- All HVs set to nominal gain (2 pC/GeV for CEM/CHA/WHA).

- Modules exposed to test beam (e, π, μ) and rad. sources.

- Dimensionless correction factors known as LERs (Linear Energy Response) are applied to correct for differences:

$$\mathrm{LER(t)} = \frac{\text{nominal gain}}{\text{real gain(t)}}$$

- After correcting for LERs one can apply unique "Scale Factor"(SCL) to all channels

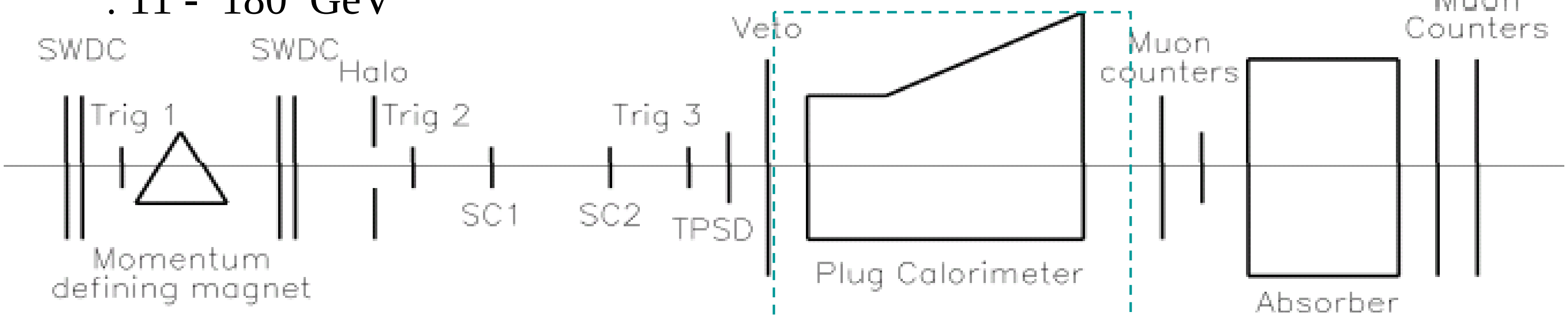
$$\mathrm{E_i(GeV)} = \mathrm{count_i^{raw}} \times \mathrm{LER_i}\left(\mathrm{t}\right) \times \mathrm{SCL(GeV/count)}$$

- calibrations are "transferred" to detector by repeating rad. Source calibrations "in situ" with eventual small adjustments to LERs

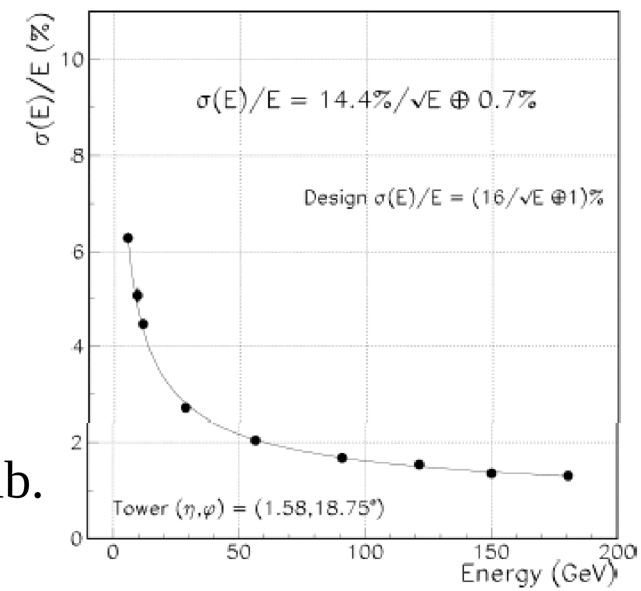
Plug calorimeter test beam

Exposed to:
e^+ and π^+ : 5 - 230 GeV
μ^+ : 11 - 180 GeV

Replica of real detector
Spanning 45º for PEM
and 60º for PHA



E/p calibration with e^+ : 5 - 180 GeV
Non – linearity < 1% (when PPR included)
Non-uniformity better than 2%



Scale factor (@57 GeV): 128.01 ADC/GeV

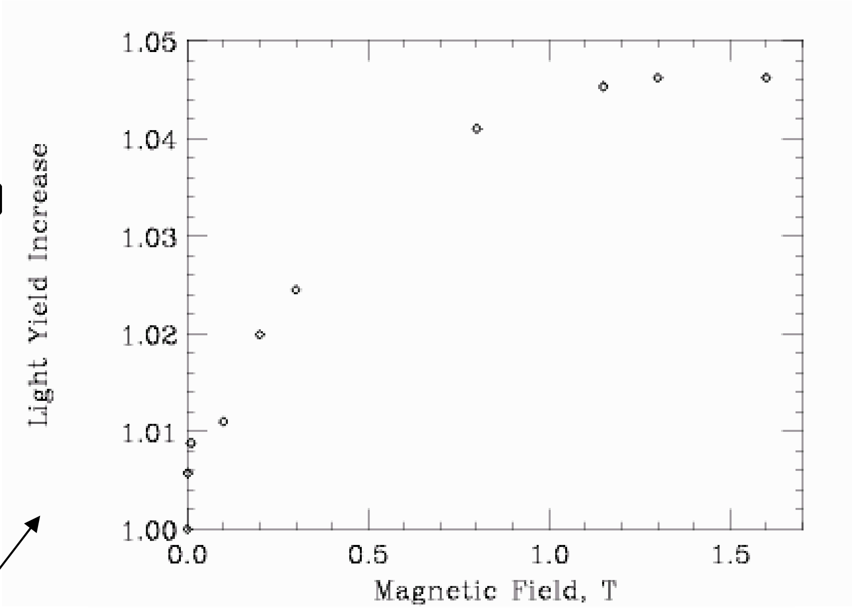
Calibration transferred using Cs^{137}/Co^{60} source calib.

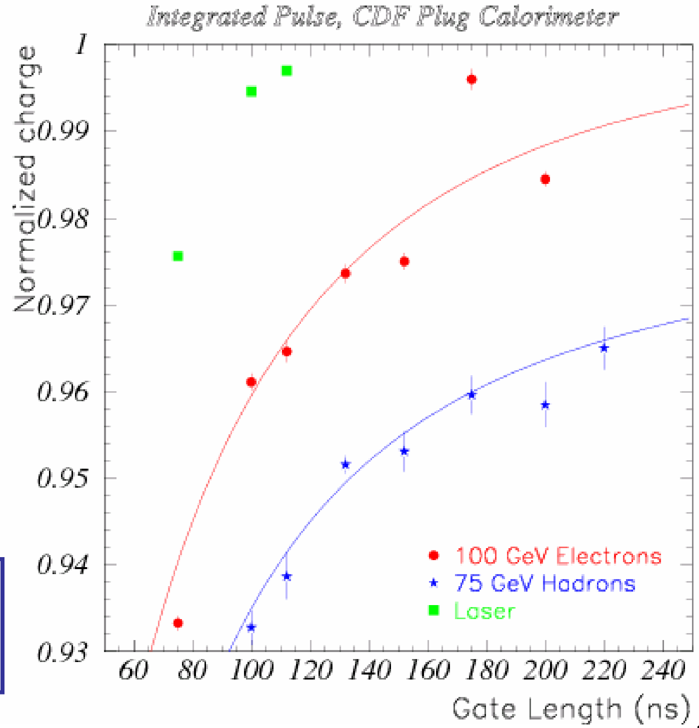
Calibration Transfer

Calibrations transferred from test beam to B0 using source calibration systems.

Transfers took into account:

- difference in sources (Cs^{137}/Co^{60})
- magnetic field effects on Scintillator (brightening)
- differences in readout electronic (RABBIT vs. QIE) gain (11.4 vs 5.758 fC/count)
- differences in charge - integration gate widths (132 ns vs 2.2 μs)





SCL(PEM) = 3.769 MeV/count
SCL(PHA) = 3.097 MeV/count

Transferred Plug LERs

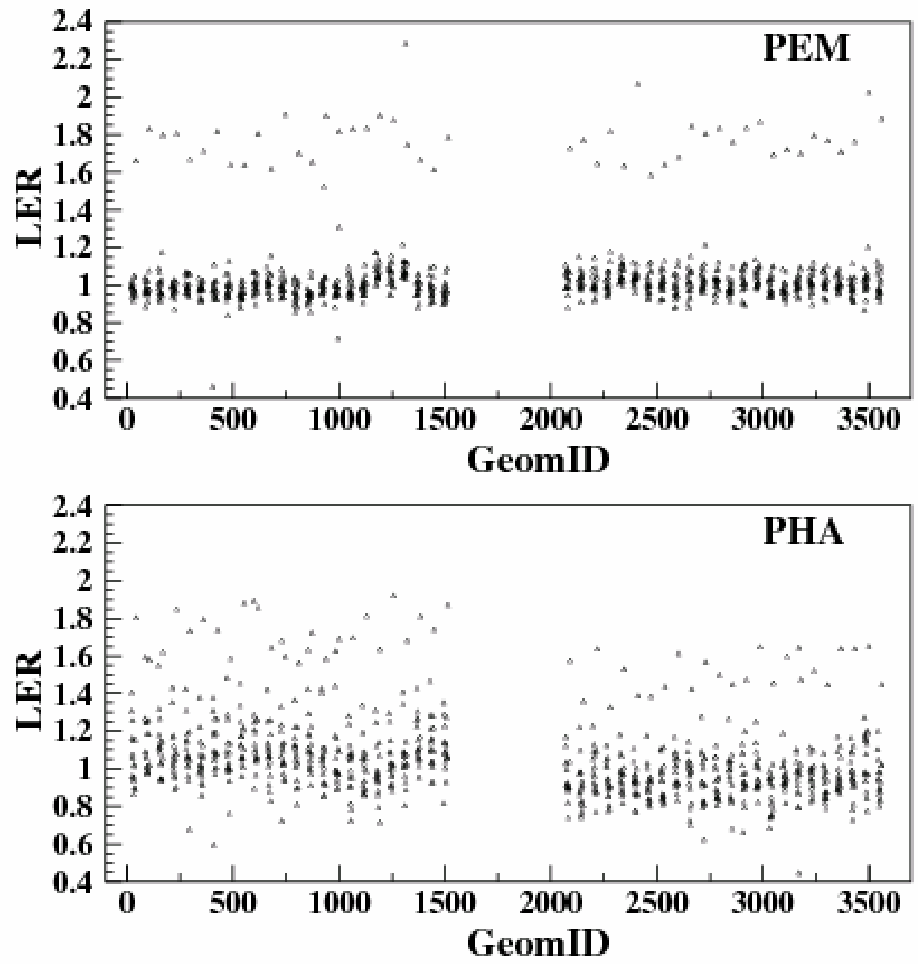


Figure 4: The Nov 2001 LERs for the PEM and PHA versus the gemetrical ID. The west side of the detector are the points on the left side. Each vertical band corresponds to the towers in a wedge.

Keeping the calibrations

Run-time Calibration and Monitoring
Organization & Management

Guidelines:

CDF data should be calibrated and run through (offline) "production" within 2 months of being taken.

Physics Coordinator

Sets schedule: calibrations in data – base every ~ 200 pb^{-1}

Calibration Coordinator

oversees "calibration group" of system experts, e.g. (for calorimeter systems)
CEM, CHA, WHA, PEM, PHA, PES, HAD/EM timing.
System experts expected to update the on-line calibration data-base weekly.

Types of calibrations:

- detector – level H/W calibrations initiated manually by shift crew at ~ fixed intervals (e.g.. daily). These are partially automated

- higher – level automated calibrations: a calibration executable, that runs continuously, strips out and stores (e.g. ntuples) events (e.g. di-muon/electron events, min-bias events, jet events) for calibration purpouses.

Monitoring:

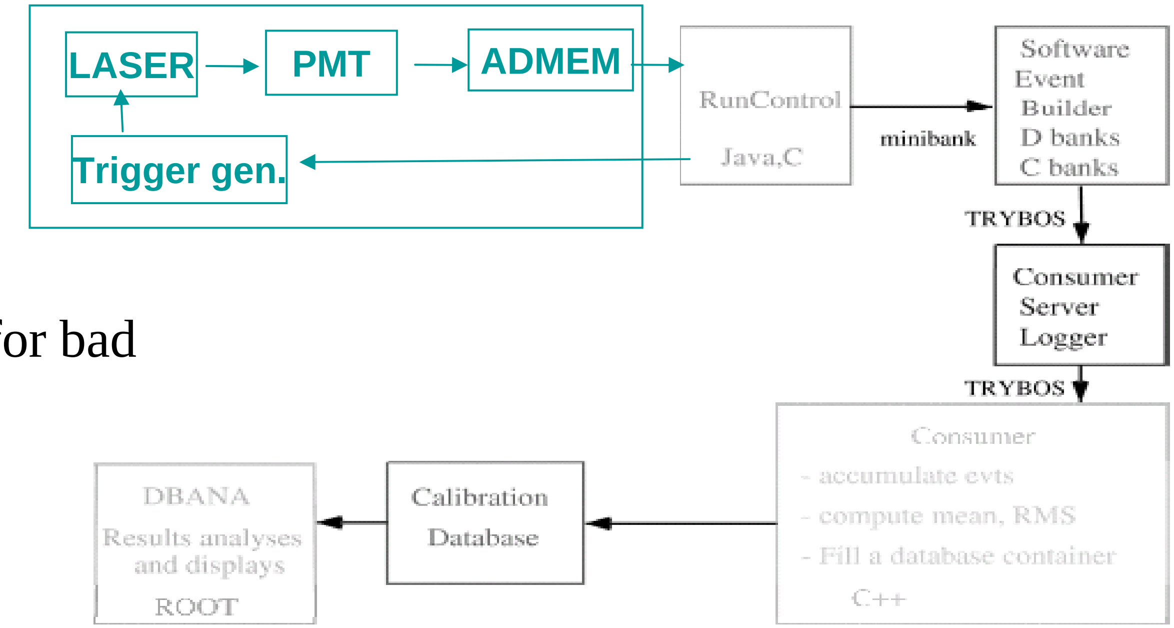
Takes place at different levels:

* at calibration time by the shift crew, for manually – initiated calibrations
* weekly by the "experts" responsible for identifying/solving problems and producing weekly calibrations
* by experts over longer periods in preparation for Offline "production"

Monitoring greatly facilitated by calibration Data Base and s/w (DBANA)

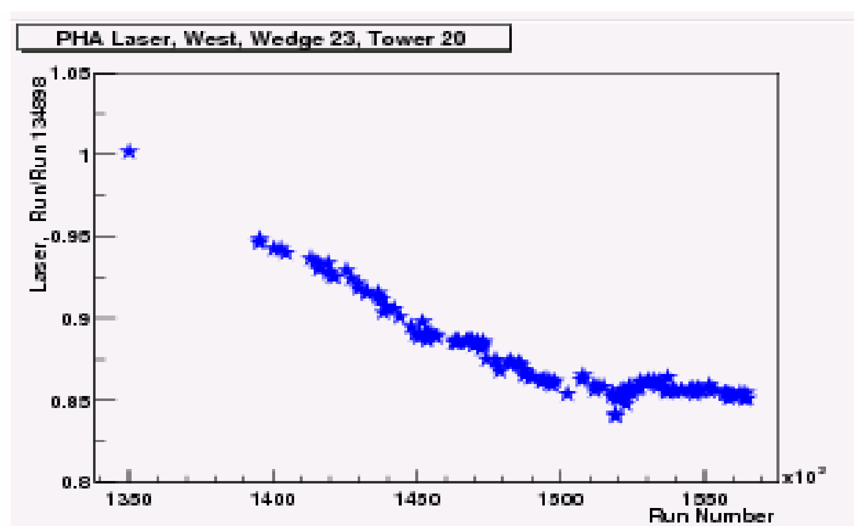
Typical detector-level calibration sequence

Plug Laser calib.



- Monitored at run – time for bad plug channels

- Monitored over long period for PMT gain drift



QIE charge injection

Montored at run – time for

For bad channel ID

calqie_badpeds.gif

Run	Wedge	Channel	Cap	Detector	Mean (Ref)	Mean	RMS (Ref)	Sig
262688	4 E	0	0	CEM	*182± 8*	191	0<rms<5	1.87
262688	4 E	0	3	CEM	*196± 8*	178	0<rms<5	1.88
262688	6 E	16	0	CEM	*201± 8*	188	0<rms<5	1.59
262688	6 E	16	1	CEM	*161± 8*	184	0<rms<5	1.47
262688	7 W	0	0	PHA	*223± 8*	176	0<rms<5	37.63
262688	7 W	0	1	PHA	*224± 8*	160	0<rms<5	35.90
262688	7 W	0	2	PHA	*144± 8*	200	0<rms<5	34.77
262688	7 W	0	3	PHA	*199± 8*	204	0<rms<5	35.30
262688	15 W	13	0	PHA	*151± 8*	141	0<rms<5	1.32
262688	15 W	13	1	PHA	*152± 8*	142	0<rms<5	1.29
262688	15 W	13	2	PHA	*151± 8*	141	0<rms<5	1.48
262688	15 W	13	3	PHA	*157± 8*	147	0<rms<5	1.33

calqie_badslopes.gif

Run	Wedge	Channel	Cap	Range	Detector	Slope (Ref)	Slope
262789	20 W	0	0	0	PHA	*3.40000±0.25000*	0.00000
262789	20 W	0	0	1	PHA	*1.70000±0.12500*	0.00000
262789	20 W	0	0	2	PHA	*0.85000±0.06250*	0.00000
262789	20 W	0	0	3	PHA	*0.42500±0.03125*	0.38033
262789	20 W	0	1	0	PHA	*3.40000±0.25000*	0.00000
262789	20 W	0	1	1	PHA	*1.70000±0.12500*	0.00000
262789	20 W	0	1	2	PHA	*0.85000±0.06250*	0.00000
262789	20 W	0	1	3	PHA	*0.42500±0.03125*	0.38909
262789	20 W	0	2	0	PHA	*3.40000±0.25000*	0.00000
262789	20 W	0	2	1	PHA	*1.70000±0.12500*	0.00000
262789	20 W	0	2	2	PHA	*0.85000±0.06250*	0.00000
262789	20 W	0	2	3	PHA	*0.42500±0.03125*	0.38870

and electronic gain monitoring

Higher-level calibrations

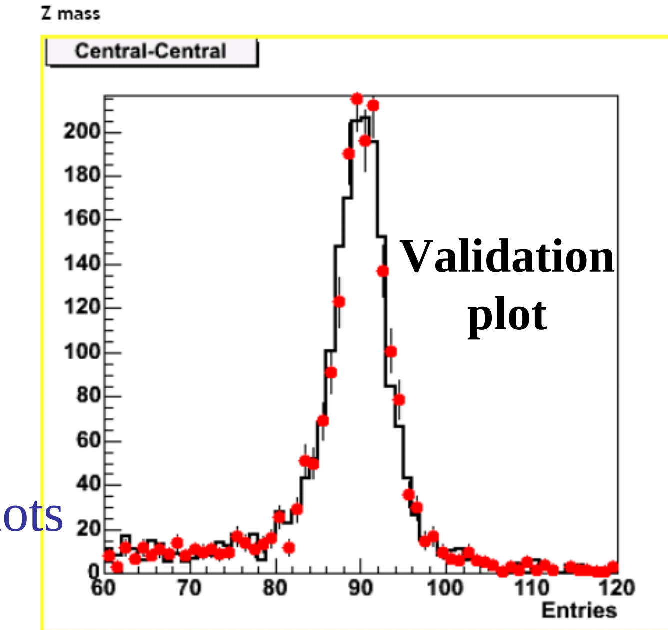
e.g. CEM LERs

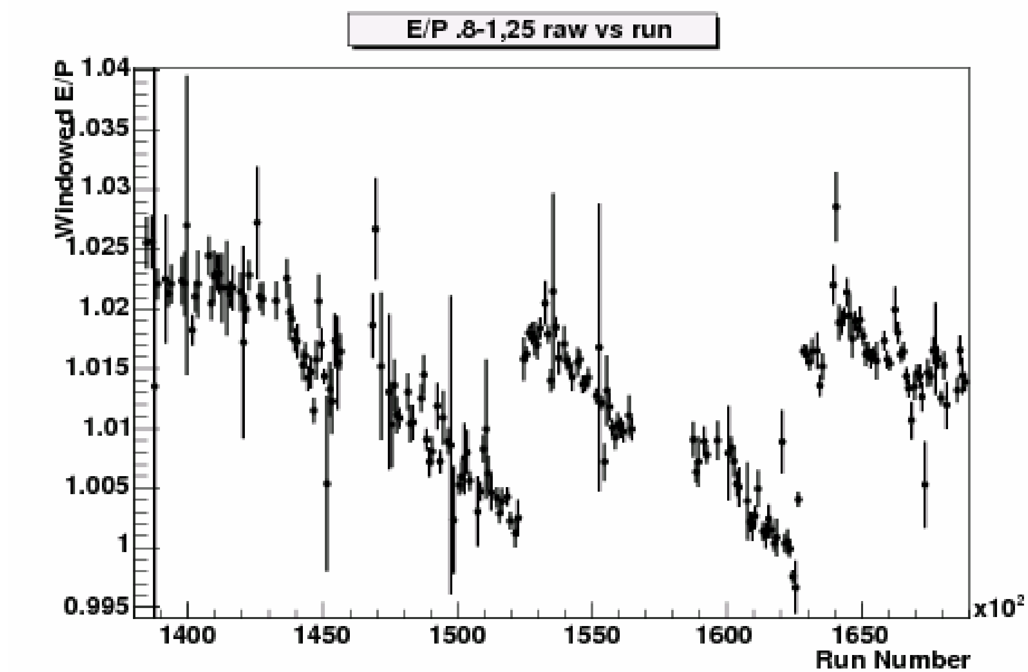
adjusted to track detector response using "in situ" E/p for em "objects" from 8 GeV calib. trigger. ~3% annual drop in response due to scintillator aging.

0. x% variations in Z peak related to instantaneous luminosity

Also monitor LERs using min. bias rate stability at fixed η

Monitor → Validation plots





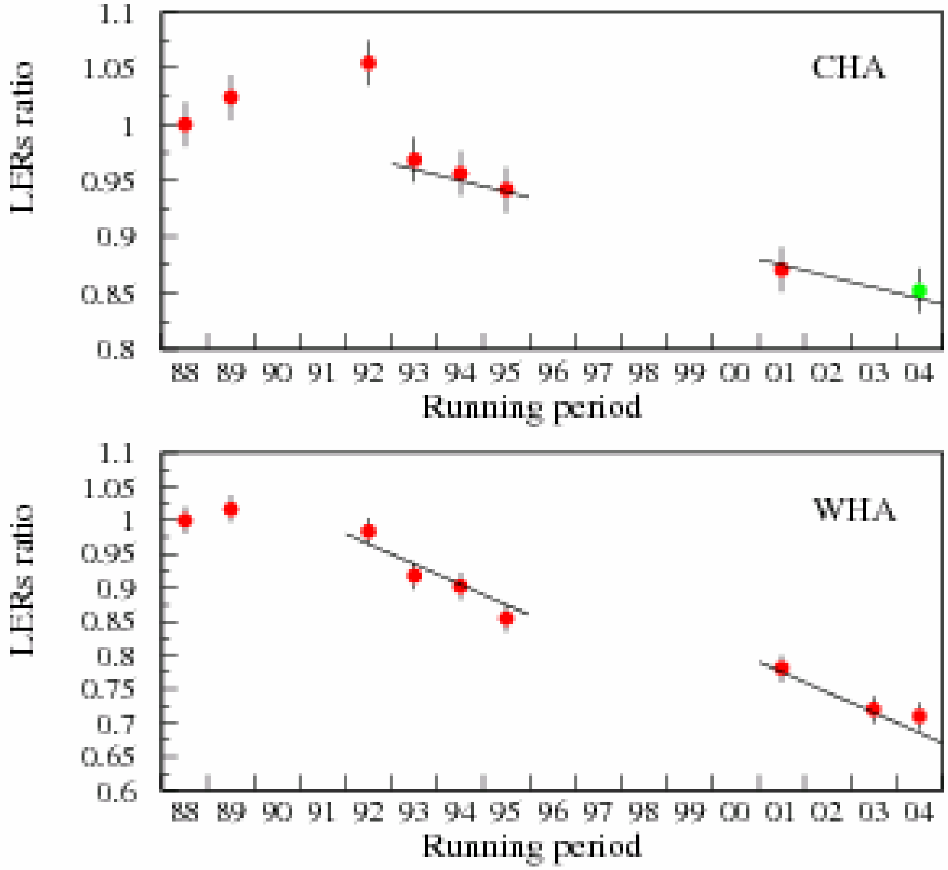
CHA LERs

Some Rad sources unreliable.
Monitor/adjust LERs using Mips (J/PSI muons).
Set muon peaks to run I values.

Where muon statistics insufficient, fall back on monitoring min. bias rates at constant eta

WHA LERs

Rad sources in good shape



Trends in CHA & WHA LERs
w.r.t.1988 source run

PEM/PHA LERs

1% – 8% η-dependent gain drop associated with both scintillator aging and PM "deterioration"(?)

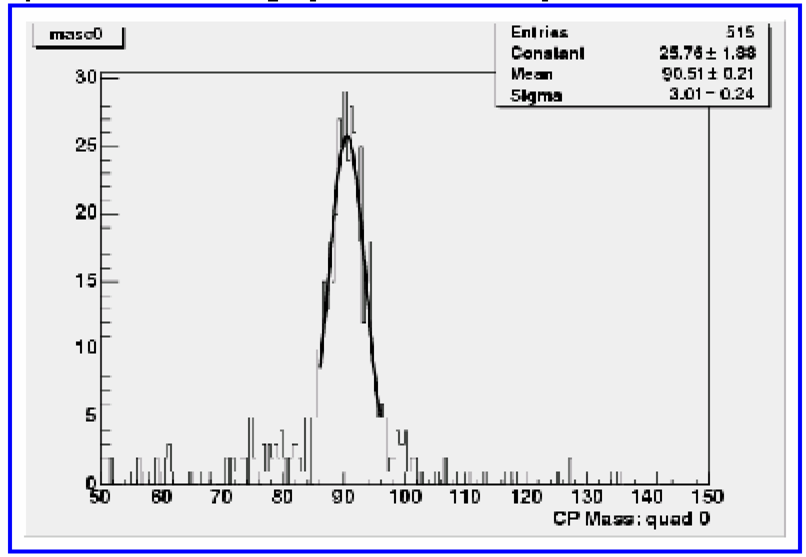
So use both rad. Sources and Plug Laser to adjust LERs and investigate

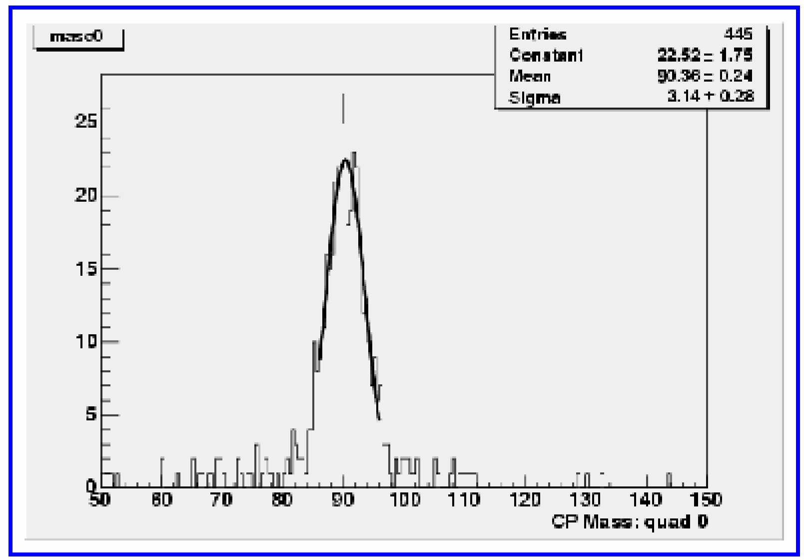
Interpolate/extrapolate gain shifts linearly with luminosity

Occasional failure of HV boards due to radiation damage

Validation plots

Quadrant 0W Left/Right plots: Current/Last period





Jet Energy scales

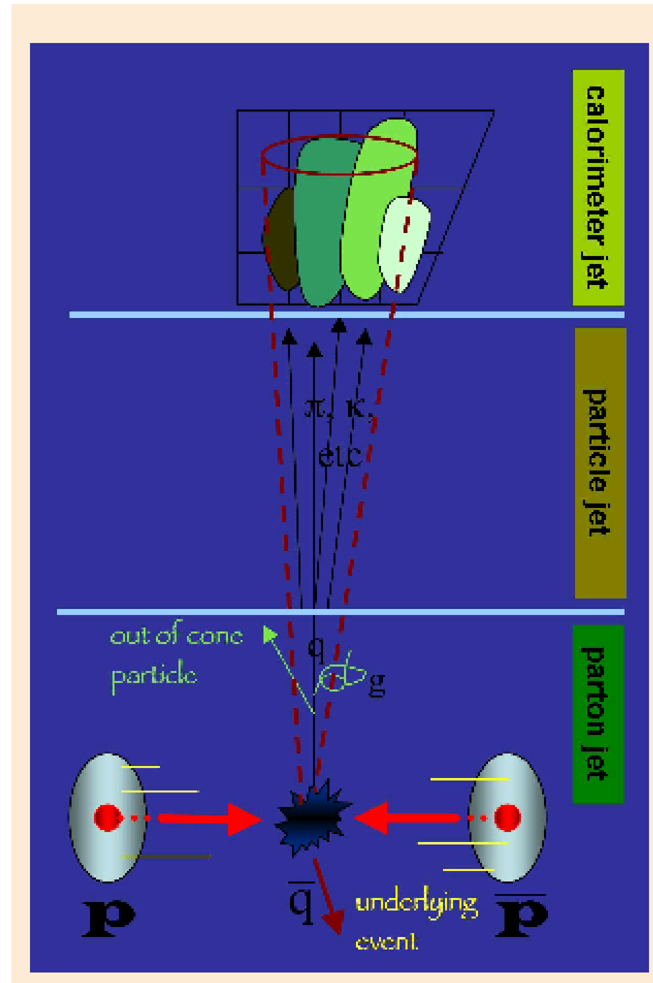
Very important for most analyses
(major source of uncertainty in the
top quark mass)

Jet energy measurement needs to be corrected for:

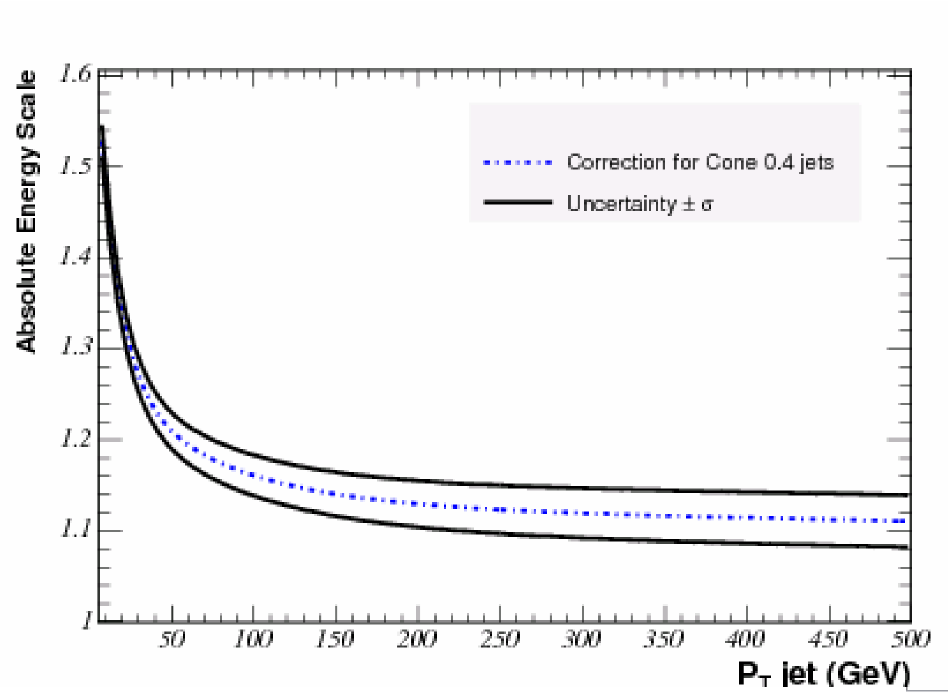
- energy loss due to acceptance
- non linearities in cal. response
- particle – dependent cal. response
- etc

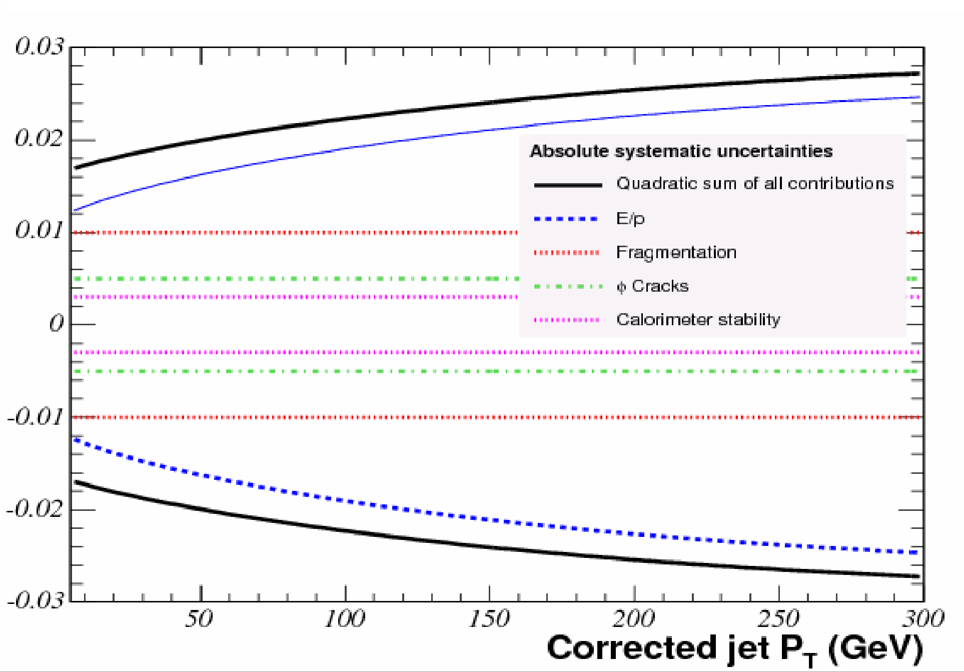
Need reliable M.C.
e.g. Pythia + GFLASH

Jet Energy & Resolution group
responsible for JE-scale



MC tuned for **absolute scale** by comparing with “in situ” particles (E/p) and measured fragmentation

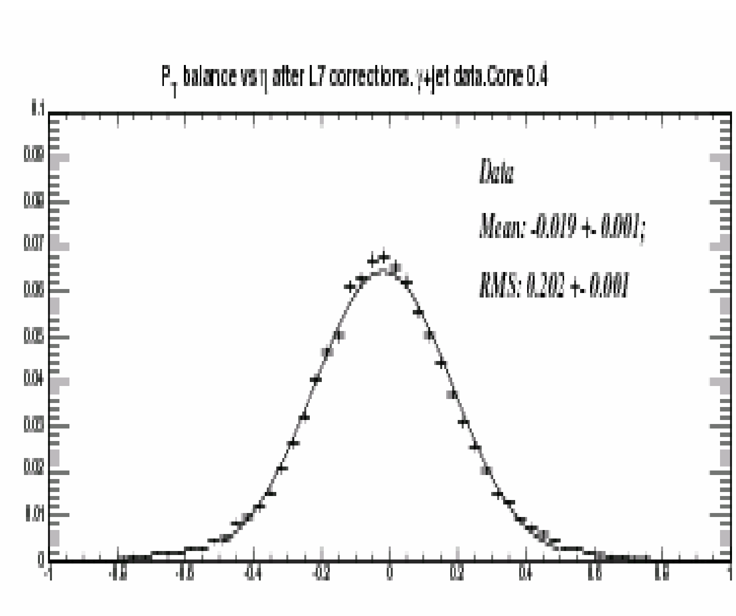


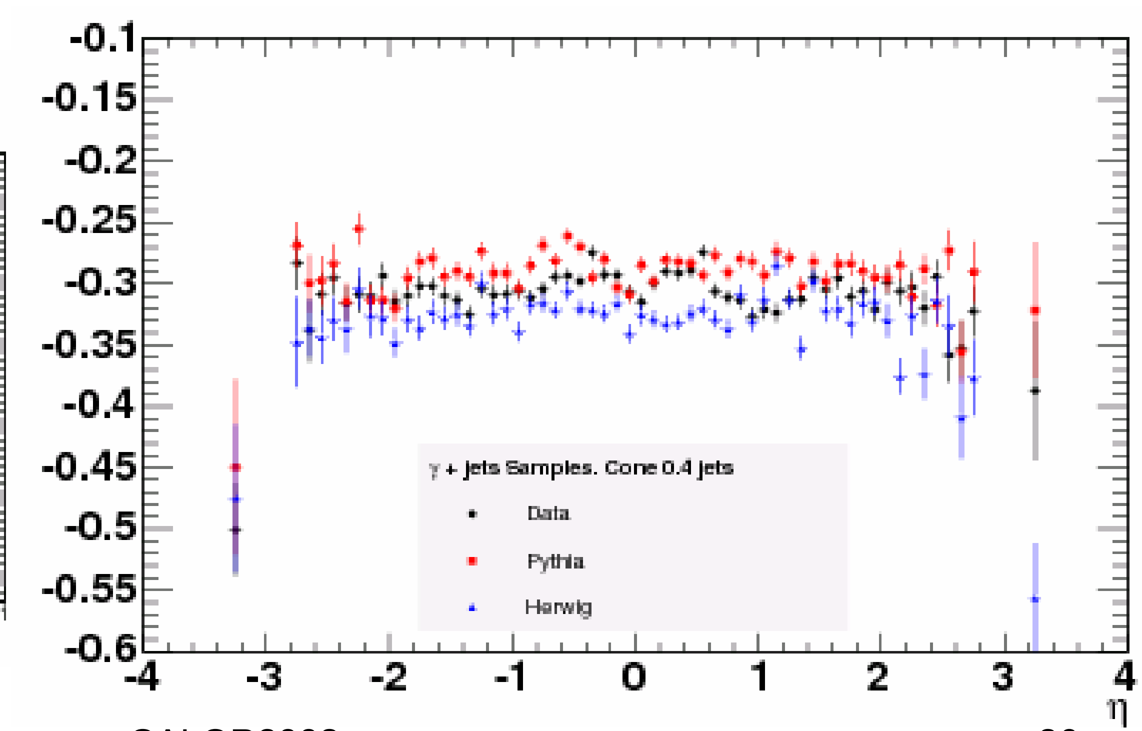


Absolute scale has now recovered from upgrade and improved on run I

Dijet balancing used to calibrate the **relative scale** for jets forward of the central region (η>0.6). The forward jet is used to set the scale while the central jet is the “reference”

Validating can be done with
Photon-Jet balancing





Conclusion

The CDF calorimeters are working at better than design expectations and are expected to survive without significant loss of performance.

Operational procedures have settled down for the home stretch.

The ball in now in the hands of the analysts who yet have to exploit all bells and whistles

More info

Table 1: Central Electromagnetic Calorimeter Summary.

Modules	
12/arch + 2 spare	50
Length	98 in.
Width	15° in ϕ (17.9 in. at 68+ in. from beamline)
Depth (including base plate)	13.6 in.
Weight	2 metric tons
Towers	
10/module	478
Length	$\Delta\eta$ 0.11 ($\frac{1}{2}$ of width)
Thickness (see Table 2)	18 X_0, 1 L_{abs} (+coil etc.)
Layers	20–30 lead 21–31 scintillator 1 strip chamber
Lead	$\frac{1}{8}$ in. aluminum clad
Scintillator	5 mm SCSN–38 polystyrene
Wavelength shifter	3 mm Y7 UVA acrylic
Photomultiplier tubes (956 channels)	Hamamatsu R580 ($1\frac{1}{2}$ in.)
Chambers (see Table 4)	
Depth	5.9 X_0 (including coil)
Wire channels (64/module)	3072
Strip channels (128/module)	6130
Angular coverage	
θ	about 39°–141°
ϕ	complete
Pseudorapidity	about ±1.1
Performance (high = 30+ GeV)	
pe/GeV	100+/tube
Energy resolution σ/E (GeV)	$13.5\%/\sqrt{E}$
Position resolution (high)	±2 mm
Strip/wire PH correlation	8–10%
Wire PH resolution (high)	±25%
Hadron rejection (at 50 GeV) without strip chamber information	$2\text{–}3 \times 10^{-3}$

	Central
EM:	
Thickness	$19X_0, 1\lambda$
Sample (Pb)	$0.6X_0$
Sample (scint.)	5 mm
WLS	sheet
Light yield	160 pe/GeV
Sampling res.	$11.6\%/\sqrt{E_T}$
Stoch. res.	$14\%/\sqrt{E_T}$
SM size (cm)	$1.4\phi \times (1.6\text{-}2.0)$Z
Pre-shower size	$1.4\phi \times 65$Z cm

Parameters of the Central hadron Calorimeter

Modules

Number of modules	48
Length	2.5 m
Width (in ϕ direction)	1.33 m.
Weight per module	12,000 kg.

Towers

Total number (8/module)	384
Length ($\Delta\phi = 15^0$)	0.56 to 0.91 m.
Width ($\Delta\eta = 0.11$)	0.28 to 0.45 m
Total depth (hadron calorimeter alone)	4.7 Λ_{abs}

Layers

Number	32
Steel thickness	2.5 cm
Scintillator thickness	1.0 cm
Scintillator type	PMMA doped with 8% Naphtalene 1% Butyl-PBD and .01% POPOP
Wave shifters	UVA PMMA doped with 30 mg/l Laser dye #481
Number of phototubes	768

Hadron:	
Thickness	4.5λ
Sample (Fe)	1 in. C, 2 in. W
Sample (scint.)	10 mm
WLS	finger
Light yield	~ 40 pe/GeV

Table 1.3: Central and Plug Upgraded Ca
parison

TABLE 2

Parameters of the End Wall hadron Calorimeter

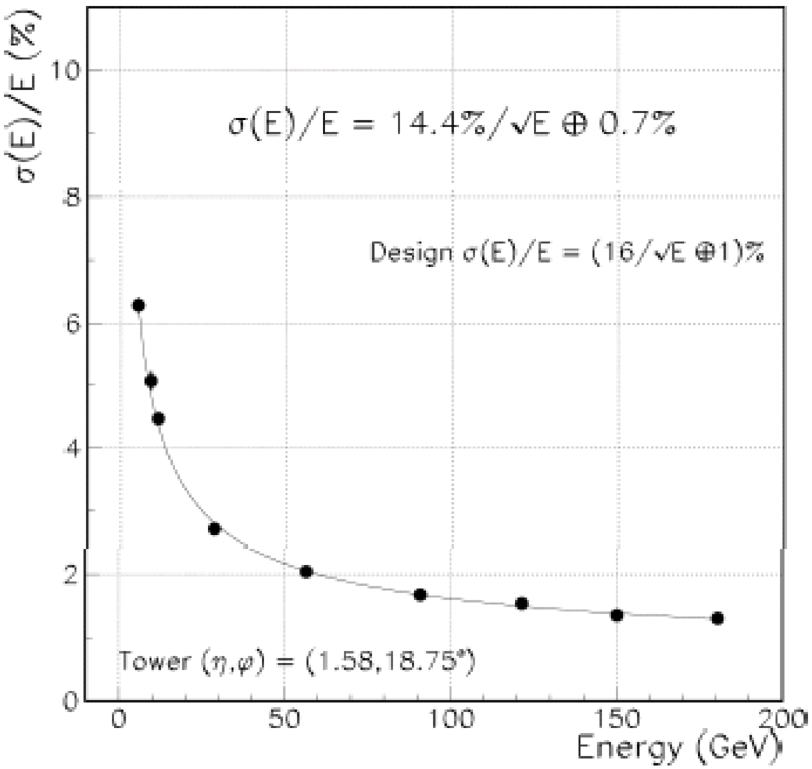
Modules	
Number of modules	48
Approximate dimensions	0.8 X 1.0 X 1.1 m^3
Weight per module	7,000 kg.
Towers	
Total number (6/module)	288
Length ($\Delta\phi = 15^0$)	0.35 to 0.78 m.
Width ($\Delta\eta = 0.11$)	0.25 to 0.40 m
Total depth (hadron calorimeter alone)	4.5 Λ_{abs}
Layers	
Number	15
Steel thickness	5 cm
Scintillator thickness	1.0 cm
Scintillator type	PMMA doped with 8% Naphtalene 1% Butyl-PBD and .01% POPOP
Wave shifters	UVA PMMA doped with 30 mg/l Laser dye #481
Number of phototubes	576

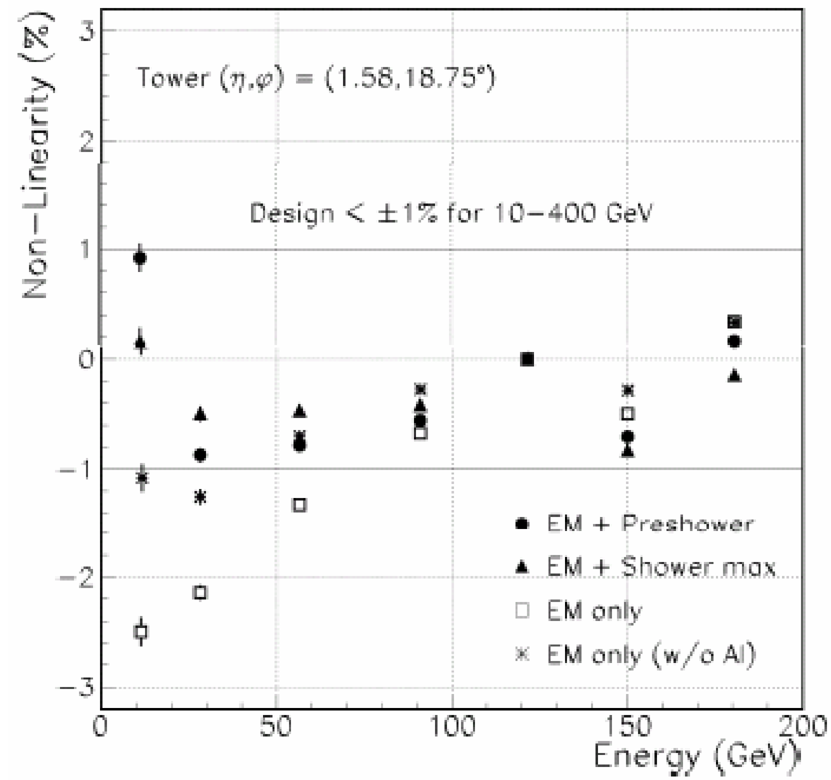
Table 1: Central Electromagnetic Calorimetry Calibration Systems Summary.

Global parameters		
	Reproducibility specification	better than 1%
	One set of systems per module	50 (12/arch + 2 spare)
Cs^{137} source drive system		
	Radioactive source	3 mCi Cs^{137} encapsulated
	Depth (from interaction region)	$5.9X_0$ (shower maximum)
	Motor	190:1 gear ratio; nominal D.C. voltage 3.5 V
	Normal source speed	$\frac{2}{3}$ cm/sec
	Normal data rate	3–5 Hz
	Source peak fitting algorithm	6th-order polynomial fit to top 20% of peak with maximum found by Newton's method
	Typical peak value (when source decay is compensated)	50.0 ± 0.2 nA
Xenon flash system		
	Light distribution	Xenon flash bulb illuminating scintillator in turn illuminating 20 quartz light fibers and 3 PIN diodes; light fibers enter each waveshifter through prism
	Light pulse characteristics	100 ns rise time; 100 ns fall time
	Regeneration time	< 10 ms
	Jitter from trigger to pulse	±15 ns
LED flash system		
	Light distribution	3 LEDs—2 of 3 illuminate 7 light fibers and one PIN diode each; remaining LED illuminates 8 light fibers, two of which share another LED for purposes of cross-calibration. Light fibers enter transition piece directly below phototubes.
	Light pulse characteristics	50 ns rise time; 50 ns fall time
	Regeneration time	< 1 ms
	Jitter from trigger to pulse	±5 ns
Performance		
	Short-term (< day) reproducibility	±0.3%
	Long-term (≈ month) reproducibility	±0.4%
	Original uniformity of energy response	±4.0%
	Current energy response mean and rms normalized to nominal	1.03 ± 0.08

PEM test beam calibration

From: E/p with e^+ and π^+ :   5 - 230 GeV





$\|\eta\|$ Range	$\Delta\phi$	$\Delta\eta$
0. - 1.1 (1.2 h)	15°	~ 0.1
1.1 (1.2 h) - 1.8	7.5°	~ 0.1
1.8 - 2.1	7.5°	~ 0.16
2.1 - 3.64	15°	0.2 - 0.6

Table 1.2: CDF II Calorimeter Segmentation

	Central	Plug
EM:		
Thickness	$19X_0, 1\lambda$	$21X_0, 1\lambda$
Sample (Pb)	$0.6X_0$	$0.8X_0$
Sample (scint.)	5 mm	4.5 mm
WLS	sheet	fiber
Light yield	160 pe/GeV	300 pe/GeV
Sampling res.	$11.6\%/\sqrt{E_T}$	$14\%/\sqrt{E}$
Stoch. res.	$14\%/\sqrt{E_T}$	$16\%/\sqrt{E}$
SM size (cm)	$1.4\phi\times(1.6\text{-}2.0)Z$	0.5×0.5 UV
Pre-shower size	$1.4\phi \times 65Z$ cm	by tower
Hadron:		
Thickness	4.5λ	7λ
Sample (Fe)	1 in. C, 2 in. W	2 in.
Sample (scint.)	10 mm	6 mm
WLS	finger	fiber
Light yield	~ 40 pe/GeV	39 pe/GeV

Table 1.3: Central and Plug Upgraded Calorimeter Comparison

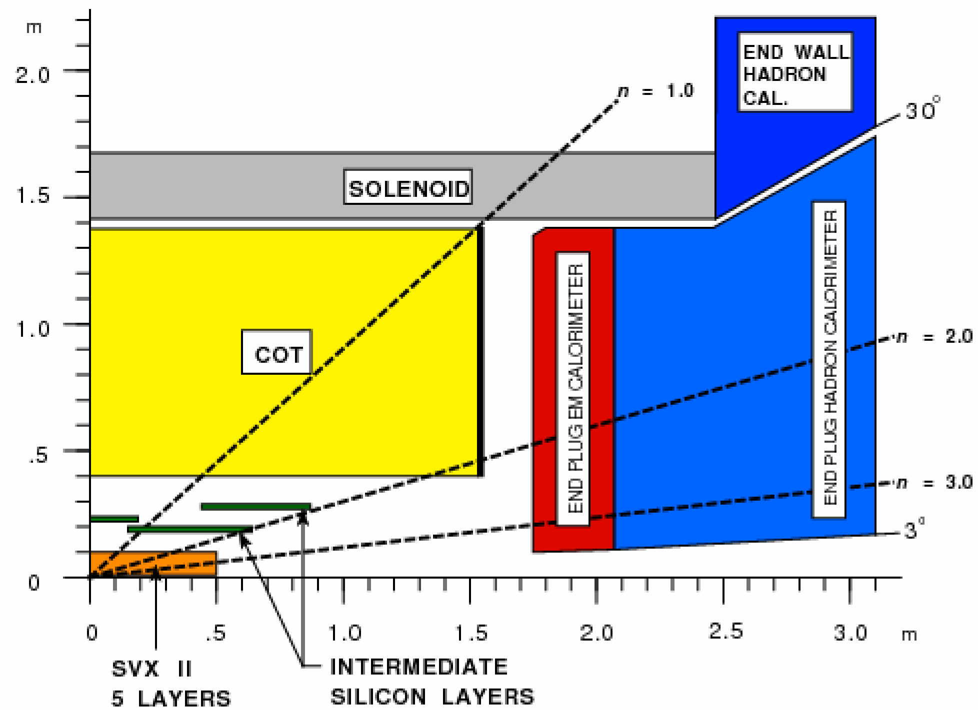


Figure 1.3: Longitudinal View of the CDF II Tracking System