HCAL and Jet/MET

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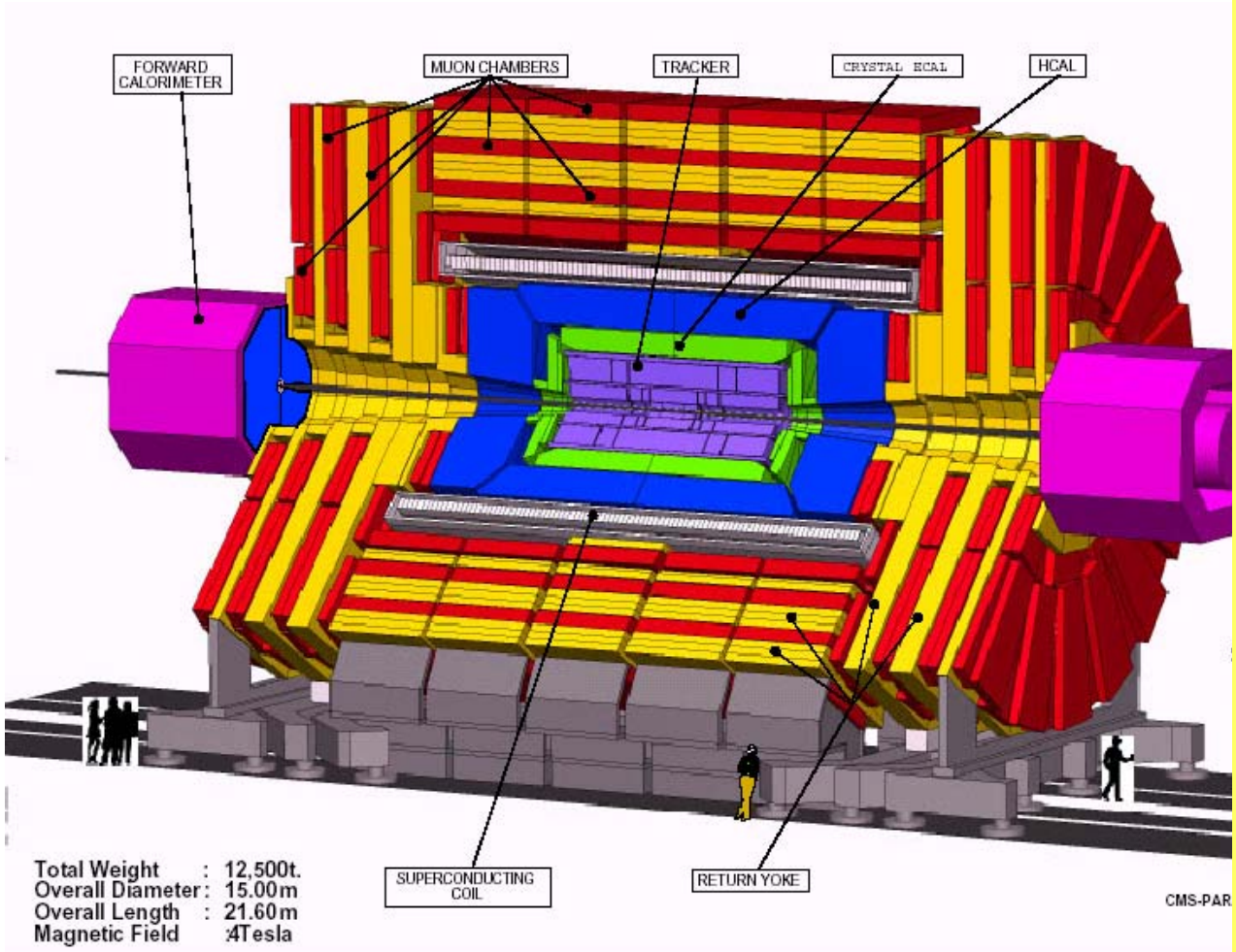
U. of Maryland

12-July-2005

CMS Detector



Tracker
- All silicon
- $|\eta|<2.4$

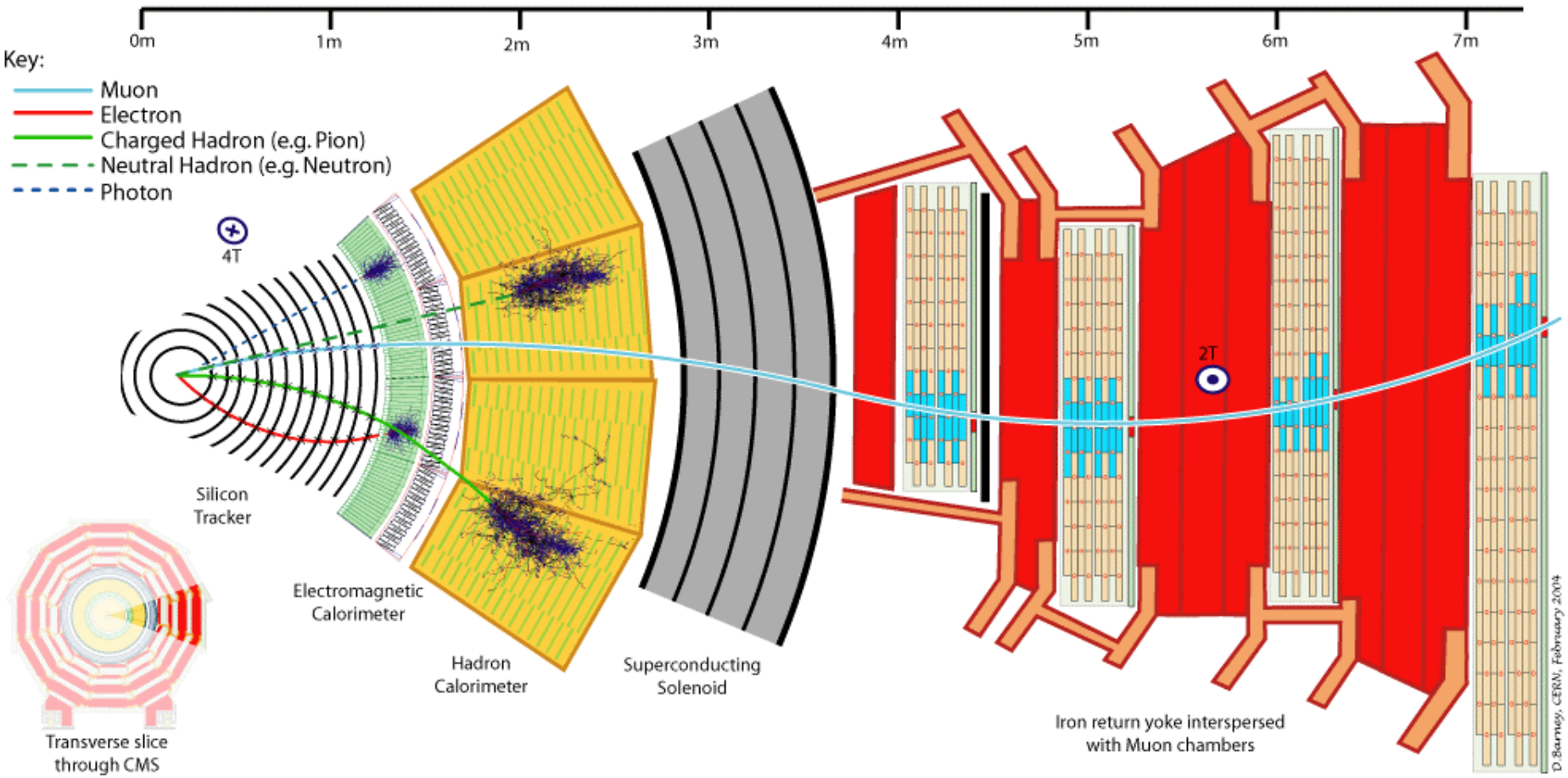
ECAL
- PbWO4 crystals
- e/h ~ 1.60
- $|\eta|<3.0$

HCAL (barrel/endcap)
- Scint-tile & brass sampling
- e/h ~ 1.39
- $|\eta|<3.0$

– 4 Tesla field –

HCAL (fwd)
- Quartz-fiber & iron
- $3.0<|\eta|<5.0$

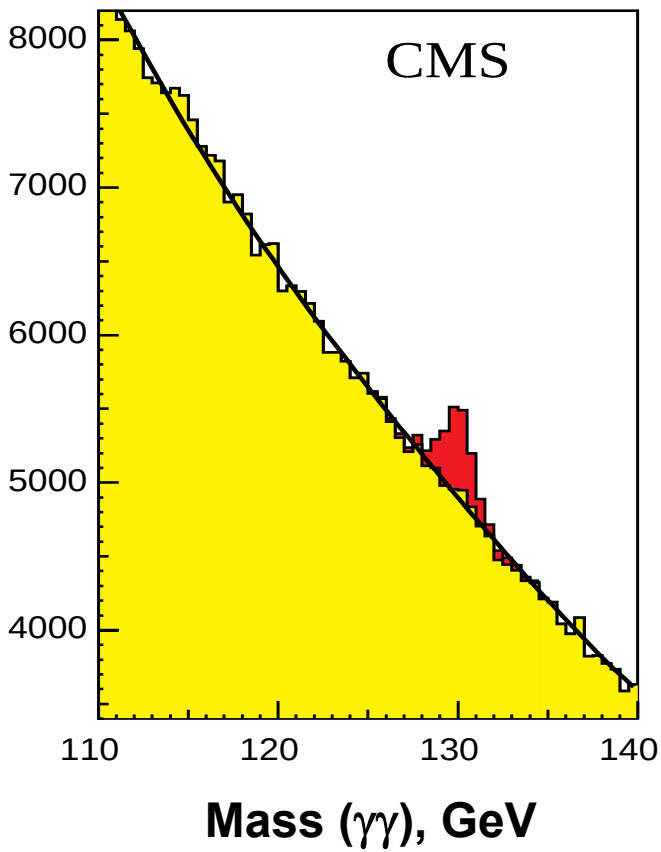
The CMS detector



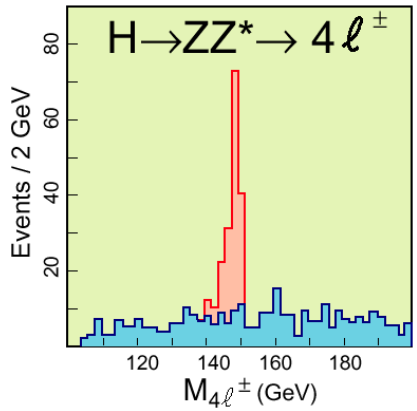
CMS_Slice.mov

Higgs

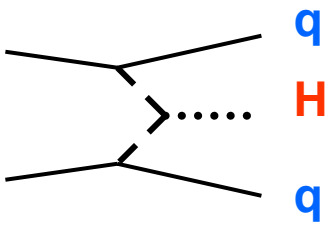
$H \rightarrow \gamma\gamma$



$H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$

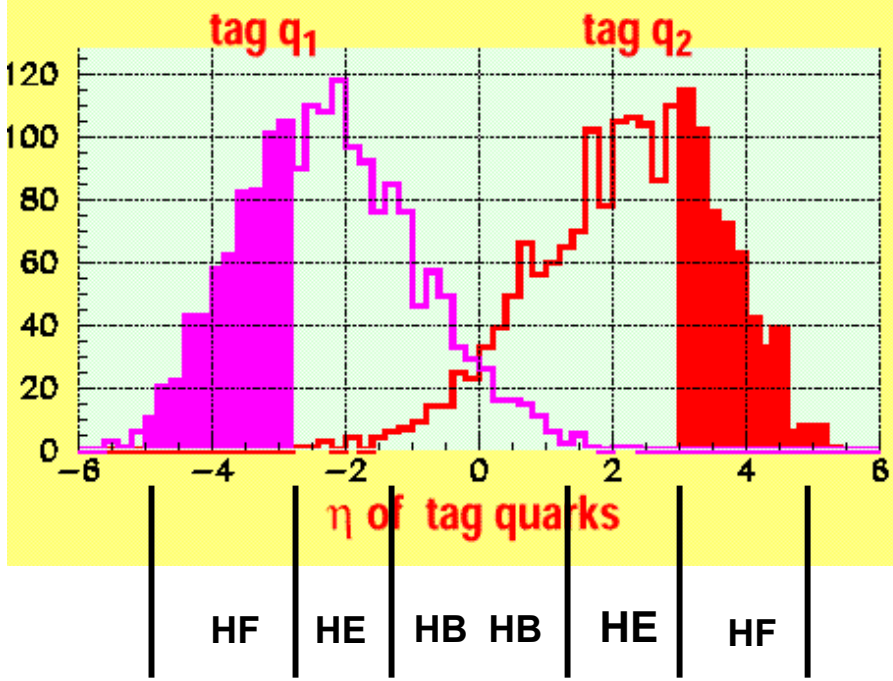


Forward Tagging jets



WWH

HF acceptance for tagging quarks of $E_t^q > 30$ GeV		
no q	1 q	2 q's
0.47	0.46	0.07



SUSY Signature: MET + Jets + …

mSUGRA : $m_0 = 1000$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$, $\tan\beta = 35$, $\mu > 0$

$\tilde{g} \to \tilde{t}_1 \bar{t}$

$\tilde{t}_1 \to W^- + \bar{b}$ (jet4, $E_T = 113$ GeV)

$W^- \to s$ (jet5, $E_T = 79$ GeV) + $\bar{c}$

$\tilde{t}_1 \to \tilde{\chi}_2^+ + b$ (jet3, $E_T = 536$ GeV)

$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ + Z \to \nu\bar{\nu}$

$\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 + W^+ \to \tau^+ \nu$

$\tau^+ \to e^+ \nu$

$\tilde{u}_L \to \tilde{\chi}_2^0 + u$ (jet6, $E_T = 1196$ GeV)

$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + h$

$h \to b$ (jet1, $E_T = 206$ GeV)

$h \to \bar{b}$ (jet2, $E_T = 320$ GeV)

$E_T^{miss} = 380$ GeV

4 hard b-jets
+2 hard jets
+2 LSP + > 4ν
(+ leptons)

$m_{\tilde{g}} = 1266$ GeV

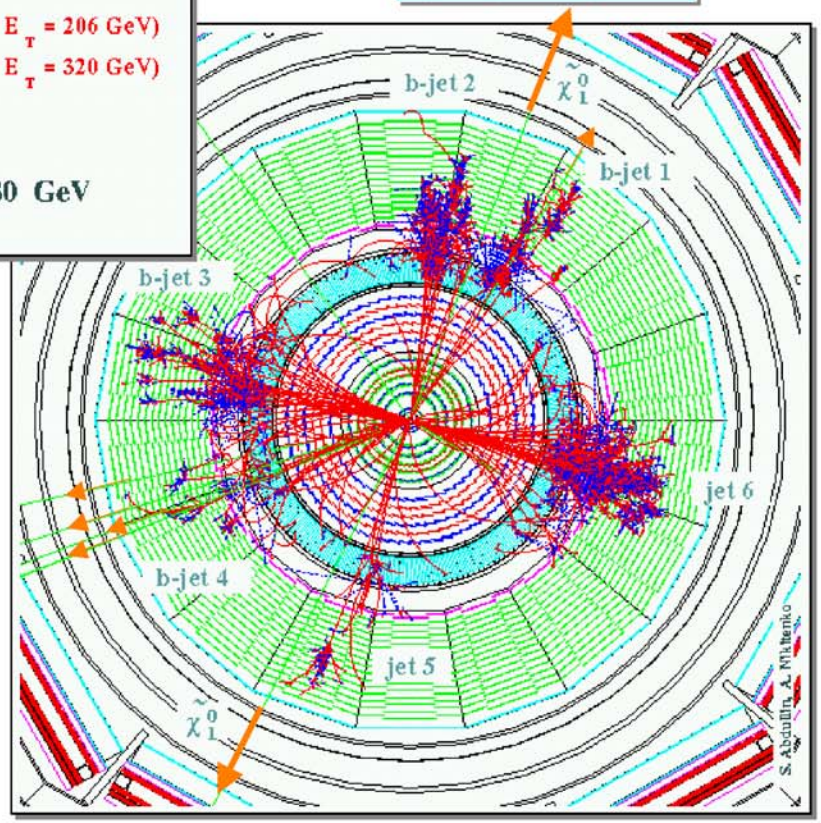
$m_{\tilde{u}_L} = 1450$ GeV

$m_{\tilde{t}_1} = 1026$ GeV

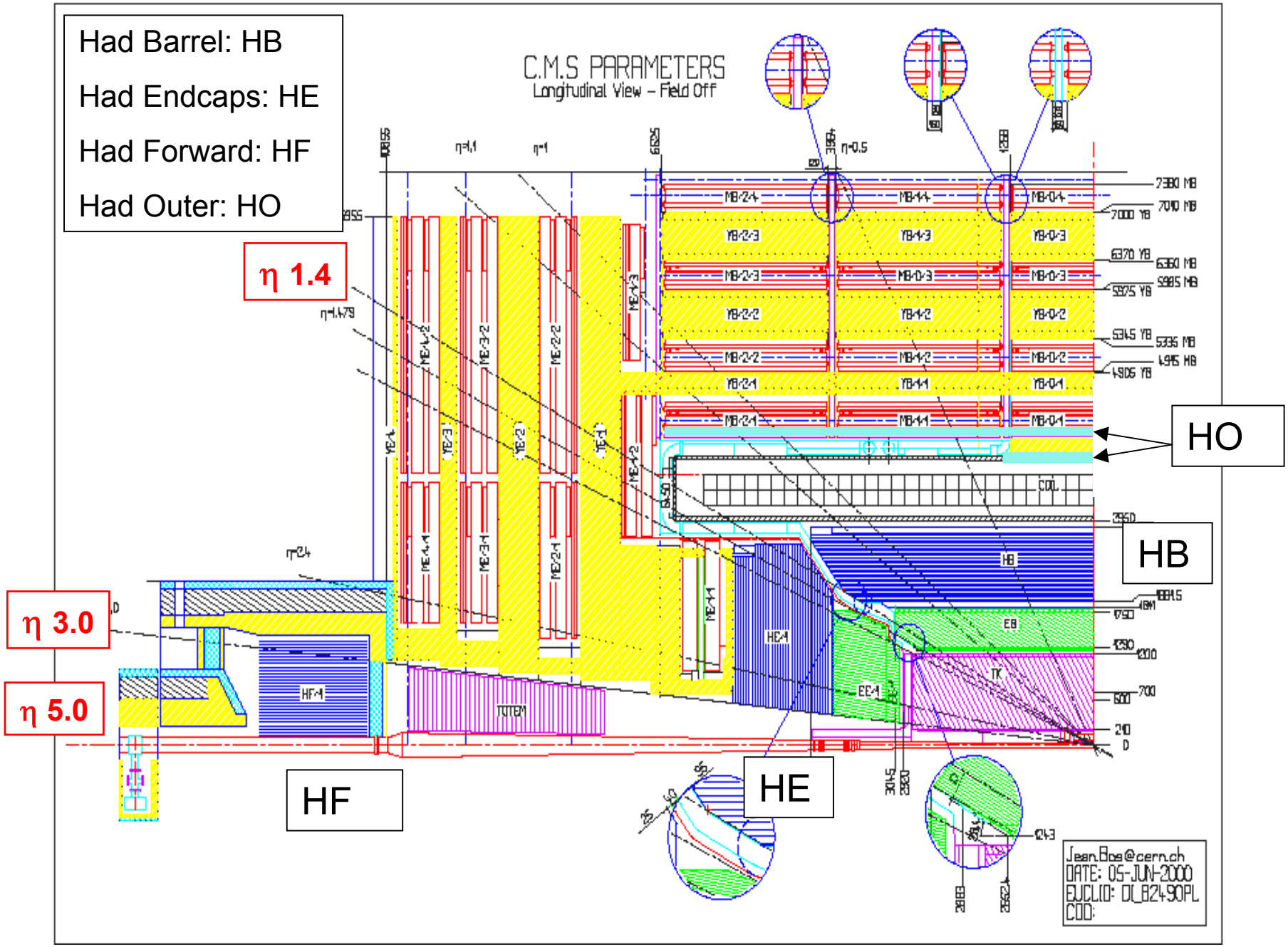
$m_{\tilde{\chi}_2^0} = 410$ GeV

$m_{\tilde{\chi}_1^0} = 214$ GeV

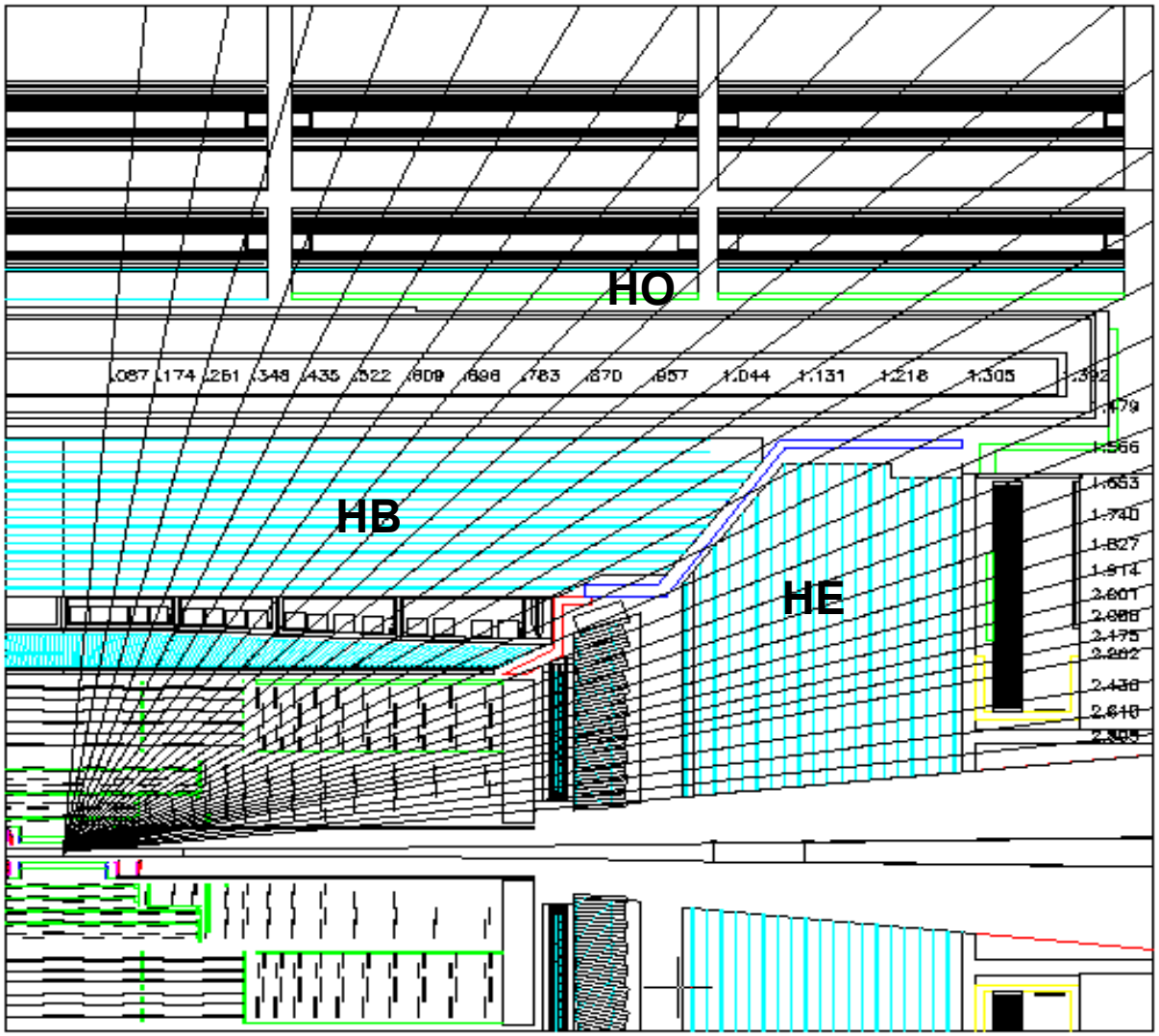
$m_h = 119$ GeV

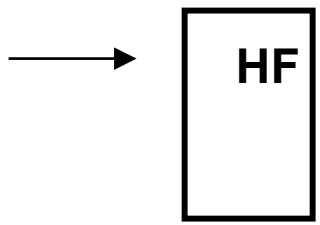


- Squark-gluino production
- Full simulation in CMS detector yet with GEANT3 ☹


Had Barrel: HB
Had Endcaps: HE
Had Forward: HF
Had Outer: HO
C.M.S PARAMETERS
Longitudinal View – Field Off
η 1.4
η 3.0
η 5.0
HO
HB
HE
HF
TOTEM
COIL
Jean.Bos@cern.ch
DATE: 05-JUN-2000

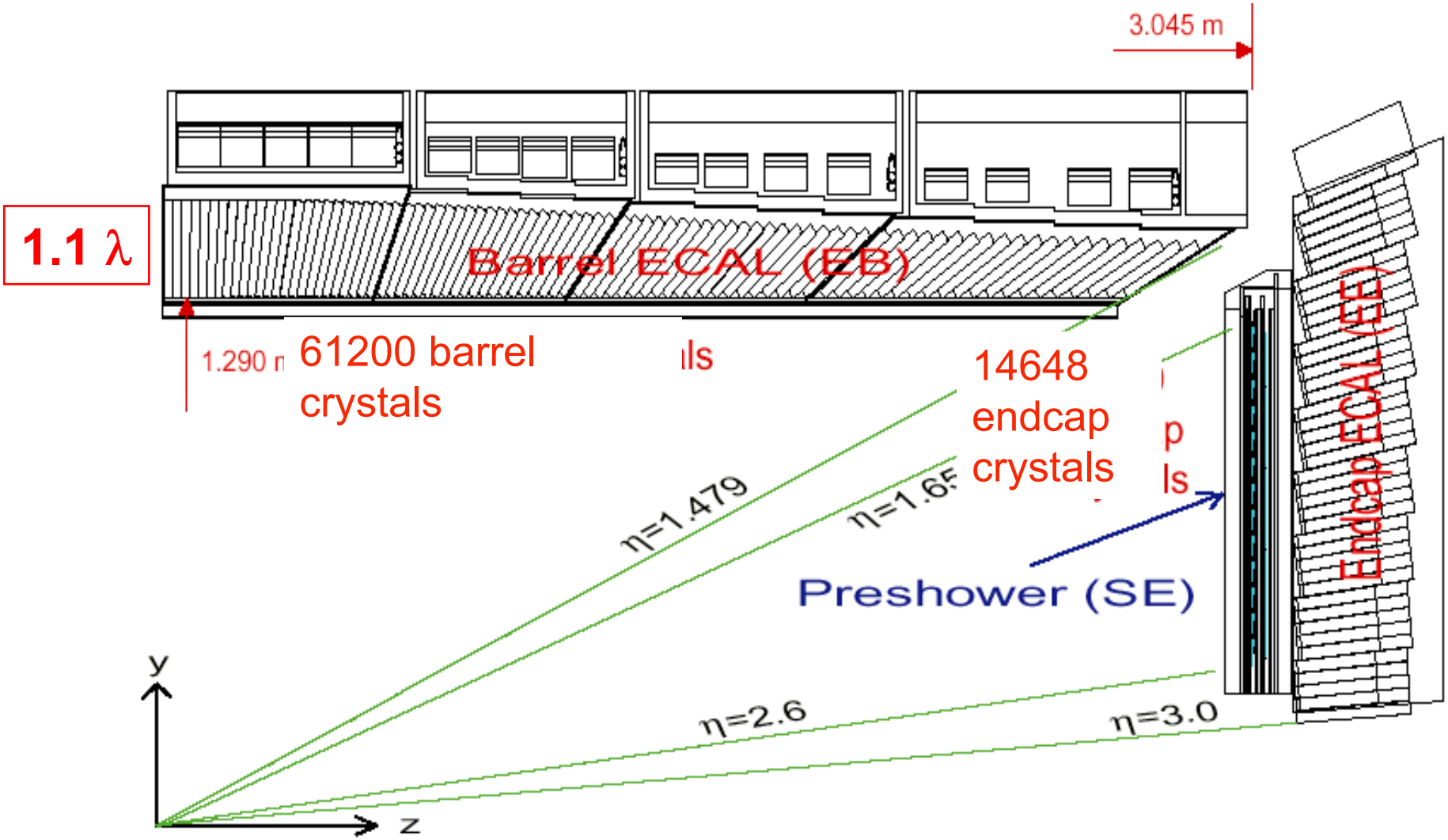
CMSIM Geometry



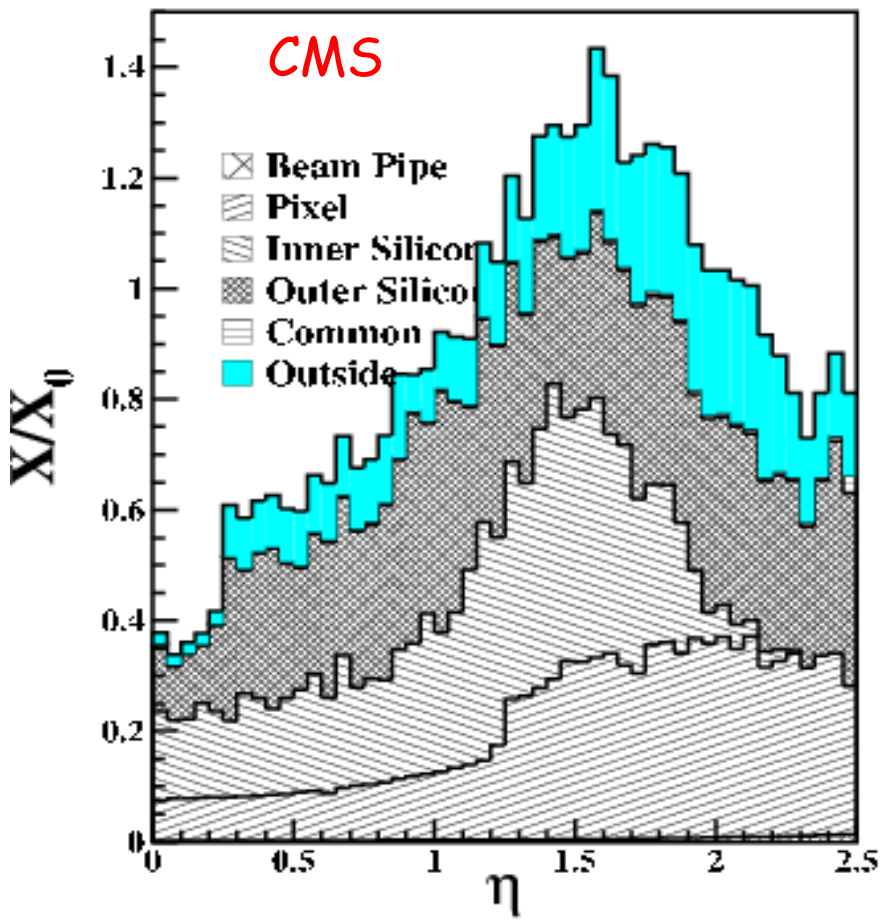


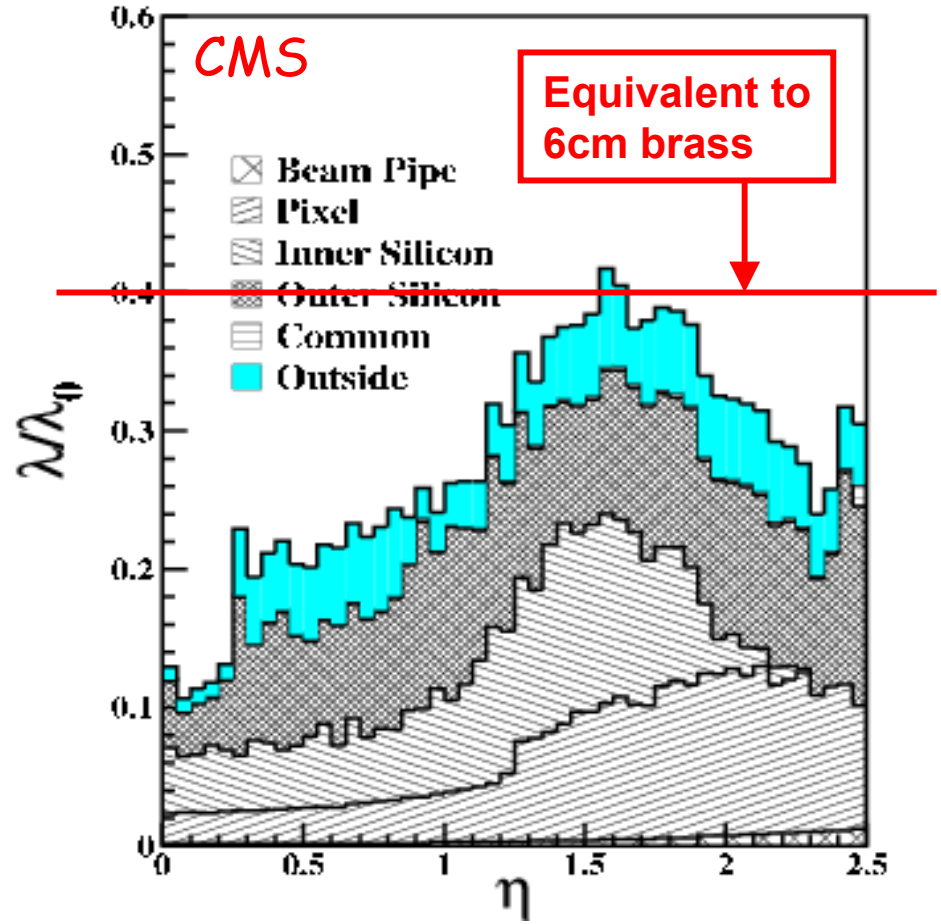
(2000)

ECAL


3.045 m
1.1 λ
Barrel ECAL (EB)
1.290 m
61200 barrel crystals
14648 endcap crystals
Endcap ECAL (EE)
η=1.479
η=2.6
η=3.0
Preshower (SE)
y
z

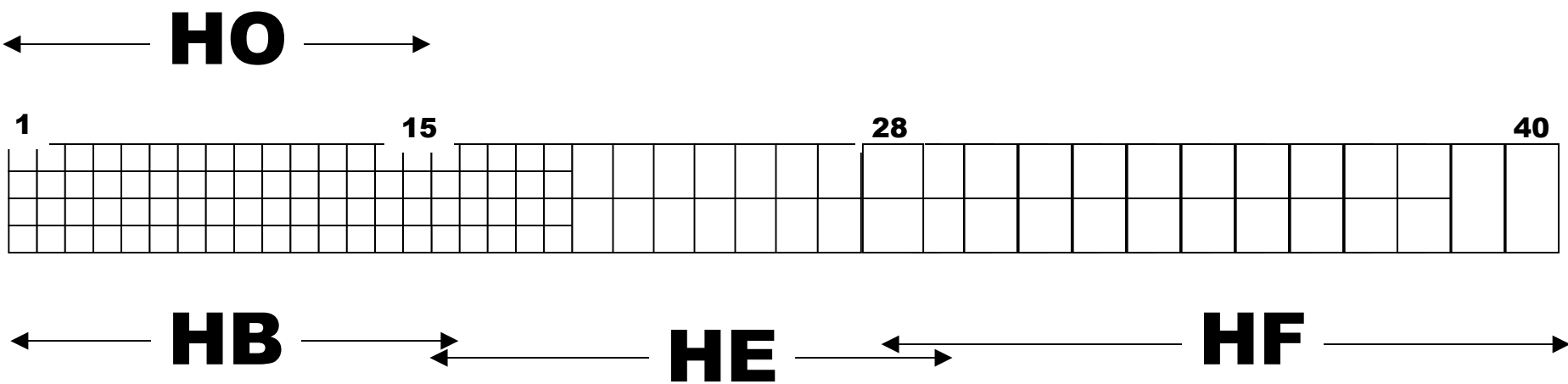
Material in Tracker

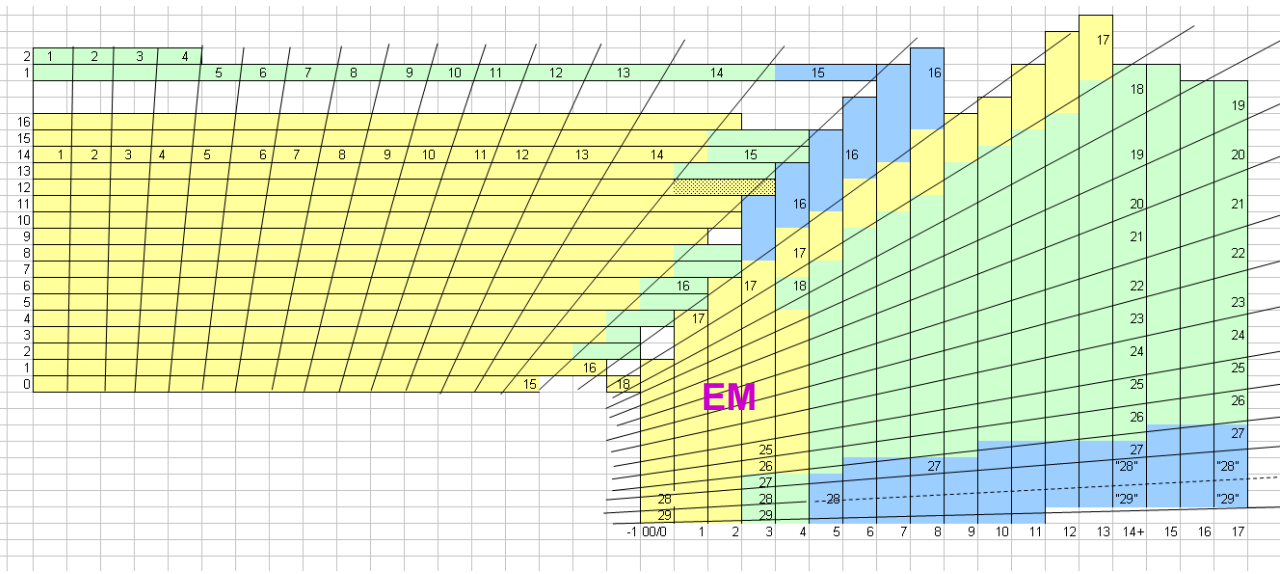


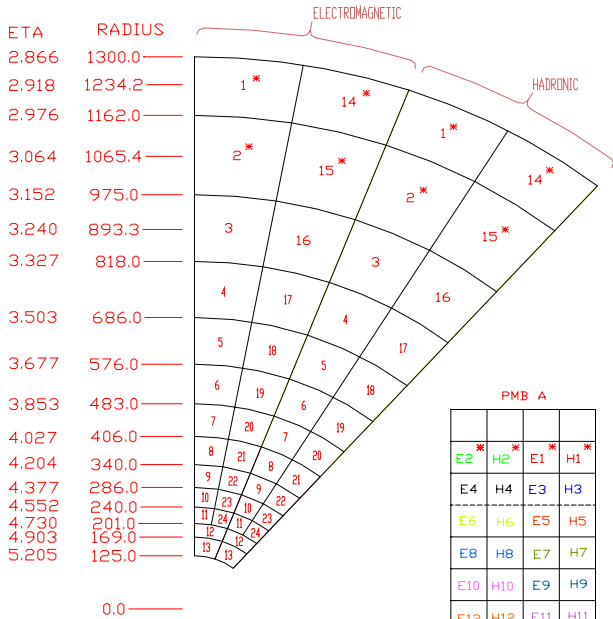


HCAL Towers (Readout)

10 tower types

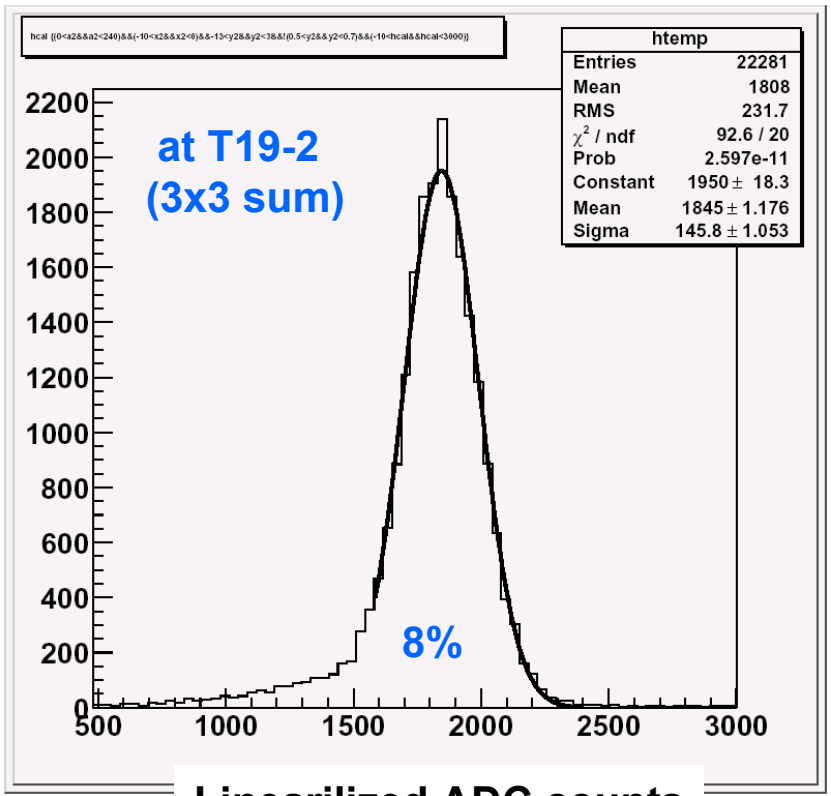






HE Response (TB03)

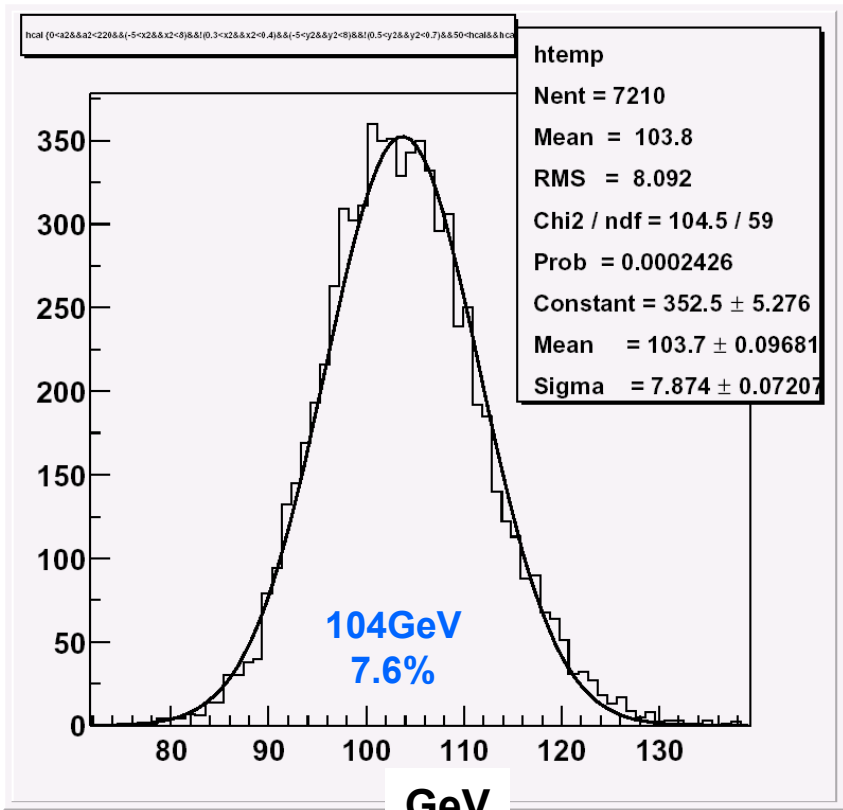
300GeV pi-



Linearilized ADC counts

0.163GeV/ADC

100GeV e-



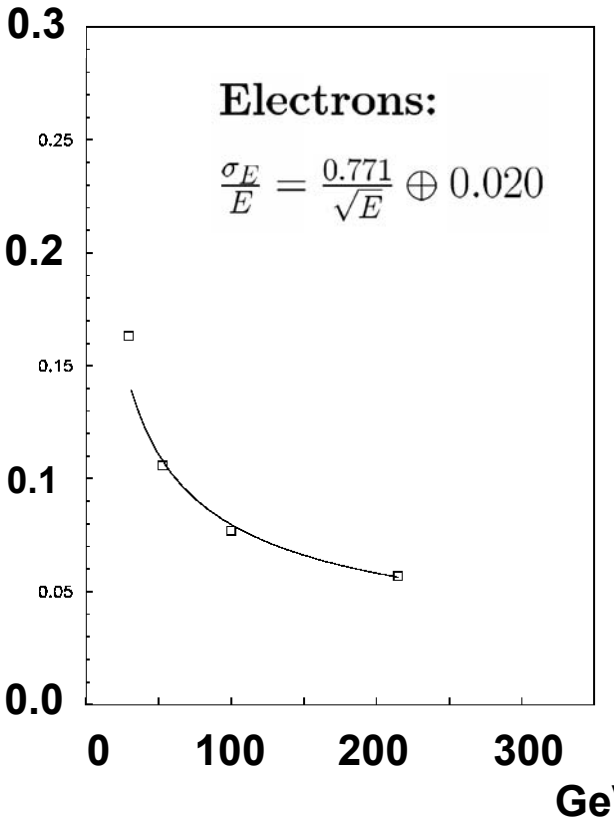
GeV

(calibrated with 300GeV pion)

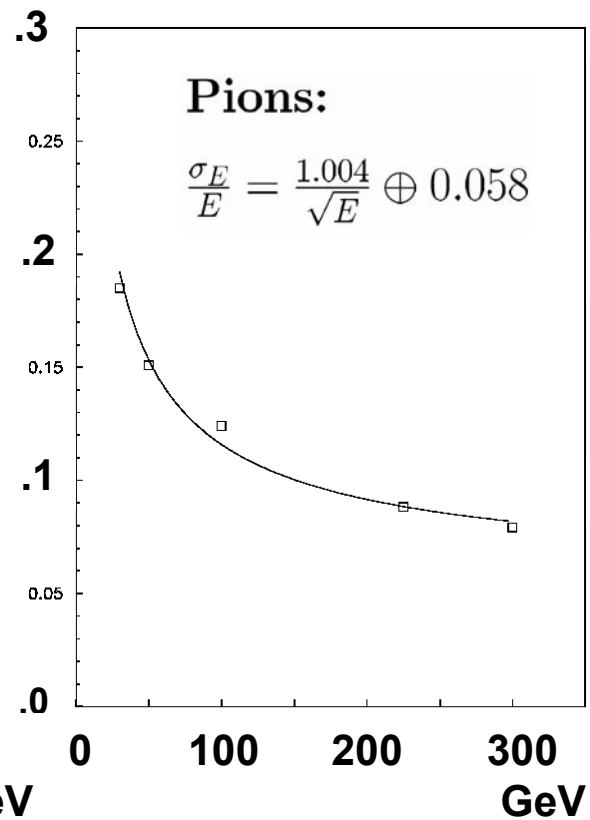
HE (TB03)

(no ECAL in front)

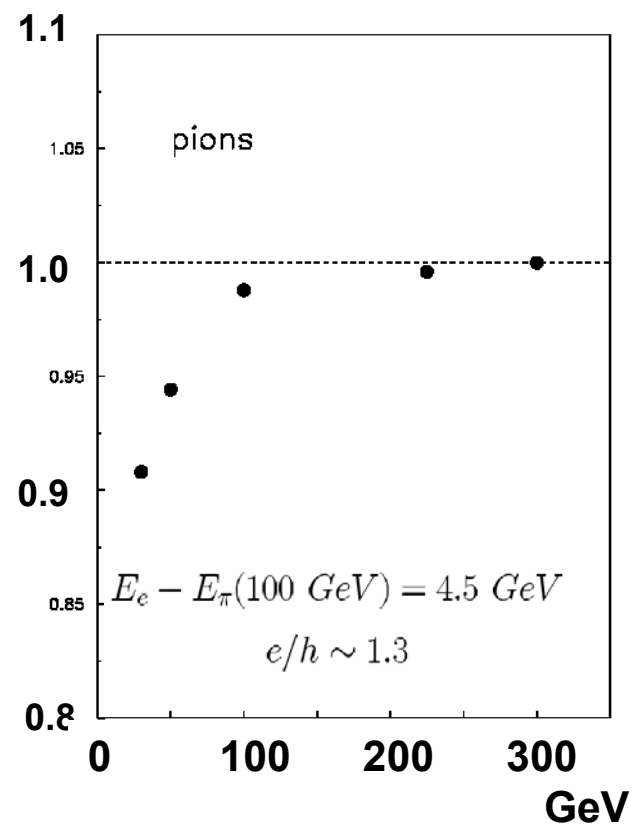
resolution



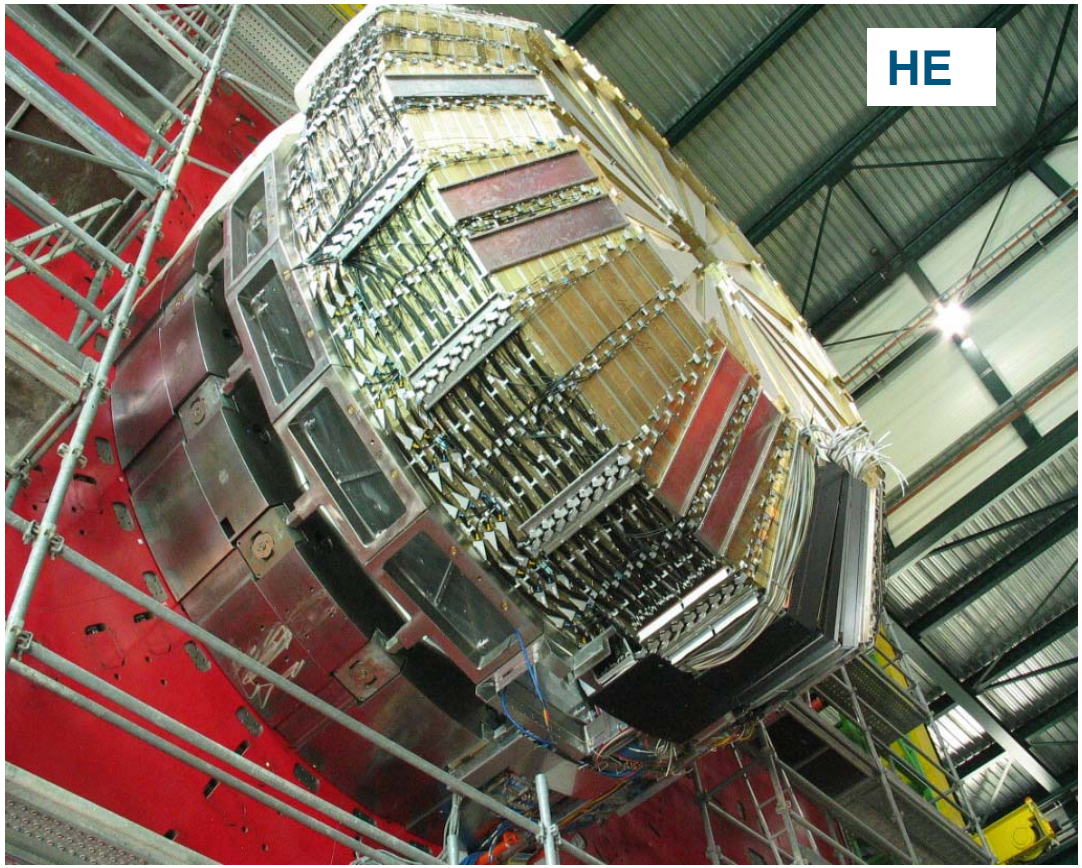
resolution

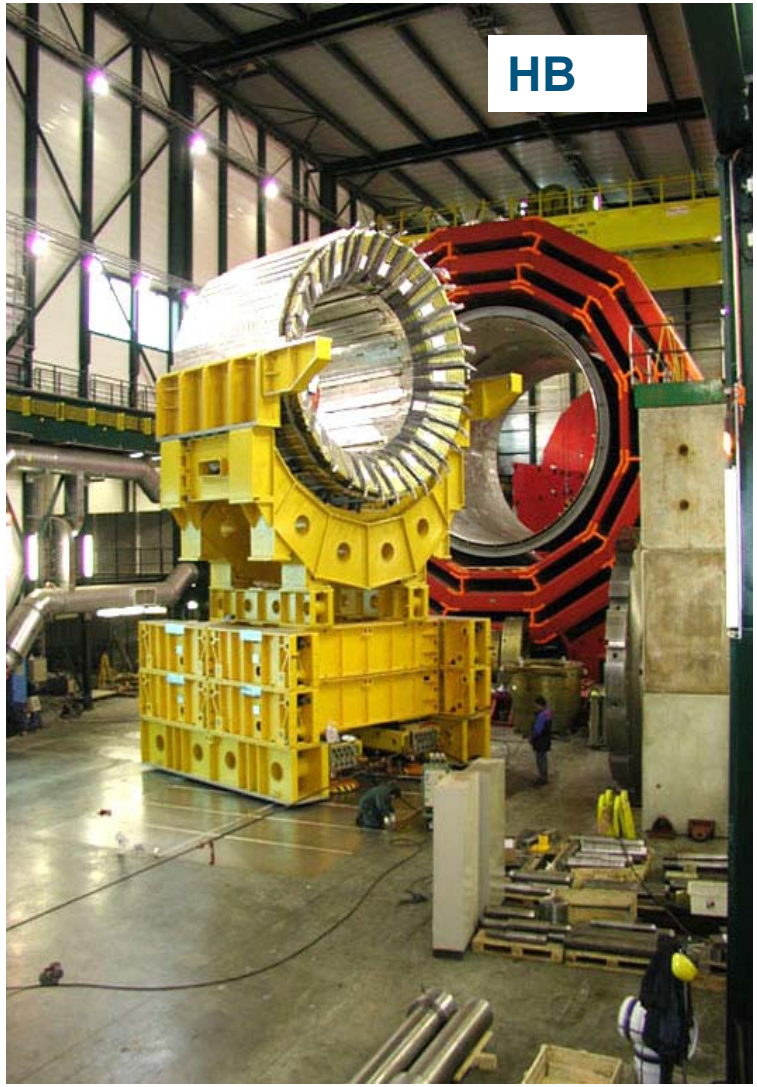


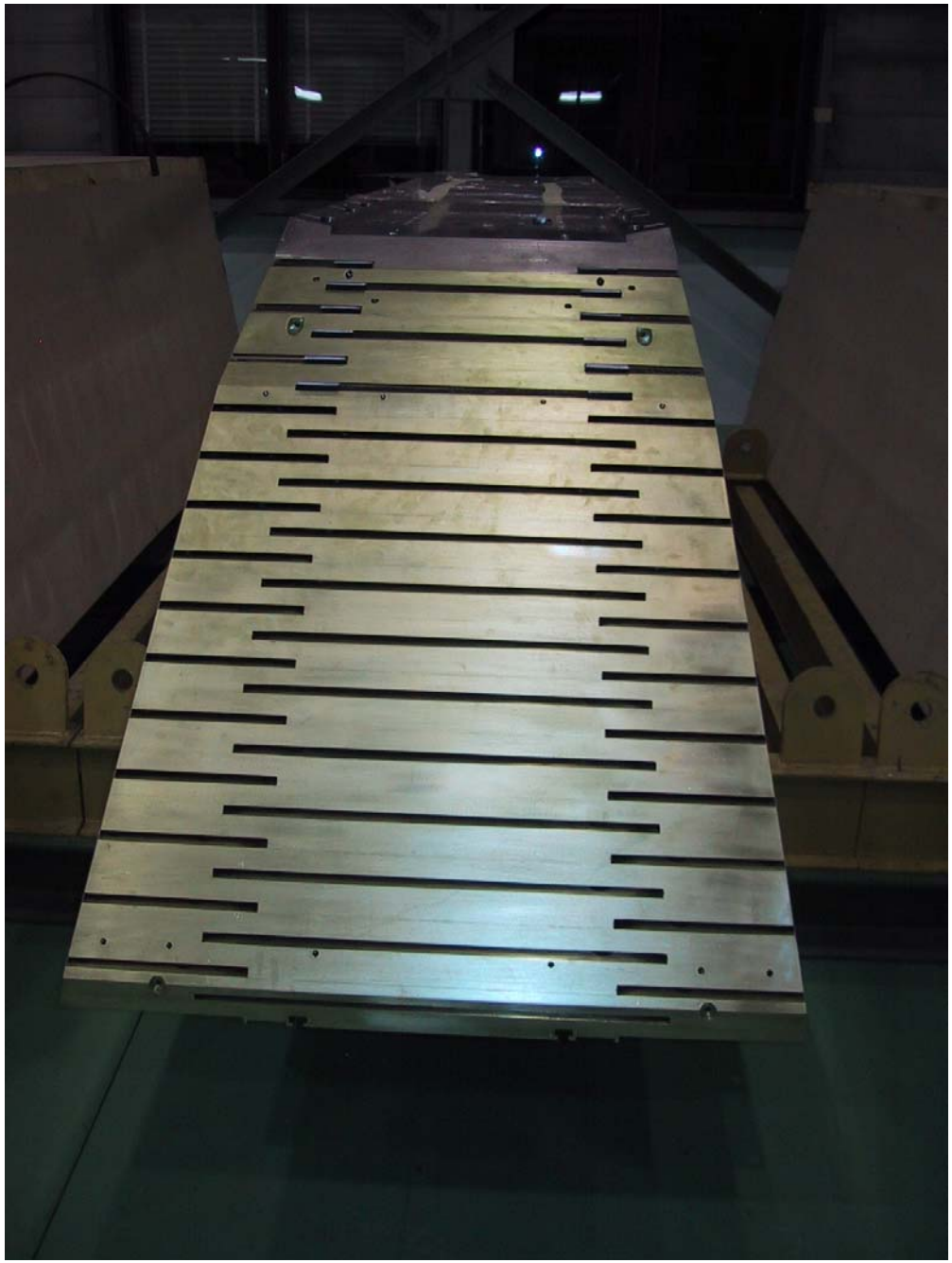
linearity



HCAL-Absorbers Complete



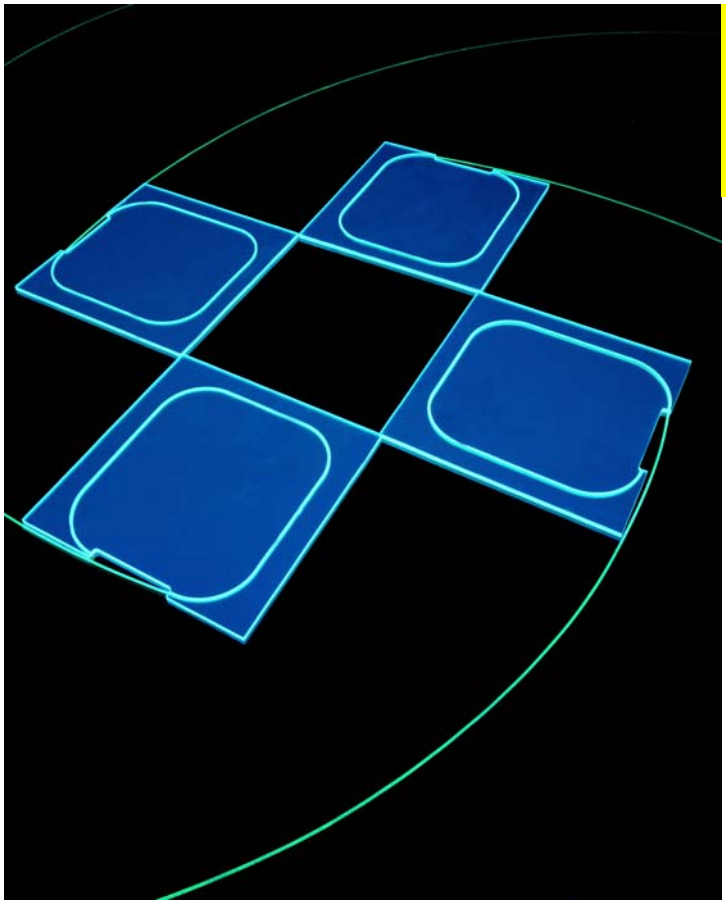




0	9 mm BC408
	40 mm steel
1	3.7 mm SCSN81
	50.5 mm brass
2	3.7 mm SCSN81
	50.5 mm brass
3	3.7 mm SCSN81
	50.5 mm brass
4	3.7 mm SCSN81
	50.5 mm brass
5	3.7 mm SCSN81
	50.5 mm brass
6	3.7 mm SCSN81
	50.5 mm brass
7	3.7 mm SCSN81
	50.5 mm brass
8	3.7 mm SCSN81
	50.5 mm brass
9	3.7 mm SCSN81
	56.5 mm brass
10	3.7 mm SCSN81
	56.5 mm brass
11	3.7 mm SCSN81
	56.5 mm brass
12	3.7 mm SCSN81
	56.5 mm brass
13	3.7 mm SCSN81
	56.5 mm brass
14	3.7 mm SCSN81
	56.5 mm brass
15	3.7 mm SCSN81
	56.5 mm brass
16	3.7 mm SCSN81
	75 mm steel

HB

Central Hadron Calorimeter HB,HE, HO

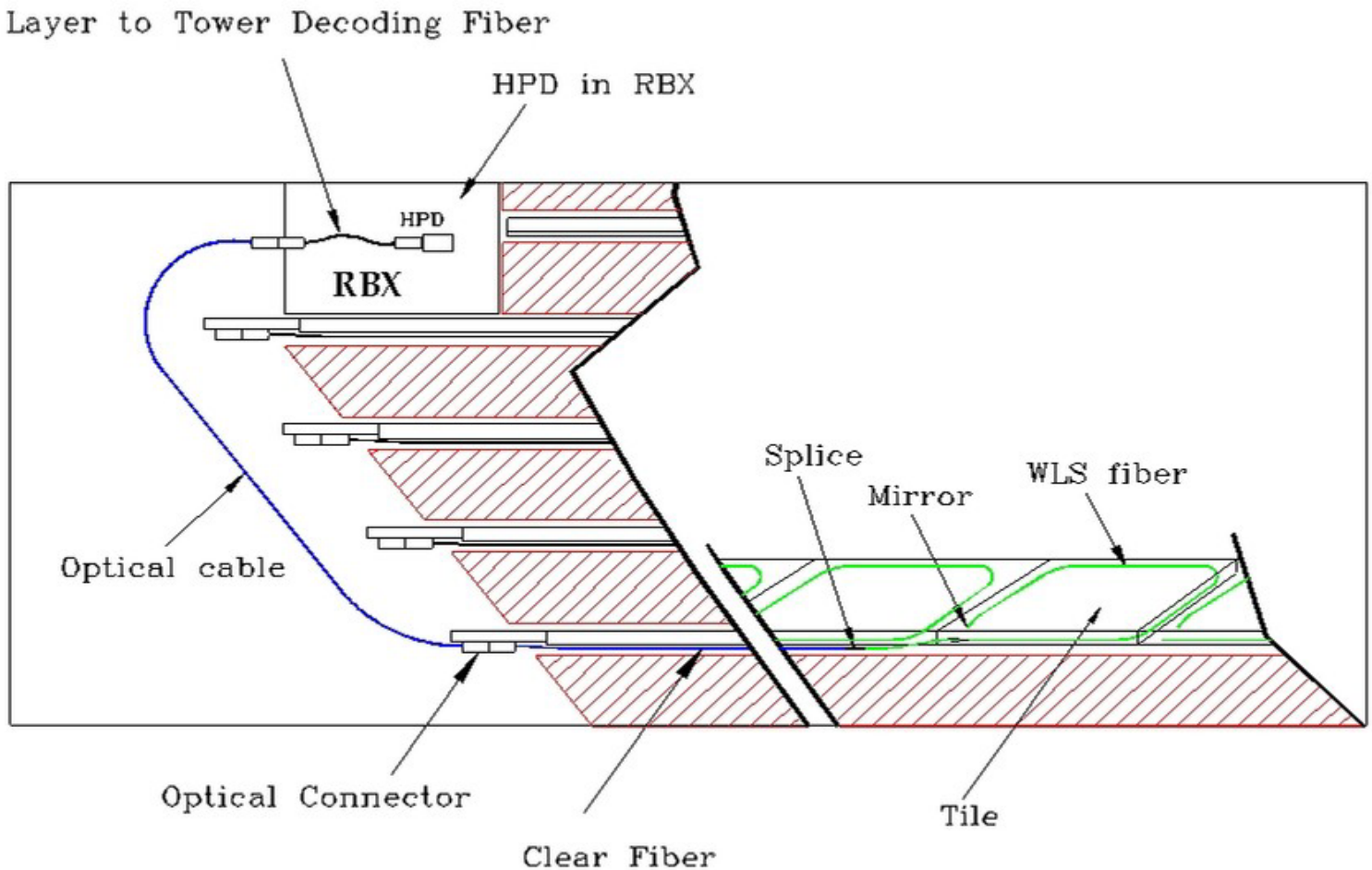


Scintillator + Wavelength Shifter Readout

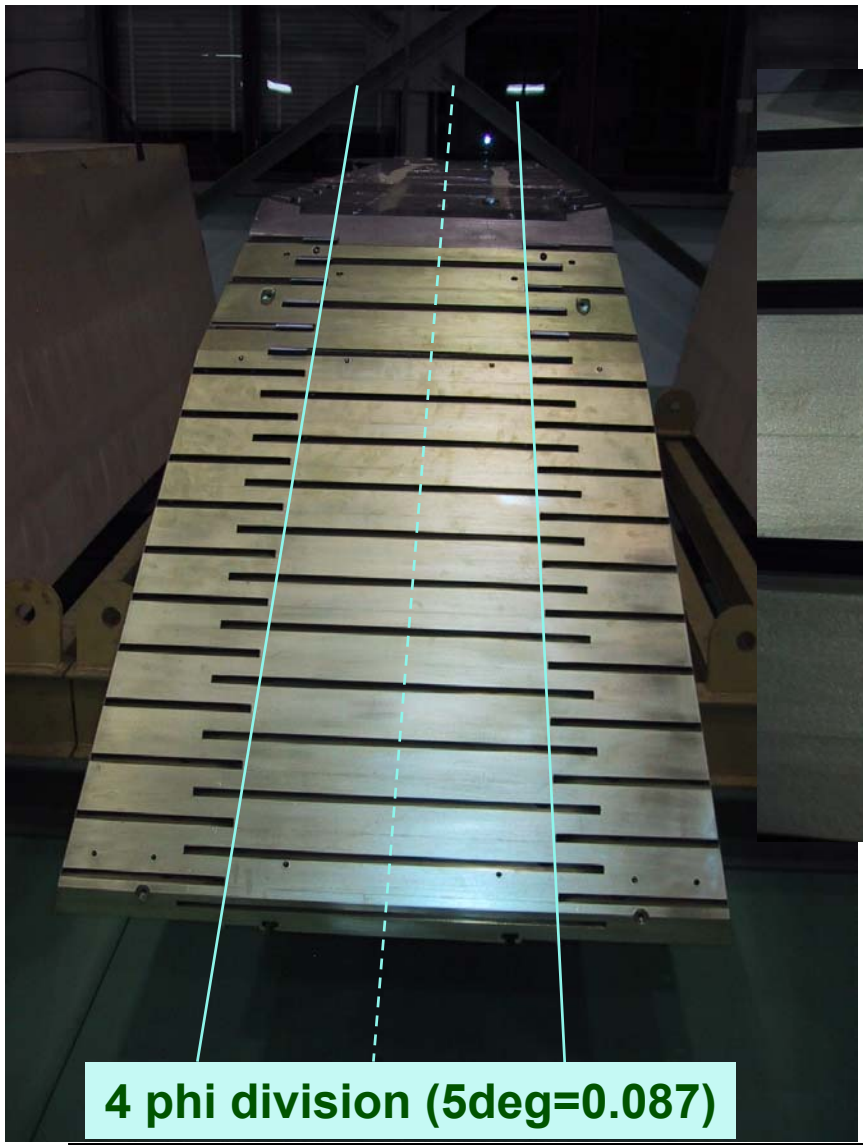
Inserting scintillator into HB wedge

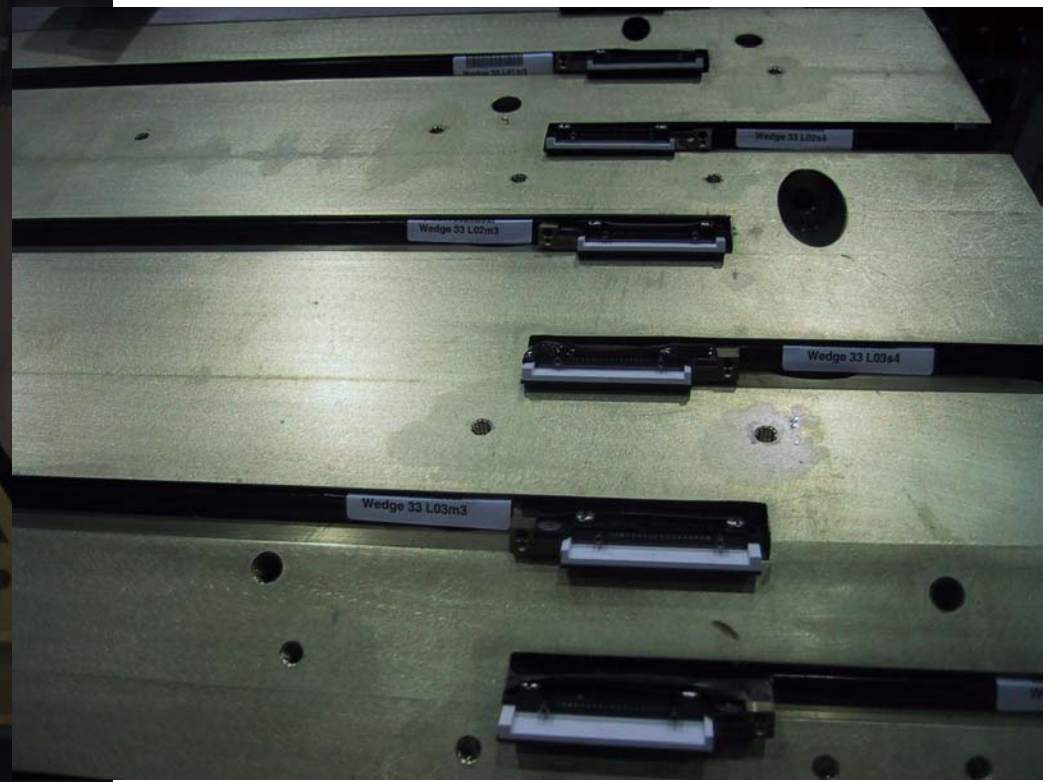
Optical Design for HCAL

Common Technology for HB, HE, HO



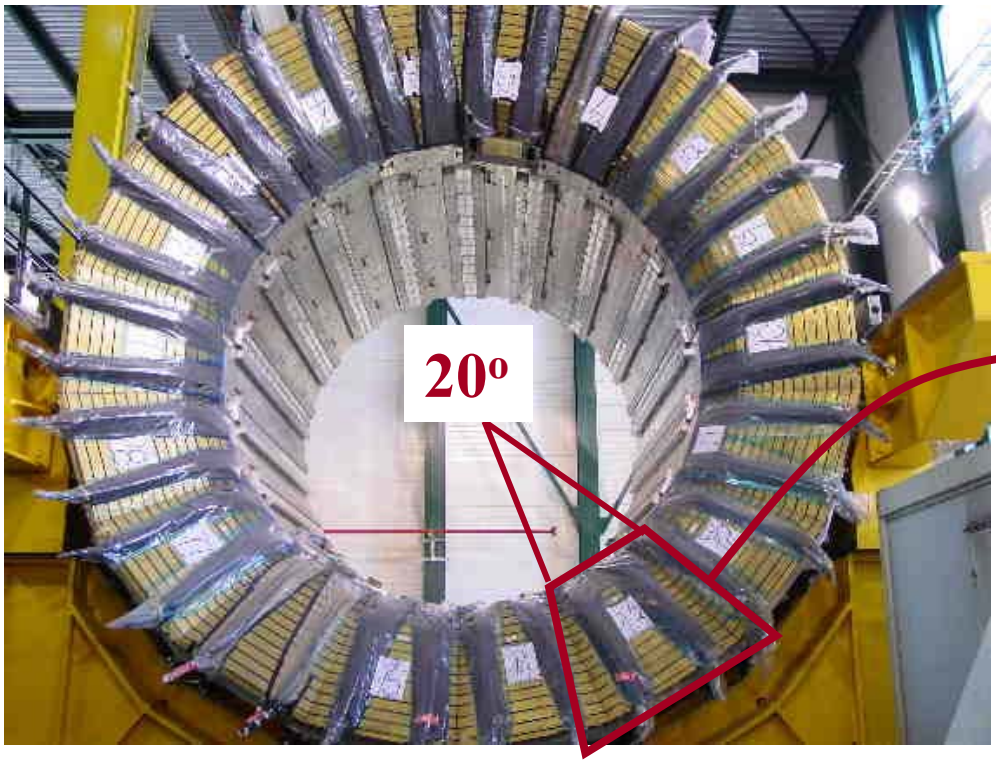
HB and Optical Connectors



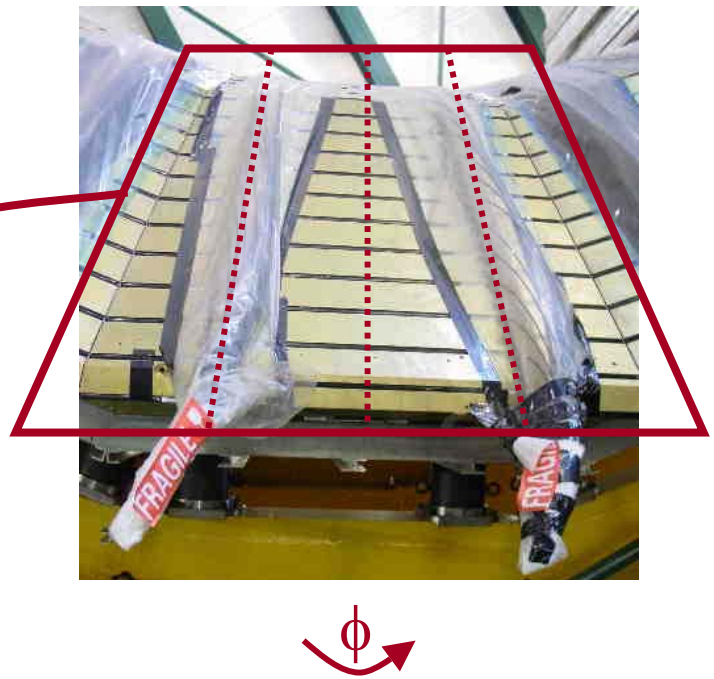


Optical Cable Connector

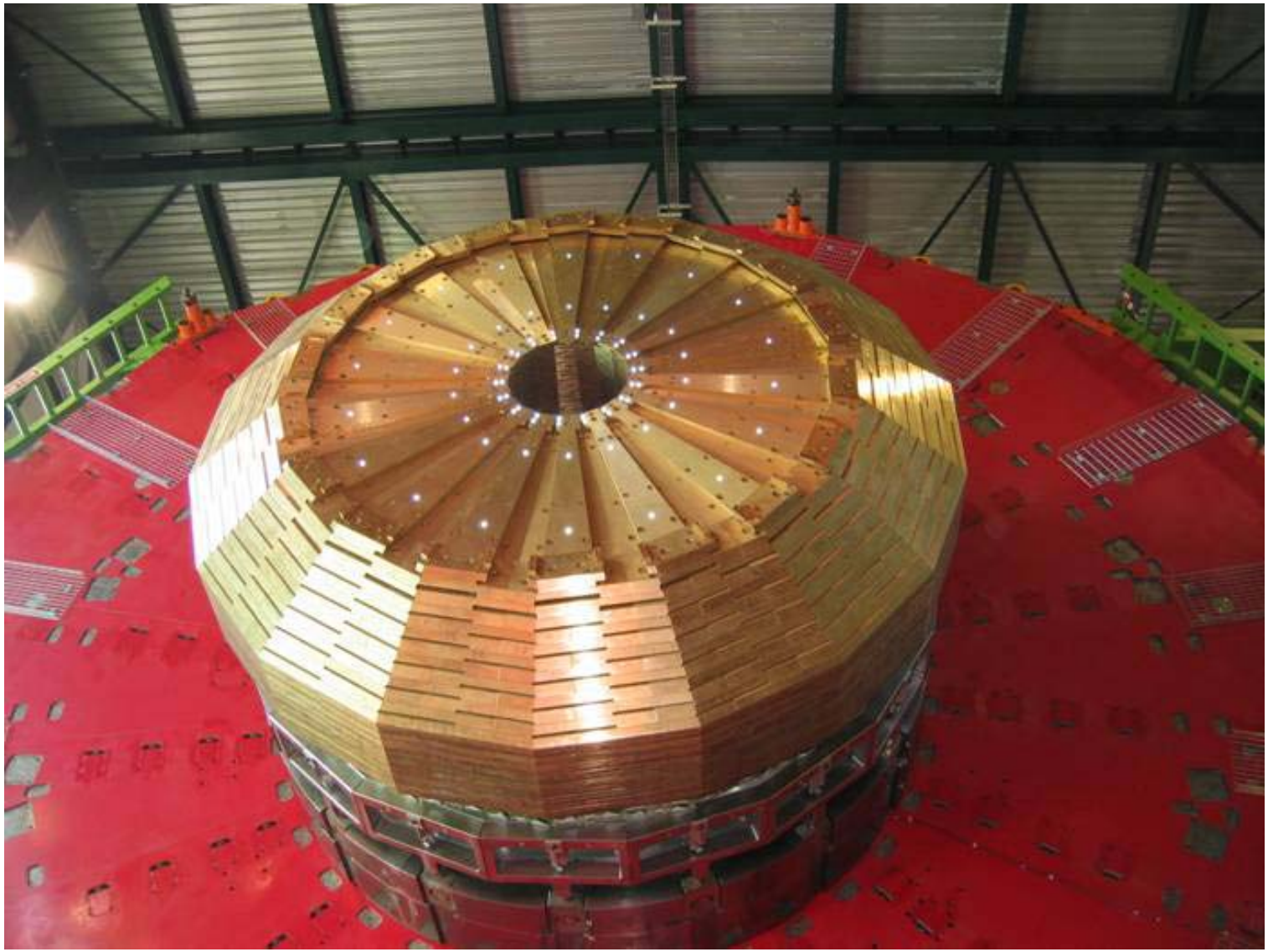
HB



17 layers longitudinally,
$\phi \times \eta = 4 \times 16$ towers



HE



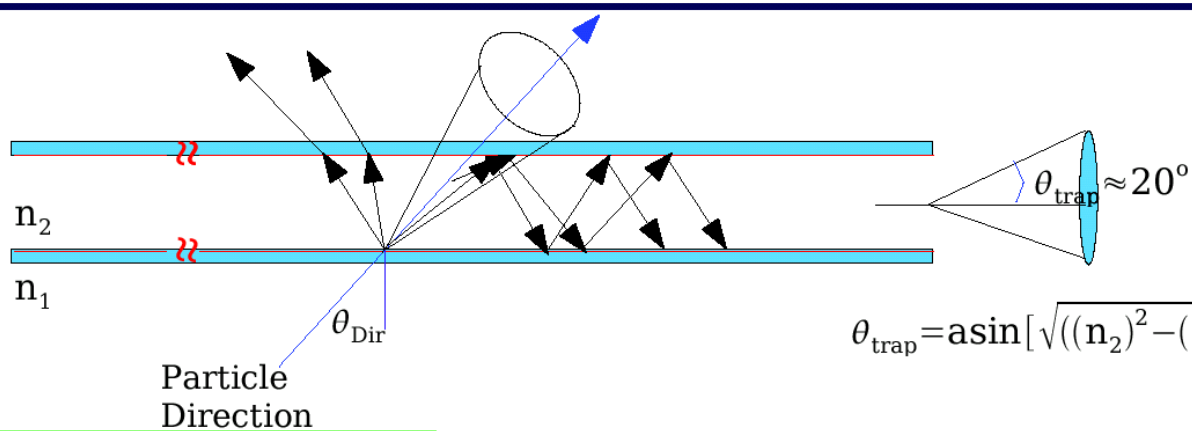
HF Status

HF are first Items to be lowered in Jan. 2006

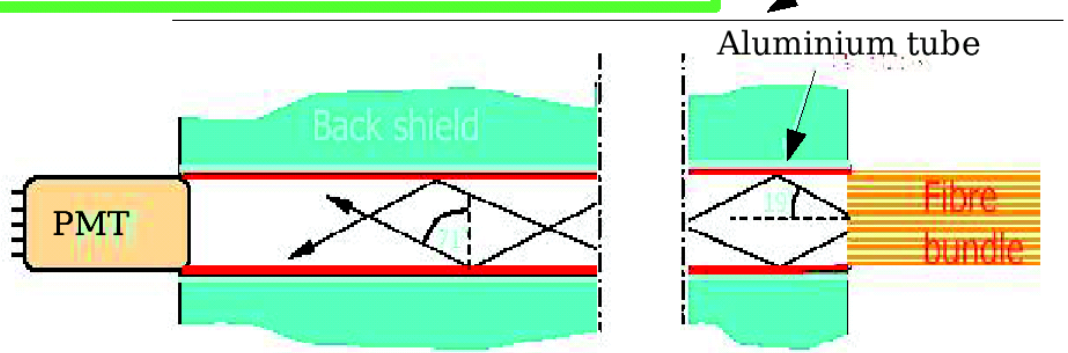
Fibers inserted in all 36 wedges

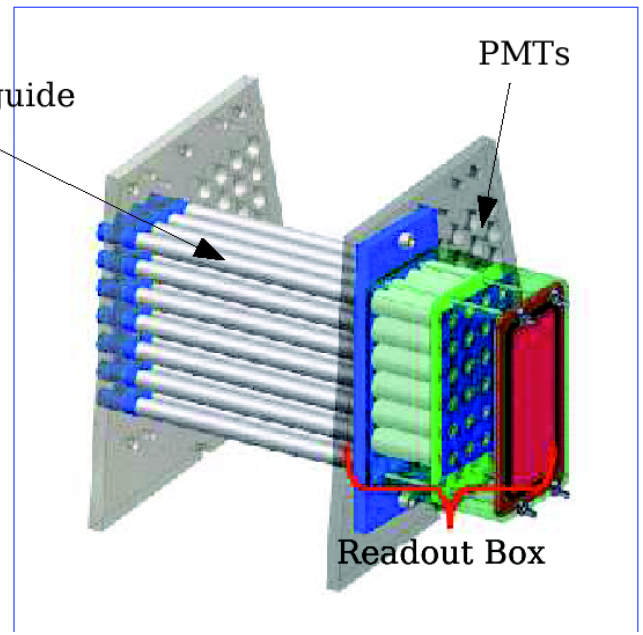
+ end assembled in Bat 186

HF: Cherenkov Photons

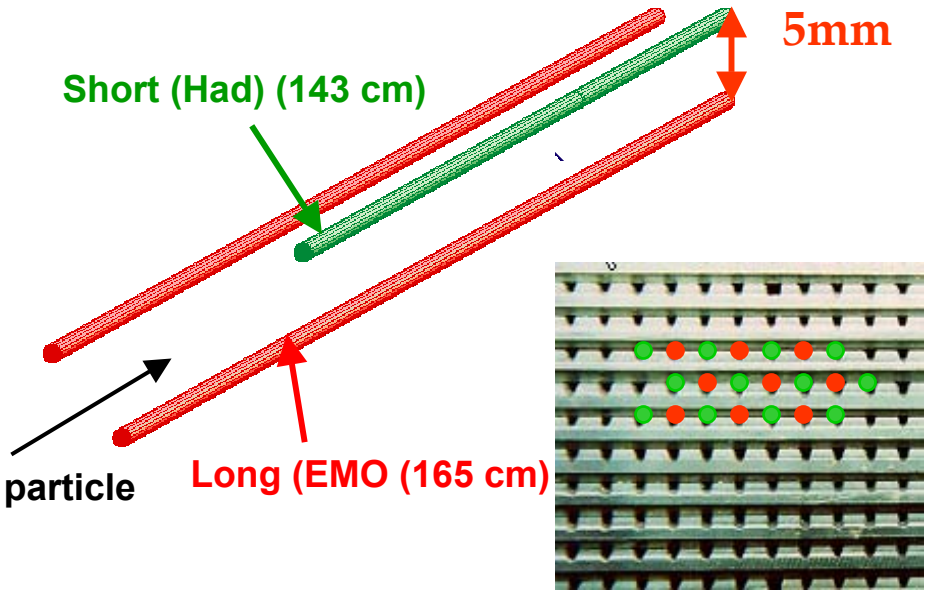


Trapping
+
Attenuation + High Eff. Mirrors
+
PMT(QEff)

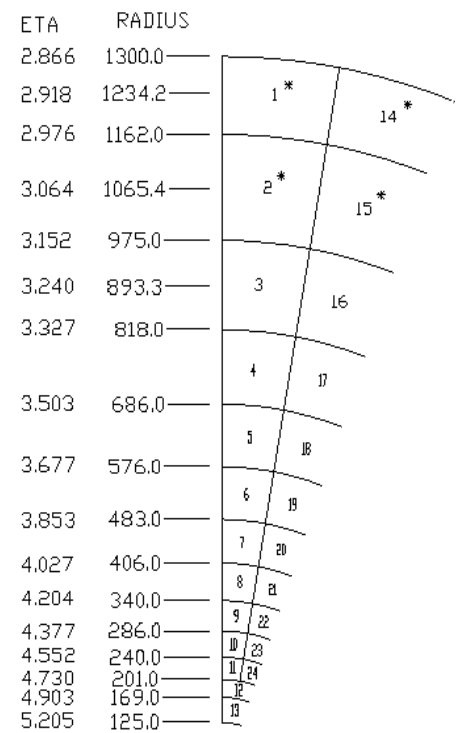




Forward Hadron Calorimeter: HF



To cope with high radiation levels (>1 Grad accumulated in 10 years) the active part is Quartz fibers: the energy measured through the Cerenkov light generated by shower particles.



Iron calorimeter

Covers $5 > \eta > 3$

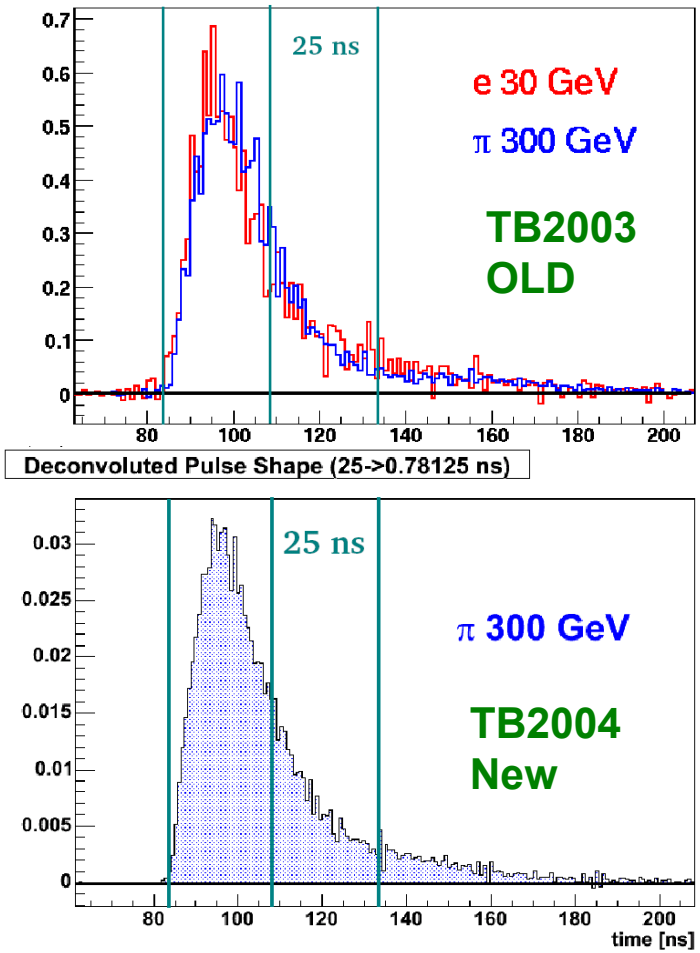
Total of 1728 towers, i.e.

2 x 432 towers for EM and HAD

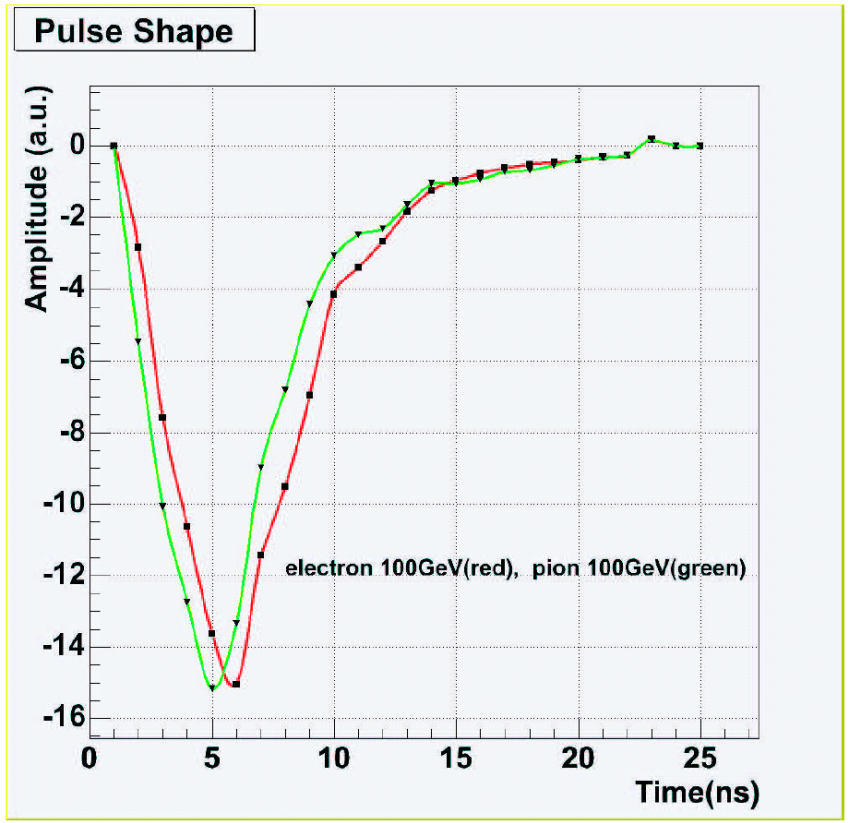
$\eta \times \phi$ segmentation (0.175 x 0.175)

QIE Pulse Shapes

HB eta=7



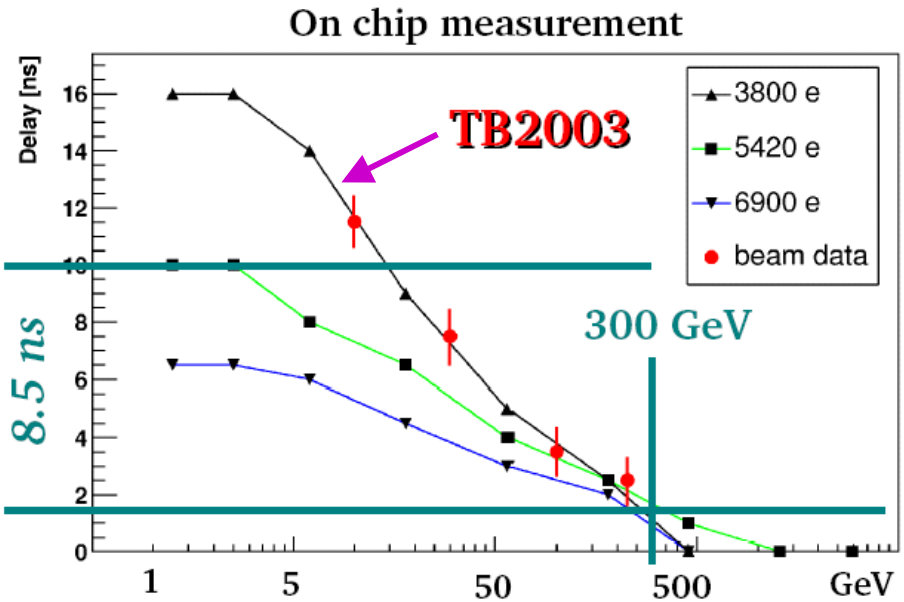
HF

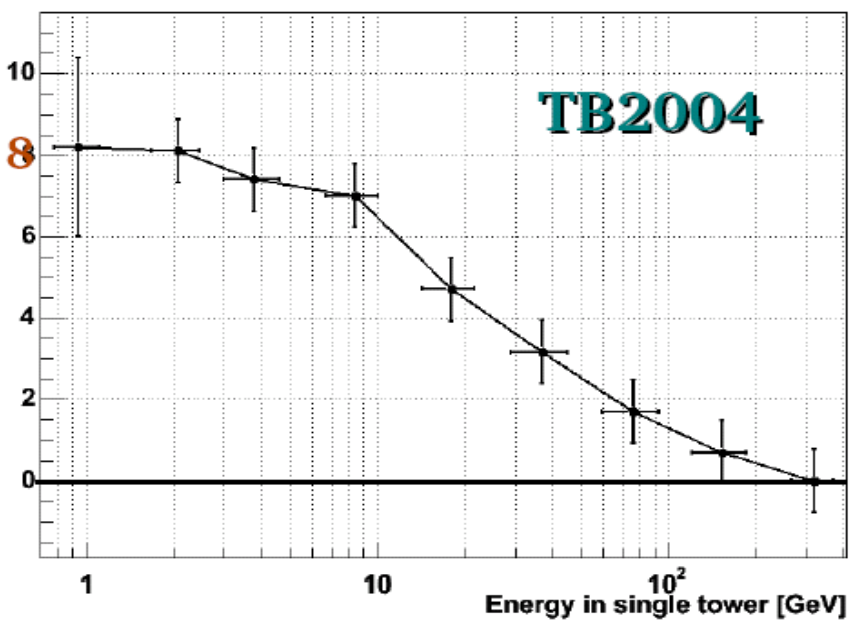


No difference between old and new.
88% signal collection in 2 time slice.

Very fast – 1 time slice for all signal.
Pion signal arrives 1ns earlier than e-.

Time Slew



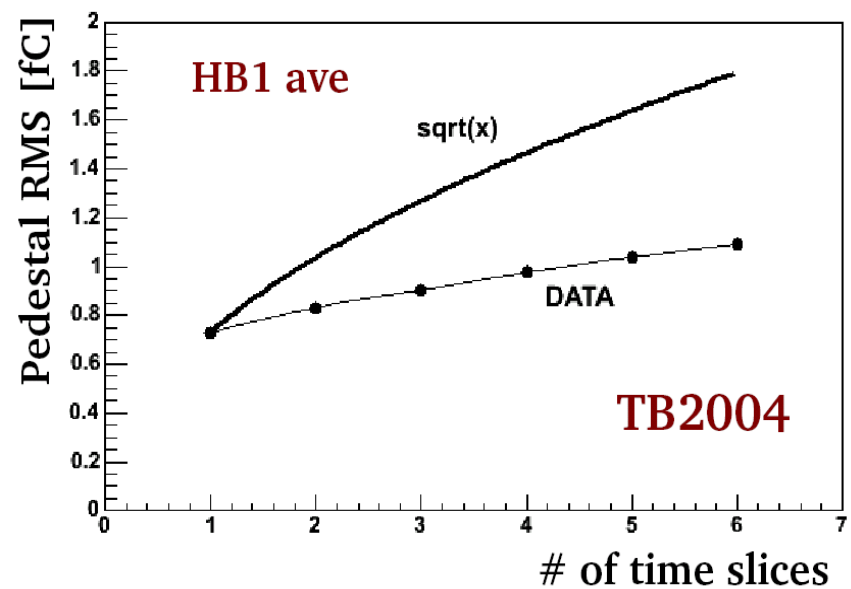


Original QIE vs New QIE

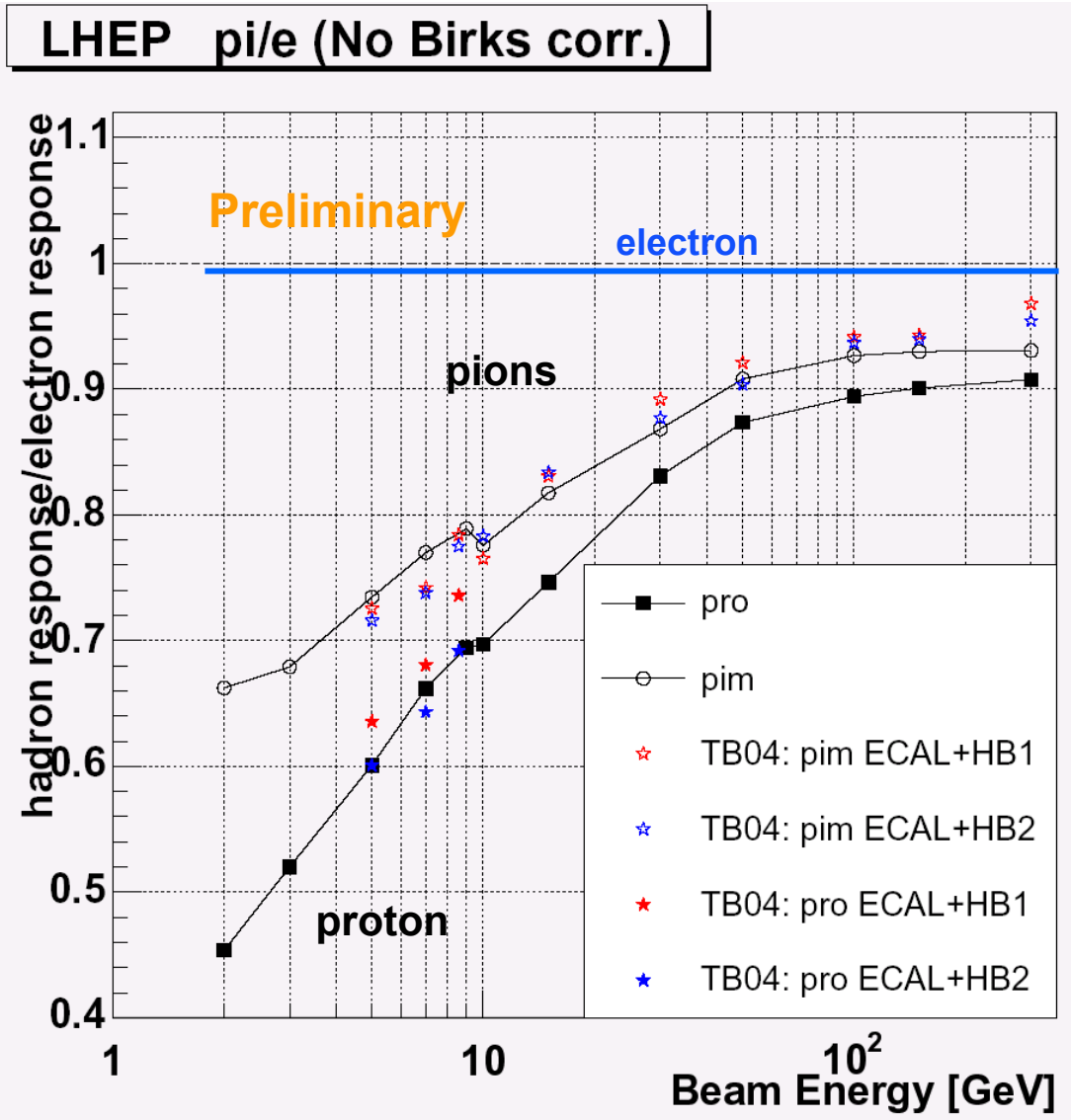
Original – quiet (for HO)
New – faster (for HB, HE)

Noise Level

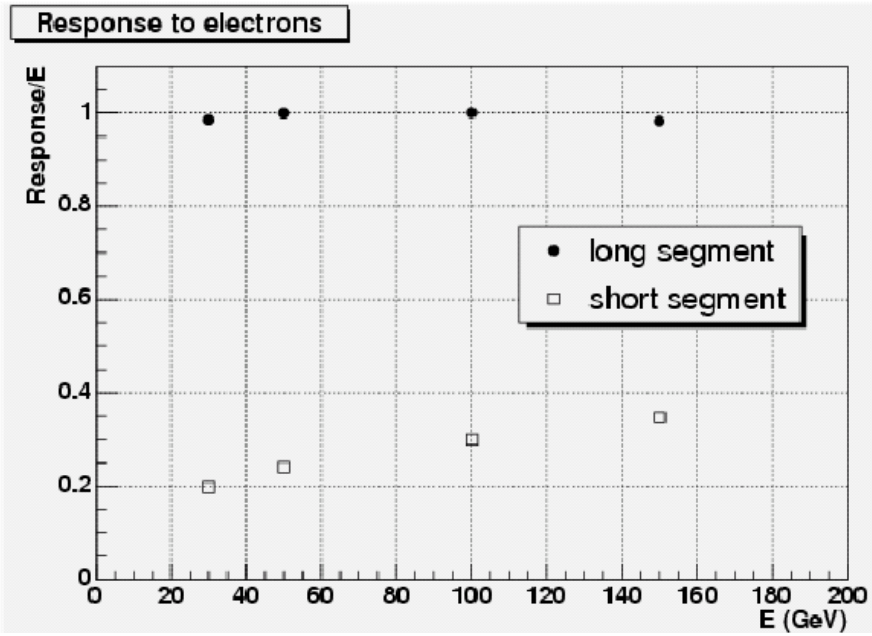
ped. RMS (1 ts.)
TB2004: 0.730 fC
TB2003: 0.586 fC

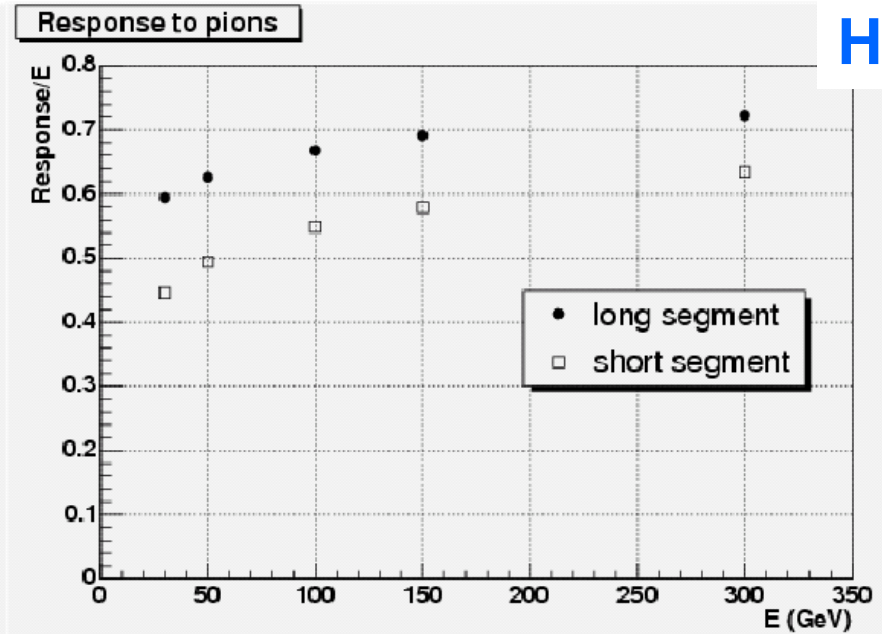


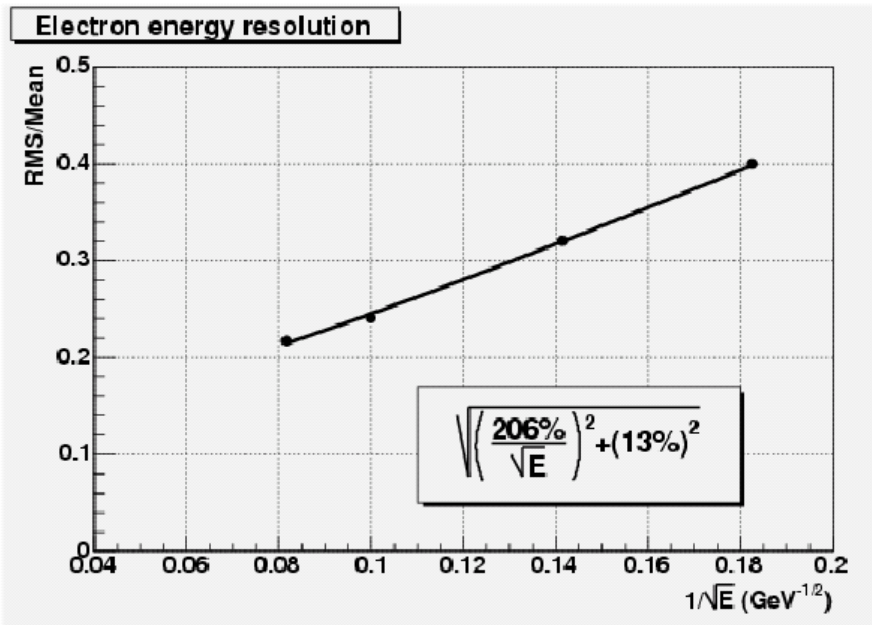
EC+HB π/e

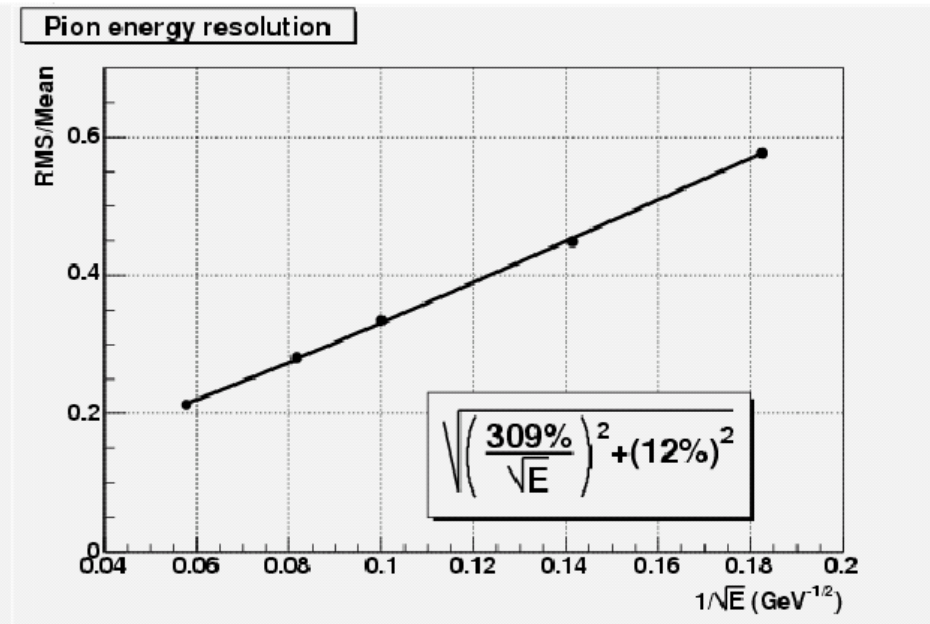

LHEP pi/e (No Birks corr.)
Preliminary
electron
pions
proton
hadron response/electron response
Beam Energy [GeV]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
1
10
10^2
pro
pim
TB04: pim ECAL+HB1
TB04: pim ECAL+HB2
TB04: pro ECAL+HB1
TB04: pro ECAL+HB2

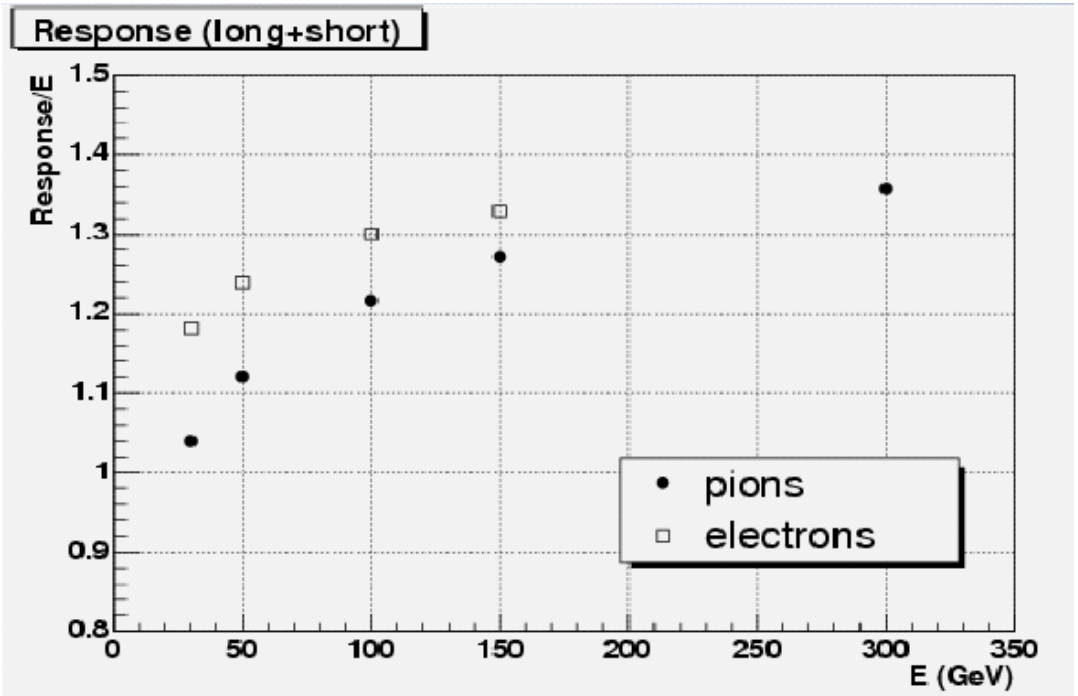
HF


Response to electrons
Response/E
E (GeV)
long segment
short segment


Response to pions
Response/E
E (GeV)
long segment
short segment


Electron energy resolution
RMS/Mean
$1/\sqrt{E}$ (GeV$^{-1/2}$)
$\sqrt{\left(\frac{206\%}{\sqrt{E}}\right)^2+(13\%)^2}$


Pion energy resolution
RMS/Mean
$1/\sqrt{E}$ (GeV$^{-1/2}$)
$\sqrt{\left(\frac{309\%}{\sqrt{E}}\right)^2+(12\%)^2}$



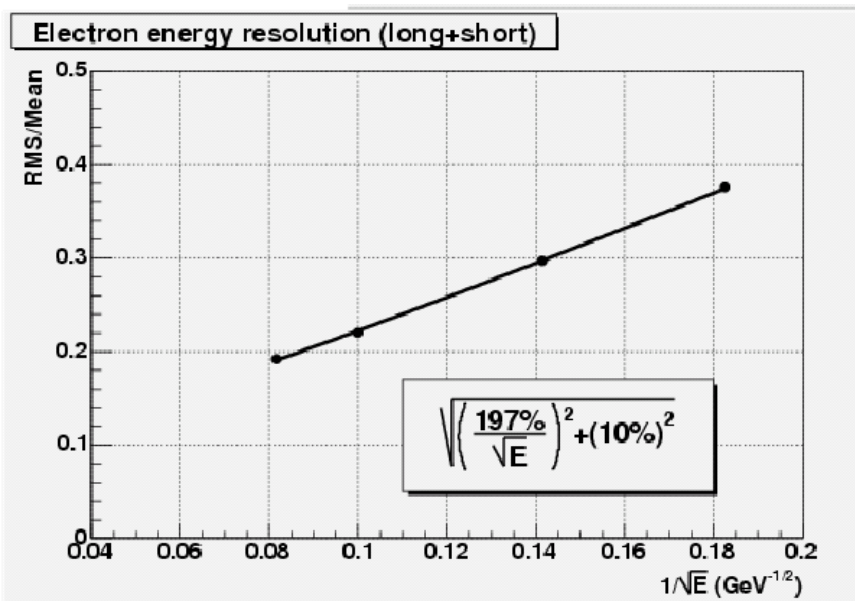
HF: Long + Short

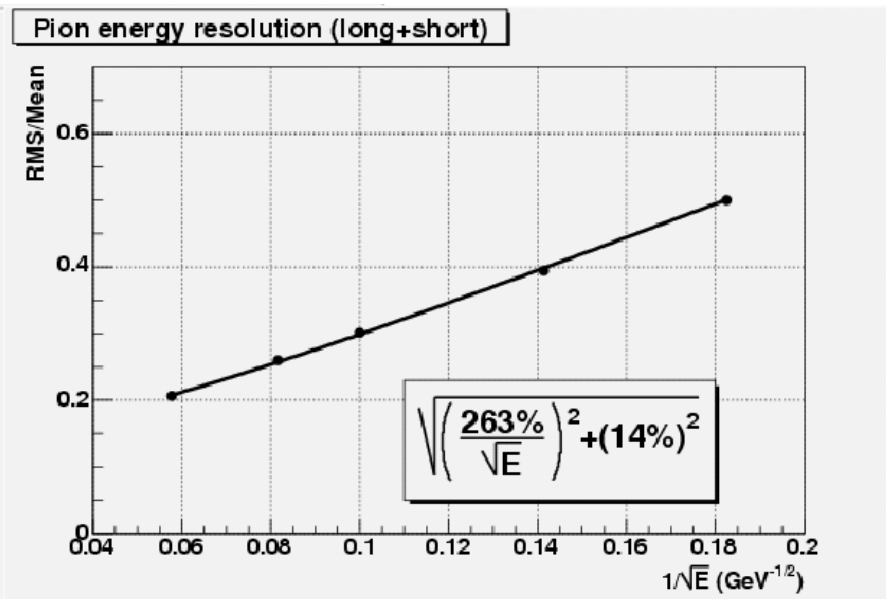
π/e: large improvement

$(0.6\text{-}0.7)_L \rightarrow (0.86\text{-}1.0)_{L+S}$

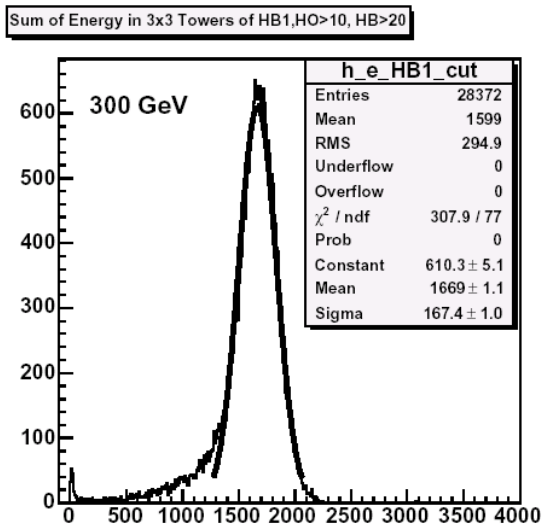
rms/E: Minor improvement

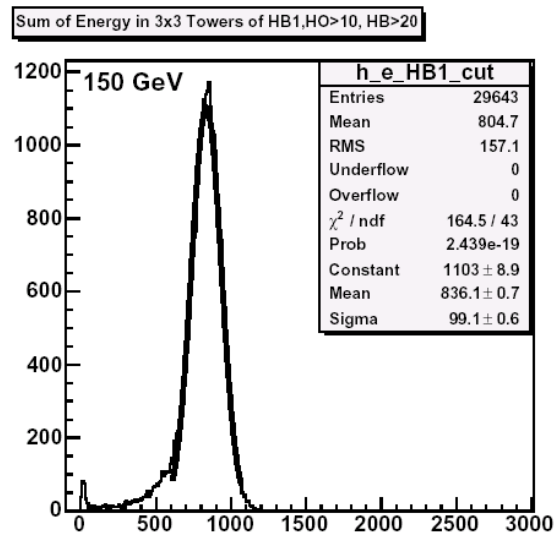
24% → 22% for 100GeV electron
33% → 30% for 100GeV pion





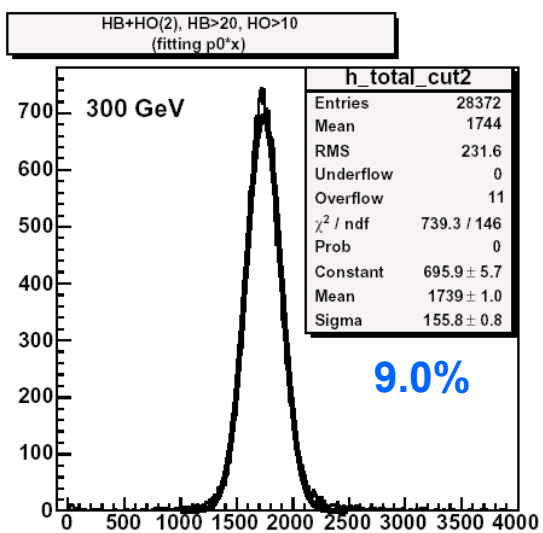
HO: Weight Optimization

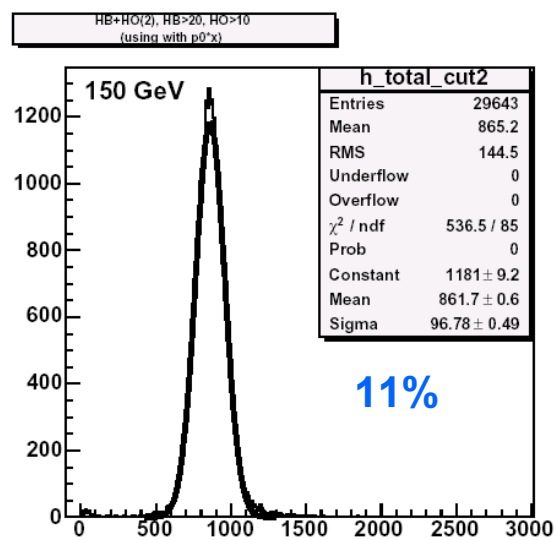




E= HB + k*HO

(MIP in ECAL event)





Leakage from HB is cleanly pushed back to Gaussian distribution.

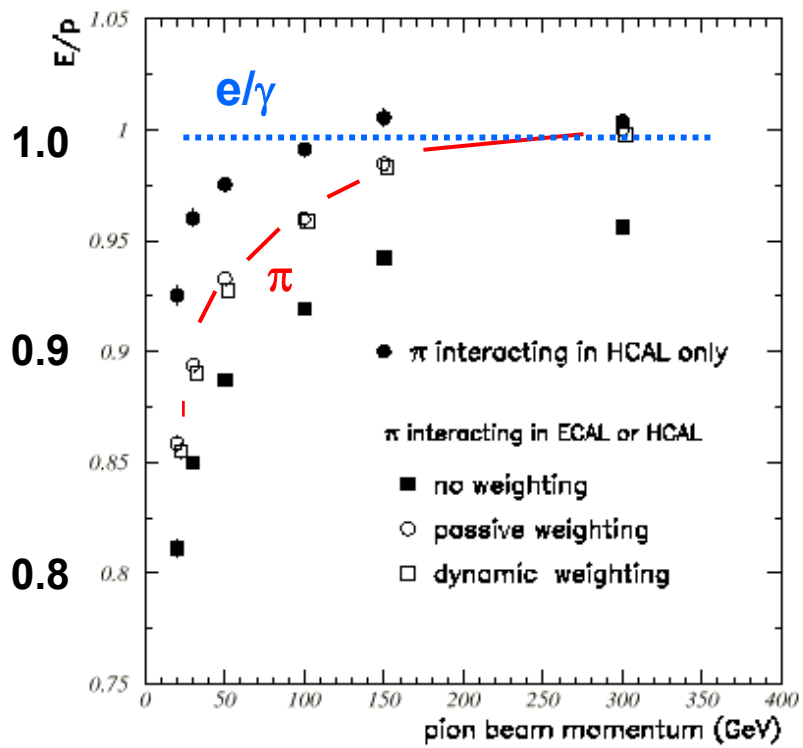
Response in CMS

Pion Response: Linearity

ECAHL+HCAL: Non compensating calorimeter

96'H2 Teast Beam Data

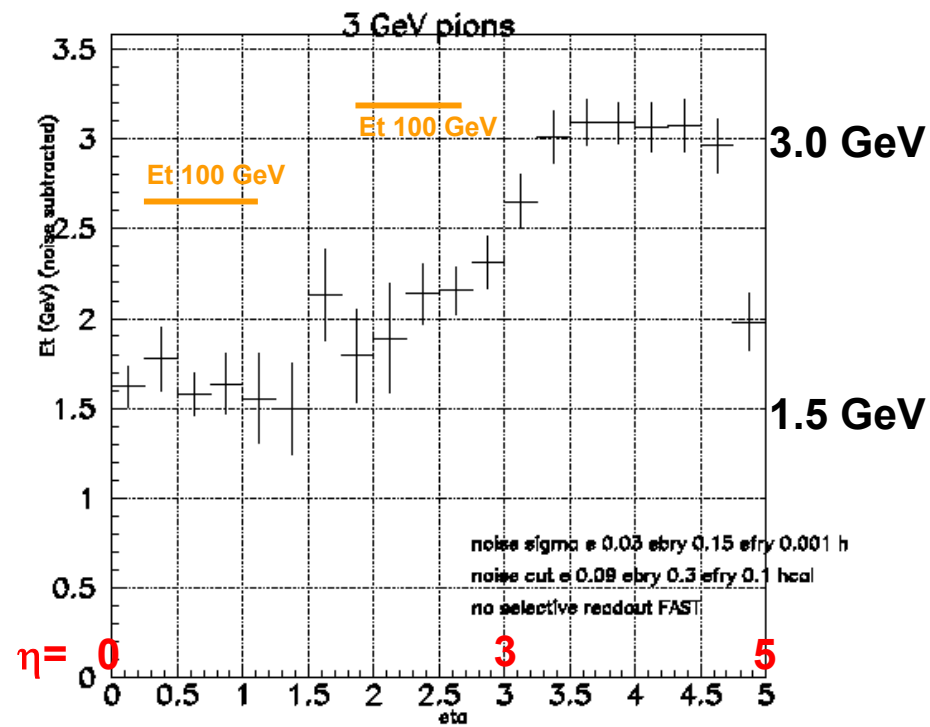
E=EC + α x H1 + H2 +HO



P= 0 200 400GeV

CMS Simulation

P_T=3 GeV pion in 0<|η|<5

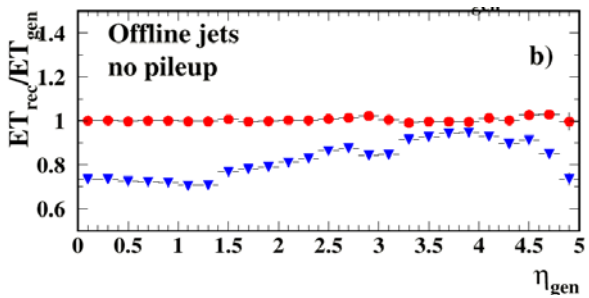


P= 3 7 30 82 227 GeV

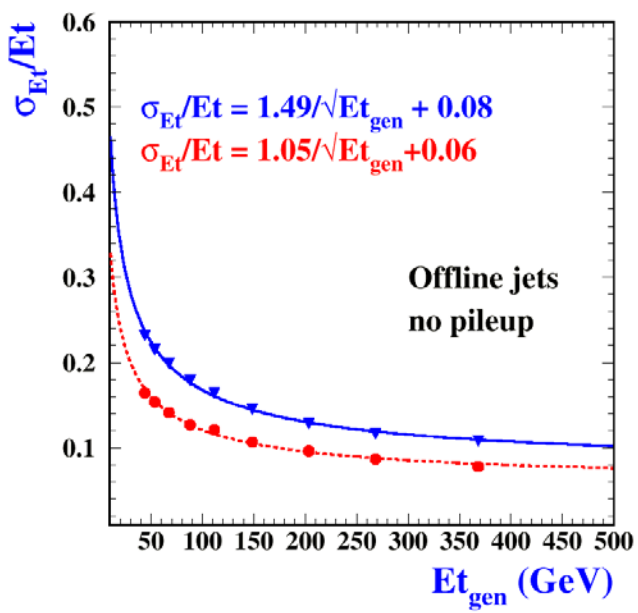
Simple Jet Energy Correction (#1)

Map of response in E_T-η: $E_T(corr)=a + b \times E_T(raw) + c \times E_T(raw)^2$

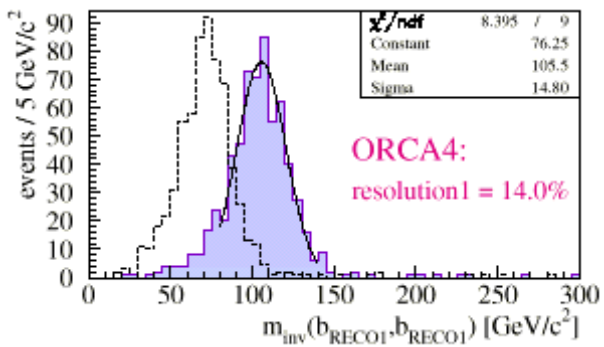
a,b,c depends on E_T and η



Offline Jets resolution, $|\eta|<5$



M(bb) in ttH



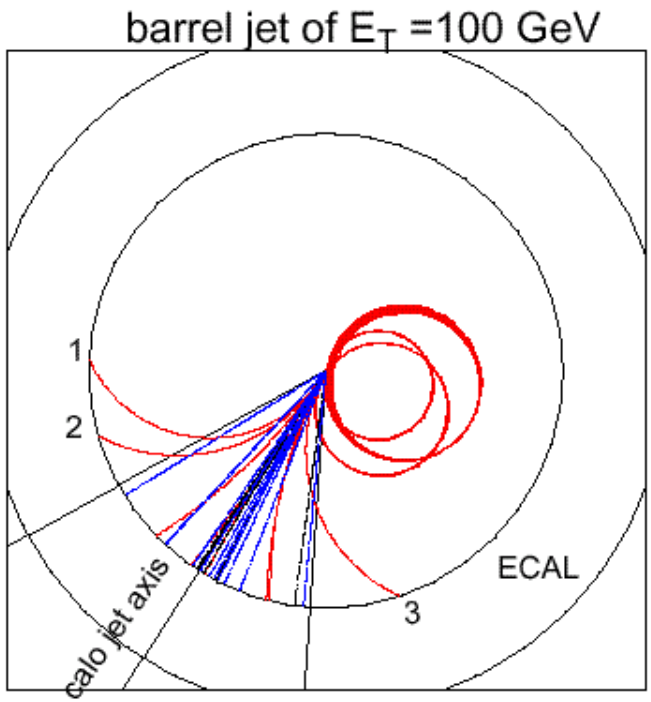
Jet energy correction

without: 19%

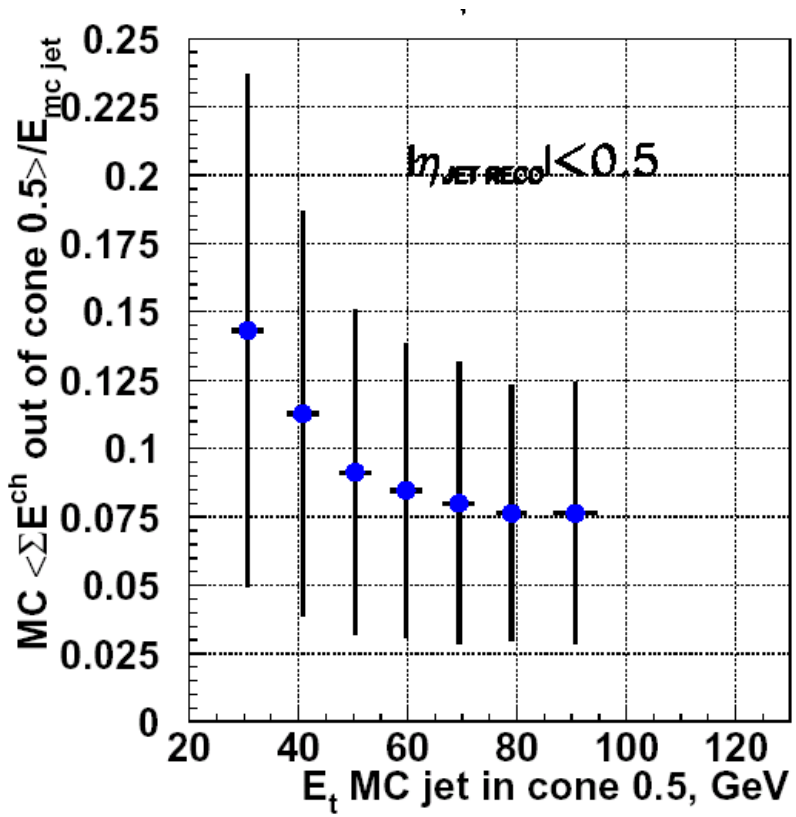
with: 14%

→ **Level 1 trigger, HLT trigger, offline**

Effect of 4 Tesla Filed



Fraction of energy escape from a jet cone (R=0.5) in 4T field.



Radius of ECAL front ~ 1.3 meters

Charged particles P_T < 0.8GeV
→ Looper in barrel.

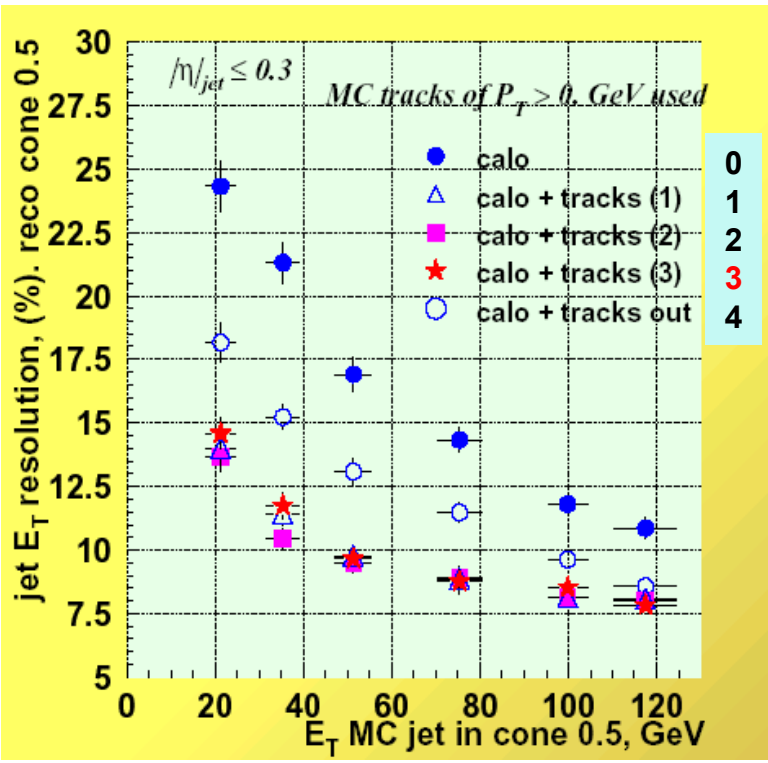
Using Tracks (#5)
Resolution & E_T Scale

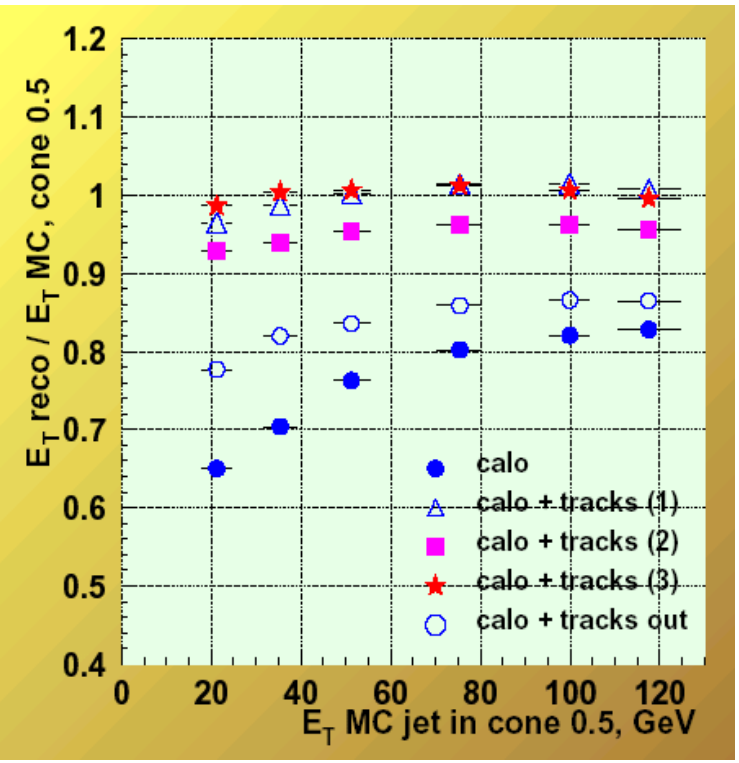
Resolution

20GeV 24% → 14%
100GeV 12% → 8%

E_T Scale

δ < 2% in 20-120GeV



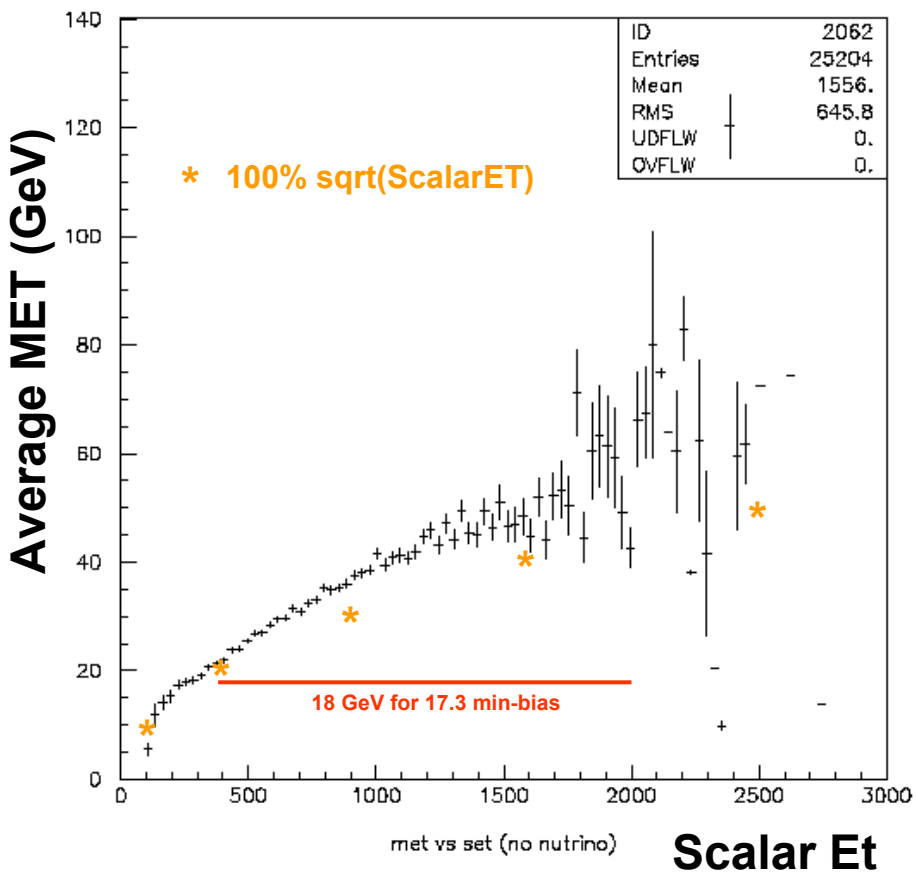


0: no correction (calorimeter only) 1: calo response - simple average 2: calo response – library
3: full correction (library of response, track-cluster match, out-of-cone tracks)
4 out-of-cone tracks correction only

Offline MET Resolution (2000.3)

QCD Jets with no neutrino/muon

(no pile-up)



$Ex = \Sigma$ (Ex-tower)

$Ey = \Sigma$ (Ey-tower)

Any way to improve this?

e.g.

$Ex' = Ex + \Sigma\ (\Delta(Ex\text{-}jet))$

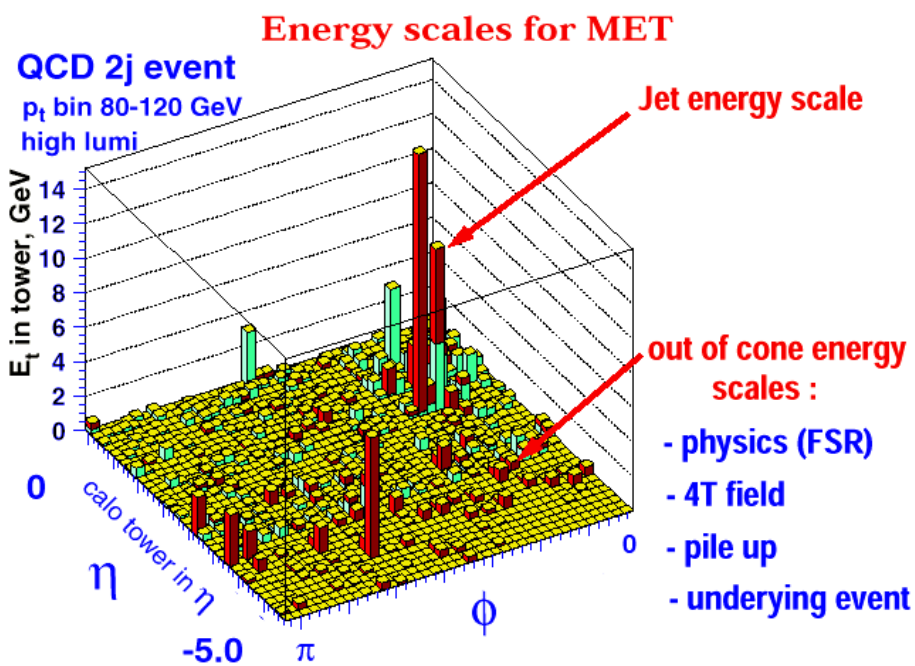
$Ey' = Ey + \Sigma\ (\Delta(Ey\text{-}jet))$

If this works in offline, can we do this at L1?

(Need study for offline, first!)

MET
(Missing Transverse Energy)

Extension of the simple jet energy correction (#1) to MET.
MET(corr) = MET(calo) + $\Sigma\{\Delta E_T(\text{jet corr})_{IN}\}$+ $\Delta E_T(\text{min-bias corr})_{OUT}$

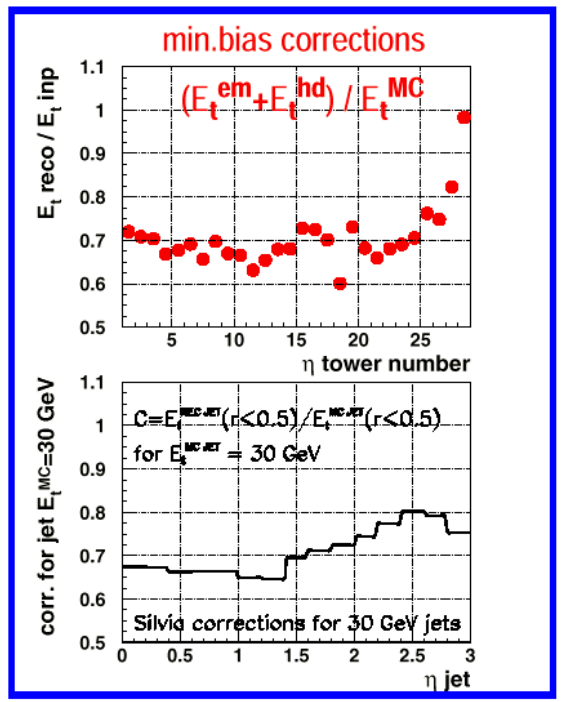


Corrections

Type 1: Jet corr.

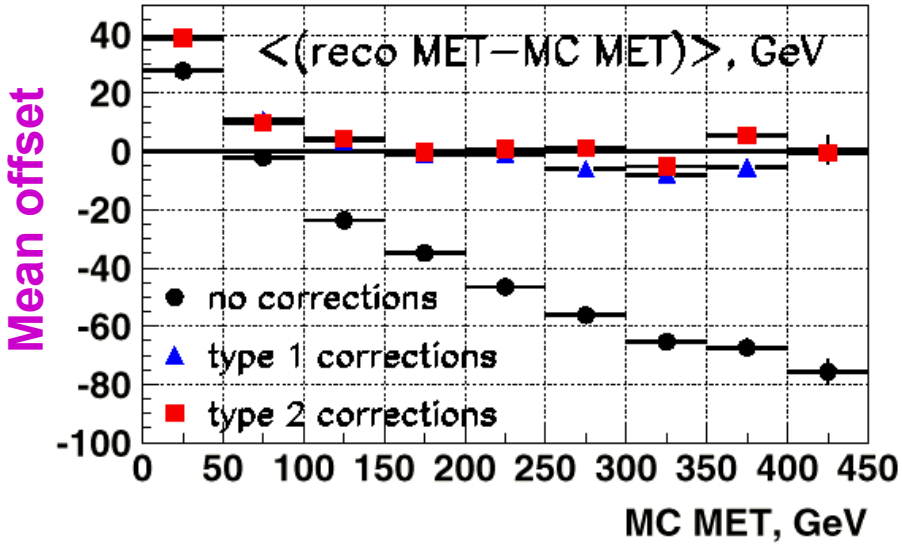
Type 2: Jet corr. + out of cone corr.

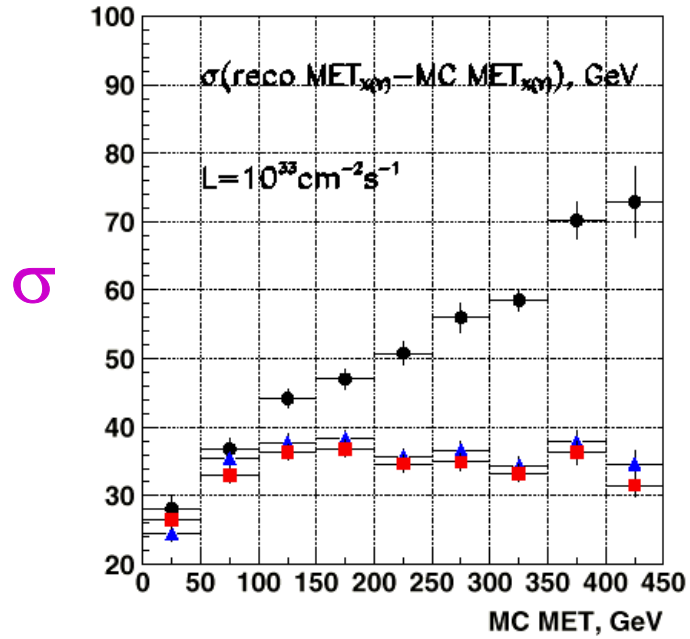
Out of cone corr. uses weights for jet(30GeV) corr.



Corrected MET for SUSY

SUSY event: multi jets + MET





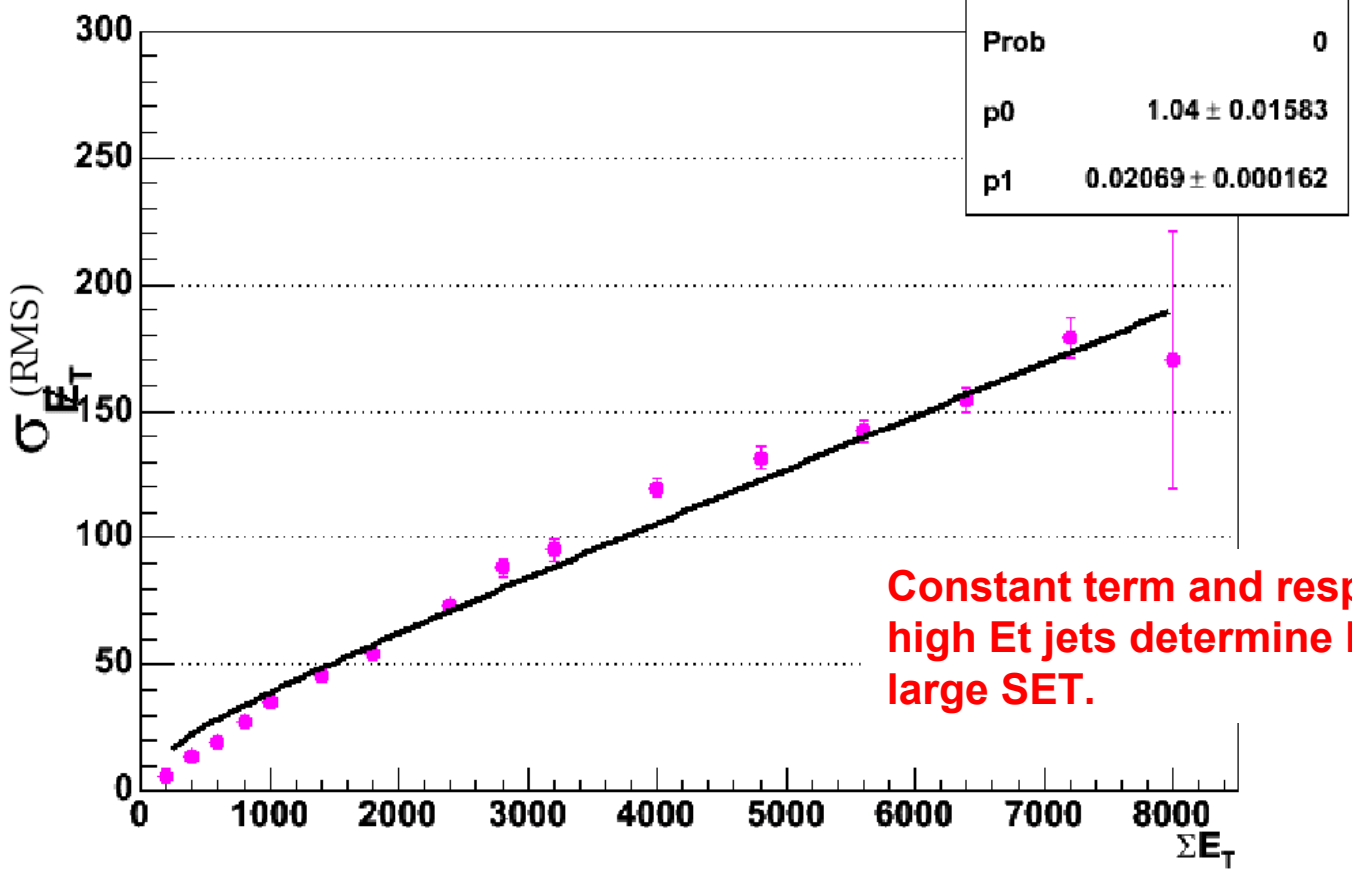
An extension of the simple jet energy correction improves also MET energy scale and resolution.

Next: Extend "energy flow" algorithm to MET.

Issues on MET

MET resolution : QCD sample

$$\sigma_{MET} = (104.0\%)\sqrt{\sum E_T} \oplus 2.07\% \sum E_T$$



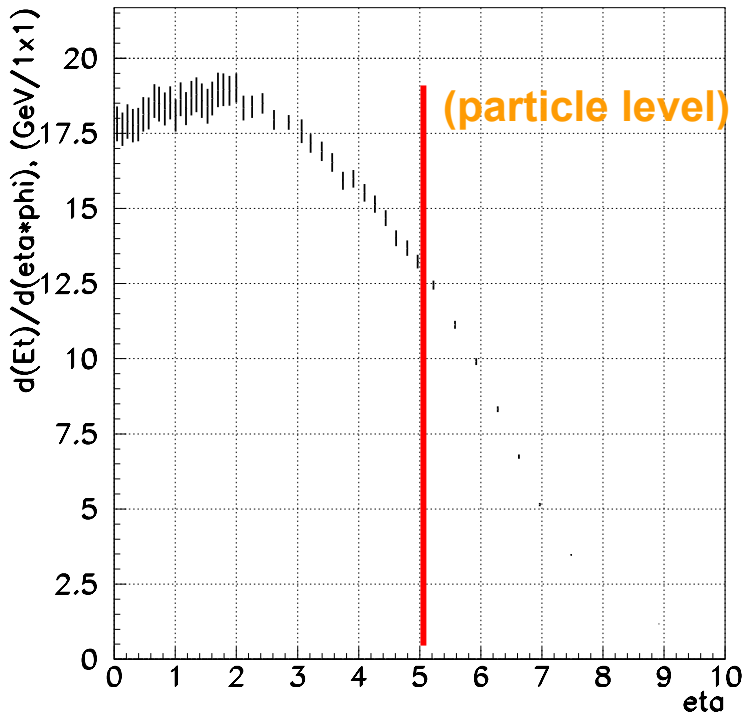
Constant term and response of high Et jets determine MET at large SET.

Taylan, LPC JetMET meeting, Oct.01, 2004

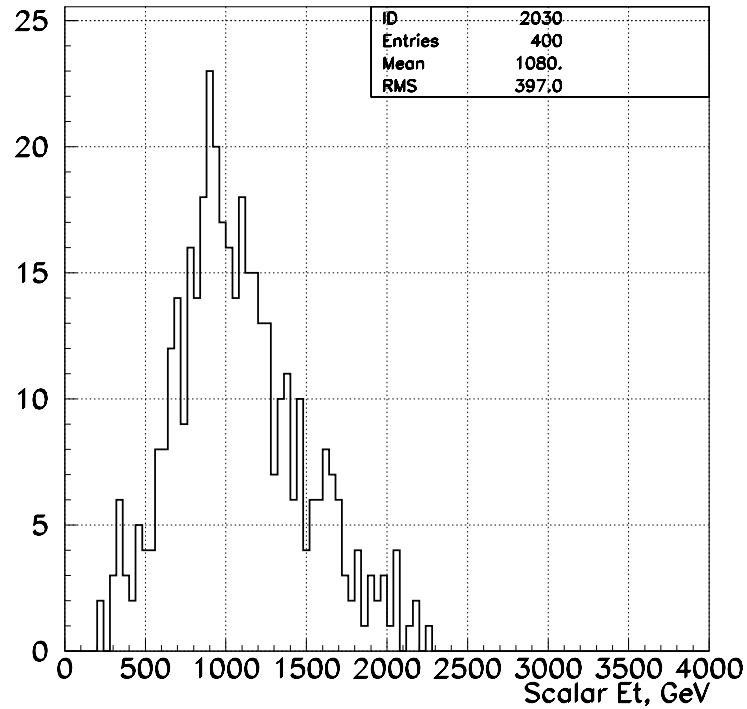
Minimum Bias Event Overlap
(in-time pile-up)

X-sec = 55mb >>> 17.3 min-bias/crossing at 10E34

Et Flow



Scalar Et (eta<5)



~17 GeV in unit (eta x phi) !

<Scalar Et> = 1080 GeV

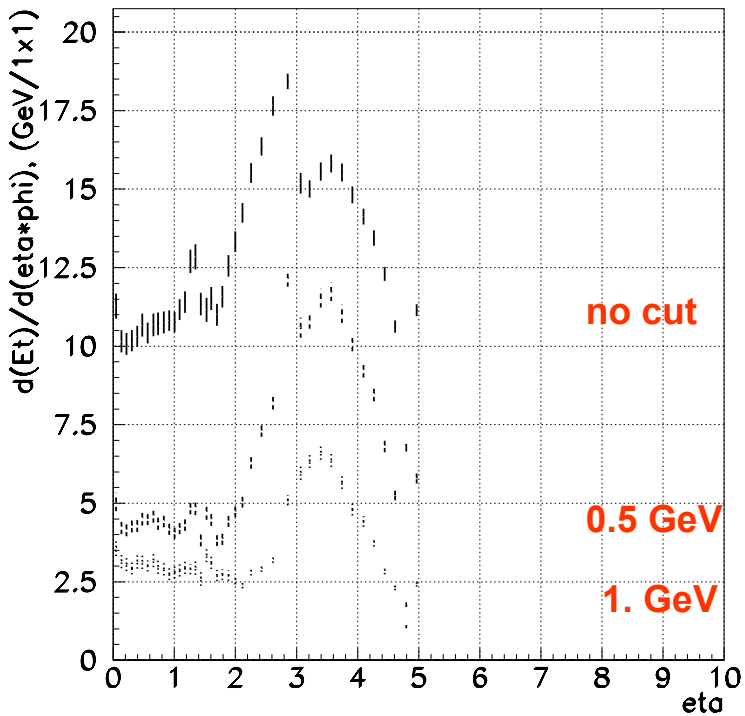
(equiv. cone radius 0.56)

Note: <Scalar Et> = 750 GeV for ttH

E_T in Calorimeter

17.3 min-bias/crossing at 10E34

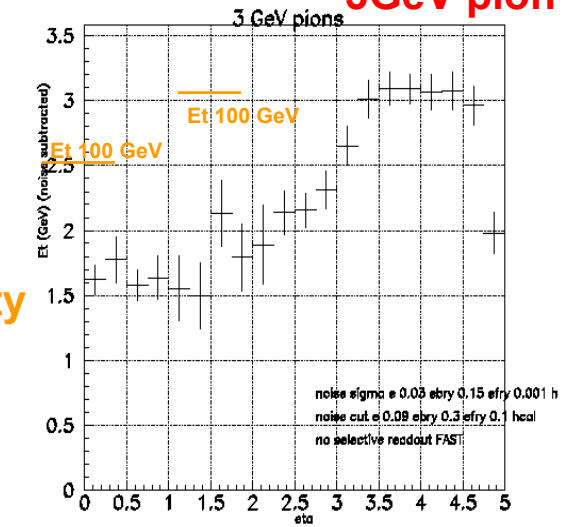
E_T Flow



(Cuts: on Tower)

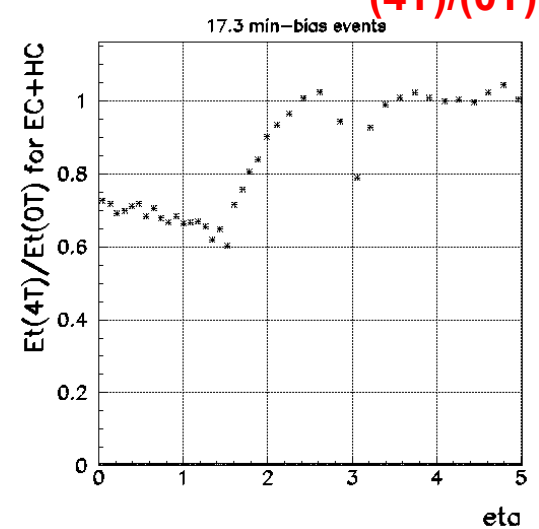
Non-linearity

3GeV pion



B-field

(4T)/(0T)

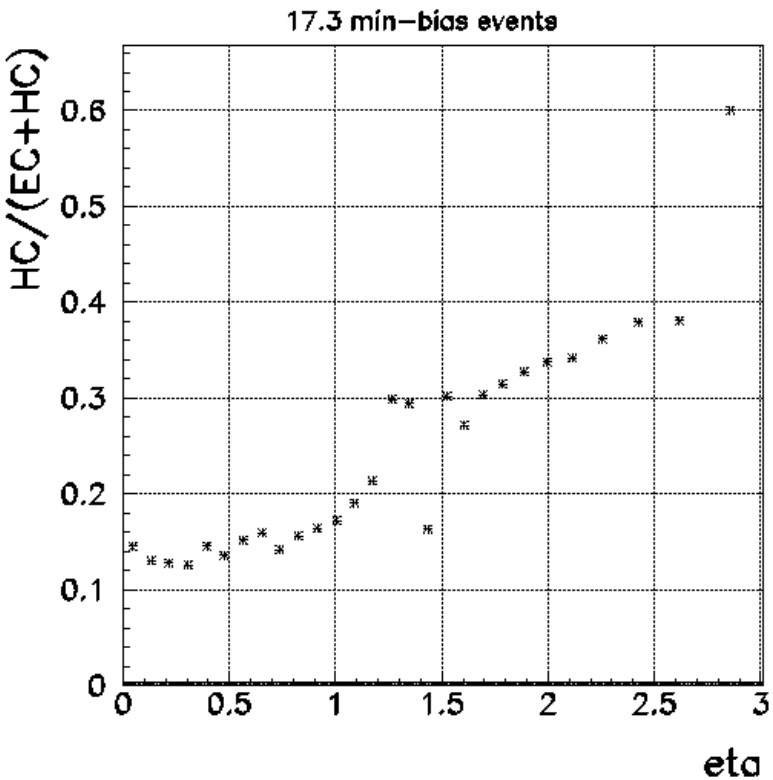


Charged particle P_T<0.8 does not reach EB

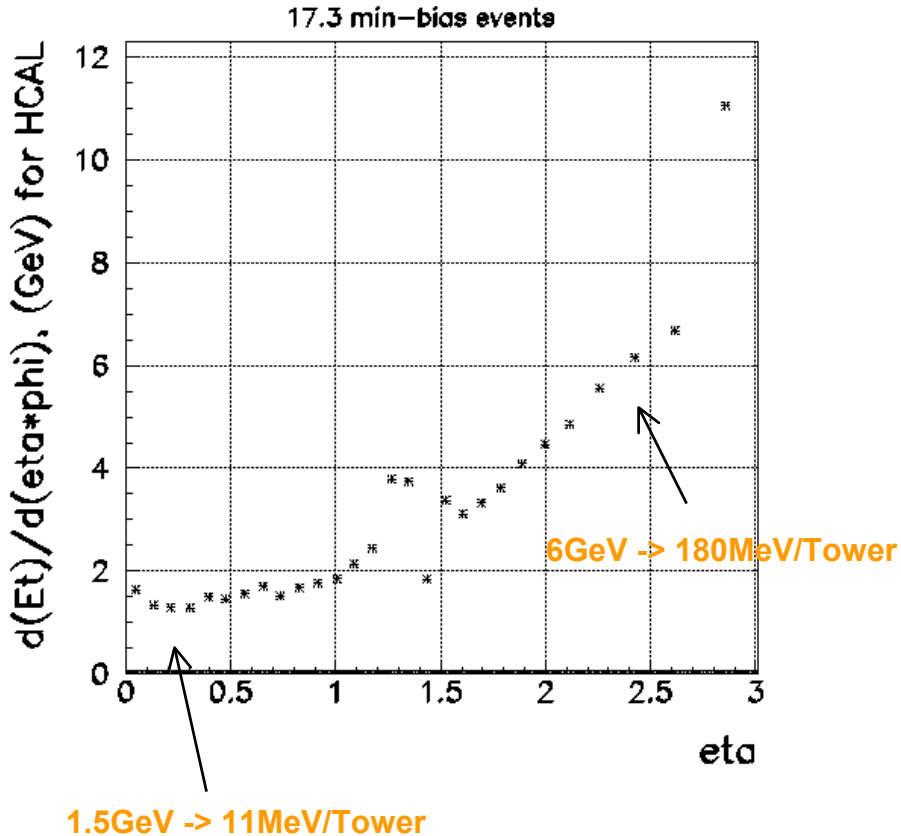
E_T in HCAL (pile-up events)

(17.3 min-bias events)

Fraction in HCAL



Et Flow

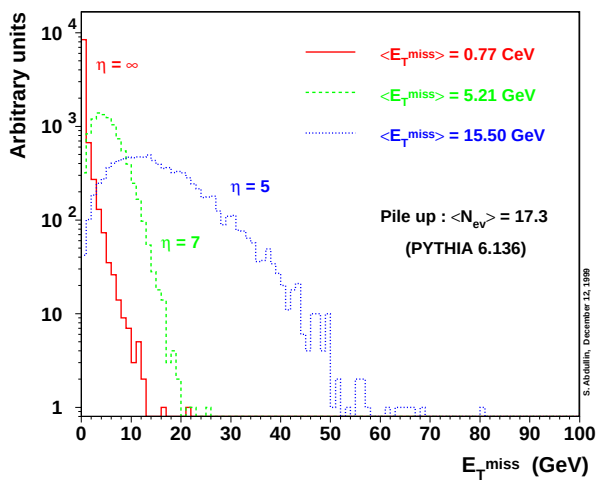


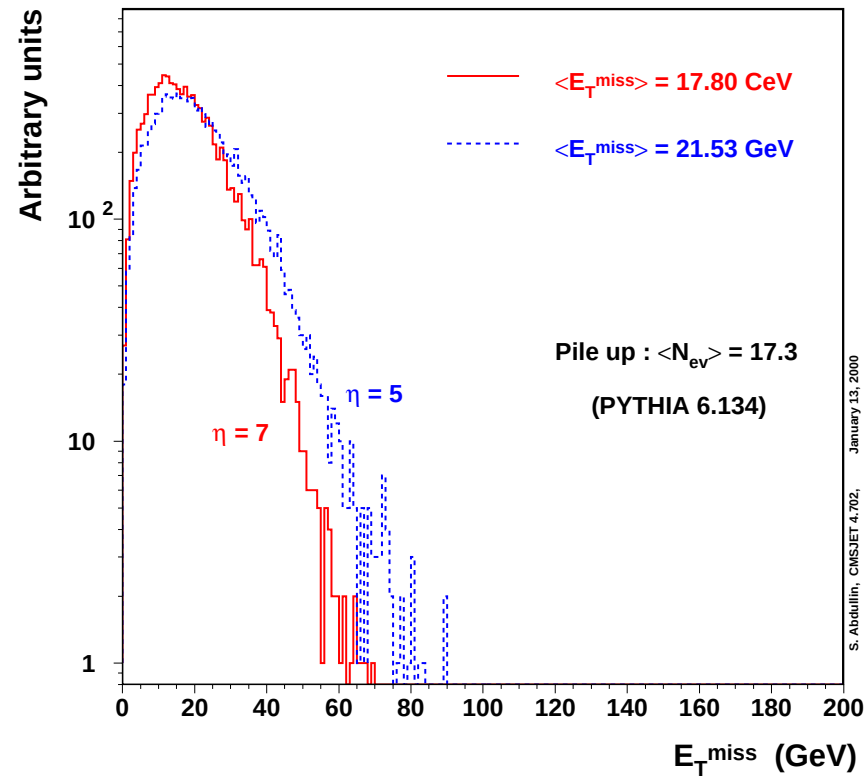
Much energy stays in ECAL!

CMSJET Simulation (2000)

(by S.Abdullin)

Particle level E_T^{miss} calculation for various η coverage





MET (GeV)

eta	gen.	cmsjet res.	cmsjet all(*)
5	15.49	19.36	21.53
7	5.21	12.92	17.80

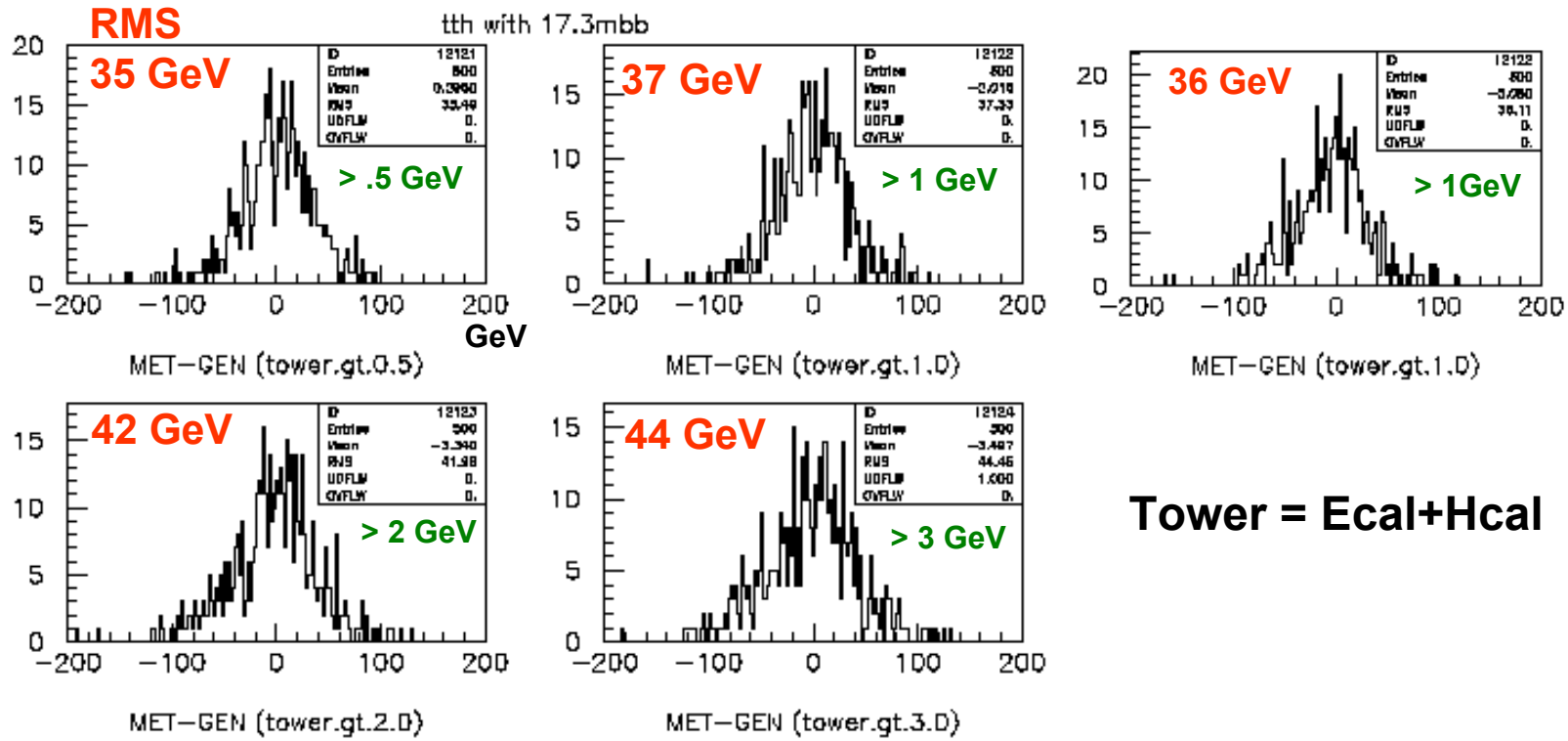
(all = res. & B-field & vtx smearing)

~ Equal contribution from eta 5-7, resolution and B-field
(15GeV) (12GeV) (9-12GeV)

(Full G3 simulation: similar results)

Pile-up and Tower Threshold (2000)

With 17.3 min-bias events **No min-bias**



Tower = Ecal+Hcal

>> Not much pile-up effect with this resolution!
>> Resolution gets worse as threshold increase.

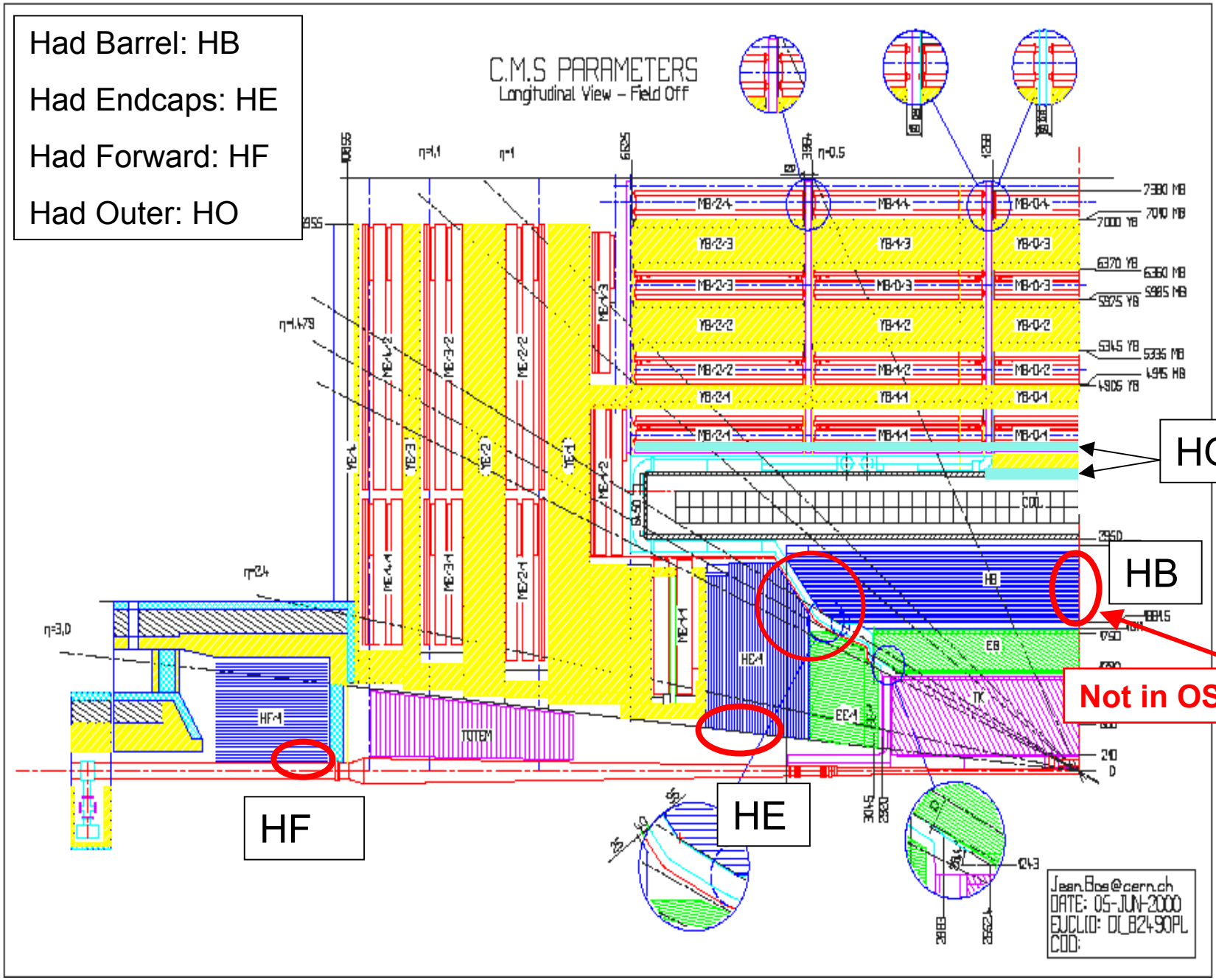
Gaps

Had Barrel: HB

Had Endcaps: HE

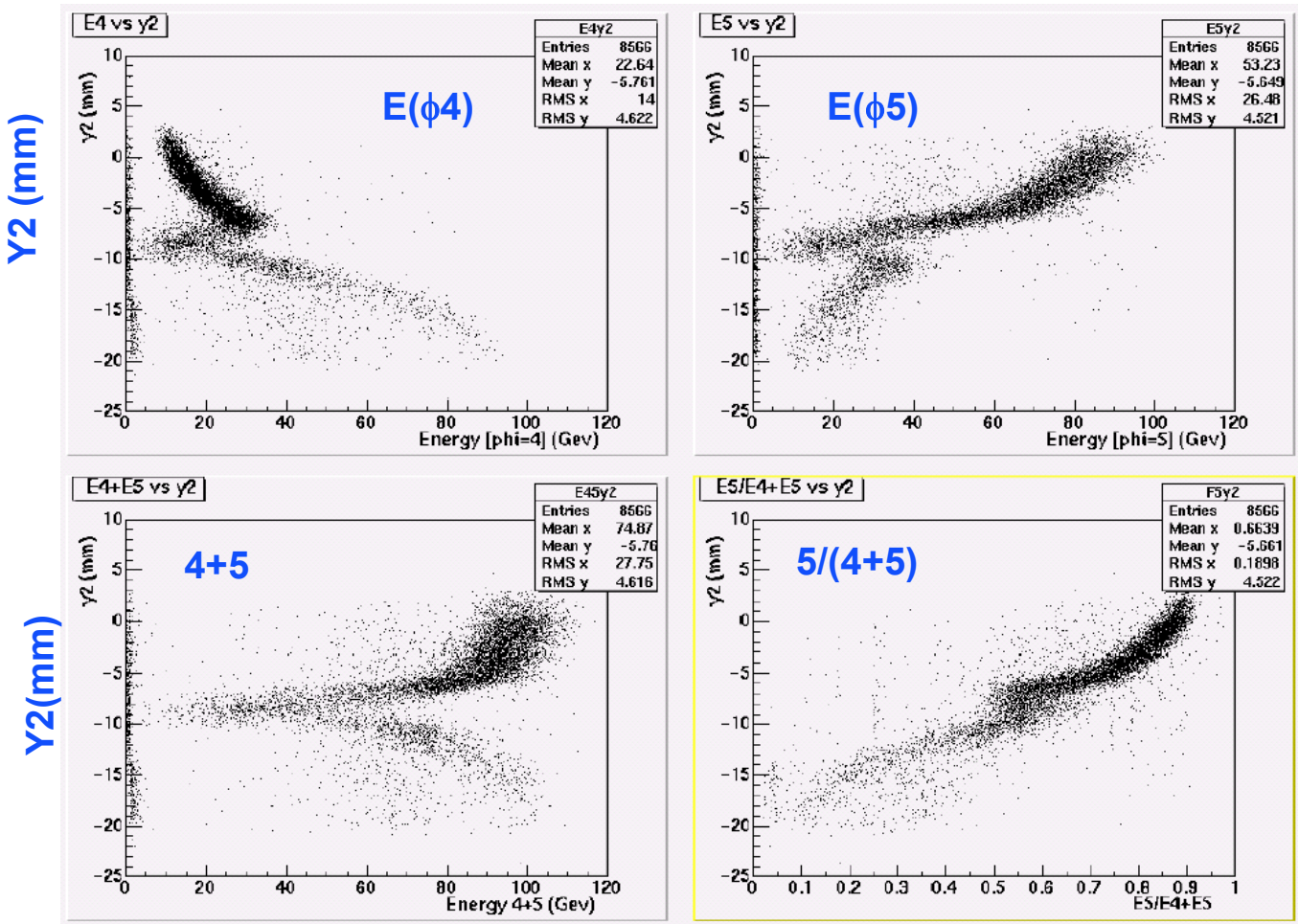
Had Forward: HF

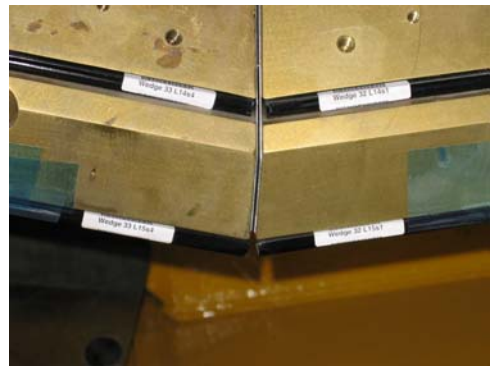
Had Outer: HO



Inter Wedge Gap

Position scan with100 GeV electrons

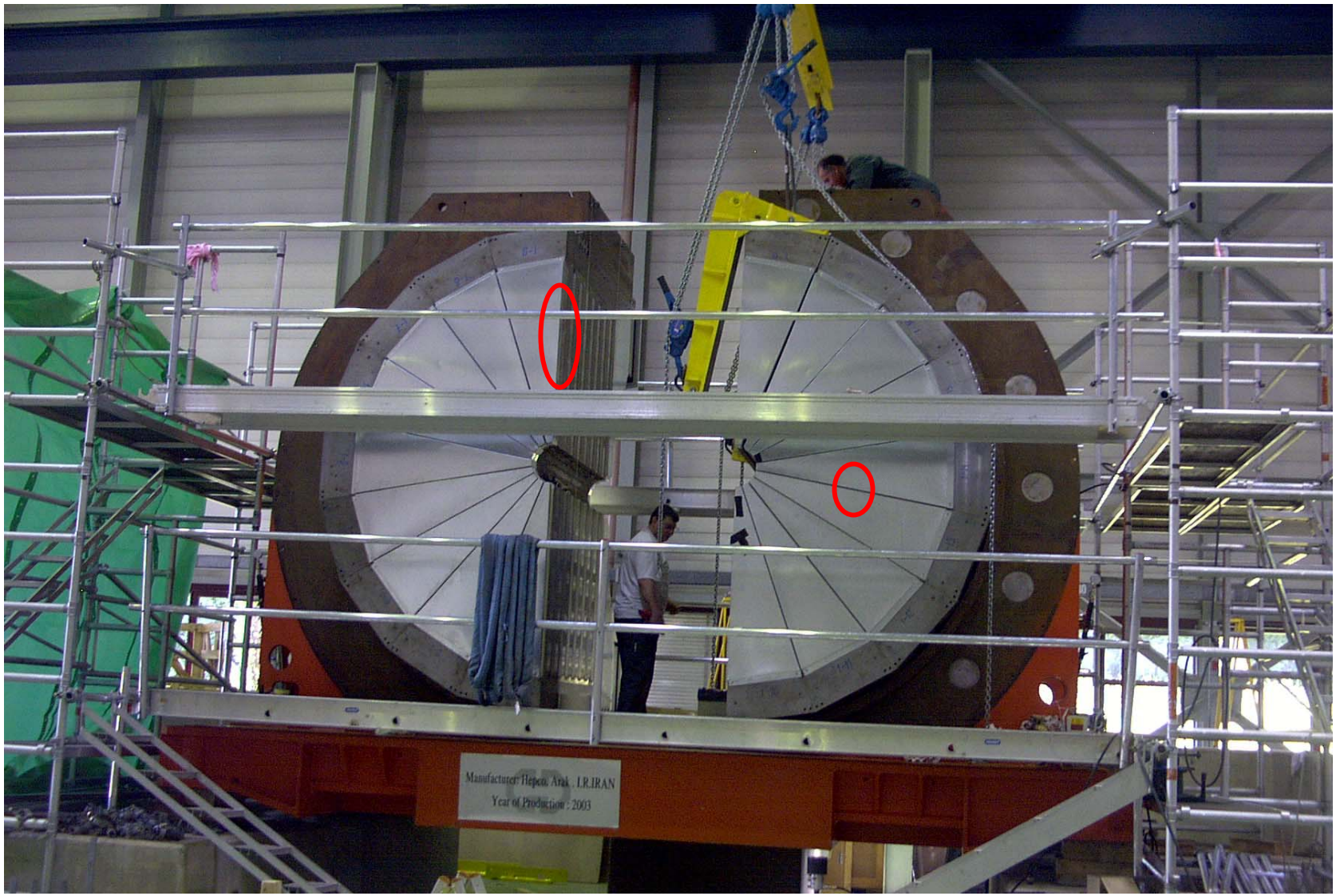




air gap: 3 mm

already in OSCAR

Gaps in HF



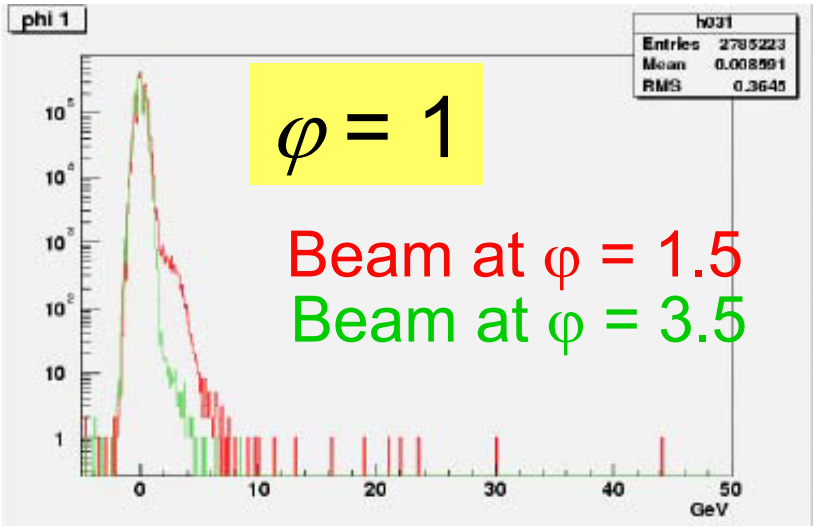
Source of Abnormal Events

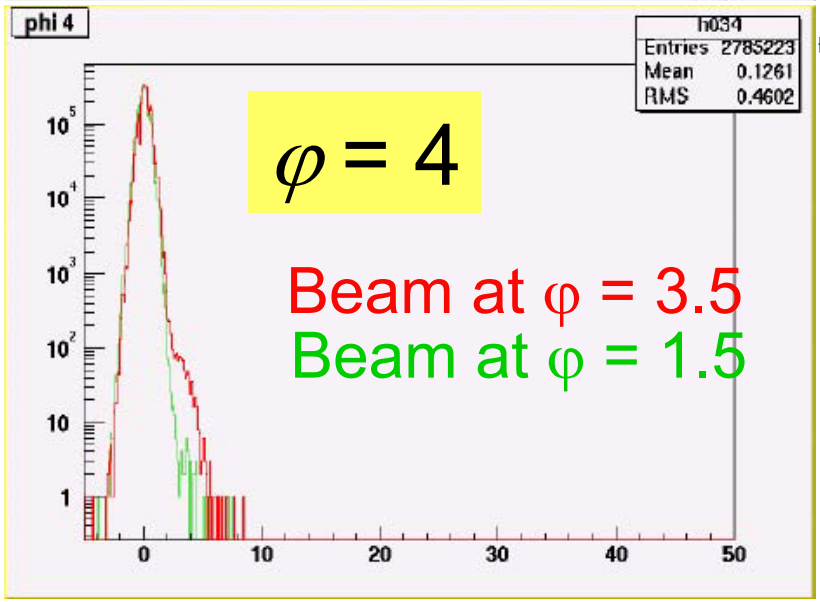
LHC beam halo

Signal in optical fibers (HB, HE, HF)
Particles through ECAL APD
Particles through HF PMT

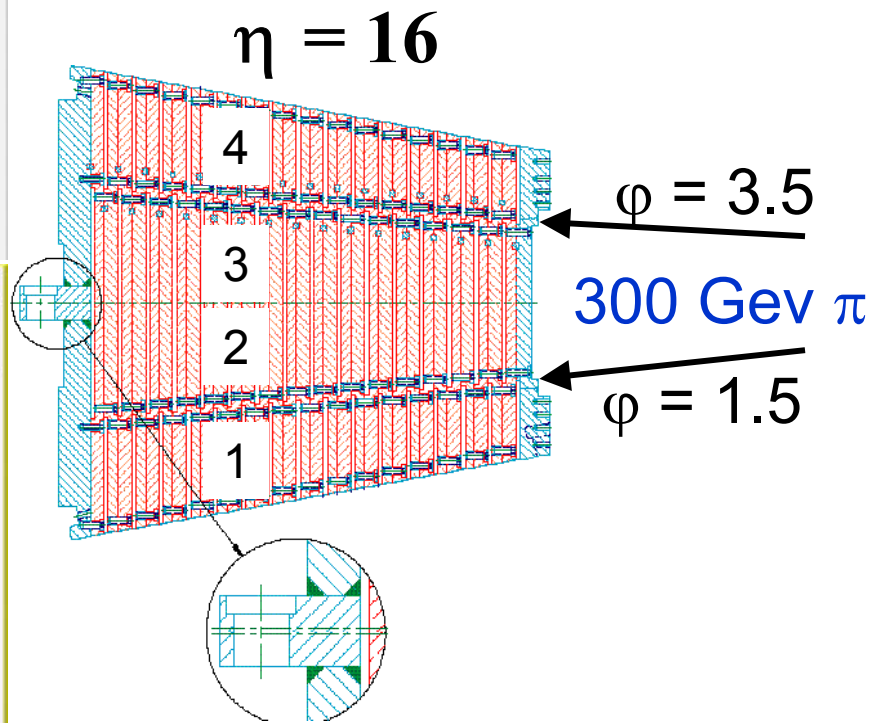
Electronic malfunction (hot channel)
:

Cerenkov Lights in 53 deg.





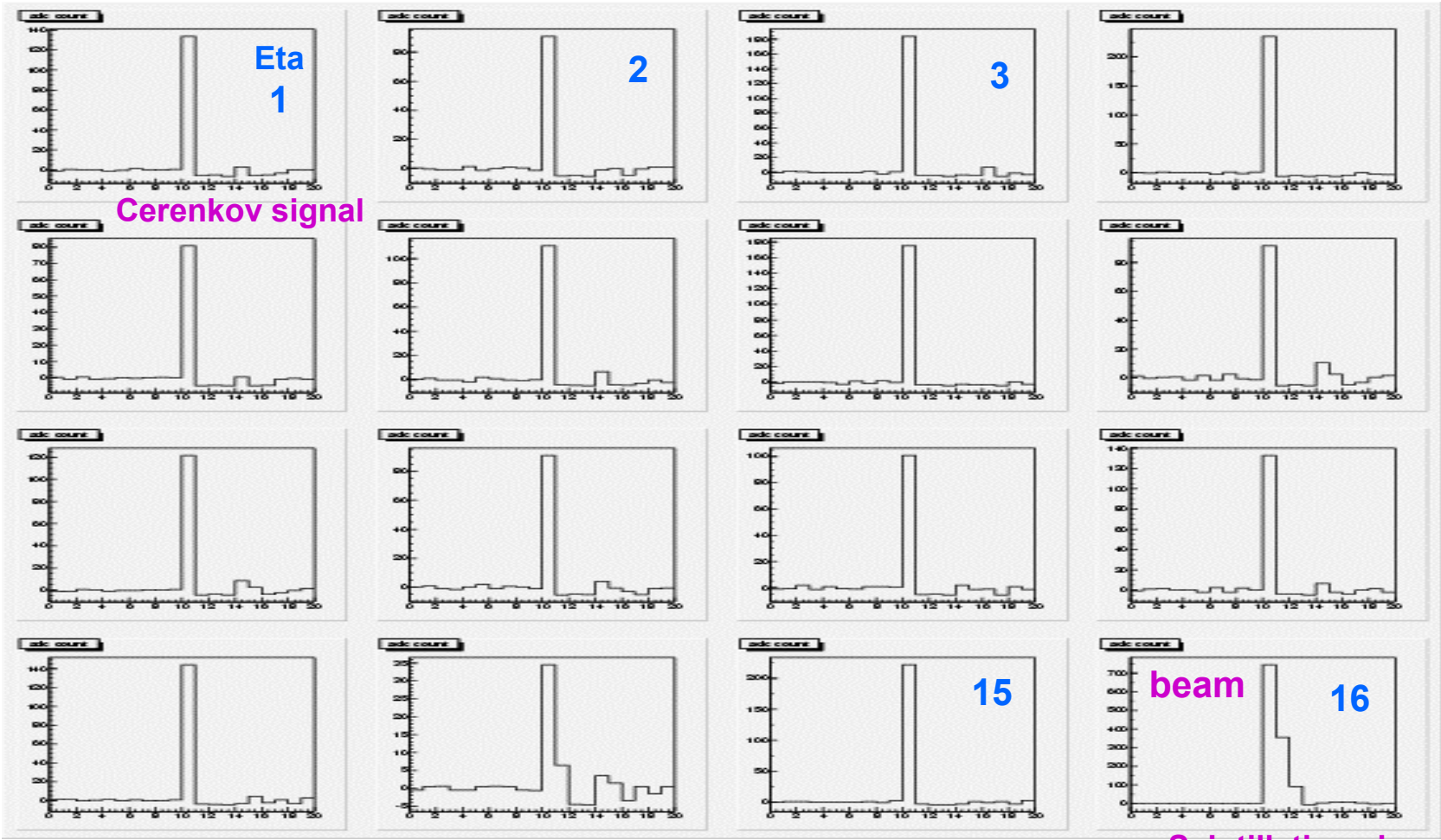
400k events



HB: Fast Cerenkov Siganl in Optical cables

#3' Cont'd

Single event, phi=1 beam at phi=1.5



→ Need a code to tag and correct(?) those events in ORCA.

HCAL JetMET Calibration

Calibration for jetMET: Three Levels

Inter channel calibration / HCAL Energy Scale — Kunori

- ADC counts → initial GeV in HCAL
  - Channel by channel correction for
    - Scintillation and Cerenkov light collection
    - photo detectors & electronics, etc.
    - Radiation damage

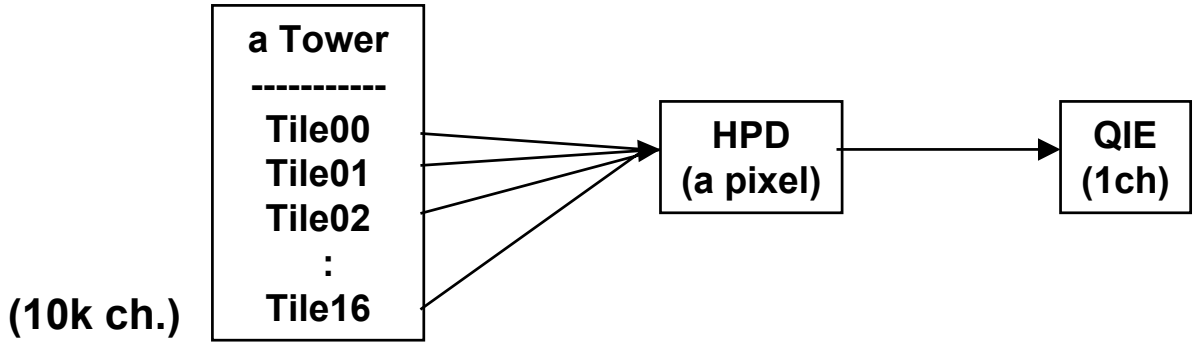
Jet (Cluster) Energy Scale (particle level) — Kodolova

- Channels (initial GeV) → particle jets/MET
  - Correction for detector effects.
    - Non-linear calorimeter response - e/h >> 1.0
    - B-field effect - 4 Tesla
    - Cracks / dead material
    - Pile-up - 17 min.bias/beam crossing

Jet Energy Scale (parton level)

- Particle jets/MET → partons or physics observable,
  e.g. Jet E_T spectrum, di-jet mass, etc.
  - Correction for physics effects.
    - Fragmentation
    - Initial & final state radiation
    - …

Basics of HCAL Calibration



Step-1: Linearize ADC count.

QIE Card Test at FNAL measured linearity of QIE in full dynamic range.

Step-2: Equalize gain of all channels using Wire Source.

a) Gain of each tile
b) Gain of each tower, I.e. average of gains of all tiles in each tower.

Step-3: Determine a conversion factor from ADC count to GeV.

Test beam, e.g. 100GeV pions, at one point in HB, HE and HF.

Step+: Verify, refine and Monitor.

Laser, LED, in-situ (min-bias, dijet, γ/Z-j, top, etc.)

HCAL Energy Reconstruction in ORCA

GeV (ch)

$= \Sigma_{ts}\Sigma_{cap}\{ (ADC[cap,ch,ts)-PED[cap,ch])]*ADC2Q[icount,ch]*CALIB(cap,ch) \}$
$* TSLEW(Q) * HOTCELL(ch)$

where,

- ts : time slice[7-10]
- cap : CapID[4]
- ch : channel [HB 2592, HE 2592, HO 2160, HF 1728, total 9072]
- icount : ADC count[128]

ADC2Q : ADC to Charge [I: 4bytes*128+1byte*9072ch] ~ [10kbytes]
PED : Pedestal [I: 1bytes*4cap*9072ch] ~ [40kbytes]
CALIB(cap,ch) [F: 4bytes*4cap*9072ch] ~ [160kbytes] worst case
= gain(cap,ch)*scale(ch)

where,

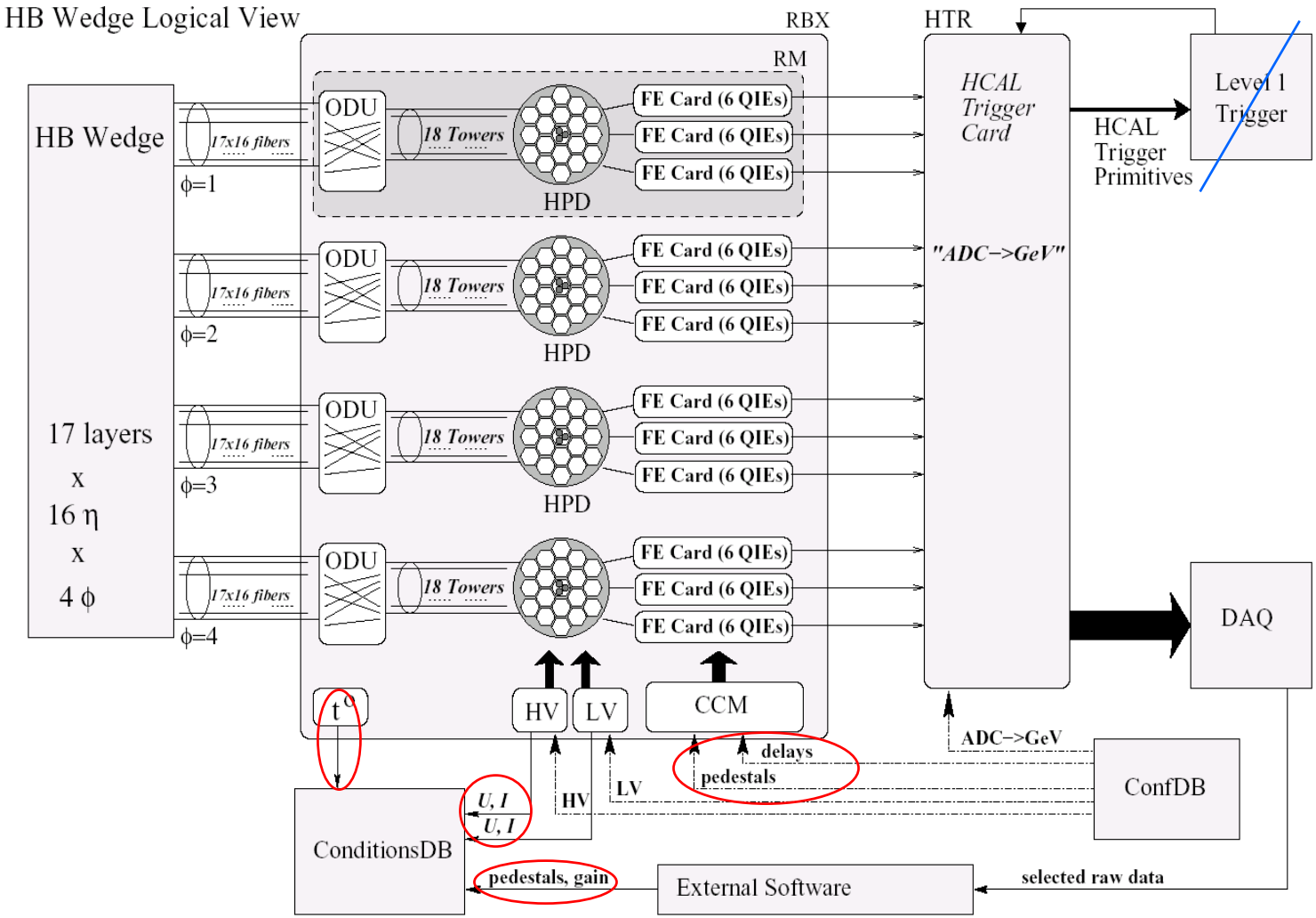
- gain : calculated with wire source data, initially.
- scale : energy scale

TSLEW(Q): a correction function for signal time slew, which depends on input charge, Q. The number of parameters is small, if it is common to all channels.

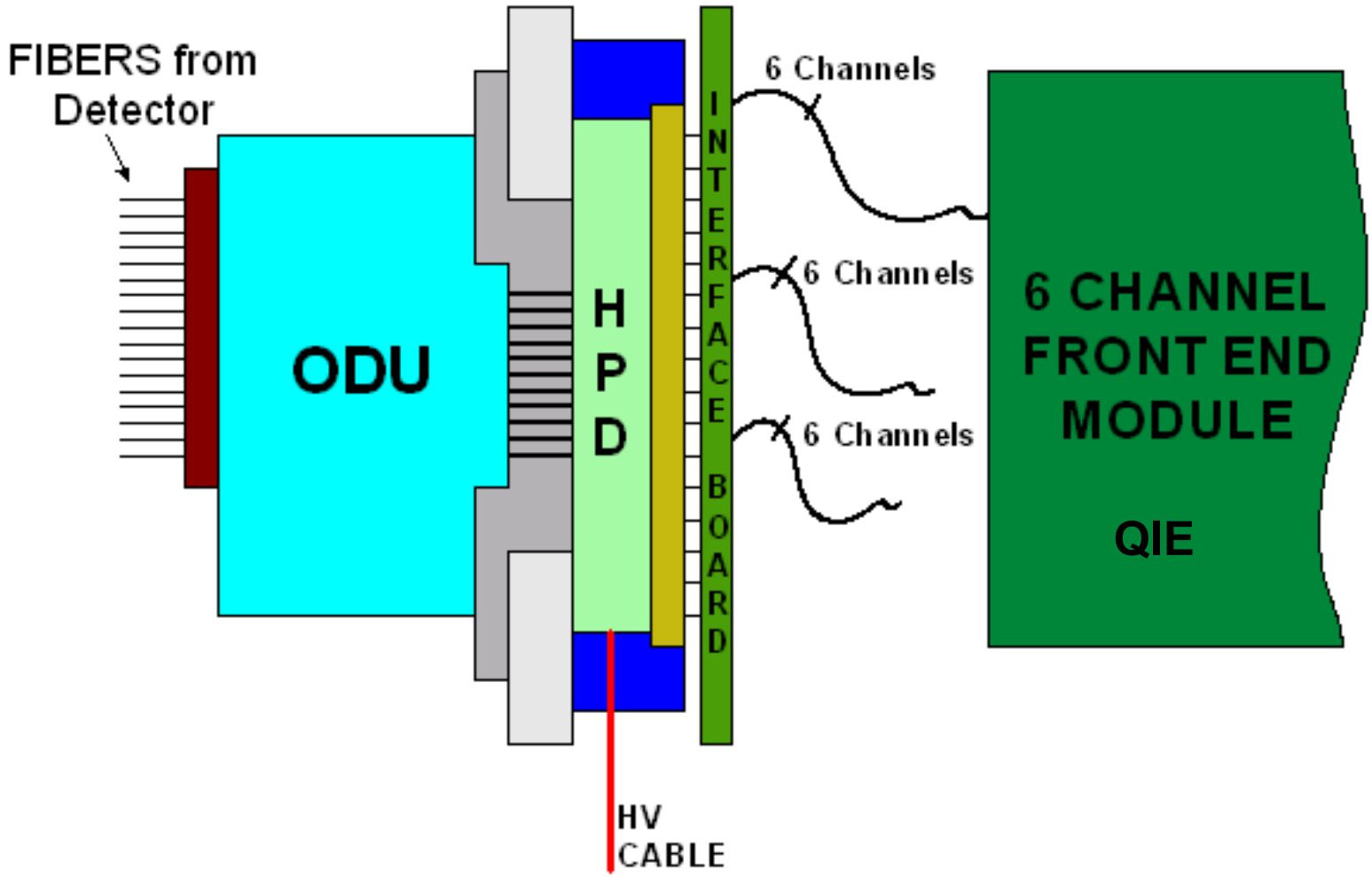
HOTCELL(ch): flag for hot cell [1bit*9072ch] ~ [1kbytes] ← hot cell killer

Readout Electronics and Trigger

TB2004 Prototype



Readout Module Overview



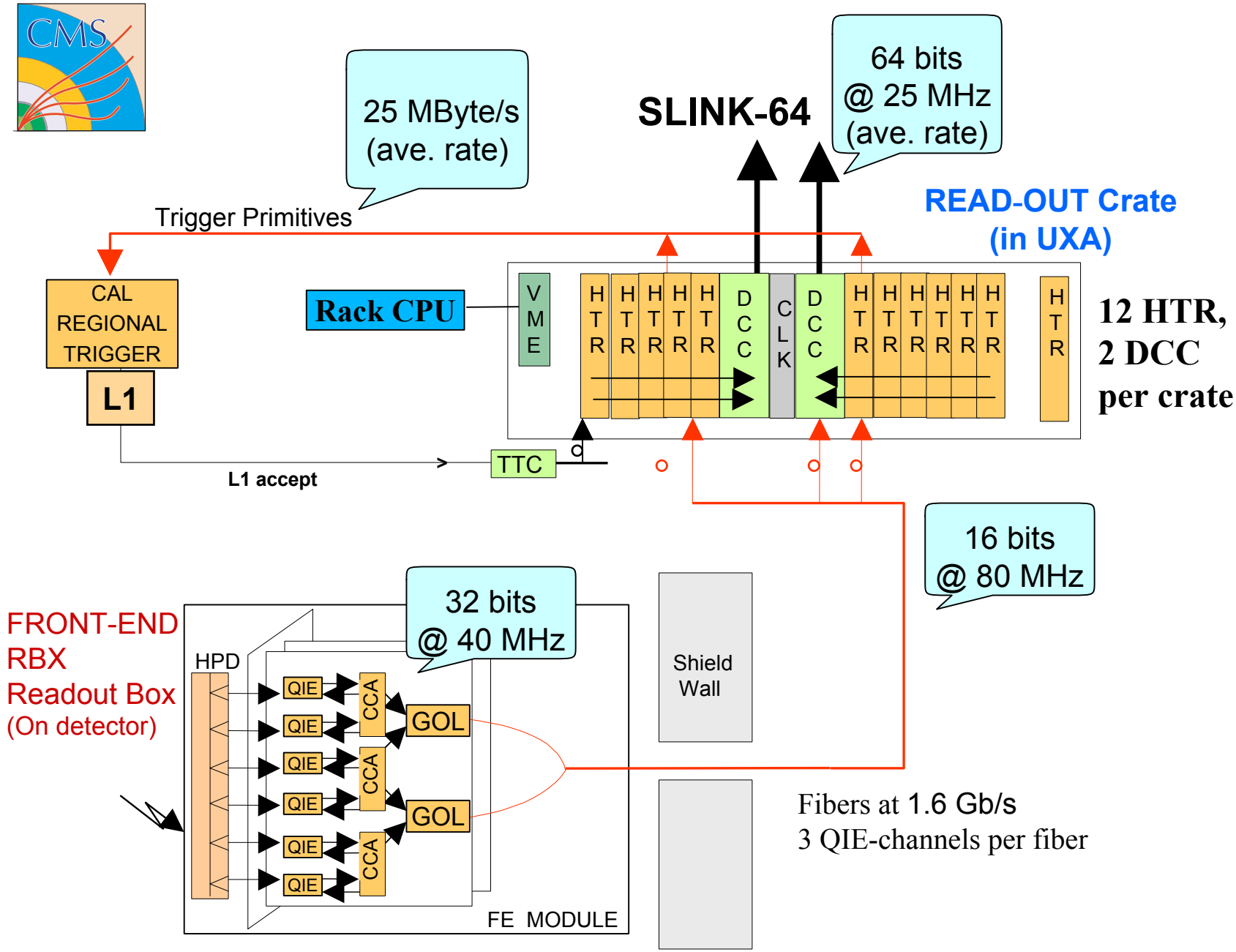
Inverting Input Scale (HPD Inputs)

Normal Mode			
Range (Exponent)	Input Charge	FADC Codes	Gain (q/Lsb)
0	-1 fC --- 14 fC	0---14	1 fC/bin
0	14 fC --- 28 fC	15---21	2 fC/bin
0	28 fC --- 40 fC	22---25	3 fC/bin
0	40 fC --- 52 fC	26---28	4 fC/bin
0	52 fC --- 67 fC	29---31	5 fC/bin
1	57 fC --- 132 fC	0---14	5 fC/bin
1	132 fC --- 202 fC	15---21	10 fC/bin
1	202 fC --- 262 fC	22---25	15 fC/bin
1	262 fC --- 322 fC	26---28	20 fC/bin
1	322 fC --- 397 fC	29---31	25 fC/bin
2	347 fC --- 722 fC	0---14	25 fC/bin
2	722 fC --- 1072 fC	15---21	50 fC/bin
2	1072 fC --- 1372 fC	22---25	75 fC/bin
2	1372 fC --- 1672 fC	26---28	100 fC/bin
2	1672 fC --- 2047 fC	29---31	125 fC/bin
3	1797 fC --- 3672 fC	0---14	125 fC/bin
3	3672 fC --- 5422 fC	15---21	250 fC/bin
3	5422 fC --- 6922 fC	22---25	375 fC/bin
3	6922 fC --- 8422 fC	26---28	500 fC/bin
3	8422 fC --- 10297 fC	29---31	625 fC/bin
Calibration Mode			
Forced 0	-2.333 fC ---- 10 fC	0---31	1/3 fC/Bin

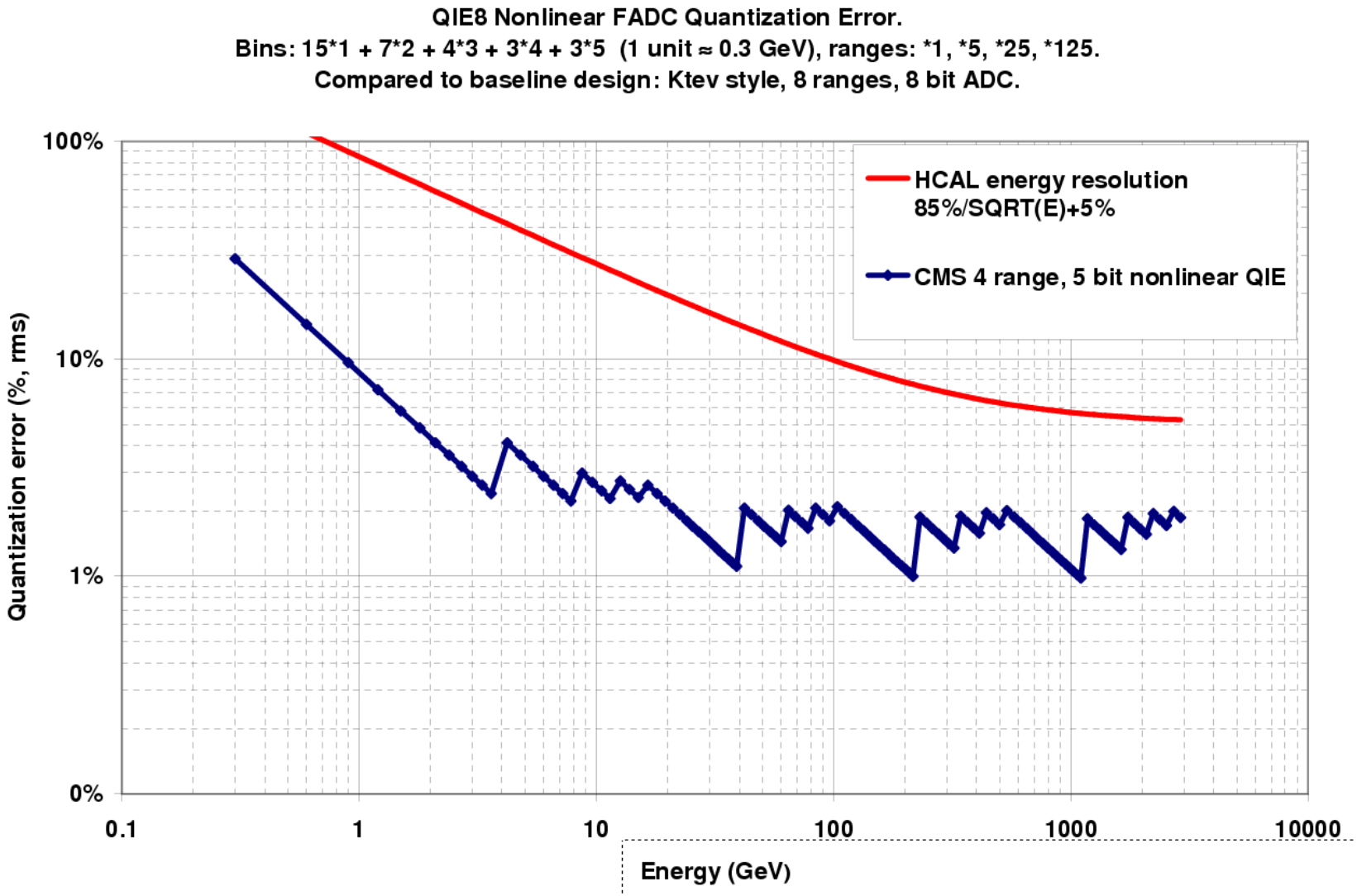
QIE – nonlinear 7-bits

0	0 GeV
31	13 GeV
32	
63	79 GeV
64	
95	409 GeV
96	
127	2 TeV

using 0.2GeV/fC

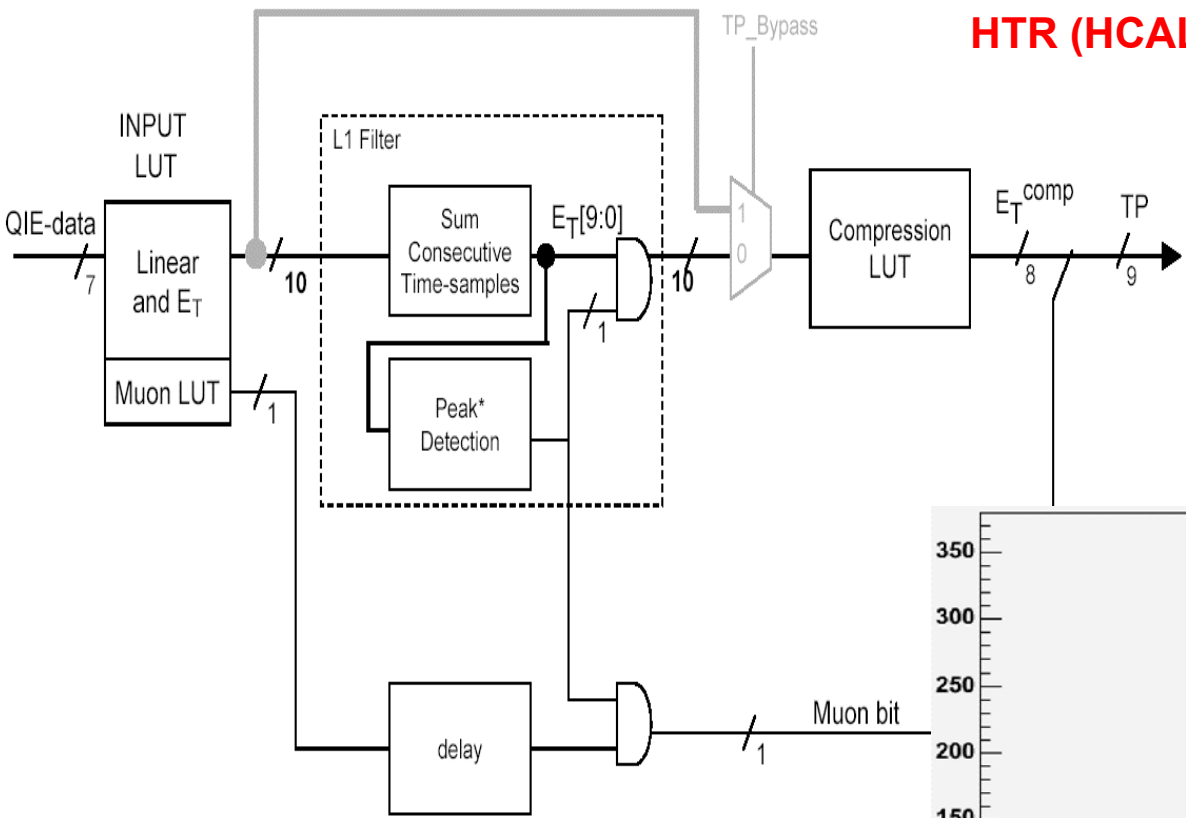

25 MByte/s
(ave. rate)
SLINK-64
64 bits
@ 25 MHz
(ave. rate)
READ-OUT Crate
(in UXA)
Trigger Primitives
CAL
REGIONAL
TRIGGER
L1
Rack CPU
VME
HTR
DCC
CLK
12 HTR,
2 DCC
per crate
TTC
L1 accept
16 bits
@ 80 MHz
32 bits
@ 40 MHz
FRONT-END
RBX
Readout Box
(On detector)
HPD
QIE
CCA
GOL
Shield
Wall
FE MODULE
Fibers at 1.6 Gb/s
3 QIE-channels per fiber

QIE Quantization Error

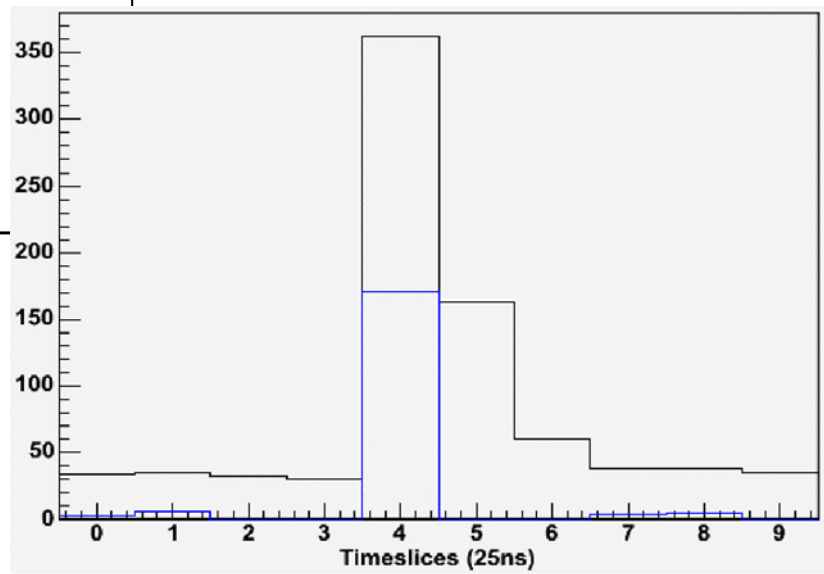


Trigger Primitive Generation

HTR (HCAL Trigger & Readout)



150 GeV pion
HE with minimal sin(θ) dependency in LUTs
(Run #23904- 25ns beam)



End

HCAL knowledge database under construction.