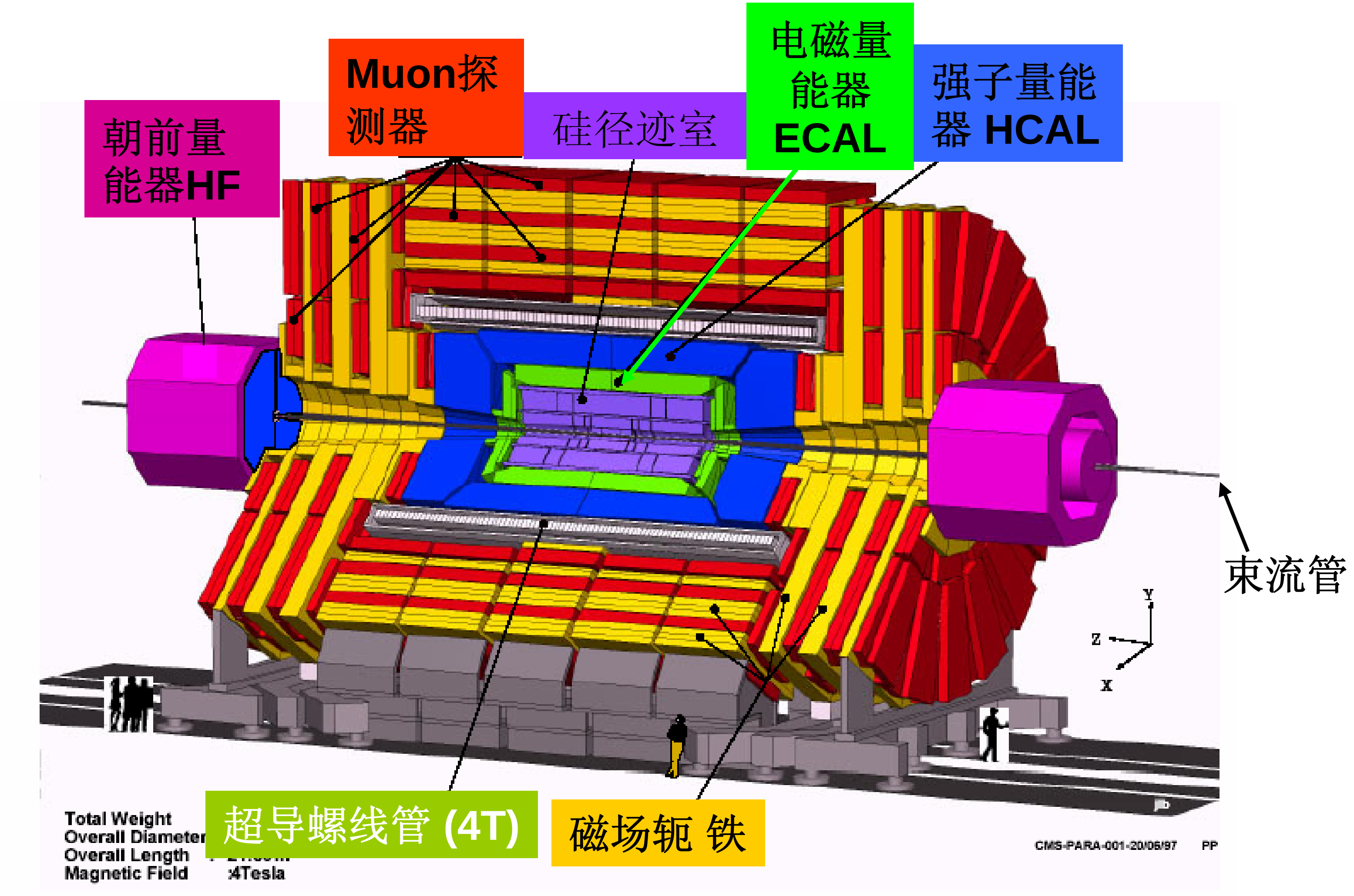
CMS subdetector
ECAL & HCAL

Mainly from PTDR Vol.1 & JINST S08004

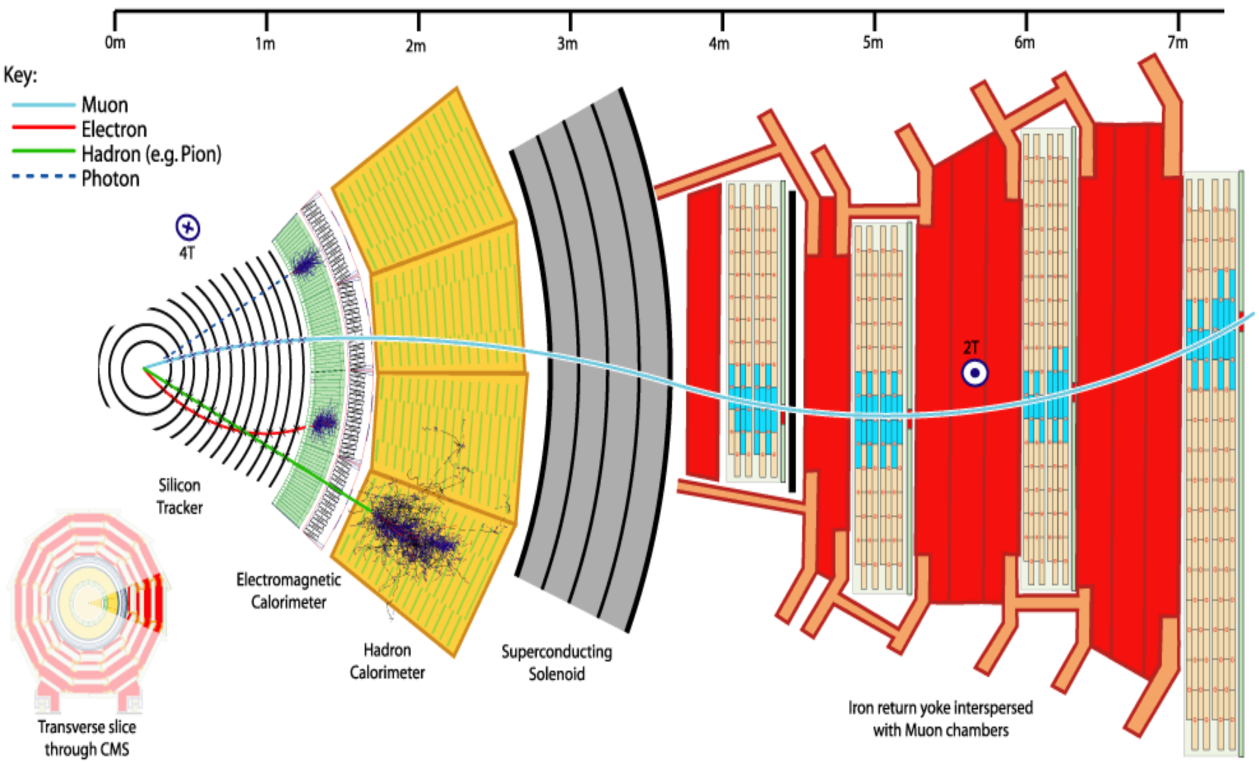
J. Tao

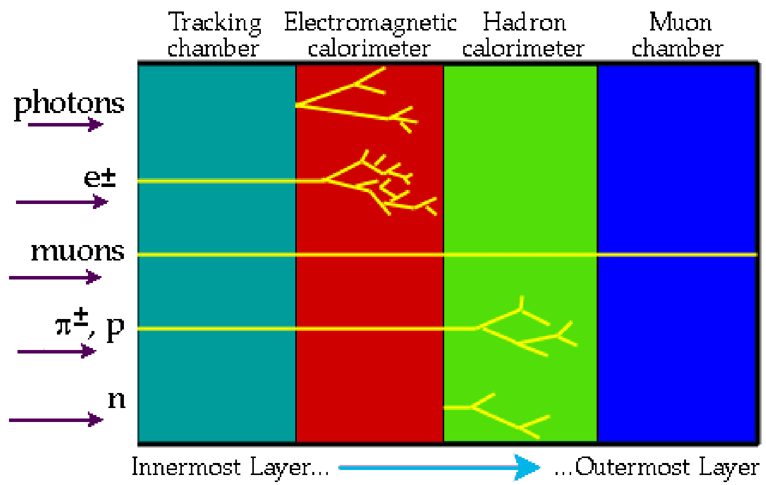
2008.11.28

CMS Detector



21.6 米长 x 15 米半径;　12.5 k 吨;　4 Tesla 磁场


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS


Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer

CMS Electromagnetic Calorimeter

- Barrel (EB)
- Endcaps (EE)
- Preshower (ES)

CMS ECAL

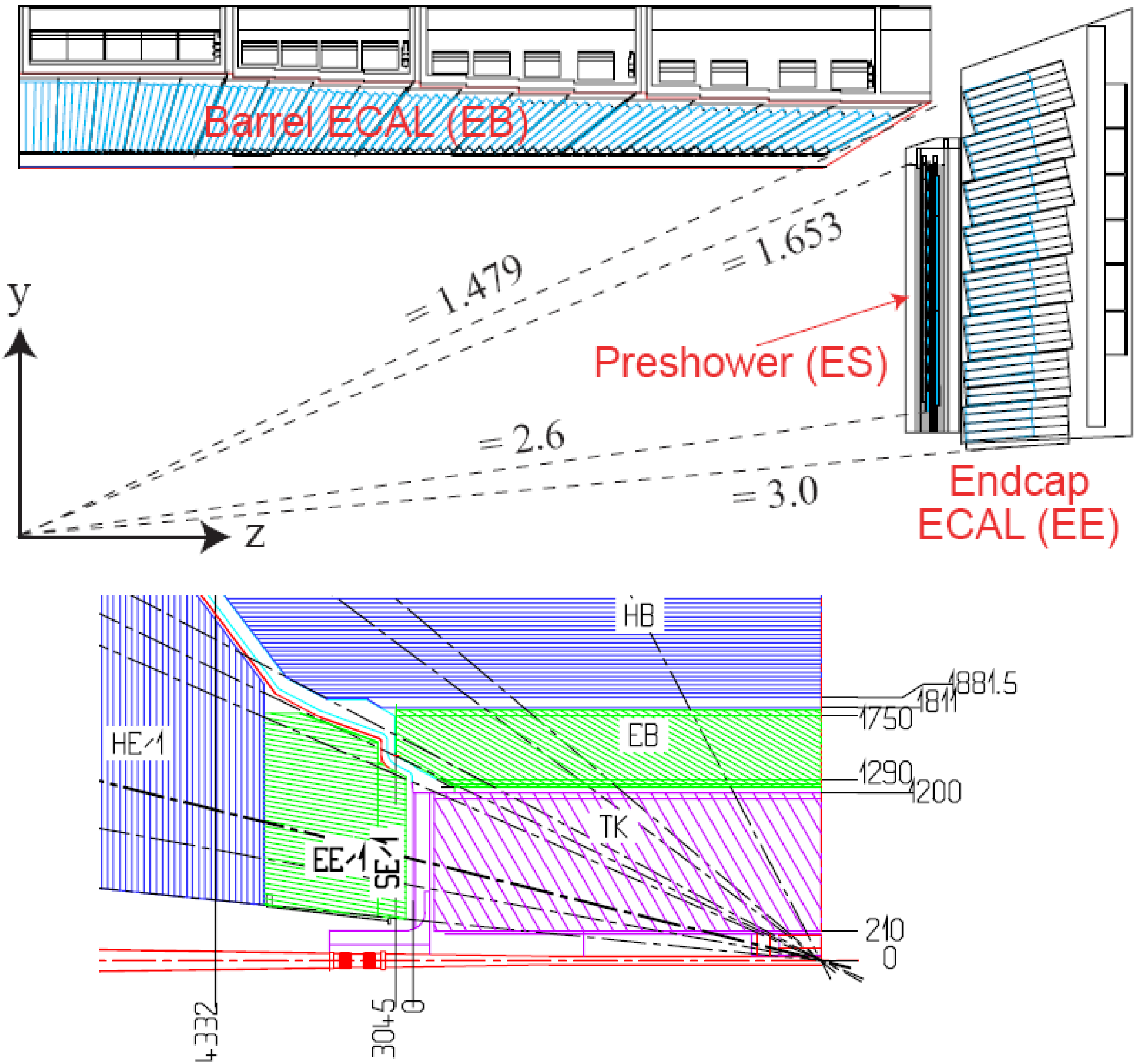
- **Designed to achieve a high precision in photon and electron energy measurements at LHC.**

- A hermetic homogeneous calorimeter with 61,200 lead tungstate ($PbWO_4$) crystals in the barrel part, covering the central rapidity region $|\eta| \leqslant 1.479$, closed by 7,324 crystals in two end-caps (3662 each) which extend the coverage up to $|\eta|=3$. Total: 75848 crystals.

- Photodetector: Avalanche photodiodes (APDs) in the barrel, vacuum phototriodes (VPTs) in the endcaps.

- Will be mounted inside a 4 Tesla superconducting solenoid.

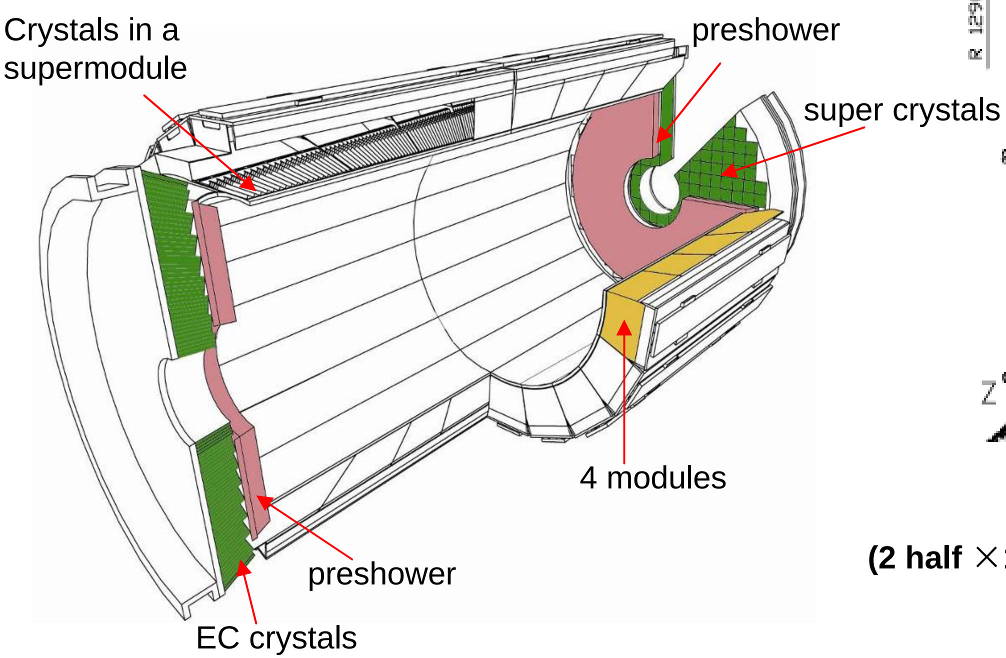
ECAL Geometry



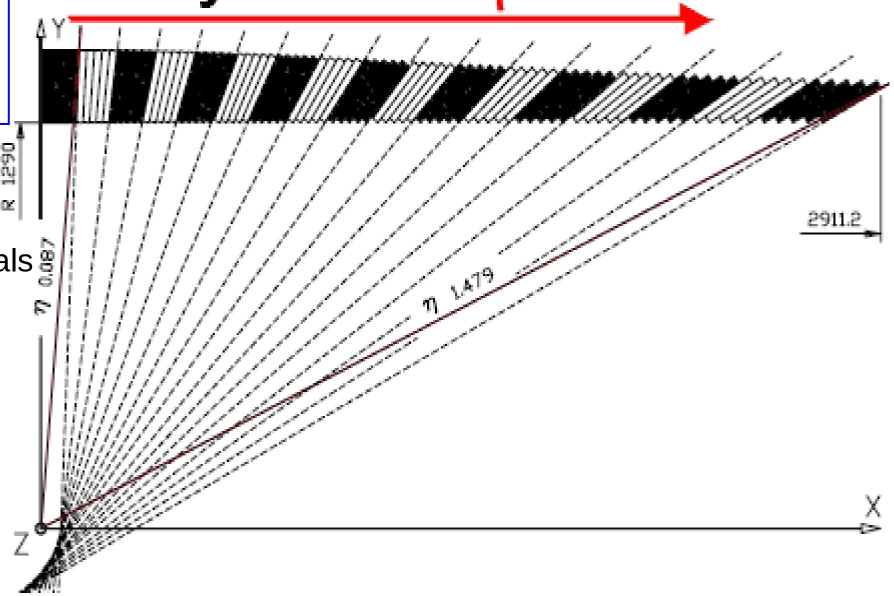
ECAL Barrel

$0 < |\eta| < 1.479$

36 identical supermodules, 18 in each half barrel, each covering 20º in Φ.
A total of 61 200 crystals.
Crystal cross-section ~0.0174 × 0.0174 in η - Φ



Each supermodule has 20 crystals in ϕ × 85 crystals in η

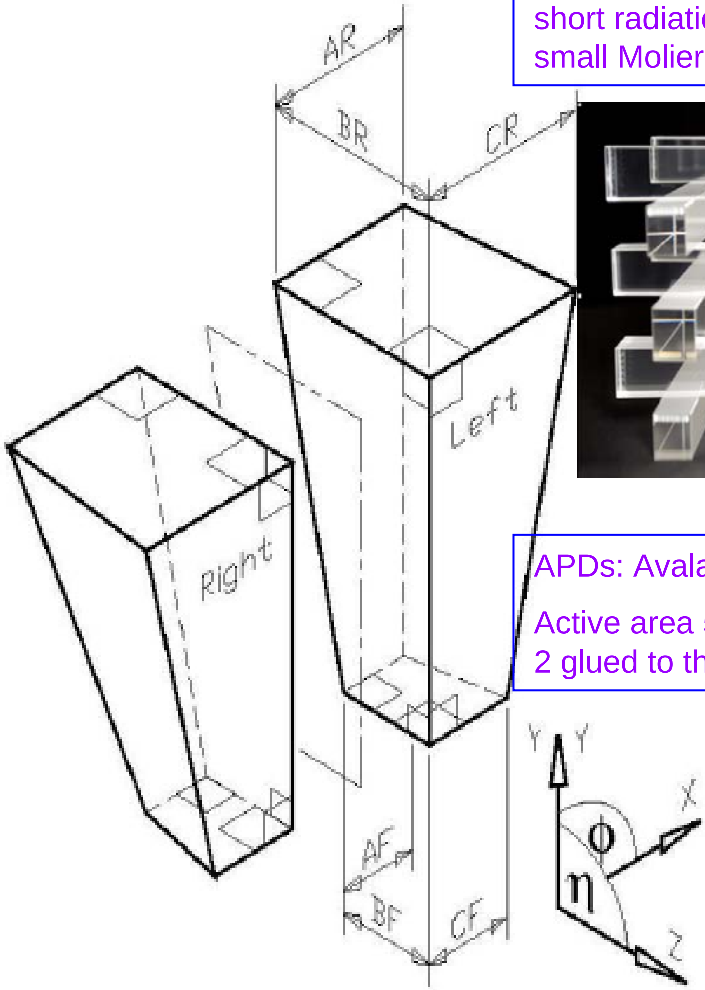


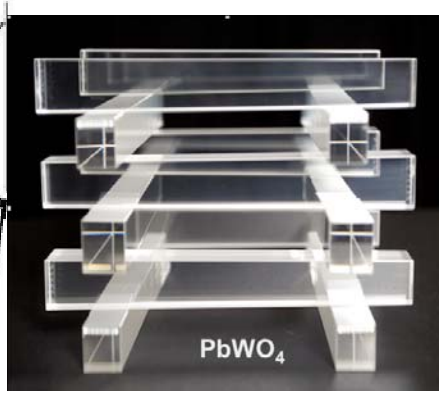
(2 half ×17subermodules ×5 in eta) ×360 (1/1 degree in phi)

ECAL Barrel

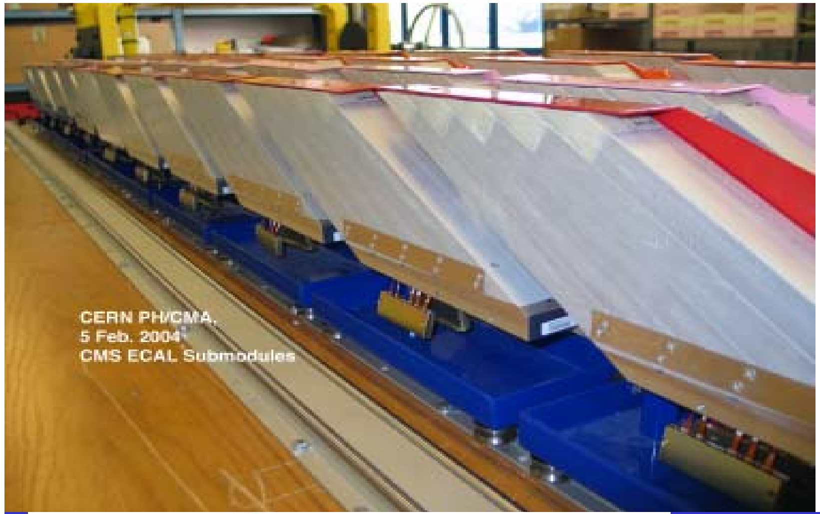
Front face: 22×22 mm^2
Rear face: 26×26 mm^2
Length: 230mm ~ 25.8 X_0

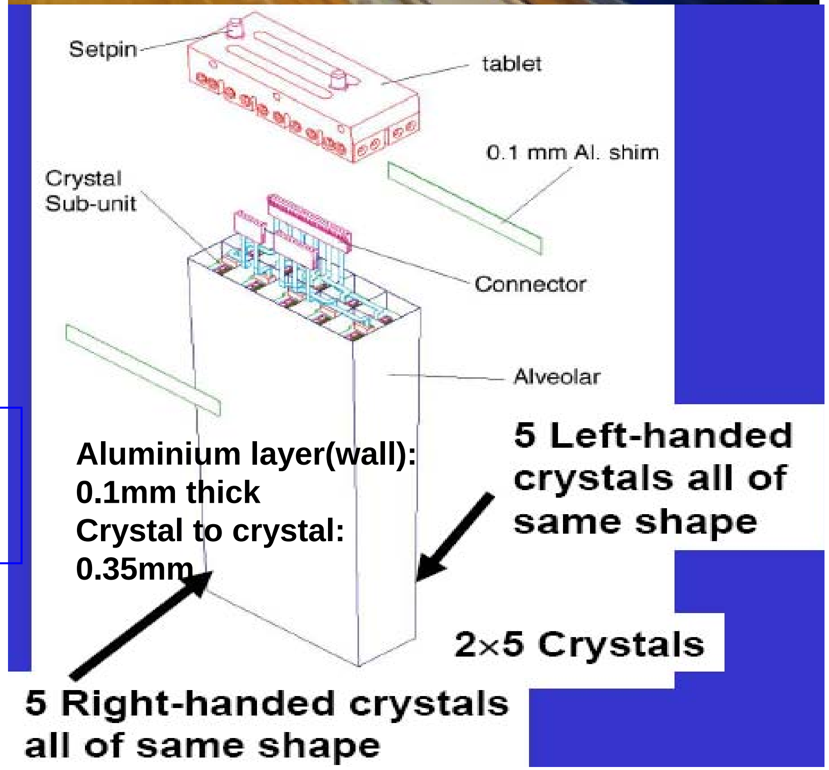
$PbWO_4$:
high density (8.3 g/cm^3)
short radiation length (0.89 cm)
small Moliere radius (2.2 cm)





APDs: Avalanche photodiodes
Active area 5×5mm^2
2 glued to the back of each crystal

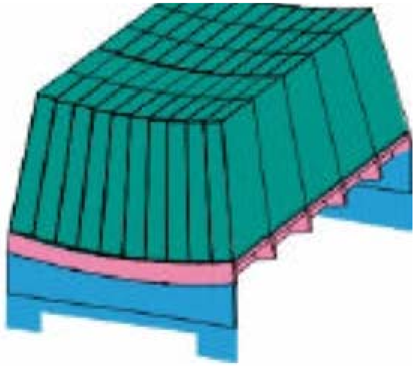


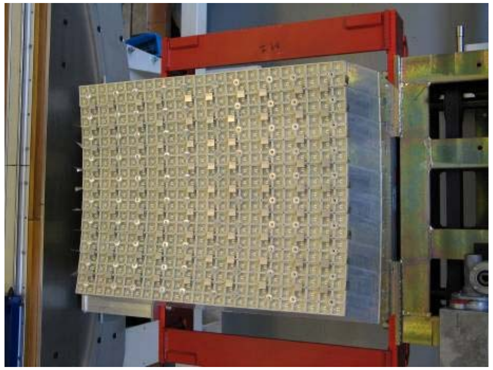


Submodules

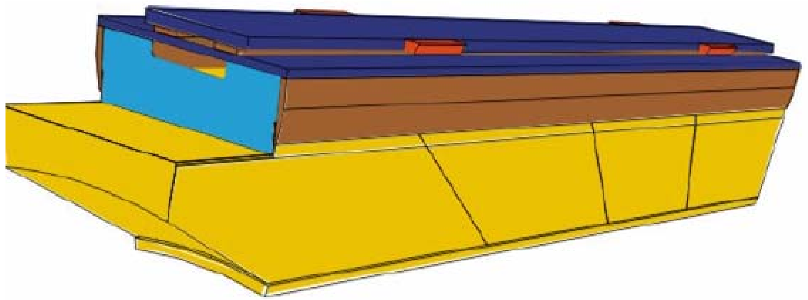
ECAL Barrel

0.5mm between submodules





Module: 50 submodules (center)/500 crystals; 40 submodules/400 crystals



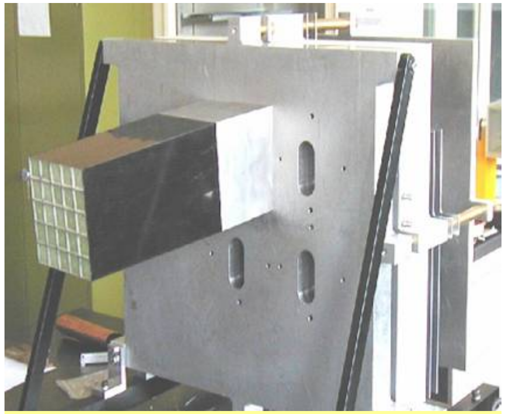
Super-module: 4 modules

1700 crystals

18 supermodules, each covering 20°,form a half barrel.
Weight of EB crystals: 67.4t

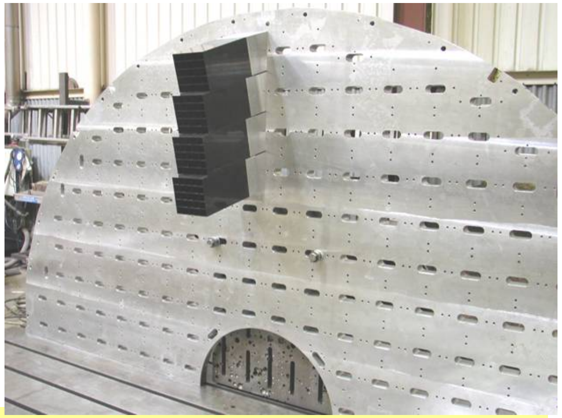
ECAL Endcap

$1.479 < |\eta| < 3.0$



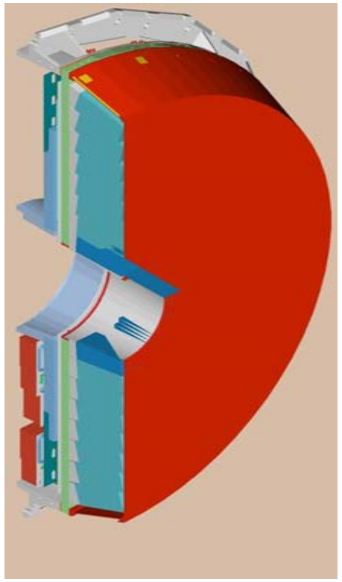
Supercrystal:

5×5 crystals

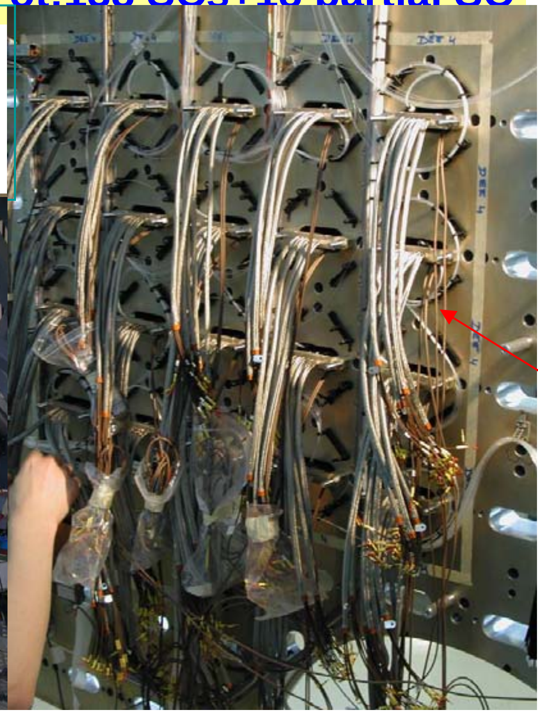


2 Dees (½ endcap): each 3662 crystals;

Tot:138 SCs+18 partial SC



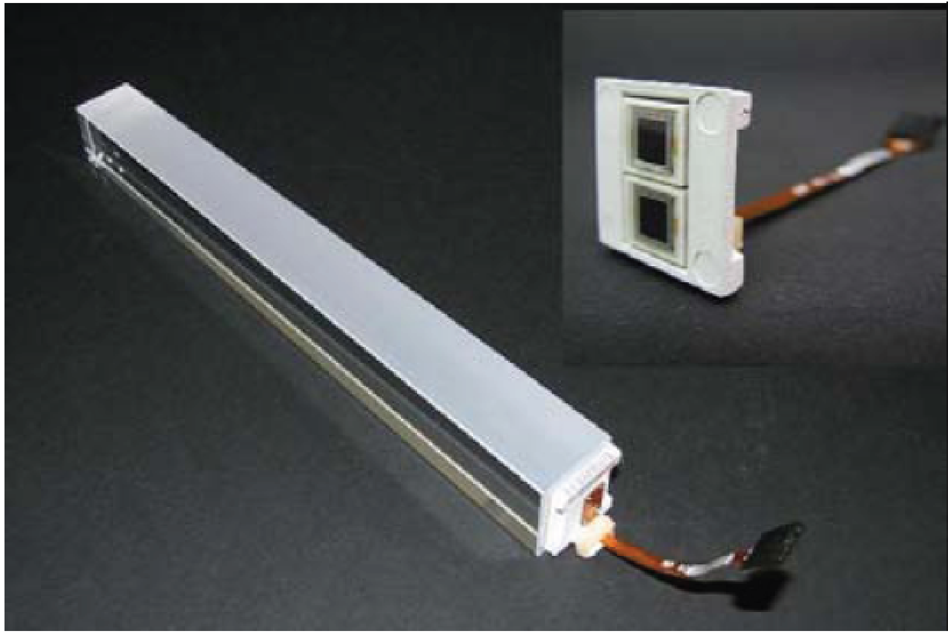
Front face: 28.62×28.62 mm^2
Rear face: 30×30 mm^2
Length: 220mm ~ 24.7 X_0

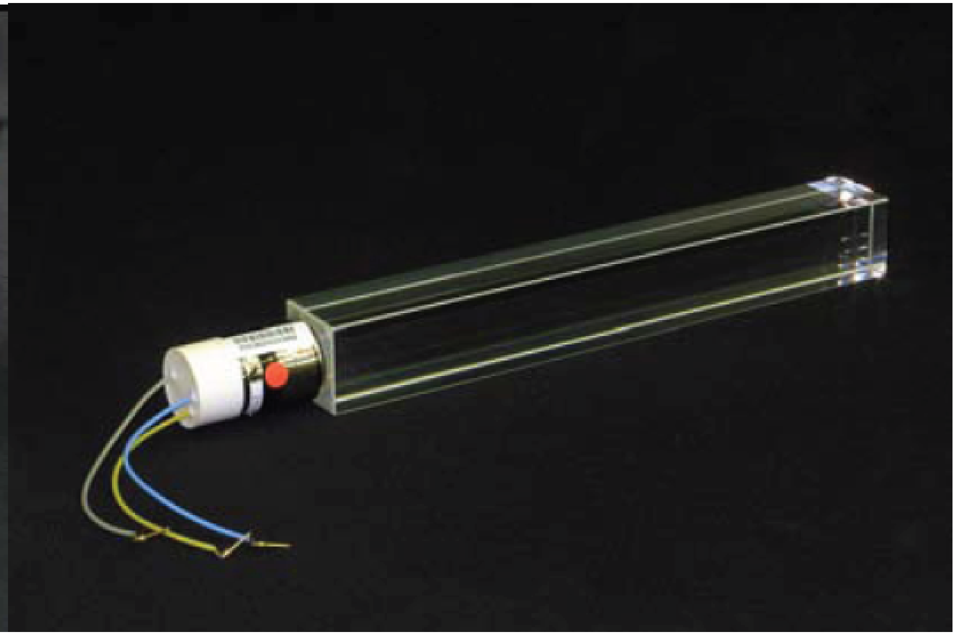


- Distance of EE envelope to to 0: 315.4cm
- Crystals point at 1300mm behind the interaction point.
- Off-pointing angles: $2^o \sim 8^o$
- Weight:24.0t

VPTs: vacuum phototriodes

Photodetector





➤Barrel:

Each APD has an active area of 5×5 mm^2

2 APDs are glued to the back of each crystal

➤Endcaps:

Each VPT is 25 mm in diameter

1 VPT is glued to the back of each crystal

Preshower detector (ES) $\boxed{1.653 < |\eta| < 2.6}$

- **Principal aim is to identify neutral pions in the endcaps.**

- Also helps the identification of electrons against minimum ionizing particles, and improves the position determination of electrons and photons with it superior granularity.

- A sampling calorimeter with 2 layers.

- Lead radiators initiate electromagnetic showers from incoming photons/electrons.

- Whilst silicon strip sensors placed after each radiator measure the energy deposited and the transverse shower profiles.

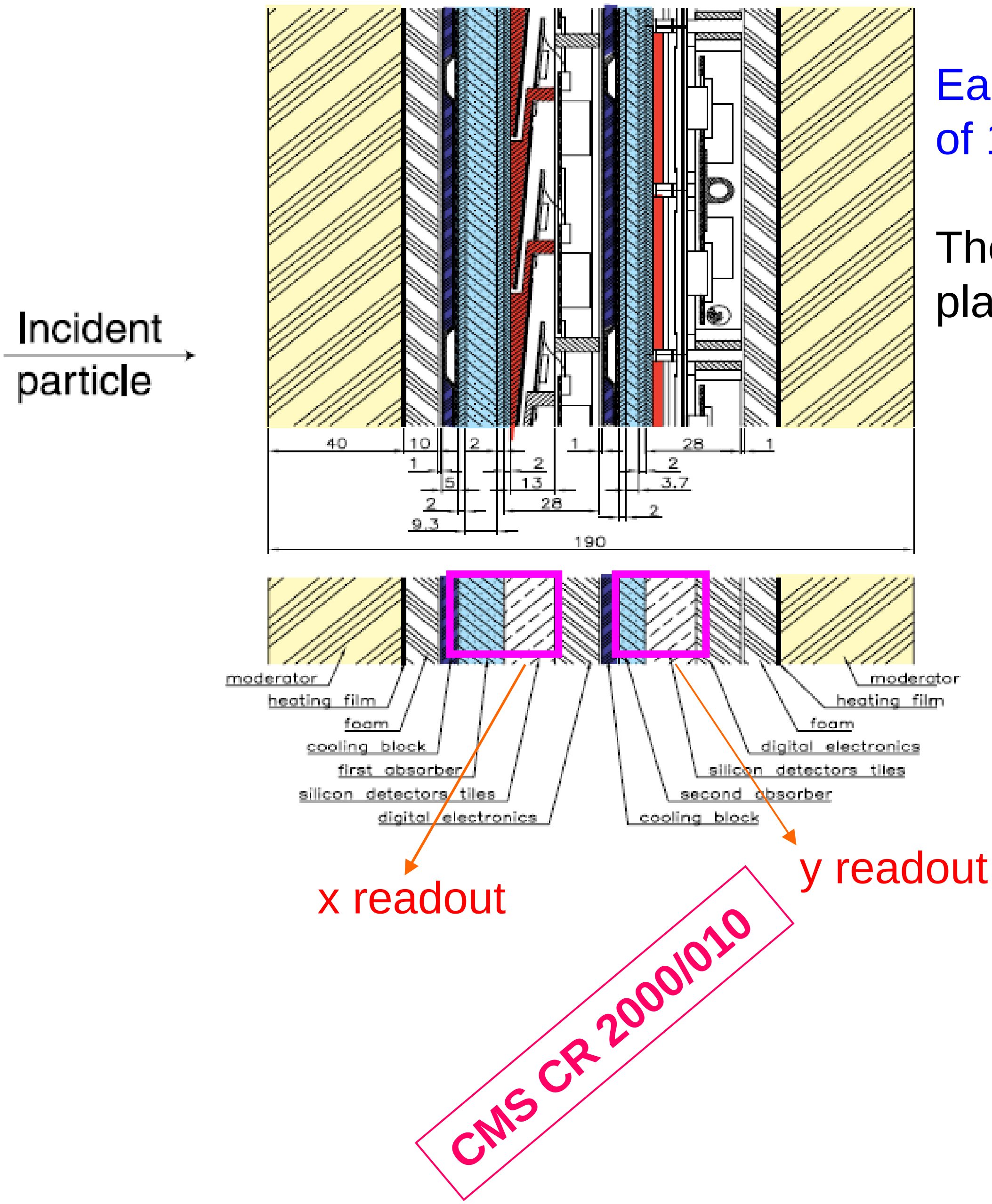
- The absorber must be sufficiently thick in order to initiate photon showers but a too thick absorber would degrade the excellent energy resolution of the crystal calorimeter. The optimum is found for a total absorber thickness of $2.8X_0$ at normal incidence.

- Total thickness of ES is 20cm.

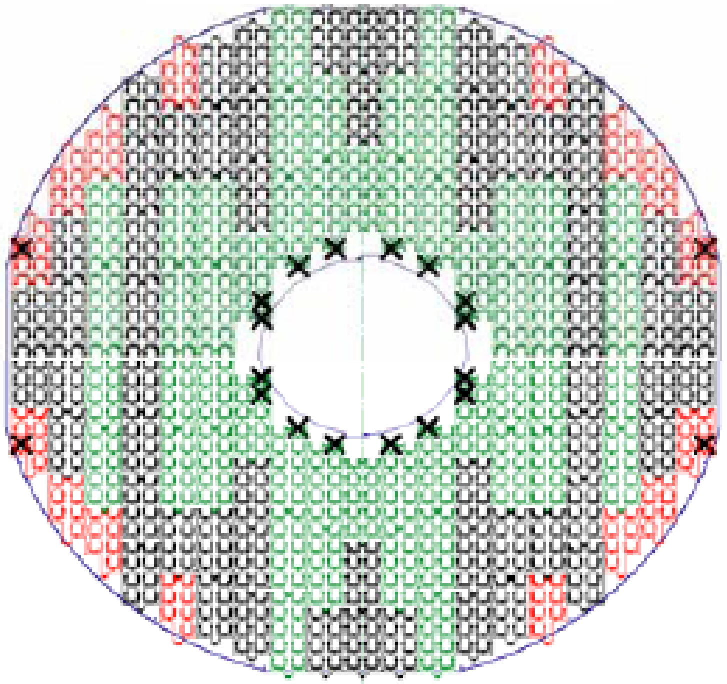
Preshower detector (ES)

Each plane is preceded by a thin absorber of 1.9 X_0 and 0.9 X_0 respectively.

The orientation of the strips in the two planes is orthogonal.

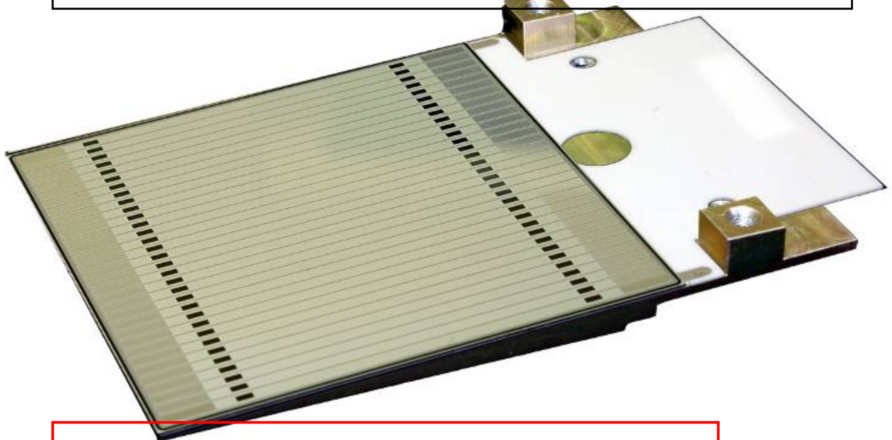


Ladders of X-plane

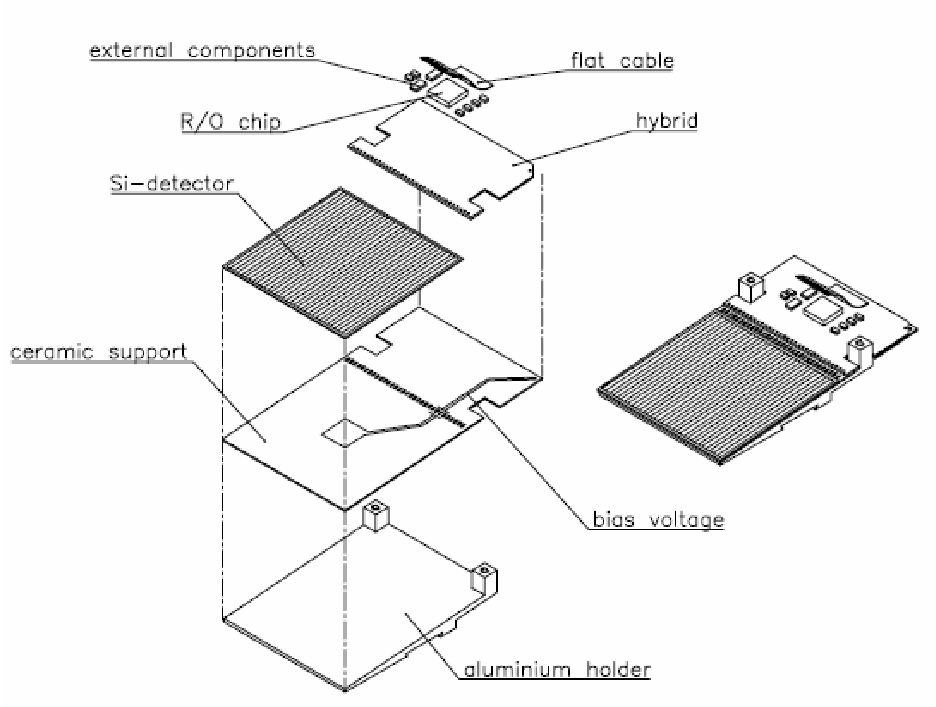


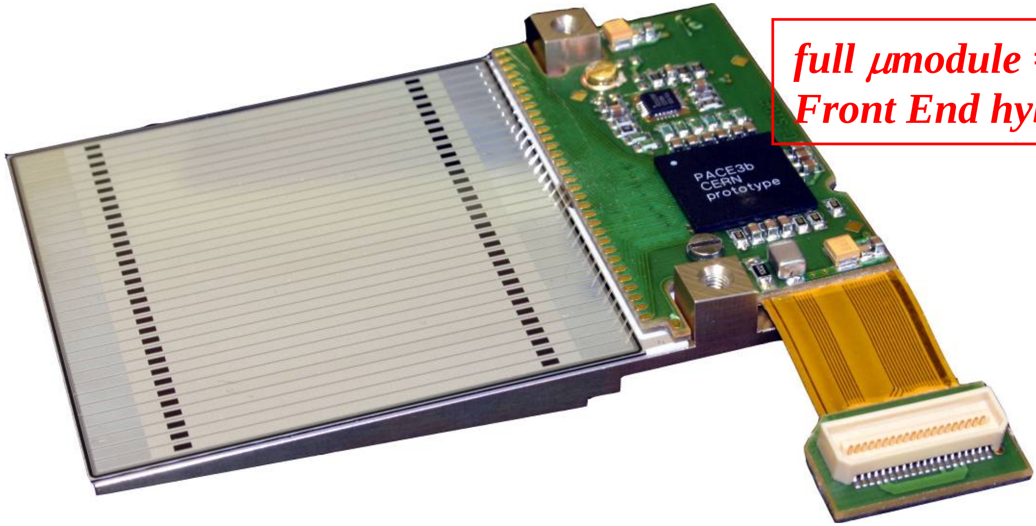
ES : silicon modules

square of 63x63 mm^2
Active area of 61x61 mm^2
divided into 32 strips of 60x1.9 mm^2



bare μmodule = glued assembly of silicon + ceramic + aluminium tile





full μmodule = bare μmodule + Front End hybrid

Each silicon divided into 32 strips with a pitch of 1.9 mm.

A total of 4304 detectors are needed, leading to 137728 channels.

CMS Hadron Calorimeter

- Barrel (HB)
- Endcaps (HE)
- Outer calorimeter (HO)
- Forward calorimeter (HF)

CMS HCAL

- Important for the measurement of hadron jets and MET (neutrinos of exotic particles).
- Also help in the identification of e, γ and μ inconjection with ECAL and Mu-subdetector.

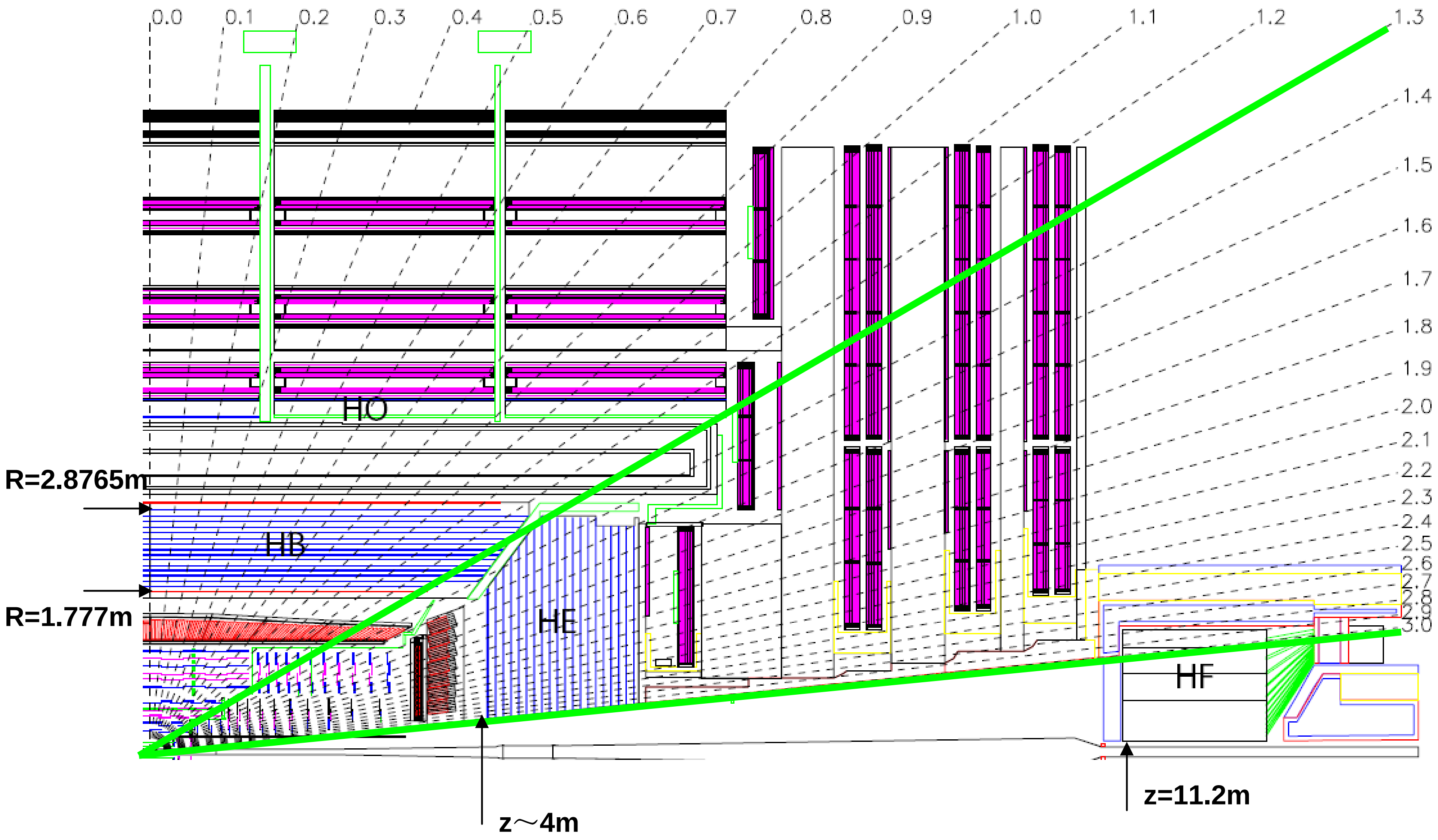
Physics Requirements

Though CMS emphasizes e, μ, γ detection and measurement, detection of jets and missing E_T is essential for:

• $H \to ZZ \to \ell\ell\nu\nu$	for heavy Higgs discovery
• $H \to WW \to \ell\nu jj$	
• $H \to ZZ \to \ell\ell jj$	
• $WW \to H$	with forward jet tags
• $t \to Wb \to 3j$	top mass measurement
• $t \to H^{\pm} \to \tau\nu$	charged Higgs search
• squarks, gluinos	search through E_T^{miss} signatures
• $H,A \to \tau^+\tau^-$	MSSM Higgs
• compositeness	search through $pp \to$ jets
• $W', Z' \to jj$	

HCAL

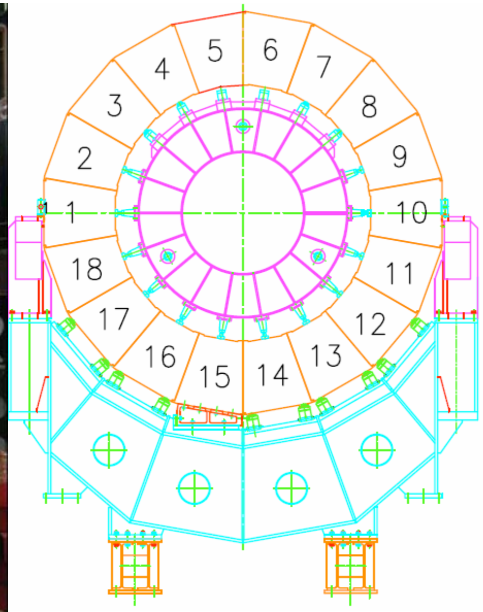
- Barrel (HB) 0<| η |<1.3
- Endcap (HE) 1.3<| η |<3.0
- Forward (HF) 3.0<| η |<5.2
- Outer barrel (HO)

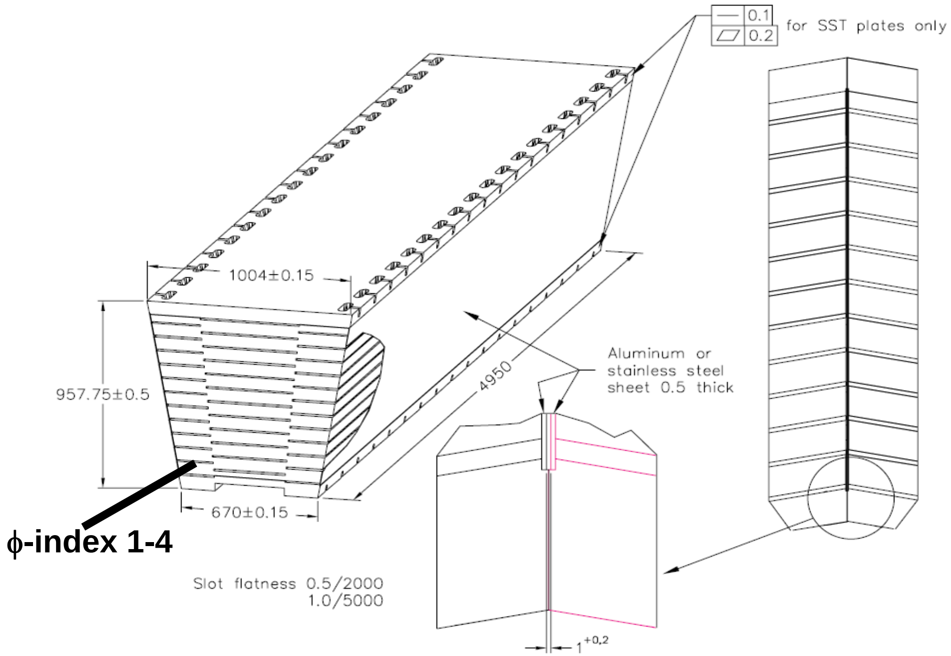


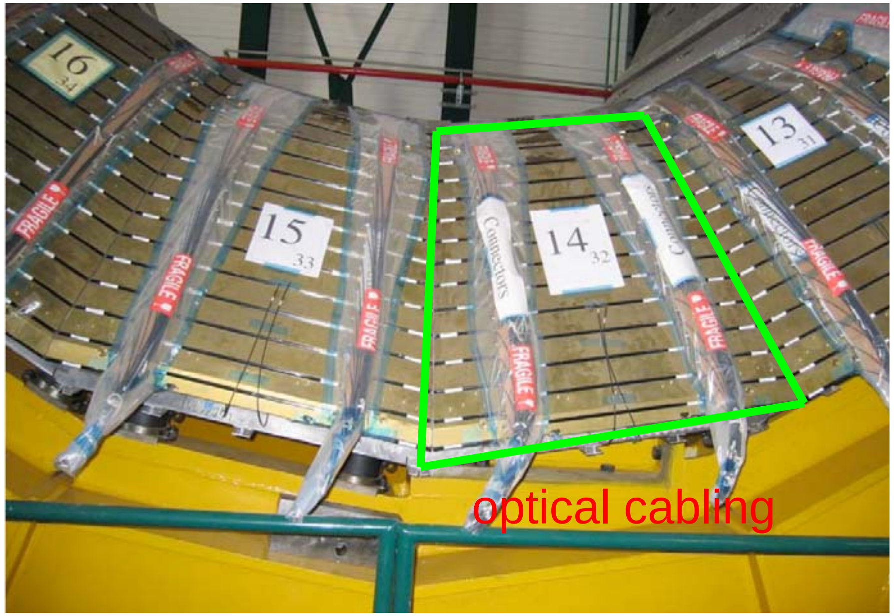
HCAL－HB

- 2 half barrel, each composed of 18 identical 20^{O} wedges in ϕ.
- Wedges: flat brass absorber plates aligned parallel to the beam axis; each is segmented into 4 sectors in ϕ.
- Physical properties of the HB brass absorber:

chemical composition	70% Cu, 30% Zn
density	8.53 g/cm^3
radiation length	1.49 cm
interaction length	16.42 cm

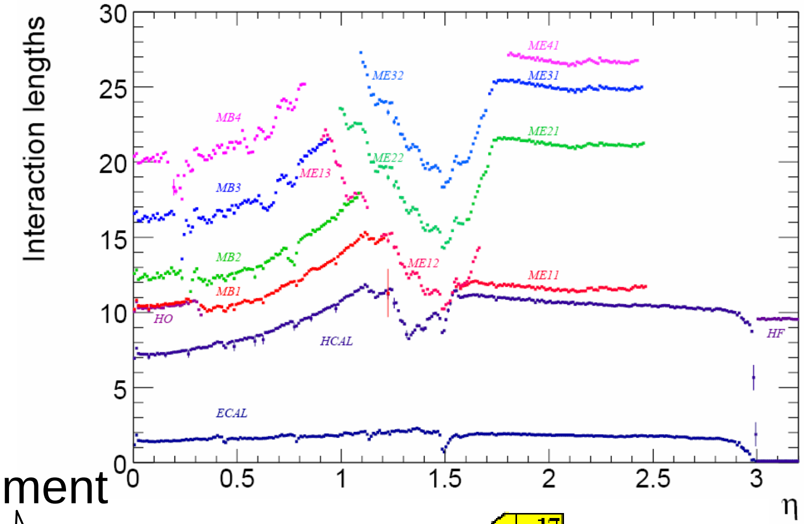


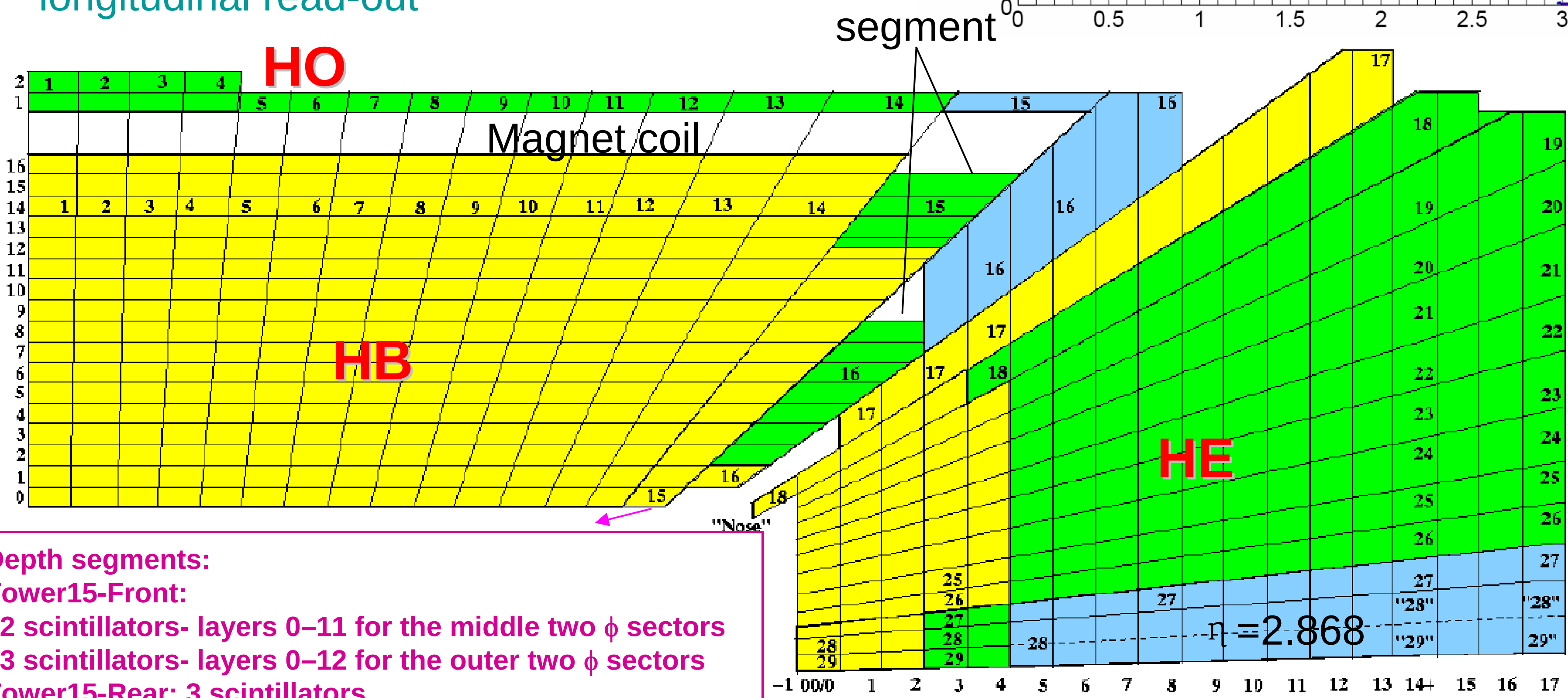




HCAL－HB

- ➢ 17 active plastic scintillator tiles
- ✓(Layer 0) 9 mm Scint/61 mm Stainless Steel
- ✓ (Layers 1-8) 3.7 mm Scint/50.5 mm Brass
- ✓ (Layers 9-14) 3.7 mm Scint/56.5 mm Brass
- ✓(Layers 15+16) 3.7 mm Scint/75 mm Stainless Steel/9 mm Scint
- ➢Plastic scintillator: 16 η sectors
- ➢HB η towers (1-14) is read out as a single longitudinal read-out

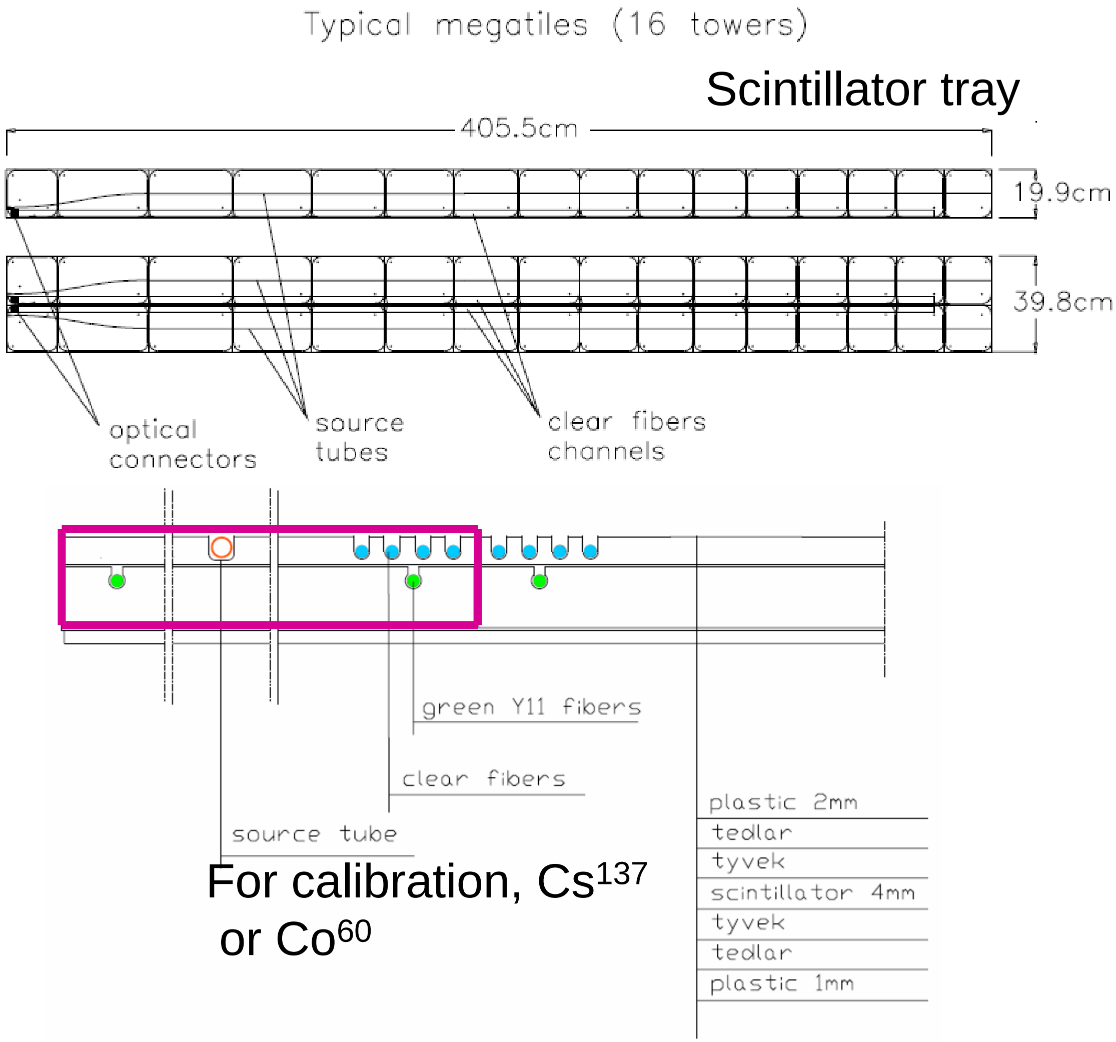




Depth segments:
Tower15-Front:
12 scintillators- layers 0–11 for the middle two ϕ sectors
13 scintillators- layers 0–12 for the outer two ϕ sectors
Tower15-Rear: 3 scintillators

HCAL－HB

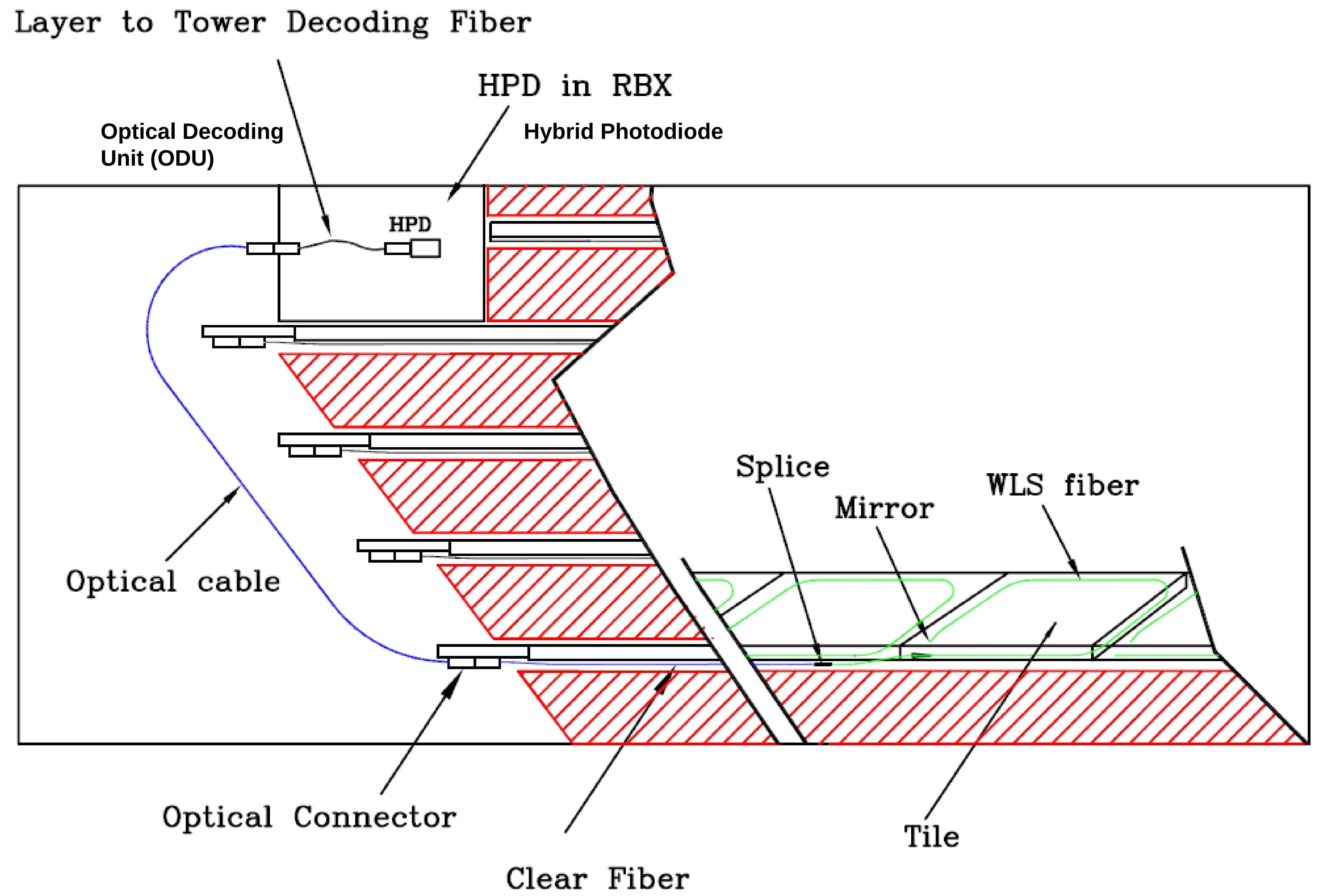
- HB: 2304 towers － 2 (half) ×18 wedges×4 sector in ϕ ×16 sector in η.
- A given ϕ: a single mechanical scintillator tray unit
- Each layer has 108 trays: 2 (half) ×18 wedges×3 trays



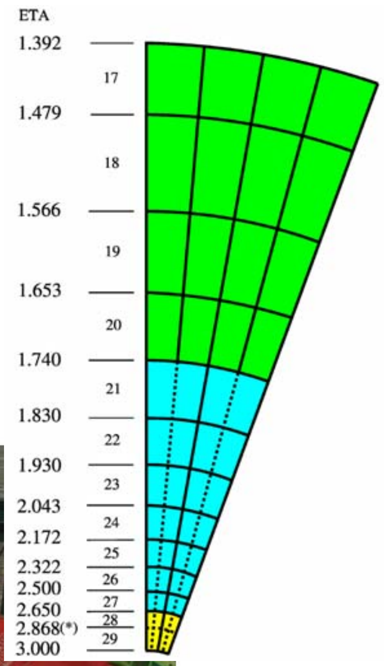
For calibration, Cs^{137} or Co^{60}

tower	η *range*	*thickness* (λ_I)
1	0.000 – 0.087	5.39
2	0.087 – 0.174	5.43
3	0.174 – 0.261	5.51
4	0.261 – 0.348	5.63
5	0.348 – 0.435	5.80
6	0.435 – 0.522	6.01
7	0.522 – 0.609	6.26
8	0.609 – 0.696	6.57
9	0.696 – 0.783	6.92
10	0.783 – 0.870	7.32
11	0.870 – 0.957	7.79
12	0.957 – 1.044	8.30
13	1.044 – 1.131	8.89
14	1.131 – 1.218	9.54
15	1.218 – 1.305	10.3
16	1.305 – 1.392	overlaps with HE

HCAL—HB optics

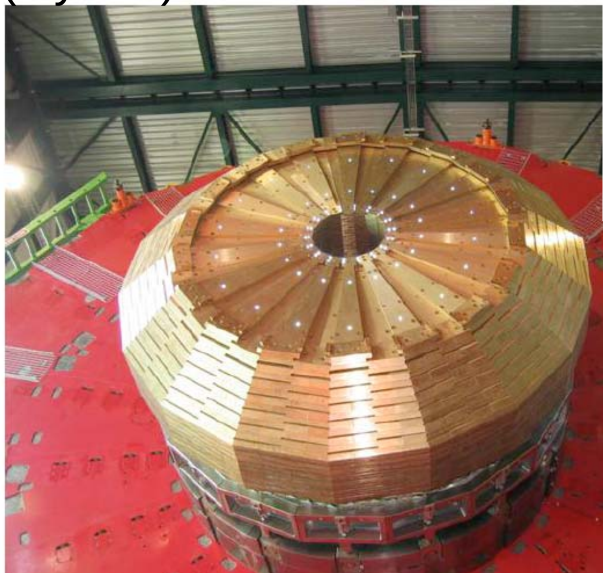


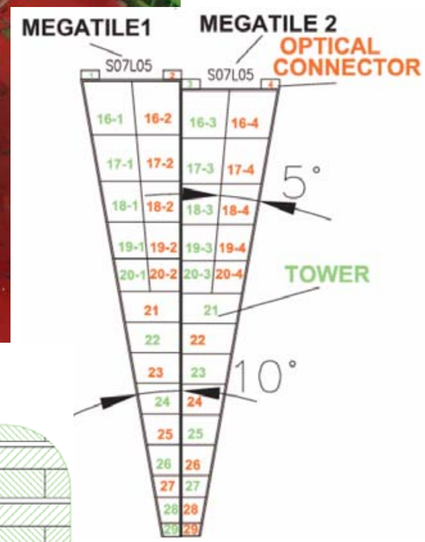
HCAL—HE



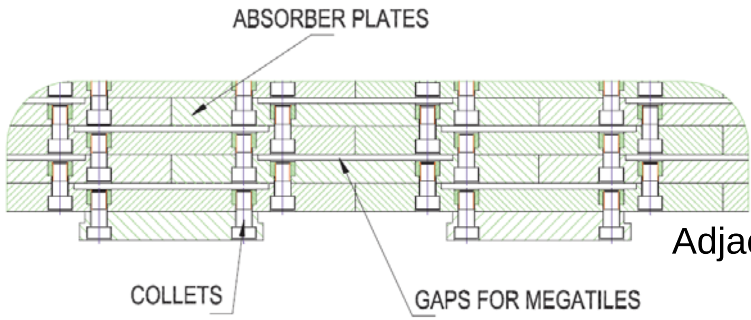
- 1.3<| η |<3.0: ~ 34% of the particles produced in the final state
- Brass absorber plates: an 18-fold Φ-geometry (20º)
- 19 active plastic scintillator layers: index -1,0,1-18
- The thickness of the plates is 78mm while the scintillator thickness is 3.7 mm (layers1-17), 9 mm (layer 0)

- 20916 tiles
- 1368 trays: 2 (half) × 19 layers × 36
- 27 ,28 plus guard ring "29": 3 divisions in depth which are read-out separately.
- Other towers (except 16 and 17 which overlap with EE) have two longitudinal readouts

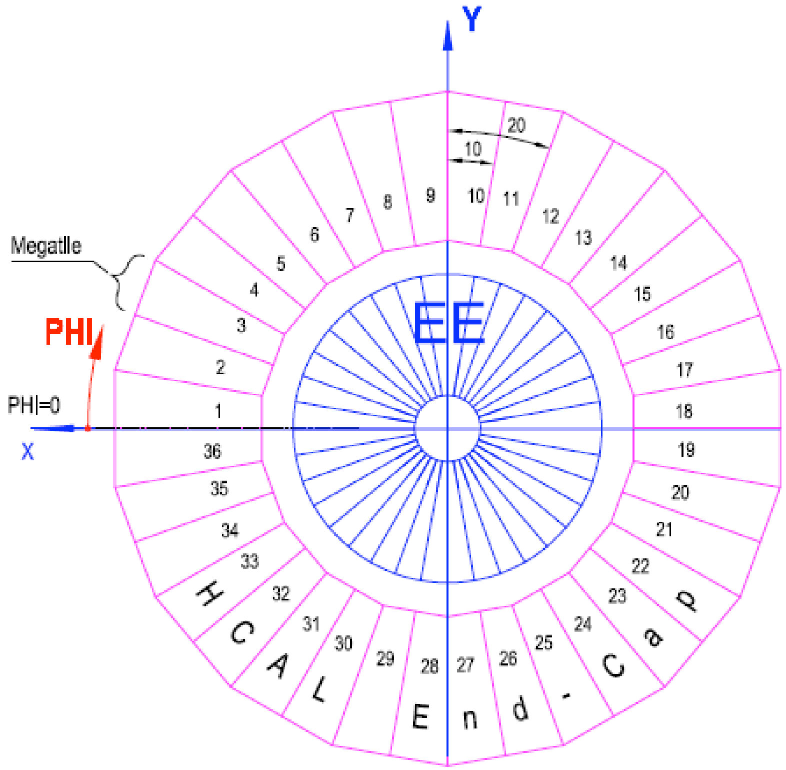




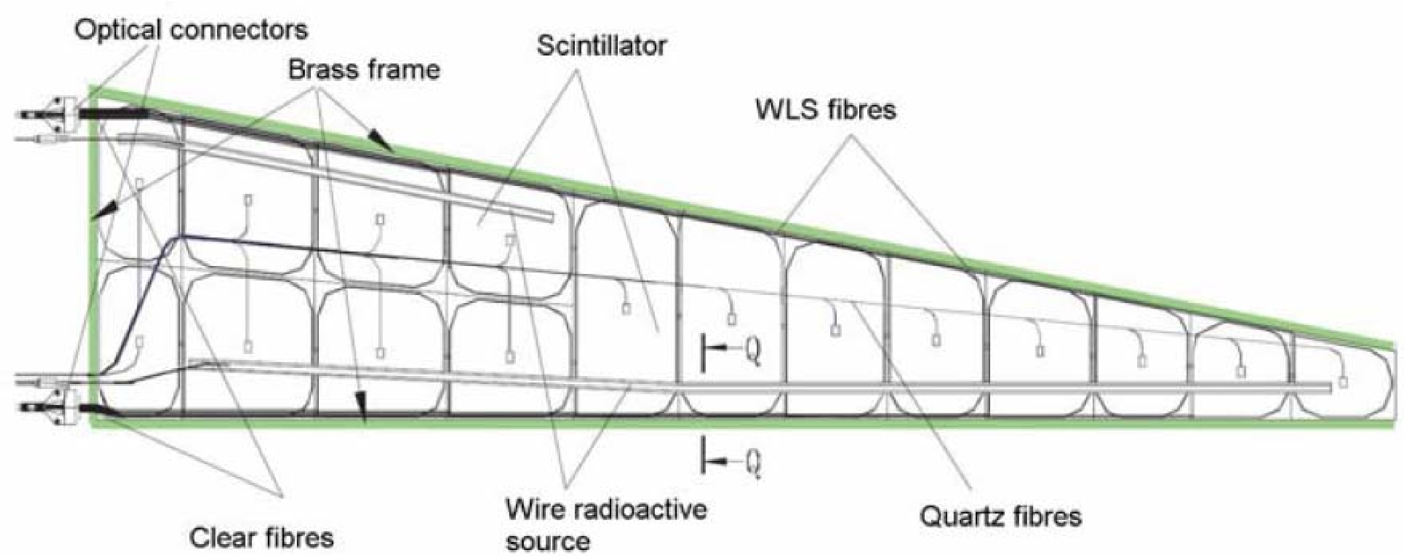
Adjacent scintillator trays



Tower index	η range Low	η range High	Detector	Size η	Size ϕ	Depth segments
16	1.305	1.392	HB, HE	0.087	5°	HB=2, HE=1
17	1.392	1.479	HE	0.087	5°	HE=1
18	1.479	1.566	HE	0.087	5°	HE=2
19	1.566	1.653	HE	0.087	5°	HE=2
20	1.653	1.740	HE	0.087	5°	HE=2
21	1.740	1.830	HE	0.090	10°	HE=2
22	1.830	1.930	HE	0.100	10°	HE=2
23	1.930	2.043	HE	0.113	10°	HE=2
24	2.043	2.172	HE	0.129	10°	HE=2
25	2.172	2.322	HE	0.150	10°	HE=2
26	2.322	2.500	HE	0.178	10°	HE=2
27	2.500	2.650	HE	0.150	10°	HE=3
*28	2.650	3.000	HE	0.350	10°	HE=3

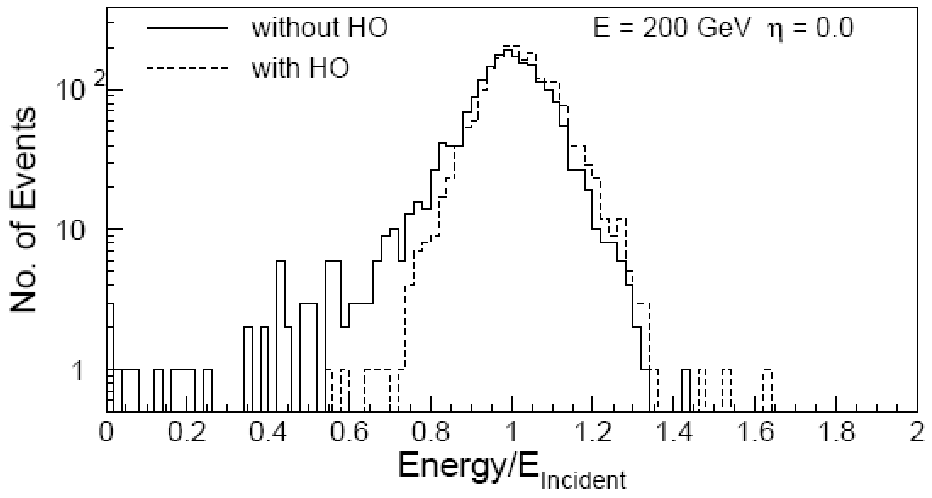


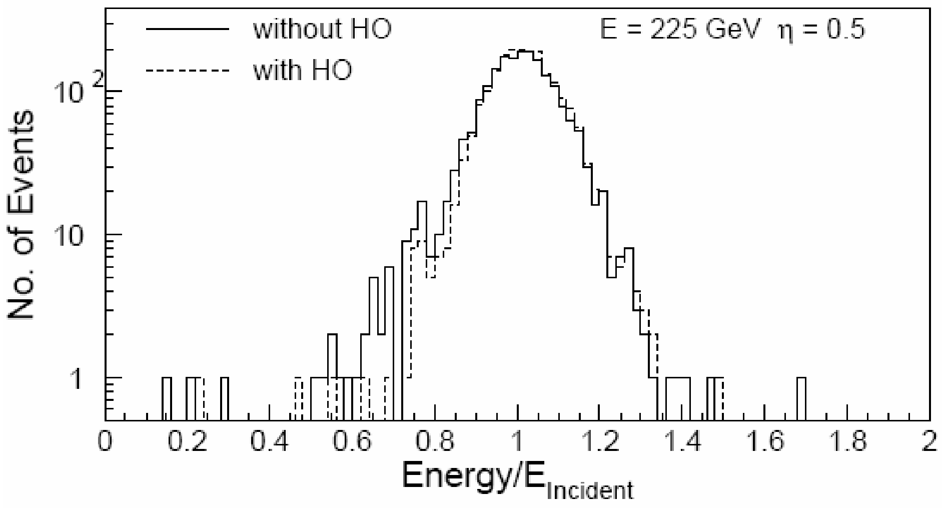
1...36 - Megatiles numbering in PHI
View from I.P.

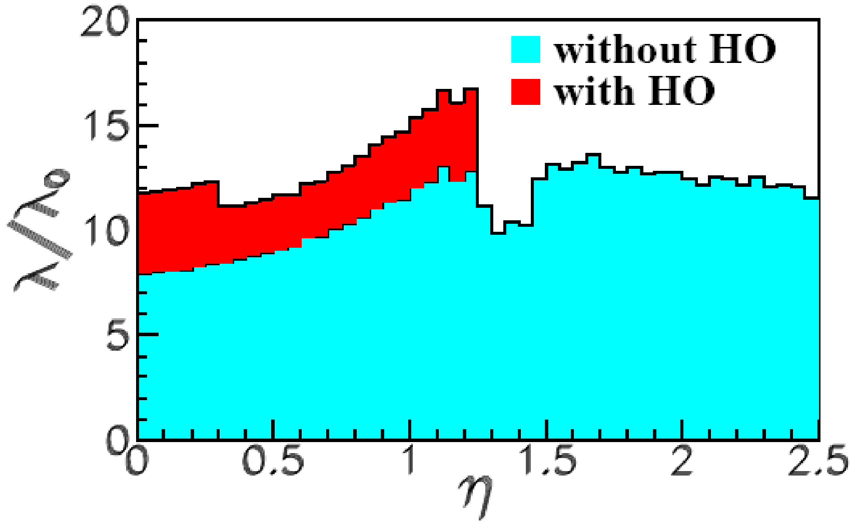


HCAL—HO

- Central region:the combined stopping power of EB plus HB does not provide sufficient containment for hadron showers.
- The mean fraction of energy in HO increases from 0.38% for 10 GeV pions to 4.3% for 300 GeV pions (η =0). "tail catcher"

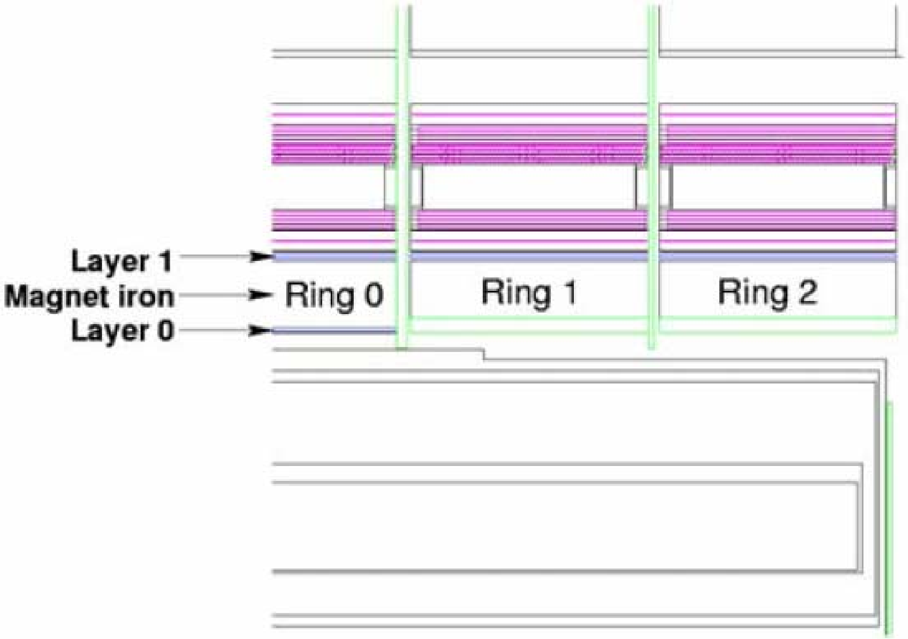




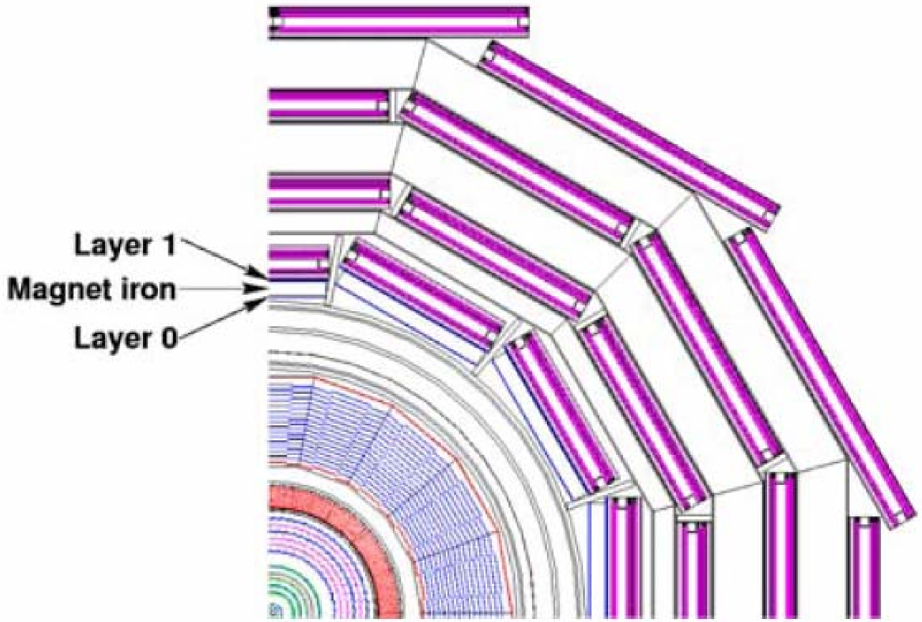


Rings & Sectors

- Consists of layers of scintillator located outside of the magnet coil.
- 5 rings (2.536 m wide along the z-axis) each having 12 sectors.
- 5 rings: -2,-1,0,+1,+2; Central z positions: -5.324m, -2.686m, 0, +2.686m, +5.342m
- Central ring (ring 0): two layers of 10 mm thick scintillators on either side of the ‘tail catcher’ iron (18 cm thick) at radial distances of 3.82m and 4.07 m, respectively. Others 4.07m.

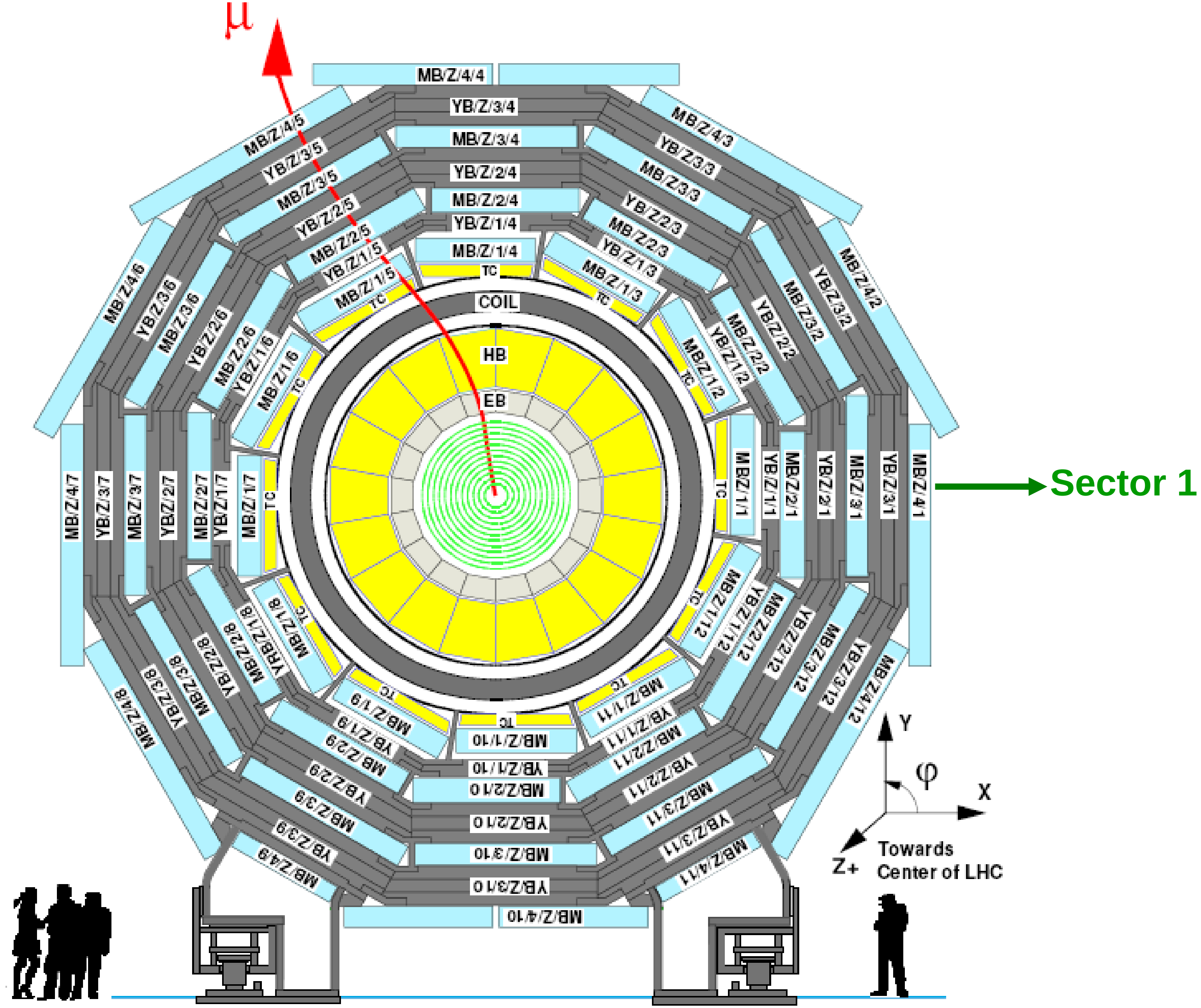


Longitudinal



Lateral

12 Sectors



A view of the yoke

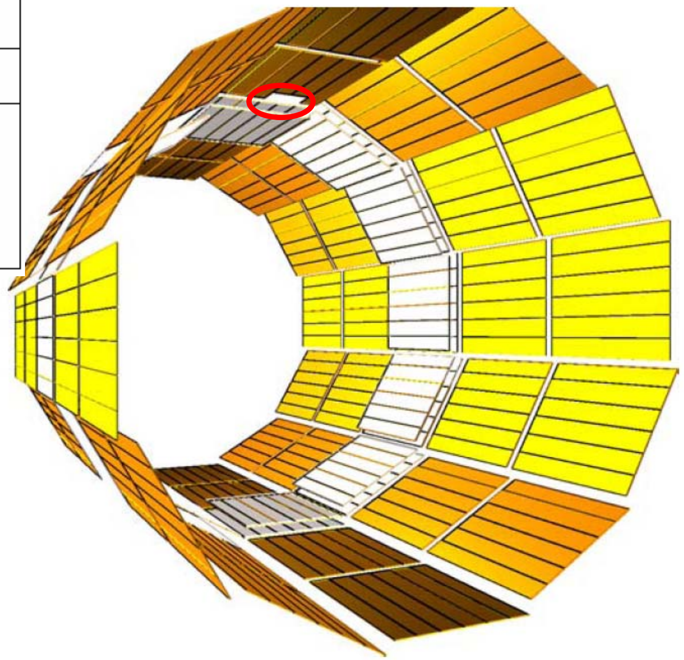
Trays & Tiles

- Each identical ϕ sector: 6 slices (trays).

Ring	Layer	Width along ϕ in mm					
		Tray 1	Tray 2	Tray 3	Tray 4	Tray 5	Tray 6
0	0	274	343	332	327	327	268
0	1	300	364	352	347	347	292
$\pm 1, \pm 2$	1	317	366	354	349	349	406

- Divisions along η (smallest scintillator unit, calle[d] a tile)
  - ✓Ring 0 (2 layers): 8 η-divisions (tiles) -4,-3,-2,-1,+1,+2,+3,+4
  - ✓Ring 1: 6 divisions 5~10 (Ring -1: -5~-10)
  - ✓Ring 2: 5 divisions 11~15 (Ring -2: -11~-15)

Without tiles: tower number $\pm$5
Trays 4&5 in sector 4 0f ring+1
Trays 3,4,5,&6 in sector3 0f ring-1



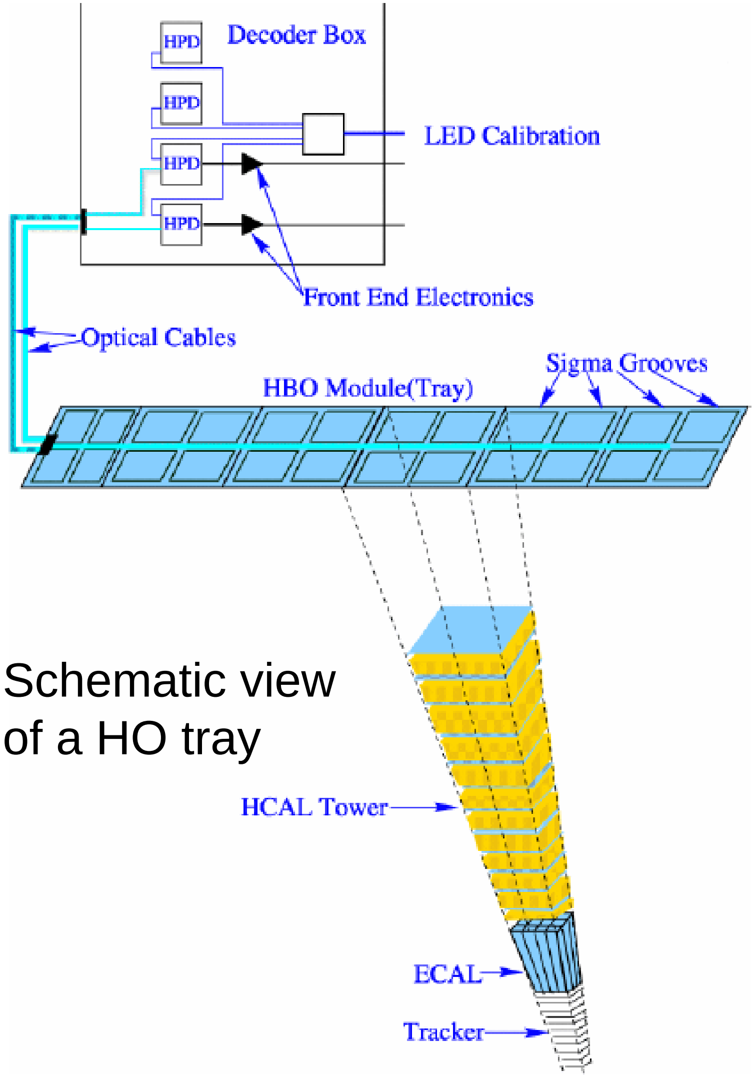
Layout of all the HO trays

- Length of a full tray: 2510mm (shorter trays: 2119mm)
- Gap between ring0 and ring$\pm$1, the η boundaries of HO tower 4 do not match the barrel η boundaries. So part of HO tower 5 overlaps with tower 4 in the barrel.
- Tiles sizes: roughly map the layers of HB to make towers of granularity 0.087$\times$ 0.087 in η and ϕ.

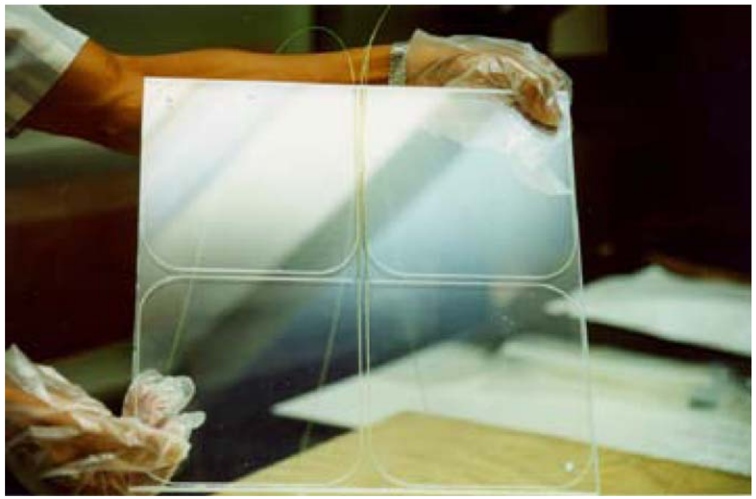
HO tile dimensions along η for different rings and layers

- Layer0: 72 trays
  1rings × 12sectors × 6trays
  Layer1: 360 trays
  5rings × 12sectors × 6trays
- Tiles: 2730 (layer1 2154; layer0 576)

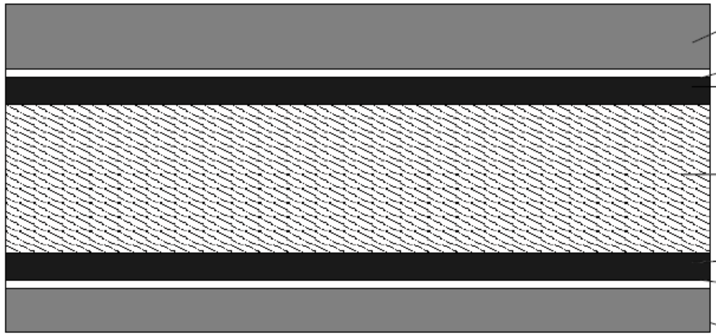
Tower #	η_{max}	Length (mm)	Tower #	η_{max}	Length (mm)
Ring 0 Layer 0			Ring 0 Layer 1		
1	0.087	331.5	1	0.087	351.2
2	0.174	334.0	2	0.174	353.8
3	0.262	339.0	3	0.262	359.2
4	0.326	248.8	4	0.307	189.1
Ring 1 Layer 1			Ring 2 Layer 1		
5	0.436	391.5	11	0.960	420.1
6	0.524	394.2	12	1.047	545.1
7	0.611	411.0	13	1.135	583.3
8	0.698	430.9	14	1.222	626.0
9	0.785	454.0	15	1.262	333.5
10	0.861	426.0			



Schematic view of a HO tray



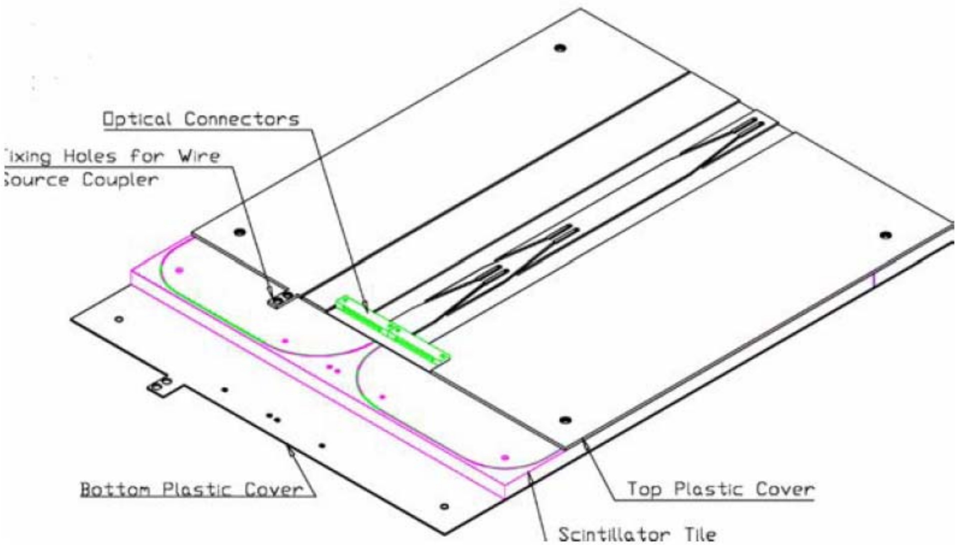
View of a typical tile of HO with WLS fibres inserted in the 4 grooves of the tile



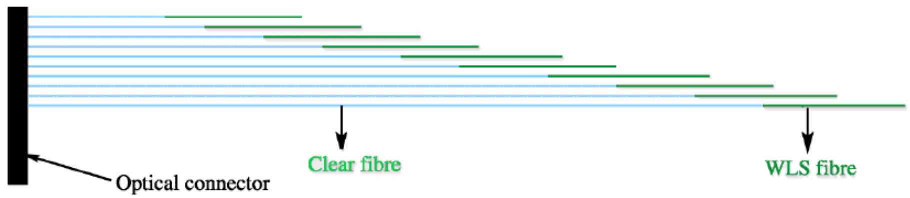
Plastic: Mechanical stability

Papers: prevent light leakage

Cross section of a HO tray showing the different components



The arrangement of scintillation tiles, plastic covers and connectors in a tray.



Tray specifications for different rings of HO

Ring #	Tiles/tray	Fibres/tray	Fibres/connector
0	8	32	16
± 1	6	24	12
± 2	5	20	10

Each tray has two optical connectors mounted on one end of the tray

HCAL－HF

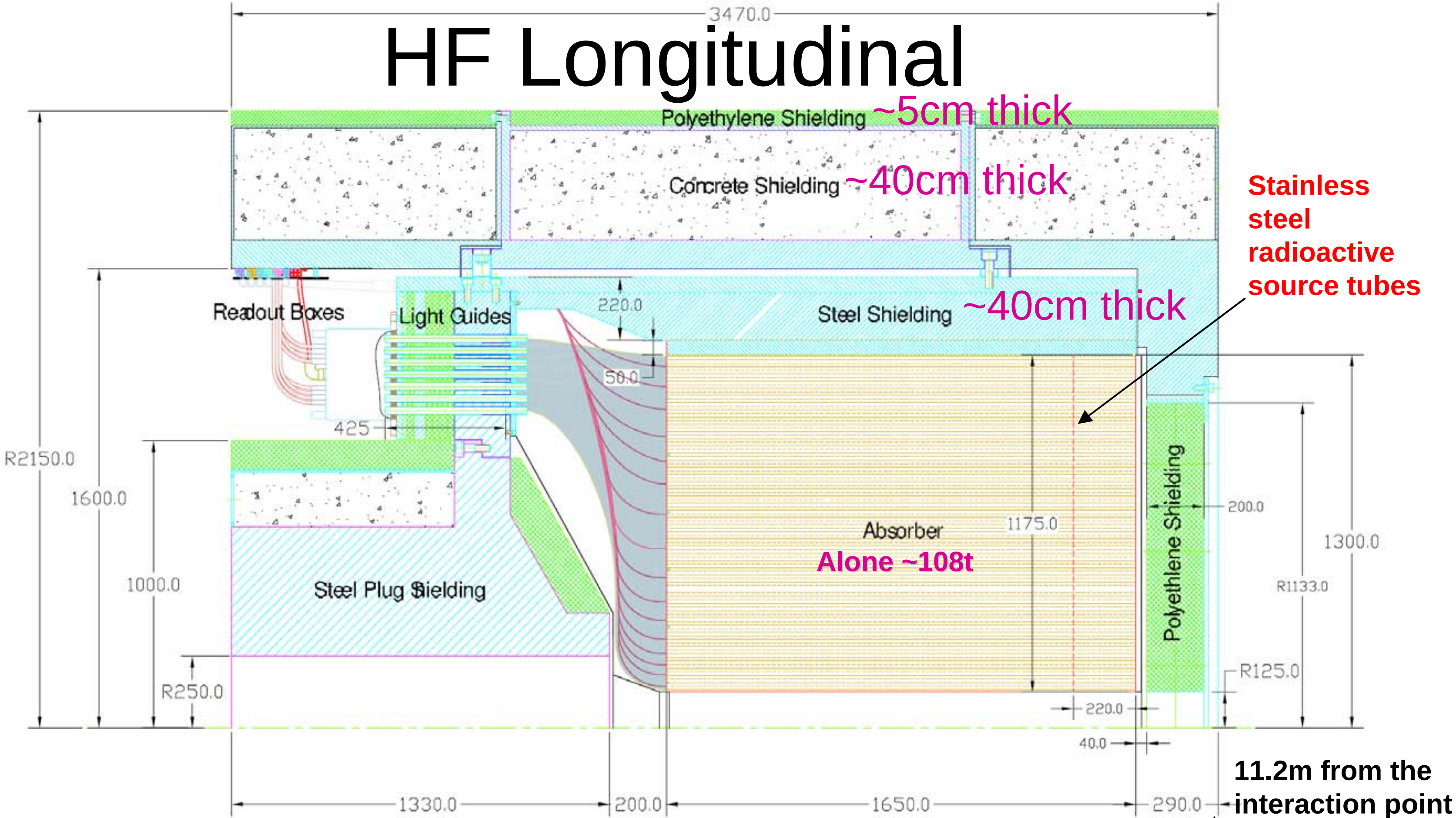
- Experience unprecedented particle fluxes.

- On average, 760GeV per proton-proton interaction is deposited into the two forward calorimeters, compared to only 100GeV for the rest of the detector.

- Not uniformly distributed, pronounced maximum at the highest rapidities

Assembled HF modules in building 186 at CERN

HF Longitudinal



➢ Steel absorber structure: 5 mm thick grooved plates; outer radius 130 cm & innner radius 12.5 cm; Length: 165cm(~10λ)

➢ Embedded radiation hard quartz fibers:

✓Provide a fast collection of Cherenkov light.

✓600$\pm$10 μm in diameter for the fused-silica core, 630$^{+5}_{-10}$ μm with the polymer hard-cladding, and 800$\pm$30 μm with the protective acrylate buffer.

✓Attenuation length: ~15 m

✓Half run over the full depth of the absorber; another half starts at a depth of 22cm from front.

✓Long (1.65 m) and short (1.43 m) quartz fibers are placed alternately with a separation of 5 mm.

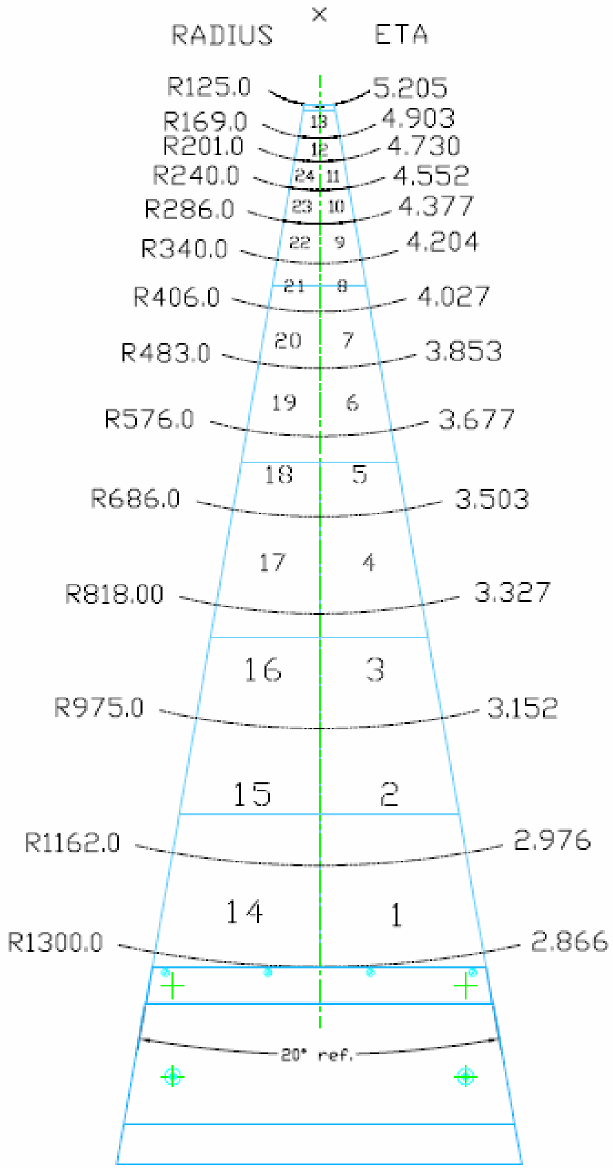
✓Over 1000km of fibers are used.

✓ Possible to distinguish EM shower and HAD shower

HF Lateral

- 20º modular wedges; 18 wedges.
- The fibers are bundled to form 0.175 × 0.175 towers in η and ϕ.

Ring No	$(r_{\mathrm{in}}, r_{\mathrm{out}})$ [mm]	$\Delta\eta$	$\Delta\phi$ [degree]	N_{fib}	A_{bundle} [mm^2]	$\frac{A_{\mathrm{bundle}}}{A_{\mathrm{photocathode}}}$
1	(1162–1300)	0.111	10	594	551	1.14
2	(975–1162)	0.175	10	696	652	1.33
3	(818–975)	0.175	10	491	469	0.96
4	(686–818)	0.175	10	346	324	0.66
5	(576–686)	0.175	10	242	231	0.47
6	(483–576)	0.175	10	171	167	0.34
7	(406–483)	0.175	10	120	120	0.25
8	(340–406)	0.175	10	85	88	0.18
9	(286–340)	0.175	10	59	63	0.13
10	(240–286)	0.175	10	41	46	0.94
11	(201–240)	0.175	10	30	35	0.71
12	(169–201)	0.175	20	42	52	0.11
13	(125–169)	0.300	20	45	50	0.10



Sizes of the HCAL trigger towers

Tower index	$\|\eta_{\max}\|$	Detector	Size	
			η	ϕ
1–15	$0.087\times\eta$	HB	0.087	5°
16	1.392	HB, HE	0.087	5°
17–20	$0.087\times\eta$	HE	0.087	5°
21	1.830	HE	0.090	5°
22	1.930	HE	0.100	5°
23	2.043	HE	0.113	5°
24	2.172	HE	0.129	5°
25	2.322	HE	0.150	5°
26	2.500	HE	0.178	5°
27	2.650	HE	0.150	5°
28	3.000	HE	0.350	5°
29	3.314	HF	0.461	20°
30	3.839	HF	0.525	20°
31	4.363	HF	0.524	20°
32	5.191	HF	0.828	20°