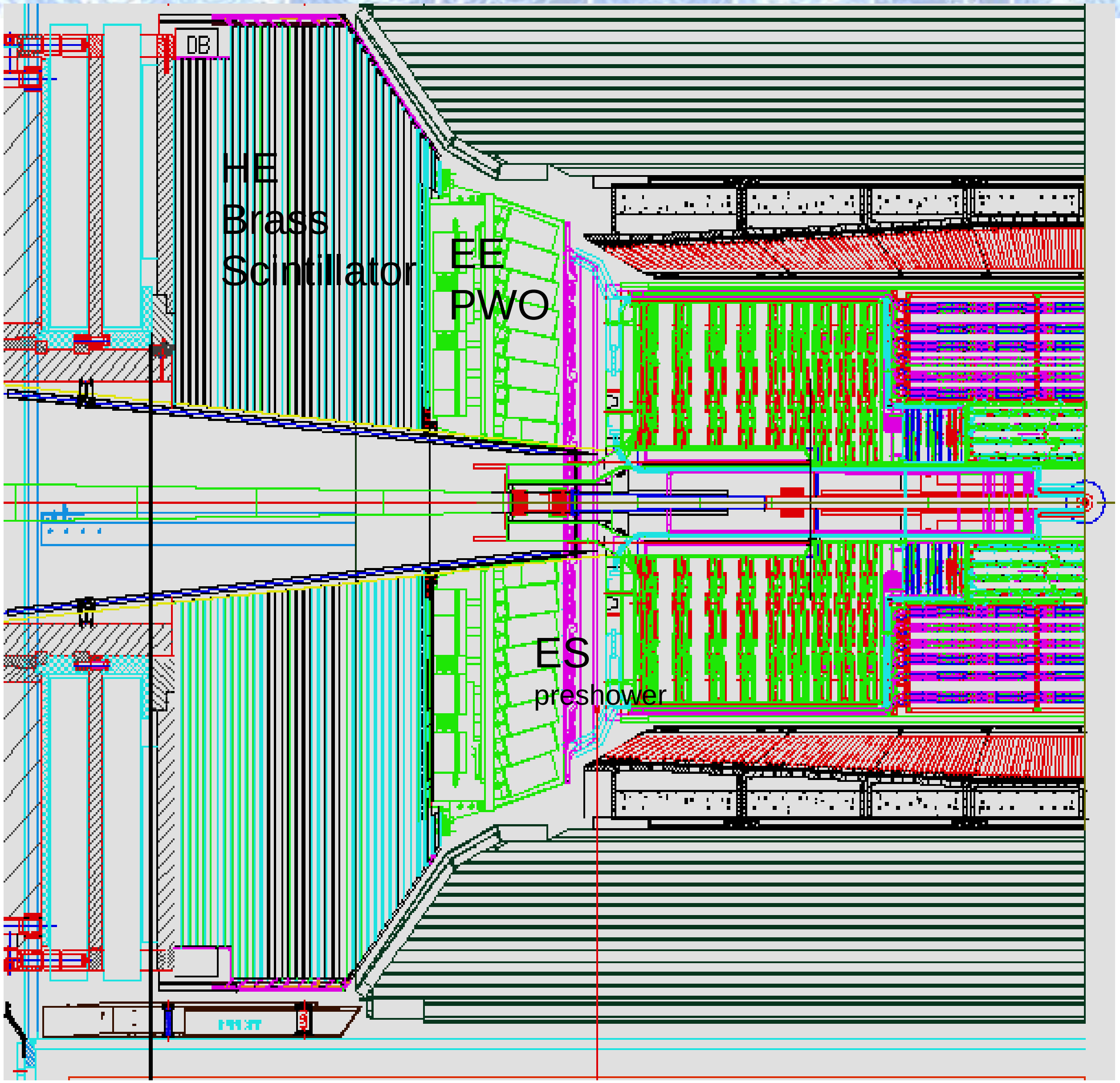
CMS plans for Endcap Calorimetry at HL-LHC

- Motivations for change and requirements
- Proposals under consideration
  - Shashlik and HE rebuild
  - High Granularity Calorimeter
- Conclusions

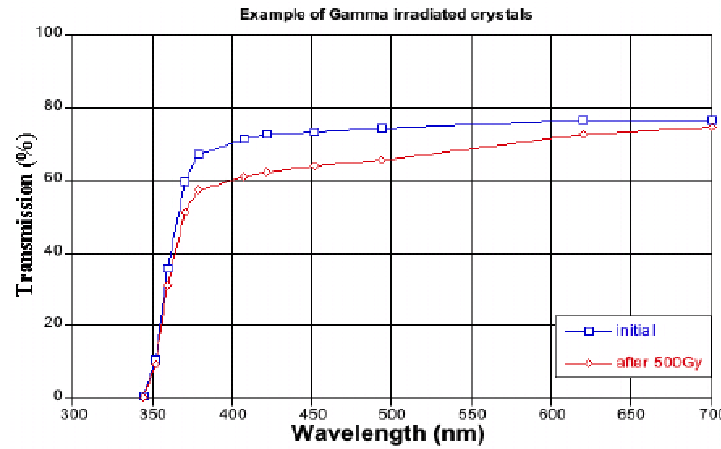
Present CMS Endcap



Radiation damage on crystals

Gamma irradiation creates color centers which reduce the crystal transparency up to a saturation level, which depends on the dose rate. The damage is spontaneously recovered at room temperature.

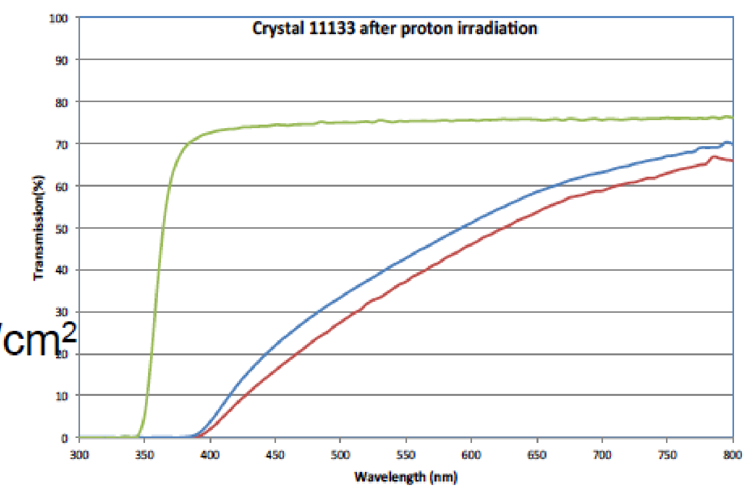
γ ,e



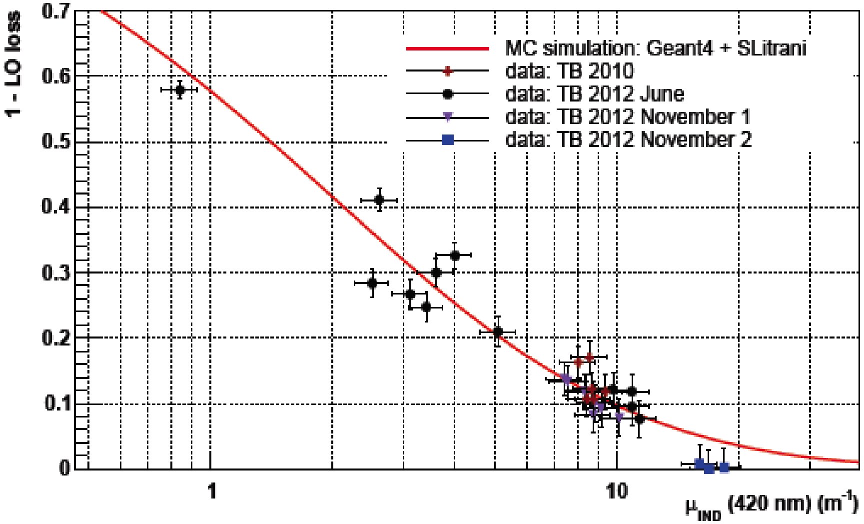
Hadron damage creates clusters of defects which cause light transmission loss. The damage is permanent and cumulative at room temperature.

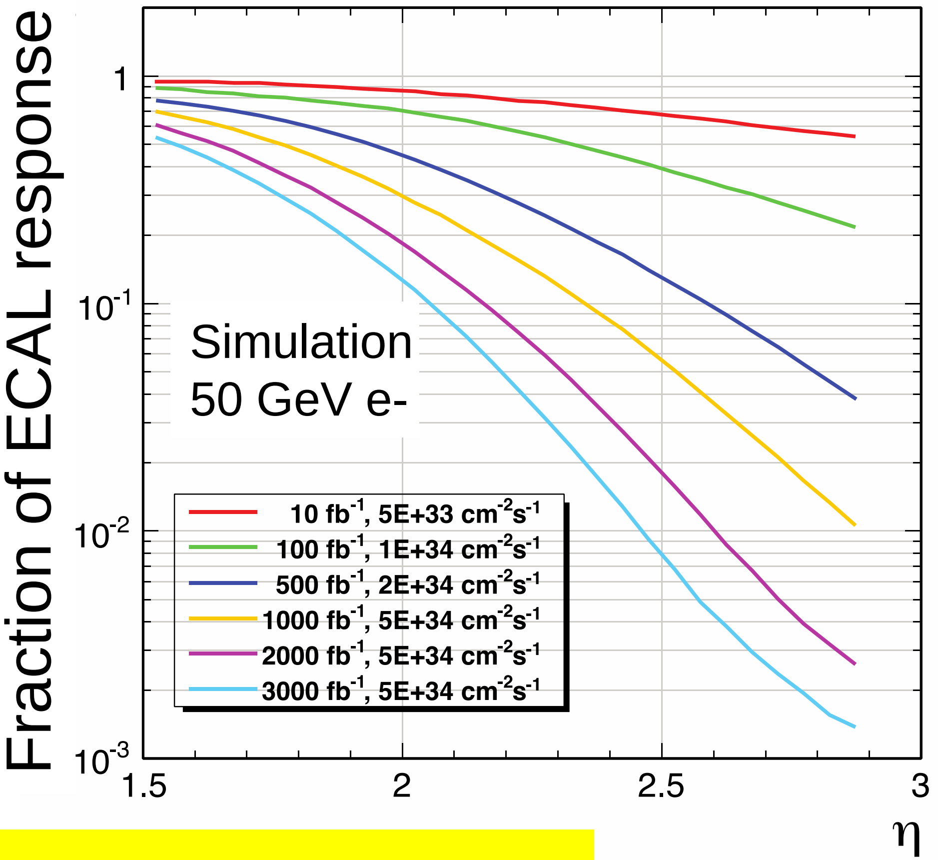
p

$2.4x10^{13}p/cm^2$



Expected Light loss in Endcaps (EE)

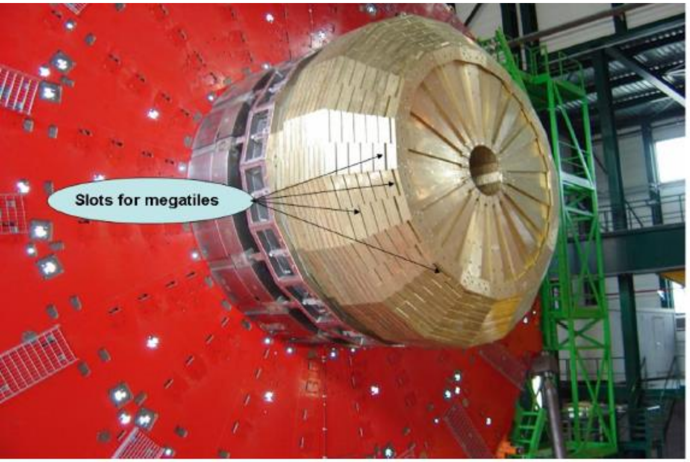


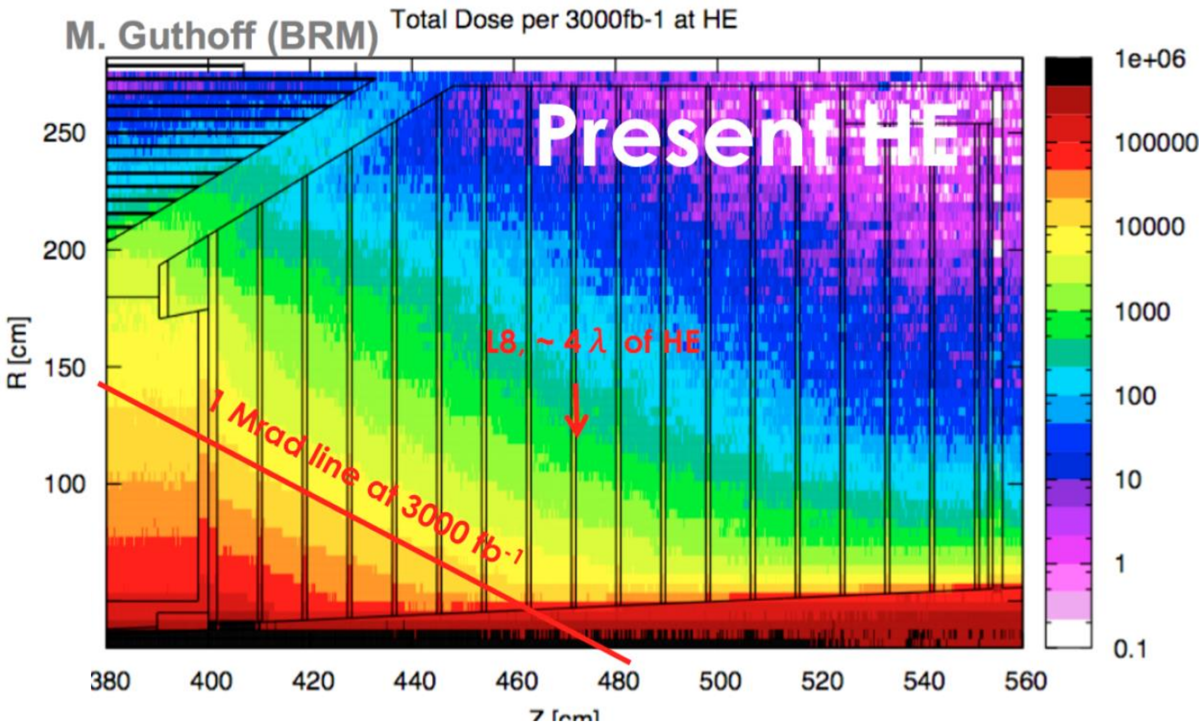


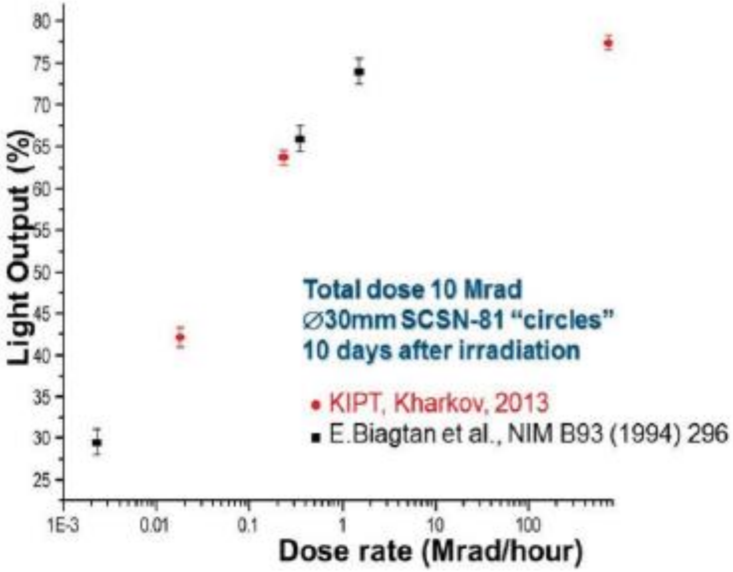
In addition, longitudinal non-uniformity builds up and creates a constant term.

The EE crystals were chosen to survive the nominal LHC 500 fb^{-1}, with the precision region up to η < ~ 2.5

Radiation damage End Cap Hadronic Calorimeter

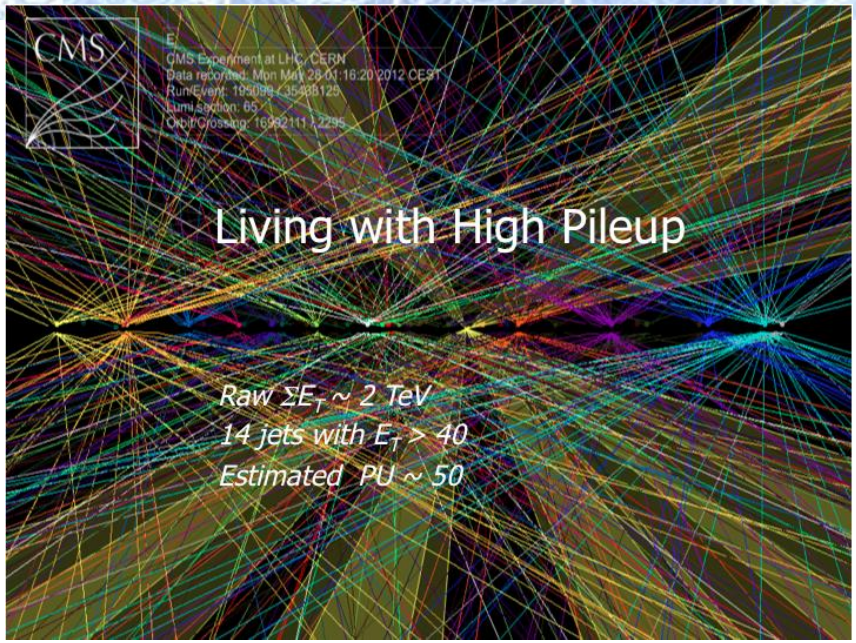






- Radiation damage is enhanced by low dose rate.
- Extrapolations show that after 500 fb^{-1}, the high η corner (first layers) will have <5% signal left.
- Need to replace ~ 20% of the current Sci. tiles

Pileup



Pileup will dramatically increase from <20-30> today to an average of <140> simultaneous interactions (in-time pileup) , or more if performance allows

- both in-time and out of time (previous/following bunches)
- increase of occupancy and "background" under physical objects (jets, electrons, photons)

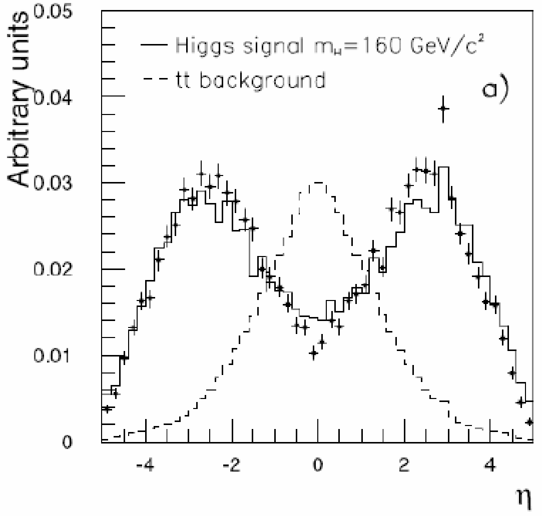
This calls for high granularity & short Moliere radius

Electronics will have to be replaced anyhow, to allow for longer Trigger latency (-> ≥10 μs) and higher L1 trigger rate.

Physics (examples)

VBF H➔$\tau\tau$

- Forward jet tagging
- Hadronic tau reconstruction
- Electron / muon id
- Missing E_T
- Low P_T threshold



HH➔bb$\tau\tau$ or bb$\gamma\gamma$ ← Wants good em resolution

$W_L W_L$ scattering (low p_T)

CMS needs to replace the Endcap electromagnetic calorimeter and replace/improve the hadron calorimeter due to radiation damage.

If anything, the HL-LHC physics is as demanding in the high η region and at low p_t than for LHC.

Maintain or improve the current performance in a much harsher environment

Calendar

- Review March 2014: aim is to reduce the three options to two, to focus effort and R&D resources

- Technical Proposal September 2014 with the two remaining options

- Selection of single option by ~ April 2015

- TDR first half of 2017

- Installation 2023-2024.

  LS3 shut down is planned to be 36 months, a lot of work on the Barrel (New Tracker, new ECAL FE electronics etc..), so one endcap of new EE+HE should be ready to install ~ at the start of the shutdown, the second whenever convenient.

3 proposals internally reviewed in March 2014

Shashlik with crystal as active medium + HE-rebuilt :

device with very good em resolution, with higher granularity and rad hardness than present EE, followed by a rebuilt HE using the same concept as now with enhanced rad hardness and segmentation.

Combined Forward Calorimeter (CFC)

Unique device with best hadron energy resolution, based on the dual readout DREAM/RD52 concept. Brass absorber with fibres (Č or Sci) every 2mm. Longitudinal segmentation by timing. Electron id by lateral shower shape and timing.

High Granularity Calorimeter (HGCAL)

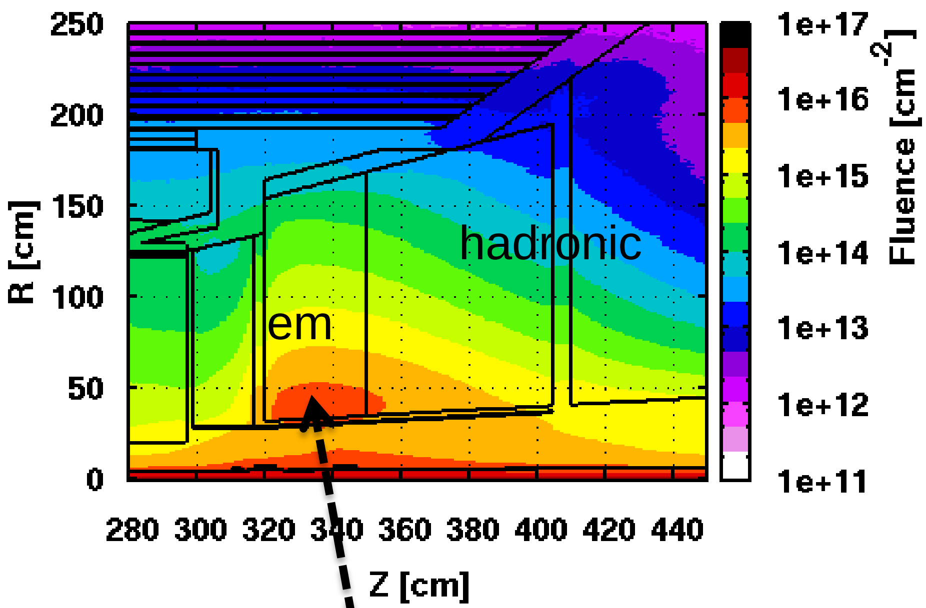
Silicon-based device “a la CALICE” with “extreme” granularity both transverse O(cm^2) and longitudinal (read independently every layer).

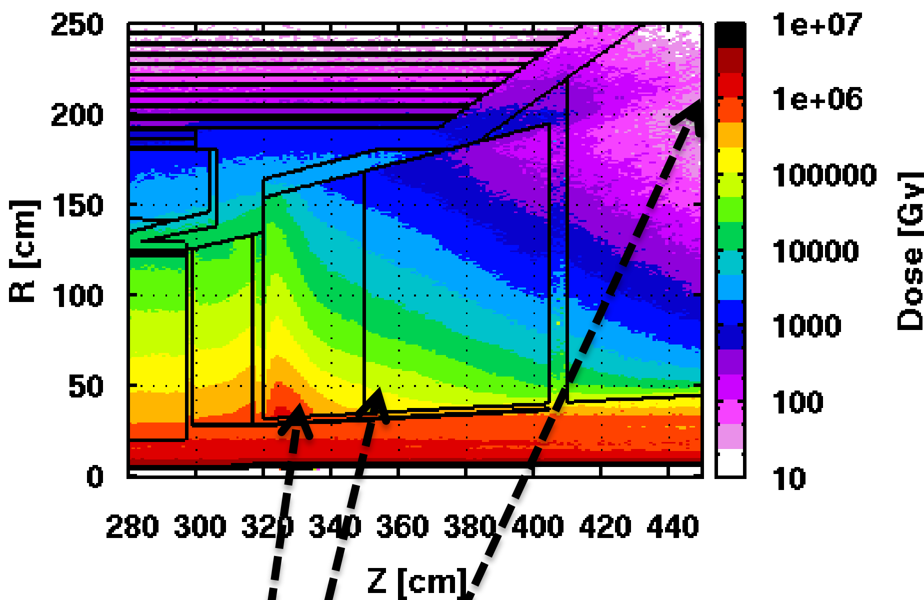
Em and Had sections (total ~ 5λ) followed by a tail catcher

Decision was to de-select CFC

Although none of the concepts is yet mature and has proven to give best performance in the CMS environment: estimated to present more risk to demonstrate performance and feasibility on expected time scale.

Reminder on radiation environment





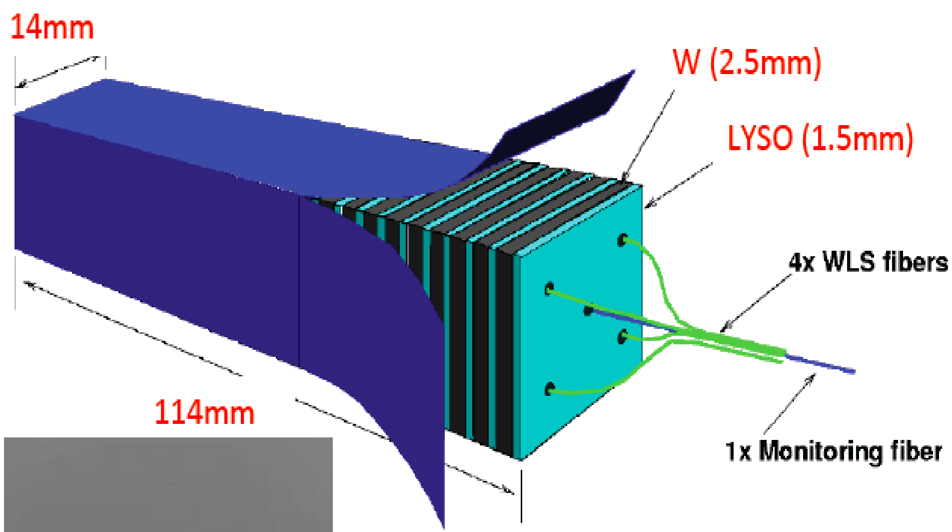
3000 fb^{-1}

Shower max at η=3 : 10^{16} n/cm^2 150 Mrad

Behind em section : 10^{15} n/cm^2 ~10 Mrad

Behind had section : 10^{12} n/cm^2 ~10 krad
(recessed photosensors
+ electronics)

Shashlik Module



Materials:
- Absorber: W
- Active Material: LYSO(Ce) (primary)
- Active material: CeF_3 also under study\

Structure:
- 2.5 mm W plates (28 per module)
- 1.5 mm LYSO(Ce) plates (29 per module)

Module Dimensions:
- Transverse Size: Front Face 14 x 14 mm^2
- Length 114 mm

Readout:
- WLS Capillaries (4 per module)
- Calibration Fiber (1 per module)
- 3x3 mm^2 GaInP Photosensors 4 per module or SiPM in recessed position

Segmentation in depth: Unsegmented except for the proposed extraction of a signal near shower max

Parametric Comparison W/LYSO Shashlik and $PbWO_4$ EE

	W/LYSO(Ce)	$PbWO_4$
Length (mm)	114	220
Transverse size (mm)	14	28.6
# modules for 2 endcaps	61,000	14,648
Average Moliere Radius (mm)	13.7	21
Average Radiation Length Xo (mm)	5.1	8.9
Light Yield (relative to NaI)	85	0.3
Emission Wavelength	420	425
Decay time (ns)	40	25
Light Output (p.e./MeV) depending on QE	8-10	2
Temp Dependence (%/C)	-0.2	-2.2

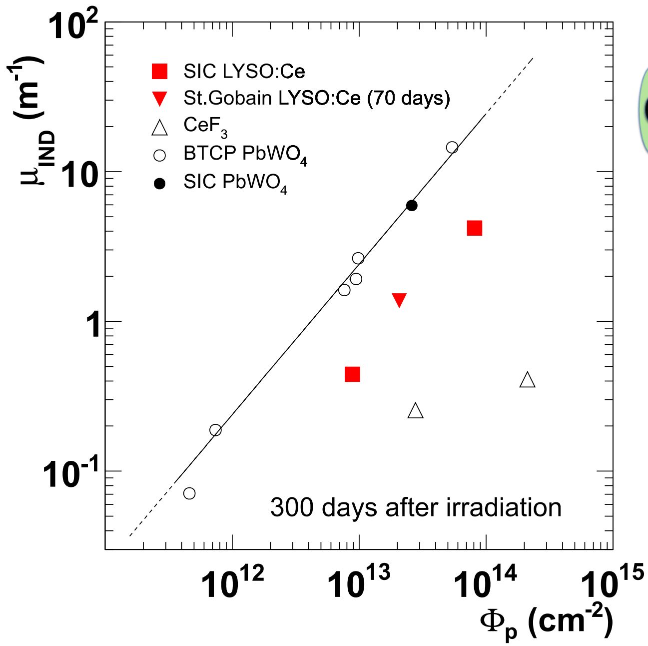
Shashlik Main Challenges

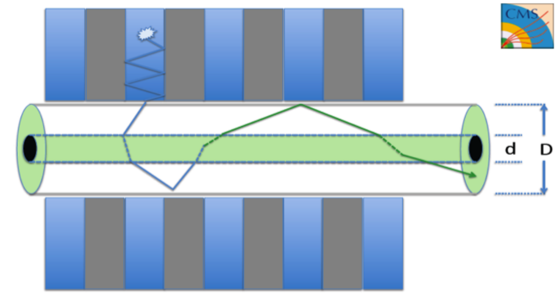
1) Confirm crystal rad. hardness

2) Develop rad-hard WLS capillary

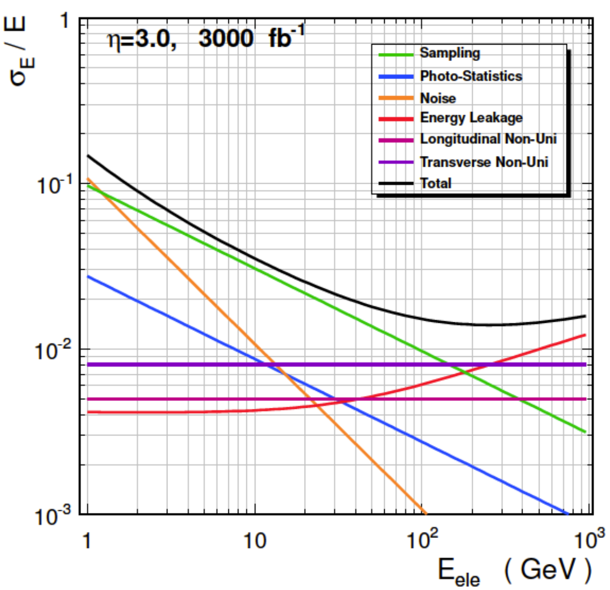
3) GaInP photosensors

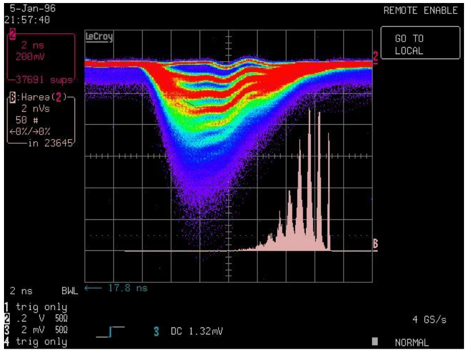
4) Confirm performance in CMS environment (pileup…)





η = 3.0 at 3000 fb^{-1}

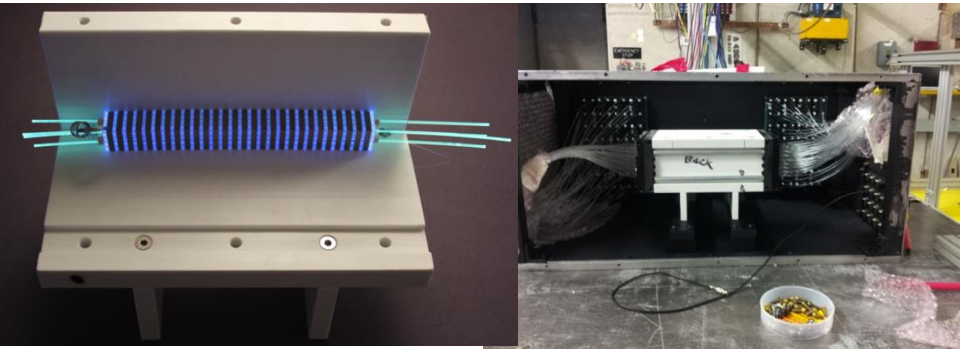




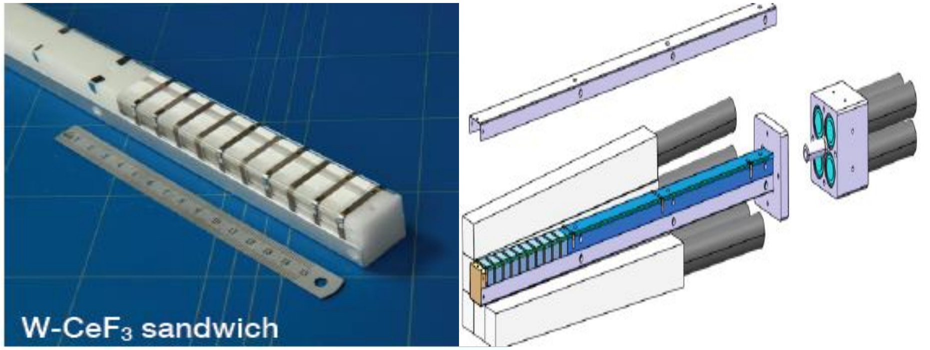
expected e/γ resolution ~ 10%/√E + 1%

EE Shashlik beam tests

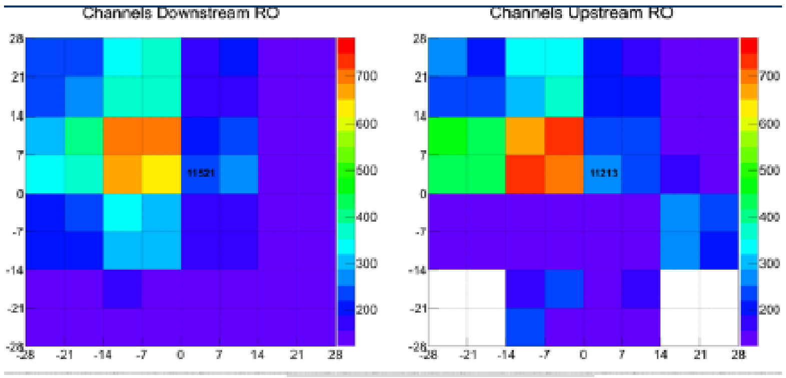
- First test of a 4x4 modules prototype
  - 364 LYSO crystals (final configuration)
  - WLS readout at both ends with SiPMs
  - Laser calibration in central fiber



- First test of a CeF_3 modules
  - 10 x (3.1 mm W + 10 mm CeF_3)
  - Scintillating fibers readout with PMTs



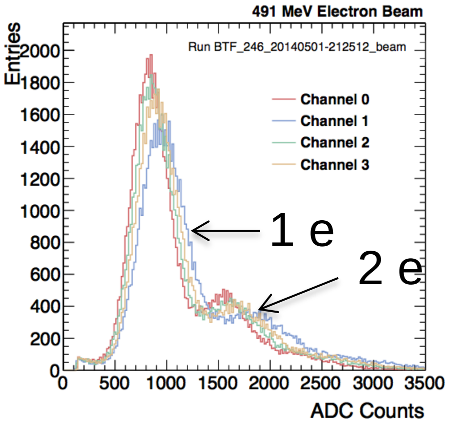
- 120 GeV protons

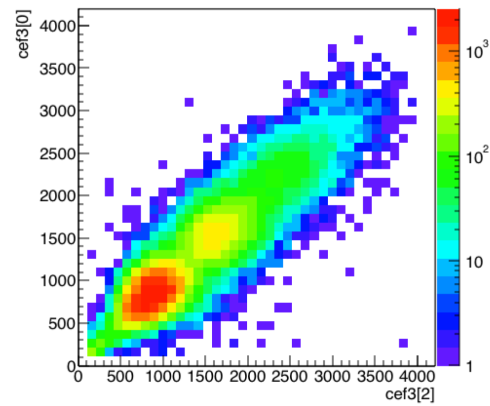


Downstream and upstream signals

- Analysis of data in progress

- 500 MeV electrons





Raw signal (left) and correlation (right)

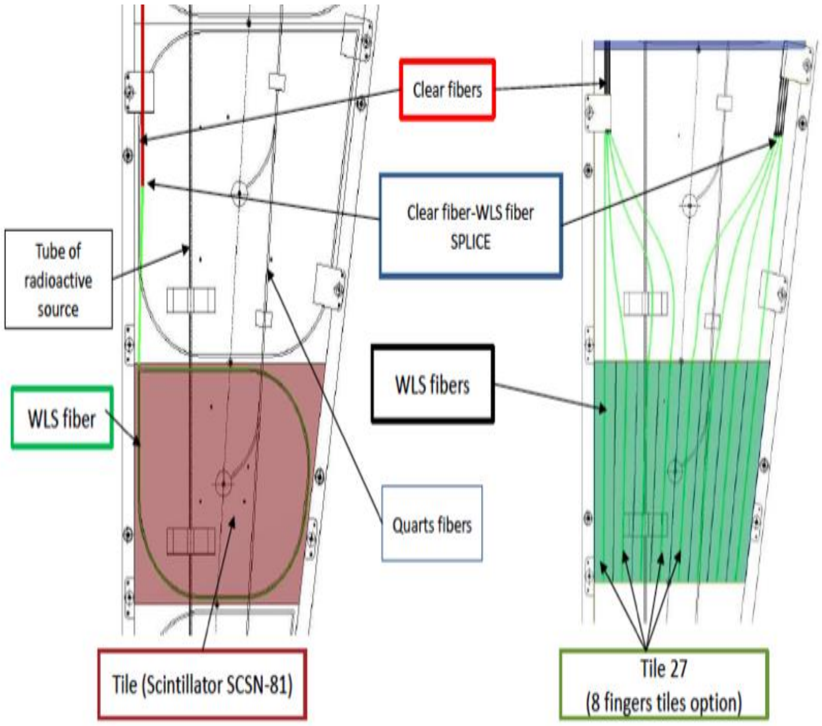
- Analysis of data in progress

HE re-build

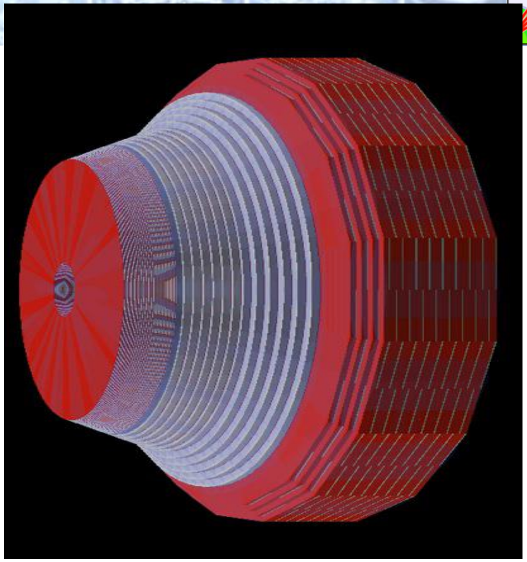
- Higher granularity in (η/φ) x 2 & longitudinal & extension towards EE Shashlik (resolution)
- Scintillating tiles in brass with finger WLS to reduce light path (80%)
- Investigating new plastic and liquid scintillators or radiation tolerant scintillating fibers quartz/glass/crystals doped with Ce3 for innermost region

Current

New



High Granularity Calorimeter (HGCAL)



Fine depth segmentation

ECAL: ~33 cm, 25 X_0, 1λ, 31 layers:

11 planes of Si separated by 0.5 X_0 of lead/Cu

10 planes of Si separated by 0.8 X_0 of lead/Cu

10 planes of Si separated by 1.2 X_0 of lead/Cu

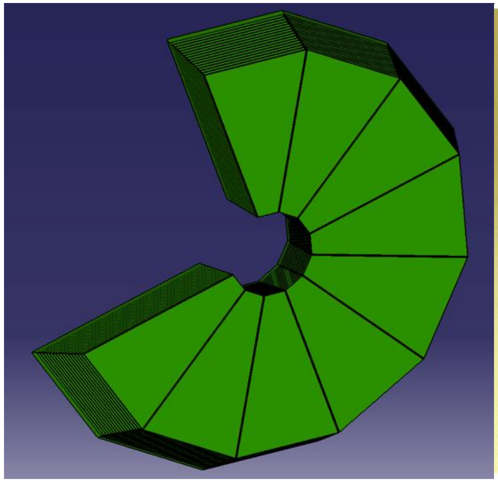
HCAL: ~66 cm, 4λ:

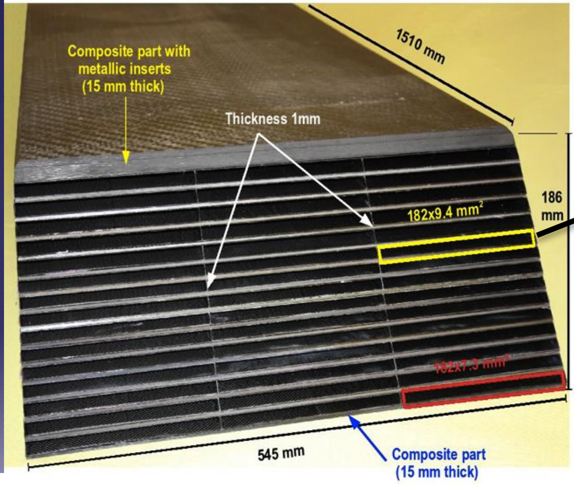
12 planes of Si separated by 40 mm of brass

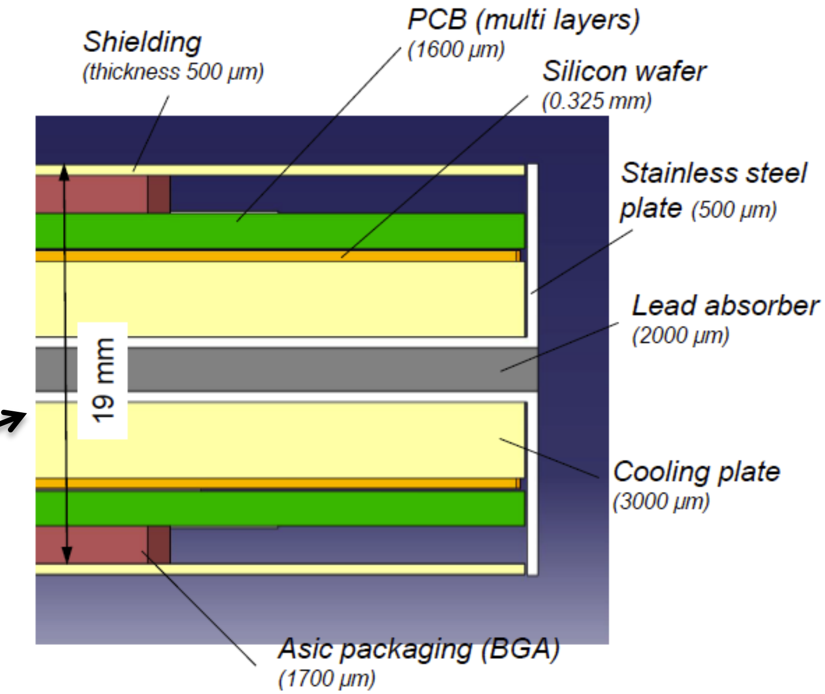
- Fine grain pads 0.9 cm^2 to 1.8 cm^2
- 3.7/1.4 Mch & 420/250 m^2 Si in E/H
- 30000 modules

Back HCAL as HE re-build 5λ

With increased transverse granularity





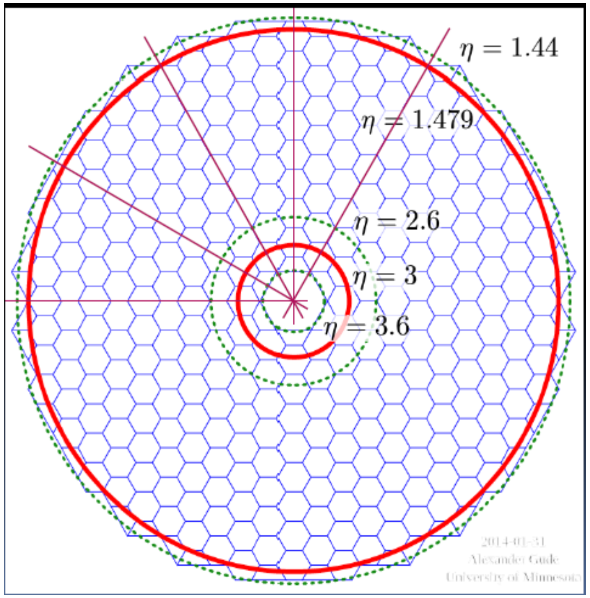


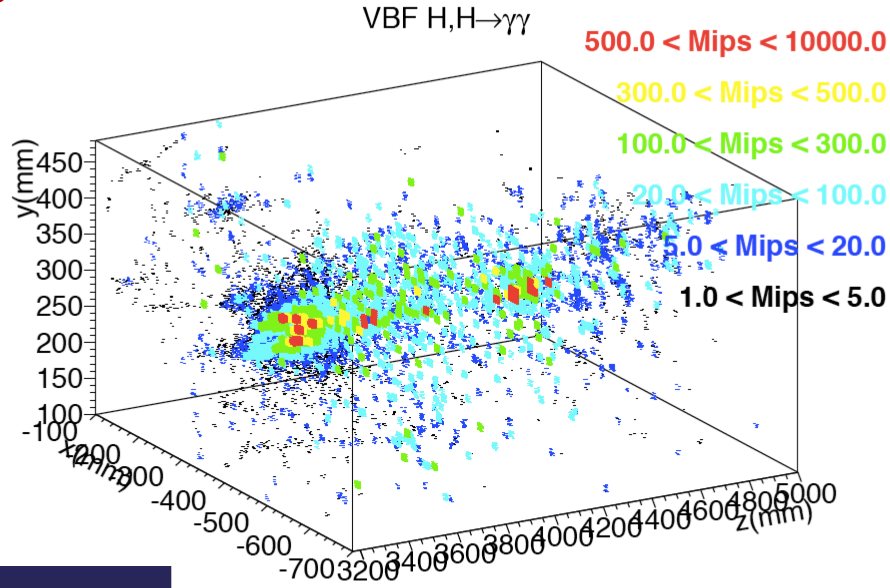
High Granularity Calorimeter (HGCAL)

3D measurement of the shower topology

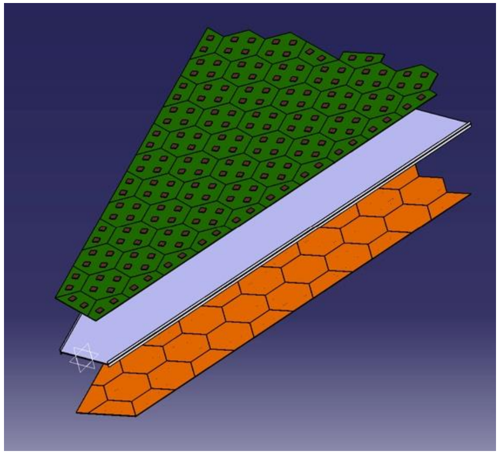
- 25 mm Moliere radius (shower narrower before max)
- Expected e/γ resolution ~ 20%/√E + ≤ 1%

Tiling of 8” hexagonal Si-sensors modules

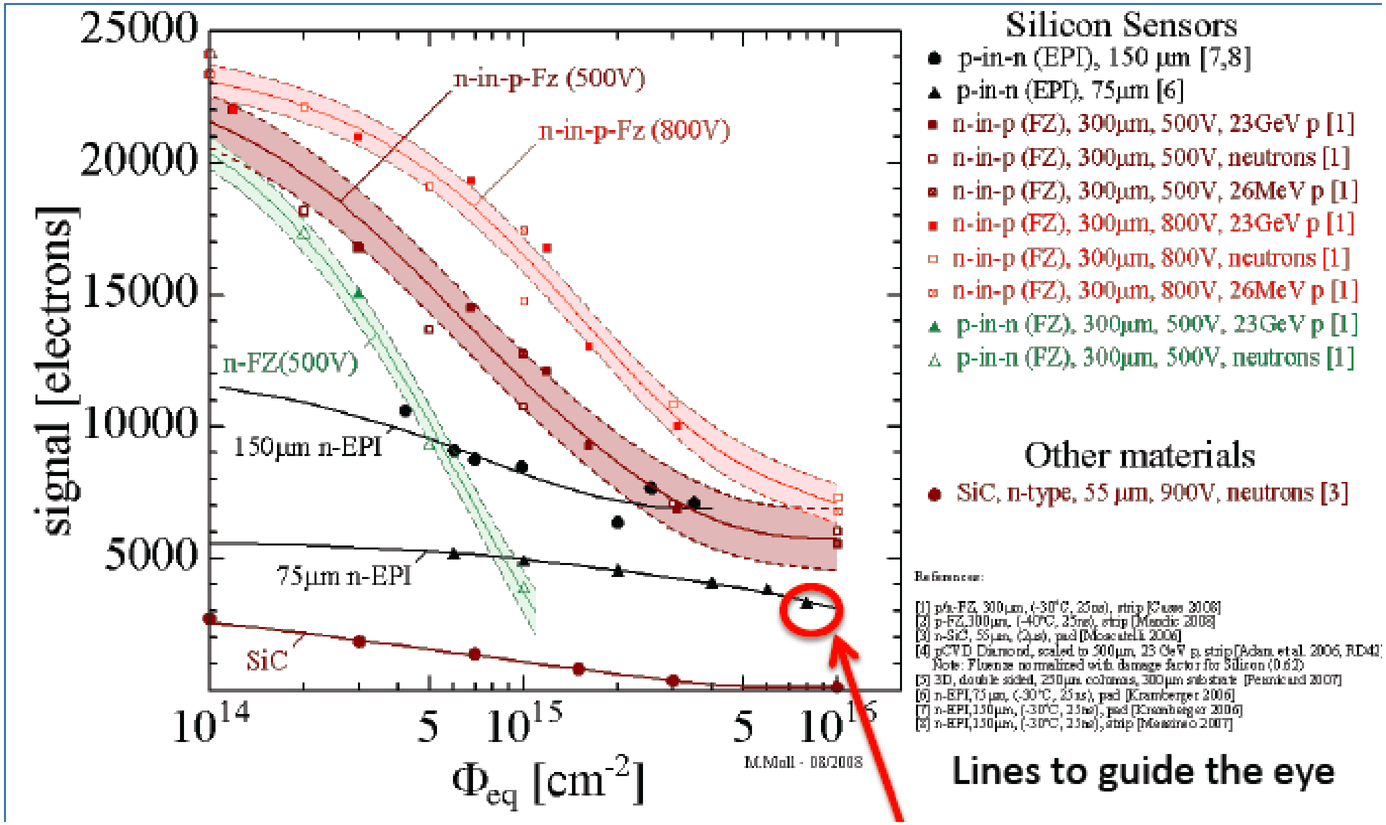




VBF Jet no PU



Challenges for HGCAL



1) **Verify radiation hardness of Silicon sensors. Similar fluence as innermost pixel but:**
   Tracker dominated by charged hadrons -> extend studies to neutrons
   Verify if p-on-n suitable (the less expensive option)
   Prototype partial implant (100µ or 200 µ on 300µ wafer) for high η region

Challenges for HGCAL(2)

2) Engineering studies

module design and thermal properties
keeping longitudinal compactness
thermal screen and exit of services through cold/warm transition

3) **Readout and Trigger definition**

FE electronics characteristics

dynamic range
optimisation in noise/power/peaking-time

Energy threshold vs occupancy & mip visibility
Powering
Data flow and data concentration
Trigger primitive
…

4**) Demonstrate benefit of high granularity in physics performance**

Conclusions

CMS needs to change its Endcap Calorimeters for the HL-LHC phase
Two concepts are being currently proposed:

Shashlik with HE rebuild
more in the line of the existing CMS
challenges are mostly in establishing the radiation hardness of the proposed components

High Granularity Calorimeter "a la CALICE"
but the LHC environment is very different from ILC:
radiation (-> low T), continuous powering, high rate
challenges are mostly in finding proper engineering solutions

In both cases, performance assessment in the CMS environment is going-on in view of the Technical Proposal.

Decision between the two solutions expected in ~ 1 year.