Options for CMS Upgrade / 1

Workshop on detectors for High Energy Physics and applications

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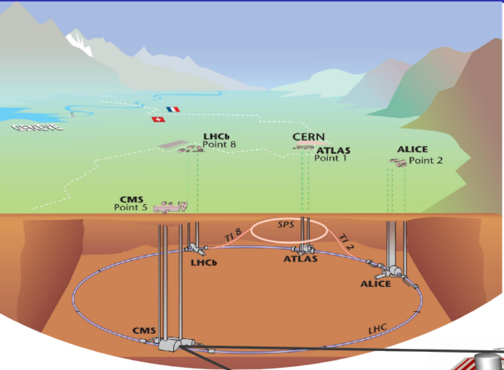
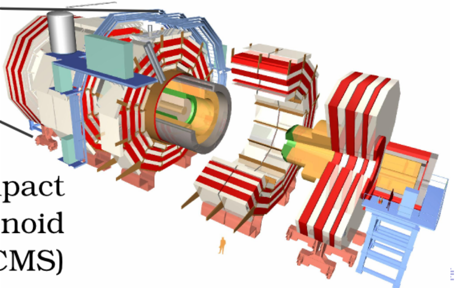
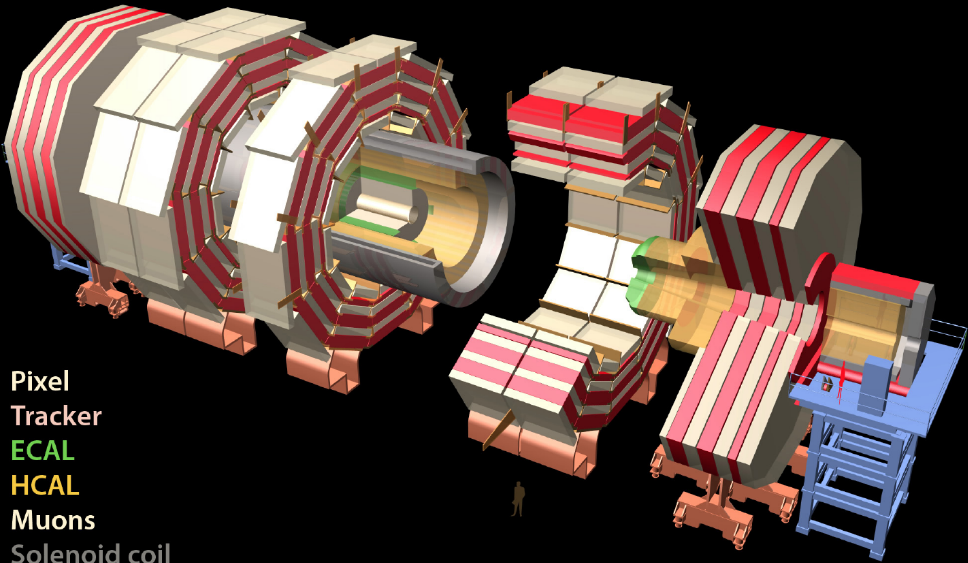


The Large Hadron Collider (LHC)

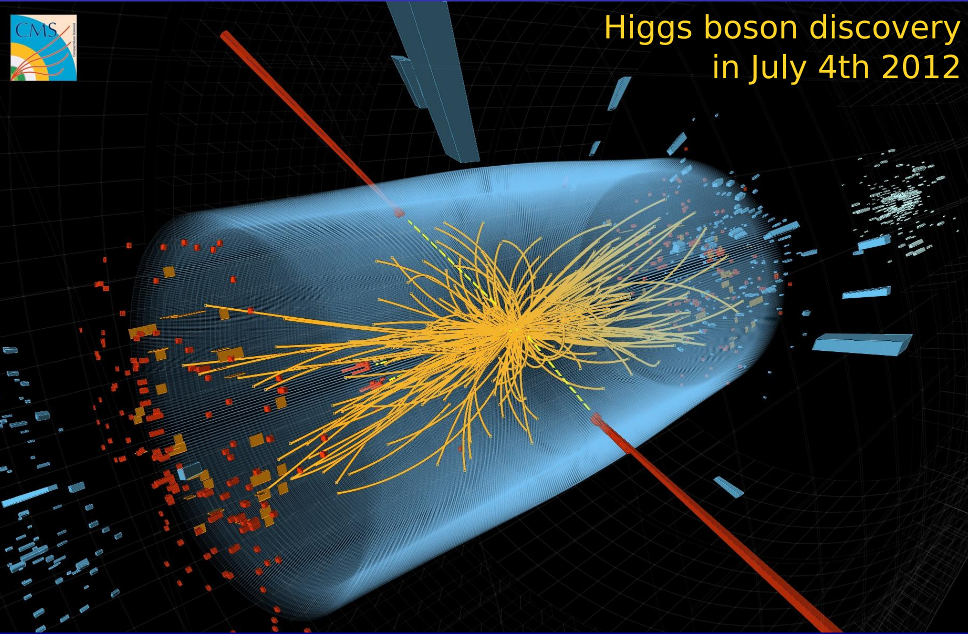


The Compact Muon Solenoid (CMS)

CMS



A CMS collision event

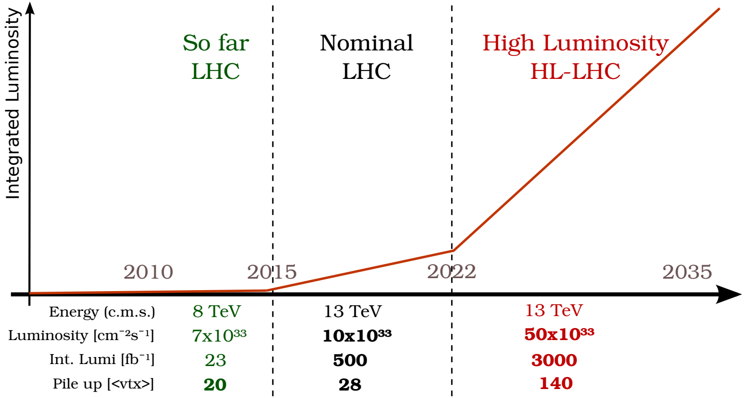


So what?

so far so good, but ...

Future plans for HL-LHC

- LHC is only at the beginning of its operating period
- Many years ahead
  to search for new physics beyond the Standard Model



The issues

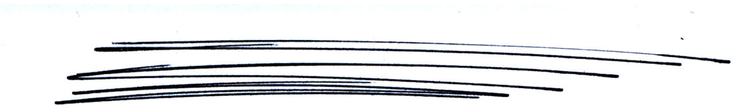
1.
The current calorimeters will not be able to operate in future LHC conditions.

Too harsh radiation environment
Extremely high collision rate

2.
Need to develop faster and more radiation hard forward calorimeters

New technologies and R&D are required
Ideas exist and are being tested

Starting from scratch



How does a calorimeter work?

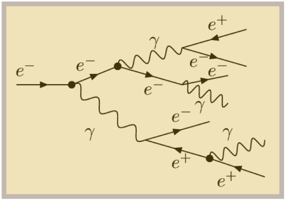
Calorimeter:

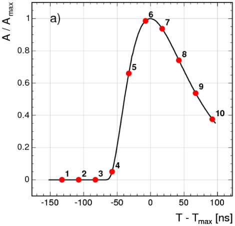
a device which measure the energy of particles by entirely stopping them

1.incident particle

2.shower inside the calorimeter

3.signal generation and detection (e.g. light, charge, heat, ...)

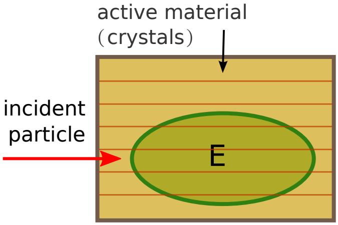




Initial Energy		Deposited Energy		Generated Signal
E_0	$\propto$	E_{dep}	$\propto$	S

The choice of CMS Calorimeters

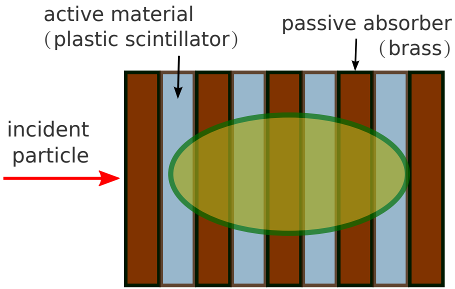
Homogeneous Electromagnetic Calorimeter



- good for e, γ
- smaller volume
- measures E
- optimal resolution

>11 m³
~70000 crystals

Sampling Hadronic Calorimeter

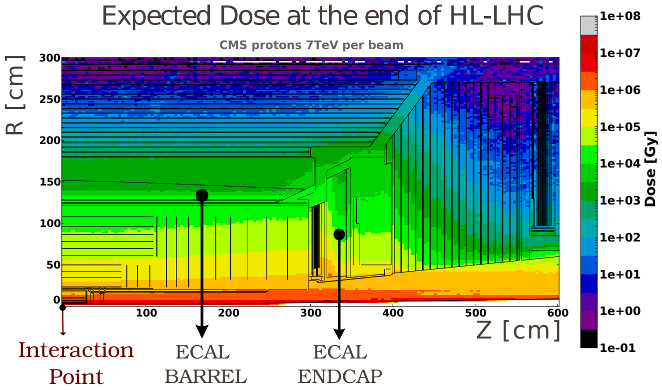


- designed for hadrons (p,n)
- larger volume
- measures a fraction of E
- cheaper technology

>100 m³
~100000 tiles

Radiation Environment

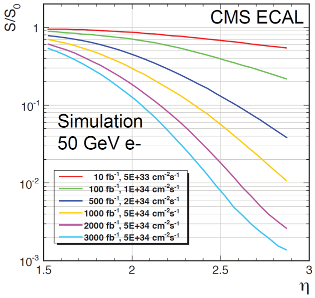
Radiation type	Radiation level design ($\eta = 2.6$)	Radiation level HL-LHC ($\eta = 2.6$)
Ionizing dose rate (e, γ)	6 Gy/h	30 Gy/h
Ionizing total dose (e, γ)	60 kGy	500 kGy
Charged hadrons (p, $\pi^{\pm}$, ...)	3×10^{13}	2×10^{14}
Neutrons (n)	$\approx 10^{15}$	$\approx 10^{16}$



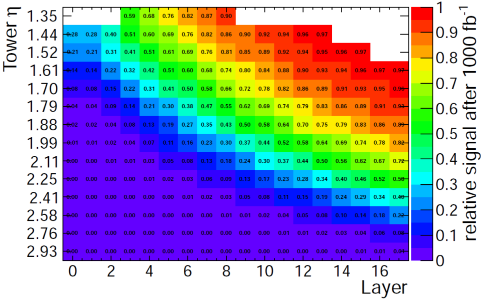
Calorimeters degradation

- The optical components will become black: loss of light!
- Especially in the forward region the signal loss will become crucial!
- Need to replace endcap calorimeters!

ECAL crystals darkening



HCAL plastic+WLS tiles darkening

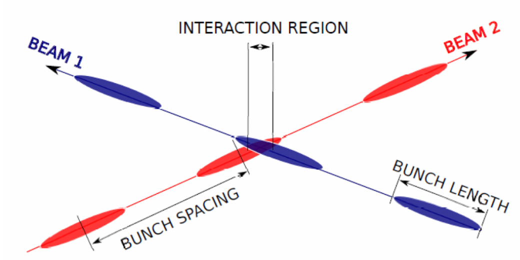


This is a first big problem ...

what else?

High collision rate and Pile up

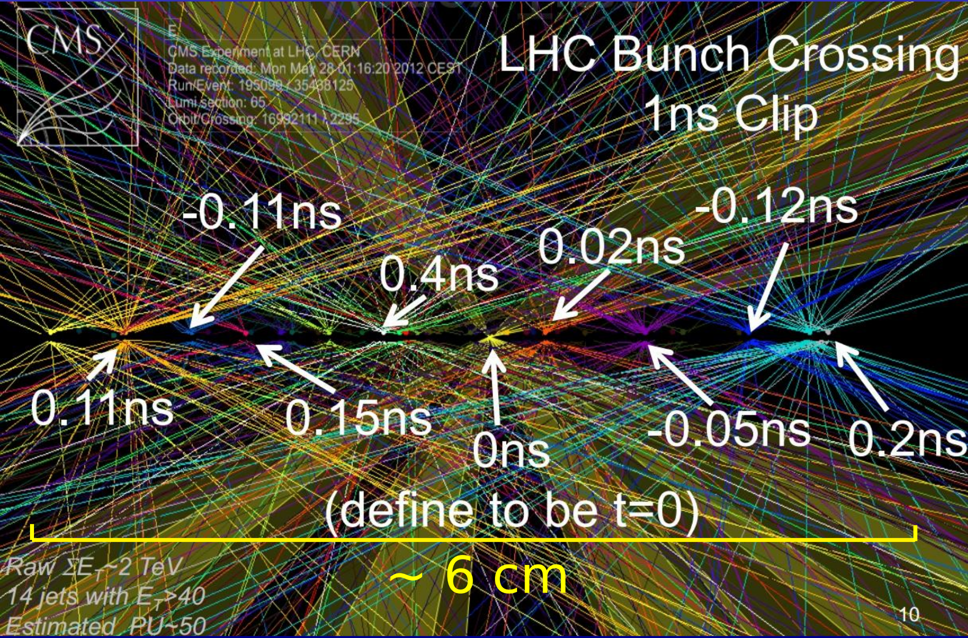
- Bunch spacing: decreasing **from 50 ns to 25 ns**
- Instantaneous Luminosity: increasing **from** 7×10^{33} **to** 50×10^{33}
- Inelastic interactions per collision (pile up): **from 20 to 140**.



HL-LHC parameters:

- Bunch spacing: 25 ns
- Bunch length: ≈ 8 cm
- Interaction region: ≈ 6 cm

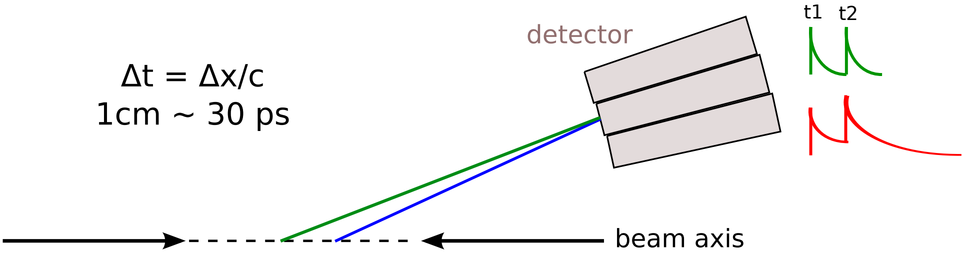
Zoom into the Interaction Region



Mitigating pile up using Time Of Flight

Assuming good time resolution of the detector, TOF can help in:

- **Photon vertexing ($H \rightarrow \gamma\gamma$)**: Use timing to measure primary vertex or assign photon to selection of vertices
- **Object cleaning**: Remove energy deposits from pile up from physics objects
- **Forward jets (VBF, $\eta \sim 3.5$, low p_T)**: Use timing to determine if jet originates from the primary vertex of hard interaction



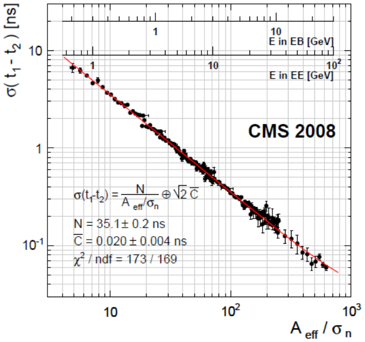
Although it was not optimized for,
current ECAL has already a fair time resolution.

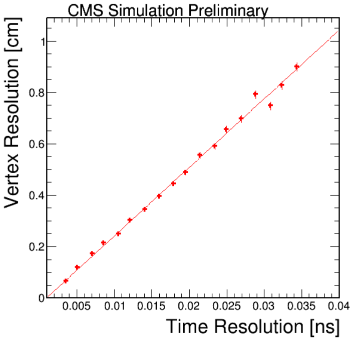
Current detector:

- Time resolution about $\sigma_t = 150$ ps

CMS is aiming to:

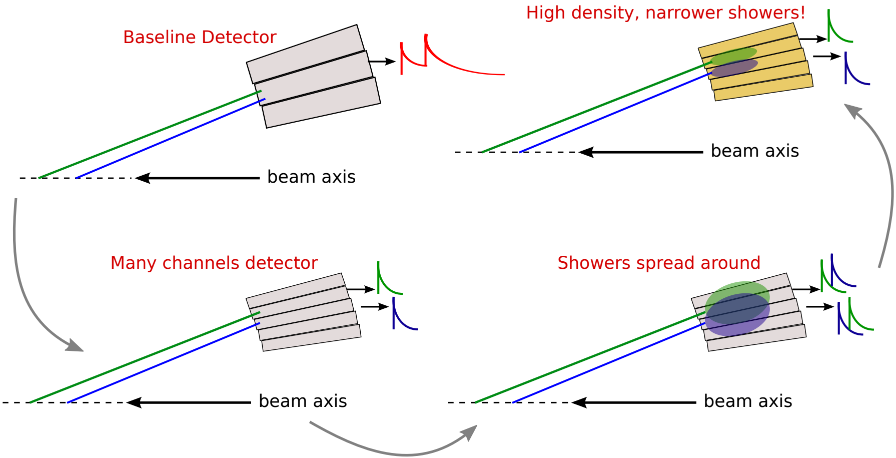
- improve timing to $\sigma_t \lesssim 30$ ps





What is granularity?

Something which would help to mitigate pileup [in addition to timing].



Many challenges for future calorimeters at LHC...

Several solutions are being investigated for
the CMS Upgrade around 2023

A choice of compromises

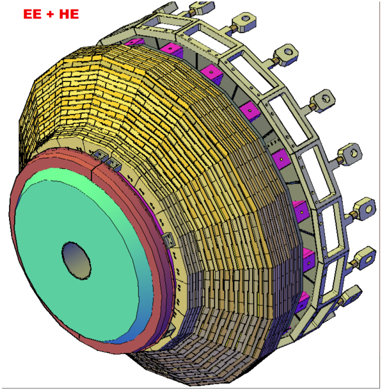
The calorimeter endcaps are **big** and **complicated** objects ...

We would like

1. a radiation hard device
2. with fast timing
3. and high granularity

But we have to deal with

1. practical mechanical constraints
2. limited time
3. and limited funds available



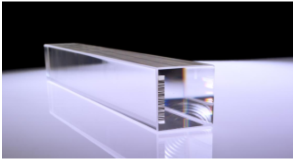
A simple option is
to replace ECAL and HCAL separately.

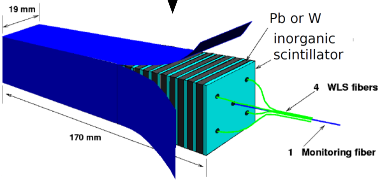
Option 1: Scintillators Based Calorimeters

1. Re-design a more radiation hard scintillating ECAL

NOW

ECAL PbWO crystals



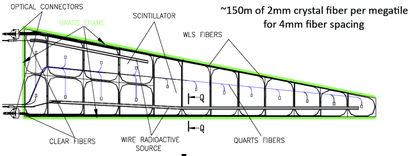


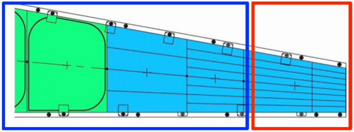
UPGRADE

Shashlik-like cells

2. Replace HE plastic scintillator

HCAL Plastic Scintillator + Plastic Wavelength Shifting Fibers





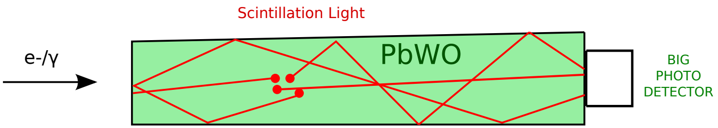
New radhard scintillator

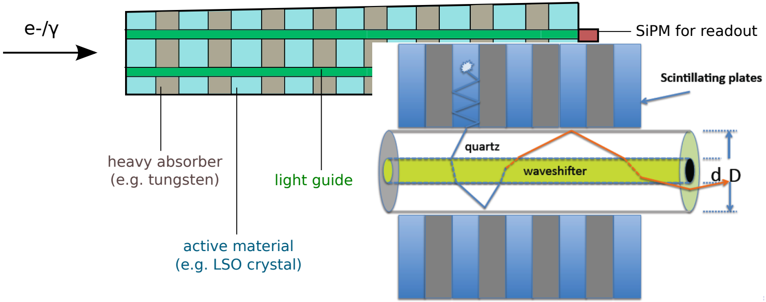
Liquid?
Quartz?
Crystals?

A "Shashlik" Calorimeter

The Shashlik idea ...

Basic principle: light has a short path inside the active material, it is captured and transported through the radhard quartz capillary.

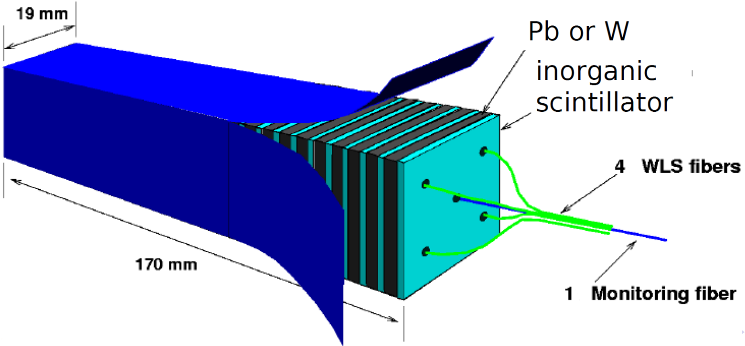




The Shashlik components

- Very dense: Tungsten + LYSO
- Quartz capillary and liquid wavelength shifter
- SiPM / GaInP photodetectors

	W/LYSO(Ce)	$PbWO_4$
Length (mm)	114	220
Transverse size (mm)	14	28.6
# modules for 2 endcaps	60800	14648
Average Moliere Radius (mm)	13.7	21
Average Radiation Length X_0 (mm)	5.1	8.9
Crystal Light Yield (relative to NaI = 100)	85	0.3
Emission Wavelength	420	425
Decay time (ns)	40	25
Light Output (p.e./MeV)	8-10	2
Temp Dependence (%/C)	-0.2	-2.2



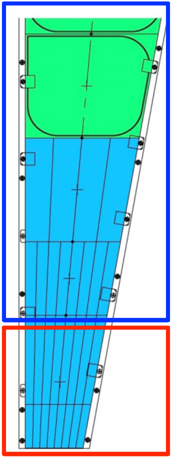
New Scintillators for the Hadronic Calorimeter

The HE Rebuild strategy

Two regions depending on the radiation levels:

- **Low radiation region [90% total volume]:** use radiation tolerant plastic scintillator.
- **High radiation region [10% total volume]:** use alternative technology.

Dose at 3000 fb^{-1}	Area of scintillator above Dose threshold
0 Mrad	600 m^2 (total area)
1 Mrad	64 m^2
2 Mrad	40 m^2
5 Mrad	14 m^2
10 Mrad	6 m^2



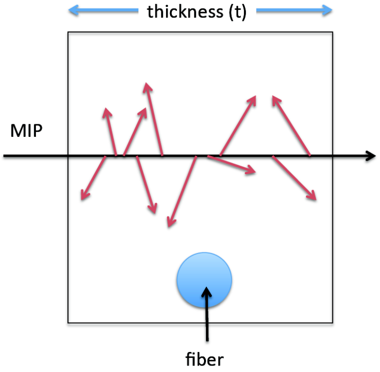
Both transverse and longitudinal granularity will be increased!

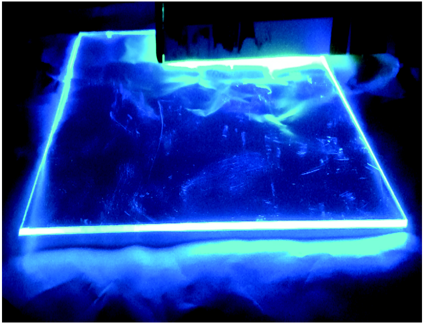
New Plastic PEN tile

Using new type of plastic scintillators
(such as PEN: Polyethilene Naphtalate)

Cheap,
Good candidate to instrument
low radiation regions

To improve:
light yield,
time response,
radiation tolerance



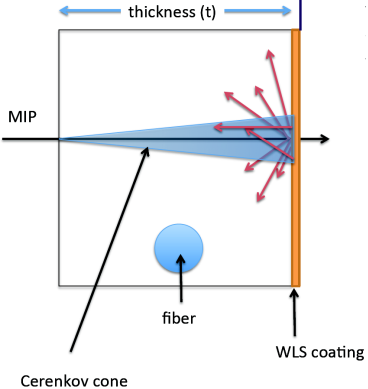


Quartz tile

Quartz plates painted with a rad-hard WLS dye (such as Zinc Oxide)

Y11 wavelength shifting fibers to readout

Cerenkov light is wavelength shifted to enhance collection efficiency

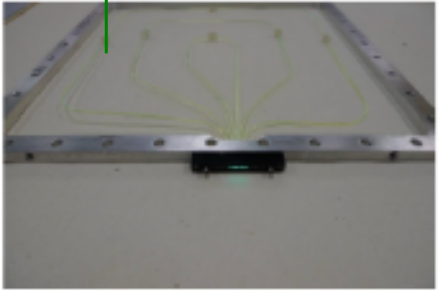


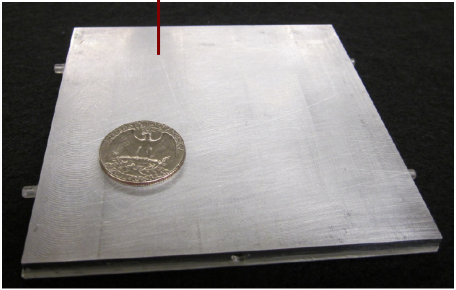
Liquid Scintillator

Using Eljen EJ-309
liquid scintillator → Cheap
Bright
Radiation tolerant

Y11 plastic WLS fibers
to collect scintillation light

Need to engineer a
leak-tight container for the liquid





Crystal Fibers

Replace plastic with crystal fibers which are more radiation hard!

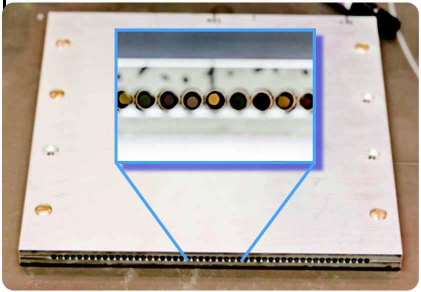
Grown via micro-pulling-down technique

$Lu_3Al_5O_{12}$
ρ = 6.73 g/cm^3
X_0 = 1.41 cm
λ_I = 23.3 cm

Undoped:
Cherenkov radiatior
Cerium-doped:
Good scintillator

Arranged into layers to match the HE tiles geometry

Good radiation hardness!



This is an option

but a completely different
and innovative approach exists...