R&D studies for the EIC Electromagnetic Calorimetry

Pilleux Noémie - IJCLab, Paris-Saclay University, France

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Supervisors : Carlos Munoz Camacho and Silvia Niccolai

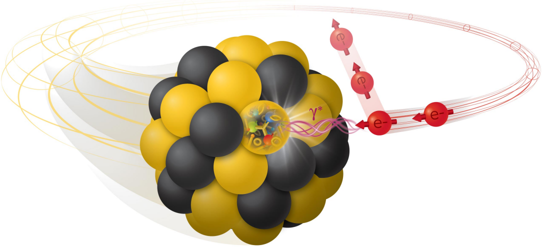
Context and motivations

Goal : build a prototype for the Electron-Endcap Electromagnetic Calorimeter (EEEMCal)

Nearly all process at the EIC require detection of the scattered e^-

ECAL physics goals :

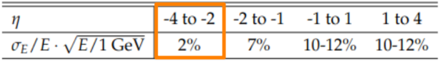
- momentum and energy reconstruction
- particle ID
- separation of e^- from hadrons
- detection of neutral particles
- separation of 2 γ in π_0 decay ...



Requirements for the EIC ECAL

From the yellow report :

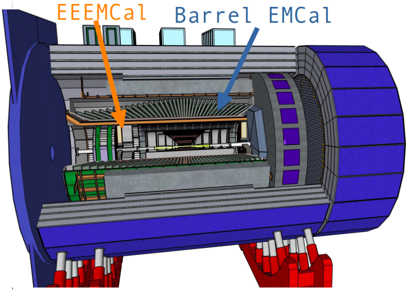
- Excellent energy resolution : large signals



η	-4 to -2	-2 to -1	-1 to 1	1 to 4
$\sigma_E/E \cdot \sqrt{E/1\,\text{GeV}}$	2%	7%	10-12%	10-12%

- Limited space : need a compact detector
- Radiation hardness : 30 $Gy/year$
- Intense magnetic field
- Large dynamic range : $\sim$10 MeV to $\sim$10 GeV

EEEMCal in the backward region : high precision for e^- kinematics measurement

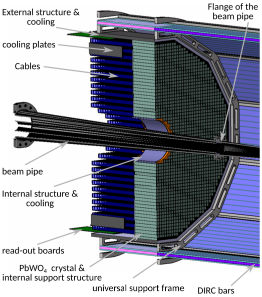


Barrel EMCal : clean e^- identification

Electromagnetic calorimetry at the EIC

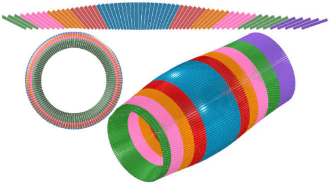
EEEMCal

- original plan : inner core of scintillating $PbWO_4$ crystals, outer layer of scintillating glass
- The detector design has changed, it will be smaller : only PWO
- Readout by SiPMs



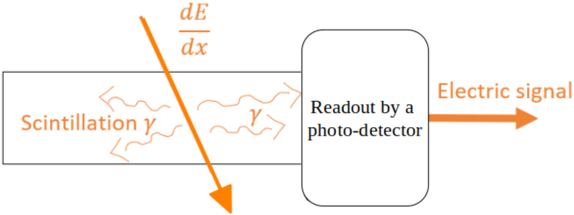
Barrel EMCal

- could be made of scintillating glass bars readout by SiPMs



I will focus on the hardware side of this project. See Pu-Kai Wang's work for the simulations !

General principle



Need to optimize the scintillating material :

- Energy resolution : high **light yield** + high **transmittance** to collect γ.
- Limited space : **short radiation length** X_0
- Need a **radiation-hard** material
- + several other considerations, notably **cost and availability** !

Need to optimize the readout + electronics :

- Intense magnetic fields
- SiPMs are compact detectors
- Need to collect light on the surface of the crystal : **matrix of SiPMs**
- Large dynamic range : **high pixel density**

Scintillating material

Possible scintillating materials

Best candidate to meet the requirements: $PbWO_4$ crystals.

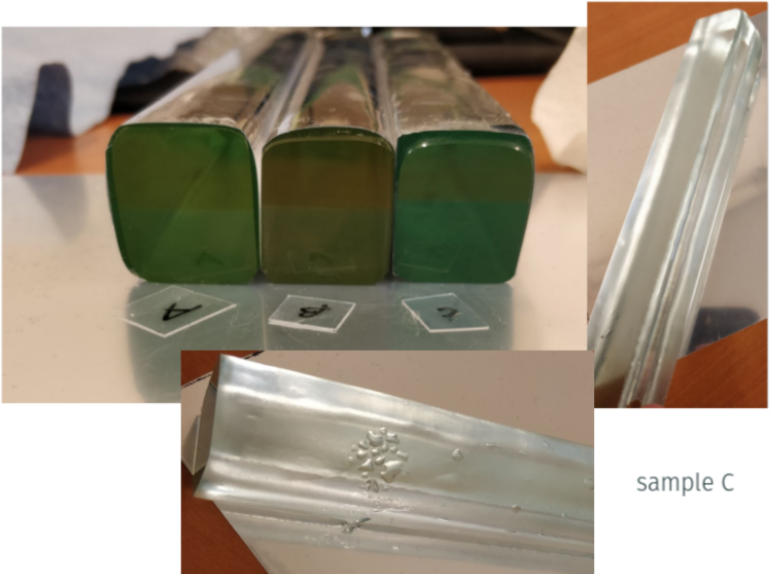
- $X_0 = 89mm$
- Can detect energies as low as 20 MeV photons
- tested to be radiation hard

Alternative : SciGlass, a new cheaper material developed by Scintilex and the Vitreous State Laboratory at CUA.

- Cost effective
- $X_0 = 2.2 - 2.8cm$
- My work was to test SciGlass light yield, transmittance and radiation hardness

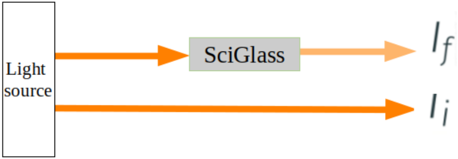
The SciGlass samples

20cm × 2.5cm × 2cm

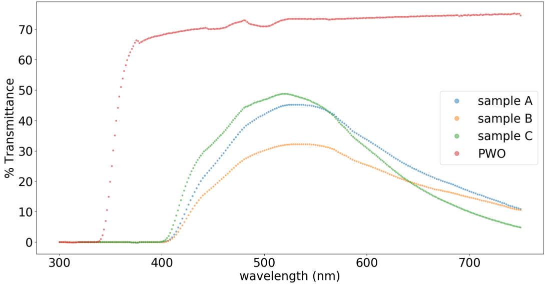


sample C

Transmittance

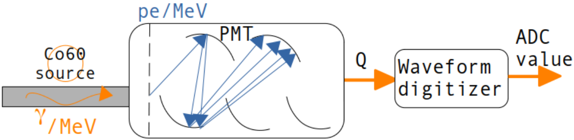


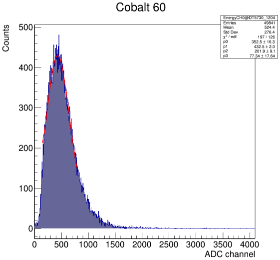
$$T = \frac{I_f}{I_i}$$

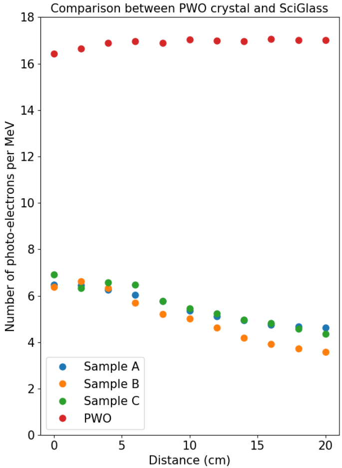


Scintillation light for SciGlass peaks at $\simeq 450nm$

Light Yield measurement



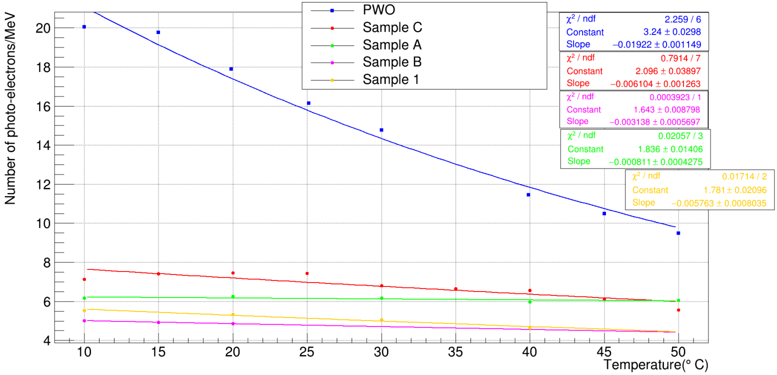




More tests with improved SciGlass samples + simulations will help determine if the LY could be sufficient for the barrel.

Temperature dependence of the LY

The setup was moved inside an environmental chamber, where the temperature can be fixed.

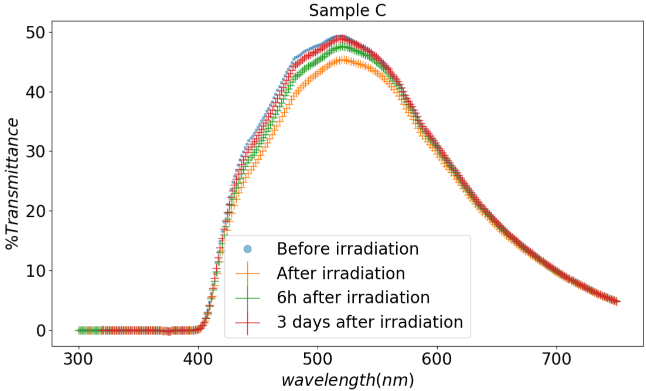


These results include the PMT gain change with temperature.

→ Small dependence of SciGlass' LY on temperature !

Radiation hardness tests

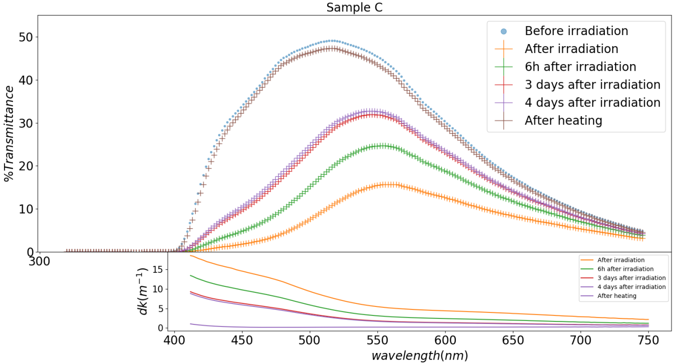
Samples were exposed to a dose of 30Gy (1 year at the EIC) at a rate of 1 Gy/min.



Losses for 1 year are recovered in a few hours + dose rate will be a lot lower at the EIC.

High irradiation

We exposed the samples to a dose of 180 Gy at a rate of 12 Gy/min.



After a few hours, the sample do not recover their original transmittance.

After a high temperature treatment (> 6h at 250°C), no full recovery.

In summary

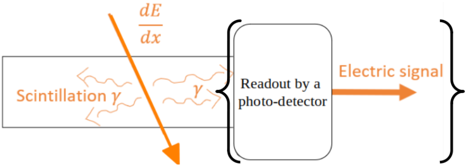
SciGlass was tested and compared to $PbW0_4$ performances

- On-going work to produce more uniform samples
- Transmittance is lower than PWO
- Light yield is $\sim$ 2.5 times lower than PWO
- Depends less on temperature than PWO
- Can resist radiation damages at the EIC

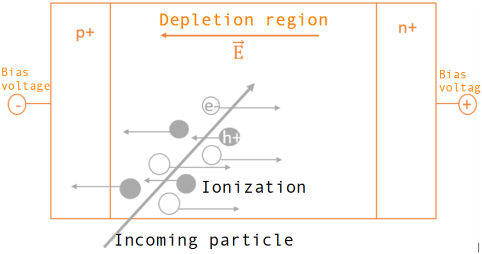
Simulations show that SciGlass performances make it a good candidate for the barrel EMCal, with a sufficient energy resolution.

Next steps : $40cm$ samples (first sample produced late 2021).

SiPM readout



SiPMs, basic principle



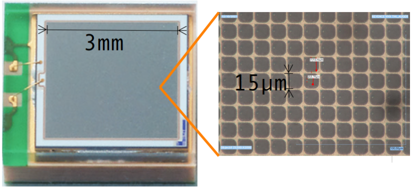
Avalanche photodiode (APD)
increasing $V_{bias} \rightarrow e^- / h^+$ have sufficient energy to ionize atoms
→ avalanche phenomenon
→ higher signal level

GAPD (Geiger mode)
increasing $V_{bias} \rightarrow e^- / h^+$ multiply faster than they can be extracted
→ digital photodetector

SiPM
a matrix of GAPDs !

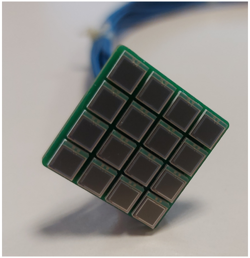
analog detector : all pixels are read in parallel

signal $\propto$ number of fired pixels

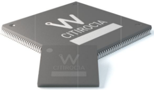


Meeting the requirements

- SiPMs are insensitive to high magnetic fields
- They are compact
- To collect as much signal as possible, need matrices of SiPMs :
  - The crystal surface is $2 \times 2cm^2$
  - Each SiPM is $3 \times 3mm^2$
- Large dynamic range required → need a high number of pixels
  2 models of Hamamatsu SiPM
  - 15 μm pixels (39984 pixels)
  - 10 μm pixels (89984 pixels)



+ operation and readout of the SiPM with dedicated electronics



Some first measurements

With a LED light in front of SiPMs

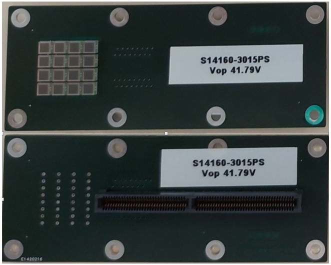
- Detected signals proportional to the intensity of the input light

Low level signals could not be detected

- No possible measurements with PWO crystals and radioactive sources. Our setup is too noisy !

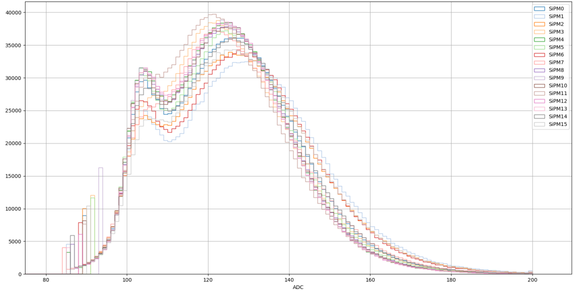
New solution ? Waiting for tests !

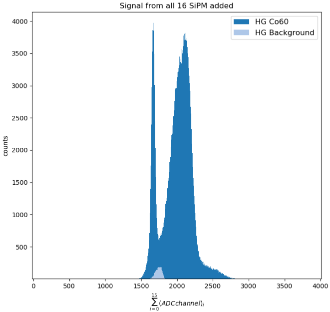
- Extensive testing with several pre-amplifiers and readout systems (thanks to Thi Nguyen Trung)
- The problem most likely comes from cable readout of the SiPMs



Measurements with a CSI crystal and radioactive sources

- Testing higher level signals
- CSI crystals (10 times higher LY than PWO) + Co60 source





- Response from each of the 16 SiPMs
- Adjusting their individual V_{bias} to align the energy peaks provides a way to calibrate their gain

- Adding the signal from all 16 SiPMs allow better separation of the signal peak.

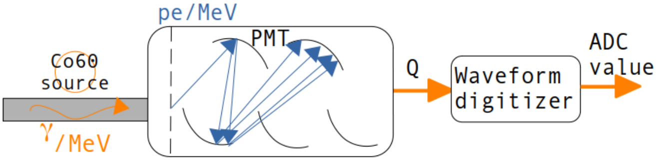
Next steps

Goal : build a 2×2 prototype with PWO crystals, each readout by 16 SiPM + dedicated electronics.

- Tests with PWO crystals and radioactive sources.
- Comparison between 10 and 15 μm pixels.
- Test for stability with temperature, radiation damage ?
- Tests to readout the 4 crystals with 64 SiPM

Questions?

Light Yield measurement



Charge

$$Q = \frac{\text{ADC value * charge per ADC}}{e}$$

Number of photo-electrons/ MeV

$$\frac{p.e}{MeV} = \frac{Q}{\text{PMT gain * mean energy of the radiation source}}$$

PMT gain measured with single p-e spectrum

Number of photons/ MeV

$$\frac{\gamma}{MeV} = \frac{\frac{p.e}{MeV}}{Q.E{*}T{*}\text{fraction of photons getting to the PMT}}$$

- QE=0.25
- fraction of reflected and scattered photons = 0.9
- T = measurement at 450nm

Operating and reading the SiPM

CAEN A5202 readout board, 2 CITIROC chips + power supply to bias the SiPM

Dedicated readout chip : Weeroc's CITIROC 1A, can read 32 SiPMs

- Can be used for photon-counting, charge and time measurements.
- Can be used to adjust the bias voltage of each SiPM to make their gain/output uniform.