R&D studies for the EIC Electromagnetic Calorimetry

Pilleux Noémie - IJCLab, Paris-Saclay University, France

July 23, 2023

Supervisors : Carlos Munoz Camacho and Silvia Niccolai

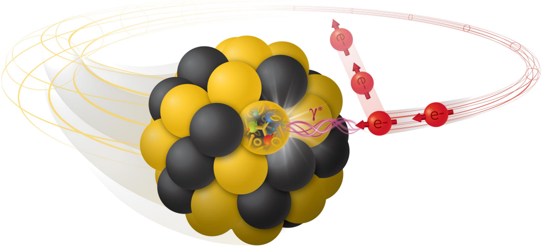
Context and motivations

R&D studies for the Electron-Endcap Electromagnetic Calorimeter (EEMC)

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

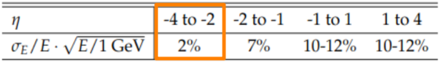
Physics goals set the requirements for the EEMC.

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



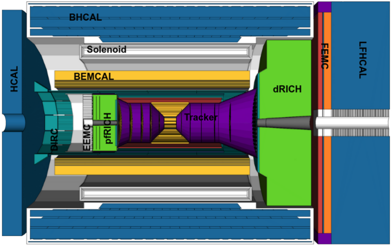
Requirements for the EIC ECAL from the yellow report

- Excellent energy resolution

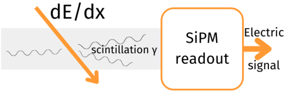


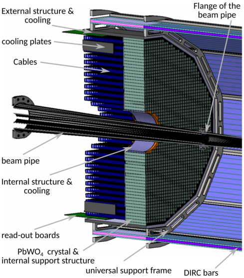
η	-4 to -2	-2 to -1	-1 to 1	1 to 4
$\sigma_E/E \cdot \sqrt{E/1\,\mathrm{GeV}}$	2%	7%	10-12%	10-12%

- Limited space : compact detector
- Radiation hardness : 30 $Gy/year$
- Intense magnetic field
- Large dynamic range : $\sim$50 MeV to $\sim$15 GeV



- $\simeq$ 3000 $PbWO_4$ crystals.
- Readout by SiPMs.
- Thin supporting and cooling structure to limit dead space.

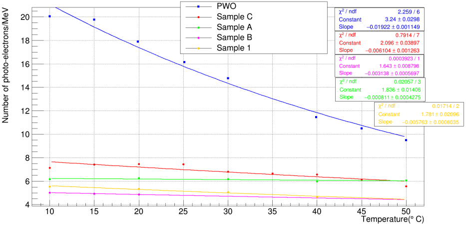


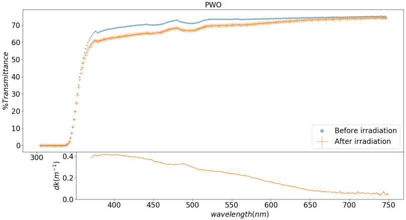


Scintillating material

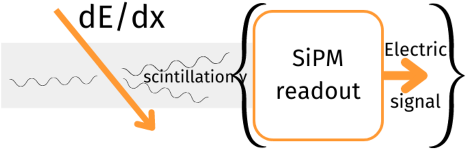
PWO crystals are the best candidates to meet the stringent requirements

- $X_0 = 8.9mm$
- Can detect energies as low as 20 MeV photons
- Tested to be radiation hard

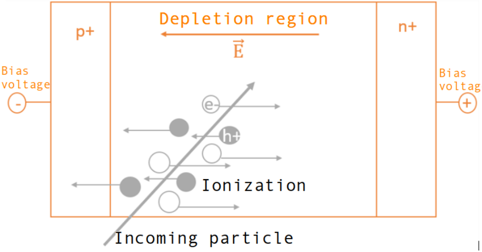




SiPM readout



SiPMs, basic principle

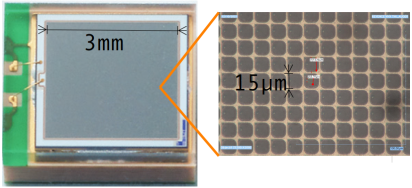


Avalanche photodiode (APD)
increasing $V_{bias} \rightarrow e^-/h^+$ have sufficient energy to ionize atoms
→ avalanche phenomenon
→ higher signal level

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

SiPM
a matrix of GAPDs !

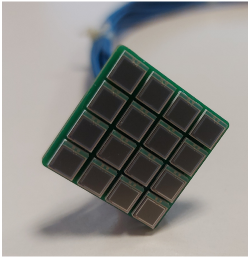
analog detector : all pixels are read in parallel



signal $\propto$ number of fired pixels $\propto$ incident number of γ

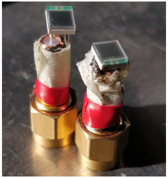
Meeting the requirements

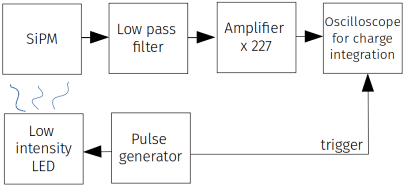
- SiPMs are insensitive to high magnetic fields
- They are compact
- To collect as much signal as possible, need matrices of SiPMs :
  - The crystal surface is $2 \times 2cm^2$
  - Each SiPM is $3 \times 3mm^2$
- Large dynamic range required $\rightarrow$ need a high number of pixels
  2 models of Hamamatsu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



Gain measurement, single photo-electron spectrum

Thanks to Vincent Chaumat (IJCLab), a test bench was set up to start characterization of the SiPMs.





SiPM

Low pass filter

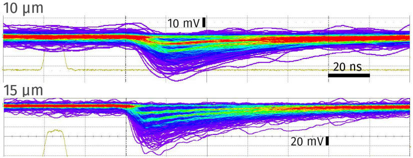
Amplifier x 227

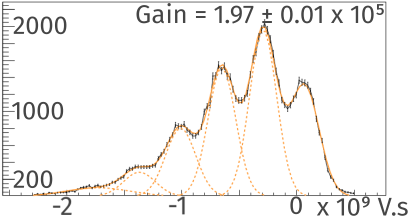
Oscilloscope for charge integration

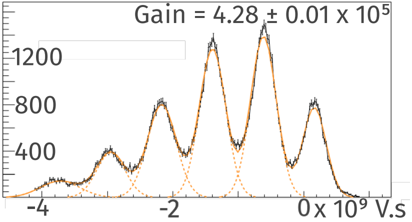
Low intensity LED

Pulse generator

trigger

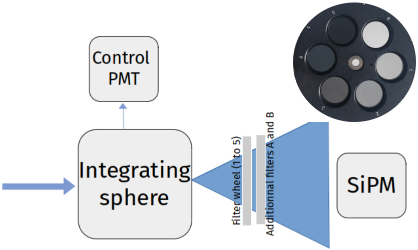






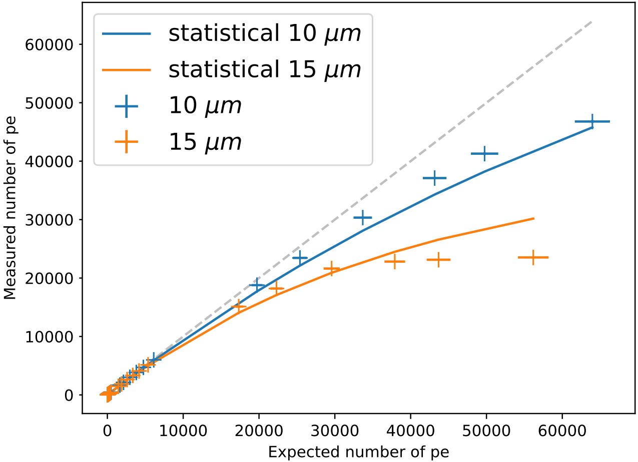
Linearity measurement

- Dynamic range of the SiPMs is crucial.
- Low light levels : output signal $\propto$ incident number of γ.
- Higher light input → more probability to have multiple γ hitting the same pixel and initiating correlated avalanches → saturation.
- We can't reach perfect linearity but we need to be able to precisely correct for non-linearity.



- Calibrated filters (transmittance T).
- Send low number of γ to the SiPM and measure their response
- Use lighter filters, the expected SiPM response is known from the filter calibration.
- Comparing it with the measured response assesses the linearity$=\frac{expected-measured}{expected}$

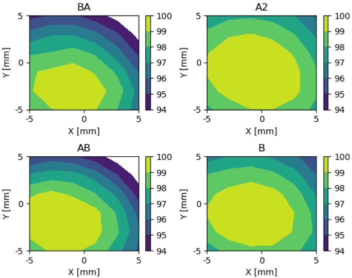
Linearity results



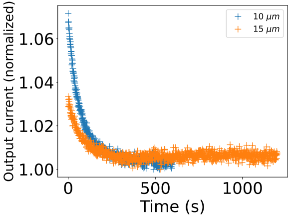
Statistical estimate = $N_{pixel}(1 - exp(-\frac{pe_{linear}}{N_{pixel}}))$

Sources of systematics

Light deviated adding filters, 2% variations.

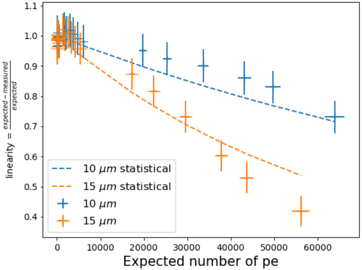


Dark noise variations $< 1\%$.



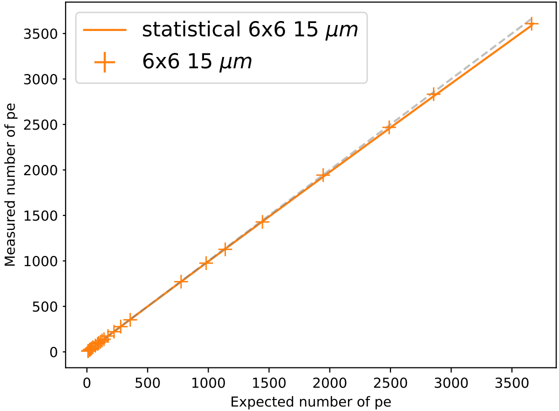
Filter calibration is the main source of systematics.

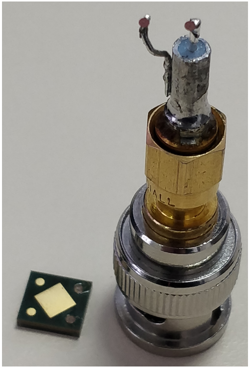
- Frequent handling of filters can get them dirty. For very dense filters this effect becomes very important.
- Use of a photo-diode to calibrate filters, its behaviour at very low current is maybe not entirely linear.
- Repeating low intensity measurements over $\simeq 10$ points indicate that linearity can be known up to 4% with the current setup.



$6 \times 6mm^2$ SiPMs

Hamamatsu recently developed larger SiPMs → reduces the number of channels to be read by a factor 4.





Conclusion and outlook

- Preliminary characterization of SiPMs for the EEMC have been performed.
- They will guide the requirements for developing readout electronics, discussions on-going between several teams at Paris-Saclay.
- Towards a prototype for the EEMC : matrices of SiPMs on the surface of PWO.

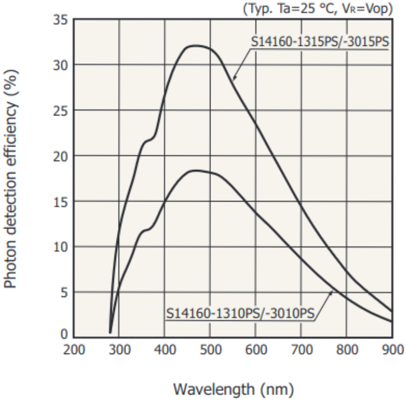
Backup

Hamamatsu S14160-3010/15

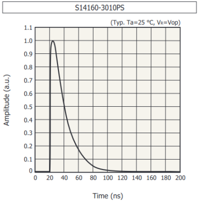
Fill factor 31 % / 49 %

PDE @460nm 18 % / 32 %

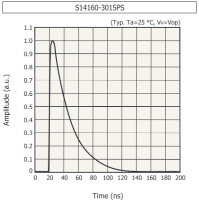
DCR 700 kcps (max 2100 kcps)



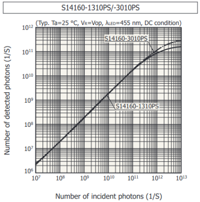
S14160-3010PS



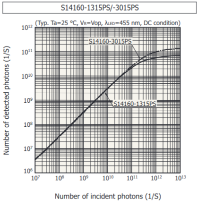
S14160-3015PS



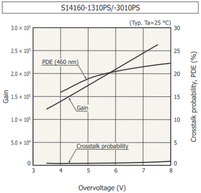
S14160-1310PS/-3010PS



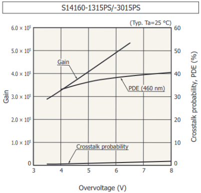
S14160-1315PS/-3015PS



S14160-1310PS/-3010PS

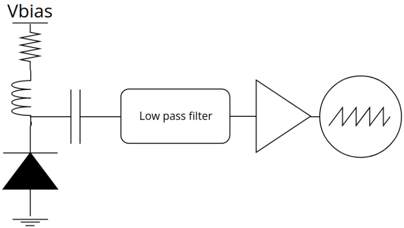


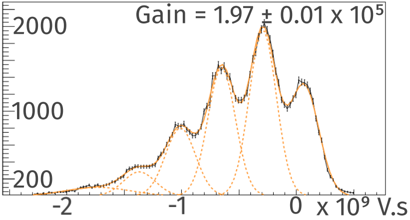
S14160-1315PS/-3015PS



Miscellaneous information about the measurements

Charge measurement setup (gain)





$$Q_{1pe} = \frac{\Delta(1pe-\text{pedestal})}{R_{oscillo}}$$

$$\text{gain} = \frac{Q_{1pe}}{g_{ampli} \times q_e}$$

Current measurement setup (linearity)

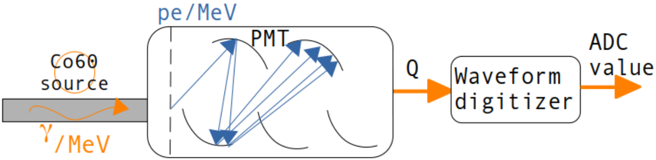
SiPMs powered and read directly with a sourcemeter.

$$\text{number of pe} = \frac{I}{\text{LED frequency} \times \text{gain} \times q_e}$$

pixel size (μm)	LY per SiPM	Number of pe at 50 MeV	Number of pe at 15 GeV
10	0.3	15	4500
15	0.4	20	6000

Filter combination allow to cover a dynamic range $\simeq$ 5000

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