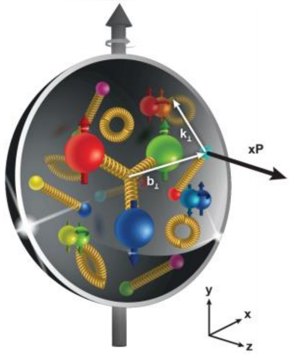
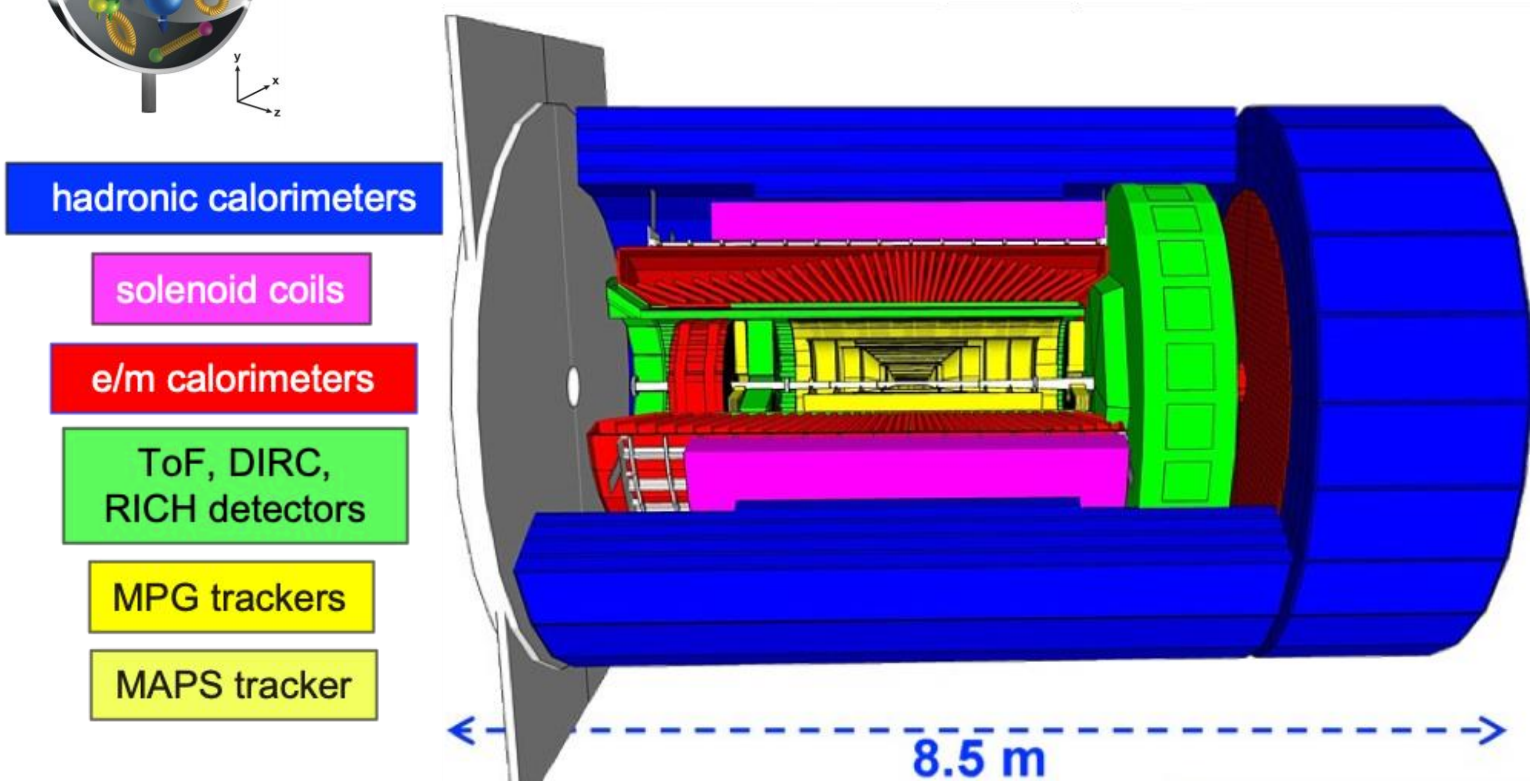
Calorimétrie électromagnétique de haute résolution pour le futur collisionneur électron-ion (EIC)



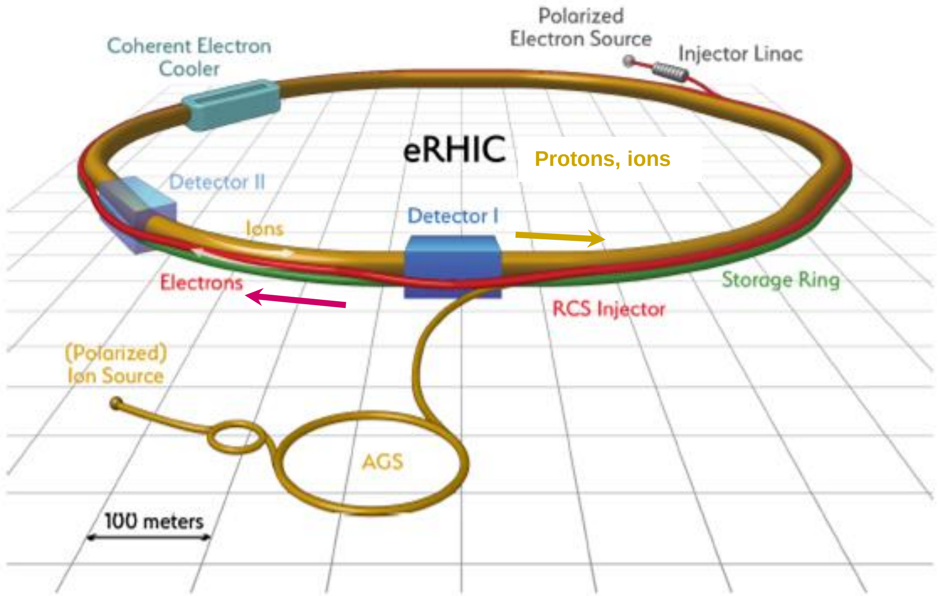


Carlos Muñoz Camacho
(IJCLab)

Journées R&T 2022
(17-19 octobre, Villeurbanne)

Electron-Ion Collider (EIC)

Collisionneur électrons - ions ≡ femtoscope dédié à l'étude des gluons



- Highly polarized electron / Highly polarized proton and light ions /Unpolarized heavy ions
- Center-of-mass energy: ~30-135 GeV
- Luminosity: ~ $10^{33\text{-}34}$ $cm^{-2}s^{-1}$

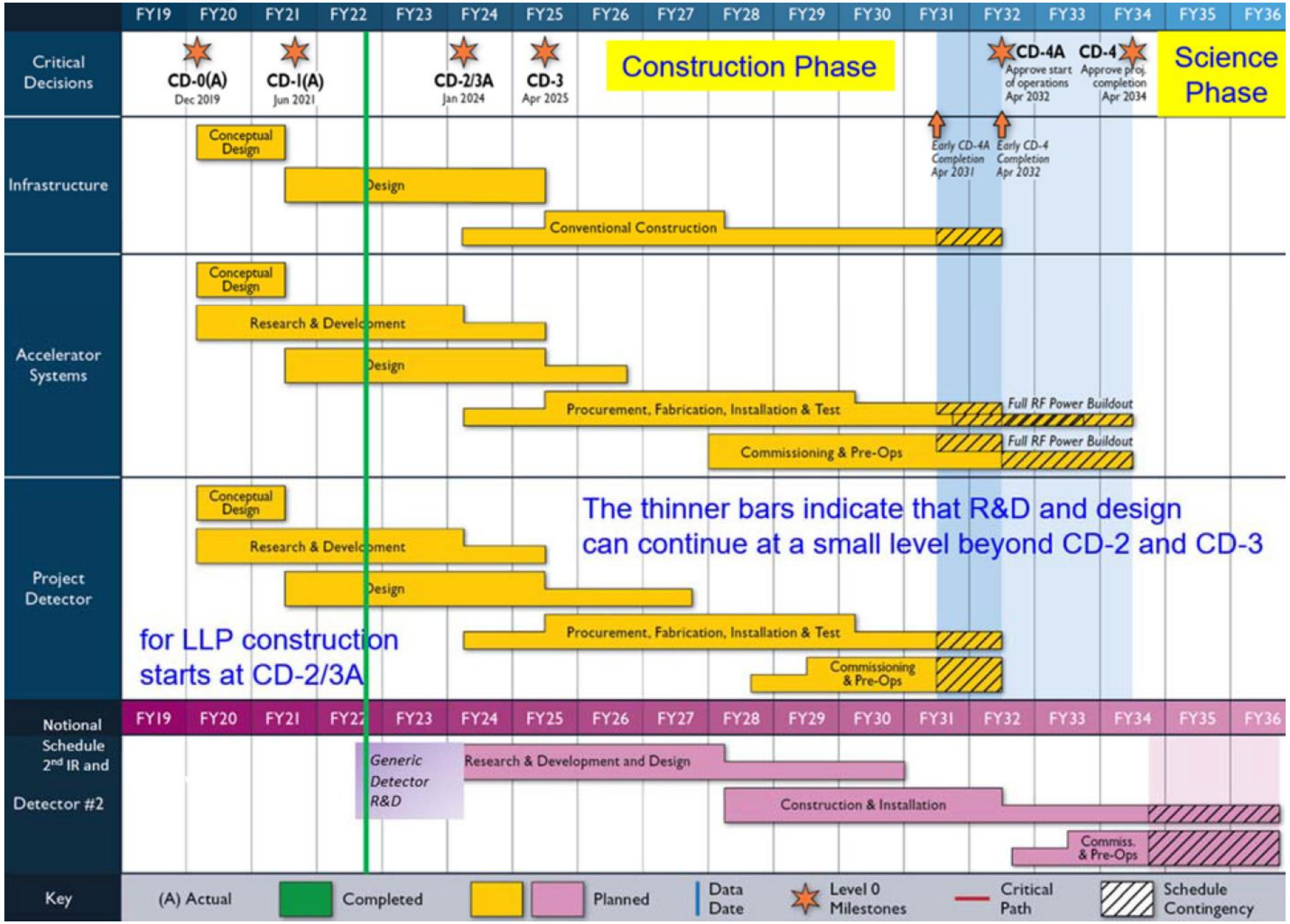
Sujets d'intérêt en ChromoDynamique Quantique (QCD) :

- Détermination des distributions de partons (GPDs, TMDs, nPDFs…)
- Tomographie 3D des nucléons
- Quantification de la contribution des partons aux propriétés intrinsèques des nucléons (spin, masse, pression)
- Dynamique du confinement
- Saturation de la densité des gluons à haute énergie ?
- Effets de milieu

Complémentarités expériences à JLab & LHC

Principal intérêt du groupe : réactions **exclusives**
(par ex. DVCS: Deep Virtual Compton Scattering)

Electron-Ion Collider: Calendrier



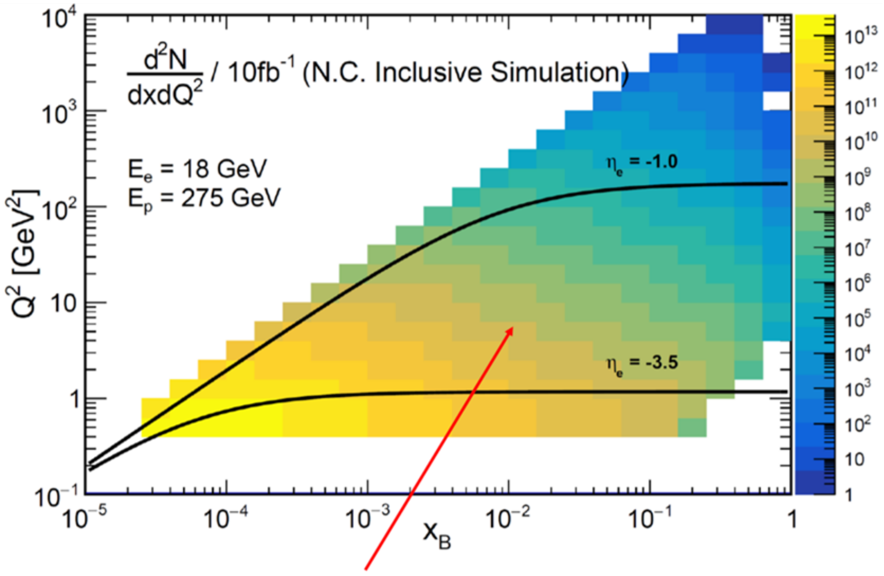
Milestones détecteur

- **Déc 2021:** Conception détecteurs
- Jan 2024: R&D completed (CD-2)
- Avr 2025: TDR completed (CD-3), début construction
- 2030: Commissioning détecteur
- 2031: Pre-ops
- 2034: Démarrage programme de physique (CD-4)

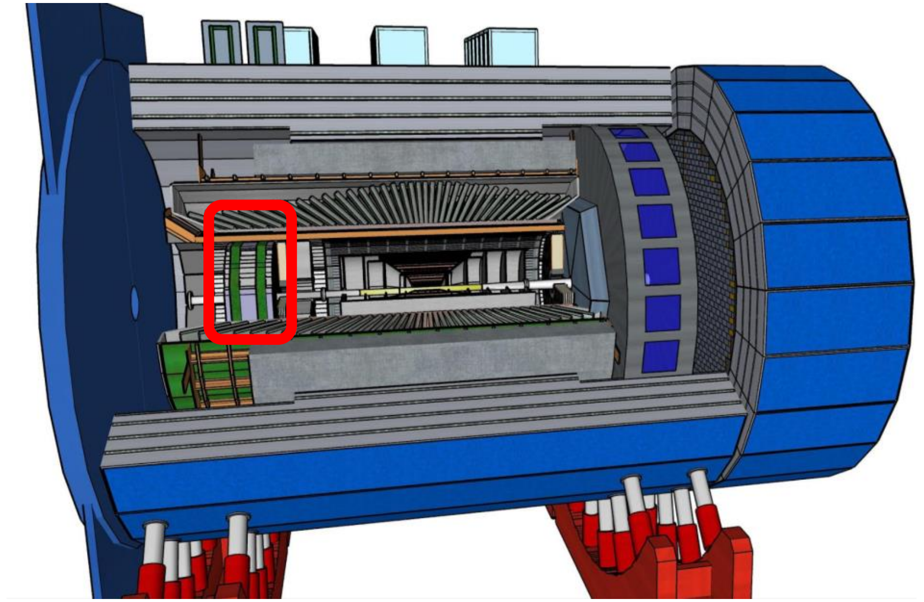
Calorimetrie haute résolution

Electromagnetic (EM) calorimetry is key to any EIC detector concept

- Almost every channel needs to measured the scattered electron
- EM e-endcap calorimeter : $-3.5 < \eta < -1$



Region of physics enabled by the EEEMCal

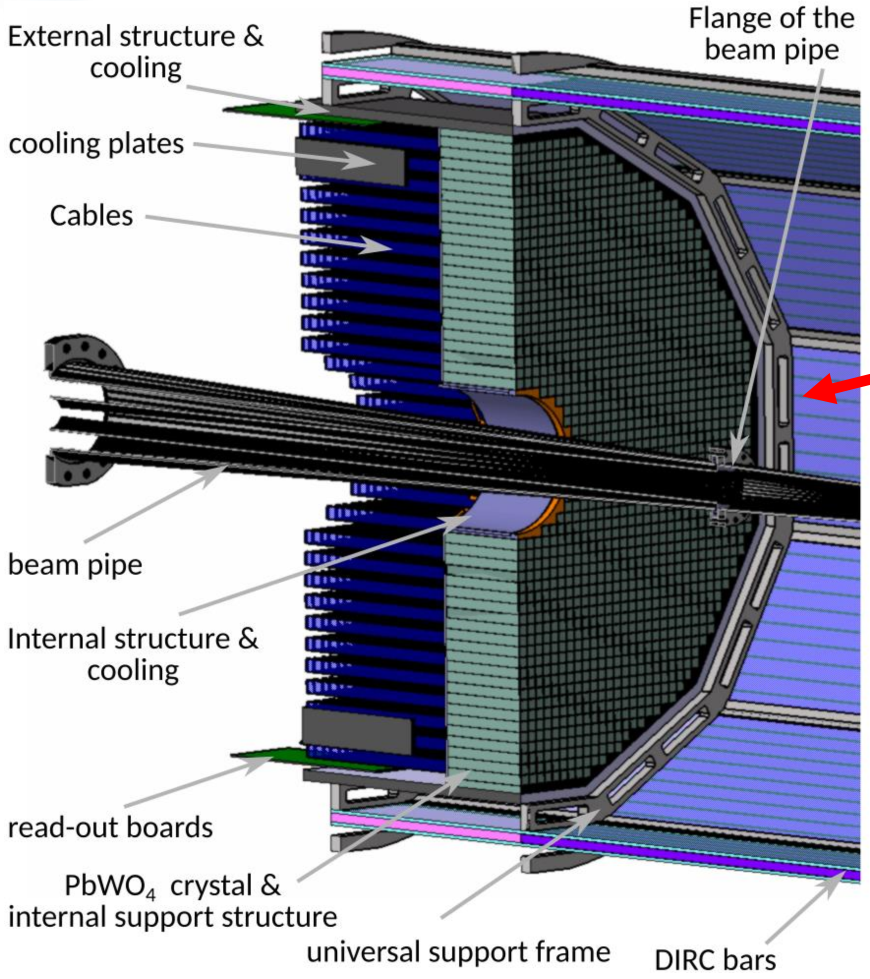


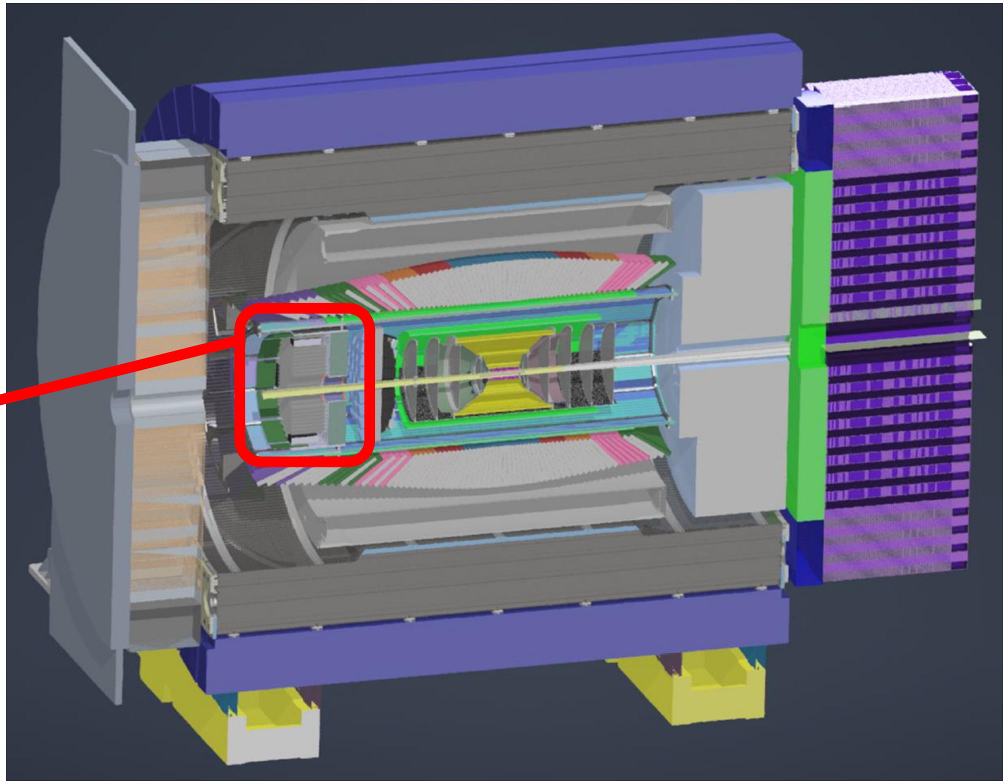
High resolution in the forward region (endcap) can only be achieved with homogeneous materials, such as crystals and glass

R&D in 2015 with funds from the generic R&D program by the US DoE:

- Building on previous experience with EM calorimeters
(JLab Hall A PbF_2, JLab Hall-B PWO IC, JLab Hall-B HPS PWO, PANDA PWO…)
- In synergy with ongoing IJCLab projects for JLab (NPS lead tungsten calorimeter)

Conception du calorimetre du bouchon e⁻



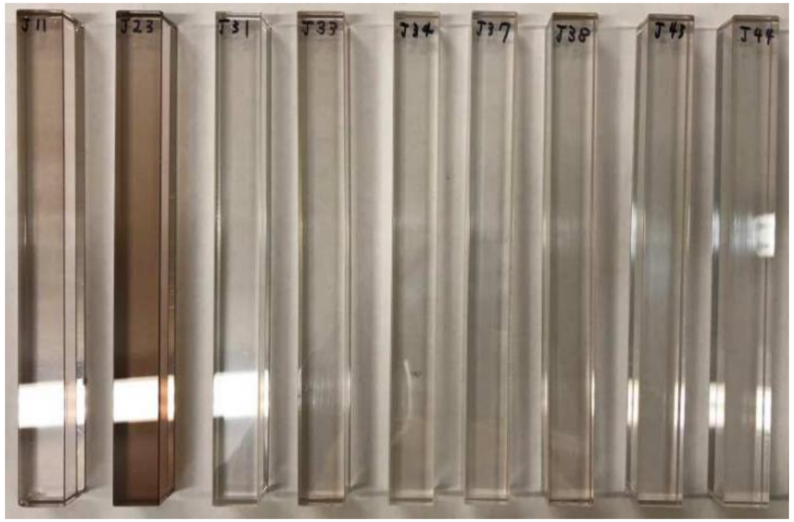


- 2932 cristaux de tungtene de plomb
- Lecture lumiere scientillante par SiPM
- Regulation en temperature (cristaux + SiPM): ± 0.1°C
- Système calibration/monitoring: fibres + laser/LED

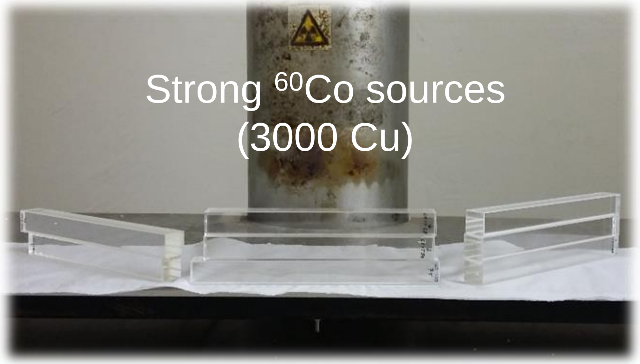
Conception: département mécanique IJCLab

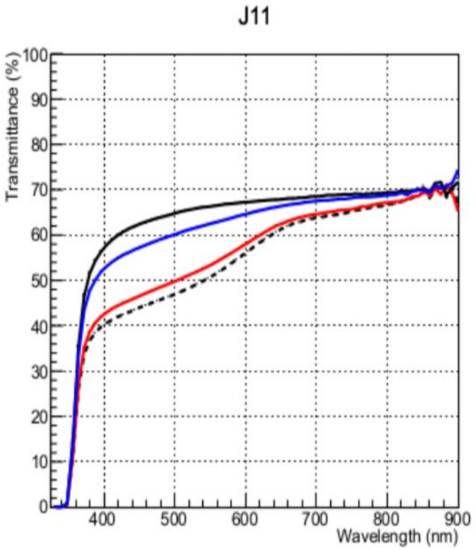
Cristaux de tungstène de plomb (PWO)

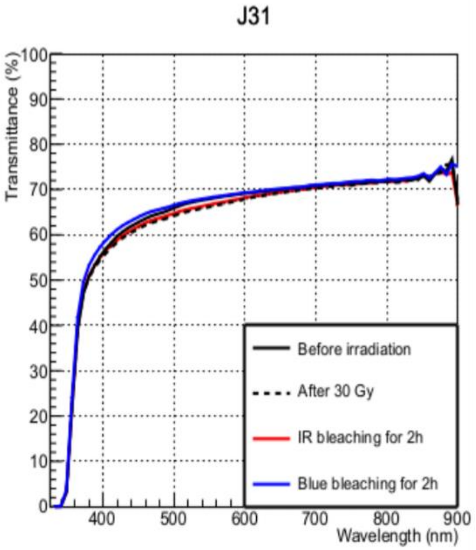
- SICCAS manufacturer has poor quality control
- CRYTUR produces high quality crystals, but production capabilities still limited (+ high cost)
- Optical bleaching with blue light validated; infrared less efficient



Radiation hardness
(in collaboration with LCP)

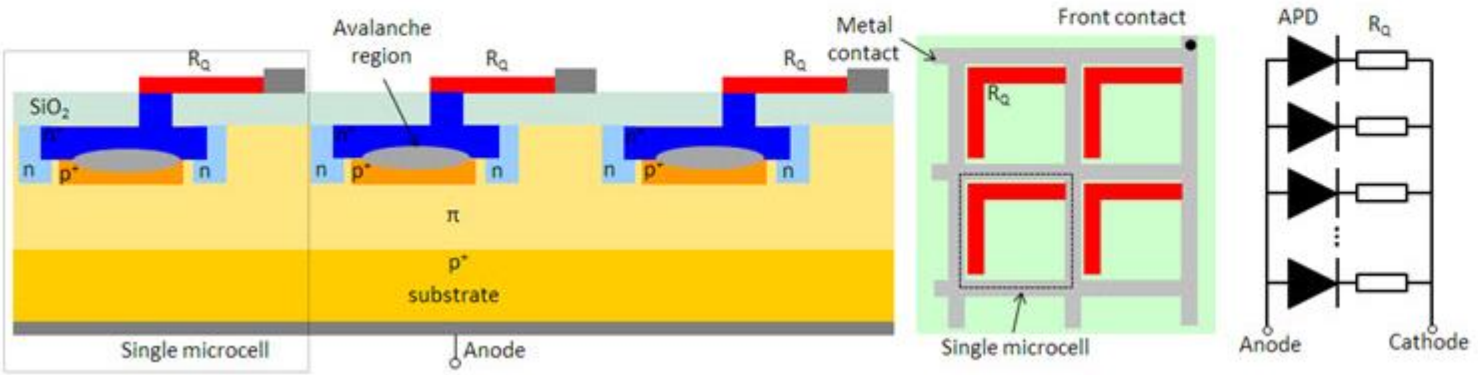




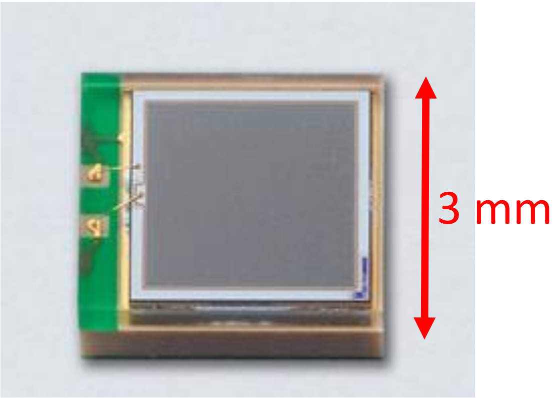


Nucl. Instrum. Meth. A956 (2020) 163375. ArXiv: 1911.11577

Lecture par SiPM



- Solid-state photodetector
- Current pulse of 20-50ns with 10^5-10^6 electrons (i.e. gain similar to a PMT)
- Insensitive to magnetic fields



- Small size
- Significant dark noise
- Not very radiation hard

➢ With PWO, readout (few p-e) requires analog amplification

➢ For calorimetry at EIC, large dynamic range needed (~50 MeV – 15 GeV)

Collaboration with INFN, BNL, JLab

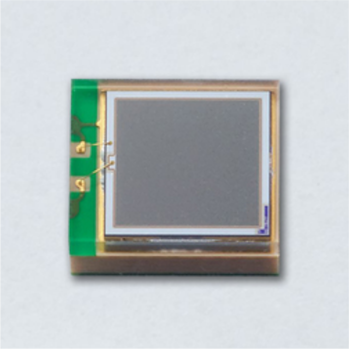
SiPM with high pixel density

Plage dynamique attendue à EIC: 0.05 – 15 GeV (1:300)

MPPC

S14160-3010PS

HAMAMATSU
PHOTON IS OUR BUSINESS



Contact us >

Low breakdown voltage, wide dynamic range type MPPC with small pixels

The S14160 series is a small-pixel MPPC that features wide dynamic range. Even with an extremely narrow pixel pitch of 10 μm, it features high fill factor ,reduced crosstalk, and dark count.

Features

-Small pixel pitch (10 μm)
-High fill factor
-Wide dynamic range
-Low voltage operation (VBR=38 V typ.)
-Low crosstalk and after pulses
-high gain: 10^5 order

Specifications

Package type	Surface mount type
Number of channels	1 ch
Effective photosensitive area / ch	3 × 3 mm
Number of pixels /ch	89984
Pixel size	10 μm
Spectral response range	290 to 900 nm
Peak sensitivity wavelength (typ.)	460 nm
Dark count/ch (typ.)	700 kcps
Terminal capacitance/ch (typ.)	530 pF
Gain (typ.)	1.8×10^5

Readout ASIC

Citiroc 1A

Scientific instrumentation SiPM read-out chip

TRL Technology Readiness Level	8 - Full system using ASIC running - learn more
Available versions	• Citiroc 1 : discontinued • Citiroc 1A : available
Detector Read-Out	SiPM, SiPM array
Number of Channel	32
Signal Polarity	Positive
Sensitivity	Trigger on 1/3 photo-electron
Timing Resolution	better than 100ps RMS on single photo-electron
Dynamic Range	0-400 pC i.e 2500 photo-electrons @ 10^6 SiPM gain

- 32-channel front-end ASIC designed for SiPM
- 1% linearity up to 0-400 pC 2500 p.e (~ 14000 p.e @1.8x10^5 SiPM gain)~
- Low power dissipation (~ 7 mW/channel)

A1702

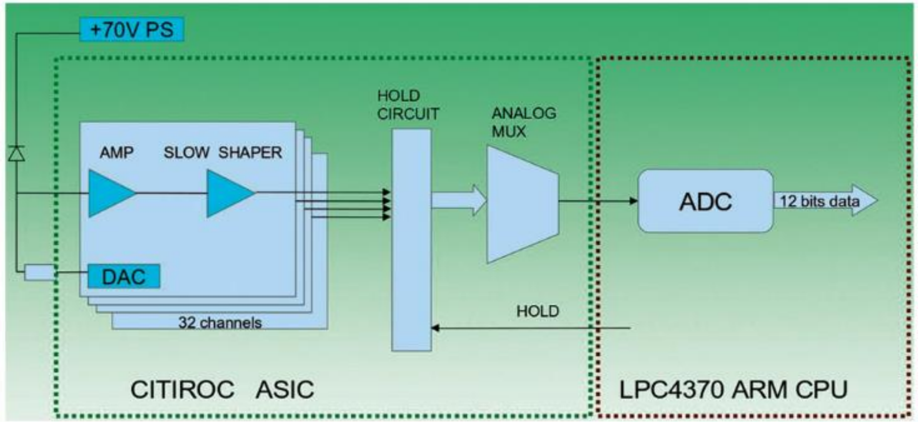
32 Channel SiPM Readout Board for Cosmic Rays Veto

Request a quote

Manual | Downloads

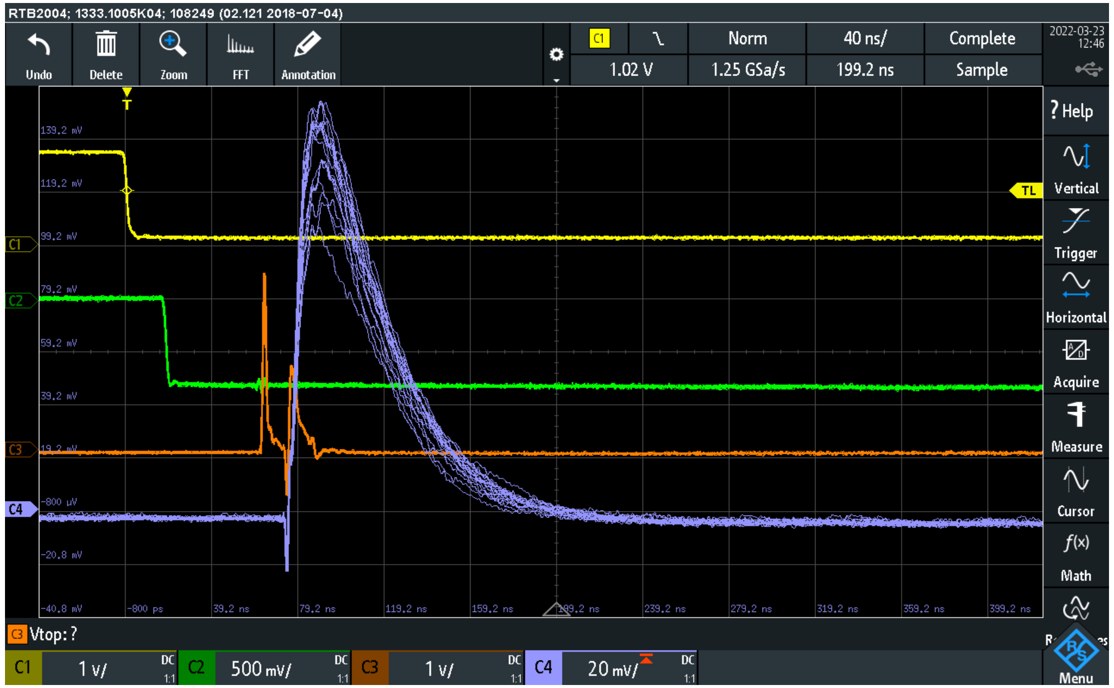
Features

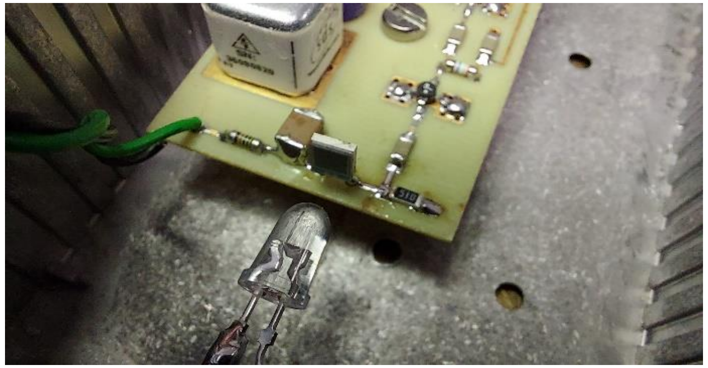
- Readout board for SiPM, tailored for **Cosmic Rays Veto** systems in Neutrino experiments.
- Based on **32-channels** WeeROC CITIROC ASIC
- **Coincidence** of signals from each pair of adjacent even-odd channels
- Provides bias voltage in the range of 20-90 V, individually adjustable for each of 32 SiPMs
- Amplification and shaping of the SiPMs output pulse on each of 32 channels
- Discrimination of shaped signal at configurable level from 0 to 50 SiPMs photo-electrons
- Timing resolution down to 1 ns with stable external reference signals

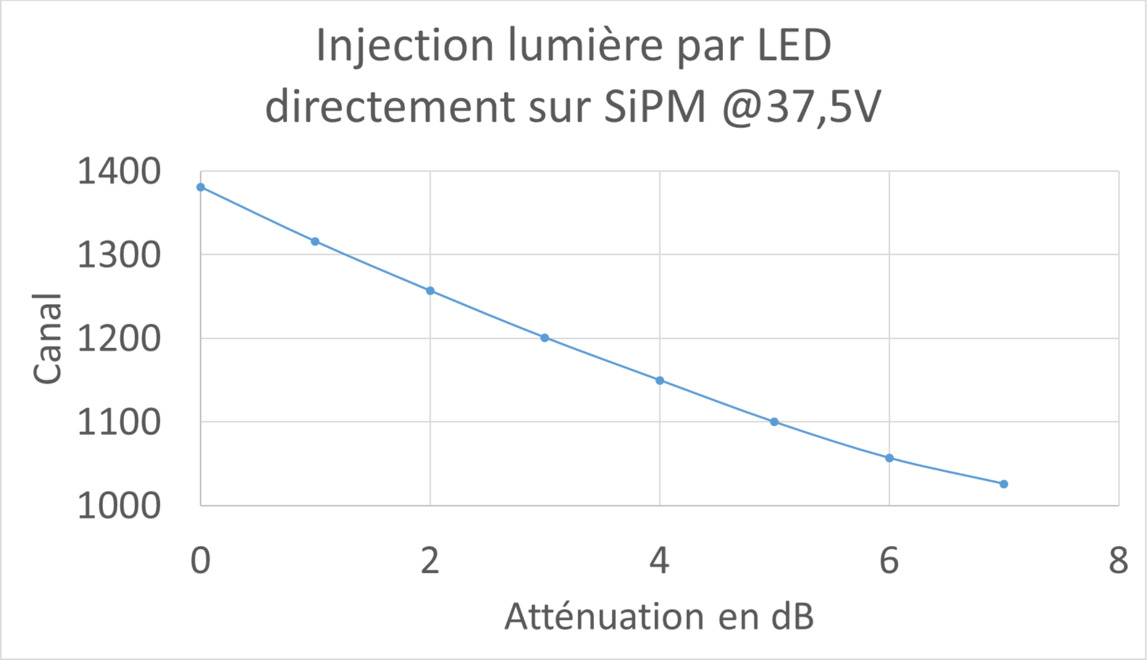


Block-scheme of analog signal processing circuit.

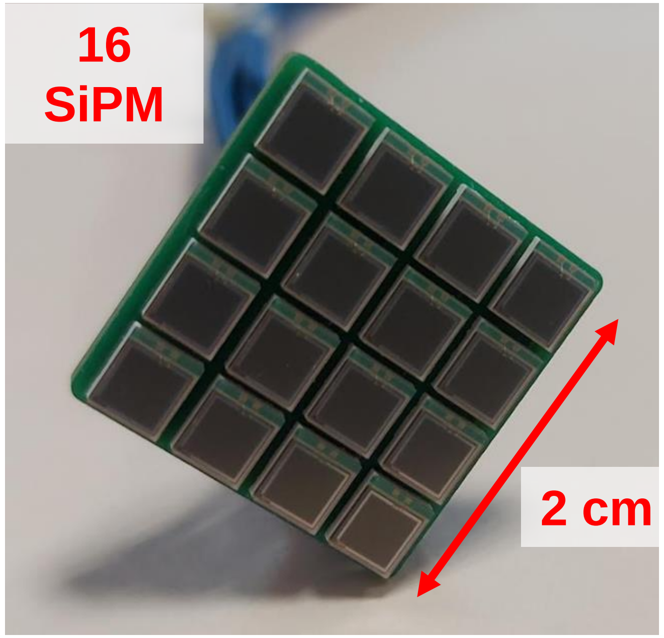
Initial tests: SiPM individuel + LED





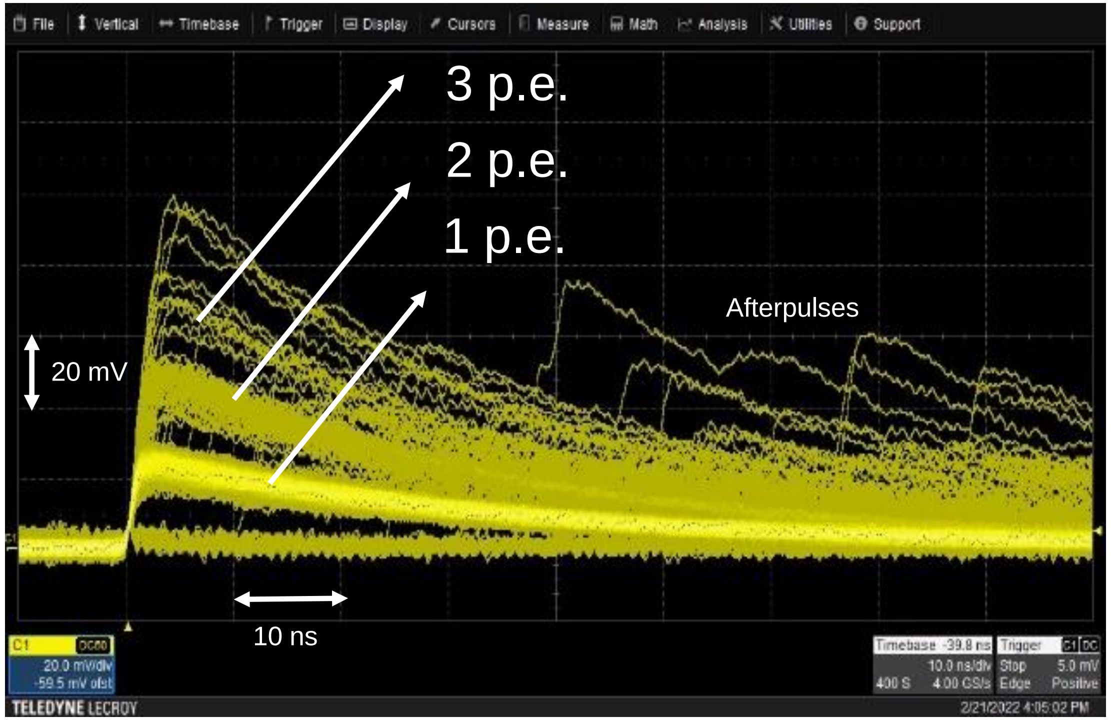


Prototype module

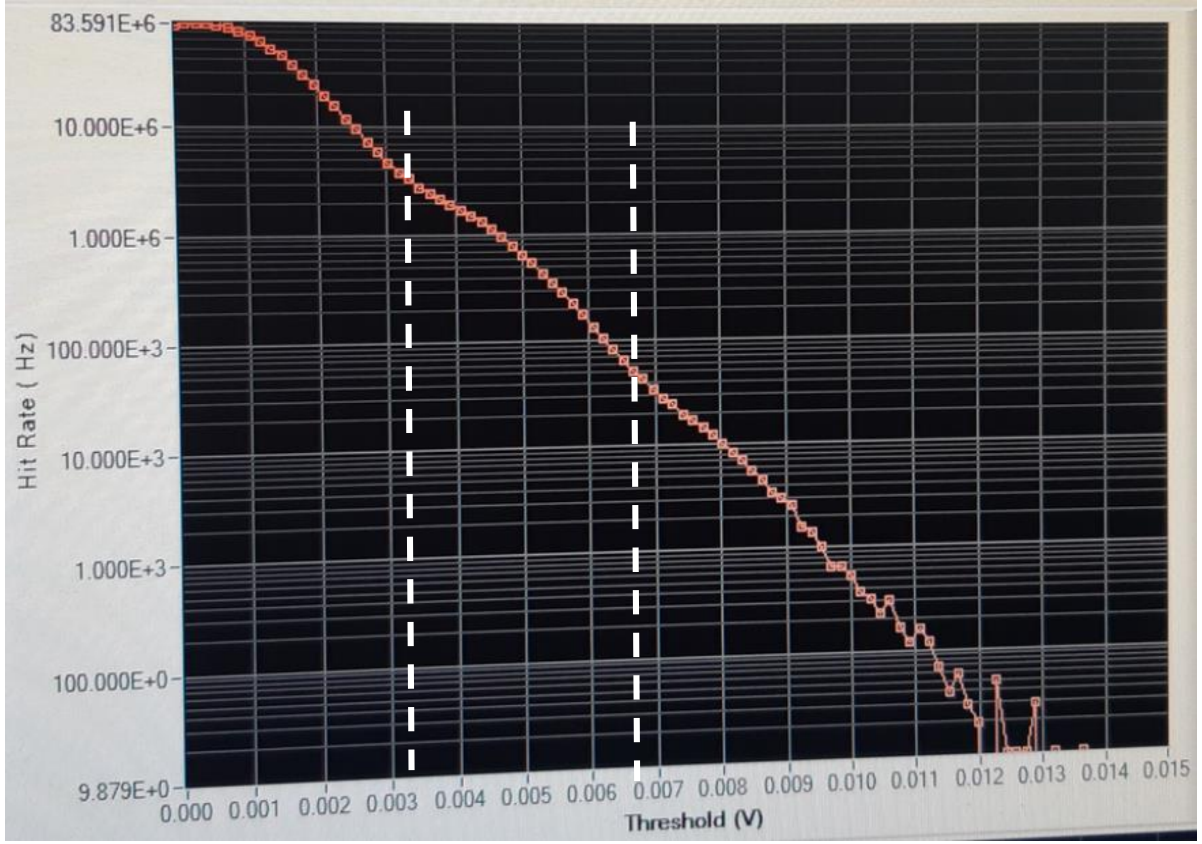


- ➢ Ensemble de 16 SiPM pour lire un cristal unique
- ➢ Conection directe aux systeme d'acquisition CAEN (A1702)
- ➢ *En cours de tests en ce moment*

Calibration: single p.e. & « staircase »



Dark count rate as a function of threshold



Rough estimate: ~3 mV per p.e

Upcoming tasks

- Développement d’un banc de test avec regulation de temperature, pour mesurer :
  - Efficacité de détection (Photon Detection Efficiency, PDE)
  - Gain
  - Taux de comptage d’obscurité (dark rate)
  - Cross-talk
  - Plage dynamique
  - Linéarité de réponse
- Adaptation du banc de test pour caractériser l’ensemble formé d’un cristal $PbWO_4$ et le système de 16 SiPM
- Construction d’un proto 4x4 cristaux et test faisceau

Objectif final du projet

Energy resolution: $$\frac{\sigma}{E} = A \oplus \frac{B}{\sqrt{E}} \oplus \frac{C}{E}$$

Geometry, leaks, relative calibration, etc

Photo-statistics

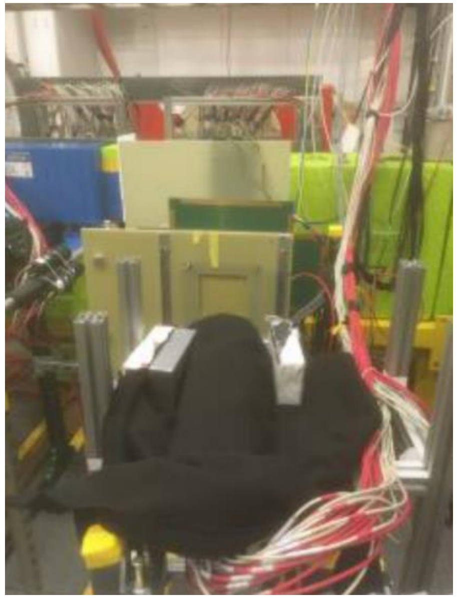
Electronic noise, etc

The constant term (A) limits the energy resolution at high energy

Factors affecting the constant term:

- Dead material between active modules (eg. crystal supports, air gaps…)
- Control of relative gain (temperature dependence, radiation damage…)
- Calibration, electronic drifts, etc

Optimization by simulation, but ultimately a prototype and a beam test is needed for a realistic estimate



Beam tests possible with photon beam in Hall D at JLab

Conclusion

- Le calorimetre electromagnetique du bouchon electron est un des détecteur le plus importants à EIC
- IJCLab a joué un role moteur dans sa conception et la R&D necessaire pendant les dernieres années
- Expertise et synergie avec projets equivalents à Jefferson Lab
- Combinaison de PWO et SiPM est une option attractive pour la lecture, mais qui n’est pas encore validée
- L’equipe souhaite continuer son implication à EIC avec une participation à la contruction de ce calorimetre