Backward Endcap Electromagnetic Calorimeter Status

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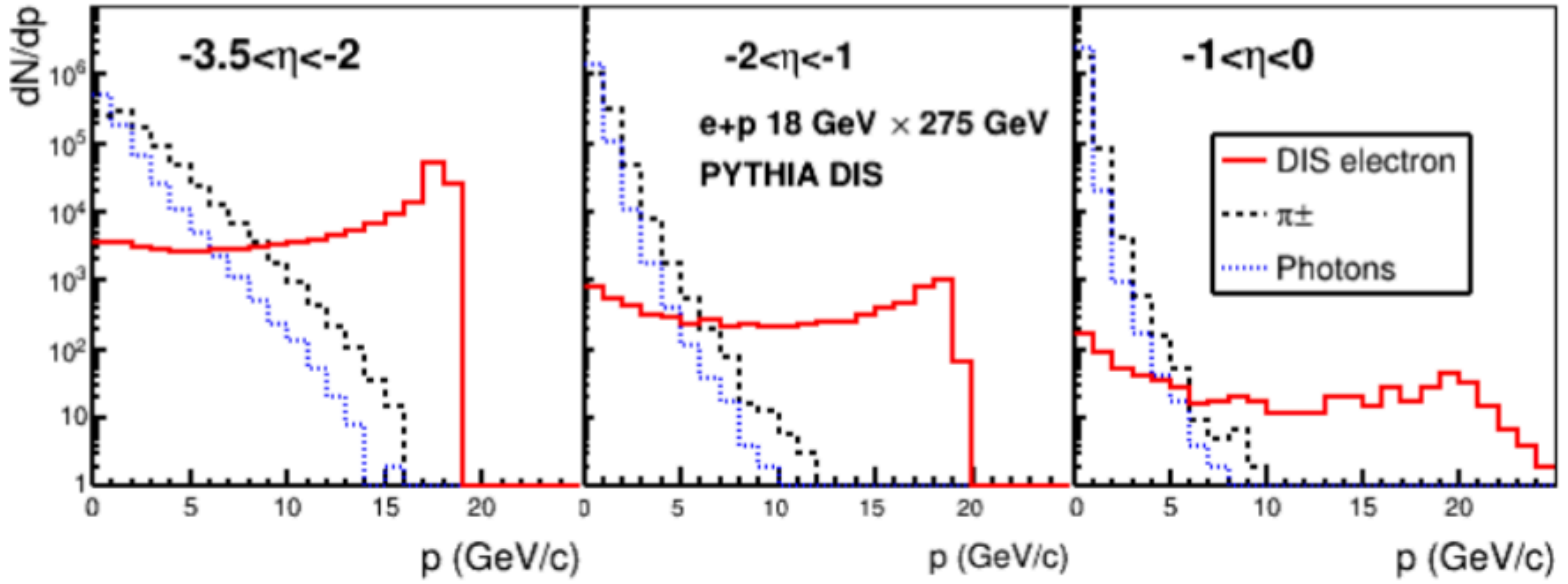
October 21st 2024

*on behalf of the French EEEMCal team

The electron-going ECAL (EEEMCal)



Requires excellent energy resolution & low energy threshold for determining event kinematics, particularly for inclusive DIS

2-3% / $\sqrt{E} \oplus$ 1-2%
particle E: ~ 0.05-15 GeV

Low occupancy & radiation compared to a hadron collider

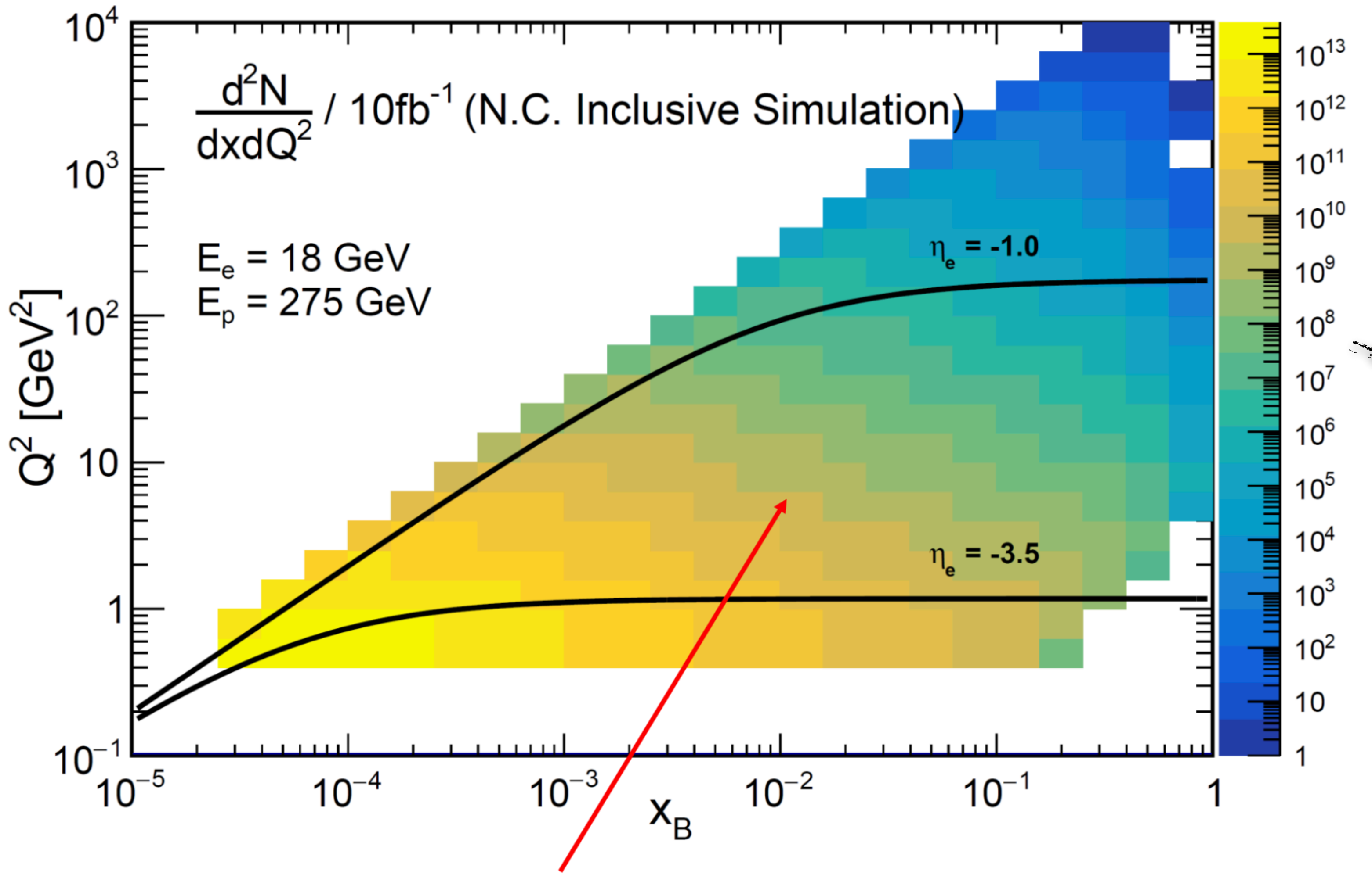
Crucial role! Measure:

- Scattered e- from DIS
- Direct γ from DVCS

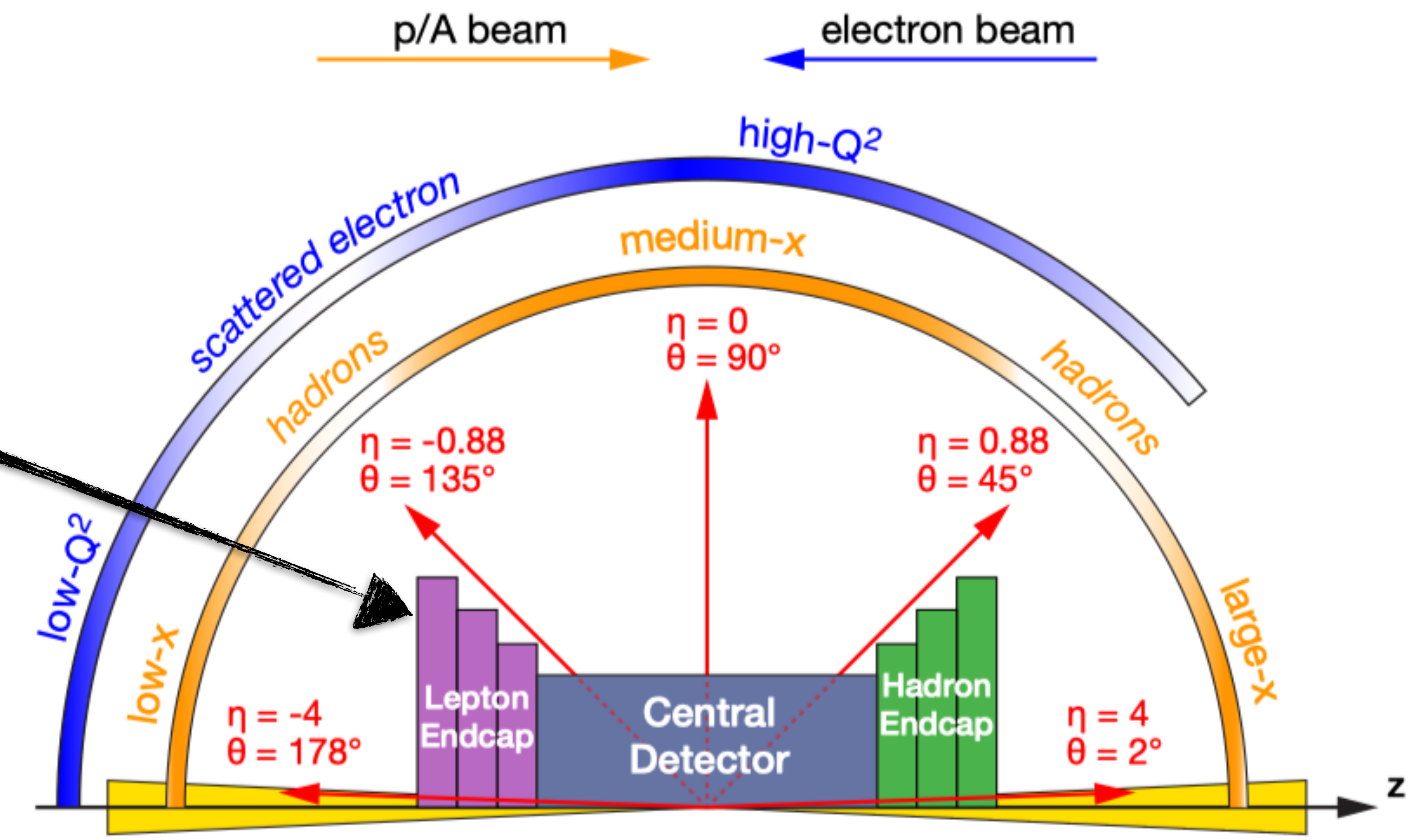
Needs to:

- distinguish e- from $\pi^{+/-}$
- collect bremsstrahlung γ's
- reject photons from π^0

Scattered electrons have to be detected in the Lepton Endcap (-3.5 < η < -1.0)



Region of physics enabled by the EEEMCal



Project scope

Design and fabricate an electromagnetic calorimeter (mechanical structure, readout electronics, etc.)

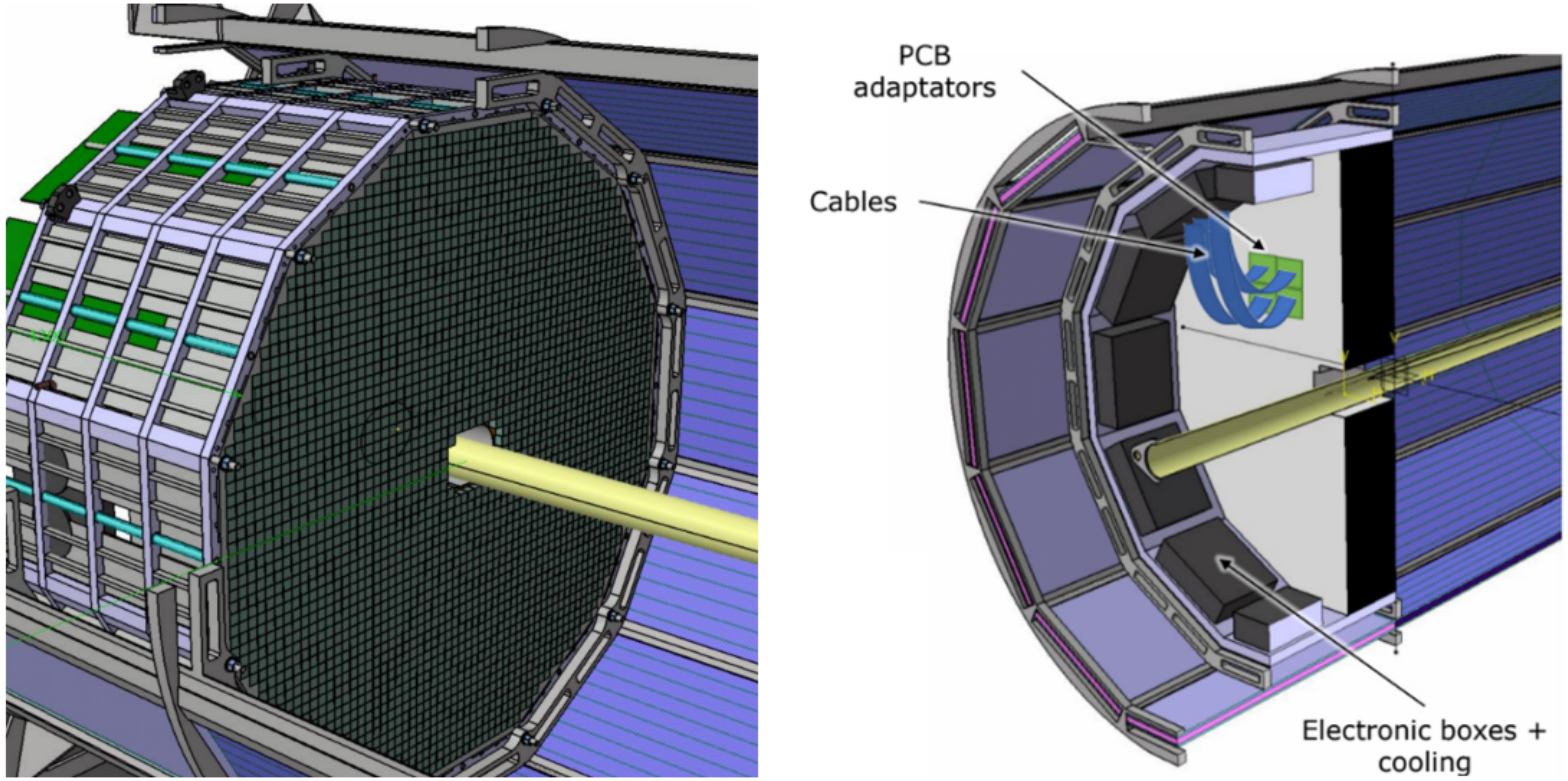


Figure 5: Conceptual design of the ePIC electron endcap electromagnetic calorimeter support, developed by IJCLab.

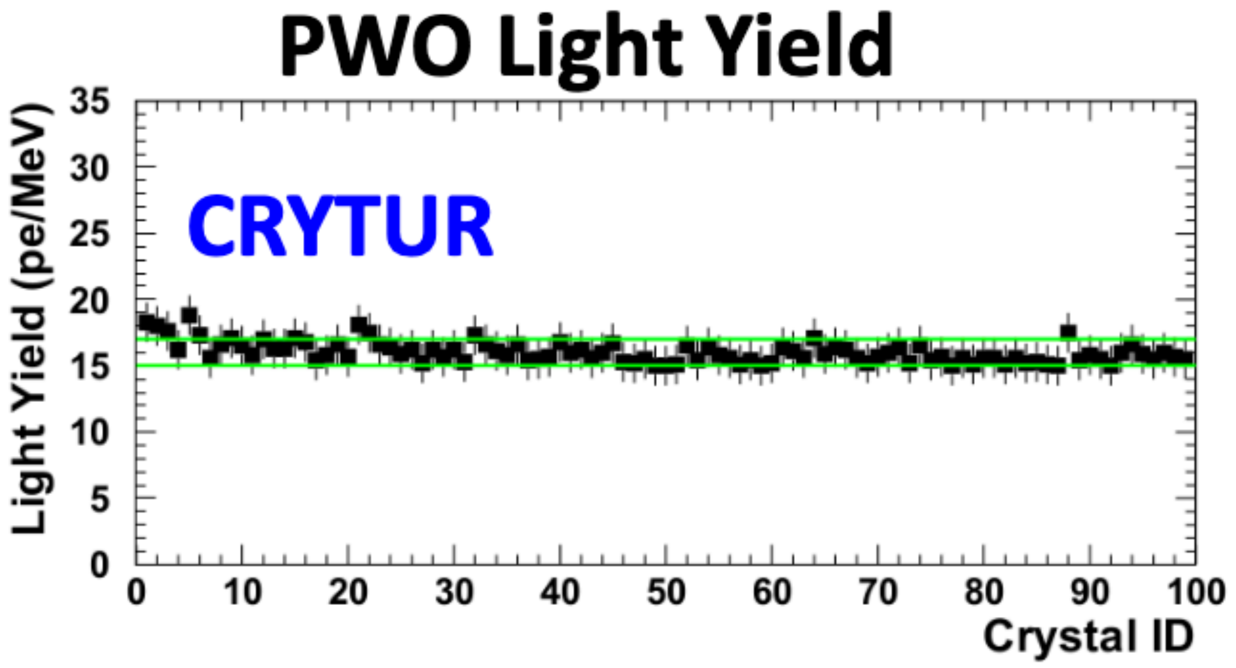
- Endcap: cylindrical geometry
- Located 175cm from interaction point
- Weight ~ 3 tons w/ support & services

- Only a homogenous electromagnetic calorimeter will fulfill the energy resolution requirements

Active material: PWO

Characteristics

- Fast
- Compact
- Radiation hard
- Mature technology used by many experiments (CMS, JLab)



ePIC specifications

- Dimensions
  - 20 cm depth ~ 22 X0 to minimize shower leakage
  - 2 cm transverse size to match Molière radius
- Fabrication
  - Fabricated by CRYTUR (Czechia)
  - PWO-II —> 50% more p.e. than PWO
- Performance
  - Energy resolution: $\sigma_E/E \approx 2\,\%/\sqrt{E} \oplus 1\,\%$
  - Position resolution: 2mm @ 1-3 GeV

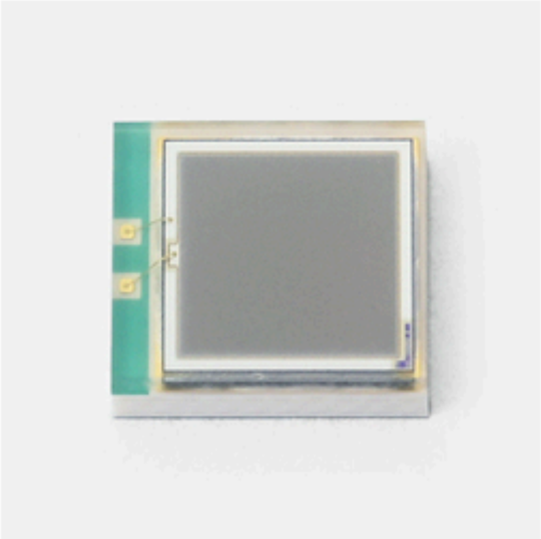
- Detailed investigation of SciGlass, a cheater alternative, were conducted at IJCLab
- Purchase of crystals assured by the U.S.

Signal Collection: Silicon Photomultipliers

SiPMs have rapidly developed over the last ~15 years
All ePIC calorimeters will use SiPMs of various models (size, pitch, etc.)

Essential features
- High gain
- Good photo-detection efficiency
- Insensitive to B fields
- Cost effective

S14160-3015PS



Package type	Surface mount type
Number of channels	1 ch
Effective photosensitive area / ch	3 × 3 mm
Number of pixels /ch	39984
Pixel size	15 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.)	3.6×10^5
Measurement condition	Ta=25 °C

Baseline SiPM version

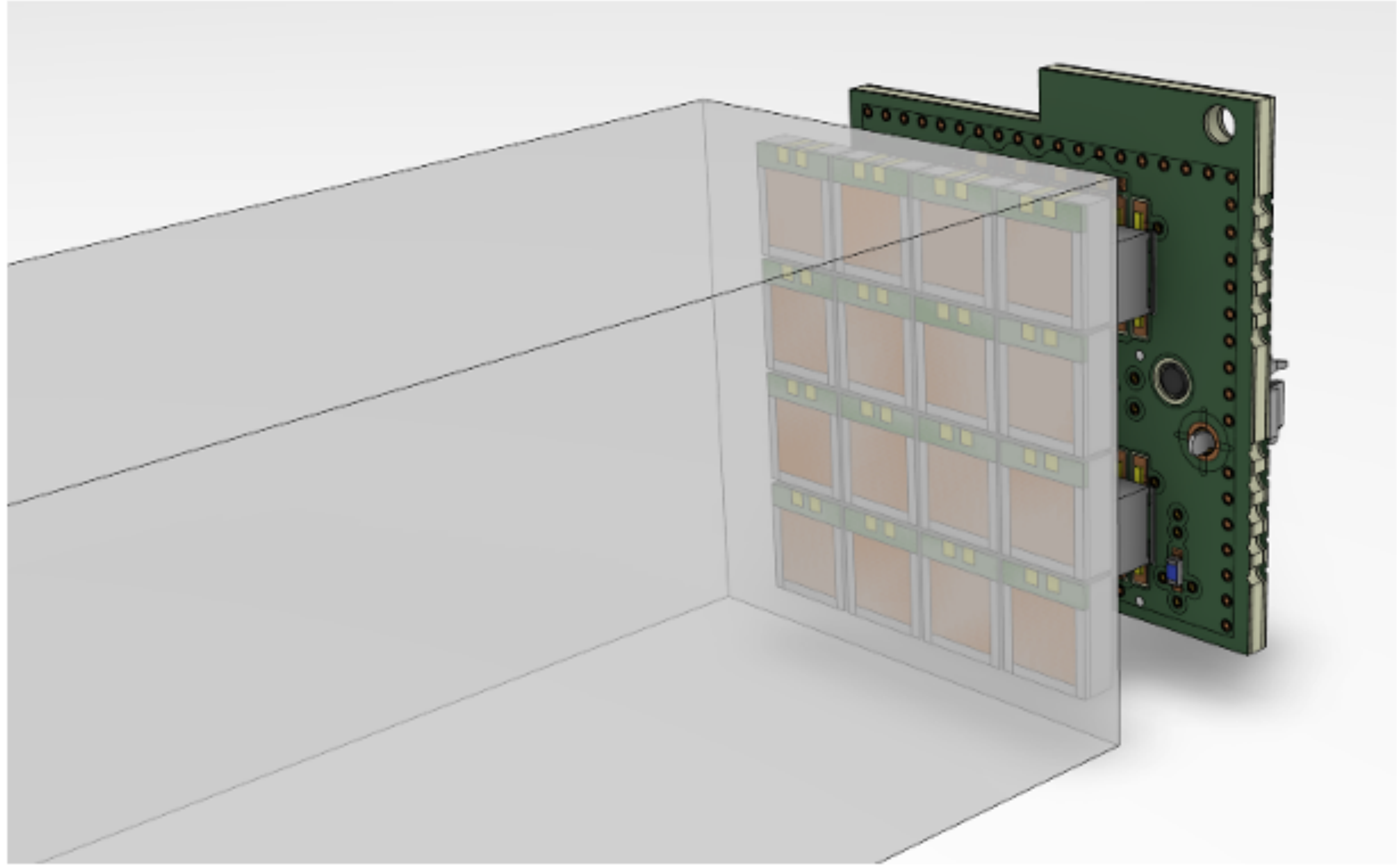


Figure 10: PWO crystal readout by an array of 16 Hamamatsu S14160-1315 SiPMs.

For baseline SiPM, each crystal read w/ a 4x4 array
If each SiPM read out independently: 48k channels

SiPM characterization

Studies of SiPMs with PWO crystals funded by an IN2P3 R&T project (2022-2024)

Various SiPM models were tested by Vincent Chaumat (IR) & Noémie Pilleux (PhD) @ ICJLab

- 3x3 mm^2 vs 6x6 mm^2
- 10 vs 15 micron pitch

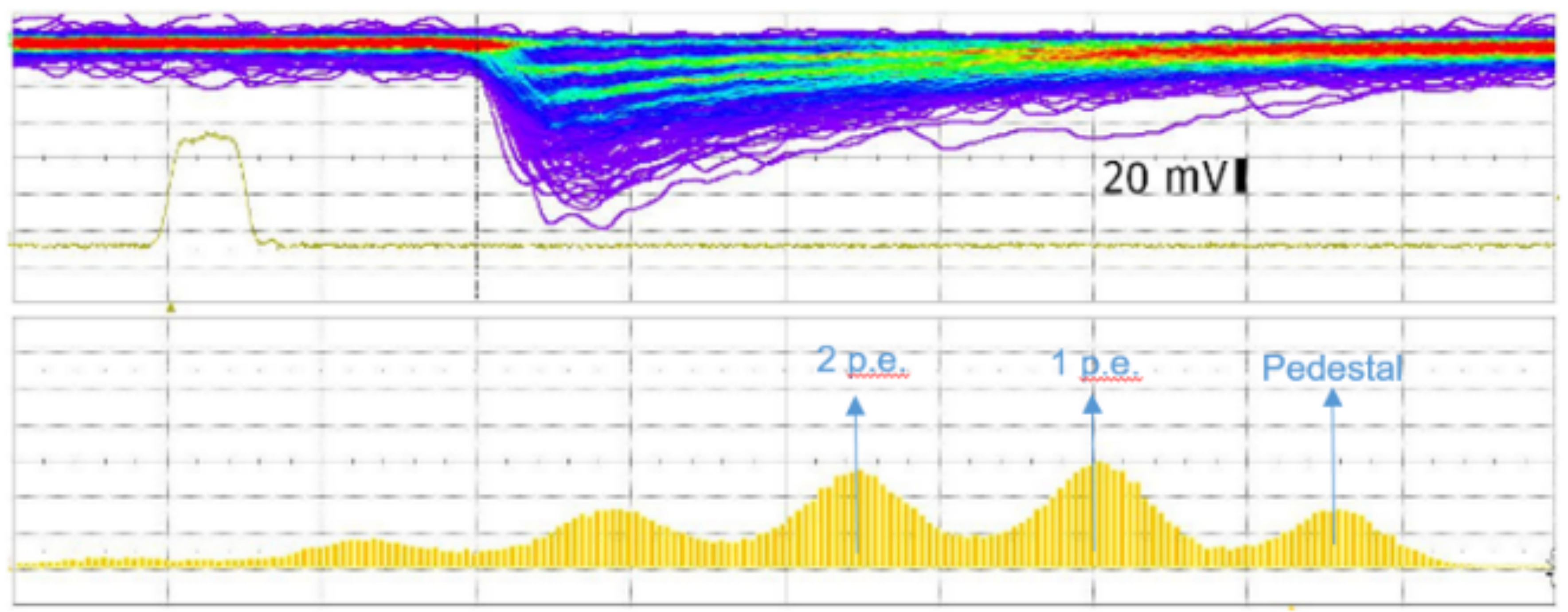
‣ 3x3 mm^2 w/ 15 micron pitch is current baseline →

Advantages

- Better signal-to-noise at very low energies
- Relatively small capacitance into ROC
- Best single photo-electron spectrum for initial gain estimation

Disadvantages

- Worse linearity over the full range
- More channels than larger SiPM, depending on readout scheme



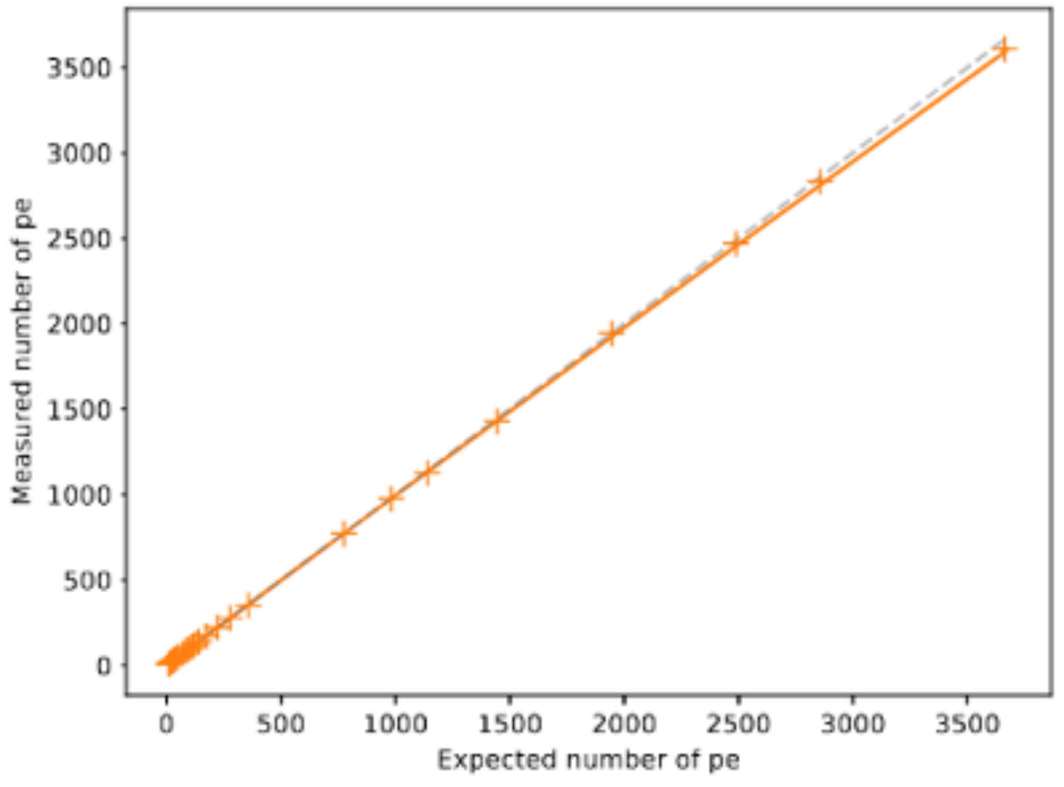
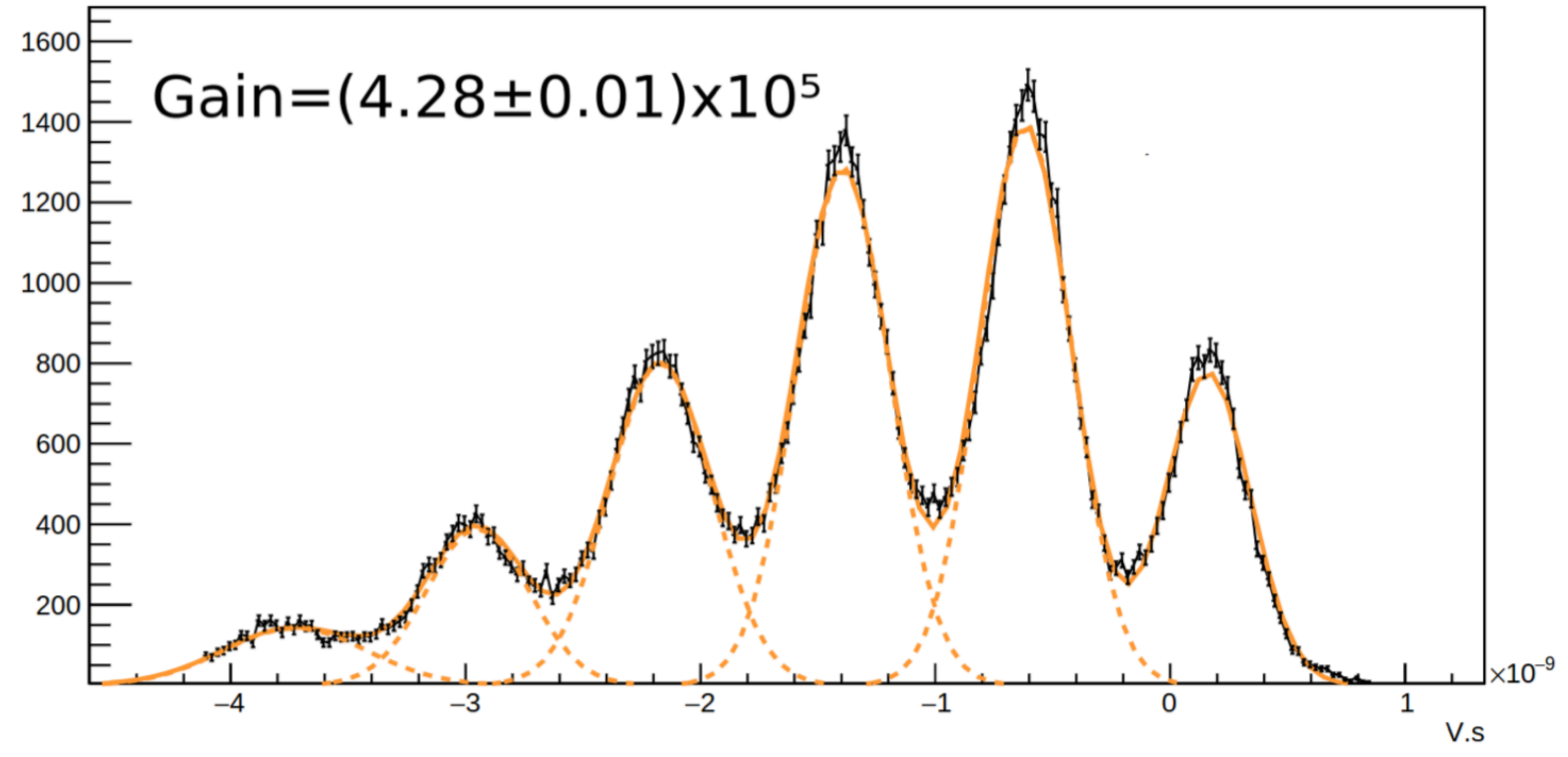


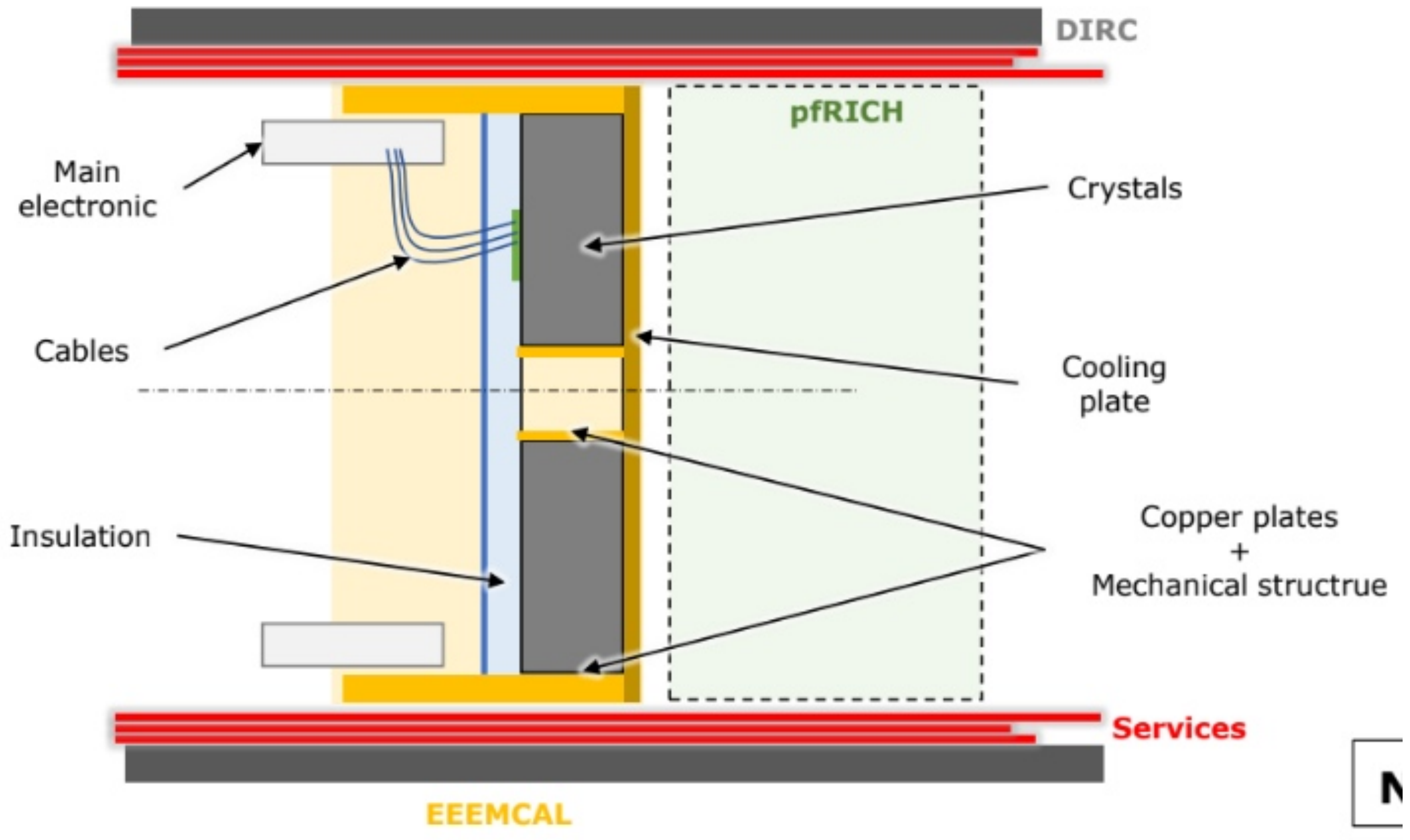
Figure 9: Left: waveform (top) and integrated signal (bottom) showing single photo-electron signals in Hamamatsu 15 um pixel SiPMs. Signals are produced with a low-intensity LED. Right: Linearity measurement, showing 2% linearity up to 3500 photo-electrons.

Single p-e spectrum (Pilleux thesis)



(b) 15 µm

Detector simulations



- Energy resolution close to specifications
- Pion rejection at about 10^3 with reasonably high efficiency

Expect 10^4 when combined with PID detectors

DD4HEP/Geant simulations done at IJCLab
Includes full material in front of detector

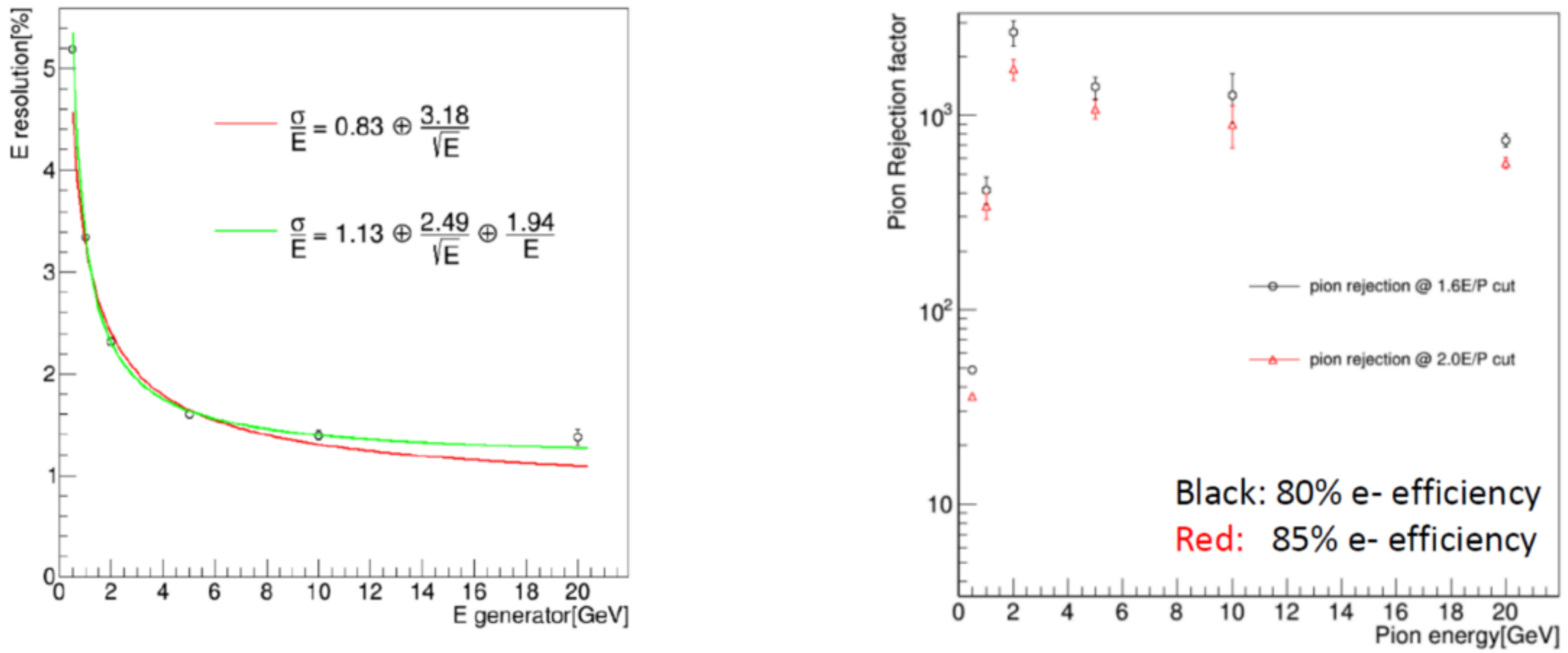
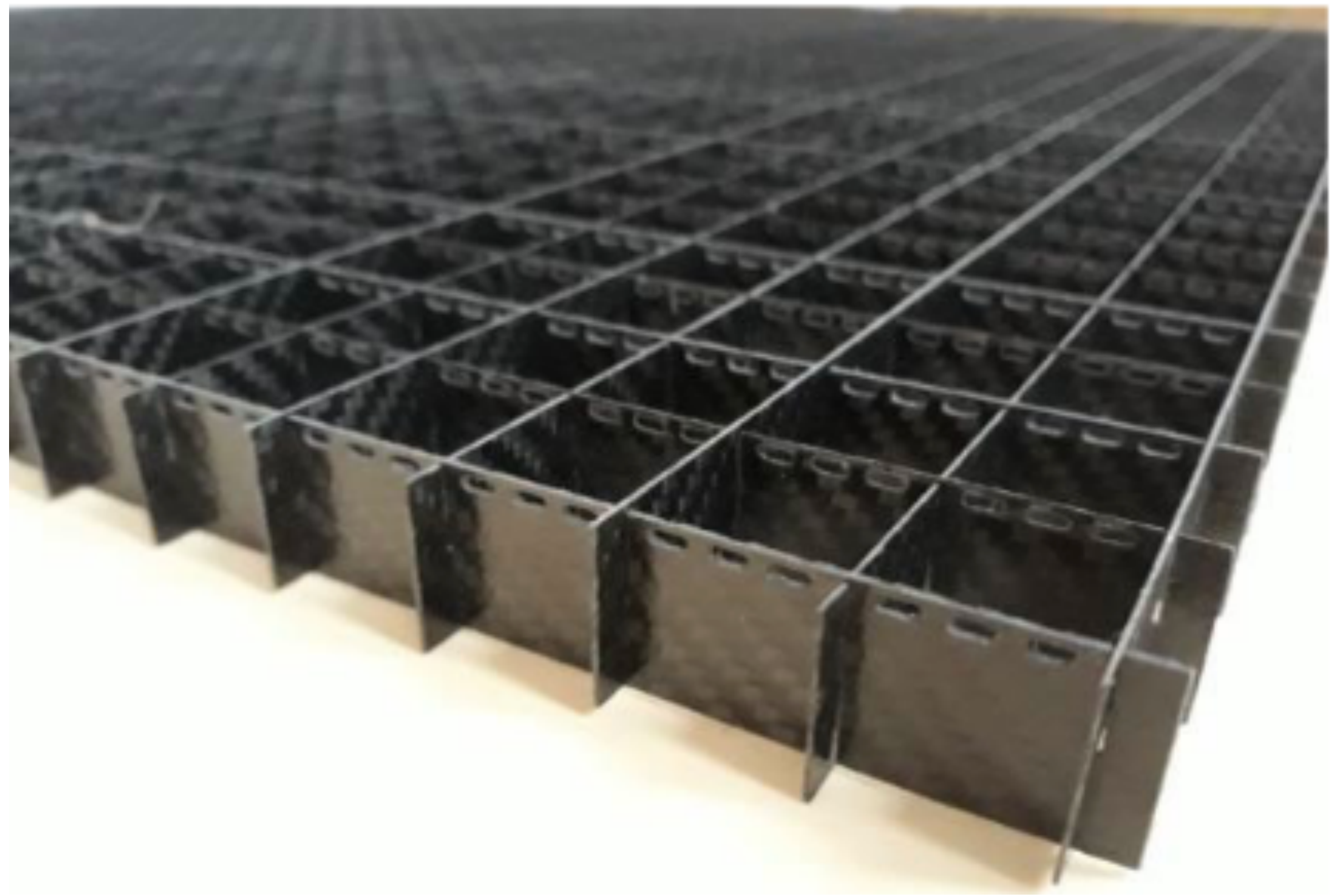


Figure 7: EEEMCal simulated performance using the ePIC detector framework including all materials. Left: energy resolution as a function of the incident particle energy. Right: pion rejection factor as a function of energy and different values of electron efficiency.

Mechanical design

Stacked w/ 0.5 mm-think carbon fiber plates on the front and back of PWO crystals



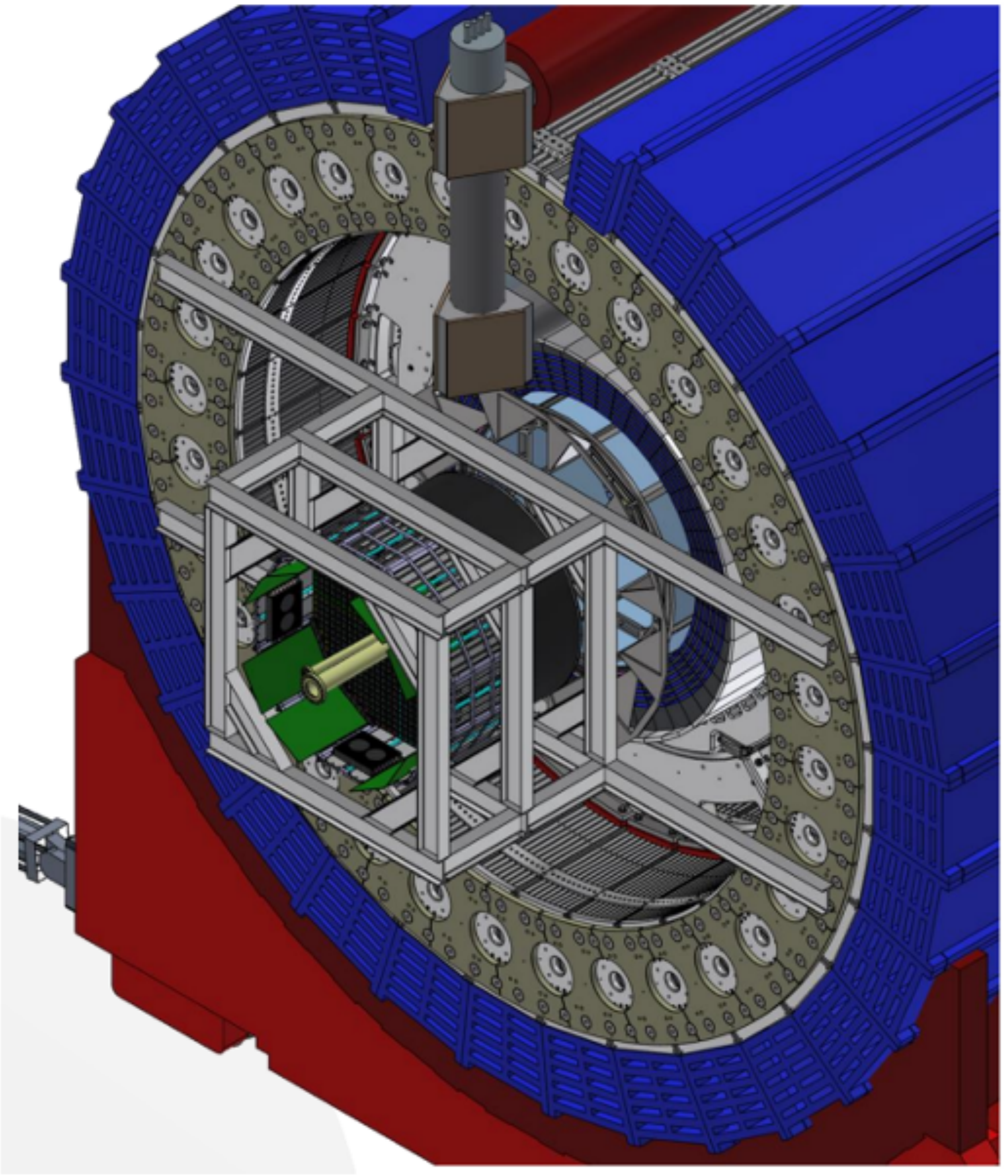


Figure 8: EEEMCal installation fixtures that allow for installing the detector safely into the ePIC detector barrel.

- Rail-guided mechanical will position the detector
- Mechanical structure includes services as well as light monitoring
- Airflow based cooling will be used to stabilize temperature

Readout electronics: CaloROC

ASIC designed by OMEGA will be used for nearly all the calorimeters of ePIC
Details covered in dedicated talk

Ongoing studies use similar chip designed for CMS (HGCROC)

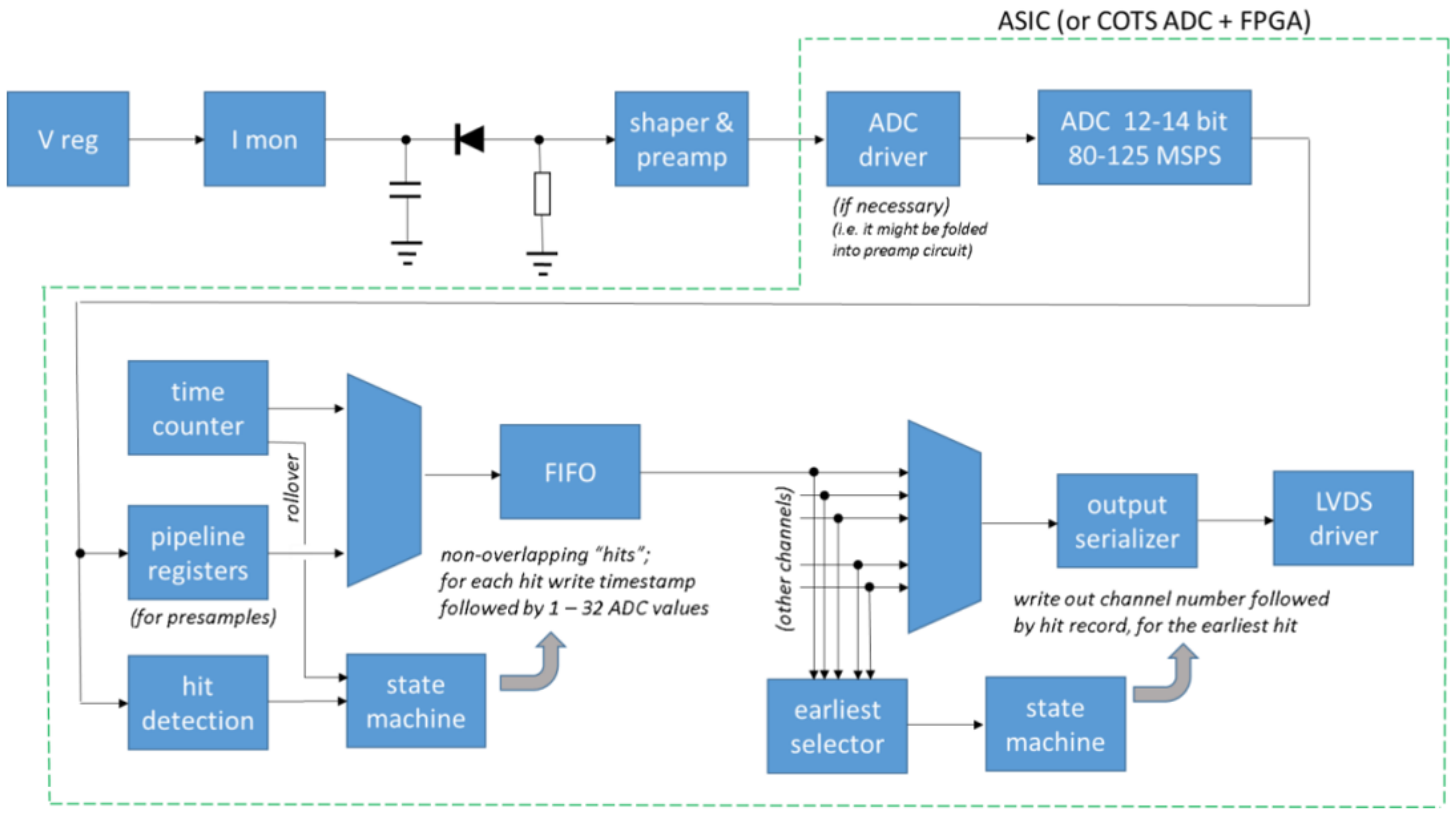
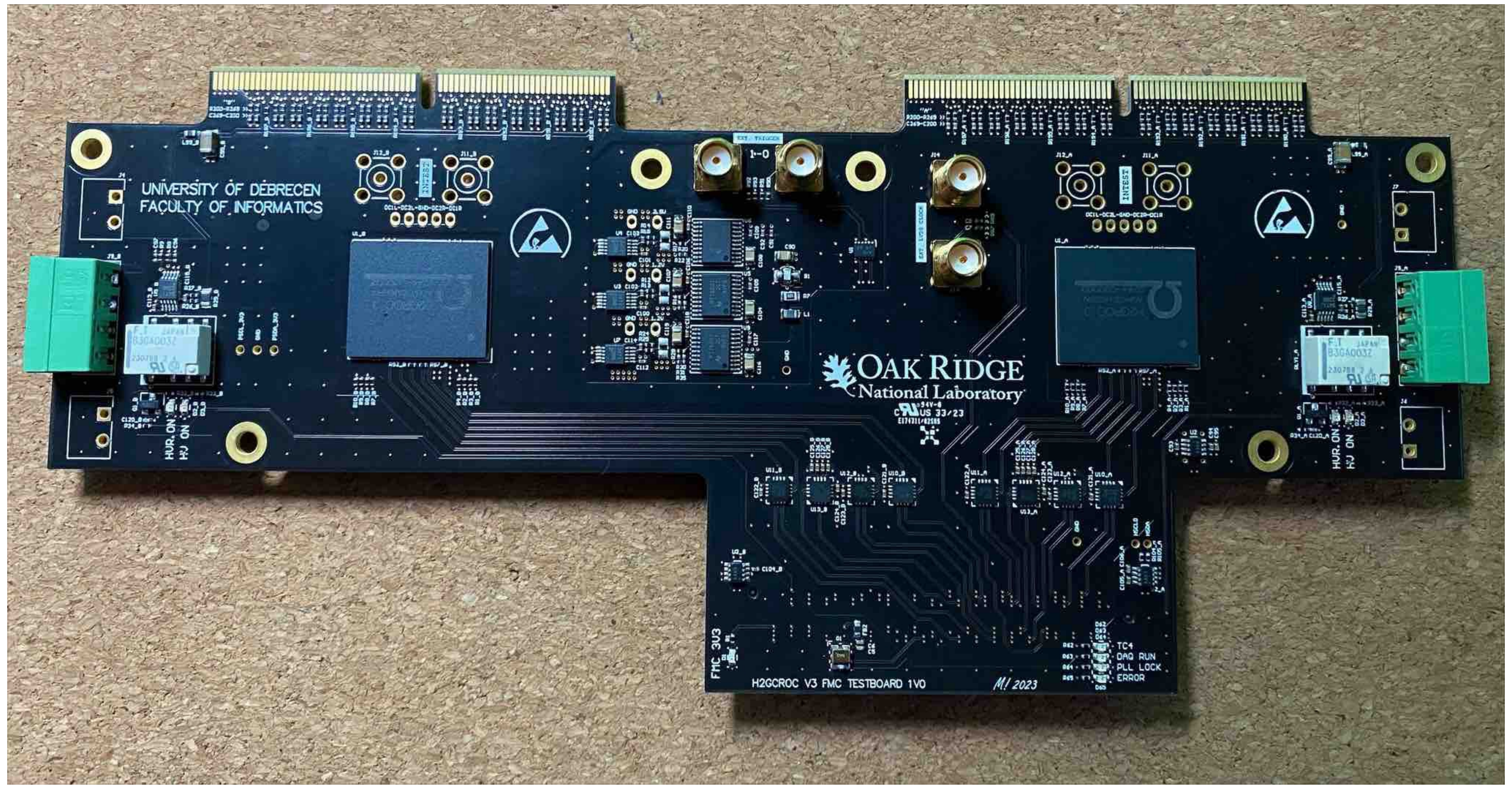


Figure 11: Signal path block diagram of the proposed front-end.



Protoboard designed by LFHCal team to read HGCROC

NB: An alternative solution based on commercial flashADC is also being considered for EEEMCal

ASIC testing/characterization

- Infrastructure for mass testing of ASICs developed at LLR & Omega for CMS
- Expertise & facilities useful for ePIC
- ASICs for protoboards tested LLR
- In addition to ASIC design/fabrication, we aim to maintain French expertise in testing & characterization

Figure 12: HGCROC robotic testing facility at LLR.

Beamtest setup

1st test of complete chain conducted in September @ CERN, jointly with forward HCAL

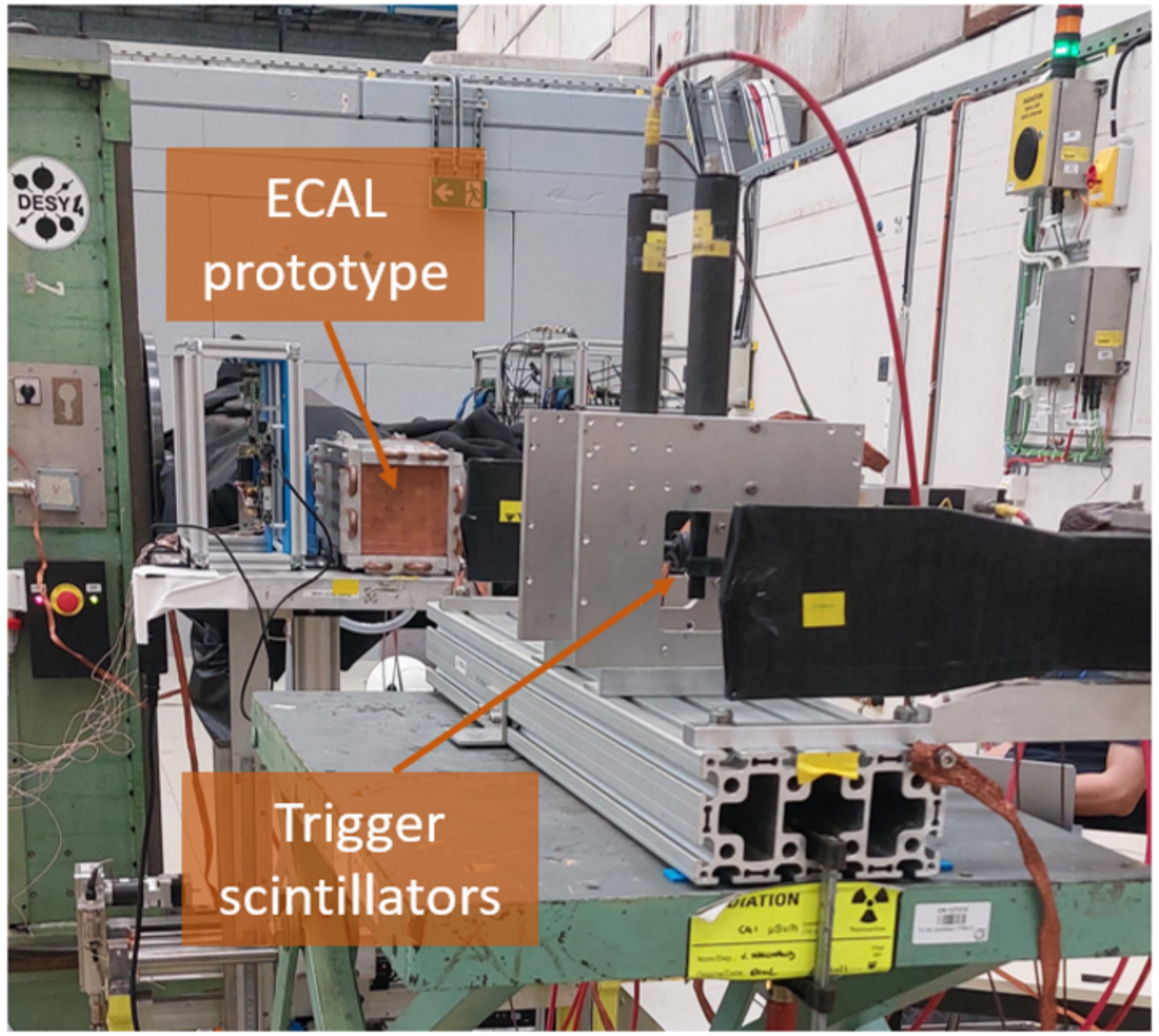


Figure 17: Beam test setup at CERN SP (September 2024).

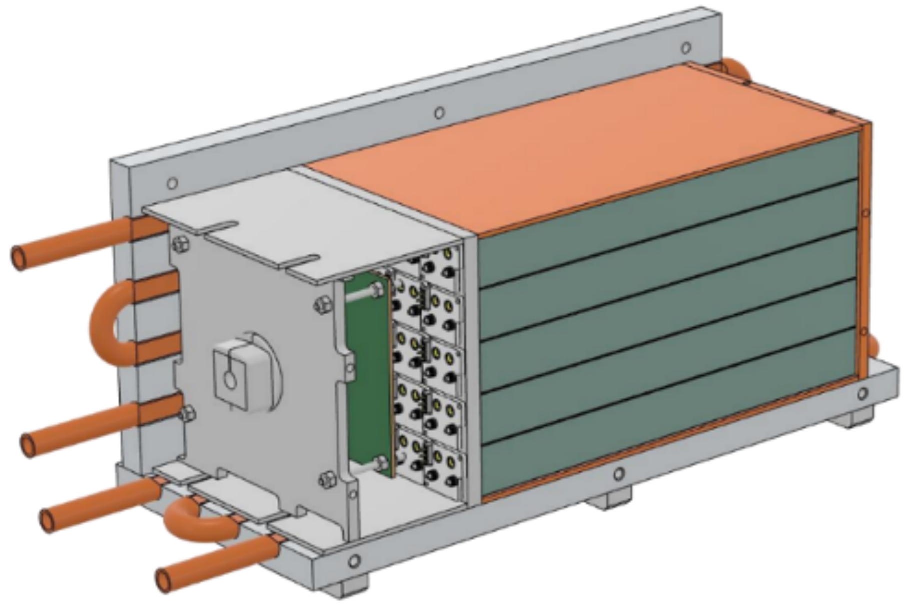
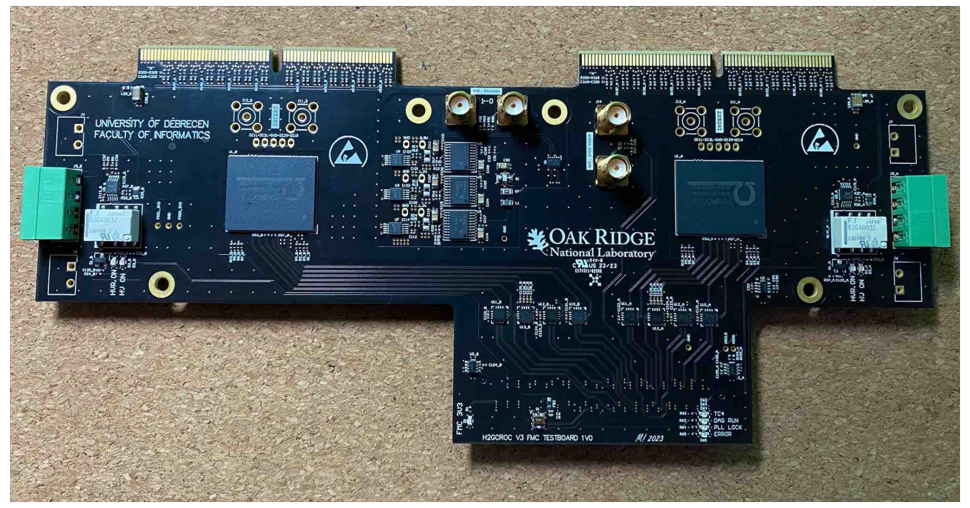


Figure 15: 5x5 PWO crystal prototype designed and built at IJCLab.

5x5 crystal prototype designed at IJCLab
Only 4 crystals equipped for 1st test



Readout identical to forward HCAL
HGCROC protoboard + KCU (FPGA)

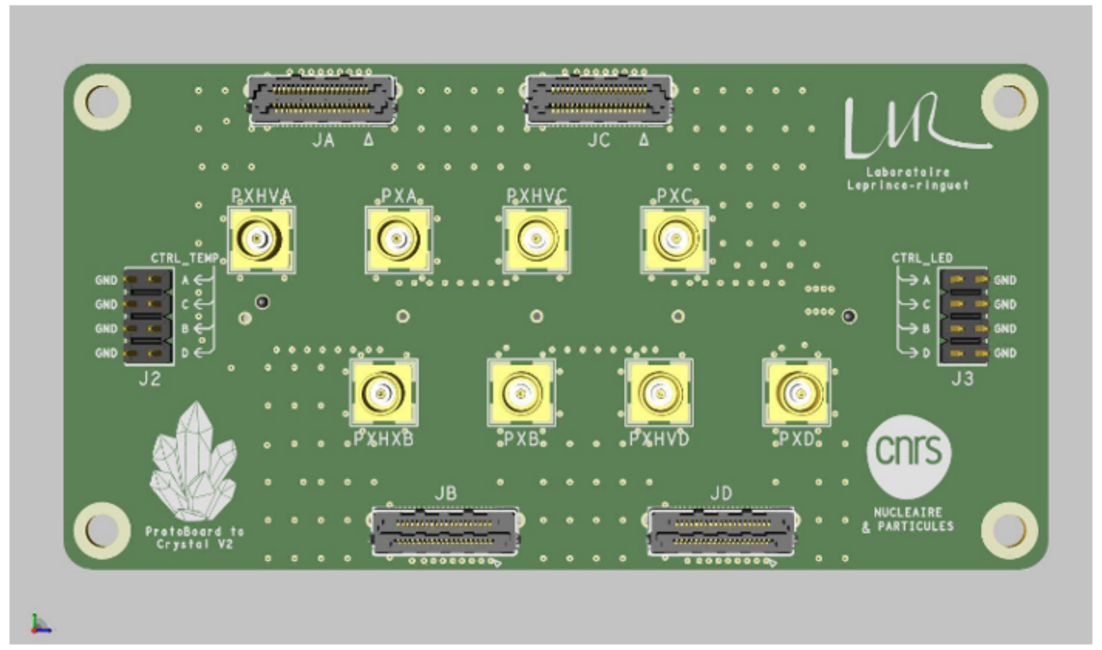


Figure 16: CAD drawing of the interface between the SiPMs and the ASICs.

Interface card between SiPM & ASIC designed by LLR

Beam-test measurements

- Electron data collected at 1-5 GeV
- Waveforms for each of the 16 SiPMs attached to a single crystal, with independent readout
- Signal rise time of 25-50 ns followed by a decay of 100 ns, close to expectation for PWO
- Similar amplitude observed in each SiPM
- Did not manage to get data for configuration with grouped SiPM →currently under investigation on test bench w/ help from OMEGA

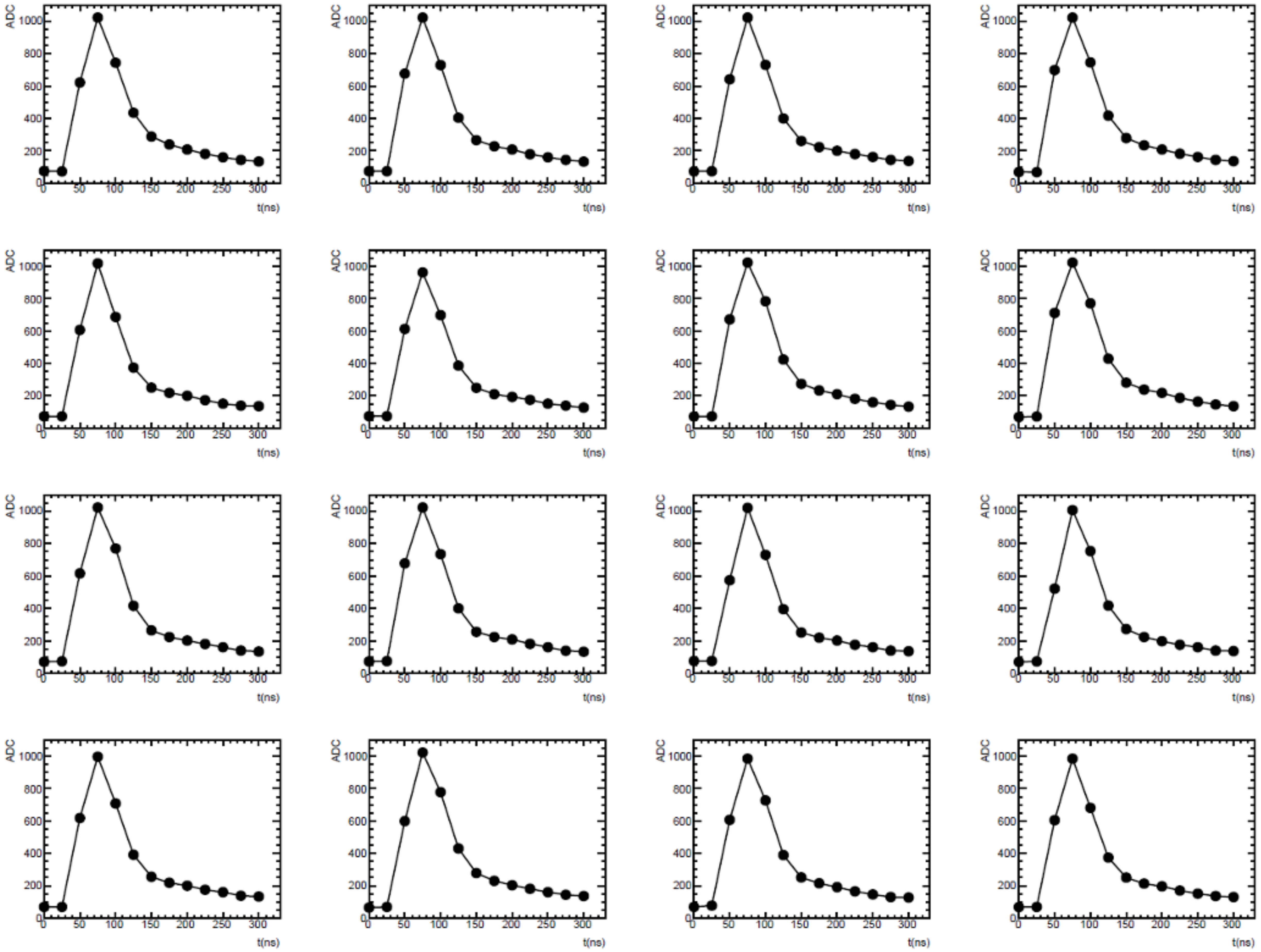


Figure 18: Waveforms for a 5-GeV electron in the 16 SiPM of PWO crystal.

Thermal studies

Thermal simulations were conducted which indicate that detector meets 0.1C stability requirement

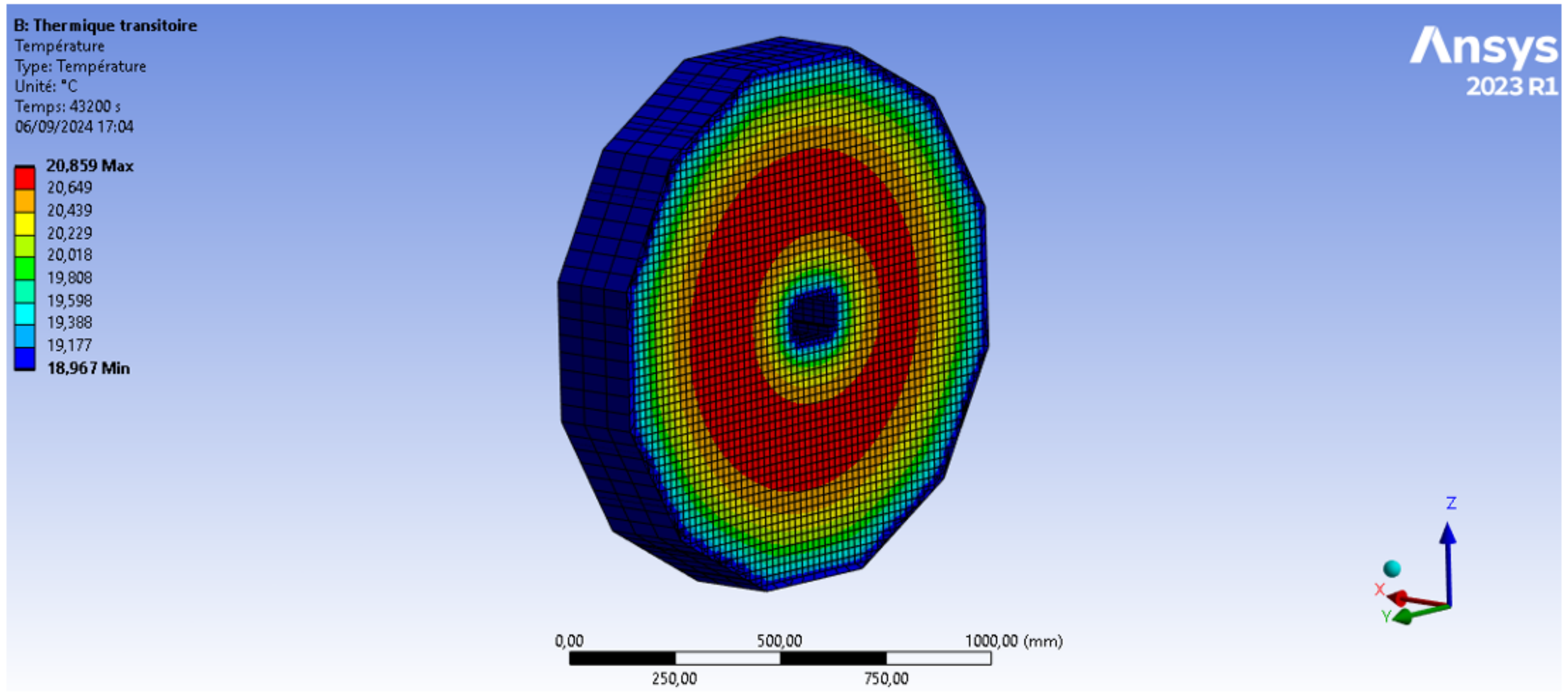


Figure 13: ANSYS simulation of the temperature of crystals. The detector is surrounded by cold (19 °C) plates. Cold plates are also placed in the inner region, around the whole to let the beampipe go through.

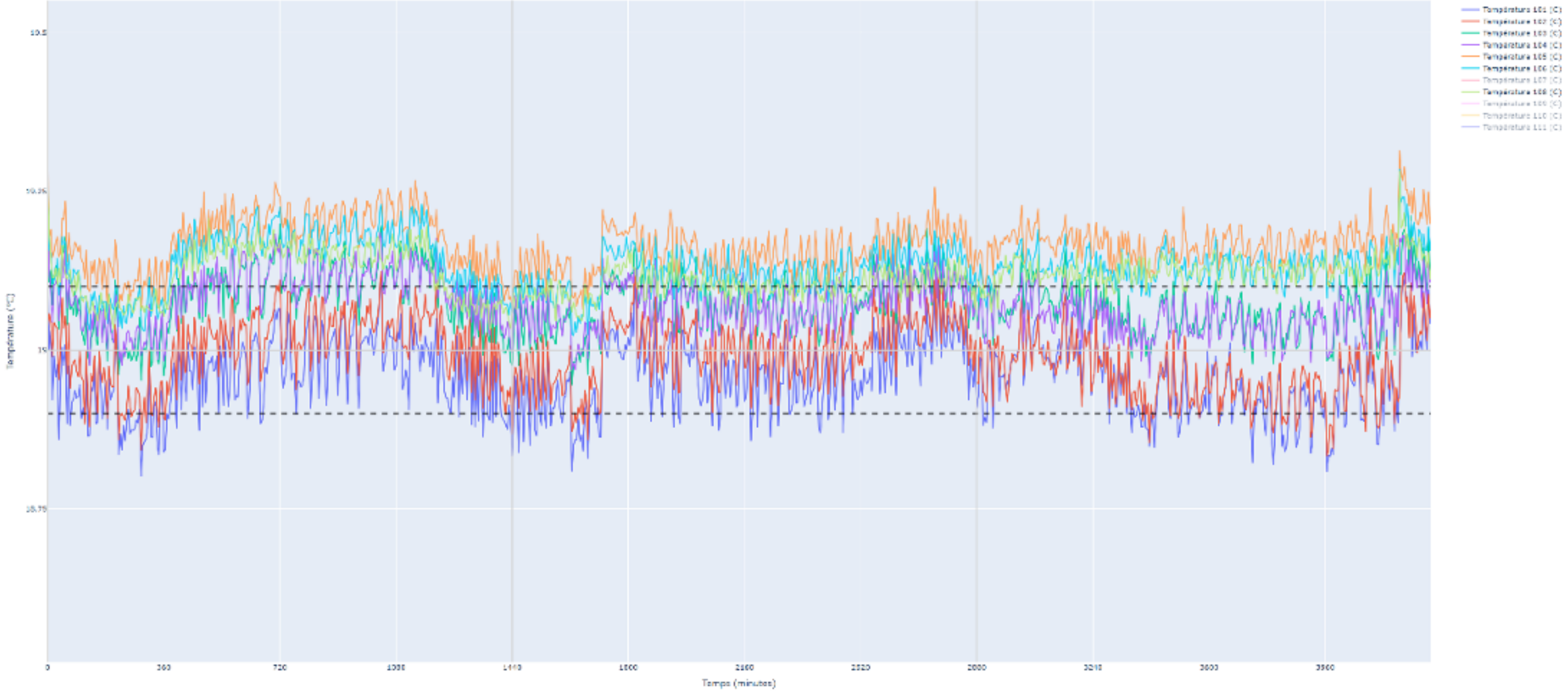


Figure 14: Temperature measured as a function of time at different positions across the PWO crystals during the beam-test measurements at CERN with the 5x5 EEEMCal prototype.

Beam test data is being studied to validate simulations

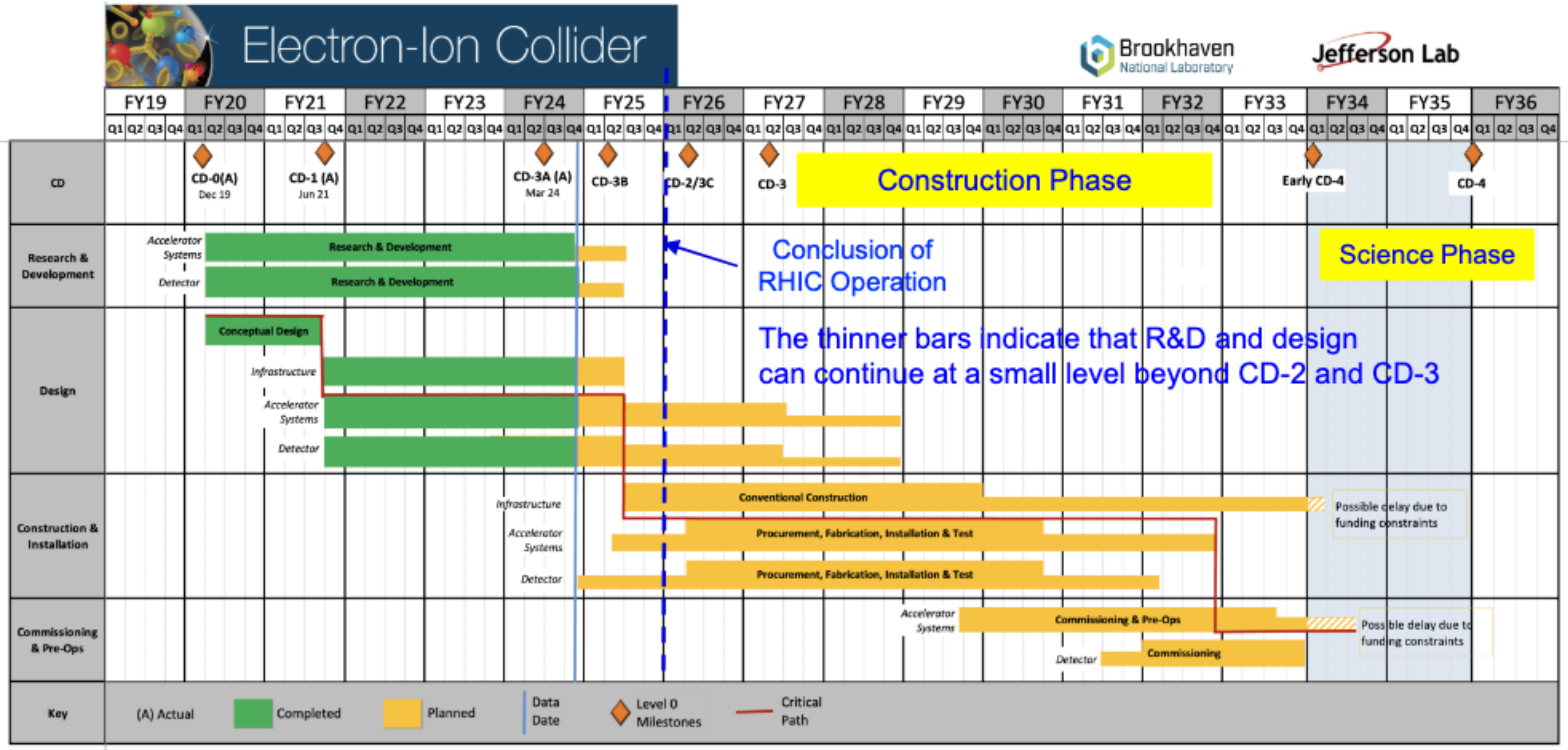
Timeline

EIC Schedule – best guess, dates still under discussion

CD-3A:
Approve start of long-lead procurements
CD-3A items passed final design review
All interfaces related to them are frozen
Authorization received March 28, 2024.

CD-2:
Approve prelim. design for all subdetectors
Design Maturity: >60%
Need "pre-"TDR (or draft TDR)
Baseline project in scope, cost, schedule

CD-3:
Approve final design for all subdetectors
Design Maturity: ~90%
Need full TDR



Past ("FY24") EIC Critical Decision Plan	
CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	March 2024 ✓
CD-3B	**October 2024**
CD-2/3	**April 2025**
early CD-4	October 2032
CD-4	**October 2034**

September 2022 EIC received \$138M DOE Inflation Reduction Act funding → CD-3A

Updated Project Schedule: based on the actual appropriated FY24 funding (\$98M), on uncertain FY25 budget scenarios (President's Budget is ~\$113M, house is ~\$128M, senate is ~\$138M, original EIC Project assumption was >\$200M)

Updated EIC Critical Decision Plan	
CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	March 2024 ✓
CD-3B Review	**January 7-9 2025**
CD-2/3C Review	End of 2025?
CD-3 Review	End of 2026?
early CD-4	December 2034?
CD-4	December 2036?

Electron-Ion Collider
EIC France 2024 R. Ent 9

Design choice should be fixed within the next year, when shift to construction phase begins

Personpower

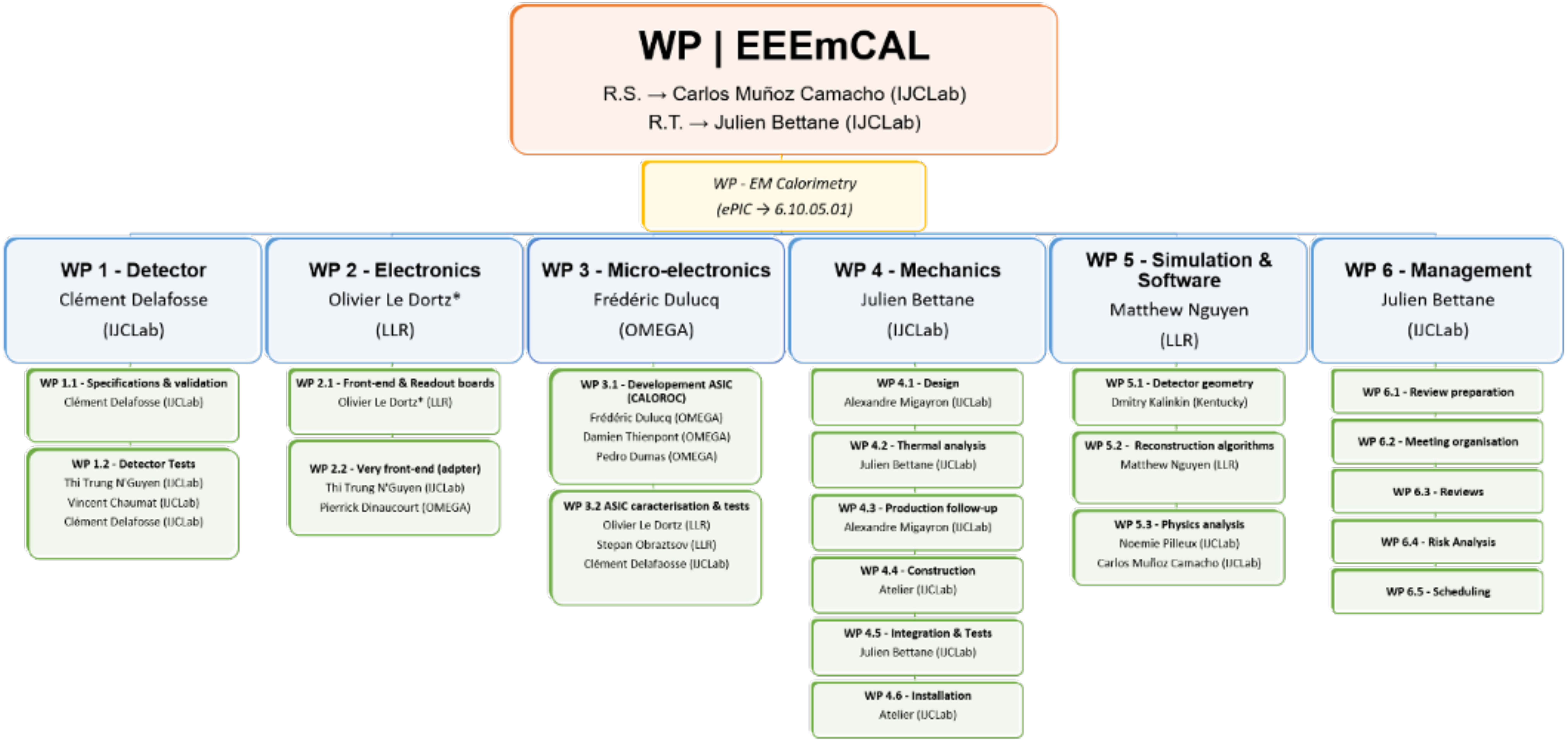
- We have estimated the workforce thru 2030,

  ~ spanning the detector construction phase
- Peak workforce in 2026-2027 at 5 FTE
- Decreases in 2028 during installation phase
- Minimal additional workforce is assumed
  - IR CDD LLR: hiring underway
  - IR LLR: from existing workforce
  - PhD LLR & IJCLab: requested
- The role of US partners TBD

			2025	2026	2027	2028	2029	2030
		Total	6.9	8.9	8.0	5.7	3.4	2.5
		IT	3.7	3.9	3.1	2.4	1.8	0.8
		Chercheur	3.2	5.0	5.0	3.3	1.7	1.7
Ressource	Statut	*Labo*	2025	2026	2027	2028	2029	2030
Bernard Mathon	IE	IJCLab	5	5	5	5	2,5	
Carlos Dominguès	AI	IJCLab	5	5	15	25	25	
Brice Geoffroy	T	IJCLab	5	5	5	5	5	
Miktat Imre	AI	IJCLab	5	5	15	25	25	
Sébastien Olmo	T	IJCLab	5	5	15	25	25	
	T	IJCLab	2,5	2,5	2,5	2,5	2,5	
Julien Bettane	IR	IJCLab	60	60	60	60	60	50
Alexandre Migayron	AI	IJCLab	75	75	75			
Alice Thiebault	AI	IJCLab	2,5					
Thi Nguyen Trung	IE	IJCLab	15					
Vincent Chaumat	IE	IJCLab	25	25	10			
Clément Delafosse	IR	IJCLab	30	30	30	20		
Jérémy Favre	AI	IJCLab	5	5	5	5		
Sébastien Pitrel	AI	IJCLab	2,5					
Olivier Le Dortz	IR	LLR	30	30	30	30	30	30
	IR CDD	LLR	100	100				
	IR	LLR		40	40	40		
Pedro Dumas	Doctorant	OMEGA	100	100	100			
Matthew Nguyen	CR	LLR	25	50	50	50	50	50
	Postdoc	LLR	13	50	50	38		
	PhD student	LLR	13	50	50	38		
Carlos Munoz Camacho	DR	IJCLab	70	70	70	70	70	70
	PhD student	IJCLab	25	100	100	75		
Mostafa Hoballah	CR	IJCLab	50	50	50	50	50	50
Eric Voutier	DR	IJCLab	20	20	20			
Jérémy Favre	AI	IJCLab	5	5	5	5		
Sébastien Pitrel	AI	IJCLab	2,5					

Table 1: Human resources for the EEEMCal project.

Work breakdown structure



*preliminary name attribution

Conclusion / outlook

- We propose a strong French contribution to the backward EMCal (EEEMCal) for ePIC
  - Essential detector for all of the physics goals of the EIC program
- France has played a leading role in the EEEMCal design choices in terms of mechanical structure, choice of active materials & signal detection technology
- We are currently in the prototype testing phase
  - We recently collected data with the full chain: crystal-SiPM-HGROC-DAQ
  - Upcoming beam tests at DESY w/ 5x5 prototype will allow us to test different readout configurations
  - Aim for adoption of Omega ASIC for this detector
- Planning for the construction phase of the detector is starting to take shape