Advancement and Innovation for
Detectors at Accelerators

WP8.2.2 status report

Future Liquid Noble Gas Calorimeters

Jana Faltova (Charles University)

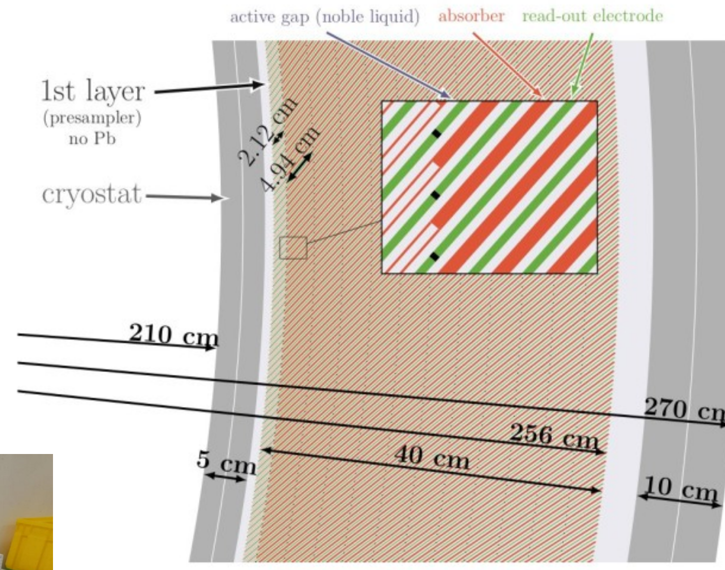
Participants: CERN, CNRS-IJCLab, Charles University

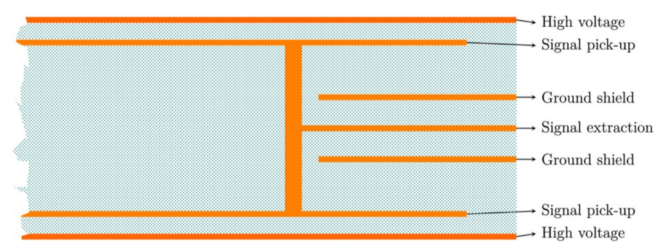
25/4/2023

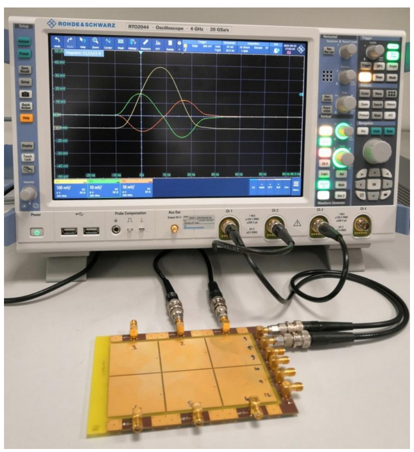
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

Introduction

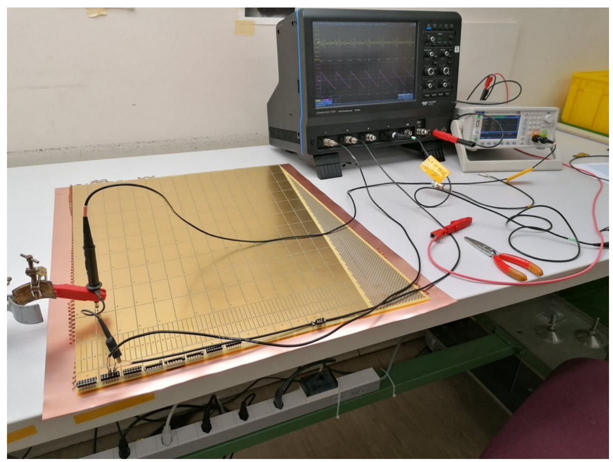
- **Task WP8.2.2**
  - Design of the read-out electrodes for the future liquid noble gas calorimeters
- **Milestone**
  - MS31: report for the St. Com. (due date: Feb 2023) **DONE**







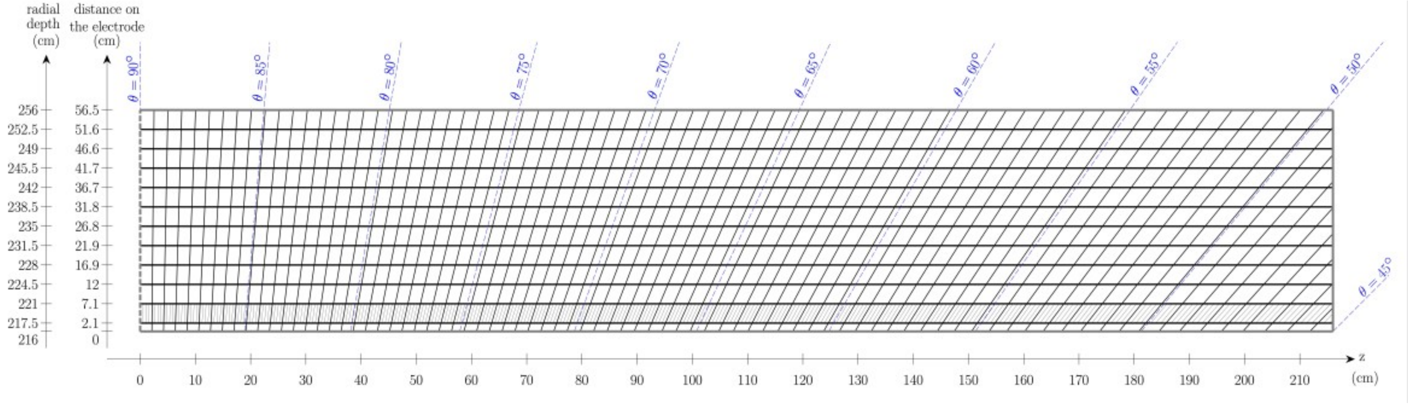
CNRS-IJCLab



CERN

Noble liquid gas calorimeter

- **Baseline geometry**
  - **1536 Pb absorbers inclined by ~50.4°, |z| ≤ 2 m along the beam axis**
  - 2 mm Pb absorber; 1.2 – 2.4 mm of LAr; 1.2 mm of readout PCB
  - 22 X_0 (40 cm) of the active ECAL region
  - Placed in the aluminium cryostat (5 cm in front, 10 cm in back)
- **Granularity**
  - 12 longitudinal compartments in radius (including pre-sampler for energy corrections and strips for π^0 identification)
  - Typical cell size ~ 2 x 2 x 3 cm^3

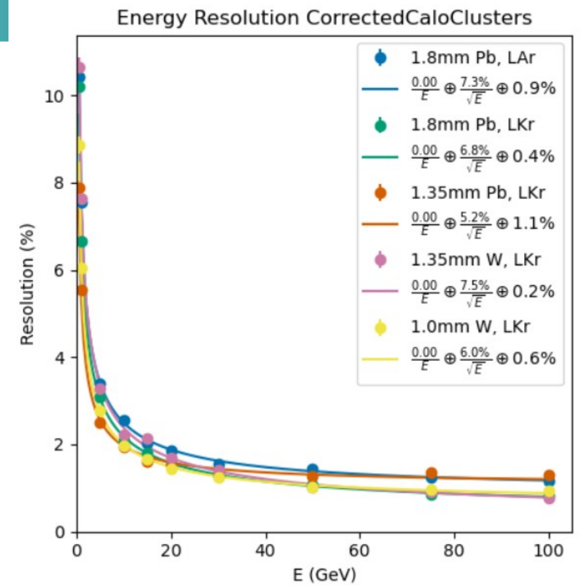


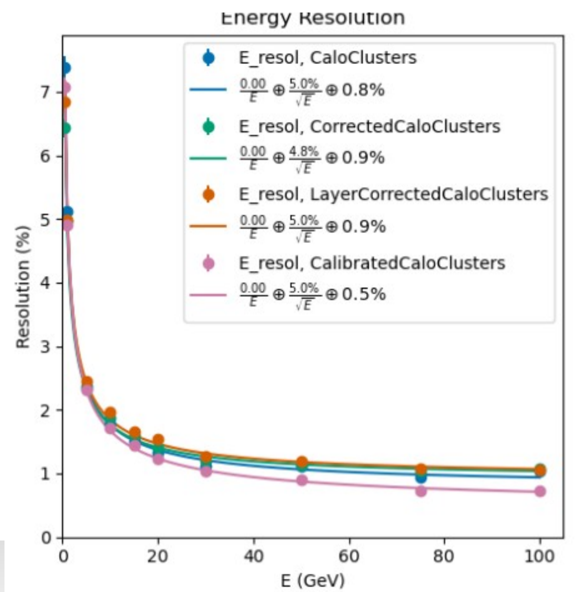
Geometry under consideration

- **Modifications of the geometry to improve performance**
  - LKr as the active medium, Pb absorbers
    - 5% sampling term
  - LKr active medium with W absorber
  - Absorbers with trapezoidal shape
    - Constant sampling fraction
    - 5% sampling term, reduction of the noise term

→ “ultimate” performant geometry

- **Advanced reconstruction techniques (clustering, energy calibration using MVA) are also options for the performance optimisation**

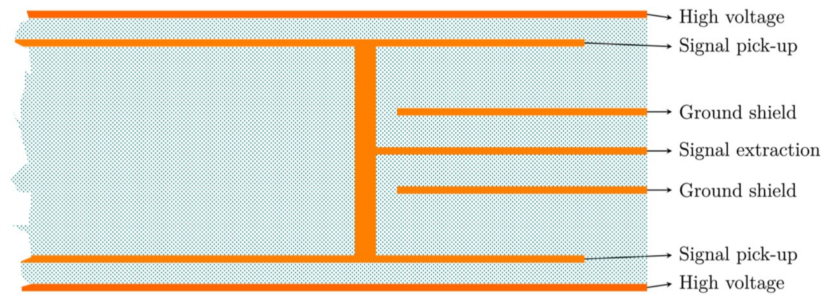


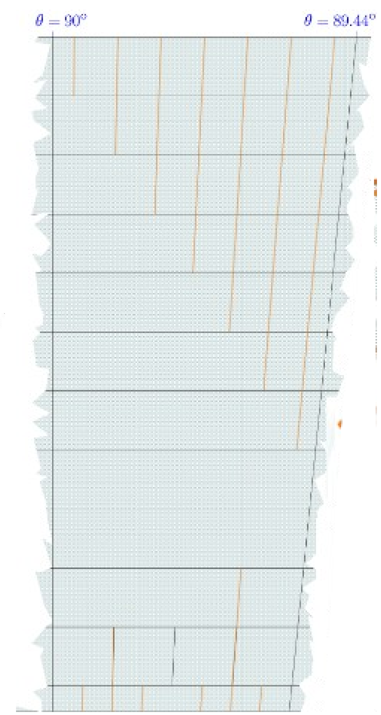


Nicolas Morange, CNRS-IJCLab

Design of PCB readout

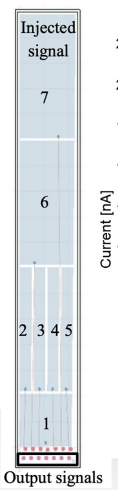
- Printed Circular Boards (PCBs) with seven layers
  - HV, signal pad, shield, signal trace, shield, signal pad, HV
- Finite Element Method calculations in ANSYS
  - Peak-to-peak crosstalk below 1% seems to be easily achievable
    (signal shaping time larger than 100 ns even without ground shields, a shorter shaping time will be possible with shields)
- Average signal-over-noise ratio for a MIP between 5 and 10 is reached

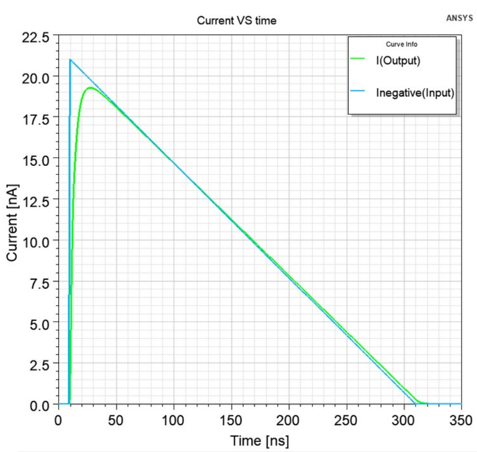


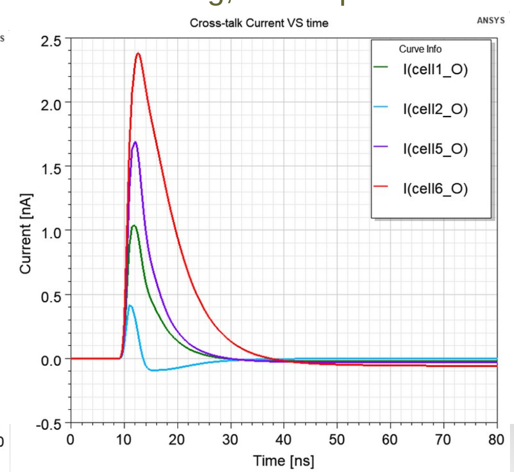


Brieuc Francois, CERN

Example: no shielding, no shaper

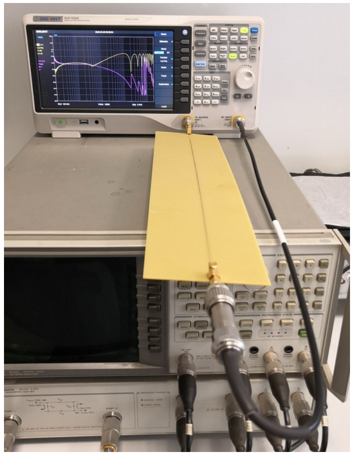




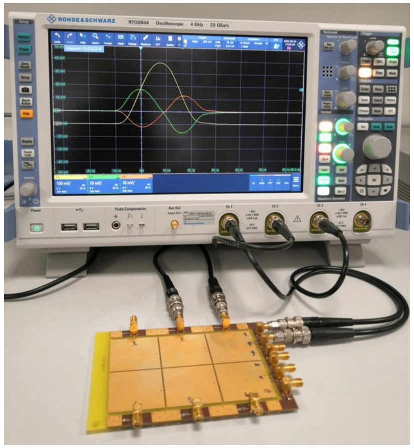


Ronic Chiche, CNRS-IJCLab

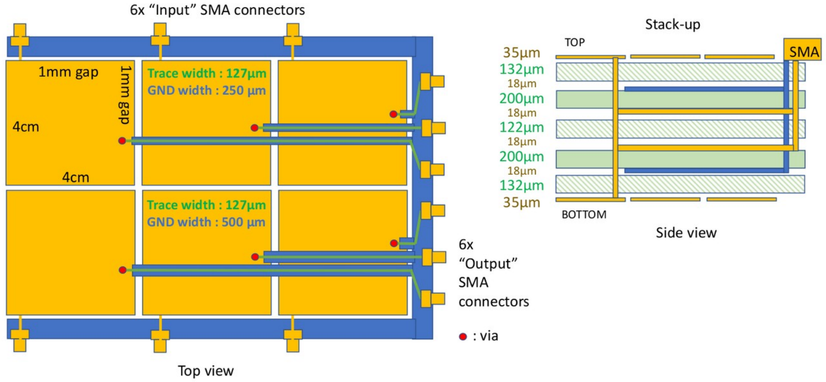
Prototype 1



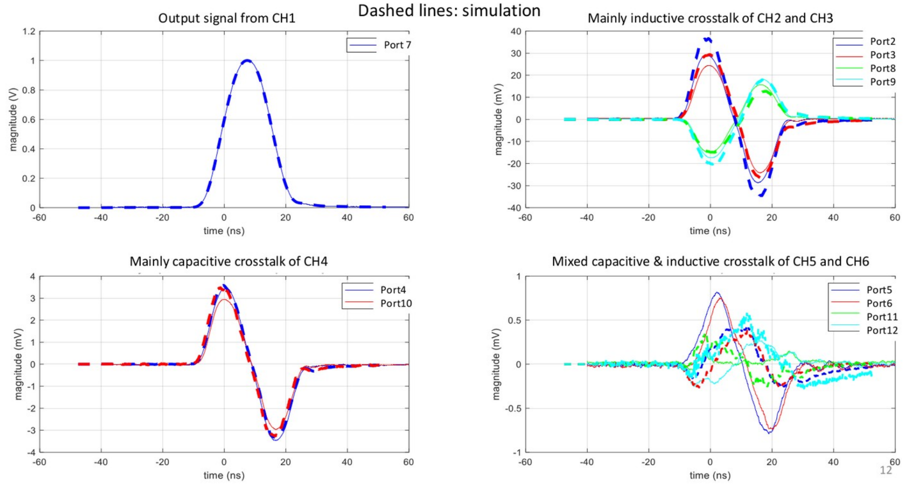
Prototype 2



Proto2 design

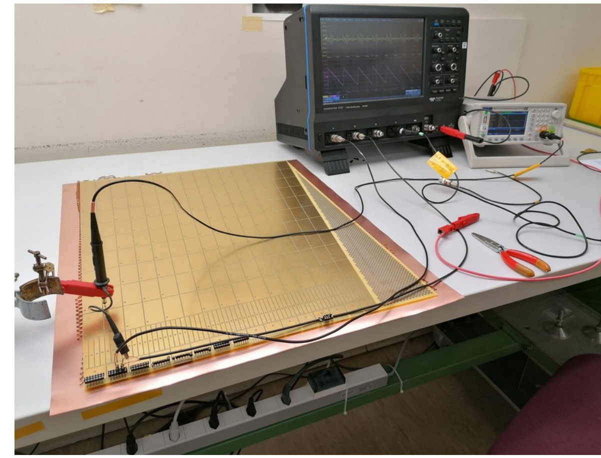


Dashed lines: simulation



- PCB with even number of layers
- Measurements of the scattering matrix *S*-parameters -> impedance and attenuation factors
- Measurements of crosstalk; total capacitance, inductance and coupling parameters per channel extracted
- Overall good agreement between simulations and measurements

CERN

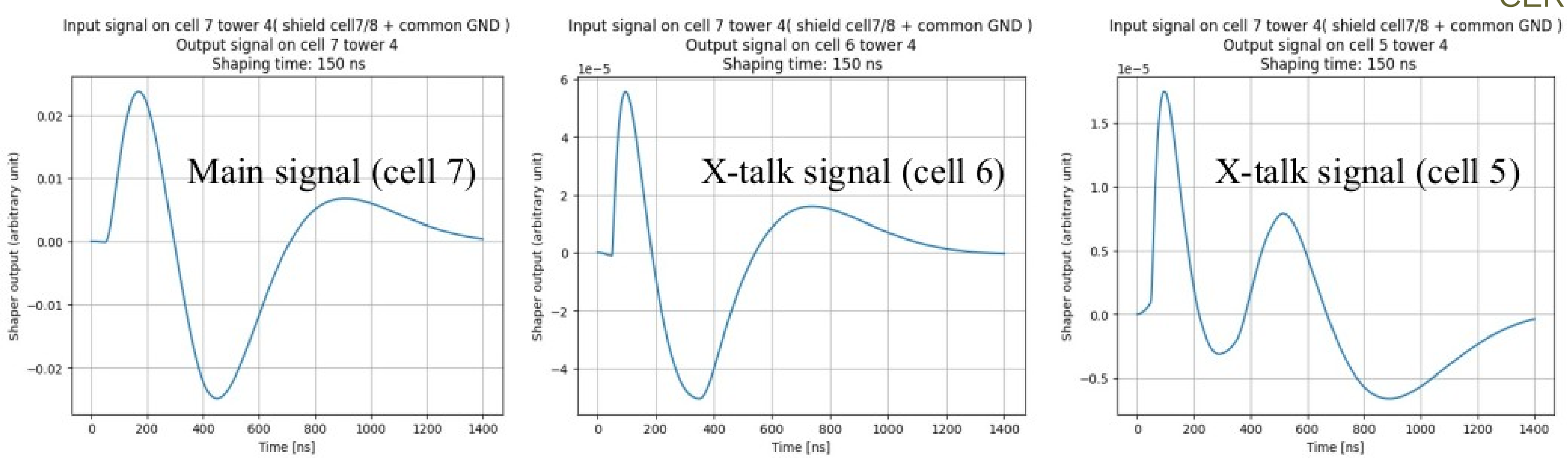


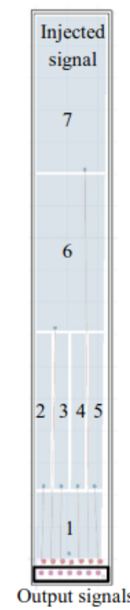
- Prototype with 1:1 scale in the radial direction with 16 'theta towers' with different layouts (58 cm x 44 cm)
- Odd number of layers PCB achieved by chemically removing one of the copper plane from the pre-preg core
- Triangular input signal injected, the response in the inner cells in the same tower extracted using a 50 Ω readout probe; software shaper
  - Good agreement with the simulations, could be improved especially for small signals and short shaping times

-> **Sub-percent crosstalk reachable for regular cells within the tower with a single ground shield**

Brieuc Francois, CERN

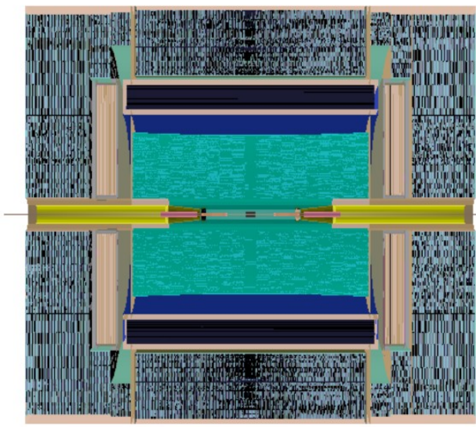
CERN





Software development

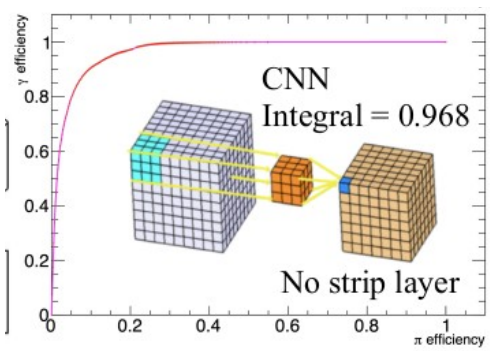
Charles Uni

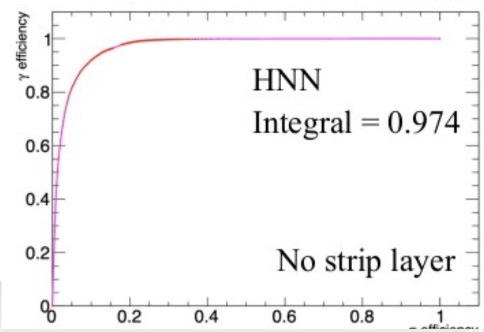


- Full simulation available in Key4HEP
  - Detector description
  - Reconstruction
    - Corrections: sampling fraction, dead material correction
    - Emulation of electronics noise
    - Clustering
- Noble liquid calorimeter in the full detector concept for FCC-ee
  - IDEA drift chamber tracker
  - LAr ECAL barrel & endcaps
  - TileCal HCAL barrel & endcaps
  - Muon tagger

-> Code ready for performance and physics studies

- γ / π^0 **separation studies with MVA**: first results lead to 95% γ efficiency for 10% π^0 contamination for the whole energy range





CERN

Summary

- Finite Element Method simulations of the readout electrodes performed
- Protypes of PCBs prepared at CNRS-IJCLab and CERN
  - Measurements show good agreement between simulations and measurements, still room for improvement
  - Sub-percent cross talk is easily reachable in the scenario with a single ground shield
- Full detector concept ready for physics studies in FCCSW
- Next steps
  - Prepare a new electrode design incorporating the lesson learned with the current version

Backup

Detailed results from simulations

B. Francois (CERN)

2 shields

Cross-talk (%) / Shaping time (ns) ↓	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
No shaper	0.54	0.85	0.85	2.31	2.62	9.11
20	0.03	0.04	0.01	0.09	0.11	0.75
50	0.01	0.02	0.0	0.04	0.05	0.37
100	0.01	0.01	0.0	0.02	0.03	0.23
150	0.0	0.01	0.0	0.02	0.02	0.18
200	0.0	0.01	0.0	0.01	0.02	0.15
300	0.0	0.0	0.0	0.01	0.01	0.13

1 shield

Cross-talk (%) / Shaping time (ns) ↓	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
No shaper	2.42	0.82	0.87	3.86	4.14	10.36
20	0.4	0.05	0.04	0.58	0.58	1.72
50	0.18	0.02	0.01	0.26	0.26	0.79
100	0.1	0.01	0.0	0.14	0.14	0.45
150	0.07	0.01	0.0	0.11	0.11	0.34
200	0.06	0.0	0.0	0.09	0.09	0.28
300	0.05	0.0	0.0	0.07	0.07	0.23

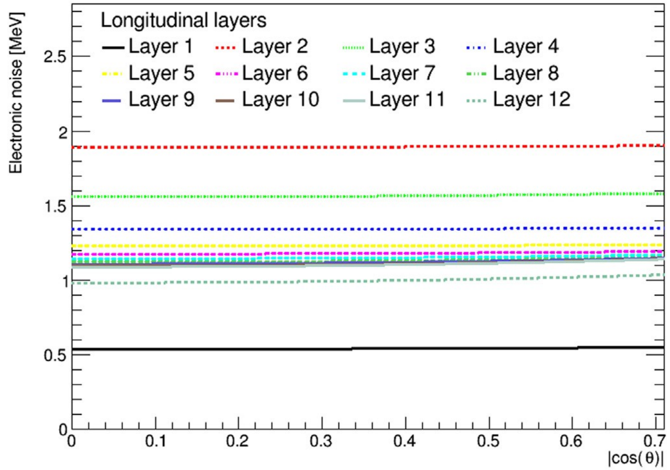
0 shield

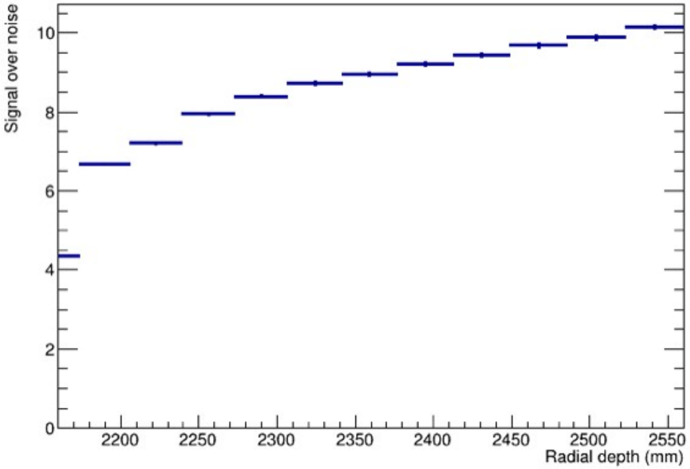
Cross-talk (%) / Shaping time (ns) ↓	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
No shaper	6.27	2.6	3.2	8.75	8.61	15.96
20	0.7	0.1	0.1	0.99	0.92	2.58
50	0.3	0.02	0.02	0.43	0.4	1.14
100	0.17	0.01	0.01	0.24	0.23	0.64
150	0.13	0.01	0.0	0.18	0.17	0.48
200	0.1	0.01	0.0	0.15	0.14	0.4
300	0.08	0.0	0.0	0.12	0.11	0.32

Full readout chain

Analytical description of the full readout chain: two ground shields, a charge preamplifier (e_n = 0.5 nV/ √Hz and i_n = 1 pA / √Hz), CR^2 – RC^2 shaper (200 ns), followed by 5 m of 100 Ω coax cable

Brieuc Francois, CERN





Cold electronics

CNRS-IJCLab

Cold electronics ?

- Noise master formula: $N \sim C_d \sqrt{\frac{4kT}{g_m \tau_p}}$
- Cold electronics: gain on C_d, T and g_m
- **Extremely low noise easily achievable**

$$C_{cable} = \frac{\tau_{delay}}{Z_c}$$

	ENC (keV)	Peaking time = 500 ns
Warm electronics L = 5 m C_{cable} = 500 pF / 1 nF	Cd = 100pF – 50/25 Ω	1400 / 2500
	Cd = 200pF – 50/25 Ω	1600 / 2800
	Cd = 400pF – 50/25 Ω	2100 / 3200
	Cd = 800pF – 50/25 Ω	2900 / 4100
Cold electronics L=10 cm C_{cable} = 10 pF / 20 pF	Cd = 100pF – 50/25 Ω	140 / 150
	Cd = 200pF – 50/25 Ω	250 / 260
	Cd = 400pF – 50/25 Ω	470 / 470
	Cd = 800pF – 50/25 Ω	910 / 910

How ?

- Challenges:
  - Heat dissipation
  - Difficulty for repair
- We know how to do it:
  - DUNE example
- Very first studies
  - HGCROC in Liquid N at IJCLab
  - Check behaviour of analogue and digital parts