Resistive technologies for Time Projection Chambers

NA61++/SHINE: Physics opportunities from ions to pions

Guillaume Eurin
for the CEA/IRFU neutrino group

CEA-Saclay/DRF-IRFU-DPhP

2022/12/16

Irfu
Institut de recherche
sur les lois fondamentales
de l'Univers

Commissariat à l'énergie atomique et aux énergies alternatives
French Alternative Energies and Atomic Energy Commission

The CEA is a public research organization

Key figures
(2020)

- **> 20 000** employees
- **5** billion euros (civil and defense)
- **> 5 000** publications
- **> 440** European Projects

Digital Transition

Remediation and dismantling

Fundamental Research

Defense and Security

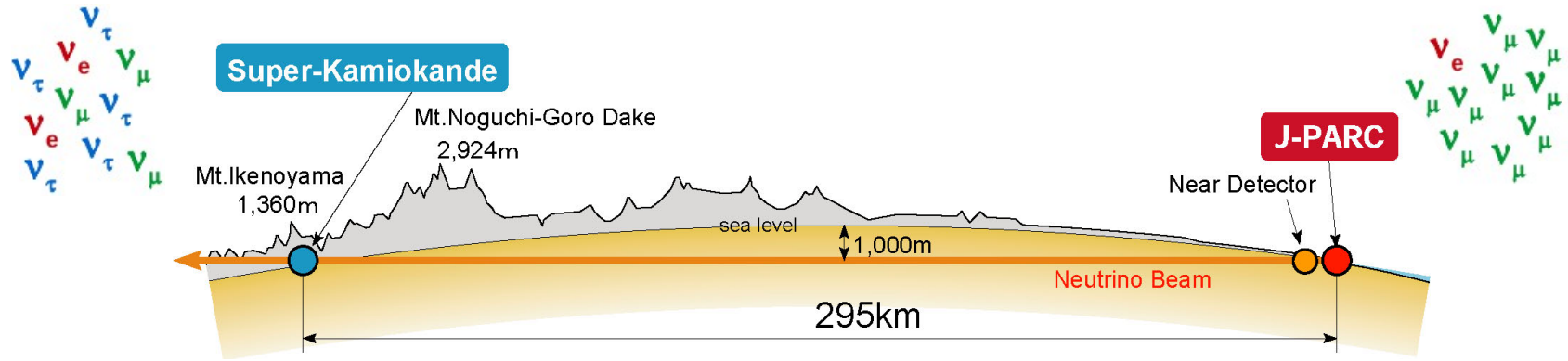
Energies

Healthcare technologies

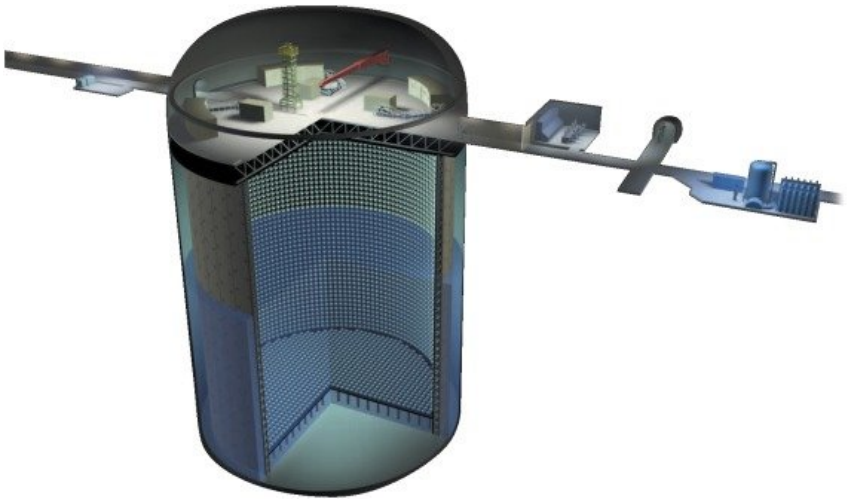
Irfu — Institut de recherche sur les lois fondamentales de l'Univers

GANIL	DPhP	DPhN	DAp-AIM	DEDIP	DIS	DACM
Département GANIL unité de gestion des personnels CEA affectés au GIE Grand accélérateur national d'ions lourds	Département de physique des particules	Département de physique nucléaire	Département d'astrophysique UMR - AIM	Département d'électronique, détecteurs et informatique pour la physique	Département d'ingénierie des systèmes	Département des accélérateurs, de cryogénie et de magnétisme

Tokai-to-Kamioka: T2K long-baseline experiment

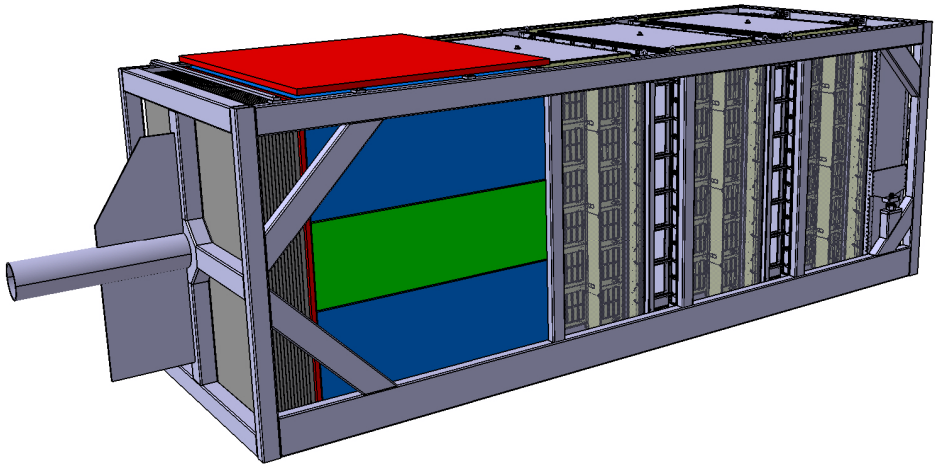


- Far detector: Water-Cherenkov Super-Kamiokande



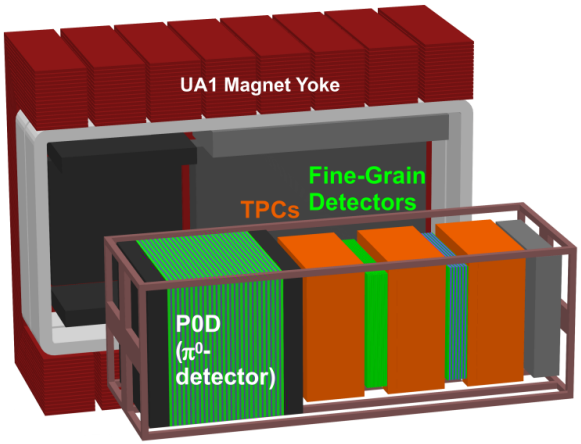
- Upgrade planned to T2HK
  SK to be replaced by HK

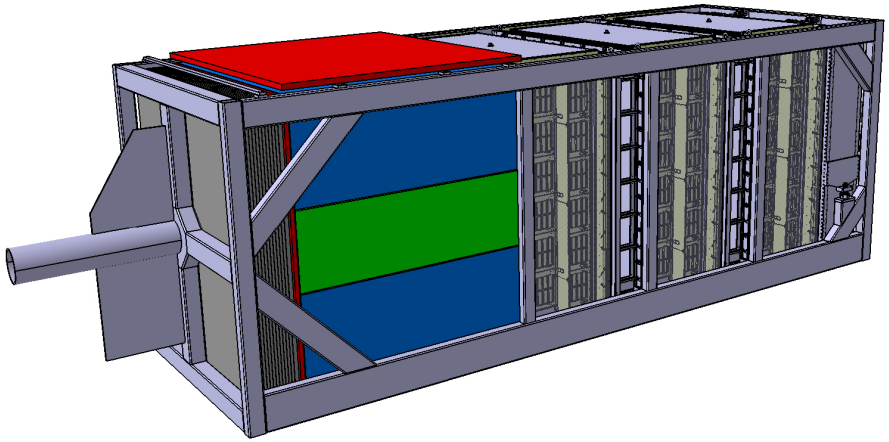
- Several near detectors:
  INGRID and ND280



- Upgrade of ND280 ongoing
  P0D $\Rightarrow$ sFGD + HA-TPCs

TPCs for the near detector of T2K-ND280

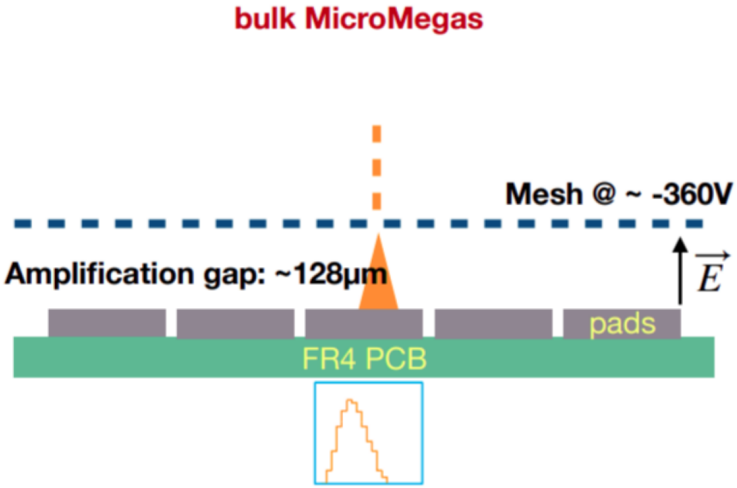


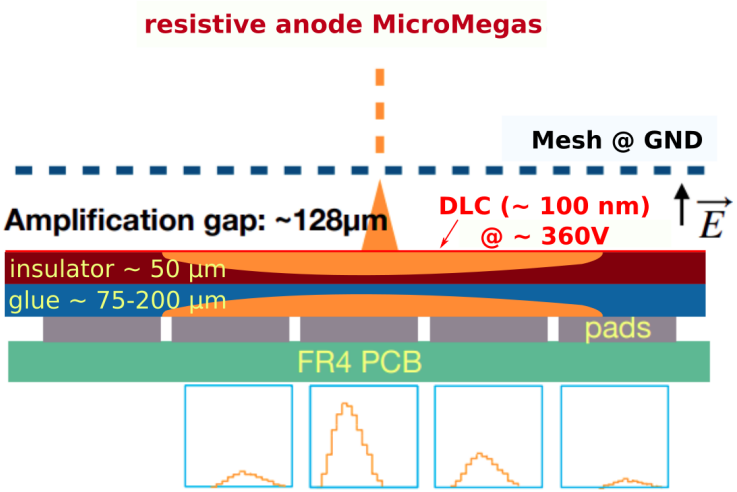


- 1998: TPC studies conducted for ILC with Micromegas R&D
- 2009: 3 vertical TPCs with 72 bulk Micromegas ($\sim$ 9 m^2)
- 2017: Encapsulated Resistive Anode bulk Micromegas (ERAM) proposed for T2K ND280-Upgrade ($\sim$ 5 m^2)
- 2023: Installation of ERAMs in ND-280
- Future: Growing community around resistive Micromegas technology, promising and innovative technology for future experiments

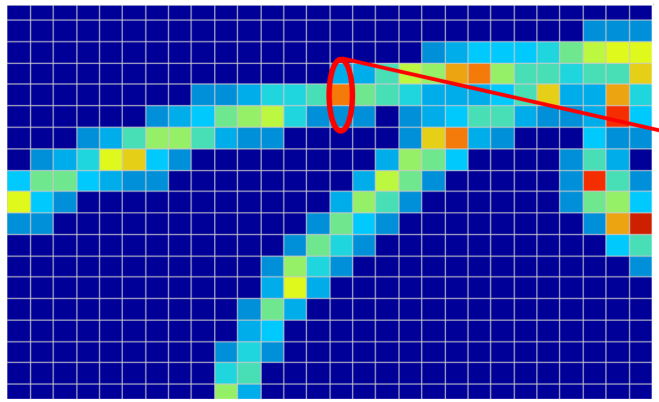
Encapsulated Resistive Anode bulk Micromegas (ERAM)

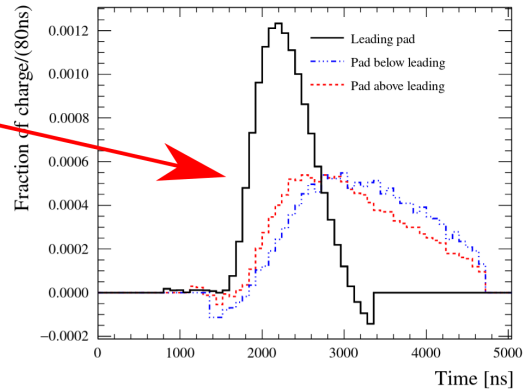
- Bulk Micromegas, mature and mastered technology
- New resistive Diamond-Like Carbon provides spark protection
- Charge spreading over multiple pads (ILC-TPC R&D) improves spatial resolution with cost-effective pad size





$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx \text{shaping time (few 100 ns)} \\ RC_{[ns/mm^2]} = \dfrac{180\ R_{[M\Omega/\blacksquare]}}{\frac{d_{[\mu m]}}{175}} \end{cases}$$





ERAMs prototyping and development steps

CERN/T9 test beam
D. Attié et al. NIM A984, (2020), 163286
doi:10.1016/j.nima.2019.163286

DESY test beam
D. Attié et al. NIM A1025, (2022), 1661109
doi:10.1016/j.nima.2019.166109

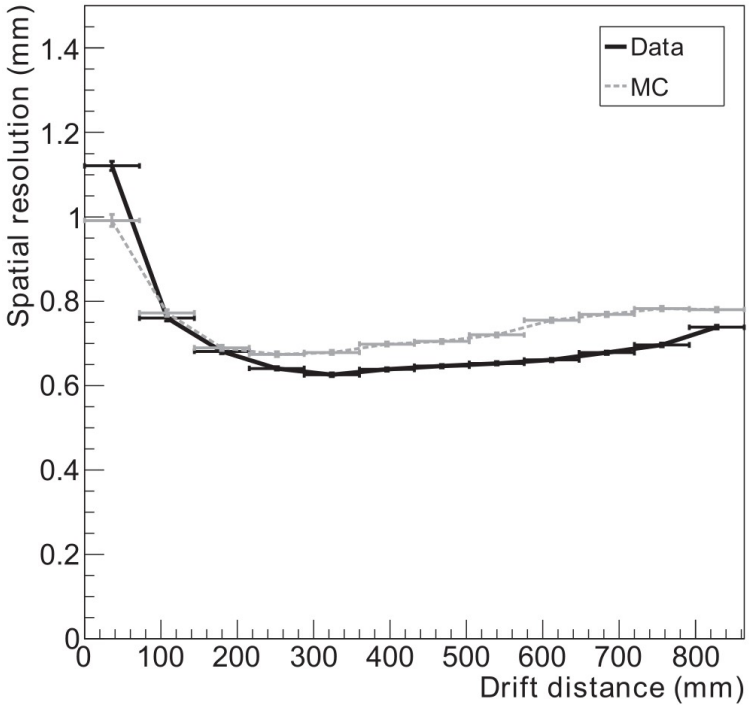
ERAM-01 @ DESY 2021
½ TPC mockup @ CERN/T10 sept. 2022

	2018 MM0-DLC#	2019 MM1-DLC1 & 2	2020 ERAM-P1 & P2	Production ERAM-xx (ERAM-01-28)
Readout PCB	Original T2K-TPC	HA-TPC V1 +ARC FEE	HA-TPC V2 +final FEE V1	HA-TPC V2 +final FEE V2
Size	34 ×36 cm²	34 ×42 cm²		
Pad size	6,85 ×9,65 mm²	10,09 ×11,18 mm²		
Number of pads	1728 (48 ×36)	1152 (32×36)		
DLC resistivity (MΩ/■)	~2,5 (original foil)	0,32-0,44 (foils) 0,2-0,27 (on detector)	0,28-0,40 (foils) 0,15-0,22 (on detector)	**~1 (foils) / ~0.28-0,4 (det.)** Top TPC: 1-1.5 (foils) **After baking: 0,4-0,55**
RC_{design} [ns/mm²] RC_{data} [ns/mm²]	~260	50<RC<70 X-ray scan to process	15<RC<23	**35<RC<50** **102<RC<145 (this talk)**
Insulation layer 50 µm APICAL +	200 µm glue	75 µm glue	200 µm glue	150 µm glue
Spatial resolution (µm) Beam (Horizontal tracks) Cosmics	300 (0T)	MM1-DLC1 200 (0 or 0.2T) 700 (MM1-DLC2, @370V)	300-350 (ERAM-Px @370V)	@ DESY 07/21 380-300 (ERAM-01)

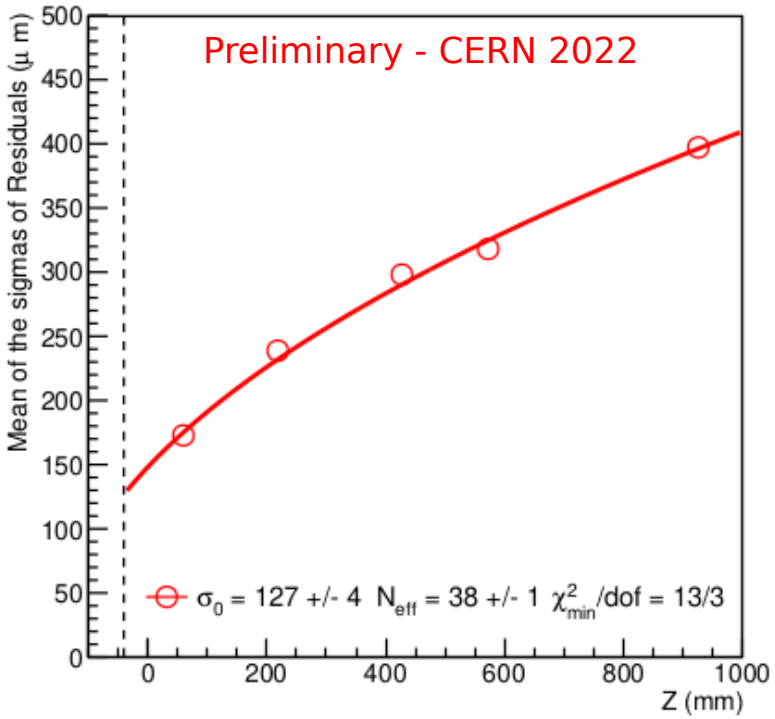
- RC_{design} from measured R and calculated C
- Main parameters changing during prototyping:
  DLC resistivity and insulation layer thickness
- Target performances reached with all designs

ND280-Upgrade TPCs performance requirements

- Current ND280 TPCs



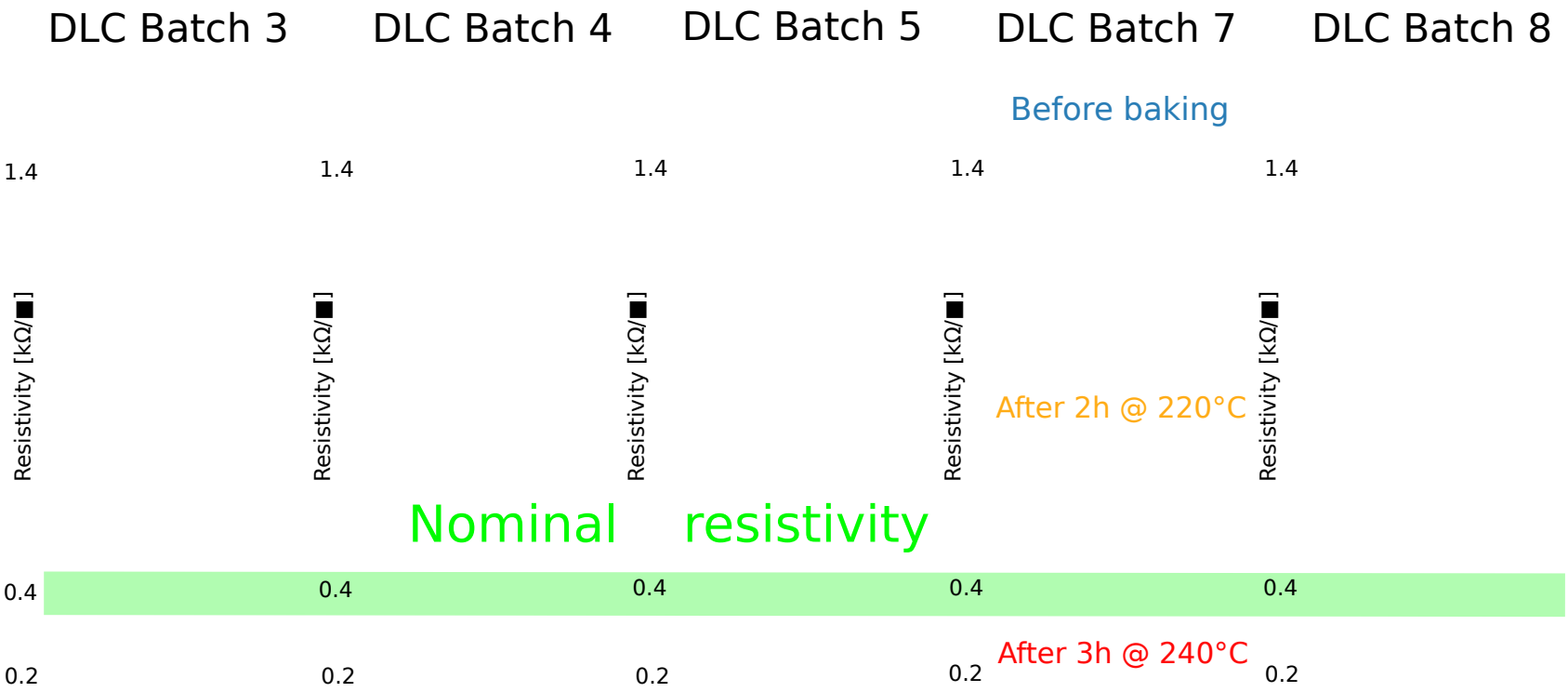
- ERAMs at CERN-T10



Ref: S. Hassani, J-F Laporte et al. (IRFU)

- Momentum reconstruction:
  - Relatively lose requirements for ND280-Upgrade: 10% @ 1GeV
  - Factor of 3+ improvement with RC and granularity tuning $\Rightarrow$ flexibility
- Particle identification through dE/dx
  - Energy resolution: $\sim$ 10 % (PID: 45 % larger dE/dx for e^- than μ/π)
- Know-how in detector building and longevity over time demonstrated

DLC foil selection for ERAMs



- Batch 4 with nominal resistivity ⇒ 9 final detectors
- Batch 3 and 5 with half nominal resistivity ⇒ Prototypes
- Bacthes 7 and 8 needed 2 bakings to provide nominal resistivity ⇒ ∼ 8 final detectors
- 21/32 final detectors produced

CERN EP-DT-DD Micro-Pattern Technologies service

Talk by Rui de Oliveira at the MPGD 2022 conference

Title of project: *DLC based electrodes for future resistive MPGDs*

Contact person: *name: Yi Zhou*
address: Jinzhai Road No.96, Hefei, Anhui, P.R.China, 23
telephone number: +86-551-63607940
e-mail: zhouyi@mail.ustc.edu.cn

RD51 Institutes:

1. *State Key Laboratory of Particle Detection and Electron*
   University of Science and Technology of China,
   contact person: Yi Zhou
   e-mail: zhouyi@mail.ustc.edu.cn

2. *Kobe University,*
   contact person: Atsuhiko Ochi
   e-mail: ochi@kobe-u.ac.jp

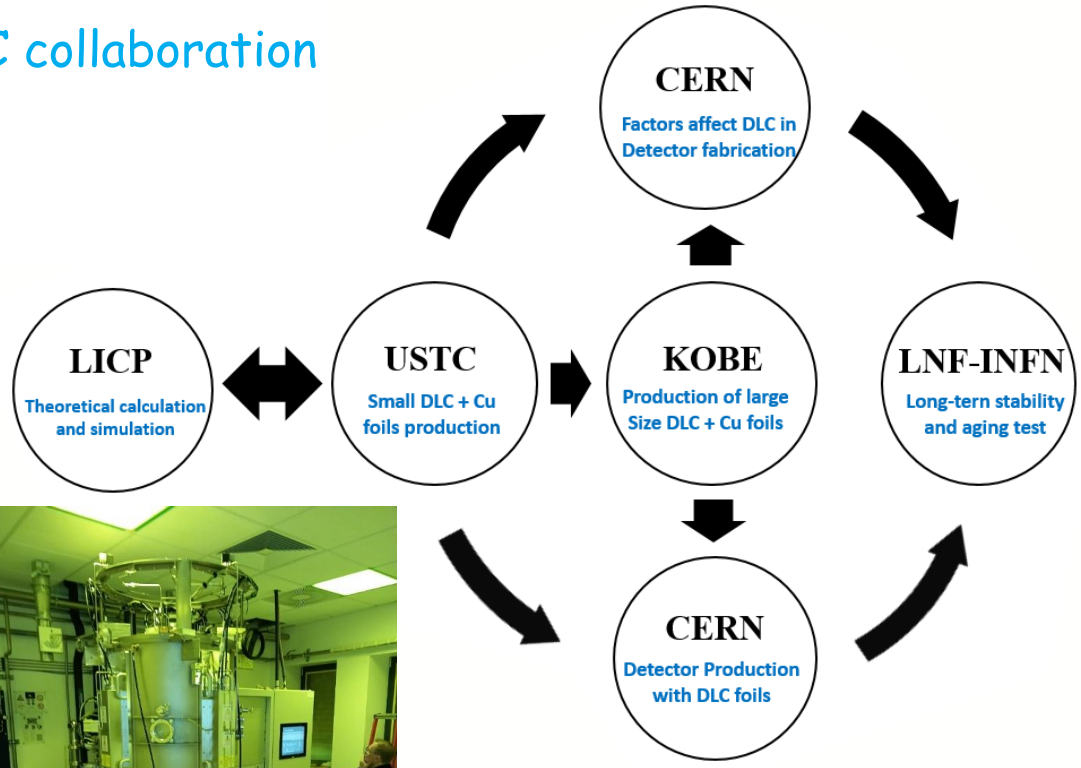
3. *CERN*
   contact person: Rui de Oliveira
   e-mail: Rui.de.Oliveira@cern.ch

4. *Laboratori Nazionali di Frascati dell'INFN*
   contact person: Giovanni Bencivenni
   e-mail: Giovanni.Bencivenni@lnf.infn.it

Ext. Collaborators:

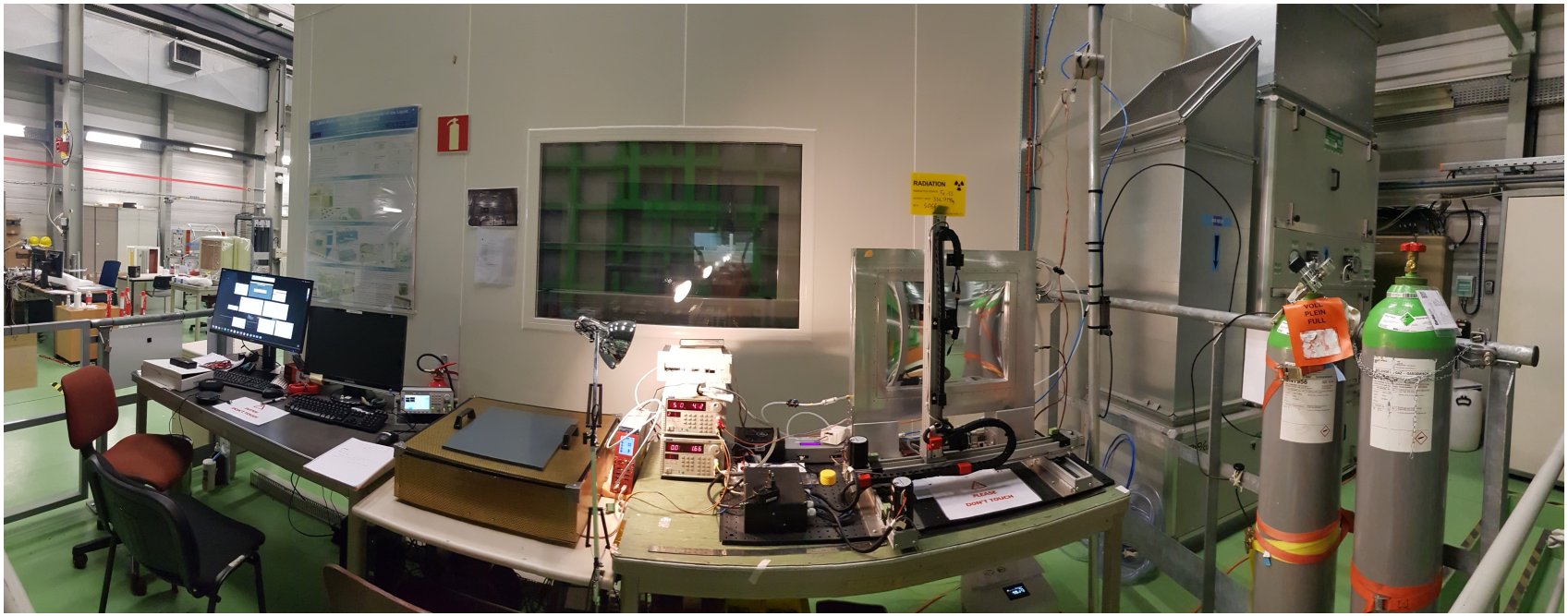
1. *State Key Laboratory of Solid Lubrication,*
   Lanzhou Institute of Chemical Physics, Chinese Academ
   contact person: Lunlin Shang
   e-mail: shangll@licp.cas.cn

DLC collaboration



- In general, key partnership with MPT workshop for ERAM production
- World renowned expertise on MPGD/PCBs, new sputtering equipment
- Promising sputtering results $\Rightarrow \sim$ 10 % resistivity homogeneity achieved

ERAM characterisation test bench

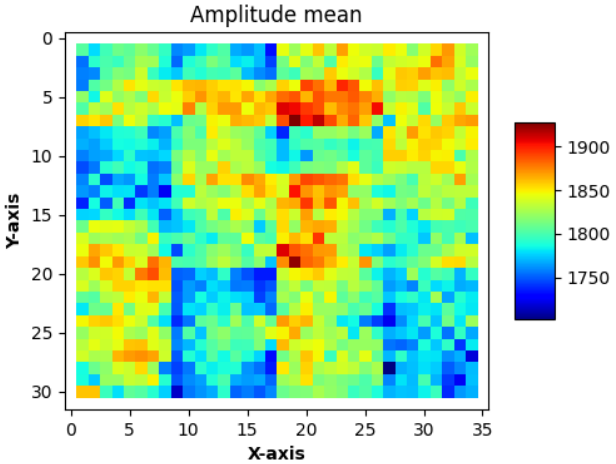


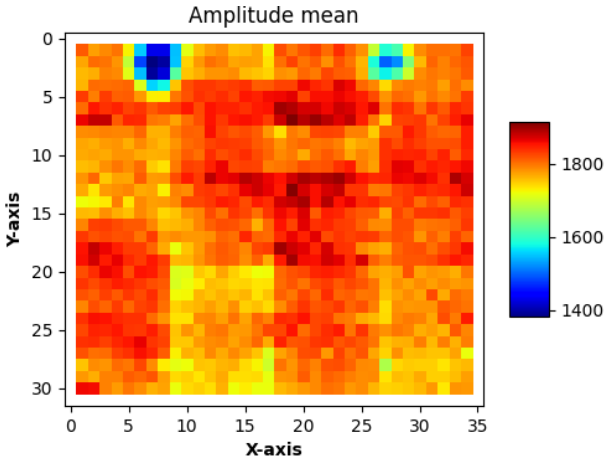
- All ERAMs individually characterised (1 week/ERAM)
- Signal pulsed on mesh without amplification
- Effective gain (ERAM * FE) and energy resolution @ 5.9 keV measurement on each pad with ERAM at nominal HV
- HV scan (330 - 360 V) in the center (gain tuning)
- Remote shifting organised with local hardware support

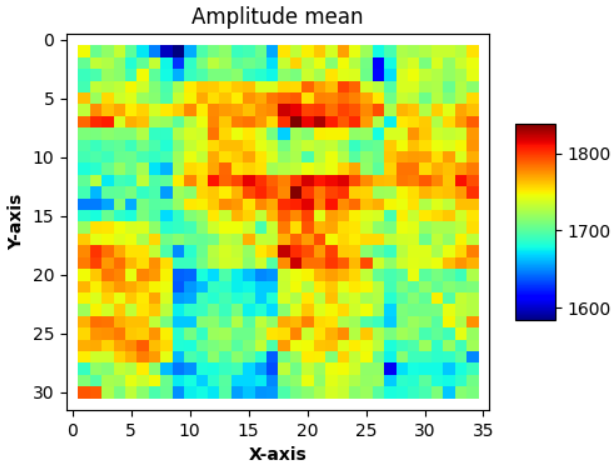
Pulsing of the ERAM mesh

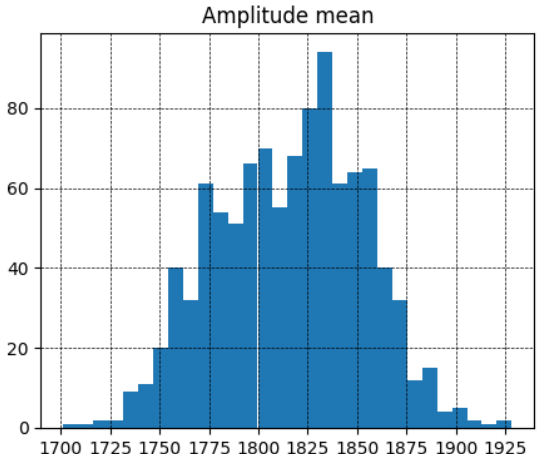
ERAM-20

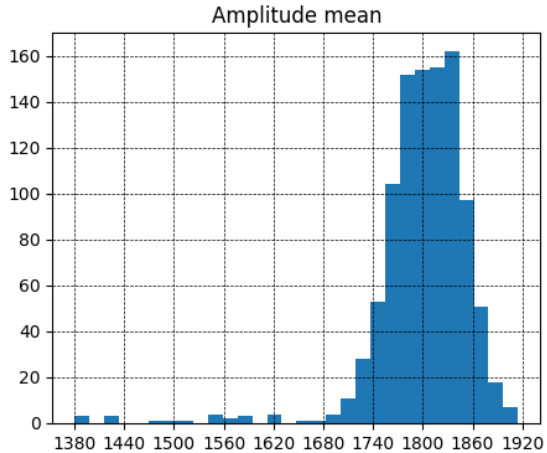
ERAM-30 | Before repair | After repair

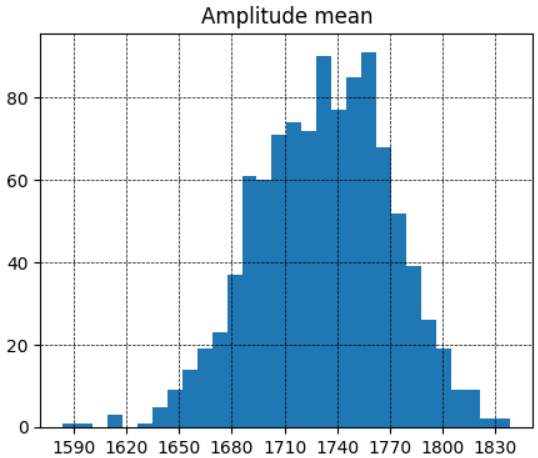






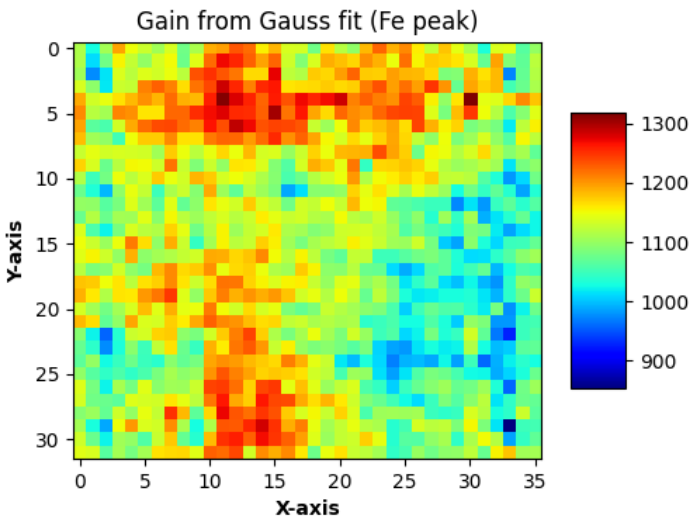


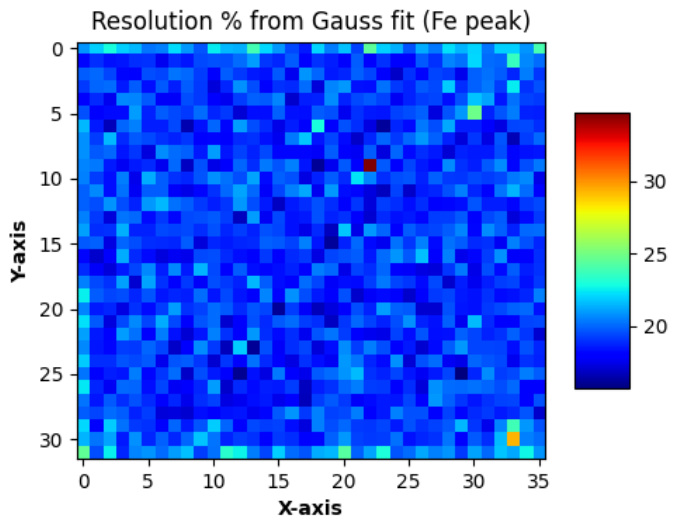




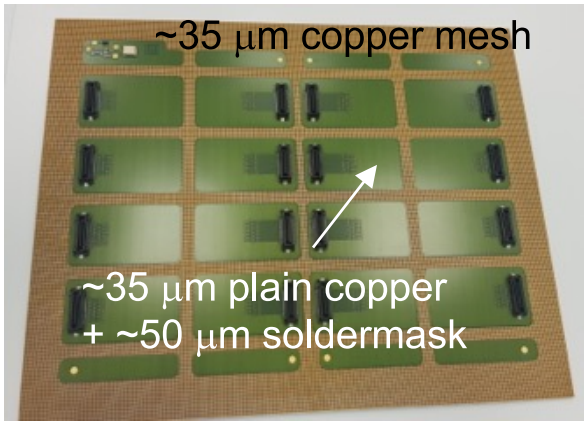
- Quality control step to detect major defects before mechanics gluing
- Mesh pulsed with a 1 kHz, 300 mV square signal
- Response of the whole detector in one test

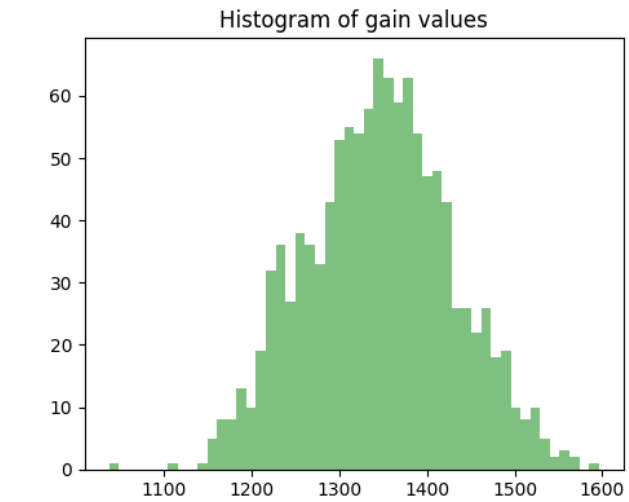
Gain scan of ERAM-30 with ^{55}Fe X-rays

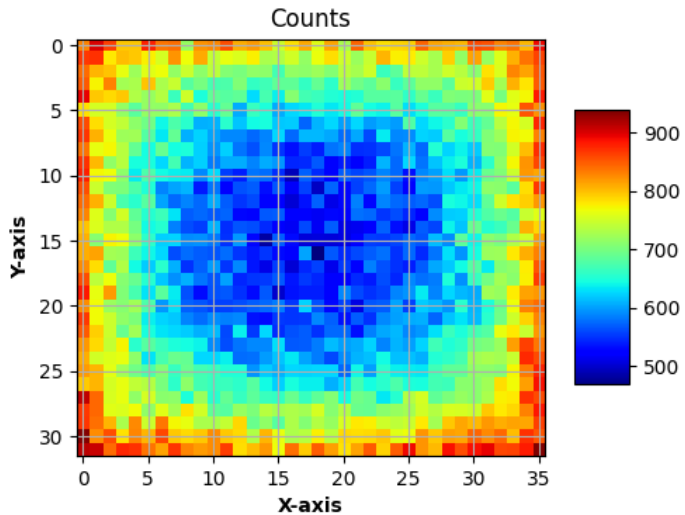




All ERAMs PCB but 23, >26



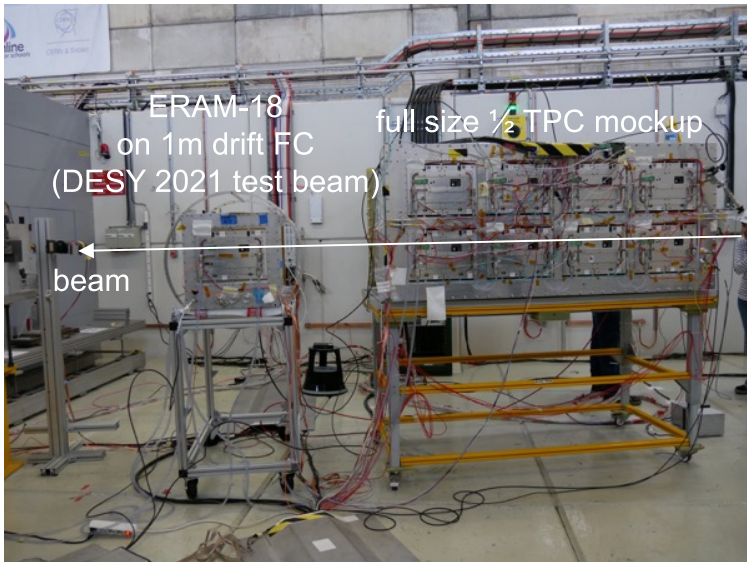




New PCB for ERAM>26

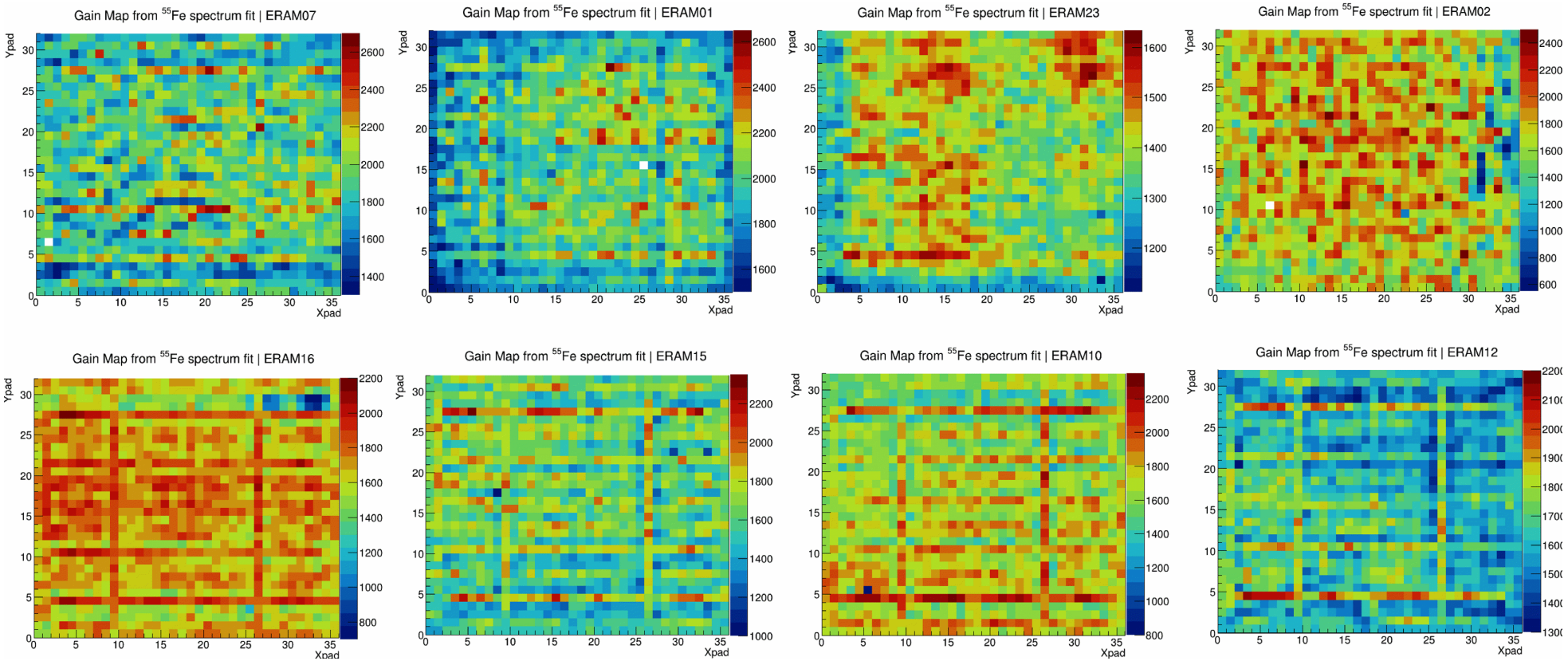
- New PCB design from ERAM-23 ⇒ No non-uniformities from mechanics

CERN test beam at PS/T10



- Field cage with different mechanical and electrical design, 1/2 HA-TPC field cage dimensions
- 8 final ERAM detectors tested on beam
- Enabled test and improvement of overall acquisition system
- 1 prototype field cage equipped with 1 ERAM at different resistivity for ERAM design validation
- Datasets with different drift distances, ERAM HV, particle types and momenta being analysed

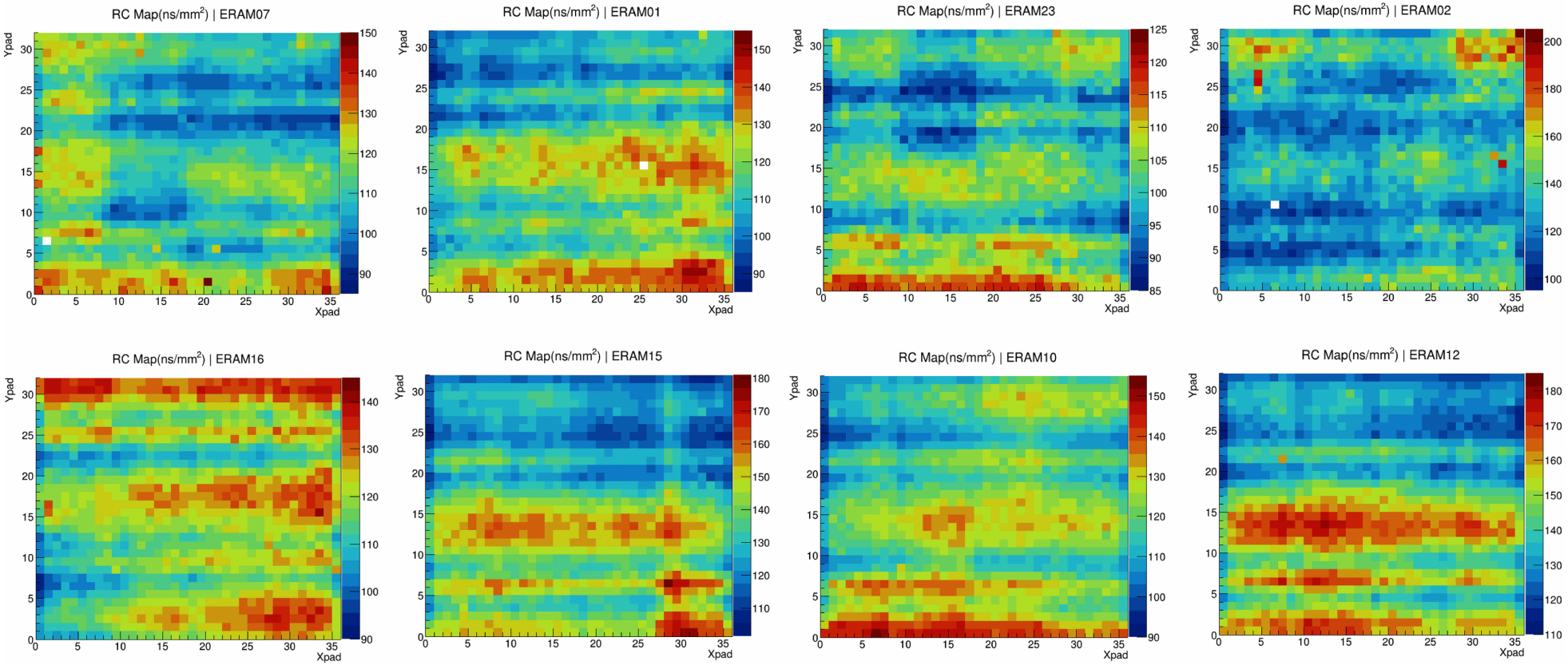
Detector used at test beam at PS/T10



- 8 detectors mounted on field cage mock-up in clean room
- Various PCB designs visible due to mechanics ribs, not since ERAM-23
- Absolute gain of ERAM detectors changes with design
  $\Rightarrow$ under investigation
- Effect of environmental conditions during gain scan under investigation

RC maps from data

Ref: S. Joshi (IRFU)

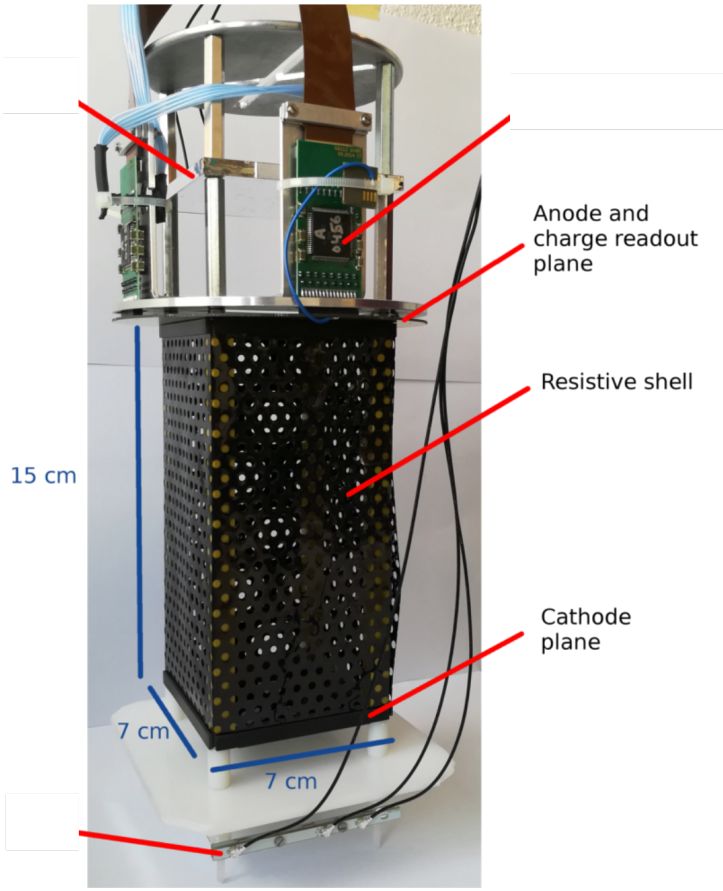


- RC value extracted from X-ray scans of each ERAM
- Modelisation of the detector and electronics response implemented
- RC fitted using the leading and neighbouring pads

Resistive field cage technology

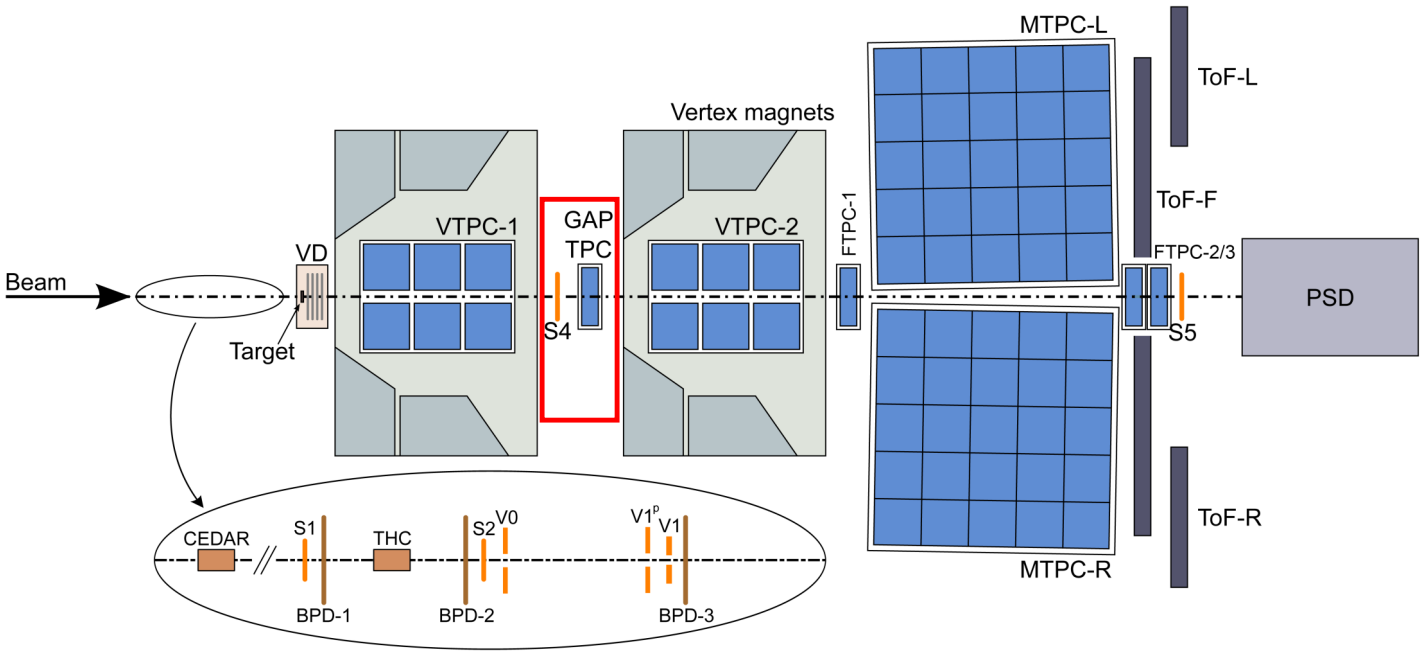
- Aim: performances improvement for TPC long-term operations
- Charge readout already exploiting resistive technology
- Need to be explored for field cages
- T2K field homogeneity requirement: $\Delta E/E \leq 10^{-4}$ **at** < 1 **cm of cage walls**
- Could be achieved with resistive field cage
- Voltage degrader requires high resistive foil homogeneity $\Rightarrow$ CERN MPT lab

DUNE-ArgonCube:
Resistive field cage prototype



Conclusions

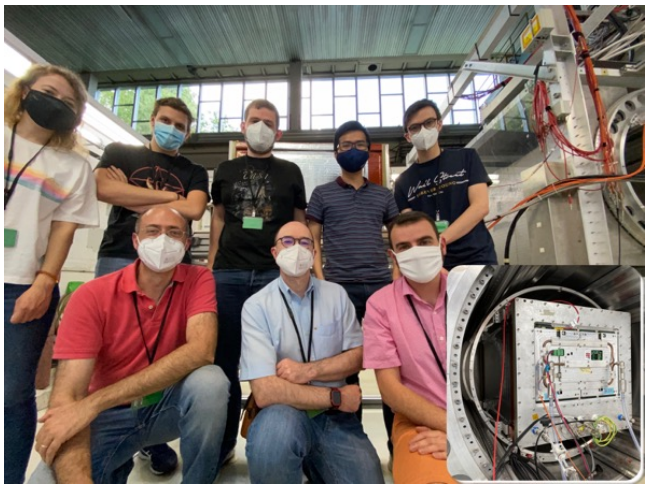
- Resistive Micromegas inherit from long and successful bulk Micromegas developments
- Strong interest of CERN for resistive technology
- Resistive readout shows good performances and large flexibility
- Highly interesting and promising R&D for resistive field cages



Thank you for your attention!

CERN/T9 2018
MM0/ 1m drift HARP TPC

DESY 2019
MM1-DLC1/15 cm drift

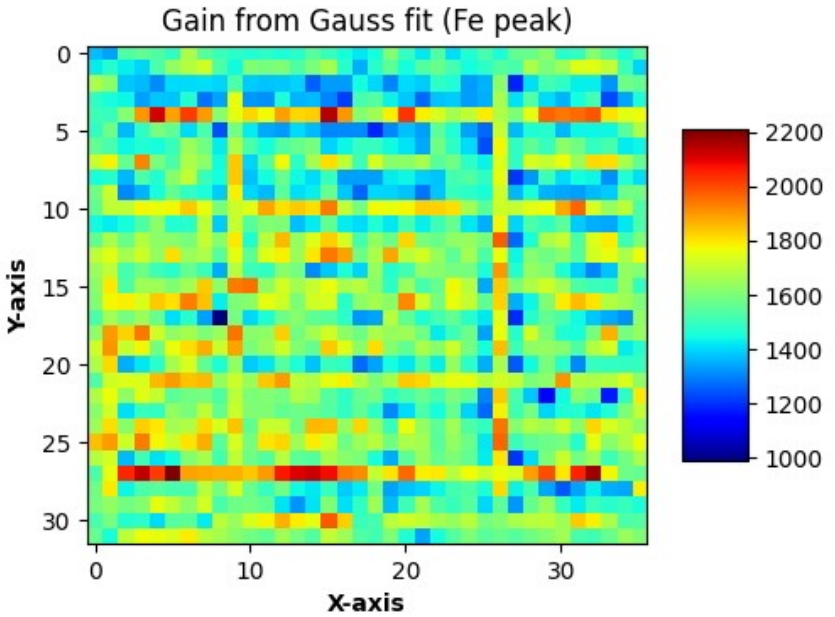


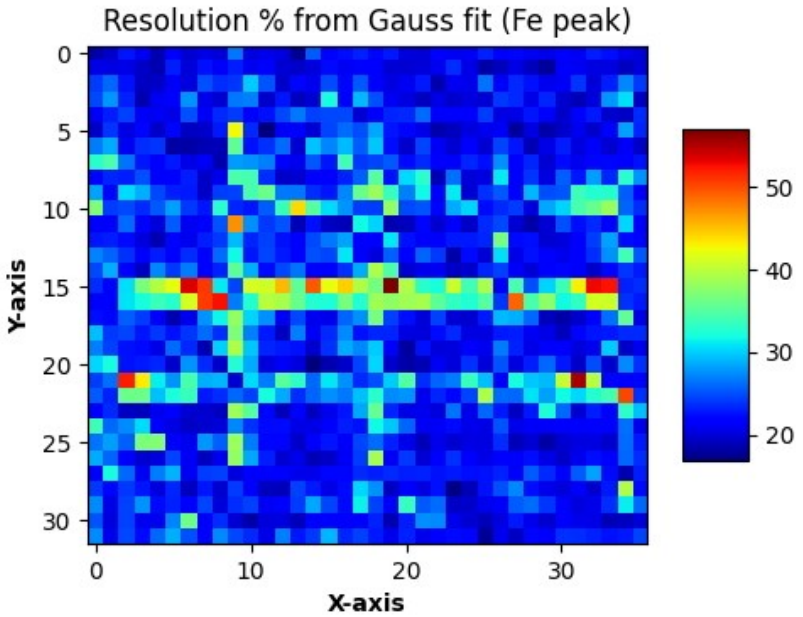
DESY 2021
ERAM-01 / 1 m drift proto FC

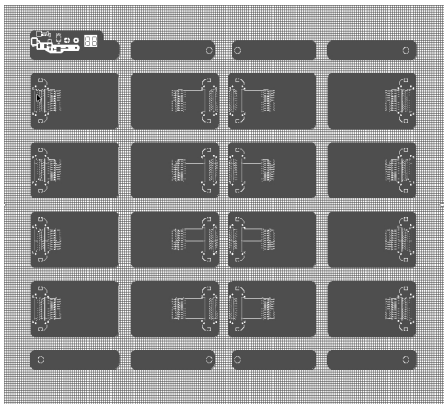
CERN/T10 2022
½ full size TPC with 8 ERAMs

Impact of the PCB design on the gain

ERAM GAIN VS STIFFENER RIBS (ERAM-15)







PCB top layer
black areas are
~20-35 µm thick copper
+ ~50 µm soldermask
(only copper from ERAM-17)
These thicknesses depends
on the PCB manufacturer

A. Delbart, T2K collaboration meeting

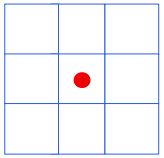
Charge diffusion

Charge diffusion function:

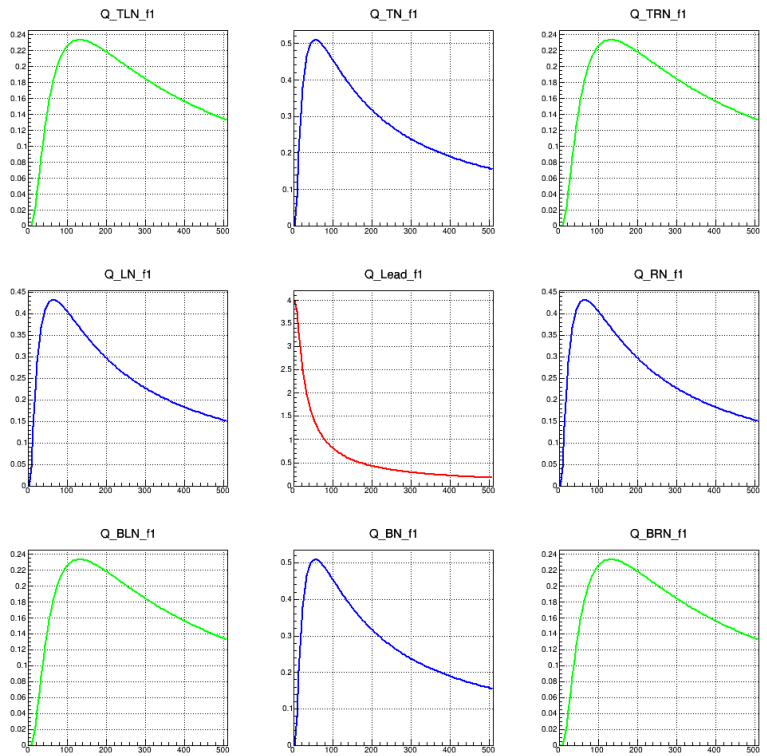
$$Q_{pad}(t) = \frac{Q_{norm}}{4}\left[erf\left(\frac{x_H - x_0}{\sigma(t)\sqrt{2}}\right) - erf\left(\frac{x_L - x_0}{\sigma(t)\sqrt{2}}\right)\right]\left[erf\left(\frac{y_H - y_0}{\sigma(t)\sqrt{2}}\right) - erf\left(\frac{y_L - y_0}{\sigma(t)\sqrt{2}}\right)\right]$$

$$\sigma(t) = \sqrt{\frac{2t}{RC}}$$

- Obtained from Telegraph equation for charge diffusion.
- Integrating charge density function over area of 1 readout pad.
- Parameterized by 4 variables:
  - x_0, y_0 } Initial charge position
  - RC : Describes charge spreading
  - Q_{norm} : Total charge deposited in an event



RC = 60 ns/mm^2
Q_{norm} = 4 ADC



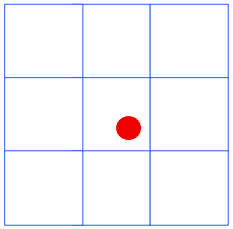
x_H, x_L: Upper and lower bound of a pad in x-direction
y_H, y_L: Upper and lower bound of a pad in y-direction

S. Joshi, talk at IRN Neutrino 2022

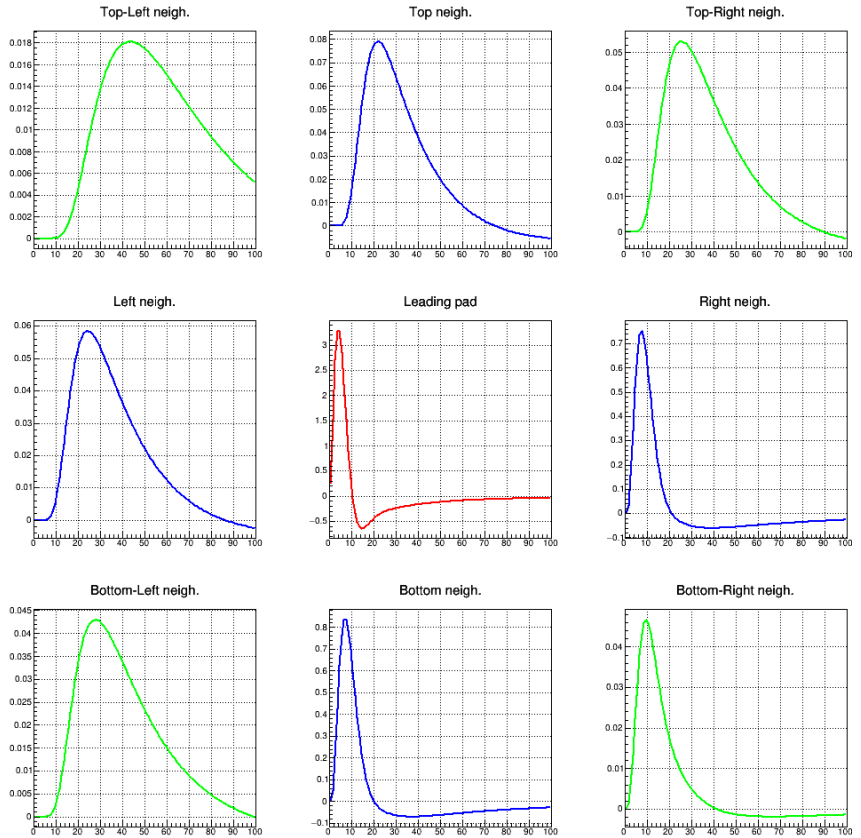
Signal Model

- Convolution of charge diffusion function with derivative of electronics response function.

$$S(t) = Q(t) * \frac{dR}{dt}$$

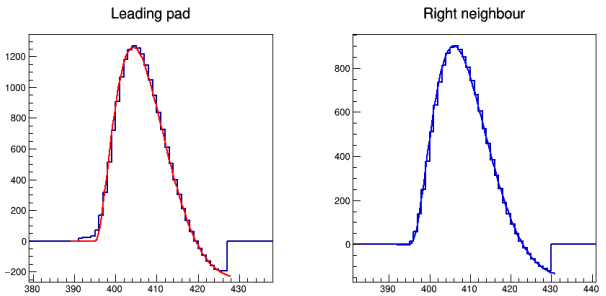


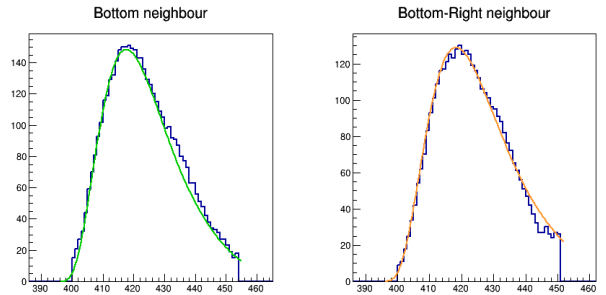
RC = 60 ns/mm^2
Q_{norm} = 4 units



S. Joshi, talk at IRN Neutrino 2022

RC extraction

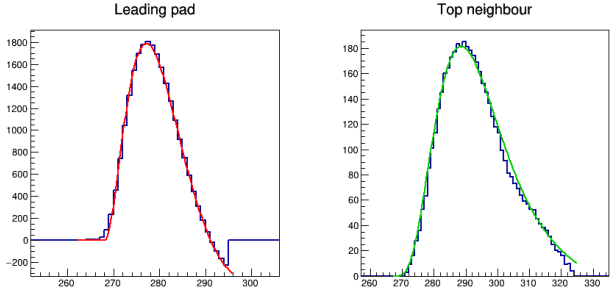


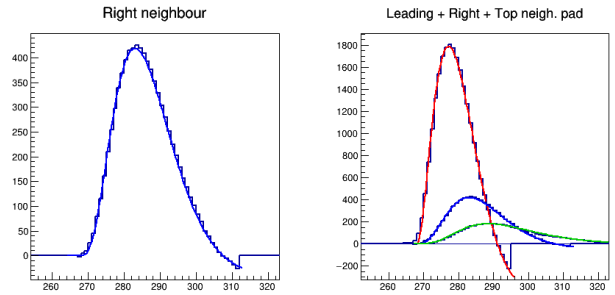


RC = (100.49 ± 1.078) ns/mm^2

χ^2/Ndf = 1.491

4-waveform simultaneous fit of an X-ray event





RC = (110.82 ± 1.363) ns/mm^2

χ^2/Ndf = 1.903

3-waveform simultaneous fit of an X-ray event

- RC is obtained for a pad by simultaneous fit of waveforms in each event.

S. Joshi, talk at IRN Neutrino 2022