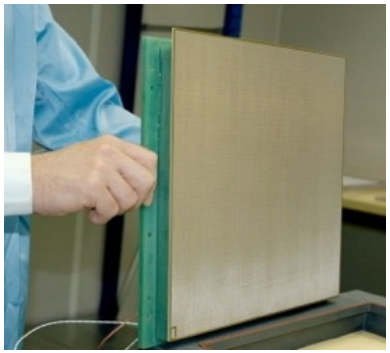
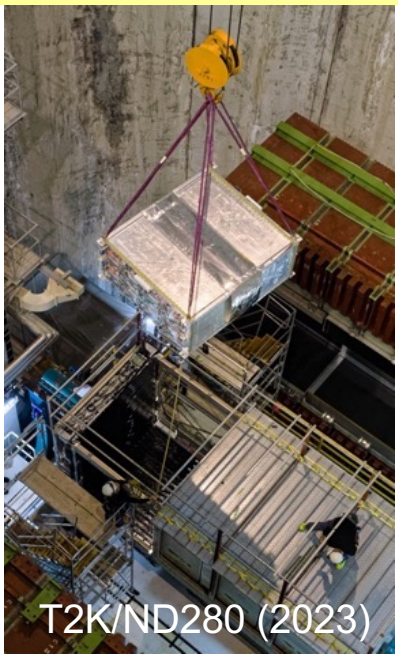
Production of T2K High-Angle TPCs

Alain Delbart, CEA/IRFU - Univ. Paris-Saclay, for the ND280/HA-TPC group

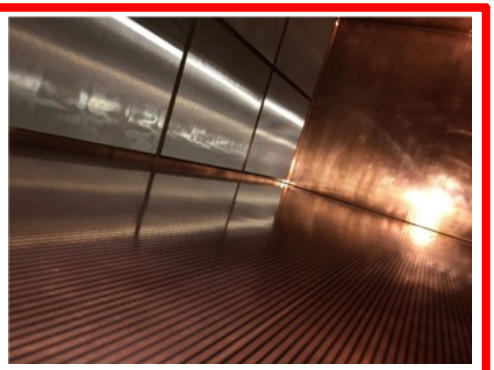
Vertical TPC (2004-) for ND280

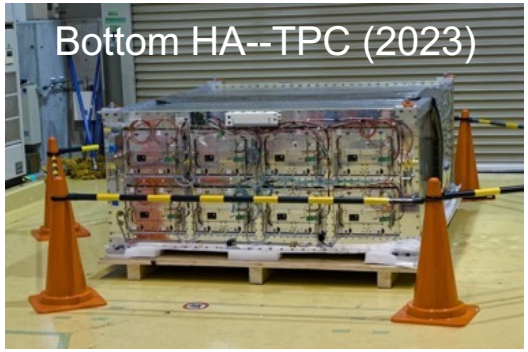


Bot. TPC down
In ND280 @ JPARC
(Japan)



High-Angle TPC (2018-) for ND280 upgrade

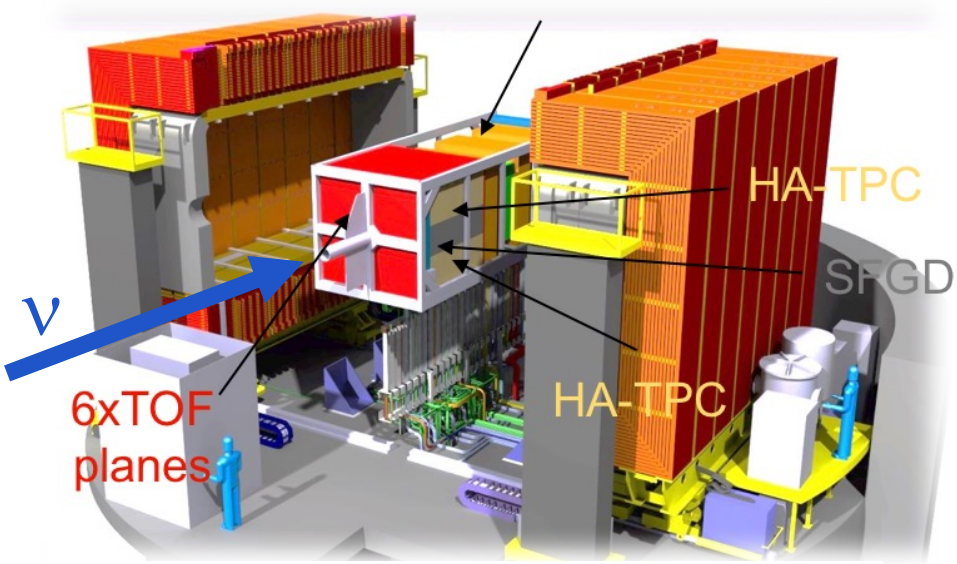


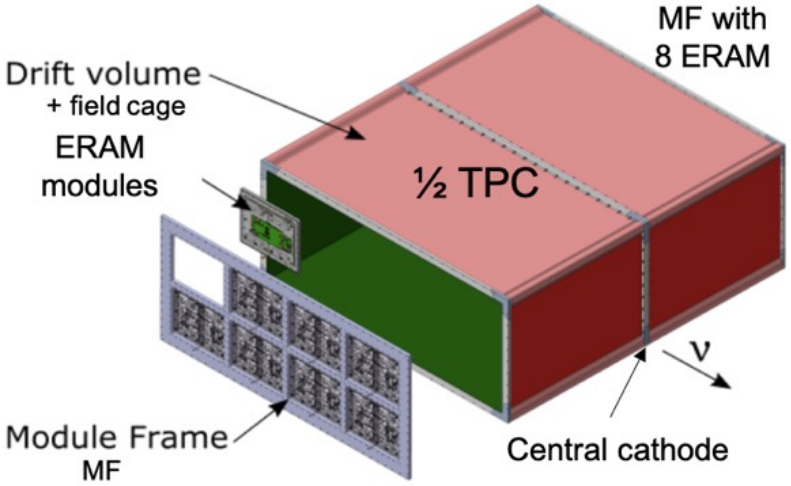


The development of the upgraded Near Detector of T2K
The HA-TPC (2018-2024)

2 new TPCs with better final state muons acceptance from new SFGD target and from downstream events

2009 TPCs (x3) + T2K Gas system by CERN (mixing, filtering, gas properties monitoring)





	HA-TPC	v-TPC
Parameter	Value	
Overall x × y × z (m)	2.0 × 0.8 × 1.8	0.85 x 2.2 x 1.8
Drift distance (cm)	90	
Magnetic Field (T)	0.2	
Electric field (V/cm)	275	
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2	
Drift Velocity $cm/\mu s$	7.8	
Transverse diffusion $(\mu m/\sqrt{cm})$	265	
Micromegas gain	1000	
Micromegas dim. z×y (mm)	340x420	340x360
Pad z × y (mm)	10 × 11	7x10
N pads	36864	124272
el. noise (ENC)	800	
S/N	100	
Sampling frequency (MHz)	25	
N time samples	511	
Channel density (nb. / cm^2)	0.9	1.4

ND280 upgrade TPCs achievements

- First experiment to use ERAM detectors
- Performances similar or better than v-TPCs with ~1/3 less electronics channel density
- New innovative field cage design for high acceptance and dead volume reduction

THE HA-TPC FIELD CAGE ORIGINAL DESIGN

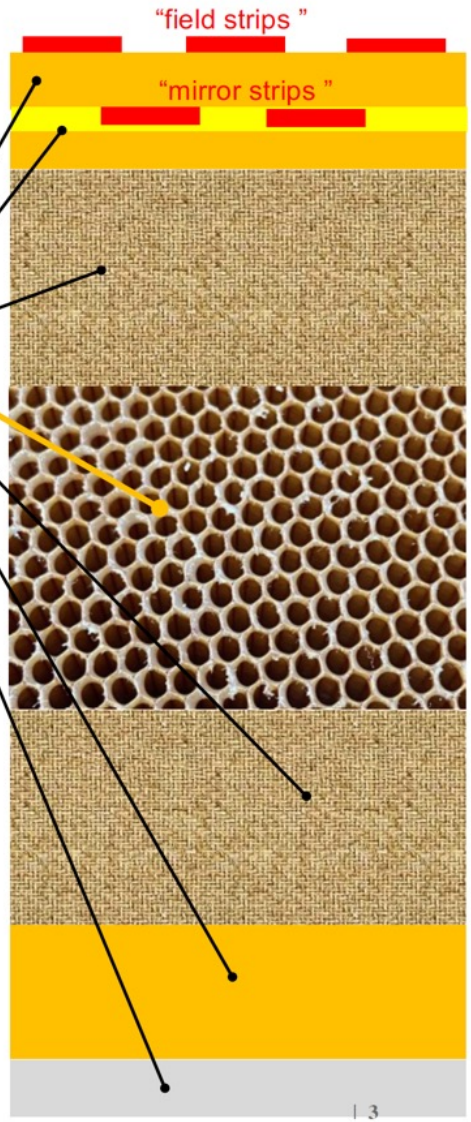
Ref: G. Collazuol (INFN/Padova)

Field Cage – layers

See G.C. talk at
15th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba, May 22-28, 2022

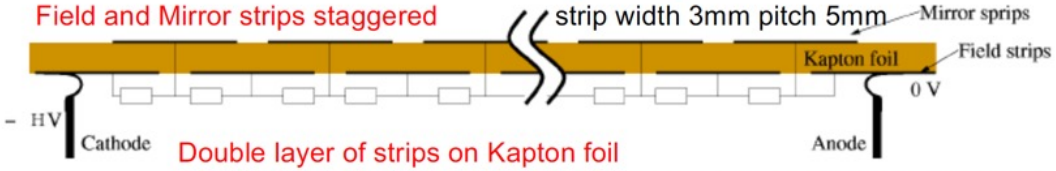
Material	Thickness
Cu Strips on Kapton foil (electrodes)	Cu 17μm / Kapton 50μm / Cu 17μm
"Coverlay" (strip insulation / protection)	Glue 20μm / Kapton 25μm
Aramid Fiber Fabric (Twaron™)	2mm
Aramide HoneyComb panel	35mm
Aramid Fiber Fabric (Twaron™)	2mm
Kapton foil (insulation)	125μm
Aluminum foil (external shield)	50μm
Total	~ 4 cm / ~ 2% radiation length

Note: V-TPC ~ 12cm / ~ 3.4% radiation length

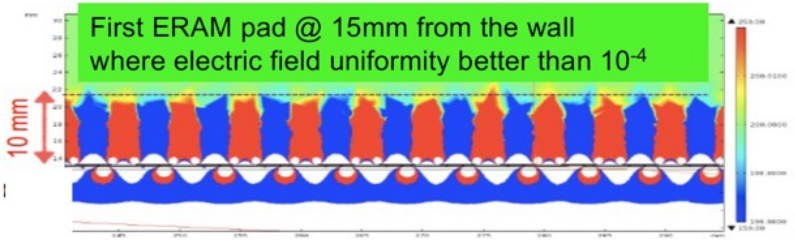


Electric field shaping

Field and Mirror strips staggered



Double layer of strips on Kapton foil
Dimensions = 5m (inner surface cage perimeter) x 1m (drift distance)

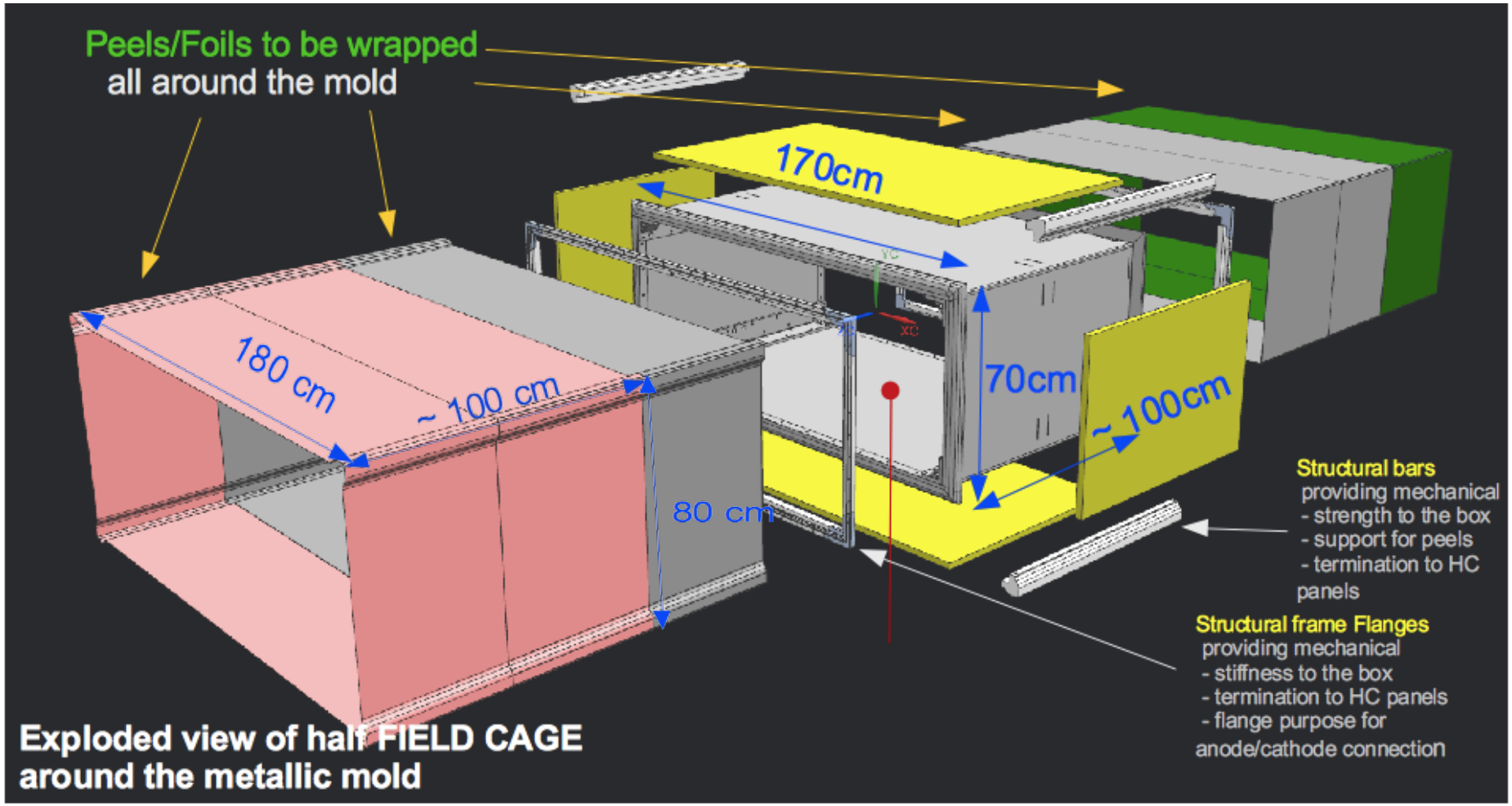


Simulation
Electric Field
near walls

MECHANICAL DESIGN & ASSEMBLY

ref: G. Callazuol (INFN Padova)

Walls and cathode flatness and parallelism to keep within ~0.2 mm and voltage divider resistors within 0.1% rms to keep $^{\Delta E}/_{E} \leq 10^{-4}$ confined at <1cm from FC walls



A 10 weeks workflow to wrap layers step by step around the high precision mold, assemble the external G10 structure and finally machin the endcap flanges.

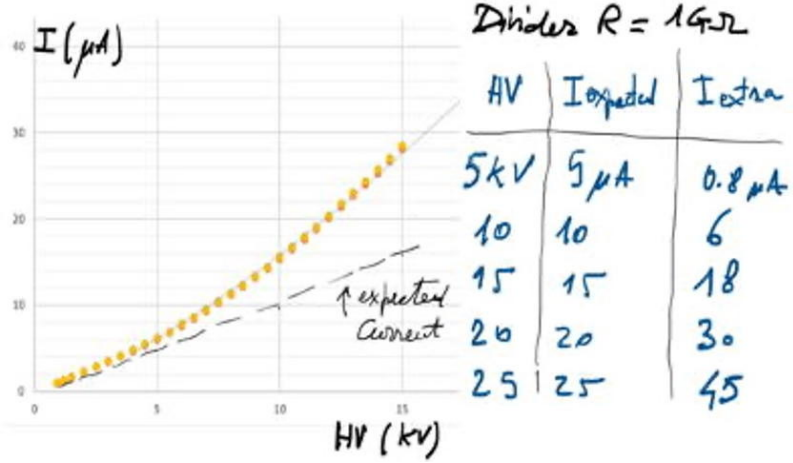
PRODUCTION OF THE FIELD CAGES (NEXUS COMPANY – BARCELONA, SPAIN)

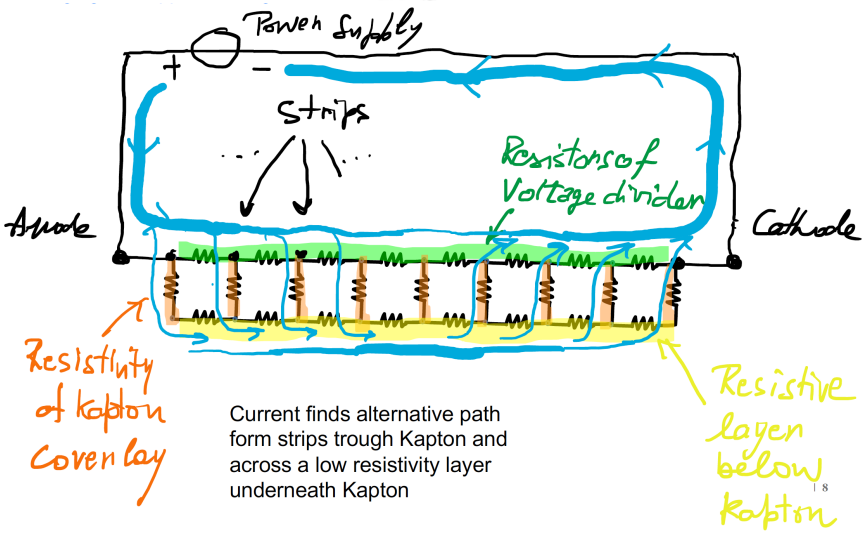
THE HA-TPC FIELD CAGE ORIGINAL DESIGN MODIFICATION

Ref: G. Collazuol et al. (INFN/Padova, Bari)

May 2022 : first scale 1 ½ field cage #0 exhibits a non-linear I(V) behaviour

→ Leakage current flow through the wall structure – Kapton has lower resistivity than expected from datasheet and resistivity strongly changing with applied volatge

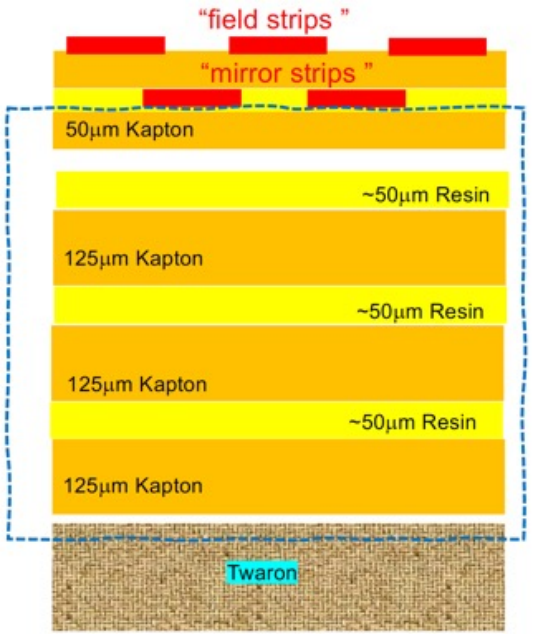




Modified design & procedures

- Keep same raw materials
- Avoid resin contamination (internal Twaron corruption next slide)
- Add thick insulator below strip foil (O(10 TΩ) @ 10 kV) :
  - a 50 μm kapton foil pressed on strip foil at MPGD workshop
  - 3x125 mμ Kapton foils wrapped at NEXUS

New stack added to the original design

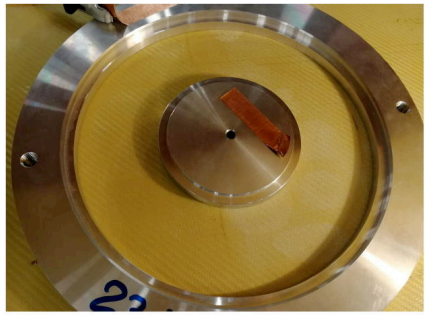


QUALITY CONTROLS
« RESISTIVITY CONTROL » IS A KEY QC …

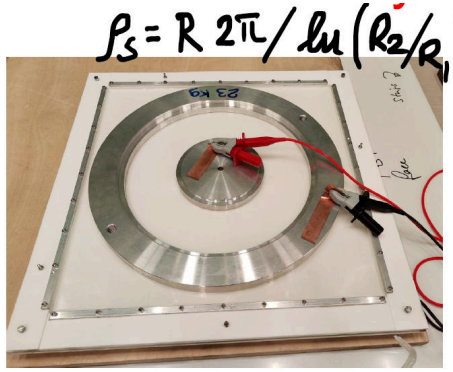
Ref: G. Collazuol et al. (INFN/Padova, Bari)

… of strip-to-strip, Twaron, Resin, and Kapton ! And measuring I(t) on insulators at fixed HV is quite difficult and takes long times with these large surfaces (charging up, polarization, relaxation,..

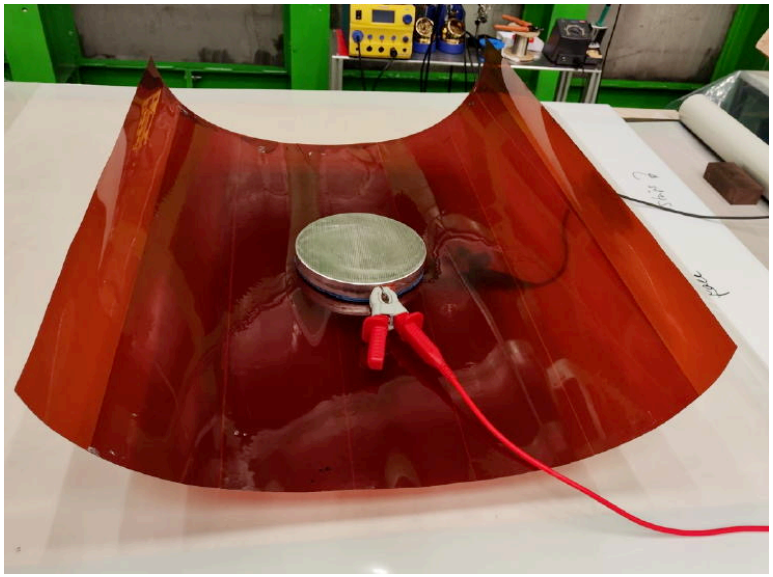
Internal Twaron layer

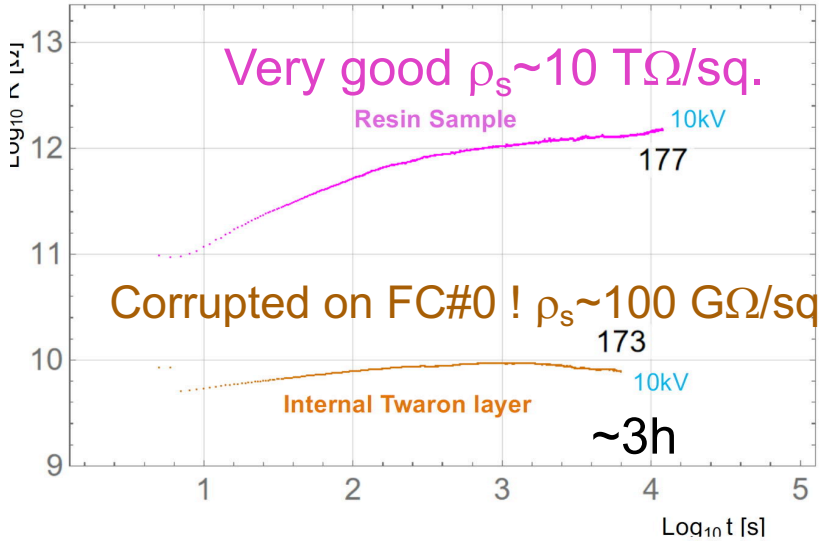


Twaron =
= 50% resin + 50% Aramid fiber

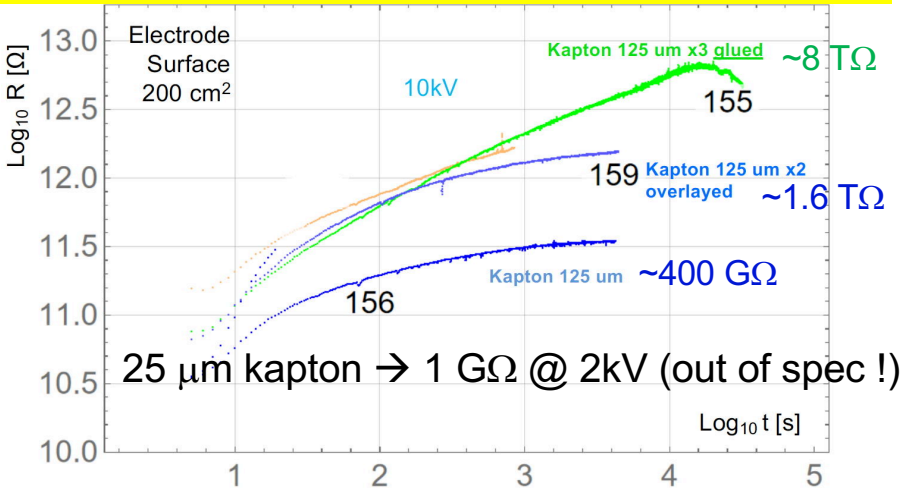


Resin sample
(Resoltech Epoxy)





"Vertical" Resistance seen by 1 strip (150 cm²)



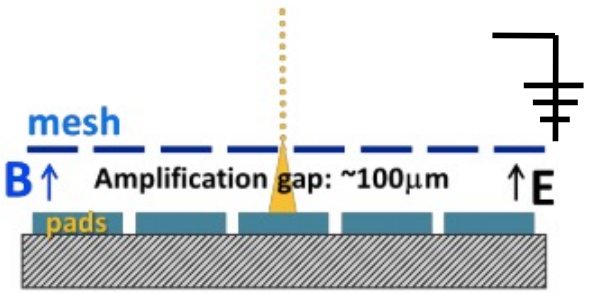
THE NEW MICROMEGAS MODULES FOR THE HA-TPC
THE ENCAPSULATED RESISTIVE ANODE MICROMEGAS

Ref: P. Colas/D. Attié ILC/TPC R&D (M.S. Dixit *et al. NIM* A518, p. 721, 2004

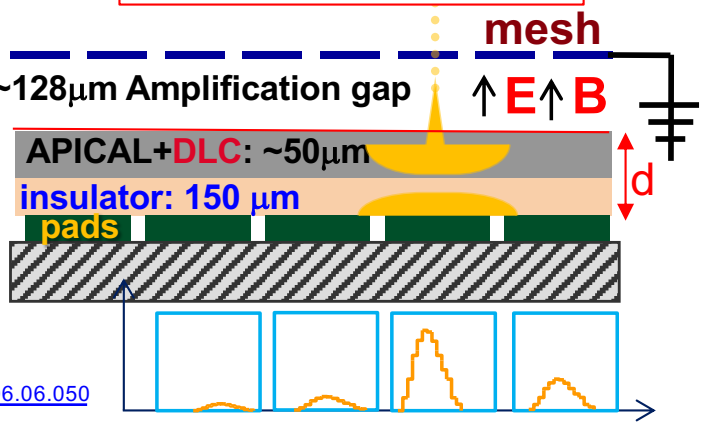
Choice of the Resistive foil technology for the HA-TPC micromegas readout

- Charge spreading which should enable keeping the ~600 μm spatial resolution with larger pads and improves it at short drift distance → less electronic channels, cost reduction
- ASIC spark protection no longer needed → more compact FEE, maximize HA-TPC acceptance
- Encapsulated mesh @ GND + insulating layer → potentially lower track distorsions & better S/N

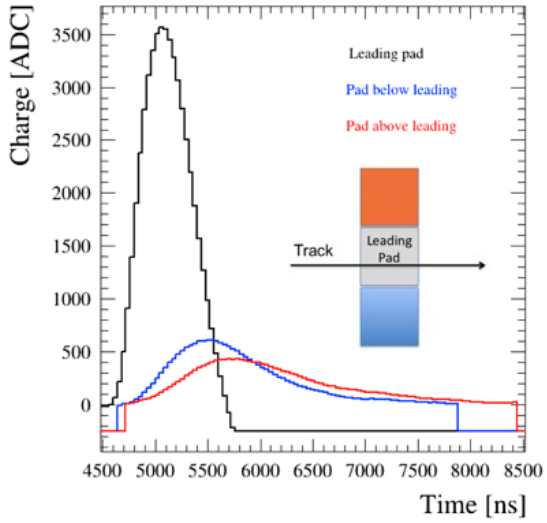
Standard bulk-mm



Resistive-bulk-mm



M. S.Dixit et al. NIM A566, (2006), 281–285. doi:10.1016/j.nima.2006.06.050



2-D RC network (telegraph equations)

$$\rho(r,t) = \frac{RC}{2t}\exp\left[-\frac{-r^2RC}{4t}\right]$$

R- surface resistivity
C- capacitance/unit area

Gaussian spreading as a function of time with :

$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx shaping\ time\ (few\ 100\ ns) \\ RC_{[ns/mm^2]} = 10^3\,\varepsilon_0\,\varepsilon_r \dfrac{R_{[M\Omega/\blacksquare]}}{d_{[\mu m]}} \end{cases}$$

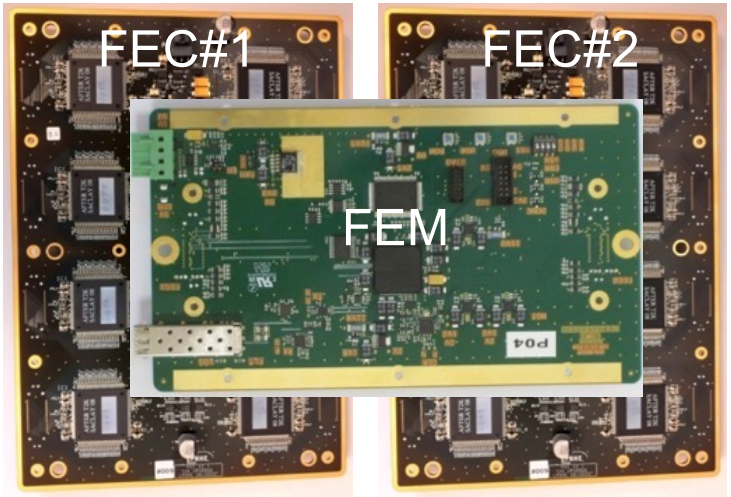
ε_r [APICAL]~3,3 and ε_r [glue] ~4,8

For ~11x10 mm² pads, DLC R is chosen $\sim 0.5\ M\Omega/\blacksquare$ and the glue thickness ~150 μm, RC_{design}~100 ns/mm²

ILC/TPC R&D : 7x3 mm² / DLC R~2.5 Mohm for an RC~750 ns/mm² σ_r<2 mm

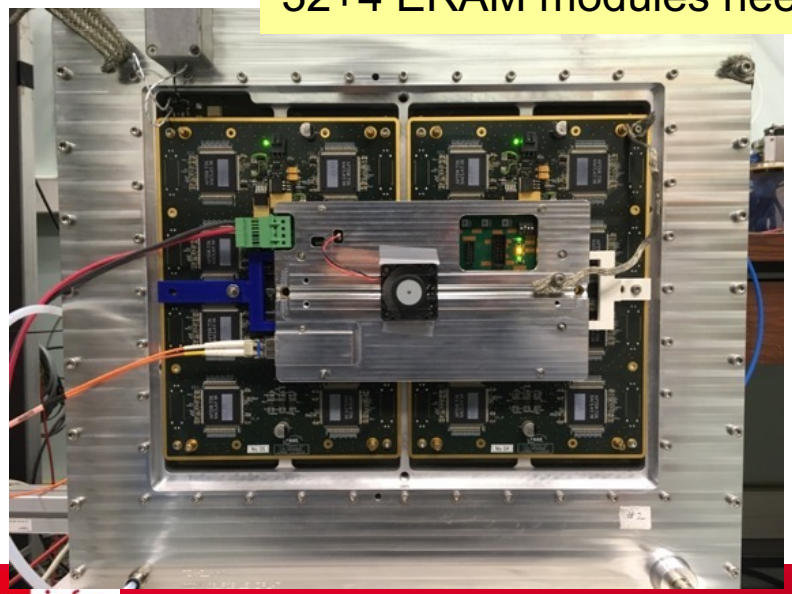
THE HA-TPC ERAM MODULE
A COMPACT TPC READOUT SYSTEM

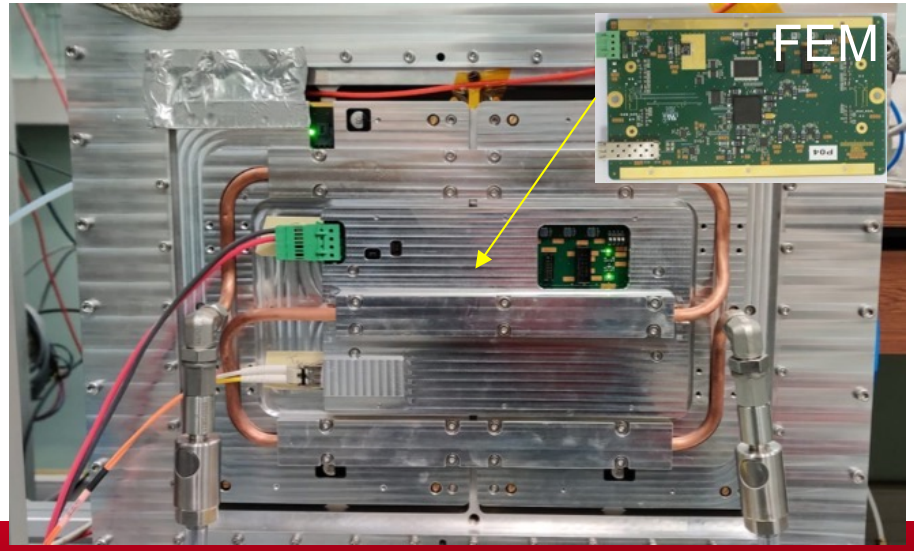
ERAM FEE : 2 x 576 ch. FECs (8xAFTER ASICs)
+ 1 digital FEM (~500 cm^2 cards)



T2K/ERAM detector (CERN MPGD workshop

32+4 ERAM modules needed (detector + FEE + cooling mechanicals)

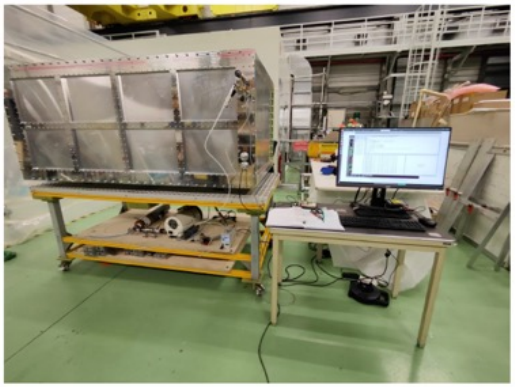




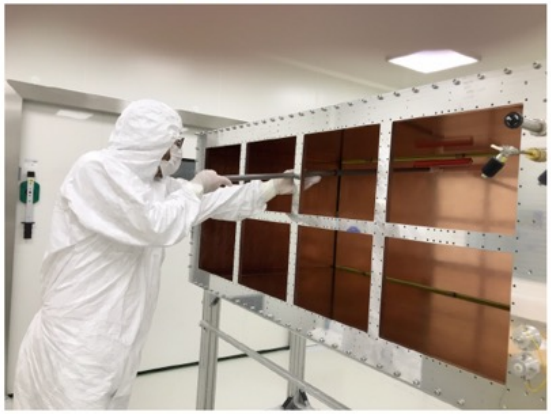
INTEGRATION OF ERAM DETECTORS IN CLEAN ROOM (~ISO 7-8)

ref: D. Henaff (CEA/IRFU)
Coordination @ CERN bdg. 182

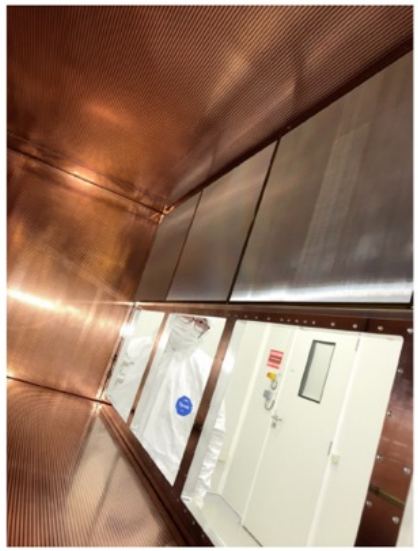
June 30, 2023



Final leak test of FC1 with Helium



Last cleaning inside the cage



First row of ERAM installed

Last ERAM installation

Leak test after ERAM installation

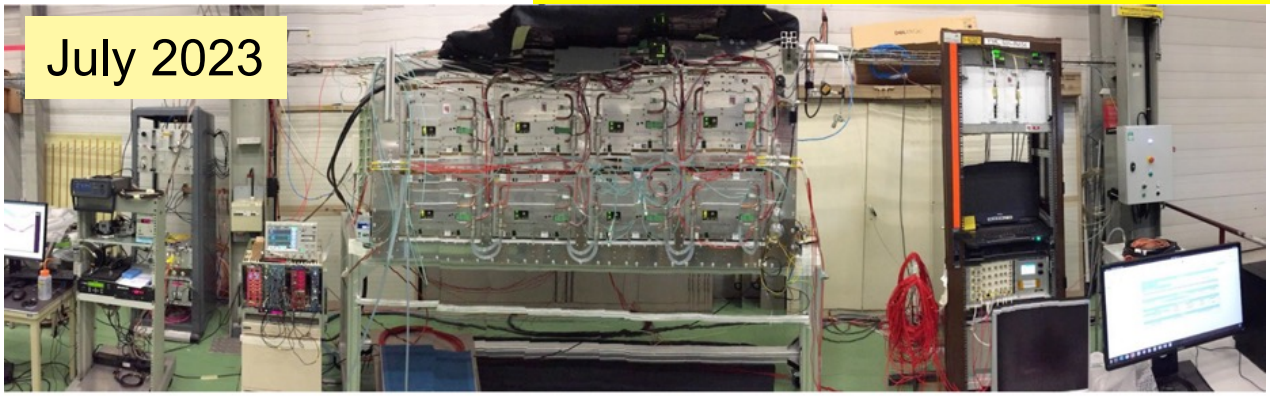
Field cage ready!

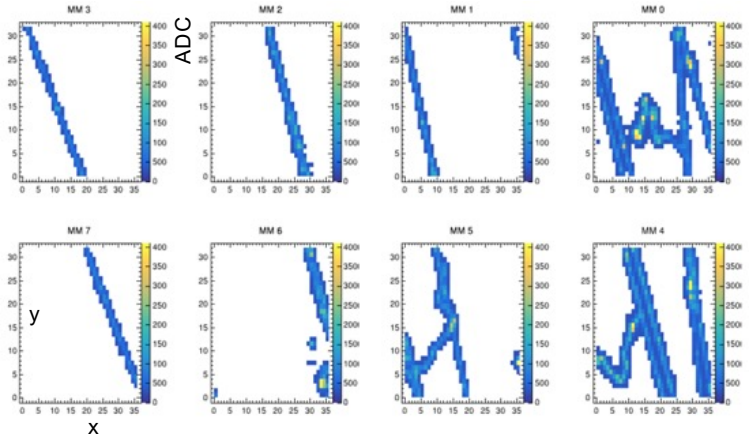
« BOTTOM » HA-TPC FROM CERN TO JPARC (JAPAN)

Final validation with cosmics at CERN

after 10 TPC vol. exchange

July 2023





Gas rack:
Control flow and monitor gas quality (GMC+sensors)

Trigger:
Readout of the two scintillator panels (1m²)

Half HA-TPC:
27.5kV and 350V on ERAMs

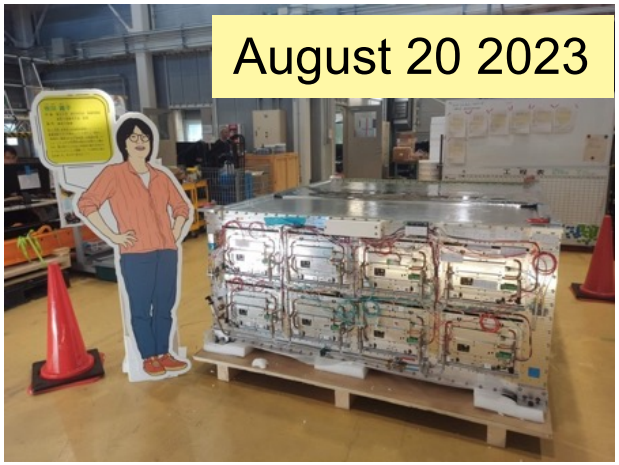
Electronic rack:
DAQ, ERAM & electronic power supplies

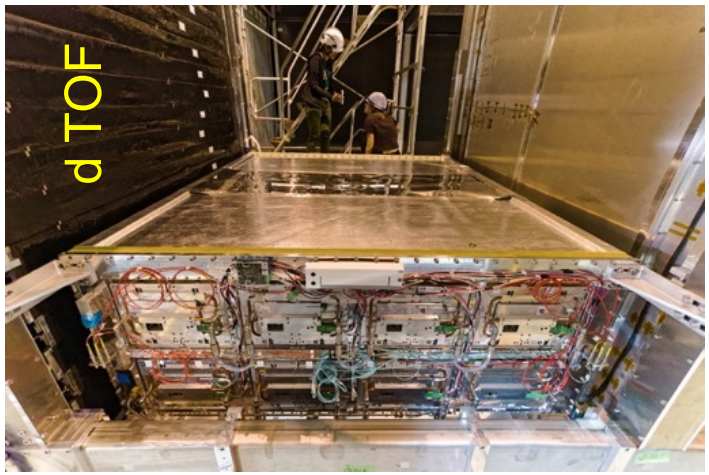
10 ppm O_2/~300 ppm H_2O

Integration in ND280 « basket » at JPARC (8 sept 2023)

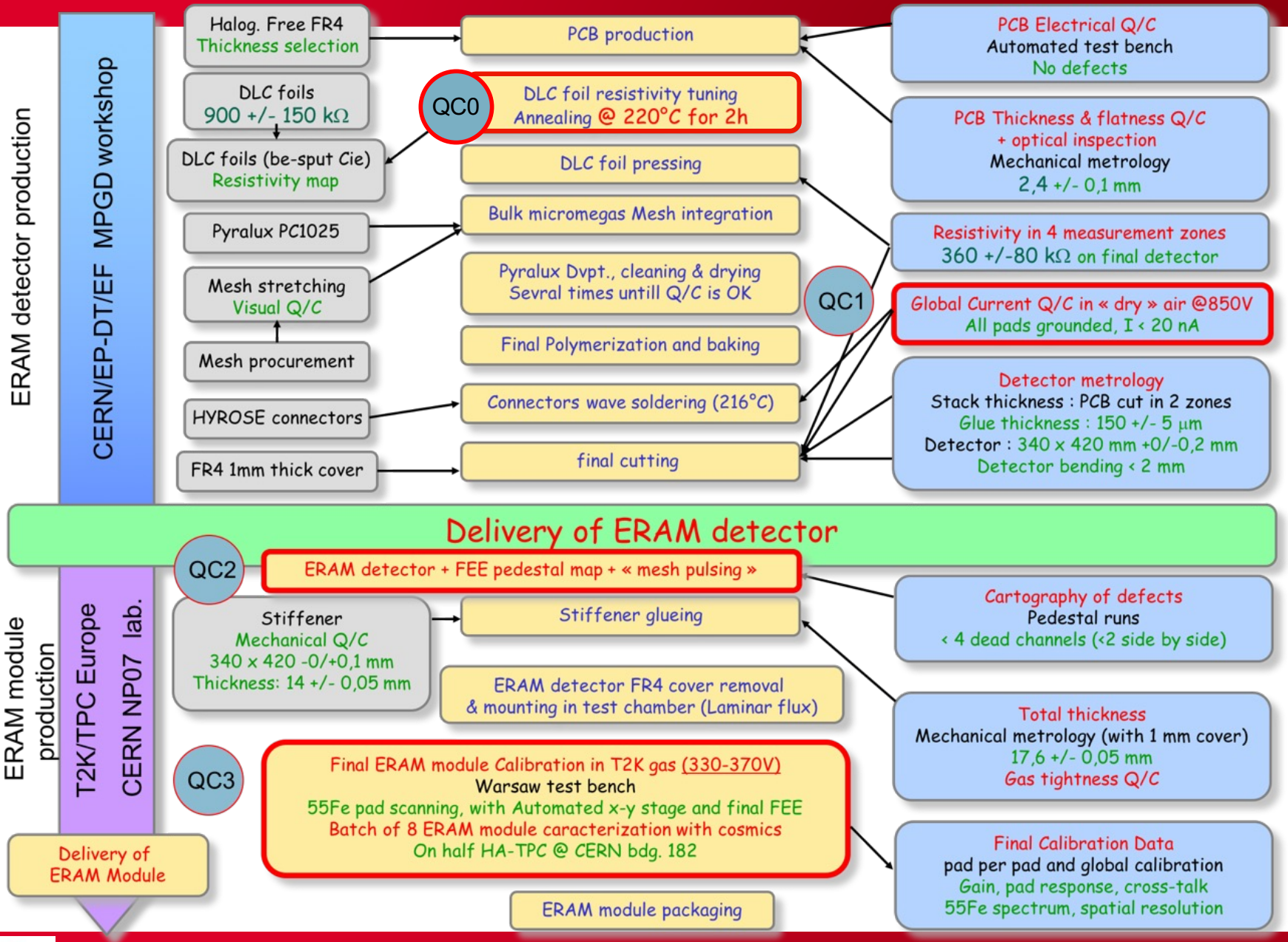
ref: T. Lux (IFAE)

August 20 2023





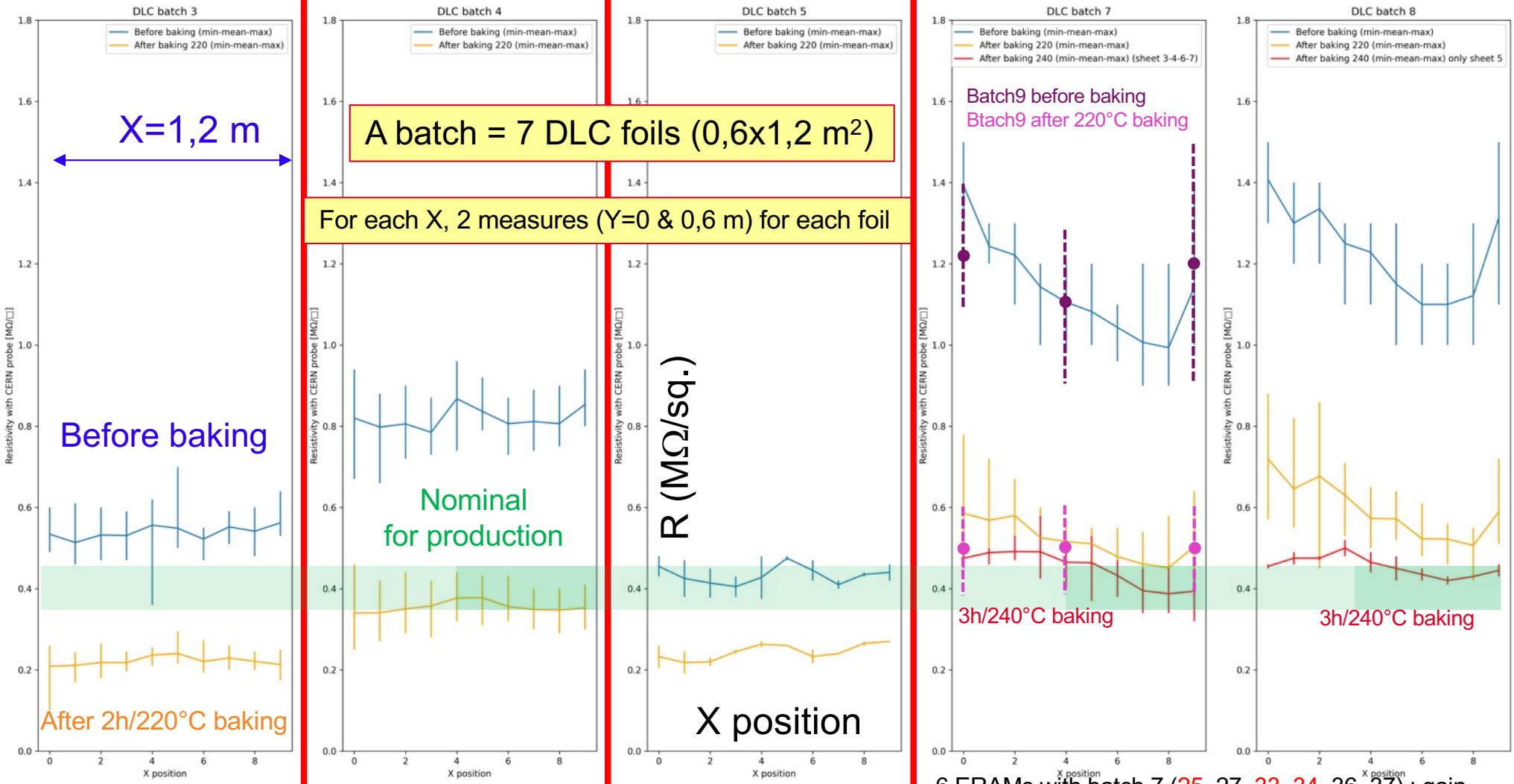
ERAM MODULE PRODUCTION WORKFLOW



QC0: DLC RESISTIVITY : FOIL SELECTION

production (batch 1,2,4) → 21 ERAM → Top. TPC production

½ RC prototype | Production prototype | Restart of production for Top TPC



½ R, ½ RC

→ **ERAM-18**

nominal R, RC

½ R, ½ glue thick. Nominal RC

→ **ERAM-29**

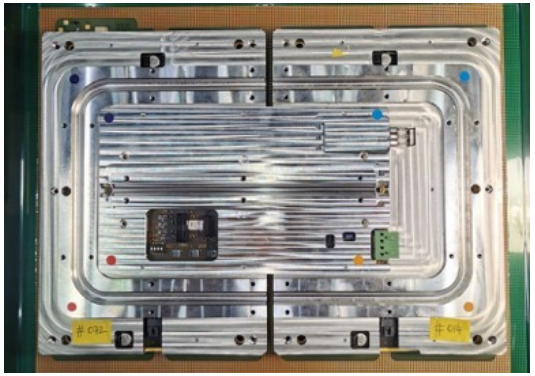
6 ERAMs with batch 7 (~~25~~, 27, ~~33~~, ~~34~~, 36, 37) : gain gradient & spreading issues

→ **11 last ERAMs done with batch 9 (R~0.5 MΩ/sq.)**

QC2 : ELECTRONIC MESH PULSING

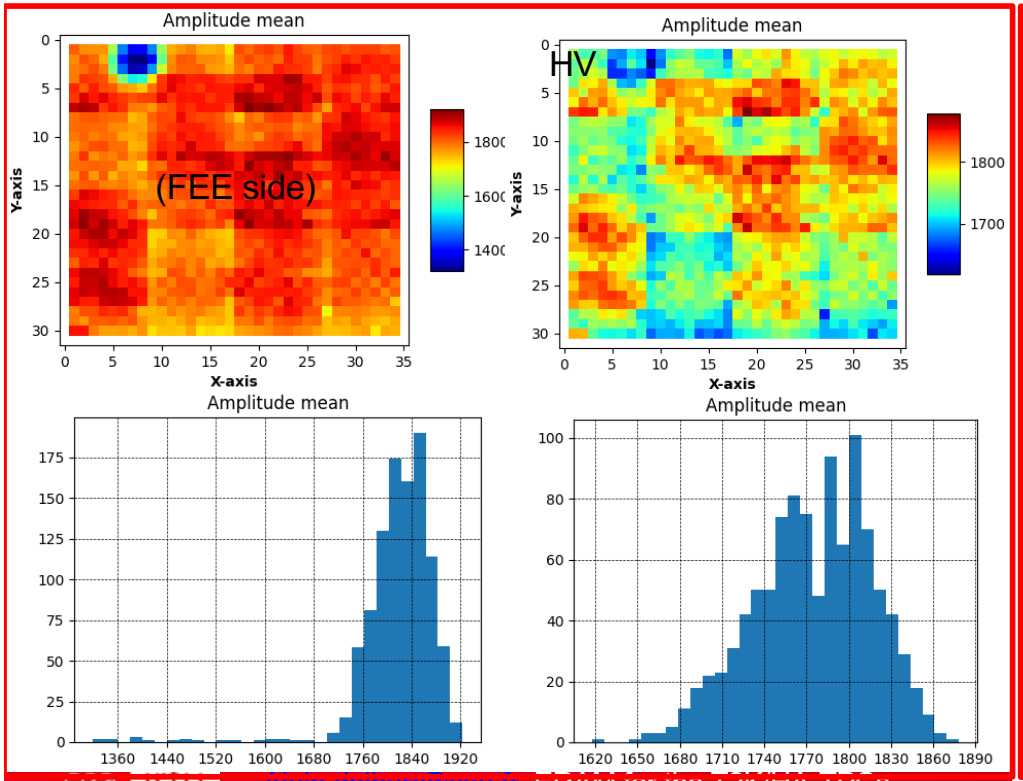
DETECTING DEFECTS BEFORE GLUING THE ALUMINUM STIFFENER

EXAMPLE OF A DEFECT ON ERAM-20

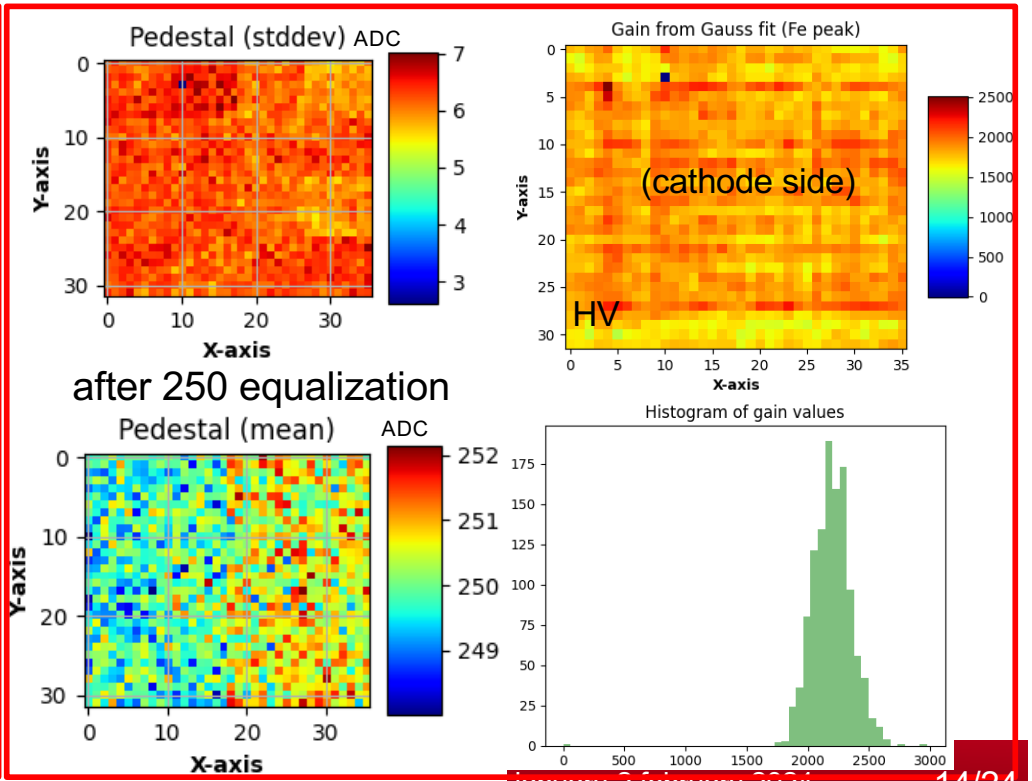


- ✓ The “mesh-pulsing” is a QC used before & after gluing of the mechanical stiffener to detect major defects
- ✓ A 1kHz, 300 mV square signal is pulsing the ERAM mesh through a 50 Ω adapted cable
- ✓ The readout electronics DAQ is triggered with a NIM signal synchronized with the mesh pulsing (~5 mn run).

QC2: mesh pulsing before & after « repair »

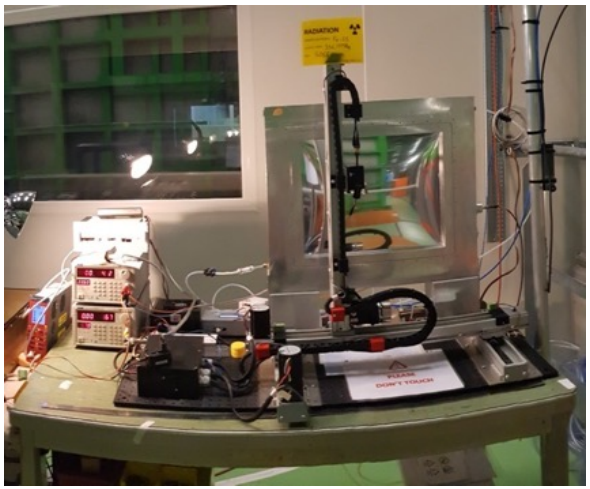


QC3: X-ray scan gain

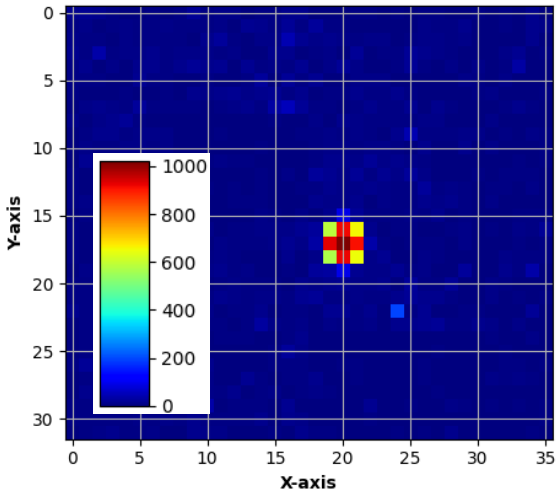


Qc3: Final validation of a module
The ERAM ^{55}Fe X-ray test bench @ CERN

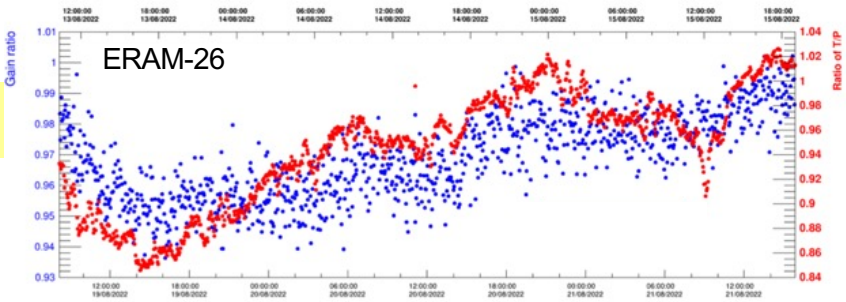
- ✓ Each ERAM is paired with 2 Front-End cards and "calibrated" for the use in the experiment
- ✓ Effective gain (ERAM * FE) and energy resolution @ 5.9 keV measurement on each pad with ERAM DLC layer at 350 V (nominal HV)
- ✓ The 280 MBq ^{55}Fe X-ray source is collimated in a Φ7 mm spot in the center of each pad
- ✓ The source is moved by an X-Y robot with respect to a reference pad which is "cross-scanned" with the source to locate its center (20 points every 1 mm in X&Y)
- ✓ Gas flow is 14l/h, the scan starts when RH<0.4% and stable, full scan duration 64h (3 mn/pad)
- ✓ Monitoring of "environmental conditions" : Gas composition (supplier certificate), T_{amb}, P_{atm}, $\Delta p_{chamber}$, T_{gas}, Relative Humidity $RH_{Gas\ out}$
- ✓ HV scan (330 - 360 V) on pad x20/Y17 (gain tuning)
- ✓ Remote shifting with local hardware support

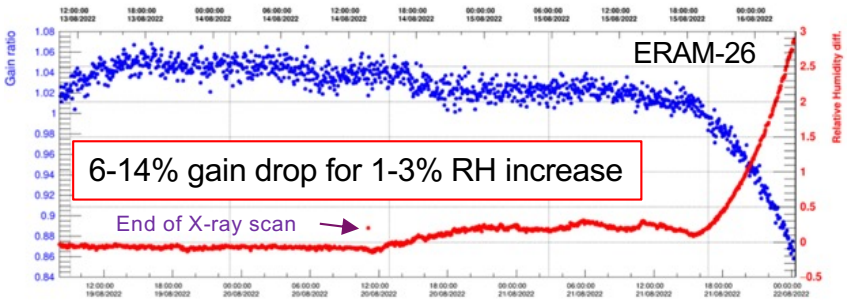


Source spot (gain scan)



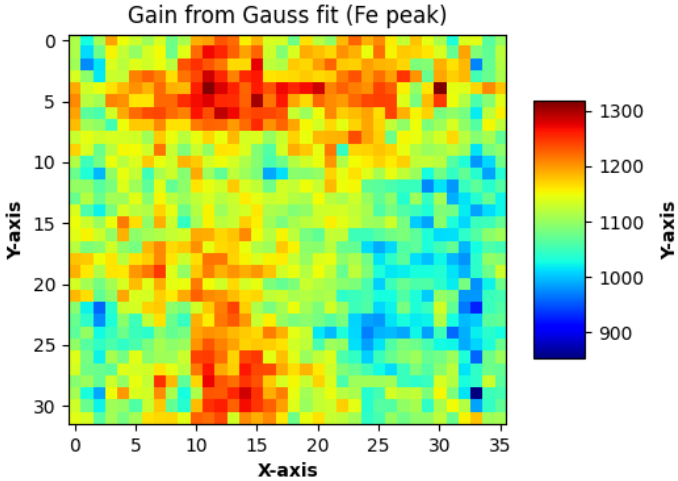
Gain correlation with T/P

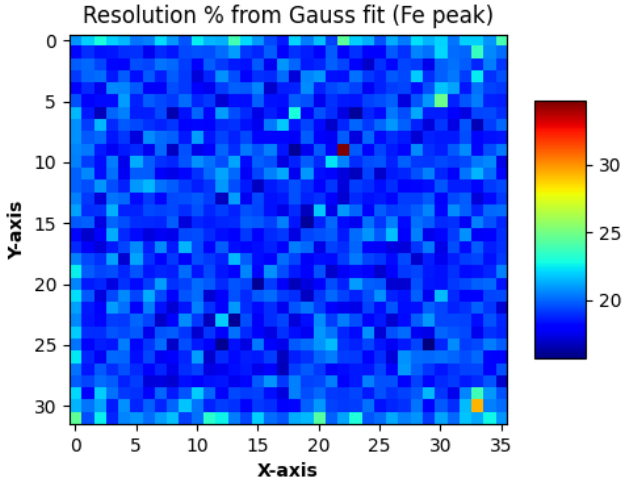


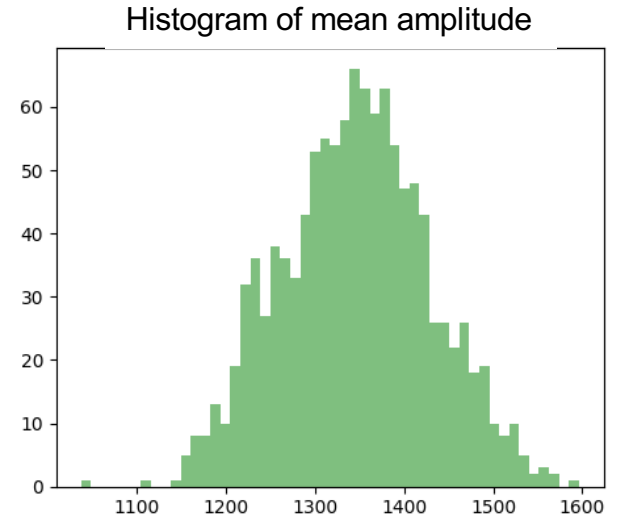


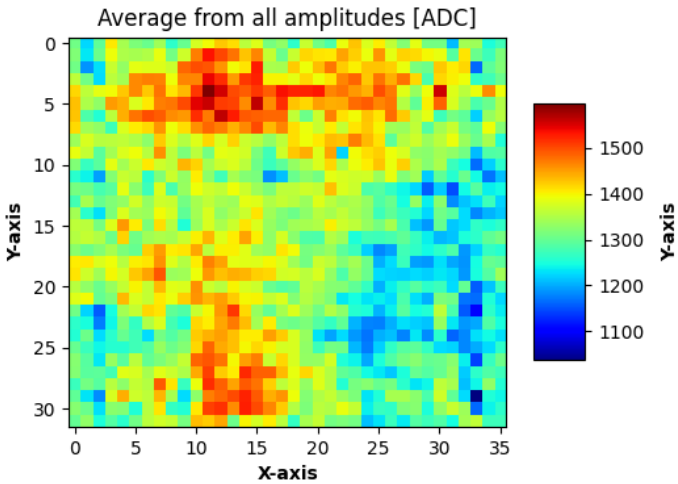
An example of a ^{55}Fe X-ray scan of a "typical" ERAM

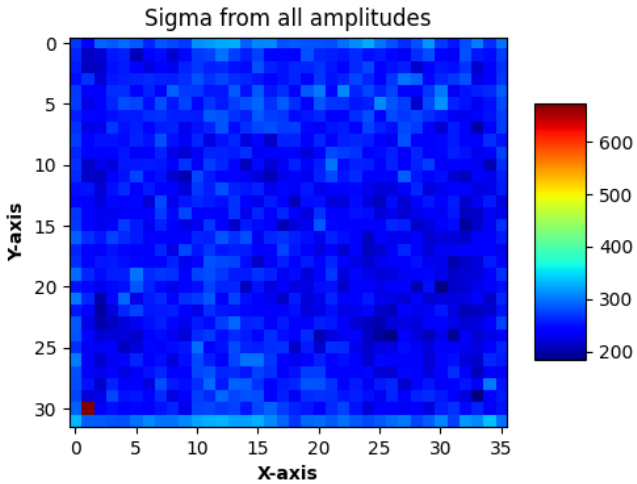
Tester name: Sara, ERAM ID: ERAM30, Date: 2022-07-22 08:47:59
Source: Fe55, Comments: full scan with coordinates from cross-scan 412ns shaping time and 180s run time
Ampl peak_thr: 50, Ampl. calc with neighbours: True
Scanned: 1152/1152, total time: 65.29 h

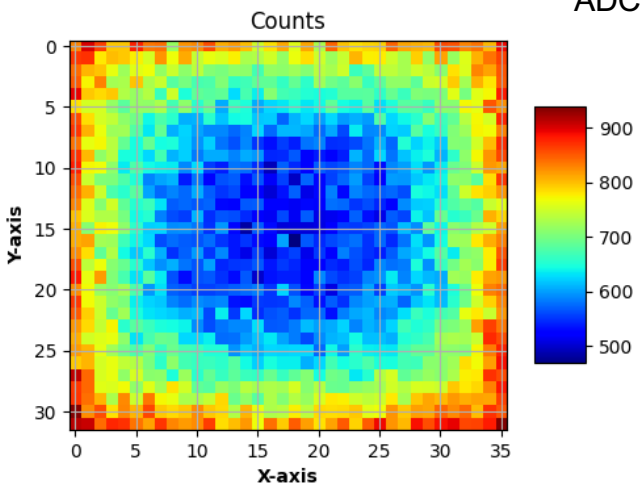






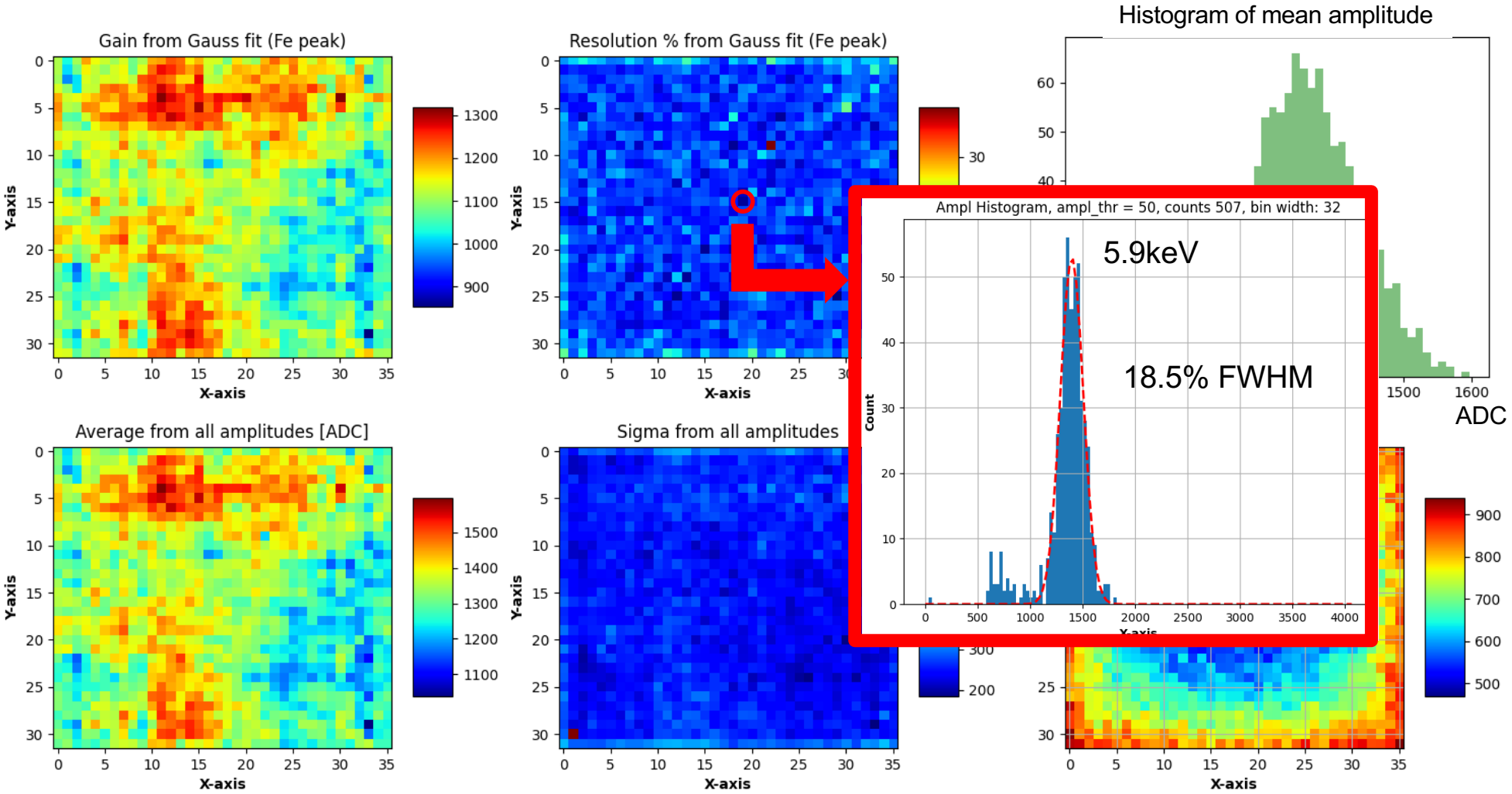






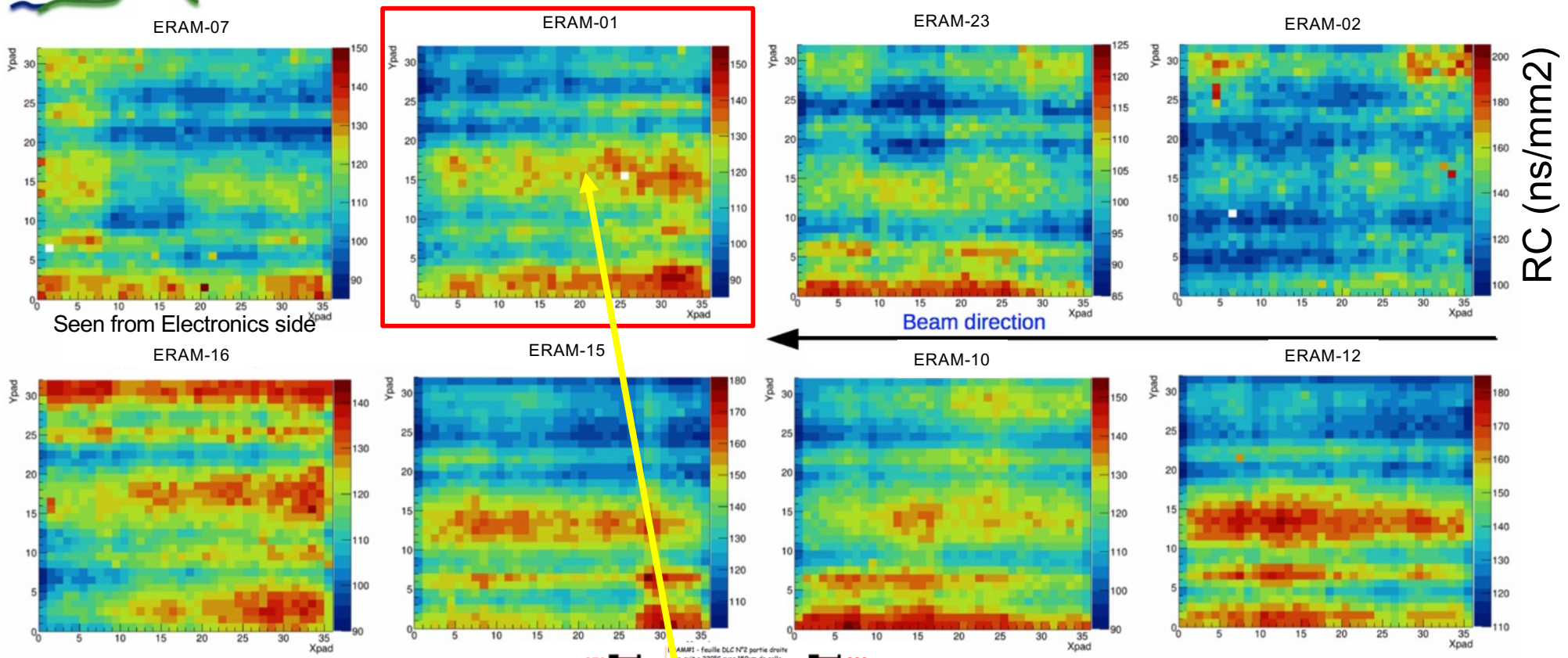
AN EXAMPLE OF A ^{55}FE X-RAY SCAN ERAM-30

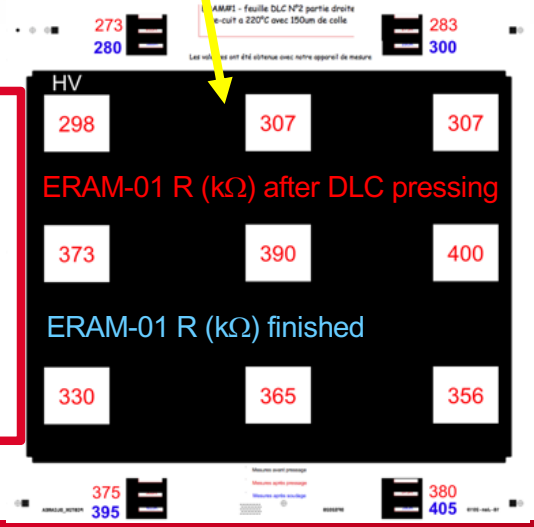
Tester name: Sara, ERAM ID: ERAM30, Date: 2022-07-22 08:47:59
Source: Fe55, Comments: full scan with coordinates from cross-scan 412ns shaping time and 180s run time
Ampl peak_thr: 50, Ampl. calc with neighbours: True
Scanned: 1152/1152, total time: 65.29 h



RC MAP DERIVED FROM X-RAY SCANS

ref: D. Attié et al, Nucl.Instrum.Meth.A 1056 (nov 2023)
Doi: 168534





Detailed model of pad signals

- Primary electrons diffusion in gas and amplification in micromegas
- Charge amplifier response
- Charge dispersion on the DLC resistive anode Vs RC

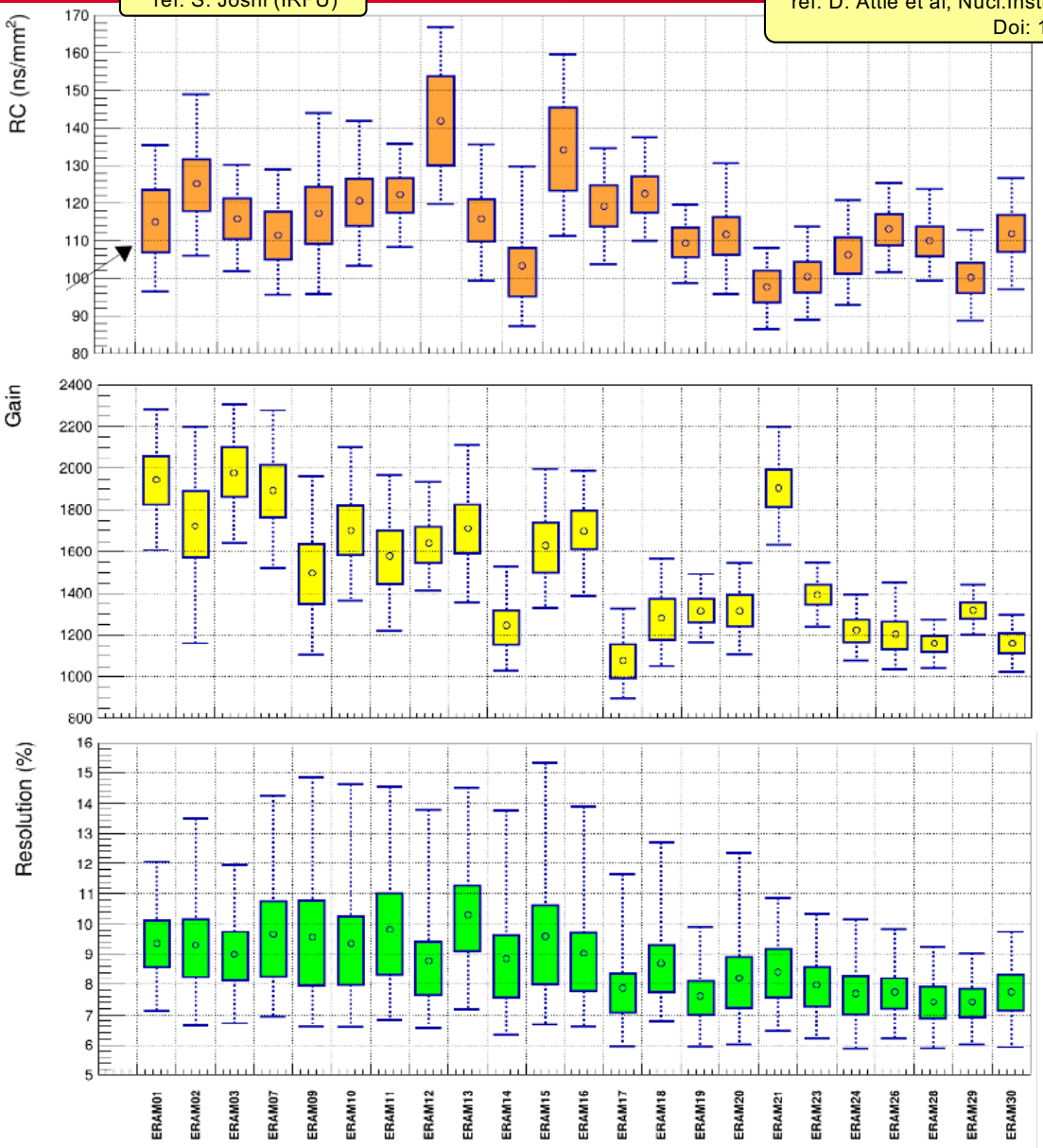
ERAM	RC_{mean} (ns/mm²)	$Gain_{mean}$	
01	116.9	1944	
02	128.6	1736	
03	116.4	1987	
07	111.8	1898	
10	120.9	1697	
12	145.4	1635	
15	135.1	1629	
16	120.4	1705	
18	68.98	1277	~1/2 RC as expected
23	101.6	1393	
29	102	1318	~ RC as expected
30	114.3	1161	

RC is quite well correlated to the measured DLC resistivity

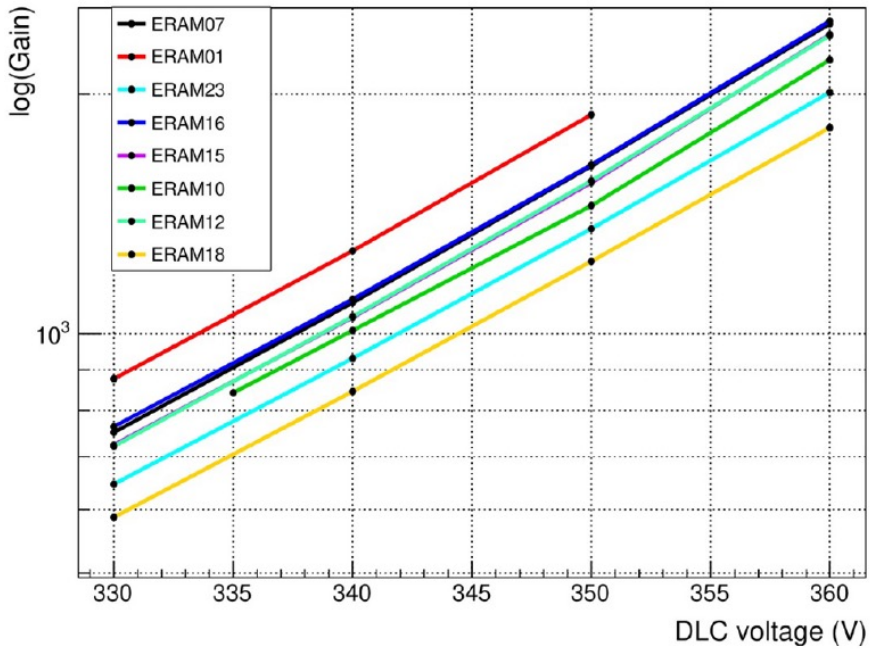
STATUS OF ERAM PRODUCTION (06/23)
TO BE COMPLETED WITH THE LAST ERAM SCANS

ref: S. Joshi (IRFU)

ref: D. Attié et al, Nucl.Instrum.Meth.A 1056 (nov 2023)
Doi: 168534



Gain v/s DLC voltage



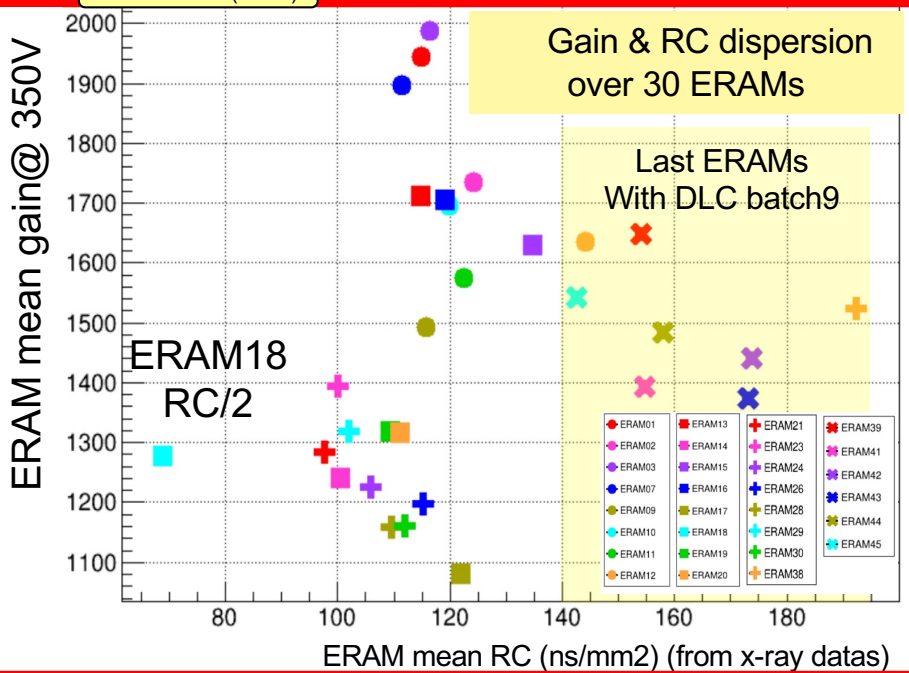
All ERAM with : 0.38 < R_{meas} < 0.56 MΩ/sq.
C fixed by 150 μm glue thickness

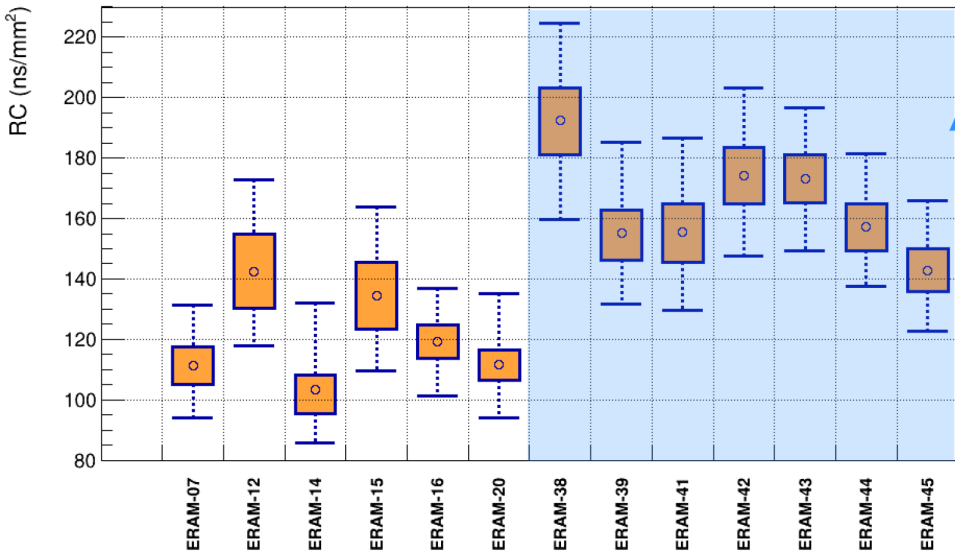
Except : - ERAM18 : ~1/2 R (1/2 RC)
- ERAM29 : ~1/2 R, ½ glue thickness
→ ~same RC

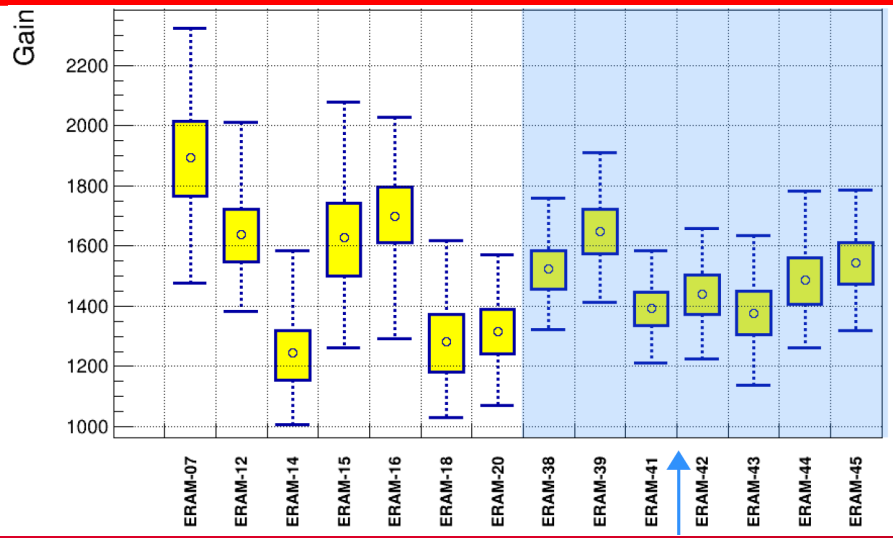
Legend :
Box boundaries = mean +/- 25% (50% of values)
Bars boundaries = mean +/- 49% (98% of values)

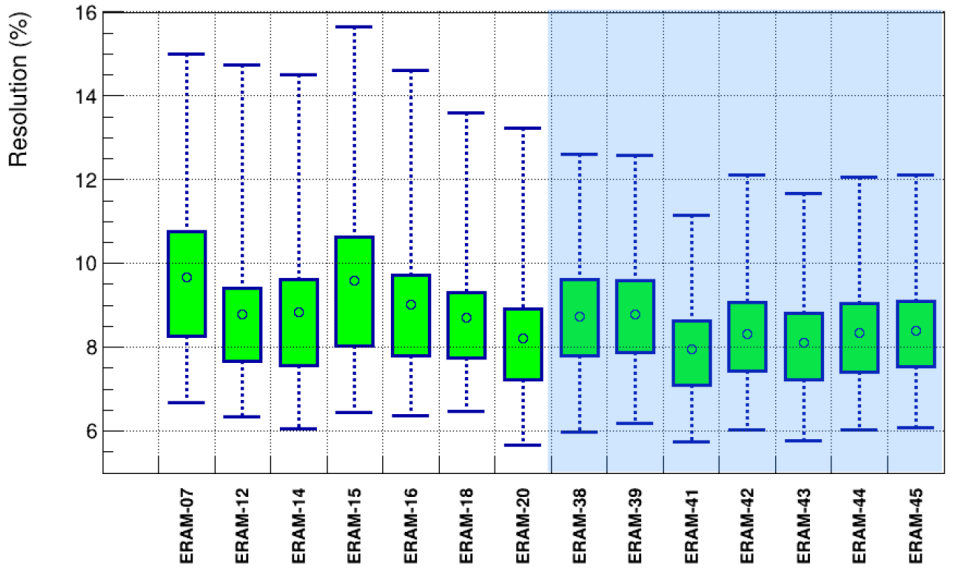
LAST STATUS OF X-RAY DATA ANALYSIS

ref: S. Joshi (IRFU)



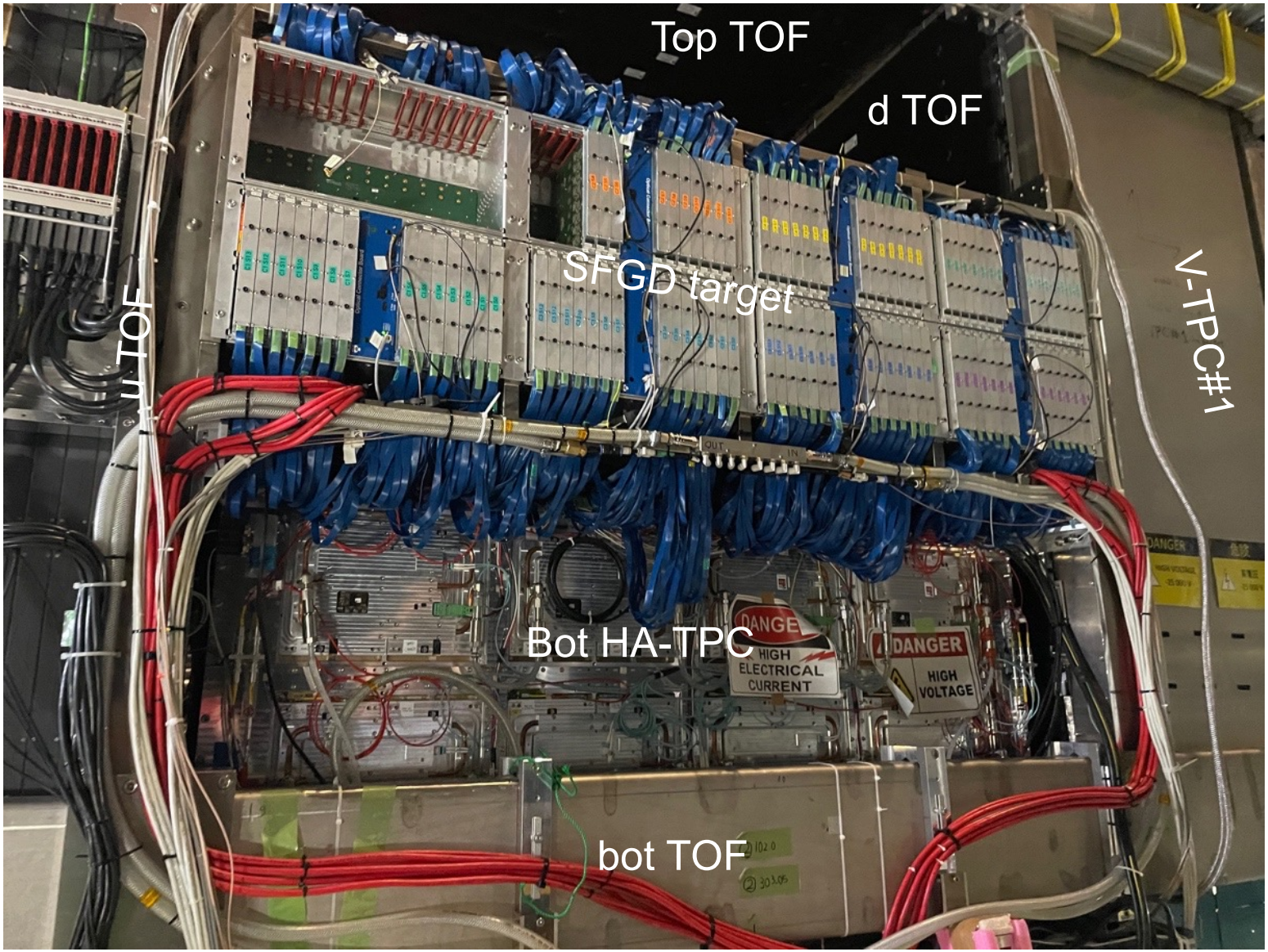






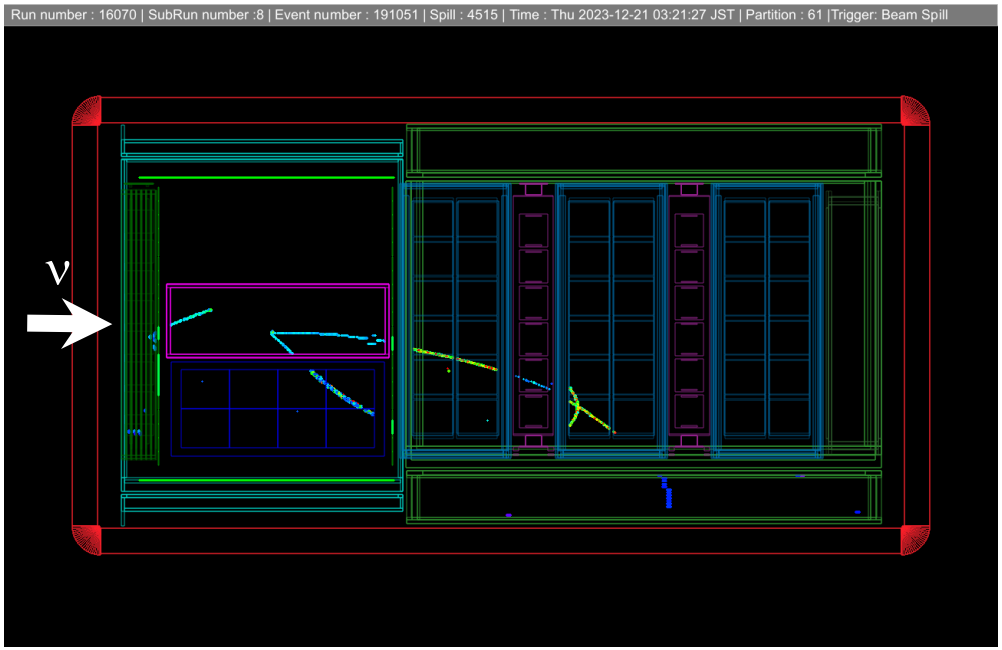
THE HA-TPC READOUT PLANE IN ND280 BASKET @ JPARC (SEPT 8)

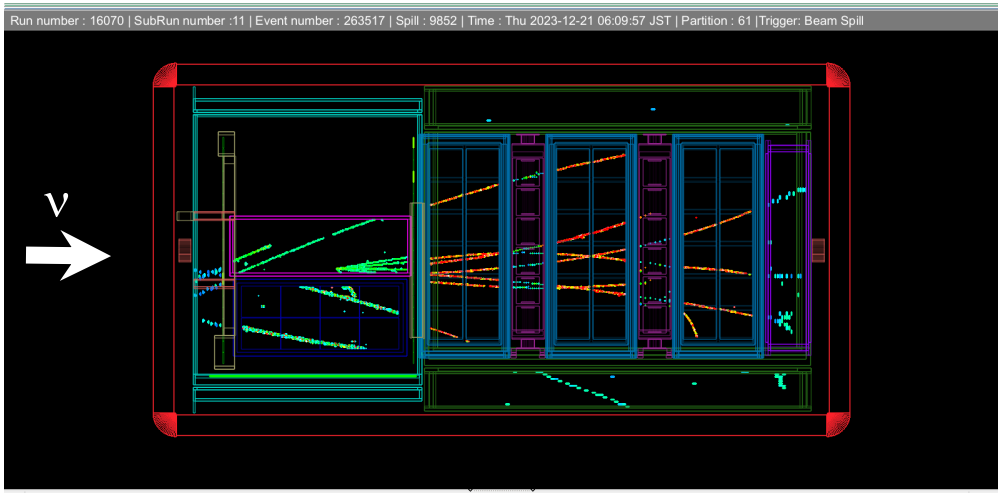
THE UPGRADED ND280 DETECTOR (READY FOR MAGNET CLOSURE (NOV 15, 2023)

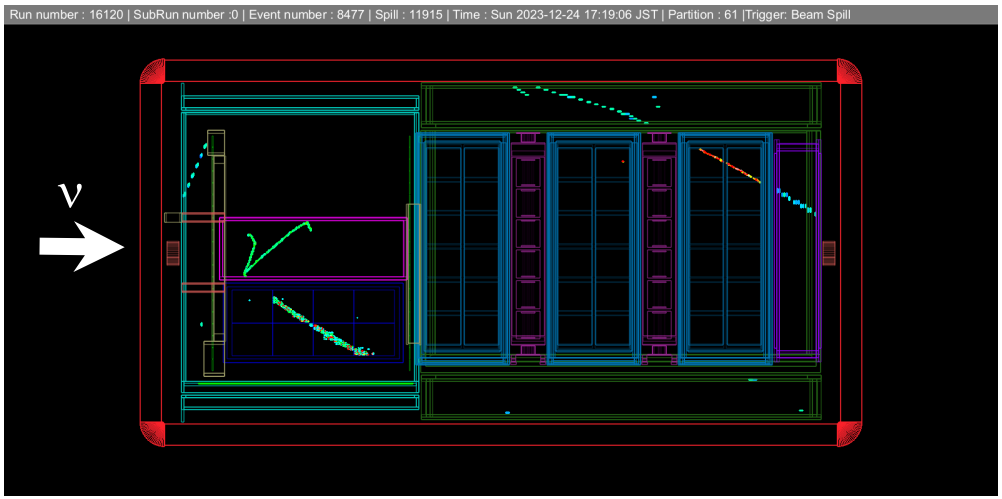


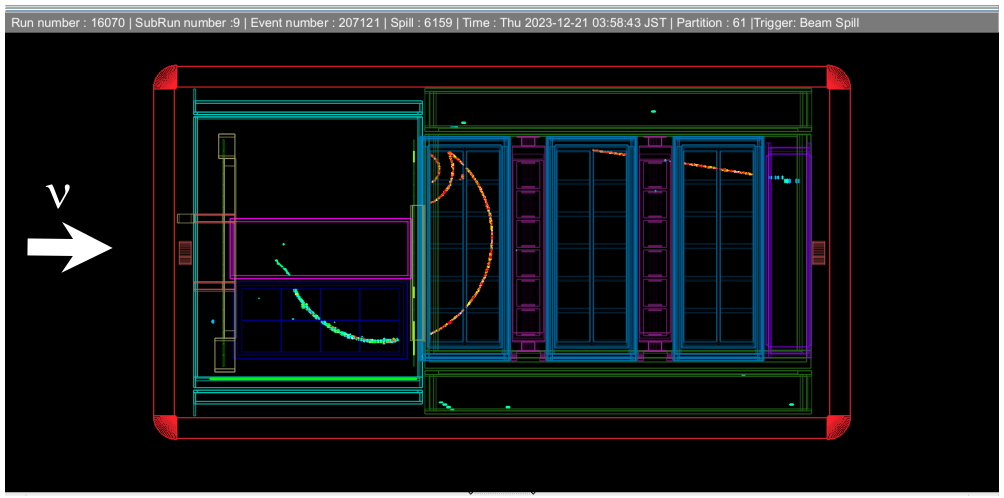
Nov-Dec 2023 T2K run
ND280 event displays

https://www.kek.jp/en/press-en/202401171405/









CONCLUSION AND PERSPECTIVES

- The T2K/HA-TPC ERAM detector module was designed to be a compact 34 x 42 x 4 cm^3 unit suitable to pave large readout endcaps of TPCs.

- The production is finished with a total of 36 detectors qualified for use in the two HA-TPCs. A lot was learnt from this 2 years production and difficulties were overcome for an overall very good quality of the detectors : less than 1/1000 “dead” pads and no major issues to operate the detectors.

- The detector response modelization is consolidated and the performances of the detectors, driven by the RC constant of the charge spreading DLC stack, are within the specifications for the readout of the ND280/HA-TPCs.

- Field cage #0 leakage current issue from the original design was understood and solved for the four HA-TPC ½ field cages.

- The bottom HA-TPC was successfully operated during the Nov-Dec 2023 T2K technical run. Data analysis is on-going. The TOP HA-TPC will be equipped with its 16 ERAMs in February 2024 for an installation of the TOP TPC in the basket of ND280 in April, finalizing the upgrade of the Near detector of T2K for the 2024 T2K physics run (June 2024 →).

A « HAPPY » HIGH-ANGLE TPC JUST BEFORE CHRISTMAS !!