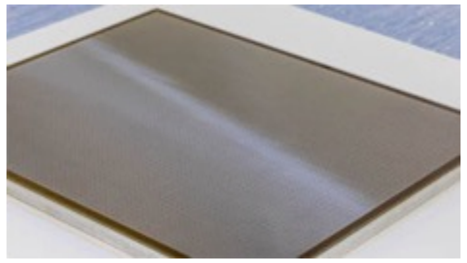
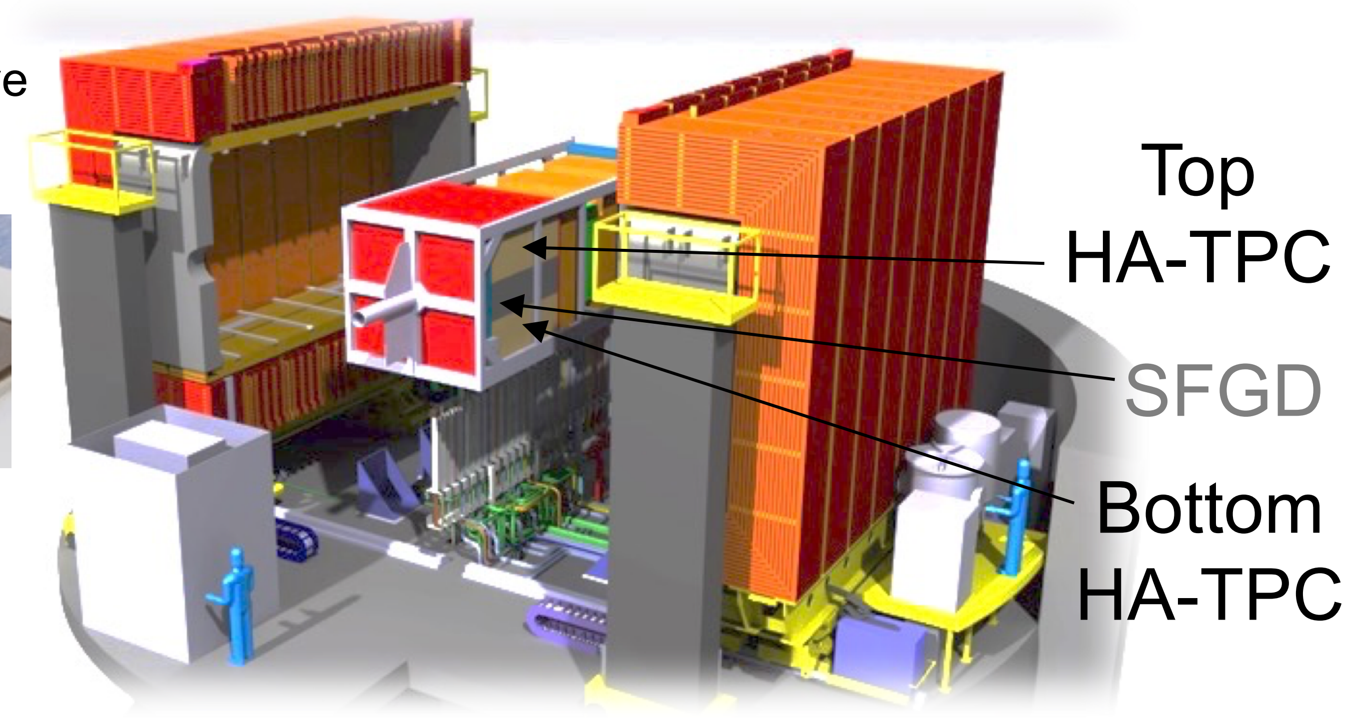
DE LA RECHERCHE À L'INDUSTRIE

PRODUCTION & PERFORMANCES OF ERAM* DETECTORS FOR THE T2K/ND280/HA-TPCs

* ERAM
Encapsulated Resistive
Anode Micromegas





A. Delbart, on behalf of the ND280/HA-TPC collaboration,
CEA-Saclay/DRF-IRFU, Univ. Paris – Saclay

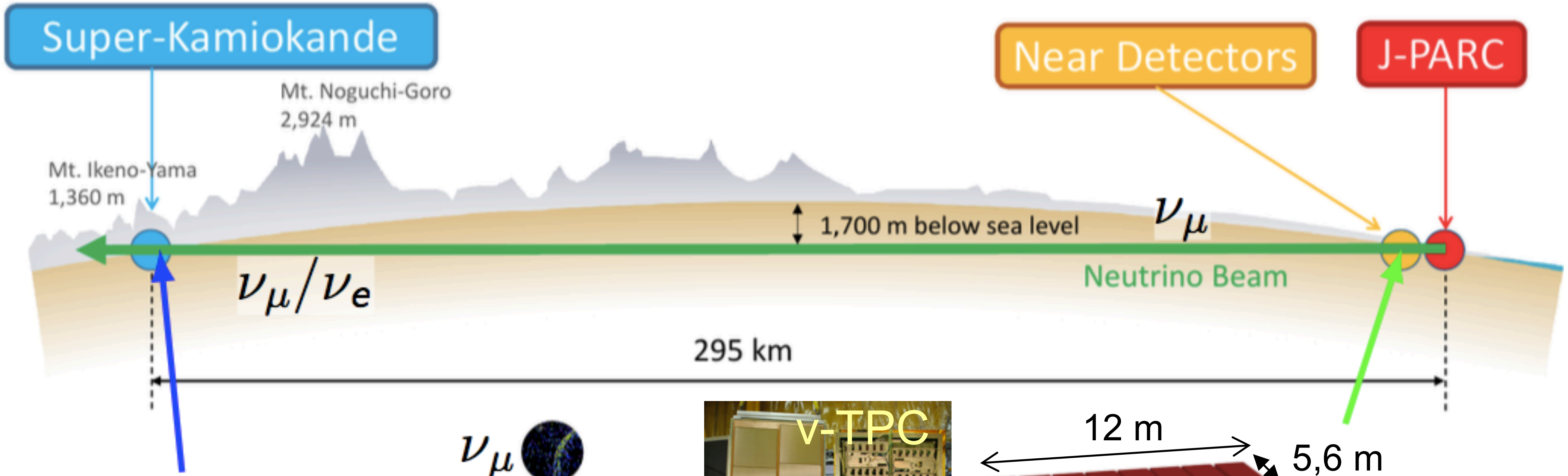
WEIZMANN INSTITUTE OF SCIENCE

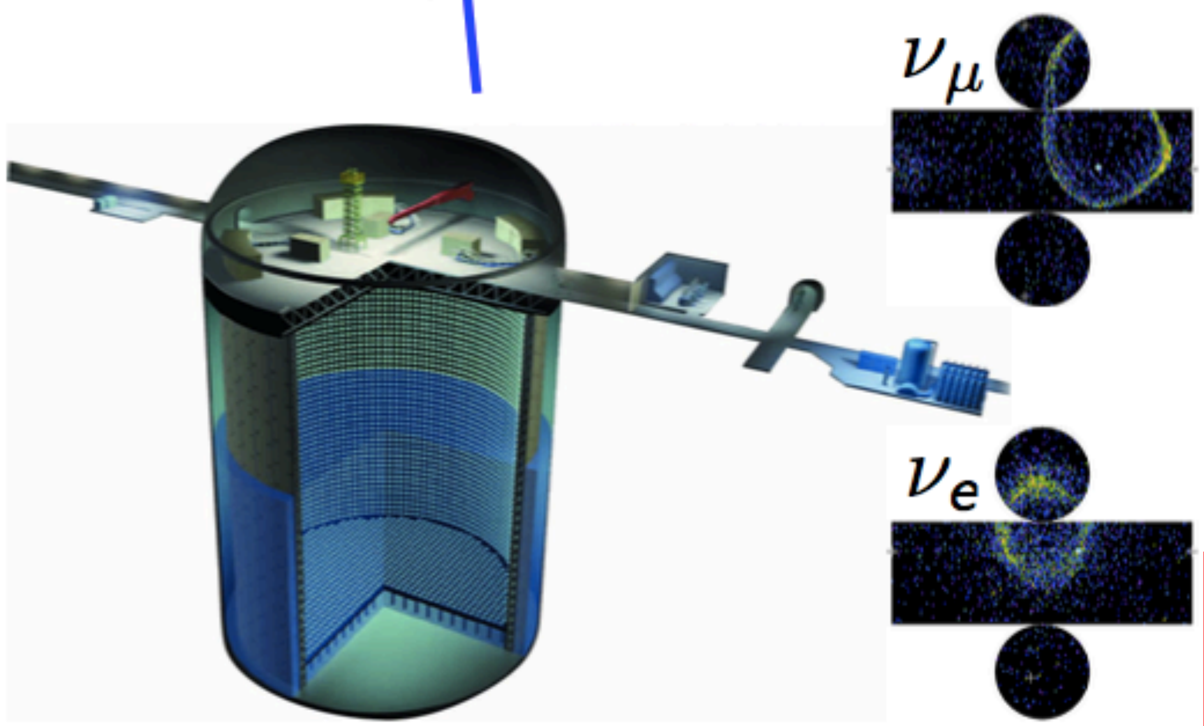
The 7th International Conference on
Micro Pattern Gaseous Detectors 2022
Weizmann Institute of Science, Rehovot, Israel

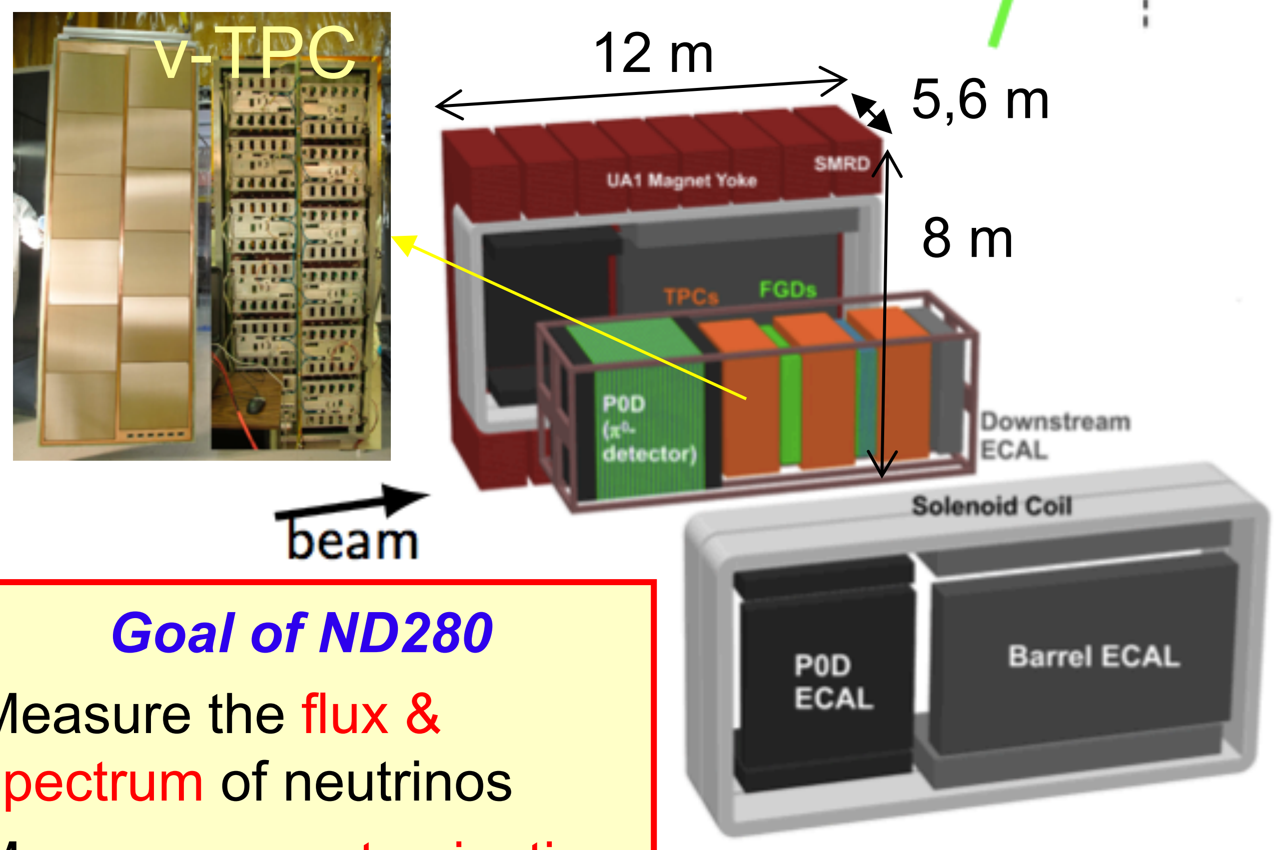
OUTLINE

- The T2K / ND280 near detector upgrade
- The new High-Angle TPCs readout by ERAM modules
- The ERAM production:
  - Diamond-Like Carbon foil Quality Control (QC) and selection
  - ERAM “mesh-pulsing” QC
  - ERAM characterization with an automated X-ray test bench
- ERAM “RC maps” derived from X-ray test bench pad waveforms
- Some preliminary data analysis results of the test beam of a mockup ½ HA-TPC at CERN/PS-T10 (september 2022)
- Conclusions & perspectives

THE T2K EXPERIMENT
THE ND280 NEAR DETETECTOR







Super-Kamiokande (SK)

22.5 kt → ~200 kt (Hyper-K)

Goal of ND280

Measure the flux & spectrum of neutrinos

Measure ν_e contamination

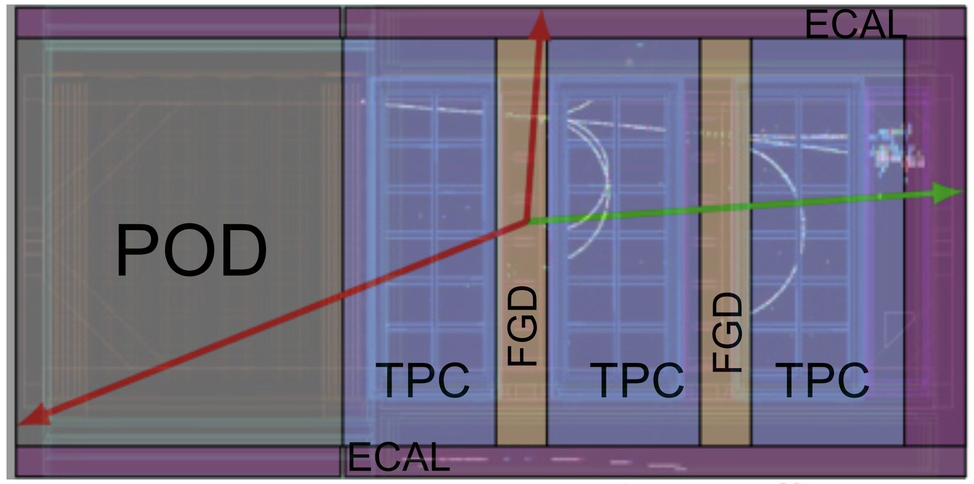
ND280

The goal of T2K-II phase (2022-) data taking after main ring upgrade is to measure δ_{CP} at 3σ thanks to a decrease in systematic errors in ND280 from 6% to 4%.

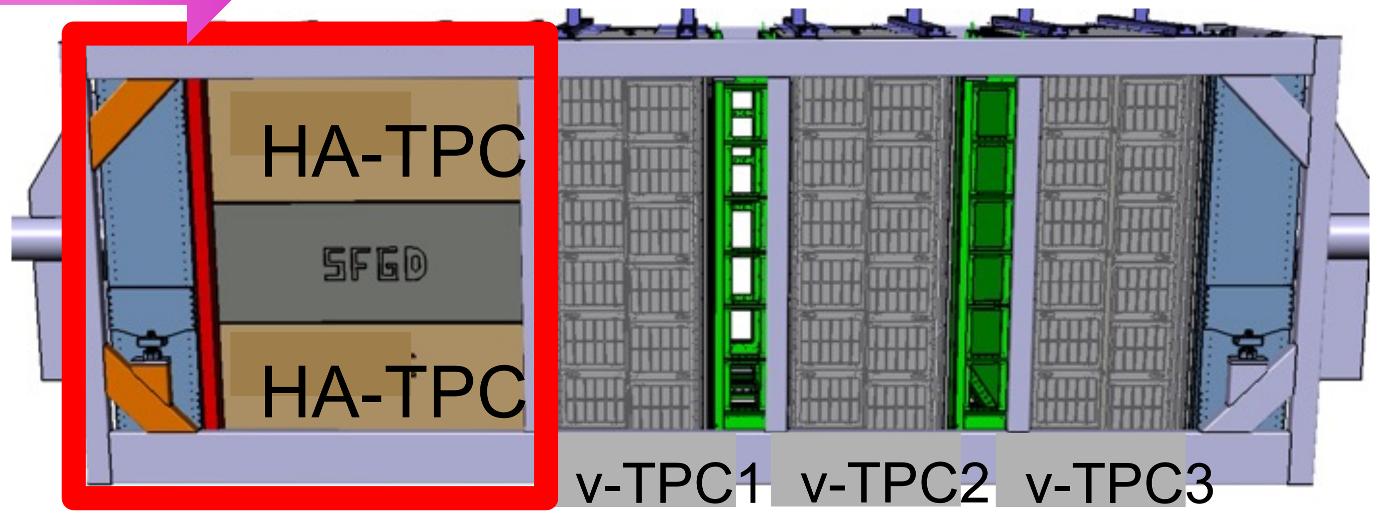
T2K/ND280/TPC PERFORMANCES
NEED FOR AN UPGRADE

T2K ν-TPC : NIM A637 (2011) p25-46
ND280 upgrade TDR : arXiv:1901.03750v1

Current ND280

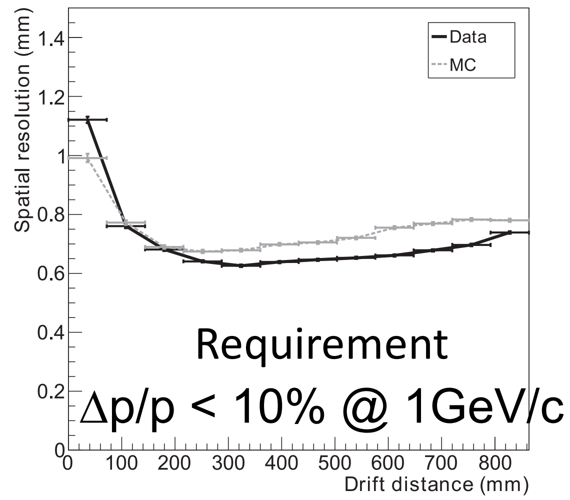


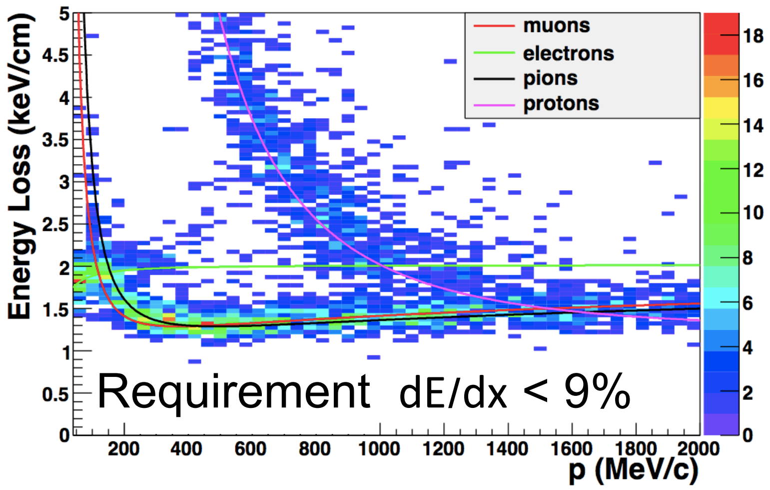
ND280 upgrade to be installed in 2023



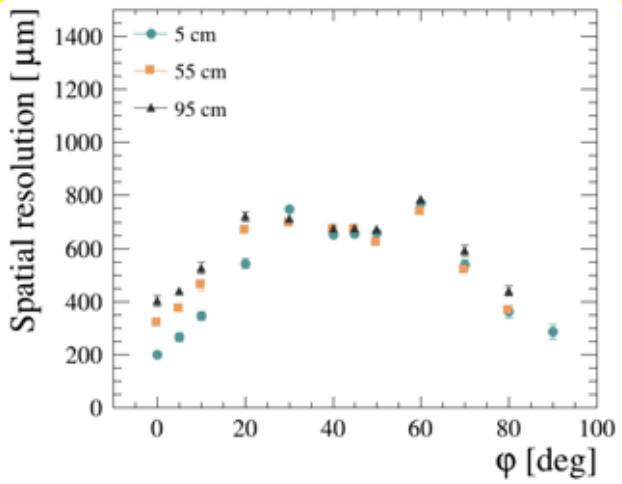
+ 6 TOF planes surrounding the new tracker

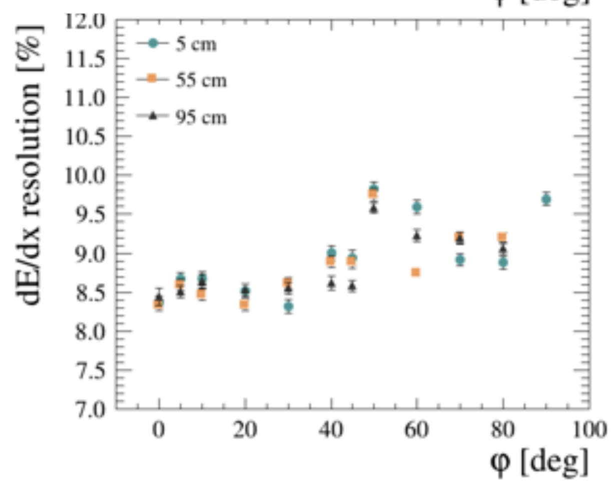
V-TPC performance requirements
« metallic » anode bulk-micromegas





ERAM-01
DESY test beam 2021
Submitted to NIM A





Parameter	HA-TPC Value	v-TPC
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

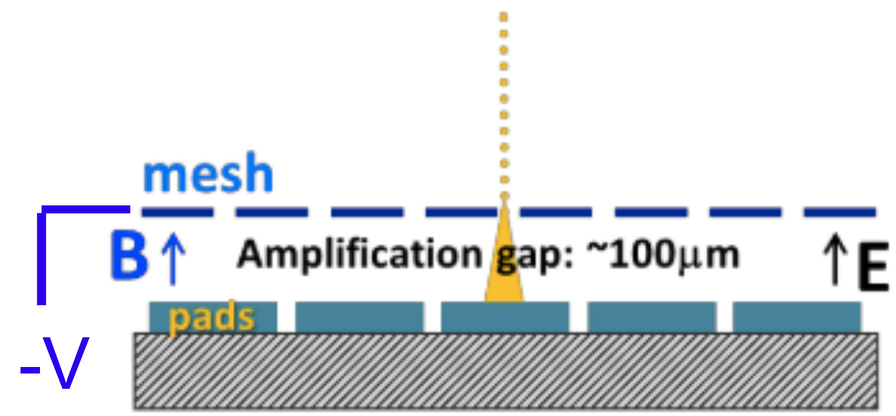
RESISTIVE BULK-MICROMEGAS WITH DIAMOND-LIKE CARBON RESISTIVE LAYER

Based on ILC/TPC prototype R&D: P. Colas et al.

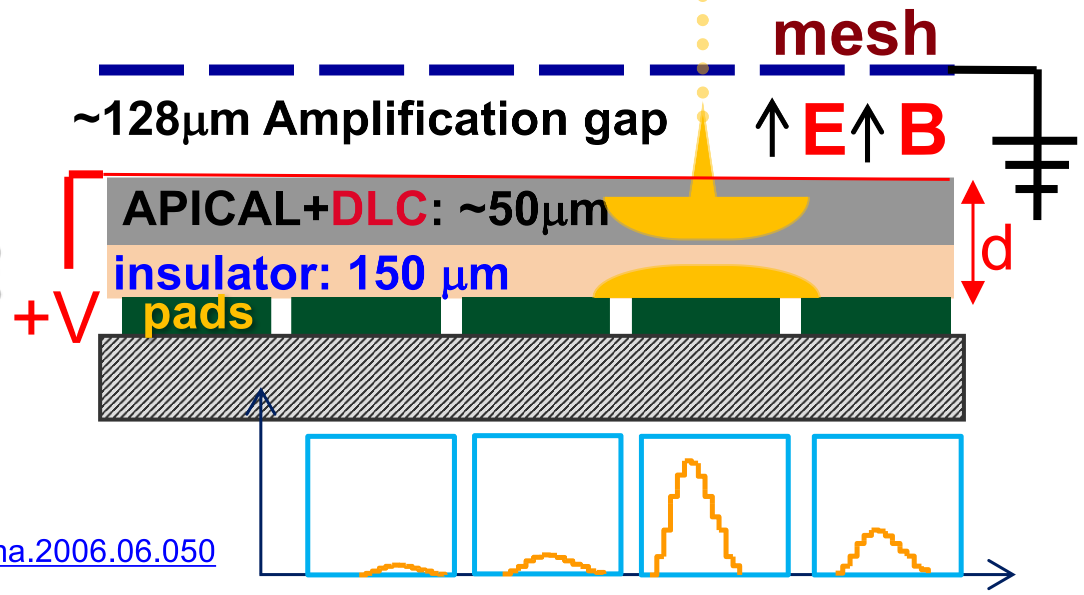
Choice of the Resistive foil technology for the HA-TPC micromegas readout

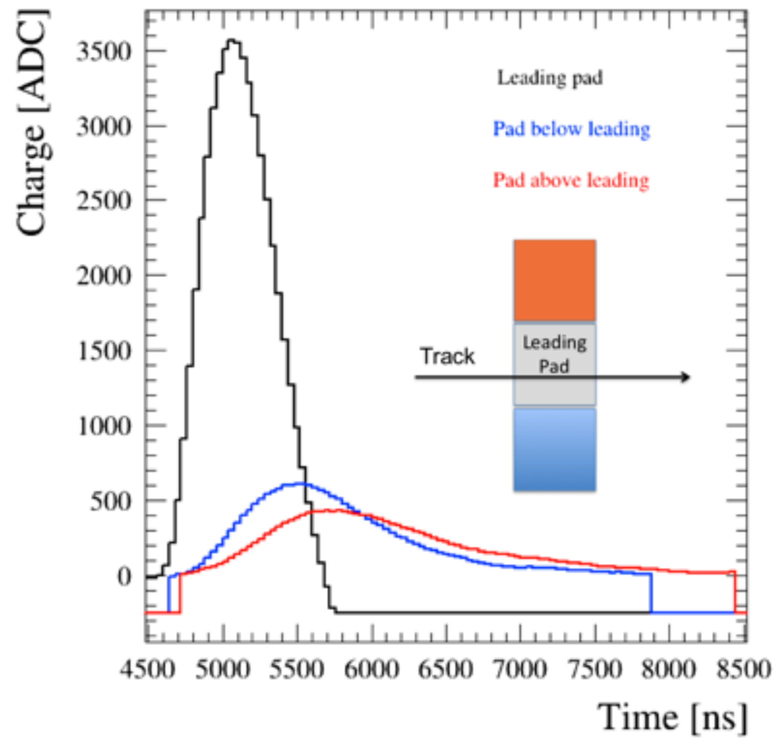
- Charge spreading which should enable keeping the ~600 μm spatial resolution with larger pads and improves it at short drift distance → less electronic channels, cost reduction
- ASIC spark protection no longer needed → more compact FEE, maximize HA-TPC acceptance
- Encapsulated mesh @ GND + insulating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

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

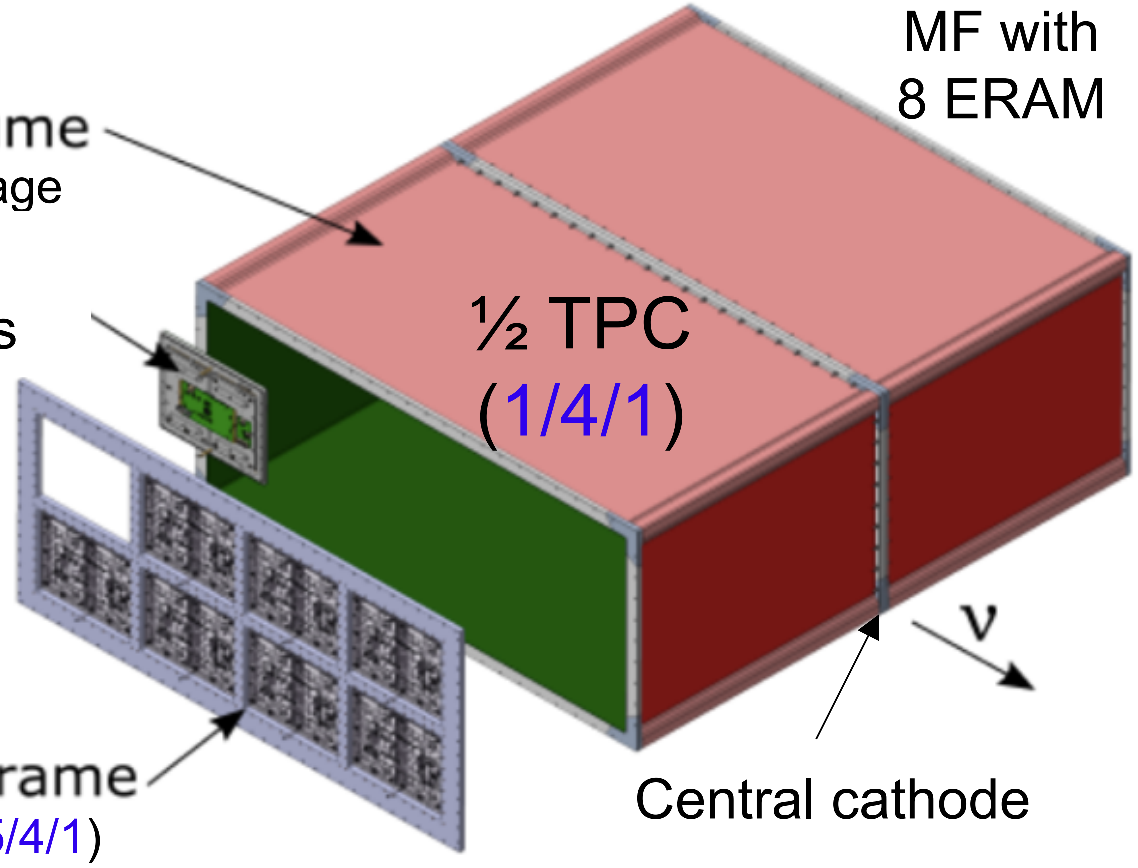
ε_r [APICAL]~3,3 and ε_r [glue] ~4,8

For pads of ~11x10 mm^2, the DLC resistivity is chosen **around** $0.5\ M\Omega/\blacksquare$ and the glue thickness **~150 μm** (RC_{th}~100 ns/mm^2) as a trade-off for charge spreading & spark protection

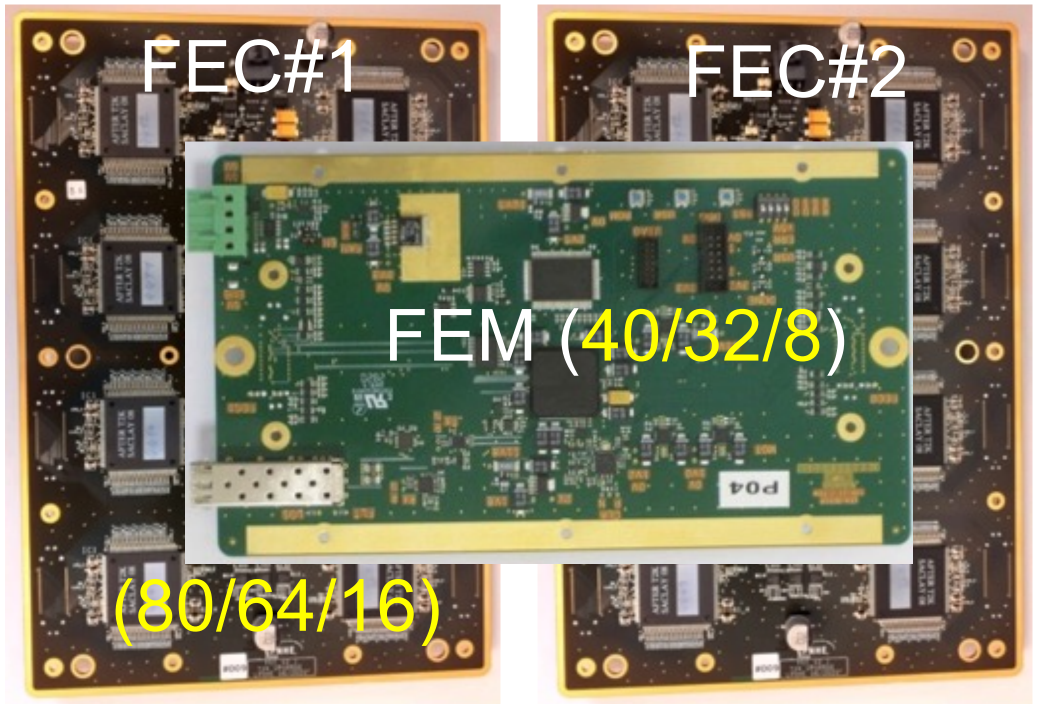
PRODUCTION STATUS

XX PRODUCED/YY NEEDED/ZZ SPARE

HA-TPC field cage
+ Gas system
+ 4 Gas Monitoring Chambers

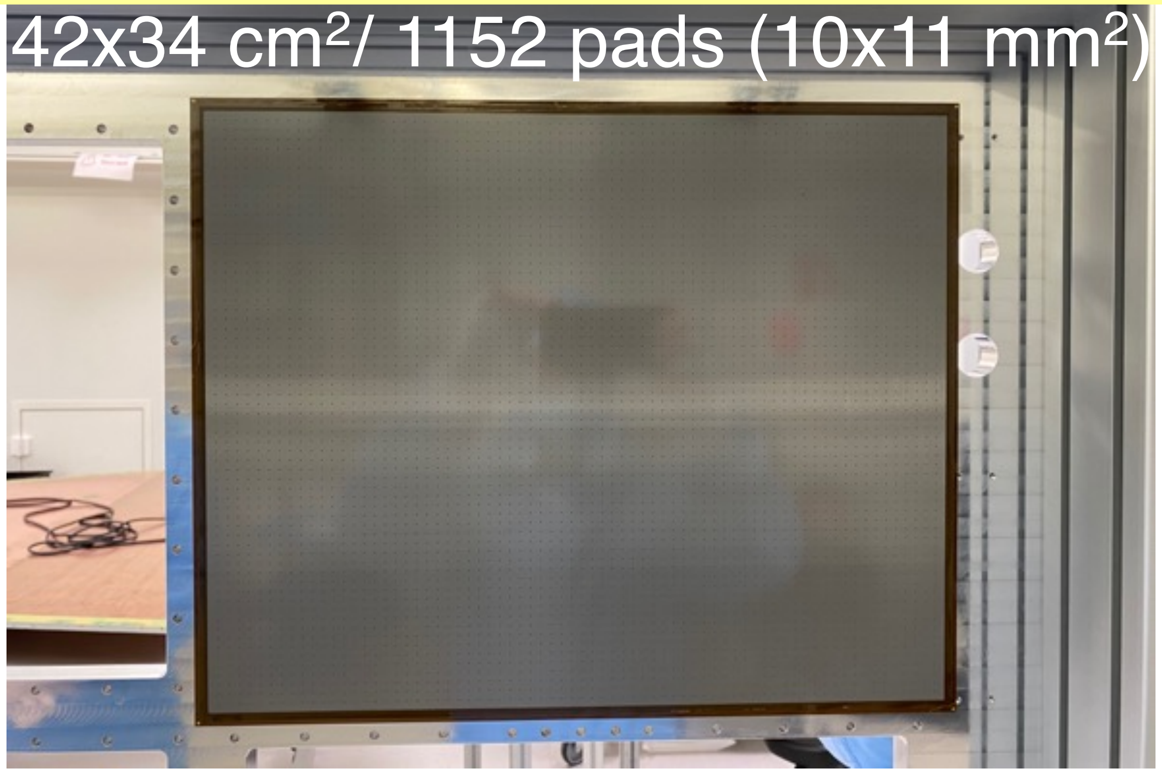


ERAM Front-End Electronics

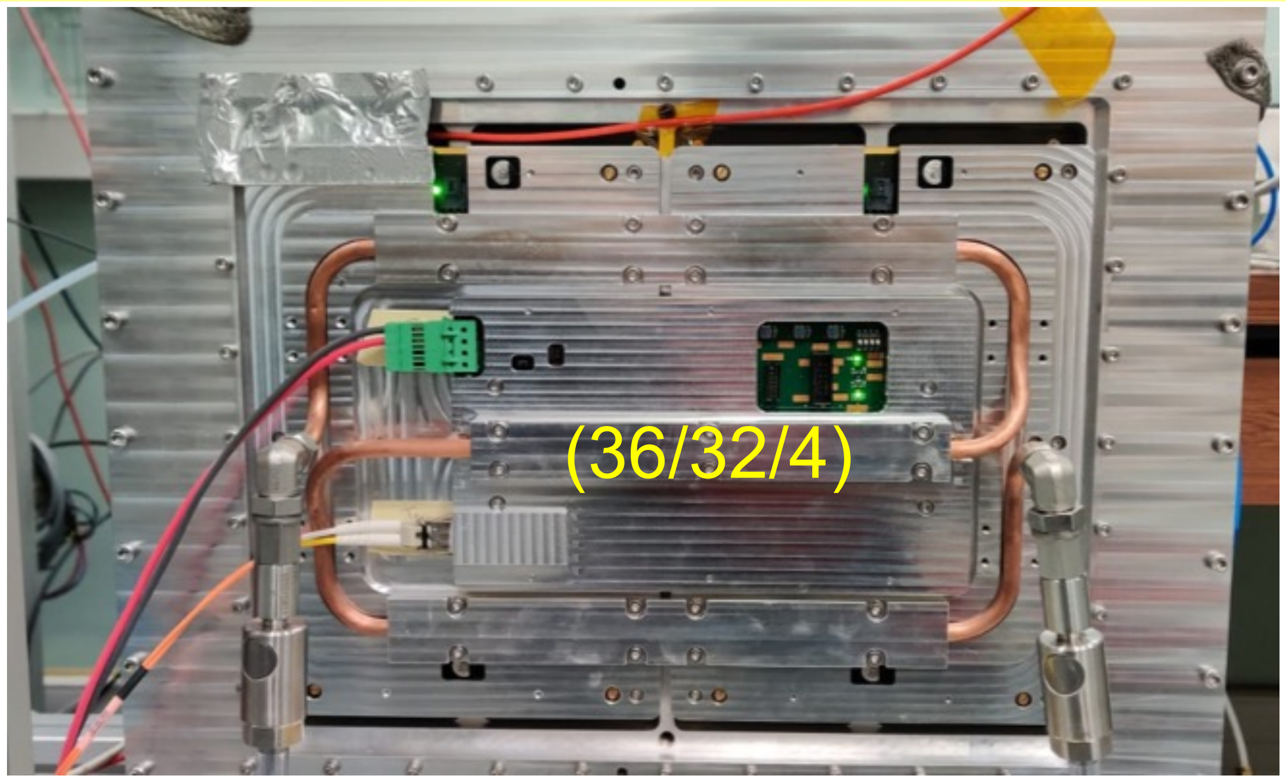


Back-End Electronics

ERAM detector (21/32/4 : 21 fully qualified)



ERAM module
Detector + FEE + water cooling mechanicals



SUMMARY OF ERAM DEVELOPMENT

D. Attié et al. NIM A984, (2020), 163286. doi:10.1016/j.nima.2019.163286
D. Attié et al. NIM A1025, (2022), 1661109. doi:10.1016/j.nima.2019.166109

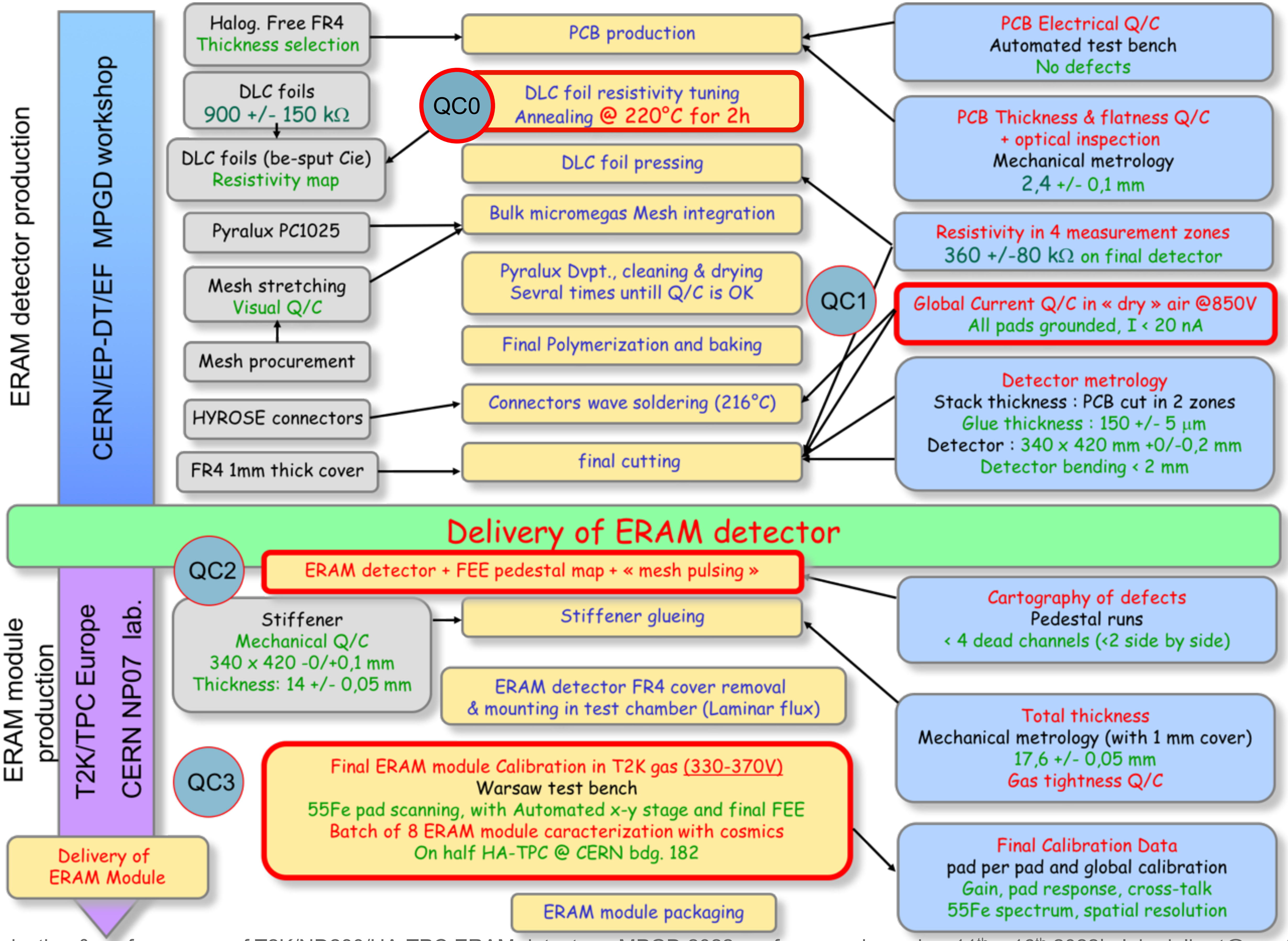
2018 — 2019 — 2020 — Nov. 12 PRR — Pre-series To series production — 2021

CERN/T9 test beam — DESY test beam

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

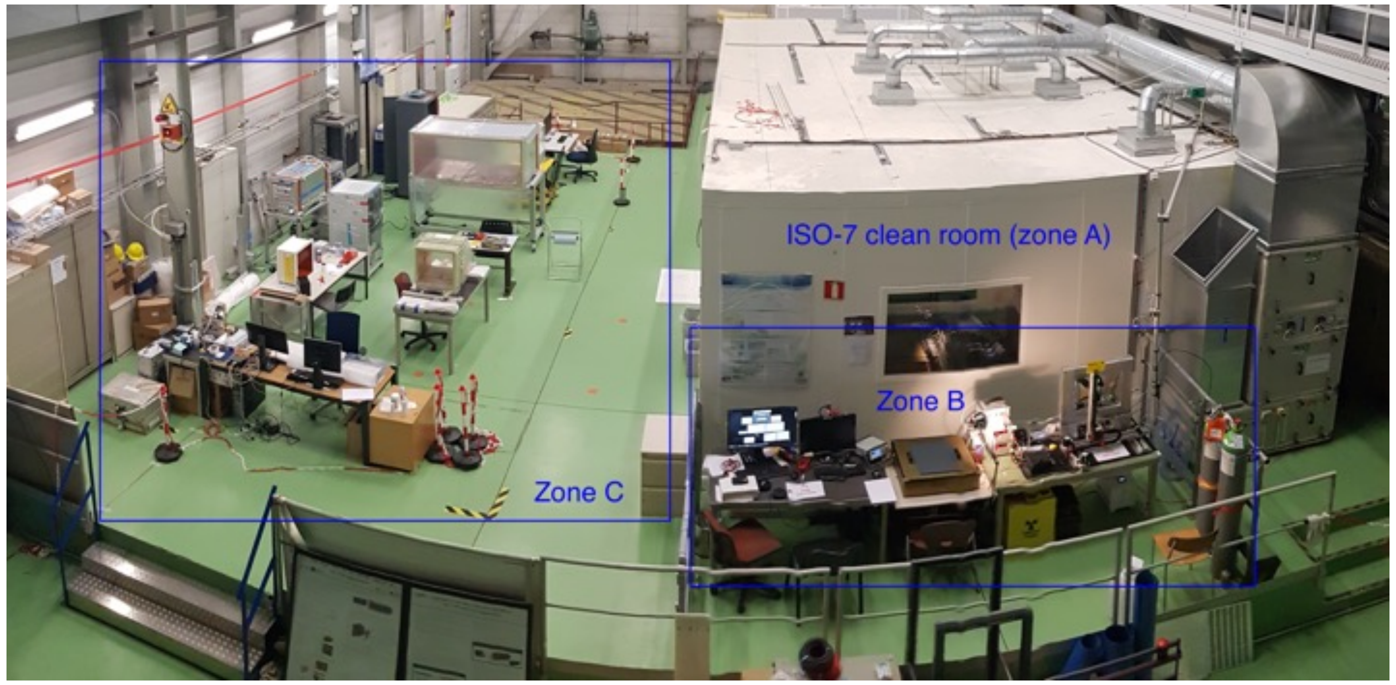
	2018 MM0-DLC#	2019 MM1-DLC1 & 2	2020 ERAM-P1 & P2	Production ERAM-xx (ERAM-01-28)
Readout PCB	Original T2K-TPC	HA-TPC V1 + ARC FEE	HA-TPC V2 + final FEE V1	HA-TPC V2 + final FEE V2
Size	34 × 36 cm²	34 × 42 cm²	34 × 42 cm²	34 × 42 cm²
Pads	48 × 36 cm²	32 × 36 cm²	32 × 36 cm²	32 × 36 cm²
Pad size	6,85 × 9,65 mm²	10,09 × 11,18 mm²	10,09 × 11,18 mm²	10,09 × 11,18 mm²
Number of pads	1728	1152	1152	1152
DLC resistivity (MΩ/sq.)	~2,5 (original foil) Not meas.on detector	0,32-0,44 (batch#P1 foils) 0,2-0,27 (meas. on detector)	0,28-0,40 (batch#P1 foils) 0,15-0,22 (meas. on detector)	**~1 (foils) / ~0.28-0,4 (det.)** Top TPC: 1-1.5 (foils) **After baking : ~0,4-0,55**
RC_{design} [ns/mm^2] RC_{data} [ns/mm^2]	~400	60<RC<80 X-ray scan to process	24<RC<35	**55<RC<78** **102<RC<145 (this talk)**
Insulation layer	200 µm glue + 50 µm APICAL	75 µm glue + 50 µm APICAL	200 µm glue + 50 µm APICAL	150 µm glue + 50 µm APICAL
σ (mm) For 200 ns peaking t For 412 ns peaking t	~1,6 ~2,3	~3,8 ~5,4	~5,8 ~8,3	~3,9 ~5,6
dE/dX (measured 1 det.) Extrapol. to 2 detectors	9 to 9.5% (e- & p) <7%	9 to 9.5 % (e-) with 0.2T <7%	Energy resolution @5.9 keV ~20% FWHM	8.5 to 10 % (e-) with 0.2T <7%
Spatial resolution (µm) Beam (Horizontal tracks) cosmics	300 (0T)	MM1-DLC1 200 (0 or 0.2T, 200/400 ns t_p) 700 (MM1-DLC2, @370V)	300-350 (ERAM-Px @370V)	@ DESY 07/ 21 200-800 µm (ERAM-01) / horizontal – 45° tracks (412ns)

ERAM PRODUCTION QA/QC

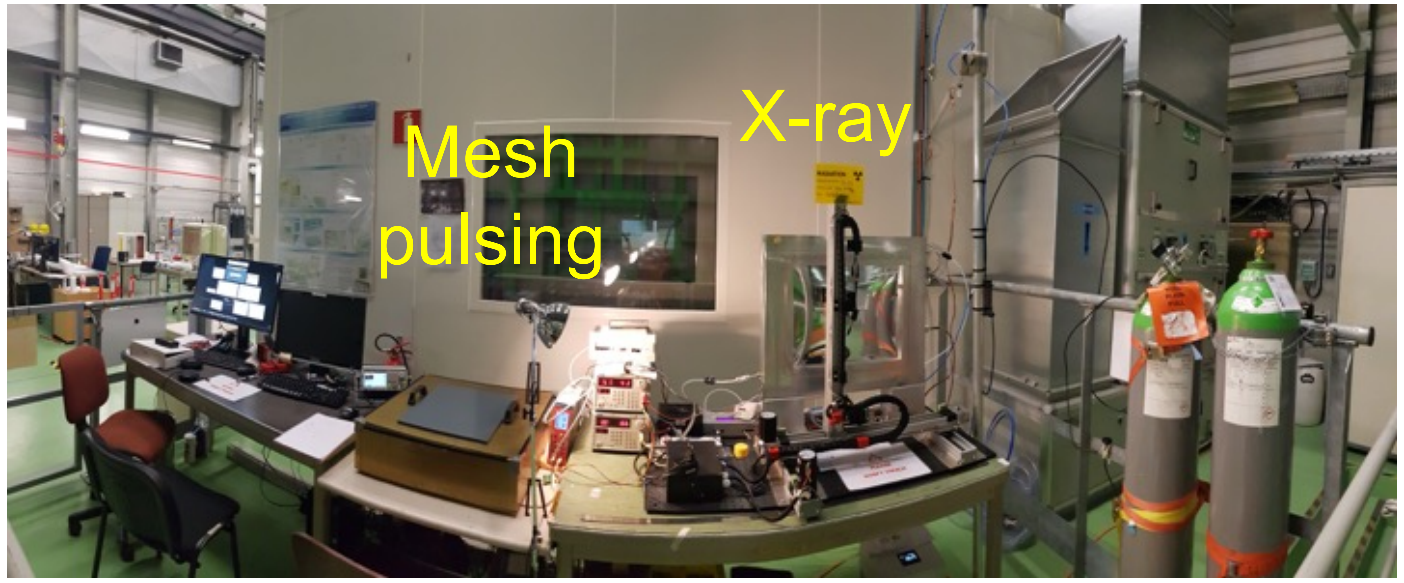


HA-TPC PRODUCTION AND QA/QC @ CERN

NP07 HA-TPC working area at bdg. 182

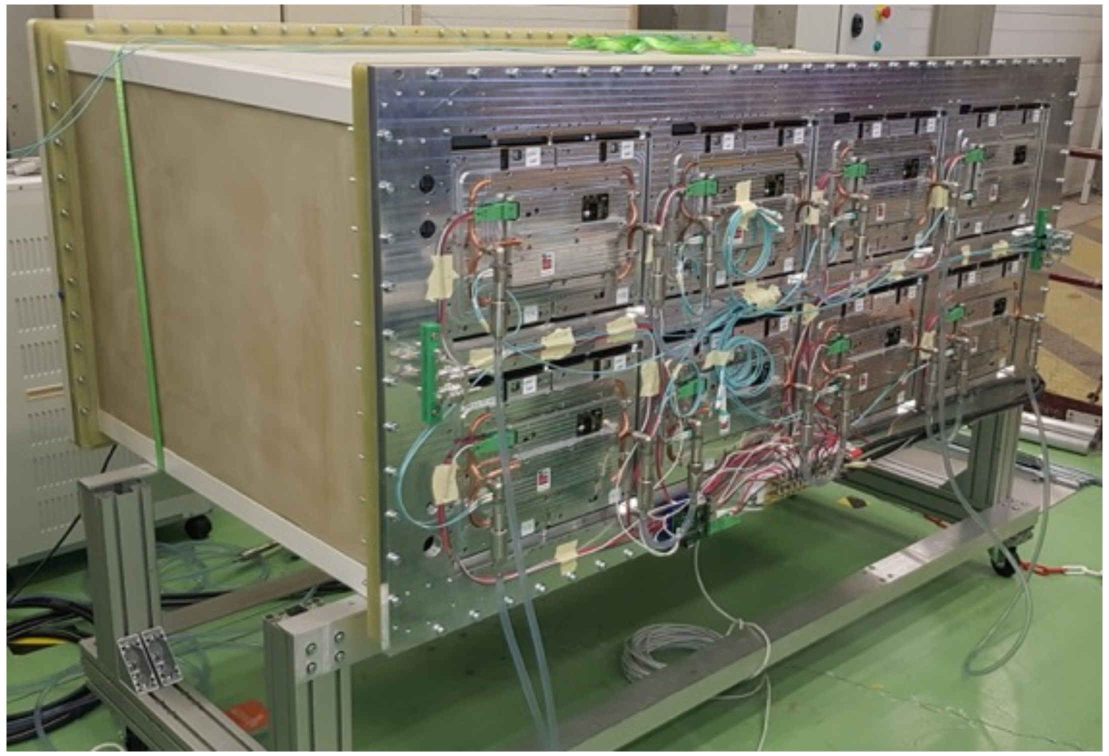


HA-TPC ERAM QA/QC working area



First ½ TPC field cage

Full scale ½ TPC mock-up (8 FEE+mechanics)

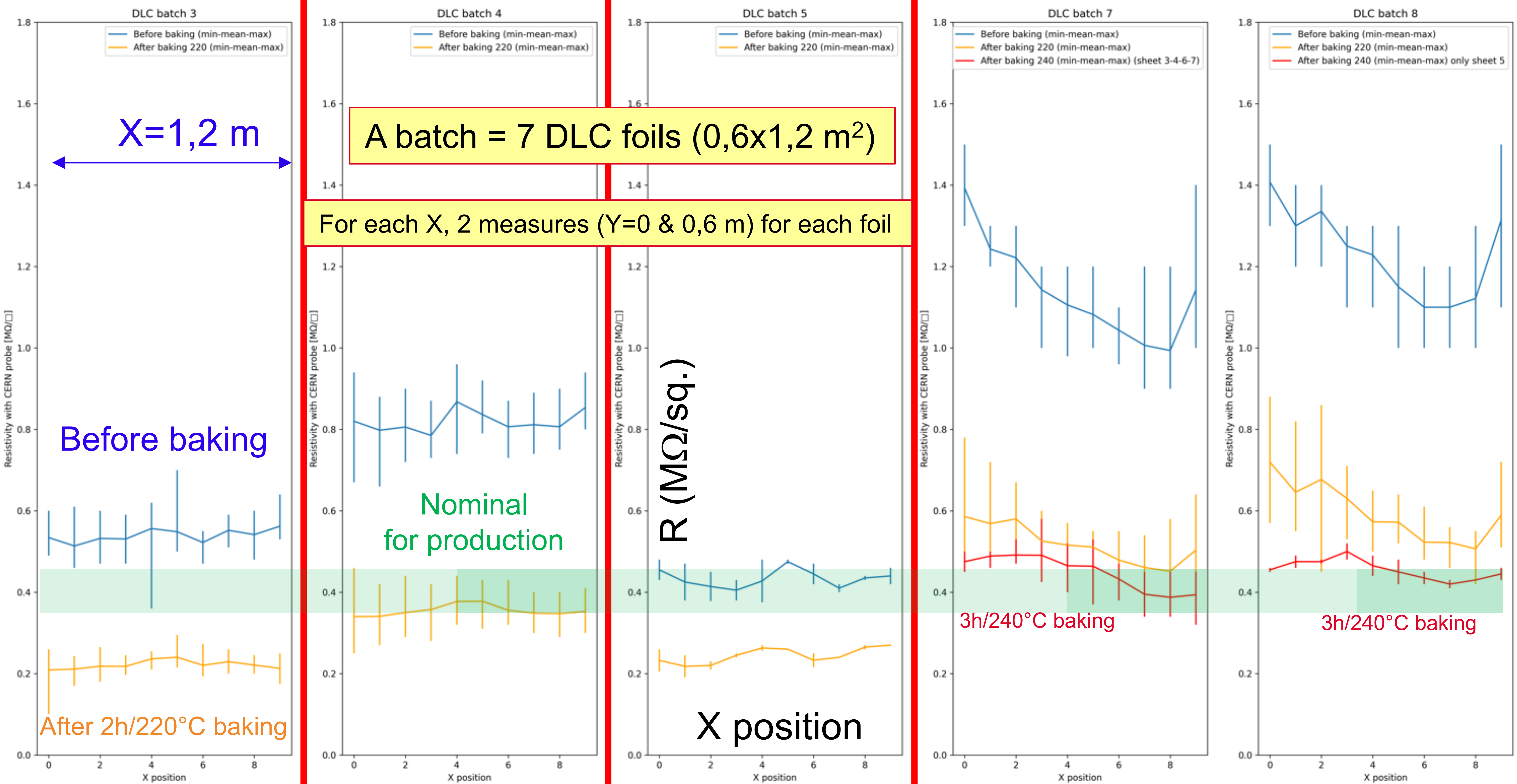


QC0: DLC RESISTIVITY : FOIL SELECTION

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

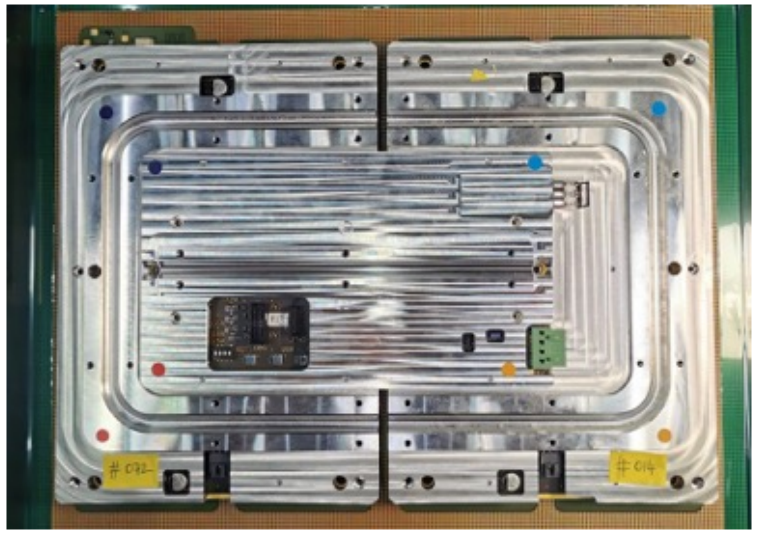
Top. TPC production →

½ RC prototype	Production	prototype	Restart of production for Top TPC



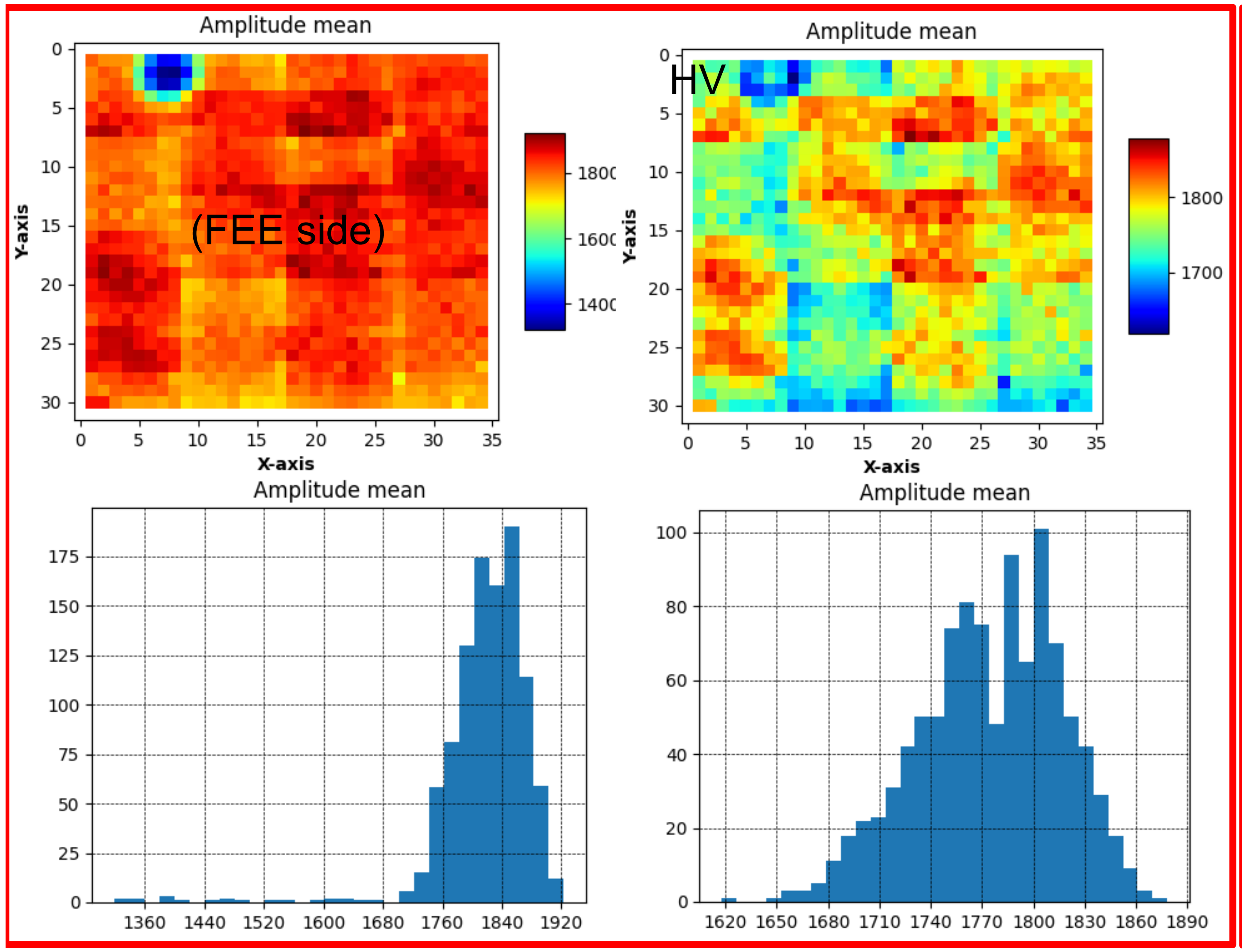
½ R, ½ RC	nominal R, RC	½ R, ½ glue thick.	~Nominal R, RC
→ **ERAM-18**	**ERAM-17,19,20,21 23,24,26,28,30**	Nominal RC → **ERAM-29**	~8 ERAMs for Top TPC Order of 2 new DLC batches

QC2 : ELECTRONIC MESH PULSING
DETECTING DEFECTS BEFORE GLUING STIFFENER
EXAMPLE OF A DEFECT ON ERAM-20

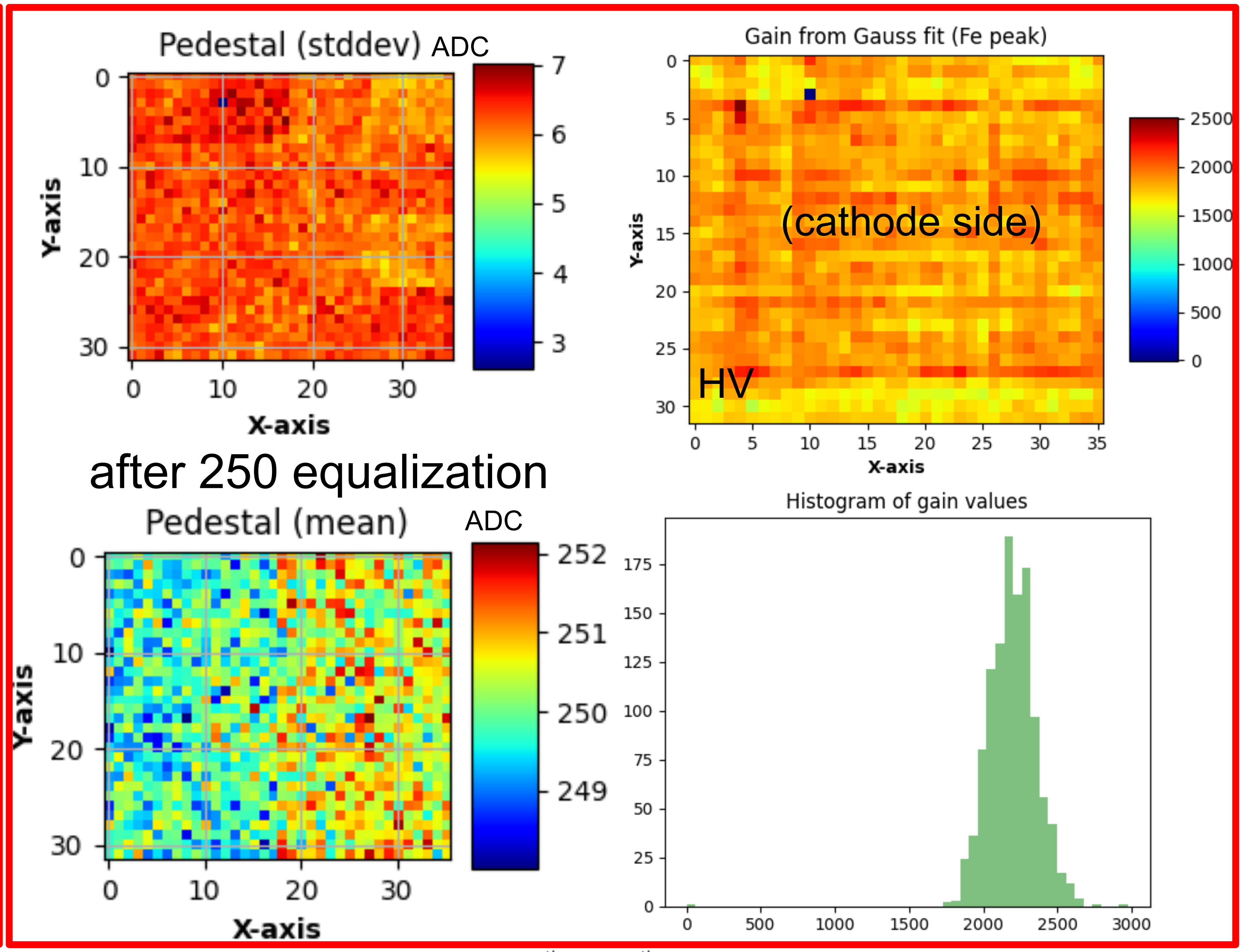


- ✓ The "mesh-pulsing" is a QC used before & after gluing of the mechanical stiffener to detect major defects
- ✓ A 1kHz, 300 mV square signal is pulsing the ERAM mesh through a 50 Ω adapted cable
- ✓ The readout electronics DAQ is triggered with a NIM signal synchronized with the mesh pulsing (~5 mn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

QC2: mesh pulsing before & after « repair »

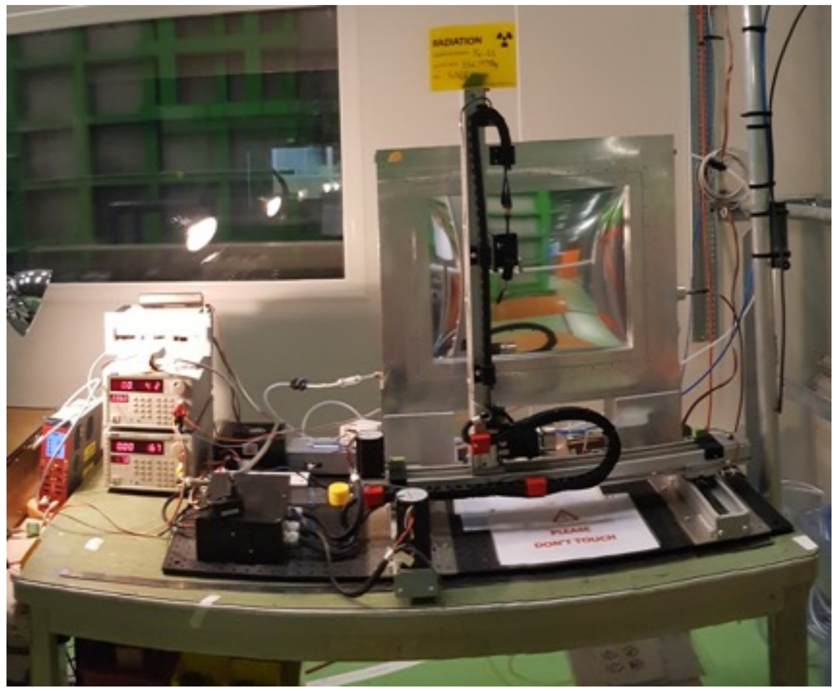


QC3: X-ray scan gain

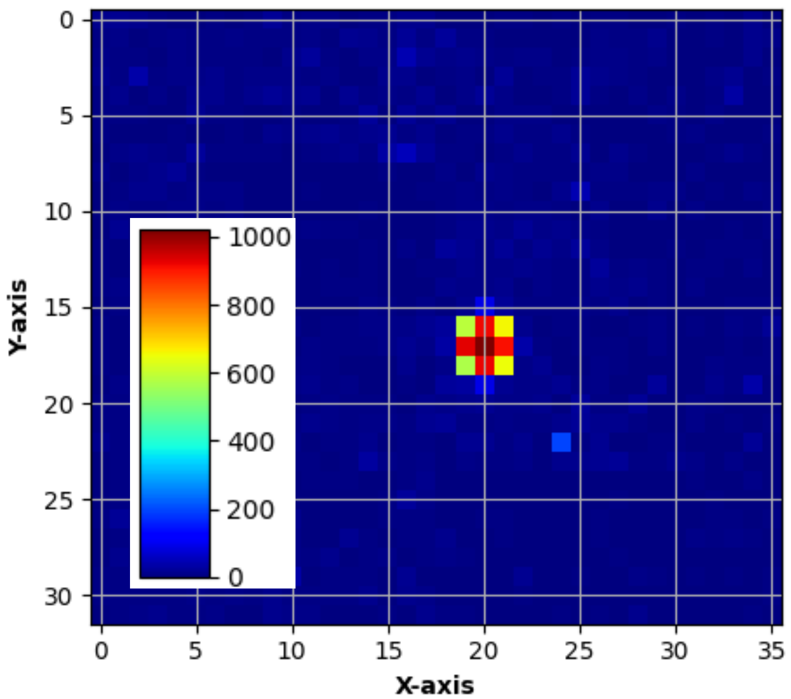


QC3 : ^{55}FE X-RAY SCAN
ERAM FINAL QUALIFICATION/CALIBRATION

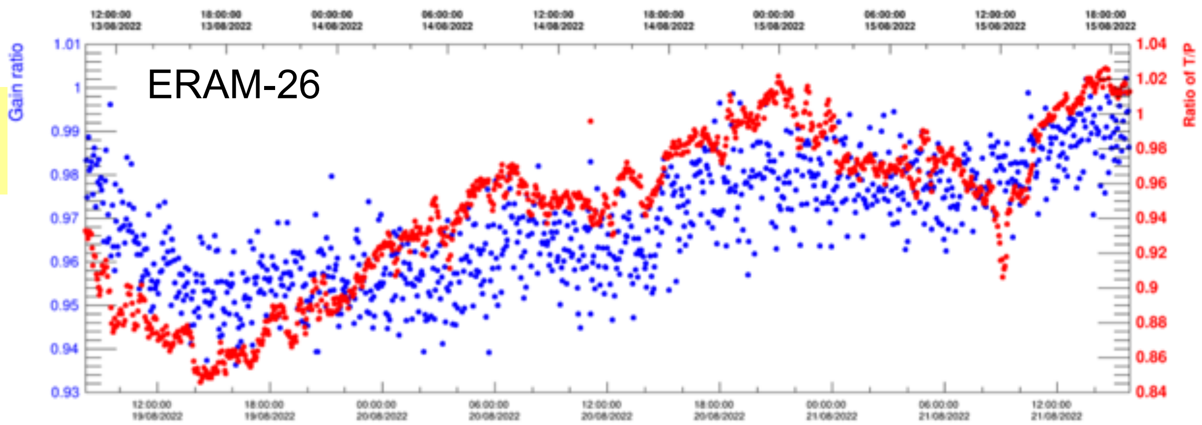
- ✓ Each ERAM is paired with 2 Front-End cards and “calibrated” for the use in the experiment
- ✓ Effective gain (ERAM * FE) and energy resolution @ 5.9 keV measurement on each pad with ERAM DLC layer at 350 V (nominal HV)
- ✓ The 280 MBq ^{55}Fe X-ray source is collimated in a Φ7 mm spot in the center 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

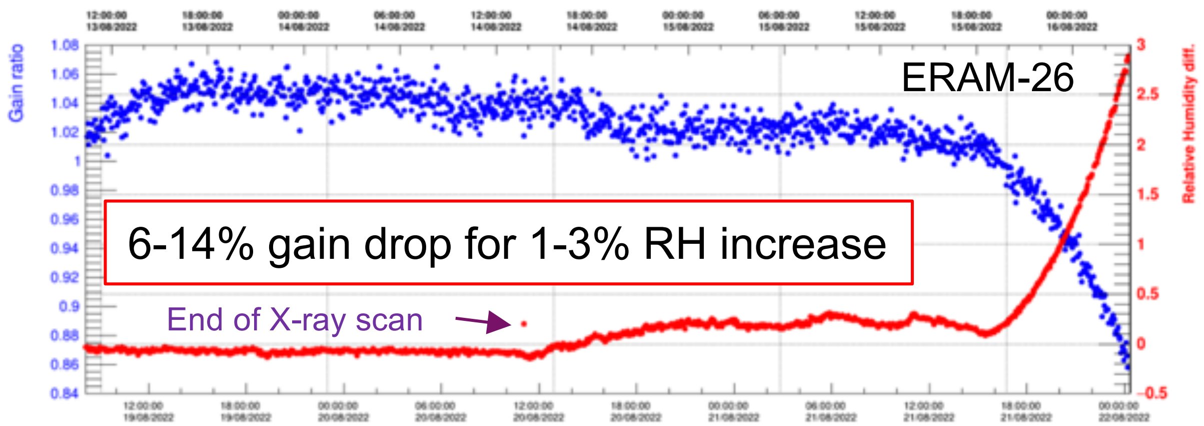


Source spot (gain scan)

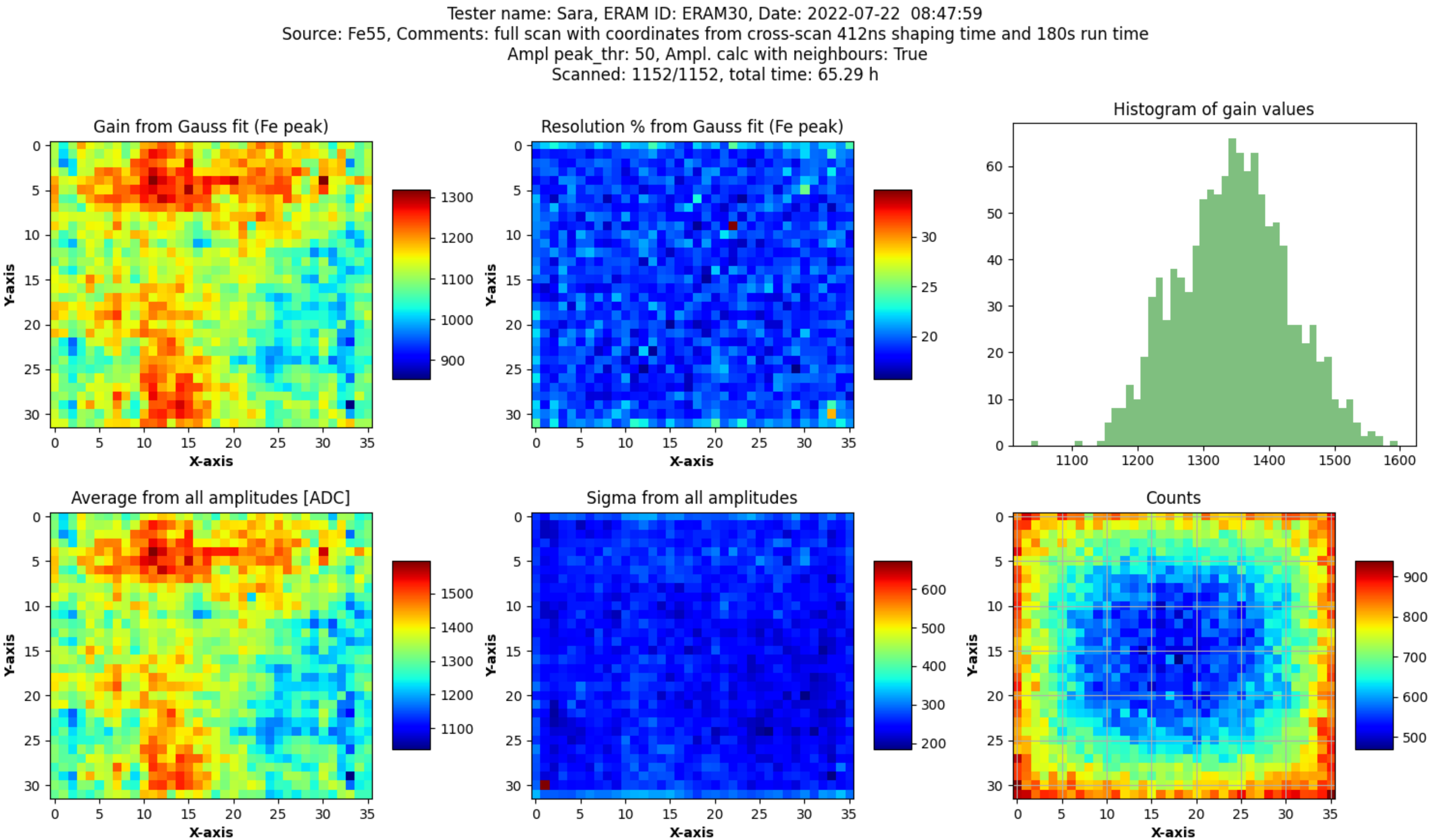


Gain correlation with T/P





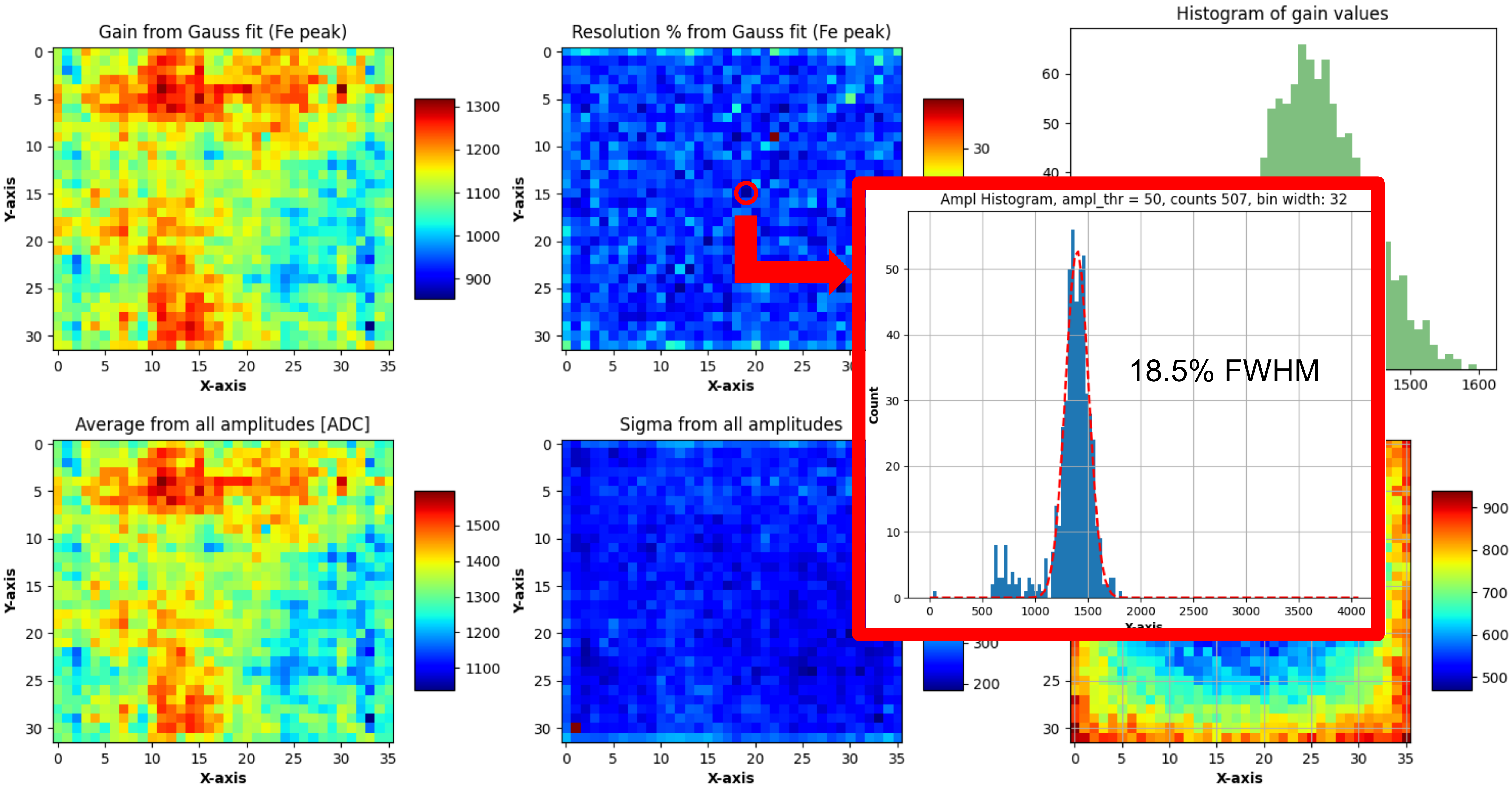
QC3 : ^{55}FE X-RAY SCAN OF ERAM-30



New PCB design V1.3 from ERAM-23 → no more non-uniformities at stiffener ribs location (see next slides)

QC3 : ^{55}FE X-RAY SCAN OF 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

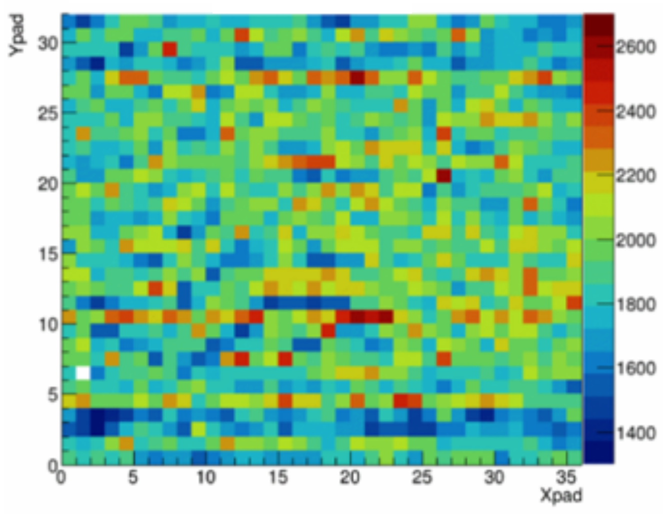


New PCB design V1.3 from ERAM-23 → no more non-uniformities at stiffener ribs location (see next slides)

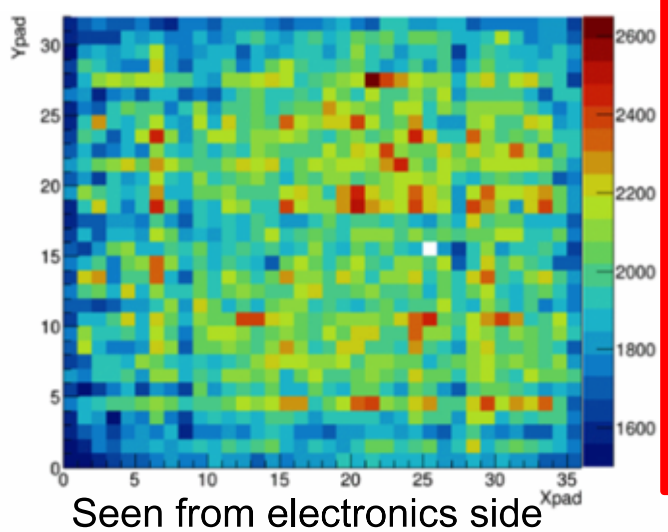
GAIN MAPS OF THE 8 ERAMs used on the ½ mockup TPC @ CERN/T10

Ref: S. Joshi (Irfu/PhD)

ERAM-07

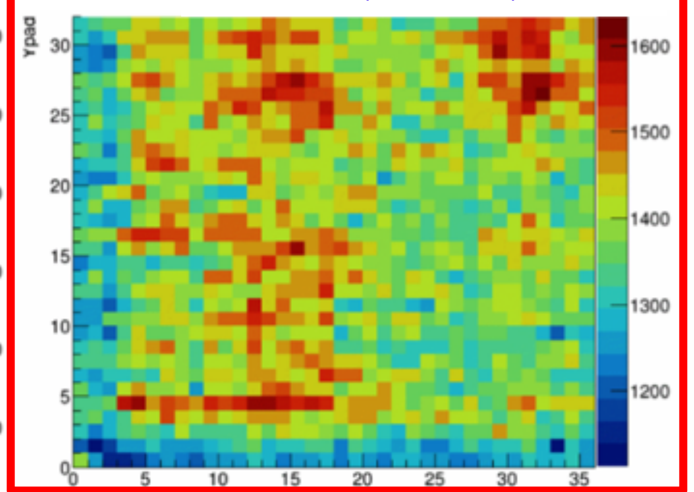


ERAM-01

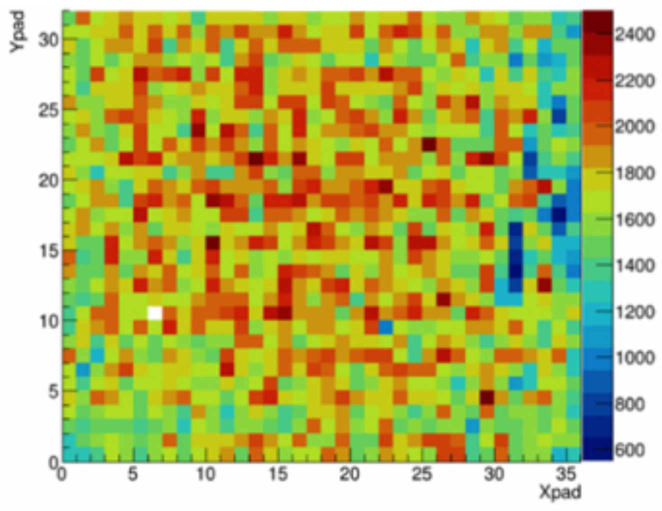


Seen from electronics side

ERAM-23 (New PCB)

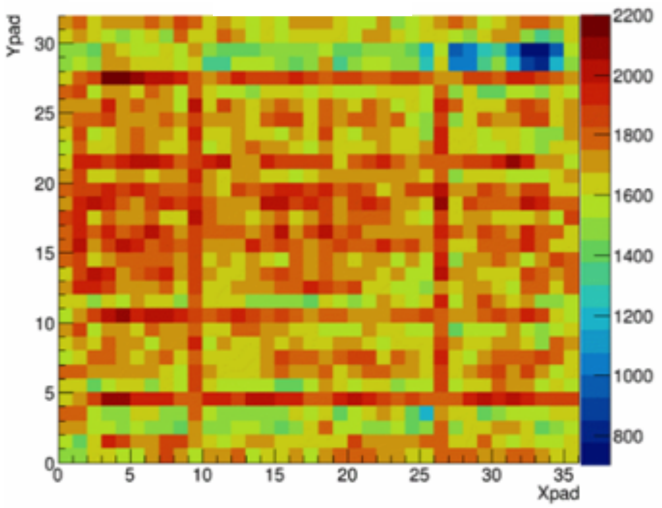


ERAM-02

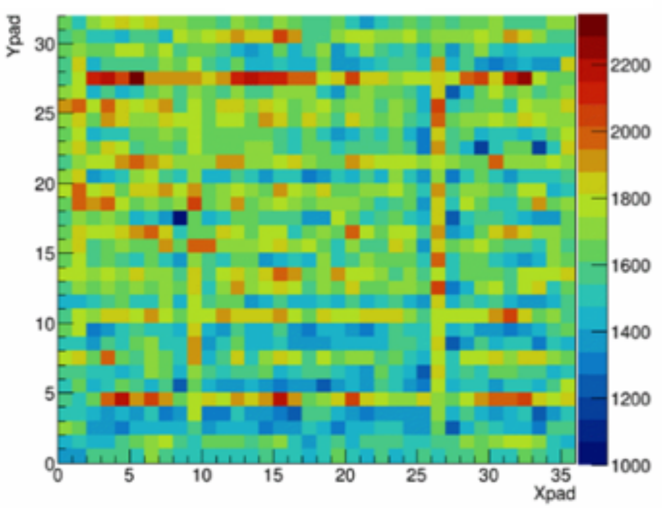


Beam direction

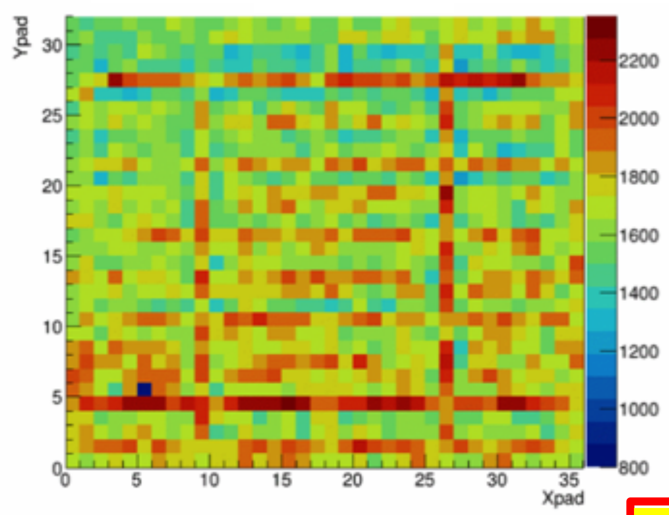
ERAM-16



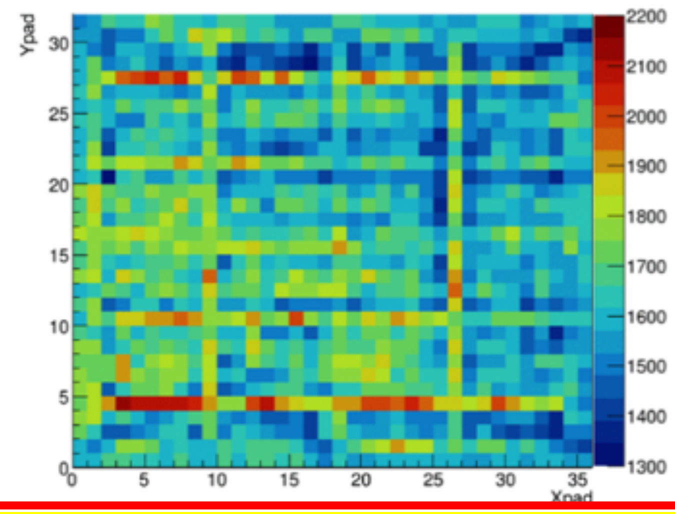
ERAM-15



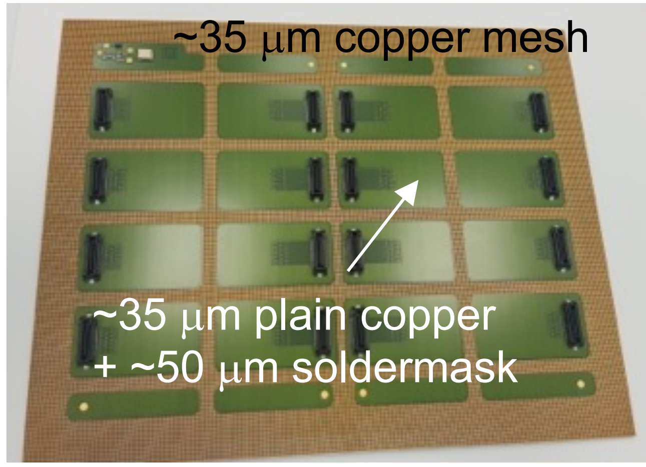
ERAM-10



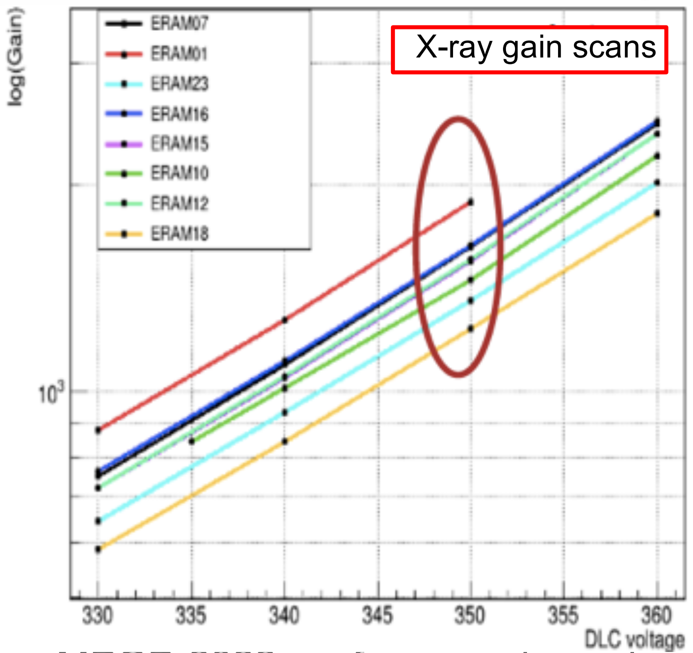
ERAM-12



All ERAMs PCB but 23, >26



New PCB for ERAM>26

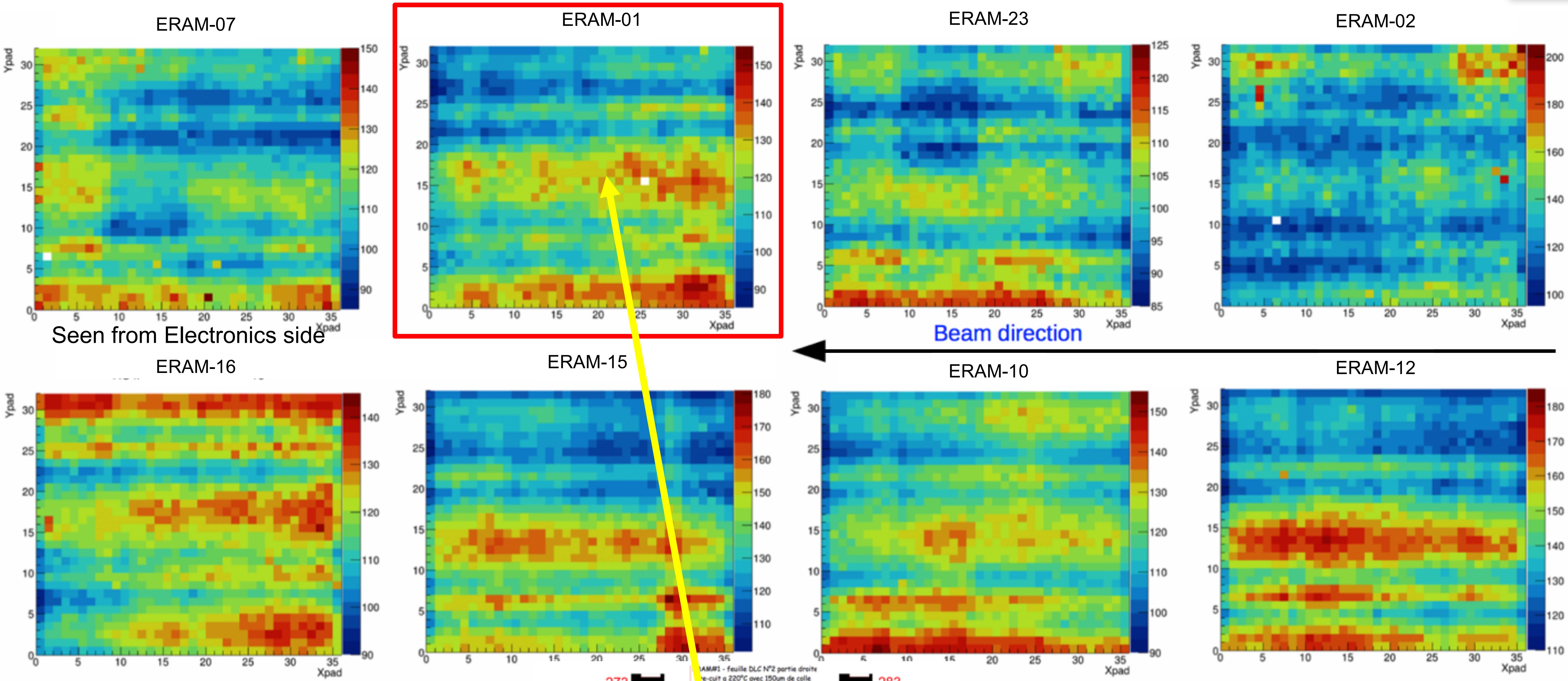


Comments & to better understand

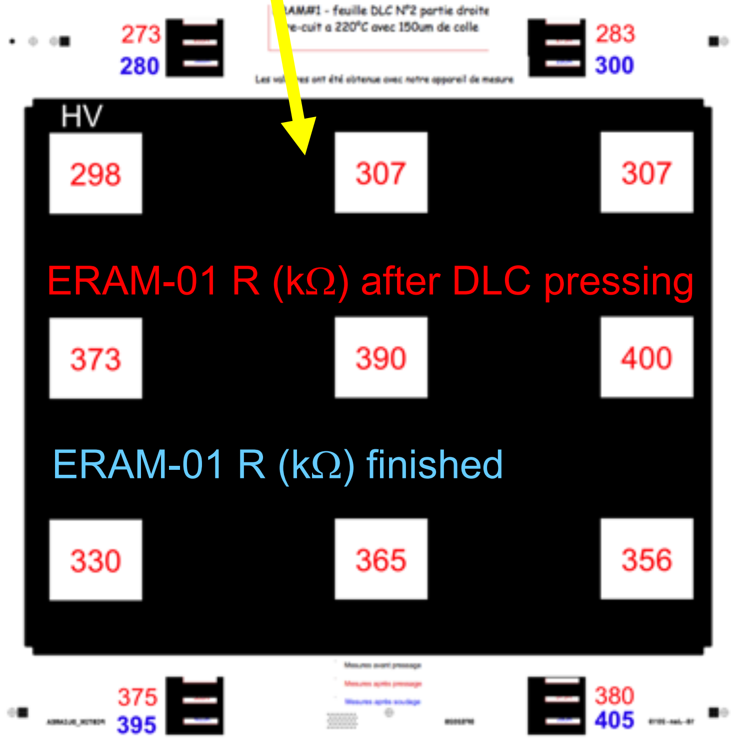
- ✓ PCB backside modification « solved » the observed gain pattern (ERAM S/N < 23)
- ✓ But a ~20% mean gain drop is still to understand
- ✓ On-going: correction for environmental parameters & FEE calibration

RC MAP DERIVED FROM X-RAY SCANS

Ref: S. Joshi (Irfu/PhD)



RC is derived from the fit of the pad signal waveforms datas (leading and neighbours) with the complete modelization of the detector response

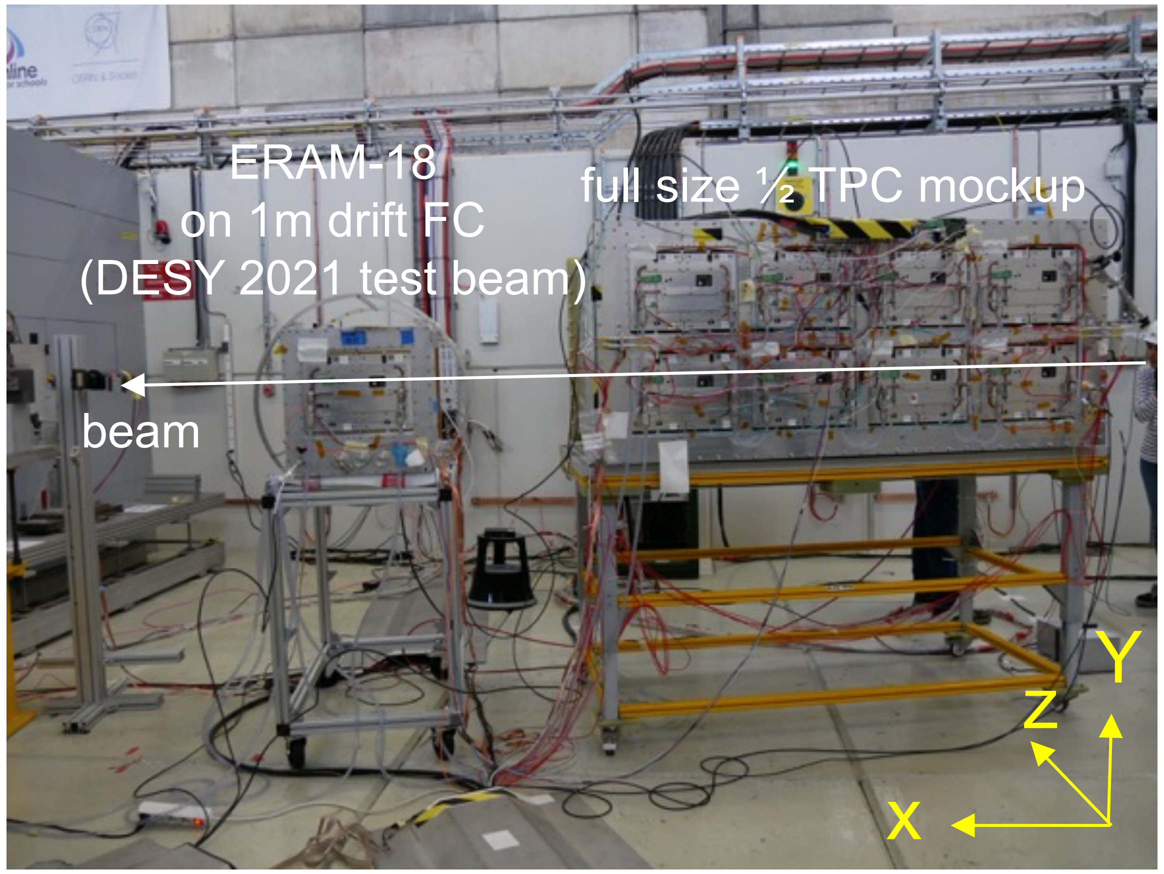


ERAM	RC_{mean} (ns/mm²)	$Gain_{mean}$	
01	116.9	1944	
02	128.6	1736	
03	116.4	1987	
07	111.8	1898	
10	120.9	1697	
12	145.4	1635	
15	135.1	1629	
16	120.4	1705	
18	68.98	1277	~1/2 RC as expected
23	101.6	1393	
29	102	1318	~ RC as expected
30	114.3	1161	

RC is quite well correlated to the measured DLC resistivity

Still to understand :
this RC is ~2 times higher than the RC_{design}

MOCKUP ½ HA-TPC TEST BEAM 2022 CERN/PS/T10



- ✓ Full system setup of a full size ½ HA-TPC field cage (FC) equipped with 8 ERAMs readout by their paired water cooled electronics cards within final DAQ & slow-control frameworks
- ✓ The ½ mockup FC has the same dimensions & endcaps design as the final ½ HA-TPC except :
  - ✓ Thick G10 walls **Vs** 4 cm thick / ~2% radiation length composite walls
  - ✓ 1 cm pitch etched copper strips **Vs** 2.5 mm pitch strips (mirror design / 3 mm strips / 5 mm pitch)
- ✓ **+** The 1m drift protoype FC used at DESY 2021 is equipped with ERAM-18 (1/2 nominal RC)
- ✓ Trigger with 4 scintillators & a Cherenkov detector to select 0.5 – 1.5 GeV/c e+, μ+, Π+, p
- ✓ 8 full days runs with horizontal tracks with combinations of 5 drift Z distances, 3 Y positions, 3 ERAM DLC HV, 200&412 ns peaking times, with selected e+, μ+, Π+, p at 4 different momentas

SOME PRELIMINARY RESULTS OF THE TEST BEAM

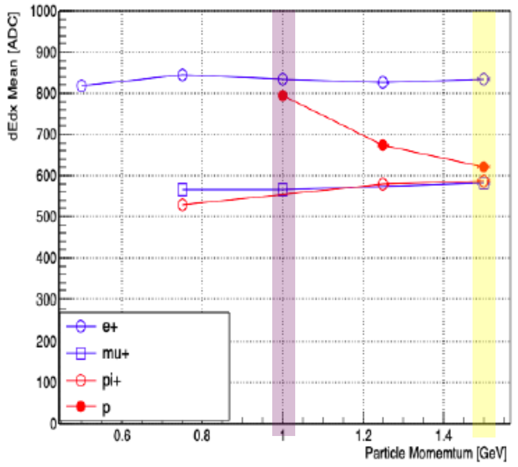
DATAS : 247 V/cm DRIFT FIELD / FEE @ 412 ns PEAKING TIME

ERAM DLC @ 350V (NOMINAL, GAINS ARE NOT EQUALIZED)

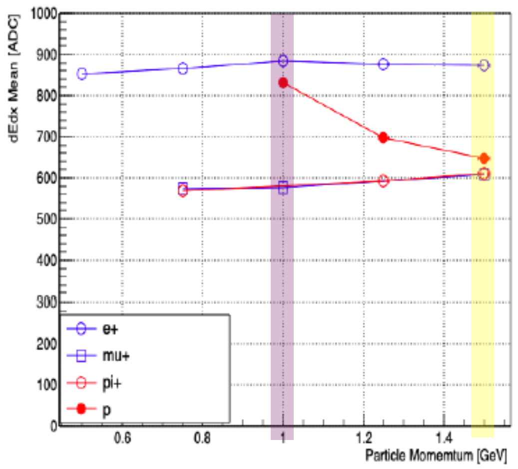
Ref: S. Hassani, J-F Laporte et al. (Irfu)

dE/dx (Y=10) for e+, μ+, π+, p @ 0.5 – 1.5 GeV/c

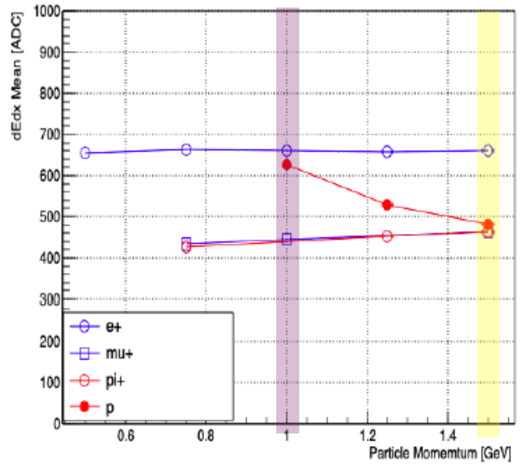
ERAM-07



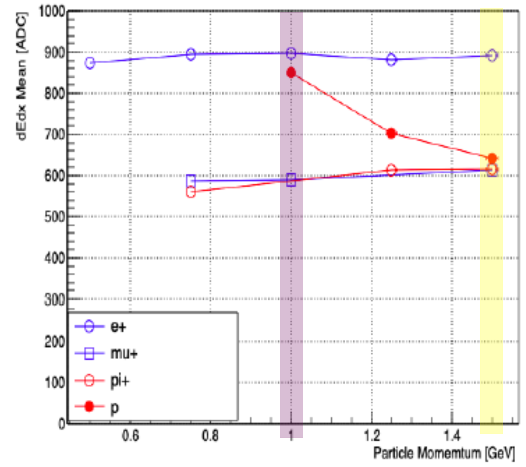
ERAM-01



ERAM-23



ERAM-02

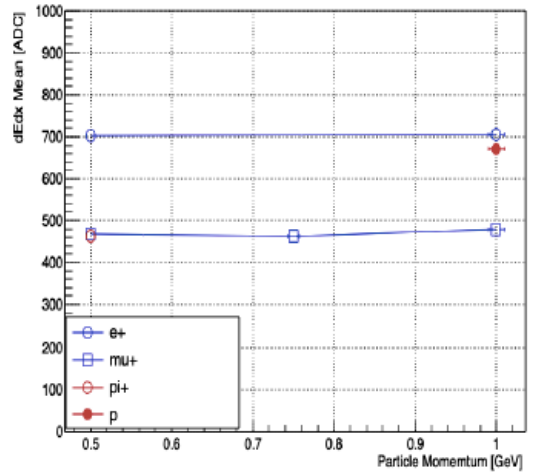


Particle ID is well following the simulations

Prototype FC

ERAM-18

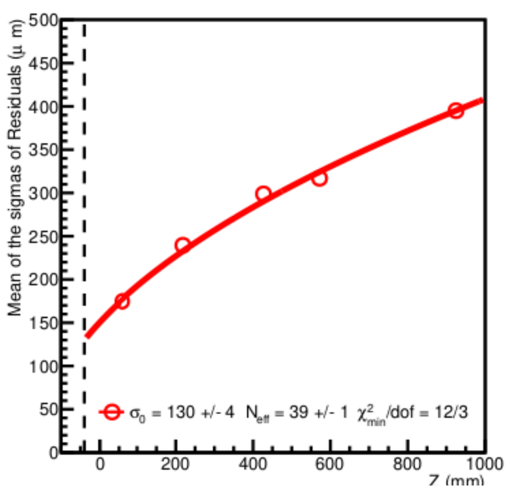
½ RC



Spatial resolution Vs drift distance for horizontal 0.5 GeV e+ tracks (Y=20)

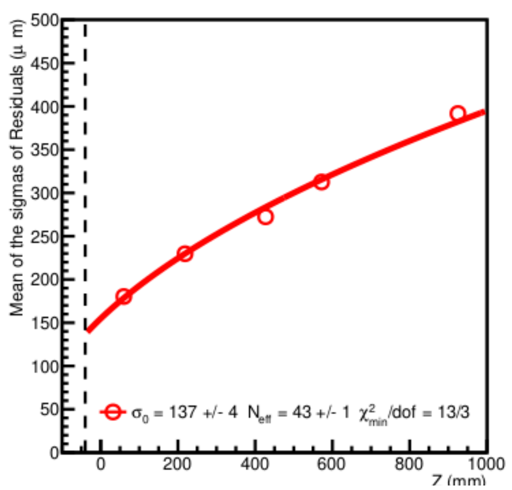
ERAM-16

PV0 Module 4



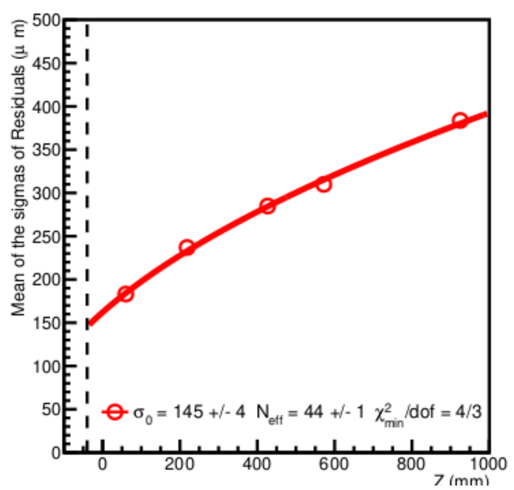
ERAM-15

PV0 Module 5



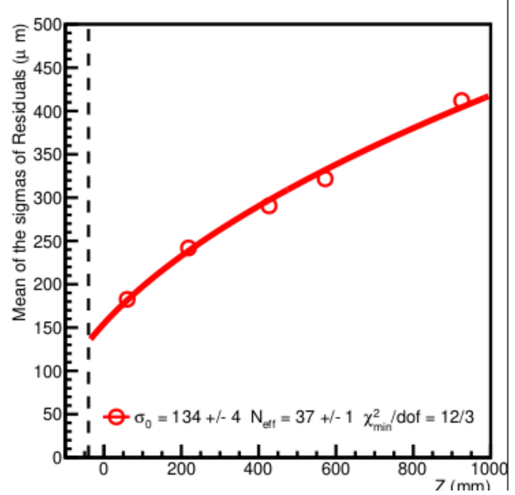
ERAM-10

PV0 Module 6



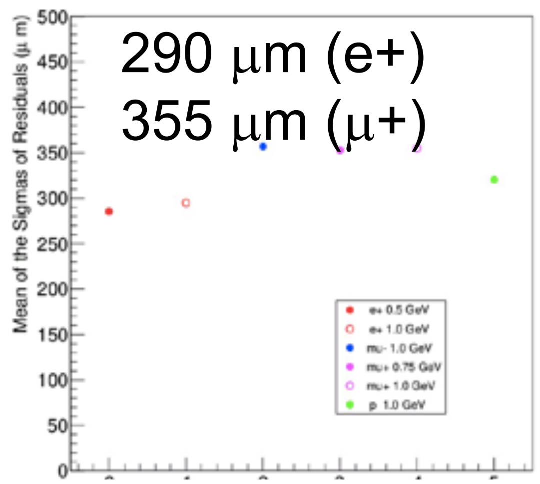
ERAM-12

PV0 Module 7



Spatial resolution @ z~415 mm / Y=15

ERAM-18 (½ RC)



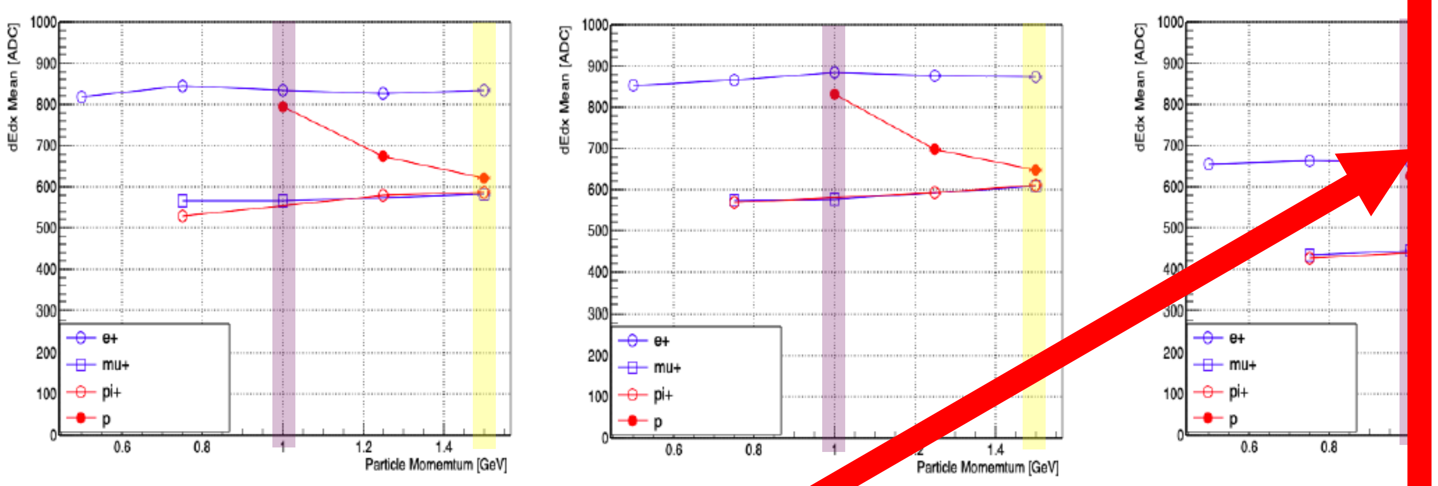
Spatial resolution @ 415 mm drift is 285-290 μm for all modules, … including ERAM-18

SOME PRELIMINARY RESULTS OF THE TEST BEAM
DATAS : 247 V/cm DRIFT FIELD / FEE @ 412 ns PEAKING TIME
ERAM DLC @ 350V (NOMINAL, GAINS ARE NOT EQUALIZED)

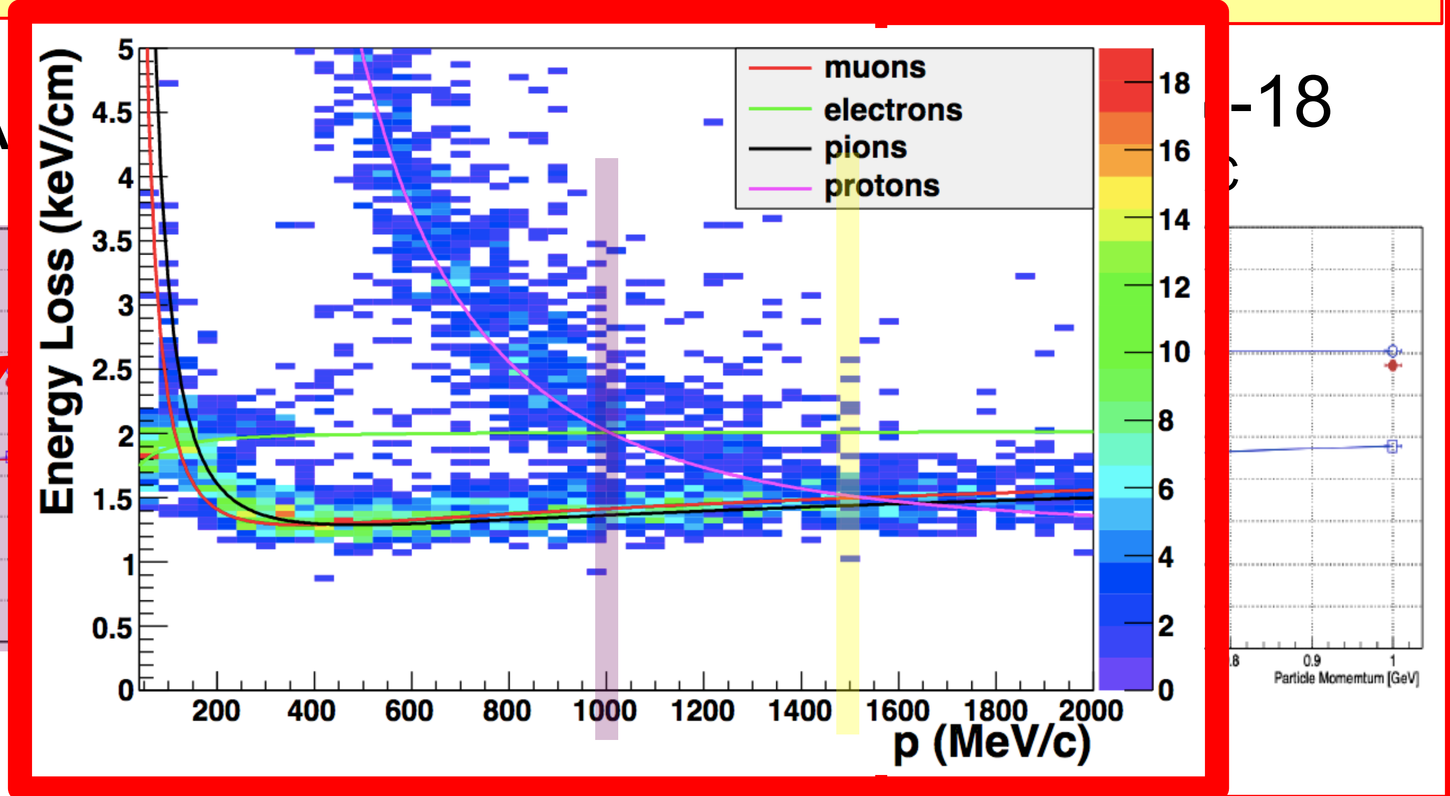
Ref: S. Hassani, J-F Laporte et al. (Irfu)

dE/dx (Y=10) for e+, μ+, π+, p @ 0.5 – 1.5 GeV/c

ERAM-07 ERAM-01 ERA



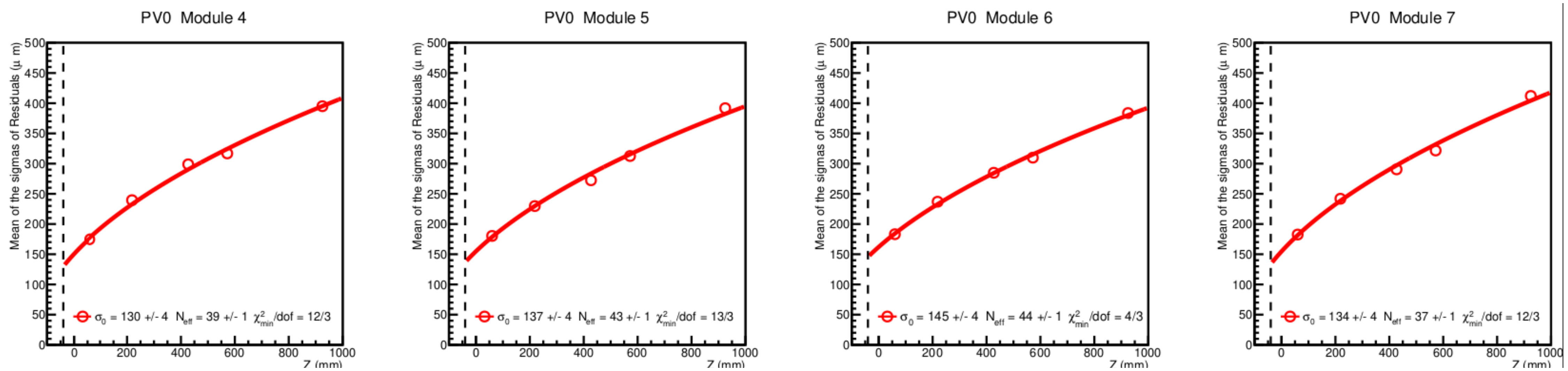
Prototype FC



Particle ID is well following the simulations

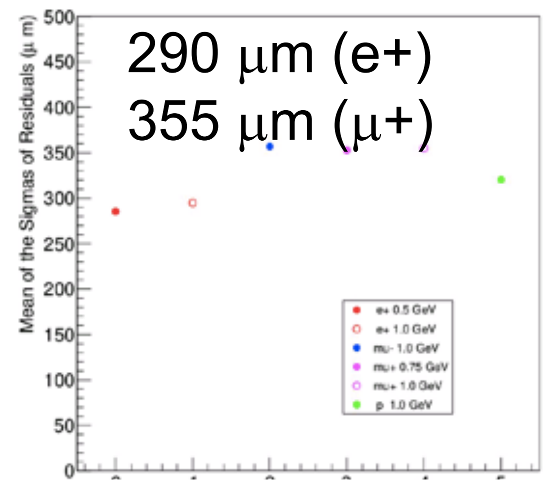
Spatial resolution Vs drift distance for horizontal 0.5 GeV e+ tracks (Y=20)

ERAM-16 ERAM-15 ERAM-10 ERAM-12



Spatial resolution
@ z~415 mm / Y=15

ERAM-18 (½ RC)



Spatial resolution @ 415 mm drift is 285-290 μm for all modules, … including ERAM-18

CONCLUSION & PERSPECTIVES

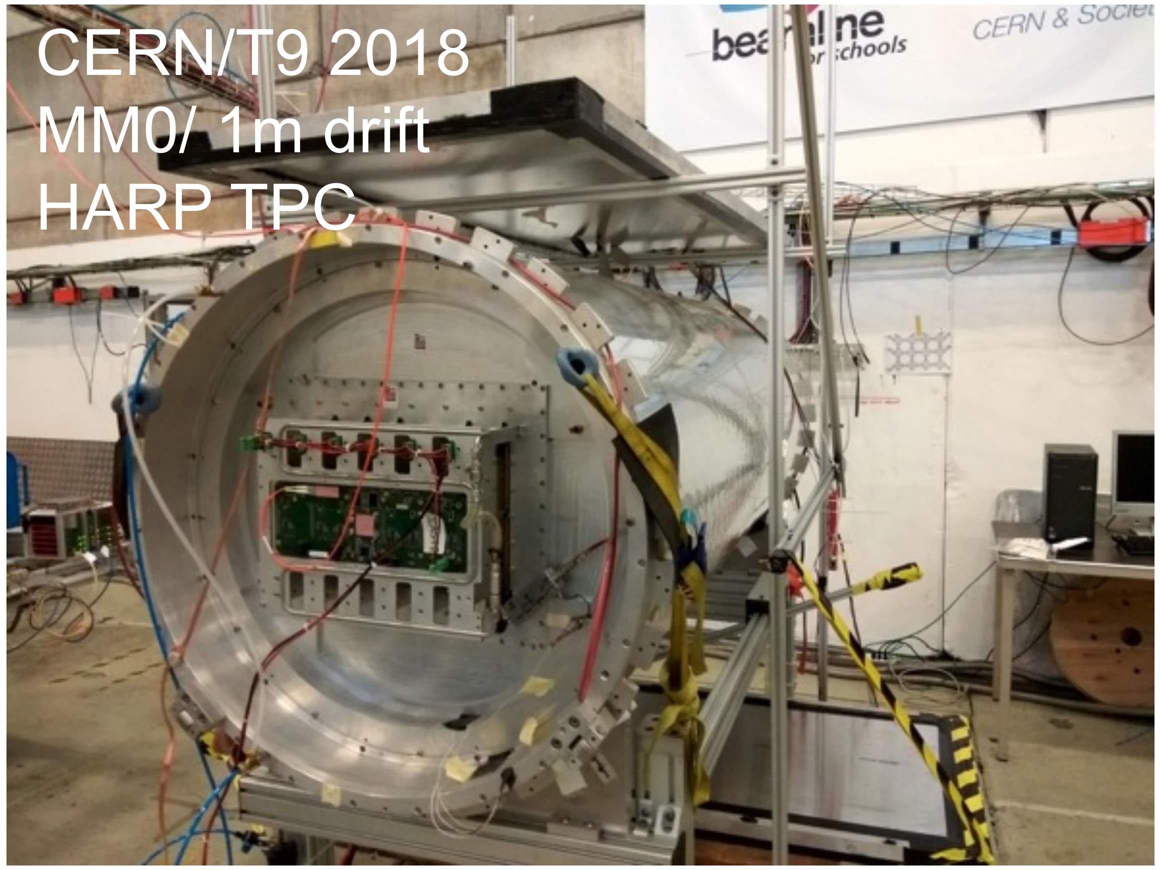
- After 3 years of development, the ERAM response modelization is now sufficiently consolidated by the the good agreement with the tests of prototypes and series detectors with different design parameters. This was particularly necessary to cope with the difficulties to control the mean resistivity and the uniformity of the DLC layer.

- The RC time constant of the ERAM was fixed to ensure the spatial and energy resolutions required for the High-angle TPCs and a safe & reliable operation in the experiment (~400 kΩ/sq. and ~1500 gain).

- The ERAM technology is complex and delicate to produce as are all the resistive MPGDs. The expertise and excellent partnership with the CERN/PCB workshop enabled a high yield (~80%) of high quality production of 21 ERAMs up to now.

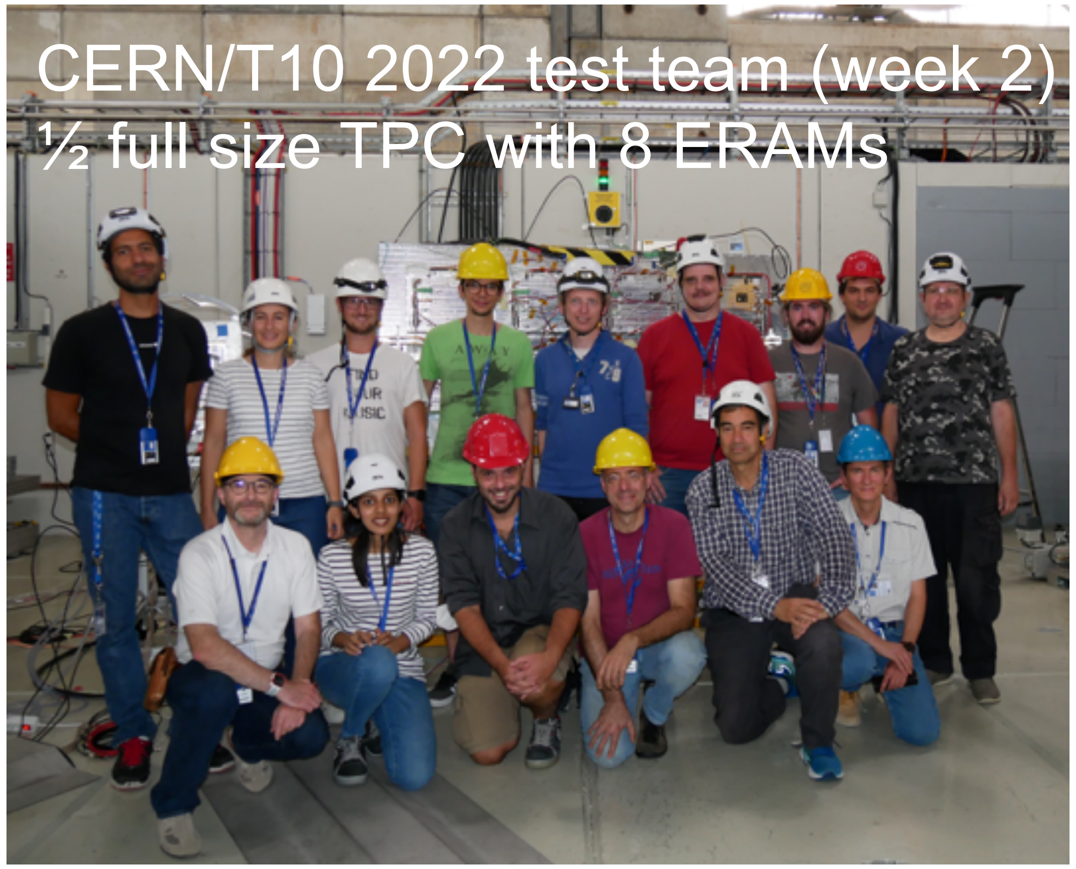
- The installations of the bottom and top high-angle TPCs in the T2K/ND280 near detector are planned for june and october 2023 respectively. By then, 16 ERAMs are to be produced and qualified for the Top TPC and the final tuning of the software tools in the ND280 event reconstruction framework using ERAM X-ray calibration datas is to be completed.

QUESTIONS ?


CERN/T9 2018
MM0/ 1m drift
HARP TPC
CERN & Societ


DESY 2019 test team (week 1)
MM1-DLC1/15 cm drift
T 24.1


DESY 2021 test team (week 2)
ERAM-01 / 1 m drift proto FC


CERN/T10 2022 test team (week 2)
½ full size TPC with 8 ERAMs