PHENIICS fest 2023

DE LA RECHERCHE À L'INDUSTRIE

X-ray characterization of resistive Micromegas for the upgrade of T2K Near Detector

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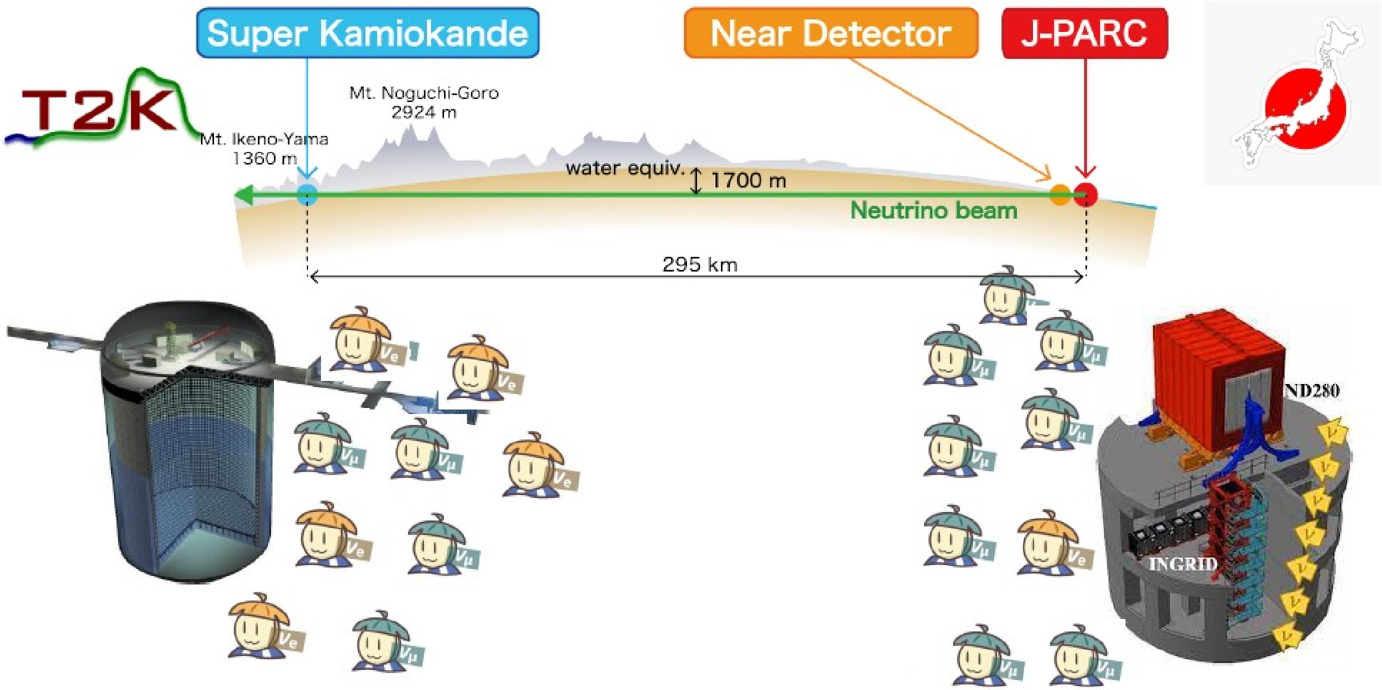
OUTLINE

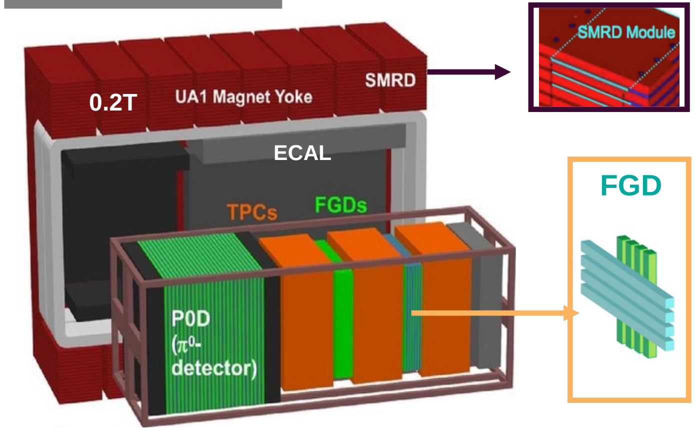
1. T2K near detector upgrade (ND280) using resistive Micromegas for HA-TPC.
2. Modelling of charge spreading with resistive Micromegas.
3. Application of charge spreading model on X-ray data.
4. Summary of all analyzed ERAMs.
5. Conclusion

THE T2K EXPERIMENT: TOKAI TO KAMIOKA



Neutrino cartoons by Yuki Akimoto

Current ND280



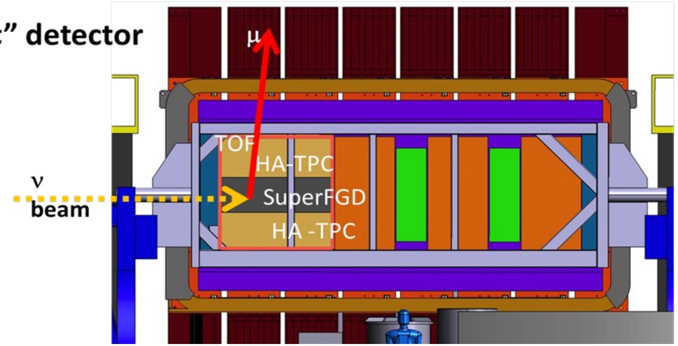
ND280 measures beam spectrum and flavor composition before the oscillations

- Detector installed inside the **UA1/NOMAD magnet (0.2 T)**
- **A detector optimized to measure π^0 (P0D)**
- **An electromagnetic calorimeter to distinguish tracks from showers**
- A tracker system composed of:
  - **2 Fine Grained Detectors (target for ν interactions).**
    - **FGD1 is pure scintillator,**
    - **FGD2 has water layers interleaved with scintillators**
  - **3 vertical Time Projection Chambers: reconstruct momentum and charge of particles, PID based on measurement of ionization**

ND280 UPGRADE: GENERAL IDEA

ND280 upgrade

“4π” detector

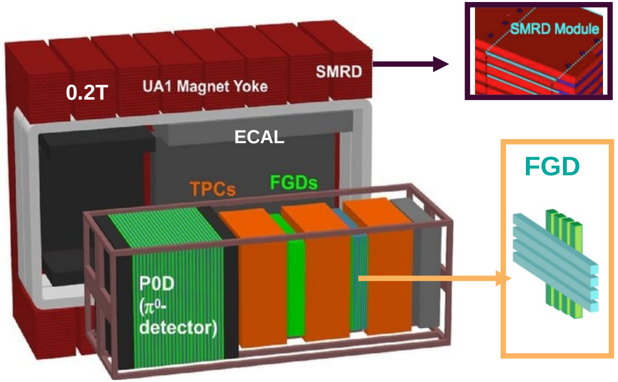


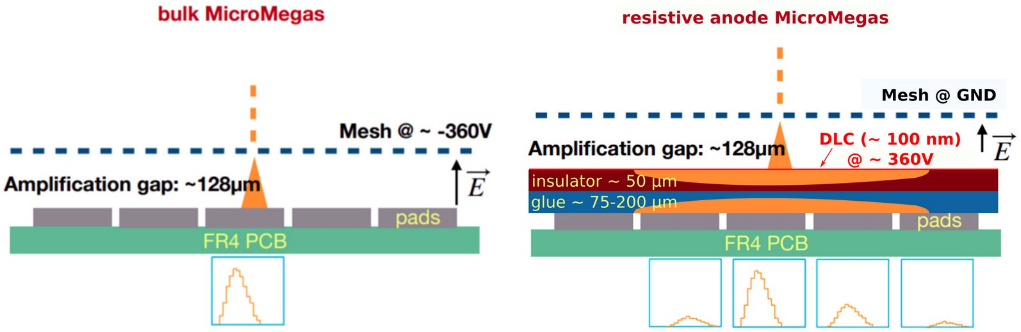
CERN-SPSC-P357

The HA-TPC should at least have the same performance as the current vertical TPCs

- Average 700μm space resolution (and possibly even better)
- 7-8% energy loss resolution for MIP
- Stability and longevity (>10 years)

Current ND280





Pad size: 1.1 * 1 cm^2

Resistive MicroMegas detectors achieved thanks to the addition of a resistive layer (DLC)

- Charge sharing between pads ⟹ More precise position reconstruction
- Better resolution with lower number of pads ⟹ Cost-effective and compact technology
- Reduced risk of sparks ⟹ No need for protection circuit on readout electronics
- Allows to put mesh at ground for better E-field uniformity.
- DLC allows smaller RC ⟹ Larger charge spreading (better spatial resolution)

$$\rho(r,t) = \frac{RC}{4\pi t} e^{\frac{-r^2 RC}{4t}}$$

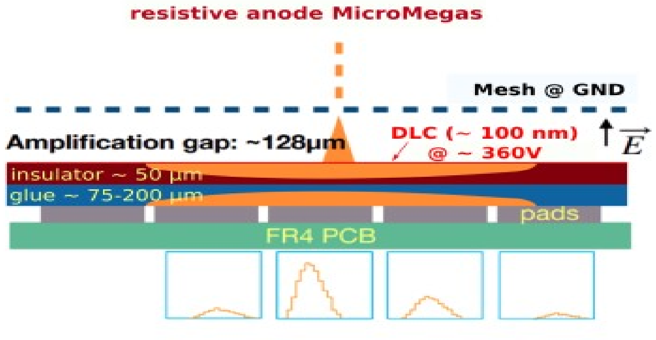
R = Surface resistivity
C = Capacitance / unit area

CHARGE DISPERSION PRINCIPLE

- Charge dispersion on anode achieved with a resistive foil glued on PCB.
- Continuous RC network, defined by material properties and geometry, shares evenly the charge among several pads.
- Obeys Telegraph equation:

$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right]$$

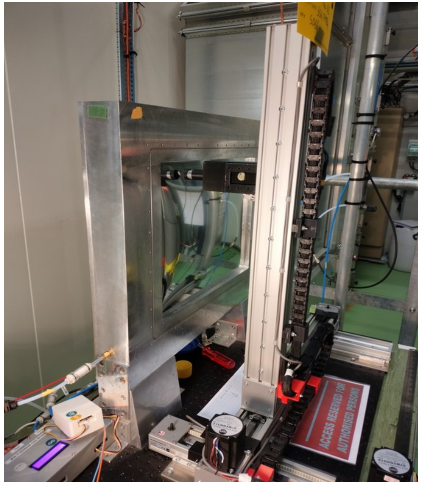
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$



- The anode charge density is time dependent and sampled by readout pads.

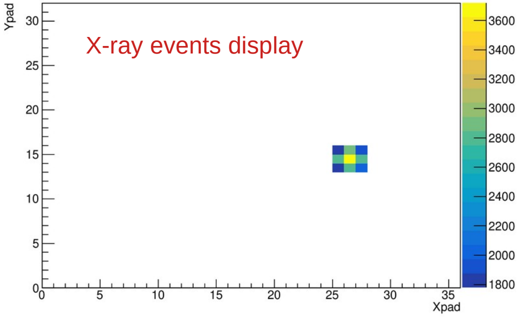
Pad size: 1.1 * 1 cm^2

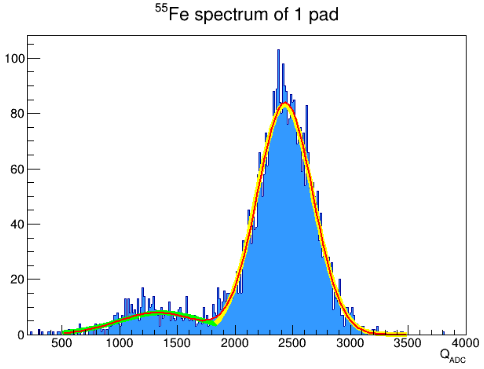
References : M.S. Dixit et.al., NIM A518, 721 (2004) , M.S. Dixit & A. Rankin, NIM A566, 281 (2006)



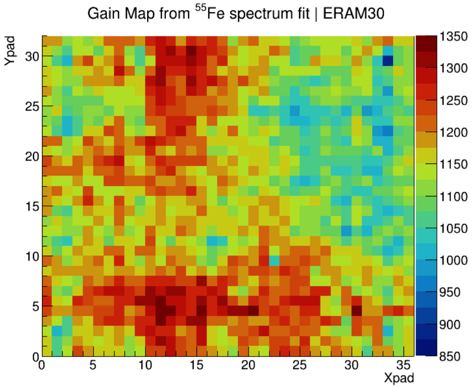
X-ray test bench @ CERN

- Each pad(1152) of an ERAM placed inside an X-ray chamber is scanned using a robot holding an ^{55}Fe X-ray source.
- ^{55}Fe spectrum can be reconstructed using all events in one pad.
- Gain is obtained for a pad by fitting its ^{55}Fe spectrum. Resolution of 10% is obtained.





Example of an ^{55}Fe spectrum

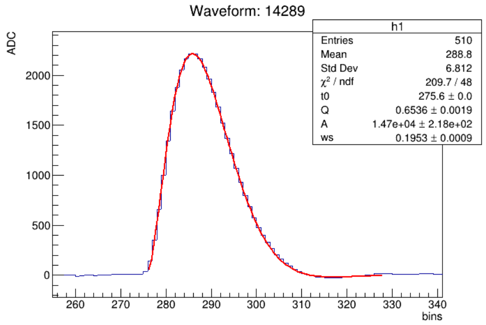


Gain map of ERAM30

ELECTRONICS RESPONSE FUNCTION

- Each channel of an Electronics card is injected with multiple pulses of different amplitudes.
- Resulting output signals(response of Electronic cards) are fitted with the Electronics response function.

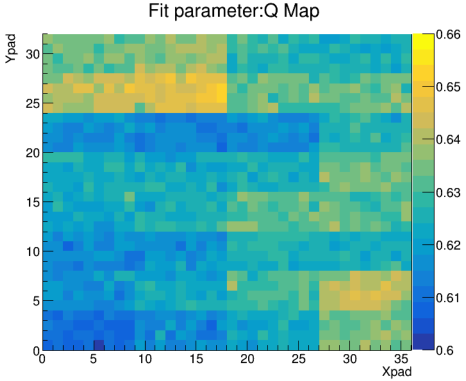
$$R(t) = A\left[e^{-w_s t} + e^{\frac{-w_s t}{2Q}}\left(\sqrt{\frac{2Q-1}{2Q+1}}\sin\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right) - \cos\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right)\right)\right]$$



- Parameterized by 2 main variables related to shape of a signal waveform: **Q** and **w$_s$.**
- Variation in these fit parameters over all the pads was studied to determine if they can be set as constants.

- $Q = 0.6368$
- $w_s = 0.1951$

} **fixed (412ns peaking time)**

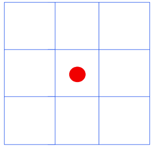


Charge diffusion function:

$$Q_{pad}(t) = \frac{Q_e}{4} \times \left[erf\left(\frac{x_{high} - x_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{x_{low} - x_0}{\sqrt{2}\sigma(t)}\right) \right] \times \left[erf\left(\frac{y_{high} - y_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{y_{low} - y_0}{\sqrt{2}\sigma(t)}\right) \right]$$

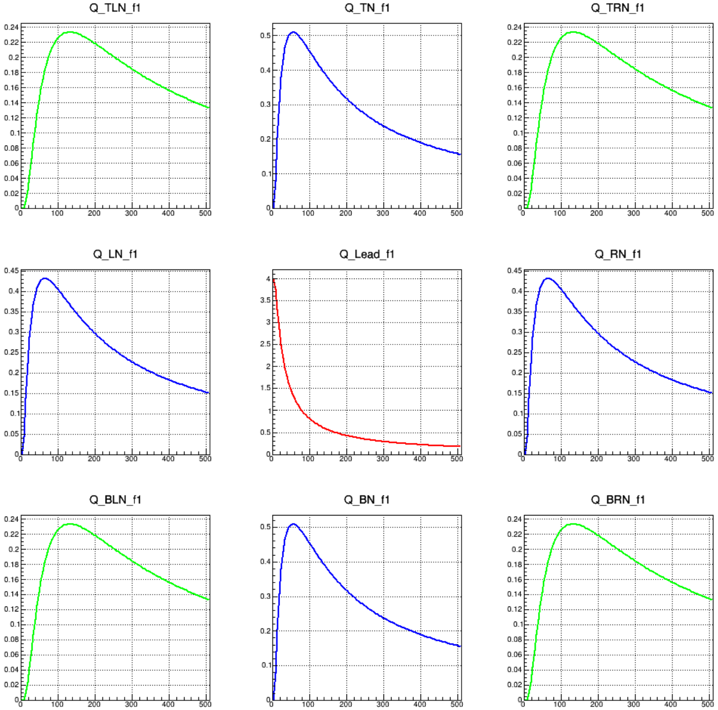
$$\sigma(t) = \sqrt{\frac{2t}{RC}}$$

- Obtained from Telegraph equation for charge diffusion.
- Integrating charge density function over area of 1 readout pad.
- Parameterized by 5 variables:
  - x_0, y_0 } Initial charge position
  - t_0: Time of charge deposition in leading pad
  - RC : Describes charge spreading
  - Q_e : Total charge deposited in an event

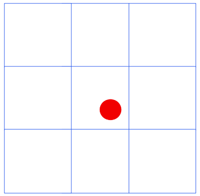


RC = 60 ns/mm^2
Q_{norm} = 4 units

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

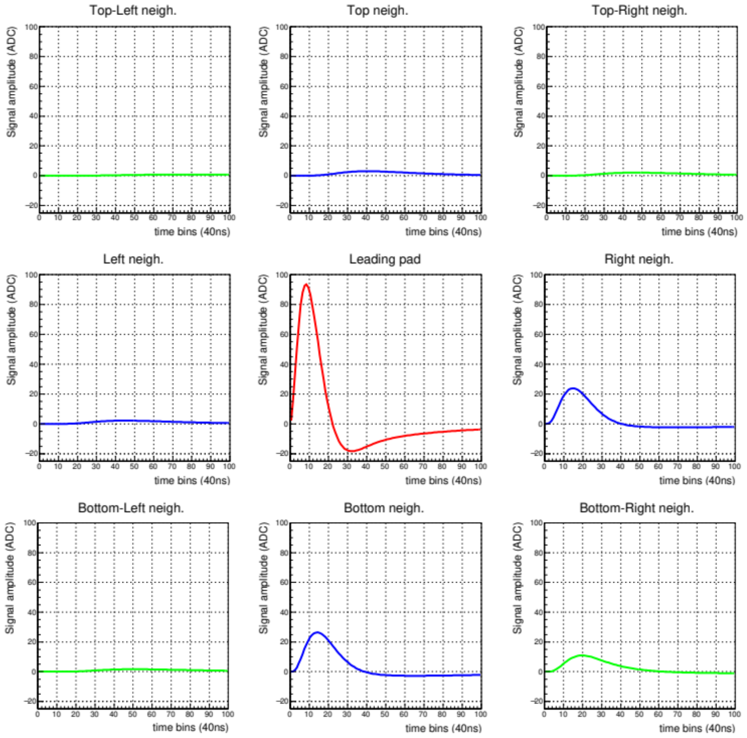


- Convolution of charge diffusion function with derivative of electronics response function.

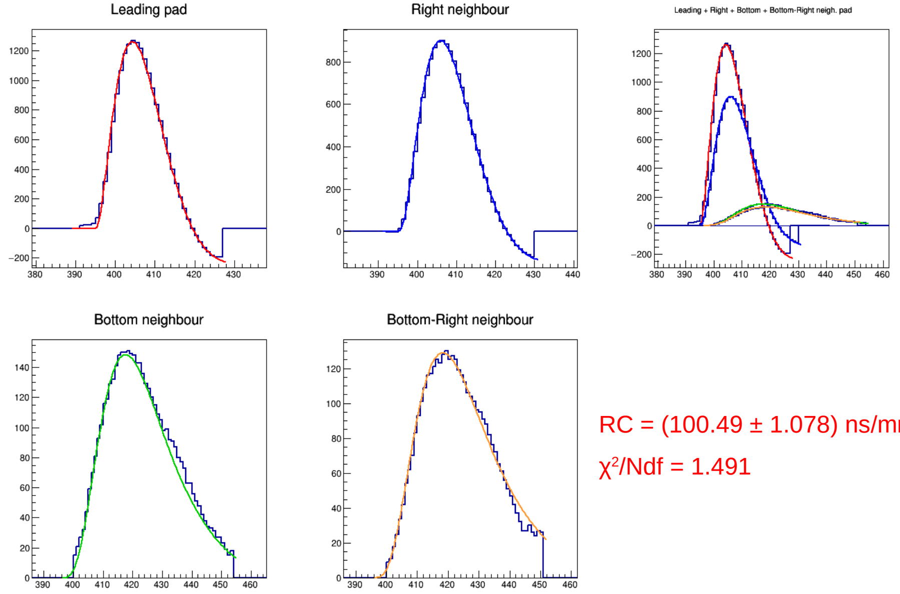


$$S(t) = Q(t) * \frac{dR}{dt}$$

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



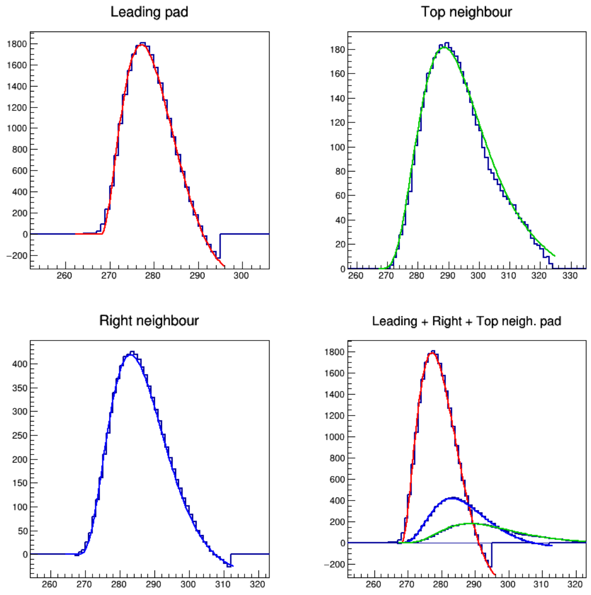
APPLICATION OF SIGNAL MODEL ON X-RAY DATA



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

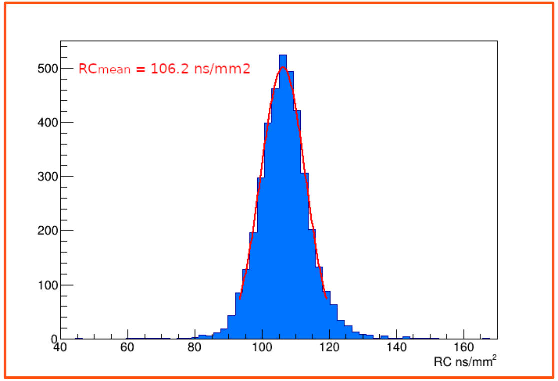
χ^2/Ndf = 1.903

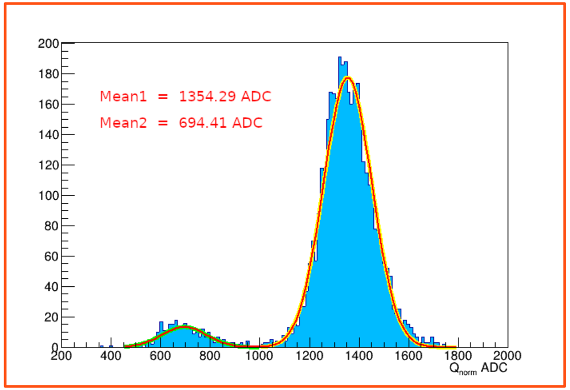
3-waveform simultaneous fit of an X-ray event

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

Simultaneous fit: Leading pad + Neighbouring pads are fitted simultaneously

RC distribution

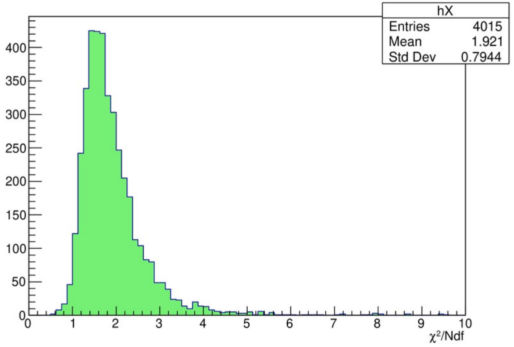


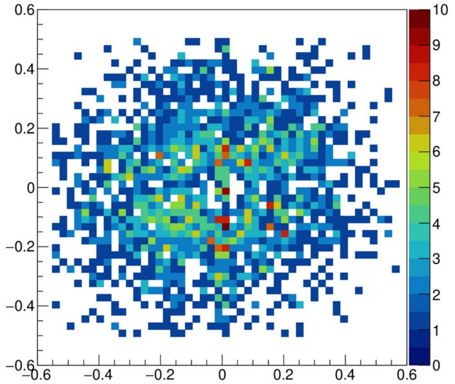


Q_{norm} distribution

- Reconstruction of ^{55}Fe spectrum.

χ^2/Ndf distribution

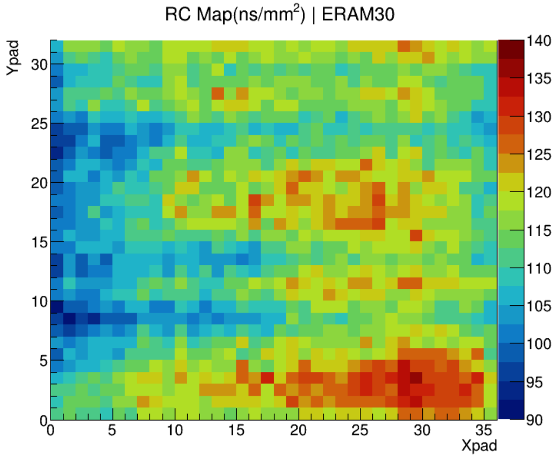




Distribution of charge deposition points (x_0, y_0)

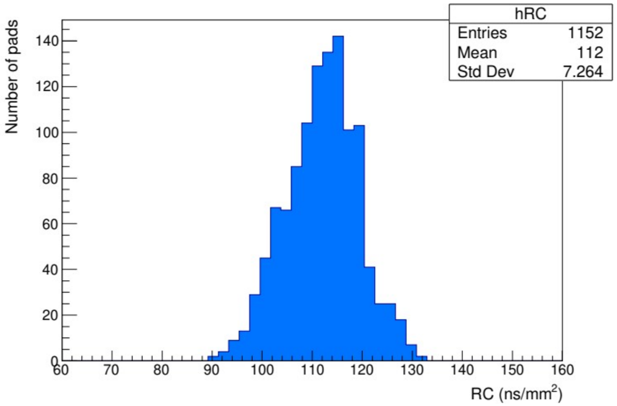
RC EXTRACTION FROM SIMULTANEOUS FIT

- Fitting process is carried out for all pads to obtain RC map.
- RC is more homogeneous in horizontal direction than in vertical direction.
- RC maps and Gain maps will be used in global event reconstruction algorithm.



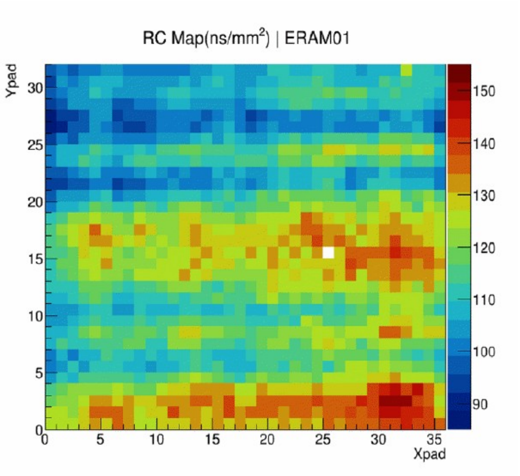
RC map of ERAM30

RC_{mean} = 112 ns/mm^2

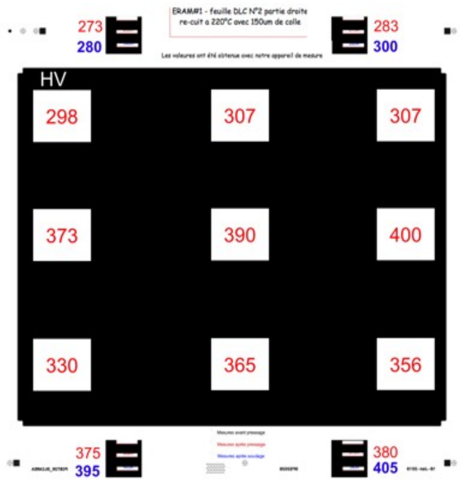


RC distribution of ERAM30

ERAM-01: RC map from fit



ERAM-01: R Measurements



- RC map structure seems to be correlated to R measurements

- **Charge density:**

$$\rho_{0D}(r,t)=\frac{Q_{primary}G}{2\pi}\frac{1}{\sigma^2(t)}e^{-\frac{r^2}{2\sigma^2(t)}}$$

- **Charge on a pad:**

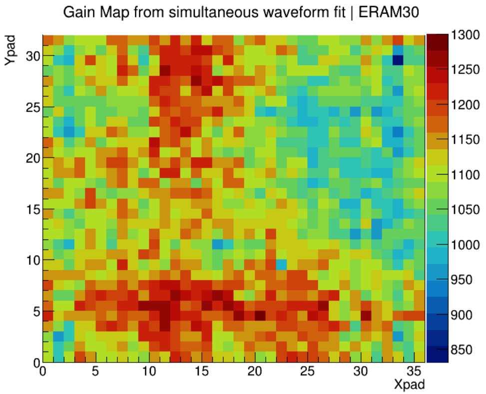
$$Q_{pad}(t)=\boxed{\frac{Q_{primary}G}{4}}\left[\mathrm{erf}\left(\frac{x_H-X_0}{\sigma(t)\sqrt{2}}\right)-\mathrm{erf}\left(\frac{x_L-X_0}{\sigma(t)\sqrt{2}}\right)\right]\left[\mathrm{erf}\left(\frac{y_H-Y_0}{\sigma(t)\sqrt{2}}\right)-\mathrm{erf}\left(\frac{y_L-Y_0}{\sigma(t)\sqrt{2}}\right)\right]$$

- **Electronics response:** (upto ADC) Dirac impulse response

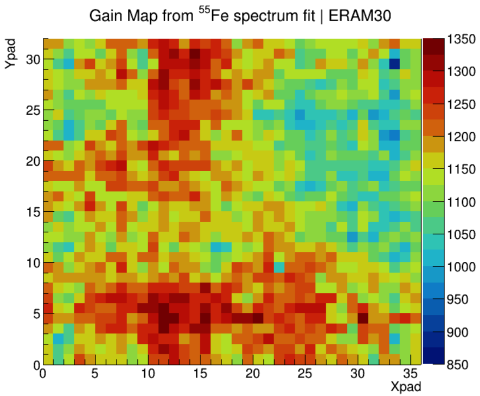
$$ADC_{Dirac}(t)=\boxed{\frac{4096}{120\,fC}\frac{F(t)}{F^{Max}}}\text{ with }F(t)=e^{-w_s t}+e^{-\frac{w_s t}{2Q}}\left(\sqrt{\frac{2Q-1}{2Q+1}}\sin\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right)-\cos\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right)\right)$$

  - Implementing the correspondence- 120 fC $\leftrightarrow$ 4096 counts.
  - Dirac current pulse carrying 120 fC ⟶ ADC(t) impulse response with a maximum amplitude of 4096 counts.

COMPARISON OF GAIN FROM TWO METHODS

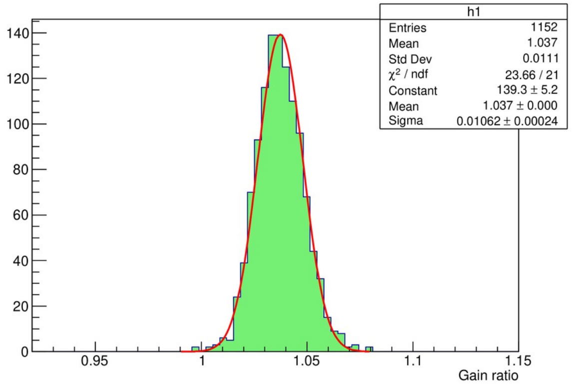


Gain map from simultaneous fit method



Gain map from waveform sum method

Ratio of Gain(of each pad) obtained from 2 different methods



$\text{Ratio}_{mean} = 1.037$

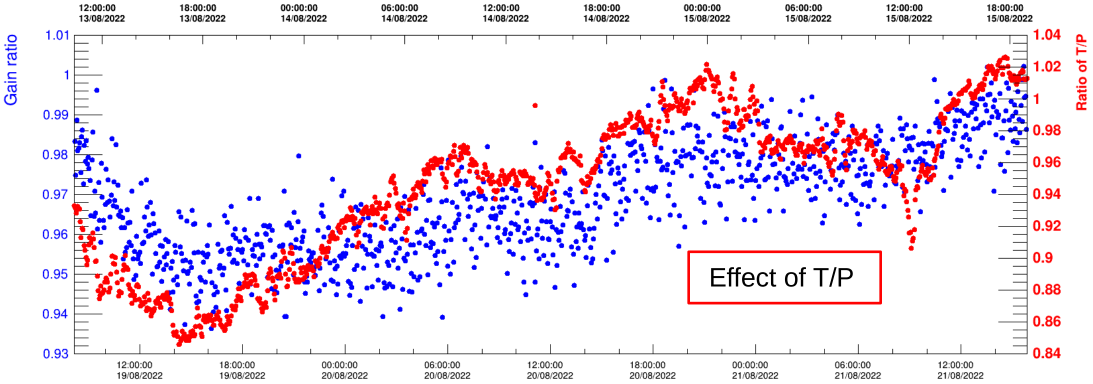
- Very high similarity in Gain maps obtained from 2 different methods.
- Gain results serve as validation for Electronics Response function, and robustness of entire model.

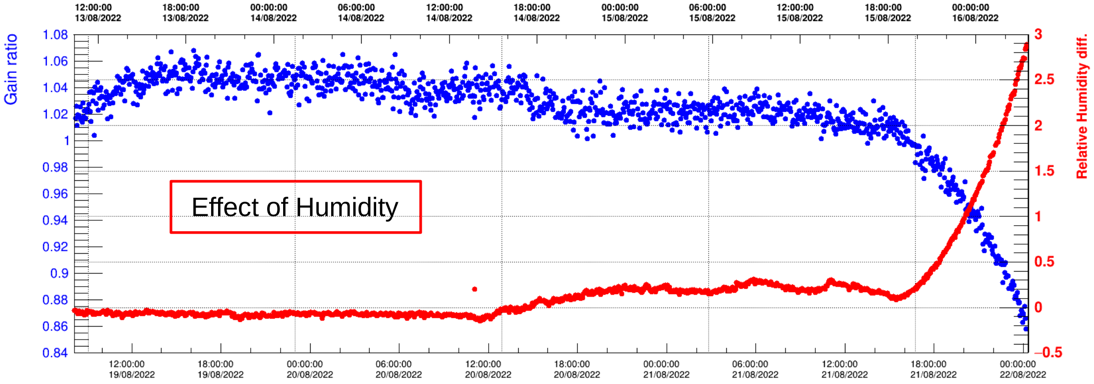
- Effect of following environmental conditions, recorded during an X-ray test bench shift, on Gain is studied:
  - Gas temperature
  - Chamber pressure
  - Relative gas humidity

- An ERAM was scanned twice at two different instances.

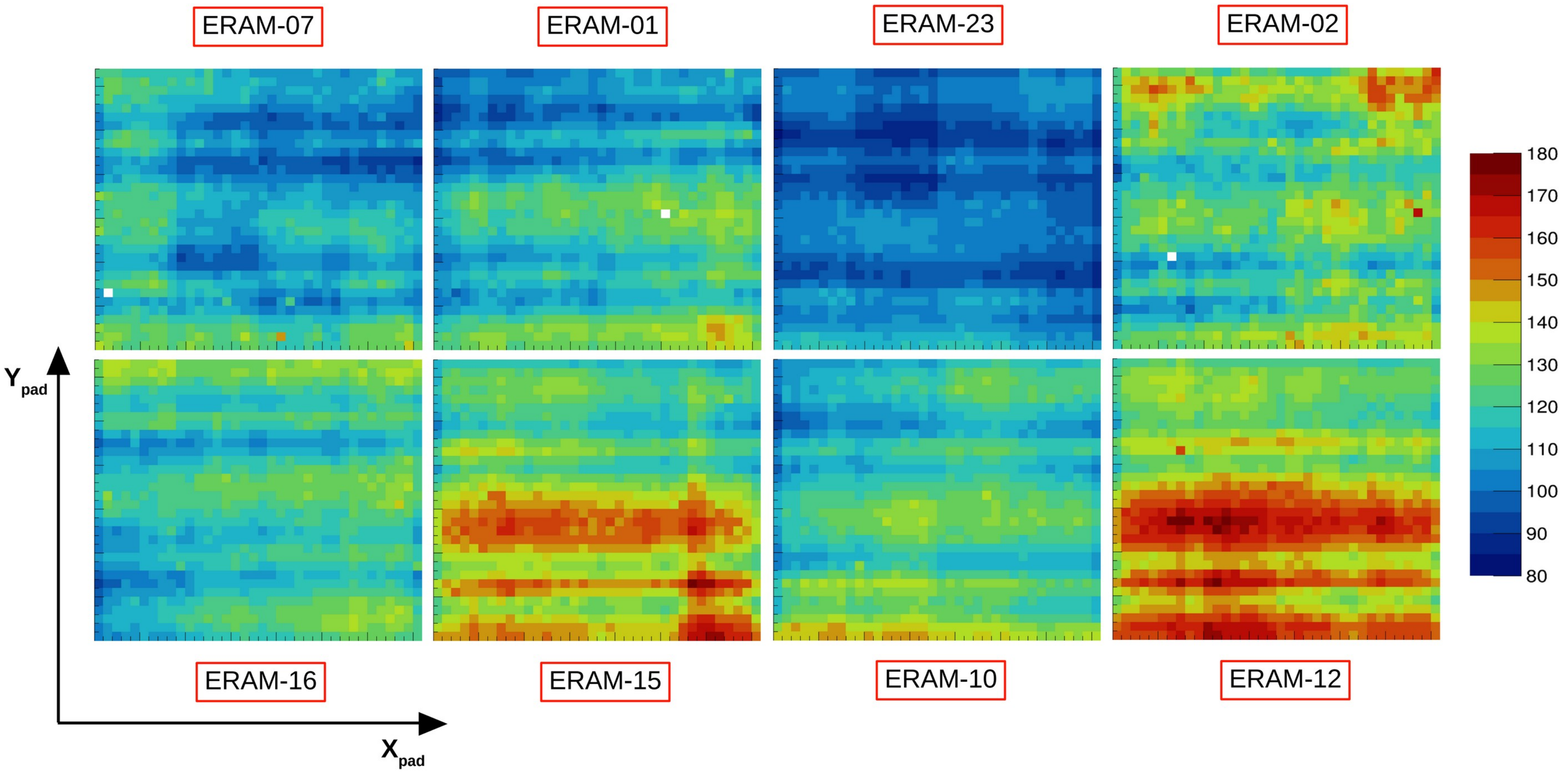
$$\frac{\text{Gain of } i^{th} \text{ pad [scan1]}}{\text{Gain of } i^{th} \text{ pad [scan2]}} \quad \text{v/s} \quad \frac{\text{Condition during } i^{th} \text{ pad scan [1]}}{\text{Condition during } i^{th} \text{ pad scan [2]}}$$

- Gain maps to be corrected in case of significant changes in environmental conditions.

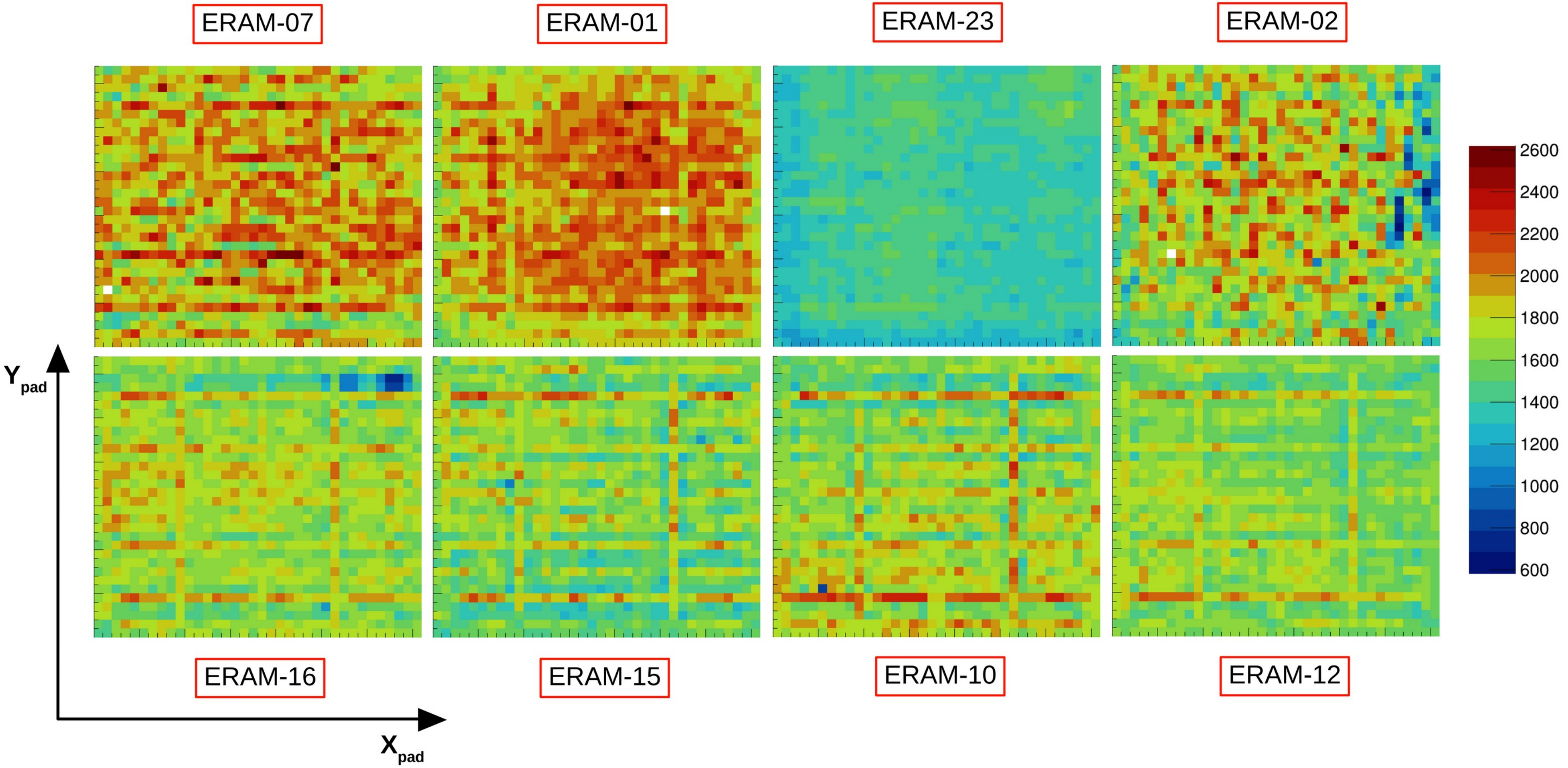




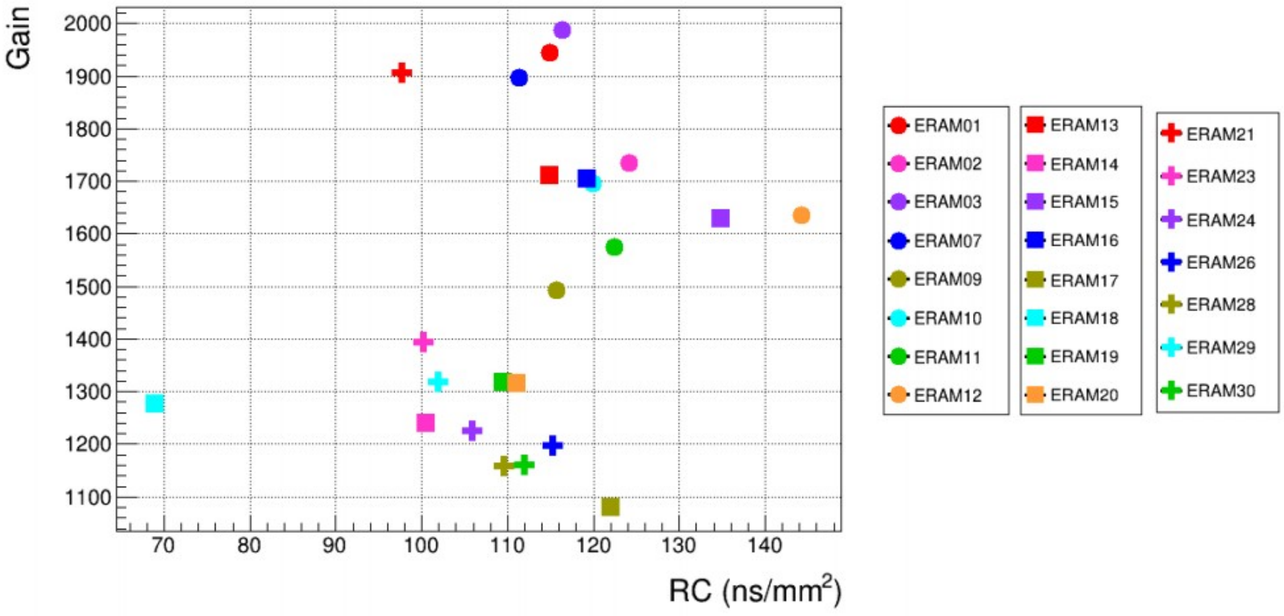
RC MAPS OF ERAMS USED IN CERN 2022 TEST BEAM



GAIN MAPS OF ERAMS USED IN CERN 2022 TEST BEAM



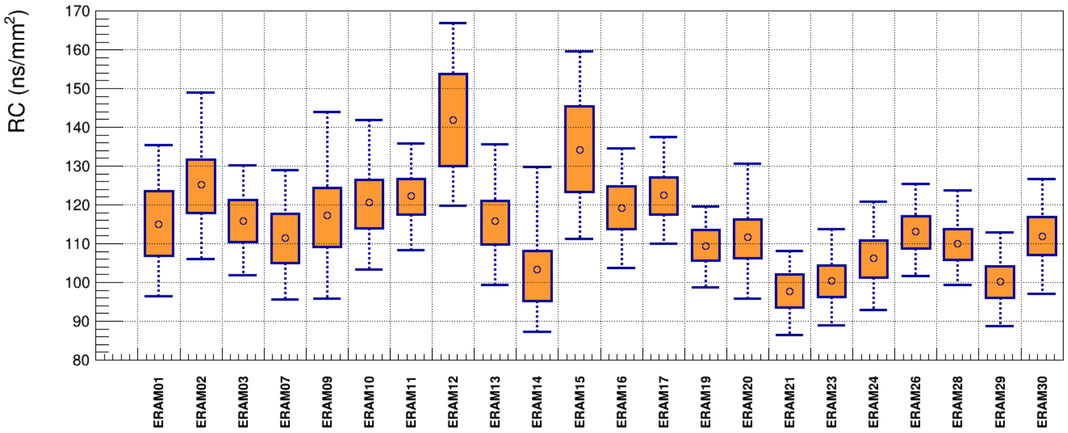
SUMMARY OF ALL ANALYZED ERAMS



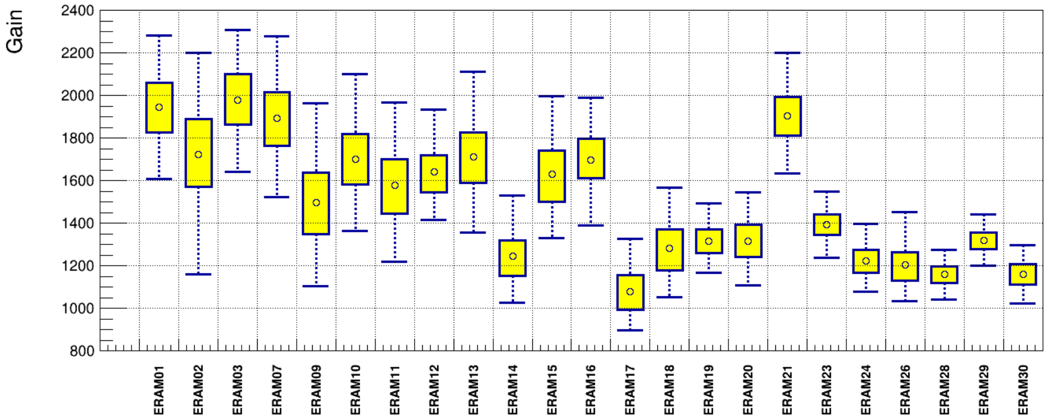
- No apparent correlation between mean RC and mean Gain of ERAMs.

SELECTION OF ERAMS FOR EACH HALF-TPC

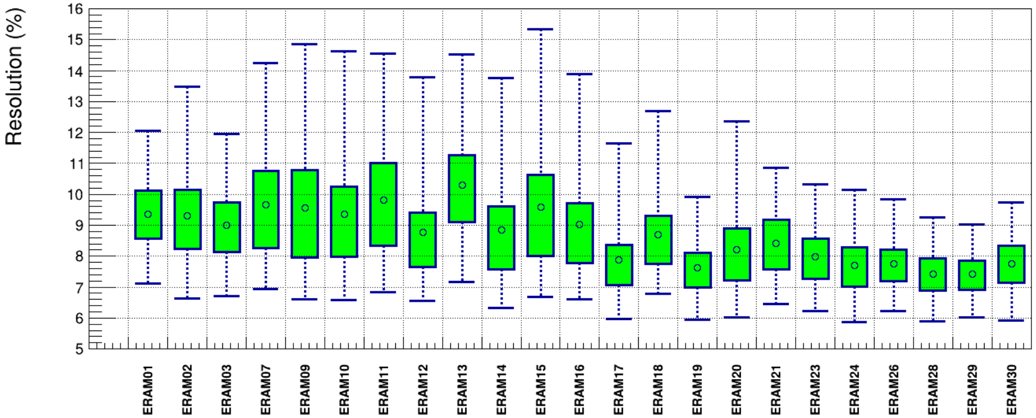
RC information of 23 ERAMs



- These plots were used to choose the combination of 8 ERAMs to equip the first field cage.



Gain information of 23 ERAMs



Resolution information of 23 ERAMs

CONCLUSION

- ND280 upgrade will employ resistive Micromegas for the read-out of HA-TPC, which works on the principle of charge spreading.
  - **23/32 produced and fully validated.**
- Resistive Micromegas will enable- better position reconstruction, reduction in sparks rate and improvement in E-field homogeneity.
- Charge spreading model is obtained from convolution of charge diffusion function and derivative of electronics response function.
- The model is able to successfully fit waveforms from X-ray data.
  - RC and Gain can be simultaneously extracted from X-ray data.
  - RC and Gain information will be a useful ingredient in the HA-TPC simulation and reconstruction.
- These results were used to select the ERAMs to equip the first field cage.