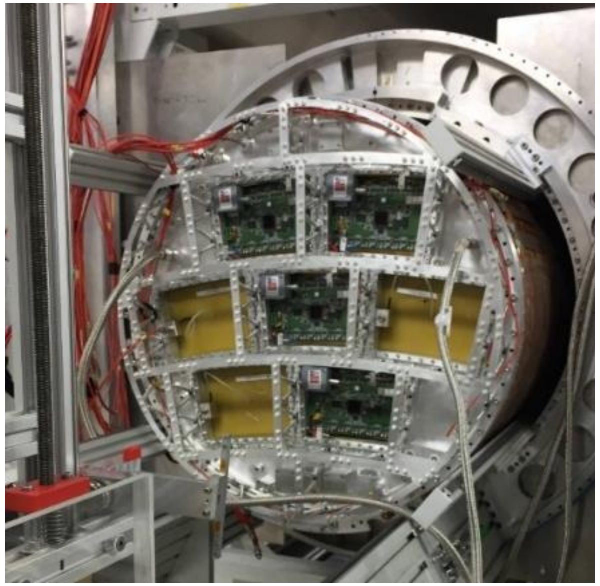
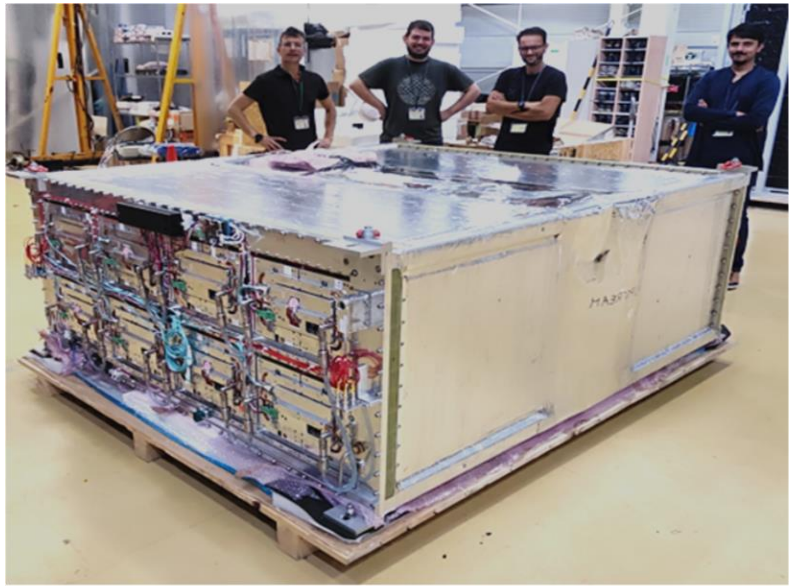
New TPCs with charge spreading resistive Micromegas for T2K near detector

EU grant n.822070

Paul Colas, U. Paris Saclay

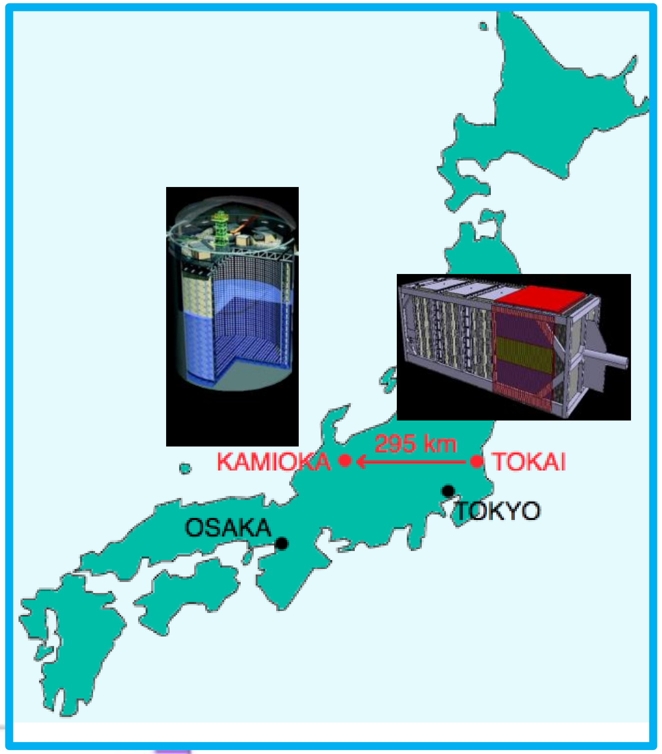


From ILC TPC R&D to a real neutrino experiment in Japan



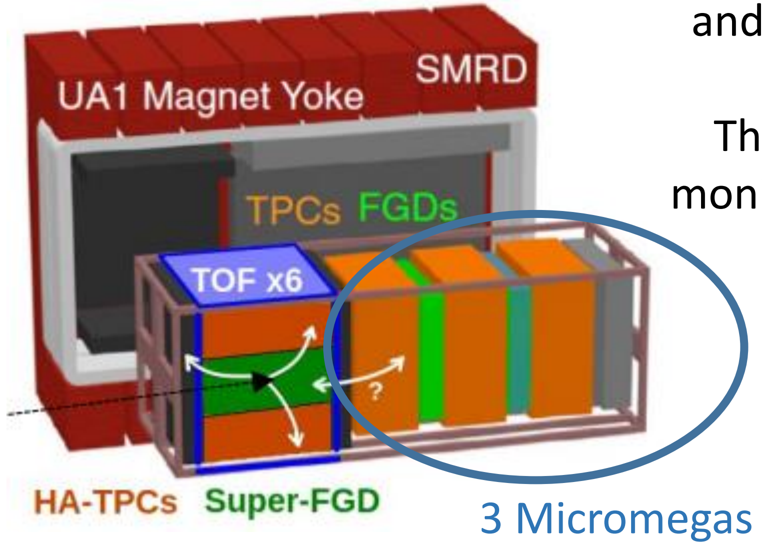
T2K/ND280 upgrade

Tokai to Kamioka



T2K is a long-baseline neutrino oscillation experiment between the Tokai neutrino source and the superKamioka giant water Cerenkov

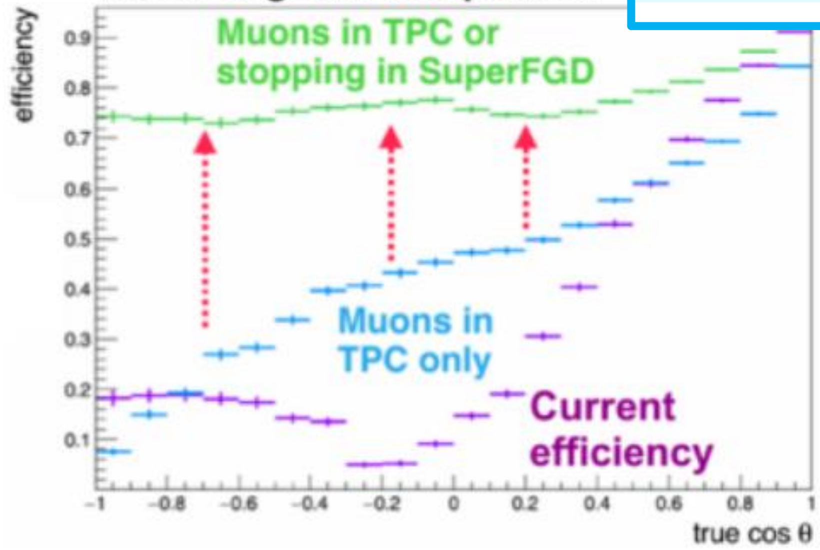
The role of the Near Detector at 280m is to monitor the neutrino beam before oscillation and to measure neutrino cross-sections

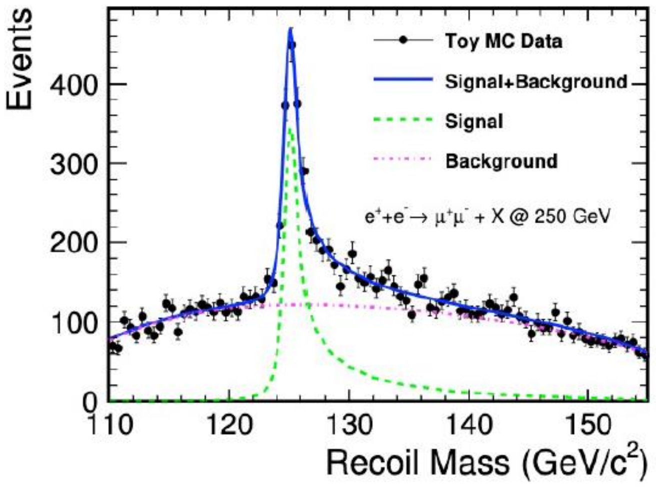


3 Micromegas TPCs since 2009.
Still operational

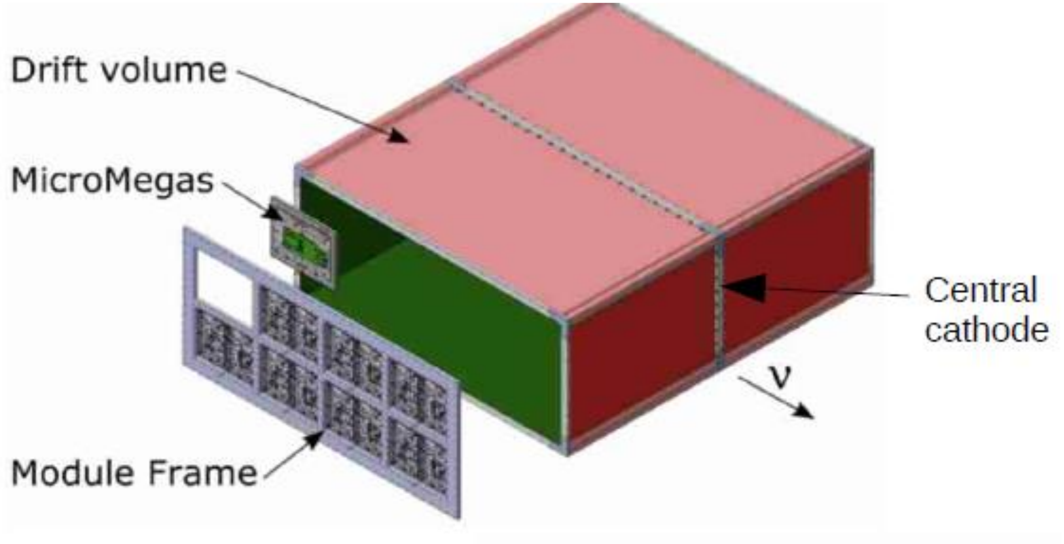
Upgrade in 2023-2024 : add a **finely segmented target** and **2 more TPCs** to improve efficiency at high angle

Muon angular acceptance



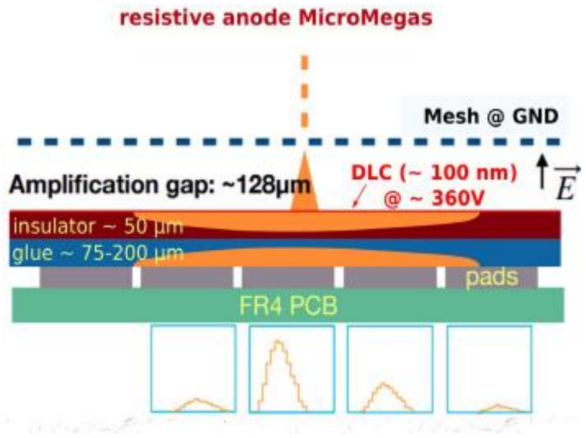


- **TPCs for ILC and T2K**
- Requirements from physics:
  - For ILC mainly point resolution for visibility of the Z recoil peak (100 µm at all drift distances) and 5% dE/dx resolution (πK separation)
  - For T2K : mainly dE/dx resolution (8%) for eµ separation and point resolution better than 700 µm
- Use of DLC (Diamond-Like Kapton) in Micromegas TPCs since 2015
  - Stabilizes Micromegas
  - Spreads the charge to improve point resolution and save electronic channels



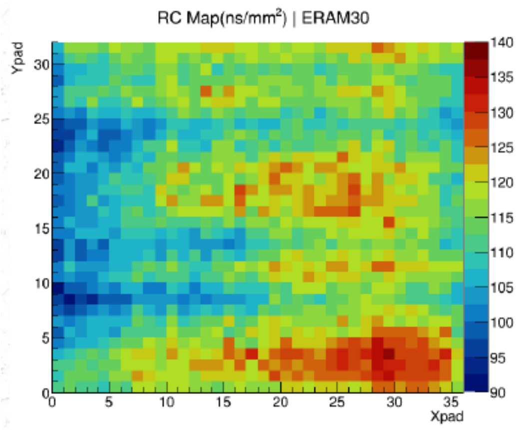
Dimensions : ~2m x 2m x 1 m
4 x 8 modules of 36x32 = 1152 pads
34 x 42 cm²

Charge spreading

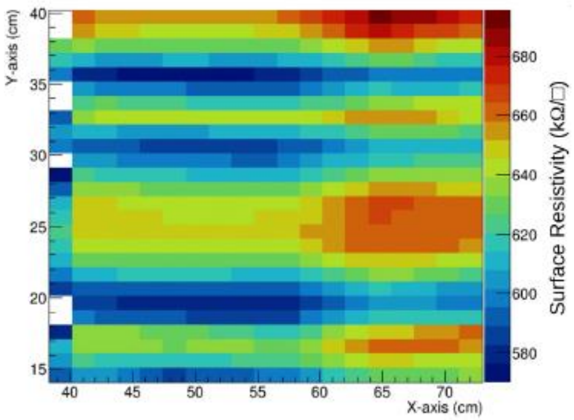


By adding a resistive layer and a dielectric layer on top of the anode, we obtain a **resistive-capacitive** continuous network that spreads evenly the charge between the hit pad and its neighbours.
This allows a barycentre to be determined, which greatly improves the resolution : resolutions as good as 1/50 times the pad size are obtained.

For an e+e- TPC, with 3mm pads, resolutions of 60 µm have been obtained in beam tests.
By fitting the wave forms of a leading pad and the subleading pad next to it, the RC parameter can be mapped:



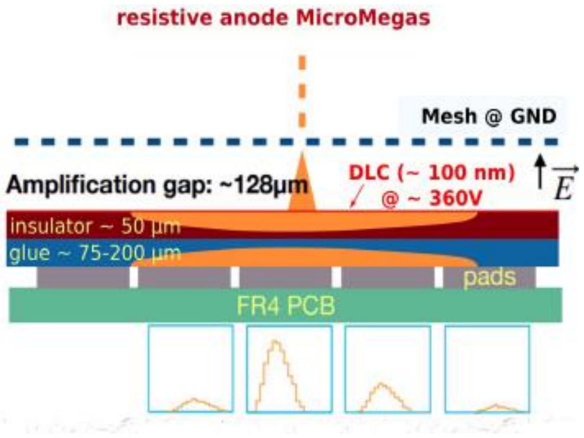
And this matches the resistivity direct measurement (C is very well constrained by the thickness of insulator)

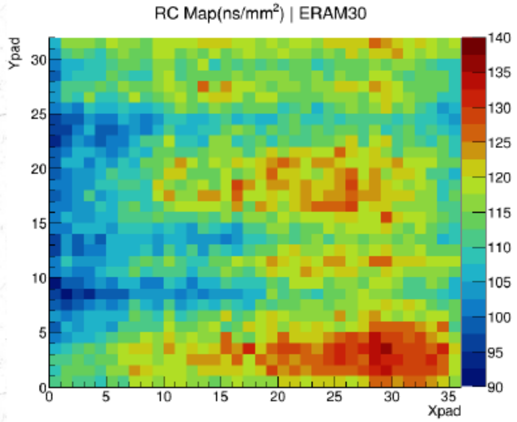


R inhomogenities in the sputtering are clearly visible in the direction perpendicular to the drum rotation axis.

Ph. Schune, G.Eurin, S. Levorato

Charge spreading





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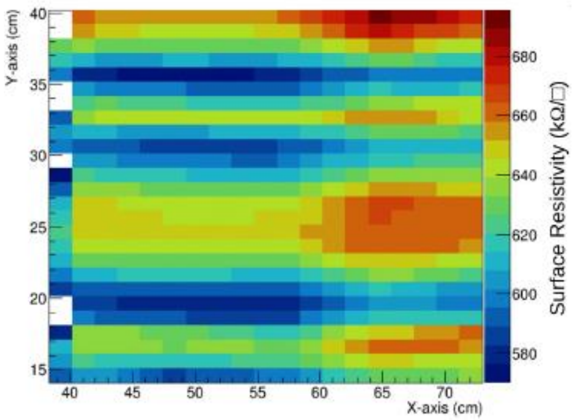

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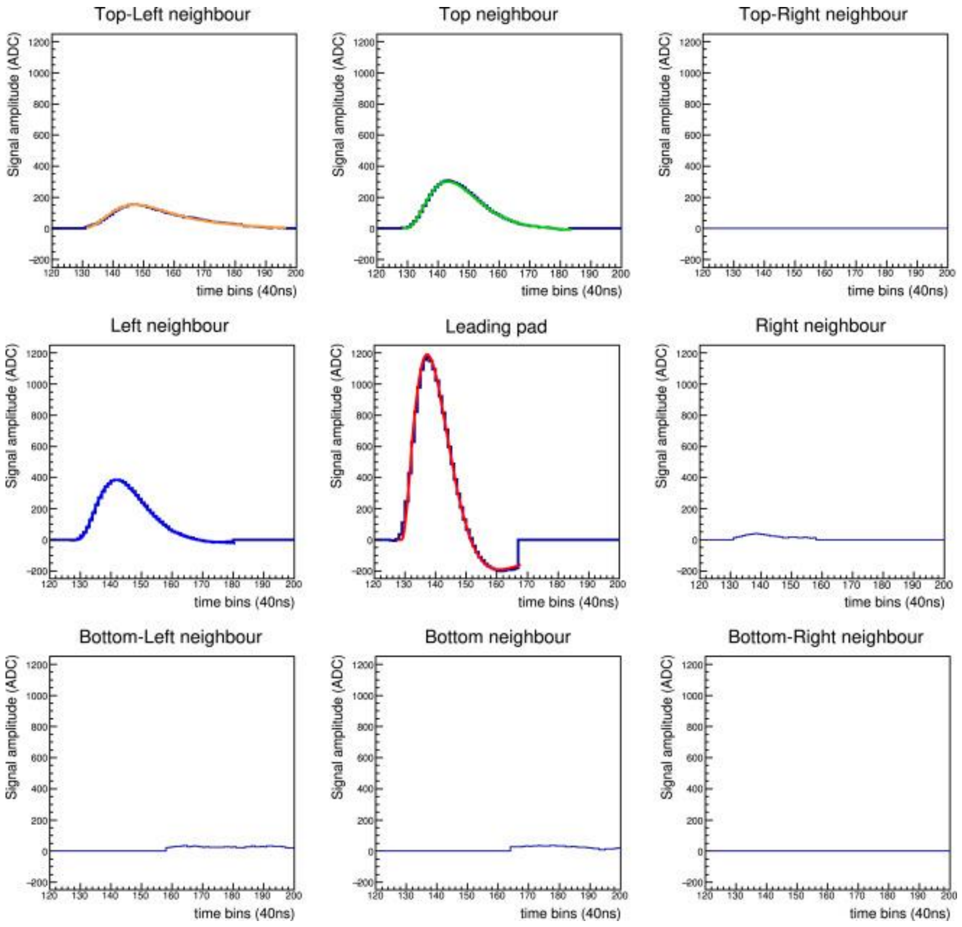
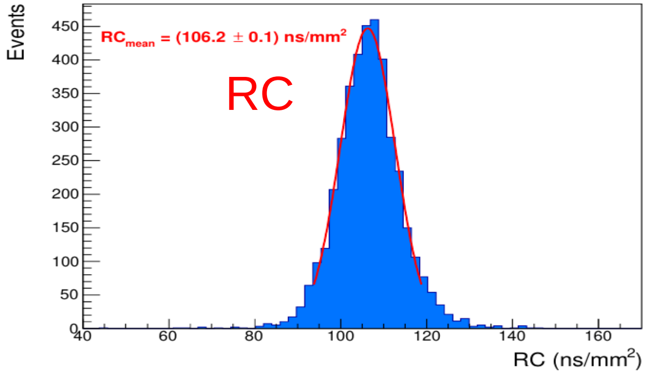
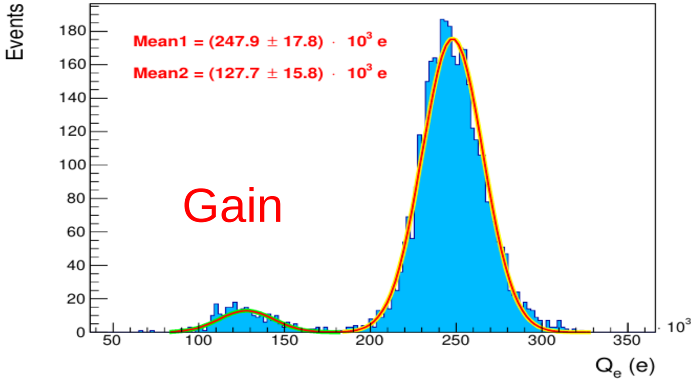


For a given pad, for each deposit
fit simultaneously the Waveforms of the leading pads

Extract RC, Gain and deposit position/time





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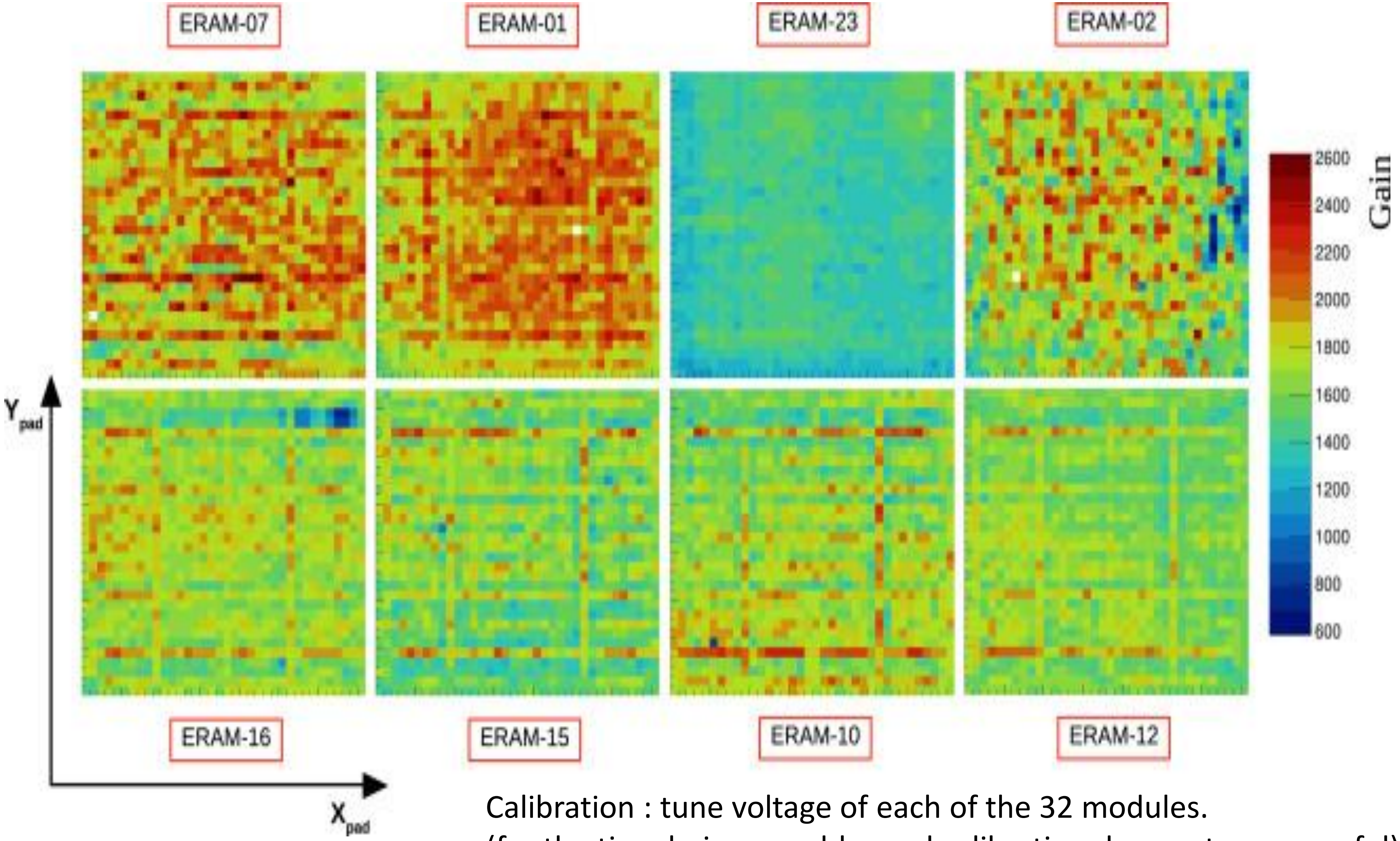
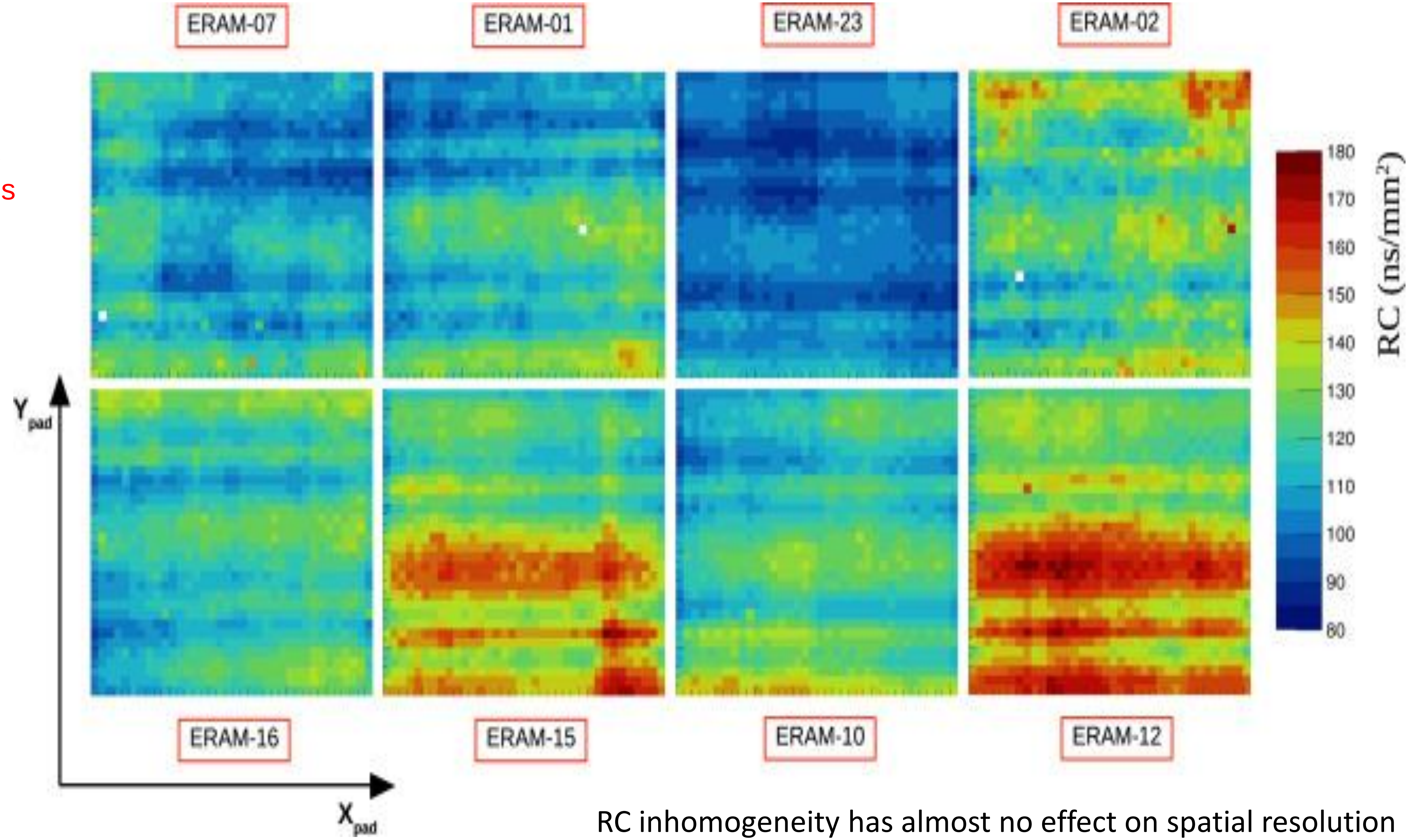
S. Joshi
J.-F. Laporte, S. Hassani

Gain maps



Calibration : tune voltage of each of the 32 modules.
(for the time being a pad-by-pad calibration does not seem useful)

RC
maps



RC inhomogeneity has almost no effect on spatial resolution

Many tests in recent years

Beam test at DESY in 2015 (LCTPC, 2 DLC modules)

Cosmic-ray test at Saclay in 2017 (T2K)

Beam test at CERN in August 2018 (T2K)

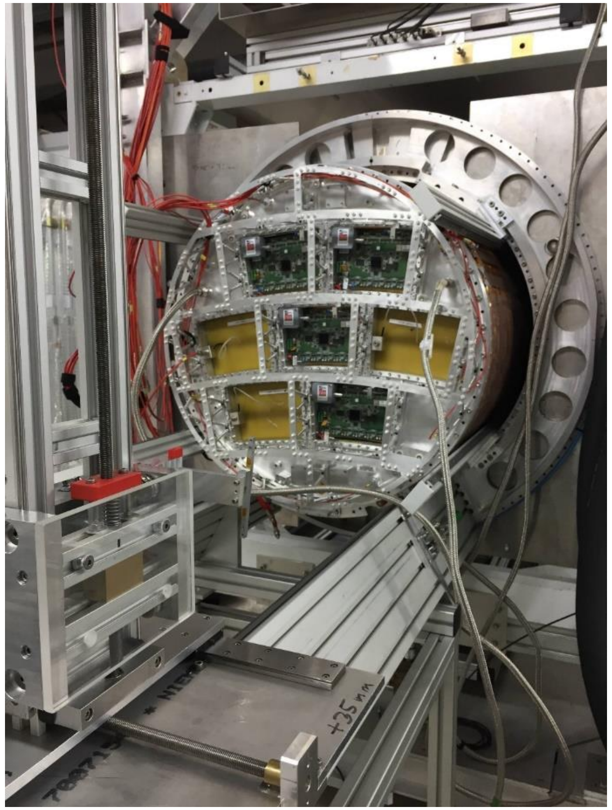
Beam test at DESY in November 2018 (LCTPC)

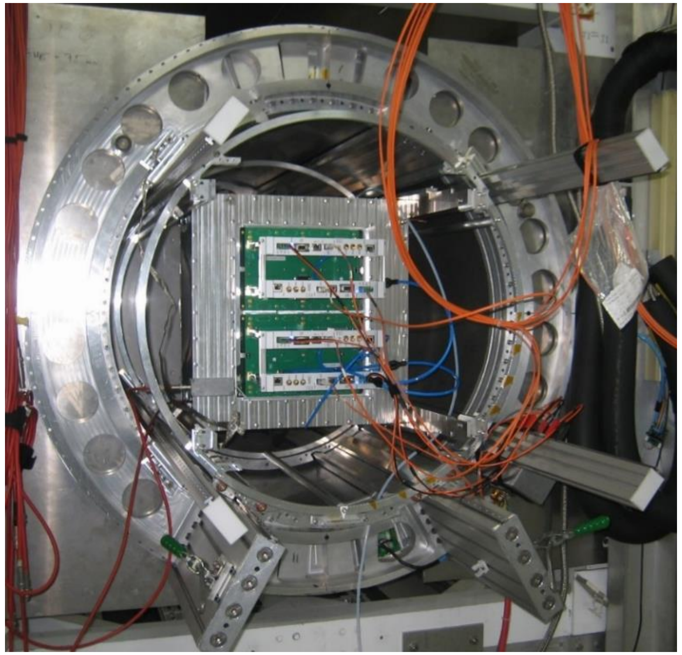
Cosmic-ray test in Saclay since January 2019 (LCTPC/FCC)

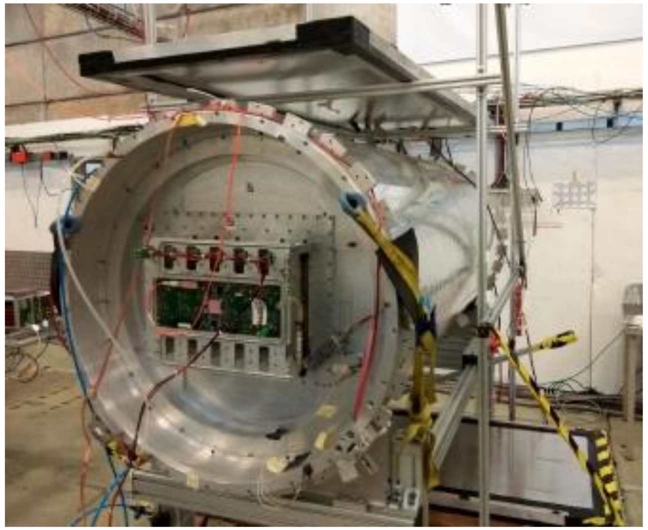
Beam test at DESY in June 2019 and 2021 (T2K)

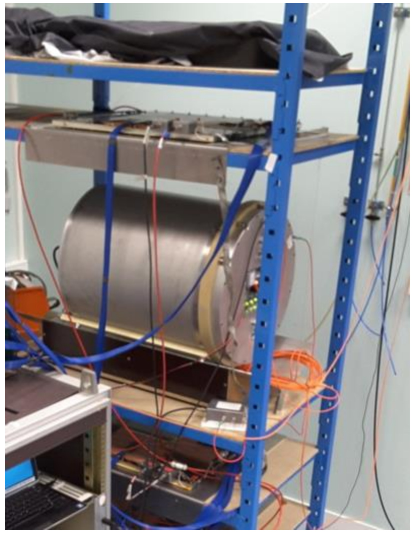
Cosmic test at CERN since December 2019 (T2K)

Cosmic tests in Saclay during the covid year (T2K) (4-6 modules)

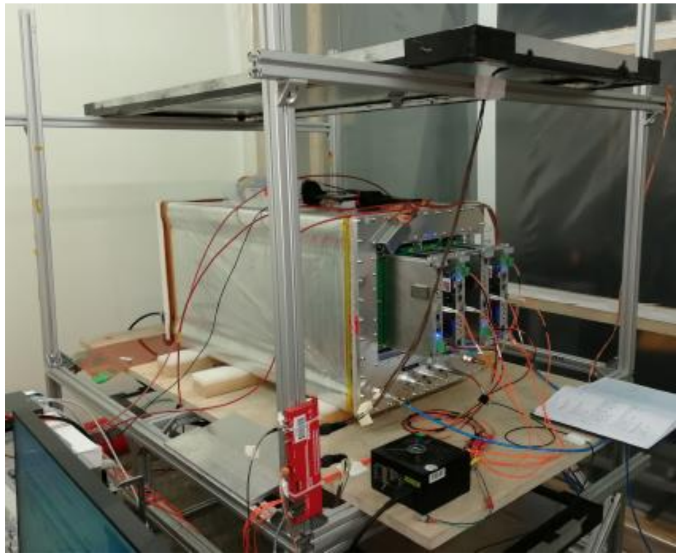








5 TPC of 15, 58, 60, 100 and 150 cm length with 1000 to 2000 channels
All with DLC charge spreading



Overal conclusion : extremely reliable and stable operation

Great progress in noise and signal modelling

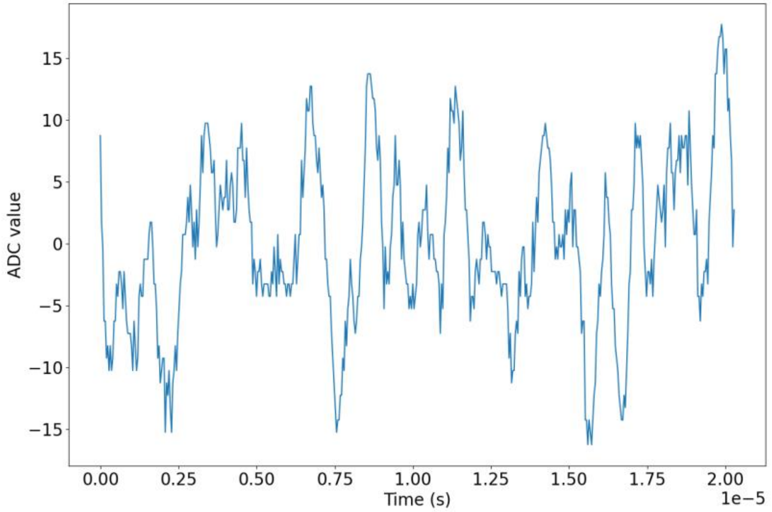
and understanding of AFTER chip

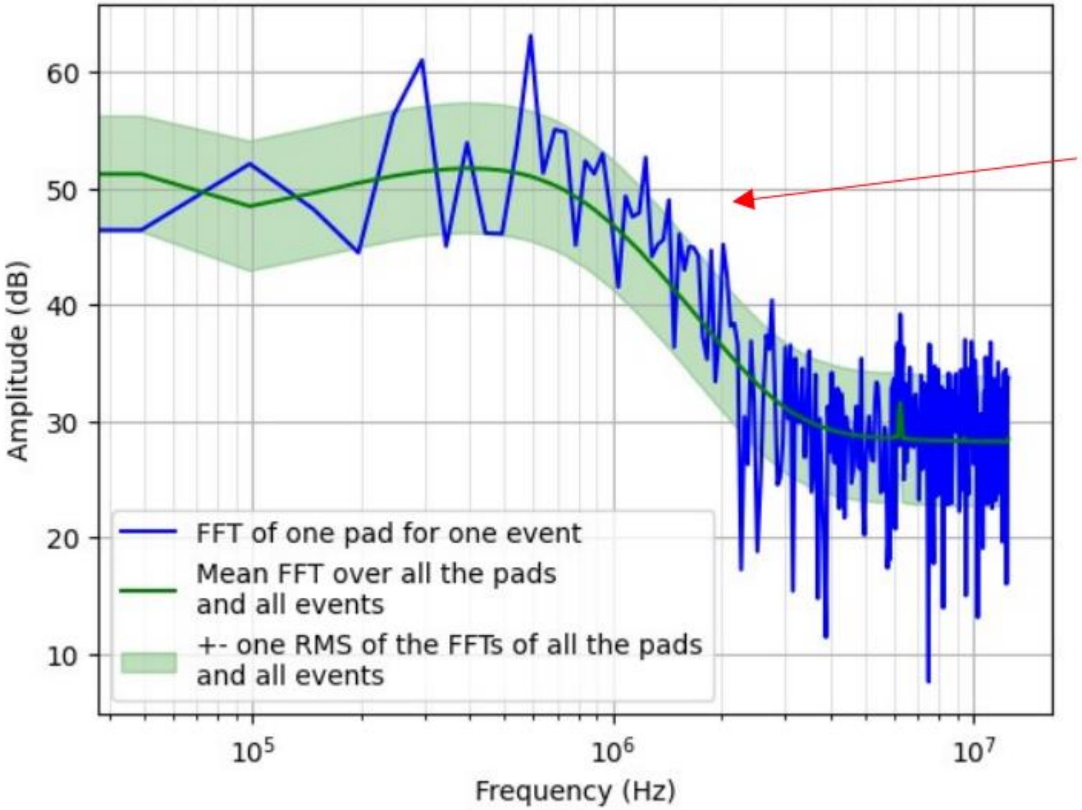
D. Calvet, J-F. Laporte, S. Hassani

- Noise modelling : Fourier transform of the noise amplitude

Record of the baseline (no trigger) by D. Calvet

One record
T_p= 412 ns
F_s = 25 MHz





Dominated by frequencies lower than 1 MHz

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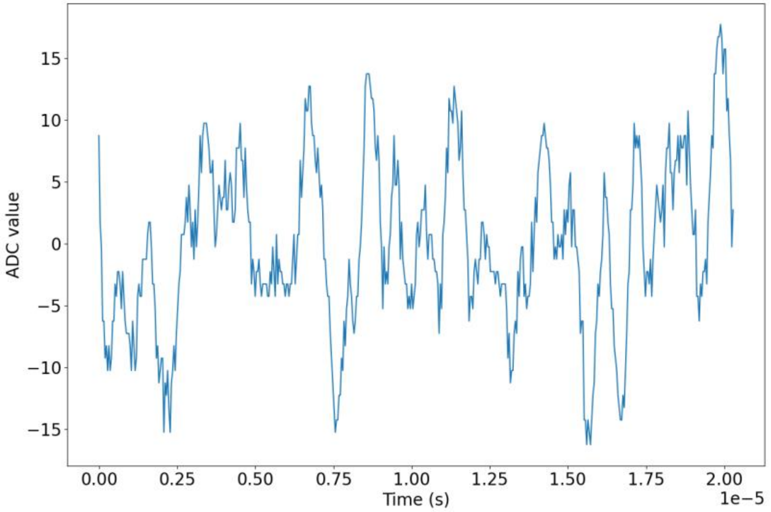
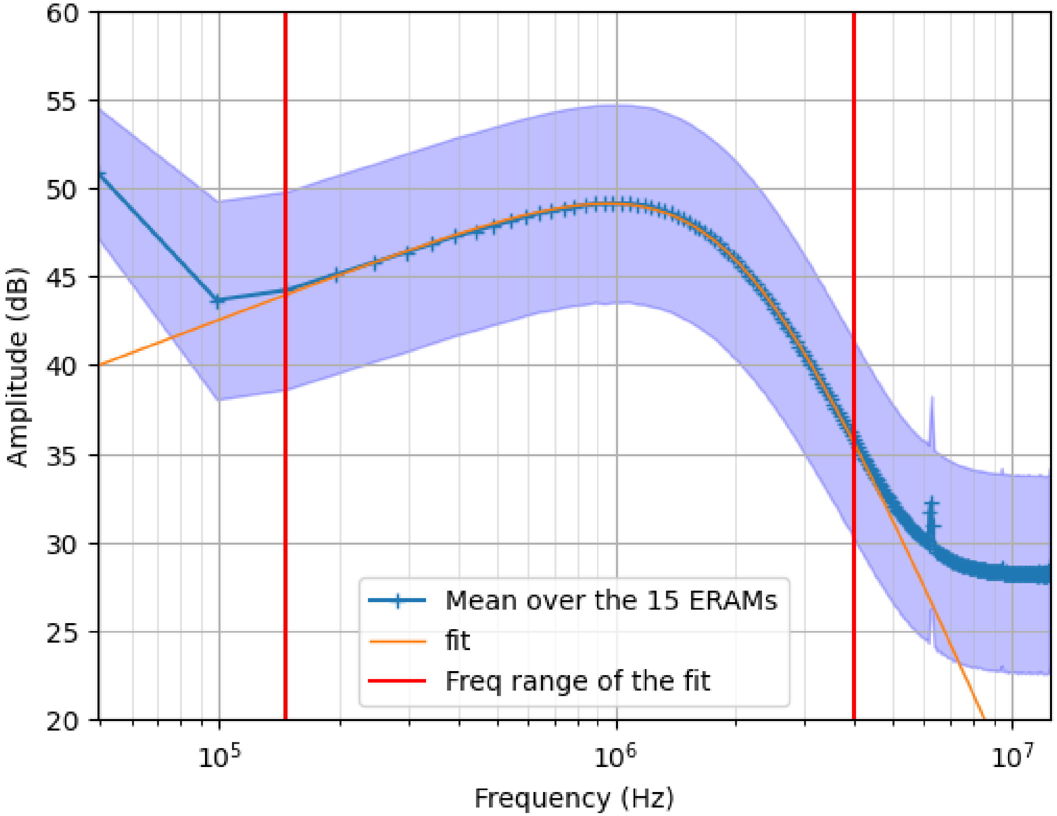
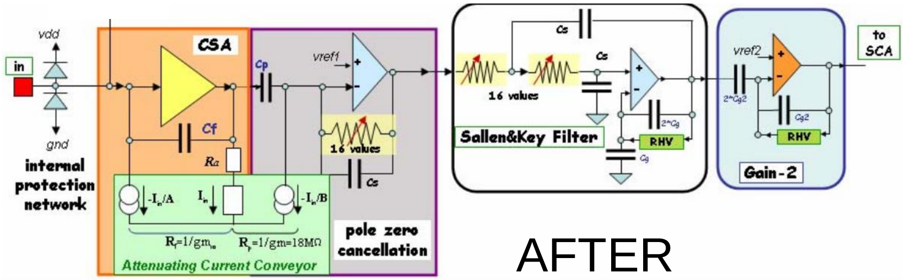


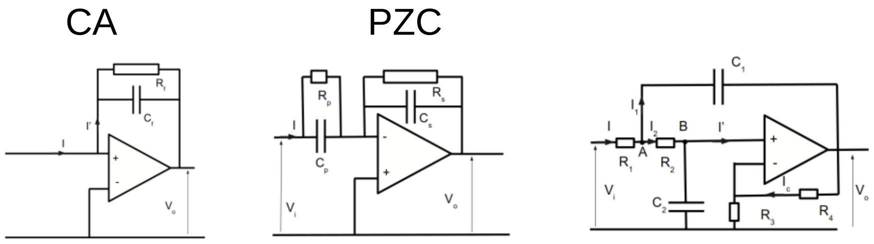


Signal modeling

Start from the charge waveform solution of the Telegrapher equation and convolute with electronic response

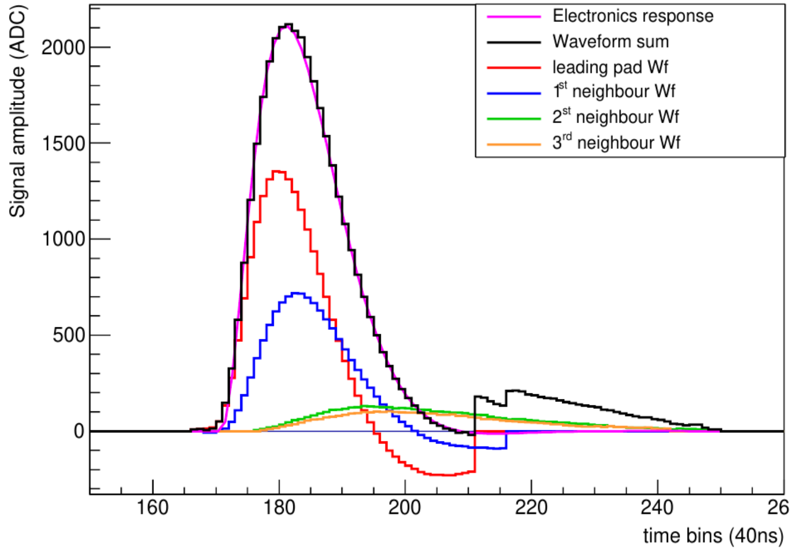


AFTER
Chip



Laplace transform ⇒ pulse response

Compare with data from X-ray tests



modelization: complete mathematics

1) **1D linear charge** function in a pad for a linear track, parametrized with an angle φ & an impact parameter d:

$$Q_{pad}(t) = \frac{\lambda\sqrt{1+m^2}}{2m}\left(\sqrt{\frac{2(1+m^2)}{\pi}}\sigma\left(-e^{-\frac{(-c+am+q)^2}{2(1+m^2)\sigma^2}} + e^{-\frac{(-c+bm+q)^2}{2(1+m^2)\sigma^2}} + e^{-\frac{(-d+am+q)^2}{2(1+m^2)\sigma^2}} - e^{-\frac{(-d+bm+q)^2}{2(1+m^2)\sigma^2}}\right)\right.$$
$$+ (c-am-q)\,\mathrm{Erf}\left[\frac{-c+am+q}{\sqrt{2(1+m^2)}\sigma}\right] - (d-am-q)\,\mathrm{Erf}\left[\frac{-d+am+q}{\sqrt{2(1+m^2)}\sigma}\right]$$
$$\left. +(-c+bm+q)\,\mathrm{Erf}\left[\frac{-c+bm+q}{\sqrt{2(1+m^2)}\sigma}\right] + (d-bm-q)\,\mathrm{Erf}\left[\frac{-d+bm+q}{\sqrt{2(1+m^2)}\sigma}\right]\right)$$

$y = mx + q$	the track equation
$(a,\ b,\ c,\ d)$	borders of the pad

with $\sigma(t) = \sqrt{\frac{2t}{RC} + zD^2}$

2) **Electronics** function depending on two parameters Q & w_s:

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

3) Finally, do the **convolution** of the derivative of the charge & the electronics:

$$ADC(t) = \frac{dQ}{dt} \otimes ADC_{\mathrm{Dirac}}$$

1st method : sum of the wave forms by clusters

Tristan Daret

2nd method: model-assisted “Crossed Pads” (XP)

Complete modelization of the detector’s response, depending on:

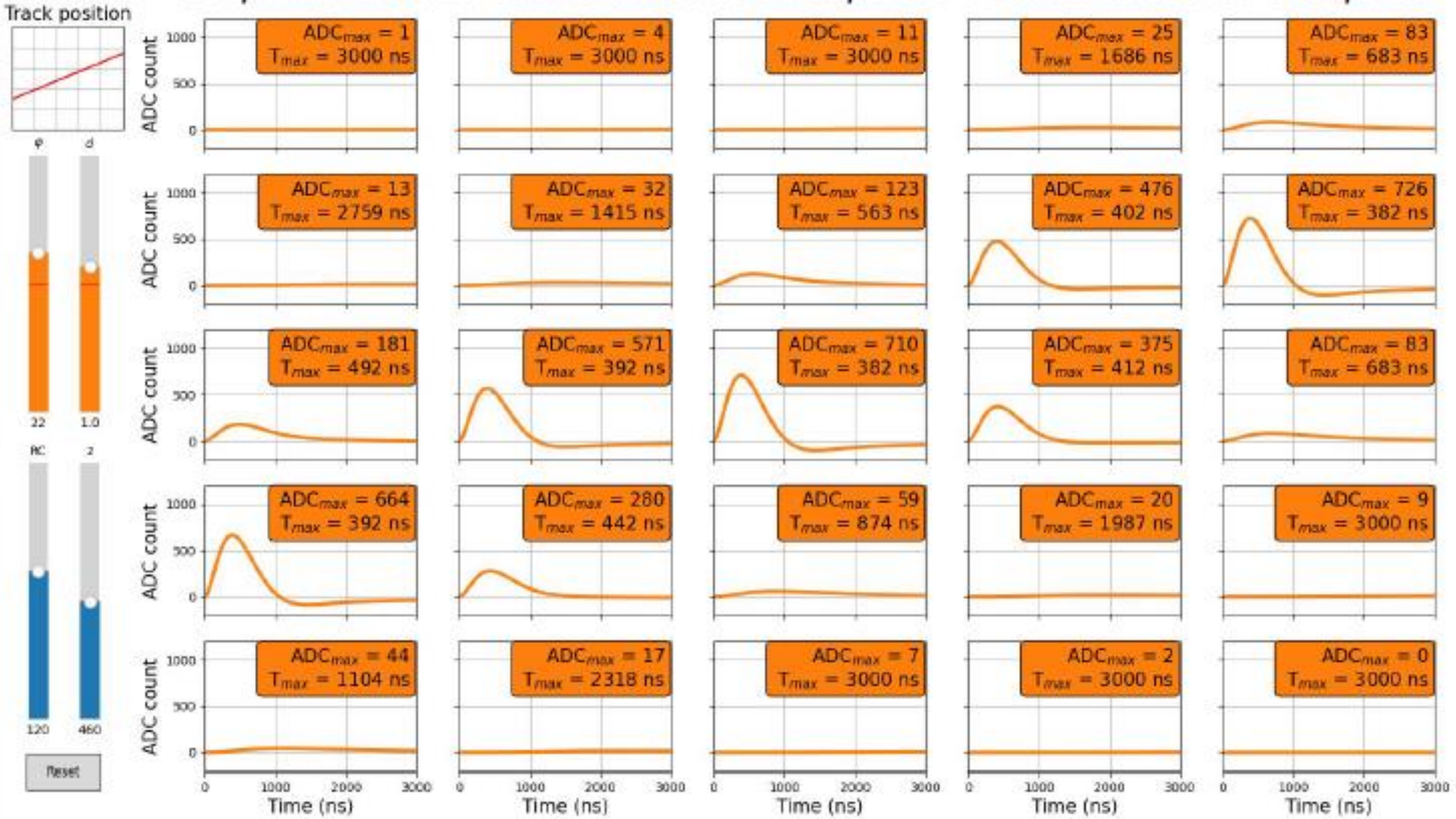
1. Track angle φ
2. Distance of the track to the pad center (i.e. impact parameter) d
3. Drift distance
4. Diffusion coefficient of the pad 1/RC

For crossed pads, the real charge deposited Q_{anode} is reconstructed using the track length, A_{max} and the data needed by the model

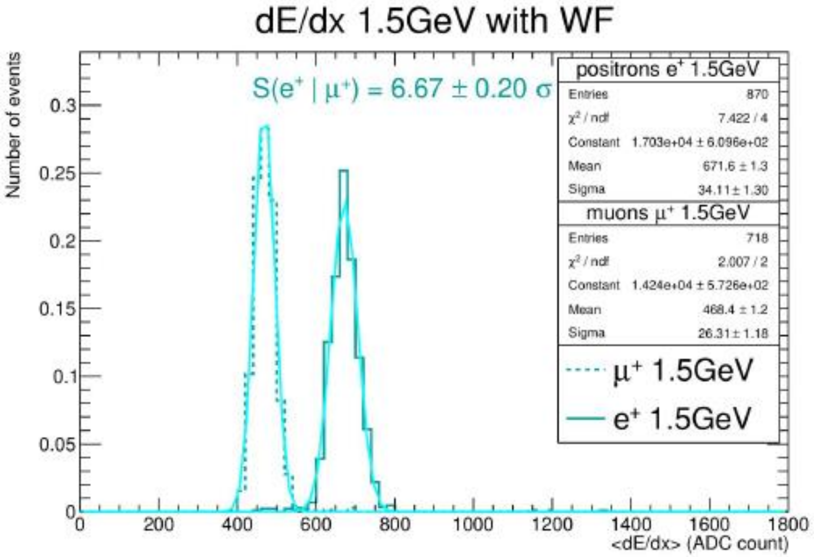
The usual truncation is applied afterwards

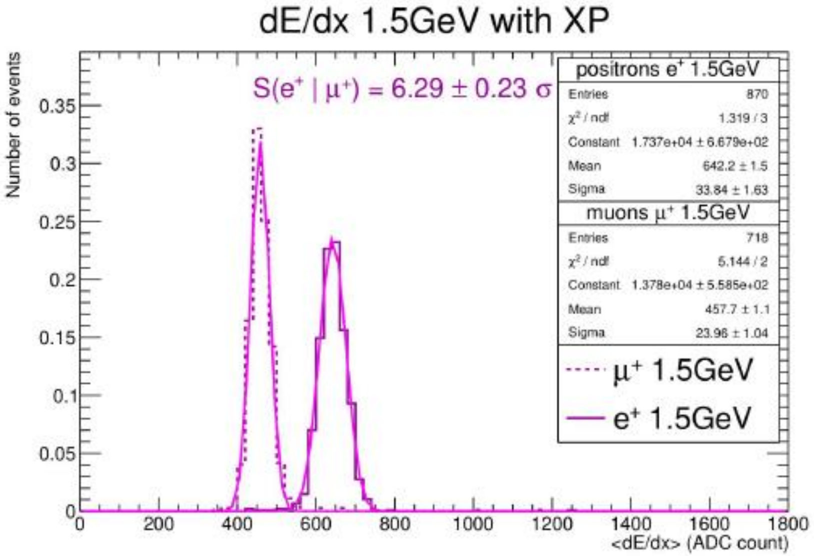
➢ No need for clusters anymore

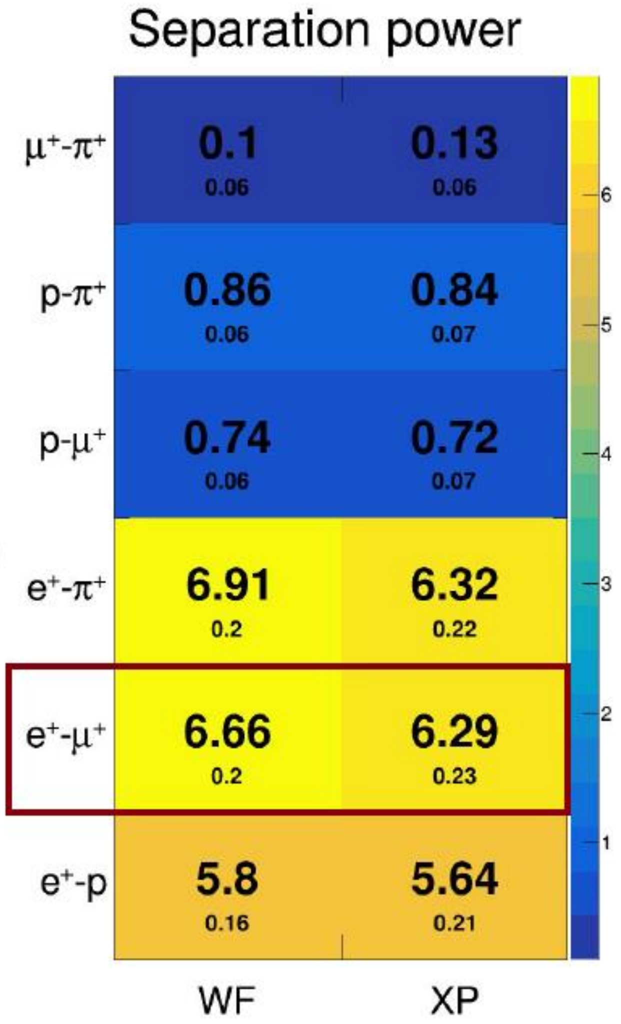
Graphic interface of the detector’s response modelization for 5x5 pads



Separation power with 4 detectors (1.5 GeV @ CERN)






Separation power

	WF	XP
μ^+-π^+	0.1 0.06	0.13 0.06
p-π^+	0.86 0.06	0.84 0.07
p-μ^+	0.74 0.06	0.72 0.07
e^+-π^+	6.91 0.2	6.32 0.22
e^+-μ^+	6.66 0.2	6.29 0.23
e^+-p	5.8 0.16	5.64 0.21

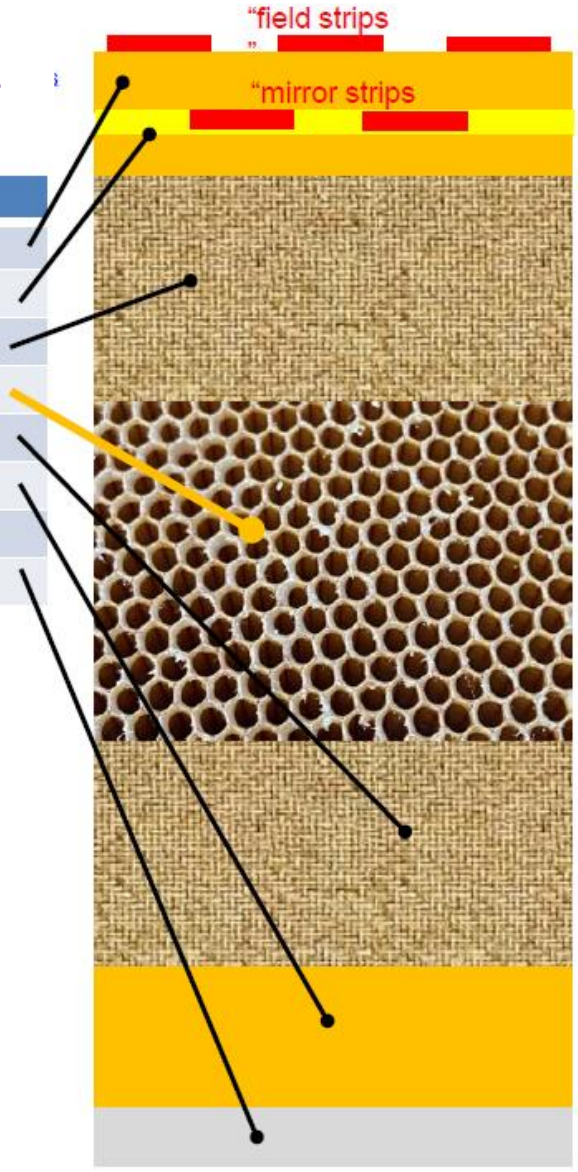
- μ^+ & e^+ split by more than 6σ
- Tracks will not fully cross 4 detectors so the effective separation power will be lower

$$S(e^+,\mu^+) = \frac{|\mu_{e^+} - \mu_{\mu^+}|}{\sqrt{\left(\sigma^2_{e^+} + \sigma^2_{\mu^+}\right)/2}}$$

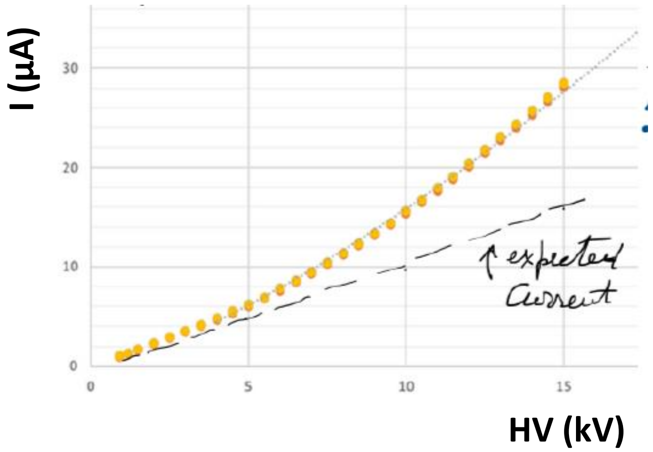
Field Cages

See G. Collazuol, 15th Pisa meeting on Advanced Detectors

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



The field cage is largely inspired of the LCTPC field cage (P. Schade, T. Behnke, et al.)



Lessons learned about field cages

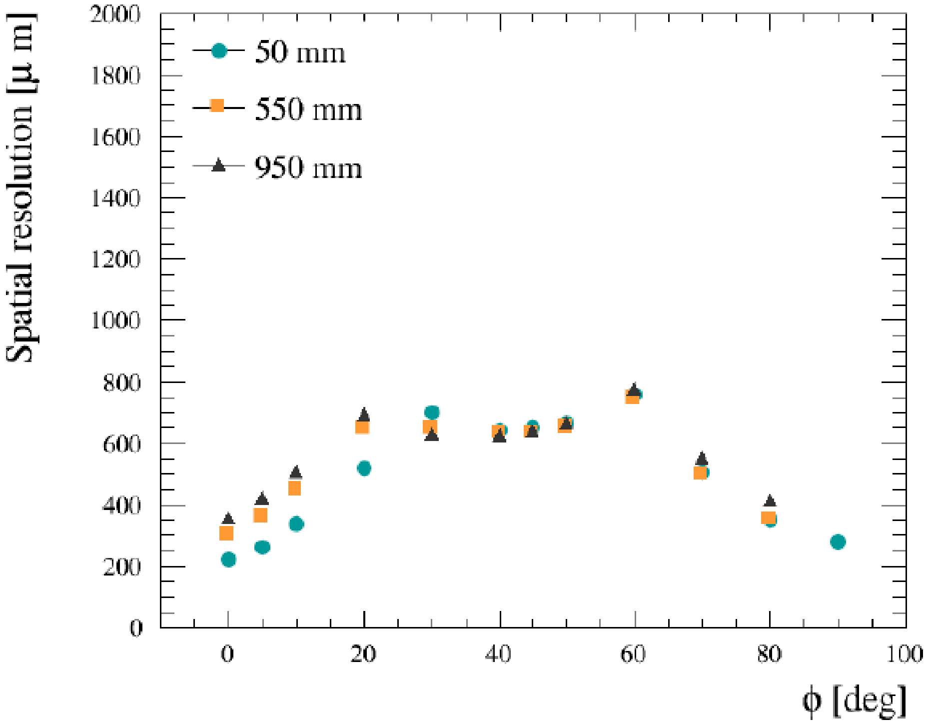
Electrostatic charge deposition on insulators create very bad field distortions (this happened to STAR and Alice TPCs)

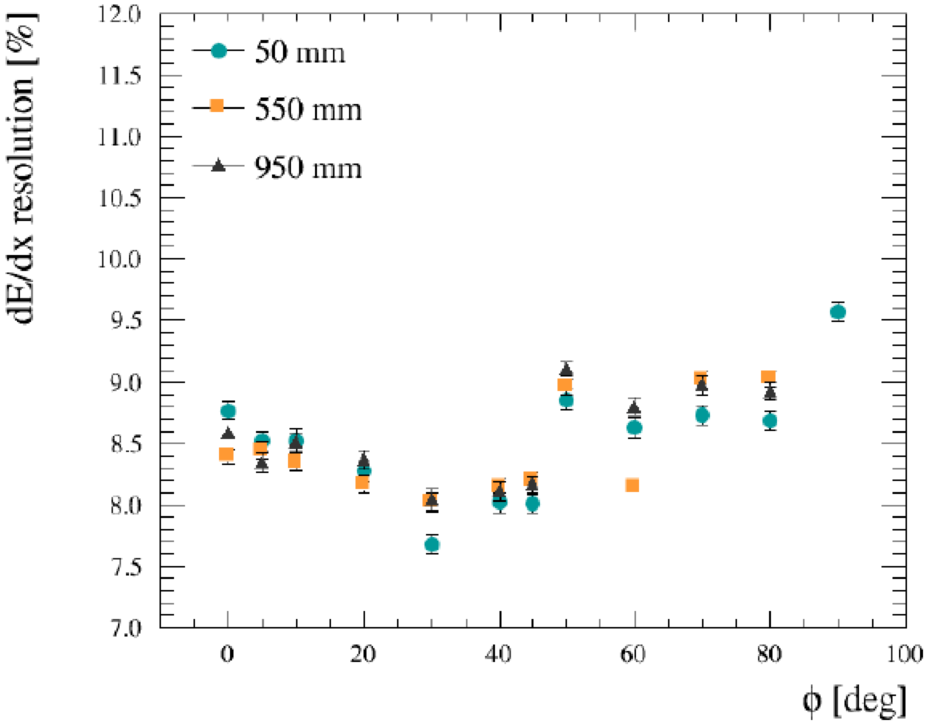
Appart from the resistor chain of the potential degrader, no other path must exist for the cage current (in T2K at the beginning a cage had its resistance lowered to a few GOhm due to the application of an antistatic spray all around the field cage. The HV could not be raised to its nominal value of 28 kV.

Two new field cages have been built with very high resistance of

O(15 TΩ)

Performance (beam test at DESY in 2021)

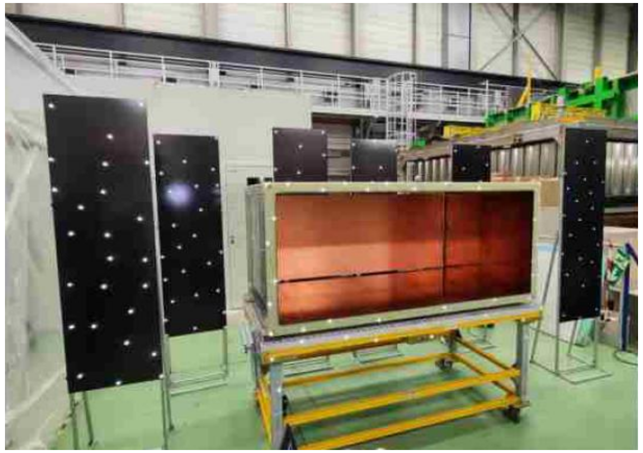


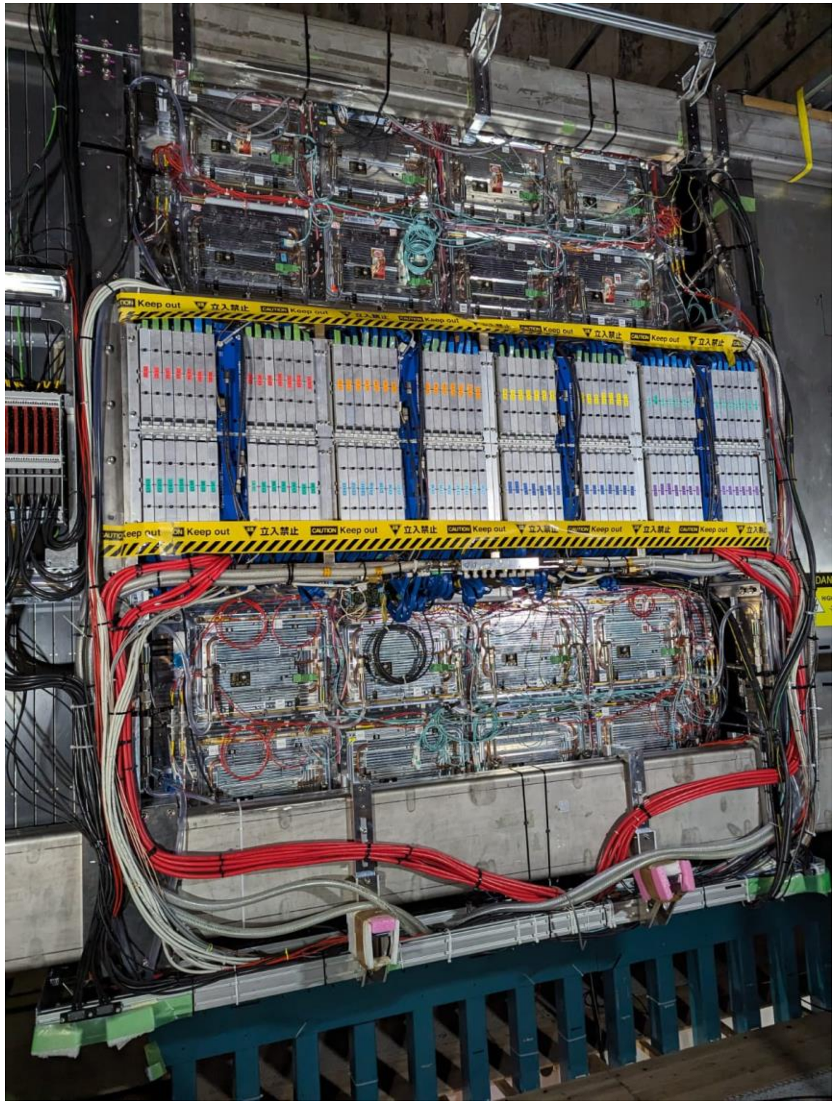


Installation at JPARC

32 (+spares) ERAM modules built at CERN (Rui de Oliveira)
and characterized/tested at CERN
Field cages built in industry in Spain under supervision by T. Lux, G. Collazuol et al.).

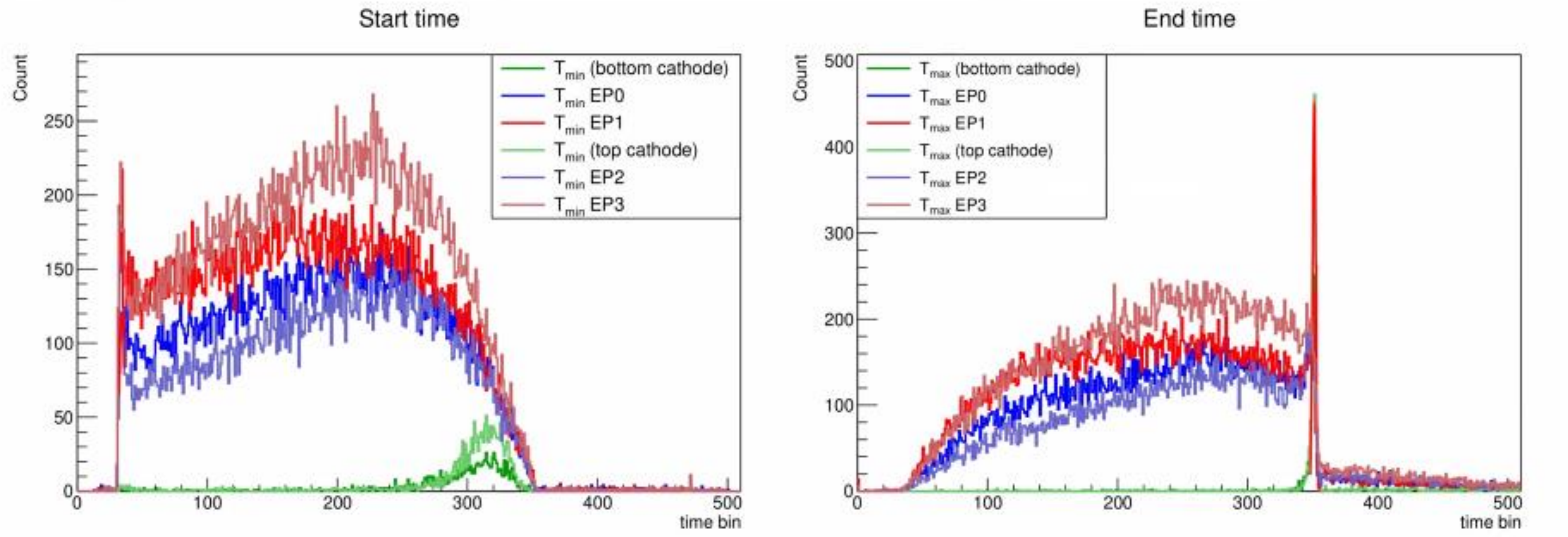
TPCs assembled at CERN (gluing stripped kapton and soldering resistor chains) and transported by plane to JPARC.
Then re-tested on surface and lowered in the T2K pit (T. Lux).
100% operationnal. Excellent gas (system by R. Guida built at CERN and commissioned by E. Radionici) : 2 ppm O_2 and 5 ppm H_2O

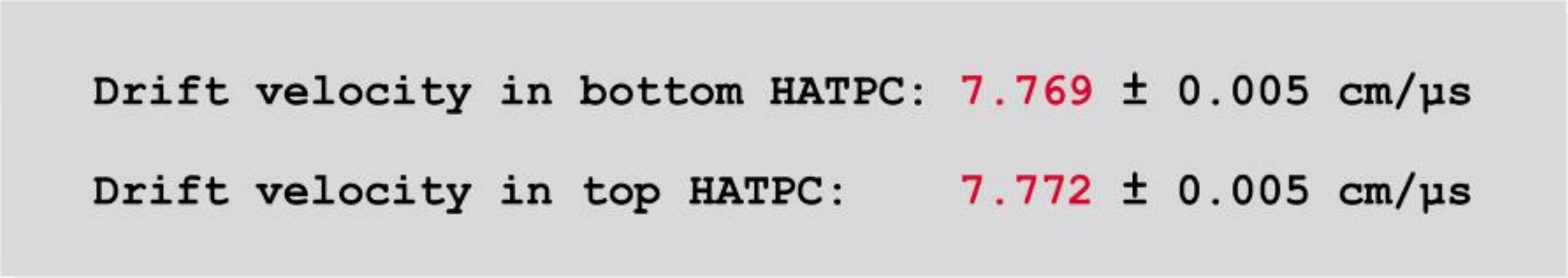




Gas : ‘T2K gas’ Ar:CF_4:isobutane / 95:3:2

Drift velocity measurement





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Drift velocity in bottom HATPC: 7.769 ± 0.005 cm/µs

Drift velocity in top HATPC:    7.772 ± 0.005 cm/µs
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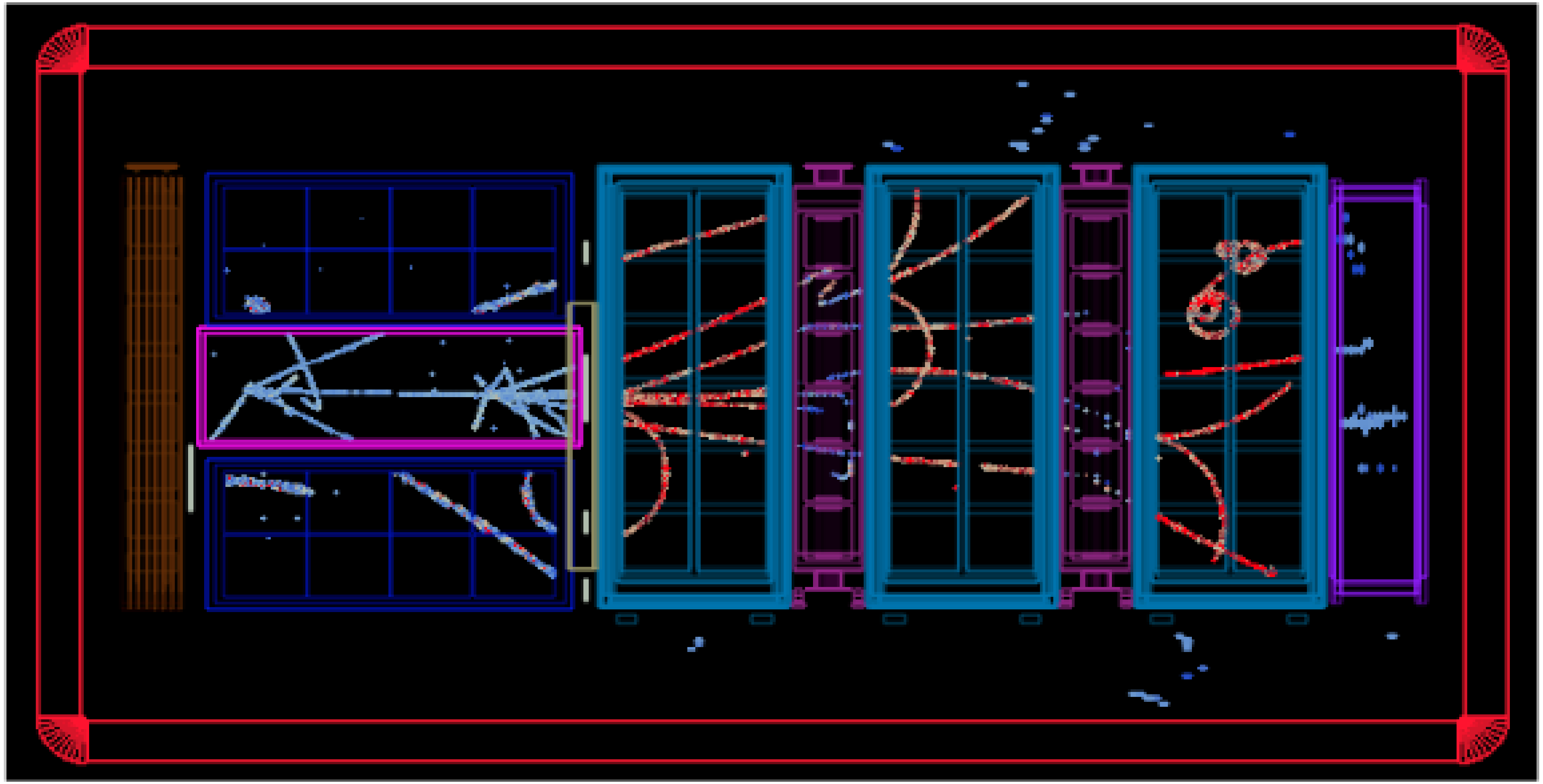
Perfect agreement with Magboltz predictions.
Excellent gas quality

Upgraded detector takes beam data (800 kW)

June 2024



Summary

- In the last 8 years, a new type of TPCs has been designed, constructed and commissioned. It uses the ERAM technology (Encapsulated Resistive Anode Micromegas) to spread the charge and protect the electronics.
- A lot of progress has been obtained within T2K to understand the charge spreading, the homogeneity of the gain and RC maps.
- Two new such TPCs have been installed and commissionned at JPARC in the T2K Near Detector, contributing to a very significant upgrade of this experiment.
- All this will prove very useful as a preparation for an ILC TPC.

Thanks to A. Delbart, G. Eurin, S. Hassani, G. Collazuol, S. Levorato, D. Calvet, D. Henaff, D. Attié, S. Joshi, L. Munteanu, and many others… Acknowledgement to the Jennifer2 EU project which funded my travels