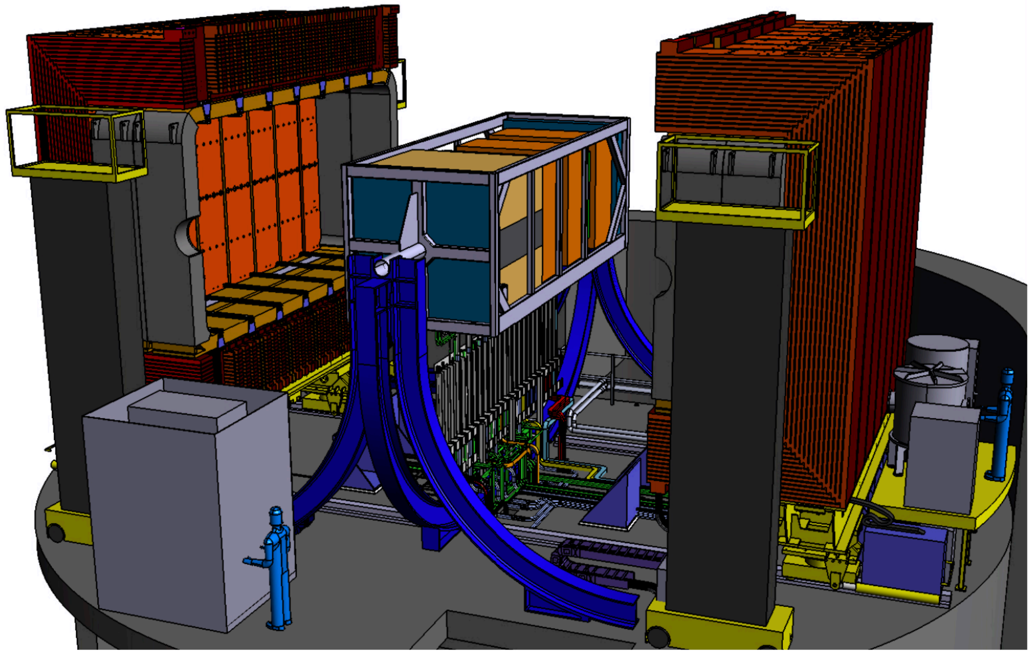
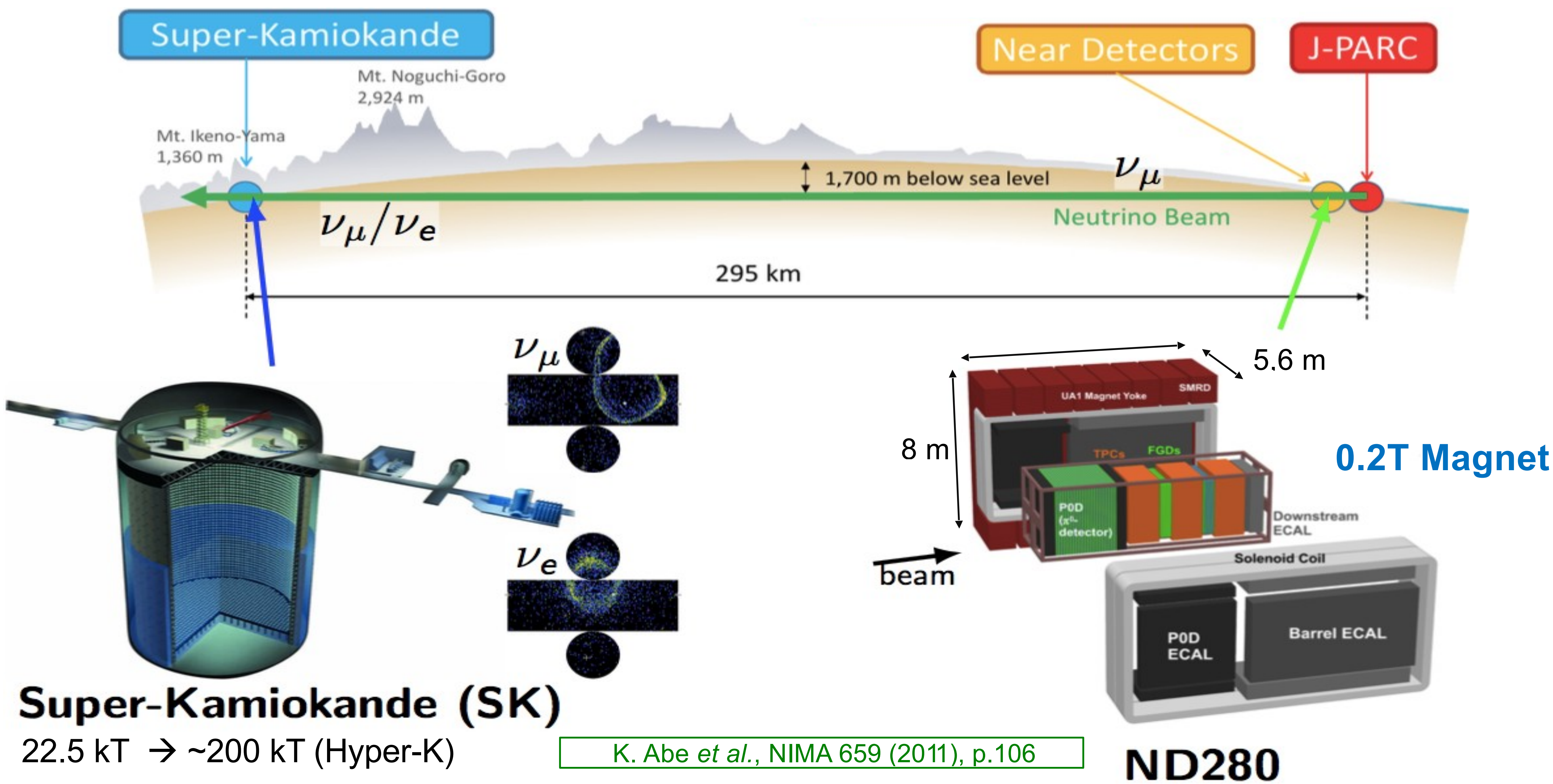
# Performances of a resistive MicroMegas module for the Time Projection Chambers of the T2K Near Detector upgrade

César JESÚS-VALLS cjesus@ifae.es
*on behalf of the ND280/HA-TPC collaboration*



# The T2K experiment
# The ND280 Near Detector

- **T2K**: Long baseline neutrino experiment from Tokai to Kamioka.
- **Goals of ND280**:
  - Measure flux & spectrum of neutrinos before oscillation.
  - Measure ν-nucleus cross-sections.
  - Measure $\nu_e$ contamination.

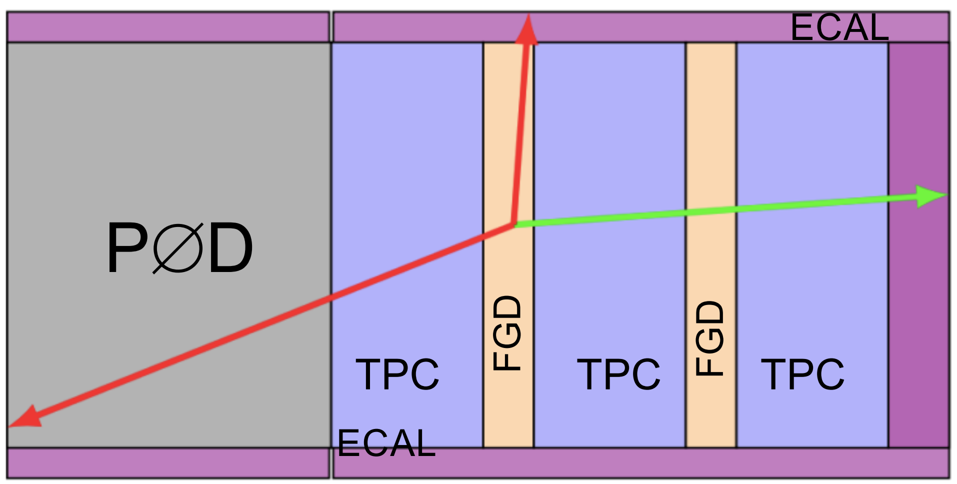


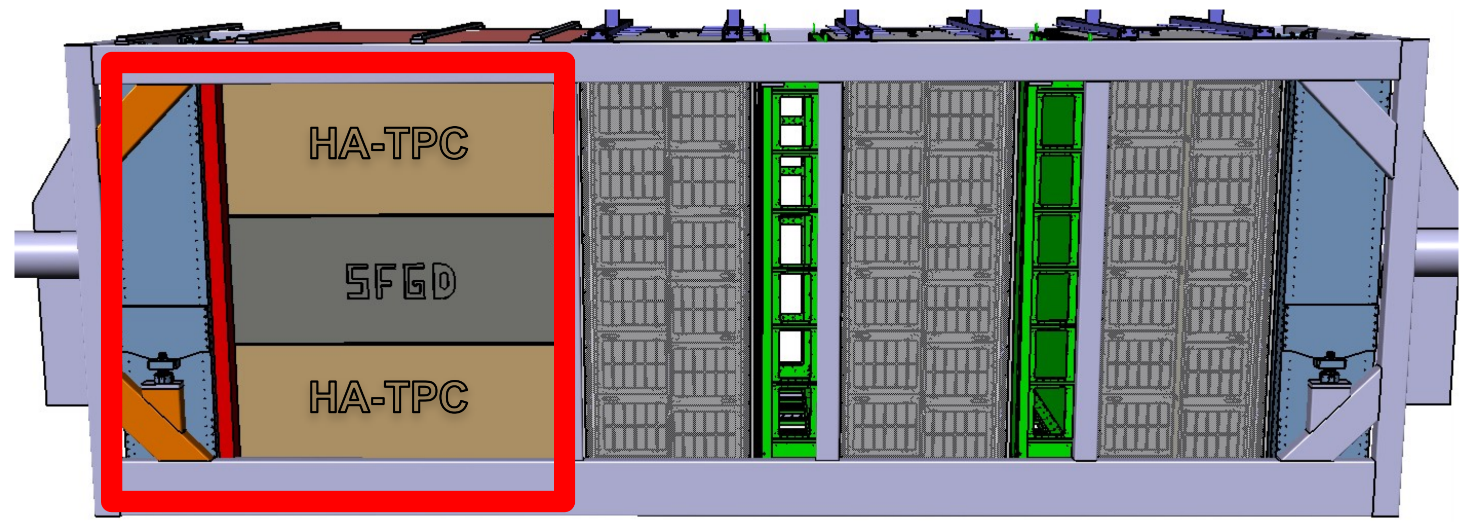

K. Abe *et al.*, NIMA 659 (2011), p.106

# The ND280 upgrade Motivations

- Current ND280 → Proposed ND280 upgrade

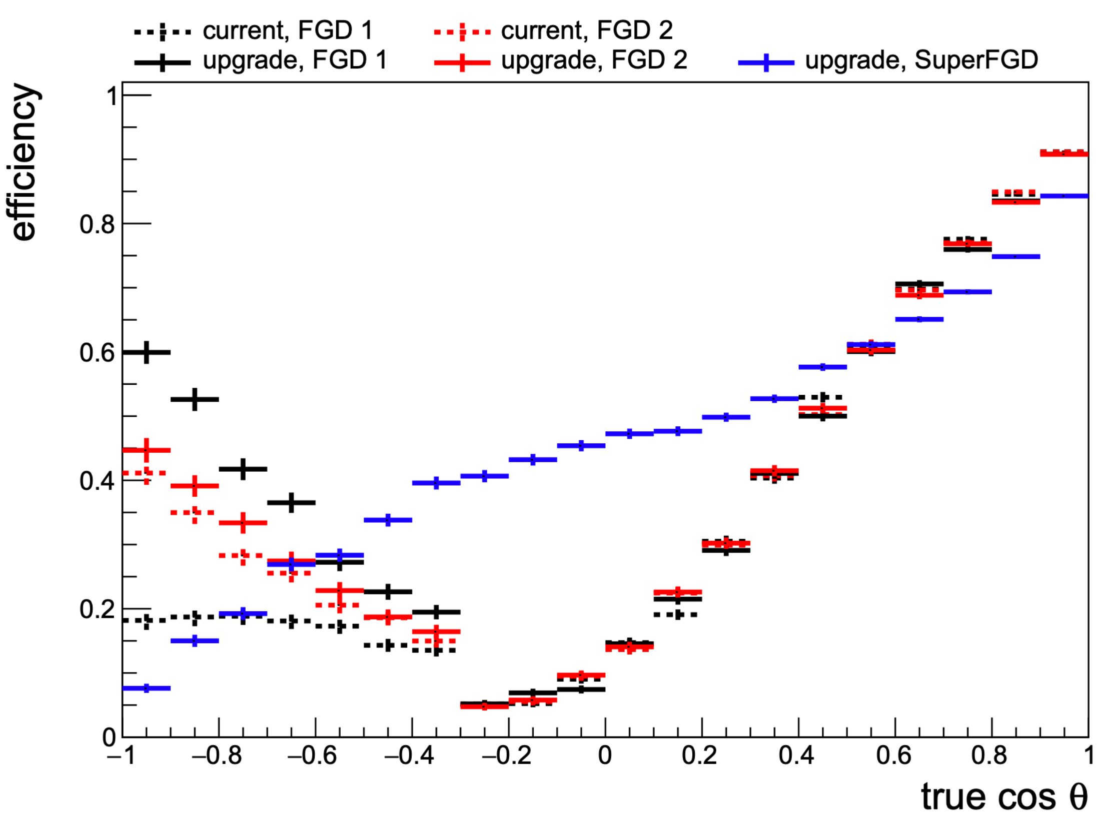
Good acceptance only for forward tracks




2 High-Angle TPCs
+ a new highly granular scintillator detector (Super-FGD)
+ 6 TOF planes surrounding the new tracker

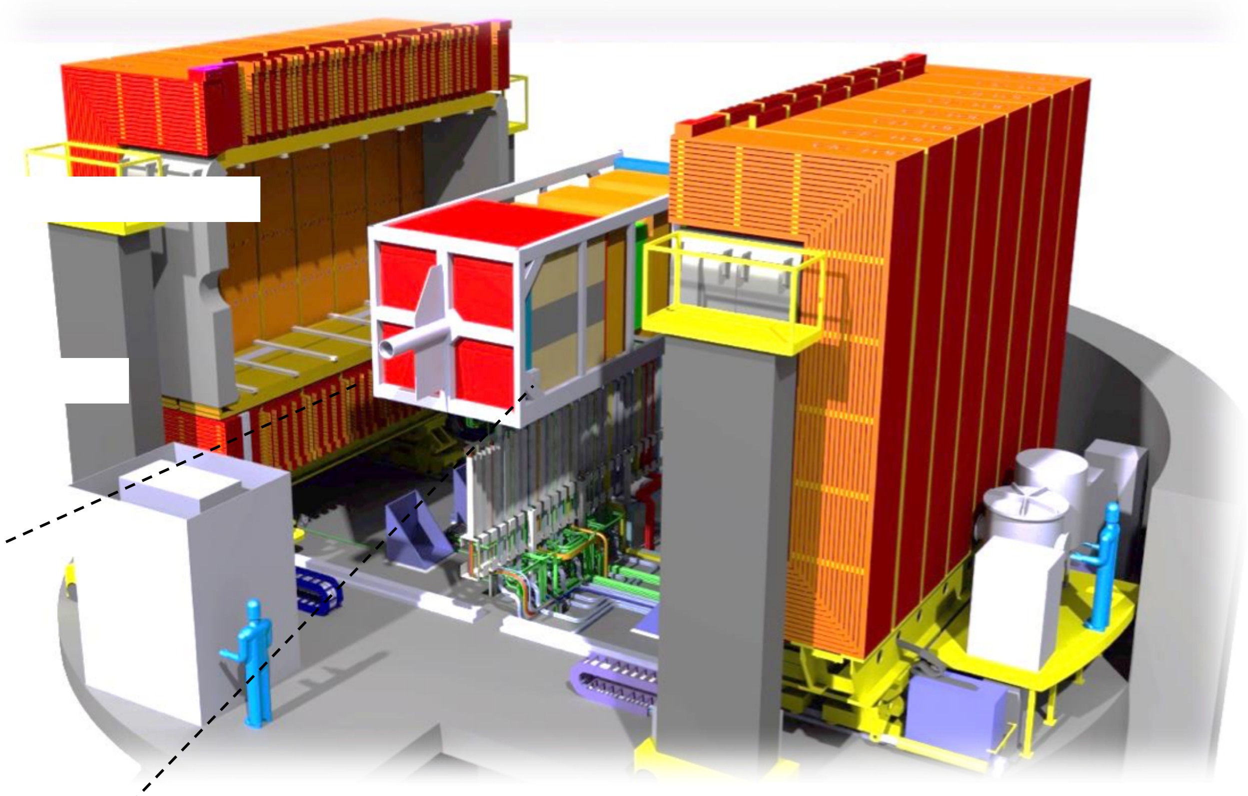
ND280 upgrade TDR: arXiv:1901.03750v1

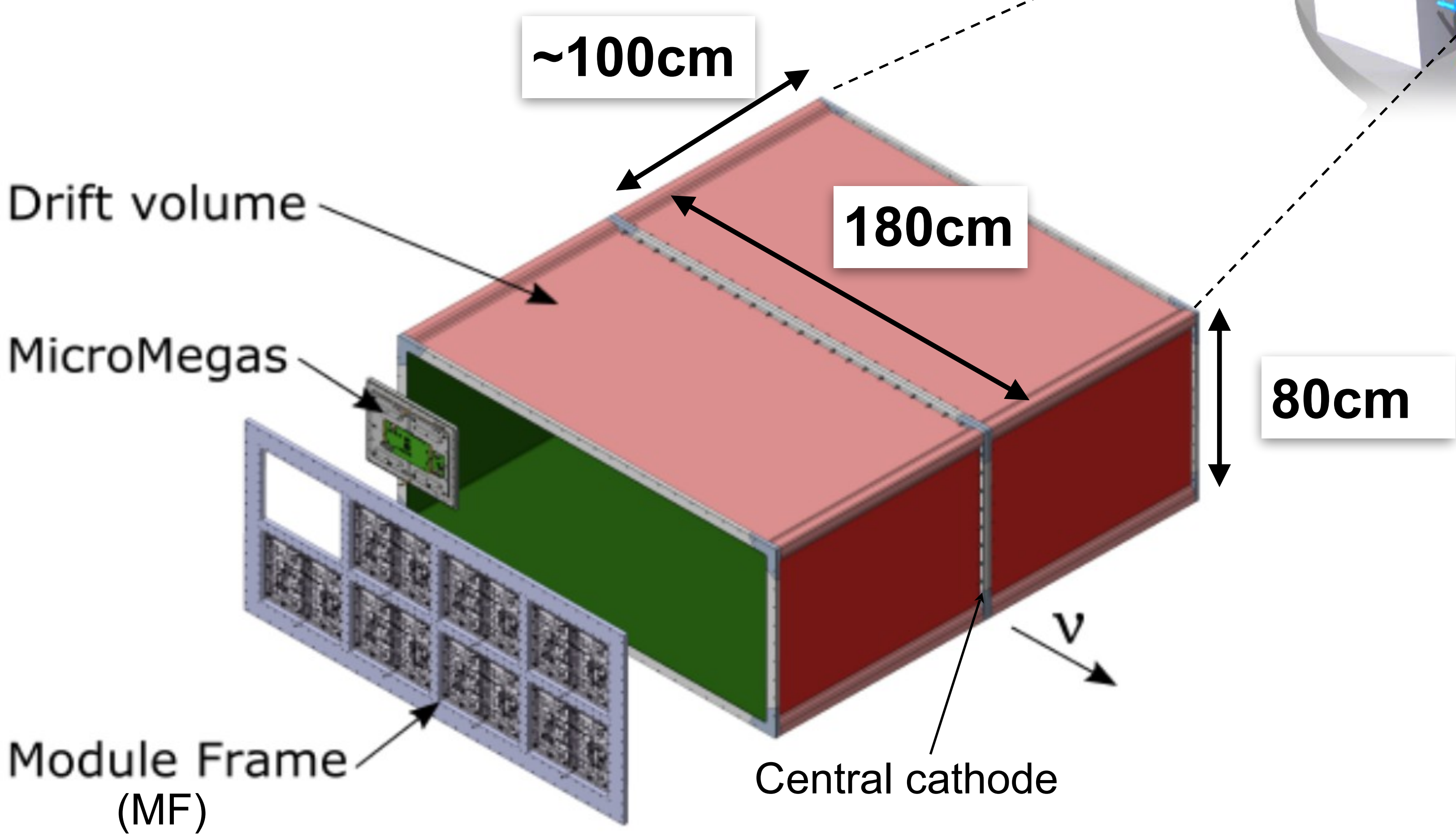



- **T2K-II phase:**
  - Installation begins in 2021
  - Beam power upgrade (~two-fold)
  - Goal: measure $\delta_{CP}$ at $3\sigma$ by decreasing of systematic errors in ND280 from 6% to 4%

# The ND280 upgrade
# The new HA-TPCs overview

- **New HA-TPCs:**
  - New field cage. Thin composite material.
  - New readout system. Based on Resistive MicroMegas

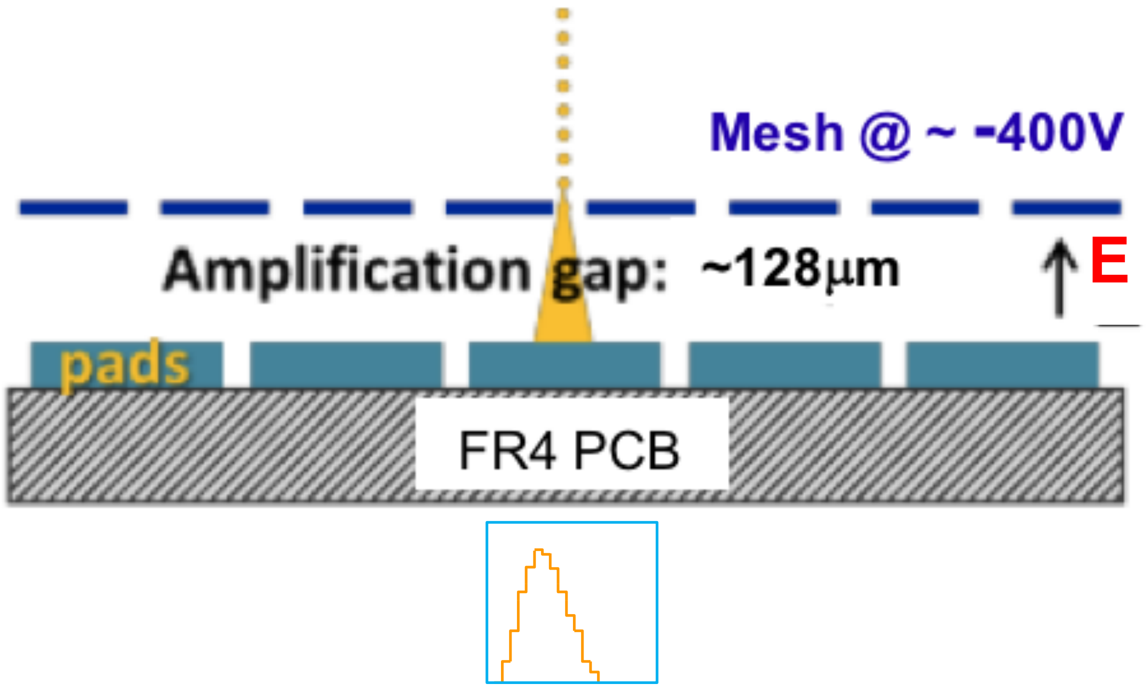





- **Goal of the TPCs:**
  - Particle identification using:
    - ionization (dE/dx)
    - Momentum via curvature (spatial resolution)

# The new HA-TPCs readout
# The resistive MicroMegas concept

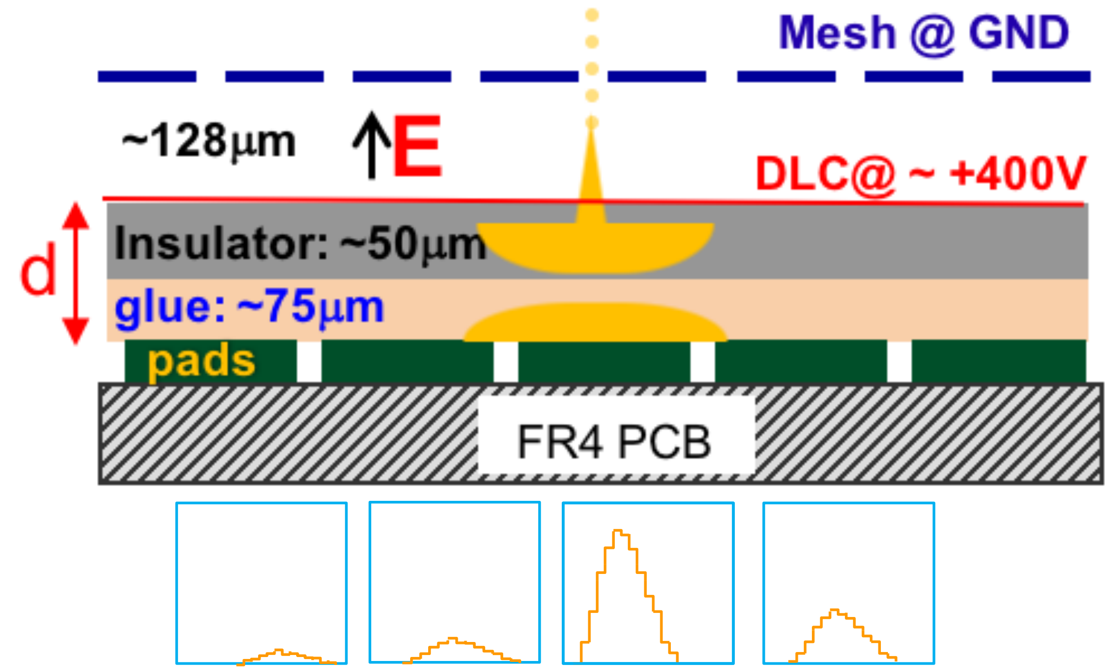
### Standard Bulk-MM




If a single pad is fired, then resolution:

$$\sim pad_{size}\sqrt{(12)}$$

### Resistive Bulk-MM




M. S. Dixit *et al.*, NIMA 518 (2004), p.721

ILC-TPC R&D: P. Colas *et al.*

- Charge dispersion in 2-D RC network
- Gaussian spreading as a function of time

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

R: surface resistivity
C: capacitance/unit area

# Resistive MicroMegas specifications
# For ND280 new HA-TPCs

**Two beam tests used 2 different resistive MM modules.**

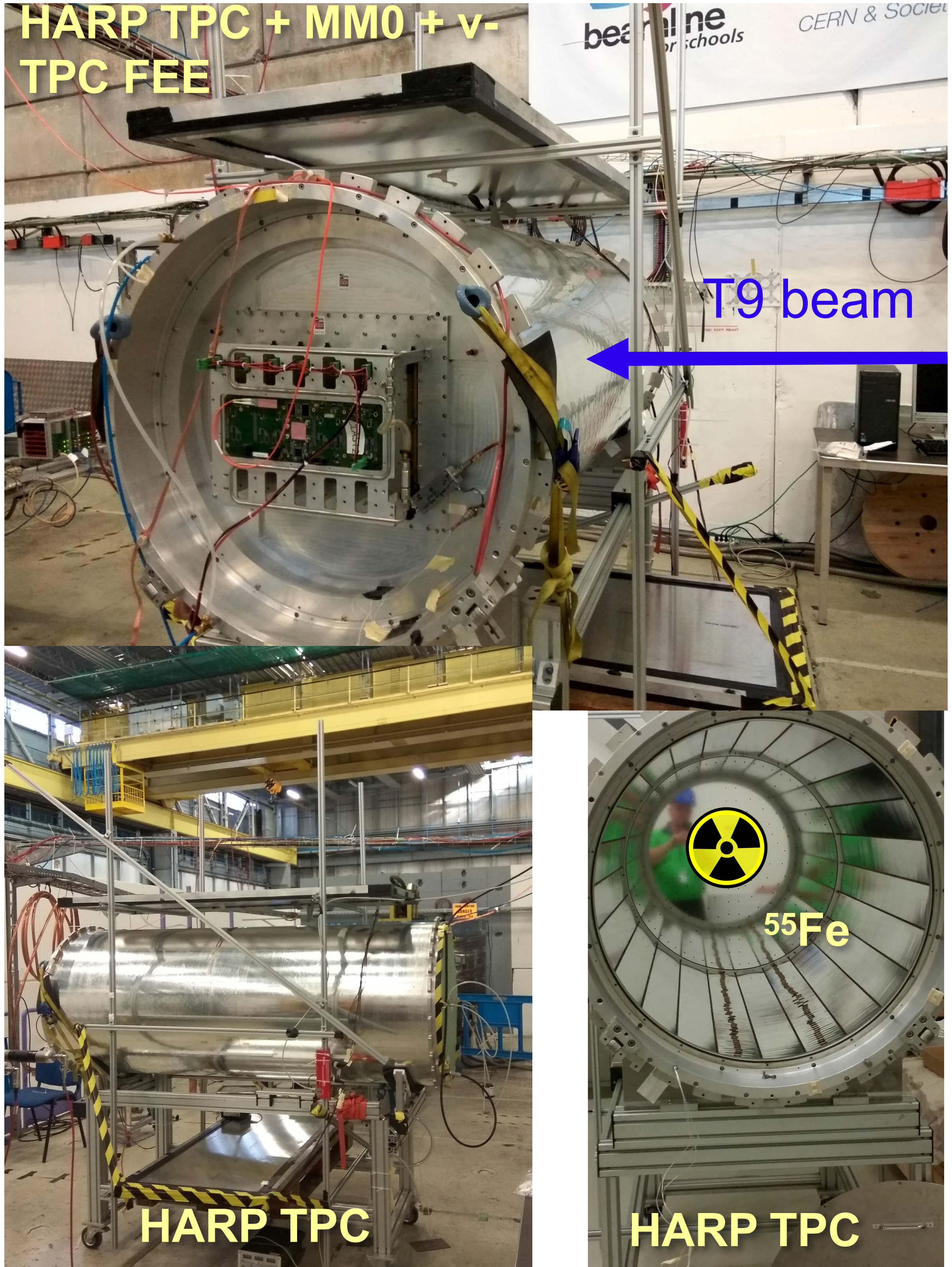
| | CERN TESTS | DESY TESTS |
|---|---|---|
| **Name** | **MM0-DLC#** | **MM1-DLC#** |
| Readout PCB | Original T2K-TPC | HA-TPC |
| Size | 34 × 36 cm² | 34 × 42 cm² |
| Pads | 48 × 36 cm² | 32 × 36 cm² |
| Pad size | 6,85 × 9,65 mm² | 10,09 × 11,18 mm² |
| Pad number | 1728 | 1152 |
| Isolation layers | 75-200 µm glue + 50 µm APICAL | 75 m glue + 50 µm APICAL |

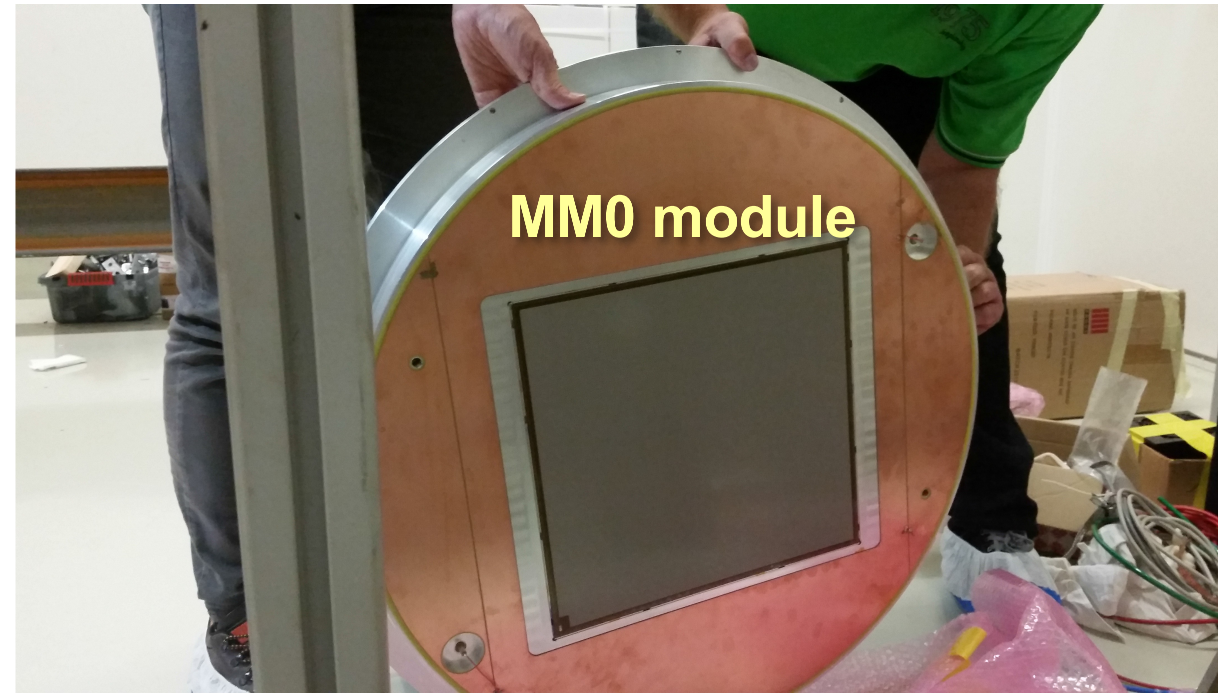
MM0 is same layout as current ND280 v-TPCs MicroMegas but with resistive foil.

MM1 is the layout for the new HA-TPCs.

**In total 33% channels reduction!**

# CERN T9 BEAM TEST
## Overview

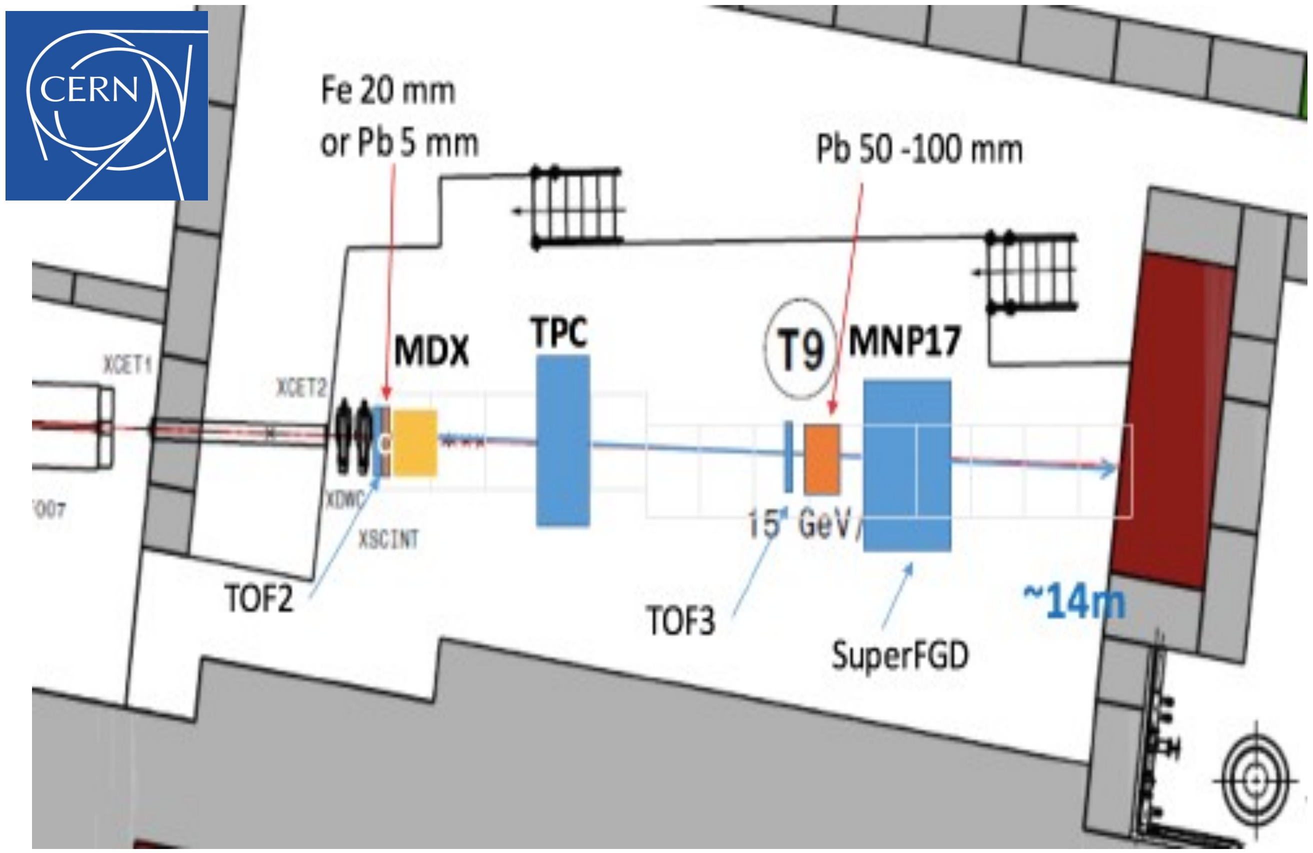


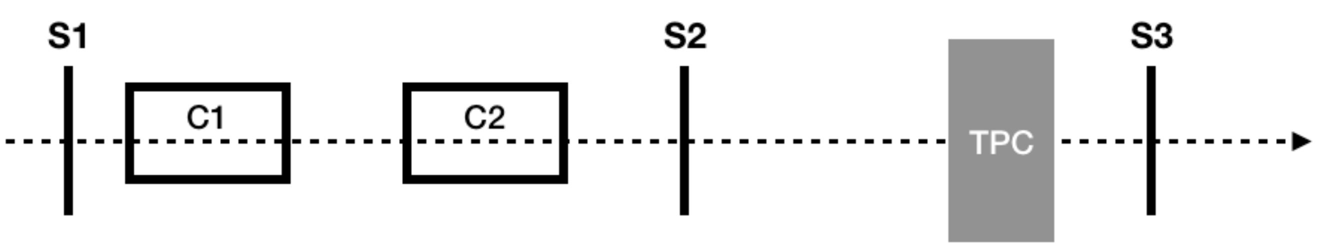




- **Remarks:**
  - Without Magnetic Field
  - Not final Field Cage
  - Looking only to beam straight tracks
- **Beam Test Goal:**
  - Prove of concept

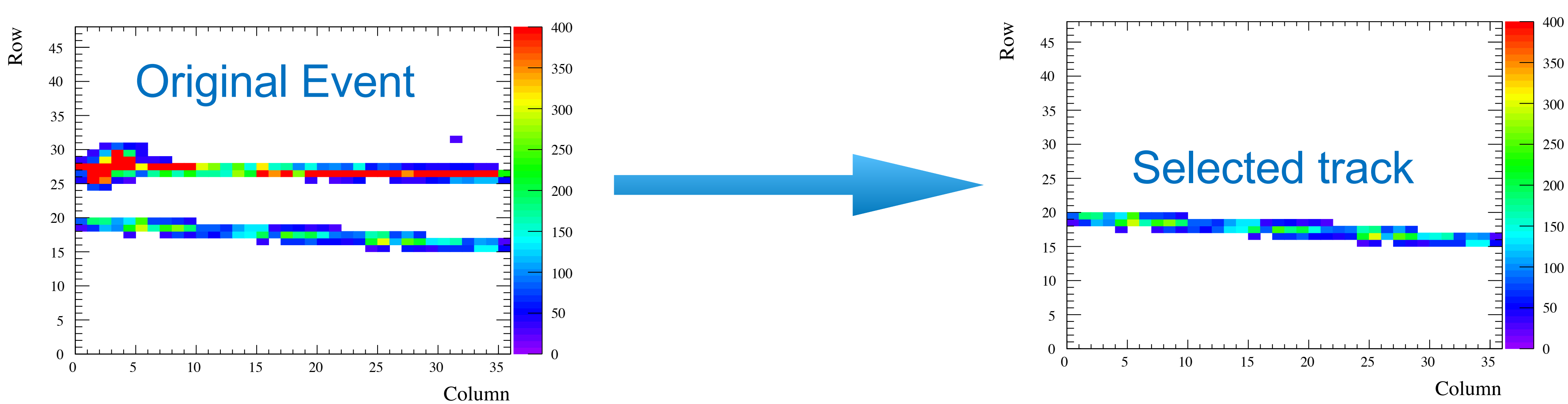
Multi-Particle beam was used

- 0.5-1GeV data
- Gain scan with MM 330-380V
- Different drift distances 10,30,80cm
- Cosmic data for gas monitoring
- $^{55}Fe$ source placed at the cathode.



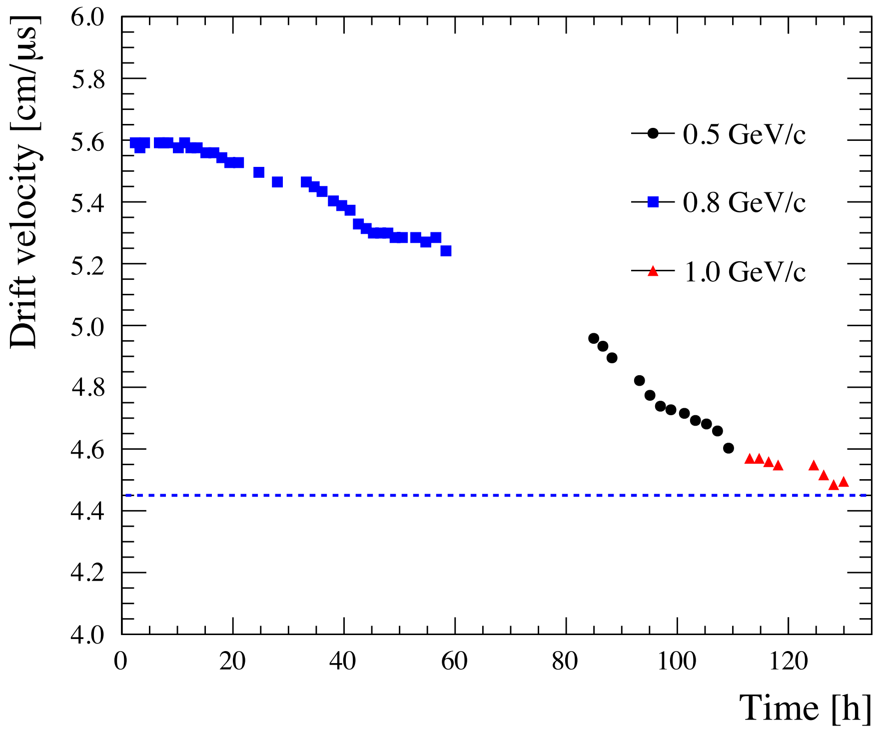




$\pi, e, p$ trigger



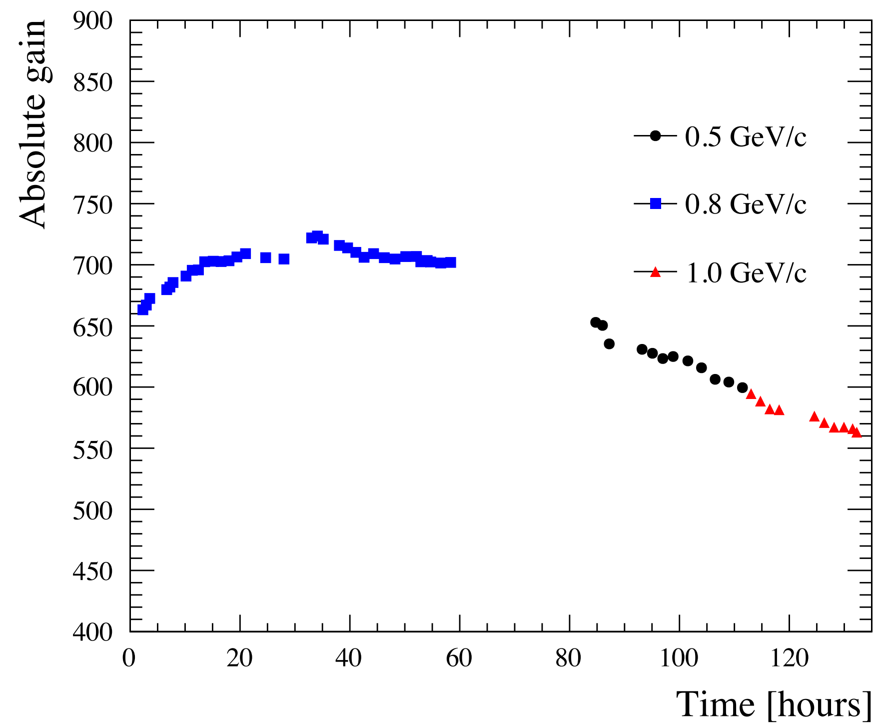
# CERN T9 BEAM TEST
## Gas quality

### Drift velocity time evolution



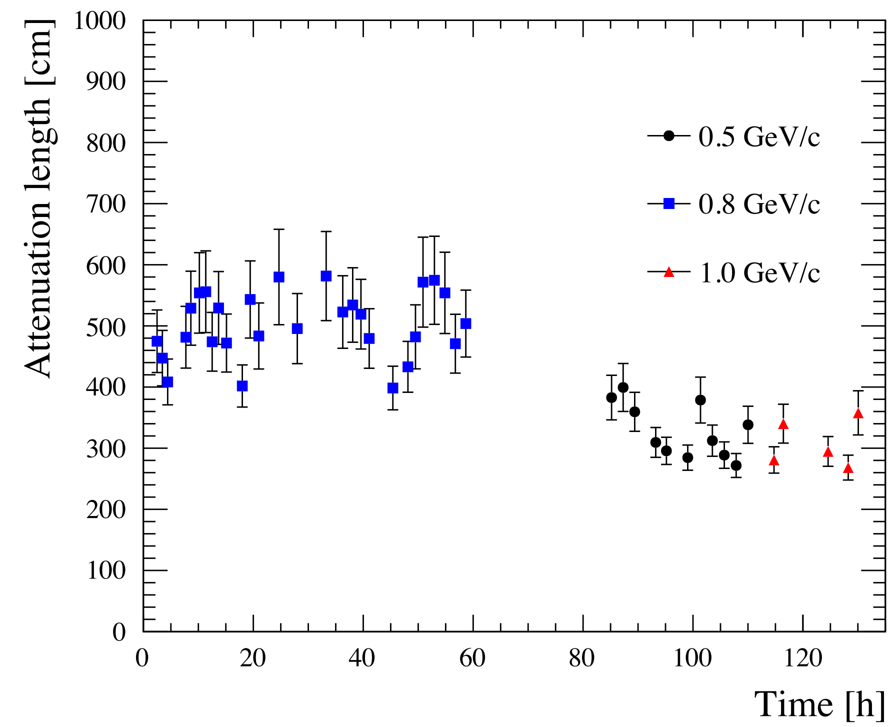

**Computed using cosmics crossing anode & cathode**

### Gain time evolution




**Computed using the $^{55}$Fe source in the cathode**

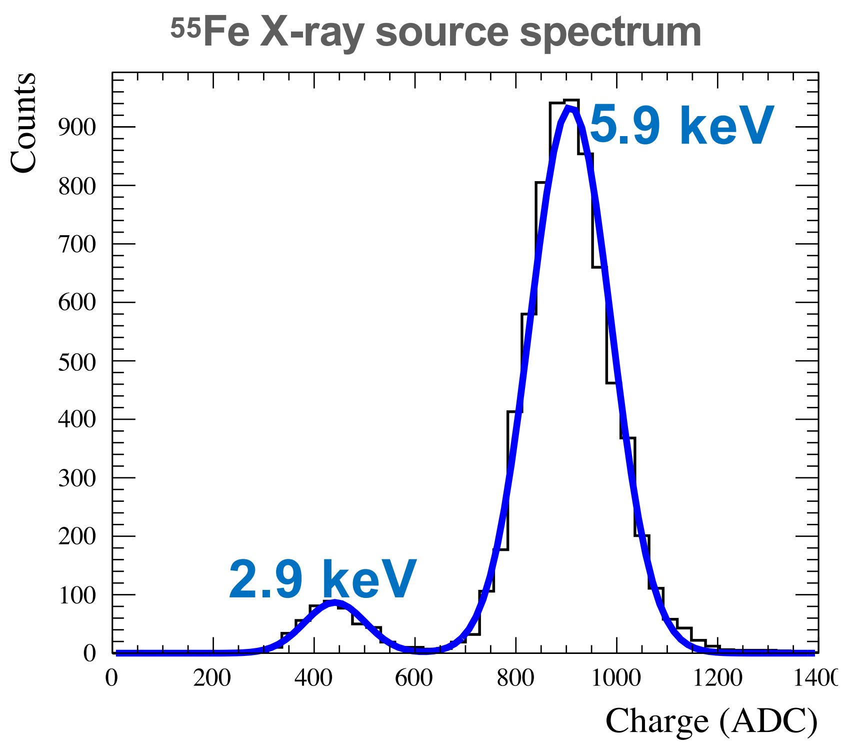
### Attenuation length time evolution

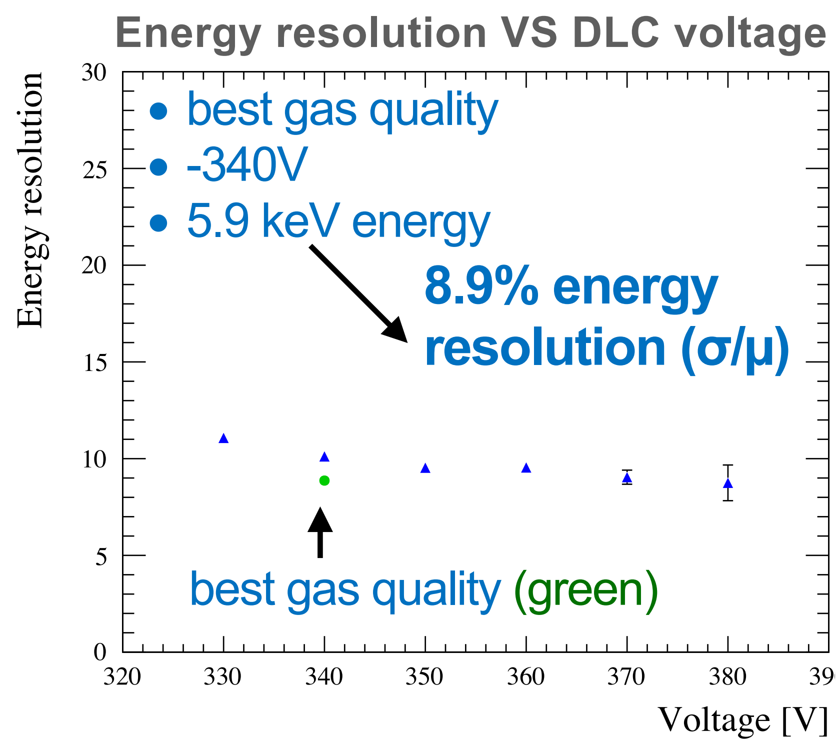


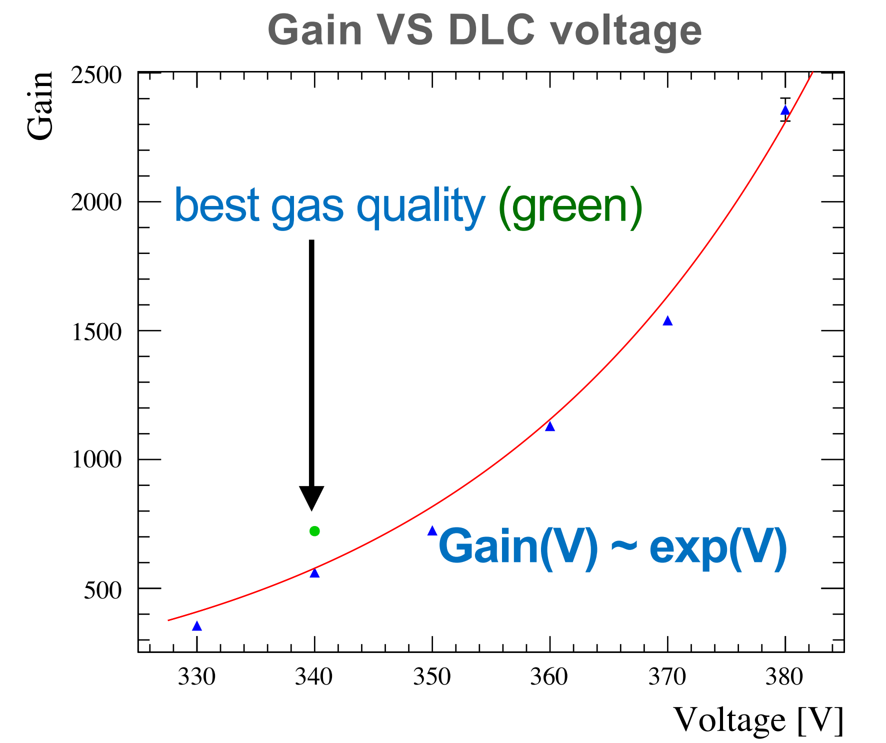

**Computed using cosmic charge collected vs distance**

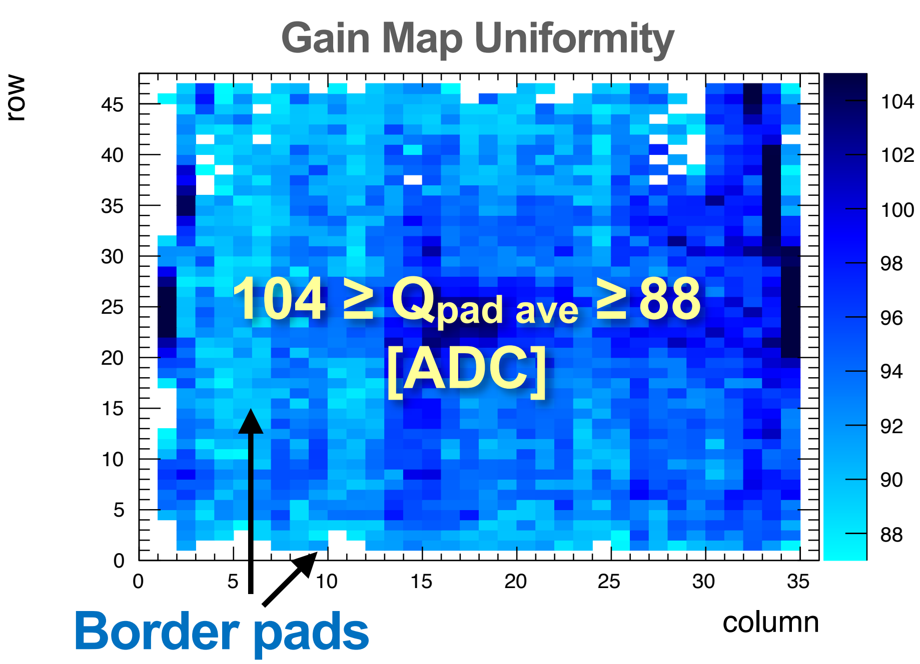
- No monitoring chambers
- Reduction on gas flow + humidity in HARP TPC decreased gas quality over time.
- Correction factors were  computed

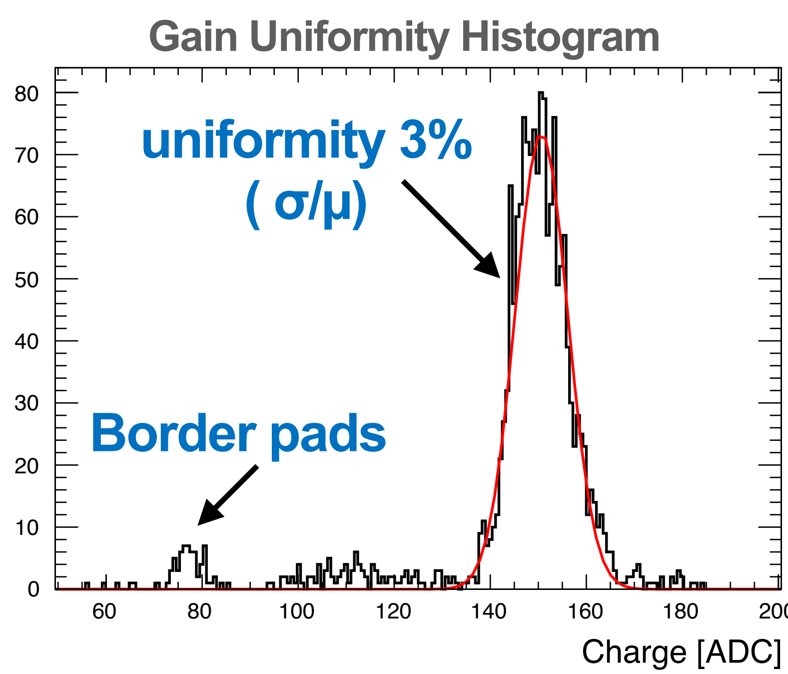
# CERN T9 BEAM TEST
## Gain studies



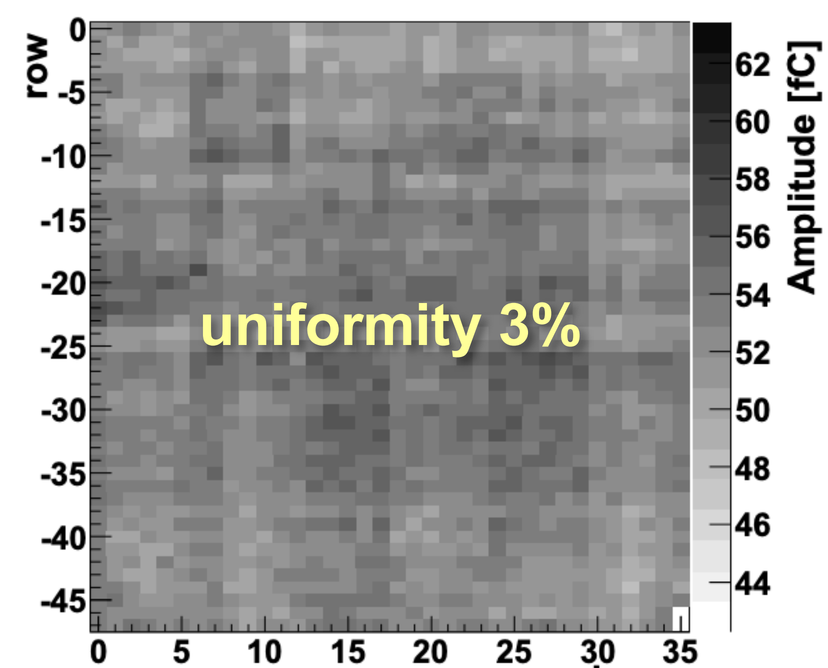



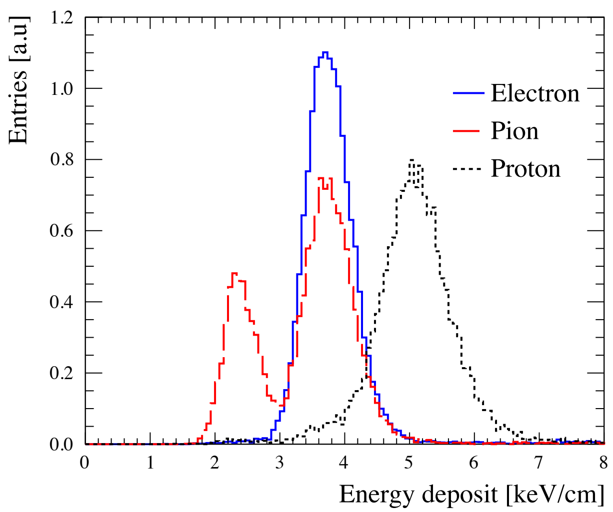

**PLOT For current v-TPCs**



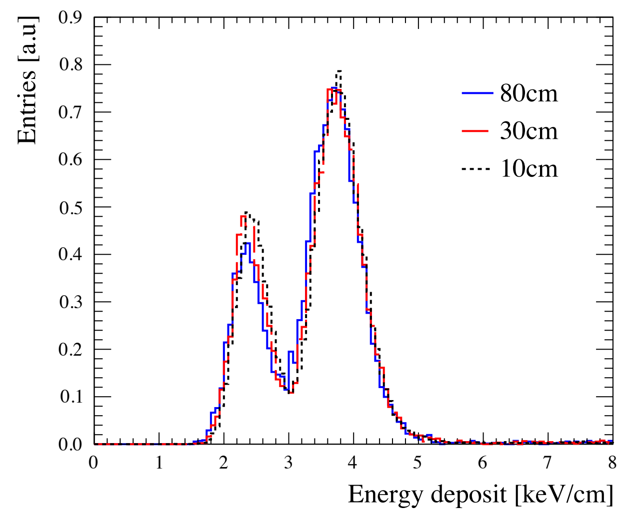

Abgrall *et.al*, NIMA 674 (2011) p.25-46

# CERN T9 BEAM TEST
# dE/dx measurements

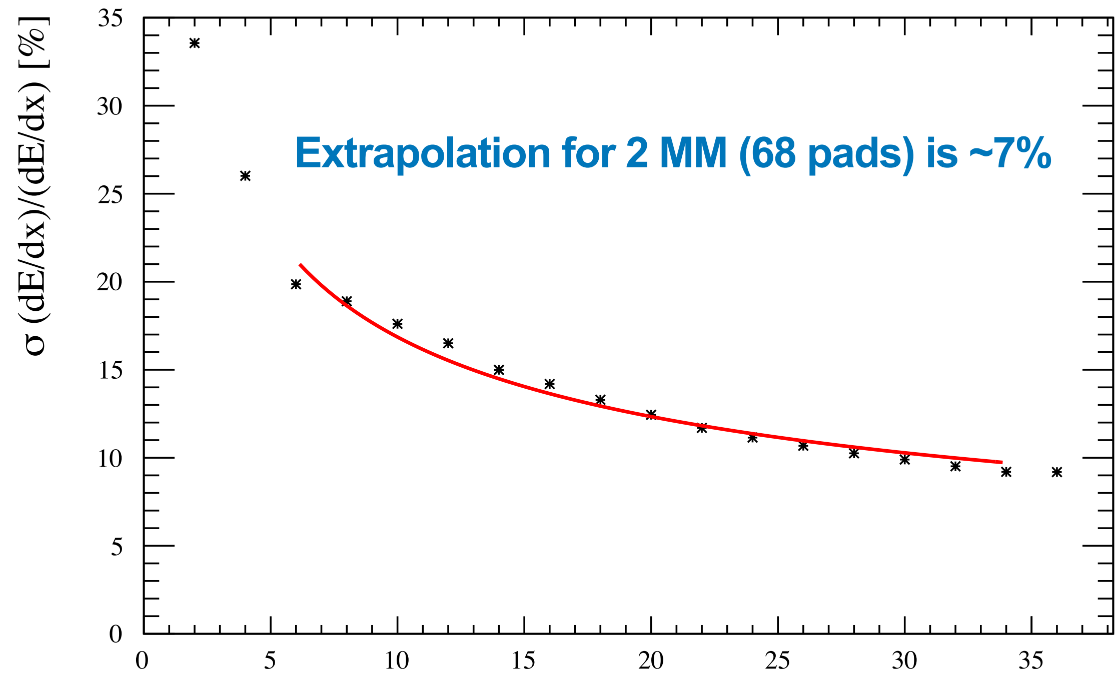
dE/dx for different triggers at 0.8GeV/c



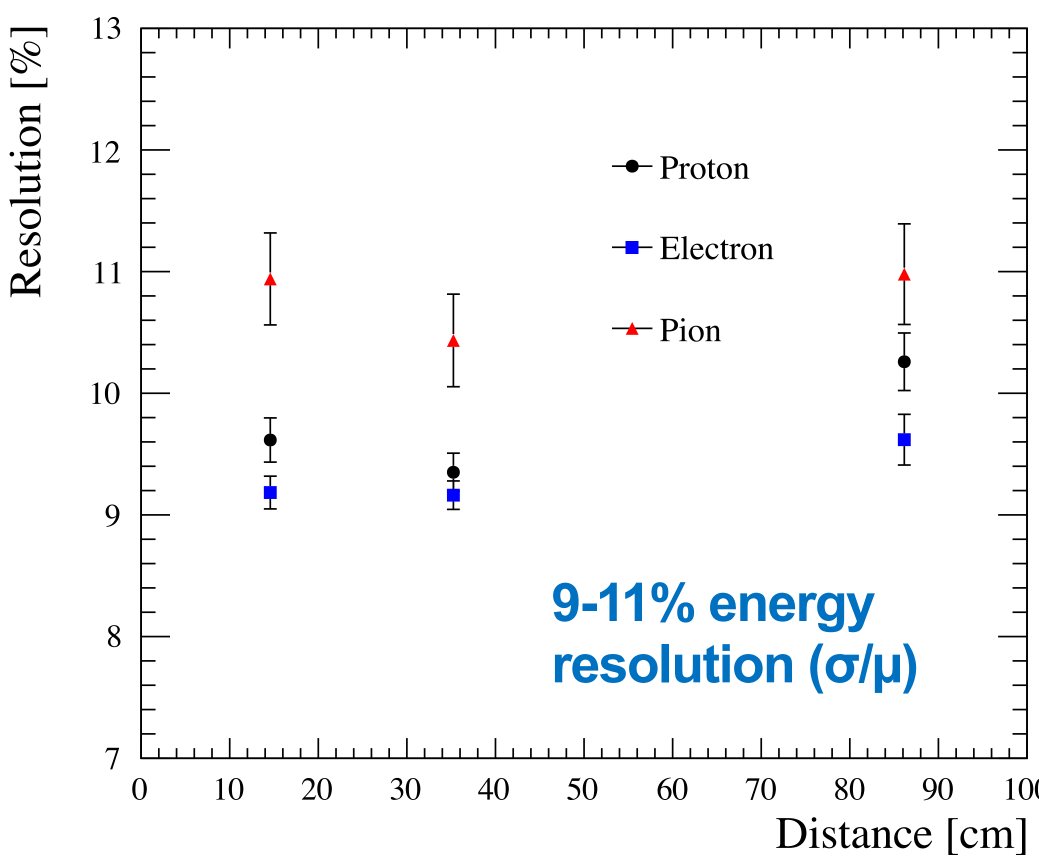

dE/dx for pion trigger vs distance after attenuation corrections

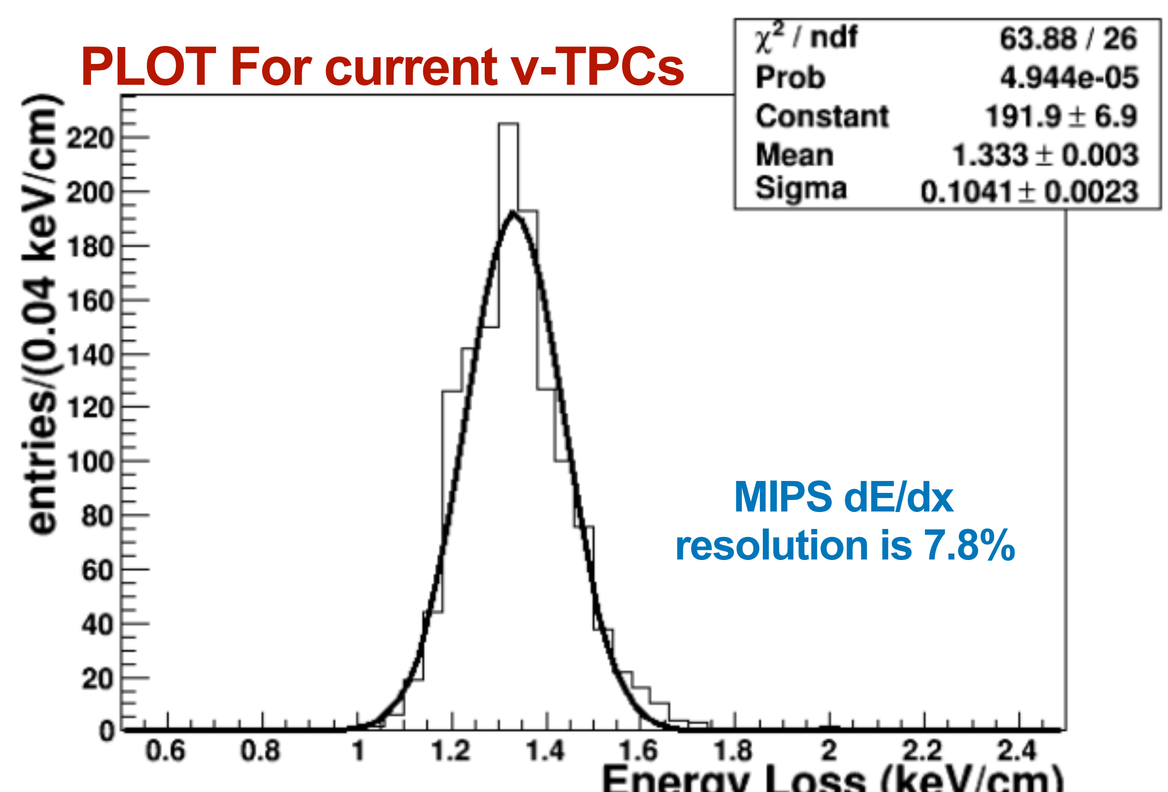



dE/dx resolution vs number of clusters




dE/dx vs Distance

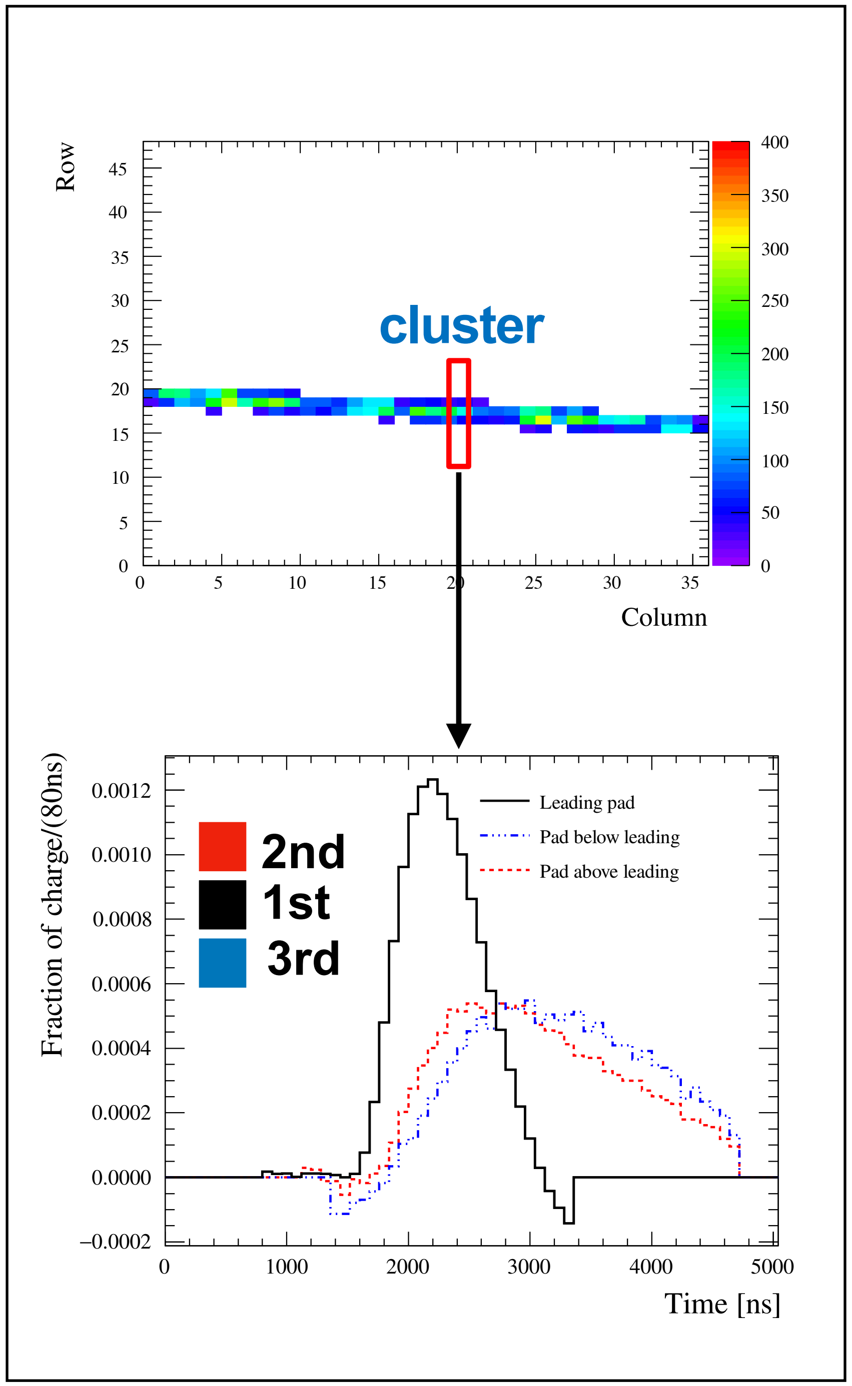


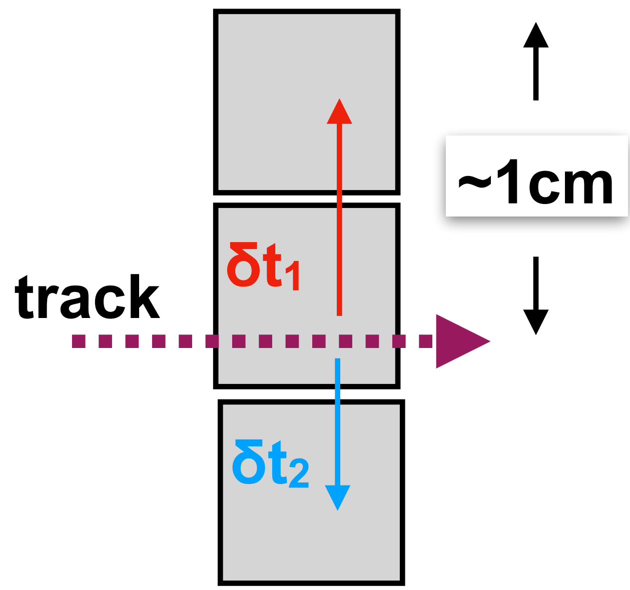



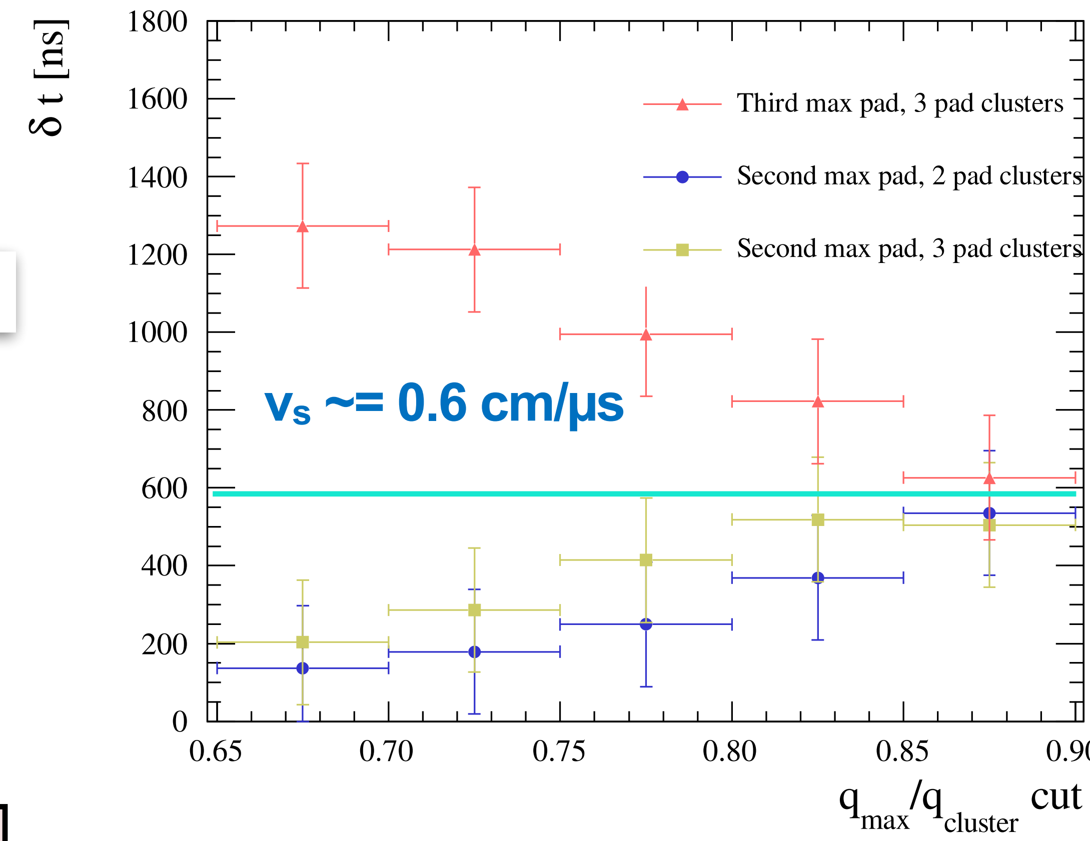

Abgrall *et.al*, NIMA 674 (2011) p.25-46

# CERN T9 BEAM TEST
# Charge spreading analysis

## Charge spread example




When the track crosses main pad center:

- $q_{max}/q_{cluster} \rightarrow 1$
- δt: $\delta t_1 \sim= \delta t_2$
- $v_s \sim= pad_{size}/\delta t$

**Clusters**

- Beam: All pads with same column.
- Cosmic: All pads with same row.

**Definitions**

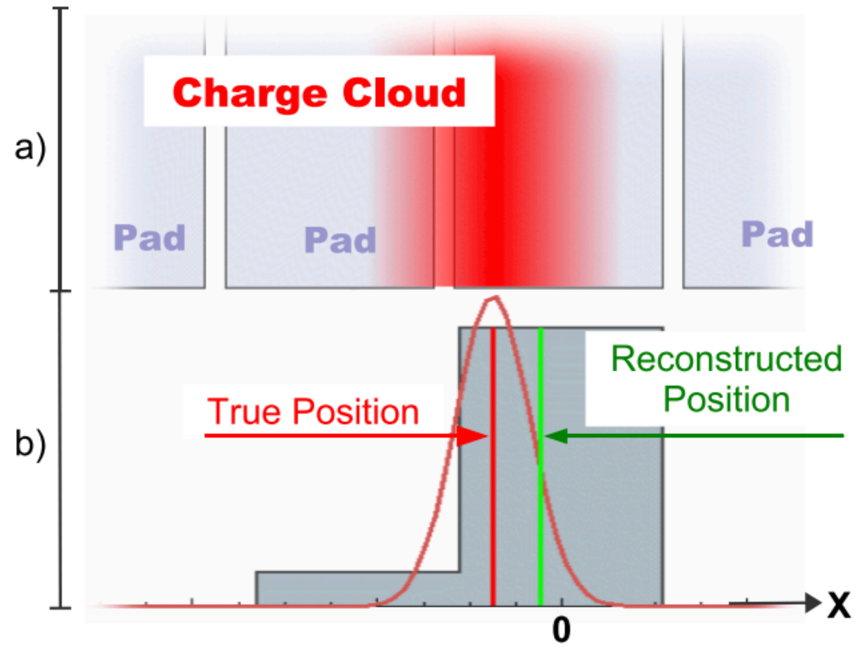
- **$q_{pad}$**: pad waveform's maximum.
- **$t_{max}$**: time for $q_{max}$
- **$q_{max}$**: max $q_{pad}$ in the cluster
- **$q_{cluster}$**: $\sum q_{pad}$ for all pads in cluster.
- **multiplicity**: number of $q_{pad} > 0$ in the cluster

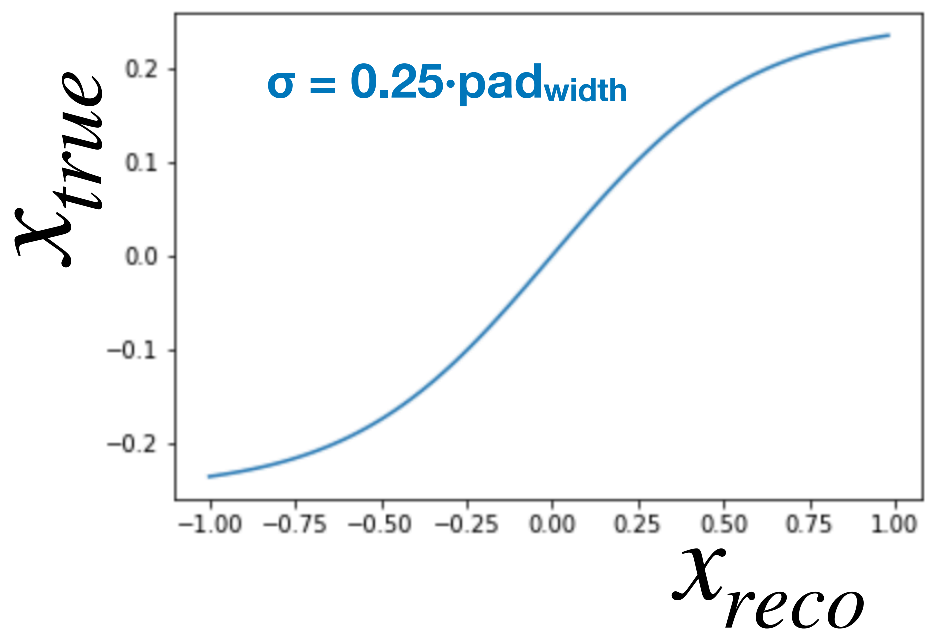
# CERN T9 BEAM TEST
# The Pad Response Function (PRF)

**Simplest way to estimate the track position in the cluster ($x_{reco}$):**

$x_{reco}$ = Center of Charge (**CoC**), i.e weighted mean of the position of the fired pads center.

**However**, there is a systematic bias in the true track position over the pad given that the pad size is finite.




- If we study this effect by quantifying $x_{true} - x_{reco}$ we can build a pad response function, such that we can correct it.
- In previous slide we have seen $q_{pad}/q_{cluster}$ is an estimator of the distance to true track position. Therefore, we can build a PRF such as:

$$PRF(x_{track} - x_{pad}) = q_{pad}/q_{cluster}$$

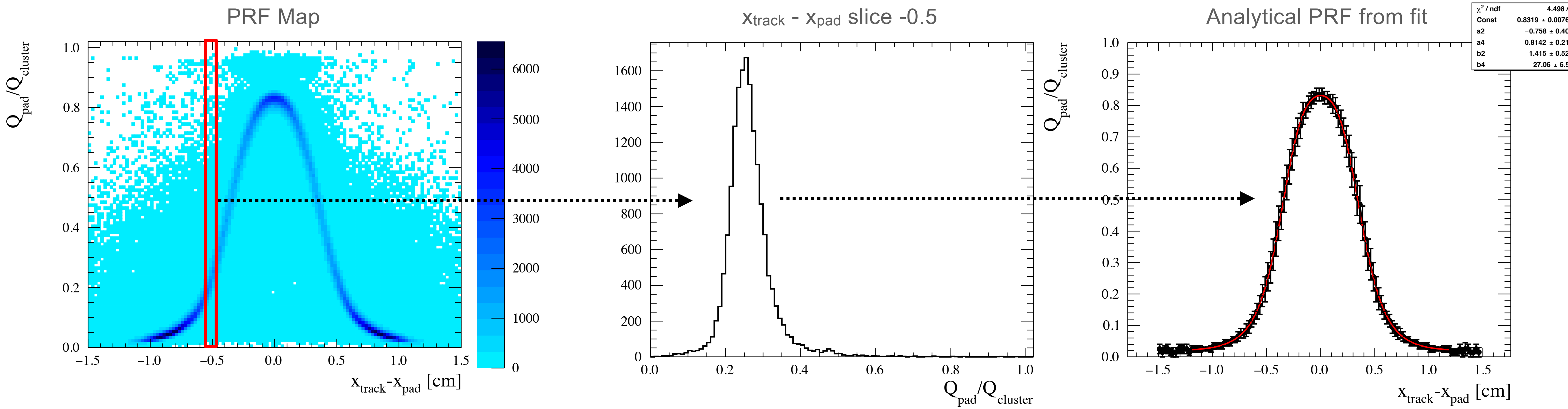
To build the PRF — Track fit → $x_{track}$

To use the PRF — Track fit ← $x_{track}$

$x_{pad}$ ← CoC

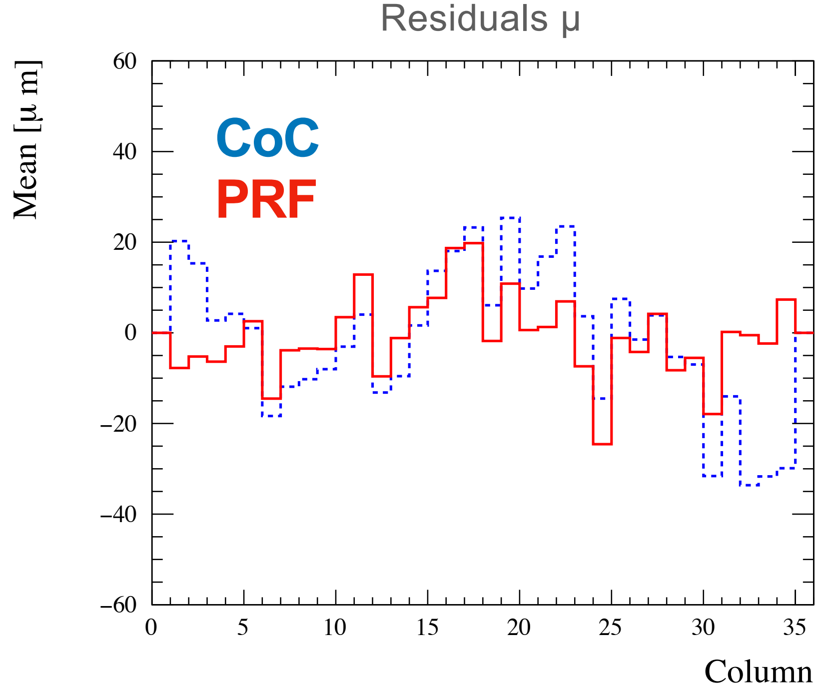
$q_{pad}/q_{cluster}$ ← Measurement

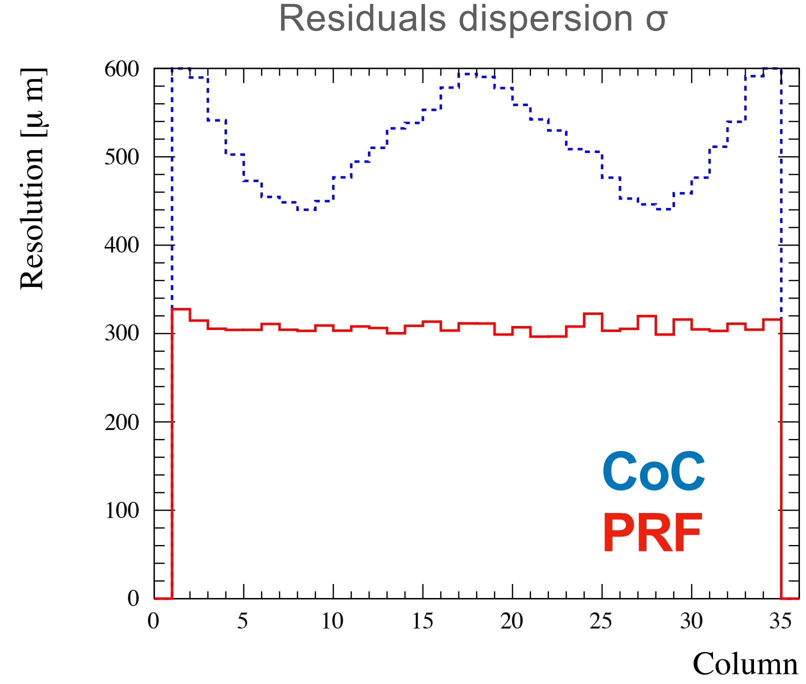
# CERN T9 BEAM TEST
# Spatial resolution and PRF




$$PRF(x,\Gamma,\Delta,a,b) = \frac{1 + a_2x^2 + a_4x^4}{1 + b_2x^2 + b_4x^4}$$

$$\chi^2 = \sum_{pads} \frac{Q_{pad}/Q_{cluster} - PRF\left(x_{track} - x_{pad}\right)}{\sqrt{Q_{pad}/Q_{cluster}}}$$



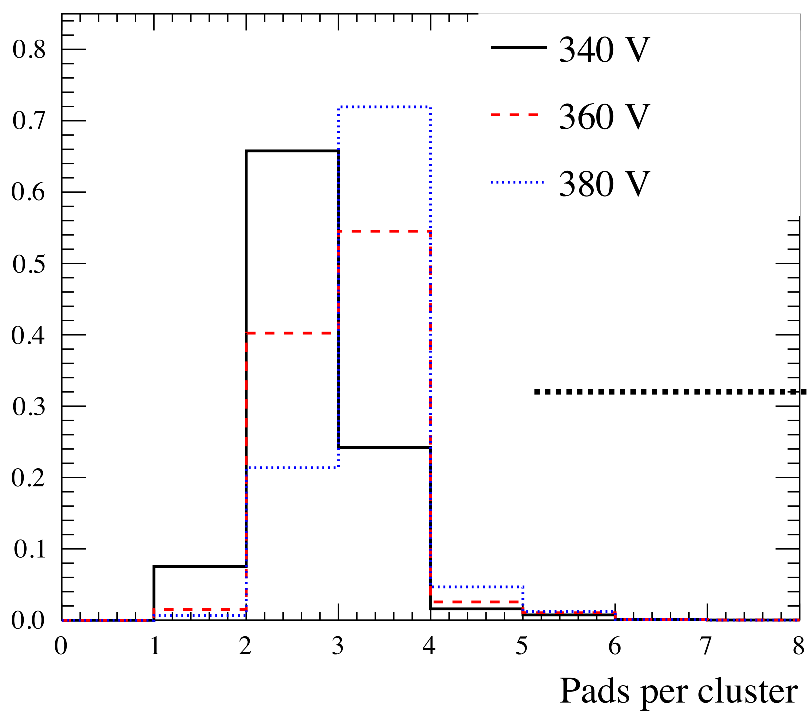

- $x_{track}$ computed from fit to track in 2D plane
- we estimate $x_{pad}$ using $Q_{pad}/Q_{cluster}$

For each column we can compute:

- $\mu = x_{track} - x_{pad}$ mean
- $\sigma = x_{track} - x_{pad}$ dispersion

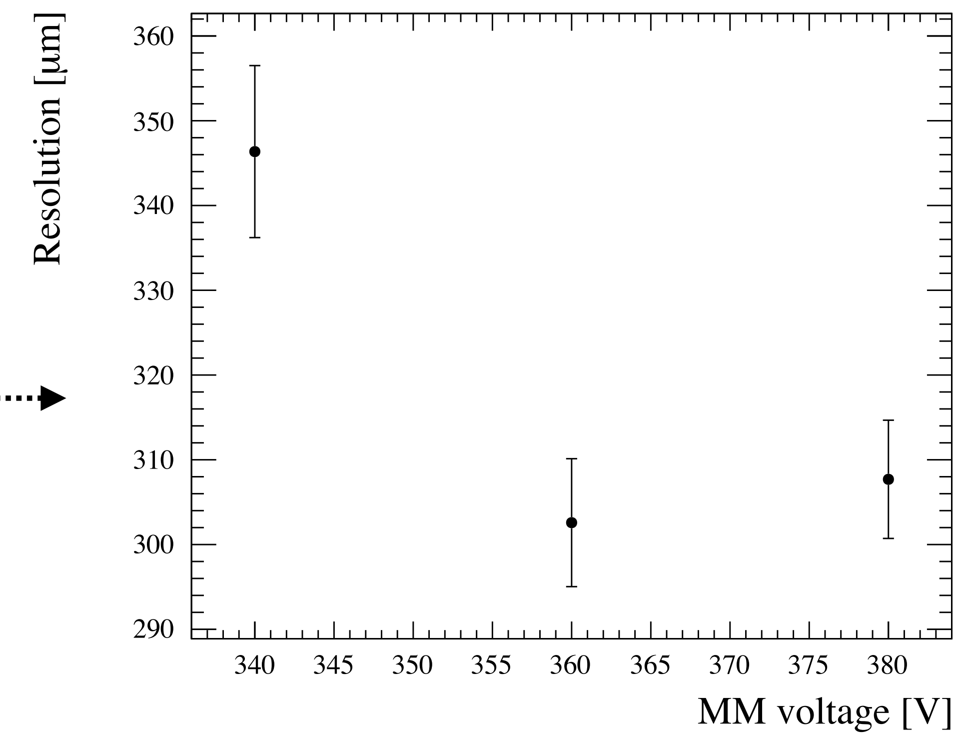
# CERN T9 BEAM TEST
# Spatial resolution analysis

### Cluster multiplicity vs Voltage



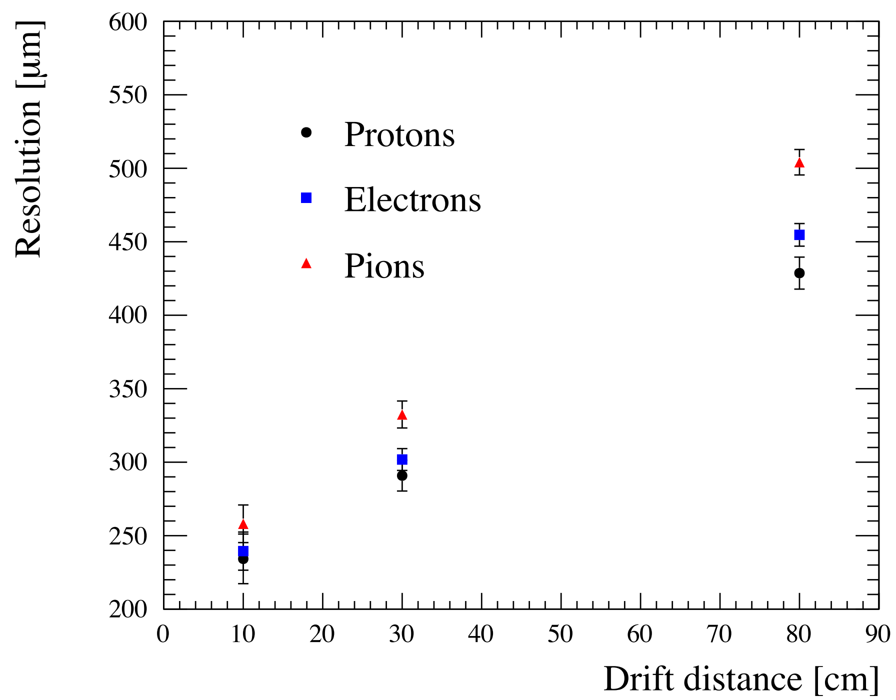

Improvement due to reduction of 1 pad clusters population

### Resolution vs Voltage



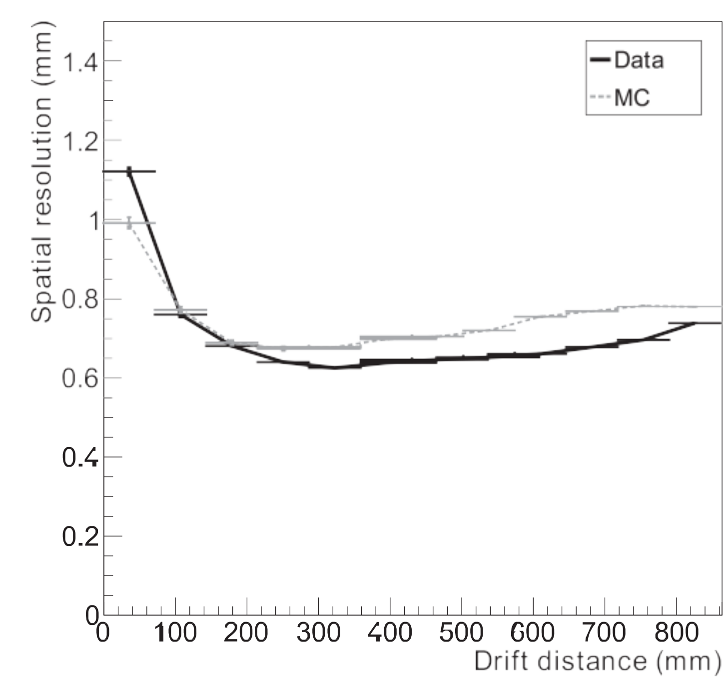

- The larger the voltage difference, the largest the multiplicity and therefore better the spatial resolution.

### Resolution vs distance



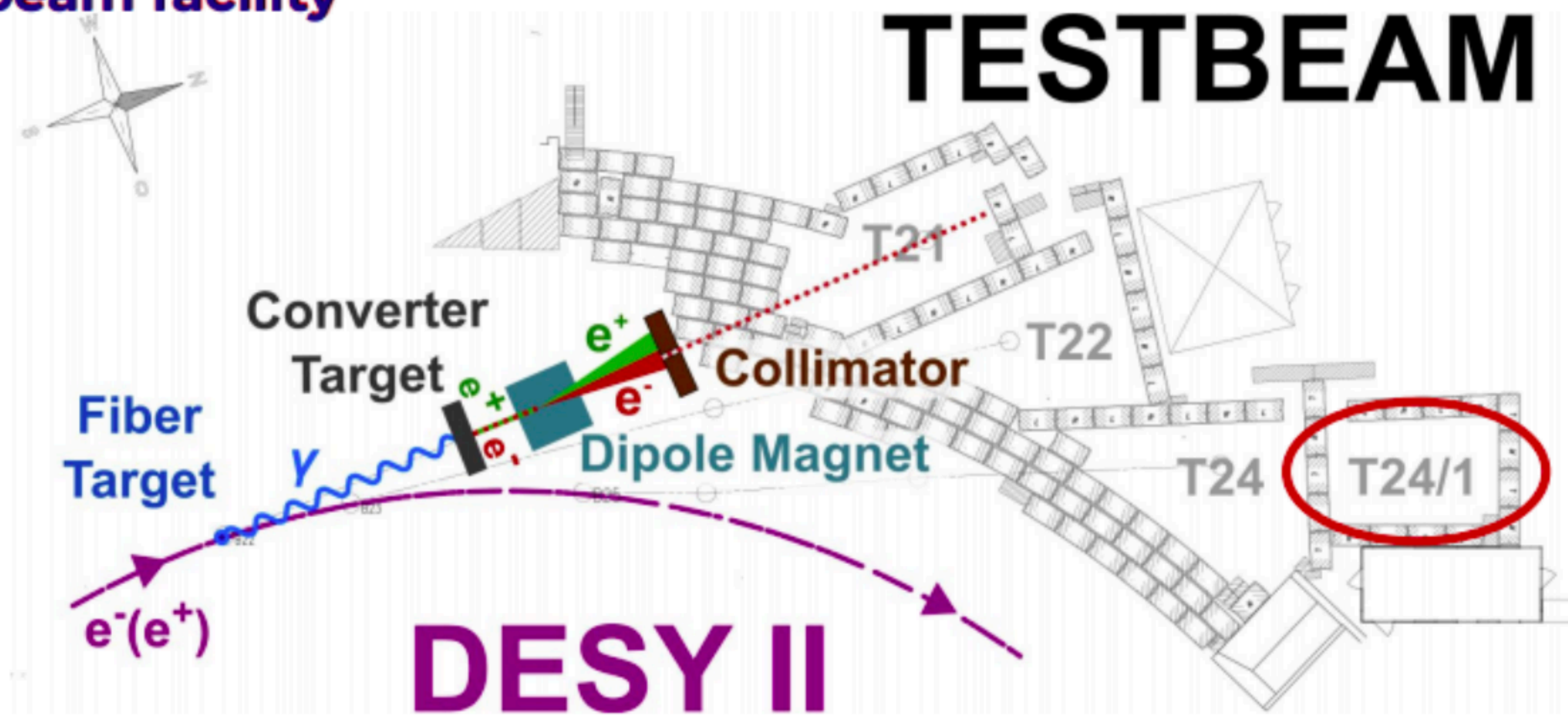

- Much better resolution thanks to charge spreading.
- Specially better for tracks close to the anode.

### PLOT For current v-TPCs



# DESY BEAM TEST
## Overview

DESY test beam facility




❑ From Monday 10/06/2019 to 22/06/2019

High energy electron beam was used

- 1-5 GeV, most of the data with 4 GeV
- Gain scan with MM voltages 330 - 400 V
- Y and Z position scan (in the detector plane and along drift distance)
- 0, 20, 30, 45, 60, 80 degree MM rotation

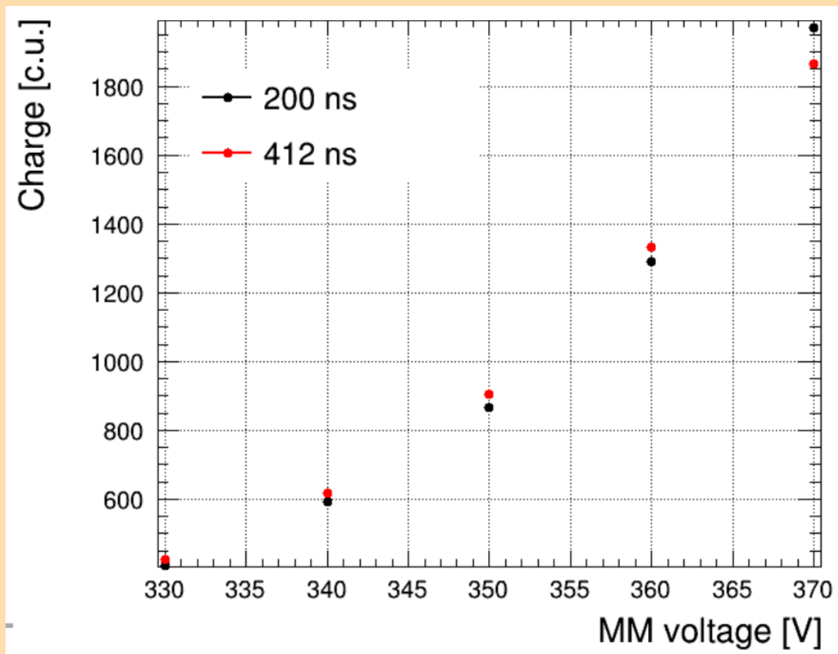
- **Remarks:**
  - Magnetic Field
  - Not final Field Cage
  - Final MicroMegas layout (Resistivity could change).
- **Beam Test Goals:**
  - Check performance in larger pads.
  - Scan over parameters.
  - Characterize the charge spreading.

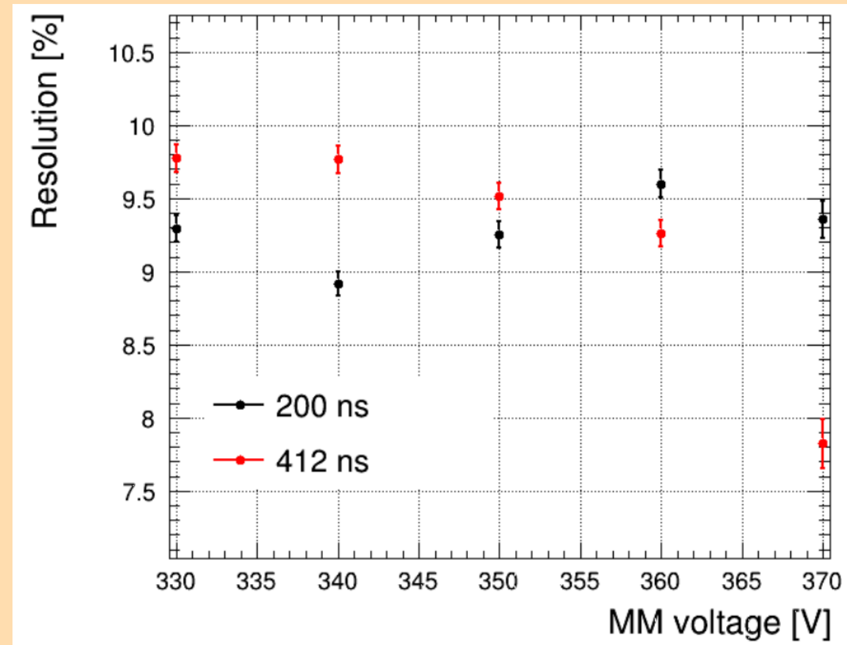
# DESY BEAM TEST
# Parameters scan

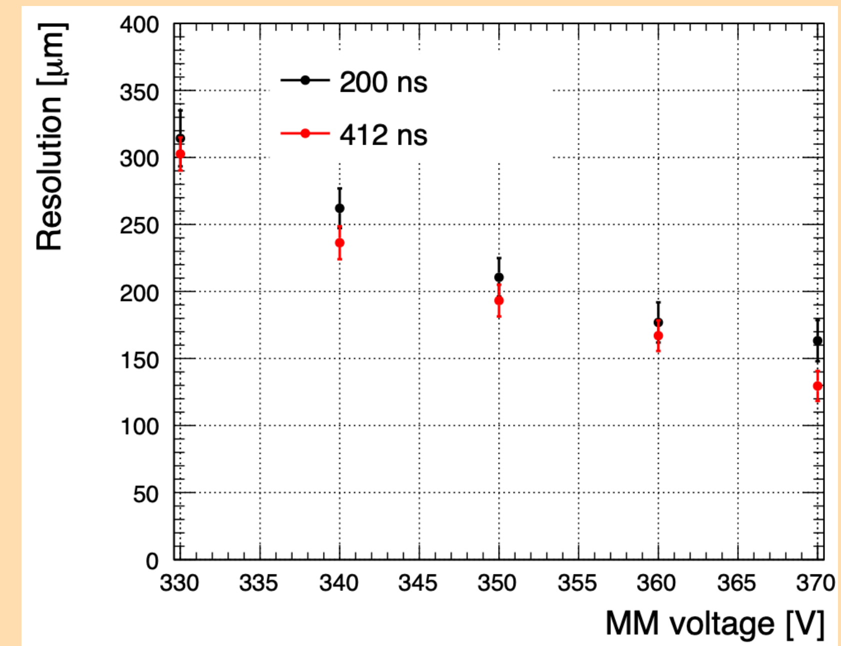
**PRELIMINARY RESULTS**

| Collected Charge | dEdx resolution | Spatial resolution |
|---|---|---|

**x axis: MM voltage**

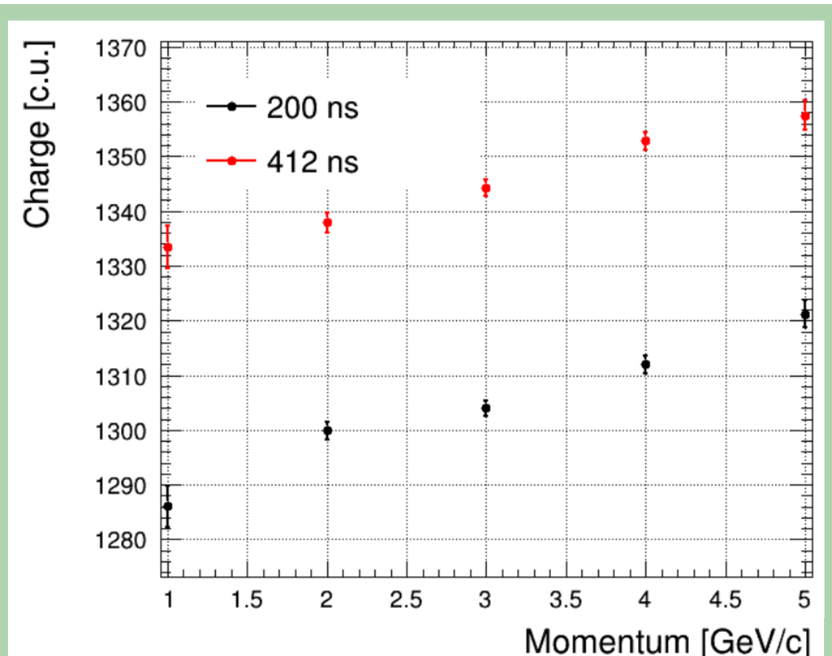


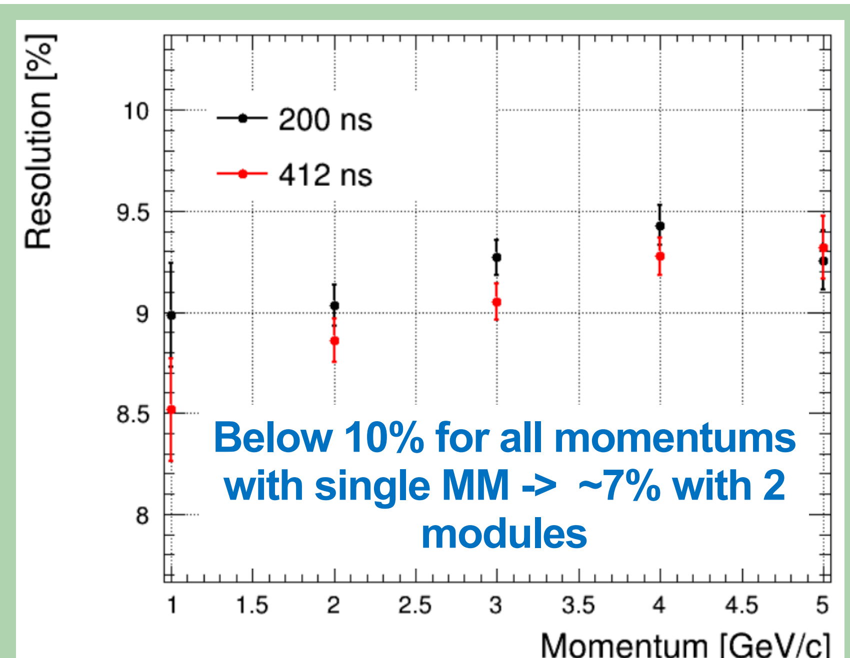



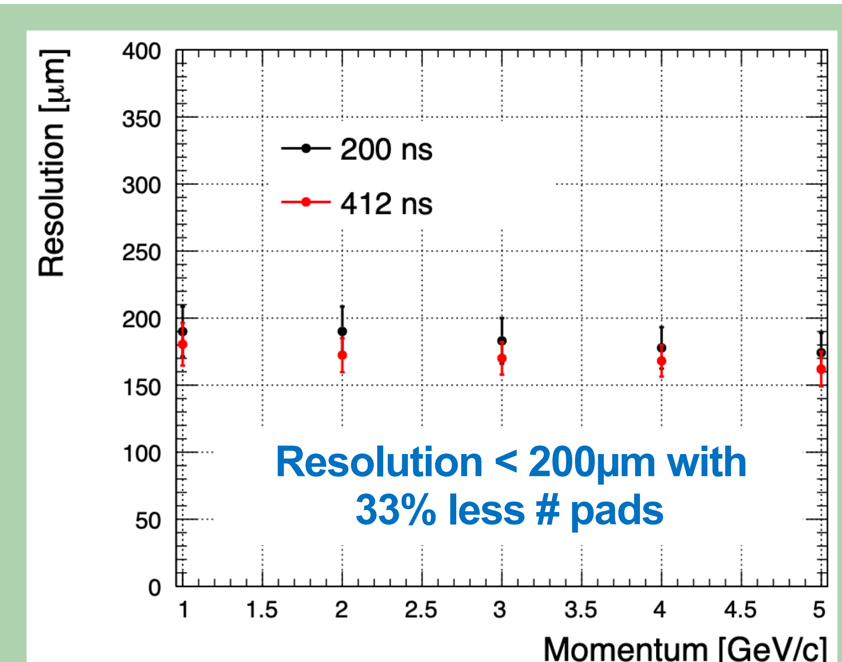




**Increasing MM voltage also increases # of saturated pads. Best compromise could be around 360V.**

**x axis: Beam Momentum**



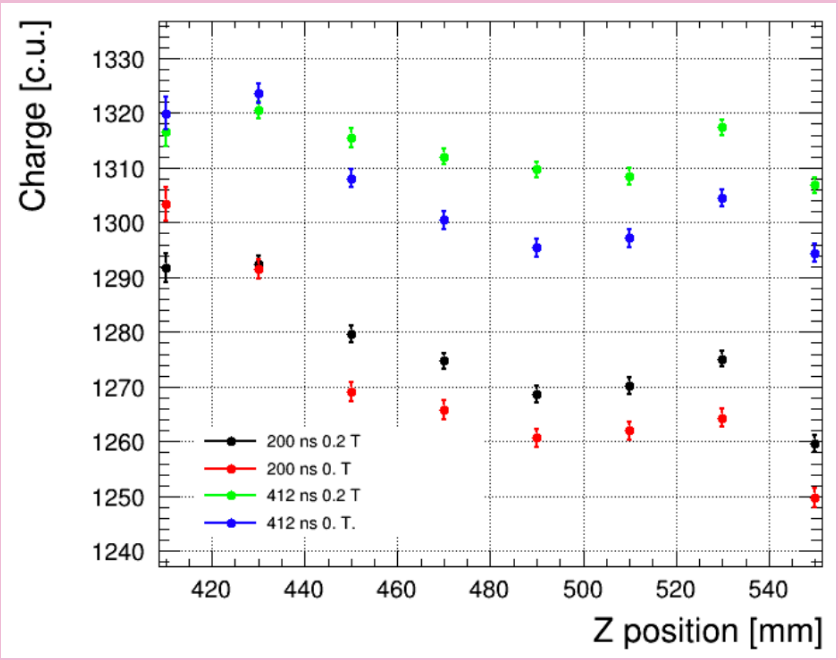



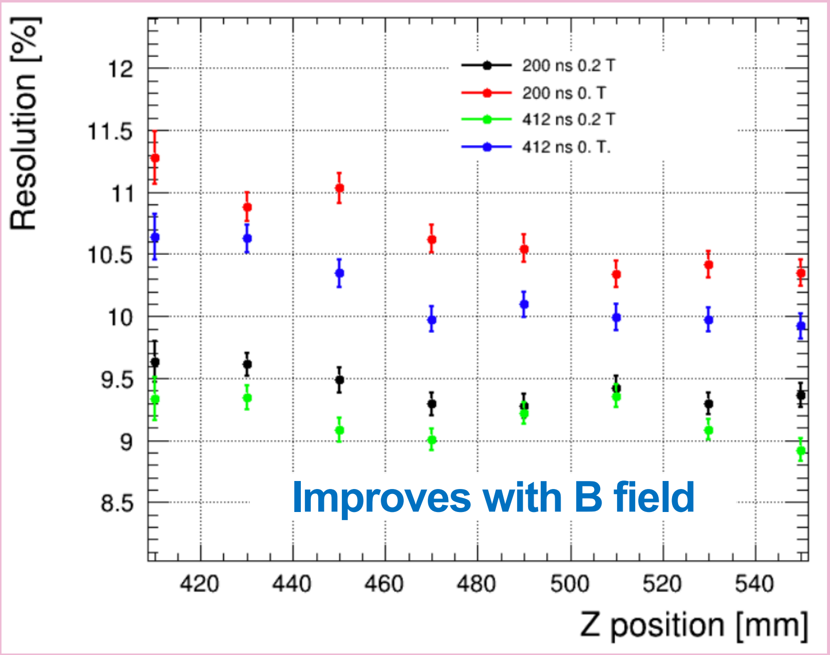
# DESY BEAM TEST
# Parameters scan

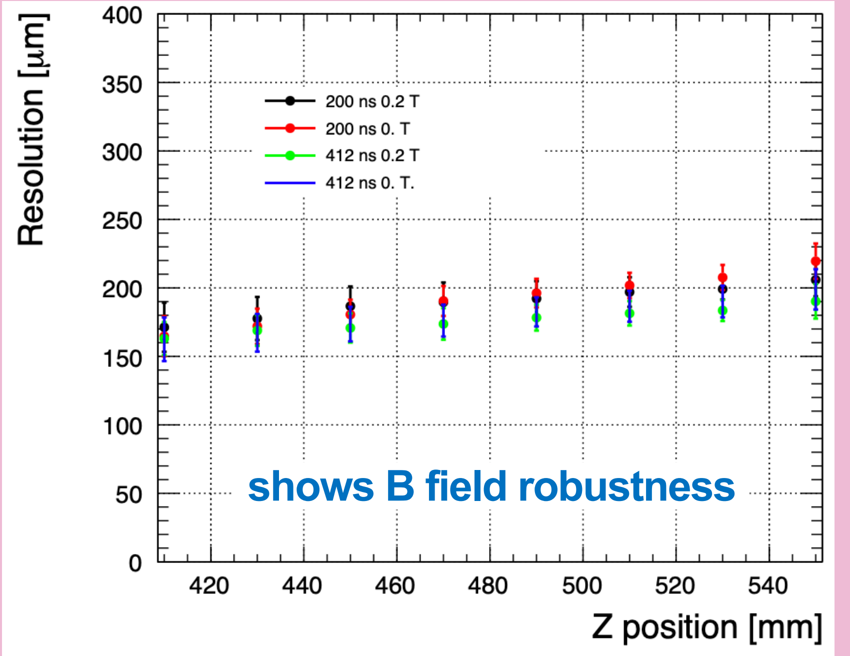
**PRELIMINARY RESULTS**

| Collected Charge | dEdx resolution | Spatial resolution |
|---|---|---|

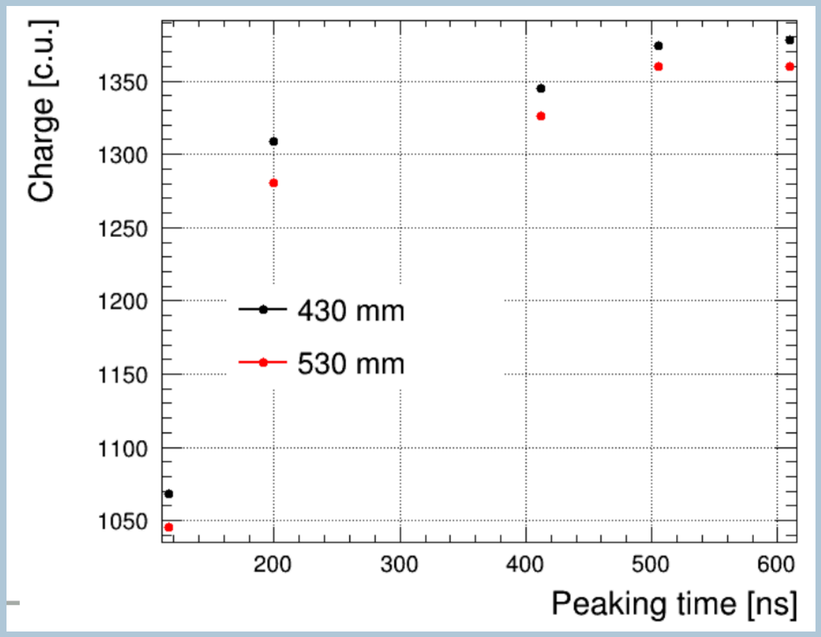
**x axis: Drift distance**

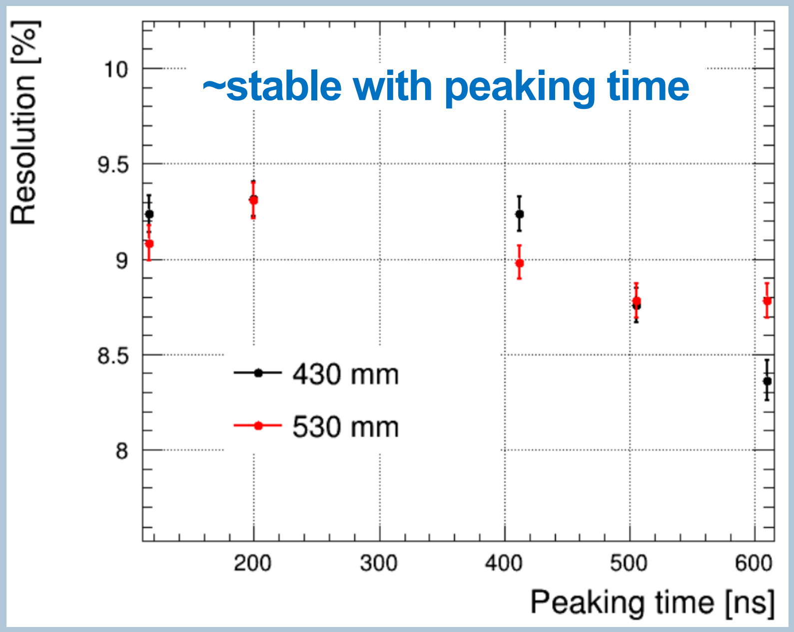


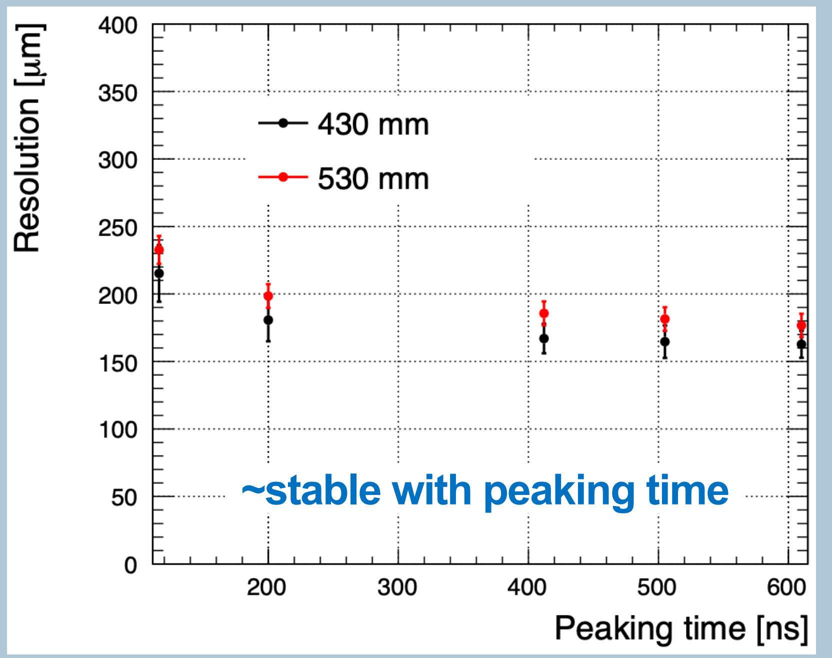




**x axis: Peaking Time**

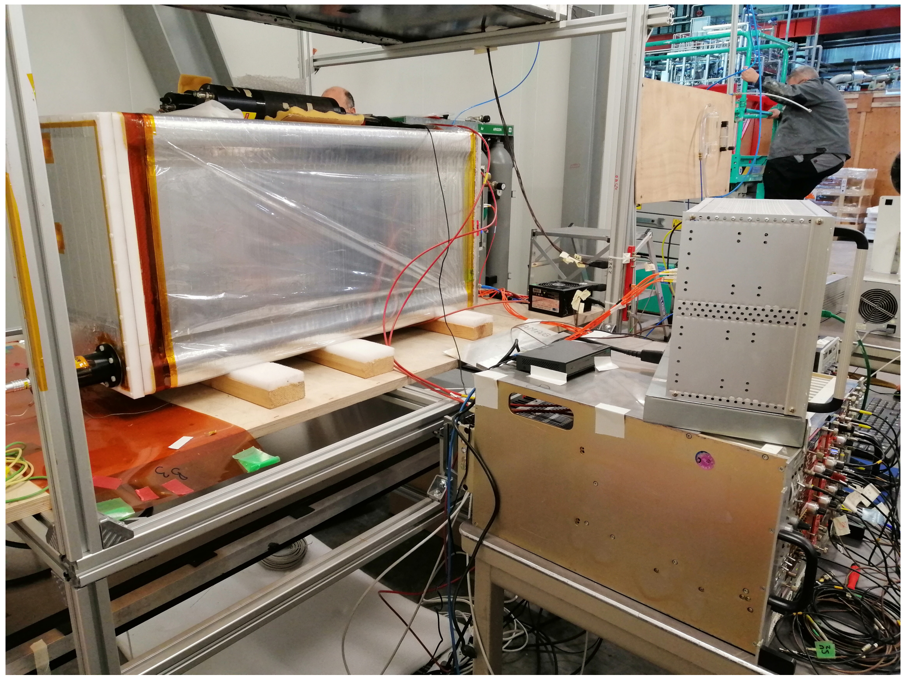


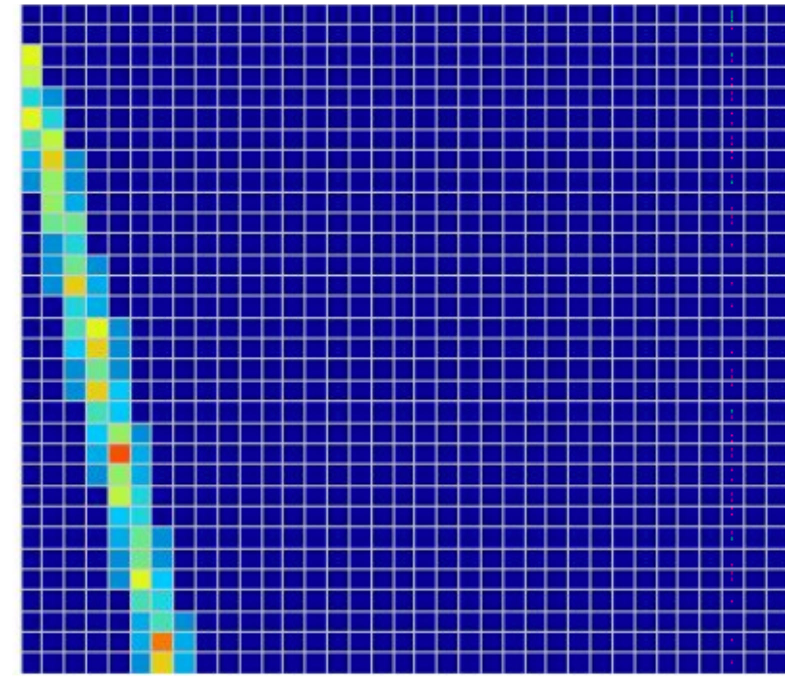



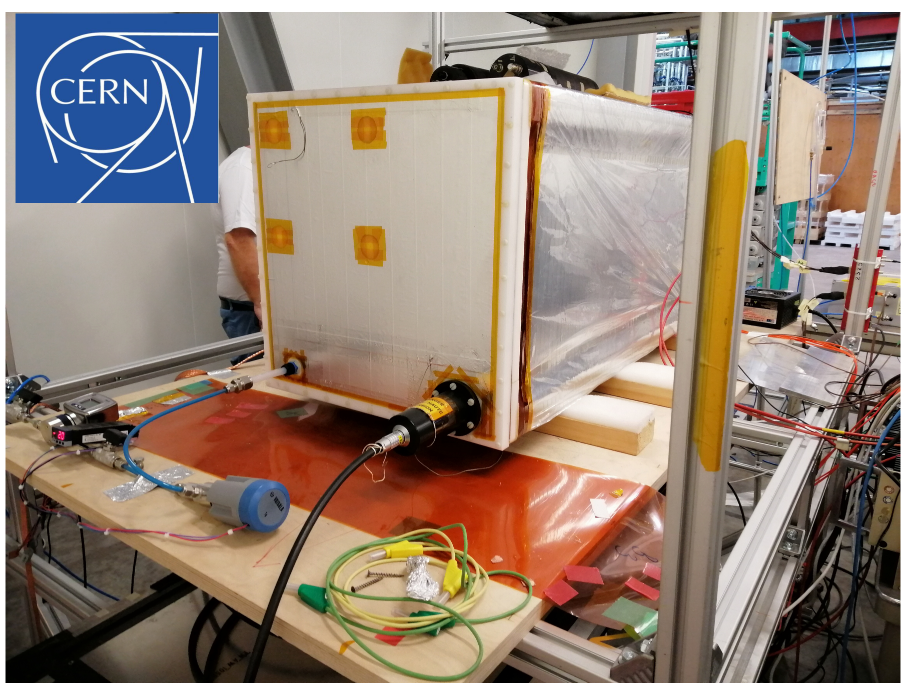



# CERN Field Cage Prototype with MM1
# Tests ongoing

T2K








- **Remarks:**
  - Magnetic Field
  - Not final Field Cage
  - Final MicroMegas layout (Resistivity could change).
- **Beam Test Goals:**
  - Check performance in larger pads.
  - Scan over parameters.
  - Characterize the charge spreading.

# Conclusions

- The resistive MicroMegas concept was successfully evaluated using CERN beam test data using current v-TPCs MM + resistive foil, providing figures of merit satisfying ND280 upgrade HA-TPCs requirements. C.Jesús-Valls, S.Suvorov *et al.*, NIMA 957 (2020): 163286
https://www.sciencedirect.com/science/article/pii/S0168900219315426

- The new layout with ~30% less pads and increased resistivity was tested last fall at DESY. Preliminary results show very good performance.
  - There are studies ongoing analyzing:
    - Foil Resistivity.
    - 2D PRF method
    - Development of simulations based on data.
  - Remarkably, preliminary results show that this new technology improves the resolution for straight tracks ~x3, while reducing ~30% de # pads.

- The first field cage prototype is being tested at CERN using cosmic tracks and there is an ongoing analysis to measured E field distortions.

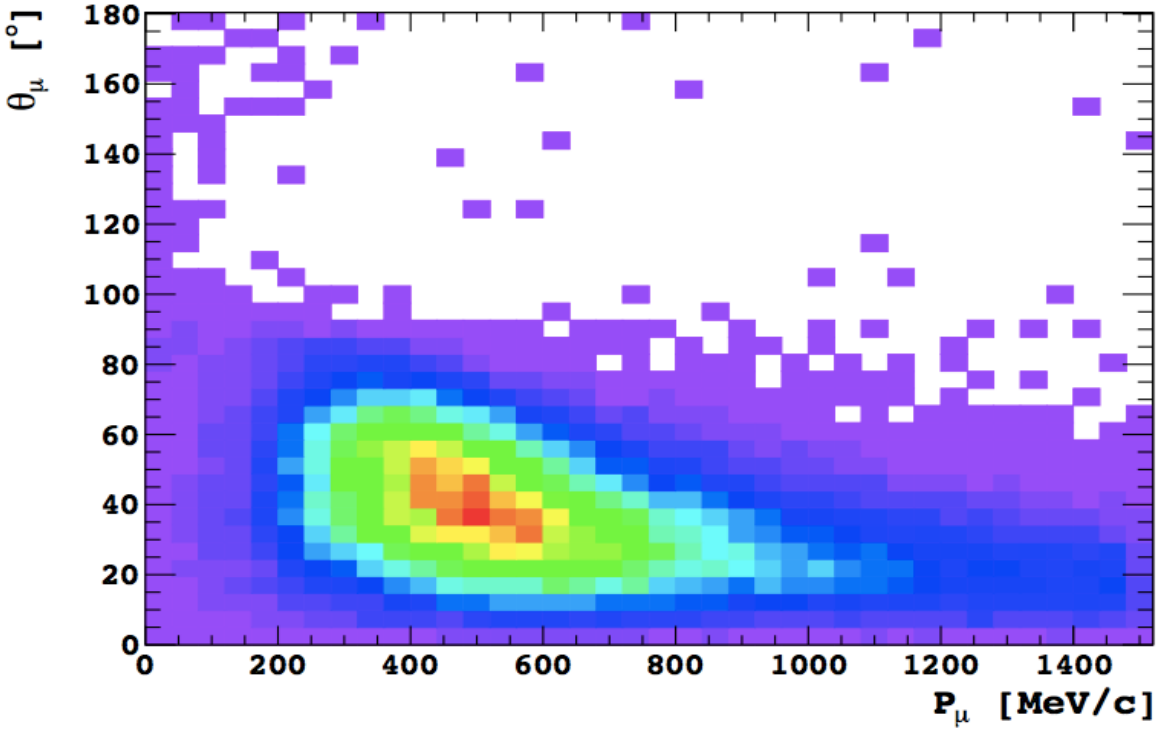
- There are plans to take new data in DESY this autumn using both a field cage prototype and the final resistive MicroMegas.

- Installation is scheduled for fall 2021.

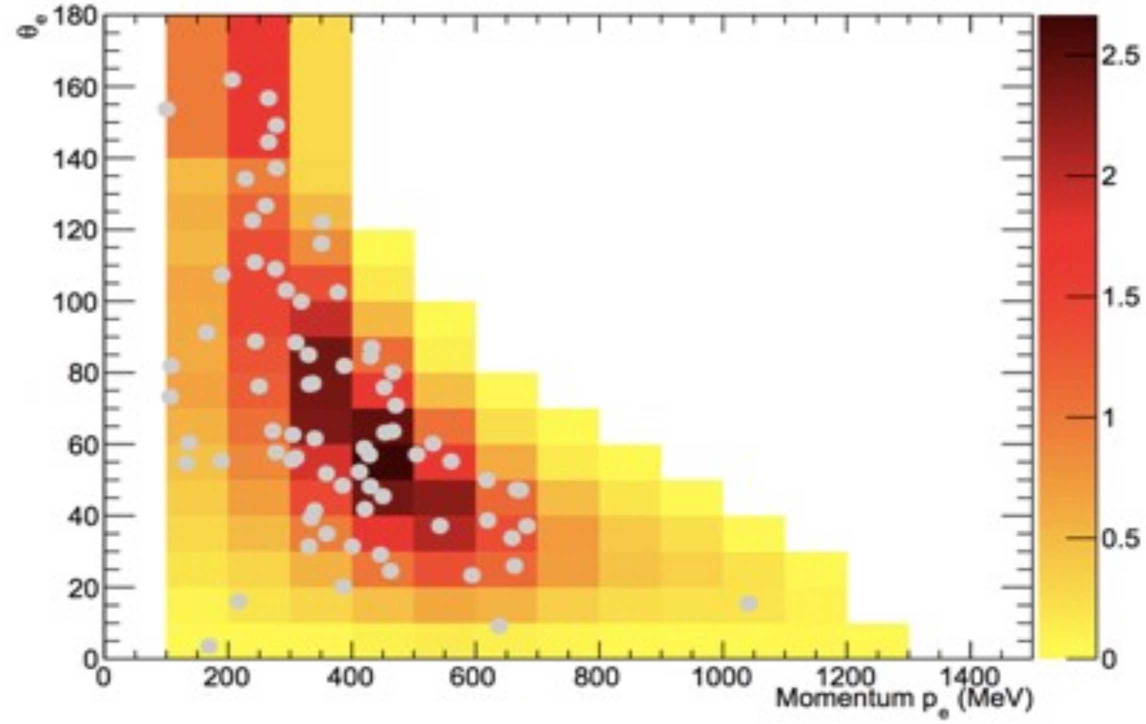
# Back Up

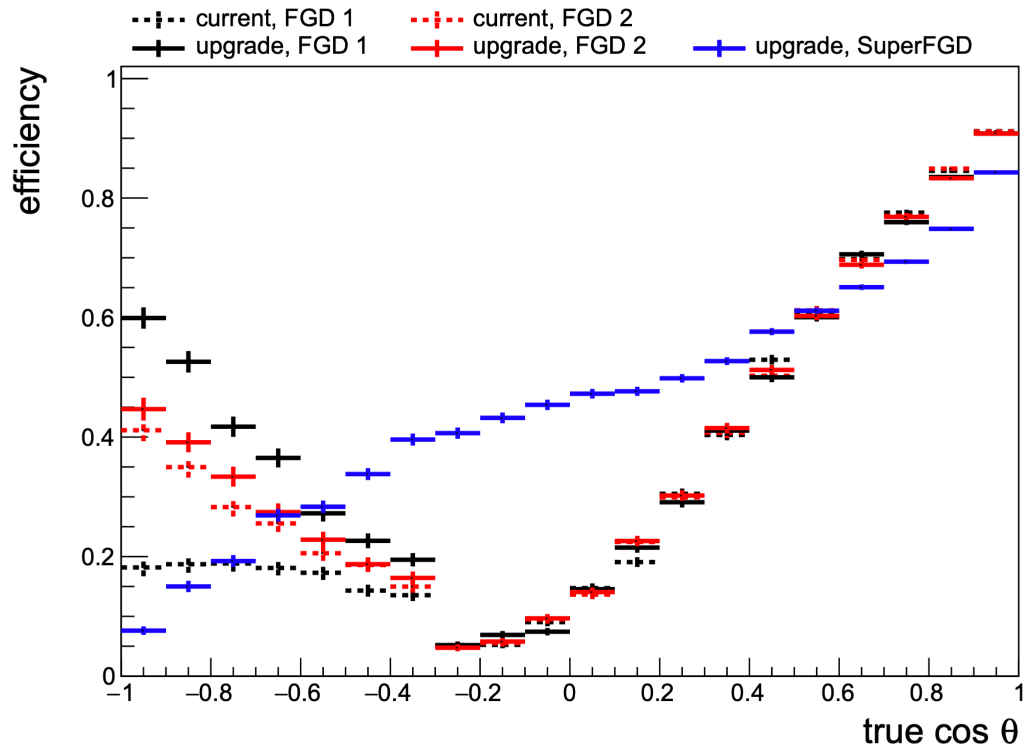
# Back Up
# Extra upgrade motivations

## μ selected at ND280



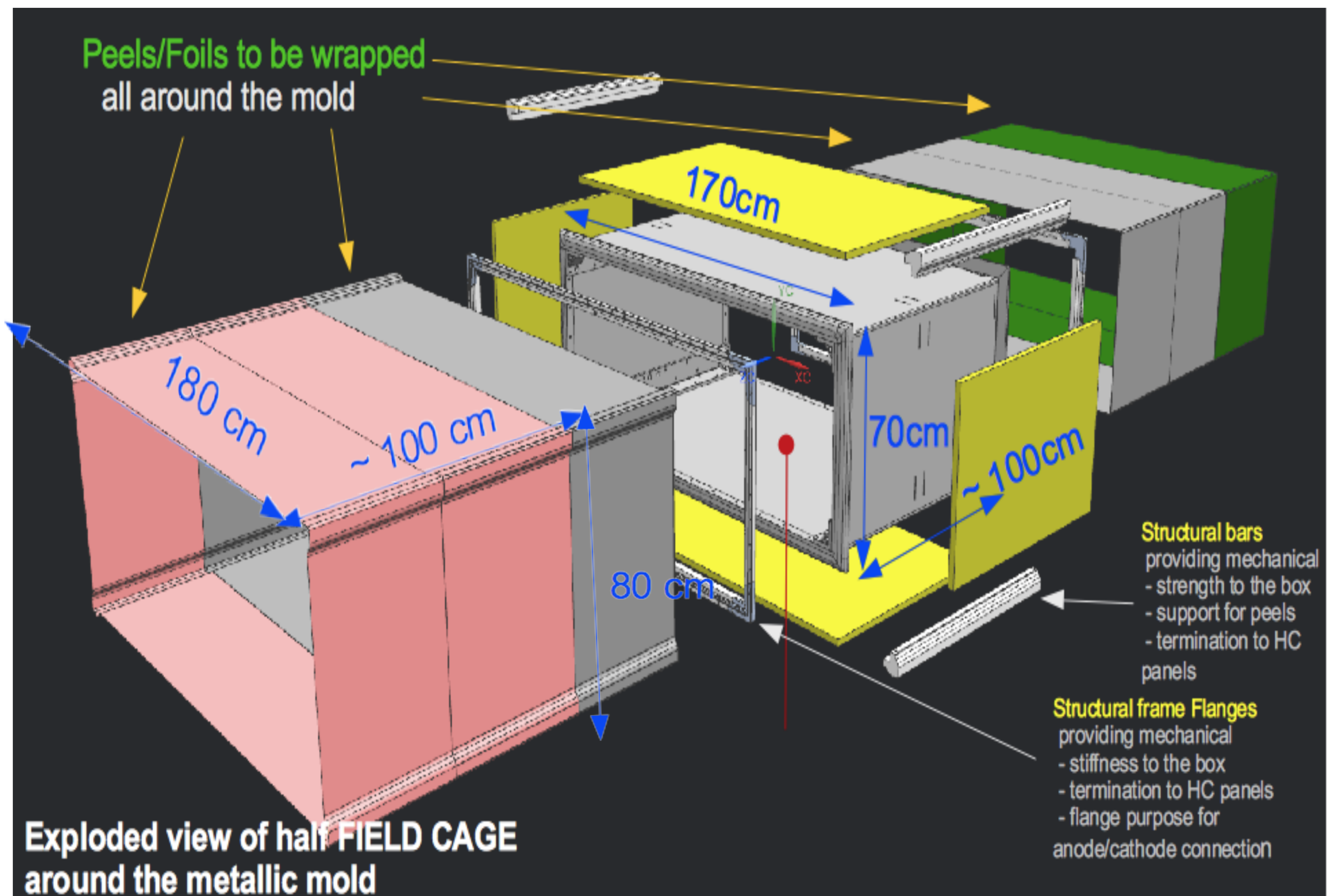

## e⁻ selected at SK



# Back Up
# The new HA-TPCs requirements

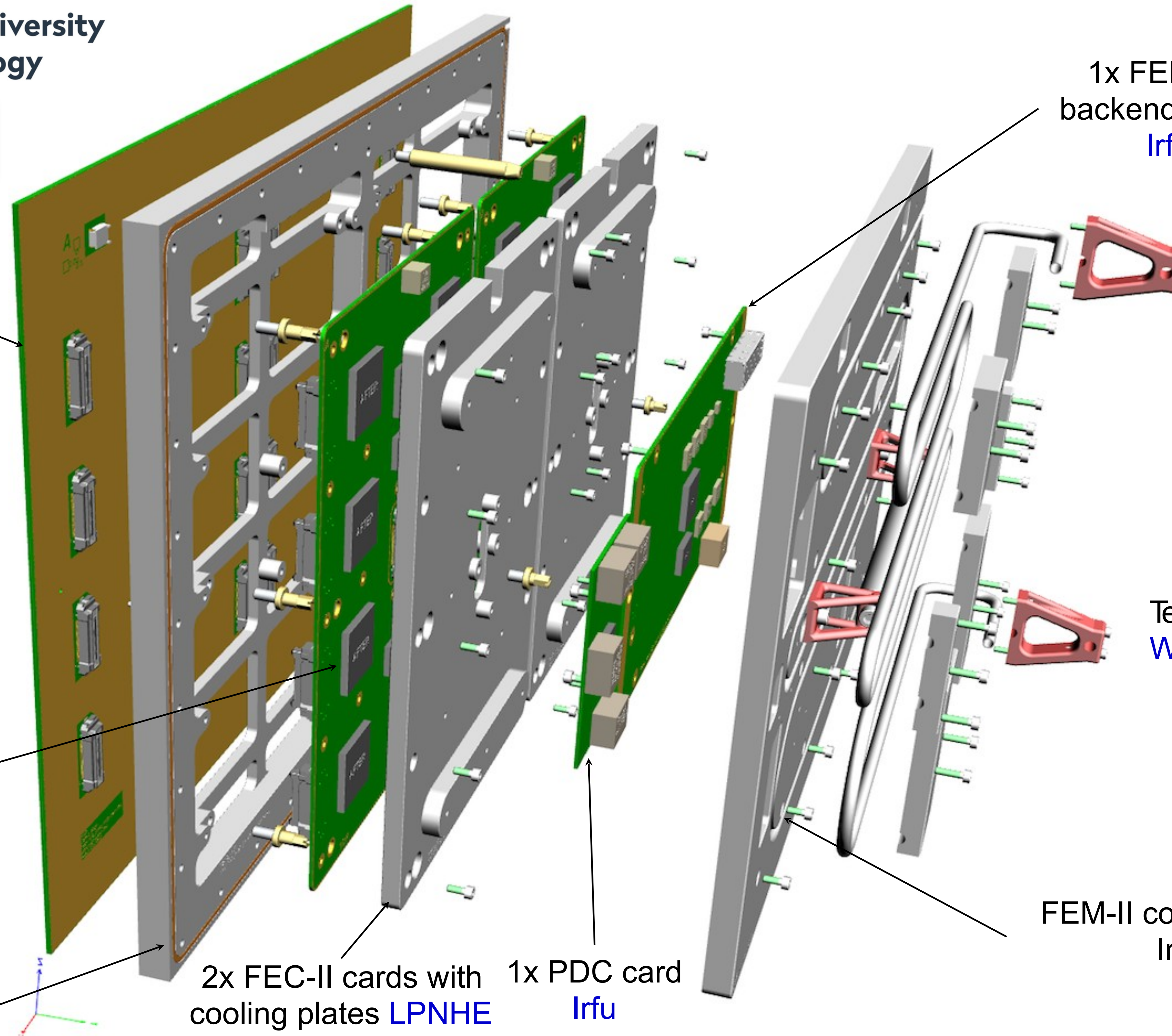
- To keep $\frac{\Delta E_{\perp}}{E_{\parallel}} \leq 10^{-4}$ confined at <1.5 cm from FC walls, the TPC cage requirements are:
  - Cathode flatness better than 0.1 mm,
  - Micromegas detector flatness better than 0.2 mm,
  - Cathode/Anode planes parallel to within 0.2 mm,
  - Field Cage walls flatness better than 0.3mm,
  - Voltage divider resistors matched within rms ~ 0.1%




| Parameter | HA-TPC | 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 | |

| Material | thickness d<br>d (mm) | average<br>$X_0$ (mm) | $d/X_0$<br>(%) |
|---|---|---|---|
| Double layer strip foil (+glue) | 0.05 | | |
| → Copper strips | ~0.005 | 14.3 (Cu) | ~0.07 |
| Aramid Fiber Fabric (Twaron) | 2.0 | ~240 | 0.70 |
| Aramid honeycomb panel (Nomex) | 25 | 14300 | 0.17 |
| Aramid Fiber Fabric (Twaron) | 2.0 | ~240 | 0.70 |
| Kapton tape (+glue) | 0.125 | 285 | 0.04 |
| Aluminized Mylar (+glue) | 0.05 | | |
| → Aluminum layer | 0.01 | 89 (Al) | ~0.02 |
| Total | ~30 | | ~1.6 |

# Back Up
# The new HA-TPCs electronics




- 36 x 32 = 1152 pads
- 2 x 576 channel FEC
- 8 vertical FX23 Hirose floating connectors

M. Riallot (CEA/Irfu)

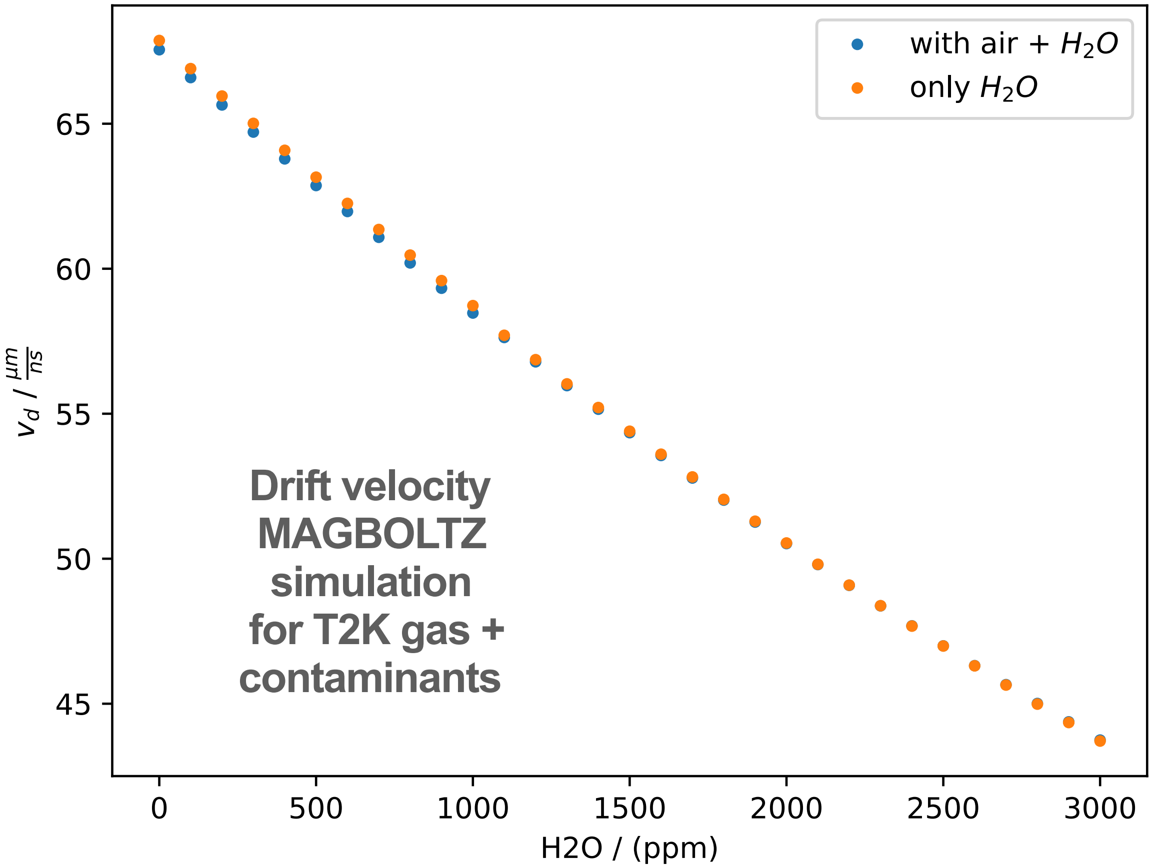
# Back Up
# Details on CERN BeamTest gas quality

### Experimental conditions:

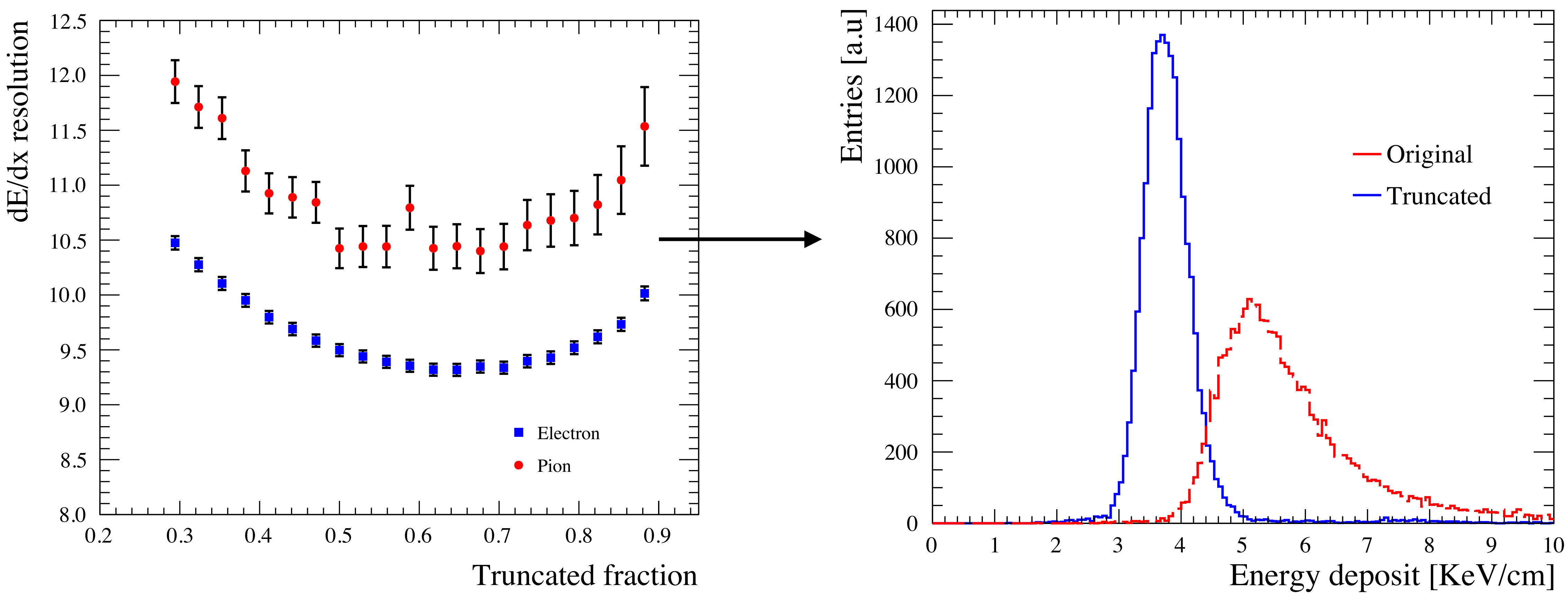
- HARP TPC stored in air for more than 10 years.
- No FC drying before operation.
- Gas gas reduced from 60L/h to 25L/h to save gas.
- There were no gas monitoring chambers.

### Simulations:

- Drift velocity was at most 5.5cm/μs, should have been 6.8cm/μs.
- Small attenuation and large reduction in drift velocity points out to humidity.

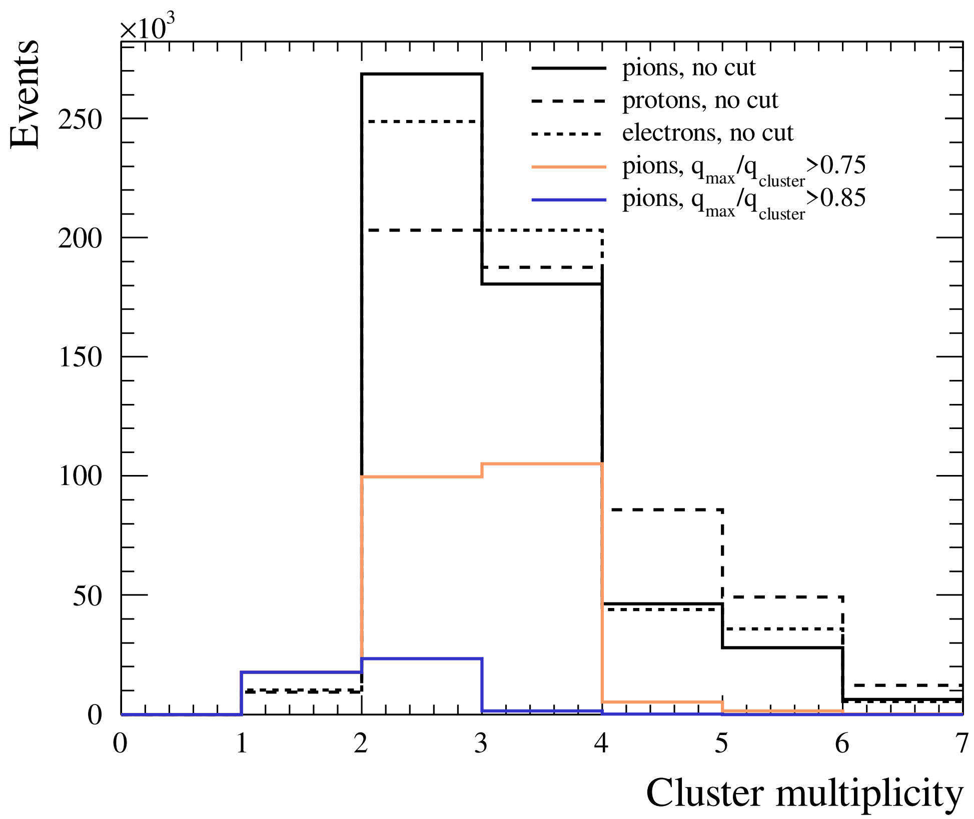


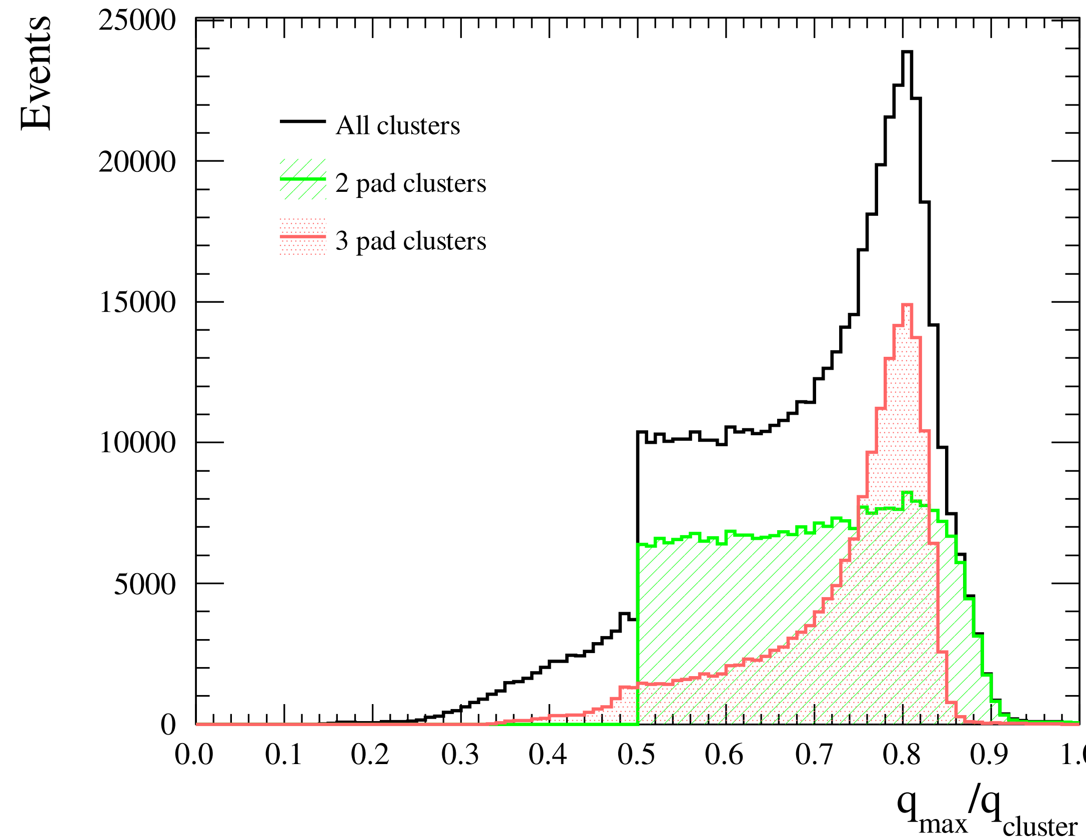
# Back Up
# Truncated mean method



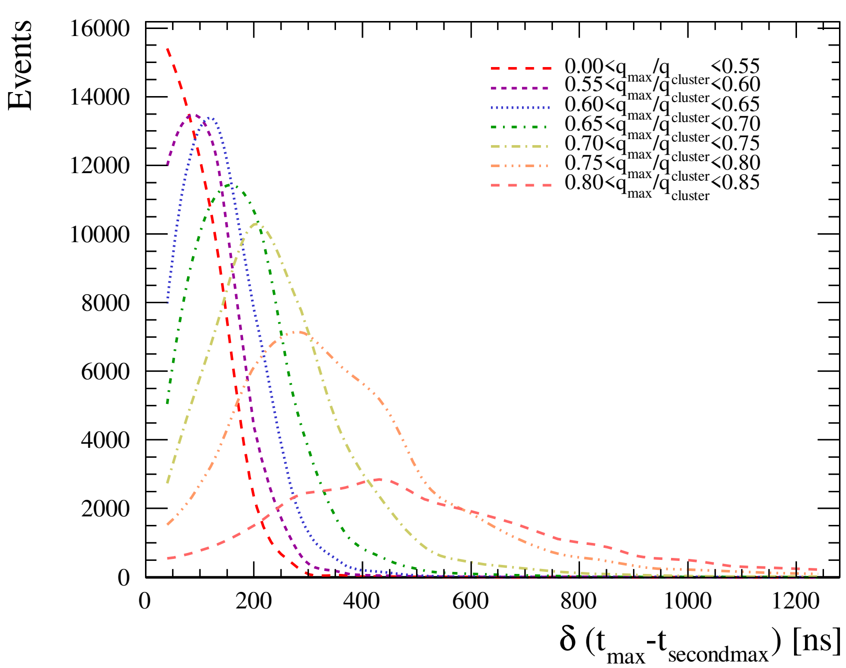

Optimum truncation keeping 21 clusters (out of 34)

# Back Up
# Charge Spread MM0 (CERN TESTS)

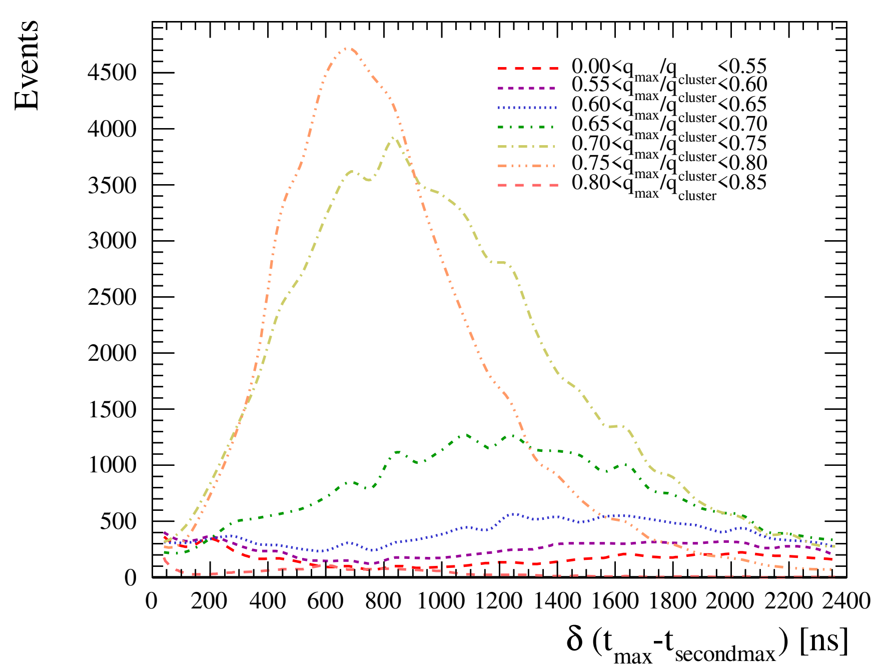



2Pad Clusters




3Pad Clusters




3Pad Clusters