Results of HA-TPC prototype characterization with DESY 2021 test beam data

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on behalf of HA-TPC group

T2K biweekly meeting

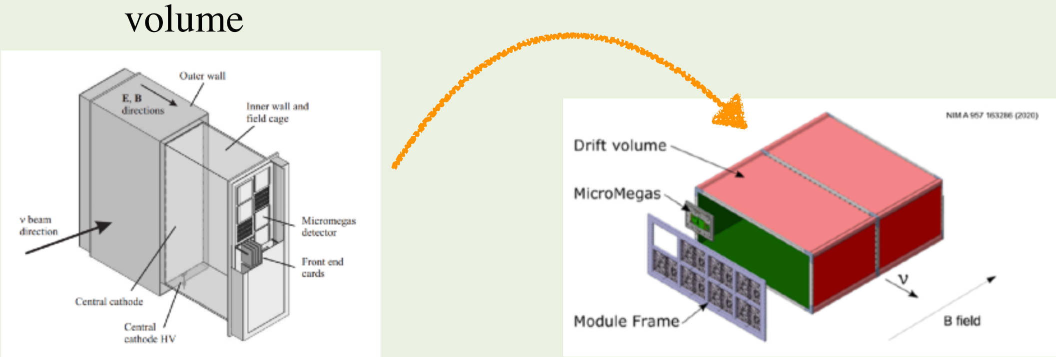
27/10/2022

High-Angle TPCs

What is new:

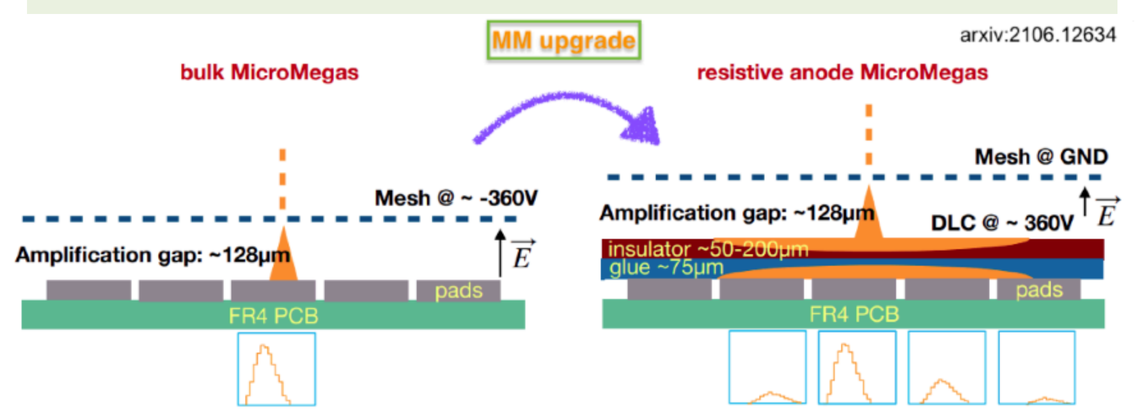
➡ **New field cage**

- ✦ Minimize the dead space and maximize the tracking volume

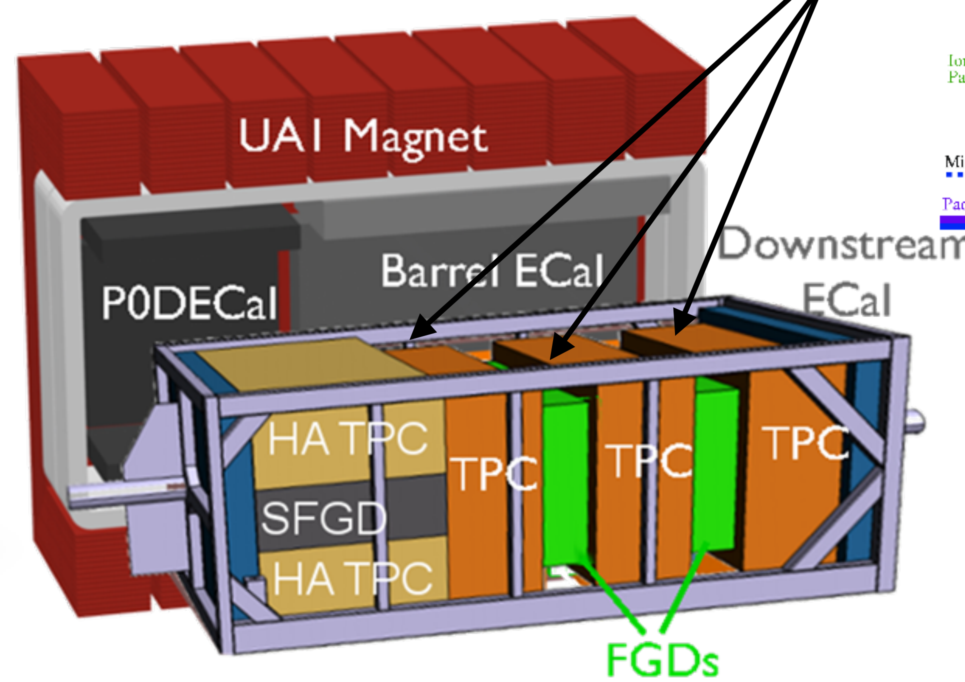


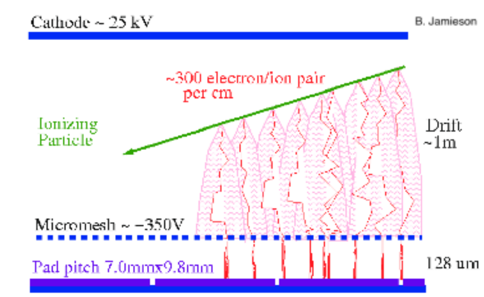
➡ **New resistive Micromegas module:**

- ✦ Bulk Micromegas readout module replaced by new resistive Migcromegas Modules (ERAM) ↣ spread the charge over multiple pads ↣ improving the spatial resolution and reducing the number of readout pads, no need in sparks protection



➡ Inherit the design of the existing TPCs





Main goal:

- High-resolution tracking (3D reconstruction) of charged particles
- Particle identification (charge and momentum measurements)

HA-TPC requirements:

- ➡ To distinguish between muons and electrons at 3σ level ↣ energy resolution < 10%.
- ➡ Momentum resolution < 10% at 1 GeV/c ↣ spatial resolution< 0.8 mm

Motivation

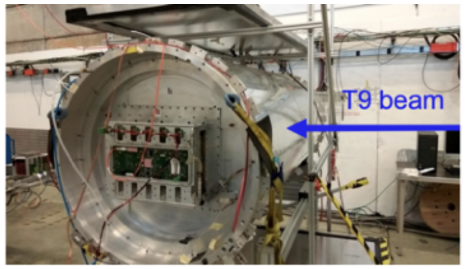
HA-TPCs test beam:

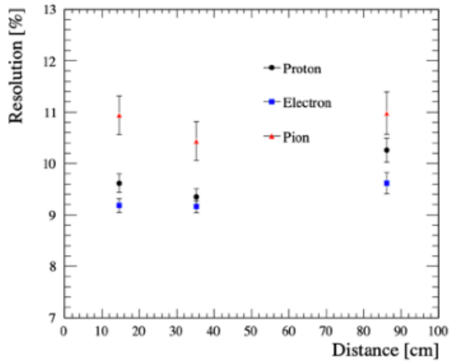
Main goal: to characterize the ERAM response and test the HA-TPC performances for horizontal and inlined tracks and for various drift distances

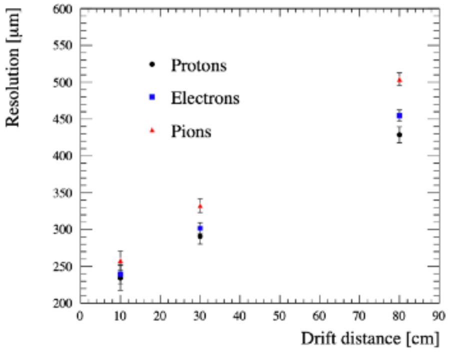
dE/dx resolution **Spatial resolution**

➡ CERN 2018 (10.1016/j.nima.2019.163286)

∗1.5m drift distance; π, e, p trigger; 2018 MM0-DLC1

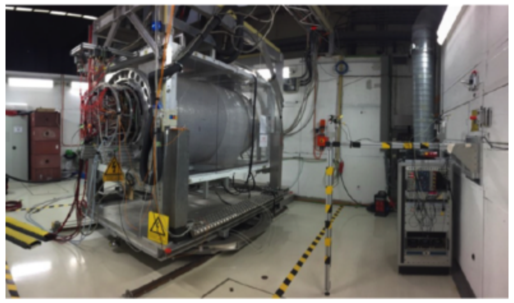


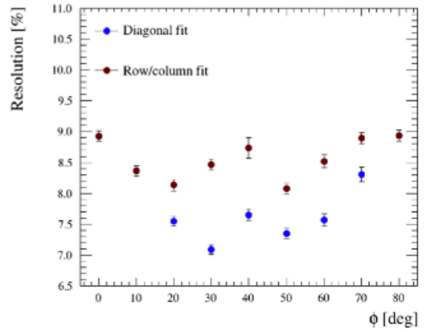


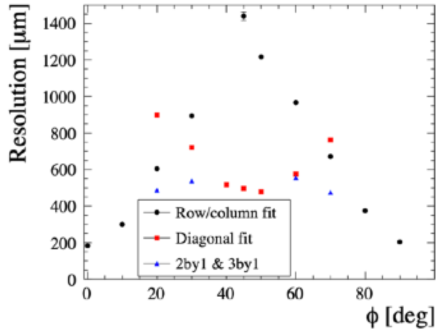


➡ DESY 2019 (arXiv:2106.12634)

∗4 GeV e- 0.15m drift distance; 2019







➡ DESY 2021

∗4 GeV e-; 1 m drift distance (**final detector drift distance!**);

∗2020 ERAM#01 (better charge spreading, ↑RC)

∗Same construction materials for field cage prototype as for HA-TPCs

➡ CERN 2018 → first test with Resistive MM for horizontal tracks

➡ DESY 2019 → ERAM prototype with inclined tracks and short drift distances

➡ DESY 2021:

- First test with TPC prototype, ERAM series detector and full electronics chain
- Check performances for all angles and drift distances of interest for T2K
- A first comparison with simulations

Content of the paper

Analysis of test beam data taken with a prototype of TPC with resistive Micromegas readout for T2K Near Detector upgrade

Content of the paper

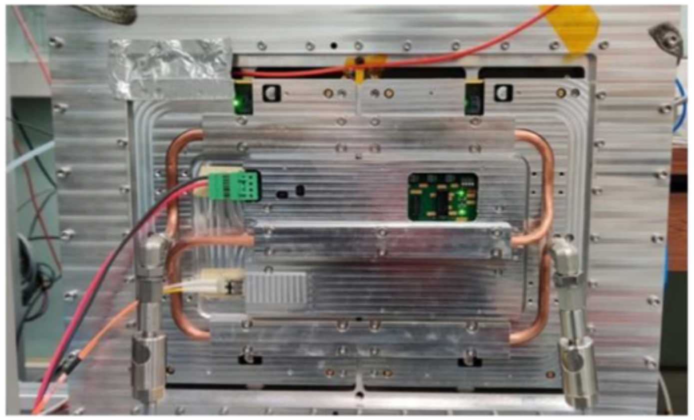
HA-TPC prototype

Field cage:

ERAM electronics (Front-end and Back-end):

ERAM detector:

ERAM module:



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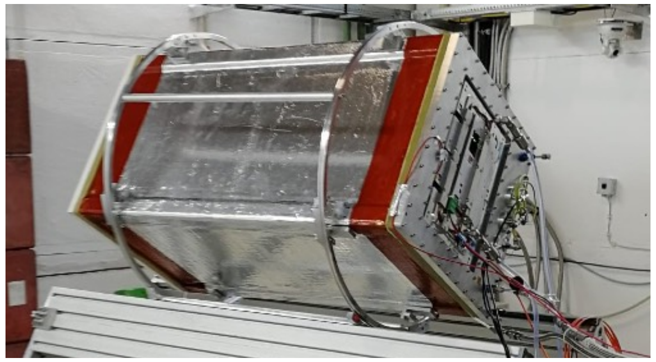
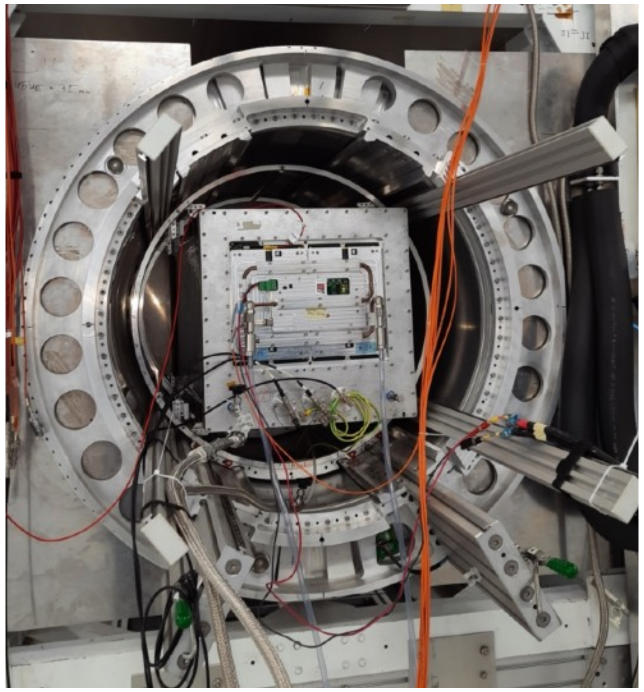
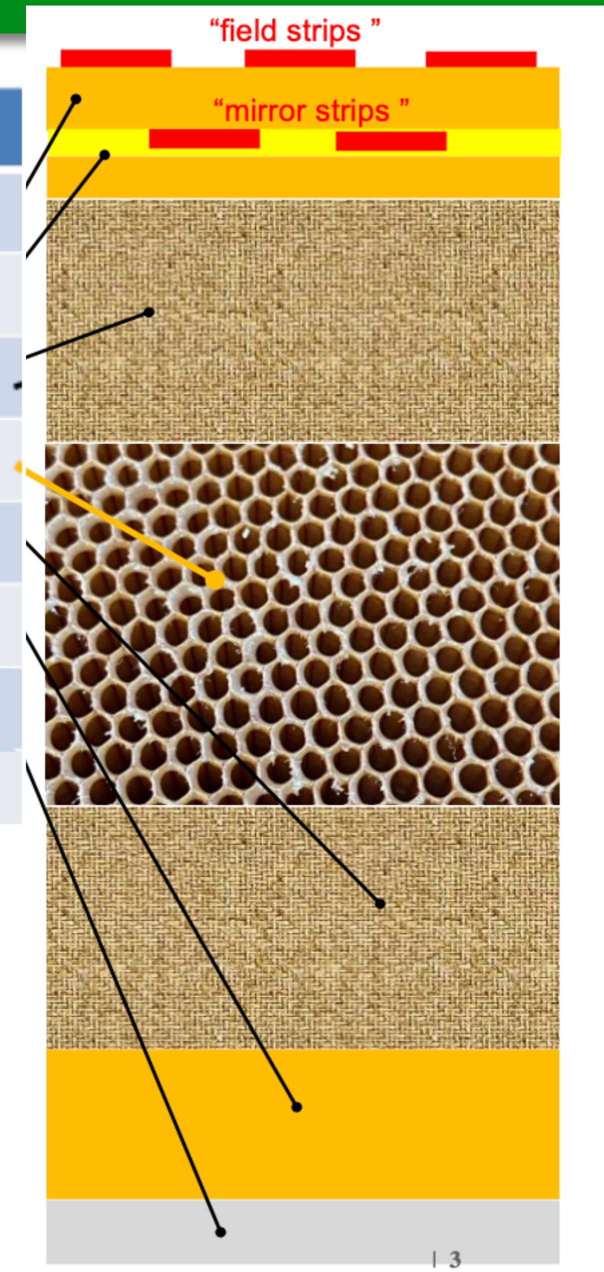




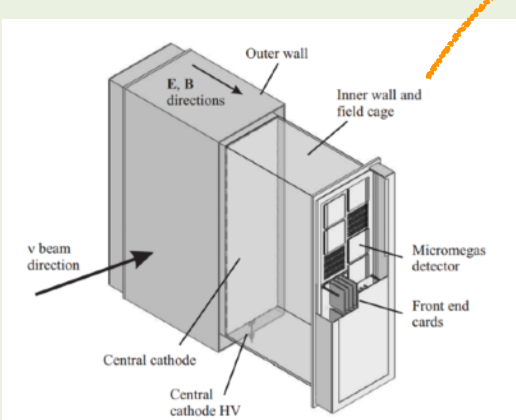
HA-TPC field cage

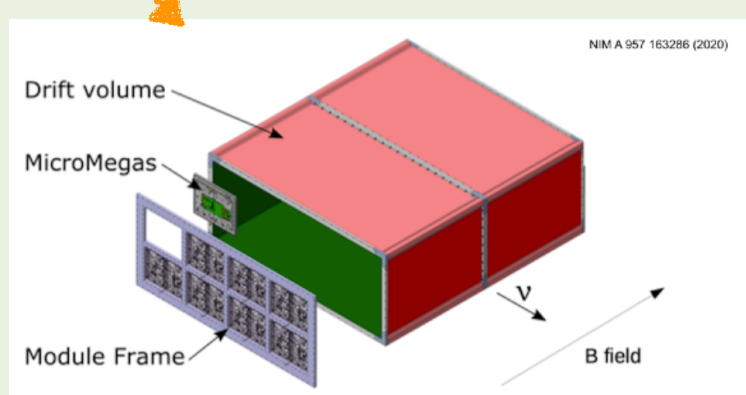
Material	Thickness
Cu Strips on Kapton foil (electrodes)	Cu 17μm / Kapton 50μm / Cu 17μm
"Coverlay" (strip insulation / protection)	Glue 20μm / Kapton 25μm
Aramid Fiber Fabric (Twaron™)	2mm
Aramide HoneyComb panel	35mm
Aramid Fiber Fabric (Twaron™)	2mm
Kapton foil (insulation)	125μm
Aluminum foil (external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



➡ Field cage

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

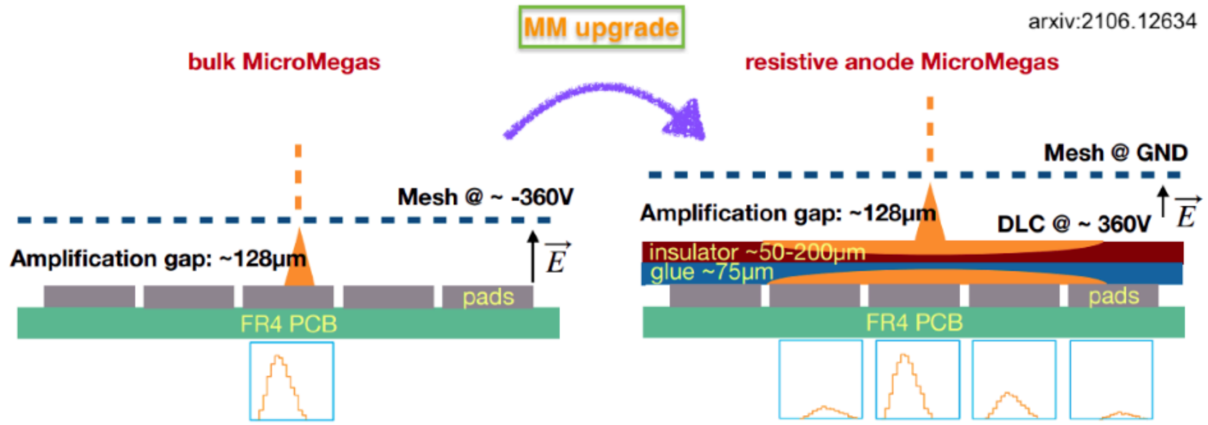




ERAM detector

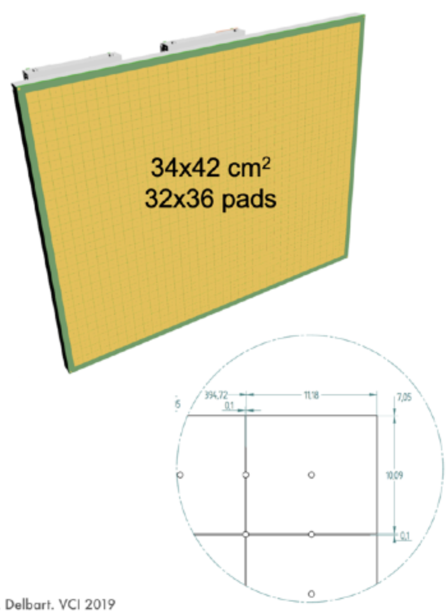
➡ New resistive Micromegas module:

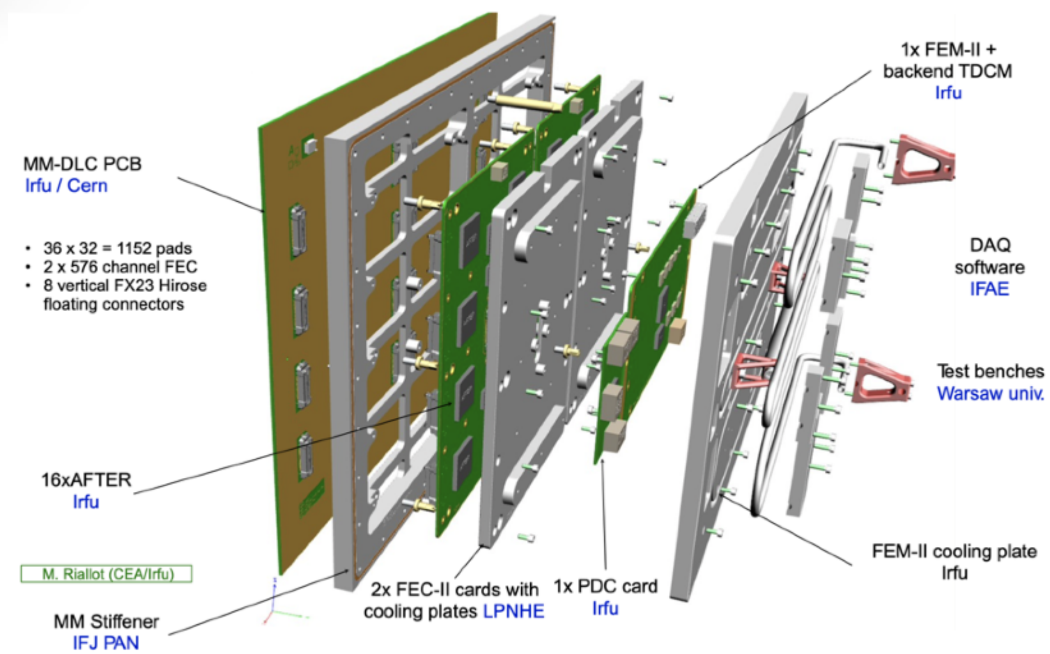
- ✦ Bulk Micromegas readout module replaced by new resistive Migcromegas Modules (ERAM) ↣ spread the charge over multiple pads ↣ improving the spatial resolution and reducing the number of readout pads, no need in sparks protection



Characteristics of the ERAM module:

- ➡ Dimensions (z×y): 340×420 (mm)
- ➡ 32x36 rectangular pads
- ➡ Pad size (z×y): 10.09×11.18 (mm)
- ➡ Gain of 1000



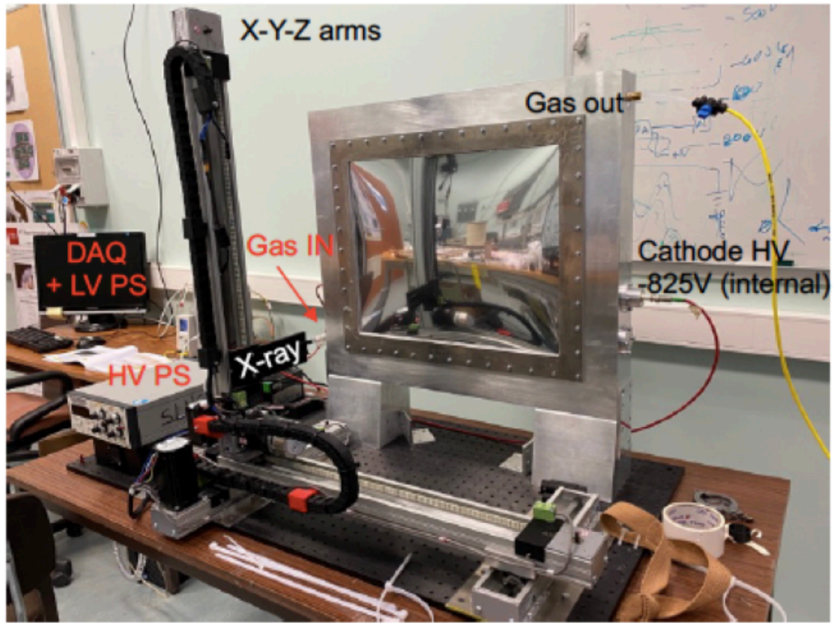


Each ERAM module is glued to a supporting stiffener and mounted on the module frame. Then Front-End cards (FEC), the Front-End Mezzanine (FEM), and FEM water cooling plates are connected to complete the design.

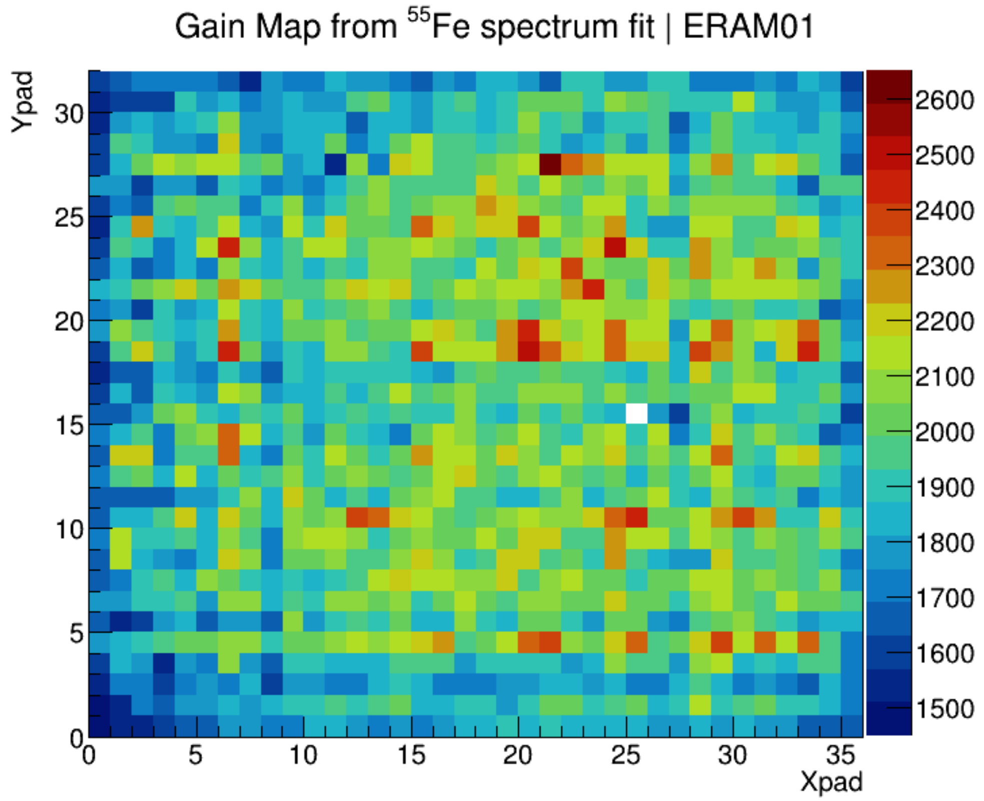
Characterization of ERAM 01

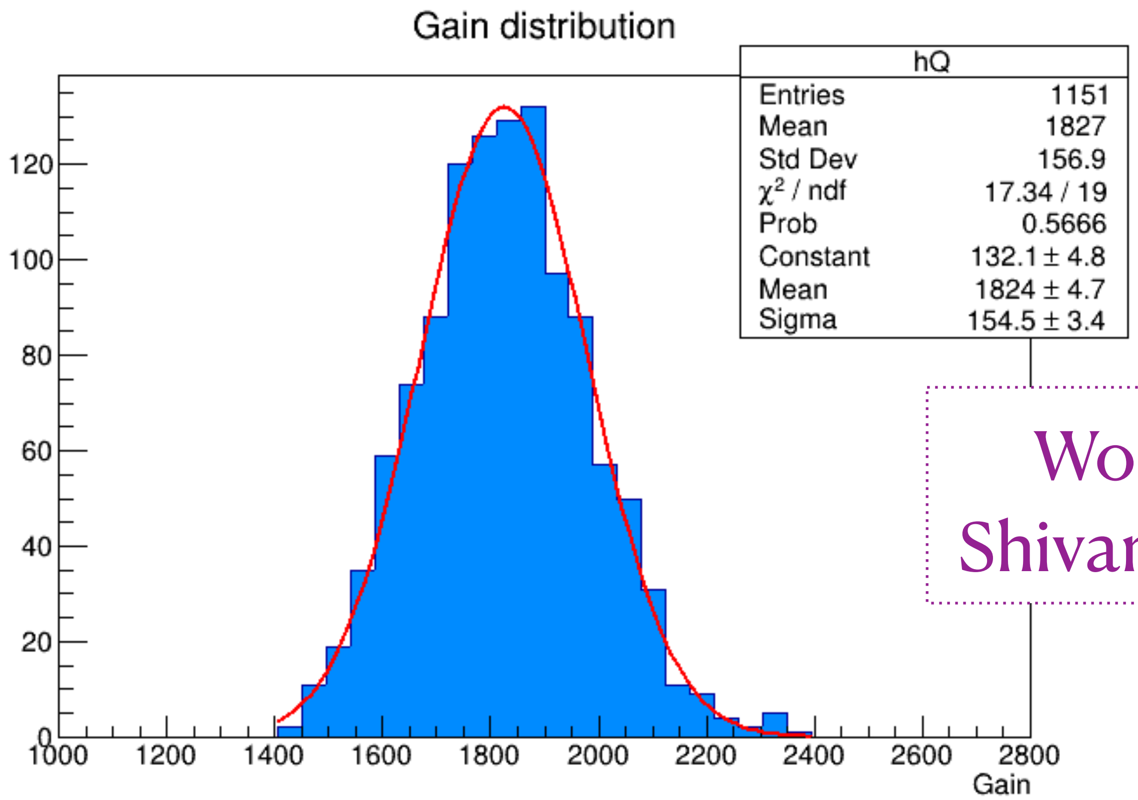
➡ X-ray ray test bench in order to scan detector pad by pad:

- ^{55}Fe of 5.9 keV photons, centered at each pad
- 3 cm drift distance
- Each scan lasts for 4 min
- Gain for each pad and ^{55}Fe spectrum were measured



Accepted nonuniformity up to 20%



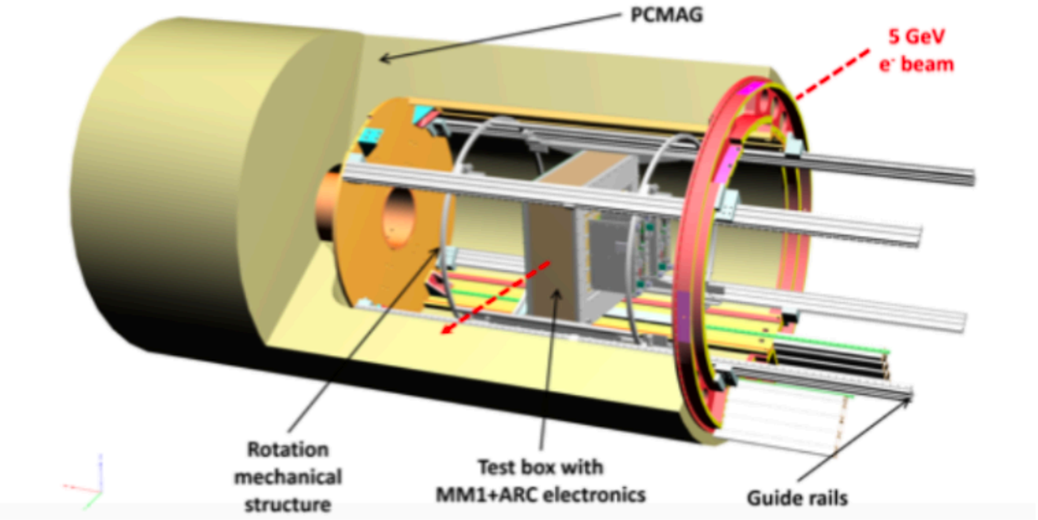


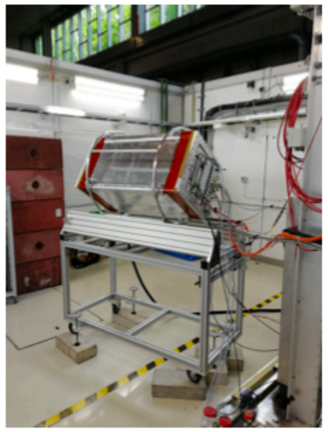
Work of Shivam Joshi

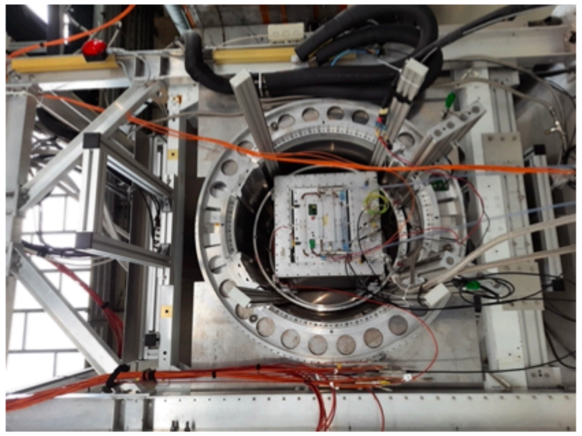
DESY Test Beam area T24/1

ERAM module (design for future HA-TPC) was tested at DESY II test beam facility:

- ⟼ electron beam from 0.5 to 5 GeV/c in a short chamber of 1 m drift distance
- ⟼ 0.2 T PCMAG magnet and 360 V
- ⟼ AFTER chip: sampling time = 40 ns, peaking time of 200 ns and 412 ns, gain of 120 fC
- ⟼ gas mixture: argon 95 %, 3% (CF_4), 2% (iC_4H_{10})
- ⟼ oxygen contamination of 30 ppm at gas flow rate of 30 l/h
- ⟼ the chamber operated under atmospheric pressure





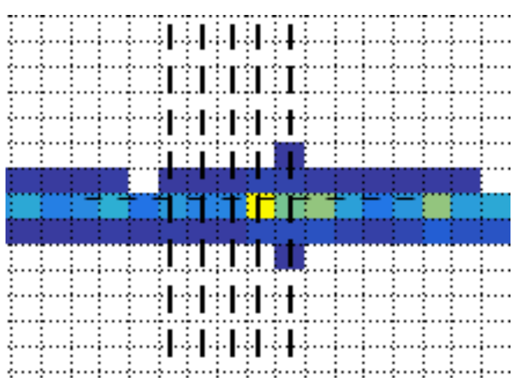


DESY 2021 test beam

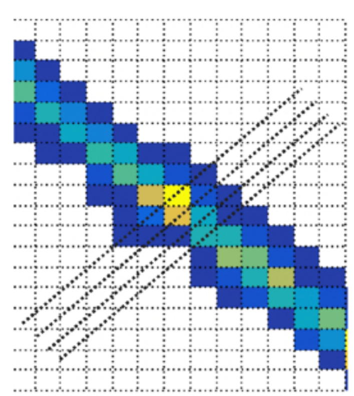
In order to ensure that setup satisfies the ND28
upgrade requirements the test beam intended t

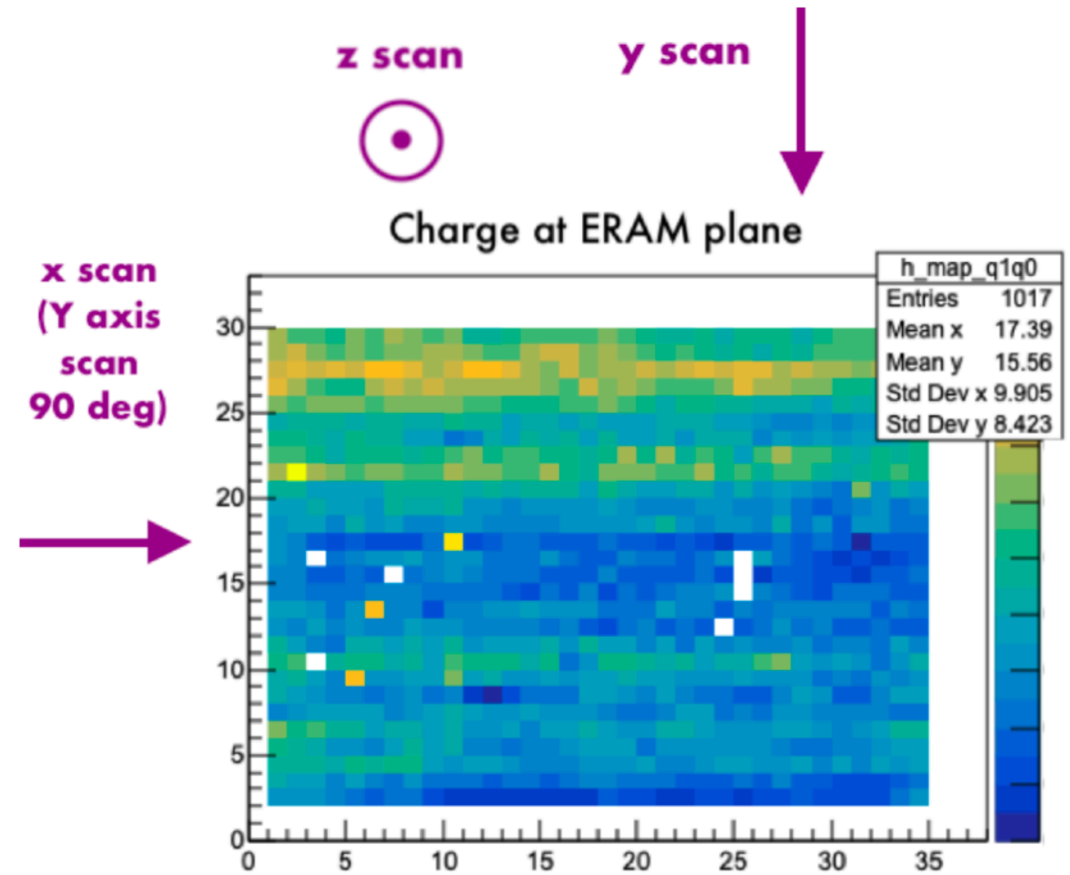
- test the setup stability
- To characterize the charge spreading and study the impact of possible non-uniformities in gain or RC on the performance of the prototype
- measure spatial and energy resolution

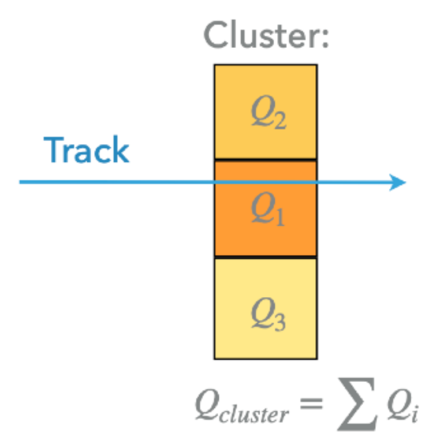
Horizontal track

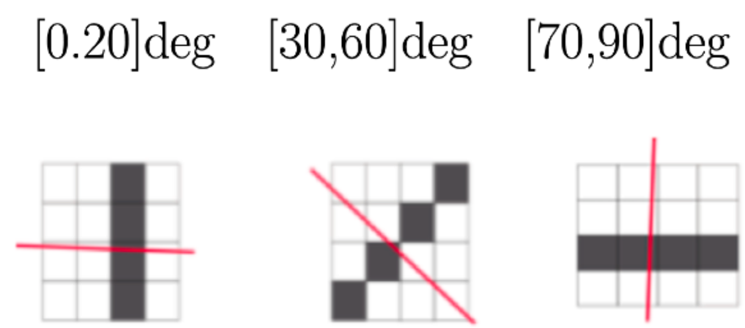


Inclined track









dE/dx resolution measurements

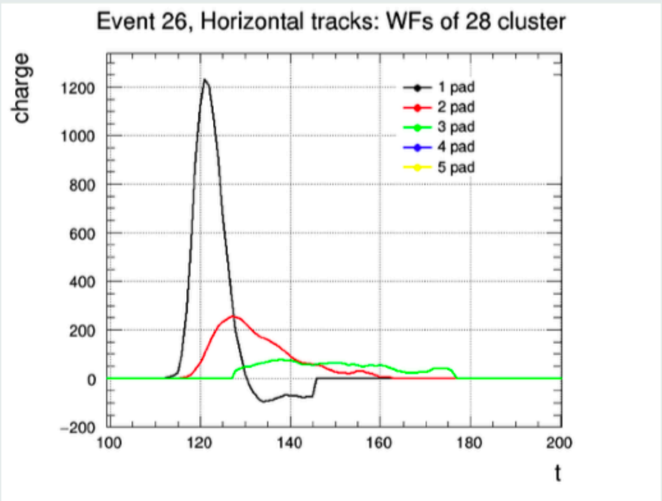
dE/dx resolution

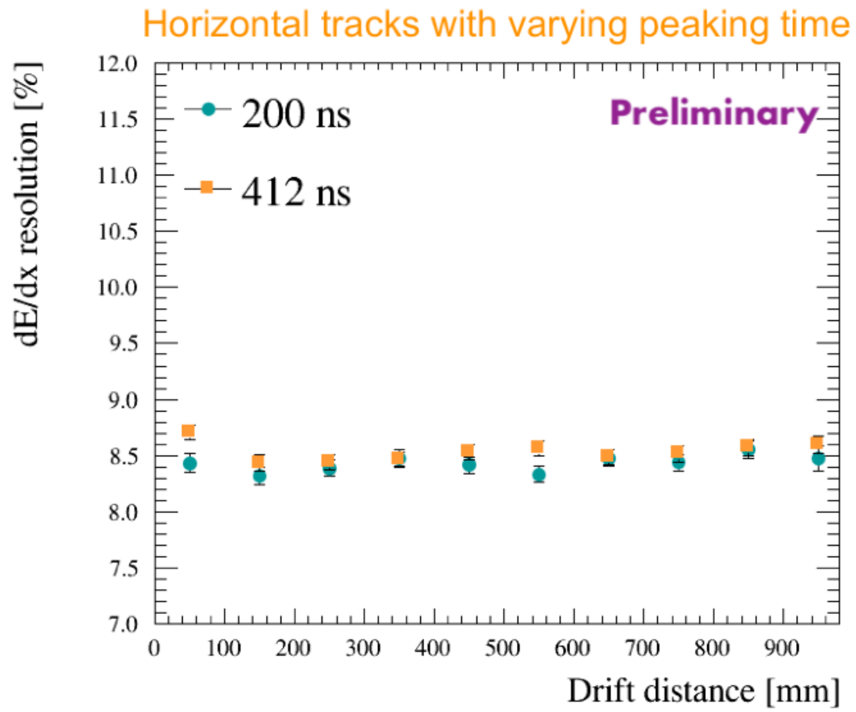
- dE/dx measurements: Truncated mean method ($\rightarrow \alpha = 0.7$)

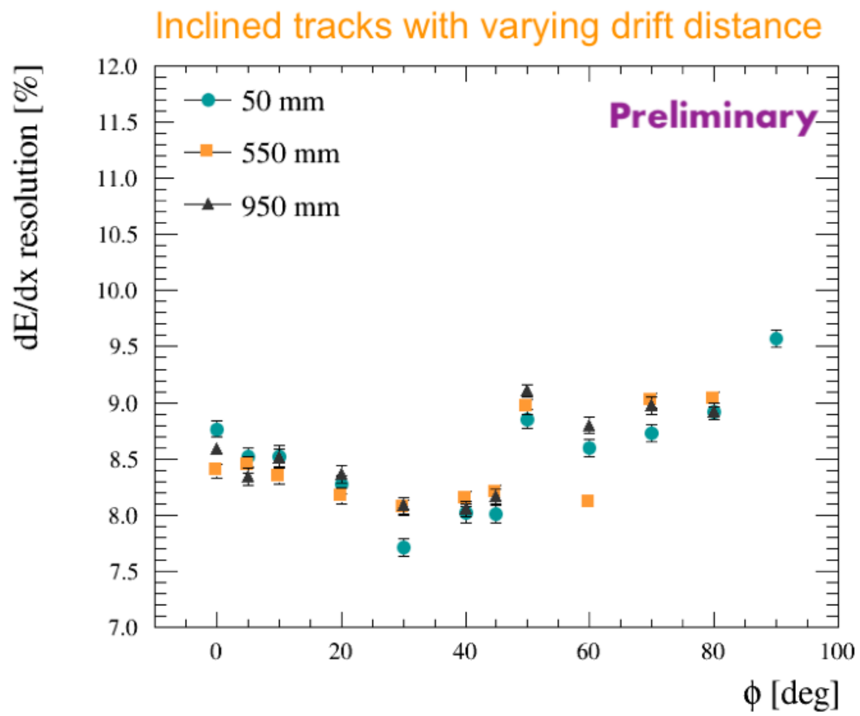
$$\frac{dE}{dx} = \frac{\sum_{i=1}^{\alpha \cdot N_{cl}} C_{cl}^{i}}{\alpha \cdot N_{cl}}$$

- Charge cluster definition: WFsum$\longrightarrow$

cluster WF at maximum







Fullfill the requirements: dE/dx resolution < 9.6%

Show independence on peaking time and drift distance

Spatial resolution measurements

Spatial resolution:

- The Pad Response Function (PRF) method is used for track position reconstruction.

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

- Prior position estimated with barycentrical method.
- Then track is fitted with "parabola" and PRF scatter plot is filled using x_{track} from the fit.
- The Y axis profile of scatter plot fitted with analytical PRF.

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

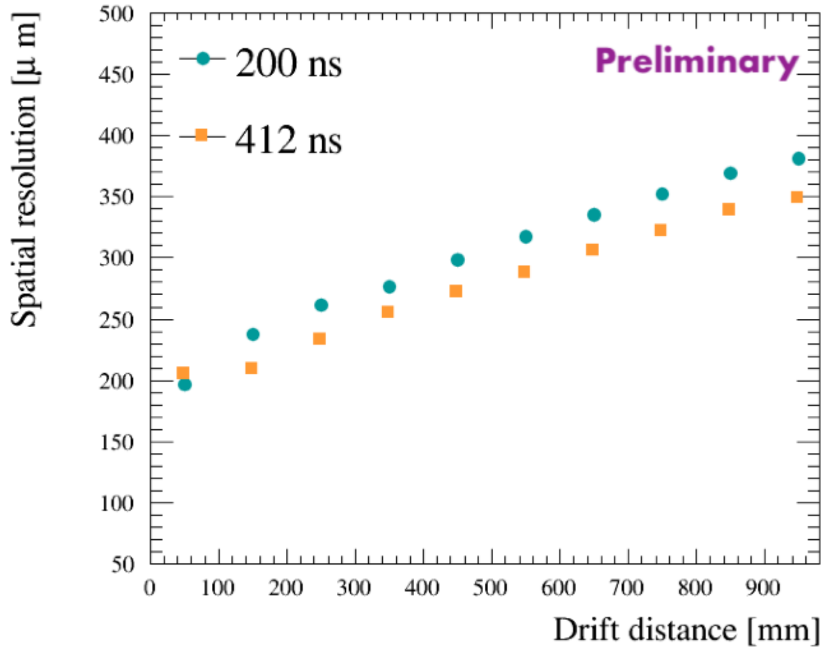
- The PRF parameters are recovered and track position per cluster estimated using minimization:

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

, where $\sigma_{Q_{pad}/Q_{cluster}} = \sqrt{Q_{pad}/Q_{cluster}}$

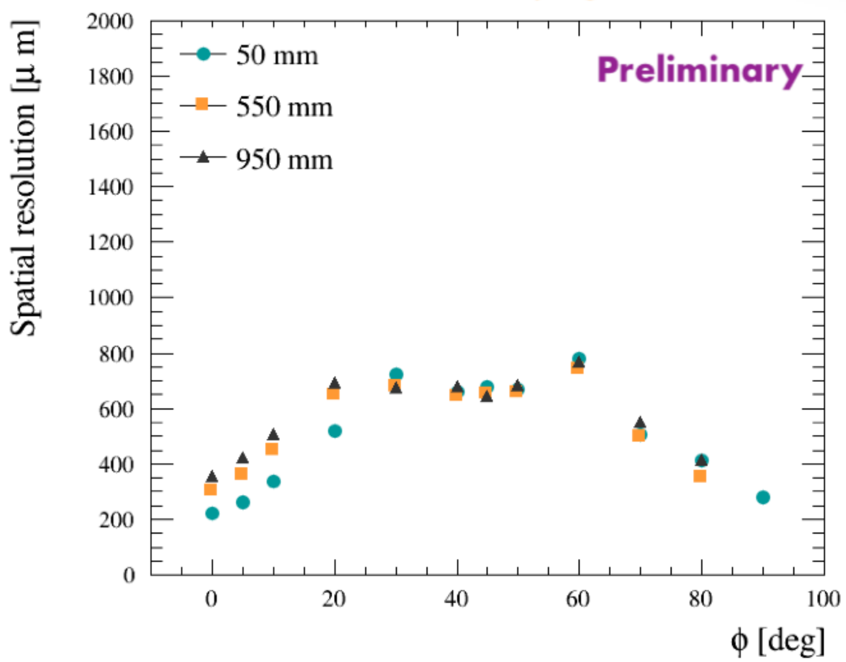
- spatial resolution (SR) extracted as a gaussian σ of residuals $(x_{track} - x_{pad})$ in each cluster. $\rightarrowtail$

Horizontal tracks with varying peaking time



Fullfill the requirements: spatial resolution < 0.8 mm

Inclined tracks with varying drift distances

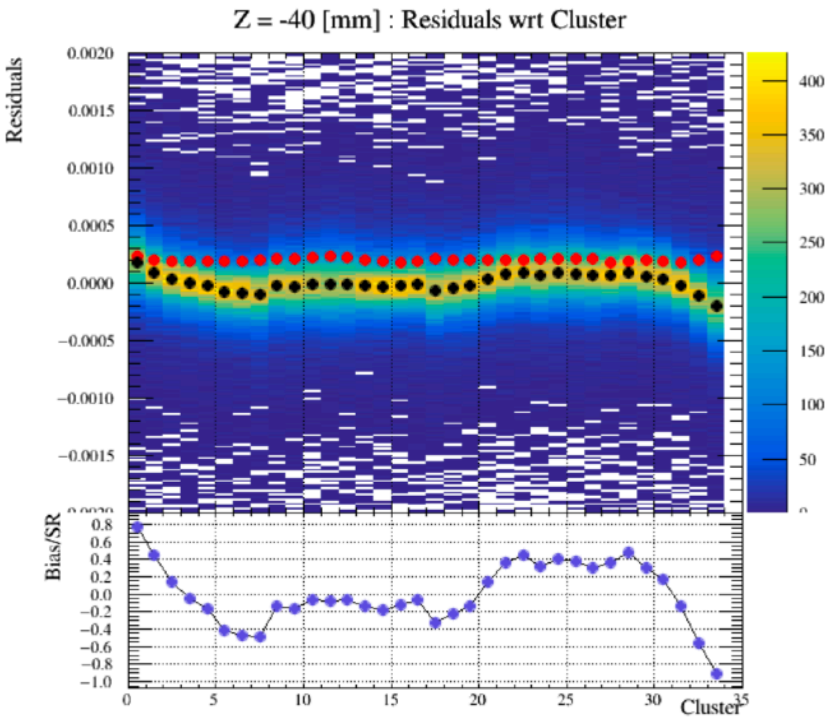


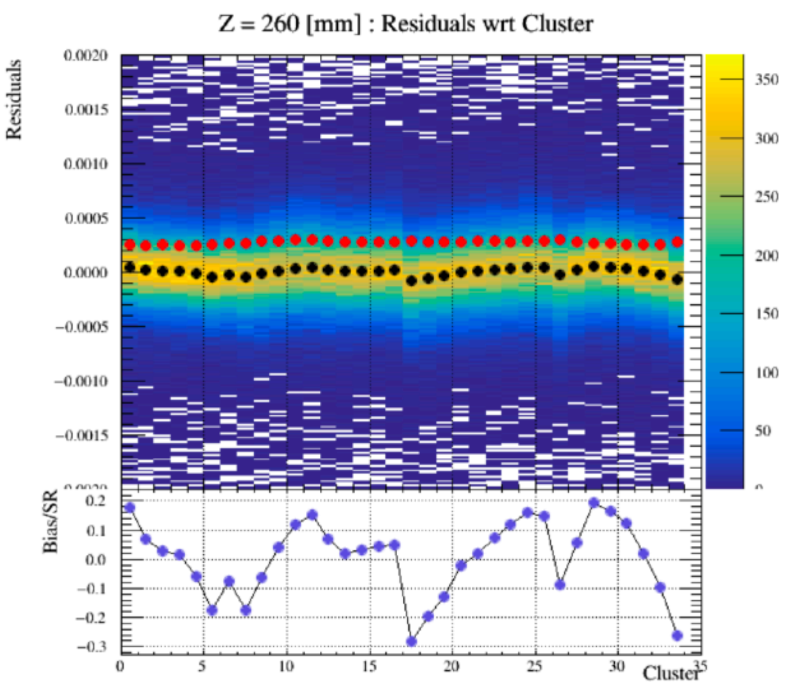
No drift distance dependence for diagonal fit tracks!

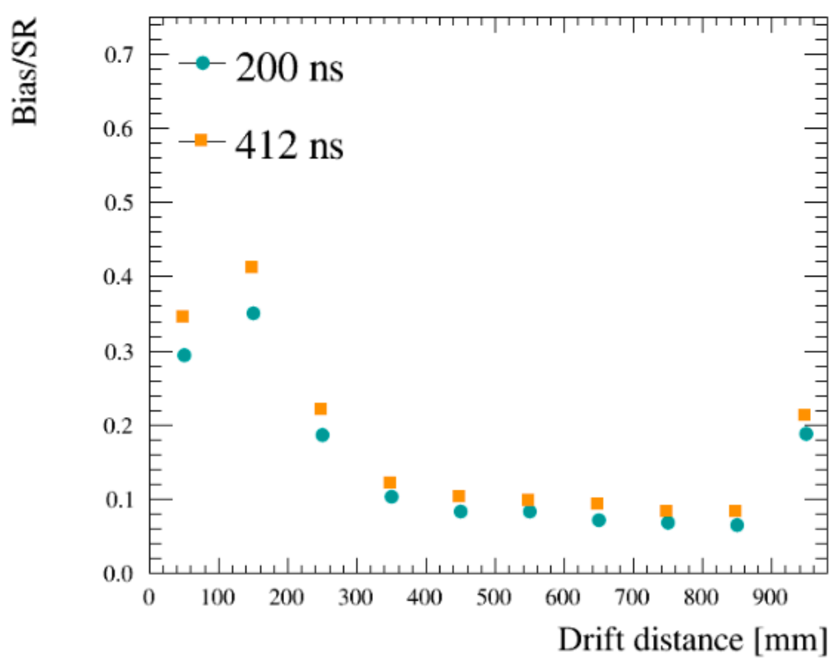
Biases

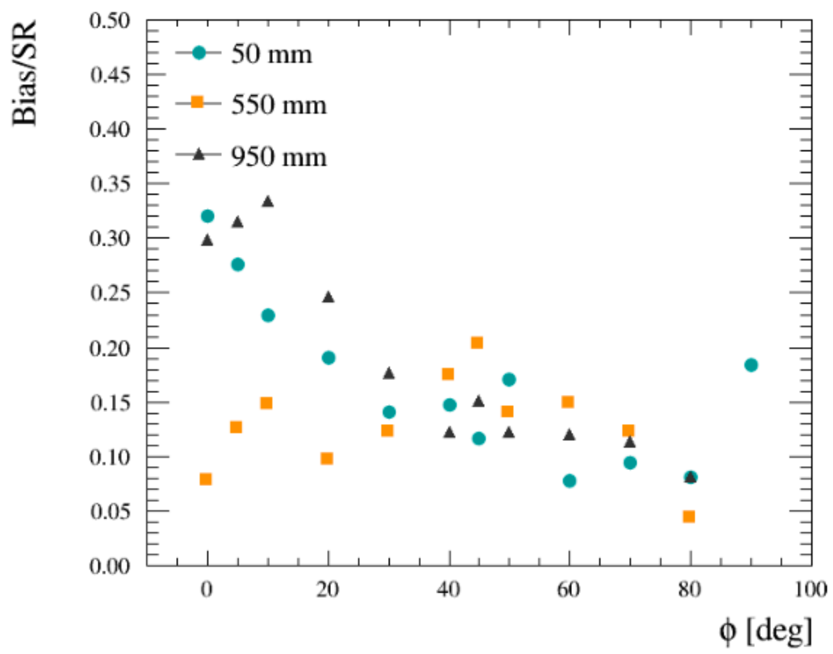
- Bias is a mean of the gaussian of the distribution of residuals per
- Biases are studies for both horizontal and inclined tracks
- Bias is a mean of the gaussian of the distribution of residuals per
- Bias dependence on drift distance and the magnetic field is observed → ExB effect

Larger biases are observed for short and long drift distances but not in the middle of the chamber!









Simulation of ERAM response

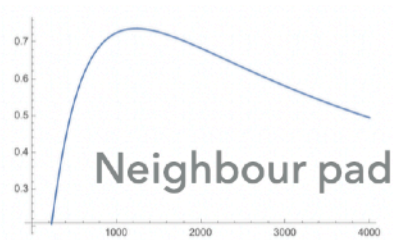
GEANT 4 → detResponseSim → CALIBRATION → RECONSTRUCTION

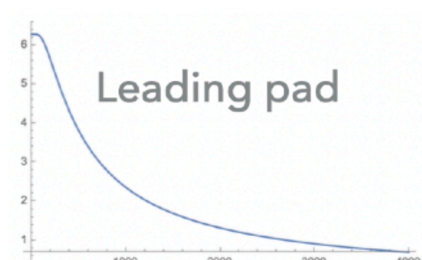
Work of S. Suvorov

Resistive layer (RC) → Diffusion equation $\Delta\rho = RC\frac{\partial\rho}{\partial t}$ → Solution: $\rho(\vec{r},t) = \frac{RC}{4\pi t}\times\exp\left(-\frac{r^2 RC}{4t}\right)$

Solution of diffusion equation (charge) integrated over pad size –> charge in pad

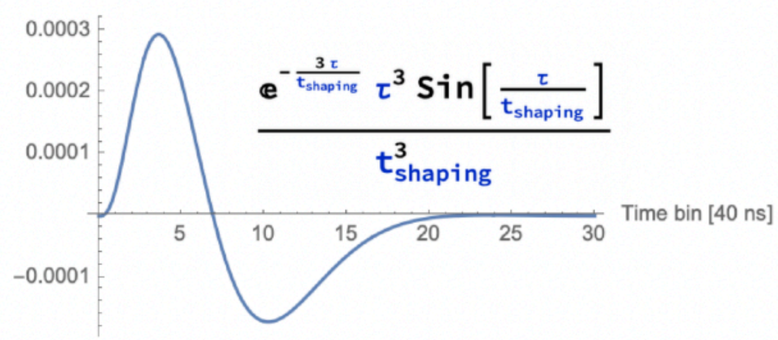
$$\frac{1}{2}\pi\left(\mathrm{Erf}\left[\frac{\sqrt{RC}\,x1}{2\sqrt{t}}\right]-\mathrm{Erf}\left[\frac{\sqrt{RC}\,x2}{2\sqrt{t}}\right]\right)\left(\mathrm{Erf}\left[\frac{\sqrt{RC}\,y1}{2\sqrt{t}}\right]-\mathrm{Erf}\left[\frac{\sqrt{RC}\,y2}{2\sqrt{t}}\right]\right)$$





+

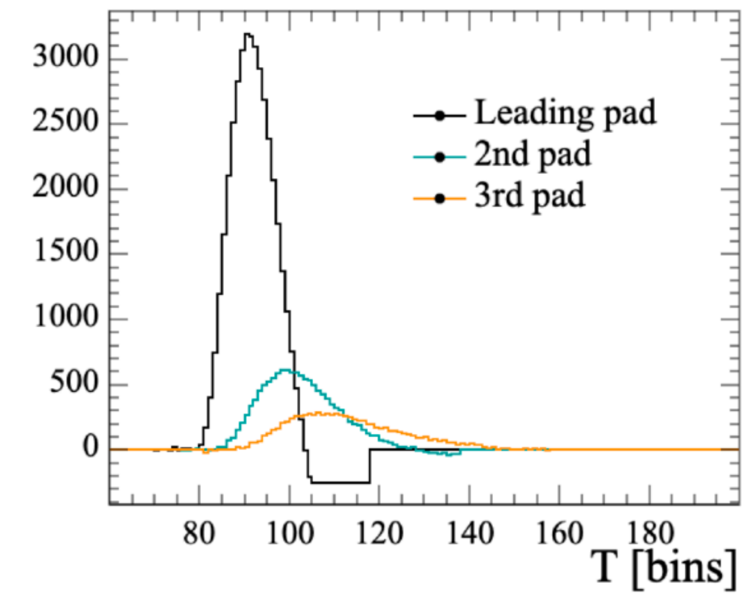
d(electronics)/dt



$$\frac{e^{-\frac{3\tau}{t_{shaping}}}\,\tau^3\,\mathrm{Sin}\left[\frac{\tau}{t_{shaping}}\right]}{t_{shaping}^3}$$

Convolution

Waveform



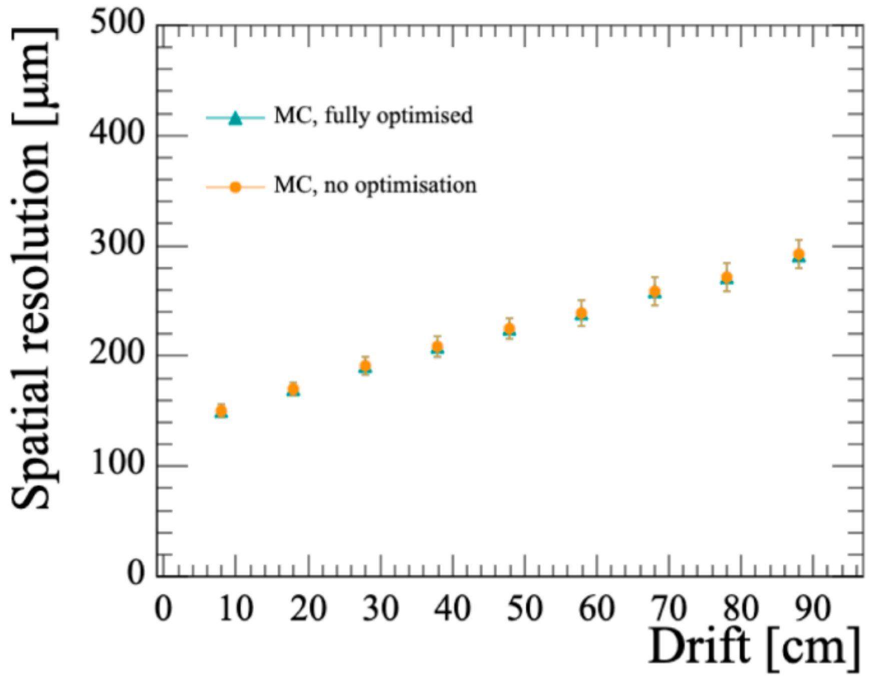
$$WF(t) = Q(t)\circledast\frac{dE}{dt}(t)$$

➡ Numerically heavy to implement convolution for each pad → need optimization

MC optimization

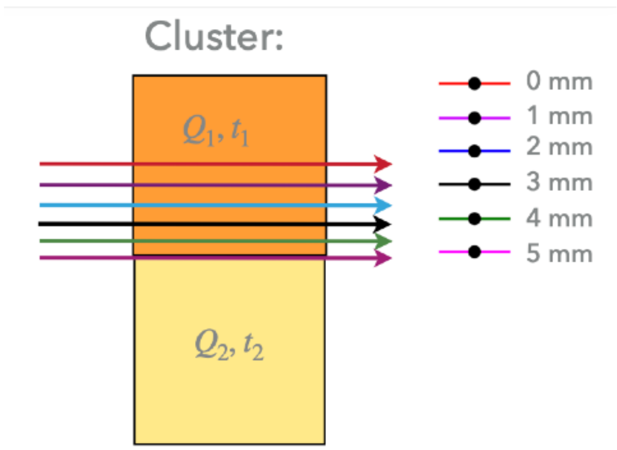
- Two algorithms are used to speed up computation:
  - Merge avalanches into "sub pads", e.g. 3x3
  - Pre-computation - compute WF at some grid
    - no computation at runtime (x4-5 faster)
    - *Before starting the production:*
      - *Q(t) w.r.t. RC and position in the pad*
        $Q_{tmp}(RC, x, y)(t)$
      - *Convolute Q(t)+dE/dt(t)) to obtain WF*
        $$WF_{tmp}(RC, x, y)(t) = Q_{tmp}(RC, x, y)(t) \circledast \frac{dE}{dt}(t)$$
      - *The WF for the particular avalanche is simply scaled from the pre-computed one for a given position with charge from G4*
        $WF(t) = Q * WF_{tmp}(RC, x, y)(t)$
    - *Precomputed files are downloaded automatically if exists*

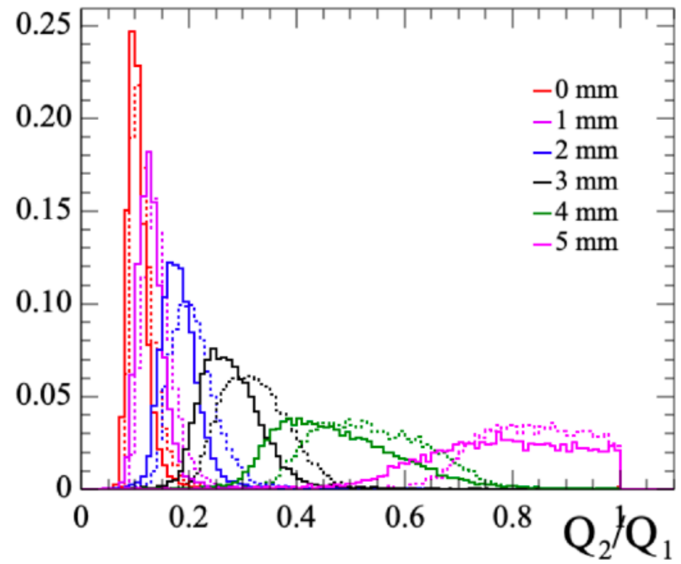
Work of
Sergey S.
Pierre B.

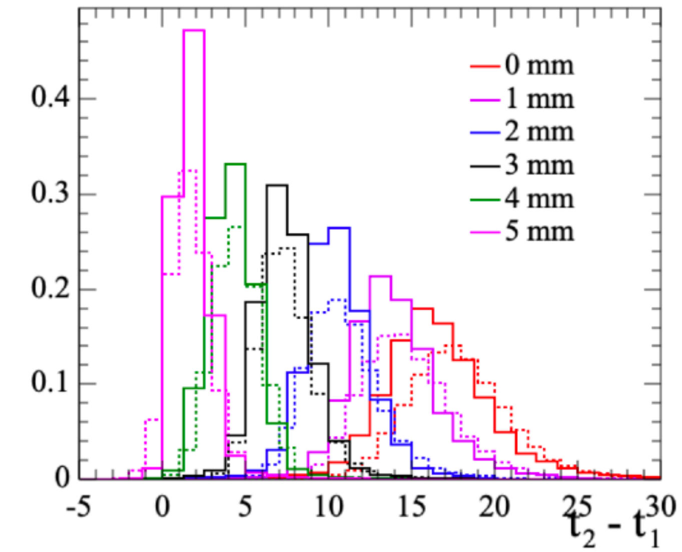


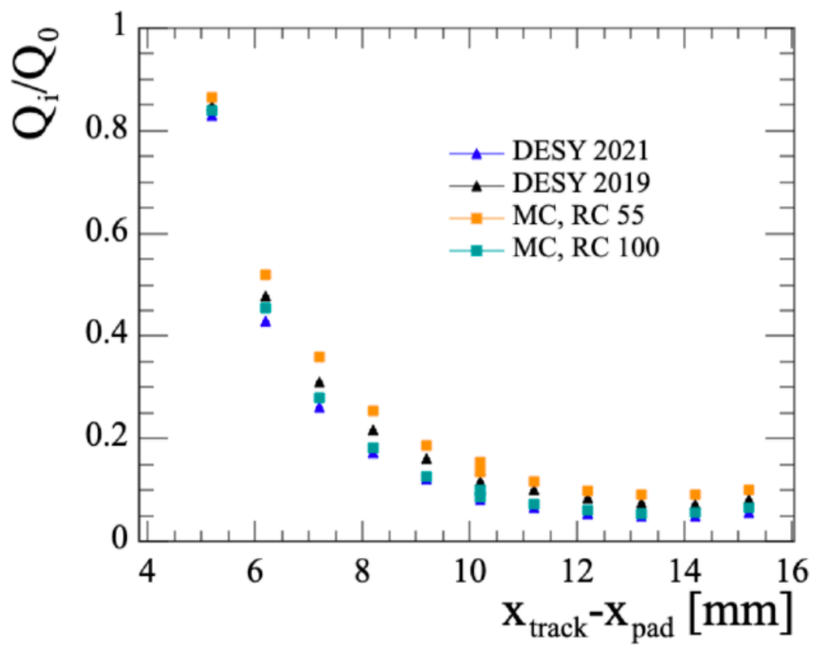
Charge spreading characterization

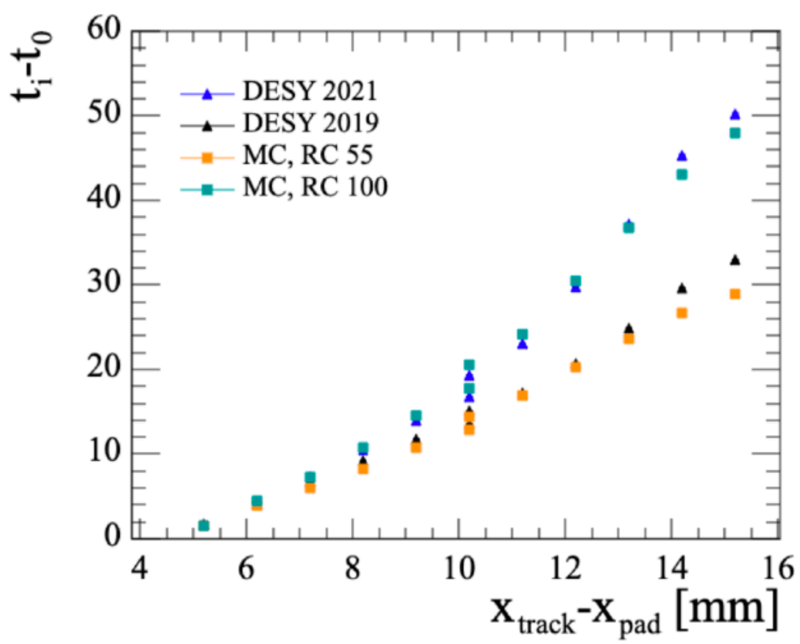
➡ Compare Data (DESY 21) and MC for low-level variables









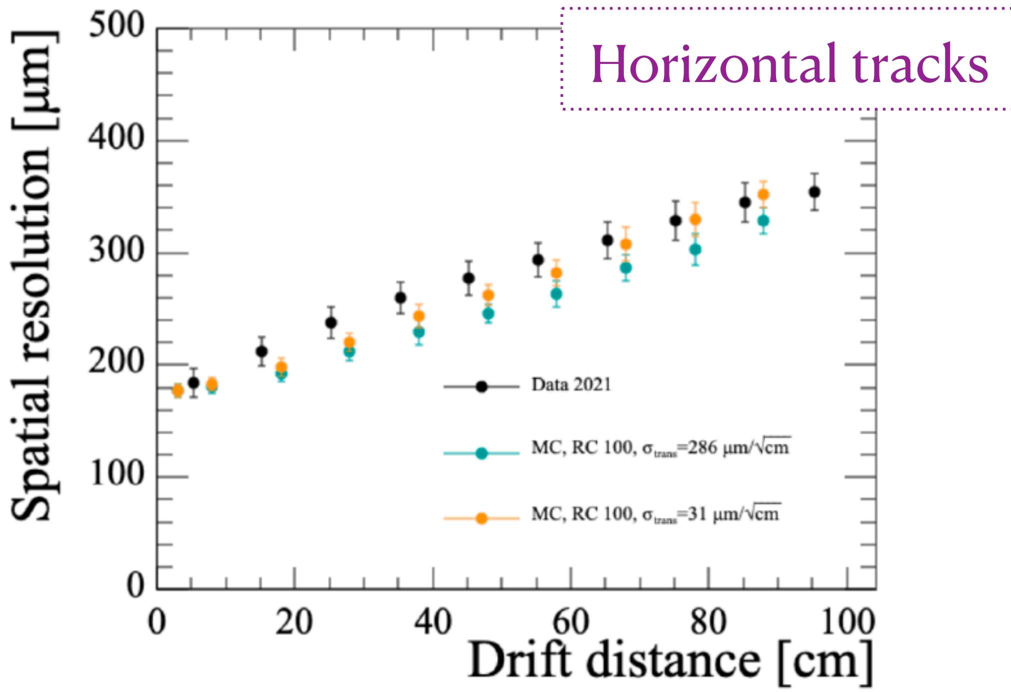


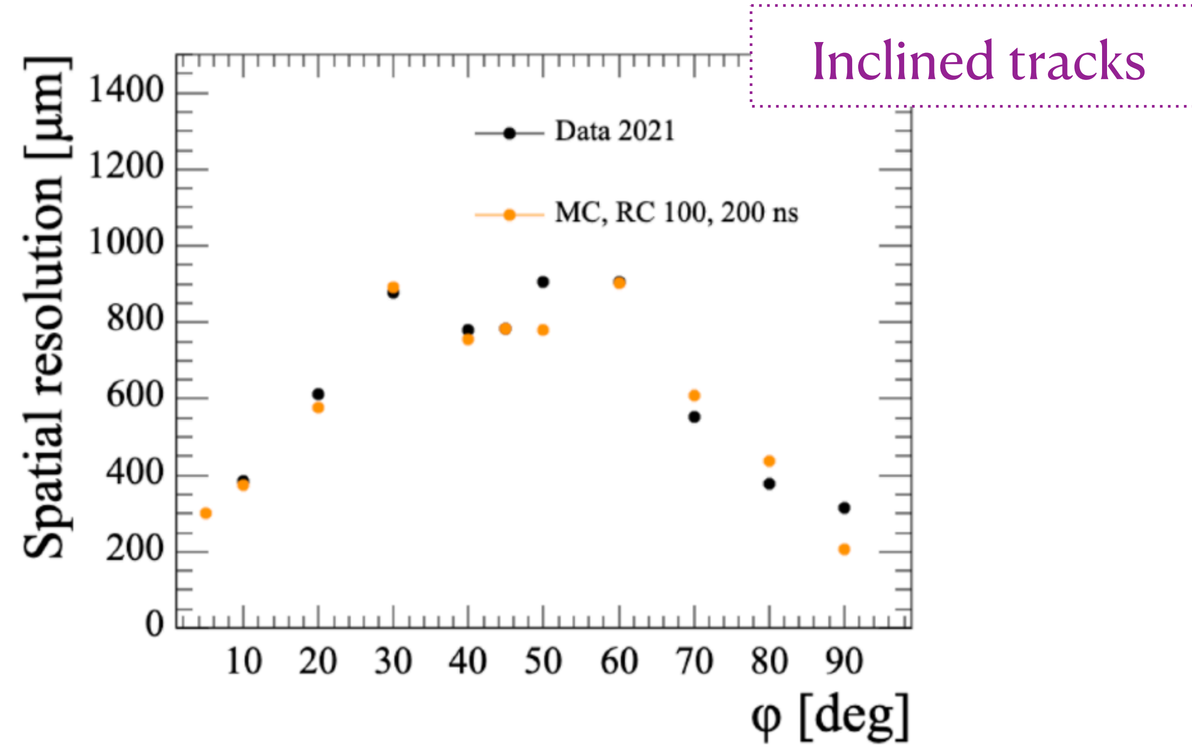
➡ DESY 21 data better reproduced with RC = 100ns/mm²

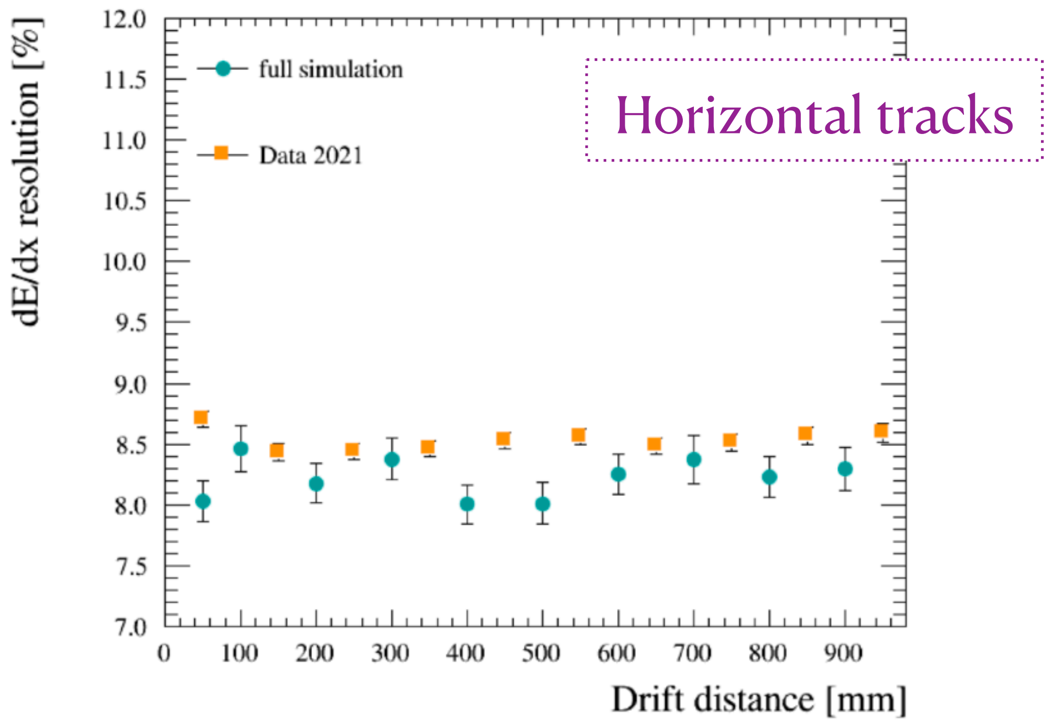
➡ MC/Data agreement is planned to be improved by using the RC from test beanch

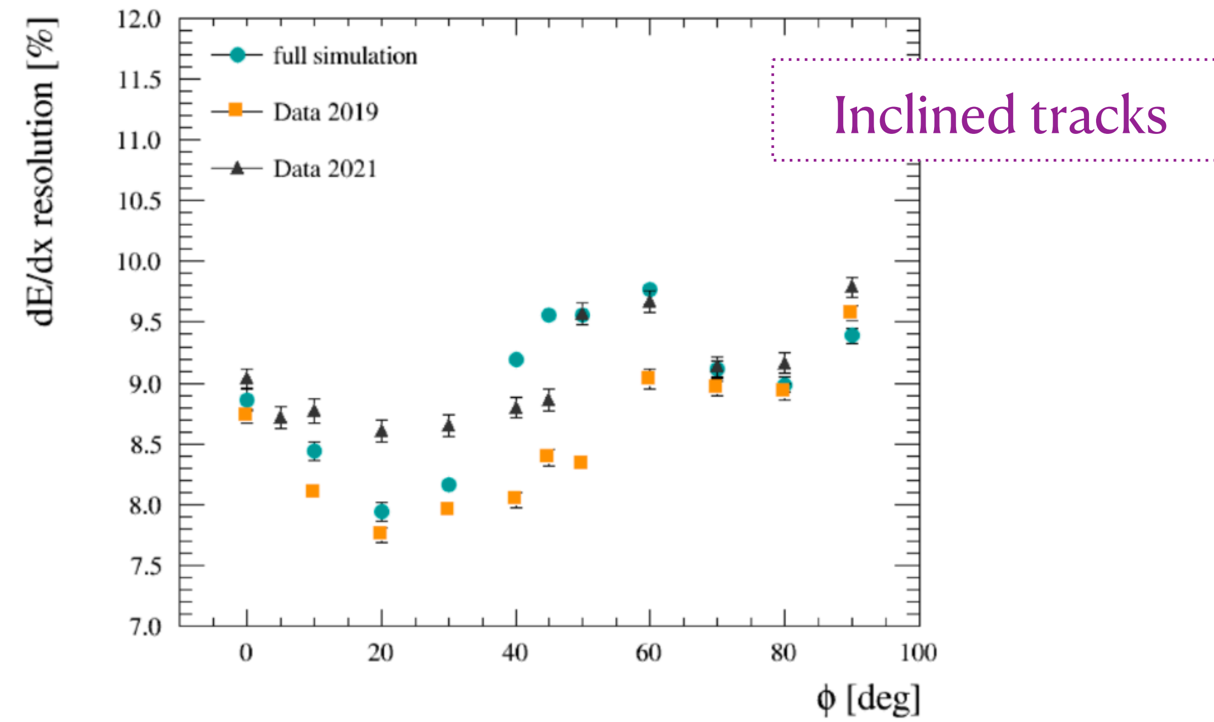
Work of S. Suvorov

Comparison between data and simulation

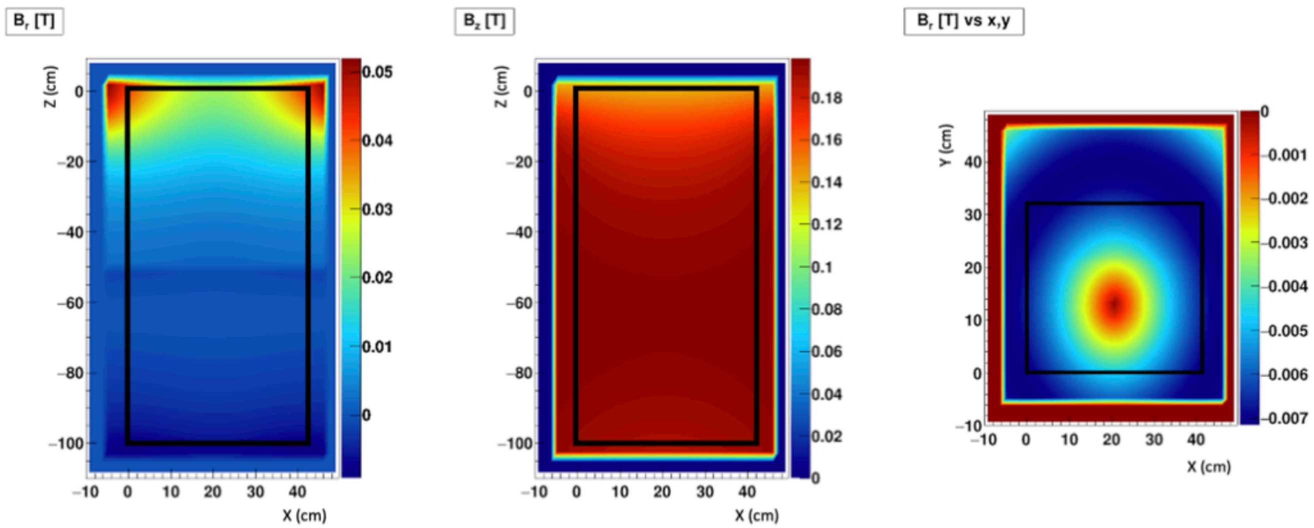




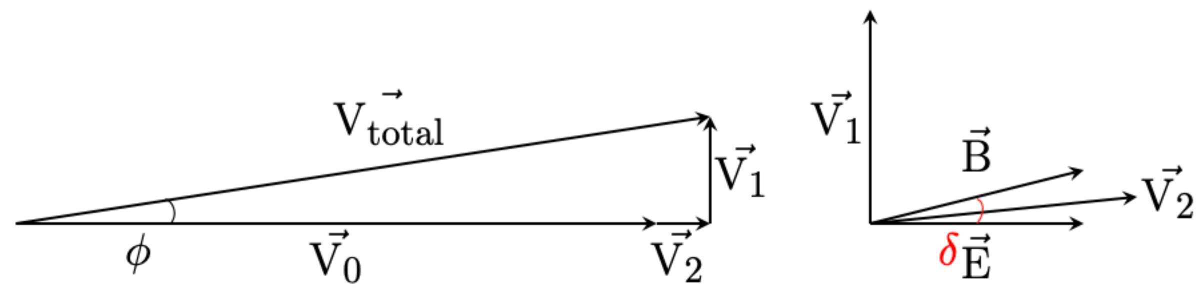


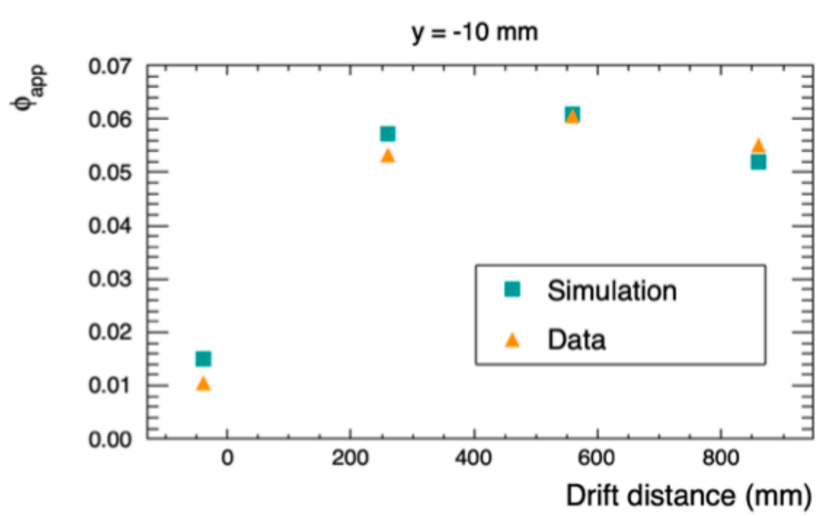


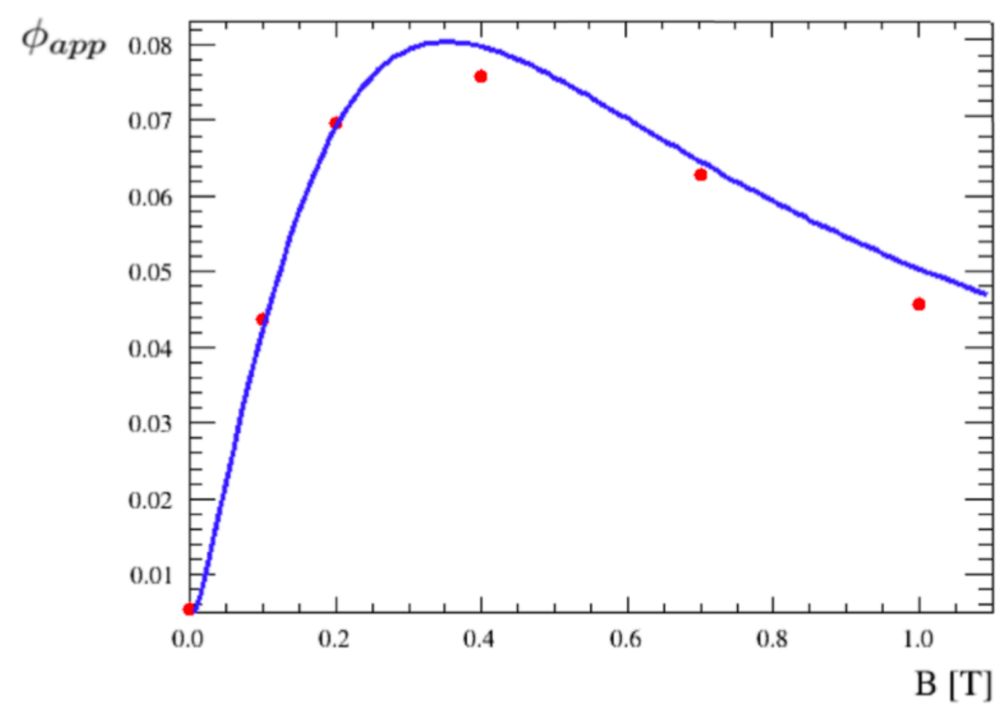
ExB effect



- Inhomogeneities of the magnetic field create distortions of the track (for example: incline the horizontal tracks)
- Track displacement angle **φ**







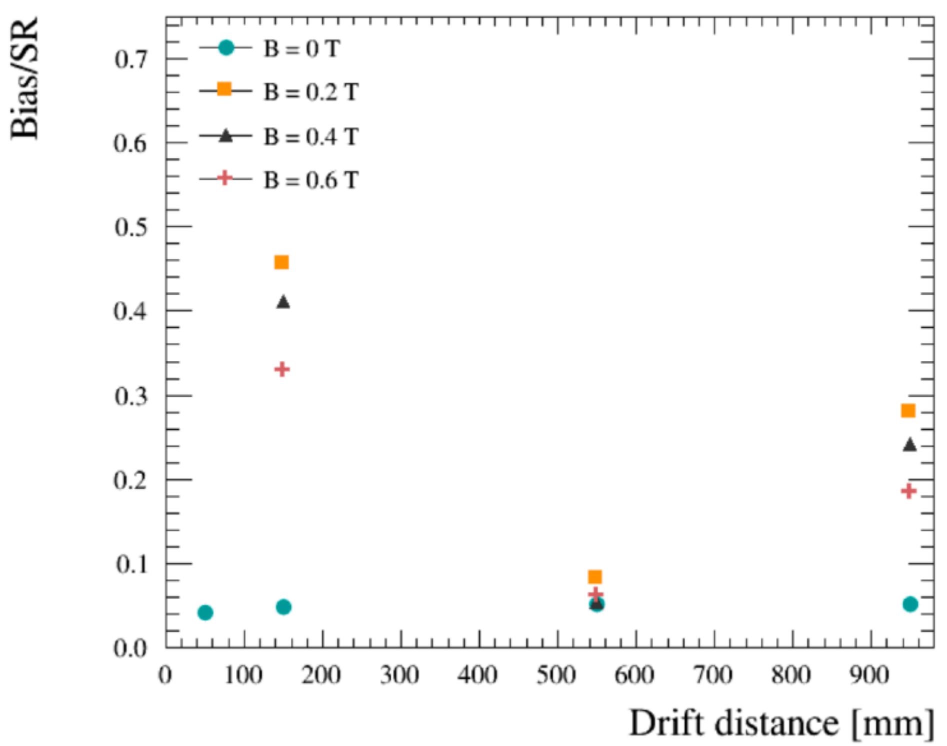
Work of
A. Ershova
L. Giannessi

- The E×B effect is stronger for moderate magnetic field (around 0.2-0.4 T) and weaker for the strong magnetic field

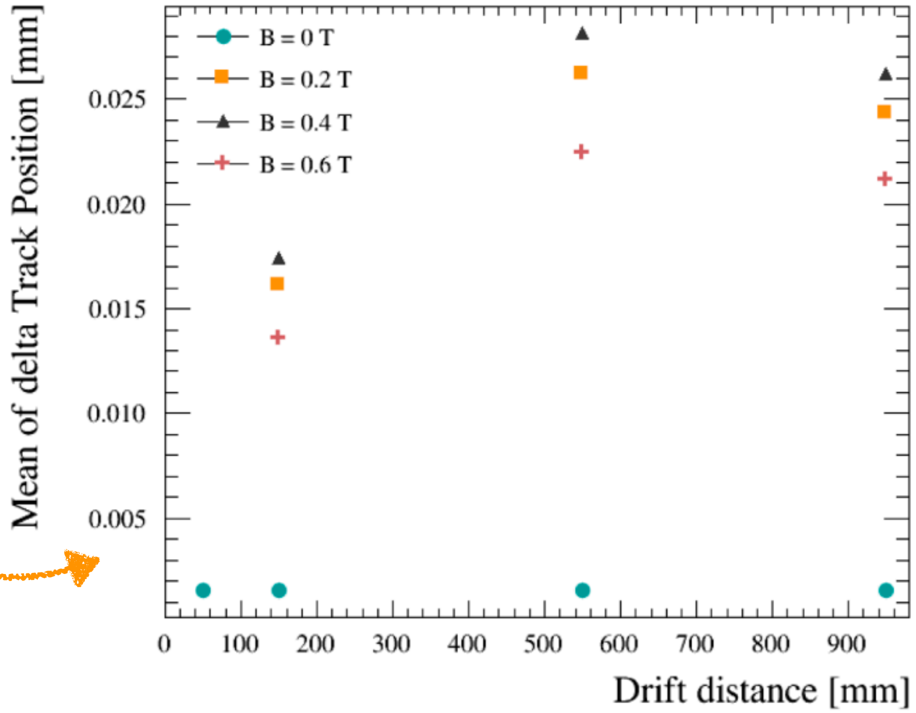
ExB effect

➡ Tracks are distorted more at lower B field

DESY 2021 data



- B = 0 T → No displacement in Y
- B > 0 T larger displacement for smaller B field



- B = 0 T → biases are small
- B > 0 T →larger biases for short and long drift distances
- B > 0 T →larger biases for smaller B field

➡ Ex B effect can be responsible for the observed biases

➡ the impact of the E×B effect is not observed in the spatial resolution or in the dE/dx resolution

Summary

➡ The performances of one prototype of the HA-TPCs with one ERAM for the T2K Near Detector upgrade during a test beam at DESY 2021 are shown

➡ Spatial resolution better than 800 μm is obtained for all the angles and all the drift distances using a dedicated clustering algorithm that is adapted to the track angle.

➡ Energy resolution better than 9.6% is obtained for all the angles.

➡ The data are compared with a simulation of the ERAM response. The simulation is able to satisfactory reproduce the observed charge sharing between neighboring pads.

➡ Spatial resolution and dE/dx resolution are also in good agreement between data and simulation.

➡ E x B effect was observed in the DESY test beam data.

➡ We are on a good track and have very nice and important results to publish

THANK YOU!