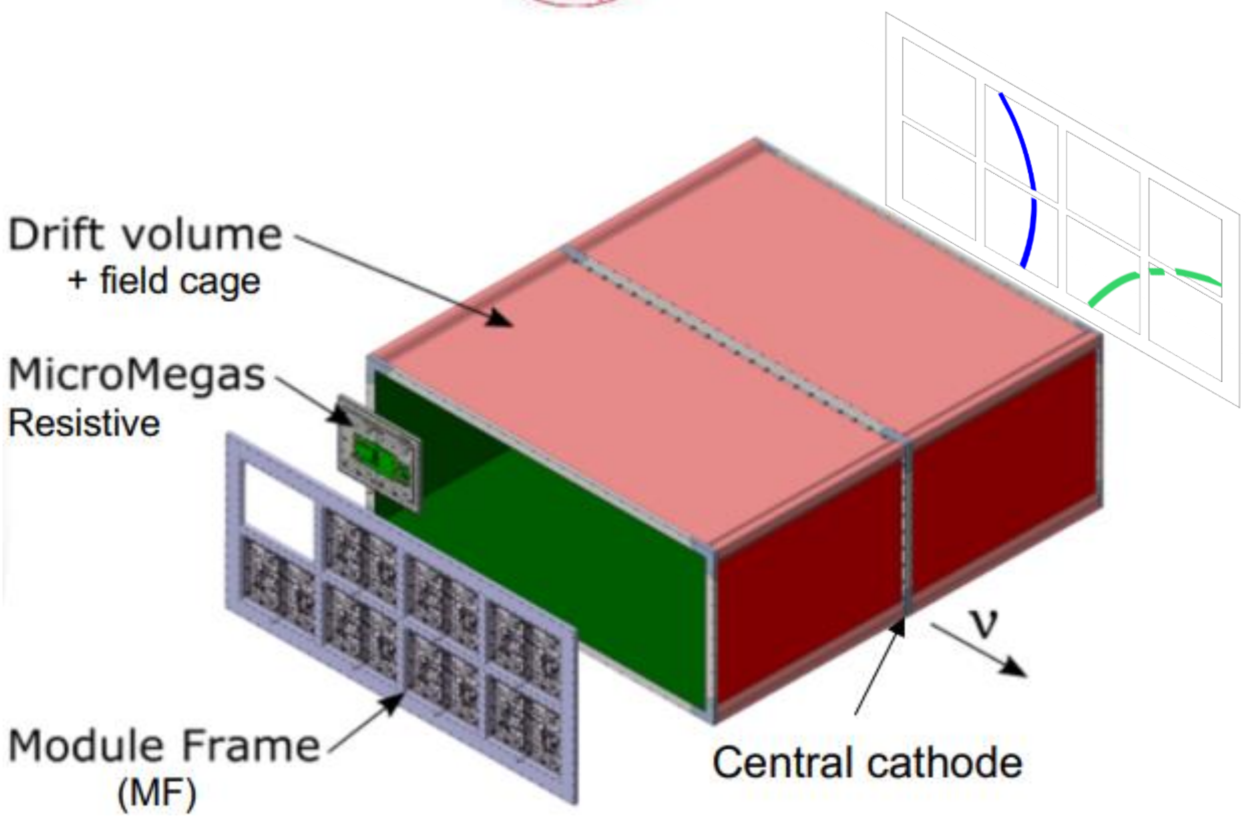
The new TPCs for the Upgraded Near Detector of the T2K Experiment

15th Pisa Meeting on Advanced Detectors
La Biodola, isola d'Elba
22-28 May 2022

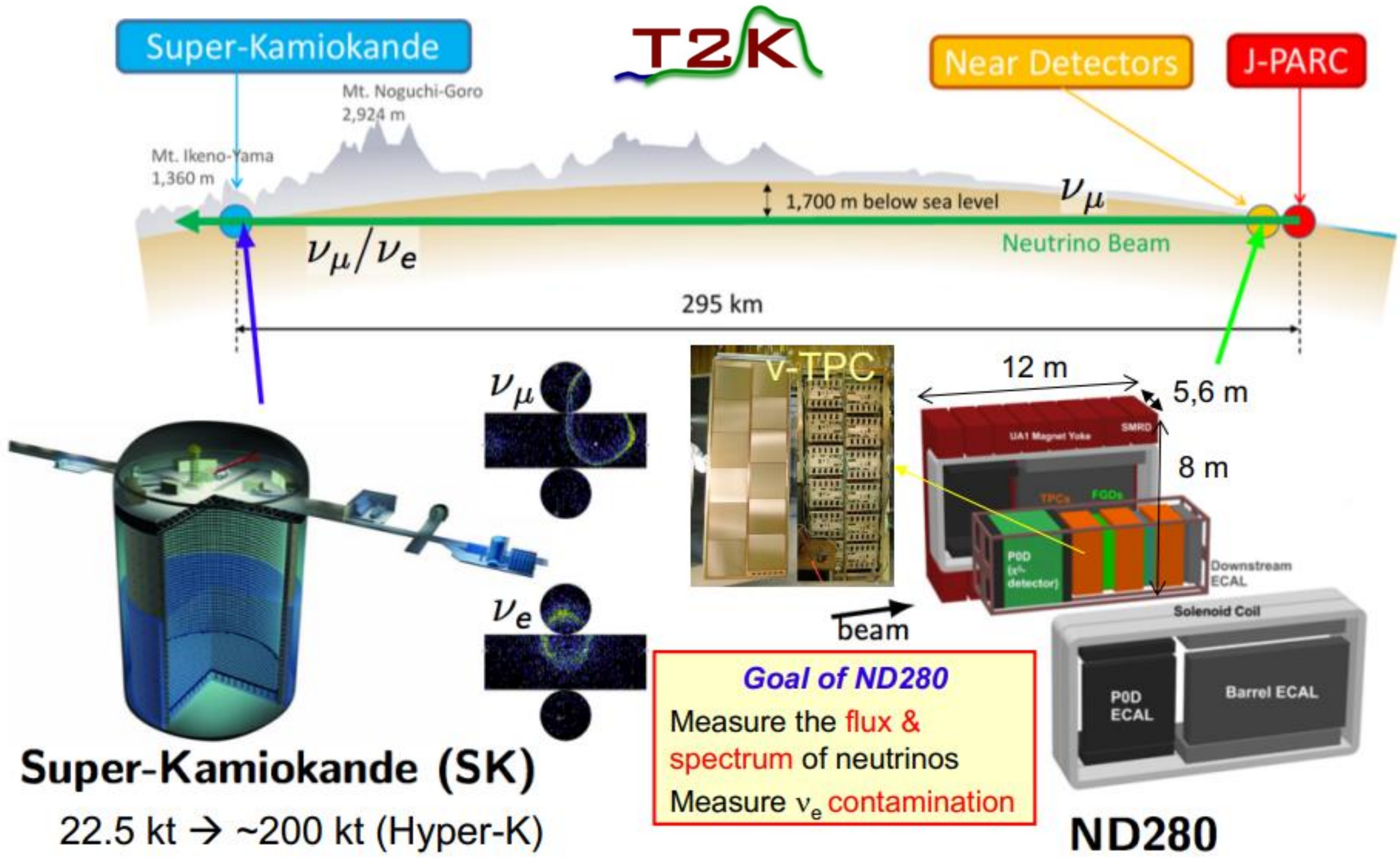
G.Collazuol on behalf of the ND280 Upgrade collaboration
Department of Physics and Astronomy
University of Padova and INFN



Overview

- ND280 Upgrade and HATPC
- Field Cages
- Resistive MicroMegas detectors
- FE & RO Electronics and DAQ
- Performances

T2K Experiment and ND280 Near Detector



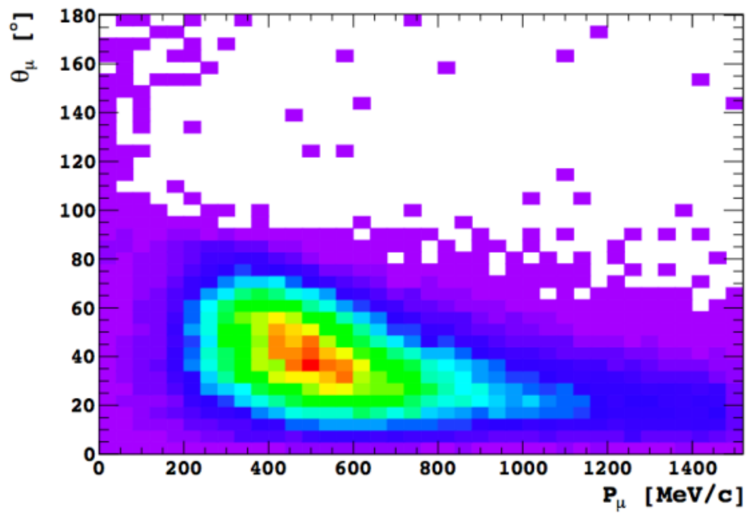
Goal of T2K-II phase (2023-) data taking after main ring upgrade is to measure δCP at 3σ thanks to a decrease in systematics in ND280 (6% → 4%)

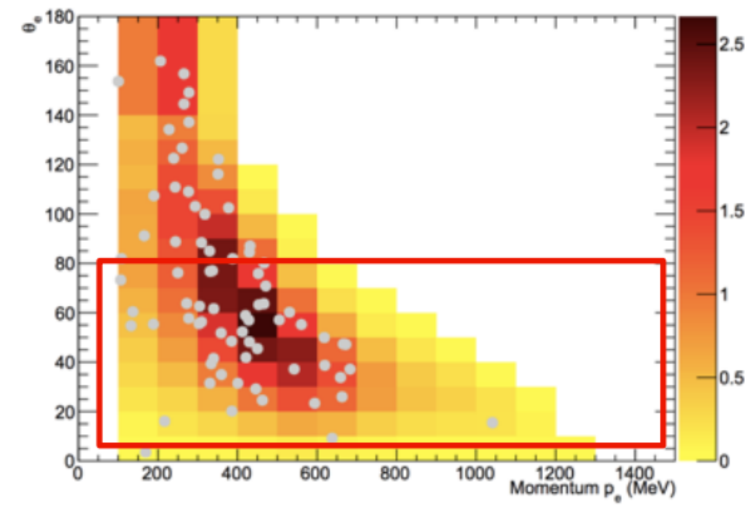
… and later (2027-) ND280 to serve as Near Detector for Hyper-K

ND280 Upgrade

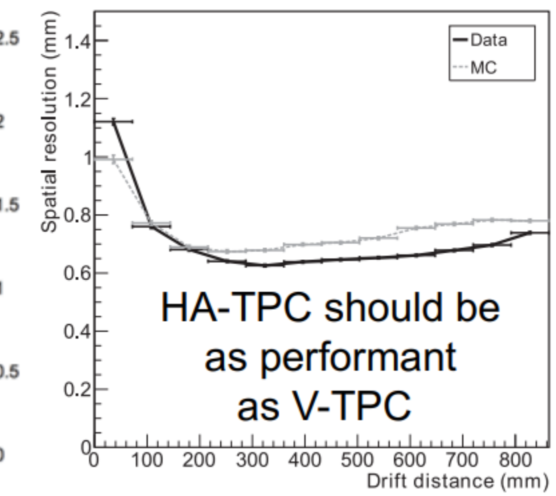
ND280 upgrade TDR arXiv:1901.03750v1

Reconstructed momentum and angle for
μ selected @ present ND280   electrons selected @ SK



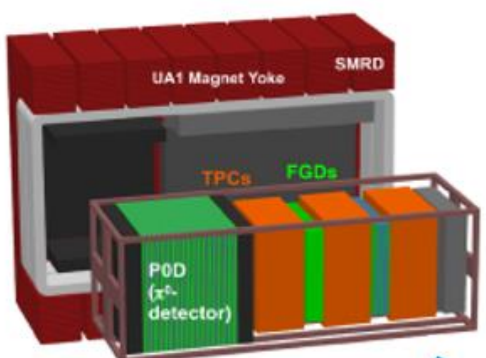


V-TPC spatial resolution
6.9x9.7 mm^2 pads



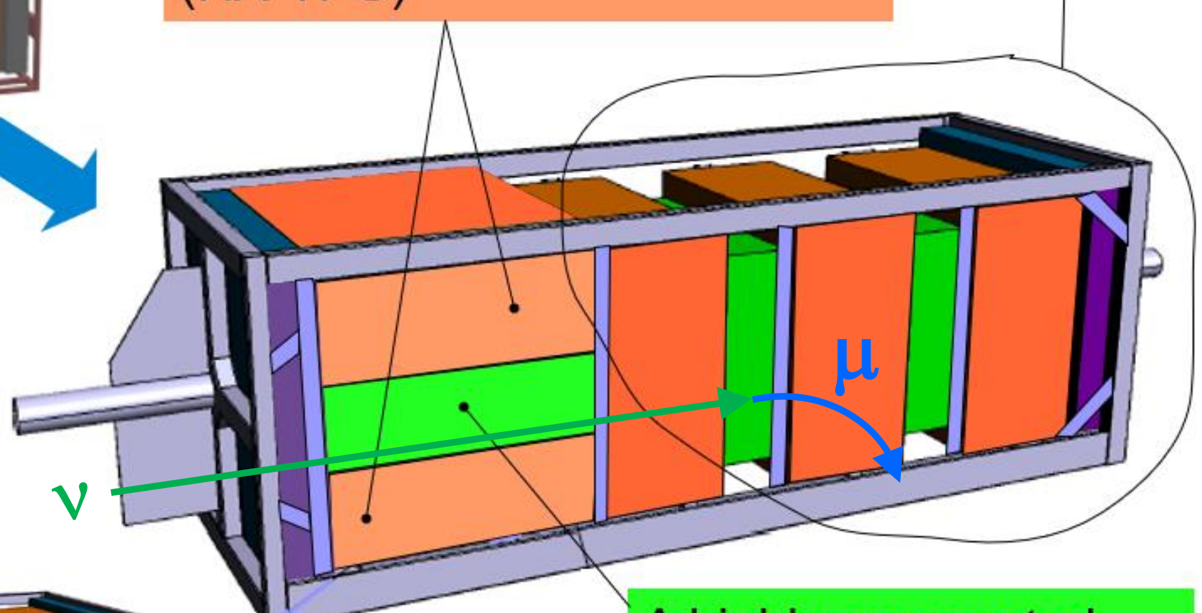
T2K V-TPC NIM A659 (2011)

Inside former UA1 magnet

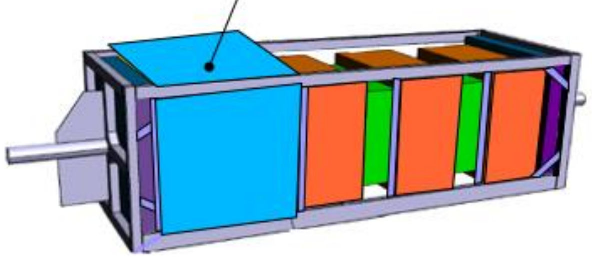


No changes to other detectors

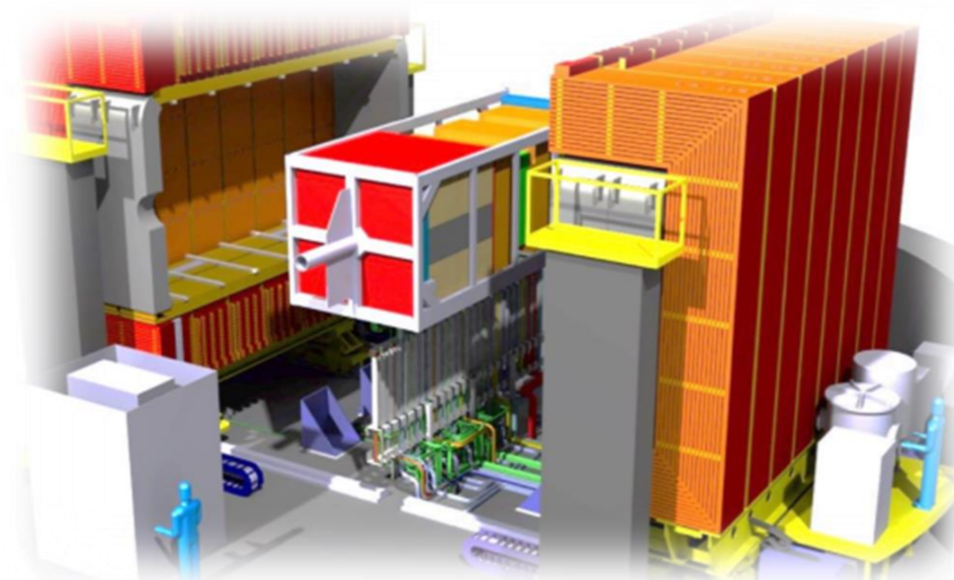
Two new High-Angle TPCs (HA-TPC)



Six ToF Scintillator planes all around



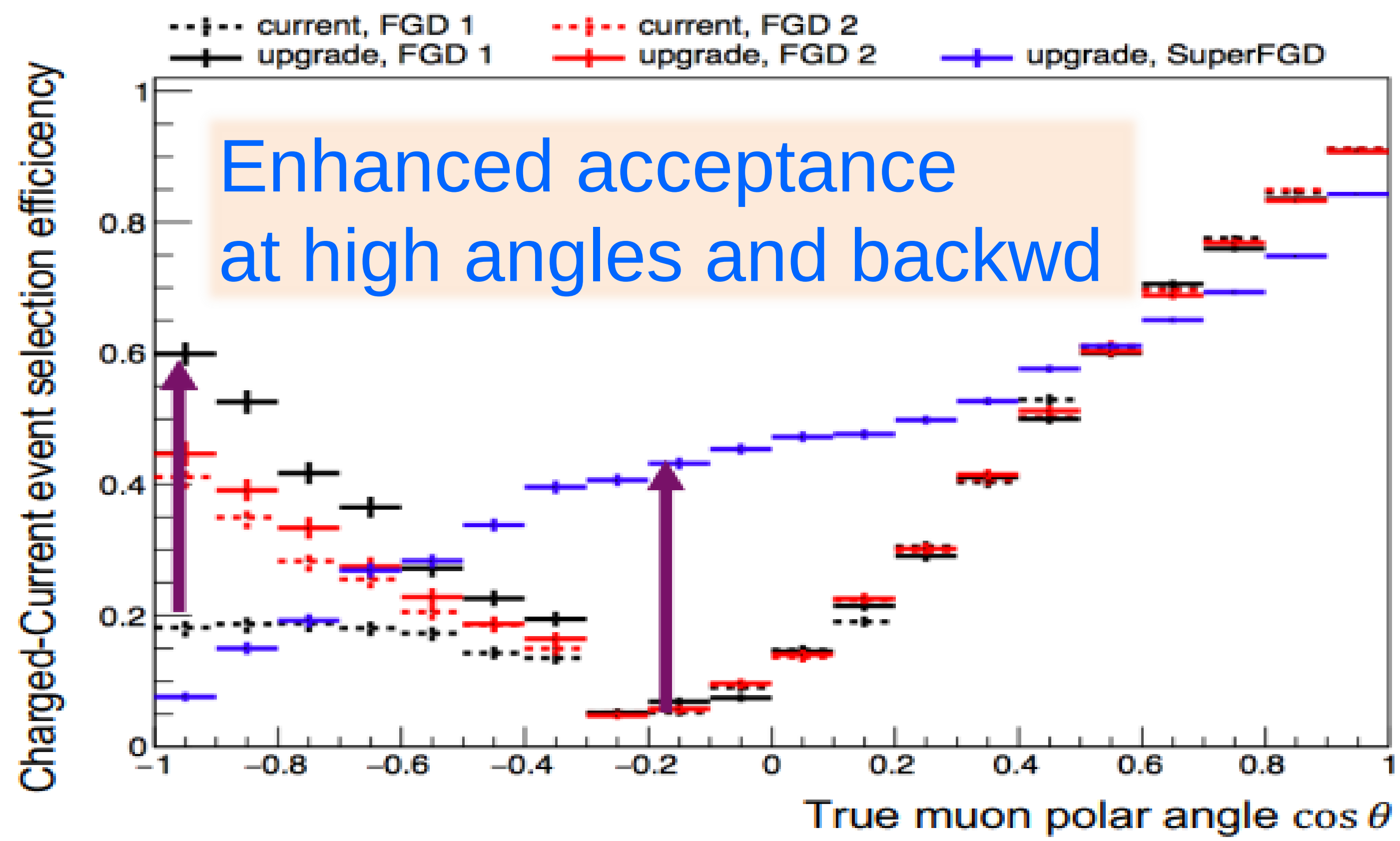
A highly segmented scintillator active target (SuperFGD)



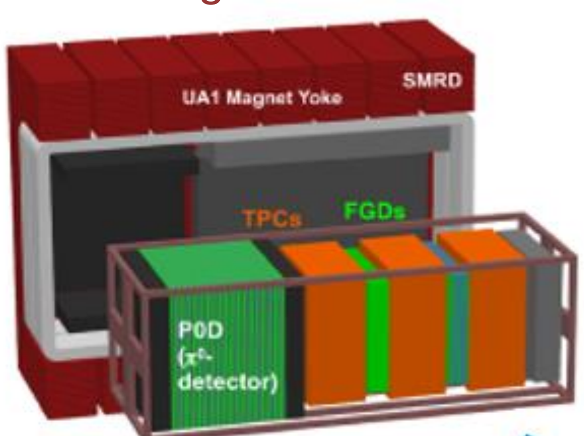
T2K

ND280 Upgrade

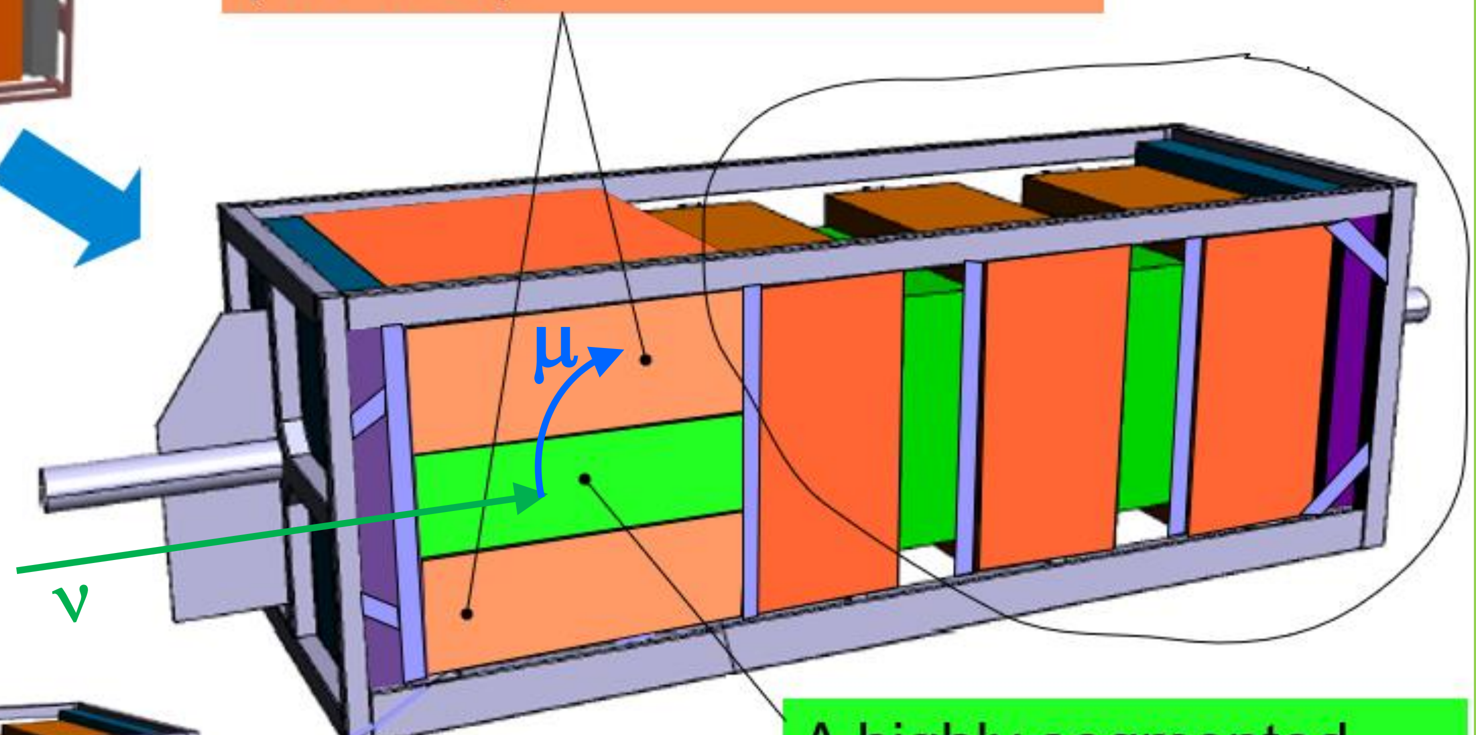
ND280 upgrade TDR
arXiv:1901.03750v1



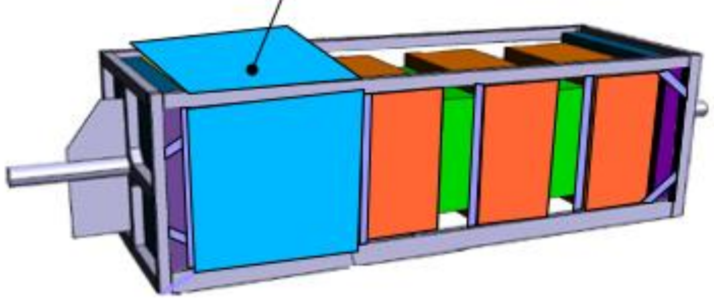
Inside former
UA1 magnet



Two new High-Angle TPCs
(HA-TPC)

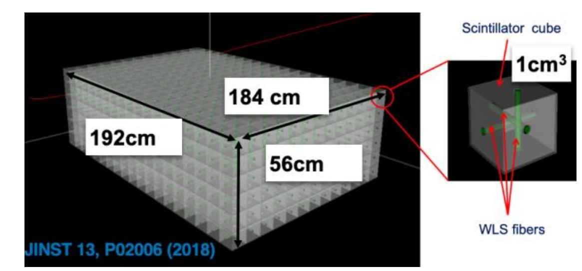


Six ToF
Scintillator
planes all
around



A highly segmented
scintillator active target
(SuperFGD)

Super FGD
New detector concept
2×10^6 $1 cm^3$ cubes
each cube read by 3 WLS
→ 3D view Super-FGD



High Angle TPC

High Angle TPC design

Momentum resolution $\sigma_p/p < 9\%$ at 1GeV/c
(neutrino energy estimate)

Energy resolution $\sigma_{dE/dx} < 10\%$
(PID muons and electrons)

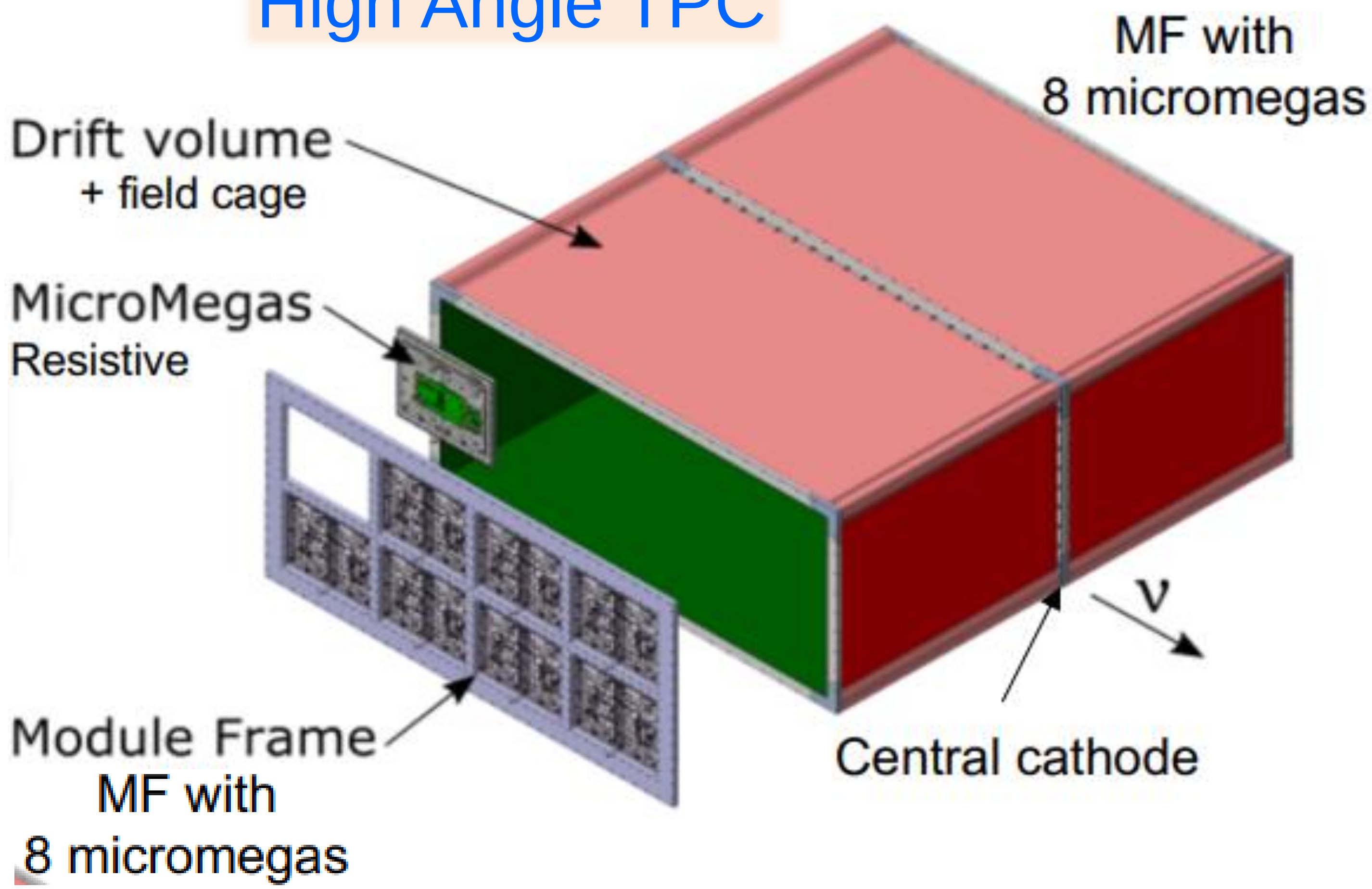
Space resolution O(500 μm)
(3D tracking & pattern recognition)

Low material budget walls ~ 5% X_0
(matching tracks from neutrino active target)

Given Bfield = 0.2T goals achieved with:

- Atmospheric pressure TPC (T2K mix gas) … few mbar overpressure to keep contamination O_2 and H_2O @ O(10ppm)
- Drift length ~ 1m → Cathode at ~ -27kV
- Sampling length ~ 80 cm
- Resistive MicroMegas w/ pad size ~ $1cm^2$
- E field uniformity < 10^{-4} @1cm from walls

High Angle TPC



Parameters	HATPC	VTPC
Overall x × y × z (m)	2.0 × 0.8 × 1.8	0.85 x 2.2 x 1.8
Drift distance (cm)	100	90
Magnetic Field (T)	0.2	
Electric field (V/cm)	275	
Gas $Ar-CF_4-iC_4H_{10}$ (%)	95 - 3 - 2	"T2K" gas mix
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	

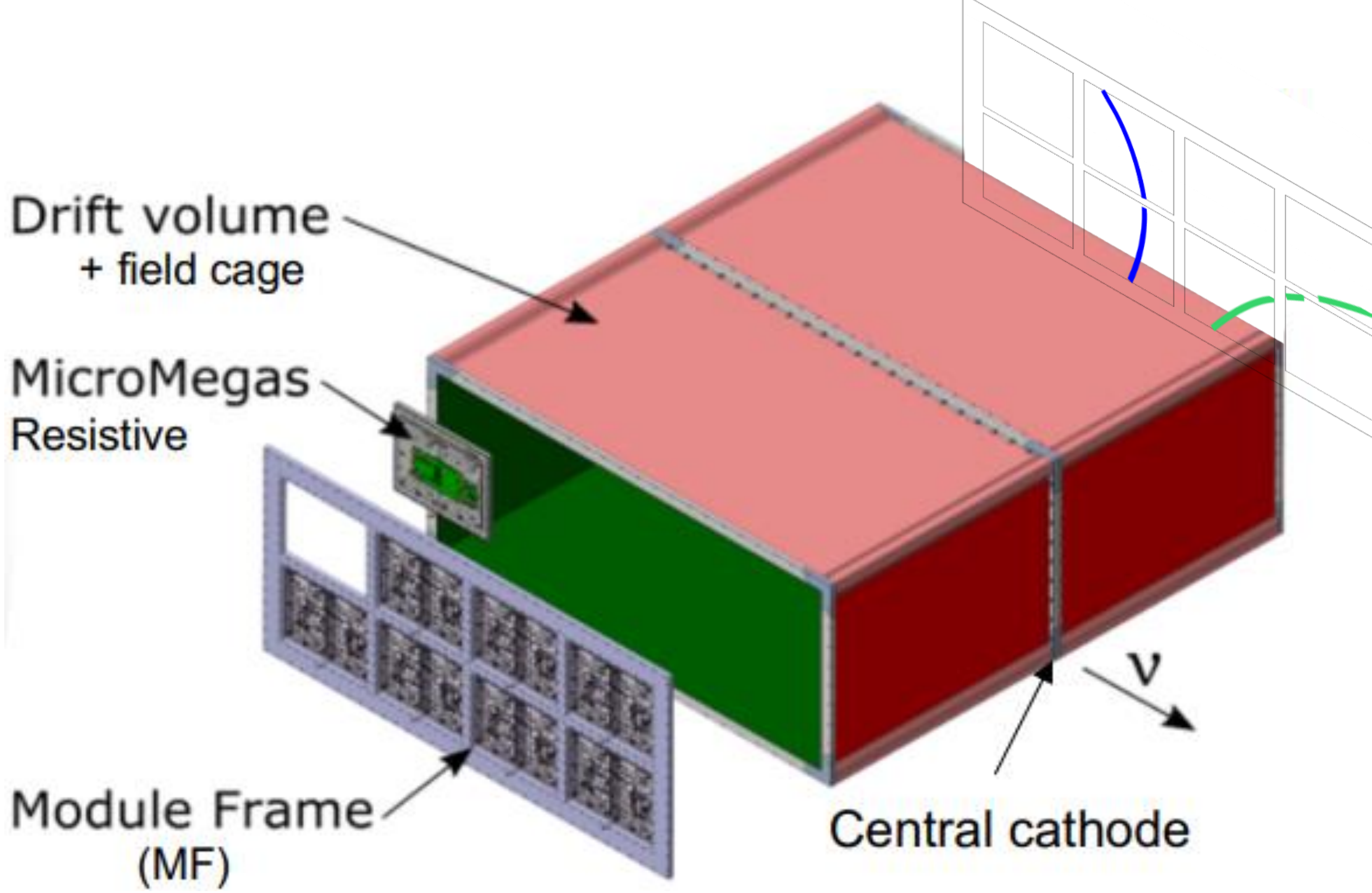
High Angle TPC

Atmospheric pressure TPC

- Drift length 1m
- Central Cathode @ -27kV
- E field unif. < 10^{-3} @1cm from walls
- Low material budget walls
- Contamination at O(10 ppm) level

Resistive MicroMegas sensors

- Sampling length ~ 80 cm
- pads ~ $1cm^2$
- 10k+10k channels / TPC @ Anodes



New Field Cage → thin walls, lightweight & robust
→ Thin walls & low Z, made of solid dielectric composite materials
→ Rectangular shape to minimize dead space & maximize tracking volume
→ Electric field uniformity better than 10^{-4} @1cm from walls obtained by
- Mechanical accuracy → inner surfaces planarity & parallelism ~ O(0.2mm/m)
- Suitable electrode design

New MicroMegas detectors → “Encapsulated Resistive Anode” (ERAM)
→ Charge spread: high space resolution with low pads density (fewer FEE chs.)
→ intrinsic spark protection: simplified & compact FE electronics

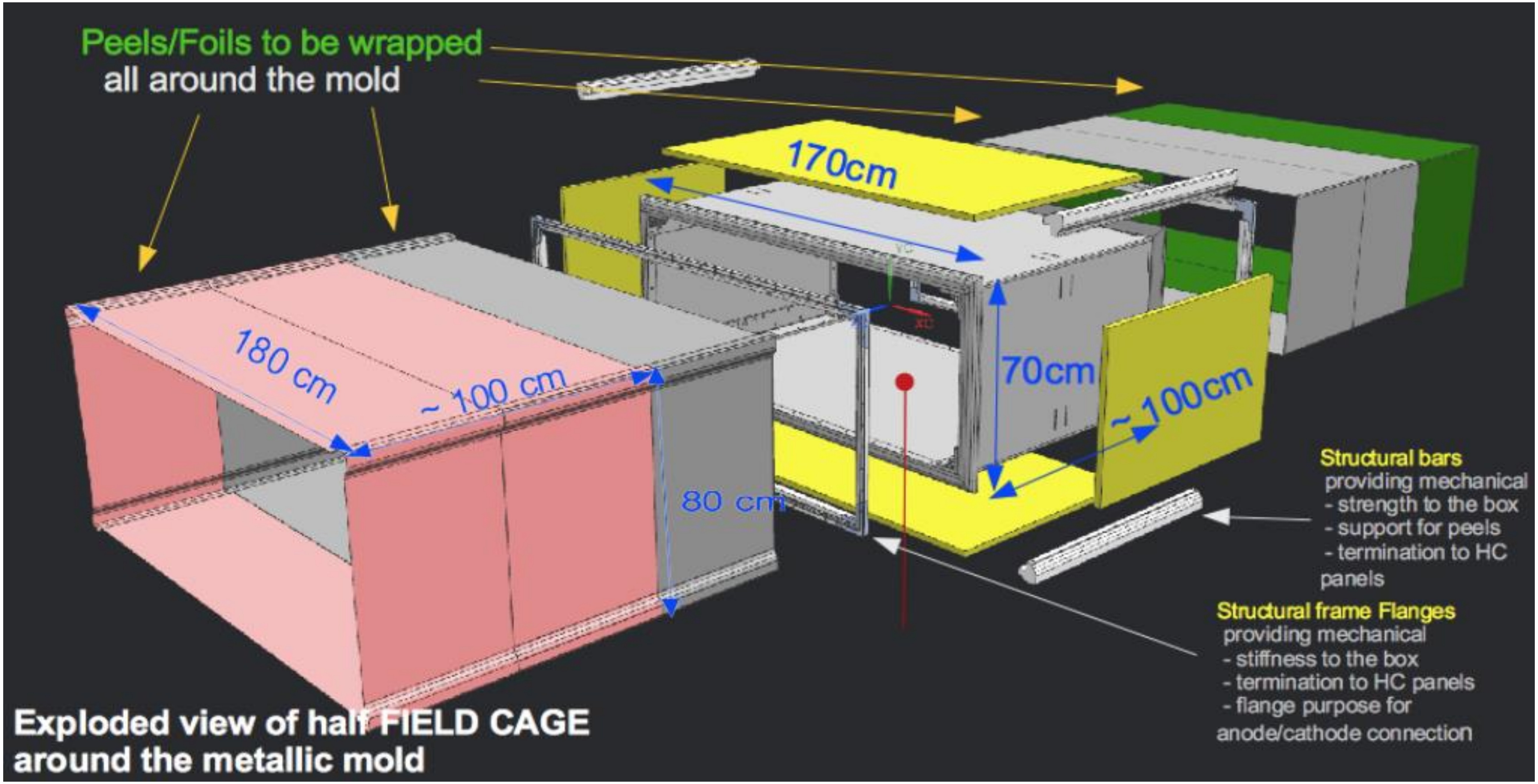
Field Cage

HATPC made of 2 half rectangular Field Cages

- Dielectric, low-Z materials
- Composite materials techniques
- Thin walls laminated on a mold

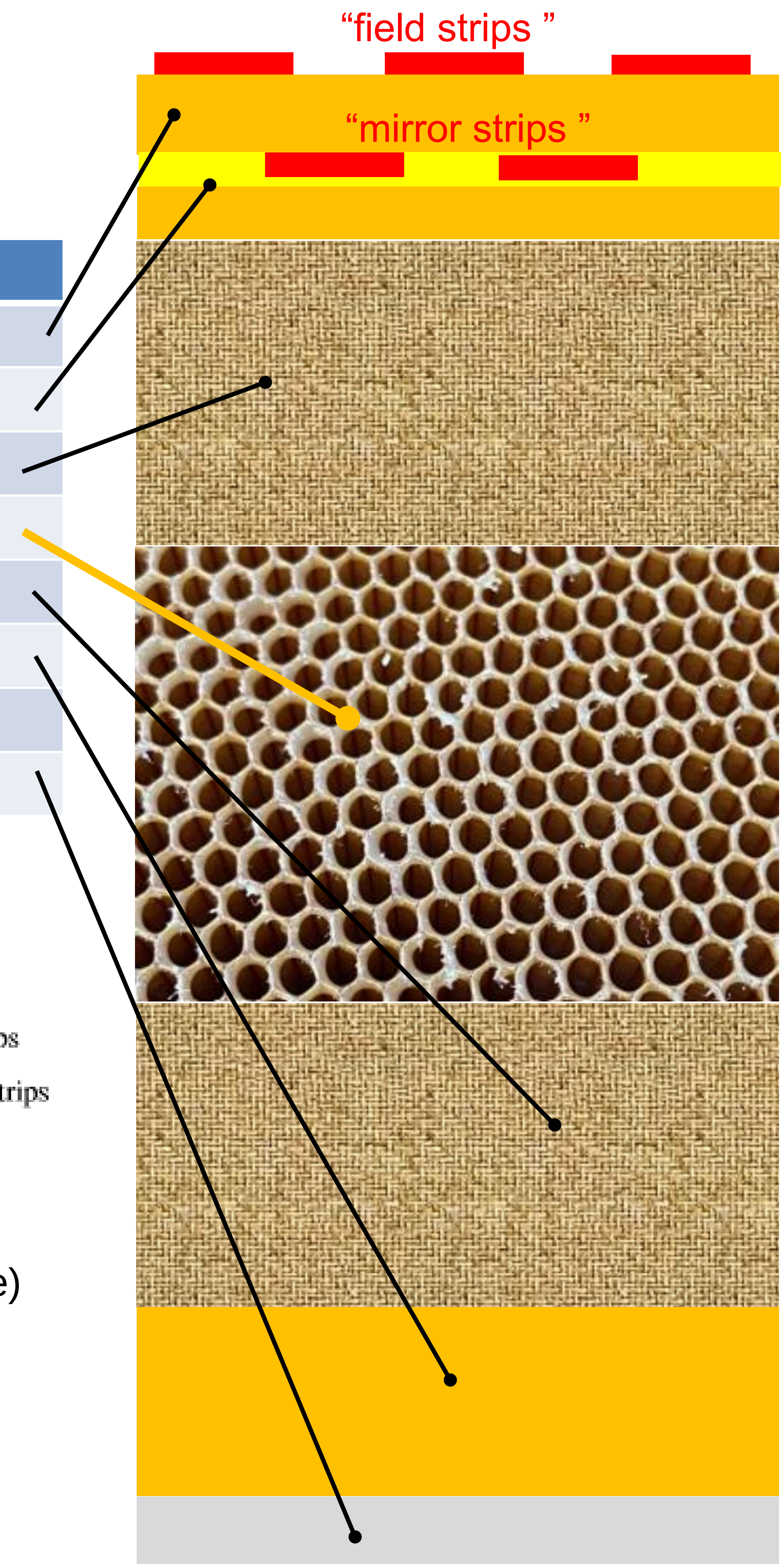
Mechanical tolerances

- Cathode flatness and ERAM plane flatness better 0.2mm/m
- Field Cage walls flatness better tham 0.2mm/m
- Cathode/Anode planes parallel to within 0.2mm/m



Field Cage – layers

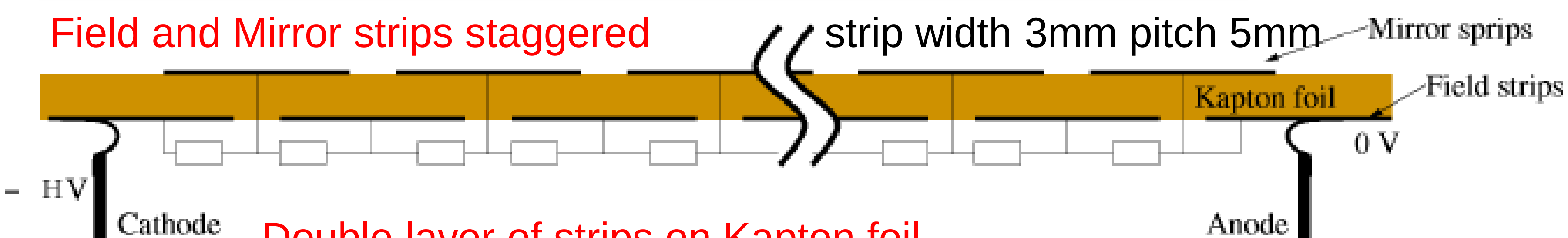
Material	Thickness
Cu Strips on Kapton foil (electrodes)	Cu 17μm / Kapton 50μm / Cu 17μm
“Coverlay” (strip insulation / protection)	Glue 20μm / Kapton 25μm
Aramid Fiber Fabric (Twaron™)	2mm
Aramide HoneyComb panel	35mm
Aramid Fiber Fabric (Twaron™)	2mm
Kapton foil (insulation)	125μm
Aluminum foil (external shield)	50μm
Total	~40mm / ~ 6% radiation length



Electric field shaping

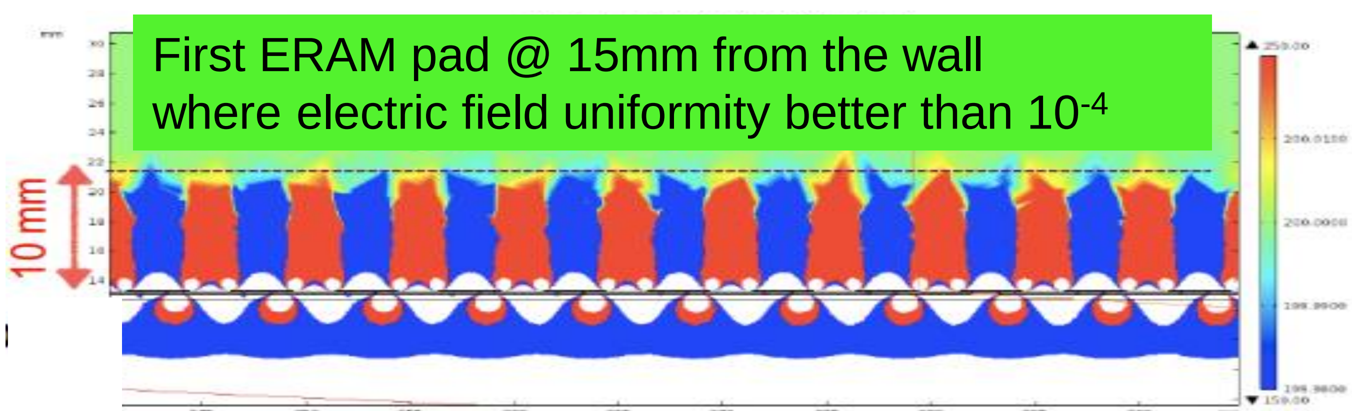
Field and Mirror strips staggered

strip width 3mm pitch 5mm



Double layer of strips on Kapton foil

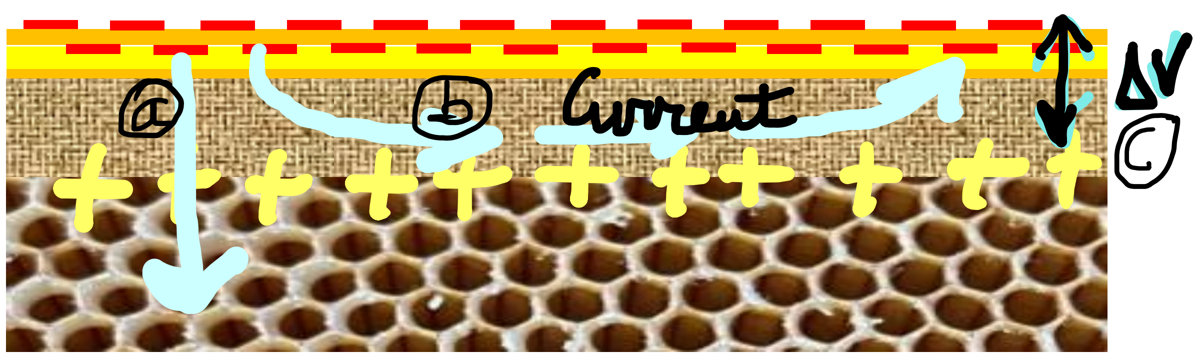
Dimensions = 5m (inner surface cage perimeter) x 1m (drift distance)



Simulation Electric Field near walls

Field Cage – 2 key points

1) Volume resistivity of each layer material > 10^{12} Ωcm



- Layers surface is huge O(5m^2)
- single Cu strip surface is large O(150cm^2)

→ "Low" resistivity layers might result in

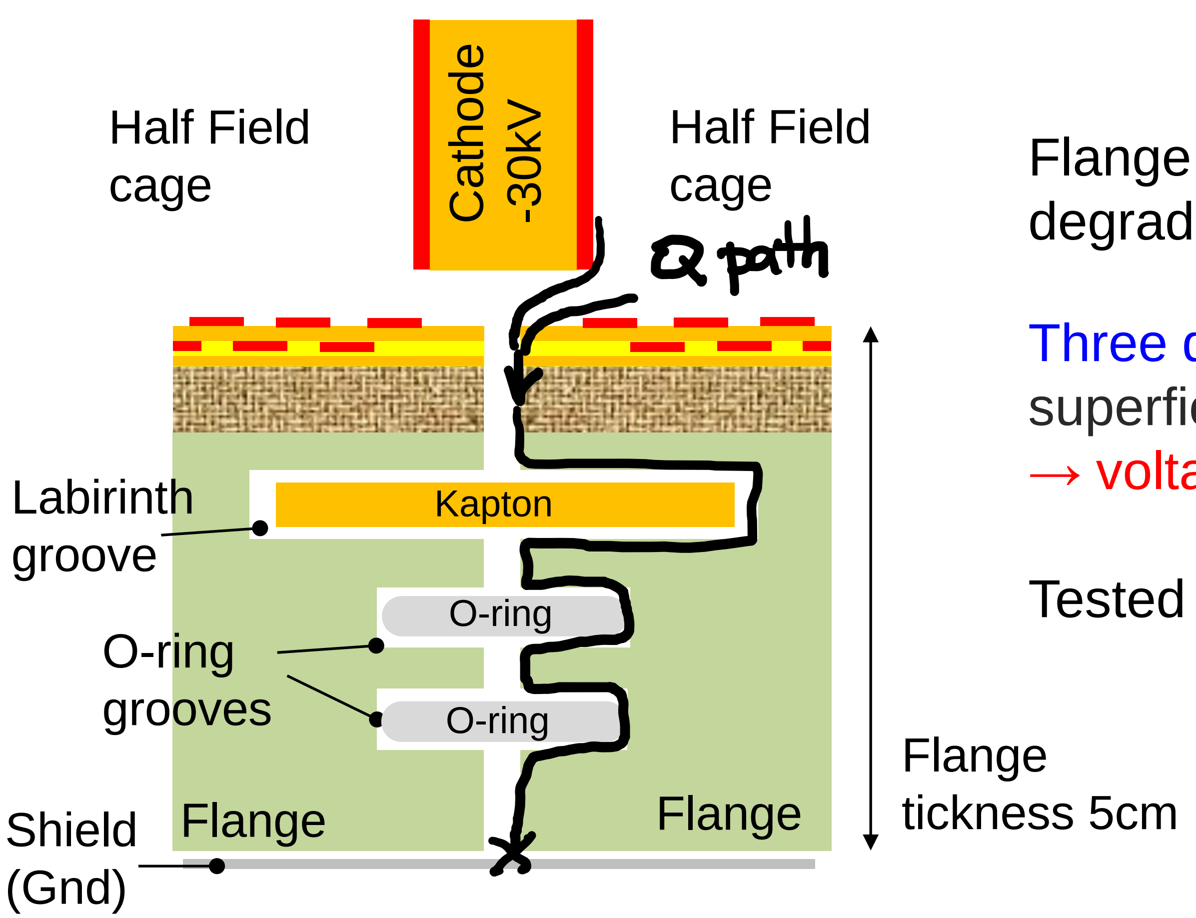
(a) Leakage currents from inside to shield

(b) Extra-currents parallel to divider current

(c) Dielectric breakdown

Note: glues weekest materials

2) Long path for superficial charge and gas @ cathode flanges



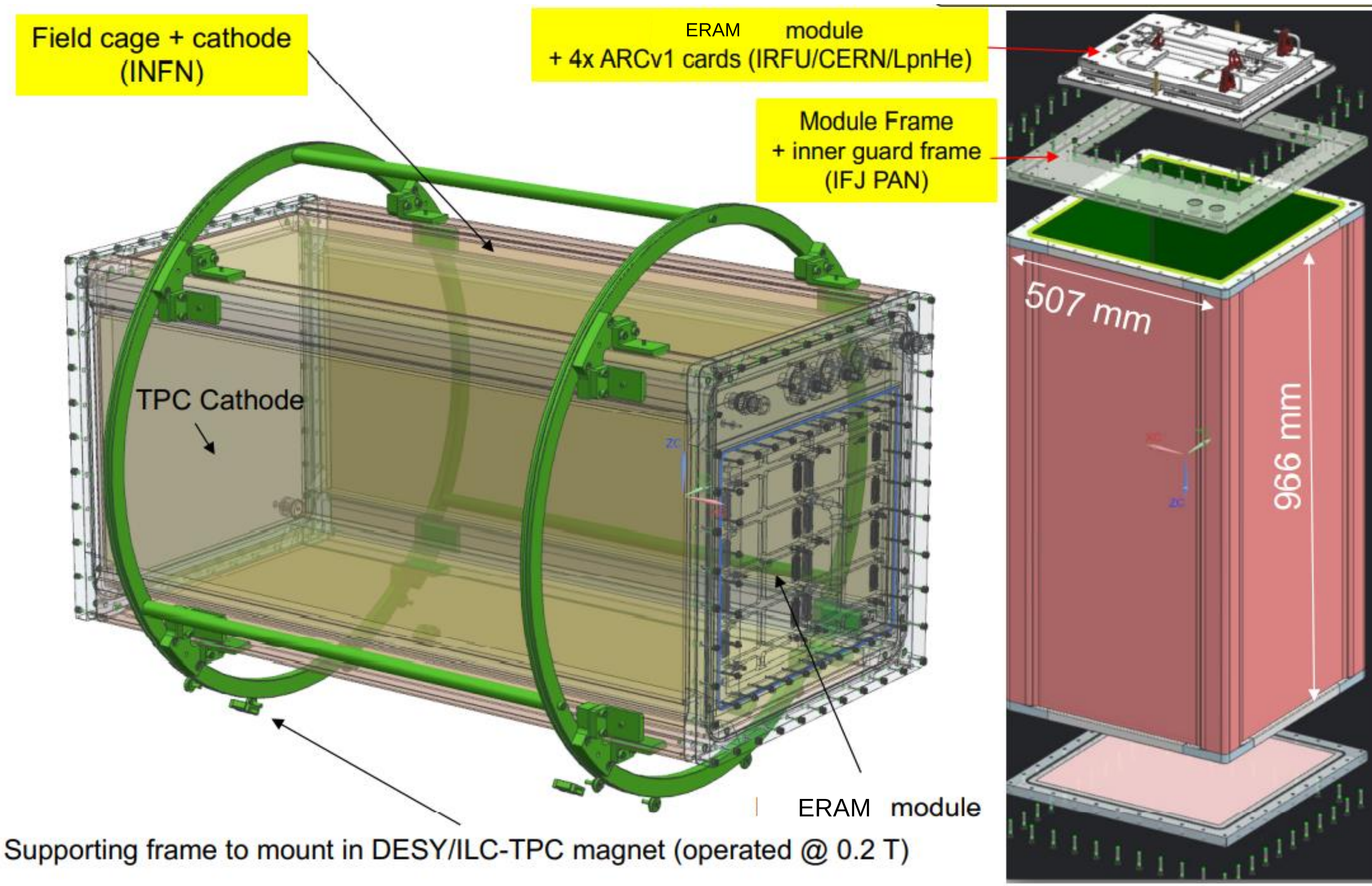
Flange thickness (5cm) too small for degrading -30kV to GND over a flat surface

Three deep grooves for enhancing superficial charge and gas path to GND
→ voltage drop / path length < 3kV/cm

Tested ok against discharges w/ mockup

FC design validation

Design and Process engineering validation
w/ prototype (1m drift length x 0.5m x 0.5m)
mechanics, material, high voltage, performance
→ since late 2019… 2020… 2021 …
→ 2 test beams in 2021 (DESY / CERN)

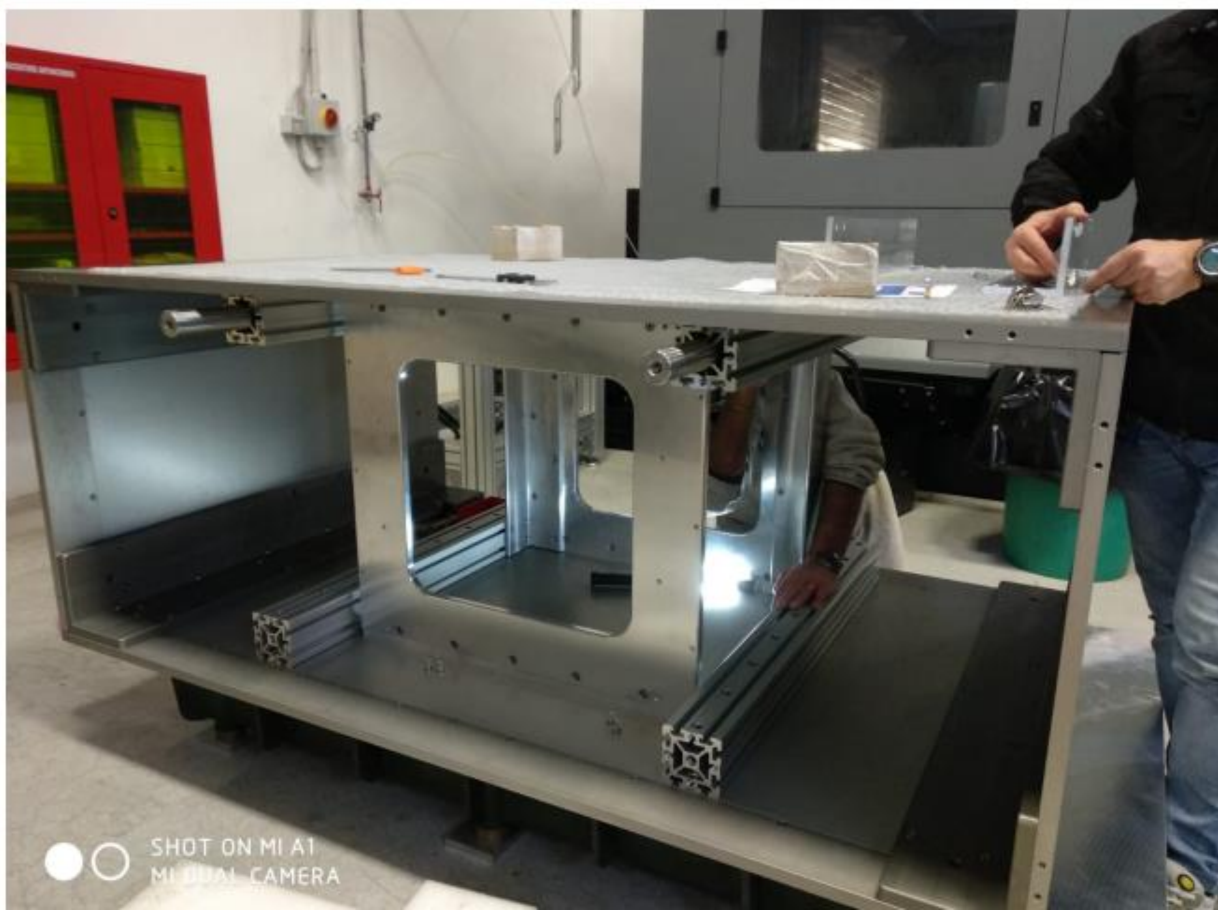


FC design validation

Design and Process engineering validation
w/ prototype (1m drift distance)
w/ mockup for HV tests on final cathode flanges

Parts and materials

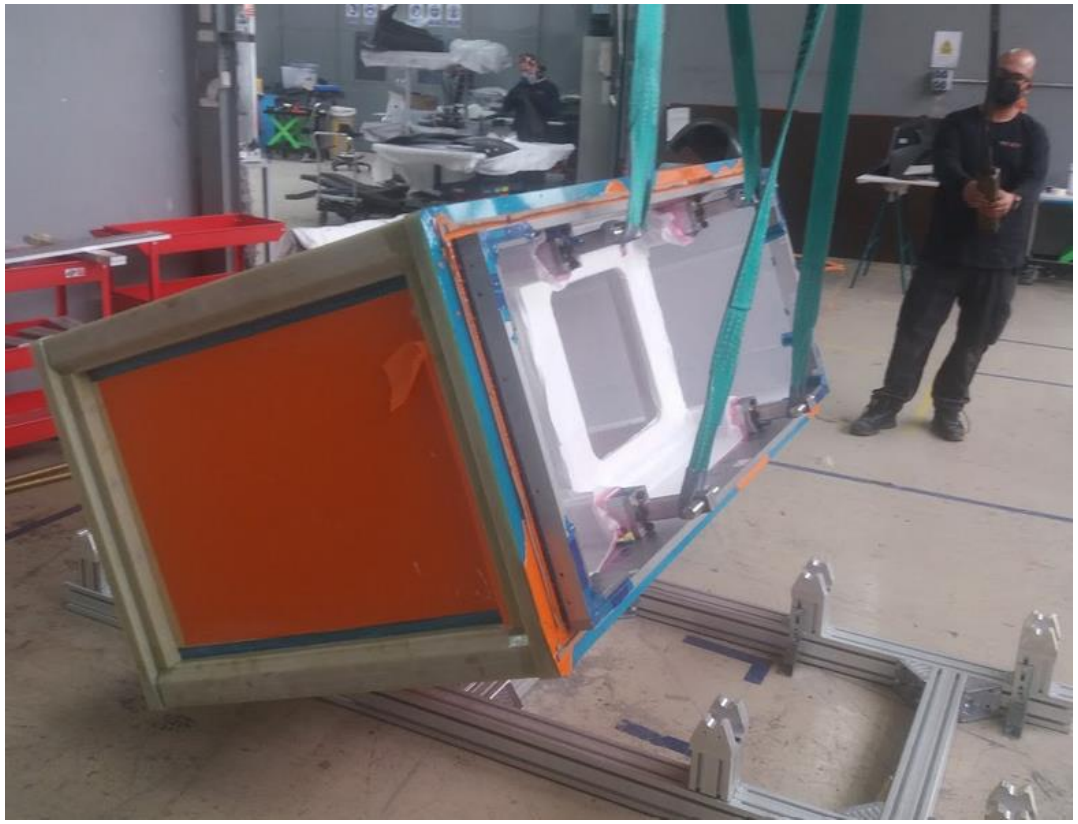
- Mold → INFN
- Double layer strip foil → CERN
- Structural parts = Flanges & Bars (G10)
  → ORVIM company (TV, Italy)
- Composite material & Production
  → NEXUS company (Barcelona)

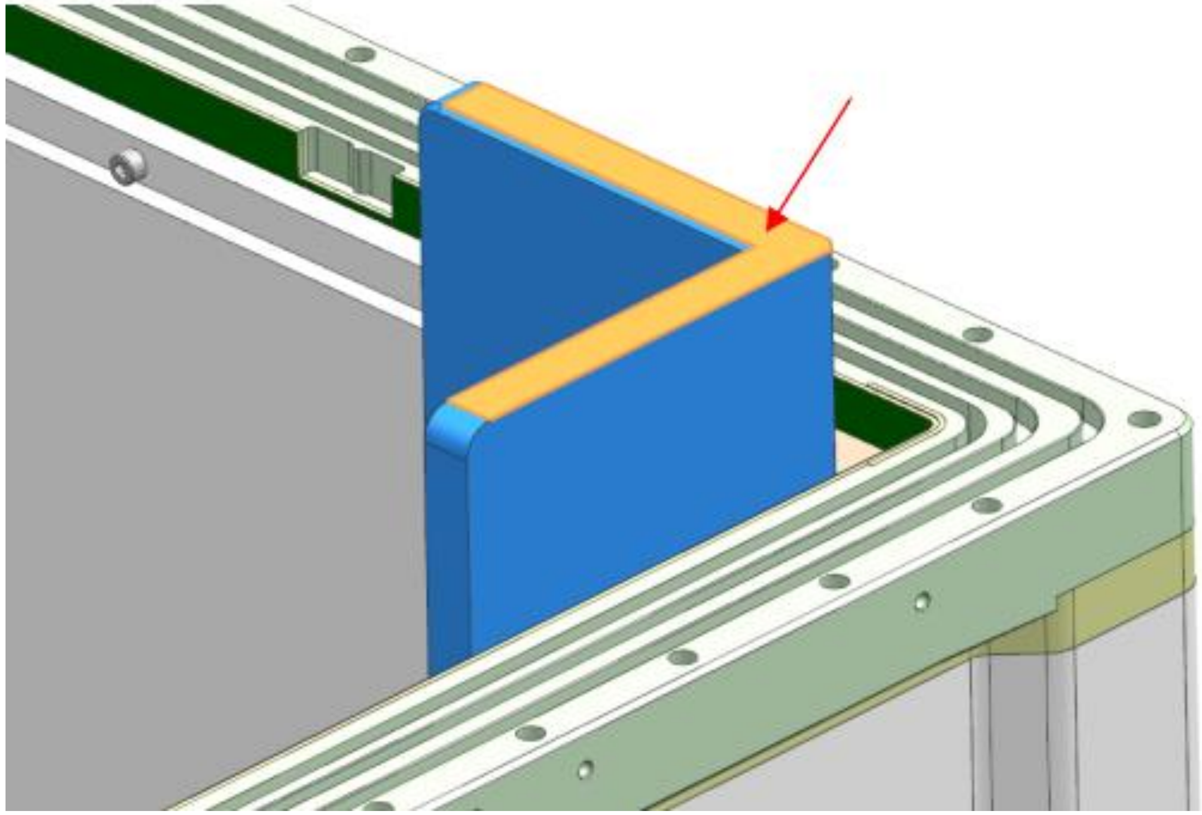


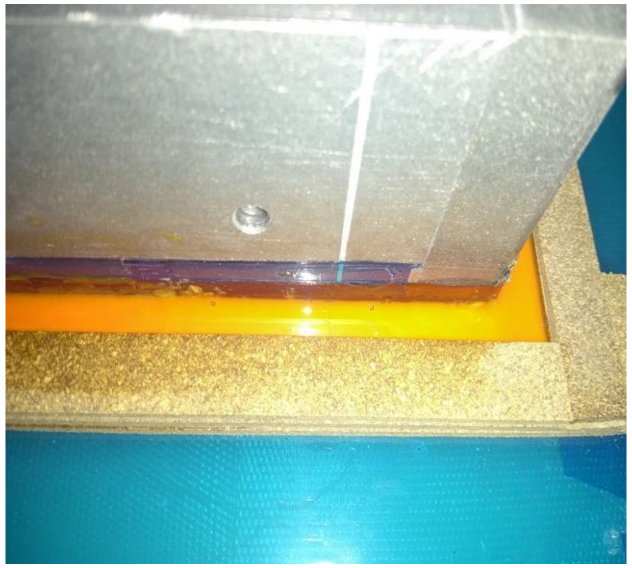
Production of first half Field Cage (Winter 2021 delivery in Spring 2022)

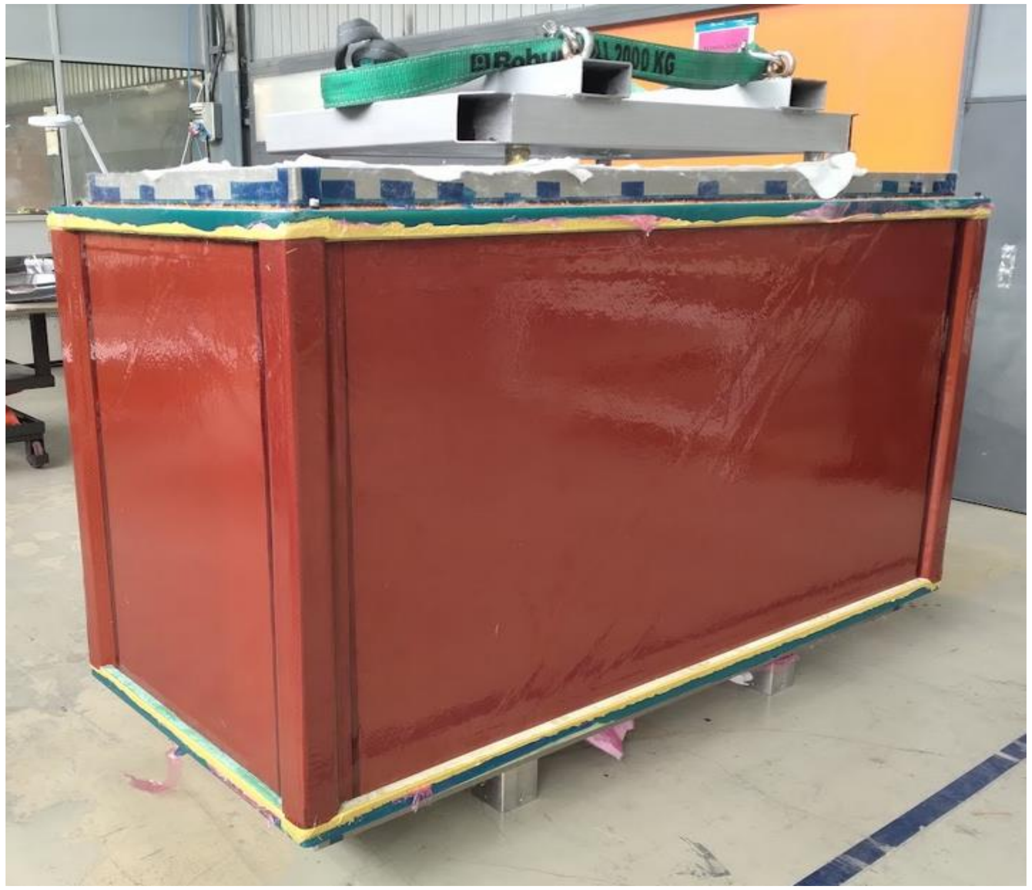
Field Cage production (@ NEXUS)

Field Cage production (@ NEXUS)



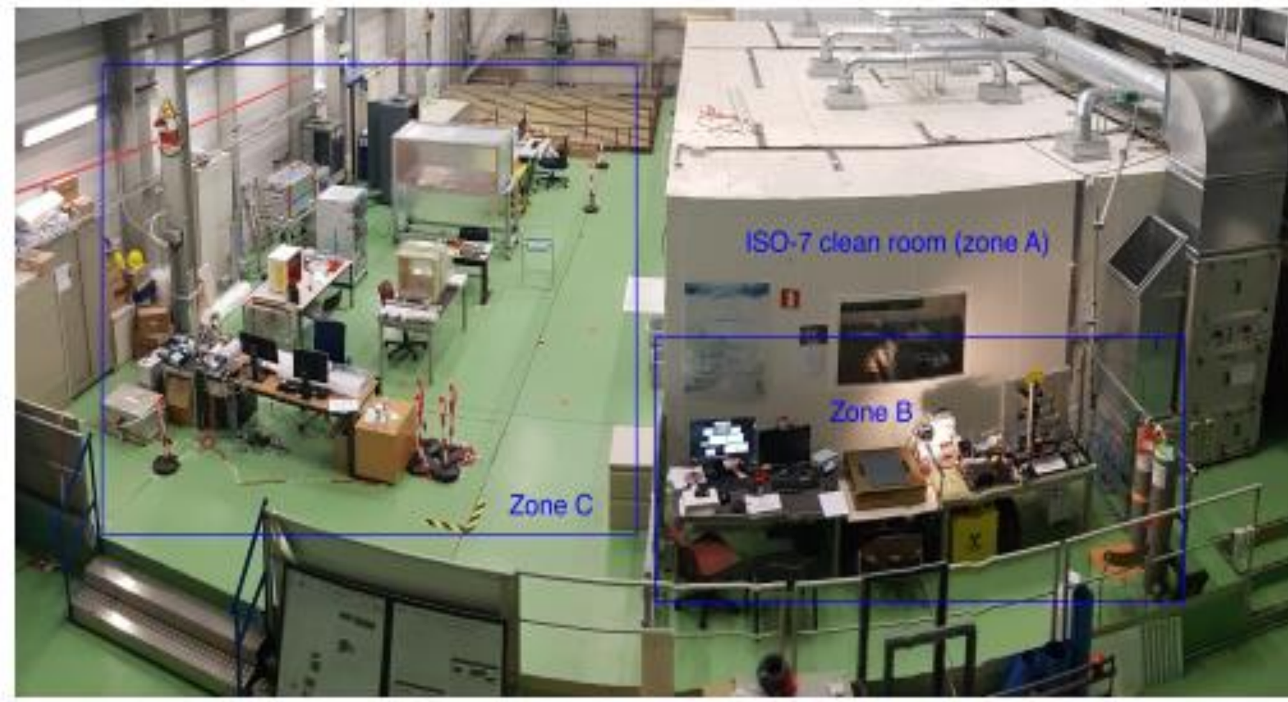


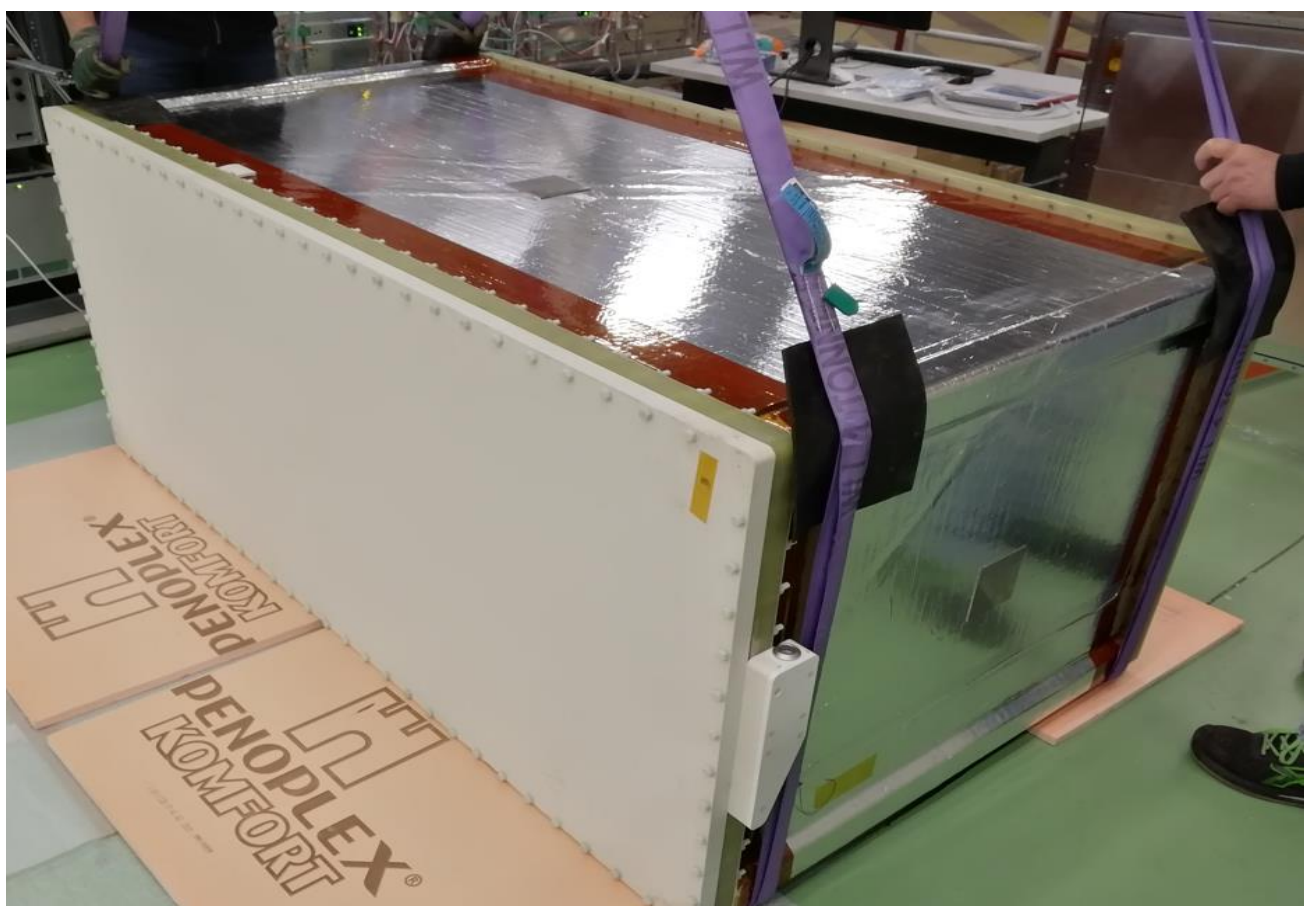




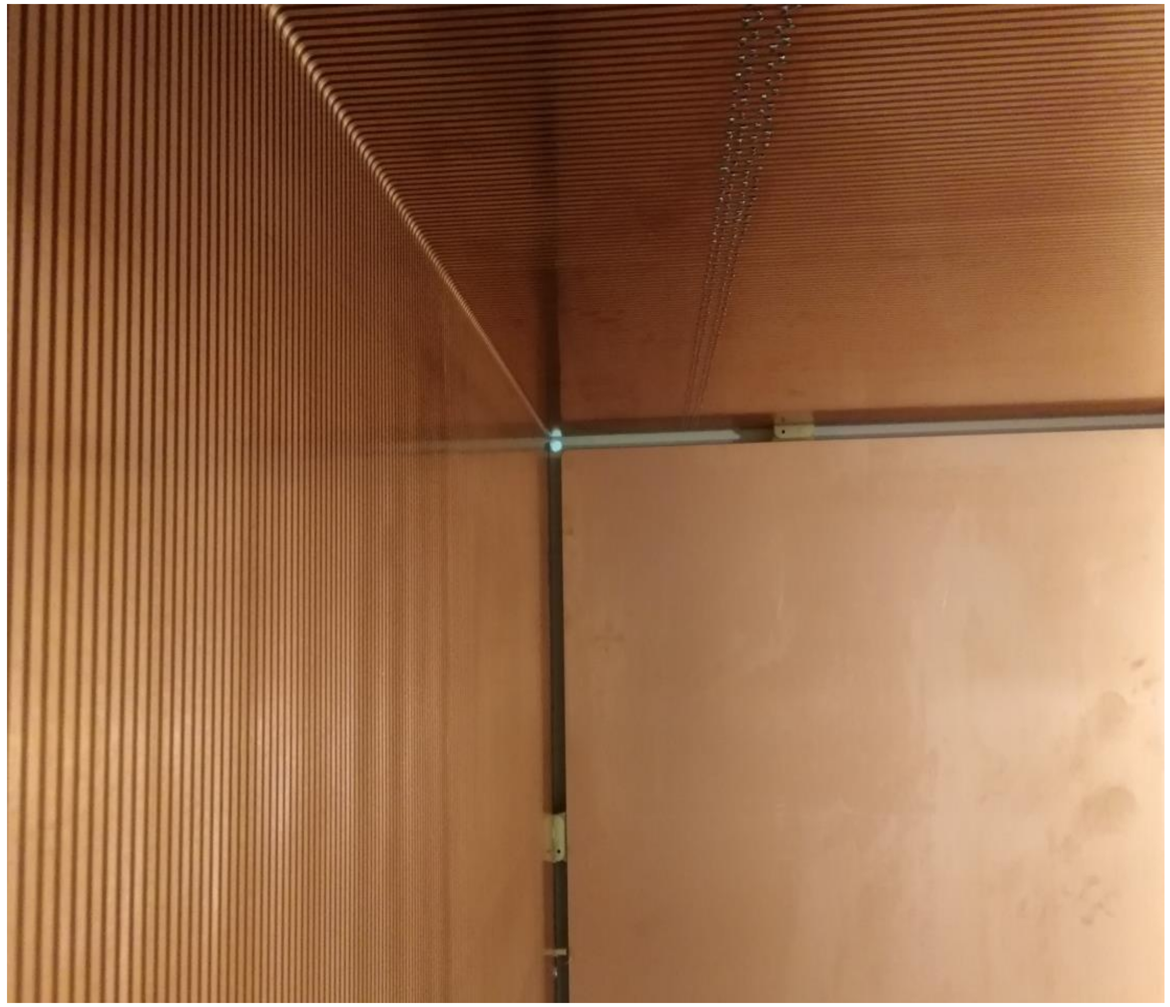
Field Cage validation (INFN @ CERN)

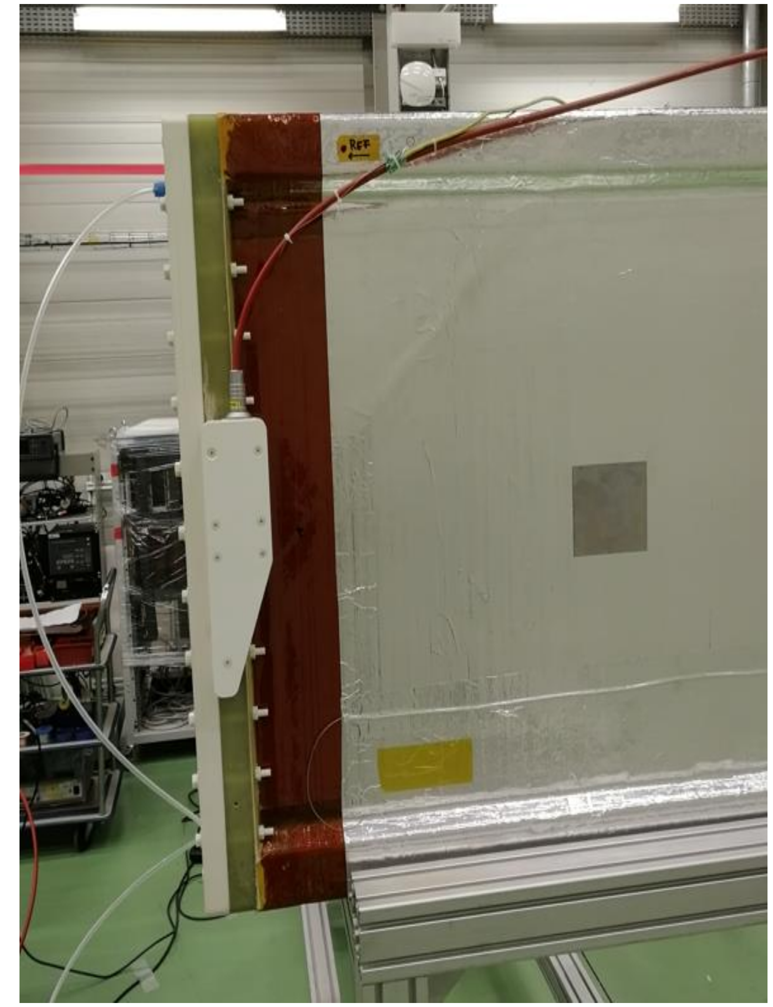
NP07 HA-TPC working area at bdg. 182

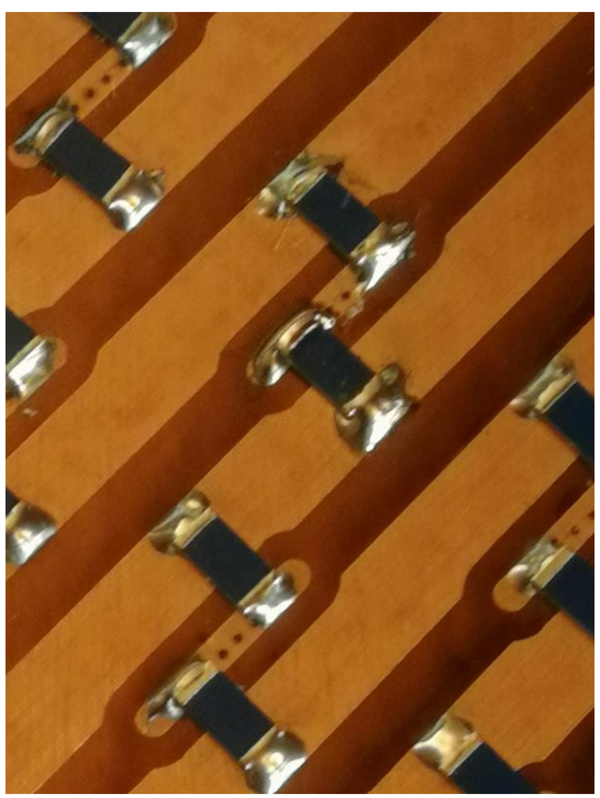




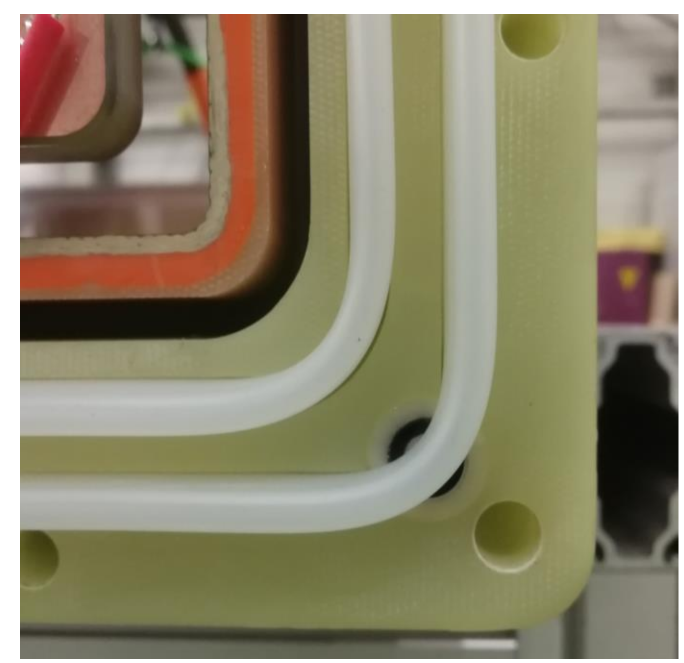
Field Cage validation (INFN @ CERN)



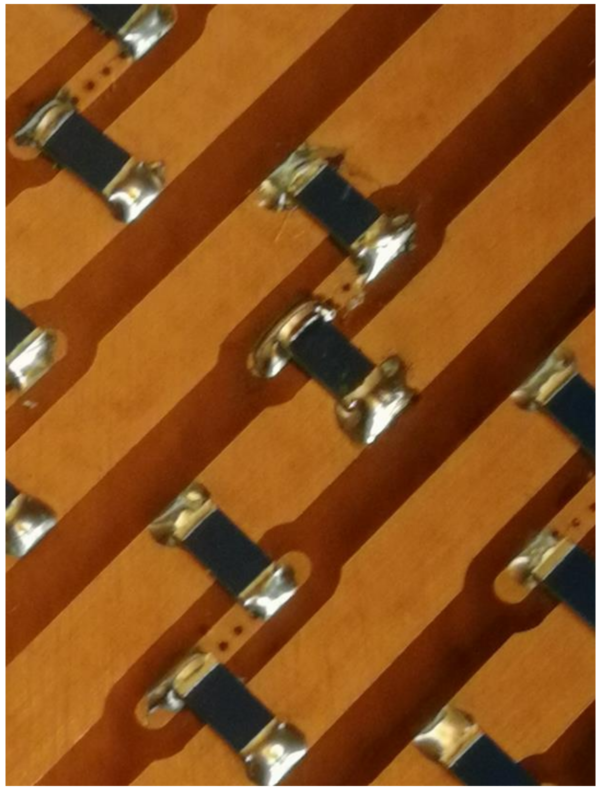


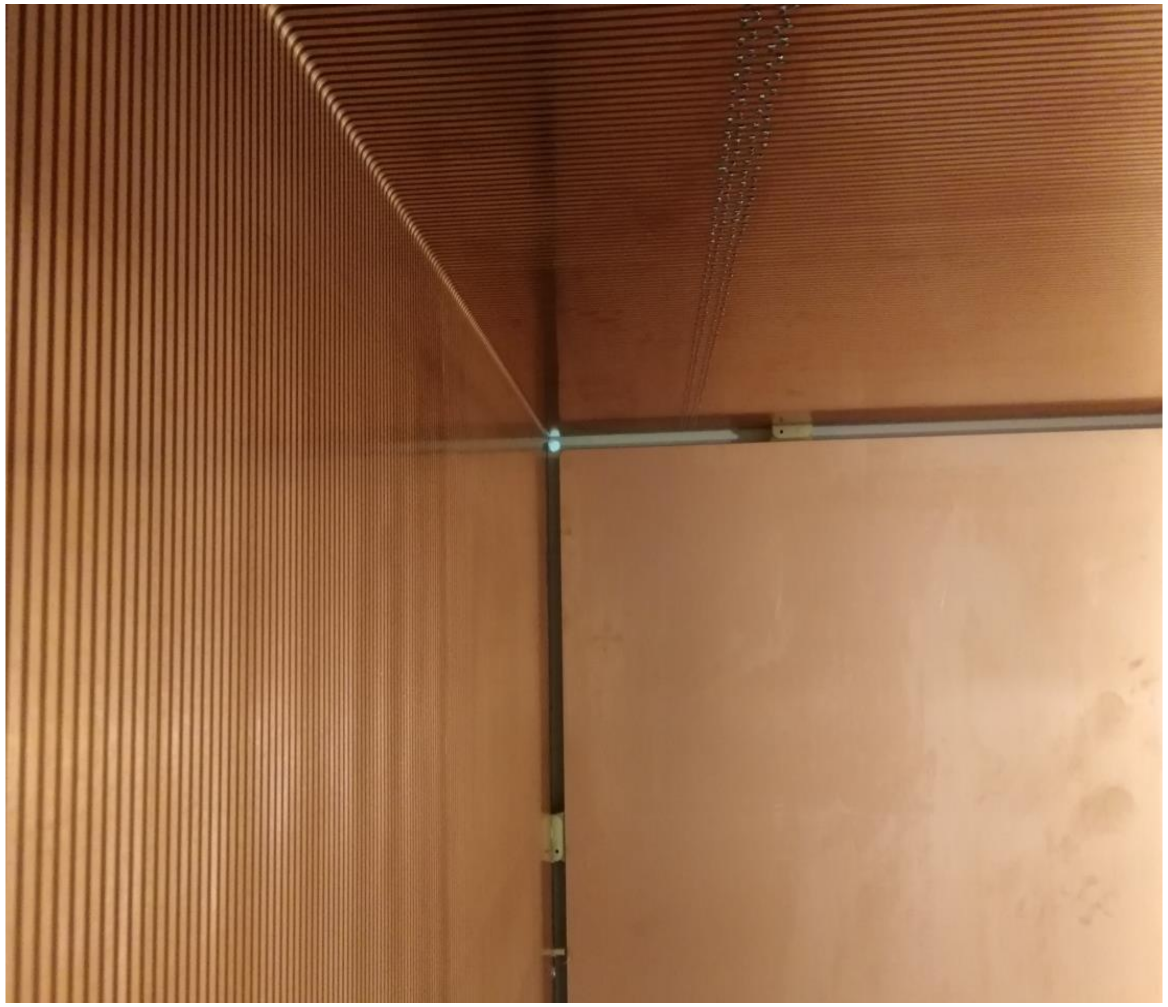


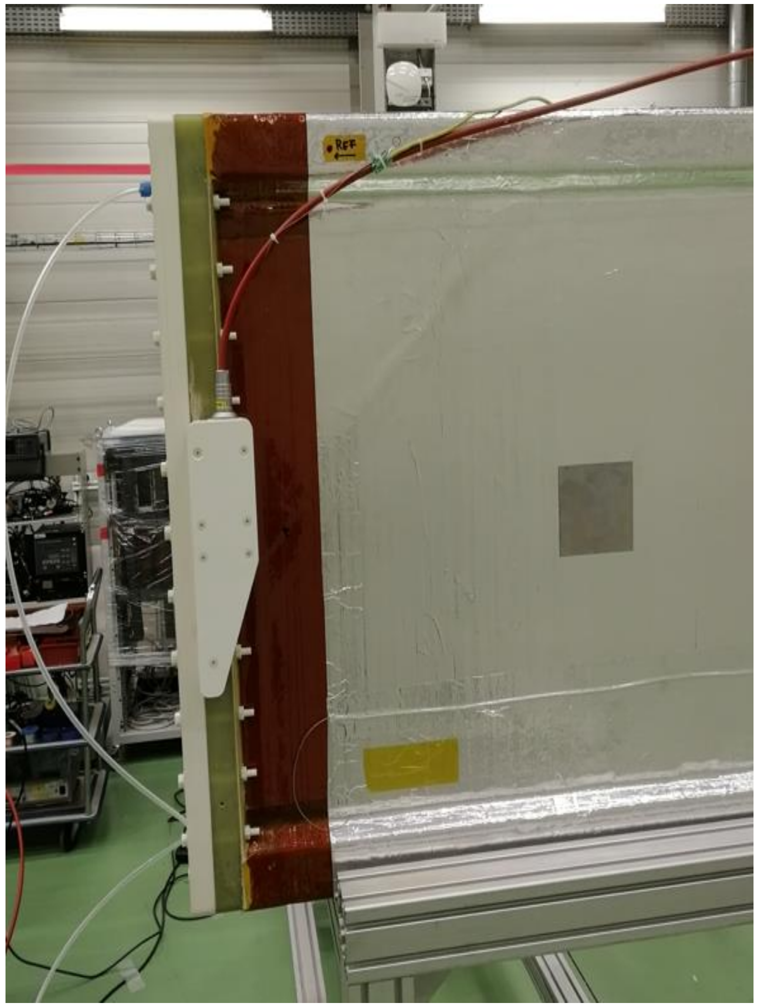
Cathode flange
double oblated o-ring
and deep groove
against discharges



Field Cage validation (INFN @ CERN)







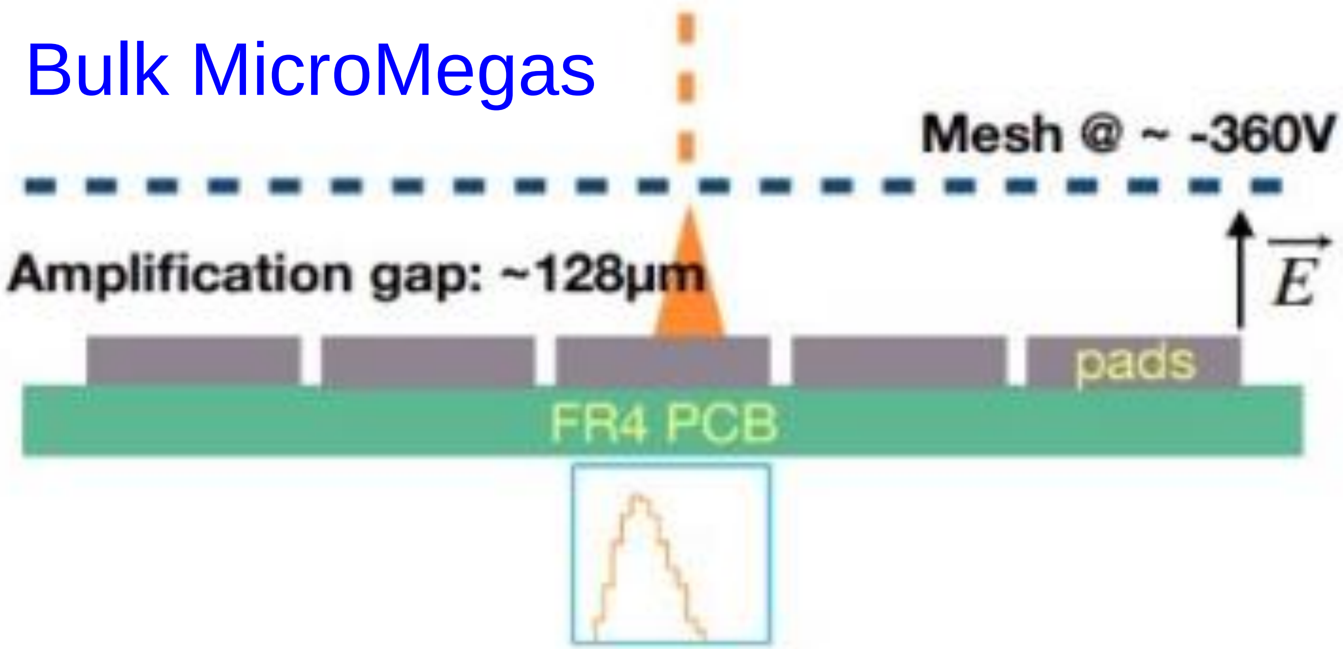
Under test / validation / characterization:

✓ Metrology → inner walls and flange surfaces within tolerances
✓ Gas tightness → well below 0.1 mbar ℓ / s
✓ Mechanical tests → walls expansion agreement w/ simulation (25μm / mbar overpressure)

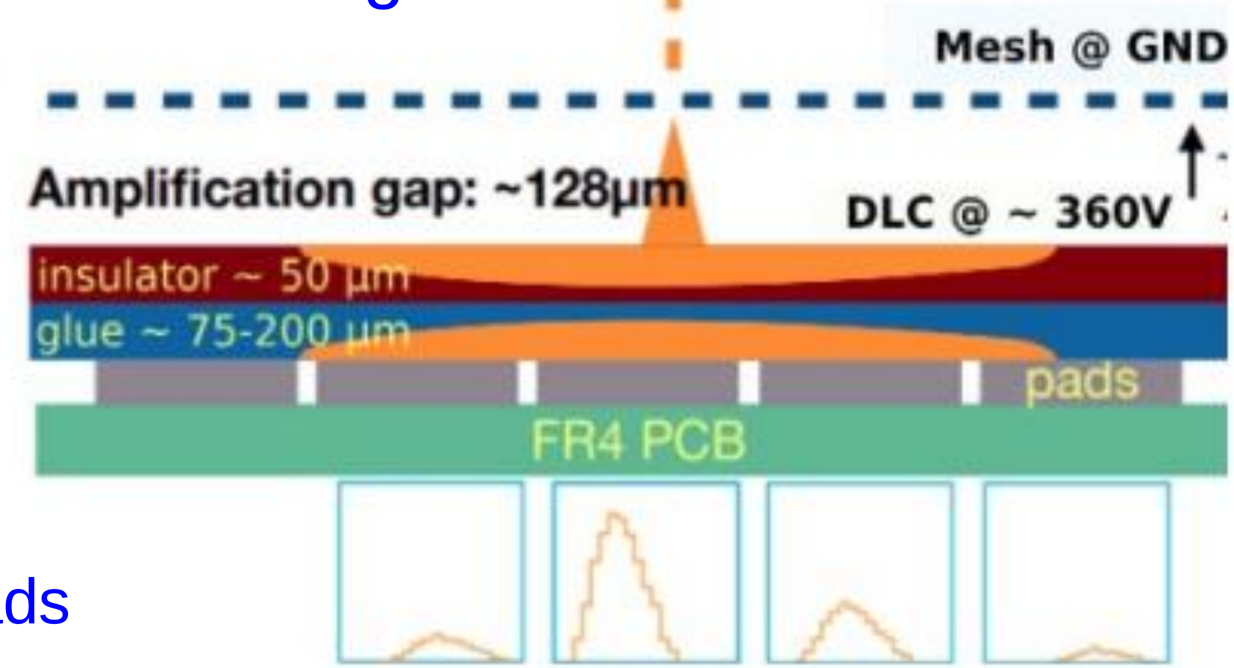
- degassing in owen @ 70ºC
- High Voltage tests
- Half TPC instrumented anode (8 ERAM)
  → test beam CERN in Sept / Oct 2022

ERAM detectors

Bulk MicroMegas



Encapsulated Resistive Anode MicroMegas



Charge spreading over Resistive Layer
→ space resolution below 500µm with larger pads
→ less FEE channels (lower cost)
→ improved resolution at small drift distance

Gaussian Charge Spread in time

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

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

R- surface resistivity
C- capacitance/unit area

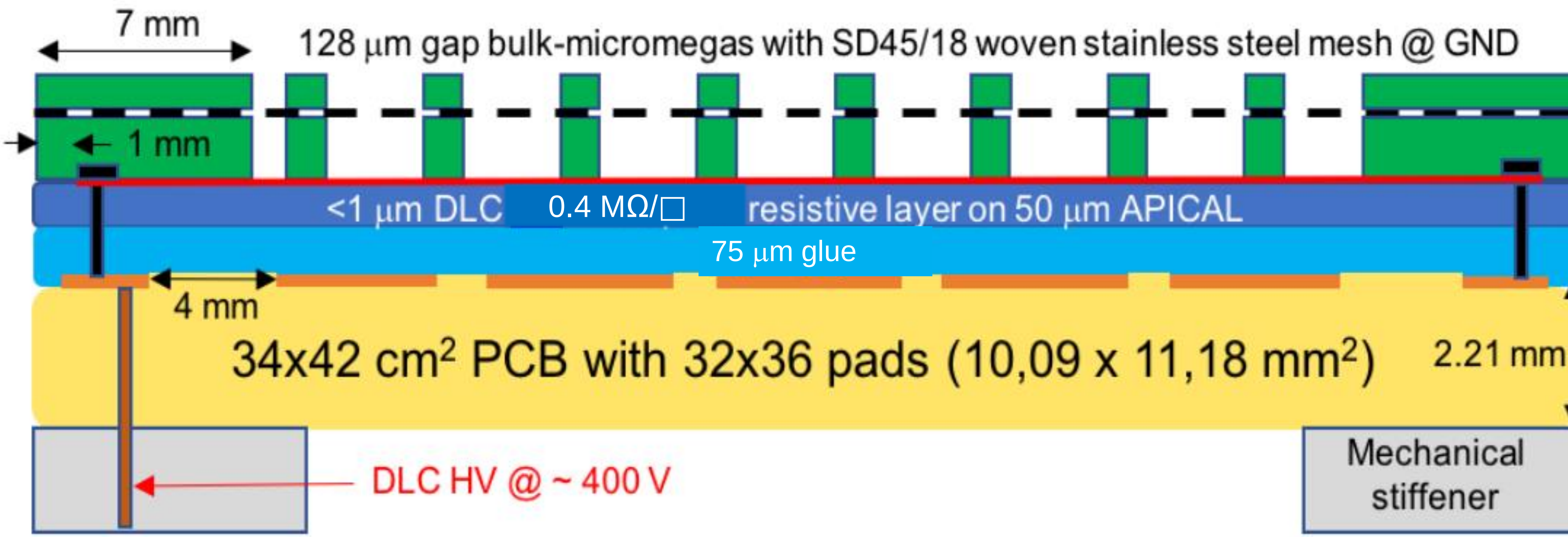
Resistive layer prevents charge build-up, ie sparks
→ enables operation at higher gain
→ no need protection circuits → compact Font End cards

$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx \text{shaping time (few 100 ns)} \\ RC_{[ns/mm^2]} = \dfrac{180\, R_{[M\Omega/\blacksquare]}}{d_{[\mu m]}/175} \end{cases}$$

Mesh at ground and shielding of Resistive layer at +HV
→ improved field homogeneity → reduced track distortions

Good charge spreading (σr ~ 3 mm) for pads of ~11x10 mm²
with DLC foil resistivity around 0.4 MΩ/□ and glue thickness ~75 µm

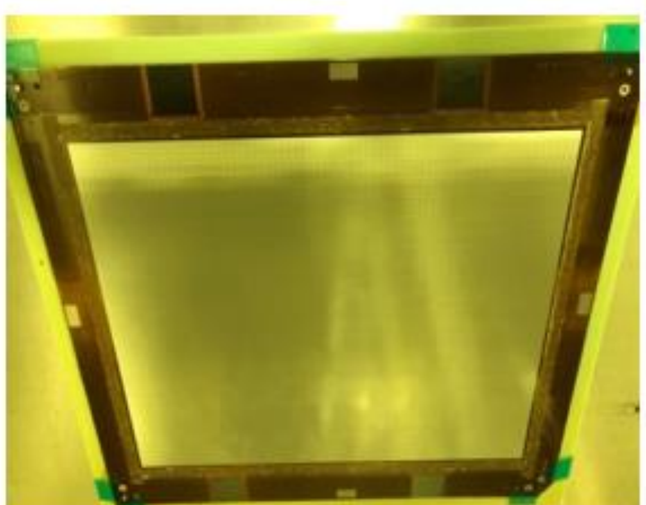
ERAM detectors for HATPC



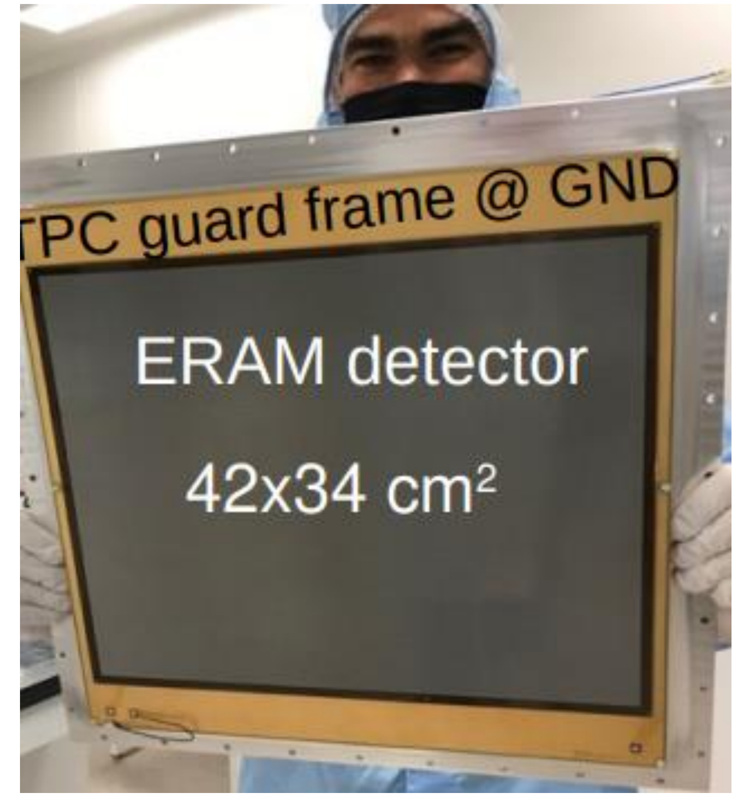
ERAM detector

ERAM detector + stiffener

ERAM module on min-TPC

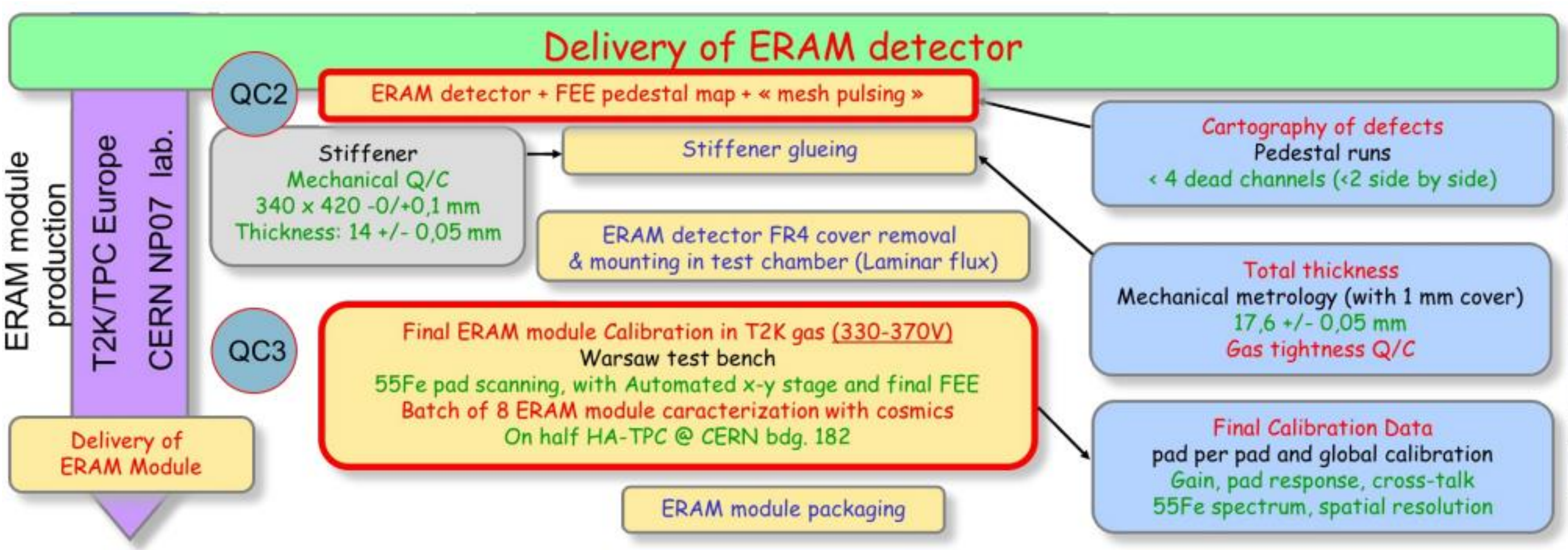


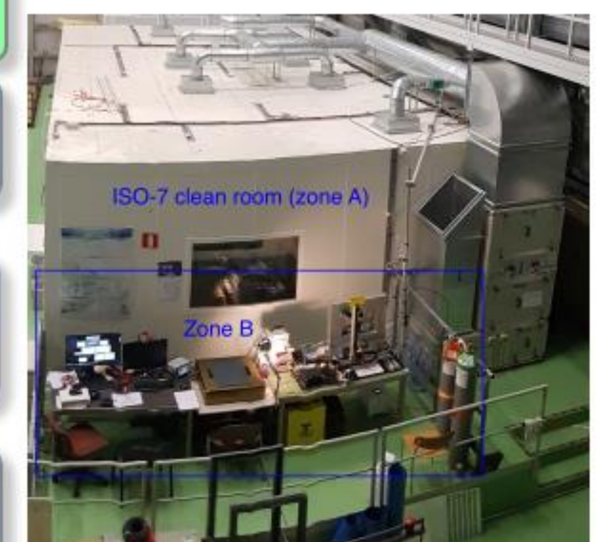
ERAM production



DLC production in Japan (Be-Sputter, Kyoto)
DLC foils production still “unstable” and randomly out of the specification
→ selection of DLC foil regions w/ uniformity better than 10%

Other production steps at CERN
→ completely under control

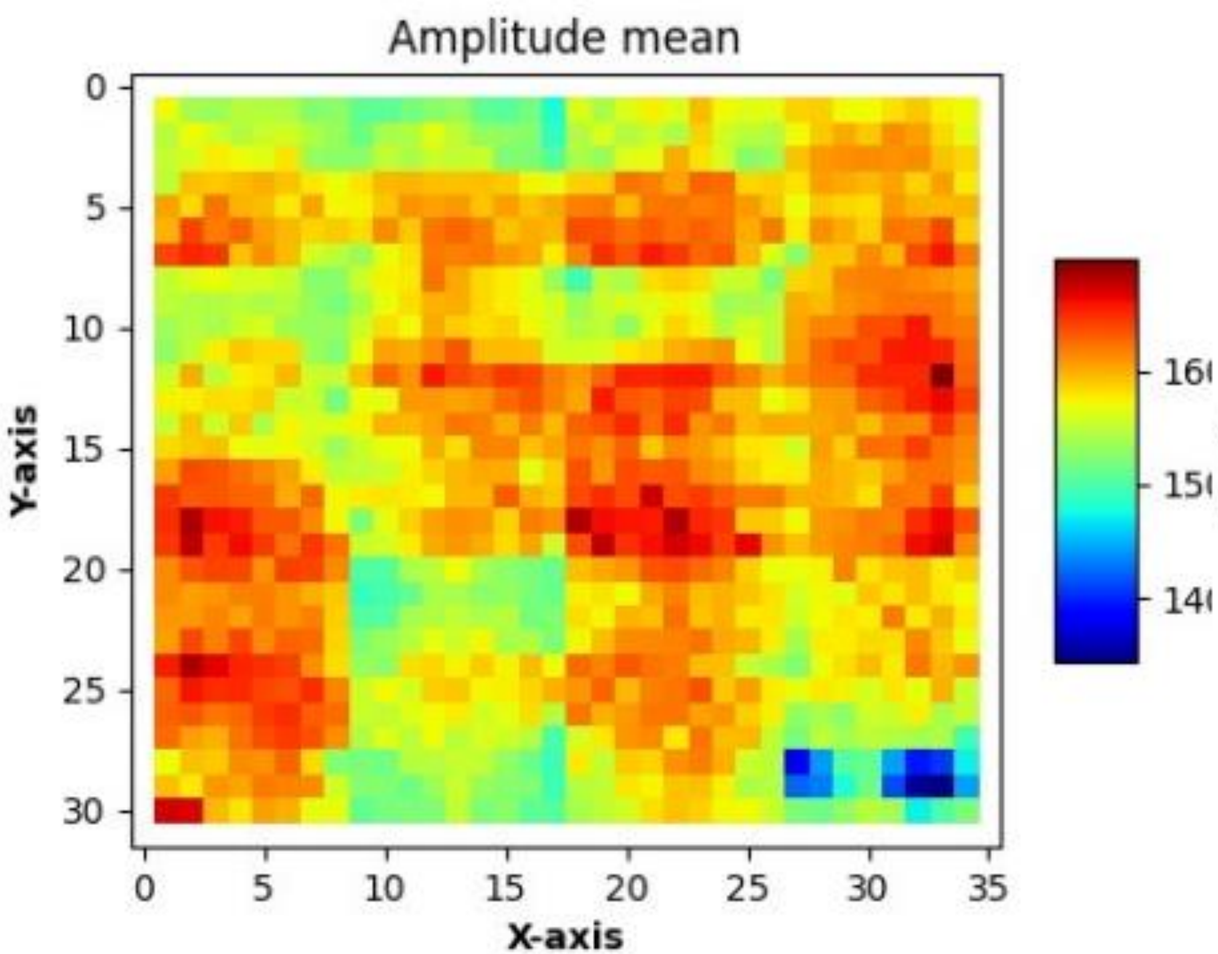




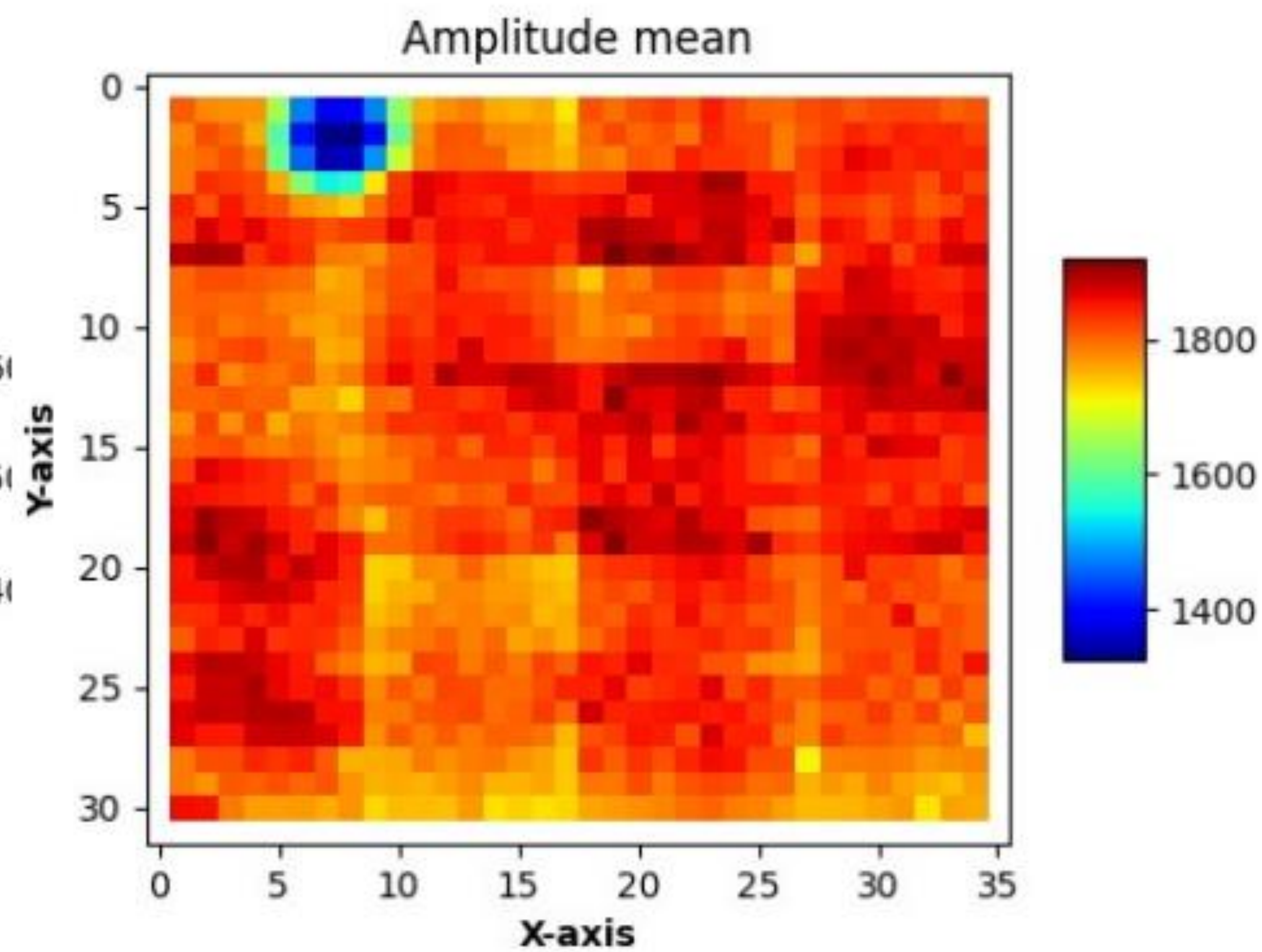
- NP07 working area is fully operational at CERN bdg. 182.
- Two Quality Control tests are performed here:
  - Mesh pulsing: spot low gain region before gluing stiffener on PCB
  - X-ray test bench: Complete characterization of ERAM response, individual pad response (gain, resolution) and gain scan as function of voltage.
  - Calibration of electronic cards and association with a detector before X-ray scan

ERAM production control – Mesh Pulsing

ERAM-16

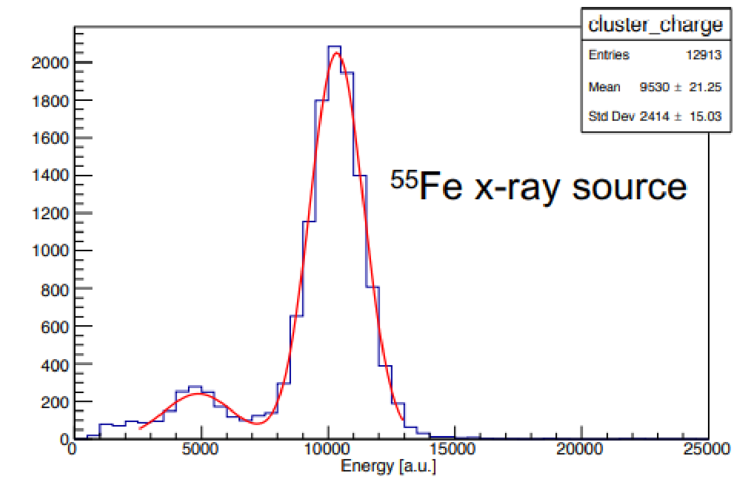


ERAM-21



- Mesh pulsing is performed before and after gluing stiffener.
  - The first one allows to spot low gain region: blue will have a 2 times lower gain with X-ray
  - Criteria to accept a detector is: uniformity of 15%
  - Calibration of electronic cards and association with a detector before X-ray scan
  - Second scan allows us to check if the gluing process change the response.

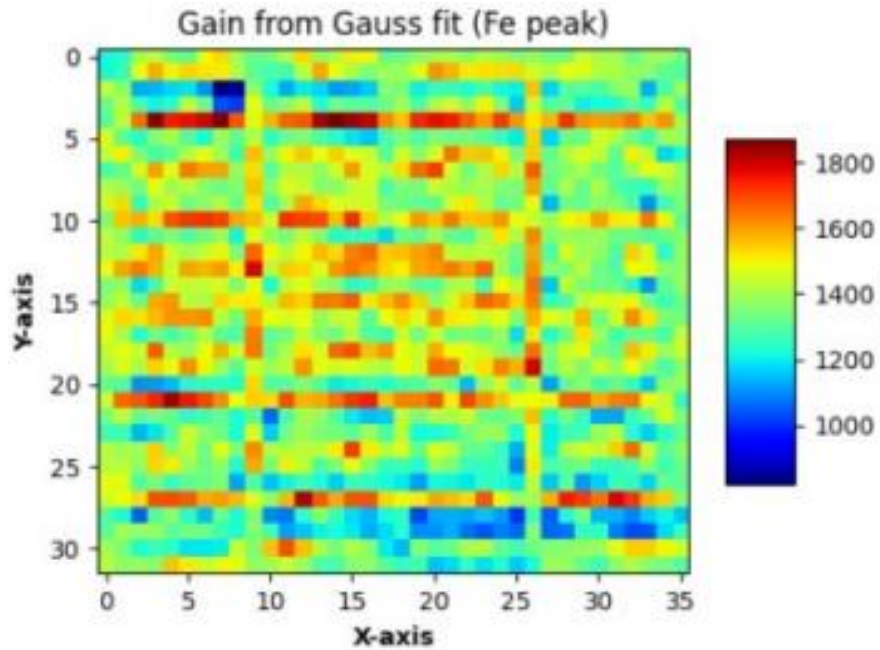
ERAM production control - X-rays

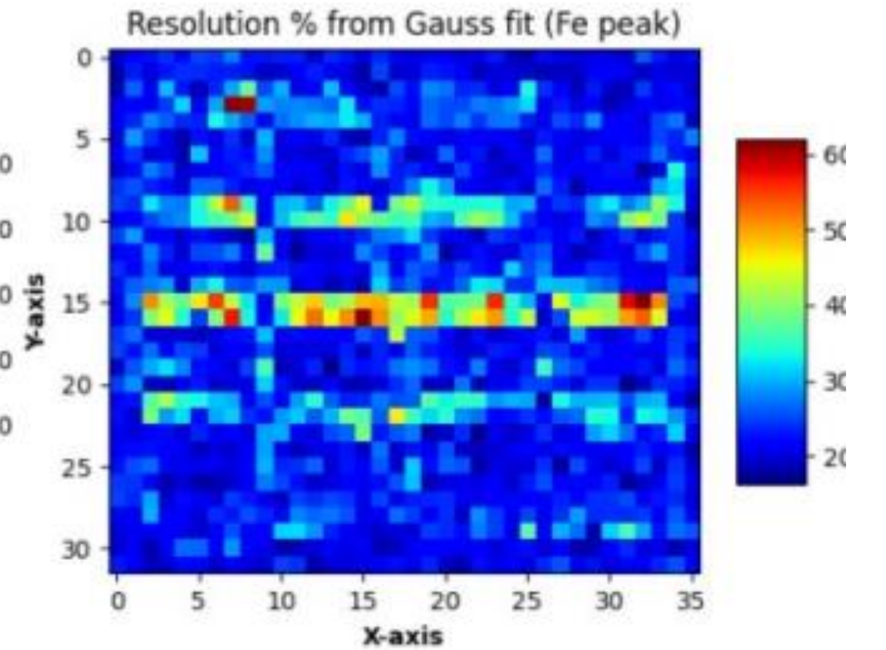


Example of early ERAM characterization

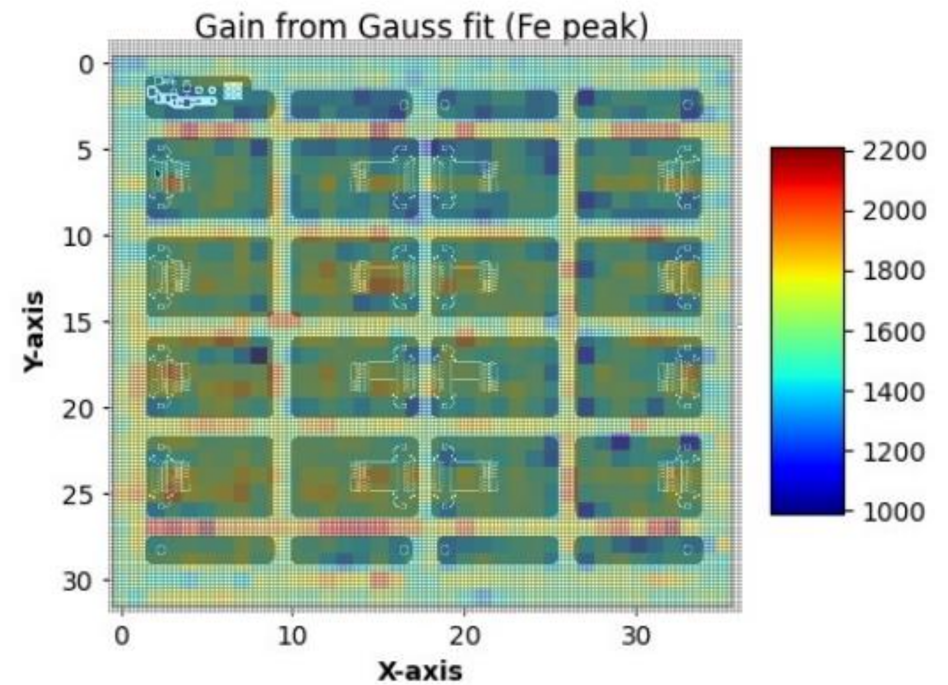
Observed larger gain and energy resolution where Aluminum stiffener was glued

Gain increase up to 20% corresponding to gap decrease by 1-2 μm





→ issue solved by new gluing procedure (uniform pressure all over the PCB)



First time Resistive MM detectors studied such very detail

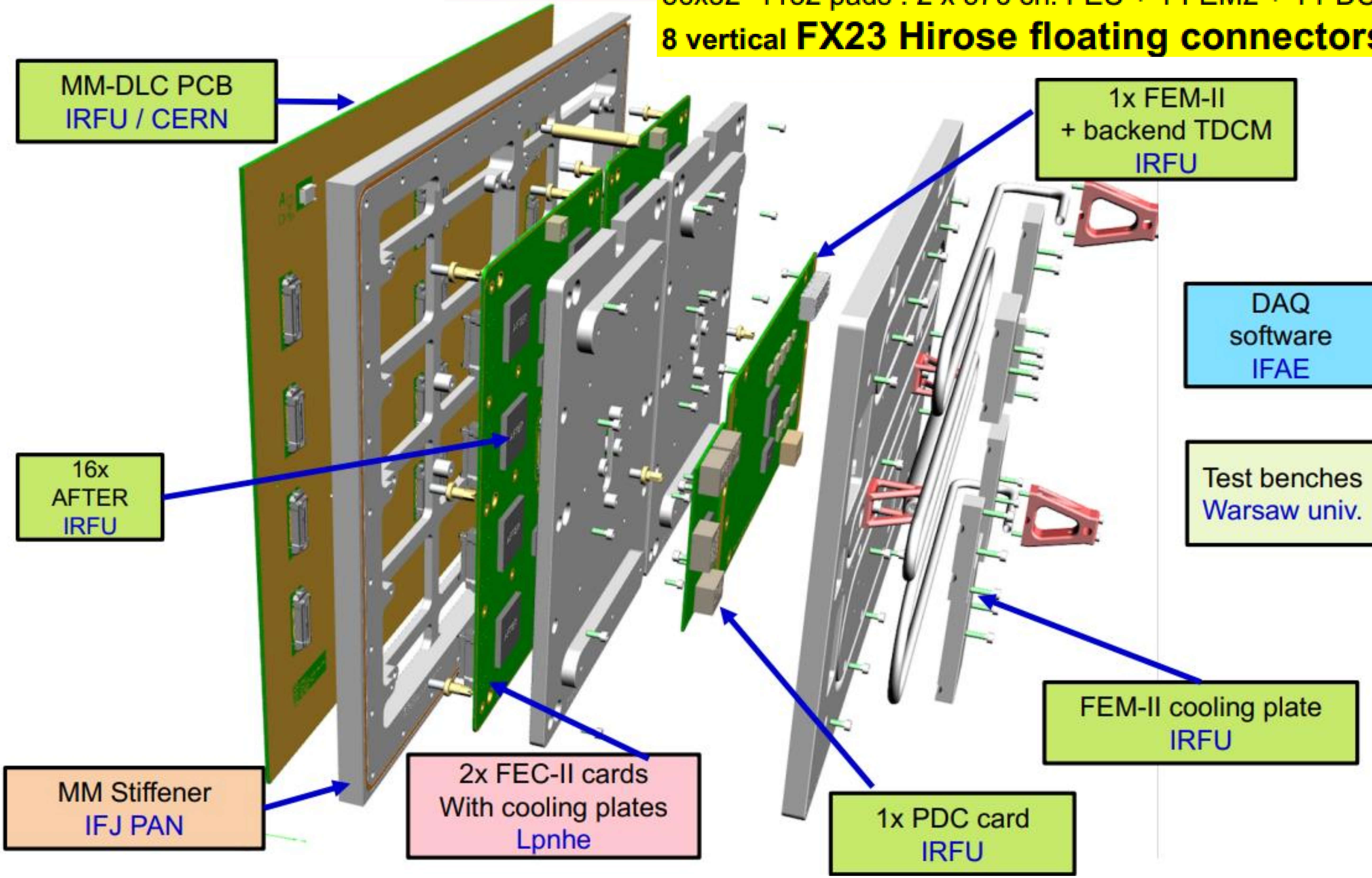
(needed for series production)

Series production for HATPC started in early 2022

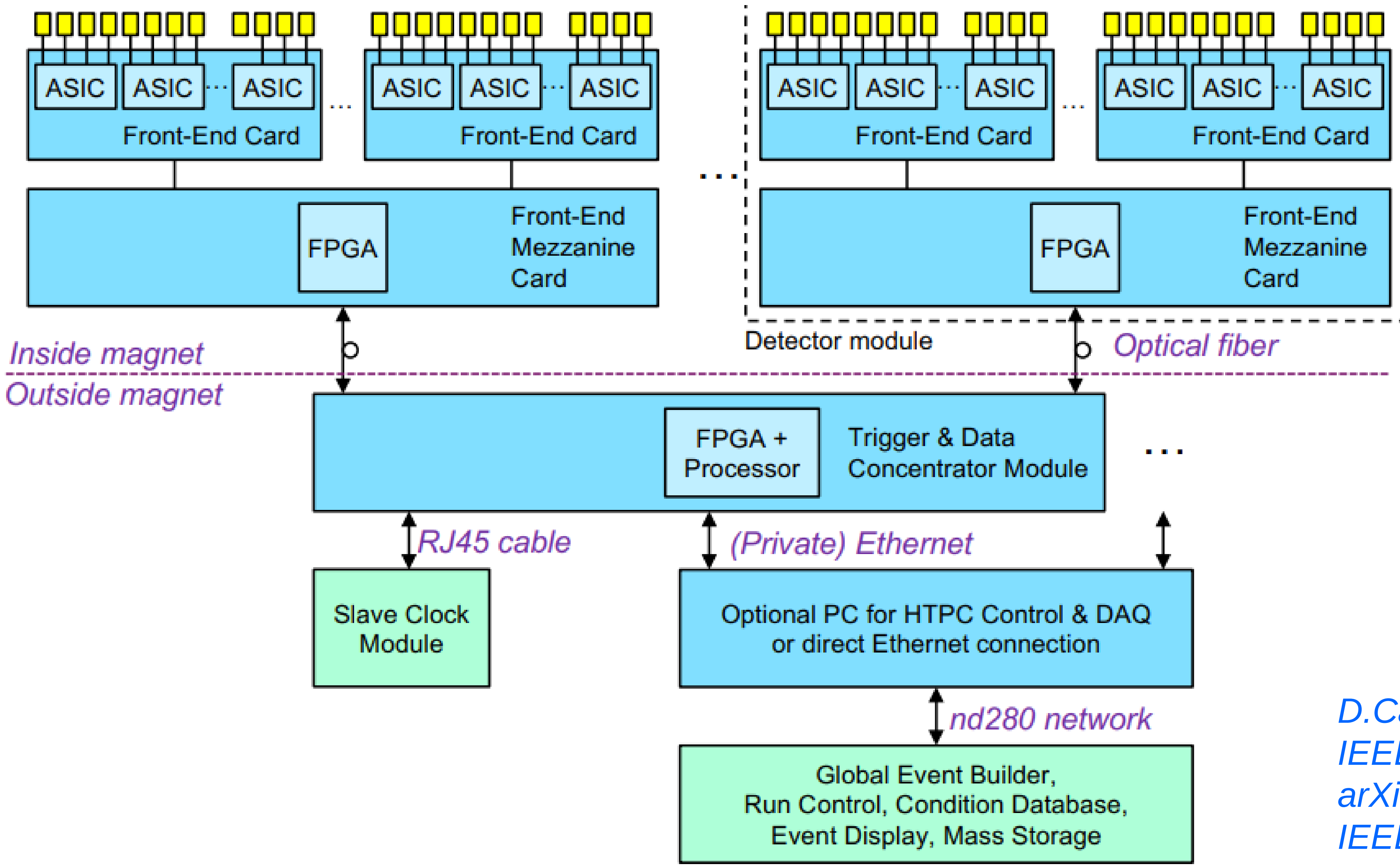
ERAM Module

- 8+8 ERAM modules per HATPC
- Reduced thickness → minimized 'dead' volume

36x32=1152 pads : 2 x 576 ch. FEC + 1 FEM2 + 1 PDC
8 vertical **FX23 Hirose floating connectors**



HATPC FE and RO Electronics



36.864 detector pads

512 AFTER (72 channels)

64 FECs (8 ASICs each)

32 FEMs (1 drives 2 FECs)

2 TDCMs (1controls 16 FEMs, i.e. 1 TPC)

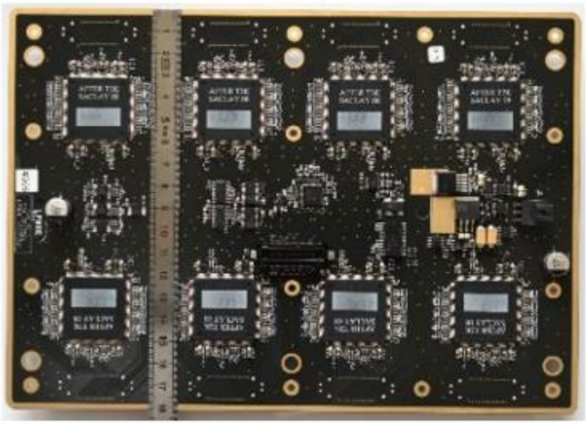
1 PC (controls 2 TDCMs)

D.Calvet (CEA-DRF-IRFU)
IEEE Real Time (2018)
arXiv 1806.07618
IEEE TNS 55 3 (2008)

Main Components

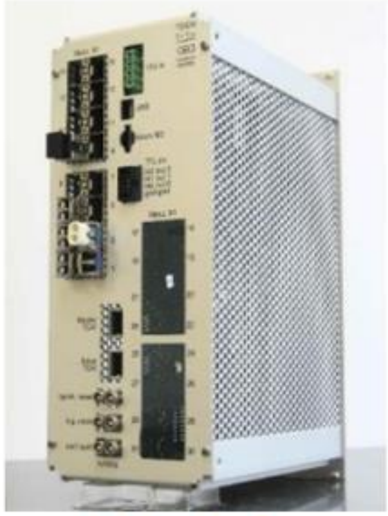
- AFTER chip designed for T2K (511 bucket SCA sampling@25 MHz, 120fC-600 fC, 100ns-2µs peaking time)
- New FEC with 8 AFTER chips which digitizes pad signal with an 8 ch. ADC (minimum dead time of 3.3 ms)
- FEM provides control (&trigger), synchronization, data aggregation, data buffering & data zero suppression
- TDCM is a generic clock and trigger distributor and data aggregator (FPGA+2 xilinx CPU+1 GB DDR3)

HATPC FE and RO Electronics



Front-End Card - FEC

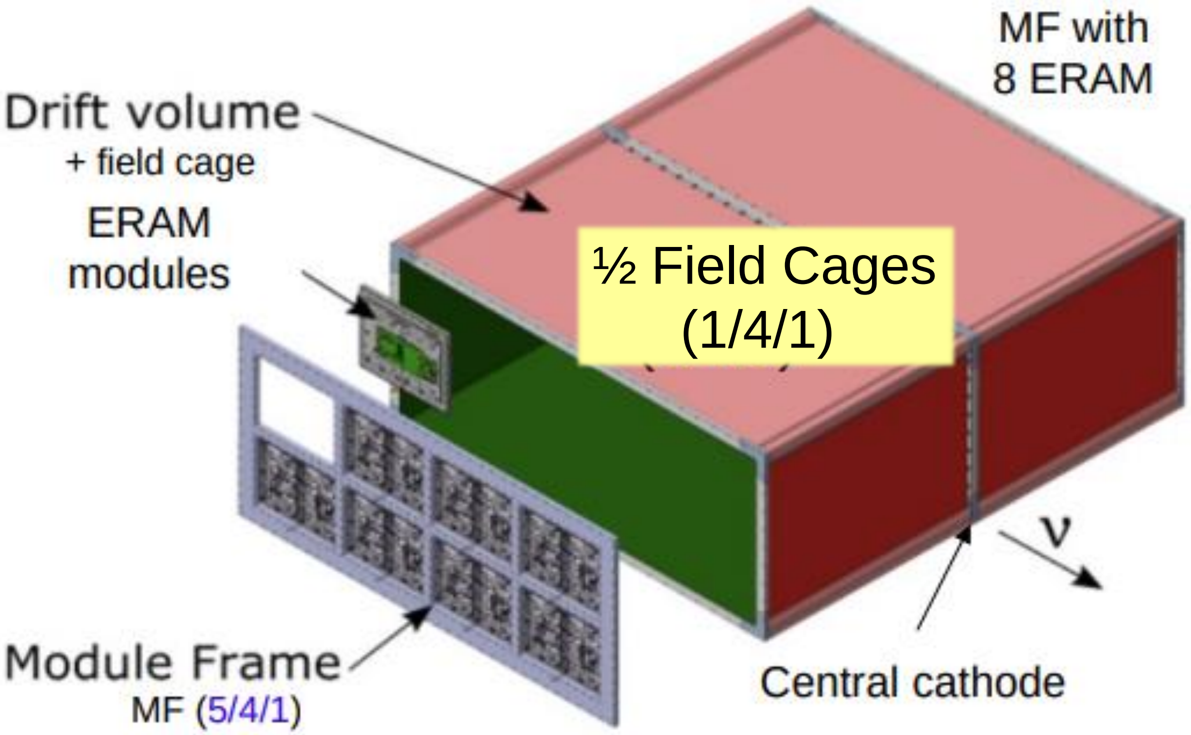
Front-End Mezzanine Card – FEM

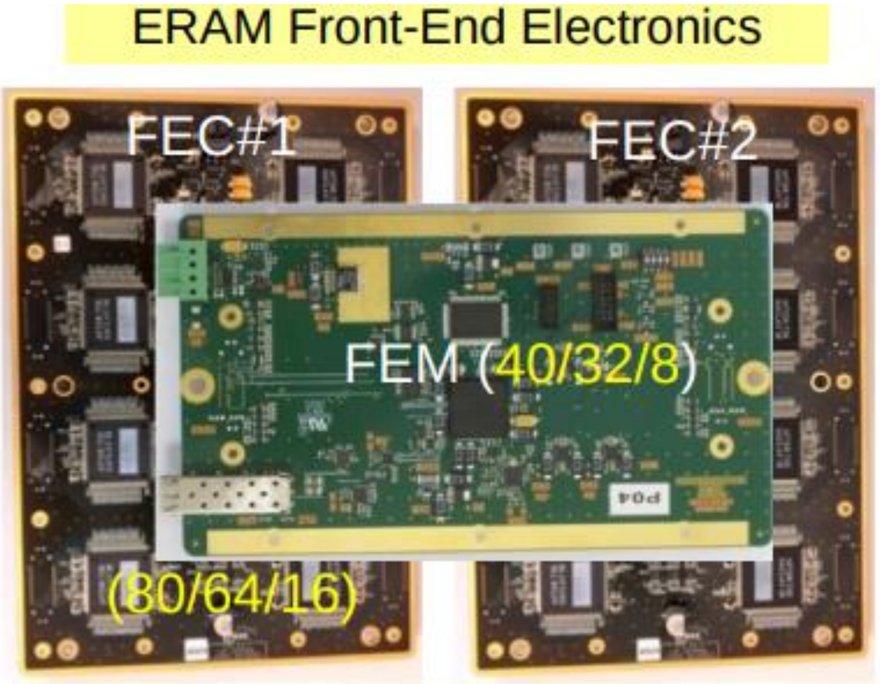


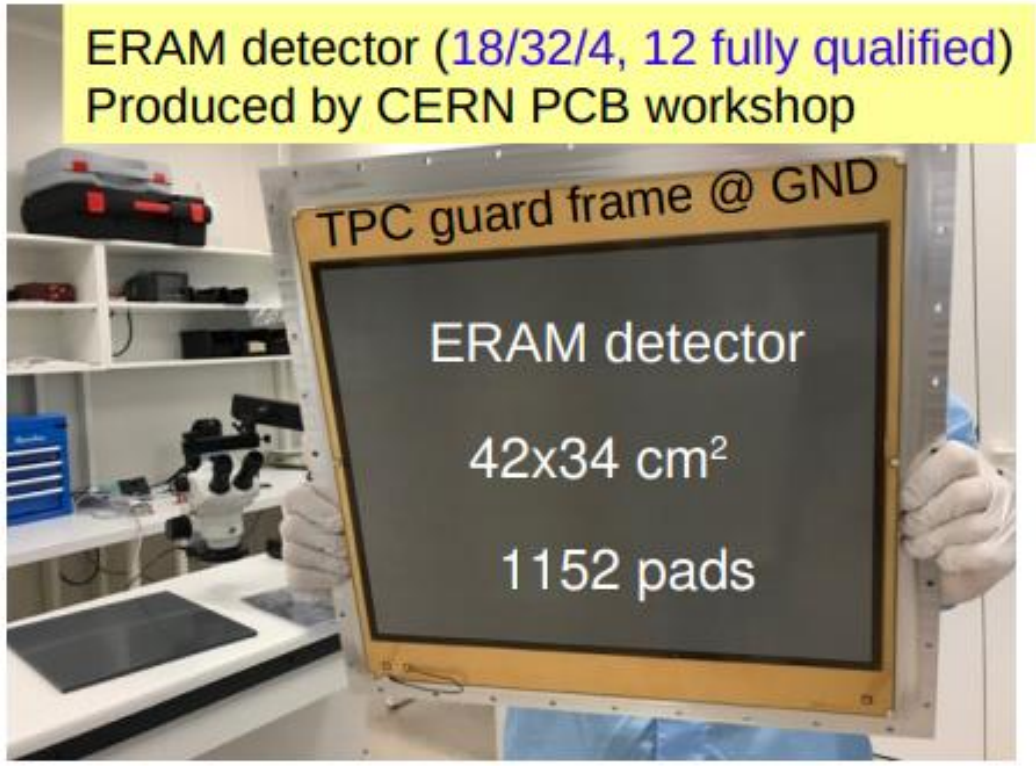
Trigger & Data Concentrator Module - TDCM

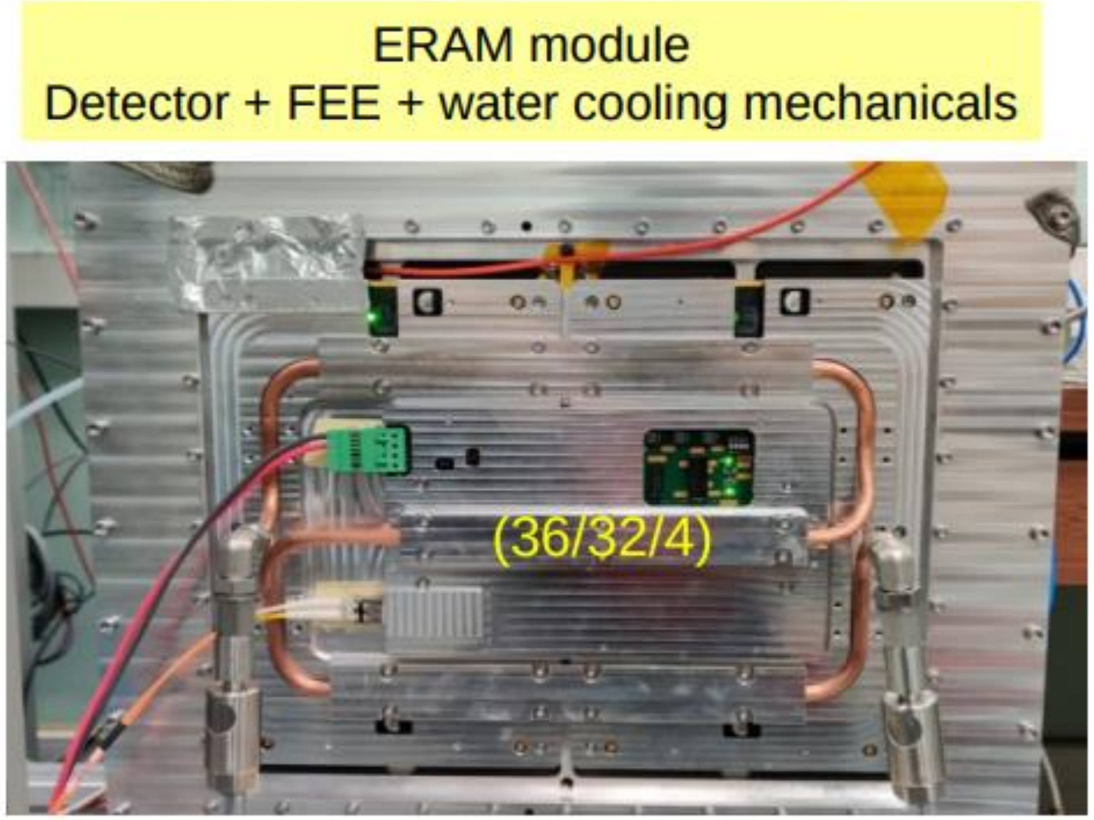
- FE and RO Electronics boards production completed
- FW and SW DAQ system completed & tested on mockup Module Frame (Anode support frame)

Production Status (x produced / y needed / z spares)









- ERAM production to be completed by end 2022
- 2x HATPC to be completed, shipped to JPARC and installed by mid 2023

New Gas System for HA-TPC and V-TPC

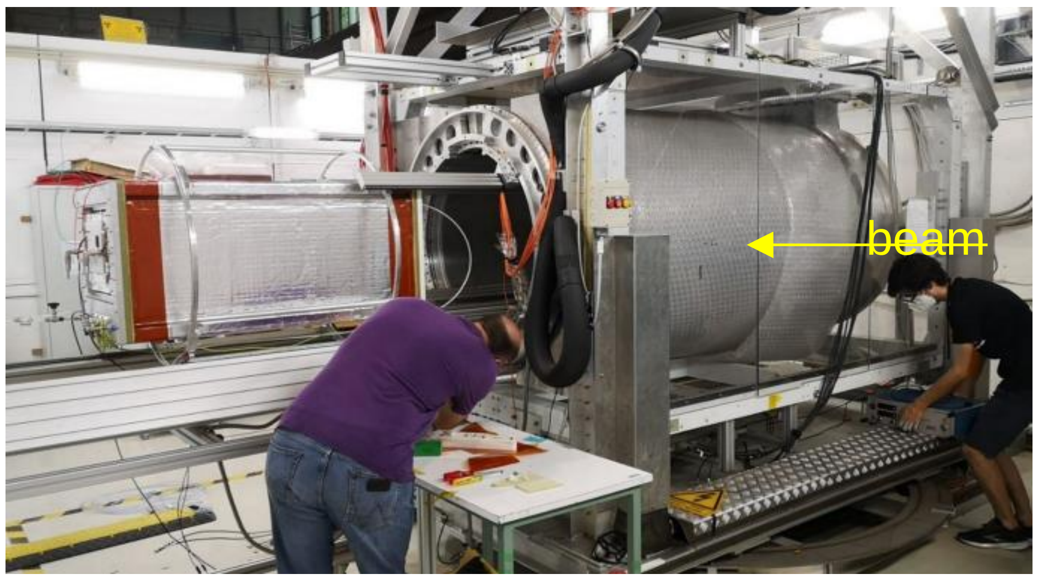
R.Guida et al
(CERN)

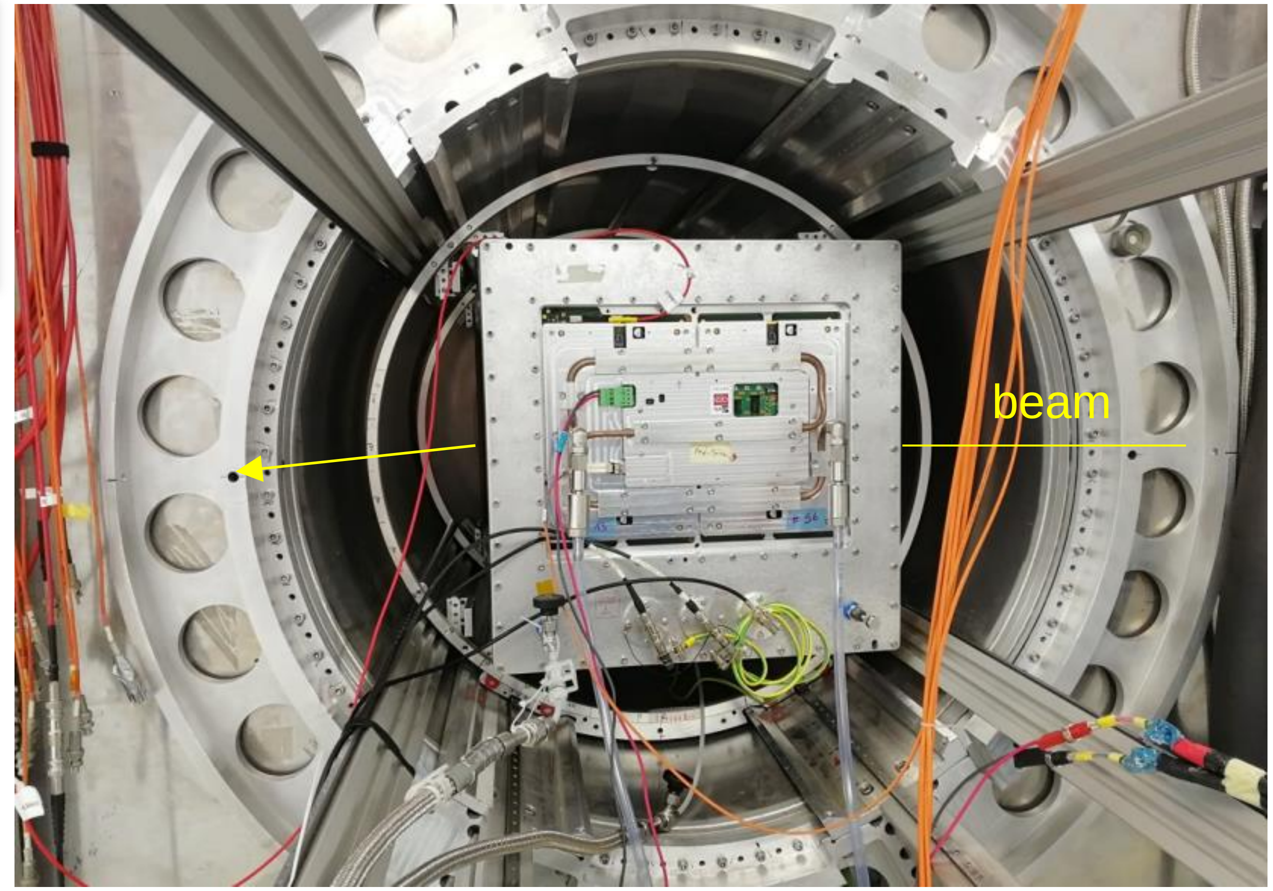
- Production completed
- Commissioning @ CERN OK
- First inspection @ J-PARC and preparation for installation in June 2022
- Installation @ J-PARC Nov 2022 or Jan 2023

HATPC Performances w/ Prototype (1m drift length)

Test Beam @ DESY (July 2021)

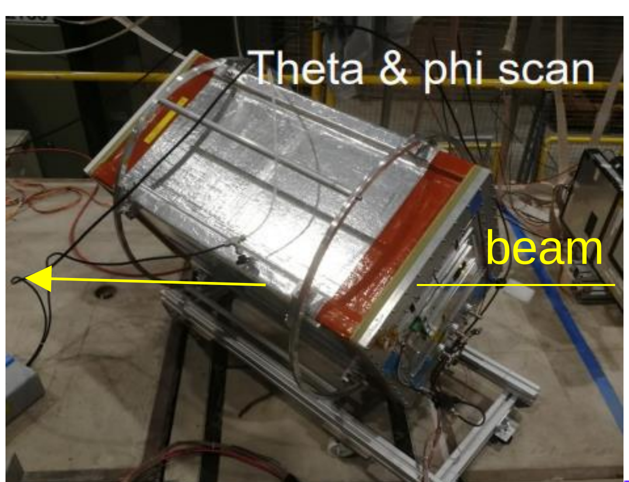
→ electron beam (0.5-5 GeV)
→ superconducting magnet (B up to 1T)

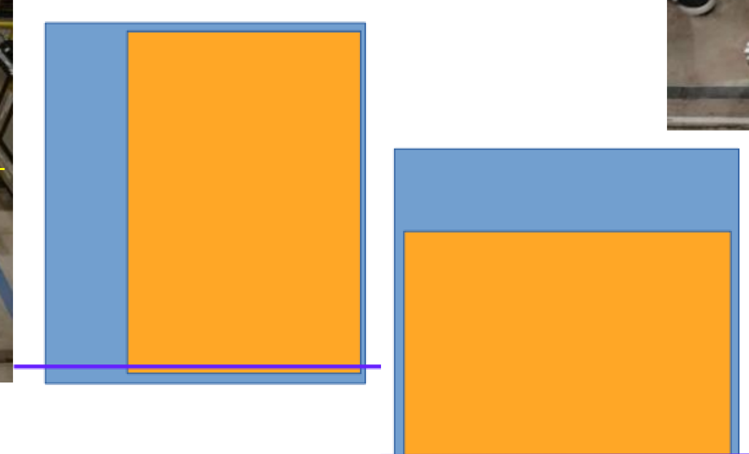


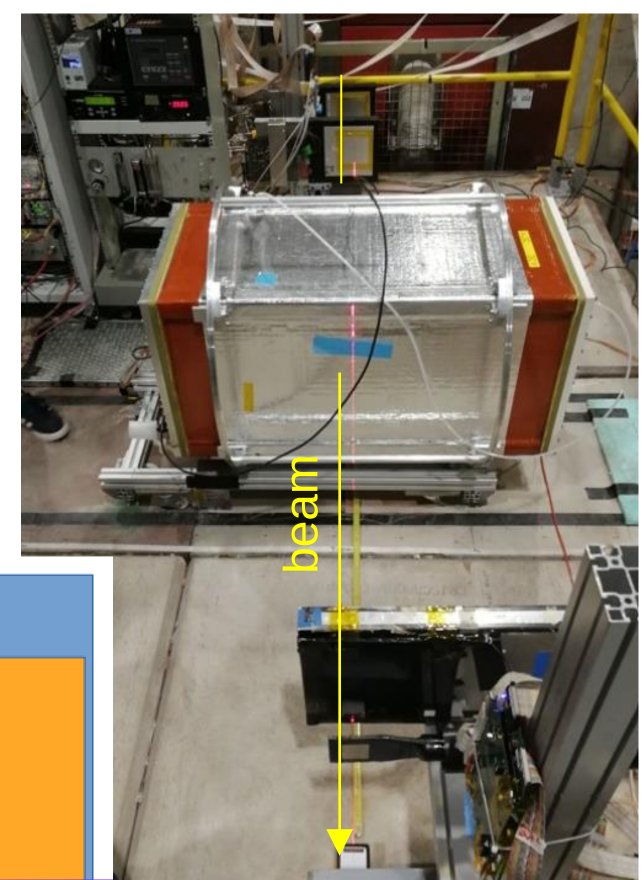


Test Beam @ CERN (November 2021)

→ muon beam (SPS H6 dump)
→ Silicon Strip Tracker (no B field)



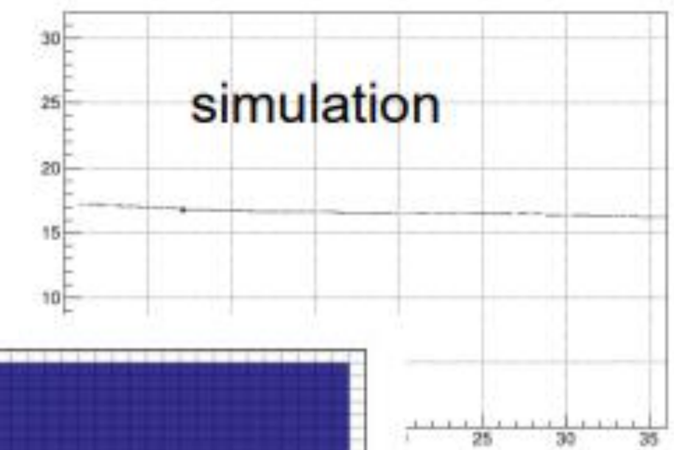


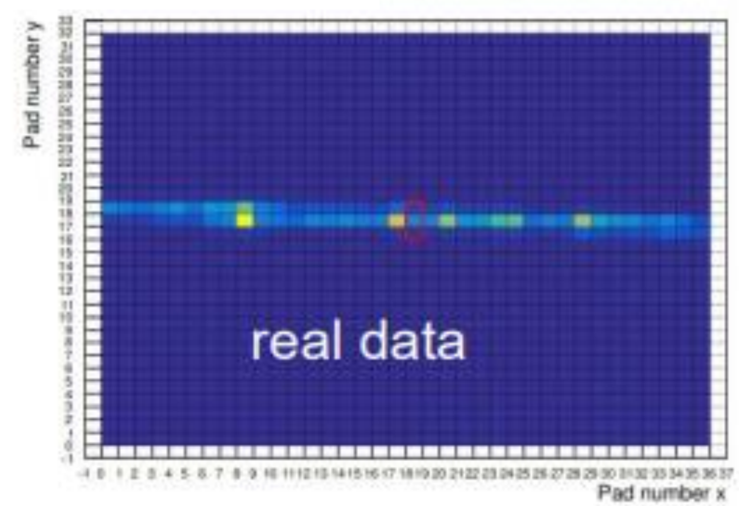


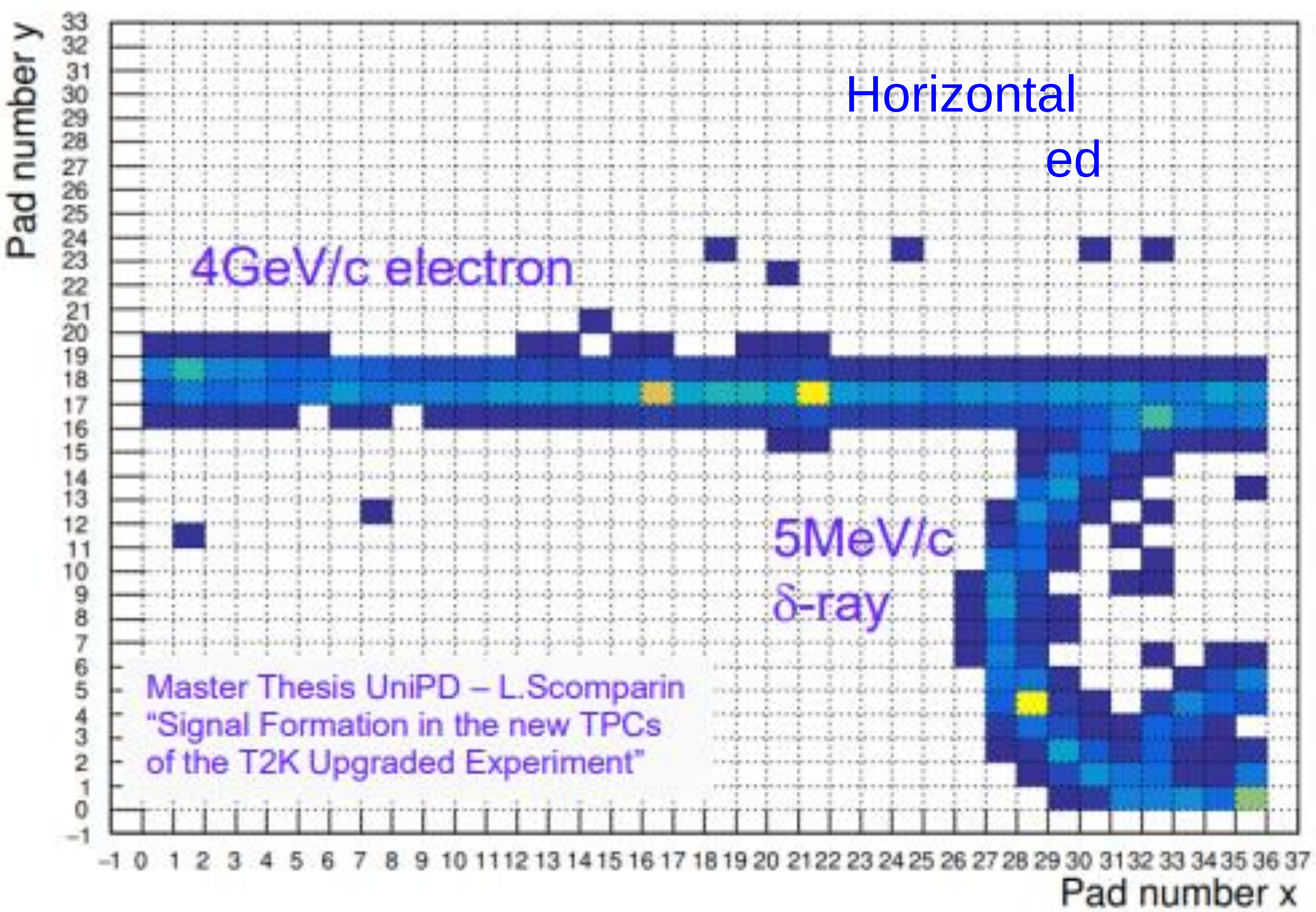
DESY Test Beam 2021 - Prototype (1m drift length)

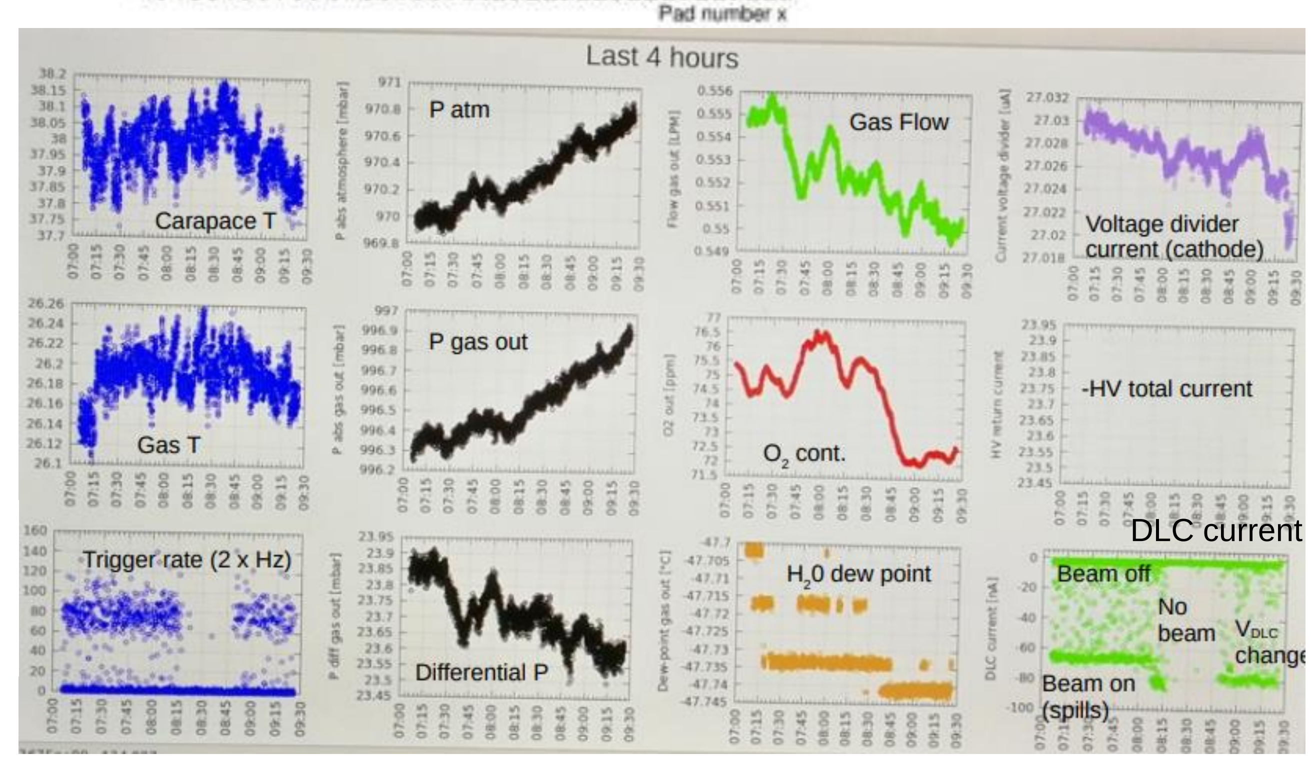
Huge amount of data collected → 13 days full beam time (no issues due to preparation at LNL)
→ various B field intensity (0–1T) & electron momenta (0.5–5GeV/c)
→ reconstruction studies with inclined tracks in theta and phy angles
→ sistematic studies of E and B fields distortions
!!! clear ExB effect from B radial components…
… protoype too long for DESY magnet :)

Horizontal track
Tilted due to
ExB effect



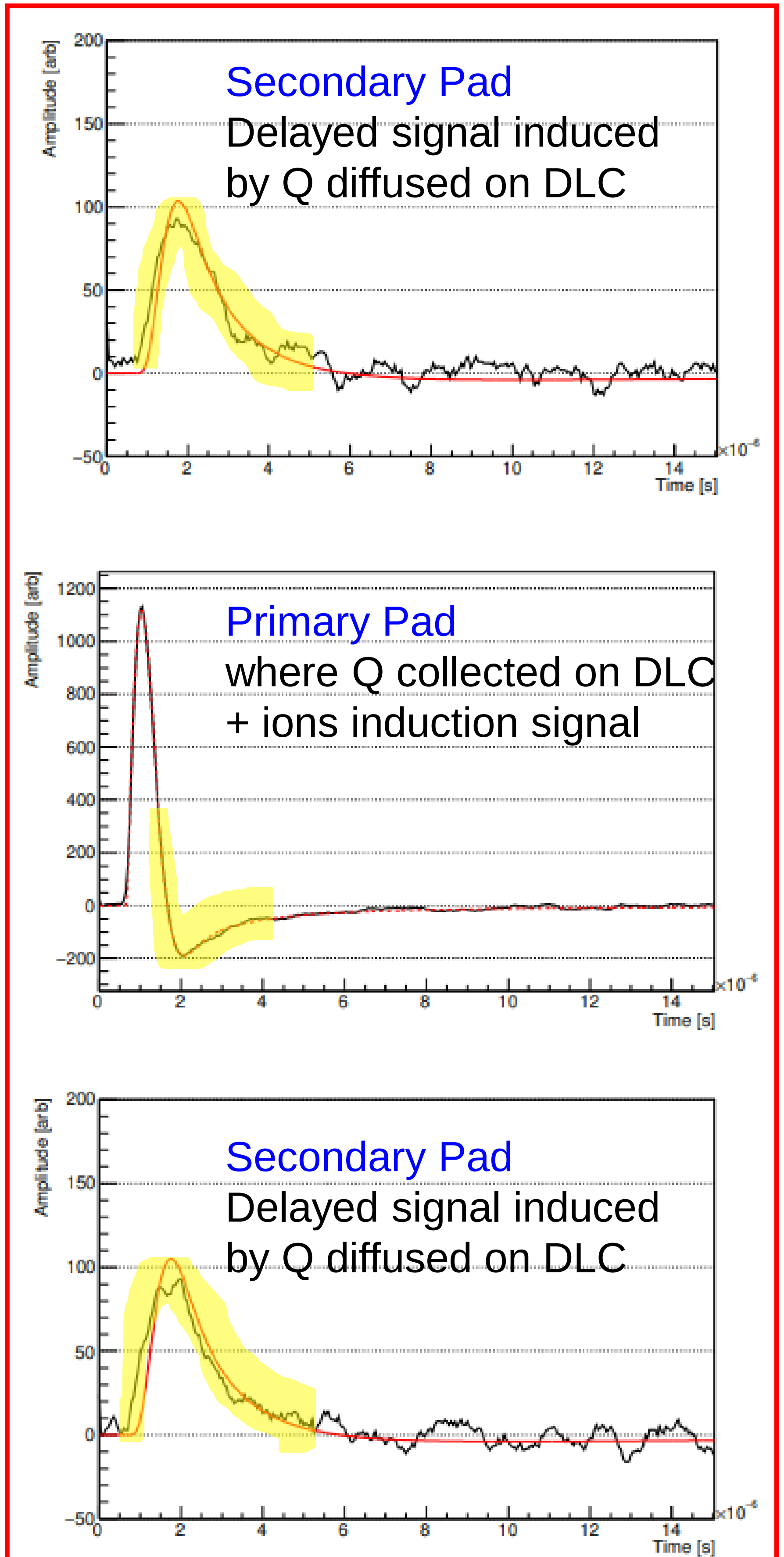


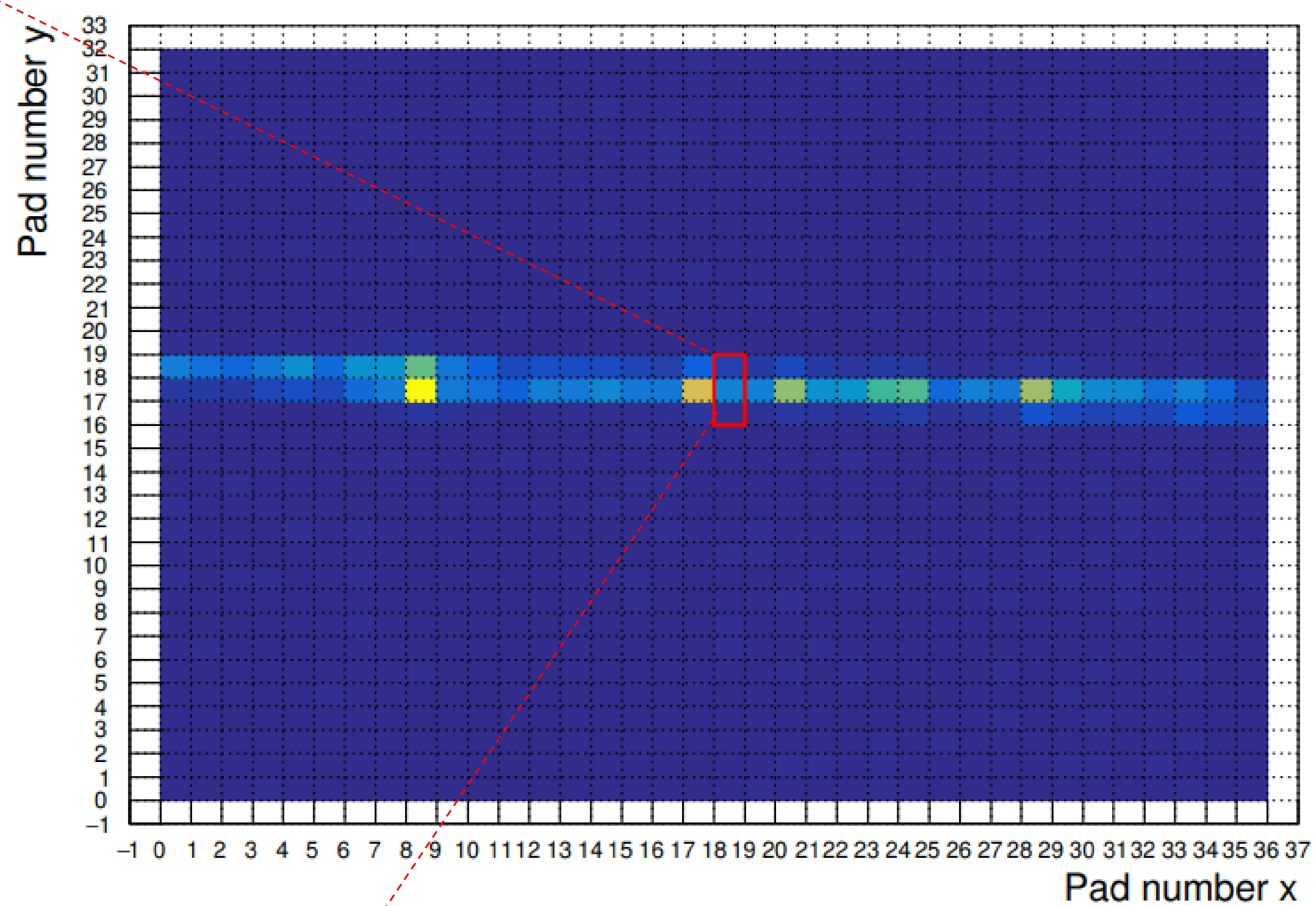




- Very stable Voltage Divider and Cathode High Voltage
  - Excellent gas quality (contaminants < few 10ppm)

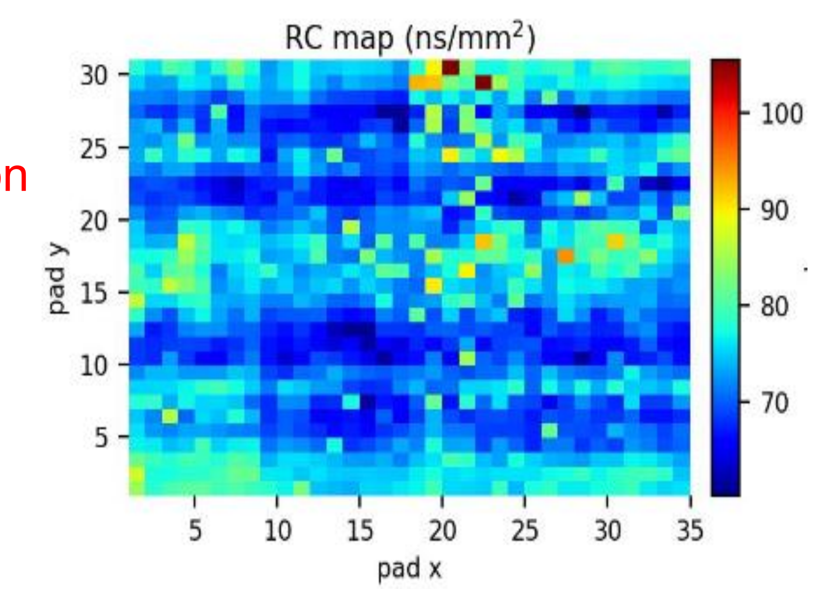
Track reconstruction from waveforms





Highighted waveform regions
sensitive to Q diffusion over DLC
→ waveform fit with telegraph equation
including RC parameter
and FEE response function
allows to measure DLC resistivity

Note: RC map measured
w/ X-rays and w/ tracks



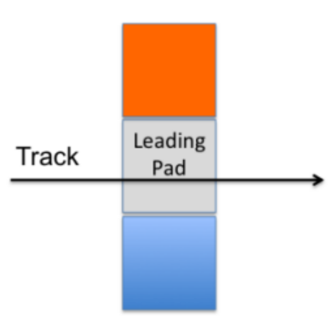
DESY Test Beam 2021 - measurements

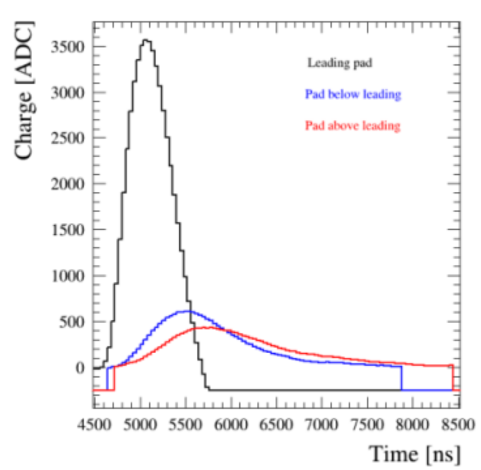
In order to ensure that setup satisfies the ND280 upgrade requirements the test beam tended to:

- test the setup stability (various scans were performed)
- characterize the charge spreading and study resistive foil uniformity.
- measure spatial and energy resolution;

Data is compared to Simulation

Cluster definition: signal ⟼ short in amplitude and long in time ⟼ charge spread in transverse direction ⟼ grouped pads in perpendicular direction of the beam.

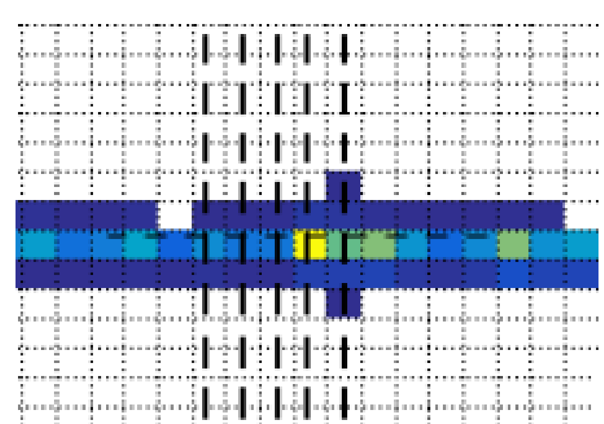




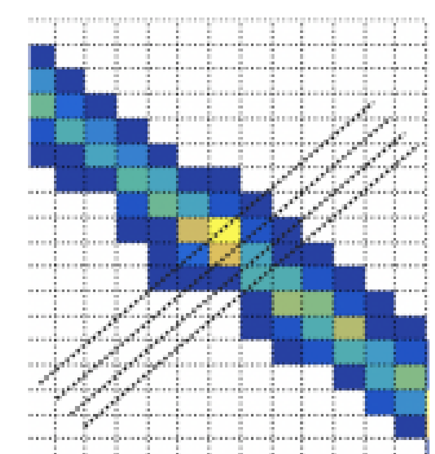
The following measurements were performed (⟼ back up slides):

- Drift distance (for both horizontal and inclined tracks and different drift velocities)
- ϕ scan (angle wrt ERAM plane)
- θ scan (angle wrt vertical axis)
- Sampling time
- B field scan
- Vertical (Y axis) scan
- Momentum scan
- Gain (DLC voltage) scan

Horizontal tracks:



Inclined tracks:



dE/dx and spatial resolution (definition)

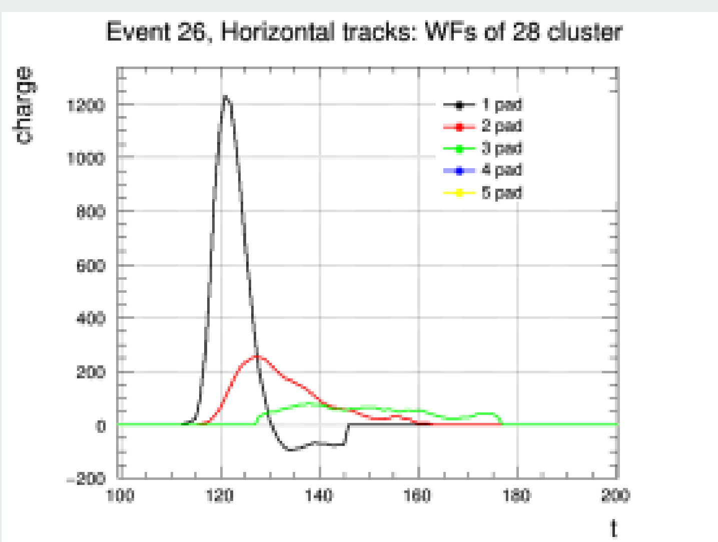
dE/dx resolution

- 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

cluster WF at maximum



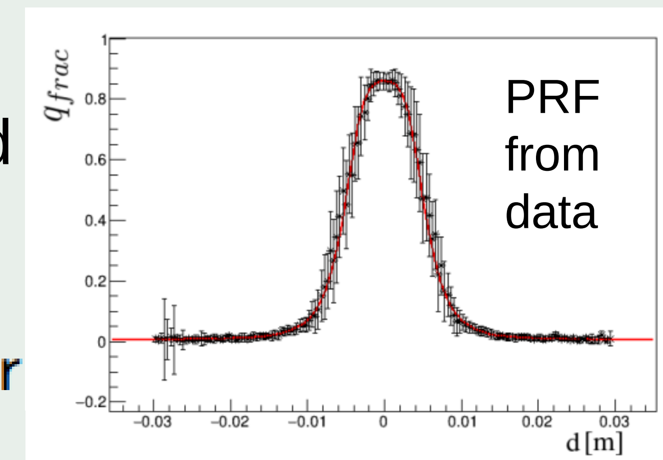
Spatial resolution

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

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

- Prior position estimated by center of mass method

1. profile 2D histo $\rightarrow$ PRF
2. Track position per cluster x_{track} estimated by minimiz.



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

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

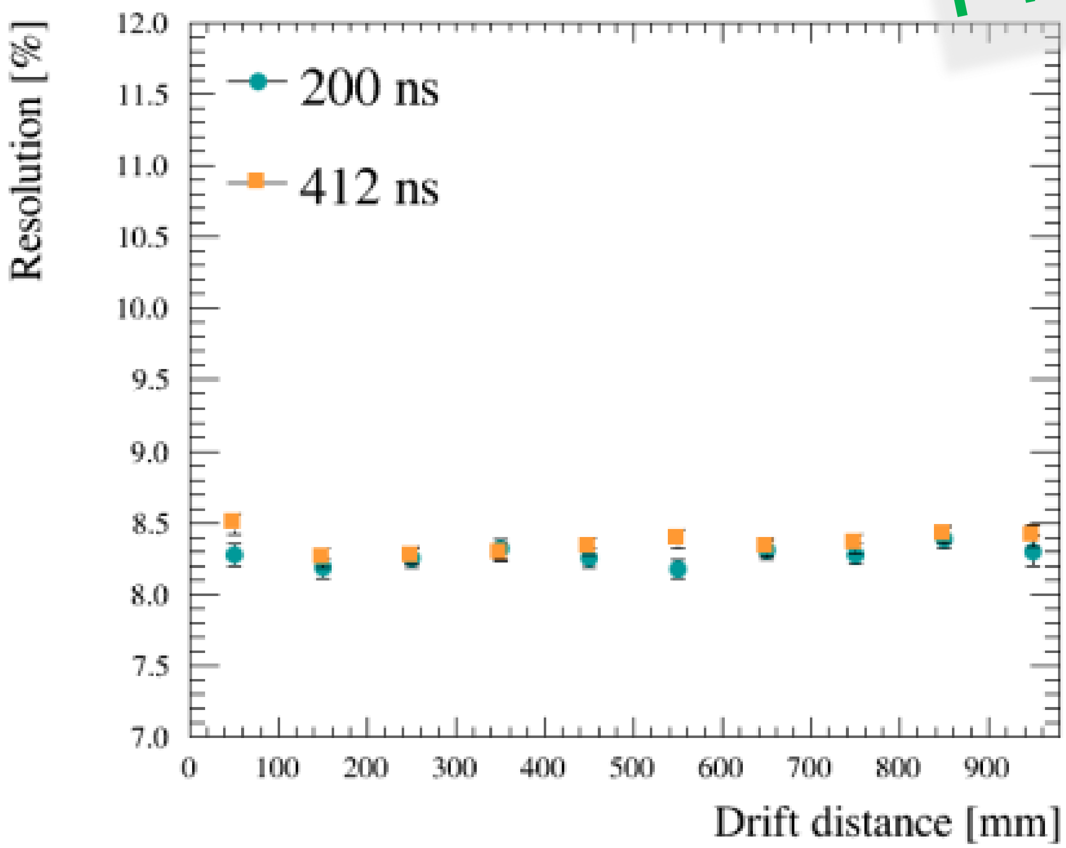
3. Track fit: $\rightarrow$ "parabola" $\rightarrow x_{fit}$

- Iterate $1 \rightarrow 2 \rightarrow 3$ … to improve fit
- σ of residuals $(x_{track} - x_{fit})$ in each cluster is spatial resolution (SR)

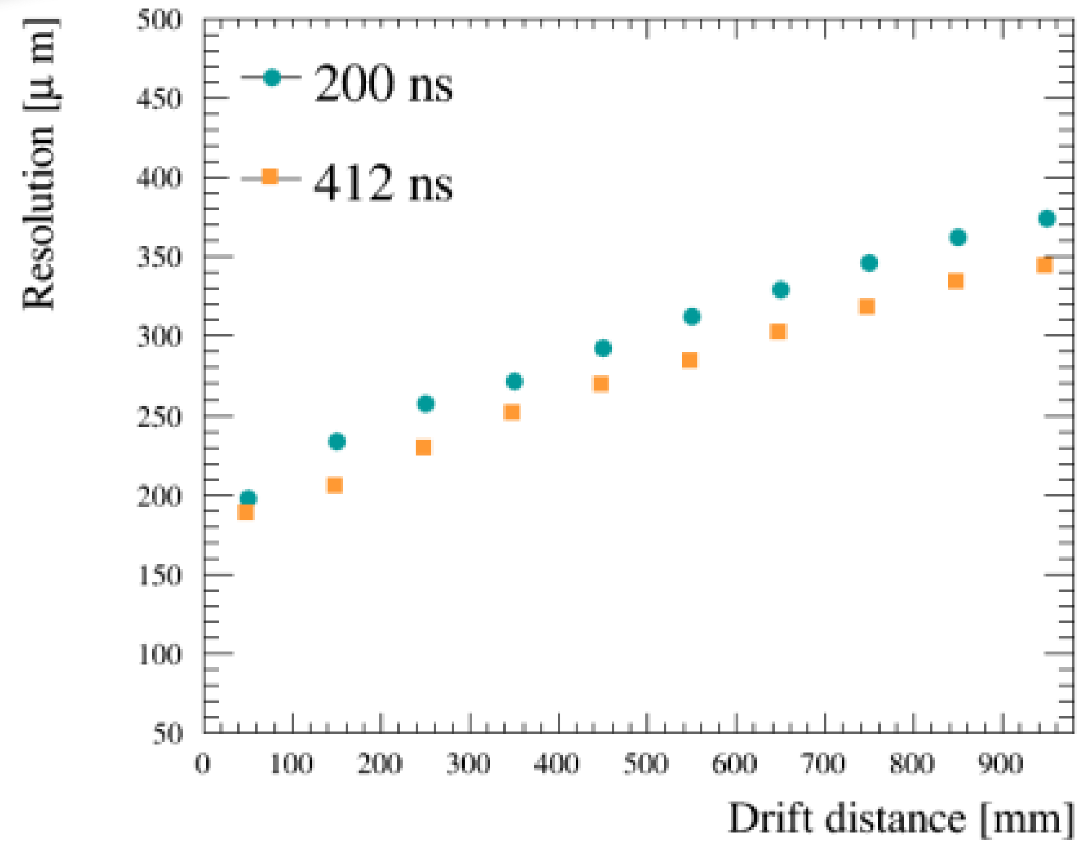
DESY TB2021 - horizontal tracks – dE/dx & σ_x

Preliminary

dE/dx resolution



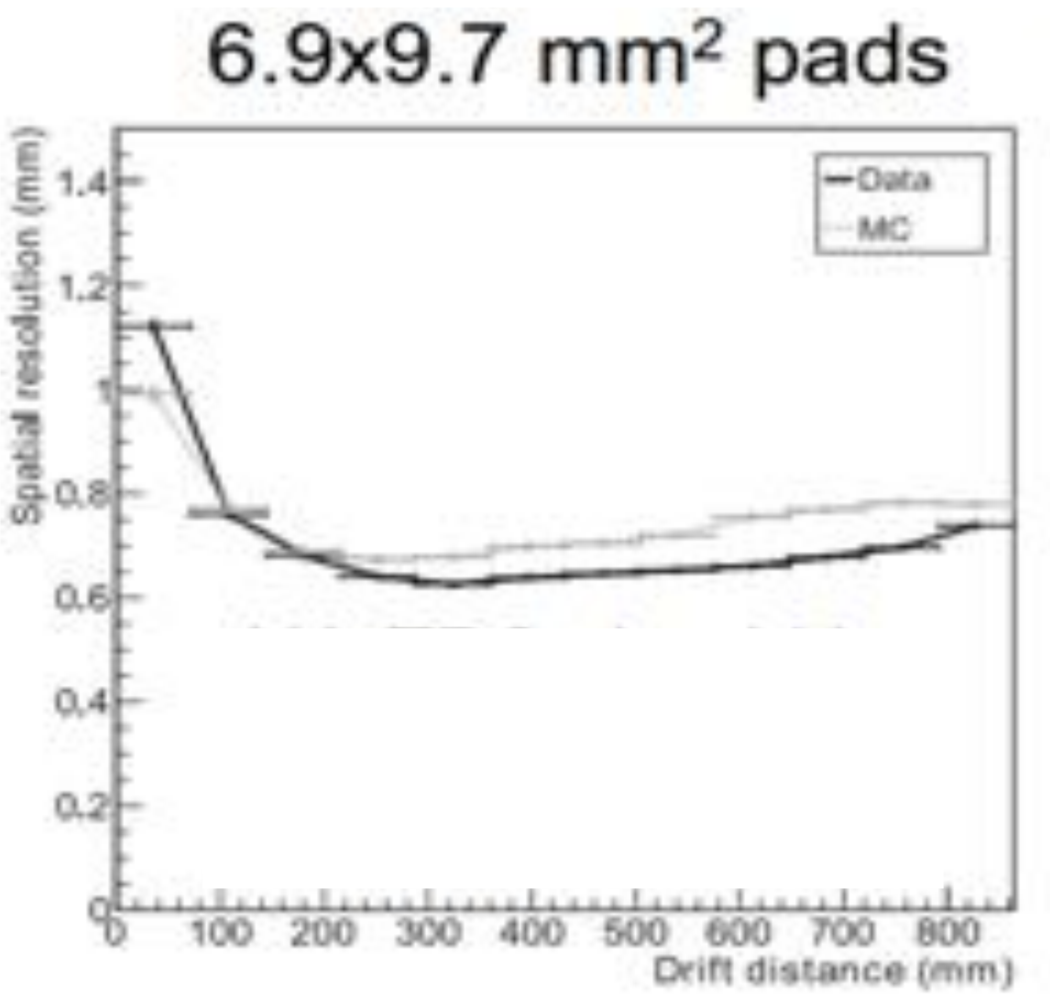
Spatial resolution



- DESY analysis 2021:
  - dE/dx resolution stays between 8% and 8.5 % and does not vary wrt peaking time. Note: 2 ERAMs (80 cm sampling length) dE/dx resol → 6%
  - Spatial resolution stays between 170μm and 400 μm and slightly vary wrt peaking time, degrades with drift distance (due to the diffusion).

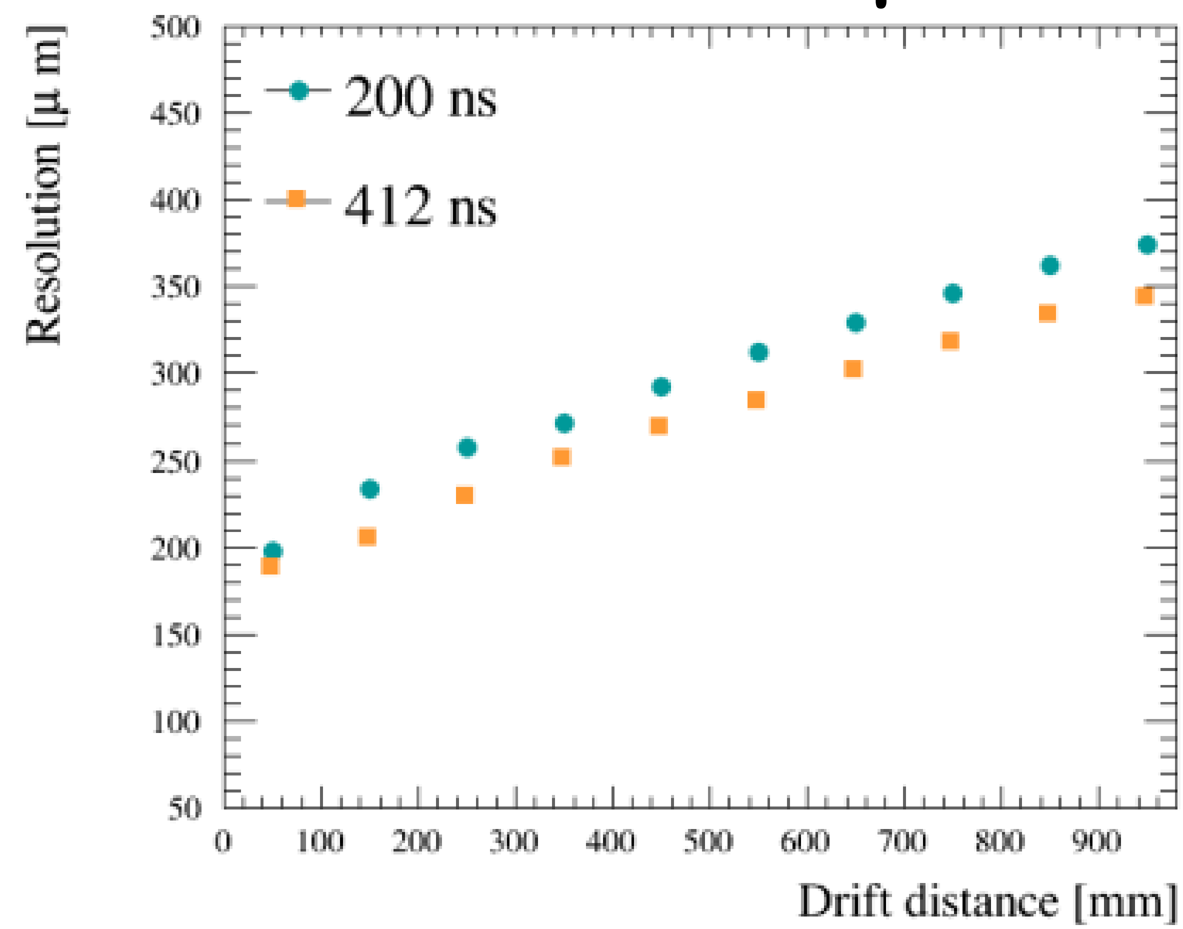
DESY TB2021 – Bulk vs Resistive Micromegas

Bulk MM



ERAM

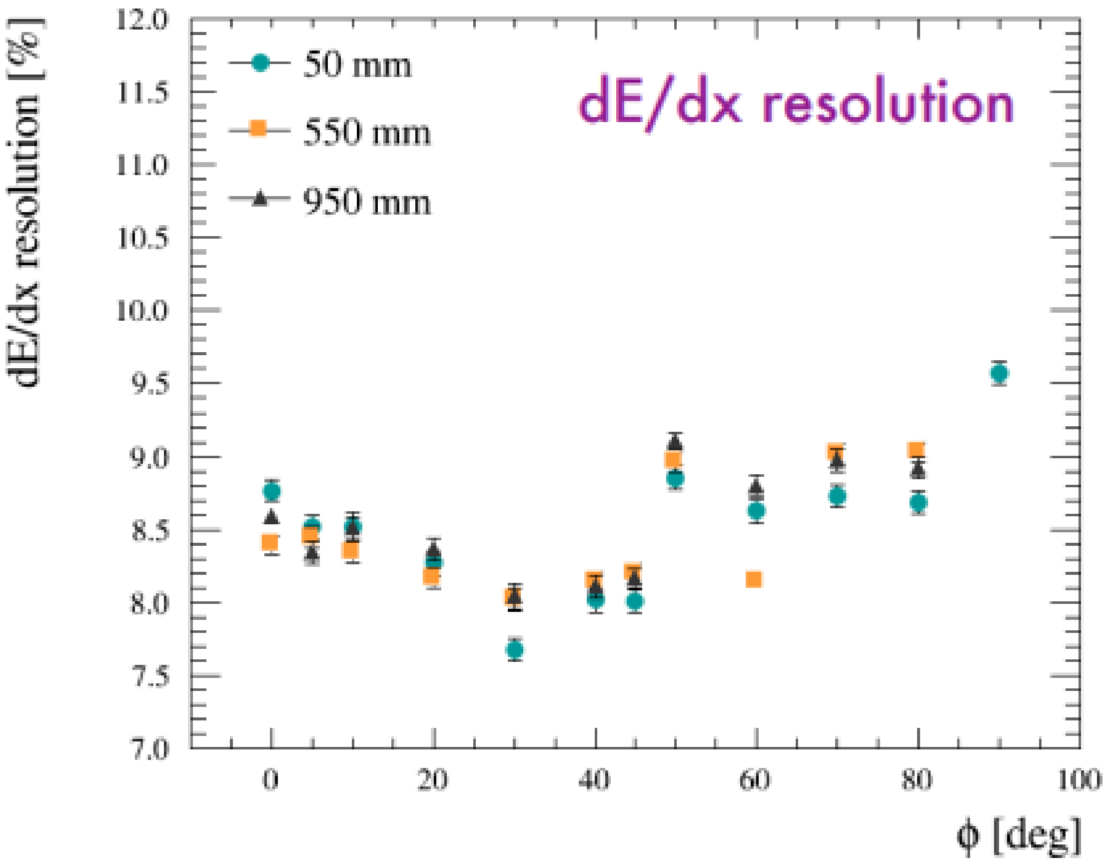
10 x 11 mm^2 pads

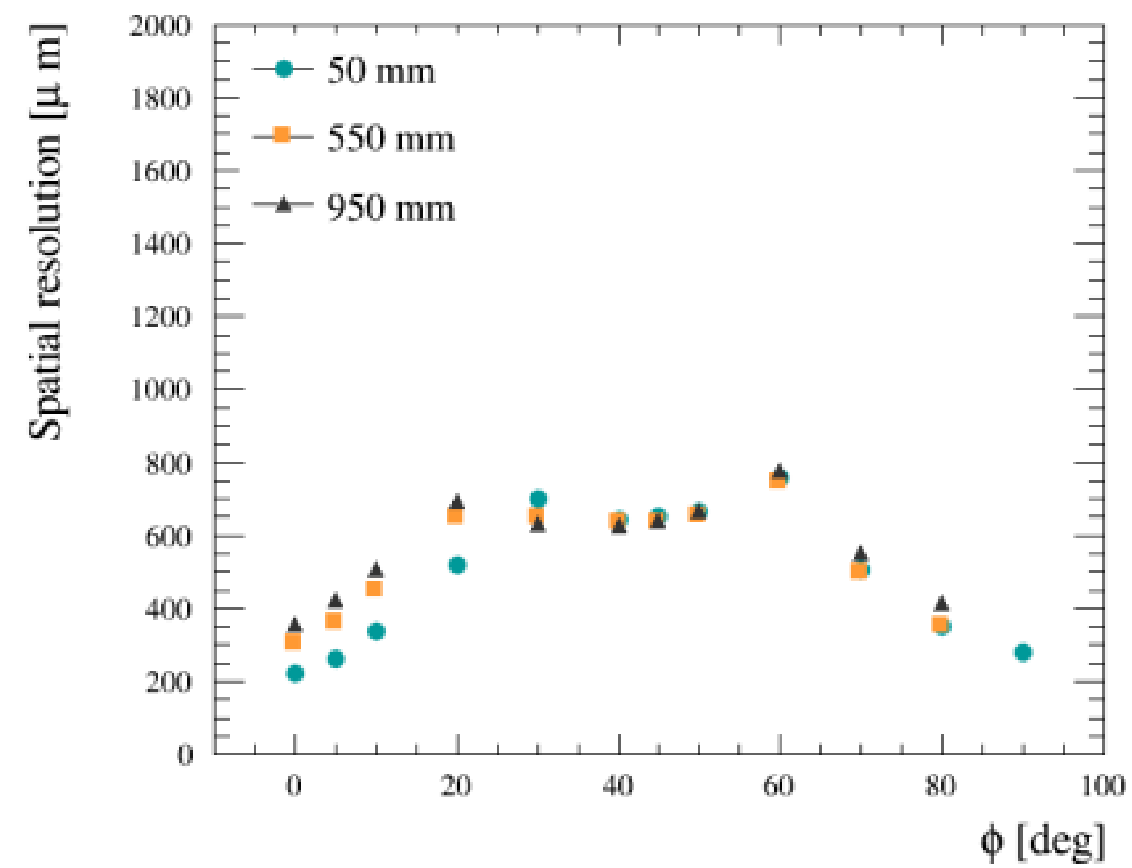


DESY TB2021 – phi angle dependence - dE/dx & σ_x

- Fit: columns $\phi[0,20]$; diagonal $\phi[30,60]$; rows $\phi[70,90]$;
- Cuts: mean multiplicity; number of clusters
- Length correction applied for diagonal clustering

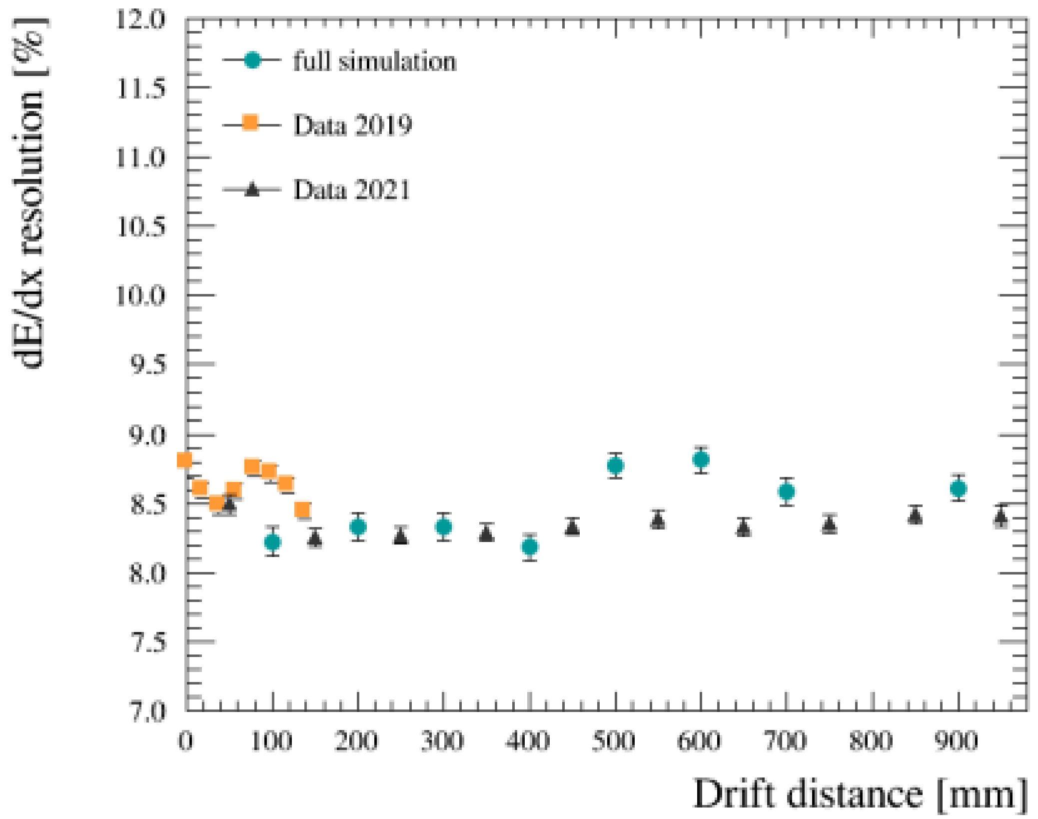
Preliminary

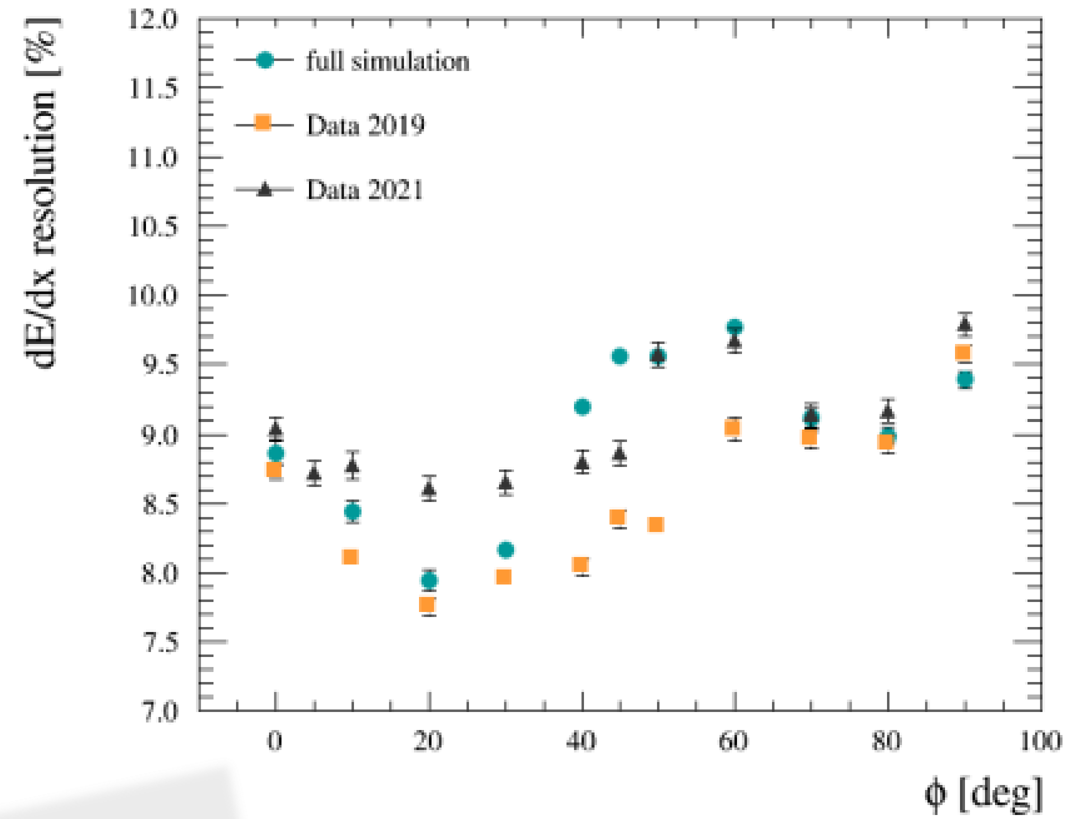




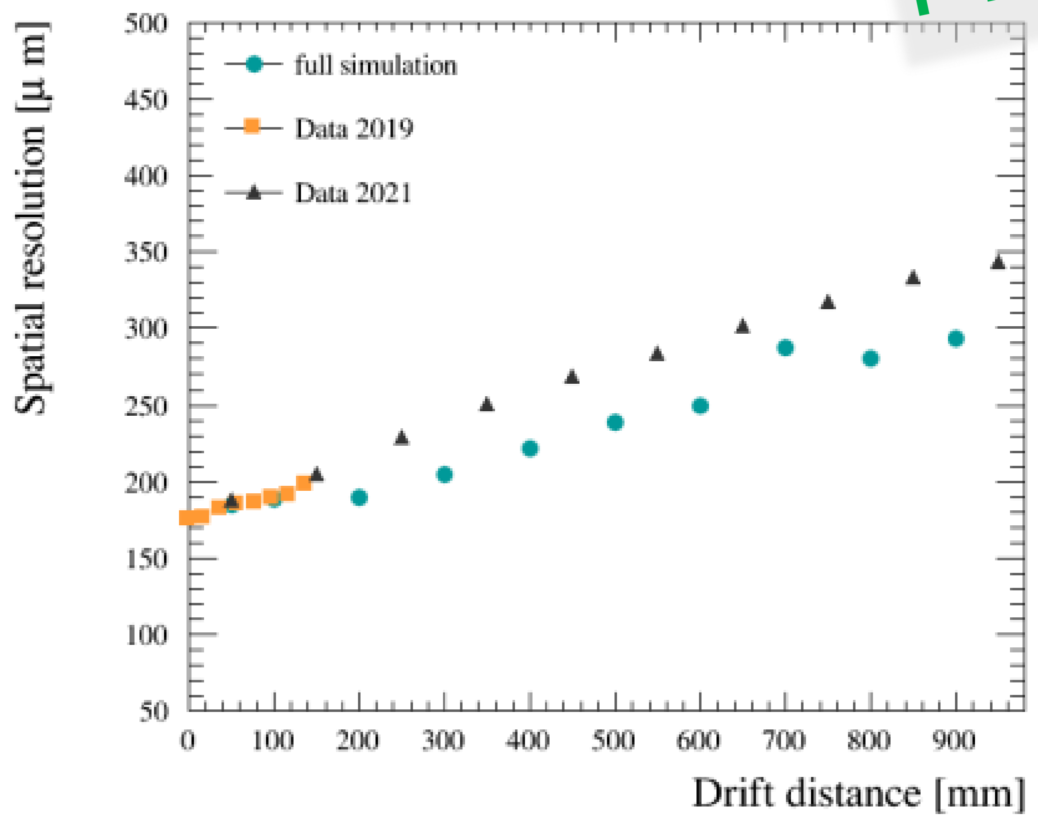
- DESY analysis 2021:
  - dE/dx resolution stays between 7.5% and 9.5 %: almost independent on drift distance.
  - Spatial resolution stays between 200μm and 800 μm. The dependence on drift distance is observed for horizontal clustering.

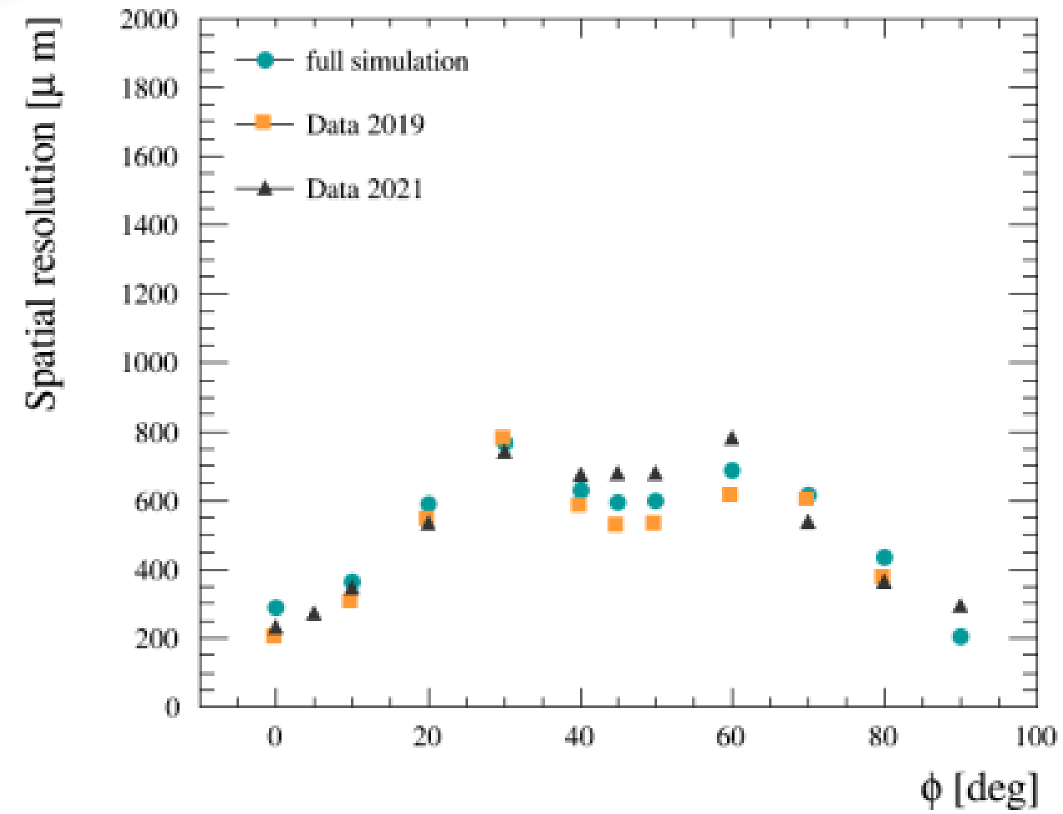
DESY Test Beam 2021 – comparison with MC



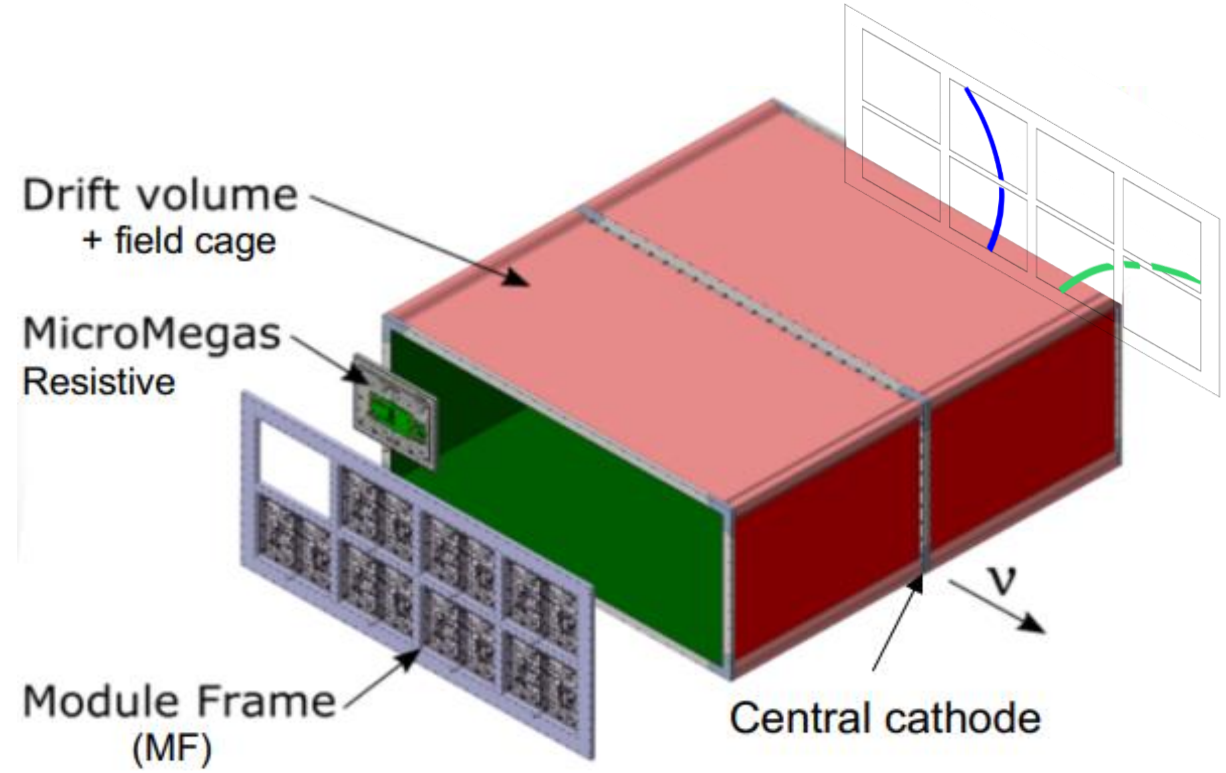


Preliminary





Conclusions



Two new HATPC for the ND280 Upgrade
in production phase

Field Cage
- Unique features: large volume, rectangular, thin insulating walls w/ electrodes on surface
- Building process & materials validated w/ prototypes and mockups
- Production started
- First ½ FC under test and validation

ERAM detectors
- Resistive Anode Embedded studied in very detail for the first time
- Production started

New Gas system
- Production and commissioning @ CERN
- Ready to be shipped to Japan

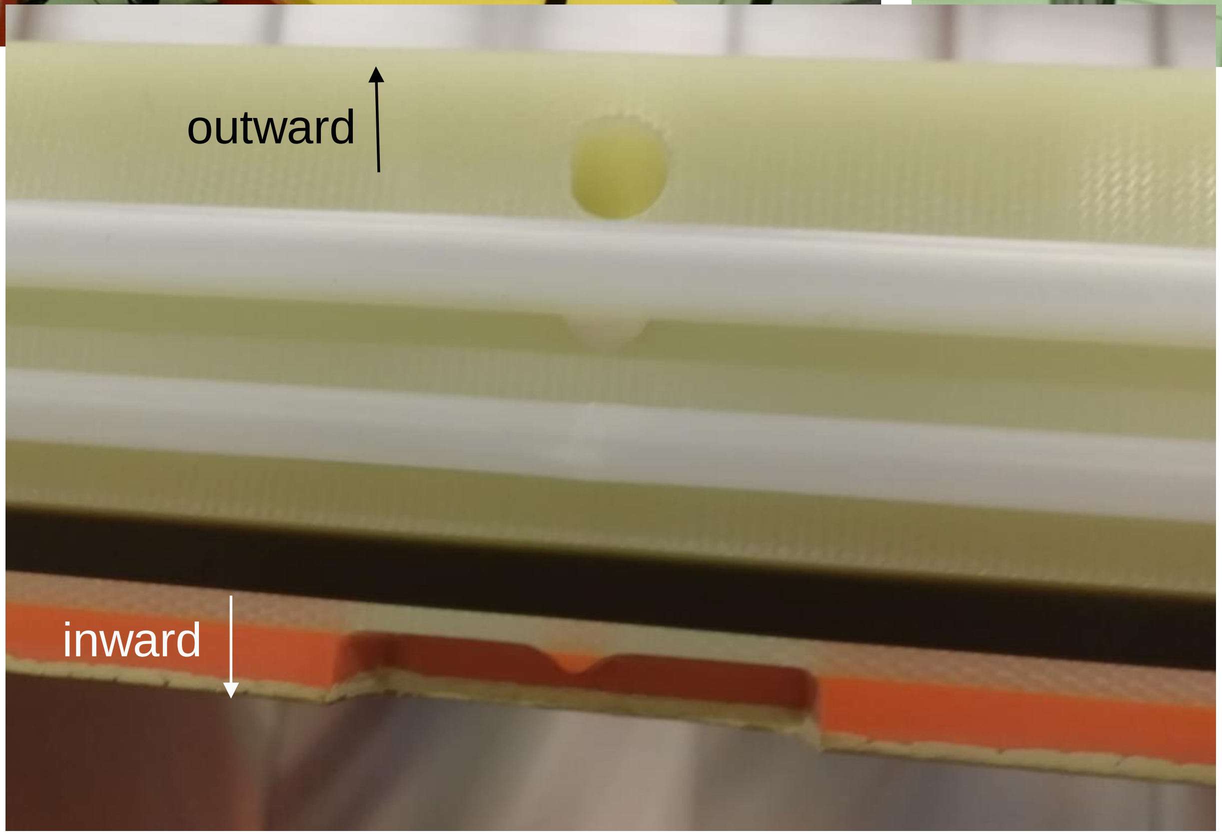
FE & RO Electronics
- Produced and ready for installation

Tracking and PID Performances (on Prototype)
- In agreement with expectations

Installation and Commissioning @ JPARC of 2 two HA-TPC
- Planned before Summer 2023

Additional Material

Field Cage – Gas leak test preparation

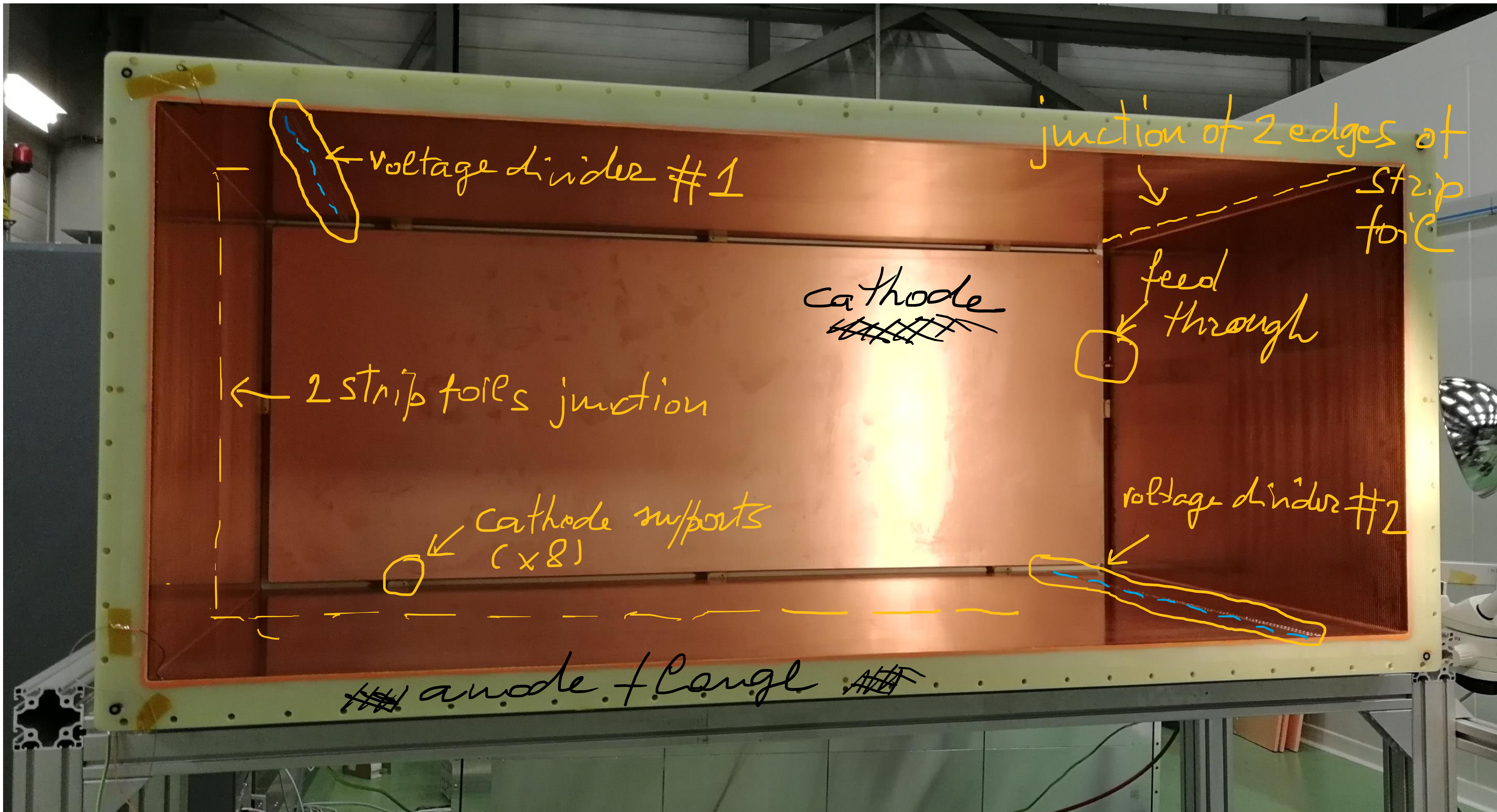


Cathode side:

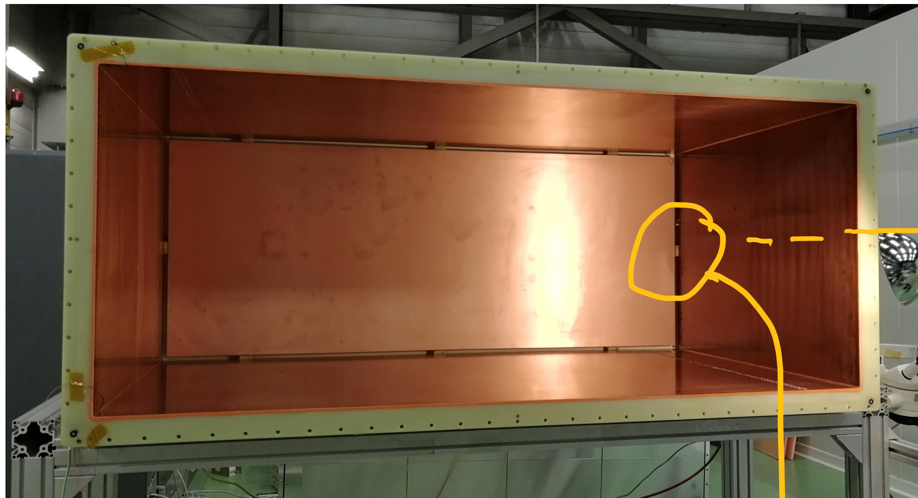
double oblated o-ring
and deep groove
Against discharges
(to be filled teflon ring)

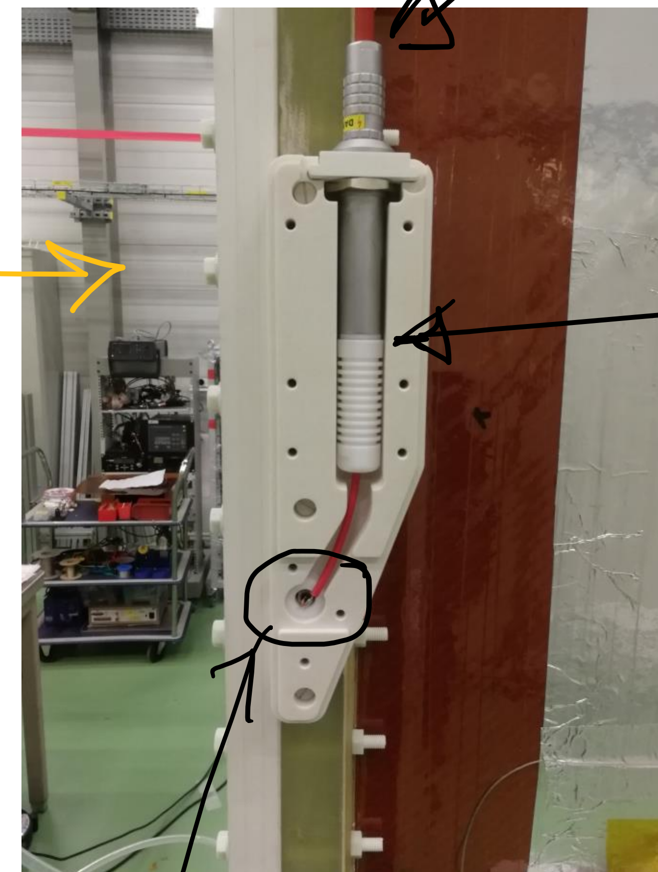
Field Cage details

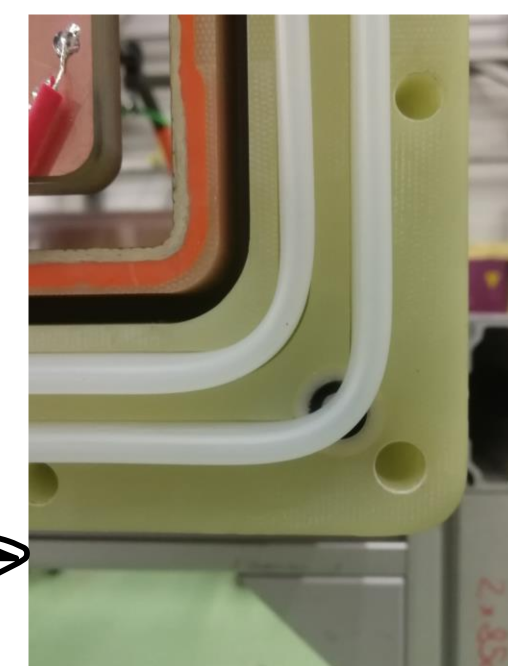
Anode side view (Anode plane removed)



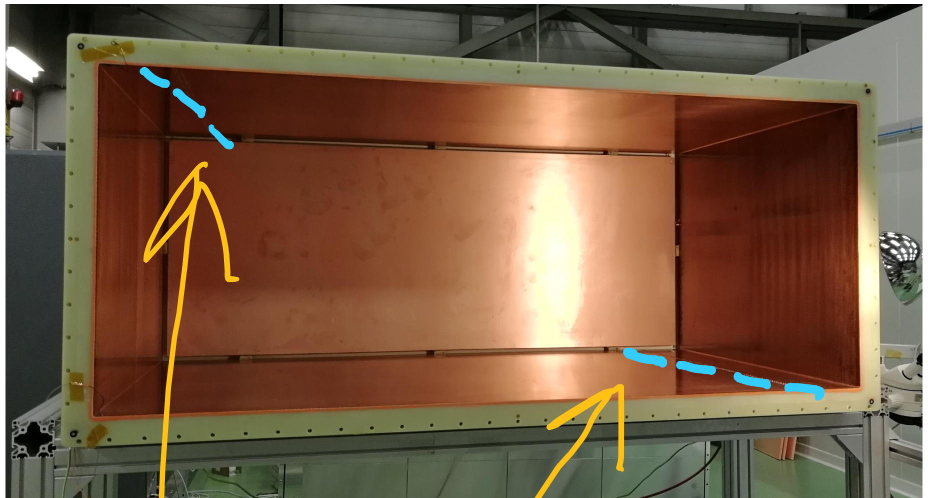
Field Cage details



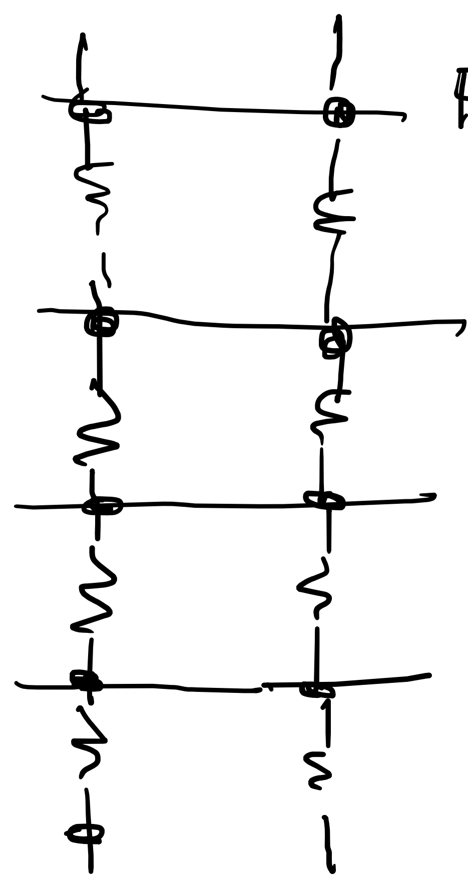


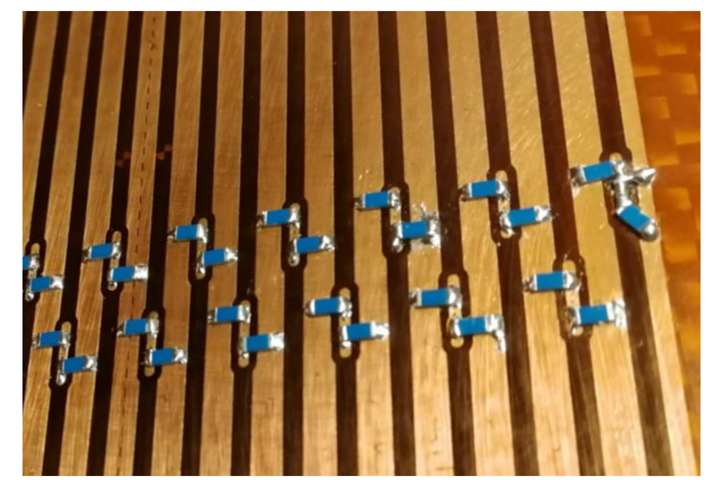


Field Cage details – focus on electrical part



196 Field strips
195 Mirror strips





Voltage divider

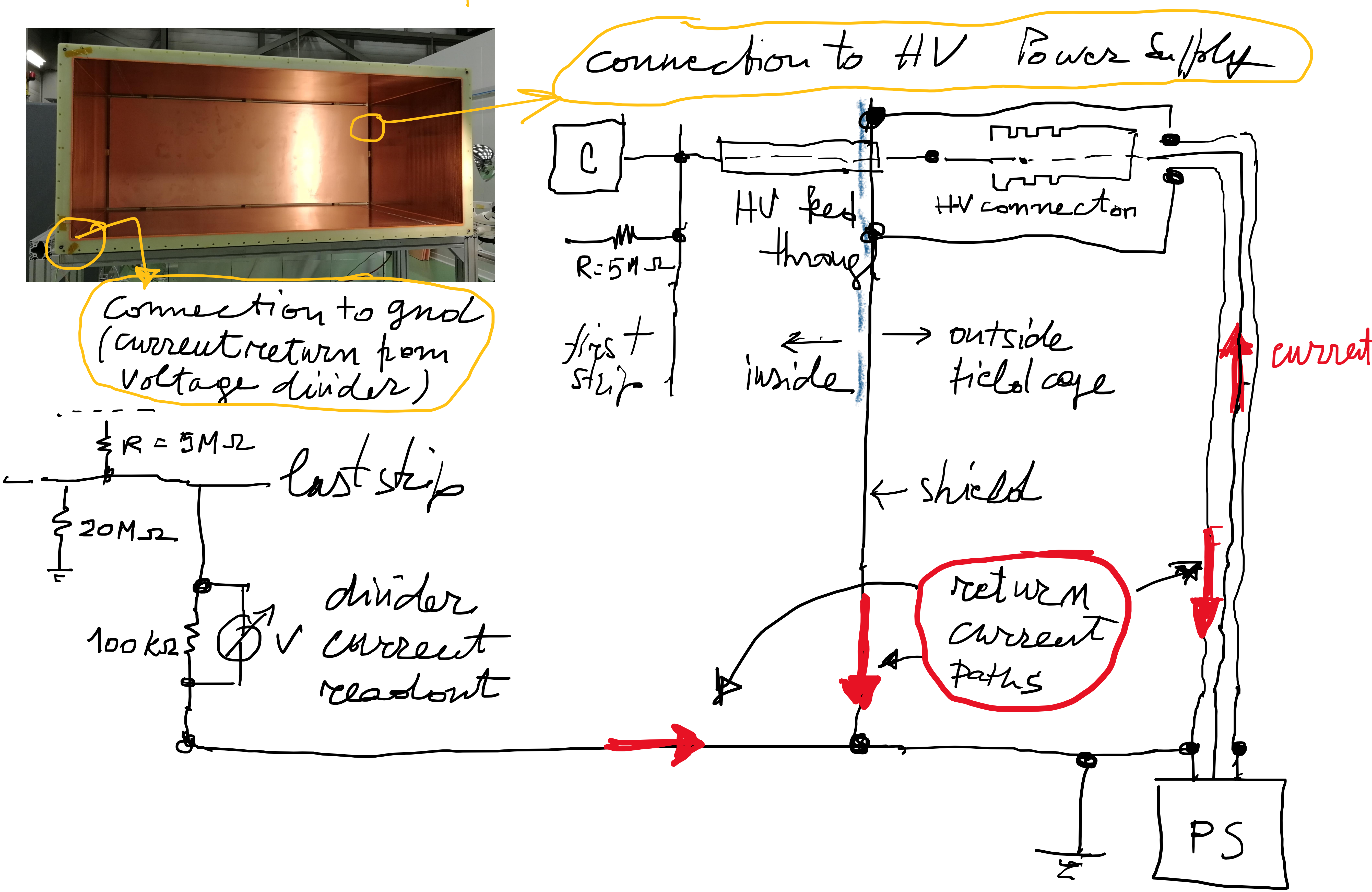
2 R chains in parallel

R = 5.1 MΩ ± 0.1 %
Thin Film

overall: 391 + 391 Resistors → Divider Resistance 997 MΩ

1 GΩ

Field Cage details – focus on electrical part



Effetto Resistenza di mantello

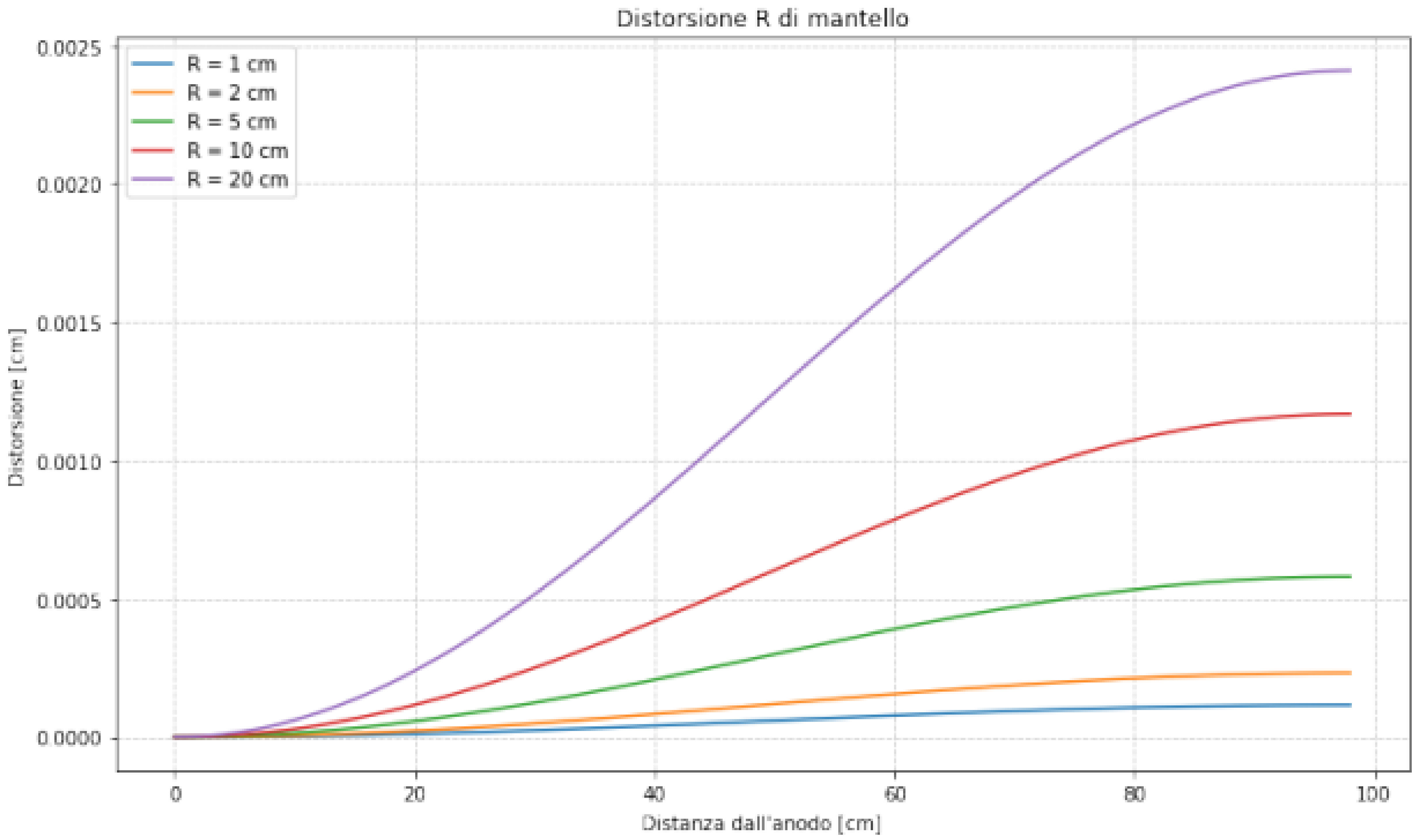
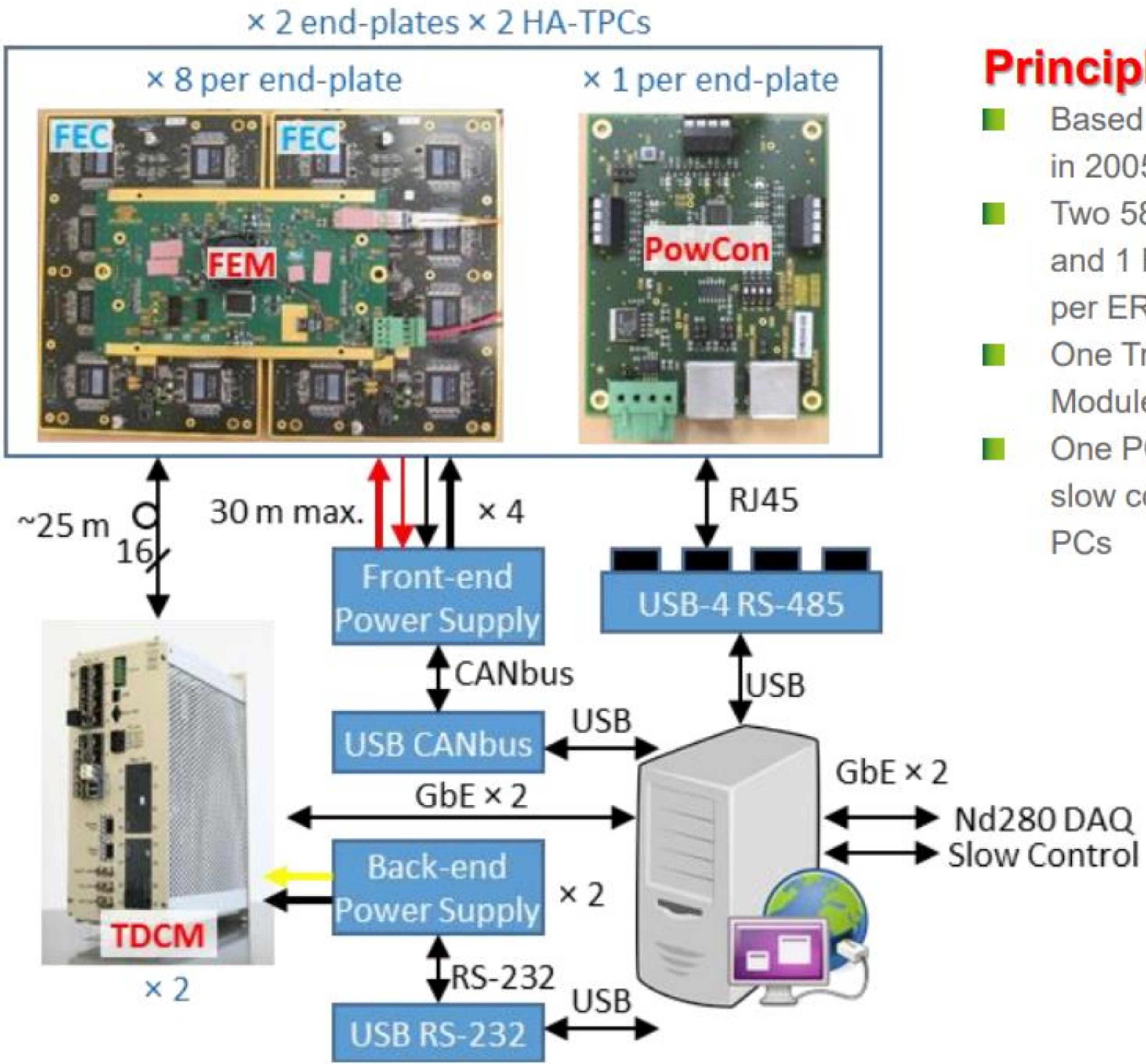


Figura 4.2: Spostamento lungo R del punto di arrivo di un elettrone causato da una resistenza R_{man} di un mantello isolante mille volte il valore della catena di resistori R. La distorsione é mostrata come funzione del punto di partenza z (Distanza dall'anodo).

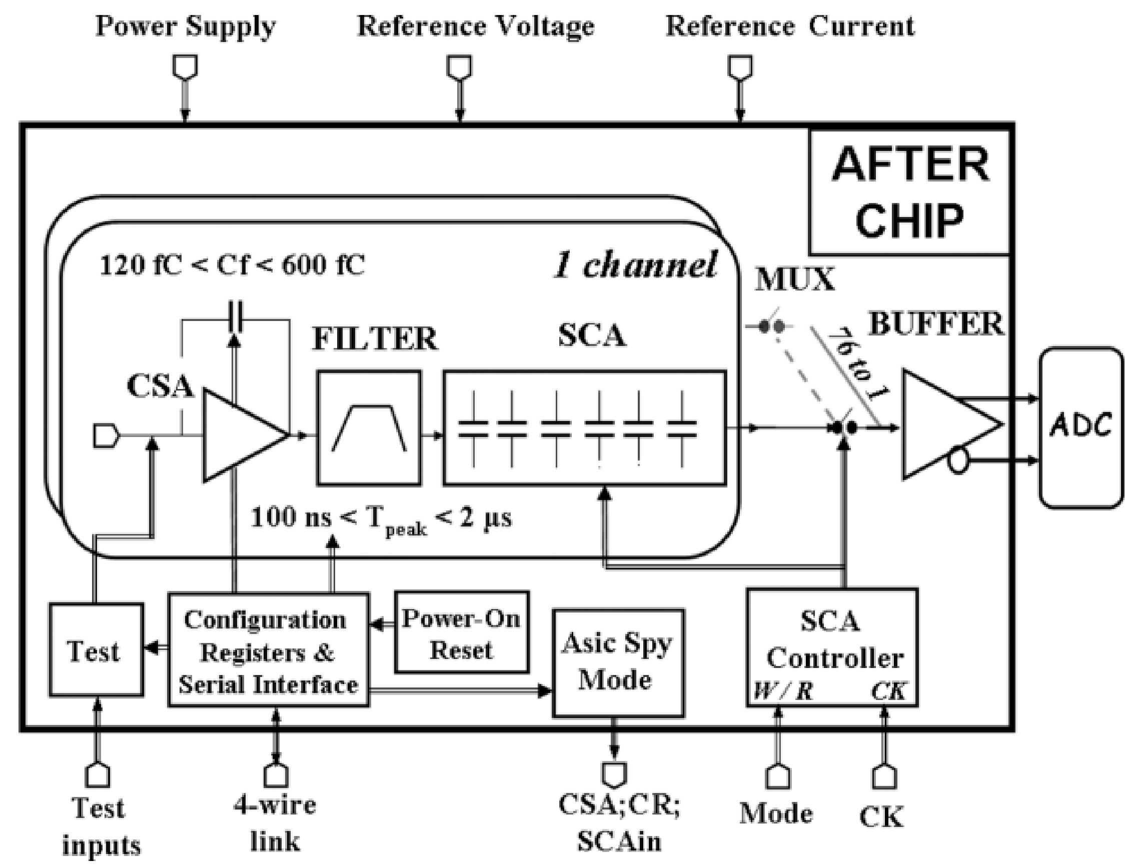
HA-TPC READOUT ARCHITECTURE



Principles

- Based on the AFTER chip designed in 2005 for T2K TPCs
- Two 588-channel Front-end Cards and 1 Front-end Mezzanine card per ERAM module
- One Trigger & Data Concentrator Module (TDCM) per HA-TPC
- One PC for configuration, DAQ and slow control. May use two distinct PCs

AFTER chip



Q max.	Cf
120 fC	200 fF
240 fC	400 fF
360 fC	600 fF
600 fC	1 pF

$\tau_f = \tau_p = 100\ \mu s$

$C_p = 6$ pF; $R_p = 17\ M\Omega$

$C_s = 2$ pF

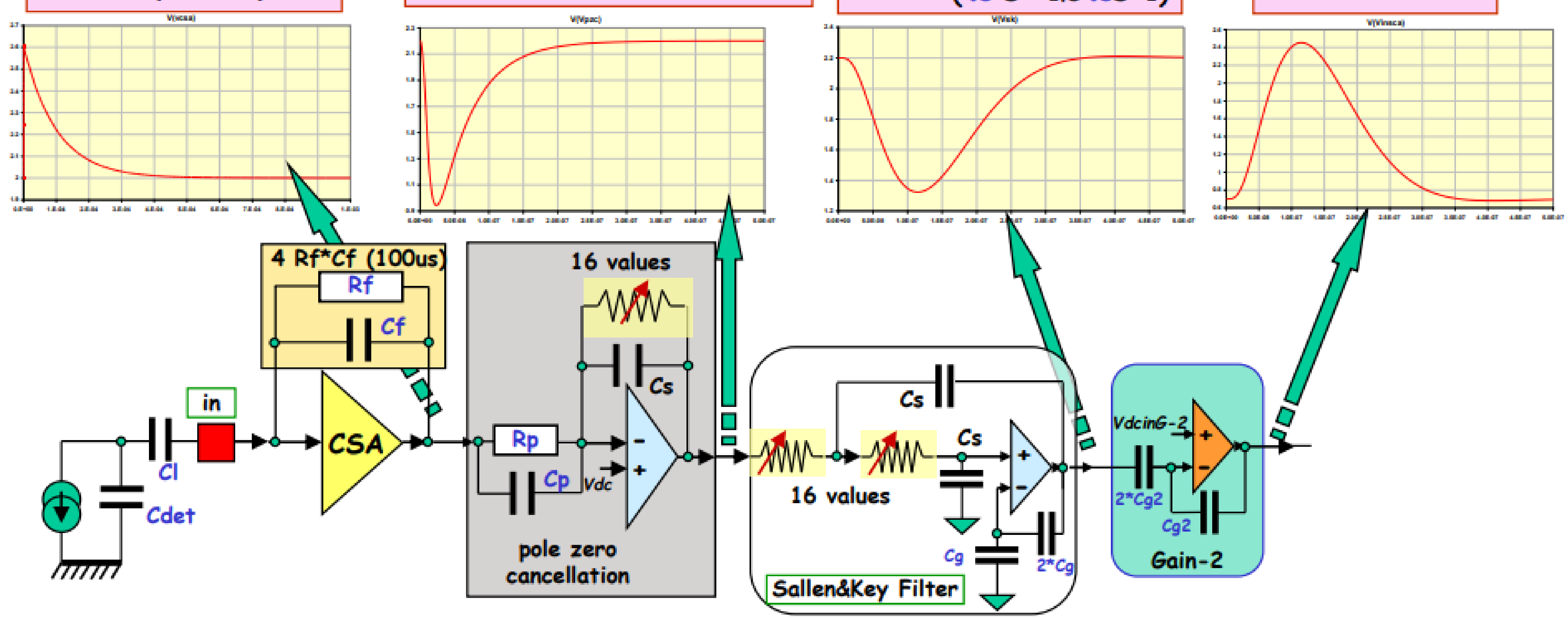
τ_s = 50 ns to 1000 ns (16 values)

$$V_{csa}(s) = \frac{-1}{(s+1/\tau_f)} \cdot \frac{Q_{in}}{C_f}$$

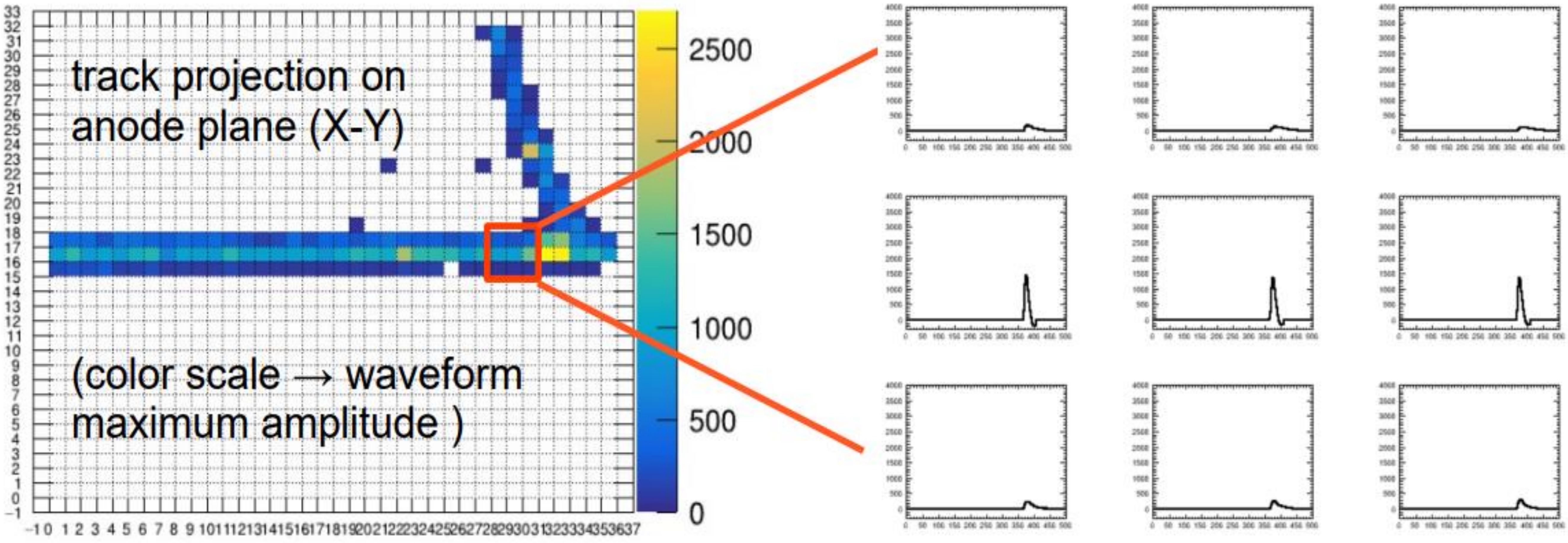
$$V_{pz}(s) = -\frac{C_p.(s+1/\tau_p)}{C_s.(s+1/\tau_s)} . V_{csa}(s)$$

$$V_{sk}(s) = \frac{1.5 . V_{pz}(s)}{(\tau_s^2 s^2 + 1.5 \tau_s s + 1)}$$

$$V_{g-2}(s) = -2 . V_{sk}(s)$$

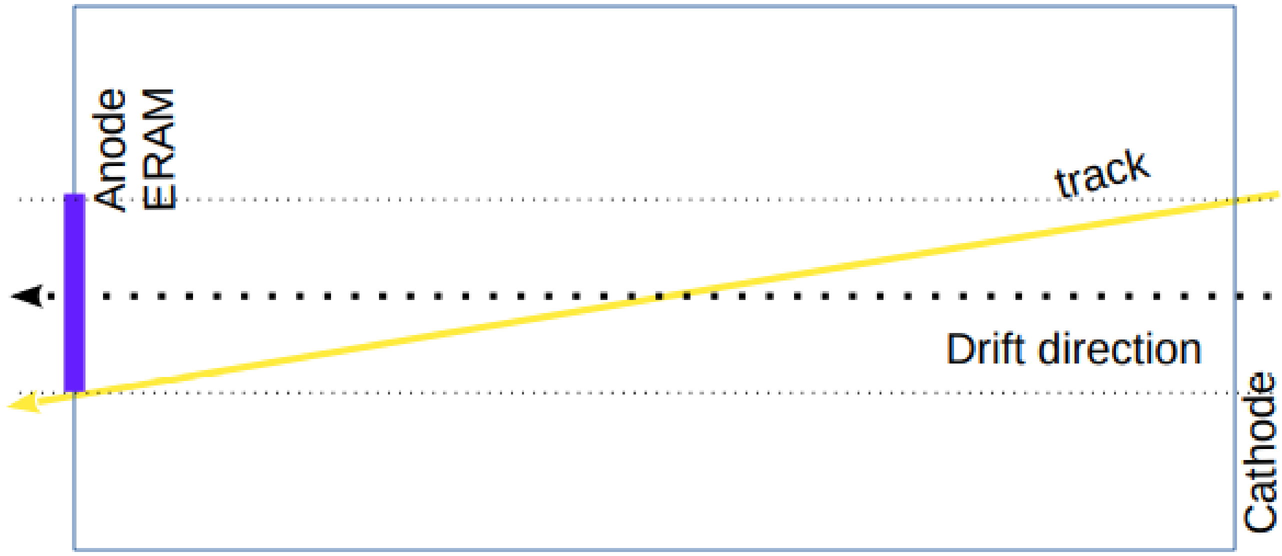


Track reconstruction from waveforms

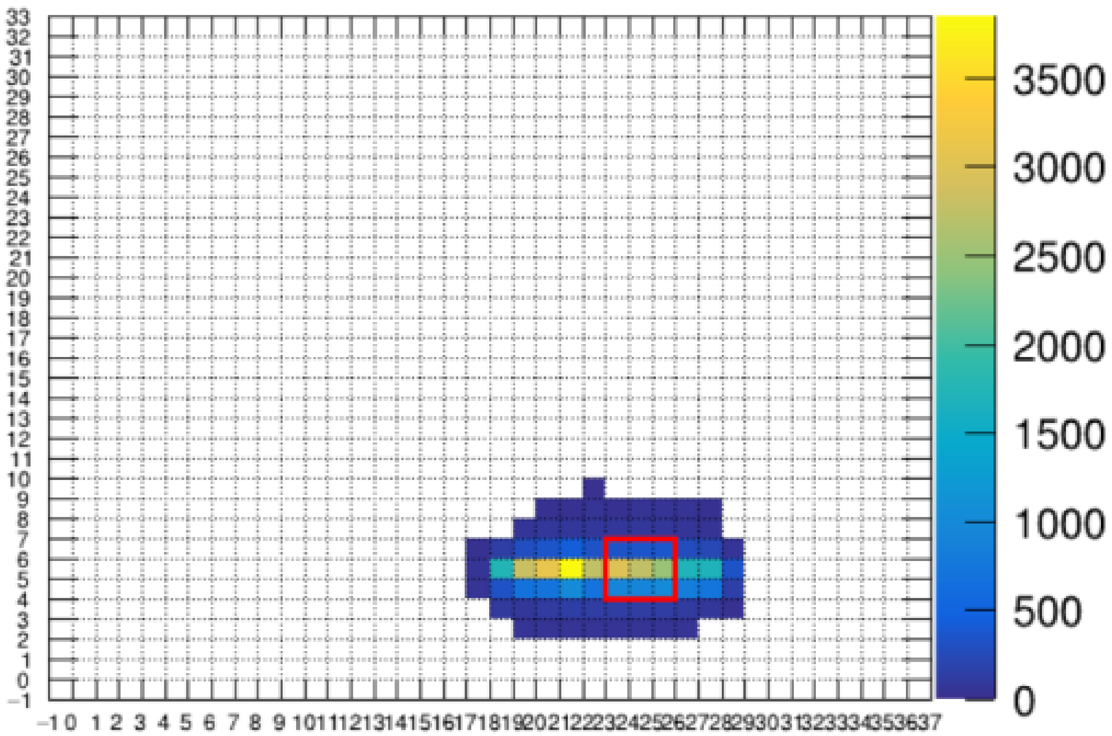


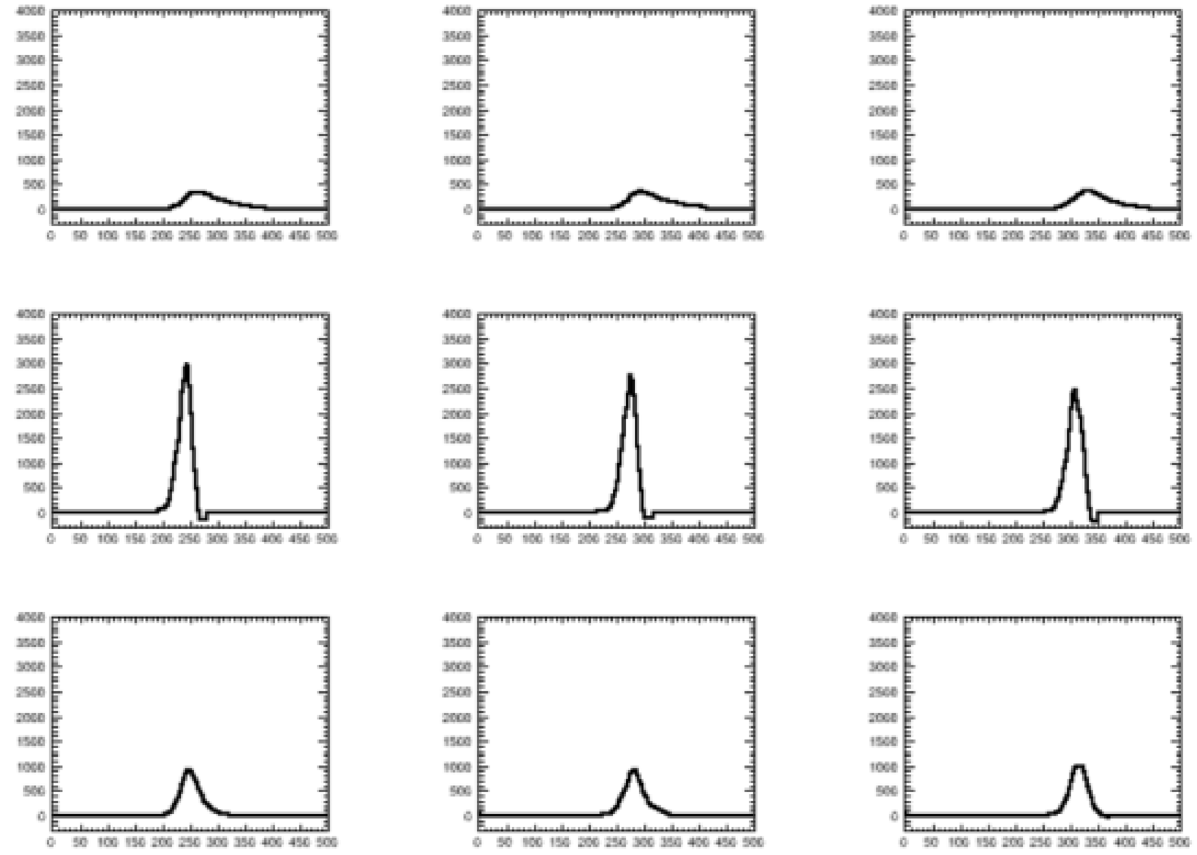
Track reconstruction from waveforms

Test Beam CERN 2021



Waveforms theta = 80°
(10° wrt drift direction)

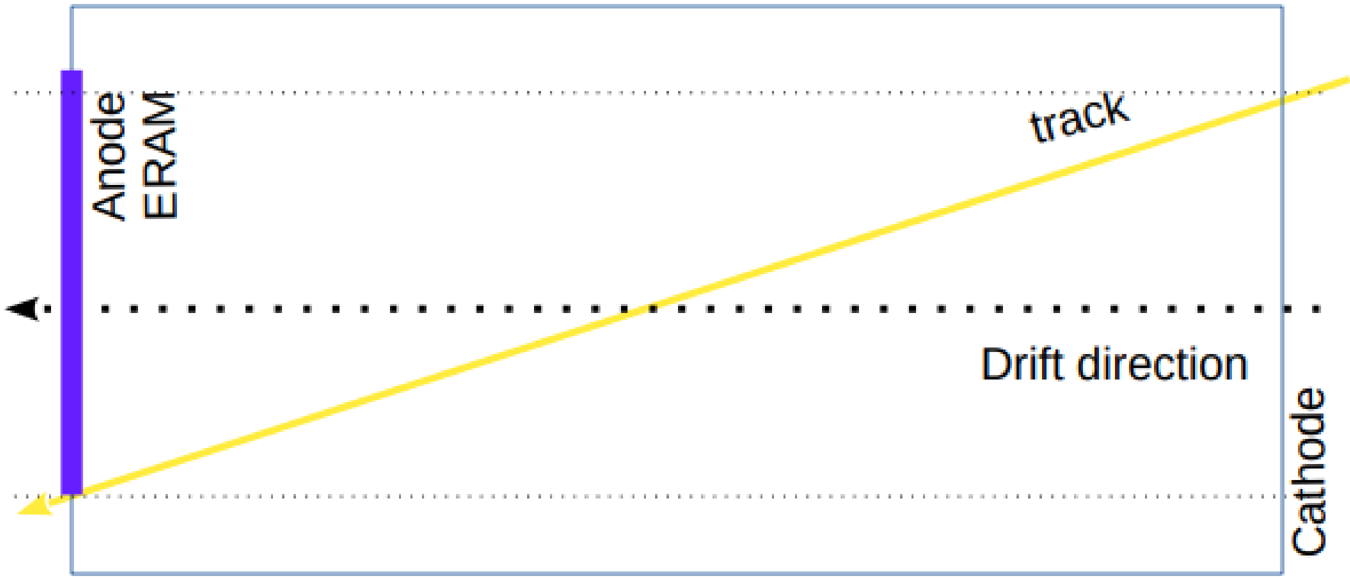


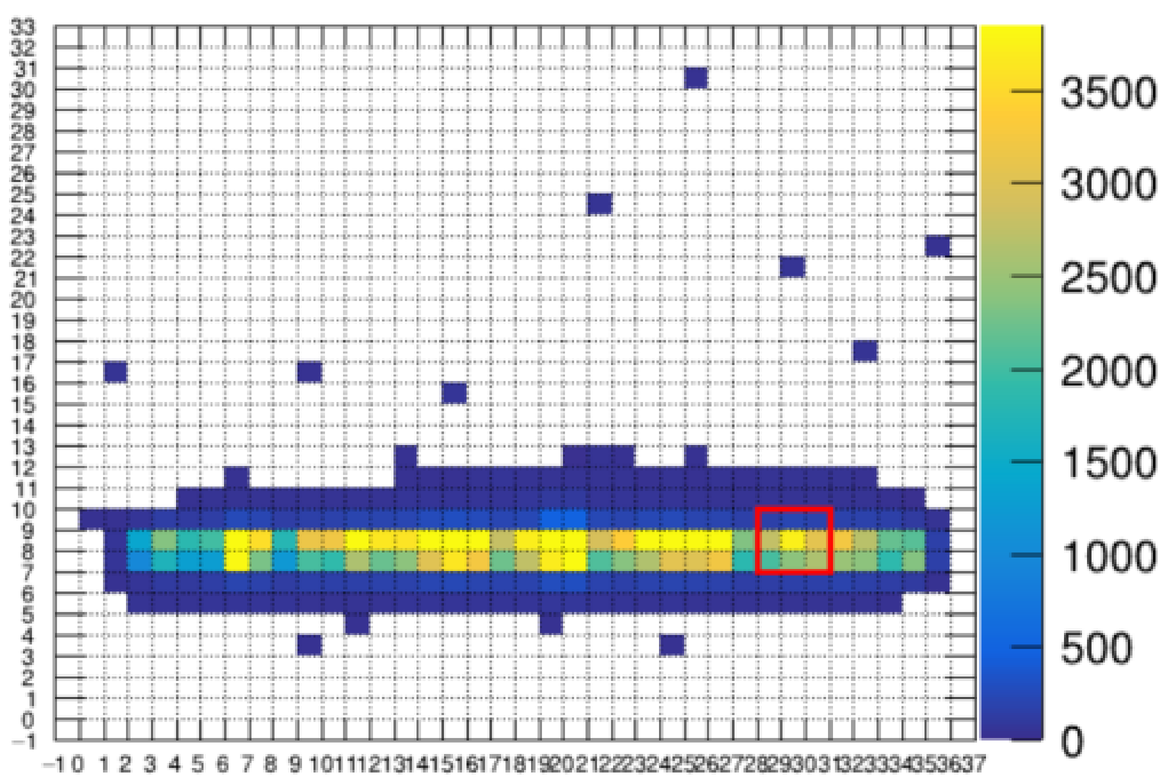


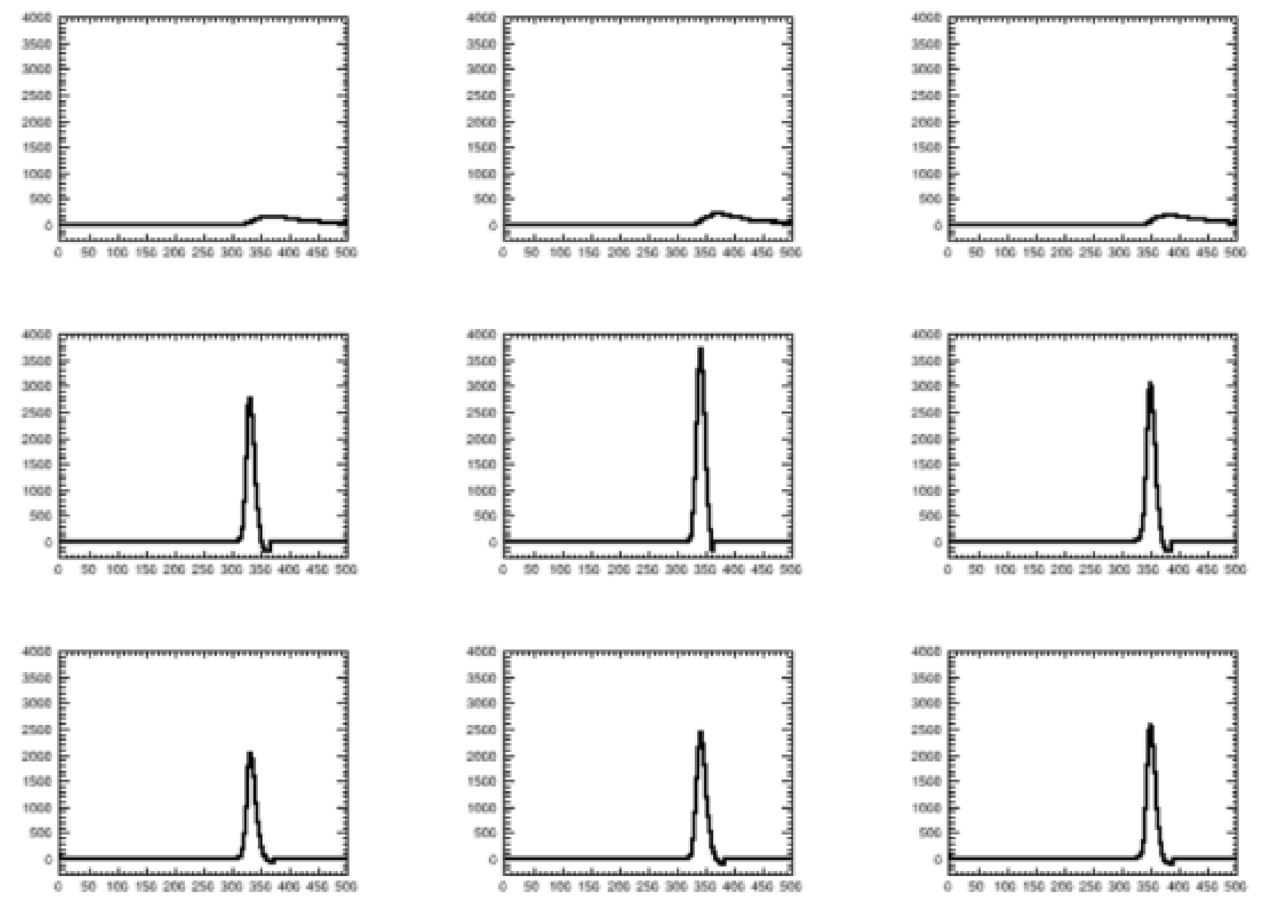
Track reconstruction from waveforms

Test Beam CERN 2021

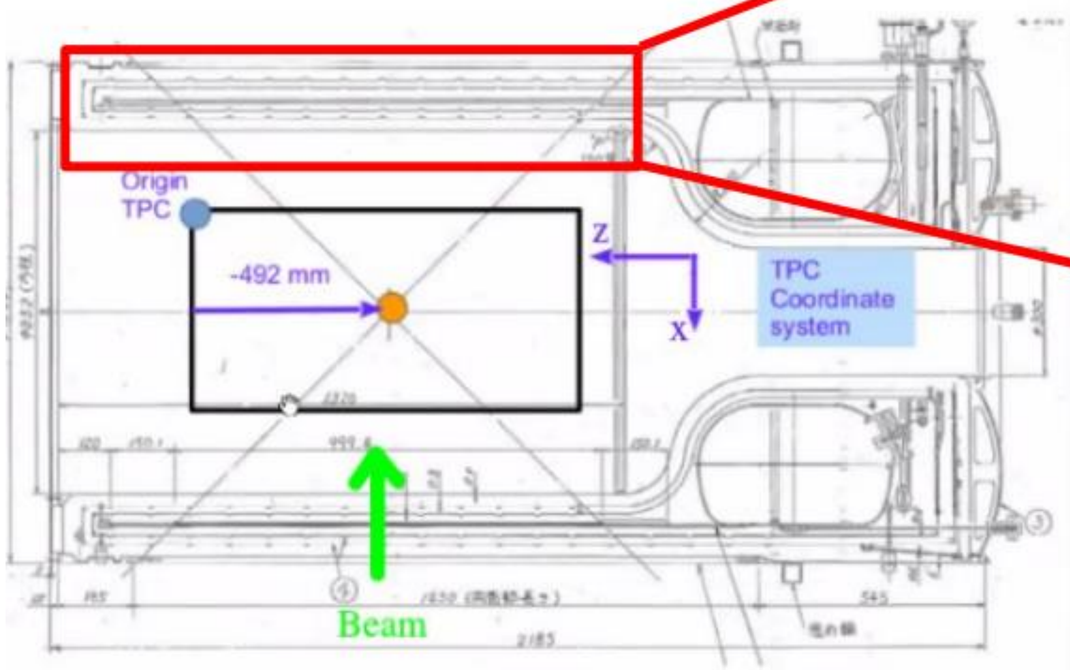
Waveforms theta = 70°
(20° wrt drift direction)



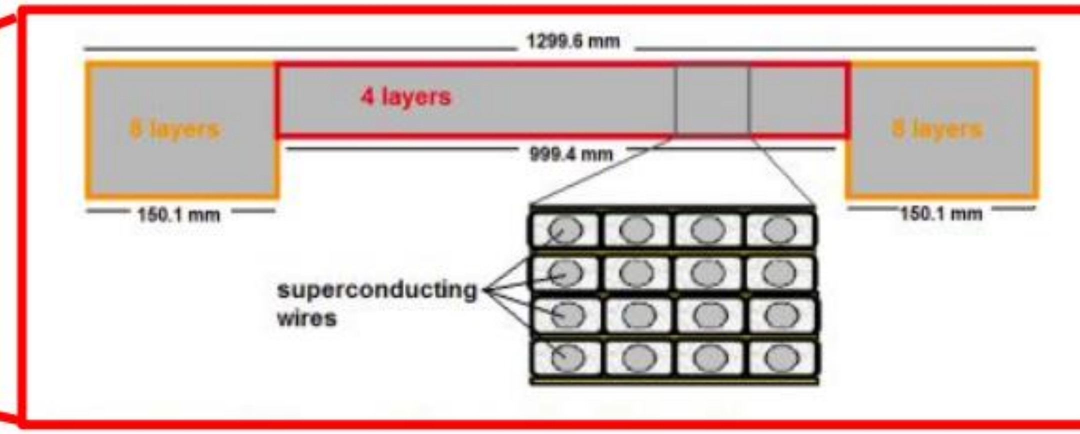




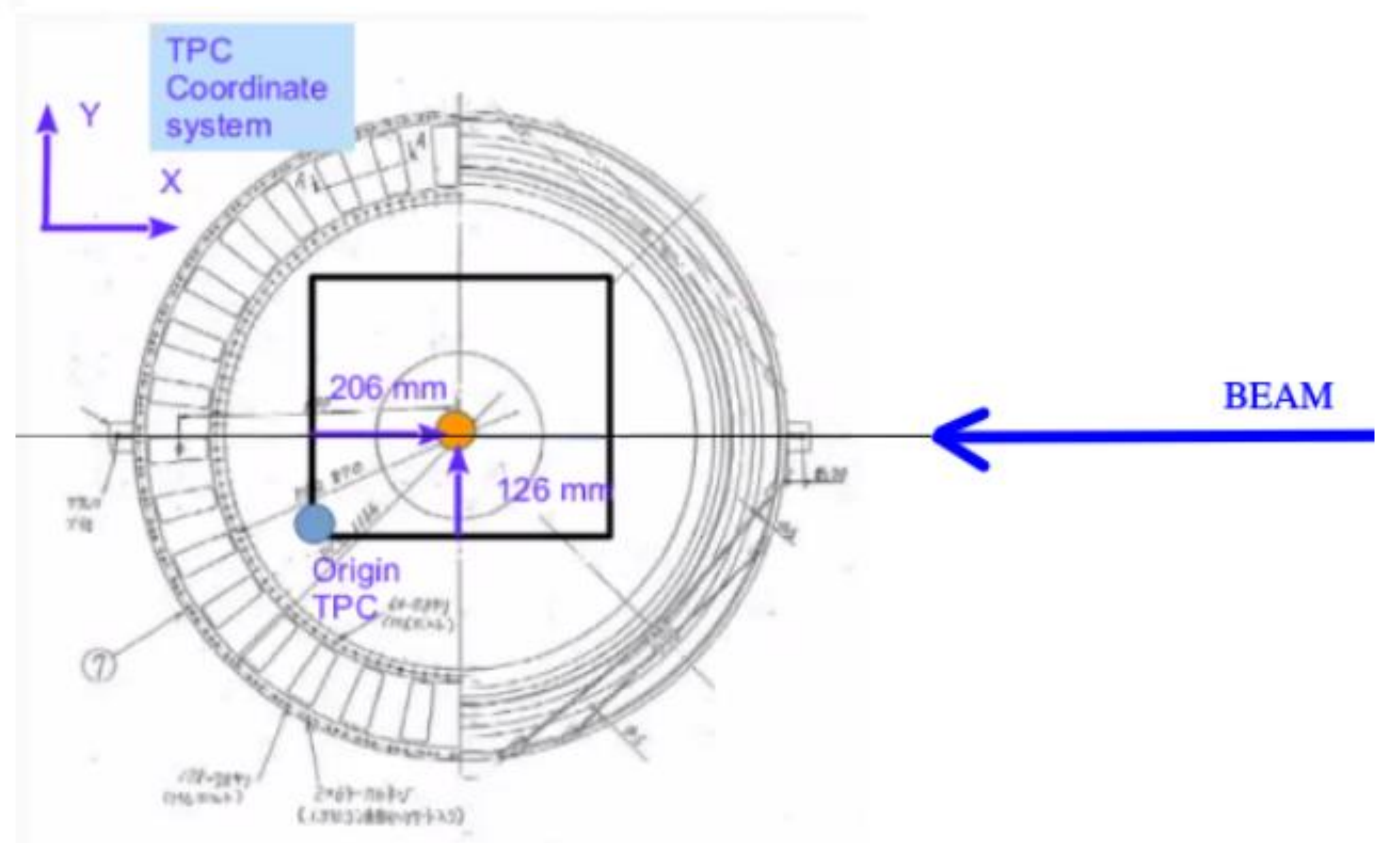
ExB effect



TOP VIEW



- Solenoid-like magnetic field -> radial components as edge effects



ExB effect

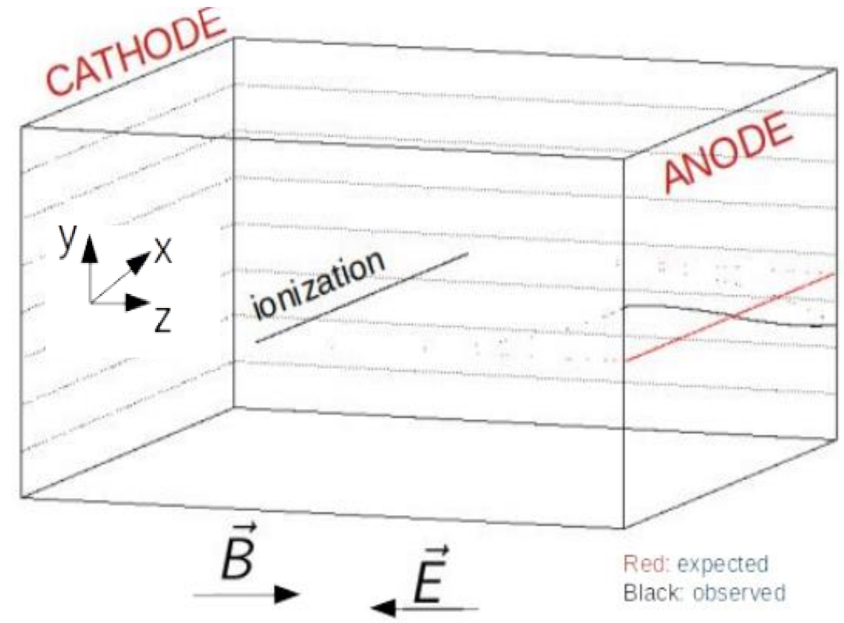
$$\vec{u} = \frac{e}{m}\tau|\vec{E}|\frac{1}{1+\omega^2\tau^2}[\hat{E} + \omega\tau(\hat{E}\times\hat{B}) + \omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B}]$$

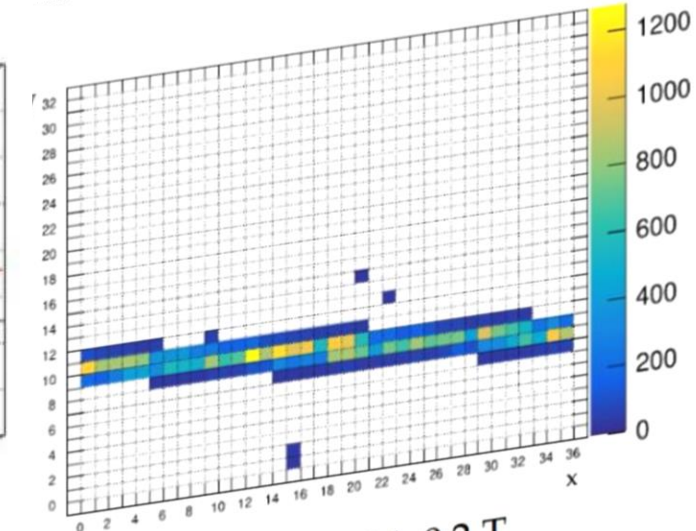
$$\omega\tau = \frac{e}{m}B \times \frac{m}{e}\mu = \mu B$$

$$u_x = \frac{-\mu E}{1+\omega^2\tau^2}\left(-\omega\tau\frac{B_y}{B} + \omega^2\tau^2\frac{B_x B_z}{B^2}\right)$$

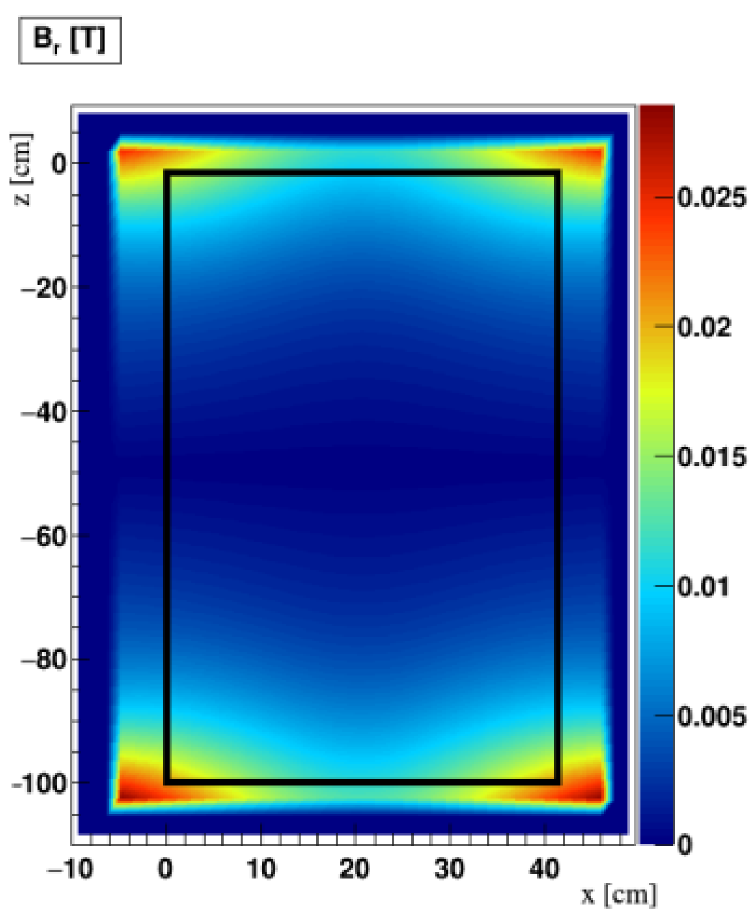
$$u_y = \frac{-\mu E}{1+\omega^2\tau^2}\left(+\omega\tau\frac{B_x}{B} + \omega^2\tau^2\frac{B_y B_z}{B^2}\right)$$

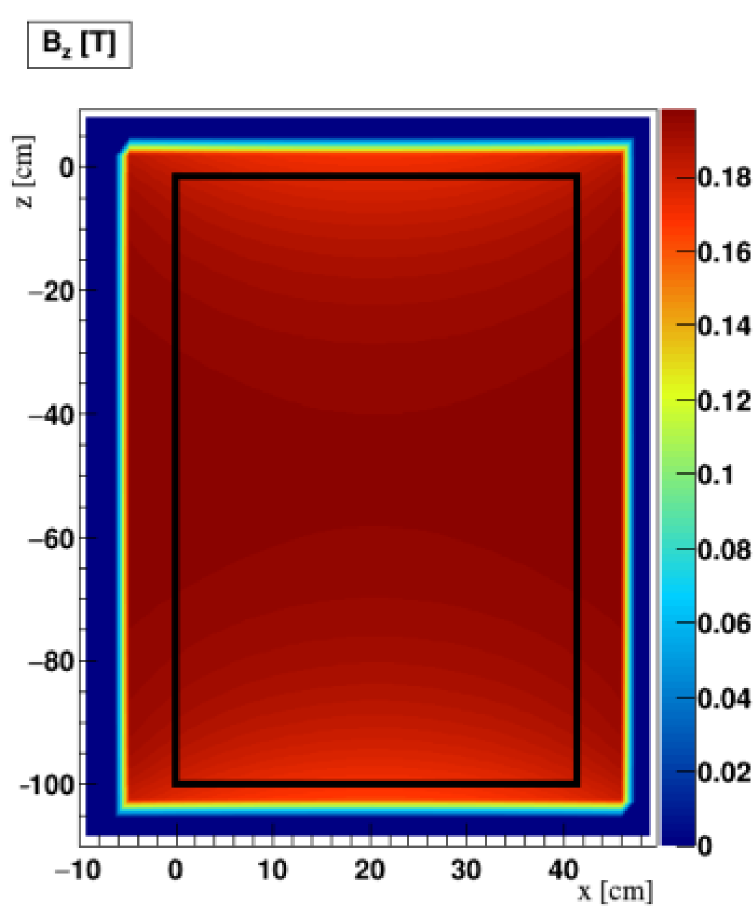
$$u_z = \frac{-\mu E}{1+\omega^2\tau^2}\left(1 + \omega^2\tau^2\frac{B_z^2}{B^2}\right)$$

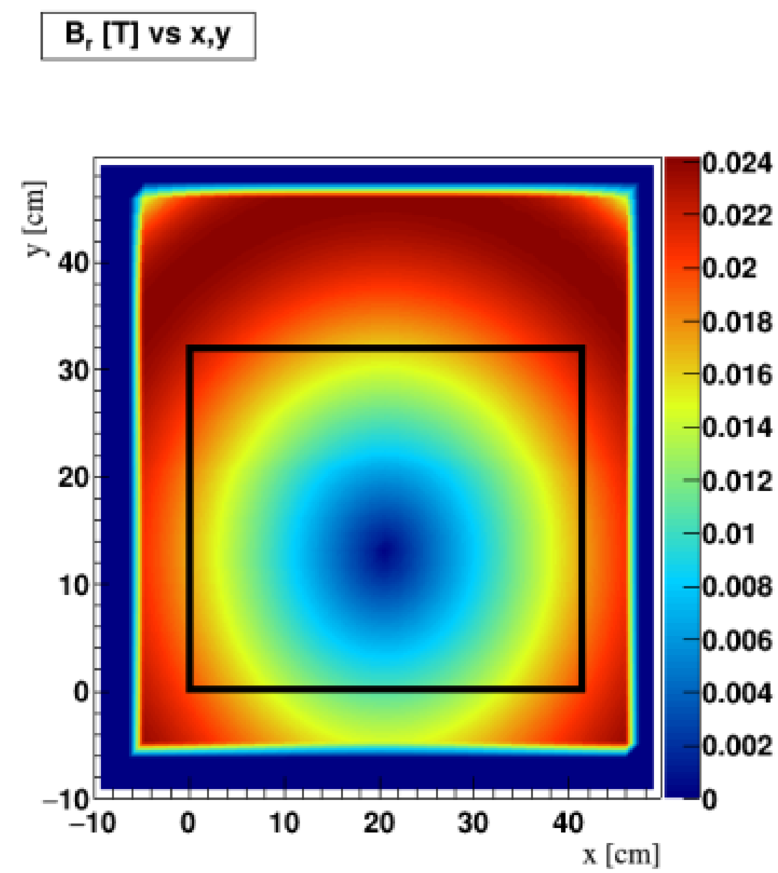




- Magnetic field: 0,2 T
- φ=0°
- Effect absent if B=0 T



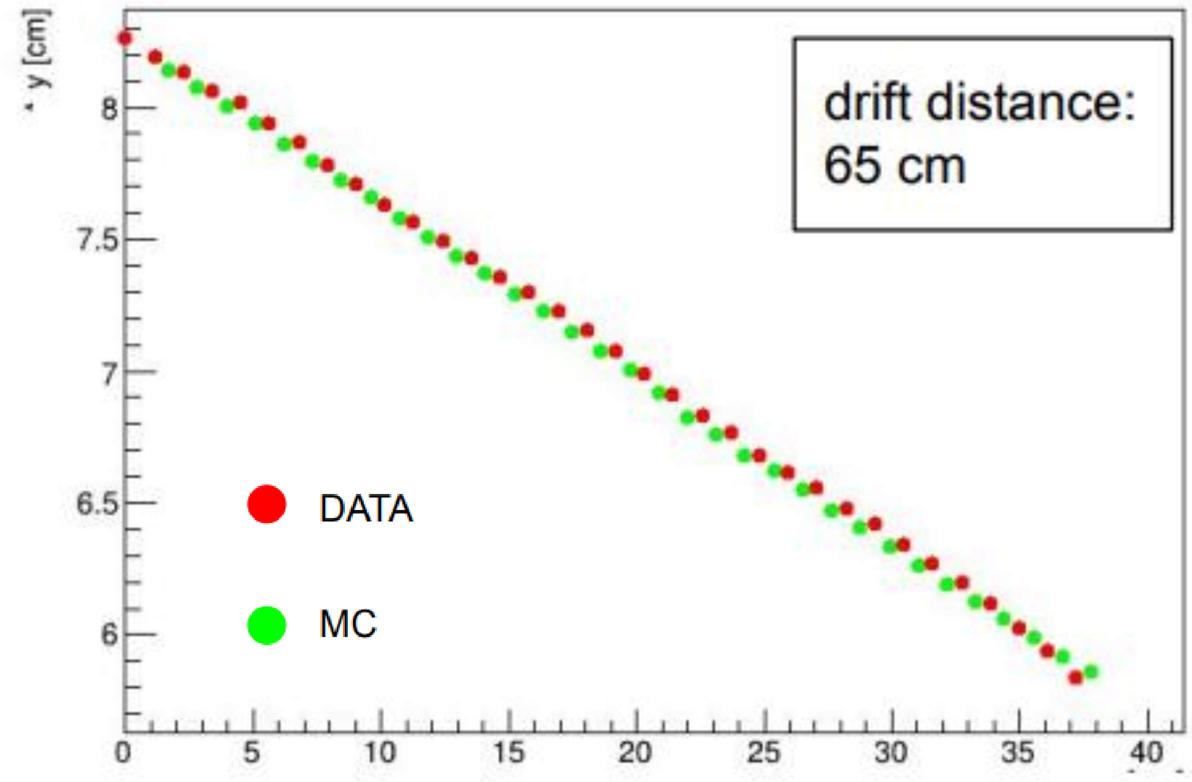


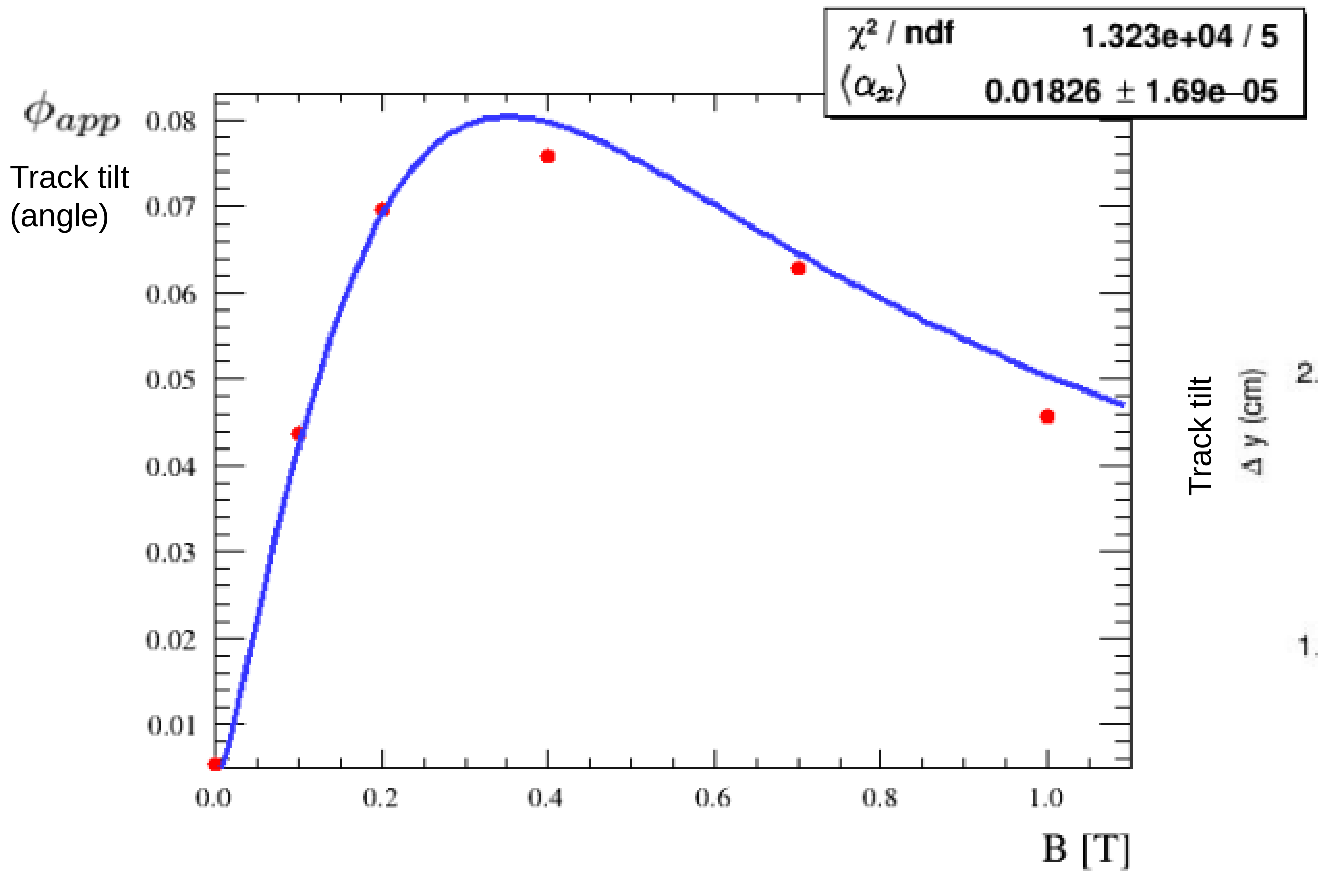


ExB effect

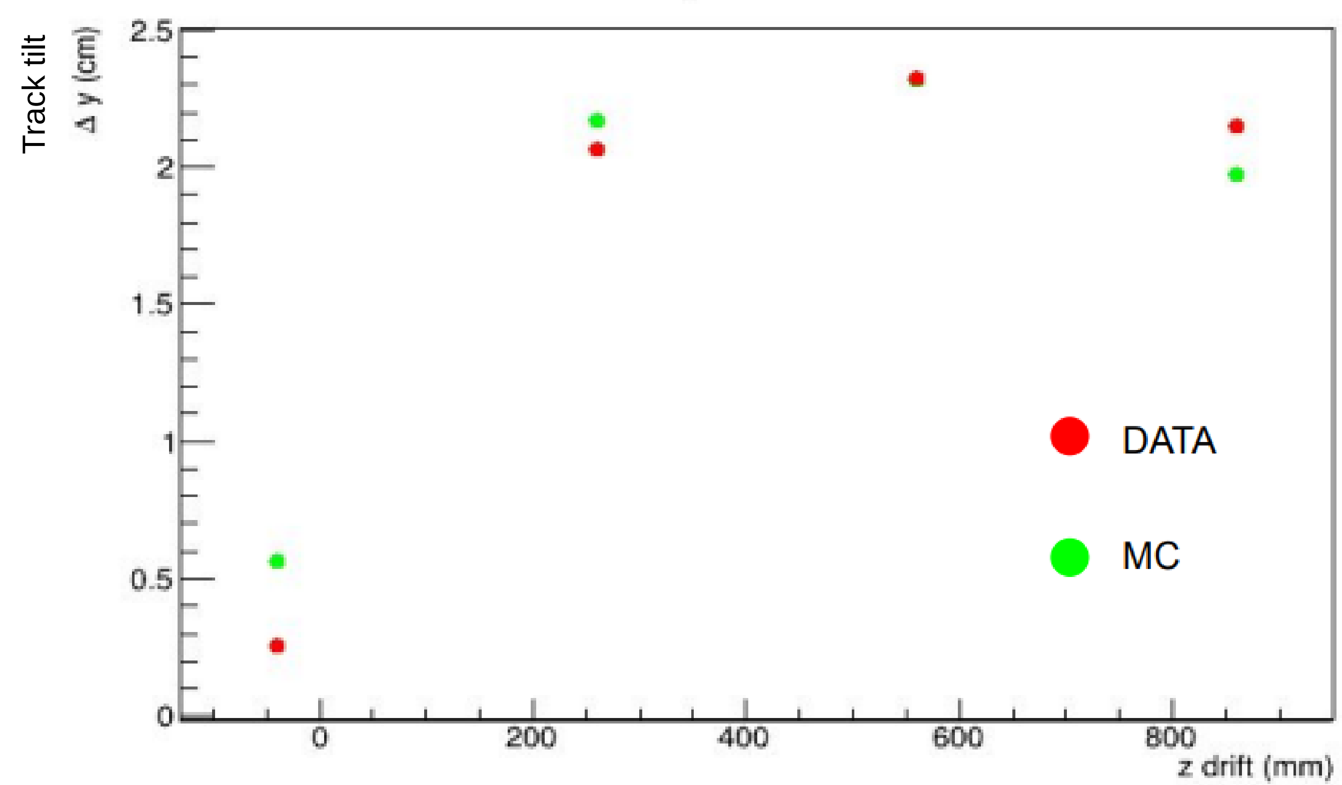
Preliminary

Track X-Y projection (average)





y = +60



Track tilt (average) vs Z drift

New Gas System

New **simplified** gas system designed to

- to serve all 5 TPC's (3 present TPC's + 2 new HA-TPC's)
  → total 18.5 m^3 detector active volume
- mix and closed-loop circulate active volume gas through filters

Main parameters (same as for present system)

- 'T2K' gas mixture: **$Ar\text{-}CF_4\text{-}iC_4H_{10}$ (95:3:2)**
- flow rates: up to 1 volume change per 6 hours (~3m^3/h)
  → for keeping O_2 CO_2 H_2O contamination at ppm level
- fresh gas injection: 10% of circulation flow
- flow CO_2 gas through outer volume of present 3 TPC's (~1.2m^3/h)
- maintain **overpressure ΔP~4mbar** wrt **atmospheric** P and ΔP~0.1mbar between inner and outer volumes old TPC's

Gas system modules design based on CERN standards

- modules: mixers, closed-loop circulation modules, analyzers, …
- PLC control via profibus connection, SW WinCC-OA SCADA2 itf

→ simplified operations and maintenance

→ fully automated system with high degree of reliability