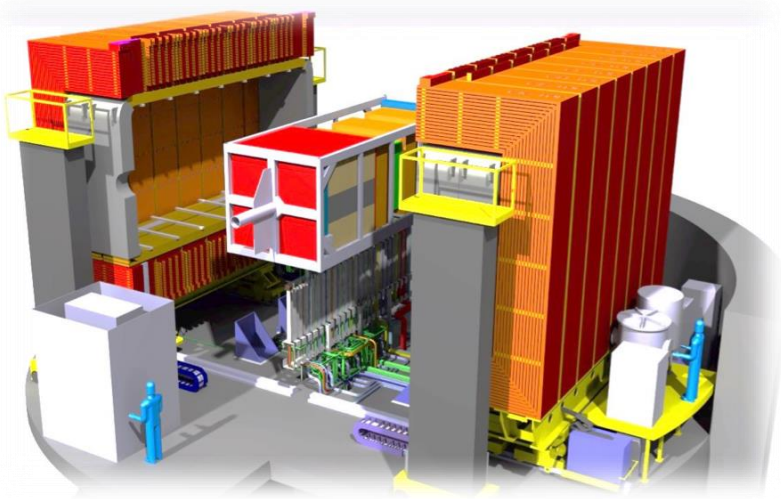
DE LA RECHERCHE À L'INDUSTRIE

Development of resistive Micromegas TPCs for the T2K experiment

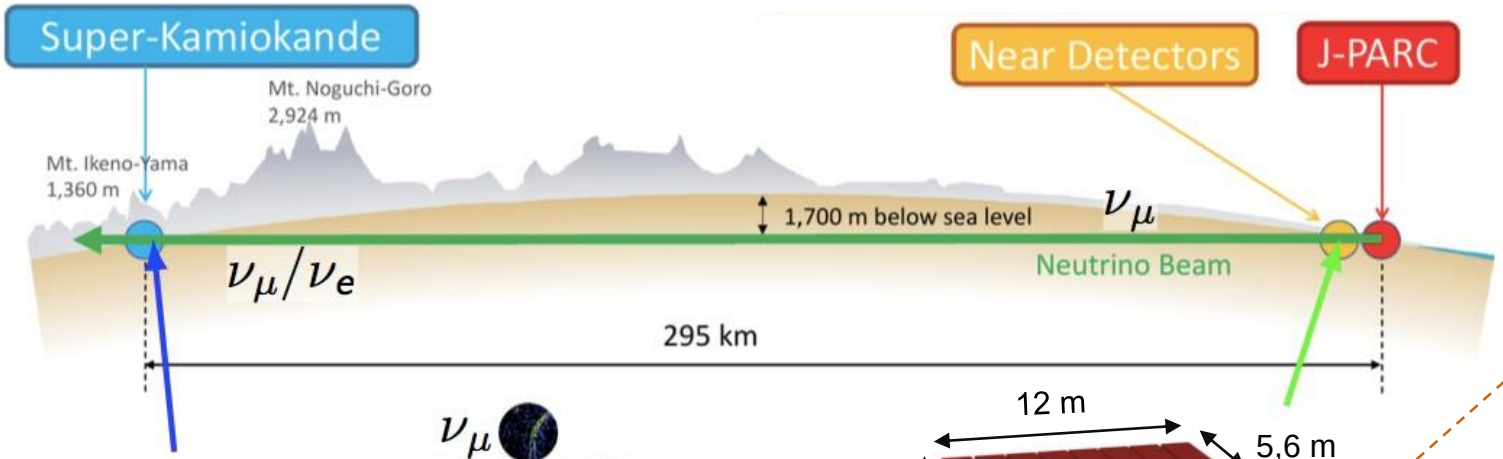


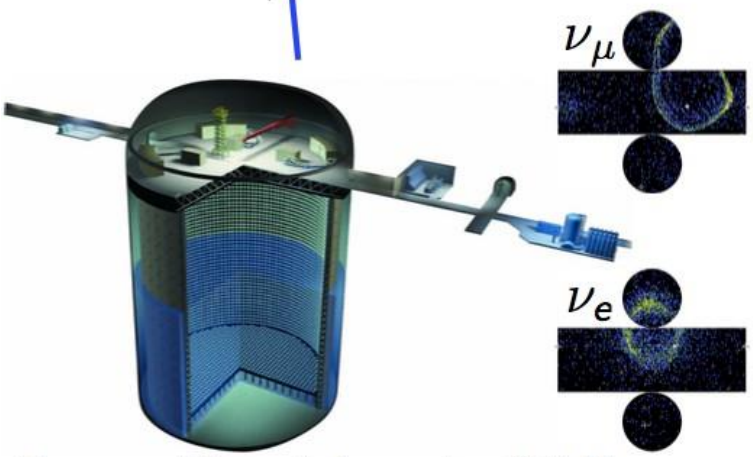
D. Attié
on behalf of the ND280/HA-TPC collaboration

CEA-Saclay/DRF-IRFU, Univ. Paris – Saclay

THE T2K EXPERIMENT
THE ND280 NEAR DETECTOR

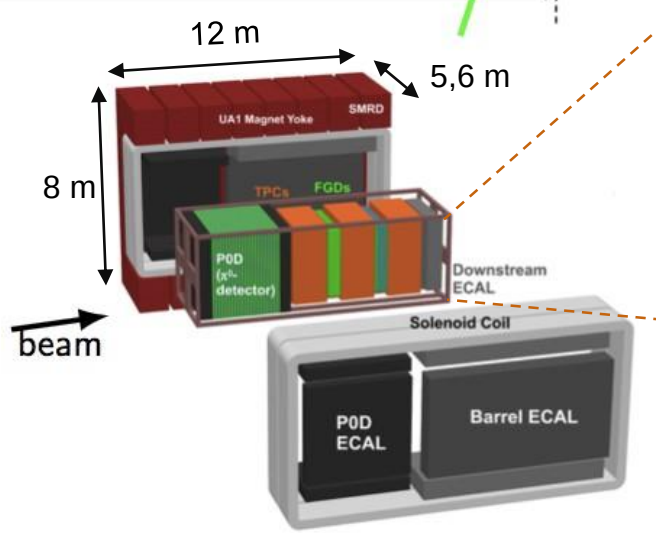
- T2K: long baseline neutrino experiment between ν_μ beam (J-Parc) in Tokai and Kamioka
- Goal of ND280: - measure flux & spectrum of neutrinos
  - measure ν_e contamination





Super-Kamiokande (SK)

22.5 kt → ~200 kt (Hyper-K)



ND280

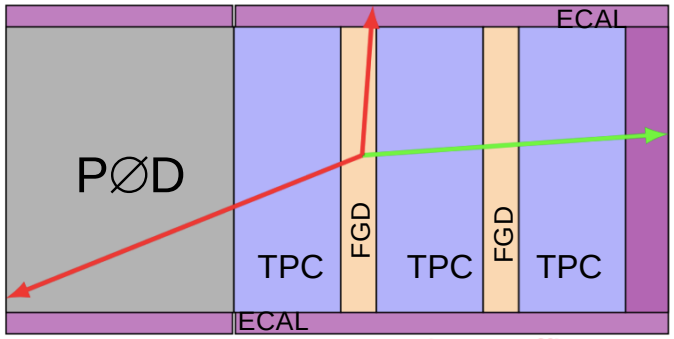
3 v-TPCs
72 MMs
124 kchs

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

T2K Performances and Limitations Proposal for Updgrade

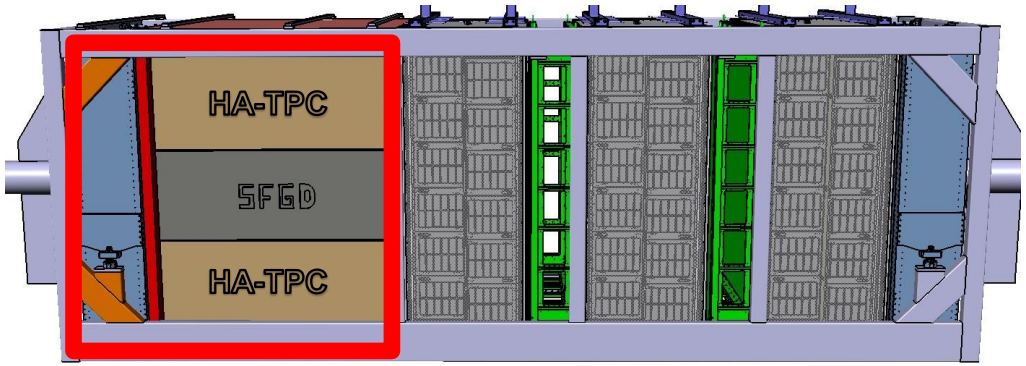
- Current ND280

Good acceptance only for forward tracks



ND280 upgrade TDR: arXiv:1901.03750v1

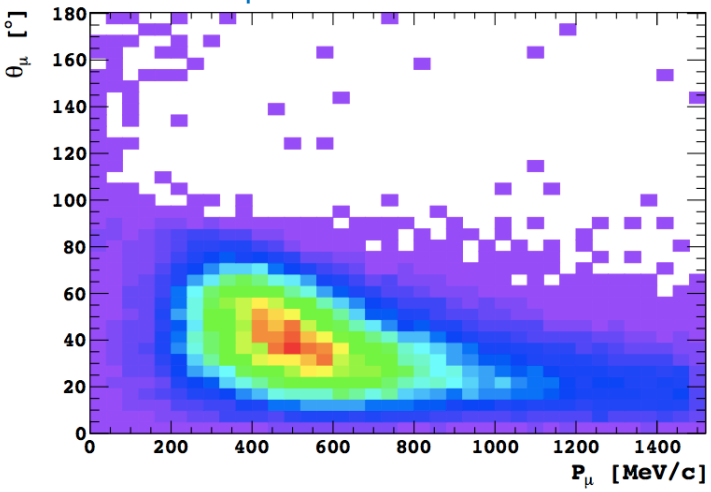
Proposed ND280 upgrade



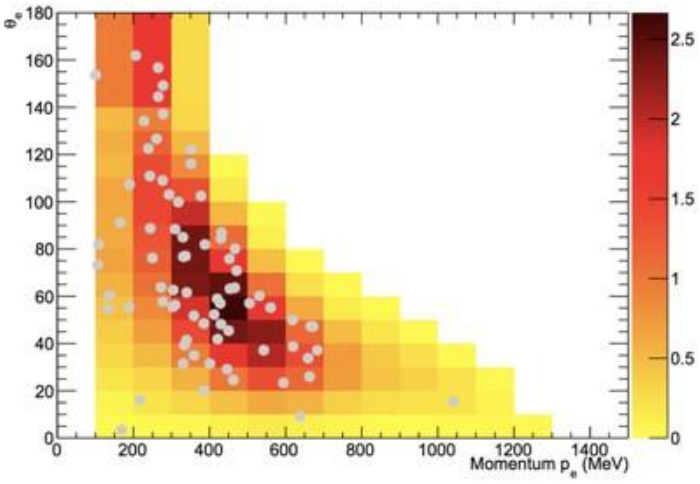
2 High-Angle TPCs
+ a new highly granular scintillator detector (Super-FGD)
+ 6 TOF planes surrounding the new tracker

- Reconstructed momentum and angle

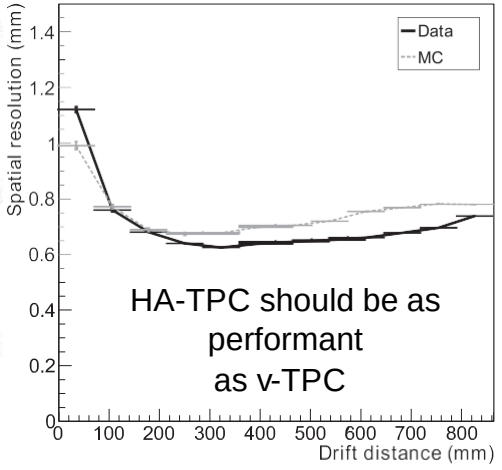
μ selected at ND280



e⁻ selected at SK

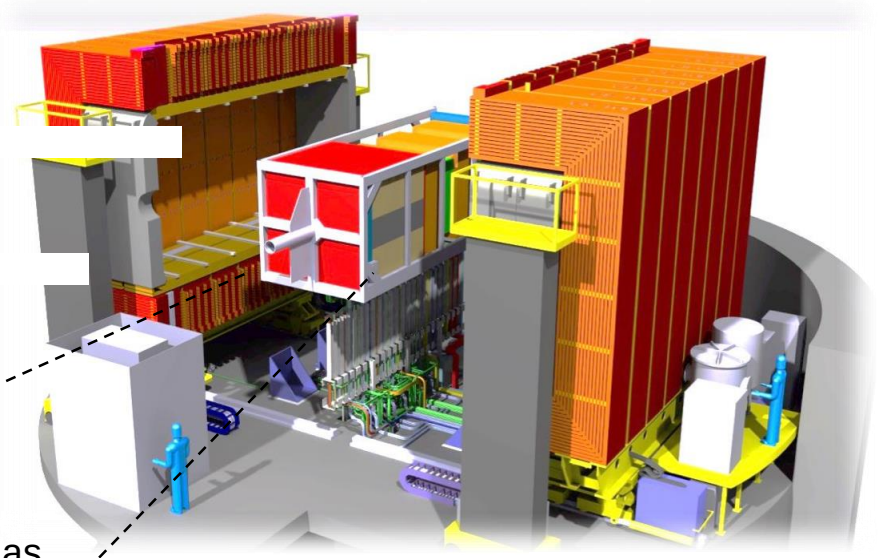


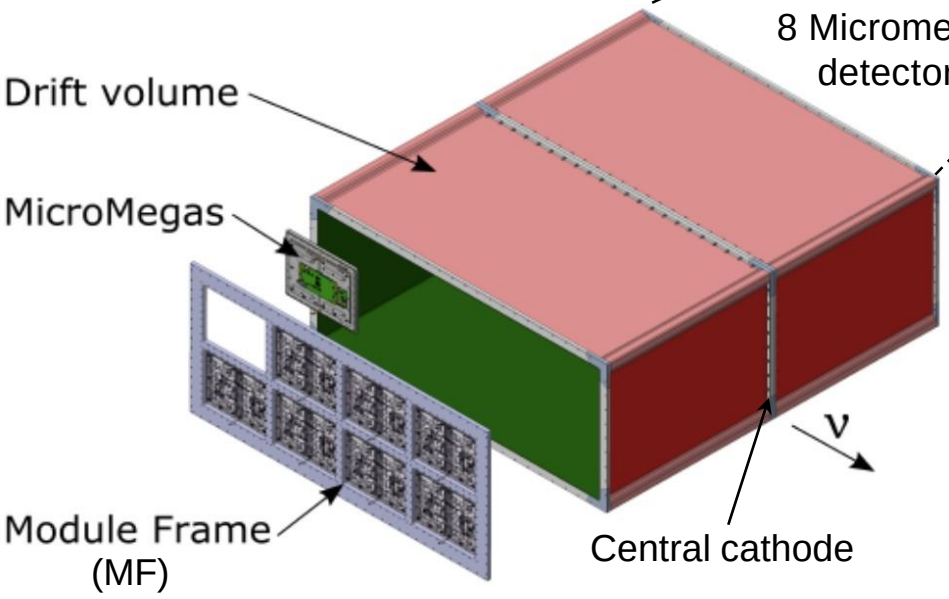
V-TPC spatial resolution



HIGH-ANGLE TPCS FOR T2K-II PHASE

- T2K-II phase:
  - Installation in 2022
  - Data taking after main ring upgrade
  - Goal: measure δ_{CP} at 3σ by decreasing of systematic errors in ND280 from 6% to 4%



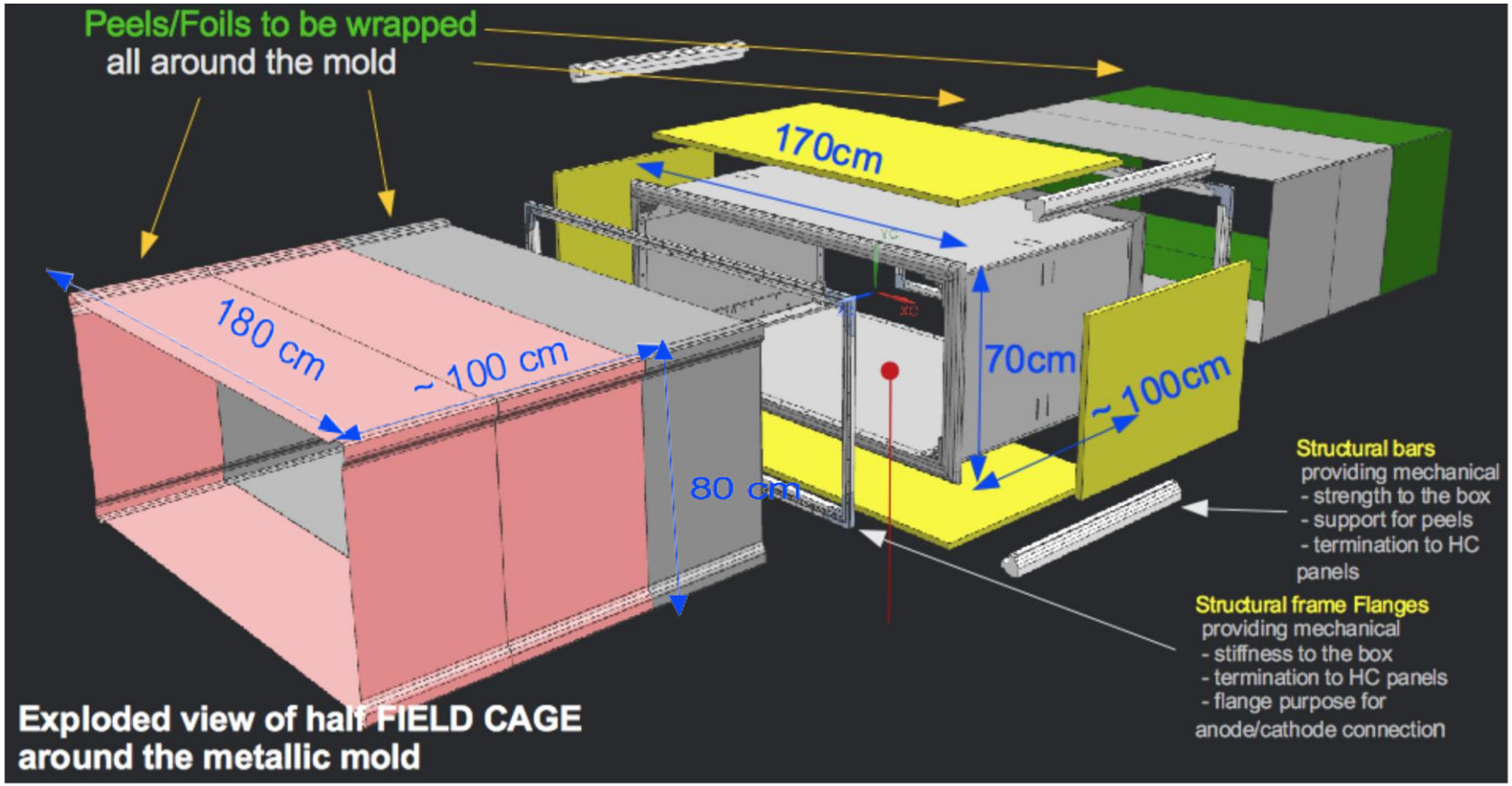


Parameter	HA-TPC	v-TPC
Overall x × y × z (m)	2.0 × 0.8 × 1.8	0.85 x 2.2 x 1.8
Drift distance (cm)	90	
Magnetic Field (T)	0.2	
Electric field (V/cm)	275	
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2	
Drift Velocity $cm/\mu s$	7.8	
Transverse diffusion ($\mu m/\sqrt{cm}$)	265	
Micromegas gain	1000	
Micromegas 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	

TPC Cage Design and Construction

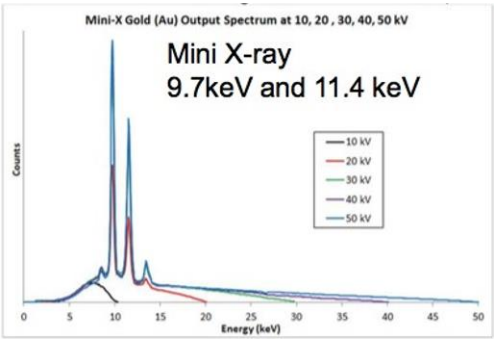
- To keep $\Delta E_{\perp}/E_{\parallel} \leq 10^{-4}$ confined at <1.5 cm from FC walls, the TPC cage requirements are:
  - Cathode flatness better than 0.1 mm,
  - Micromegas detector flatness better than 0.2 mm,
  - Cathode/Anode planes parallel to within 0.2 mm,
  - Field Cage walls flatness better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

G. Collazuol (INFN Padova)

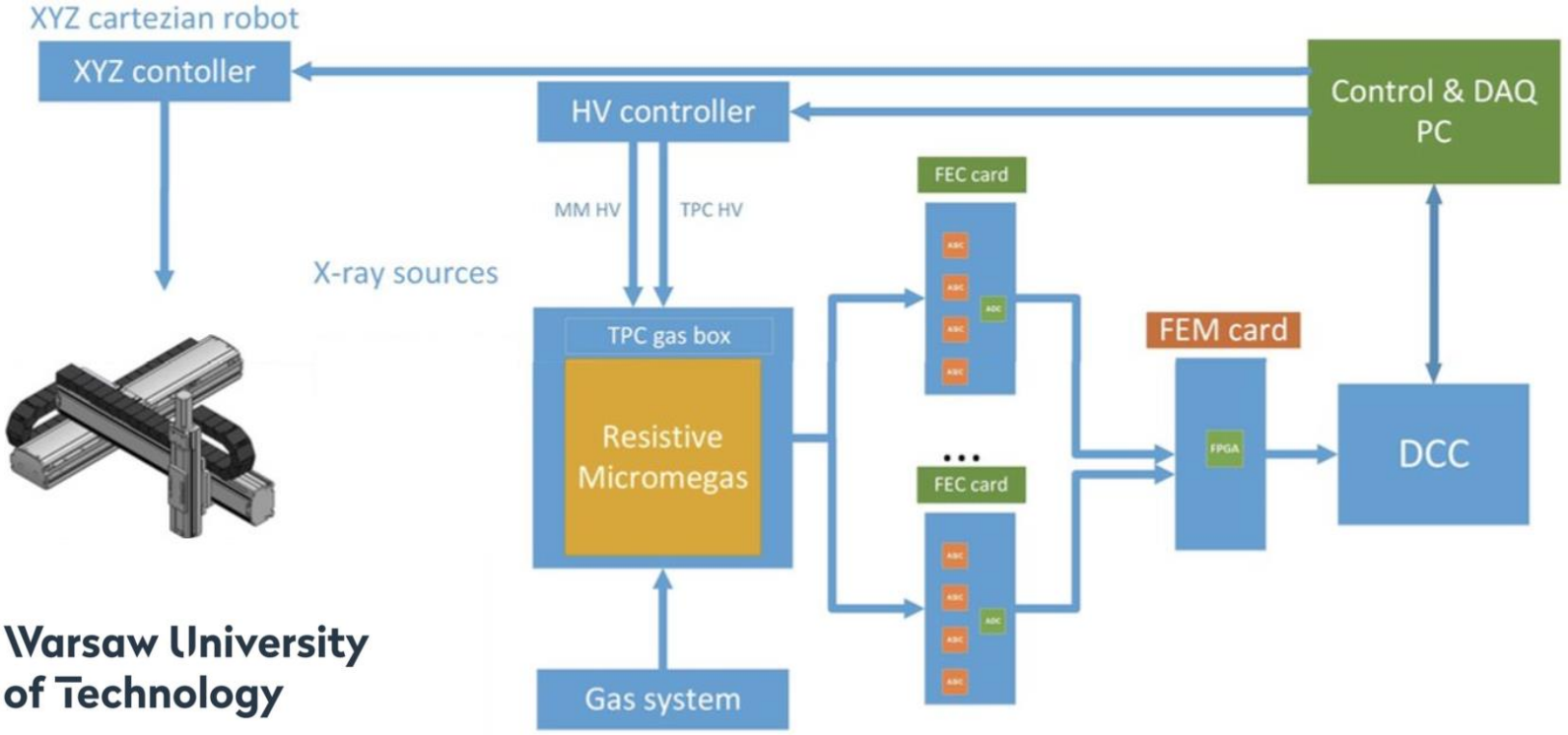


MODULE TEST BENCH FOR PRODUCTION

- Test bench to measure, verify and calibrate:
  - Quality: find dead pads, inhomogeneity, etc.
  - Mapping for all MM modules of:
    1. Signal amplitude/gain
    2. Energy resolution
    3. Charge signal spreading–verify spatial resolution



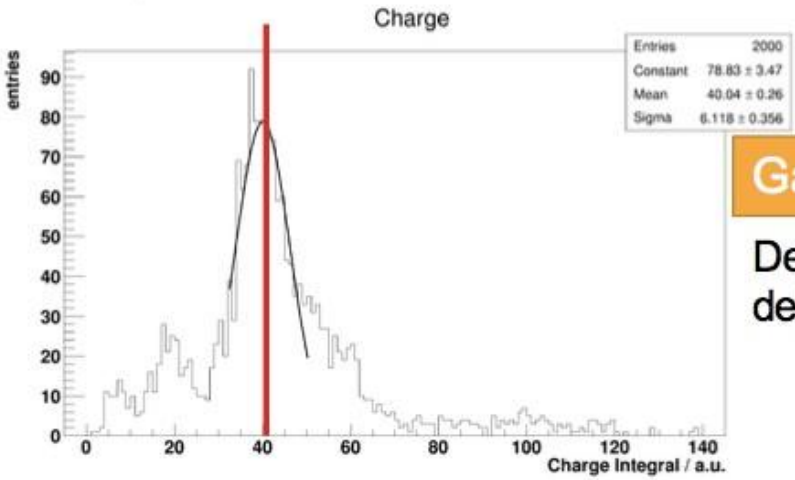
- Need to scan the active surface with a strong radioactive source or small X-ray lamp.



HA-TPC GAS MONITORING CHAMBER

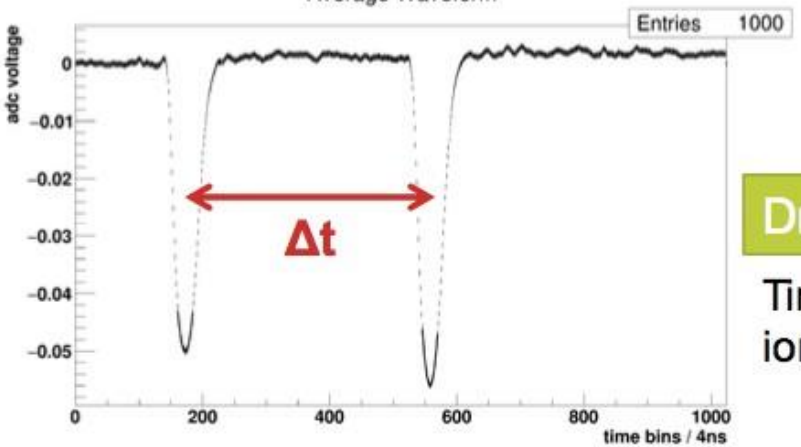
- Two identical chambers for supply and return gas
- Sequential measurement of drift velocity and gain

P. Hamacher-Baumann (RWTH Aachen Univ.)



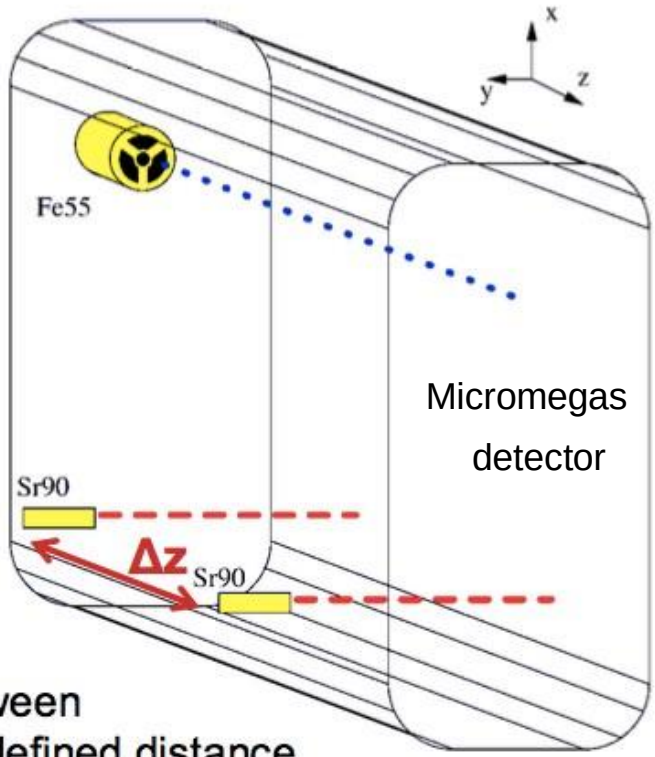
Gain Measurement

Detected charge from defined deposition



Drift Velocity

Time difference between ionization tracks of defined distance



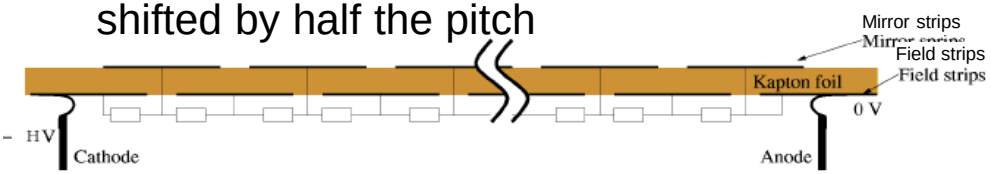
FIELD CAGE DESIGN

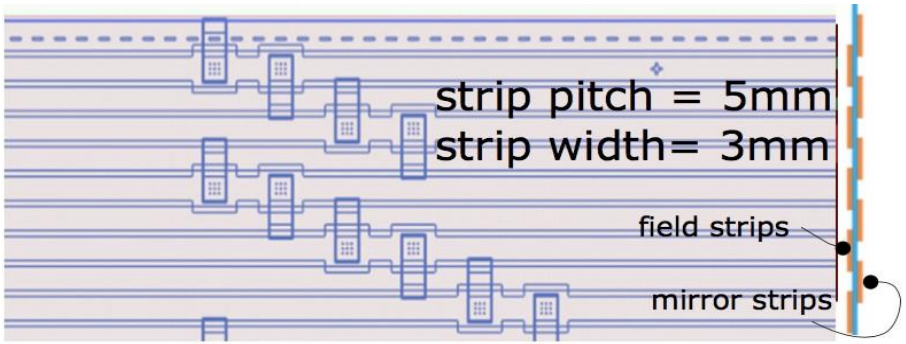
- Thin & low Z composite materials of the wall

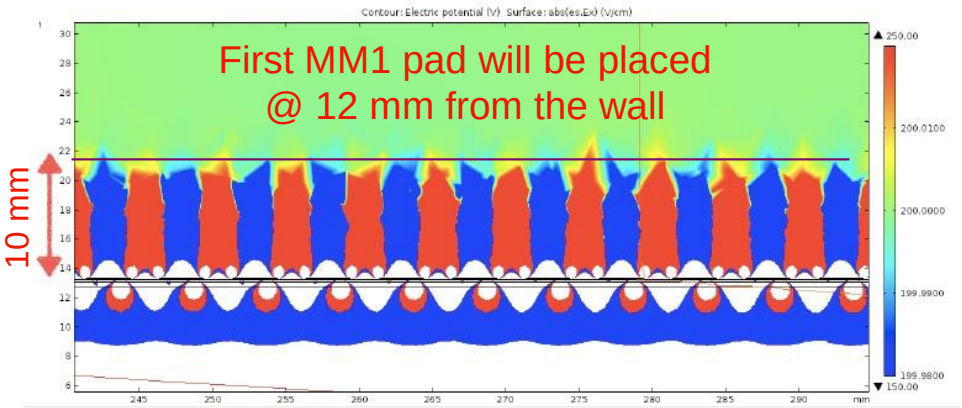
Layer of the wall	Material	thickness d d (mm)	average X_0 (mm)	d/X_0 (%)
1 (inner layer)	Double layer strip foil (+glue)	0.05		
	→ Copper strips	∼0.005	14.3 (Cu)	∼0.07
2	Aramid Fiber Fabric (Twaron)	2.0	∼240	0.70
3	Aramid honeycomb panel (Nomex)	25	14300	0.17
4	Aramid Fiber Fabric (Twaron)	2.0	∼240	0.70
5	Kapton tape (+glue)	0.125	285	0.04
6 (outer layer)	Aluminized Mylar (+glue)	0.05		
	→ Aluminum layer	0.01	89 (Al)	∼0.02
Total		∼30		∼1.6

G. Collazuol (INFN Padova)

- 220 strips on both sides of a Kapton foil shifted by half the pitch

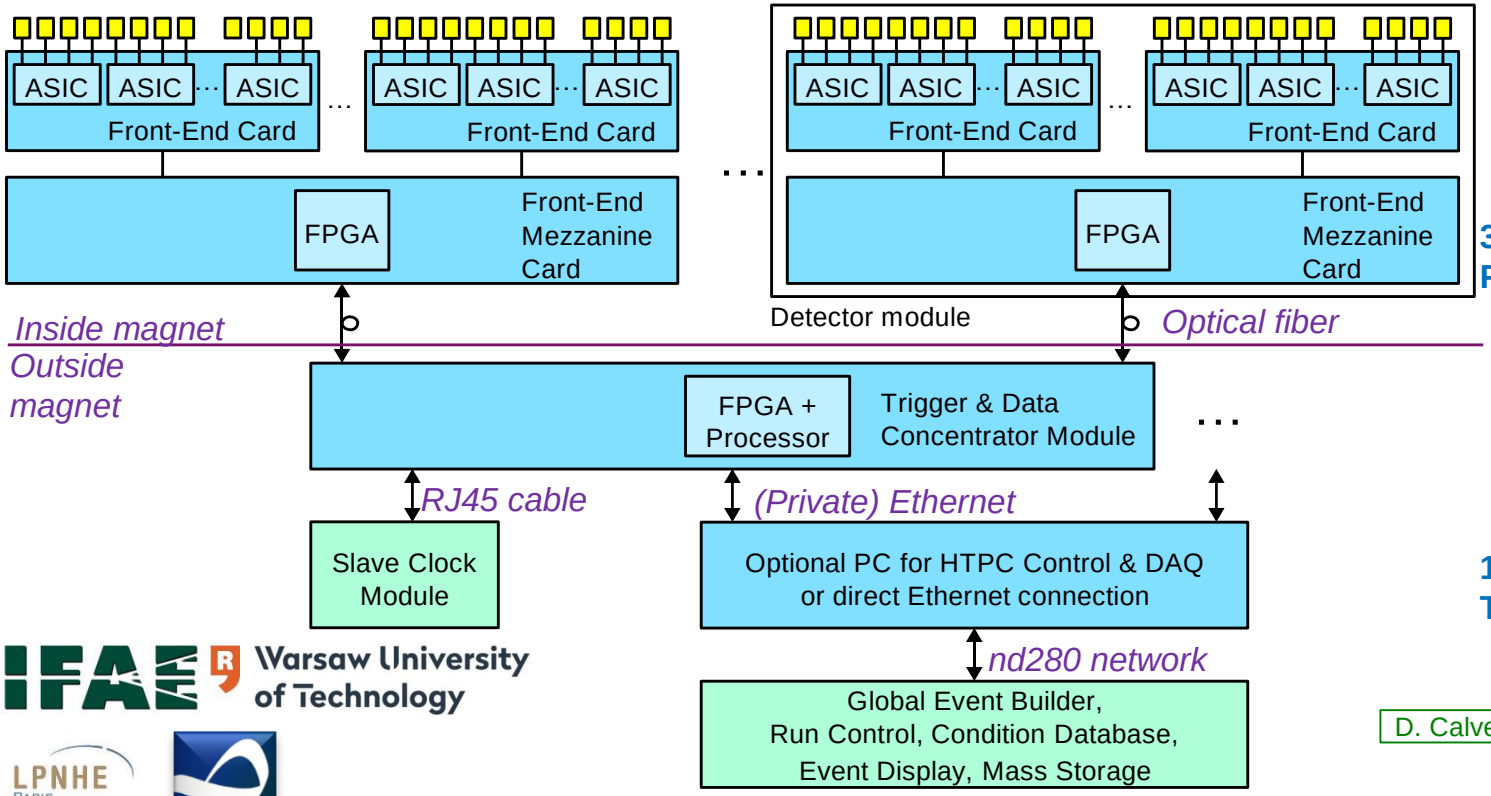






HA-TPC Readout Electronics
A New After-Based Architecture

- AFTER chip designed for T2K (511 bucket SCA,120fC-600 fC, 100ns-2µs peaking time)
- ~700 chip left from the initial dice funding already tested
- New FEC with 8 AFTER chips to digitize pad signal with an 8 ch. ADC (dead time of 3.3 ms)
- FEM for control (&trigger), synchronization, data aggregation, data buffering & zero suppression
- The TDCM is a generic clock and trigger distributor and data aggregator (FPGA+2 xilinx CPU+1 GB DDR3)



36.864 detector pads

512 AFTER (72 channels) 64 FECs (8 ASICs each)

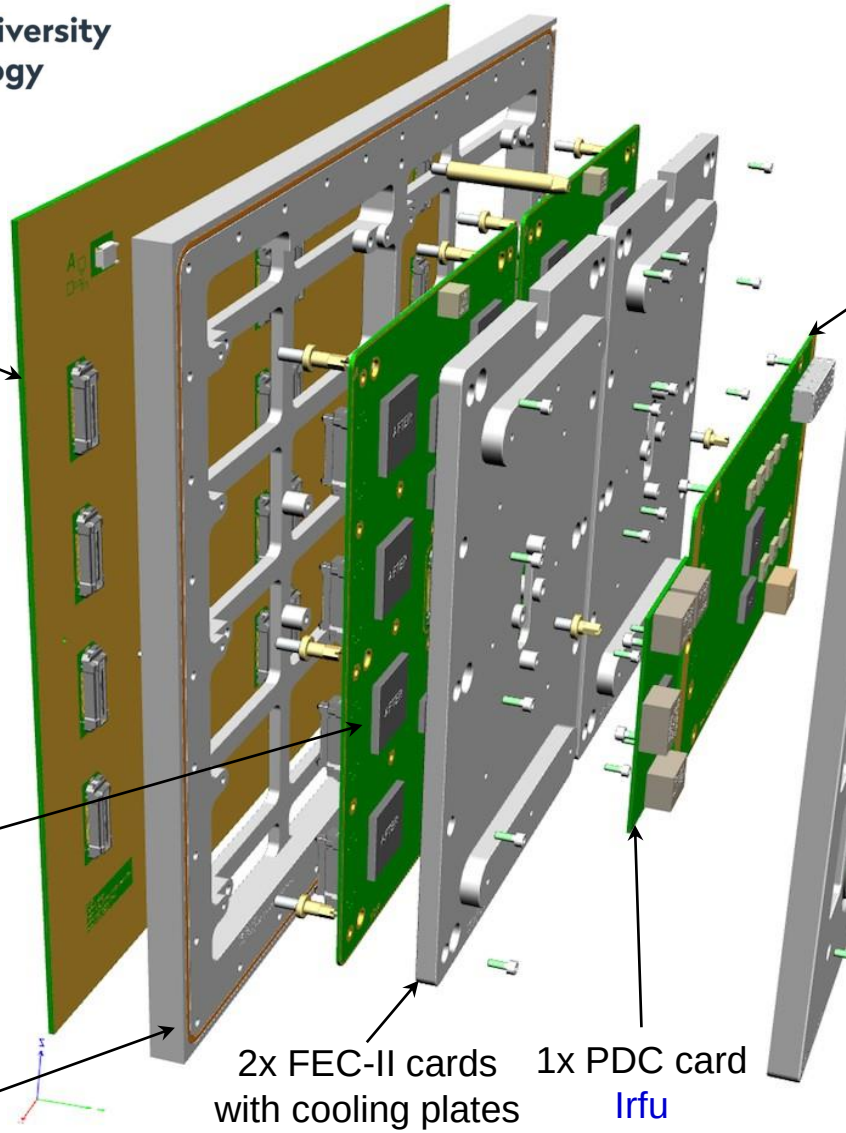
32 FEMs (1 drives 2 FECs)

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

1 PC (controls 2 TDCMs)

D. Calvet: arXiv 1806.07618

RESISTIVE BULK MICROMEGAS MODULE



1x FEM-II + backend TDCM
Irfu

MM-DLC PCB
Irfu / Cern

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

DAQ software
IFAE

Test benches
Warsaw univ.

16xAFTER Irfu

FEM-II cooling plate
Irfu

M. Riallot (CEA/Irfu)

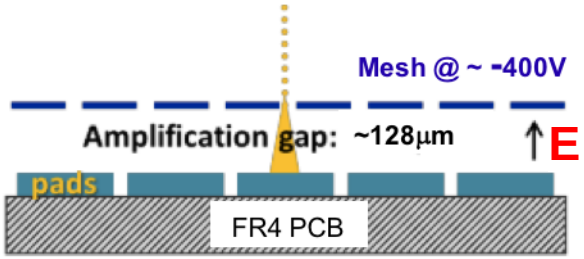
MM Stiffener
IFJ PAN

2x FEC-II cards with cooling plates
LPNHE

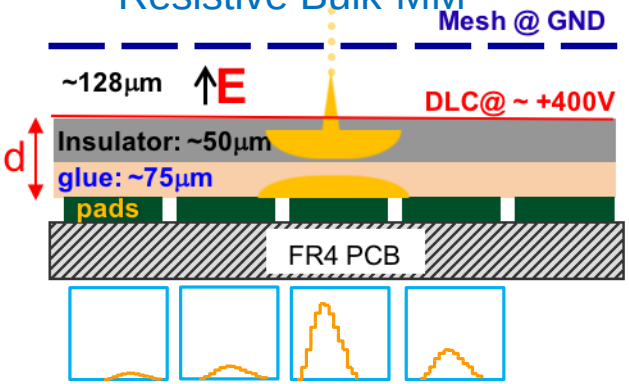
1x PDC card
Irfu

Resistive Bulk Micromegas (MM) with Diamond-Like Carbon Layer

- Standard Bulk-MM



- Resistive Bulk-MM



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

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

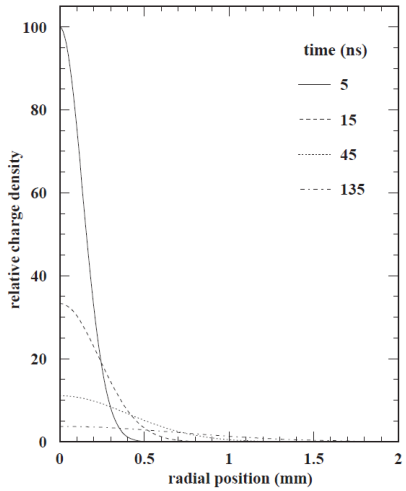
R: surface resistivity
C: capacitance/unit area

- Charge dispersion in 2-D RC network

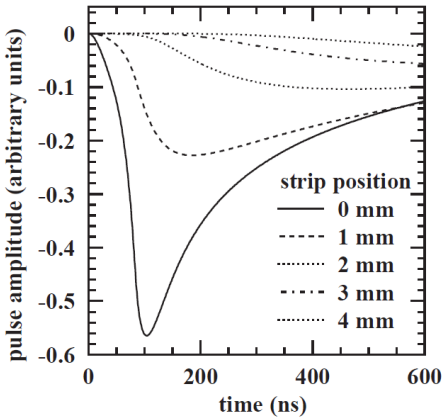
$$\rho(r,t) = \frac{RC}{2t} e^{\left[\frac{-r^2 RC}{4t}\right]}$$

- Gaussian spreading as a function of time

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



- Signals expected over contiguous strips

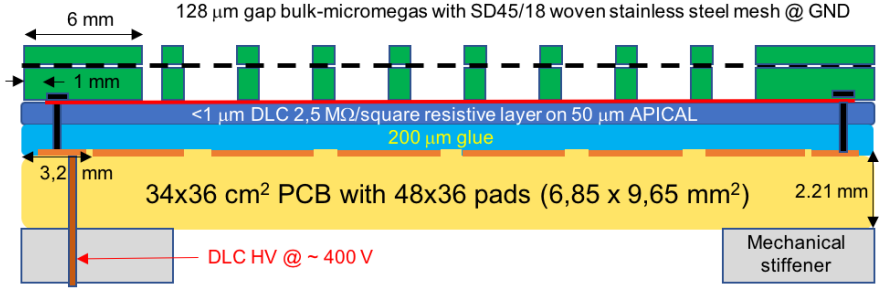


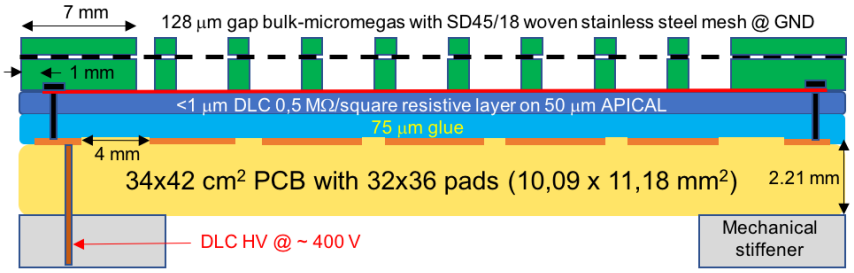
Resistive Bulk Micromegas (MM) with Diamond-Like Carbon Layer

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-DLC1 (2,5 MΩ/sq):
  σ~ 1,6 mm for t=400 ns
- MM0-DLC3 (~0,5 MΩ/sq) with MM1 stack design:
  σ~ 2,5 mm for t=400 ns
  σ~ 1,75 mm for t=200 ns

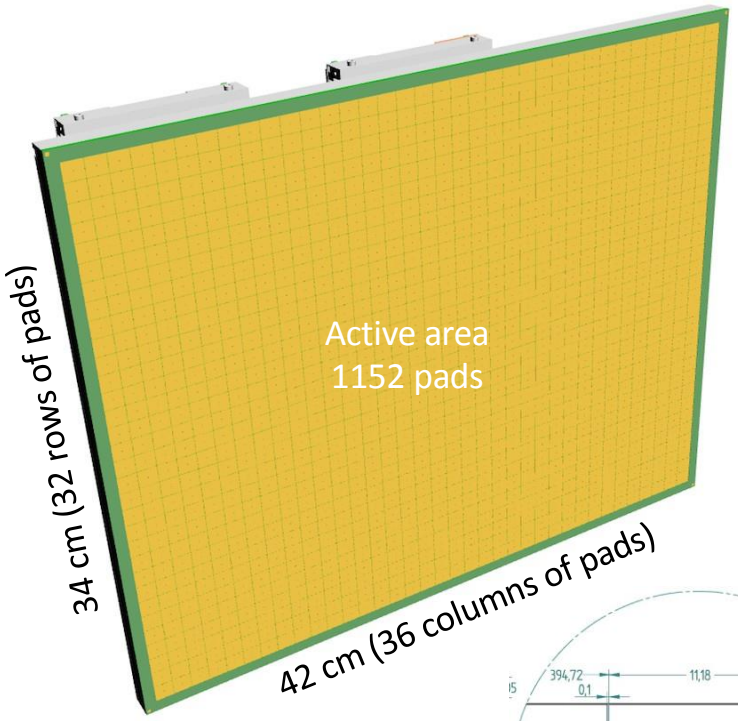
- MM1-DLC1 (~0,25 MΩ/sq):
  σ~ 2,5 mm for t=200 ns
  σ~ 3,5 mm for t=400 ns

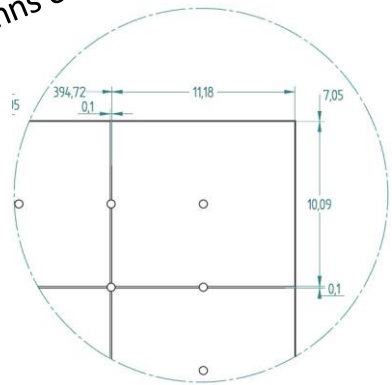


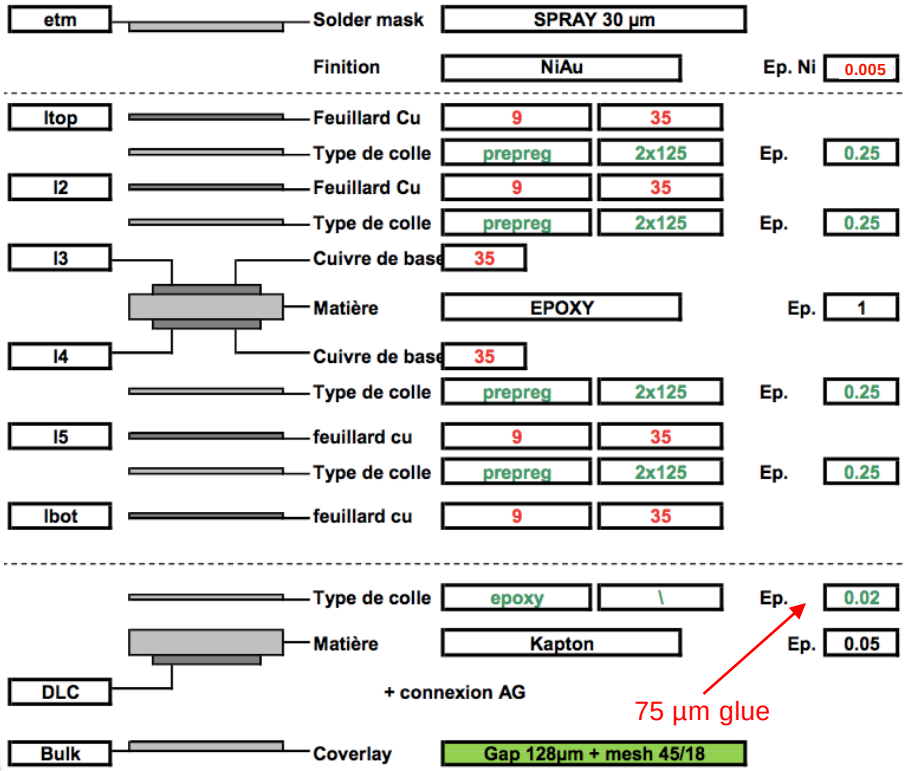


READOUT PCB DESIGN FOR MM1

- Epoxy (~0,02 mm) is used to fill the gap between copper pads of 10,09 × 11,18 mm²
- 75 µm thick glue layer is used for the 50 µm Kapton +0.4 MΩ/□ DLC





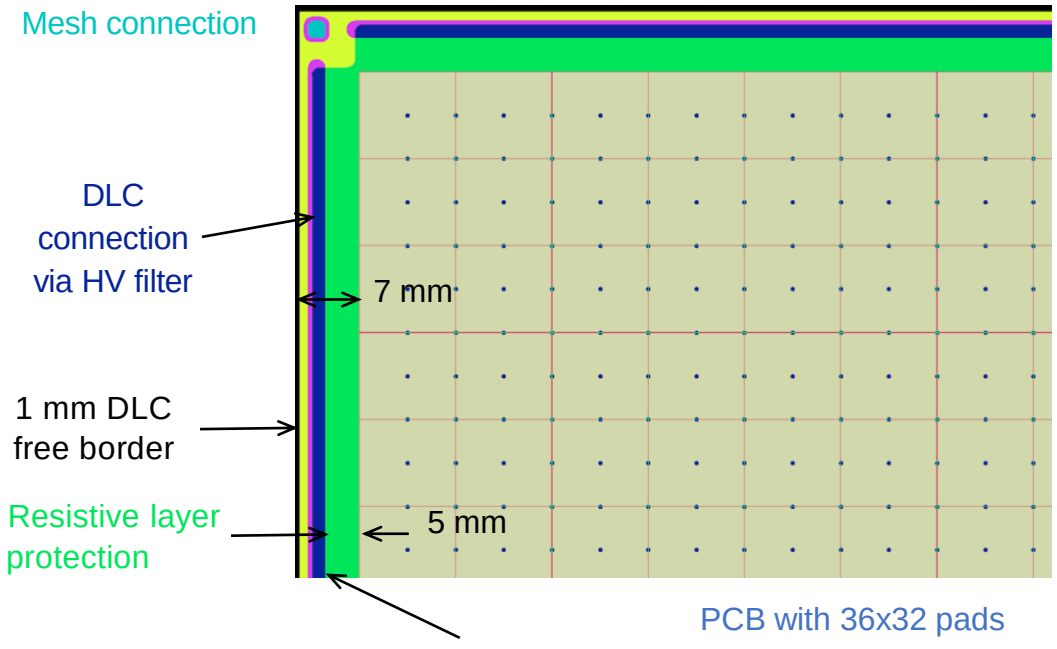


PCB design thickness : 2.21 mm

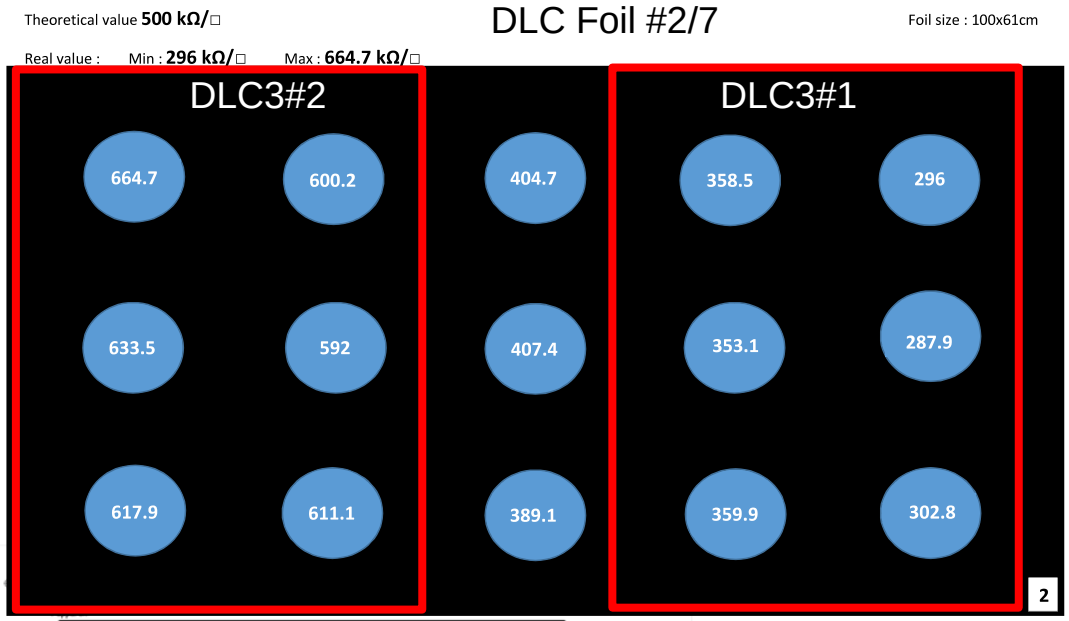
B. Mehl, R. de Oliveira, O. Pizzirusso (CERN-EP-DT-EF)

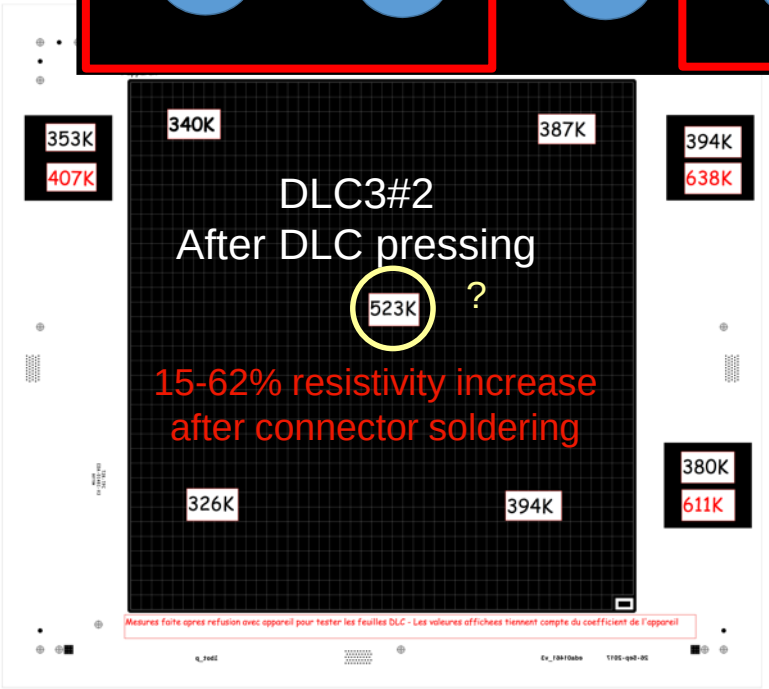
DLC Bulk Micromegas Design

- 7 x DLC foils (1x0.6 m²) at CERN
- Resistivity dispersion: 0.3-0.7 MΩ/□
- Provided by Be-sputter (Japan) with help from A. Ochi
- Micromegas mesh grounded in 4 points (PCB corners)
- DLC polarised using a continuous connection



MM0-DLC Resistivity Control





- MM0-DLC3 #1

- Resistivity dropped down to ~half its original 290-407 kΩ/□ value after DLC pressing
- A ~20% increase is observed after connector wave-soldering
- Final resistivity 220 kΩ/□ measured in active area

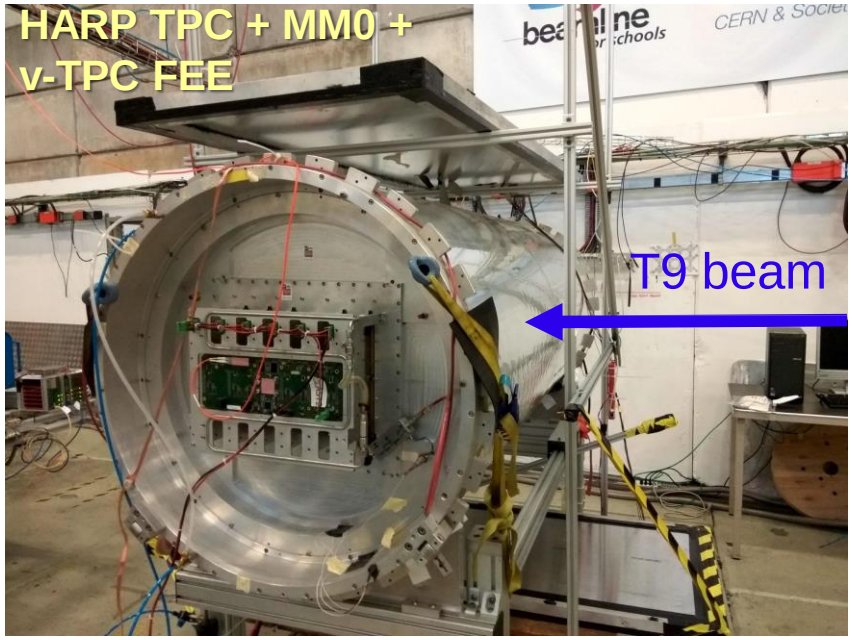
- MM0-DLC3 #2

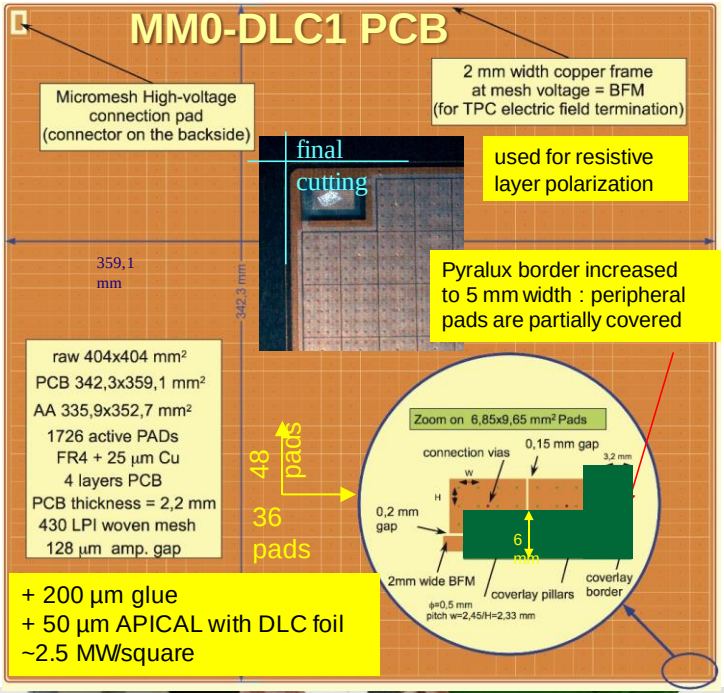
- Resistivity dropped from 400-660 kΩ/□ down to ~320-400 kΩ/□ after DLC pressing
- Final resistivity 400-640 kΩ/□ measured outside the active area borders (to be checked again)

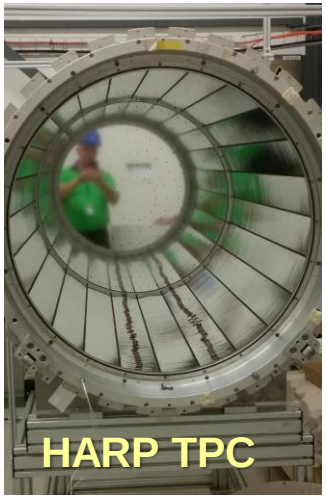
Variations of DLC resistivity under investigation

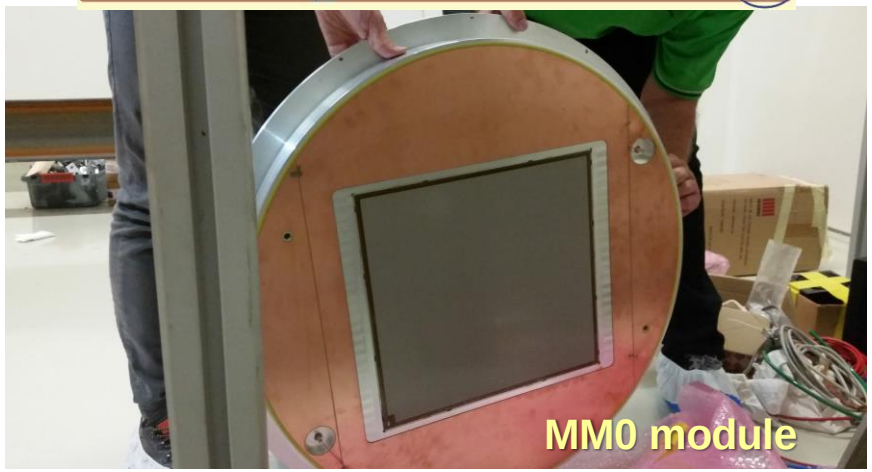
- Tests on small samples + investigations on the measurement protocol & reproductibility
- Need to assess the spatial resolution & dE/dx sensitivity to resistivity non-uniformities

Resistive Micromegas Module MM0 Beam Test at CERN/PS-T9 (Summer 2018)





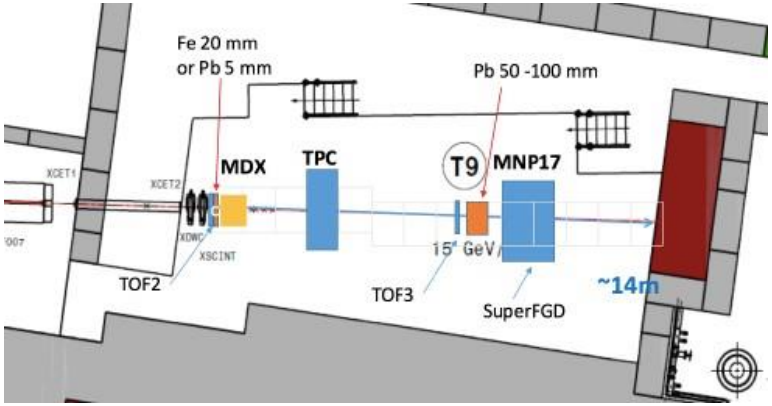


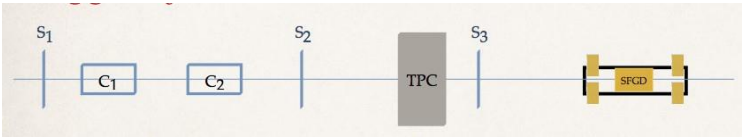


Resistive Micromegas Module MM0 Beam Test at CERN/PS-T9 (Summer 2018)

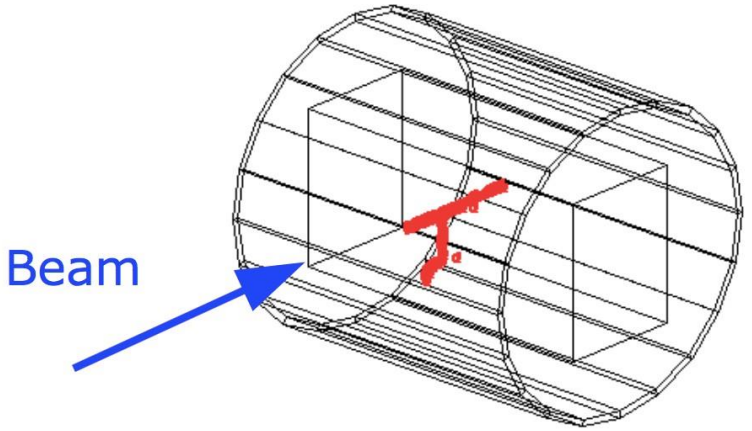
- Gas volume: HARP TPC
  - 1.5 m drift distance
  - 25 kV (166 V/cm)
  - 25 L/h Argon(95%)/CF4(3%)/isobutane(2%)
- Detector: module MM0-DLC1
  - Micromegas module with 2.5 MΩ/□ DLC
  - horiz. x vert. = 36 x 48 pads
  - each pad 0.97 x 0.69 cm
  - nominal MM voltage 340 V (up to 380 V)
  - v-TPC FEE: sampling time 80 ns (12.5 MHz)
- Data taking
  - Cosmic trigger with 2 plastic scintillators +MPPC
  - Fe55 source for 5.9 kEv X-rays
  - Beam: 0.5,± 0.8, 1, 2 GeV/c momentum

+ ^{55}Fe X-ray source in the middle of the cathode

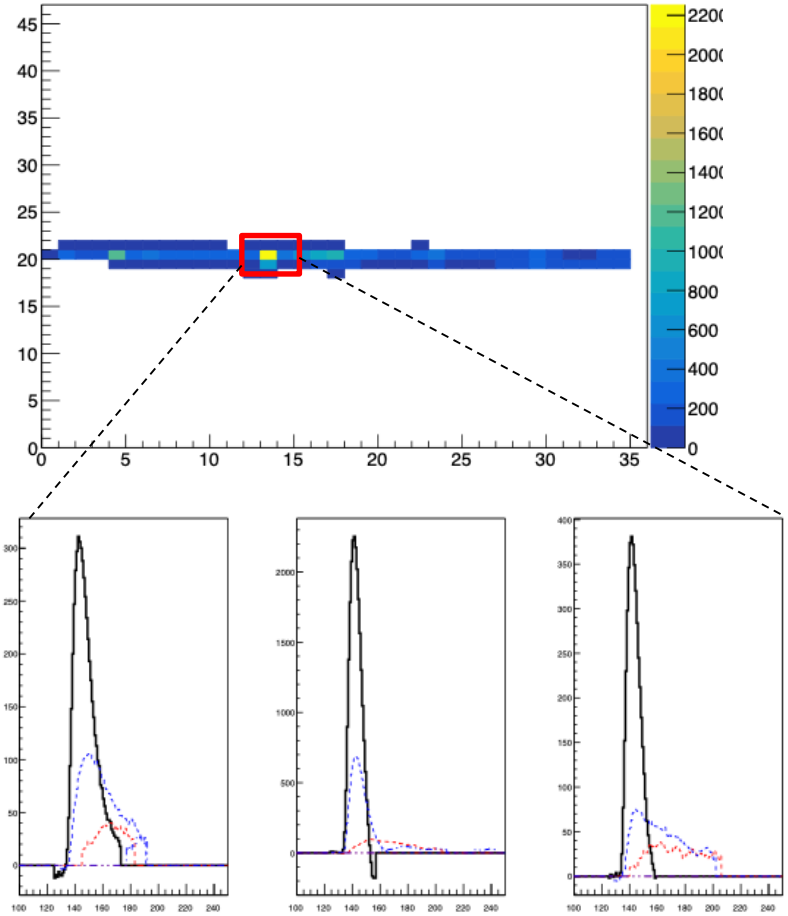




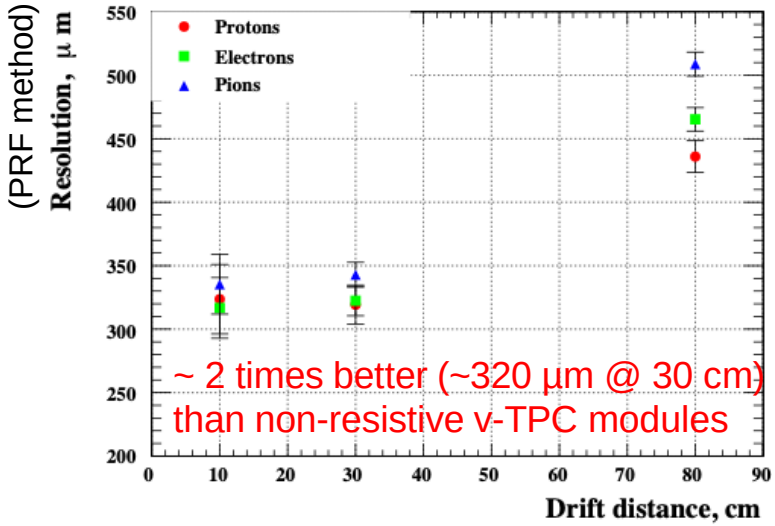
π, e, p trigger

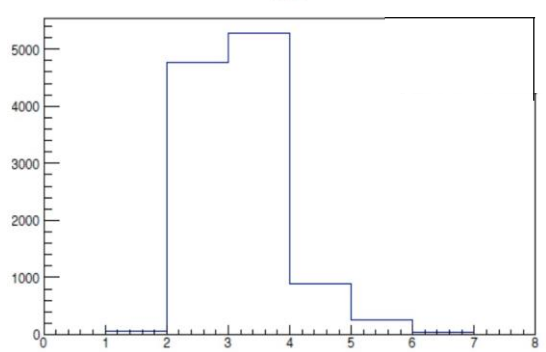


Preliminary Results
Charge Spreading, Spatial Resolution



Waveforms on adjacent pads



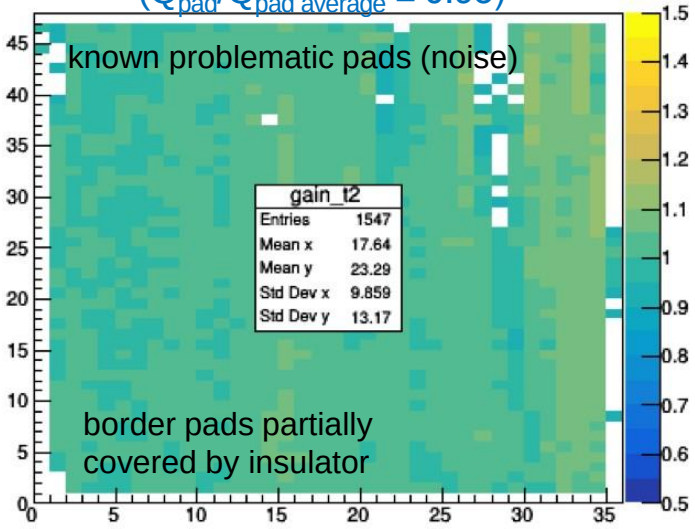


Spread over 2.7 pads ~1.8 cm

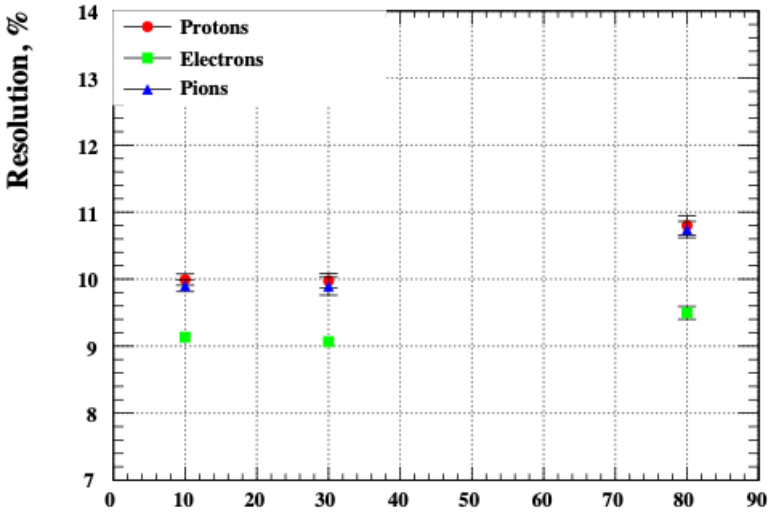
- Still margin for going from MM0 [6.9 × 9.7 mm²] to MM1 [10.09 × 11.18 mm²] pads by decreasing the resistivity to ~0.4 MΩ/□ (trade-off btw charge spreading & spark protection)

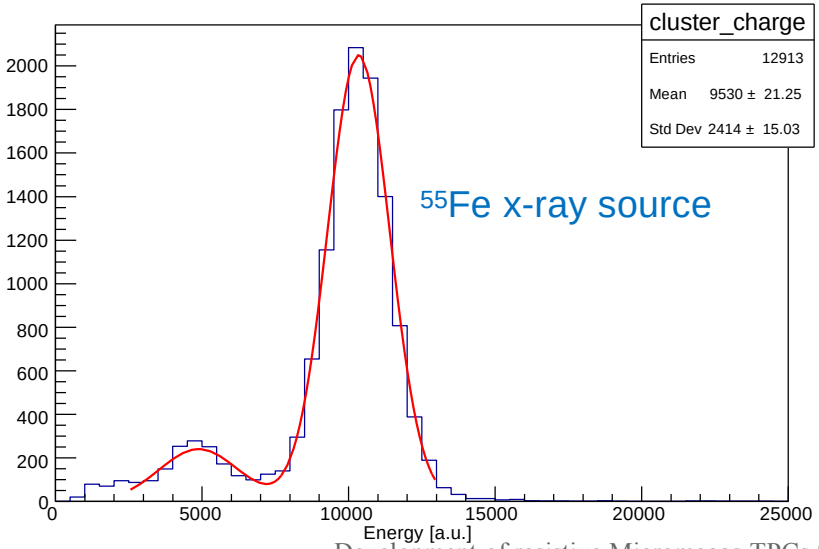
Preliminary Results
Micromegas Gain, dE/dx resolution

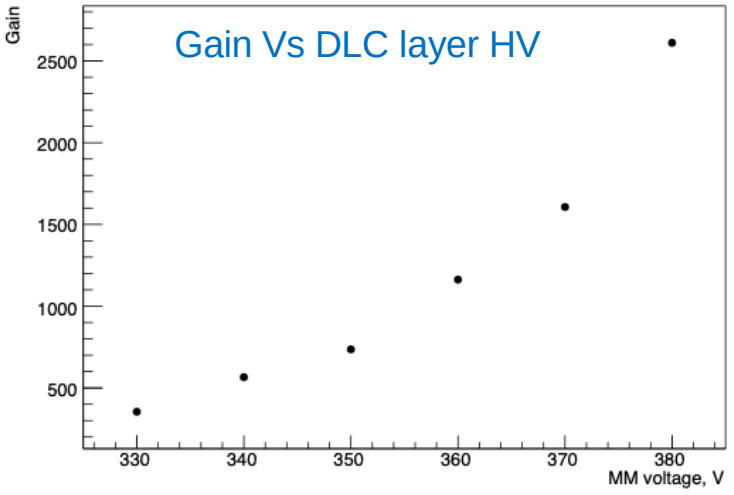
Micromegas gain uniformity
($Q_{pad}/Q_{pad\ average} \geq 0.93$)



dE/dx resolution using
truncated mean method with 36 clusters

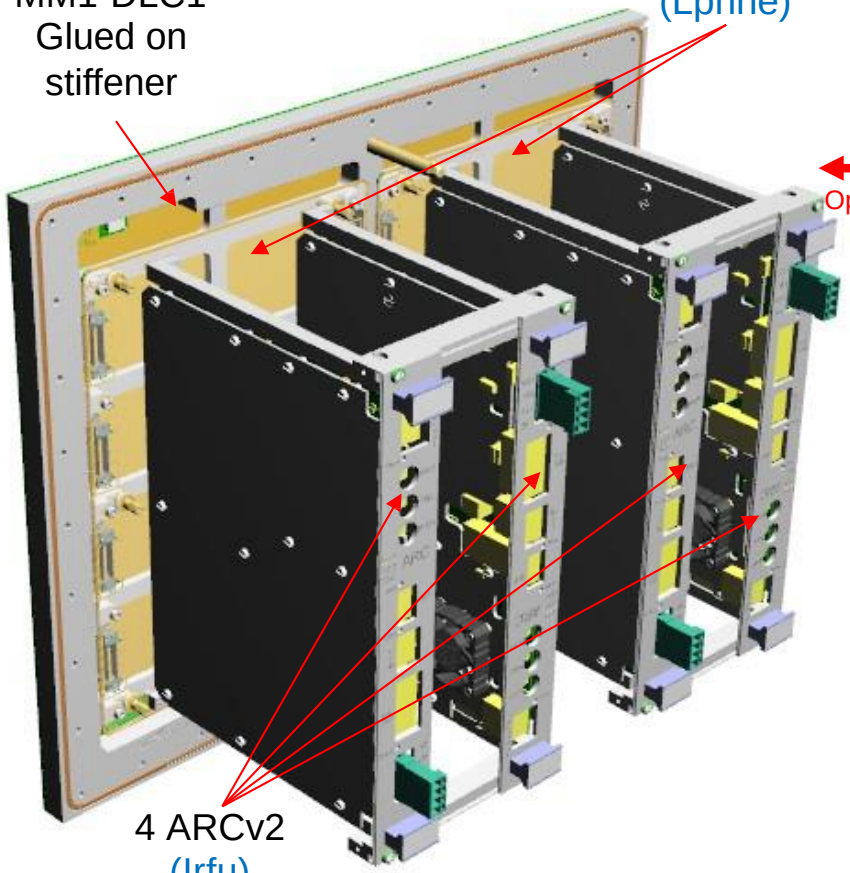


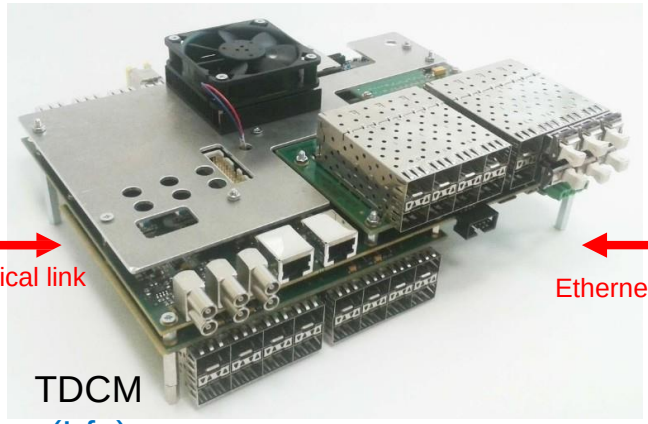




READOUT ELECTRONICS FOR TEST PROTOTYPE OF MM1

- Front-end: 4 x 288-channel ARCv2-AFTER (minor corrections compared to ARCv1)
- Back-end: TDCM + PC running MIDAS for configuration and DAQ

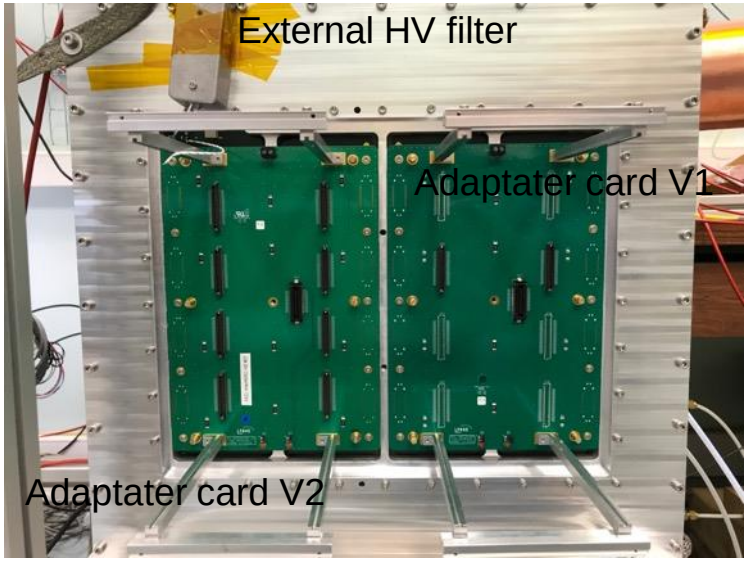




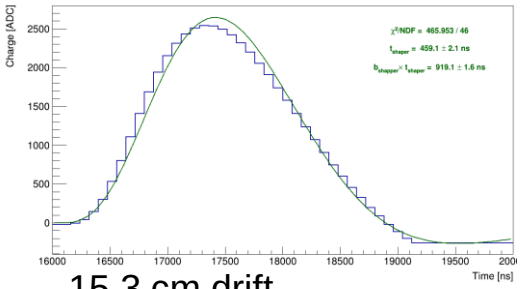

ARCv1


TDCM mechanics for insertion in a 6U crate

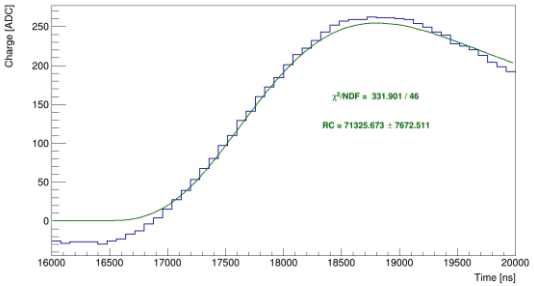
READOUT ELECTRONICS
FIRST SIGNALS FROM MM1-DLC1

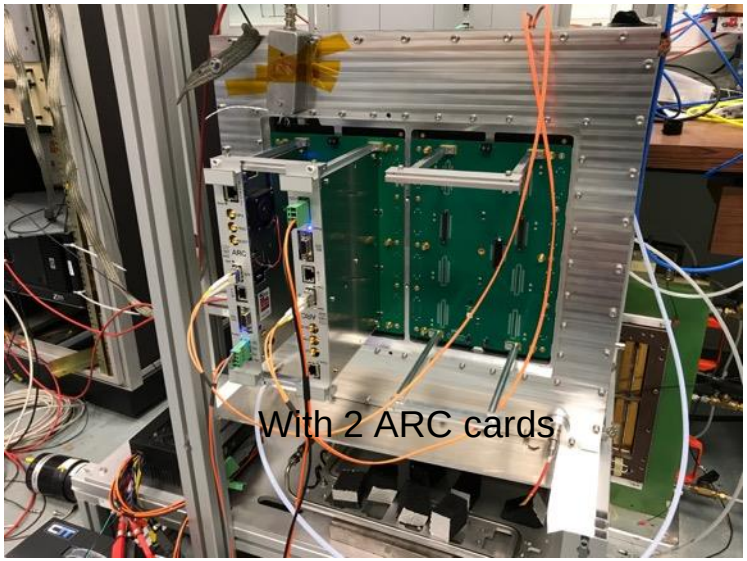


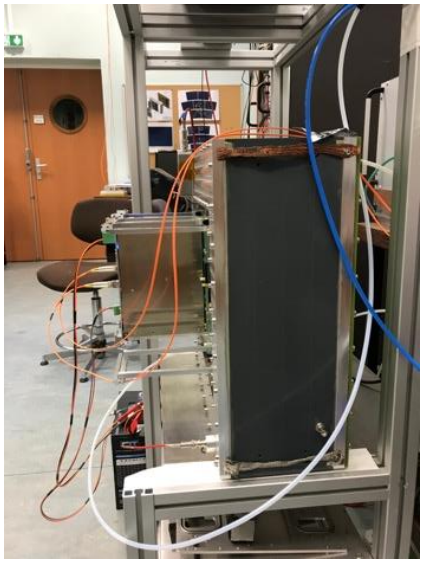
- Cosmic data taking started 02 May
- Software for hit display being finalized
- Only one FEC adapter V2 available
- RC can be evaluated by fitting the signal pulses

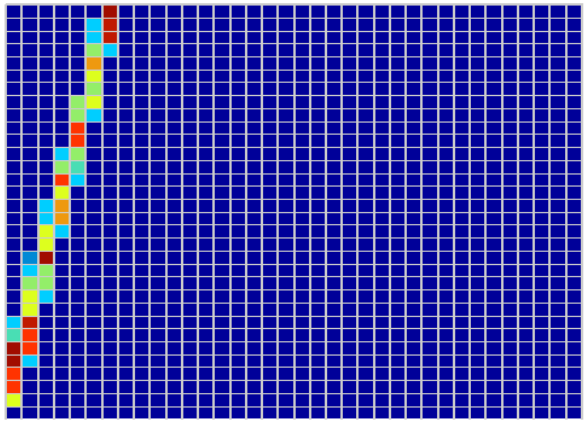


15,3 cm drift









CONCLUSIONS & PERSPECTIVES

- The tests of a resistive bulk-Micromegas module on CERN/PS-T9 beam showed a 2 times better spatial resolution while keeping the dE/dX capabilities in control (9-10% with only one module track length)

- Analysis is on-going to understand, measure the DLC resistivity non-uniformity

- A small prototype of a HA-TPC field cage equipped with a full-size resistive bulk Micromegas module MM1 will be tested with beam at DESY in June 2019

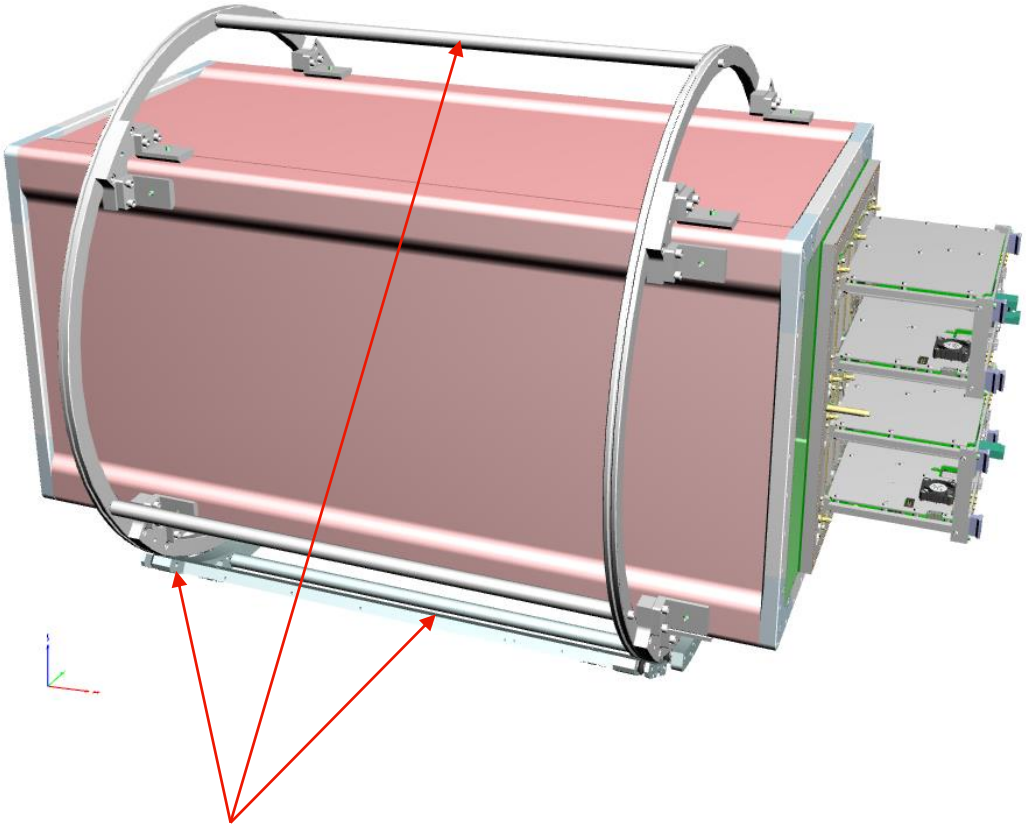
- The T2K / ND280 near detector upgrade development is on-going (FEC, FC, test bench

- The 2 new HA-TPCs design will be soon fixed and production should start in October 2019 for a completion scheduled for march 2021

THANK YOU

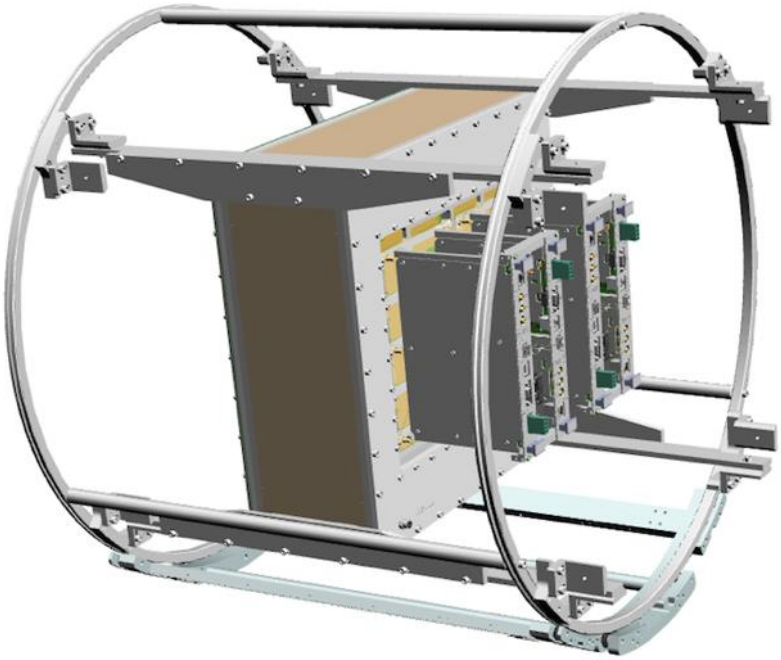
THE T2K-II PHASE

2019 HA-TPC prototype



Under production at INFN Lagnaro workshop

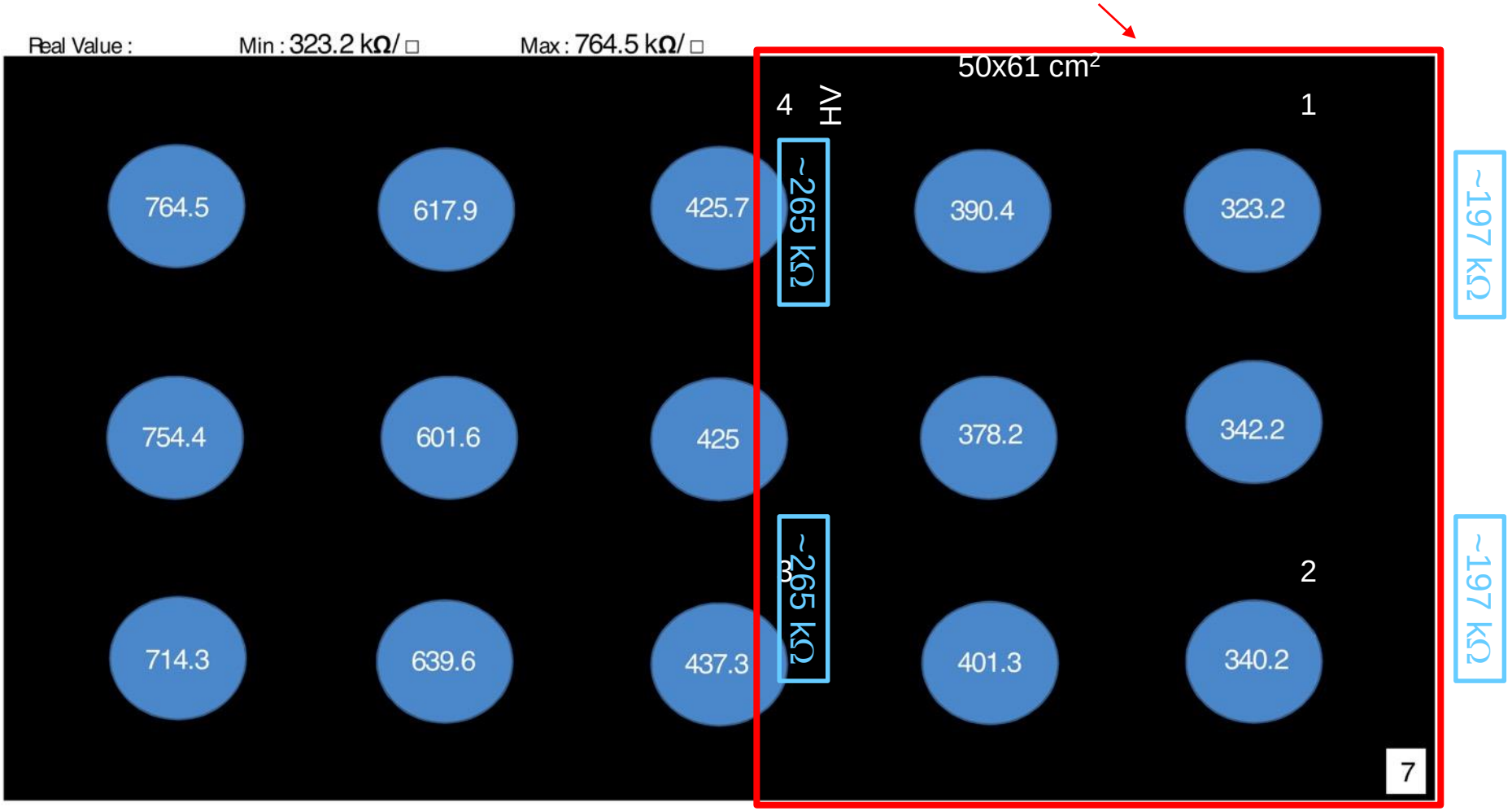
Saclay mini-TPC



New parts to be produced

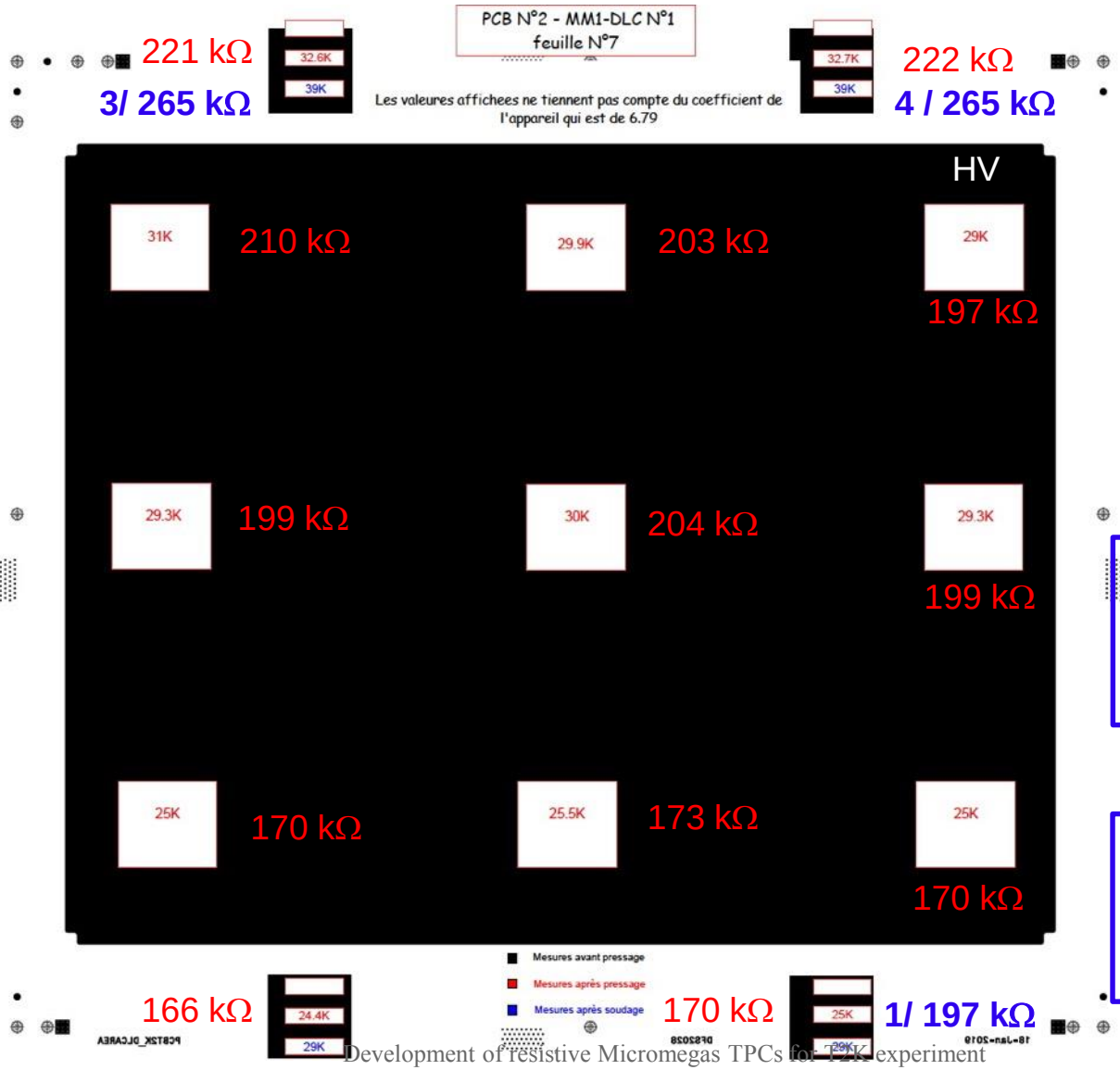
Preliminary Results
Micromegas Gain, dE/dx resolution

Part of DLC foil #7/7 used for MM1-DLC1

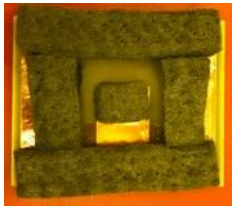


MM1-DLC1: RESISTIVITY MEASUREMENT @ CERN WITH "OCHI" PROBE

- MM1-DLC1 resistivity – active area side (CERN "ochi" probe, k=6,79)



Saclay Probe (front) Saclay Probe (back)



Rx9.78 → not consistent with CERN

MM1-DLC1 resistivity
(CERN "ochi" probe, k=6,79)