DE LA RECHERCHE À L'INDUSTRIE

T2K/ND280 HA-TPC

ENCAPSULATED RESISTIVE ANODE MICROMEGAS DETECTOR

D. Attié, S. Bolognesi, D. Calvet, P. Colas, **A. Delbart,** S. Emery, S. Hassani, M. Lehuraux, J. Porthault, M. Riallot, F. Rossi, S. Suvorov
CEA/DSM-IRFU, Univ. Paris – Saclay

R. De Oliveira, B. Mehl, O. Pizzirusso,
CERN-EP-DT-EF, MPGD Lab.

Within the T2K/ND280 - HA-TPC collaboration

ERAM module

HA-TPC

ERAM : Encapsulated Resistive Anode Micromegas

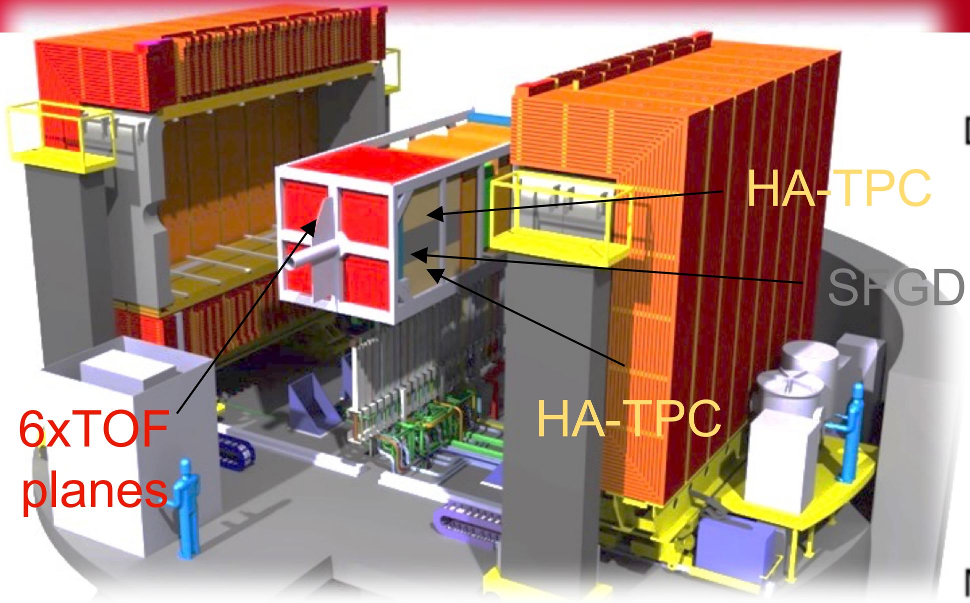
- ND280 upgrade ERAM modules history

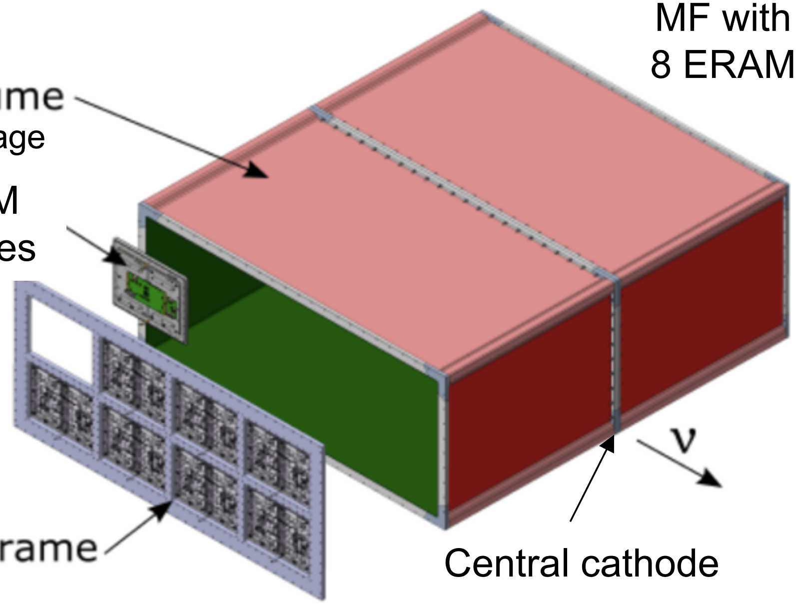
- 2019 MM1 & 2020 ERAM#1 prototypes
  - DLC resistivity mesaurements
  - Beam tests (CERN & DESY)
  - First operation of an ERAM with its final FEE

RD51 collaboration meeting, vidyo, june 22nd-26th 2020

T2K/ND280 UPGRADE : HA-TPCS

HA-TPCS

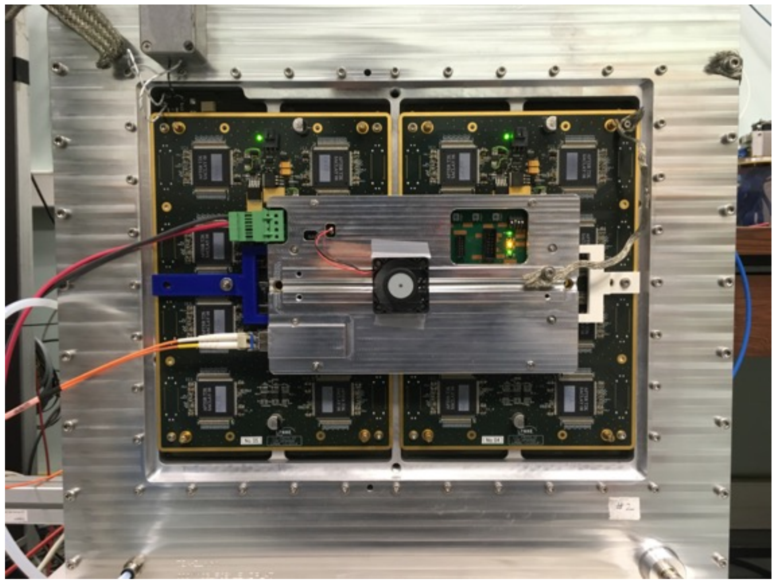




2x T2K/ HA-TPC (2022) — 3x T2K/ V-TPC (2010)

Parameter	Value	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 (32)	340x360 (72)
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	

T2K HA-TPC ERAM module (2020)



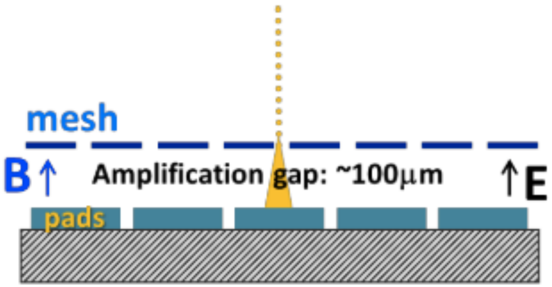
RESISTIVE ANODE BULK-MICROMEGAS WITH DIAMOND-LIKE CARBON

ILC/TPC R&D: P. Colas et al.

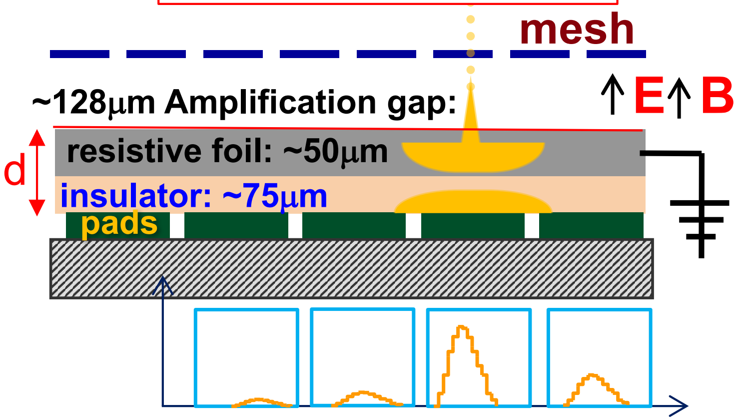
Ref: M.S. Dixit *et al.* *NIM* A518, p. 721, 2004

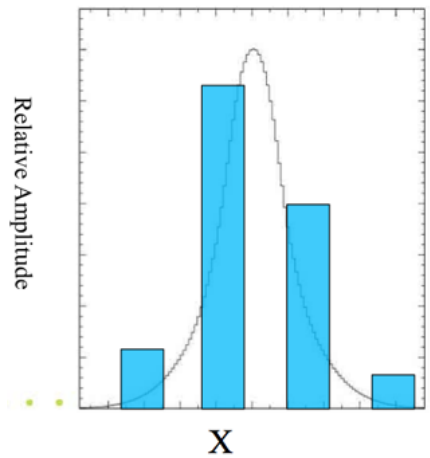
Choice of the Resistive foil technology for the HA-TPC micromegas readout

- Charge spreading which should enable keeping the ~600 μm spatial resolution with larger pads and improves it at short drift distance → less electronic channels, cost reduction
- ASIC spark protection no longer needed → more compact FEE, maximize HA-TPC acceptance
- Encapsulated mesh @ GND + insulating layer → potentially lower track distorsions & better S/N



Resistive-bulk-mm





2-D RC network

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

R- surface resistivity
C- capacitance/unit area

Gaussian spreading as a function of time with :

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

For pads of ~11x10 mm^2, the Kapton foil resistivity could be **around** $0.4\ M\Omega/\blacksquare$ and glue thickness **~75 μm** for a good charge spreading (σ~ 5 mm) RC ~50 ns/mm^2

ERAM DEVELOPMENT HISTORY

Version	Delivery date	pad number (Y x Z) Pad size (mm) FE Type	DLC R (Mohm) foil	DLC R (Mohm) detector	Glue thick. (µm) (not measured)	RC (ns/mm2)	expected sigma (mm) for 200 ns peaking time	Goal	Main results
R&D (MM0) T2K v-TPC design 34 x 36 cm2	*2018*	36 x 38 (1726) 6.9 x 9.7 T2k v-TPC						charge spreading testing	
MM0-DLC1	january 2018		2.5 (not measured)	?	200	310	1,6	tested on HARP TPC @ CERN (08/2018) Nucl Instrum Meth A 957 (july 2019)	Manufacturing procedure validation achieved required performances for 412ns peaking NIM A957 (july 2019) 10.1016/j.nima.2019.163286
MM0-DLC2	june 2018		2.5 (not measured)	?	200	310	1,6		
MM0-DLC3#1	november 2018		0.29 to 0.40 foil #2/7	~0.2	75	50	4,0	destroyed after connector soldering	bulk delamination after 216°C soldering
MM0-DLC3#2	january 2019		0.4 to 0.66 foil #2/7	0.40 to 0.64	75	100 to 159	2,2 to 2,8	at INFN	7/24 wrong connectors ! Non reproductible Resistivity change during manufacturing process
Pre-design (MM1) 34 x 42 cm2	*2019*	32 x 36 (1152) 10.09 x 11.18 ARC						Final size / first RC optimization FEE connection + shielding validation	
MM1-DLC1	april 2019		0.32 to 0.44 foil #7/7	0.2 to 0.27	75	50 to 67	3,5 to 4	tests at DESY 2019 tests on single-RMM 2019 prototype @ CERN (EHN1)	Detector / FEE interface validation Manufacturing process control achieved required performances for 412 ns peaking time
MM1-DLC2	june 2019		0.32 to 0.43 foil #5/7	0.2 to 0.27	75	50 to 67	3,5 to 4	FEE cooloing mock-up (feb 2020-)	to be compared to DLC1
Pre-series (ERAM) 34 x 42 cm2	*2020*	32 x 36 (1152) 10.09 x 11.18 ARC & Final FEE V1						Final design / Last RC optimization for 200 ns peaking time	
ERAM #01 (S/N002)	january 2020		0.28 to 0.40 foil #3/7	0.16 to 0.22	200	20 to 27	5,4 to 6,3	Desy test beam (oct 2020)	First cosmic tracks on june 10 with final FEE
ERAM#2	30 august 2020 ?				TbC			Possible use of new DLC foils	
ERAM production 34 x 42 cm2	*dec 2020 to feb 2022*	32 x 36 (1152) 10.09 x 11.18 Final FEE							
ERAM #03-#10	feb 2021		goal : same ERAM #01 with better uniformity		TbC			New DLC foil production better R uniformity ?	first new DLC batch (7 foils) received 16 february (R x 2 !)

PROTOTYPES PARAMETERS

Name	2018 MM0-DLC#	2019 MM1-DLC#	2020 ERAM#
Readout PCB	Original T2K-TPC	HA-TPC	HA-TPC V2 + final FEE
Size	34 × 36 cm²	34 × 42 cm²	34 × 42 cm²
Pads	48 × 36 cm²	32 × 36 cm²	32 × 36 cm²
Pad size	6,85 × 9,65 mm²	10,09 × 11,18 mm²	10,09 × 11,18 mm²
Pad number	1728	1152	1152
Isolation layers	75 -200 µm glue + 50 µm APICAL	75 µm glue + 50 µm APICAL	200 µm glue + 50 µm APICAL

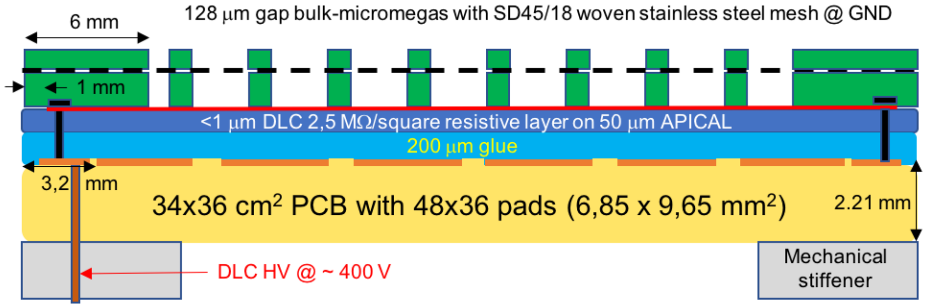
Expected charge Spreading:

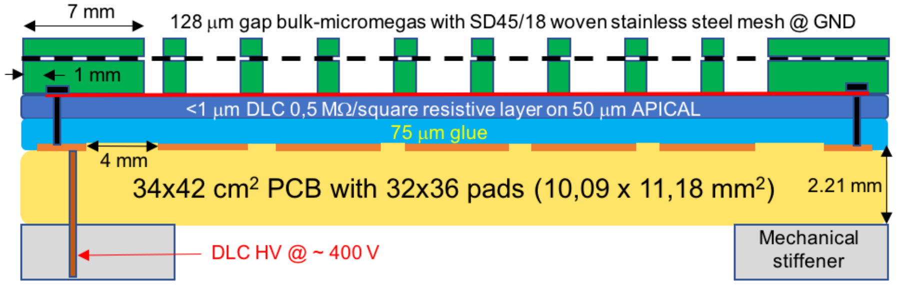
- MM0-DLC1 (2,5 MΩ/sq): **σ~ 1,6 mm for t=400 ns**
- MM1-DLC1 (~0,25 MΩ/sq): σ~ 2,5 mm for t=200 ns **σ~ 3,5 mm for t=400 ns**
- ERAM#1 (~0,2 MΩ/sq): σ~ 4,2 mm for t=200 ns **σ~ 6 mm for t=400 ns**

2018 CERN test beam : 2-3 pads Multiplicity, ~320 µm @ 30 cm drift 2x better than non-resistive 2010 TPCs

2019 DESY test beam

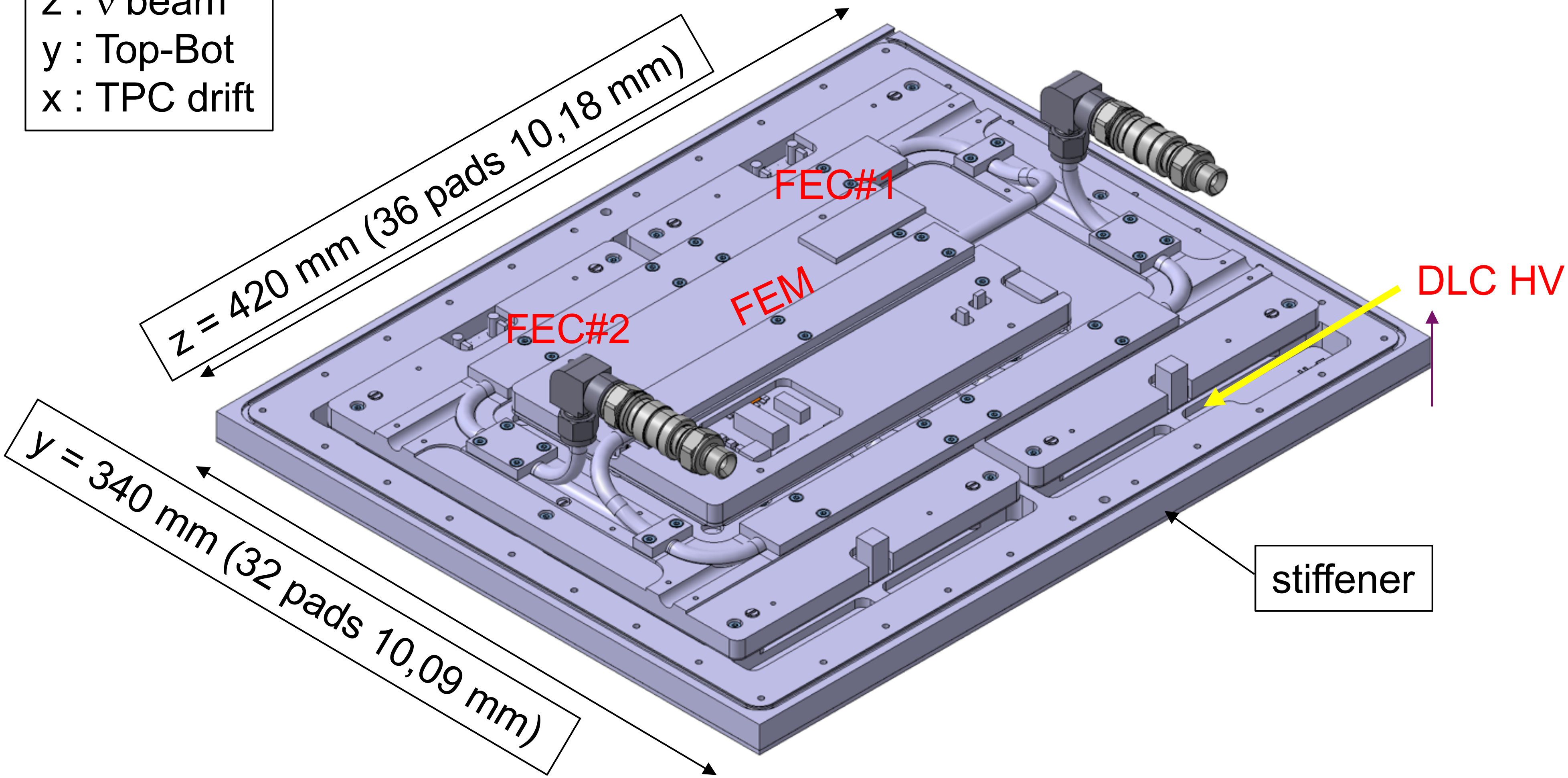
Oct 2020 DESY test On-going data taking with cosmics





THE ERAM MODULE : A COMPACT DESIGN

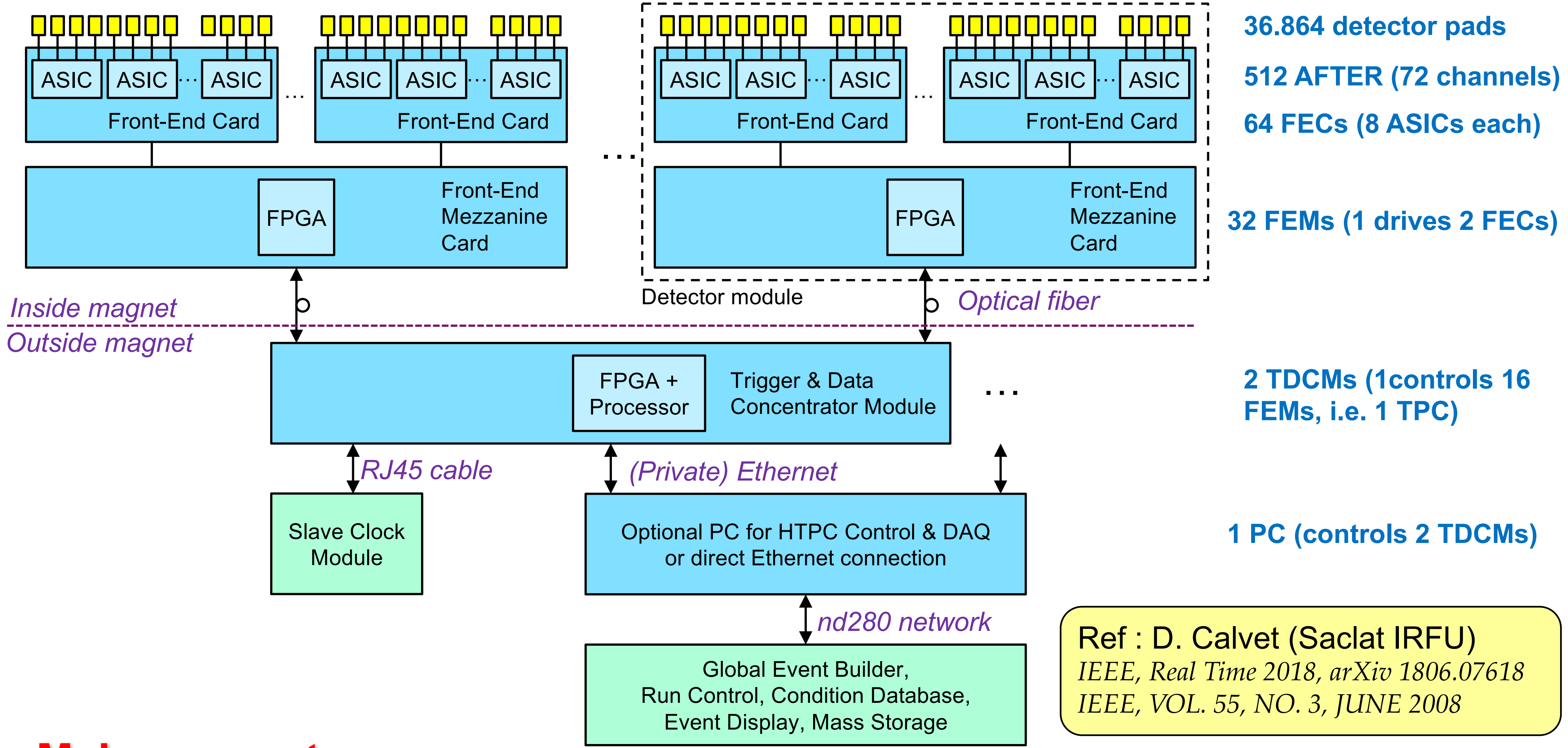
z : ν beam
y : Top-Bot
x : TPC drift



Total x thickness < 20 mm

Ref: J. Porthaul/F. Rossi (Saclay Irfu)
H. Przybilski (IFJ-PAN)

HA-TPC READOUT ELECTRONICS
A NEW AFTER-BASED ARCHITECTURE

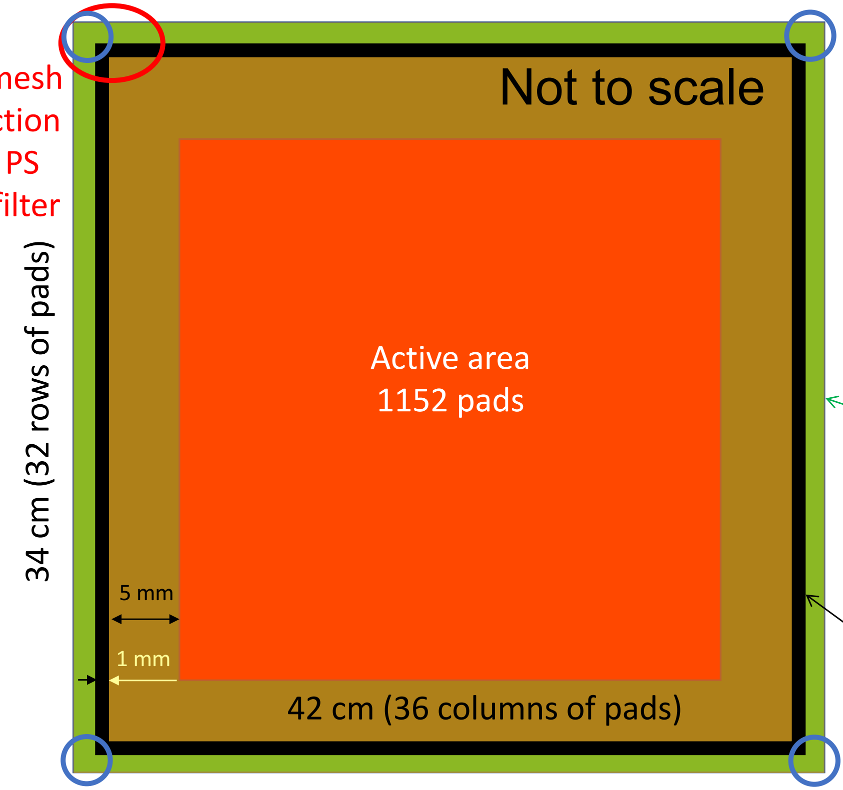


Ref : D. Calvet (Saclat IRFU)
IEEE, Real Time 2018, arXiv 1806.07618
IEEE, VOL. 55, NO. 3, JUNE 2008

Main concepts

- 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
- The TDCM is a generic clock and trigger distributor and data aggregator (FPGA+2 xilinx CPU+1 GB DDR3)

THE HA-TPC MM1 PROTOTYPE



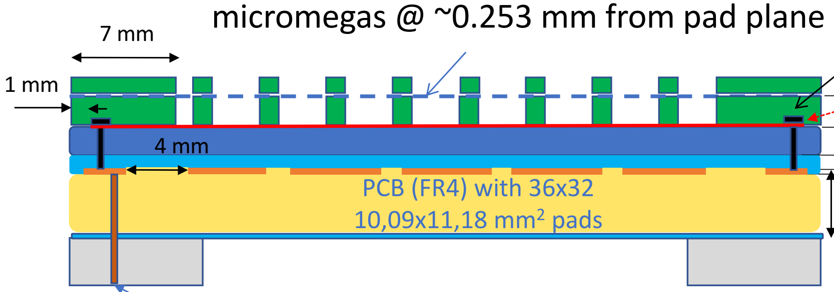
DLC & mesh connection To HV PS via HV filter

Mesh connection (silver paste) In the 4 corners

1 mm DLC free border

Silver paste strip (1 mm width) connected to 2 mm width PCB copper strip

Grounded mesh encapsulated in bulk-micromegas @ ~0.253 mm from pad plane



<1 μm DLC resistive layer (~0,4 Mohm after DLC pressing)

128 μm (Pyralux plillars)

50 μm (resistive Kapton)

75 μm (Glue)

35 μm (copper pad) With epoxy filling inbetween

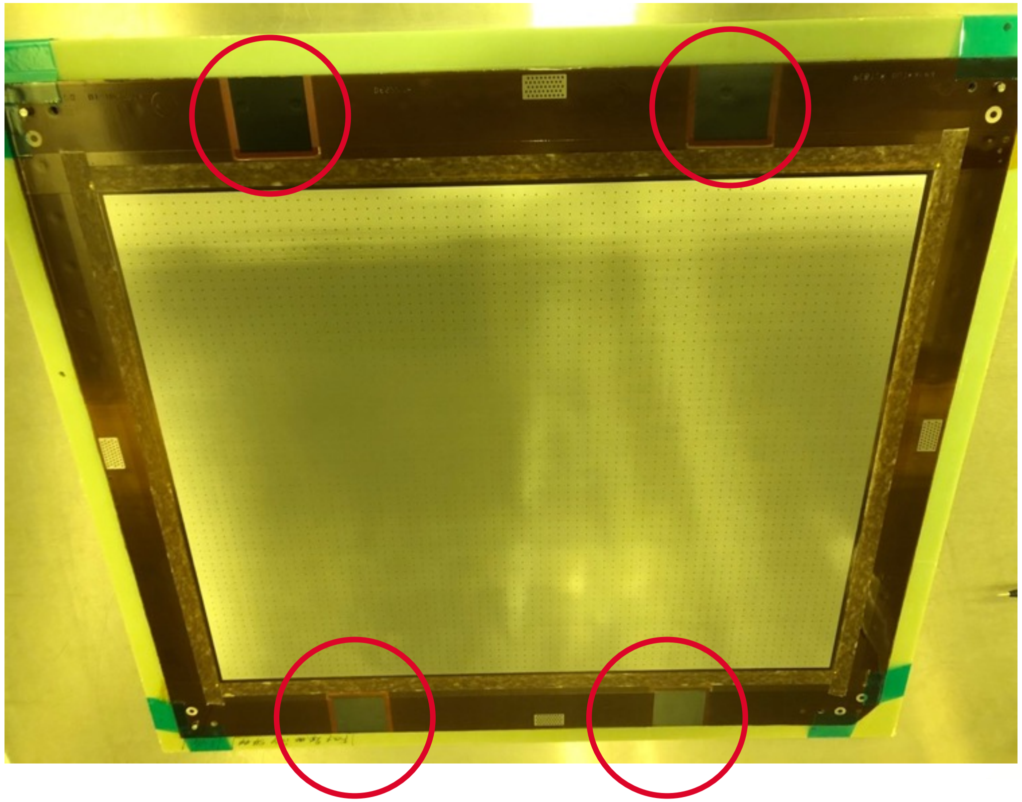
DLC HV ~+400 V (2 contacts in corners)

Aluminum stiffener

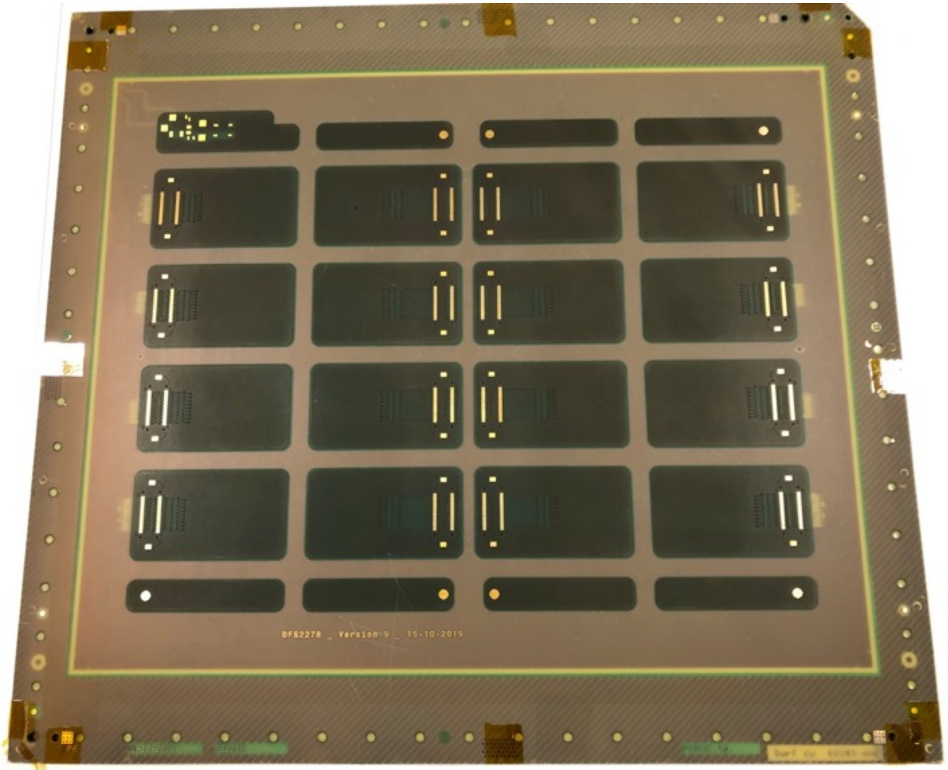
DLC RESISTIVITY MEASUREMENTS
ERAM#1 (S/N 002) PICTURES

ERAM#1 before connector soldering

4 zones to measure final detector DLC resistivity



Bulk-micromegas side

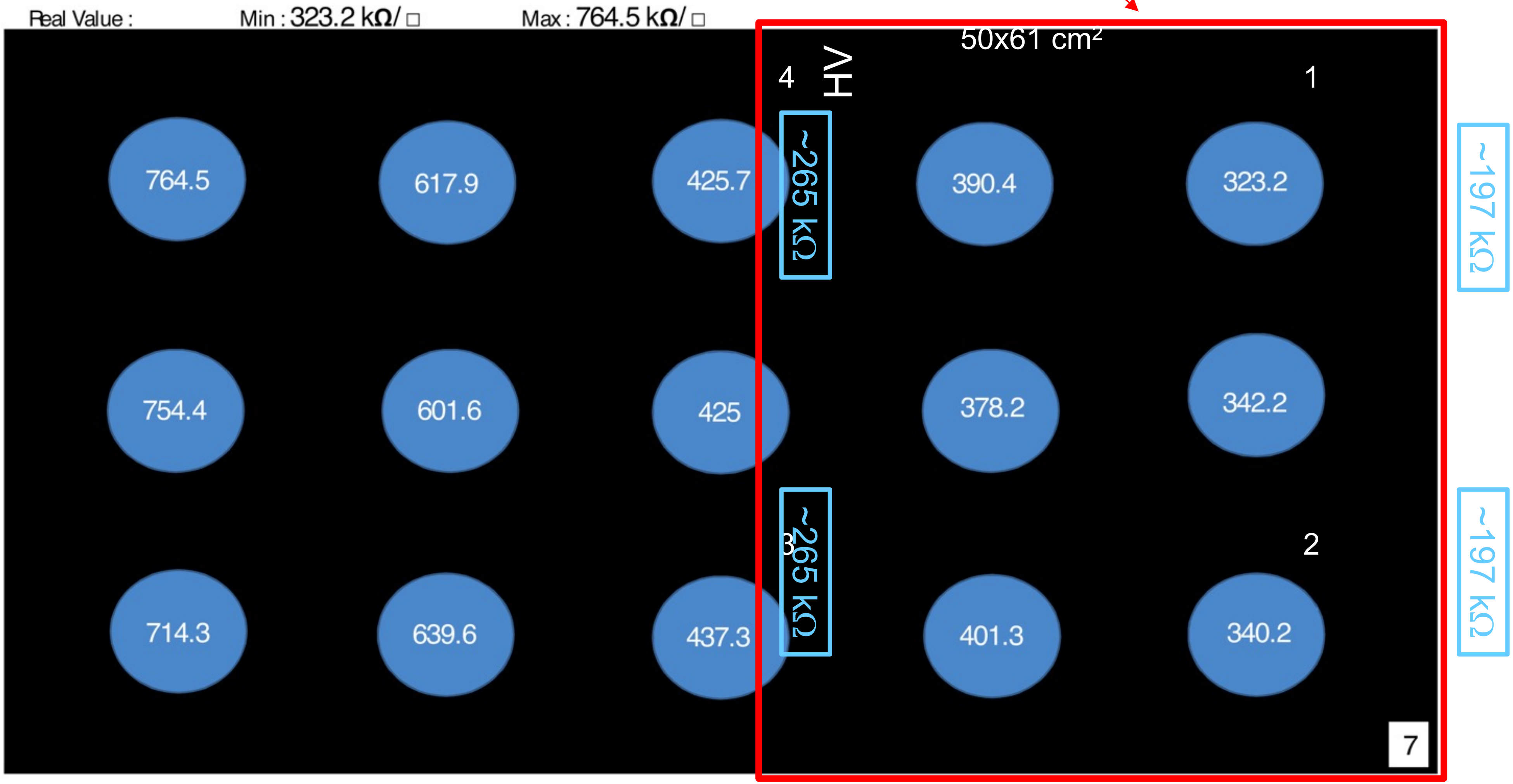


Connector side

DLC was polarized @ 850V in air with a measured current of 7 à 8 nA.

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

Part of DLC foil #7 used for MM1-DLC1

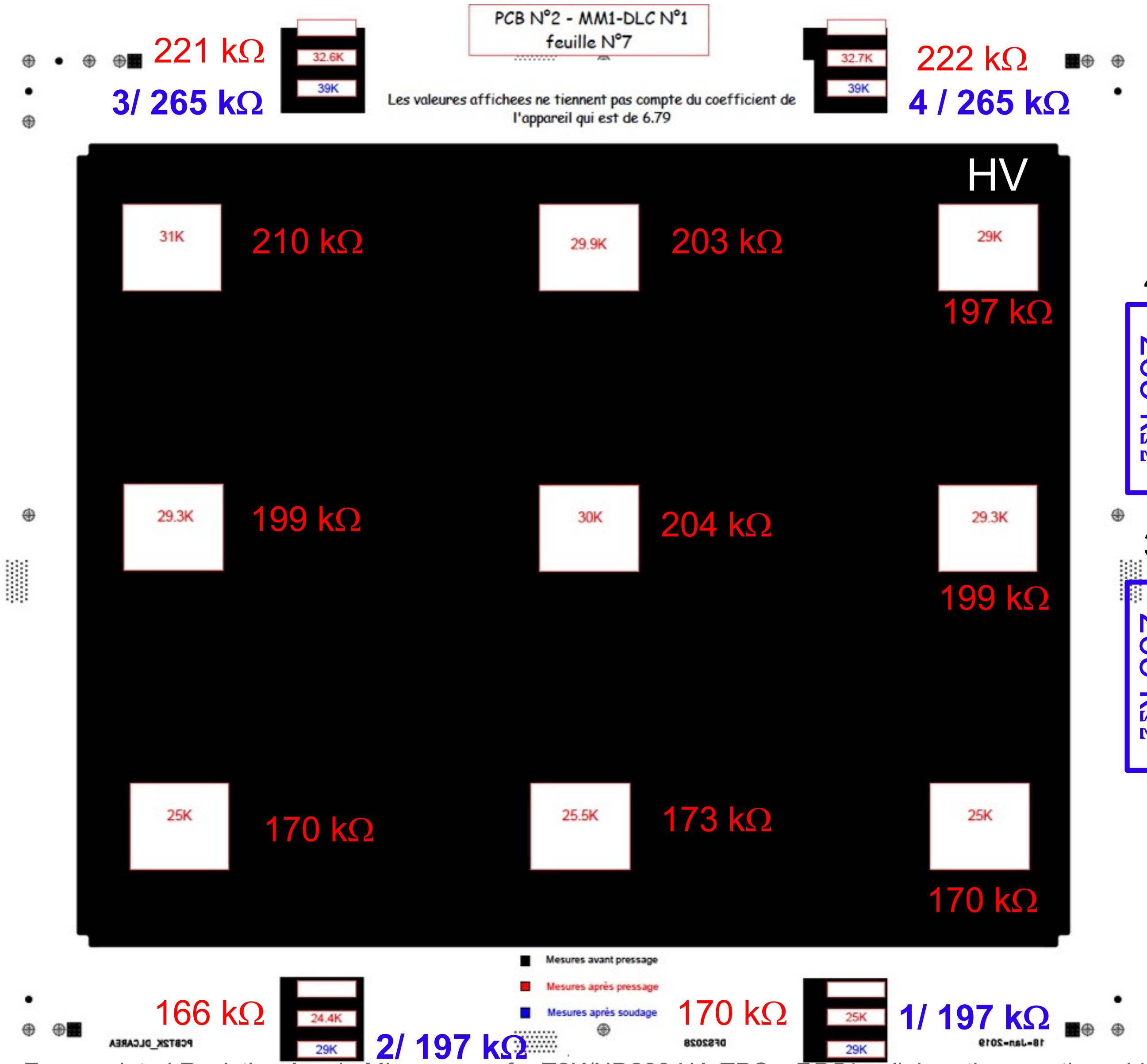


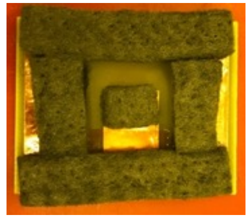
In blue : measured value outside detector area once detector is finished

~60% drop after DLC foil pressing & connector soldering

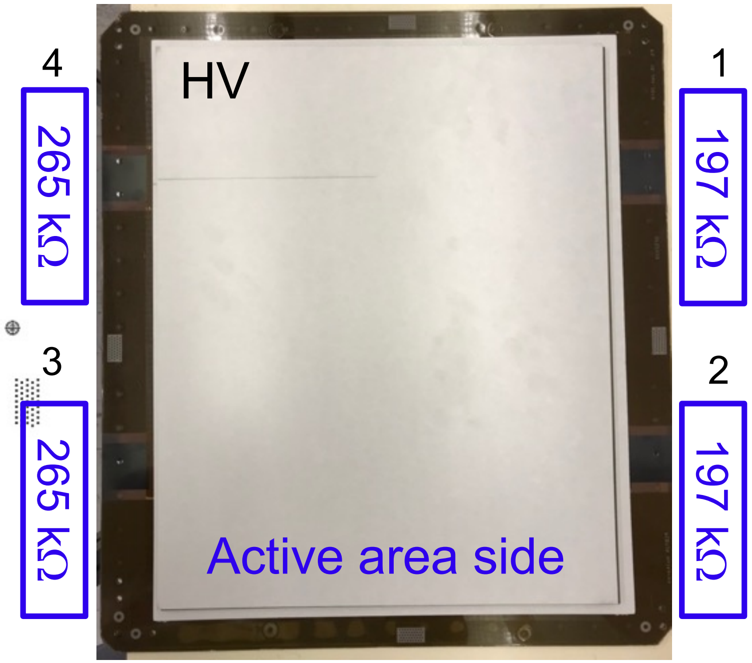
MM1-DLC1 : RESISTIVITY MEASUREMENT @ CERN WITH "OCHI" PROBE

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



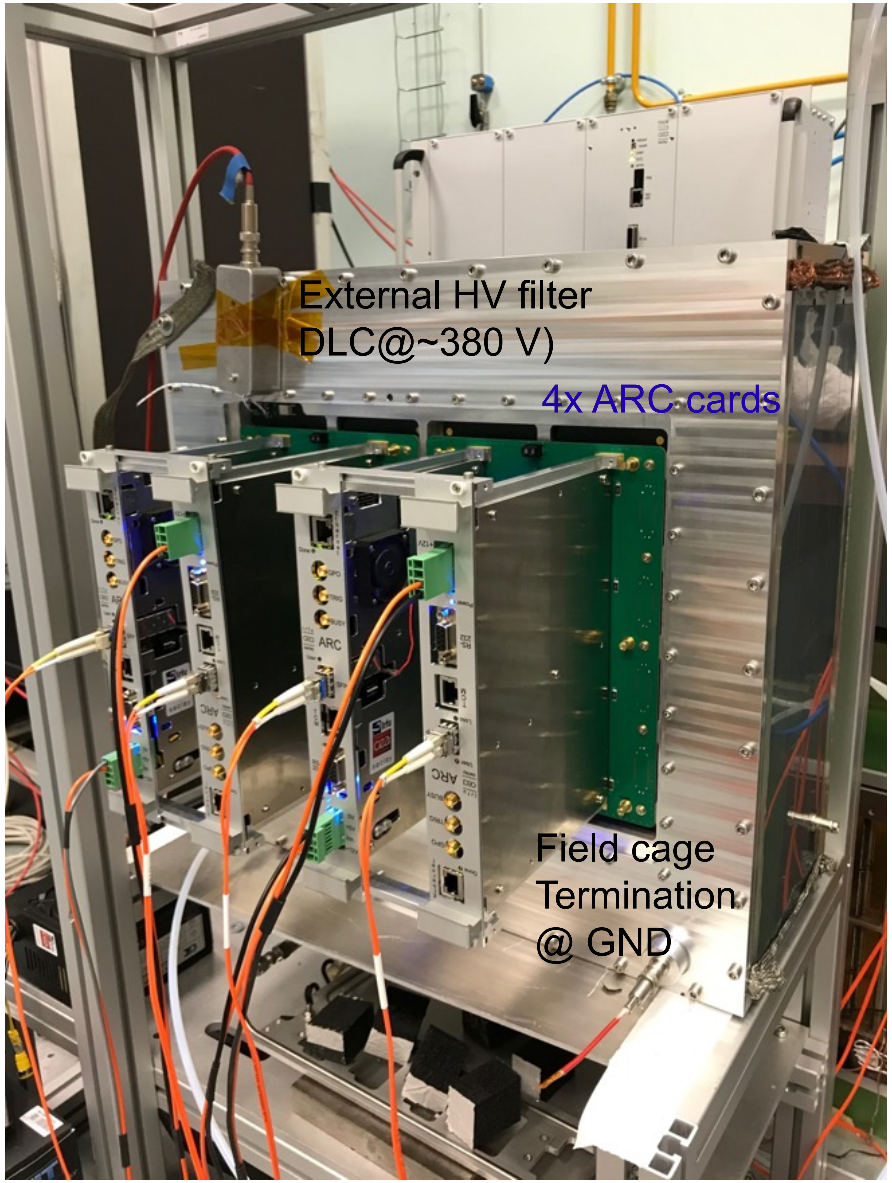


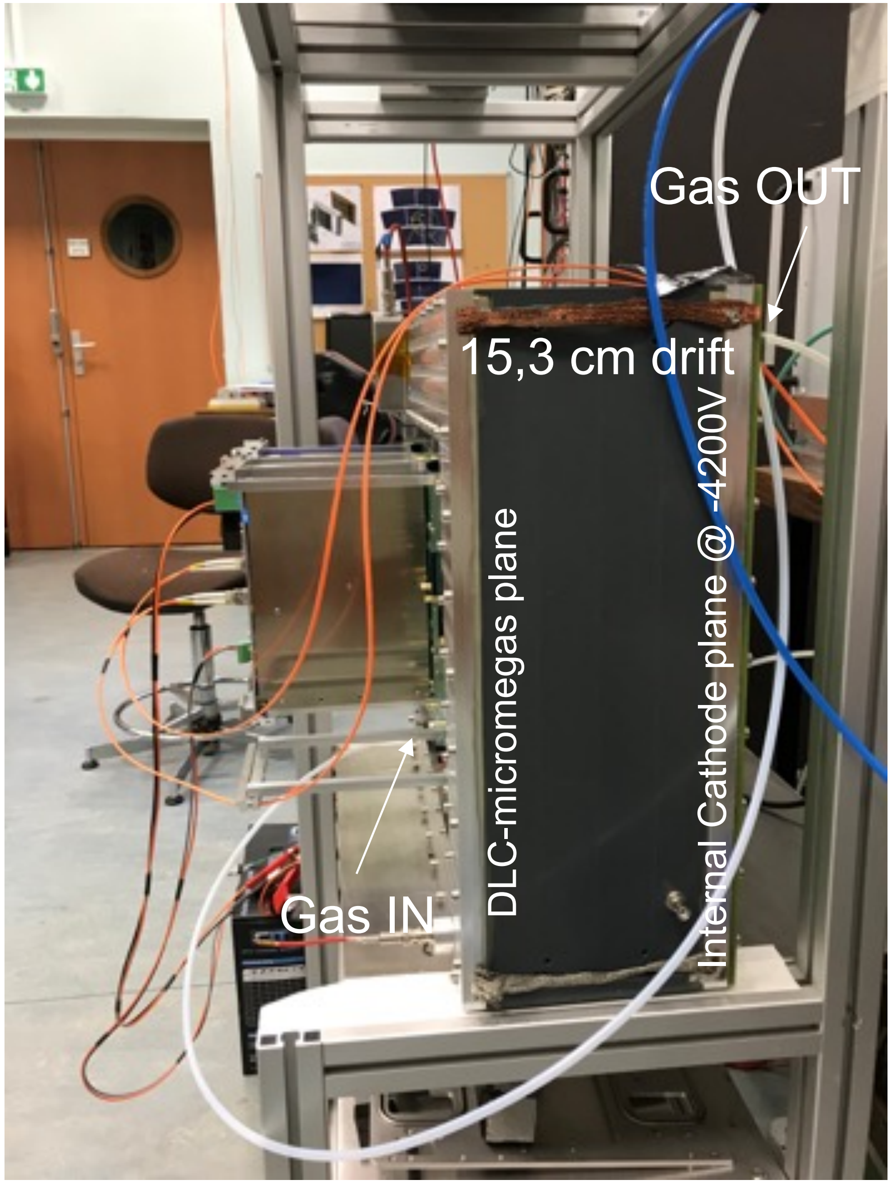
MM1-DLC1 resistivity



Foil#5 used for MM1-DLC2
→ Same resistivity within 10%
→ Same Final resistivity

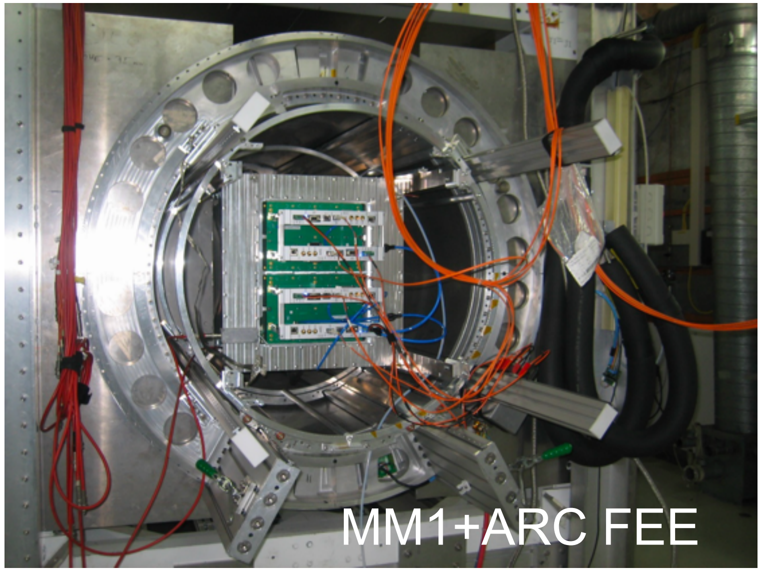
MM1 ON ITS MINI-TPC CHAMBER
ARC ELECTRONICS (2019)

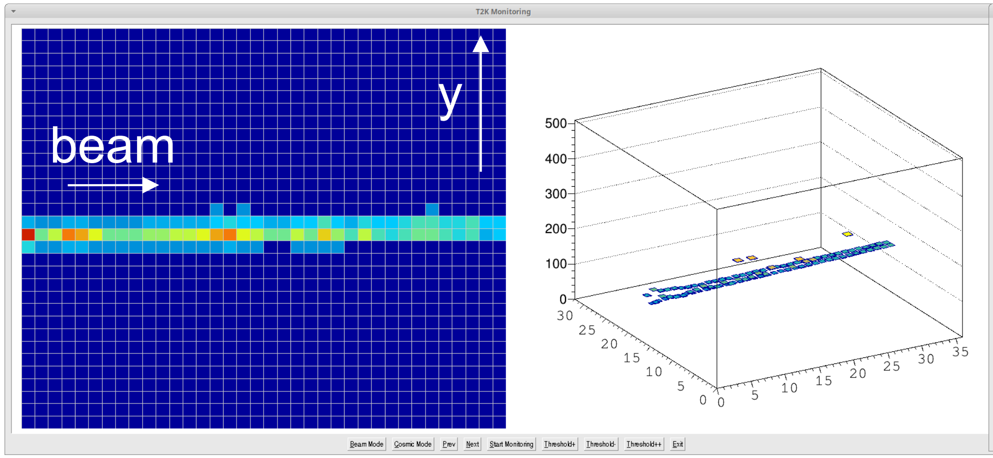


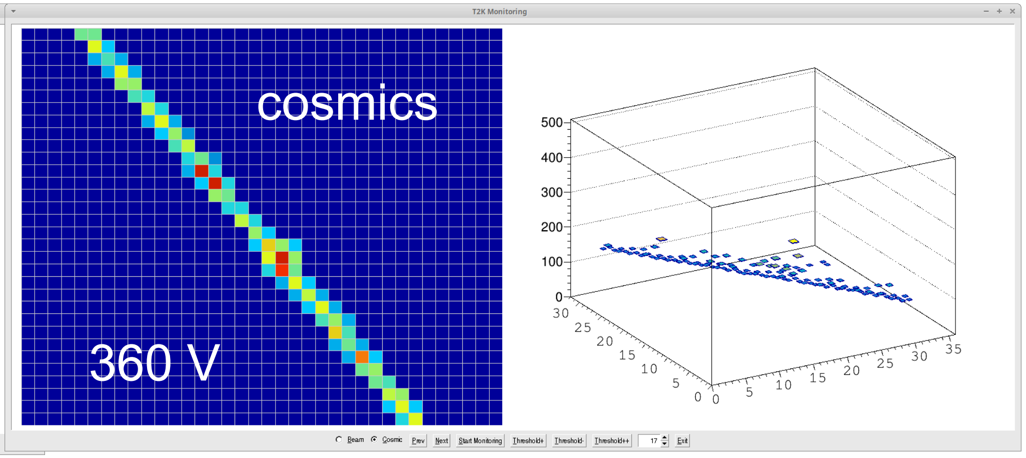


MM1 PROTOTYPE TESTS BEAM @ DESY T24/1 (JUNE 2019)

- T2K gas Argon(95%)/CF4(3%)/isobutane(2%), 280 V/cm drift field
- Front-end electronics : 4 x 288-channel ARCv2-AFTER
- 4 GeV e- beam, PCMAG magnet set @ 0,2 T (ND280 B field)



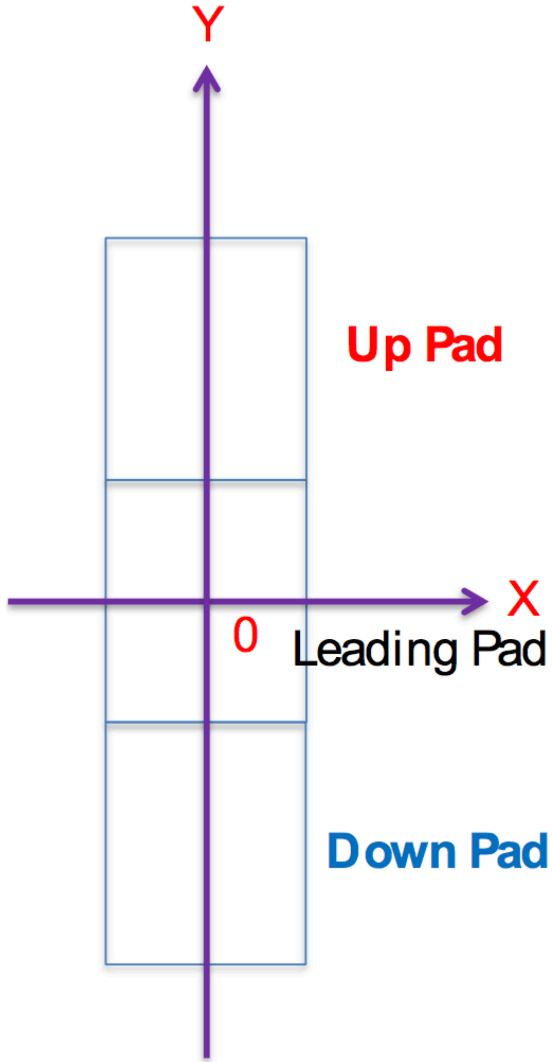


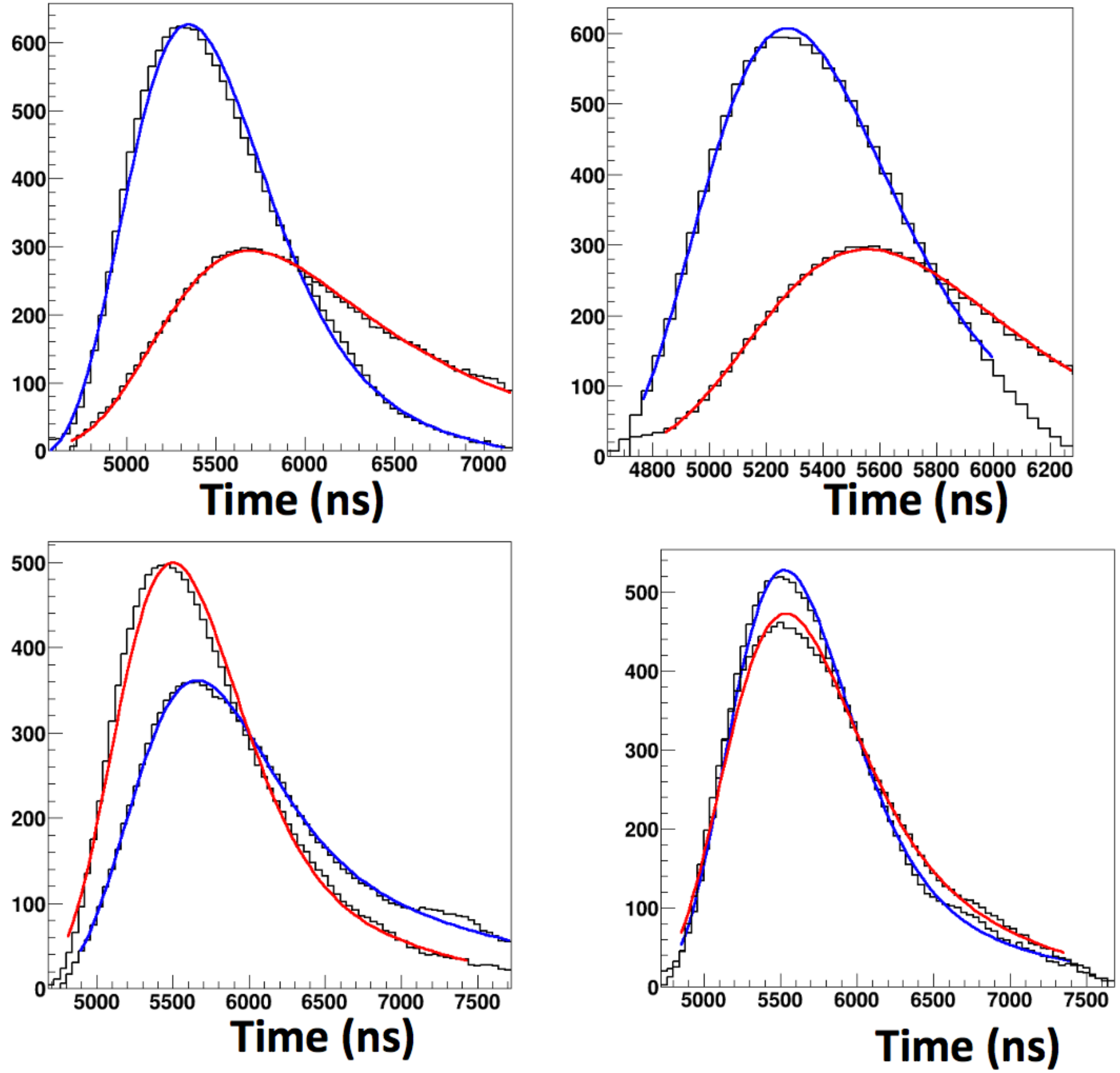


PAD SIGNAL WAVEFORM MODELIZATION

Down resistive pad ; Up resistive pad

Ref : S. Hassani / S. Emery (Saclay Irfu)



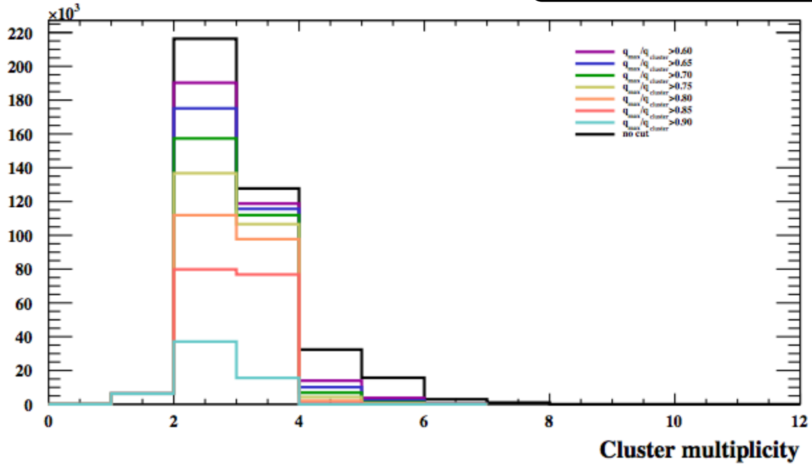


On-going work to extract RC map

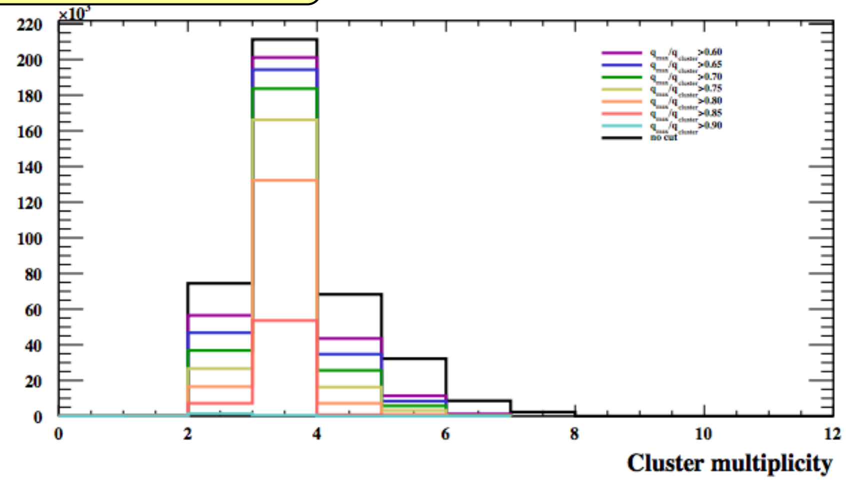
PADS MULTIPLICITY VS PEAKING TIME

Ref : S. Hassani / S. Emery (Saclay Irfu)

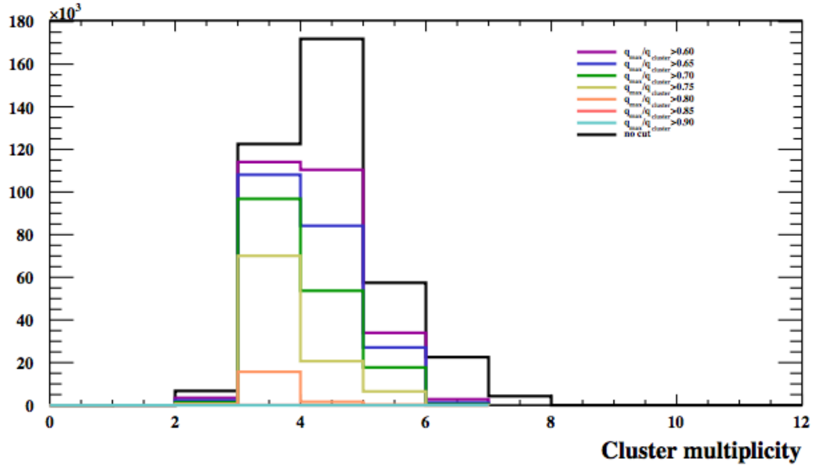
Peaking Time =116 ns



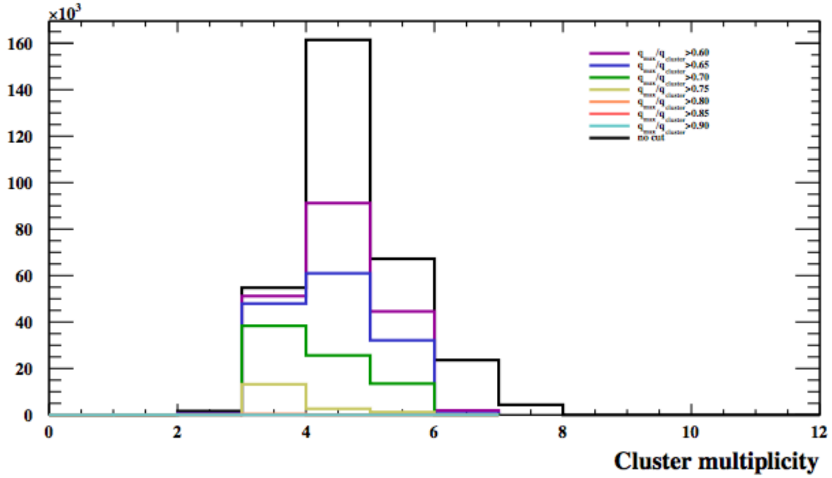
Peaking Time =200 ns



Peaking Time =400 ns



Peaking Time =612 ns

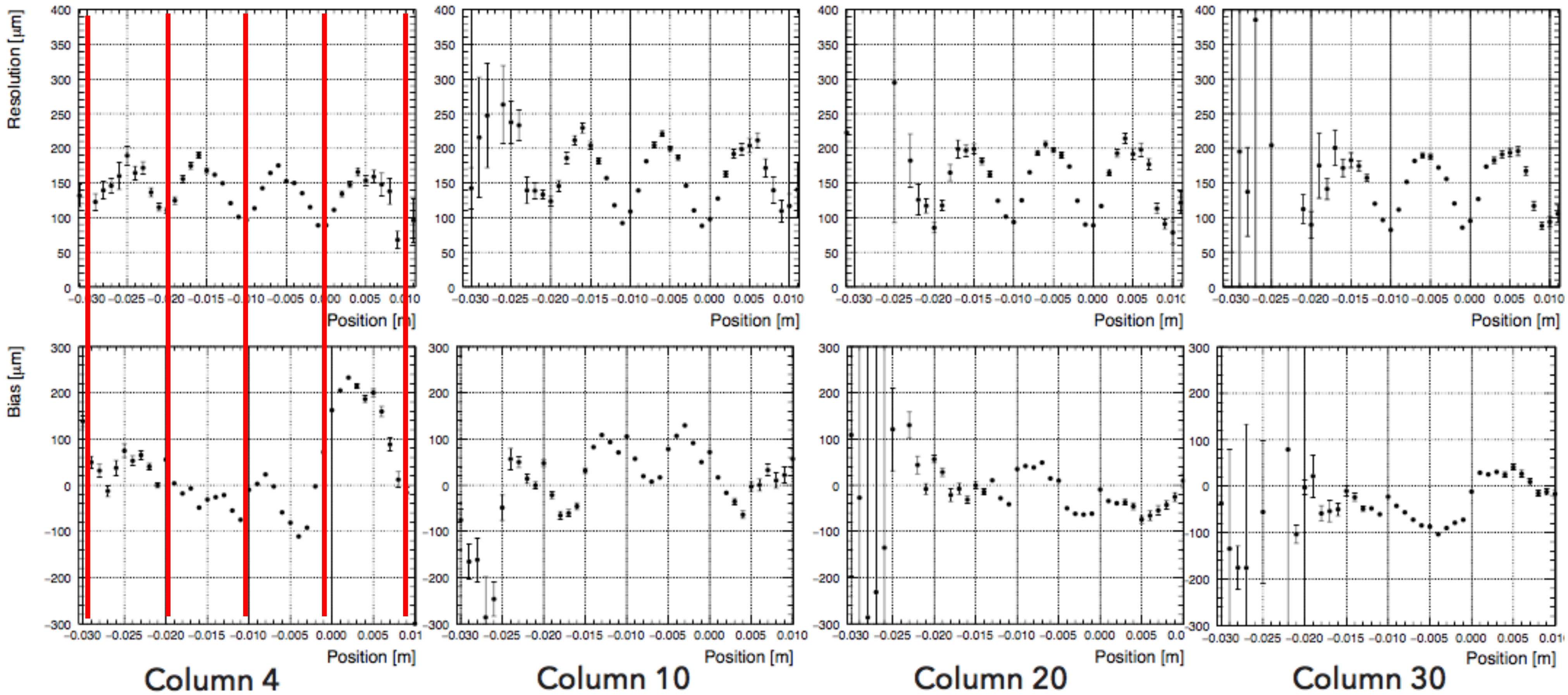


SPATIAL RESOLUTION : BIAS BETWEEN PADS (Y BEAM SCAN)

Y axis

row 14 15 16 17

Ref : S. Suvorov (Saclay Irfu)

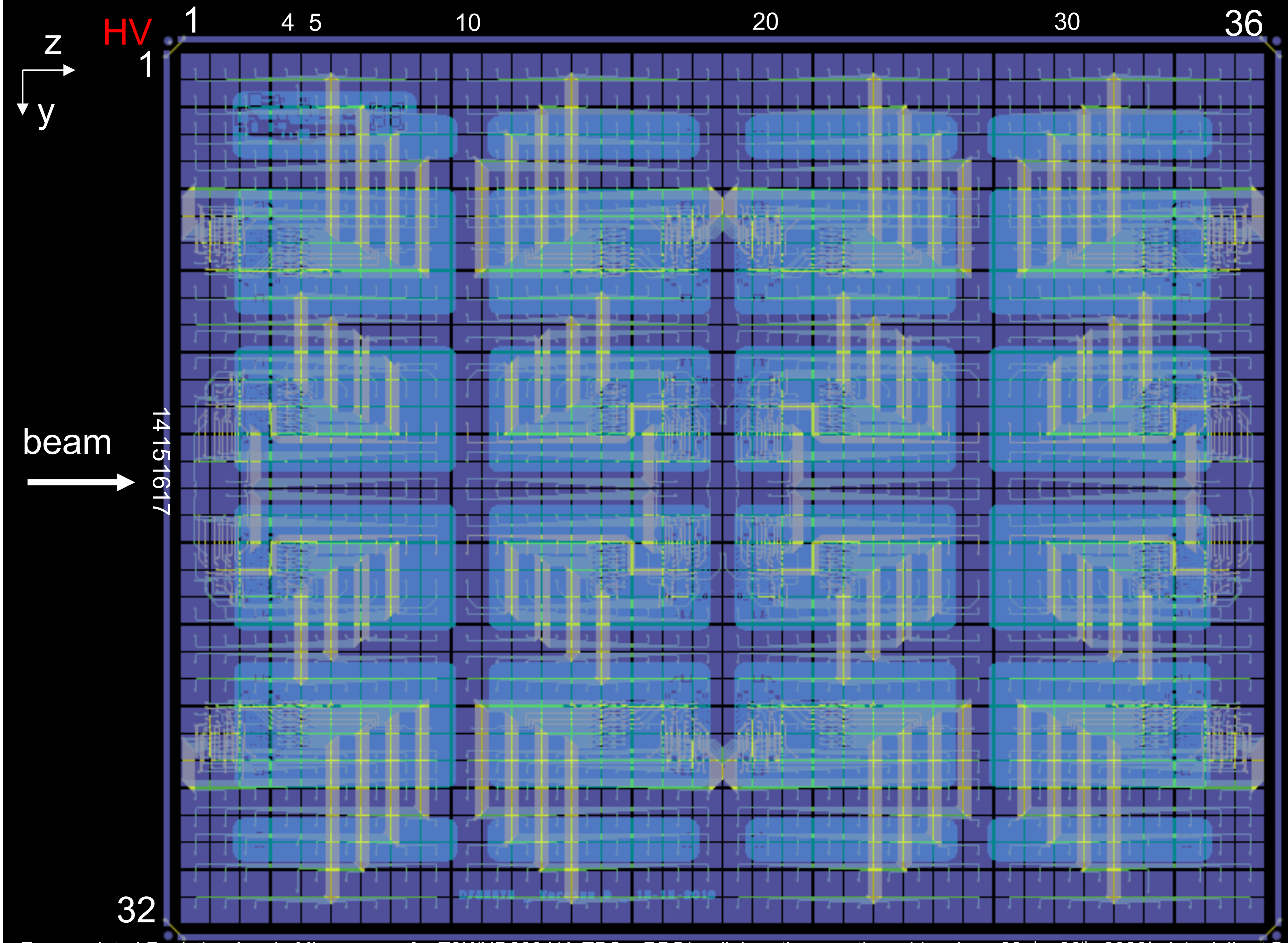


Column 5 is similar

Column = z axis

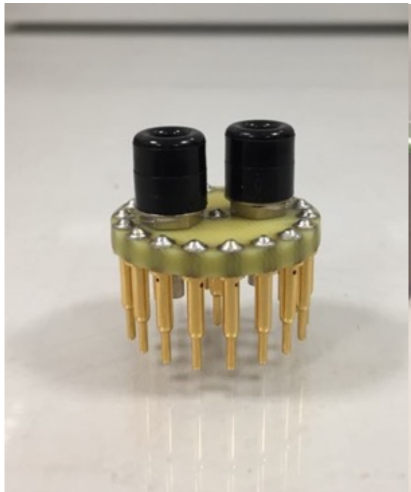
The bias is still under investigations : may be due to large capacitance steps between neibouring pads coming from the PCB layout (pad to connector layout) (measurements to be done)

ERAM PCB DFS-2278
PAD-CONNECTOR LAYOUT



NEW RESISTIVITY MEASUREMENTS @ CERN (SEPT 19)

R. DE OLVEIRA / O. PIZZIRUSSO / E. AKAR



CERN calibrated custom-made probe

- Two rulers were adjusted to take surface resistivity measurement from 10cm x 10cm squares. The bottom-left corner of the film was assigned as origin point.

- By measuring the center of the squares, the film is scanned and results are transferred to Excel for 3D graph.

This new probe will be used for ERAM production

Ref: Elcin Akar (CERN/EP-DT-EF)

Foil #4/7 used for ERAM #01

0 Seen from pad side 100 mm

4th Film	5	15	25	35	45	55	65	75	85	95
5	612	660	741	525	400	394	368	341	297	283
15	613	690	769	536	414	392	372	344	305	277
25	629	665	759	511	446	391	344	348	296	279
35	603	634	723	510	404	390	357	321	297	275
45	589	638	752	516	417	389	357	331	295	280
55	567	610	750	501	417	394	379	360	285	283

HV

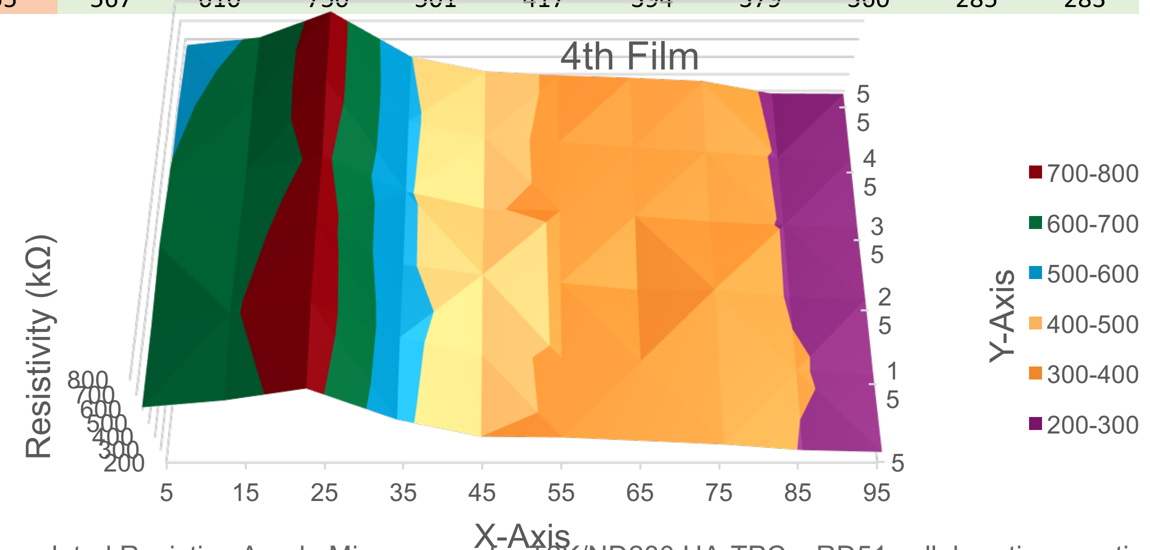
4 1 3 2

60 mm

Y (10.09 mm pad)

Z (11.18 mm pad)

34 x 42 cm^2 ERAM
in
44 x 52 cm^2 raw PCB



- Non-uniformity along Y due to sputtering process
- Very good uniformity in z (along neutrino beam)

Comparison of resistivity measurement for ERAM#01 DLC foil #4

CERN Custom made probe

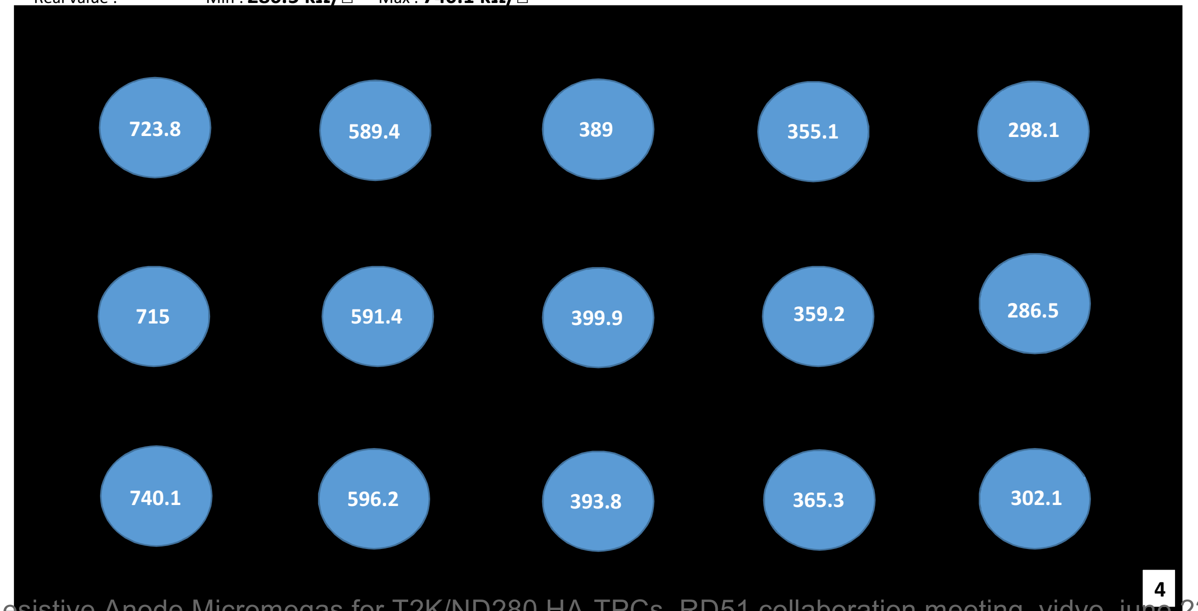
4th Film	5	15	25	35	45	55	65	75	85	95
5	612	660	741	525	400	394	368	341	297	283
15	613	690	769	536	414	392	372	344	305	277
25	629	665	759	511	446	391	344	348	296	279
35	603	634	723	510	404	390	357	321	297	275
45	589	638	752	516	417	389	357	331	295	280
55	567	610	750	501	417	394	379	360	285	283

Theoretical value **500 kΩ/□**

CERN « Ochi » probe (2018)

Foil size : 100x61cm

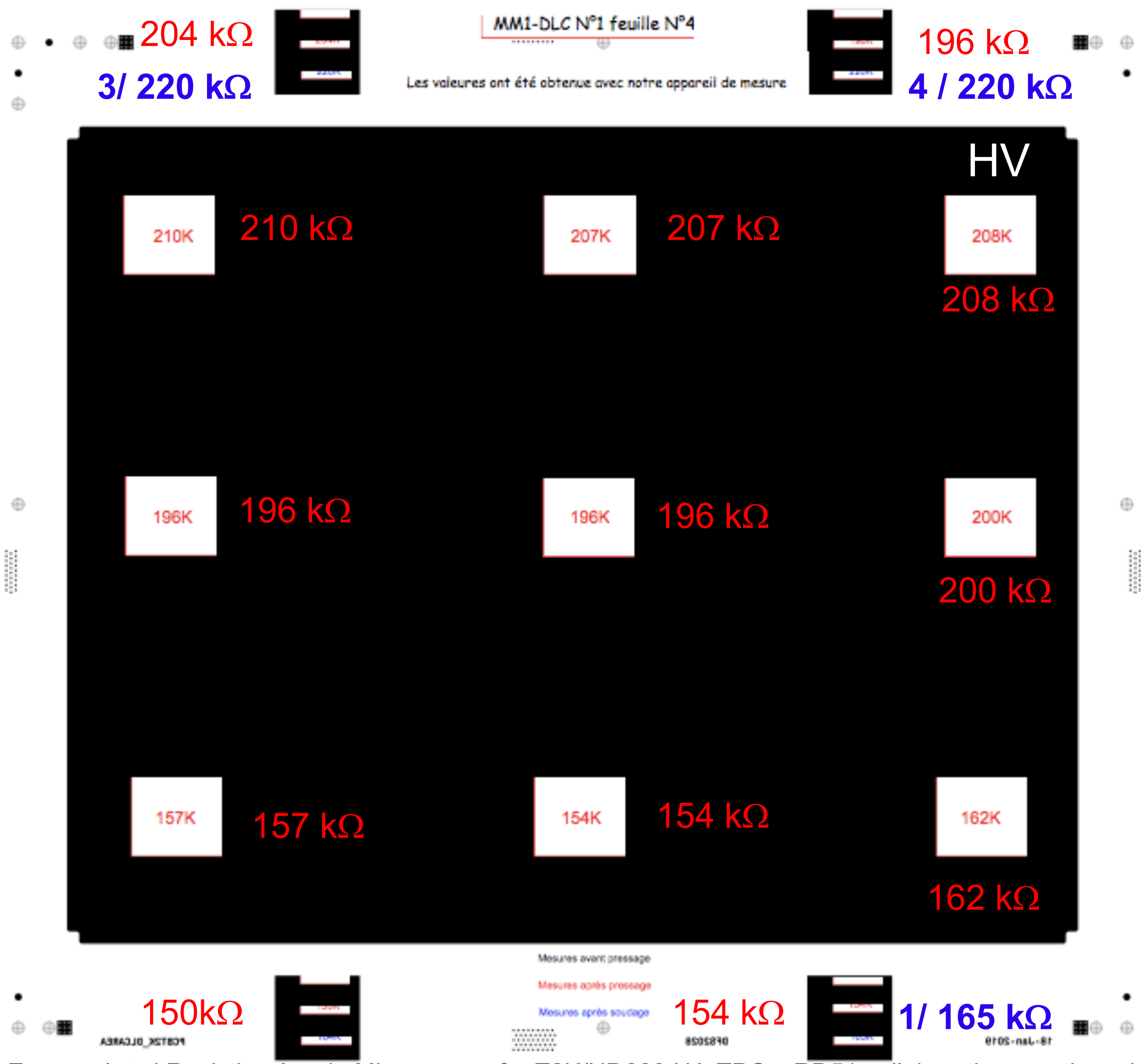
Real value : Min : **286.5 kΩ/□** Max : **740.1 kΩ/□**



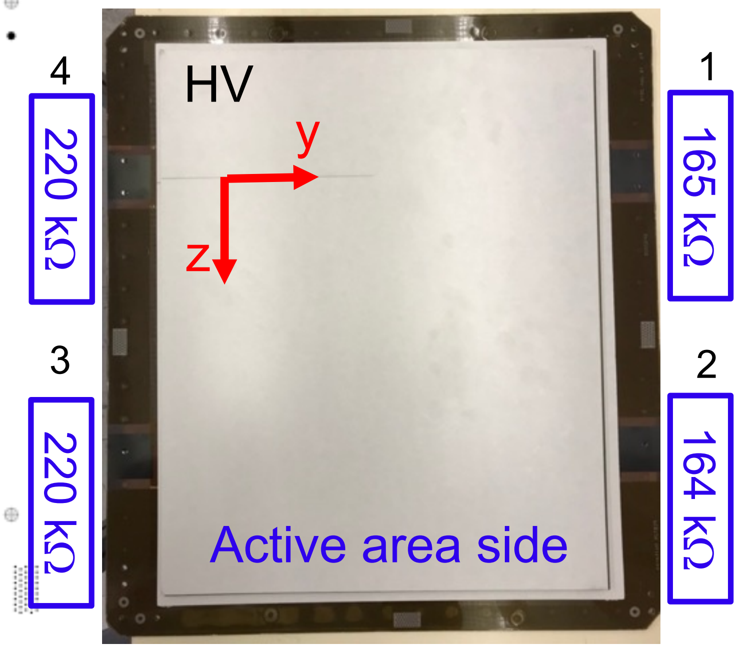
7-15 % difference
better reproductibility with CERN probe
~2-3 %

ERAM#1 : RESISTIVITY MEASUREMENT WITH CERN CUSTOM MADE PROBE

ERAM#1 (S/N 002) resistivity – active area side



ERAM#1 (S/N 002)

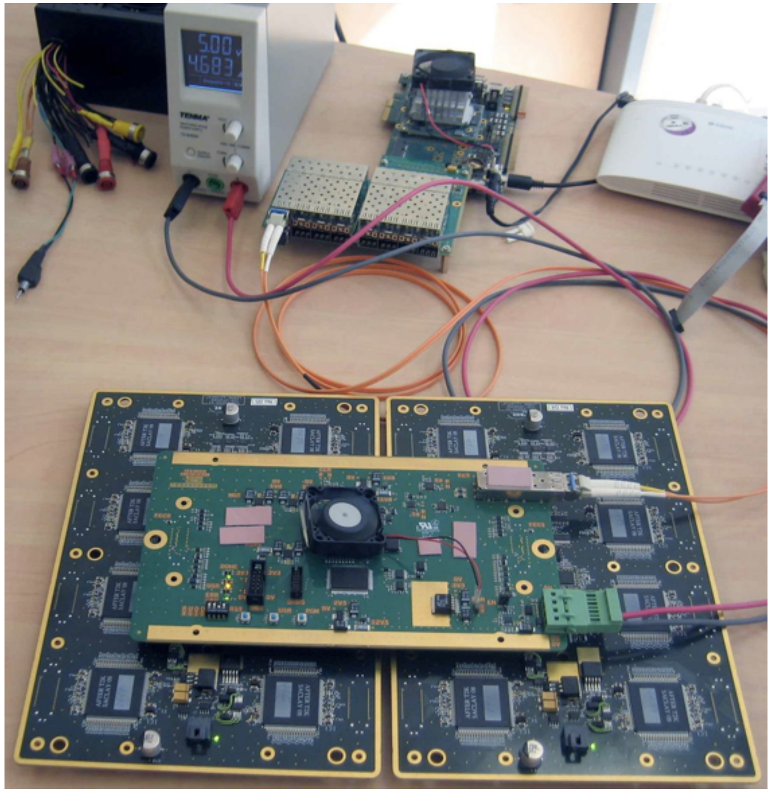


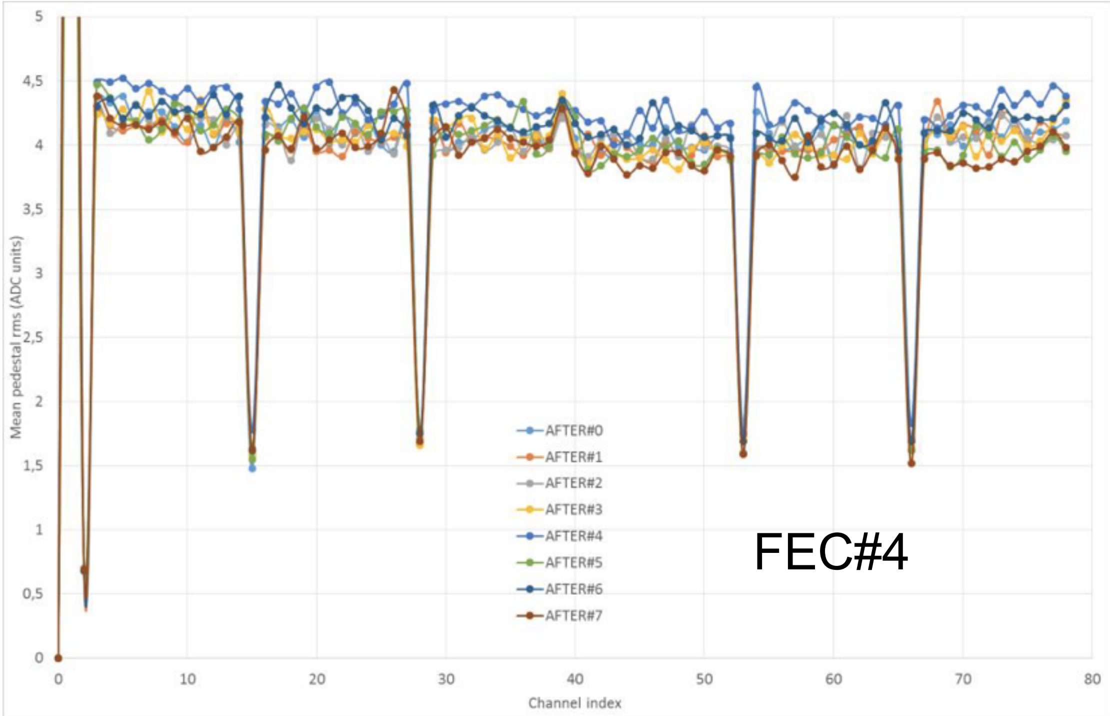
Same ~60% drop as for MM1

Reminder for MM1-DLC1 & 2

1: 197 kOhm
2: 197 kOhm
3: 265 kOhm
4: 265 kOhm

AFTER BASED NEW ELECTRONICS FIRST COMPLETE READOUT TESTS





120 fCrange; 116 ns peaking time; 25 MHz Fwrite

- 800 to 1200 e-rms of pedestal noise seen in average for the 72 channels of each chip
Still some debug needed (card shielding, power of FEC through the FEM unstabilities, ..)

But thes first card prototypes are a very robust design which validates the technical choices

including its coupling to the dectector …..

Ref : D. Calvet (Saclay Irfu)
J-M Parraud (LpnHe)

COSMIC TEST BENCH
FIRST OPERATION SINCE JUNE 9TH

Noise issues

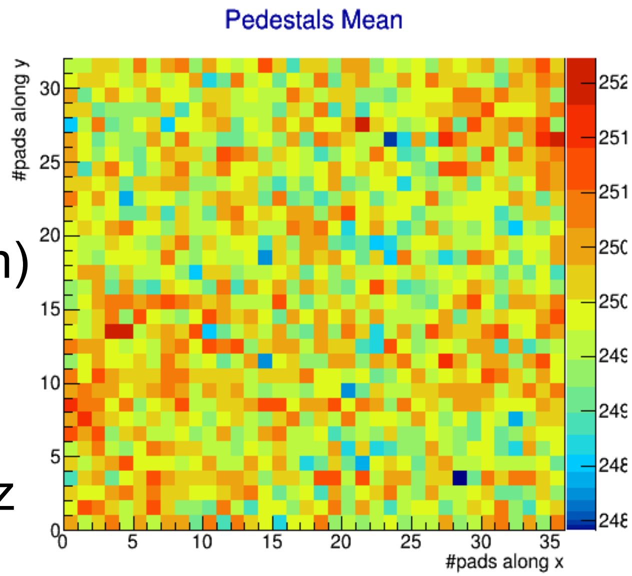
- Identification of floating ground (FEM/FEC): rms~17-20 ADC after correction (> 100 ADC before)
- Using an external RCR HV filter, noise was lowered to the ususal 7-8 ADC rms
- → GND or shielding problem with on-board HV filter

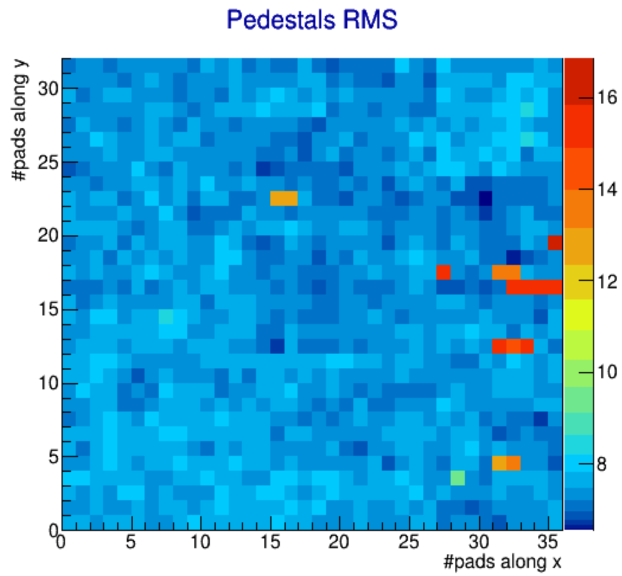
ERAM active area (mesh@ GND)

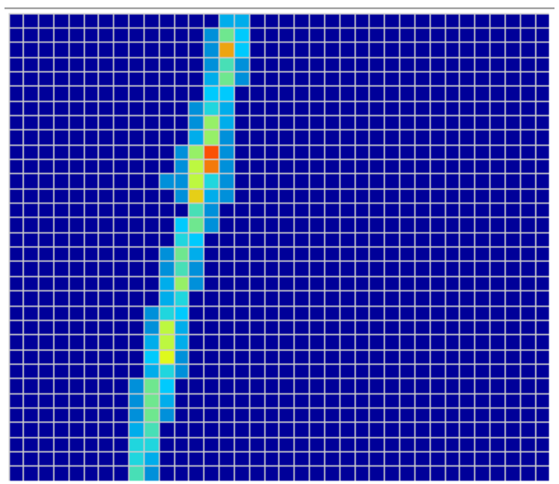
Experimental setup

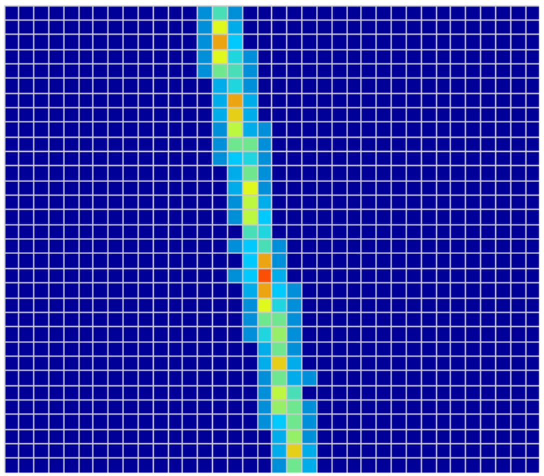
Experimental setup

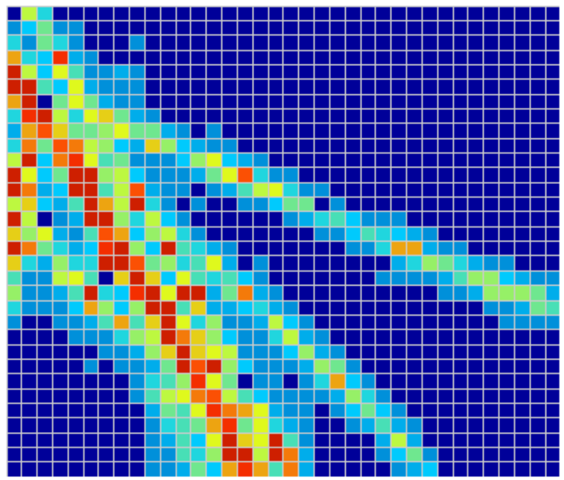
- Zero-suppressed data
- Ddrift = 15 cm
- $V_{cathode}$ = - 4207 V (280 V/cm)
- V_{DLC} = 380 V
- Peaking time: 220 ns
- Sampling frequency: 25 MHz
- Trigger rate ~0.6 Hz







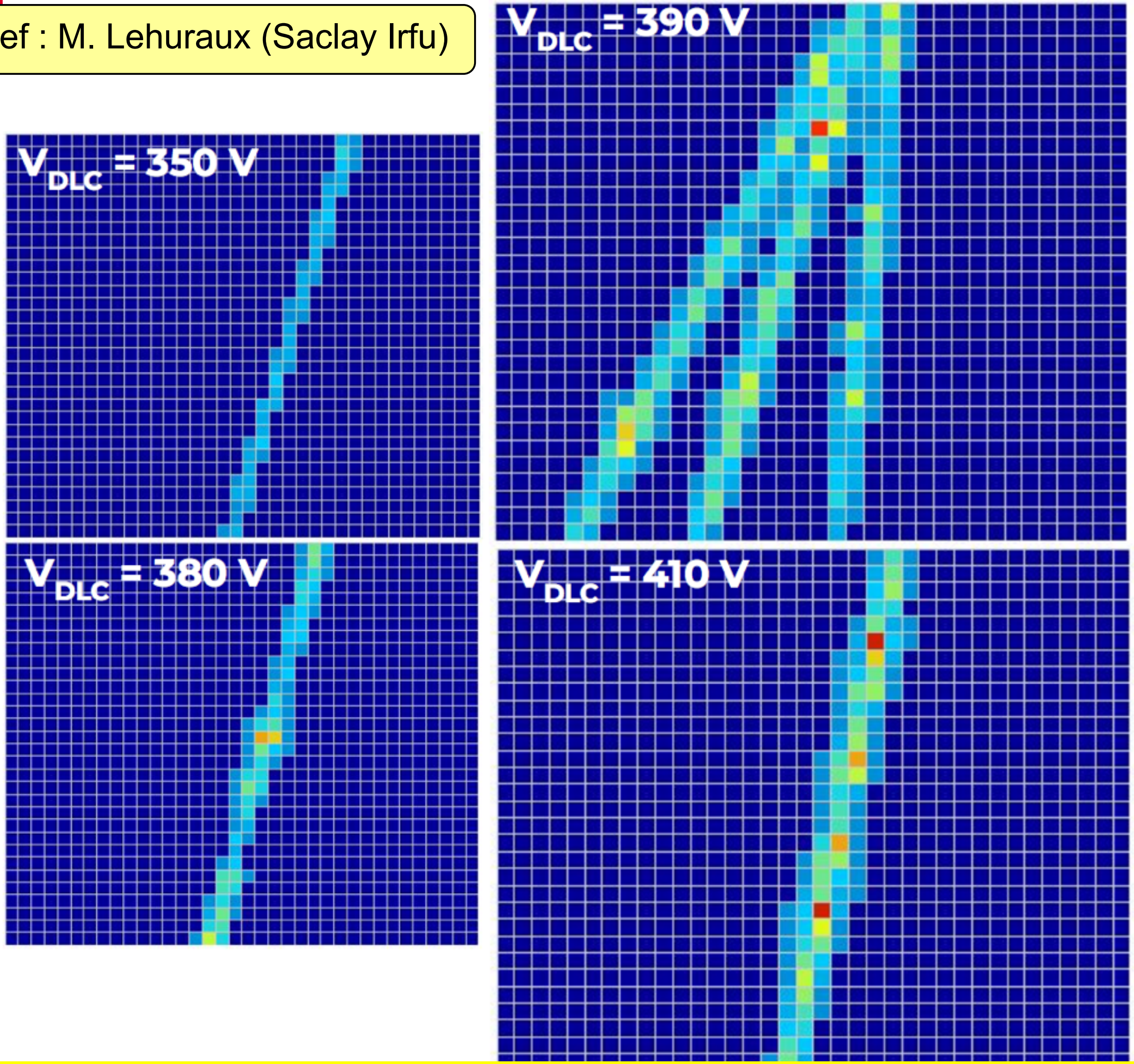




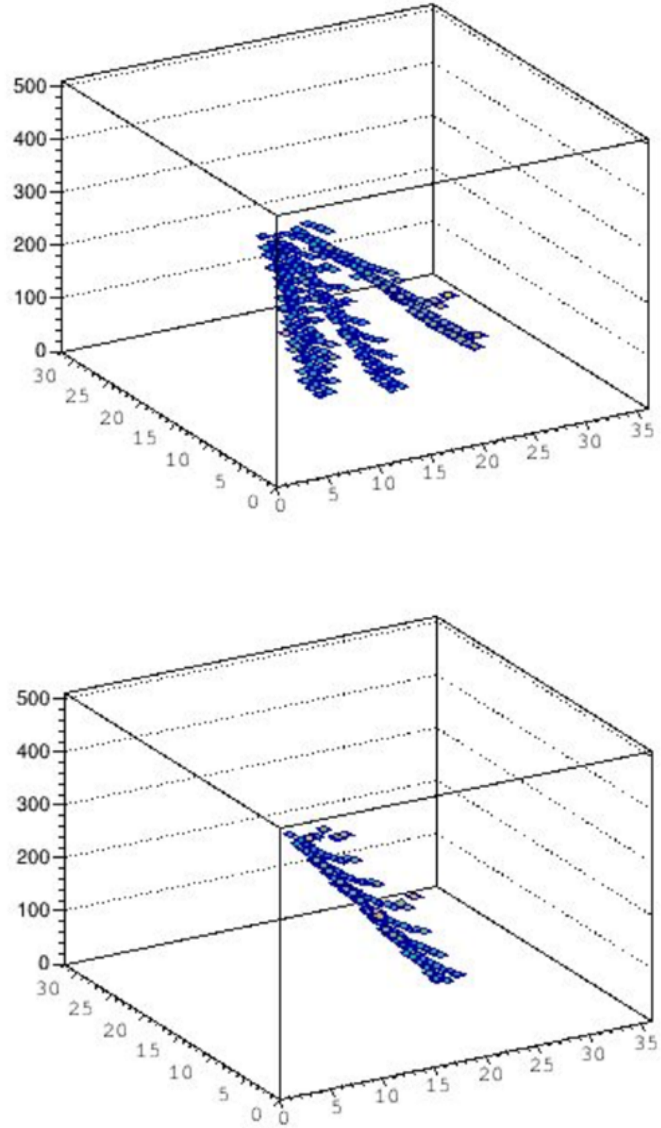
Ref : D. Attié / M. Lehuraux (Saclay Irfu)

FIRST COSMIC TRACKS WITH ERAM CHARGE SPREADING VS DLC VOLTAGE (GAIN)

Ref : M. Lehuraux (Saclay Irfu)



Peaking time = 200 ns



Larger charge spreading to be confirmed, but less effective charge collection (thicker glue)

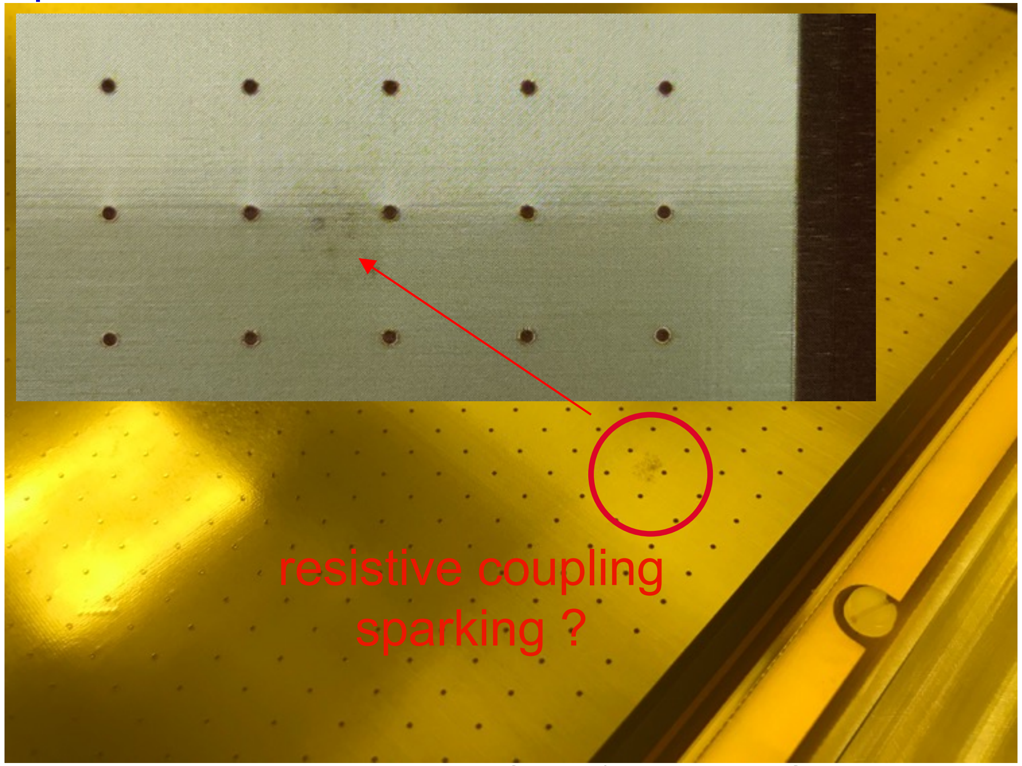
RESISTIVE DETECTOR & DUST … WITH ERAM#1

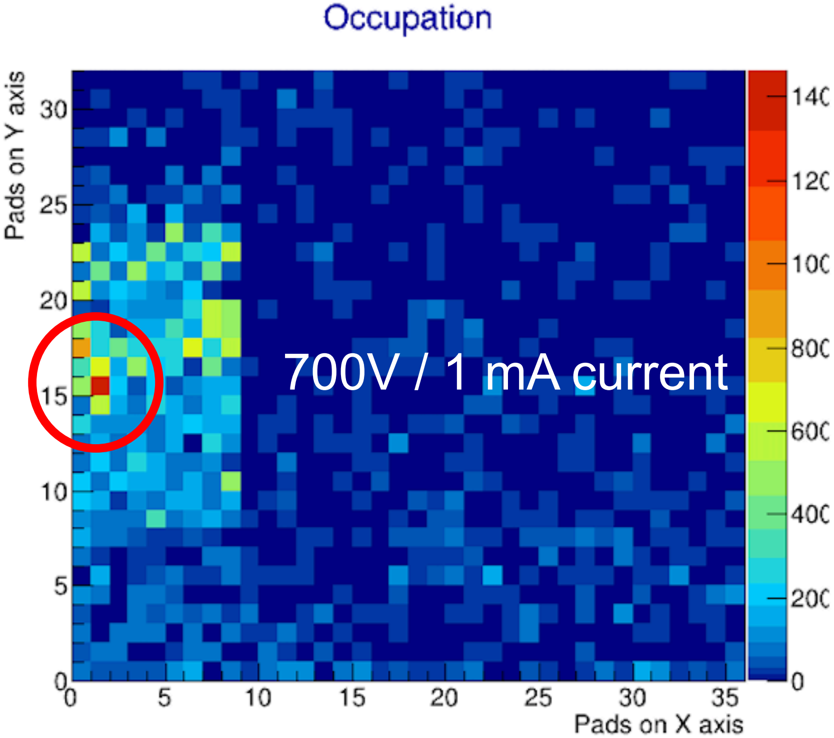
After 2 days of operation current fluctuations occurred followed by a permanent ~400 kOhm DLC-mesh short

- A “Dark” zone was identified.
- Solved with washing using soap, rincing with deionized pressurized water & drying @ 50 °C during 5h

→ But reappeared after 3 more days …

→ Probably due to dust released when the melamine protection was removed in clean room





CONCLUSION & PERSPECTIVES

- The resistive anode Micromegas technology will be used for the new HA-TPCs of the T2K Near Detector upgrade.

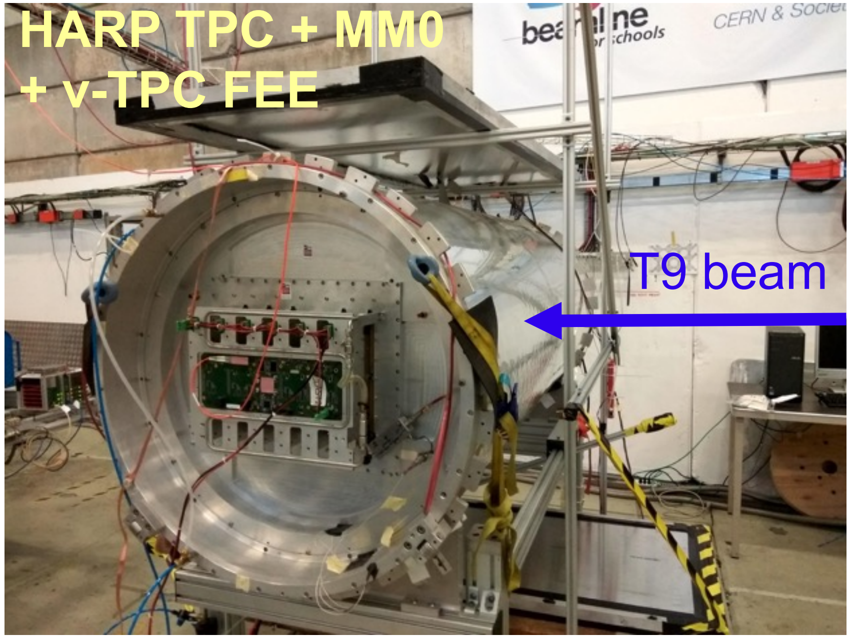
- The ERAM design is close to be ready for production. Data analysis of test beams of prototypes and modelization of the signal waveforms are on-going to fix the DLC foil resistivity and the RC of the structure. The sensitivity of the detector performances on the RC non-uniformities also needs to be characterized.

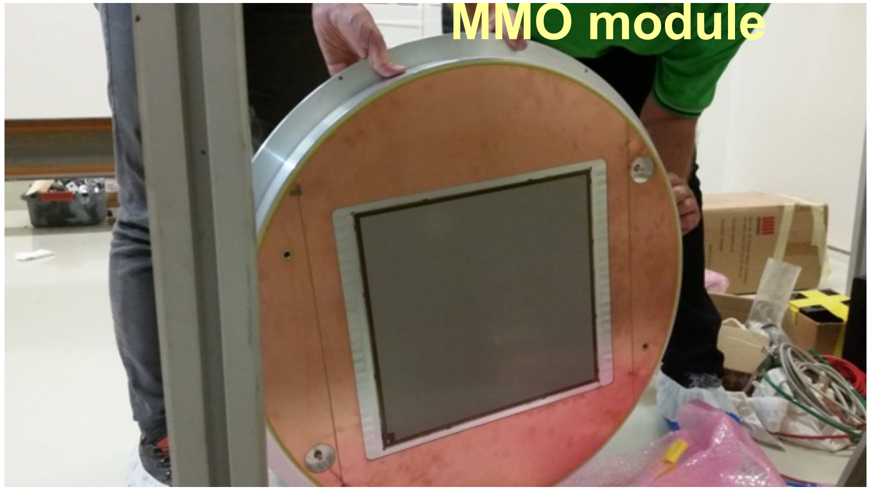
- DLC resistivity seems under control for the ERAM production stage at CERN (DLC foil pressing & wave soldering) but the required tolerances on the DLC foils resistivity needs to be discussed & fixed with the manufacturer.

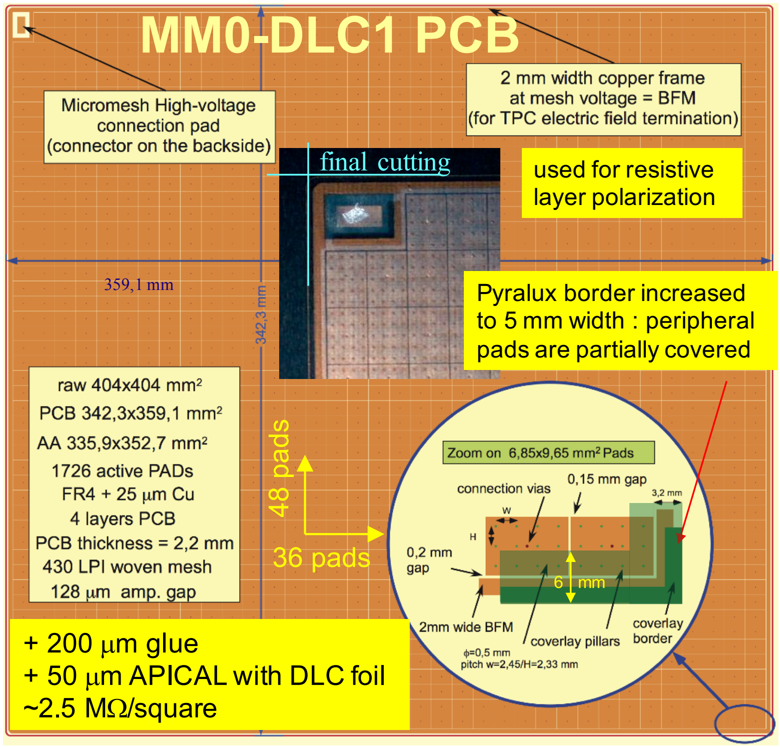
- HA-TPCs are planned to be installed in ND280 in summer 2022. We are on the path to start the production of 32 ERAM modules at CERN and the corresponding FEE cards for 40k ch. at the end of this year after a test beam at DESY.

BACKUP

2018 MM0 PRE-PROTOTYPE TEST BEAM @ CERN/PS-T9 SETUP







RESISTIVE MICROMEGAS MODULE MM0
TEST BEAM @ CERN/PS-T9 (AUGUST-SEPT 2018)

Gas volume : HARP TPC

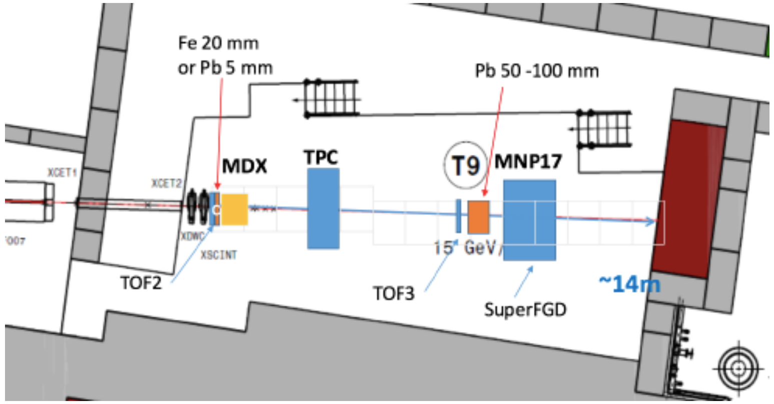
- 1.5 m drift distance / 25 kV (166 kV/cm)
- 25 l/h Argon(95%)/CF4(3%)/isobutane(2%)

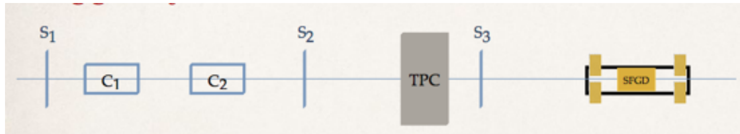
Detector : MM0 module

- Micromegas module MM0 with $2.5\ M\Omega/\blacksquare$ 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)
- nominal peaking time 600 ns

Data taking

- Cosmic trigger with 2 plastic scintillators +MPPC
- Fe55 source for 5.9 kEv X-rays
- Beam : $0.5, \pm 0.8, 1, 2$ GeV/c momentum

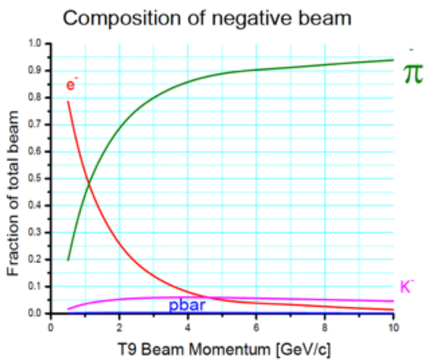


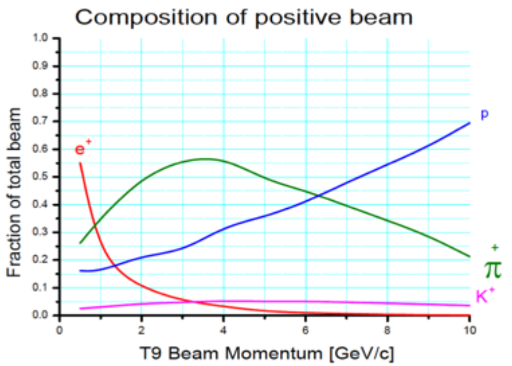


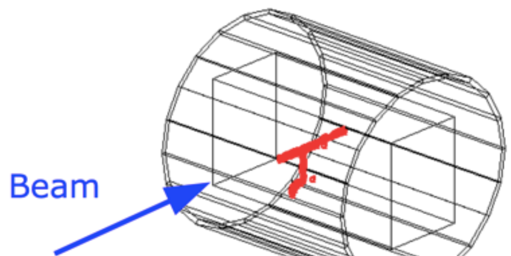
π, e, p trigger

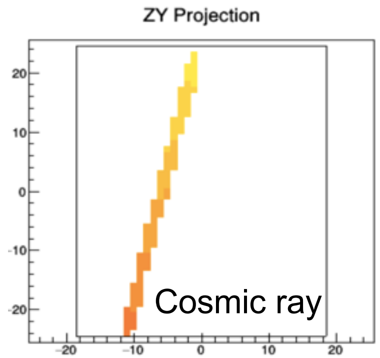
Particle	Selection
Electrons	Scintillators + Cherenkov
Protons (+Kaons)	S1(delayed) * S2 (delay proton TOF between S1 and S2)
Pions (+ muons)	Scintillators * protons * electrons
Cosmic ray	from the scintillators panels (only out of spill)

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



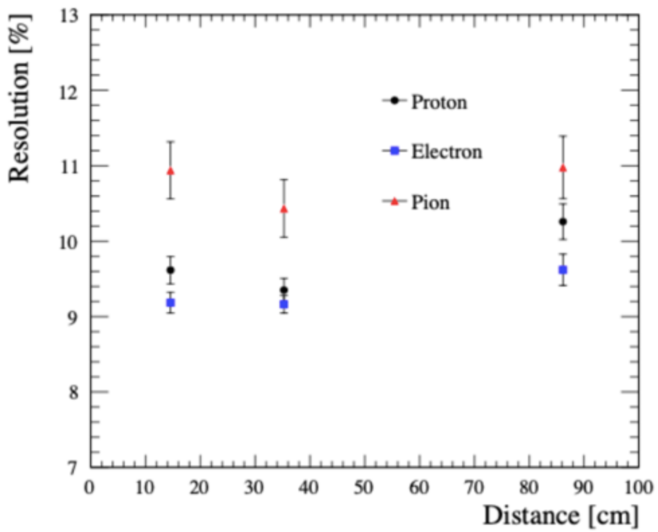




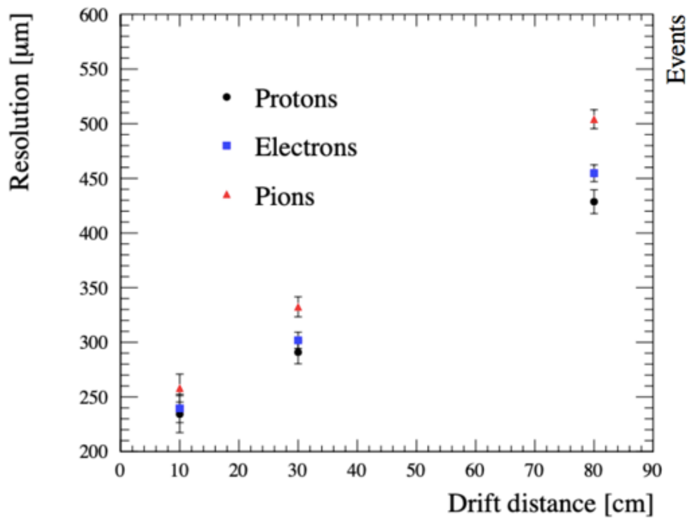


RESISTIVE MICROMEGAS MODULE MM0
TEST BEAM @ CERN/PS-T9 SETUP : RESULTS

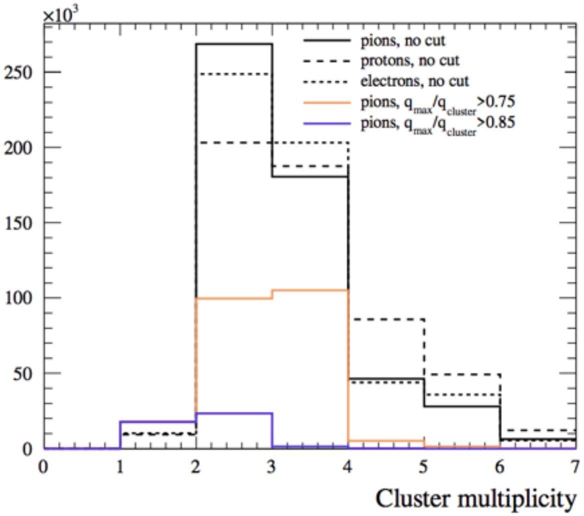
D. Attié et al., Nucl Instrum Meth A 957 (july 2019) DOI: 10.1016/j.nima.2019.163286



7% for 2 modules track length
<10% requirement



~ 2 times better ~320 μm
@ 30 cm than non-resistive
v-TPC modules (~600 μm)

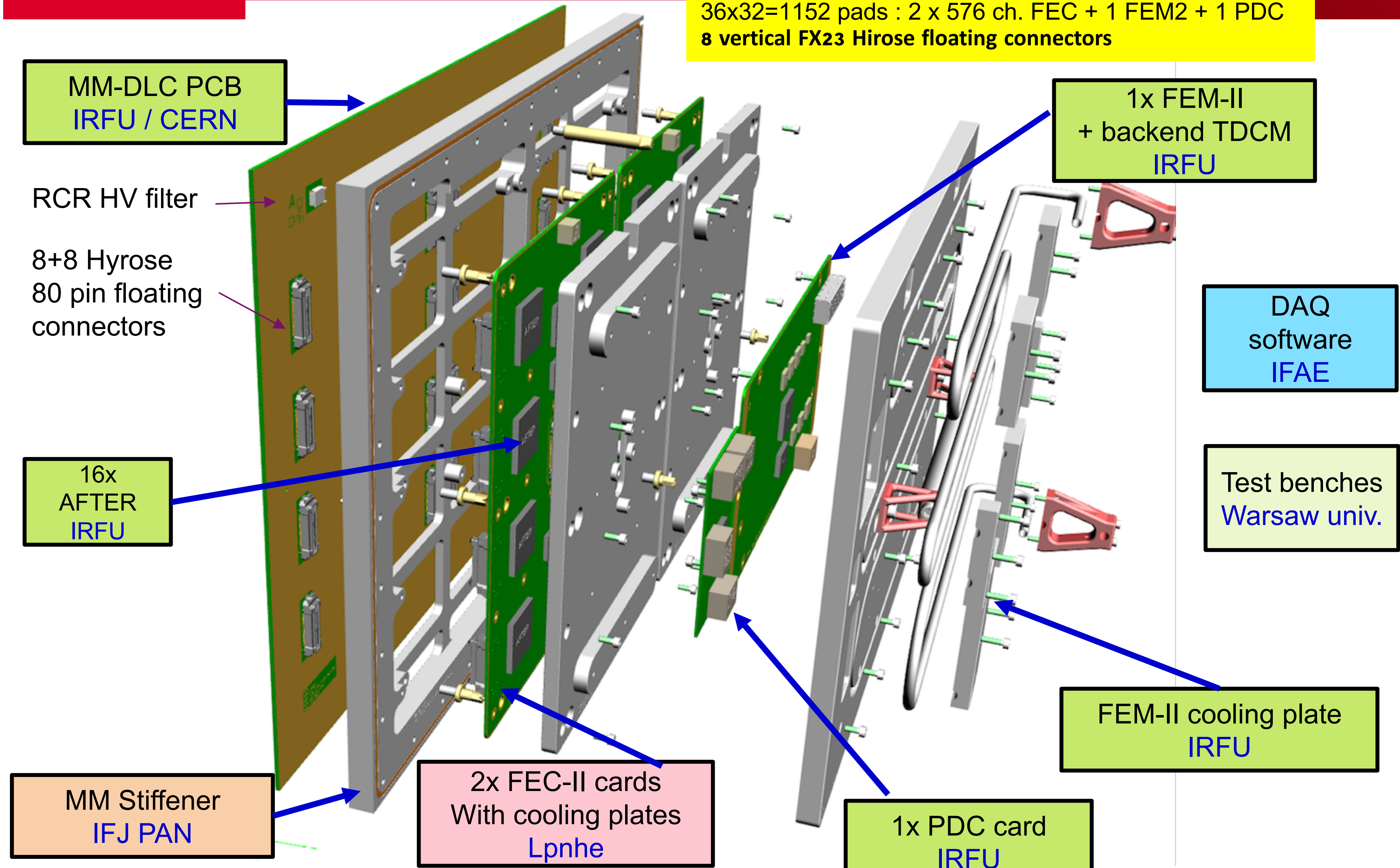


Multiplicity of 2-3
(for 600 ns shaping time)

→ Next step : lower the number of electronics channels with full size ERAM module
→ Increase charge spreading for final ERAM segmentation (~10x11 mm² pads)

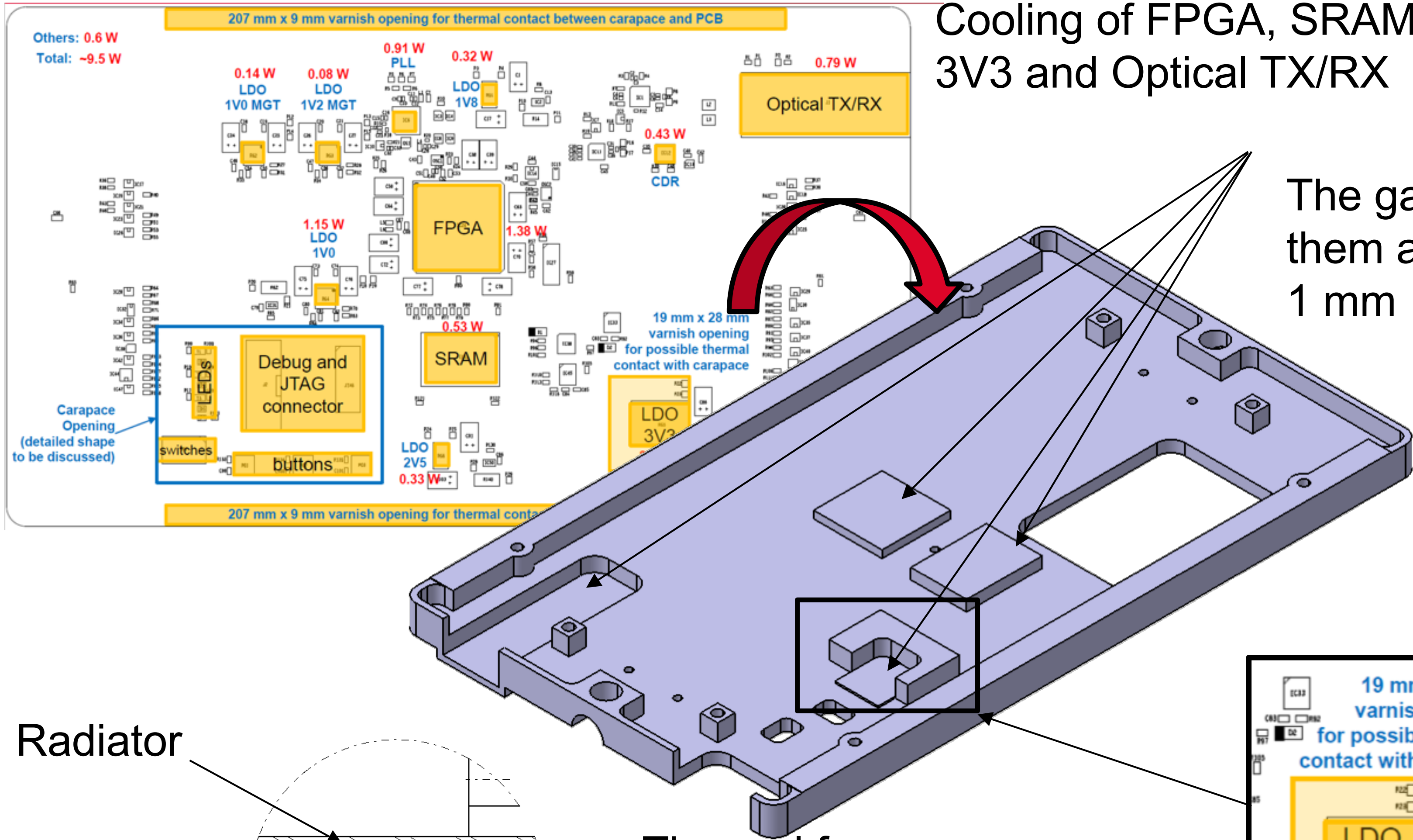
The ERAM module

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

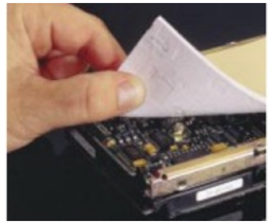


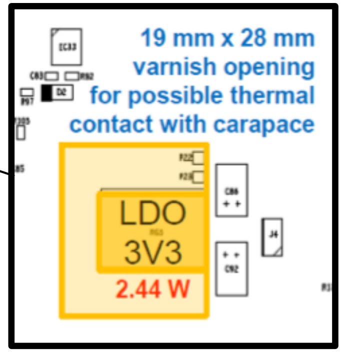
AFTER BASED NEW ELECTRONICS
FIRST TESTS 2XFEC + FEM (1152 CHANNELS)

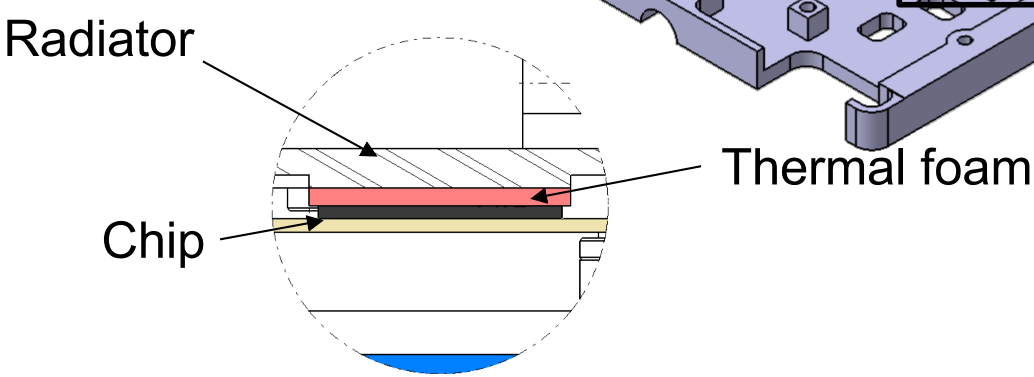
Cooling of FPGA, SRAM, LDO 3V3 and Optical TX/RX



The gap between them and the chips is 1 mm





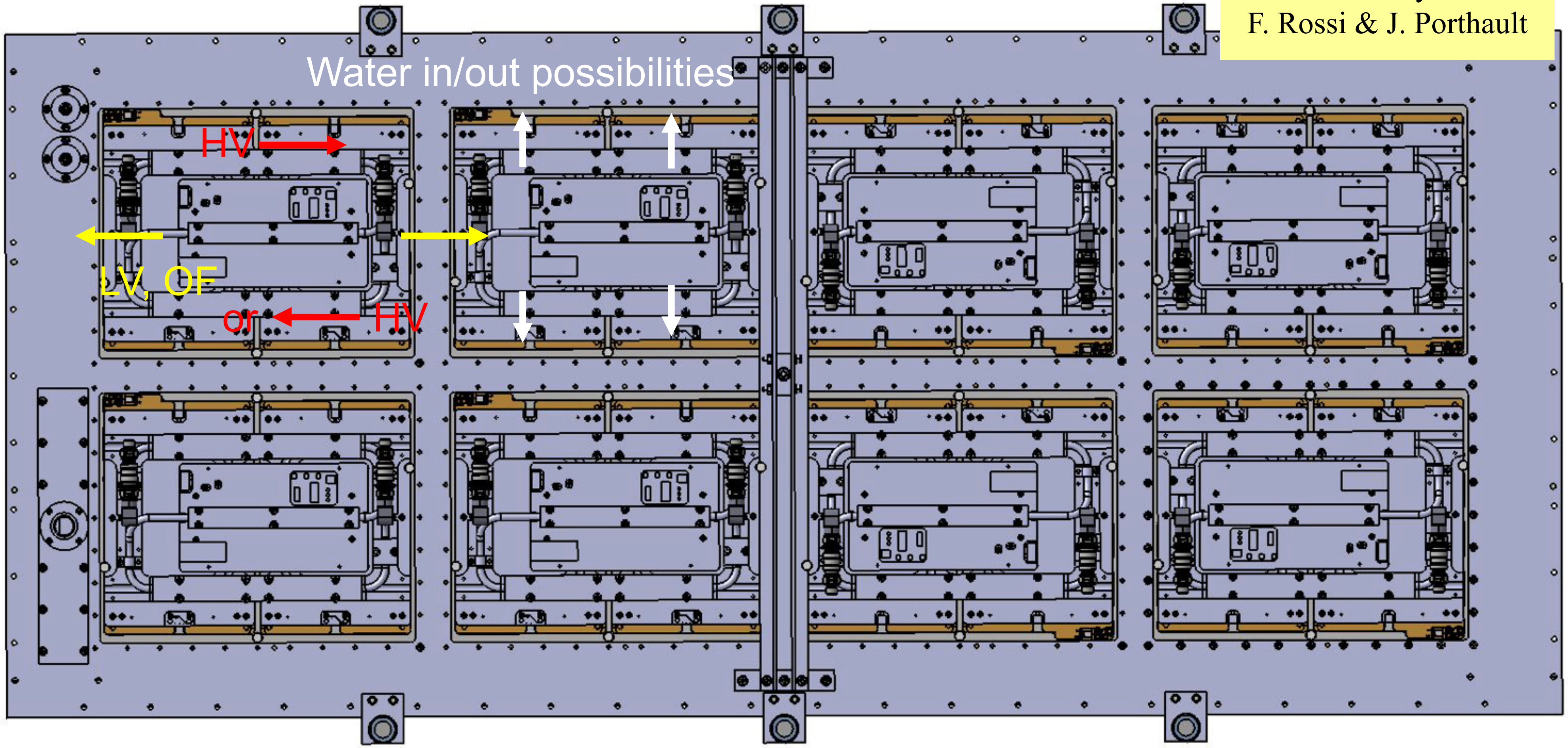


Ref: J. Porthaul/F. Rossi (Irfu)

MODULE FRAME SERVICES CABLING

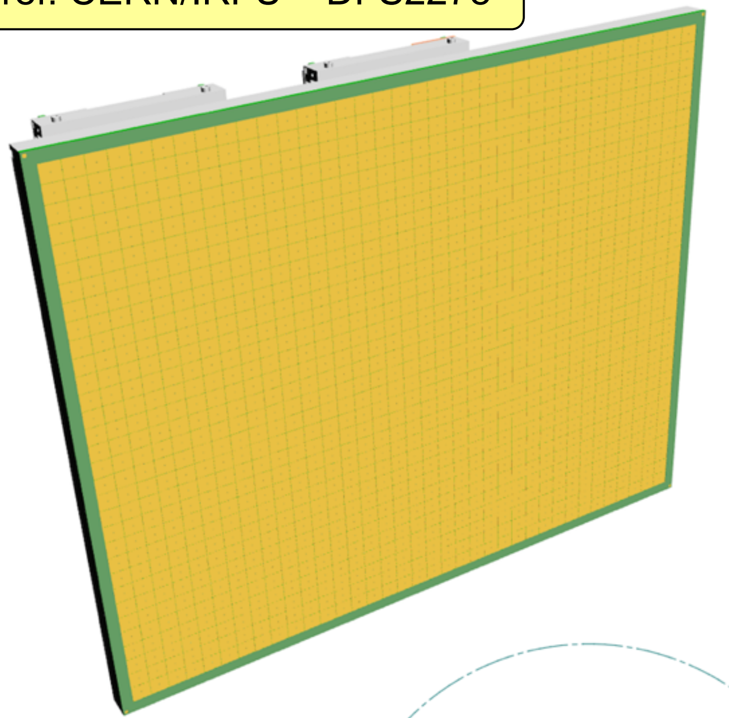
- MF dimensions : 820 mm x 1865 mm
- cooling pipes connectors, cooling pipes path, HV and LW cables paths to be defined & fixed
- Cooling pipes paths to be fixed in order to fix connectors orientation on ERAM
- Symmetries : ERAM can be flipped 180° on MF

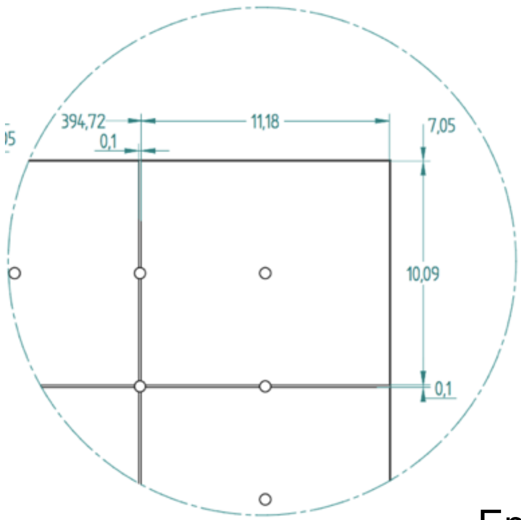
Ref: H. Przybilski
F. Rossi & J. Porthault



ERAM PCB FINAL 6 LAYERS STACK

ref: CERN/IRFU – DFS2278



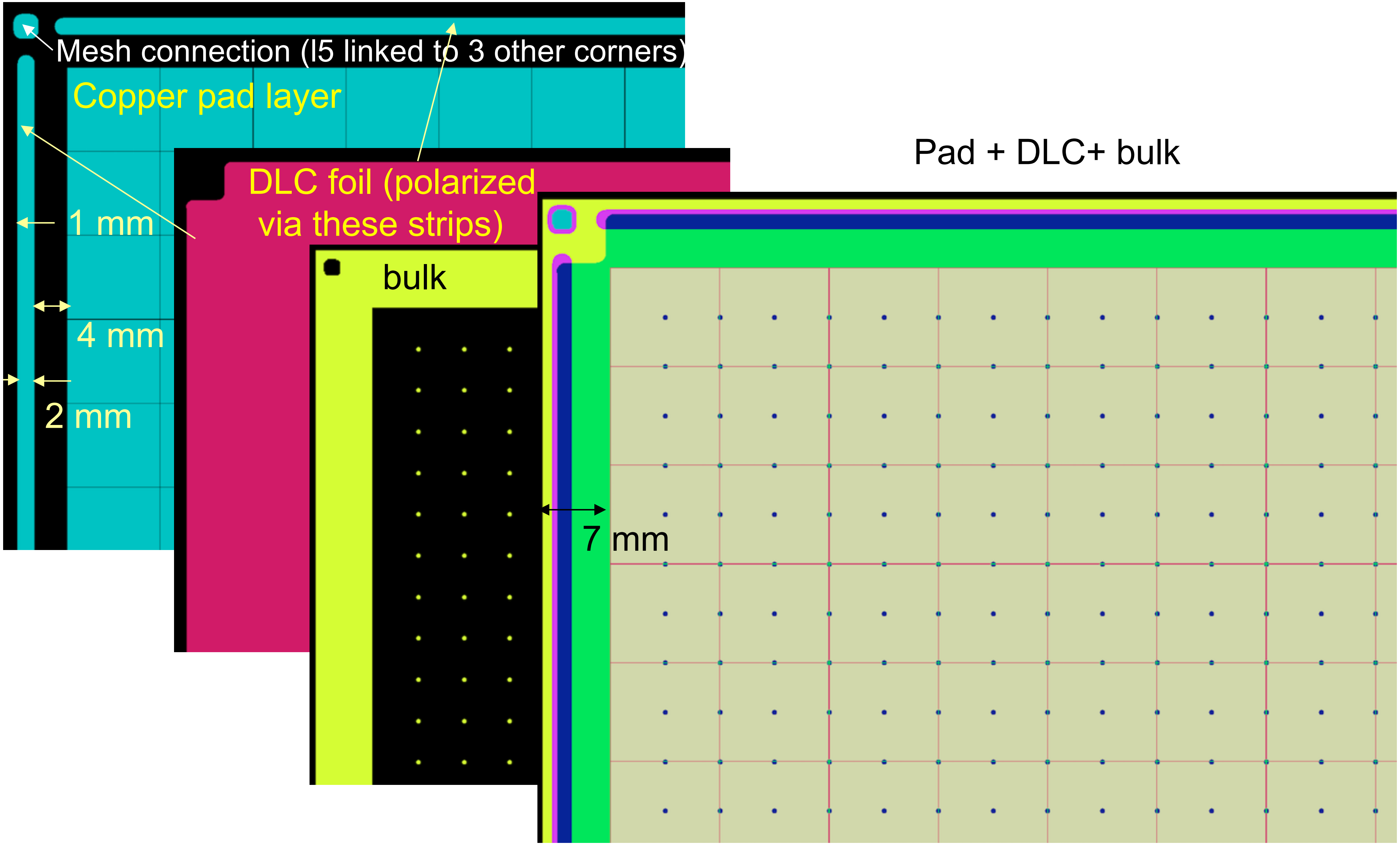


6 Couches

	CLASSE	5		Ep. TOTALE	2.4
EMPILAGE		TOP-BOT => 2.2mm +0.2/-0			
Nom					
etm	Solder mask	SPRAY 30 µm			
	Finition	NiAu		Ep. Ni	0.005
ltop	Feuillard Cu	9	35		
	Type de colle	prepreg	3x125	Ep.	0.375
L2	Feuillard Cu	9	35		
	Type de colle	prepreg	3x125	Ep.	0.375
L3	Cuivre de base	35			
	Matière	EPOXY		Ep.	1
L4	Cuivre de base	35			
	Type de colle	prepreg	3x125	Ep.	0.375
L5	feuillard cu	9	35		
	Type de colle	prepreg	3x125	Ep.	0.375
lbot	feuillard cu	9	35		
	Type de colle	prepreg	125 ss fibre	Ep.	0
	Type de colle	prepreg	1x75	Ep.	0.075
	Matière	APICAL NP		Epaisseur	0.05
DLC	DLC	500-600 K ohm + ligne AG			
BULK	Coverlay	BULK gap 128µ mesh 45/18			
DÉBIT MATIÈRE	P6:508x457		TAILLE FINALE	420 x 340	

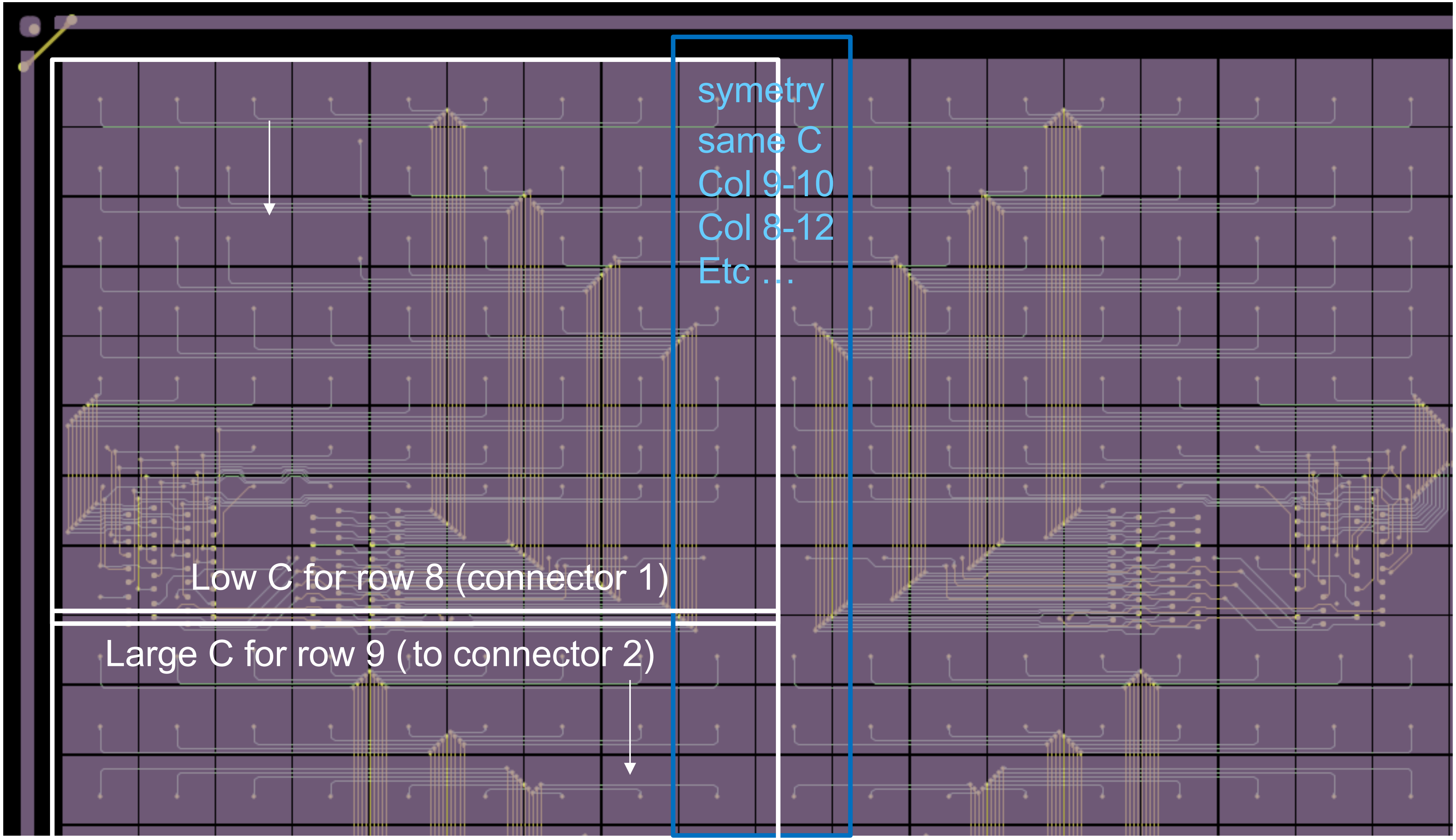
Epoxy (~0,02 mm) is used to fill the gap between copper pads

ERAM PCB FINAL DESIGN
BOTTOM (ACTIVE AREA) : UNCHANGED / MM1



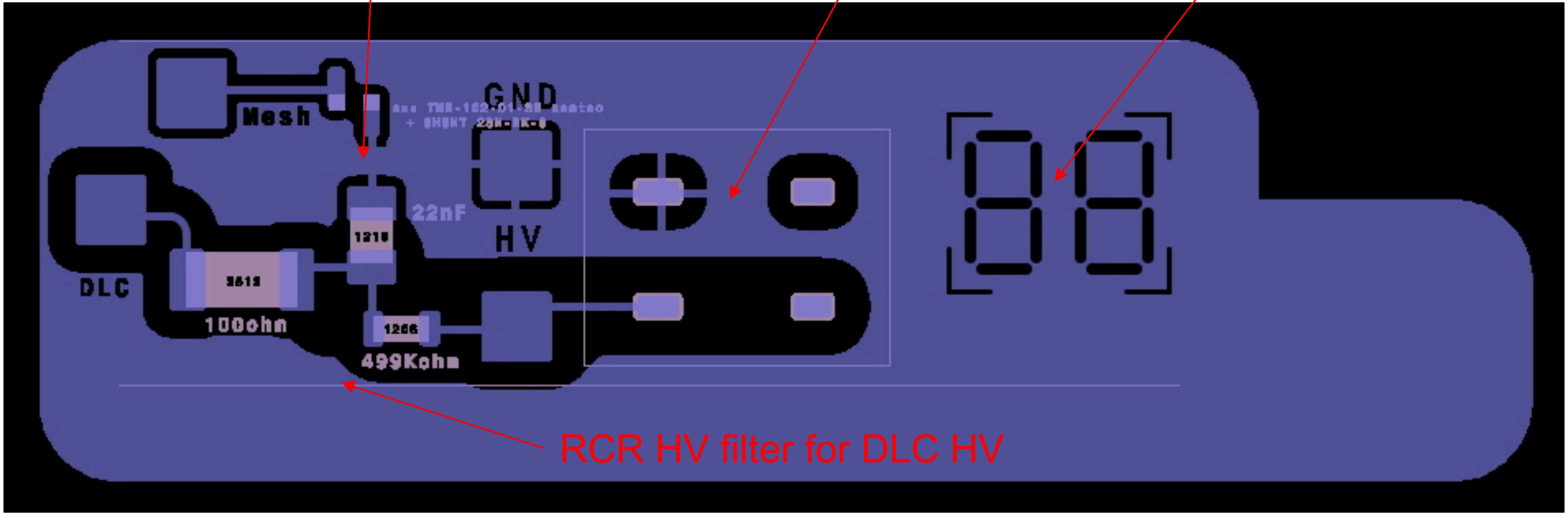
EXAMPLE OF CAPACITANCE STEPS DUE TO THE PAD-CONNECTOR LAYOUT

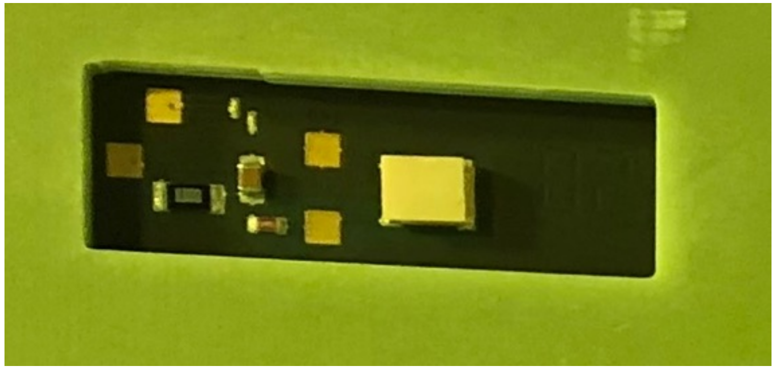
Largest C steps between two connectors with no layout symetry



ERAM PCB : TOP (CONNECTOR SIDE)
NEW DLC HV FILTER & OPTIONAL MESH CONNECTION

ref: CERN/IRFU – DFS2278
Top layer, upper left corner





ERAM#01 RCR cabled filter
(january 18, 2020)

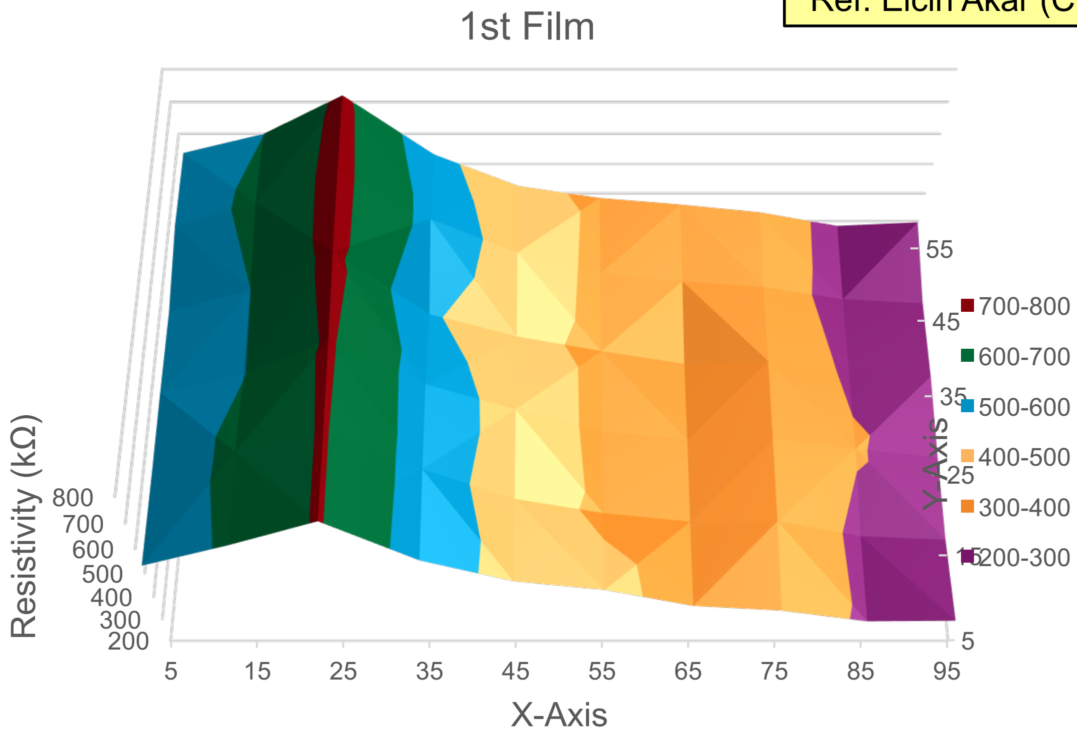
Resistivity measurements of foil #1 & #3
With CERN custom made probe

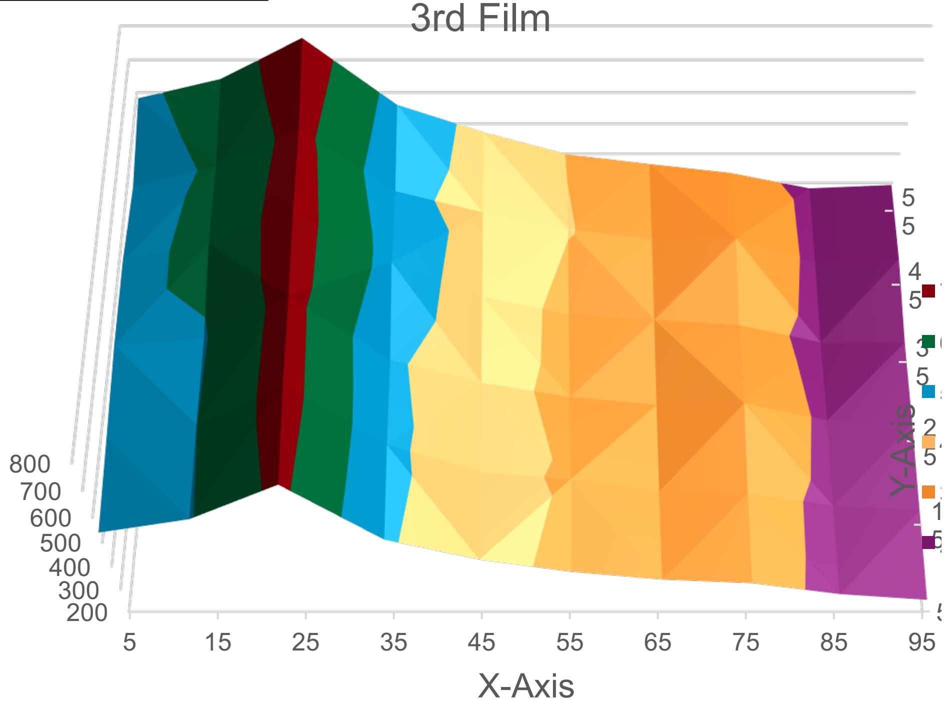
1st Film	5	15	25	35	45	55	65	75	85	95
5	532	615	708	554	467	430	360	339	290	293
15	526	625	708	559	442	384	348	350	286	270
25	525	597	712	556	462	377	342	346	305	270
35	520	600	726	512	431	376	327	338	293	278
45	546	623	728	570	453	380	349	328	282	267
55	537	599	721	532	425	383	360	332	283	296

z
y

3rd Film	5	15	25	35	45	55	65	75	85	95
5	540	593	723	512	430	378	345	329	281	255
15	554	599	742	526	419	392	342	333	282	264
25	569	593	738	516	432	378	348	354	287	273
35	570	625	745	565	445	380	360	340	275	275
45	547	615	733	532	460	403	368	370	283	296
55	582	642	765	561	472	398	365	334	280	292

Ref: Elcin Akar (CERN/EP-DT-EF)





Comparison with previous "ochi" probe measurements

CERN Custom made probe

z

y

1st Film	5	15	25	35	45	55	65	75	85	95
5	532	615	708	554	467	430	360	339	290	293
15	526	625	708	559	442	384	348	350	286	270
25	525	597	712	556	462	377	342	346	305	270
35	520	600	726	512	431	376	327	338	293	278
45	546	623	728	570	453	380	349	328	282	267
55	537	599	721	532	425	383	360	332	283	296

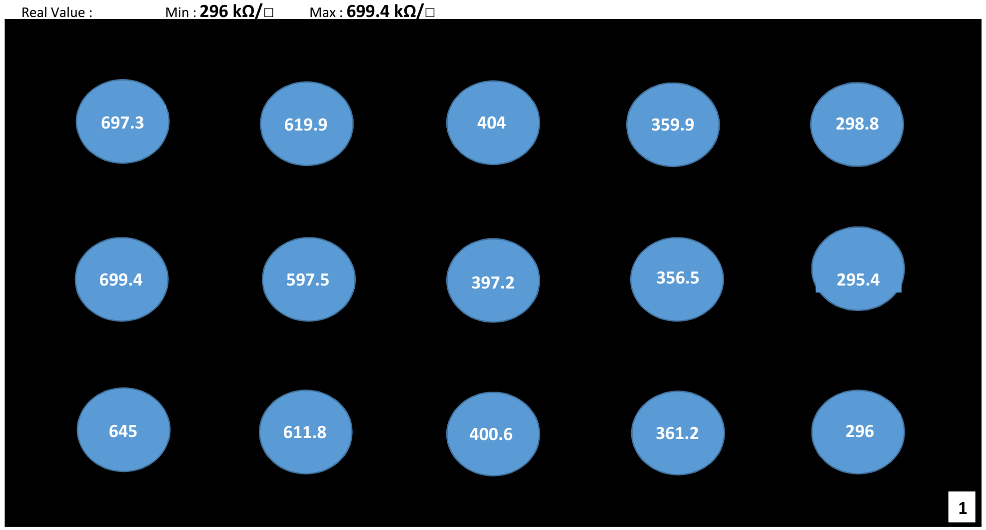
3rd Film	5	15	25	35	45	55	65	75	85	95
5	540	593	723	512	430	378	345	329	281	255
15	554	599	742	526	419	392	342	333	282	264
25	569	593	738	516	432	378	348	354	287	273
35	570	625	745	565	445	380	360	340	275	275
45	547	615	733	532	460	403	368	370	283	296
55	582	642	765	561	472	398	365	334	280	292

Ref: Elcin Akar (CERN/EP-DT-EF)

CERN « Ochi » probe (2018) → 10-20 % higher

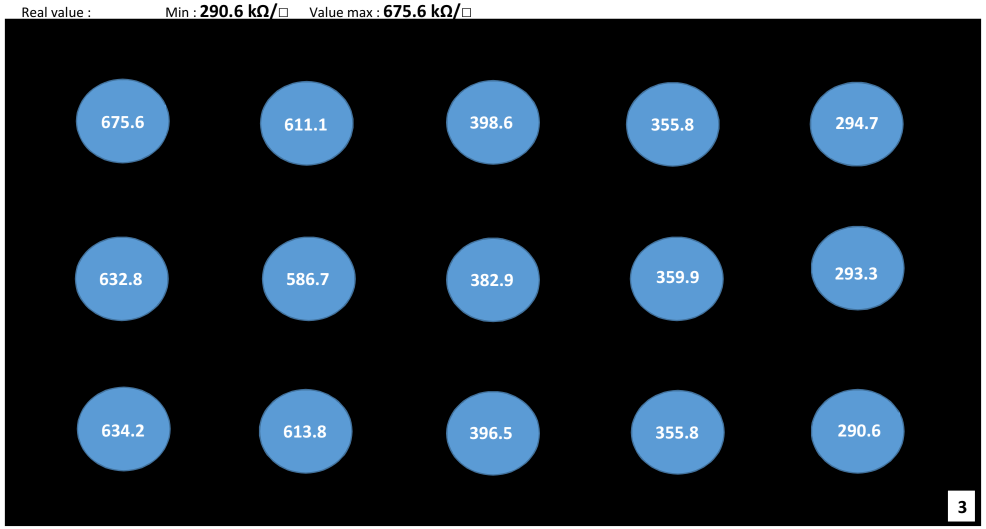
Theoretical value **500 kΩ/□** Foil size : 100x61cm

Real Value : Min : **296 kΩ/□** Max : **699.4 kΩ/□**



Theoretical value **500 kΩ/□** Foil size : 100x61cm

Real value : Min : **290.6 kΩ/□** Value max : **675.6 kΩ/□**



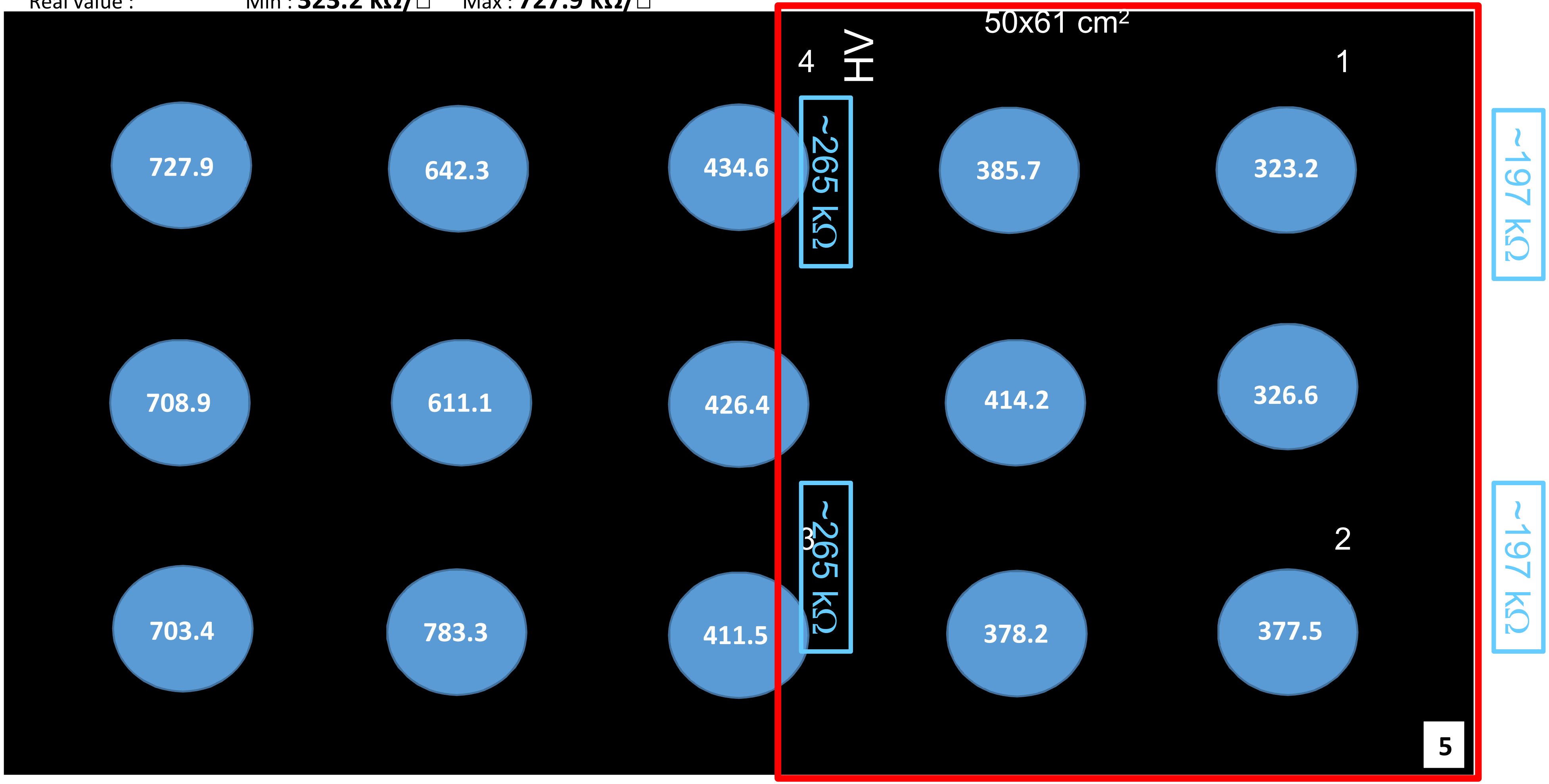
MM1-DLC2 : RESISTIVITY MEASUREMENT WITH CERN "OCHI" PROBE

Part of DLC foil #5 used for MM1-DLC2 (same as DLC1 at 10%)

Theoretical value **500 kΩ/□**

Foil size : 100x61cm

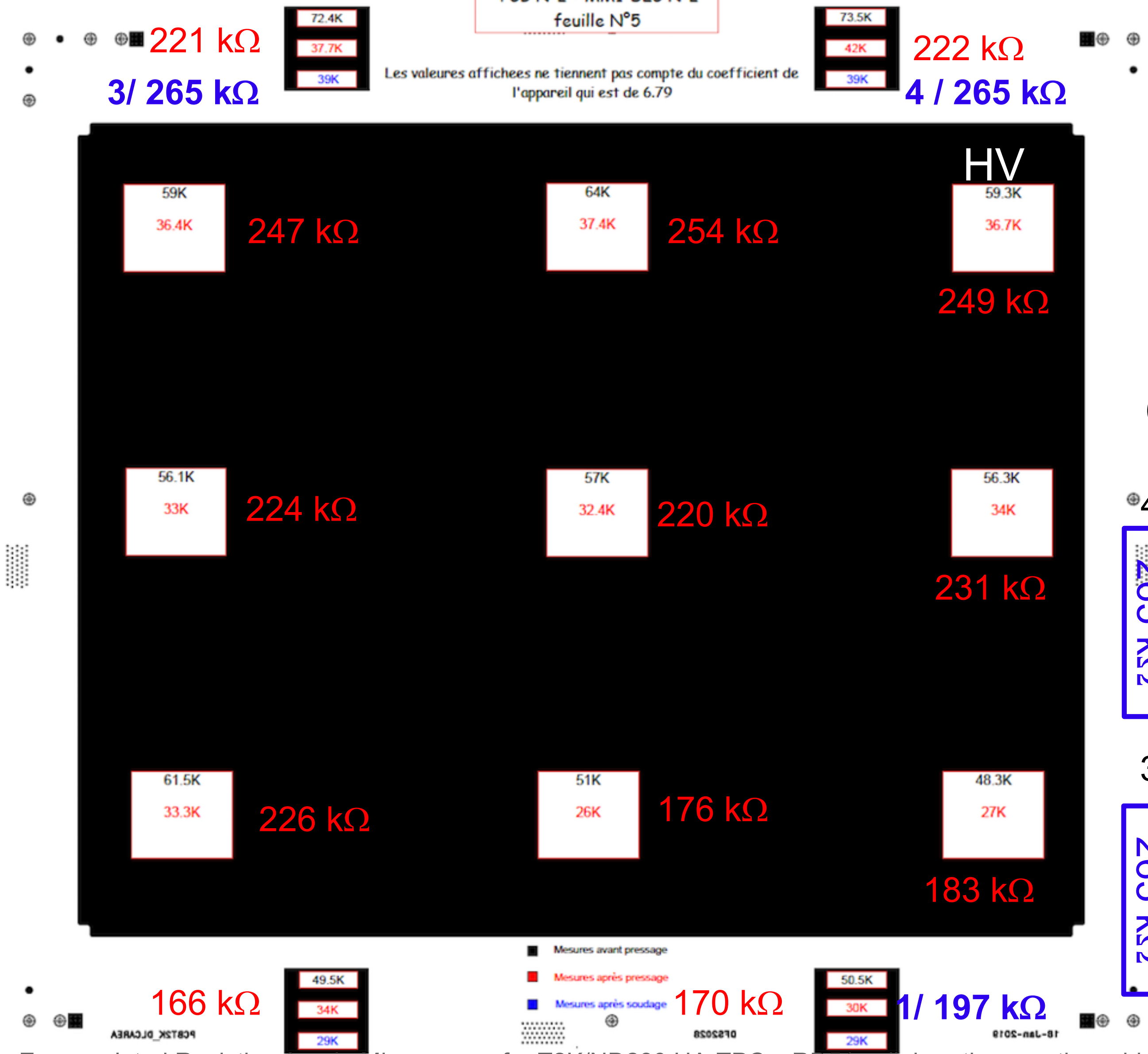
Real value : Min : **323.2 kΩ/□** Max : **727.9 kΩ/□**



In blue boxes: measured value outside detector area once detector is finished

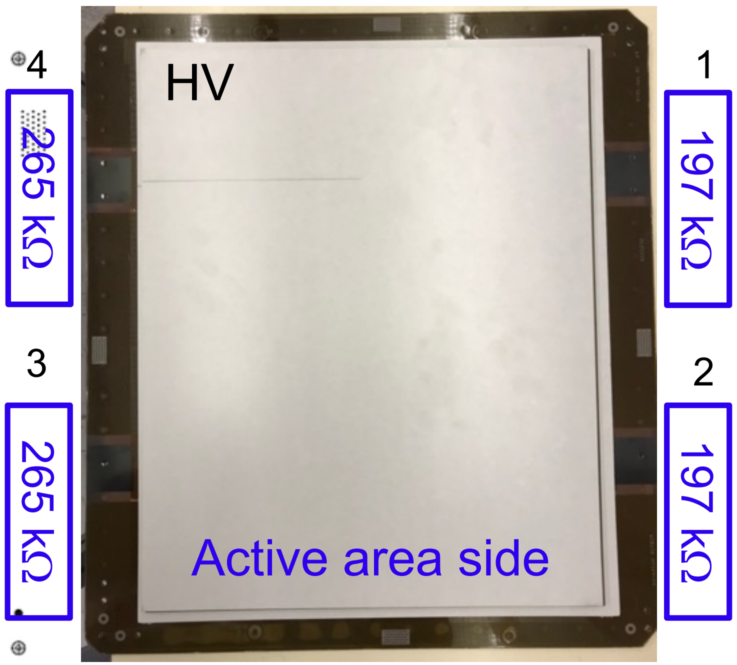
MM1-DLC2 : RESISTIVITY MEASUREMENT @ CERN WITH "OCHI" PROBE

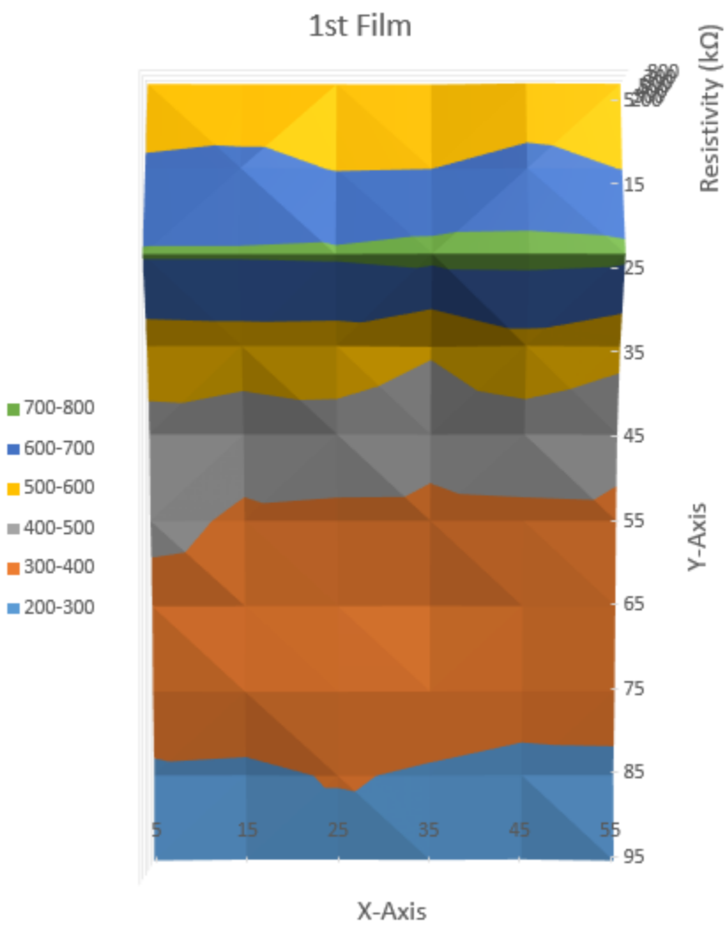
MM1-DLC2 resistivity – active area side

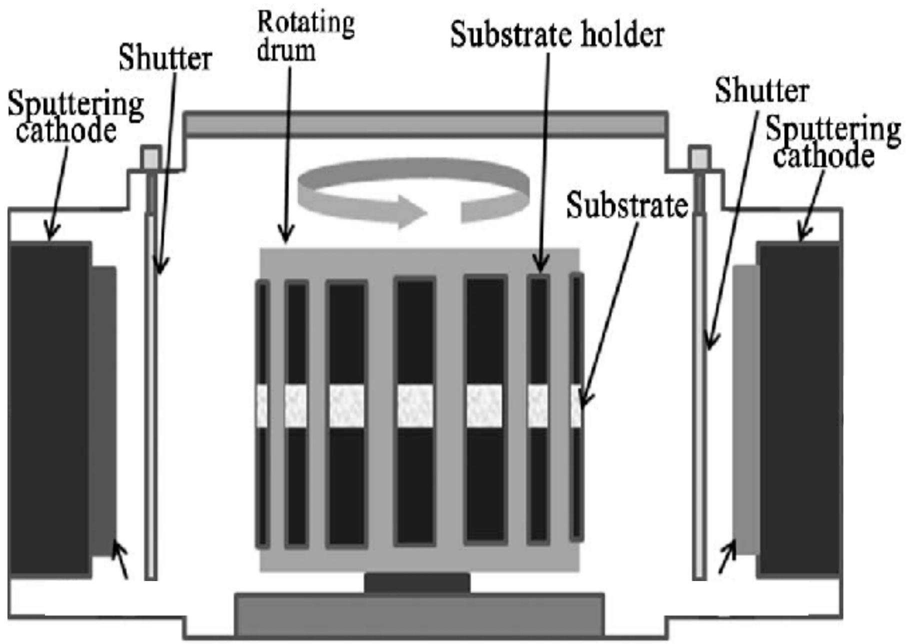


Same resistivity as DLC1 !

MM1-DLC2 resistivity
(CERN "ochi" probe, k=6,79)







Schematic representation of magnetron sputtering mechanism.