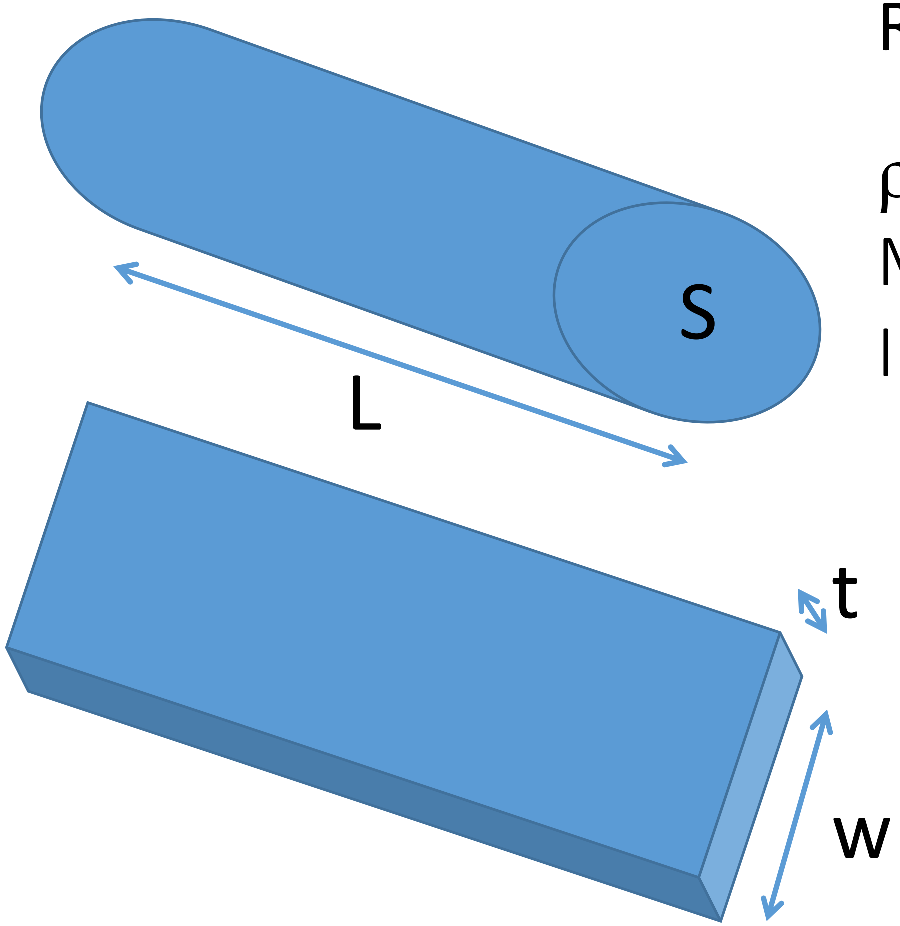
Bari, RCGD19, May 13-14 2019

Traditional techniques for Resistive Gaseous Detectors

Paul Colas, CEA/ Irfu,Université Paris Saclay

Surface resistivity



$R = \rho\, L/S$

ρ : bulk resistivity

Metal : 10^{-6} - **10^{-5}** Ω.cm

Insulator $>10^{17}$ Ω.cm

$R = \rho\, L/wt$

Flat layer: t small

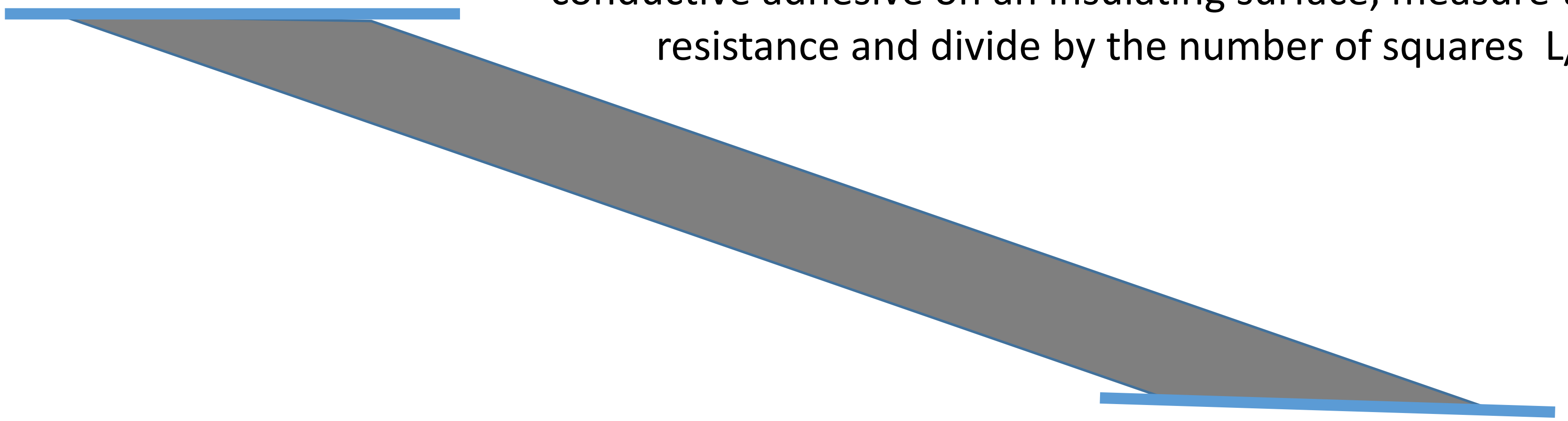
Square L=w

Surface resistivity $R= \rho/t$

Units : Ohm per square

Measurement techniques (1)

Cut a long band of resistive. Hold it both ends with conductive adhésive on an insulating surface, measure the resistance and divide by the number of squares L/w.



Measurement techniques (2)

Circular probe
(for example ETS model 803B)

Measure the resistance
between 2 rings

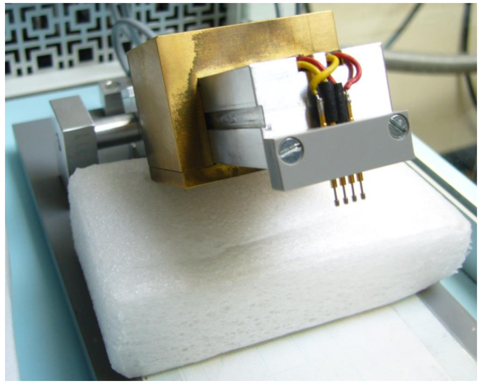
$$\rho_s = \frac{(D_1 + D_2)}{(D_2 - D_1)} \pi R_m \text{ Ohms/sq}$$

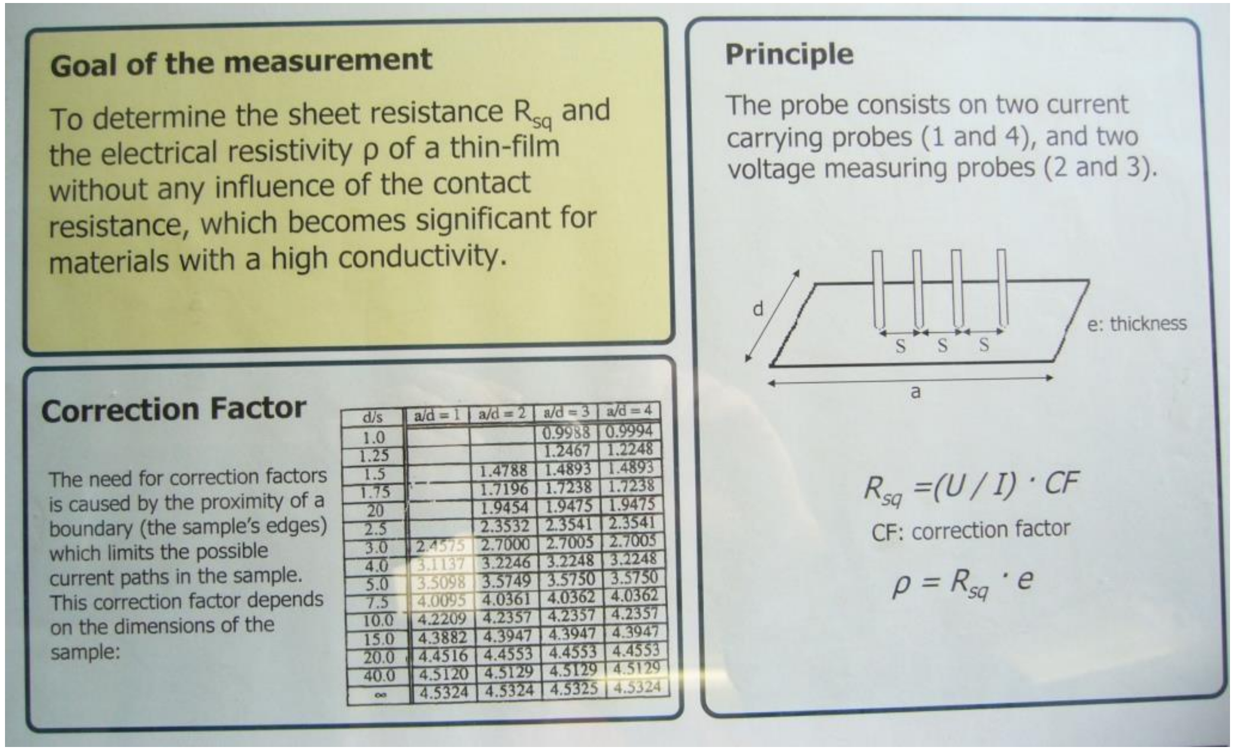
D_1 = Outside Diameter of inner ring
D_2 = Inner Diameter of outer ring
R_m = Measured resistance in ohms

Measurement techniques (3)

Four-point probe

Necessary for uniformity measurements, but might scratch the layer





Goal of the measurement

To determine the sheet resistance R_{sq} and the electrical resistivity ρ of a thin-film without any influence of the contact resistance, which becomes significant for materials with a high conductivity.

Principle

The probe consists on two current carrying probes (1 and 4), and two voltage measuring probes (2 and 3).

$$R_{sq} = (U / I) \cdot CF$$

CF: correction factor

$$\rho = R_{sq} \cdot e$$

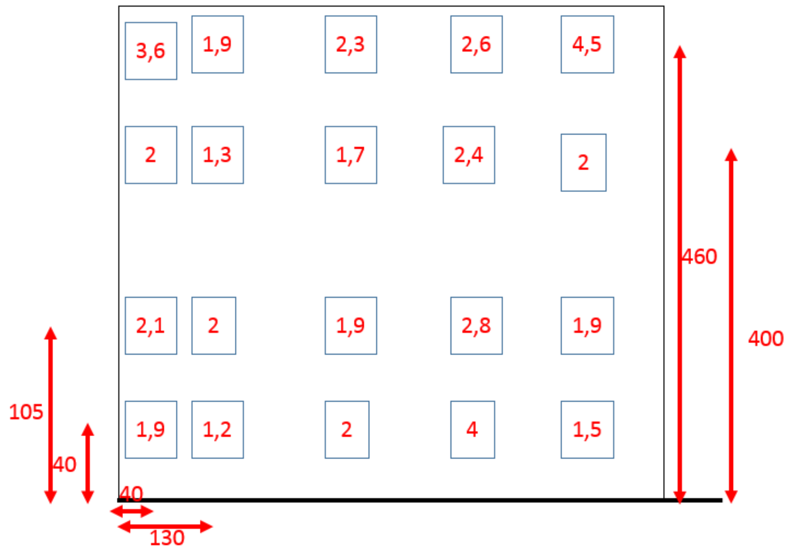
Correction Factor

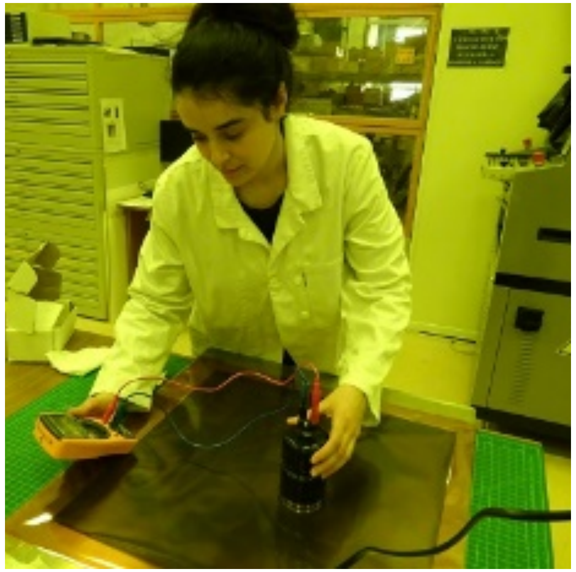
The need for correction factors is caused by the proximity of a boundary (the sample's edges) which limits the possible current paths in the sample. This correction factor depends on the dimensions of the sample:

d/s	a/d = 1	a/d = 2	a/d = 3	a/d = 4
1.0			0.9988	0.9994
1.25			1.2467	1.2248
1.5		1.4788	1.4893	1.4893
1.75		1.7196	1.7238	1.7238
20		1.9454	1.9475	1.9475
2.5		2.3532	2.3541	2.3541
3.0	2.4575	2.7000	2.7005	2.7005
4.0	3.1137	3.2246	3.2248	3.2248
5.0	3.5098	3.5749	3.5750	3.5750
7.5	4.0095	4.0361	4.0362	4.0362
10.0	4.2209	4.2357	4.2357	4.2357
15.0	4.3882	4.3947	4.3947	4.3947
20.0	4.4516	4.4553	4.4553	4.4553
40.0	4.5120	4.5129	4.5129	4.5129
∞	4.5324	4.5324	4.5325	4.5324

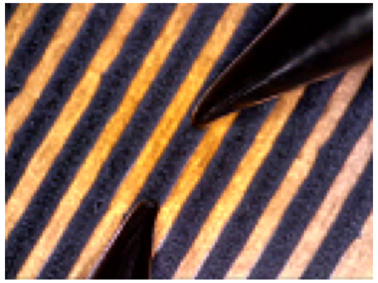
Resistivity Measurements

Resistivity measurement protocole defined and reproducible, using circular probe and square 'Ochi' probe for plain coating





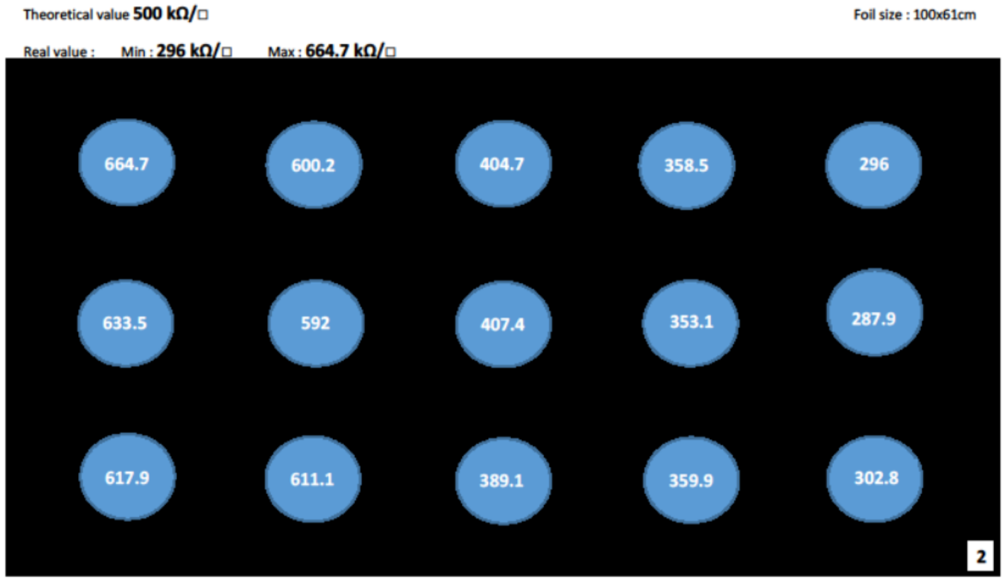
And 'square counting' for resistive strips



under Microscope

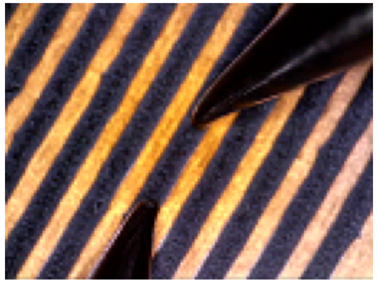
Resistivity Measurements

Resistivity measurement protocole defined and reproducible, using circular probe and square 'Ochi' probe for plain coating



Lower resistivity DLC-coated foil for T2K TPC

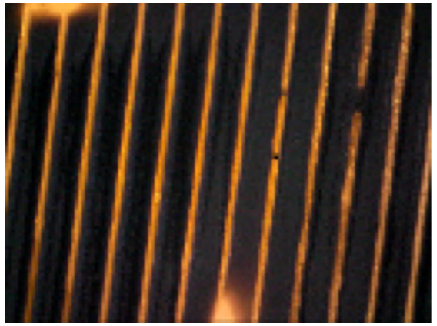
And 'square counting' for resistive strips

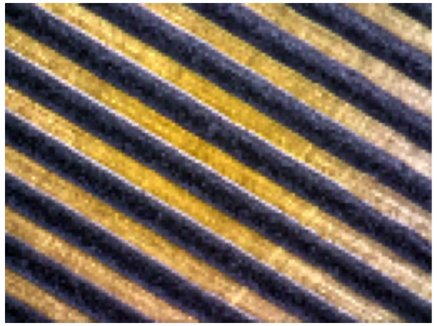


under Microscope

IMPROVEMENT OF STRIP QUALITY

Problem 1 : ink spreads so that strip width is larger than what is on the mask





Solution: adapt the mask to fine enough pitch to compensate

Problem 2 : Static electricity and dust degrade the stips

Solution : Discharge the base foil and work in a dust-free environment

Resistive inks

Screen printing : 60x60 cm² mesh stretched on a robust Aluminum frame.

Ink from ESL Europe Company,
100 KΩ/□ (ESL RS12115) and 1 MΩ/□ (ESL RS12116).
Need to be mixed with a solvent before use.

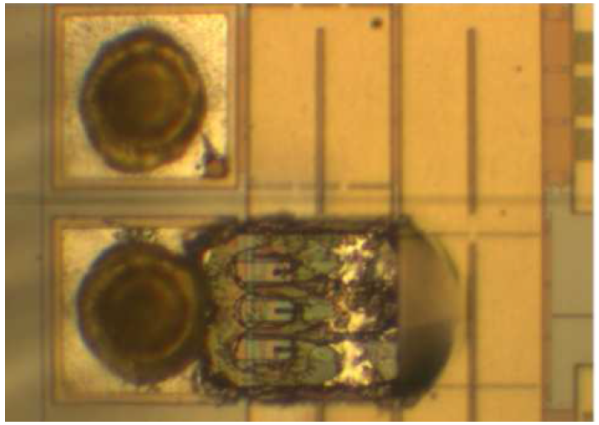
Problem 3 : unstable high resistivity (pressing at 12 bar at ELVIA for NSW takes the 400 kOhm/sq made in Japan to 800 kOhm/sq).

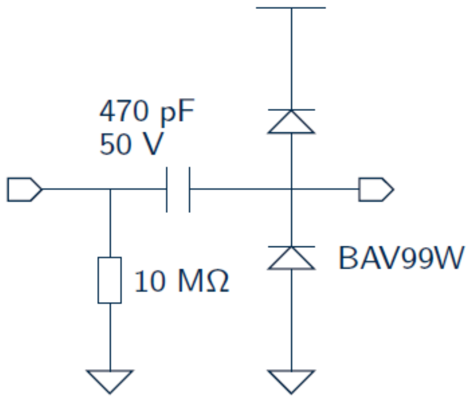
Solution : after 11 trial productions spread from Feb. 2018 to October 2018, a process to make homogeneous production was determined:

- Humidity control
- Improvement of the clean room
- 1 Mohm paste + 10 to 30% of 100 kOhm + 5% of neutral paste (insulating) + a few drops of solvant, careful mix and immediate screen-printing.
- Pressing at 7 bar at ELVIA.
- The result is more uniform than DLC, at 3.4+-0.2 Mohm/sq

Use of resistive coatings in detectors

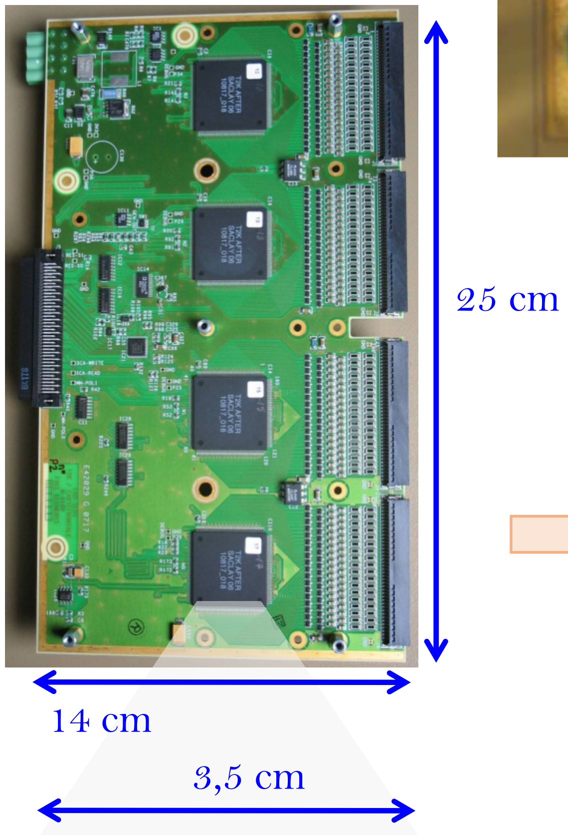
- Stabilization of gain and protection of electronics
- Charge spreading
- Chip protection
- Potential degrading for E-field shaping

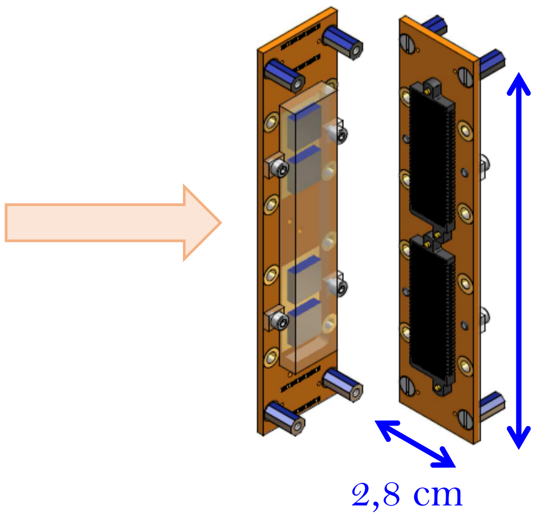




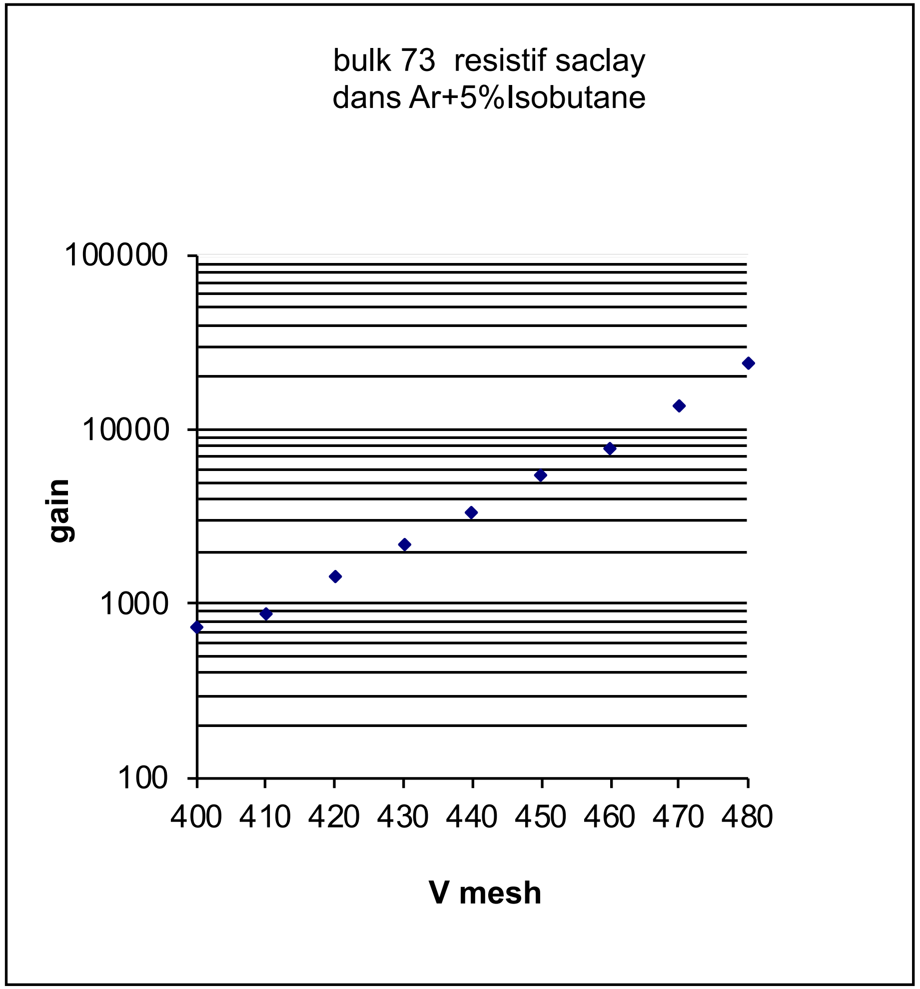
COMPASS

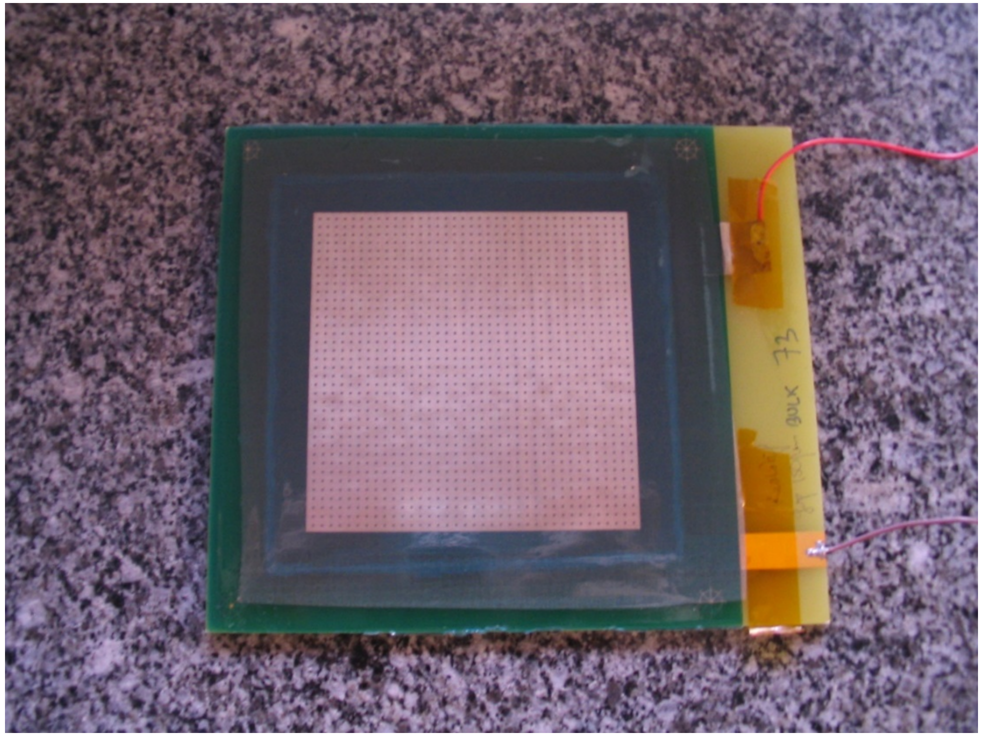
Protection diodes, resistors and capacitors no longer needed : this saves space on the FE boards



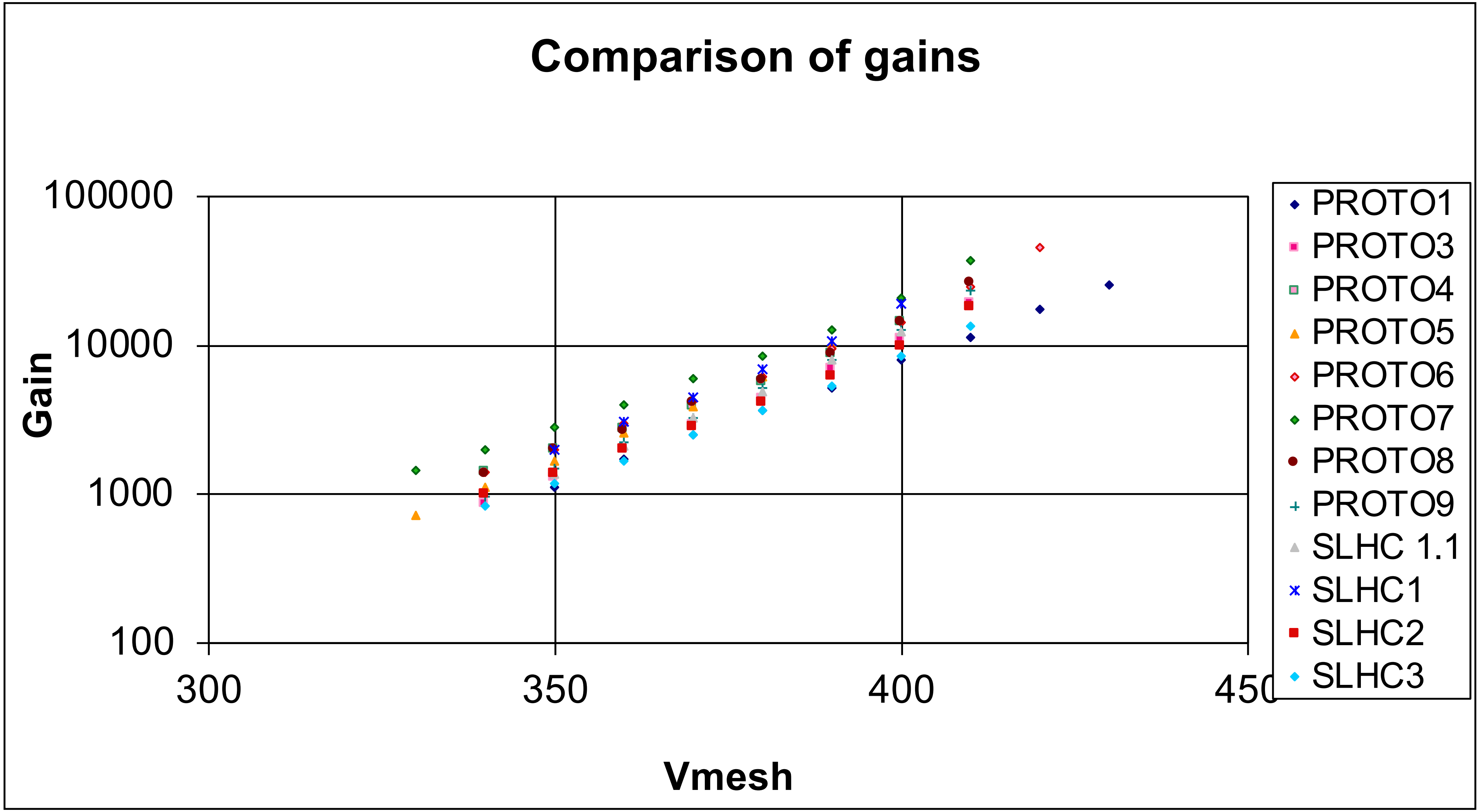


Resistive Bulk Micromegas





October 2007: resistive bulks for HL-LHC (SLHC)
(became ATLAS MAMMA, and later NSW)



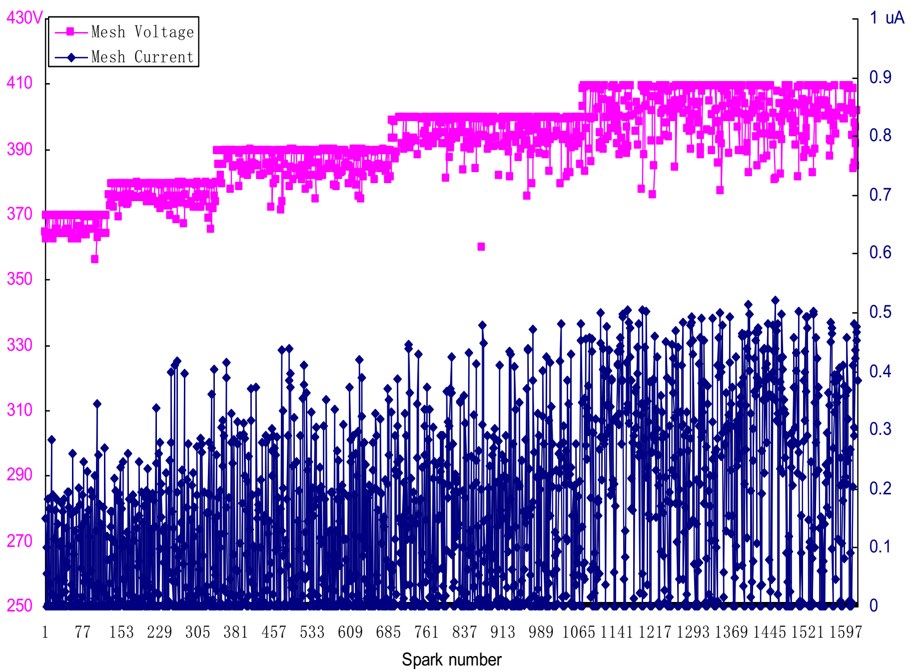
June 2010 measurements

Applications of resistive coatings : spark mitigation

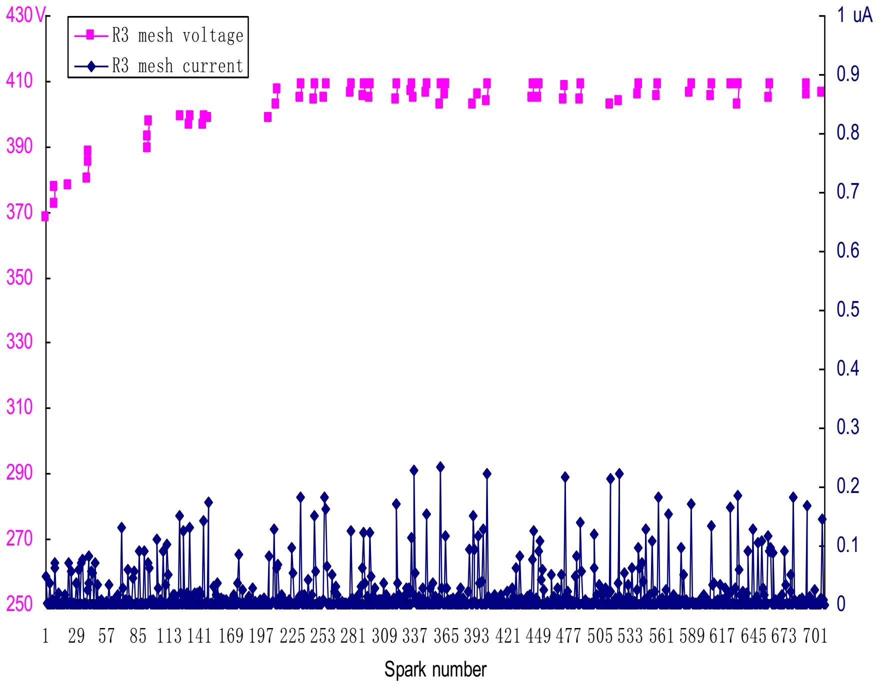
- The avalanche charge is kept locally for some time
- This lowers the potential locally
- This in turn lowers the gain and avoid the Rather limit to be attained
- Moreover, as the charge goes to ground through a resistance, this limits the current through the preamplifiers, protecting them
- You can also pattern resistors in your PCB (Rui de Oliveira, Max Chefdeville)

Different sparking behaviours of standard and resistive detector:

Standard SLHC2(@10KHz):



Resistive R3(@wide beam,15KHz):



S. Wu

SLHC2: HV=400 V (Gain ~3000): current when sparking < 0.4 μA
voltage drop< 5%

R3: HV=410 V (Gain ~3000): current when sparking < 0.2 μA
voltage drop<2%

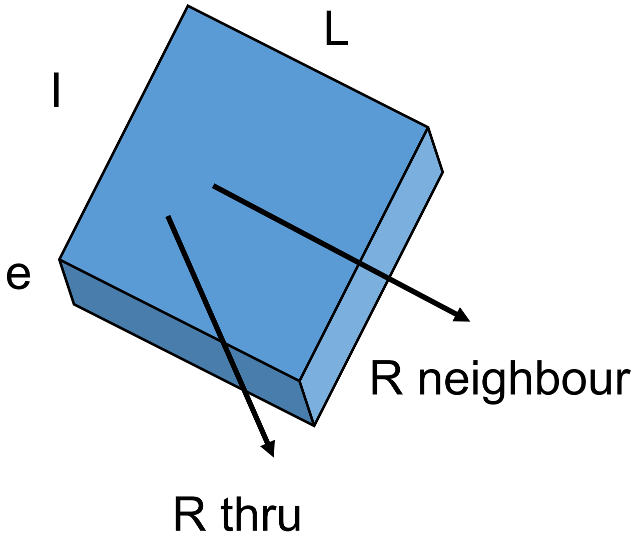
Chip protection in Gridpix

- **A single spark kills a TimePix chip**
  - High current, hot plasma -> destroys circuit
  - A sufficiently thick SiProt layer reduces and softens the sparks

- **How protection works?**
  - Allows charge to stay over the pad, lowering the local potential
  - Limits the current thru the amplifier
  - Protects mechanically
  - Avoids points, smoothens the surface?

- **Any damage to the signal?**
  - Amplitude loss?
  - Charge sharing with neighbouring pads?
  - Short-circuit of the amplifiers
  - Introduces dead time?

Chip protection in Gridpix



$R_{neighb} = \rho\ L/el = \rho/e$ for square pads

For 10 μ aSi, $\rho=10^{11}\ \Omega.cm$, $R=10^{14}\ \Omega$/square

$R_{thru} = \rho\ e/Ll \sim 0.04\ 10^{14}\ \Omega$

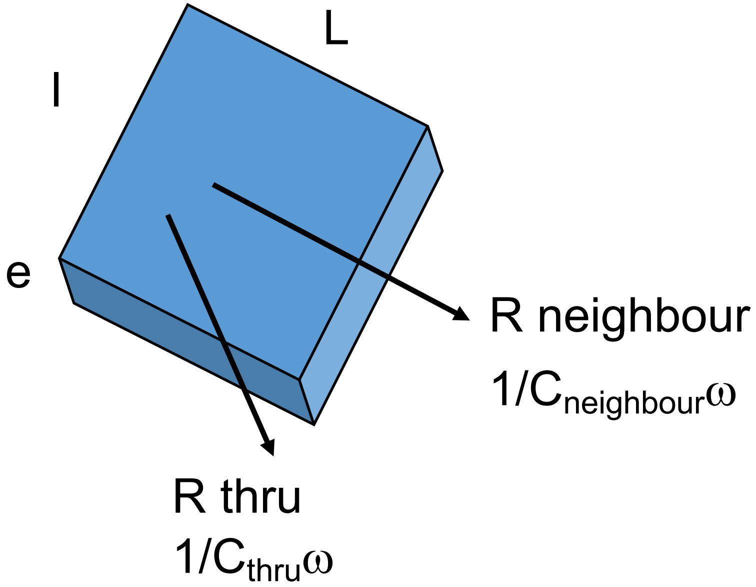
$R_{neighb}/R_{thru} = L^2/e^2$

e<<L to avoid spreading the charge by side conductivity. The charge preferentially escapes thru the pad, but with an extremely high resistance.

$C_{neighb} = \varepsilon_r\ \varepsilon_0\ Le/l = \varepsilon_r\ \varepsilon_0\ /e$ for square pads

$C_{thru} = \varepsilon_r\ \varepsilon_0\ Ll/e$ (note ε_r ~11 for Si)

The influence acts preferentially thru the pad if L>>e



Also $R_{thru} >> 1/C\omega$ to leave the induced signal

(OK with 10^{11} Ω.cm within 3 orders of magnitude for 10 ns signals)

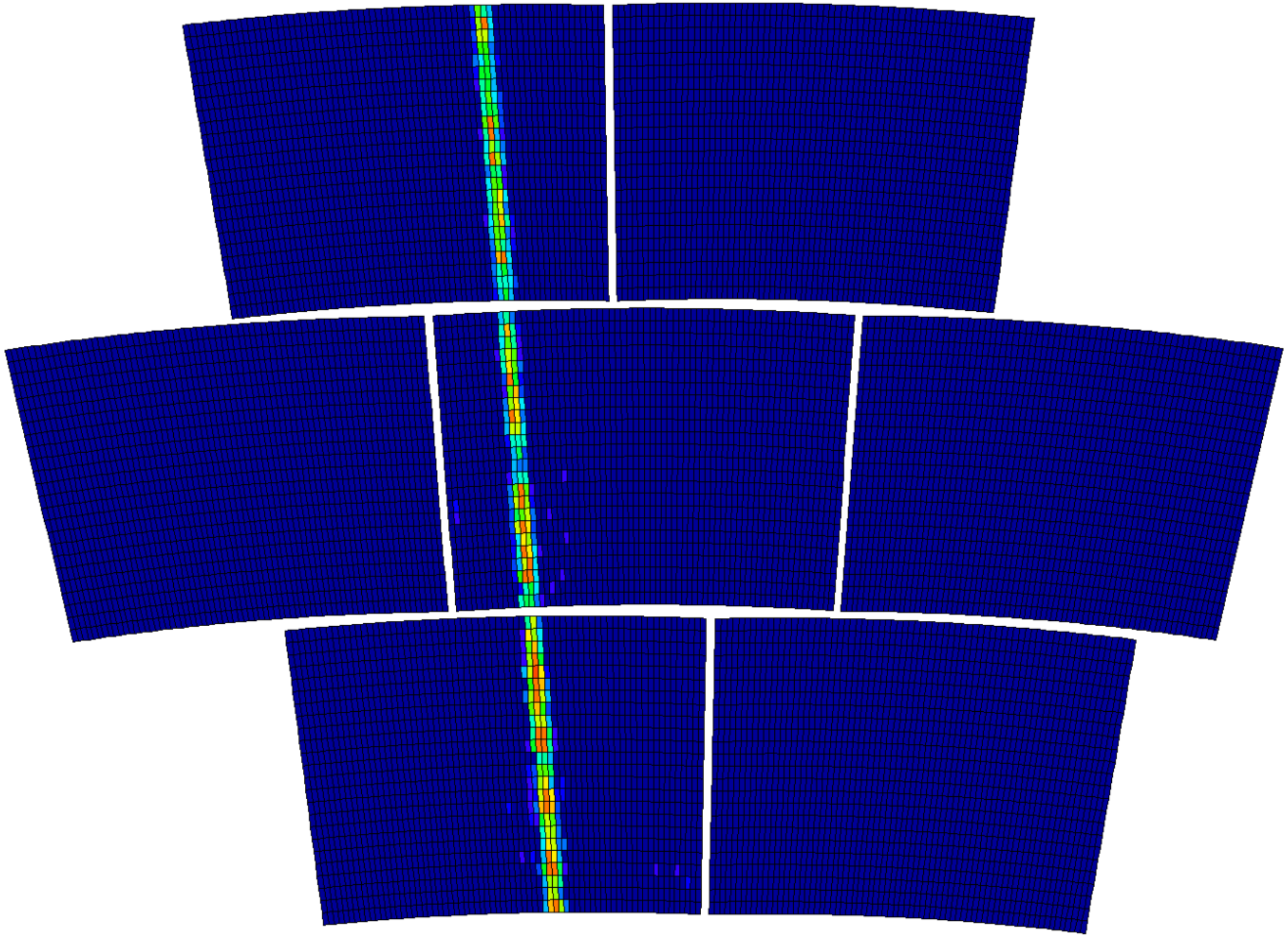
Equivalently, RC time constant >> 10ns

The signal is fully capacitive

Resistive materials in use or to be developped

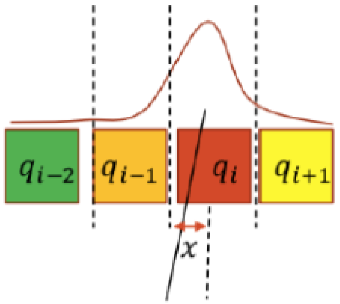
- Sheldal film + cermet (Al Si) (Madhu Dixit)
- Resistive paste or ink (Carbon-loaded epoxy resine) (Rui de Oliveira, Imad Laktineh, Nick Lumb, José Répond)
- Spray of carbon powder in glue (G. Mikenberg)
- Kapton with Diamond-like Carbon by sputtering (see Atsuhiko Ochi's talk)
- Amorphous silicon, Hydrogenated A-Si (Nicolas Wyrsch) SiNi (SiNx)
- Carbon-loaded Polyimide
- Resistive pastes Ruthenium Dioxide (Michael M. Steeves, *Electronic Transport Properties of Ruthenium and Ruthenium Dioxide Thin Films*

Charge sharing in a TPC



Pad Response function

2D distribution :
Charge fraction vs Xpad-Xtrack

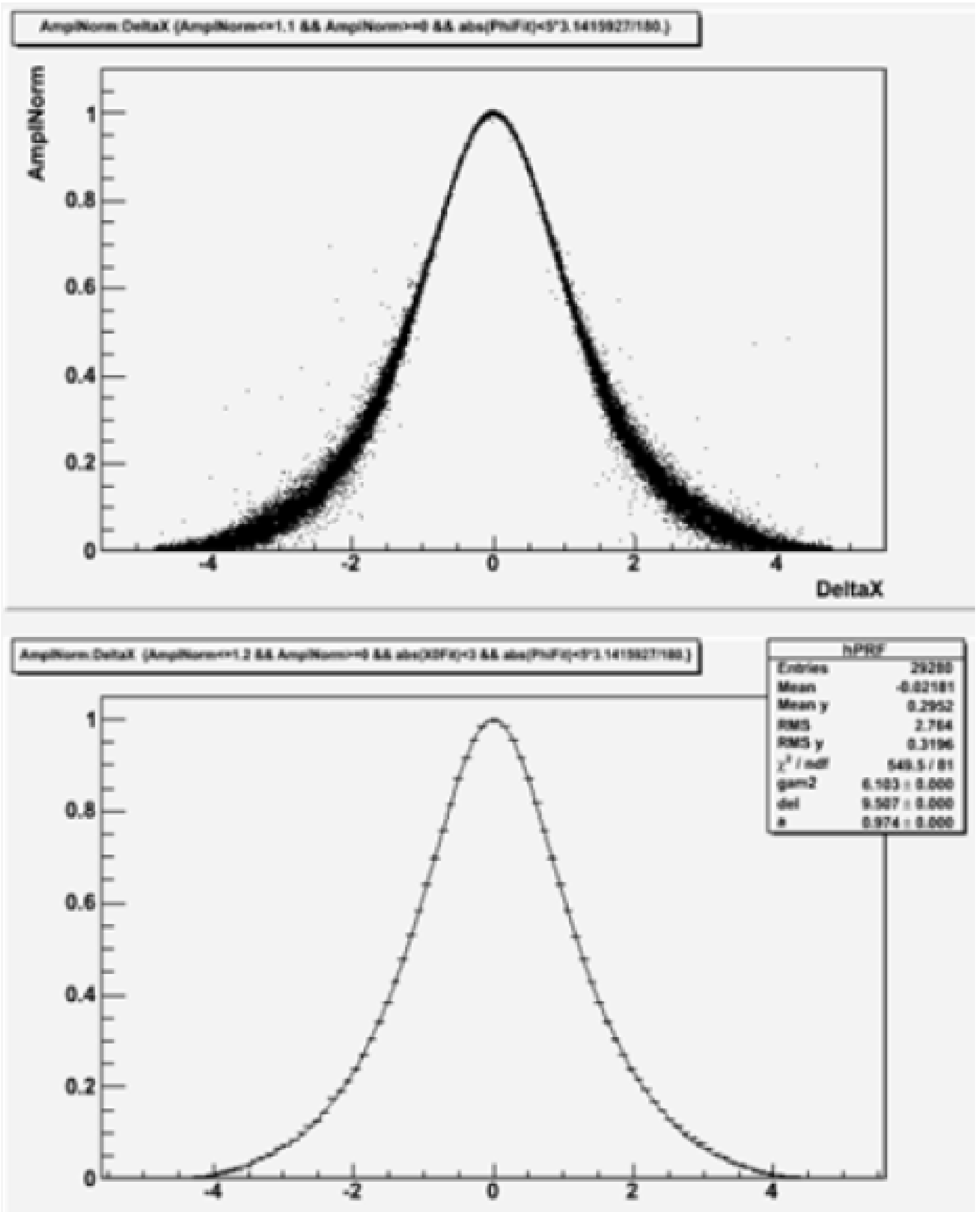


Fit a parameterization to the profile, for i

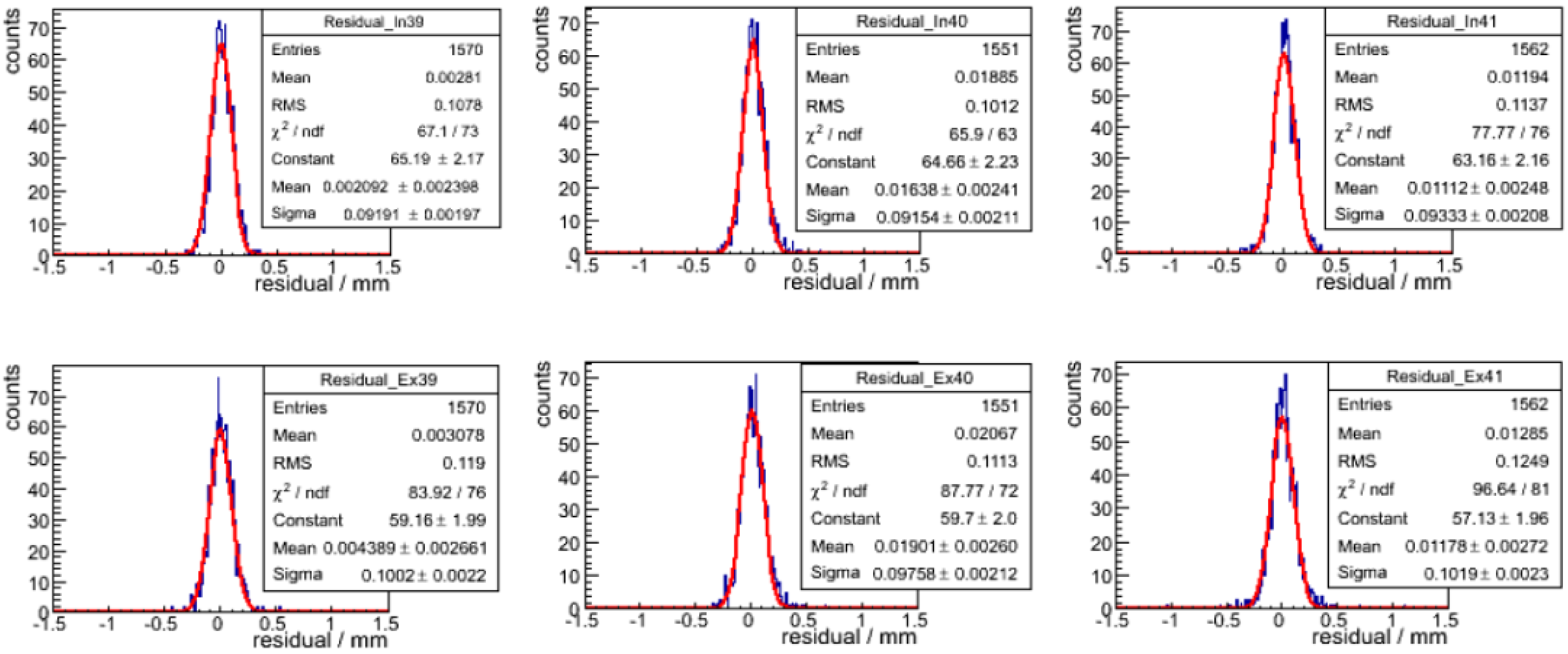
$$PRF(x,r,w) = \frac{\exp[-4\ln 2(1-r)x^2/w^2]}{1+4rx^2/w^2}$$

Use the Pad Response Function to obtain the track postion in each padrow from the charge fraction

Re-fit the track and iterate



Residuals of the fitted track (after iterations)

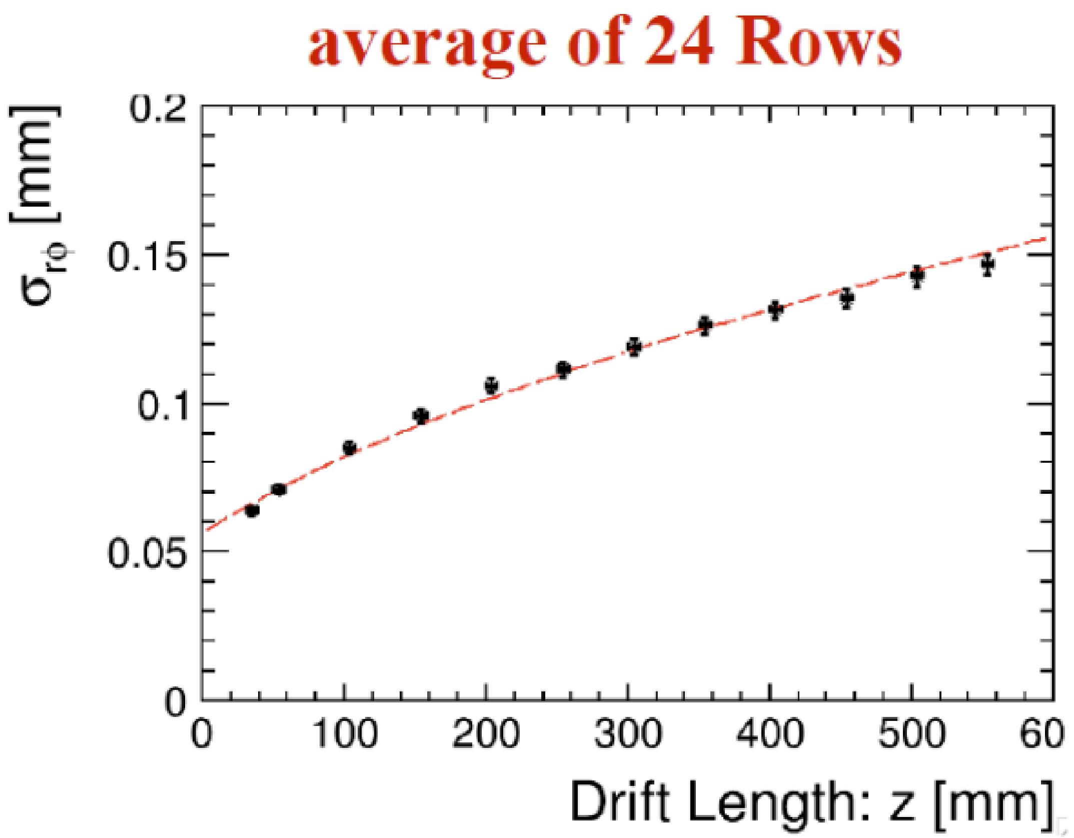


Take the geometrical mean between resolution including and excluding the hit in question to get an unbiased result

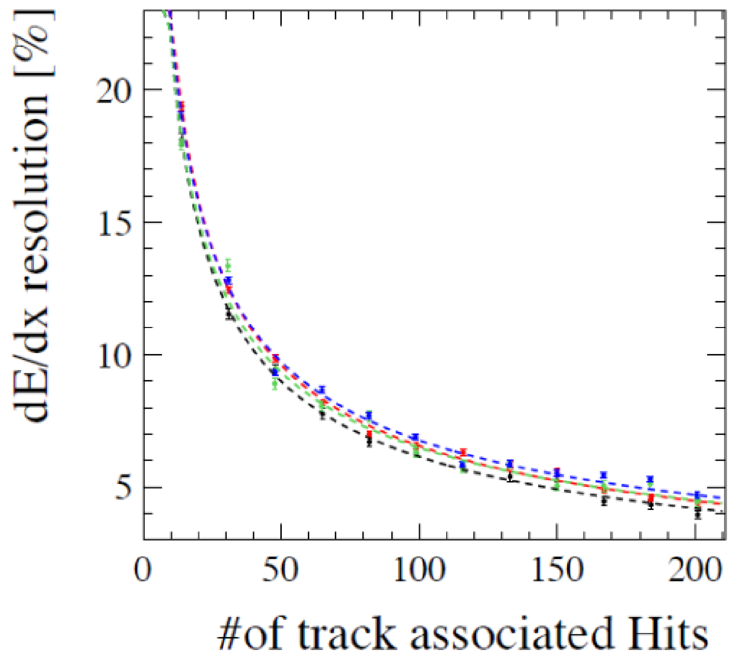
Position resolution

Constant term ⊕ sqrt(z) diffusion contribution

Constant term = 60 µm with 3mm pads!
(1/50th pad witdth)



dE/dx resolution



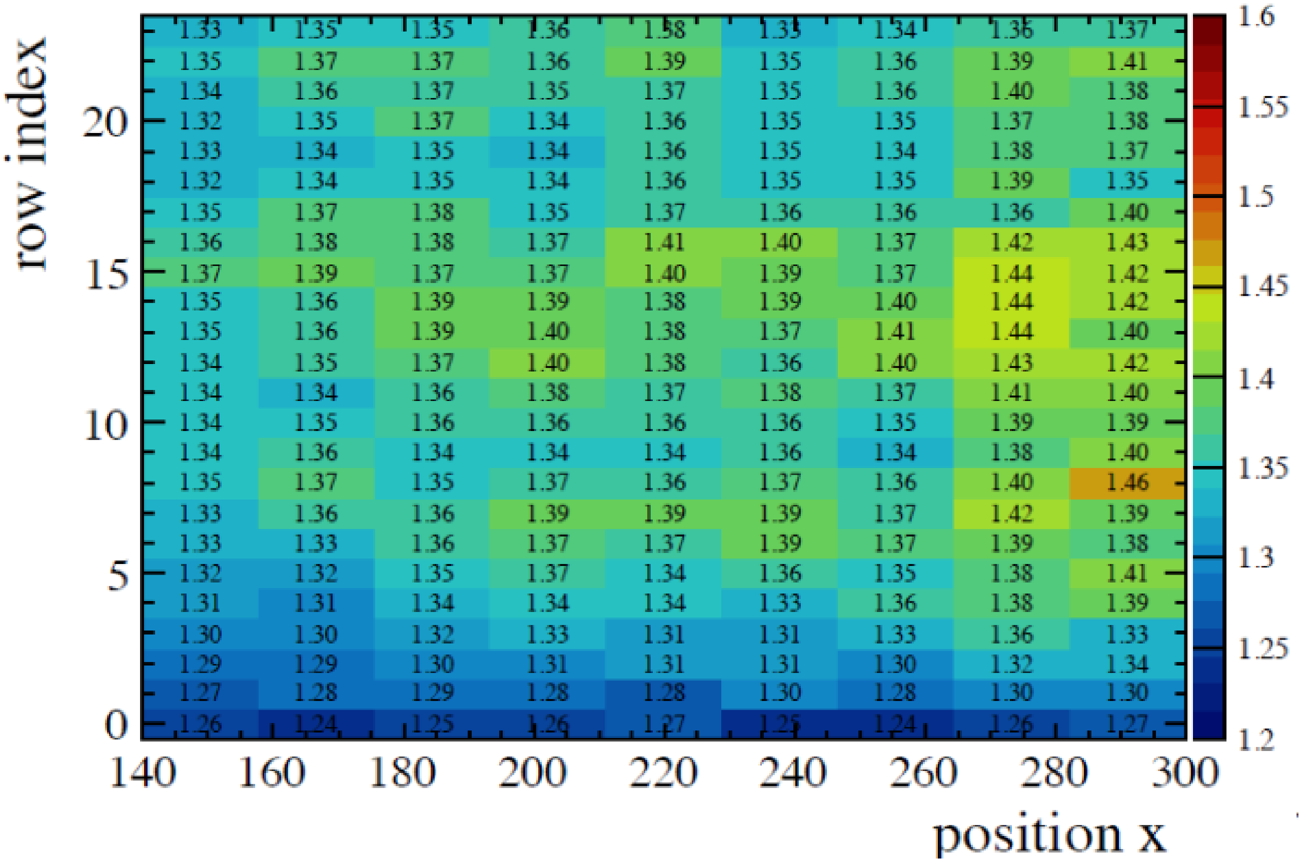
4.8% resolution for nominal track length (192 hits)

Conclusion : Beam test shows that the high performances are preserved in the new scheme

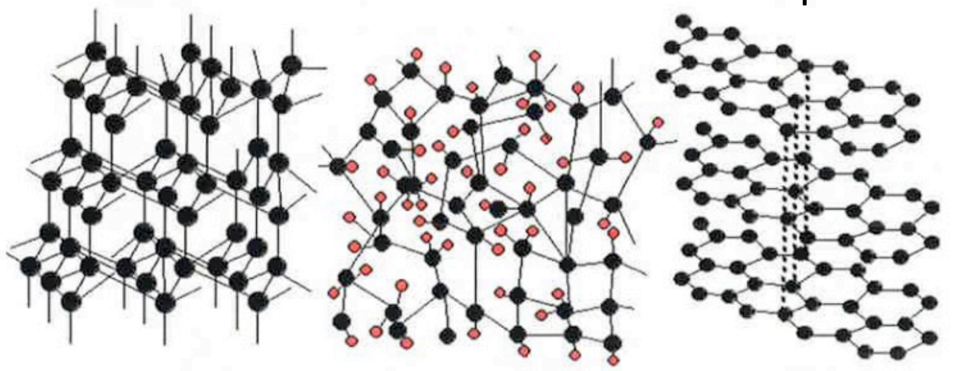
Uniformity of the charge spreading

σ = sqrt(2t/RC)

Width parameter of the PRF (mm)



What is DLC?



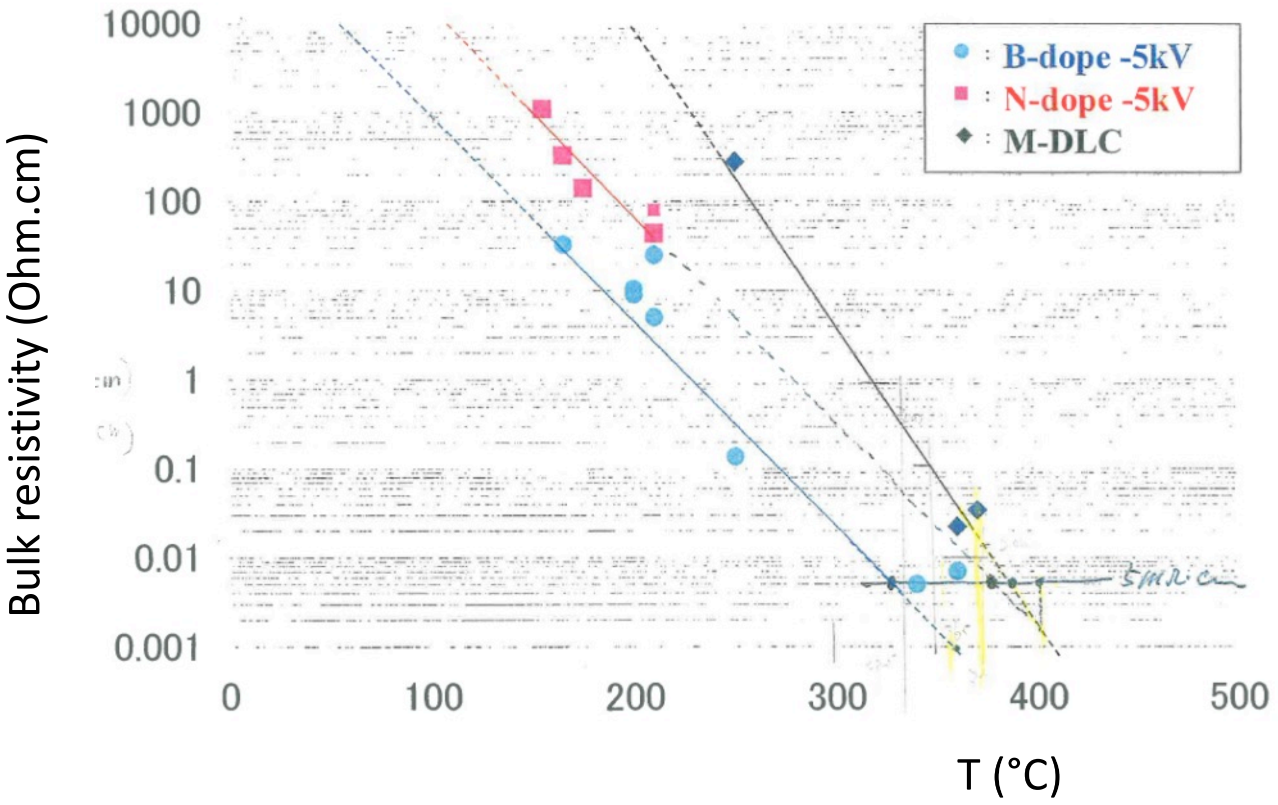
- Diamond-like Carbon
- Properties
  - Electric : resistive
  - Mechanical : hardness, anti-corrosion protection, solid lubricant
- Applications in MPGD
  - Charge spreading anode: deposited on an insulating substrate makes a continuous resistive-capacitive network, evenly spreading the charge, improving point resolution by allowing a barycenter between pads or strips
  - Anti-spark protection (O(1 to 10 or 100) $M\Omega/\square$). Needs several microns to get to low enough resistivity for T2K (400 Kohm/sq)
- Other applications
  - Fuel cell battery component

Two fabrication techniques

- Sputtering : use an argon plasma to vaporize a graphite target
  - BE-sput company in Kyoto (contact by Atsuhiko Ochi). Successfully produced resistivity in the range 0.4-several 10 Mohm per square.

- Plasma Assisted ion deposition : use a methane plasma in a high E field to deposit carbon on the substrate. Deposition rate 5-10 µ/hour. Need ~2 microns for 400 Kohm/sq (T2K requirement)
  - PAI company in Kyoto (contact by Takeshi Matsuda)

With the PIA technique, bulk resistivity below 10^{-2} Ω.cm requires temperatures in excess of 350 °C



PAI first test for 400+/-200 KΩ/sq
On HN kapton
PC+MZ, 2018/6/25

Scratches from the 4-point probe
4-point probe measurement : 103.6

First test : the coating is not uniform enough. Will try again with APICAL (etchable polyimide)

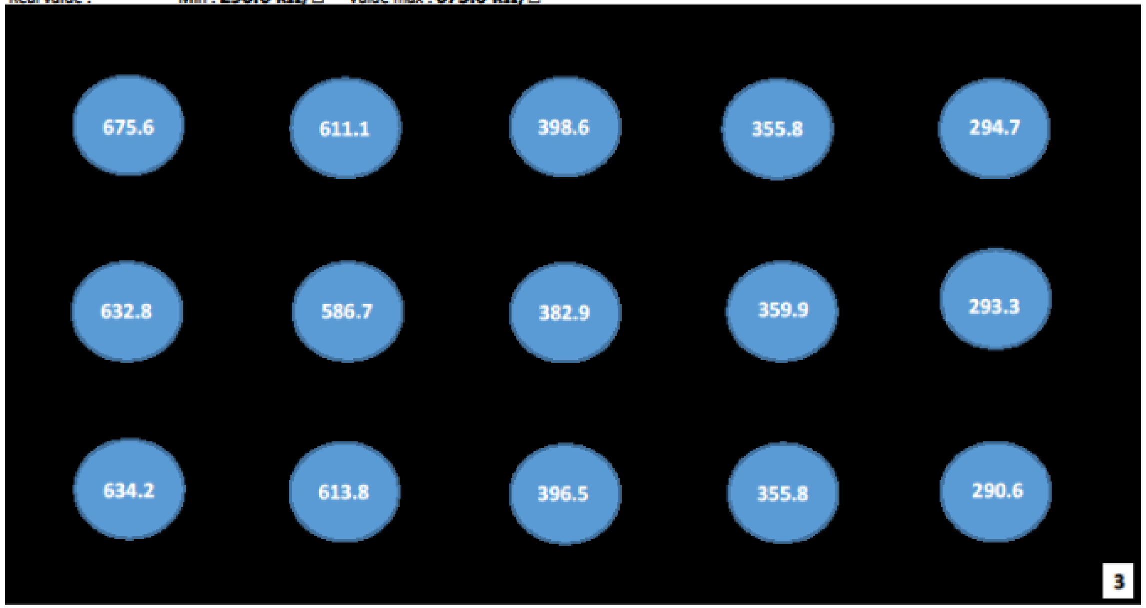
Uniformity of DLC resistivity by sputtering

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

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

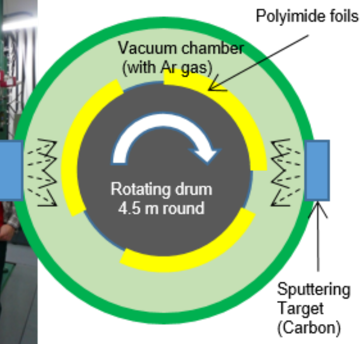
Theoretical value **500 kΩ/□** Foil size : 100x61cm

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



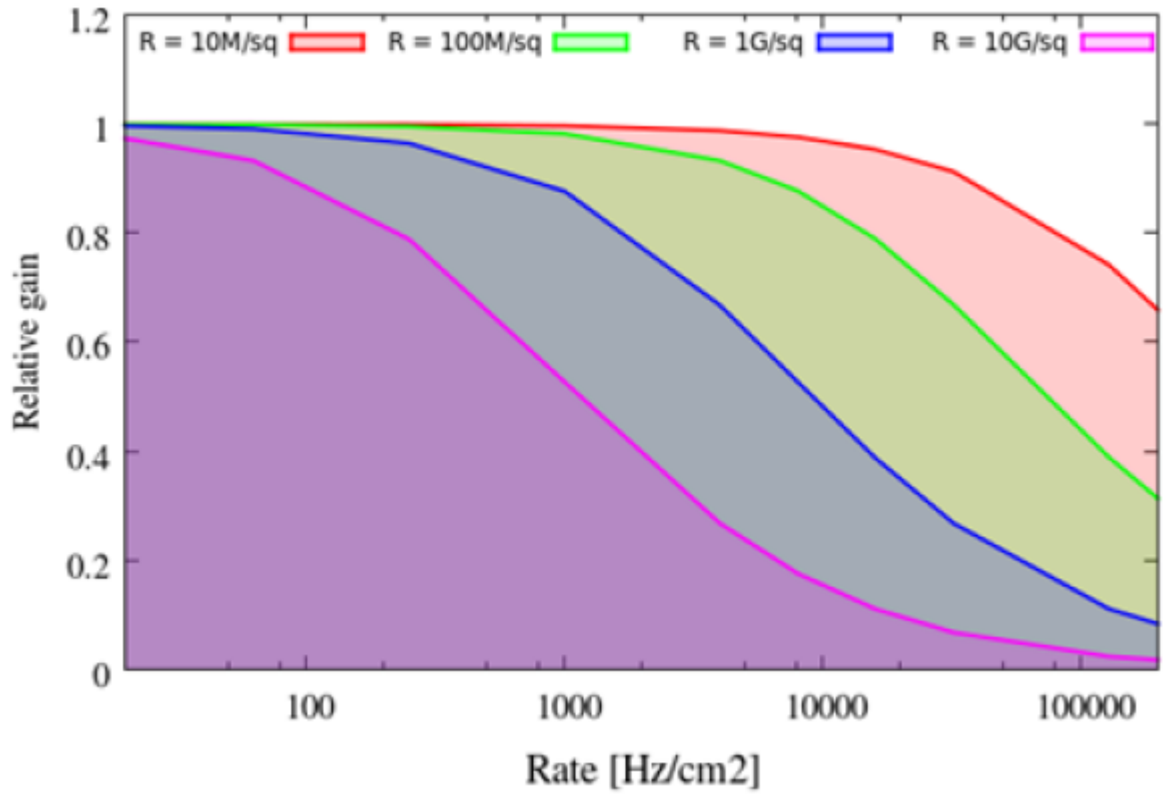
Same pattern for each horizontal lines, vertical iso-resistivity lines

BE-sput, 7 foils measured at CERN with 'Ochi probe' for T2K-ND280 upgrade



RATE CAPABILITY

Resistive layers slow down the detector, as the charge remains some time on the anode. They degrade slightly the rate capability.



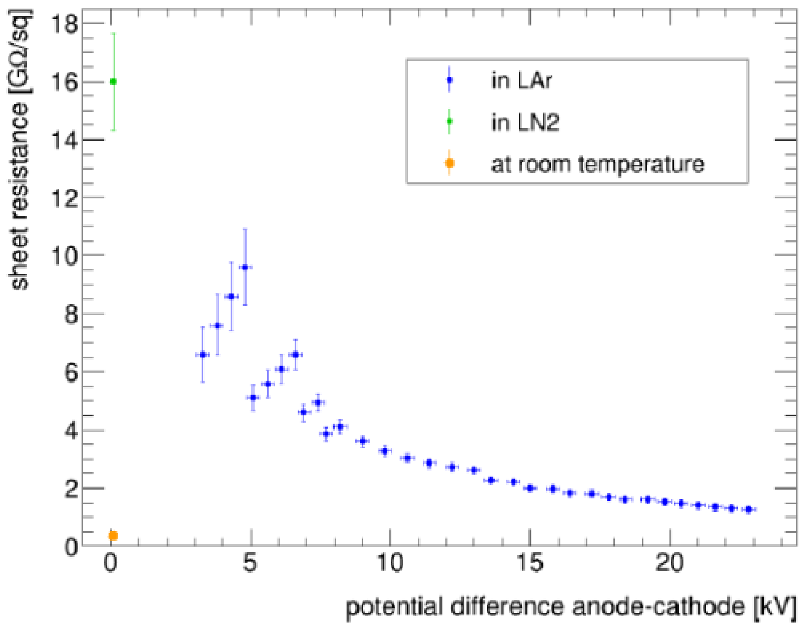
Simulation by J. Galan

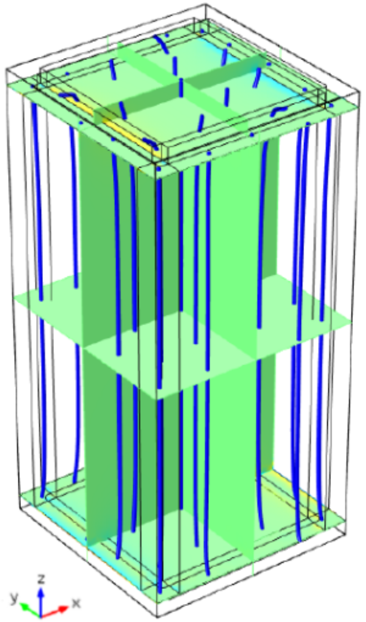
D. Attié et al., JINST (2013), 'A piggyback Micromegas'

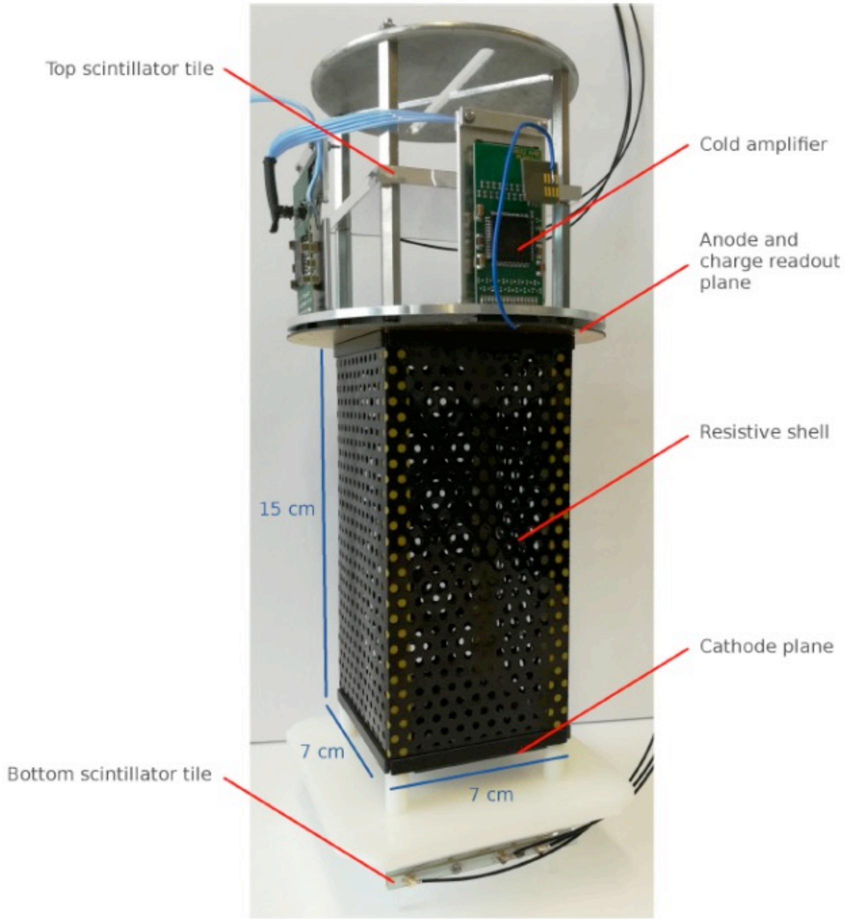
For 10 MΩ, there is a 20% gain drop at 100 kHz/cm2

Use of resistive sheets for TPC Field cages

Replace set of conductive rings interconnected by resistors by a continuously resistive vessel to degrade the potential
Application to cryogenic TPCs (strong dependence of the resistivity with T and potential difference)







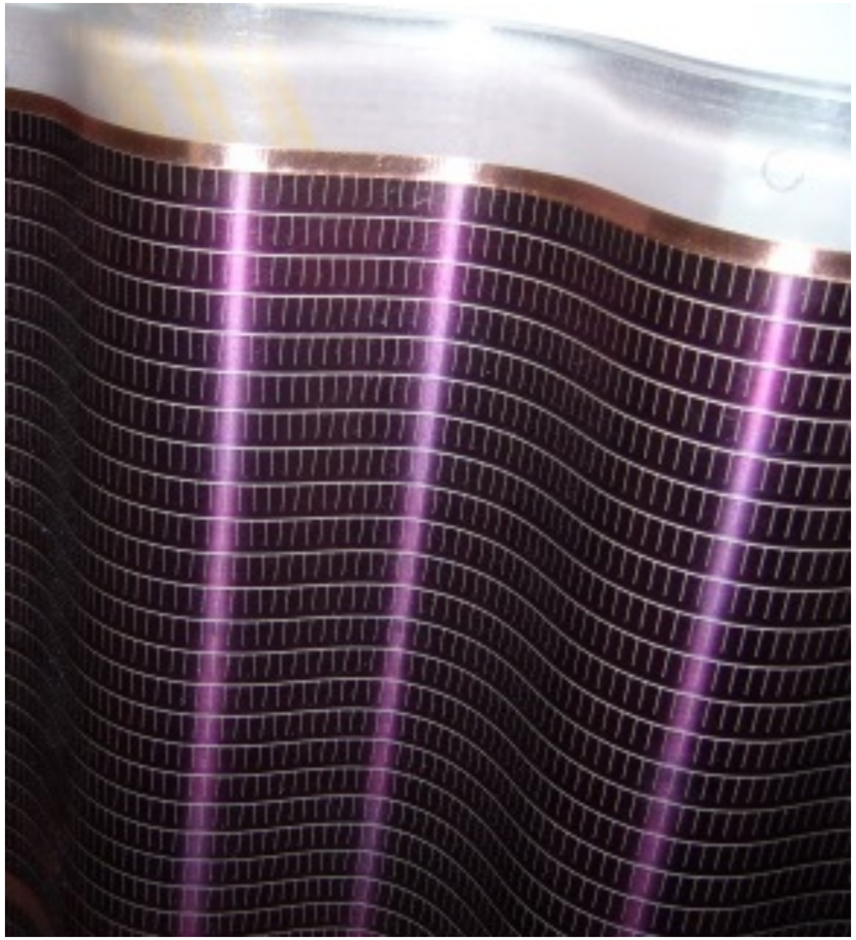
R. Berner et al., *'First Operation of a Resistive Shell Liquid Argon Time Projection Chamber - A new Approach to Electric-Field Shaping'*, *Instruments* **2019**, *3*(2), 28

CONCLUSIONS

There are many applications of resistive coatings in MPGDs.

They can improve the operation stability and the resolution of detectors.

In the future, we will need more materials and more patterning



'Wallpaper' ASIP photo-cell (EPFL/MIT)

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AIDA 2020