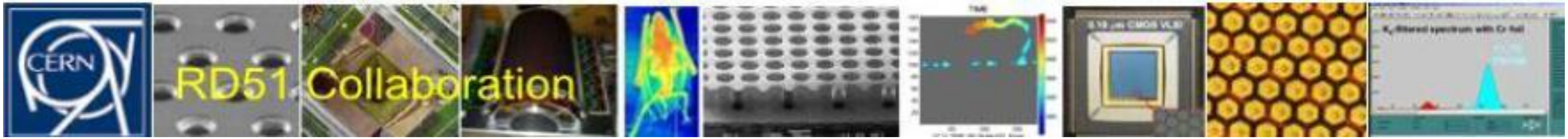


DLC layers for MPGDs

Rui De Oliveira

On behalf of the Resistive DLC Collaboration

University of Science and Technology of China · KOBE UNIVERSITY · CERN · LNF · Lanzhou Institute of Chemical Physics CAS · INFN BARI Istituto Nazionale di Fisica Nucleare Sezione di Bari · EUROPEAN SPALLATION SOURCE

Novosibirsk , 28-02-2020

DLC based electrodes for future resistive MPGDs

Title of project: *DLC based electrodes for future resistive MPGDs*

Contact person: *name: Yi Zhou*
address: Jinzhai Road No.96, Hefei, Anhui, P.R.China, 23
telephone number: +86-551-63607940
e-mail: zhouyi@mail.ustc.edu.cn

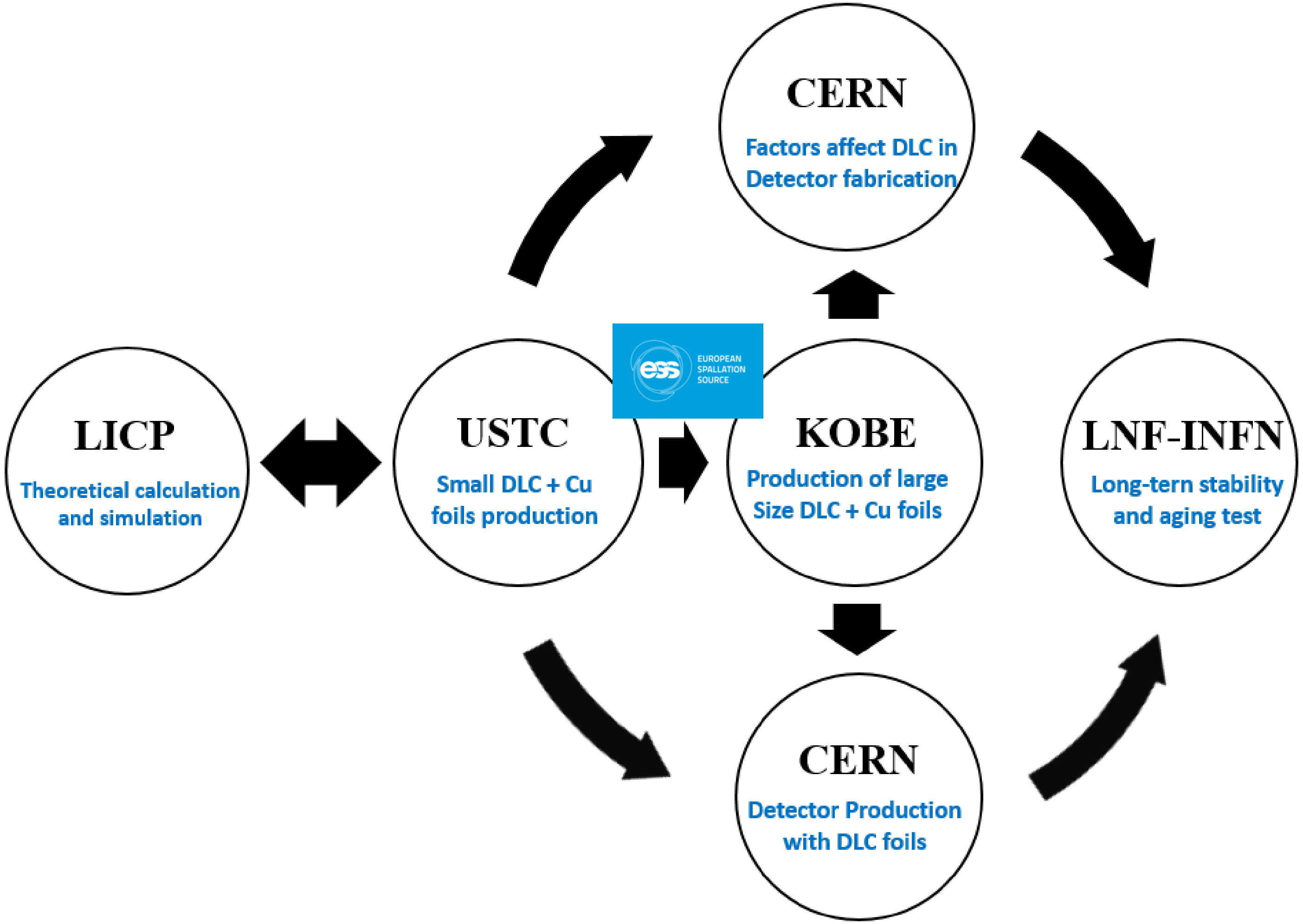
RD51 Institutes:
1. *State Key Laboratory of Particle Detection and Electron*
University of Science and Technology of China,
contact person: Yi Zhou
e-mail: zhouyi@mail.ustc.edu.cn

2. *Kobe University,*
contact person: Atsuhiko Ochi
e-mail: ochi@kobe-u.ac.jp

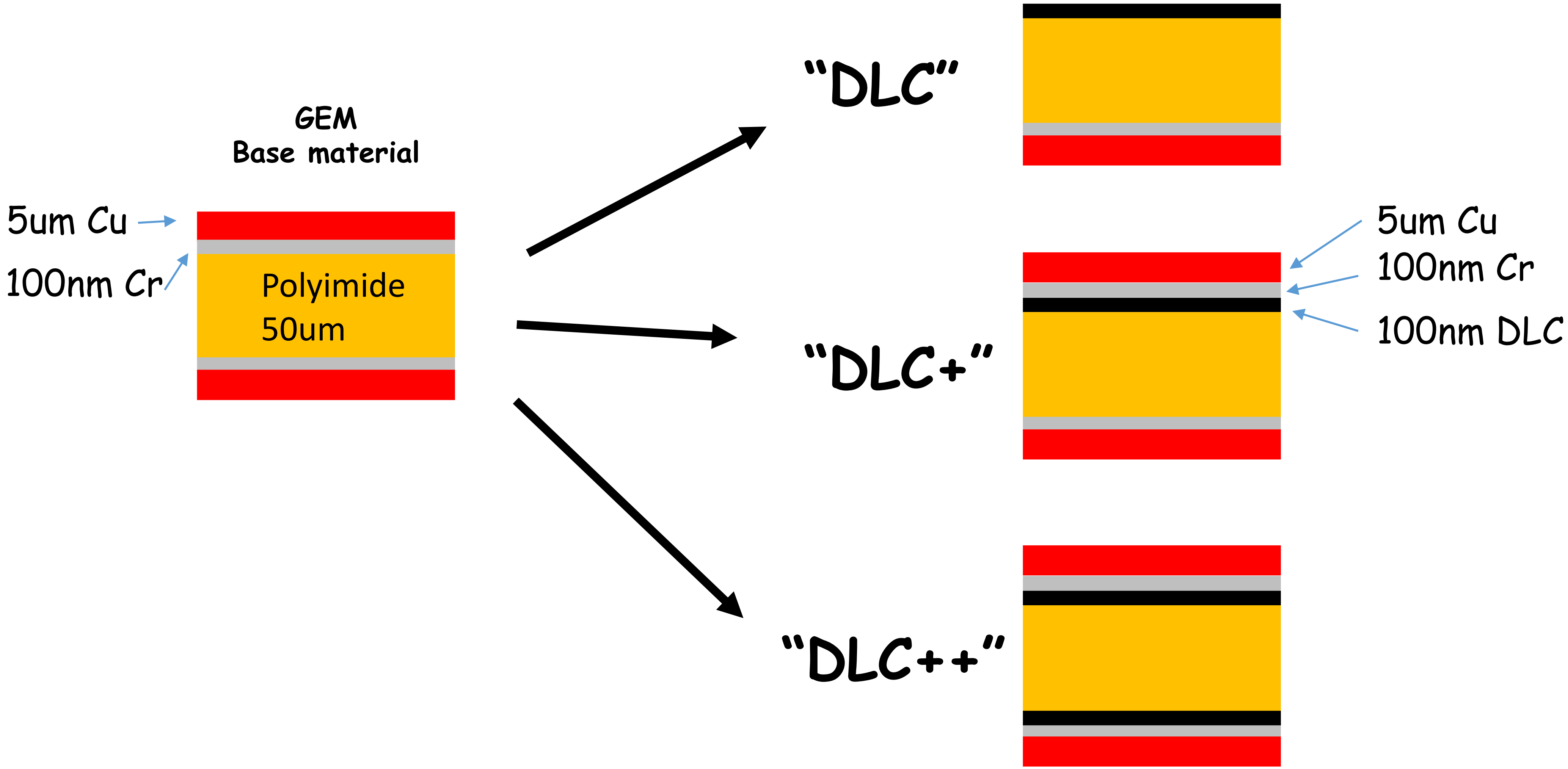
3. *CERN*
contact person: Rui de Oliveira
e-mail: Rui.de.Oliveira@cern.ch

4. *Laboratori Nazionali di Frascati dell'INFN*
contact person: Giovanni Bencivenni
e-mail: Giovanni.Bencivenni@lnf.infn.it

Ext. Collaborators:
1. *State Key Laboratory of Solid Lubrication,*
Lanzhou Institute of Chemical Physics, Chinese Academy
contact person: Lunlin Shang
e-mail: shangll@licp.cas.cn



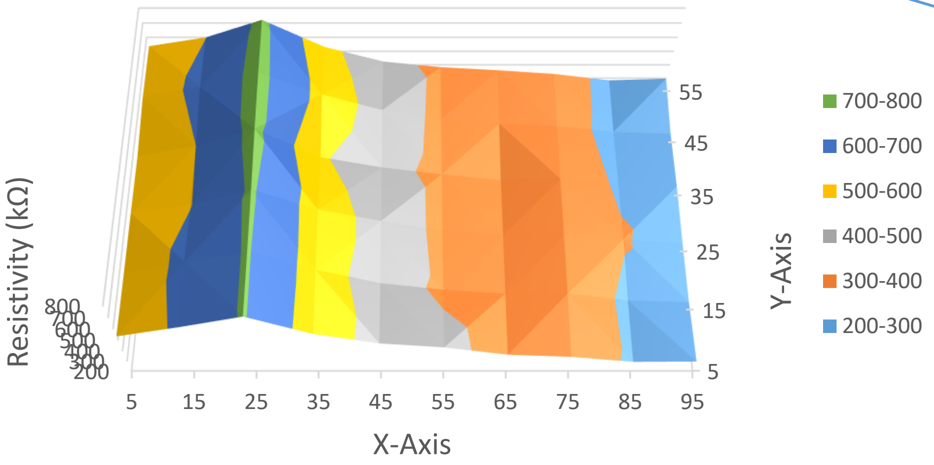
Diamond like Carbon base material

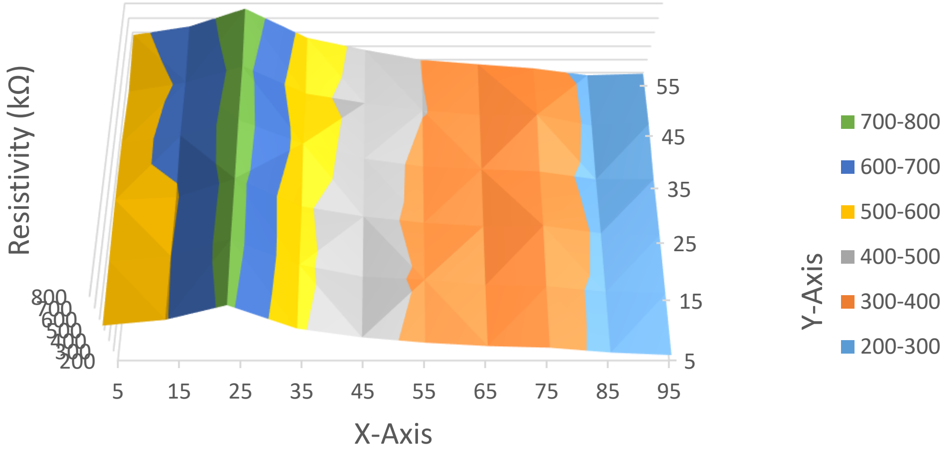


Kobe Japan
B-sputter
4 m x 1m real

ESS
2.1 m x 400mm ?

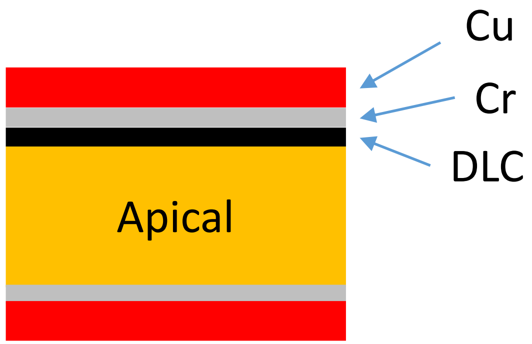
China USTC
1.2 m x 500mm?

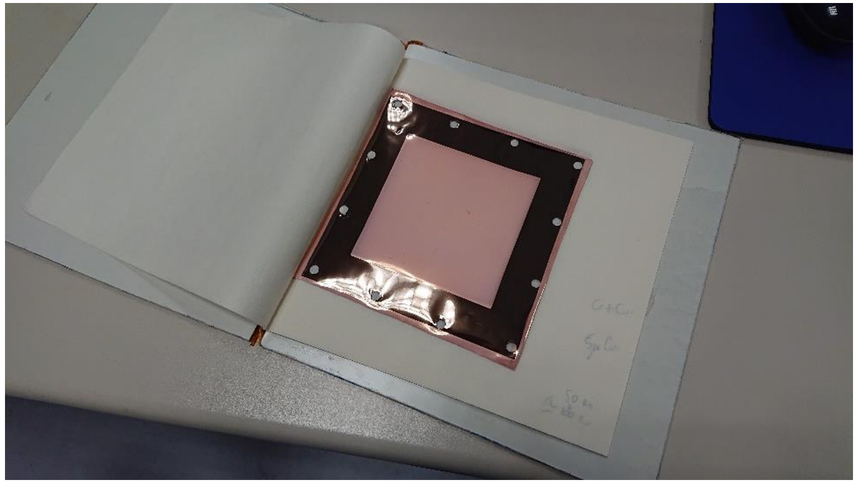


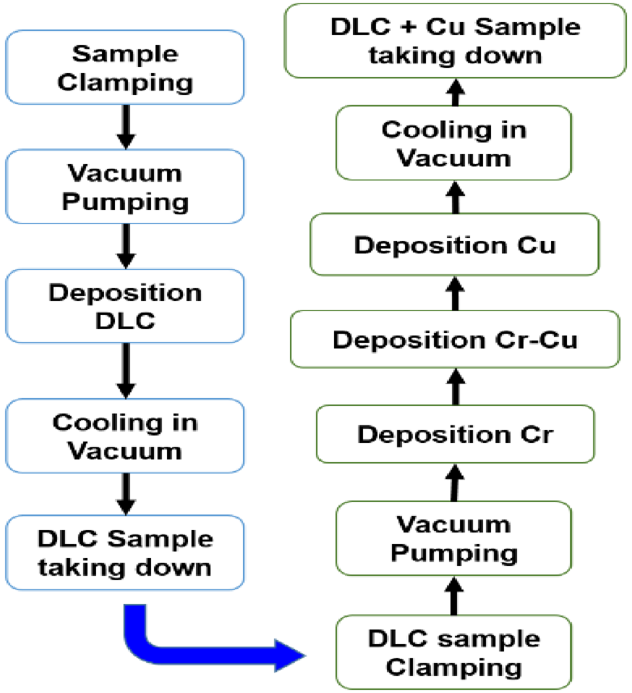


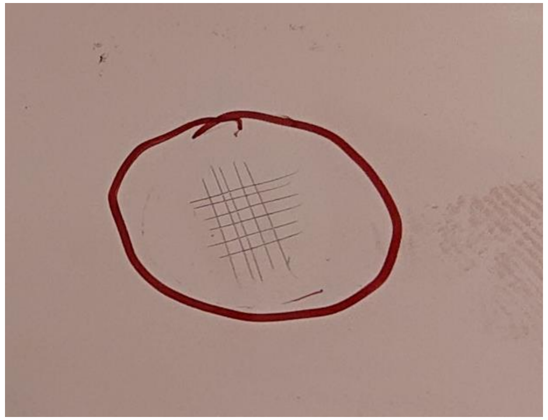
1m x 0.6m foils 500Kohms/square target

“DLC+” adhesion test

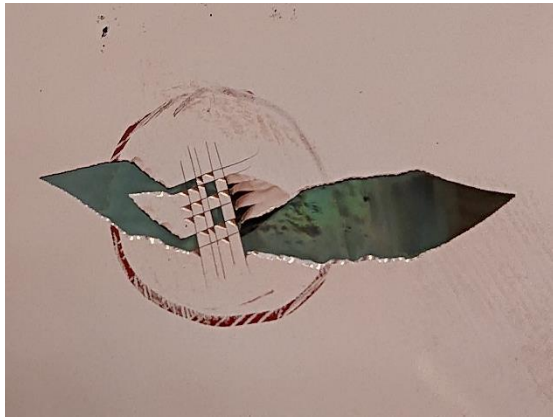








Copper skin scalpel cut



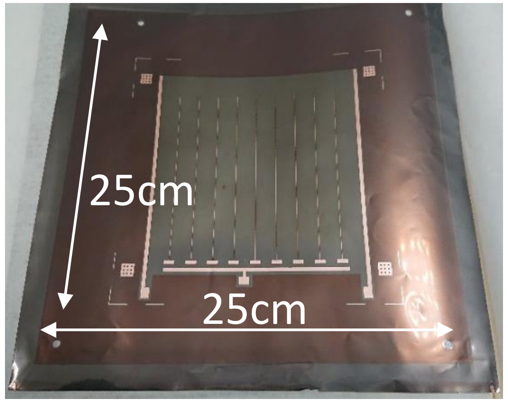
After tape peeling

<u>Copper adhesion force estimation</u>

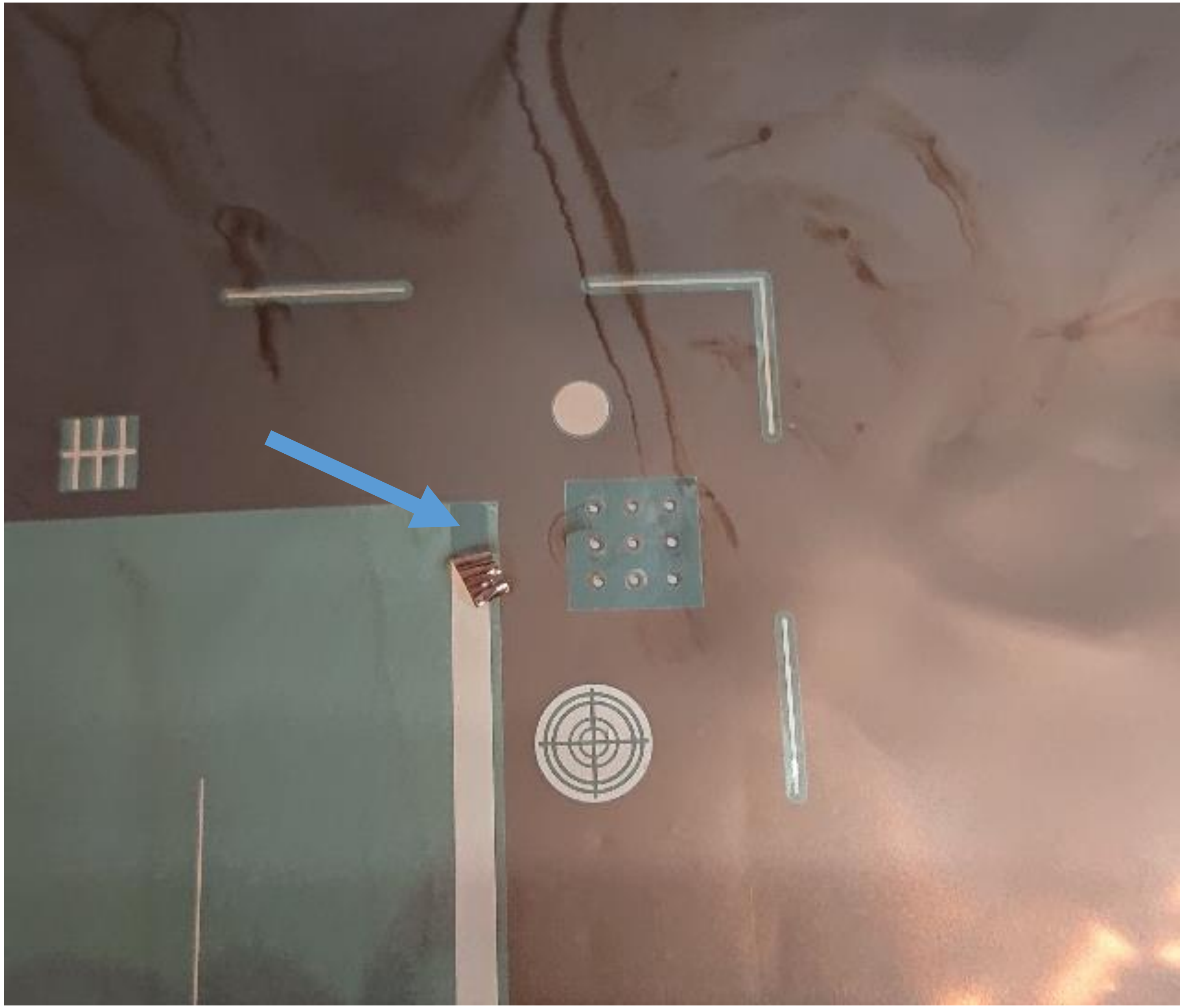
100%	GEM Base material
50%	USTC 300 deg deposition
40%	ESS
30%	USTC

The DLC Value is always lower after copper removal (at USTC and ESS) by a factor of 4 to 10 ?

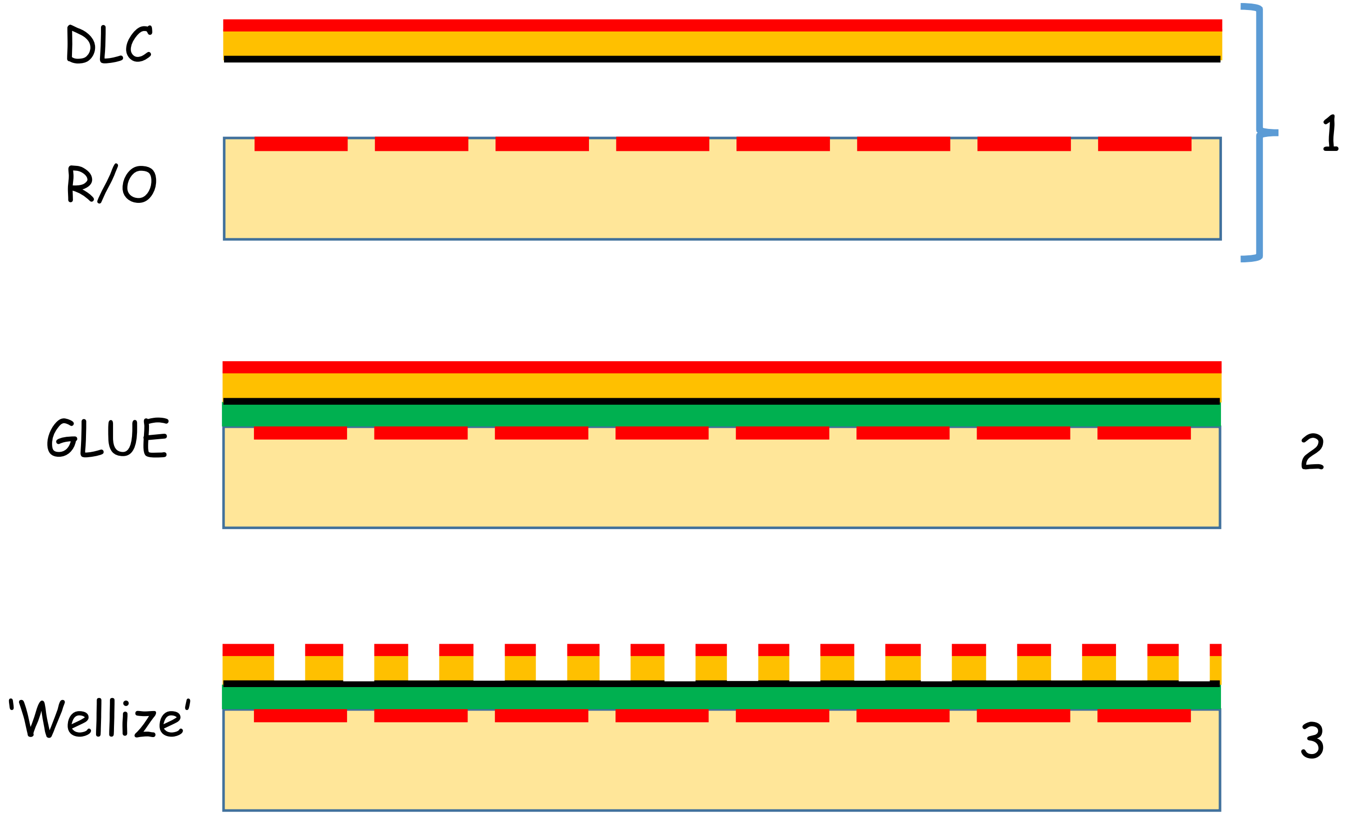
"DLC+" : present adhesion is just at the acceptable level



-20 foils produced recently
-Really Good resistive value repeatability
-Signs of weak adhesion of Cu/Cr on DLC
-Problems on 3 foils over 20



STD uRwell production steps

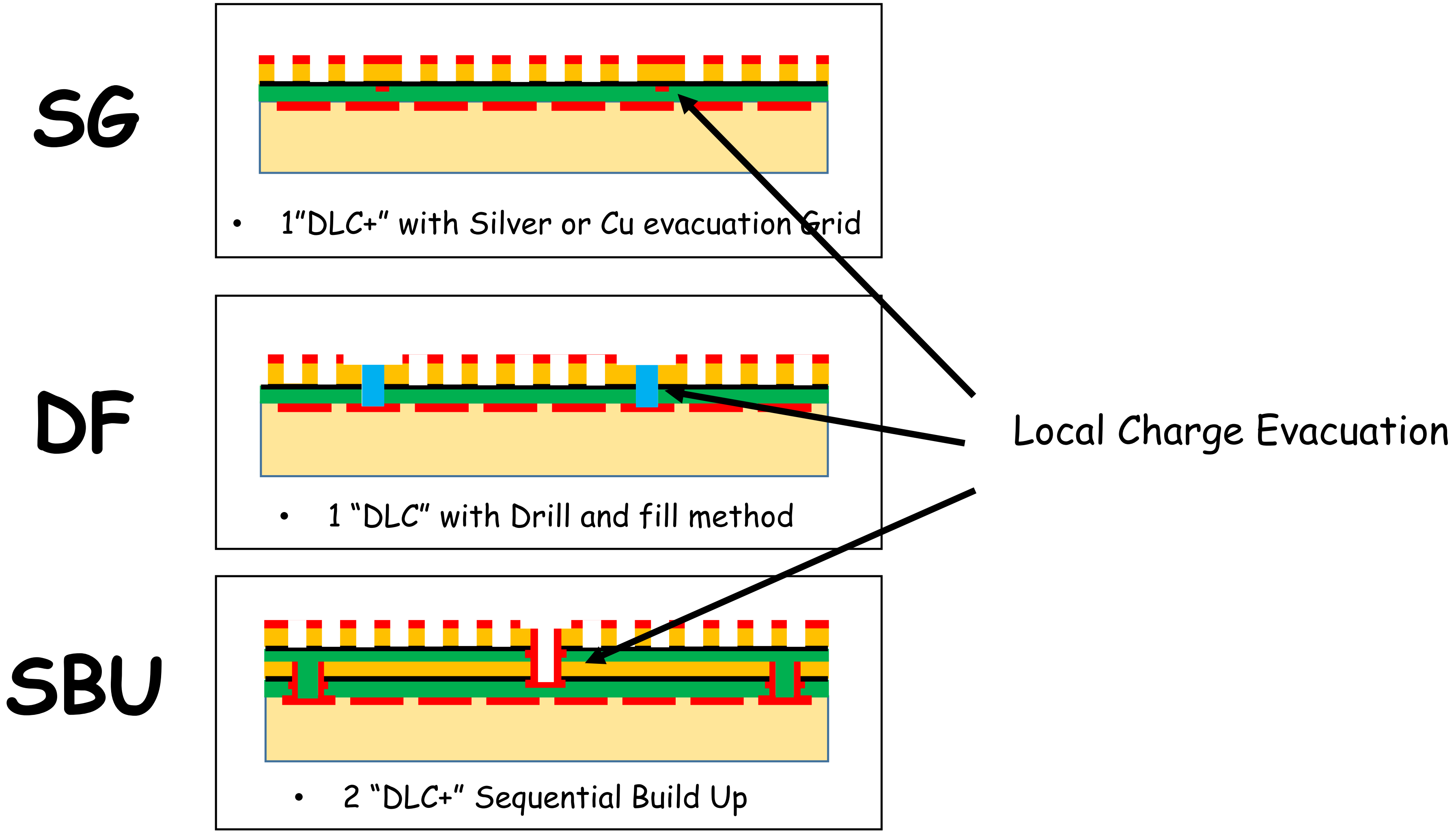


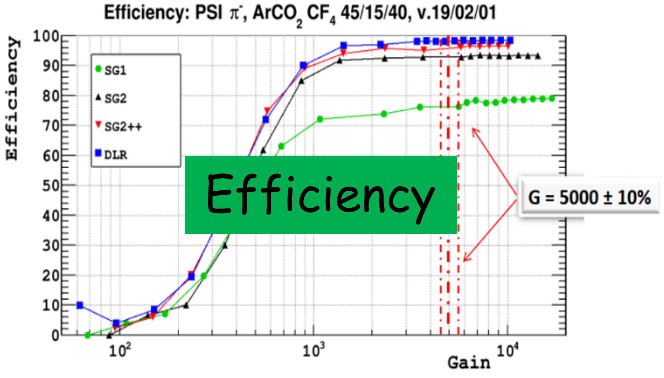
-Really simple construction
-Flexible
-Low cost
-Low mass < $0.15\% X_0$

- rate limitation

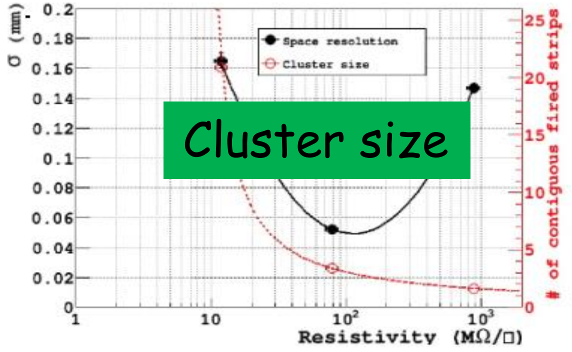
Large μRwell detector
Like CMS GE21 module M4
120cm x 55cm

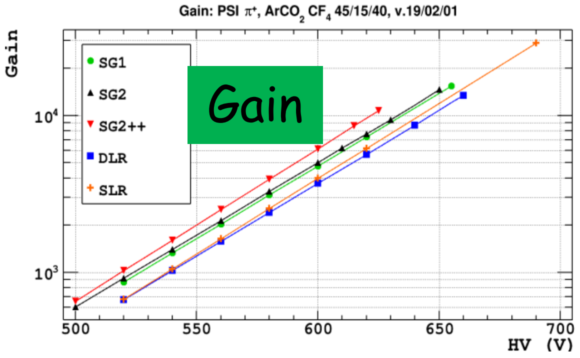
Different high rate μRwell structures

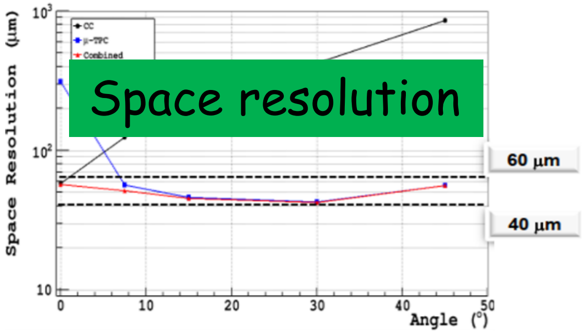


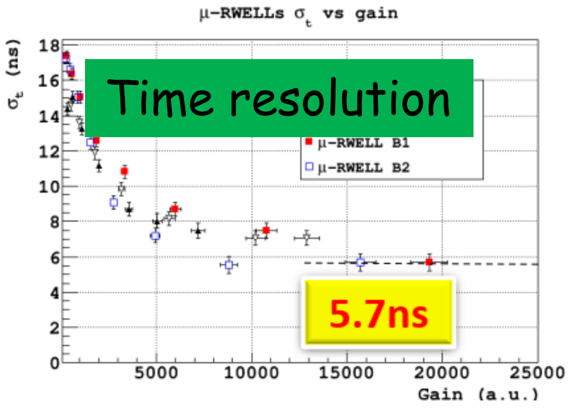


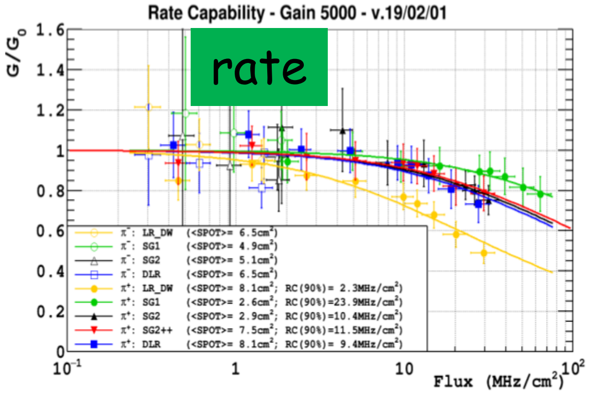
0.4mm strip pitch







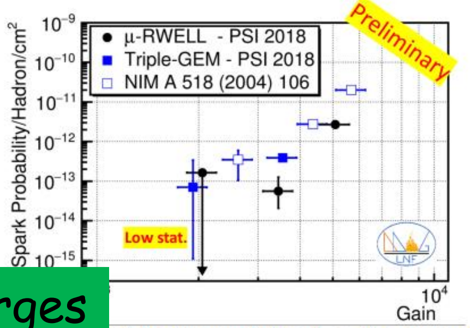




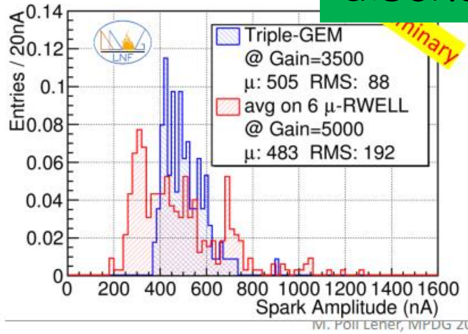
Discharge studies

The μ-RWELL discharge probability measured at the PSI, and compared with the measurement done with GEM at the same time and in the 2004 (*same gas mixture* - ***Ar:CO$_2$:CF$_4$ 45:15:40***).

The measurement has been done in current mode, with an intense 270 MeV/c π^+ beam, with a proton contamination of the 3.5%.



discharges



…e” has been defined as the current spike exceeding the steady current level correlated to the particle flux (~90 MHz on a ~5 cm^2 beam spot size).

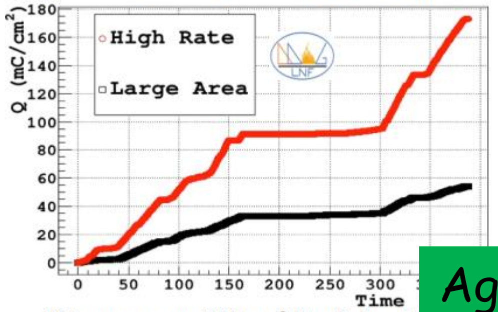
The discharge probability for μ-RWELL comes out to be slightly lower than the one measured for GEM.

Moreover its discharge amplitude seems to be lower than the one measured for GEM.

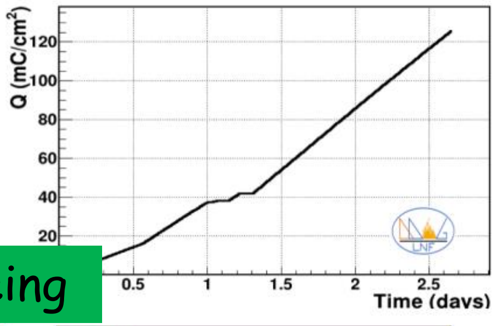
M. Poli Lener, MPDG 2019 - La Rochelle, 10/05/2019 16

Ageing studies (on going)

GIF++ - Full area & Flux = 200 kHz/cm^2

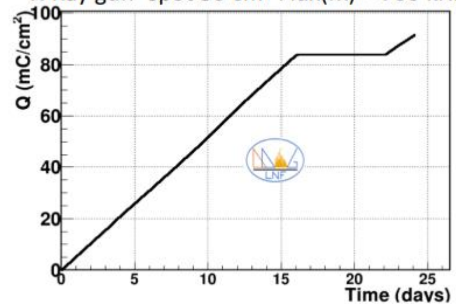


TB PSI – beam spot 9 cm^2 – Flux= 10 MHz/cm^2



Ageing

X-Ray gun- spot 50 cm^2 Flux(rx) = 700 kHz/cm^2



GOAL:
Integrate a charge up to 6 C/cm2

Slice test of u-RWELLs during RUN3 in the LHCb Muon APPARATUS under discussion

17

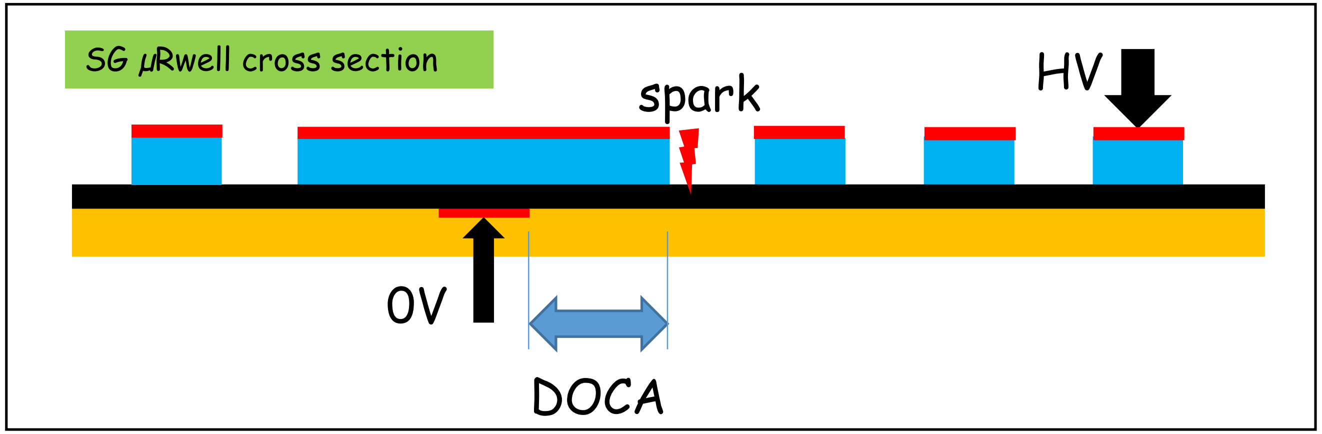
+Material long term stability

Protections to survive overvoltage

Overvoltage means sparks
→Possible voltage breakdown of materials and large local energy release
→DOCA protection (Distance Of Closest Approach)

Breakdown voltage	
PI	420 V/um
Perfect DLC	650 V/um
real DLC (average)	10 V/um
Copper	NA

Of course, dielectric strength are greatly impacted by impurities, dopants, structure, interconnected porosity, flaws and micro-cracks from thermal expansion mismatches



Material	Thermal conductivity W/mK	Melting Celcius
Glass epoxy	0.2	200
PI	0.18	400
Copper	384	1085
Natural diamond	1350	700

First problem: DLC layer breakdown due to the voltage set by the spark.

-if DLC is damage by Voltage Breakdown → no spark control

- Good DOCA cancel this problem

Second problem : electron/ion bombardment during spark

- bombardment →temperature rise due to joule effect → material evaporation → material condensation→ current instabilities

- Bonbardment effects can be mitigated

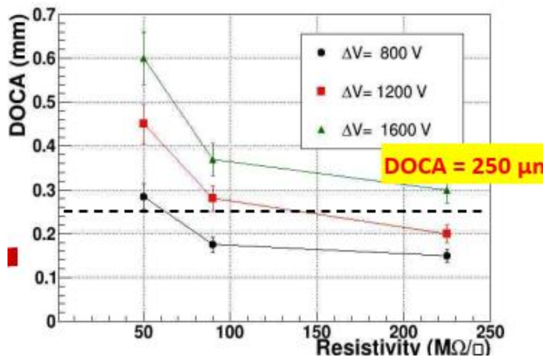
-avoid repetitive sparks → remove contaminants (dust, ions from chemicals).

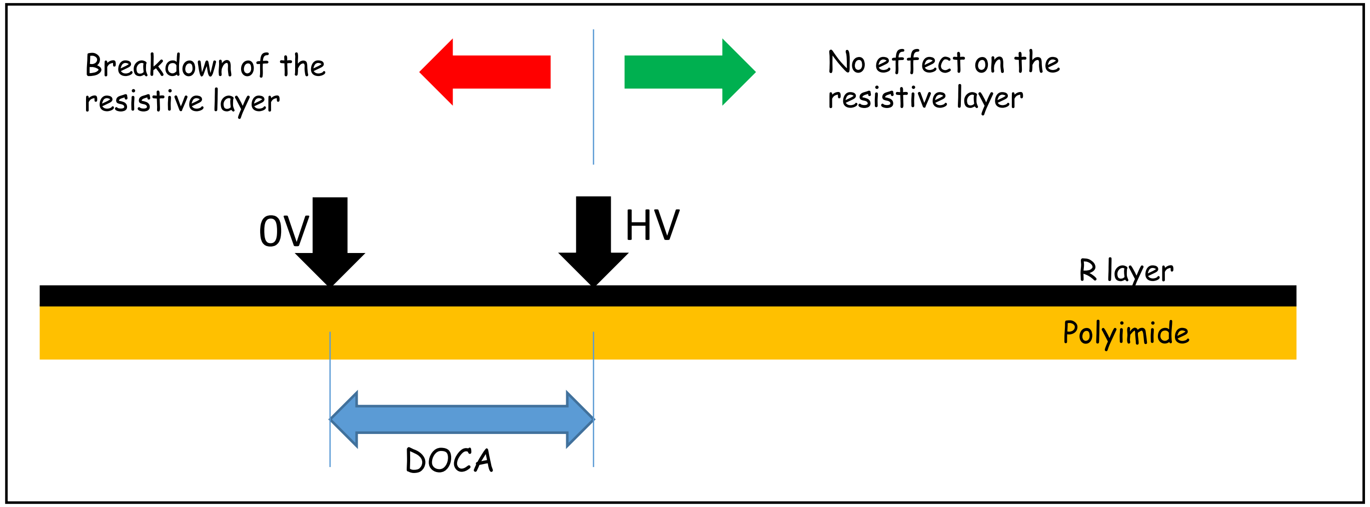
- choose high melting temperature materials to lower the evaporation

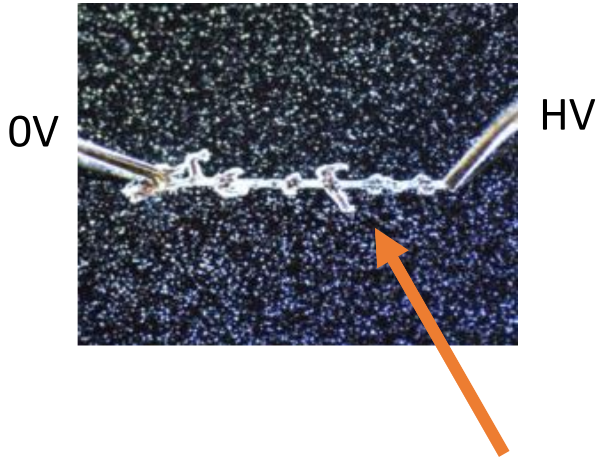
-choose good thermal conductivity & thicker layers materials to cool the reaction

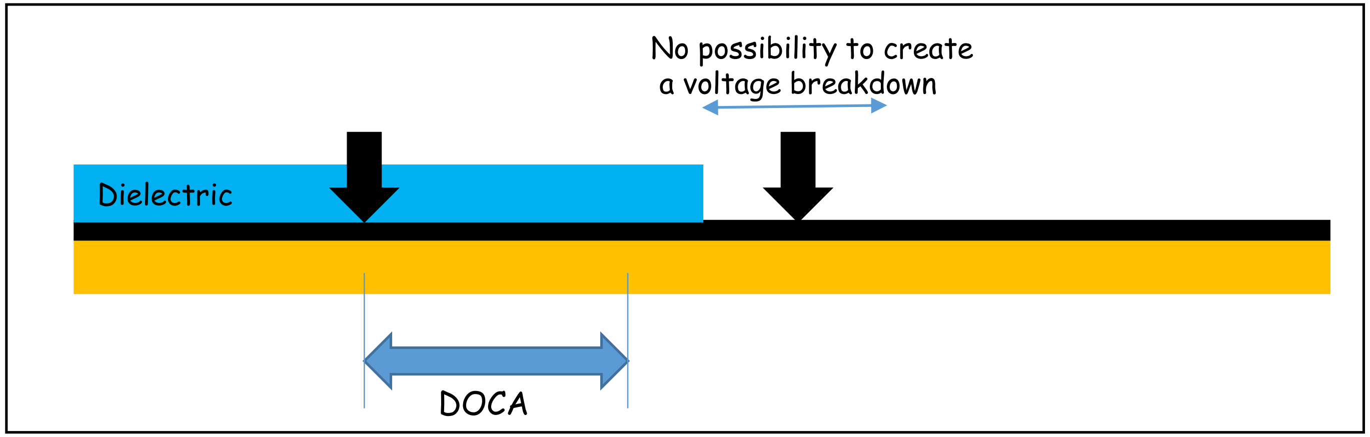
-DLC value can reduce spark energy

DOCA to prevent DLC BV



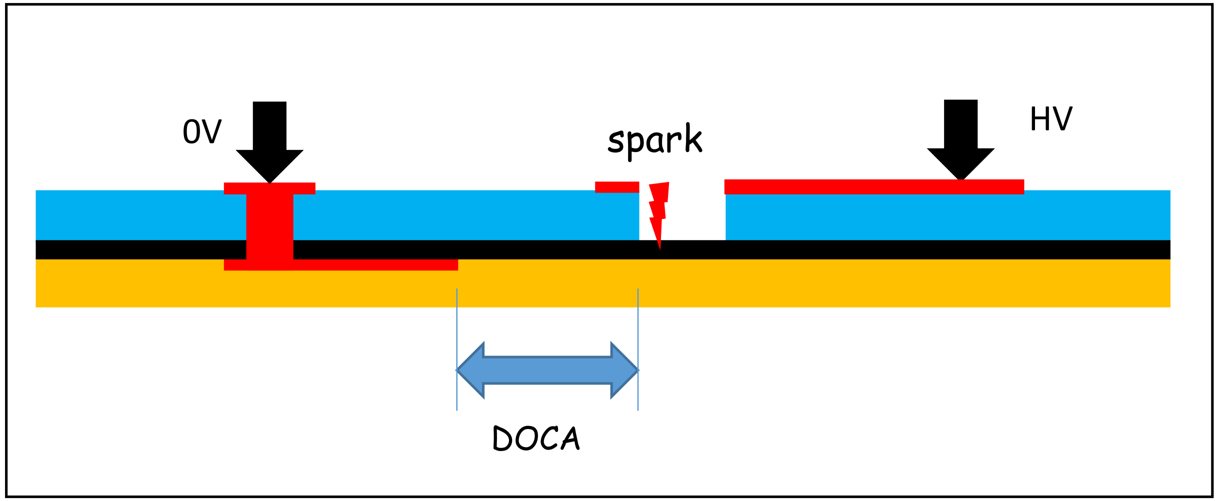


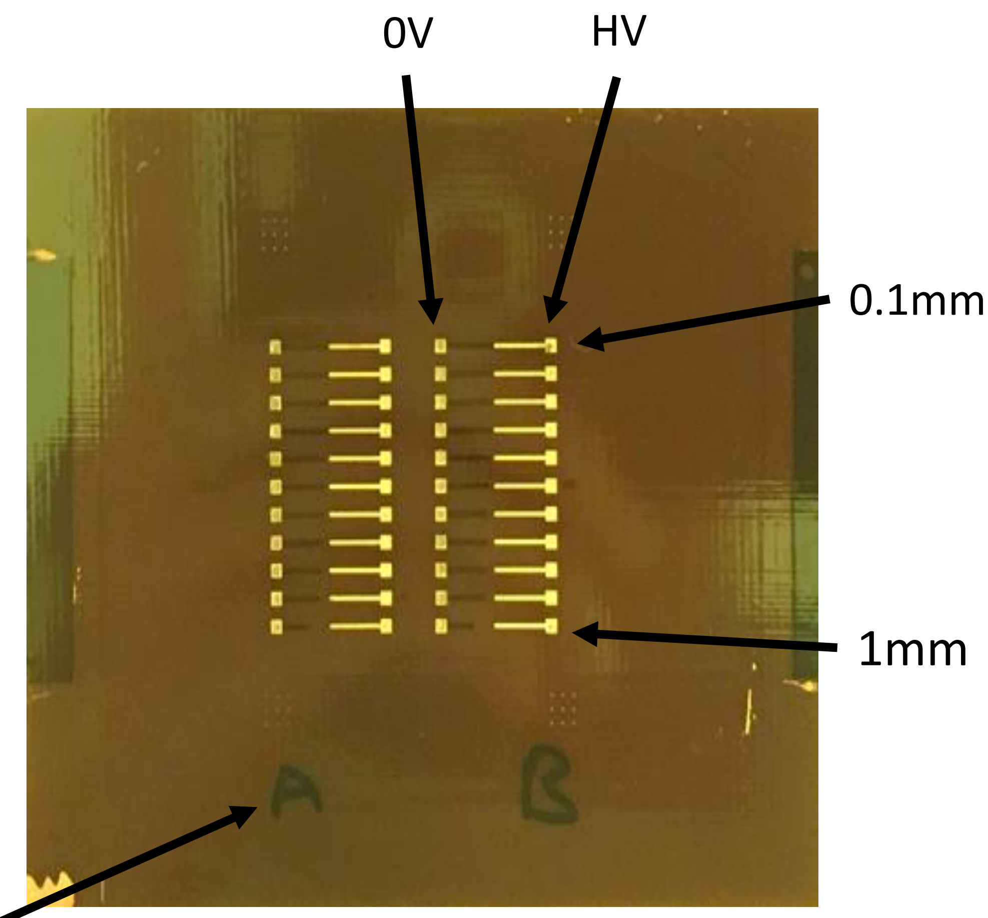




A breakdown of the resistive layer means creating a low Ohmic channel in the layer

test with real sparks

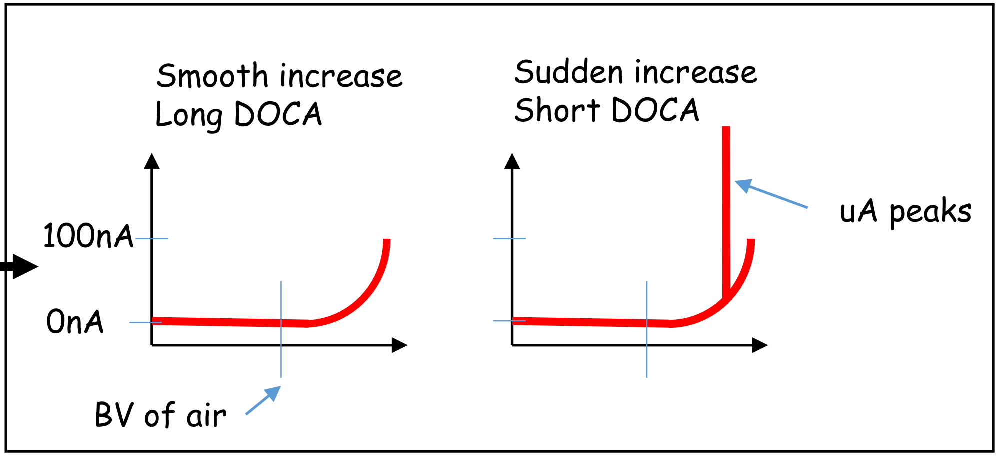




-Columns of 11 patterns → DOCA ranging from 0.1 up to 1 mm
-Single hole test
-DLC 60M-70M/Sqr
-4 columns of 11 patterns have been tested (A,B,C,D)

Observations

- Leakage current start at 800V in air!
  - We were expecting 650V air BV for a 50um gap (like GEMs)
- The current shape during overvoltage depends on DOCA distance
  - Smooth current increase with long DOCA → small material deposition after evaporation ?
  - Sudden increase to uA with small DOCA → larger deposition ?



- After 30 sec with 30nA in one hole we start to see voltage drop
  - After several session of 30s , it stabilize at 550V / 650V (0 current voltage)
  - No visible damages on any structures.
  - There is obviously electric signs of material deposition
  - Unfortunately it was impossible to count sparks
- Next step will be to look at the "sparks" current shape when operating above Air BV
  - We would like to study the single hole spark current shape and rate with a fast oscilloscope .
  - This is possible with DLC since we have time before damaging the device
- Preliminary results : with 60Mohms/Sqr DLC , the DOCA can be as low as 0.1mm without visible damages

Observations

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  - We were expecting 650V air BV for a 50um gap (like GEMs)
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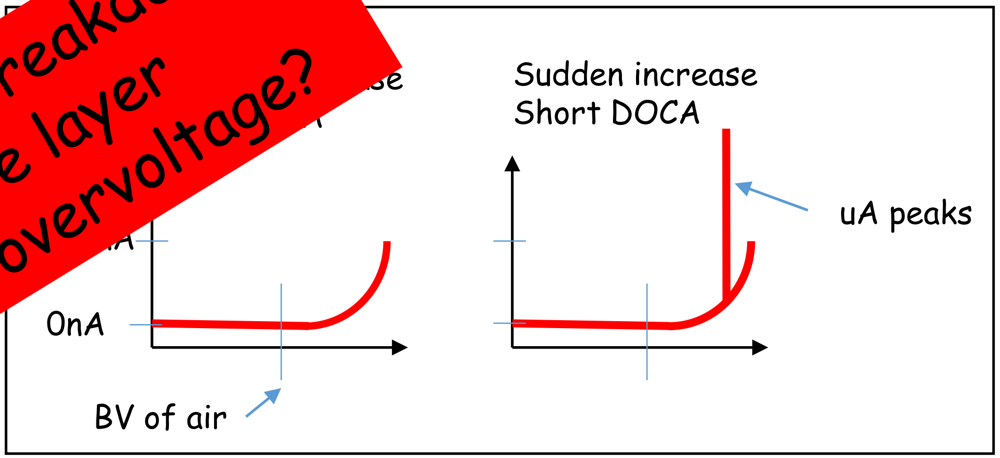
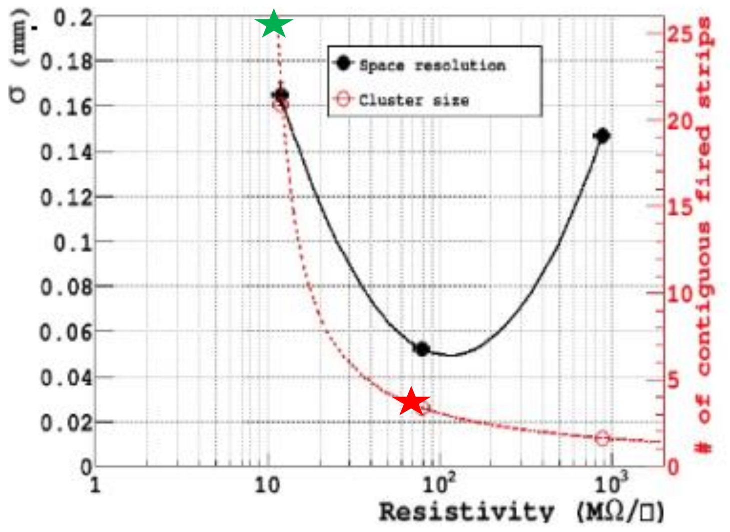


We were looking for resistive layer breakdown
→No breakdown of the resistive layer
instead 2 different behaviours at overvoltage?

What is the energy released level during spark ?

0.4mm strip pitch



★ Cluster size 10M → 25 strips

★ Cluster size 70M → 4 strips

1 X

★ 70M DLC → 4 strips fired

fired area : 1.6mm diameter

"fired area" capacitor C=C1+C2

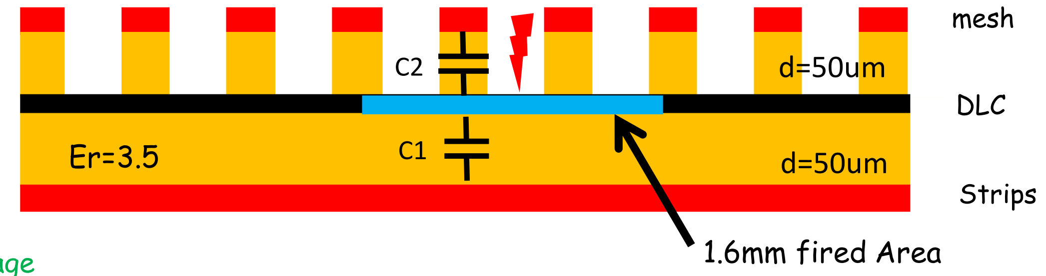
C1 = E0 x Er x A/d → 2pF

C=C1+C2→ 4pF

E=1/2 CV2

E= 0.5 uJ → reference energy

Smooth current increase in overvoltage



25 X

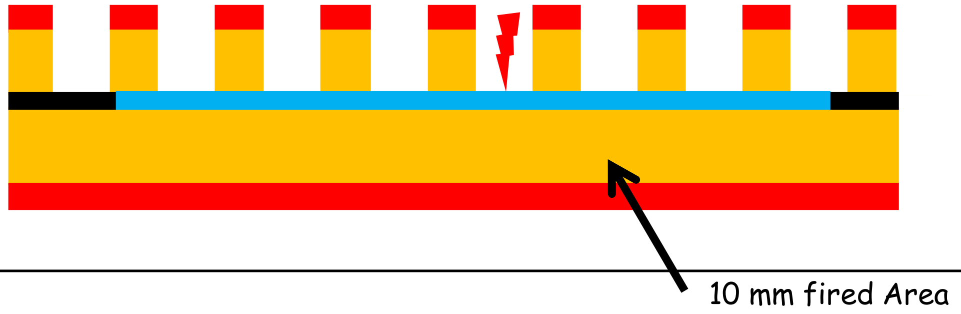
★ 10M DLC → 25 strips fired

fired area : 10mm diameter

C=C1+C2→ 100pF

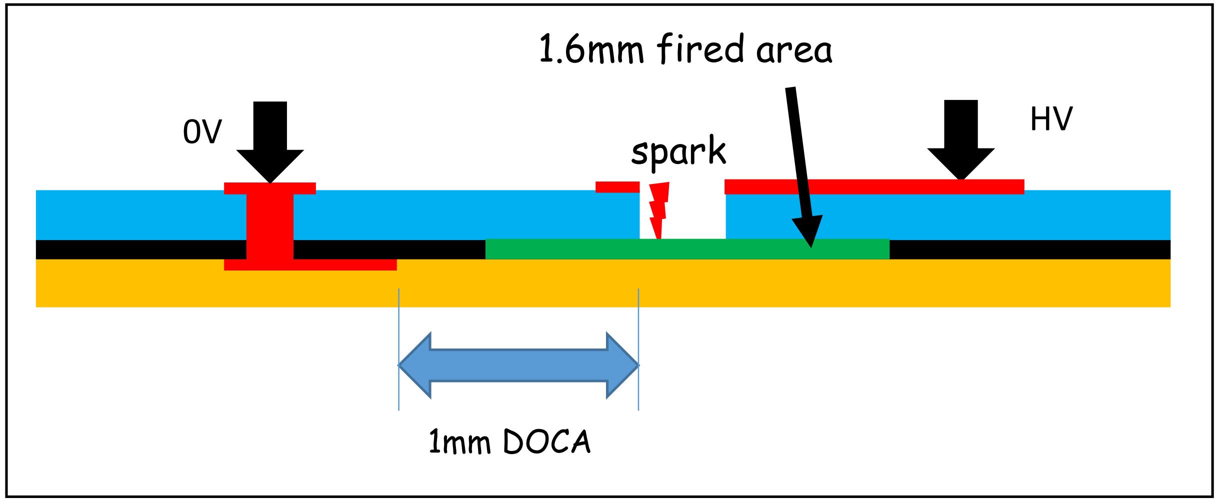
E= 12.5 uJ → 25x more energy

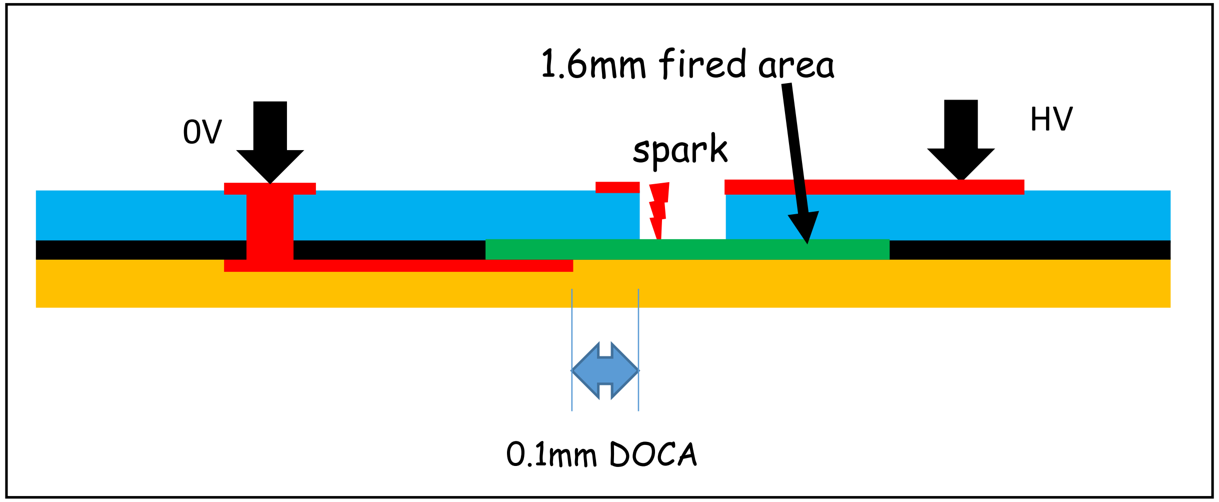
High current spikes in overvoltage



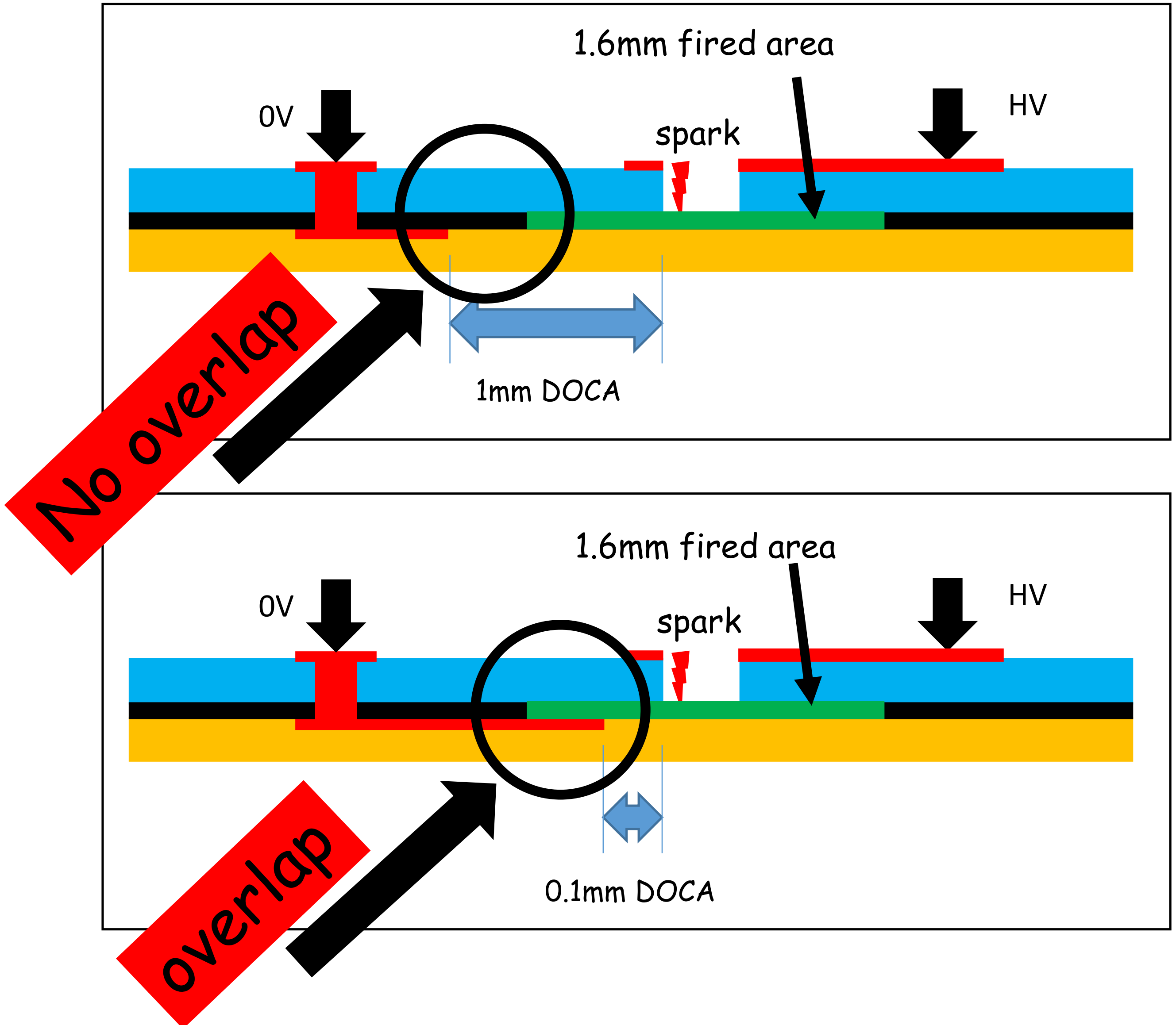
1000 X for a 10cm x 10cm GEM

Possible explanation of the DOCA Test results ?

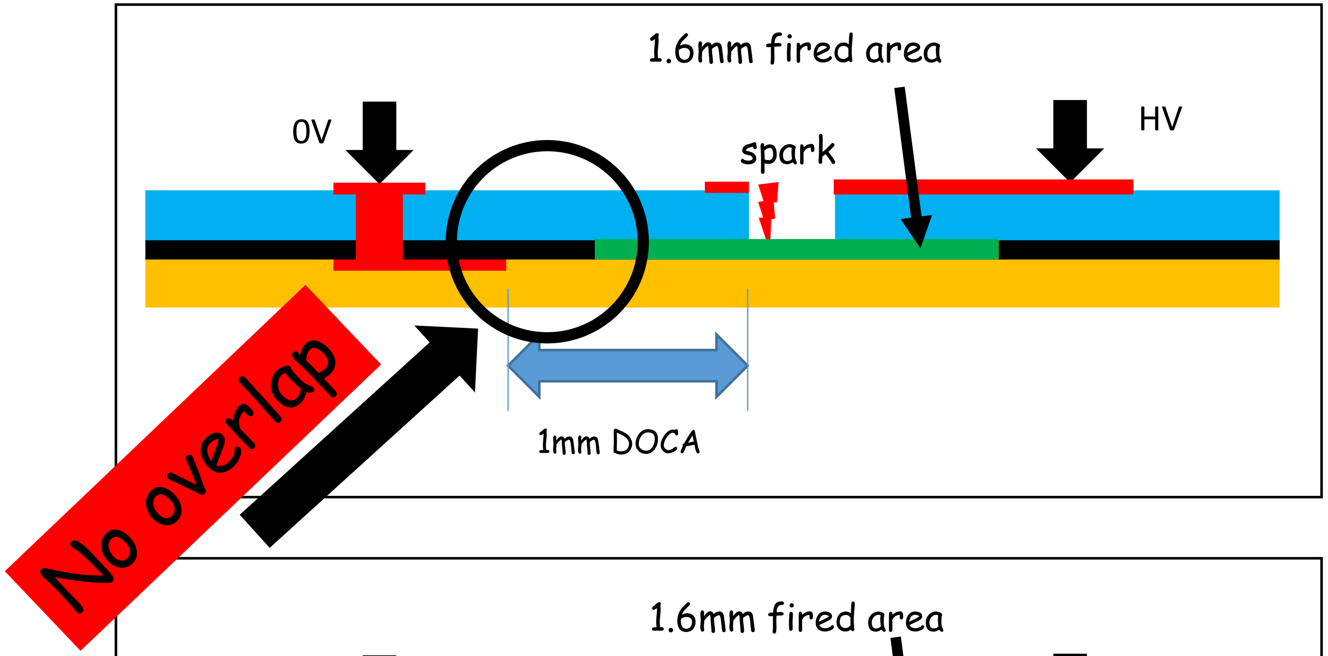




Possible explanation of the DOCA Test results ?

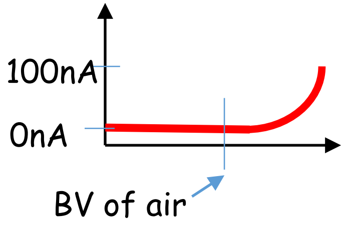


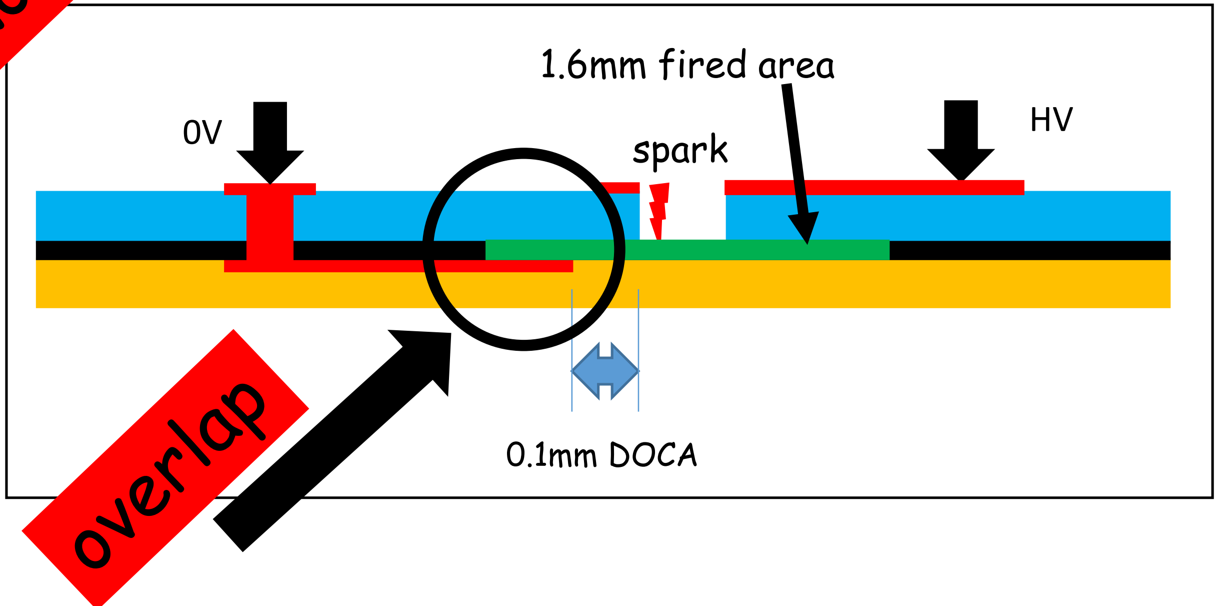
Possible explanation of the DOCA Test results ?



The spark energy comes only from the fired area capacitor

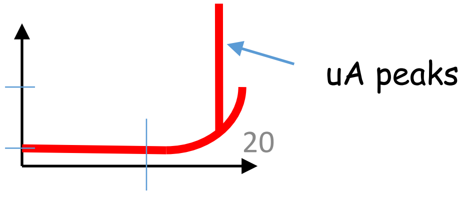
We keep control



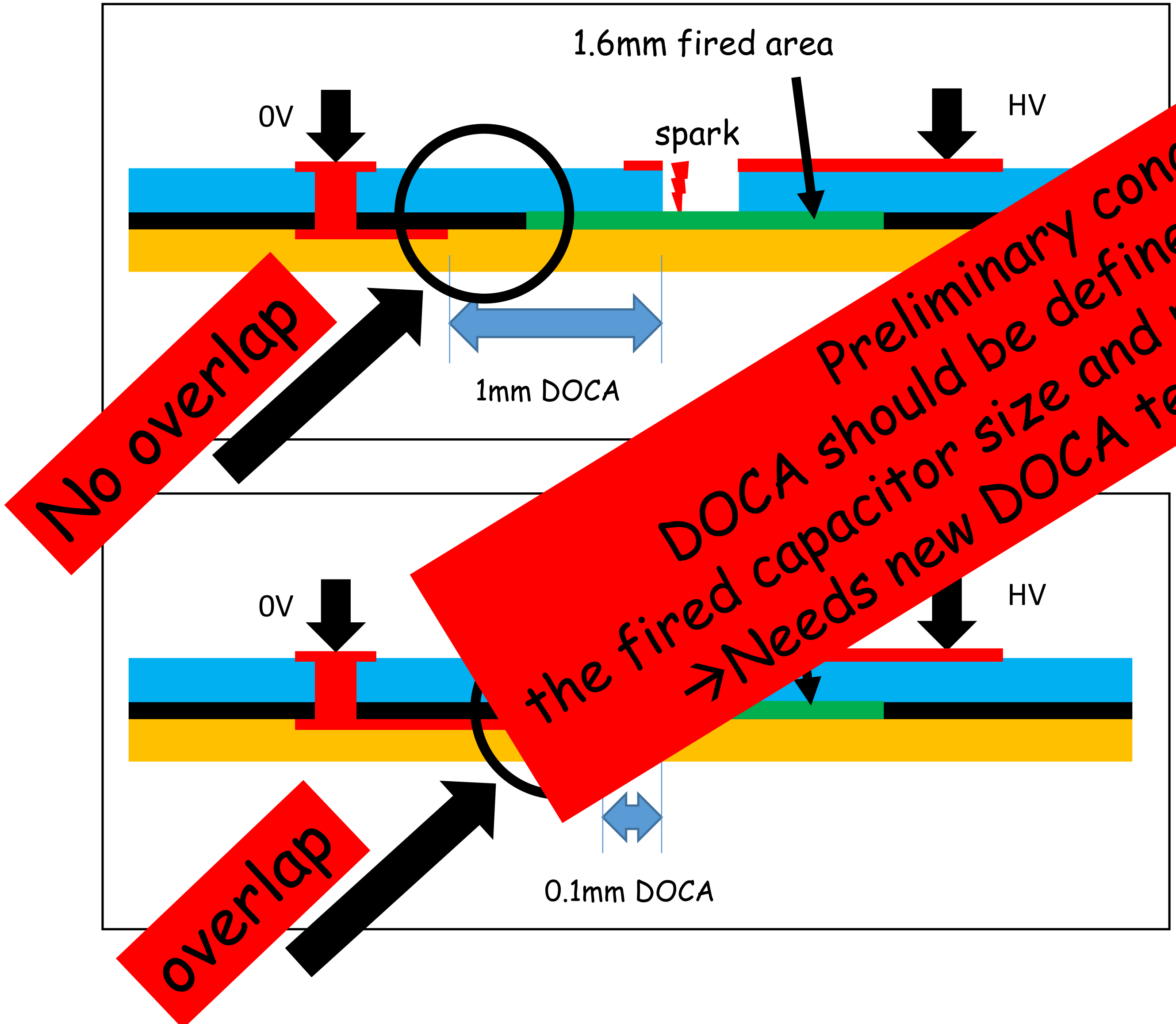


The spark energy comes from the fired area capacitor
+ HV connection + cabling
+ power supply effects

We loose control



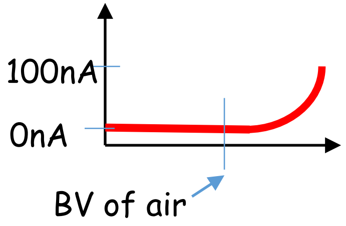
Possible explanation of the DOCA Test



Preliminary conclusion
DOCA should be defined taking care of
the fired capacitor size and resistive grounding design
→Needs new DOCA tests for precise values

...rgy comes only from
...area capacitor

...e keep control



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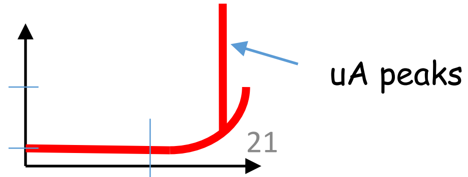
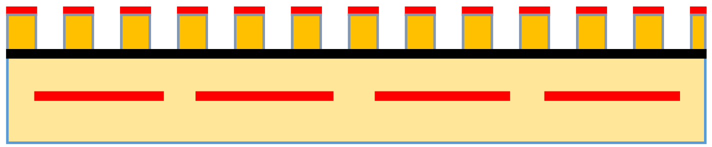


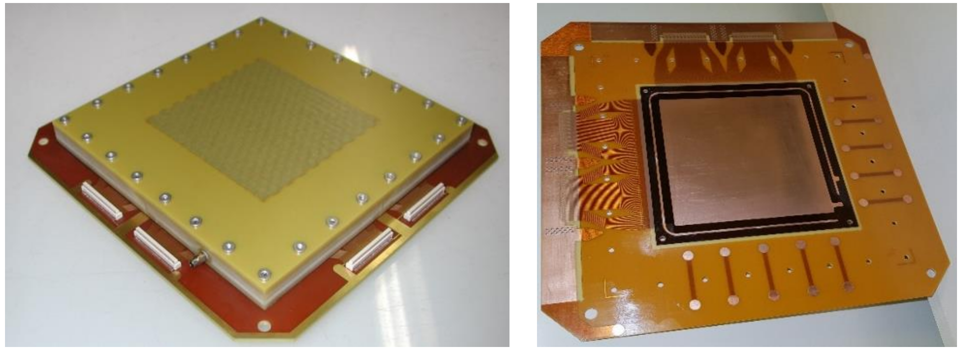
Production

Different μRwell structures

μRwell



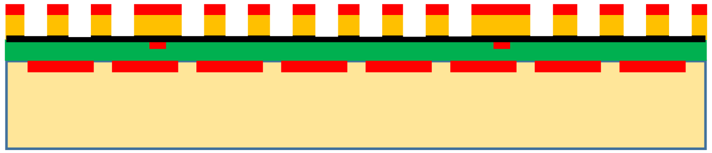
- Single "DLC" layer



10cm x 10cm
μRwell detector
"study kit"

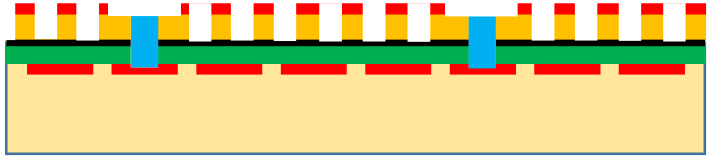
High rate detectors

SG



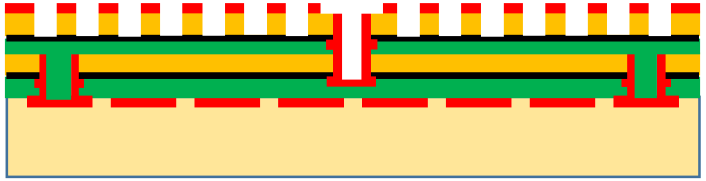
- 1"DLC+" with Silver or Cu evacuation Grid

DF



- 1 "DLC" with Drill and fill method

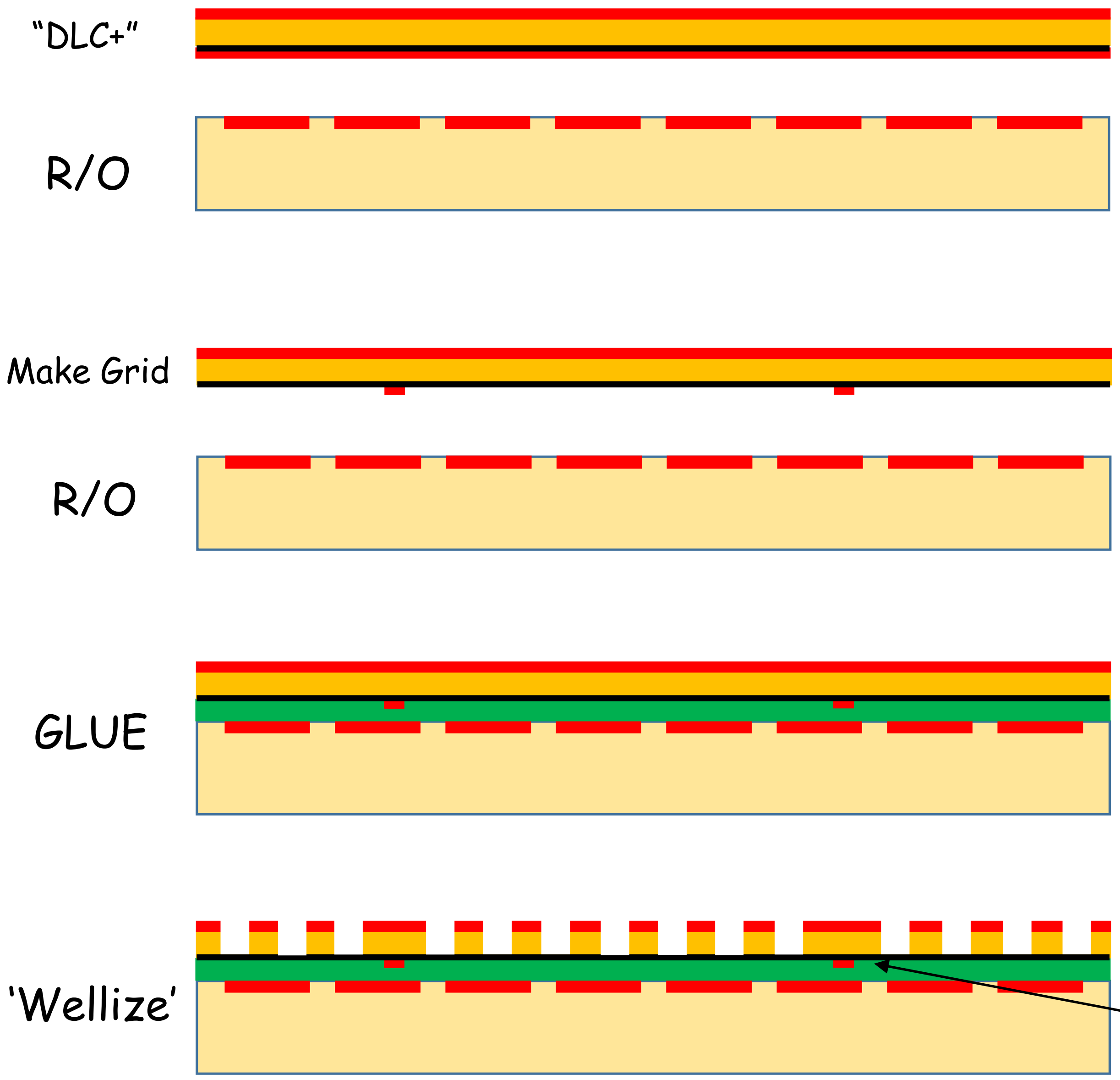
SBU



- 2 "DLC+" Sequential Build Up

SG type:

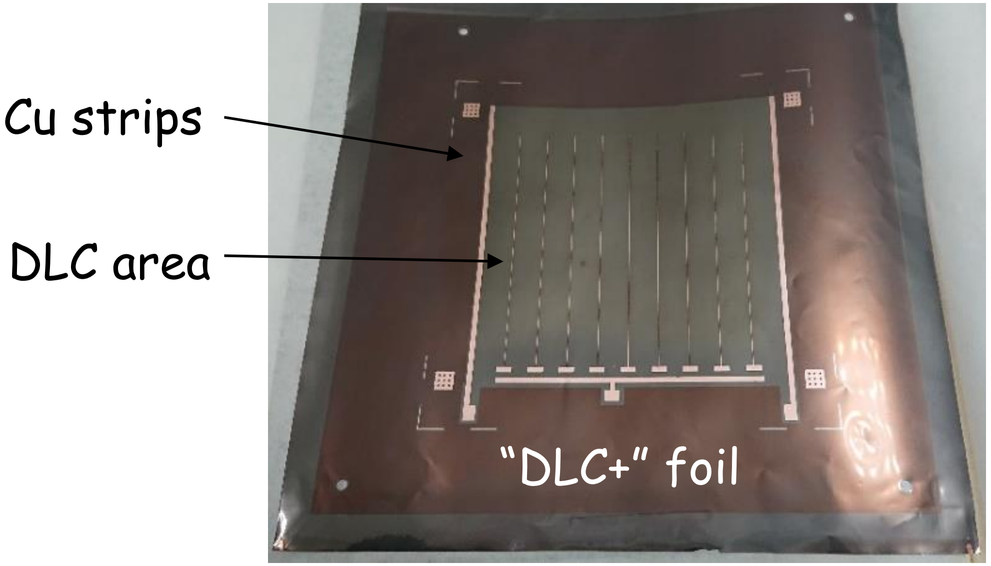
Silver/Cu Grid



-Simple construction
-Adjustable evacuation point density VS rate

-Needs precise DOCA

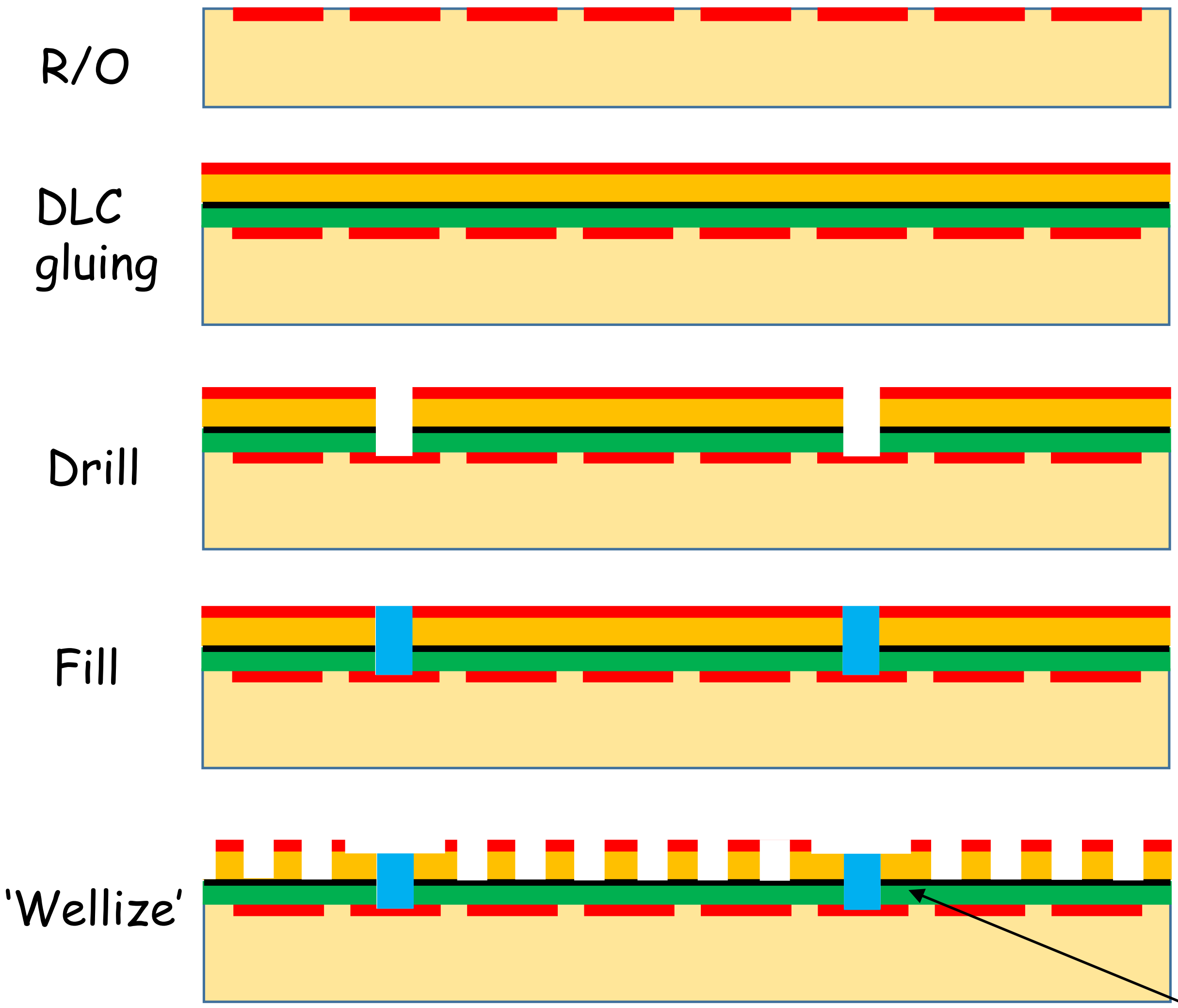
-Needs "DLC+" Foils
-Large size detector registration



DOCA : 0.25mm
0.1mm grounding line
0.6mm dead line

DF Type

Drill and Fill

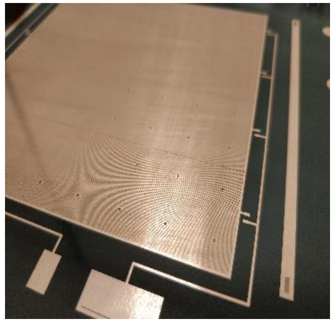


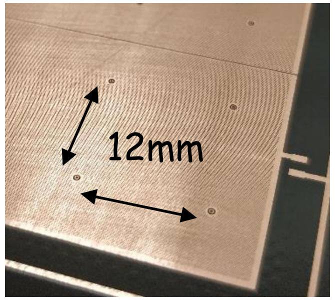
-Simple construction
-Adjustable evacuation point density VS rate
-Needs simple DLC foils
-No problem for large size production

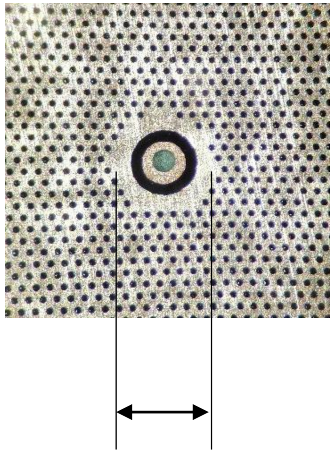
-Needs precise DOCA

-DLC to silver contact need to be improved

DOCA : 0.25mm
0.2mm hole
0.7mm dead zone







SBU type

Sequential Build Up

R/O

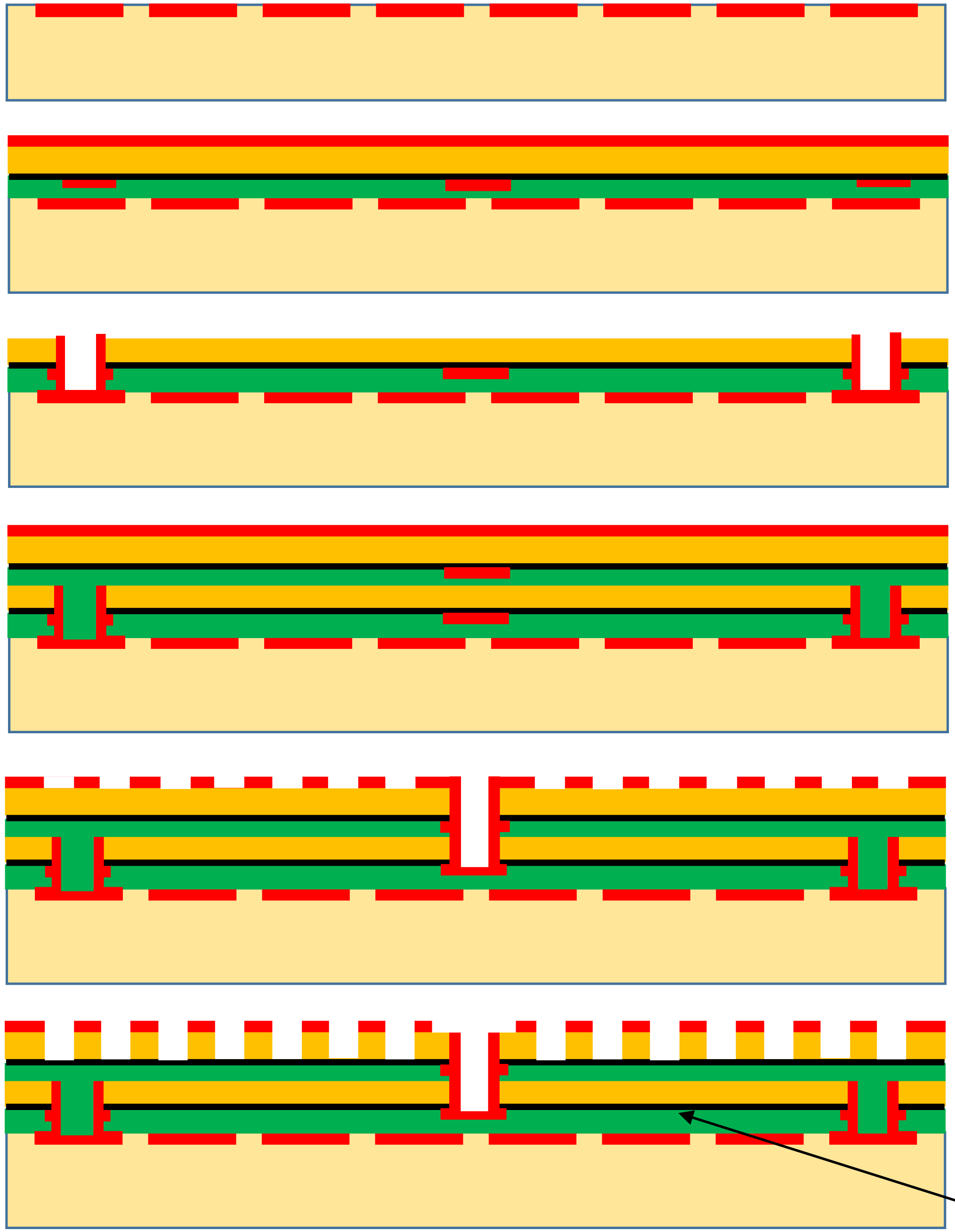
DLC+
Pattern Pads
& Glue

Drill
Plate
& Etch

DLC+
Pattern Pads
& Glue

Drill
Plate
& Etch

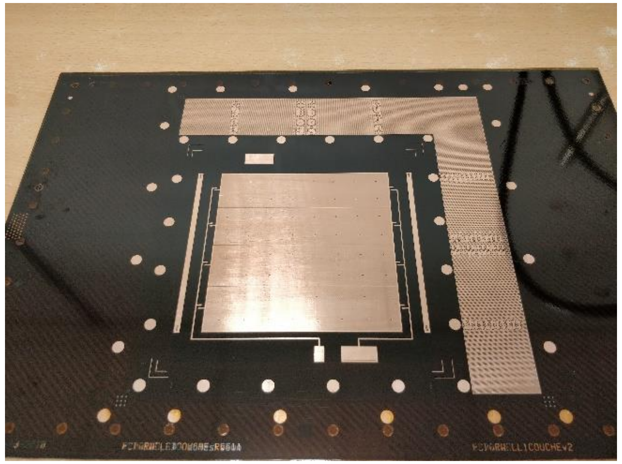
'Wellize'

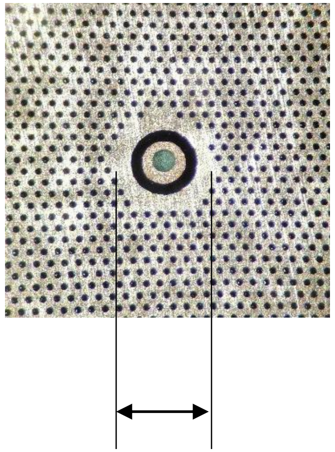


DOCA : 6mm

- -Extra Large DOCA
- -Adjustable evacuation point density VS rate
- -100% compatible with STD PCB processes

-Needs DLC+ base material

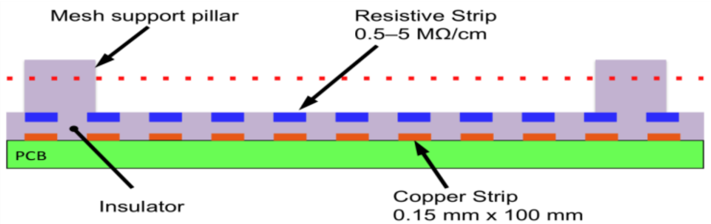




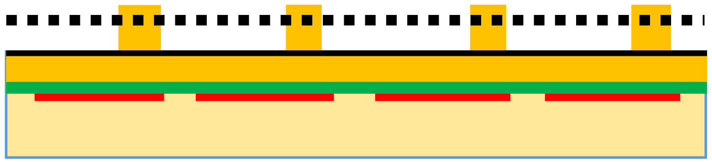
0.7mm

Different Resistive protection approach with Micro-Megas

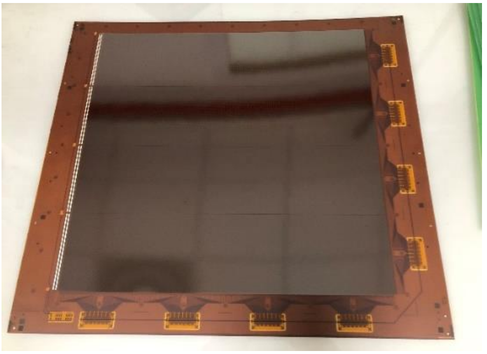
Medium rate detectors



- Single layer screen printed



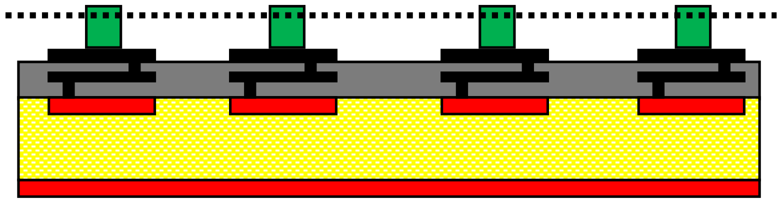
- 1 "DLC"



20 LSBB
50cm x 50cm
X/Y 1mm/1mm
30M/Sqr sharing layer

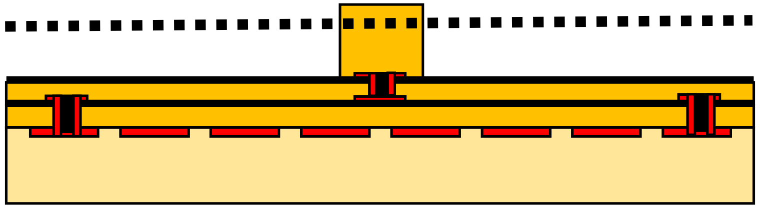
High rate detectors

Printed



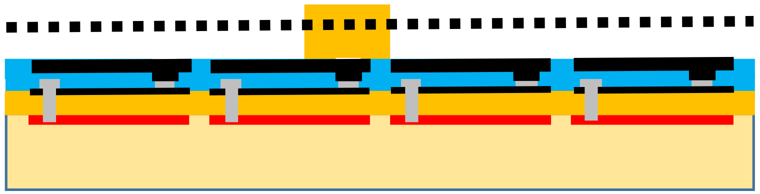
- 2 layers screen printed resistors

SBU



- 2 "DLC+" layers → SBU

Mix

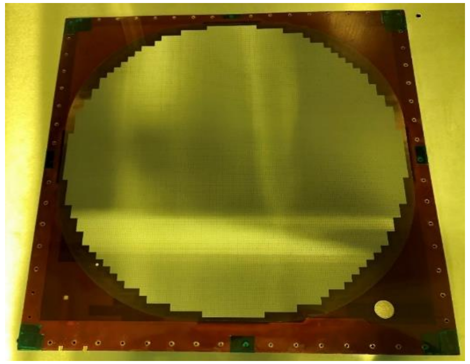


- MIX "DLC" and screen printed

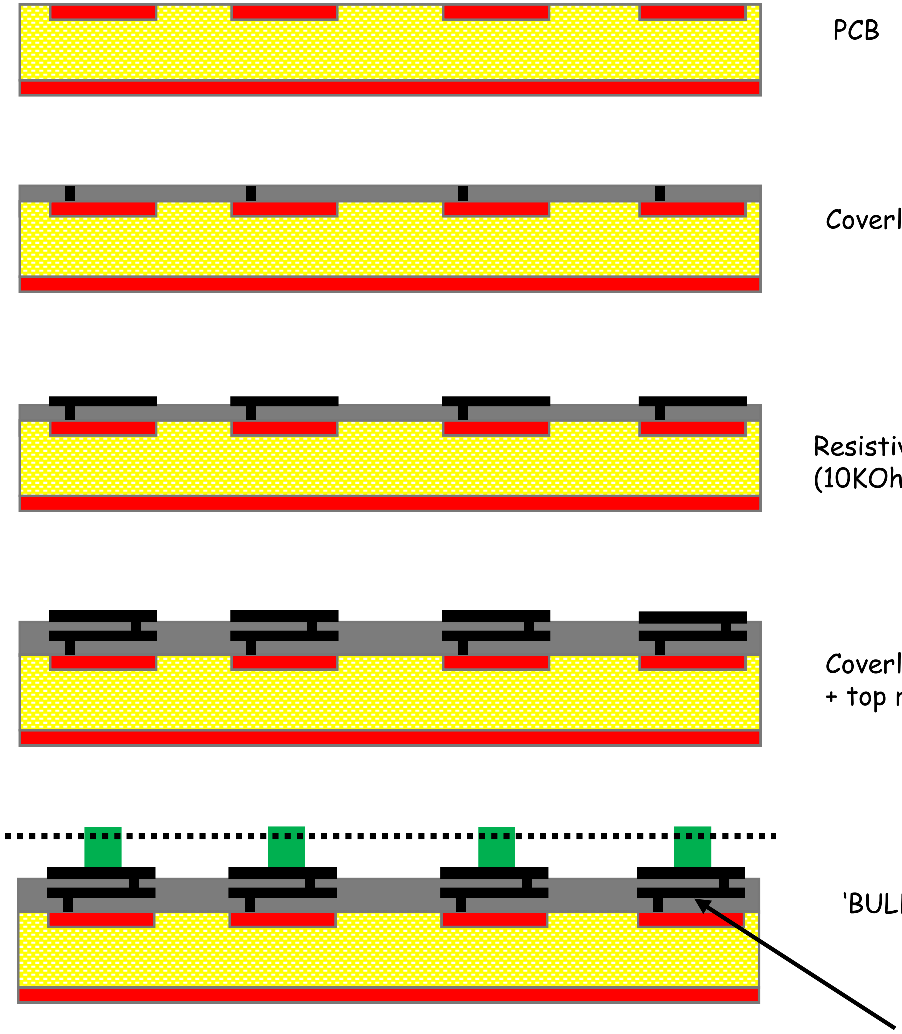
2 Printed layers

-Extra Large DOCA
-Accurate layers registration in large size
-No DLC needed
-High rate detectors

-Embedded Res should be less than 10KOhms/square
-Large pads only
-low energy resolution



5 ILC DHCAL
50cm diameter
pads 1cm x 1cm
5M/Pad



PCB

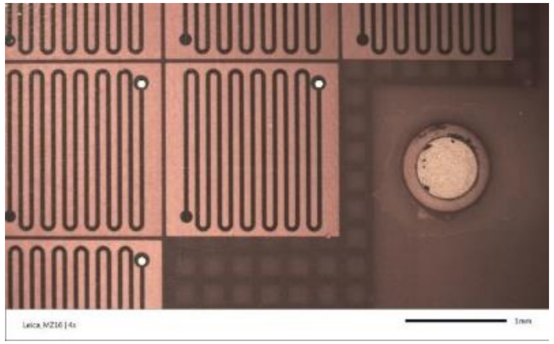
Coverlay gluing + drilling + via fill

Resistive paste resistors
(10KOhms/square max)

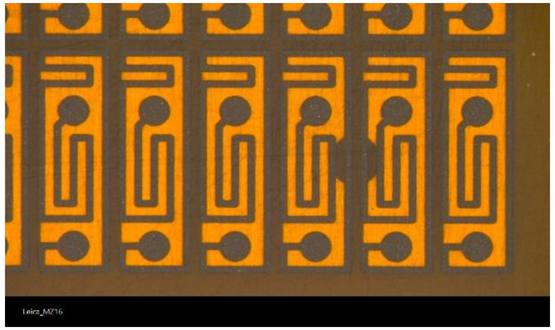
Coverlay gluing + via fill
+ top resistive printing (100K max)

'BULKage'

DOCA: 10mm

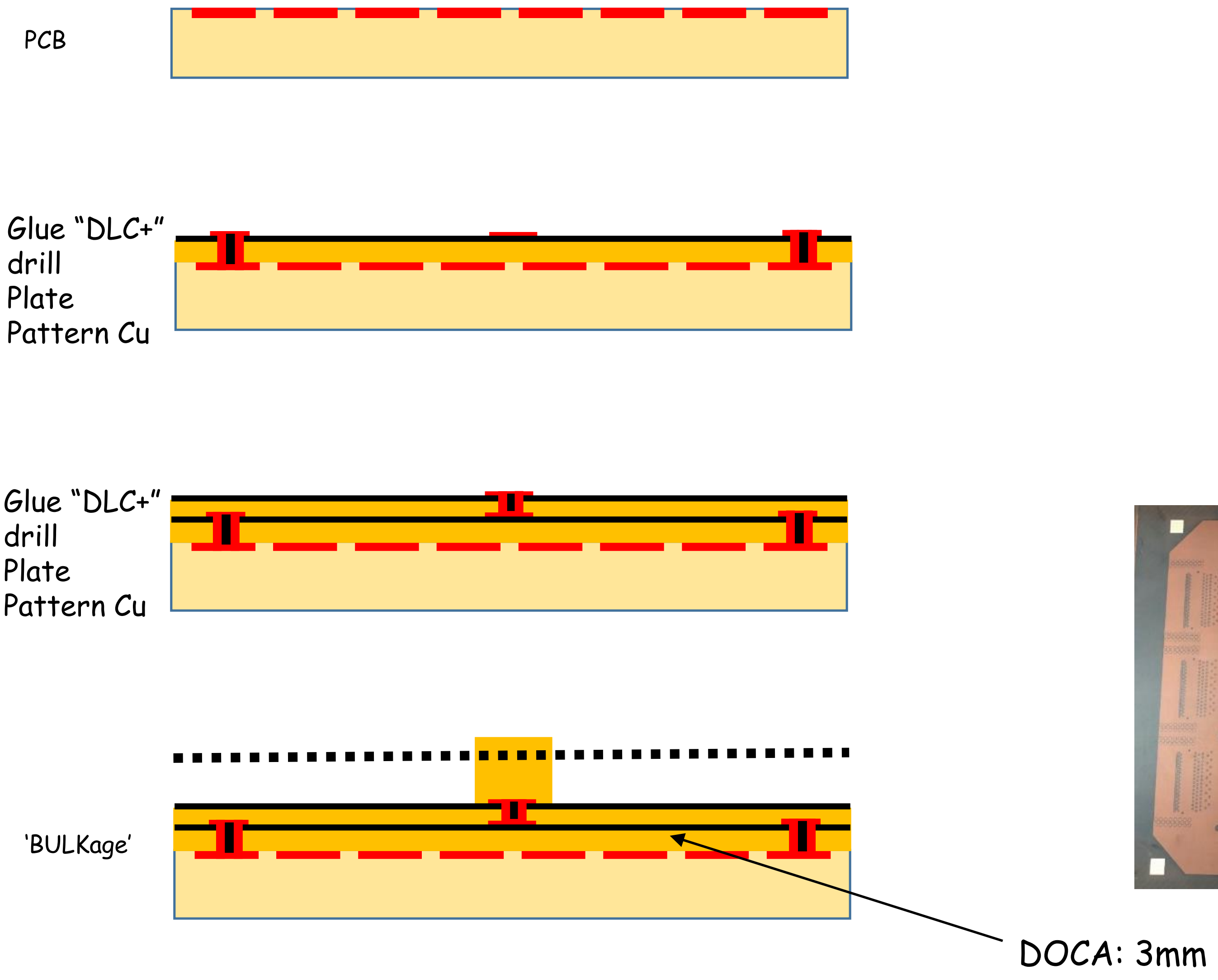


1cm x 1cm pad→ Ok
There is space to create a
2 Mohms Resistor
with 10K/sqr paste



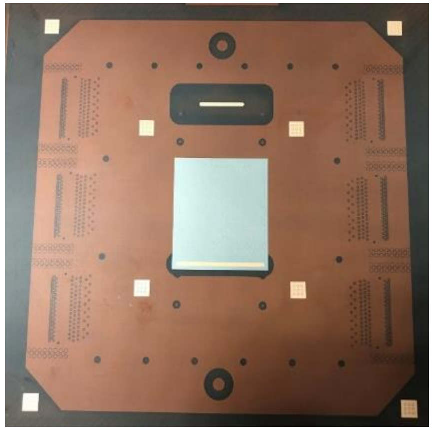
1mm x 3mm pad→ Bad result
There is no space to create a
2 Mohms Resistor
with 10k paste

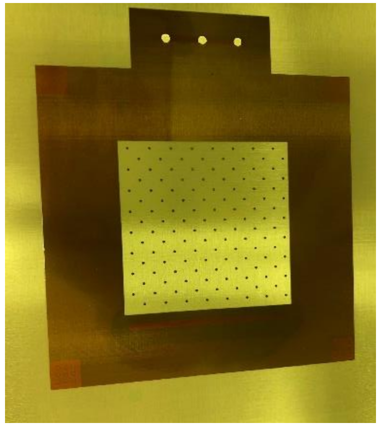
2 "DLC+" structure with SBU process
Sequential Build Up



-Extra Large DOCA
-Adjustable evacuation density VS rate
-no problem with layers registration
-good energy resolution
-100% compatible with STD PCB processes

-Needs "DLC+"

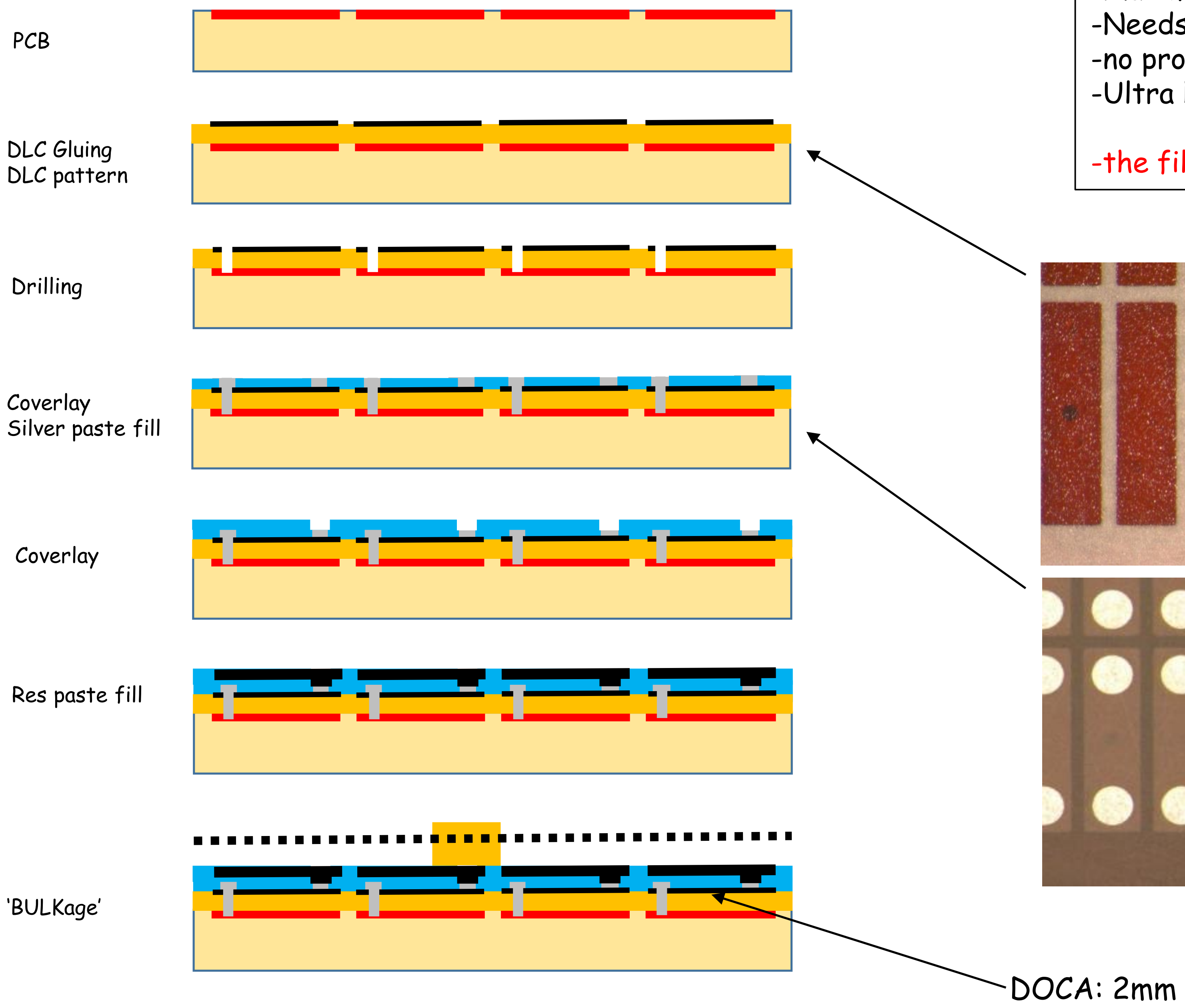


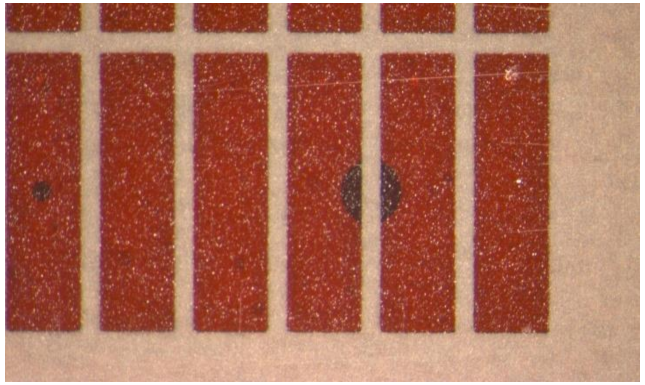


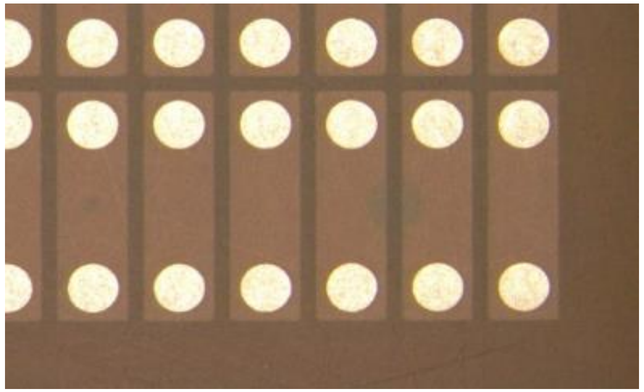
MIX method

-Large DOCA
-Maximized evacuation density points
-Needs simple DLC foils
-no problem with large size
-Ultra high rate detectors

-the filling technic is not STD in PCB world





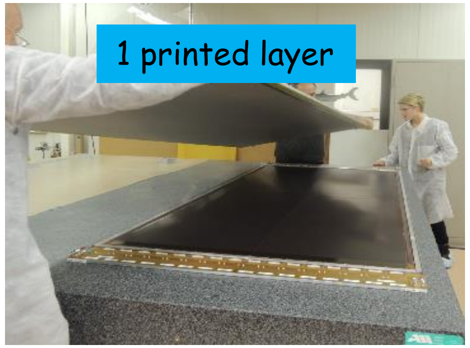


conclusion

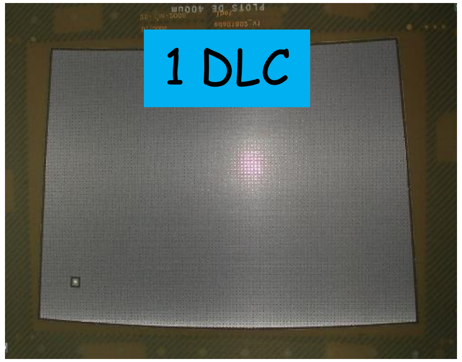
- Simple DLC material
  - Ready for large size and high rate detectors
  - For some application we need to get better resistive uniformity
- We need to improve the “DLC+” materials (Cu adhesion)
  - Main goal is to propose solutions 100% compatible with industry STD processes
  - There is still work to be done to produce large sizes “ DLC+” foils
- DOCA & “Energy Release” study should be continued to optimize protection
  - Fine study of currents during quenched sparks

Thank you

examples:

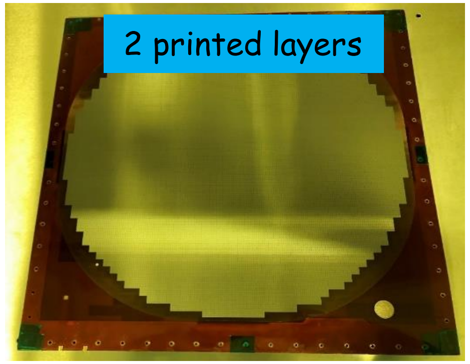


ATLAS NSW
Strips 100k/Sqr
2m x 1m

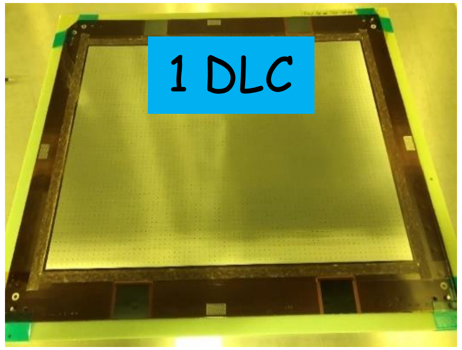


ILC TPC
30cm x 15cm
3mm x 8mm pads
2M/Sqr sharing layer

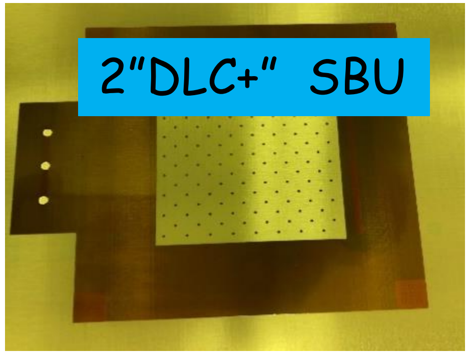
20 LSBB
50cm x 50cm
X/Y 1mm/1mm
30M/Sqr sharing layer



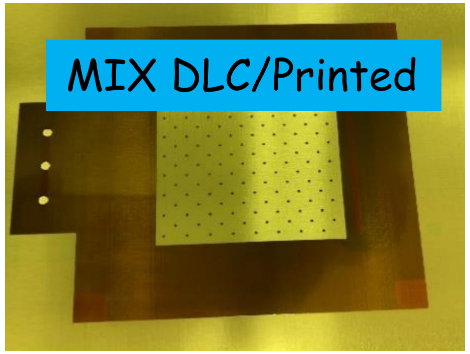
5 ILC DHCAL
50cm diameter
pads 1cm x 1cm
5M/Pad



32 T2K upgrade
40cm x40cm
1cm x 1cm pads
500K/Sqr sharing layer



2 Demonstrator
5cm x 5cm
1mm x 3mm pads
2R layers 30M/5M
2R layers 60M/60M



2 Demonstrators
5cm x 5cm
pads 1mm x 3mm
5 M/pad
20M/pad

TOTEM GEM

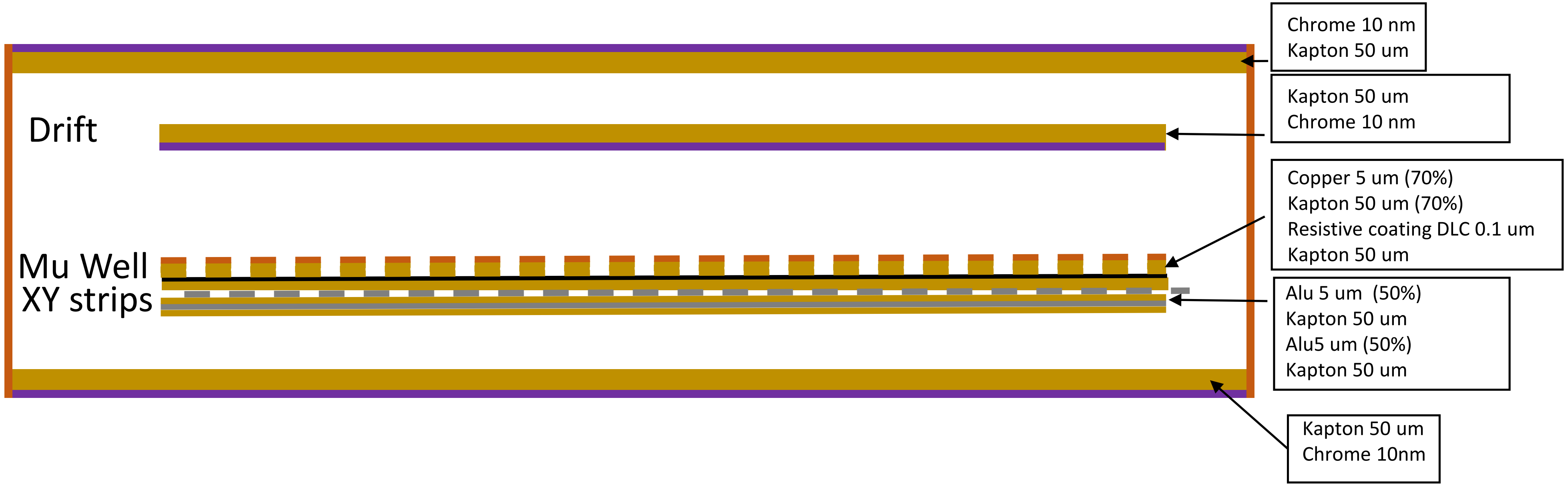
Item	Details	$^o/_{oo}$ of X_o
3 GEMs	6 x 5 μm copper [0.7]	1.68
	3 x 50 μm kapton [0.7]	0.42
	TOTAL:	2.10
1 Drift	5 μm copper	0.35
	50 μm kapton	0.17
	TOTAL:	0.52
3 Grid spacers	3 x 2 mm fiberglass [0.008]	0.25
1 Readout board	80 μm strips: 5 μm copper [0.2]	0.07
	1536 pads: 5 μm copper [0.85]	0.26
	50 μm kapton [0.2]	0.03
	120 μm fiberglass	0.62
	60 μm epoxy	0.30
	TOTAL:	1.28
1 Shielding	10 μm aluminium	0.11
2 Honeycombs	2 x 3 mm Nomex	0.46
4 Fiberglass foils	4 x 120 μm fiberglass	2.47
	TOTAL:	7.19

TOTAL 0.719 %X_0

Table 1.1: Material in one GEM detector

Micro Well with XY aluminum strip , Chrome drift

TOTAL
$0.153\%X_0$



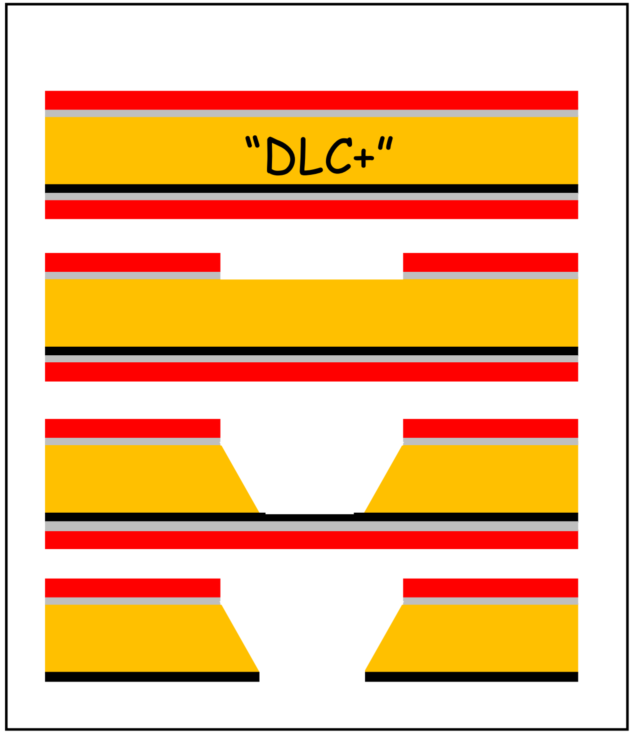
Conservative approach, copper is used in the place of avalanche discharges.
If we use only aluminum it makes $0.16\ \%X_0$

DLC Resistive GEM

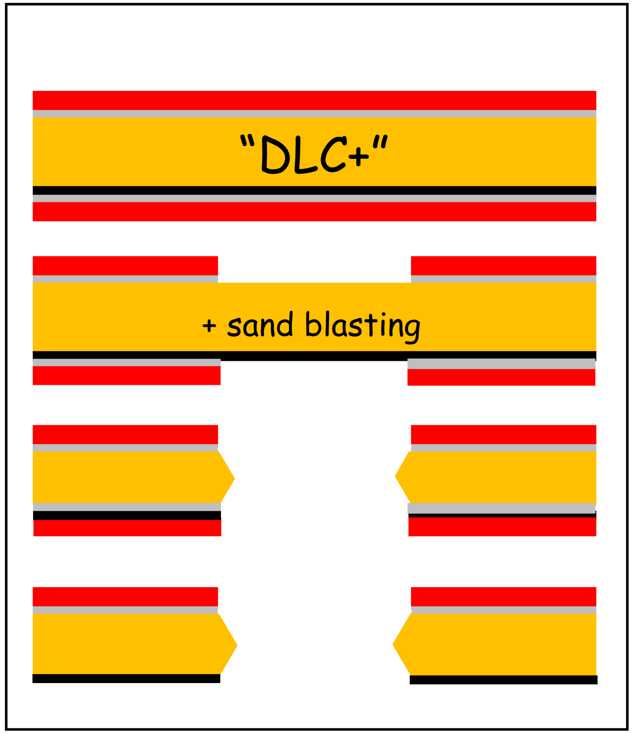
Cu/Cr pattern

Kapton etch

Cu/Cr etch

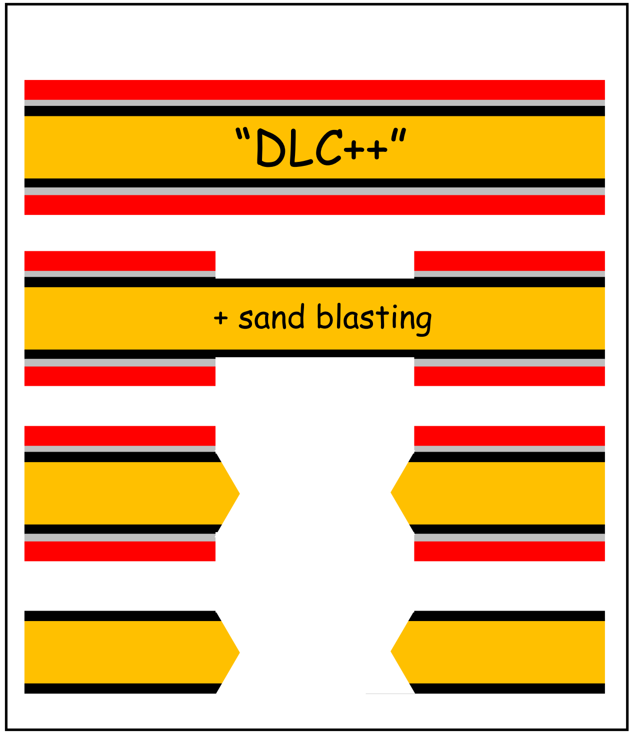


FTM process



Minimizing distortions with sectored GEM electrodes

A.P. Marques[a,b], F.M. Brunbauer[a,*], H. Müller[a], R. de Oliveira[a], E. Oliveri[a], D. Pfeiffer[a,c], L. Ropelewski[a], J. Samarati[a,c], F. Sauli[a], L. Scharenberg[a,d], L. Shang[e], M. van Stenis[a], S. Williams[a], Y. Zhou[f]



In progress
Waiting for good base material

158 *3.4. Full holes in DLC-coated sector gap*

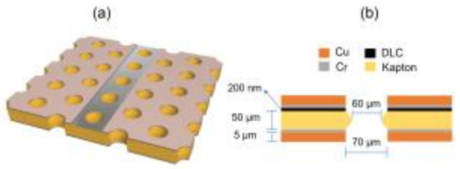
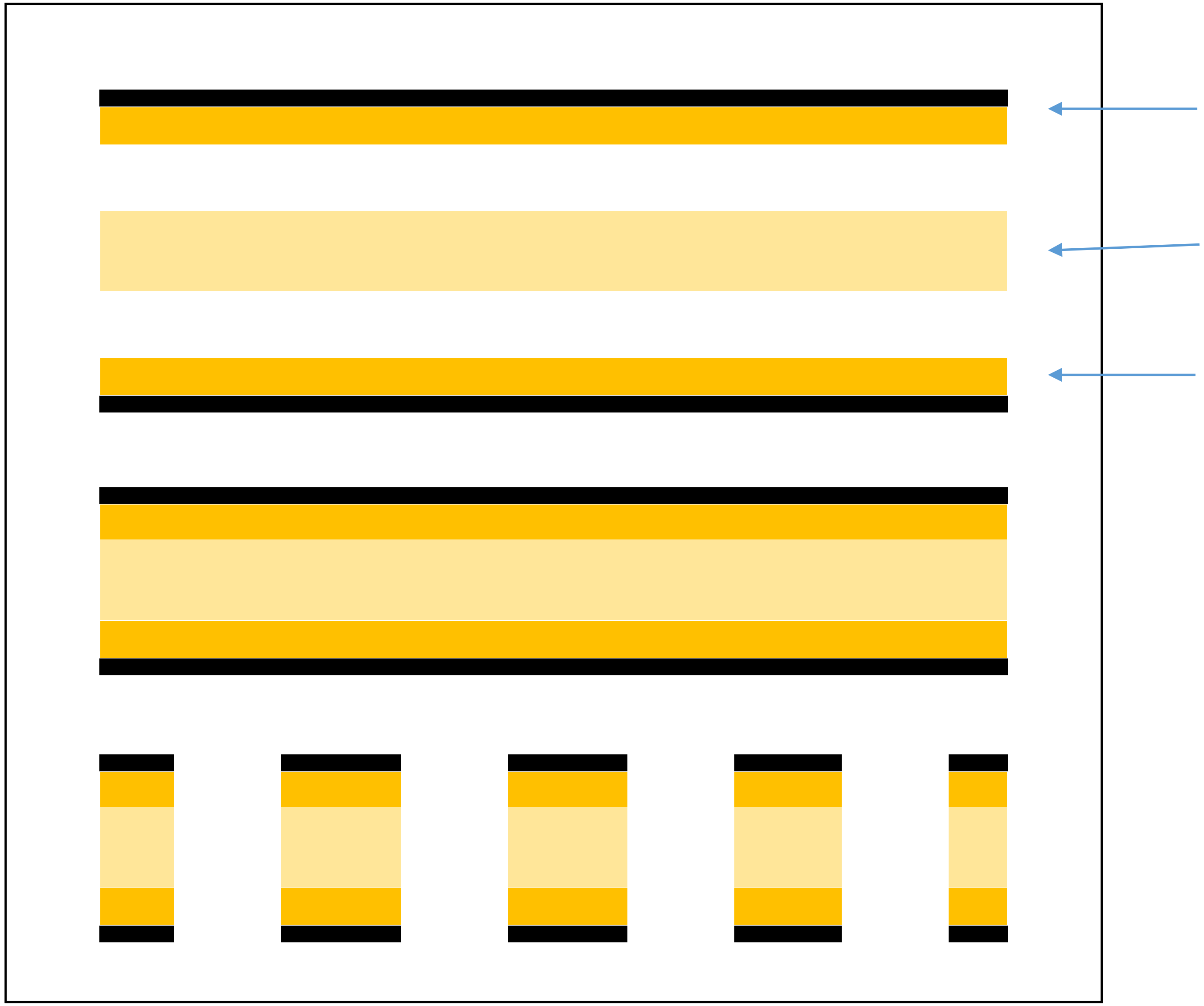
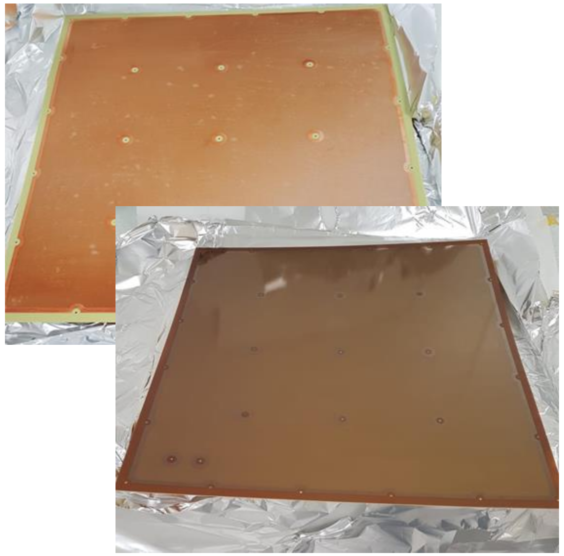


Figure 9: (a) - 3D model of the DLC-coated GEM; (b) - Cross section of the structure. Schematic not drawn to scale.

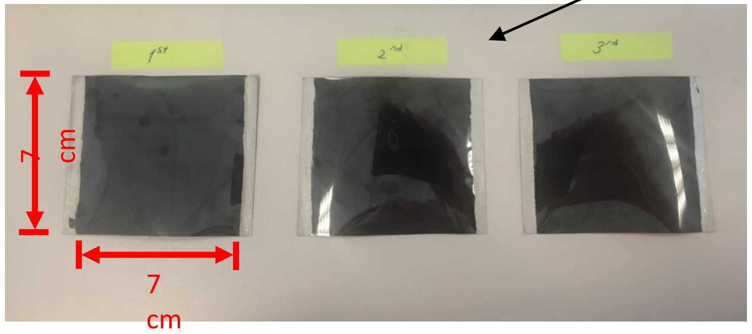
Resistive THGEM





Resistive measurements

Probe calibration

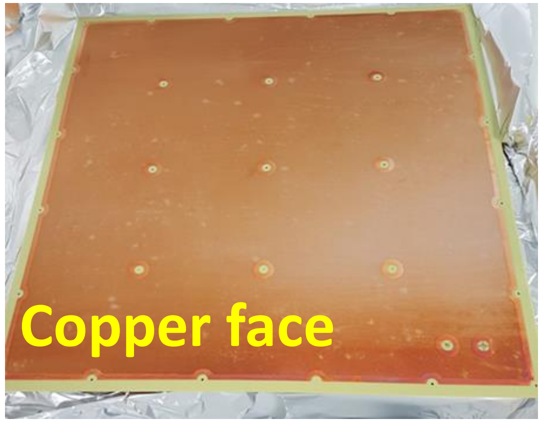


DLC Film	Surface Resistivity (kΩ/□)	Surface Resistance From The Probe (kΩ)	Coefficient Factor	Error (%)
1	359	345	1.041	4
2	386	364	1.060	6
3	403	380	1.061	5

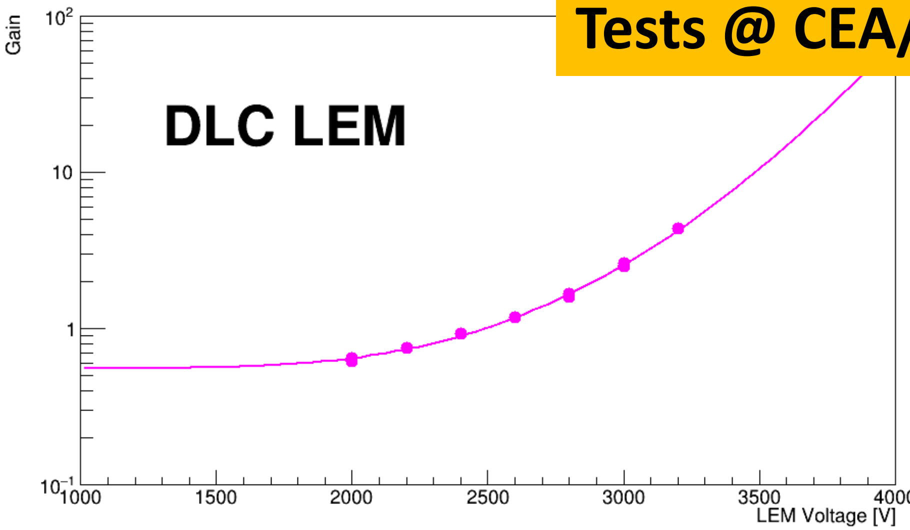
- 7cm x 7cm square of DLC
  - lateral silver connection to create 1 Square
- Connect probe to Ohm-meter
- Compare probe measurement to silver connections measurement
- Error in the range of 5%
- We can directly read the value from the Ohm-meter

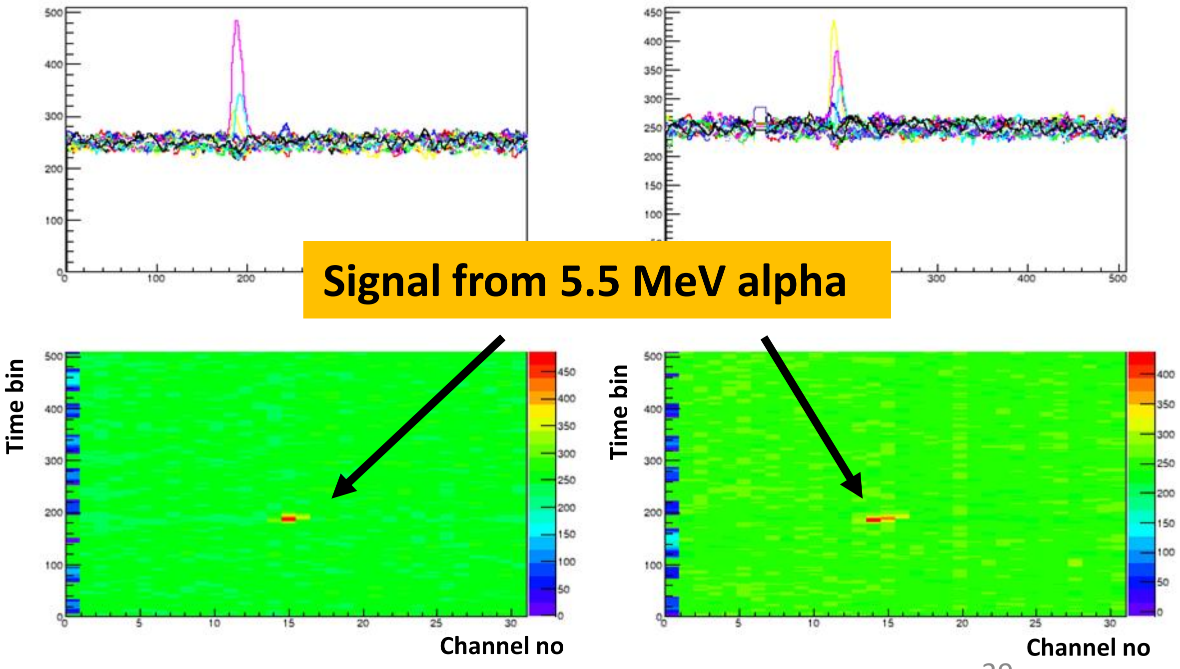
Resistive LEM

- Quenching of discharges with resistive 50×50 cm^2 LEM :
- Made at CERN EP-DT-EF :
  - copper side facing readout anode
  - DLC on 50 μm APICAL polyimide film (250 MΩ/□)
  - same geometry as CFR-35 (ProtoDUNE-DP)
  - no rims, no gold plating on copper face.
- Tests in progress at CEA/Irfu.
- R&D will continue in collaboration with CERN.



Tests @ CEA/Irfu





Goal of resistive protections

- Make Sparks invisible
- Simplify detectors
  - Reduce the cost
  - Be large size compatible
  - Aim to use only industrial processes
- Keep best “existing” MPGDs features
  - Rate
  - Space resolution
  - Time resolution
  - Energy resolution
  - Mass