The µ-RWELL technology

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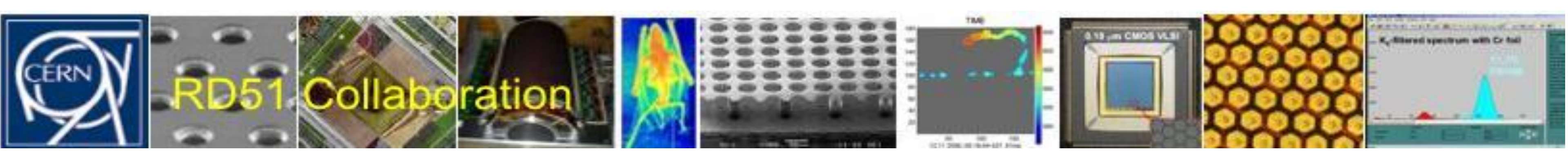


OUTLINE

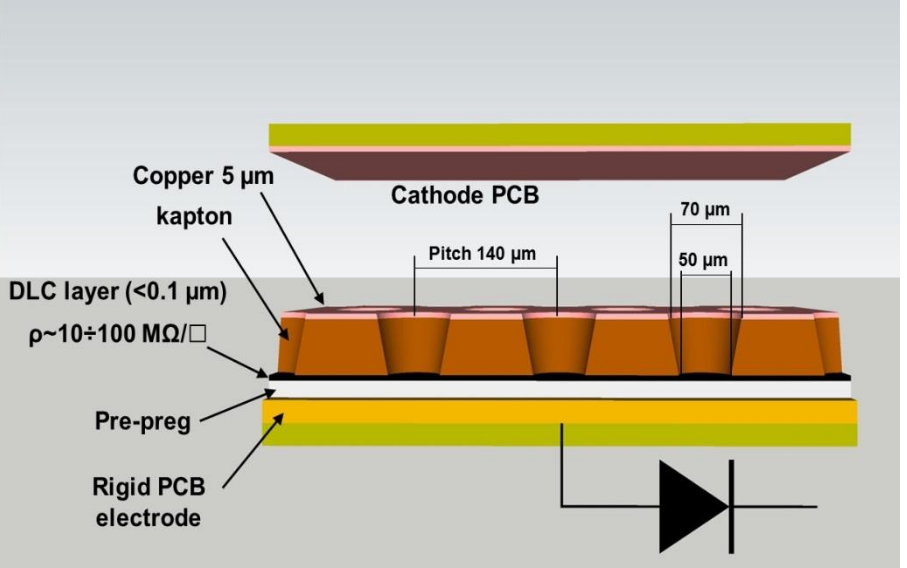
- Detector architecture & principle of operation
- The baseline layout
- The high rate layouts
- Detector performance
- Applications & requirements
- DLC studies
- Technology transfer to industry
- Summary

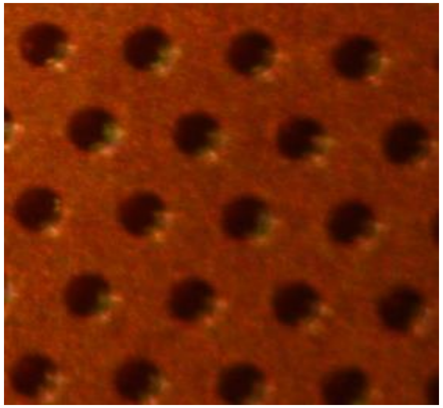
The µ-RWELL architecture

The µ-RWELL is composed of only two elements: the µ-RWELL_PCB and the cathode defining the gas gap.

The µ-RWELL_PCB, the core of the detector, is realized by coupling:

1. a WELL patterned Apical® foil acting as amplification stage
2. a resistive layer for discharge suppression w/surface resistivity ~ 10÷100 MΩ/□ - different current evacuation schemes can be implemented
   i. LR << 1 MHz/cm^2 - SHiP, STCF, EIC, HIEPA
   ii. HR >>1 MHz/cm^2 - LHCb-Muon phase 2-upgrade & future colliders - CepC, Fcc-ee/hh
3. a standard readout PCB

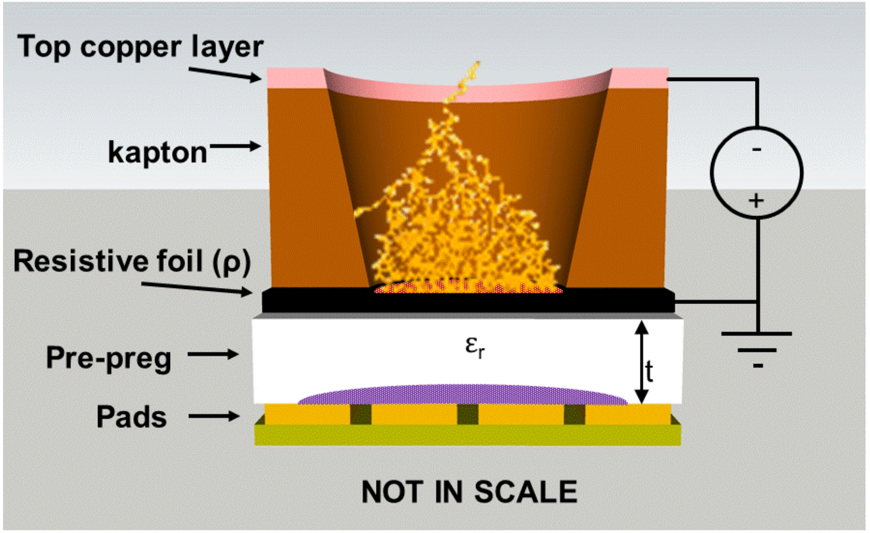




The µ-RWELL amplification stage

Principle of operation

Applying a suitable voltage between the top Cu-layer and the DLC the "WELL" acts as a multiplication channel for the ionization produced in the drift gas gap.



The charge induced on the resistive layer is spread with a *time constant*, *$\tau \sim \rho \times C$* [*M.S. Dixit et al., NIMA 566 (2006) 281*]:

- the DLC surface resistivity → ρ
- the capacitance per unit area, which depends on the distance between the resistive foil and the pad/strip readout plane → t
- the dielectric constant of the insulating medium → ε_r

$$C = \varepsilon_0 \times \varepsilon_r \times \frac{S}{t}$$

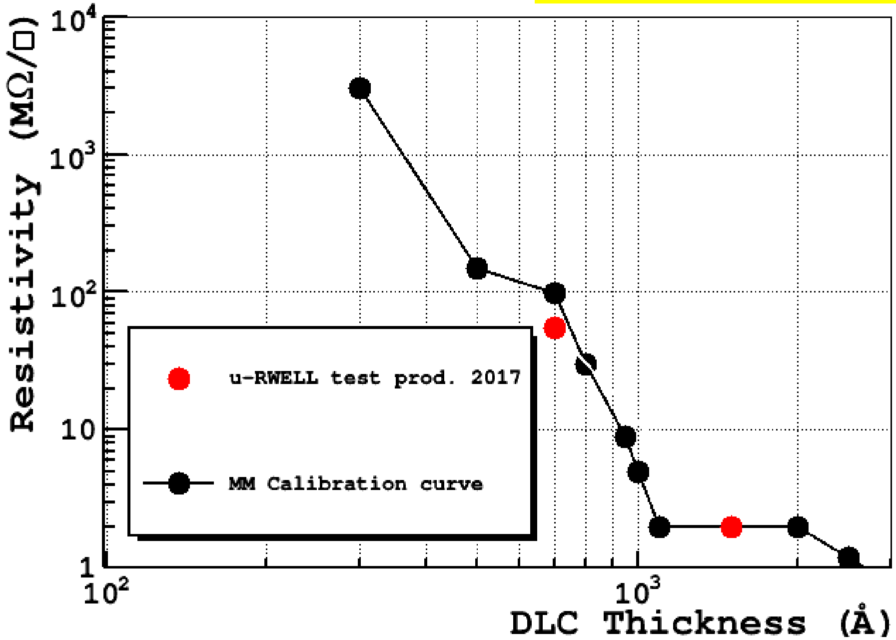
- The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark, with a consequent reduction of the spark-amplitude
- As a drawback, the capability to stand high particle fluxes is reduced, but appropriate grounding schemes of the resistive layer solves this problem (*see High Rate layouts*)

The resistive layer: DLC sputtering

The **Diamond Like Carbon (DLC) is sputtered** on one side of a **50 µm thick Apical® foil** using a pure graphite target, on **the other side** of the **foil the usual 5 µm thick Cu layer**, as for the base material used for GEM foil, is deposited.

The **resistivity, parametrized** as a function of the **DLC thickness**, can reach a uniformity on large foils, 1.2×0.6 m^2, at level of ± 30% .

Courtesy of A. Ochi

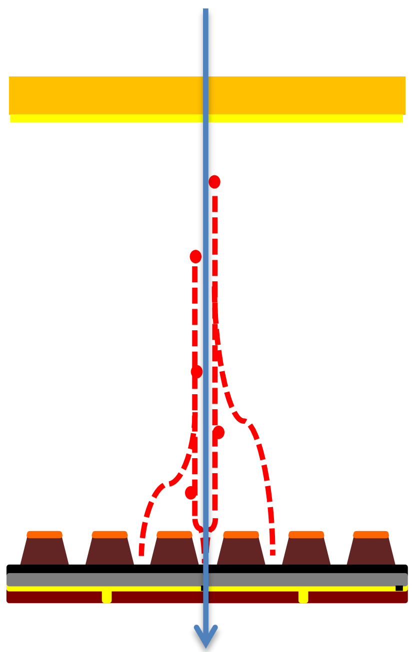


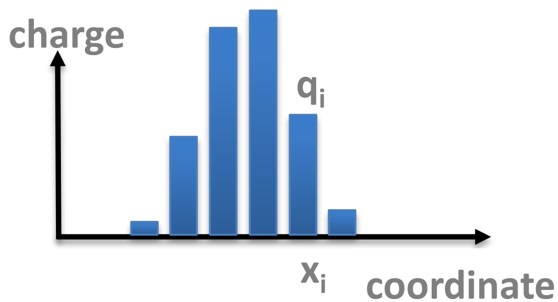
Very recent developments, at **USTC – Hefei (Zhou Yi**), brought to the manufacturing **of DLC+Cu sputtered Apical® foils**, where an **additional layer of few microns of Cu above the DLC** coating has been deposited.

This new coating open the way towards **improved high rate µ-RWELL layouts** .

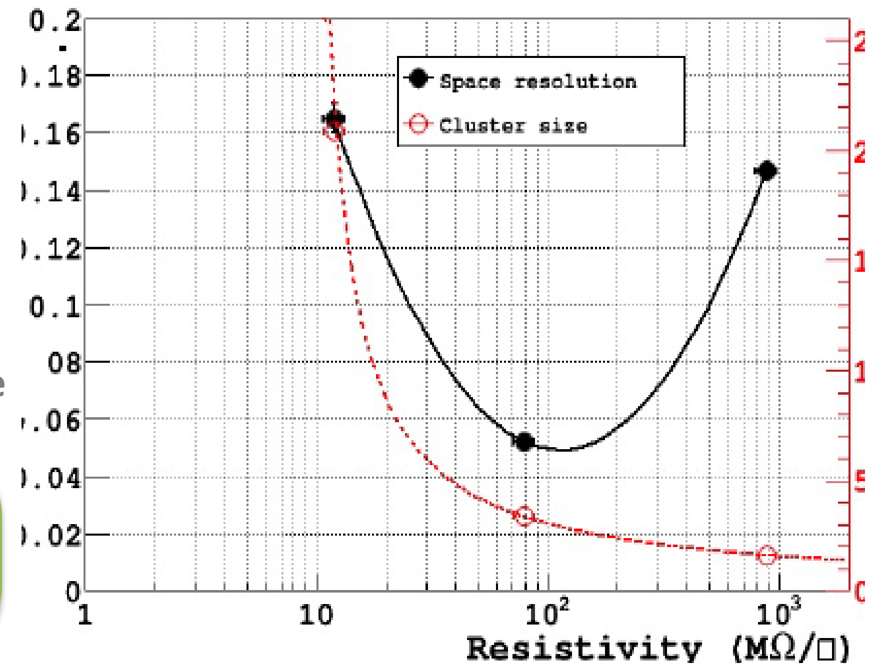
Space resolution *vs* DLC resistivity

With the charge centroid analysis (for orthogonal tracks) the track position is determined as a weighted average of fired strips.





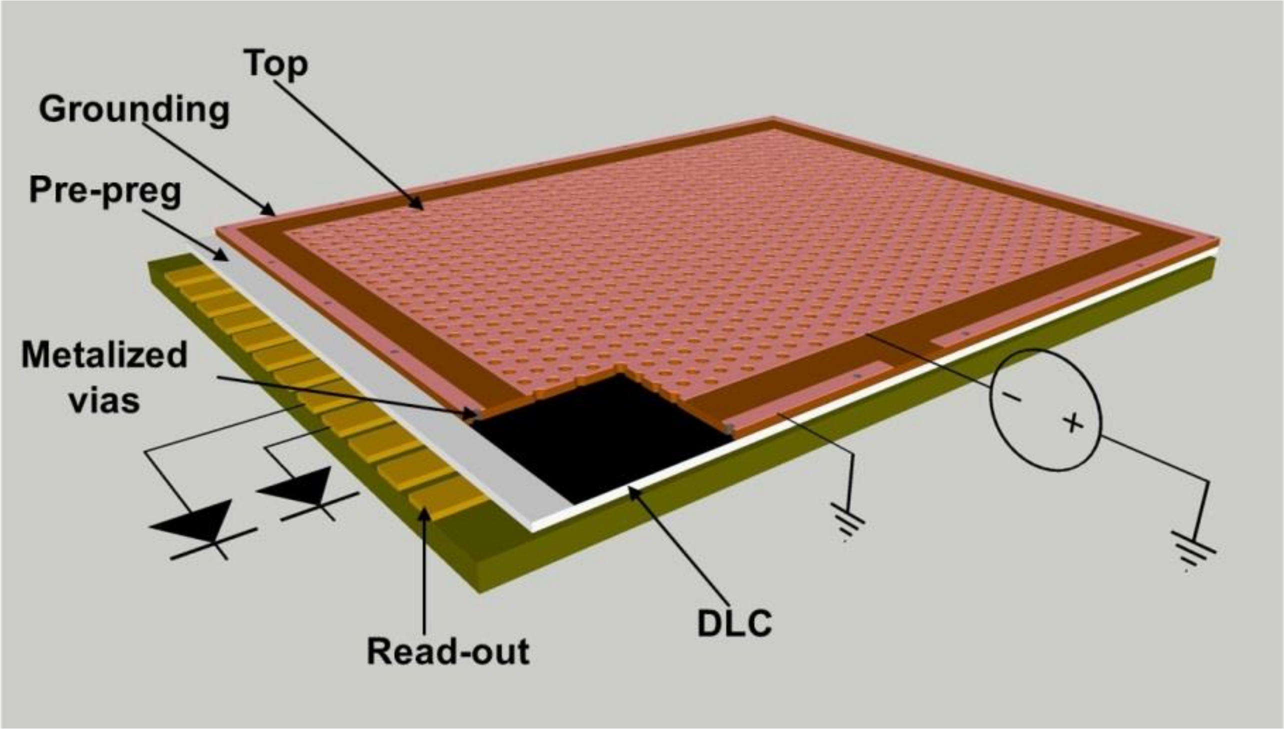
$$x_{hit} = \frac{\sum x_i * q_i}{Q_{TOT}}$$



The space resolution exhibits a minimum around 100 MΩ/□:

- at low resistivity the charge spread increases and then σ is worsening
- at high resistivity the charge spread is too small (Cluster-size → 1 fired strip) then the Charge Centroid method becomes no more effective (σ → pitch/√12)

The Low Rate Layout



Single Resistive Layer (SRL): a simple **2-D current evacuation** scheme based on a **single resistive layer** with a conductive **grounding all around the perimeter** of the active area.

For **large area detectors** the **path of the current towards the ground connection** could be large and strongly dependent on the particle incidence point, giving rise to **detector response inhomogeneity → limited rate capability.**

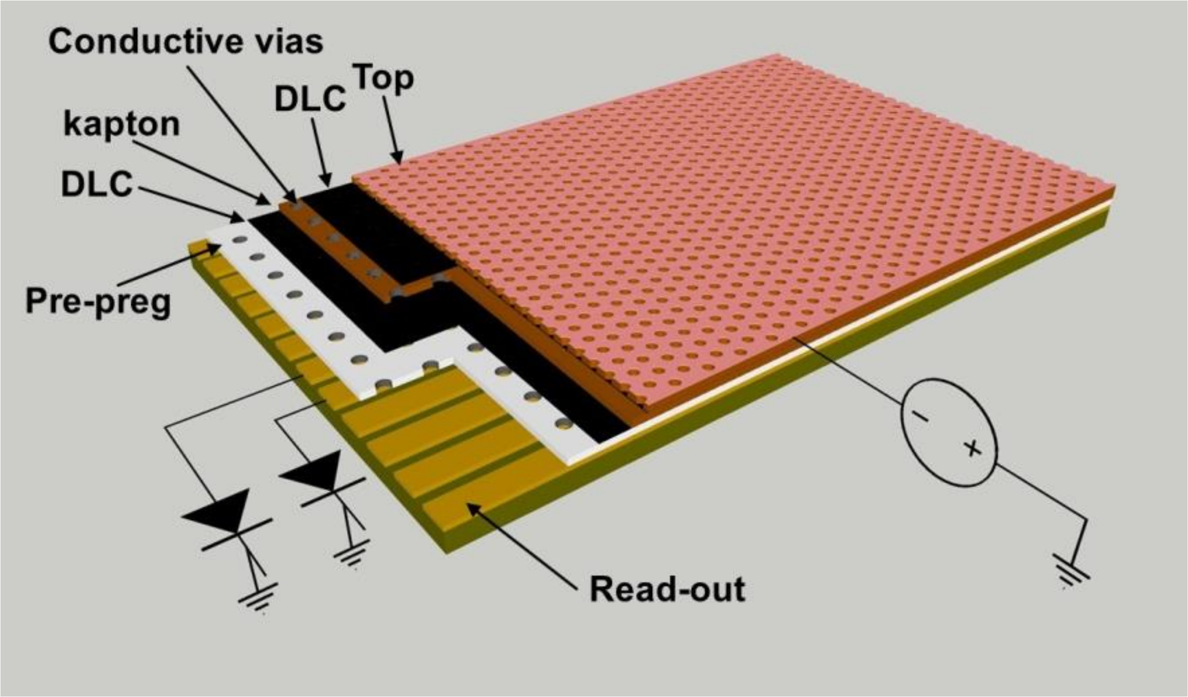
Towards high rate layouts

To overcome the **intrinsic limitation of the Single Resistive layout** with edge grounding **the solution** is to **reduce as much as possible the current path towards the ground connection** introducing a **high density "grounding network"** on the resistive stage of the detector.

Two layouts with a "dense" grounding network scheme have been designed and implemented:

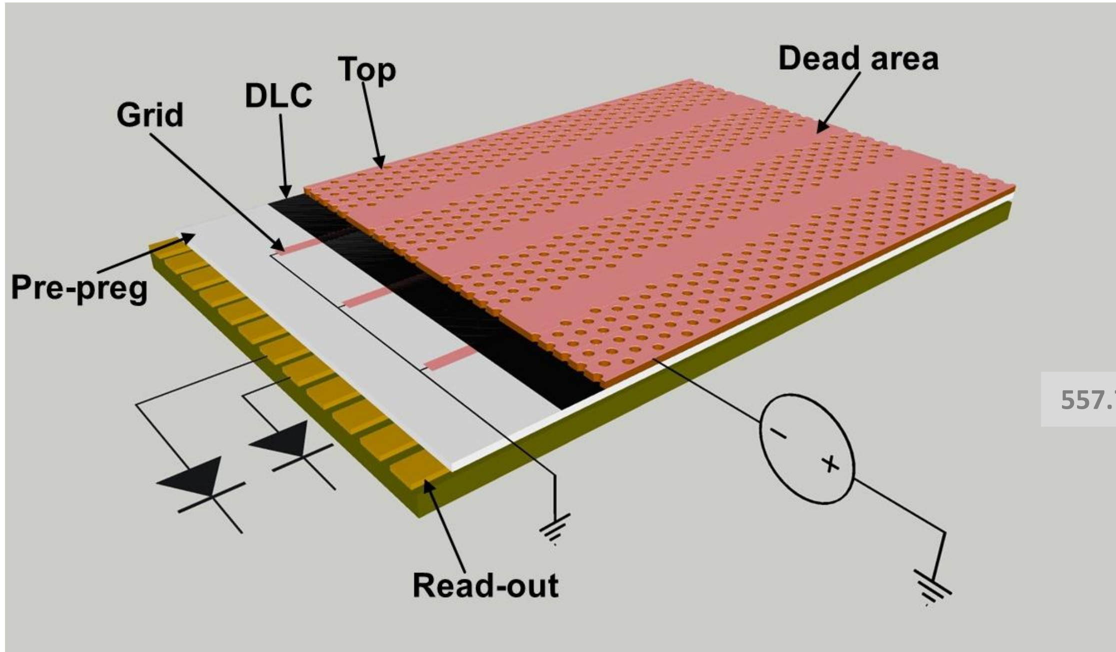
- the **Double Resistive layer** (**DRL**) with a sort of 3-D grounding scheme
- the **Single Resistive layout with a grounding grid** (**SG**) deposited on the resistive stage

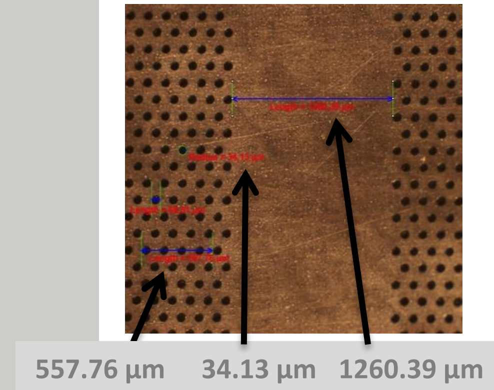
HR layouts: the double-resistive layer



Double Resistive Layer (DRL): 3-D current evacuation scheme based on **two stacked resistive layers** connected through a **matrix of conductive vias** and **grounded through a further matrix of vias to the underlying readout** electrodes. The **pitch of the vias** can be done with a density **less than 1/cm²**.

HR layouts: the Silver grid





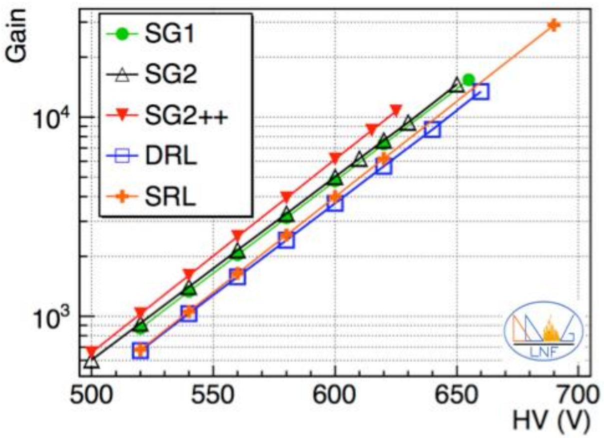
The **SG** is a **simplified HR scheme** based on a **Single Resistive layer** with a **2-D grounding** by means a **conductive strip lines grid** realized on the DLC layer.
The **conductive grid lines** can be screen-printed or **etched** by photo-lithography (*using the DLC+Cu deposition technology developed at USTC – Hefei*).

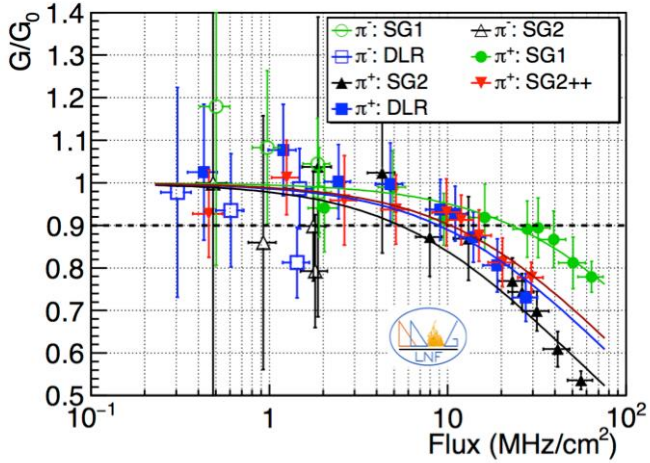
The **conductive grid** can **induce instabilities due to discharges over the DLC surface**, thus requiring for the **introduction of a small dead zone** on the amplification stage.

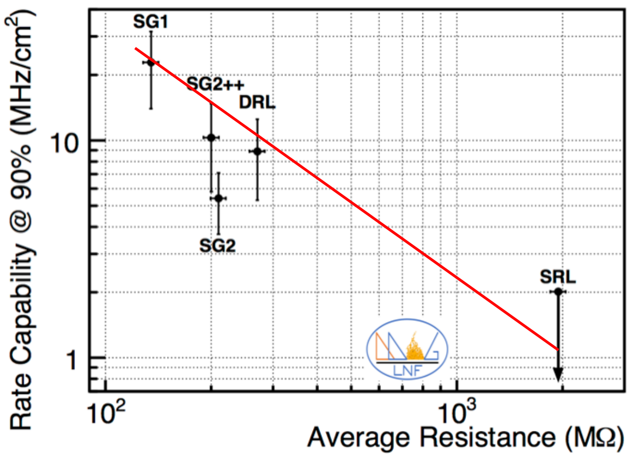
Detector performance

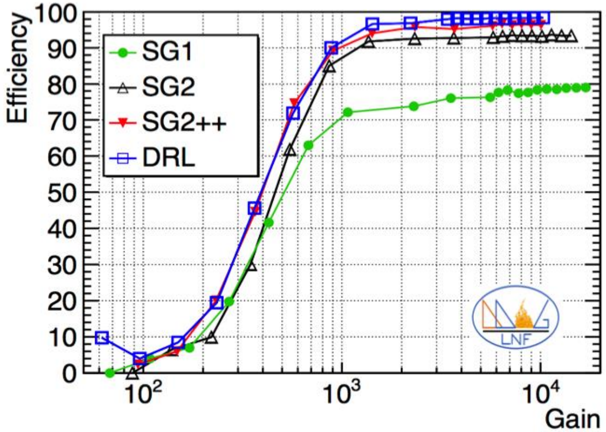
G ~ 10^4

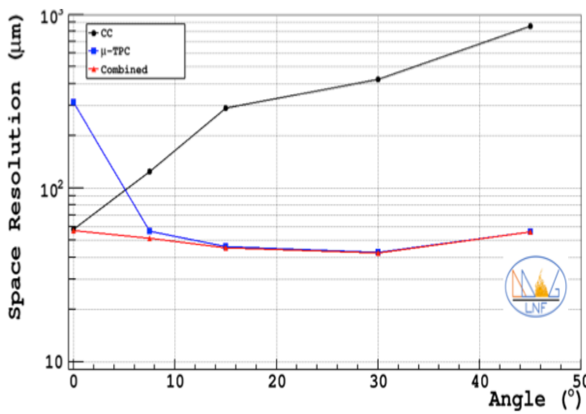
Rate capability ~ 10 MHz/cm^2

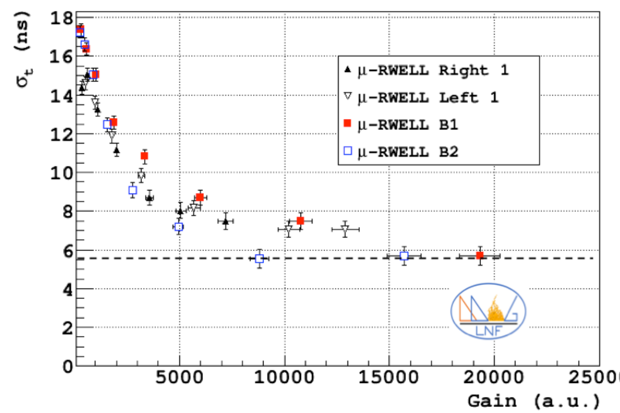












Efficiency ~ 98%

σ_x ~ 40 – 60 μm

σ_t ~ 5- 6 ns

Applications & requirements

muon apparatus upgrade (ready for construction ~2022-2023):

- **R1÷R2** → **288** detectors, size **30x25** to **74x31 cm^2**, **45 m^2** det. - **65 m^2 DLC+Cu**
- **R3** → **384** detectors, size **120x25** to 149**x31 cm^2**, **145m^2** det. - **207 m^2 DLC**
- **R4** → **1536** detectors, size 120**x25** to **149x31 cm^2**, **582 m^2** det. - **831 m^2 DLC**

Expected rate @ L= $2x10^{34}$ $cm^{-2}s^{-1}$ considering attenuation of Fe/Fe+concrete shielding:

- **R1-R2** rate up to **3 MHz/cm^2**
- **R3-R4** rate up to **35 kHz/cm^2**

Electronic Target Tracker for neutrino – emulsion spectrometer (construction ~2024-2026):

- **120** detectors, ~ 50**x50 cm^2**, **30 m^2** det. - **45 m^2 DLC** (low rate, few kHz/cm^2)

CepC (2030):

- **pre-shower: 450 X-Y** detectors , **50x50 cm^2 , 115 m^2** det., **65 m^2 DLC+Cu**
- **muon apparatus** : **3600** detectors, **50x50 cm^2 , 900 m^2** det., **1200 m^2 DLC**

Applications & requirements

LHCb muon apparatus upgrade (ready for construction ~2022-2023):

- **R1÷R2 → 288** detectors, size **30x25** to **74x31 cm^2**, **45 m^2** det. - **65 m^2 DLC+Cu**
- **R3 → 384** detectors, size **120x25** to 149**x31 cm^2**, **145m^2** det. - **207 m^2 DLC**
- ~~**R4 → 1536** detectors, size 120**x25** to **149x31 cm^2**, **582 m^2** det. - **831 m^2 DLC**~~ **NO-RWELL**

Expected rate @ L= $2x10^{34}$ $cm^{-2}s^{-1}$ considering attenuation of Fe/Fe+concrete shielding:

- **R1-R2** rate up to **3 MHz/cm^2**
- **R3-R4** rate up to **35 kHz/cm^2**

SHiP Electronic Target Tracker for neutrino – emulsion spectrometer (construction ~2024-2026):

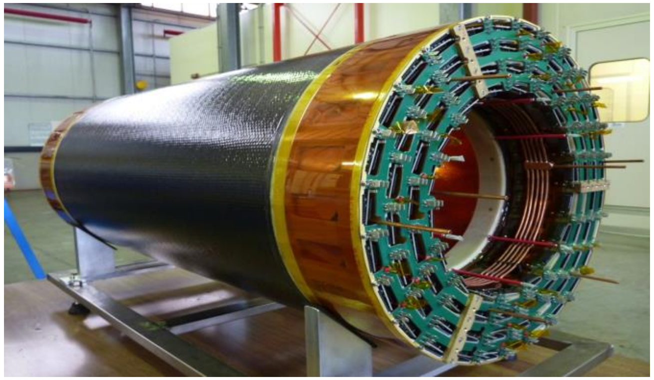
- **120** detectors, ~ 50**x50 cm^2**, **30 m^2** det. - **45 m^2 DLC** (low rate, few kHz/cm^2)

CepC (>2030):

- **pre-shower: 450 X-Y** detectors , **50x50 cm^2 , 115 m^2** det., **65 m^2 DLC+Cu**
- **muon apparatus** : **3600** detectors, **50x50 cm^2 , 900 m^2** det., **1200 m^2 DLC**

Applications & requirements (I)

KLOE – CGEM–IT



The **Cylindrical μ-RWELL (C-RWELL)** concept (having the **KLOE-CGEM**, as well as the **BESIII-CGEM**, as precursors) has many advantages wrt the CGEM technology:

- **very lower material budget,** down to ~**1 % X_0** for **n.4 C-RWELL** layers (tbc with 2% X_0 for KLOE2-CGEM)
- **simple construction/assembly**, **cost effective technology**: less cylindrical electrodes (2 instead of 5), **less toolings** required (2 molds instead of 5)
- The **C-RWELL is a good candidate** as a **ultra-light high resolution** Inner Tracker in several future medium-energy lepton colliders: **SCTF at Novosibirsk, HIEPA in China, EIC in USA**.

Requirements: rate O(10 – 100 kHz/cm^2) → DLC/DLC+Cu technology required

*Possible collaboration/synergy on **joint R&D** among **DDG-LNF, INFN-Ferrara, SCTF, HIEPA and EIC**: first **prototypes foreseen for 2020-2022***

Applications & requirements (II)

	detector/tiles	detector area (cm^2)	Total detector area (m^2)	Totale DLC area (m^2)	expected particle rate
LHCb/ Muon	288 ÷ 672	30x25 to 149x31	45 ÷ 190	65÷272	3MHz/cm^2
SHiP /e-TT	120	50x50	30	45	kHz/cm^2
CepC /pre-shower	450	50x50	115	165	<100kHz/cm^2
CepC/Muon	3600	50x50	900	1200	10 kHz/cm^2

Applications & requirements (III)

All these examples of possible applications in HEP show that **in a couple of years** we could **exit from R&D phase** and we should **start to prepare the construction of medium/large size detectors**. In some cases we will clearly face a mass production.

With **ELTOS** since a couple of years (in collaboration with CERN) we already are working on μ-RWELL manufacturing → good results (see later)

Concerning **DLC** (*Common Project RD51 – USTC, Kobe Univ, CERN, LNF-INFN*)

- **large area DLC** foil sputtering at **Be-sputter in Japan** (Ochi supervision)
- **R&D on improved DLC** manufacturing (**Zhou Yi, USTC – Hefei - PRC)** → DLC+Cu, thick vs thin DLC (small samples !!!)
- **large area DLC+Cu sputtering** → **mass production required** (?)
- **validation test of DLC** used as component in gaseous detectors should be done → aging studies, surface discharge … (**work in progress – LNF …)**

The Goal → a sort of industrial production of **DLC+Cu/PI/DLC+Cu roll** like the standard raw material used for the GEM foil manufacturing.

DLC studies

Taking as a reference the requirements of the **Muon apparatus at LHCb**:

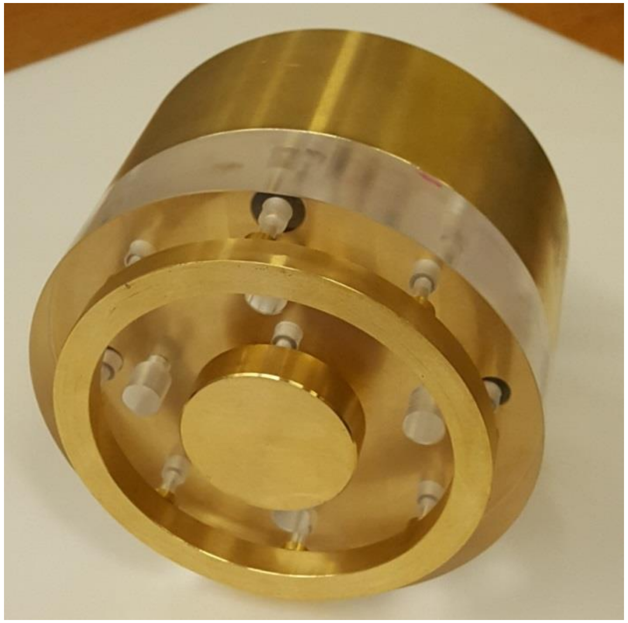
- **particle bkg rate** up to **3 MHz/cm^2 on detector**
- **detector and DLC stability must be verified** up to **6 C/cm^2 (**integrated charge in **10 y** of operation in **M2R1**)

Test are planned (and partially already ongoing):

- **long term test of DLC foils** (thin vs thick) **under high current**
- **aging test of detectors** with different radiation (X-ray, gammas, hip)

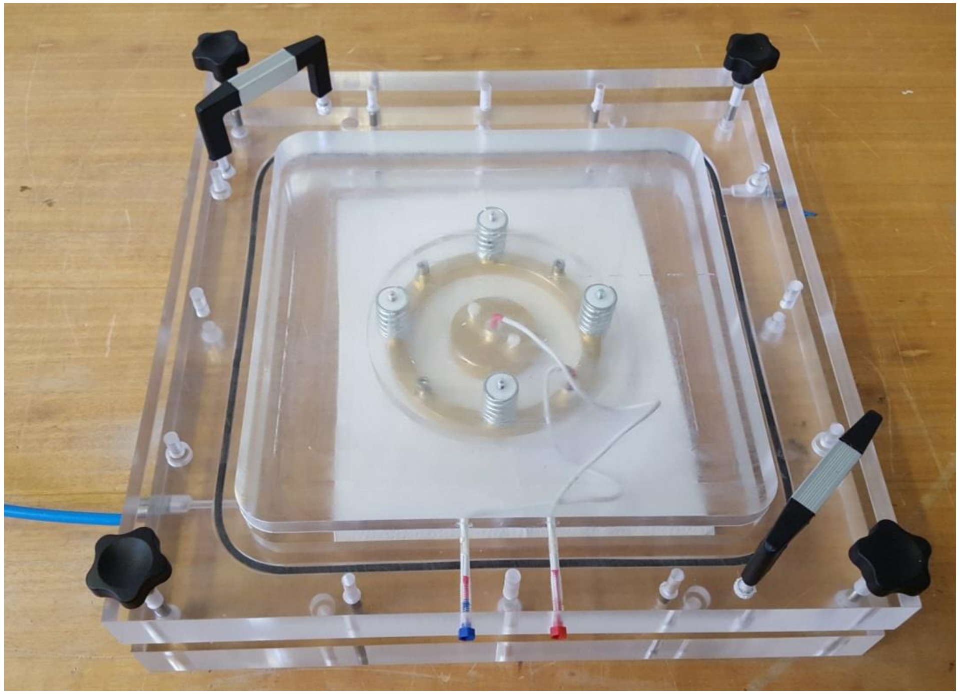
DLC studies (I)

annular tool for surface resistivity measurement



$$\Omega = \rho_s * \log(\frac{R_{out}}{R_{in}})\frac{1}{2\pi} = \rho_s * \frac{1}{8}$$

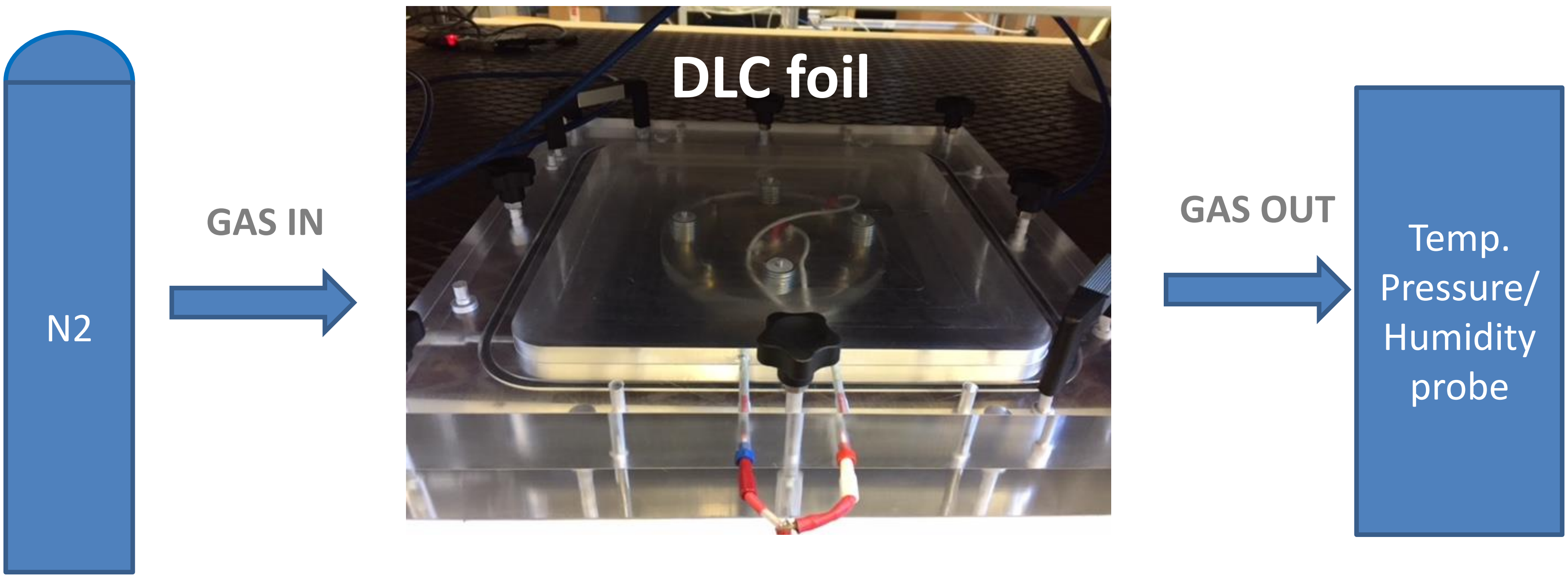
gas tight box for DLC surface resistivity measurement in controlled atmosphere



DLC studies (II)

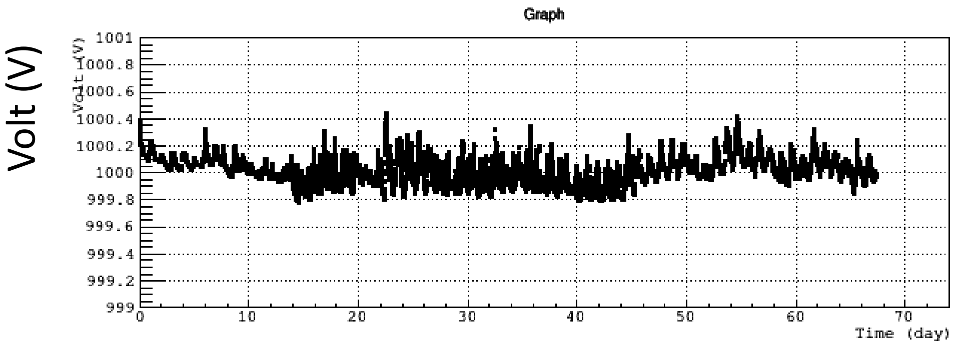
The HV and the current drawn by DLC is recorded every 30 s, together with the ambient parameters

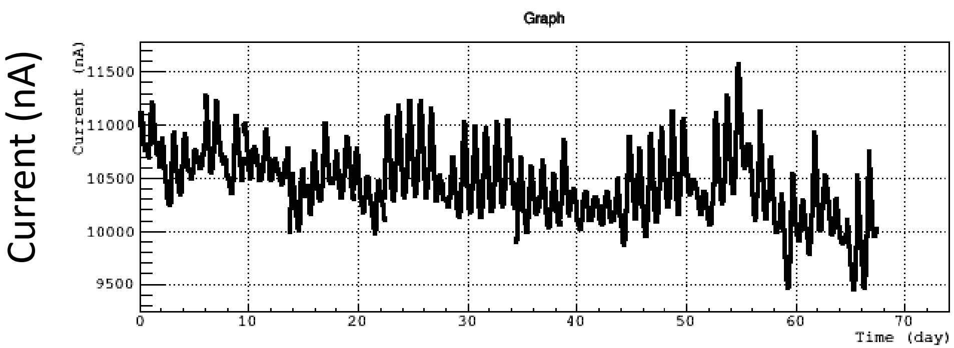
N2 Bottle- 100 cc/min

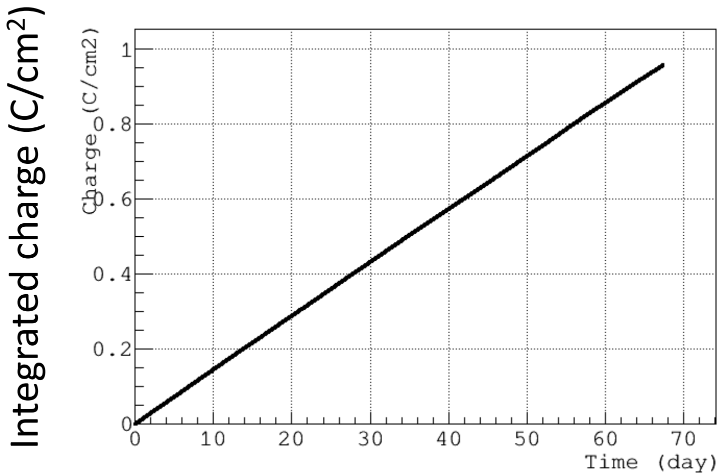


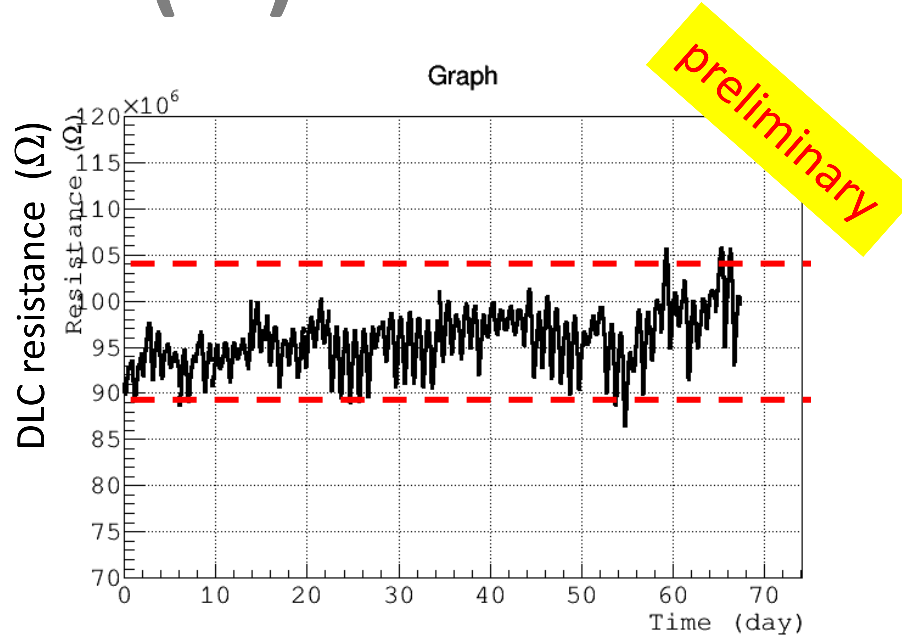
HV

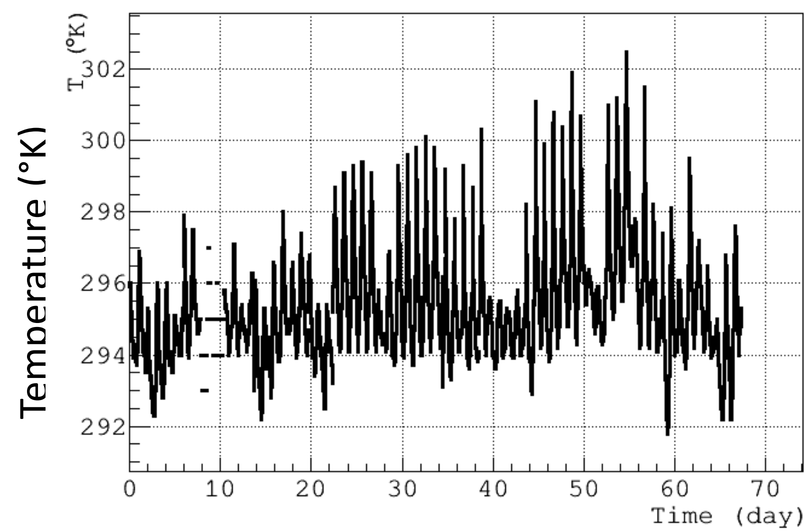
DLC studies (III)





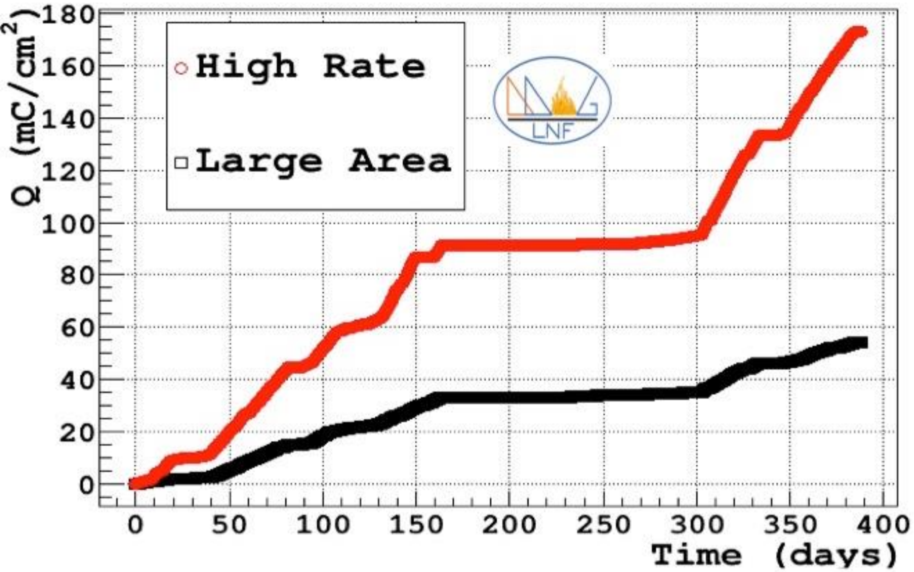




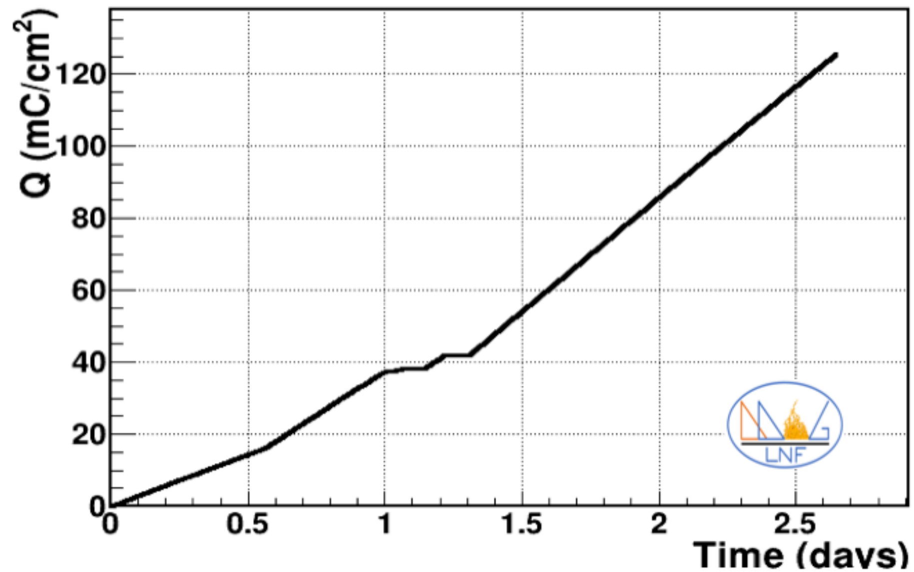


Ageing studies

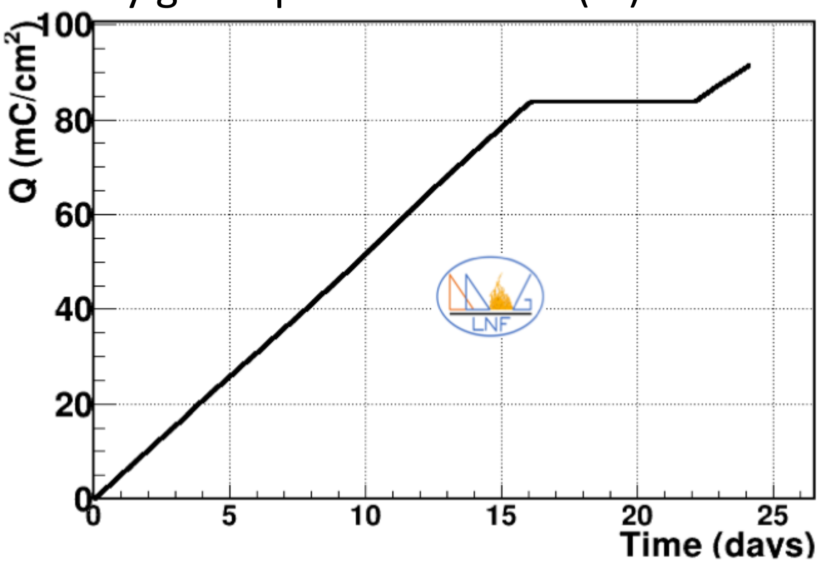
GIF++ - Full area & Flux = 200 kHz/cm²



TB PSI – beam spot 9 cm² – Flux= 10 MHz/cm²



X-Ray gun- spot 50 cm² Flux(rx) = 700 kHz/cm²



GOAL:
Integrate a charge up to 6 C/cm2

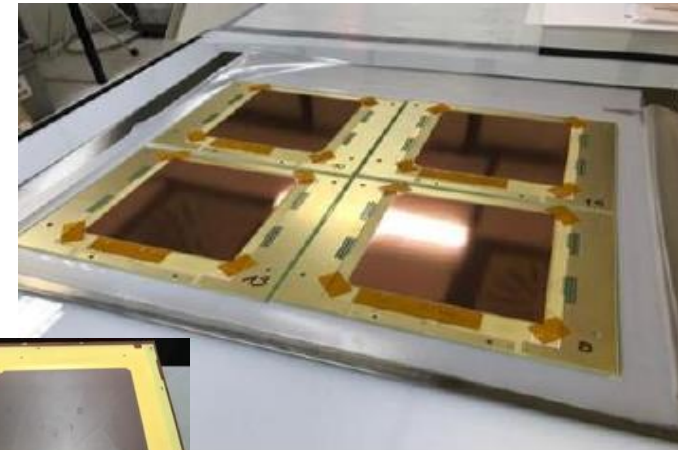
Slice test of u-RWELLs during RUN3 in the LHCb Muon APPARATUS under discussion

Technology Transfer to Industry

The **engineering and industrialization** of the μ-RWELL technology is one of the main target of the project.

Production Tests of the SRL @ ELTOS:

- 10x10 cm^2 PCB – (PAD r/o)
- 10x10 cm^2 PCB – (strip r/o)



1.2x0.5m^2 μ-RWELL

1.9x1.2m^2 μ-RWELL

Production Tests @ ELTOS, large area detectors (w/CMS):

- 1.2x0.5m^2 with strip r/o
- 1.9x1.2m^2 with strip r/o - (**w/PCB splicing**)

kapton etching done @ CERN

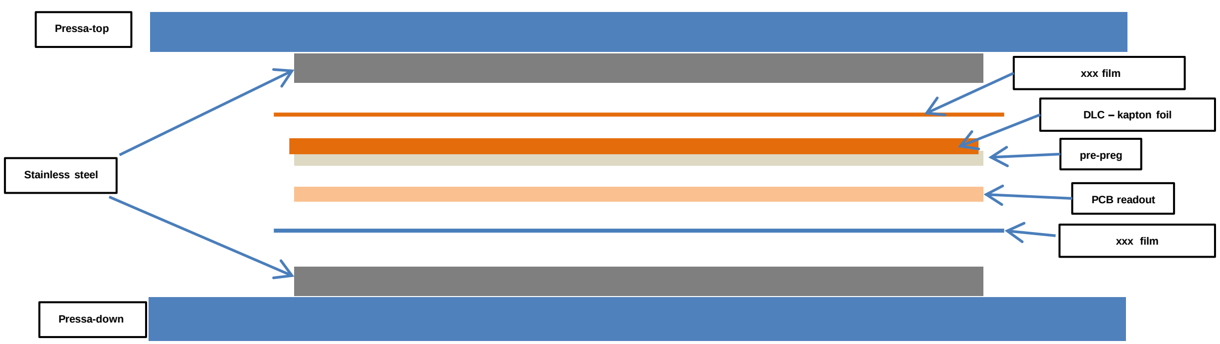
Prototypes proposed for CMS phase-2 muon upgrade

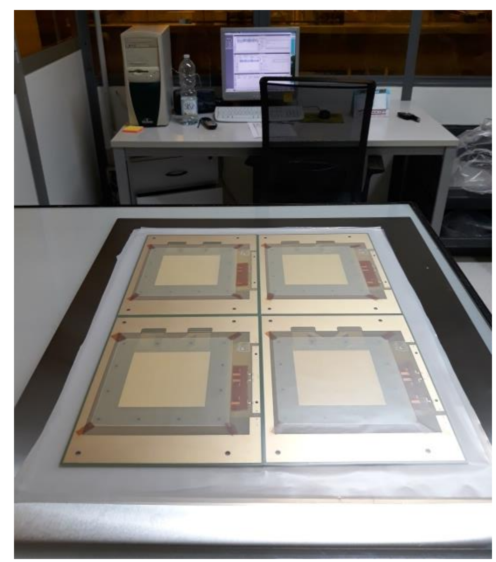
The micro-RWELL manufacturing at ELTOS

The **ELTOS SpA is a PCB company** founded in **1980 in Arezzo (Italy)**.

The **ELTOS** has been recently involved in the **manufacturing of about 1200 PCBs (with size up to 220x50 cm^2) for the MicroMegas detectors** for the upgrade of the **ATLAS** experiment at **CERN**. It also produced **THGEMs** for the **Weizmann Institute (Israel), and for the DUNE experiment.** In **the past they manufactured about 2200 PCBs** for **the anodes and cathodes of the MWPC of the Muon apparatus at the LHCb experiment (CERN)**.

For the **μ-RWELL** project they do the **coupling of the DLC-foil with the readout PCB** (produced by them). The **max size of the μ-RWELL-PCB** that the press could allocate is about **600x700 mm^2. Up to 4** max size **μ-RWELL-PCB** can be manufactured at the same time or **equivalently 16 small size (100x100 mm^2 active area)**.





Tentative plans @ ELTOS for the 2019-2020

- Production tests of **HR – layouts** (SG2++ type):
    - n. **2/3 batches** of **100x100 mm^2 active area** (w/pad readout)
    - n. **1/2 batches** of medium-large **size 300x250 ÷ 600x250 mm^2** (w/pad readout) → for the slice test of **LHCb-muon**

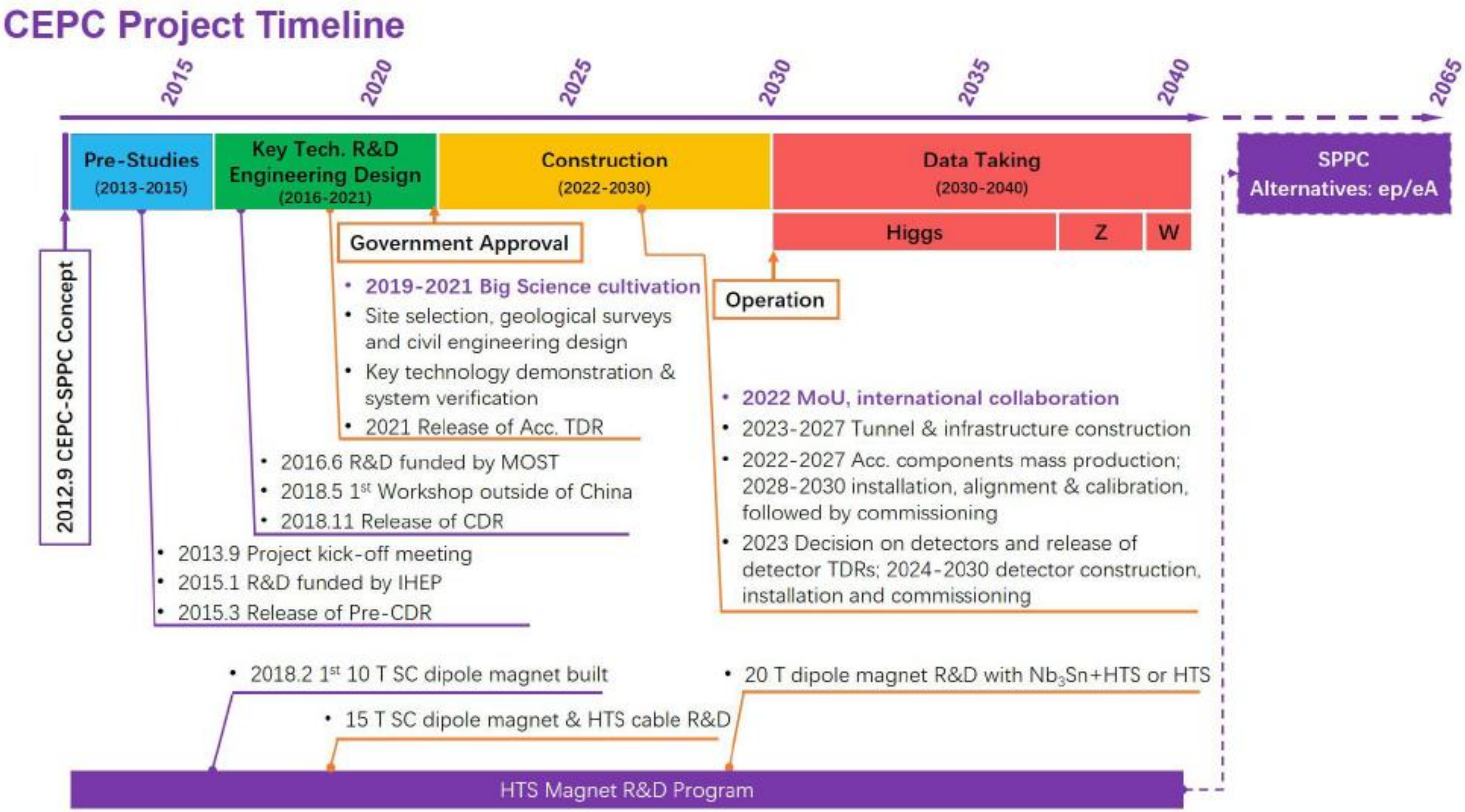
- Manufacturing of **thin μ-RWELL-PCB for the Cylindrical-RWELL** prototypes

SUMMARY

- The R&D phase on μ-RWELL is well advanced
- Plans are now focused on discharges & long term stability studies under heavy irradiation
- Technology Transfer to industry on-going: production test of HR-layouts (SG2++ type) & medium-large size manufacturing are planned
- DLC R&D with long-term stability studies is on-going in the framework of CP-RD51
- Large area DLC+Cu sputtering: industrial partner needed

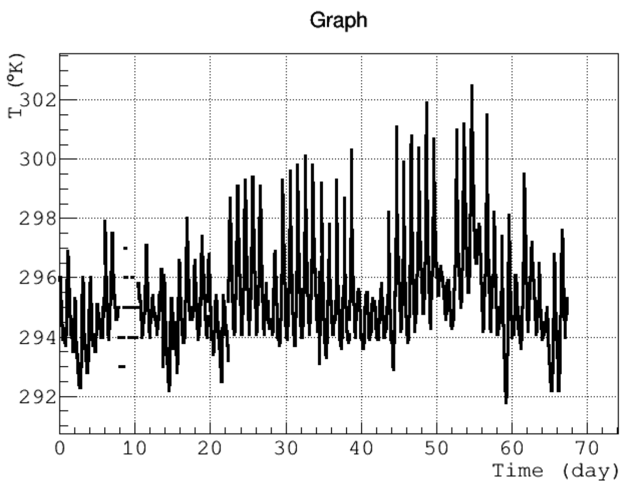
Spares Slides

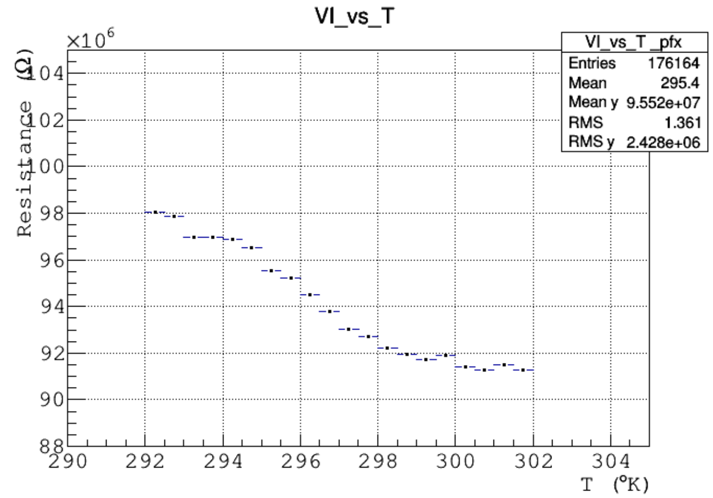
CEPC timeline



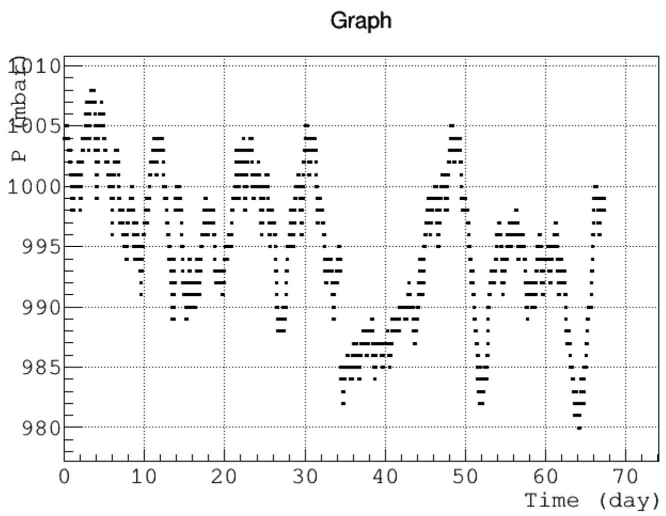
DLC studies (IV)

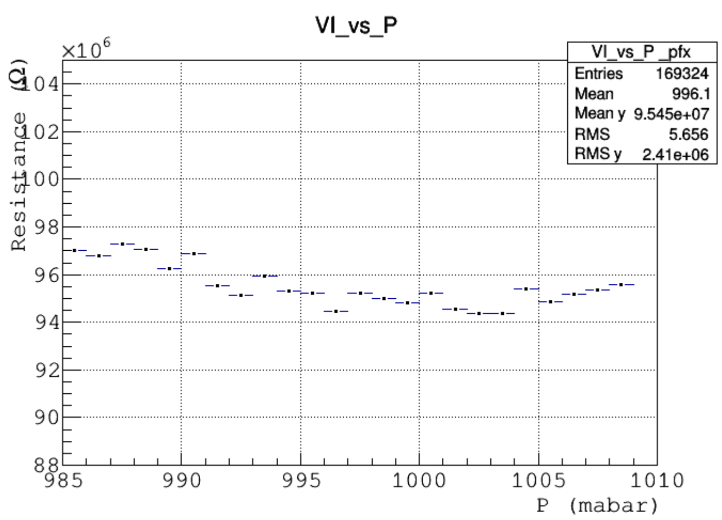
Temperature (°K)





Pressure (mbar)

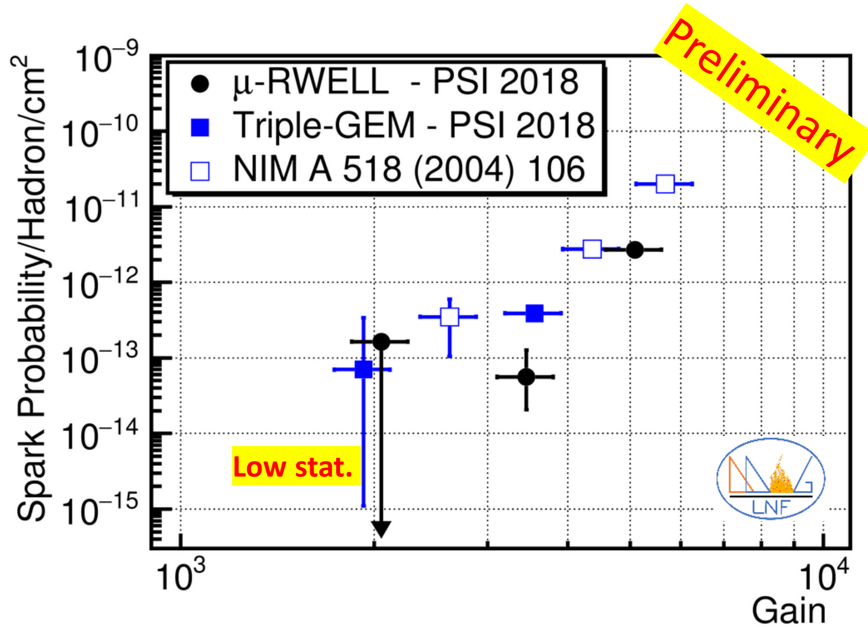


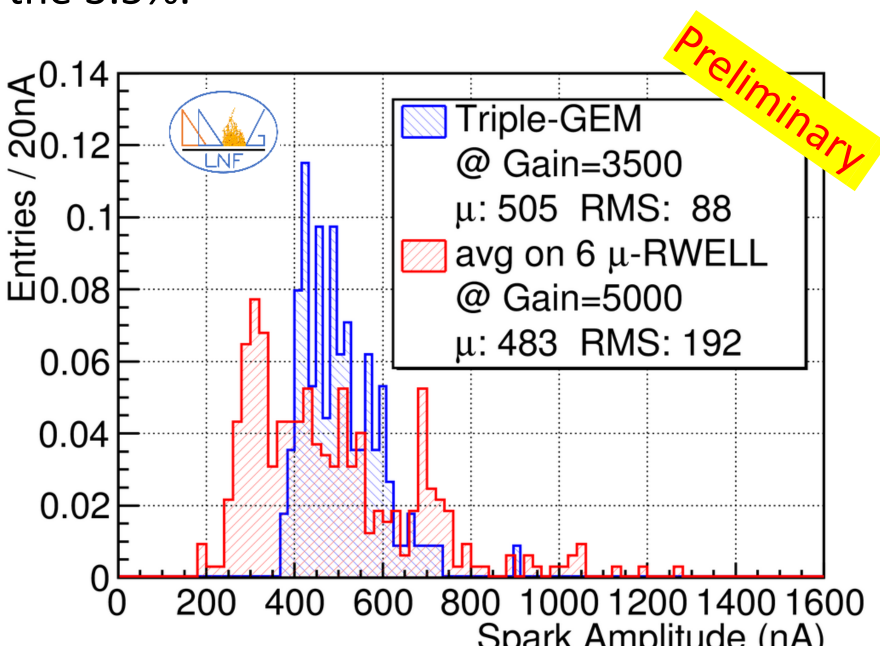


Discharge studies

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%.





A "discharge" 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.