High Granularity Resistive Micromegas for high particle rates environment.

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on behalf of RHUM R&D Project:

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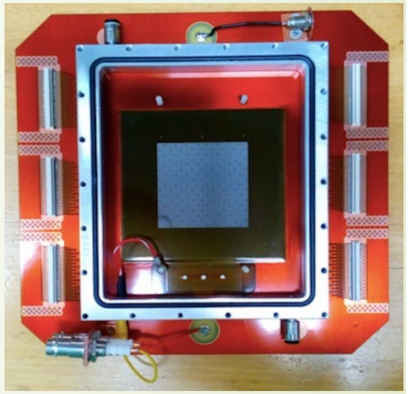
Istituto Nazionale di Fisica Nucleare

12th International Conference on POSITION SENSITIVE DETECTORS

Hosted by UNIVERSITY OF BIRMINGHAM

Introduction

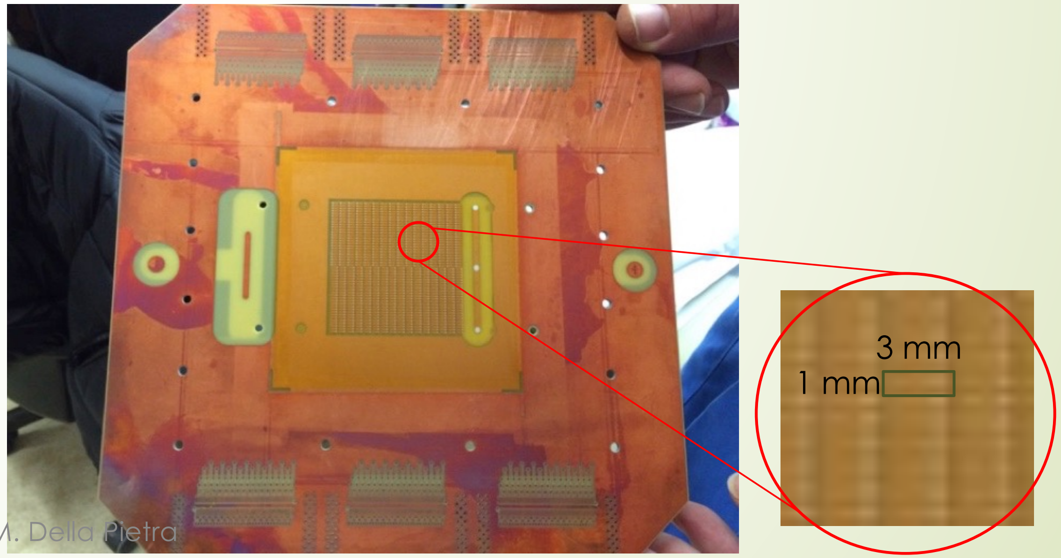
- Development of Resistive Micromegas detectors, aiming at precision tracking in high-rate environment without efficiency loss up to several MHz/cm^2
- Roadmap for RHUM R&D project (**R**esistive **H**igh gran**U**larity **M**icromegas):
  - Implementation of a Small Pad Readout (allows for low occupancy under high irradiation);
  - Optimisation of the spark protection resistive scheme;
  - Layout optimisation (embedded electronics);
  - Scaling to larger area.
- Possible applications:
  - ATLAS very forward extension of muon tracking (Large eta Muon Tagger as an option for future upgrade),
  - Muon Detectors and TPC at Future Accelerators,
  - Readout for sampling calorimeters.



Readout pad segmentation

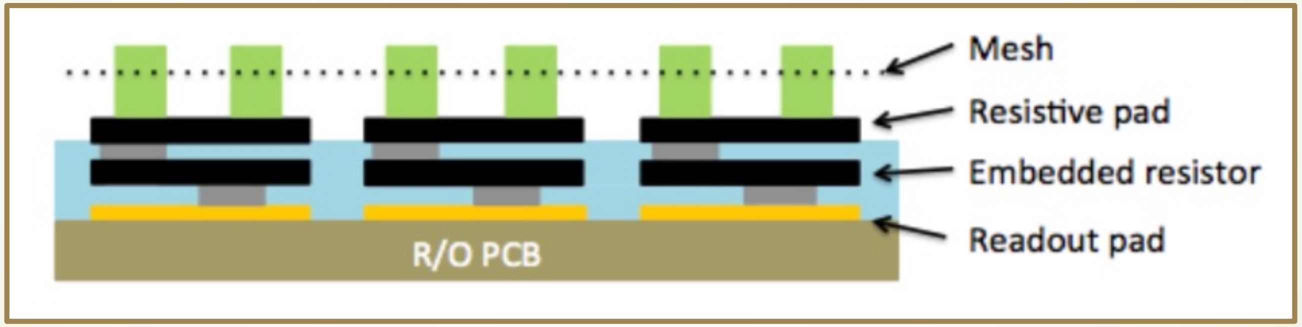
- Basic idea: The finer is detector granularity, the lower is the detector occupancy
- Readout plane segmented in pads O(mm^2) to ensure high rate capability and good spatial resolution in both coordinate.
- All the prototypes share the same cathode segmentation:
  - 16 x 48 = 768 readout Pads matrix with (1 mm x 3 mm) covering 4.8 x 4.8 cm^2 active area;
  - Circular pillars with r = 200 μm, height 100-120 μm (bulk technique) and 6 mm pitch;

- Technical solution inspired by a similar **R&D** by COMPASS and other groups within RD51 Collaboration;
- **R&D** started in 2015 (INFN and University of Napoli and Roma3) in collaboration with CERN and with the CERN PCB Workshop (Rui De Olivera) for prototype construction.



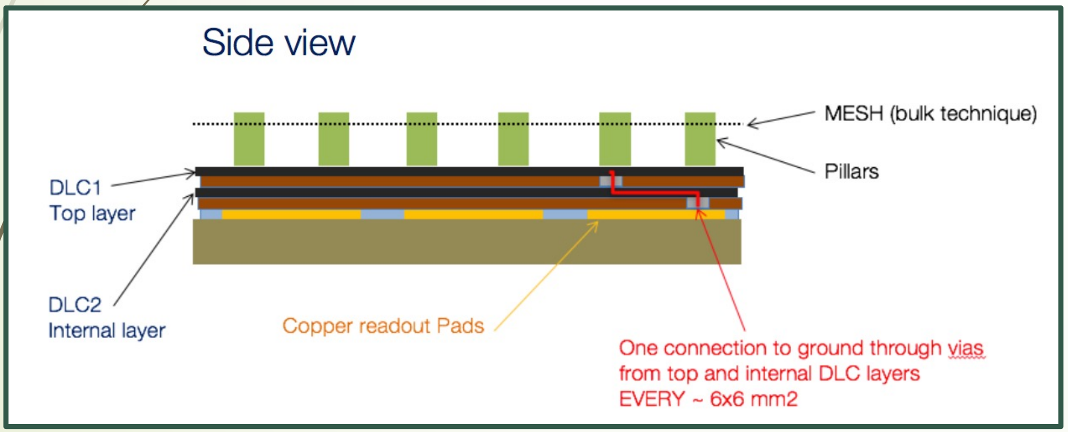
Spark suppression resistive layout

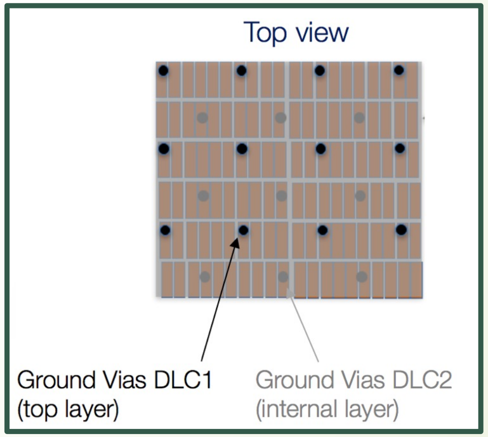
- Scheme 1: PAD-Patterned embedded resistor:
  - Two planes of independent screen printed carbon resistive pads with the same geometry of copper readout pads;
  - The overlapped pads in the different planes are interconnected by silver vias, as shown in the picture.
  - Each pad has an overall impedance ranging within (3 – 7 MΩ) and is completely separated from the neighbours



Spark suppression resistive layout

- Scheme 2: Double DLC (Diamond Like Carbon) uniform resistive layer
  - Two continuous resistive DLC layers (20 - 50 MΩ/□) interconnected between them and to the readout pads with network of conducting links with the pitch of few mm, to evacuate the charge;
  - Same concept of uRWell (see G.Bencivenni et al. 2015_JINST_10_P02008)



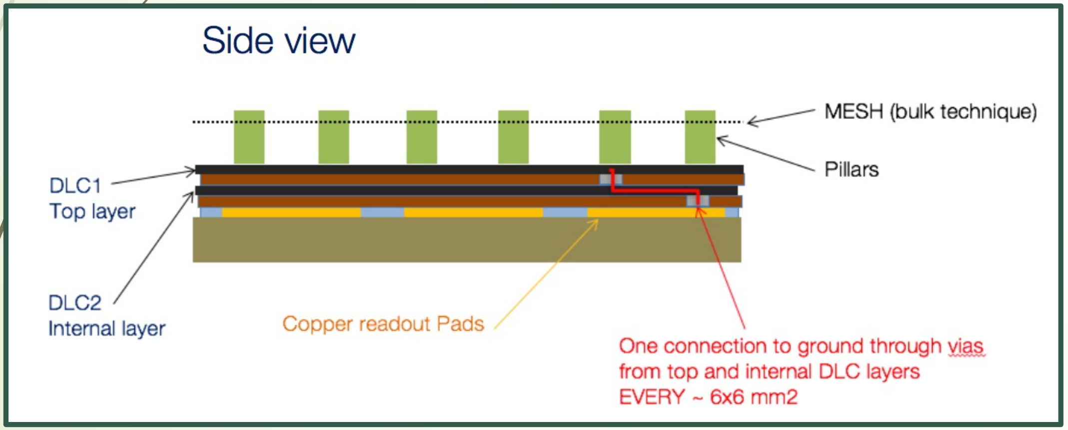


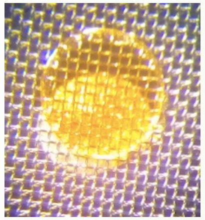
Two prototypes with different surface resistivity:

DLC 20
DLC 50

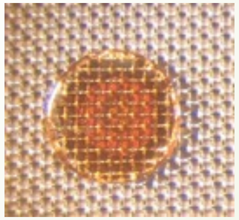
Spark suppression resistive layout

- Scheme 2: Double DLC (Diamond Like Carbon) uniform resistive layer
  - An improved production technique have been developed (**SBU sequential built-up**): with copper cladded DLC foils.
  - This allows an easier photolithographic construction process improving of the alignment of vias and centering of the pillars.





DLC series:
Case of a pillar not aligned with the silver via
This can cause sparks



SBU series:
Perfect alignment of each pillar.

Spatial resolution and cluster size

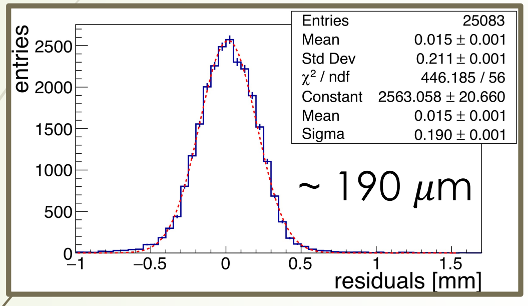
- Several prototypes have been tested @ CERN-SPS using muon and pion beams:

$$\sigma_{resol} = \sqrt{\sigma^2_{resid} - \sigma^2_{track}}$$

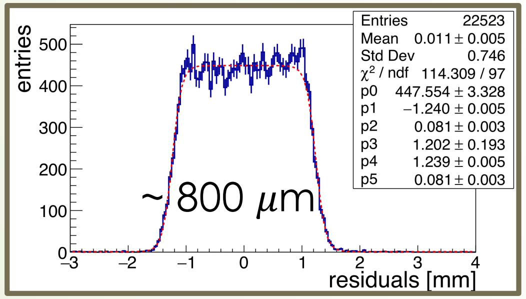
$(\sigma_{track} \simeq 50\ \mu m)$

PAD Patterned

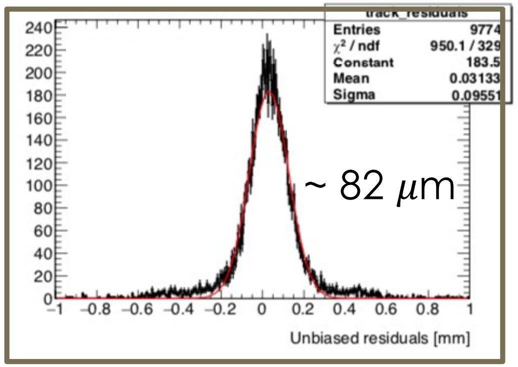
first coordinate 1 mm pitch



second coordinate 3 mm pitch



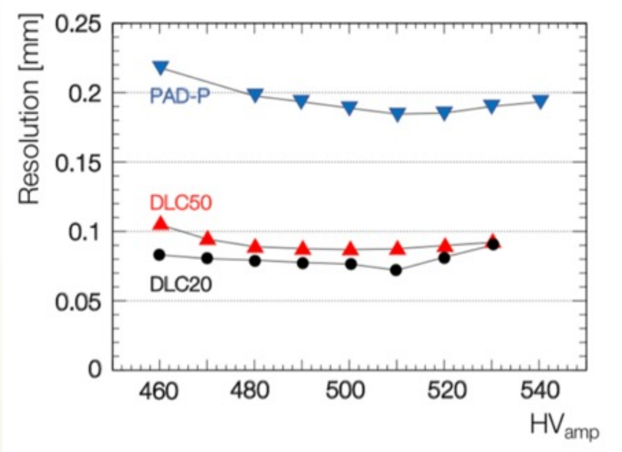
DLC 20



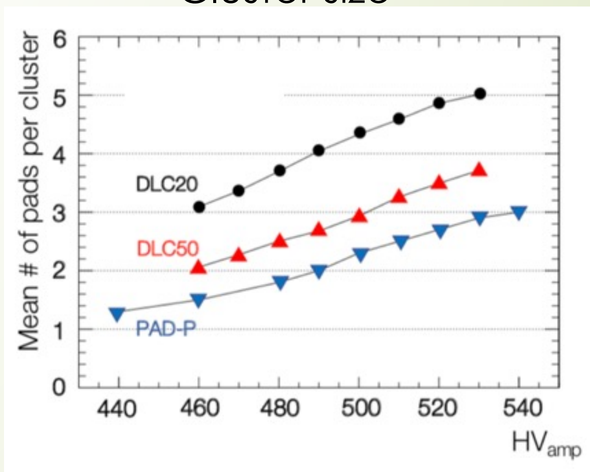
More uniform charge distribution among pads in the clusters leads to:

- Significant improvement of spatial resolution of the DLC prototypes (pad charge weighted centroid)
- The lower is the resistivity of the DLC layer the higher is the size of the cluster

Precision coordinate resolution

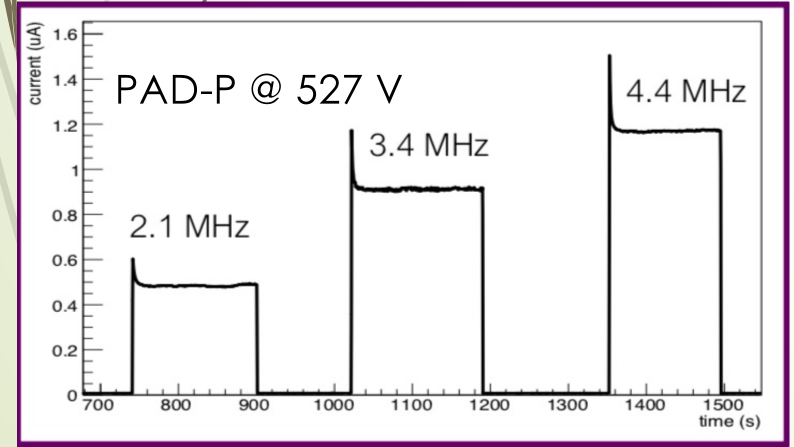


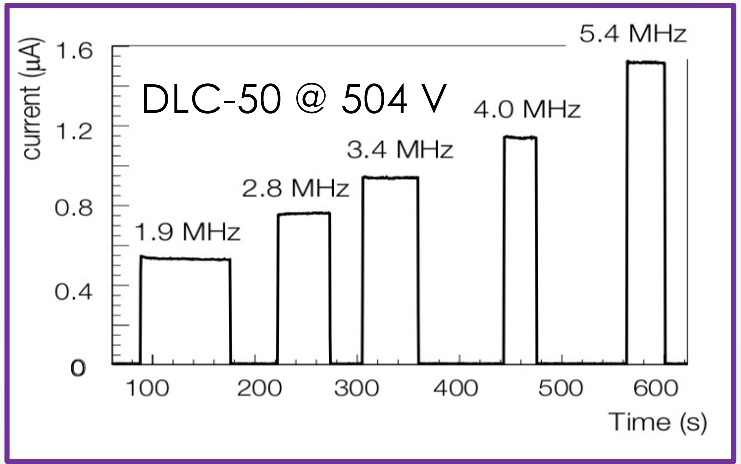
Cluster size



Detector current vs time: charging up

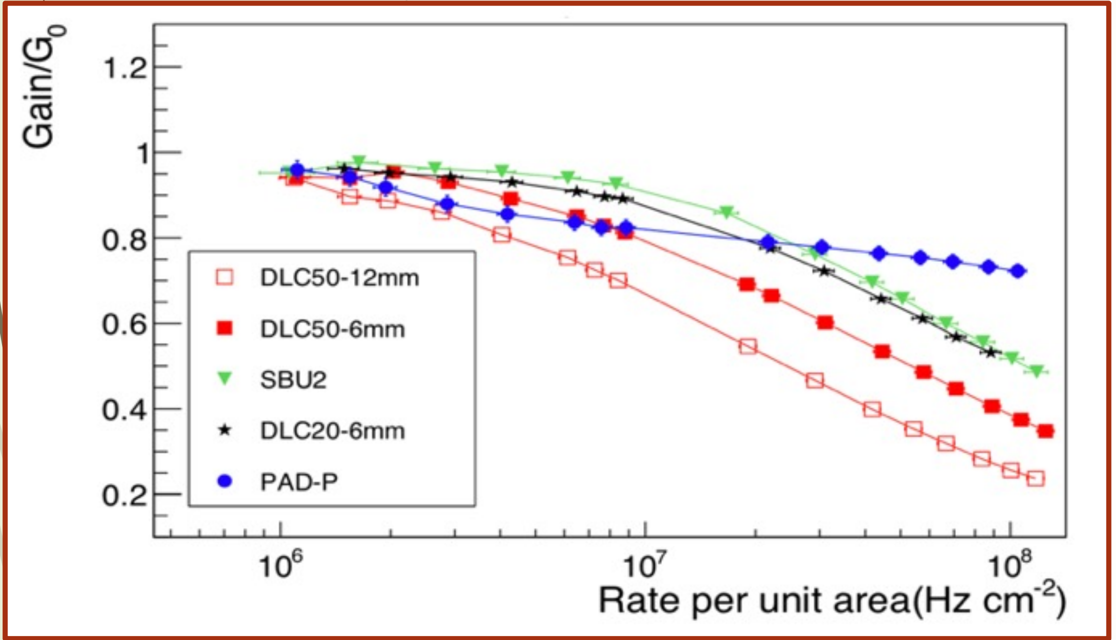
- All prototypes with Pad-Patterned resistive layout shows sizeable effects of charging-up (gain reduction by ~20%) in **current as function of time**.
  - a possible explanation is due to dielectric charging-up of exposed Kapton surroundings the resistive pads. **Still under investigation.**
- DLC detectors do NOT show any sizeable charging-up effects (less than few %)
  - expected from the uniformity of the resistive layer and from the absence of exposed dielectric, with the exception of the pillars.
  - Very stable on short time scale (several minutes). we also observed a slow increase of gain over long time - few percent - still under investigation





Current measurement Vs Time during cycles of X-Rays irradiation

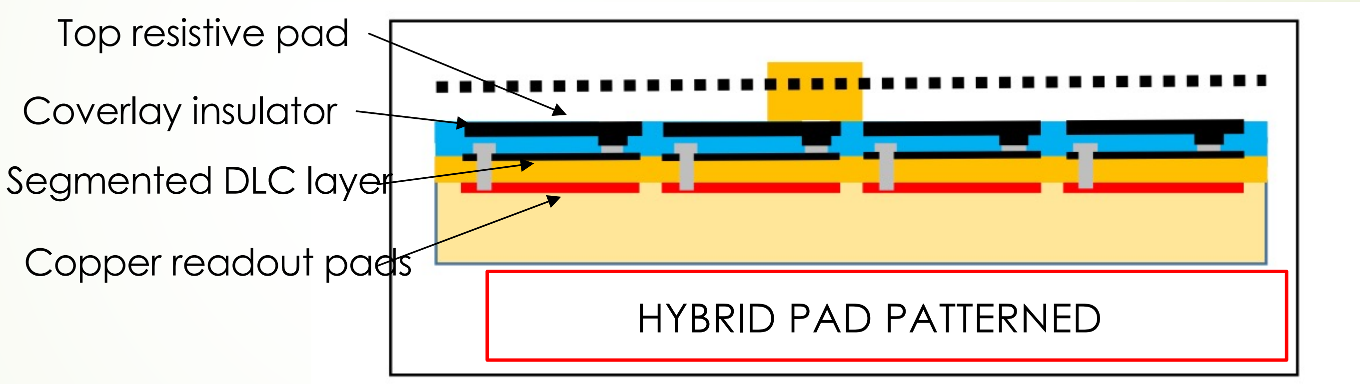
Rate capability



- PAD-P shows a sizeable gain drop due to the charging-up at lower rates (up to few MHz/cm^2) but a lower ohmic drop due to the fact that each pads behaves as an independent resistor to ground.
- DLC20, SBU have a comparable behaviour in the explored region (up to ~100 MHz/cm^2):
  - mean values of the resistance between first and second DLC protection foils are almost the same
  - For rates greater than 20-30 MHz/cm^2 they shown a higher gain drop w.r.t. PAD-P
- As expected DLC20 and SBU better than DLC50 (due to lower resistivity)
- Clear difference between the regions with 6mm and 12 mm grounding vias pitch (the larger the vias pitch the greater the impedance to ground seen by the collected charge)

More resistive layouts

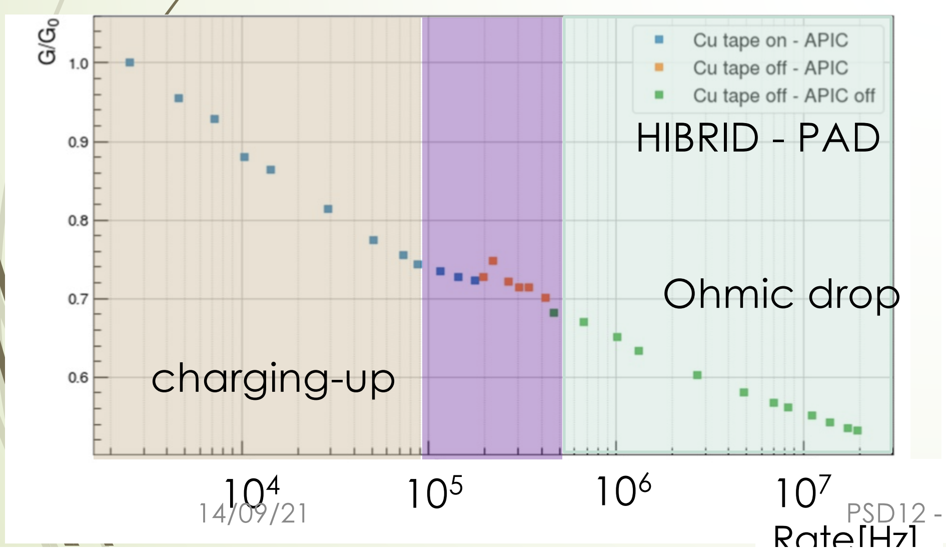
- Hybrid PAD Patterned solution:
  - The resistive pad facing the amplification gap is always screen printed
  - The intermediate resistor is done by DLC layer

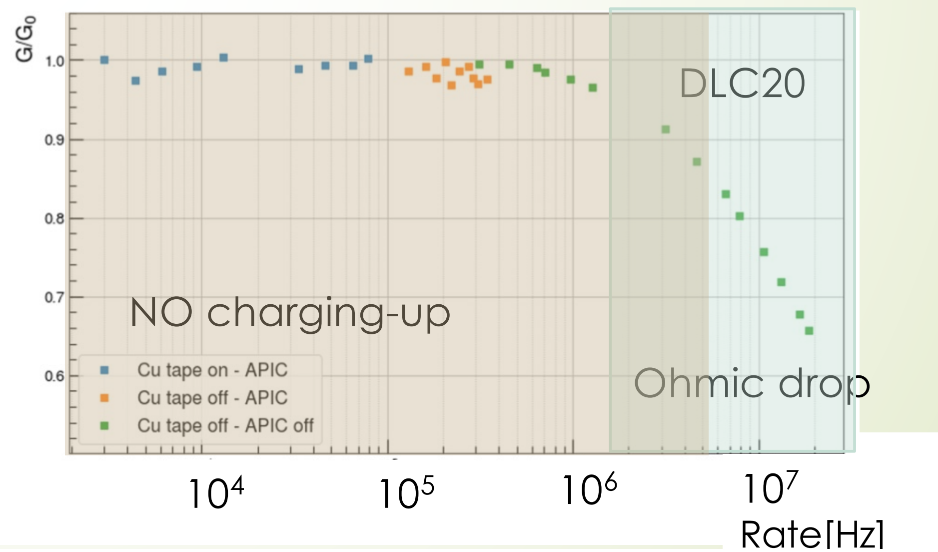


This solution combines the independence of the resistive pads in collecting the charge with a better uniformity of the impedance seen by the charge.

Gain vs Rate over 4 orders of magnitude

- X-rays exposure area 0.79 cm^2 (shielding with 1cm diameter hole)
  - PAD-P schema (and its hybrid version):
    - Significant gain drop at "low" rates dominated by charging-up effects
    - Negligible ohmic voltage drop for the individual pads for rates between 0,1 and ~2 MHz/cm2
  - DLC and SBU series:
    - Almost constant gain at "low" rates (up to few MHz/cm^2.
    - Significant ohmic voltage drop at higher rates



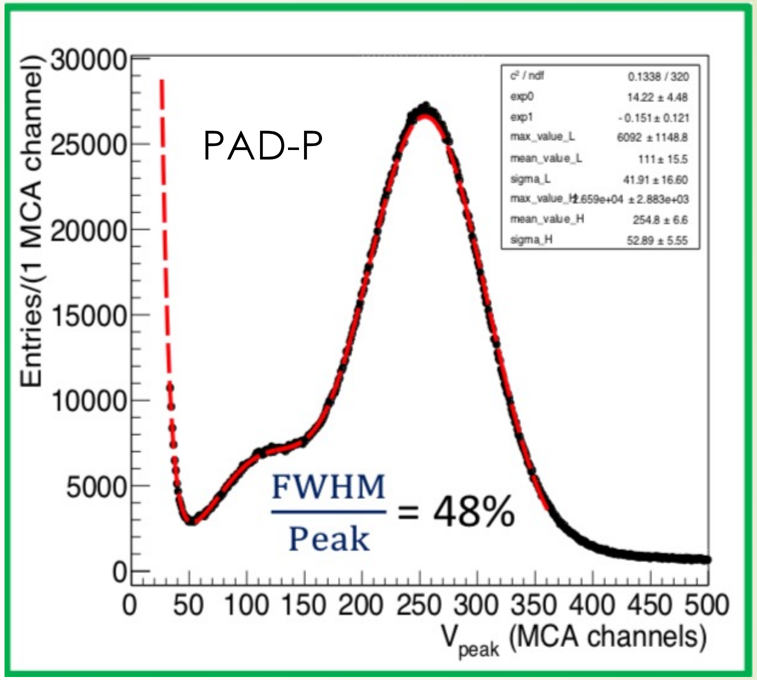


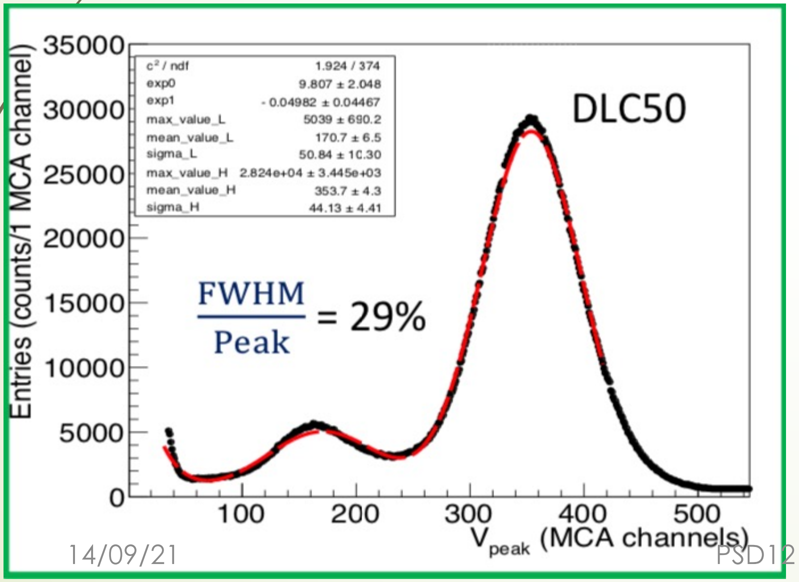
Energy resolution

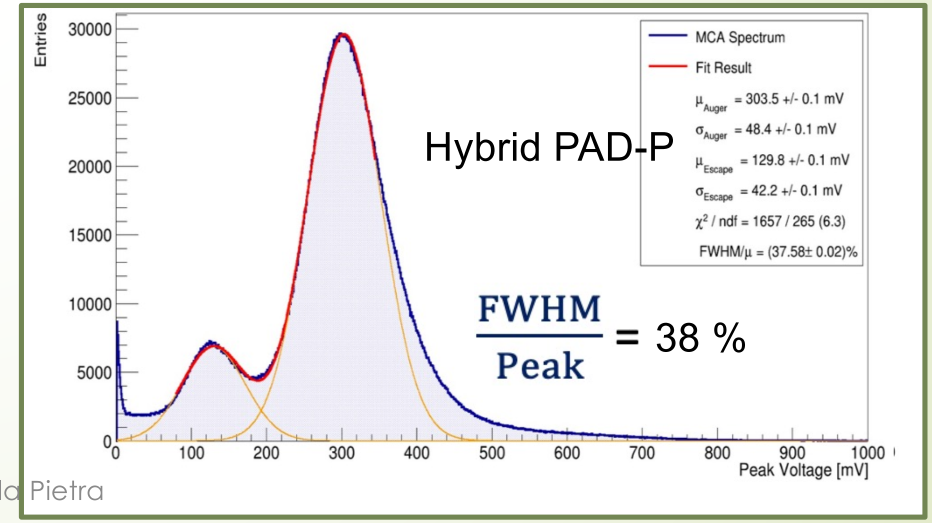
Energy resolution measured looking at the ^{55}Fe spectrum

The DLC resistive protection scheme shows a better energy resolution with respect to the "PAD-P" and "Hybrid PAD-P" schema due to:

- more uniform electric field
- no pad border effects

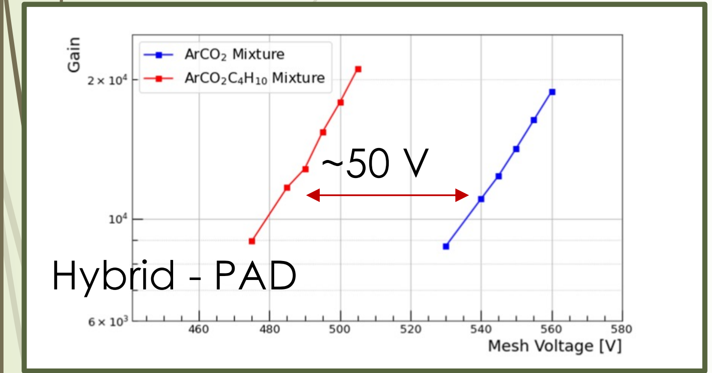


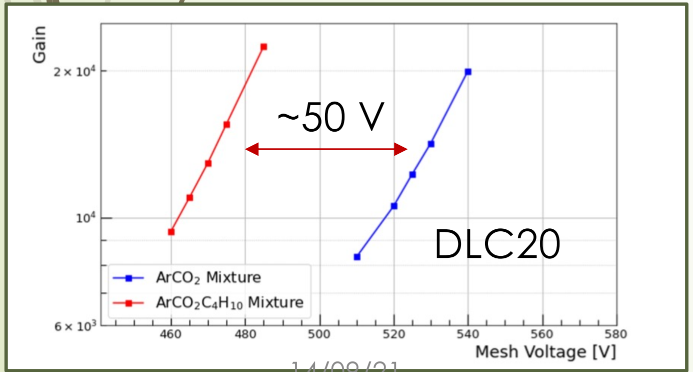




Studies with different gas mixture

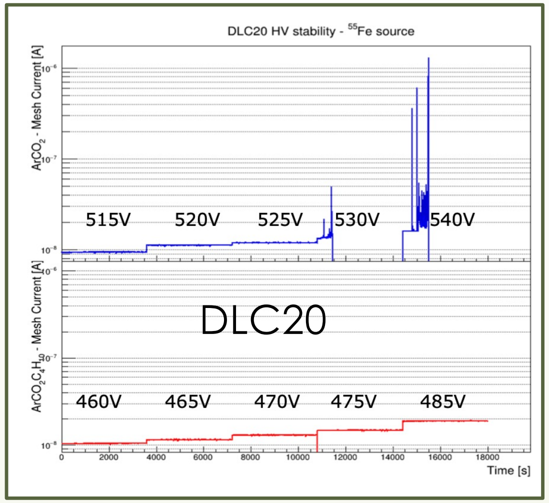
- Added 2% of Isobutane to our standard gas mixture in order to improve the detector stability
  - From Ar:CO_2 93:7 to Ar:CO_2:iC_4H_{10} 93:5:2
- Very high gain reachable in very stable conditions (^{55}Fe sources)

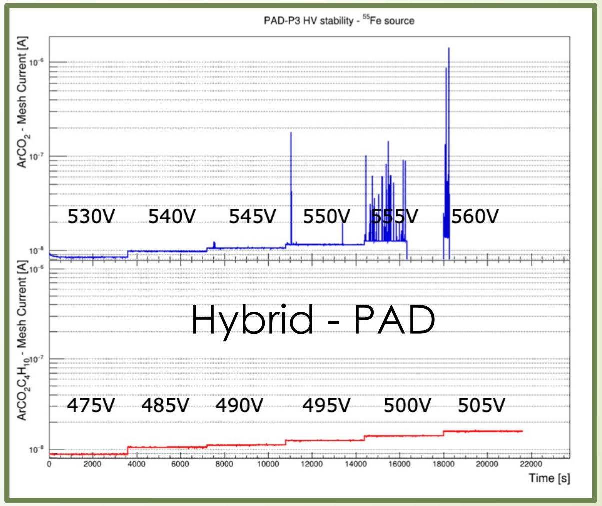




Without isobutane: Instability for Gain > ~15k

With isobutane: Stable operation up to Gain >20k





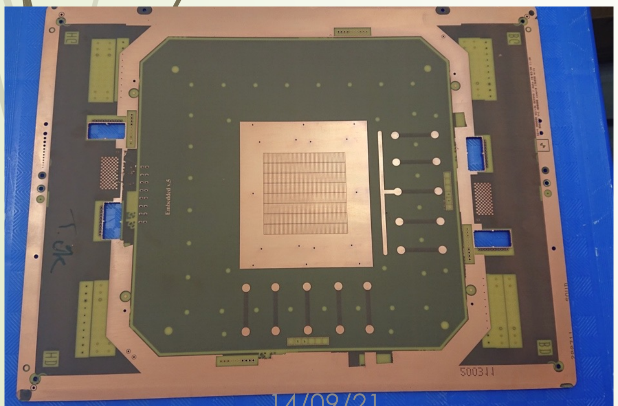
Different resistive layouts comparison

- All different sparks suppression resistive layouts have been extensively studied during last years in similar conditions gas mixture and of GAIN
- All the prototypes can be operated with a robust gain (7000) up to 20 MHz/cm^2.
- DLC prototypes, and particularly the improved SBU series, show a better spatial and energy resolution with respect the PAD patterned ones.
- PAD Patterned prototypes show a decrease of gain at low rates (charging up) but present a less important ohmic drop at very high rates.
- Detector stability is good with $Ar:CO_2$ 93:7 up to very high rate but adding 2% of isobutane ($Ar:CO_2:iC_4H_{10}$ 93:5:2 is not flammable mixture) a gain of 20k can be reached without any spark.

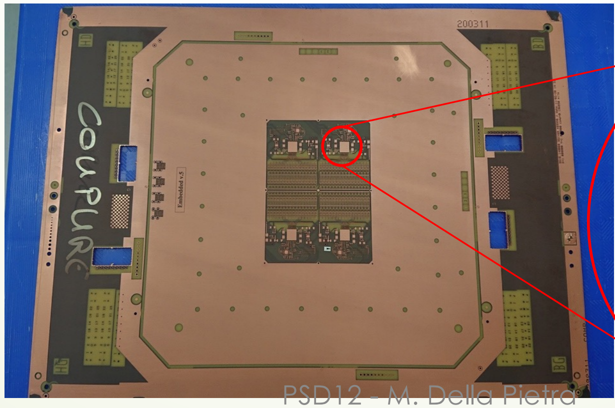
Next Step: Larger surface and integrated Electronics

- A larger area (20 x 20 cm^2) detector is under construction:
  - SBU resistive layout; 4800 readout pads (1x8 mm^2) only partially instrumented
- In order to solve the problem of the signal routing when scaling to larger surface a small prototype (64 x 64 mm^2) with integrated electronics on the back-end of the anode PCB has been built.
- APV25 FE chip used for the proof-of-concept: looking for alternative and more suitable solutions

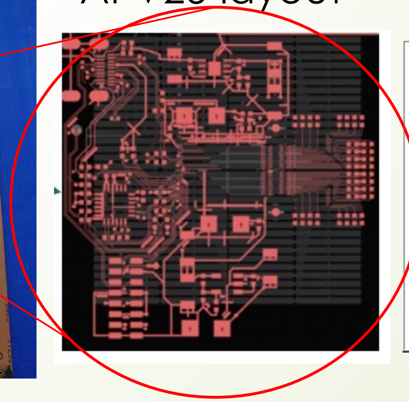
FRONT VIEW



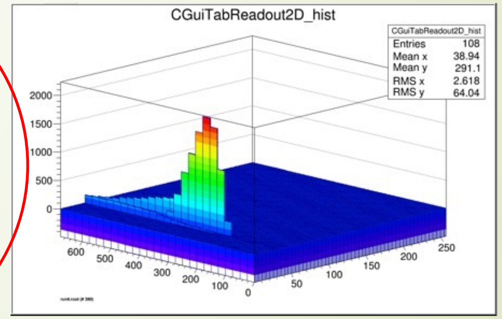
BACK VIEW



APV25 layout



Signal from 55Fe



Summary

- Several small-pad resistive micromegas prototypes, with different concepts of the spark protection resistive system, have been tested and compared.
- Prototype with embedded electronics is built and under test.
- Gas mixture optimization studies are ongoing
- Wide R&D program still to be completed:
  - Evaluate new FE chips alternative to APV25;
  - Produce and test larger prototypes (20x20) cm^2 with embedded electronics;
  - Ageing studies;
  - Detector simulation studies and resistive layout parameters optimization.

Acknowledgements and bibliography

Many thanks to:

- R. De Oliveira, B. Mehl, O. Pizzirusso and A. Texeira (CERN EP-DT) for ideas, discussions and the construction of the detectors
- CERN RD51 Collaboration CERN GDD Lab for the continuous support during prototypes testing.

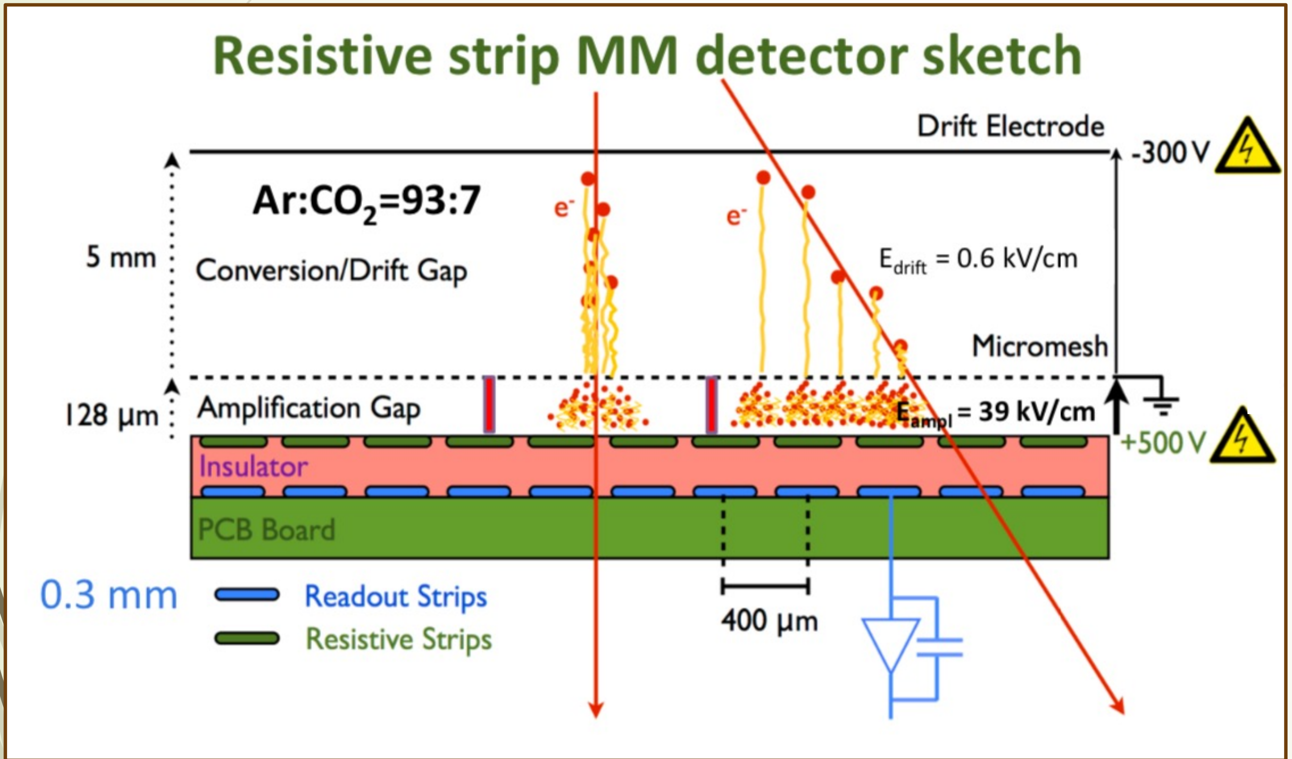
More significant publications and conference proceedings from our R&D:

- M. Alviggi et al., "*Construction and test of a Small-Pads Resistive Micromegas prototype*", JINST 13 (2018) no.11, P11019
- M. Iodice et al., "*Small-pad Resistive Micromegas: Comparison of patterned embedded resistors and DLC based spark protection systems*" J. Phys.: Conf. Ser. (2020) 1498 012028

Thanks.
Questions are welcome!

Backup slides

Our ancestor: Resistive Micromegas for ATLAS New Small Wheel upgrade

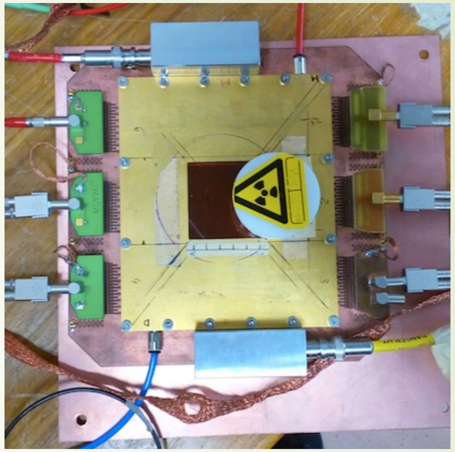


- A metallic micro mesh separates the drift volume (2-5 mm thick) from the amplification volume (~100 μm thick);
- electrons and ions produced in the amplification volume are collected in ~1 ns and ~100 ns respectively;
- spatial resolution < 100 μm independently from the incoming track angle;
- resistive anode strips on the top of the readout strips (with insulator in between) to suppress discharges.
- The "ATLAS" resistive strip micromegas with a wide surface (about 2 m^2) will operate at a moderate rate of about 20 KHz/cm2.

Gain measurements setup

Measurements have been carried out by means of two radiation sources:

- ^{55}Fe sources with two different activities
  - Low activity (measured rate ~ 1 kHz)
  - High activity (measured rate ~ 100 kHz)
- 8 keV Xrays peak from a Cu target with different intensities varying the gun excitation current



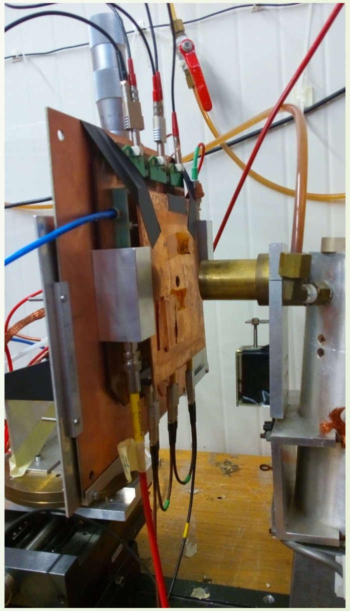
^{55}Fe source

Different gain measurement methods:

- Reading the detector current from the mesh (or from the readout pads) and counting signal rates from the mesh
- Signals amplitude (mesh) from a Multi Channel Analyser.

At higher rates

- Rates measured at low currents of the X-Ray gun
- Extrapolating Rate Vs X-Ray-current when rates not measurable or not reliably anymore



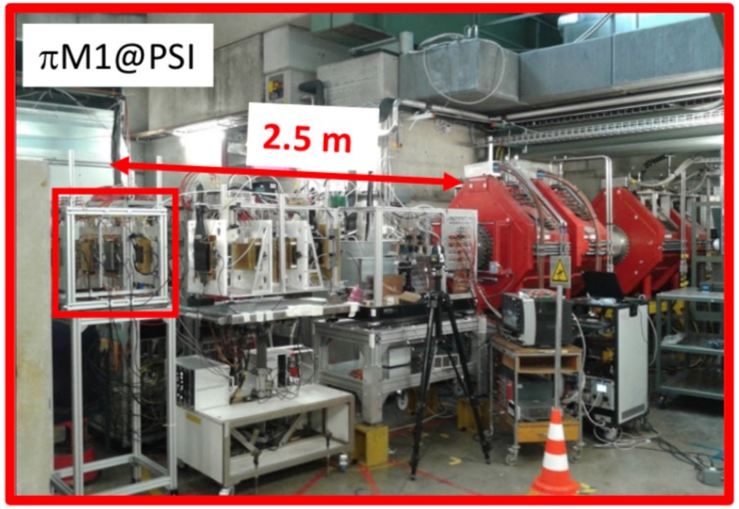
Xrays Gun

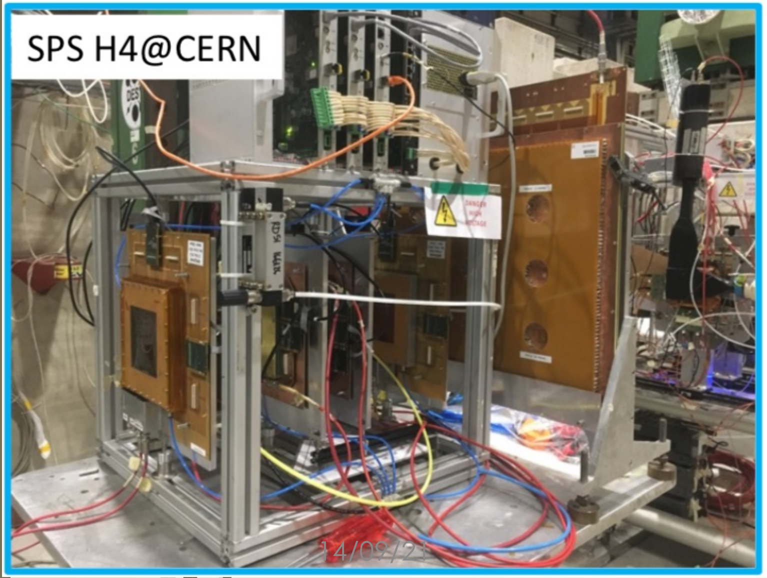
Comparison between prototypes has been done @ fixed gain (~ 7 x10³)

Gas Mixture Ar: CO_2 93:7
Chosen as the safest gas to operate under high irradiation for long time

Test beam (CERN and PSI) setup

2016/17	2018	2019
SPS H4@ CERN μ,π @ 150 GeV/c low/high rates	SPS H4@ CERN μ,π @ 150 GeV/c π @ 80 GeV/c	πM1@PSI π @ 300MeV/c p contamination ~7%
PAD-P, DLC50	DLC50 – DLC20	PAD-P, DLC20, SBU1 SBU2

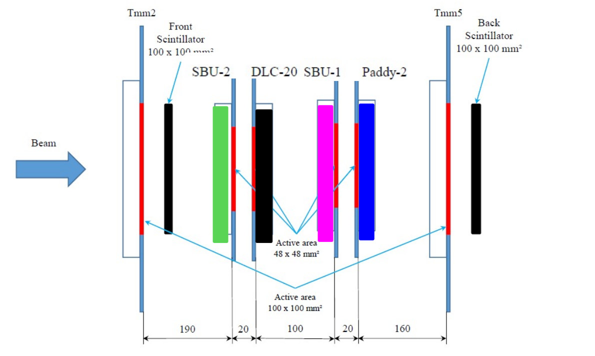




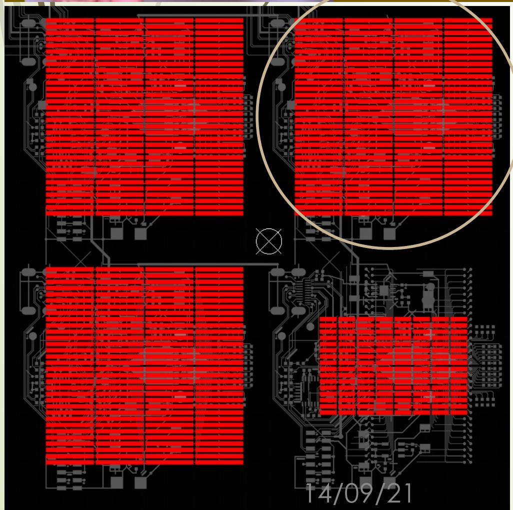
Typical setup:

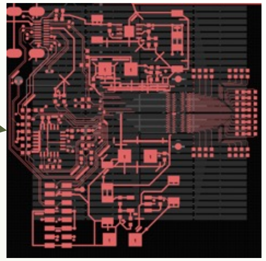
- Two small scintillators for triggering
- Two double coordinate (xy) bulk strips micromegas (10 x 10 cm2) for tracking
- Small-pads MM in between
- gas mixture: Ar/CO_2=93/7 pre-mixed
- DAQ: SRS+APV25

SBU2 DLC20 SBU1 PADP

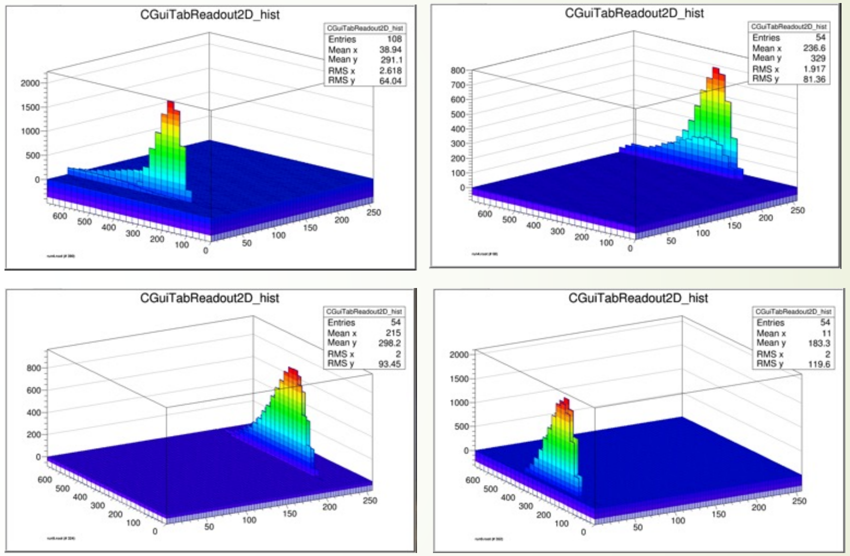


Prototype with Integrated Electronics





APV FE chip layout

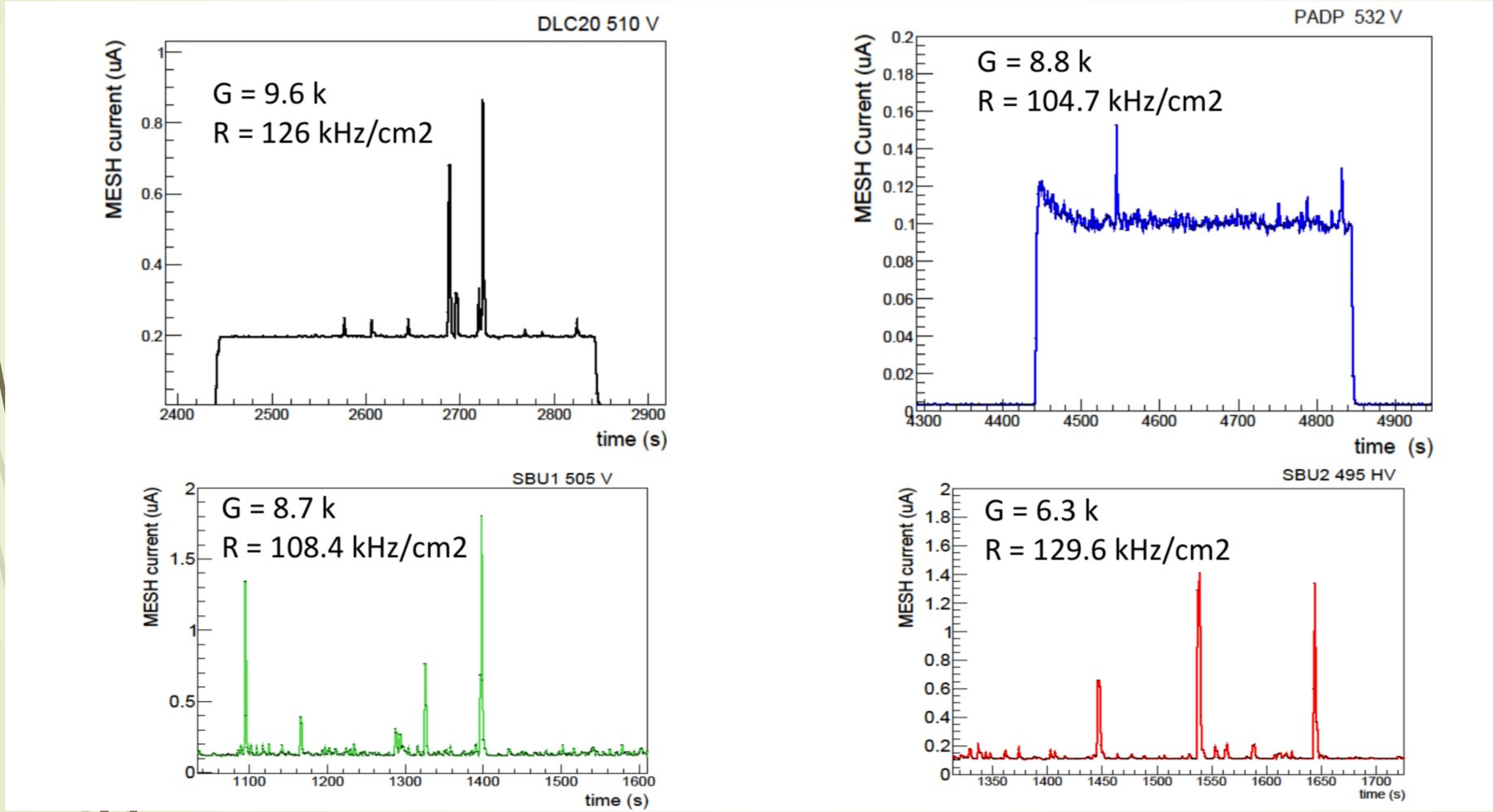


First tests promising:

- Nice Pedestals structure and signal response from APV using ^{55}Fe source and random trigger for DAQ → **BUT ONLY on some channels**
- Reason understood (issue in the elx Layout)

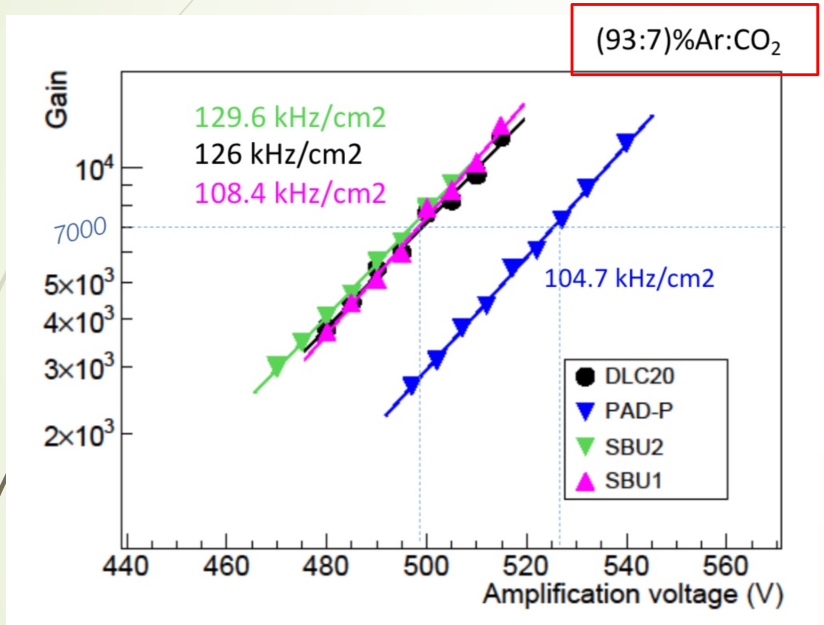
→ fixed it in the next prototype !

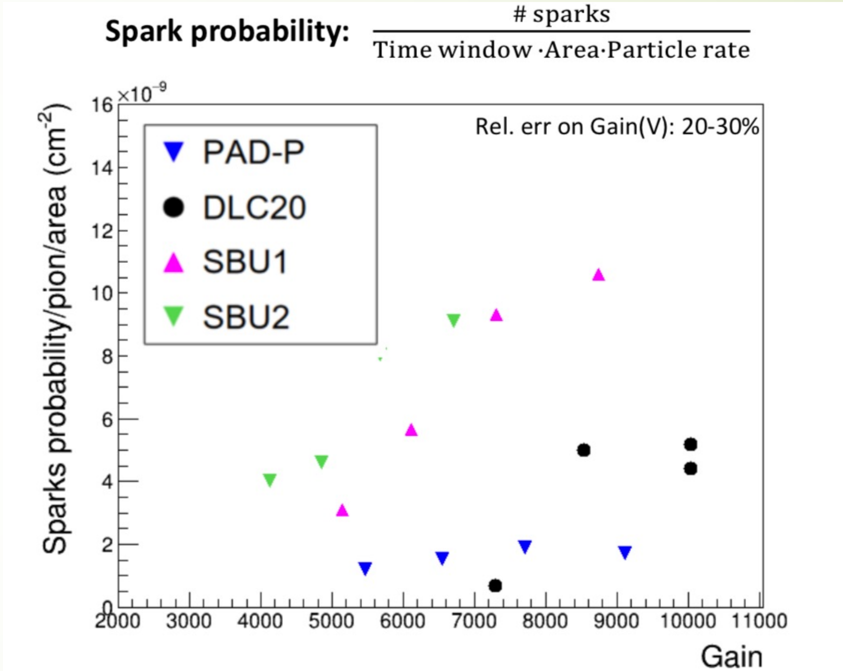
Example of spark events



Studies on sparks probability (TB @PSI)

Test beam with 300 MeV/c pions @ PSI with a rate of ~0.1 MHz/cm^2 has been mainly devoted to study the sparks probability for different prototypes

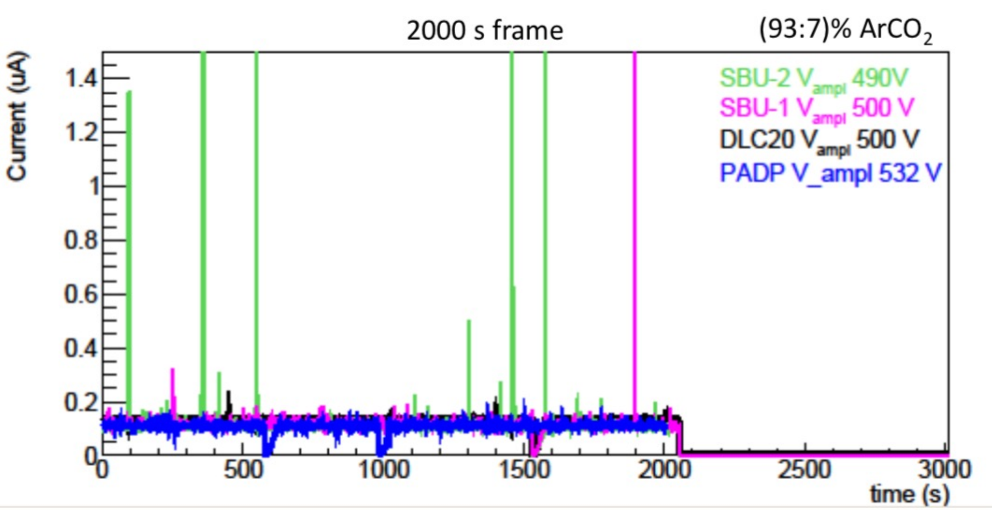


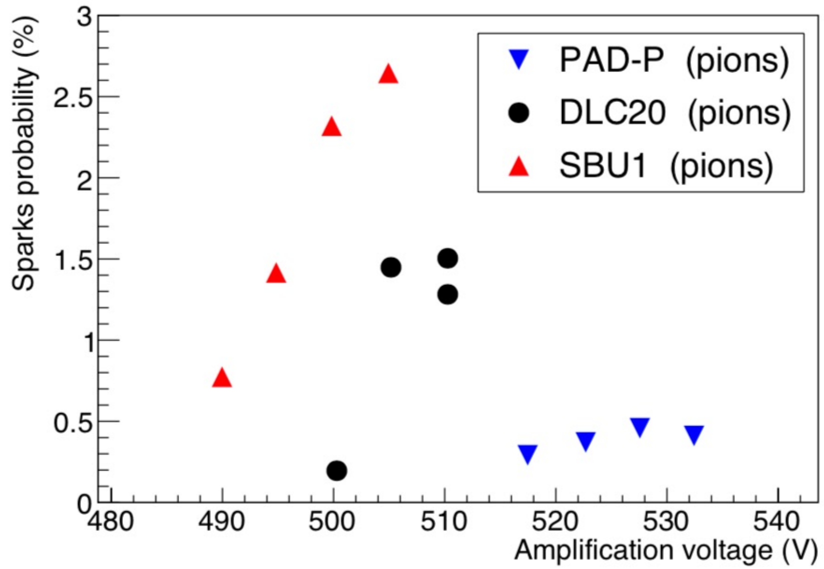


- Gain measurements with pions are in good agreement with ^{55}Fe and Cu-target X-Rays measurements.
- With a gain greater than 7500 PAD-P is the more robust prototype.

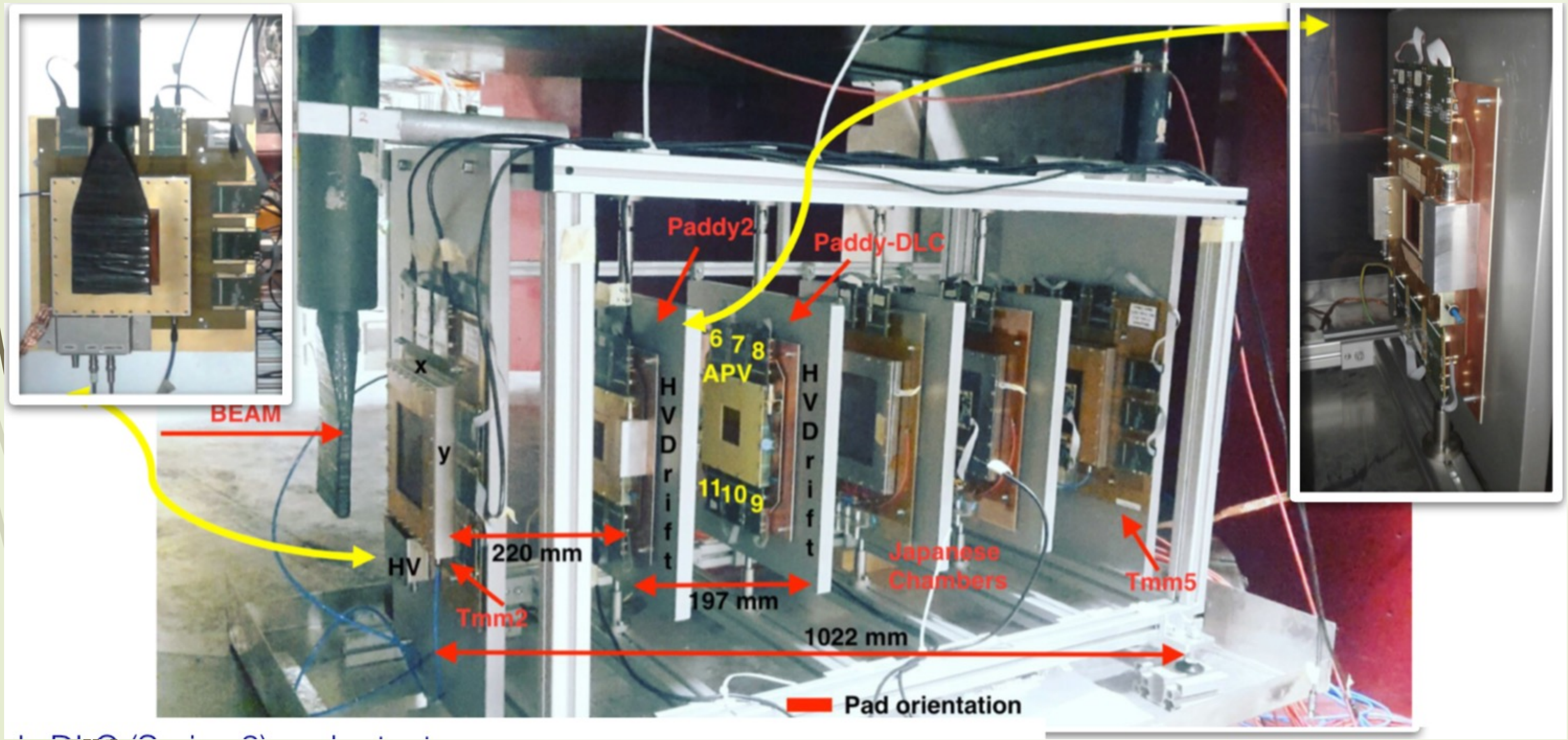
We count as "a spark" any change in drawn current greater than 30%

Discharge studies @ PSI



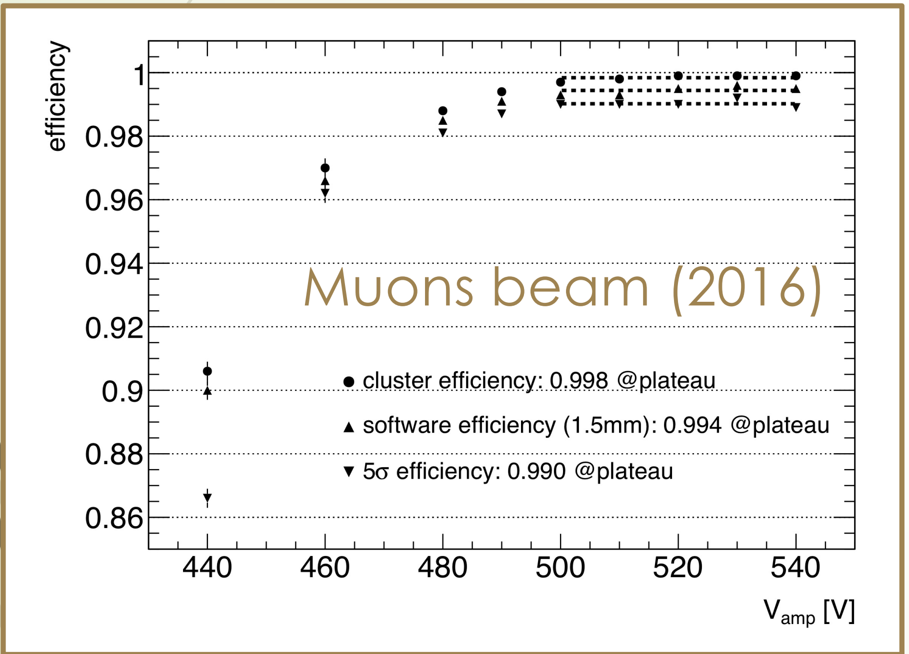


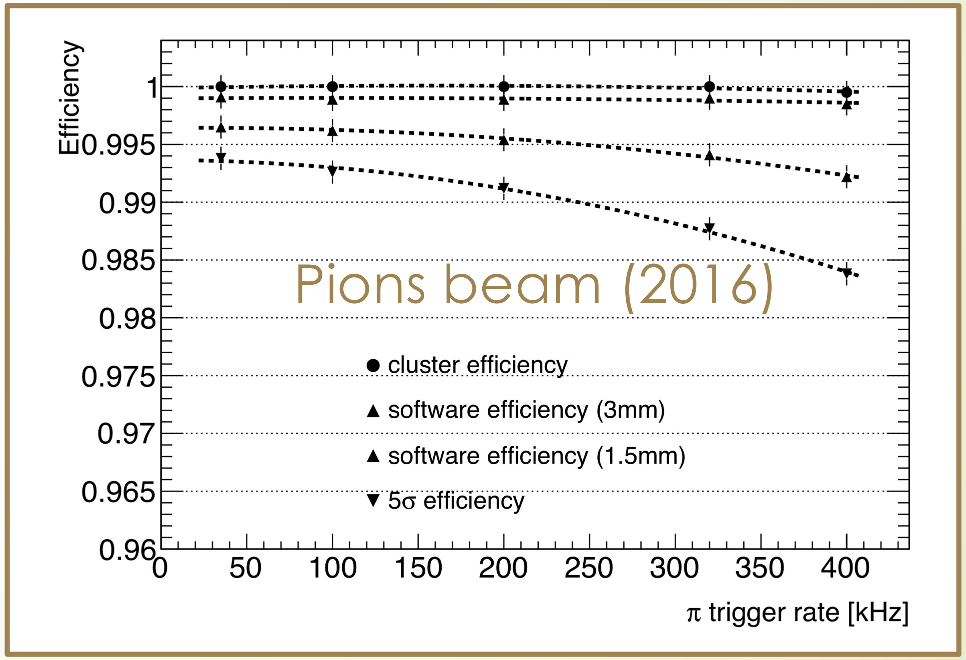
Test beam Setup in 2017



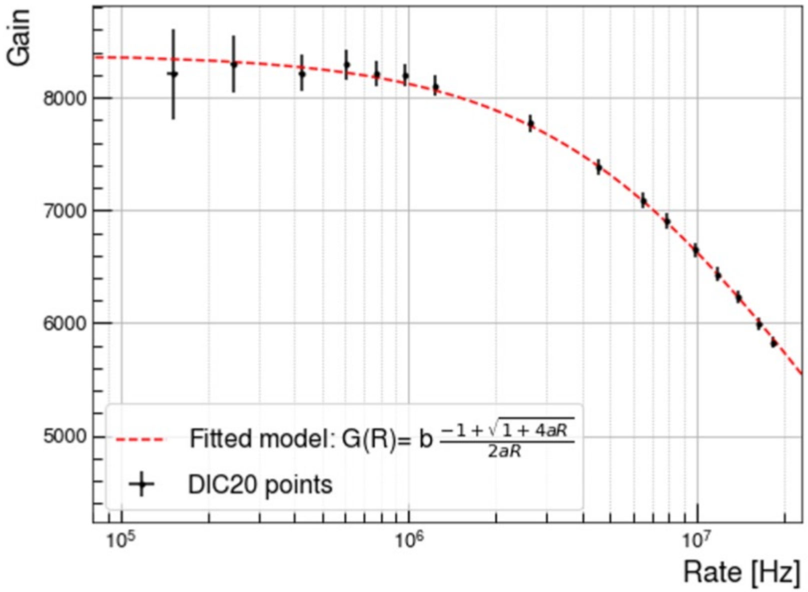
Efficiency for PAD-P prototype in TB 2016

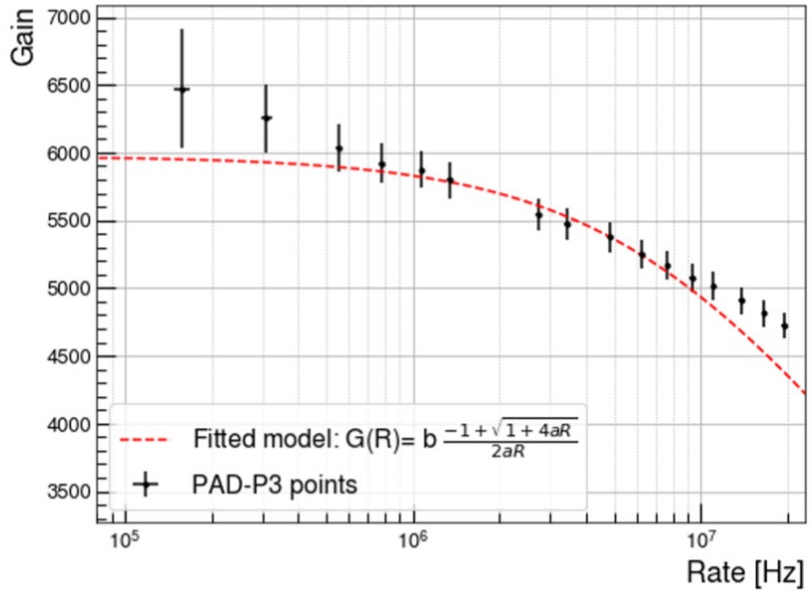
- Efficiency greater than 99% for muons and still above 98% for high energy pions up to a trigger rate of 400 MHz, corresponding to a pion rate of few MHz/cm2 in the middle of the pion beam spot





Gain ohmic drop @ very high rates

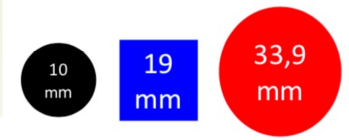


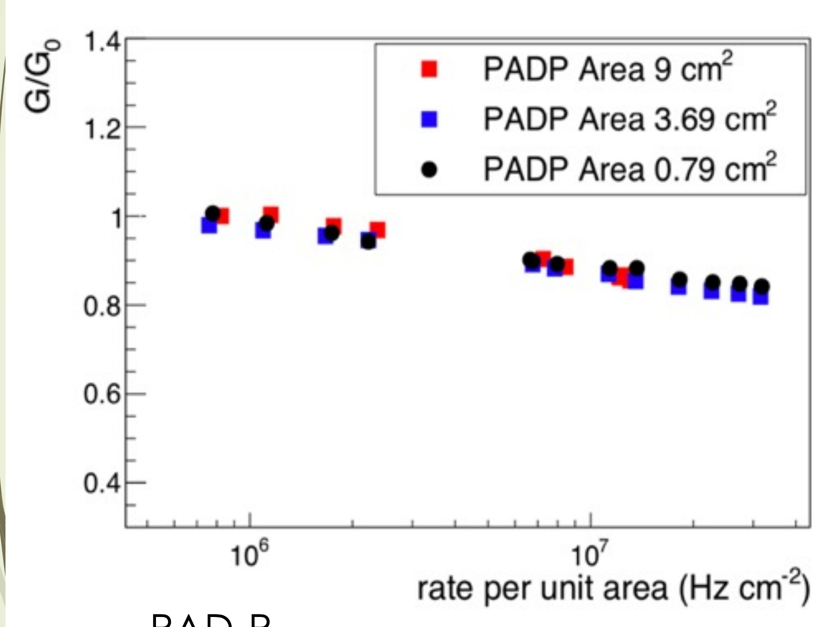


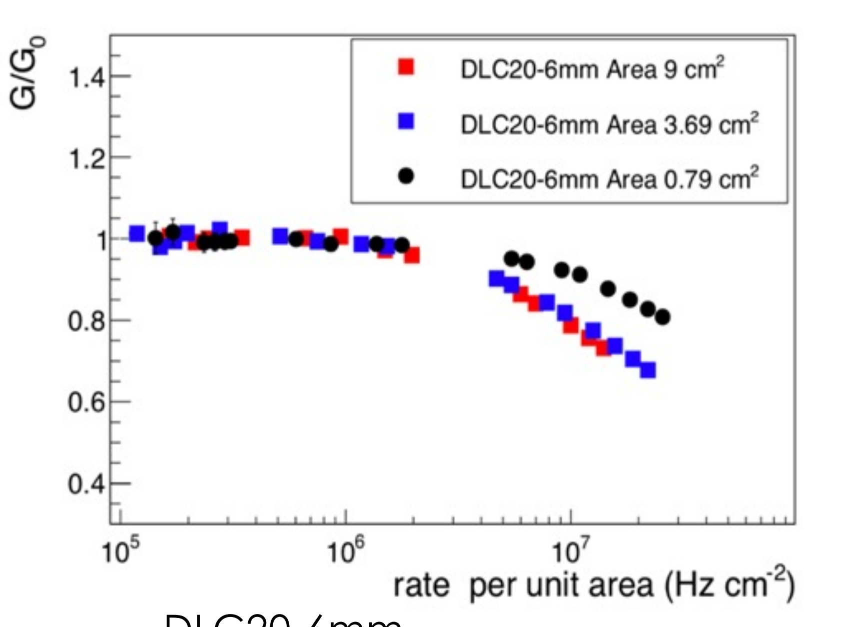
Fit attempted with the model in **G. Bencivenni et al. 2015 JINST 10 P02008** considering a Ohmic drop

- Fit in good agreement with data for DLC20
- Fit failure on Paddy3 as expected due to the different contribution to the drop (charging-up)

Rate capability dependence on irradiated area







PAD-P

- Thanks to independent pads there is no dependence on the exposed area.

DLC20-6mm

- For rates greater than 5 MHz/cm2 a dependence of the gain drop from exposed area is measured.
- For irradiated surface bigger than ~3.7 cm^2 (~10 times the grounding vias (0.6 x 0.6) cm^2 cell) gain drop does not scales with the area.

Charging – up with Xrays

- Test to probe effects of charging up on Pad-P3 ramping up and down I_{xray}, successive measures taken within short period of time (but the whole measure lasted > 3 hours)
- No strong effects of charging-up seen on DLC20