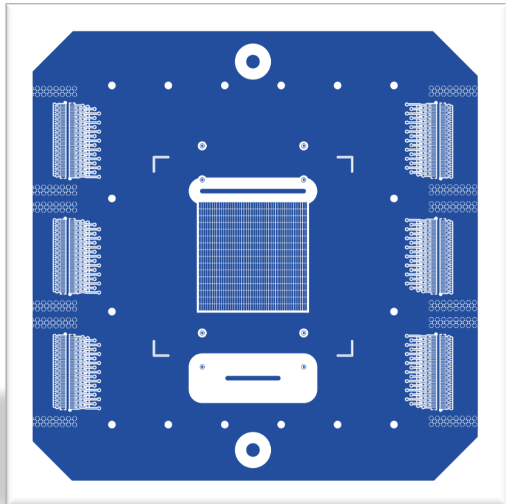
Pixelated Resistive Micromegas for Tracking Systems in High Rate environment

Mauro Iodice – INFN Roma Tre

for the “Small-pad micromegas” R&D Collaboration

(INFN Italy and CERN)

M. Alviggi, M.T. Camerlingo, V. Canale, M. Della Pietra, C. Di Donato,
P. Iengo, M. Iodice, F. Petrucci, E. Rossi, G. Sekhniaidze



INSTR 2020 24-28 February 2020 Novosibirsk, Russia

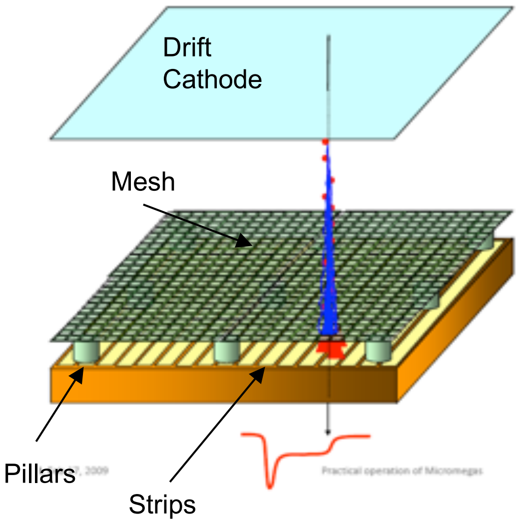
Introduction – Resistive Micromegas detectors

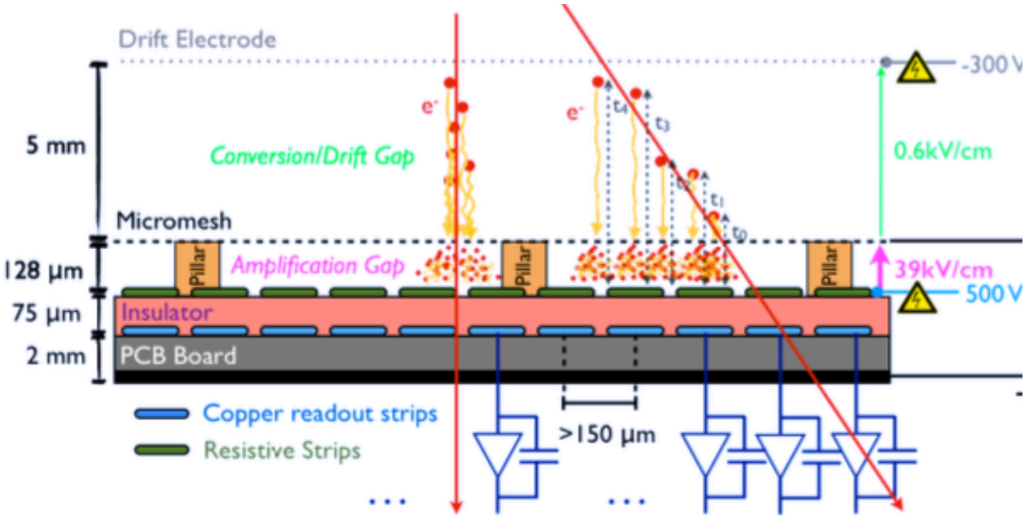
Resistive Micromegas:

Now a mature technology for HEP experiments also taking advantage of the intense phase of R&D for the ATLAS Experiment were resistive strips MM will be employed in the New Small Wheel upgrade of the Muon Spectrometer

(see talks by Ivan Gnesi and P. Tzanis)

- Resistive anode strips → suppress the intensity of discharge
- Large area: total surface of ~1200 m2 of gas volumes
- Operation at moderate hit rate up to ~15 kHz/cm^2 during the phase of High-Luminosity-LHC





Pixelated (Small Pad) Resistive micromegas

GOAL:

Development of Resistive Micromegas detectors, aimed at operation under very high rates 10's MHz/cm^2

R&D BASIC STEPS:

- **Optimisation of the spark protection resistive scheme**
- **Implementation of Small pad readout** (allows for low occupancy under high irradiation)

- From existing R&D (see acknowledgement) we aim at reducing the pad size from ~1cm^2 to < 3mm^2.
- Possible application: ATLAS very forward extension of muon tracking (Large eta Muon Tagger – option for future upgrade), Muon Detectors and TPC at Future Accelerators, …

Pixelated (Small Pad) Resistive micromegas

GOAL:

Development of Resistive Micromegas detectors, aimed at operation under very high rates 10's MHz/cm^2

R&D BASIC STEPS:

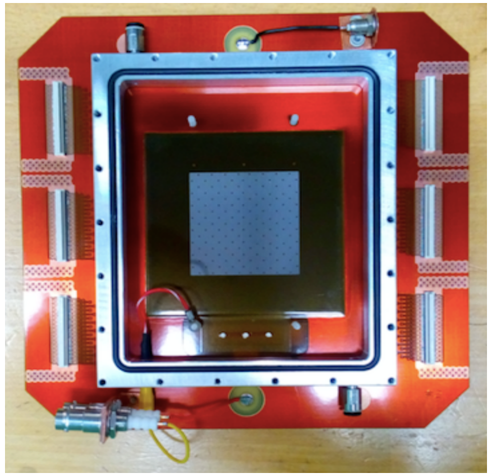
- Optimisation of the spark protection resistive scheme
- Implementation of Small pad readout (allows for low occupancy under high irradiation)

- From existing F … to < 3mm^2.
- Possible applic … agger – option for future upgra…

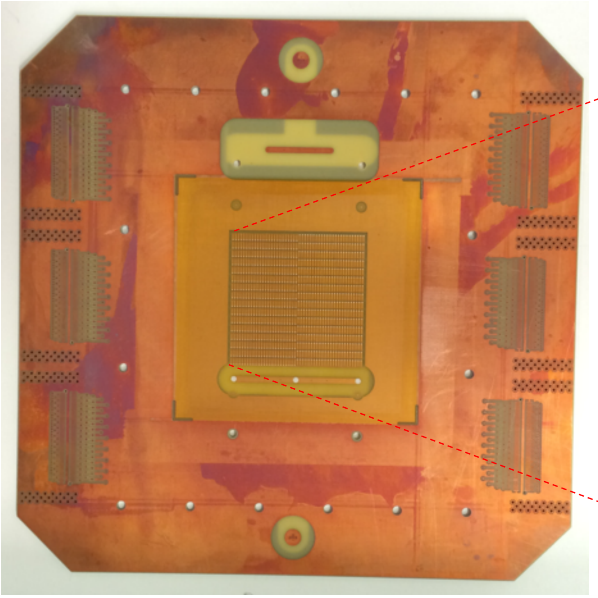
Keywords:

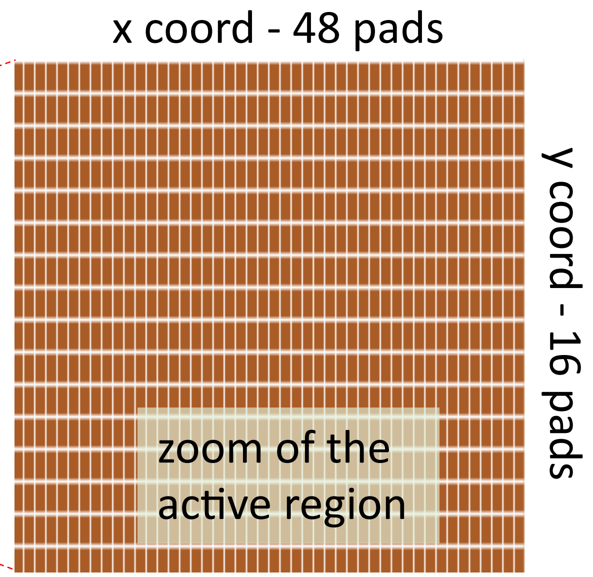
- Rate capability (10's MHz/cm2)
- Low occupancy → high granularity (pad readout $\mathcal{O}$(mm^2))
- Spatial resolution (depending on applications) ~100 μm
- Robustness

Layout of the small size prototypes



- Matrix of 48x16 pads – 768 channels
- Each pad: 0.8mm x 2.8mm - pitch of 1 x 3 mm^2
- Active surface of 48x48 mm^2



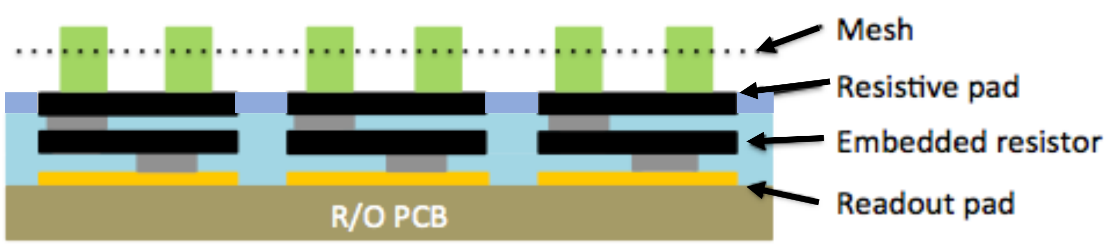


Two different implementations of the Resistive layer

Two series of small pad resistive micromegas prototypes built so far with **pad dimension 3 mm^2**.

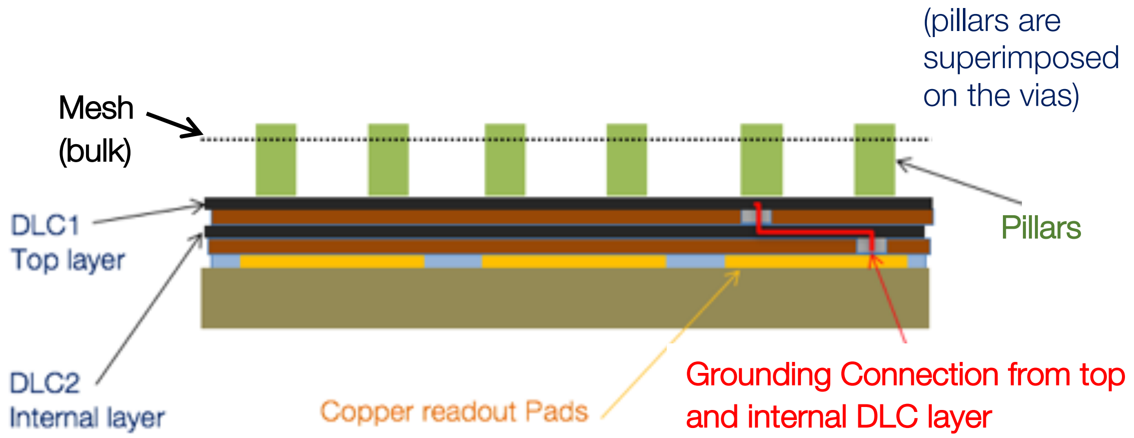
Different implementation of the resistive protection system against discharges :

PAD-Patterned resistive layer



- Embedded resistors by Screen-Printing
- Resistive pads by paste filling of photoimaging created vessels
- each pad is totally separated from the others, for the anode, as well as for the resistive part

Double DLC (Diamond Like Carbon) uniform resistive layer



- Same concept of uRWell (see G.Bencivenni et al. 2015_JINST_10_P02008)
- Double DLC layer with connection vias to ground every “few” mm

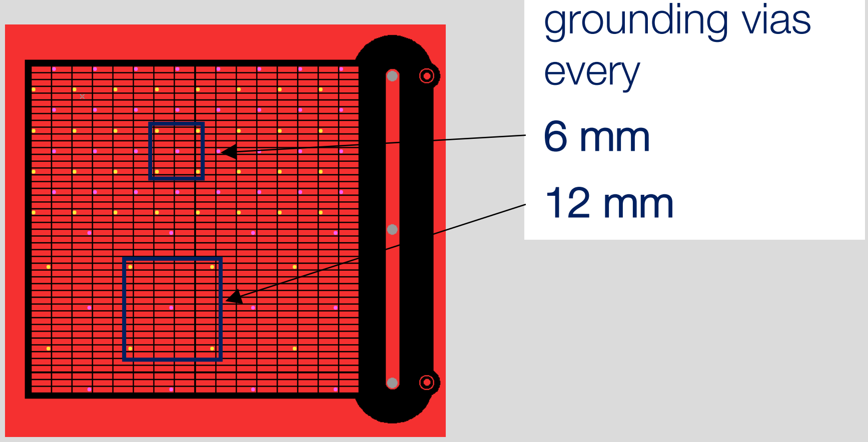
PROTOTYPES

PAD-P: Embedded resistor

- mean value of the embedded resistors ≈ 3-7 MΩ

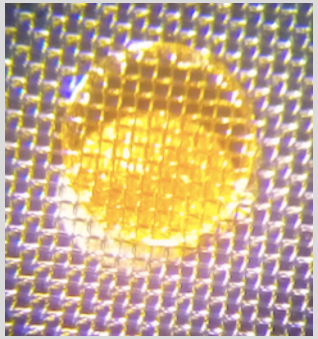
DLC20, DLC50: ‘standard’ DLC, sputtered on kapton

- surface resistivity 20 MΩ/□ (DLC20)
- surface resistivity 50-70 MΩ/□ (DLC50)
- two regions, with conductive vias every 6 and 12 mm

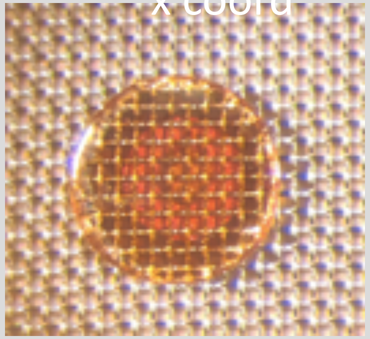


SBU1, SBU2: Sequential Build Up of DLC foils copper cladded on both sides

- easier photolithographic construction process
- improving of the alignment of vias and centering of the pillars with the silver vias (every 6 mm)
- for both prototypes: 1st layer (nearest to the pads) resistivity 35 MΩ/□ , 2nd layer 5 MΩ/□ (lower than requested)



DLC20/50
Case of uncovered vias
→ can cause sparks



SBU
Perfect alignment of vias

Characterization of the detectors

Measurements with sources and X-rays

Two radiation sources have been used:

- ^{55}Fe sources with 2 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

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

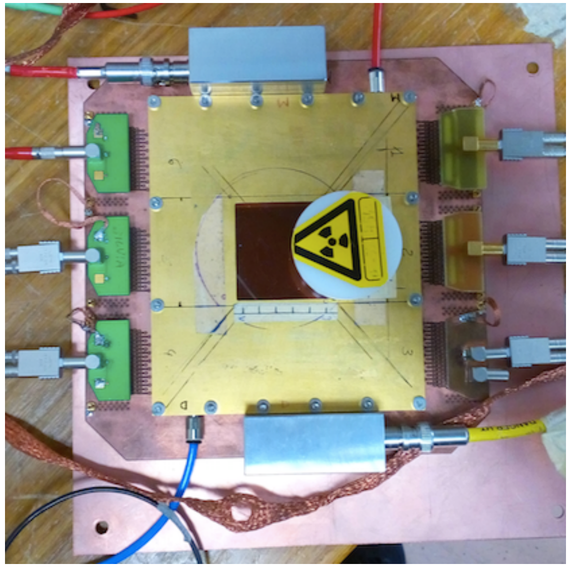
At High Rates (with X-Rays):

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

Gas mixture:

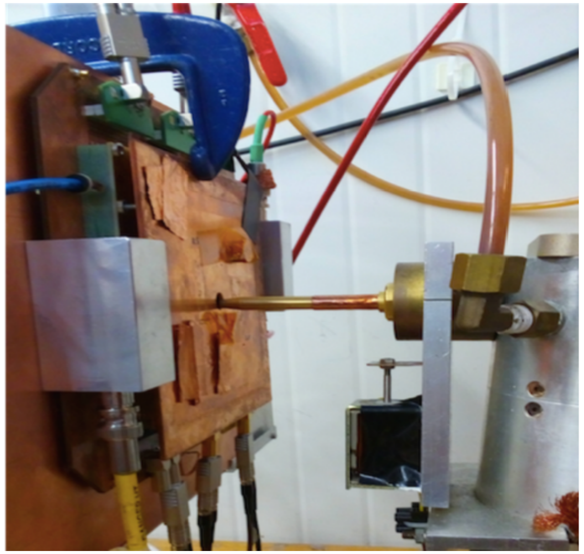
$Ar:CO_2$ 93:7

Chosen as the safest gas to operate under high irradiation for long time



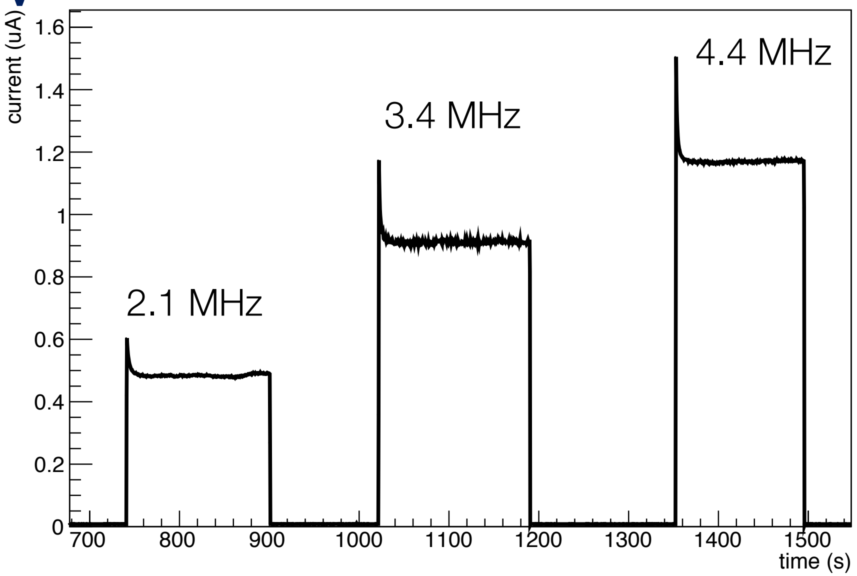
^{55}Fe source

Xrays Gun

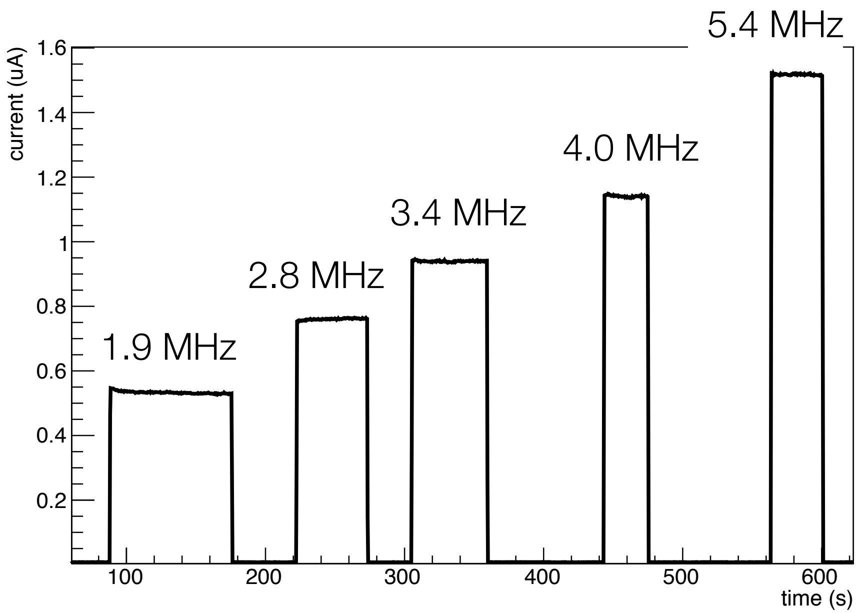


PAD-P vs DLC – Charging-up

PAD-P AT 527 V



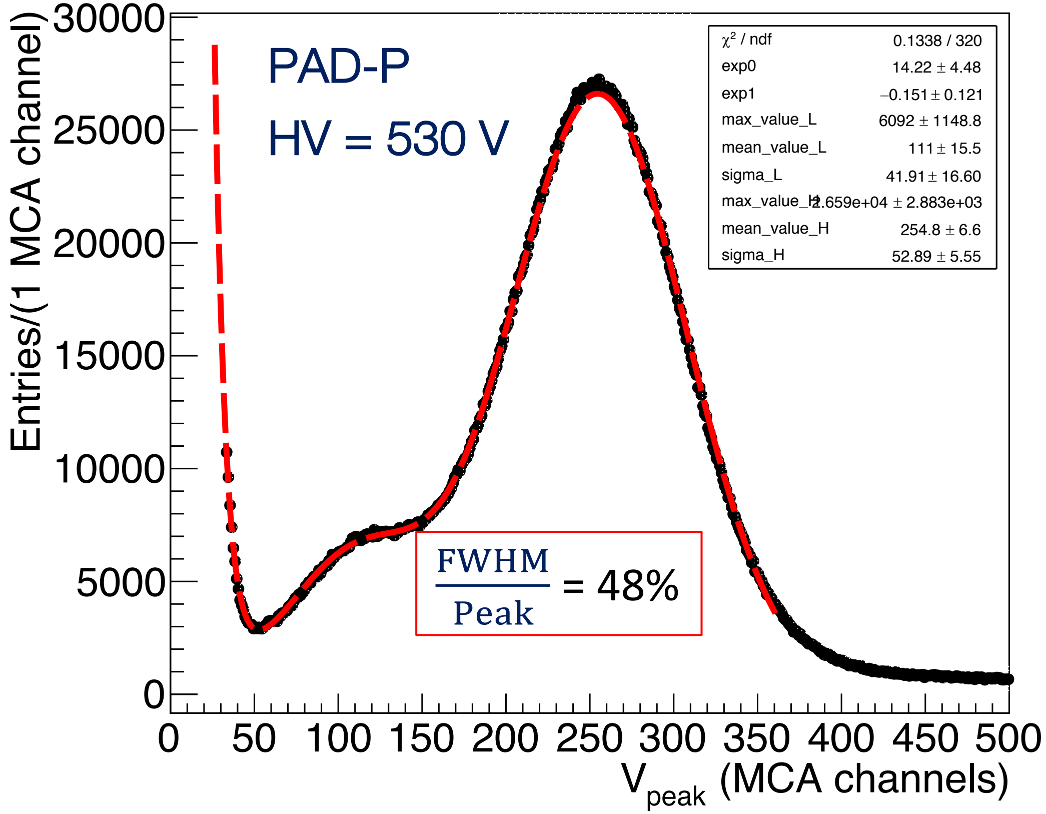
DLC50 AT 504 V

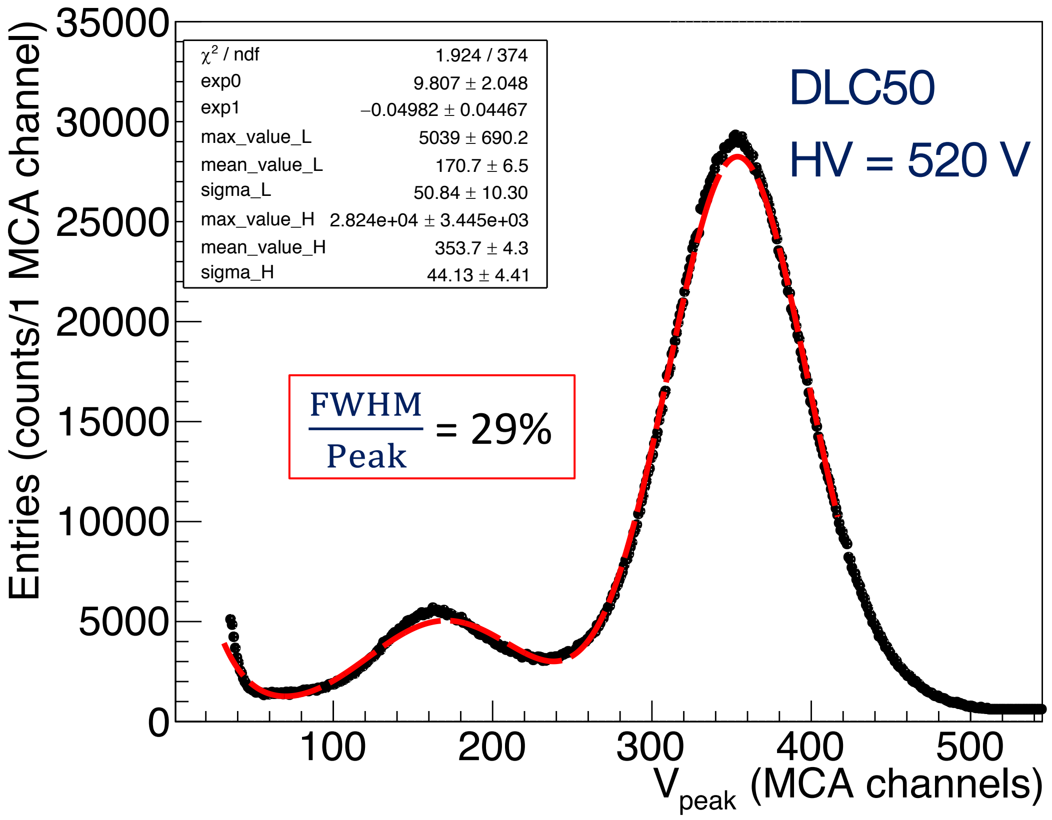


Current measurement Vs Time during cycles of X-Rays irradiation

- PAD-P response compatible with dielectric **charging-up** of exposed Kapton surroundings the resistive pads
- DLC detectors do show any sizable charging-up effects (expected from the uniformity of the resistive – no exposed dielectric, with the exception of the pillars)

PAD-P vs DLC – Energy Resolution

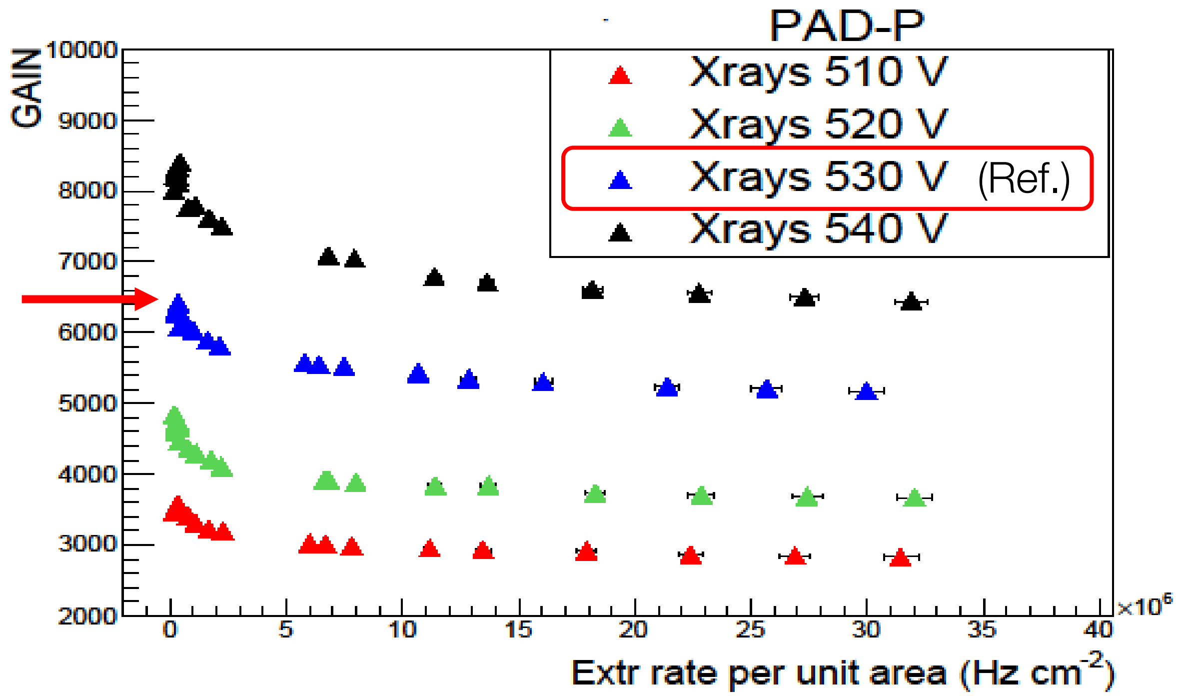


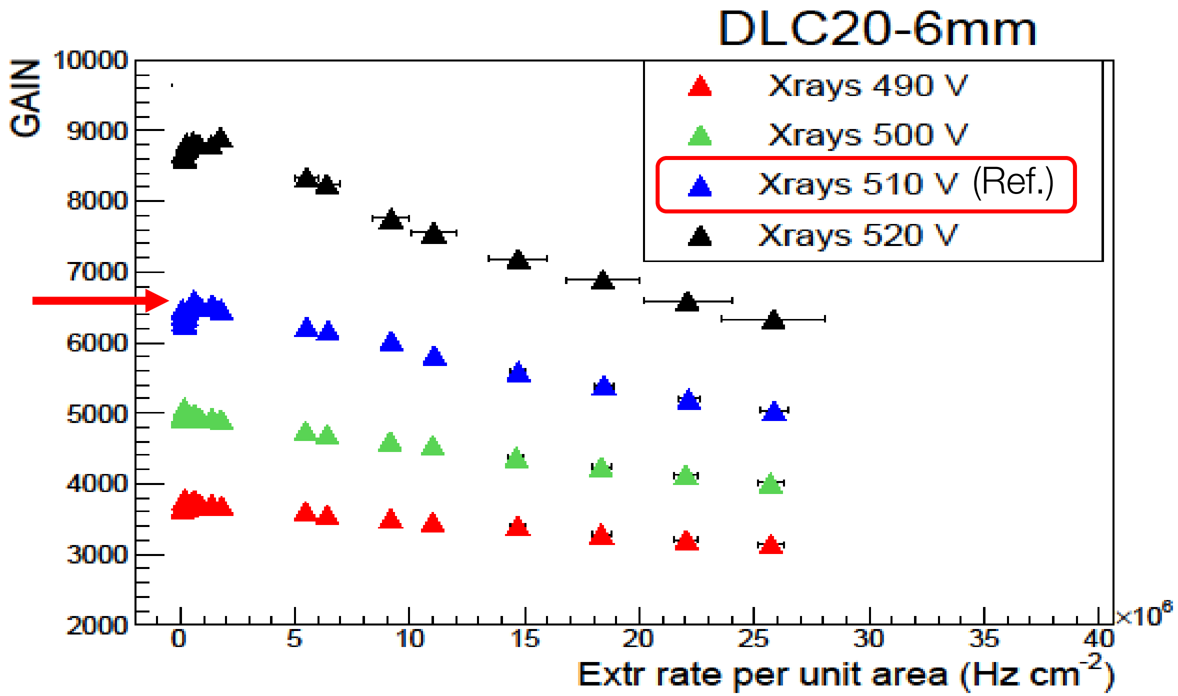


DLC prototypes have better energy resolution
- more uniform electric field
- no pad border effects

Gain Vs rates up to 30 MHz/cm^2

X-rays Exposure area 0.79 cm^2 (shielding with 1cm diameter hole)





PAD-P:

- Significant gain drop at “low” rates dominated by charging-up effects
- Relative drop~20% at 20 MHz/cm2 at 530 V
- Negligible ohmic voltage drop for the individual pads for rates > few MHz/cm^2

DLC20:

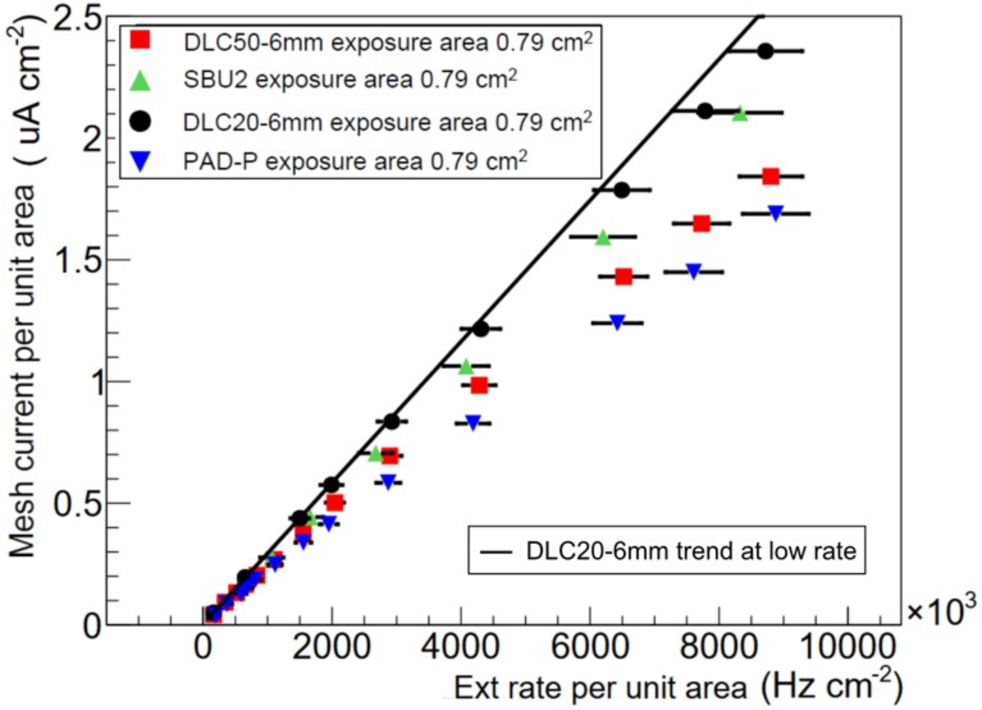
- Significant ohmic voltage drop for rates > few MHz/cm^2 (relative drop ~20% at 20 MHz/cm^2 at 510 V)
- Gain DLC20 > PAD-P.
  Same gain if HV PAD-P = HV_DLC + (20-30) V

High irradiation with X-rays – Rate Capability

COMPARISON done at a gain of ~6500

X-rays Exposure area 0.79 cm^2 (shielding with 1cm diameter hole)

The rate region < 10 MHz/cm^2



DLC20 and SBU show a significantly better behaviour than DLC50 (expected from the low resistivity)

PAD-P below DLC for rates < 10 MHz/cm^2 (charging-up+Ohmic drop)

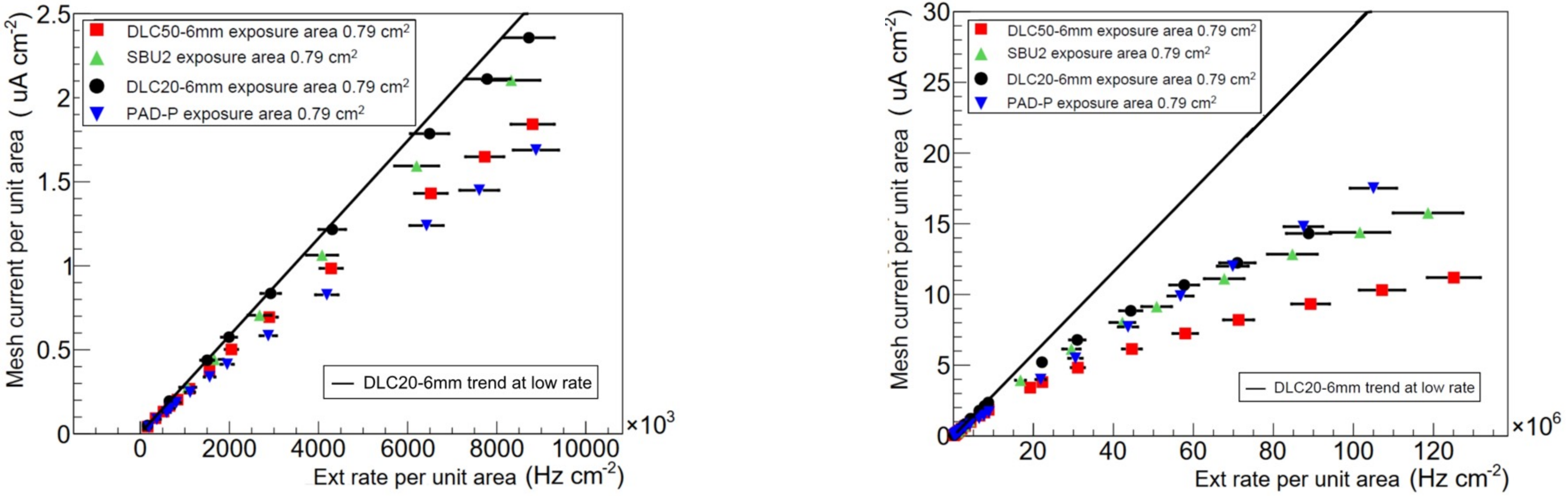
High irradiation with X-rays – Rate Capability

COMPARISON done at a gain of ~6500

X-rays Exposure area 0.79 cm^2 (shielding with 1cm diameter hole)

The rate region < 10 MHz/cm^2

Extended rate region up to ~100 MHz/cm^2



DLC20 and SBU show a significantly better behaviour than DLC50 (expected from the low resistivity)

PAD-P below DLC for rates < 10 MHz/cm^2 (charging-up+Ohmic drop)

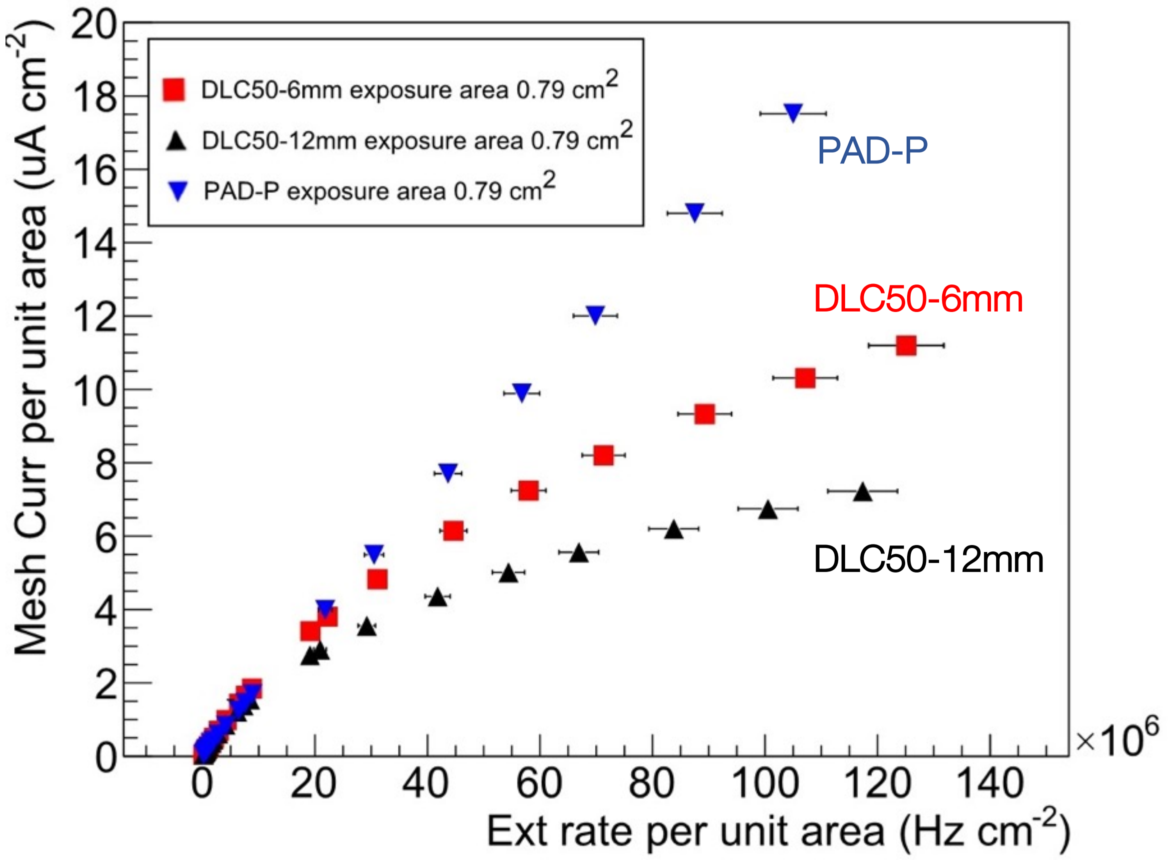
PAD-P, DLC20, SBU have a comparable behaviour in the explored region (up to ~100 MHz/cm^2)

As expected DLC20 better than DLC50 (due to lower resistivity)

Dependence on the grounding vias pitch

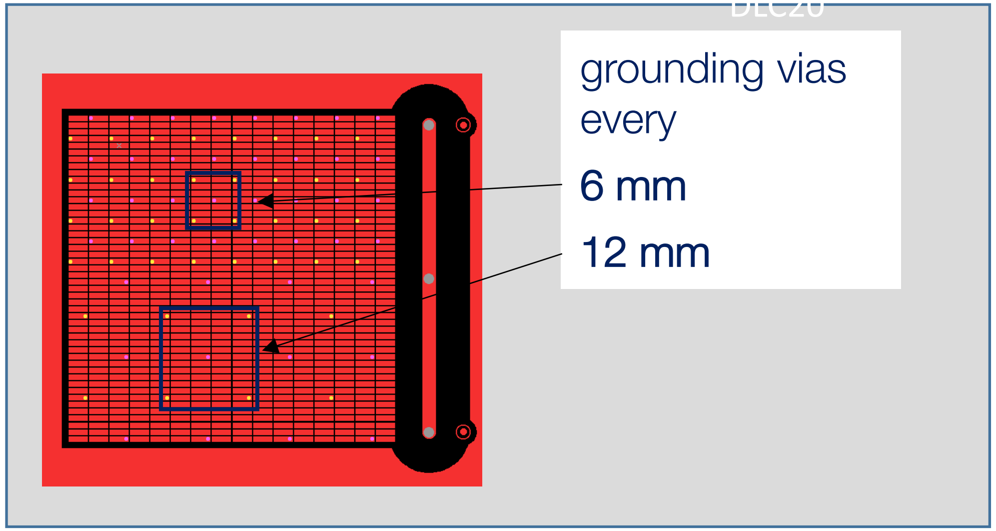
COMPARISON done at a gain of ~6500

X-rays Exposure area 0.79 cm^2 (shielding with 1cm diameter hole)

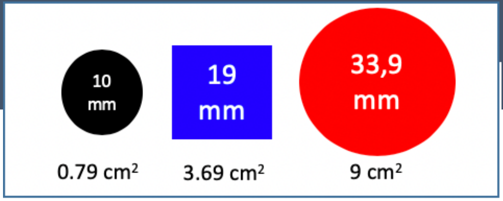


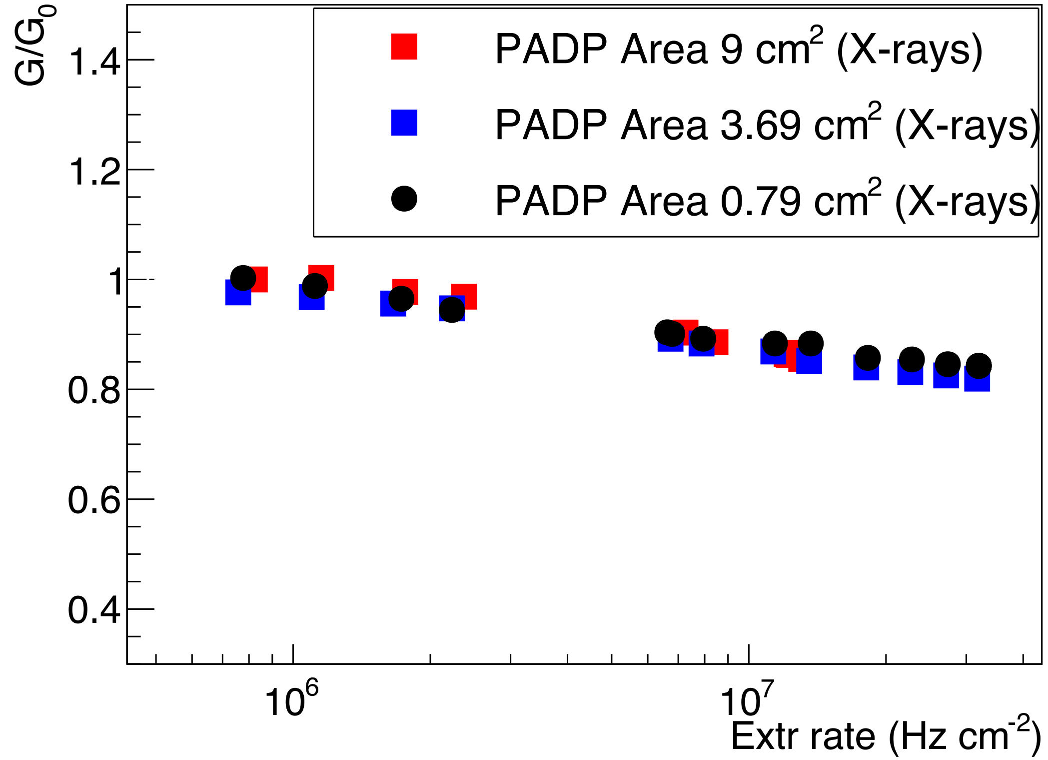
DLC-50:

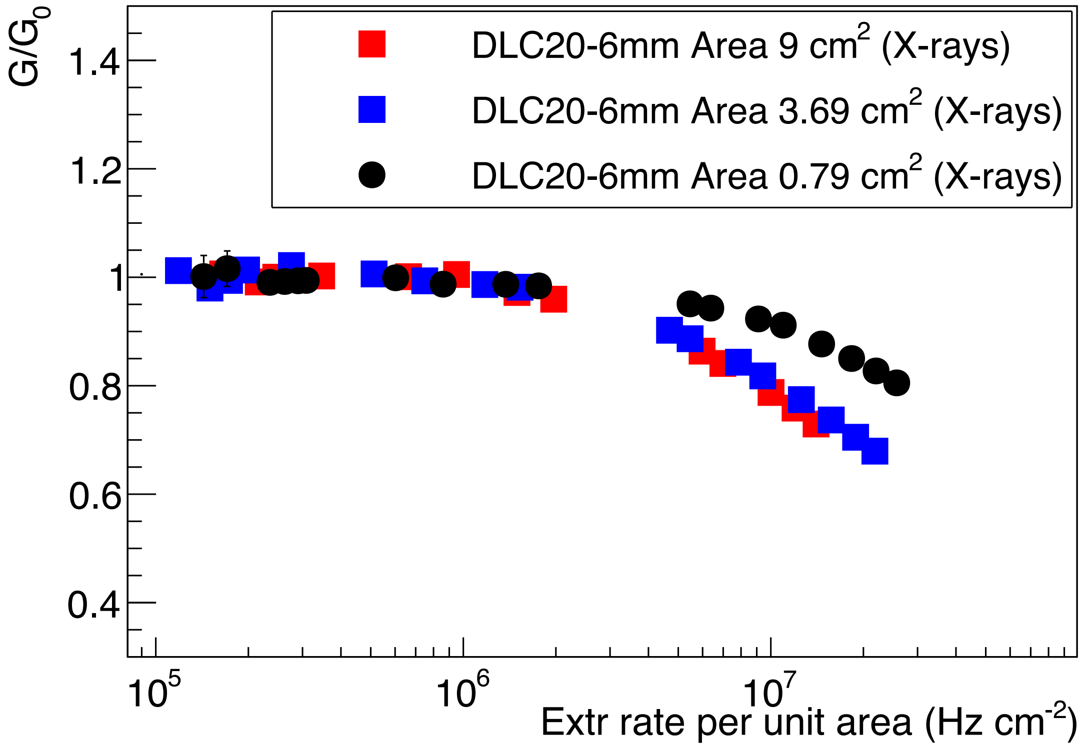
- Onset of ohmic voltage drop due to high current/high resistance.
- Clear difference between the regions with 6mm and 12 mm grounding vias pitch



Dependence on the exposed area





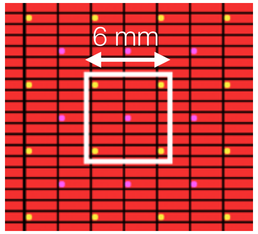


PAD-P:

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

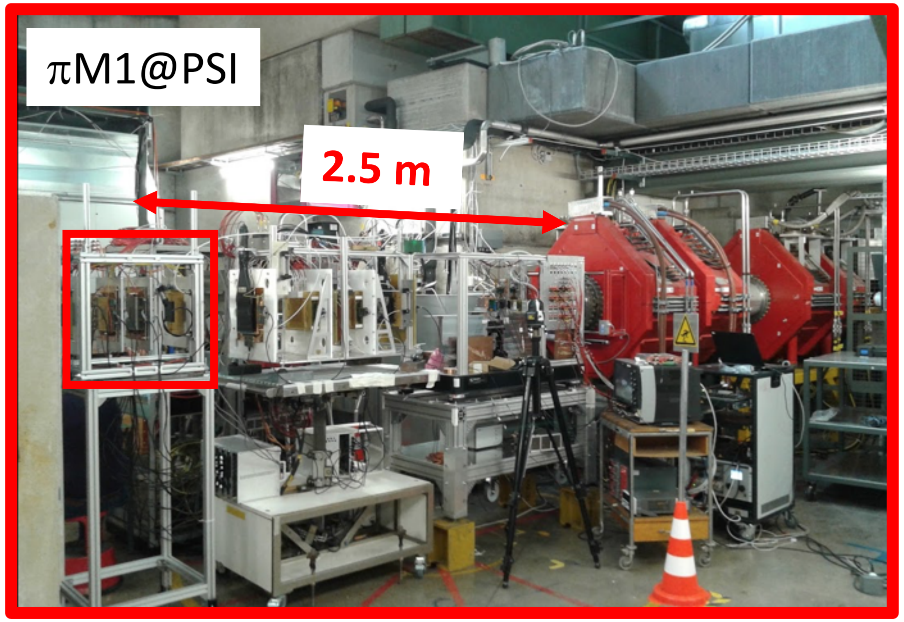
DLC:

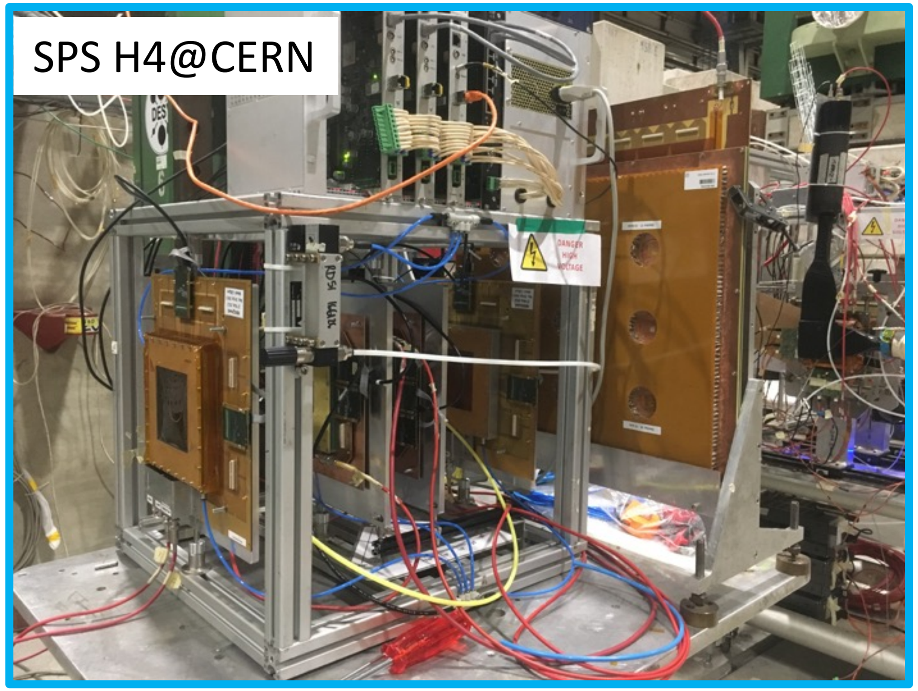
- Dependence of gain on the irradiated area above ~5 MHz/cm^2
- **The gain drop do not scale for areas > 3.7 cm^2 - i.e. when the exposed area is >> cell dimension of grounding vias** (0.36 cm^2)



Test Beams at CERN and at PSI

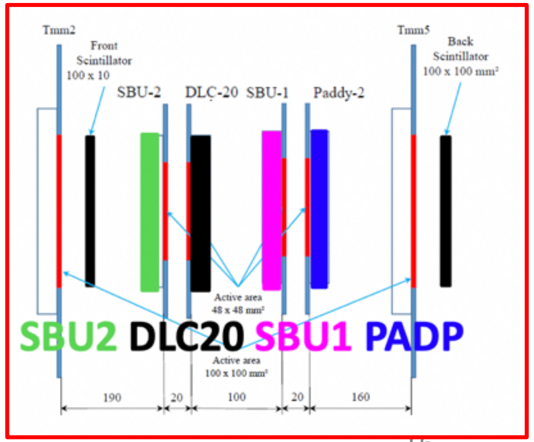
2016/17	2018	2019
SPS H4@CERN μ, π at 150 GeV/c low/high rate	SPS H4@CERN μ, π at 150 GeV/c π at 80 GeV/c	πM1@PSI π at 300 MeV/c p contamination ~7%
PAD-P, DLC50	DLC50, DLC20	PAD-P, DLC20, SBU1&2





Typical Test Setup:

- Two small scintillators for triggering
- Two double coordinate (xy) bulk strips micromegas (10 x 10 cm^2) for tracking
- Small-pads MM in between
- gas mixture: Ar/CO_2=93/7 pre-mixed
- DAQ: SRS+APV25

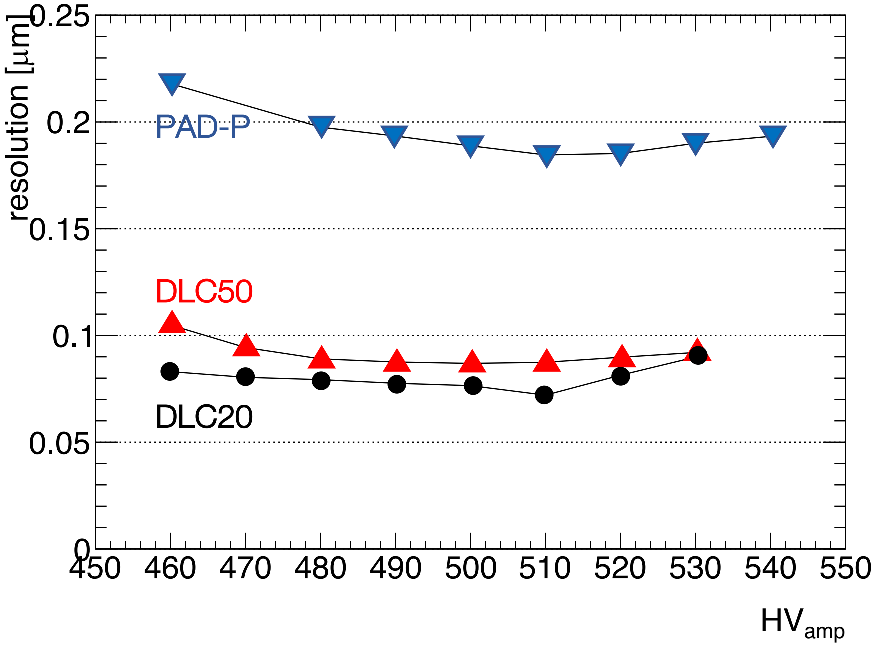


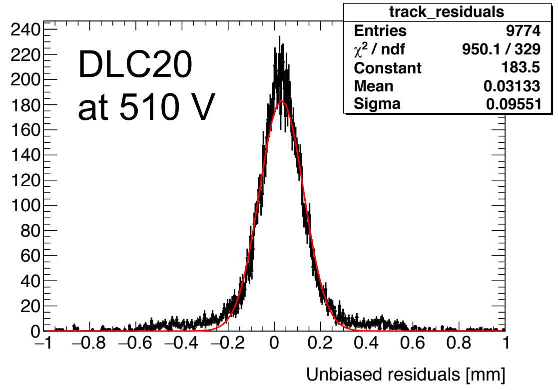
Spatial Resolution and cluster-size (TB CERN)

(see M.Alviggi, et al. JINST 13 (2018) no.11, P11019)

Position resolution:

Cluster residual wrt extrapolated position from external tracking chambers.

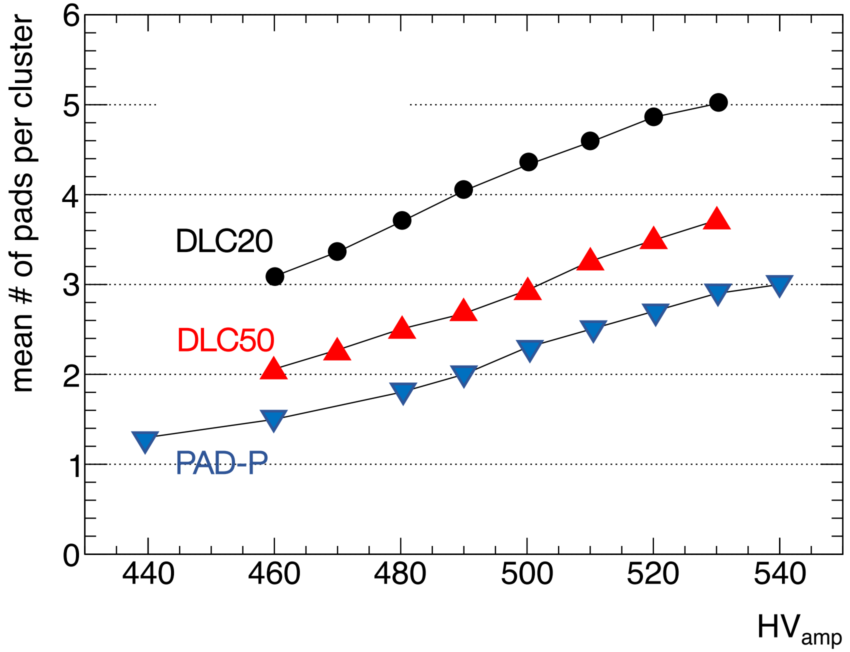




Unbiased Residuals

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

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



Cluster-size vs HV

Precision coordinate (pad pitch 1 mm)

Significant improvement of spatial resolution on the DLC prototypes (pad charge weighted centroid)

- More uniform charge distribution among pads in the clusters

- Larger Cluster size for DLC due to uniform layer. Larger clusters for lower resistivity (DLC20 Vs DLC50)

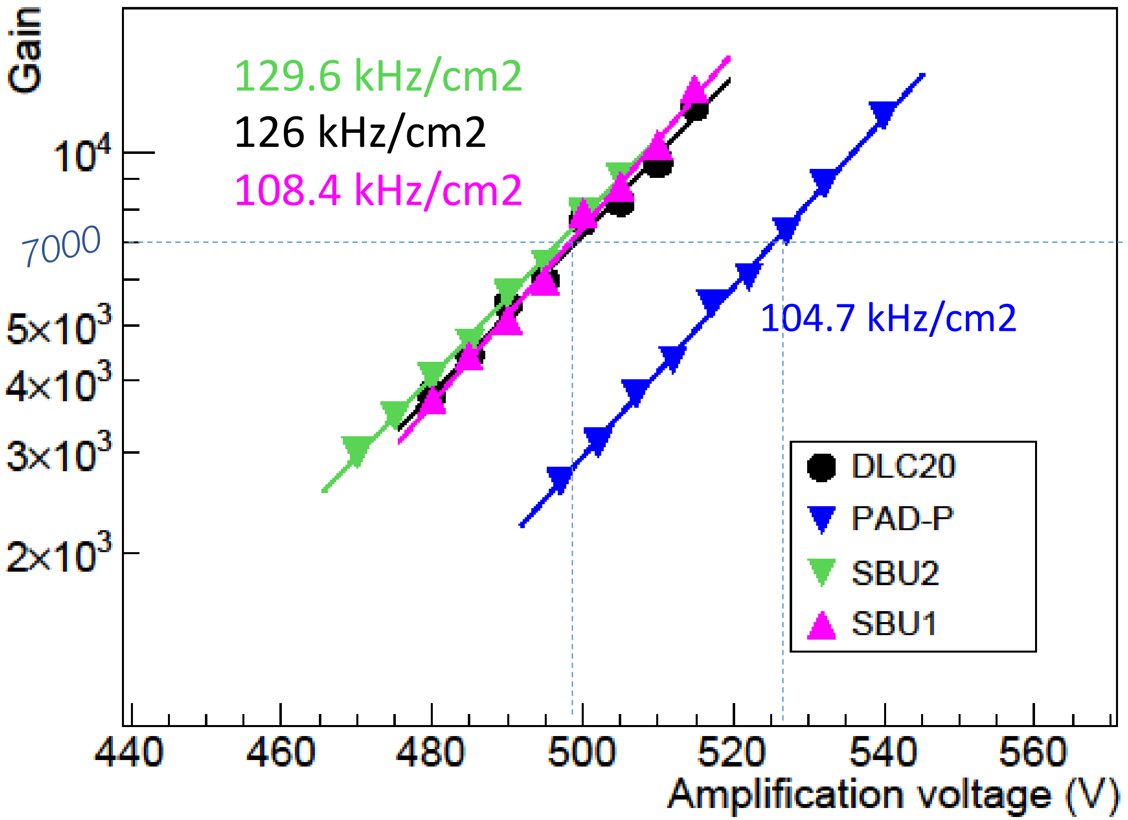
Test-beam at PSI (analysis ongoing)

- Main purpose was to test the stability under a high intensity particle flow
- Unfortunately our setup could only be placed far downstream → Max flow was few MHz on the full area (about 25 cm^2) of our detectors

→ Preliminary studies on gain and stability;

Analysis on tracking in progress

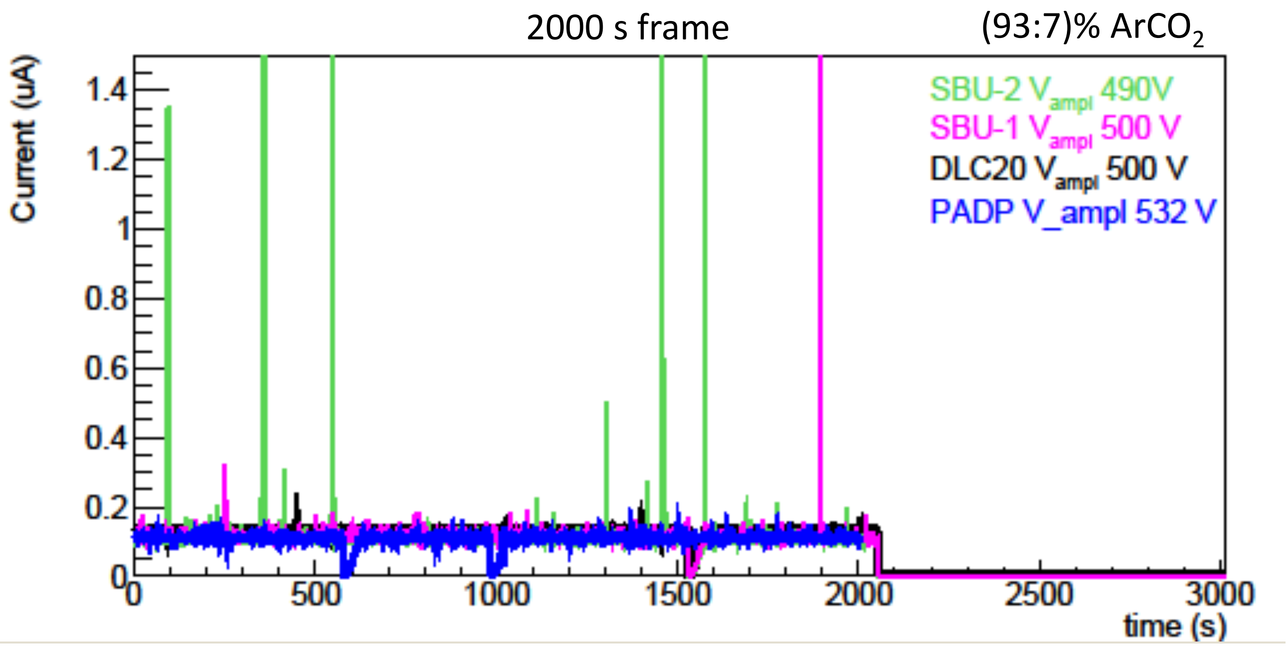
(93:7)%$Ar:CO_2$

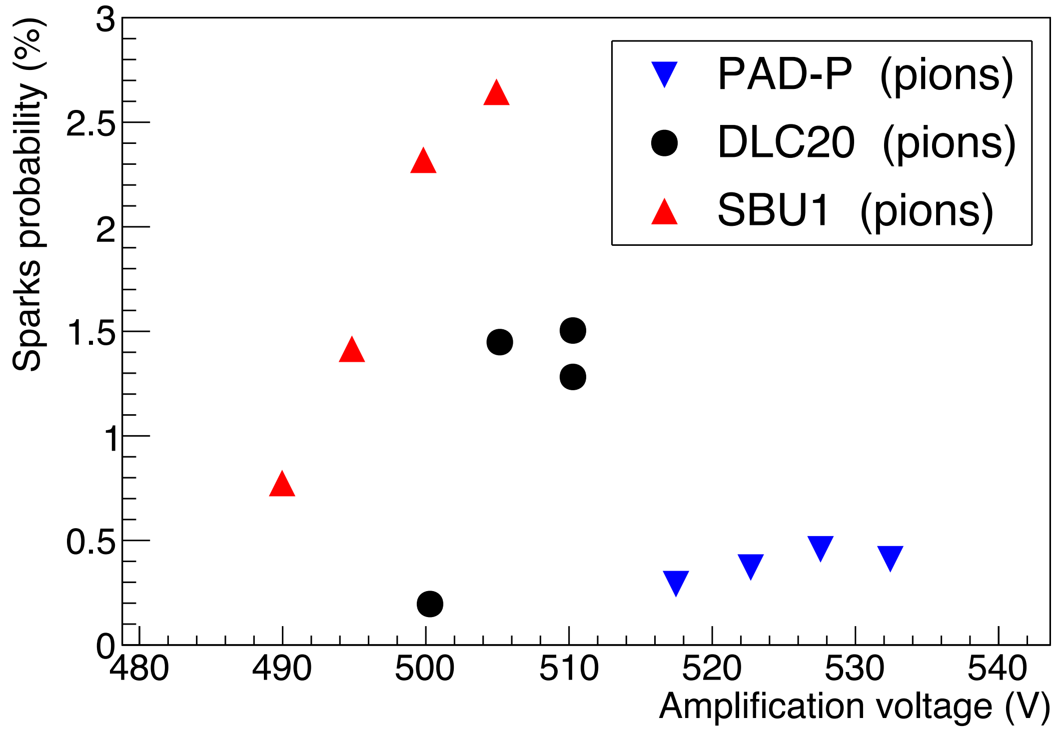


Gain estimated from the detector current (mesh)

- The measurements with pions confirmed the previous results with 55Fe/X-rays on the difference of gains PAD-P Vs all DLC's

Test-beam at PSI – Discharge studies





- A part of the test beam was dedicated to DLC and PAD-P spark studies
- Spark rates and probabilities evaluated as a function of HV settings and at constant rates of about 100 kHz/cm^2

- **PAD-P prototype confirm its very high stability**
- DLC20 is the most robust among the DLC series, despite to the constructive improvement of SBUs
- Possibly due to the LOW resistivity of the TOP DLC layer (5 MΩ/□ instead of the required 20 MΩ/□)

Summary

PAD PATTERNED and DLC based resistive scheme have been compared in similar conditions:

Gas mixture (possibly not the best) chosen to be on the safe side for ageing: Ar/CO2 93/7

Comparison in similar conditions: GAIN ~ 6500 – 7000 (most of the measurements with X-rays → ionisation >> MIP)

PAD PATTERNED PROTOTYPE

- Quite significant charging-up that nevertheless saturate at $\mathcal{O}(1\mathrm{MHz/cm^2})$
- ~20% gain drop at 20 $\mathrm{MHz/cm^2}$
- No dependence on the irradiated area
- Very stable up to gains >> 10^4
- Degraded performance on energy and spatial resolution compared to DLC
- A new prototype has been built and is currently being tested for further checks of the results

DLC PROTOTYPES

Best performance with the “low resistivity” DLC (~20 MΩ/□) and with fine network of grounding vias (~6 mm)

- Gain reduction with rates dominated by ohmic voltage drop
- gain reduction is ~20% at 20 MHz/cm2 when irradiated on a 1 cm spot (as for PADP); it increases to ~30% for larger areas.
- Excellent energy and spatial resolution
- Robustness not yet at the level of PAD-P → the DLC-SBU technique promising but not yet conclusive

THANK YOU!

Many thanks to:

CERN RD51 Collaboration for the continuous support and the CERN GDD Lab for MPGD tests.

R. De Oliveira, B.Mehl, O.Pizzirusso and A.Teixeira (CERN EP-DT)

R&D based on previous developments of Pad micromegas for COMPASS and for sampling calorimetry:

- C. Adloff et al., *"Construction and test of a 1x1 m^2 Micromegas chamber for sampling hadron calorimetry at future lepton colliders"* NIMA 729 (2013) 90–101.
- M. Chefdeville et al. *"Resistive Micromegas for sampling calorimetry, a study of charge-up effects"*, Nucl. Inst. Meth. A 824 (2016) 510.
- F. Thibaud at al., *"Performance of large pixelised Micromegas detectors in the COMPASS environment"*, JINST 9 (2014) C02005.

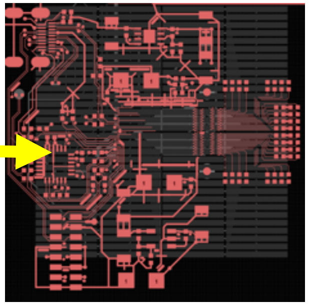
DLC double resistive layer configuration re-arranged from micro-Resistive Well R&D:

- G. Bencivenni et al., "*The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*" 2015_JINST_10_P02008
- M. Poli-Lener "*The µ-RWELL detector for the the phase 2 upgrade of the LHCb Muon System Upgrade*" ICHEP 2018 (PoS forthcoming publication)

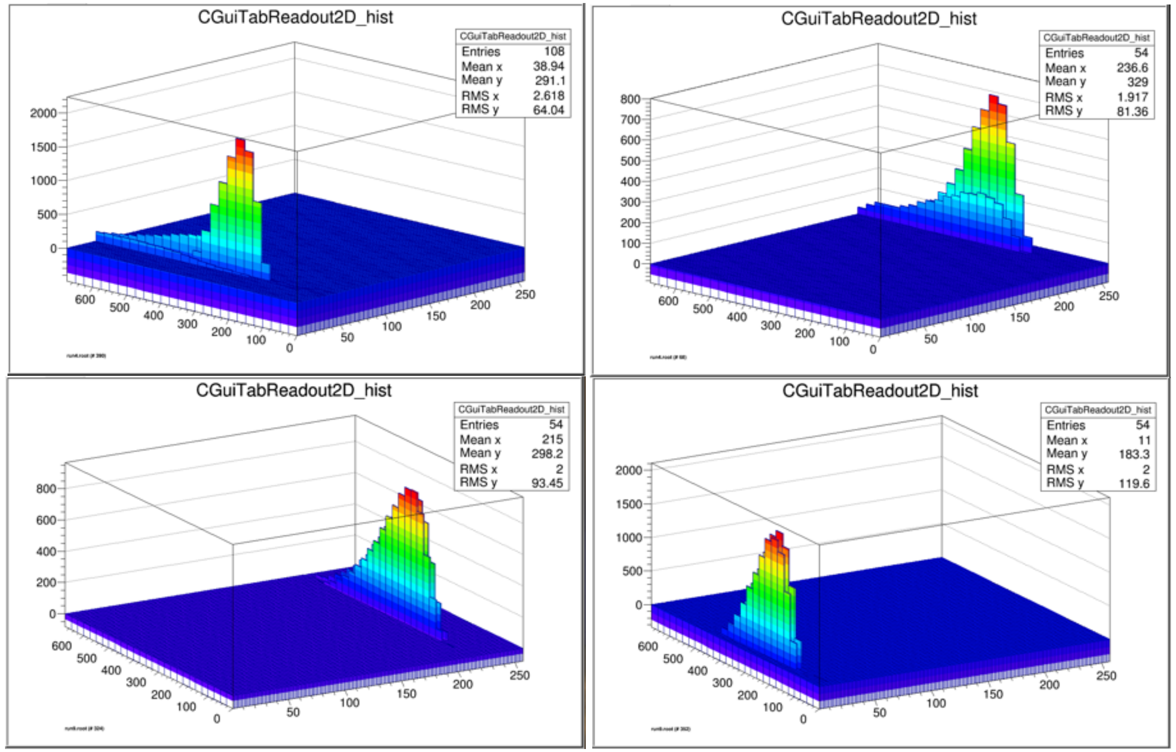
BACKUP

Next Step: the prototype with Integrated Electronics

- Prototype with integrated electronics on the back-end of the anode PCB built to solve the problem of the signal routing when scaling to larger surface
- APV FE Layout implemented



APV FE Layout

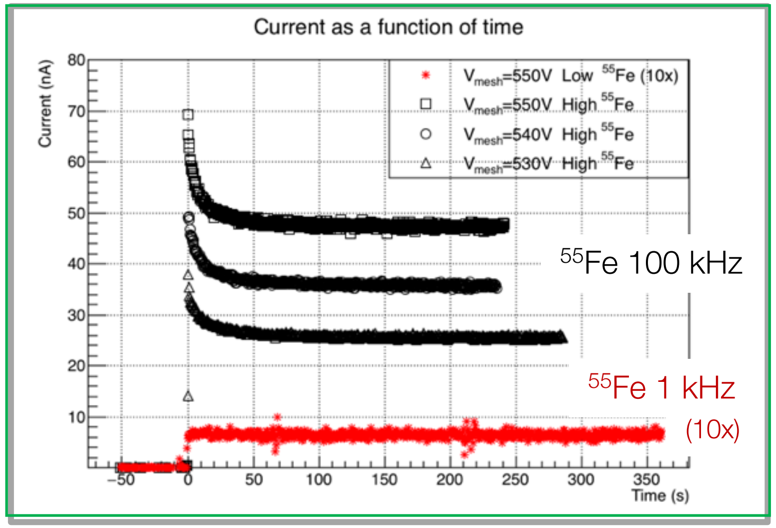


First tests look promising:

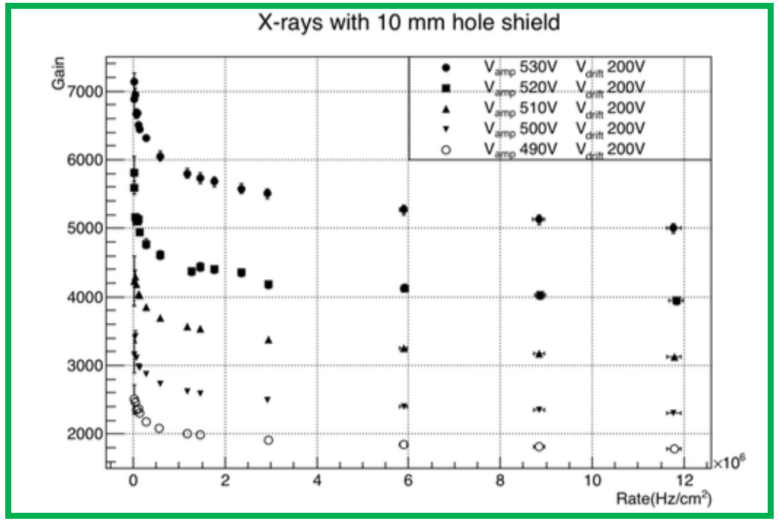
- Nice Pedestals structure and signal response from APV using Fe55 source and random trigger for DAQ → BUT ONLY on some channels
- We know the reason (issue in the elx Layout) → fixing it in the next proto !

Summary of PAD-P Results

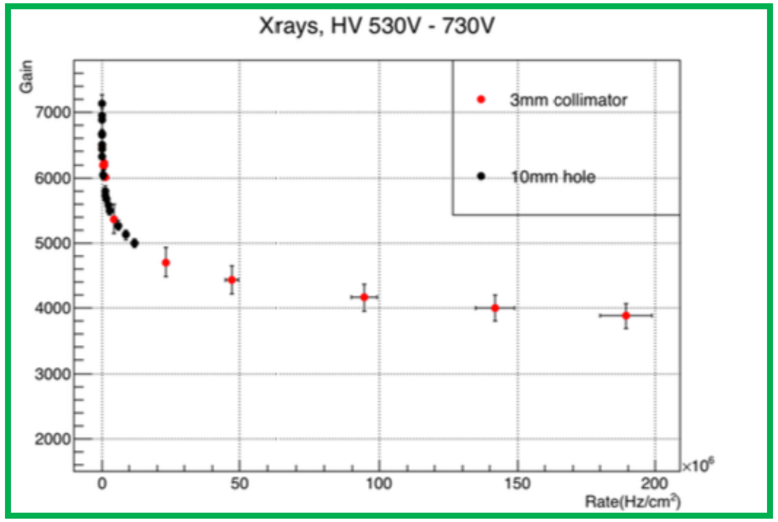
M. Alviggi, et al. *"Construction and test of a Small-Pads Resistive Micromegas prototype"*, JINST 13 (2018) no.11, P11019



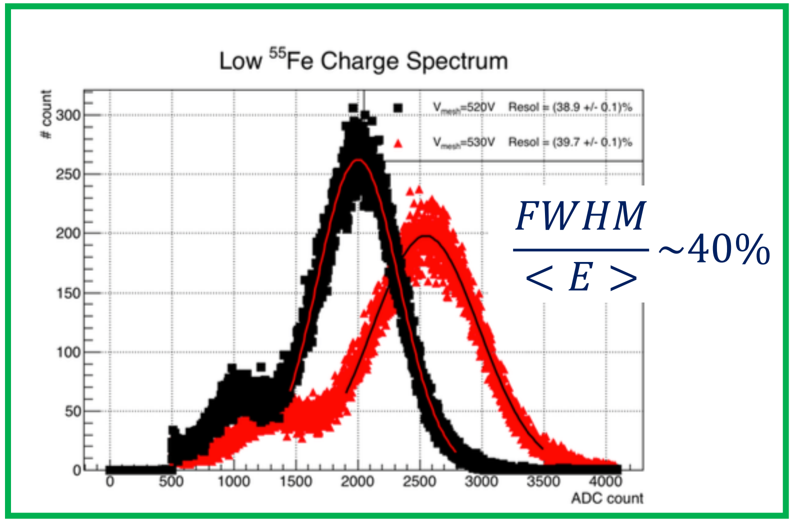
Reduction vs time of the detector current with High intensity ^{55}Fe source [CHARGING-UP]



Gain reduction ~30% up to 12 MHz/cm^2 [CHARGING-UP + Ohmic Voltage Drop]

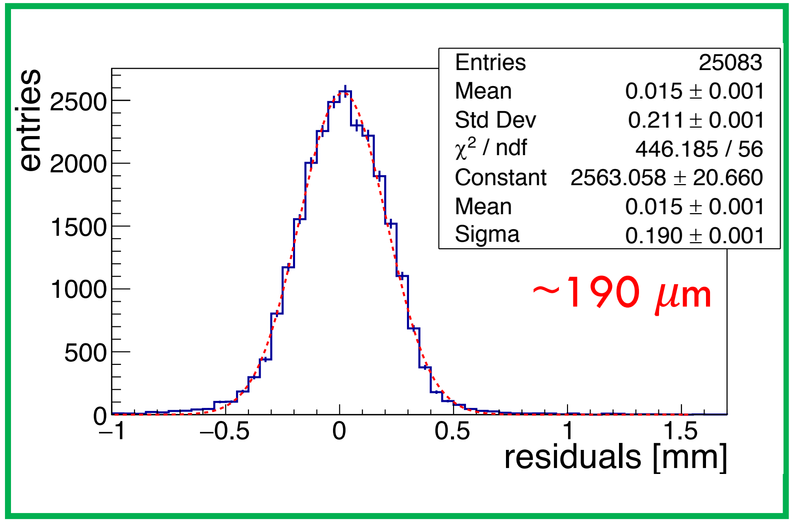


Gain drop increases as rate goes up.
Still able to reach gain of 4×10^3 at a rate of 150 MHz/cm^2 of 8 keV photons



Modest Energy resolution

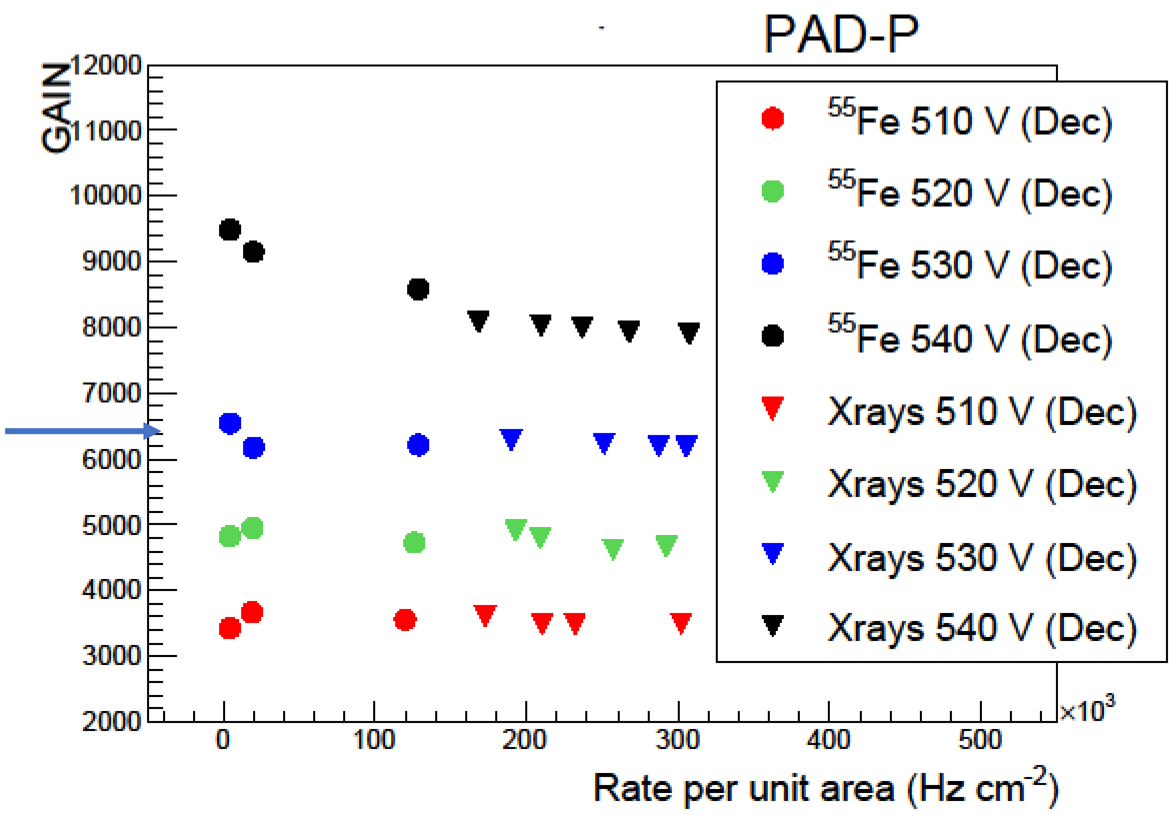
TEST-BEAM
spatial resolution along the "precision coordinate" (1mm pad-pitch)
~190 µm

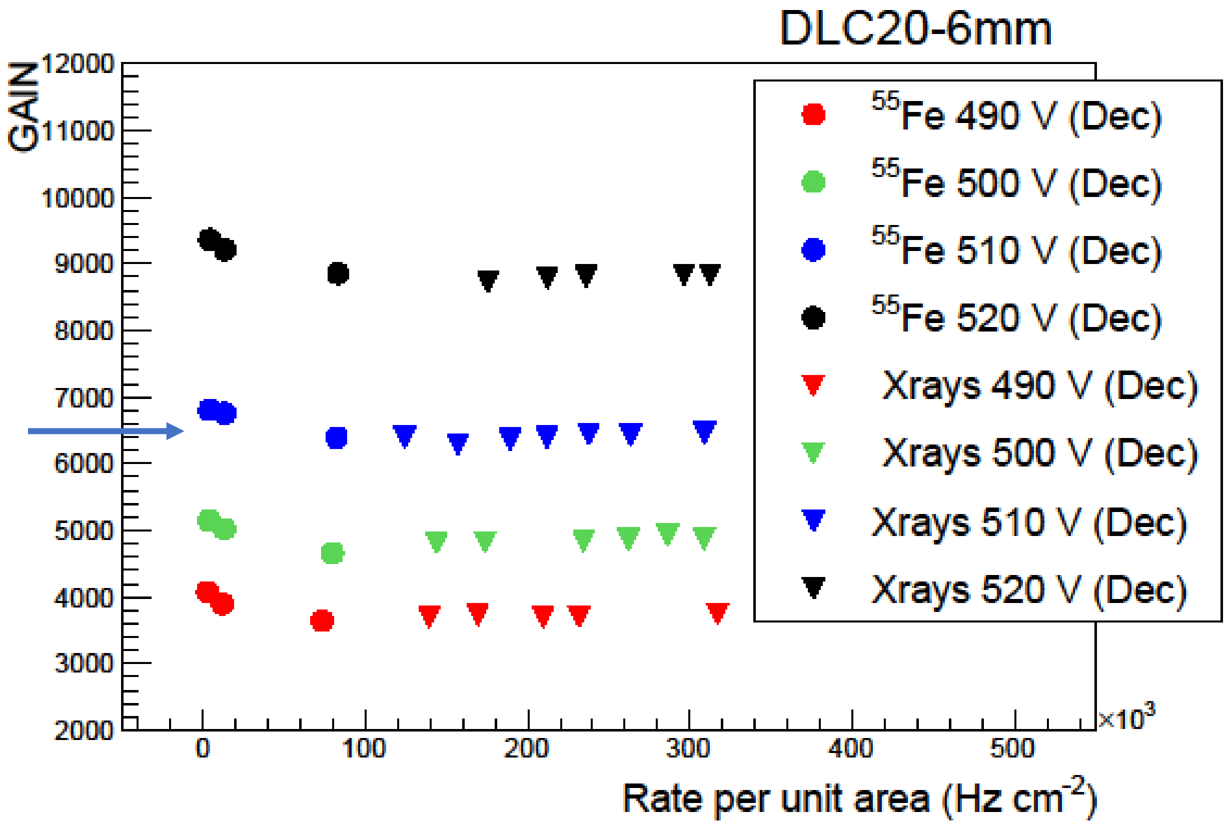


SCAN in Ampl. voltage @ Low rates < 0.3 MHz/cm2

Gain measurement in RD51 LAB: with ^{55}Fe and Xray(Cu target) sources and 0.79 cm^2 exposed area, (93:7)%Ar:CO_2

- To set the working amplification voltages for which the detectors have the same gain at low rates





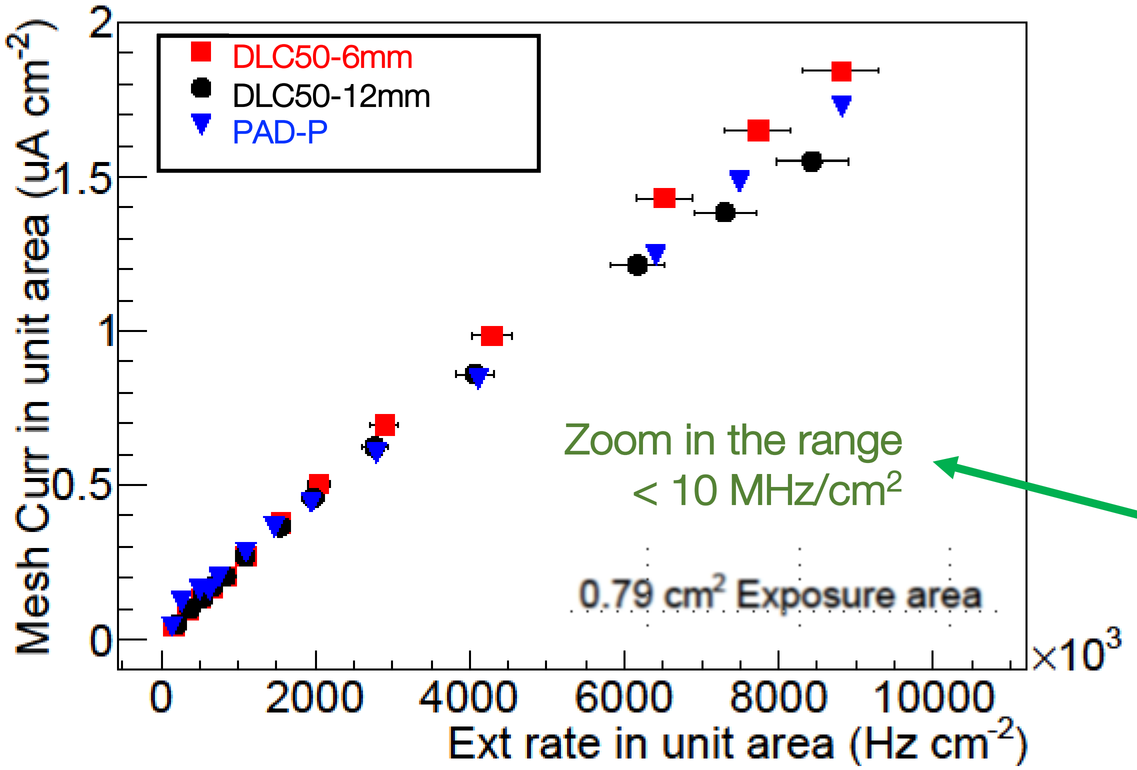
The ohmic voltage drops on the resistive layers are negligible in this range while the charging-up effects are already visible in PAD-P prototype at high gain

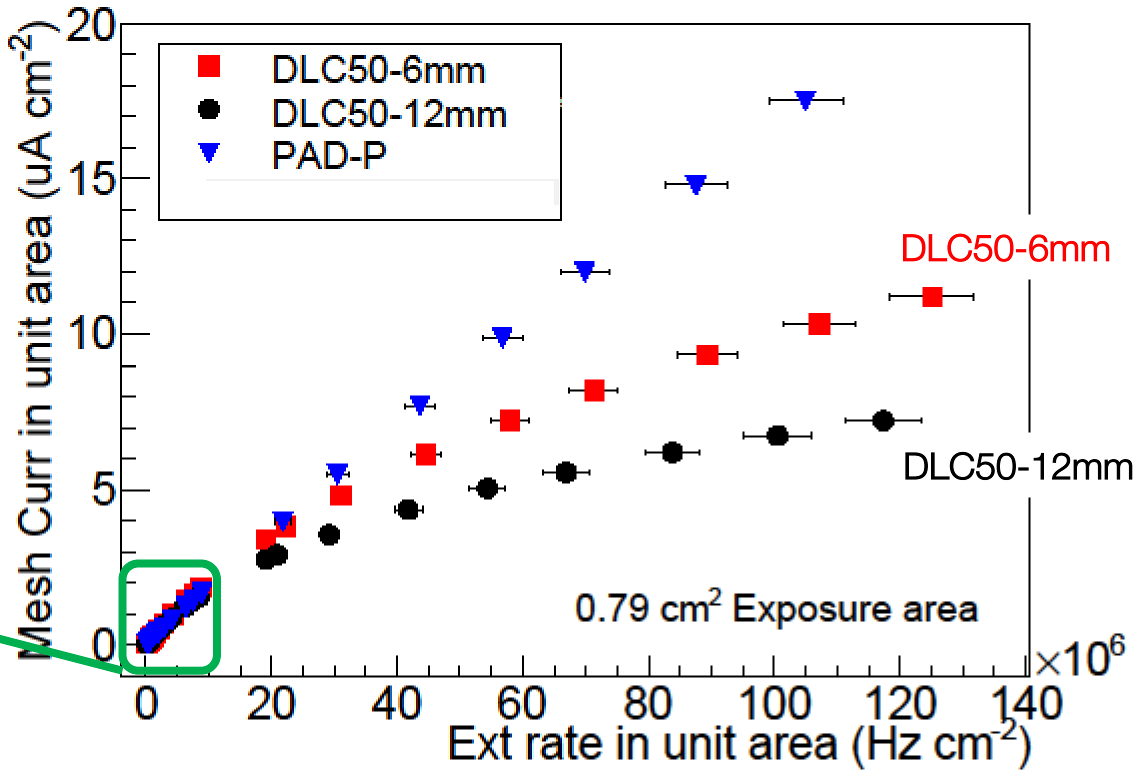
PAD-P require an amplification voltage + (20-30) V respect to DLC20

High Rates – PAD-P vs DLC50-6-12mm

	PAD-P	DLC50-6mm	DLC50-12mm	DLC20-6mm	DLC20-12mm
Configuration of the Resistive layer	Pad-patterned screen printed resistive layers with embedded resistors	DOUBLE DLC foil with resistivity ~50-70 MOhm/sq		DOUBLE DLC foil with resistivity ~20 MOhm/sq	
Connection to ground	Each pad through Embedded resistor R~3-6 MOhm	6mm pitch of grounding vias	12 mm pitch of grounding vias	6mm pitch of grounding vias	12 mm pitch of grounding vias

X-rays Exposure area 0.79 cm^2 (shielding with 1cm diameter hole)





No significant differences among PAD-P and DLC50 below 10 MHz/cm2

PAD-P: still a good behaviour up to ~100 MHz/cm2

DLC-50:

- Onset of voltage drop due to high current/high resistance.
- Clear difference between the regions with 6mm and 12 mm grounding vias pitch

Test Beam SPS H4 at CERN – SETUP

SPS H4 CERN 2016, 2017

Beam: muons/pions 150 GeV/c (low/high rates)

- Prototypes Tested:

  PAD-P, DLC50

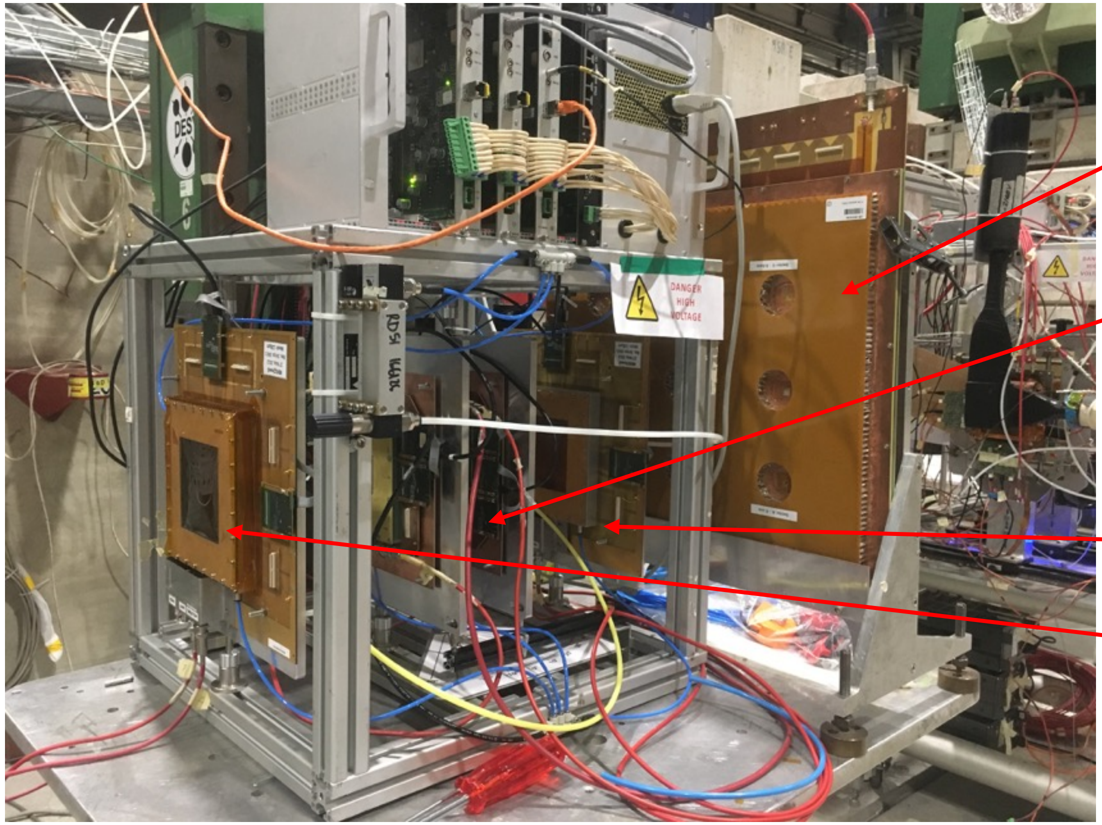
(see M.Alviggi, et al. JINST 13 (2018) no.11, P11019)

SPS H4 CERN OCTOBER 2018

Beam:

- 1^{st} period: muons/pions 150 GeV/c
- 2^{nd} period: pions 80 GeV/c
- Prototypes Tested:

  DLC20, DLC50



ExMe at 30°

DLC50, DLC20

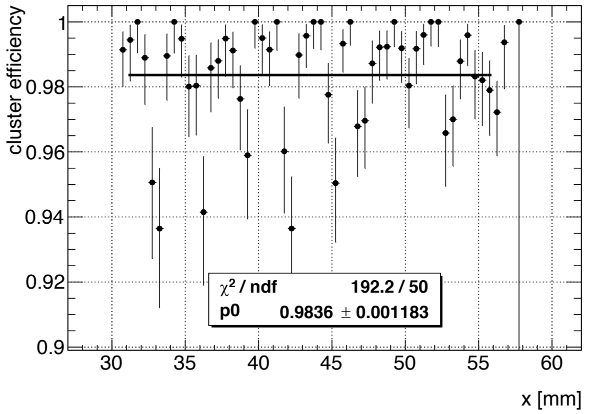
TMMdownstream

TMMupstream

OCTOBER 2018 SETUP: Chambers under test: DLC50 (50-70 MOhm/sq), DLC20 (20MOhm/sq), ExMe

- o Tracking system: 2 Tmm strips micromegas (x-y readout) for external tracking
- o Operating gas on DLC20, DLC50: Ar:CO2 93:7 Gas studies on ExMe: Ar:CO2 93:7 and 85:15 – Ar:CO2:Iso 88:10:2
- o Scintillators for triggering
- o DAQ: SRS + APV25 with custom DAQ

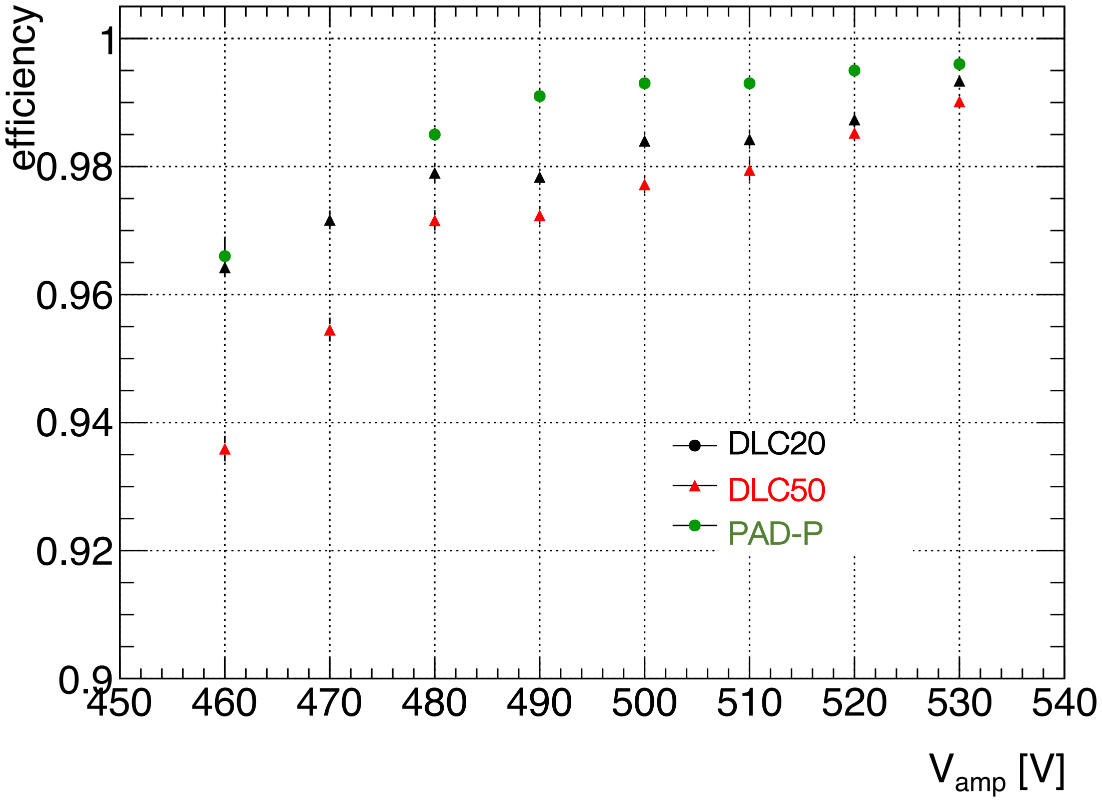
TB Results - Efficiencies



Cluster Efficiency of DLC50 @ 500 V Vs extrapolated track impact position

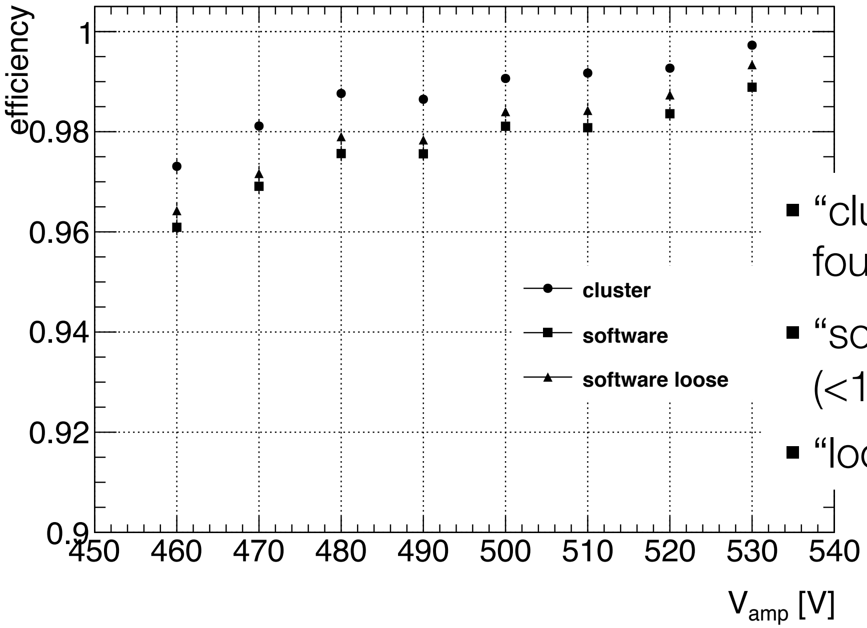
- Inefficiencies are clearly seen in correspondence of pillars.
- These inefficiencies decrease with HV

EFFICIENCY Comparison of all chambers (software-loose)



Differences at the level of 1% still under investigation.
Possible causes:
different gains, different charge spread and cluster-size, ...

"Cluster" and "software" efficiencies for DLC20 Vs HV



- "cluster": any cluster found in the detector
- "software": within 5σ (<1mm) from the track
- "loose" within 1.5 mm