Performance of high-granularity resistive Micromegas at high particle rates, and future developments

Paolo IENGO (CERN & INFN)

On behalf on the RHUM R&D Collaboration:

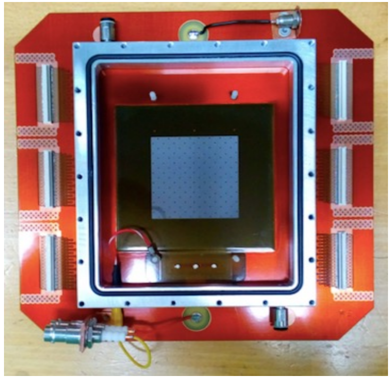
M. Alviggi, M.T. Camerlingo, M. Della Pietra, C. Di Donato, R. Di Nardo,

S. Franchellucci, P. Iengo, M. Iodice, F. Petrucci, , G. Sekhniaidze, M. Sessa

Introduction

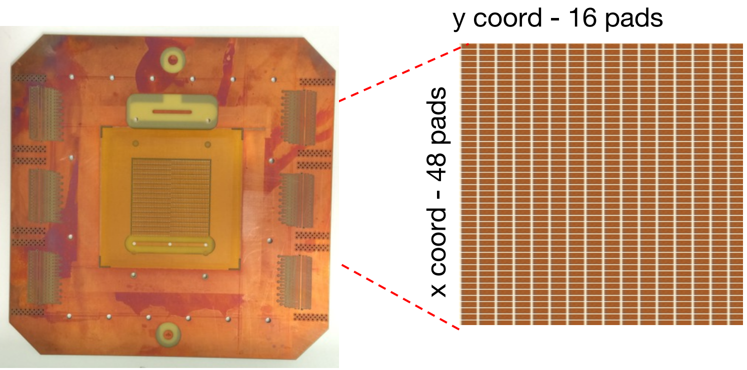
- Development of Resistive Micromegas detectors, aimed at operation under very high rates 10’s MHz/cm^2
- R&D roadmap:
  - Implementation of Small pad readout (allows for low occupancy under high irradiation)
  - Optimisation of the spark protection resistive scheme
  - Layout optimisation (embedded electronics)
  - Scaling to larger area
- Possible application: ATLAS very forward extension of muon tracking, Muon Detectors and TPC at Future Accelerators, …

- Inspired by work done by:
  - ATLAS → Development of resistive Micromegas (ATLAS NSW TDR: CERN-LHCC-2013-006
  - R&D of Micromegas with ‘large’ pad readout for calorimetry (COMPASS), see e.g.: M. Chefdeville et al. Nucl. Inst. Meth. A 824 (2016) 510

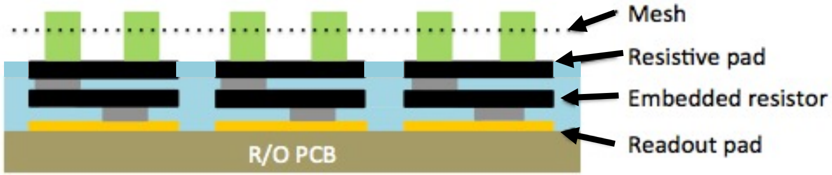


Small pad readout

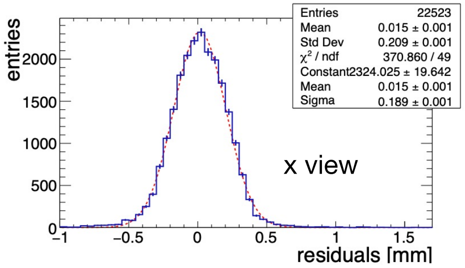
- All prototypes built with the same R/O pattern:
  - Matrix of 48x16 pads – 768 channels
  - Each pad: 0.8mm x 2.8mm - pitch of 1 x 3 mm^2
  - Active surface of 48x48 mm^2

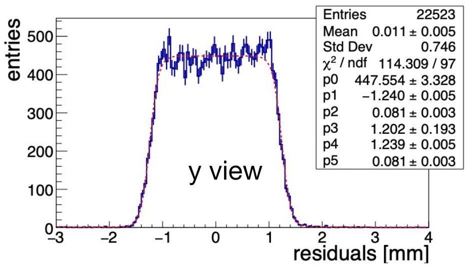


First resistive design: PAD-Patterned resistive layer



- Embedded resistors by Screen-Printing
- Resistive pads by paste filling of photoimaging created vessels; mean value of the embedded resistors ≈ 3-7 MΩ
- Each pad is totally separated from the others, for the anode, as well as for the resistive part

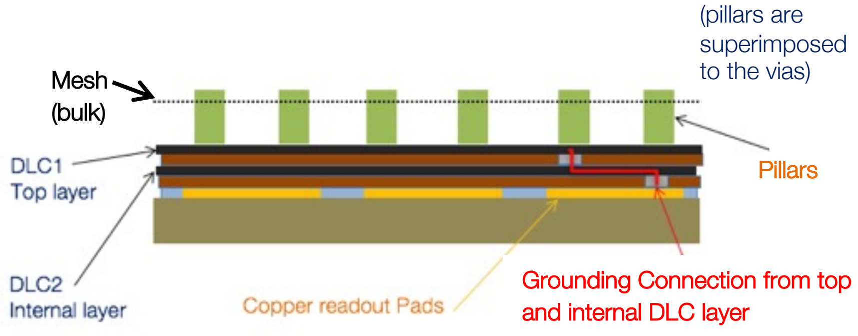




Space resolution from test beam (CERN SPS): 190 μm on 1 mm pad
Can be improved with a larger charge sharing between pads

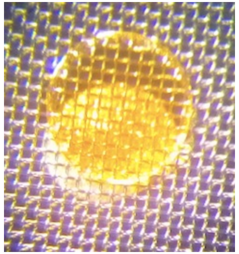
Optimisation of the spark protection resistive scheme

- Alternative resistive protection design: uniform layer DLC-based

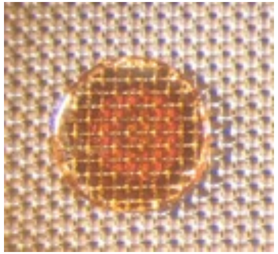


- Double DLC layer with connection vias to ground every 6 or 12 mm (square pattern)
- Surface resistivity: 20 MW/□ (DLC20)
  and 50 MW/□ (DLC50)

- DLC MM produced with sequential built-up technique (SBU): 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)
  - resistivity: top layer: 5 MW/□ (lower than requested)
    bottom layer: 35 MW/□



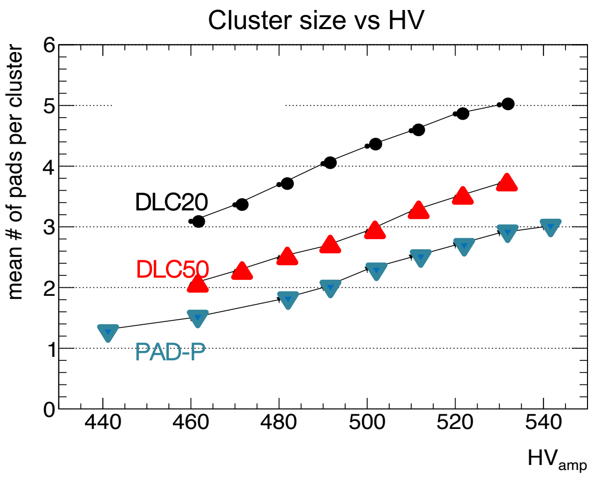
DLC series:
Case of uncovered vias
→ can cause sparks

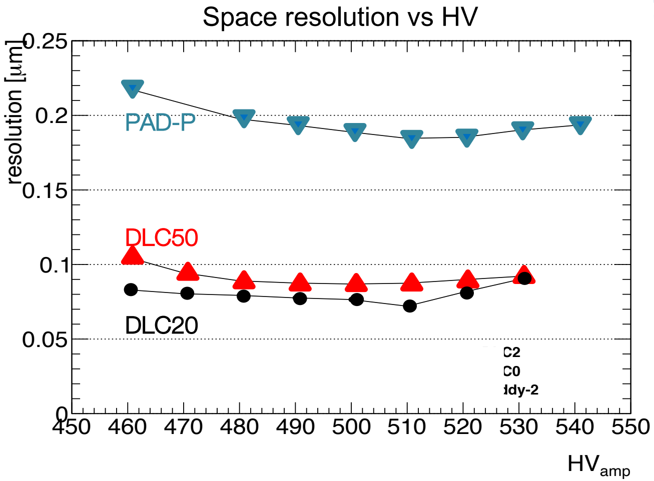


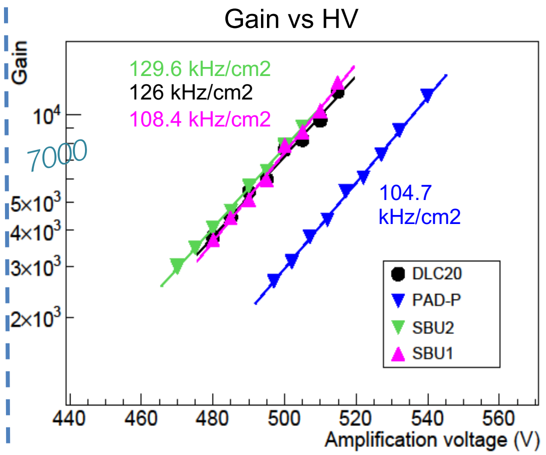
SBU series:
Perfect alignment of vias

Spatial resolution & gain comparison

- Cluster residual wrt extrapolated position from external tracking chambers. Precision coordinate (1 mm pad pitch)







- Larger cluster size and better spatial resolution on the DLC series → charge sharing at work
- Cluster size on DLC series increases with lower resistivity
- Price: different behaviour for rate capability
- DLC series show higher gain wrt PAD-P series

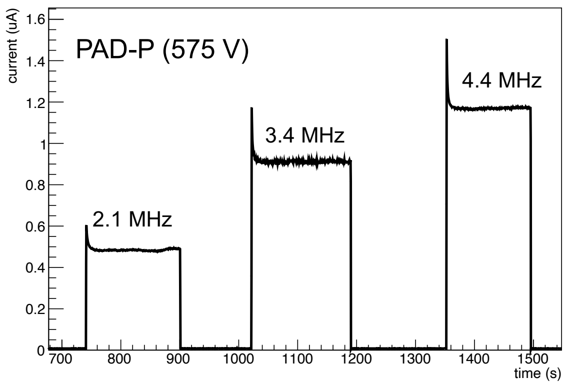
Gas: Ar:CO_2 (93:7)

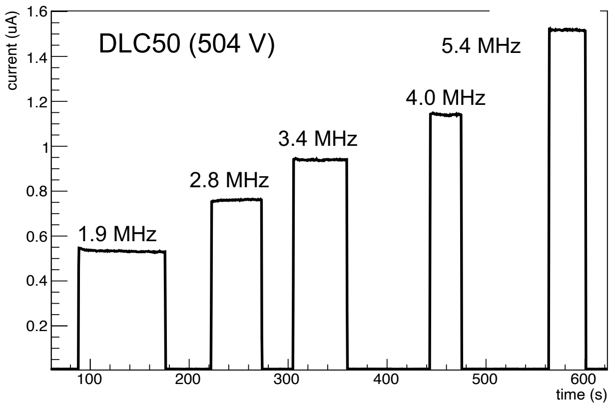
Test beam at SPS CERN

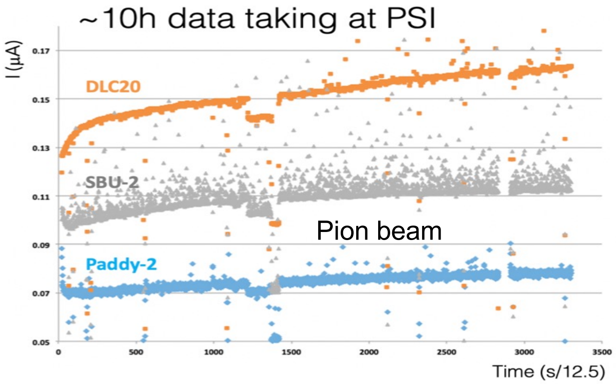
Test beam at PSI

Charging-up

- Irradiation with X-ray gun



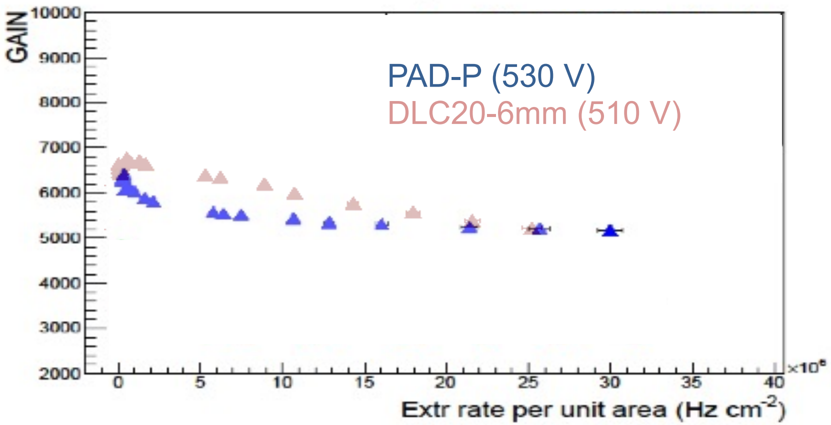




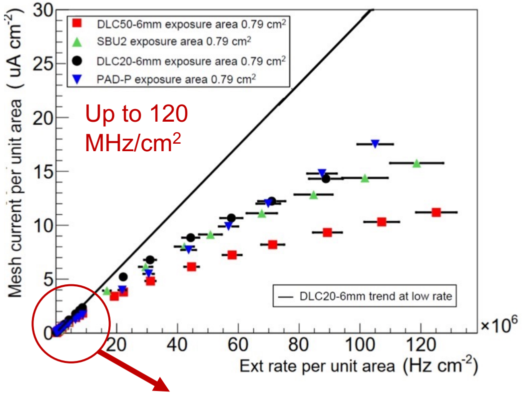
- PAD-P: typical fast charge-up → gain reduction ~20%
- DLC: very small charge up → gain reduction <few%; very stable at short time scale
- All detectors show a gain increase on a longer time scale (hours) observed also during high-rate irradiation with pions at PSI

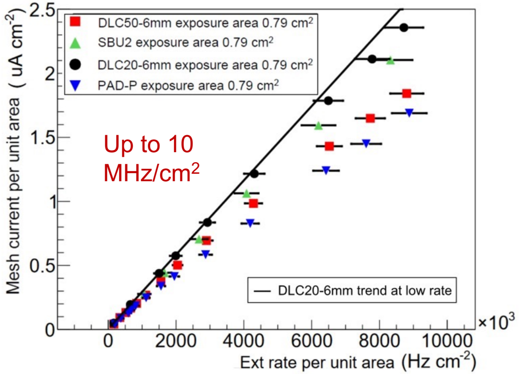
Rate capability

- X-ray irradiation (exposed area: 79 mm^2)



Linearity (mesh current vs rate)



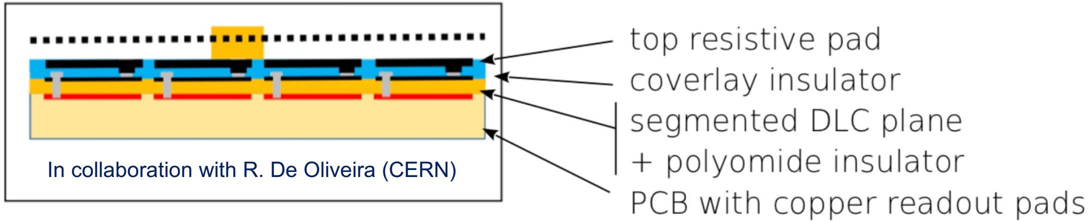


- PAD-P: Gain drop (~20%) at lower rates dominated by charging-up effects. Immune from ohmic voltage drop up to few MHz/cm^2
- DLC20: Ohmic voltage drop for rates > few MHz/cm^2 (~20% at 20 MHz/cm^2)

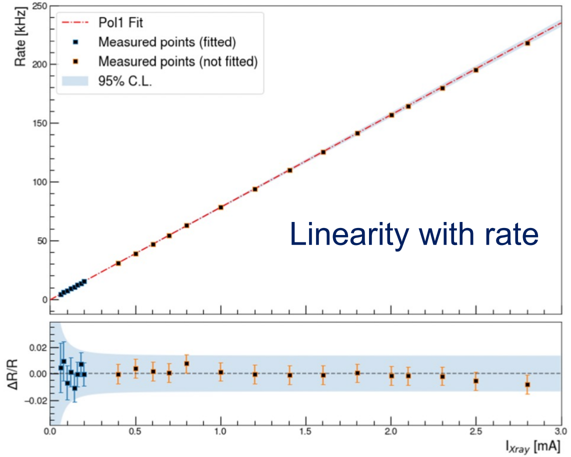
- At very high rates all detectors perform similarly but DLC50 (higher ρ)
- At intermediate rates (several MHz/cm^2) PAD-P shows a larger gain drop owing to both charge-up and voltage drop

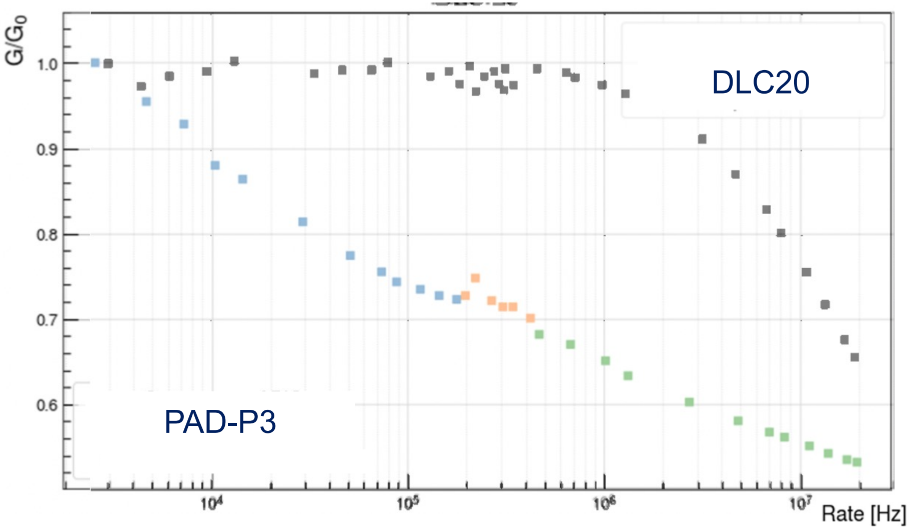
More resistive layouts – 1 (PAD-H)

- Hybrid configuration: DLC (bottom) & screen-printed (top): PAD-H



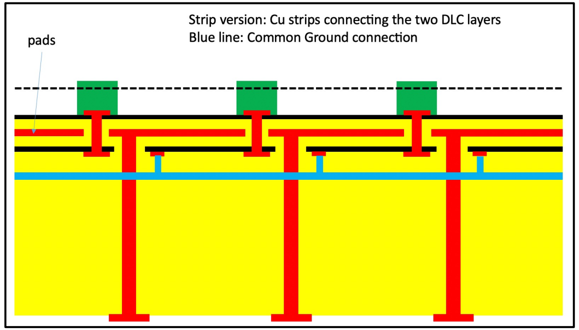
- Irradiation with X-ray gun





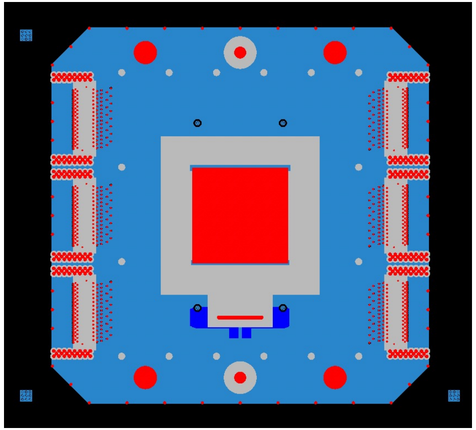
- Rate: excellent linearity of response up to >200 kHz/cm^2
- Gain: reduction similar to what has been measured on other PAD-P series (same structure of top detector surface)

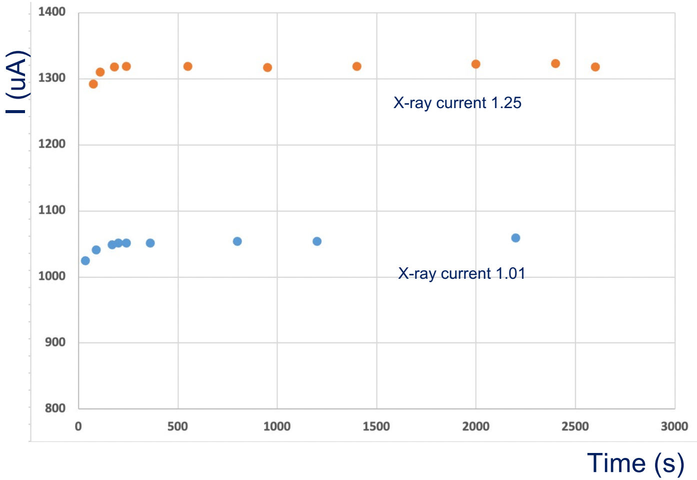
More resistive layouts – 2 (DLC-Strip)

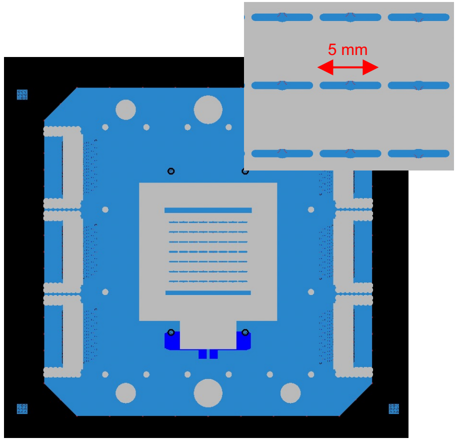


In collaboration with R. De Oliveira (CERN)

- Readout pads in-between the two DLC layers → better capacitive coupling for signal induction
- Connection between DLC layers with metal strips covered by elongated pillars
- Preliminary tests ongoing:
  - Negligible gain drop for charging-up observed (same as previous DLC or SBU series)
  - Fast gain increase (~3% in 200 s at rates of 100s kHz/cm^2) attributed to the larger pillar surface of the structure (0.6 mm x 5mm)

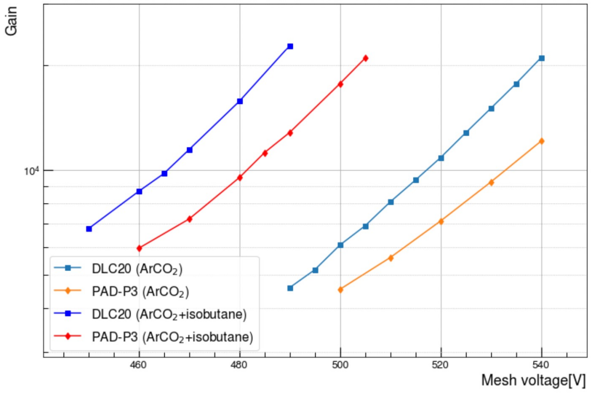


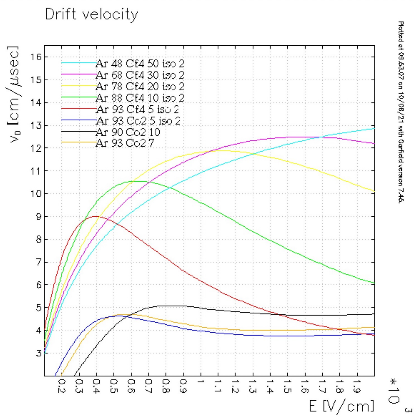




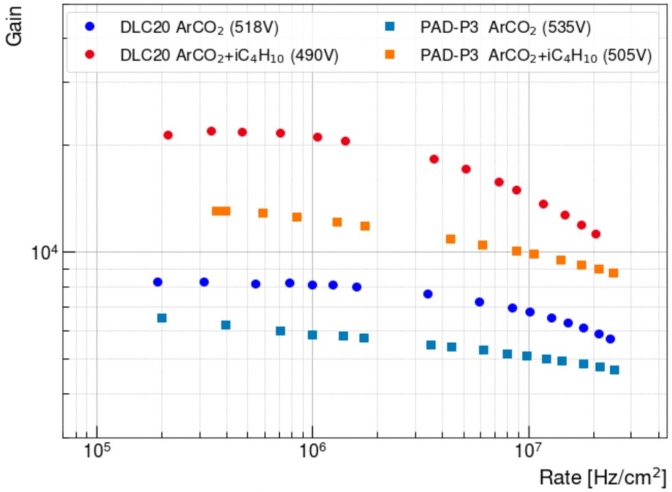
Gas optimisation

- Detector characterised so far with Ar:CO_2 93:7 mixture for sake of simplicity → not the best gas for MPGD performance optimisation
- Test performed with with 2% isobutane (Ar:CO_2:iC_4H_{10} 93:5:2) showed improved stability.
  - ~50V difference between the two mixtures for a given gain
  - Gain ~20k reached at very high irradiation rates (>10 MHz/cm^2) in stable conditions → remarkable results!
  - $N_{primary}$ ~300 → $N_{electrons}$ ~6x10^6 not far from Reather limit





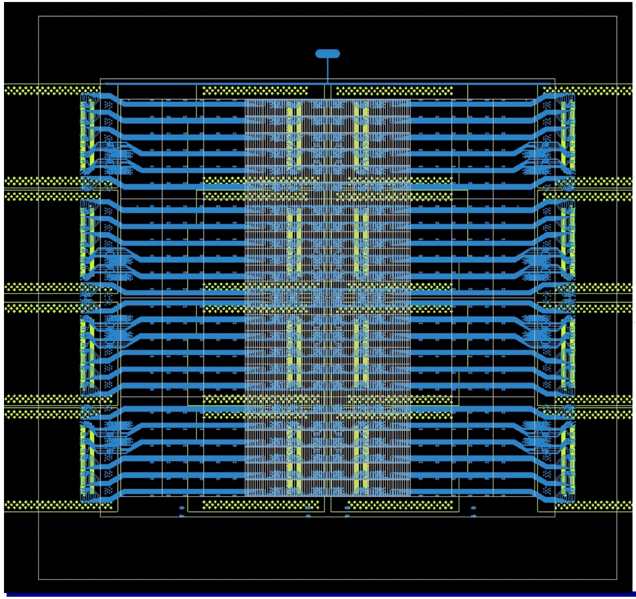
- Irradiation with X-ray gun

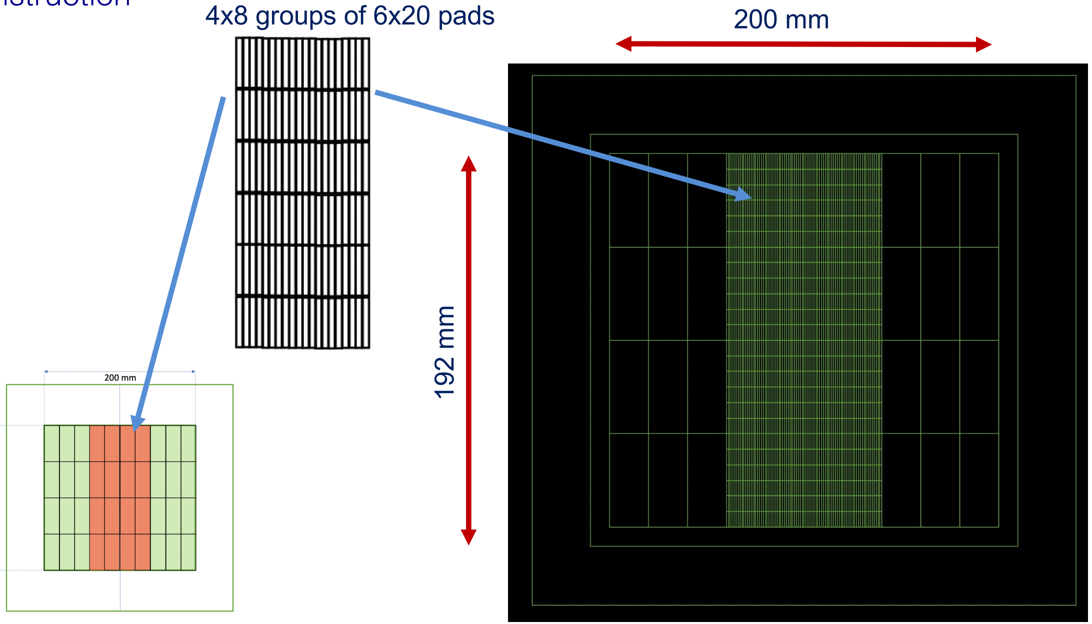


- Plans to go to faster mixtures, adding CF_4 to improve time resolution → simulation studies for gas optimisation ongoing

'Large'-size prototype

- Large-size demonstrastor under construction
  - 1x8 mm^2 pads
  - 4800 readout pads
  - 192x200 mm^2 active area
  - SBU-type



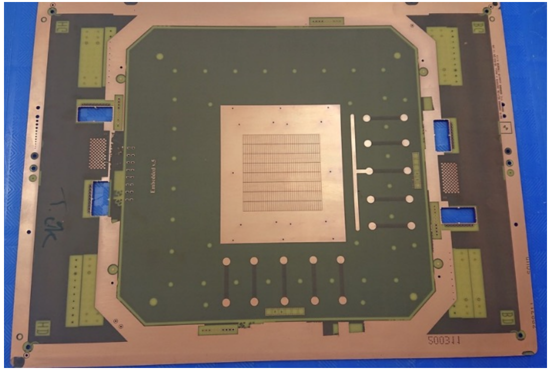


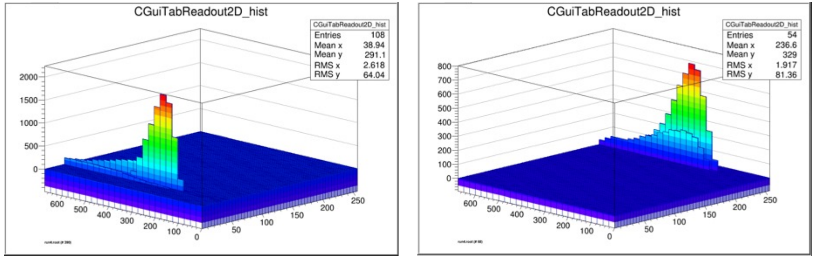
- R/O electronics on the sides
- Only ½ of the pads will be connected to FE elx
- Routing to side connectors too complex (requiring too many layers on PCB) → simplification possible placing elx on the back side

Integrated electronics

- Prototype built with integrated electronics on the back side of the anode PCB
  - 512 pads
  - 64x64 mm^2 active area
  - APV-25 chip used → investigation of alternative chips ongoing
  - A first prototype has been built demonstrating the proof-of-principle. A second one is currently under test to fix some issues in the chip bonding

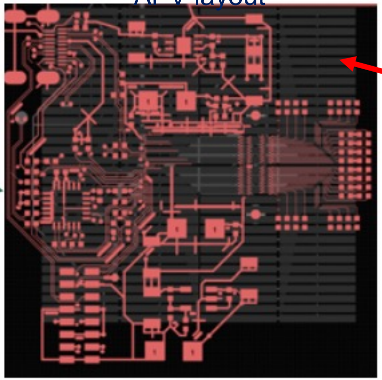
Front view



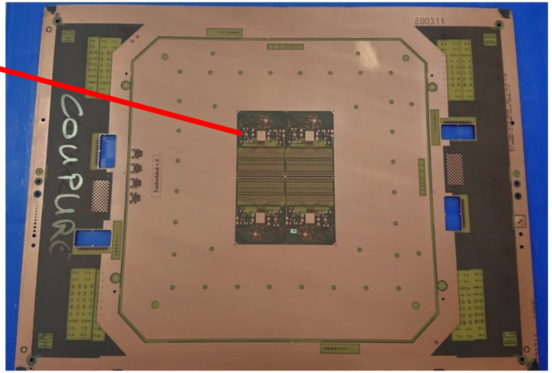


^{55}Fe induced signals

APV layout



Back view



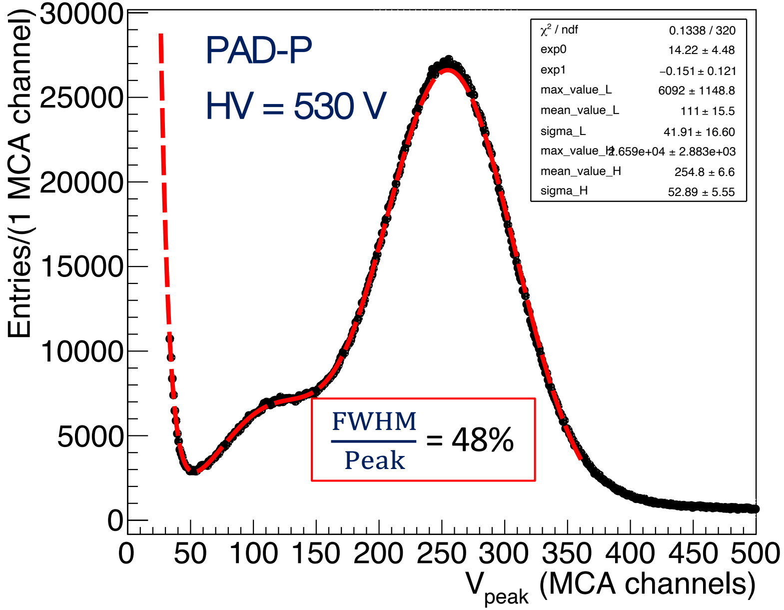
Summary

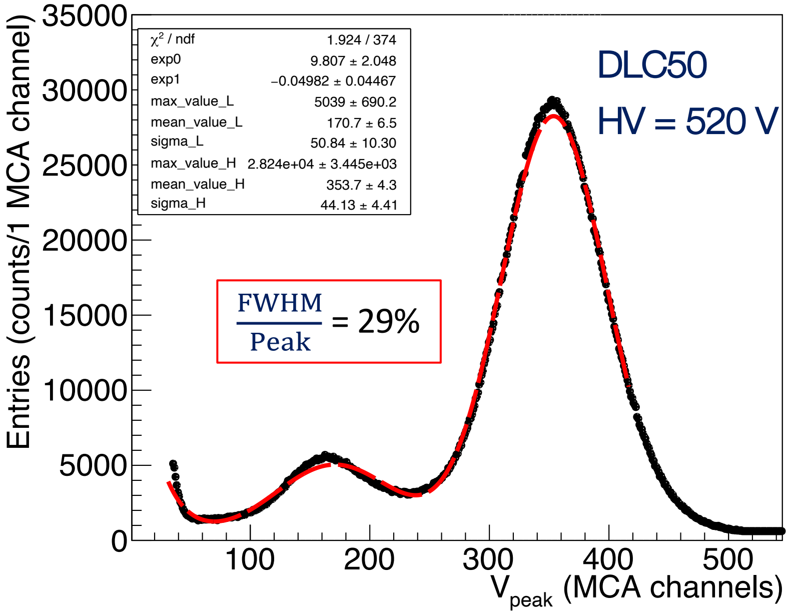
- The RHUM collaboration is developing resistive Micromegas for applications at very high particle rates (~10s MHz/cm^2)
- Several prototypes implementing different resistive layouts have been built and tested
  - PAD-P series: Pad-patterned, screen-printed resistive layer
  - DLC & SBU series: uniform resistive DLC layer (standard and with sequential built-up technique)
  - PAD-H: hybrid DLC and screen-printed resistive layer
  - DLC-Strip: new scheme with RO electrodes in between the resistive layers
- Tests included characterization on beam at CERN and PSI and lab tests with sources and X-rays
- Stable operations at rates of 20 MHz/cm2 with gain of 20k successfully reached

- Ongoing work:
  - Characterisation of newest prototypes (DLC-Strip)
  - Optimisation of gas mixtures
  - Construction of large-area detector (20x20 cm^2 active area)
  - Construction and test of prototype with embedded electronics
  - Next test beam campaign: at CERN GIF++ in September and at SPS in November

Thank you!

PAD-P vs DLC – Energy Resolution



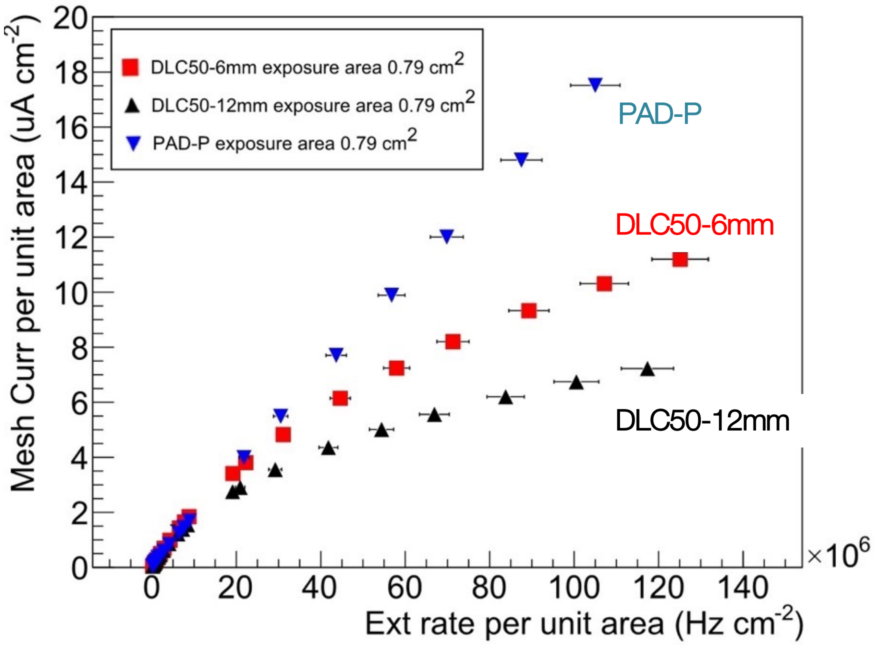


DLC prototypes have better energy resolution

- more uniform electric field
- no pad border effects

Dependence on the grounding vias pitch

COMPARISON done at a gain of ~6500 X-rays Exposure area 0.79 cm² (shielding with 1cm diameter hole)



DLC-50:

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