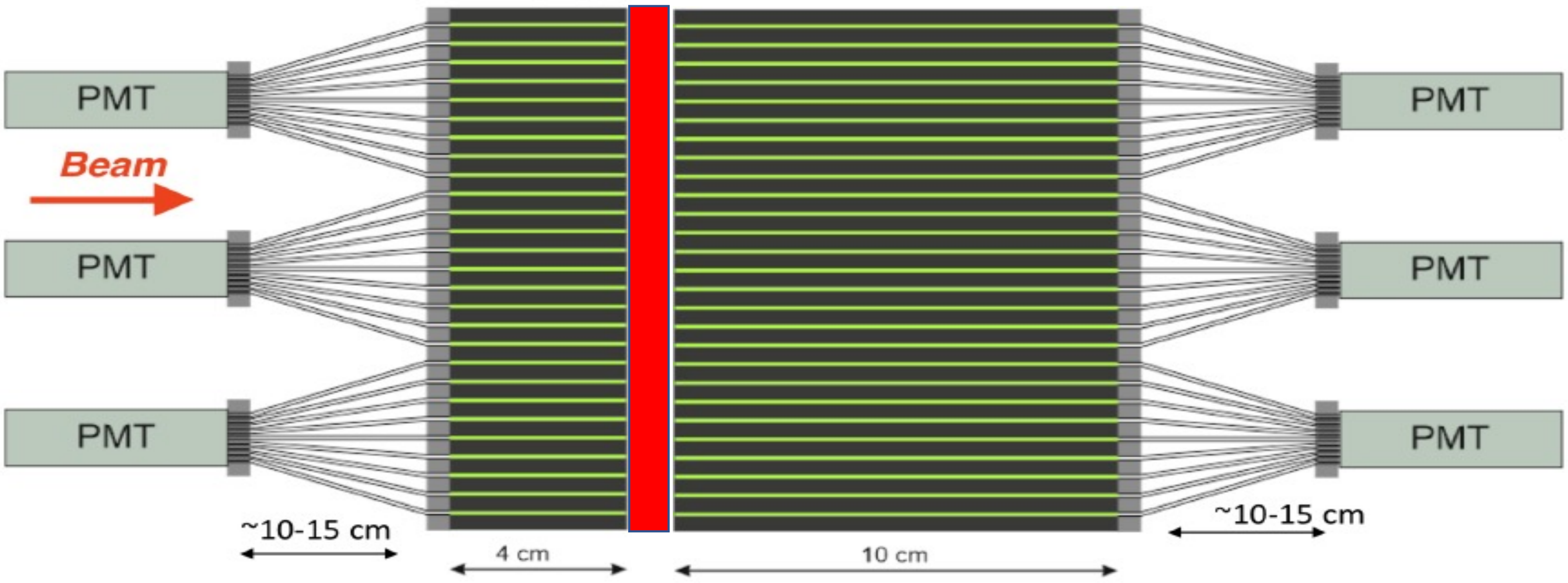
Timing layer technologies

Vincenzo Vagnoni, for the timing-layer enthusiasts

LHCb ECAL Upgrade-2 workshop, Orsay
14 December 2022

Embedding a timing layer into a double-side readout LHCb ECAL module

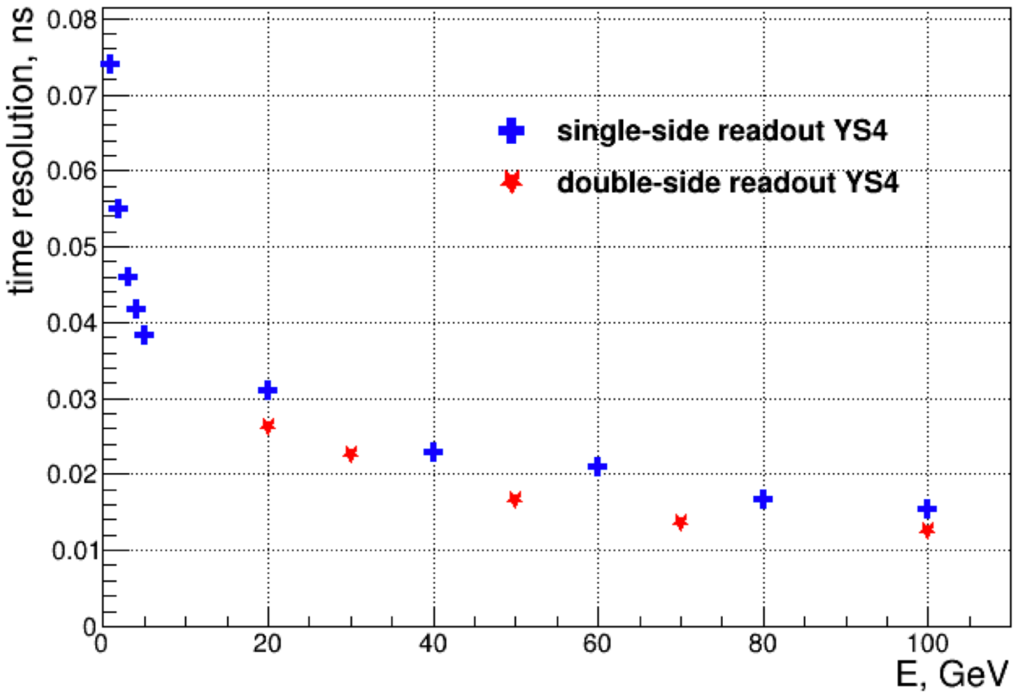


- Achieve < 20 ps timing resolution on the arrival time of EM showers
- A timing layer can be made thin enough to be inserted within the two halves of a SPACAL or Shashlik module
- Possible to adopt such a solution without disrupting baseline ECAL technologies

Why a timing layer within the ECAL?

- Obvious question: if we need to reach a time resolution <20 ps in the range 5-100 GeV, and ECAL modules are capable of doing that without an additional timing layer, do we need a timing layer at all?
- Obvious answer: probably not, unless such devices bring additional information
- However, we are not there
  - E.g., Shashlik modules with double-side readout, although showing amazing performances which were unthinkable a couple of years ago, reach 20 ps resolution at 40 GeV, and at 5 GeV approach 40 ps
  - SPACAL is more performant, at least at low rates, but, as we have seen during this workshop, there's still a number of issues to address like, e.g., crystal decay-time shortening

Shashlik state of the art

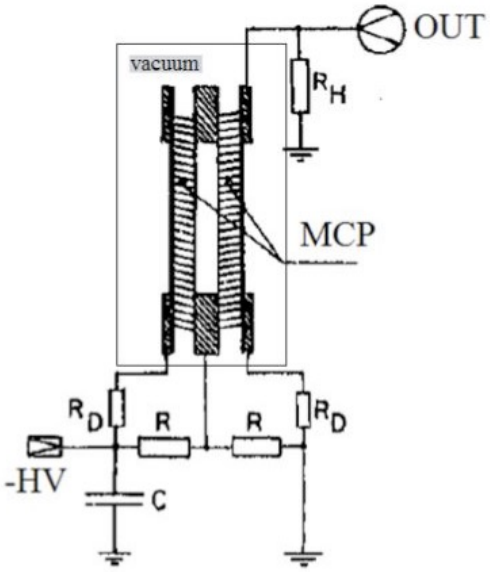


Timing layer technologies under study

- Up to now, two technologies are being explored in LHCb, namely
    - Cost-effective MCP-based multianode devices with no photocathodes
    - Silicon layers for timing/imaging
- In the following we'll go through some details of the two options

Idea of using MCP-based devices in calorimeters

- Old idea, first proposed: “On possibility to make a new type of calorimeter: radiation resistant and fast”, A. I. Ronzhin *et al.*, IFVE 90-99, Protvino, 1990
  - Use of secondary emitter material as an active element in a sandwich type calorimeter
- Secondary particles from an EM shower are detected by an MCP with signal proportional to the number of secondaries
  - Most of secondary particles have low energy → MCP is very efficient
- MCPs are intrinsically very fast → can make a calorimeter with very good timing capabilities



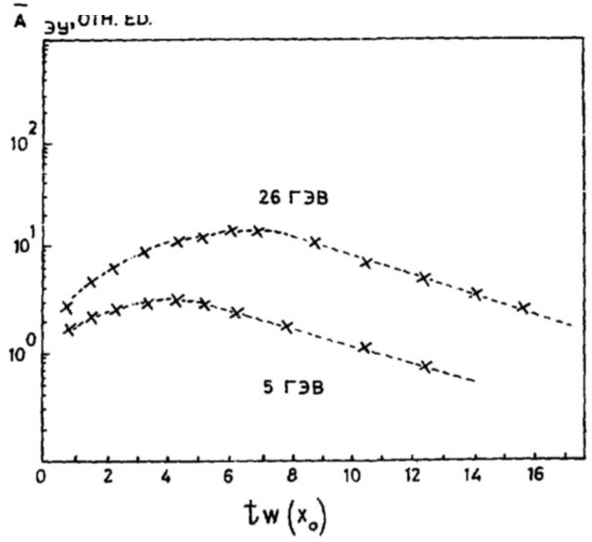
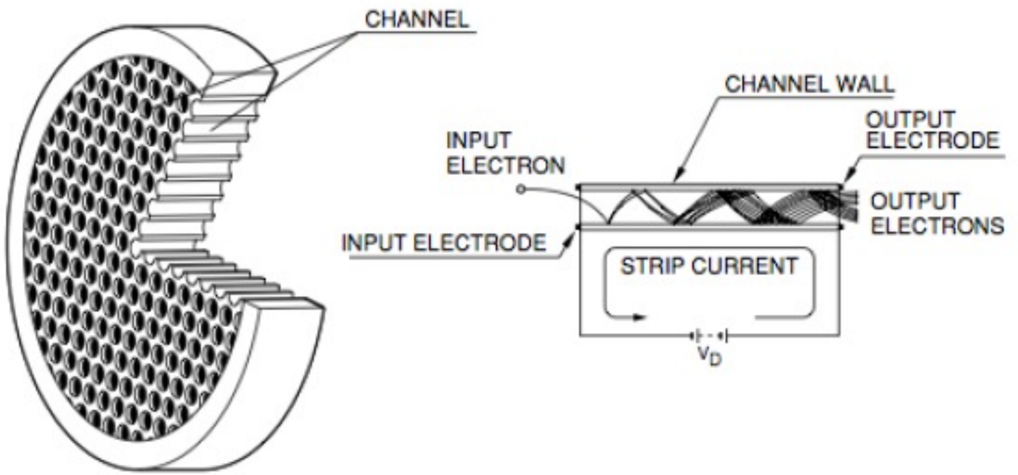


Fig.3. Shower longitudinal development for electron energy 5 and 26 GeV, measured by MCPs.

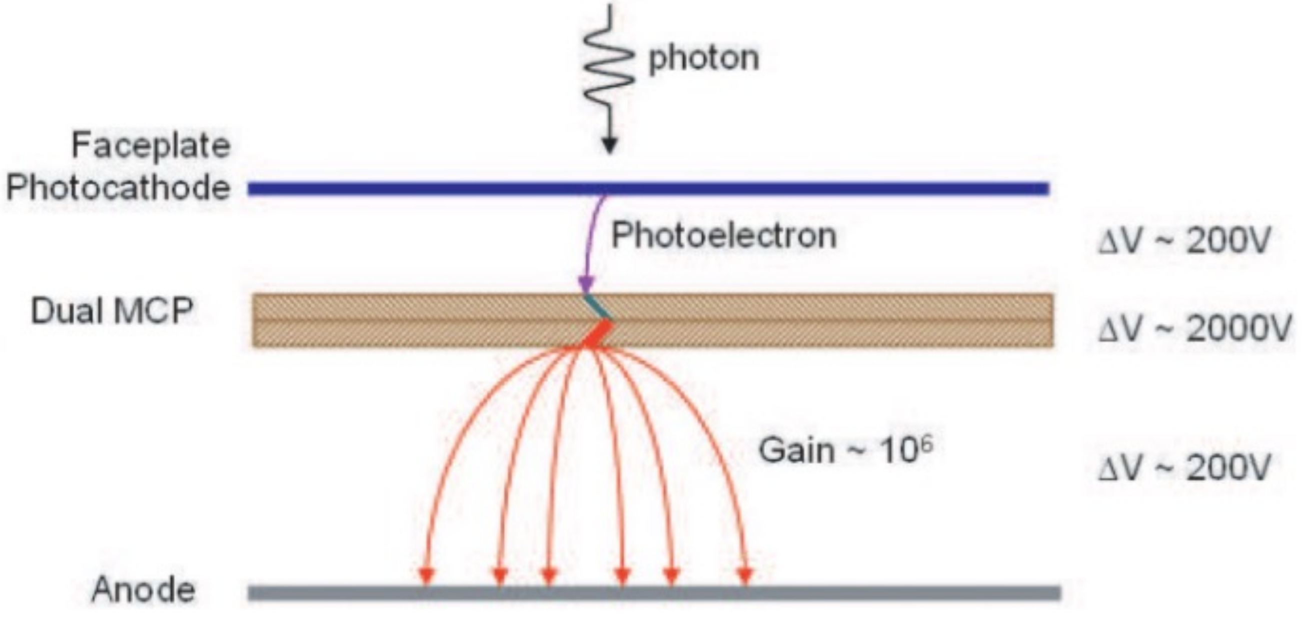
MCPs in a few words

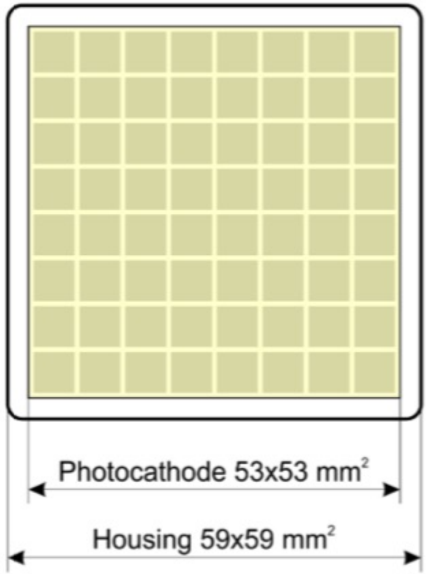


- Traditionally produced from stacks of optical fibres with lead-glass cladding
  - Array of miniature electron multipliers
- Typical diameters (d) of micropores in the range 6-20 µm, with wafer thickness (L) of 0.4-1 mm
- The characteristic parameter is the ratio L/d which is roughly proportional to the log of the gain (G)
  - $\log G \propto L/d$
- Typical gain of a single MCP: $O(10^3 - 10^4)$
  - With a stack of two MCPs one can easily reach gains of $10^6 – 10^7$

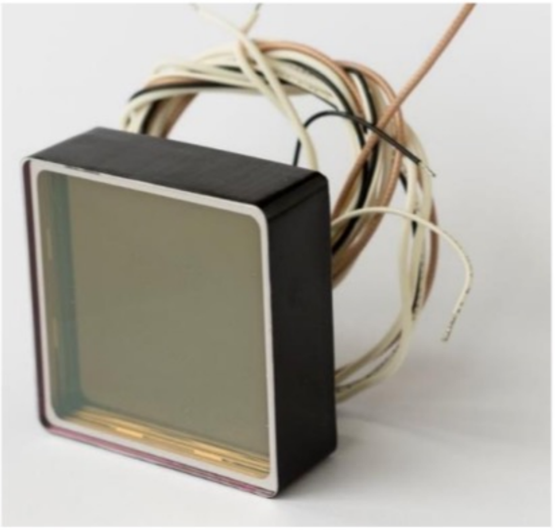
MCP-PMTs

- Photocathode + MCPs + anode in a vacuum tube
- Single or multi-anode devices available commercially from several vendors
- Typical timing precision to charged particles around 10-15 ps
  - Commonly employed as fast triggers and time reference in beam tests



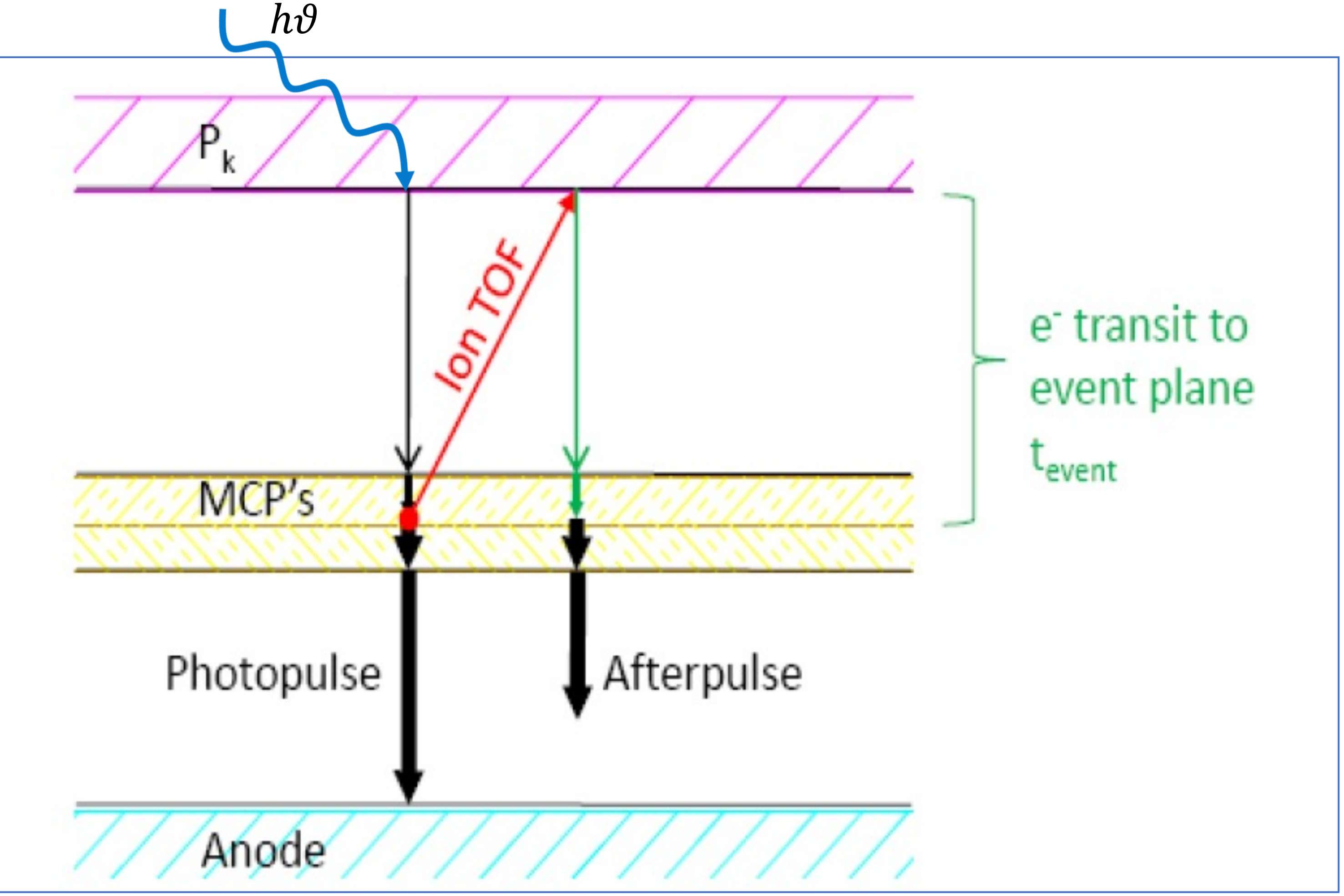


Planacon XP85012 layout



PLANACON® **XP85012** or XP85112

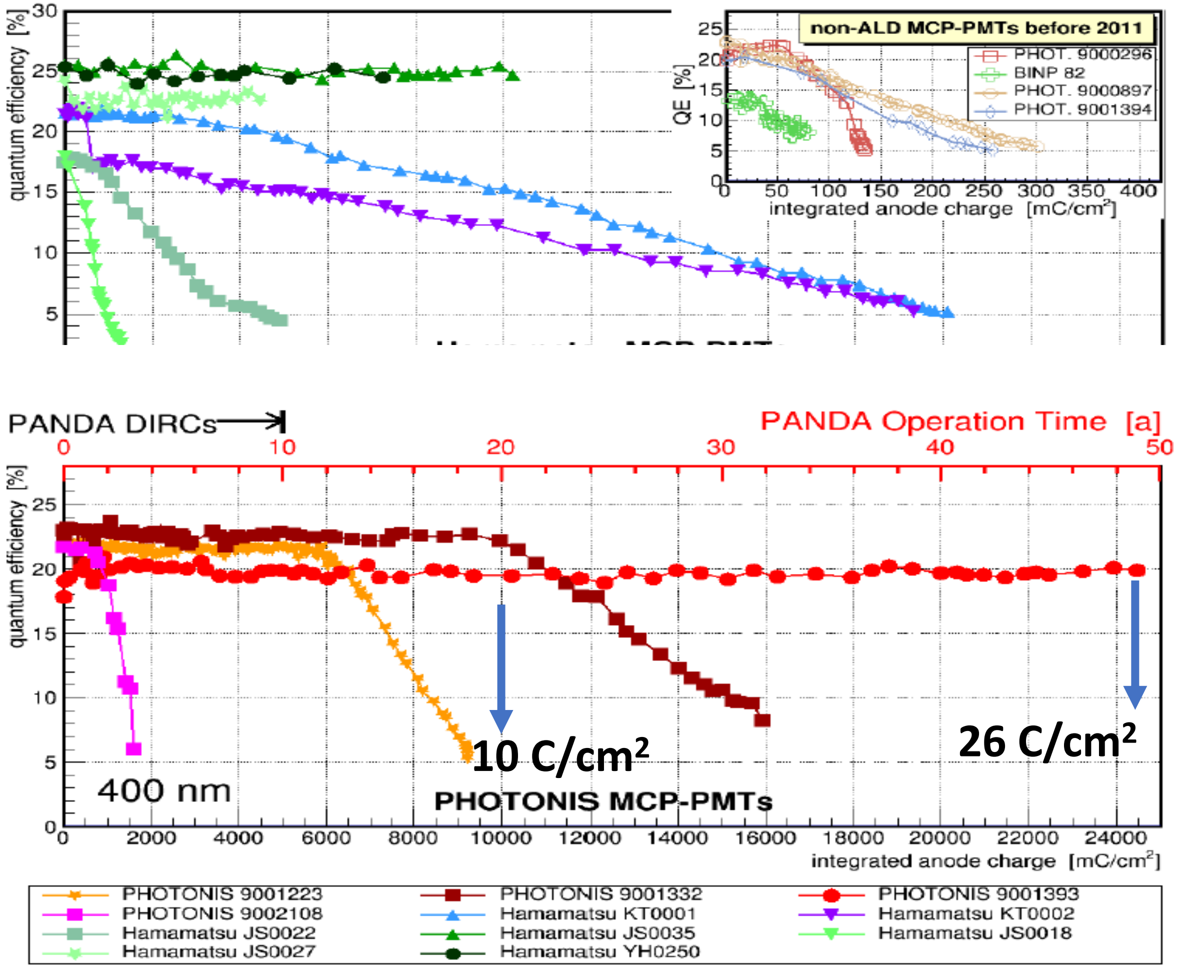
MCP-PMT lifetime



V. A. Chirayath & A. Brandt

- Electron collisions within MCPs can give rise to ionization of the residual gas or desorption of positive ions from the MCP surface → Ion feedback
- Ions then become bullets accelerated towards the anode by the electric field and can react with or sputter the photocathode material → degradation of quantum efficiency
- Photocathodes are the most fragile part of these devices

MCPs with enhanced lifetime

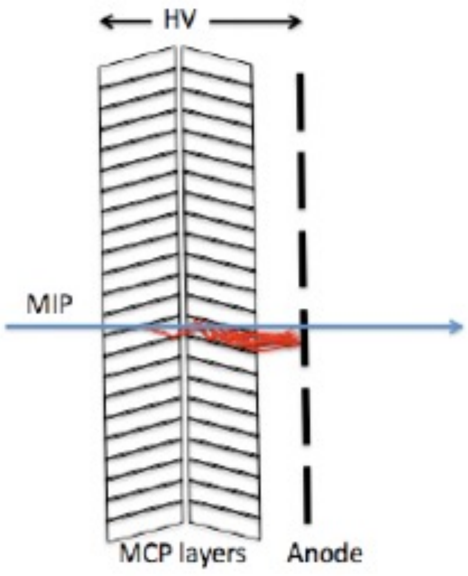


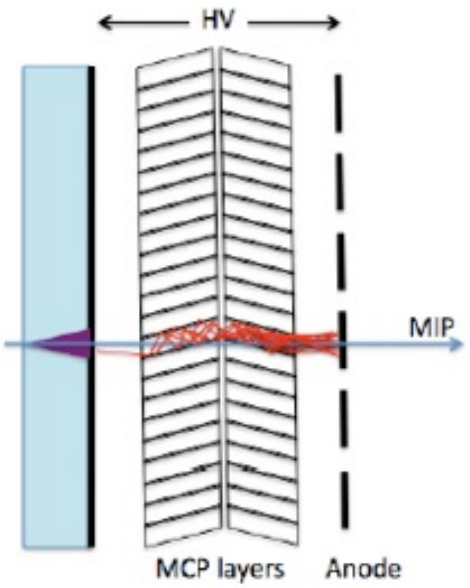
Lehmann et al., Nuclear Inst. and Methods in Physics Research, A 958 (2020) 162357

- Significant improvements made in recent years to improve the photocathode's lifetime, but best results so far extend up to ~30 C/cm^2
- In our case, our target is more than one order of magnitude larger emitted charge
- Traditional MCP-PMT layouts are probably ruled out for now

Photocathode-less operation

- Photocathode is important to achieve high efficiency and large input signal to the multiplication MCP layers
  - Its employment is important for single MIP detection, but it’s not fundamental when dealing with a large number of particles as in the middle of an EM shower

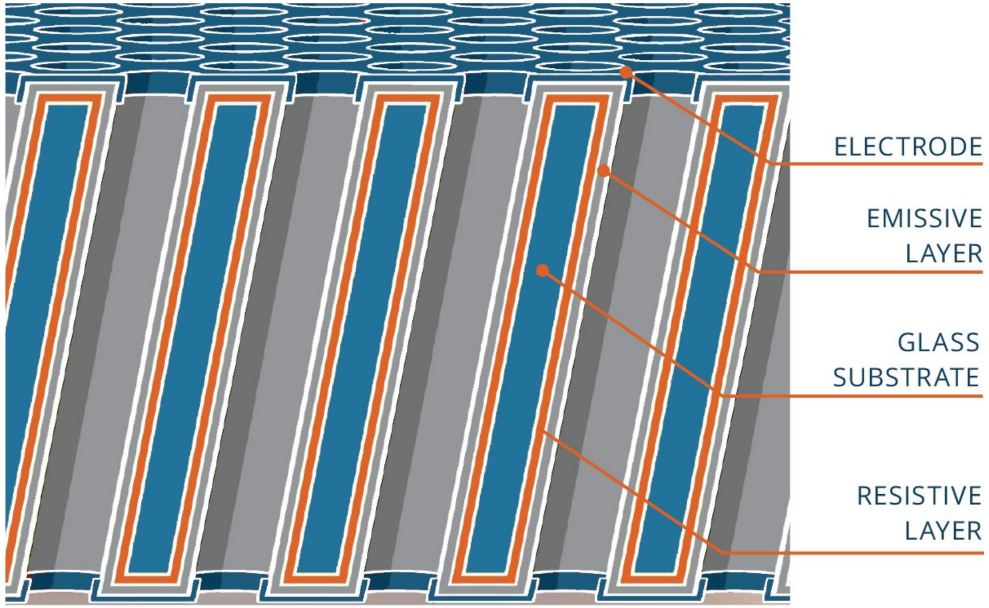


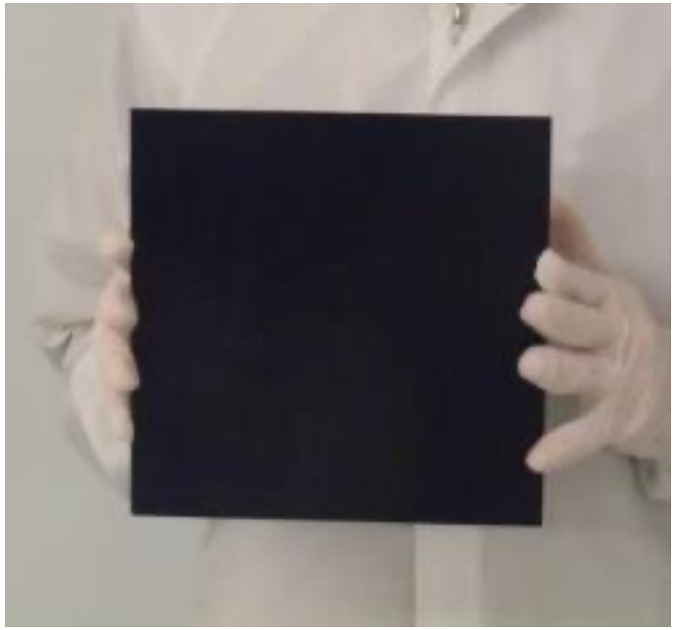


- Photocathode’s removal simplifies the design and the assembly, reduces cost and makes the device more robust

Another issue to be solved: large area and cost

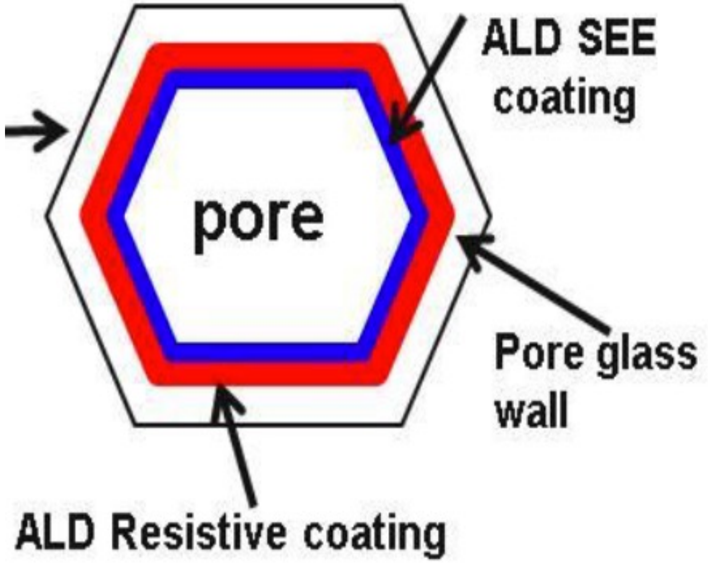
- With traditional lead-glass MCP technology, it’s difficult to produce large area MCPs
- Technology for the production of large surface MCPs developed during last years by the LAPPD collaboration and Argonne, manufactured and commercialized by Incom Inc.
  - MCP wafers made of commercial borosilicate glass produced with hollow fibers (glass capillary arrays), then activated with atomic layer deposition (ALD) of resistive and emissive layers
- Wafer size up to 20x20 cm^2 and pores down to 10 μm diameter regularly produced nowadays

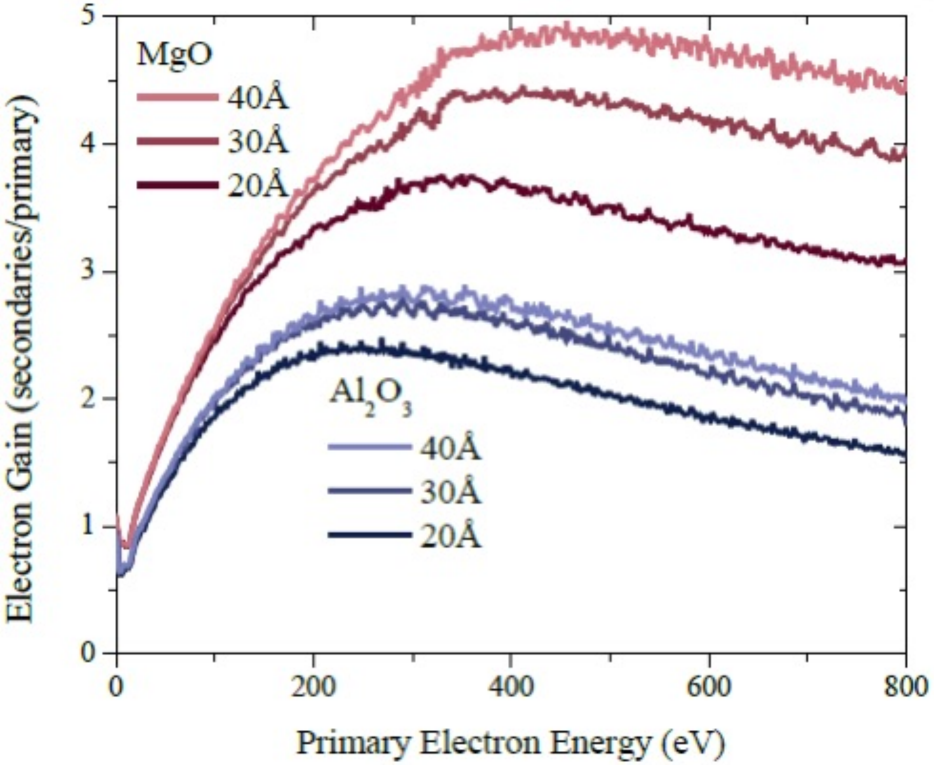




Enhanced secondary electron emission by ALD

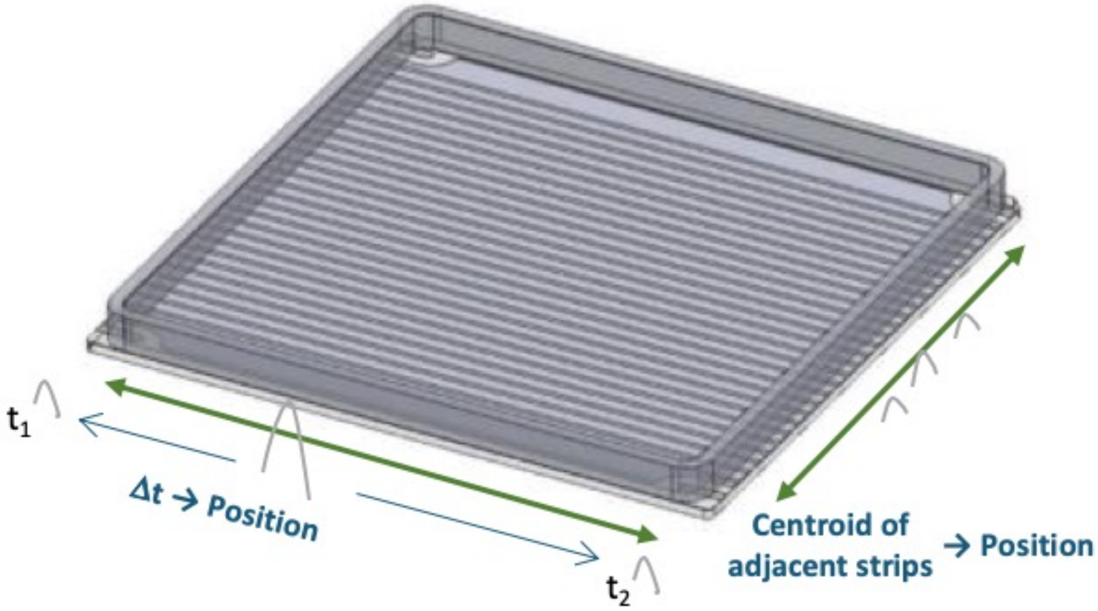
- Emissivity in the MCP pores is enhanced with appropriate coating, such as MgO



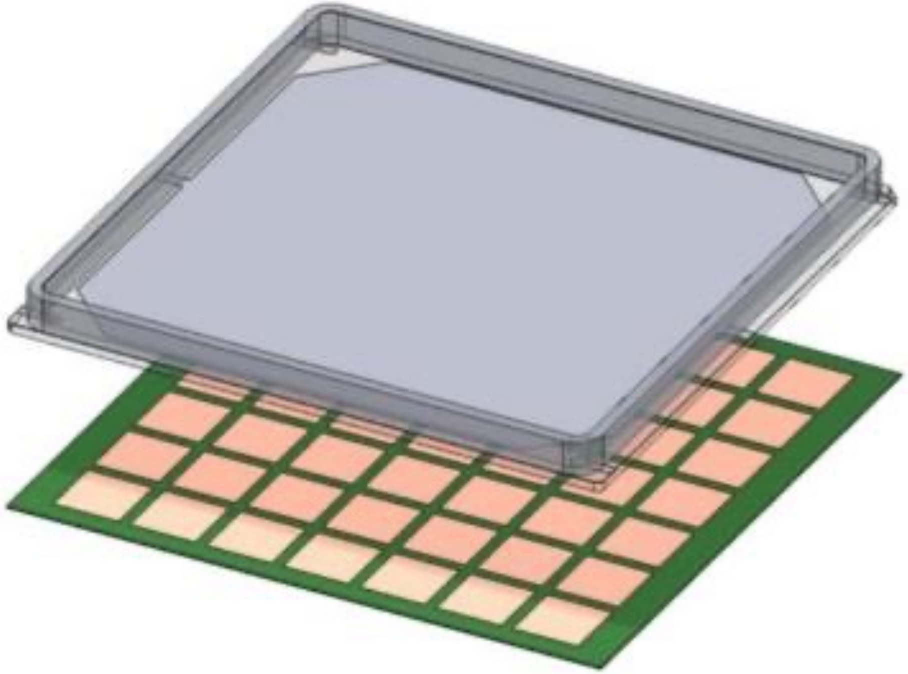


Two LAPPD versions

Gen-I: Direct Read-out with internal delay line Anode

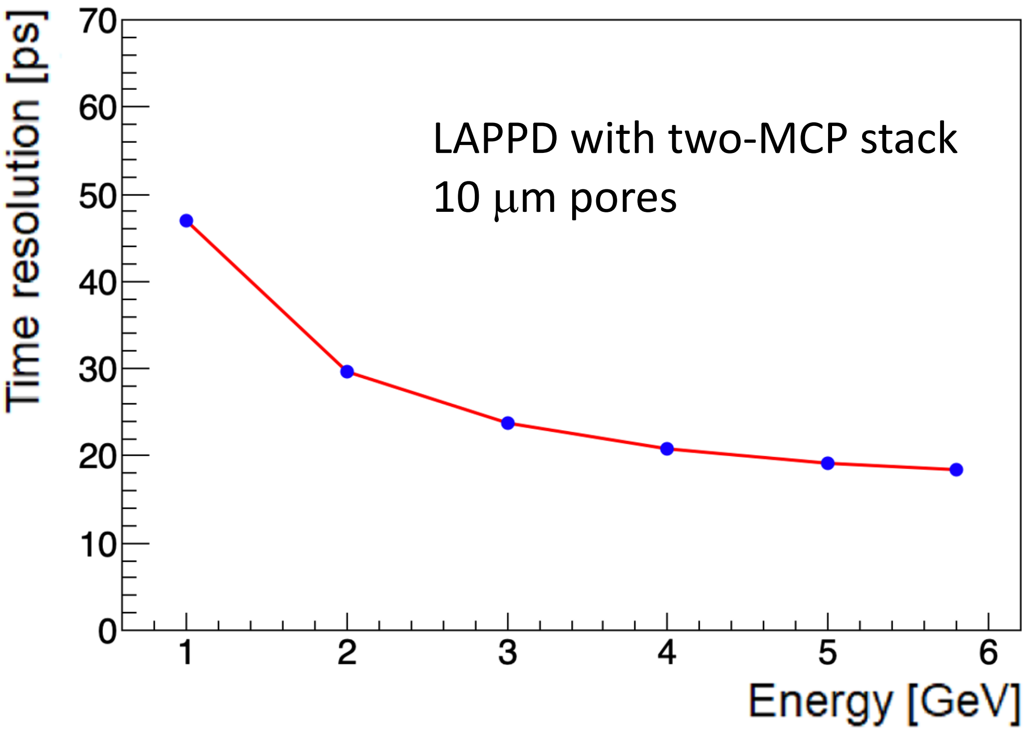


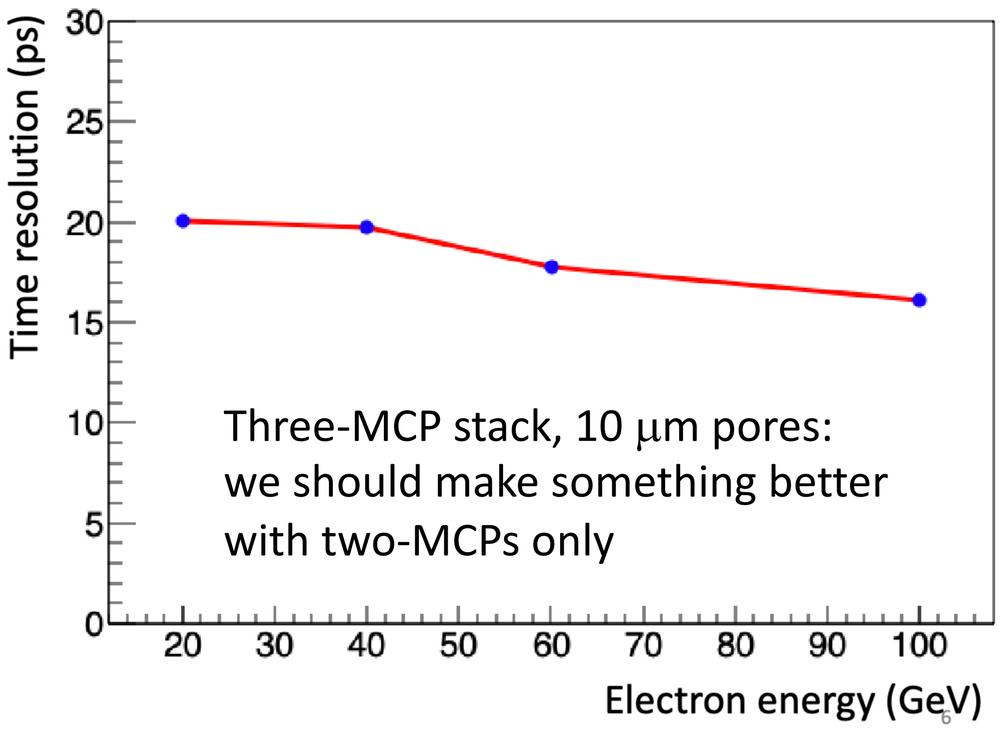
Gen-II: Resistive internal anode with capacitively coupled external anode PCB



Good performances at low-rate beam tests

See Stefano’s talk on Monday

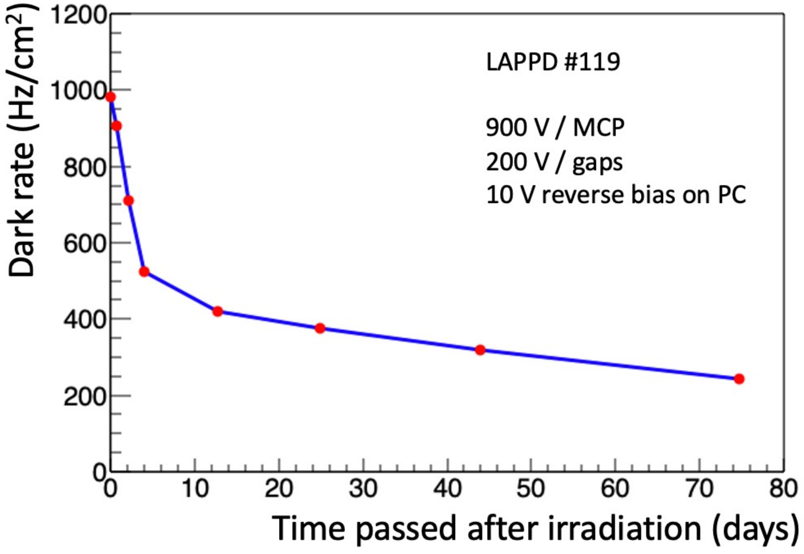


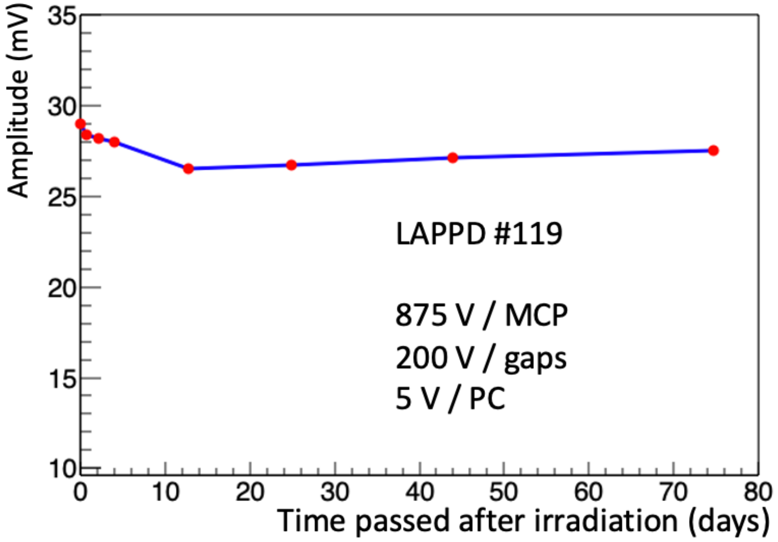


- Basic performances with pixels of 2.5 x 2.5 cm^2 well understood (the smaller the better, still further room for improvements)

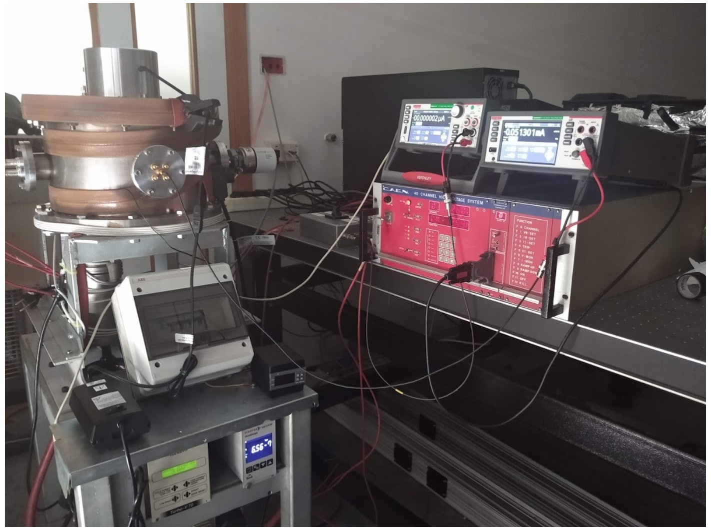
Radiation tolerance and lifetime studies

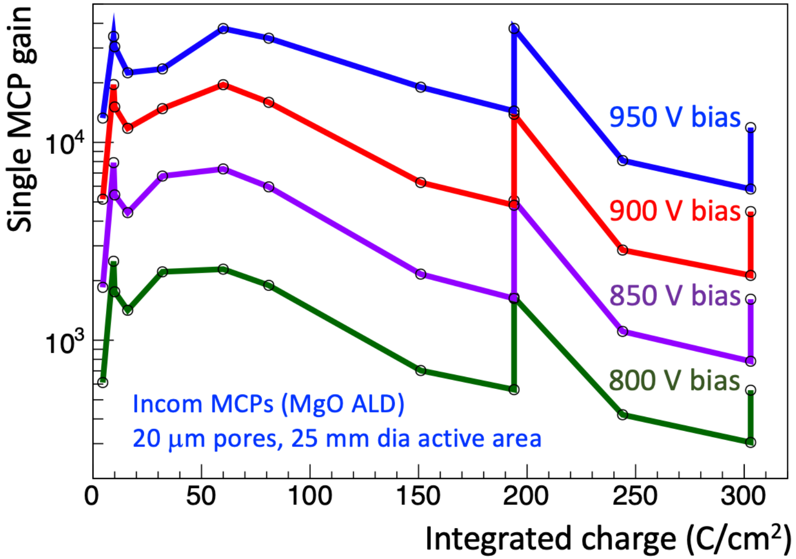
- Irradiation test with 24 GeV protons didn’t show sizeable performance degradation up to 10^{16} protons/cm^2





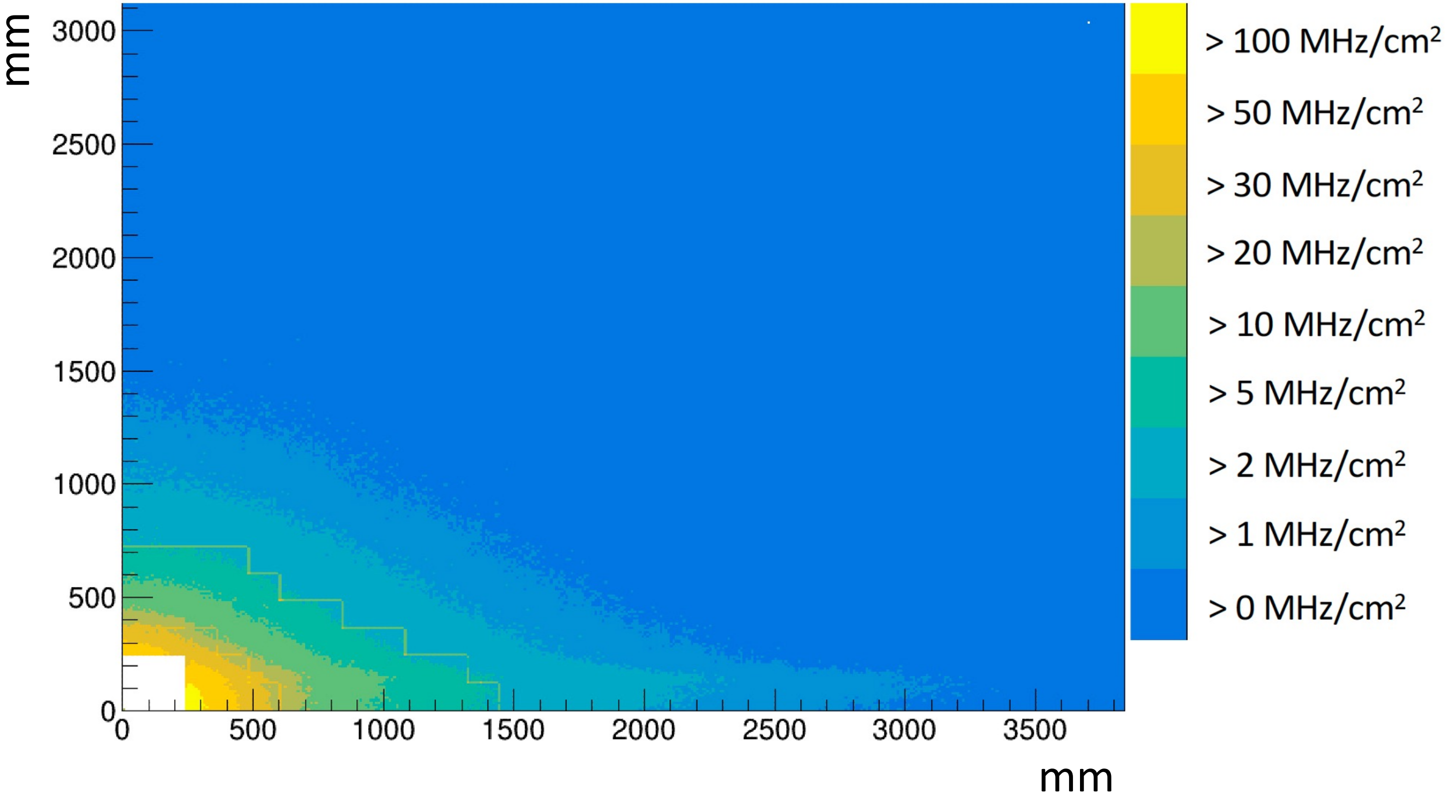
- Ageing campaign of an Incom MCP with UV light in vacuum chamber showed a gain reduction of about a factor 7 up to 300 C/cm^2, easily recoverable by increasing the MCP voltage bias by about 100 V



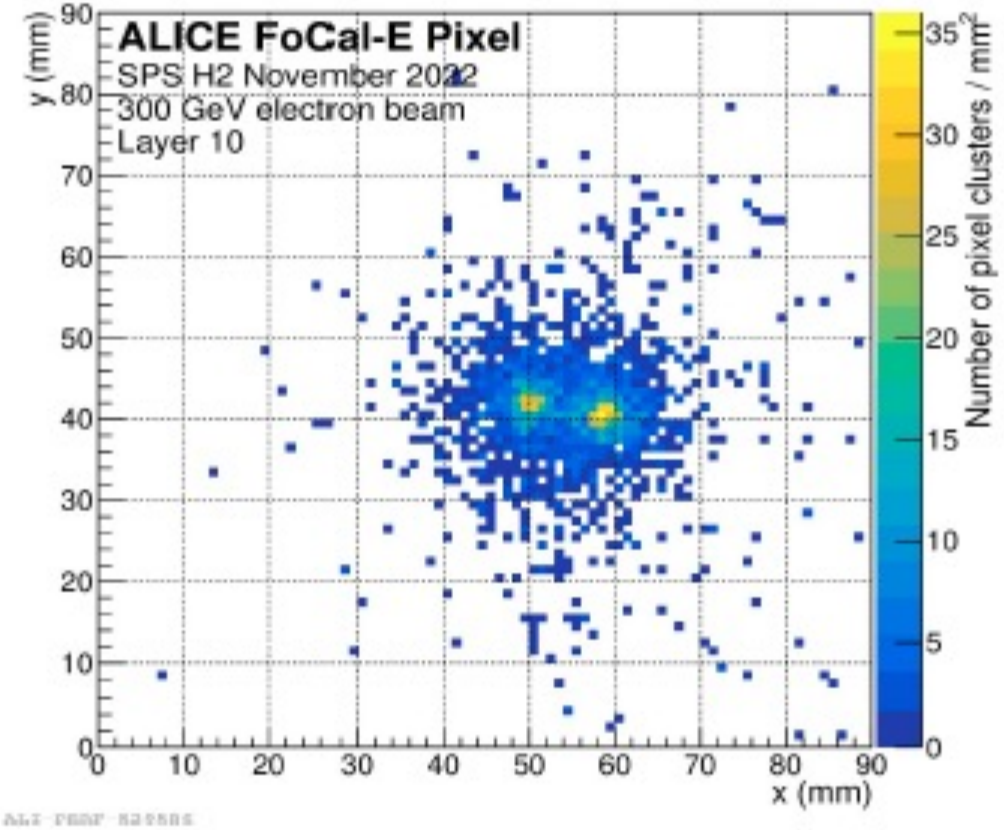


Not yet the end of the story…

- Concept, performances at low rate, irradiation and and ageing tests → OK
- Still, we need to understand limitations at high rate
- MCP pores have typical recharging time after multiplication in the range of hundreds of microseconds
- This translates to a gain reduction at high rates, that can impact dramatically the timing performance above a given rate → to be understood in detail next year



Silicon layers for timing/imaging



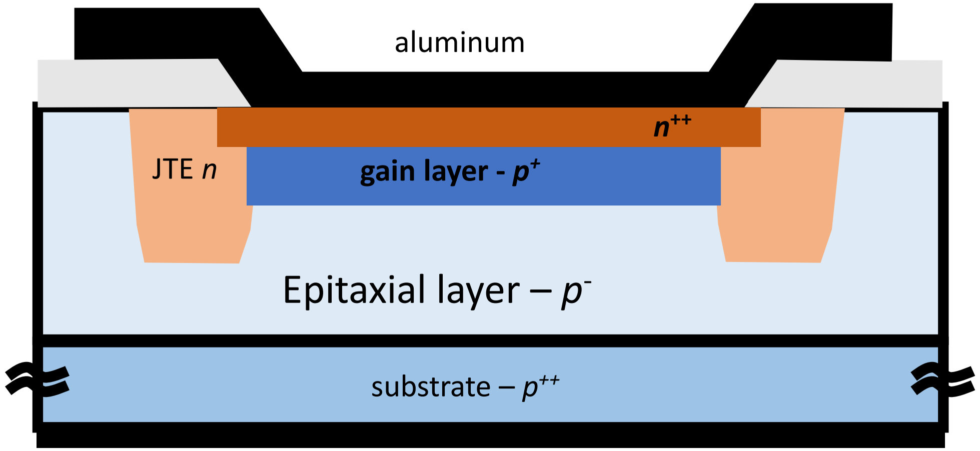
- Advantages of Si
  - Silicon is a well-understood material, widely used in tracking detectors for many years and large areas (LHC detectors)
  - Thin sensors (50 μm - 500 μm), depending upon the technology chosen (with/without multiplication) and the electronics performance (equivalent noise charge)
  - Cell elements can be of different shapes (e.g., square, rectangular, hexagonal…) and pitch (from tens of μm to cm)
  - With proper thermal management can withstand anticipated radiation

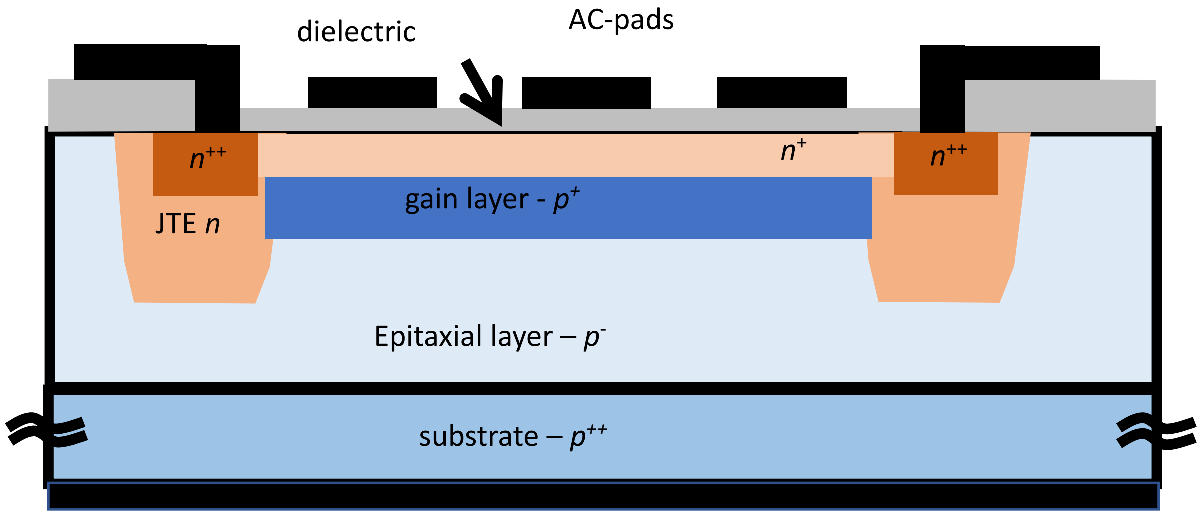
Planned R&D

- Simulation studies to identify the optimum cell size/tile size to achieve the best spatial/temporal resolution
- Timing/spatial resolution performance before and after irradiation to be validated in test beam studies
- Investigation of alternative technologies/substrate materials

Silicon with multiplication (LGADs)

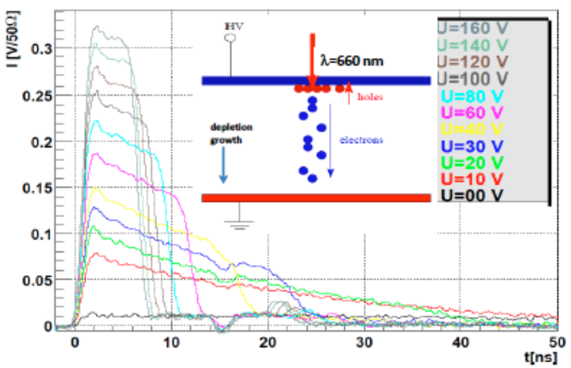
- LGADs are avalanche diodes specifically tailored for the detection of MIPS in HEP
- For MIPS: if the substrate is thin (~ 50 μm) and the gain is ~ 20 → signal is fast (~30 ps)
- LGADs are 20-50 μm thick as compared to hundreds of μm of standard strip/pixel sensors
- LGADs feature a p+ layer (gain layer) under the n+ layer
- Amplification is needed to have a good S/N when reading-out fast
- Use in 5D silicon sampling calorimeter has started being investigated

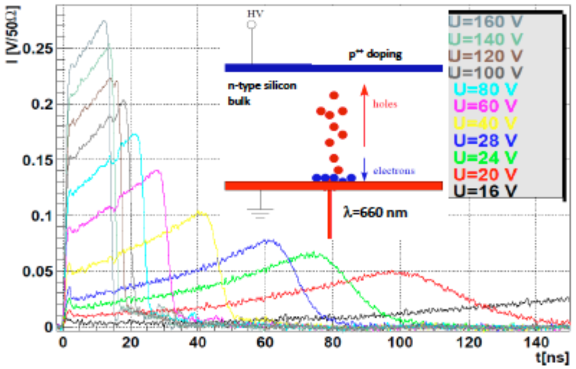


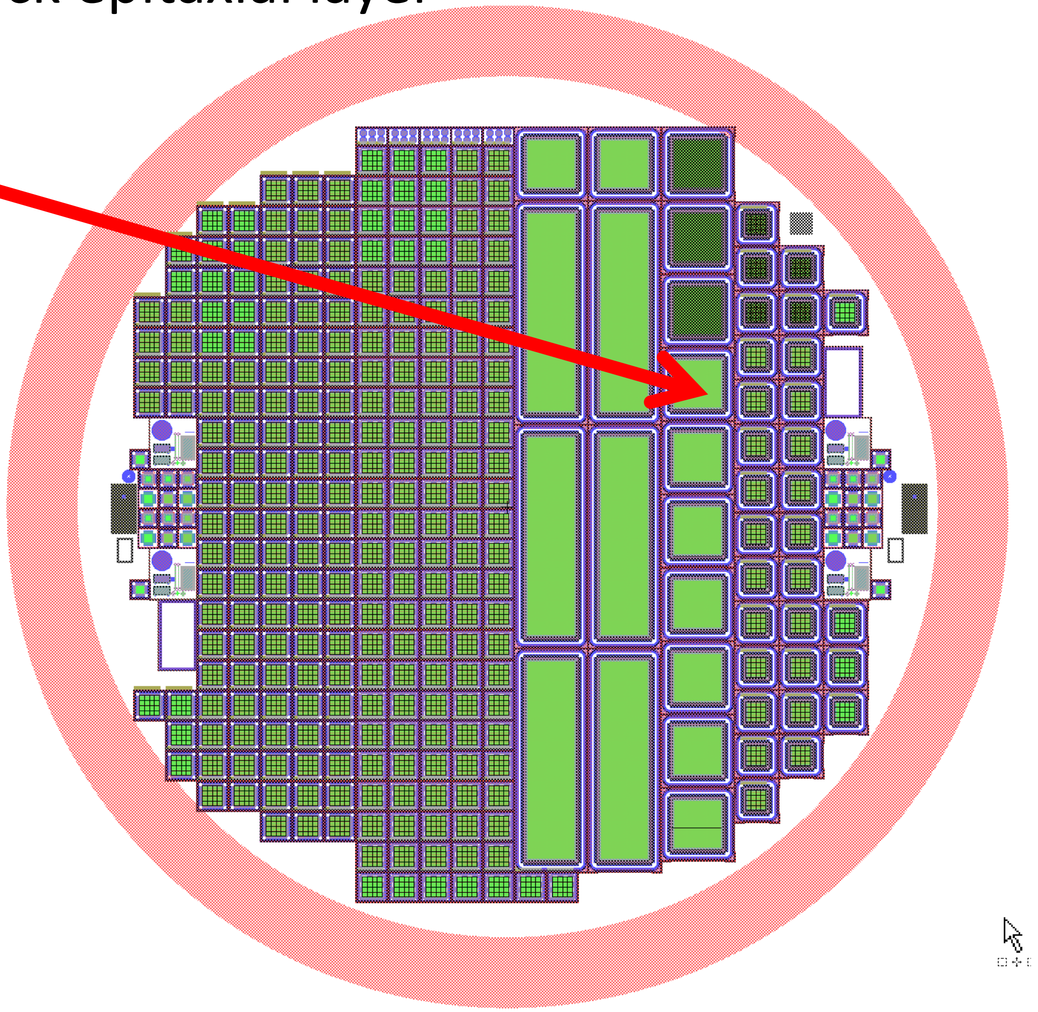


Large-area LGAD (BNL) almost ready for submission

- Total of 6 4” wafers: 2x20, 2x30, and 2x50 μm thick epitaxial layer
- AC-LGAD technology (try to do also DC-LGAD)
- 12 0.5 cm x 0.5 cm LGADs for this project
- Expected delivery: end of December 2022
- To be studied (Syracuse): signal formation with TCT scanner







- Response with two different FE approaches
  - See Marina’s talk

Summary

- Studies on photocathode-less MCP-based timing layer well advanced and showing good performances, with margins for further improvements
  - Need to focus on performances at high rate → main item for next year's studies
- R&D on Si layers for timing/imaging resuming, also with some first hardware prototypes based on LGADs