Micro Channel Plates

And an application:

LAPPD

High Energy Seminar
Ph.D. cycle XXXVII

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Introduction

1. Introduction to Photon Detection

2. Micro Channel Plates

3. Large Area Picosecond Photo Detectors

4. High Energy Application of LAPPDs

Photon Detection

Light detection has been developed using multiple techniques

Operating principle:

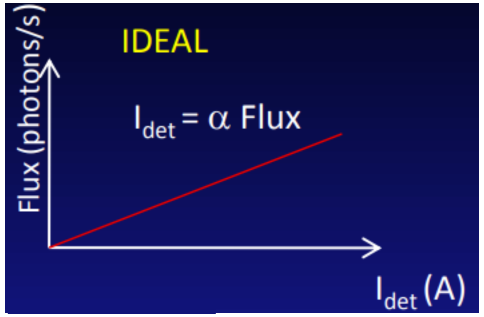
1. **Photon Absorption:** production of a photo-electron or a electron-hole pair
2. **Signal Amplification:** secondary emission
3. **Collection** of amplified signal

Characteristics:

- **Quantum Efficiency**: Probability that a photon produces an electron

$$QE = \frac{N_e}{N_\gamma}$$

- **Gain**: # of electrons per initial photon
- **Characteristic Timings**
- **Noise** (e.g. Dark Count Rate)
- **Linearity**
- **Flux limitations and Rate Capability**
- **Radiation Tolerance**
- **Magnetic Field Operation**



	PMT	HPD	MCP-PMT	APD	SiPM
Dynamic range (p.e.)	10^6	10^7	10^7	10^7	10^3

Classes:

1. Vacuum detectors: (PMT, MCP)
2. Gaseous detectors
3. Solid State Detectors

External Photocathode (1–2)

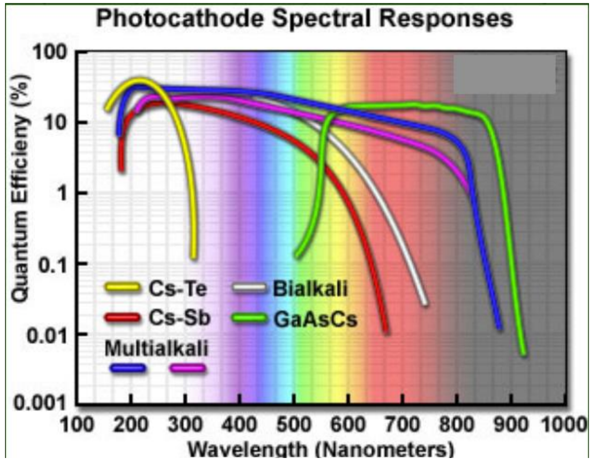
Internal Photocathode (3)

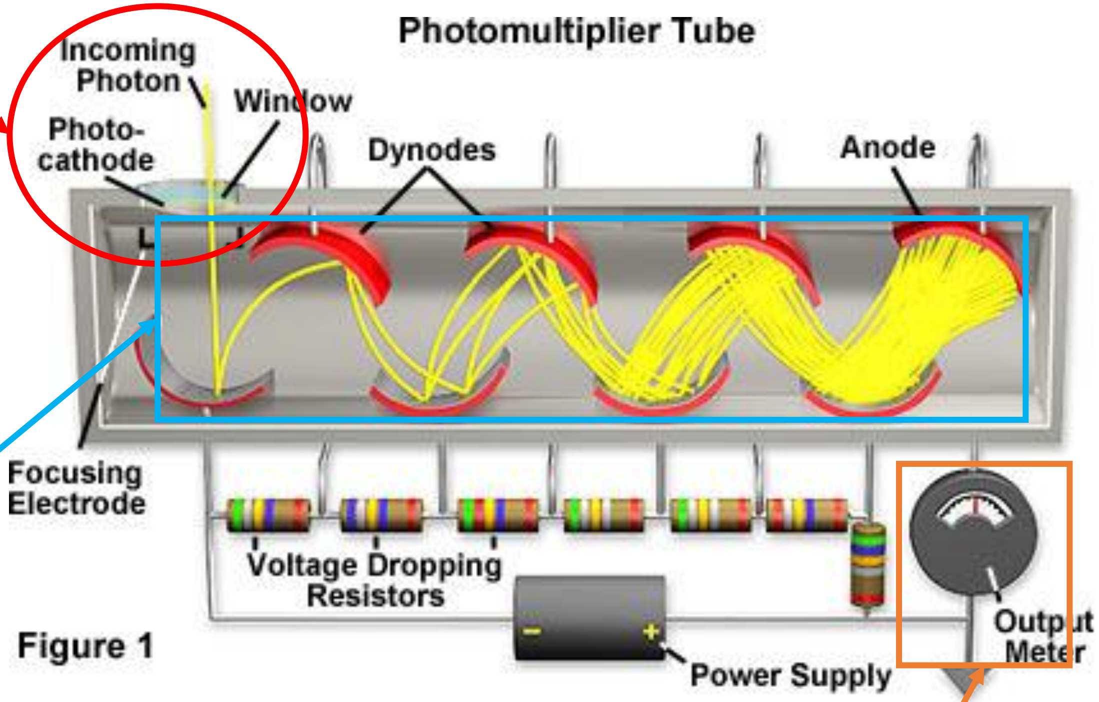
Vacuum Detectors: Photo Multipliers Tubes

Photo-Multiplier Tubes have been developed since the ‘30s and are widely used in many fields of Physics

A photon enters through the photocatode

Quantum Efficiency is close to 25 %





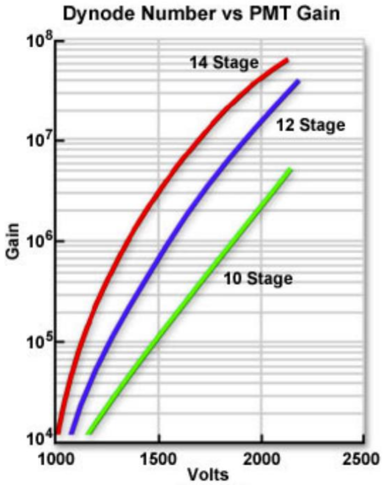
Electrons are multiplied by extractions

Signal Collection

Gain is exponential!

$$G \sim \delta^N$$

$$\delta \sim 5$$



Characteristic timings are very short

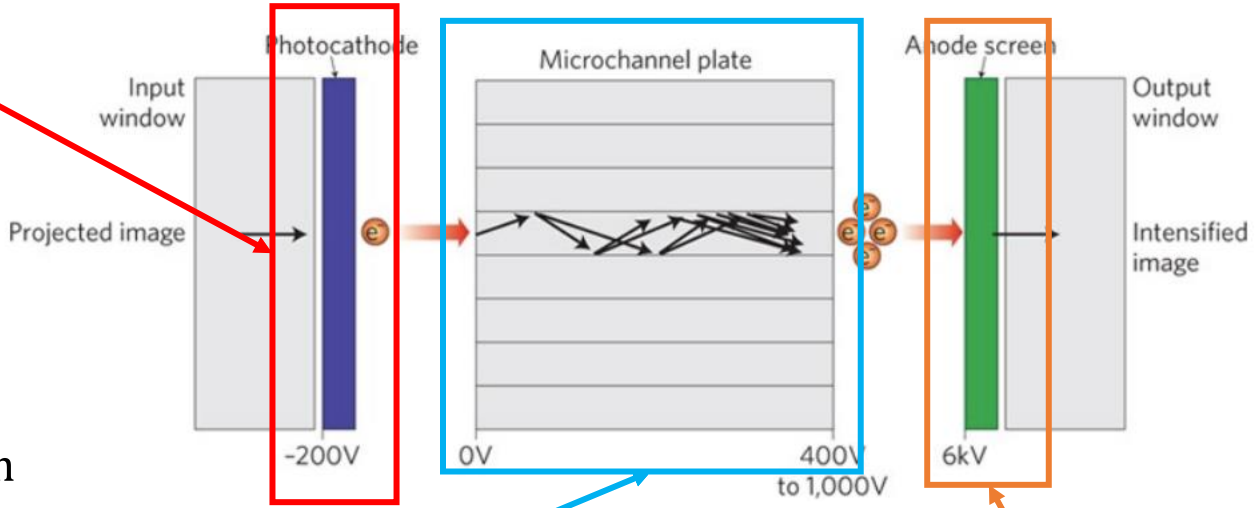
- Rising time ~ 1 ns
- Pulse width $\sim 1 - 5$ ns
- Transit time $\sim 10 - 50$ ns
- Transit time spread ~ 1 ns

But … **not working (well) in Magnetic Field !**

Vacuum Detectors: Multi Channel Plates

Devices with continuous amplification channels made of resistive materials

A photon enters through the photocatode



Electrons are multiplied by extractions

Signal Collection

Comparison with PMT characteristics:

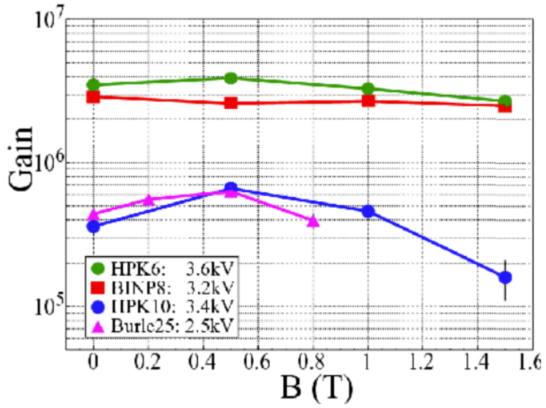
✓ **Possibility of improved spatial resolution!**
Electrons are multiplied in a narrow channel: $d \sim 10\ \mu m$

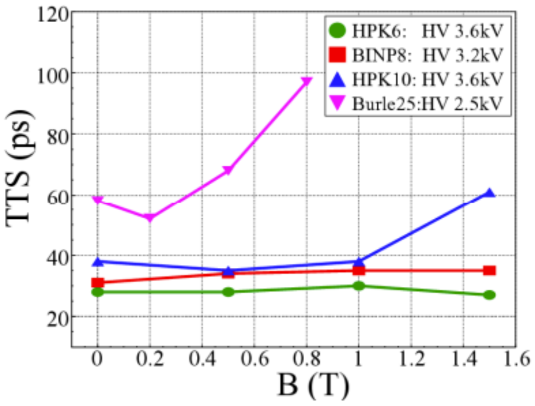
✓ **Very Fast Characteristic Timings!**
Rising time ~ 100 ps
Transit time $\lesssim 1$ ns

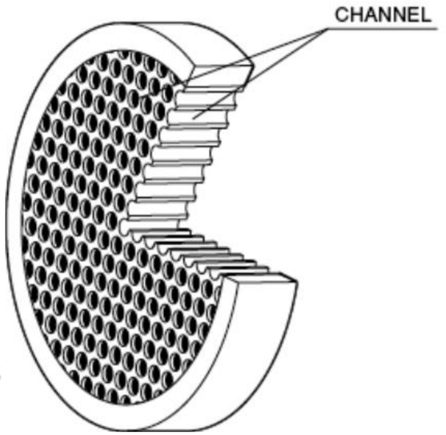
✓ **Less Affected by Magnetic Field!**

× **Smaller Photo-electron collection efficiency!**

× **Limited Linearity!**

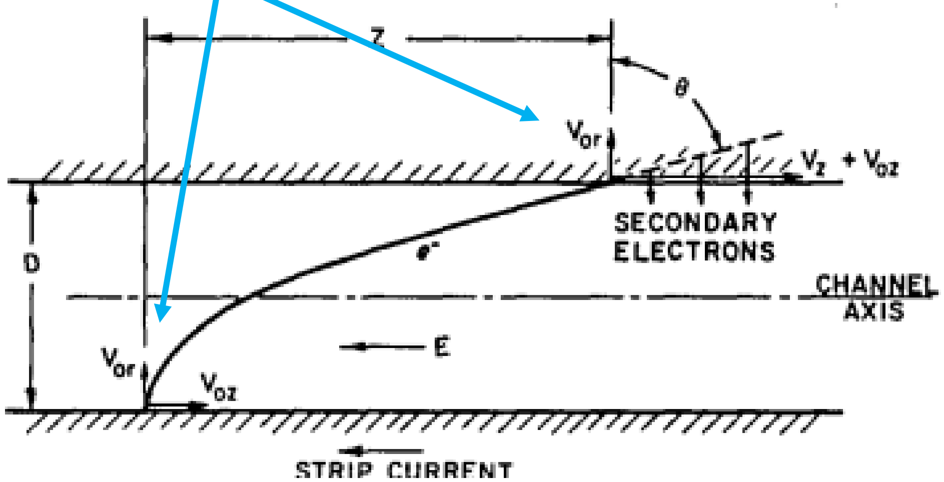






PMT - Multi Channel Plates: Operating Principle

After an electron hits a wall on a channel, secondary electrons are freed



Radial emission energy depends on the axial energy of bombarding electrons

$$V_{or} = \frac{V_z}{4\beta^2} \qquad \text{for } \sqrt{V_{or}V_{oz}} \ll V_z$$

Proportionality Hypothesis

$$z \sim \frac{1}{2}\left(\frac{V_z}{V_{or}}\right)^{\frac{1}{2}} D = \beta D$$

The axial distance travelled is:

$$\bar{z} \sim \frac{4ED^2}{\overline{V_{or}}}$$

The total number of steps is given by:

$$n = \frac{L}{z} = \frac{L}{D} \cdot \frac{1}{\beta} = \frac{\alpha}{\beta}$$

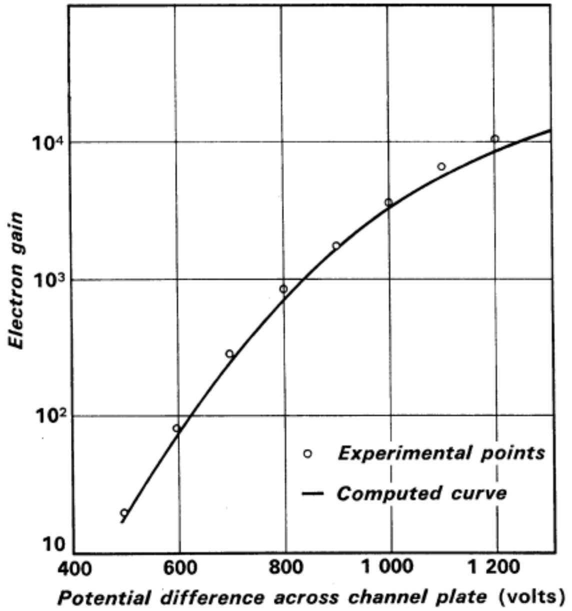
$$\mathbf{n \propto \alpha = \frac{L}{D}}$$

The final gain can be expressed as:

$$G = \left(\frac{KV_0^2}{4V\alpha^2}\right)^{\frac{4V\alpha^2}{V_0}}$$

In which:

- V_0 is the energy gained by an electron traversing the channel
- V is the initial energy of a secondary electron
- V_0 is the energy gained by an electron traversing the channel



But the **experimental curve behaves differently** due to:

1. Ion feedback
2. Secondary electrons are not emitted orthogonally

High Gain Micro Channel Plates

In a **straight type MCP** a gain of just $\mathrm{G} \sim 10^3 - 10^4$ can be achieved without significant **ion feedback**

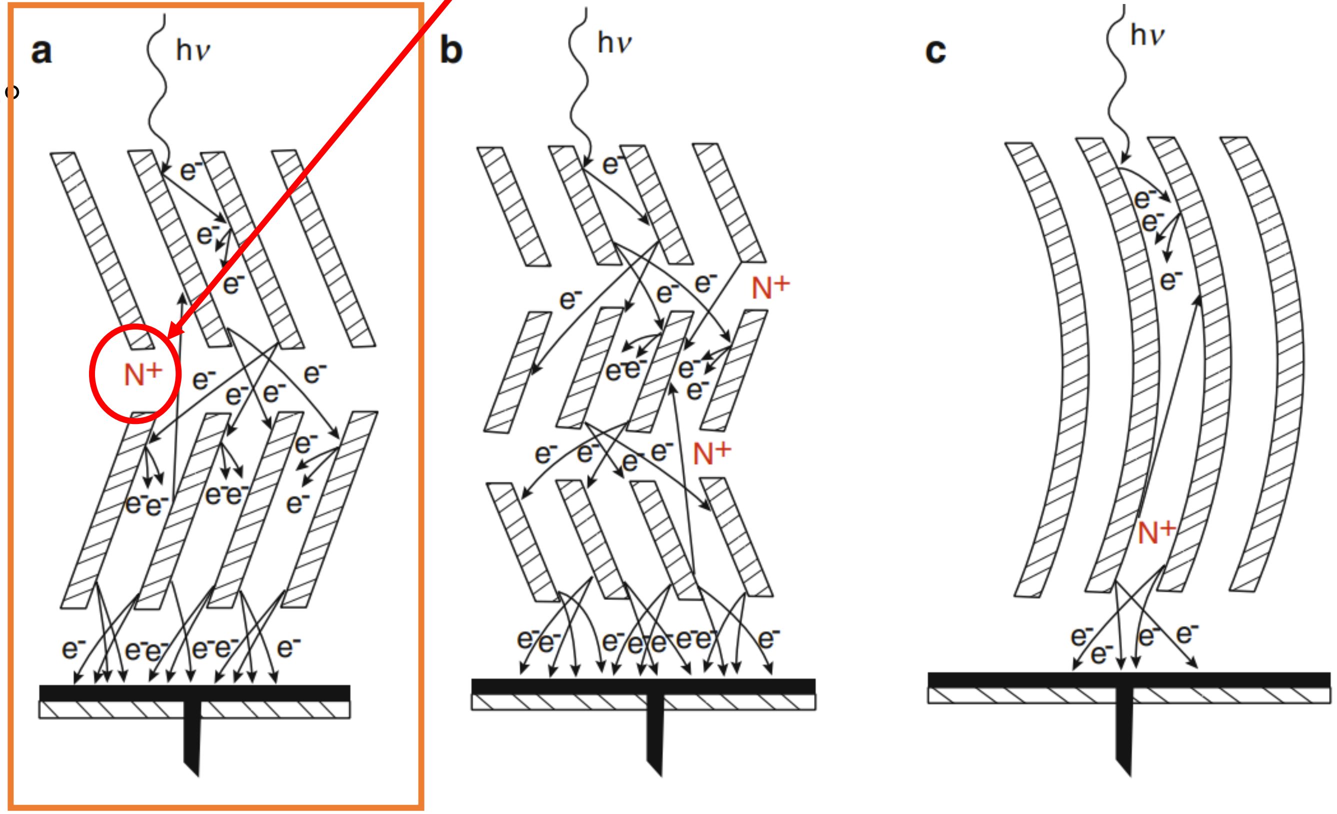
This is not enough for electronics readout systems!

Three types of high-gain MCP configurations are in use:

Chevron MCP Stack

Two layers of straight MCP with a bias angle of about $8° - 10°$

Ions are trapped in the area of the junction



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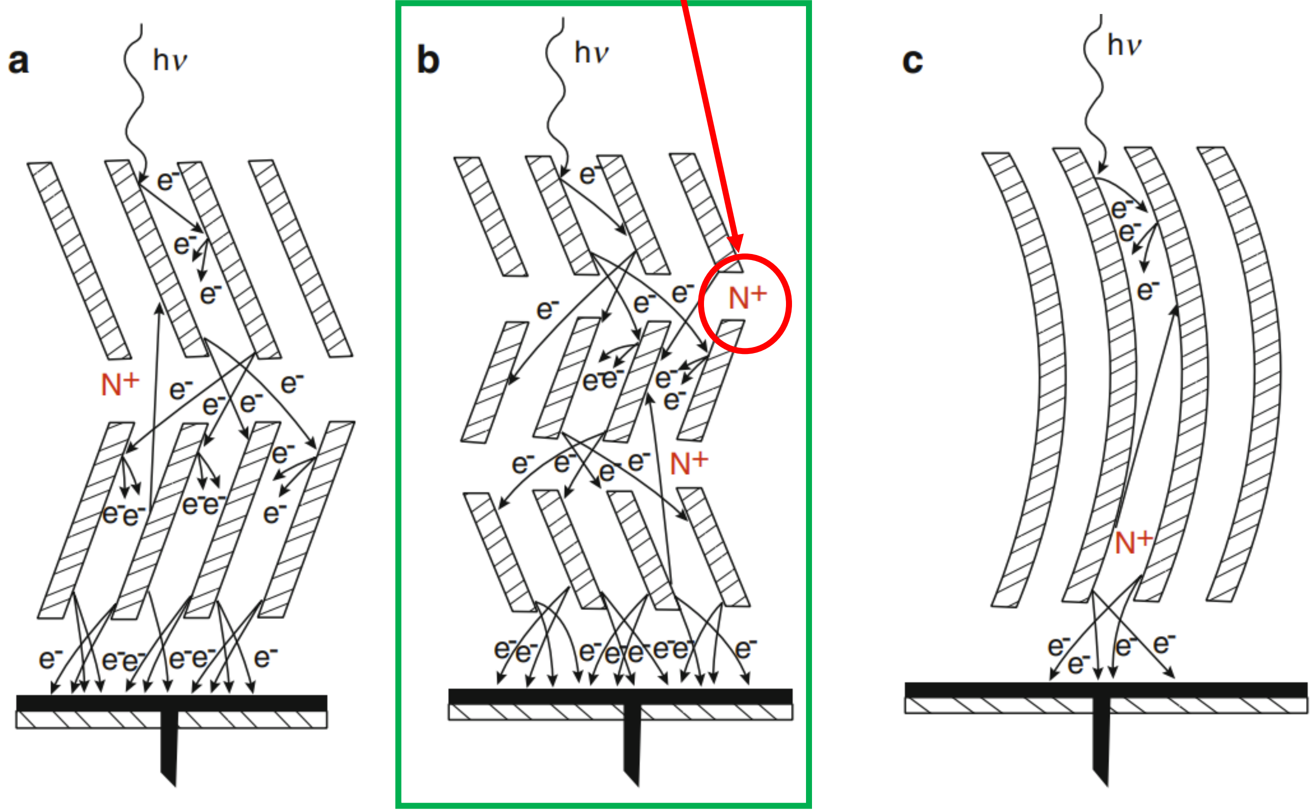
Z-plate MCP Stack

Three layers of straight MCP with matching resistances are mounted
Ions are trapped in the two interfaces



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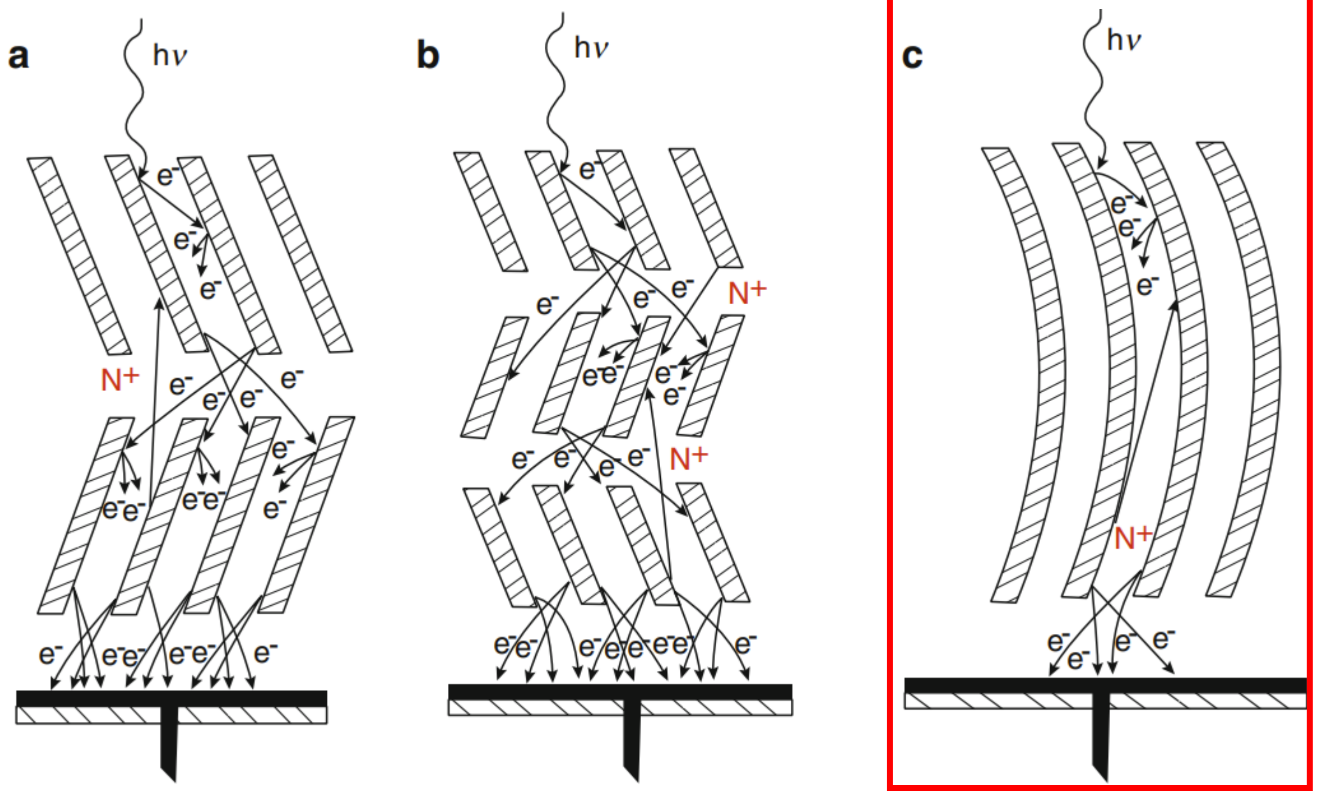
Curved-channel C-Plate MCP
Most stable
Least amount of ion feedback
Least spreading of output electron cloud
Very difficult to manufacture

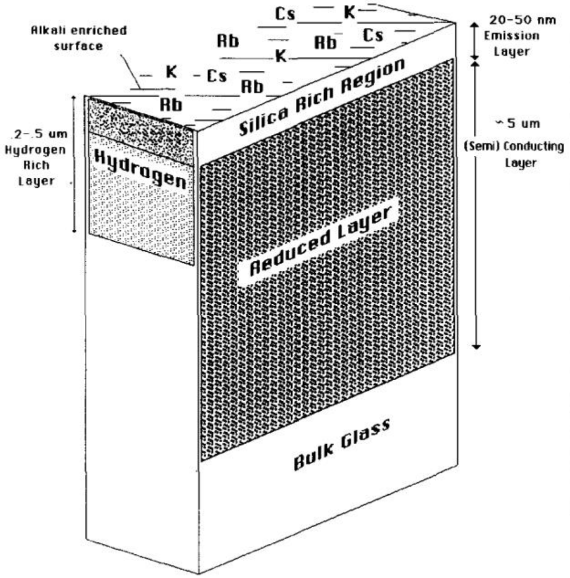


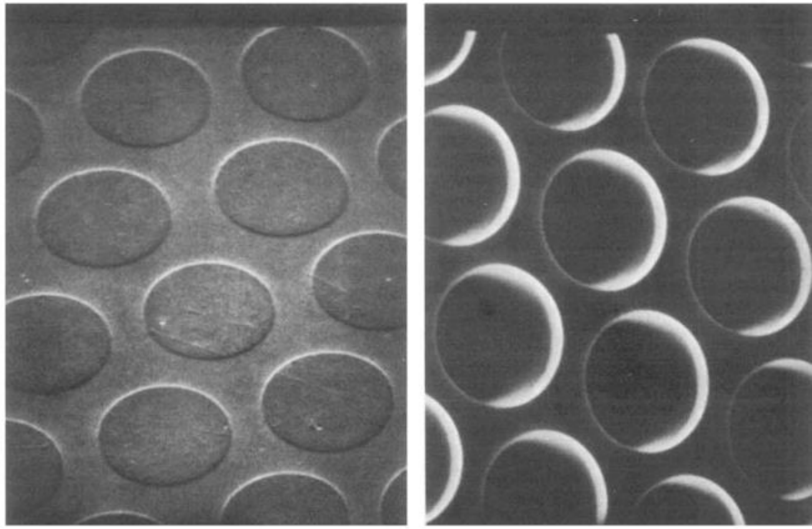
	Chevron	Z-plate	Curved C-Plate
Rel. resolution %	$60 - 120$	$35 - 60$	$35 - 50$
At Gain…	10^7	10^8	10^6

Applications for MCP

Traditional MCP Manufacturing Technique

- Lead glass tubes are filled with glass rods
- The tube collapses around the rod to obtain a **lead glass cladding** and an **inner core glass**
- Fibers are stacked in parallel and stretched together
- Fibers assemblies are fused
- Wafer is cut nearly perpendicular to fibers axis
- **Core glass is etched away** leaving an array of pores
- Reduction in Hydrogen





← Surface Composition Change Versus Microchannel Plate Gain →

Aging

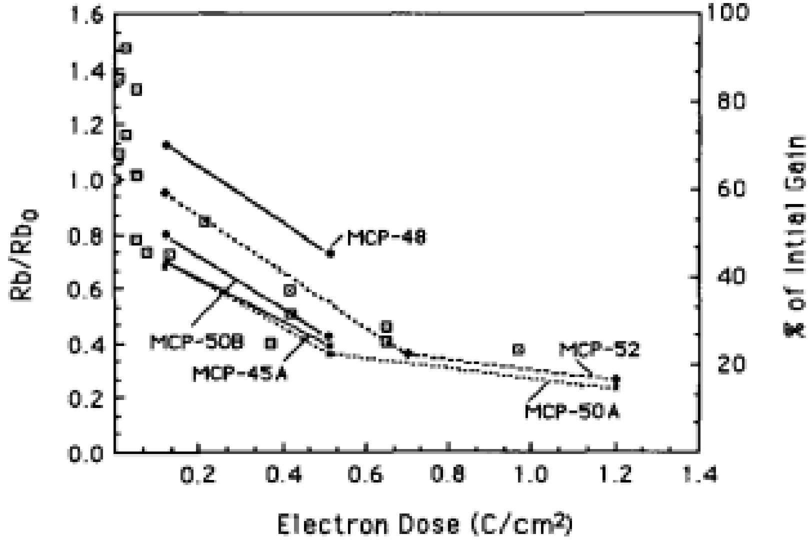
- Reduction in gain and a slow decline over lifetime

Why?

Investigation of surface:

- In the traditional technique, the surface of pores is rich of alkaline metals

After exposure to 500 eV electrons, content of Potassium and Rubidium were reduced

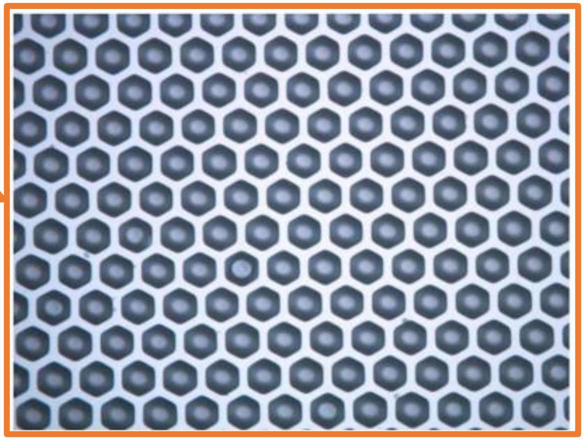


- Potassium is a source of background due to natural radioactivity

Applications for MCP

Recent progesses (2010s) have been made to improve MCP gain and performances by:
Functionalizing conventional non-activated MCPs with thin films

How to develop large area and economical MCPs?
Convergence of two innovations:
- **Production of large blocks of micro-capillary arrays:**
  Hollow borosilicate capillaries
- **Atomic Layer Deposition (ALD)**

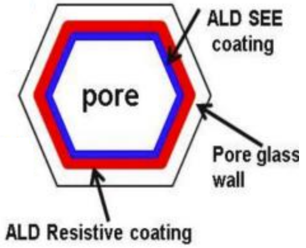


✓ **Elimination on any upper limit on L/d**

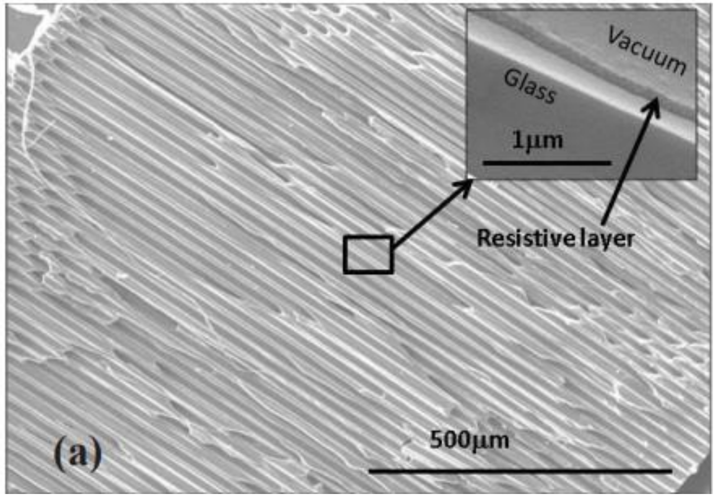
✓ **Open area ratio up to 74%**

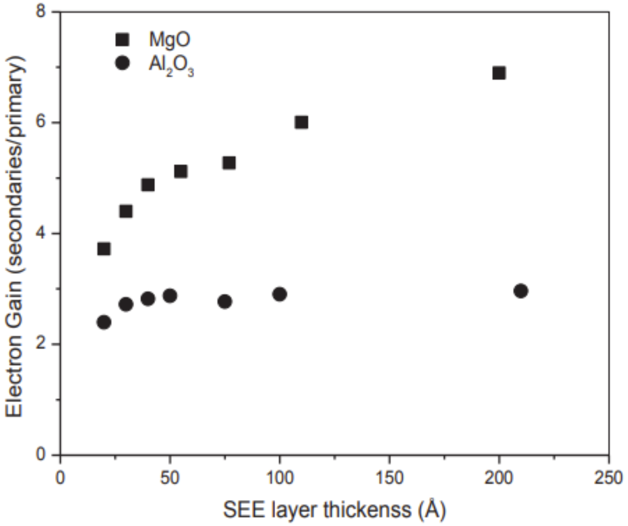
✓ **Borosilicate glass: low radioactivity**

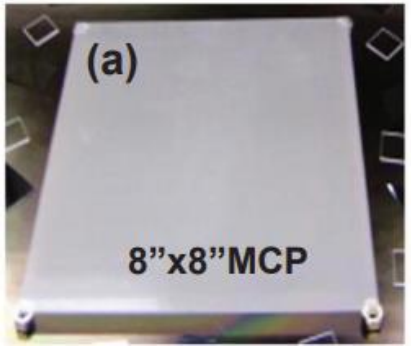
✓ **Larger Resistivity: Lower Operational Voltage**

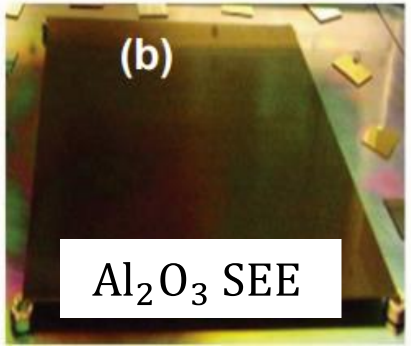


Schematic of ALD MCP

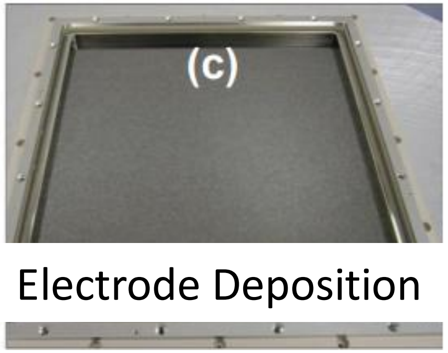








Al_2O_3 SEE



Electrode Deposition

An example: Large-Area Picosecond PhotoDetector (LAPPD)

The idea of the project is to develop a **large-area photodetector** with:

- **Time resolution** of the order of picoseconds
- **Spatial resolution** in sub-millimeter region

Why?

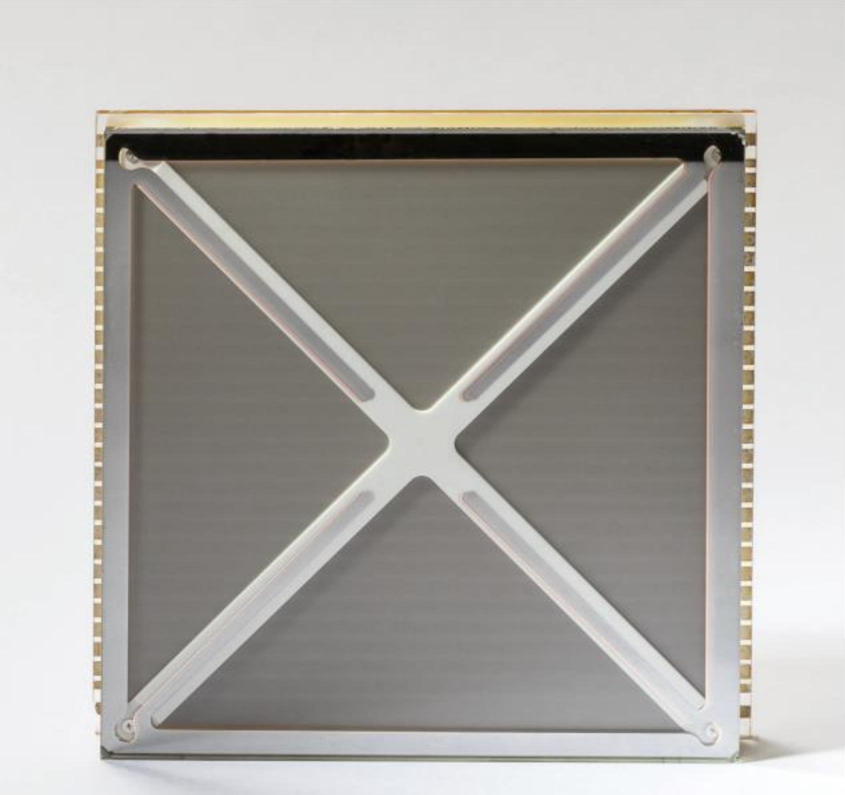
- **Extract all measurable information (4-vector)** from particle collisions
- **(Cost savings** respect to cover large areas)

Applications

- **High Energy Physics**
- Nuclear Physics
- Medical Imaging

As an example LAPPD are considered as an option in ElectroMagnetic Calorimeter of LHCb Upgrade 2:

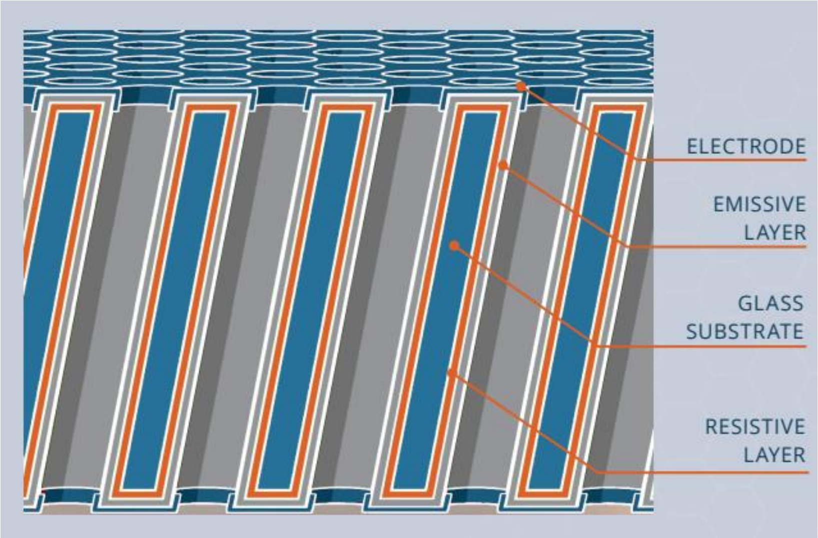
- Detection of EM showers by ionization inside MCP wafers
- Excellent timing resolution for avoiding pile-up

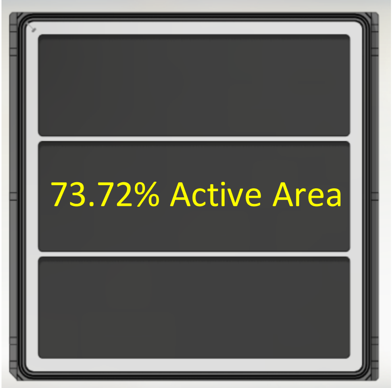


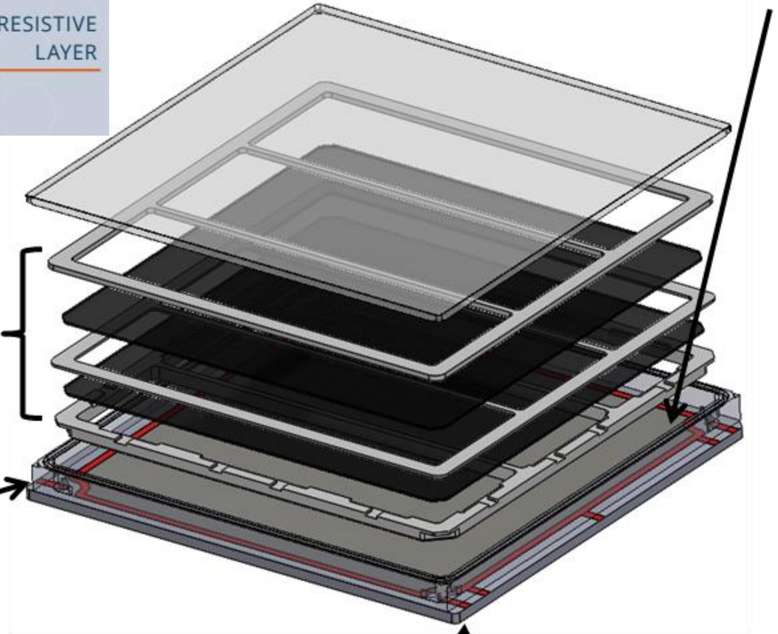
20cm x 20cm LAPPD square

LAPPD Overview

- **20cm x 20cm MCP-PMT**
  Chevron pair of MCPs (10-20μm)
- About 370 cm^2 **effective area** ($\sim 74\%$)
  High Gain ($\sim 10^7$)
- **Time Resolution**
  Single Photo-Electron: ~ 50 ps
  150 GeV induced EM shower: ~ 8 ps
- **Position Resolution**
  $O(\text{mm})$
- **Magnetic Field Tolerance**
  ~ 1.4 T



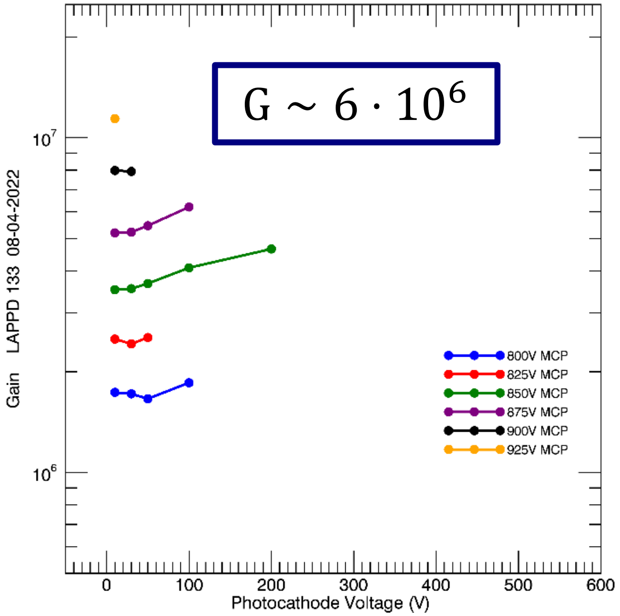


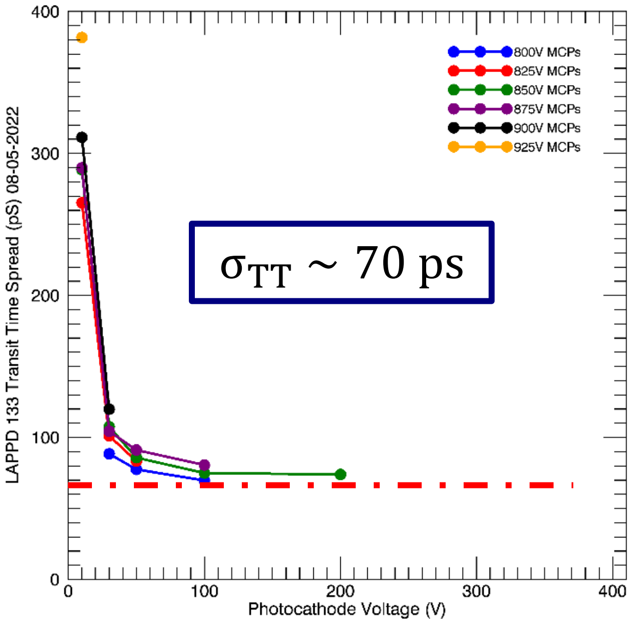


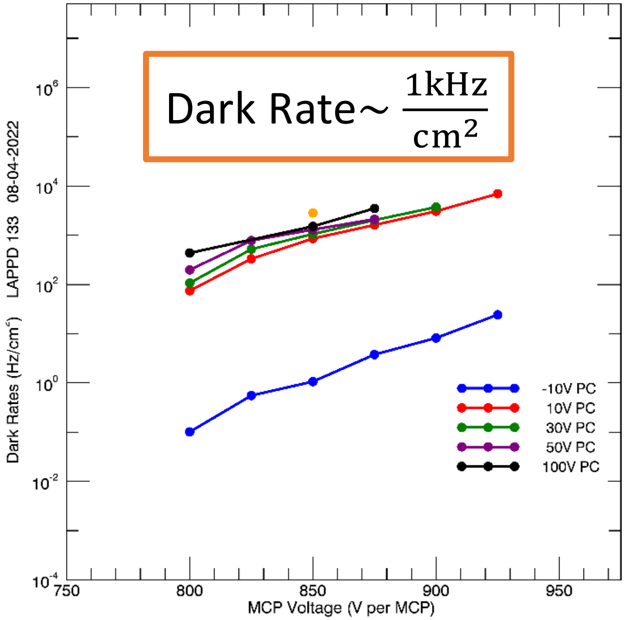
LAPPD Performances

Performances of LAPPD depends on the operating regime of its components:

- **Photocathode Voltage**
- **MCP Voltage**

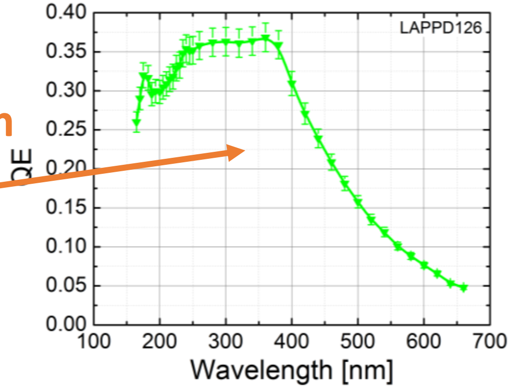


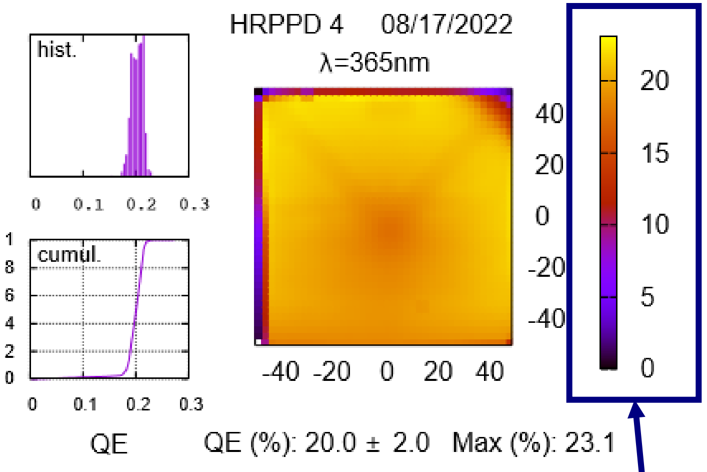


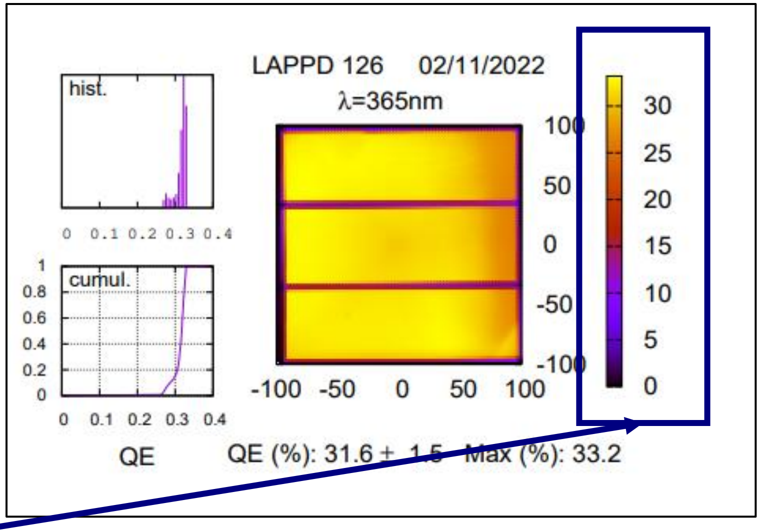


The performances of cathodes for two different LAPPDs are reported

Change in **Quantum Efficiency** over wavelength







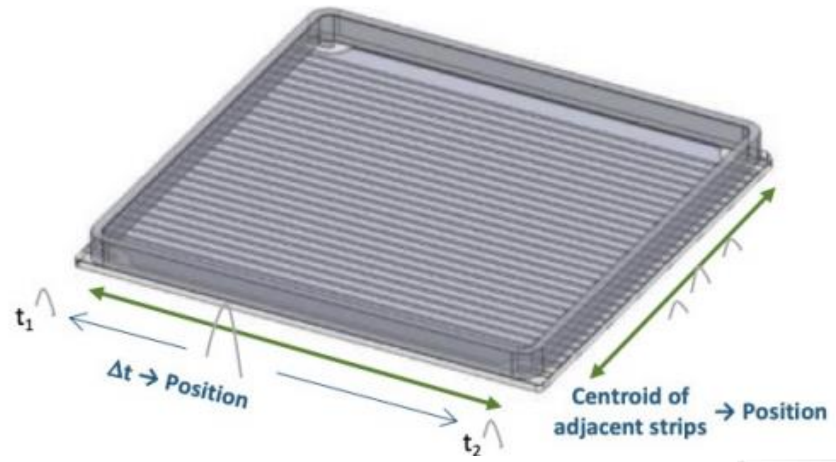
Due to large area, a typical **problem** is the **uniformity of overall response** of many channels

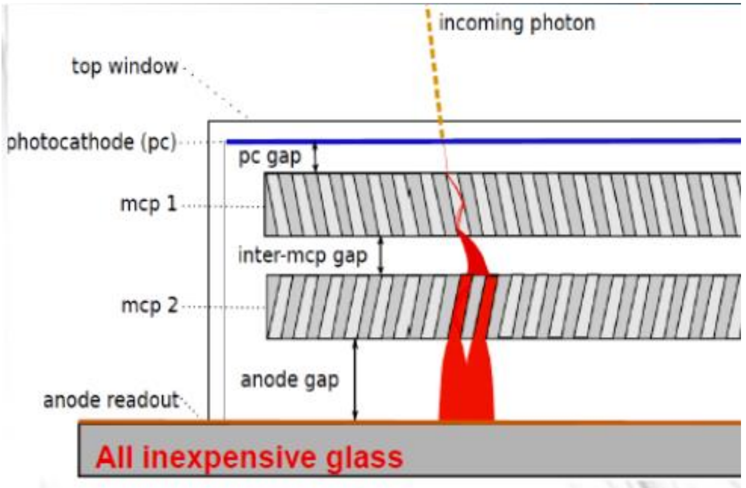
LAPPD Overview

Two generations of LAPPD:

- **Generation I**

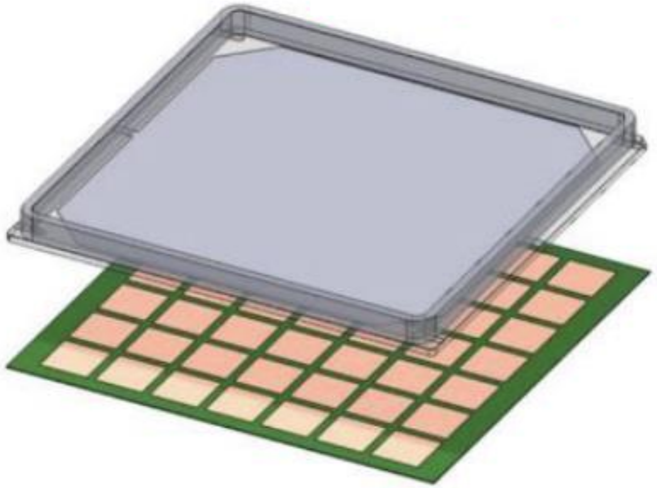
Direct read-out with strip-line anode with ~1 mm spatial resolution





- **Generation II**

Resistive interior anode with capacitively coupled external anode PCB with customizable pixel pattern

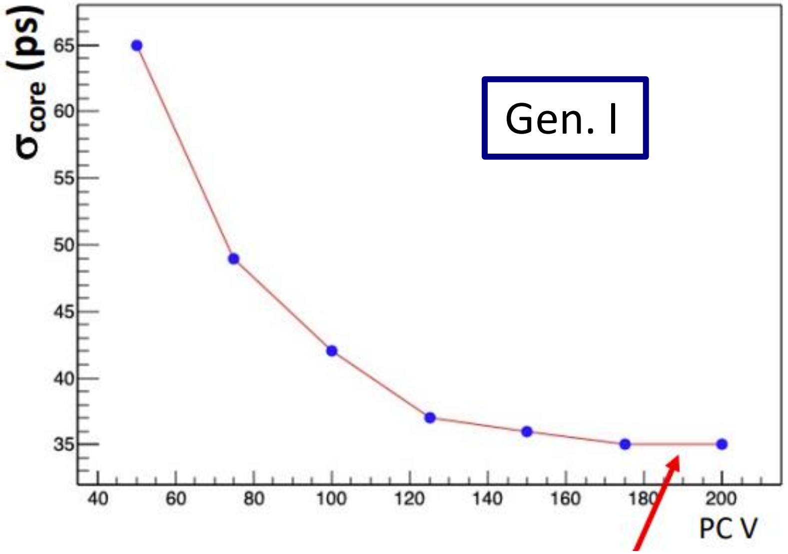


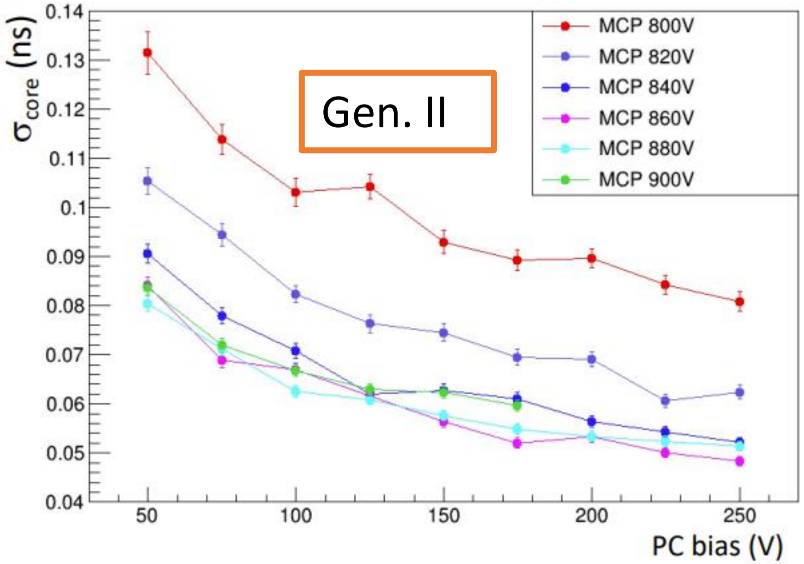
More suitable for high occupancy environment

LAPPD properties characterization

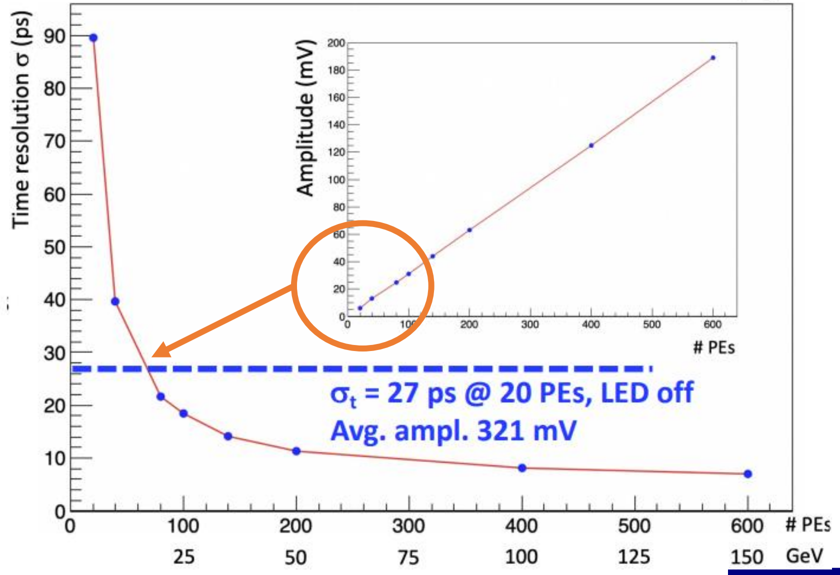
A comparison between generation I and II of LAPPDs has been made

Resolution for a **single photo-electron** response



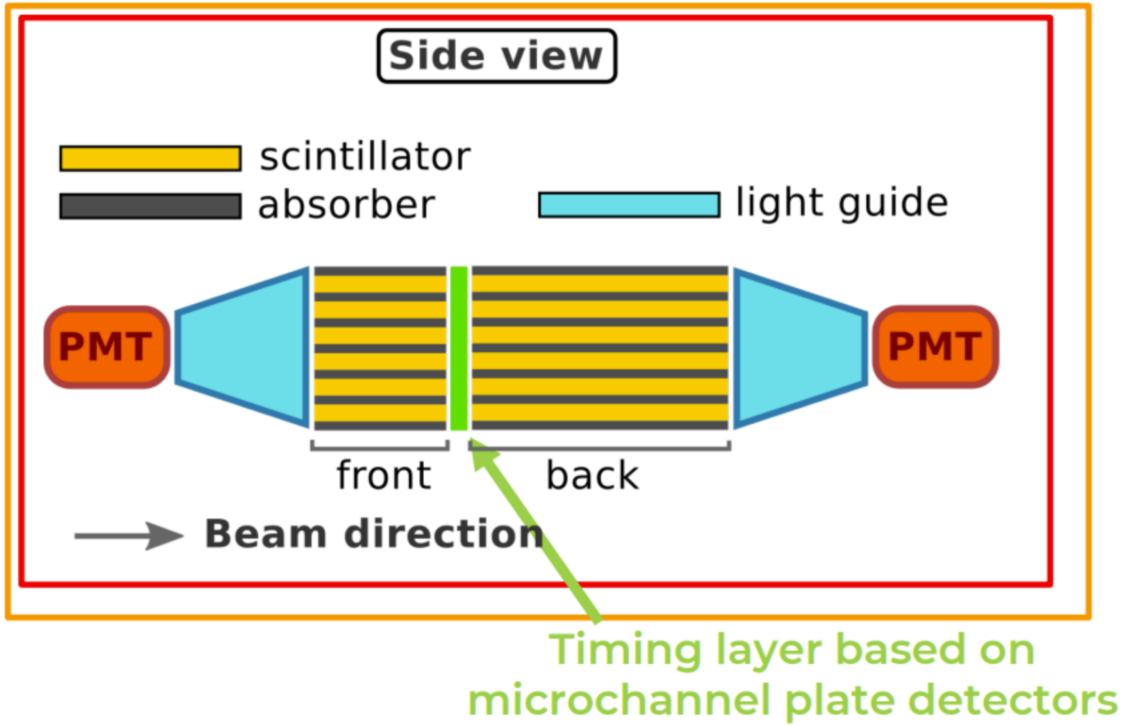


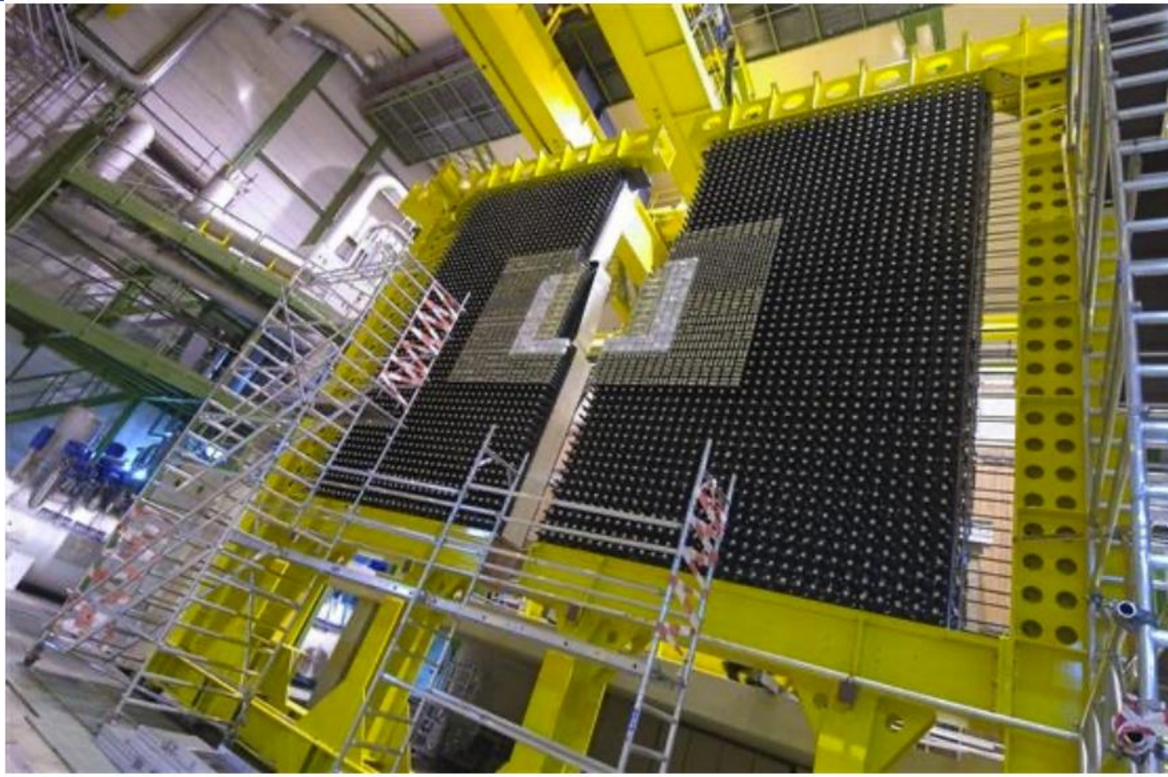
Expected results in a **realistic environment** similar to LHCb ECal

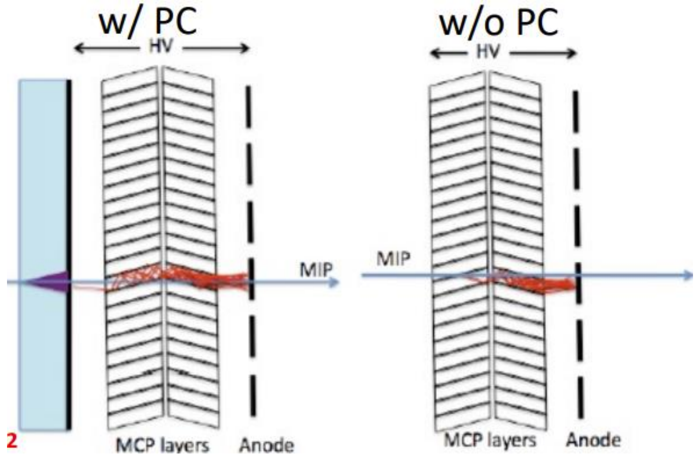


Application to LHCb EM Calorimeter Upgrade

Addition of LAPPD based photo-detectors will introduce a timing component on particle detection





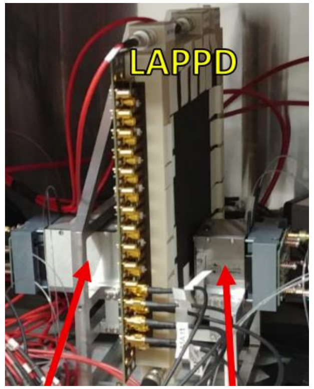


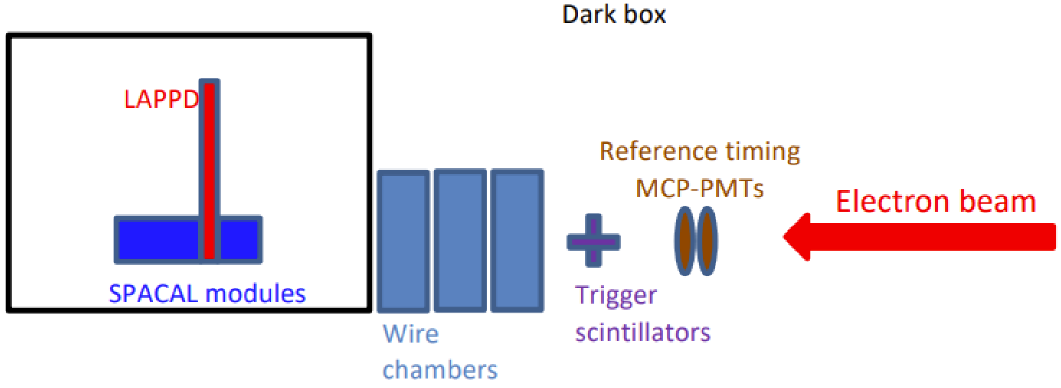
Thin detector based on MCP-PMT between two sections of double readout sampling calorimeter split at shower maximum

But need to withstand emitted charges up to hundreds of C/cm^2

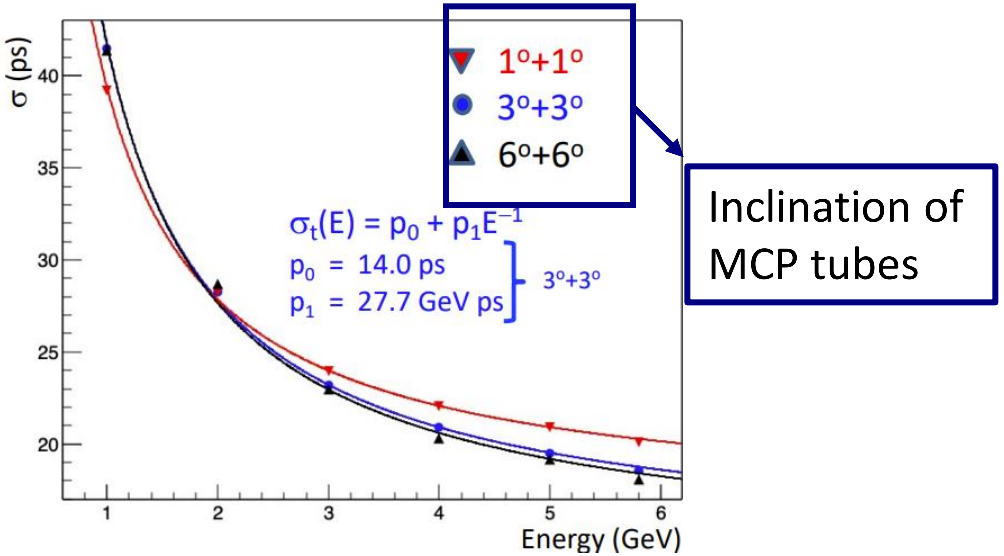
LAPPD properties characterization

LAPPDs have been tested in several test beams, to simulate ECAL working conditions

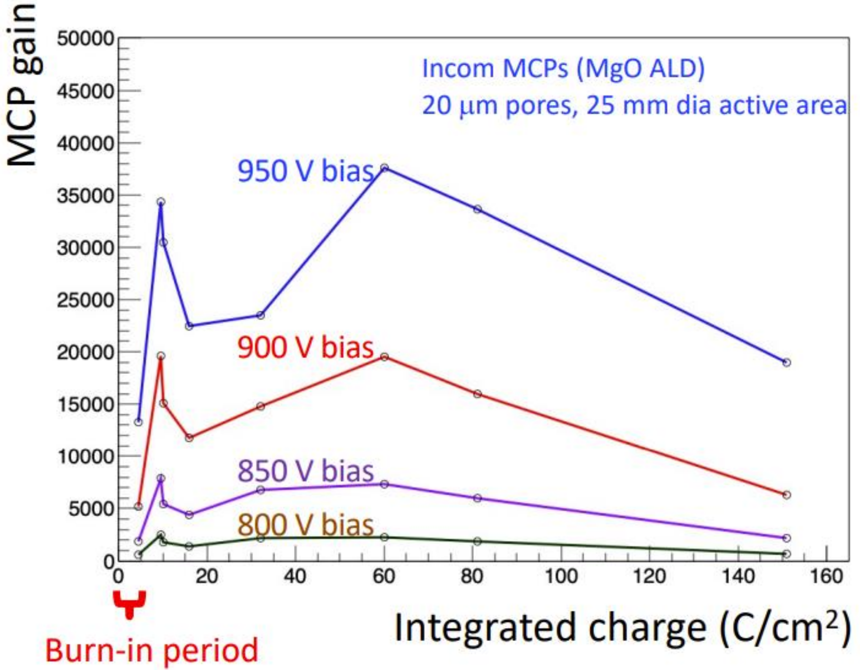




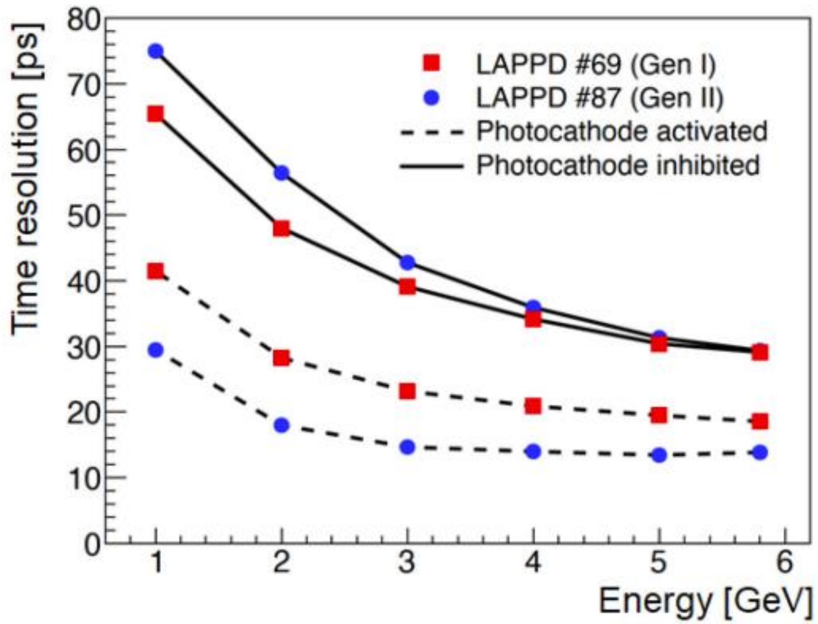
Time resolution of Generation I and II LAPPDs



LAPPDs have to withstand a large number of incoming particles…



$\sim 10^{21}$ electrons!



Conclusions

1. Multi-Channel Plates are a technology developed since the second half of 20th century

2. They are a multi purpose detector with applications to many fields:
- The presentation was focused on MCP applied to Photo Detection in High Energy Physics

3. The production technique improved in the last decades thanks to Atomic Layer Deposition

4. A smaller production cost allowed to large area coverage (e.g. LAPPD)

5. LAPPD are at the same time in production and in a phase of development and testing

6. Application of LAPPD to new experiments is under examination