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INFN BOLOGNA

Feasibility studies of LAPPD as a timing layer for the Upgrade-2 of LHCb calorimeter

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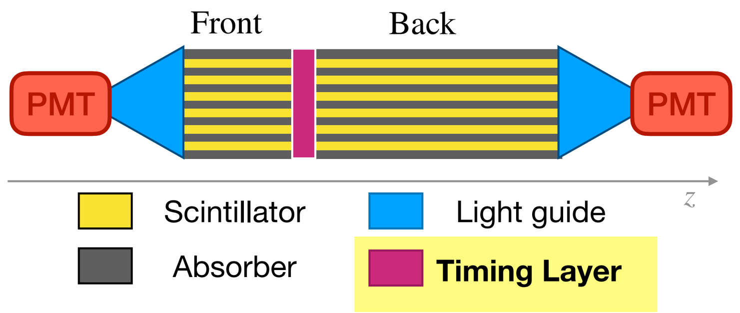
on behalf of the LHCb PicoCal group

INTRODUCTION

The LHCb experiment will undergo a major upgrade in early 2030s to operate with an instantaneous luminosity a factor seven higher than the current one. The electromagnetic calorimeter will be completely redesigned to keep the current performance at a much higher occupancy and radiation background. One of the key feature of the upgraded calorimeter, also known as PicoCal, is a time resolution below 20 ps, that is essential to separate the primary proton-proton collisions and mitigate the increased pileup. To achieve this goal, one of the possibilities is to install a dedicated timing layer in the middle of the longitudinally segmented calorimeter.

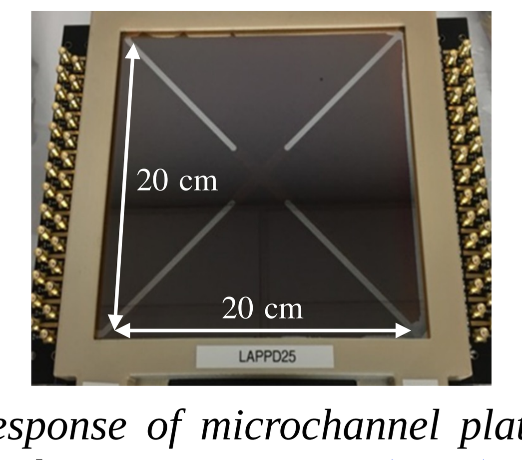
Side view of PicoCal cell



Such a timing layer can be based on microchannel plates (MCP) — intrinsically very fast electron multipliers which can directly detect the charged component of an electromagnetic shower (see [1] and refs therein).

The «Large Area Picosecond PhotoDetector» (LAPPD) produced by «Incom» (USA) is the largest and potentially inexpensive microchannel plate device. We tested LAPPD as a promising candidate to constitute the timing layer of PicoCal.

LAPPD

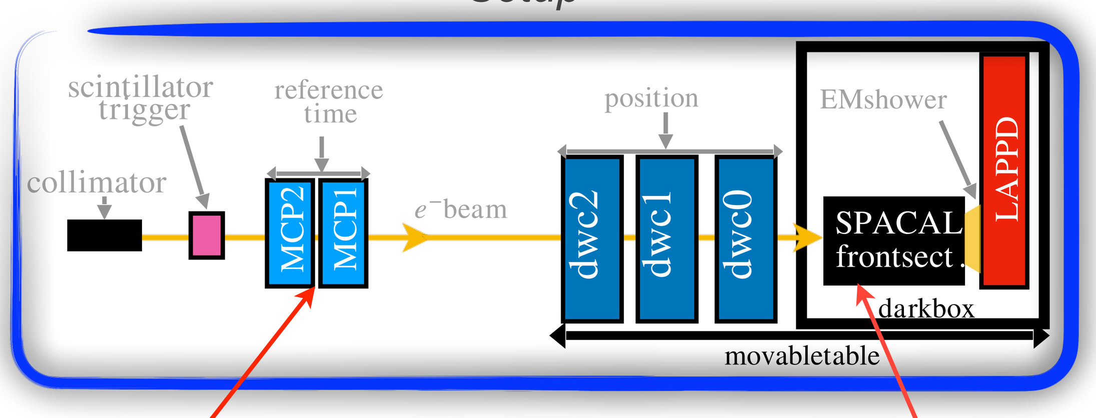


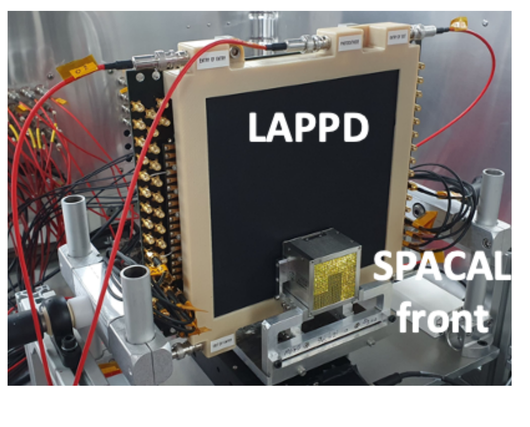
[1] A. Yu. Barnyakov et al., *Response of microchannel plates in ionization mode to single particles and electromagnetic showers*, NIM A879 (2018) 6

BEAM TESTS RESULTS

An LAPPD sample with 3 MCPs with ⌀10 μm pores and 2.5×2.5 cm² anode pixels has been tested with electron beams at DESY and CERN SPS.

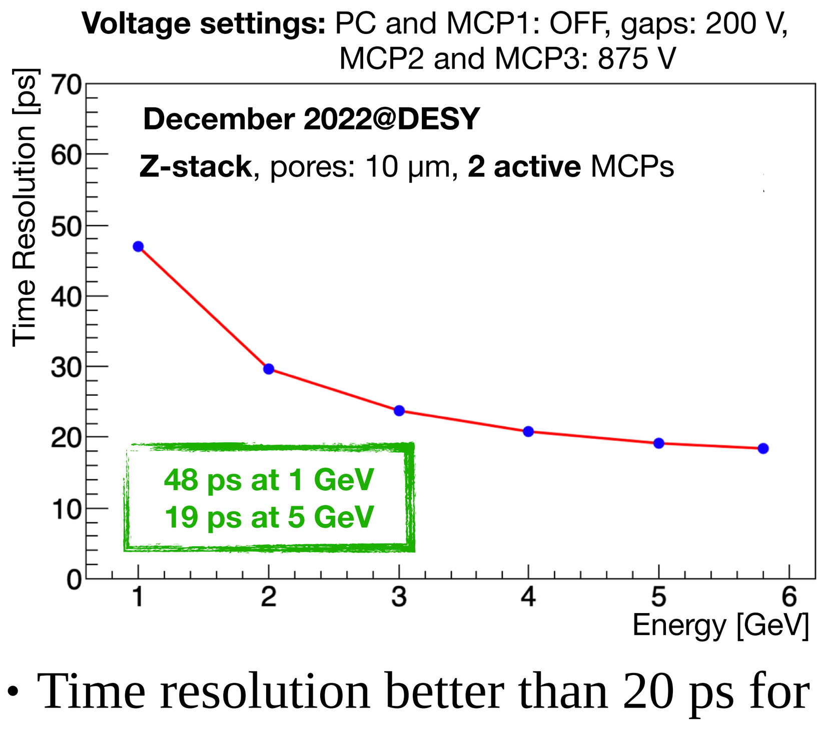
Setup

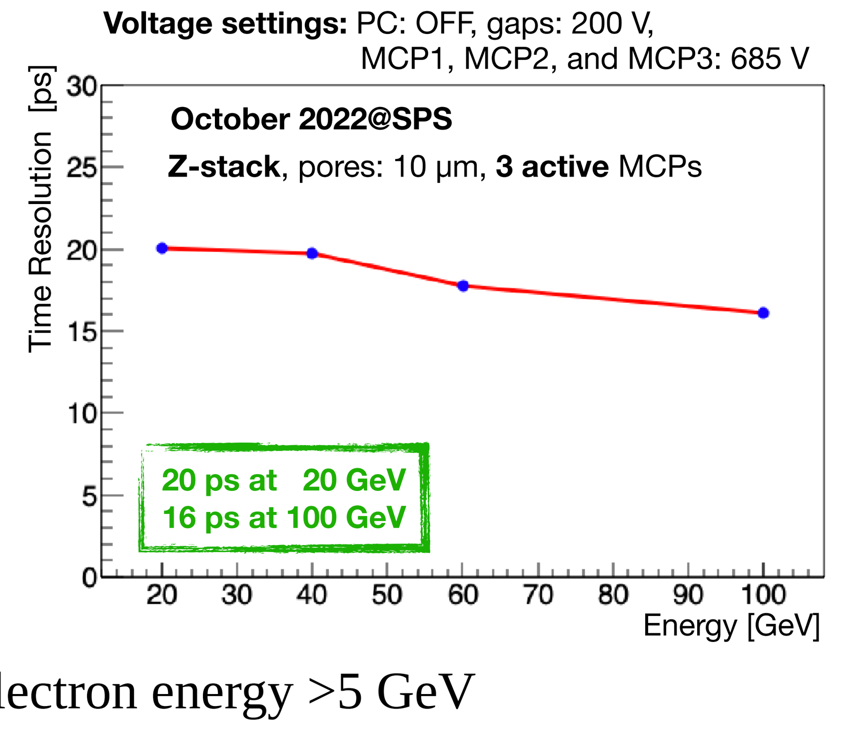




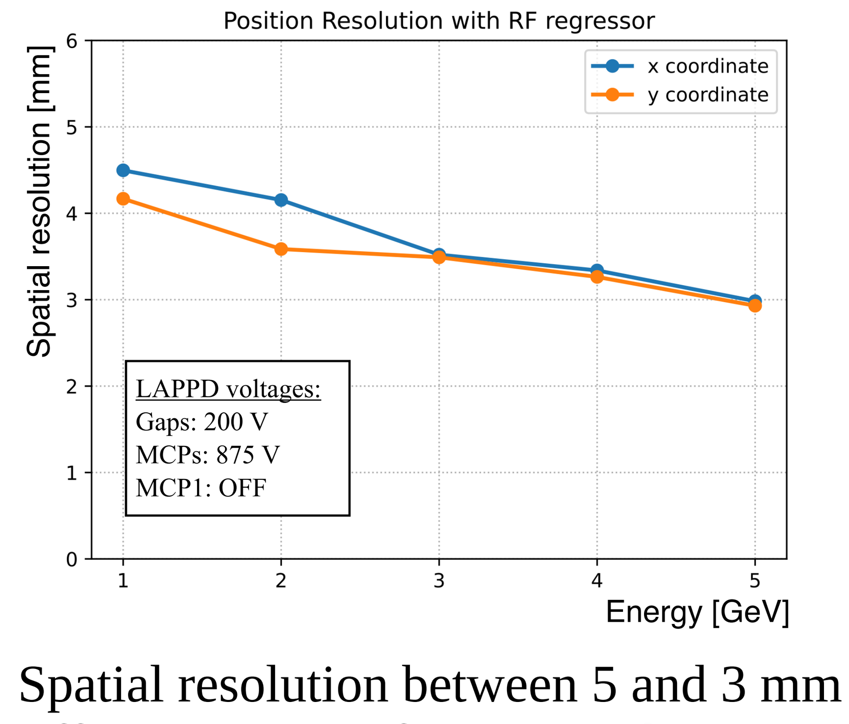
Two MCP-PMTs: $\sigma_t \sim 12$ ps — ~7 X_0 in front of LAPPD

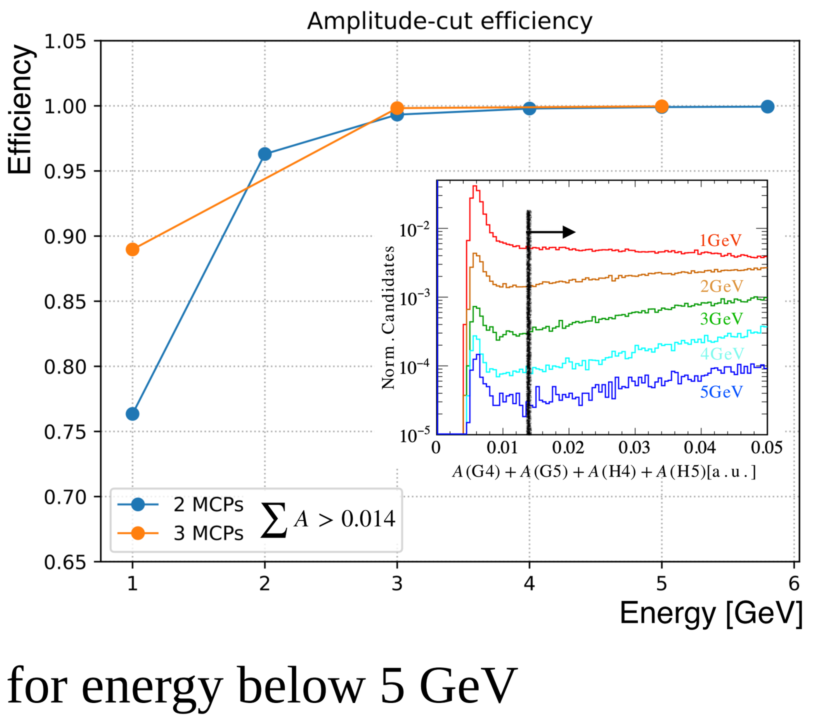
- The photocathode of LAPPD was switched off by applying reverse voltage
- Four LAPPD pixels were instrumented
- Signals were read-out with CAEN V1742 digitizer (5 GS/s)
- Data from 4 pixels was combined with a Random Forest Regressor algorithm





- Time resolution better than 20 ps for electron energy >5 GeV



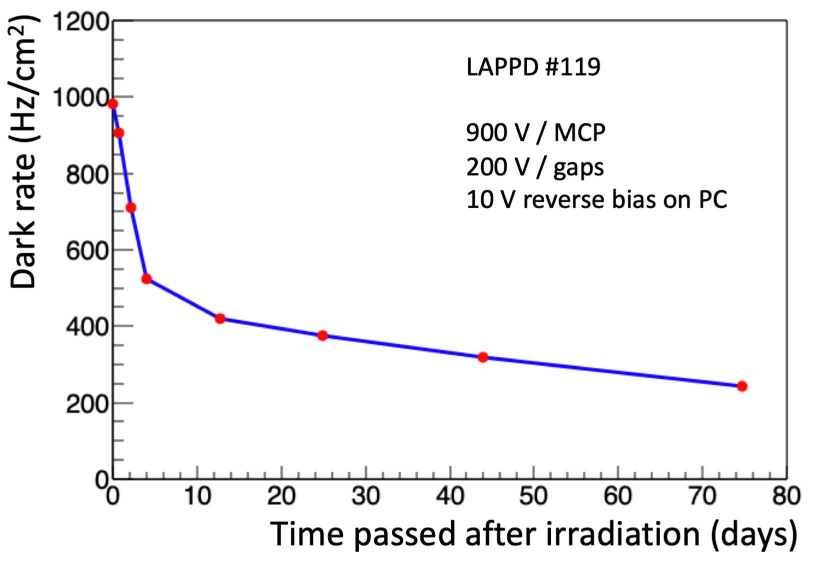


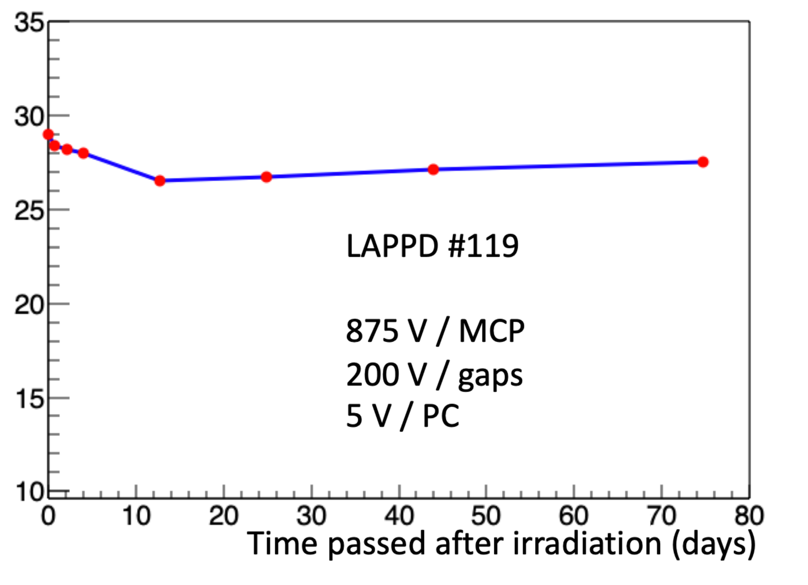
- Spatial resolution between 5 and 3 mm for energy below 5 GeV
- Efficiency >99% for energy above 3 GeV

MCP RADIATION HARDNESS

The particles fluence up to 6x10¹⁵ neq/cm² is expected in the innermost parts of the PicoCal. The gain and the dark rate of MCP were tested after irradiation of a LAPPD sample at CERN IRRAD facility.

- LAPPD with 10 μm pore diameter MCPs
- Irradiated area of about 2 cm in diameter
- 10¹⁶ protons integrated in ~1 week, that corresponds to ~5x10¹⁵ neq/cm²
- HV on MCPs was turned on during irradiation





- The dark rate increased by two orders of magnitude after irradiation (initial dark rate was ~10 Hz/cm²) and then decreased in 4 times during 75 days
- Only minor variation of the gain was observed

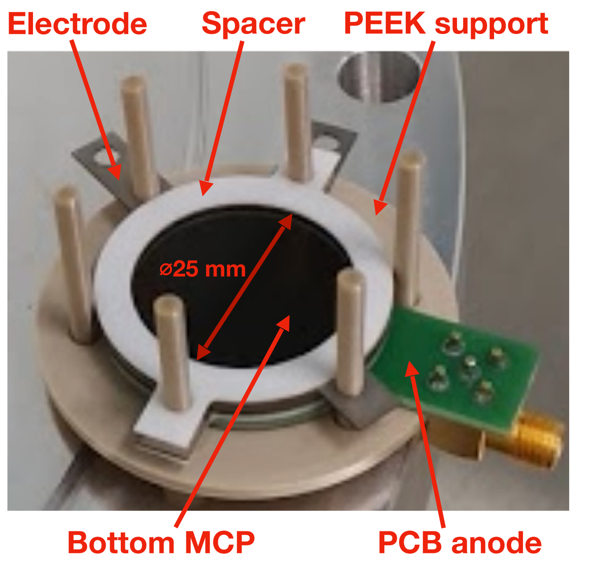
MCP AGEING

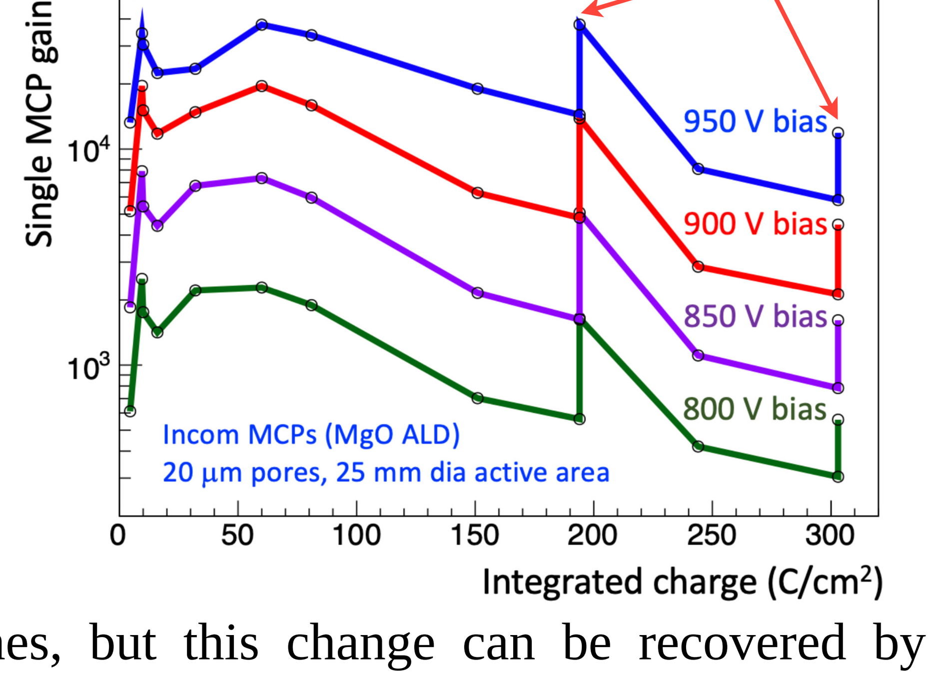
To check the MCP ageing a Chevron stack of two round MCPs was placed in a vacuum chamber and illuminated by a mercury lamp (λ=185 nm) in order to induce a current through MCPs.

- MCPs with 20 μm pores made by «Incom» using ALD technic (as in LAPPD)
- The output current from MCP stack is ~100 μA
- A total charge of ~300 C/cm² was collected, corresponding to the expectation in the innermost part of the PicoCal

Steps due to the exposure interruptions

Setup view



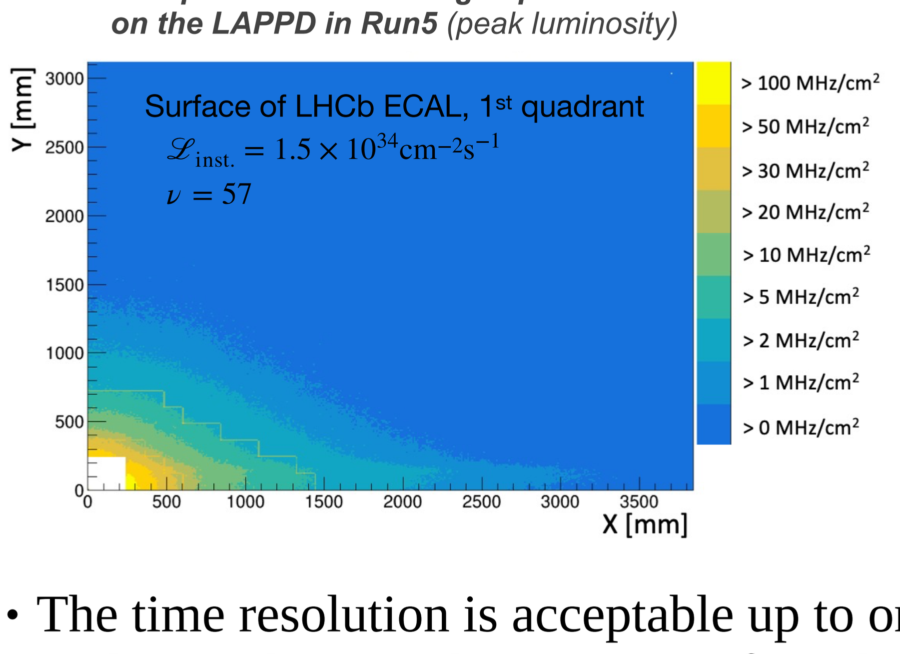


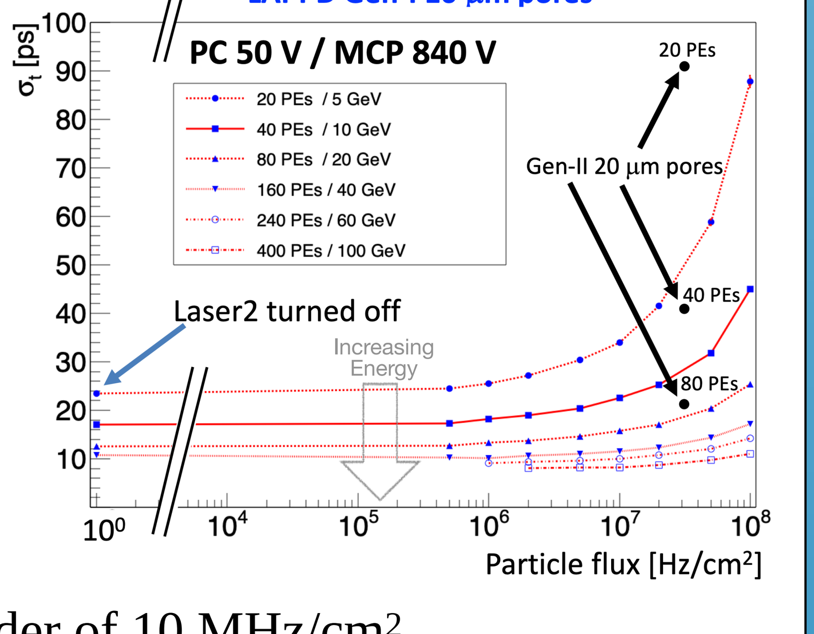
- The gain dropped in several times, but this change can be recovered by moderate voltage increase

MCP RATE CAPABILITY

The particle rate in the hottest region of PicoCal can reach 100 MHz/cm². The MCP rate capability was studied using two defocused laser beams.

- Laser 1: fixed frequency, number of photoelectrons per laser pulse is changed to mimic the electromagnetic showers of different energies
- Laser 2: the pulse power is adjusted to produce 10 photoelectron/cm², frequency is changed to mimic the background of different fluxes
- Light spot of 30 mm diameter
- The LAPPD samples with MCPs of 10 and 20 μm pore diameter were tested





- The time resolution is acceptable up to order of 10 MHz/cm²
- Reducing the pore diameter significantly improves the rate capability
- Further R&D efforts are needed to improve the LAPPD rate capability for its application in the innermost regions of PicoCal

REFERENCES

1. S. Perazzini et al., *Development of an MCP-Based Timing Layer for the LHCb ECAL Upgrade-2*, Instruments 2022, 6, 7
2. M. Barnyakov et al., *Latest feasibility studies of LAPPD as a timing layer for the LHCb Upgrade 2 ECAL*, 2024 JINST 19 C02045