LAPPD R&D studies for the LHCb Upgrade-2 ECAL

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INFN Bologna

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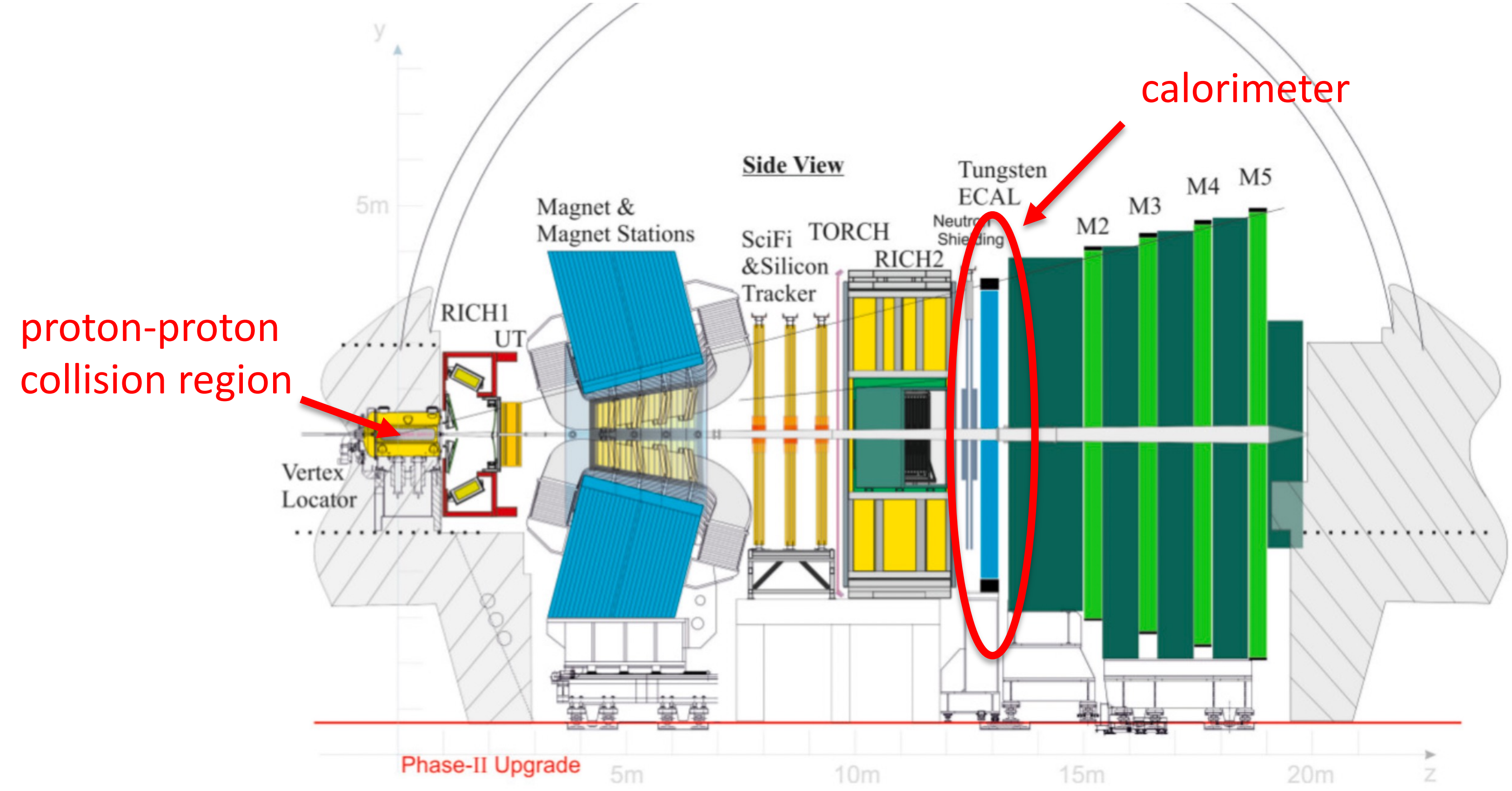
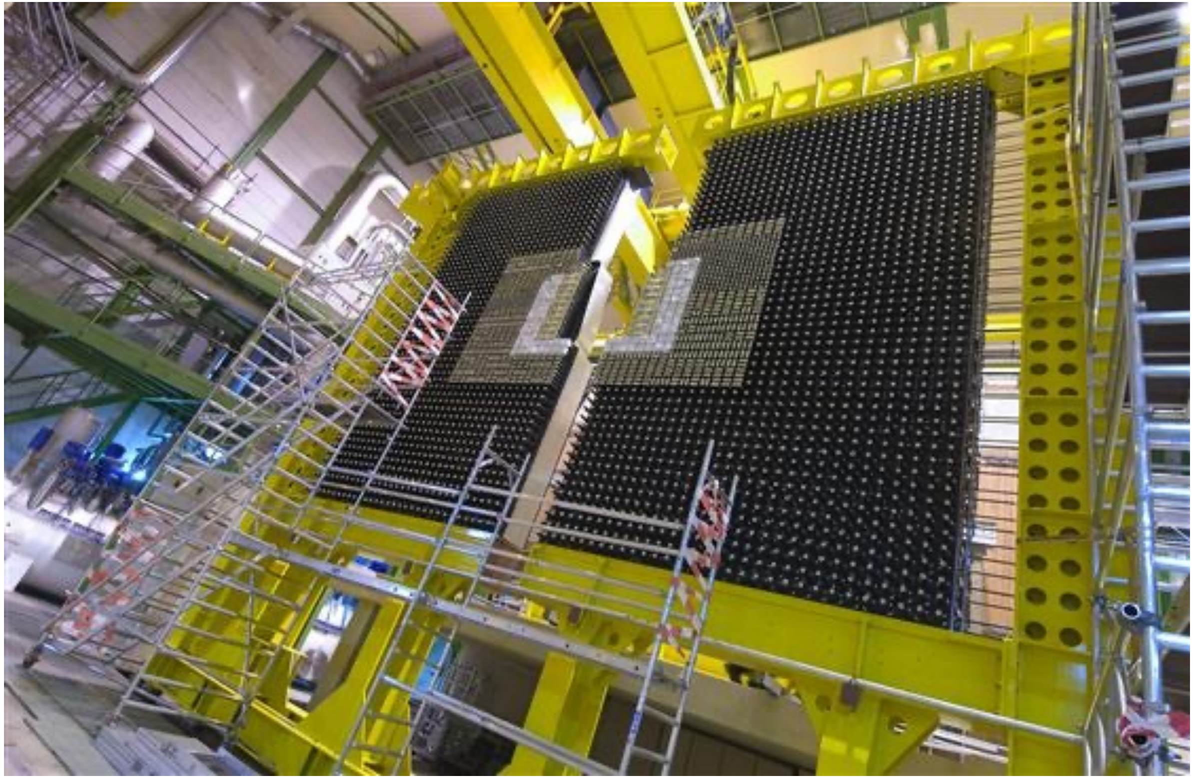
LHCb Upgrade-2 detector



LHCb Upgrade-2 timelines

- Framework Technical Design Report just released
  - http://cds.cern.ch/record/2776420/files/LHCB-TDR-023.pdf
- Will be followed by dedicated sub-detector TDRs in 2025
  - Meanwhile the collaboration is looking for new experimental groups to join the effort!
- Right after the TDRs, the construction phase will start, in order to commence data taking in the early 2030s

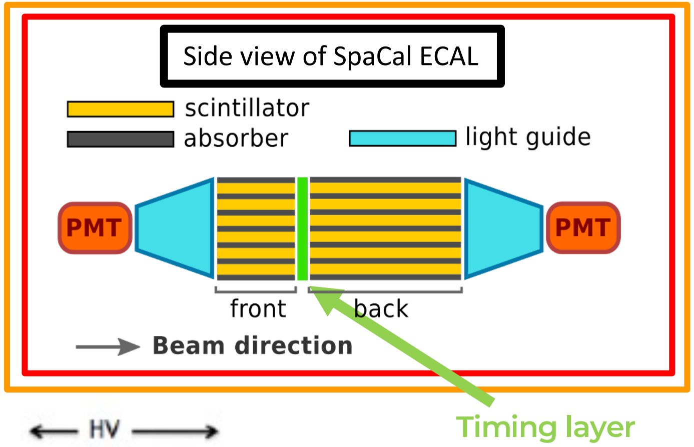
LHCb calorimeter

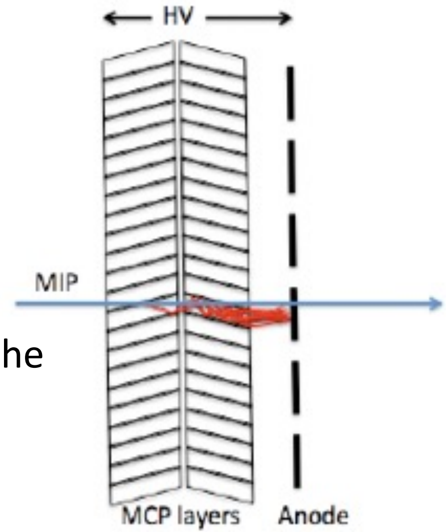


- Large area planar detector
  - ~50 m^2
- Far outside dipole magnet
  - No need to take care of sensitivity to magnetic field

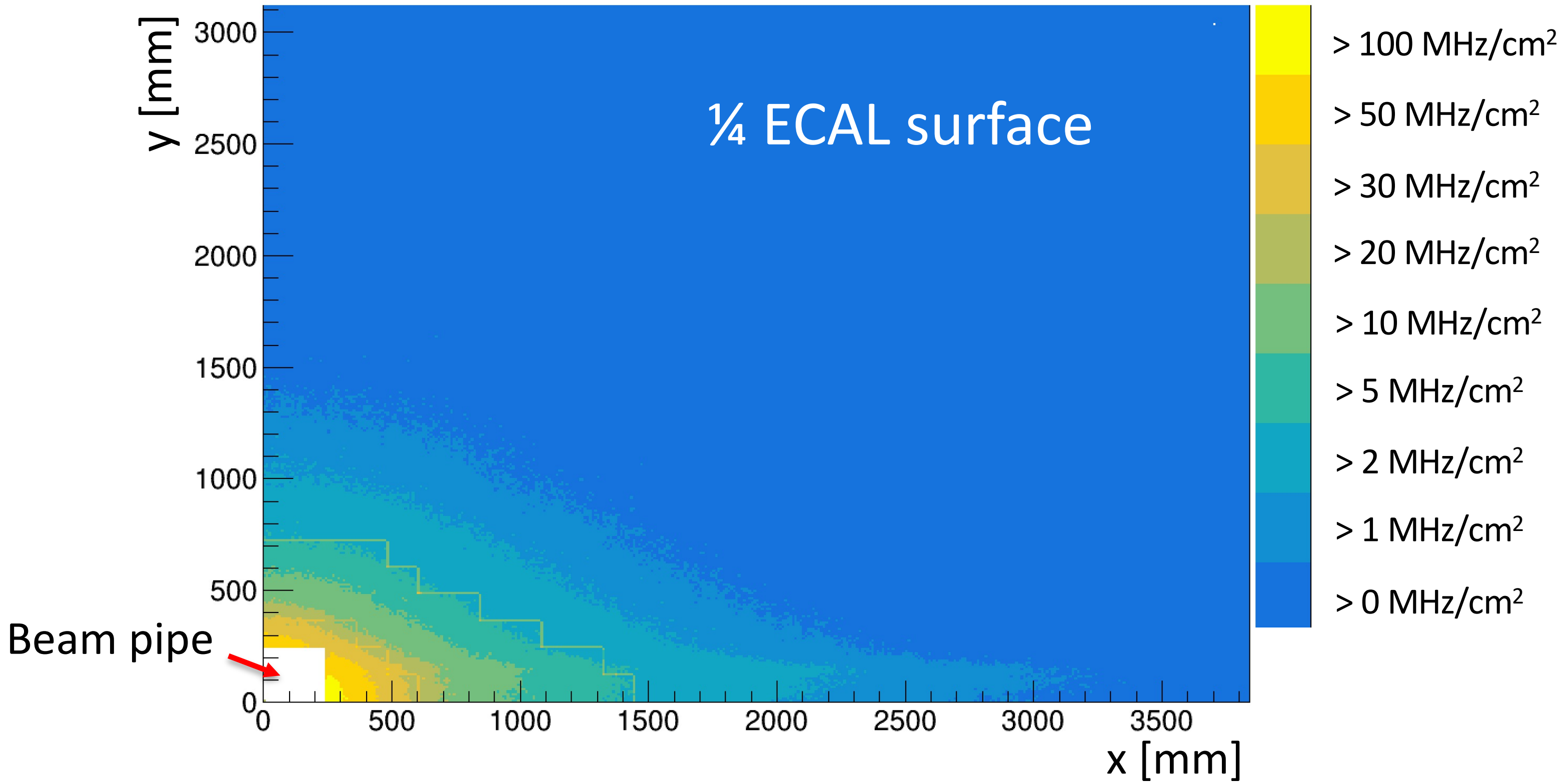
A timing layer for the LHCb Upgrade-2 ECAL

- The LHCb Upgrade-2 will operate in a very harsh environment
  - Instantaneous luminosity of proton-proton collisions up to 1.5 x 10^{34} $cm^{-2}s^{-1}$
  - High background in most central region
  - Measuring time of hits will be crucial to resolve pileup
    - Simulations indicate a time resolution of O(10-20) ps as necessary
- Insert a LAPPD-based detector between two sections of a sampling calorimeter
  - Detect charged component of EM showers by direct ionization within MCP wafers (no photocathode)
  - Exploit excellent time resolution of MCPs to determine the time of EM shower with O(10-20) ps precision





Expected occupancy



- In the most inner region the timing layer should sustain a rate of incoming particles up to O(100) MHz/cm^2
- The rate decreases widely at larger distance from the beam pipe

Form factor, pixelation, spatial resolution

- Segmentation needs to be matched with ECAL modules
  - In the current prototype design, they are about 10 cm in side
- EM showers are O(1) cm in transversal size
  - Pixel size needed at the same order of magnitude
- In any case, need to match the geometry of ECAL cells
  - ECAL cells are O(1) cm in side in the highest occupancy region, but get larger (up to 10 cm) in the region farther from the beam pipe
  - But LAPPD pixels will have to stay within O(1) cm to achieve design time resolution
    - Electronics should be able to limit the number of LAPPD output channels by aggregating multiple pixels in the outer regions
- Spatial resolution is not an issue in itself, provided that matching between ECAL cells and LAPPD pixels is made

Readout and electronics

- Gen I with stripline anode is not an option, at least for the most inner parts, as pileup would be an issue
  - However, it could be an option for the outer regions with lower occupancy
- Capacitively coupled LAPPDs would be much preferred, allowing for a more robust production as well as more flexibility for better customization across the ECAL surface
- Electronics is still behind
  - The ECAL R&D group is envisioning a system based on SCAs for waveform readout, but other solutions can be explored

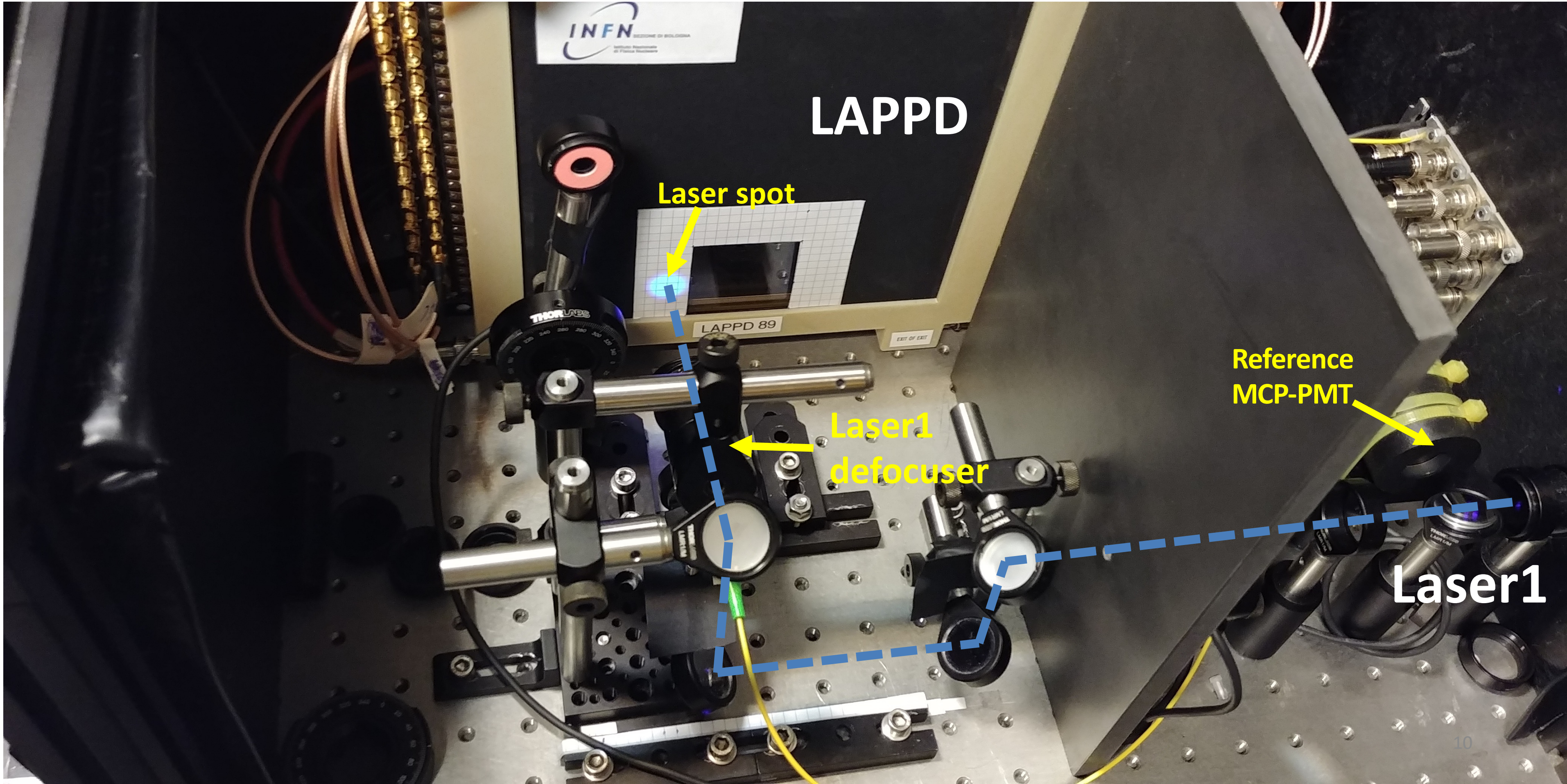
Tests made so far

- Three LAPPDs have been tested
  - Gen-I and Gen-II with 20 μm pore size
  - Gen-I with 10 μm pore size
- Which tests
  - Measurements with picosecond lasers in Bologna
  - Measurements with 1-6 GeV electrons at DESY
  - Measurements with 20-100 GeV electrons at CERN SPS
- In addition, lifetime studies with MCP wafers in vacuum chamber are being conducted
- Focusing in the following only on a few selected results

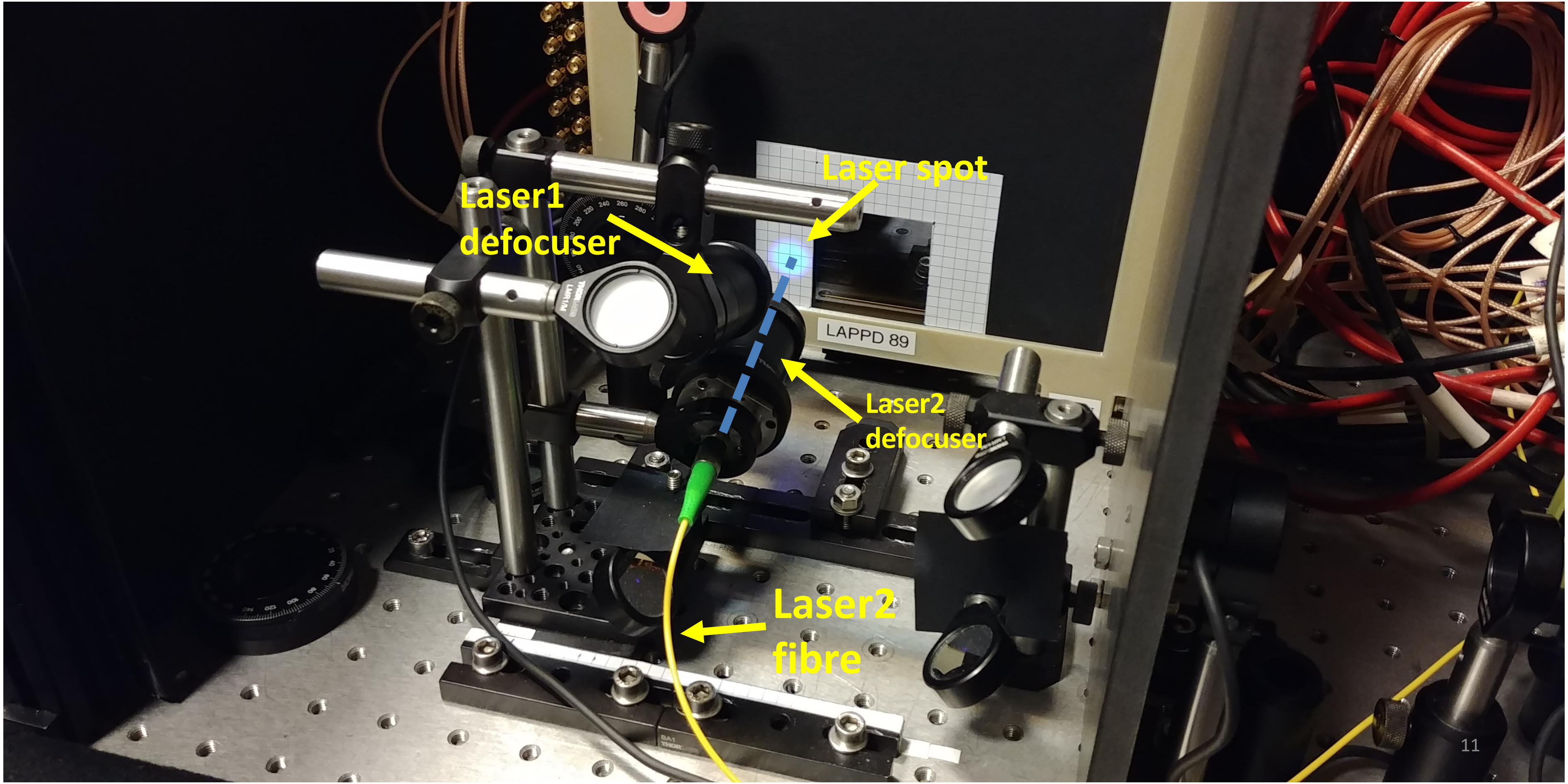
Mimicking high-occupancy environment

- We want to mimic particle flux expected at LHCb in the laboratory
  - Each charged particle entering the LAPPD is assumed to produce order of one cascade-initiating electron with the PC inhibited (to first order this is probably not far from reality, but needs further understanding)
- A first laser (Laser1) is used to mimic signal electromagnetic showers
  - Defocused beam (Ø = 15 mm)
  - Pulse power tuned to mimic electromagnetic showers with different energies (e.g., according to GEANT4 simulations, 5 GeV → 20 PEs, 10 GeV → 40 PEs…)
  - Signal laser injected at low rate (typically 500 Hz)
- An additional laser (Laser2) is used to mimic the background particle flux
  - Defocused beam (Ø = 15 mm)
  - Pulse power and rate adjusted to mimic particle flux in different regions of the calorimeter, hence up to an effective background rate of 100 MHz/cm^2
- The two lasers are operated simultaneously
  - Study mean time shifts for the signals produced by Laser1 as a function of the pulse rate of Laser2

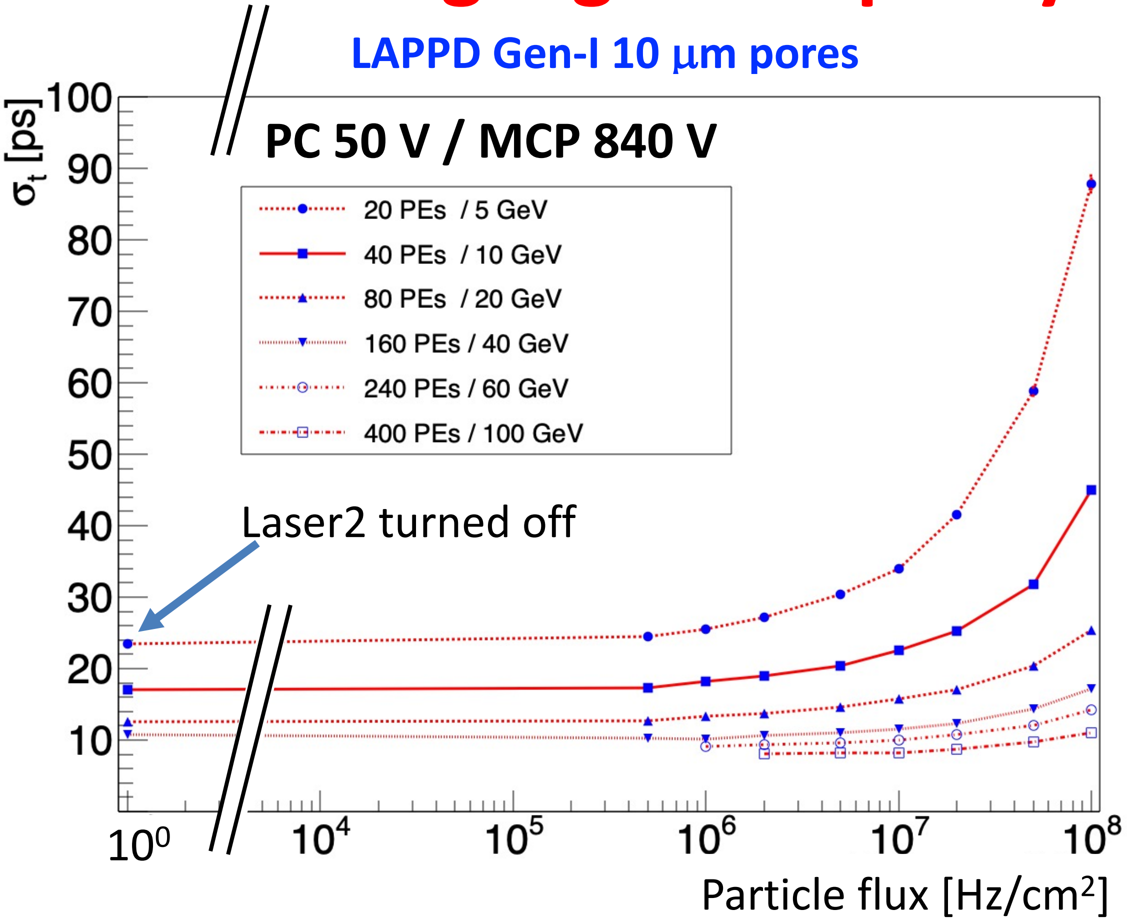
Mimicking high-occupancy environment



Mimicking high-occupancy environment



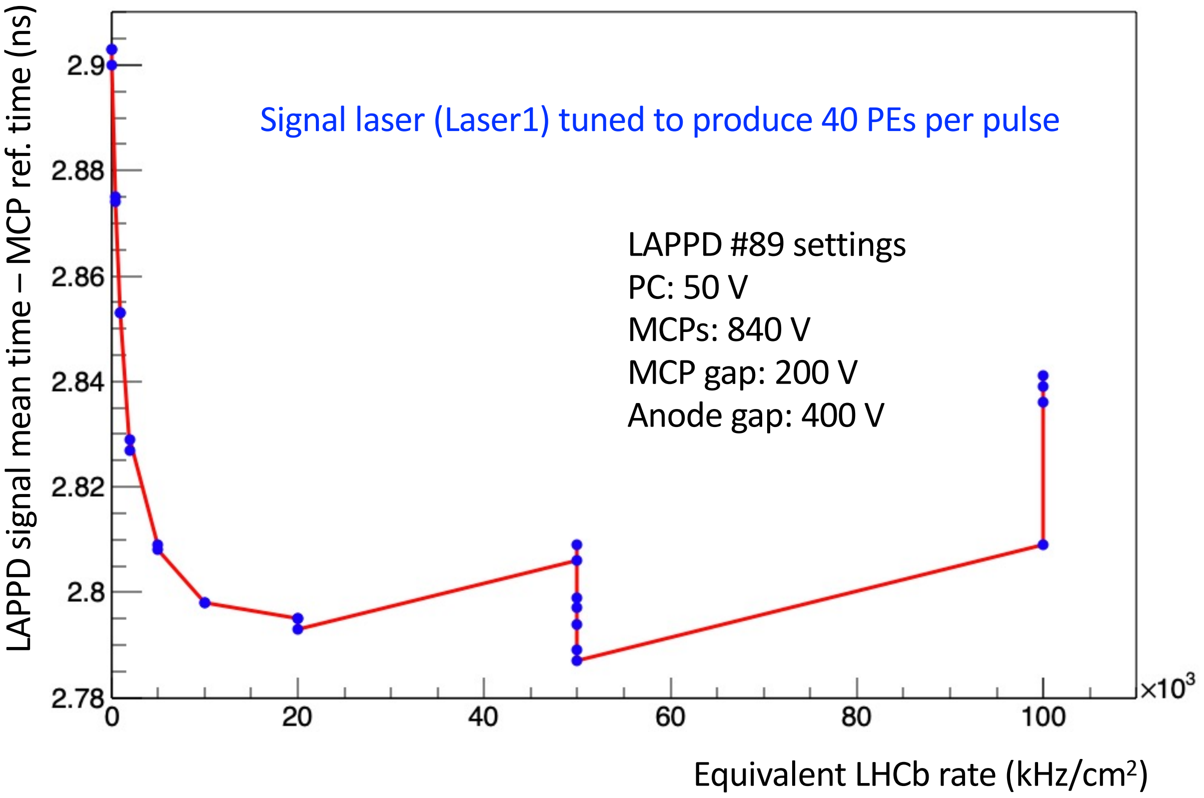
Mimicking high-occupancy environment



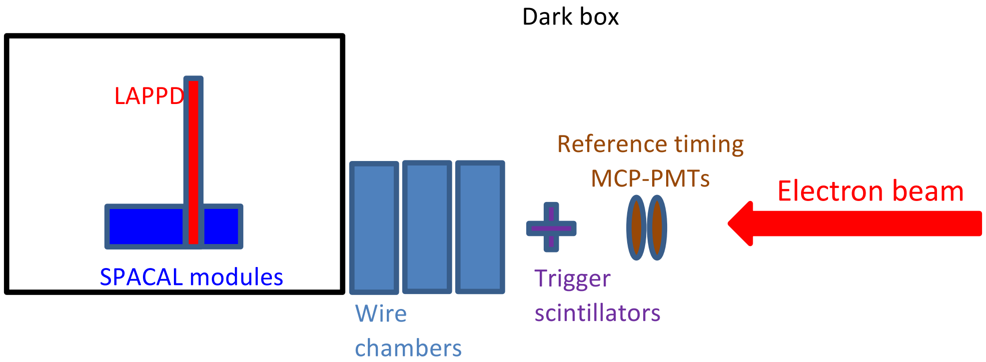
- Charged particle flux in central regions of LHCb U2 ECAL are between 30 and 100 MHz/cm^2
- Important degradation of time resolution at above few MHz/cm^2
- Work needed to improve at the highest possible rates

Shift of signal mean time

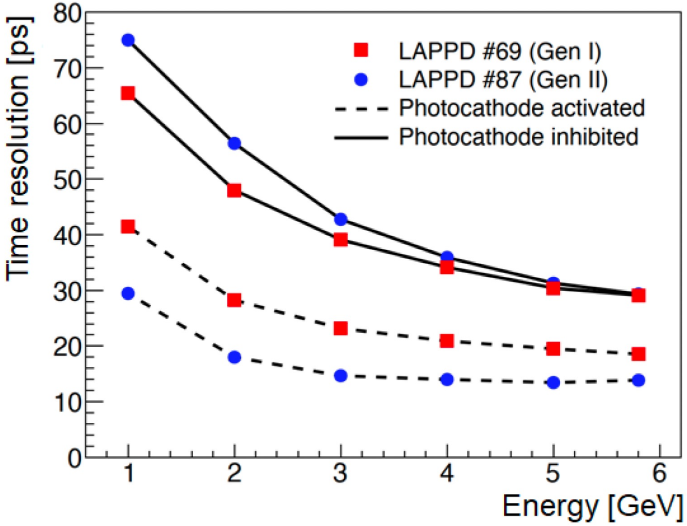
- The mean of the signal arrival time distribution is observed to be rate-dependent
- It decreases up to a certain rate, and then starts to increase again
- The decrease can be explained by the fact that, with increased rate, the pores will have less SEY towards the bottom → the gain decreases with rate but electrons arrive to the anode earlier (on average)
- It is however unclear why above a given rate the mean time inverts the trend and starts to increase
- A proper time calibration strategy for the real detector will have to take this effect into account

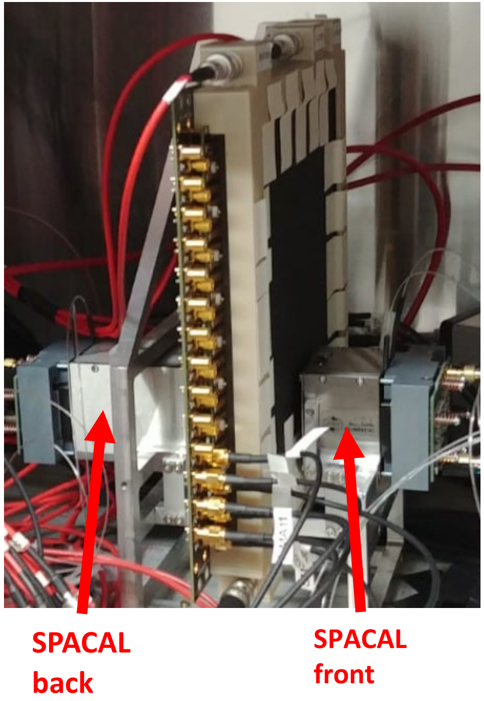


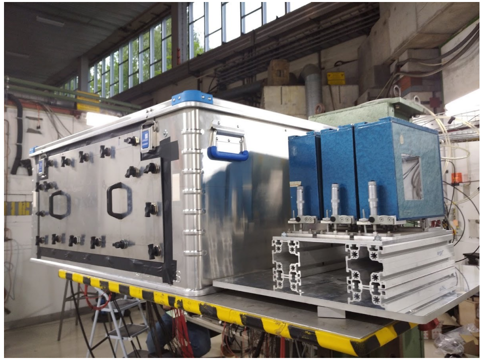
DESY beamtests



- Time reference obtained from two MCP-PMTs ➔ ~12 ps resolution
- DRS4 sampling rate set to 5 GSa/s
- Gen-I and Gen-II with 20 µm pores:
  - Electron beam with 1, 2, 3, 4, 5 and 5.8 GeV

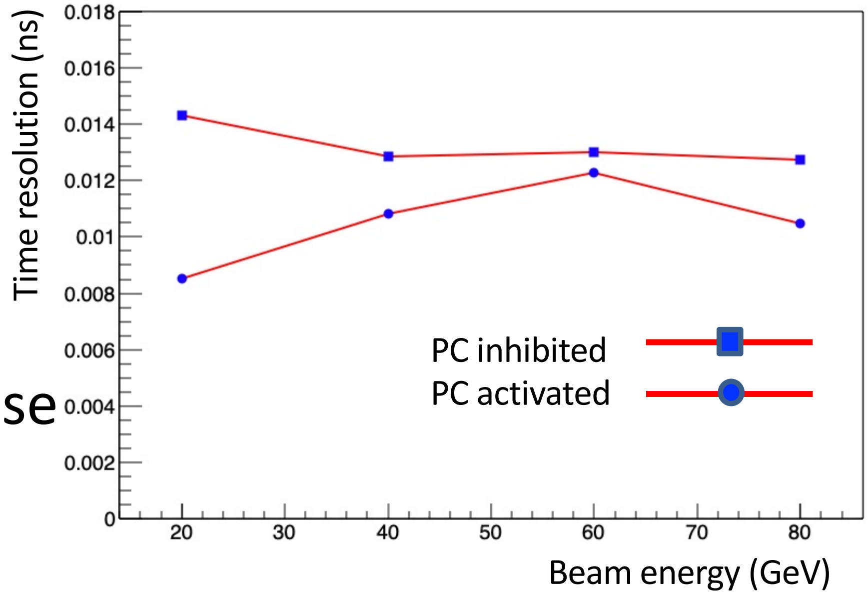


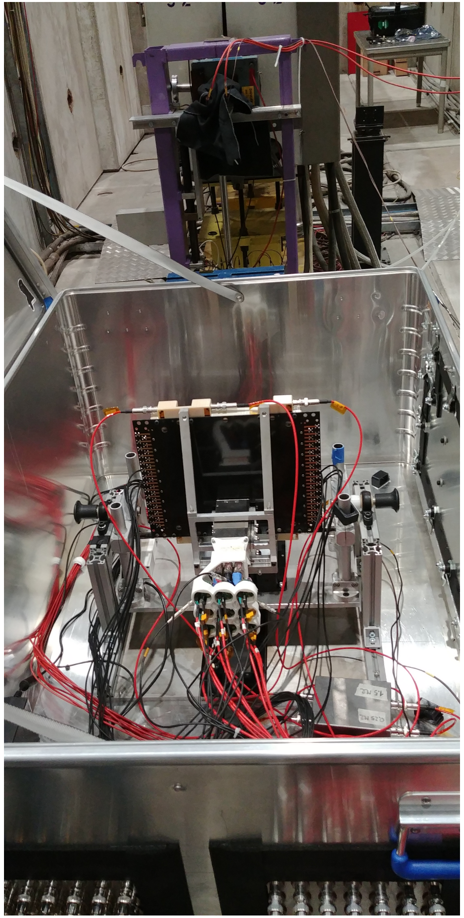




SPS beamtests

- Electron beam with high purity (>99%) in a wide range of energies
- LAPPD Gen-I tile with 10 μm MCP pores operated with high-energy electron beams at CERN SPS
- Time resolutions with inhibited PC comparable to those with activated PC

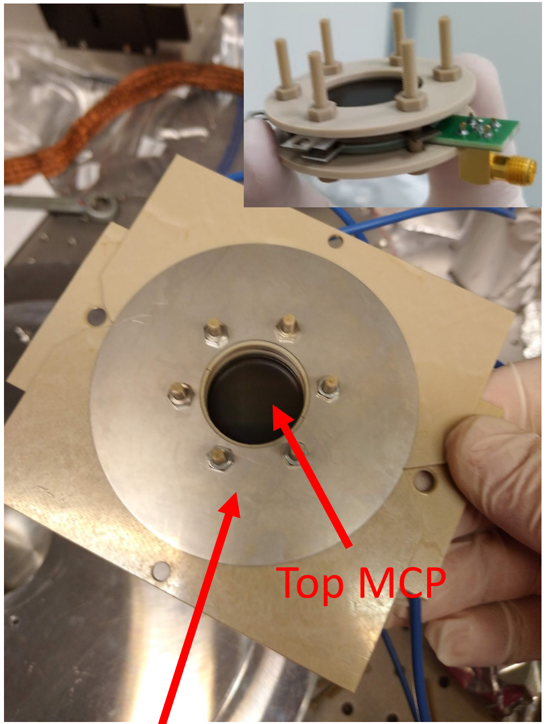




MCP lifetime tests in vacuum chamber

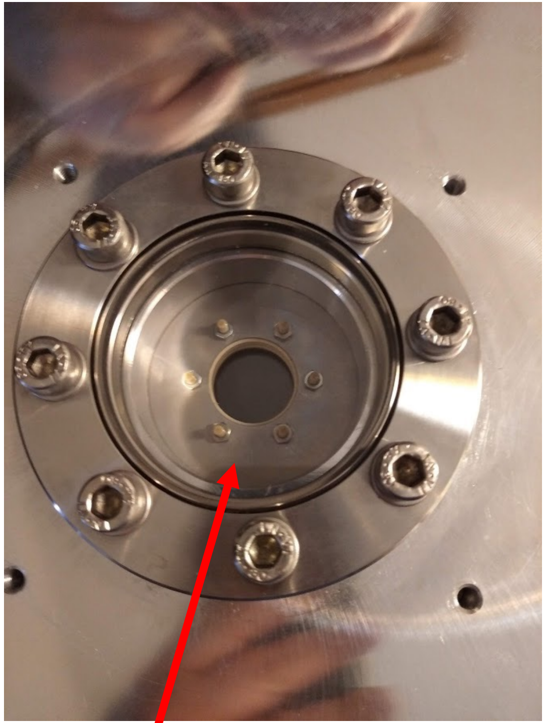
- A stack of MCPs is placed inside a vacuum chamber whose upper flange is equipped with a viewport
  - High quality fused silica with cut off well below 200 nm
- A mercury lamp is placed on top of the viewport and its light is used to trigger the extraction of primary electrons from the MCPs
  - UV light (in particular a line at 185 nm) leads to low but nonzero quantum efficiency for electron emission from MCP surface
- Electrons are then multiplied by the MCP stack and the charge is collected by a metallic anode placed below the stack, which is read out
  - Very high currents can be reached this way, thus allowing for large emitted charge to be accumulated
- A Chevron stack of two round MCPs is used, each of 33 mm diameter
  - 25 mm active area once electrodes and separators are put in place

Final assembly



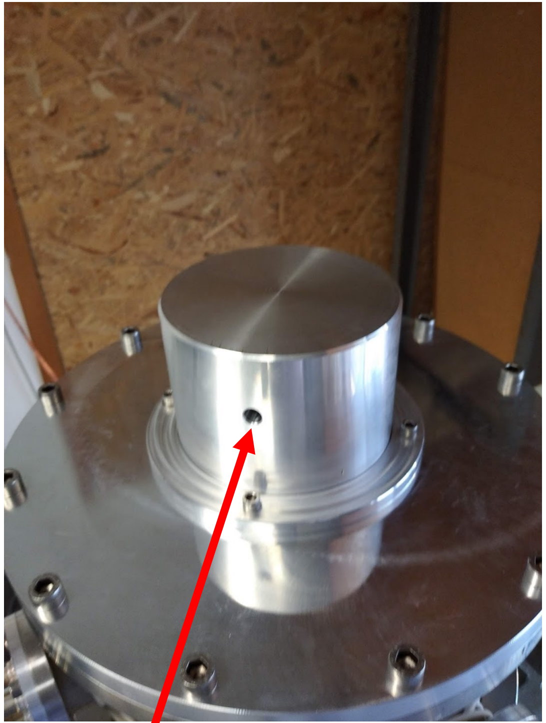
Metal contact to the vacuum chamber to avoid creating charge on the PEEK support by UV light

Viewport installed on the top flange



Corning HPFS 7980 excimer-grade fused-silica window with 90% external transmittance at 185 nm

Top hat covering the viewport



Mercury lamp to be inserted into the lateral hole of the top hat

Experimental setup

Mercury lamp inserted in top hat

Top flange with viewport

Vacuum chamber

Heating tape

HV flange

Signal flange

Mercury lamp power supply

Turbo pump controller

Vacuum gauge

Selector to switch between gain measurements and high-current settings

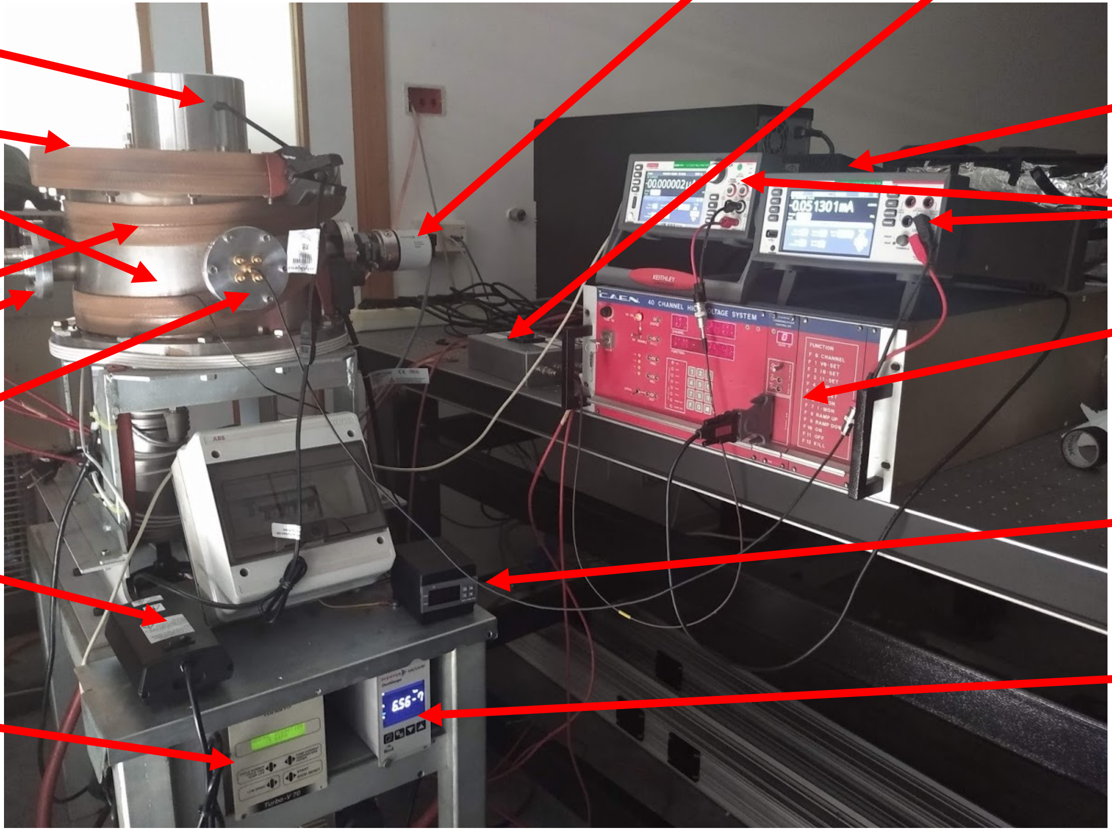
Mini PC for data acquisition and control

Multimeters

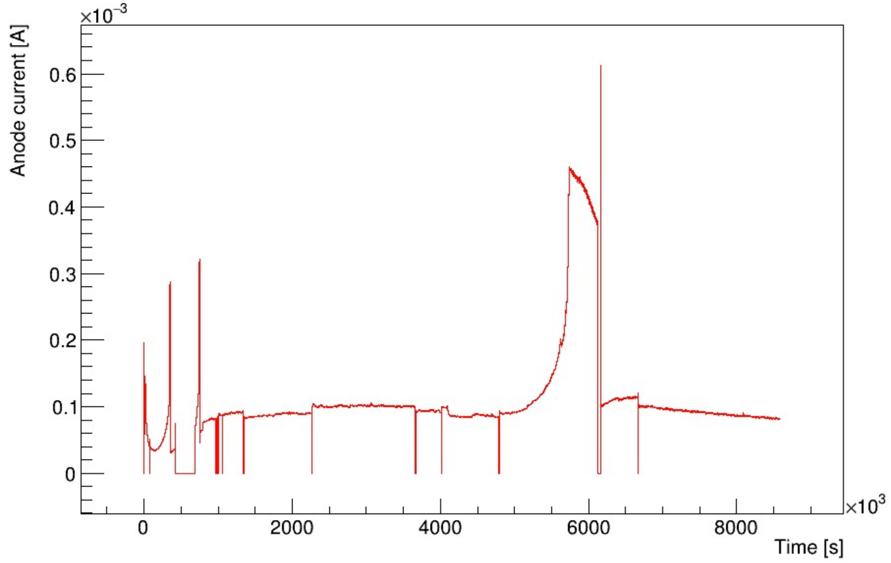
HV power supply

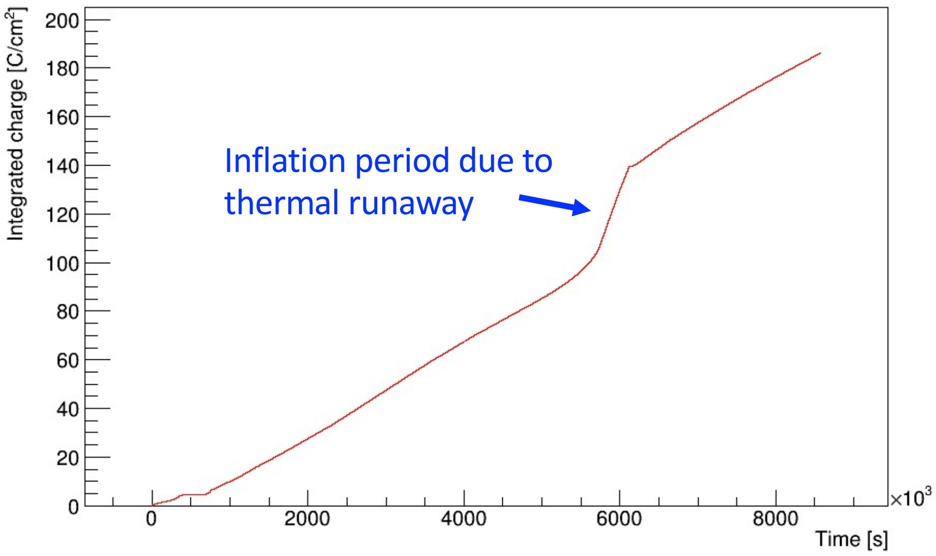
Thermostat for heating tape

Vacuum gauge controller



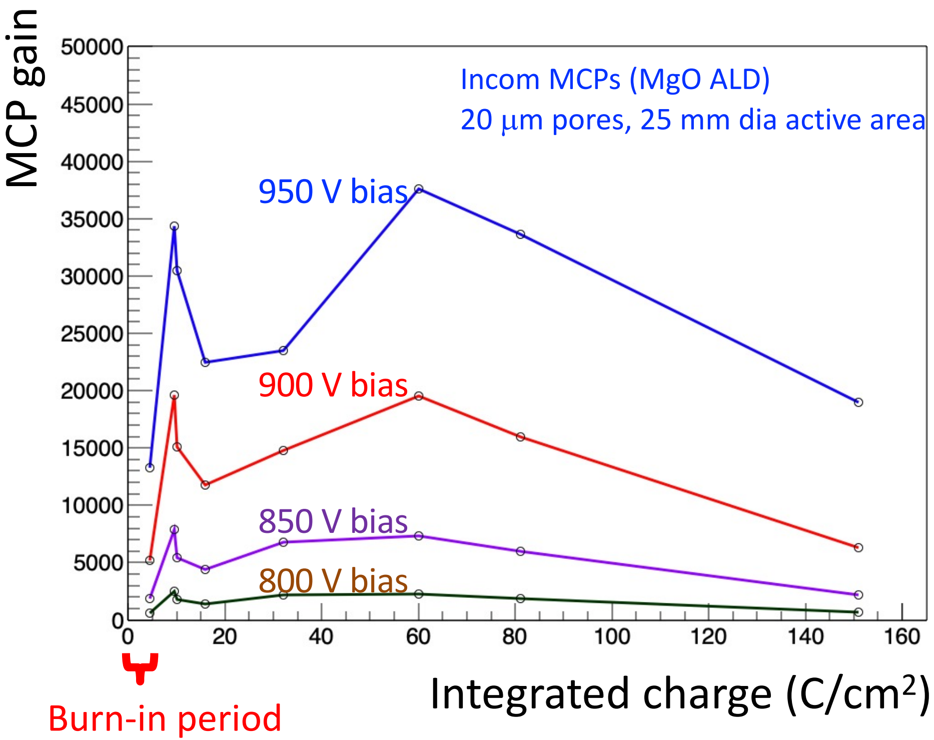
Results of lifetime campaign

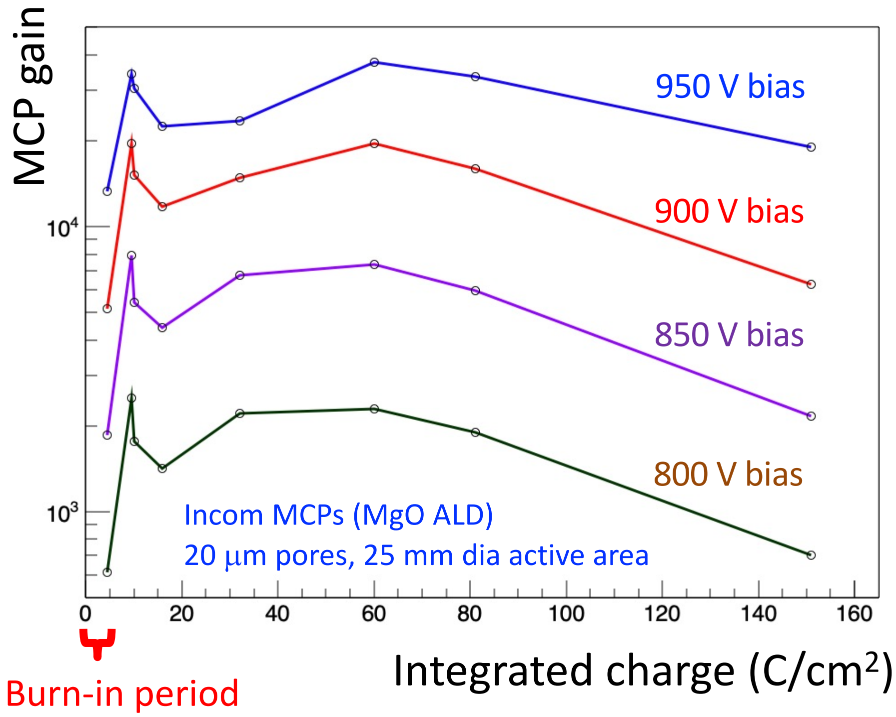




- Started at the end of October 2021
- We have now reached 240 C/cm^2, but for today we will show only results up to 150 C/cm^2

Results of lifetime campaign





Conclusions

- Last year of measurements in Bologna, at DESY and at CERN very productive, but there's still a lot to do
- In particular, we have to focus on behavior at very high rates, above 10 MHz/cm^2
  - Not necessarily the LHCb ECAL timing layer will have to cope with the highest possible rates, as we may think of excluding the most inner area, but we want to push for the largest acceptance
- Collaboration with Incom is just excellent!