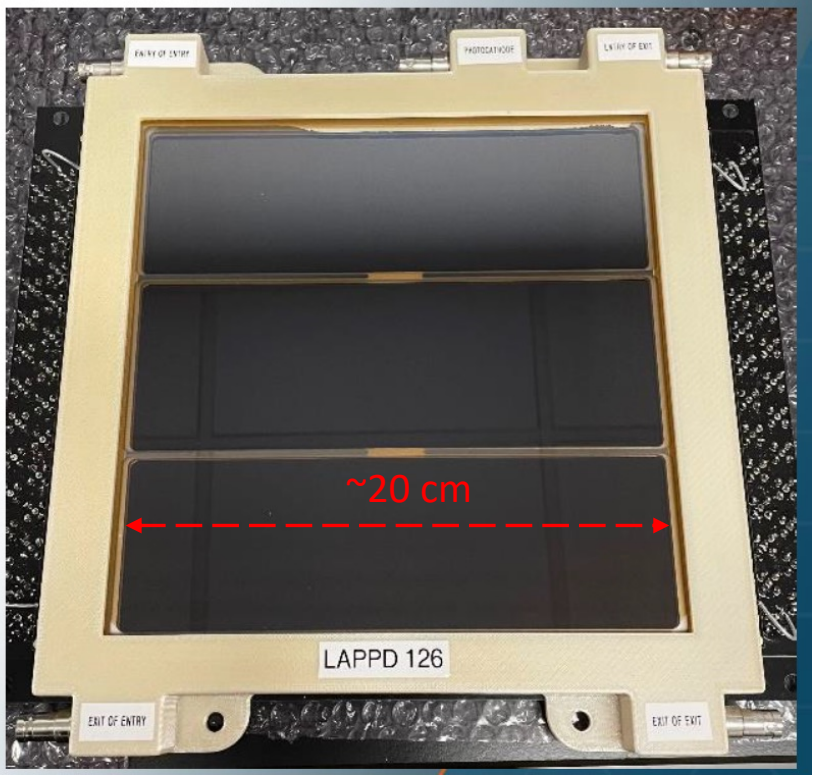
History & notation

- **2009**: LAPPD Collaboration founded by Prof. Henry Frisch (U Chicago)
  - Motivation: Low cost, large detection coverage with picosecond timing
- **2015**: Early commissioning trials at Incom, Inc.
- **2018**: Demonstrated pilot production of LAPPDs
- **2022**:
  - 141 LAPPDs starts all time
  - 6 HRPPDs starts in 2022
  - Current capability of 36 LAPPDs / year
  - Current max capacity of 96 LAPPDs / year
- **Future**:
  - Improved performance
  - Commercial production

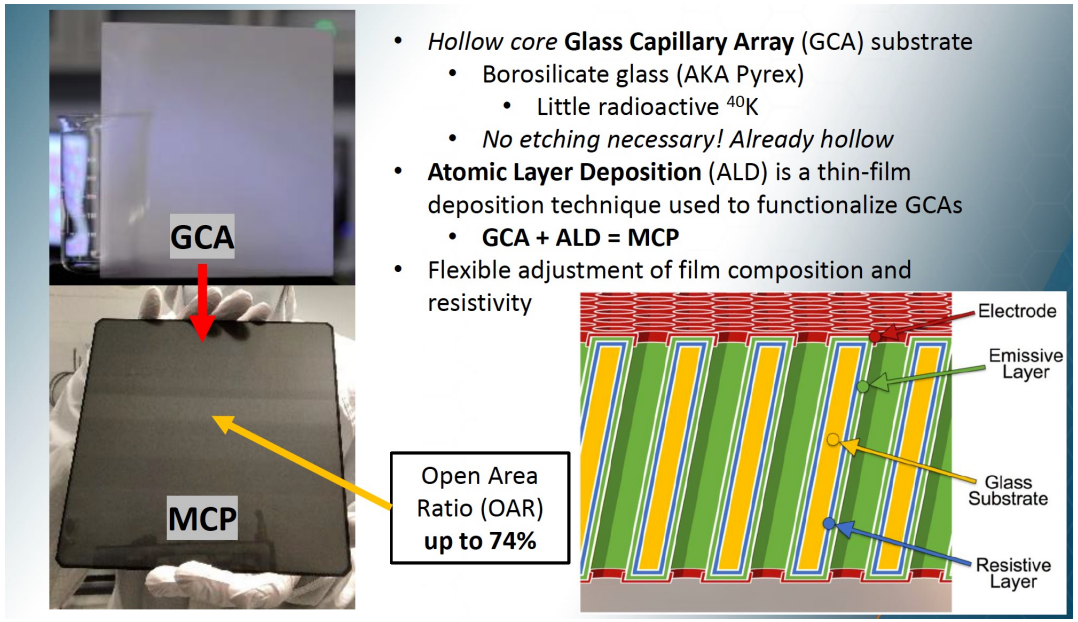
Incom Inc. ⇨



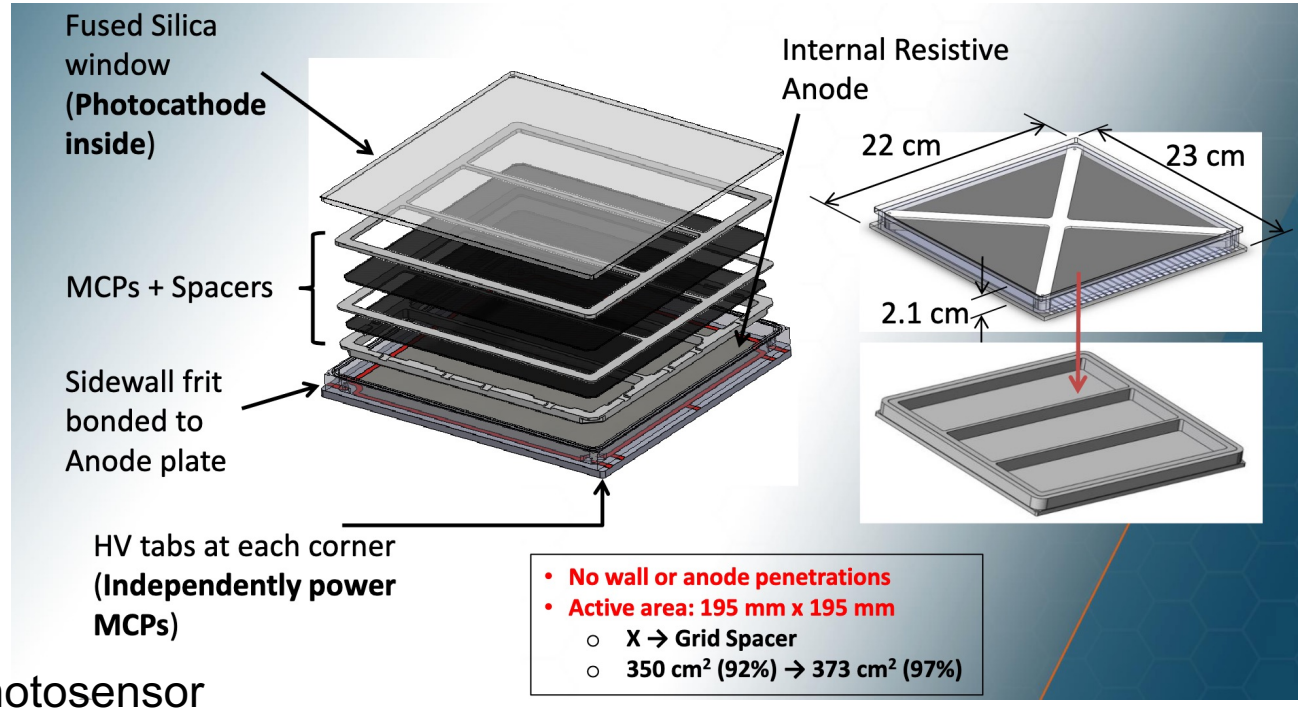
LAPPD (20cm): Large Area Picosecond Photon Detector

HRPPD (10cm): High *Rate* Picosecond Photon Detector

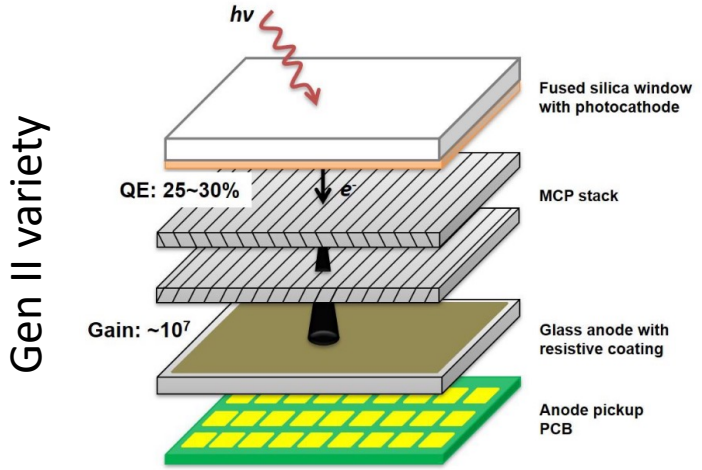
LAPPDs / HRPPDs by Incom Inc.



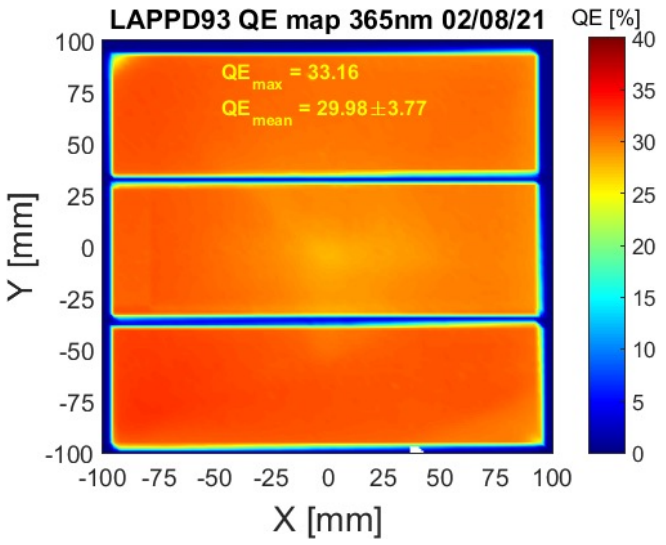
- *Hollow core* **Glass Capillary Array** (GCA) substrate
  - Borosilicate glass (AKA Pyrex)
    - Little radioactive ^{40}K
  - *No etching necessary! Already hollow*
- **Atomic Layer Deposition** (ALD) is a thin-film deposition technique used to functionalize GCAs
  - **GCA + ALD = MCP**
- Flexible adjustment of film composition and resistivity

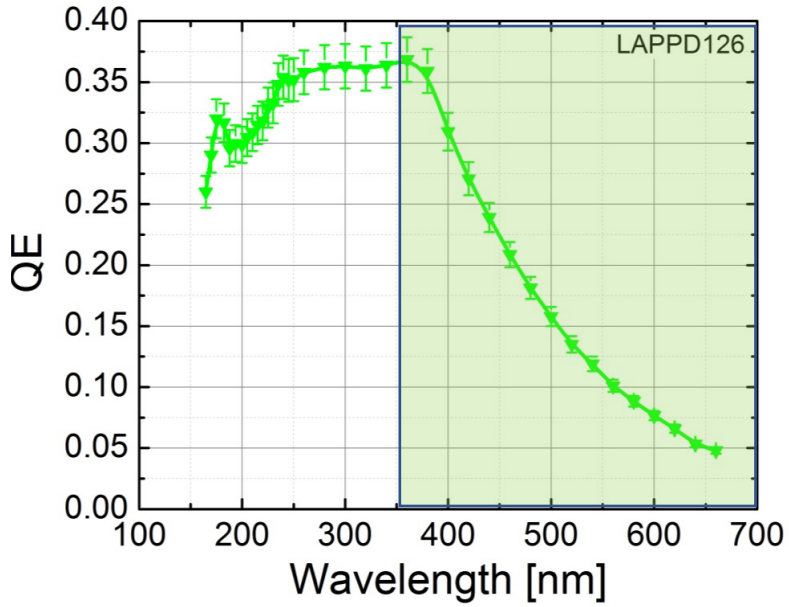


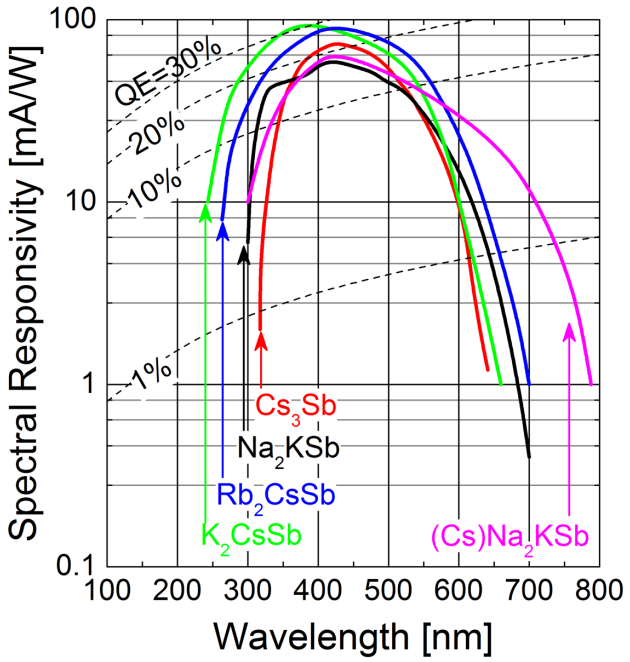
- An affordable large area (finely pixelated) vacuum photosensor
- 10x10 cm^2 or 20x20 cm^2 active area
- DC- (Gen I) or capacitively (Gen II) coupled species
- DC-coupled strips or 2D pixellation
- Expected to be (very) cost efficient in mass production
- High enough quantum efficiency and uniform high gain up to ~10^7
- Sub-mm spatial resolution for finely pixelated tiles
- Single-photon timing resolution on a ~50ps level or higher



Quantum Efficiency & PDE





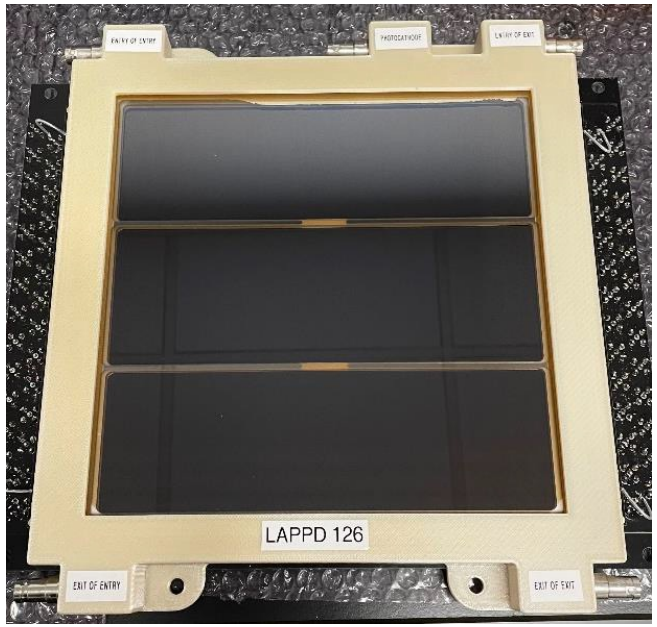


- QE is high enough, but peaked at ~300 nm
- As such, the wavelength range is not optimized for aerogel
- Besides this, the actual PDE was not yet measured

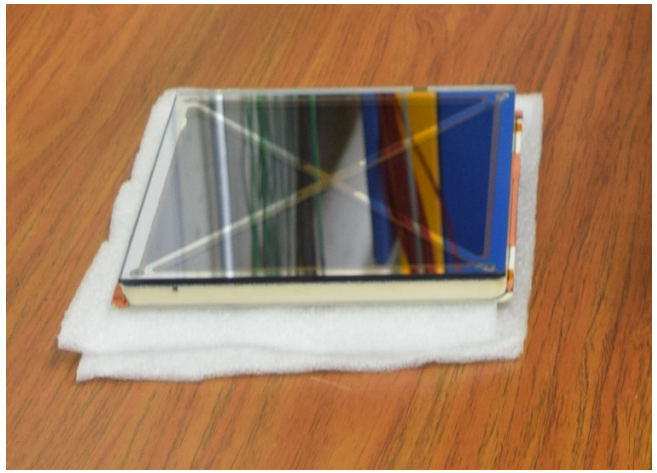
This is a concern, but Incom is making an effort to fix the problem for EIC

- This proposed SBIR would bring LAPPD PC QE to 30% at 450 nm
  - At best PDE=QE
  - Measure this value
- Steps to improve LAPPD PDE
  - Higher QE
  - Funnel-shaped MCP Pores
  - Electron Steering

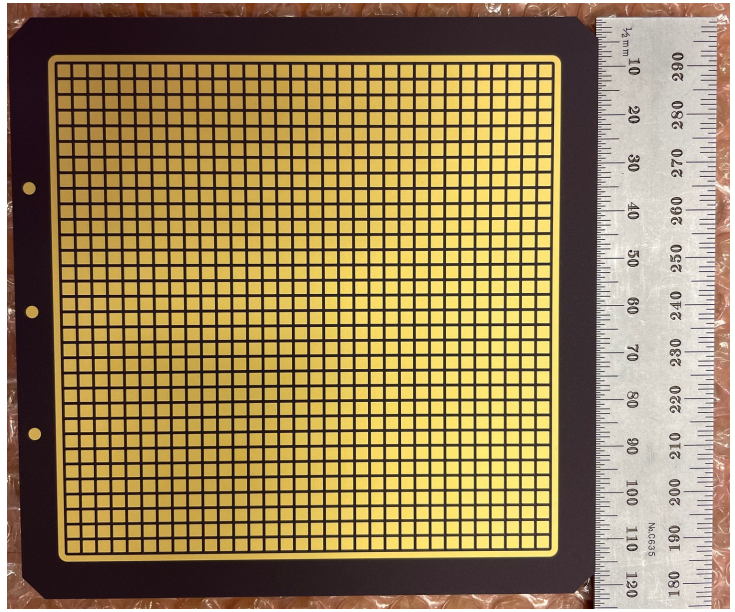
Formfactor & geometric acceptance

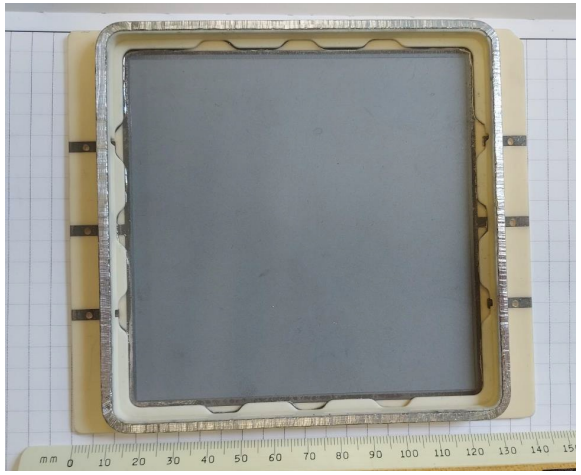


Capacitively coupled 20cm LAPPD



DC-coupled 10cm HRPPD



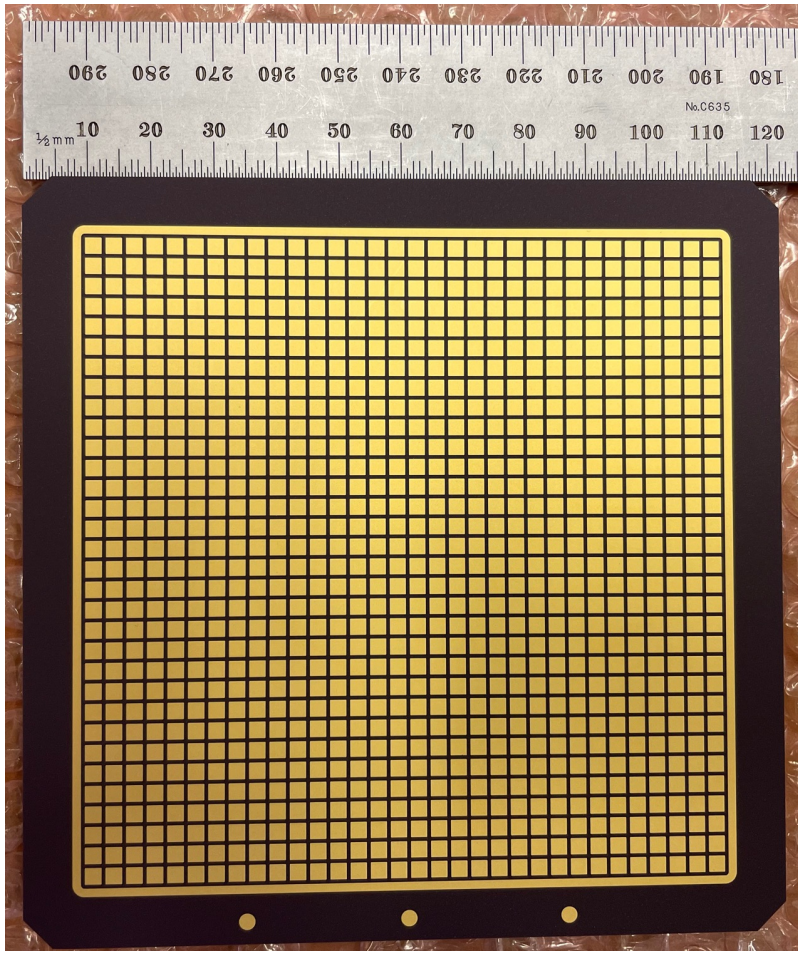


Capacitively coupled 10cm HRPPD

- None of them was initially designed for high geometric acceptance efficiency
- Can be fixed of course (meeting with Incom on this particular topic today)

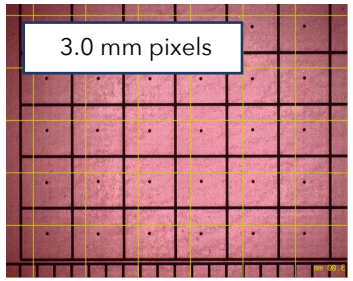
Pixellation

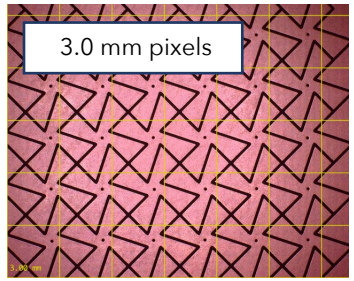
DC-coupled HRPPD

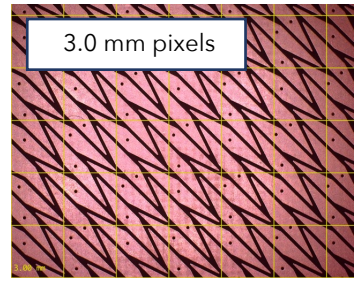


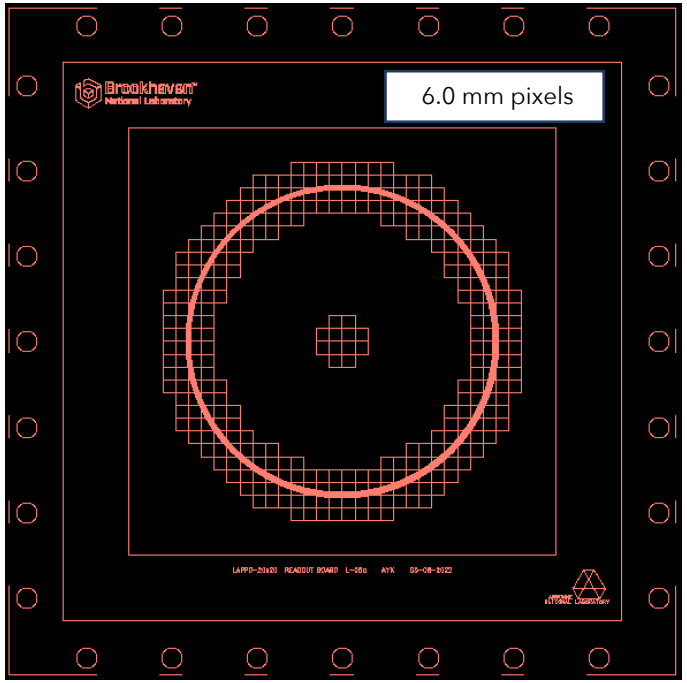
- ~100x100 mm^2 active area
- 1024 pads, 1/8” (~3.2 mm) pitch

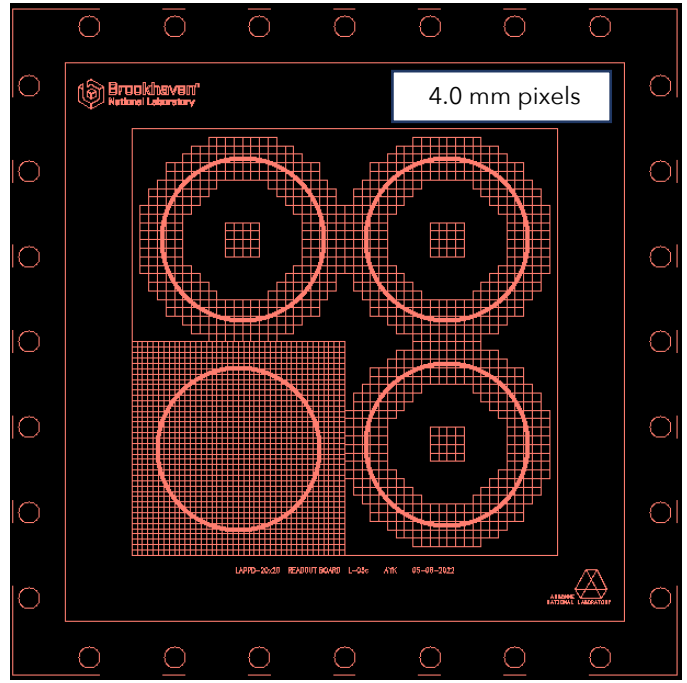
Capacitively coupled LAPPD / HRPPD







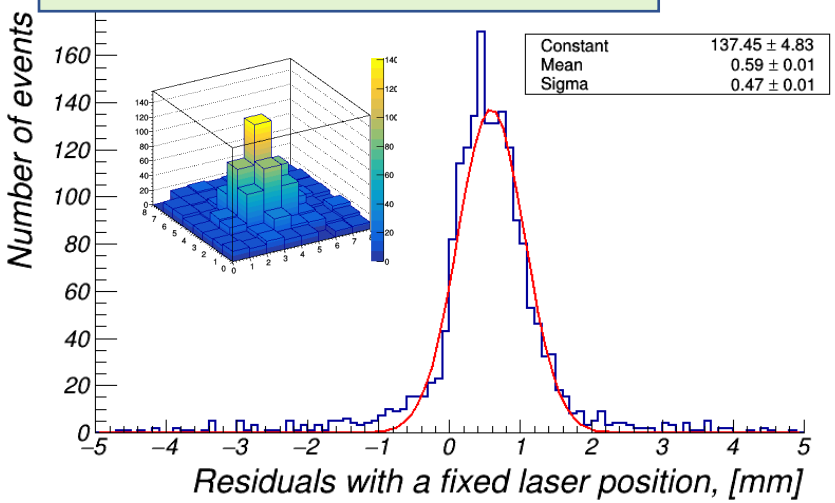




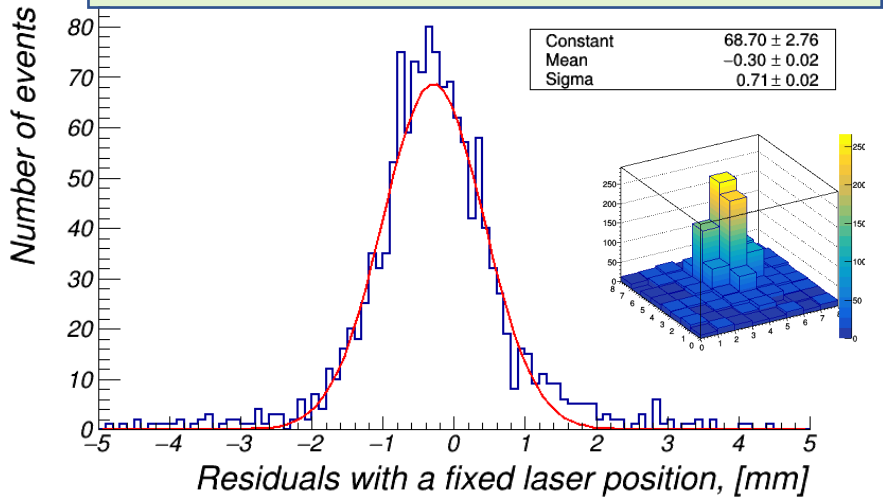
- Pixellation is defined by the user

Spatial resolution (capacitively coupled LAPPDs)

3mm square pixels: σ ~500 μm

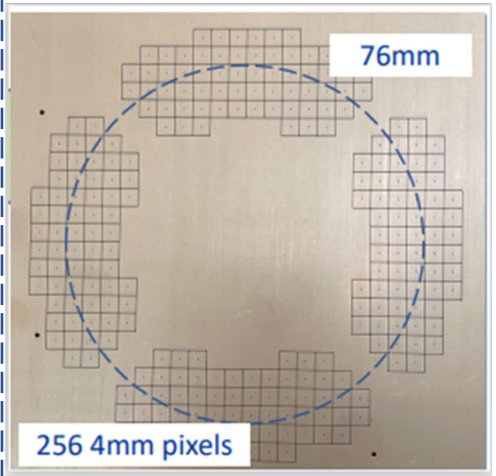


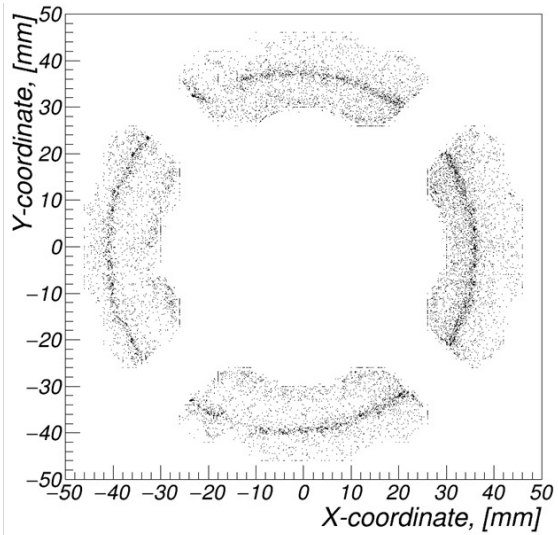
6mm segmented pixels: σ ~700-800 μm

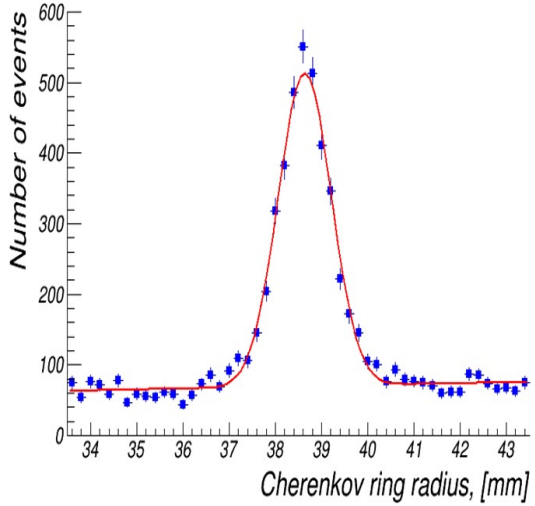


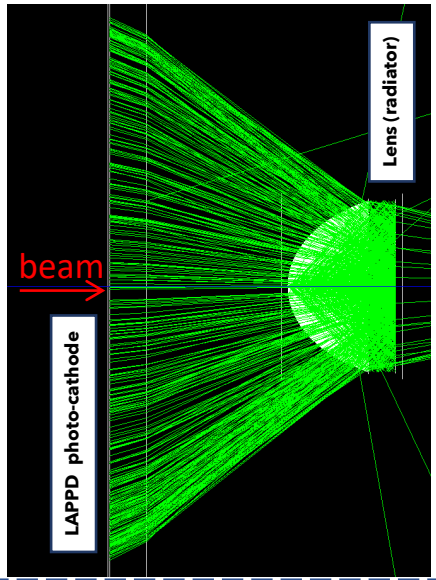
Lab results with a laser

$$\chi \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$





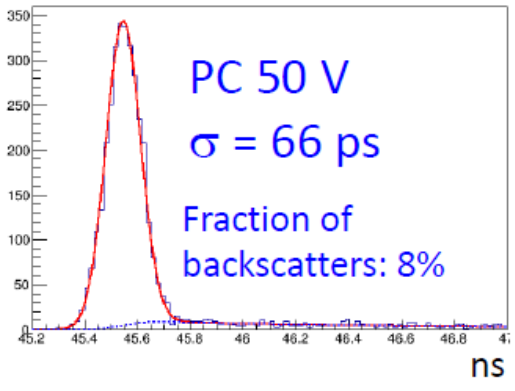


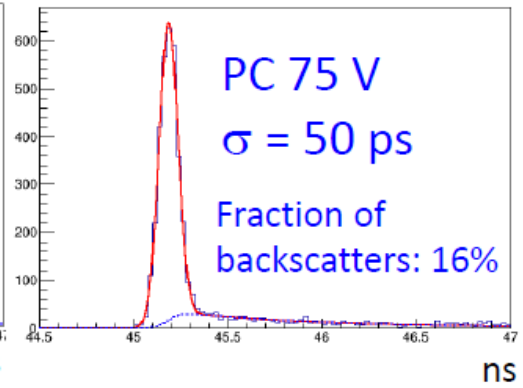


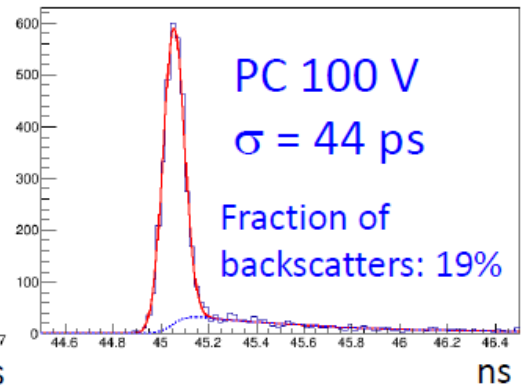
Beam data

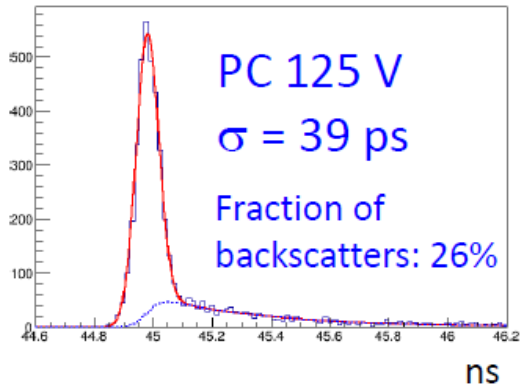
Sub-mm resolution, even without pre-amplification

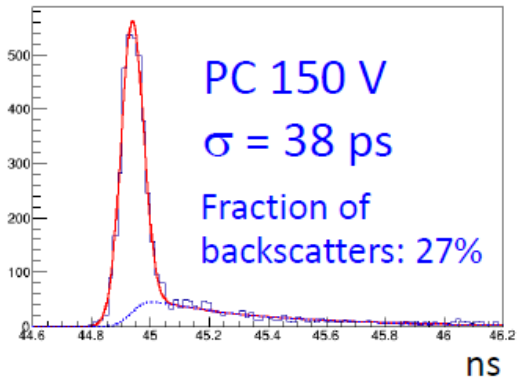
Single photon timing resolution

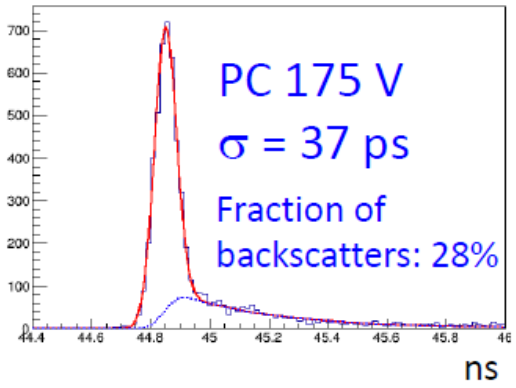


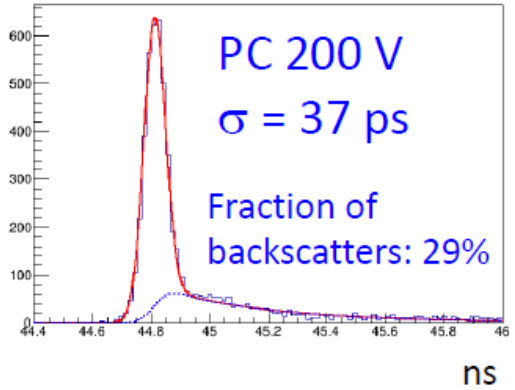




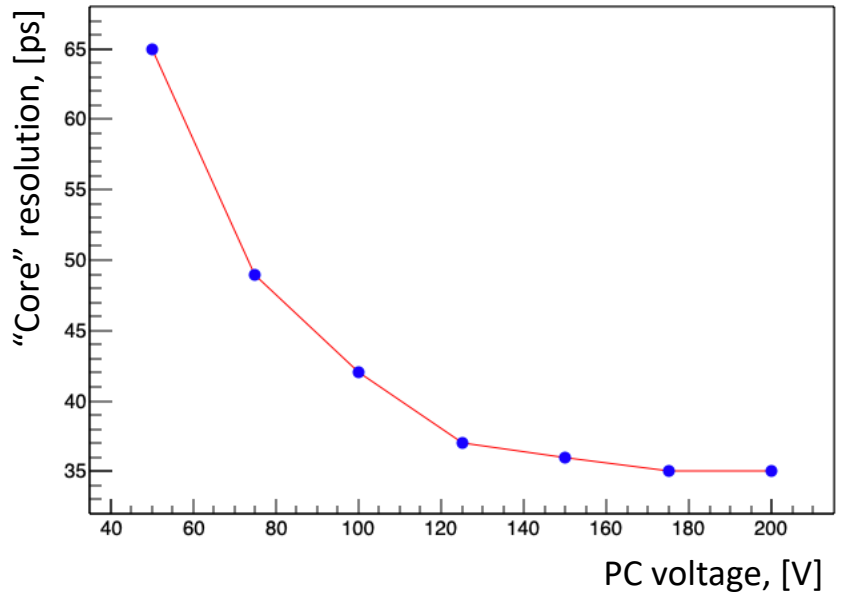








Data: V. Vagnoni (INFN Bologna)



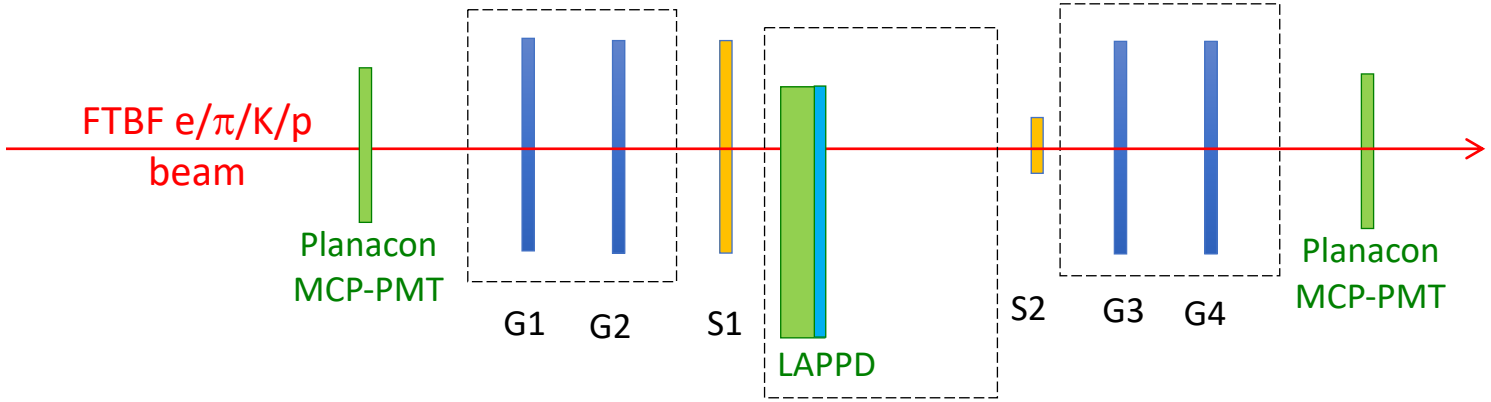
Data: V. Vagnoni (INFN Bologna)

- Remember: EIC requirement is "<100 ps"
- Tail is of course a concern for the DIRC
- We are collecting our own beam data on this (INFN, BNL)

Timing resolution for Time-of-Flight purposes

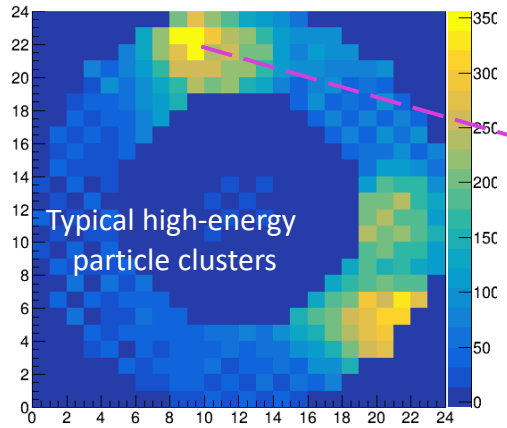
- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters

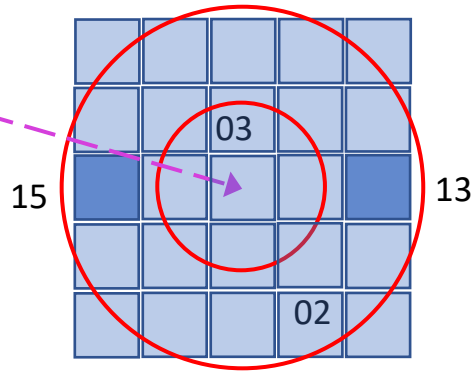
Our June 2022 FTBF data

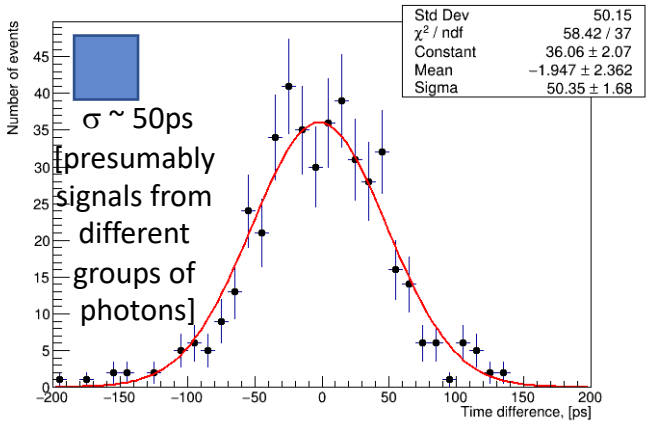


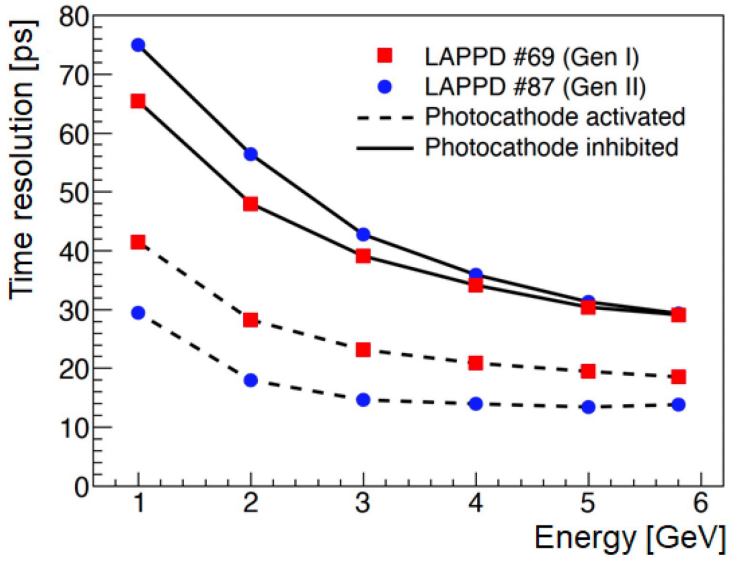
LAPPD quartz window as a Cherenkov radiator

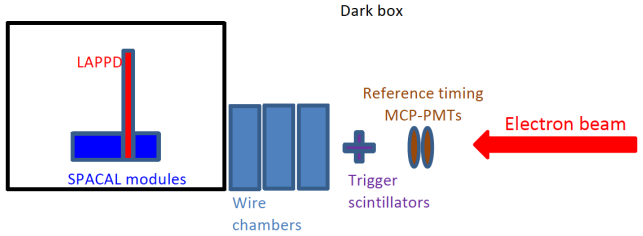
- *Single* photon TTS ~50 ps
- UV grade quartz window: a 120 GeV proton produces a **blob of ~100 p.e.'s**







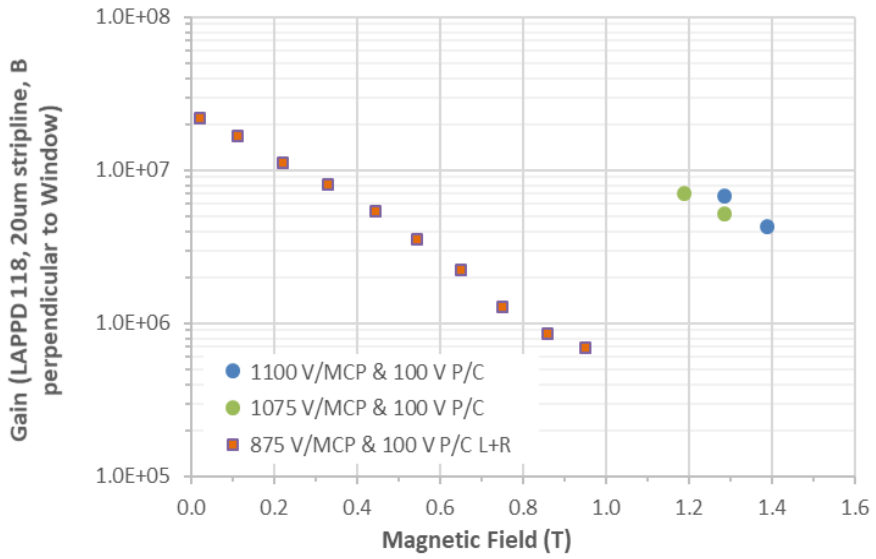


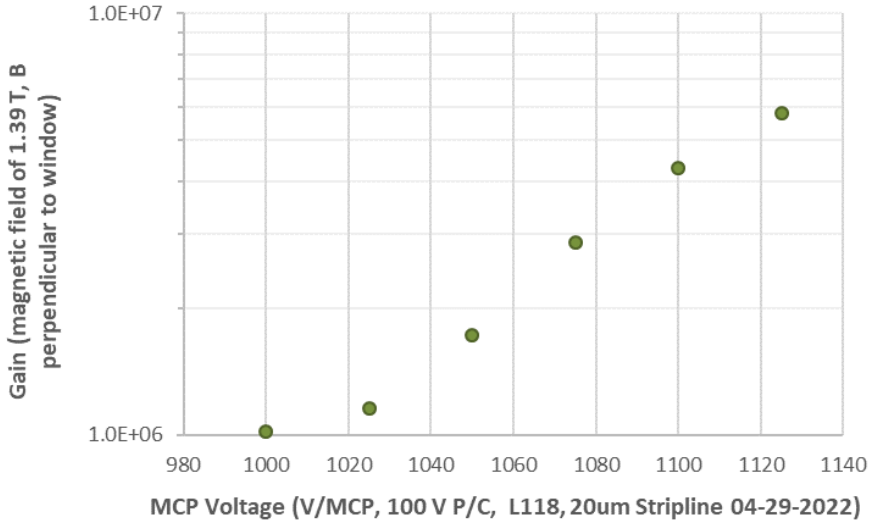


LHCb spacal tests at DESY

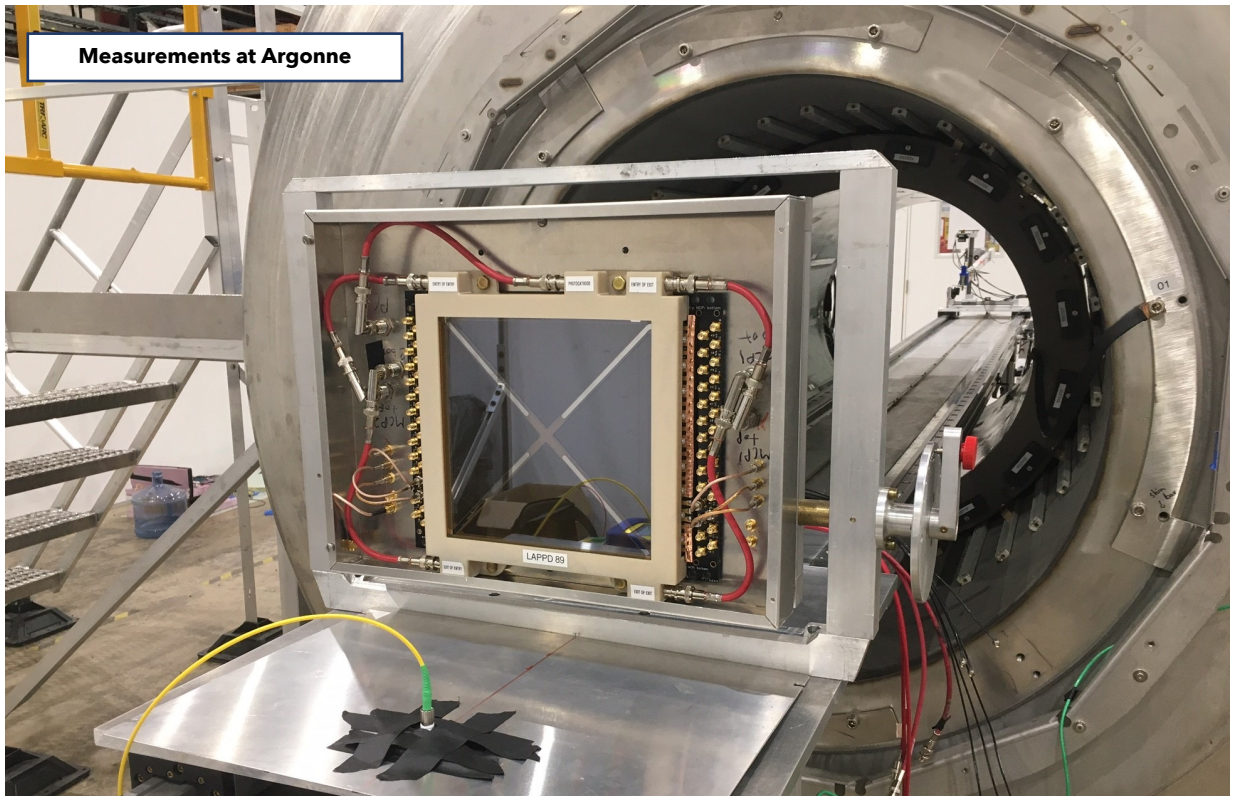
- Expect resolution σ < 15-20 ps in the mRICH / pfRICH configuration

Magnetic field tolerance





Gen I LAPPD; magnetic field normal to the sensor surface



- LAPPD shows similar behavior trends as R&D MCP-PMT
  - Gain went down from over $2x10^7$ to ~$7x10^5$ as the field strength was increased from 0.02 T to ~0.9 T.
- At a field strength of 1.39 T, the gain was recovered to $6x10^6$ by significantly increasing the MCP voltages.

Need to verify up to ~2T and at (reasonable) non-zero angles