BNL / Argonne / Incom LAPPD quest 2020-2021

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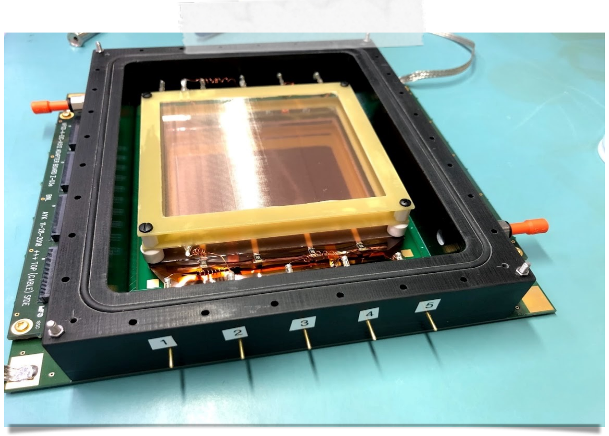
eRD14 PID Consortium Meeting
April 27 2020

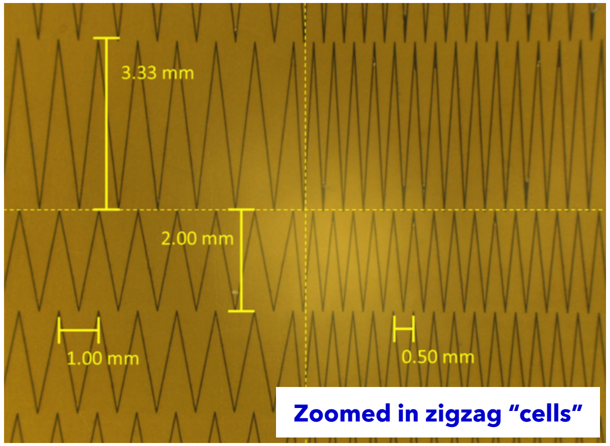
Outline

- MPGD studies @ BNL and motivation to expand into the MCP PMT turf
- 2020 R&D campaign
  - Goals
  - Cast and crew
  - Existing equipment
  - New readout boards and other equipment
  - Experimental setup
  - GEANT and CAD modeling
- Outlook

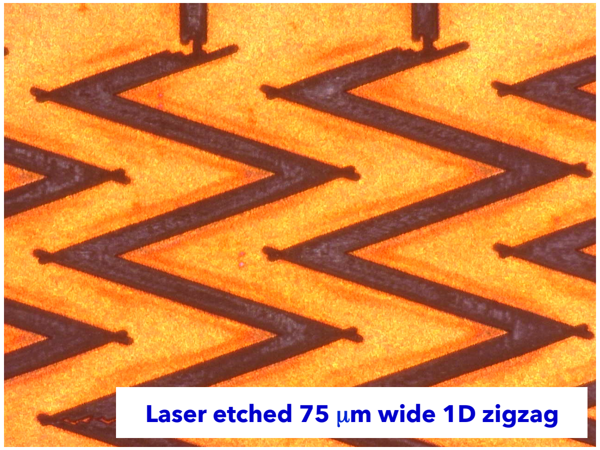
MPGD studies at BNL

- Participation in eRD6 Tracking Consortium from day one
- BNL LDRD 18-033 “Micro-Pattern Gas Detectors for EIC” (in collaboration with Stony Brook and CEA Saclay)
- Lately a particular focus on MPGD spatial resolution optimization for “large” (few mm) pitch anode plane configurations
  - Dozens of detector prototypes ...
  - ... in GEM, micromegas, μRWELL implementation
  - Hundreds of 1D and 2D charge-sharing patterns
  - Several systematic scans in the parameter space
  - Chemical etching and laser ablation technique

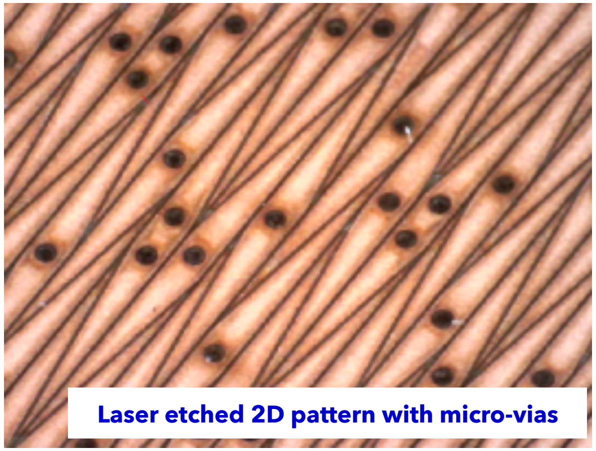




Zoomed in zigzag “cells”



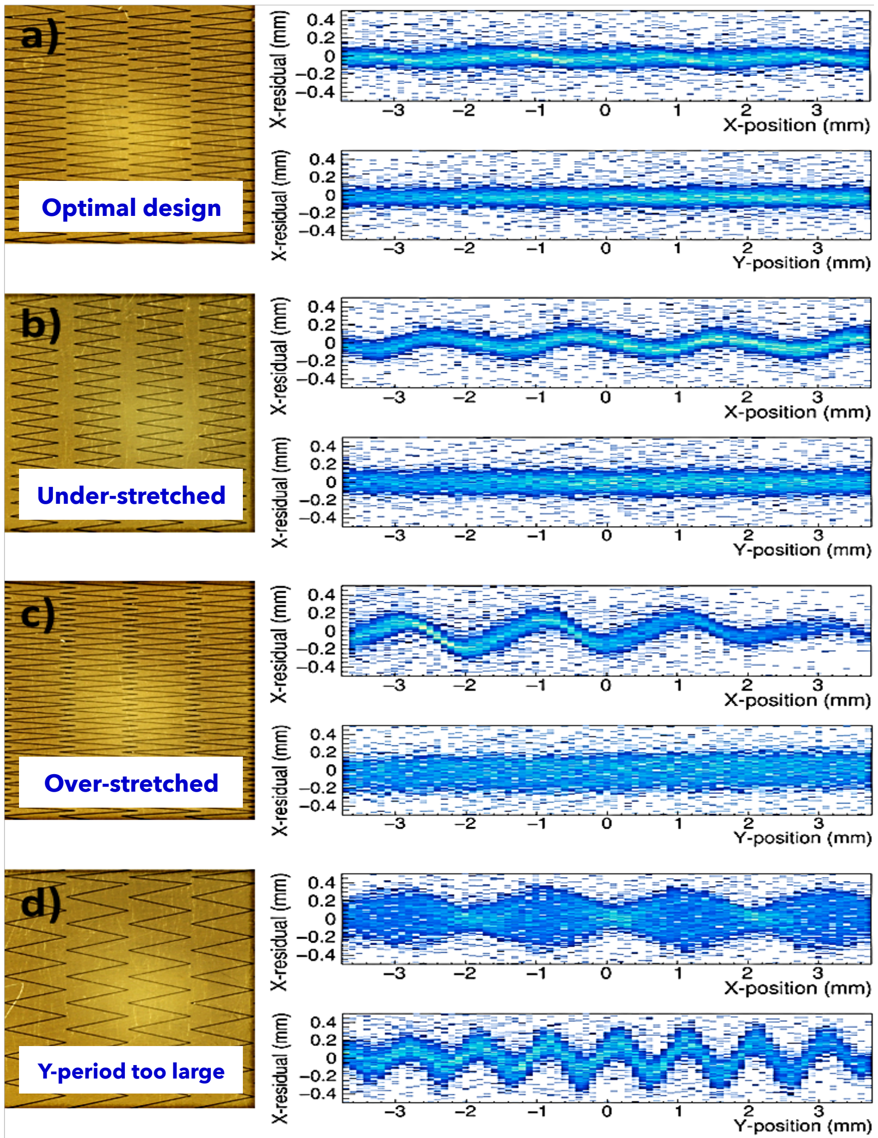
Laser etched 75 μm wide 1D zigzag



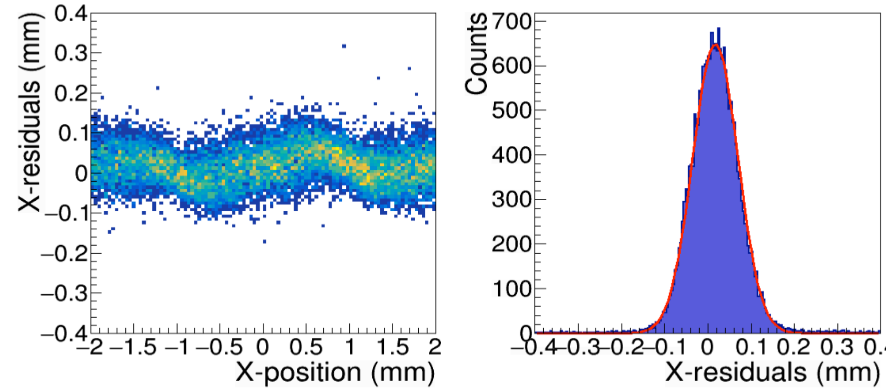
Laser etched 2D pattern with micro-vias

MPGD studies at BNL (data)

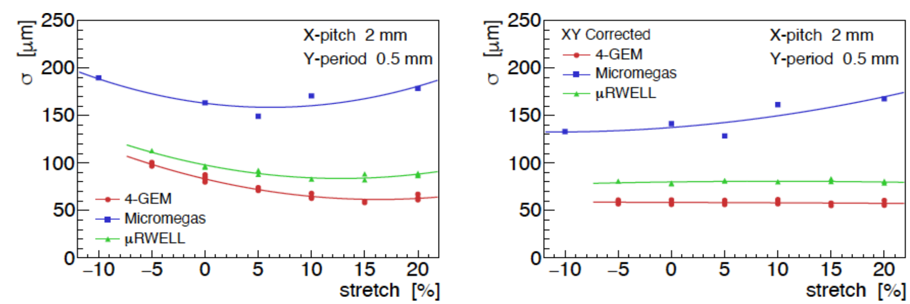
A typical scan in 1D zigzag parameter space



4-GEM with 2mm pitch: 53μm resolution

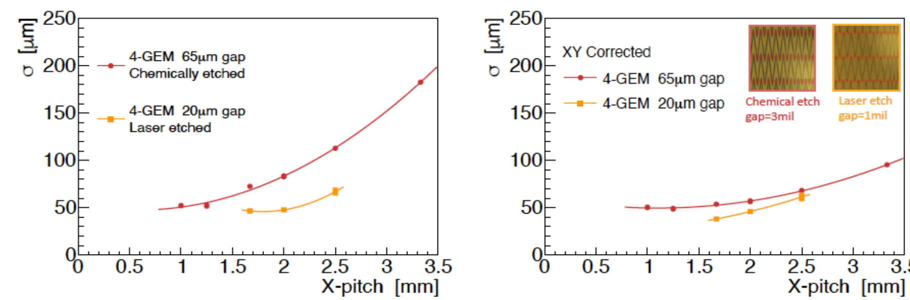


2mm pitch: 4-GEM vs μRWELL vs μMegas



Raw residual (Cluster X - Silicon X) width as a function of stretch for a particular X-pitch (2mm) and Y-period (0.5mm) showing the response for 4-GEM, Micromegas and μRWELL detectors working in ArCO$_2$(70-30).

Achievable residual width after non-linear corrections as a function of stretch for a particular X-pitch (2mm) and Y-period (0.5mm) showing the response for 4-GEM, Micromegas and μRWELL detectors working in ArCO$_2$(70-30).



Comments on charge sharing

- Consider a 1D detector with a pitch of 3 mm and *straight* strips
- Assume for simplicity that signal typically fits in ~1mm area

Spatial resolution ~900 μm

Do you want to improve the performance of this detector?

No, it is perfect as is → **DO NOTHING**

Yes, I'd like to decrease channel occupancy by a factor of ~3; spatial resolution is of less interest → **Decrease pitch to 1mm**

Yes, I'd like to improve spatial resolution *and I can tolerate occupancy increase by a factor of ~3* → **Use charge sharing, e.g. zigzag**

(A)

- Channel count went up by a factor of 3
- Occupancy went down by a factor of 3
- Spatial resolution improved to ~300 μm

(B)

- Channel count remains the same
- Occupancy went up by a factor of 3
- Spatial resolution improved to ~75 μm

-> if now in case (B) one also decreases pitch to 1mm (channel count goes up; occupancy returns back to where is was in the 3mm straight strip case; resolution becomes better than ~50 μm *perhaps*), we have an apple to apple comparison of two detectors with the same 1mm pitch: *<u>one optimized for occupancy, the other one for spatial resolution</u>*

Comments on charge sharing

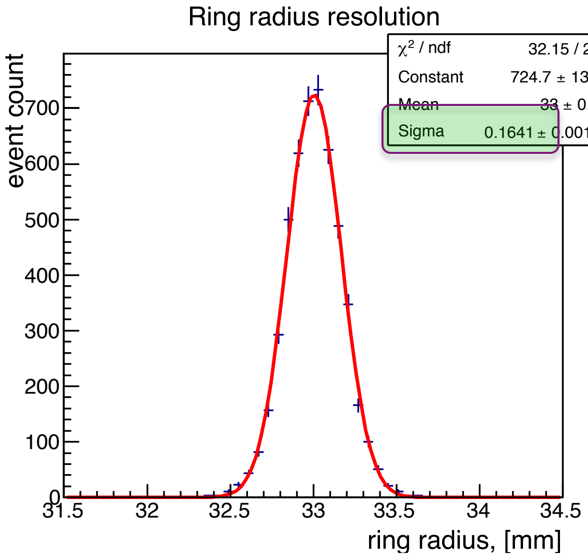
-> by the way, decreasing *strip length* may also be an option to beat occupancy, but maintain the same spatial resolution

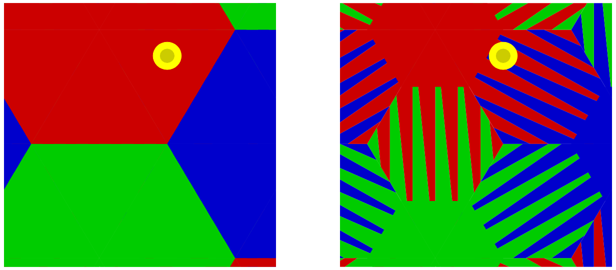
- 2D case is more complicated:
  - Decreasing pixel size blows up the channel count quadratically
  - It is harder to get a decent increase in spatial resolution in two projections at once
  - Resolution for a RICH-like detector is to first order only important in 1D (radial) direction

-> a side remark: if you use AC coupling to increase the charge sharing, then *not* using zigzag-like strips (pads) is seemingly only good if you have a postdoc who can waste his / her time to calibrate the PRFs as a function of signal spread, since straight strips will most likely still exhibit a substantial DNL, *dependent on the actual signal width*

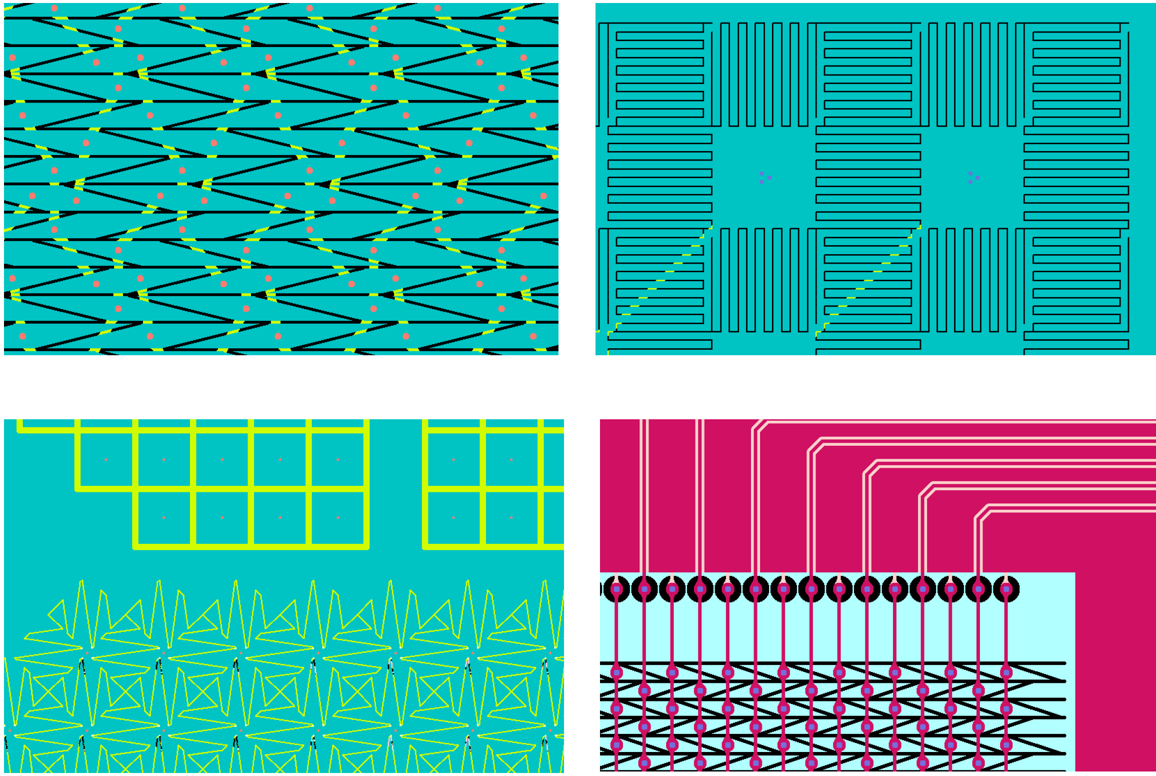
MPGD studies at BNL (modeling)

MC simulation of RICH pad designs



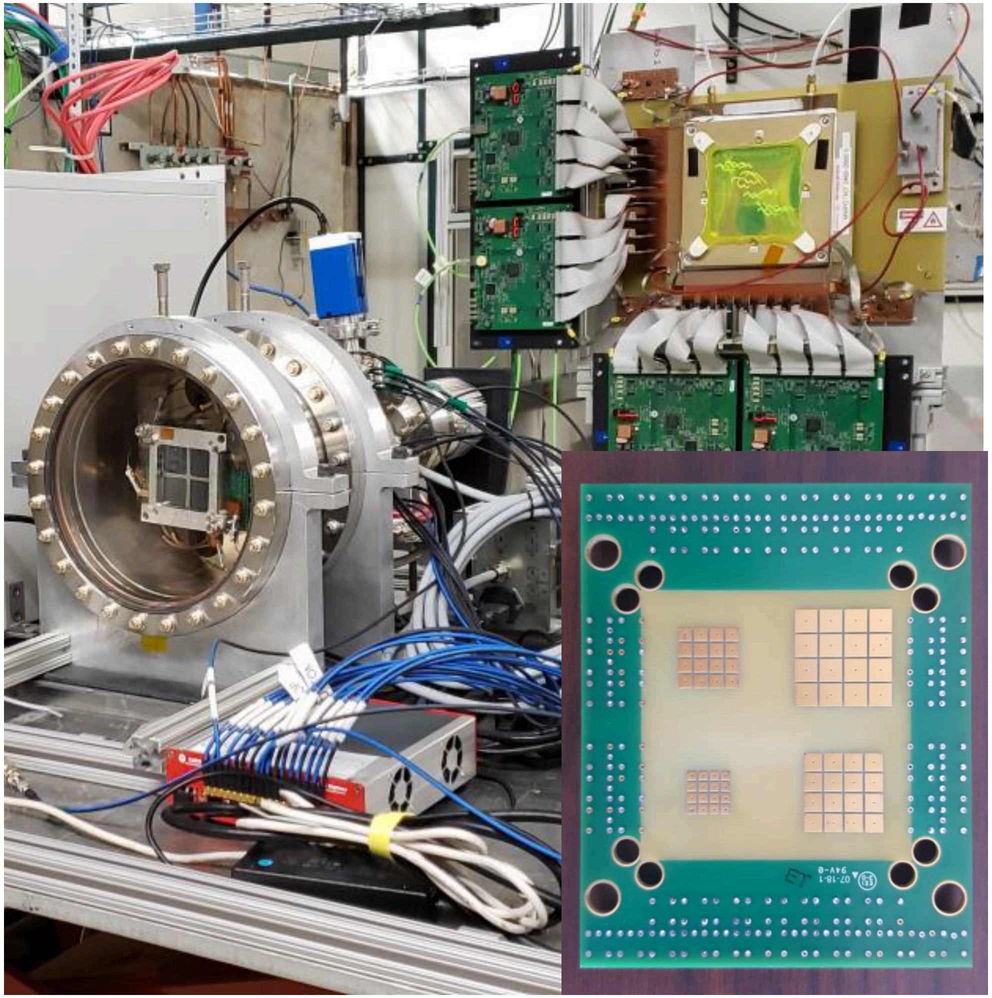


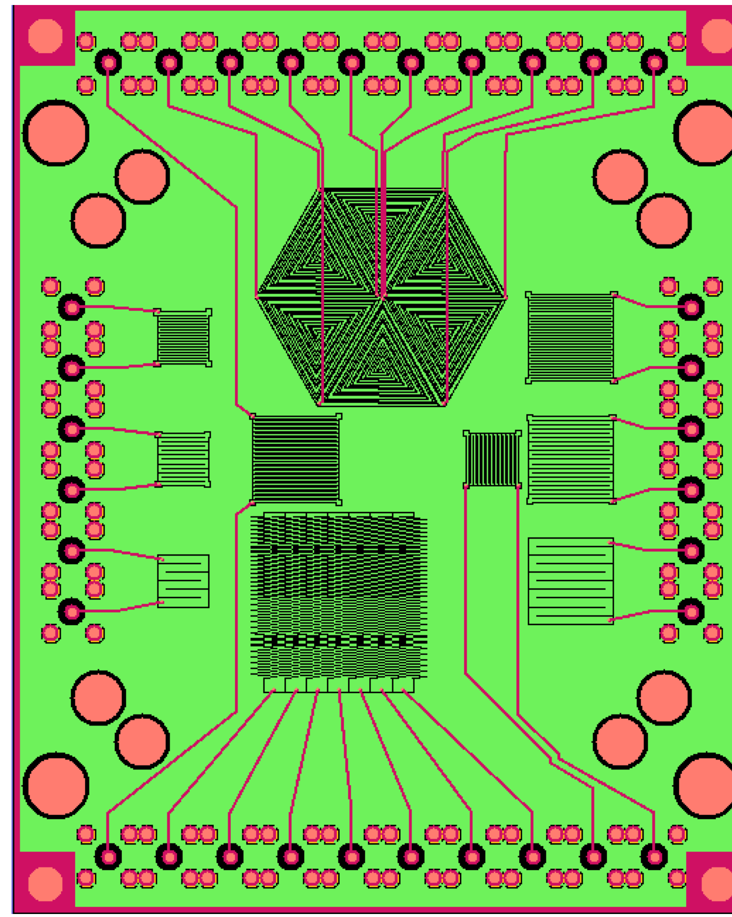
2D strip and 2D pad gerber views



-> the proposal is to "port" this expertise and know-how to MCP-based devices and *unify an ultra-high timing and a decent spatial resolutions in one detector*

Pre-history (FTBF run 2019)





- A small board with a few charge-sharing and delay line patterns was designed @ BNL for the Argonne de-mountable chamber
- Was never implemented in hardware

R&D campaign of 2020

Focus on the capacitively coupled Argonne MCP-PMTs and Incom Gen II LAPPDs in a highly pixelated configuration

- Use existing 128 channels of DRS4 electronics (CAEN VME 1742 digitizers)
- Collaborate with UVa (Kondo) to get a second set of 4x 2D COMPASS GEM chambers (expected spatial resolution of ~20-30μm at the LAPPD location)
- Use existing APV25 cards (SRS electronics)
- Use existing picosecond laser and other lab equipment at BNL

- Take advantage of the existing RCDAQ implementation ...
- ... and custom PCB design software developed for the MPGD project

- Core team: Junqi (Argonne), Mickey / Bob / Martin / AK (BNL), Mark (Incom) and Carlos (Stony Brook)
- Two Elke's postdocs (Ana and Alex) and BNL junior scientist (Brian) volunteered to work in the test run, with a focus on the online data analysis

R&D campaign of 2020

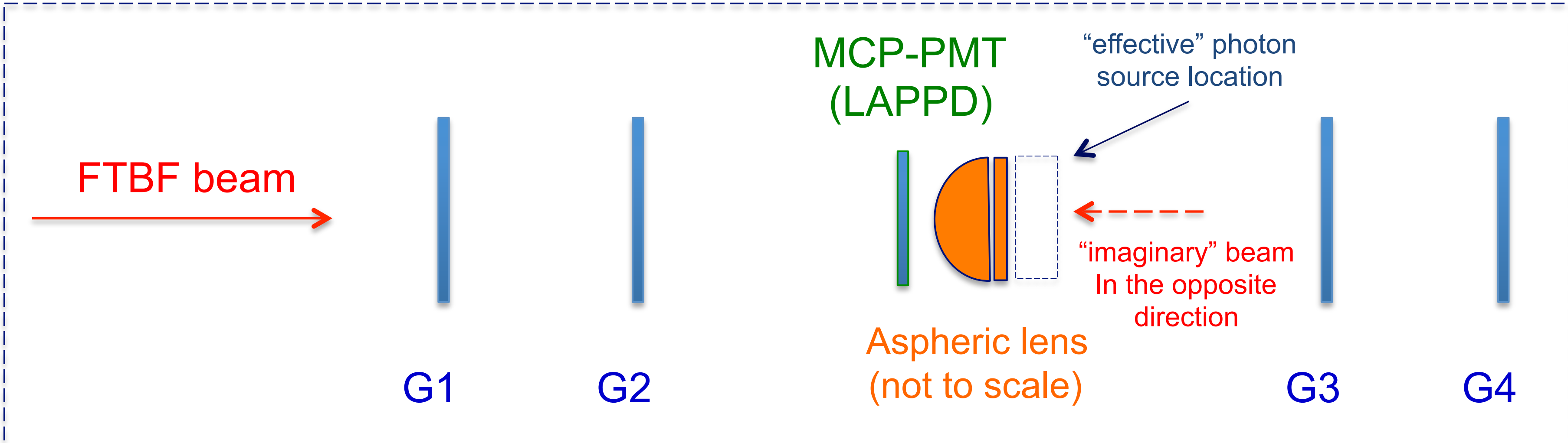
- Argonne provides a pair of fresh MCP-PMTs
- Incom provides a pair of LAPPDs with different anode plane resistivity

- Build new pixelated PCBs and MCX adapter cards
- 3D print the optical enclosure elements, including LAPPD holding frame
- Borrow miniature optical translation stages and other optical equipment
- Acquire Cherenkov radiator lenses, MCX->MCX cables, ...
- Build 8020 frames and base plates, etc

- Have all this ready (and tested :-) by the April,22 − May,5 FTBF test run

-> by this time the essential long lead time fraction of the new equipment is either acquired or ordered, but the lab trials essentially have not started yet and the test run itself was cancelled

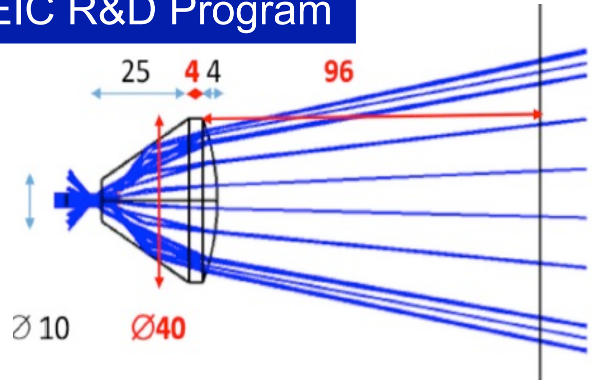
Beam line configuration



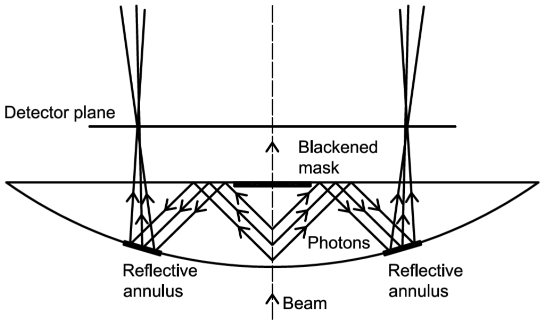
- GEM tracker (2x2 100x100 mm^2 COMPASS 2D chambers)
- *Either* Argonne MCP-PMT *or* Incom LAPPD (only 128 DRS4 channels)
- Small thick fused silica aspheric lens from Edmund Optics:
  - MCP-MPT: #87-975, 12.5 mm diameter, 10.0 mm effective focal length, 8.0 mm central thickness
  - LAPPD : #67-265, 25.0 mm diameter, 20.0 mm effective focal length, 14.0 mm central thickness
- *Backward reflection of Cherenkov light* on the rear flat lens surface
  - A single ~$400 off the shelf optical component ...
  - ... with minimum of required modifications (the ground side needs to be black painted though)
  - "Perfect" optics for all photons, which do not hit the side surface (those will be absorbed): a single refraction of a mirror-imaged Cherenkov light cone + refraction on the MCP-PMT window; no spherical aberrations and no parasitic reflections inside the lens

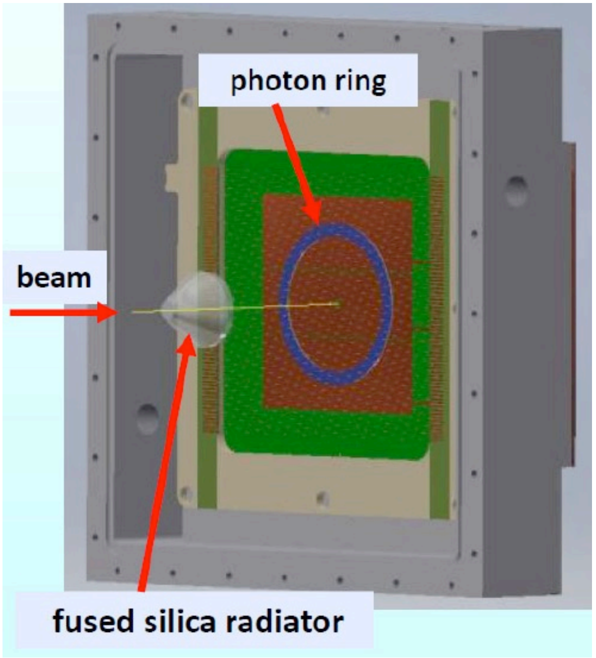
Other ways to “create” optical photons

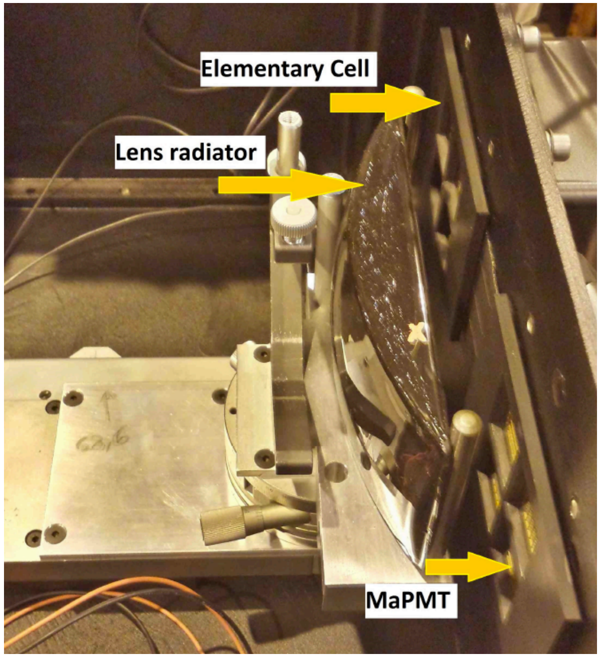
EIC R&D Program



LHCb R&D



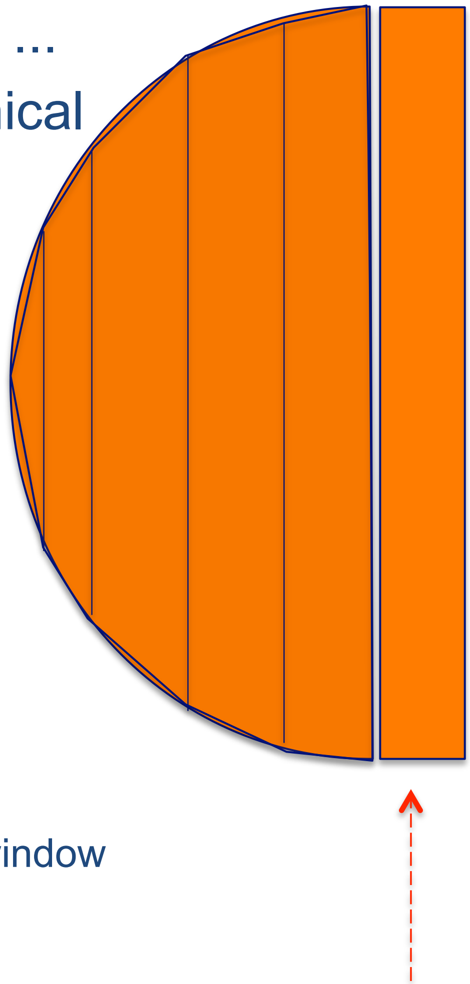




-> in both cases a thick custom spherical lens is used, and an additional effort is required so suppress “parasitic” Cherenkov light

Lens & optics modeling in GEANT

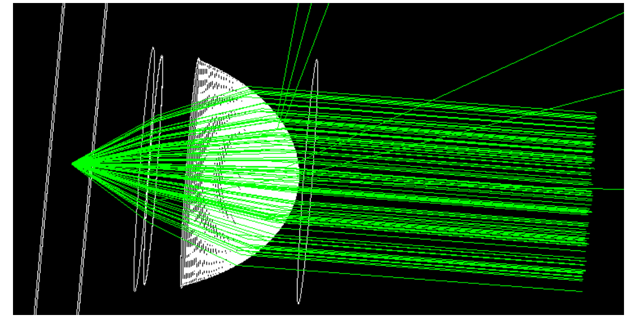
- Aspheric lens: a complicated parameterized surface ...
- ... which can be approximated by a sequence of conical slices and represented as such in GEANT
- Side surface assumed to be black painted (!)
- What is included in the model:
  - Fused silica refractive index dependency on the wave length
  - Optional acrylic layer transmission efficiency
  - MCP-PMT(or LAPPD) quantum efficiency
- What is NOT included:
  - Possible surface imperfection for both the lens and the entrance window
  - Absorbtion in the lens material and the window



-> the former can hardly be modeled reliably (and actually should not play a role given a small number of optical surface crossings)
-> the latter must be a ~10% effect on the overall photon count

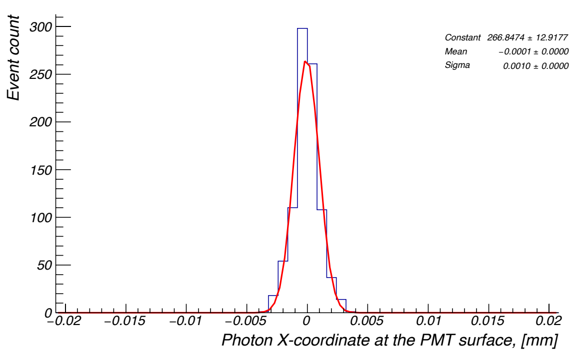
Optics simulation: photon “beam”

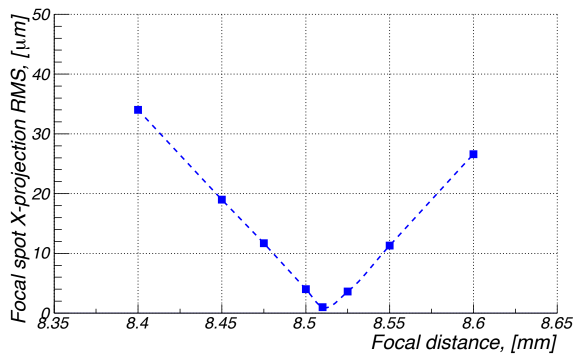
- GEANT4 configuration:
  - 10mm diameter spot on the lens, uniform distribution
  - Beam axis parallel to the lens axis
  - Fixed nominal wave length of 587.6 nm (fused silica refractive index 1.458)

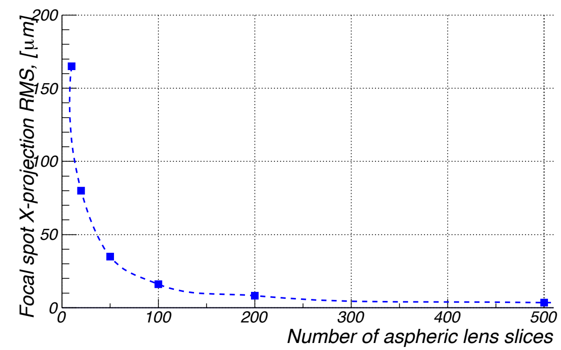


parallel photon beam

(!) “Nominal” focusing configuration (convex->planar refraction sequence)







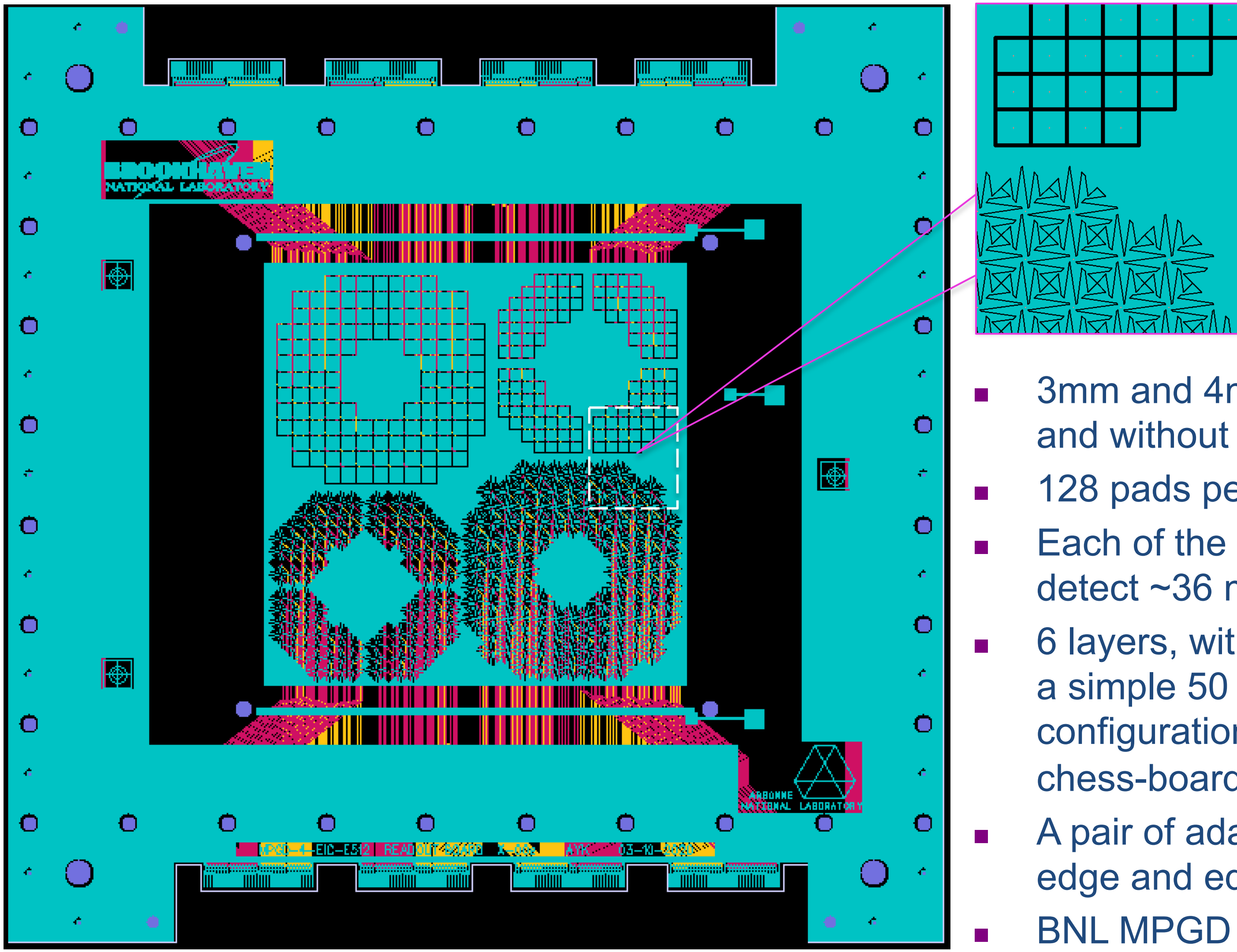
Here the lens is sliced into 3000 layers and the focal distance is set to 8.51mm: spot size ~1μm (nominal tech spec value is 8.52mm, so the lens description is correct)

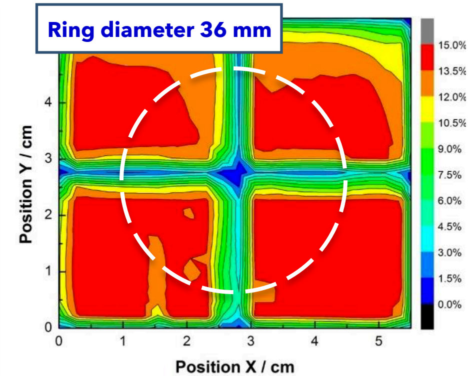
Focal distance scan: focal depth is not great, but it matters only for the basic lens performance proof with a laser and a CCD camera

Lens slice count scan: geometry approximation with ~200 slices suffices for all practical purposes

geometric optics assumed everywhere (no diffraction effects)

Readout PCB for Argonne MCP-PMTs

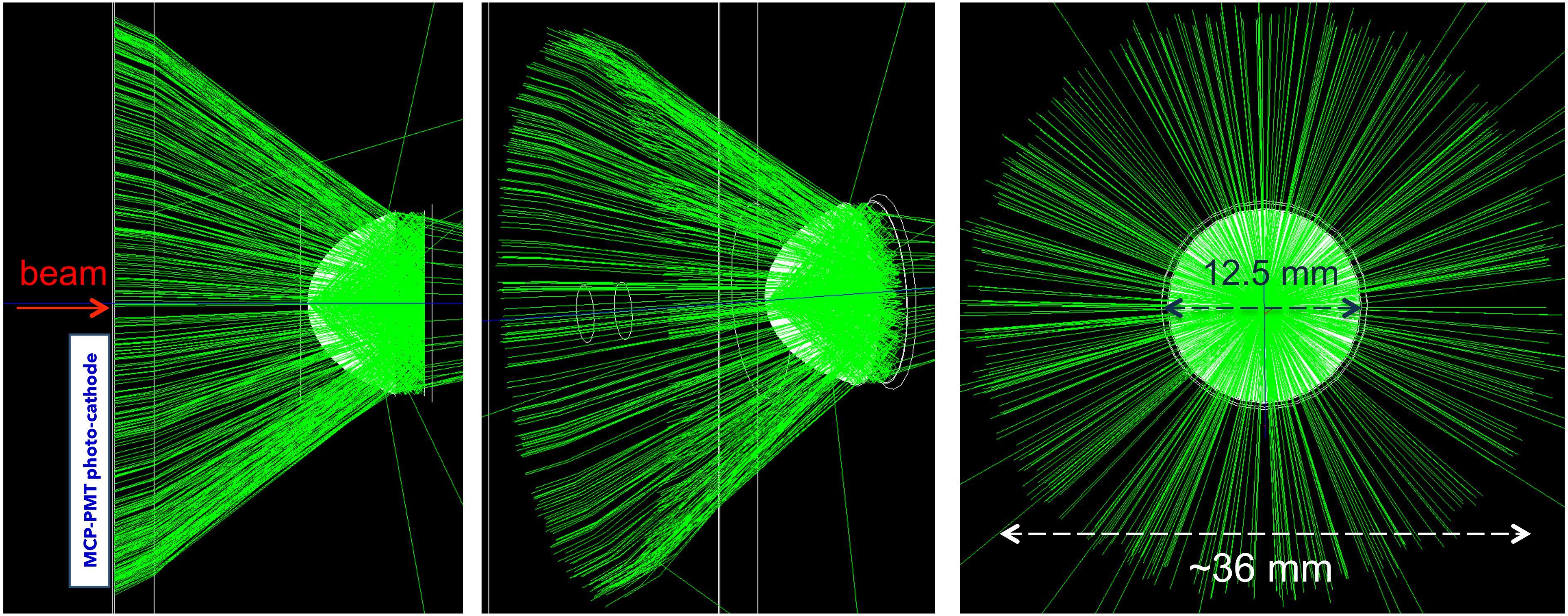




- 3mm and 4mm pad quadrants, with and without charge sharing
- 128 pads per quadrant
- Each of the quadrants is tuned to detect ~36 mm diameter rings
- 6 layers, with traces routed away in a simple 50 Ohm micro-strip configuration (two signal layers in a chess-board-like fashion)
- A pair of adapter cards (edge-to-edge and edge-to-MCX) will be used
- BNL MPGD prototype form-factor

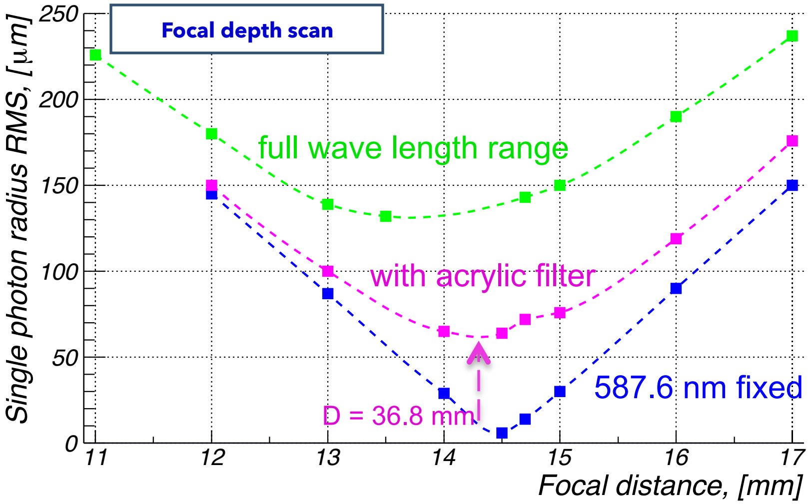
-> shipped to BNL already (but we have not seen it yet)

Optics simulations: 120 GeV protons



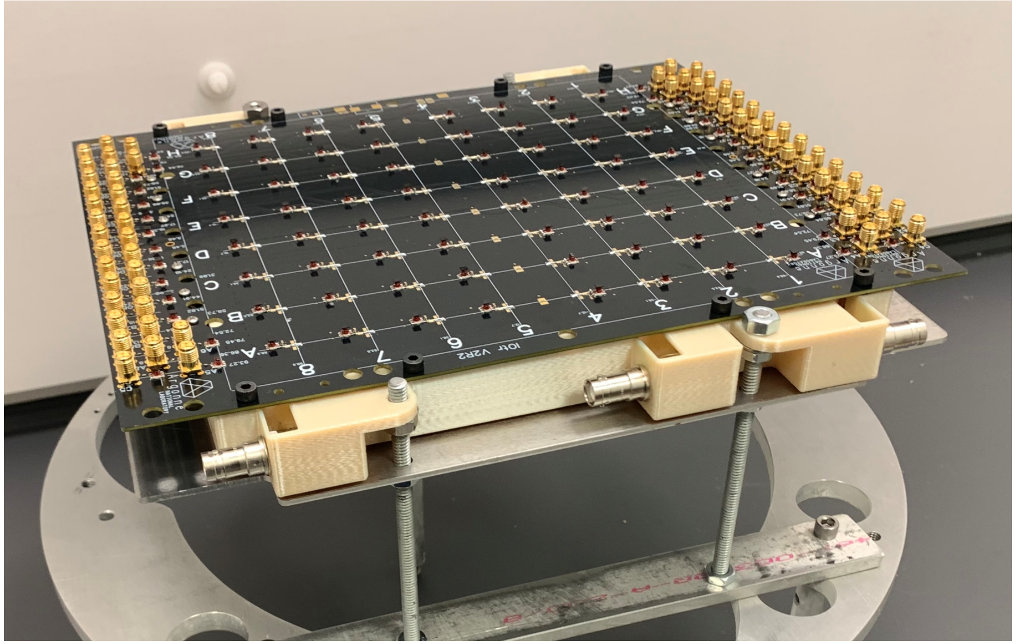
- Argonne MCP-PMT case is shown (*without filter*)
- Optics seems to work
- Focal depth is comfortably large (a couple of mm)

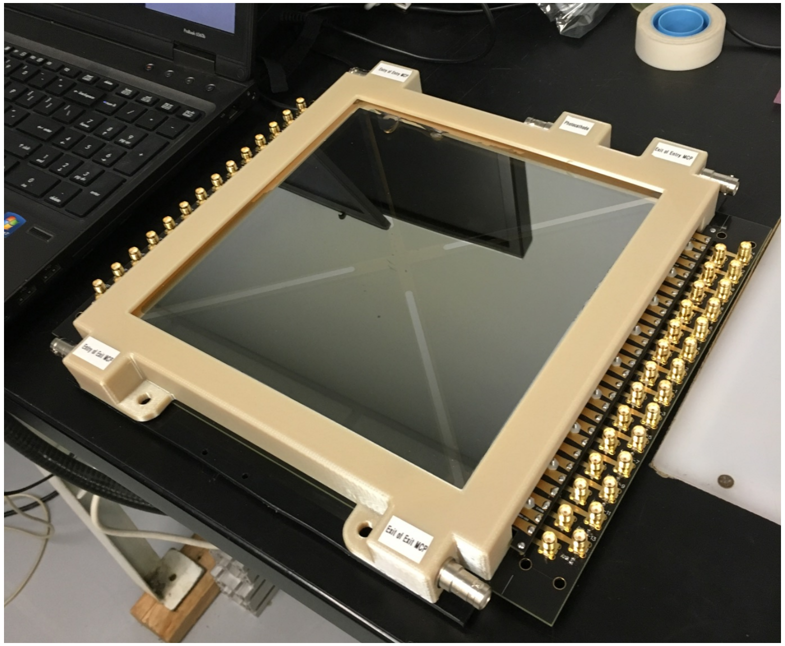
- A "clean" case (*with acrylic filter*):
  - $\langle N_{ph} \rangle \sim 10$ (will be less because of MCP-PMT spacers)
  - Double hit probability: ~10% (3mm pixels), ~12% (4mm)

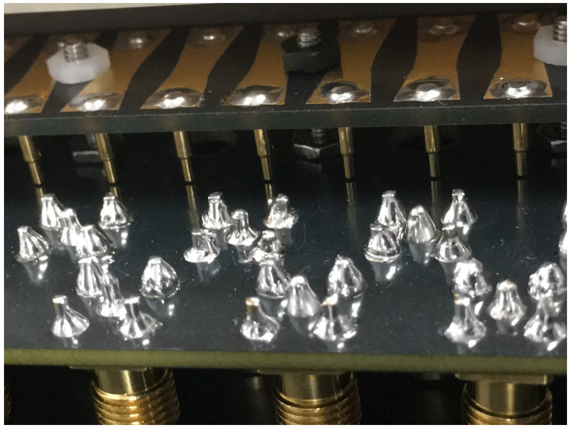


Incom LAPPD enclosure

The "standard" Incom design



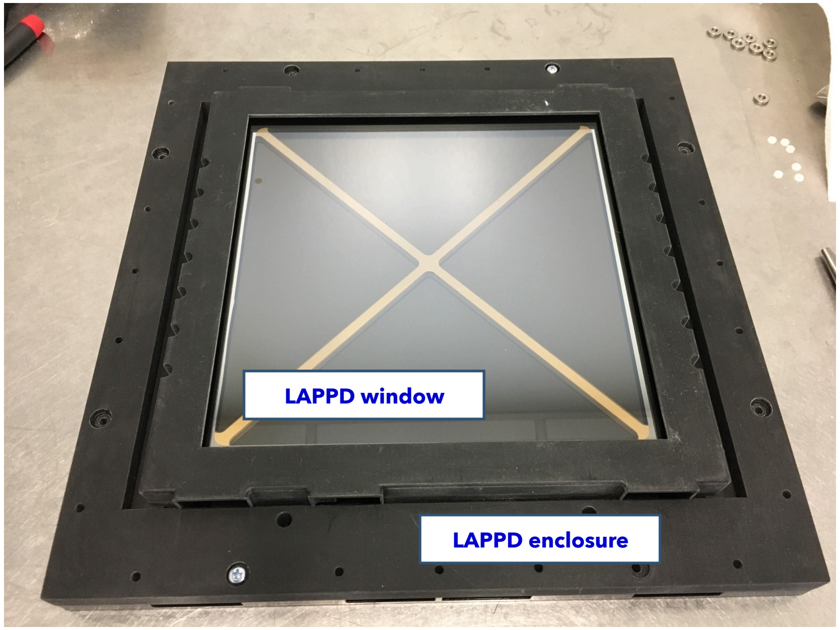


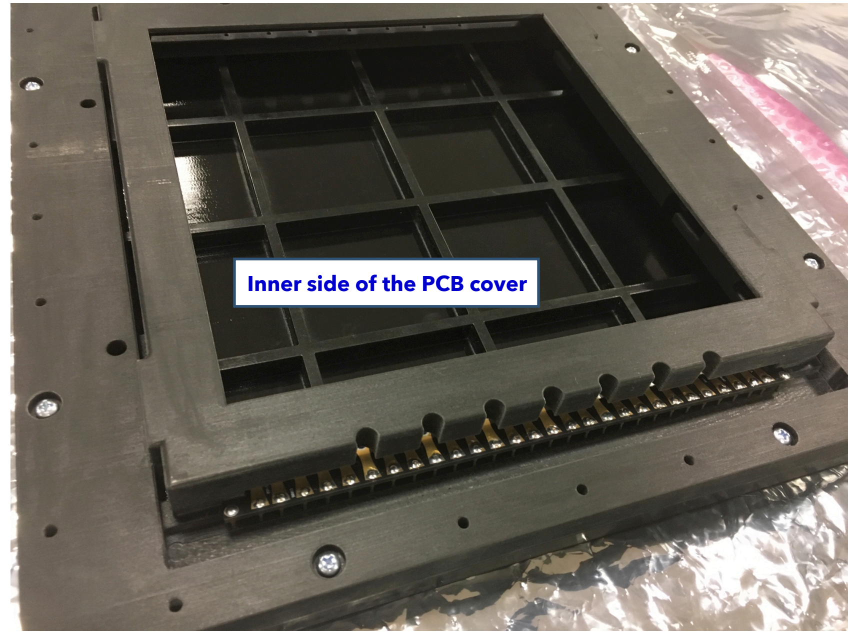


- No optical separation between LAPPD tile compartment and the readout PCB, therefore can not make the setup light-tight "in the right place"
- Can seemingly be improved for integration purposes in general: sealed flange added along the circumference, etc.

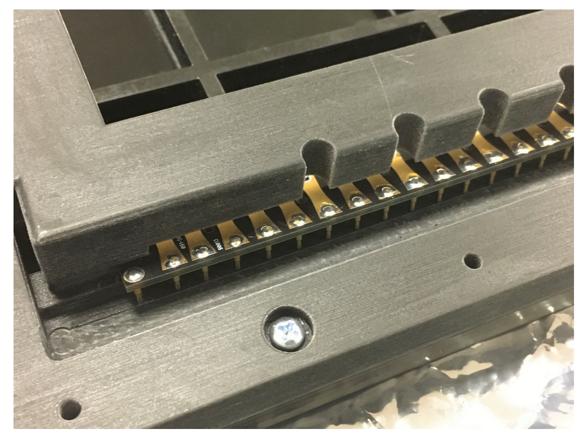
Incom LAPPD enclosure

The variation, modified for easier integration @ Fermilab



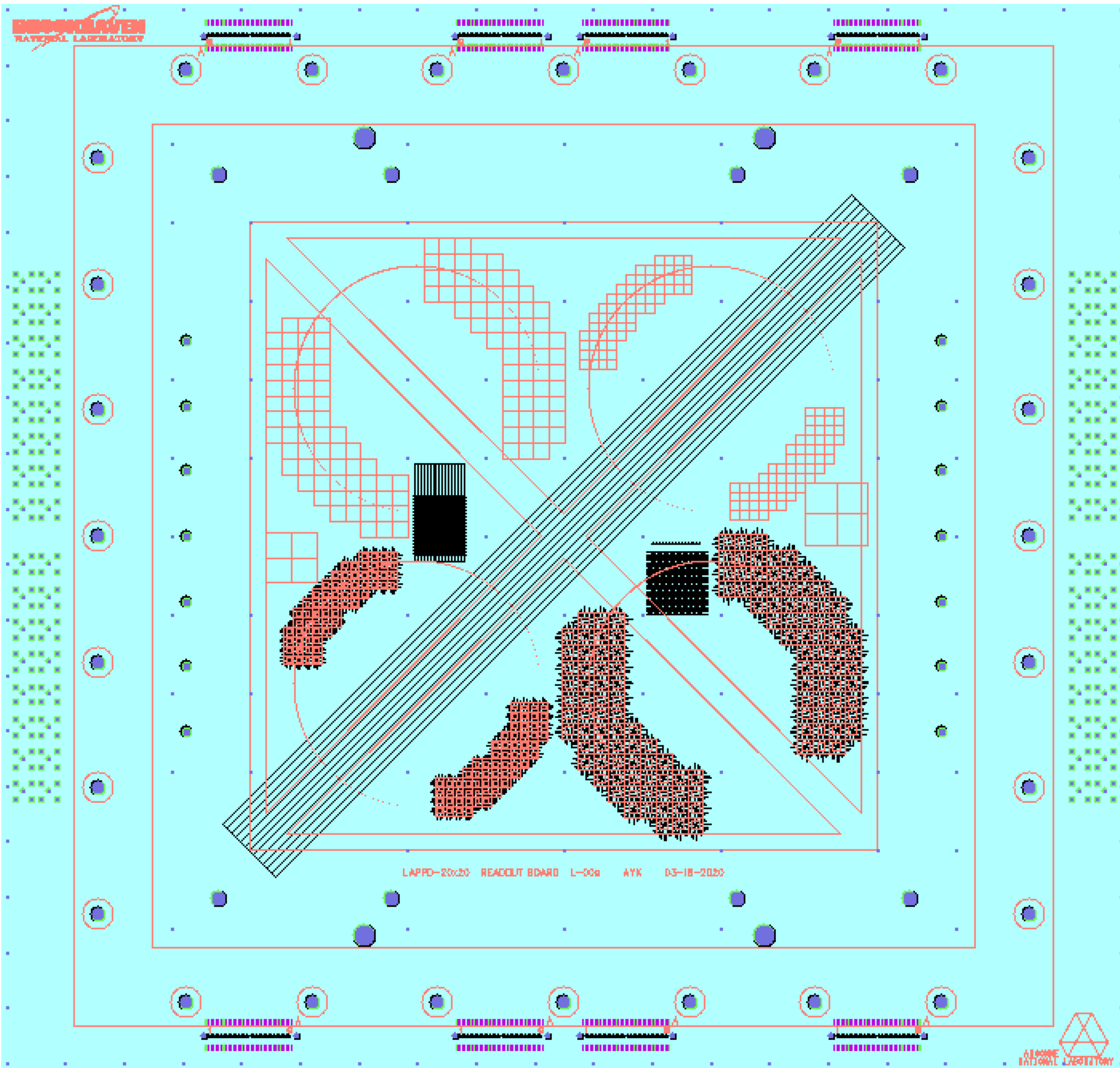


- Merge the existing CAD model with a flange part
- Move the mechanical holes to the outside area
- Integrate support of the retaining pins into the enclosure itself (no need to press against the readout board, therefore no direct contact with it)



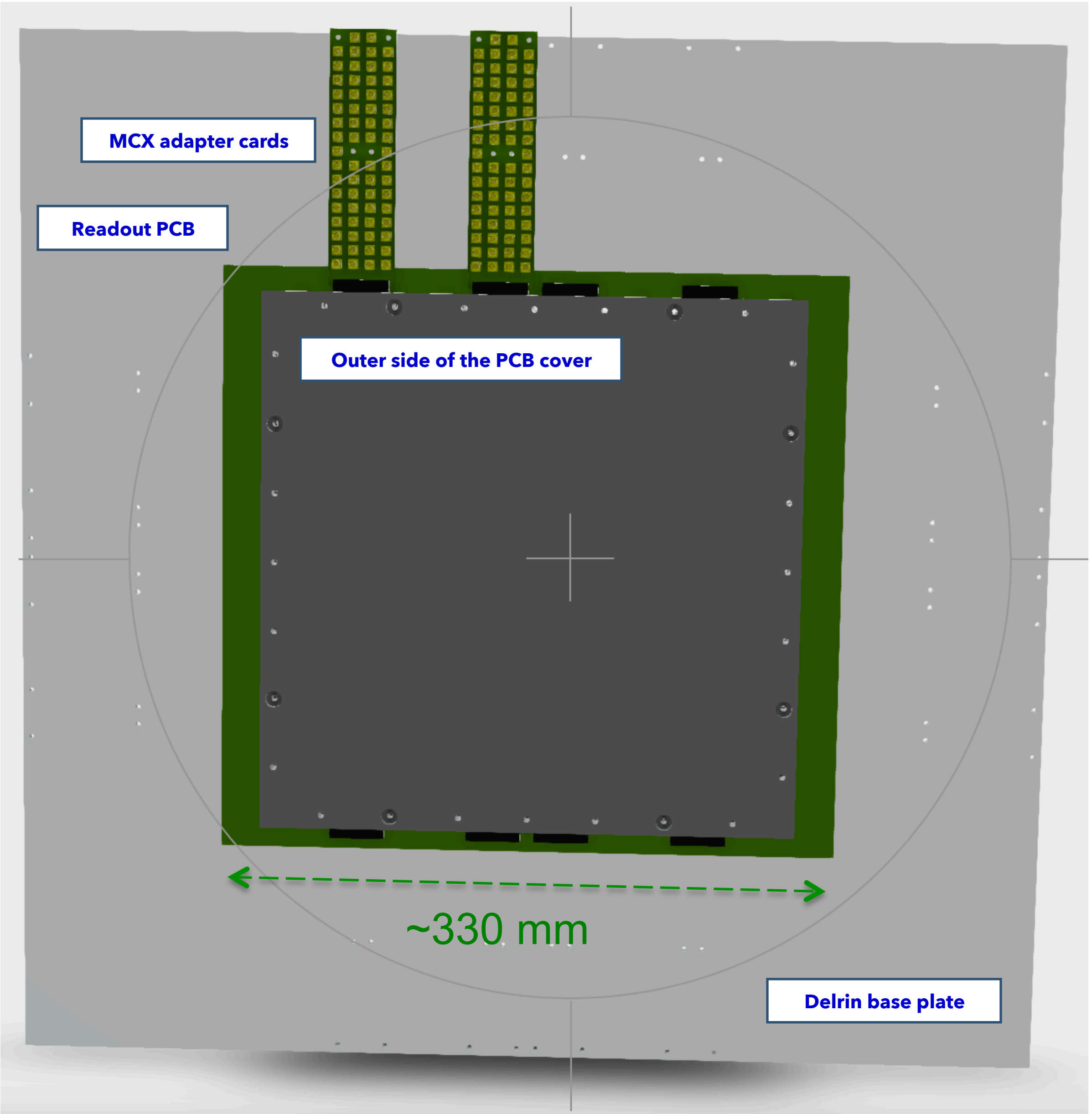
-> can trivially isolate LAPPD tile from the PCB by a sheet of optically tight material (e.g. flock paper)

Readout board for Incom LAPPDs

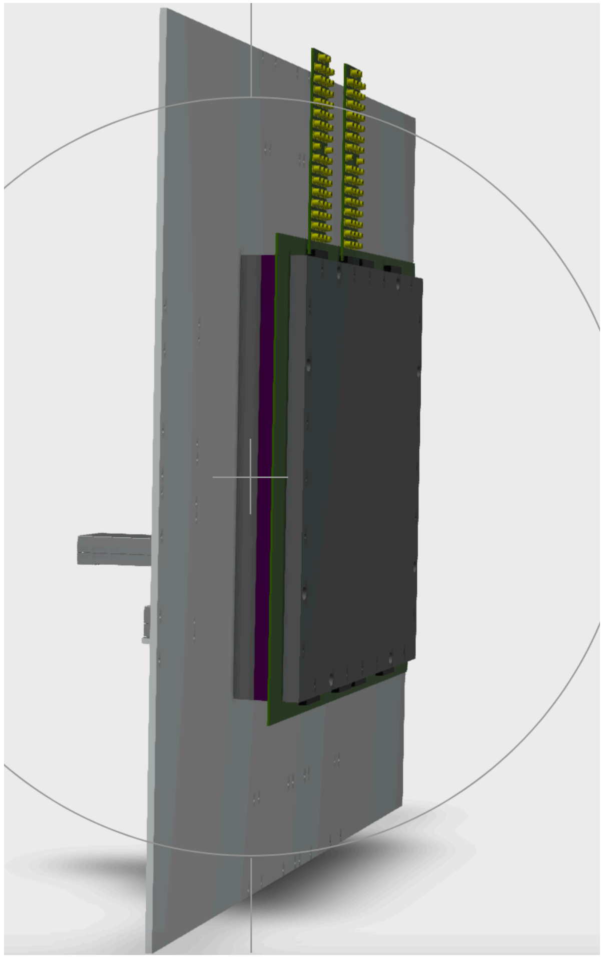


- 3mm and 5mm pad quadrants, with and without charge sharing
- 128 pads per quadrant
- Each of the quadrants is tuned to detect ~76 mm diameter rings
- 8 layers, with traces routed away in a shielded 50 Ohm coplanar waveguide configuration
- Soldered high density connectors and edge-to-MCX adapter cards will be used
- Several other pad spots through the onboard MCX connectors
- Form-factor and mounting scheme match the “new” LAPPD enclosure

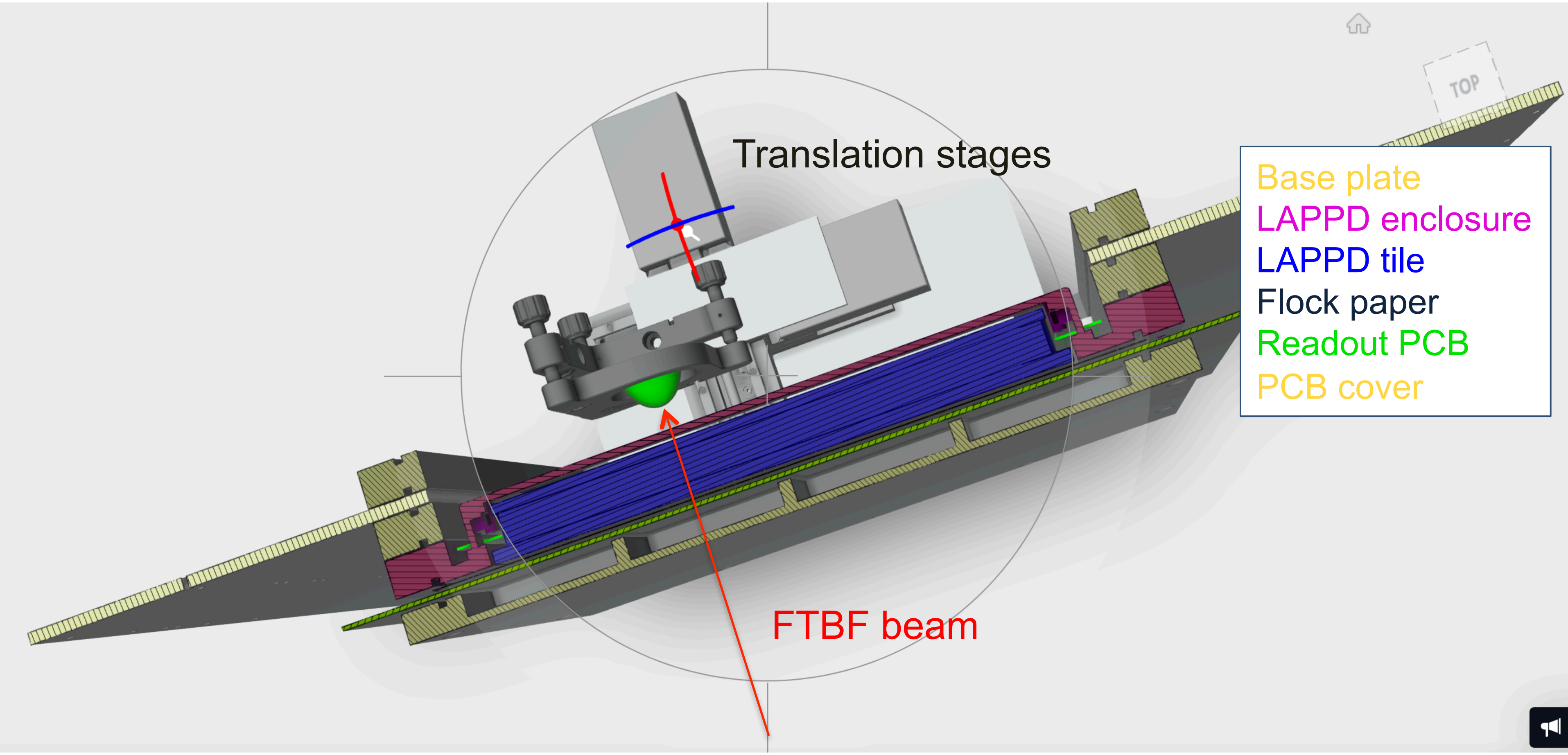
LAPPD setup CAD model, front side



- Beam comes into plane
- Adapters are connected to a single quadrant

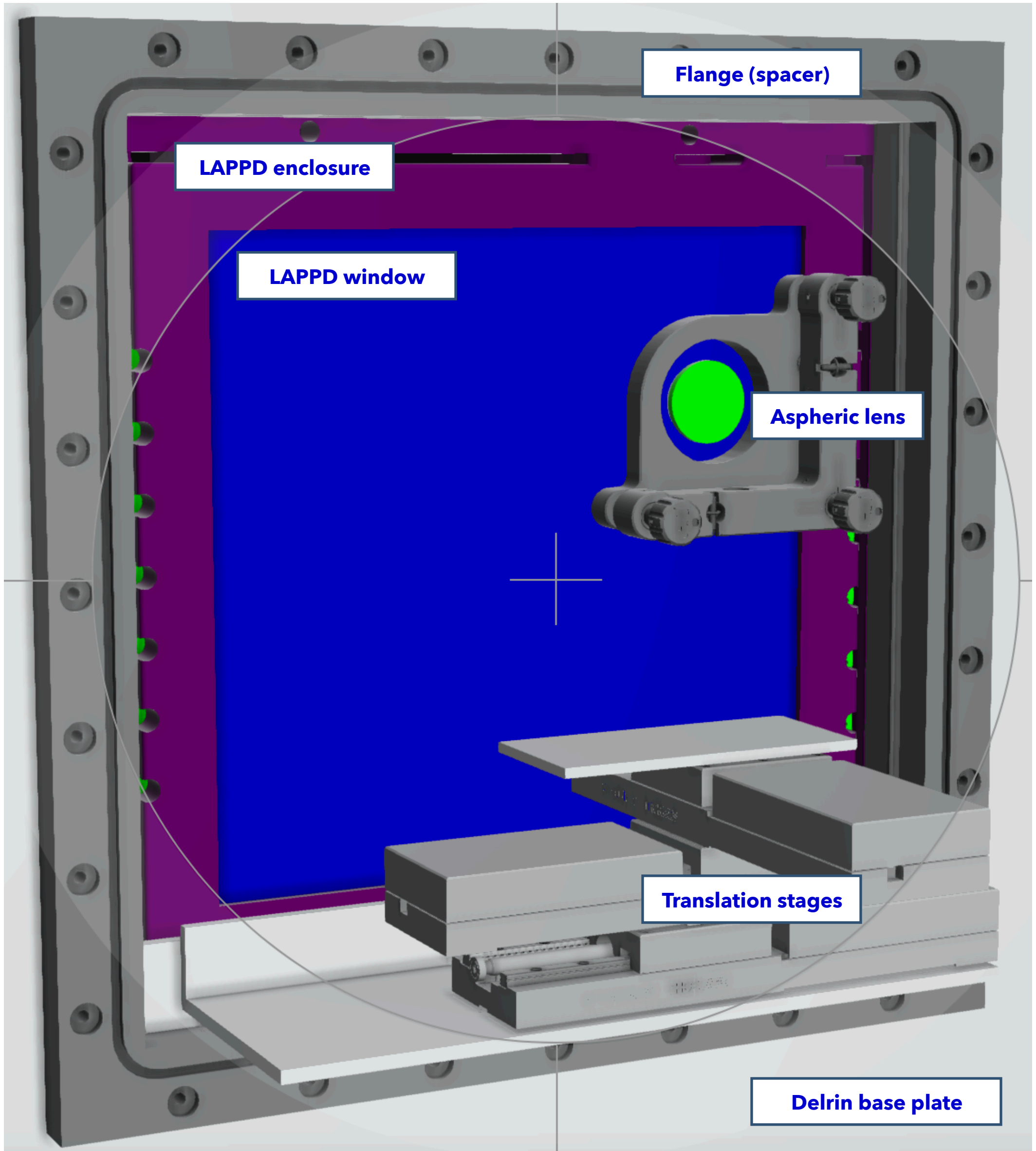


LAPPD setup CAD model, cut top view



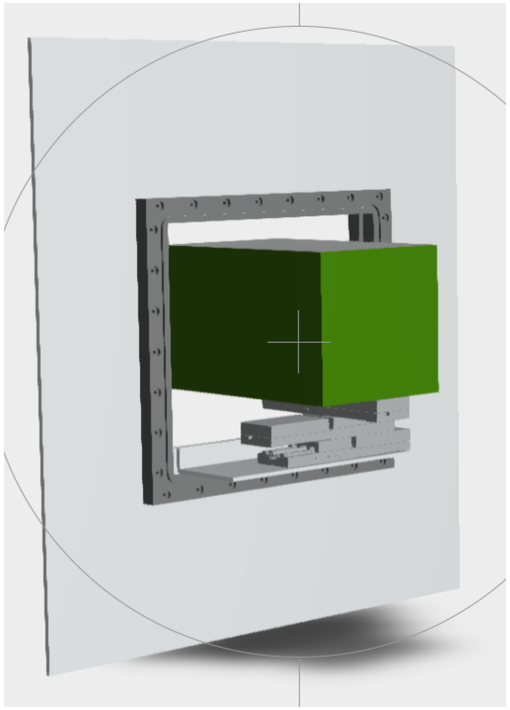
- Cherenkov light radiator (aspheric lens), translation stages and LAPPD tile are optically isolated from the readout PCB; their cover box is not shown
- Cherenkov light is reflected backwards onto the LAPPD entrance window

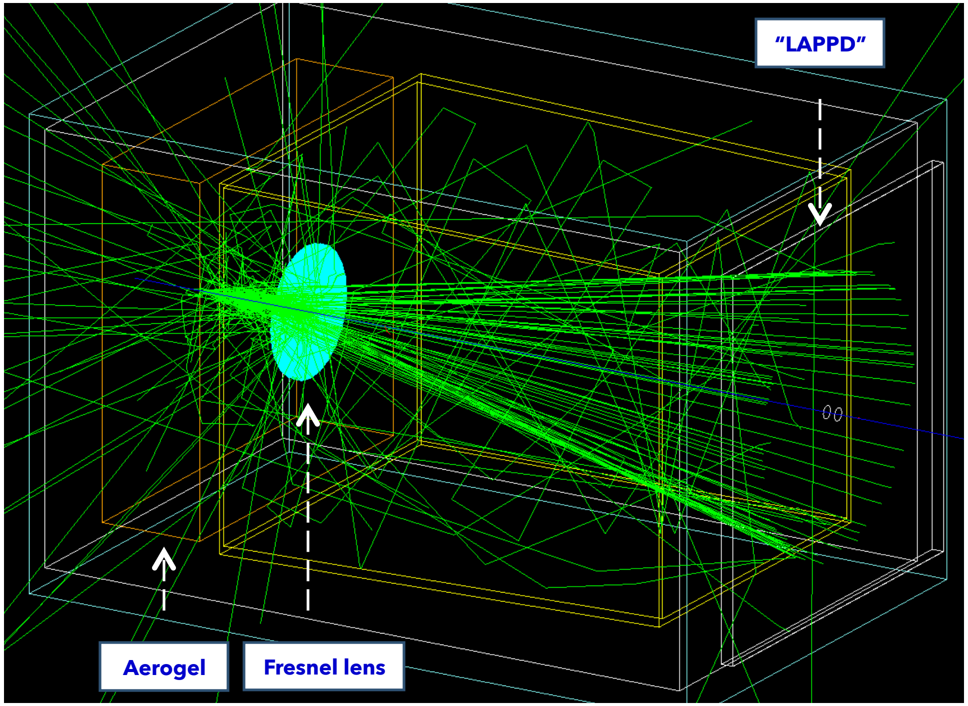
LAPPD setup CAD model, rear side



- Enclosure is light tight and gas tight (assume small continuous air or argon flow to evacuate heat produced by the translation stage motors)
- Translation stages installed either in XYZ configuration (+/- 25 mm travel in all directions) or in XZ configuration (as shown, +/- 25 mm in Z and +/- 50 mm in X)
- Enclosure cover, cables and kinematic mount post are not shown

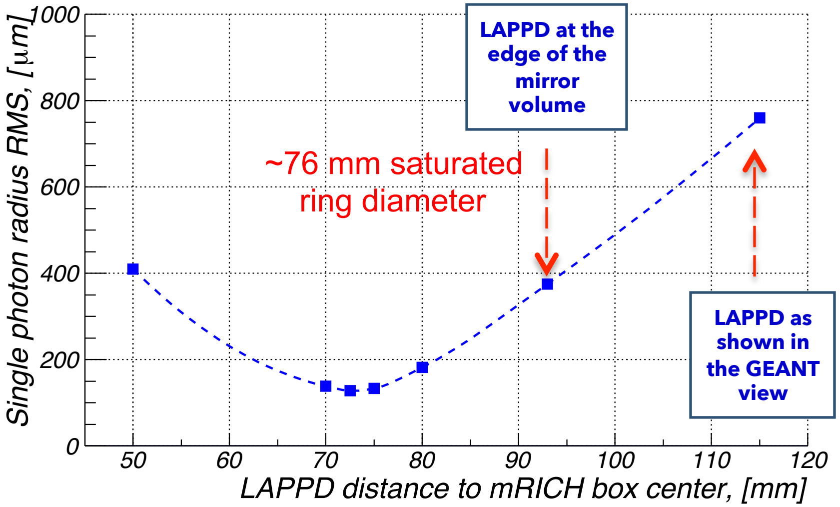
mRICH in CAD & GEANT4 models





- One has to swap front and rear sides of the LAPPD assembly of course (so that mRICH is located *upstream* of the LAPPD)
- A module would fit in even with its external box
- This is rather pointless though, since LAPPD photocathode will be way out of the focal plane

-> obviously more (joint) effort is required



“Life after the coronavirus”

- Get back to work and start checking the equipment in the lab

- GEANT4 optics modeling:
  - Implement missing features and the actual pixel layouts of the LAPPD board
  - Finalize LAPPD setup (so far worked on the Argonne MCP-PMT configuration)
  - Consider ~2 GeV/c momentum particles
- CAD modeling & 3D printing:
  - Finalize the “external part” of enclosure and the LAPPD “internal part”
  - Design MCP-PMT “internal part” implementation
  - 3D print 2x complete sets (for simultaneous installation, but also as a spare)

- Book FTBF time for the spring 2021 run and test it all

- R&D afterwards: collaborate with the ASIC designers?, work on more sophisticated 2D designs?, participate in LTCC design for a HRPPD?, ..?
- Promote adoption in the EIC, facilitate any activities towards implementation