1ST INTERNATIONAL WORKSHOP ON A 2ND DETECTOR FOR THE ELECTRON-ION COLLIDER

Temple University, Philadelphia, PA
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EIC Photosensors R&D

Yordanka Ilieva

University of South Carolina

Work by eRD14, eRD110

ANL, BNL, CUA, GSI, INFN, JLab, MSU, ODU, SBU, UCLA, UErlangen, USC

The Effort

Photonis and Photek MCP PMTs

SPE, position resolution, fast, low dark current rate, reasonable B-field performance, studied for PANDA, TORCH; cost

- **gain and ion feedback evaluation in High-B field**

SiPM

Cheap, reasonably fast, B-field immune; radiation damage, dark current

- **evaluation of radiation tolerance and mitigation procedures**

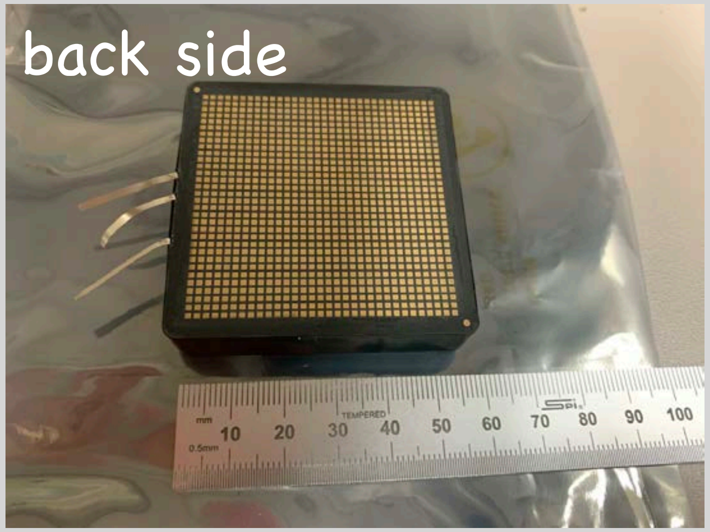
Incom LAPPD/HRPPD

Design optimized for B-field performance, position resolution, hopefully lower cost, LAPPD characterizations by several groups worldwide

- **optimization of design (B-field tolerance, pixelization)**
- **characterization, High-B evaluation**

Photonis MCP PMT

XP85122-S, HiCE



Geometric Specifications:

10 μm pore size

32x32 channels by design

5.3x5.3 cm^2

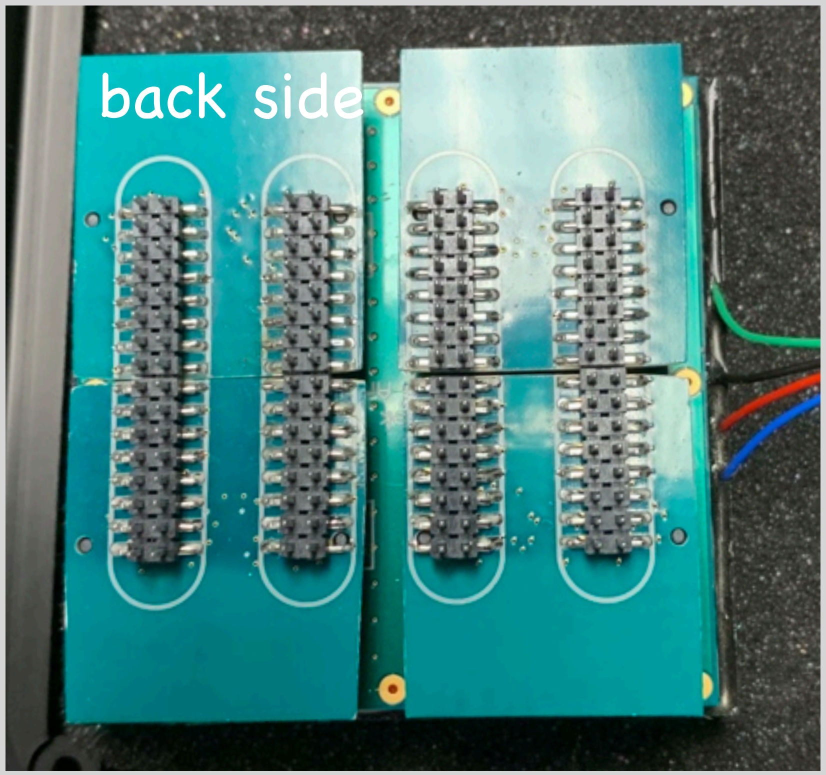
Relationship with Photonis

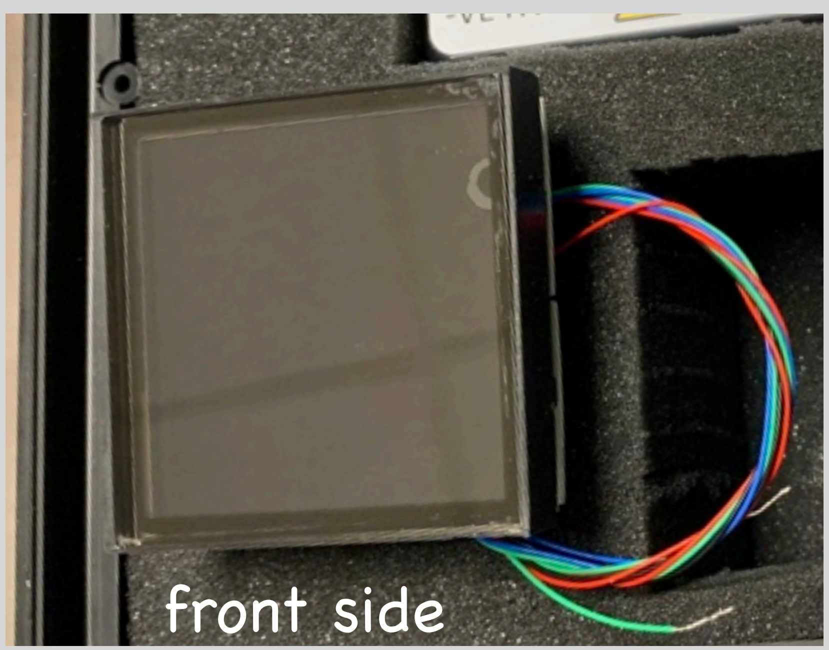
- builds on PANDA-DIRC - Photonis relationship
- has provided tubes on loan for free for EIC
- established MCP-PMT commercial MCP PMT manufacturer
- mature design
- Best known MCP PMTs

Baseline solution for DIRC in ePIC

Photek MCP PMT

MAPMT253





Geometric Specifications:

6 μm pore size (good for high B-fields)

16x16 channels by design

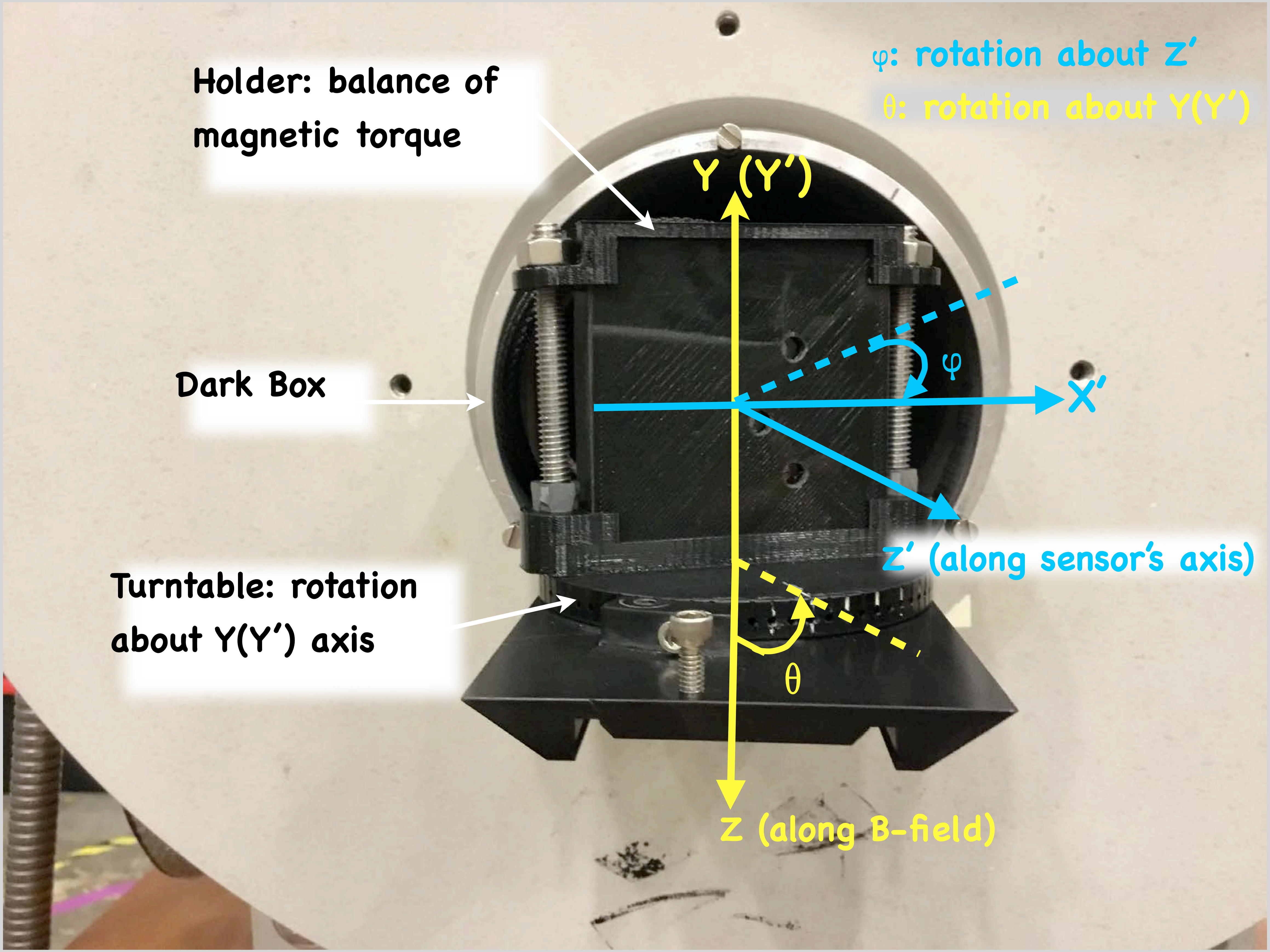
5.3x5.3 cm^2

Relationship with Photek

- builds on PANDA-DIRC - Photek relationship
- has provided tubes on loan for free for EIC
- Established MCP-PMT commercial MCP PMT manufacturer
- relatively new tube
- while some basic characterizations have beed done, further work will be beneficial

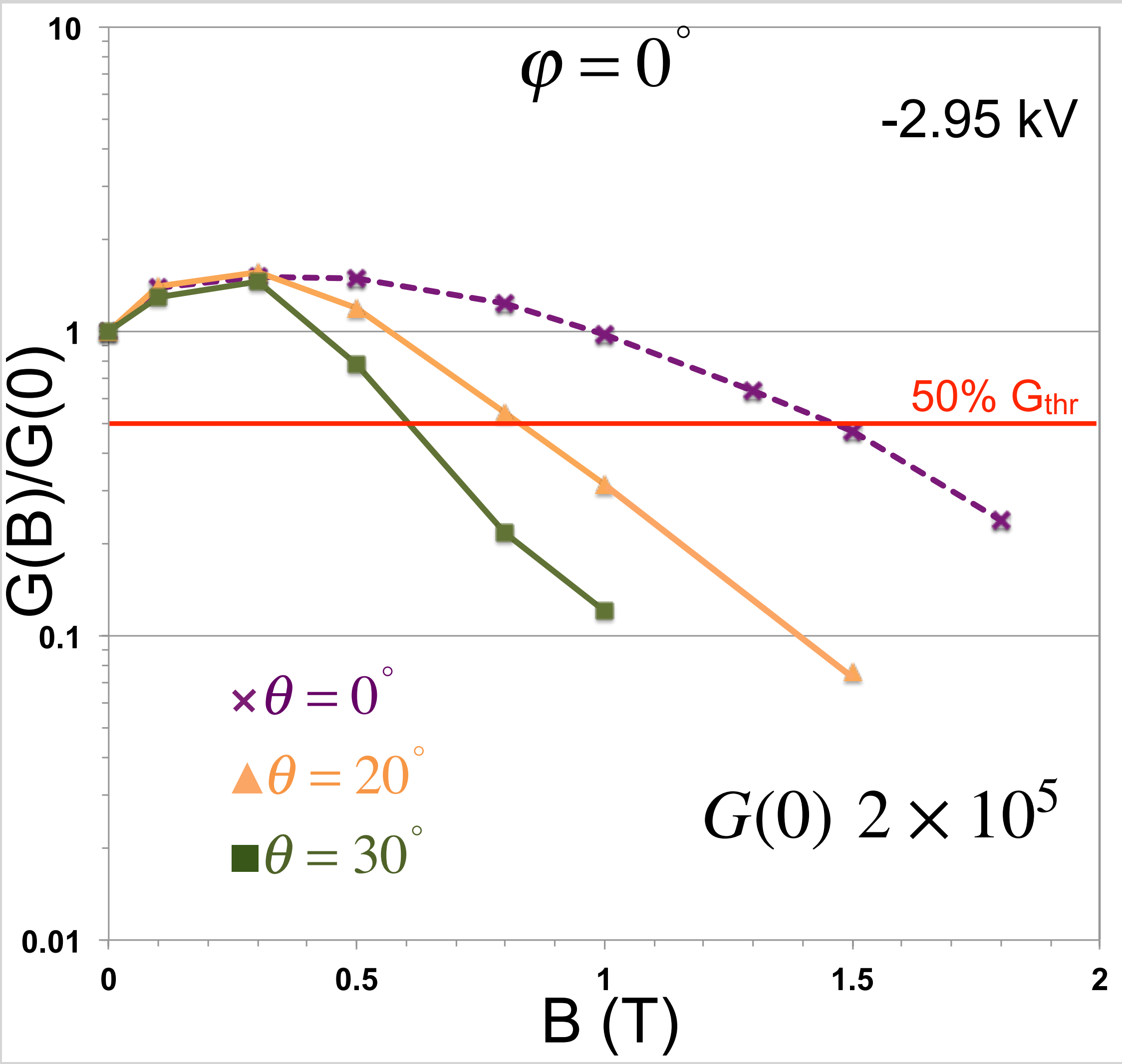
Interesting if B > 1.5 T

Rotation Angle Definitions

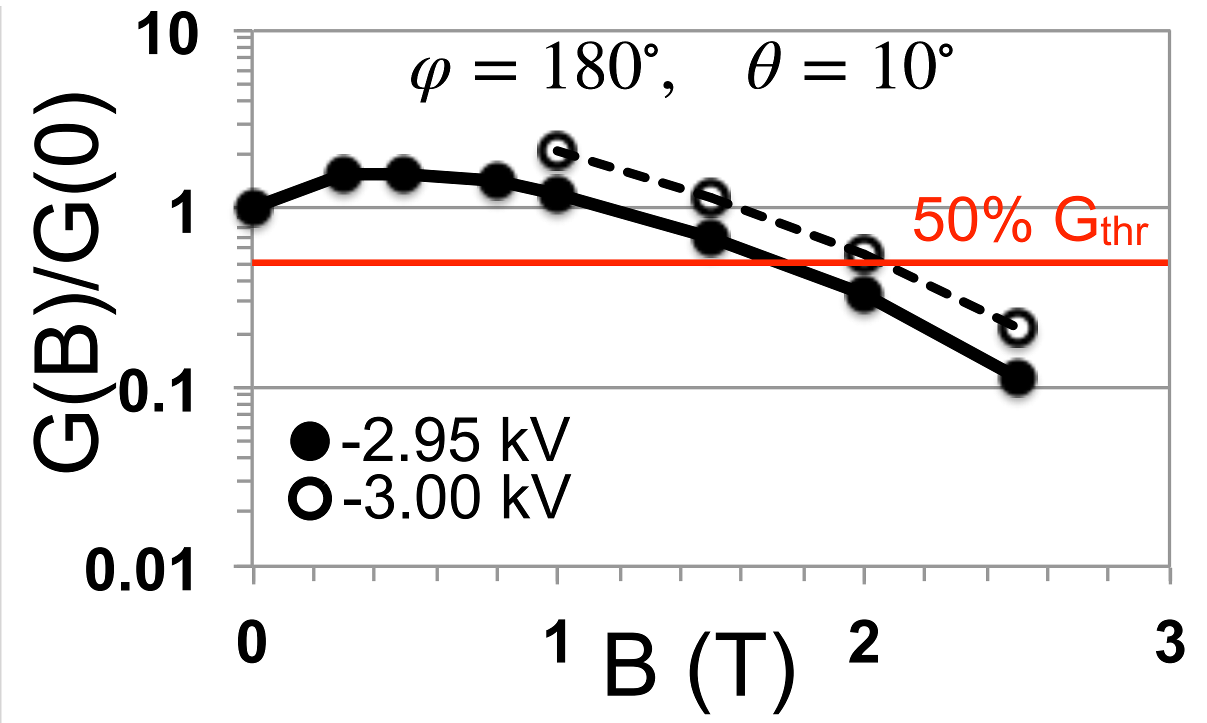


EIC R&D: High-B Performance

Photek MAPMT253 Gain Scan (single channel)



Gain recovery by increasing applied HV



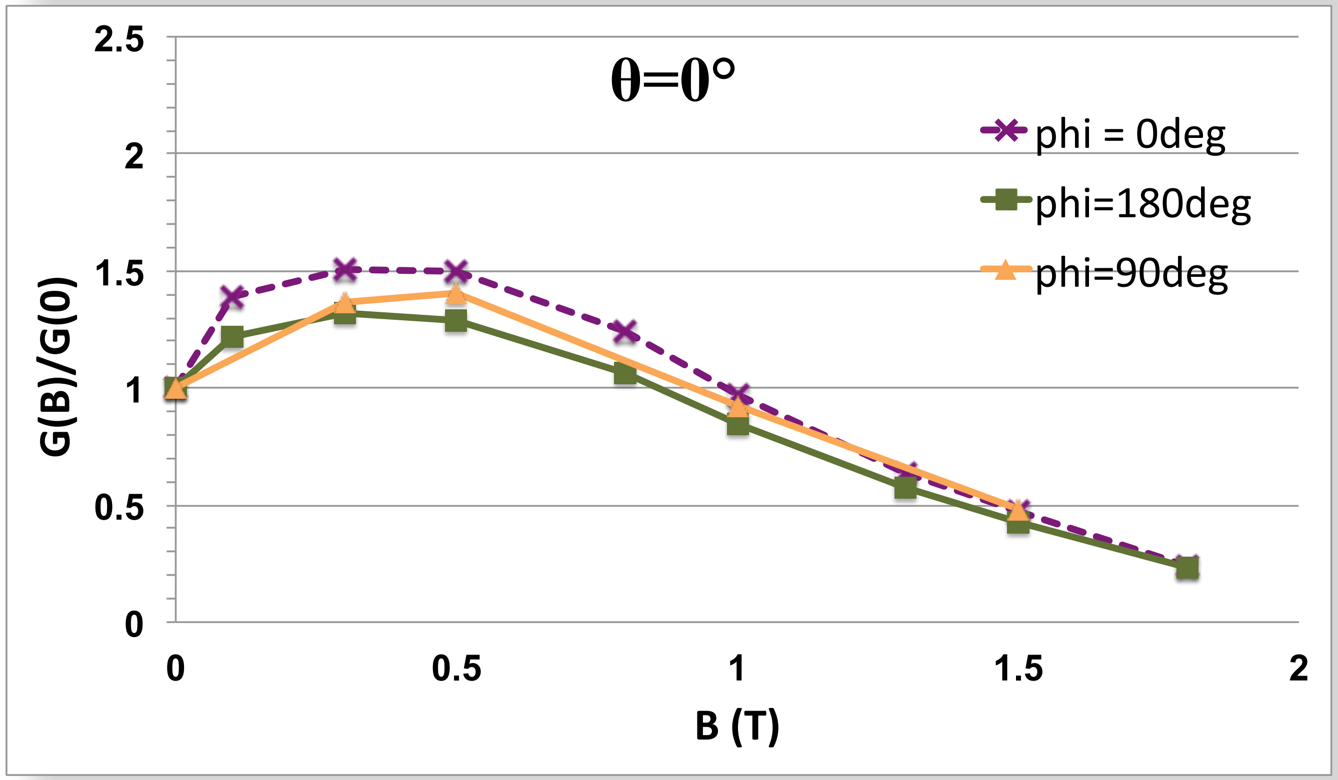
@θ=10°:
G(1 T)/G(0 T) ~ 1
G(1 T)/G(2 T) ~ 3.6

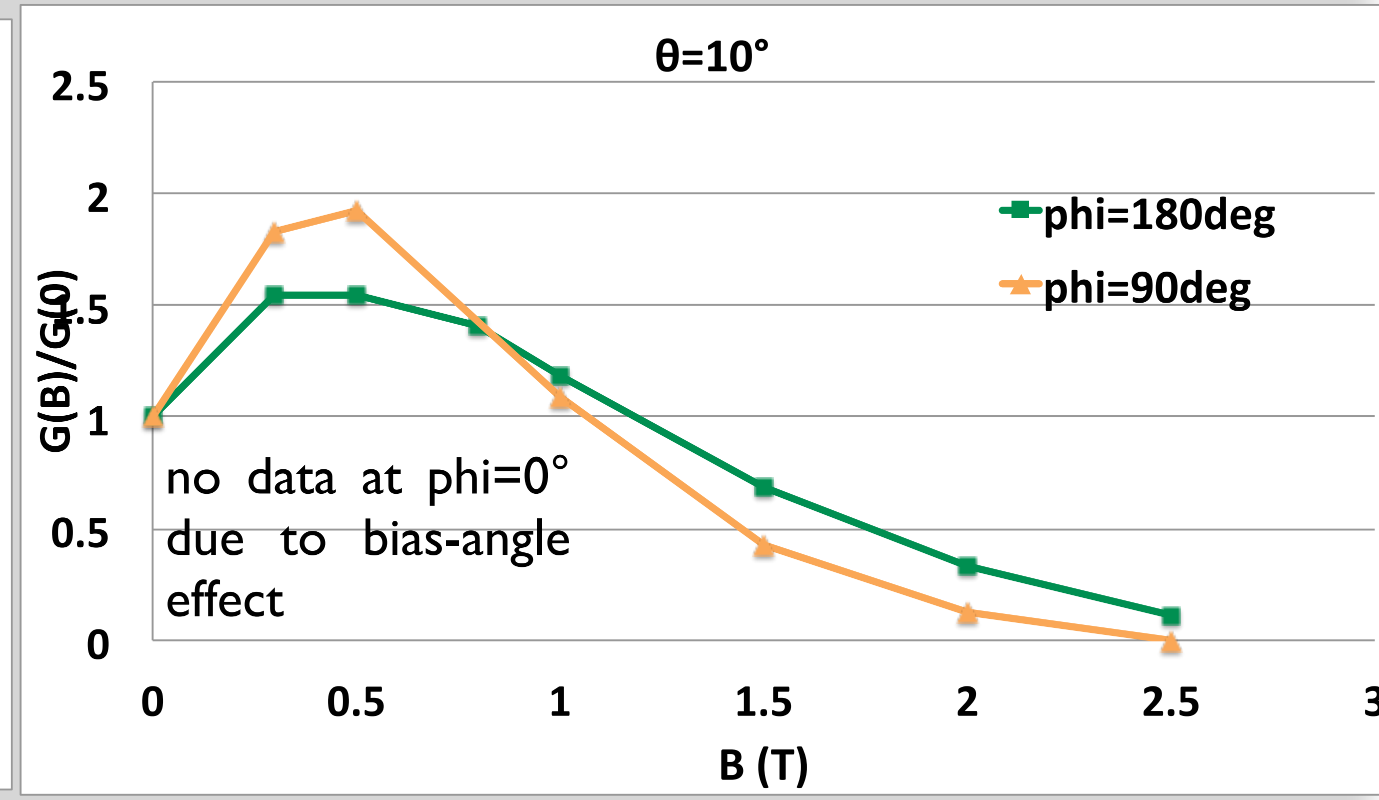
@θ=0°:
G(1 T)/G(0 T) ~ 1
G(1 T)/G(1.8 T) ~ 4

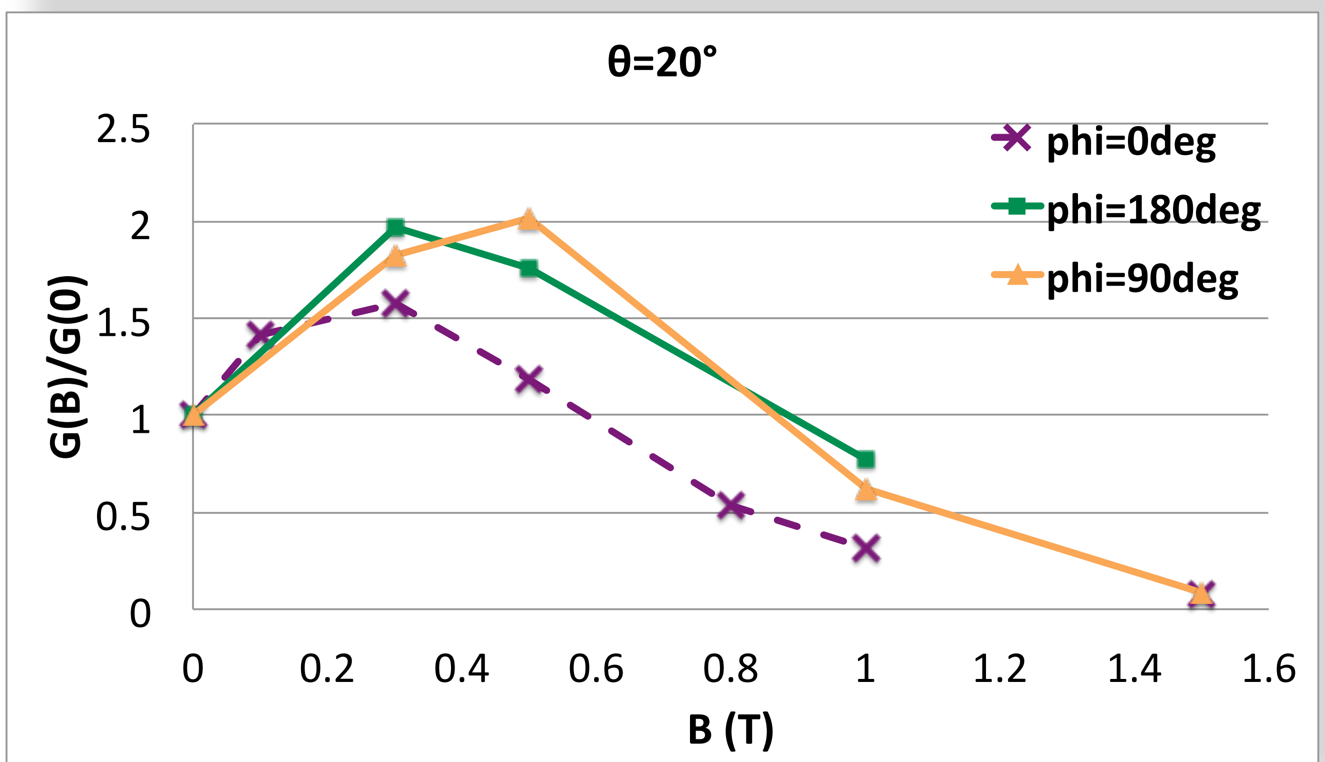
Some φ dependence

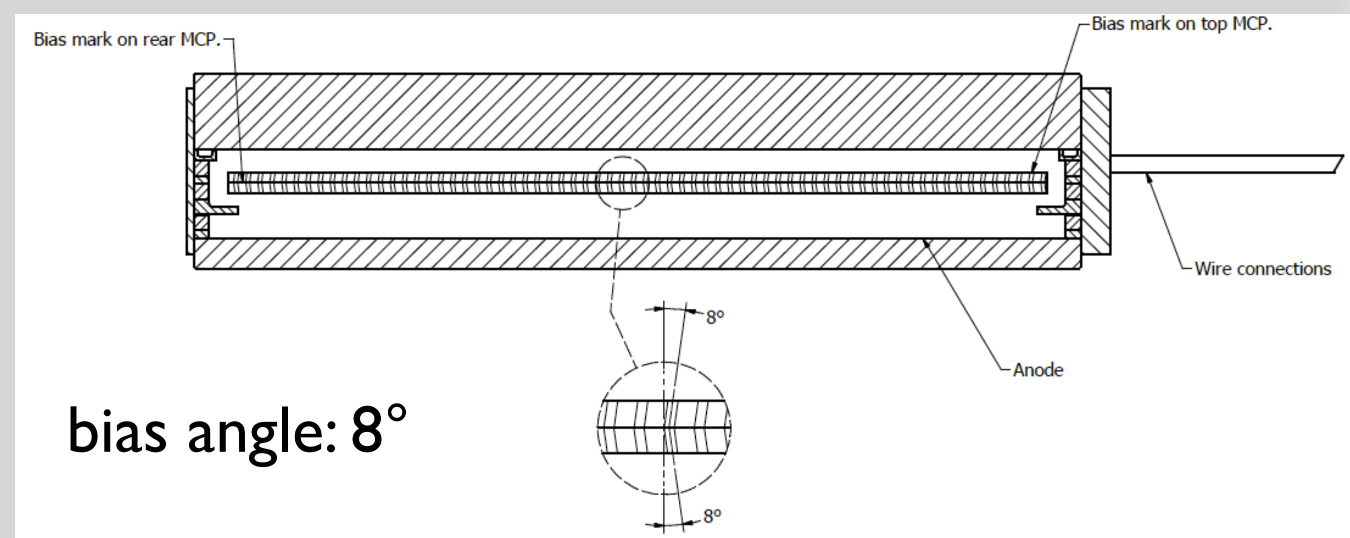
EIC R&D: High-B Performance

Photek MAPMT253 Gain Scan (single pixel)





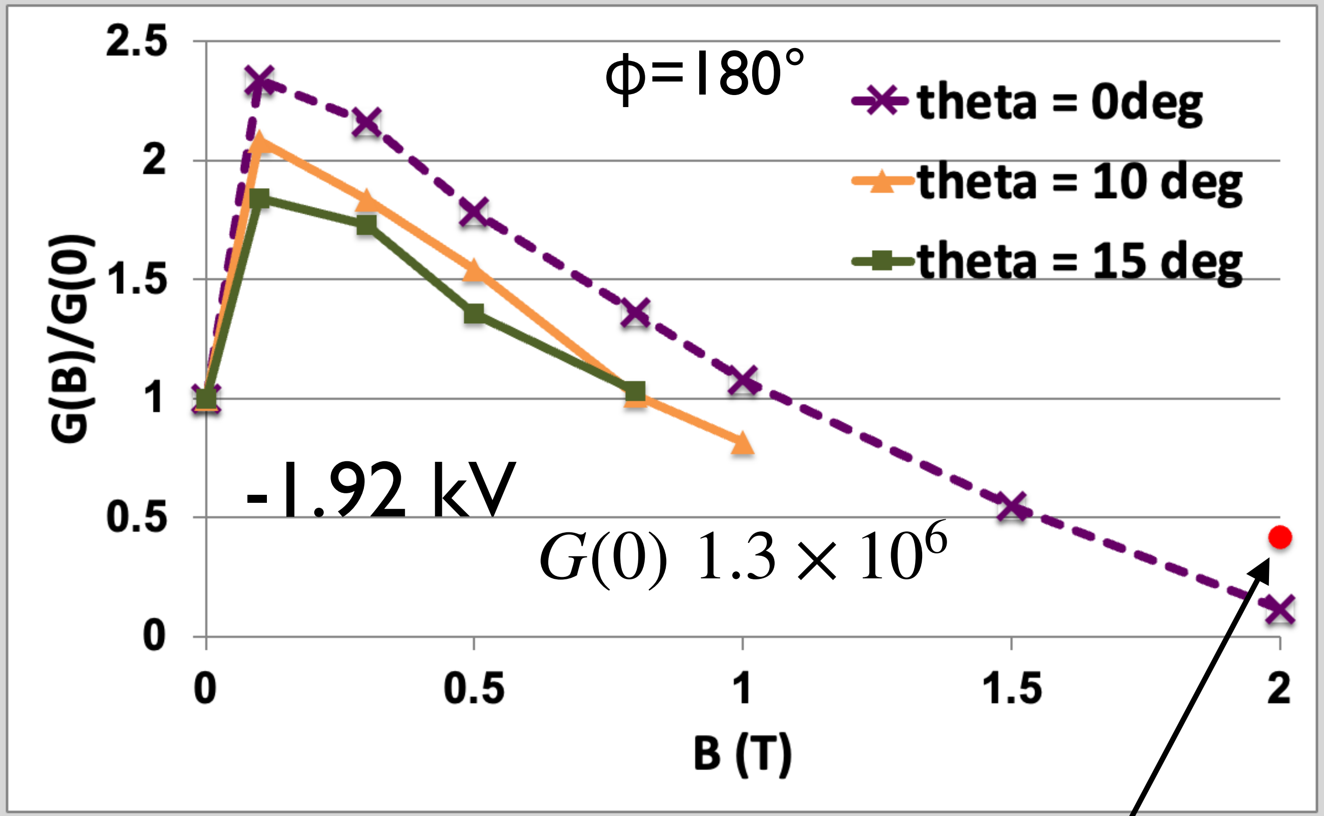


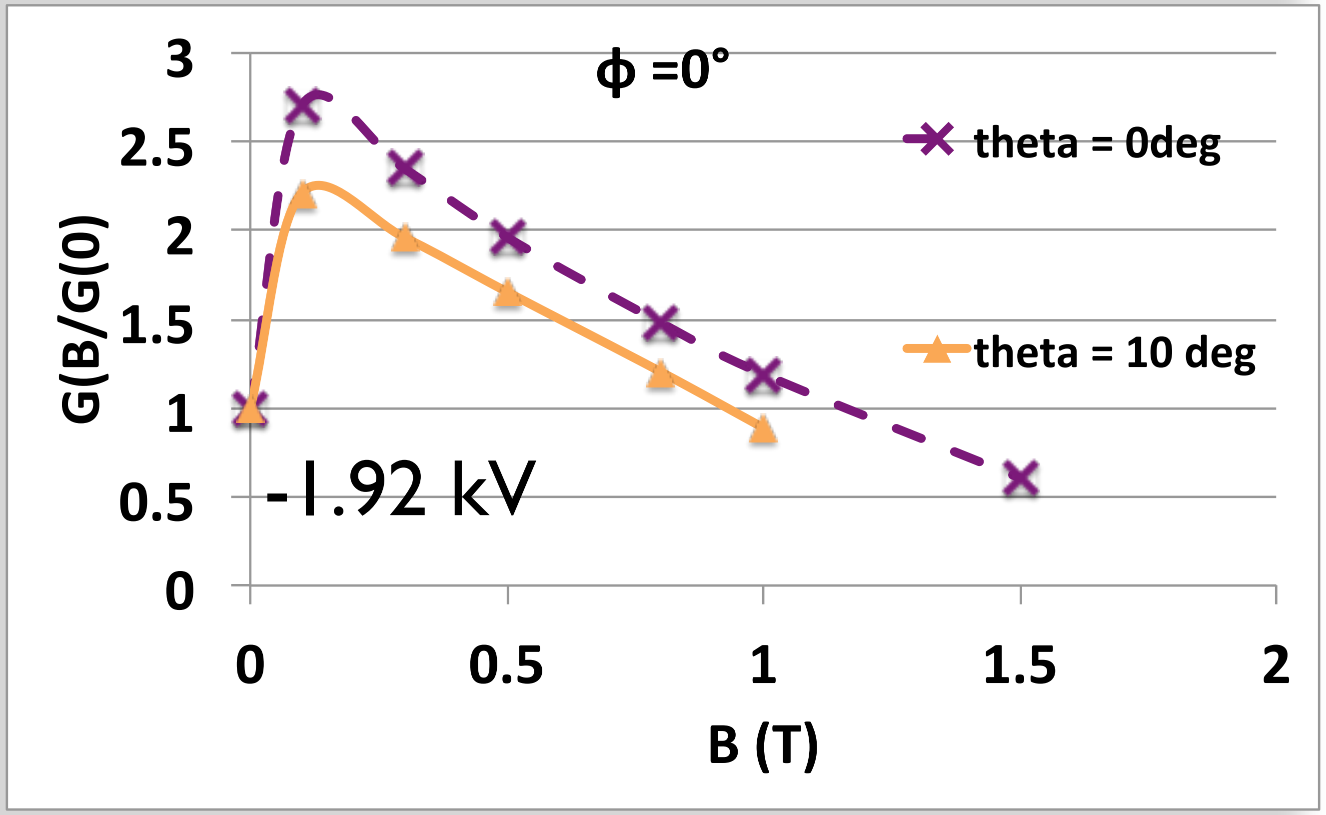


$\varphi = 180^\circ$: overall best gain performance

EIC R&D: High-B Performance

Planacon XP85122-S-HiCE Gain Scan (single channel)





@θ=0°:
G(1 T)/G(0 T) ~ 1
G(1 T)/G(2 T) ~ 9

Gain recovery by means of HV increase

@ -1.99 kV:
G(1 T)/G(2 T) ~ 3

Weak dependence on φ angle

Summary and Outlook

MAPMT253

Gain is within the specs up to 2 T for small θ

Optimal φ

Promising for high-B operations - only multi-anode MCP PMT with 6 μm pore size

XP85122-S HiCE

Gain is within the specs up to 1.5 T for small θ

No dependence on φ

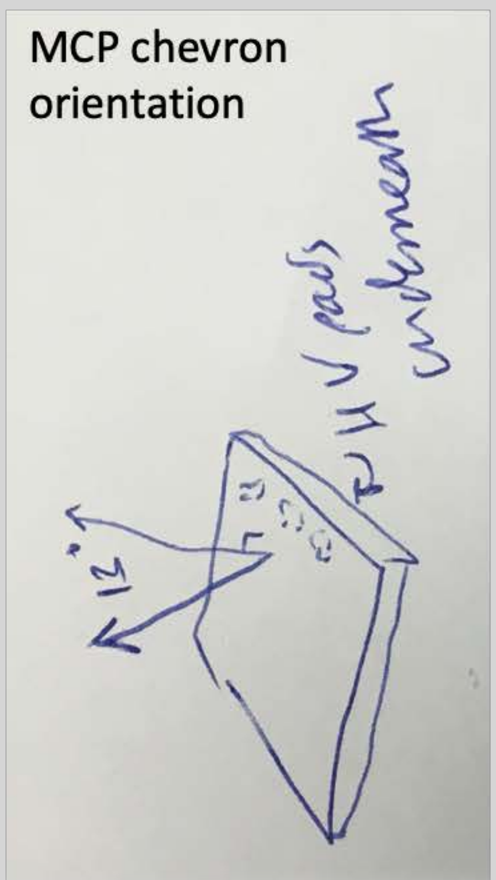
Studies needed with a full 16x16 readout: gain uniformity, cross talk, timing resolution, collection efficiency (B-field).

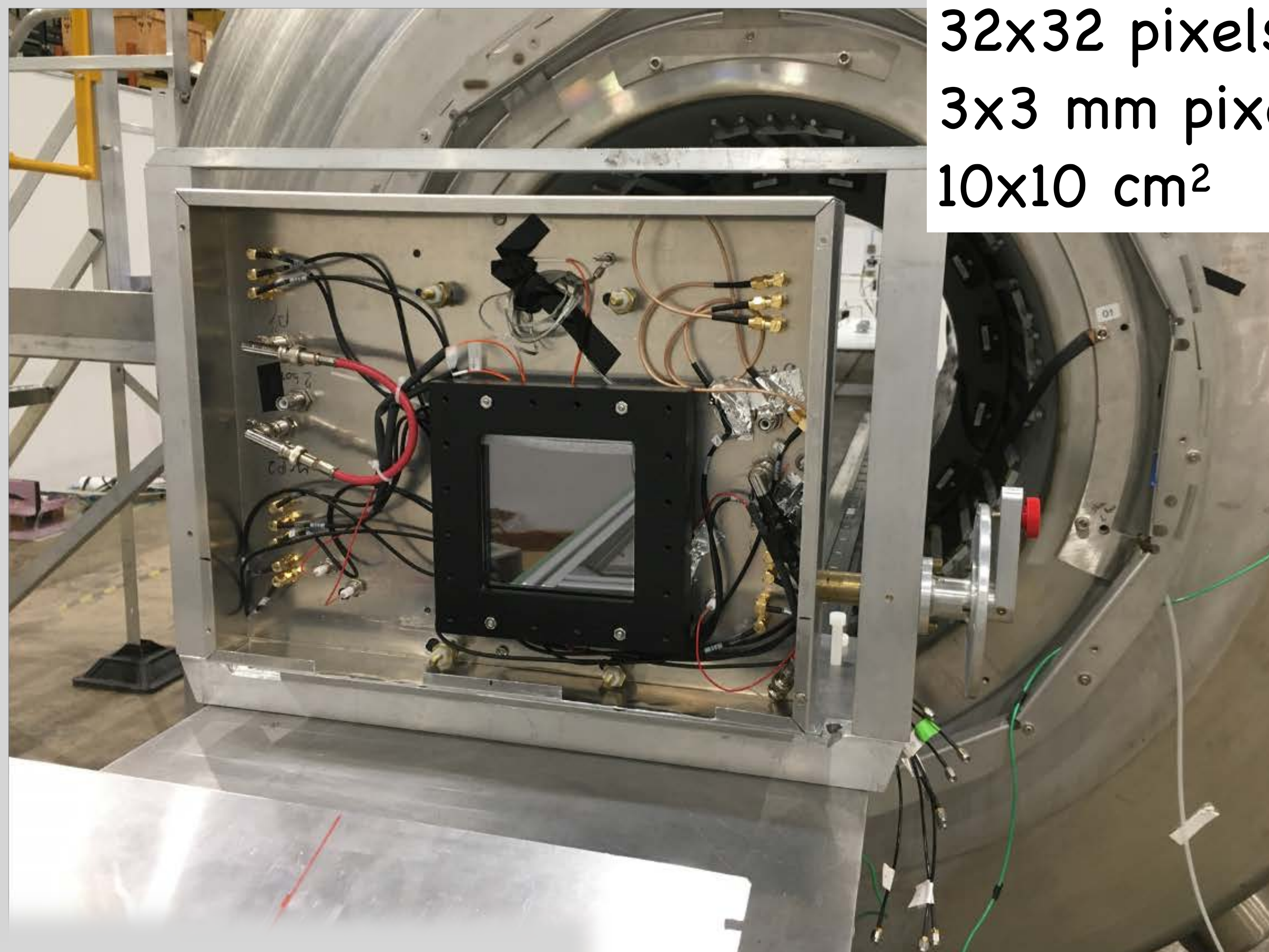
Incom High Rate Picosecond Photodetector

Slide from Mark Popecki

B-field test campaign, Feb 2023 (first operating HRPPD)

HRPPD 6





10 μm pore size
32x32 pixels
3x3 mm pixel size
10x10 cm²

Baseline solution for backwardRICH in ePIC

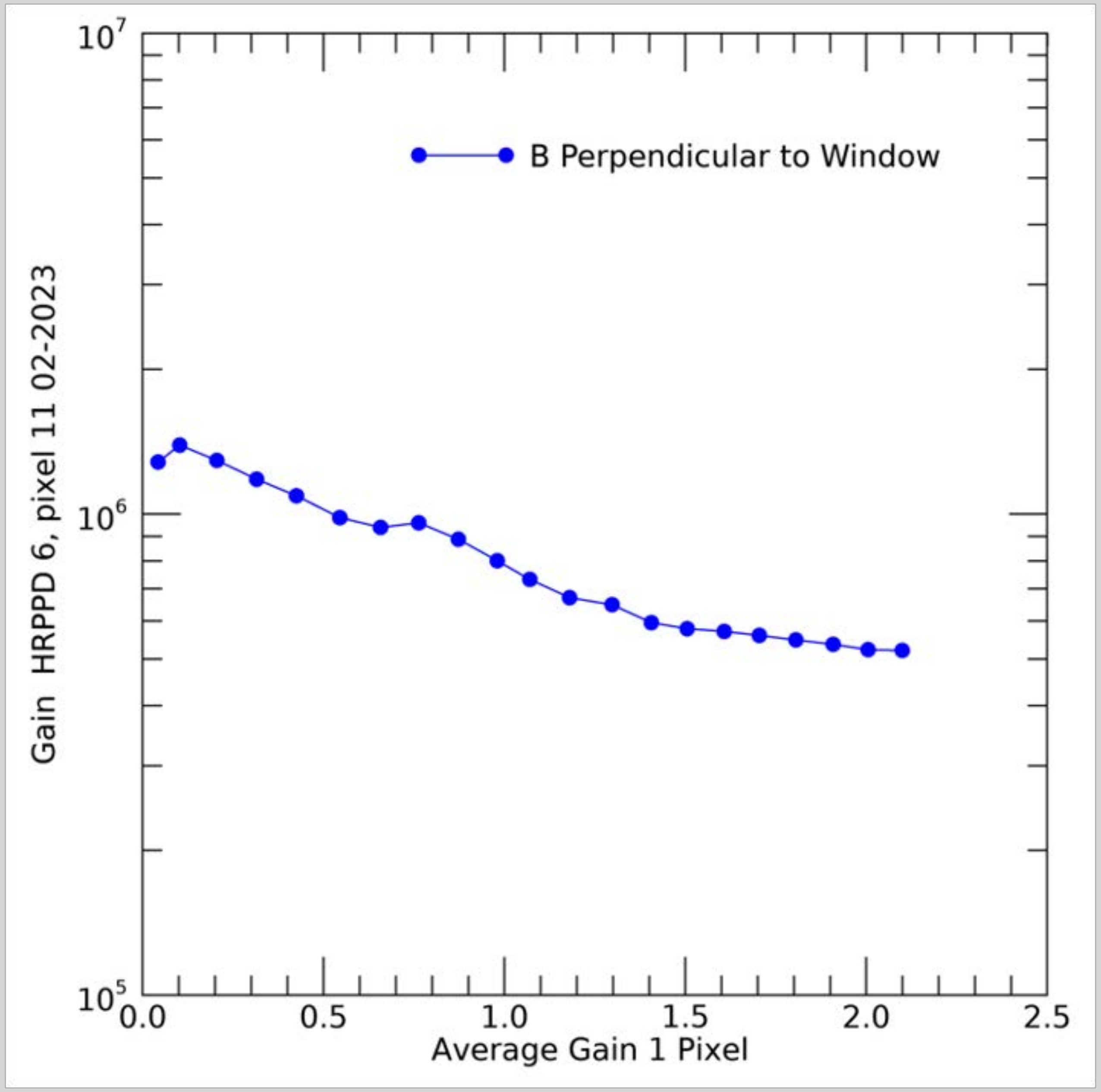
Incom High Rate Picosecond Photodetector

Gain vs. Magnetic Field Magnitude: H6

- HRPPD 6, Directly coupled anode, stacked MCPs
- 02-2023, ANL
- MCP V: 950 V/MCP nominal
- P/C V: 100 V

@θ=0°:
G(1 T)/G(0 T) ~ 1.6
G(1 T)/G(1.8 T) ~ 1.4

Can operate up to 2.1 T or more



Slide from Mark Popecki

Incom High Rate Picosecond Photodetector

Slide from Mark Popecki

Next Steps

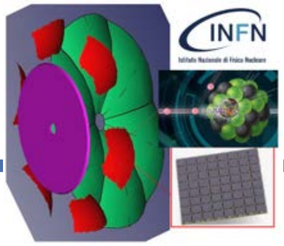
- Data characterizing performance with fields at an angle to the window will be processed next.
- Time resolution data have been partially processed. The uncertainty in the laser trigger must be measured and incorporated in the resolution calculation.
- Improved HRPPDs will be fabricated.
  - HRPPD 6 has MCPs with hotspots that generate afterpulses.
  - It is the first operating HRPPD, and undesirable features were accepted as a means of uncovering unknown design flaws.
  - The magnet test revealed two issues, which will be resolved in the next few devices:
  - The top clamp for the MCPs has rather sharp edges that produce unwanted electron emission at the very high voltages needed for strong fields. This will be revised to the stable LAPPD design.
  - The HRPPD directly coupled device has MCPs face to face with no gap in between. This appears to drive the MCPs rapidly to saturation in strong fields or large field angles. A gap will be introduced, as in the LAPPD design.

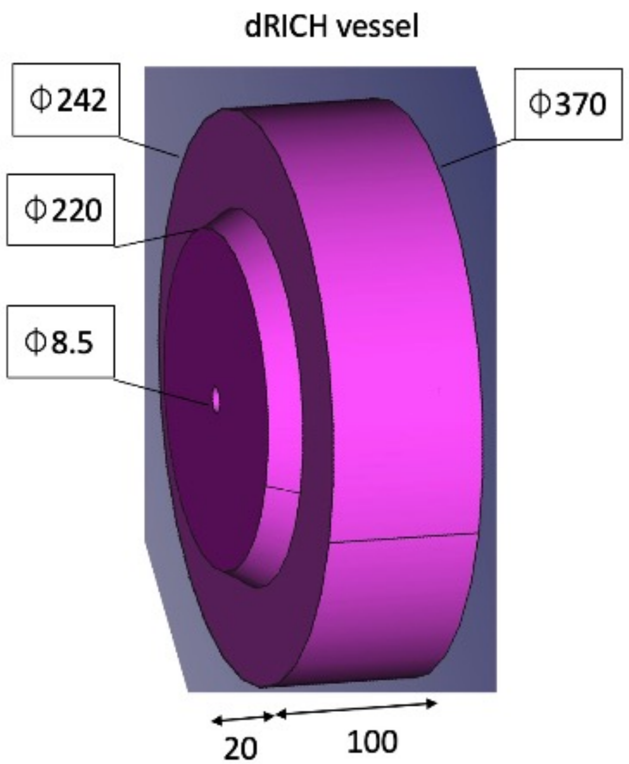
See next talk by A. Lyashenko (Incom)

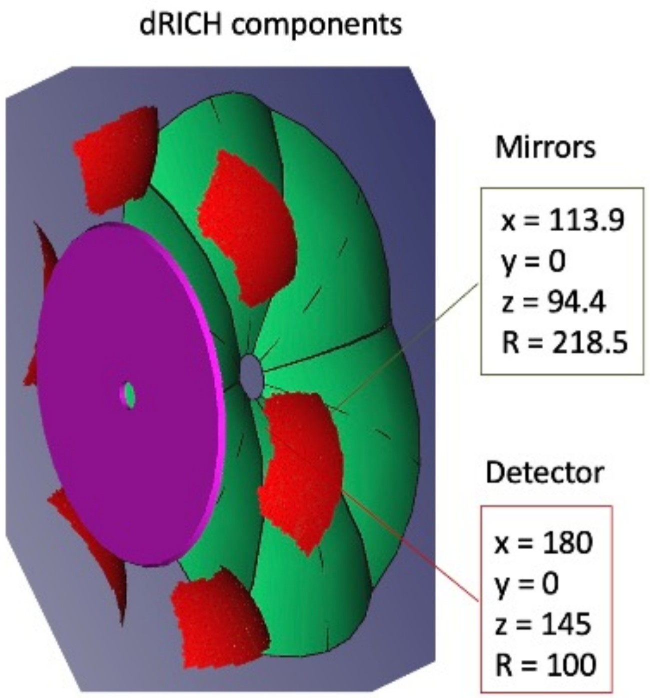
SiPM EIC R&D Efforts

Slide from P. Antonioli

A SiPM readout for a RICH detector?







Silicon photomultipliers

- ✓ Insensitive to magnetic field
- ✓ Cheap / Integrated arrays
- ✓ Time resolution within requirements (< 200 ps RMS)
- ✓ Commercially available

- ? Single Photon resolution needed!
- ? DCR vs temperature → cooling
- ? Not radiation tolerant: DCR increases!

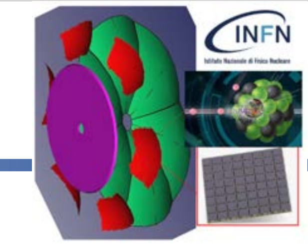
Our R&D: evaluate radiation tolerance and mitigation procedures (annealing)

→ test large O(10-100) samples of different commercial (HPK/OnSemi) and prototypes (FBK)
→ establish annealing protocol, evaluate DCR after repeated annealing cycles
→ characterize sensors and test them on beam conditions
→ use/test realistic readout with ALCOR ASIC

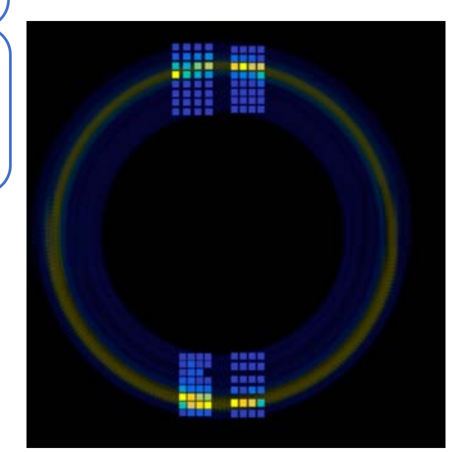
SiPM EIC R&D Efforts

Slide from P. Antonioli

The R&D program so far (an outline)



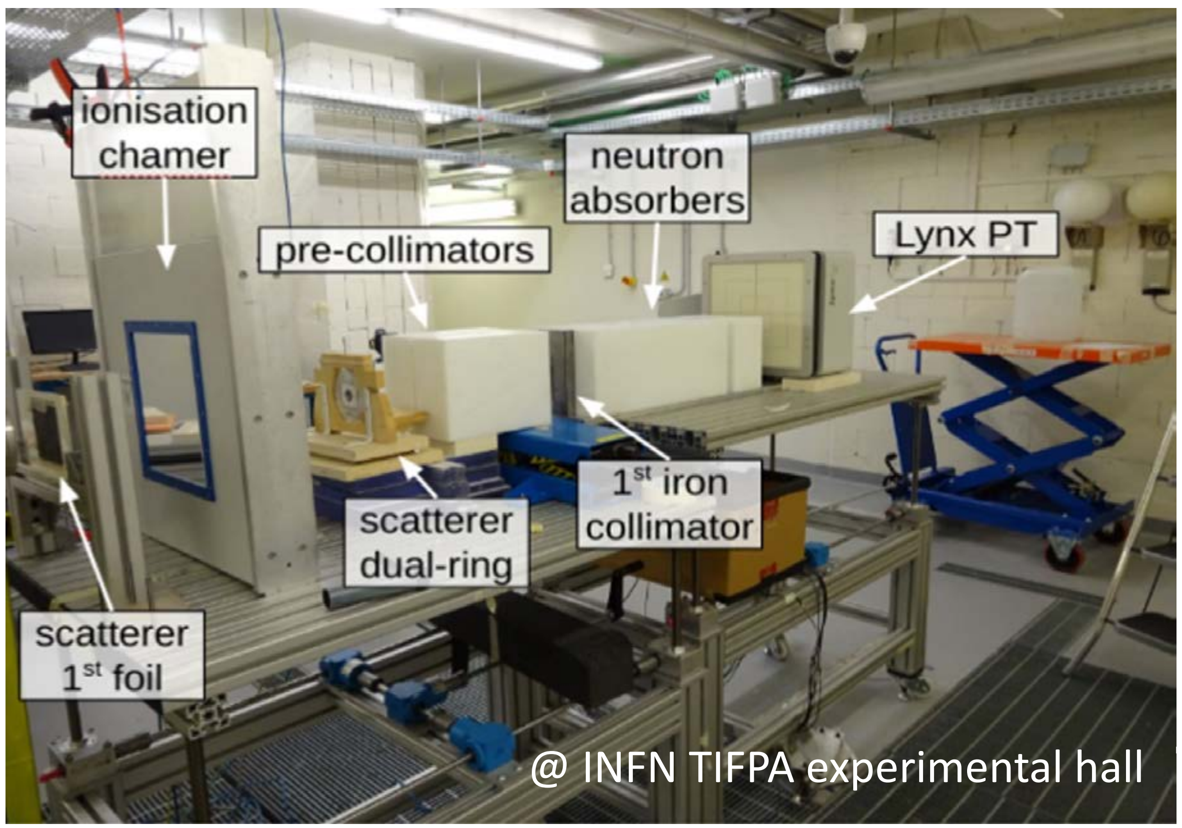
- **SiPM**
  - selection by manufacturer, V_{bd}, SPAD cell
- **Electronics**
  - SiPM carriers and adapters
  - readout cards with ALCOR ASIC
- **Irradiation**
  - 2021 and 2022 campaigns with proton beams (140 MeV)
  - fluences from 10^9 to 10^{11} 1-MeV n_{eq}/cm^2
- **Annealing**
  - High-temperature cycles (oven)
  - Exploring "in-situ" alternatives
- **Characterization**
  - I-V, DCR, LED pulse in climatic chamber
  - picosecond laser in 2023 for timing resolution
- **Test beam**
  - test on dRICH prototype irradiated & annealed sensors

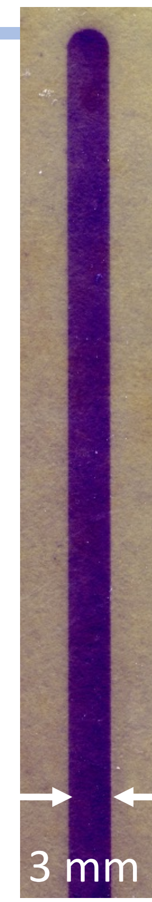


SiPM EIC R&D Efforts

Slide from P. Antonioli

Irradiation at Trento protontherapy center





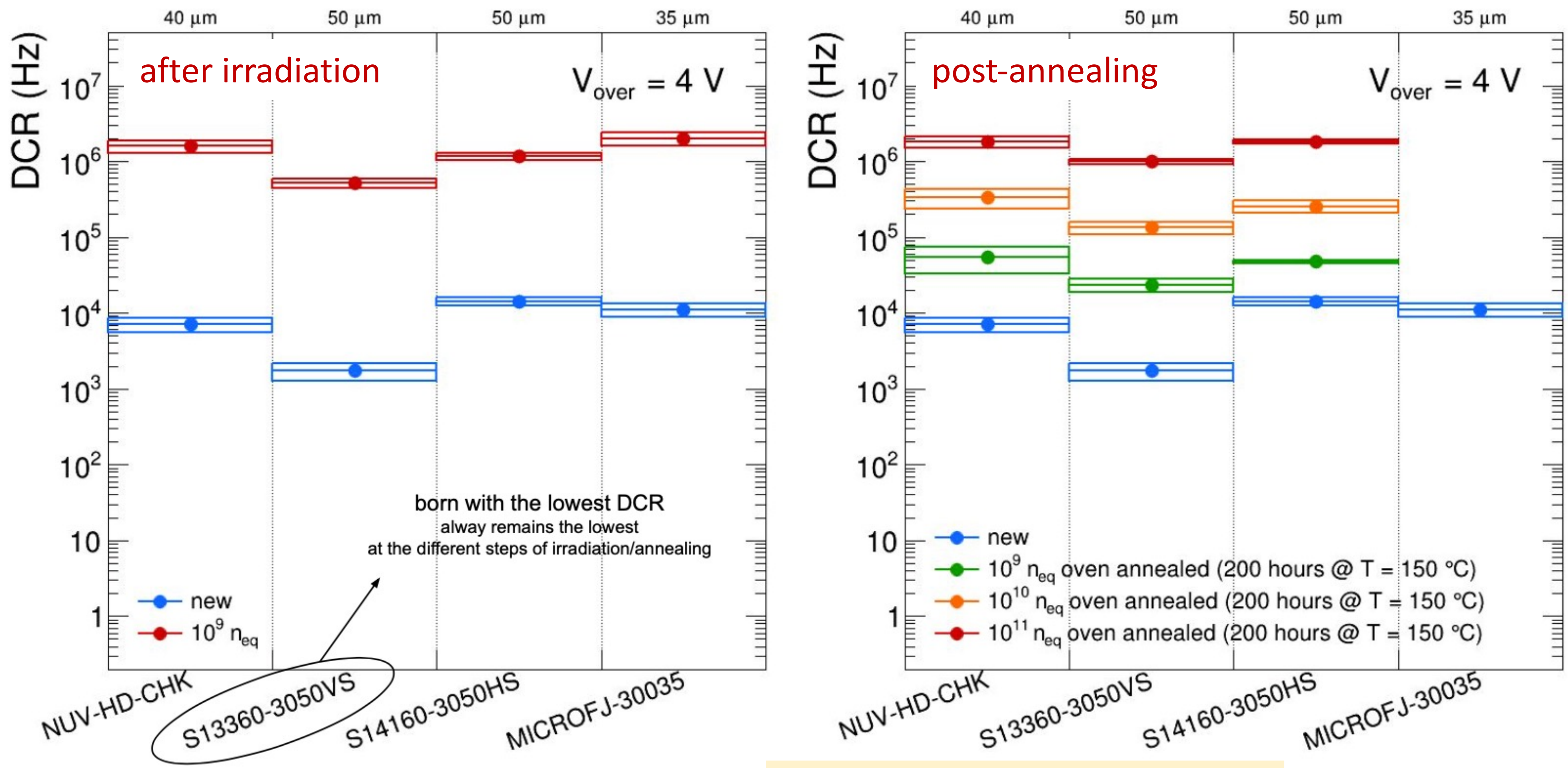
2021 campaign: irradiation of carriers "by column" at 10^9, 10^{10}, 10^{11} 1-MeV n_{eq}/cm^2
2022 campaign: repeated irradiation at 10^9 1-MeV n_{eq}/cm^2 and annealing cycles on same sensors

148 MeV proton beam (fix pencil beam/uniform 6 cm diameter spot)
On the beam line facility: F. Tommasino et al., NIMA 869 (2017) 15 and F. Tommasino et al., Phys. Med. 58 (2019) 99

SiPM EIC R&D Efforts

Slide from P. Antonioli

DCR: after irradiation and post-annealing



O(100) DCR increase after 10^{11} n_{eq}

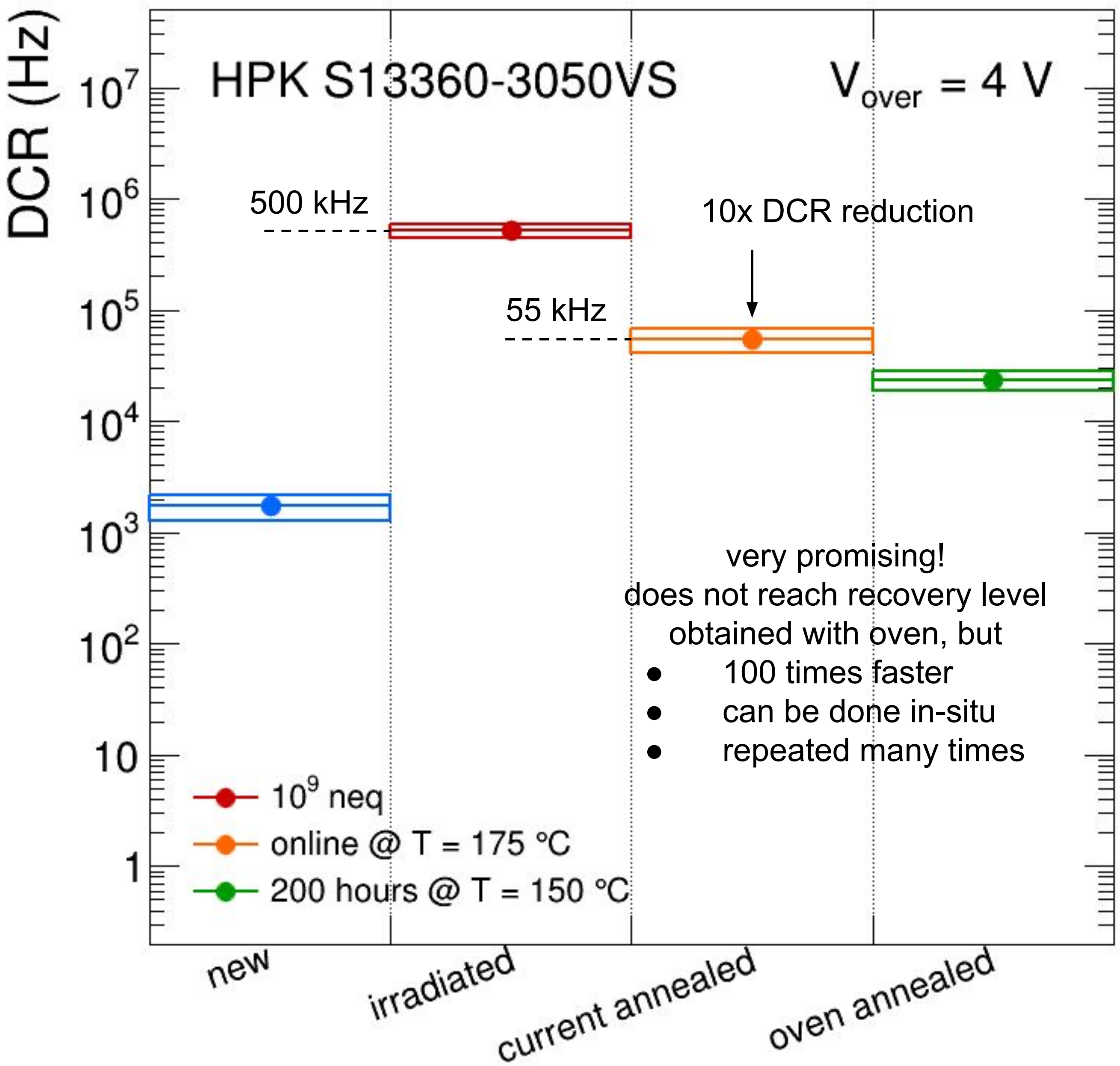
O(10) DCR recovery post-annealing

SiPM EIC R&D Efforts

Slide from R. Preghenella

Online annealing

explore solutions for in-situ annealing



SiPM EIC R&D Efforts

Slide from R. Preghenella

SiPM plans for FY 2023

we have not been originally funded and eventually only partially, but we'll keep the milestones alive as much as possible

Milestones FY 2023
critical results for pre-TDR

- Timing measurement of irradiated (and annealed) sensors (6/2023)
- Comparison of the results achieved with proton and neutron irradiation sources (8/2023)
- Study of annealing in-situ technique with a proposed model selected as baseline for the pre-TDR (9/2023)

- **single-photon time resolution**
  - of full SiPM-ALCOR readout chain
    - no capacity to measure it so far
  - critical to set performance simulation
- **alternative annealing solutions**
  - so far done with industrial oven (days)
  - address ideas for faster / in-situ recovery
    - exploration started, promising
    - critical to become structured R&D
- **irradiation campaigns**
  - so far only with 150 MeV protons
  - critical to collect data on neutron damage
    - might be topologically different
    - effectiveness of annealing
    - test NIEL damage hypothesis
  - irradiation needed to test new annealings
- **operation at low temperature**
  - so far characterisation in climatic chamber
    - compare results with TEC (Peltier) cooling
  - explore alternative solution to TEC
    - liquid, hybrid (liquid + TEC) approaches
- **development of new sensors**
  - within INFN-FBK collaboration agreement
    - critical for procurement risk mitigation
  - reduction of DCR
    - field / thickness optimisation
    - exploration of advanced microlensing
  - development of "monolithic" SiPM sensor array
    - wire bonded, cost reduction

Photosensors R&D Summary

2013 - present

The last decade saw a significant effort and result in photosensors for EIC

- Gain assessment and ion feedback in High-B field for various MCP PMTs were performed (single channel readout);
- New 6 μm pore size multi-anode MCP PMT on market - potential for B-fields above 1.5 T in a 2nd detector (initial characterization)
- New Income HRPPD produced - first characterization completed, improvements needed;
- Aggressive SiPM irradiation-annealing-characterization campaign coupled with the use of an in-house readout chip (ALCOR), and development of new sensors

ePIC baseline: Photonis MCP PMT (hpDIRC), HRPPD (backRICH), SiPM (dRICH)

Extensive research capacity useable for 2nd EIC detector photosensors