# Evaluation of Small Photo-Sensors in High Magnetic Fields for EIC PID Detectors

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University of South Carolina

for the **EIC PID Collaboration**

1st EIC Physics and Detector Conceptual Development Workshop
March 19-21, 2020

# Photon Sensor Parameters for EIC PID Cherenkov Detectors

| Parameter | DIRC | mRICH | dRICH |
|---|---|---|---|
| Gain | ~$10^6$ | ~$10^6$ | ~$10^6$ |
| Timing Resolution | ≤ 100 ps | ≤ 800 ps | ≤ 800 ps |
| Pixel Size | 2–3 mm | ≤3 mm | ≤ 3 mm |
| Dark Noise | ≤ 1kHz/cm$^2$ | ≤ 1 MHz/cm$^2$ | ≤ 1 MHz/cm$^2$ |
| Radiation Hardness | Yes[14] | Yes[14] | Yes[14] |
| Single-photon mode operation? | Yes | Yes | Yes |
| Magnetic-field immunity? | Yes (1.5–3 T) | Yes (1.5–3 T) | Yes (1.5–3 T) |
| Photon Detection Efficiency | ≥ 20% | ≥ 20% | ≥ 20% |

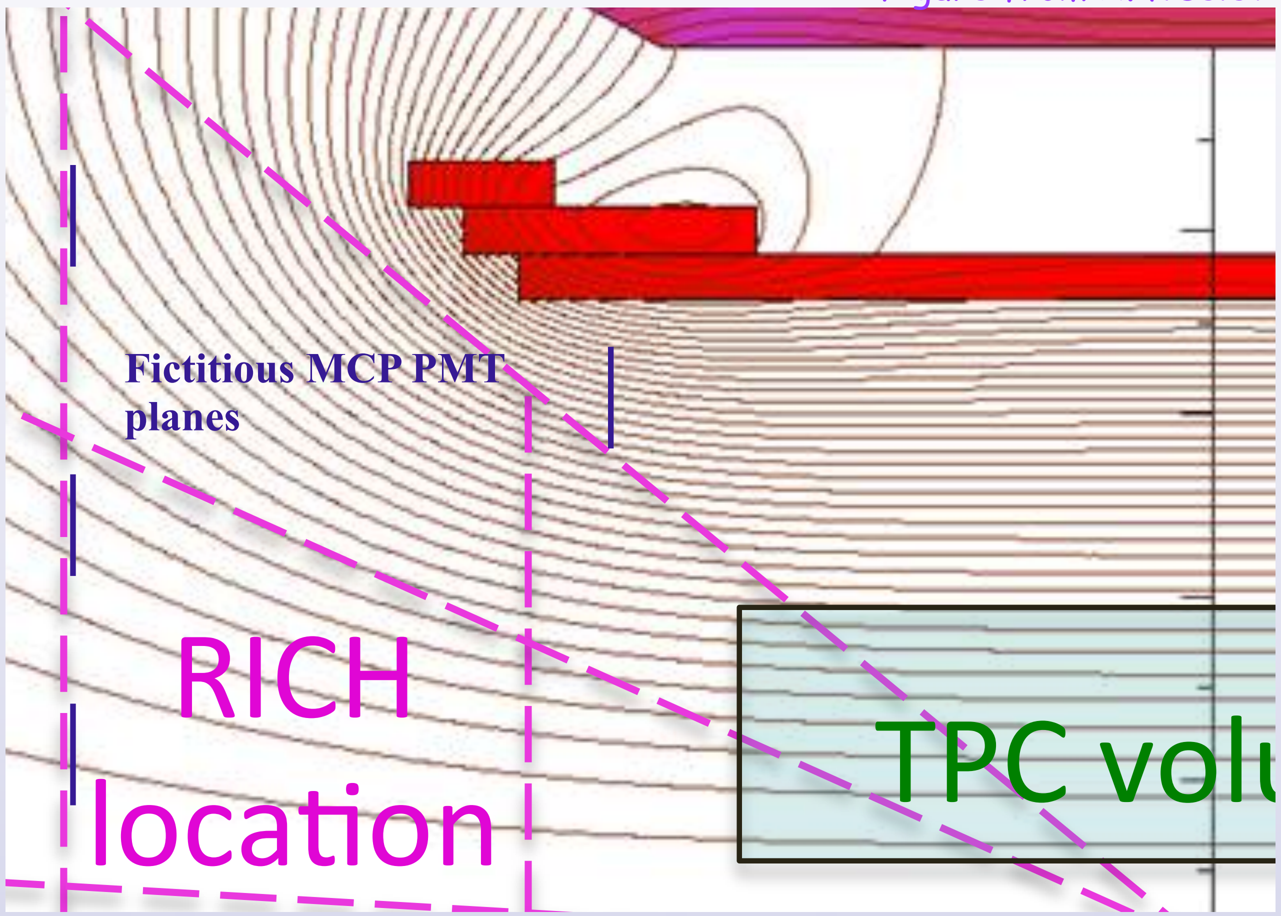
## Objective of High-B Sensor Program of eRD14

To identify the limitations of commercially-available MCP-PMT design and operational parameters for High-B operations.

# High-B Facility at Jefferson Lab

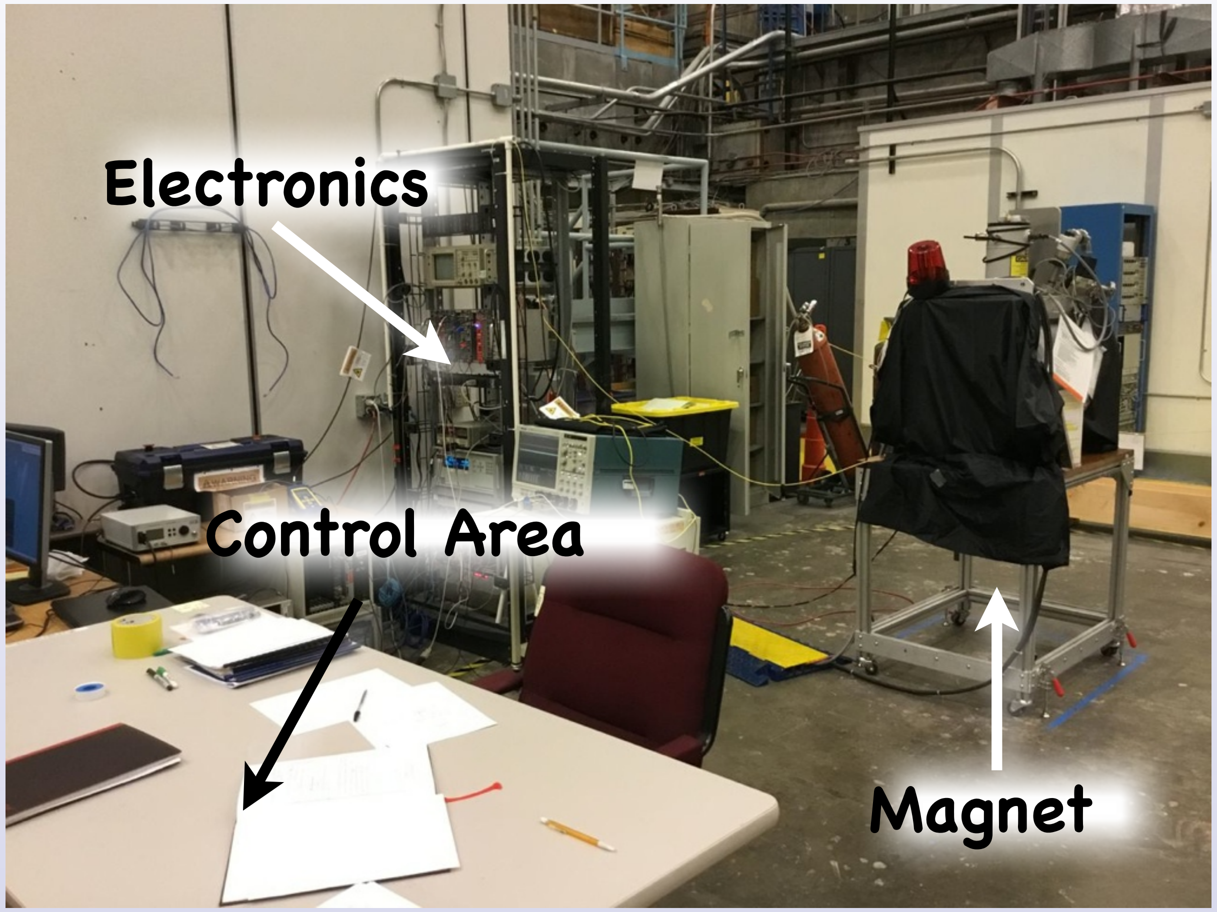
## Motivation

Figure from A. Kiselev




- The PID-detector sensors would be located in a volume of a non-uniform magnetic field of
  - varying magnitude
  - varying direction
- Photosensor performance needs to be evaluated as a function of
  - **B-field strength and orientation relative to sensor**

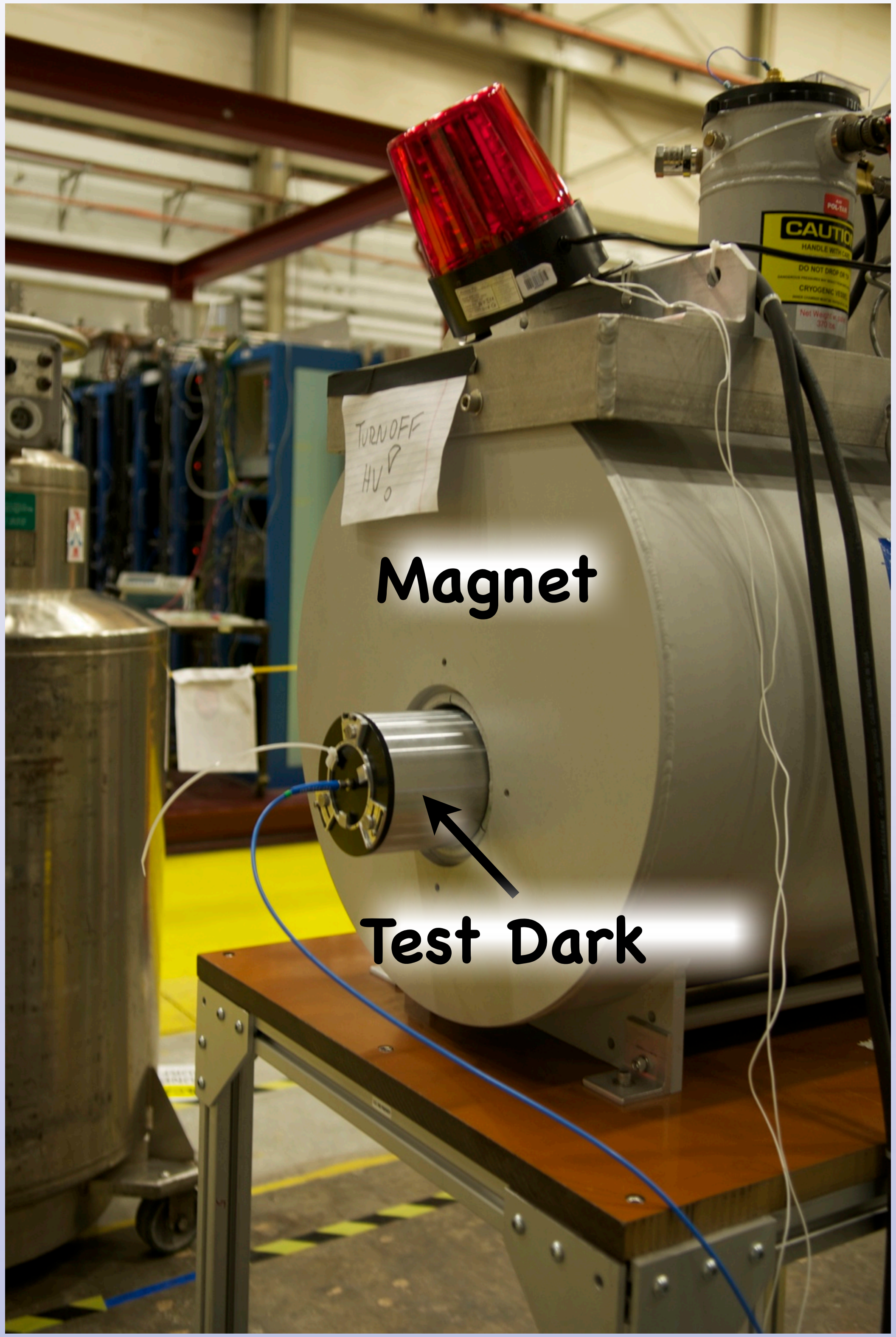
## Overview




- Purpose: Evaluation of small-PMT gain, efficiency, and timing resolution in B fields
- Commissioned in July/August 2014
- Data taking: November 2014
- People: SB: P. Nadel-Turonski, JLab: C. Zorn, J. McKisson; CU: G. Kalicy, USC: Y. Ilieva, E. Bringley, C. Barber, J. Rapoport, A. Rowland, B. Tumeo; UNH: T. Cao, IU: C. Gleason, ODU: K. Park, L. Allison

# Facility Capabilities

## Major Components




Magnet:

- superconducting solenoid
- max. field: 5.1 T at 82.8 A
- 12.7-cm (5-inch) diameter warm bore
- length of bore: 76.2 cm (30 inch)
- central field inhomogeneity: $\leq 5\times10^{-5}$ over a cylindrical volume of a diameter of 1.5 cm and length of 5 cm

Test Box:

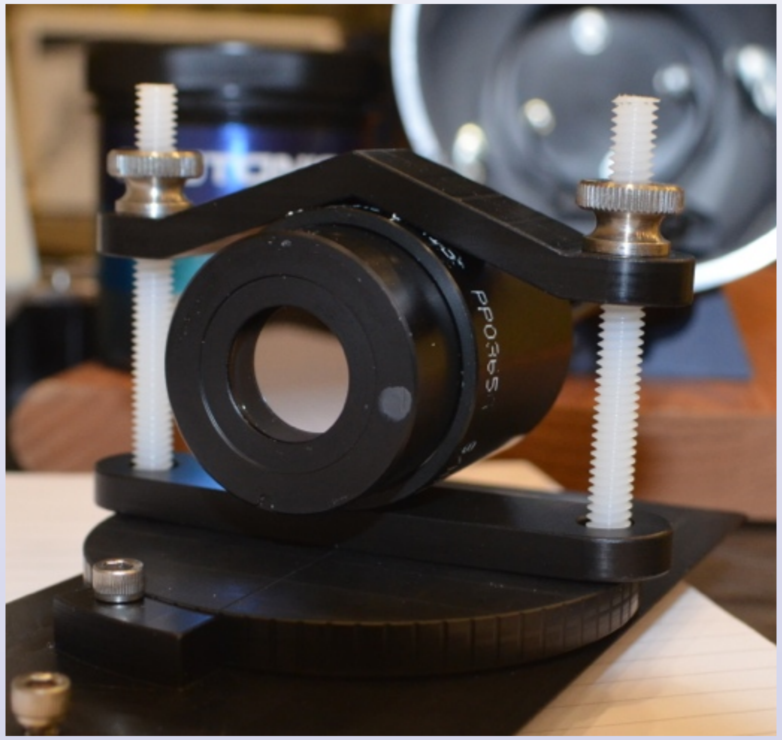
- non-magnetic, light-tight
- cylindrical shape: $d_{in} \sim 4.5$ inch, $L \sim 18$ inch
- allows for rotation of sensors
- light source (LED or fast laser)

Functionality:

Timing resolution, Gain, Ion Feedback, Efficiency

# Gain Characterization of Single-Anode MCP PMTs

Photonis PP0365G

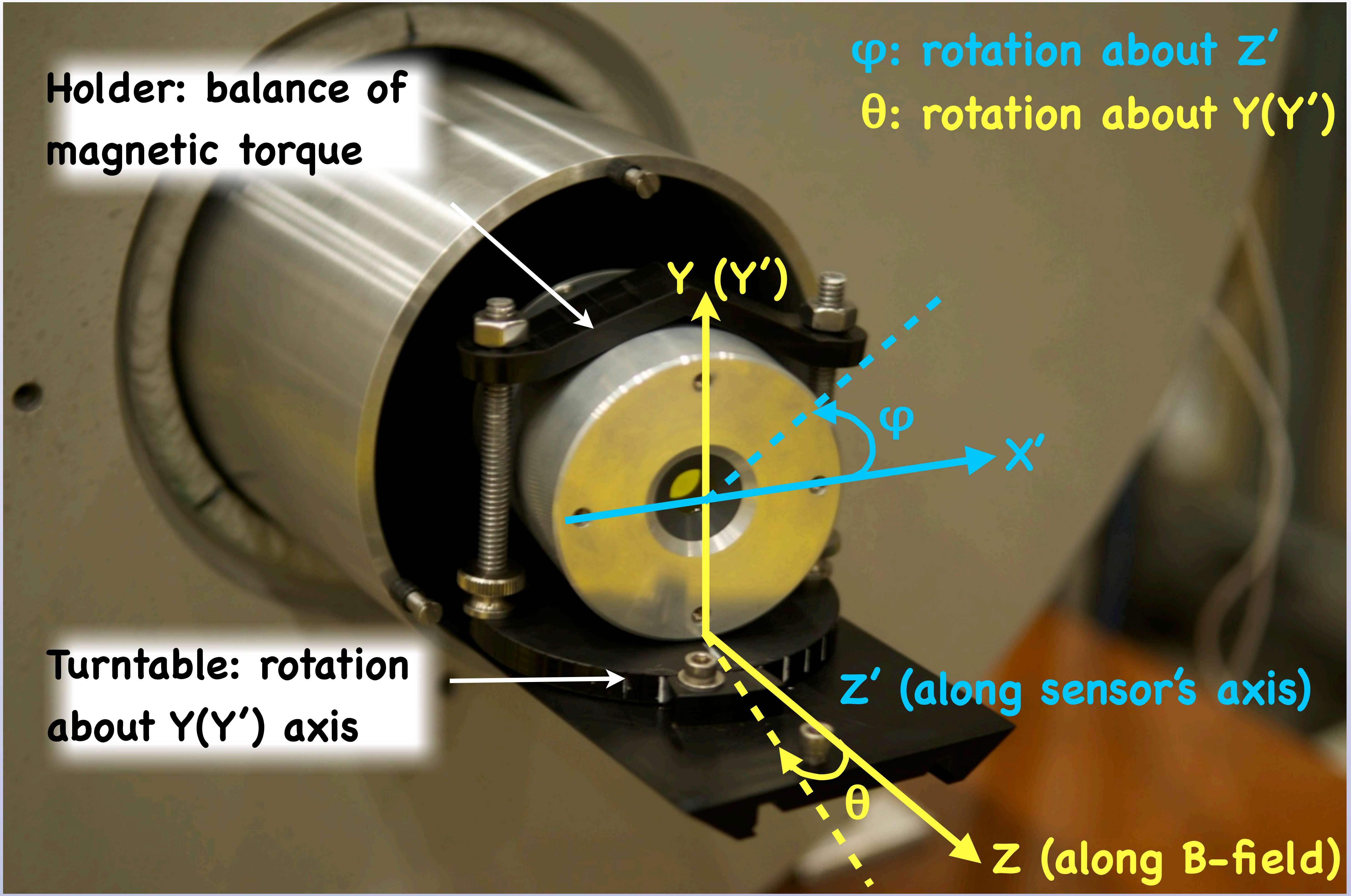


pore size: 6 μm
max. gain: $\sim 10^5$
QE: 18% at 470 nm

Photek PMT210, PMT240

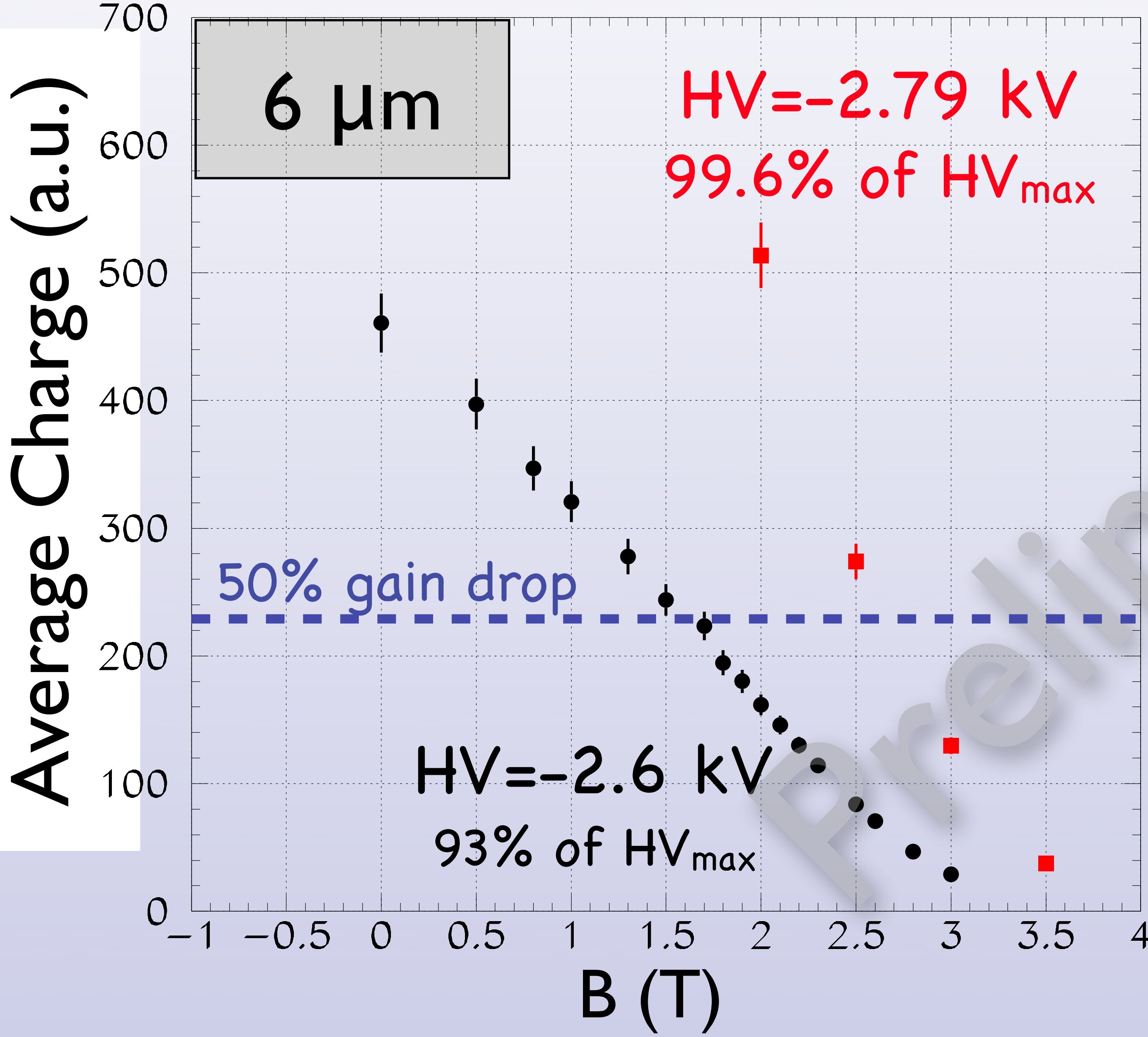

pore size: 3 μm, 10 μm
max. gain: $10^6$
QE: 15% at 470 nm

# Sensor Orientation Capabilities

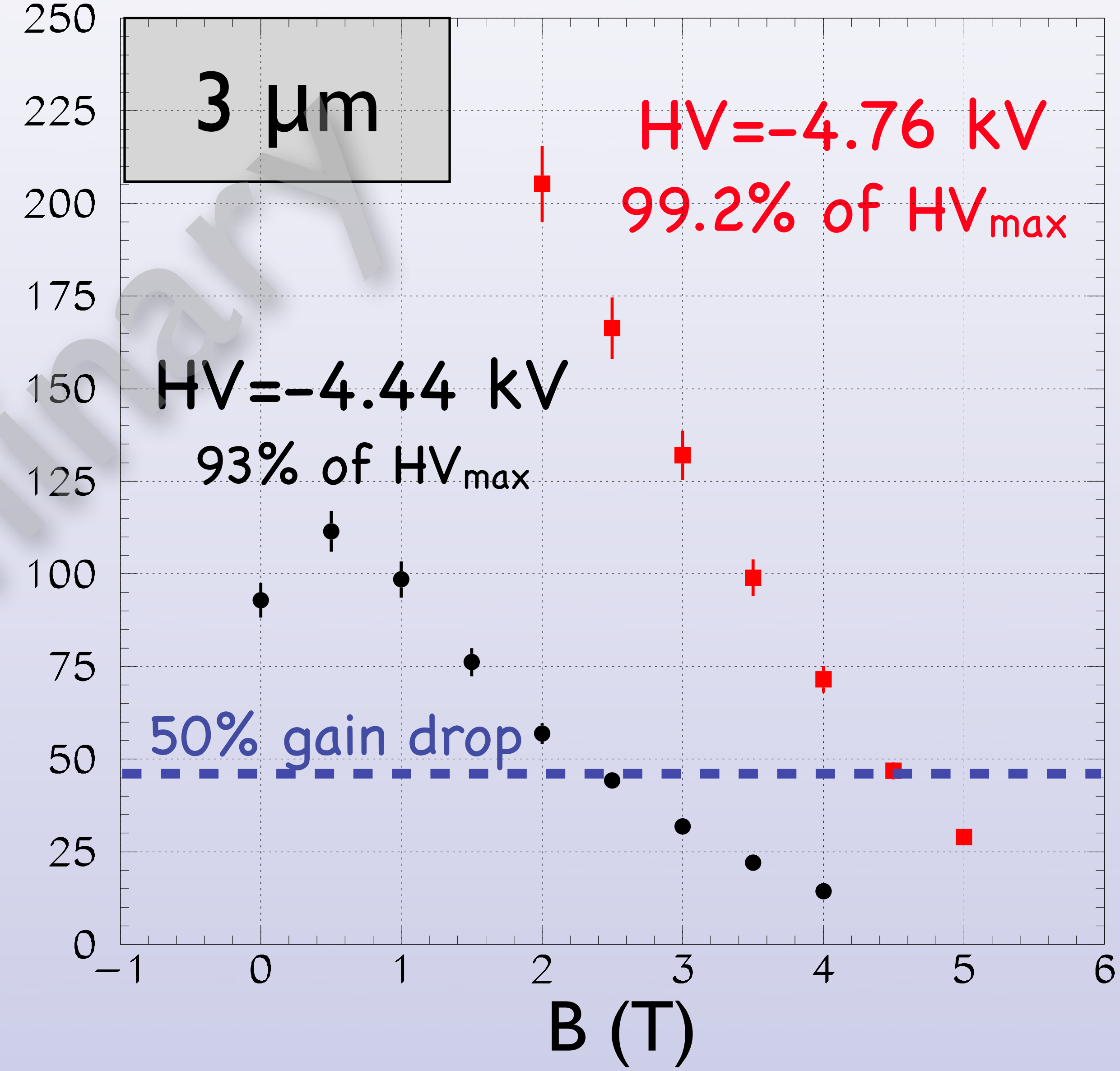


# Gain Characterization of Single-Anode MCP PMTs

## Results at 0 deg



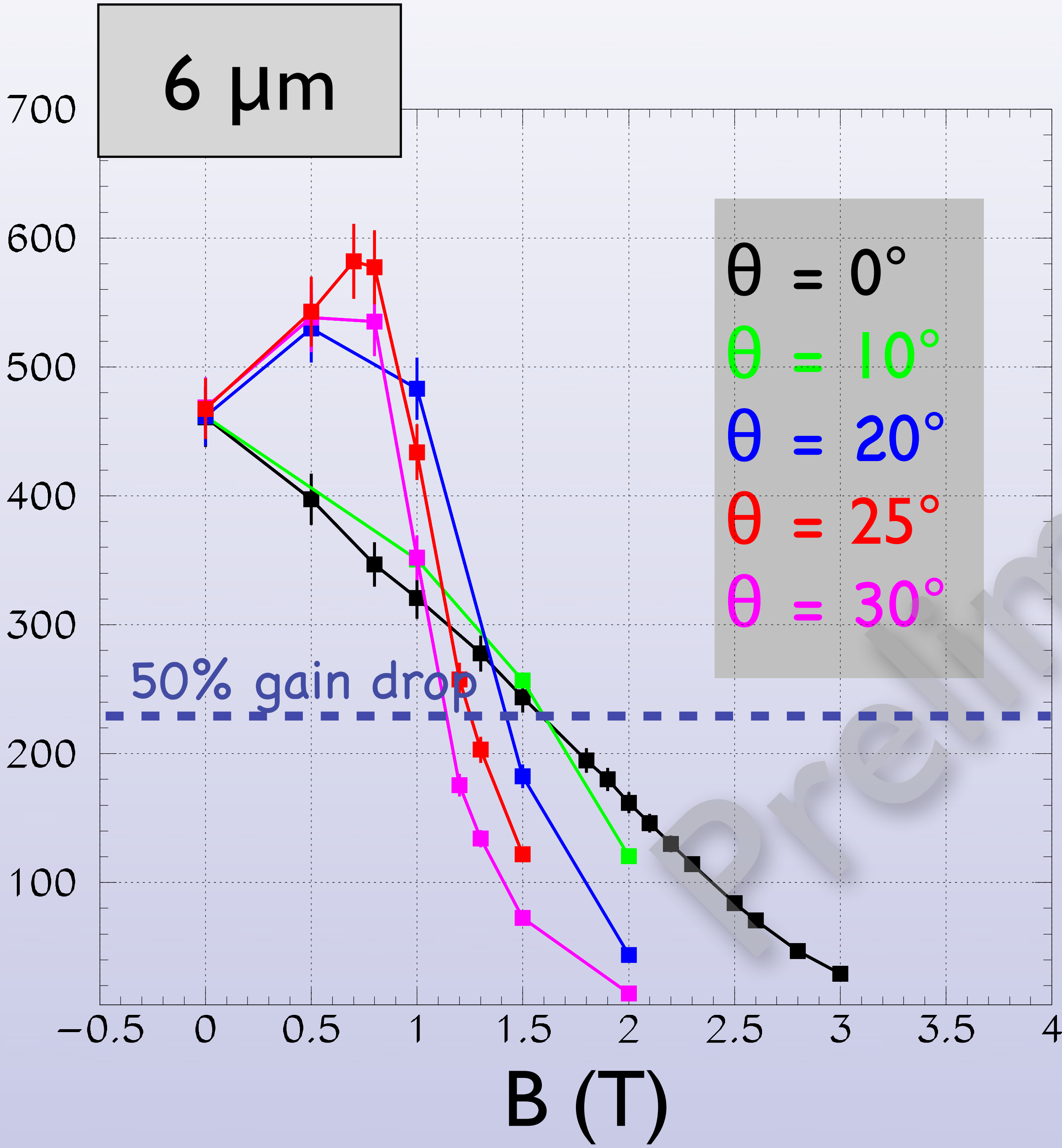

- about a factor of 15 decrease of signal between 0 T and 3 T (-2.6 kV)
- 5% preliminary uncertainty

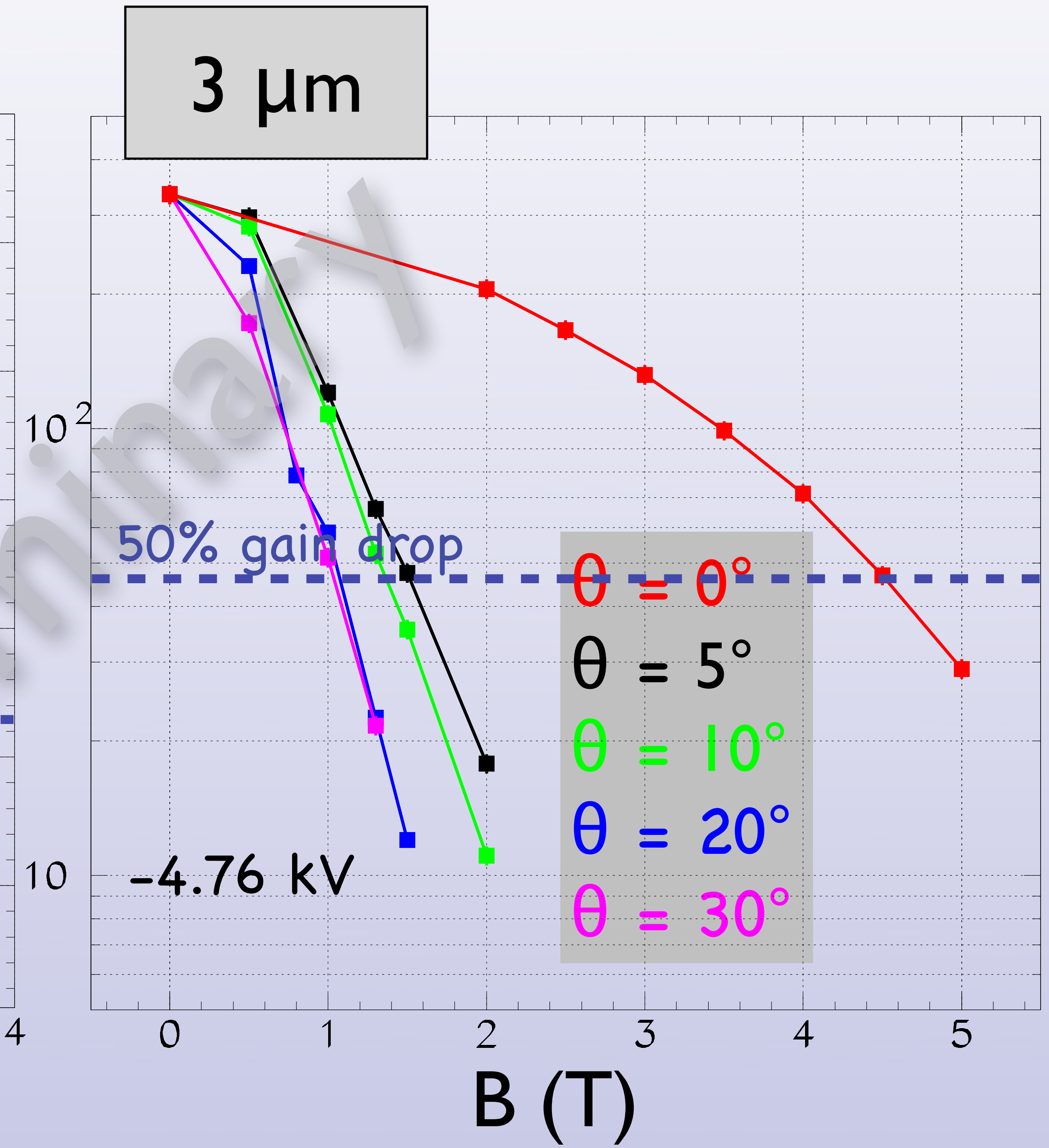



- about a factor of 6 decrease of signal between 0 T and 4 T (-4.44 kV)
- 5% preliminary uncertainty

# Gain Characterization of Single-Anode MCP PMTs

## Results at other angles



# Gain Characterization of Single-Anode MCP PMTs

## Overview

- Smaller pore size yields better gain performance in B-fields

  3 μm: about a factor of 6 decrease of signal from 0 T to 4 T.

  - 6 μm: about a factor of 15 decrease of signal from 0 T to 3 T.

- B-field gain performance varies among different types of sensors

  Shape of gain B-field dependence at various polar angles strongly depends on the sensor.

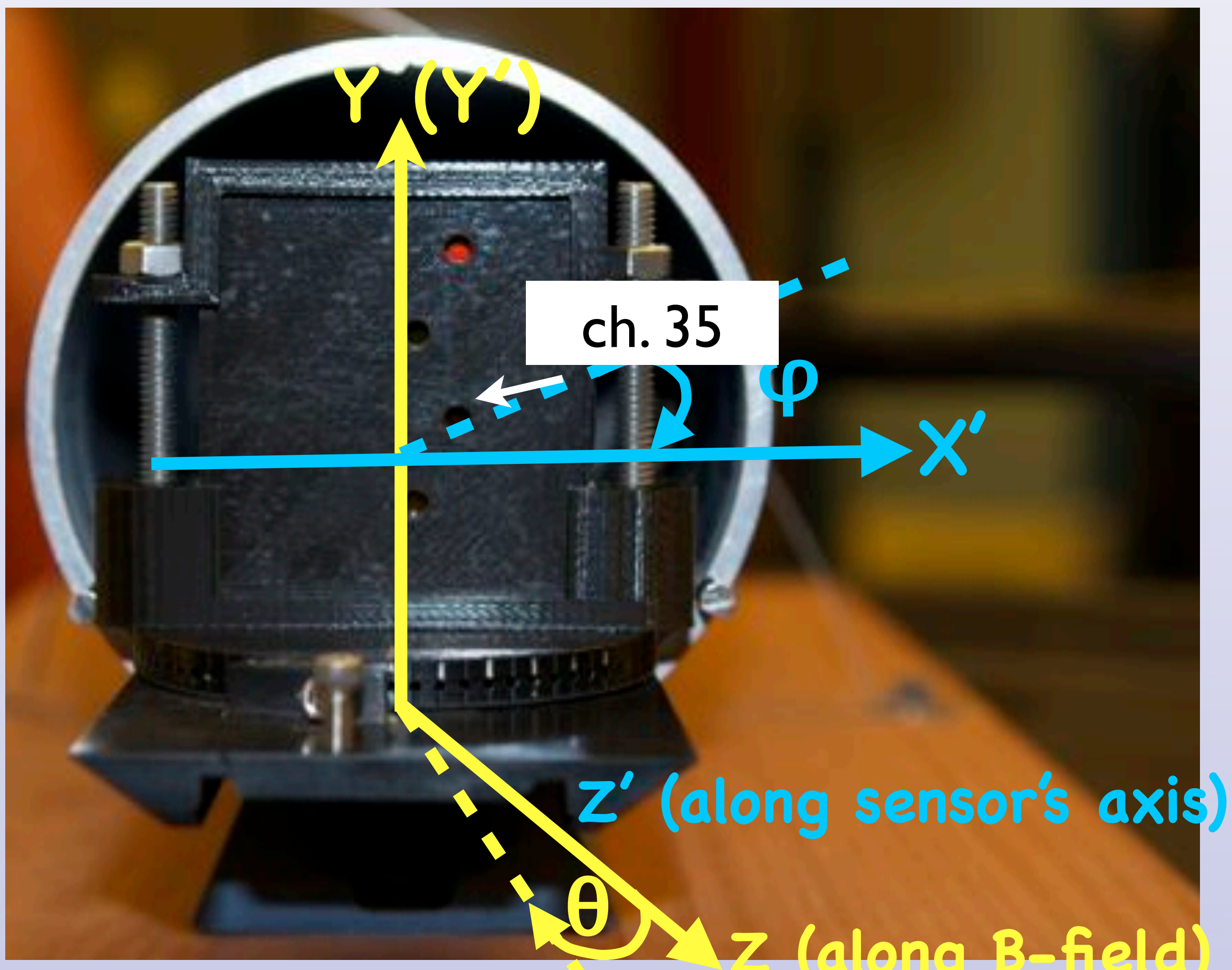
  Azimuthal dependence strongly correlated with polar angle.

  Overall, reasonable performance up to 2 T.

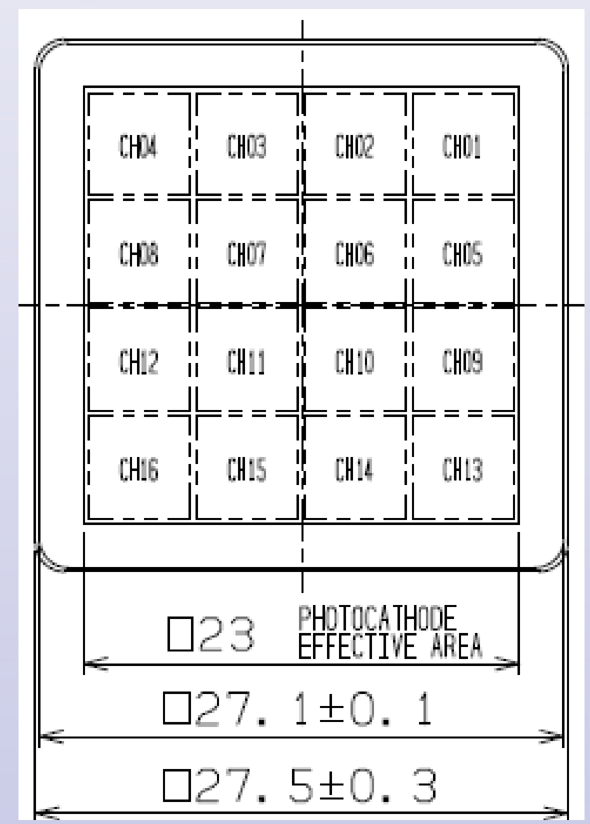
- Design optimizations needed if the orientation of the sensors relative to the field varies significantly.

# Gain Characterization of Multi-Anode MCP PMTs

Photonis XP85112, 10 µm pore size

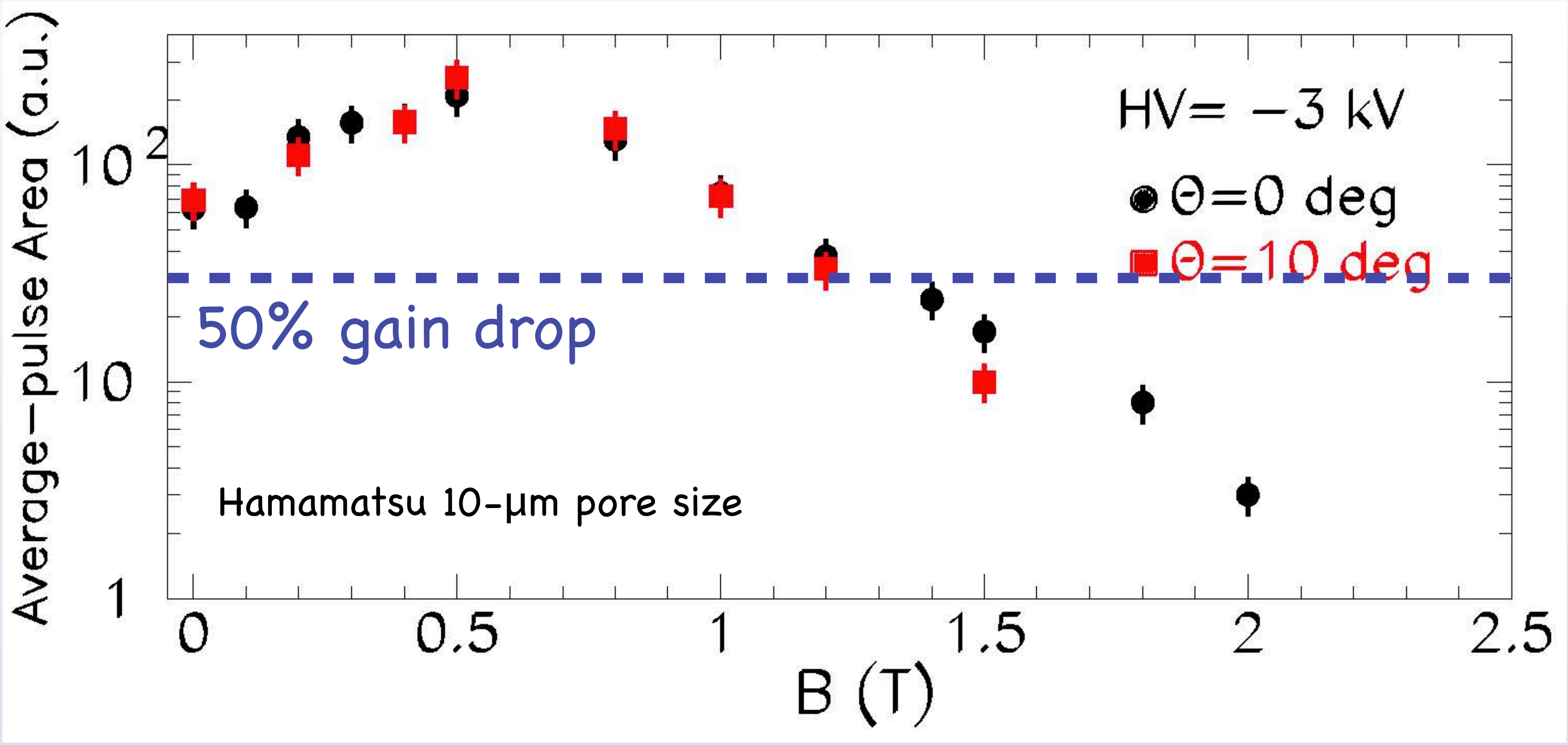


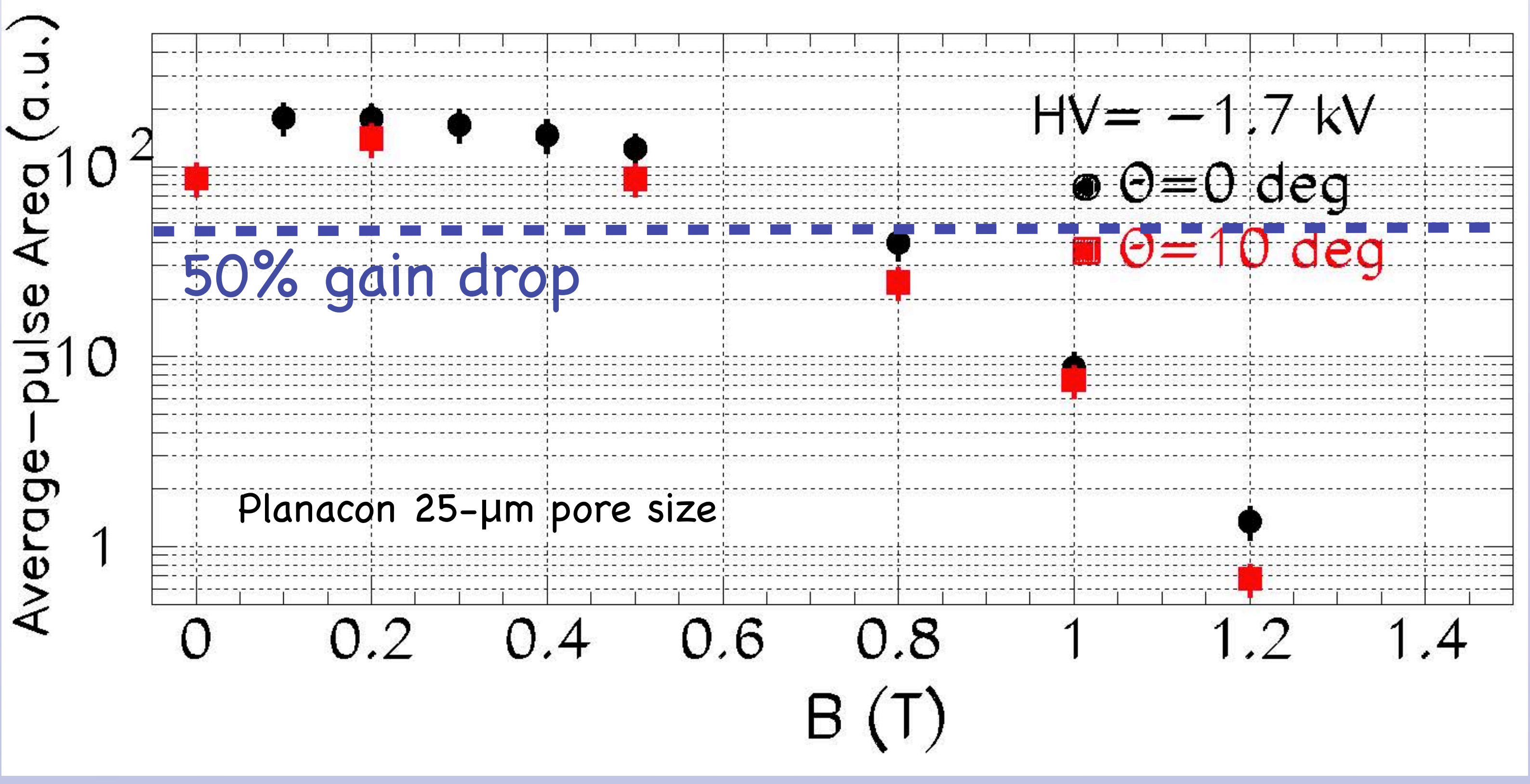

Hamamatsu
R10754-07-M16X
10 µm pore size



# Gain Characterization of Multi-Anode MCP PMTs

## Results



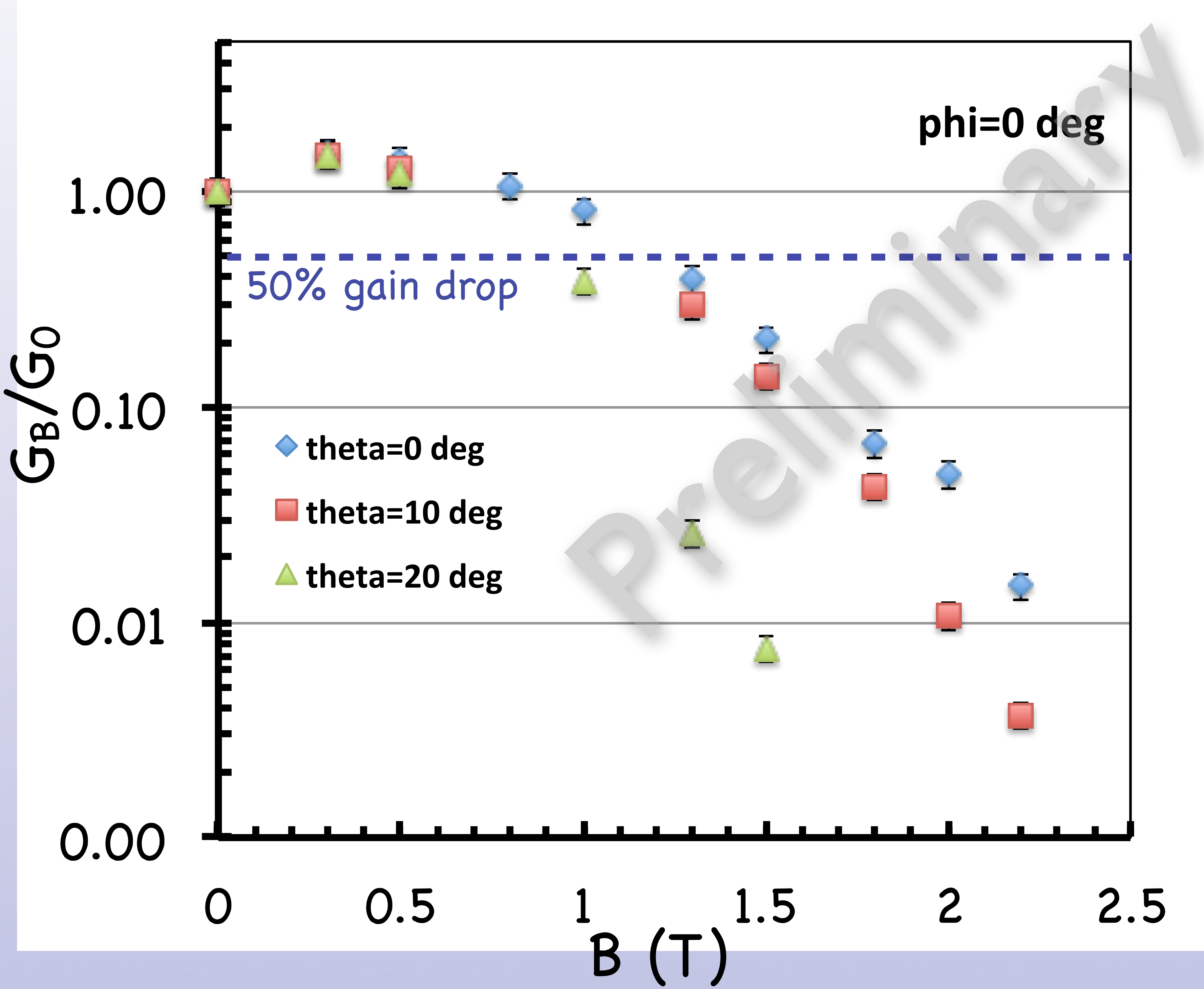




- Measurements performed at 96% of maximum allowed high voltage.
- 10-μm sensor
  - Delivers signals up to about 2 T at standard orientation.
  - Delivers signals up to about 1.5 T at larger angles.
- 25-μm sensor
  - At both orientations, the sensor produces signals up to about 1.2 T.

# Gain Characterization of Multi-Anode MCP PMTs

## Results

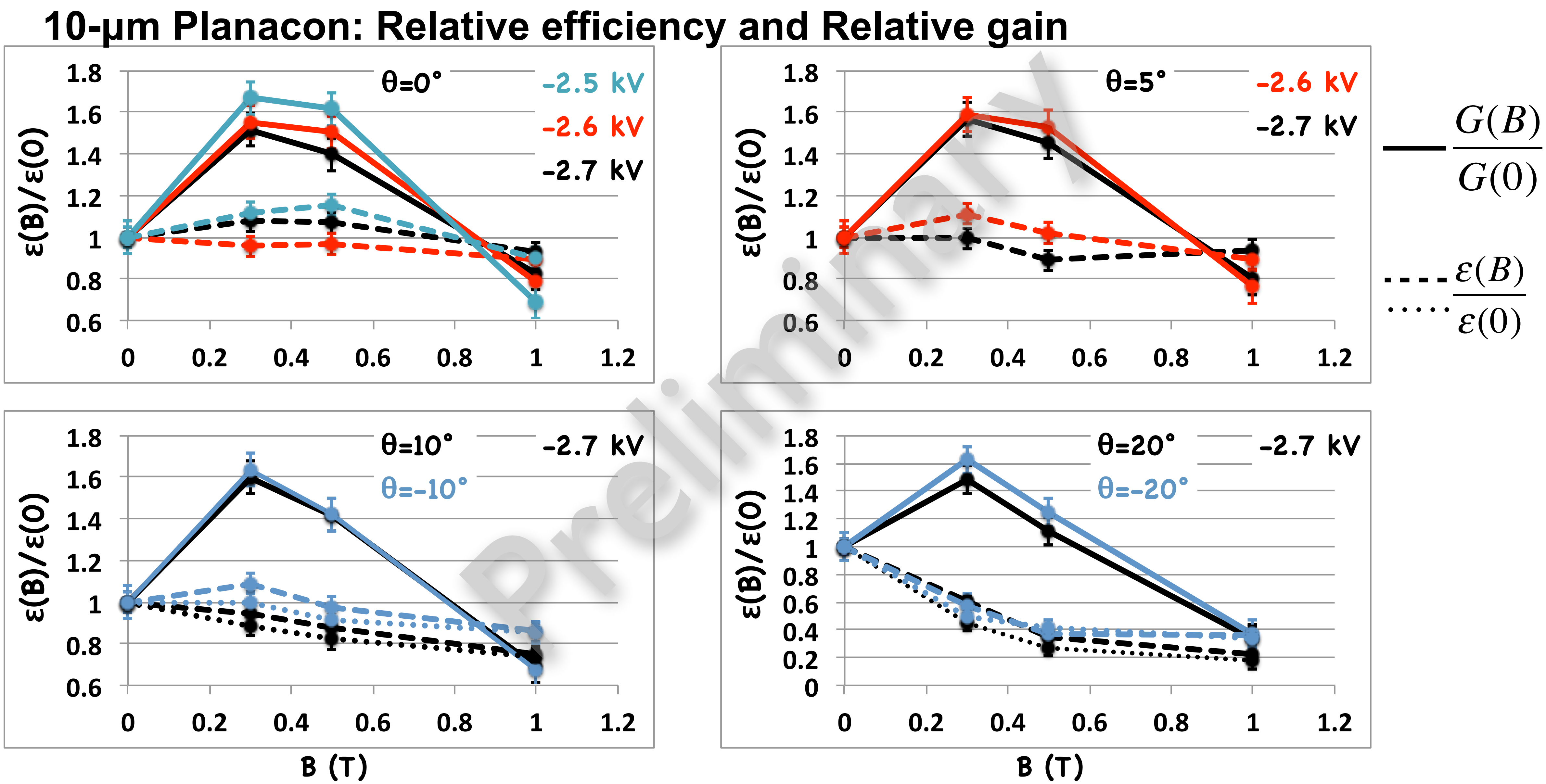
### Photonis XP85112




- Measurements performed at 96% of maximum allowed high voltage.
- Data
  - Maximum gain at 0.3 T.
  - 50% gain: 1.3 T.
  - Value of $B_{max}$ strongly depends on orientation.
  - The larger the polar angle, the lower $B_{max}$.

# Gain Characterization of Multi-Anode MCP PMTs

## Results

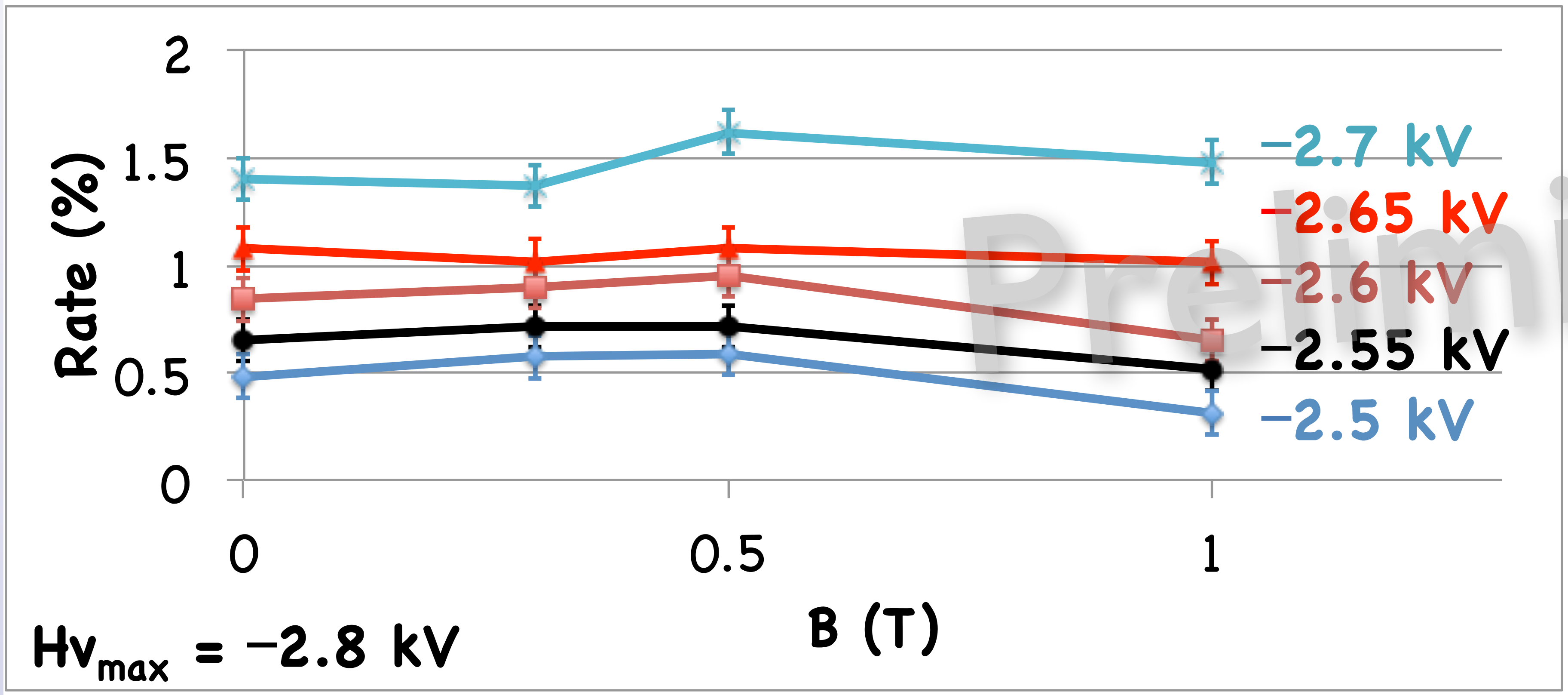


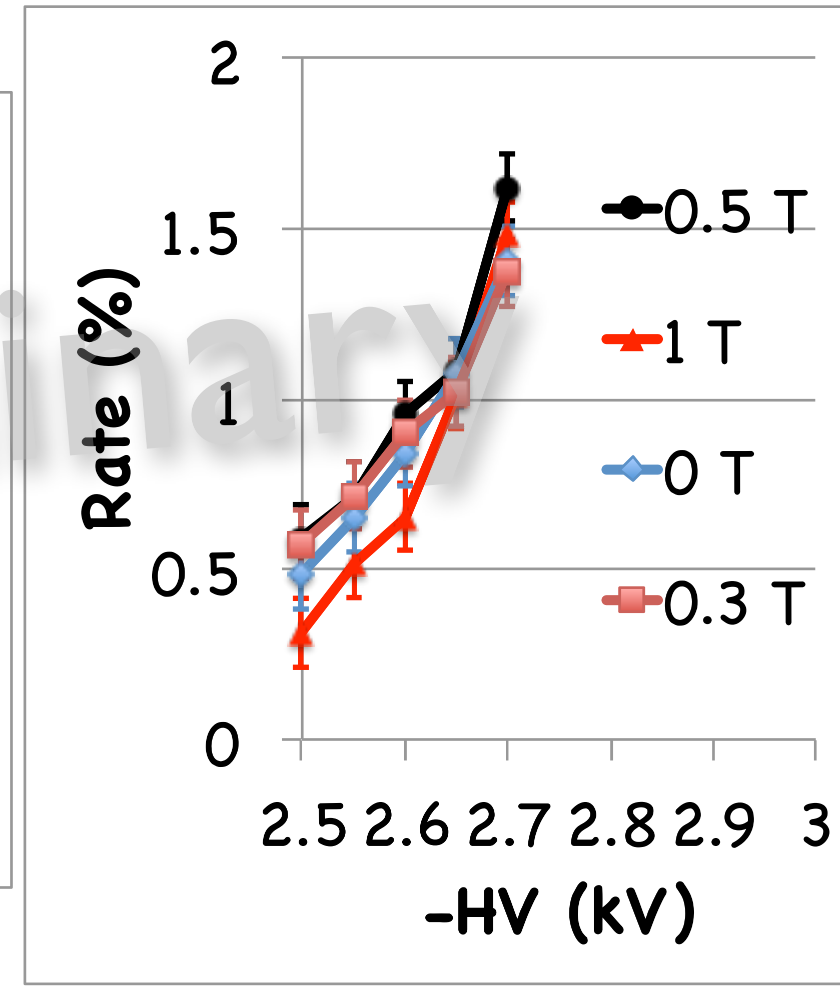

- Efficiency: $\varepsilon = N_{1phe}/N_{ped.}$
- At θ=20° between the sensor and the B-field axes, the efficiency drops continuosly as B increases even though the gain shows a maximum at 0.3 T.
- An increase of $HV_{photocathode\text{-}MCP1}$ by 200 V (close to maximum allowed) recovers only about 13% of the efficiency (θ=20°).

# Gain Characterization of Multi-Anode MCP PMTs

## Results

### 10-µm Planacon: Ion Feedback




$\Delta = Rate(A_{thr}=\text{Pedestal}) - Rate(A_{thr}=233)$. $\bar{\Delta} = 0.13$. Reported above: $Rate(A_{thr}=233) + \bar{\Delta}$

- At all voltages the ion rate is below 2%.
- Results suggest that ion-feedback is primarily driven by HV.
- Ion-feedback rate dependence on B-field magnitude is relatively weak.

# Future Work

## FY20

- Characterize a 32x32 10-μm pore size Planacon XP85122
- Characterize an 8x8 6-μm pore size Photek sensor.

Timing resolution, gain, efficiency, ion feedback

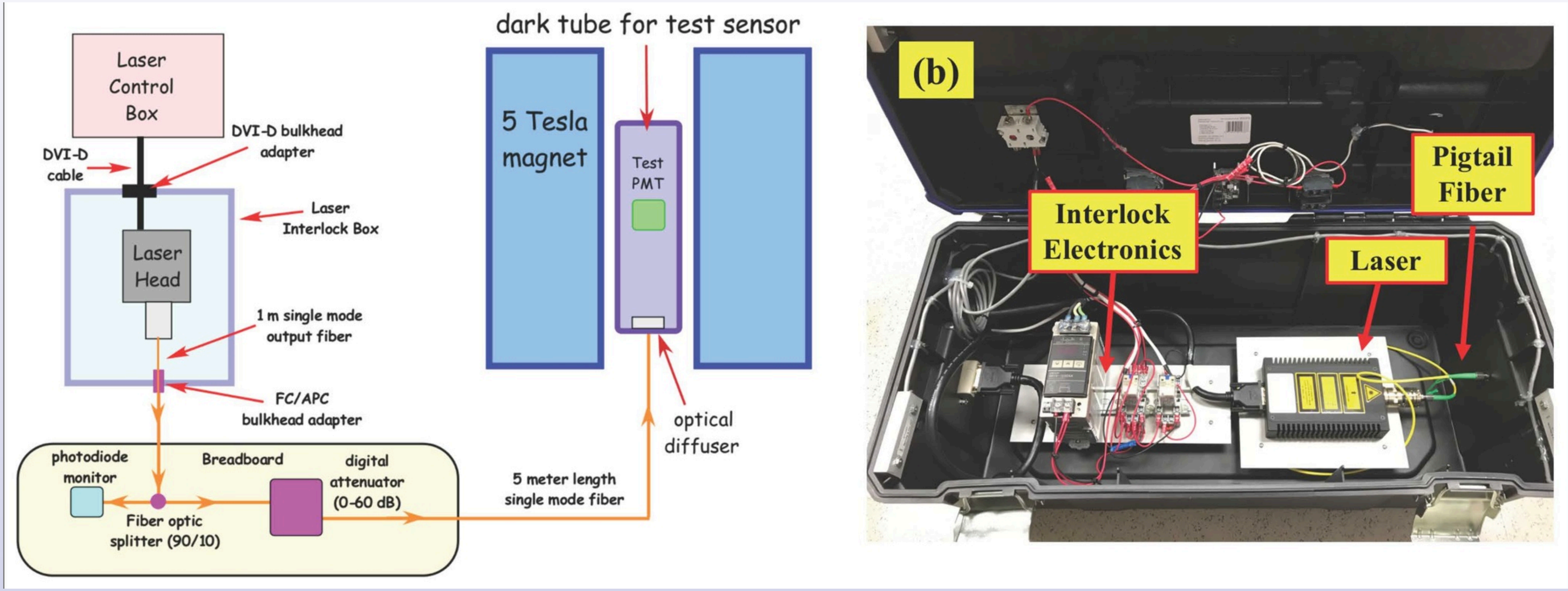
## FY21 - FY23

- Prepare for large-scale characterization of MCP PMTs for DIRC prototype using planned SiREAD readout (share resources at JLab with INFN-Ferrara, ANL LAPPD project)
  - cross talk
  - uniformity
  - gain, timing, efficiency per channel

# The End

# Facility Capabilities

## Major components



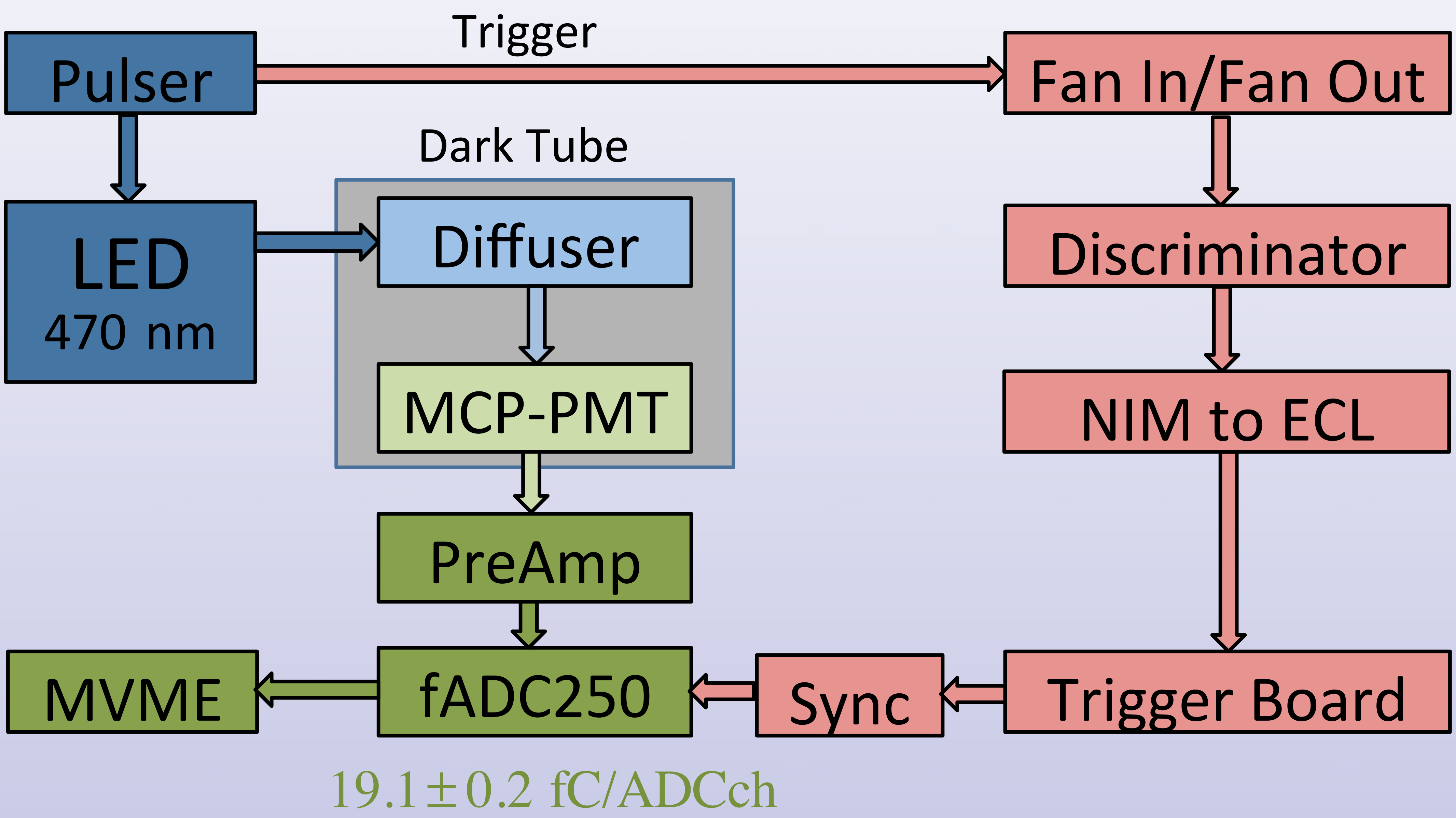

A **picosecond laser** added in **Summer 2018** (procured by ODU)

Laser setup (JLab Detector Group)

Laser safety system (JLab electronics Group)

# Facility Capabilities

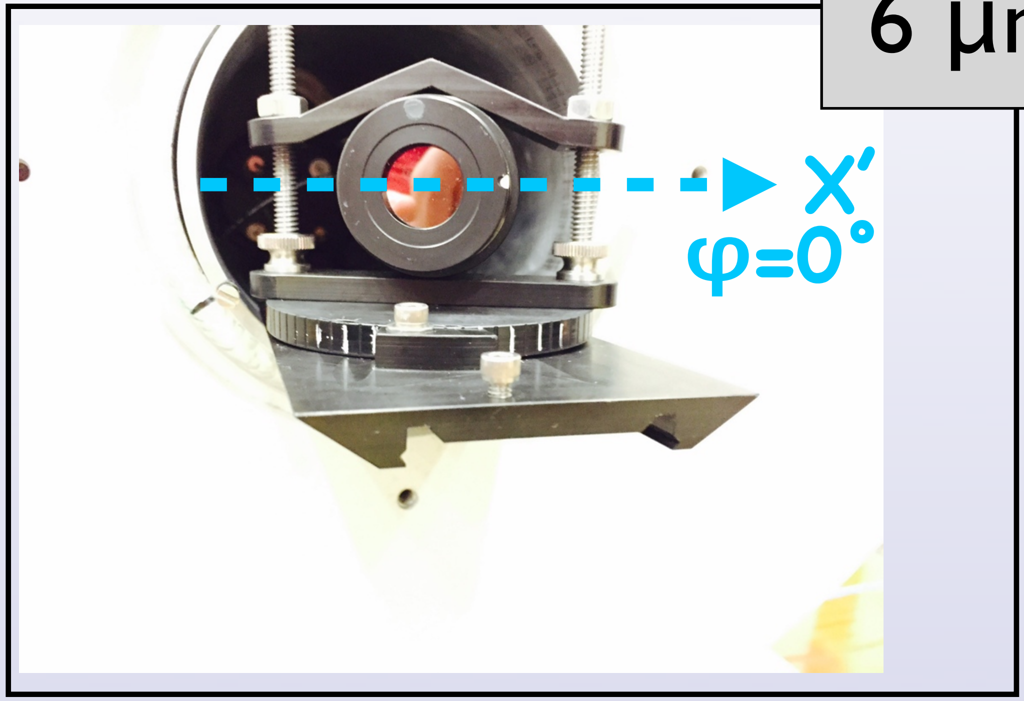
## Major components

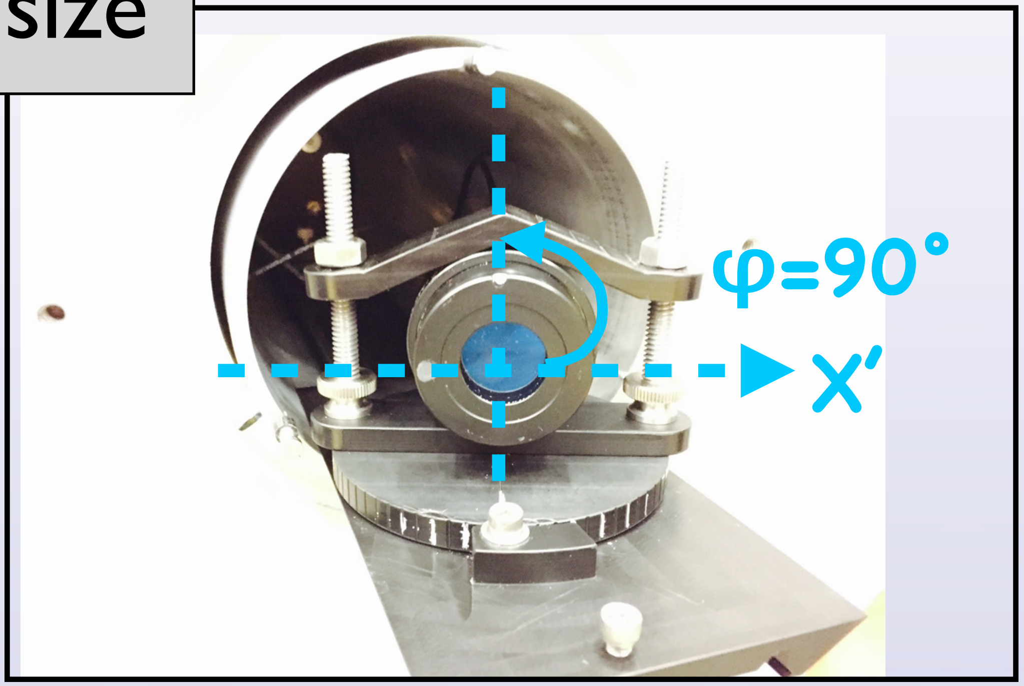


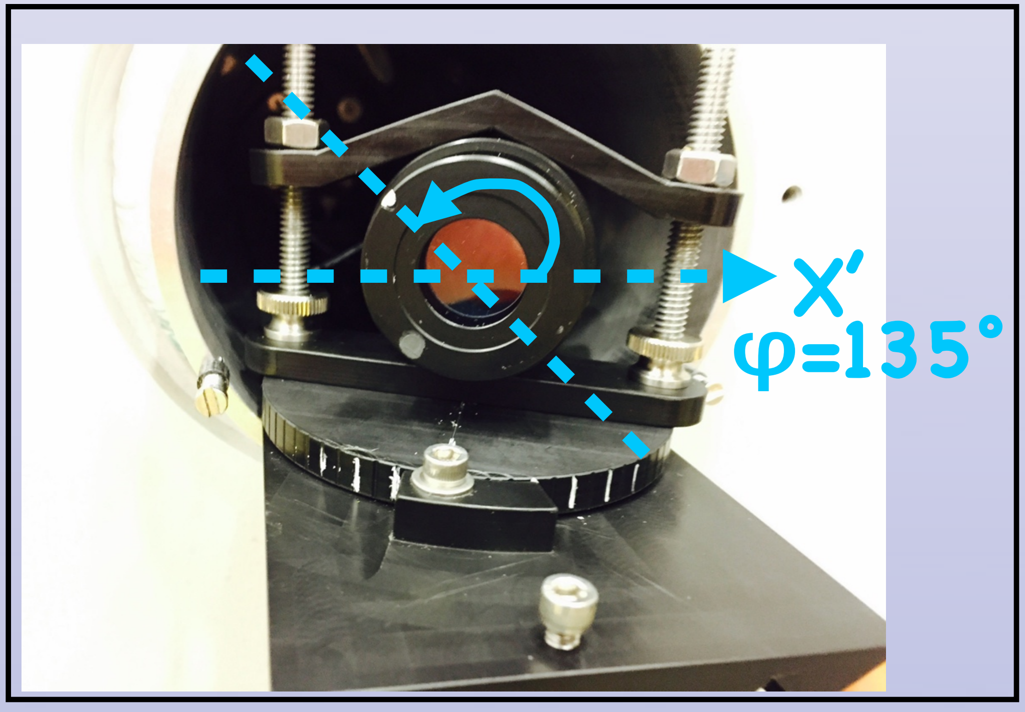
# Gain Characterization of Single-Anode MCP PMTs

## Studies of Azimuthal Angle Dependence

6 μm pore size

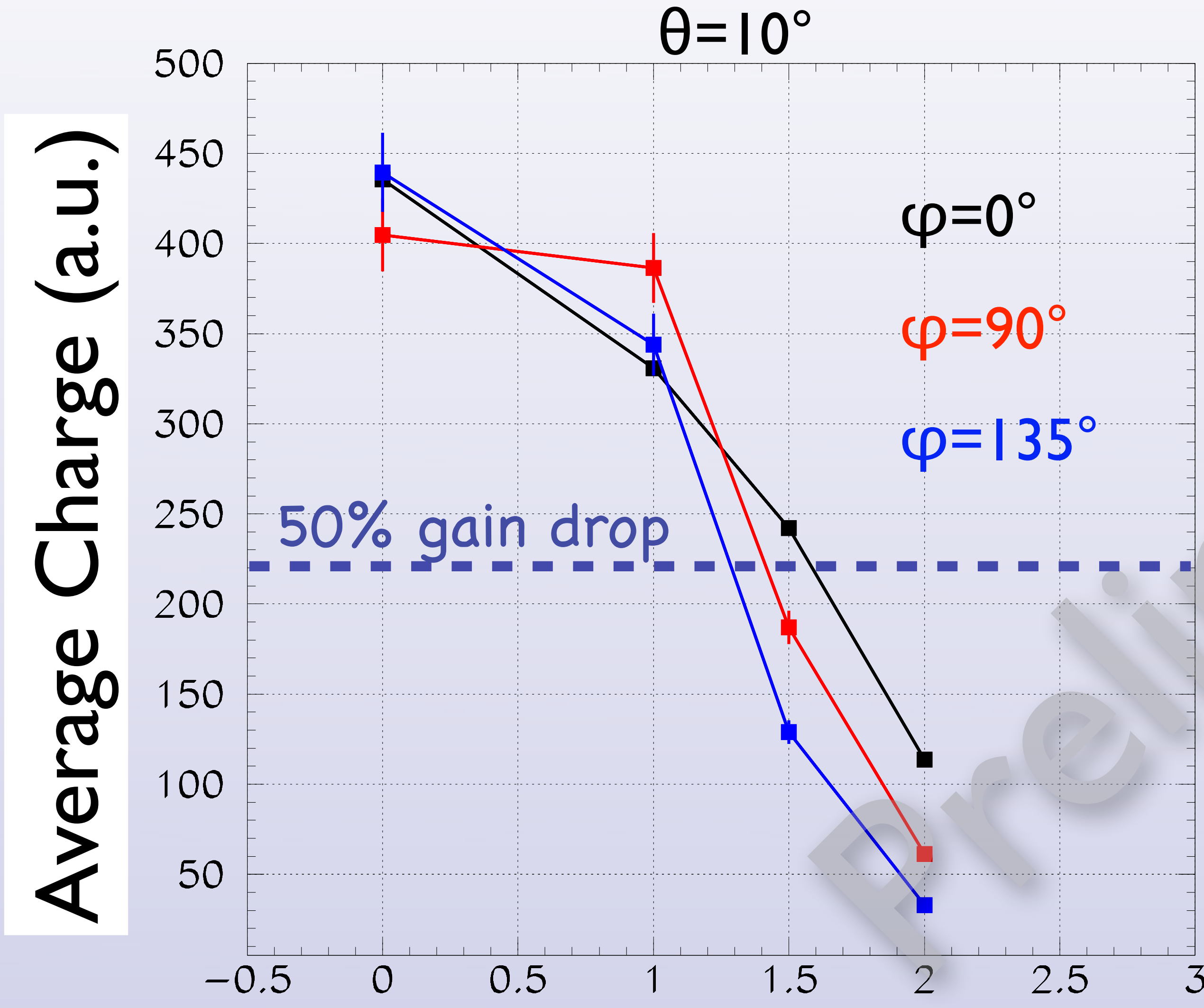


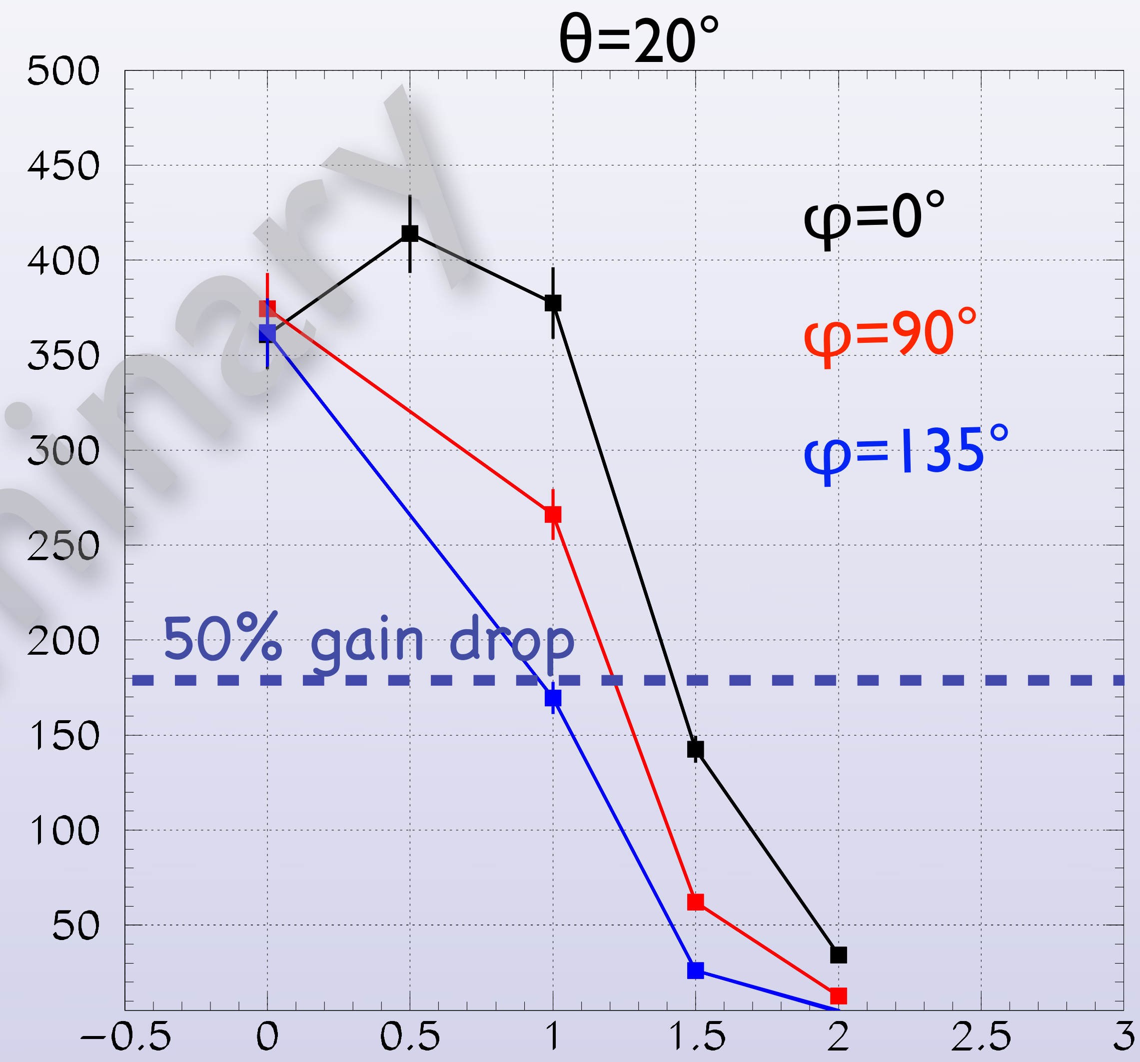



# Gain Characterization of Single-Anode MCP PMTs

## Studies of Azimuthal Angle Dependence



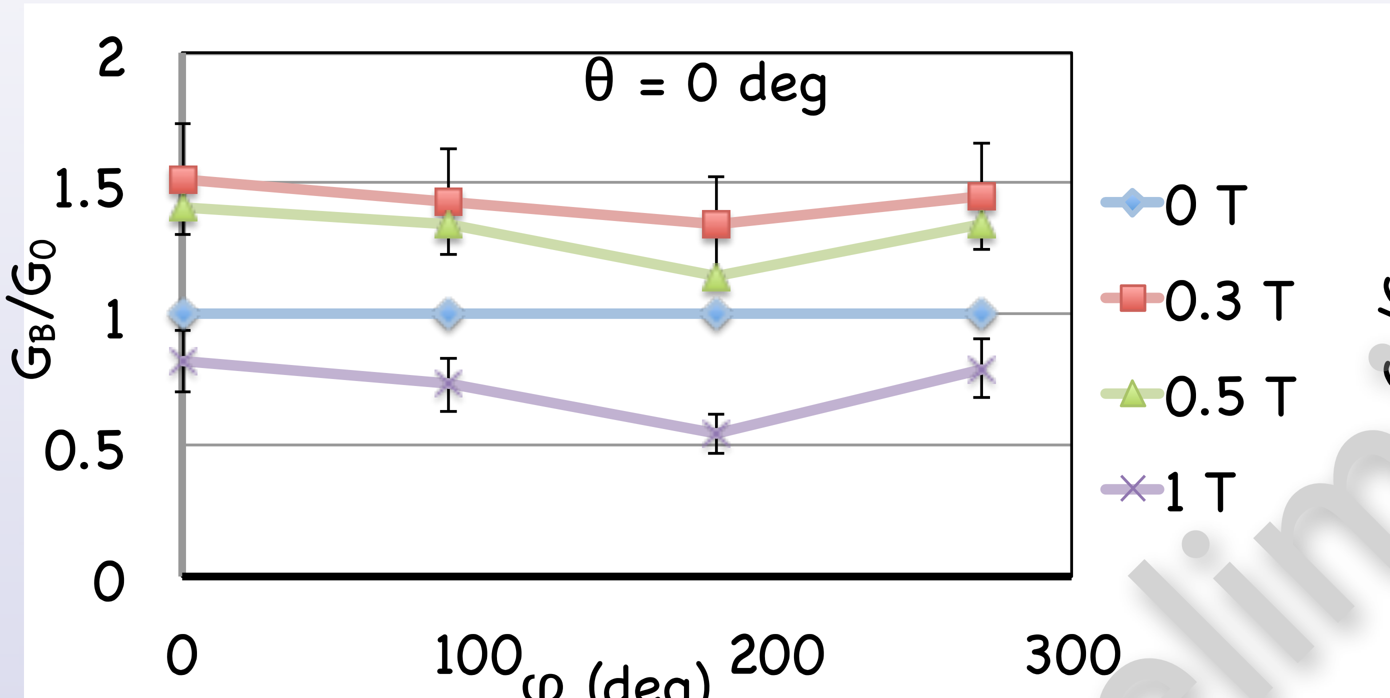

- operating voltage: -2.6 kV
- no normalization applied
- overall data suggest that the total collected charge depends on the φ angle, especially above 1 T
- the φ dependence is strongly correlated with θ

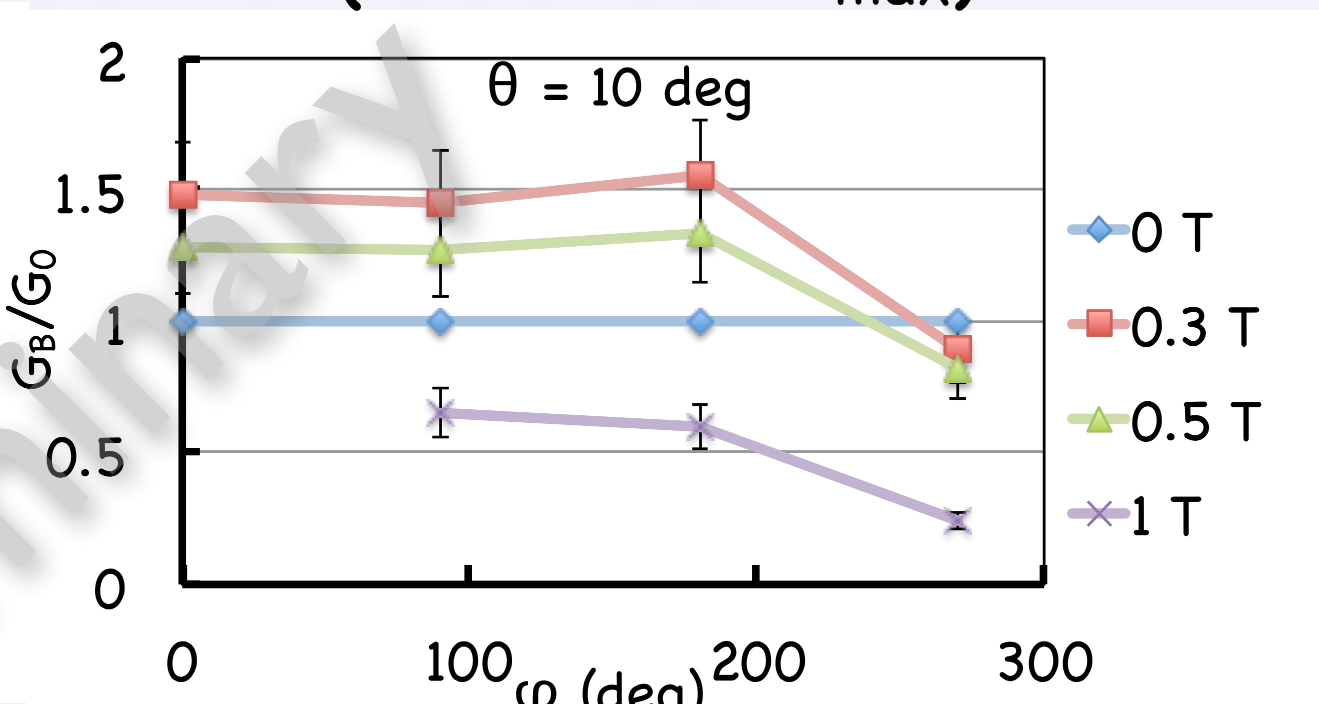
# Gain Characterization of Multi-Anode MCP PMTs

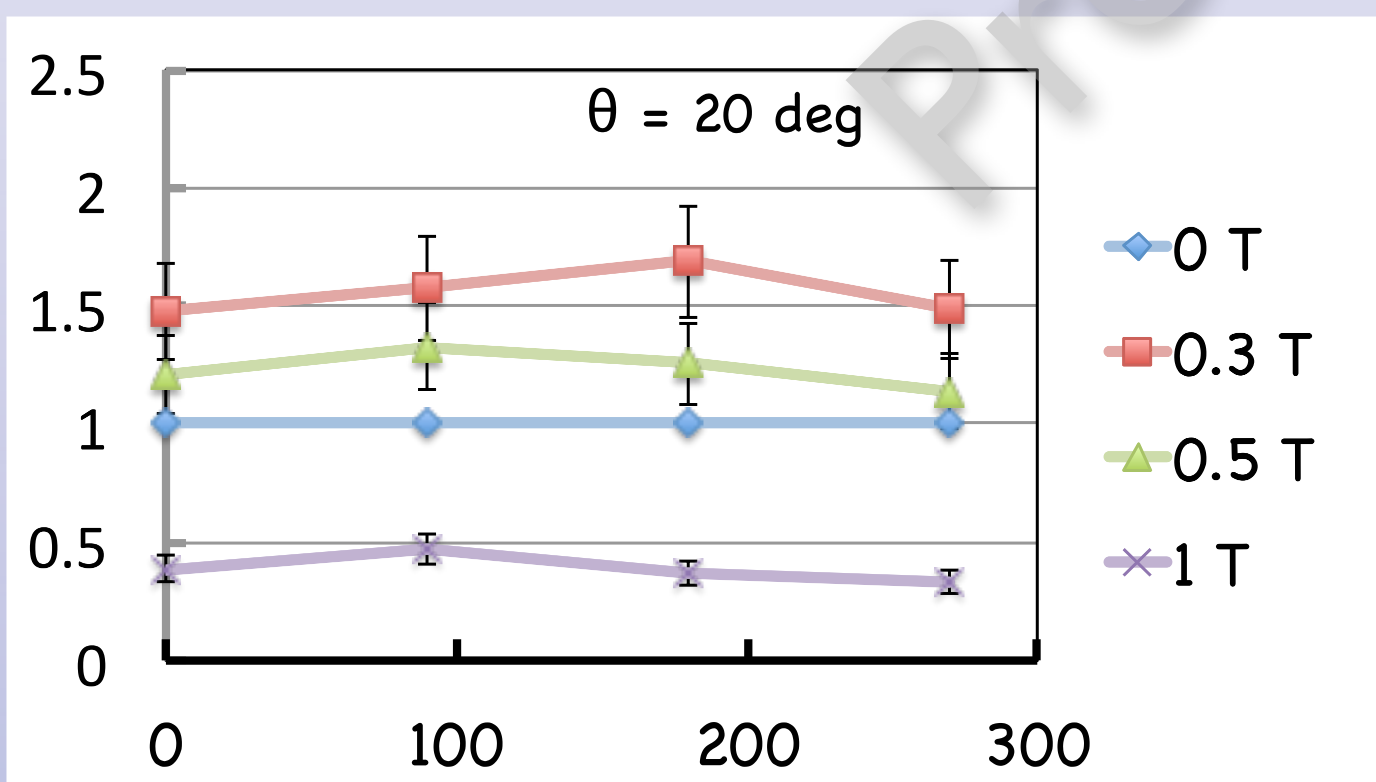
## Results

**Photonis XP85112**

HV=-2.7 kV (96% of $HV_{max}$)






Azimuthal-angle dependence is correlated with the polar angle

- θ = 0° – minimum at φ = 180°
- θ = 10° – minimum at φ = 270°
- θ = 20° – no characteristic features