QuARC 2025 Experiments: Scintillator Sheet Response Comparisons

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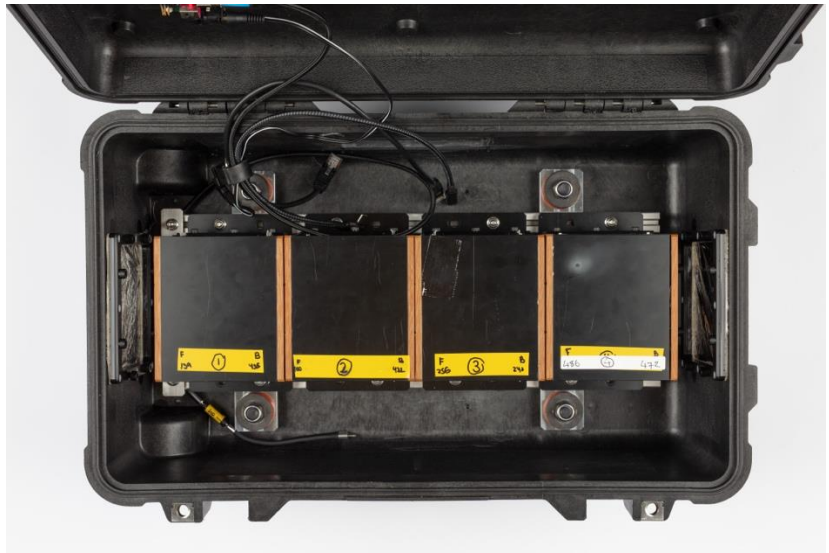
Overview

- QuARC Detector Upgraded in 2025
  - New scintillator sheets (modules contained mix of transparent machined sheets, translucent sheets and injection moulded transparent sheets)
  - Updated electronics to reduce noise and have dual-sided readout of sheets.

- 3 beam tests in 2025
  - Prague PTC in April 2025 (1 morning) – 4 modules
  - UCLH in May 2025 (1 day) – 4 modules
  - Trento Proton Therapy Centre (2 nights of QuARC measurements) – 3 modules



QuARC Module Assembly

- Module 1:
  - Front of module: mostly sanded translucent sheets
  - Back of module: intertwined translucent sanded sheets, and machined polished sheets (combo of thick and thin)

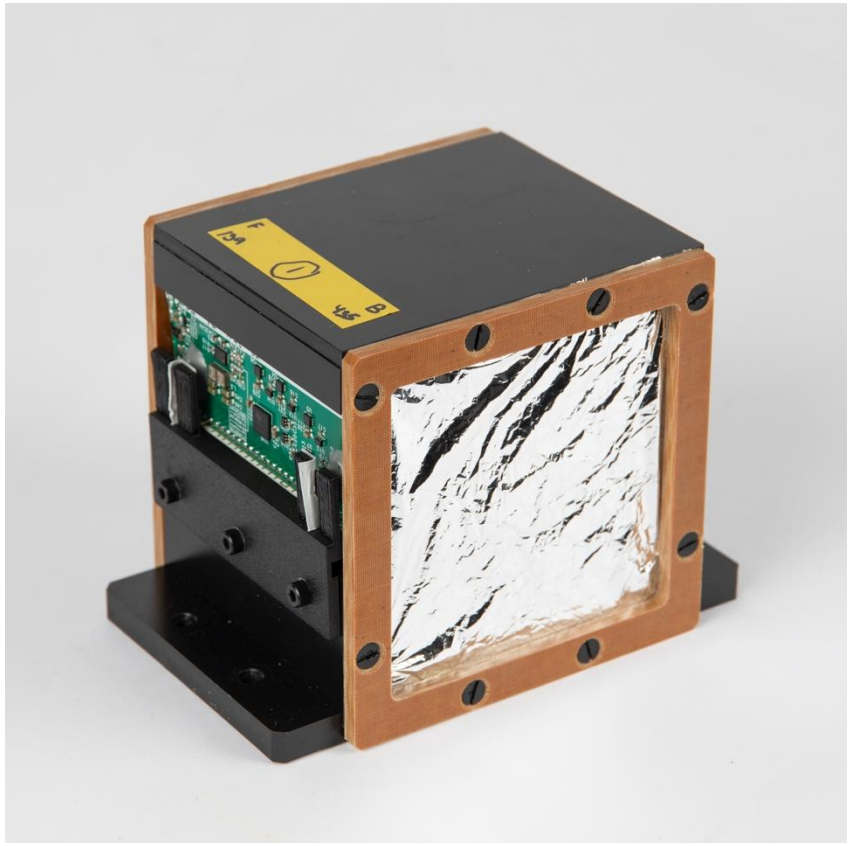
- Module 2 (best module):
  - All machined polished sheets and those closets to 3mm (i.e. between 2.99mm and 3.01mm)

QuARC Module Assembly

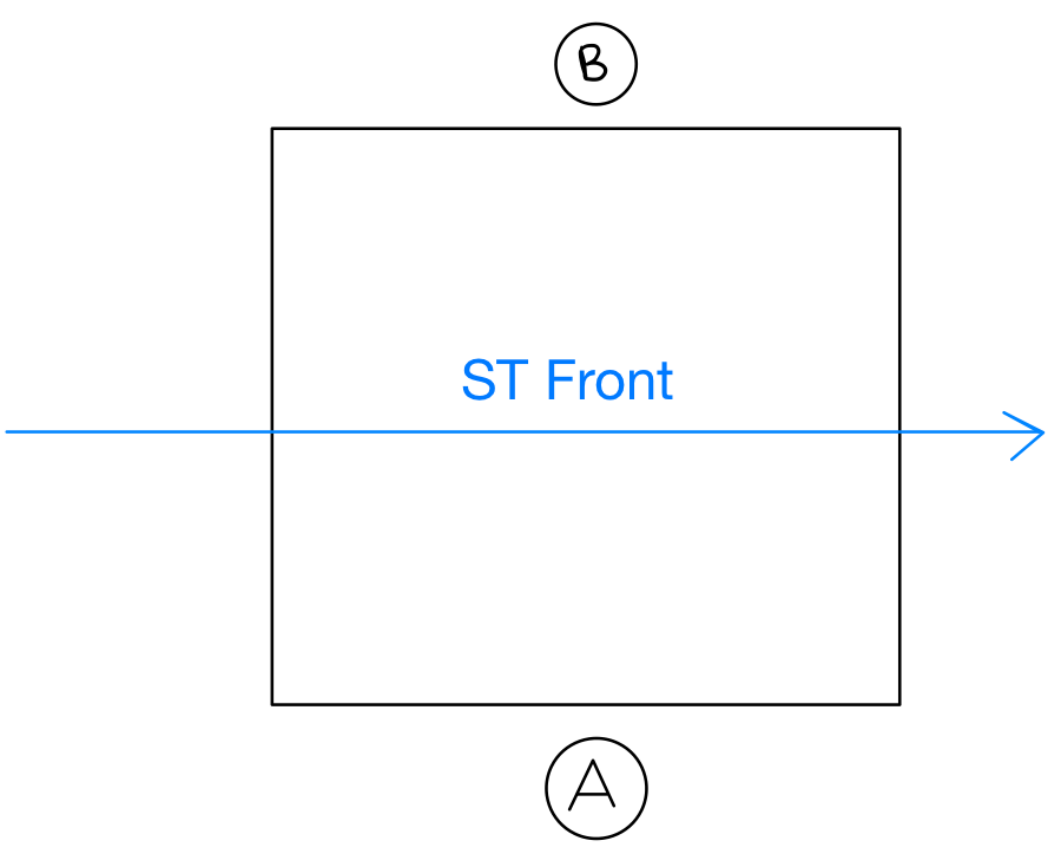
- Module 3:
  - All sanded translucent sheets (all under 3mm: 2.96 – 2.99 mm thicknesses)

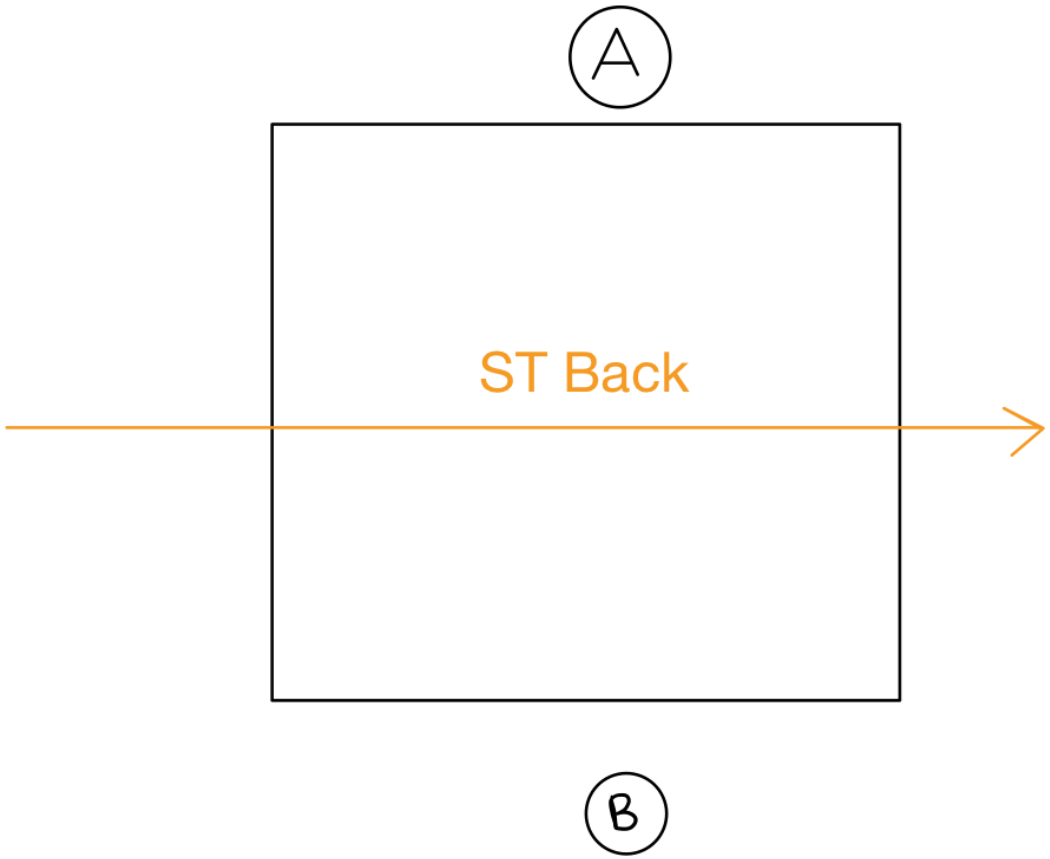
- Module 4:
  - Prague experiment:
    - Front half – combination of injection moulded sheets and transparent polished sheets
    - Back half: combination of injection moulded and translucent sanded sheets
    - Irregularity of injection moulded sheets meant stack was too large for holder and difficult to assemble hence PD's did not align well to sheets.
  - UCLH experiment:
    - Combination of sanded sheets and polished sheets (only a few near the front)

QuARC Module Side View



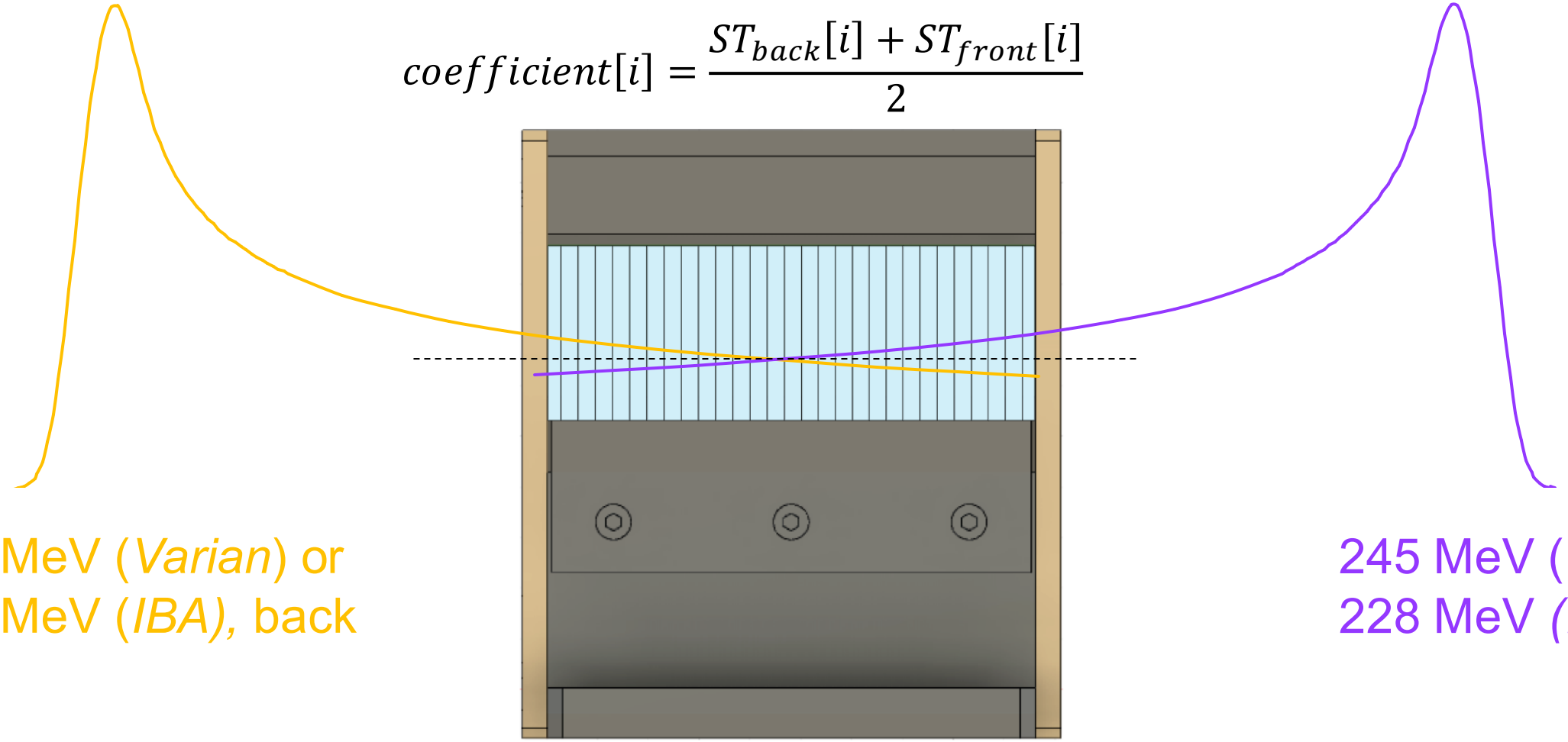
Detector Calibration





Detector Calibration

$$coefficient[i] = \frac{ST_{back}[i] + ST_{front}[i]}{2}$$



245 MeV (*Varian*) or
228 MeV (*IBA*), back

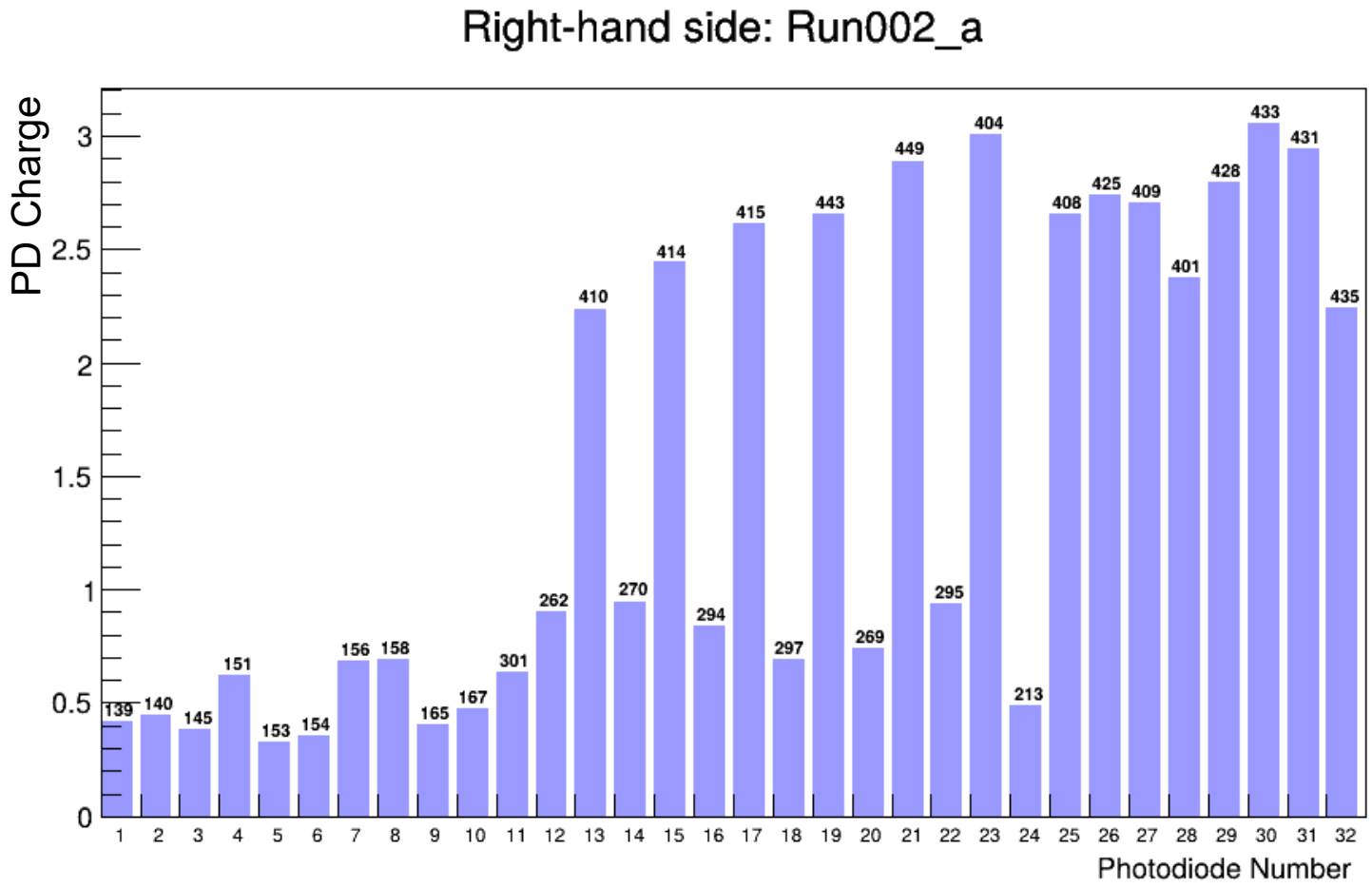
245 MeV (*Varian*) or
228 MeV *(IBA)*, front

Prague PTC

- IBA Machine so 228 MeV is max energy.
- Two shoot through measurements performed per module (1 in each orientation).
- Shoot-through irradiations performed at clinical current – 8 nA.
- To note in next set of slides – A-side electronics more reliable – the less reliable PDs and boards were put on B-side

MODULE 1

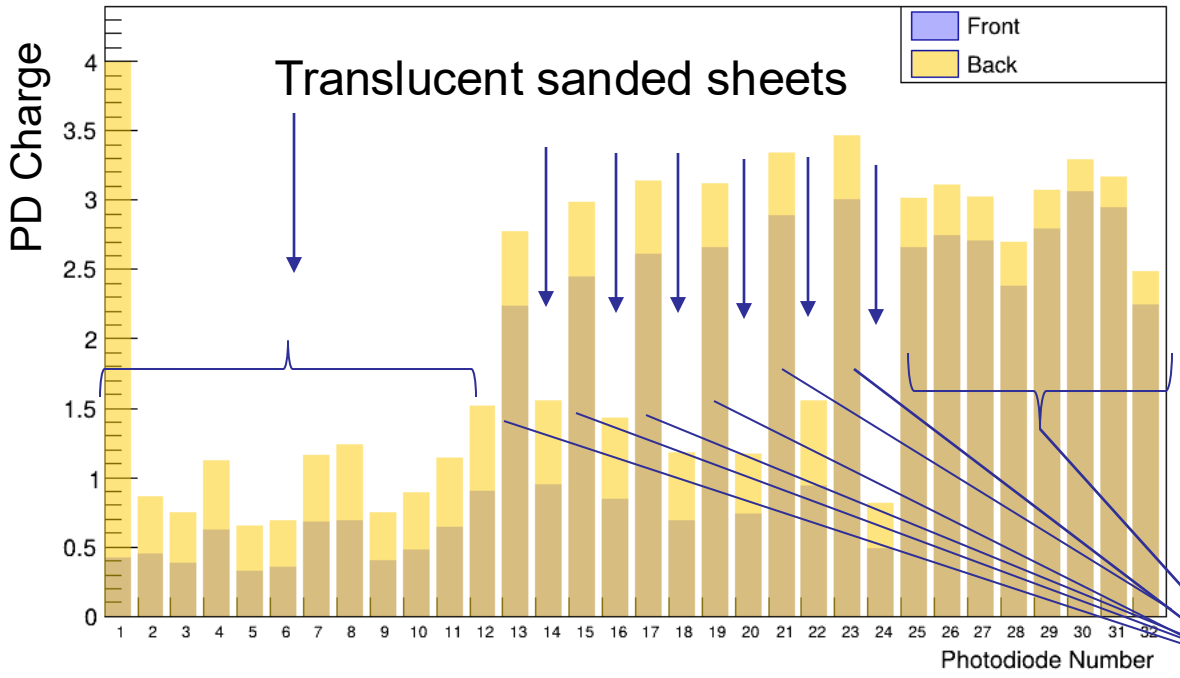
Different scintillator sheets, so light output differs.
Much higher light output on machined polished sheets (number 400 onwards)



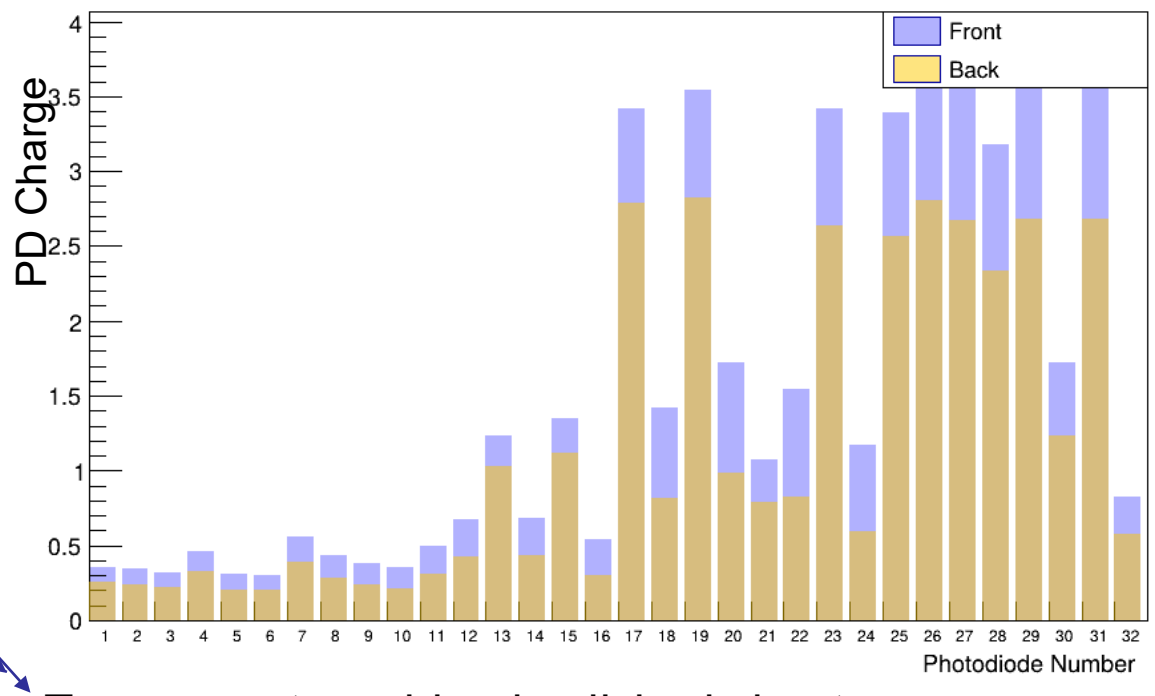
MODULE 1: compare STFront and STBack

A side (right) sees more light with STBack and B side (left) side sees more light with STFront -> Always more light when the board is placed on the left hand side of the beam.

A side



B side

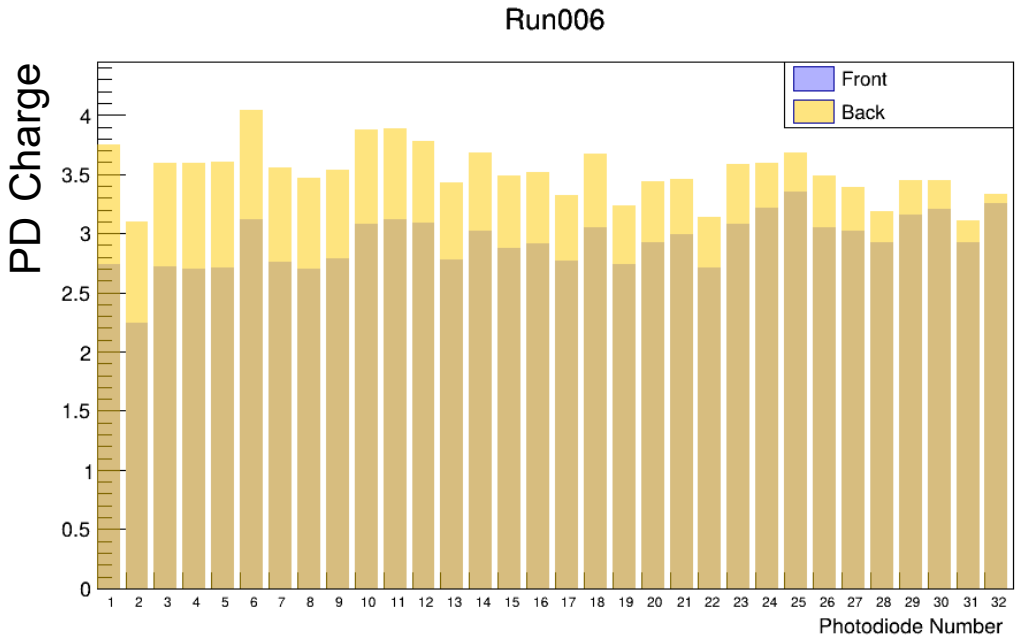


Transparent machined polished sheets

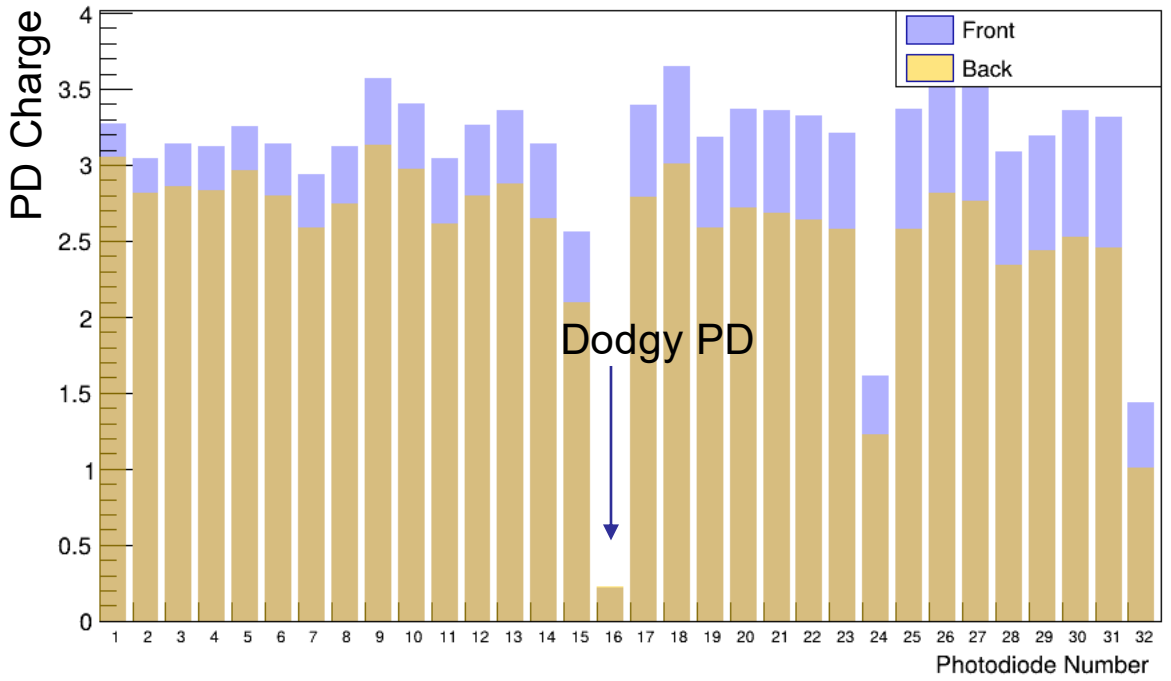
MODULE 2: compare STFront and STBack

- A side (right) sees more light with STBack and B side (left) side sees more light with STFront again -> Always more light when the board is placed on the left hand side of the beam.
- More uniform overall response due to all sheets being machined transparent sheets

A side



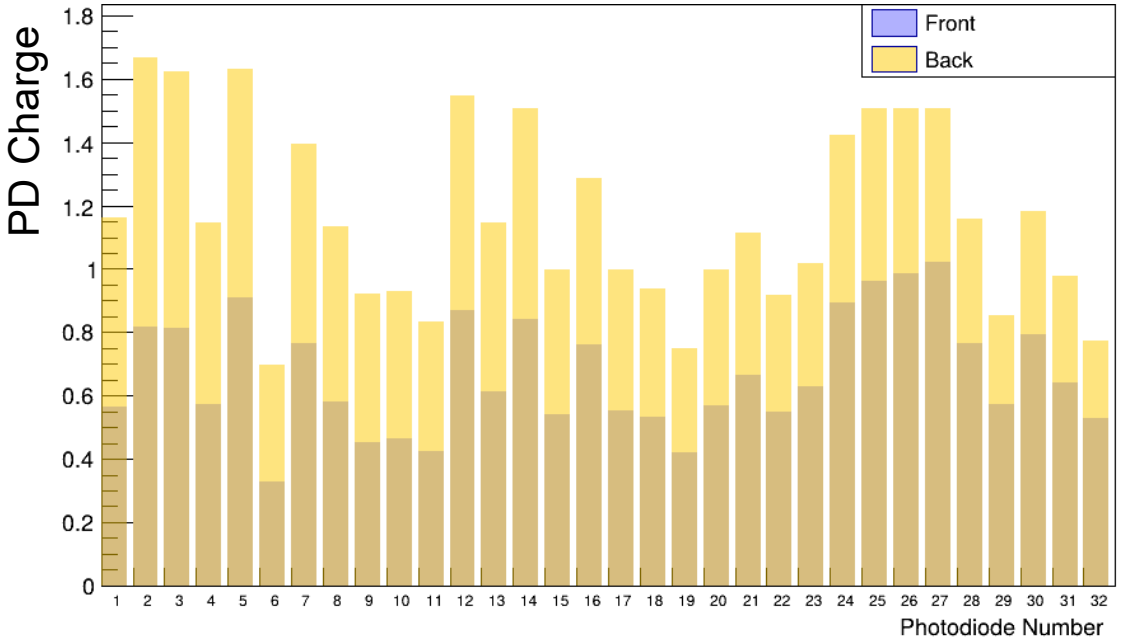
B side



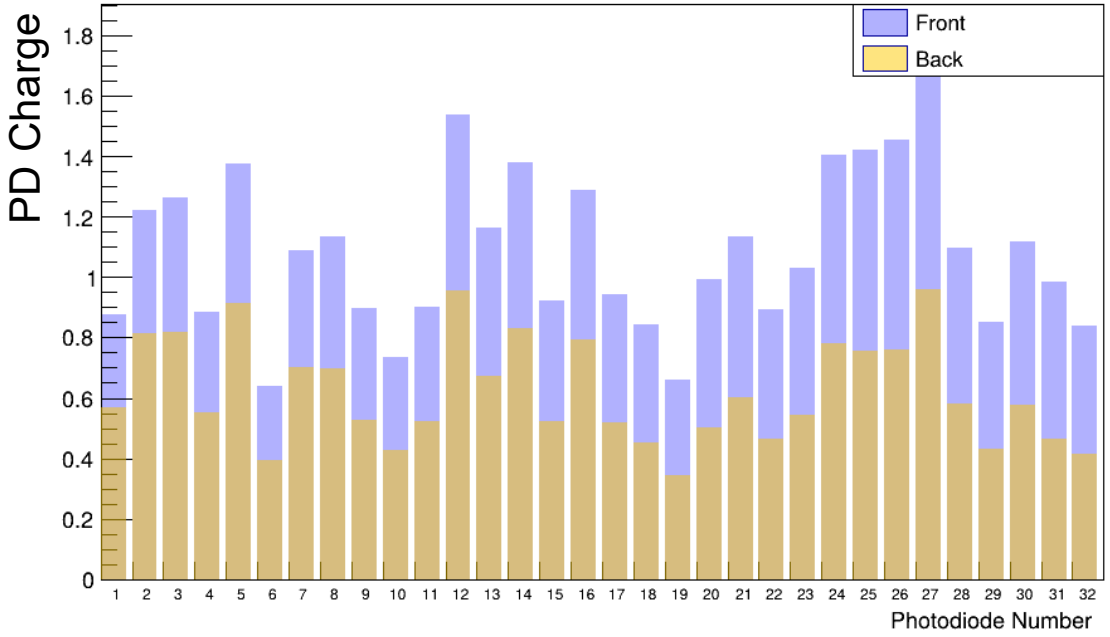
MODULE 3: compare STFront and STBack

- Older sanded translucent sheets are showing much larger variation in response despite being all the same ‘type’ of sheet.

A side



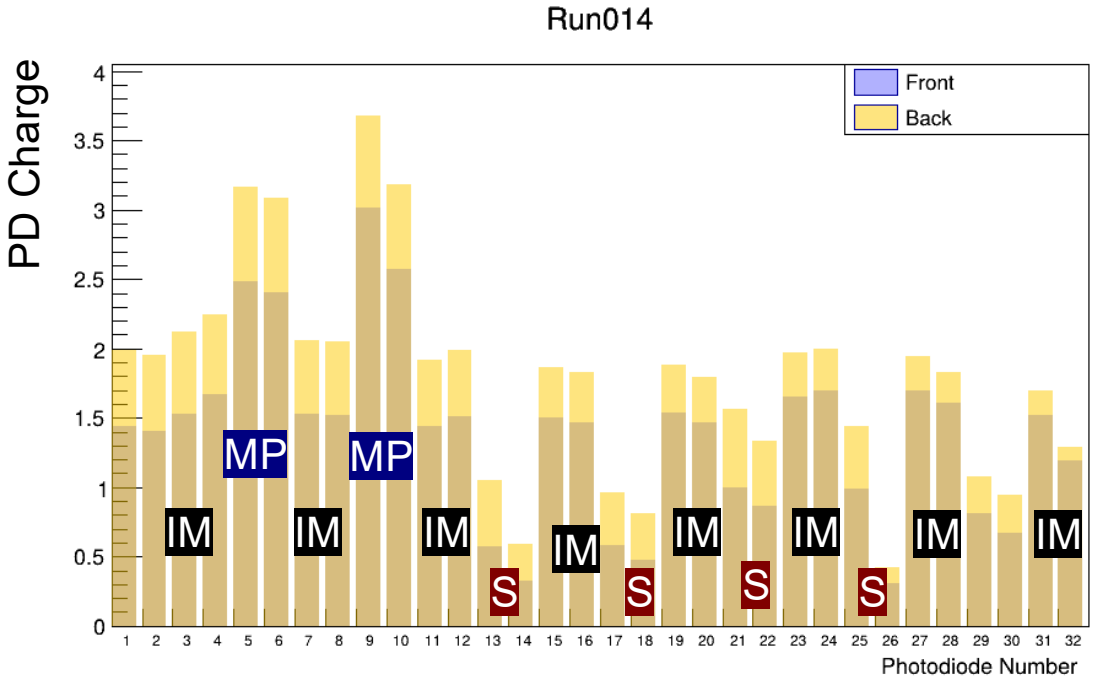
B side



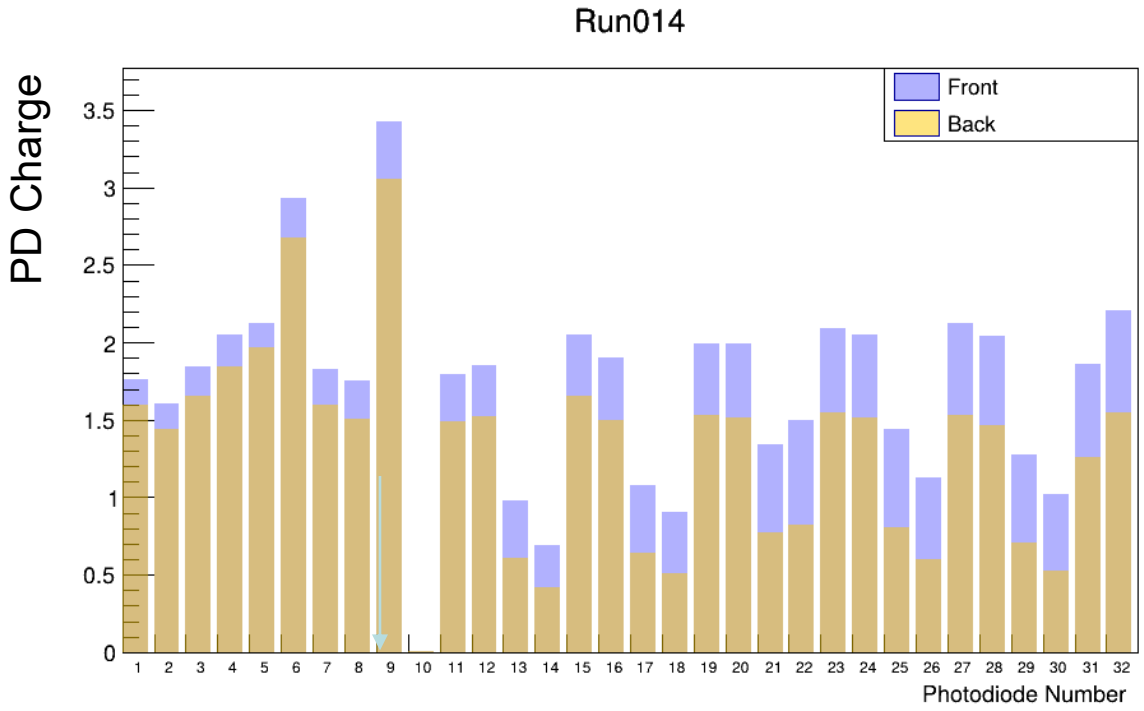
MODULE 4: compare STFront and STBack

- Machined and polished sheets (MP) showed greatest light output
- Injection moulded (IM) sheets showed better light output than sanded translucent sheets (S)

A side

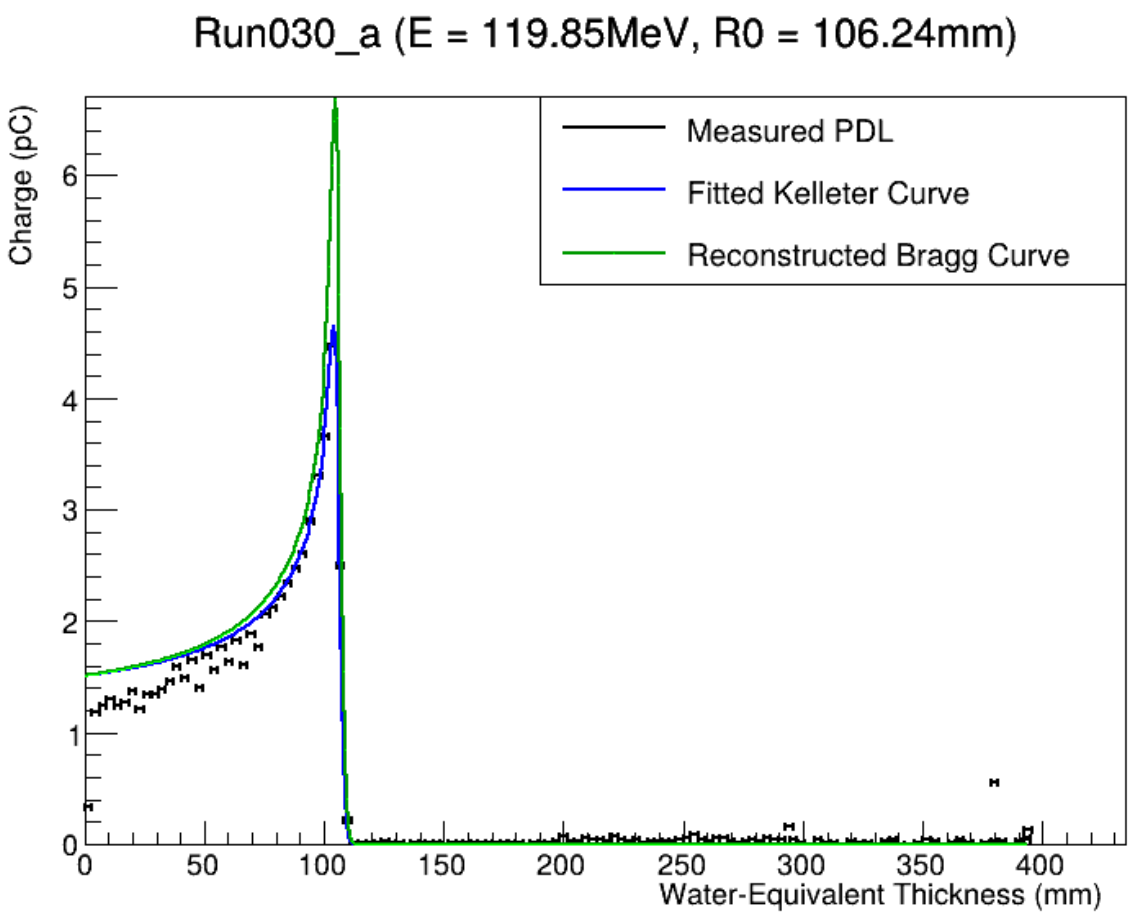


B side

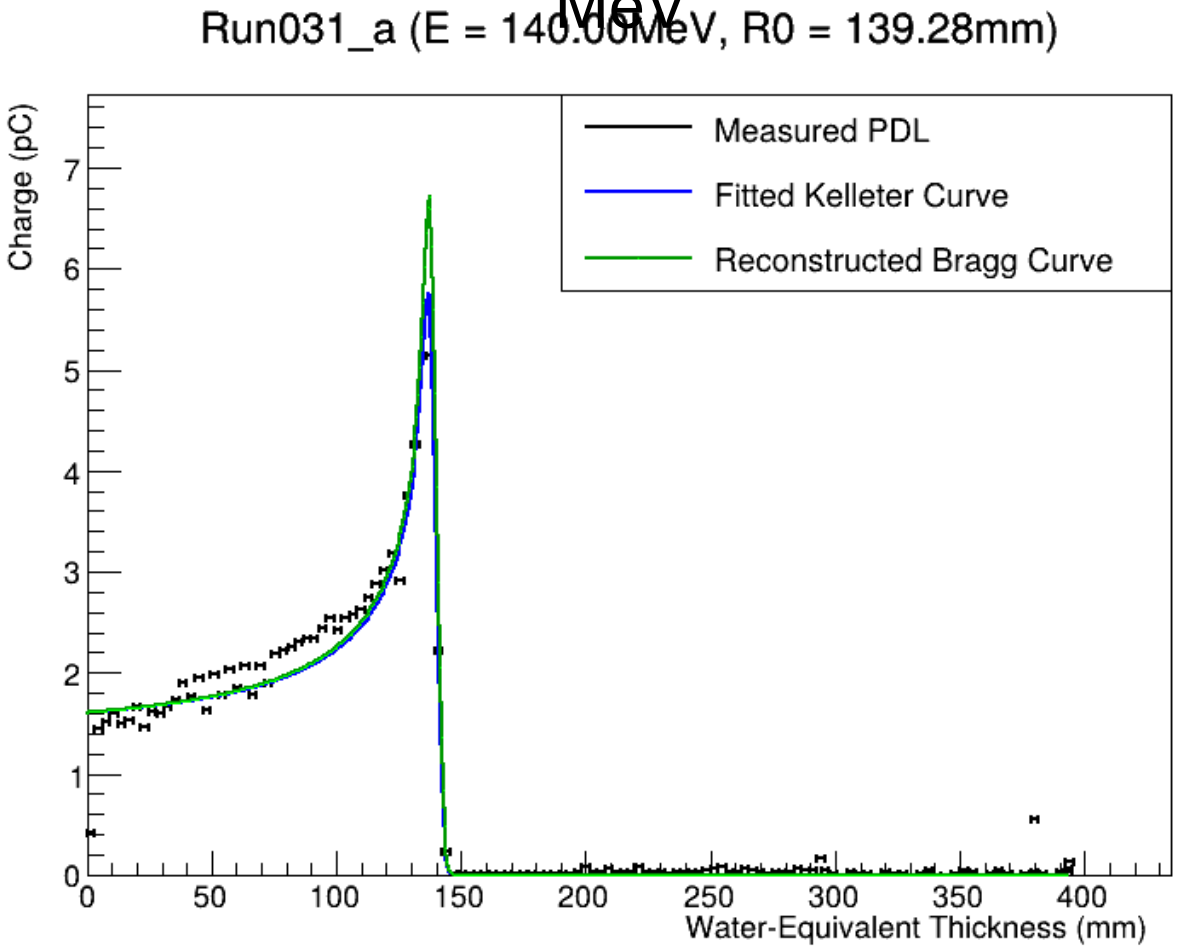


Bragg Peak results

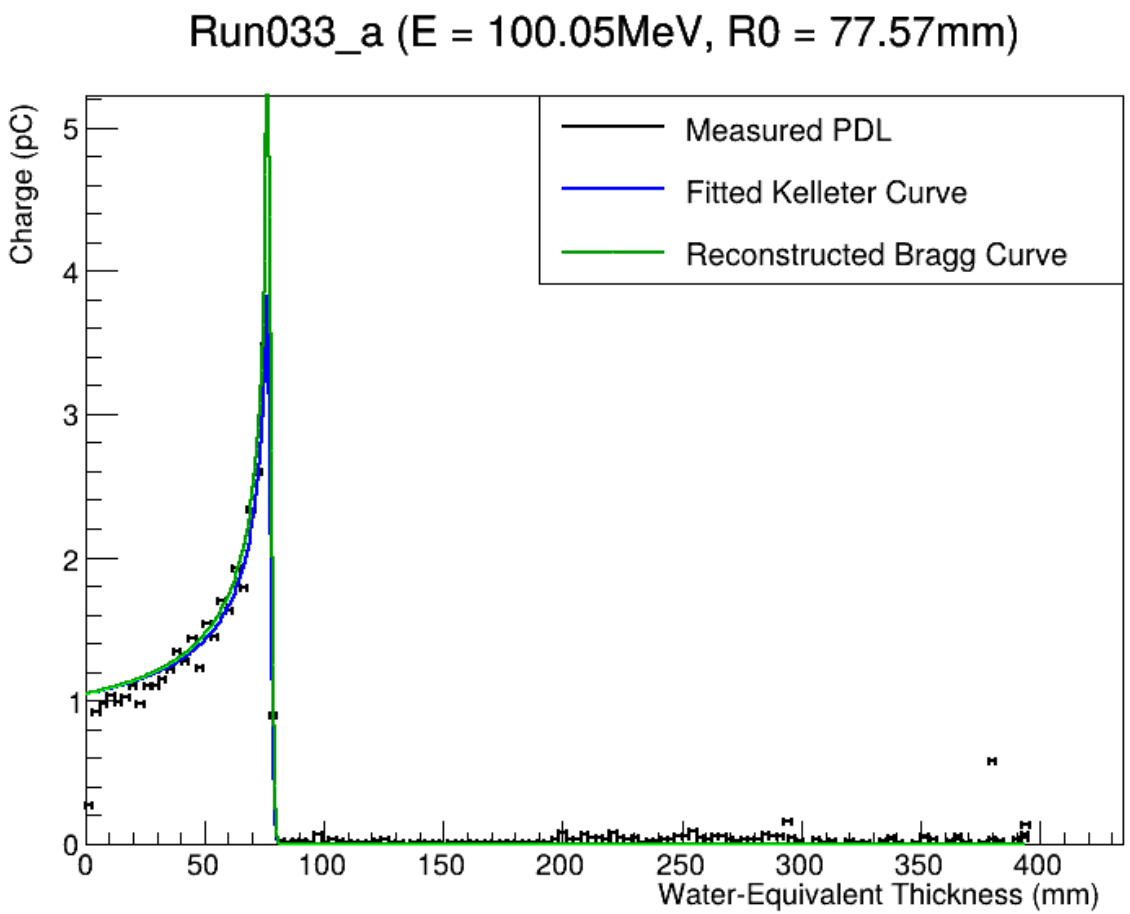
120 MeV

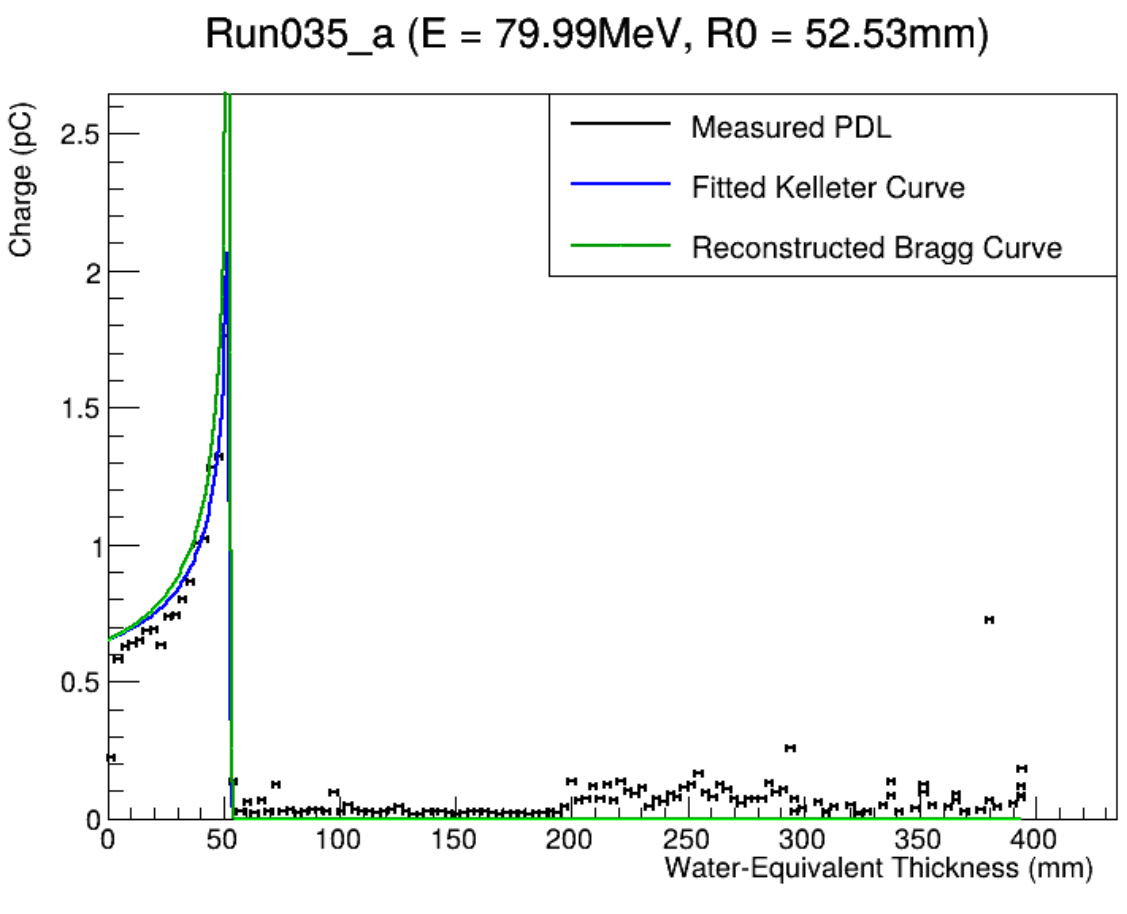


140 MeV



Bragg Peak results II





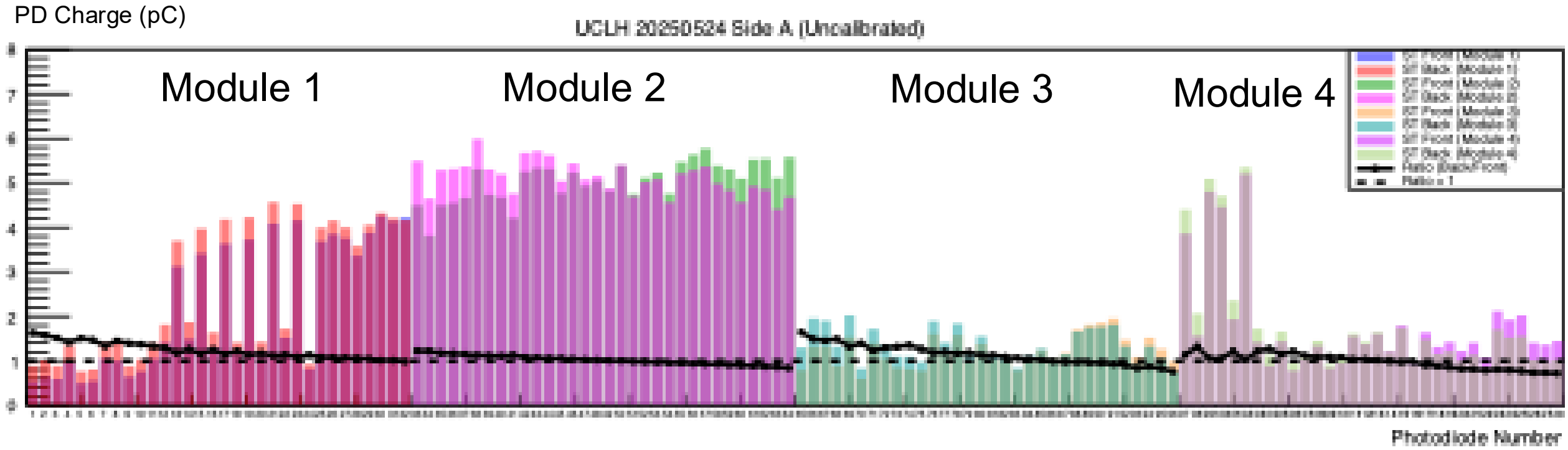
UCLH

- Measurements with 4 modules (4th module different Prague measurements and consists of mostly sanded sheets and a couple polished sheets but no injection moulded).

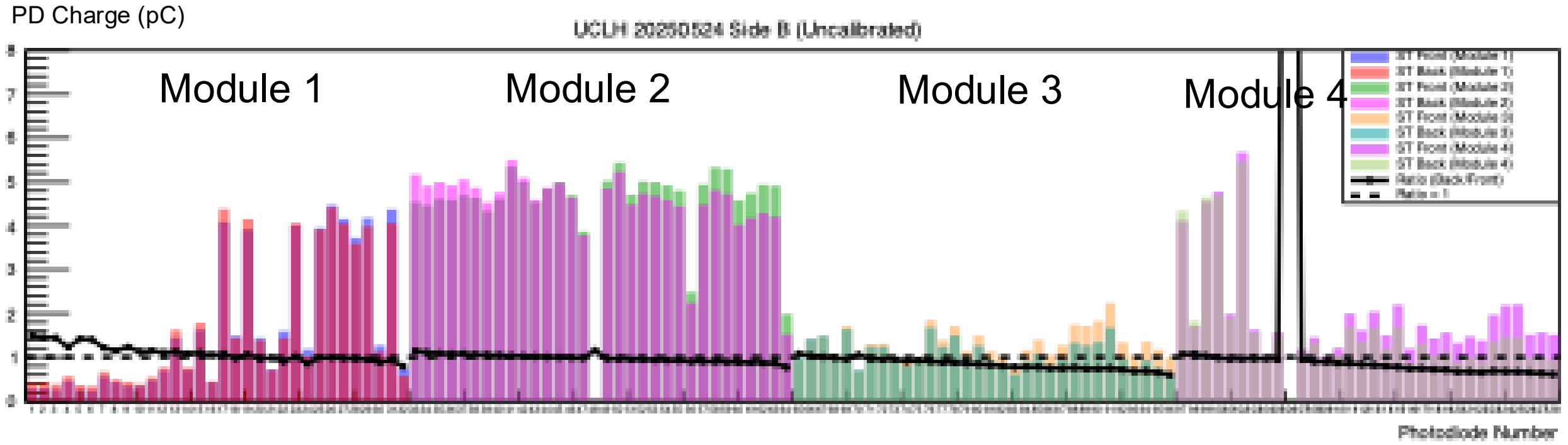
- 2 shoot throughs per module (front and back) - approx 10,000 MU was sufficient for 30,000 measurements

- Pristine Bragg peak measurements across entire clinical range (70 – 245 MeV) and SOBPs

Side A Shoot through comparisons

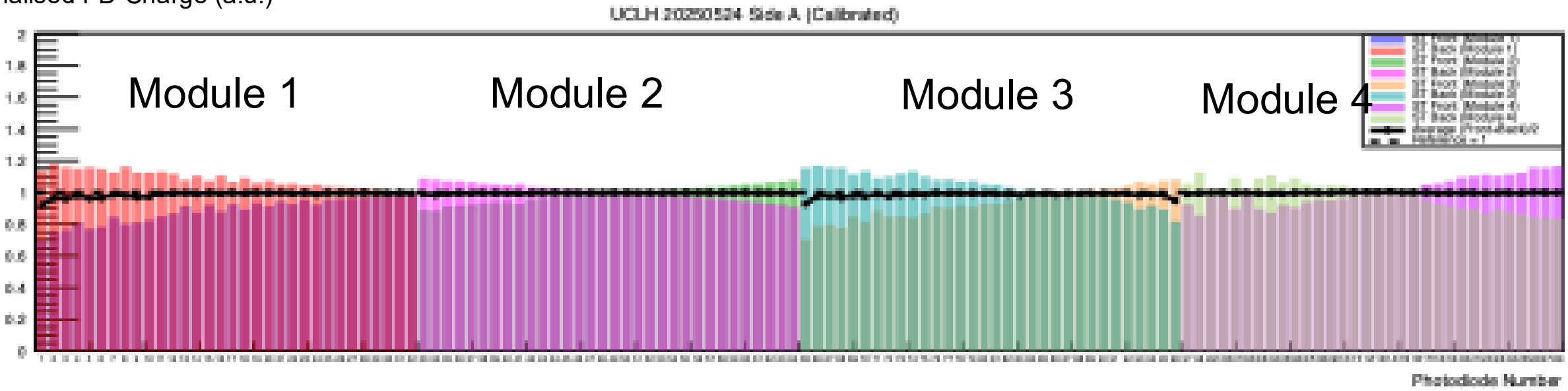


Side B Shoot through comparisons



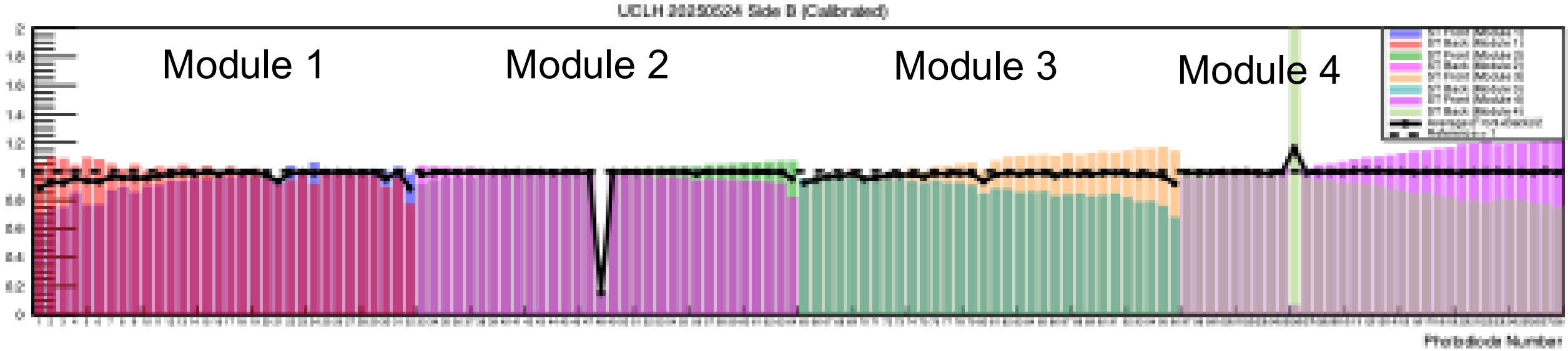
Side A Calibrated

Normalised PD Charge (a.u.)



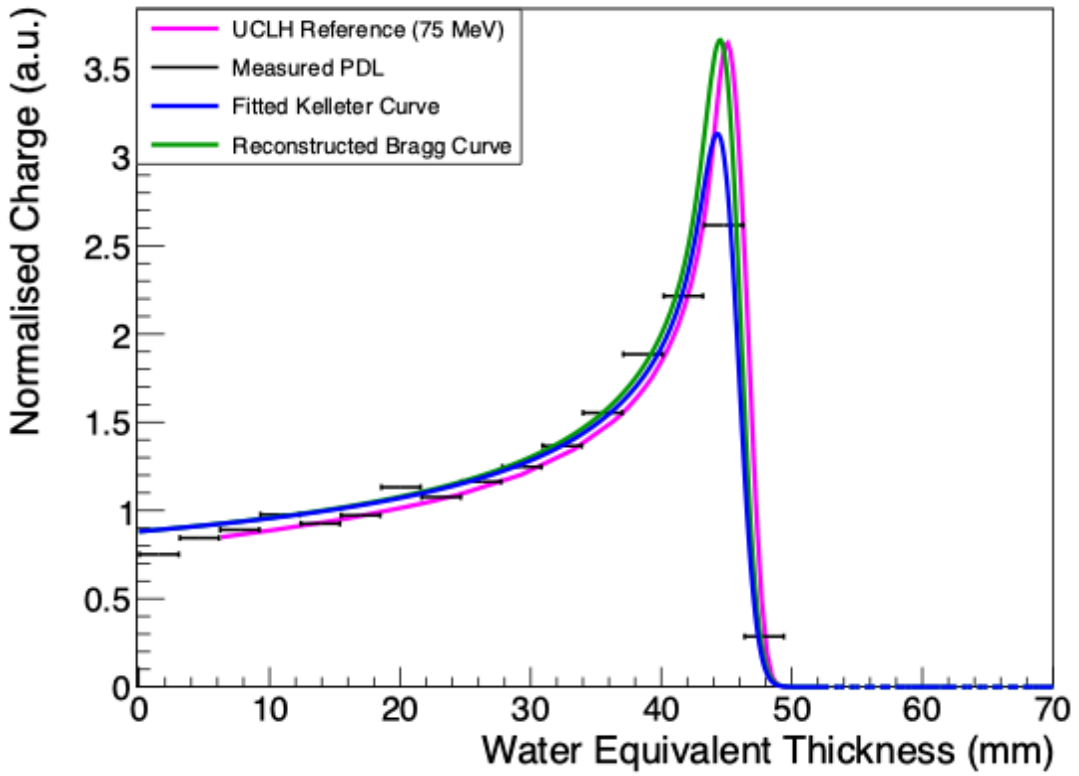
Side B Calibrated

Normalised PD Charge (a.u.)



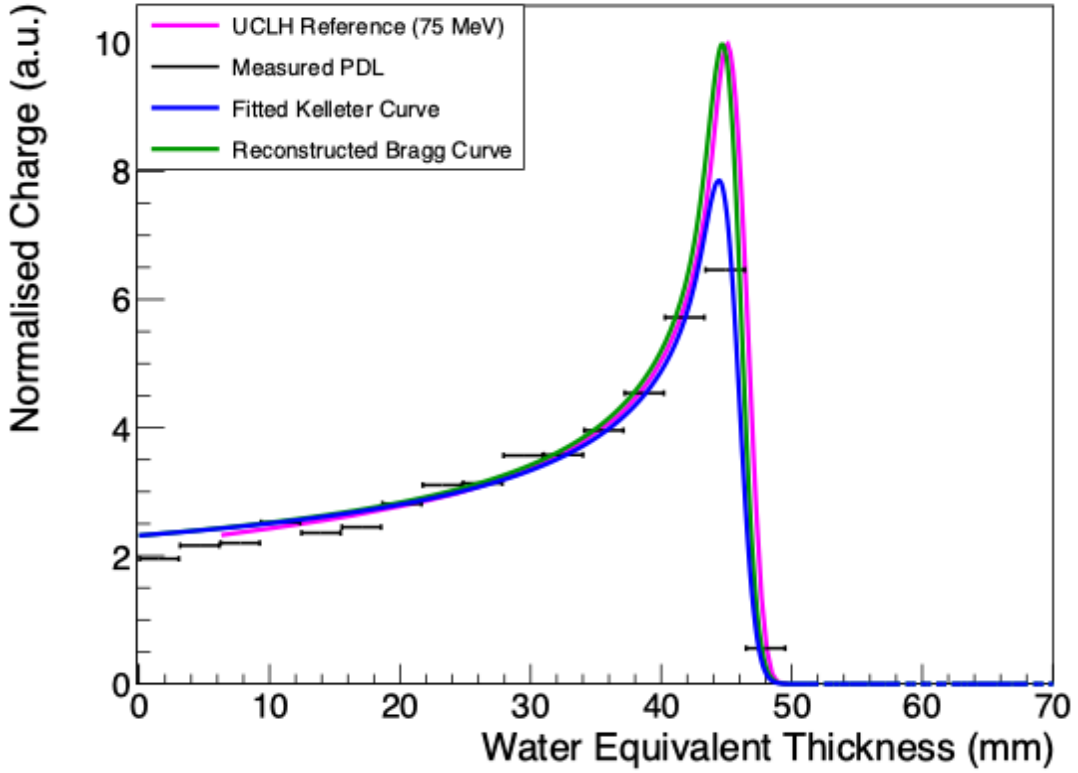
75 MeV – BP in Mod 1

Side A



Range: 45.54 mm, Energy: 73.69 MeV

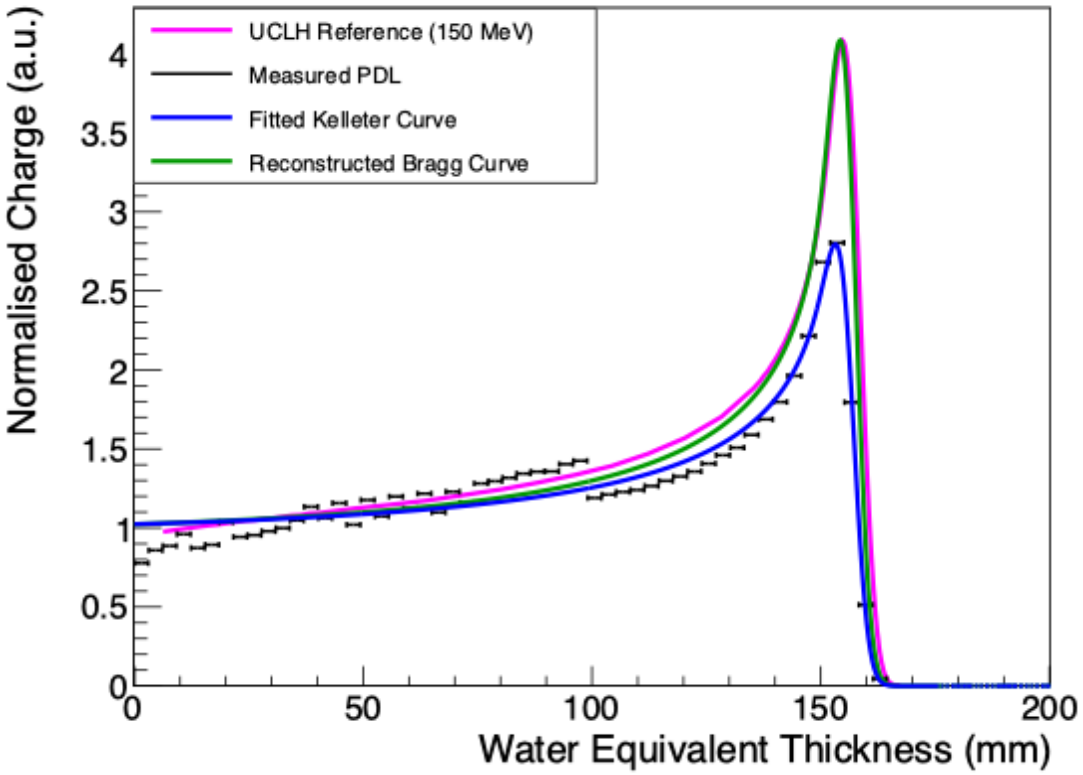
Side B



Range: 45.65 mm, Energy: 73.79 MeV

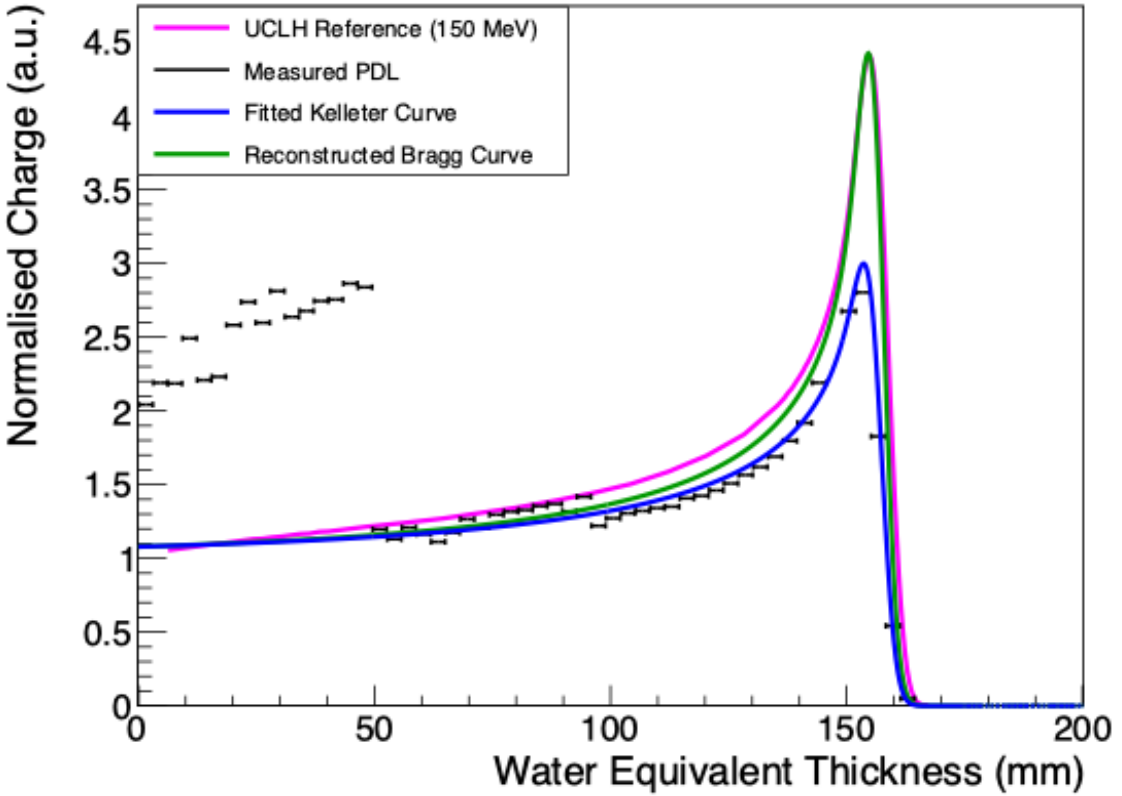
150 MeV – BP in Mod 2

Side A



Range: 156.59 mm, Energy: 149.73 MeV

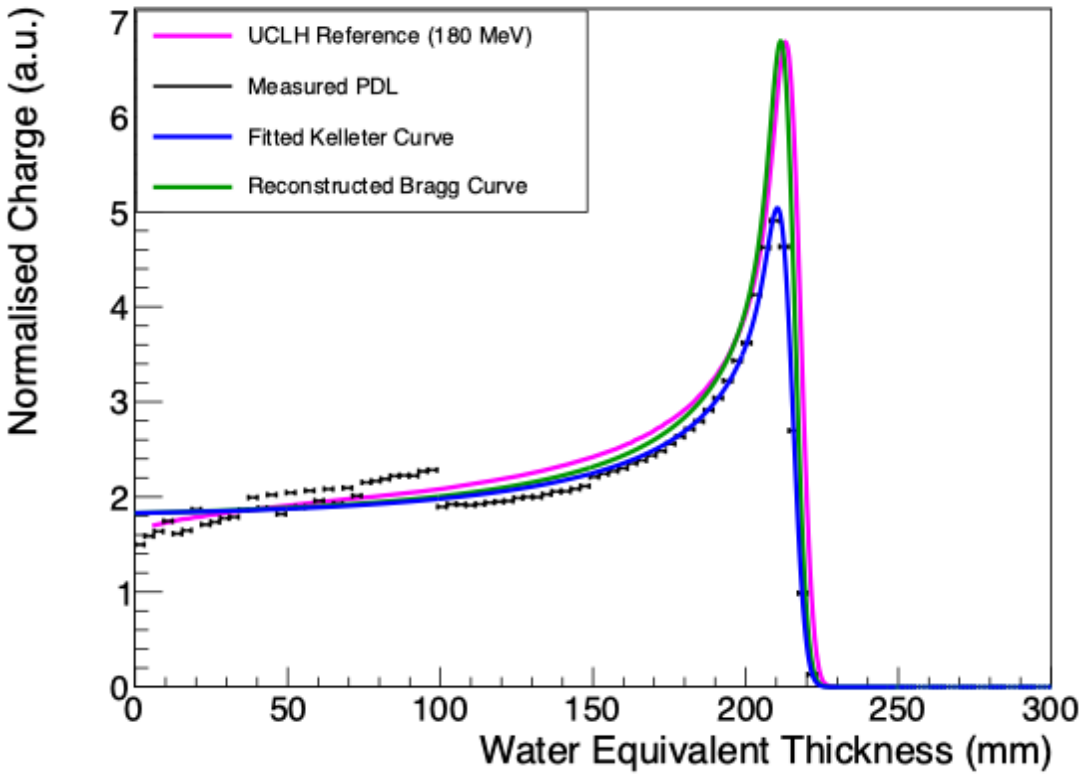
Side B



Range: 156.82 mm, Energy: 149.86 MeV

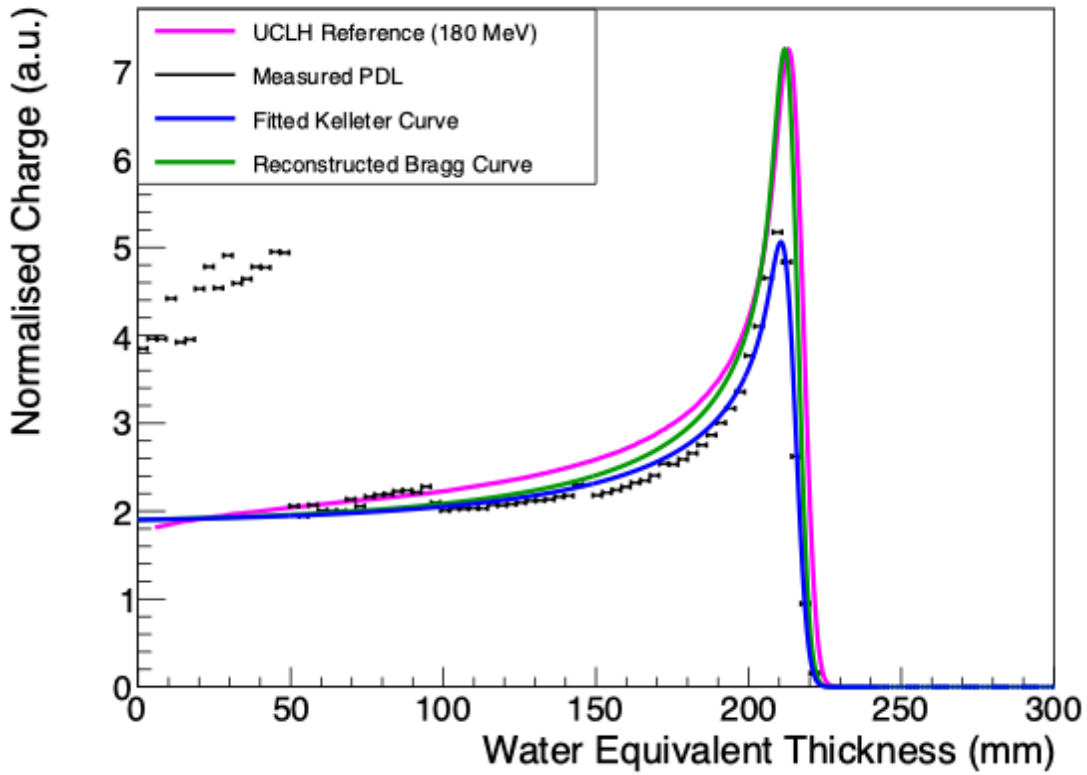
180 MeV – BP in Mod 3

Side A



Range: 214.57 mm, Energy: 179.41 MeV

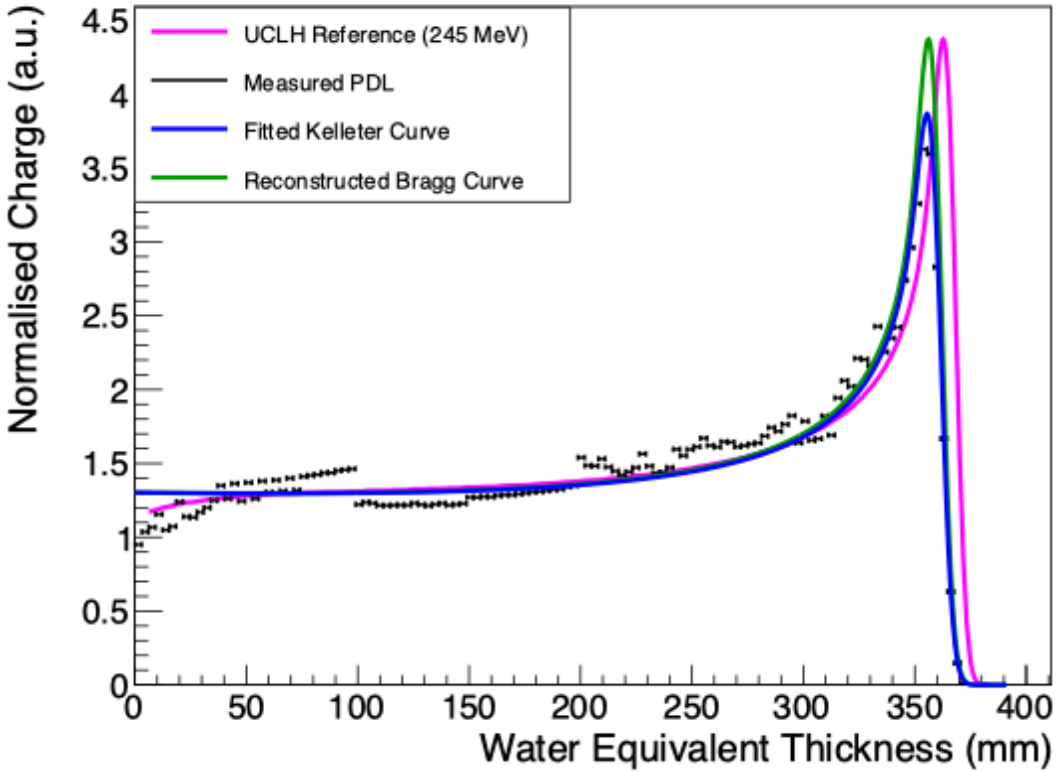
Side B



Range: 214.7 mm, Energy: 179.48 MeV

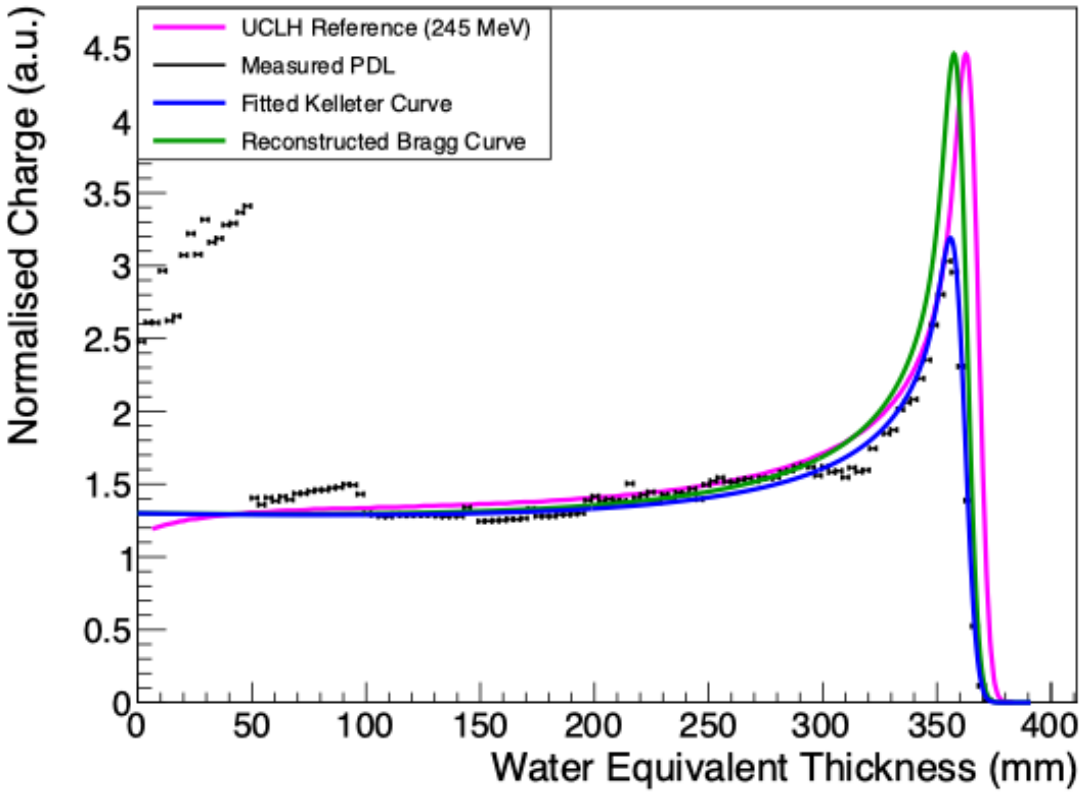
245 MeV – BP in Mod 4

Side A



Range: 360.17 mm, Energy: 241.54 MeV

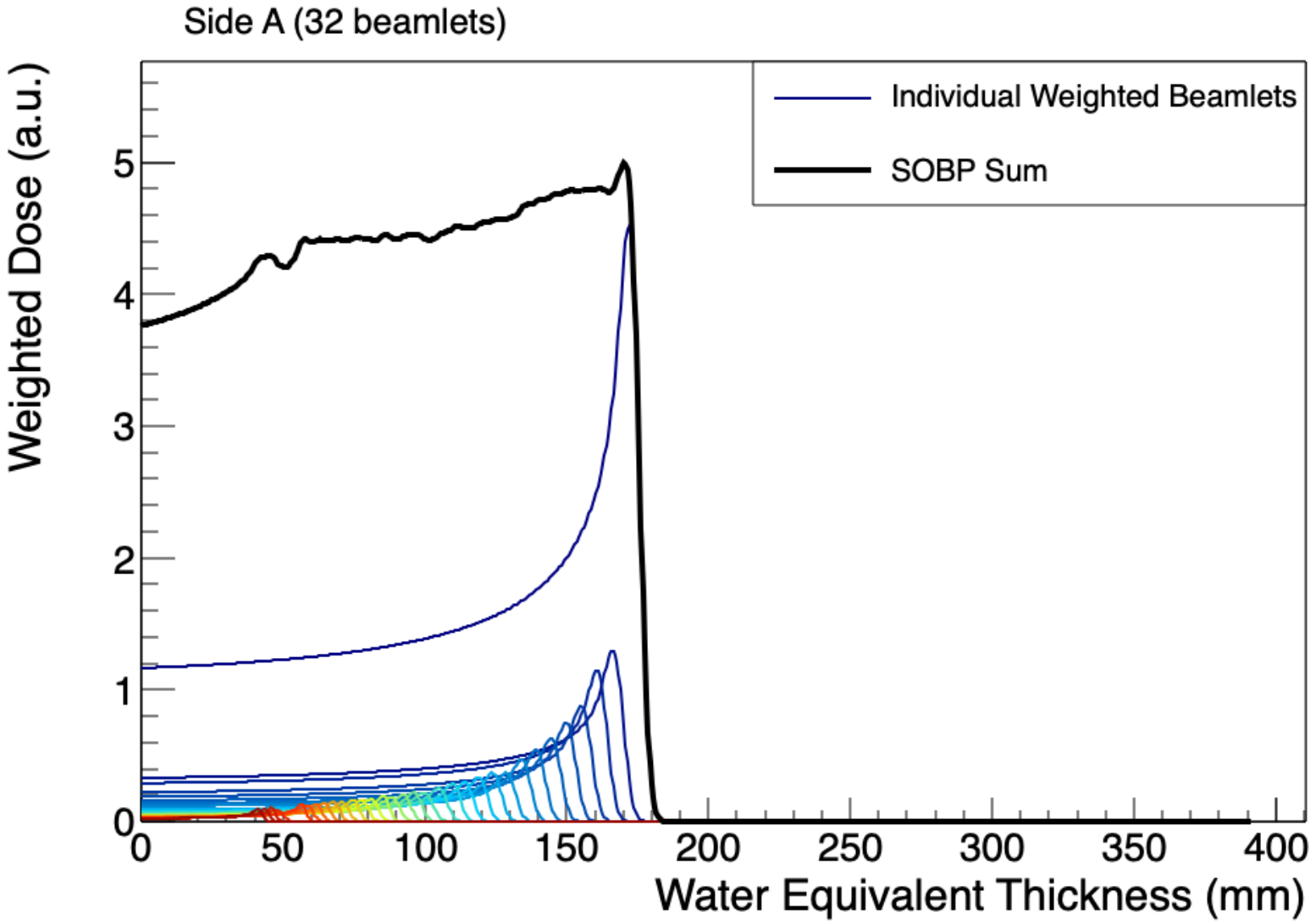
Side B



Range: 361.29 mm, Energy: 241.97 MeV

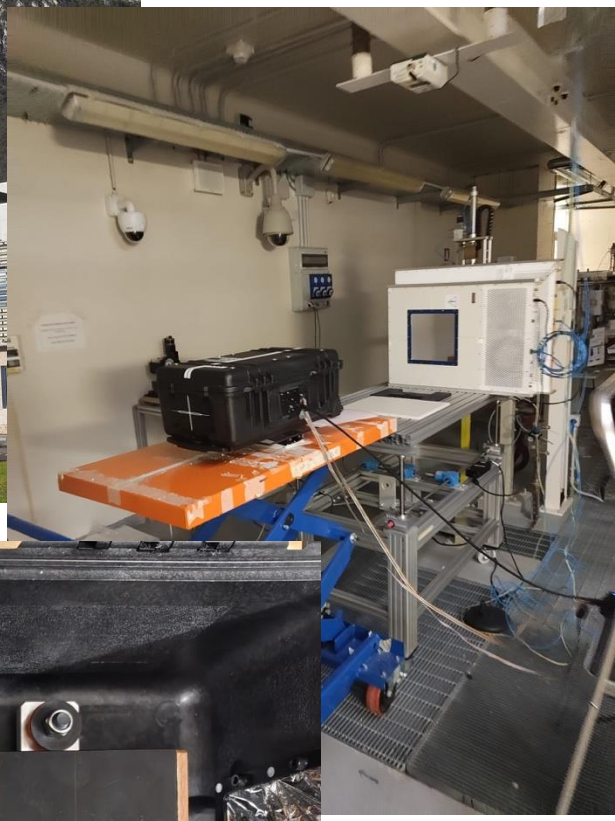
UCLH SOBP Reconstruction

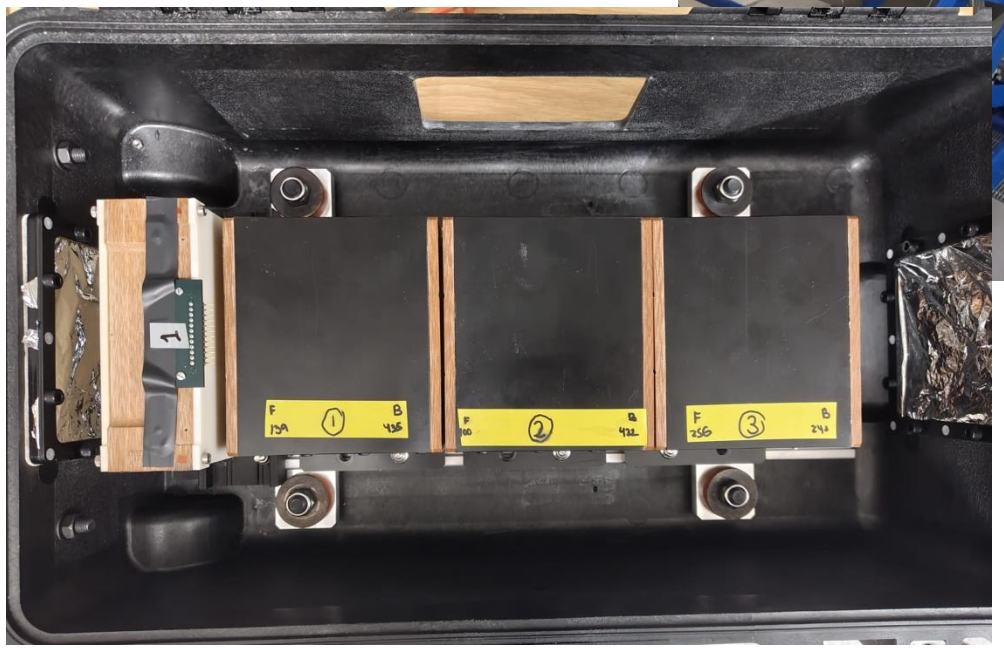
SOBP Statistics
Plateau (90% level): 109.545 mm to 172.58 mm
Plateau width: 63.035 mm
Plateau mean : 4.68837 a.u.
Plateau std dev: 0.129093 a.u.
Flatness: 2.75347%



Trento Beam Test

- 3 nights of measurements in the research room at Trento PTC
  - Night 1: QuARC
    - Calibrations and **Bragg Peak measurements** scaling current up to FLASH (briefly).
  - Night 2: Combined QuARC + SciFi:
    - Dynamic range testing (fibres at low gain)
    - Beam position measurements
  - Night 3: SciFi Measurements
    - Dynamic range testing (fibres at high gain)
    - Different spot sizes (varying energy)

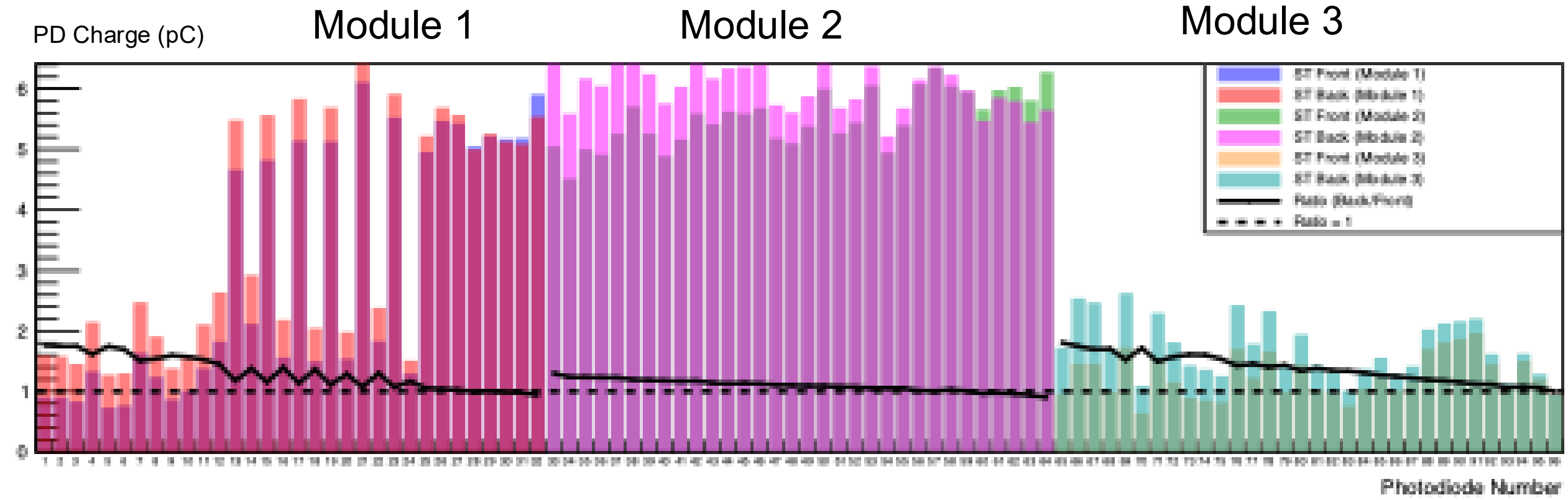




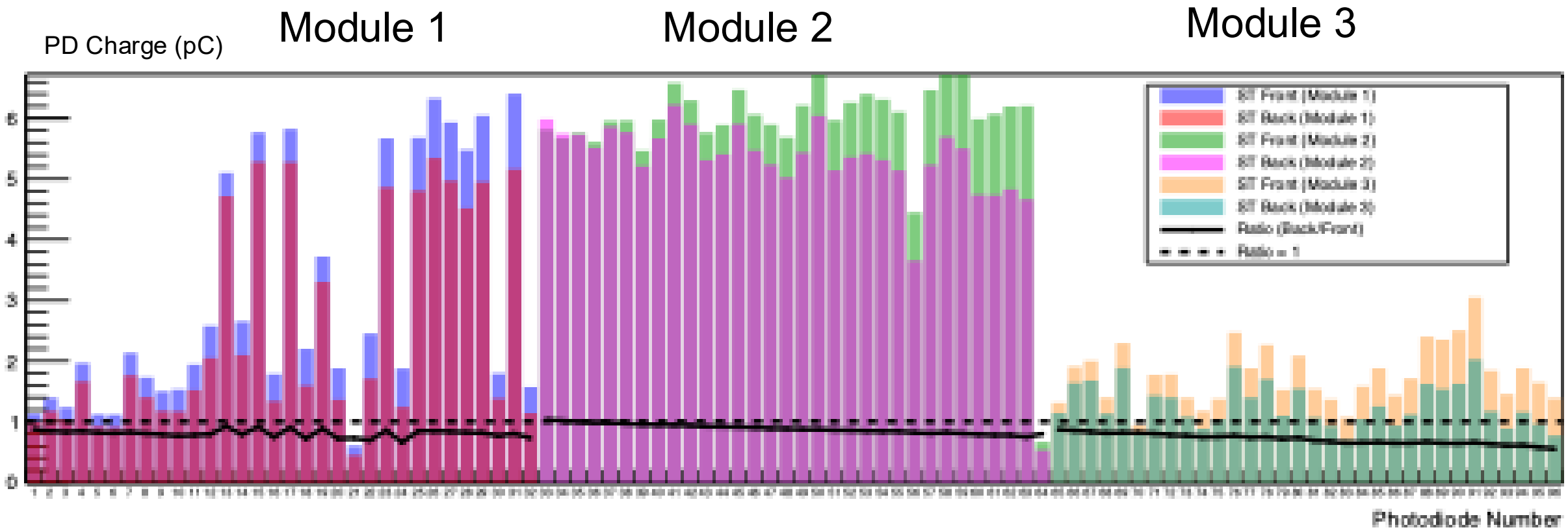
Trento

- Measurements with 3 modules (to allow for fibre detector inside case).
- 2 shoot throughs for each module at 10 nA ion source current (~ 1.5 nA nozzle current).
- Current scan performed on front shoot throughs of module 1 in both CONV and FLASH mode.
- Response linearity current scan to measure linearity of detector response.
- Beam position measurements to correlate QuARC dual-sided position measurement with fibre array position measurement by moving detector in 5mm increments horizontally.

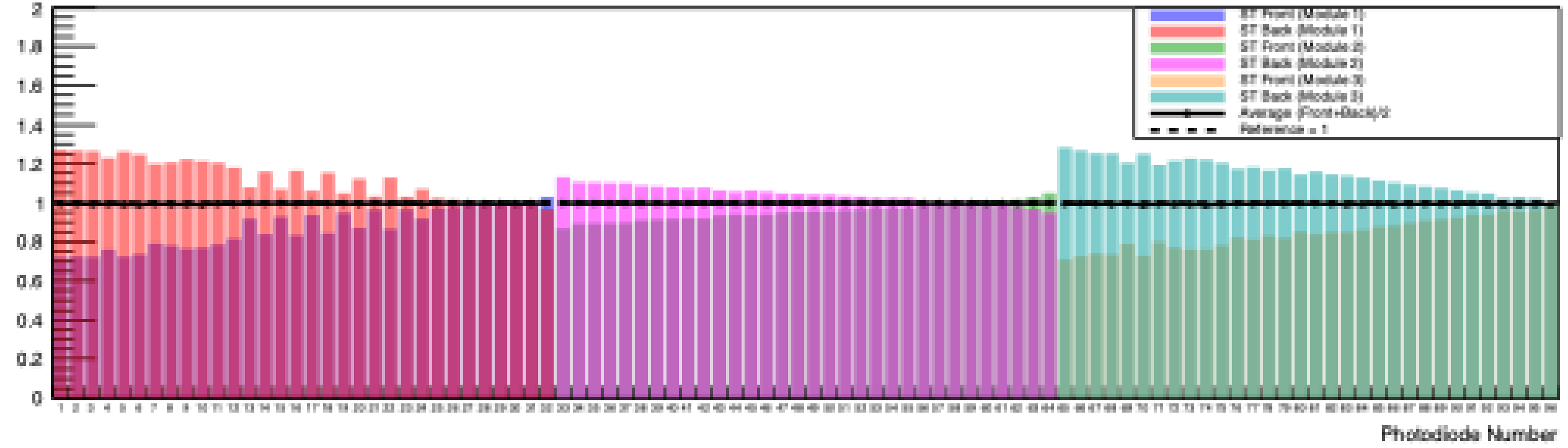
Side A Shoot through comparisons



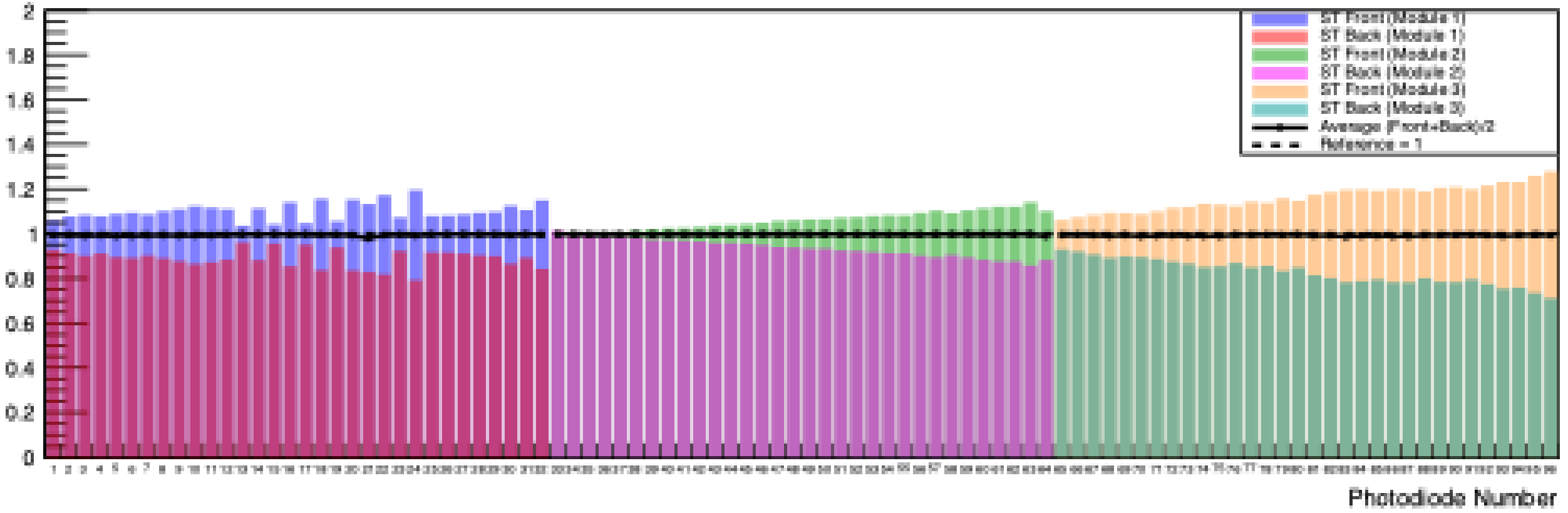
Side B Shoot through comparisons



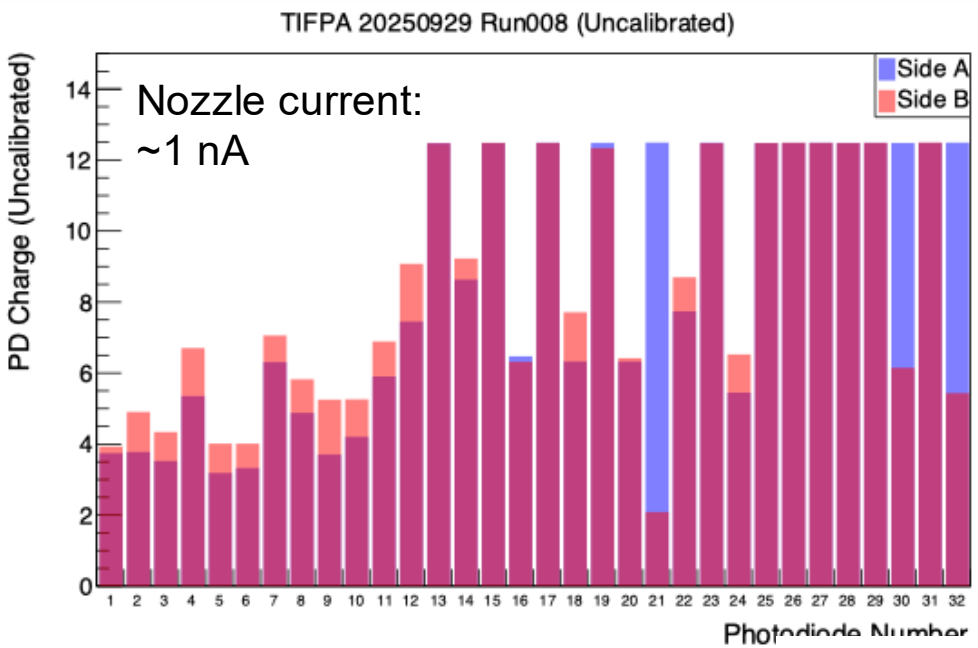
Side A Calibrated

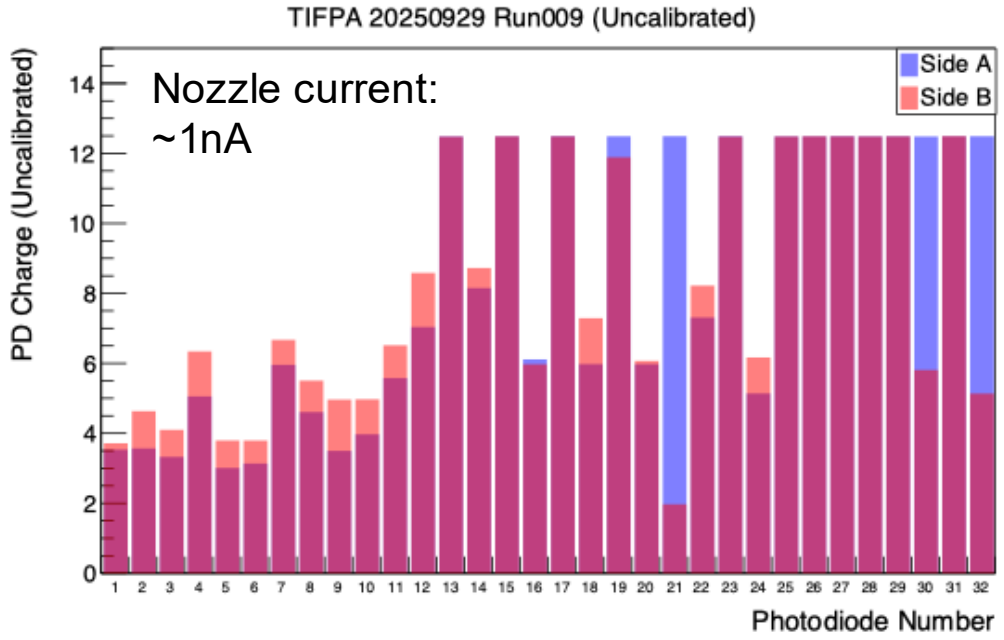


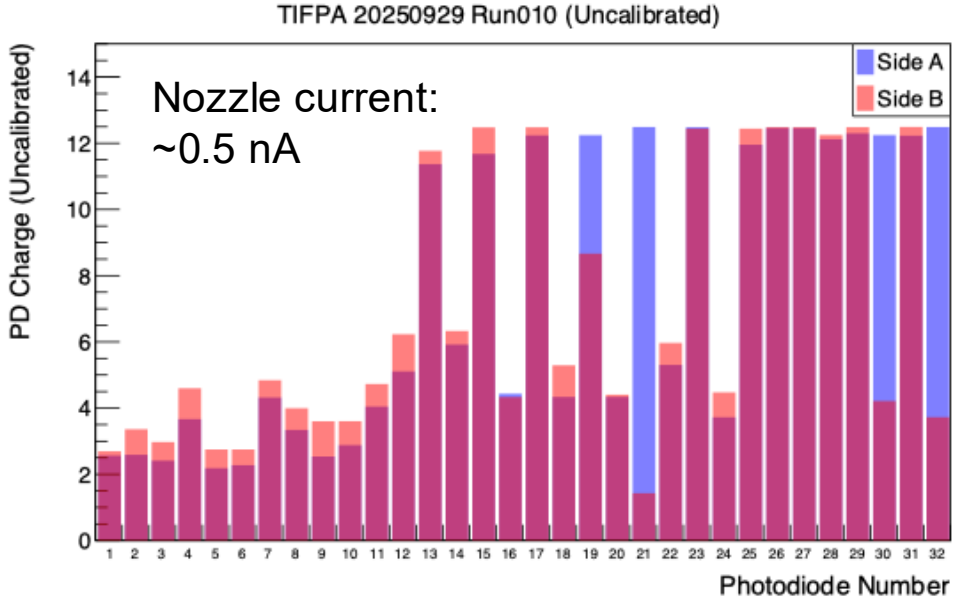
Side B Calibrated



Module 1: ST Front



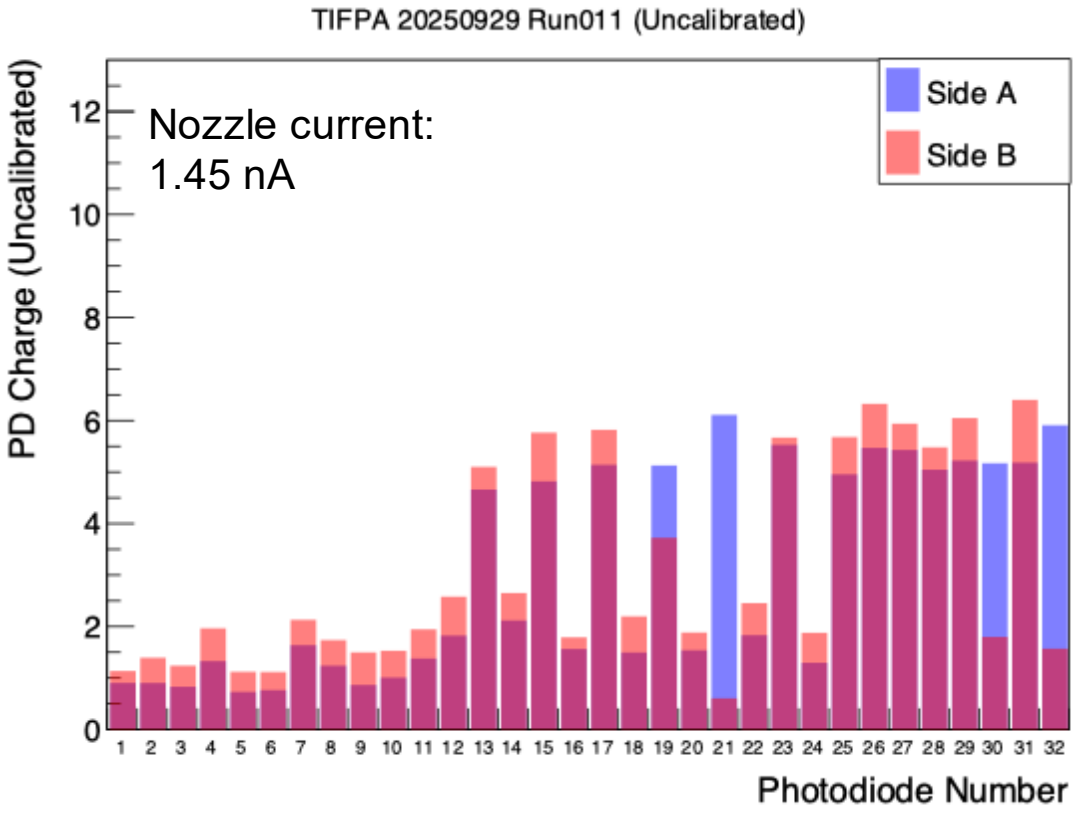


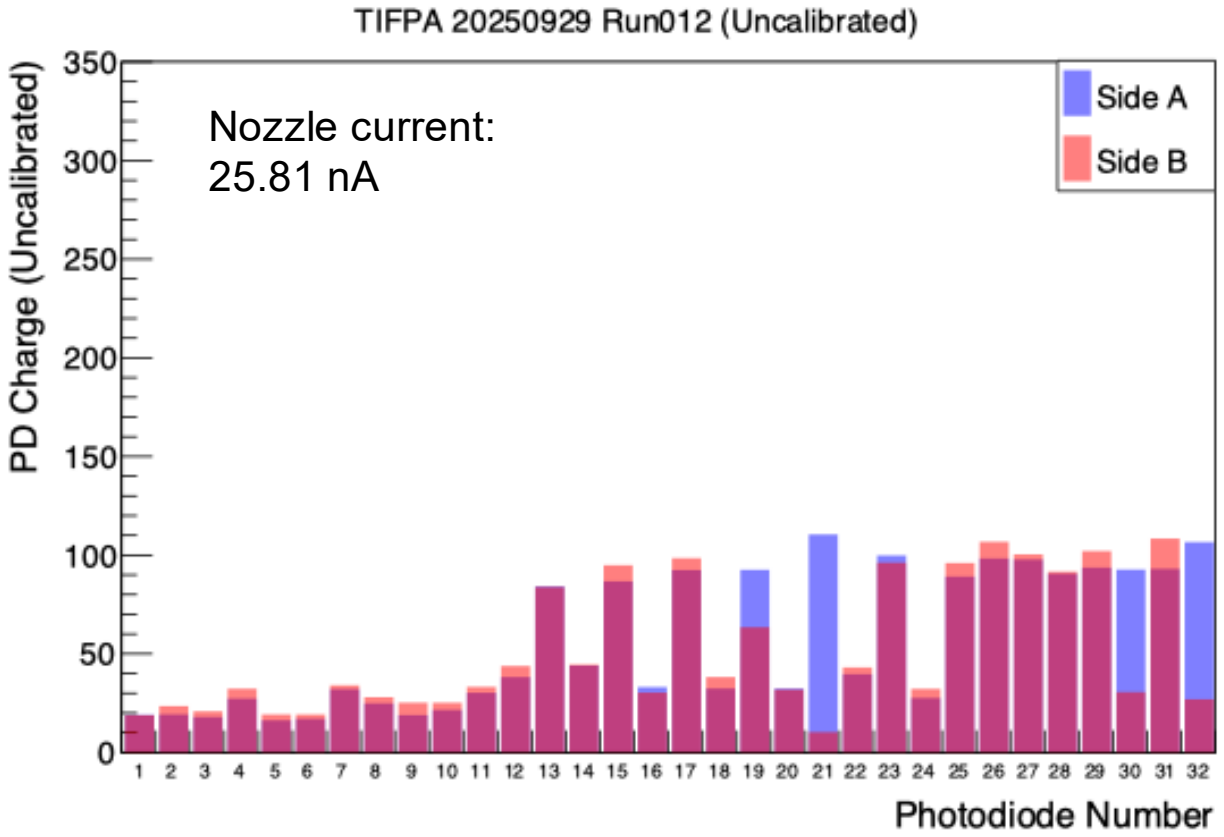


No log file data from Trento from these runs so nozzle current based on PBT wiki notes

Note that only polished sheets appear to saturate

Module 1: ST Front





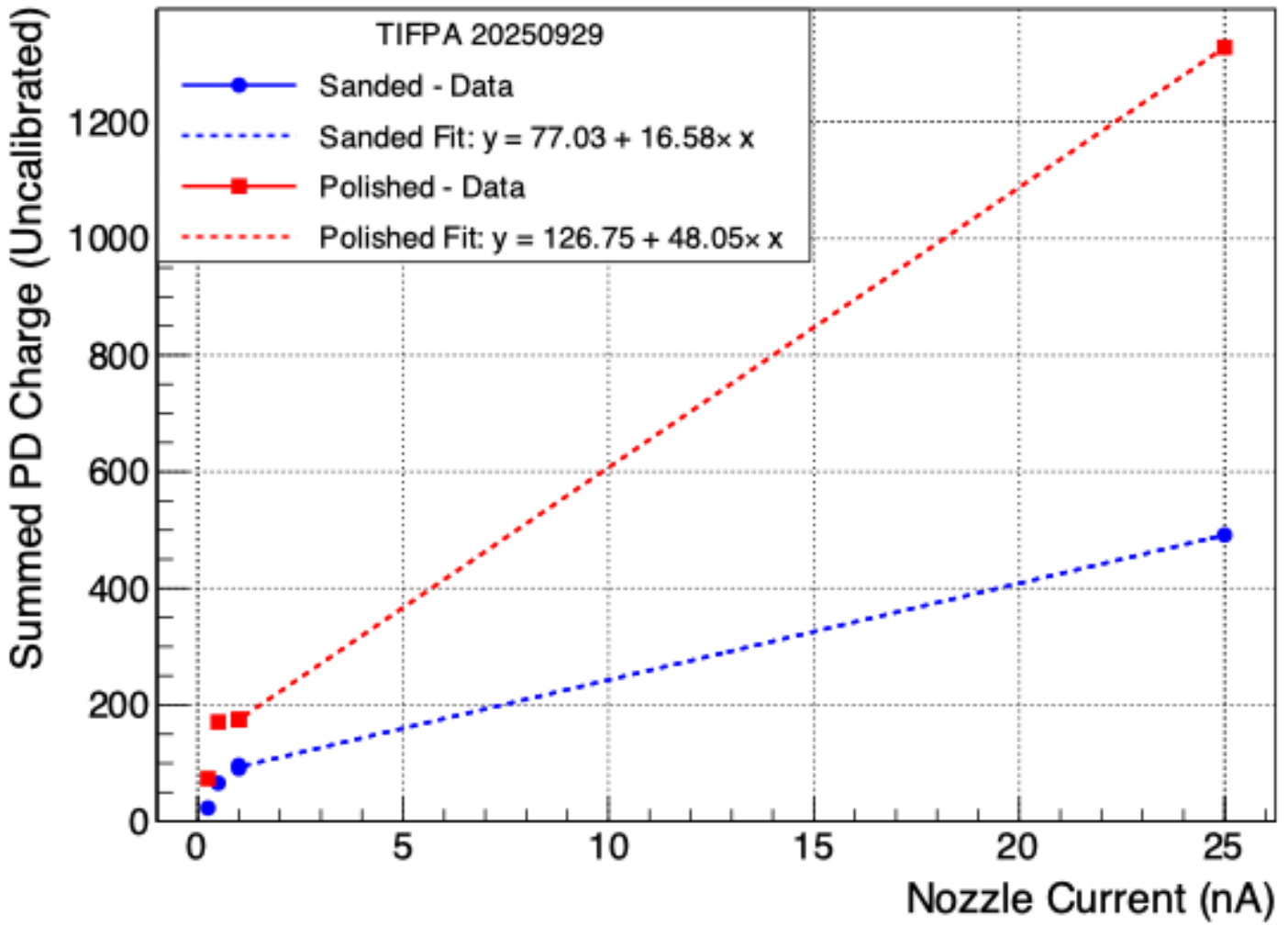
FSR 12.5 pC

FSR 350 pC

Module Front Shoot Throughs Comparison

Summed the charge from
a) Sanded sheets
b) Polished sheets

Evident from previous plots that the polished sheets have much higher light output, here it can be seen they have steeper response also.

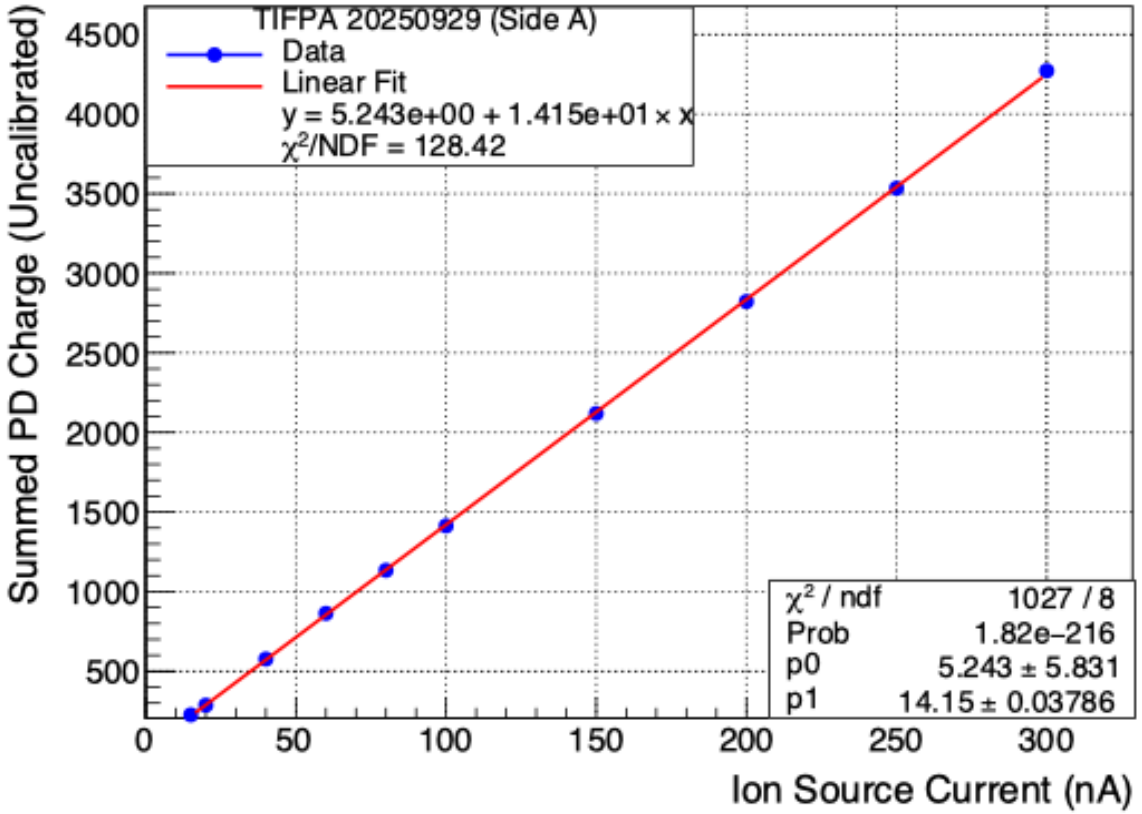


Lack of accurate nozzle current data from Trento is reason for data at start looking odd.

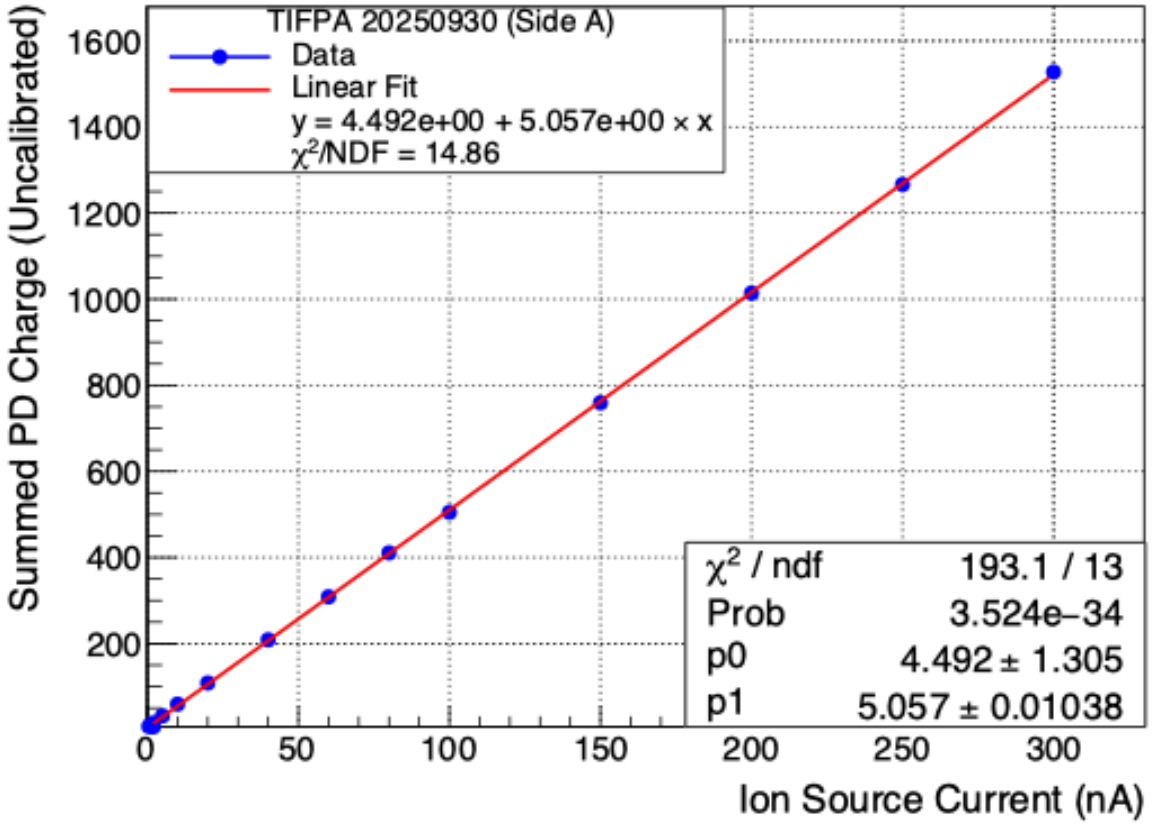
Response Linearity

Response linearity of entire QuARC detector by summing the average PD values across the measurement time.

179 MeV

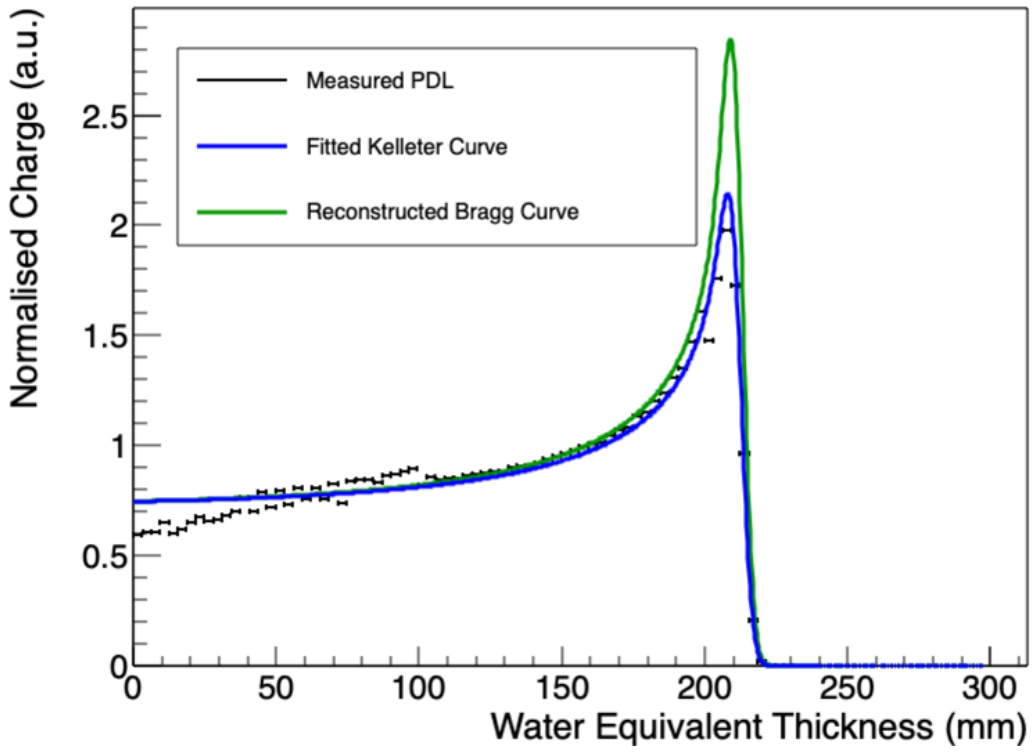


148 MeV



179 MeV 20 nA

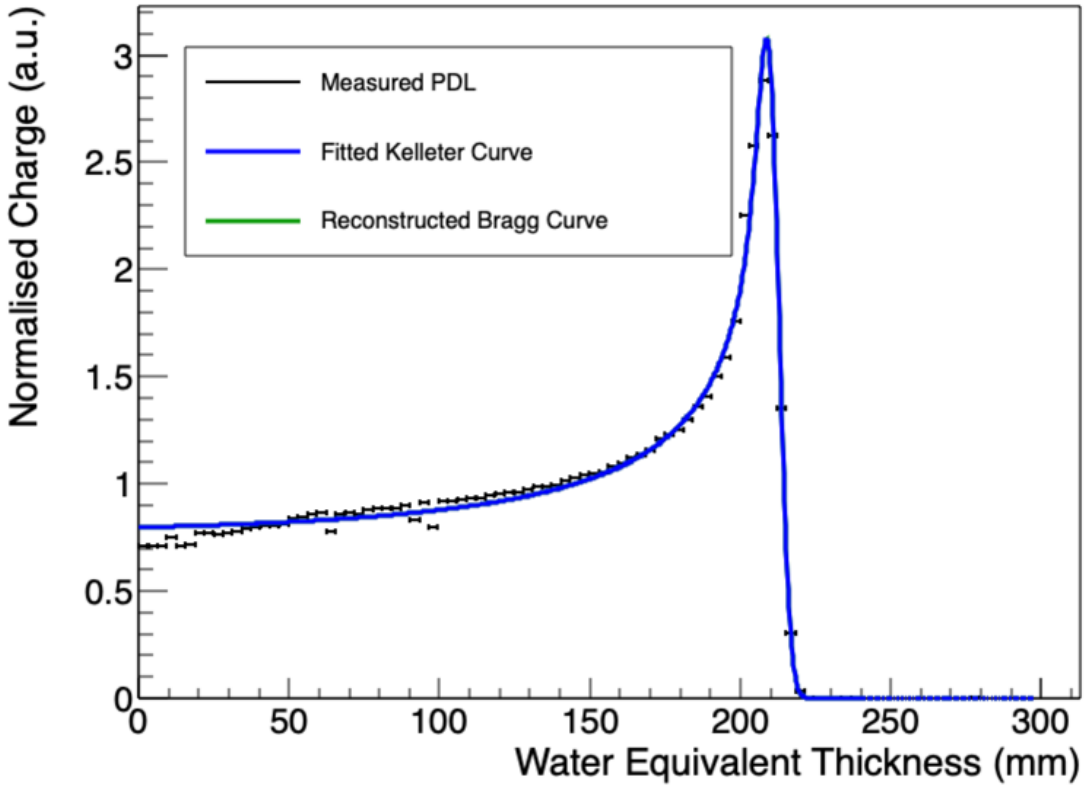
Side A



kB = 0.105512

Sigma_0 = 3.11298

Side B

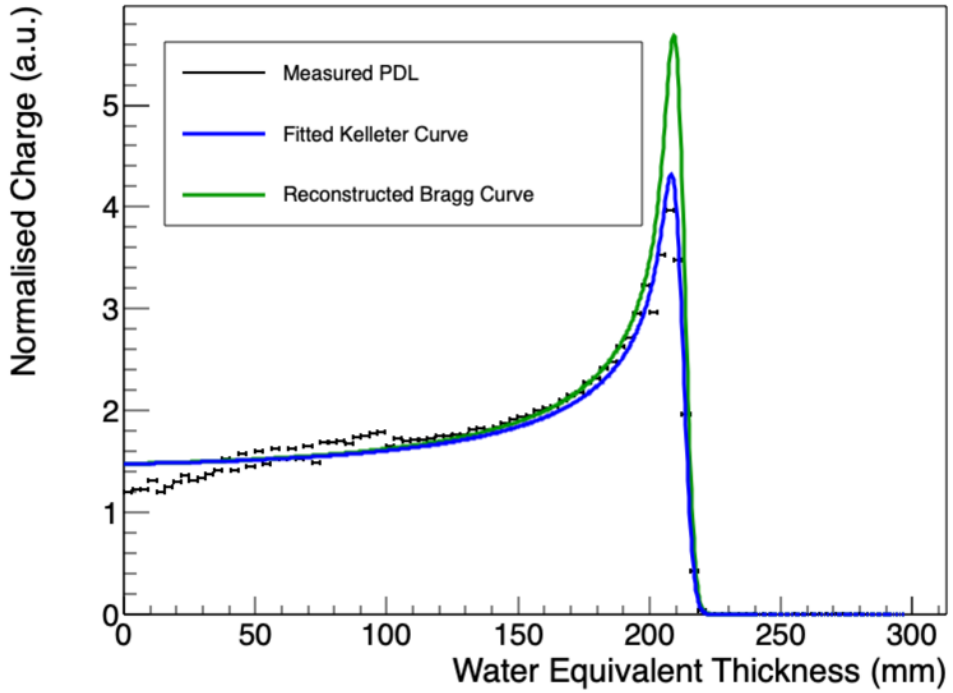


kB = 7.32185e-06

Sigma_0 = 3.03636

179 MeV 40 nA

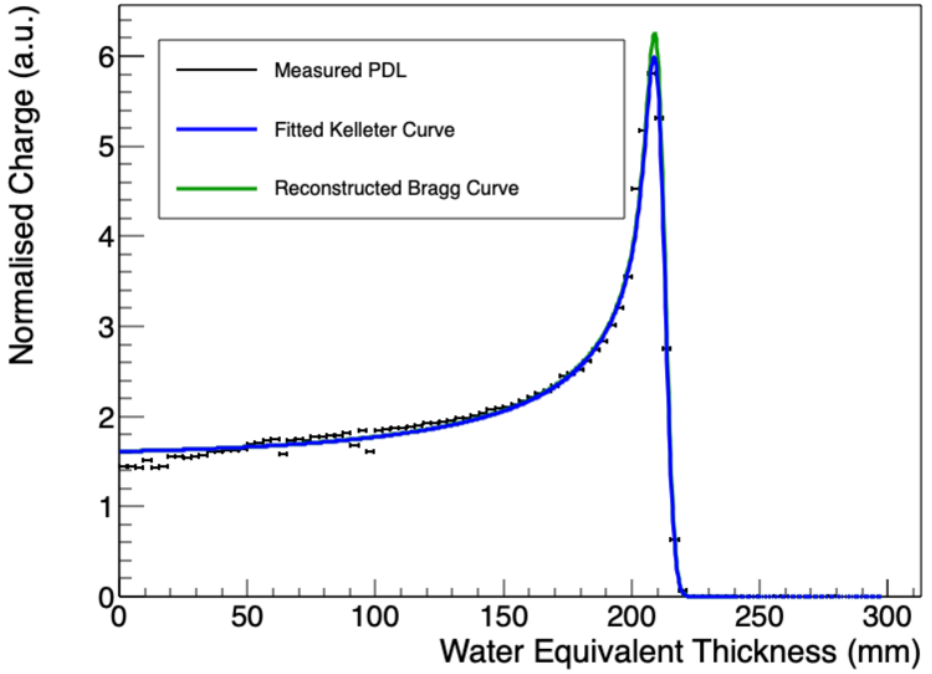
Side A



E_0 = 178.18 MeV

kB = 0.10059

Side B

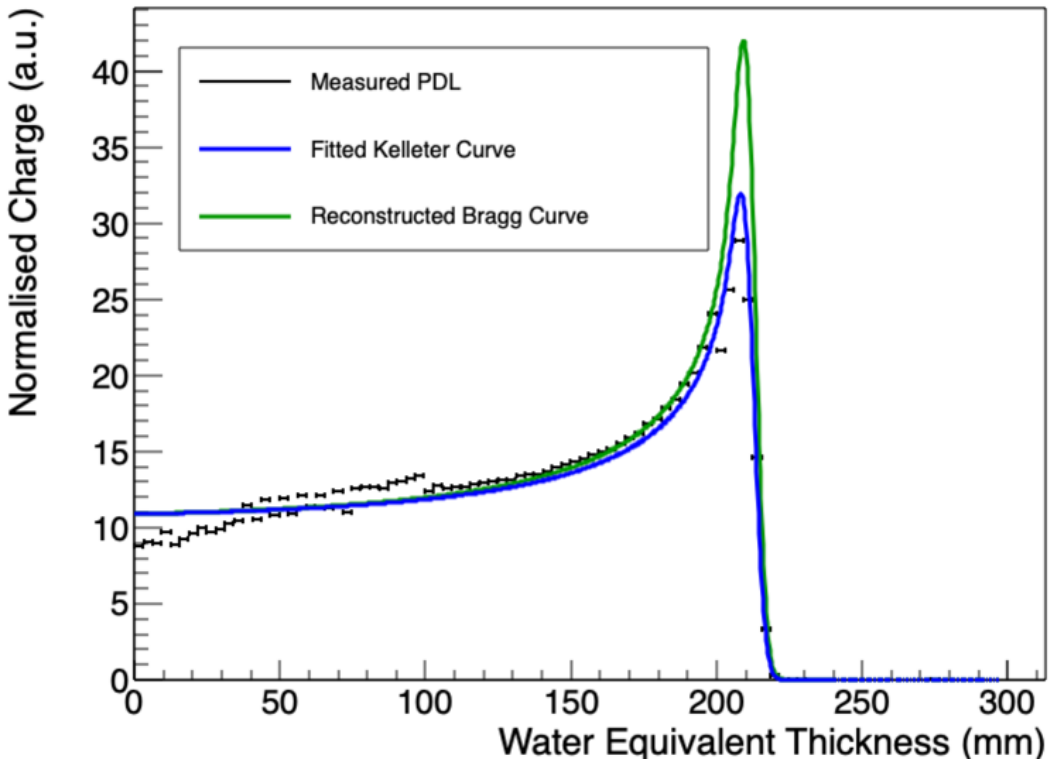


E_0 = 178.03 MeV

kB = 0.01

179 MeV 300 nA

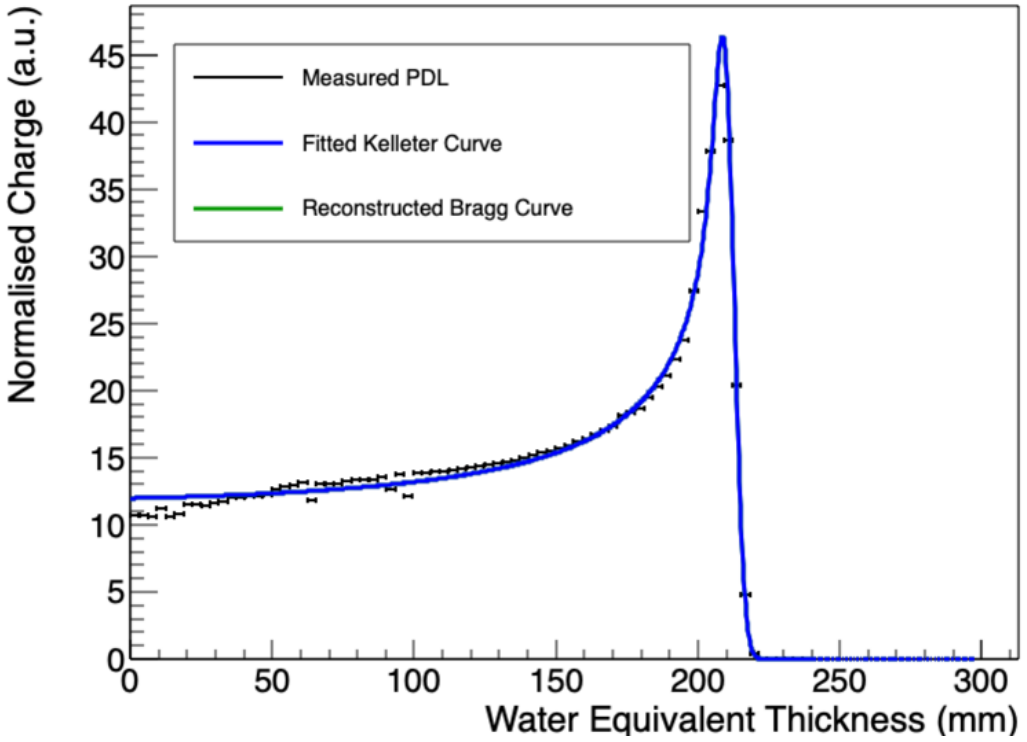
Side A



E_0 = 178.18 MeV

kB = 0.0995859

Side B

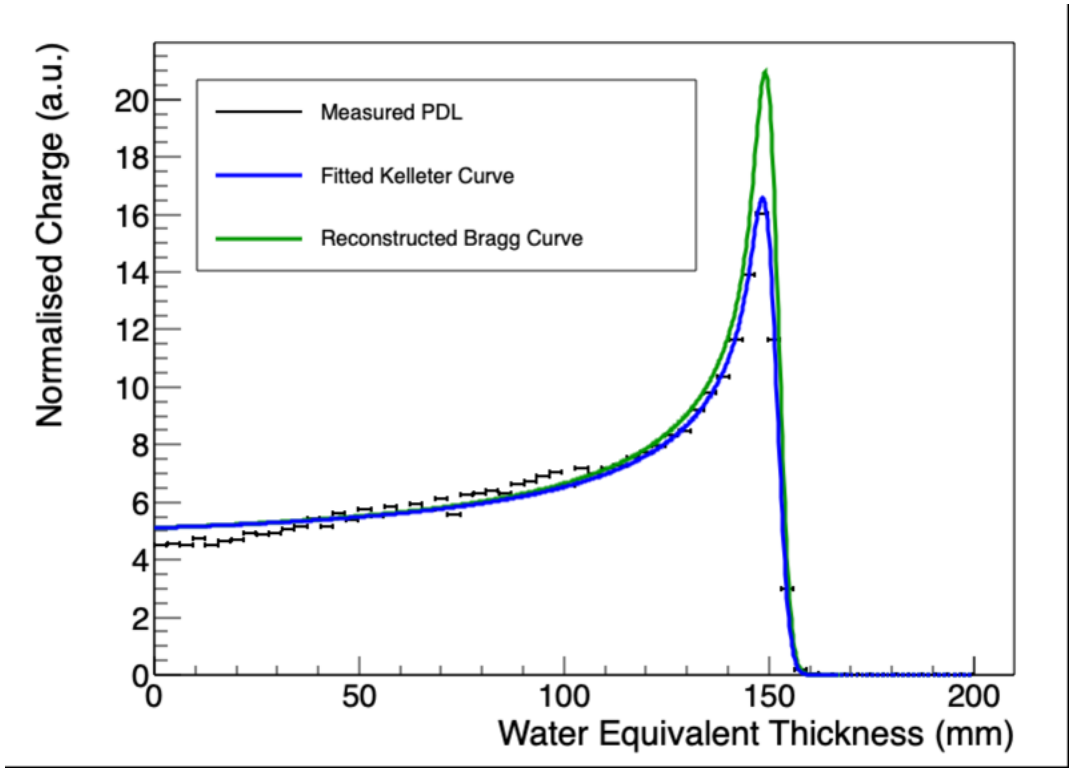


E_0 = 177.9 MeV

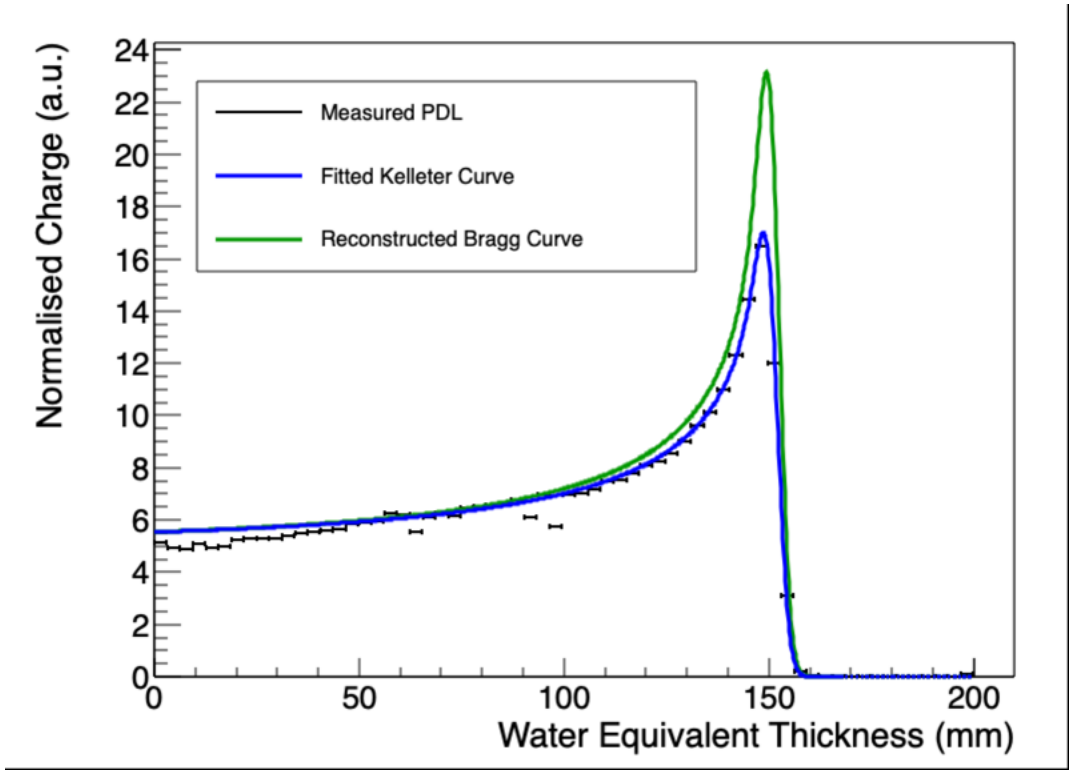
kB = 1.87366e-05

149 MeV Centered

A

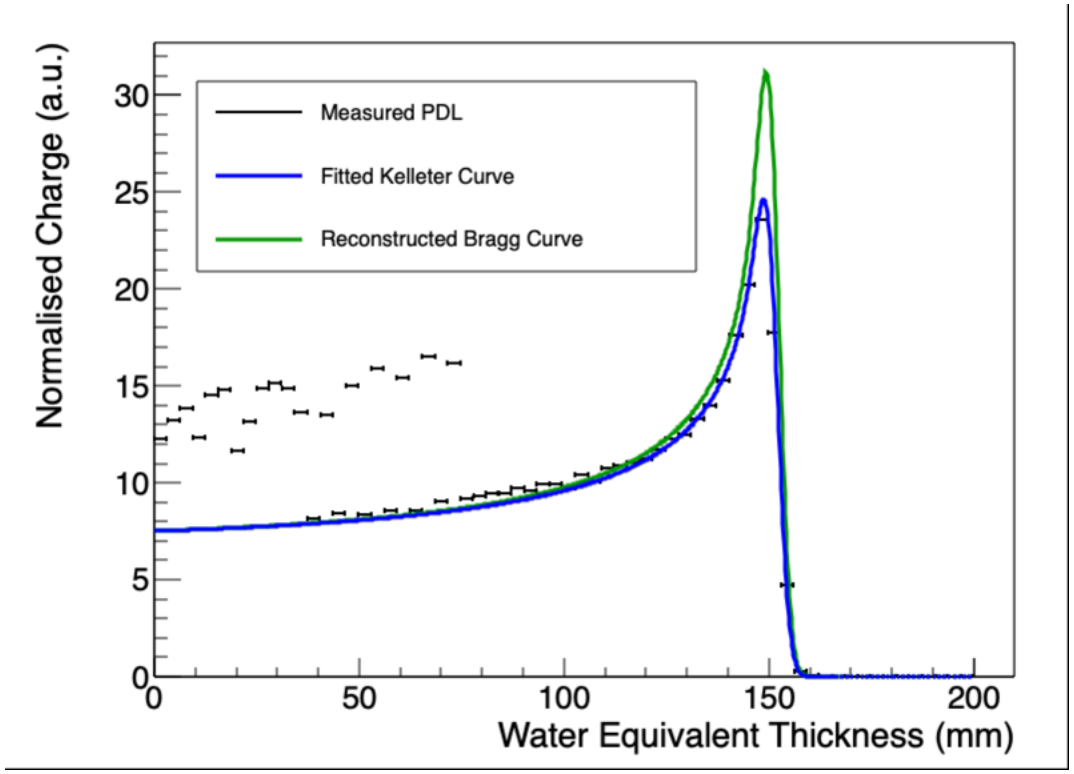


B

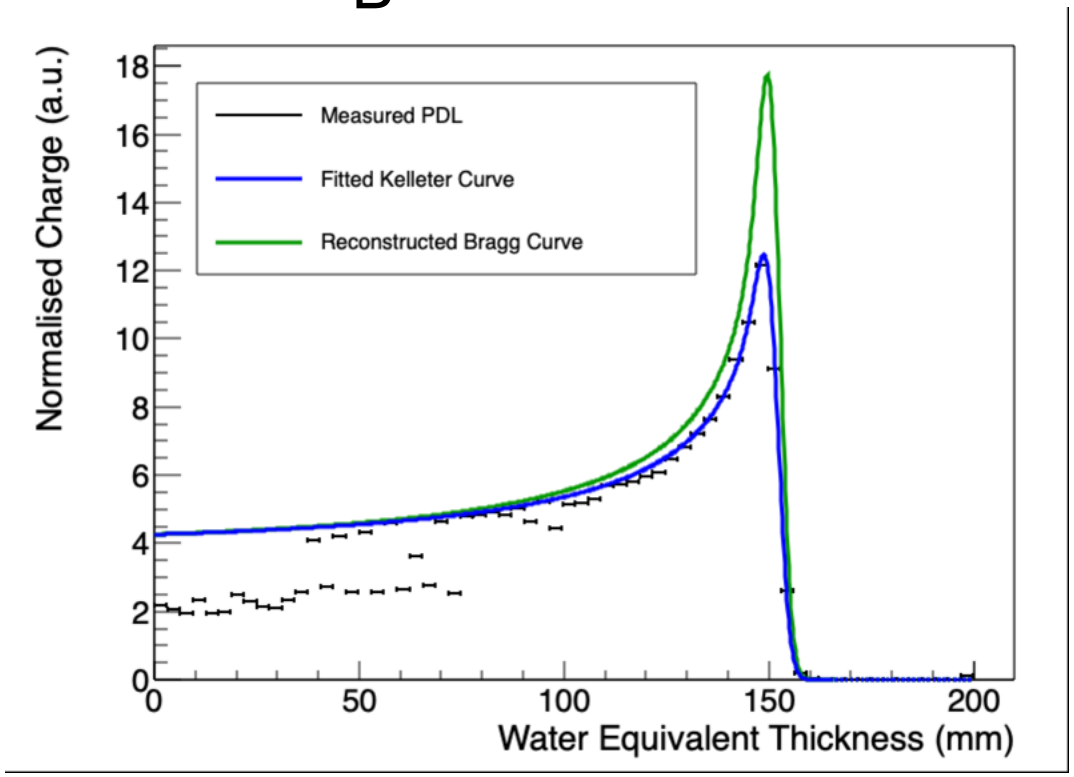


149 MeV Beam Spot 20 mm to right

A



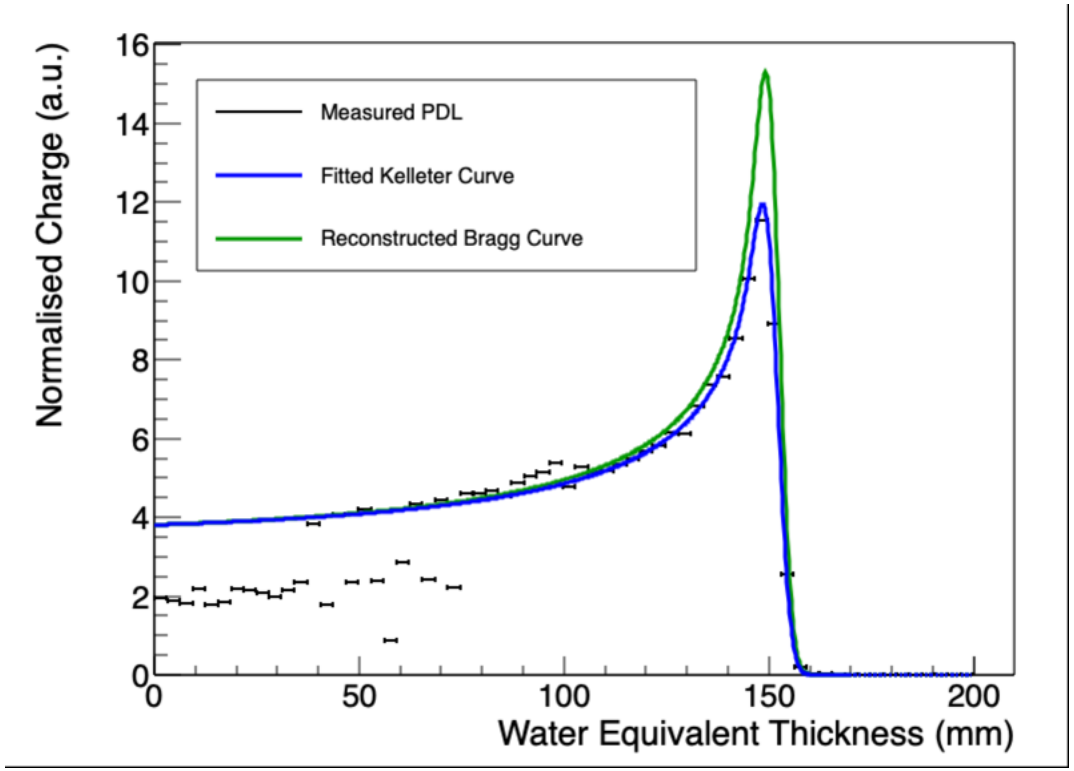
B



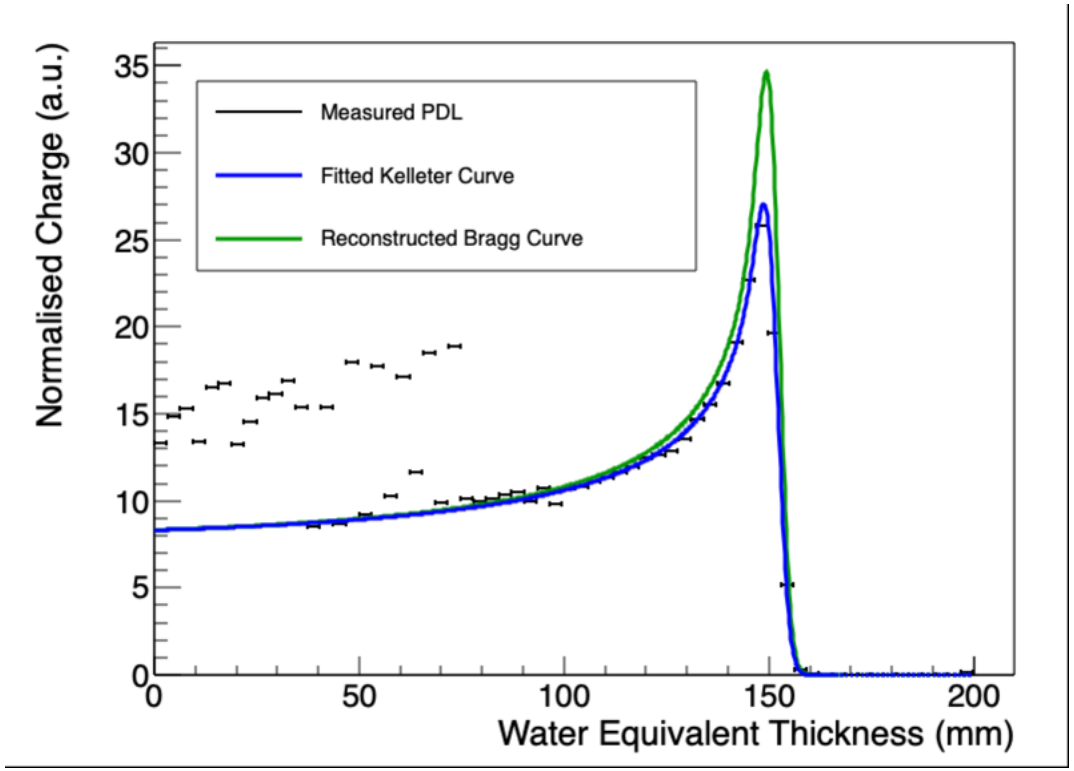
Note how the sanded sheets in module 1 respond when the beam is scanned – due to large calibration factor being less reliable for these sheets

149 MeV Beam Spot 20 mm to left

A

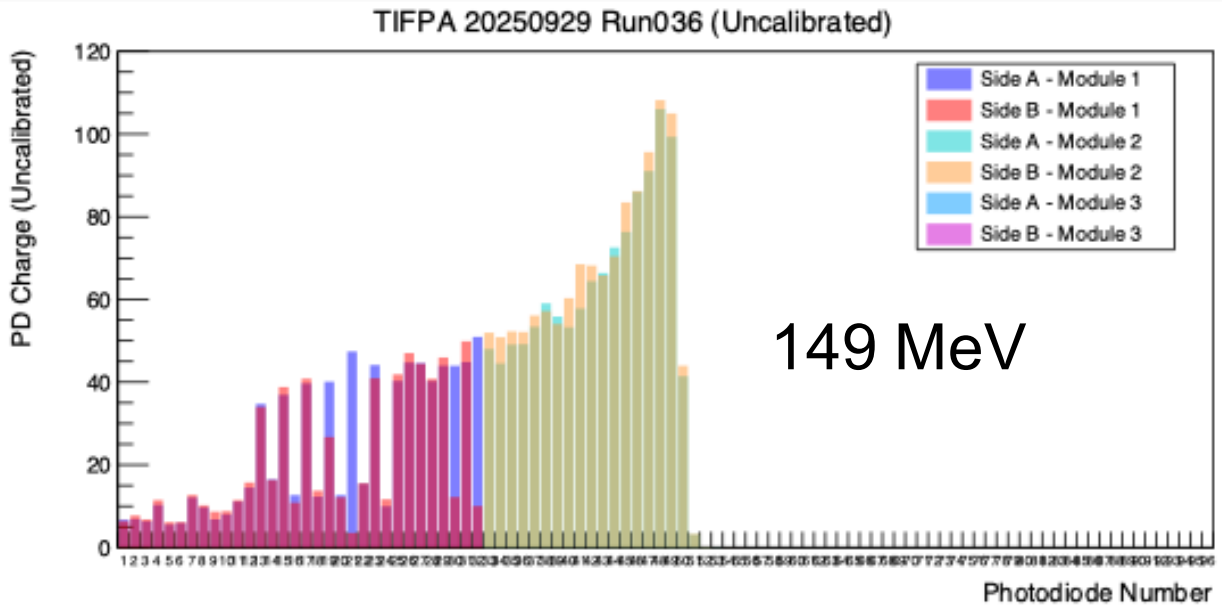


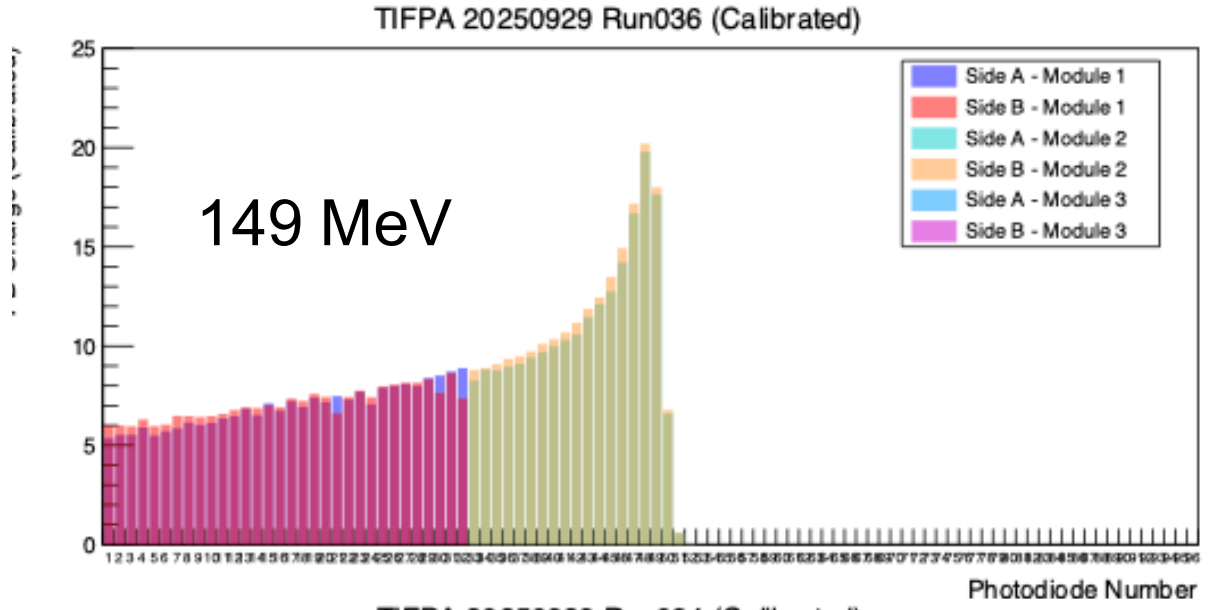
B

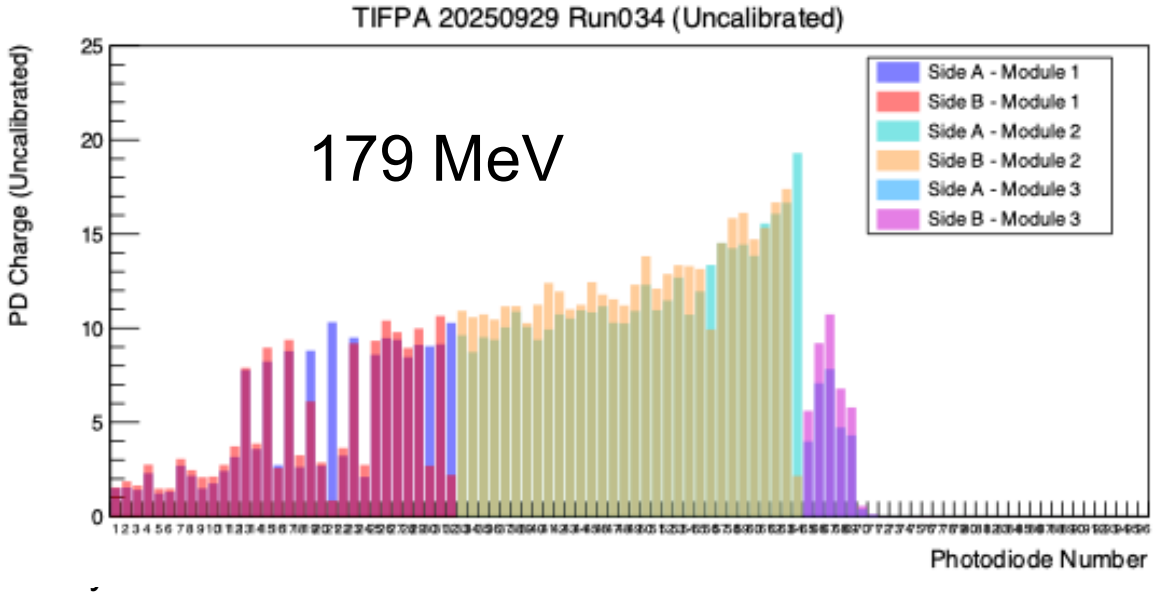


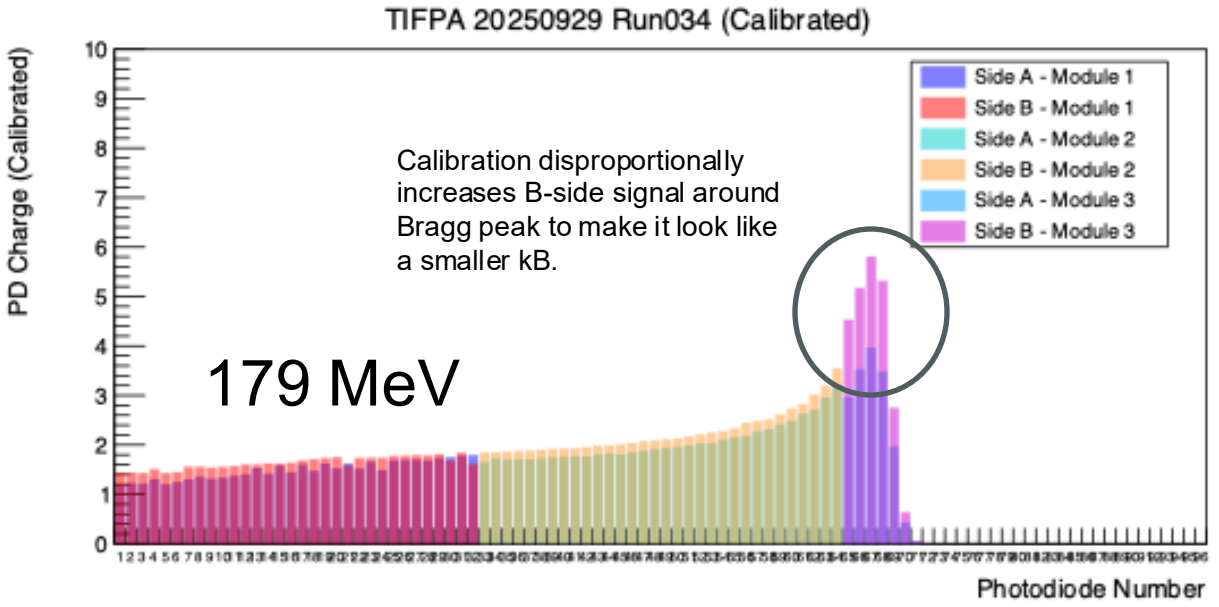
Note how the sanded sheets in module 1 respond when the beam is scanned – due to large calibration factor being less reliable for these sheets

Calibration Effect





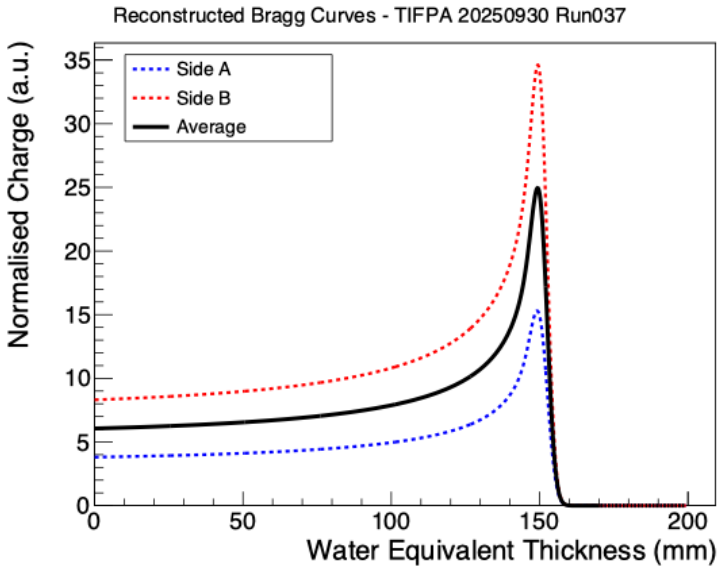




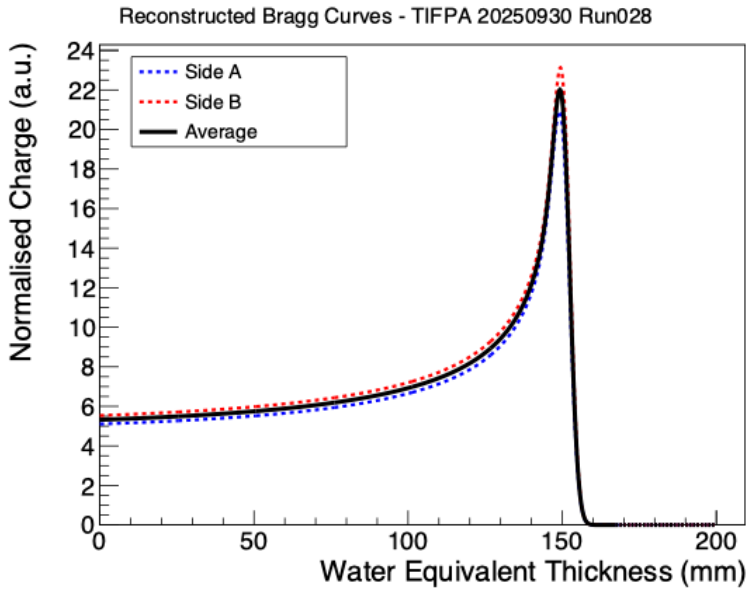
Calibration Effect

- To summarise this effect:
- Poor light output on module 3 sheets (sanded sheets) and slight misalignment of beam in calibration.
- Hence large calibration factors on module 3 sheets with large uncertainties.
- This leads to over exaggeration of peak on percentage depth light (PDL) curve and hence appears as lower kB when it isn't.
- Effect isn't present when Bragg peak is in module 2 (where there are good sheets) – so isn't explicitly a position effect.
- Similar effect also causes sanded sheets in module 1 to fluctuate when beam position is being scanned.

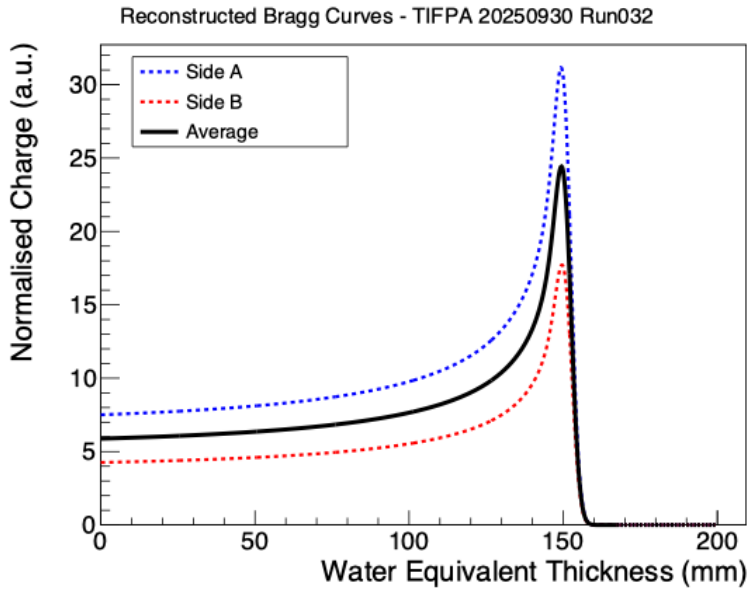
Position Scan - reconstructed 148 MeV Bragg Curves



Beam 20mm to left
A: R_0 = 151.47 mm, E_0 = 146.91 MeV
B: R_0 = 151.51 mm, E_0 = 146.93 MeV
Avg: R_0 = 151.49 mm, E_0 = 146.92 MeV



Beam in centre
A: R_0 = 151.29 mm, E_0 = 146.81 MeV
B: R_0 = 151.51 mm, E_0 = 146.93 MeV
Avg: R_0 = 151.4 mm, E_0 = 146.87 MeV



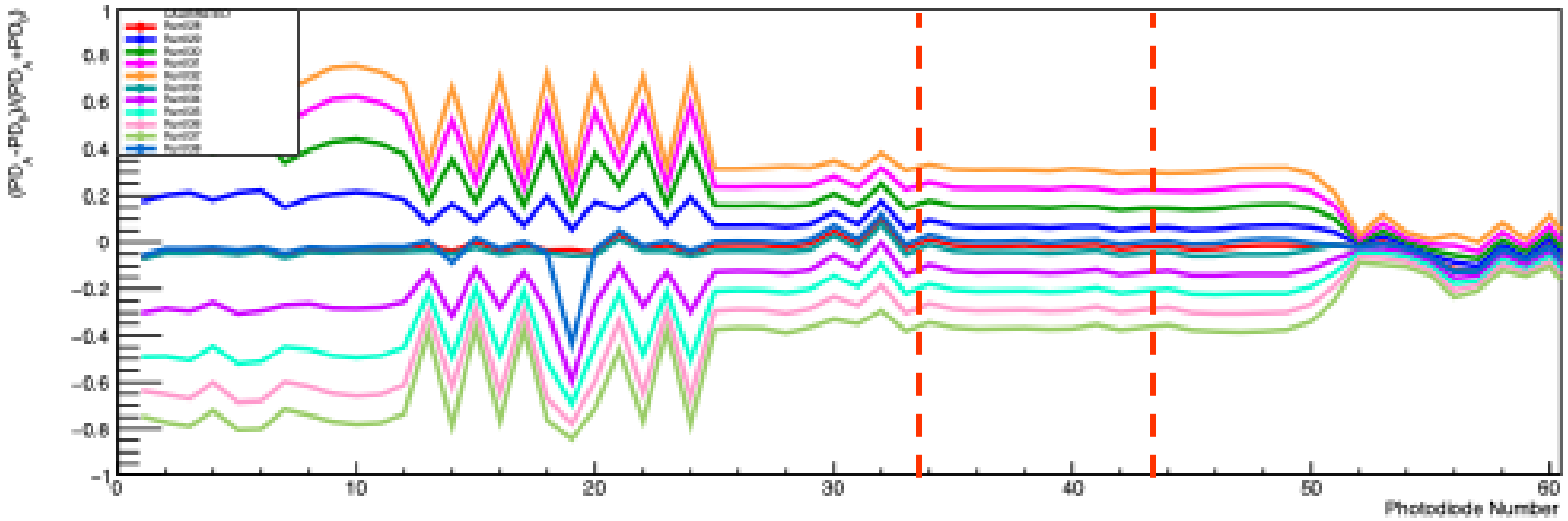
Beam 20mm to right
A: R_0 = 151.46 mm, E_0 = 146.9 MeV
B: R_0 = 151.73 mm, E_0 = 147.05 MeV
Avg: R_0 = 151.595 mm, E_0 = 146.975 MeV

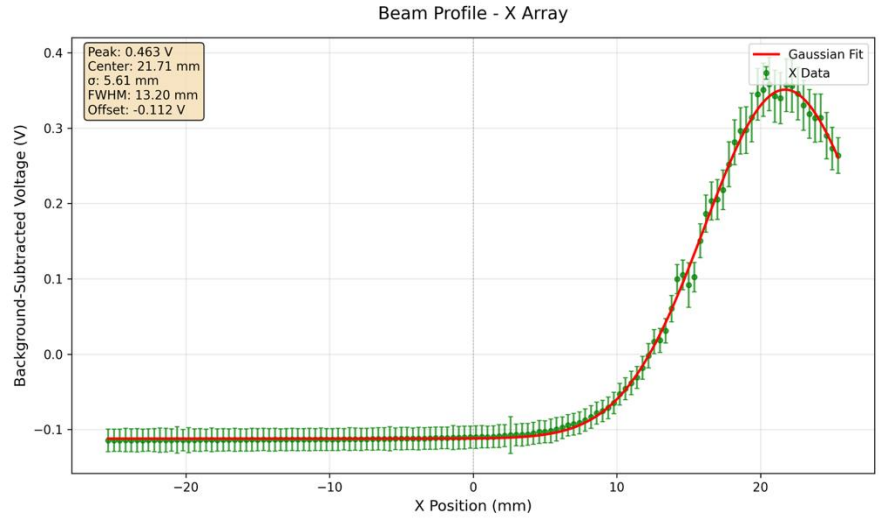
Consistent range reconstruction across entire range of beam spot positions.

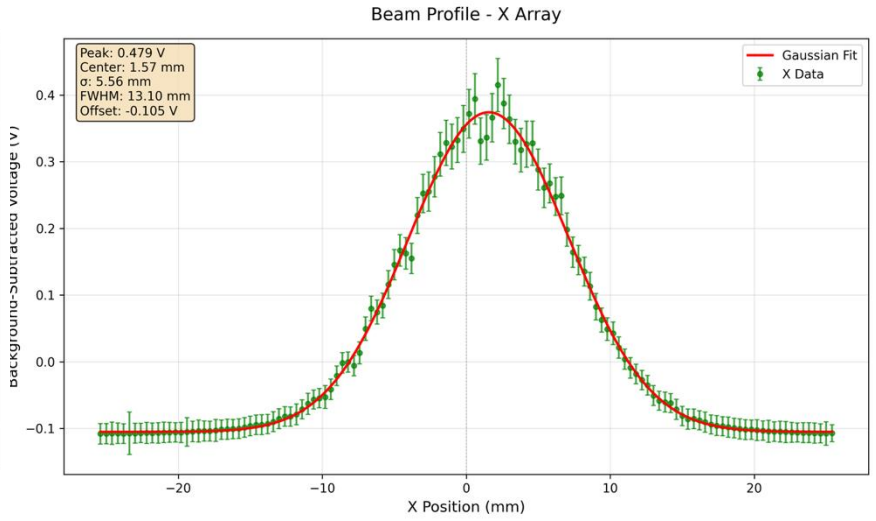
QuARC Δ/Σ & Fibre μ Measurements

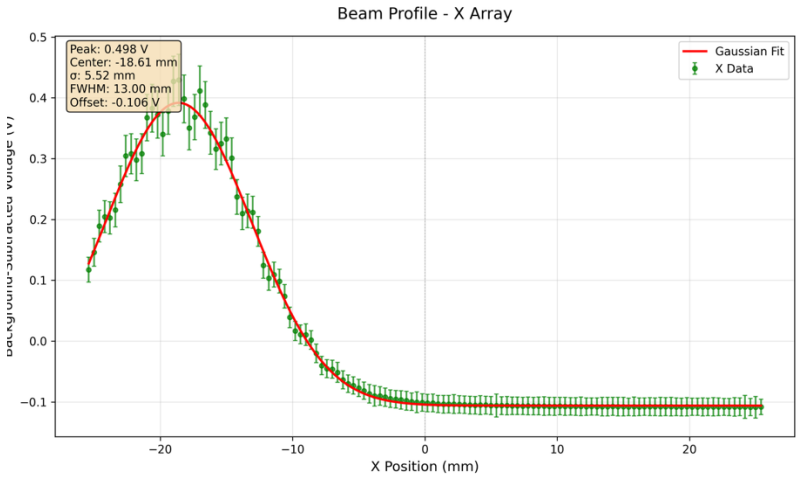
$$shift[i] = \frac{PD_A[i] - PD_B[i]}{PD_A[i] + PD_B[i]}$$

Calibrated









QuARC + Fibre Position Measurements