PBT Meeting 08-10-2025

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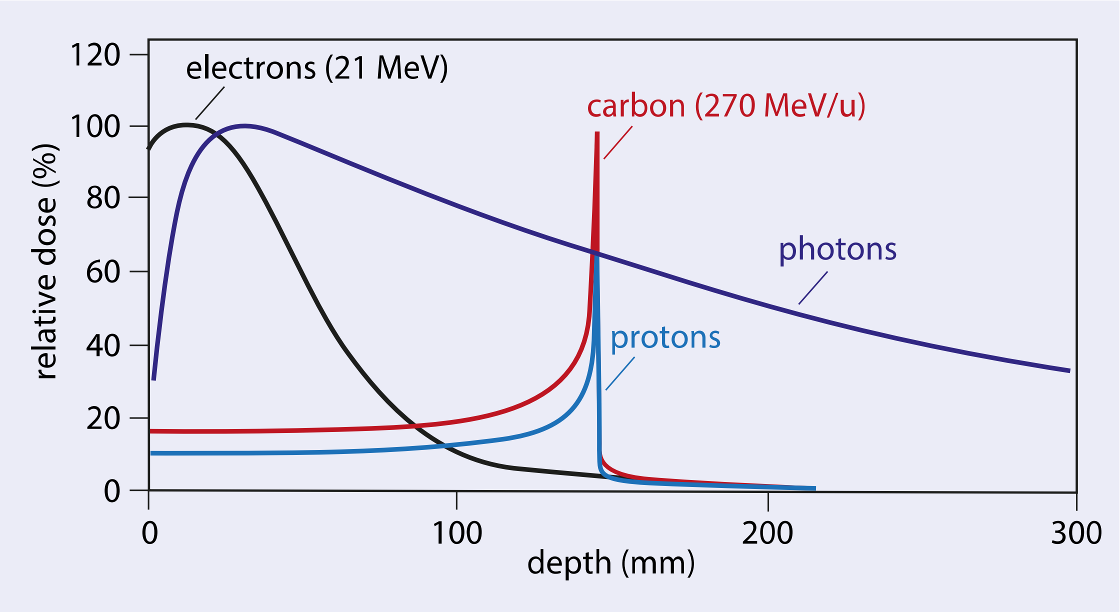
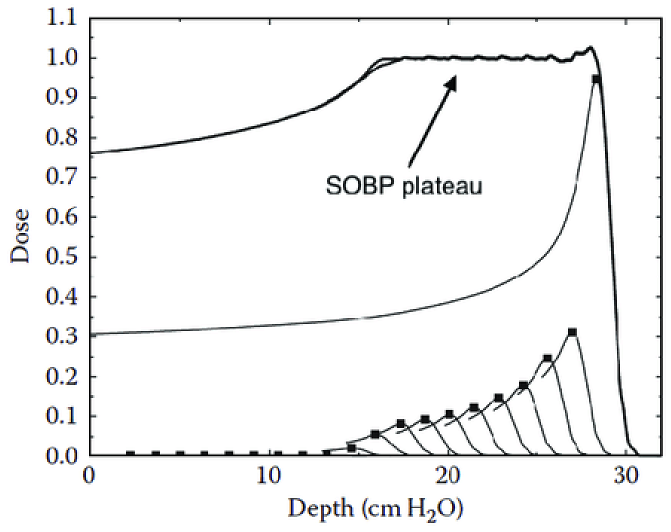
Proton Therapy QA

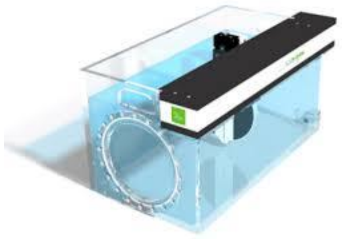
- Protons can provide a more targeted and localised dose distribution.
- However more susceptible to to range uncertainties etc.
- Accurate and efficient QA is vital to maximise clinical benefit of PBT.





PBT QA

- 4 key quantities to verify in particle therapy beam QA:
  - Absolute dose
  - Beam range
  - Spot size
  - Spot position



- In PBT every treatment plan requires some form of patient-specific QA
  - Either measurement based (time and resource consuming and ability to spot errors is limited)
  - Or log-file based (fast and efficient but not allowed by every vendor and requires more stringent verification of parameters)

QuADProBe

QuADProBe: **Qu**ality **A**ssurance **D**etector for **Pro**ton **Be**am Therapy

- Aims:

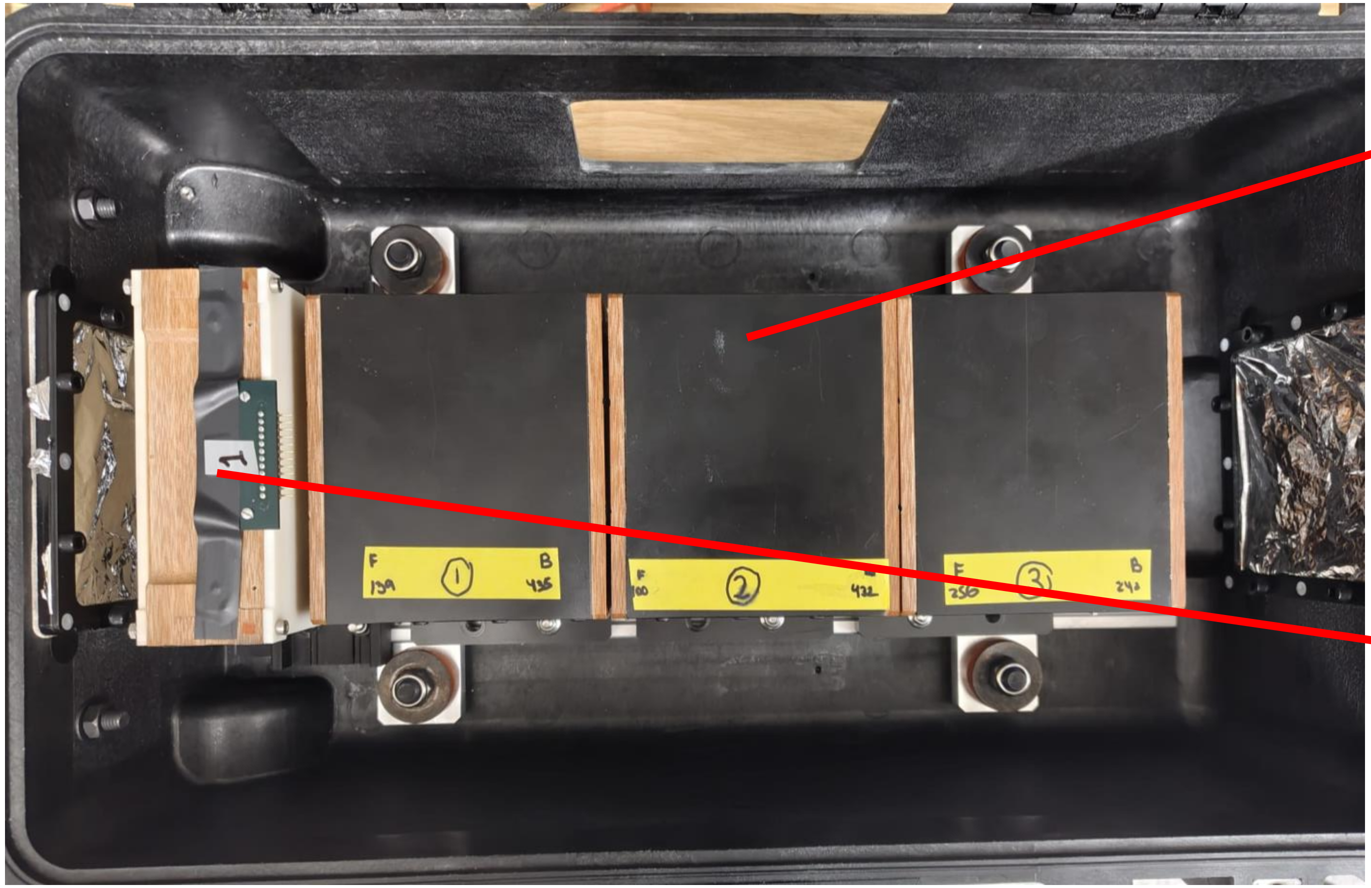
Develop a robust and affordable detector capable of providing:

1) All necessary beam measurements for PBS Machine QA: dose output, spot size, spot position and energy.

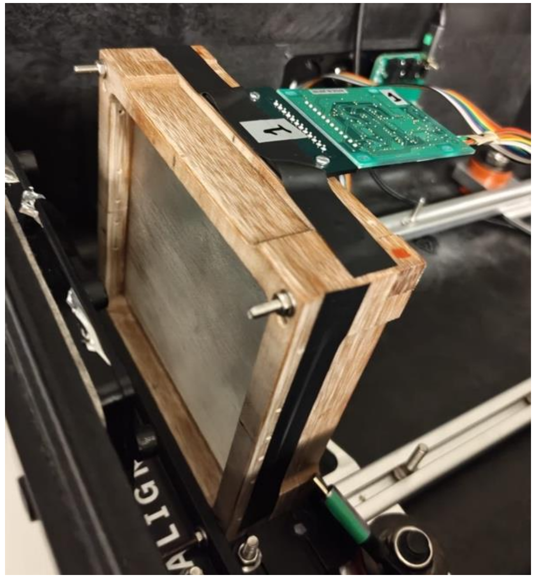
2) Real-time measurements of these parameters during a PSQA "dry-run".

QuADProBe Current Status

QuARC

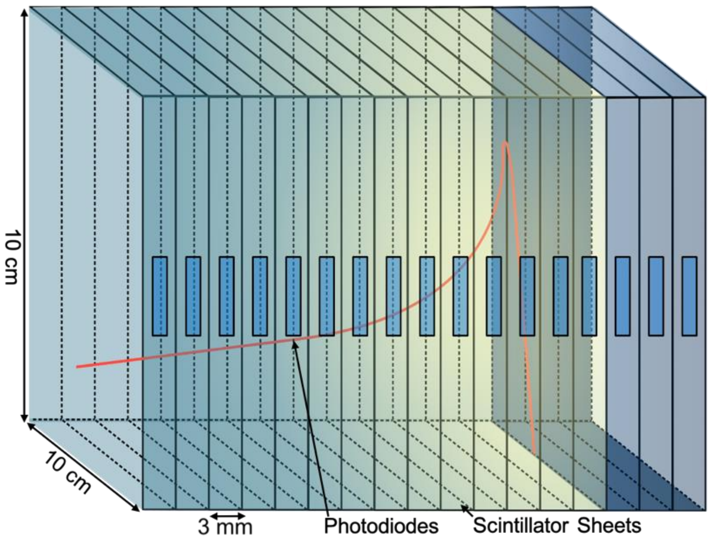


SciFi Tracker



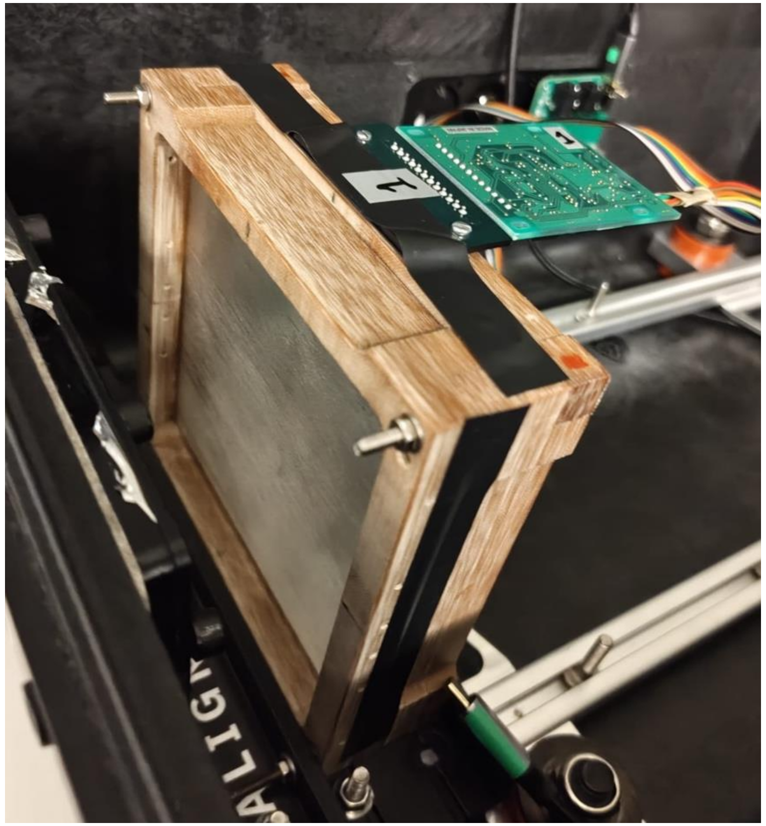
QuARC

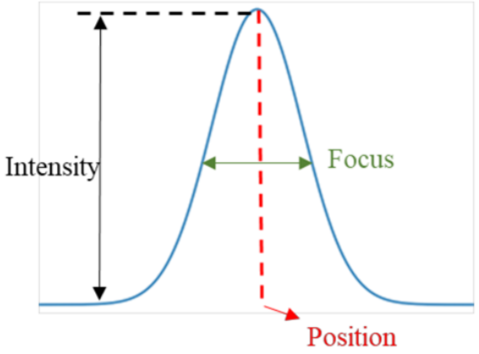
- The Quality Assurance Range Calorimeter (QuARC) constructed from plastic scintillator:
  - Protons intercepted by a series of optically-isolated polystyrene scintillator sheets.
  - Measure light output with photodiodes.
  - Light output of each sheet nonlinear to dose, but quenching described by Birks' Law:
    - Fit data with analytical depth-light model.
    - Reconstruct Bragg depth-dose curve and measure proton range.
  - Photodiodes coupled to fast, modular electronics and an FPGA to read light levels at over 5 kHz.
  - FPGA connects to on-board PC (Raspberry Pi) via USB.
  - Connection to on-board PC via ethernet/WiFi.
- Key benefits:
  - Plastic scintillator inexpensive and water-equivalent.
  - Range reconstructed with single beam delivery.
  - Easy detector setup and no optical artefacts.



SciFi Profile Monitor

- 2 orthogonal 10 cm x 10 cm arrays made of BCF-60 plastic scintillating fibres by Saint-Gobain, 0.50 $\pm$ 0.13 mm diameter. Emission peak at 530 nm.
- 128-photodiodes array (Hamamatsu S13865), single and cascade operation. Image size: 51.2 x 0.6 mm, pixel pitch 0.4 mm
- Hamamatsu C9118-02 CMOS driver circuit provides multiplexed data at up to 4 MHz
- Analogic video output from the pixels array readout using NI USB-6366 Multifunction I/O
- In low gain the dark output voltage is typ. 0.005 mV, max 0.1 mV
- The saturation output voltage is min. 3 V typ 3.5 V
- MCLK 1 MHz. Suggested min. reset time 10us and suggested min. integration time 17+4x128 clocks = 529 us.
- FPGA high period of RESET clock (reset) = 50 us, low period (integration) 950 us





QuADProBe: My Working Areas

- **Detector Hardware**
  - 2nd SciFi prototype with digital readout photodiode arrays

- **DAQ, GUI, Postprocessing and Analysis**
  - Trento fibre data analysis
  - Trento / UCLH / PPTC QuARC data analysis
  - GUI upgrades
  - Development of DAQ chain for next fibre readout electronics + 4 sided QuARC readout

- **Detector Simulation**
  - Geant4 QuARC simulation
  - Geant4 QuADProBe Simulation

- **3D Dose Reconstruction**
  - TOPAS simulation pipeline over plus1 + HEP batch farm
  - Alternatives for faster reconstruction
    - GPU-based MC codes e.g. FRED
    - AI based dose reconstruction: CNNs/PINNs for dose in water – 3D CNNs / Transformers for patient CT

Immediate term goals

- Trento Beam Test Data Analysis
  - SciFi Measurements
    - Preliminary analysis
    - Continue code upgrades with Raffy
  - QuARC Measurements
    - Continue analysis with Sonia’s code as well as looking at beam position measurements
    - Make any necessary modifications
- Paper preparation from PPTC/UCLH/Trento (& Geant4 simulations?)
  - Dual-sided QuARC readout
  - Correlation of position and size with SciFi

Immediate goals

- GUI functionality and upgrades
  - Make sure to **fully understand** how GUI in its current form works
    - First test on debugging since currently only displays data for 6 boards but not for 7 or 8

Short/medium term goals

- GUI functionality and upgrades
  - Make necessary upgrades i.e. improve responsiveness and replay function
  - Add fibre profile functionality

Short/medium term goals

- Preparations for new readout electronics for SciFi
  - Gather as much info from Kirsty on signal requirements for S17285-128G photodiodes in order to assist for development of front end readout board
    - Initial board for testing of new photodiodes with USB104 -> possible beam test at HIT
    - Final board once decided whether to proceed with digital readout or analogue readout with full Kria integration.

Immediate term goals

- Preparations for new readout electronics for SciFi
  - Gather as much info from Kirsty on signal requirements for S17285-128G photodiodes in order to assist for development of front end readout board
    - Make sure to understand signal requirements etc to level of Saads QuARC powerpoint
    - Download labview and prep NI for mocking up programme to test digital photodiodes

Short/medium term goals

- Development of DAQ chain for next fibre readout electronics + QuARC
  - C++ code (or other if deemed more appropriate) for real-time readout and Gaussian fitting of fibre array profiles and display on GUI
  - Methods to reconstruct 2d profile and position using 2x 1D profiles
  - Development “Event Tagging” system to sync SciFi and QuARC “Events”

MC Simulations

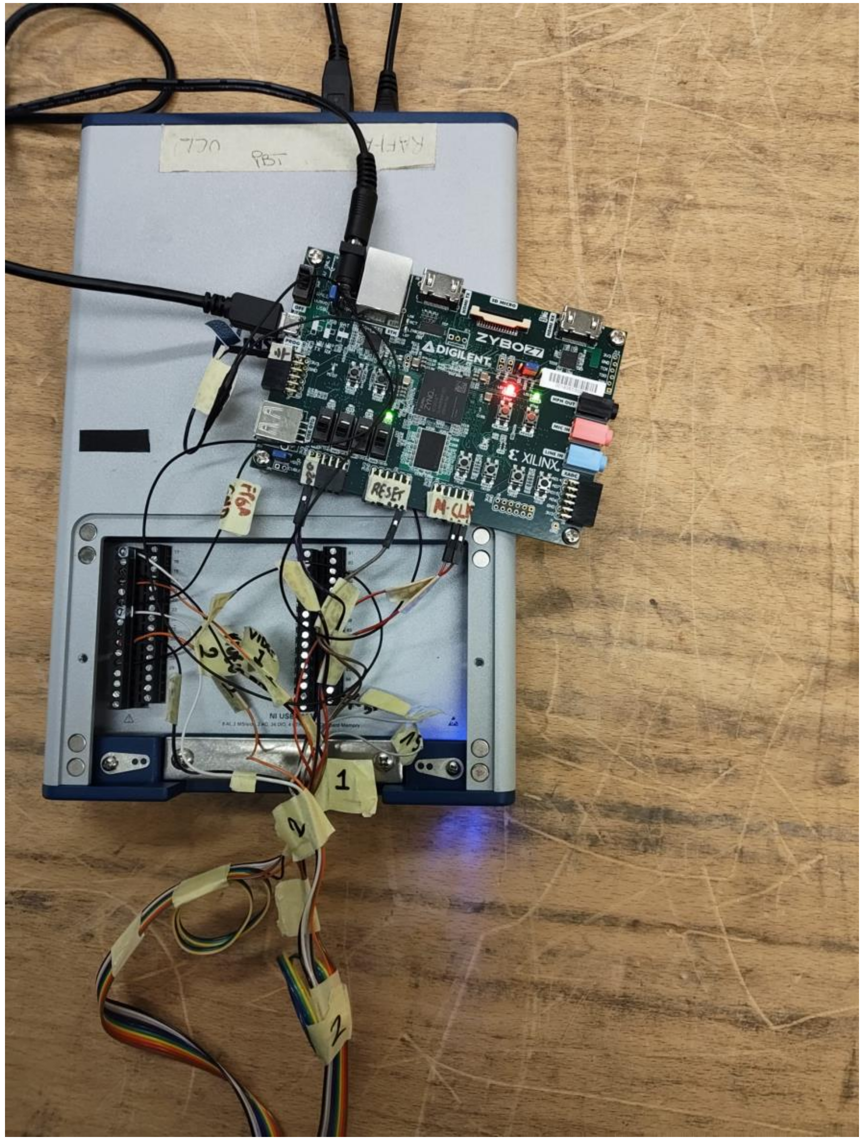
- Detector Geant4 Simulations
  - Further optimisations for QuARC simulation
  - Work with Raffy to add on fibre arrays

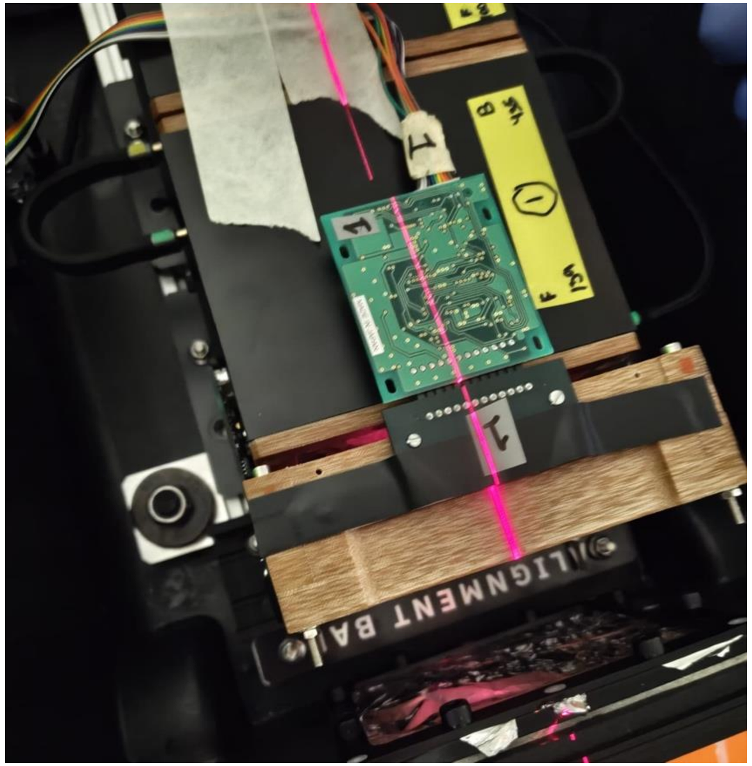
- 3D Dose reconstruction
  - TOPAS pipeline on plus1 and HEP batch farm working well
  - FRED on GPU cluster? Worth seeking access to Hypatia or any other UCL ARC GPU clusters or cloud-based GPU computing?
  - Other alternatives such as AI-based dose reconstruction – Matt from UCLH working on this for UCLH PBT PSQA

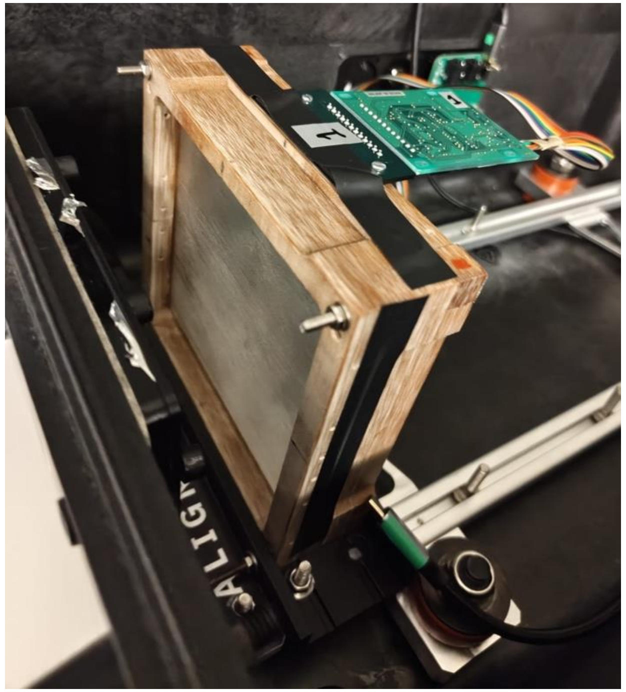
Trento Beam Test Summary and Prelim Results

- 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 low gain)
    - Different spot sizes (varying energy)

SciFi Measurements

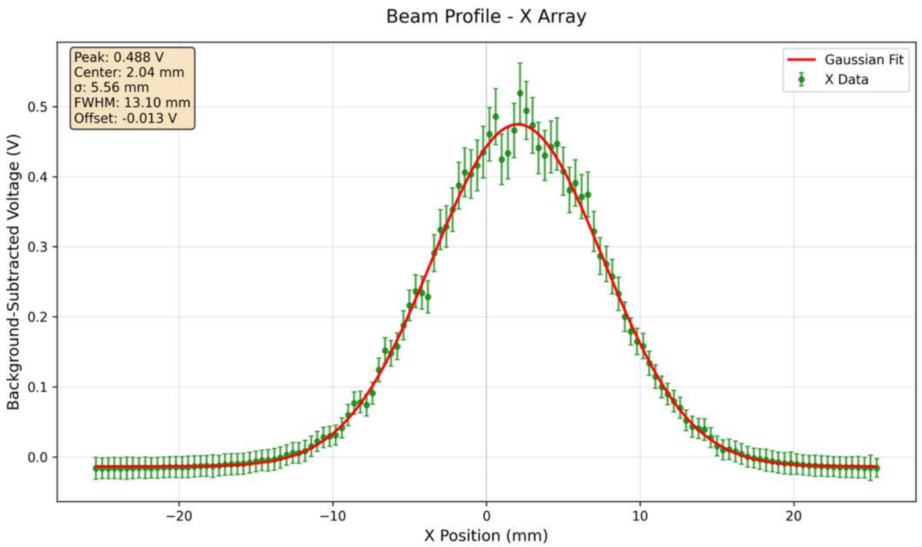


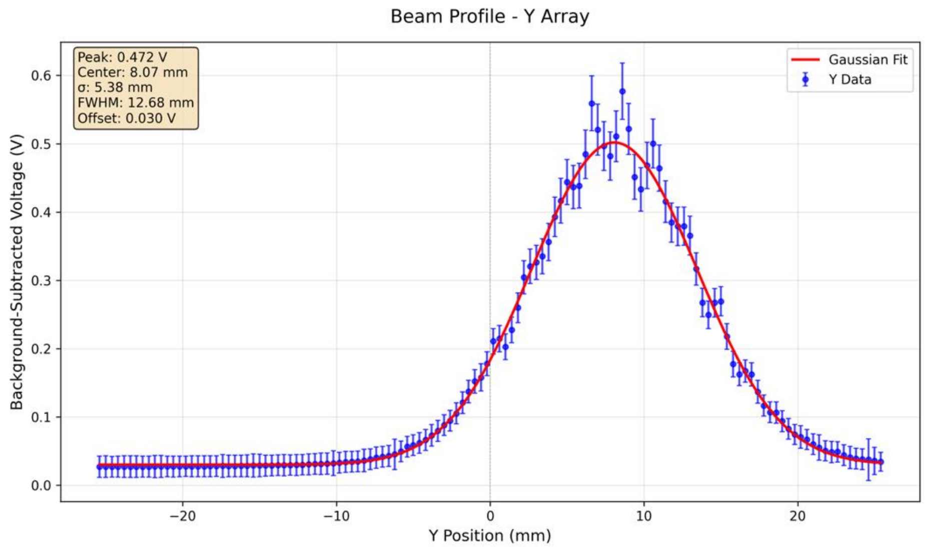




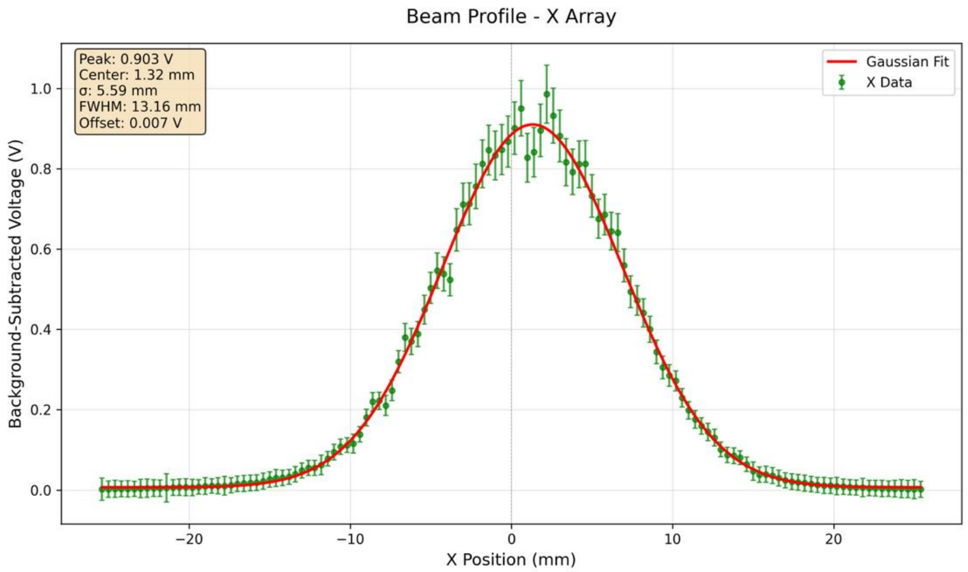
148 MeV 300 nA Profiles at Low Gain and High Gain

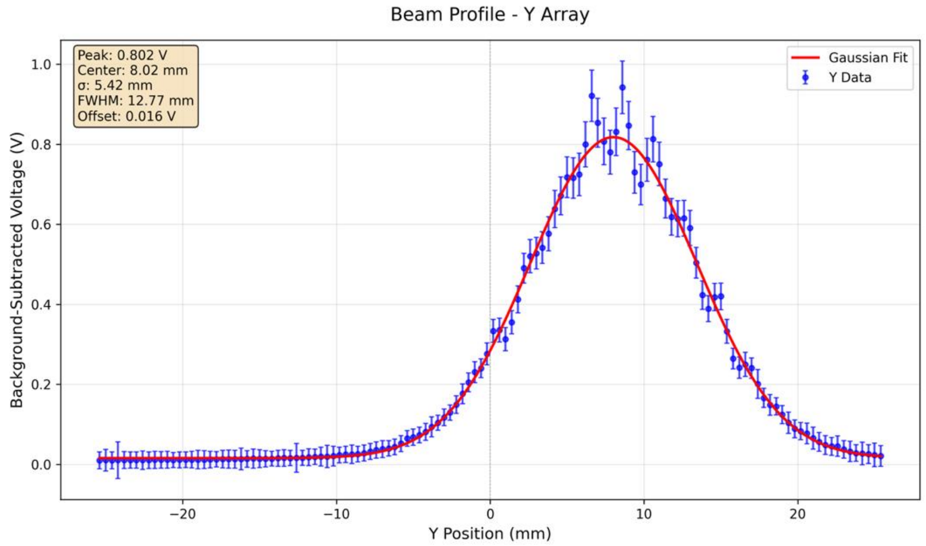
Low gain



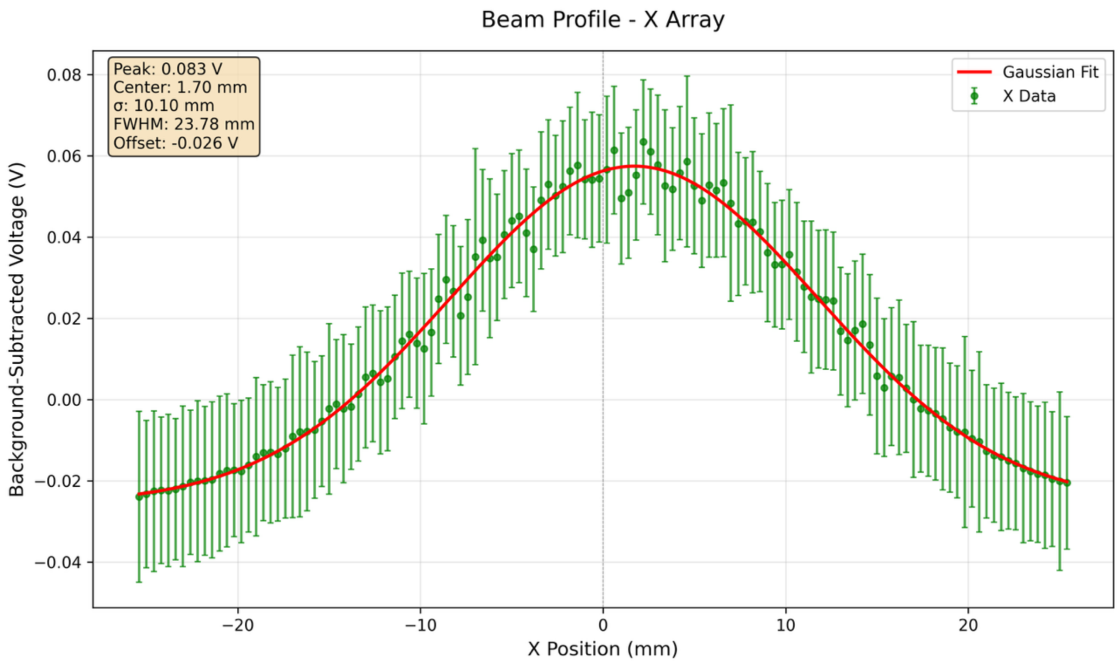


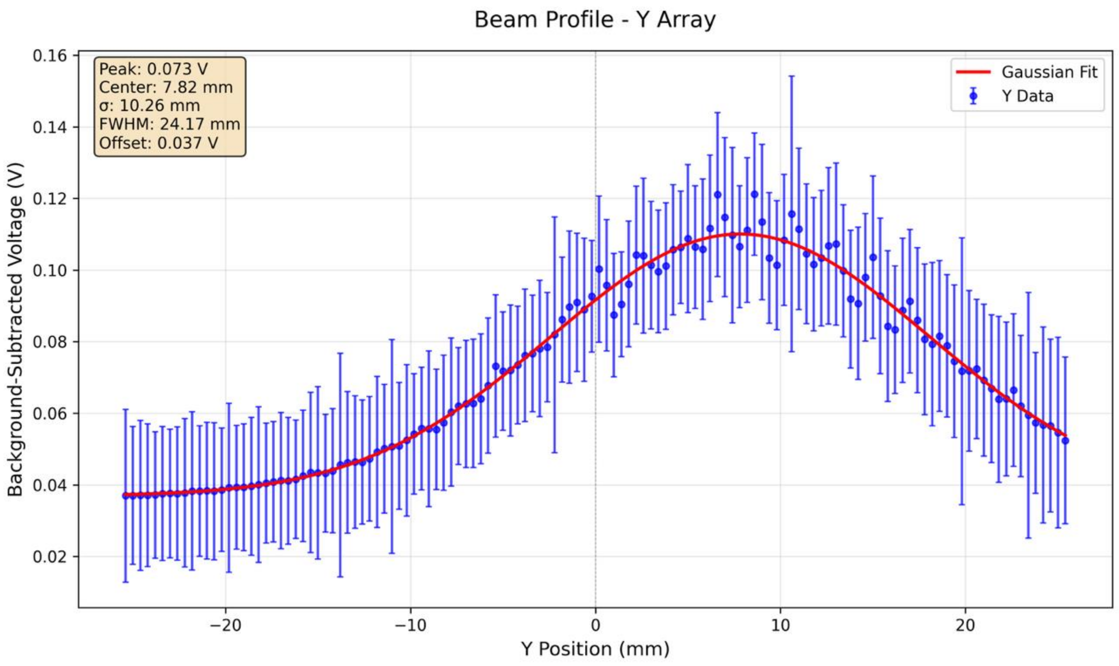
High gain





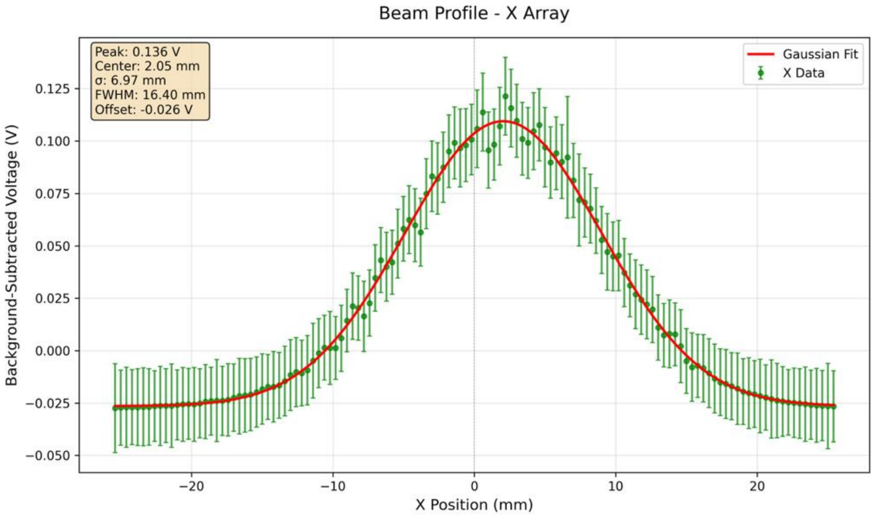
70 MeV 300 nA (max ion source current) High Gain

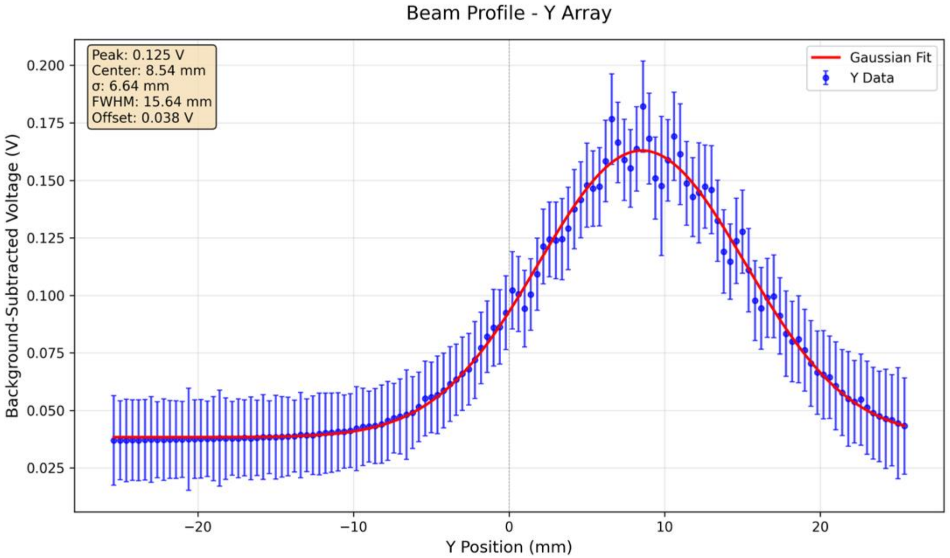




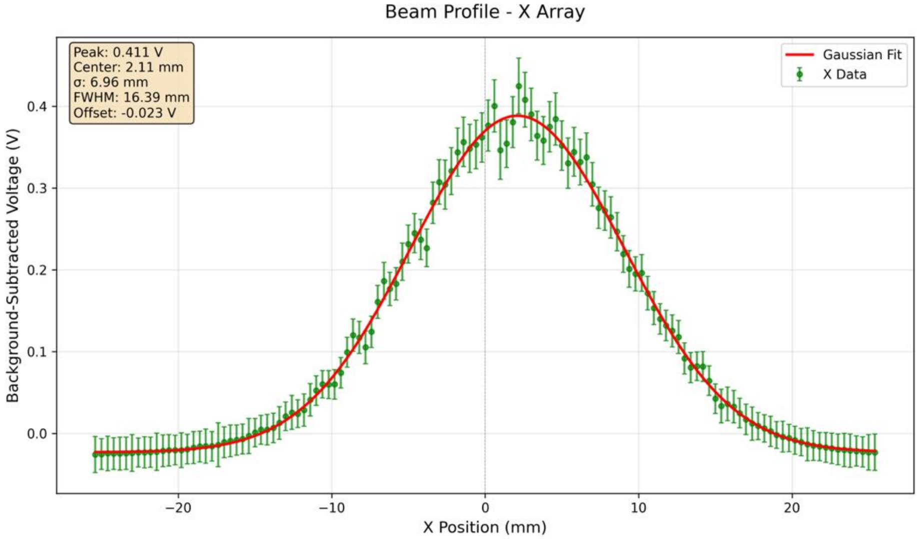
112 MeV High Gain

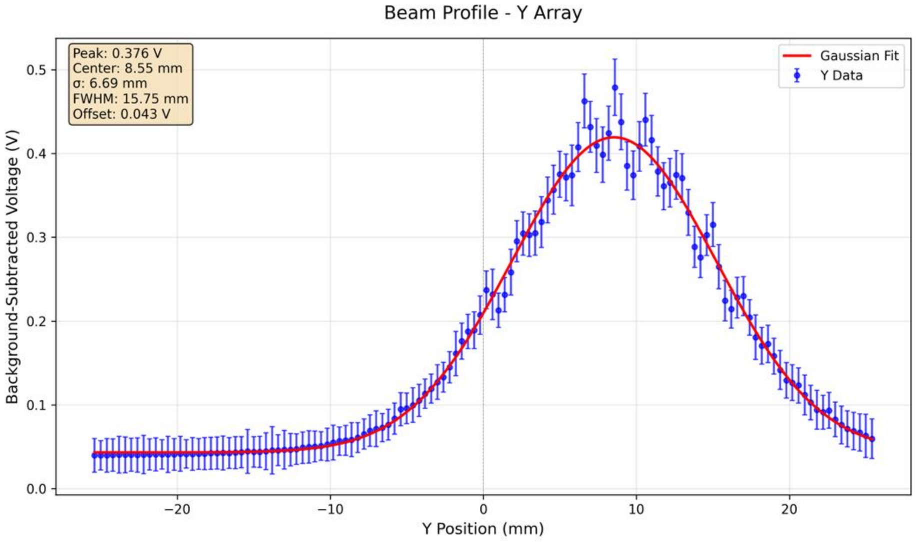
100
nA



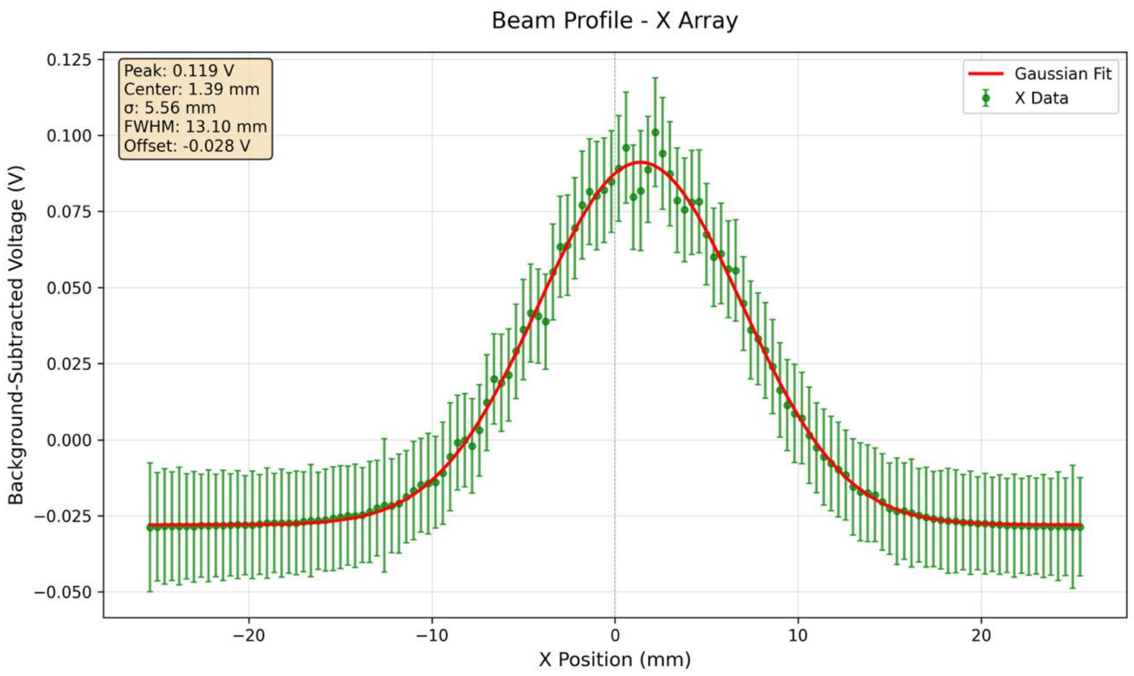


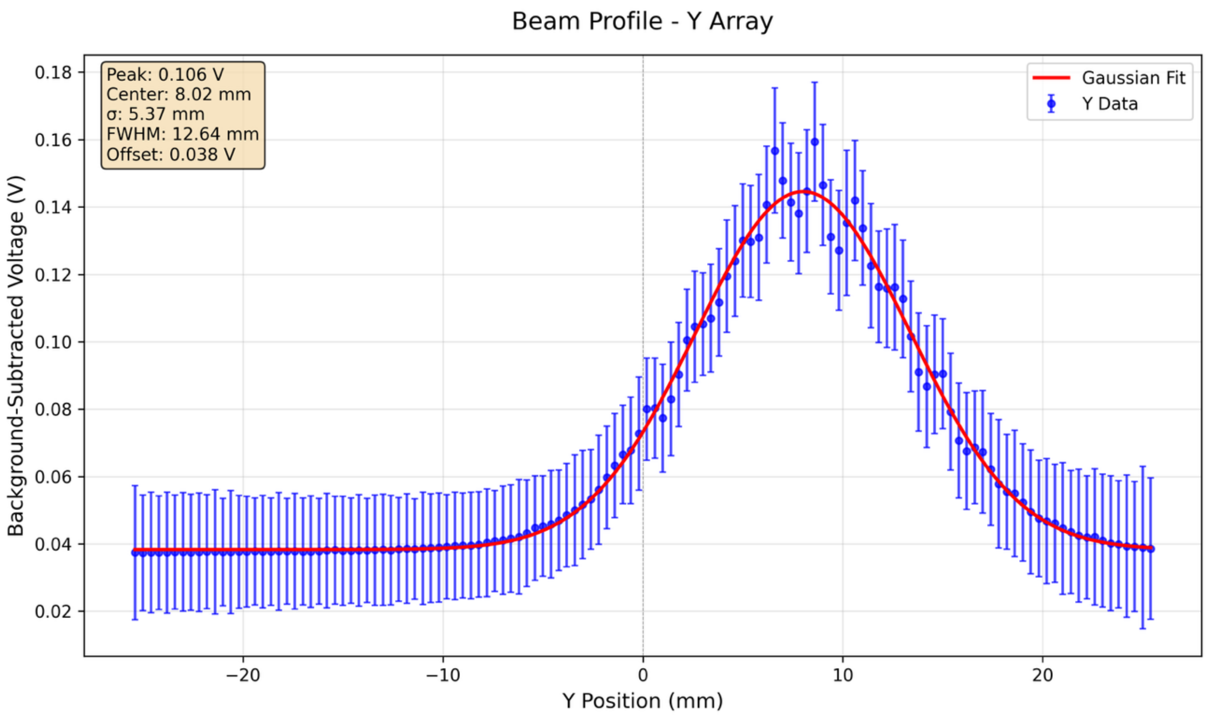
300
nA





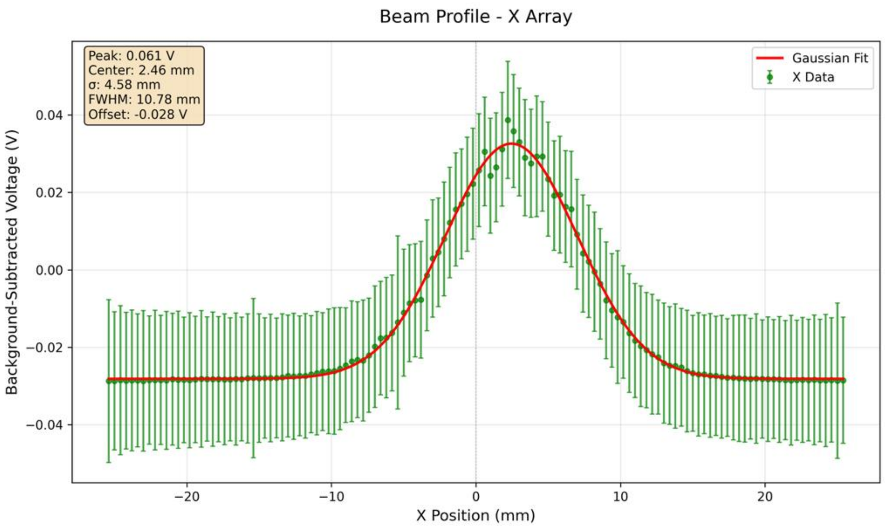
148 MeV 40 nA High Gain

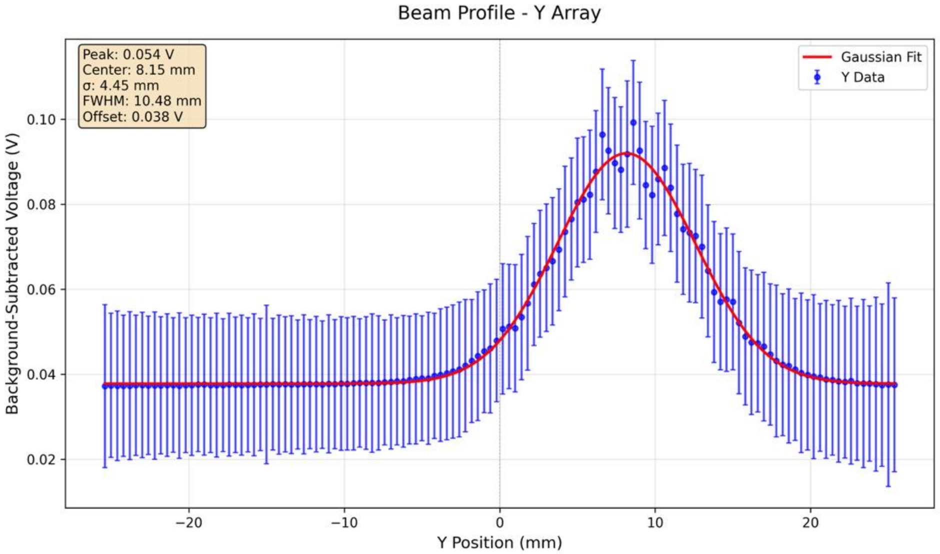




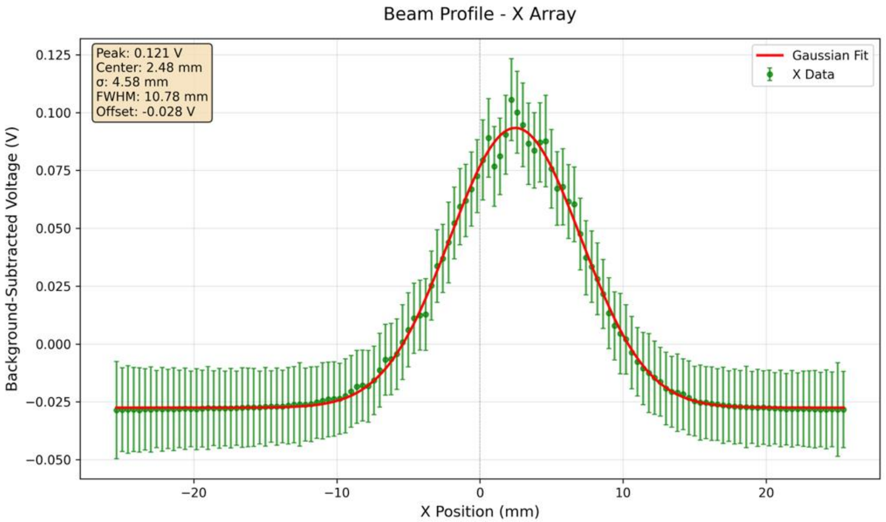
179 MeV High Gain

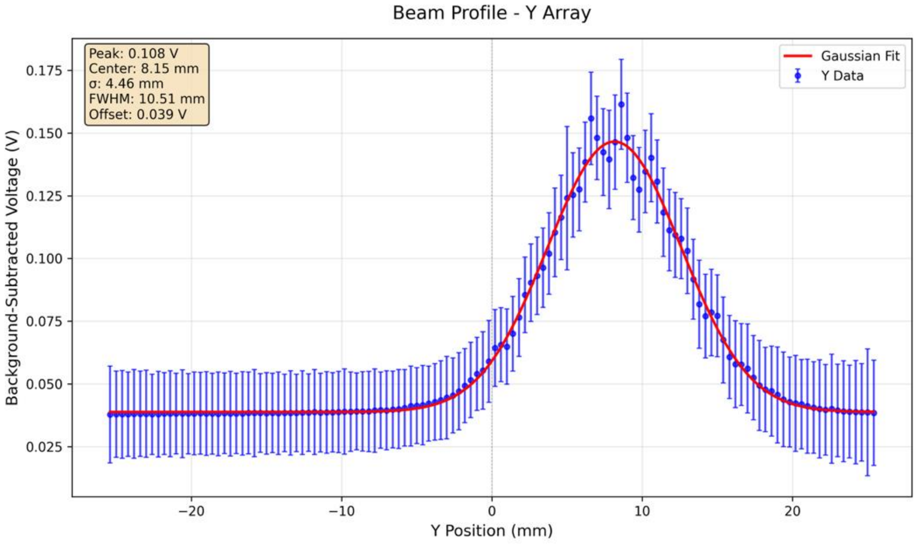
10 nA



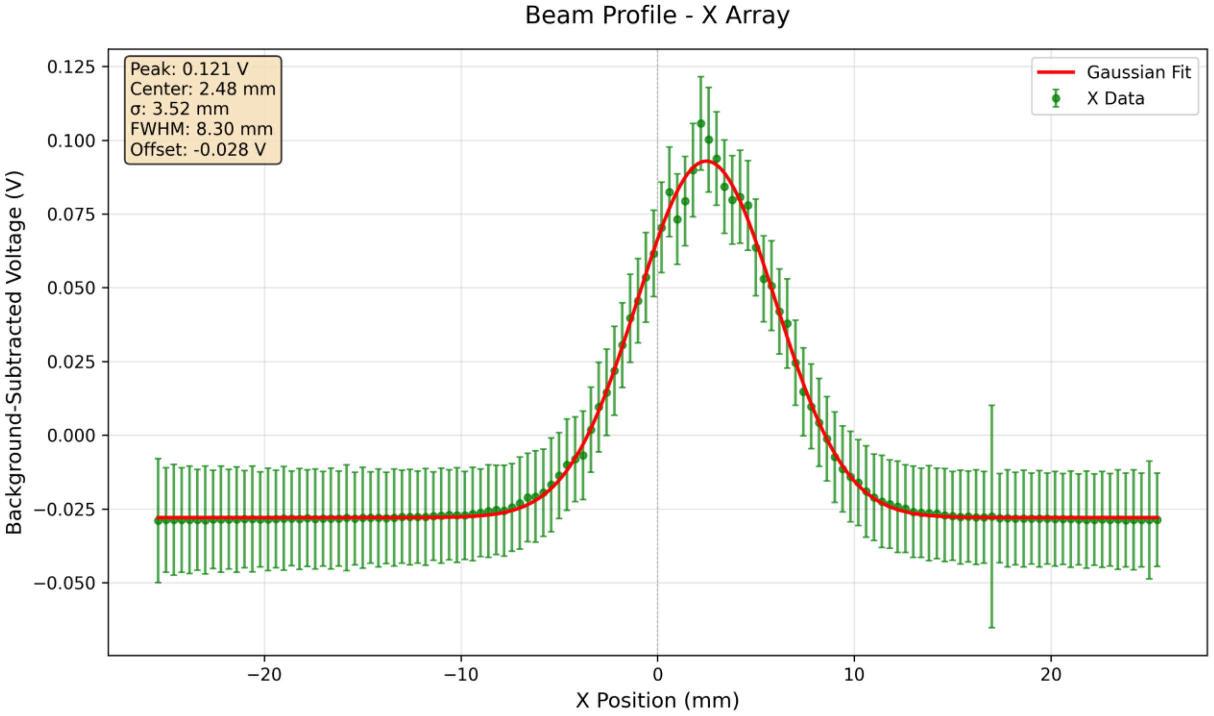


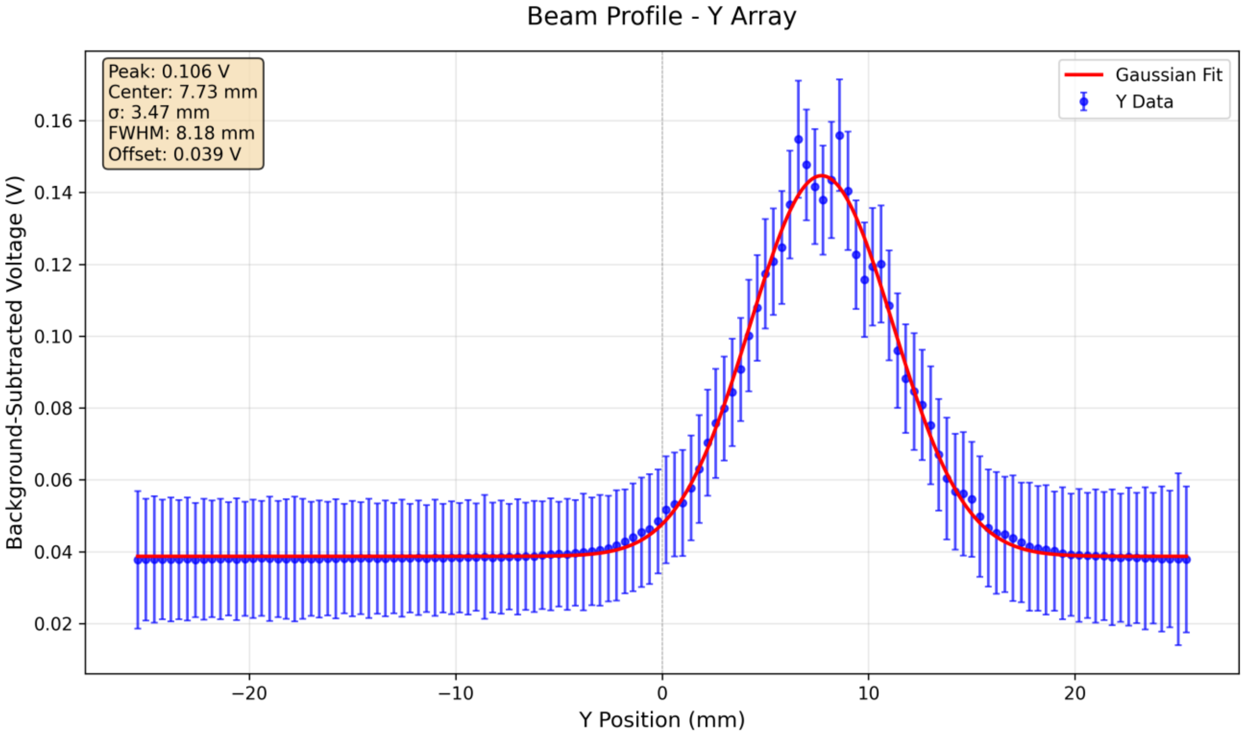
20 nA



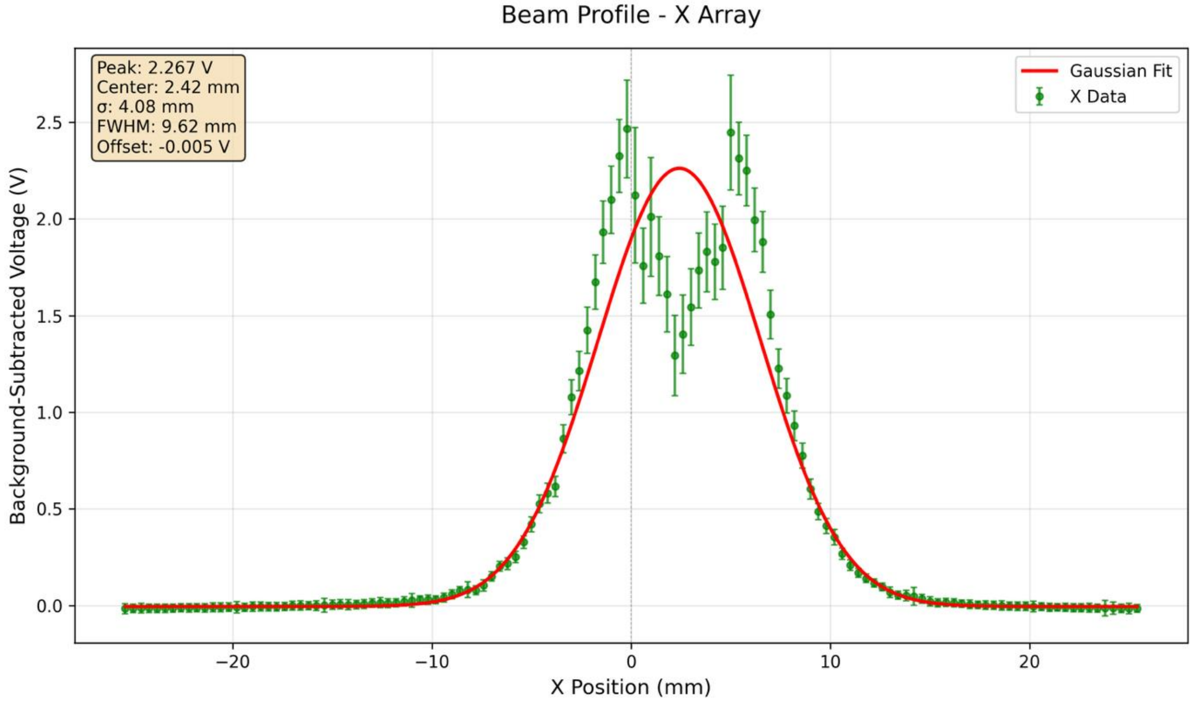


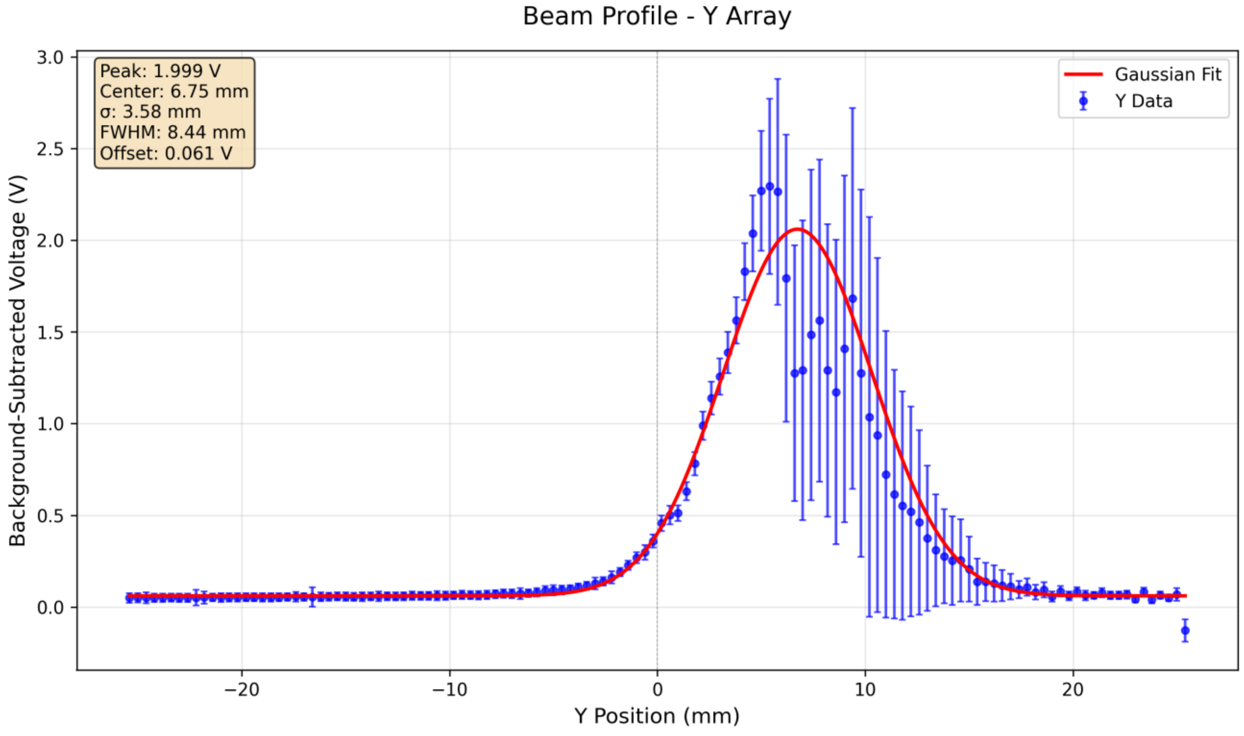
228 MeV 5 nA High Gain



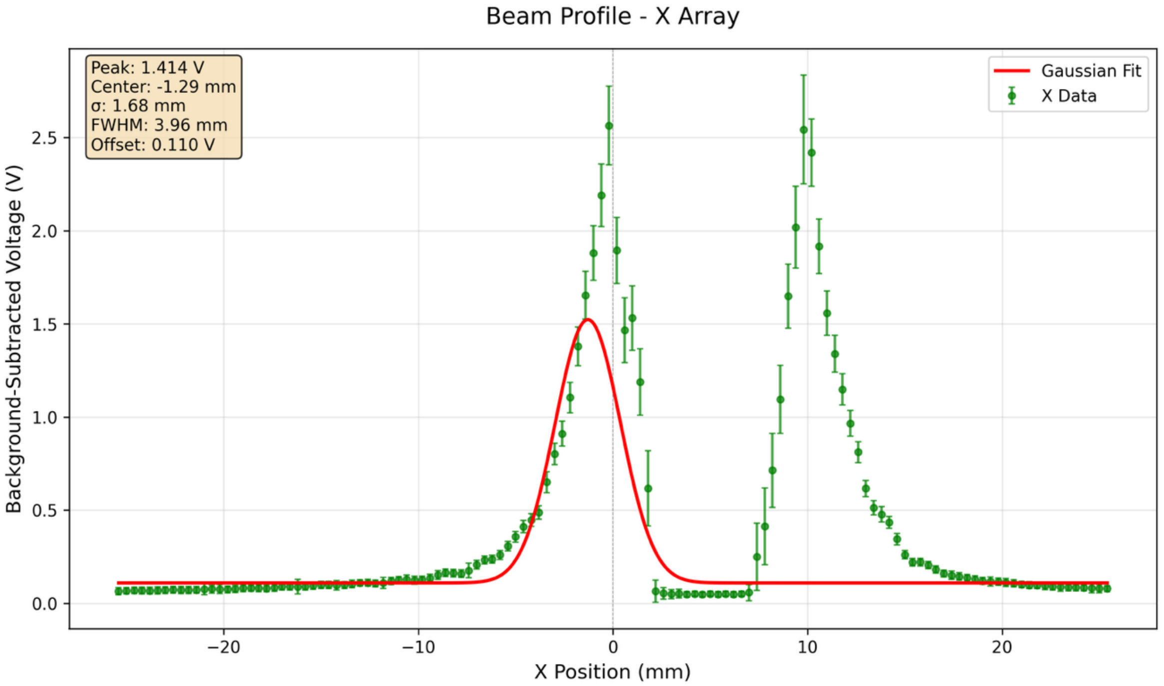


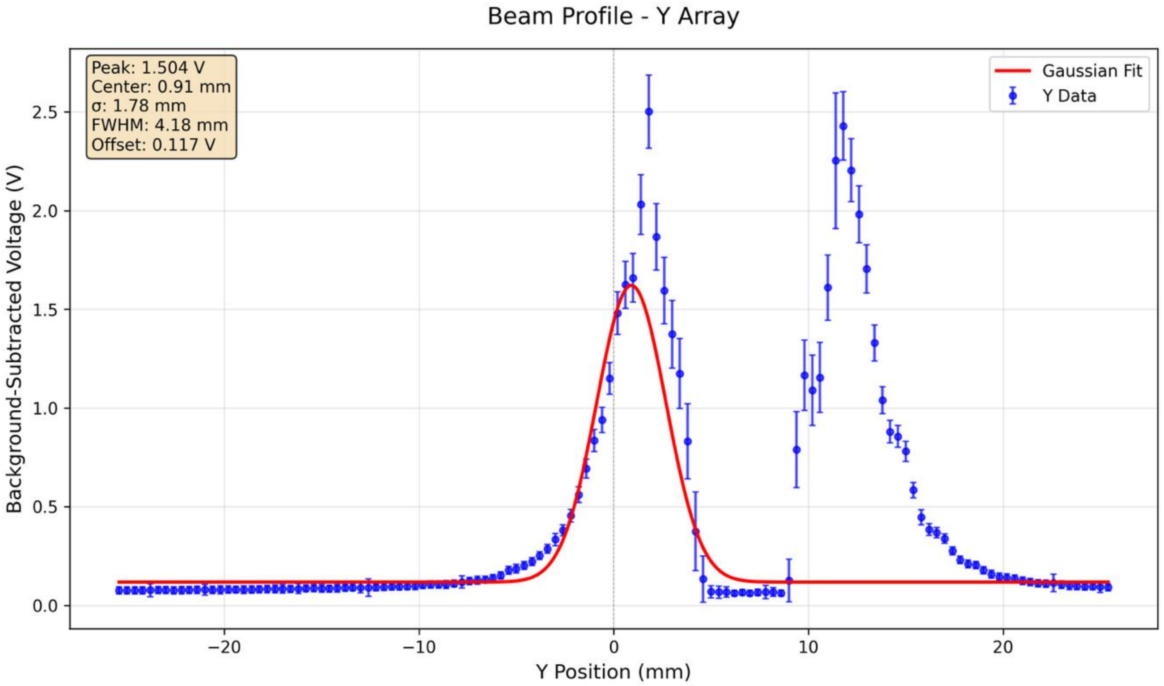
228 MeV 150 nA High Gain



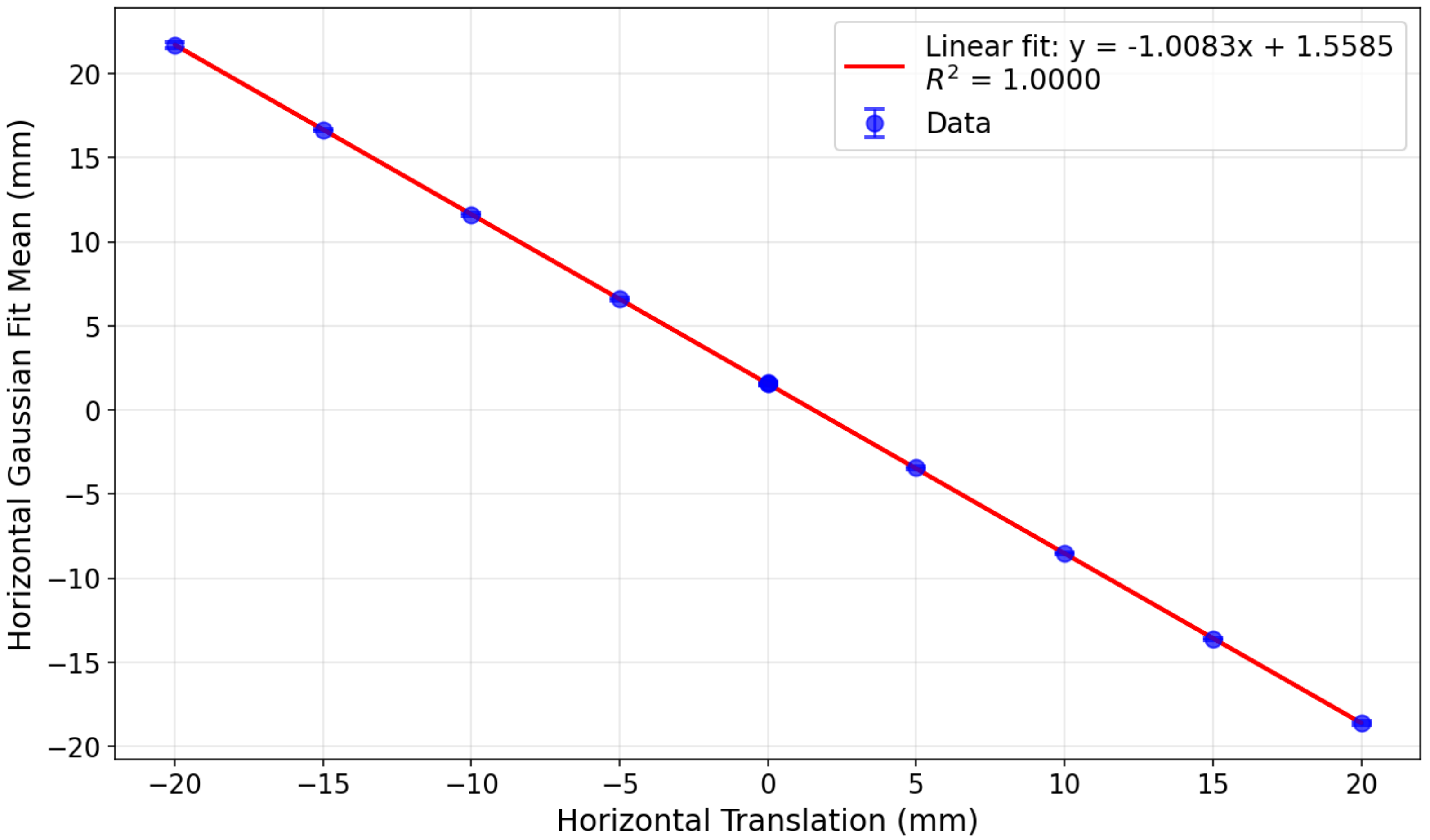


228 MeV 150 nA High Gain



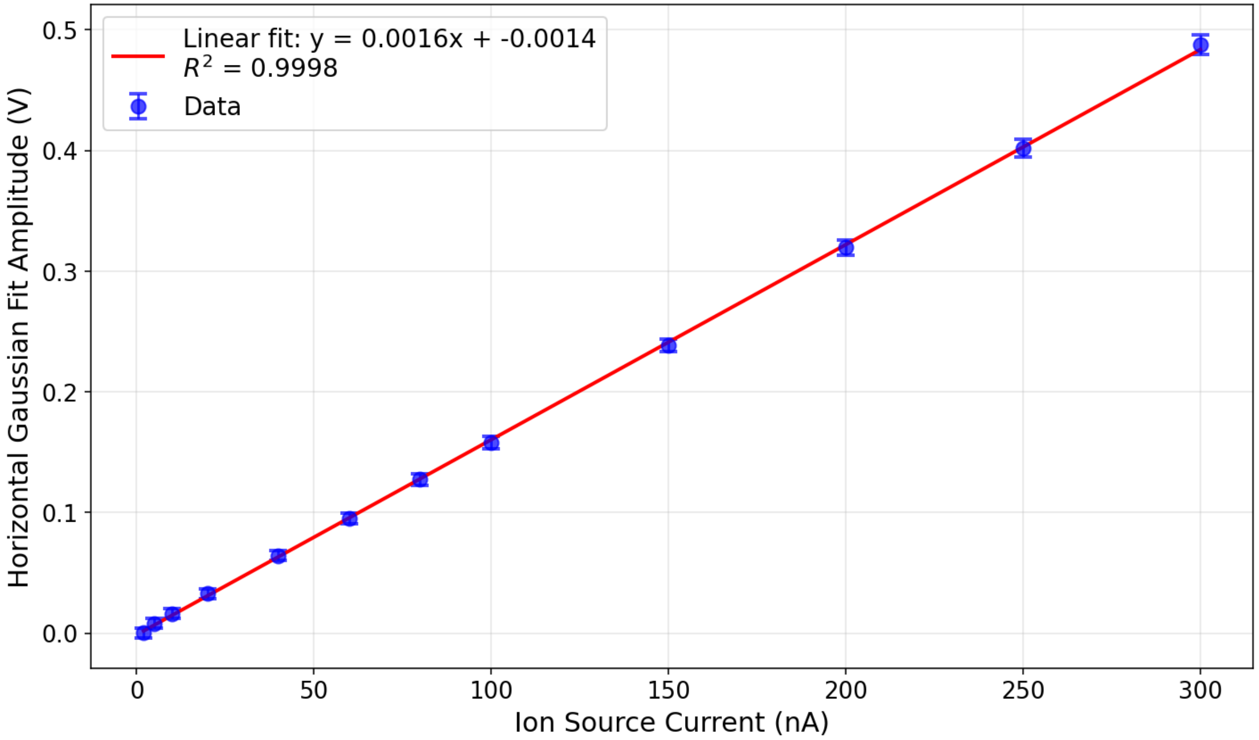


Position measurements using stage translation at 148 MeV 300 nA

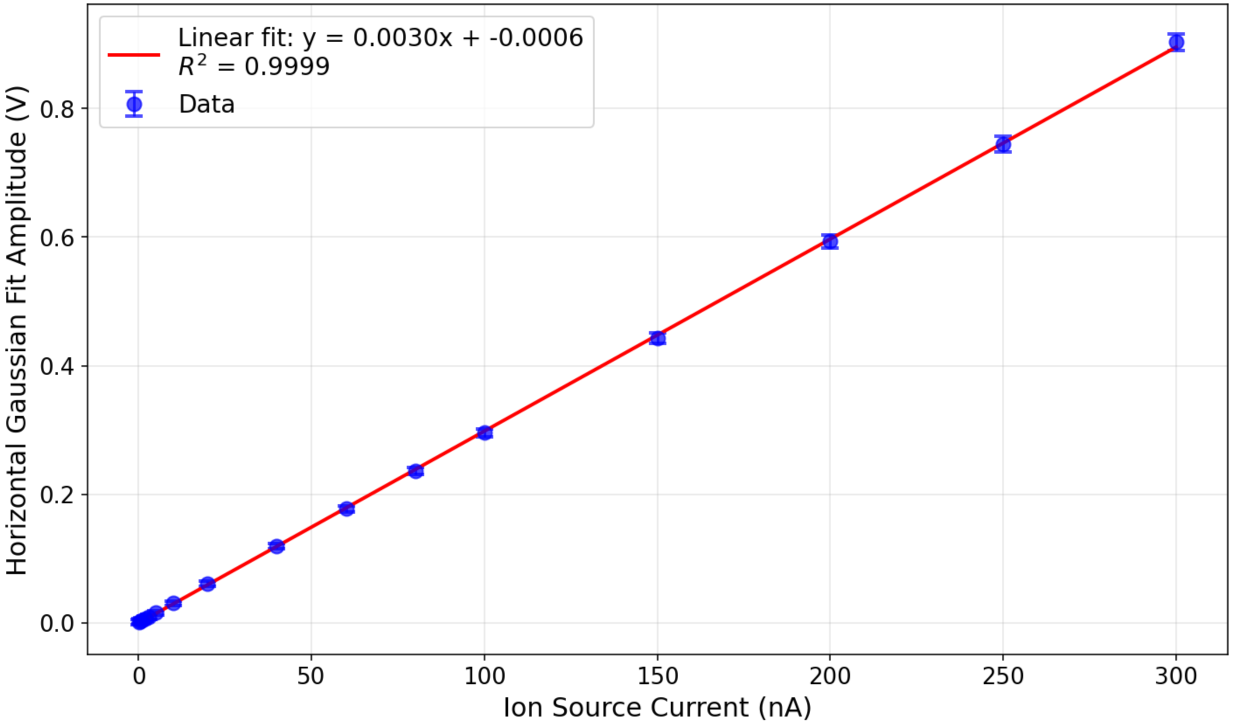


Response Linearity at 148 MeV (using Amplitude of Gaussian Fit on Horizontal Array)

Low gain



High gain



NI Output Traces