The RD50-MPW2 High Voltage-CMOS sensor chip DAQ and preliminary testbeam results

23/06/21

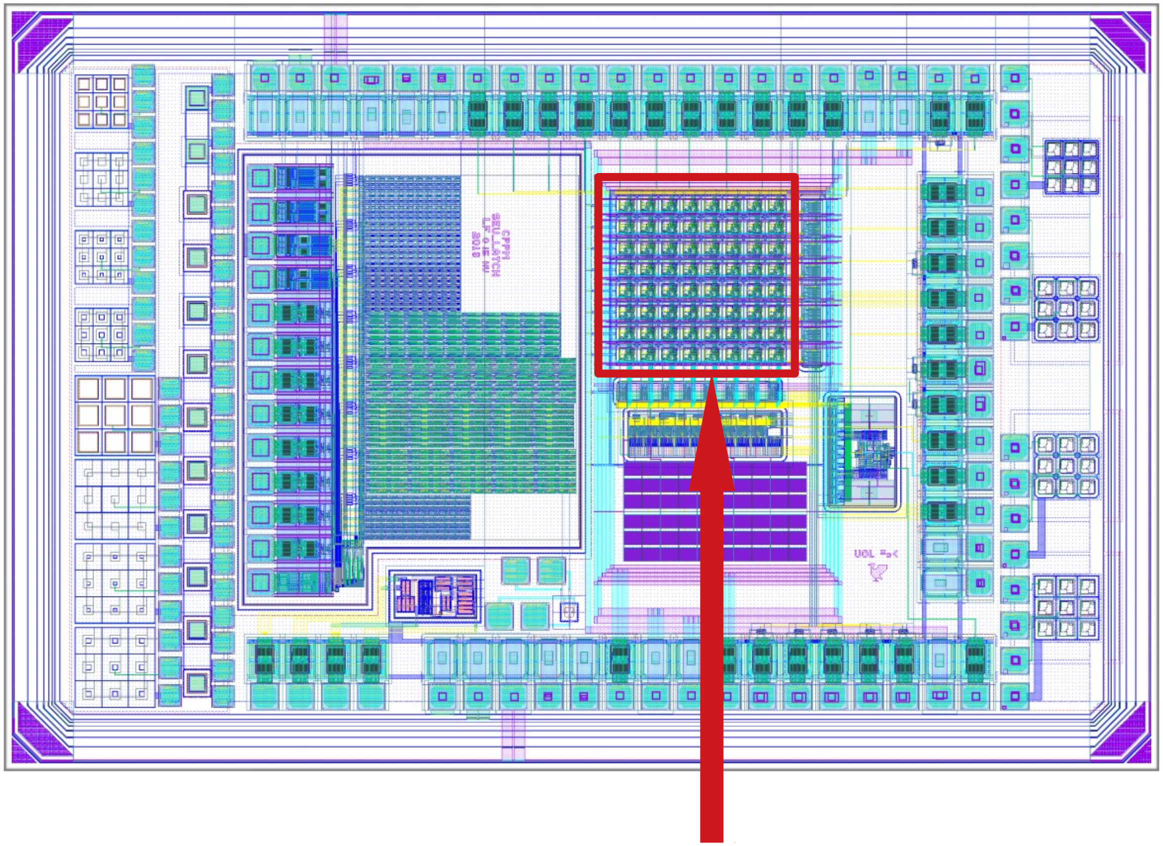
UK Research and Innovation

OUTLINE

- BRIEF OVERVIEW OF RD50-MPW2
- AN OVERVIEW OF THE MEASUREMENTS PREVIOUSLY PERFORMED TO CHARACTERISE RD50-MPW2
- TCT RESULTS OF THE ACTIVE MATRIX MEASURED AT Ljubljana WILL BE PRESENTED
- PRELIMINARY RESULTS OF A TESTBEAM PERFORMED AT RUTHERFORD CANCER CENTRE WILL BE PRESENTED

RD50-MPW2 FEATURES

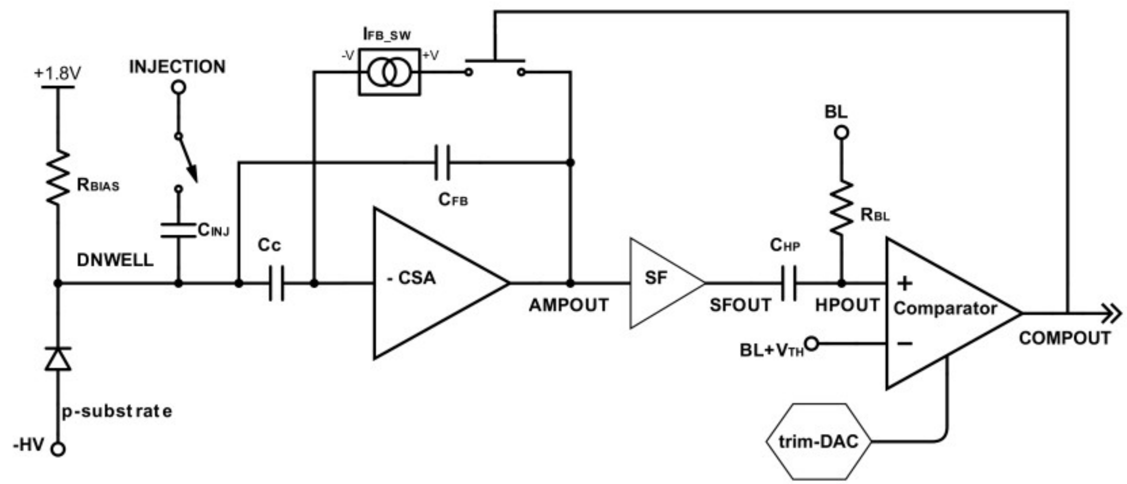
- RD50-MPW2
  - 150nm LFoundry process
  - 280um wafer thickness
  - Wafer resistivities of 10 Ω·cm, 200 - 500 Ω·cm, 1.9 kΩ·cm, 3 kΩ·cm
  - Chip size 2120 µm × 3211.66 µm
- Contents
  - Active matrix of 8 x 8 pixels – pixel size 60um x 60um
  - Bias Block
  - Configuration registers
  - Analougue multiplexer and buffer
  - Passive test structures
  - SEU tolerant memory
  - Bandgap reference



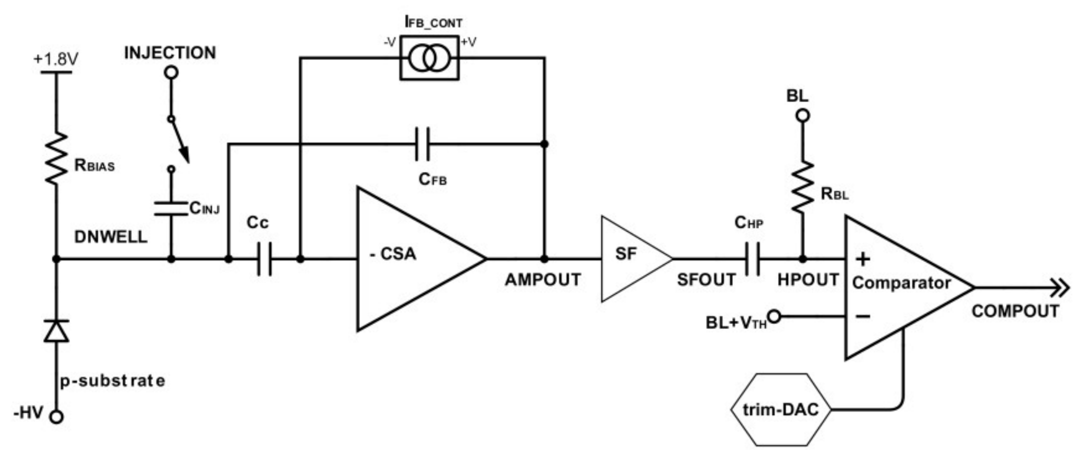
ACTIVE MATRIX

RD50-MPW2 FEATURES

- The pixel matrix is split into 2 types of pixels
  - Continuous-reset pixels (column 0 to 3)
  - Switched-reset pixels (column 4 to 7)



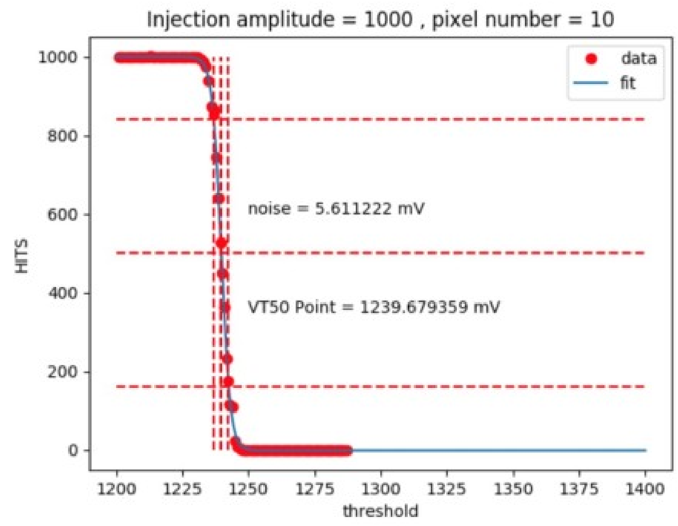
Schematic diagram of the switched-reset pixel

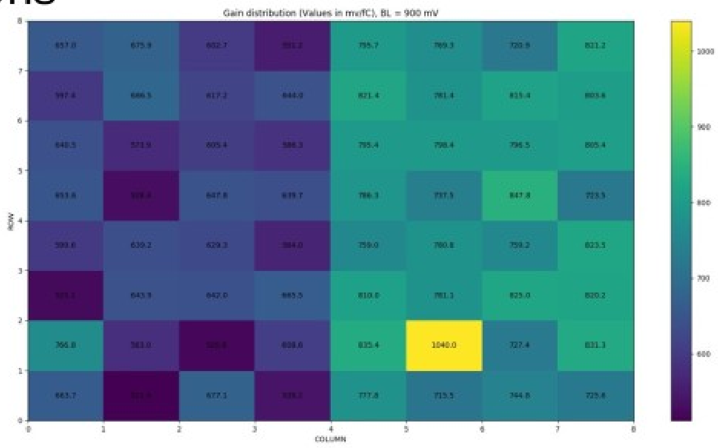


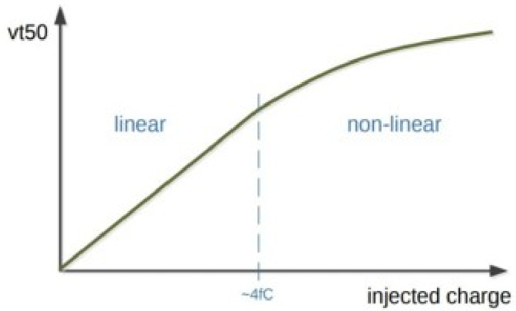
. Schematic diagram of the continuous-reset pixel

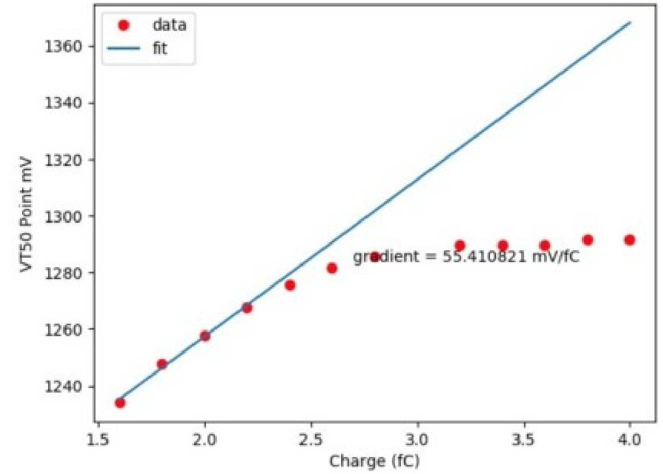
RD50-MPW2 Measurements and Characterisation

- Software and firmware developed to configure, readout and analyse RD50-MPW2
- Measurements including S-curves, Response Curves DAC trimming, Gain calculations and pixel to pixel gain and noise distributions
- MPW2 has now been very well characterised



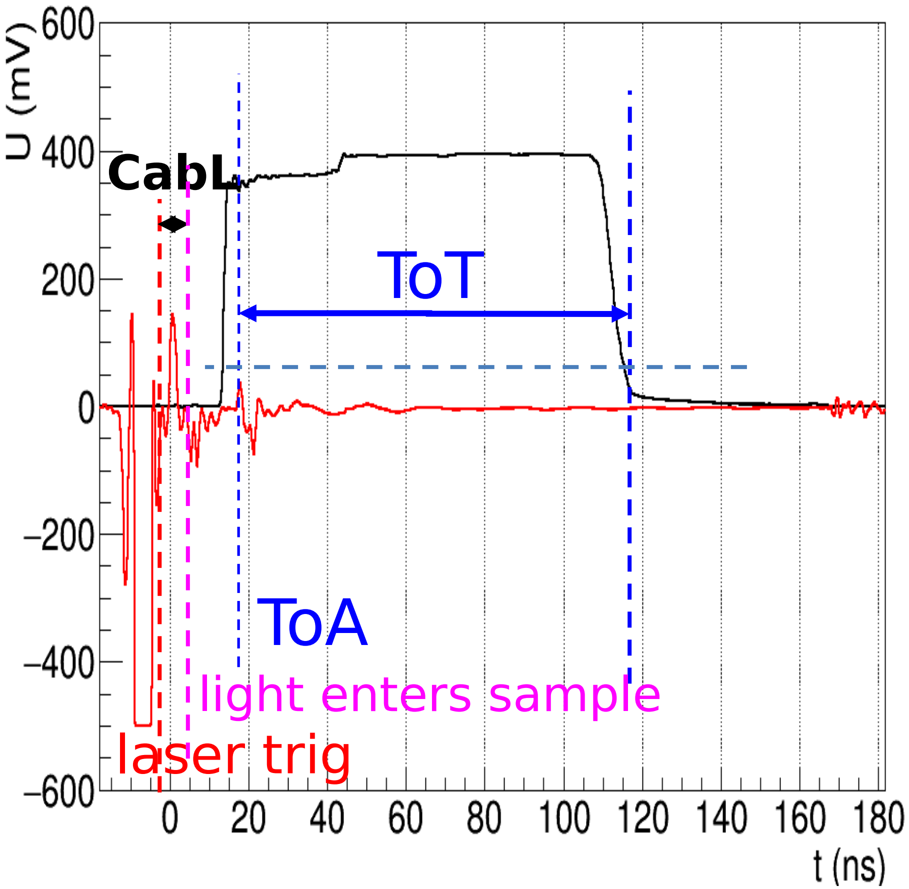






- Plotting the VT50 point of these S-curves as a function of injection amplitude gives us the gain of the pixel

Edge-TCT with active pixels



(Presented on behalf of Ljubljana)

- Motivation:
  - Passive devices enable measurement of **charge collection efficiency (CCE)**, but **in-time efficiency** is also important for real application
  - Smaller signals on pixel edges larger time walk
  - Edge-TCT with active devices allows measurement of **time walk** dependence on position within pixel

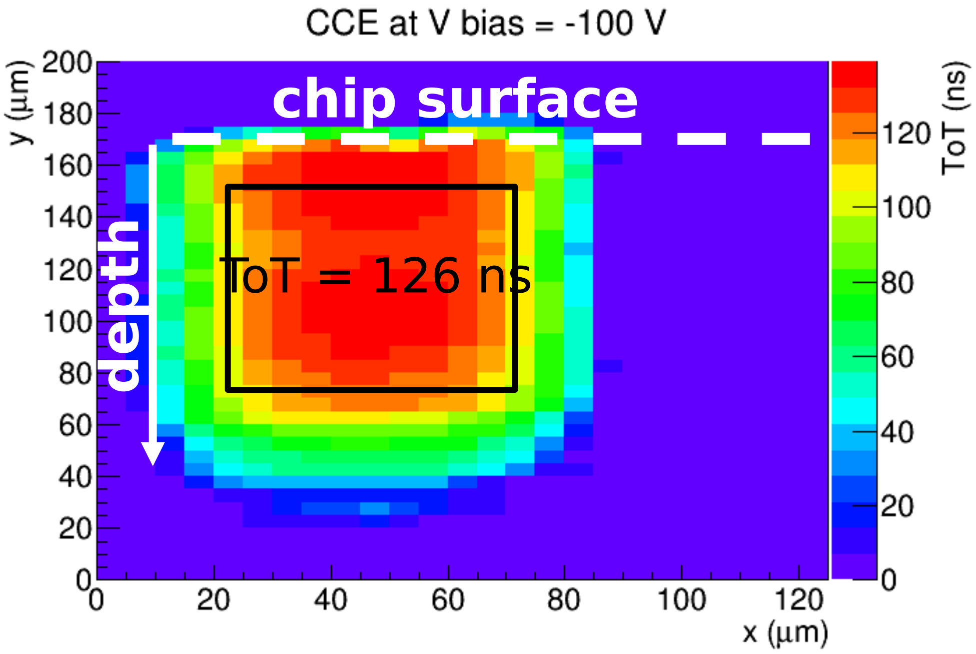
Method:

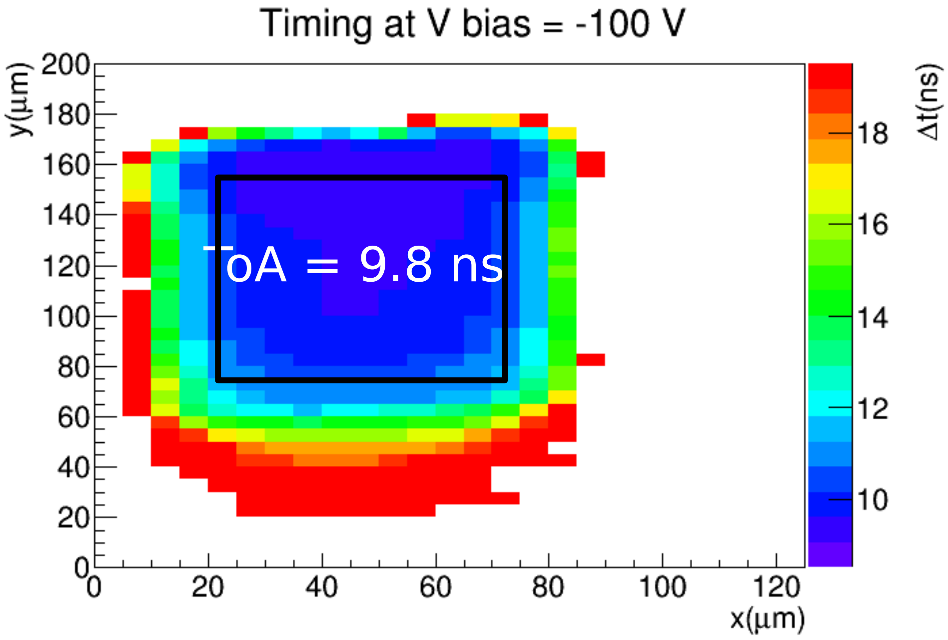
- Acquisition triggered by laser driver output, adjustment for **cable and fibre length**, light hits the sample at t=0
- Measure **Time of Arrival (ToA)** and **Time over Threshold (ToT)** of the in-pixel comparator output
  - ToT – signal size
  - ToA – time walk information
- Change signal size by varying laser power

Samples

- RD50-MPW2 W11 (1.9 kOhm cm)
- Unirradiated and 5e14 neutrons (TID 0.5 MRad)

Edge-TCT example





- Example of CCE and timing measurement
- Evaluate average ToT (left) and ToA (right) in a volume 50 µm x 80 µm (W x H), starting 20 µm below surface

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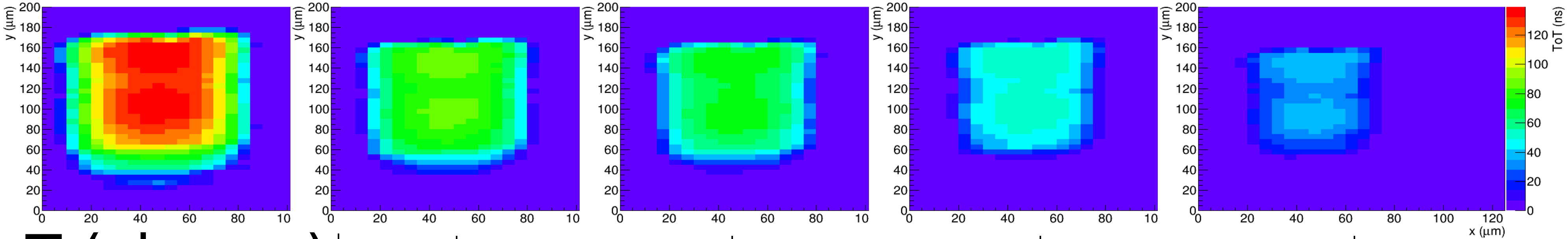
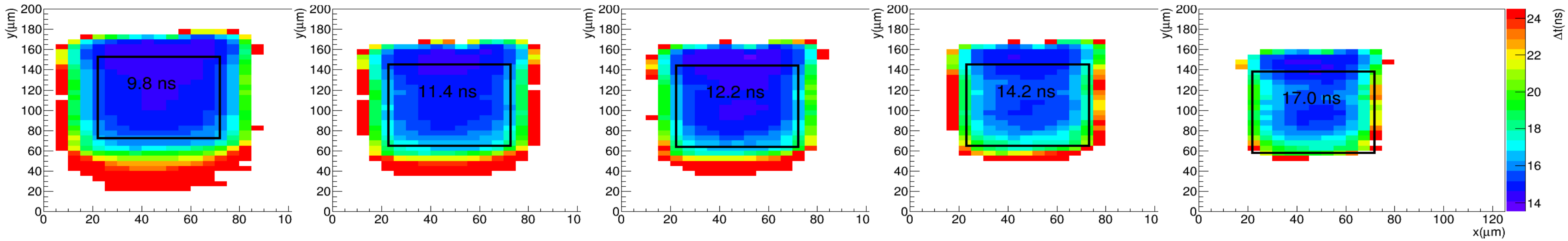
CCE and timing for different laser power (5e14)

Reducing laser power



ToT (charge)



ToA (time walk)

Reducing laser power

- Reducing laser power gives lower charge collection, lower ToT and greater ToA/time-walk

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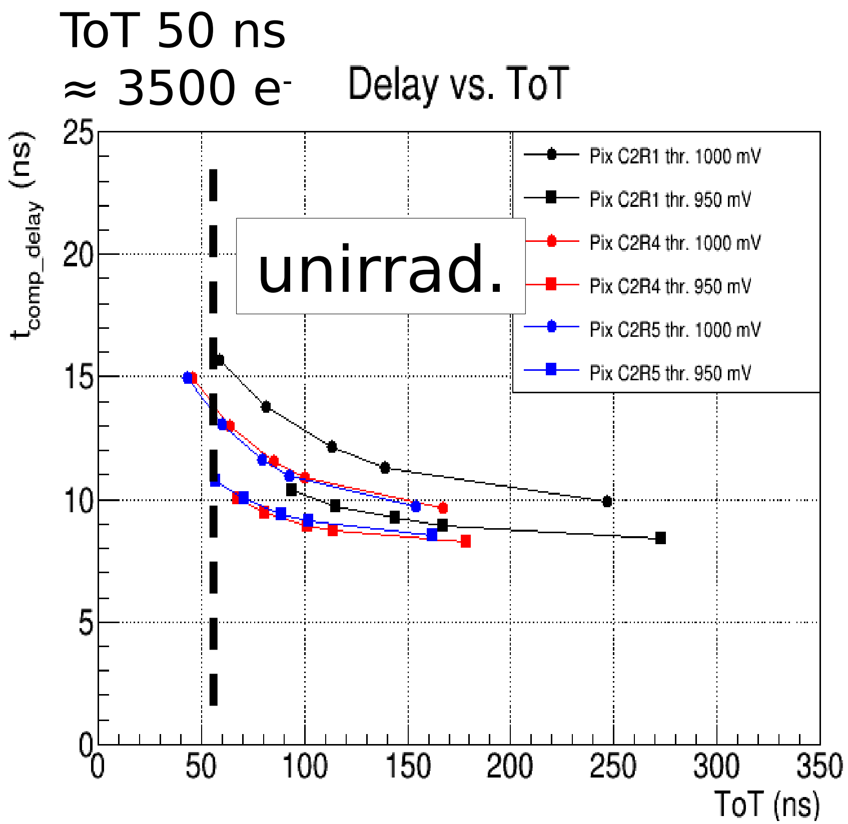
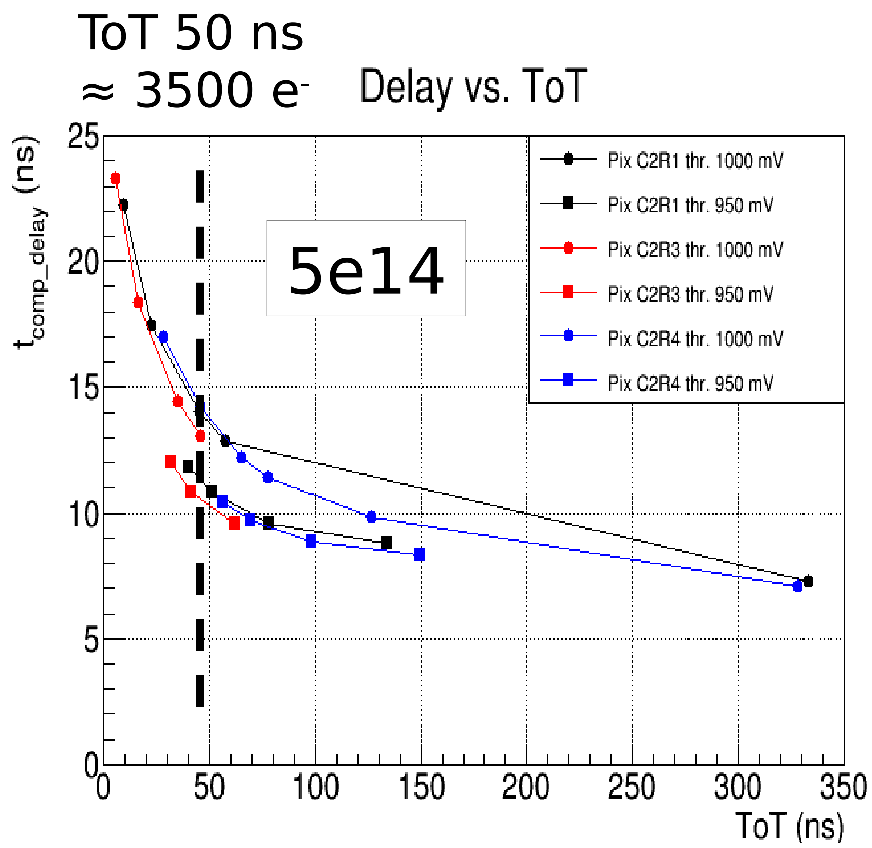
Time walk Edge-TCT



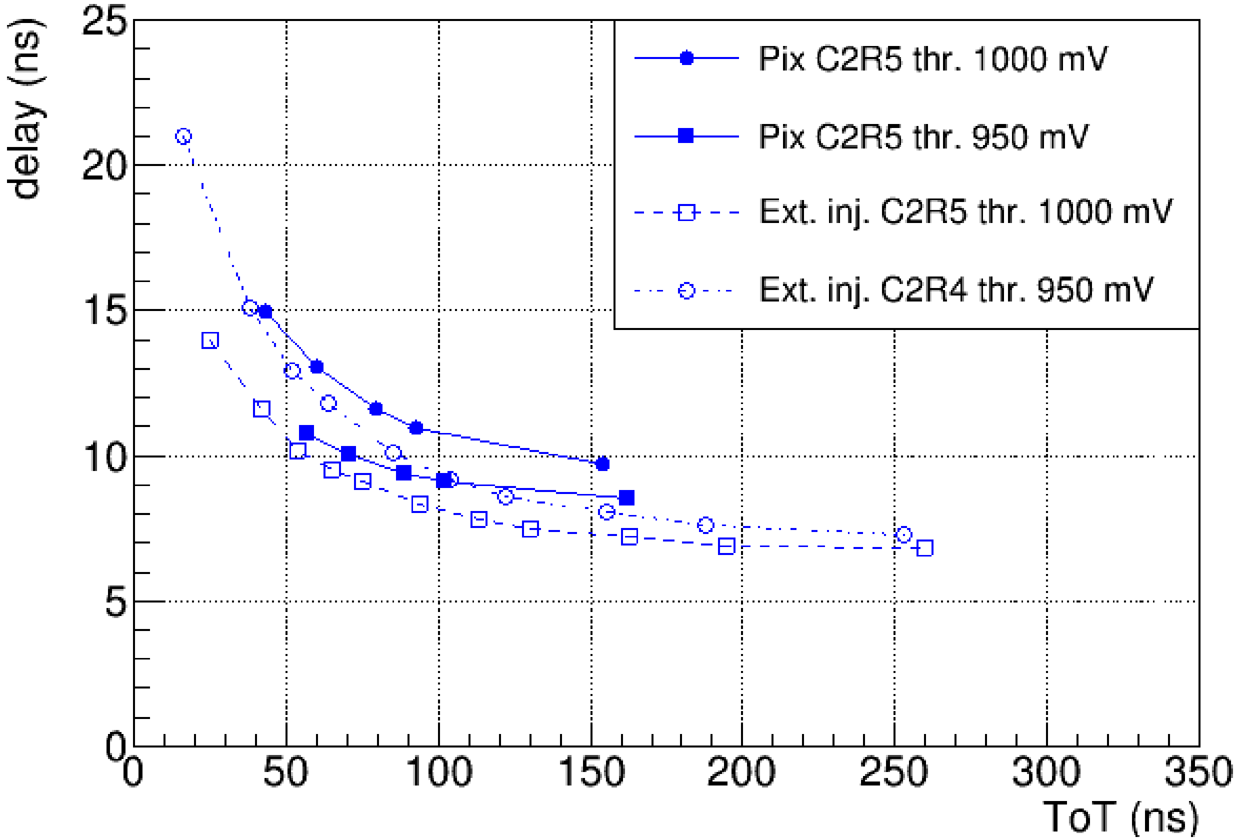


- These plots show the information in the previous slide represented in a different way – we can see from these plots that a large ToT gives a lower time-walk

- Edge-TCT time walk measurement in three different pixels before and after irradiation
- Time walk increases with higher threshold (as expected)
- Significant pixel-to-pixel variations (manufacturing variations)
- Time walk similar before and after irradiation
- Measurements in low ToT range limited by noise level

(Presented on behalf of Ljubljana)

Time walk – comparison between Edge-TCT and external injection



- This plot shows the result of cross checking the laser injection method with a charge injection performed with a voltage source
- Cross check – direct charge injection into front-end via 2.8 fF injection capacitance
- Both methods in agreement within 1– 2 ns

(Presented on behalf of Ljubljana)

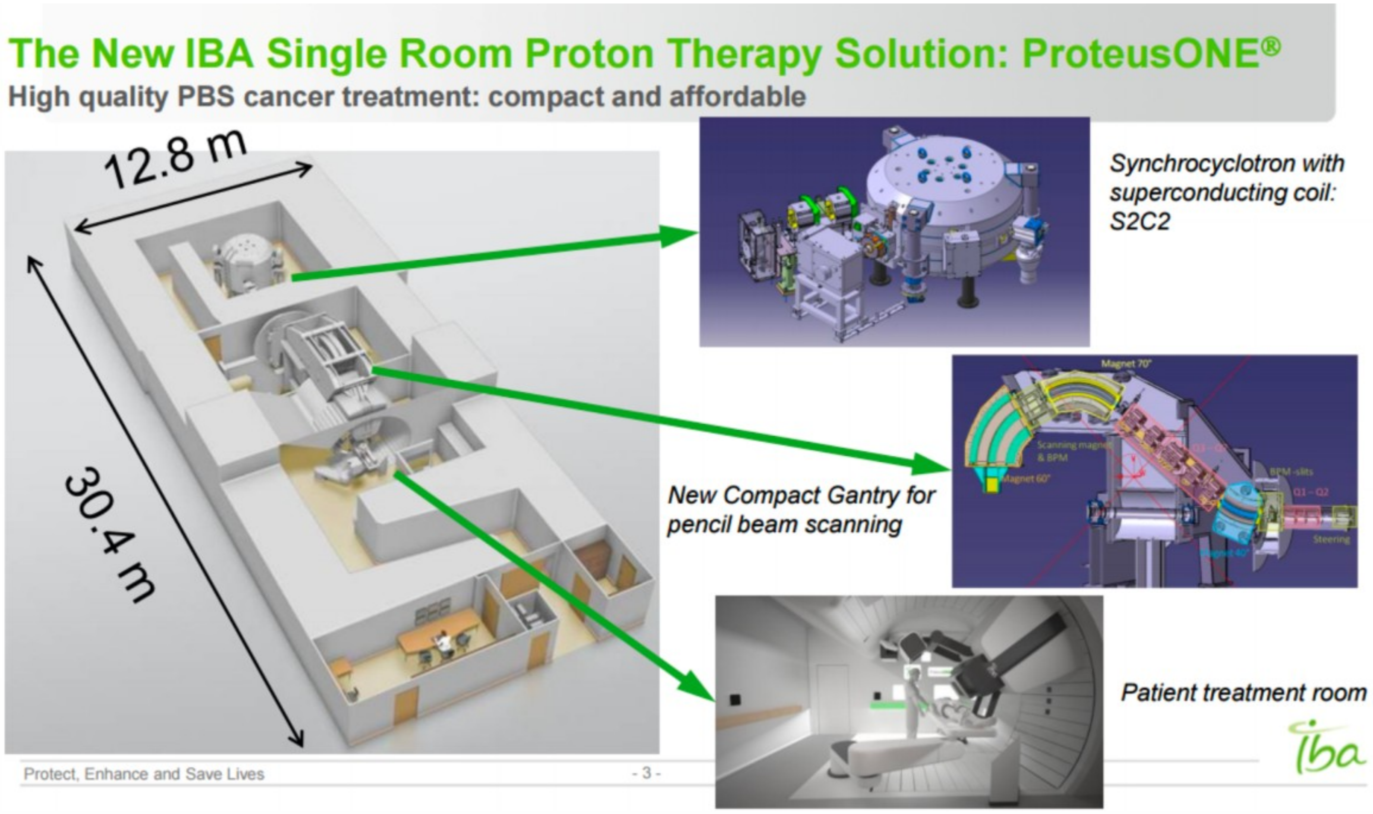
NORTHUMBRIA RUTHERFORD CANCER CENTER

Each Rutherford Cancer Centre Contains an IBA Proteus One

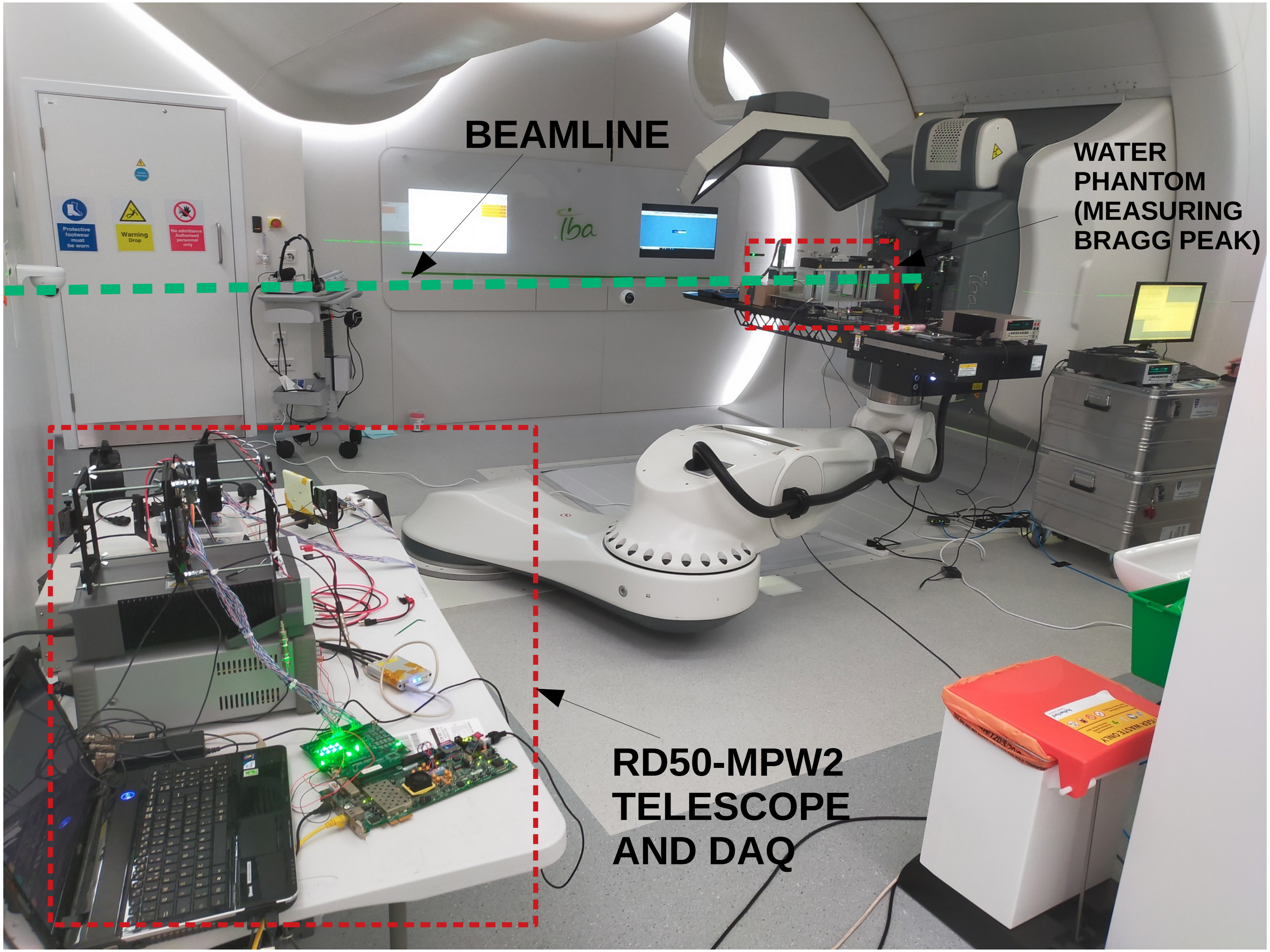
IBA Proteus One – S2C2 Synchrocyclotron characteristics

- Protons delivered in bunches with
- 1KHz repetition rate

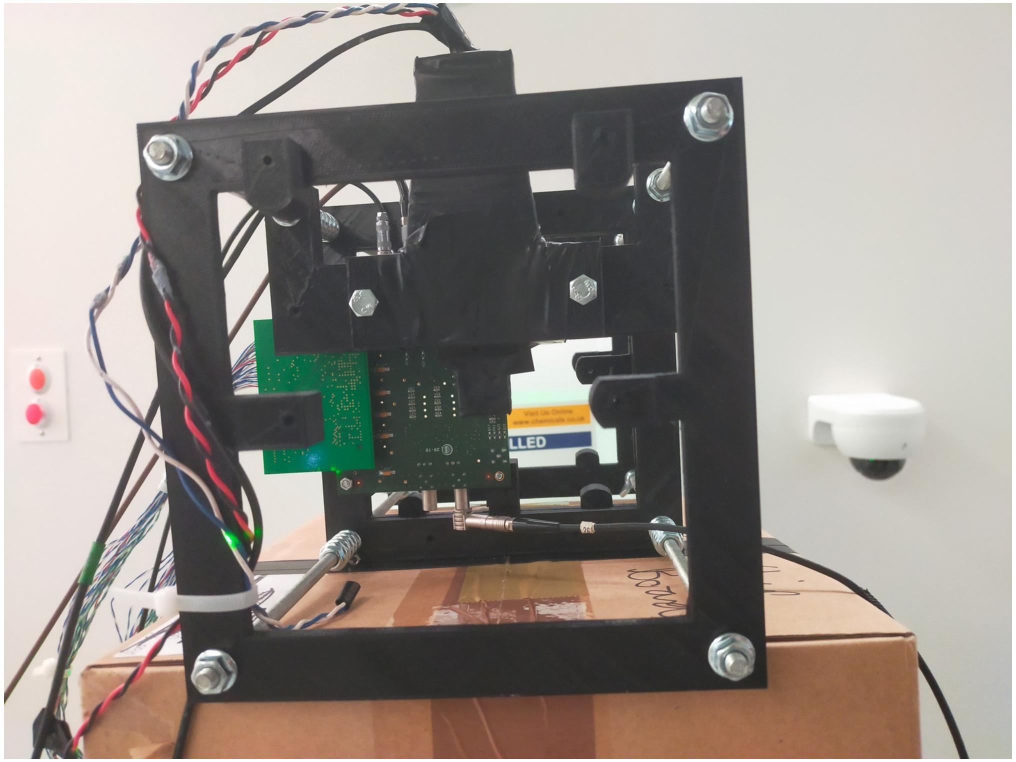
- Bunch length – 10uS
- Min. Protons/s – 10^7
- Min. Protons/bunch – 10^5
- Beam energies from 70-229 MeV
- Min. beam spot size – 3.5mm radius
- Gantry angles – 0 to 270 deg

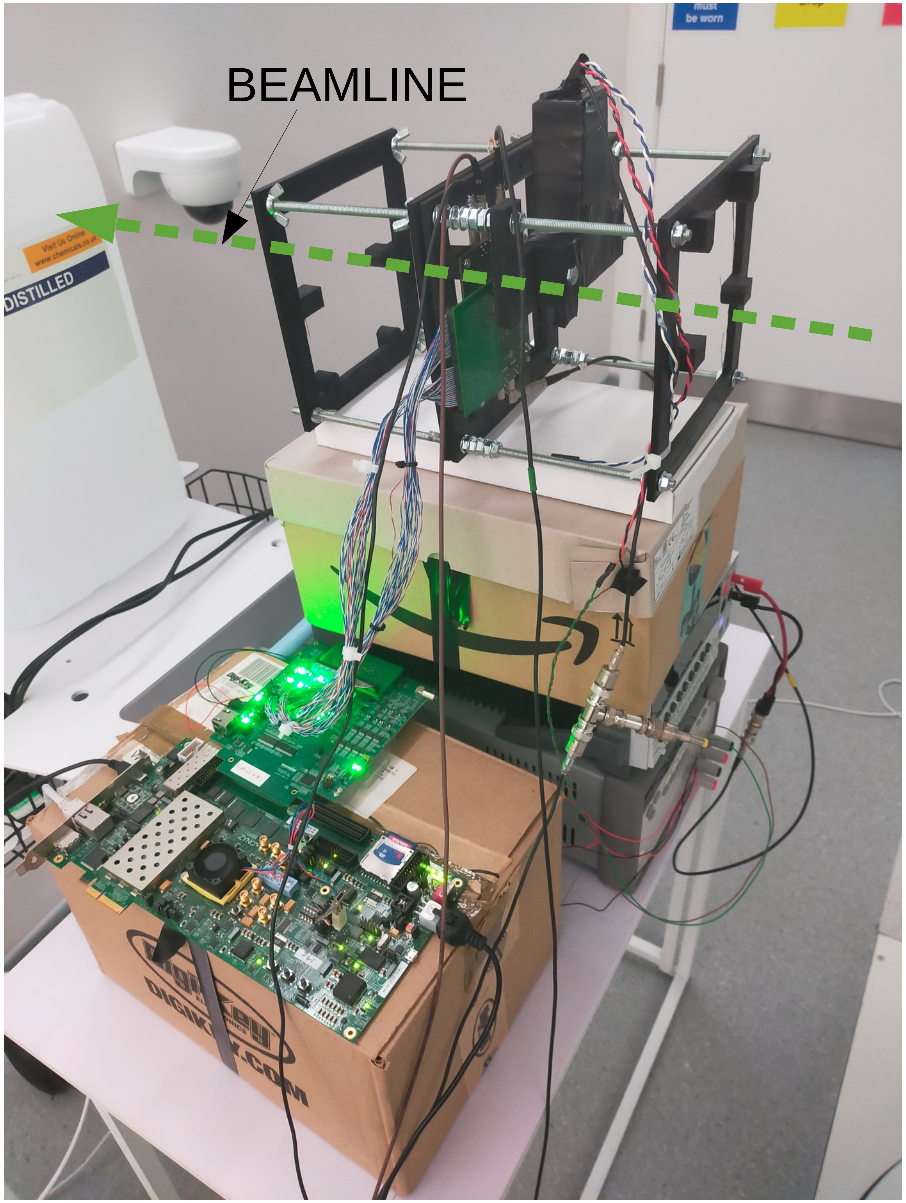


PROTON BEAM TREATMENT ROOM



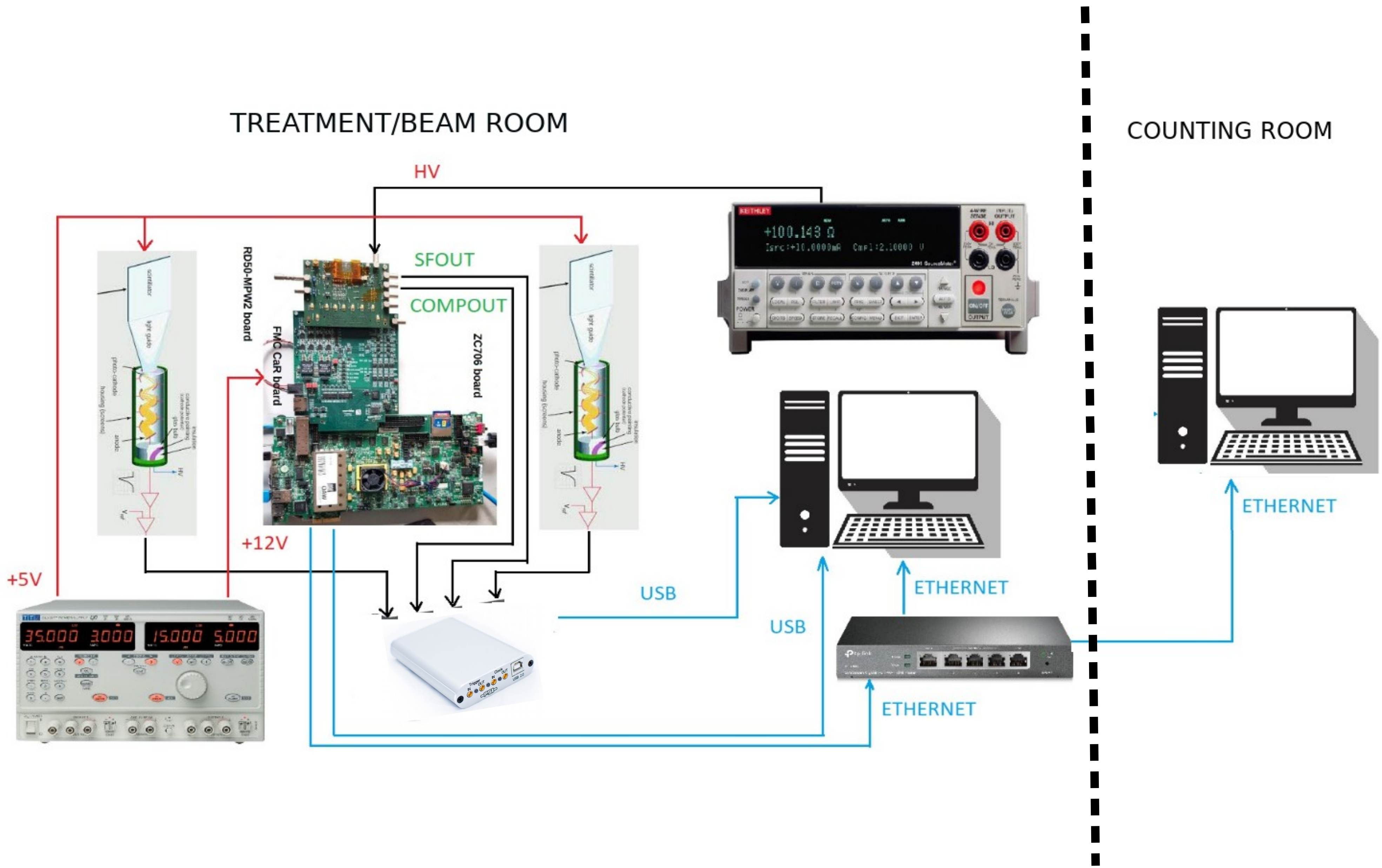
MPW2 TELESCOPE





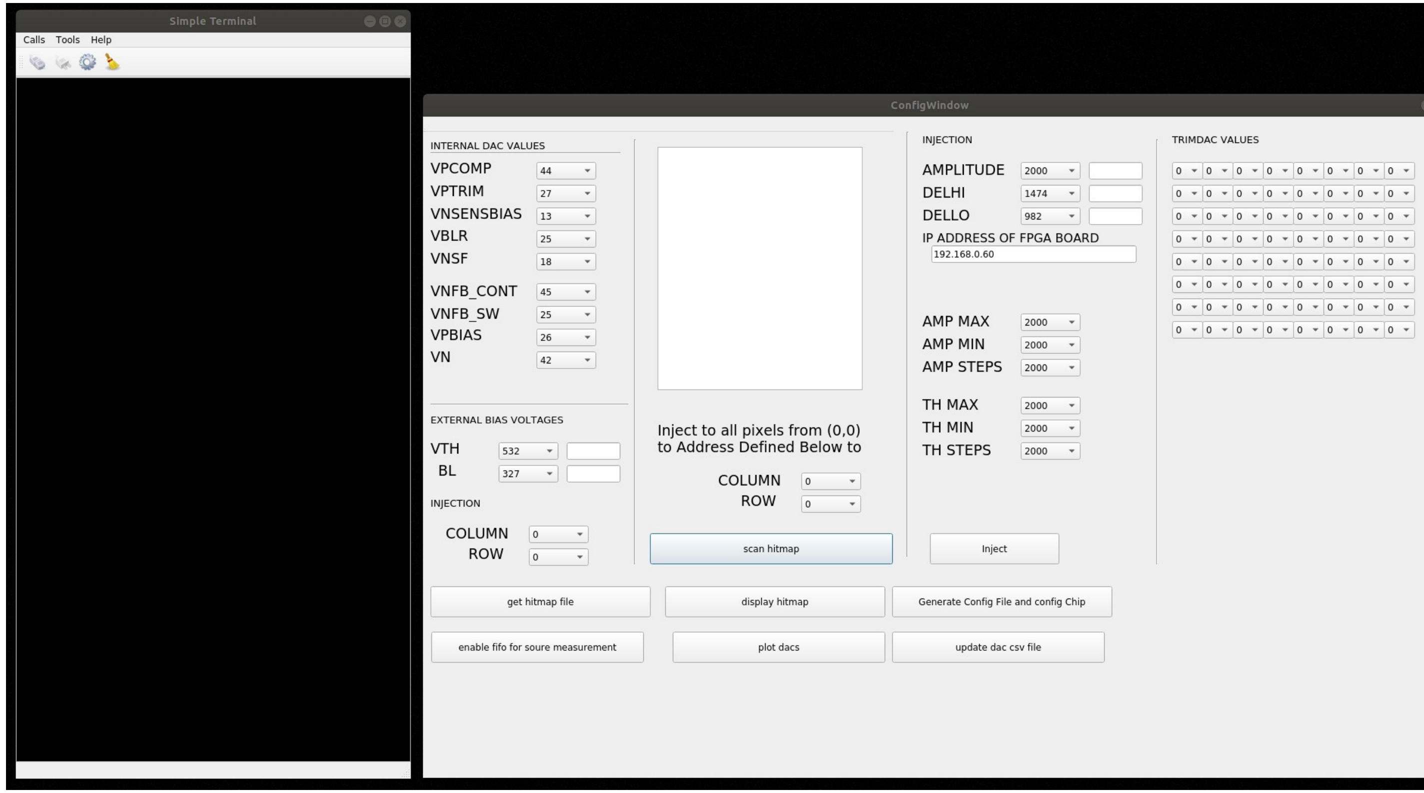
- These images show the RD50-MPW2 TELESCOPE in it's final position – moved directly in the beam line

RD50-MPW2 TESTBEAM – ACTUAL SETUP

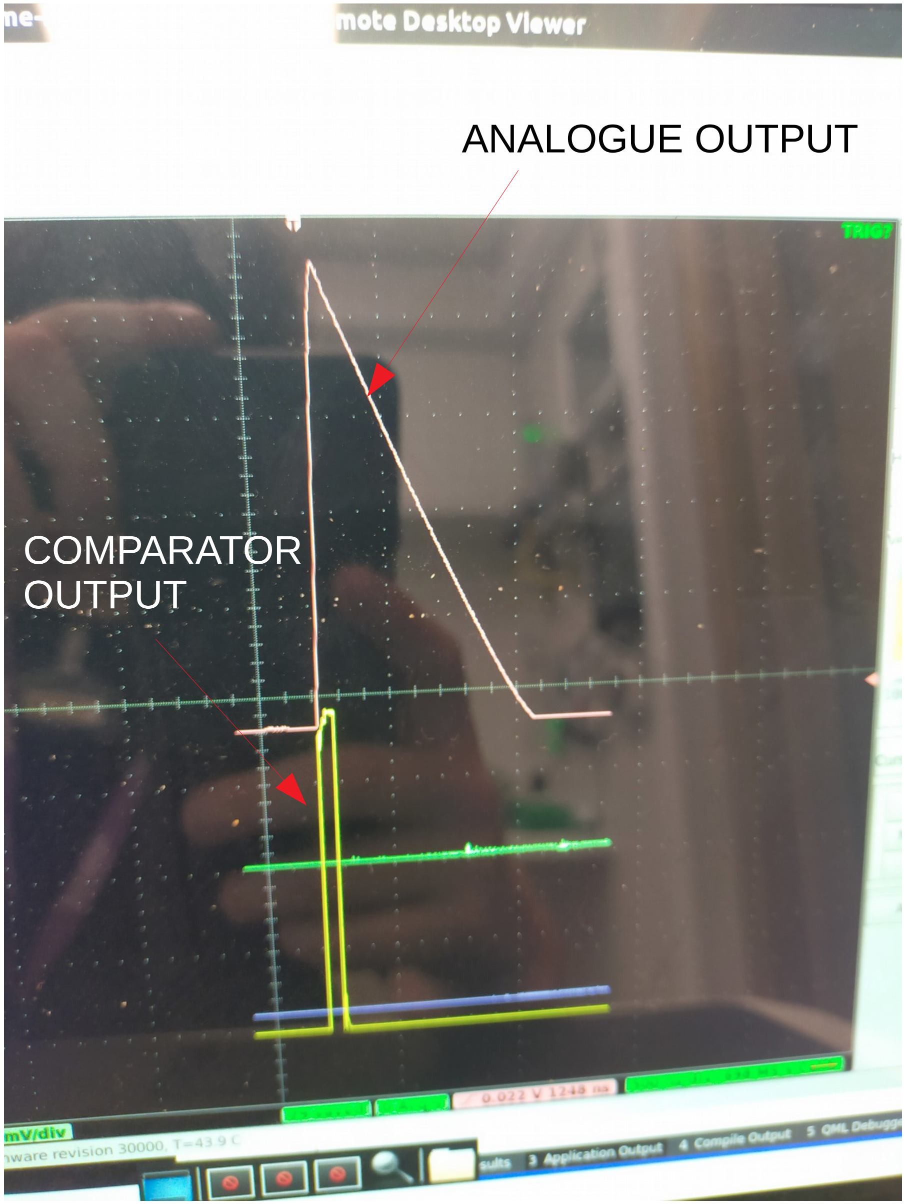


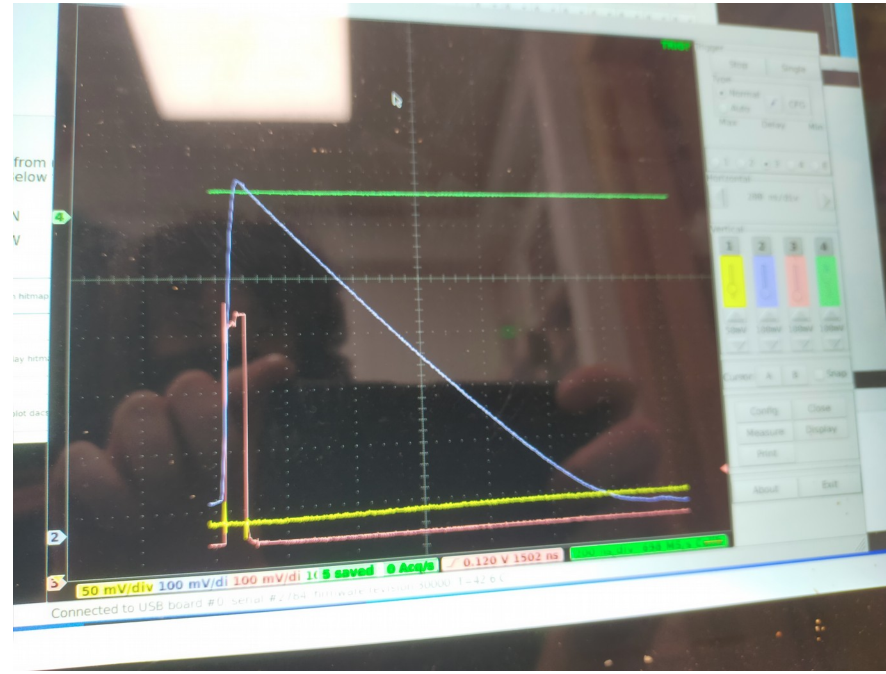
RD50-MPW2 TESTBEAM – Firmware and Software components

- Firmware in VHDL and C for the Xilinx ZC706 FPGA board – written by Helmut Steininger
- A modified version of the firmware allows the chip to be configured from a custom GUI via the CERN Caribou DAQ system
- GUI written in C++ and python (in use by several groups within the RD50 Colaboration)
- Analysis software in a combination of root and python



DAQ STAND

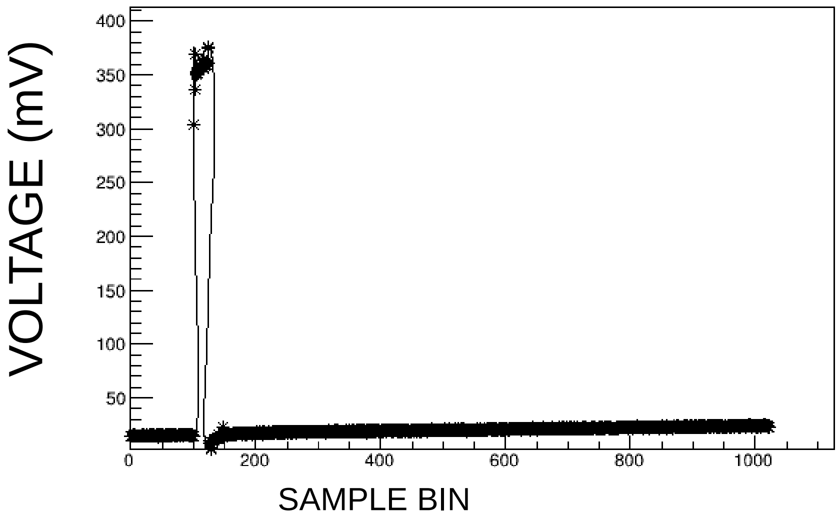




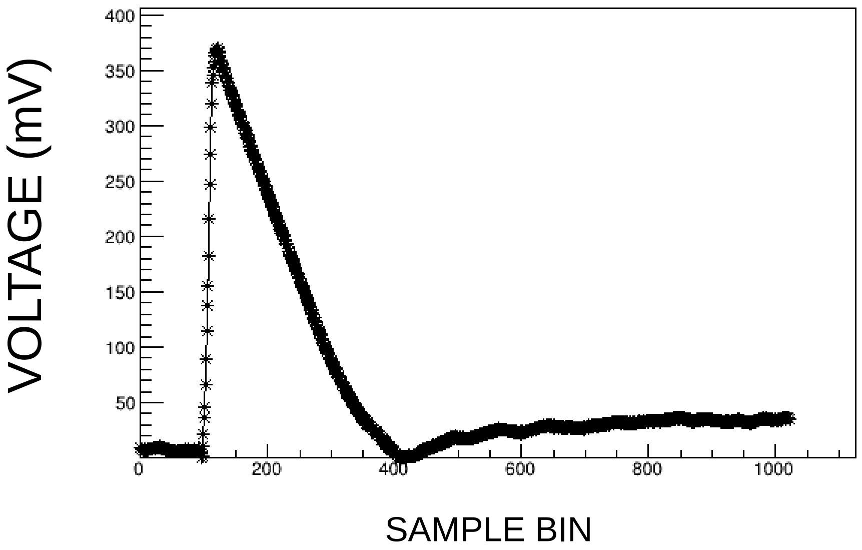
- These images are just to illustrate the shapes of the initial signals recieved
- Good signals for both switched reset and continuous pixels
- Data taken initially for scattered protons (very low rate) – initially another experiment was measuring a bragg peak in a water phantom
- Data also take directly in the beam (extremely high rate) – Data for beam energies 70.2, 120, 150 and 200 MeV

PRELIMINARY RESULTS

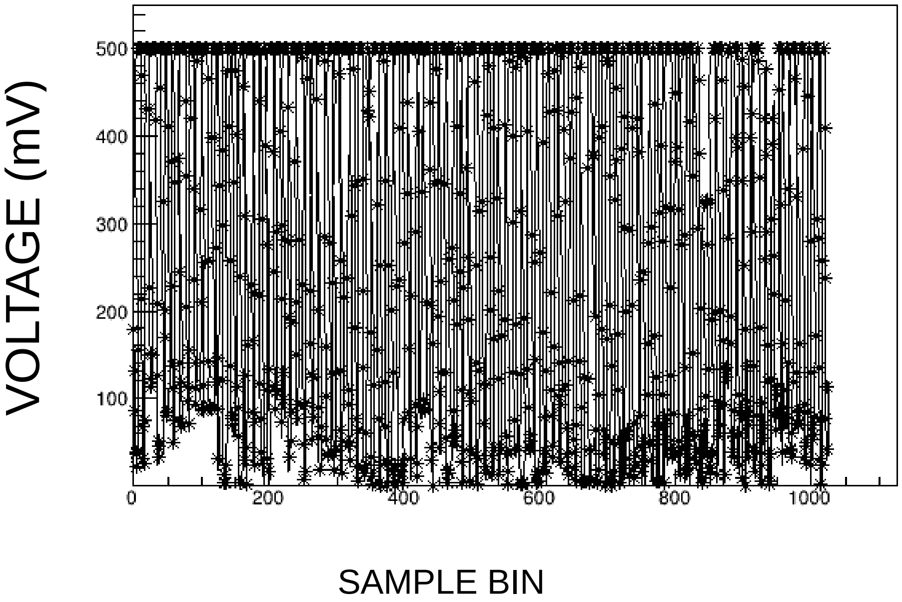
COMPARATOR OUTPUT



ANALOGUE OUTPUT



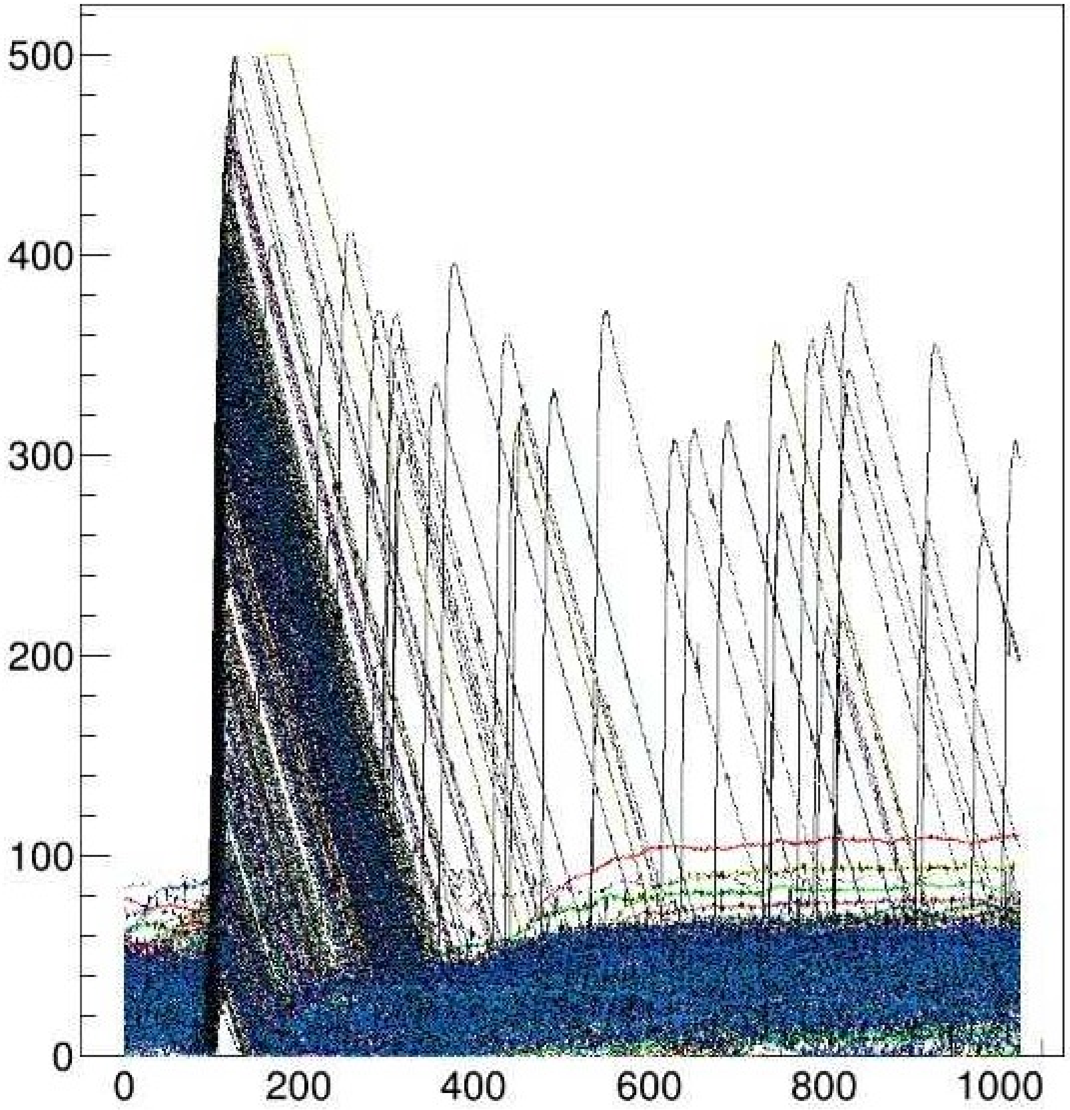
PMT OUTPUT



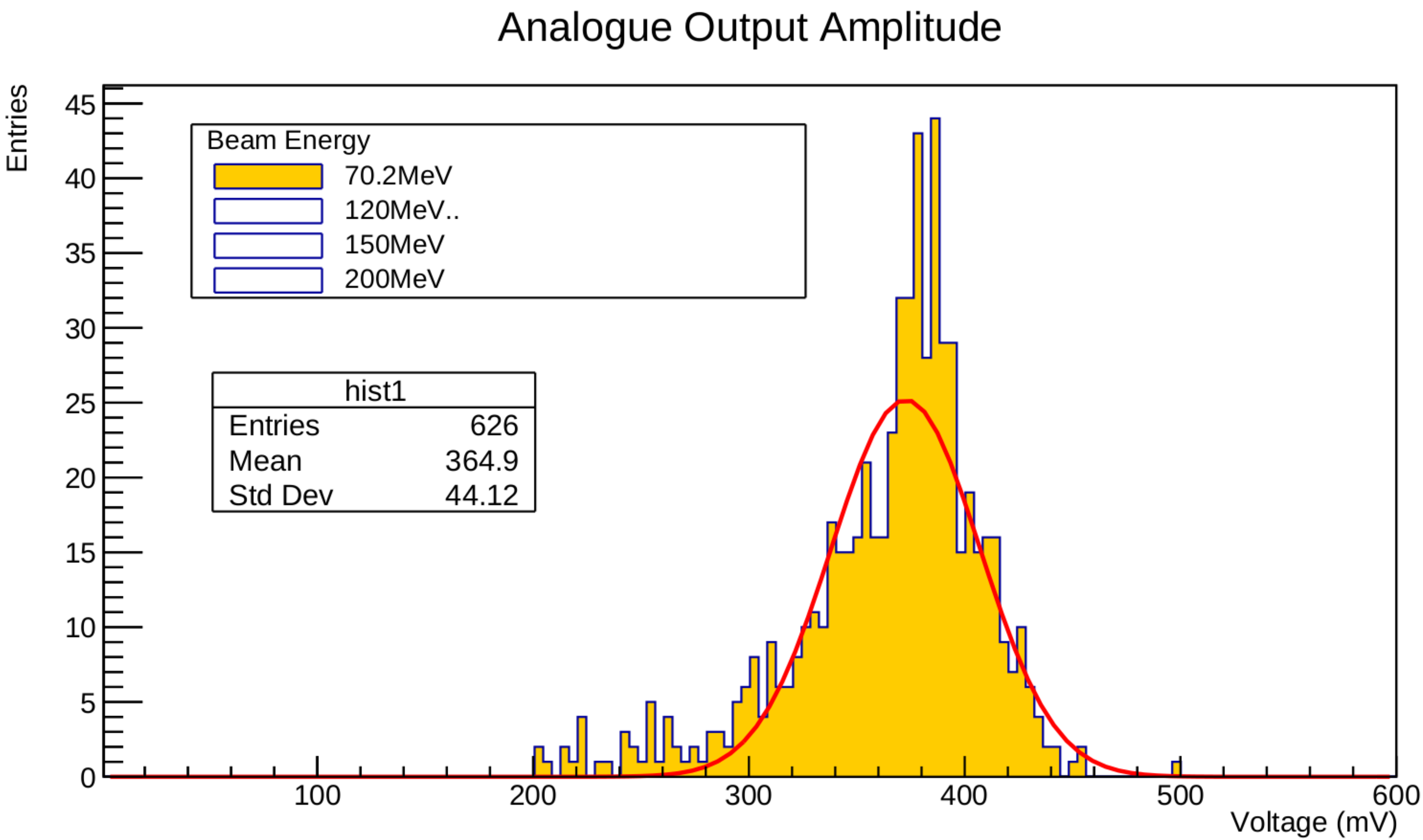
- Initial plots of XML data
  - Digital output from comparator
  - Analogue output from the AMUX/ABUFF
  - PMT output from direct beam

TESTBEAM RESULTS

- Here I am showing the raw data from which I will be extracting histograms for the various beam energies in the following slides
- 0.1nA Beam current
- Data aquisiton rate limited by DRS4 buffers
- 1000 Analogue output events plotted overlaid on top of each other

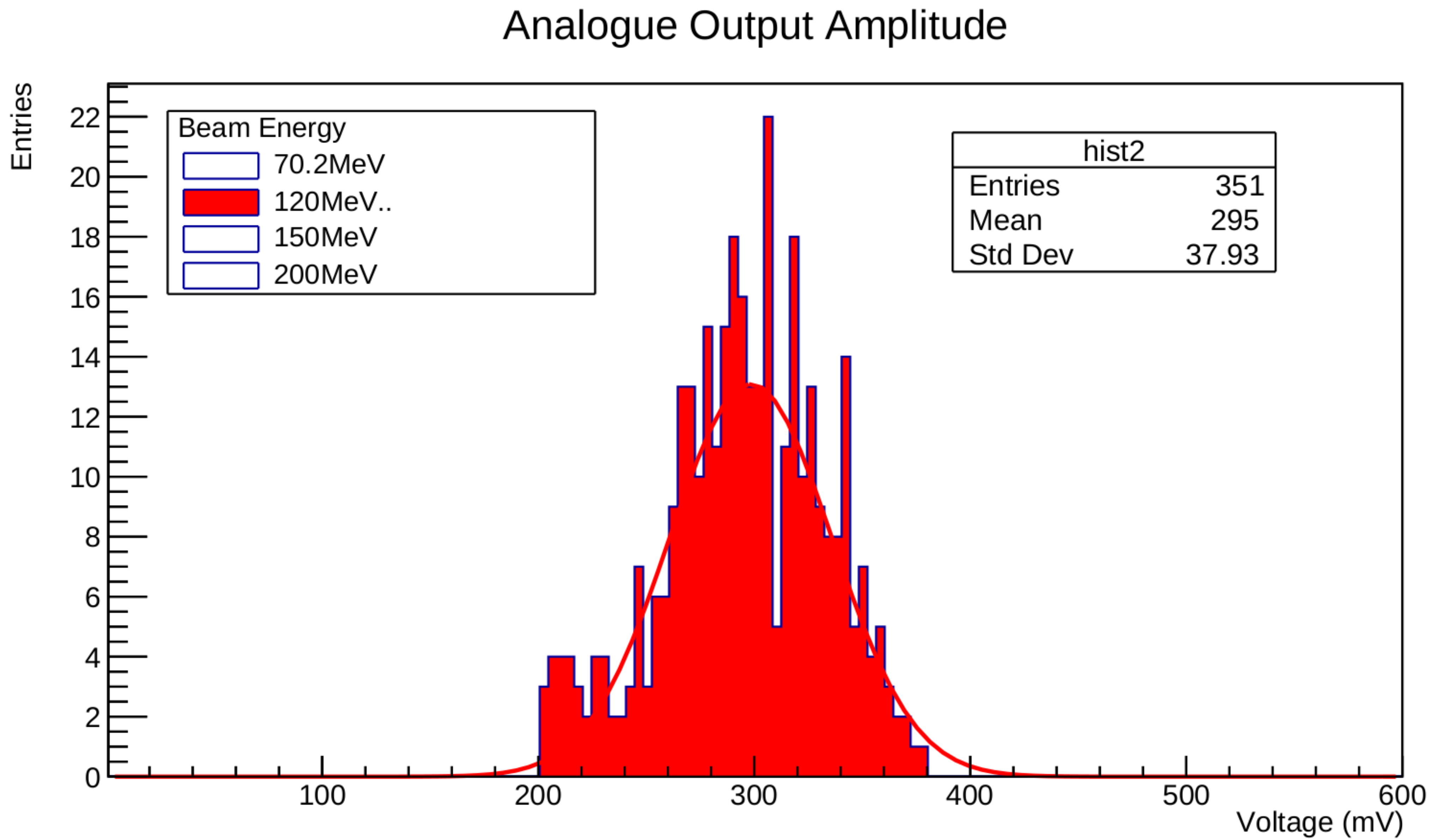


TESTBEAM RESULTS

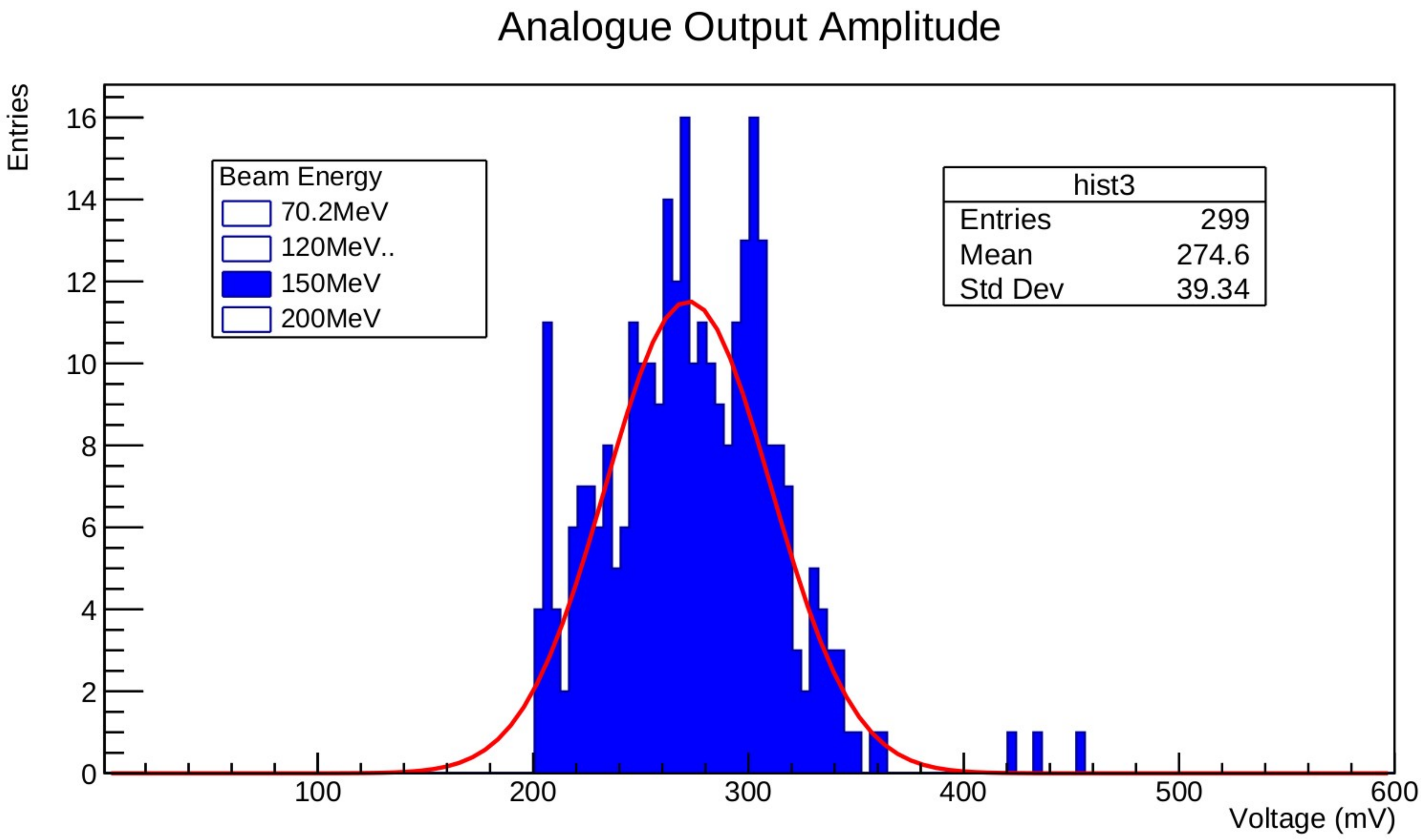


- The following plots show histograms of the analogue output amplitude for different beam engergies

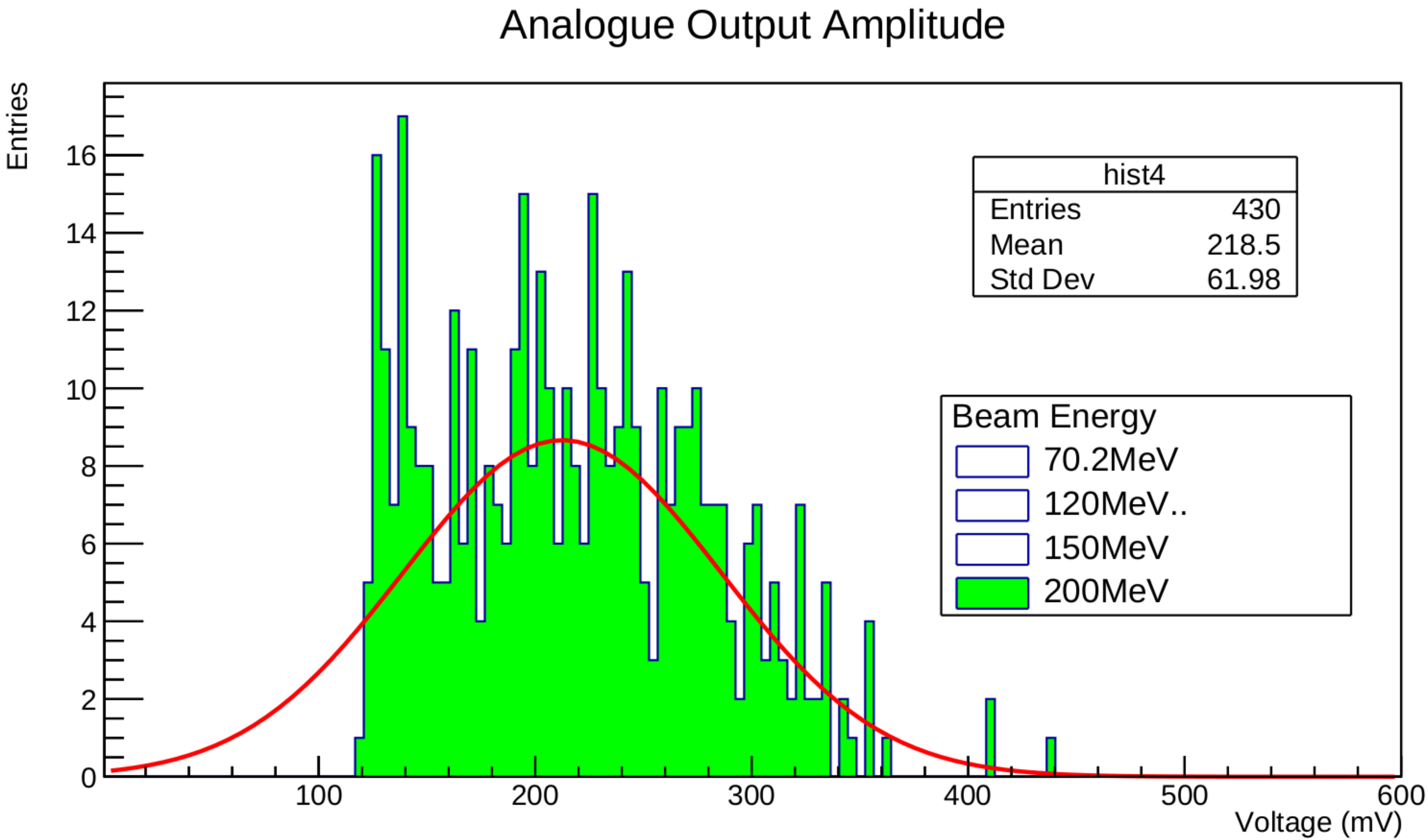
TESTBEAM RESULTS



TESTBEAM RESULTS

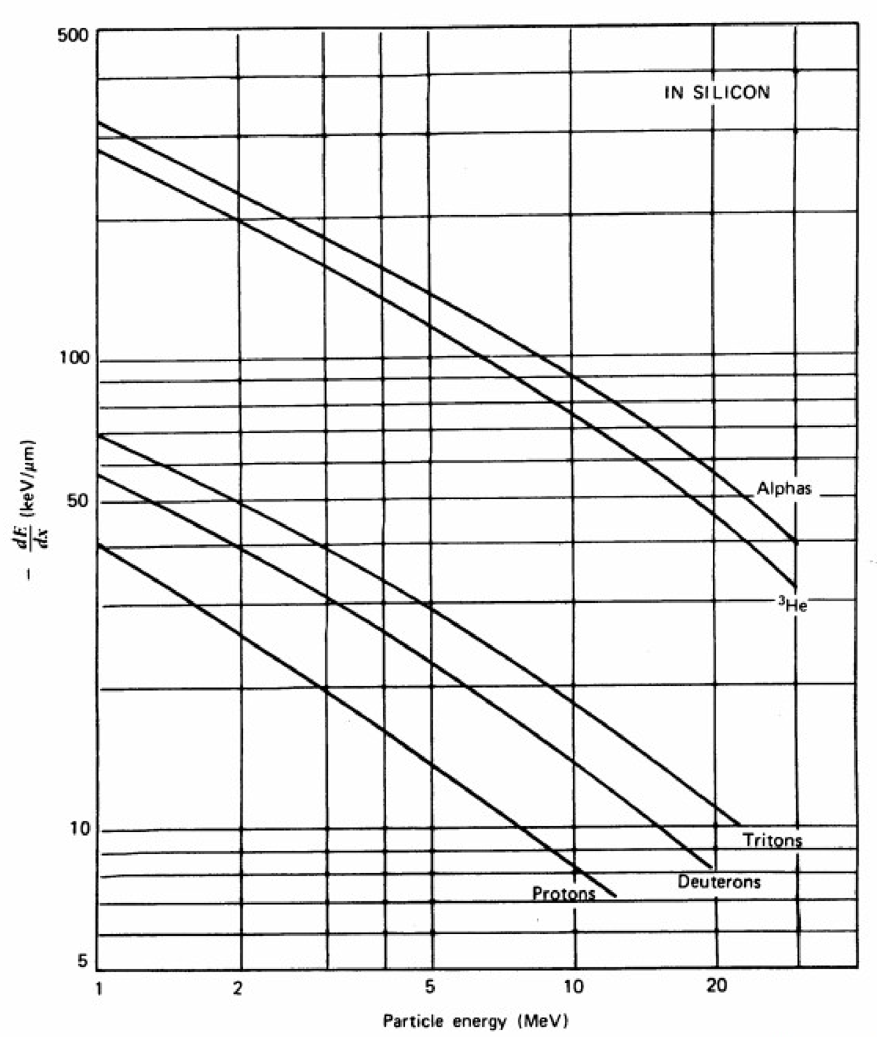


TESTBEAM RESULTS



TESTBEAM RESULTS

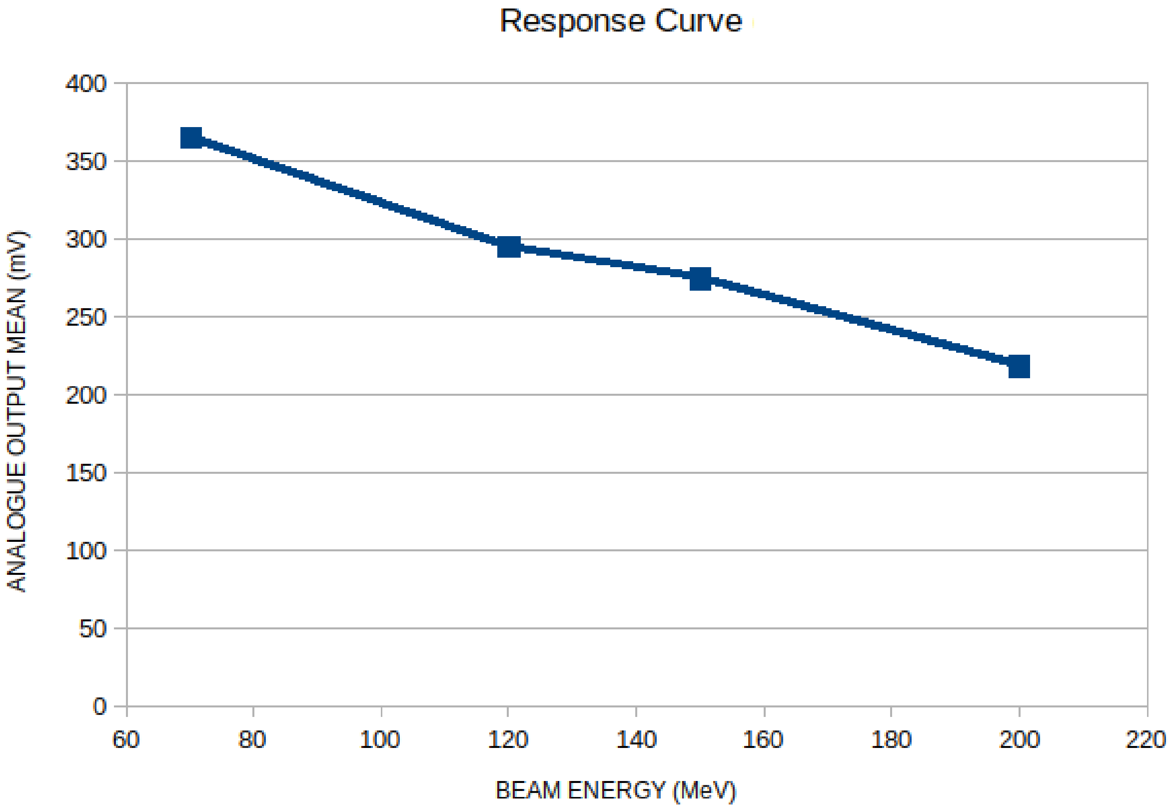
- The plot to the right shows what we would expect to see for protons in silicon



(from Knoll)

TESTBEAM RESULTS

- The results I have presented here today are the first testbeam to be performed by the liverpool HVCMOS group
- Initial results show increased charge deposition at lower beam energy as expected
- Further analysis to be carried out
- The chip, telescope and DAQ all performed well
- A future testbeam is planned for August to gather higher statistic



CONCLUSIONS

- First liverpool HVCMOS group testbeam a success
- Initial results show increased charge deposition at lower beam energy as expected
- The chip, telescope and DAQ all performed well
- S-curves/ noise and thresholds similar before and after irradiations to 5e14 neutrons
- Charge collection efficiency relatively uniform (reduced depletion depth due to acceptor removal)
- Time walk measurement: 7 – 25 ns in pixel center
- Future testbeam planned for August – valuable lessons learned from initial testbeam