Active Target Time Projection Chamber

A TPC for low energy nuclear physics

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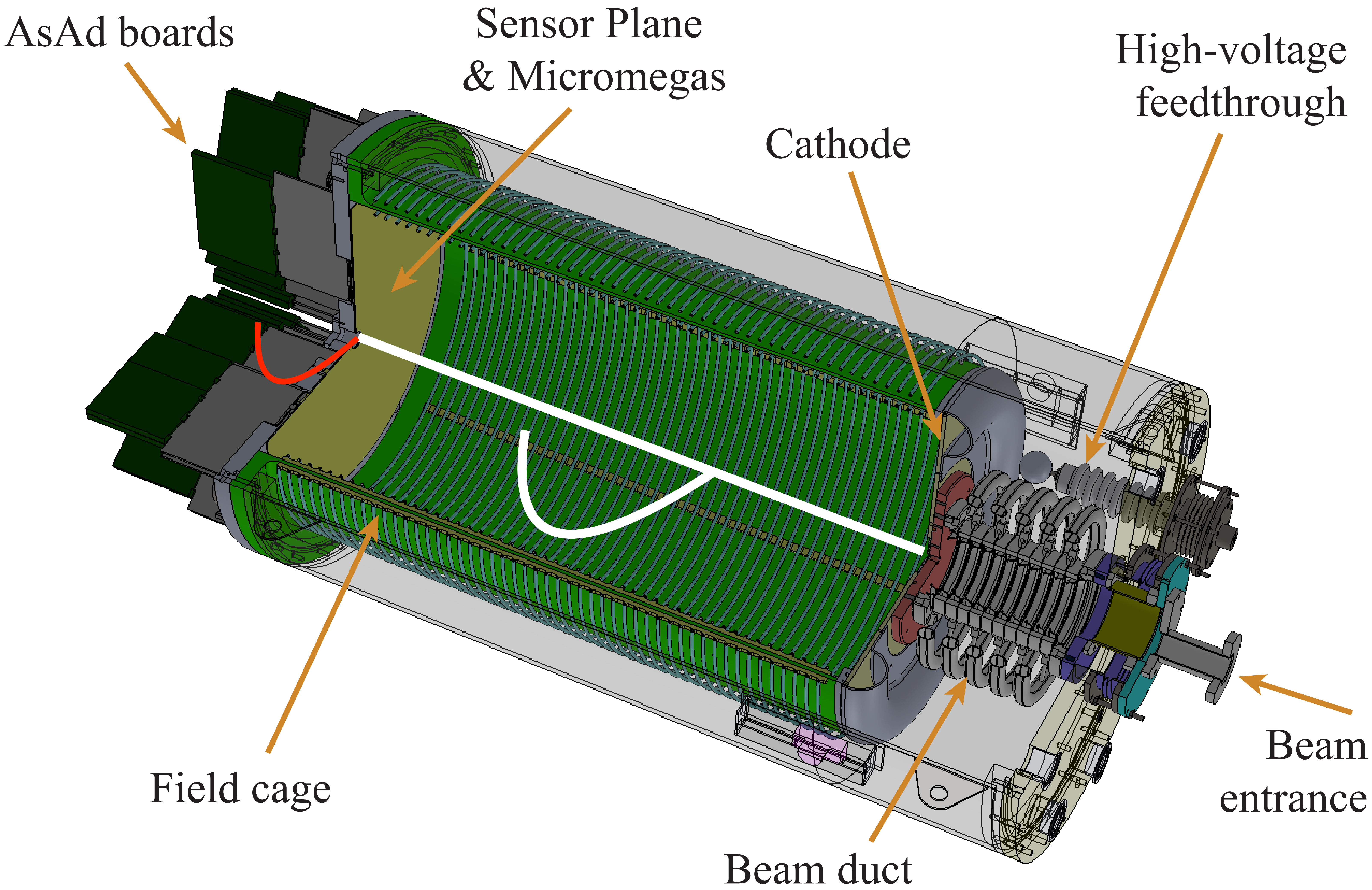
TPC for an active target

- Experimental conditions very different from high energy particle physics
  - Energy of recoil particles much lower
  - Most experimental information is contained inside the TPC
  - Beam particles are inside the active volume!
  - Choice of TPC gas dictated by the goals of the experiment
- Characteristics of a TPC built for an active target
  - Wide range of possible (preferably pure) gases
  - Wide range of energies deposited by particles
  - Trigger generation (selecting the events of interest) has to come from TPC
  - Data analysis requires new techniques: very wide variety of track shapes

The AT-TPC at NSCL

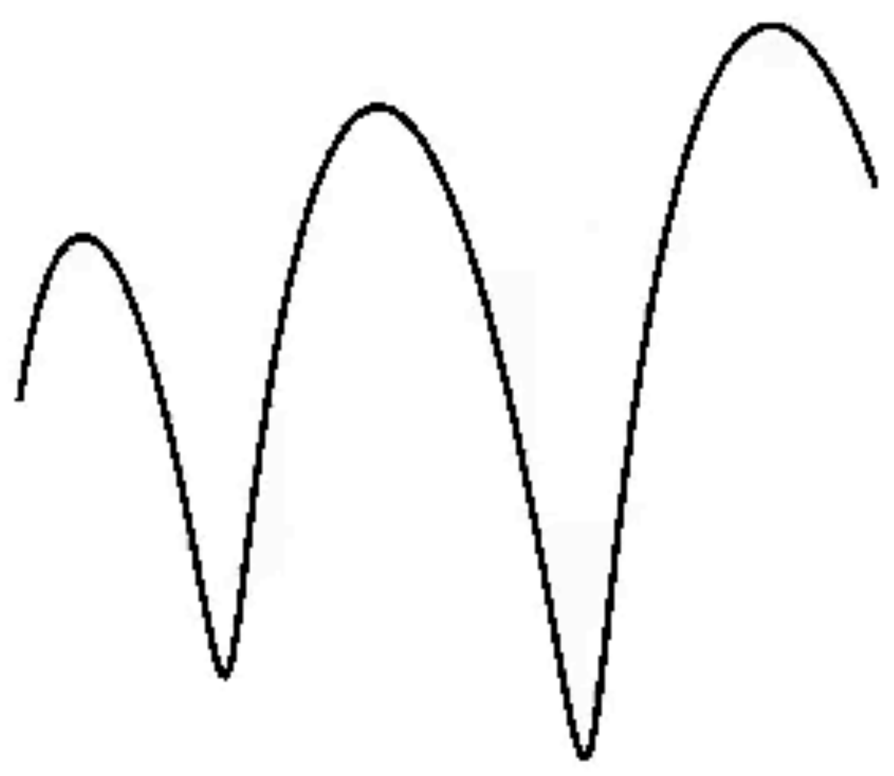
- Cylindrical volume
- 250 liters (1 m long by 55 cm wide)
- Oriented on beam axis
- Electrons produced in gas drift towards sensor plane parallel to beam direction
- Surrounding volume filled with insulator gas such as N_2



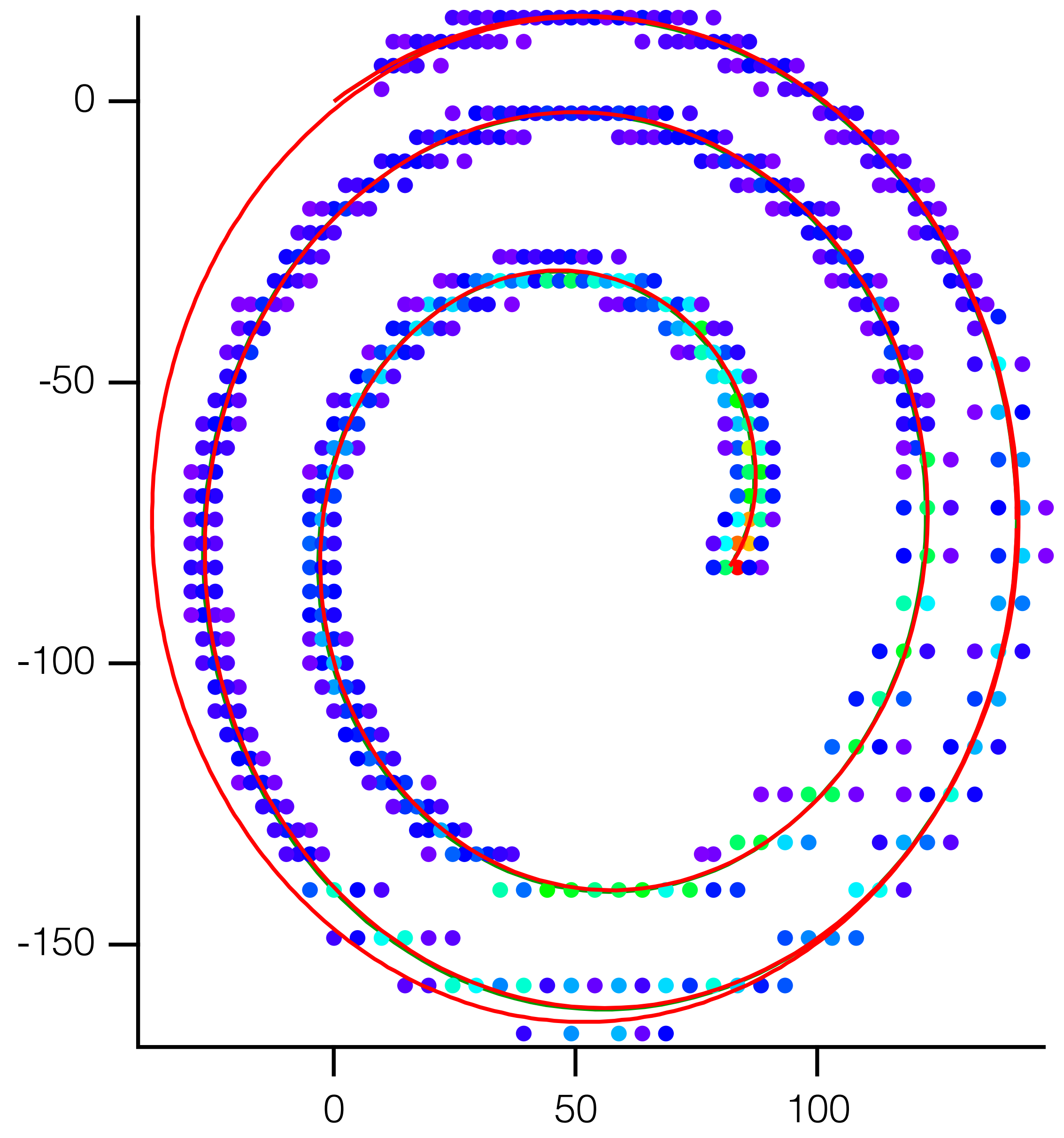
Axial magnetic field

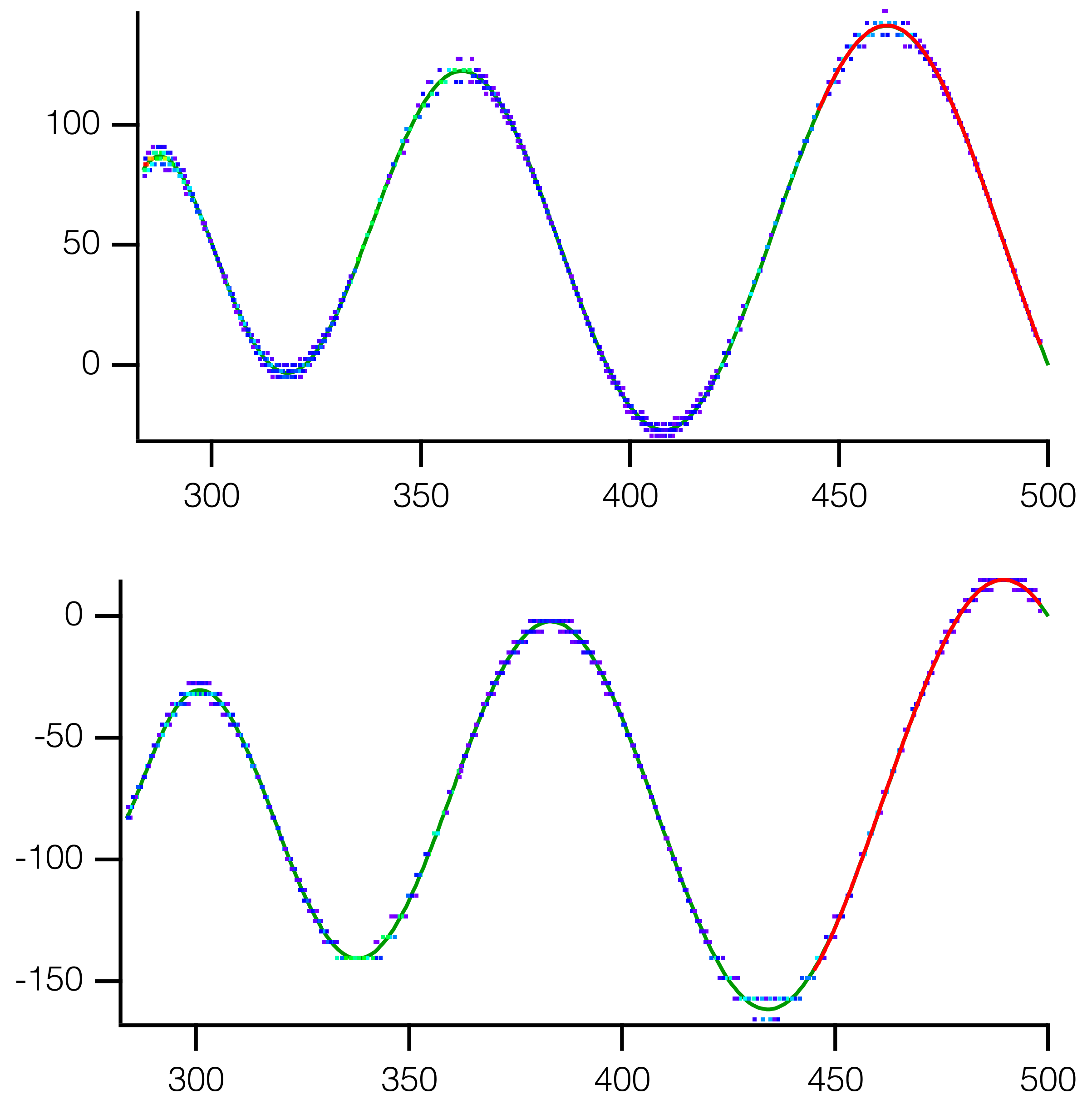
- AT-TPC detector placed inside large bore MRI solenoid
- SOLARIS solenoid can go up to 4 Tesla
- Curve trajectories of scattered particles
- Increase their trajectory length and measure their range
- Measure their magnetic rigidity

Spirals!



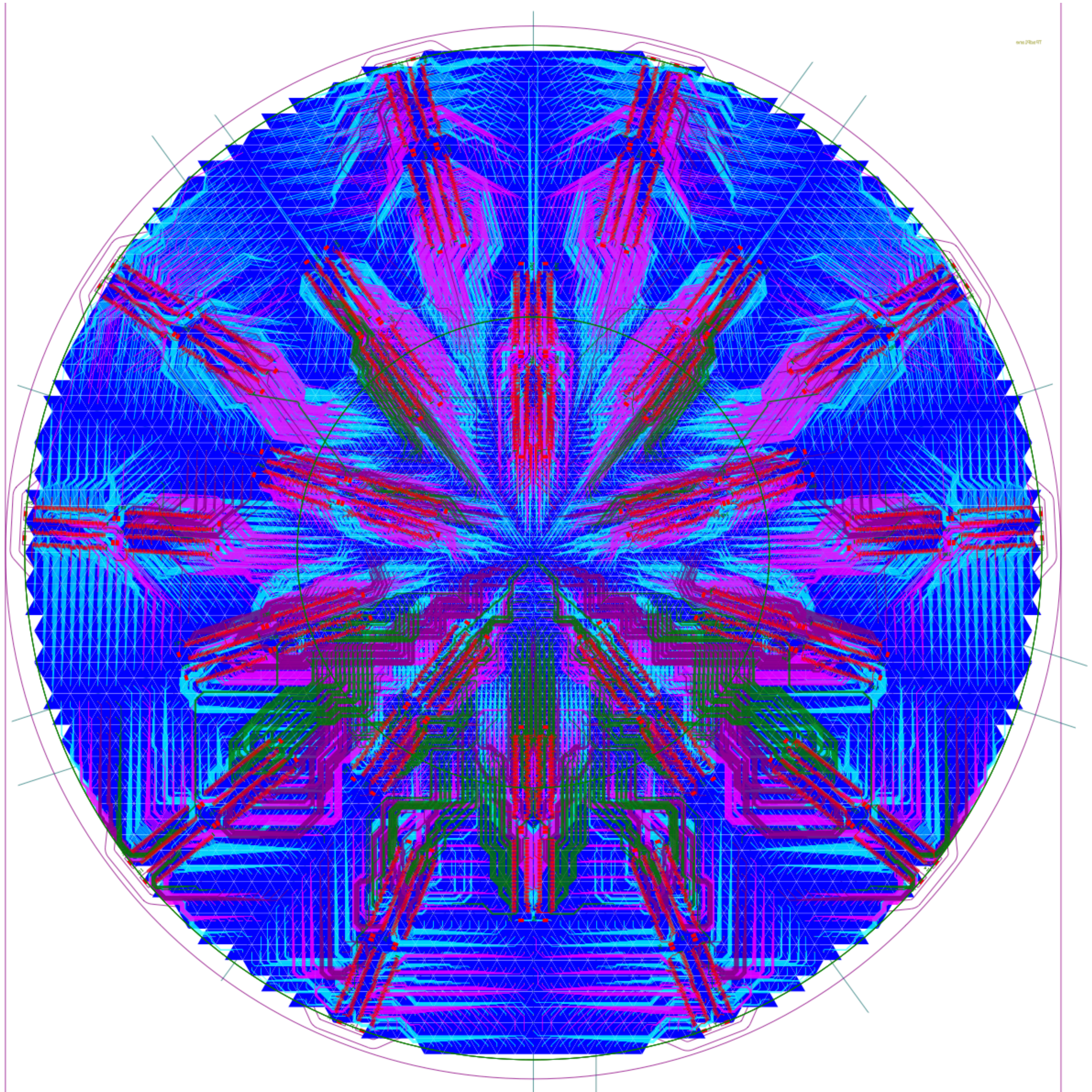
- Recoil particles slow down in the gas
- Radius of curvature decreases with velocity
- Resulting trajectory is a 3D spiral
- Shape of spiral depends on many parameters (mass, charge, …)
- No analytical formula to describe it
- Calculation has to be performed using numerical integration (Runge-Kutta)





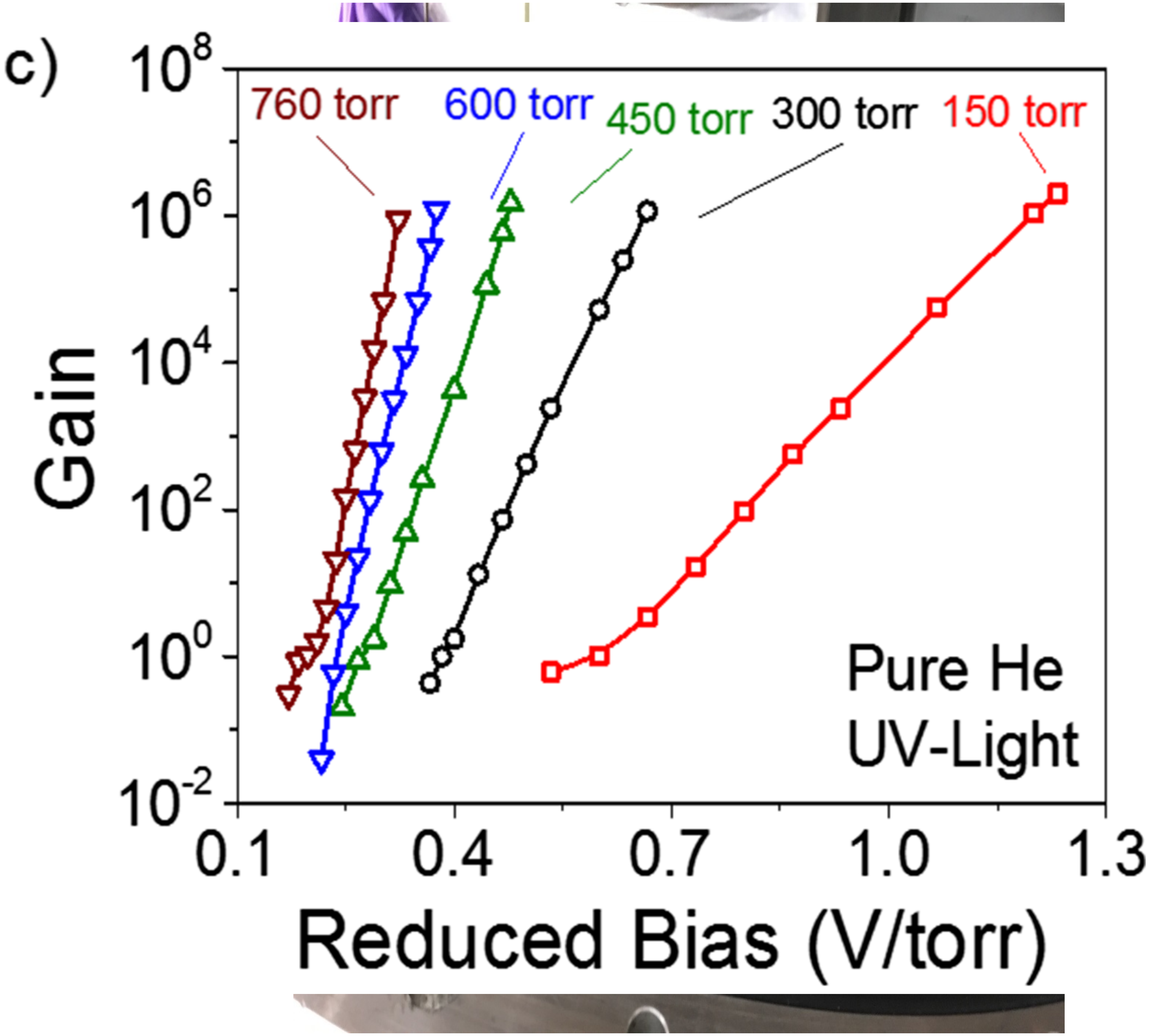
Sensor plane

- Mosaic composed of 10,240 triangular pads
- Smaller size triangle region in center to increase granularity
- Pad sizes of 0.5 and 1 cm
- Routing to connectors realized on 8-layer Printed Circuit Board
- Favorite picture of Michelle!



Electron multiplication for pure gases

- Sensor plane equipped with Micromegas
- Stack of two THGEMs used as electron "preamplifiers"
- Electron gains up to 10^6 obtained in pure He gas from 150 Torr to 1 atm

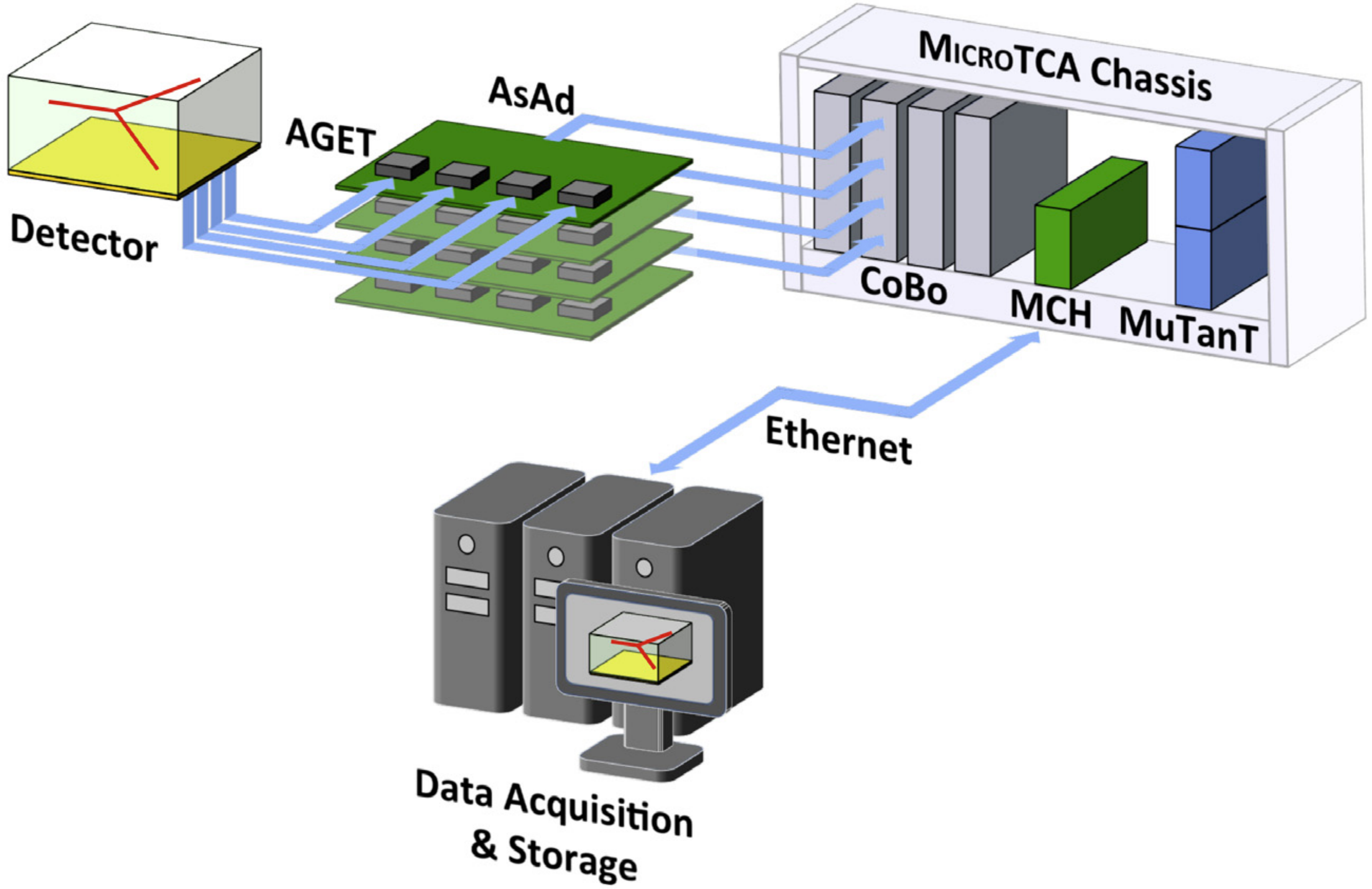


Requirements for electronics

- Requirements
  - Time evolution of signals contains essential information: record traces
  - Large number of pads: cost per channel should be minimized
  - Huge amounts of data: parallel architecture and data reduction are paramount
  - Active Targets without trigger detectors: good trigger generation
- Technology choices
  - Analog memory arrays (Switch Capacitor Array or SCA) are the cheapest
  - Data reduction schemes implemented in fast FPGA (Field Programmable Gate Arrays)
  - Trigger generation scheme using discriminators to generate live multiplicity

General Electronics for TPC (GET)

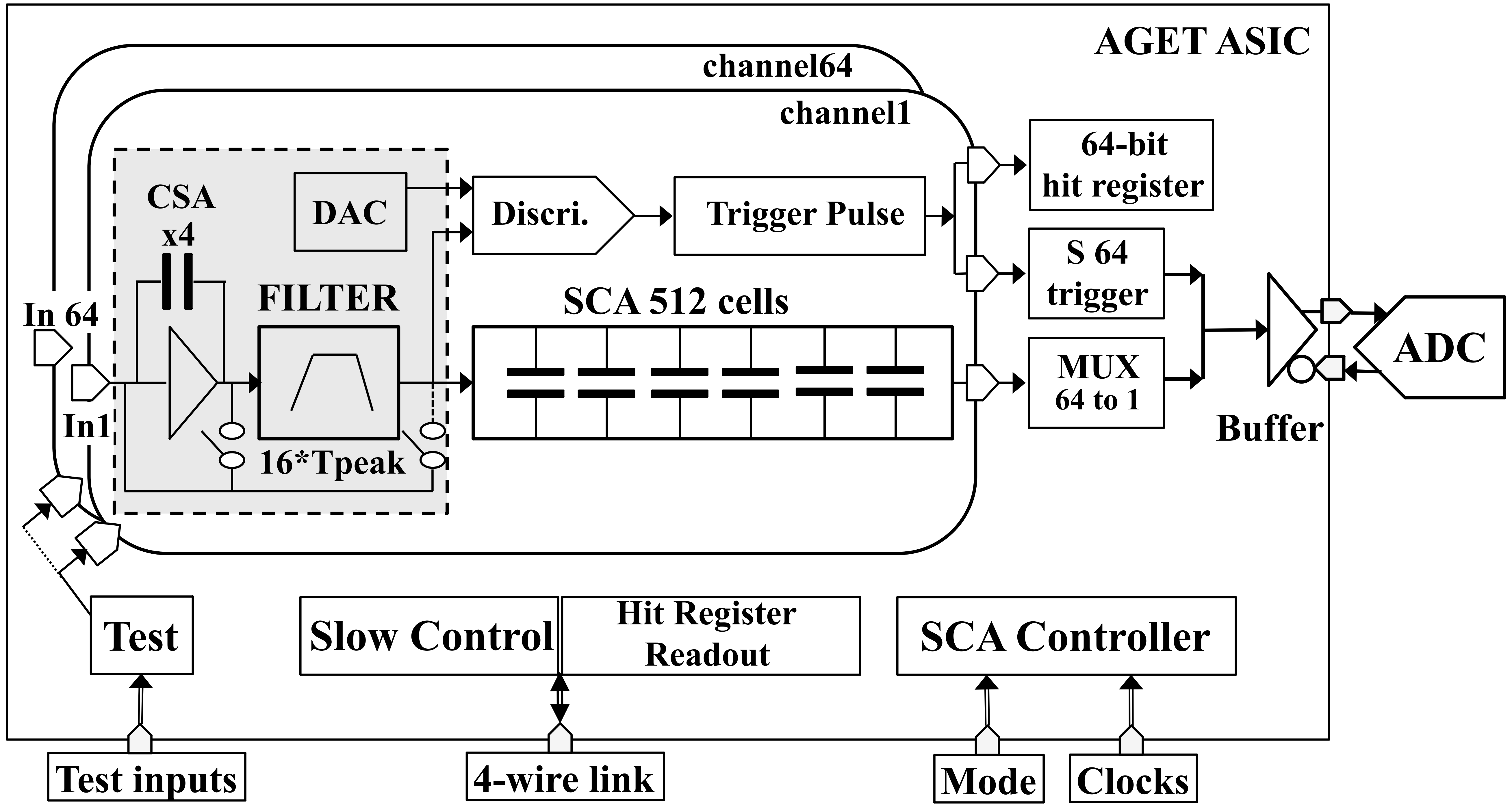
- Specifically designed for Active Targets
- Adjustable gain on each individual pad
- Up to 512 time samples recorded
- Sampling frequency range 1-100 MHz
- Each channel equipped with discriminator and threshold
- Shaping time from 70 ns to 1 μs
- Charge resolution < 850 e-



E. Pollacco et al., NIM 887, 81 (2018)

Front end features

- Writing phase:
- Live analog signals are stored in SCA used as a circular buffer
- Live discriminator bits are combined in hit register and summed as multiplicity signal
- Multiplicity signal is converted by flash ADC and sent out to back end electronics
- Some stages of the CSA can be bypassed



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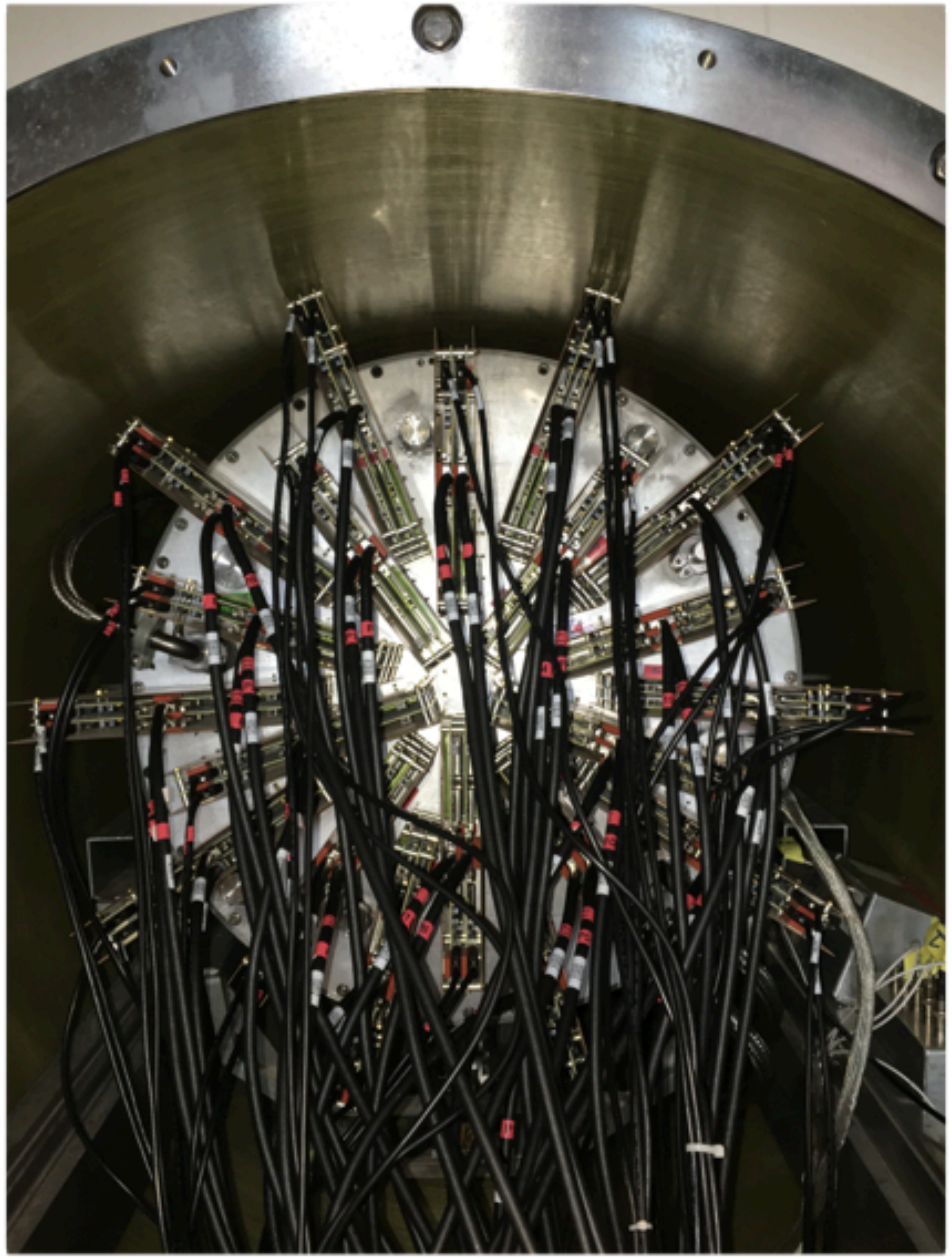
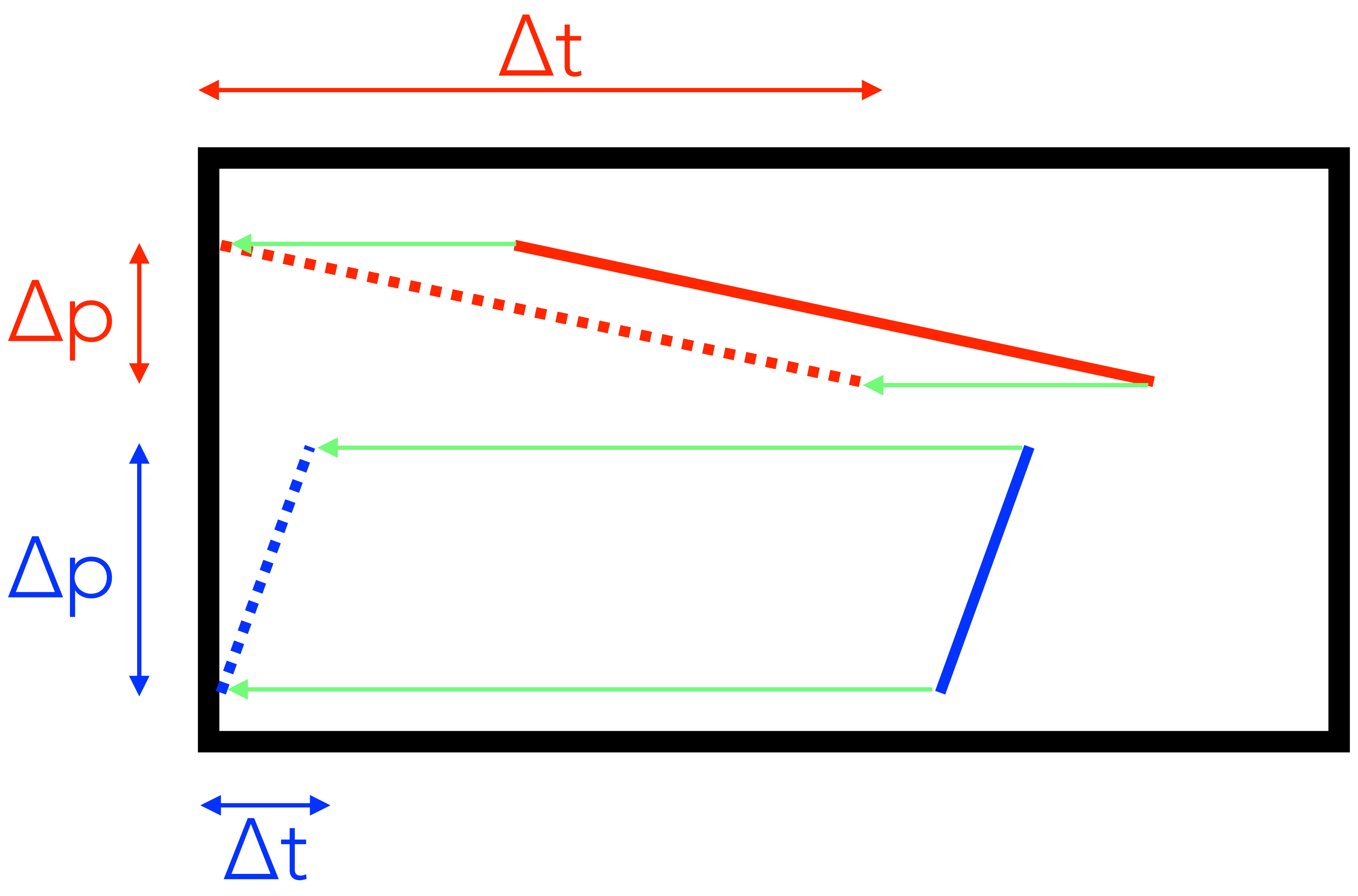
Front end features

- Reading phase:
- SCA array set in read mode
- Pointer of first time sample set to desired value (going back in time)
- Depending on reading mode, selected SCA cells are converted by flash ADC and sent to back end
- Data reading is multiplexed and sent through a single flash ADC
- Data from front-end (AsAd) is serial



Back end processing

- Concentration Boards (CoBo)
  - Data reduction and multiplicity integration
- Readout modes
  - Full (no reduction)
  - Partial (pads above threshold)
  - Zero-suppressed (baseline removal)
- Multiplicity sliding window
  - Integrate multiplicities within time window
  - Essential to generate self trigger!

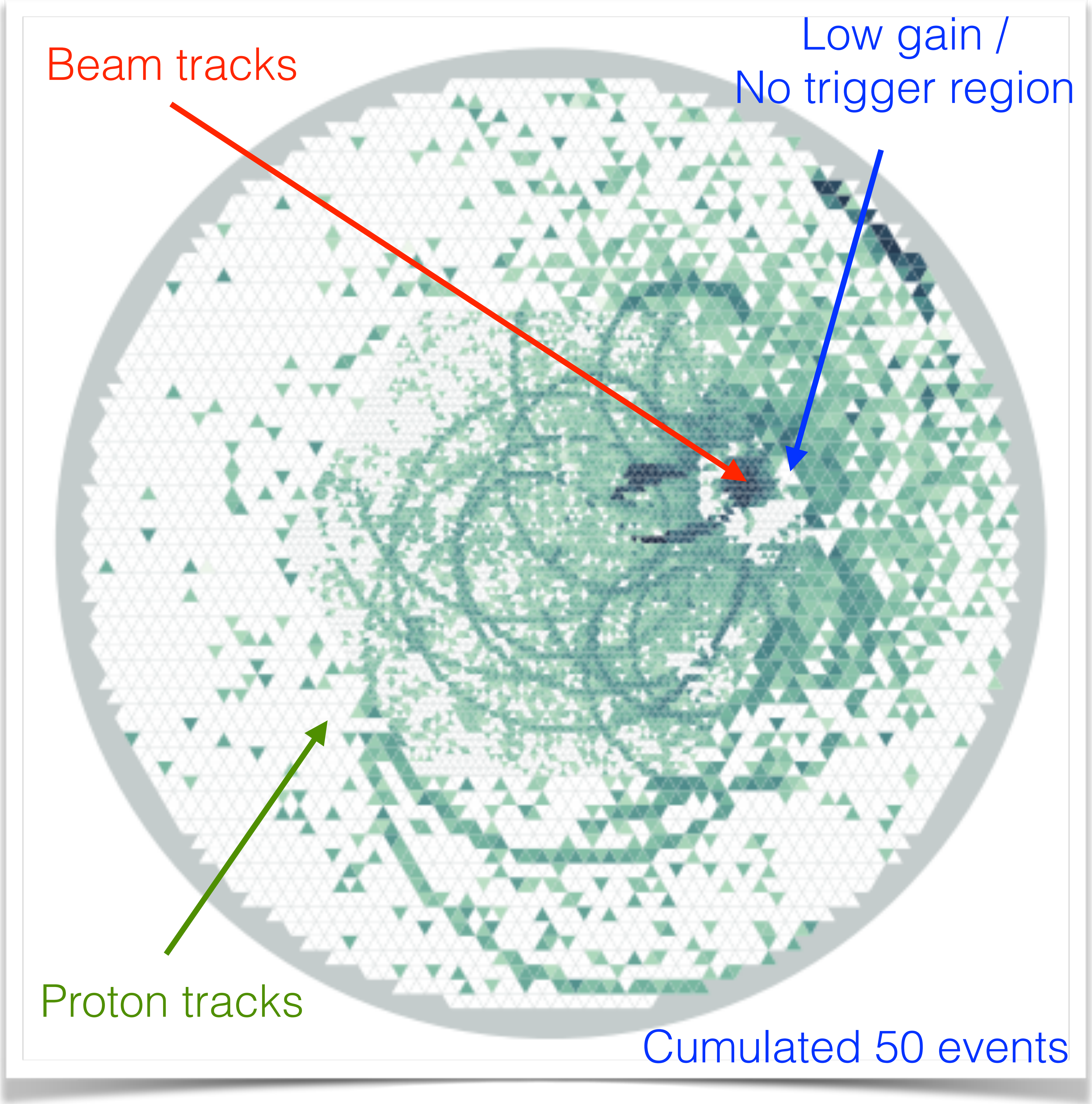


Clock and trigger

- Mutant module:
- Clock distribution throughout the whole system
- Trigger generation
  - Gather sliding window multiplicities from all CoBos and sum them
  - Also gather hit patterns (level 2)
  - Level 1: trigger if global multiplicity above (or below) a given threshold
  - Level 2: trigger if hit pattern matches predefined configuration

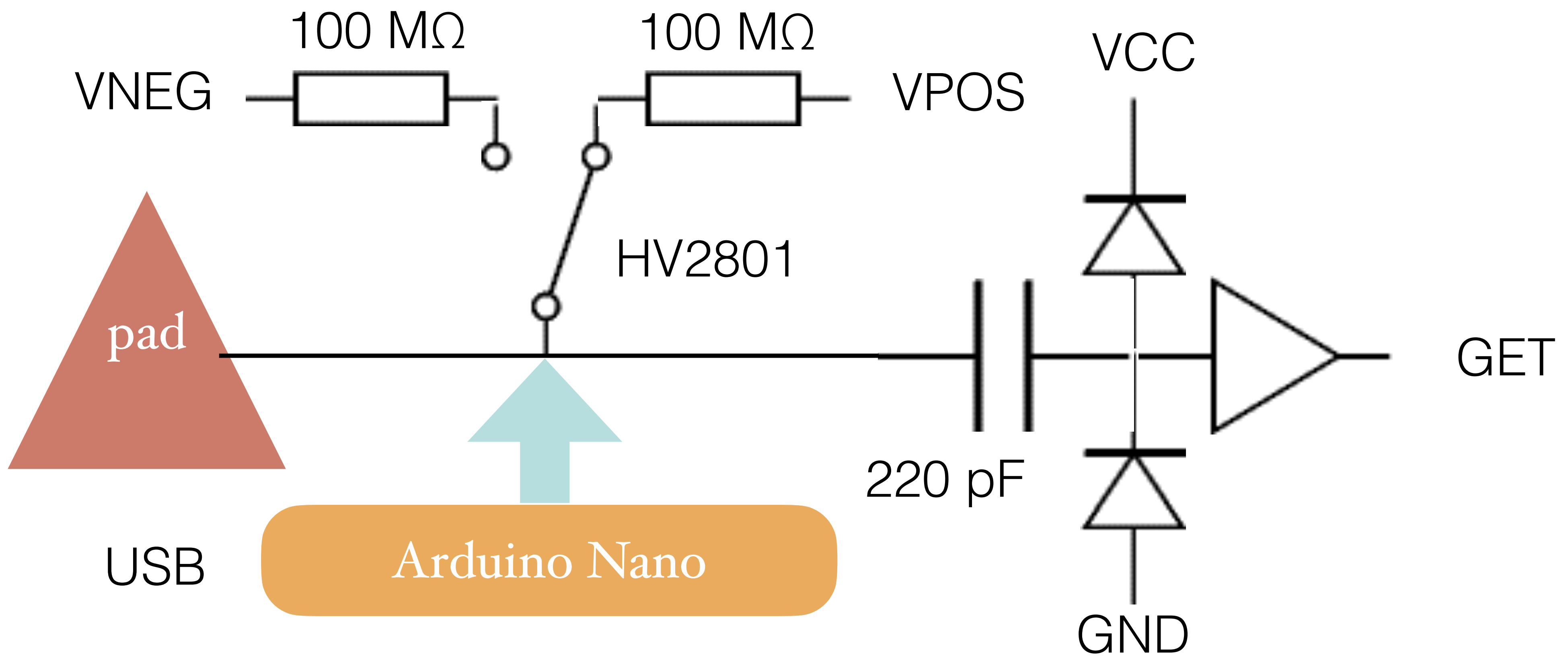
Internal trigger generation

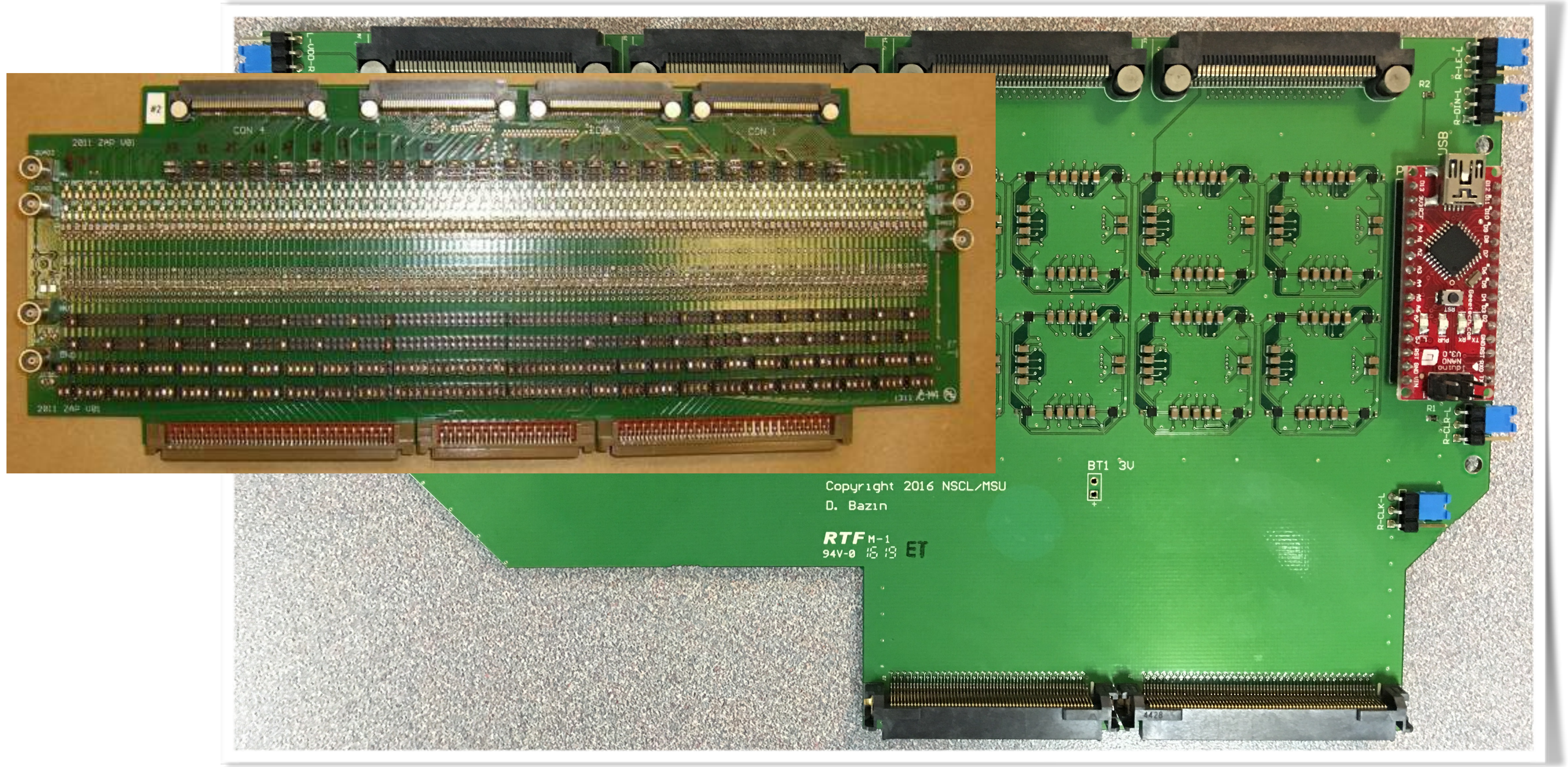
- Trigger exclusion regions
- Discriminators on each individual pads can be enabled or disabled
- Region where electrons from beam tracks are collected (“beam pads”) can be excluded from multiplicity
- Scattered particles that exit the beam exclusion region generate a trigger



Individual pad polarization

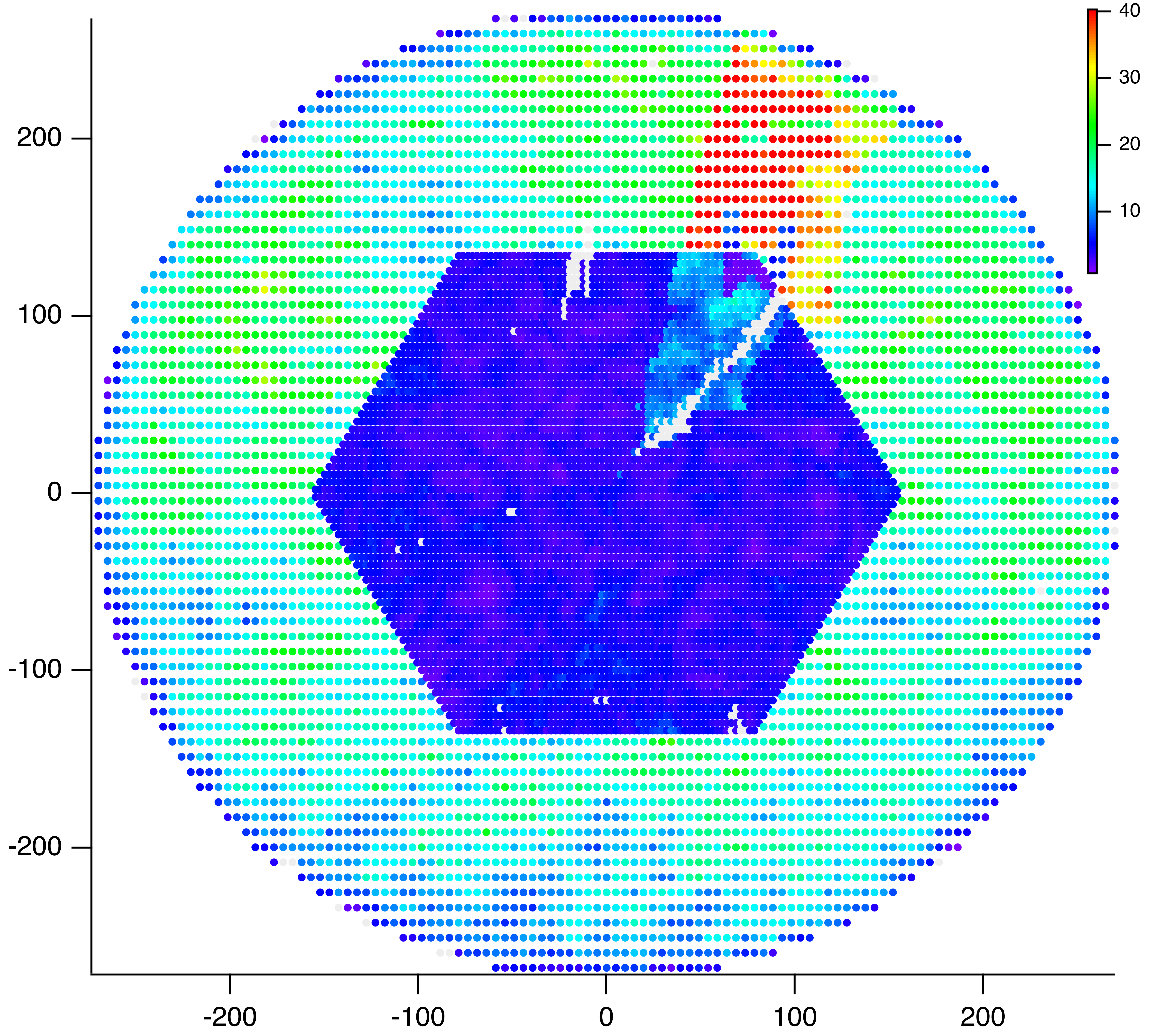
- Define pad regions where electron multiplication gain is reduced
- Beam projection region has very high density of charge
    - Beam particle rate much high than recoil particle rate
    - Beam particles usually much more ionizing than recoil particles
- Saturation and cross-talk effects
- Solution: apply voltage on individual pads to reduce electron gain





Test using alpha particle tracks

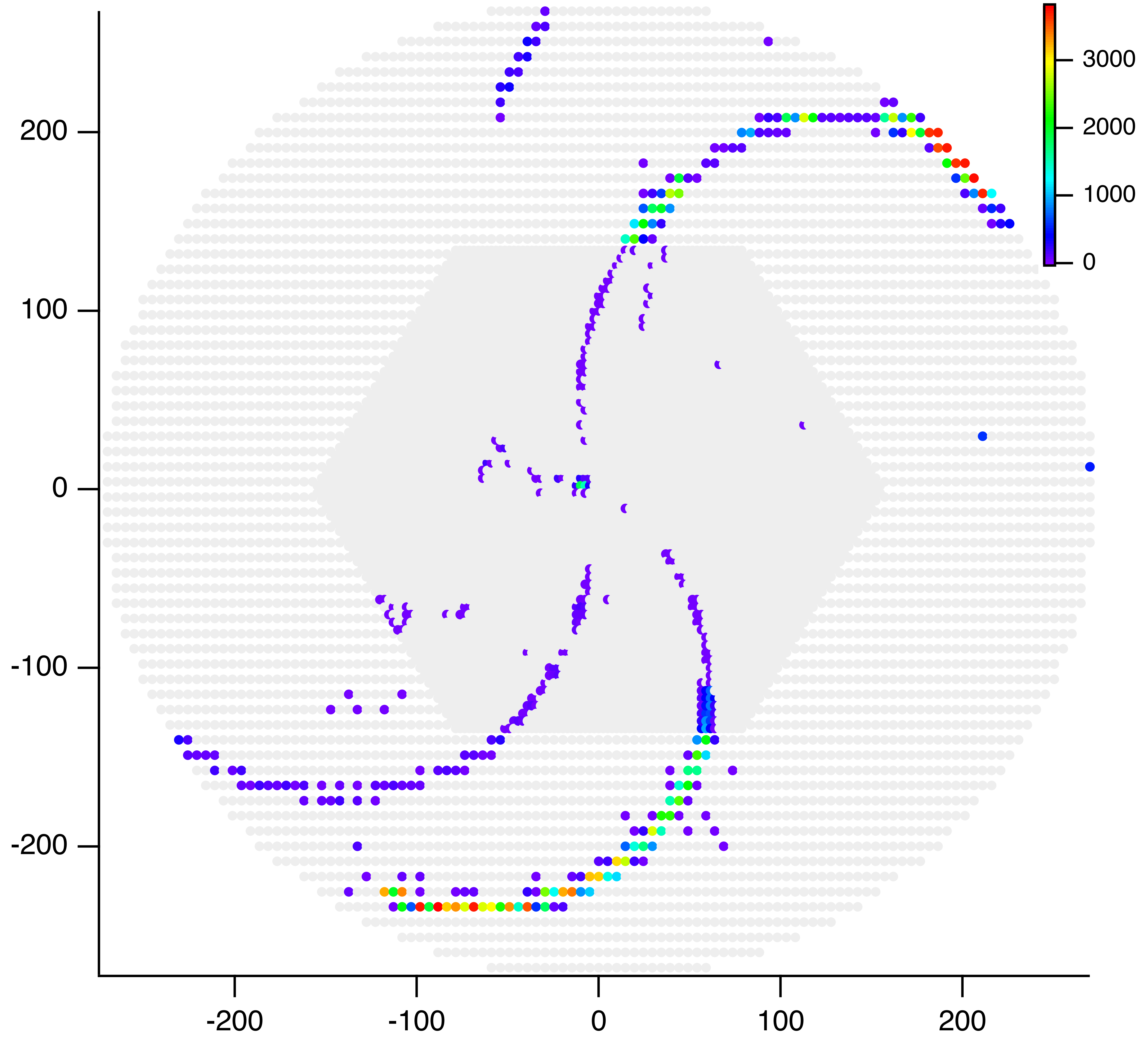
- Programmatic method necessary
- 10,240 pads to consider!
- Map of pads assigned via software
  - Green: ground (0V)
  - Blue: -40V (more gain)
  - Red: +40V (less gain)
- Data taken using α particles from source covering whole volume
- All pads have same electronic gain



Cumulated alpha tracks

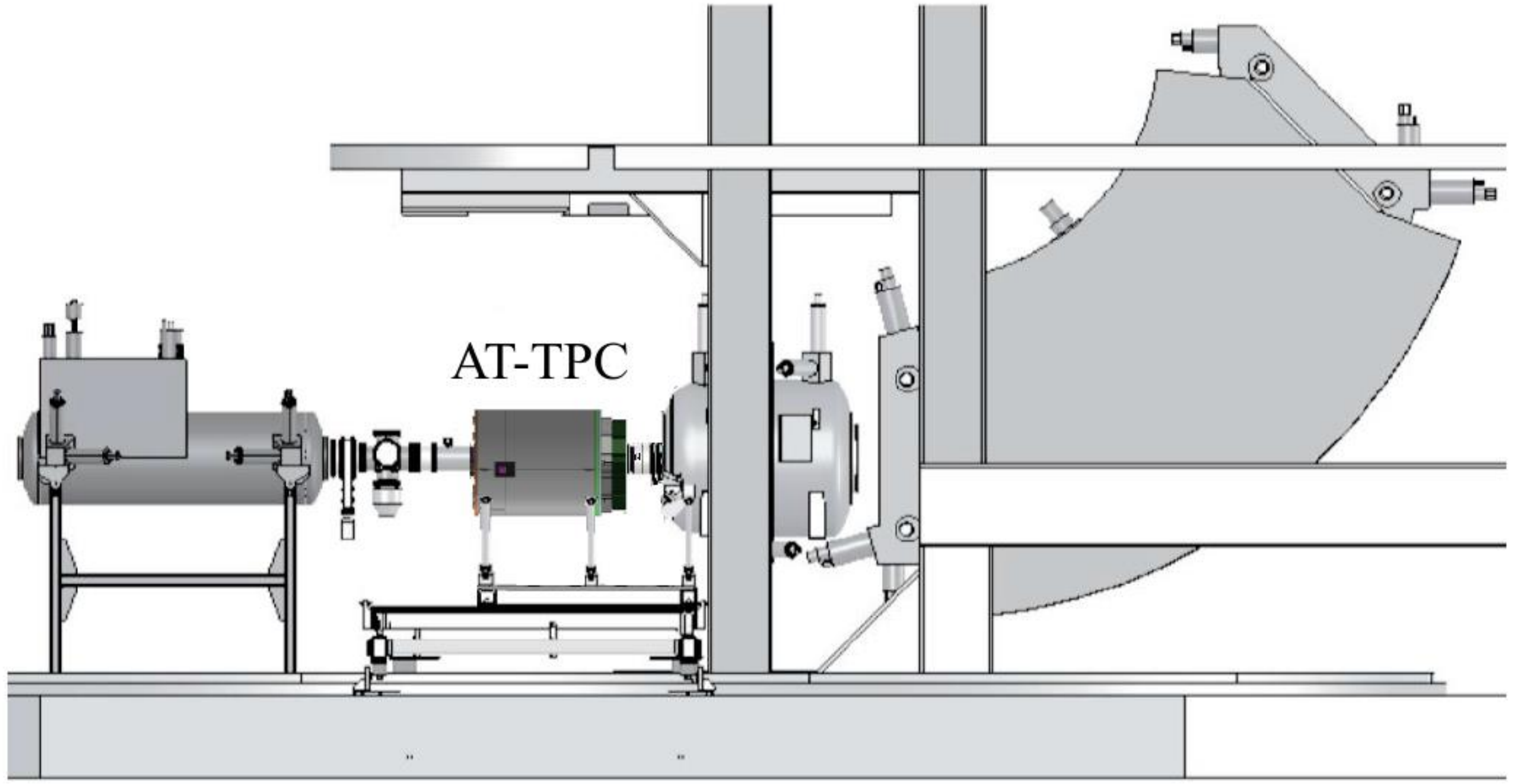
Used during experiment

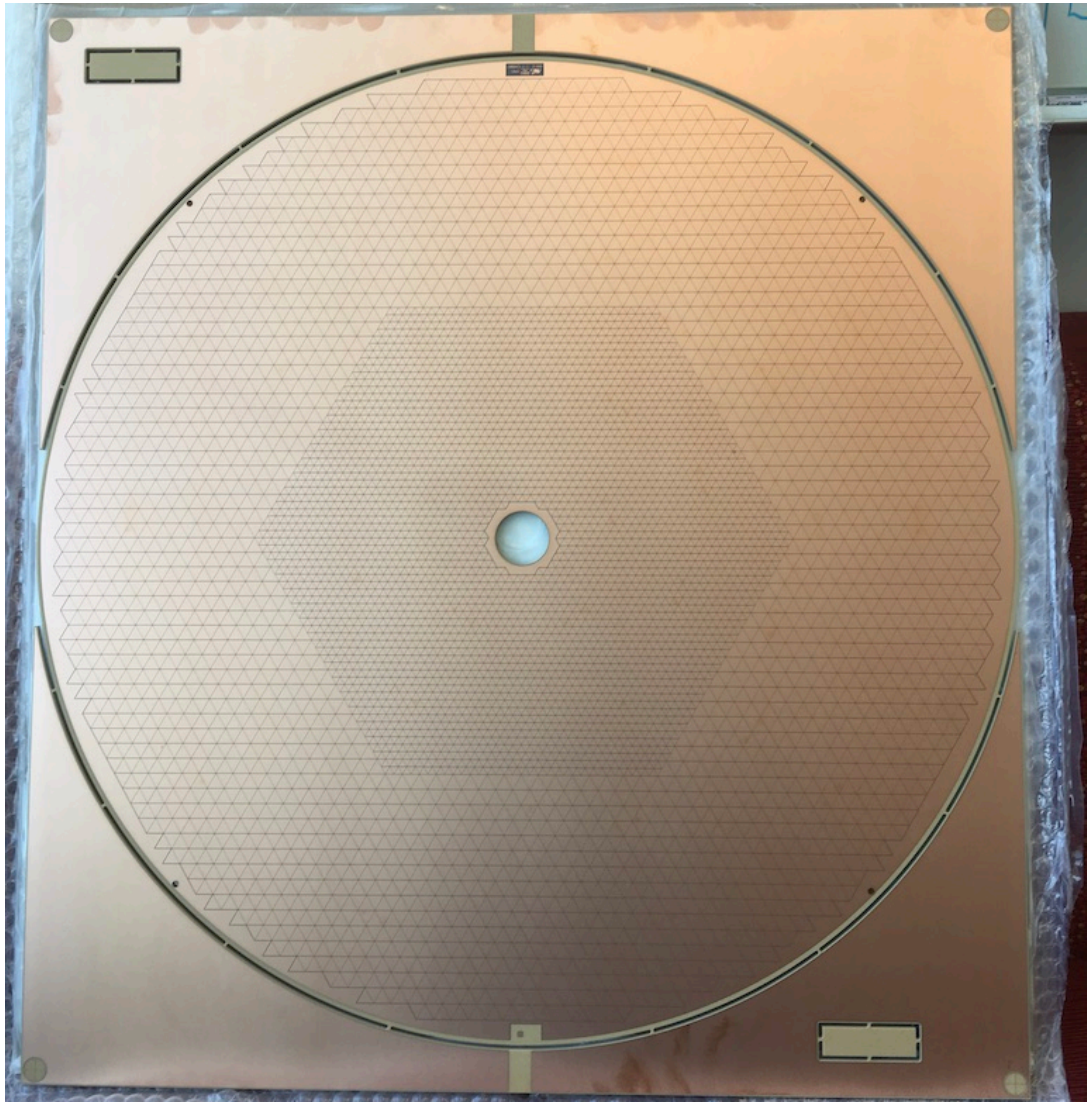
- Beam: ^{22}Mg particles
- Target: He gas
- Central region of pad plane polarized to lower gain
- Signal amplitude from beam track similar to recoil tracks
- Recoils: protons
- Ionization from ^{22}Mg particles greater than protons by > 100x



Experiments using high energy beams

- New pad plane to let beam in and out the active volume
- Beam projection region blind
- AT-TPC @ S800 spectrometer
- Reaction channels filtered by S800





Future experimental program

- High energy beam campaign (2020)
  - Fission barrier of ^{196}Pb
  - ^{14}O(d,^{2}He) charge-exchange reaction
  - Giant monopole resonance in ^{70}Ni
- ReA6 campaign @ SOLARIS (2021)
  - Spectroscopy of ^{12}Be (transfer), cluster structure in ^{16}O* (elastic scattering), ...
- RCNP campaign in Japan (2021-22)
  - Several (4-5) experiments approved using radioactive beams
- FRIB beams become available in 2022!