Commissioning of an MPGD-Based Tracking System for Neutron Invariant-Mass Spectroscopy Experiments

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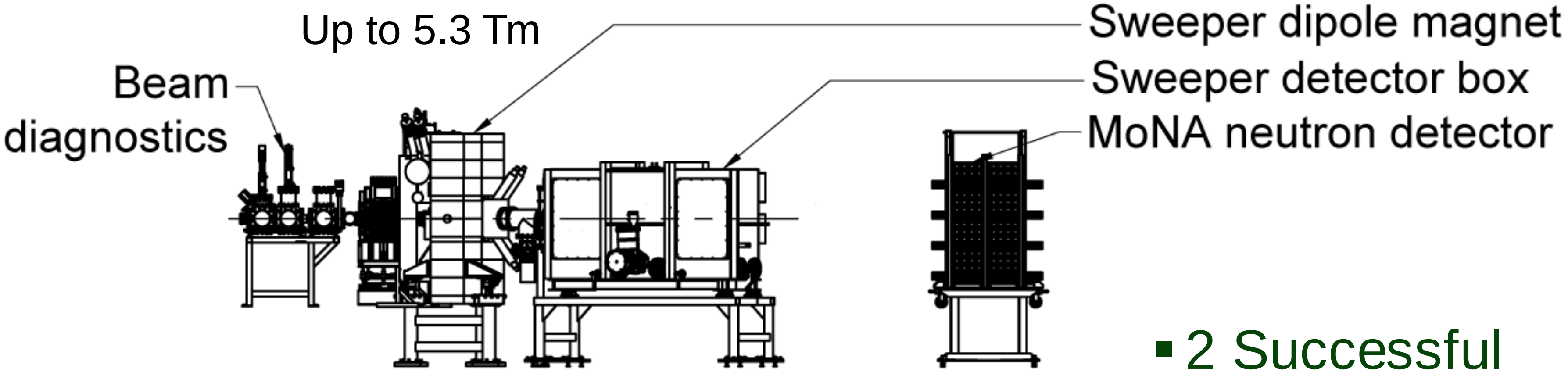
Outline

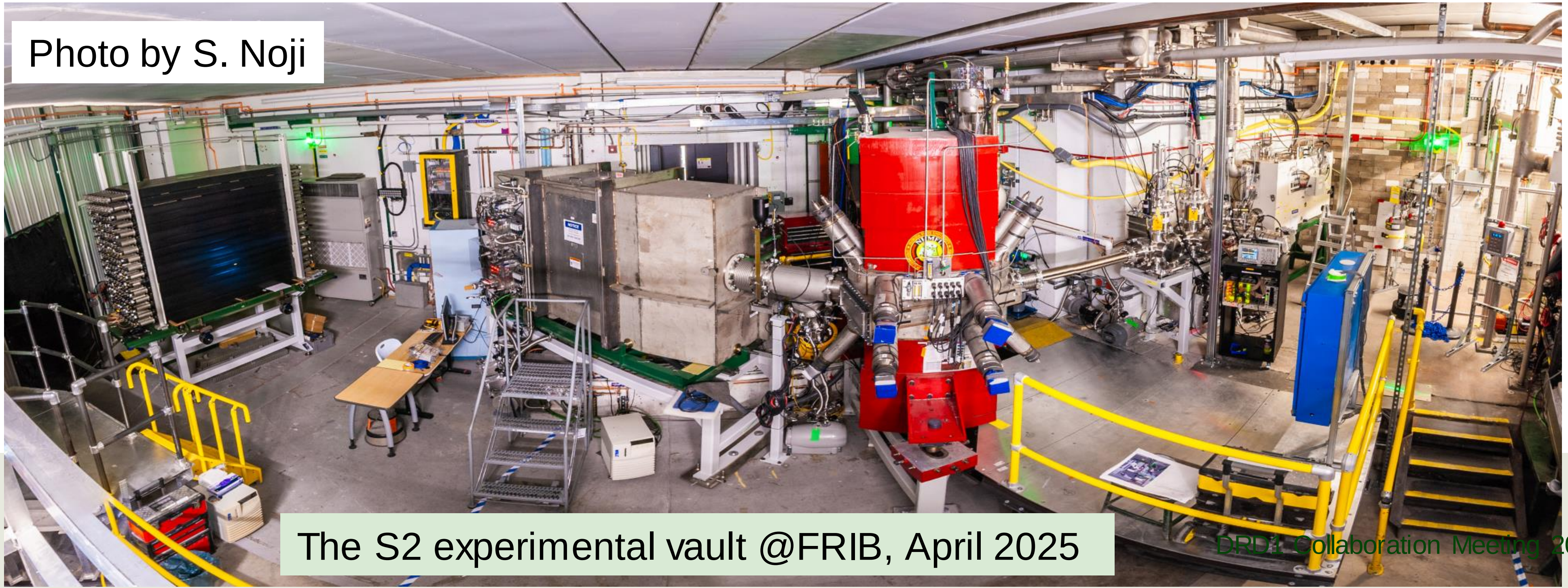
- The Sweeper Magnet System for Neutron Invariant-Mass Spectroscopy @FRIB:
  - » Overview
  - » Requirements
  - » Upgrades
- Design and operation of a new M-THGEM base Drift Chamber:
  The Micro Pattern Drift Chamber (MPDC)
- The Scalable Readout System (SRS) as a DAQ for the new MPDCs:
  - » Overview
  - » Gain matching of the channels
  - » Trigger capabilities
- Performance evaluation of the new MPDCs using radioactive source measurements
- Requirements met in in-beam commissioning: Ready for operation
- Remaining issues to be understood and addressed for the S800 MPDCs operation

The Sweeper Magnet System for Neutron Invariant-Mass Spectroscopy (NIMS): An overview

- Pivotal component of the low-energy nuclear science program @NSCL and now @FRIB
- Fully re-commissioned in 2025 @FRIB



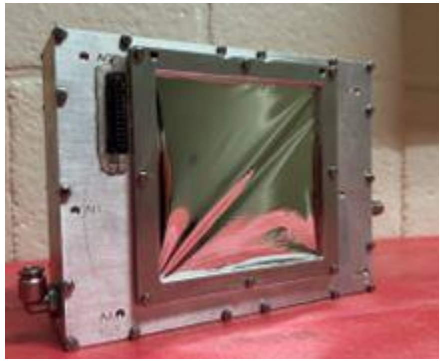
- 2 Successful experiments concluded
- 2 more PAC approved experiments scheduled to run in 2026

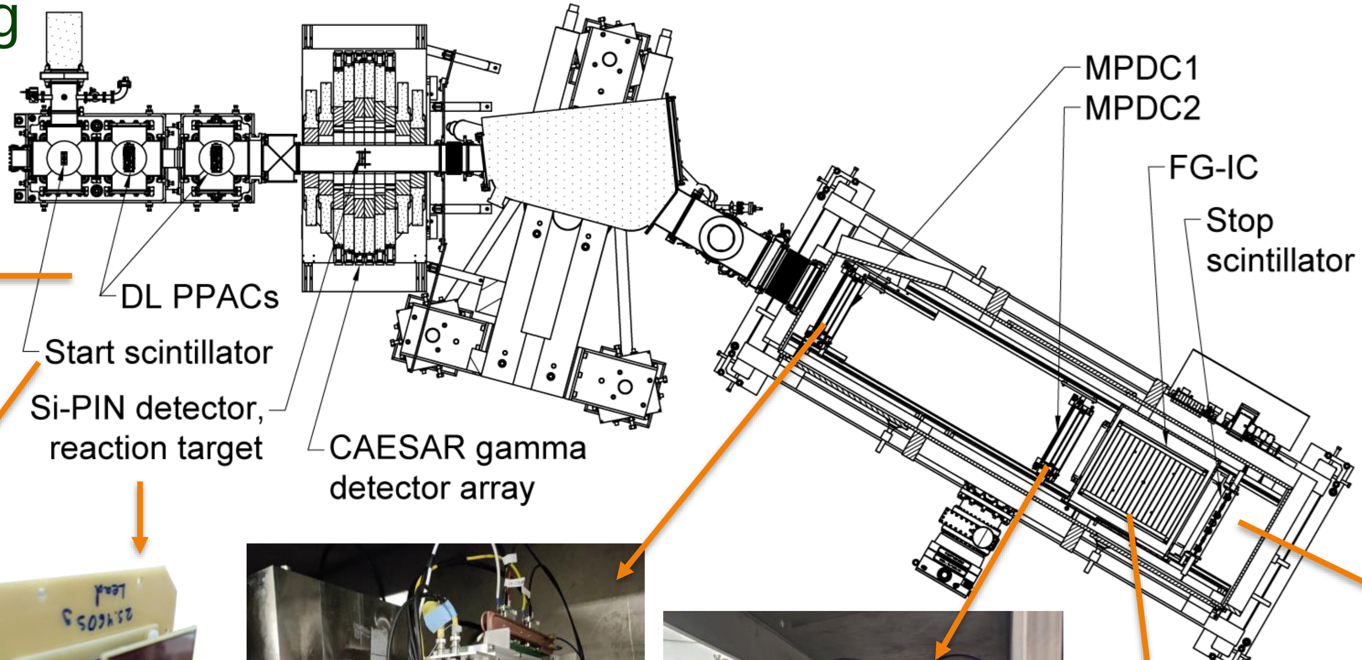


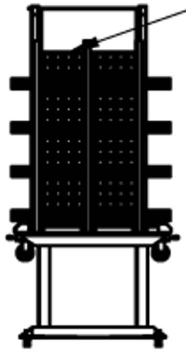
The S2 experimental vault @FRIB, April 2025

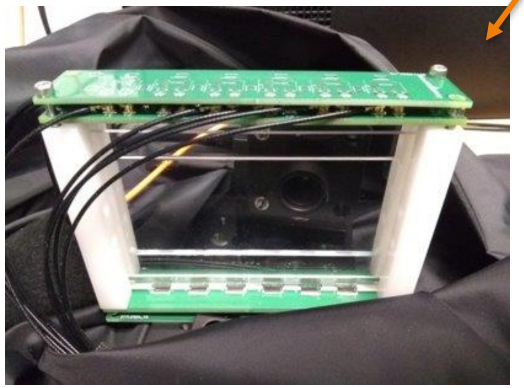
The Detectors of the Sweeper Magnet System
Requirements for PID before and after the Reaction Target

- NIMS: dE, ToF, tracking







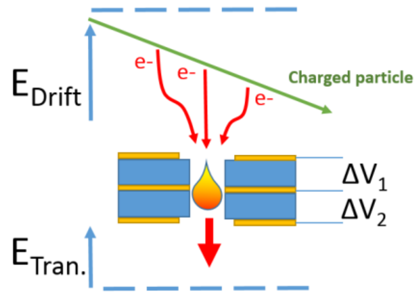


12 x SiPM readout:
~ 60 ps time resolution

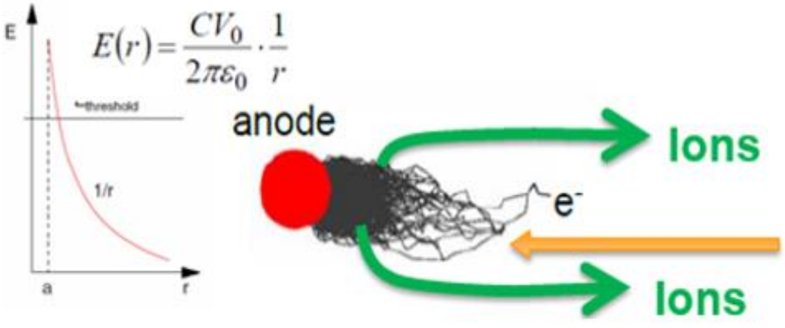
10 x PMT readout:
time ~ 70 ps

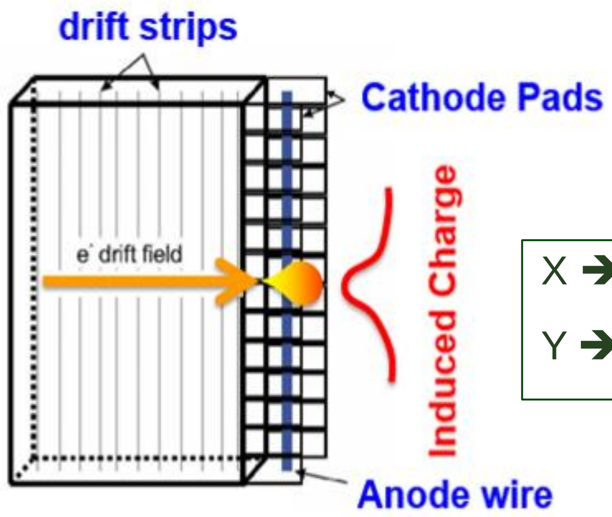
Upgrade for the Sweeper Magnet System: Precise Tracking via New Technology and DAQ

- Cathode Readout Drift Chambers + obsolete STAR electronics
  - To reduce aging effects, operated in only 20% isobutane + 80% CF_4



Wire-based detector:
- Fragile during installation
- Secondary effects -> Gain limits
- Space charge effects -> Rate limits
- Aging -> Damage during operation

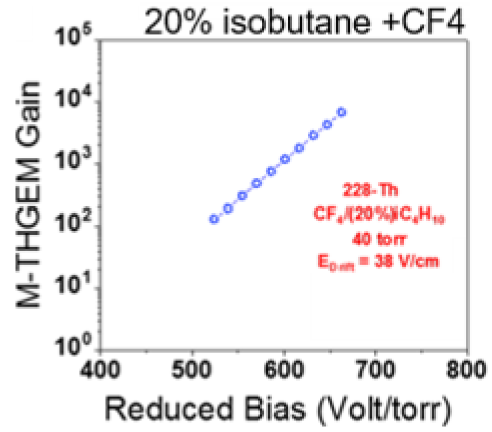


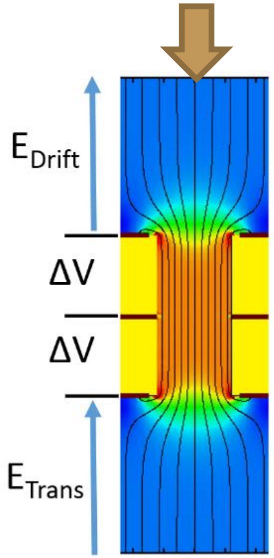


X ➔ charge distribution

Y ➔ Derived from the drift time

2-Layer M-THGEM

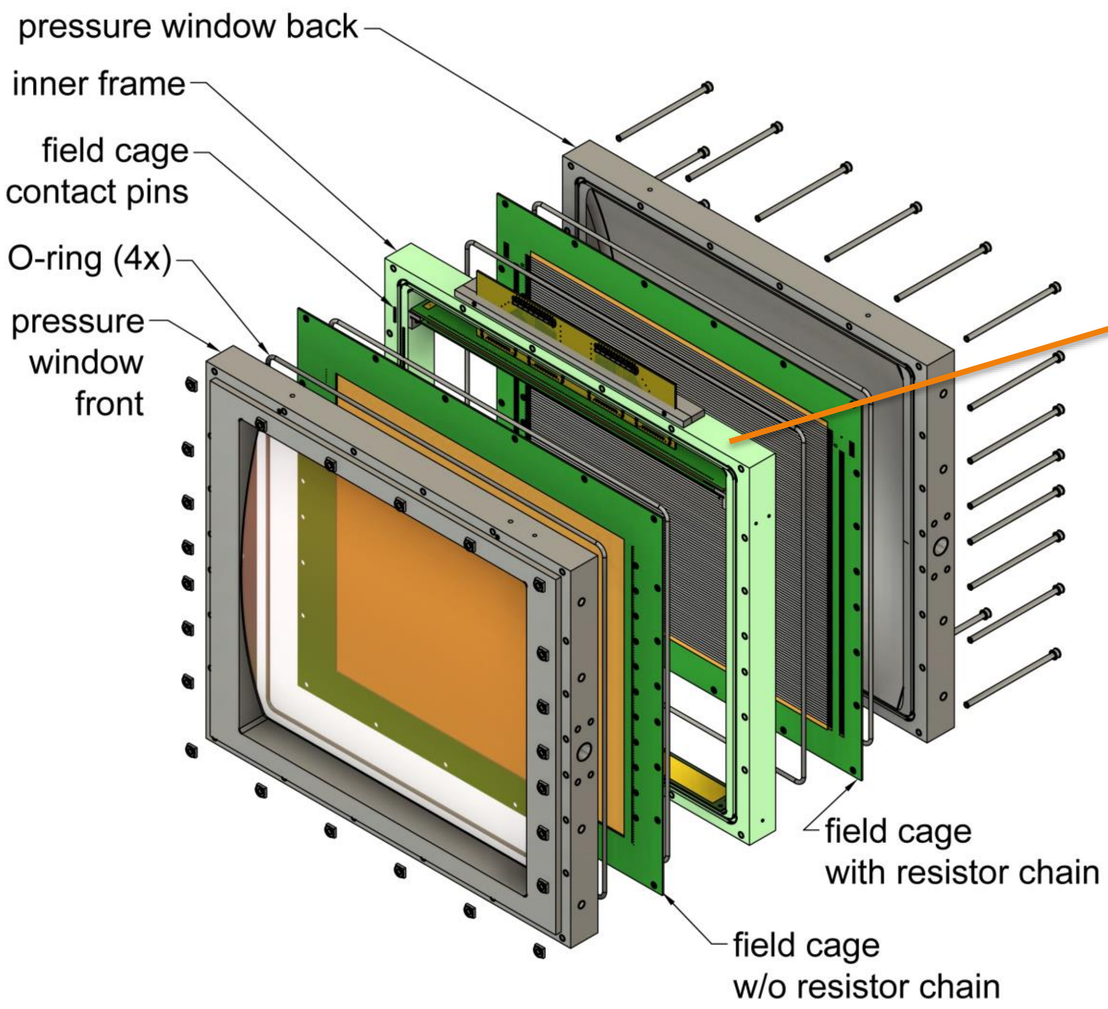


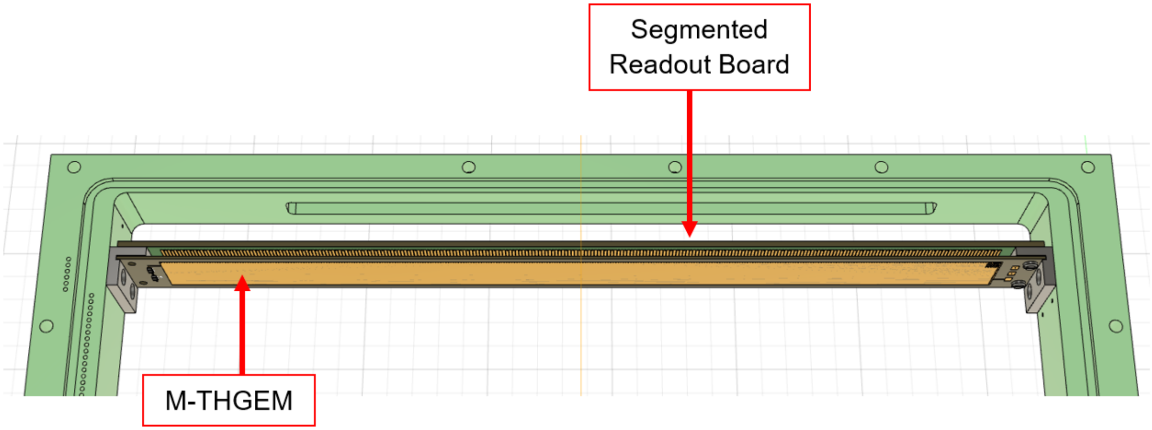


- Micro Pattern Drift Chambers + SRS electronics
  - No loss of charge ➔ High gain @ low voltage
  - Robust avalanche confinement ➔ lower secondary effects
  - Long avalanche region ➔ high gain @ low pressure
  - Lower energy released during sporadic discharges → Lower probability of failure

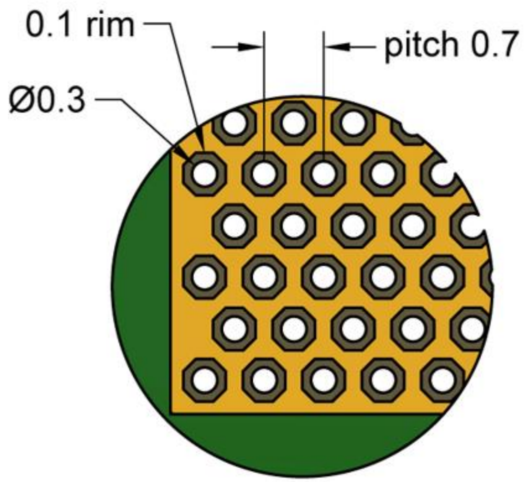
Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)
M. Cortesi et al 2020 JINST 15 P03025

Design and Operation Principle of the new Micro Pattern Drift Chamber (MPDC) Based on the M-THGEM





- 2 Layer M-THGEM
- Readout board with 256 pads 1.1 mm wide
- Field cage
  - ~70ug/cm^2 with 180nm Ag strips
  - 33 V/cm through resistive chain
- Operated in mixtures of isobutane +CF_4

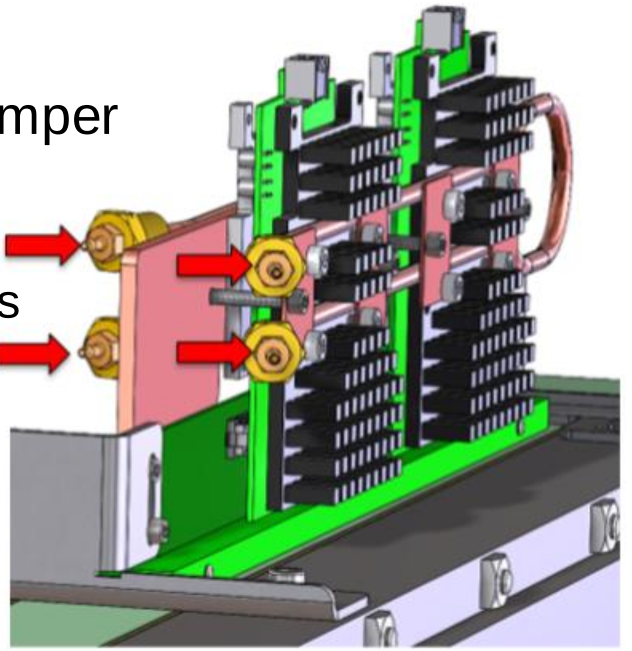


M-THGEM details

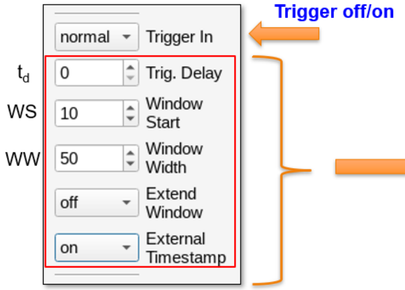
The DRD-1 Scalable Readout System (SRS) in Trigger Mode as a DAQ for the new MPDCs

- Fully implemented into the FRIBDAQ
  - Modified firmware to operated in trigger mode with The FRIB FEC Timestamper
  - High-rate capability (> 1 MHz)
  - SRS output: time and amplitude of signals
- Operated in vacuum
  - Custom designed cooling plates
  - Temperature ~ 35° C in vacuum by water cooling via dedicated chiller
  - HDMI cables length > 6 meters: PBX needed to avoid power drop

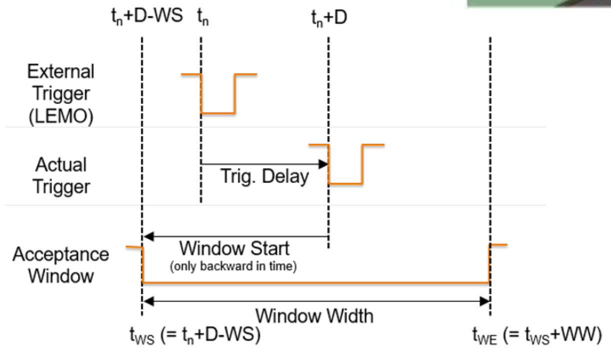
Water lines



Slow control software modified defined extra parameters:



Unit: 22.5 ns (44.444 MHz)
Max: 1023 (23 μs)

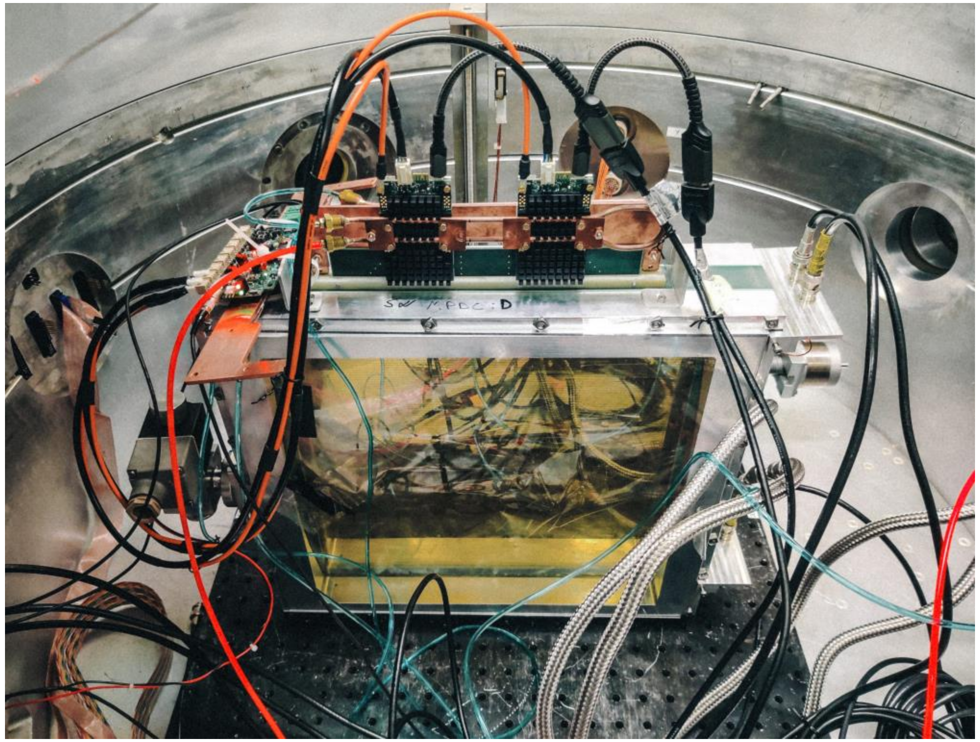


Adjustable settings via the Slow Control GUI

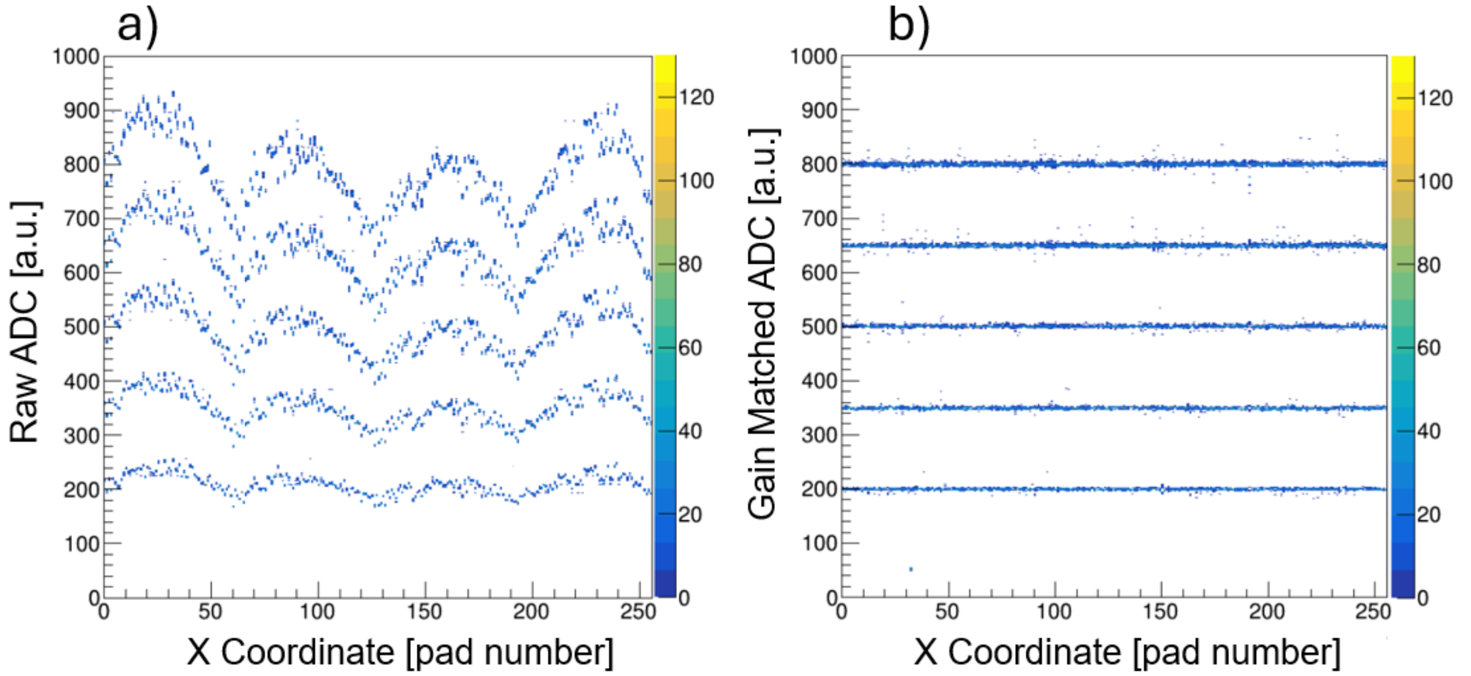
Mitigation Plan Defined and Followed After S800's MPDCs Commissioning in 2024

- Most of the issues reported during DRD-1 Collaboration Meeting Dec. 2024 solved:
  - Improve stability of HV on the M-THGEM-B and SNR (noise)
    - » Added a resistor and a signal pickup capacitor to keep the bias on the THGEM-B fixed with respect to the Top and Middle layer
  - Improve quality of the SRS hardware:
    - » QA defined with the DRD-1 collaborators in CERN → Thoroughly check all hybrids, we need all channel properly functioning with good ADC response
    - » Bias SRS hybrids through dedicated PBX instead of DVMM
    - » Defined calibration procedure to gain match all VMM channels → now integrated also in SpecTcl (online data monitoring tool at FRIB)
  - Poor ADC resolution (few % of events in 6bit ADC) from VMM hybrids → does not affect the position capability but limit the dynamic range (for the localization capability over large range of Z number)

Gain Matching of the SRS VMM Channels

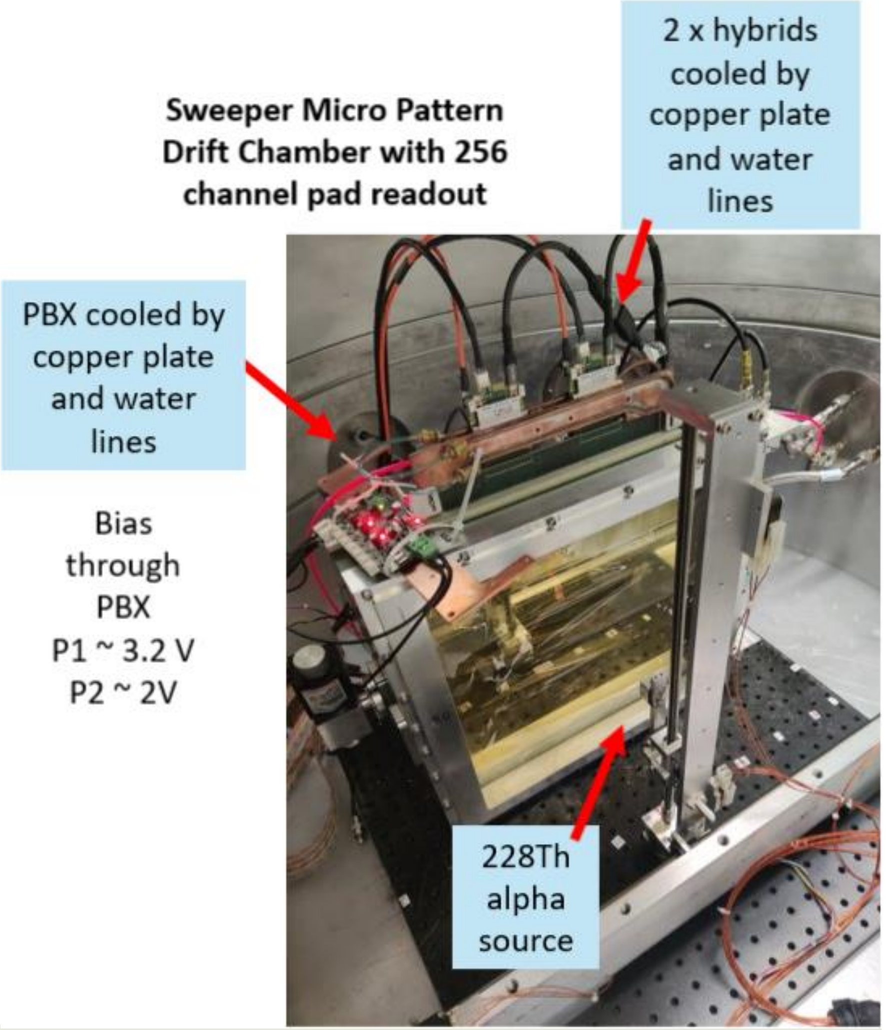


- Response to an external pulse generated to the THGEM bottom layer to induce impulses on the VMM channels
- Linear calibration to an average value to reduce the response inhomogeneity

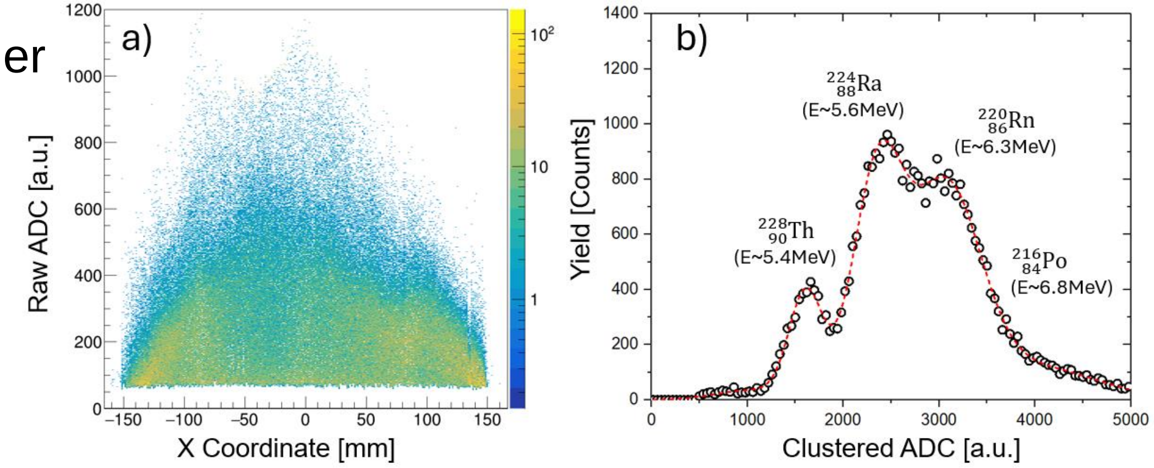


Performance Evaluation of the MPDC in Alpha Source Measurements with ^{228}Th

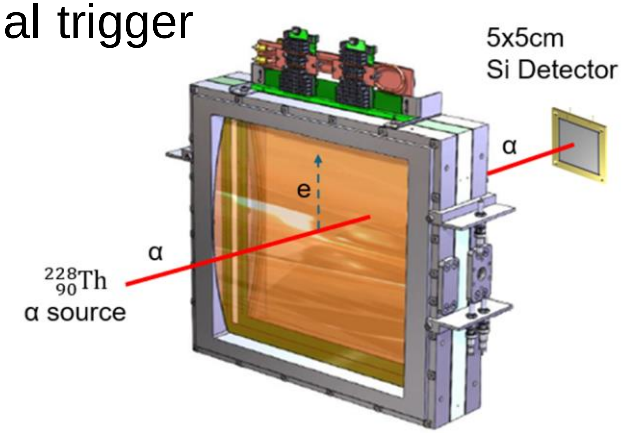
- No missing channels in VMM hybrids

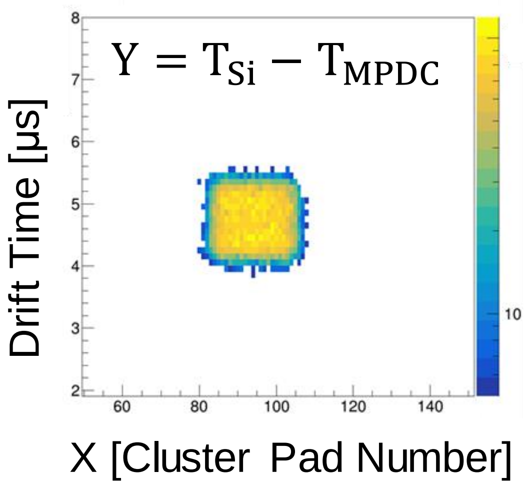


Self trigger



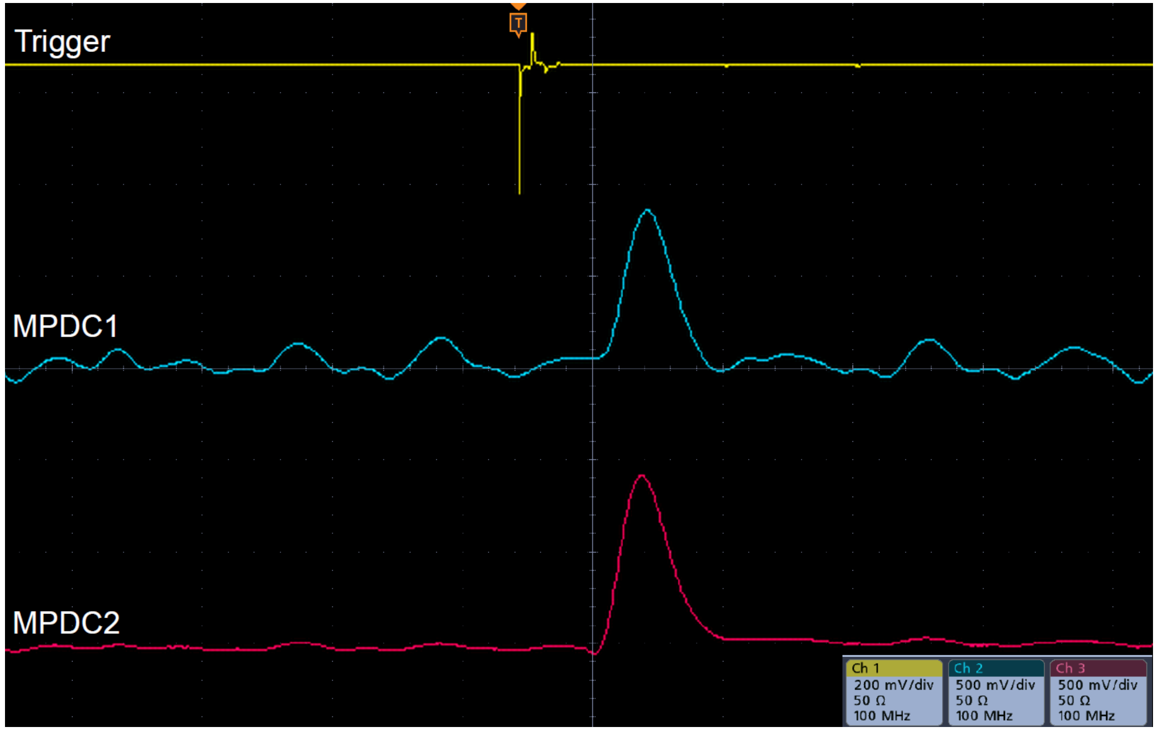
External trigger

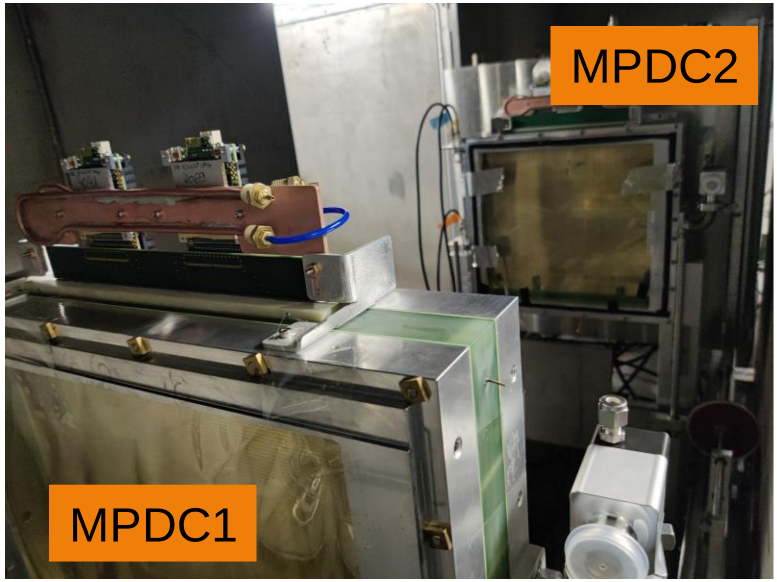




In Beam Commissioning of 2 x MPDCs for Tracking in the Sweeper Magnet System

- Two beams delivered by the Advanced Rare Isotope Separator
  - Cocktail beam Z = 8 to 20, tuned to ^{24}Mg, E ~120MeV/u
  - ^{17}C beam, E~120 MeV/u





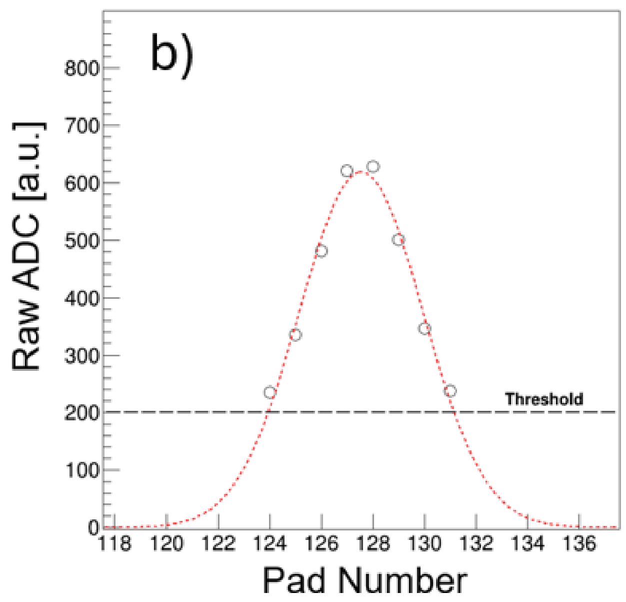
- Stable operation over several weeks with new PBX
- MPDCs triggered by the Start Timing Plastic Scintillator
- Charge collected at the bottom layer of the M-THGEM → charge sensitive preamplifier and linear amplifier

Position Reconstruction of the MPDC in the Sweeper Magnet System

- The vertical (Y coordinate): drift time of ionization electrons relative to the external trigger
- The transverse (X coordinate): center of gravity of charge distribution on the pads

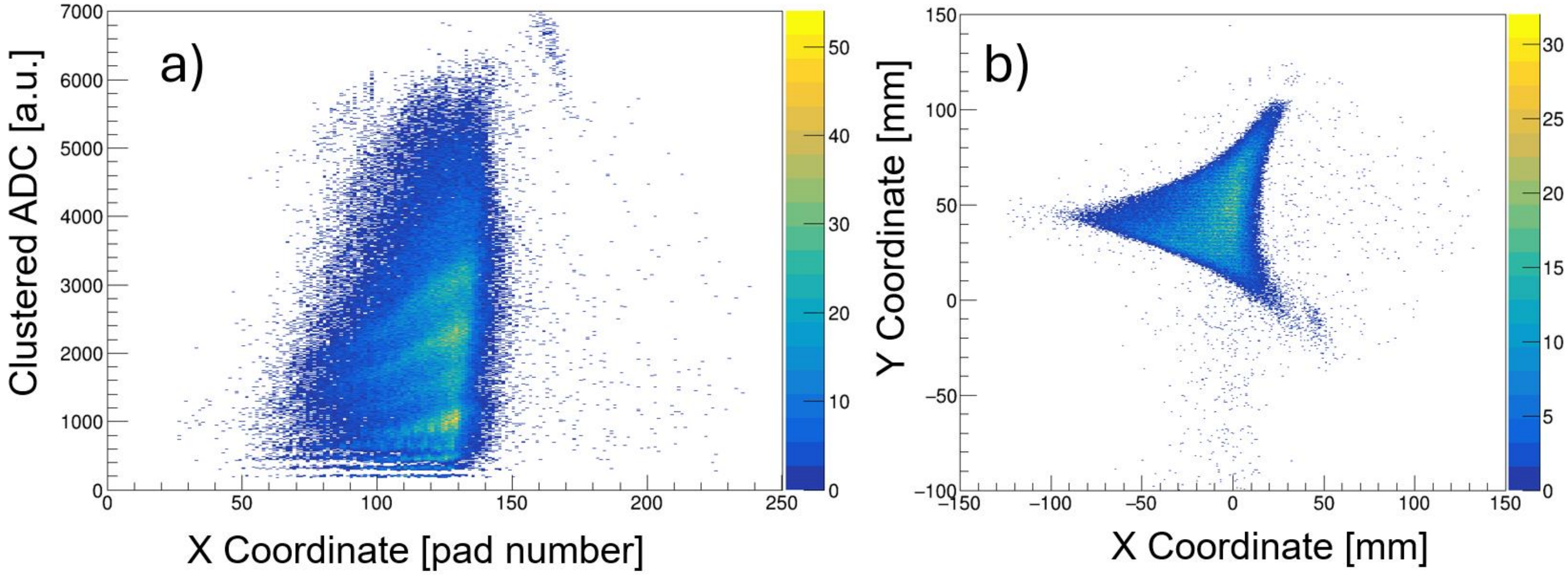
$$X_{\mathrm{grav}} = \frac{\sum_i X_i \cdot \mathrm{ADC}_i}{\sum_i \mathrm{ADC}_i}$$

1 event: charge distributed across pads



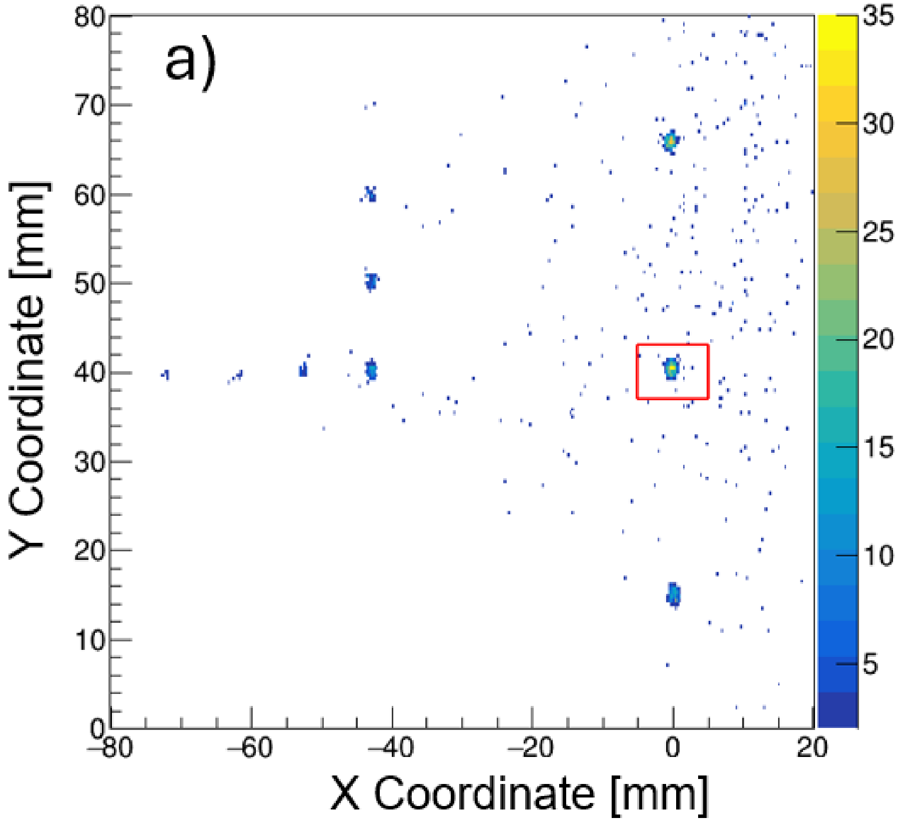
Cocktail beam Z = 8 to 20,
E = 120 MeV/u

Response on MPDC#1: dE (10-bit ADC resolution), X and Y reconstruction

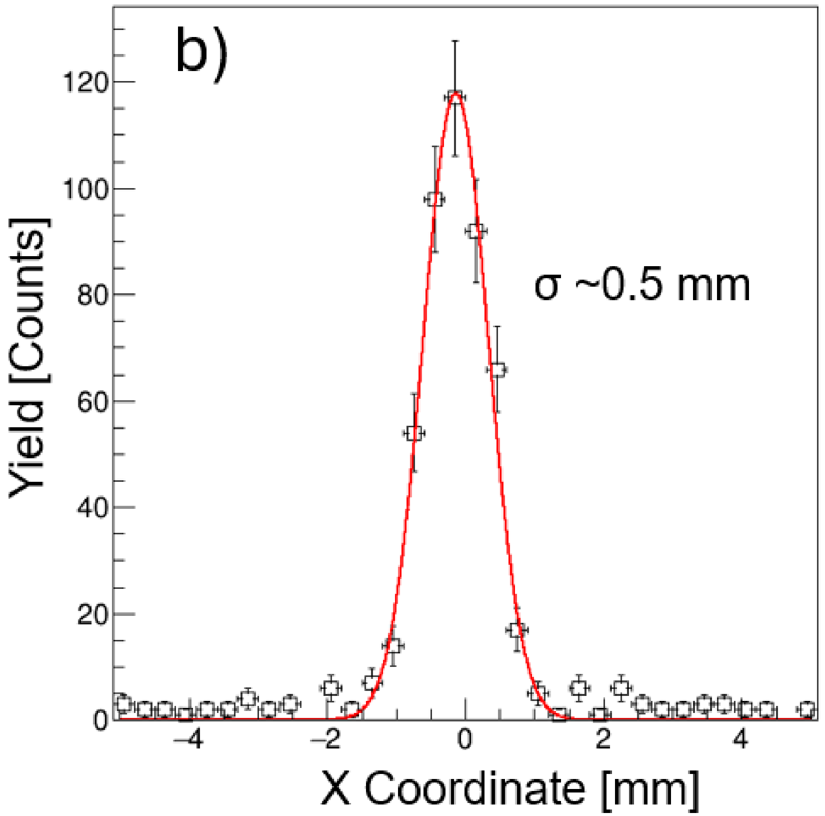


Position Resolution Requirement Met: Ready for Operation

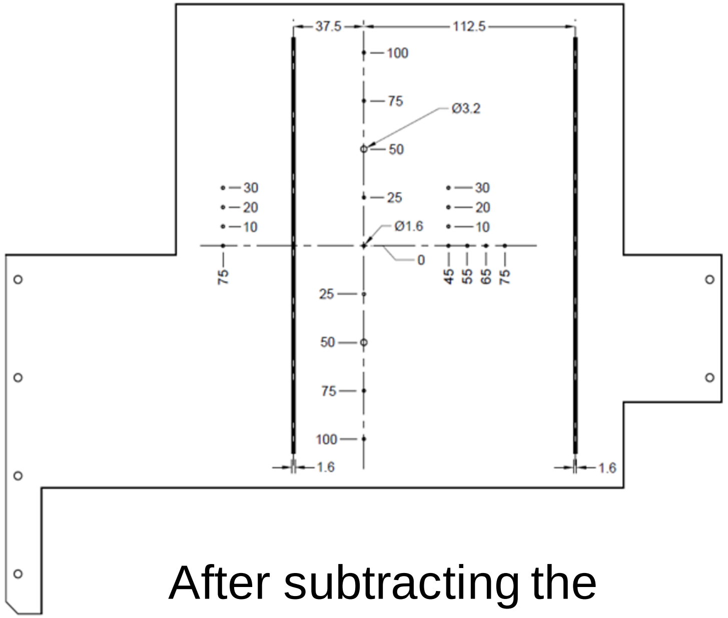
- ^{17}C beam: Calibration Mask measurements
  - Position resolution FWHM < 1mm



Projection of 1 pin hole



Drawing of the calibration mask

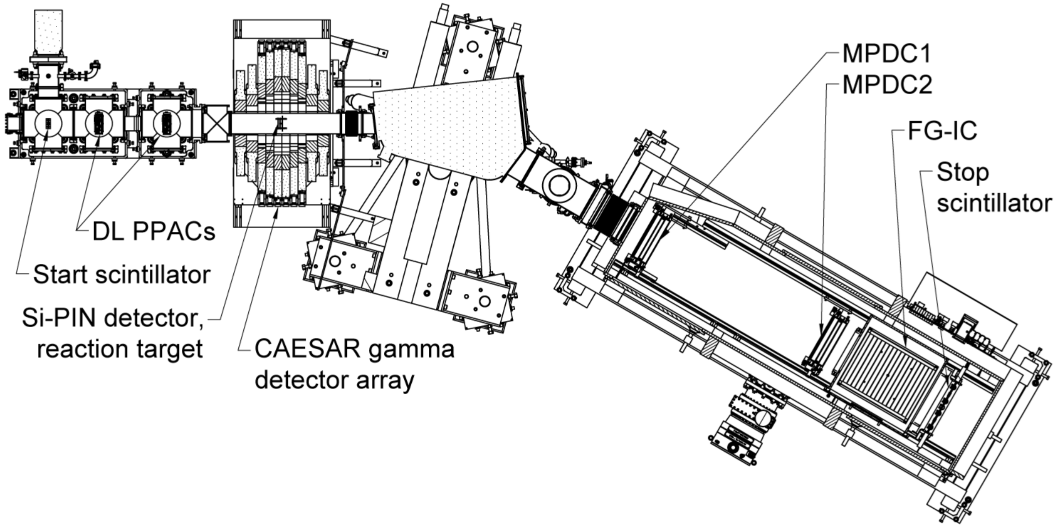


After subtracting the contribution from the 1.6 mm pinhole diameter, the intrinsic resolutions are

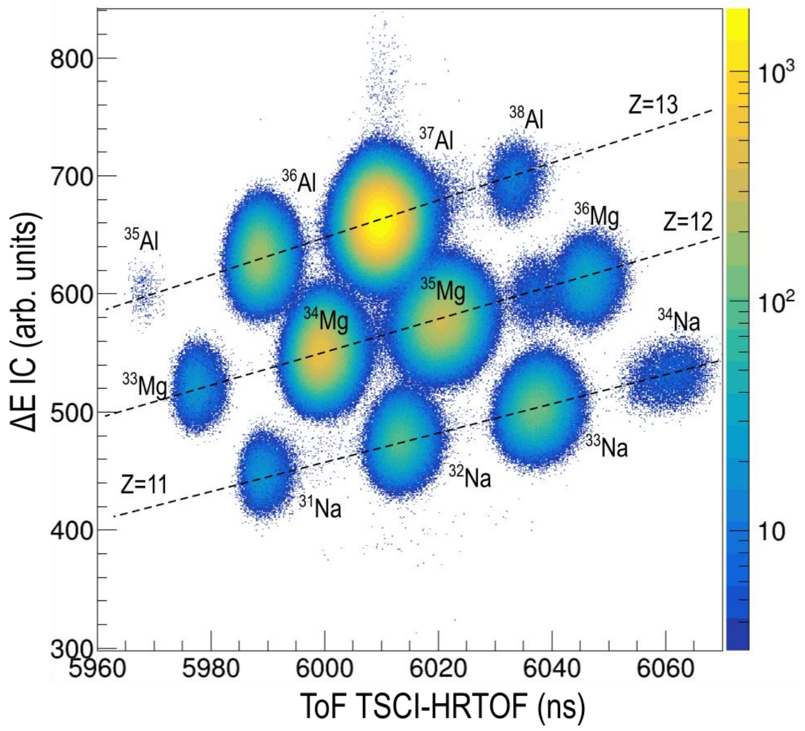
σ_x = 0.30(10) mm

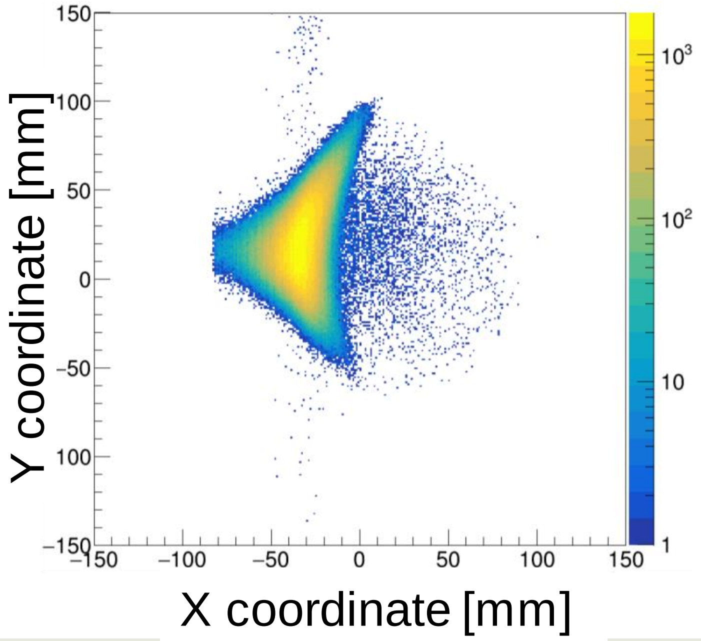
σ_y = 0.42(4) mm

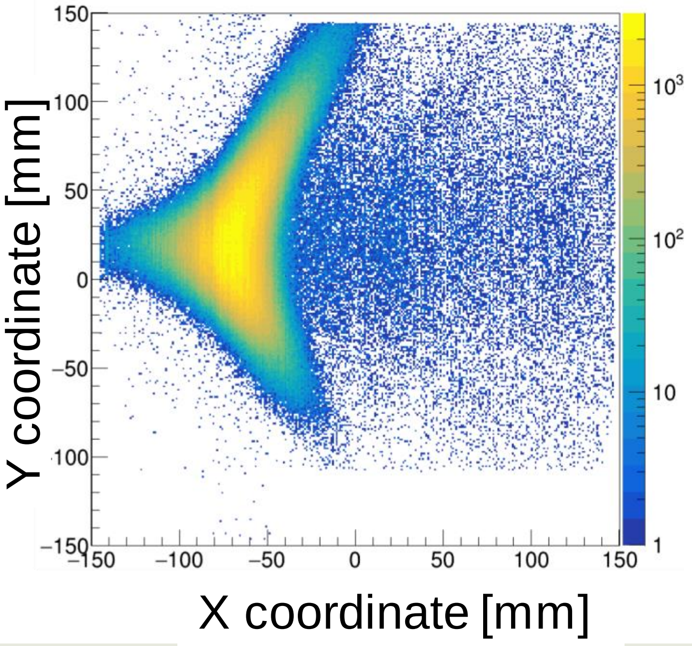
Sweeper Magnet System Operation: Experiment with Cocktail Beam Around Z ~ 11 on ^{12}C Target



PID after the reaction target
& Sweeper Magnet
Preliminary results







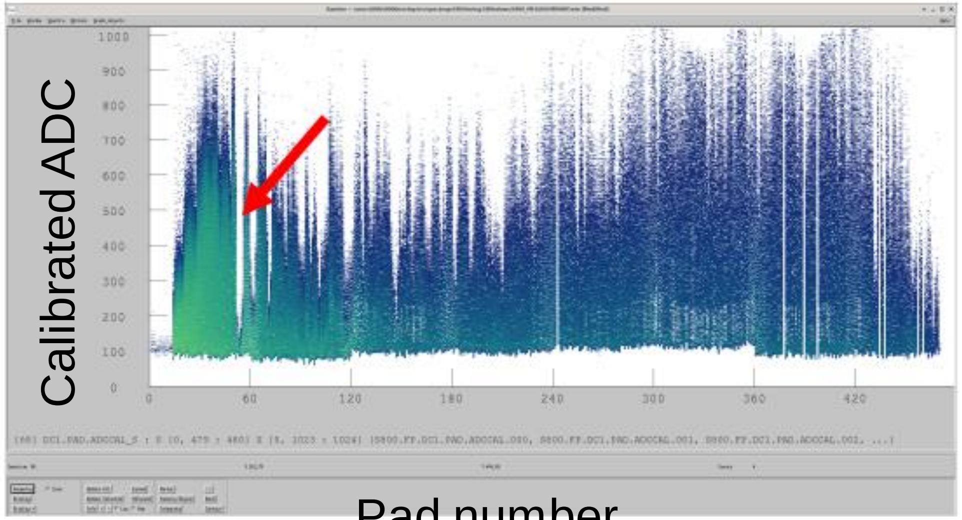
MPDC#1 and MPDC#2
Gated on unreacted ^{37}Al incoming beam

Courtesy of J. Lois-Fuentes and The MoNA collaboration

e23068

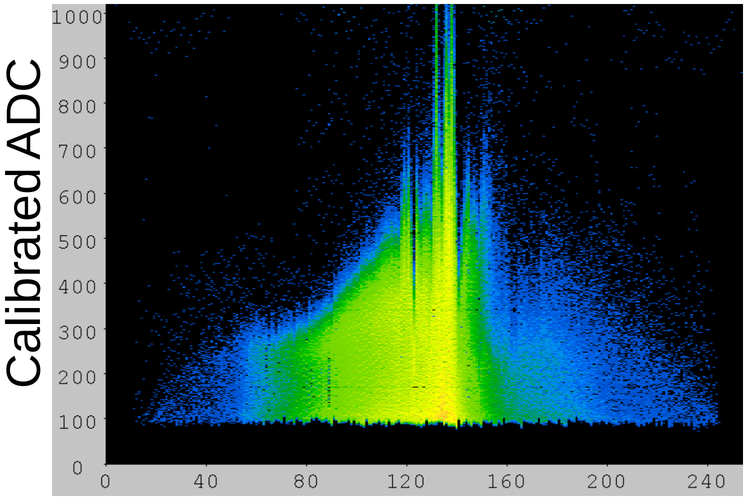
Ion Feedback Effects Still Limiting Performance at High Gain with Light Ions at High Rates

- S800: 23Si beam in Nov 2024

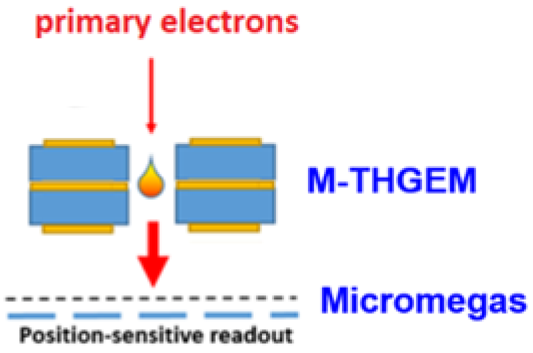


Pad number

Sweeper: 17C beam May 2025



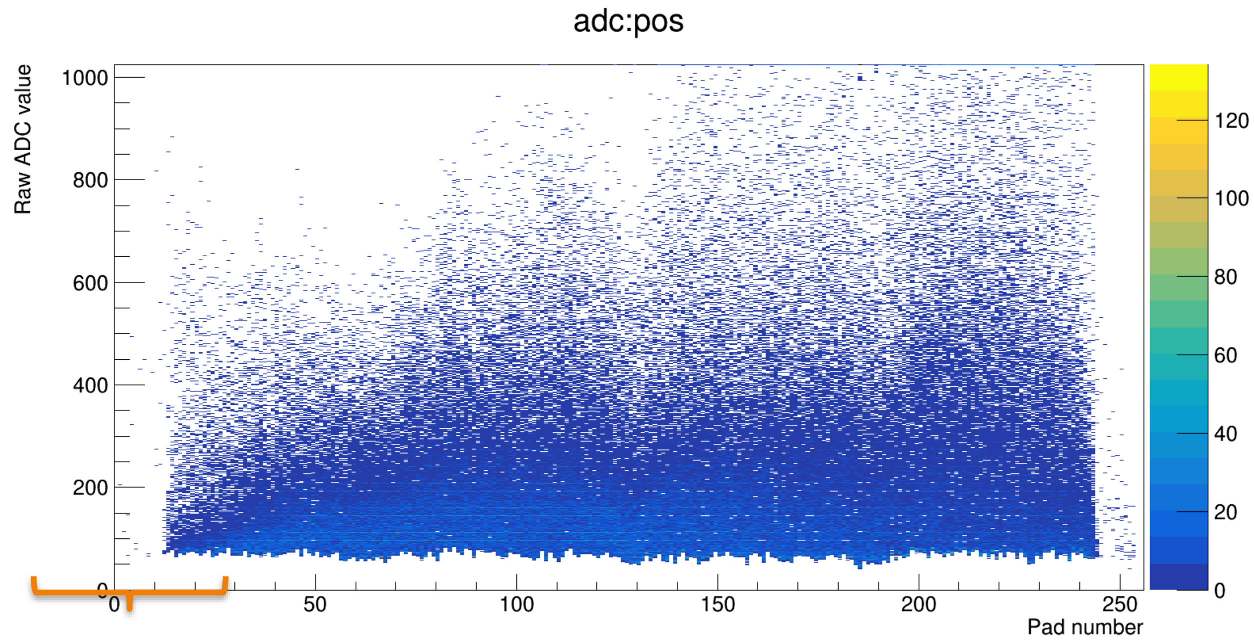
Pad number



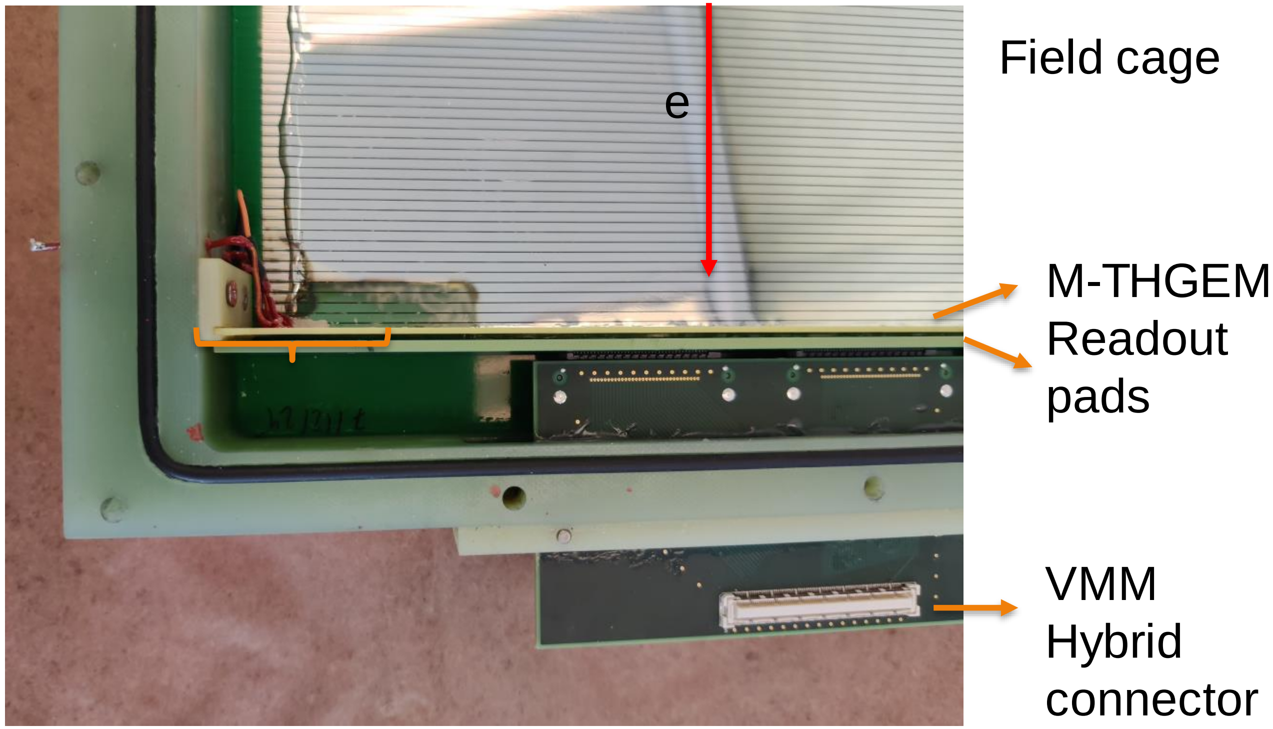
- Possible solution:
  - » Reconfigure the amplification structure by adding Micromegas or a Multi-Mesh THGEM to reduce ion backflow from the gas avalanche structure into the drift region.

Ongoing Efforts to Understand and Mitigate Edge Effects in the S800

- Solution for the Sweeper: Enlarged the length of the readout to 33 cm → effective only 30 cm
  - Possible issue related to the transport of the avalanche electrons to the segmented pad: distortion of the induced field at the edges



Missing ~1.5 cm on each edge



- Solution for the S800? Micromegas or MM-THGEM might solve the issue

Conclusions

- A new micro-pattern gaseous detector based on the two-layer M-THGEM was developed for FRIB's Sweeper Magnet System: a low-pressure Micro Pattern Drift Chamber (MPDC)
- Two MPDCs have been tested and commissioned with the SRS DAQ in preparation of experimental campaign of Neutron Invariant Mass Spectroscopy in FRIB's Sweeper Magnet System
  - Timestamping capabilities allow external triggering the SRS DAQ and synchronize all other VME electronics
  - Position resolution FWHM < 1 mm
  - High gain operation in low pressure (40 Torr)
  - Stable operation at moderate rates of heavy ions (no discharges observed)
- Two experiments have been successfully completed with 2 more to follow in the beginning of 2026
- Two issues still need to be addressed:
  - Space charge effects due to ion feedback
  - Edge effects

Collaborators on this work: J. Lois Fuentes, M. Cortesi, G. Jhang, G. Cerizza, T.Baumann, J. Pereira, C. Benetti, R. Chyzh, M. Kuich, L. Rakieten and S. Noji