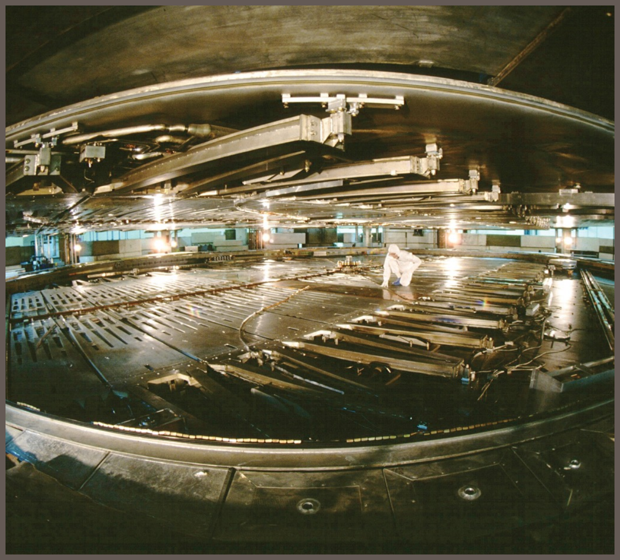
TRIUMF
Canada’s national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Initial Tests of the Recoil Mass Spectrometer EMMA

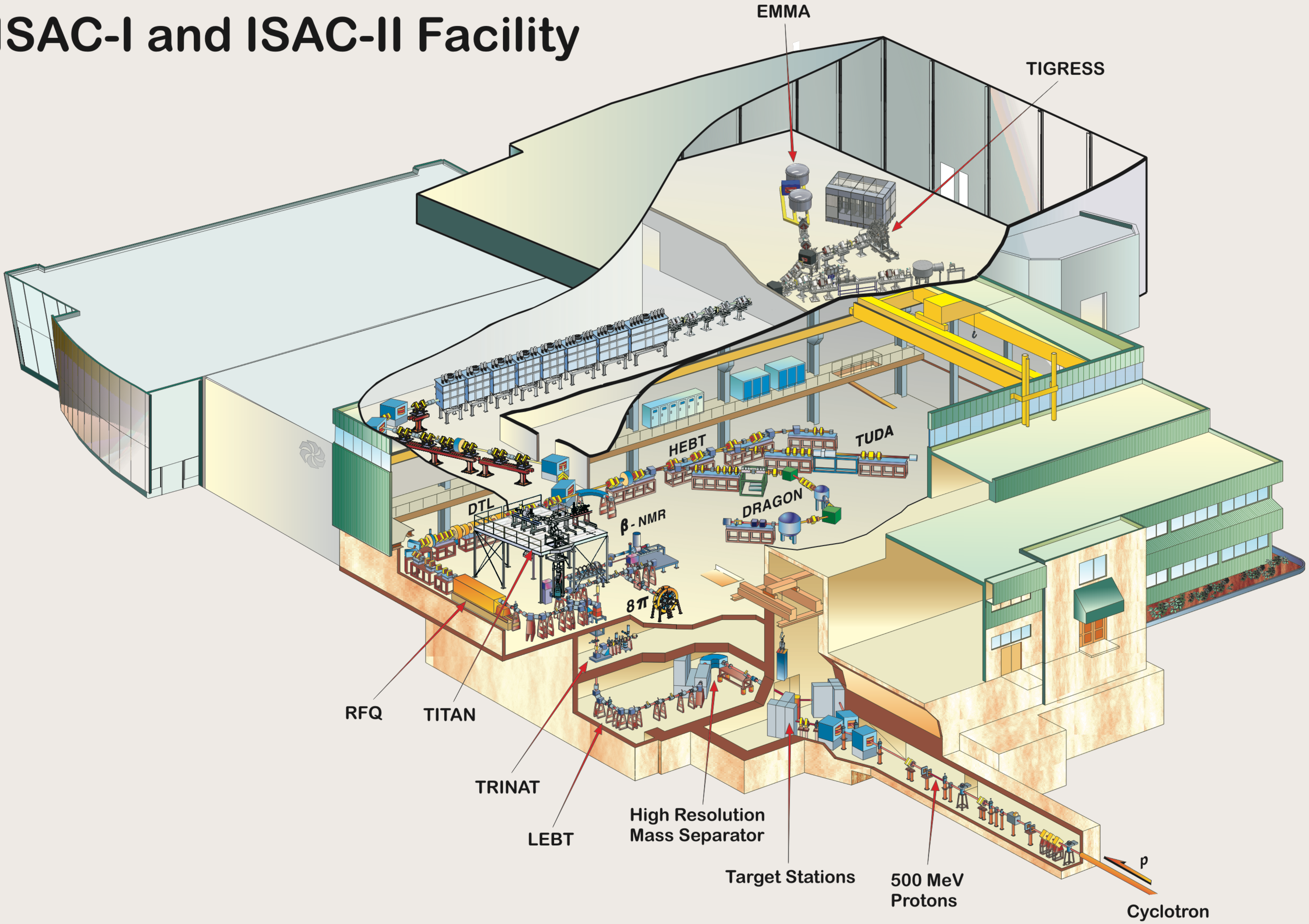


May 30th, 2017

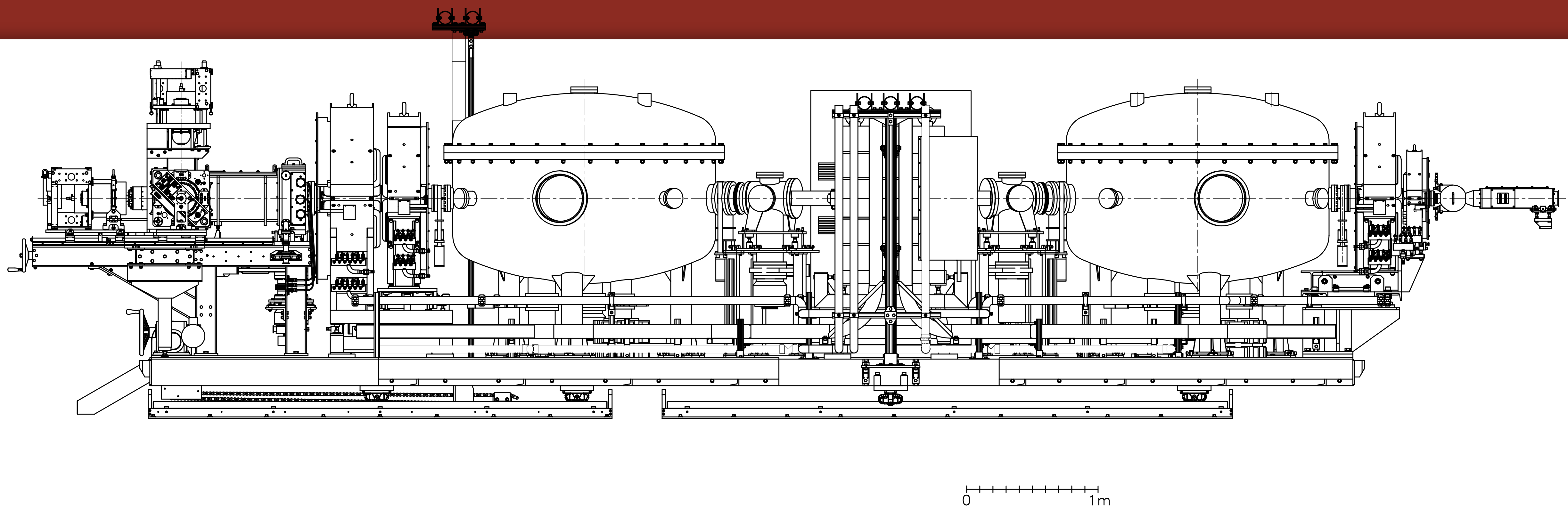
Barry Davids

EMMA in ISAC-II

ISAC-I and ISAC-II Facility



EMMA: The ISAC-II Recoil Spectrometer



- EMMA: recoil mass spectrometer spatially separates heavy products of nuclear reactions from beam & disperses according to mass/charge ratios
- 4 magnetic quadrupole lenses, 1 dipole magnet, 2 electrostatic deflectors, 3 slit systems, target chamber with integral Faraday cup, and modular focal plane detection system w/ PGAC, ionization chamber, and Si detectors
- Magnets and deflectors from contractor, other components TRIUMF-built

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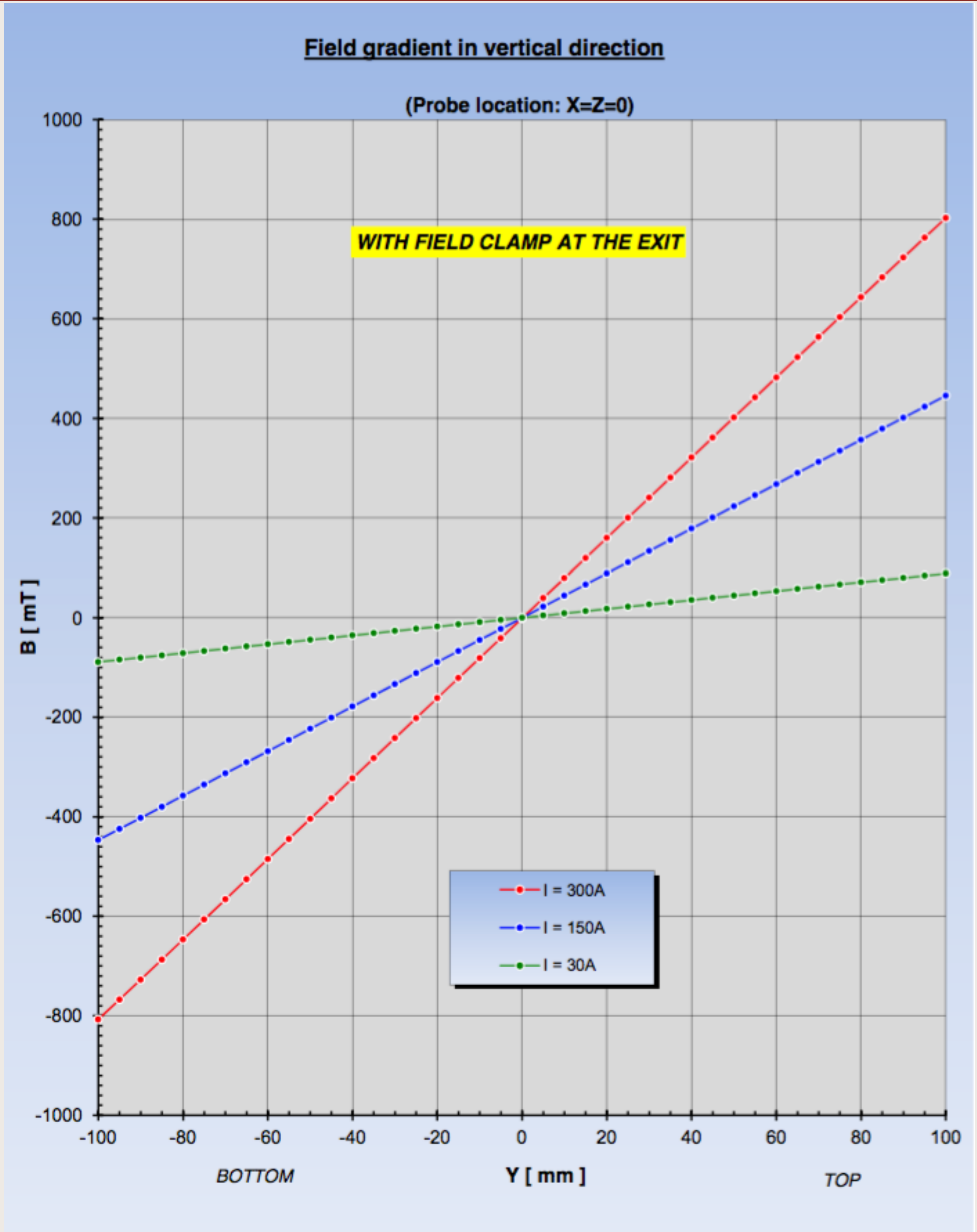
Quadrupole Tests at Manufacturer

- Various properties of 4 quadrupole magnets measured by manufacturer:
- Field Gradient
- Effective Length
- Effective Field Boundary Locations
- Higher Harmonic Content
- Deviation of Mechanical and Magnetic Axes



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Quadrupole Tests at TRIUMF

- Field gradients of all 4 quadrupoles measured as a function of current using Hall effect magnetometer, which was calibrated using an NMR system and the uniform field of our dipole magnet
- Field is measured at all times using a reference probe, which was calibrated simultaneously

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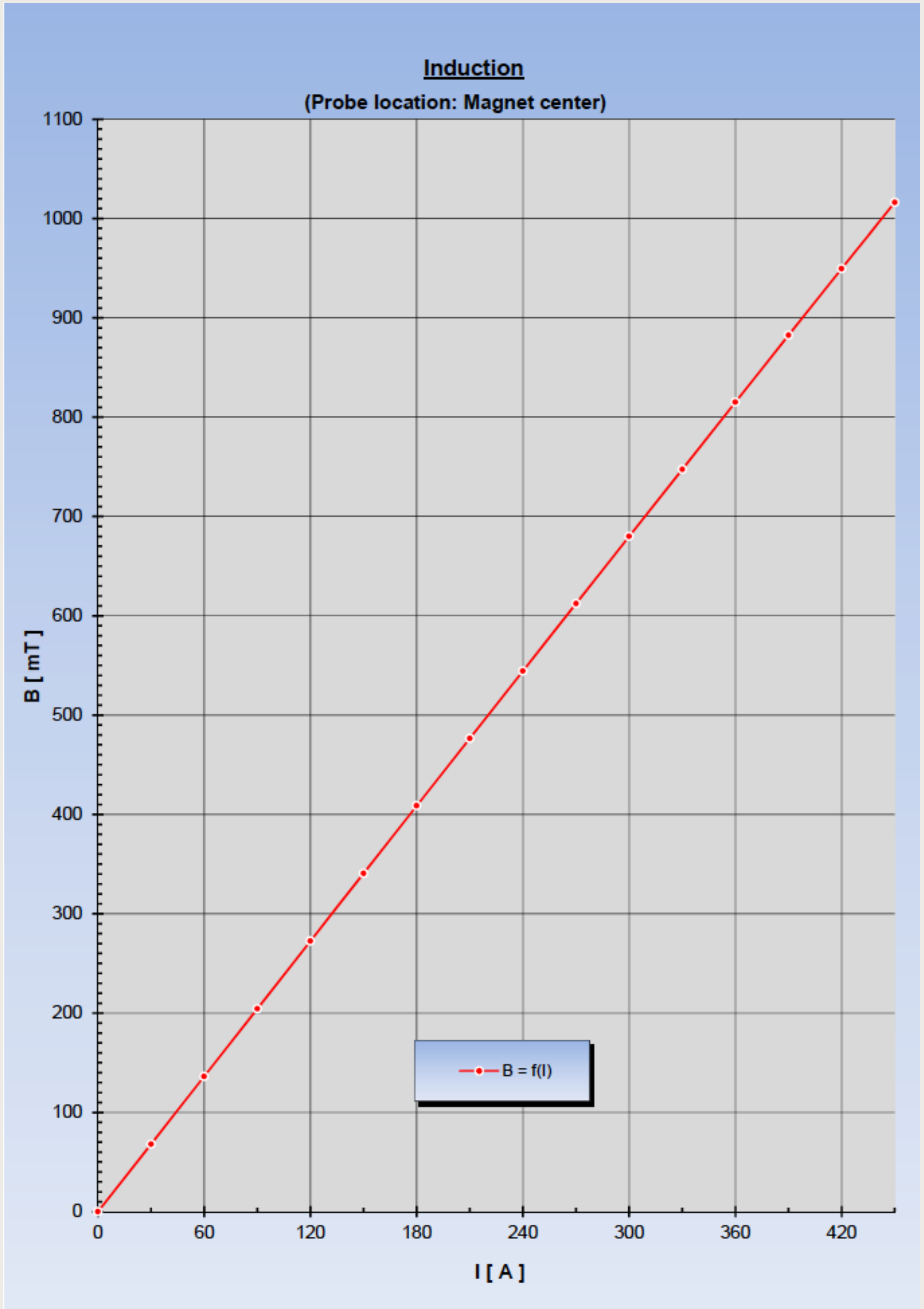
EMMA Quadrupole Lenses

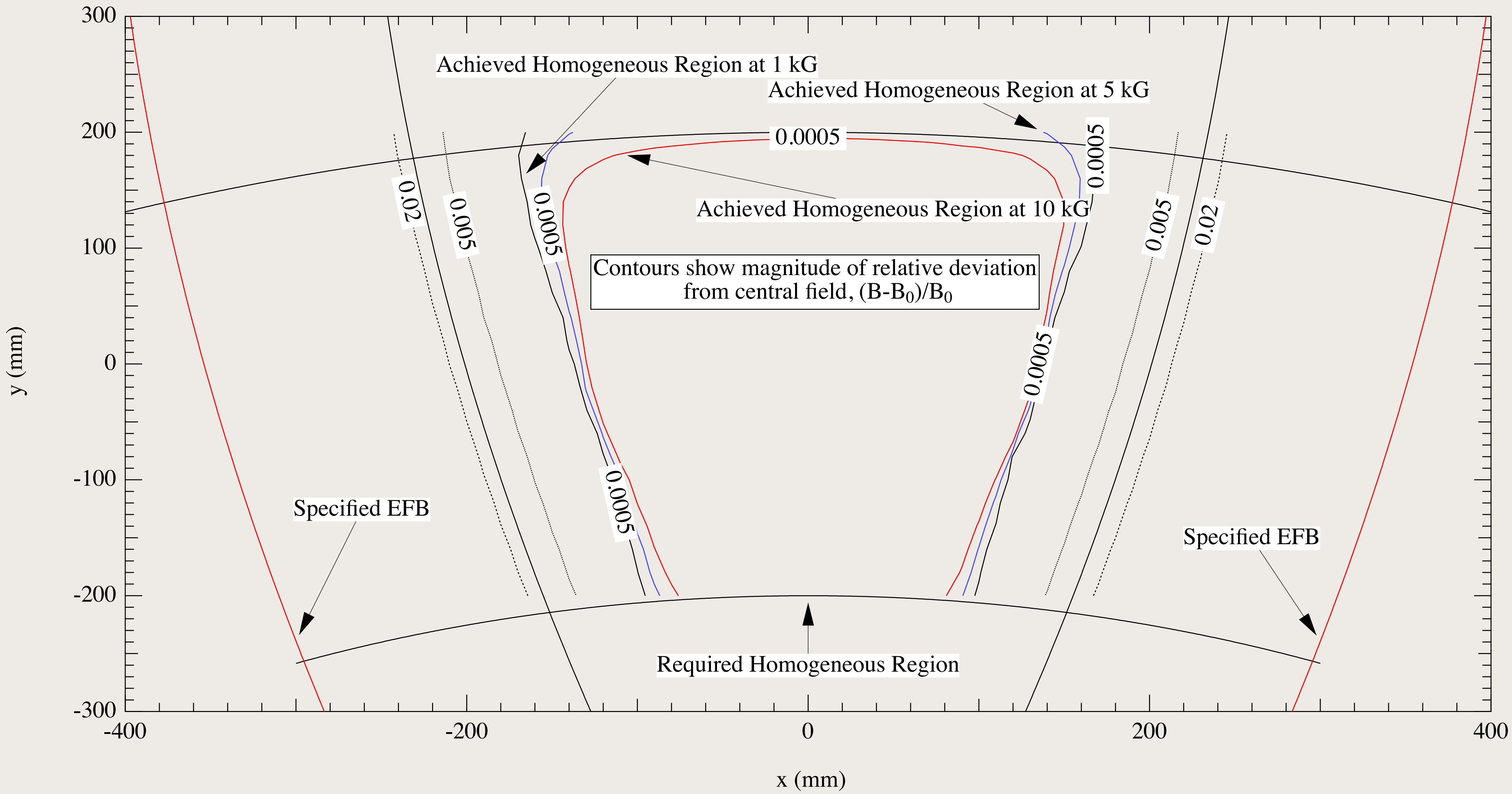
Magnetic Lenses	Quadrupole 1	Quadrupoles 2 & 3	Quadrupole 4
Bore Diameter	7 cm	15 cm	20 cm
Specified Effective Length	14 cm	30 cm	40 cm
Achieved Effective Length	13.98 cm	29.98 cm/29.88 cm	40.18 cm
Specified Maximum Pole Tip Field	1.21 T	0.87 T	0.81 T
Achieved Maximum Pole Tip Field	1.21 T	0.84 T	0.80 T
Achieved Field Gradient	34.6 T m^{-1}	11.3 T m^{-1}	8.4 T m^{-1}

Dipole Tests at Manufacturer

- 40 degree dipole magnet's field mapped at manufacturer
- Removable pole shims had to be machined three times before acceptance



Dipole Field Map Analysis



- Homogeneity and field boundary shape at 4 different currents analyzed at TRIUMF; magnet remapped at TRIUMF
- Maximum deviation from required effective length found at bending radius of 800 mm to be just under 0.3%; on average better than 0.1%

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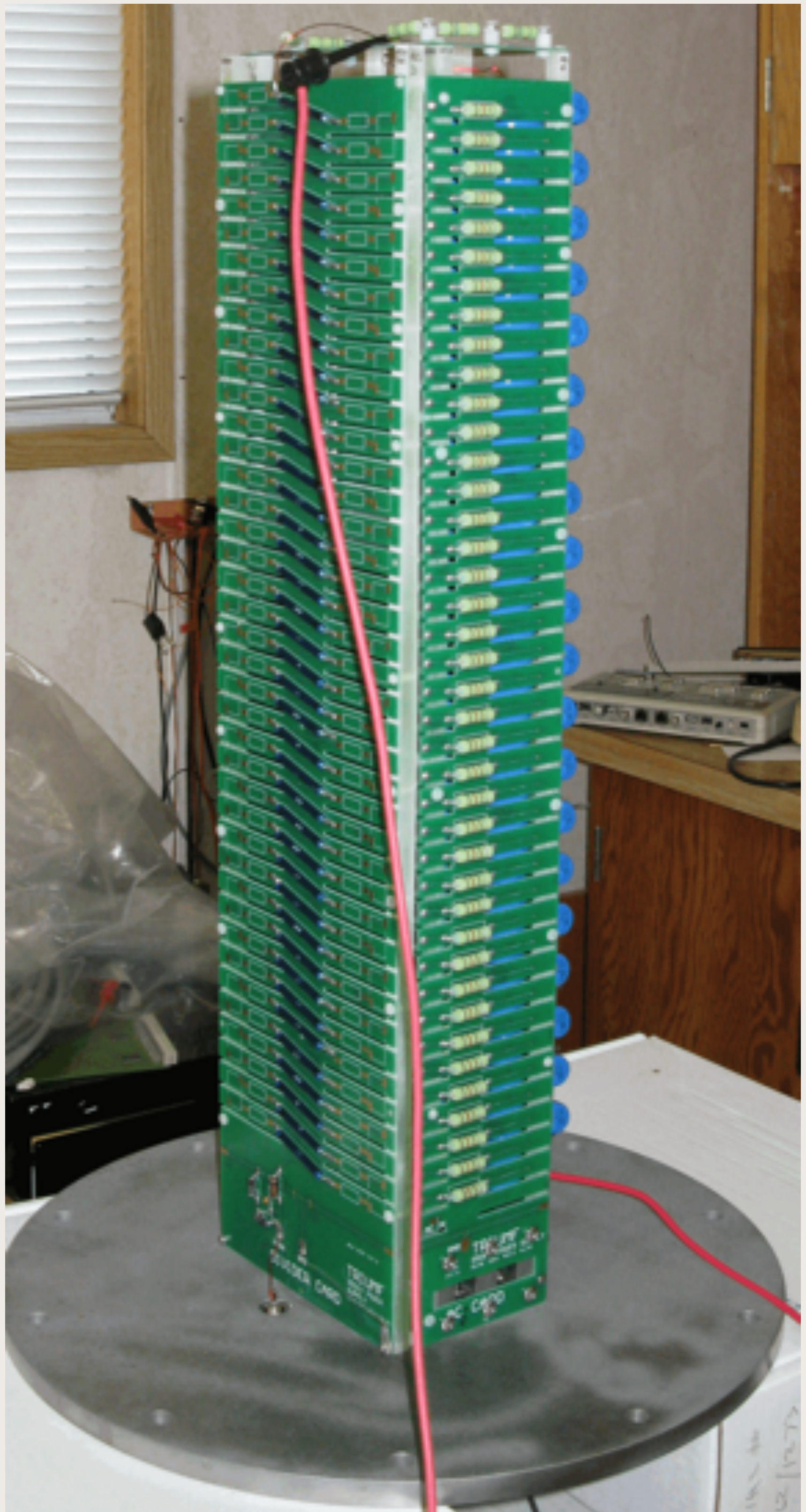
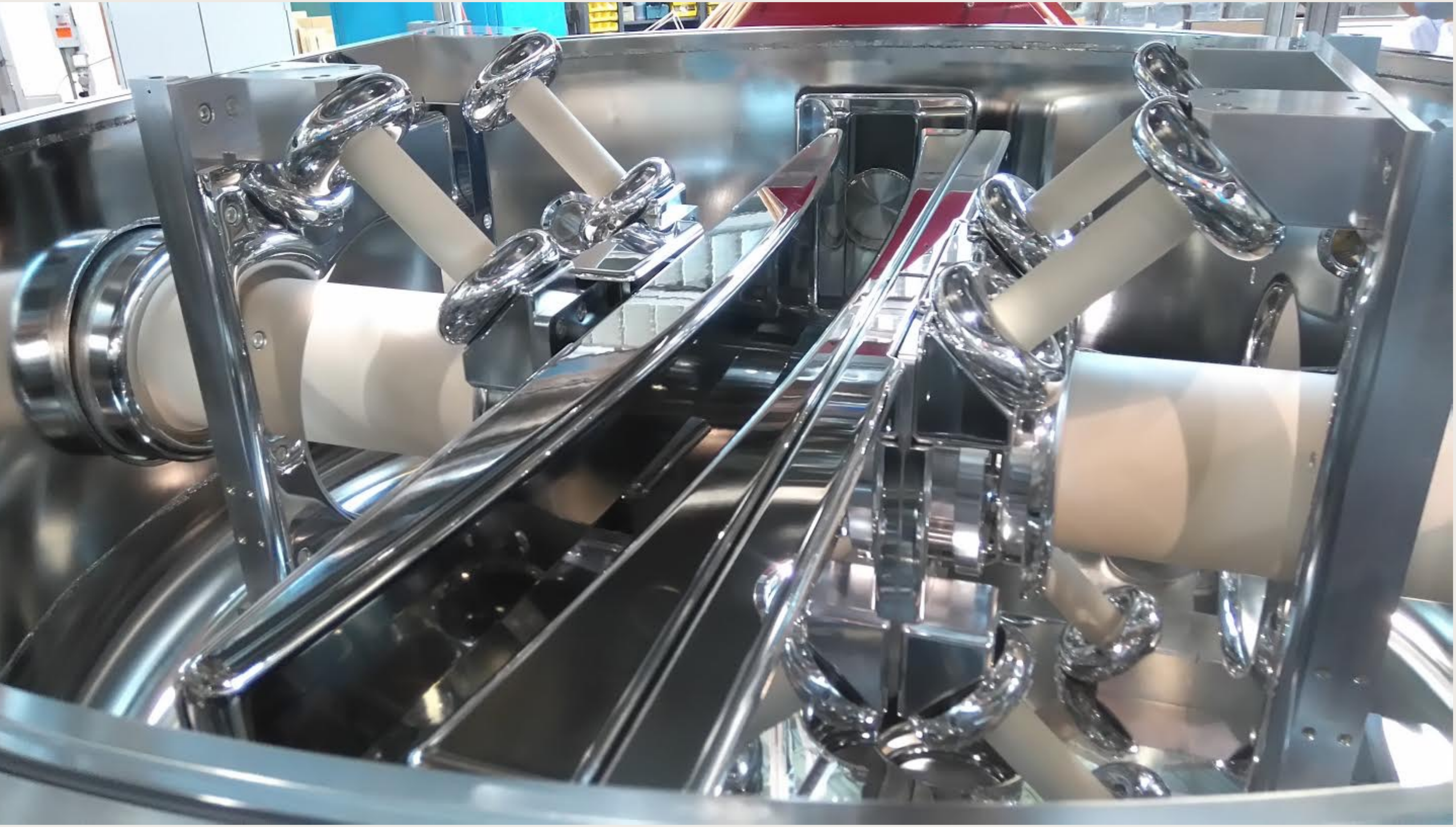
TRIUMF-Built HV Supplies



- Built 3 positive and 3 negative
- All have been tested to $|V| \geq 325$ kV
- Housed in re-entrant ceramic vessel
- Pressurized with 3 bar SF_6

Complete ED2 Electrode Assembly



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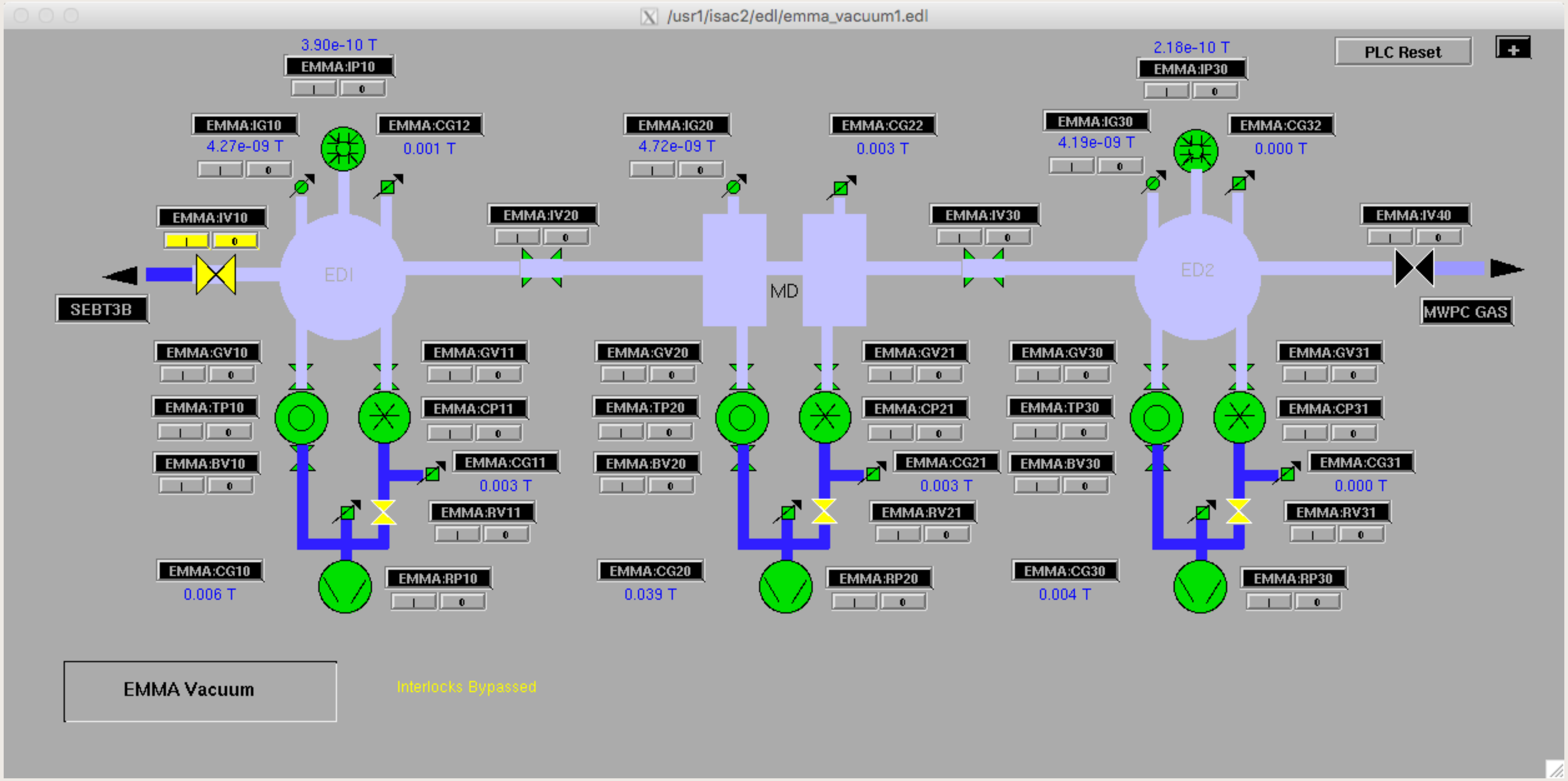
EMMA Dipoles

Dipoles	Magnetic	Electric
Radius of Curvature	1 m	5 m
Specified Deflection Angle	40.00°	20°
Achieved Deflection Angle	40.11°	20.05°
Specified Effective Field Boundary Inclination Angle	8.3°	0
Achieved Effective Field Boundary Inclination Angle	7.93° and 8.67°	
Effective Field Boundary Radii	3.472 m	-
Maximum Field	1 T	40 kV cm^{-1}

Vacuum Systems

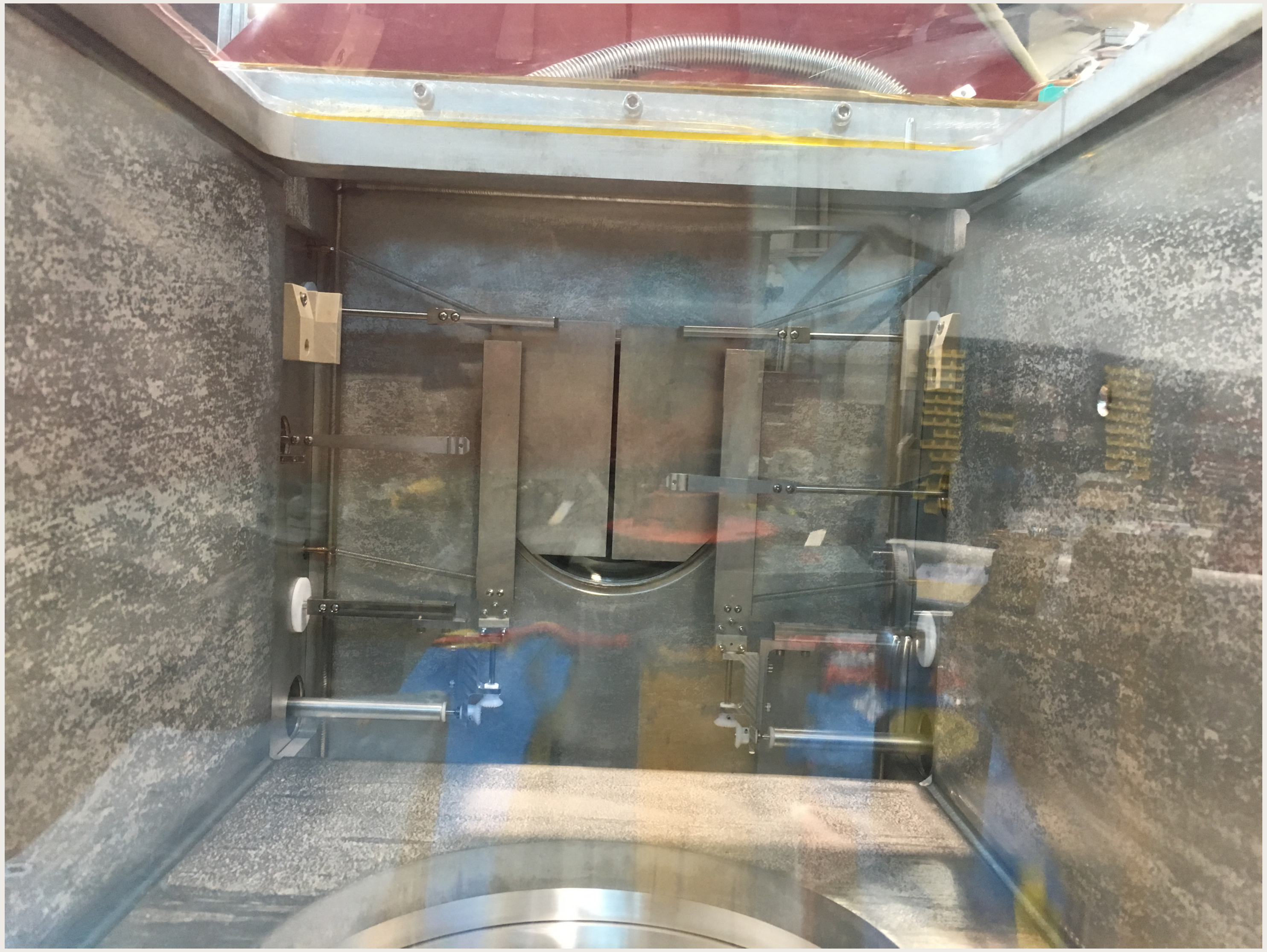


- Typical pressures in 3/4 vacuum sections of 4×10^{-9} Torr; 1000 l/s turbos and 1500 l/s cryos
- Focal plane box has a single 1000 l/s turbo; pressure in low 10^{-6} Torr range

Target Chamber

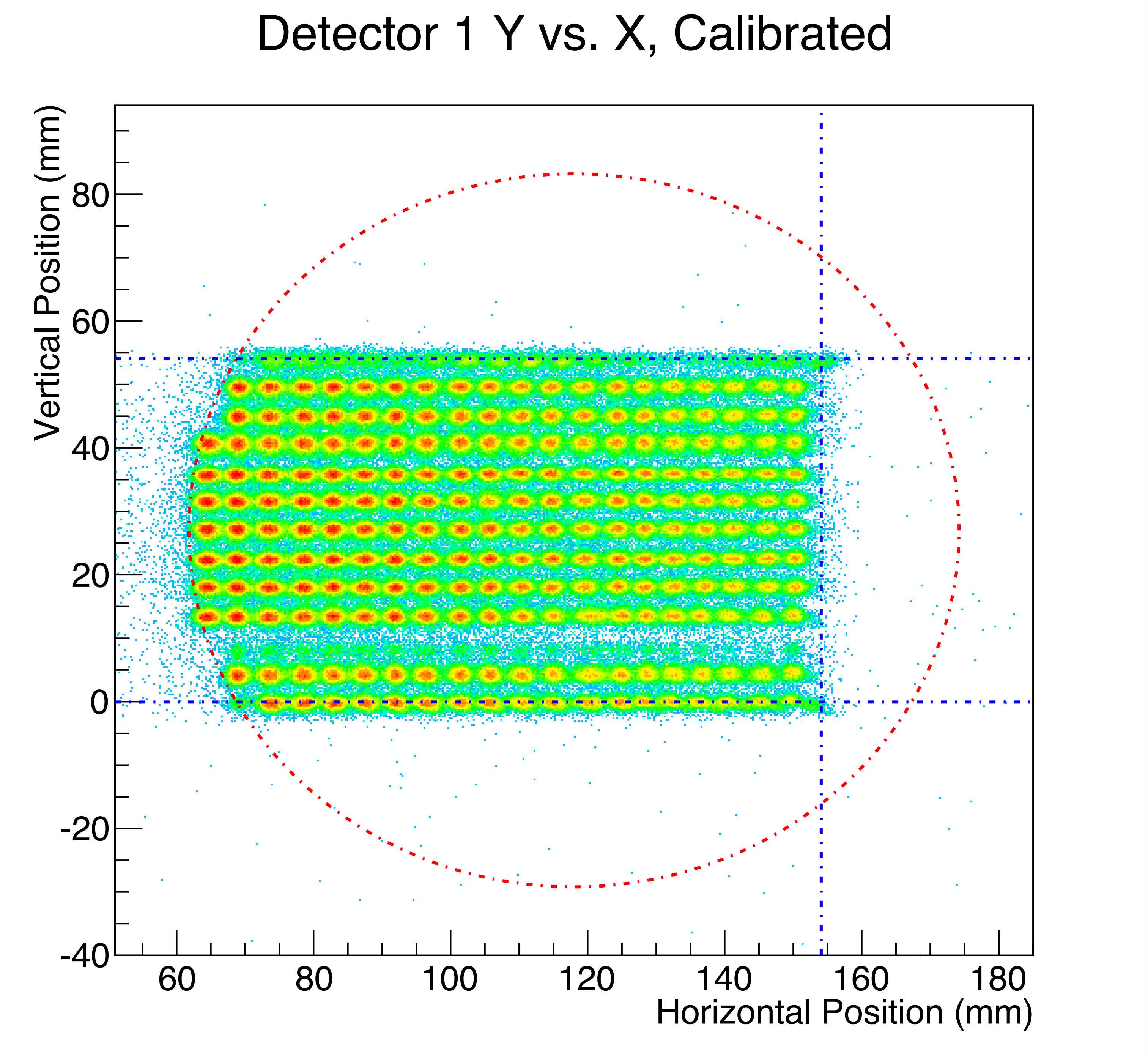
- Integral Faraday cup with 1 mm entrance aperture coincides spatially with target position
- Target wheel with 3 positions
- Pumped by SEBT3B 500 l/s turbo; pressure in low 10^{-7} Torr range

Slit Systems



- Plate slit systems upstream and downstream of dipole magnet
- More complex focal plane slit system has 2 plates and 2 rotatable fingers, allowing for 3 openings of variable width and position

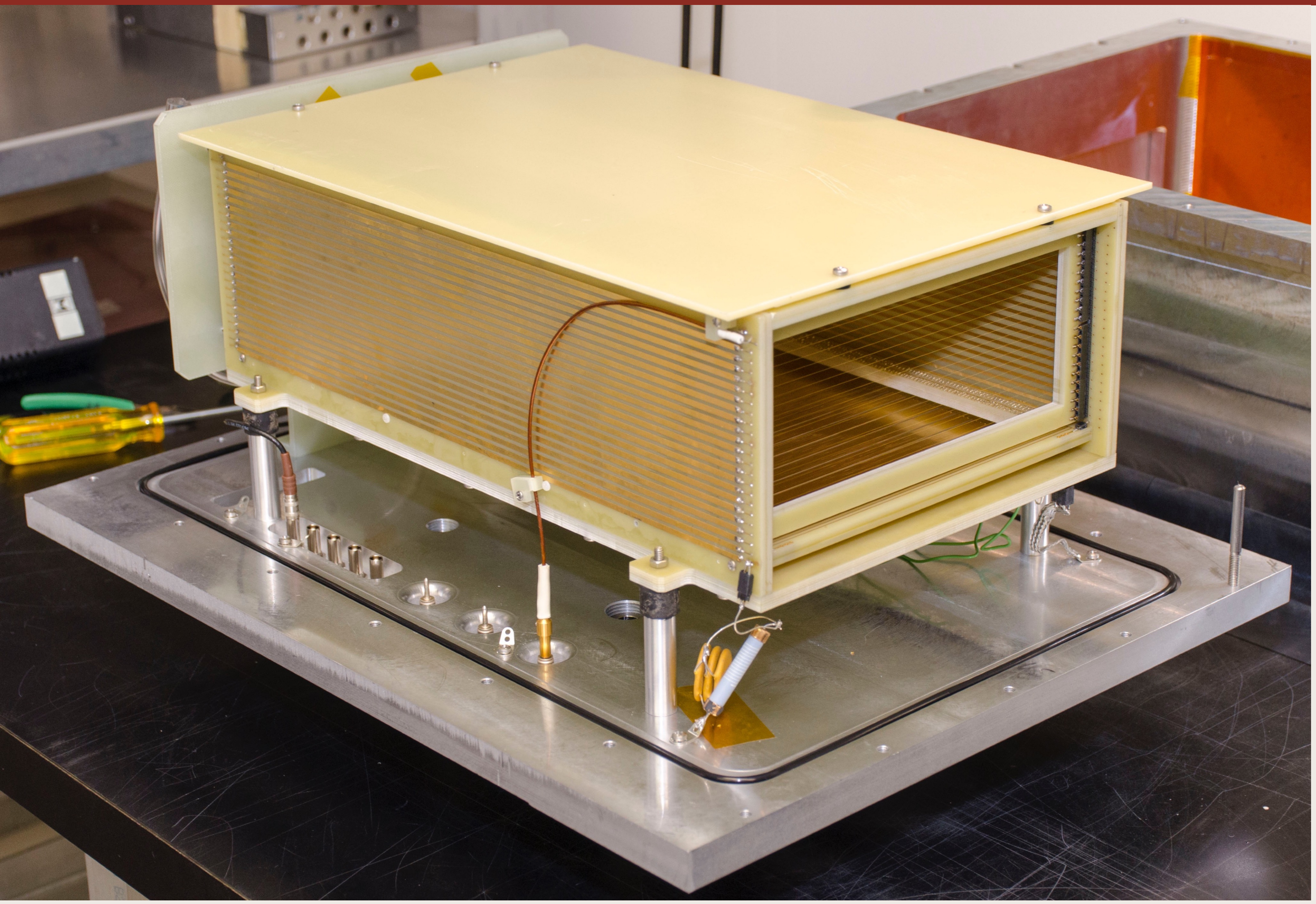
Focal Plane Detectors

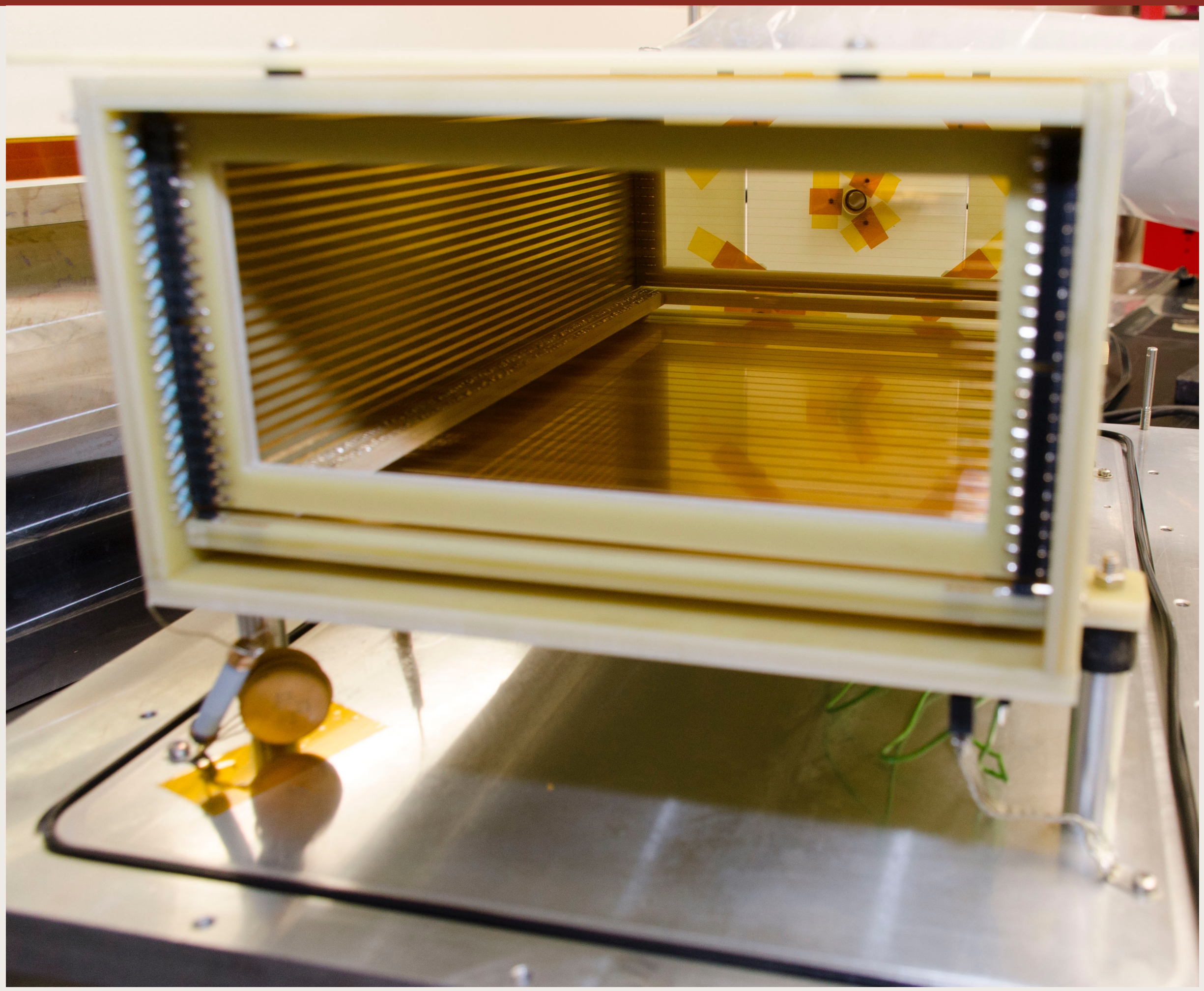


Position resolution 1 mm

Timing resolution 660 ps

Ionisation Chamber

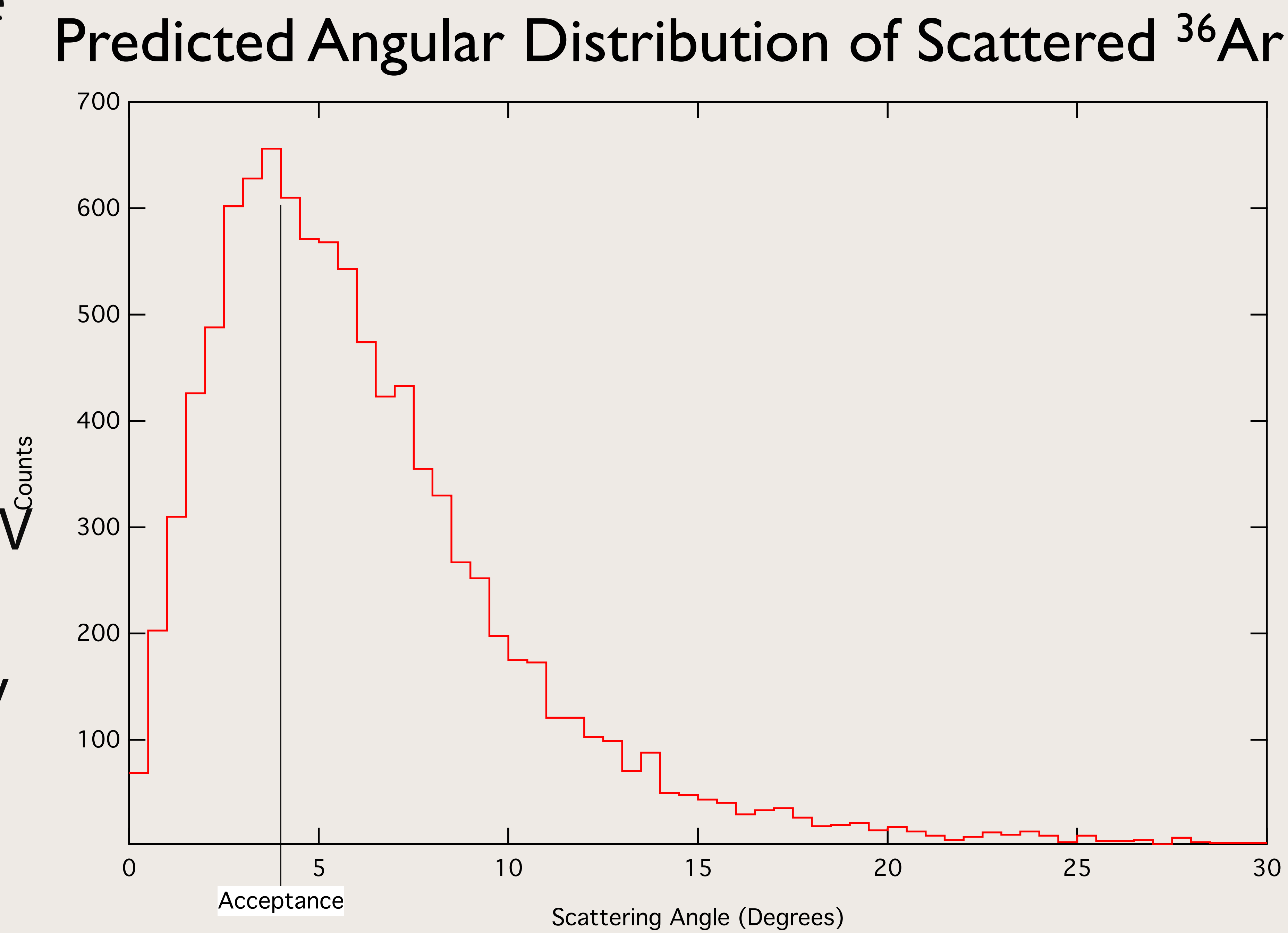




Ionisation chamber tested with alpha and fission sources on bench

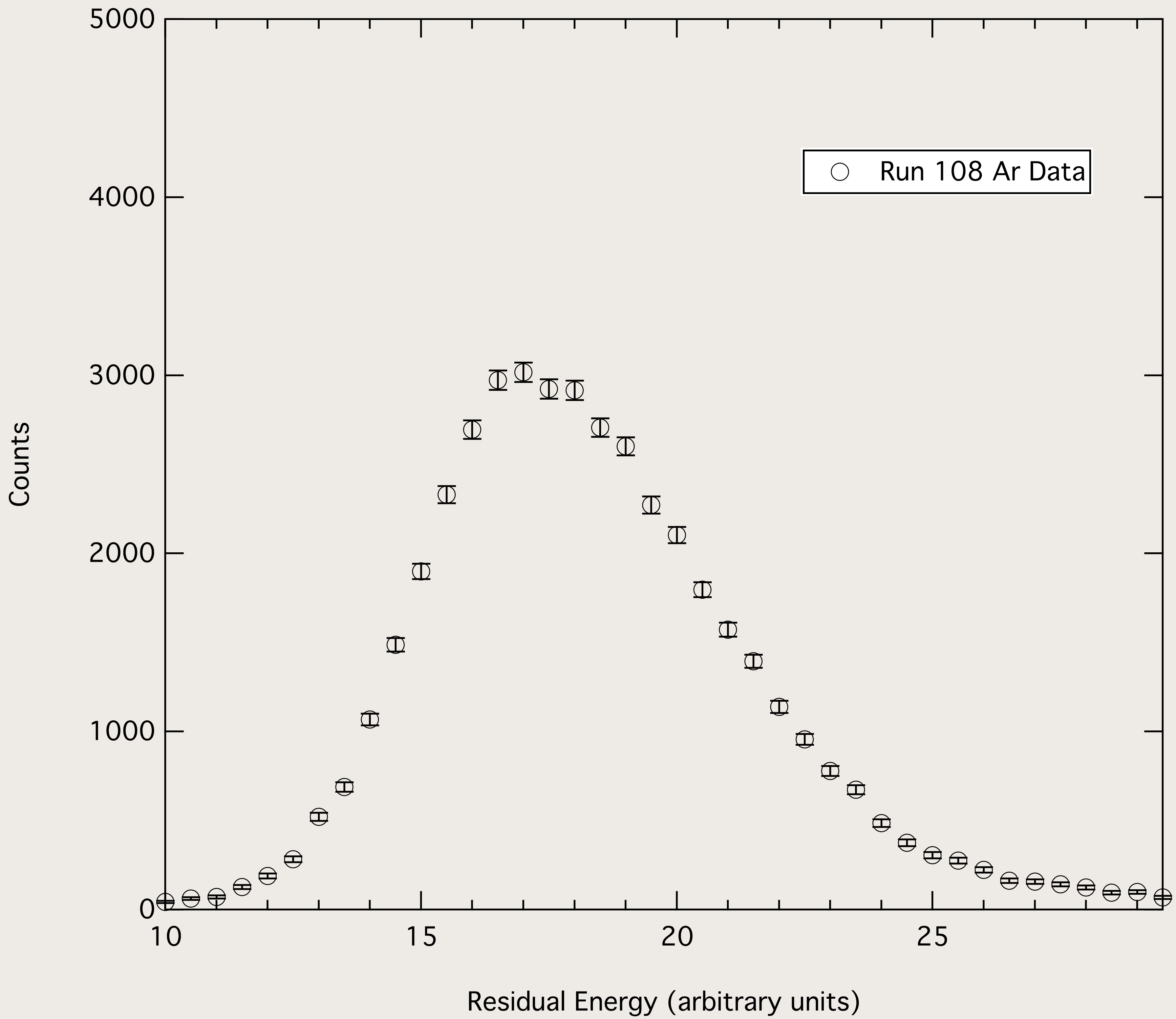
December 2016 Test

- There was no time to commission with an alpha source prior to December 16th beam time
- Bombarded thick Au foil with 80 MeV ^{36}Ar beam
- Tuned for multiply scattered beam with very large angular spread



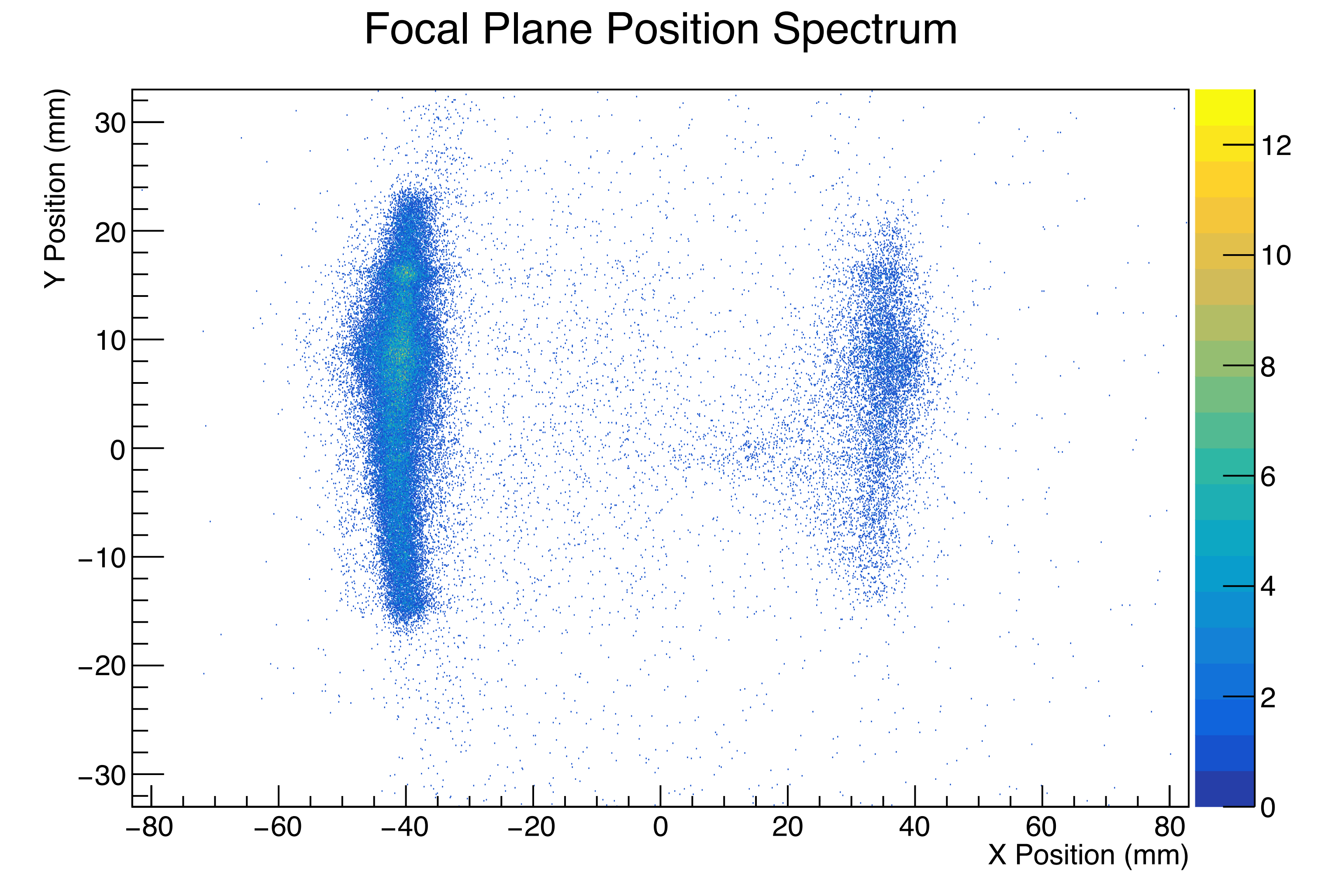
December 2016 Test

- Si-detector measured residual energy spread of 40% FWHM
- Consistent with filling nominal energy acceptance of +25%, -17%



December 2016 Test

Measured Focal Plane Position Spectrum of Scattered ^{36}Ar



EMMA's First M/Q Spectrum

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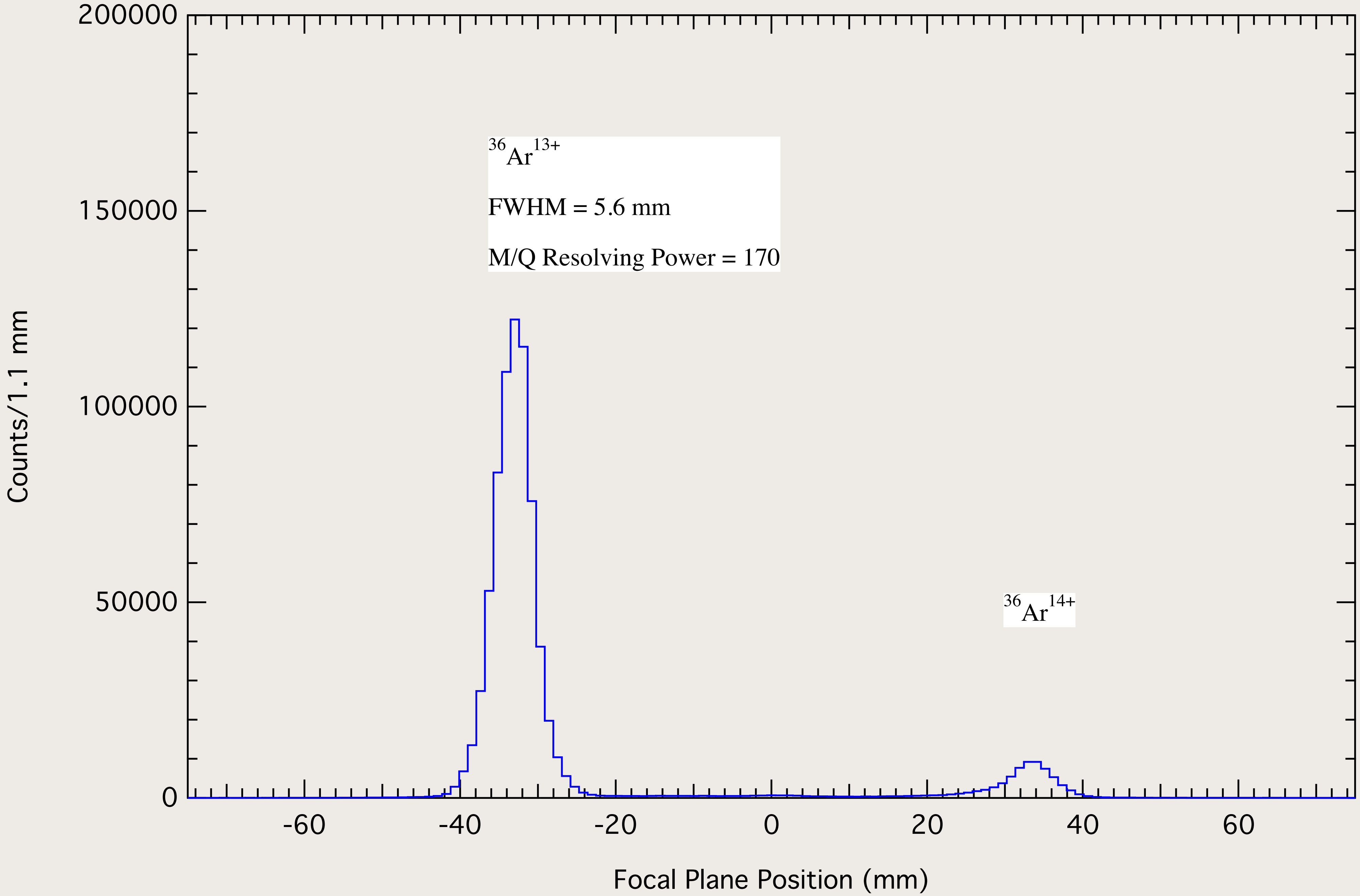
December 2016 Test

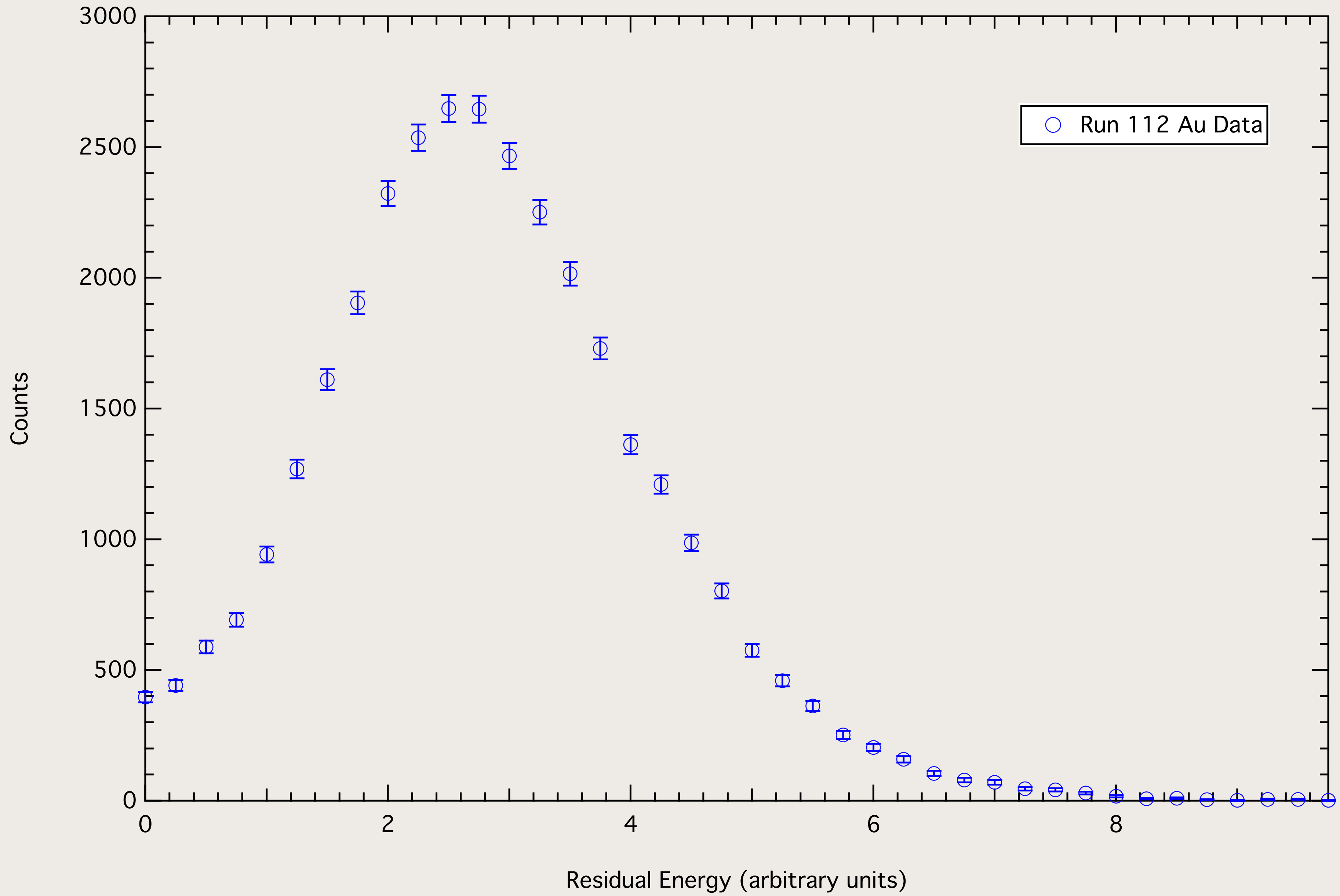
Measured Focal Plane Position Spectrum of Scattered ^{36}Ar



Measured mass/charge dispersion & resolving power consistent with ion optical calculations

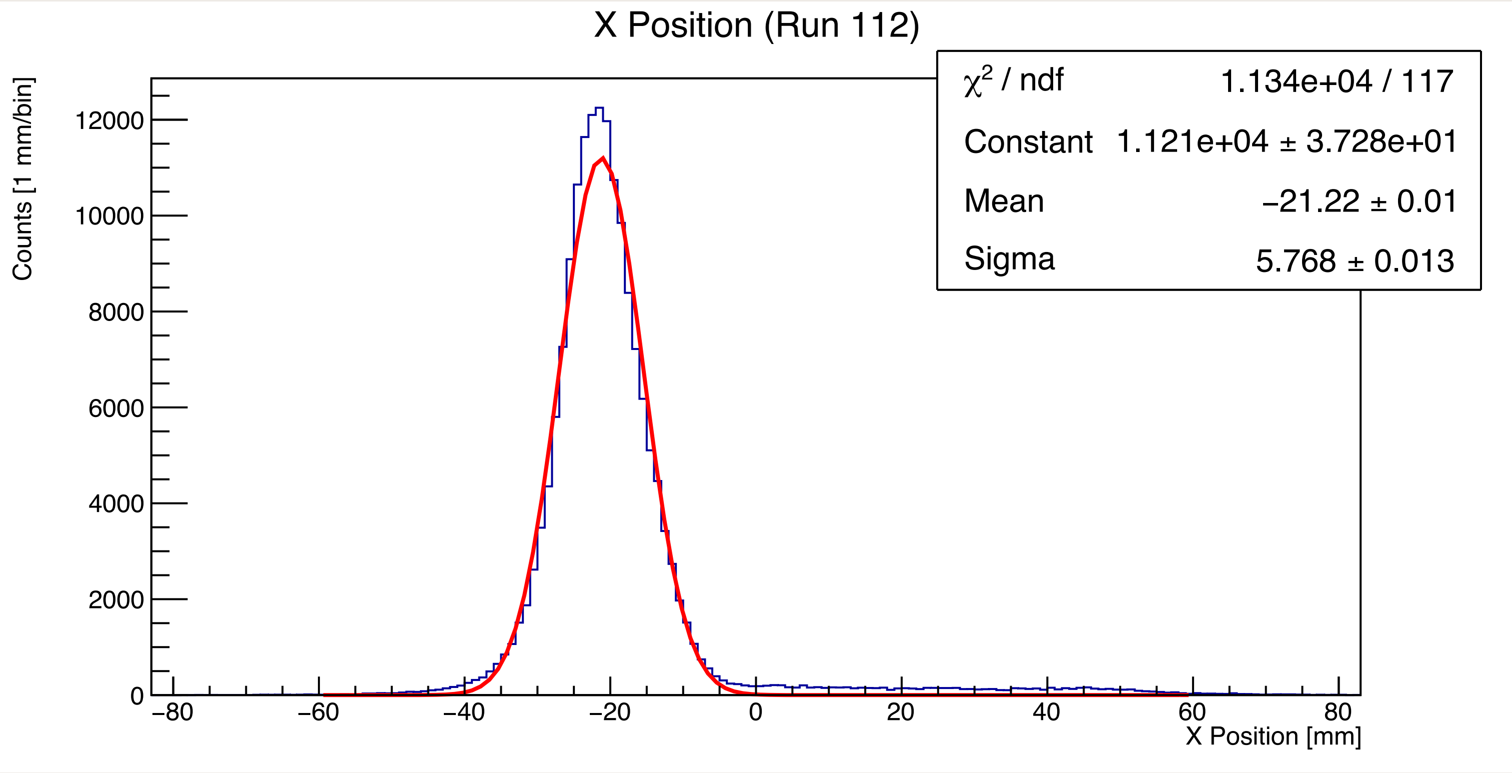
December 2016 Test

- Si-detector measured residual energy spread of 111% FWHM
- Consistent with filling energy acceptance + energy loss straggling in PGAC windows



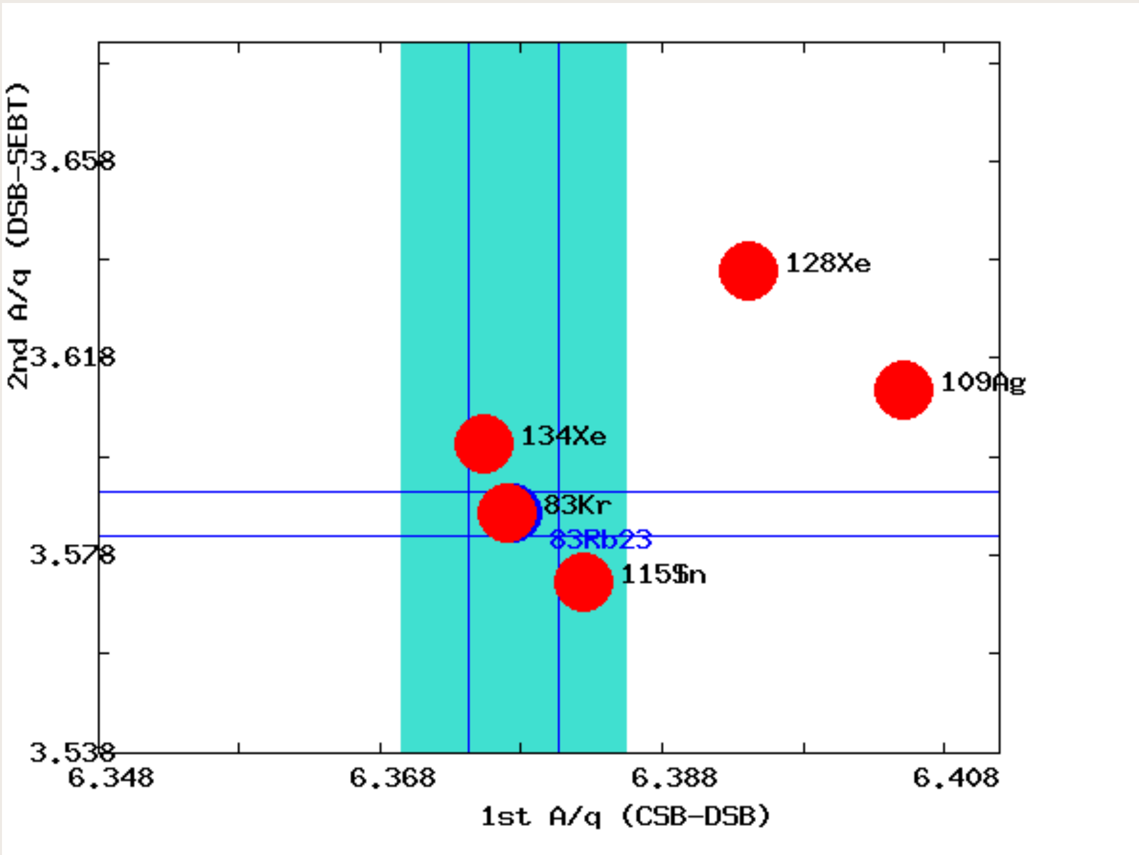
December 2016 Test

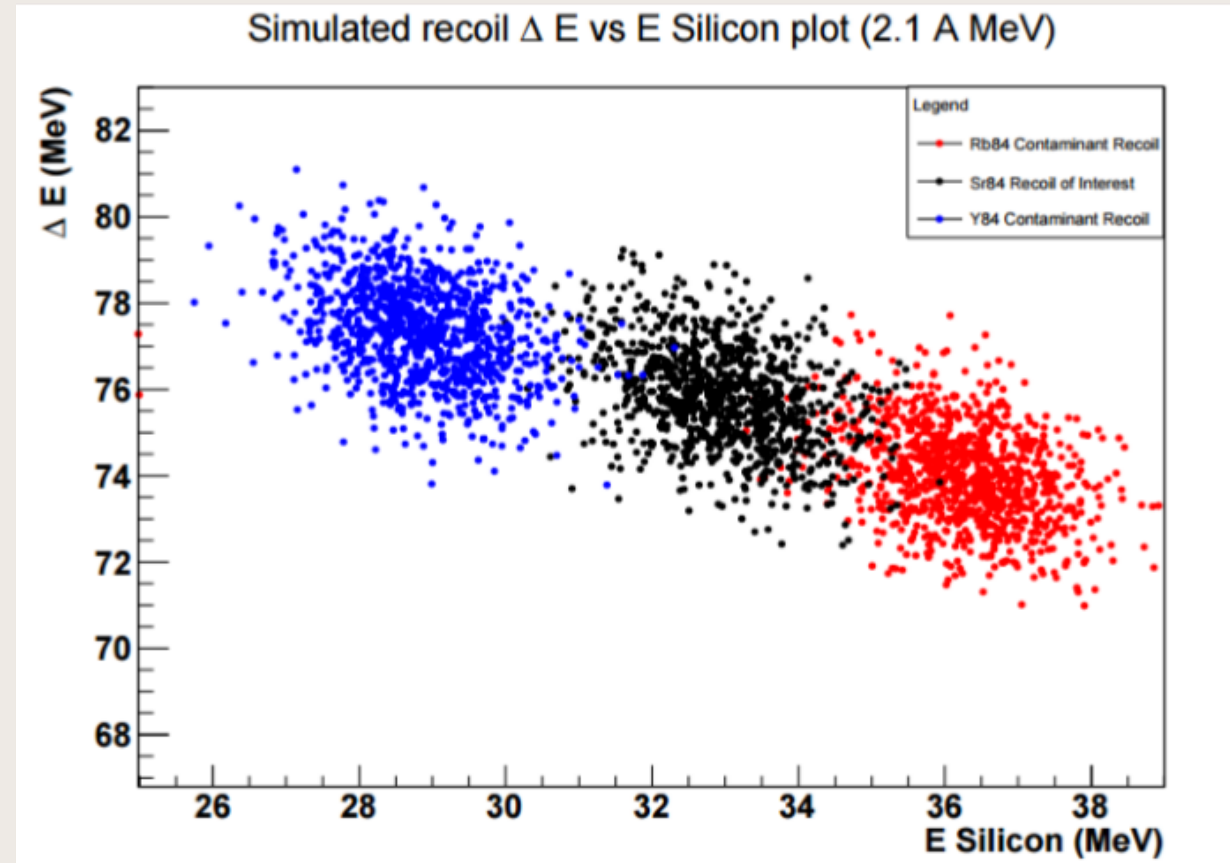
Measured Focal Plane Position Spectrum of Scattered ^{197}Au



Set for $^{197}Au^{9+}$, observed single mass peak, no background in hour-long run with 10^9 ions/s on target implying hardware beam suppression > 10^{12}

Approved Experiments





- Typically EMMA will be required to detect heavy products of fusion and transfer reactions
- Two approved experiments, both of which require TIGRESS to be installed around EMMA target position
- Stable beam experiment: ^{6}Li(^{17}O,d)^{21}Ne to infer ^{17}O(α,γ)^{21}Ne reaction cross section for the *s* process; also requires SHARC
- RIB experiment: direct measurement of p(^{83}Rb,γ)^{84}Sr reaction cross section at *p* process energies

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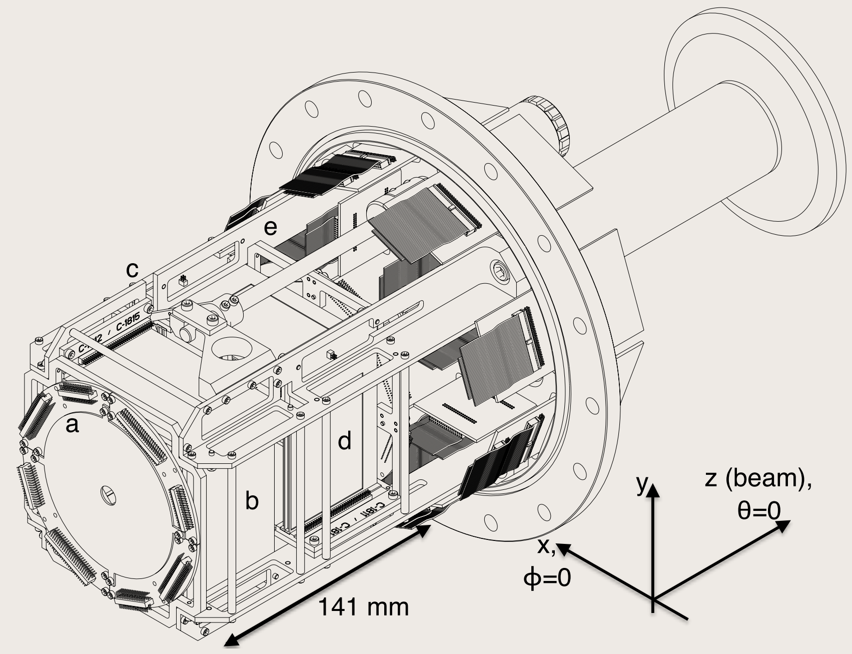
Experiments to be Proposed



- With SHARC: p(^{21}Na,α)^{18}Ne to infer ^{18}Ne(α,p)^{21}Na reaction cross section for Type I X-ray bursts
- With TIGRESS: direct measurements of p(^{78}Kr,γ)^{79}Rb and p(^{79}Br,γ)^{80}Kr reaction cross sections at *p* process energies

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Future Plans

- Continue HV conditioning
  - Both anodes conditioned to 250 kV with <100 nA load current
  - ED2 cathode conditioned to -250 kV with <200 nA load current
  - ED1 cathode drew excessive load current at low voltages, likely due to field emission from dust on cathode and/or field clamp; cleaning underway
  - ED2 reached $\Delta V = 340$ kV this weekend
- Alpha source tests this summer
- Elastic scattering and fusion evaporation reaction with stable beam starting Sep. 23, to complete commissioning
- Standalone experiments possible in fall schedule
- TIGRESS move to EMMA target position during shutdown 2017-2018

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Core Personnel

- Martin Alcorta, ISAC Target & Detector Physicist
- Nicholas Esker, Postdoctoral Researcher
- Kevan Hudson, MSc Student
- Naimat Khan, Project Engineer
- Peter Machule, Expert Technician
- Matt Williams, PhD Student