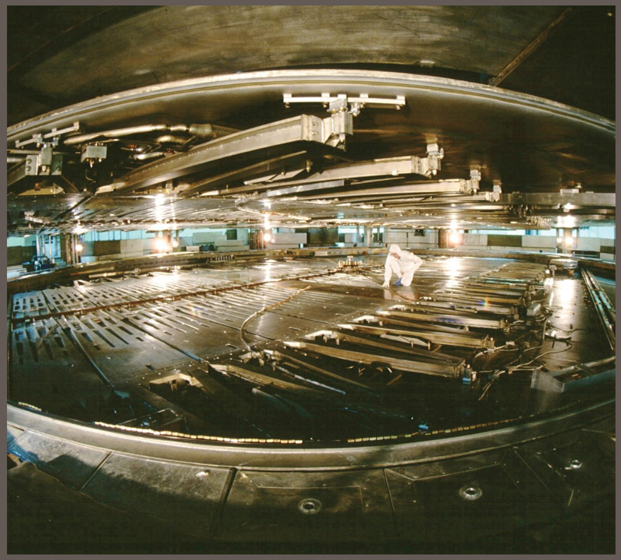
TRIUMF

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

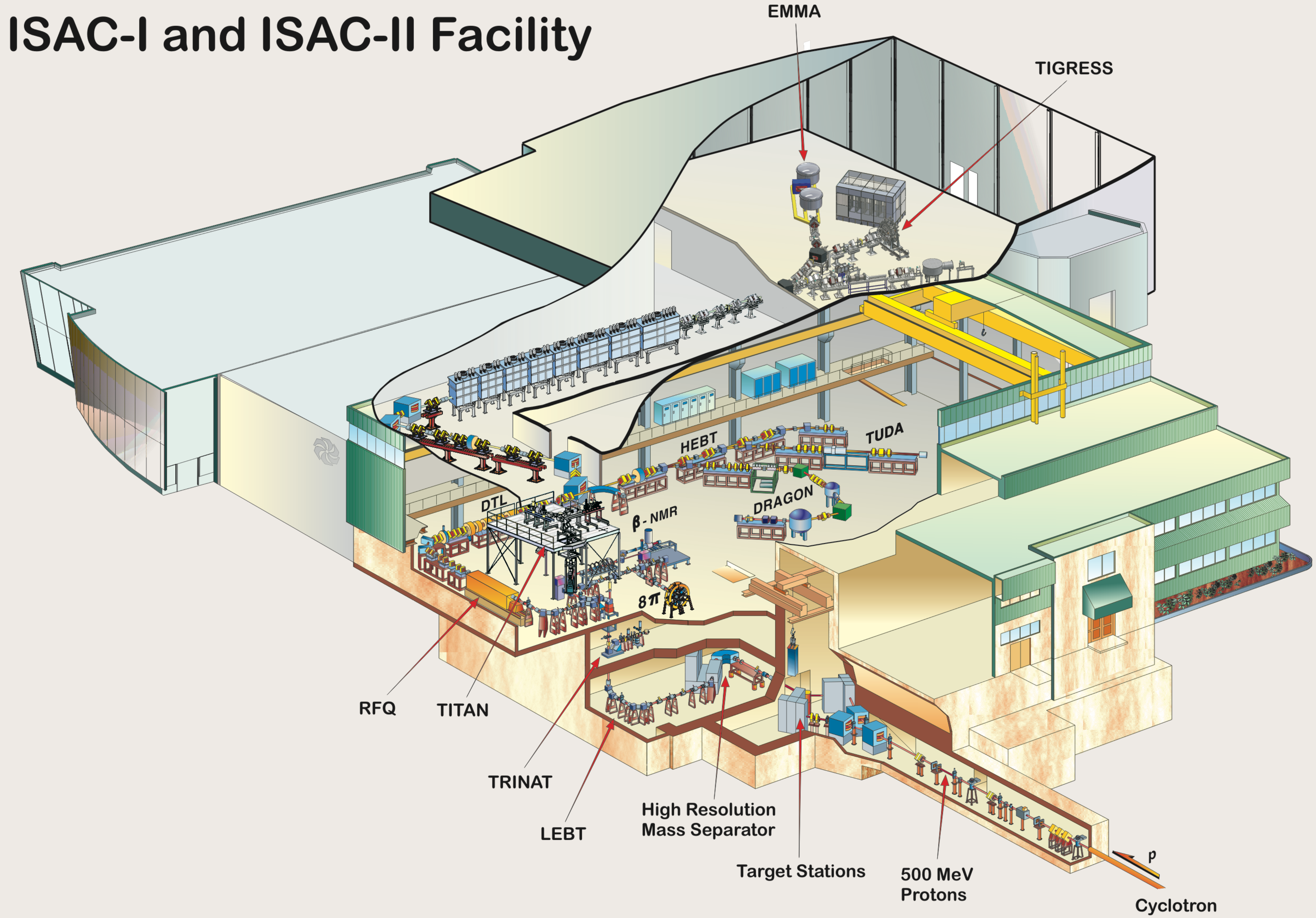


July 14th, 2017

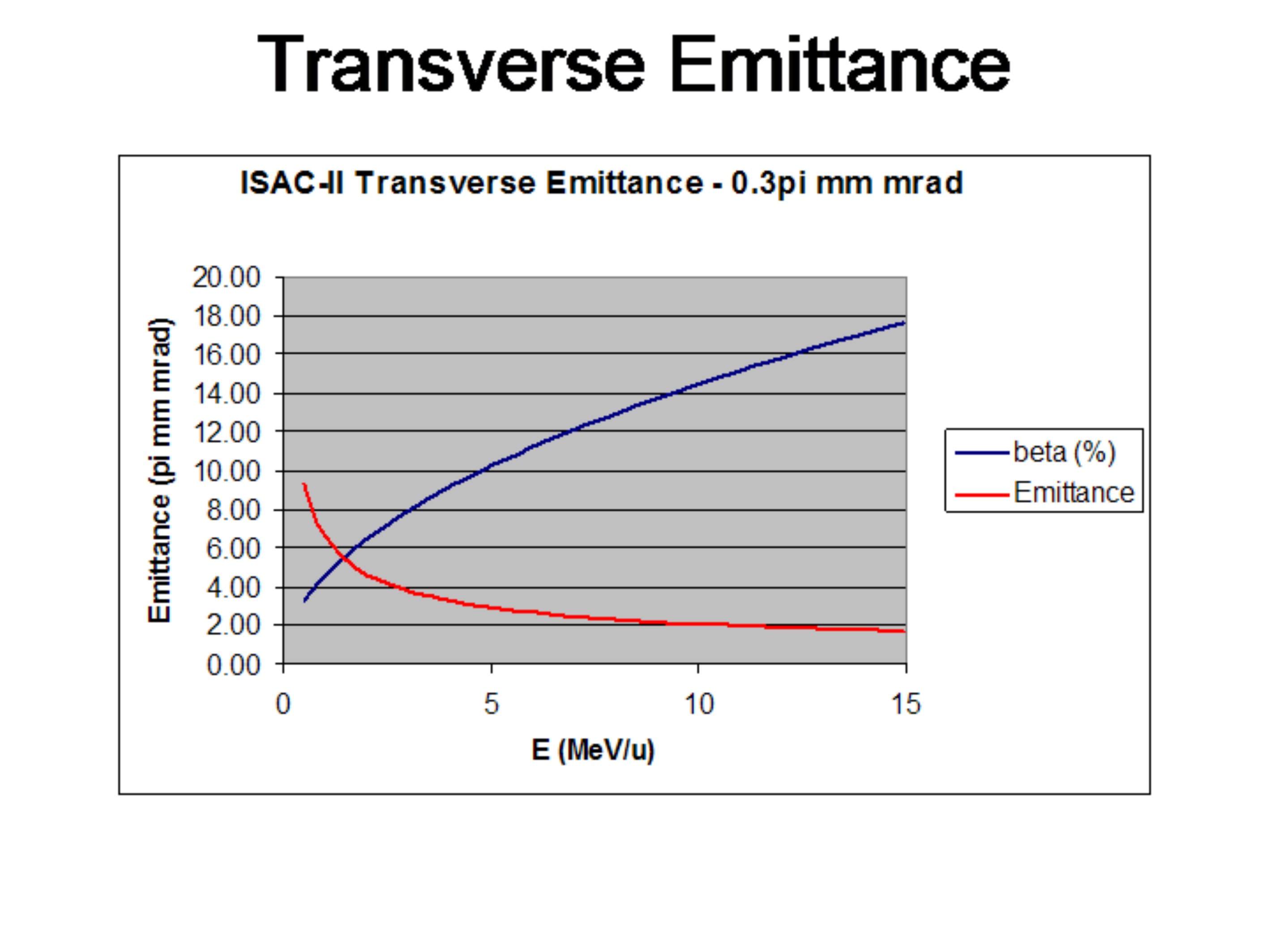
Barry Davids

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

EMMA in ISAC-II



ISAC-II at TRIUMF



High quality RIBs with 2 ≤ A/Q ≤ 6

0.6A MeV ≤ Energy ≤ 16.5A MeV

At 6A MeV, implies at the target position 95% of the beam can be within 0.5 mm of the optic axis with an angle of 5 mrad or less

Nuclear Structure at the Extremes

- Single-particle structure at extreme N/Z values, particularly at and near closed shells (single-nucleon transfer)
- Pairing interactions in N ~ Z nuclei via (p,t), (^{3}He,p), (d,α), (t,p)
- Production and decay studies of highly neutron-rich nuclei via multi-neutron transfers, e.g. (^{18}O,^{15}O)
- High-spin physics in neutron-deficient nuclei via fusion-evaporation reactions (including isomers)

Nuclear Astrophysics

- Direct Studies:
  - Radiative capture reactions
  - (α,n) and (α,p) reactions
  - Time-reversed (α,p) reactions
- Indirect Studies:
  - Spectroscopy of unbound states
  - Particle-decay branching ratios

Defining the Problem I

- In transfer and fusion-evaporation reactions, spectroscopic information obtained from detecting light ejectiles and gamma rays
- Interpretation of spectra complicated or rendered impossible by background from other channels
- For transfers with light ejectile detection, kinematic lines obscured by diffuse background
- For fusion-evaporation, gamma spectra contaminated by lines from other nuclei, frequently produced much more copiously than the nucleus of interest
- Direct identification of residual nuclei required

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Defining the Problem II

- Use of particle detectors to directly detect recoils complicated by 2 problems:
  - In both fusion-evaporation and transfer reactions in inverse kinematics, heavy recoils emerge from target within the cone of elastically scattered beam particles; for sufficiently intense beams, these detectors cannot count fast enough
  - For heavy recoils (m > 100 u), energy resolution of these detectors is insufficient to permit unique identification
- Recoil separator needed to separate recoils from beam, identify according to A and Z, and localize them for subsequent decay studies

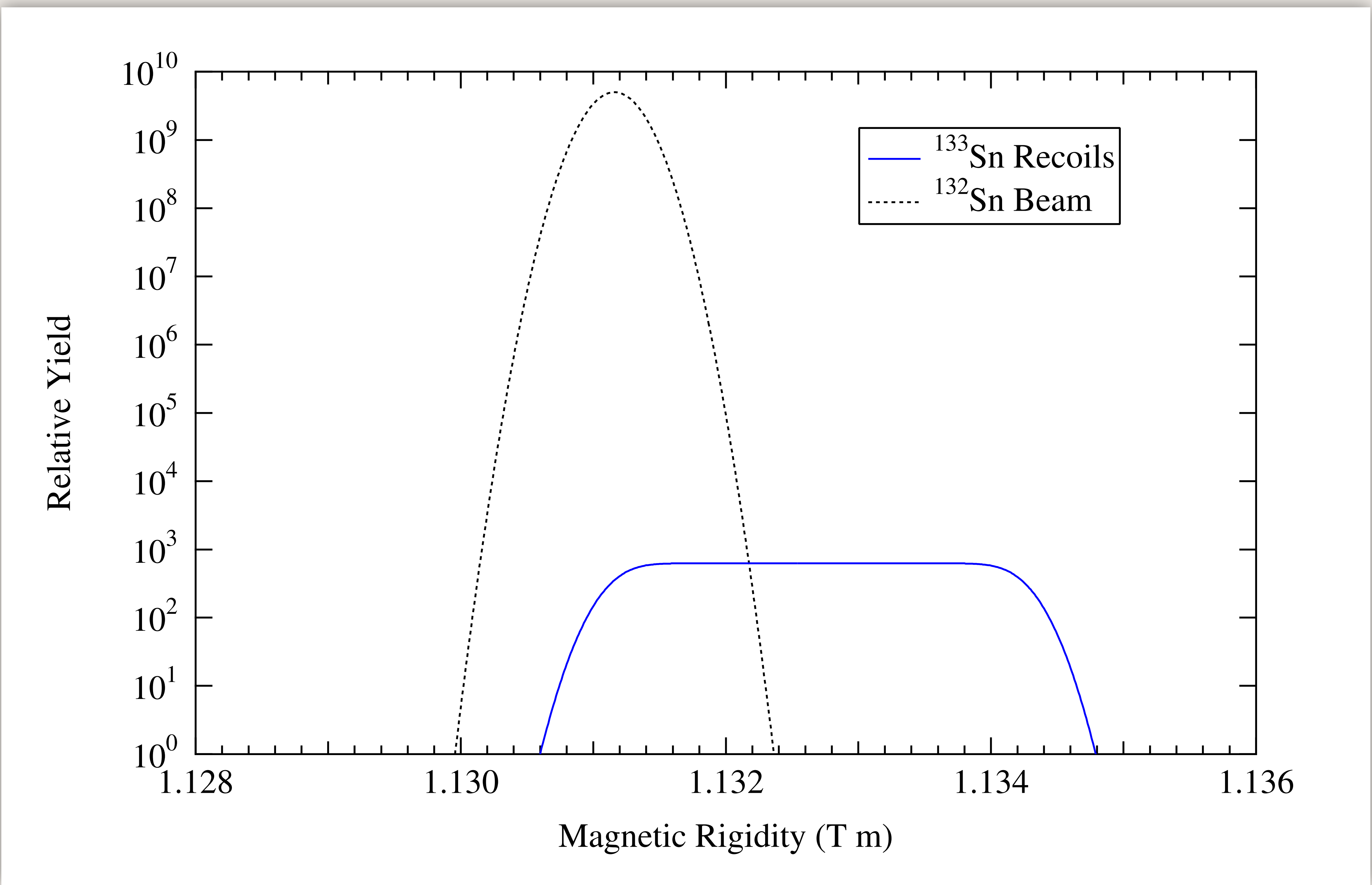
Requirements

- Must be capable of 0° operation with good beam rejection
- Short flight time will allow study of short half-life radioactivities
- Good energy resolution is not helpful
  - Energy and angular resolution of detected heavy recoils insufficient to resolve states for A > 30 beams
  - Energy-focussing operation desirable
- Large angular, mass/charge, and energy acceptances required for high collection efficiency
  - Angular acceptance should be symmetric
  - At least 2 charge states for sufficiently massive recoils

Acceptance and Resolution

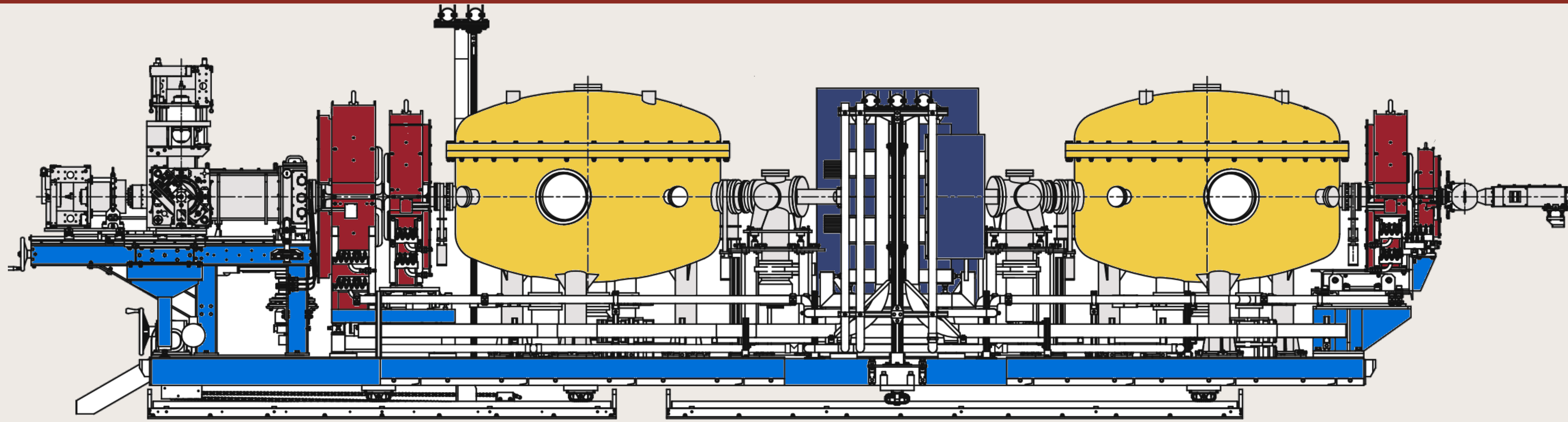
- Angular and energy spreads largest for fusion-evaporation reactions ($\Omega \sim$ 10-30 msr, $\Delta E/E \sim \pm$ 20%)
- Angle and energy spread not independent
- To take advantage of large angular acceptance, need large energy acceptance
- Large energy acceptance requires minimal chromatic aberrations to maintain resolving power
- Mass resolution requirement set by single-nucleon transfer reactions in inverse kinematics: must have first order resolving power $M/\Delta M \geq 400$

How About a Magnetic Spectrometer?



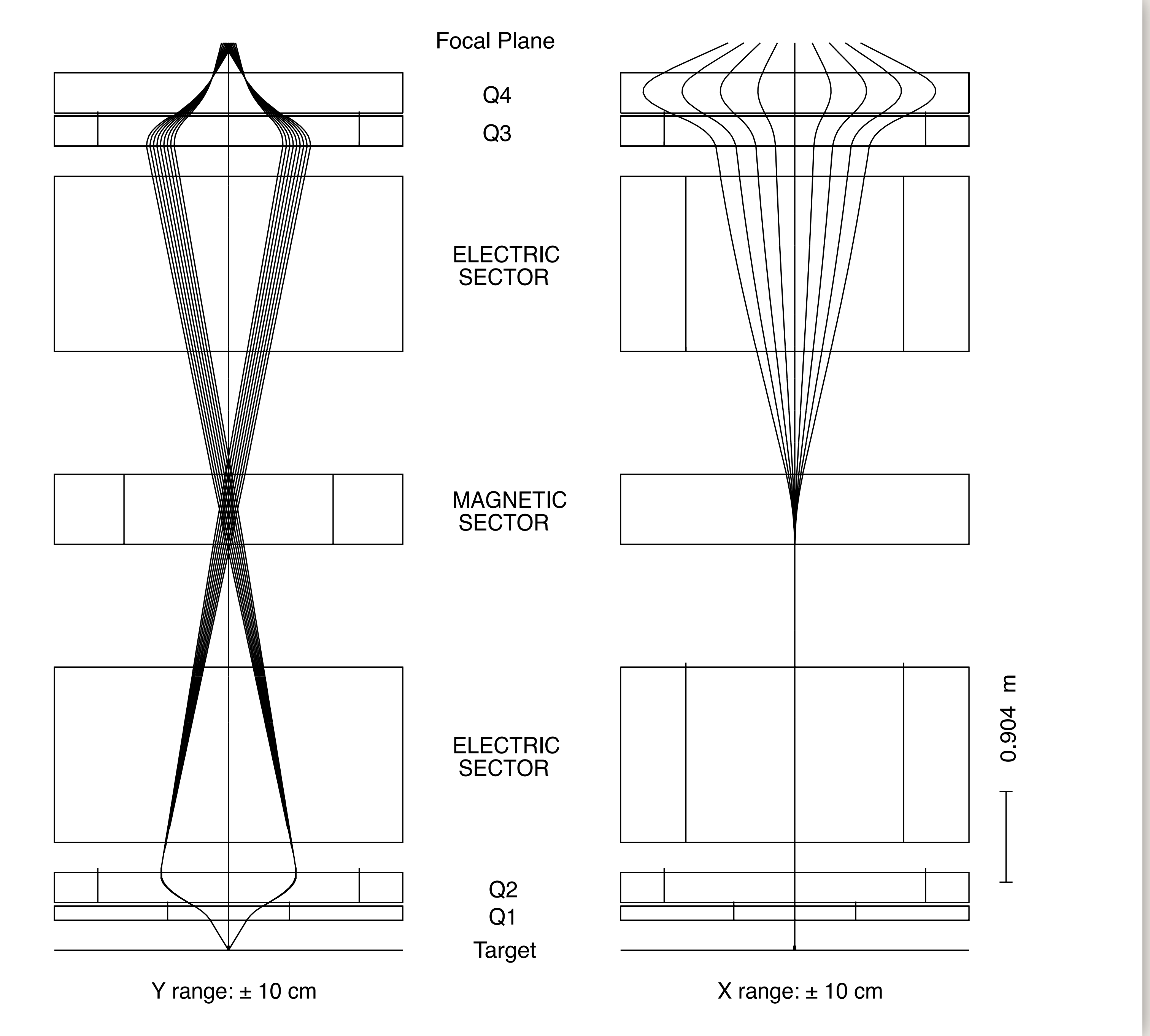
d(^{132}Sn, p)^{133}Sn at 6 A MeV with 100 μg cm^{-2} $(CD_2)_n$ target; smallest achievable beam energy spread; protons from 90-170 deg in lab

EMMA: The ISAC-II Recoil Spectrometer



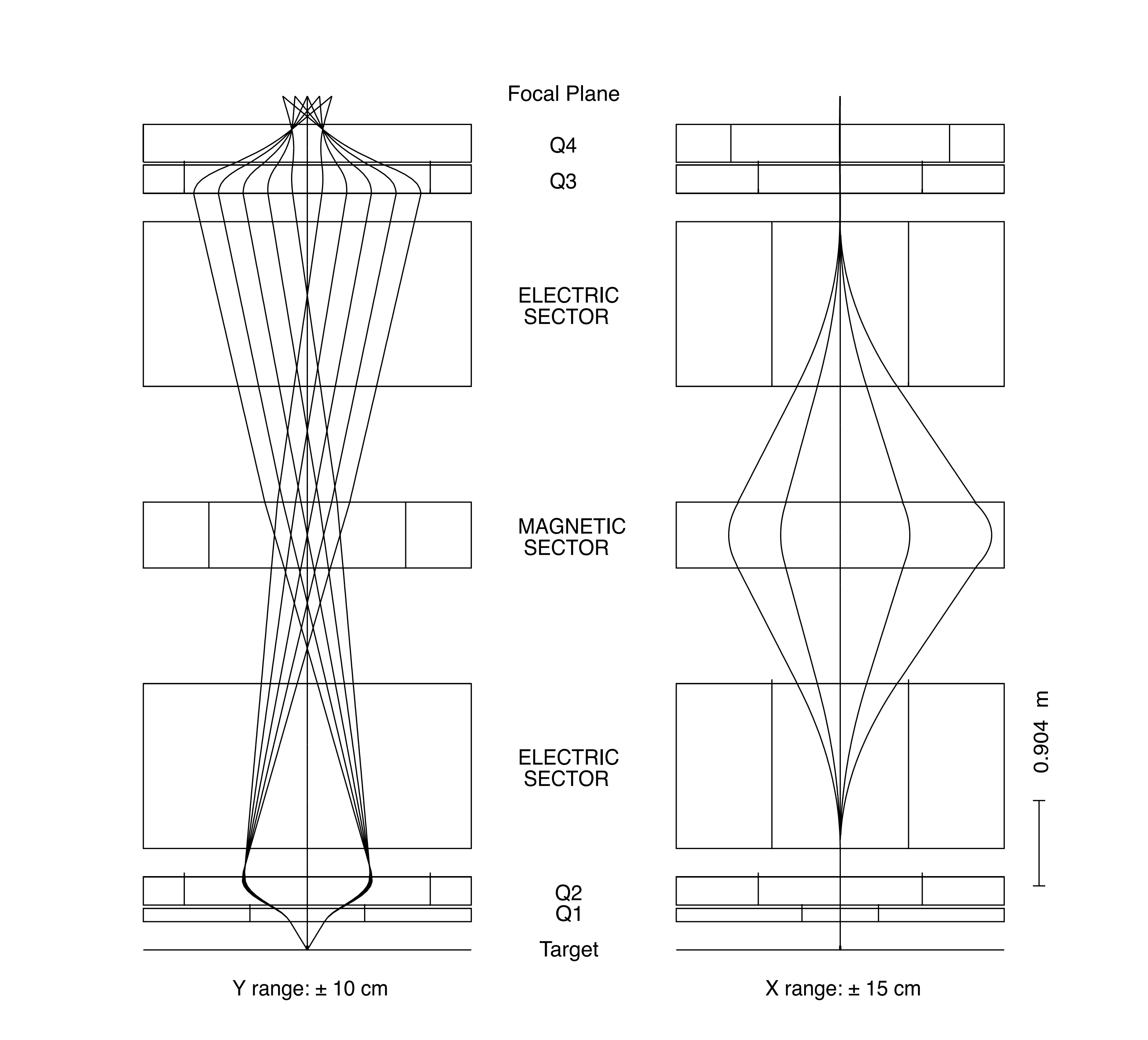
- EMMA: recoil mass spectrometer spatially separates heavy products of nuclear reactions from beam & disperses according to mass/charge ratios
- Solid angle = ± 3.6° by ± 3.6° = 15 msr
- Energy acceptance = +25%, -17%
- Mass/charge acceptance = ± 4%
- 1st order m/q resolving power = 551

EMMA Ion Optics: Mass Focus



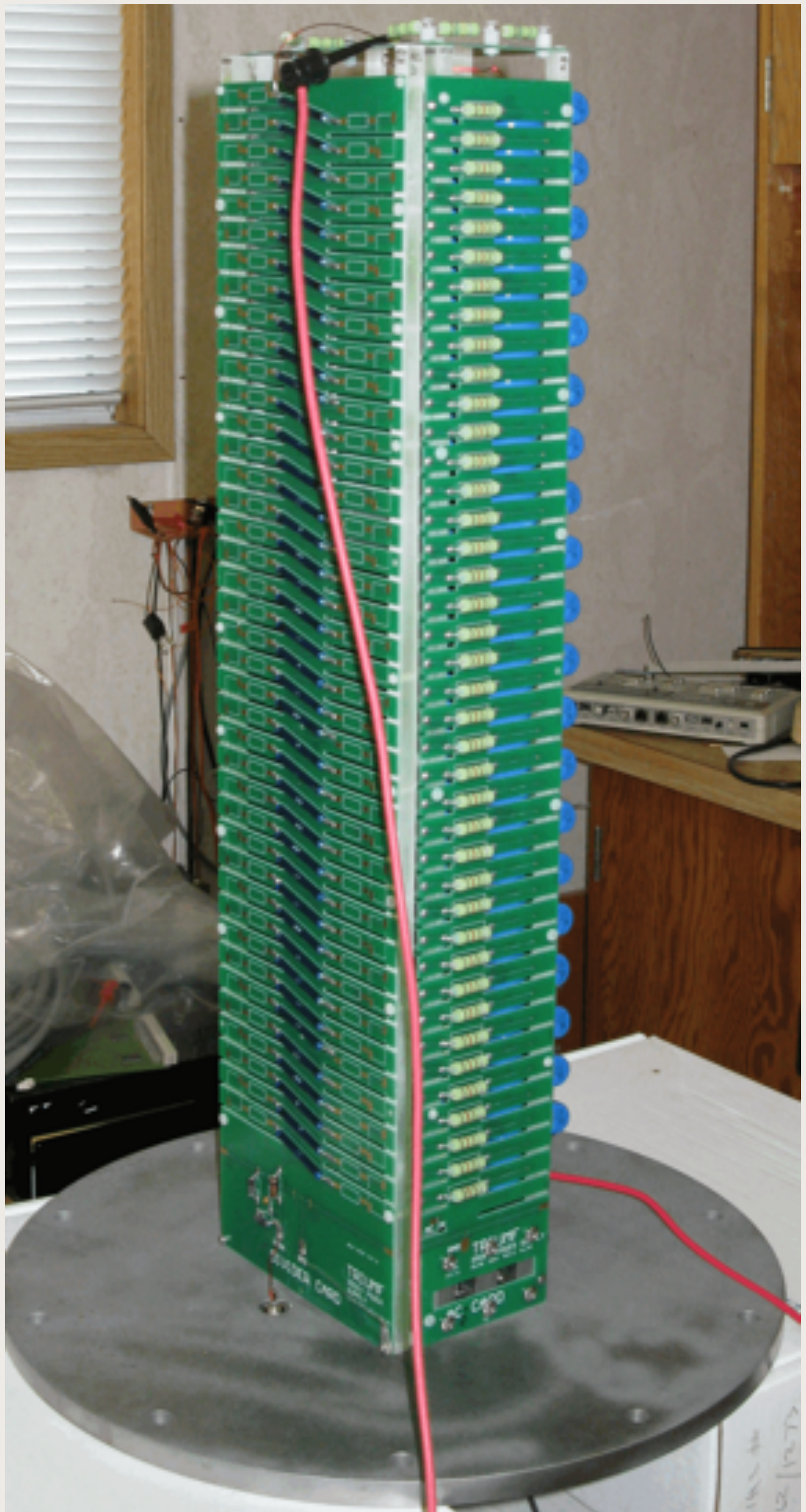
9 Adjacent Masses Emitted from Target with Vertical Angles of 0, ±2°

EMMA Ion Optics: Energy Focus



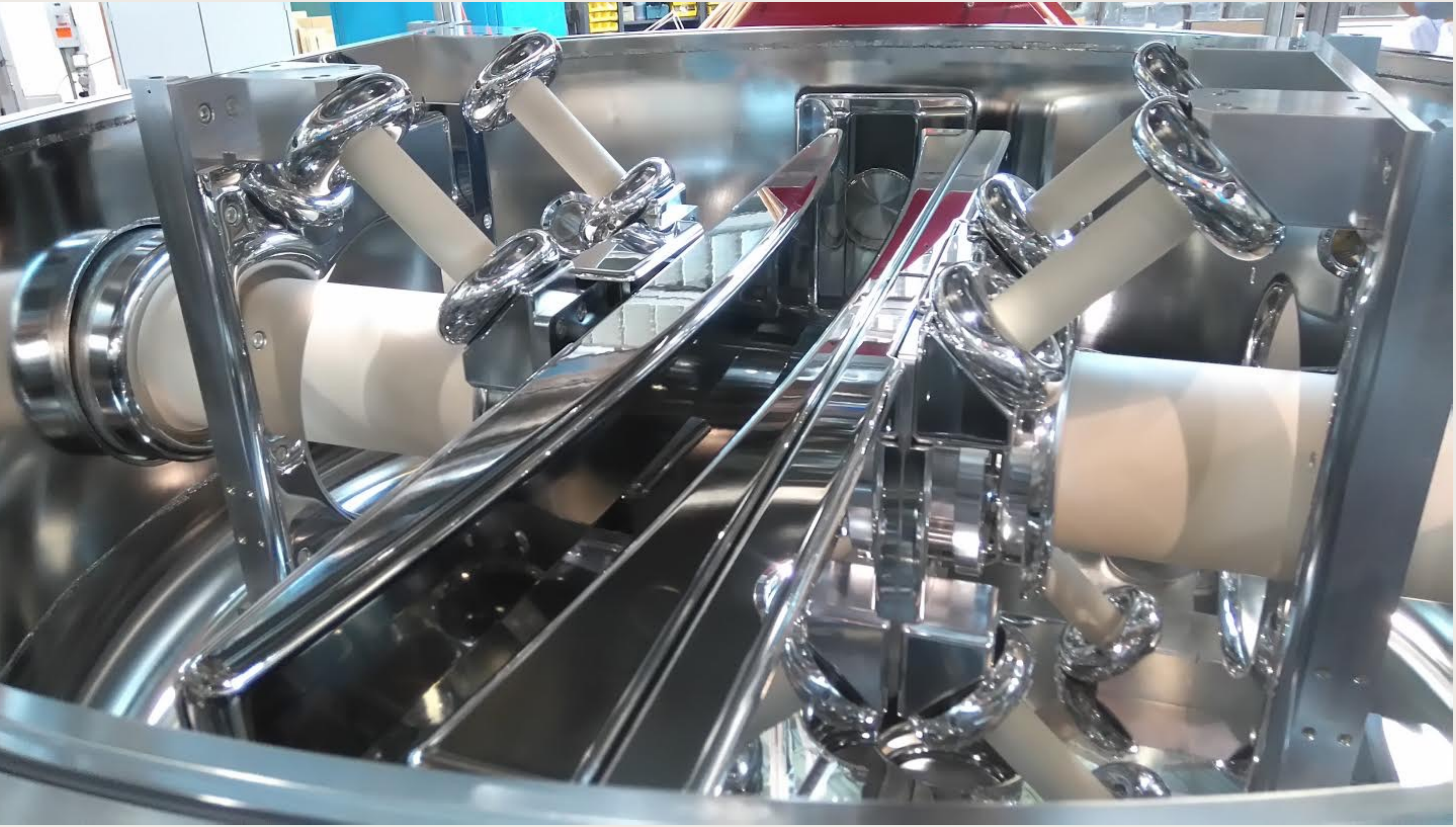
Single Mass, Vertical Angles of 0, ±2°, Energies Deviating from Central Value by 0, ±7.5% and ±15%

TRIUMF-Built HV Supplies

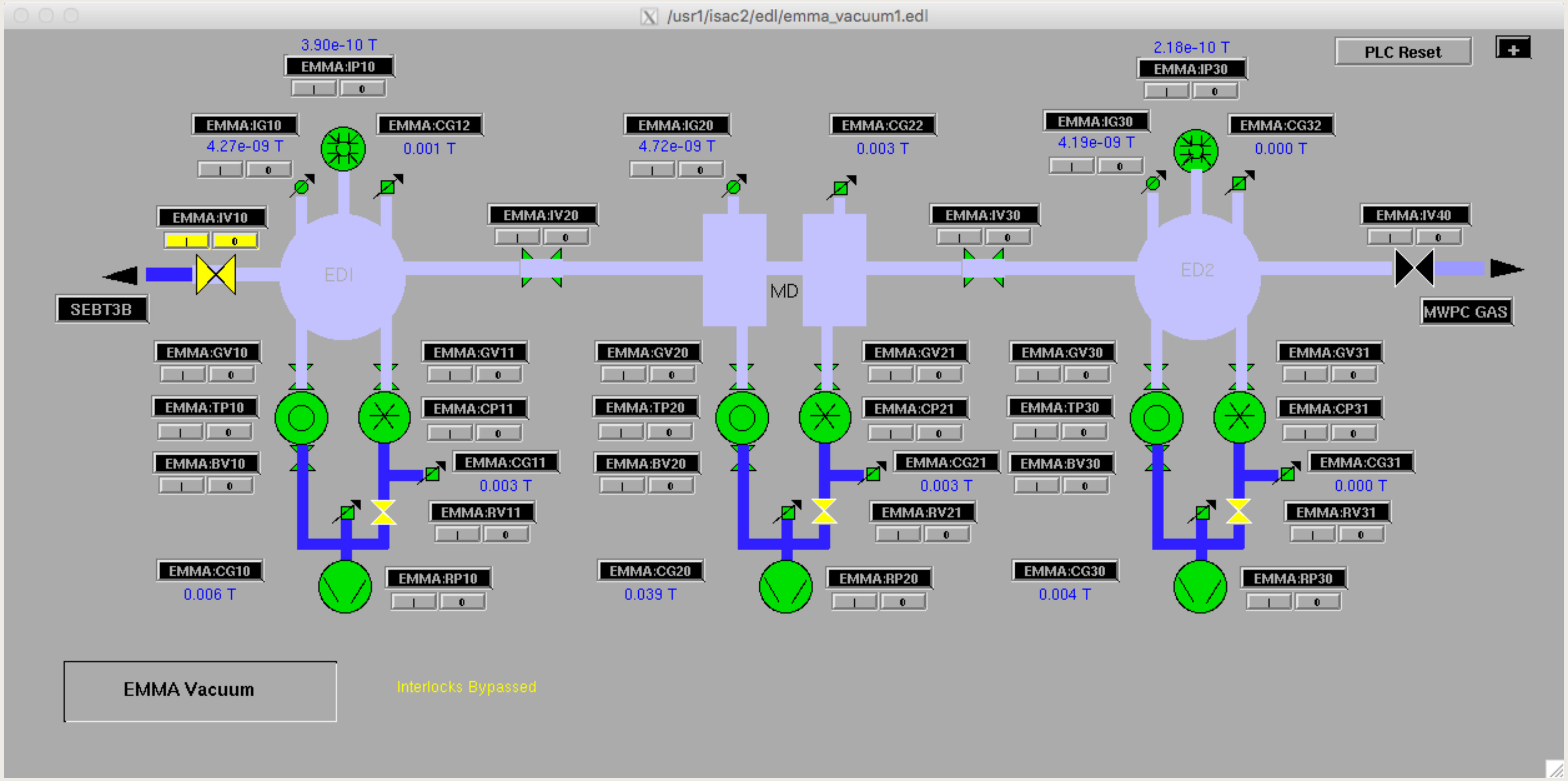


- Built 3 positive and 3 negative
- All have been tested to |V| ≥ 325 kV
- Housed in re-entrant ceramic vessels
- Pressurized with 3 bar SF_6

Complete ED2 Electrode Assembly



Vacuum Systems

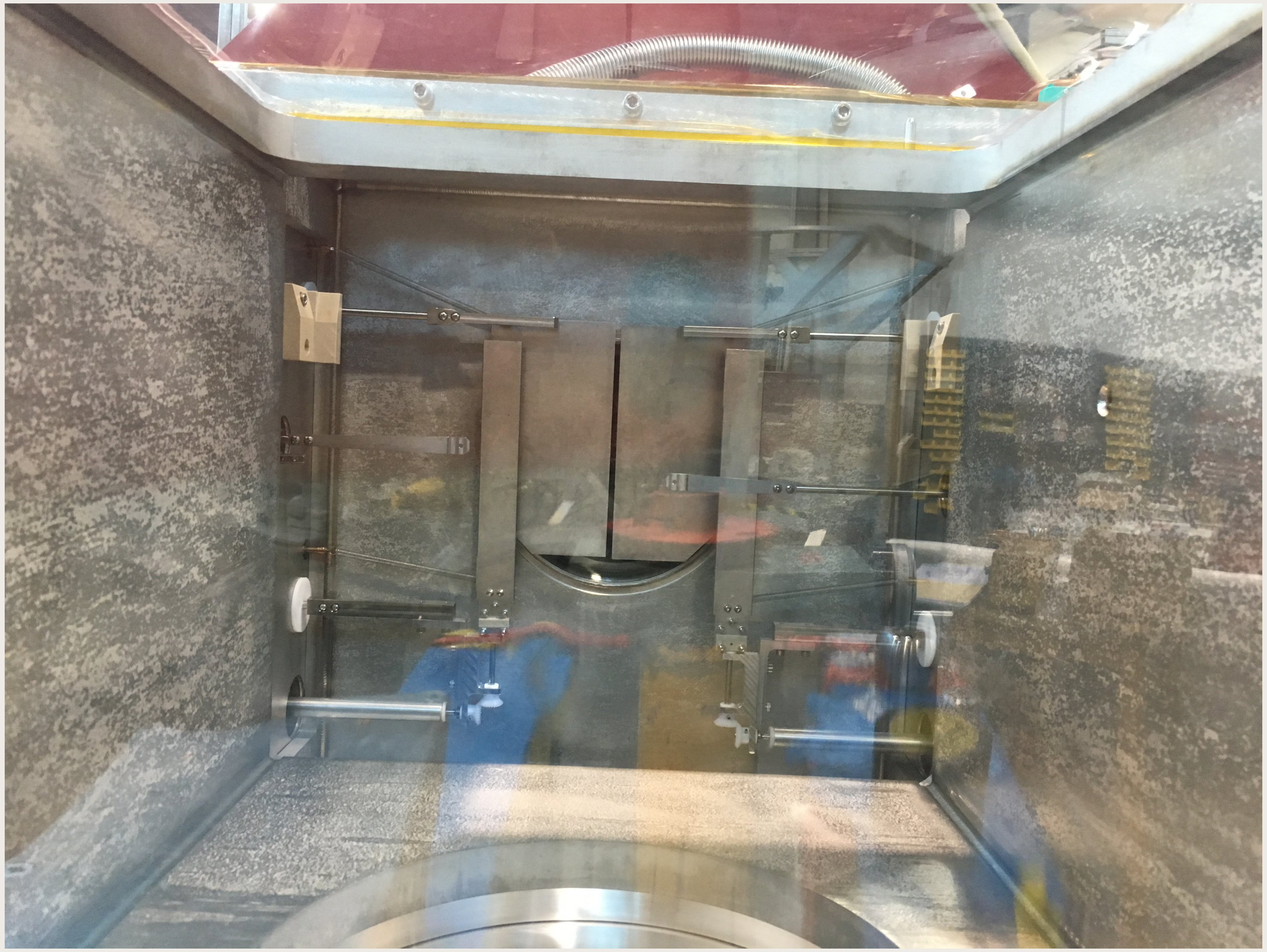


- Typical pressures in 3/4 vacuum sections in nTorr range; 1000 l/s turbos and 1500 l/s cryos
- Focal plane box has a single 1000 l/s turbo; pressure in low 10^{-6} Torr range

Target Chamber

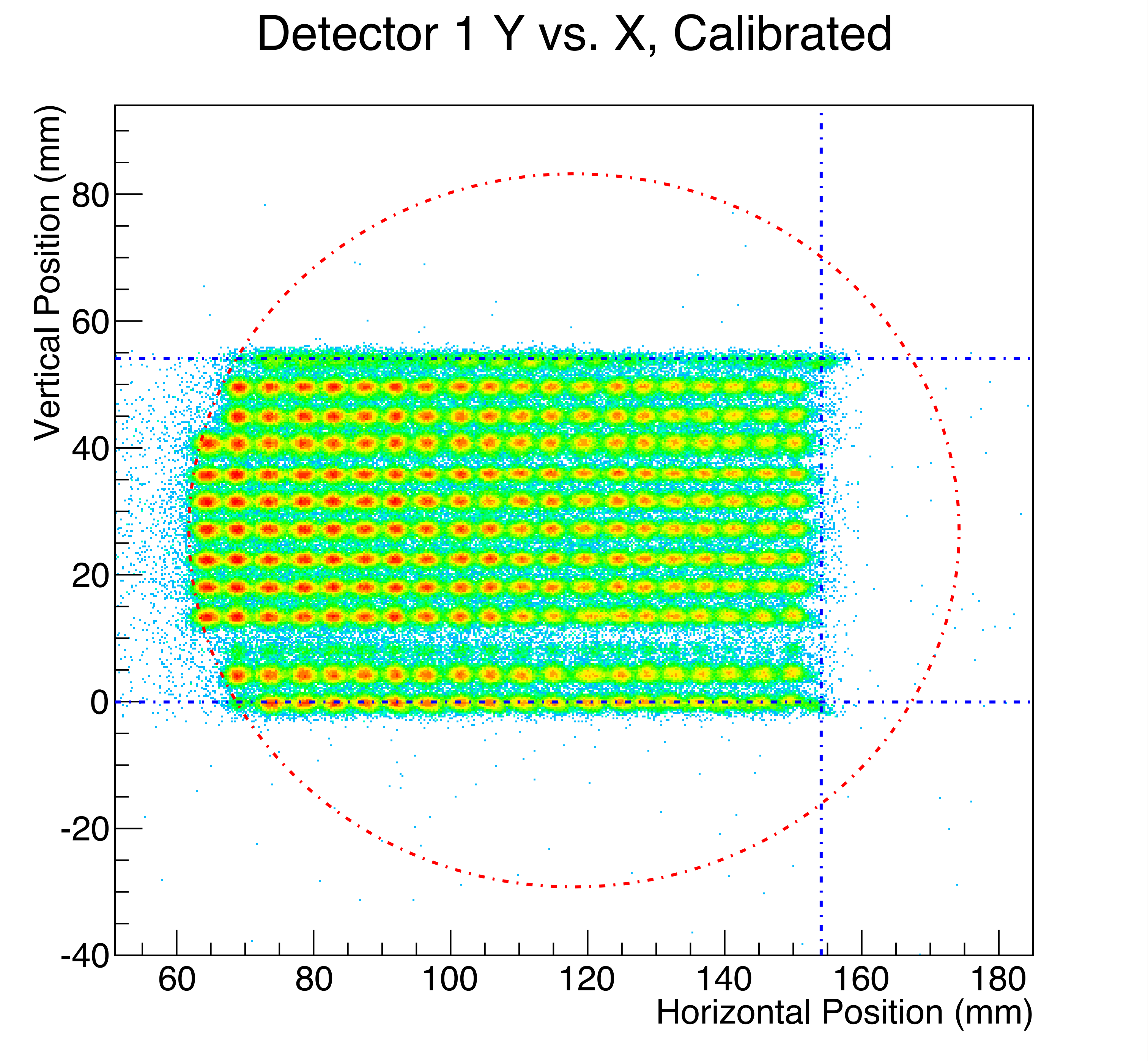
- Integral Faraday cup with 1 mm entrance aperture coincides spatially with target position
- Target wheel with 3 positions
- Pumped by beam line 500 l/s turbo; pressure in low 10^{-7} Torr range

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

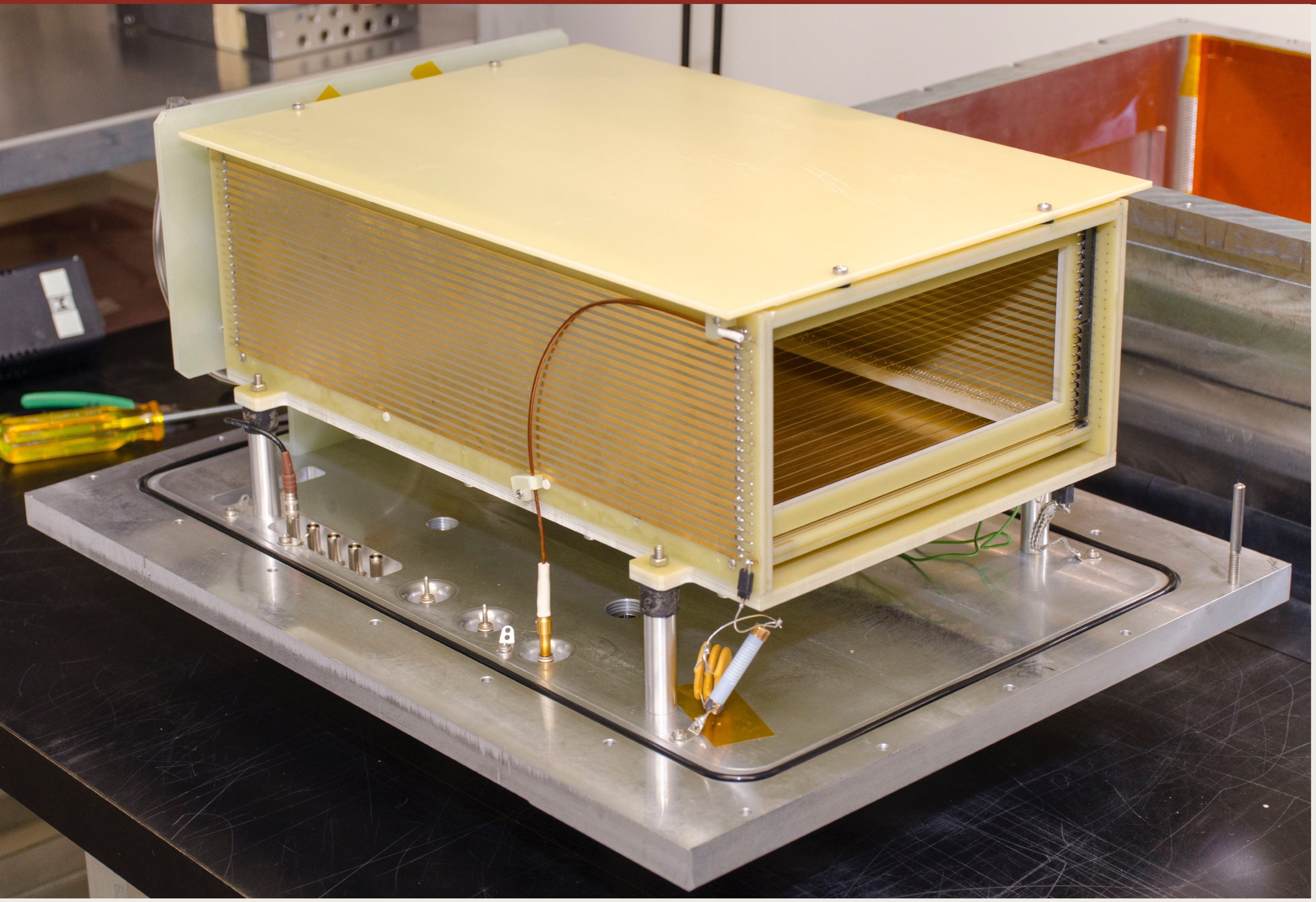
Focal Plane Detectors

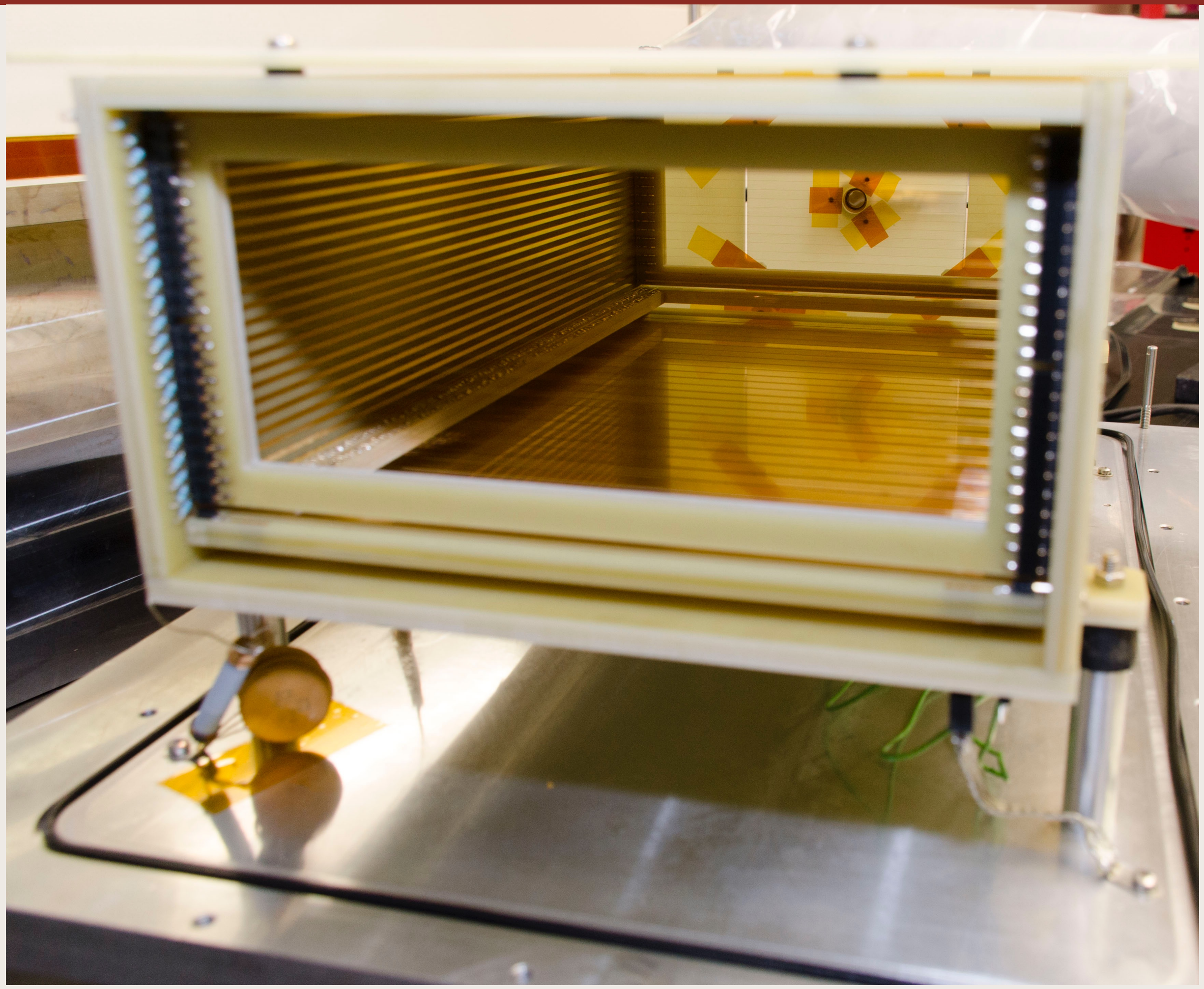


Position resolution 1 mm

Timing resolution 660 ps

Ionisation Chamber



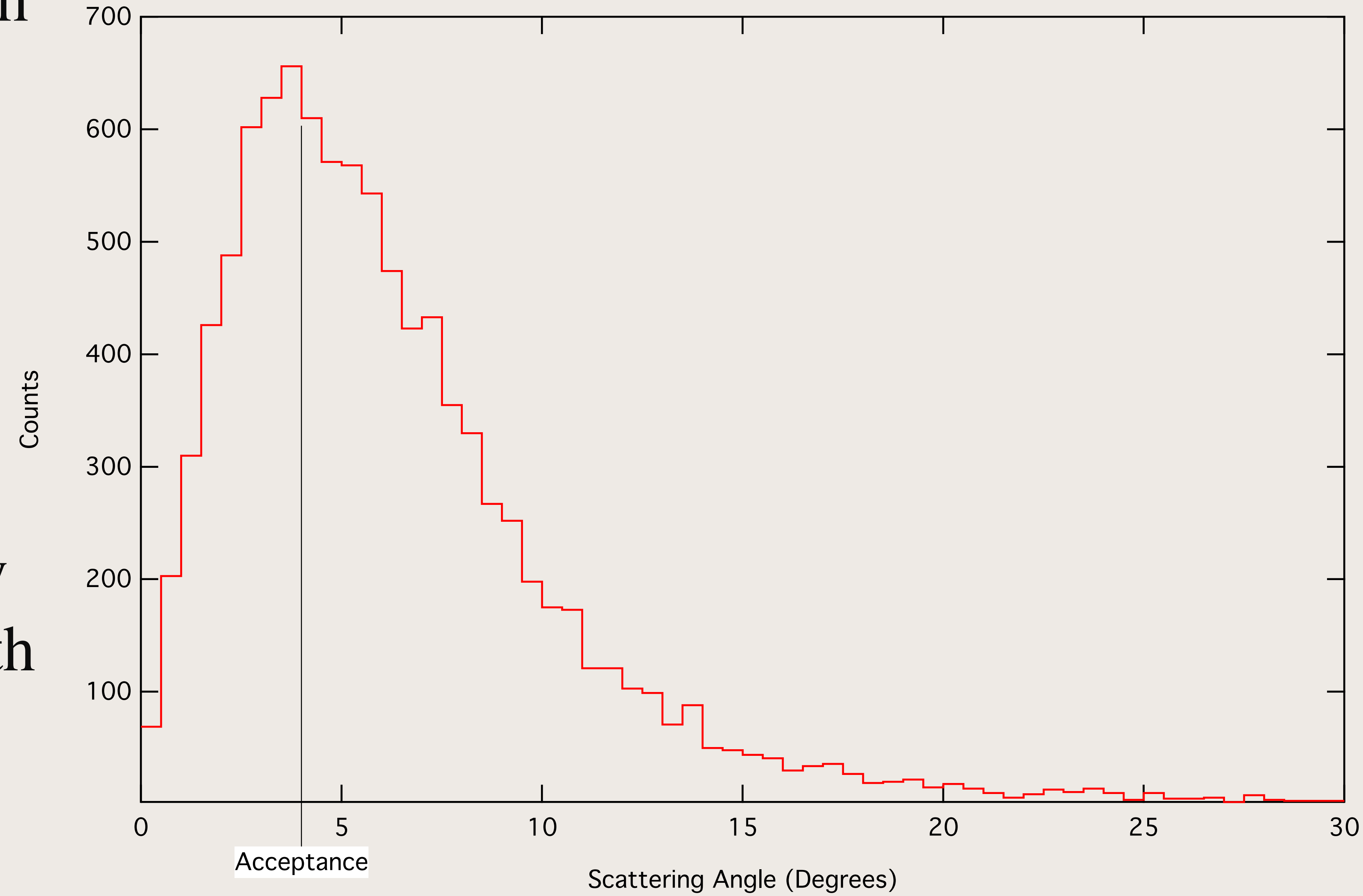


Ionisation chamber tested with alpha and fission sources on bench

December 2016 Test

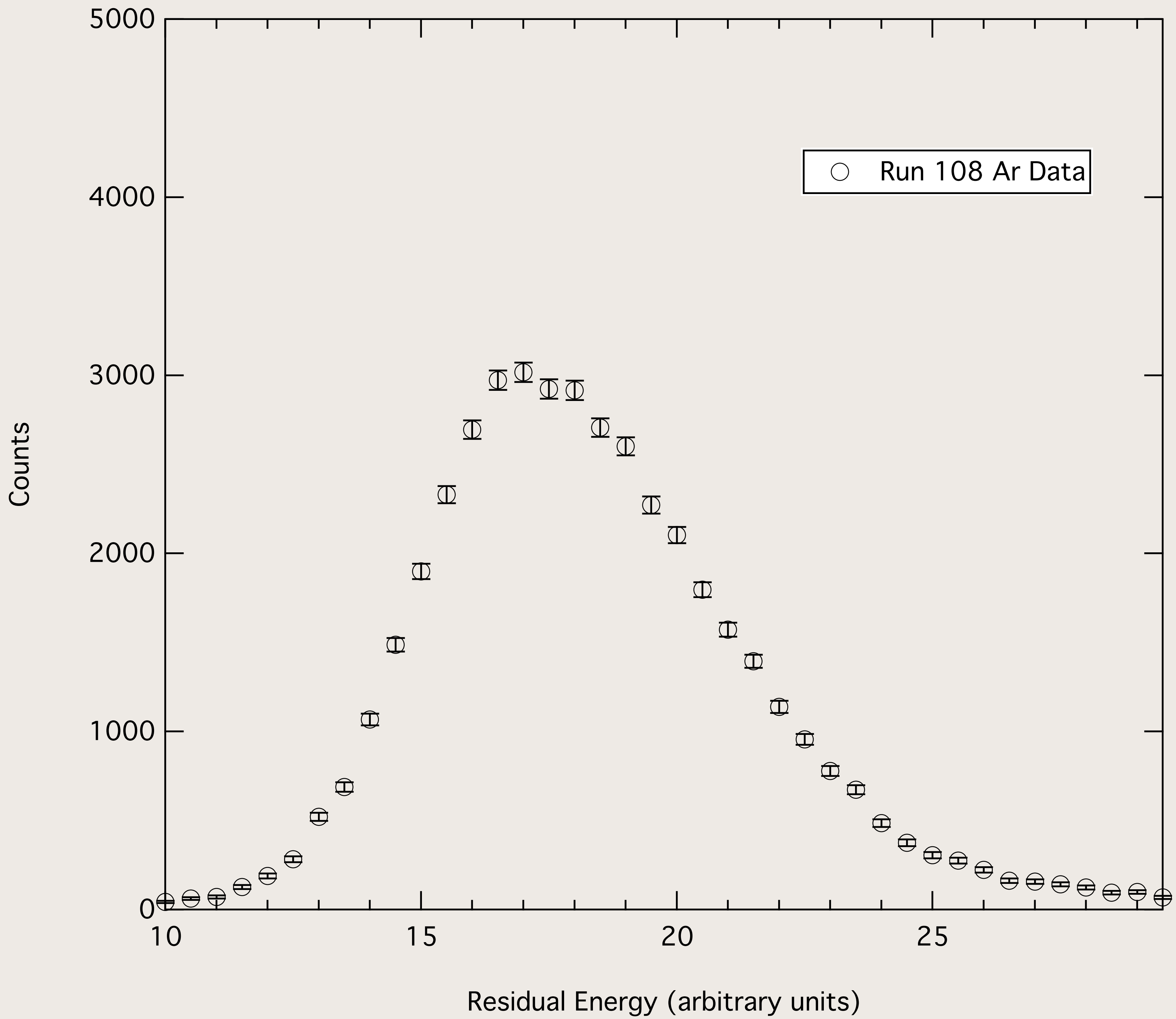
- There was no time to commission with an alpha source prior to December 16th beam time
- Bombarded thick Au foil with 80 MeV ^{36}Ar beam
- Tuned for multiply scattered beam with very large angular spread

Predicted Angular Distribution of Scattered ^{36}Ar



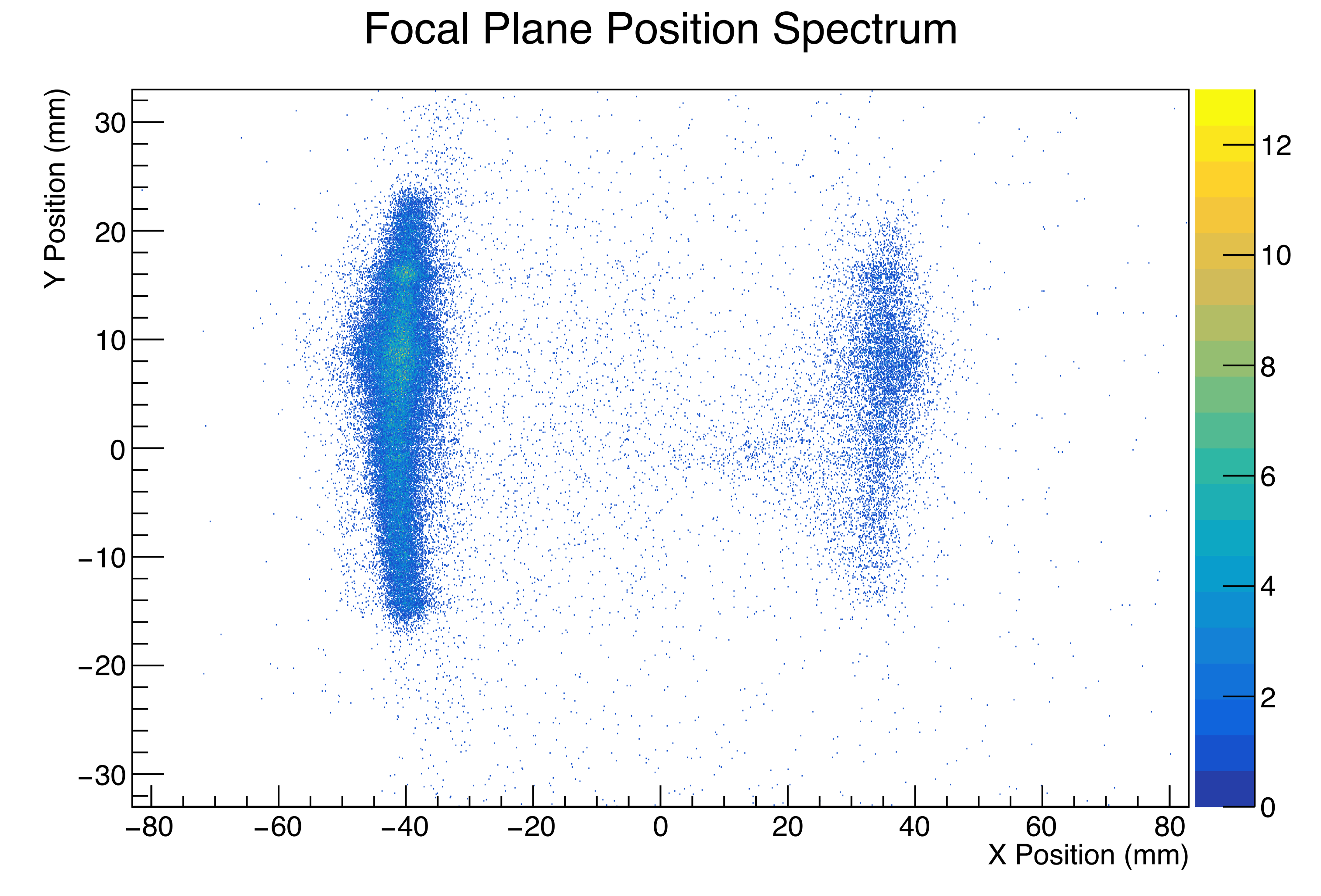
December 2016 Test

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



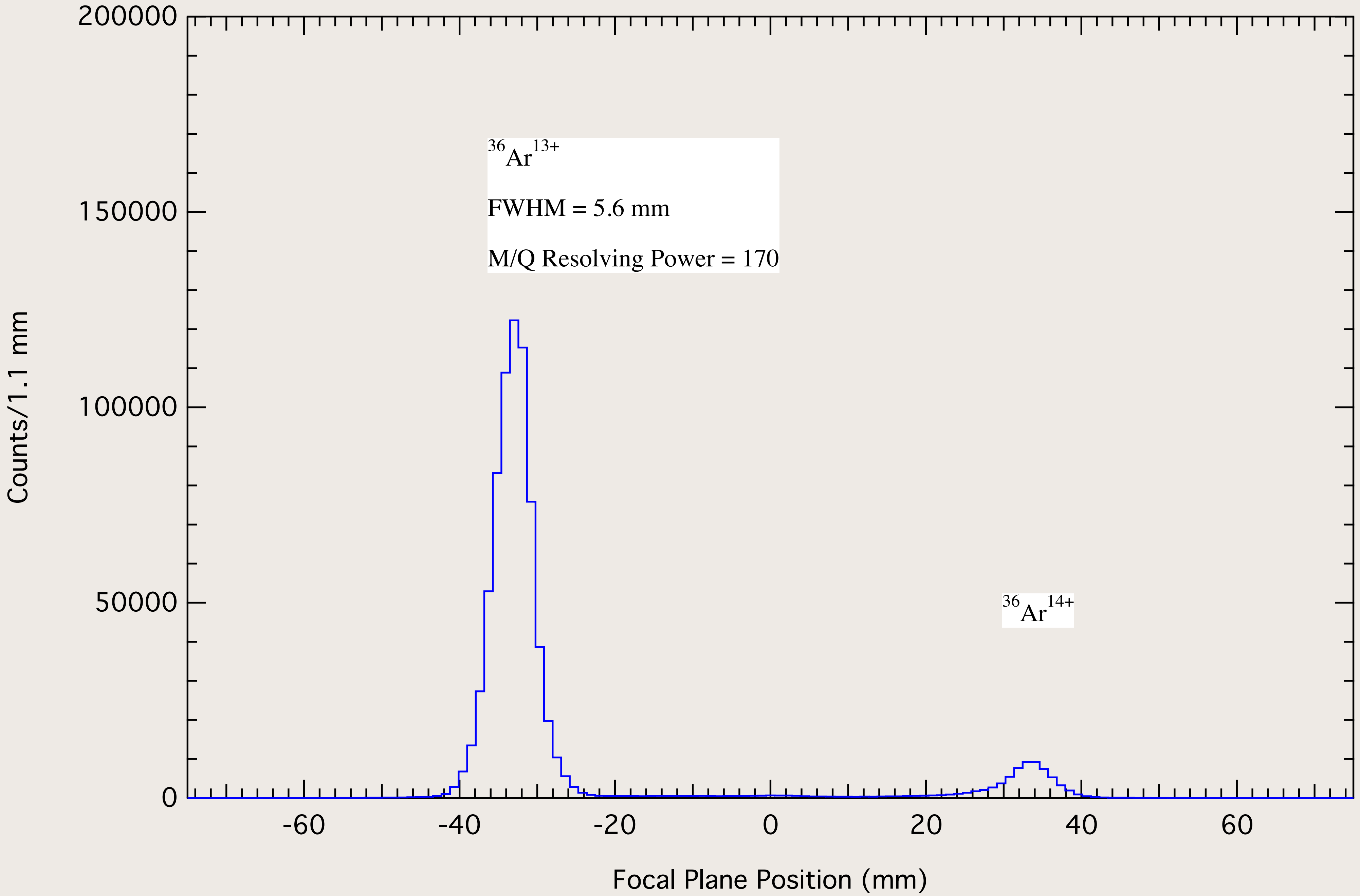
December 2016 Test

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



EMMA's First M/Q Spectrum

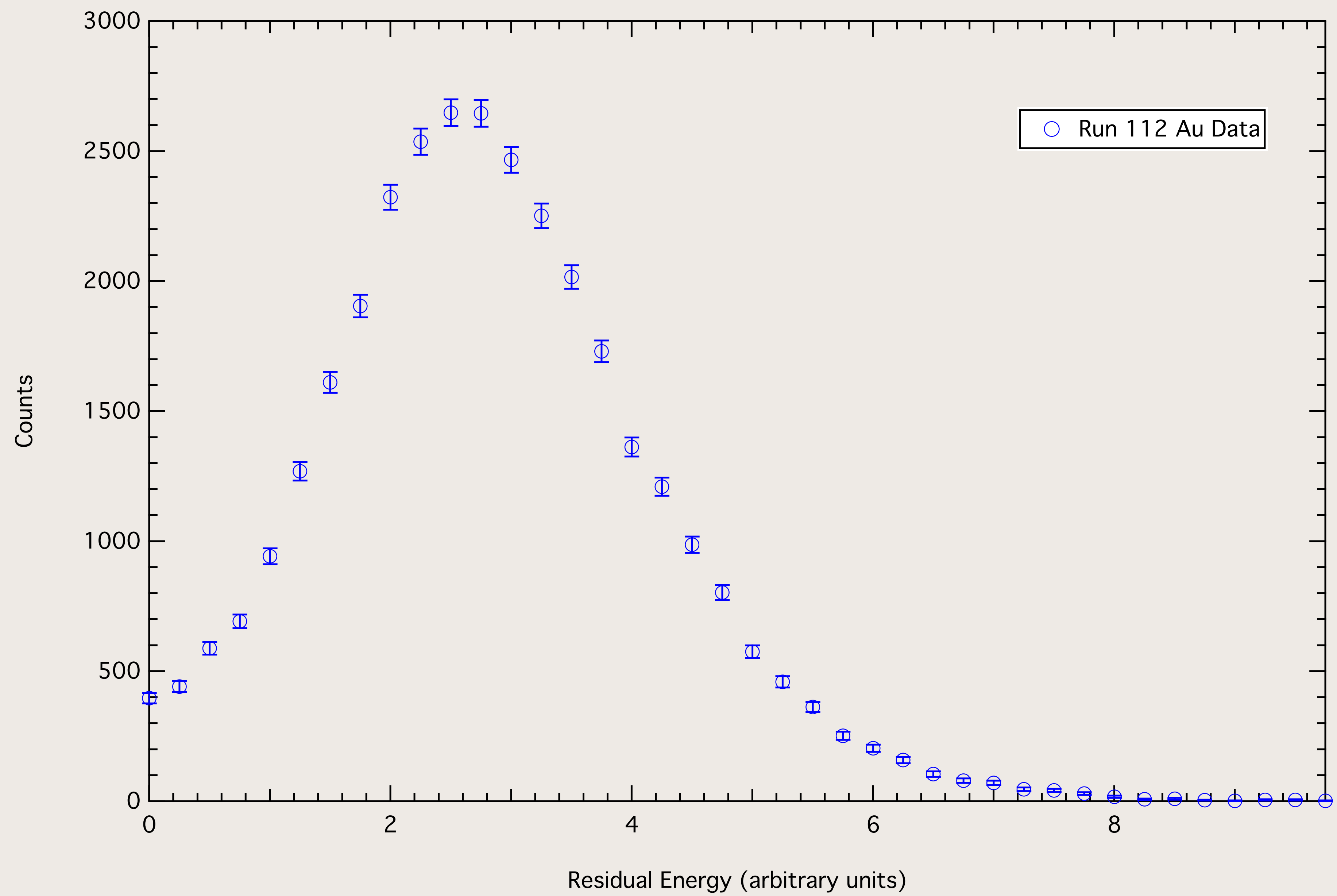
December 2016 Test



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

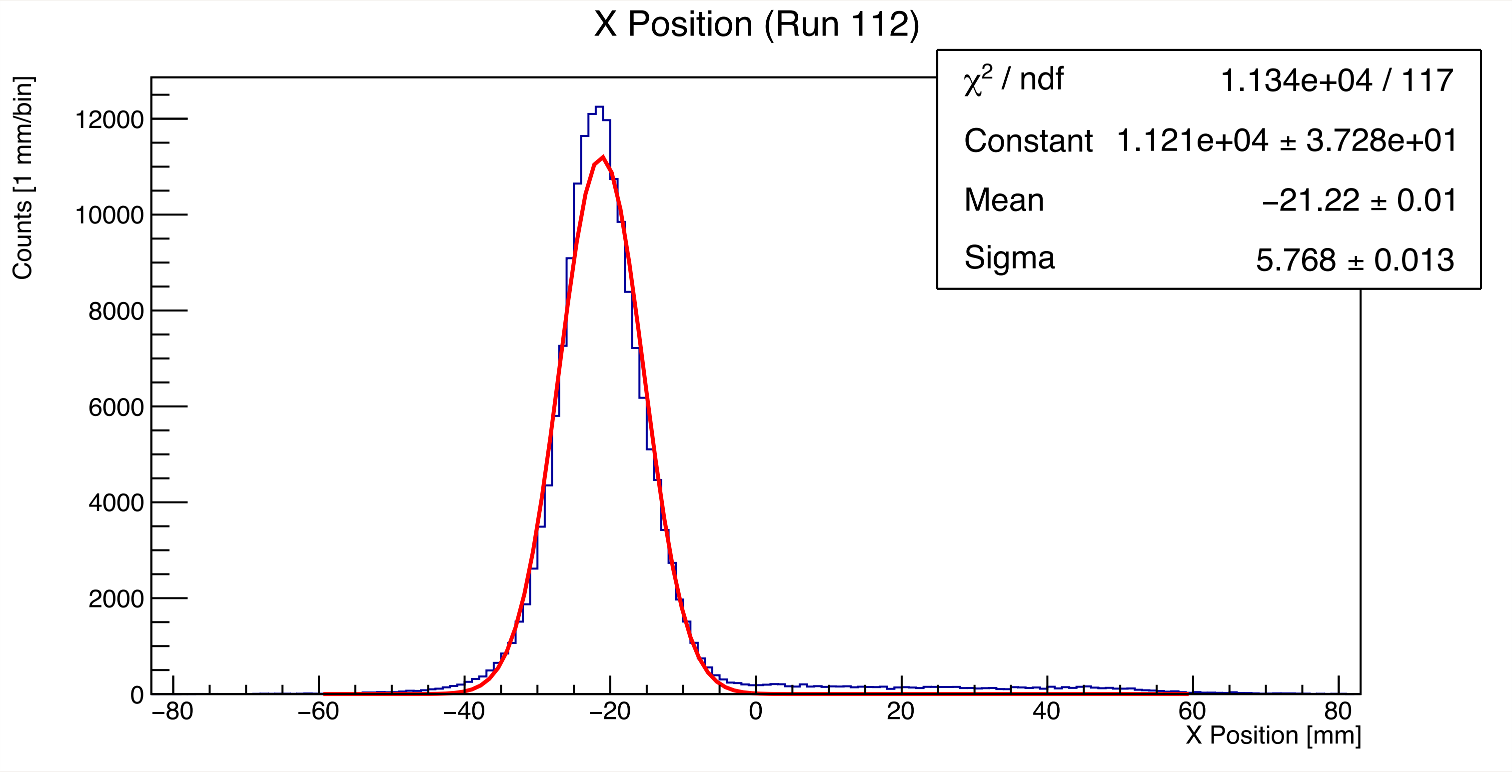
December 2016 Test

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



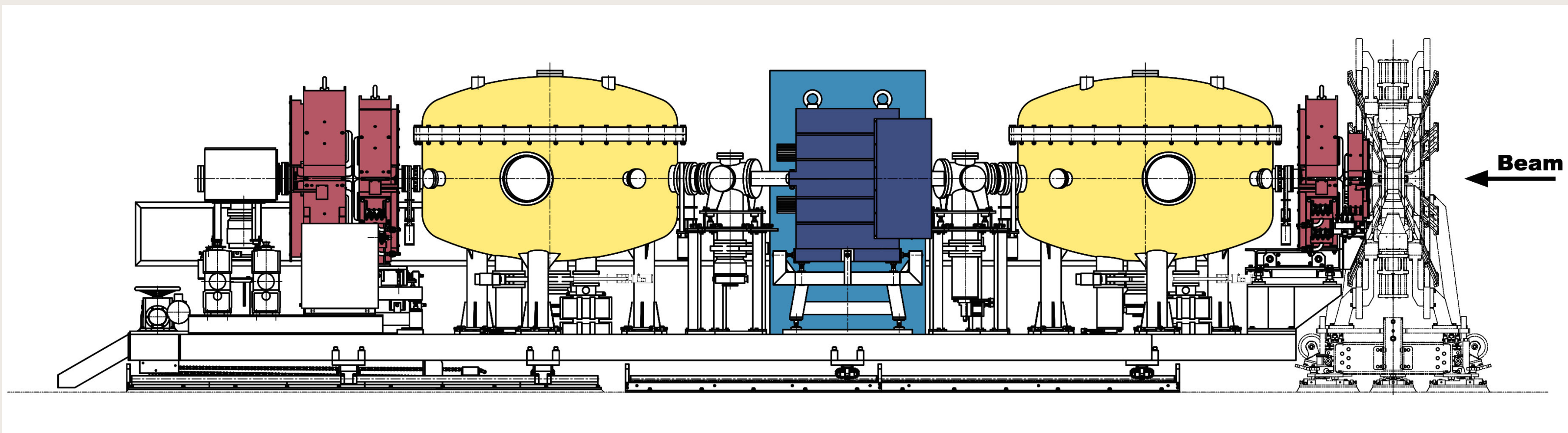
December 2016 Test

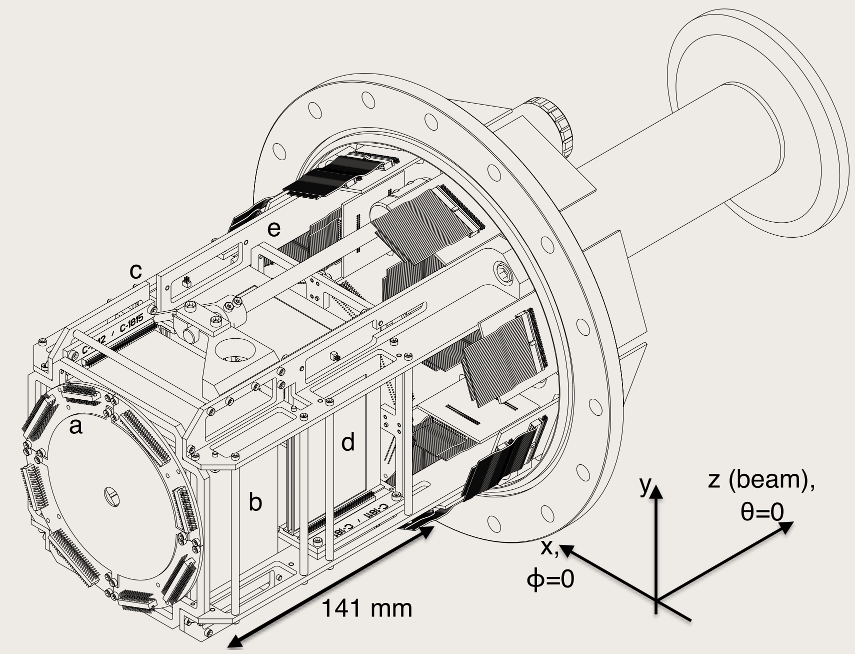
Measured Focal Plane Position Spectrum of Scattered ^{197}Au



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





- Three approved experiments, two of which require TIGRESS to be installed around EMMA target position
- Transfer experiment: $^{6}Li(^{17}O,d)^{21}Ne$ to infer $^{17}O(\alpha,\gamma)^{21}Ne$ reaction cross section for the *s* process; also requires SHARC
- Radiative capture experiment: direct measurement of $p(^{83}Rb,\gamma)^{84}Sr$ reaction cross section at *p* process energies
- $p(^{21}Na,\alpha)^{18}Ne$ to infer $^{18}Ne(\alpha,p)^{21}Na$ reaction cross section for Type I X-ray bursts
- Approved Letter of Intent: direct measurement of $p(^{79}Br,\gamma)^{80}Kr$ reaction cross section

Future Plans

- Continue HV conditioning
  - Both anodes and cathodes conditioned to 250 kV
  - ED2 conditioned to ΔV = 425 kV, ED1 has only reached 340 kV so far
- Alpha source acceptance/resolving power tests in August
- Elastic scattering and fusion evaporation reactions with stable Ar beam starting Sep. 23, to complete commissioning
- Standalone experiments possible in fall schedule
- TIGRESS move to EMMA target position anticipated during shutdown 2017-2018
- Inviting nuclear structure proposals

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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