The ElectroMagnetic Mass Analyser EMMA, a Recoil Mass Spectrometer for ISAC-II

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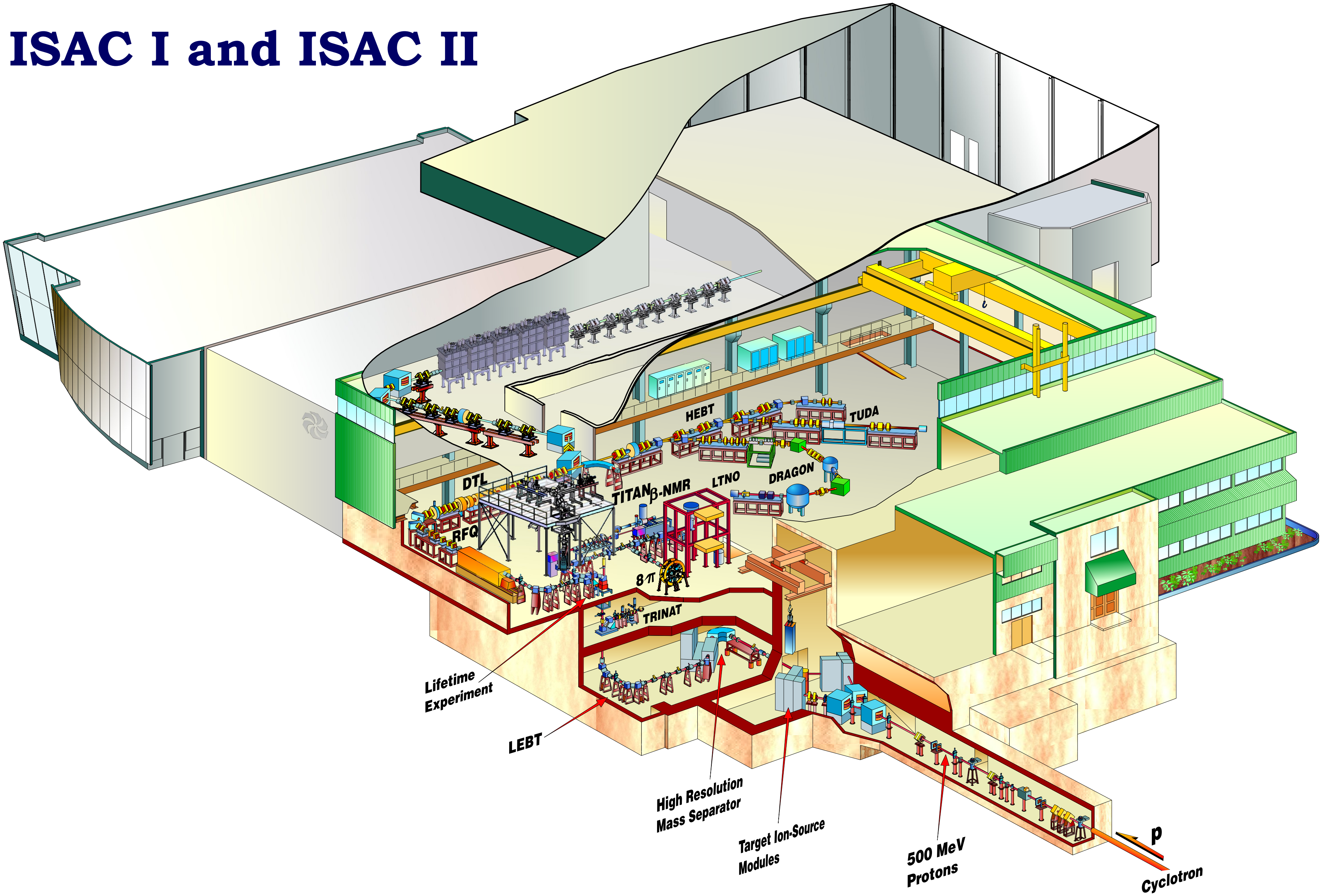
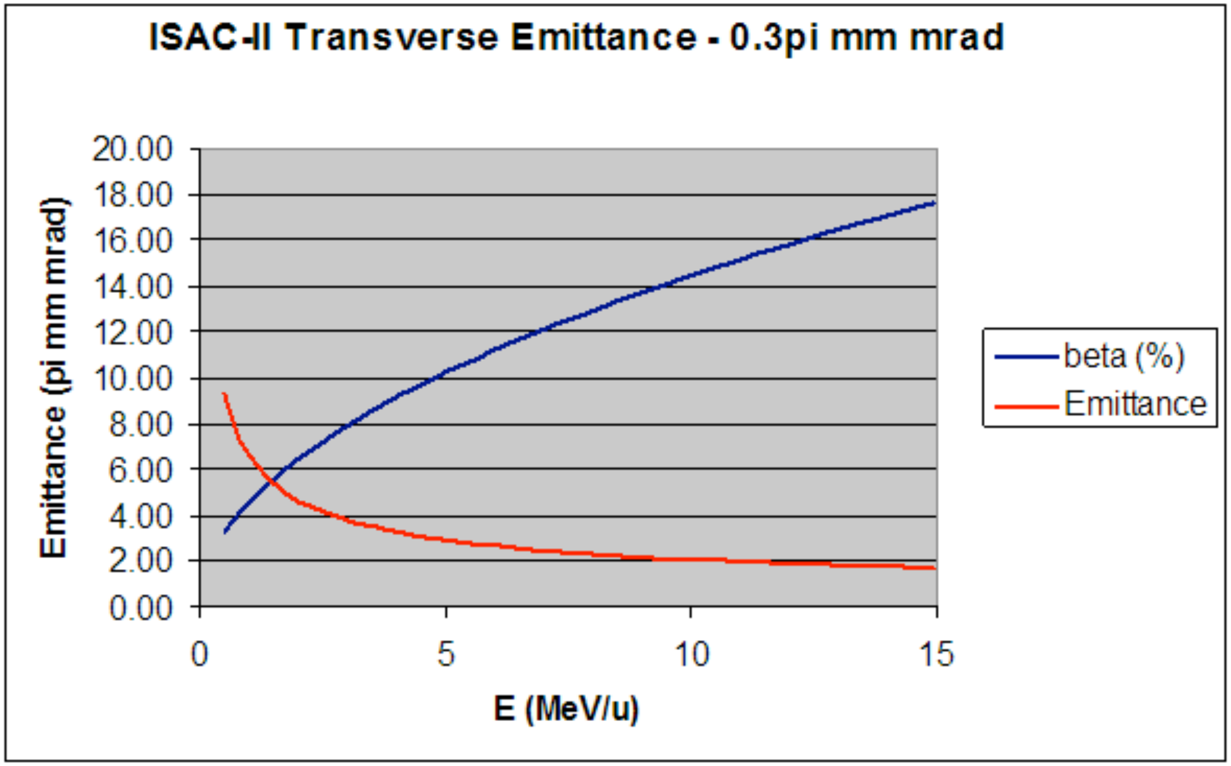
TRIUMF

ISAC I and ISAC II



ISAC-II at TRIUMF

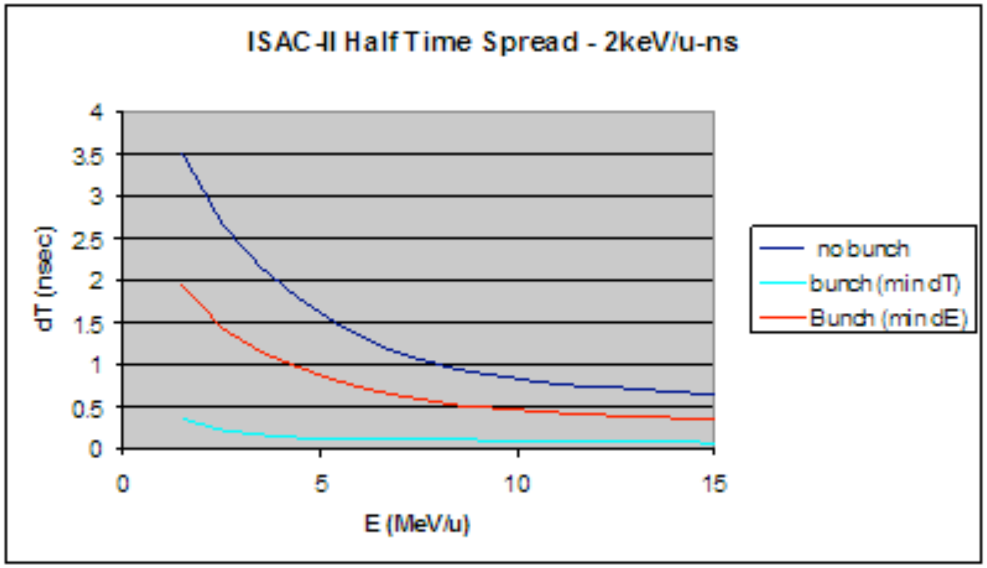
Transverse Emittance

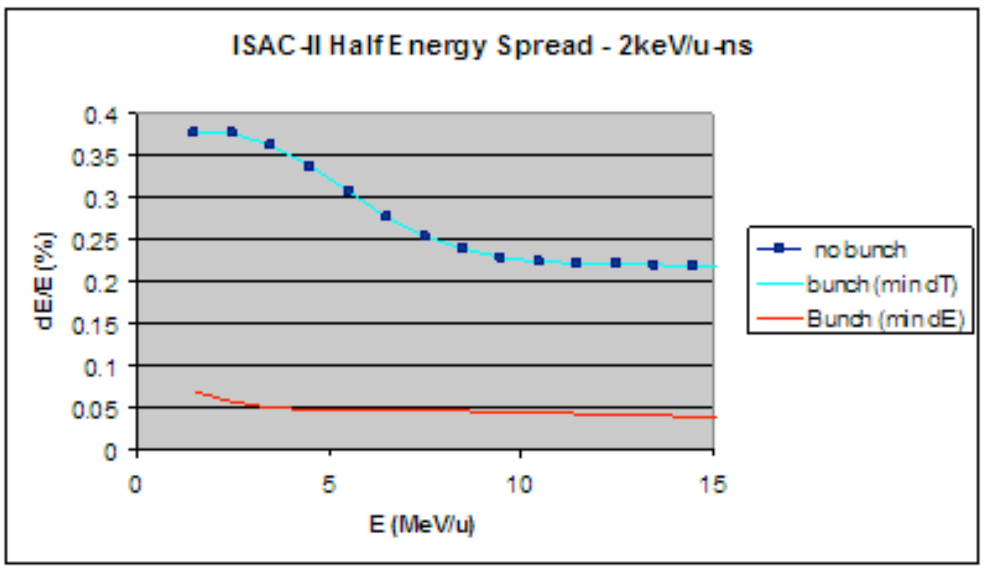


High Quality RIB's with A < 150, Max. Energy ≥ 6.5 A MeV

Beam Properties

Time Domain





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)
- Production and decay studies of highly neutron-rich nuclei via multineutron transfers e.g. (^{18}O,^{15}O)
- Proton radioactivities above tin via ^{56}Ni-induced fusion-evaporation reactions
- High-spin (including isomers) physics in both neutron-deficient and neutron-rich nuclei via fusion-evaporation reactions

Nuclear Astrophysics

- Time-reversed (α,p) reactions
- Spectroscopy of particle-unbound states
- Q_β values, lifetimes, β-delayed neutron emission probabilities
- 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

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

EMMA(-O)

閻魔王坐像●えんまおうざぞう
鎌倉時代前期　木造　彩色
像高160.9cm　京都、宝積寺
十王中、もっとも有名な閻魔王は、もとヤマ神というインドの古い神で、人界最初の死者だったため冥界の支配者となった。のちに中国で死者の判定をつかさどる裁判官の王へと転じ、やがて地獄の主宰者として定着した。中国の役人ふうの服装は道教の影響。じつは閻魔は地蔵菩薩の化身であることから、外見は怒りの表情をしているが、内心は慈悲の心にあふれている。この剛と柔を併せもった写実的な像は、鎌倉時代前期の優品である。
特集 1
死んだら
どうなる
——閻魔と十王の審

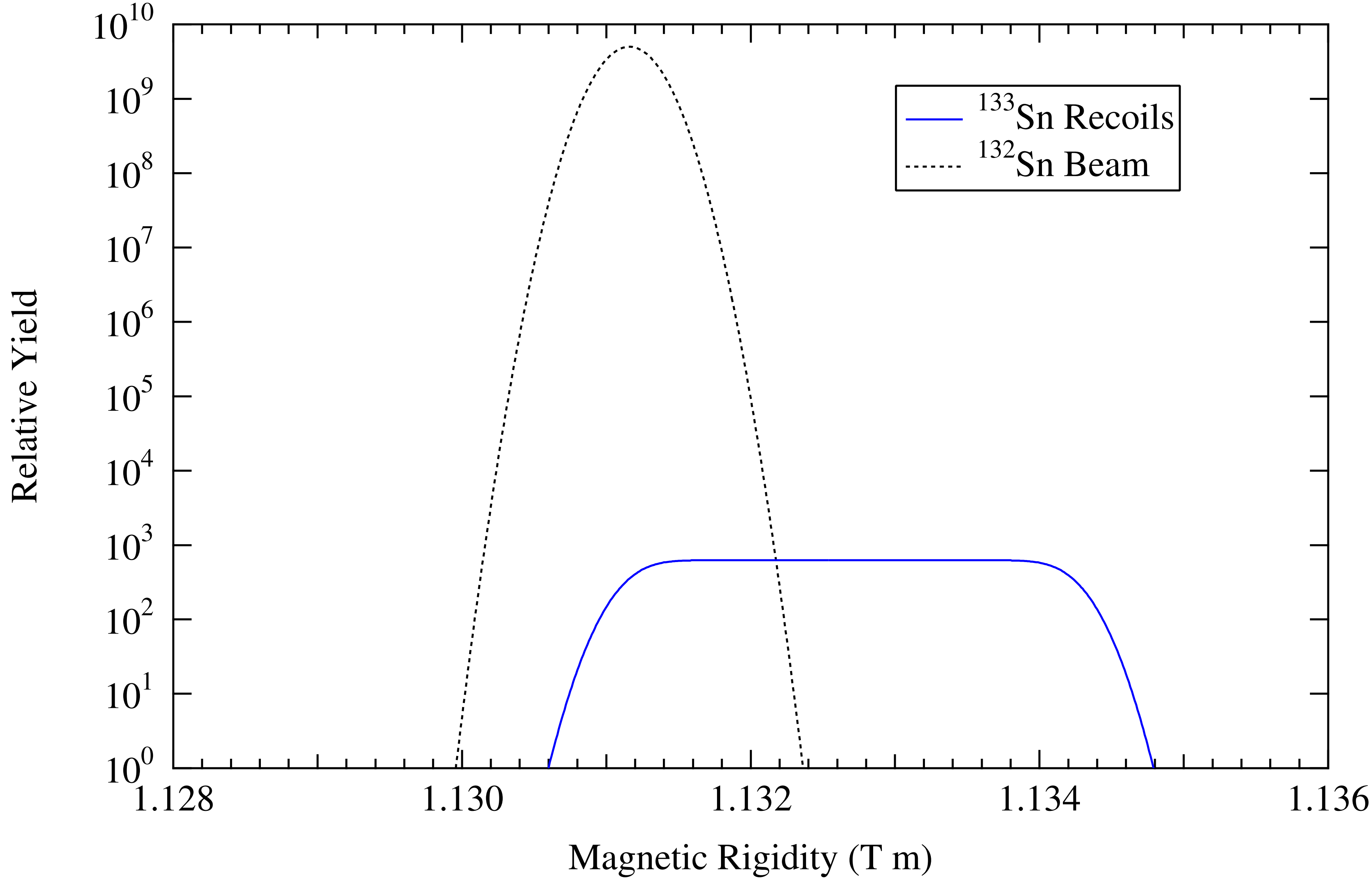
Requirements

- 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-dispersionless 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

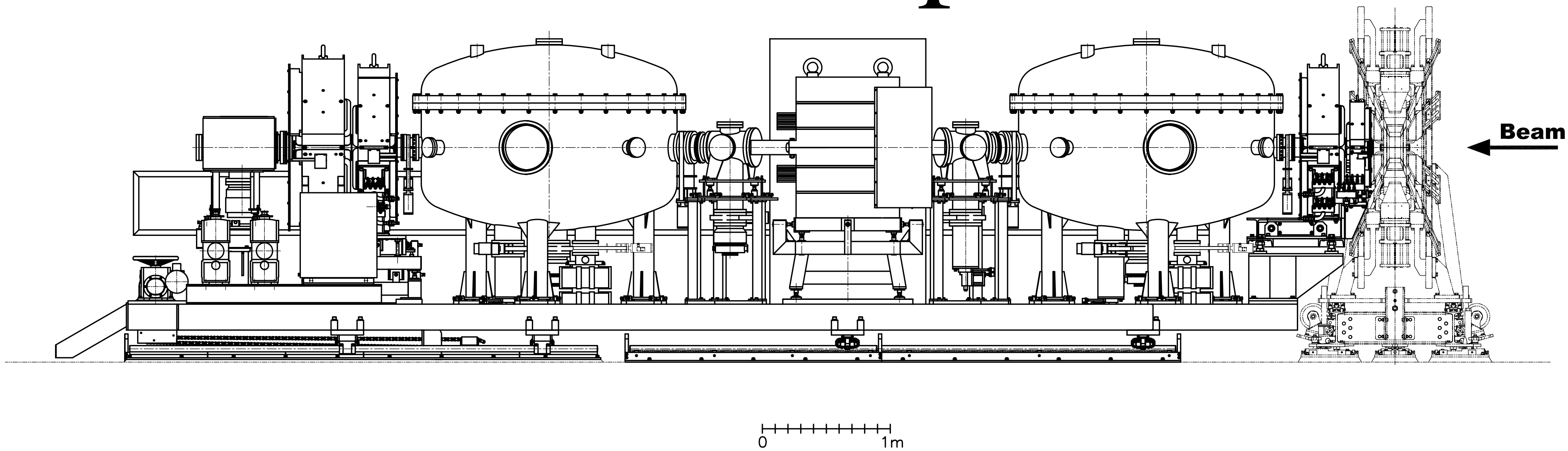
- Angular and energy spreads largest for fusion-evaporation reactions ($\Omega \sim$ 10-30 msr, $\Delta E/E \sim \pm 20\%$)
- Angle and energy spread not independent
- To take advantage of large angular acceptance, need large energy acceptance
- Large energy acceptance requires minimal chromatic aberrations 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?



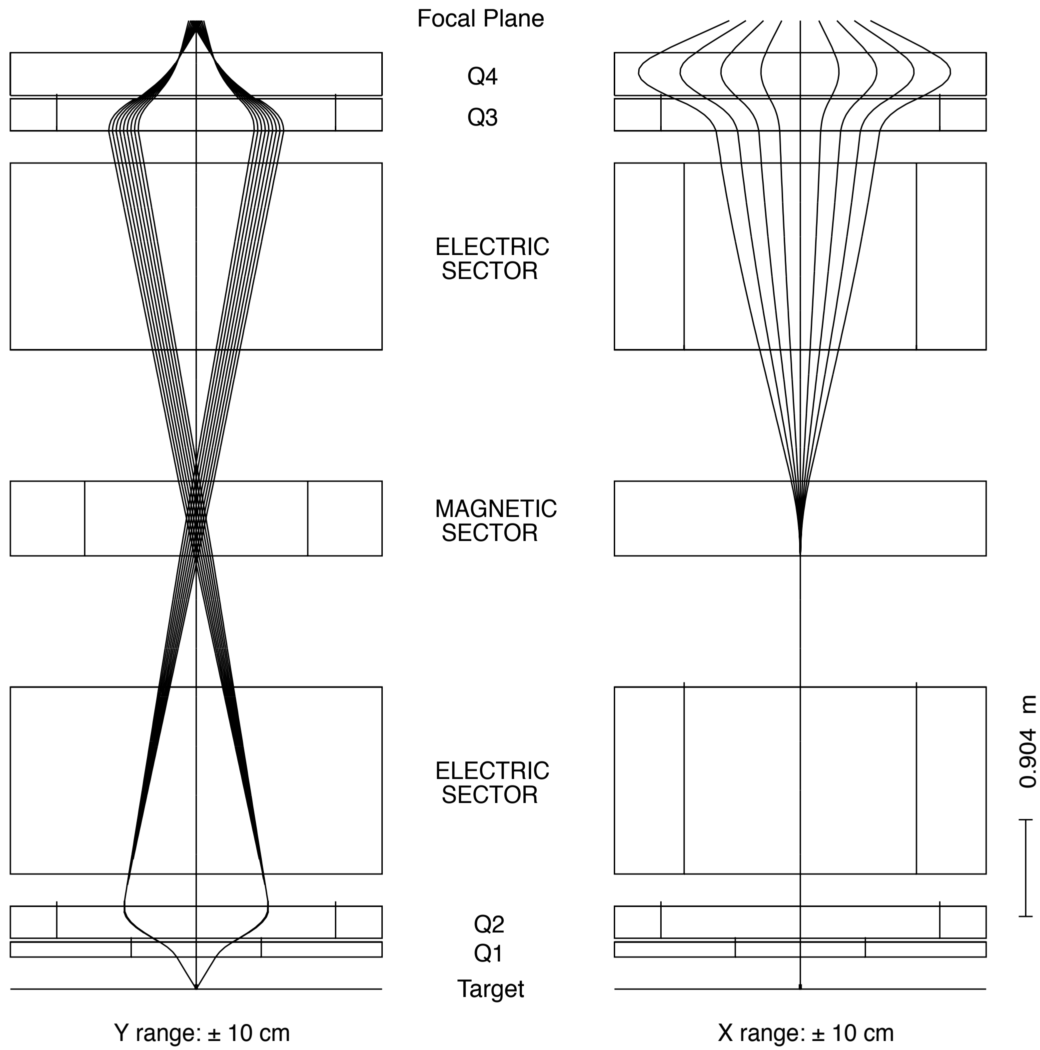
d(^{132}Sn, p)^{133}Sn at 6 A MeV with 100 μg cm^{-2} $(CD_2)_n$ target; smallest achievable beam energy spread; protons from 90-170 deg in lab

EMMA Optics



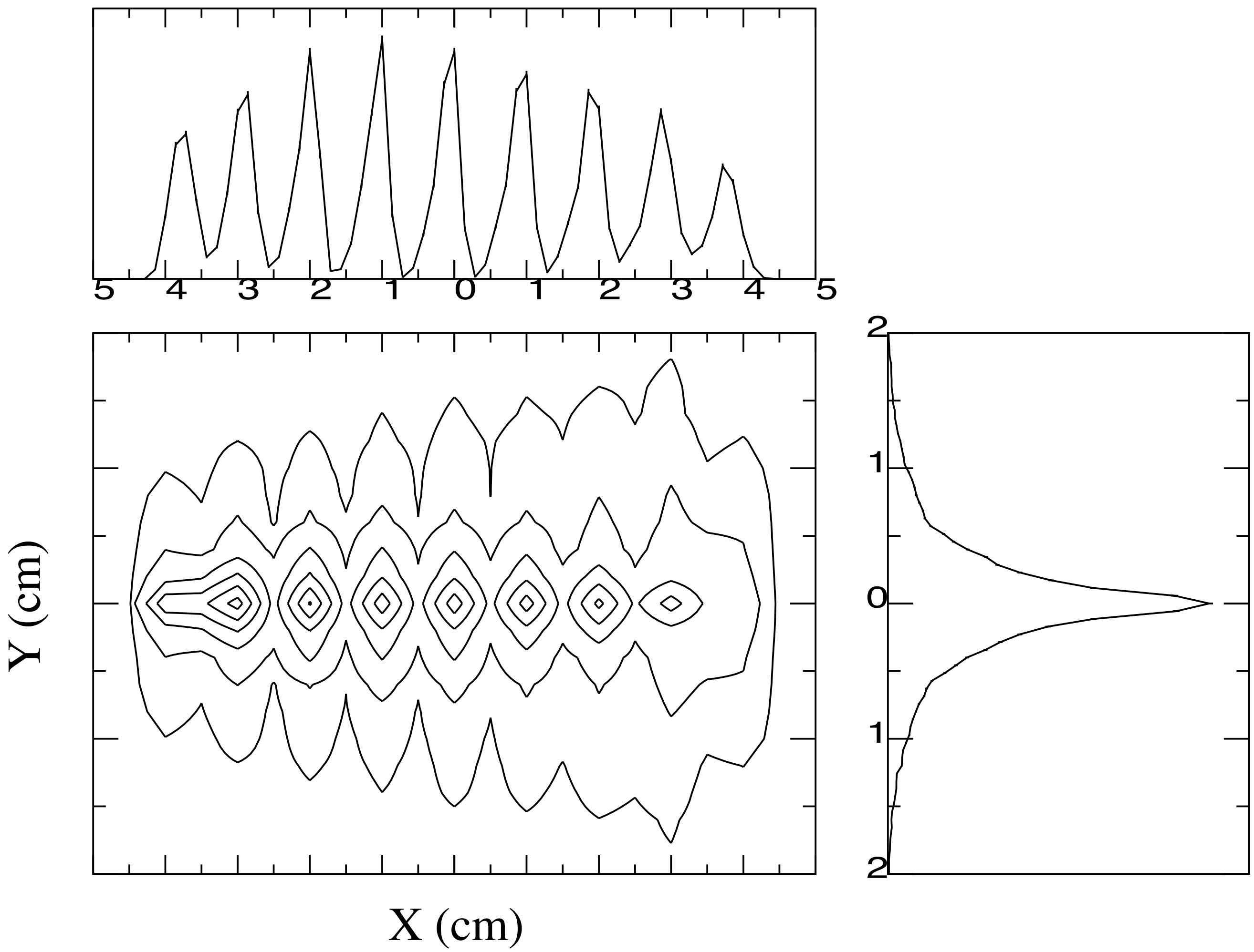
- Solid angle = ± 4° by ± 4° = 20 msr
- Energy acceptance = ± 20%
- Mass/charge acceptance = ± 4%
- 1st order m/q resolving power = 450
- 3rd order m/q resolving power for uniform spreads of ± 3° by ± 3° (11 msr), ± 10% $\Delta E/E$ is 366 (FWHM)

EMMA Design



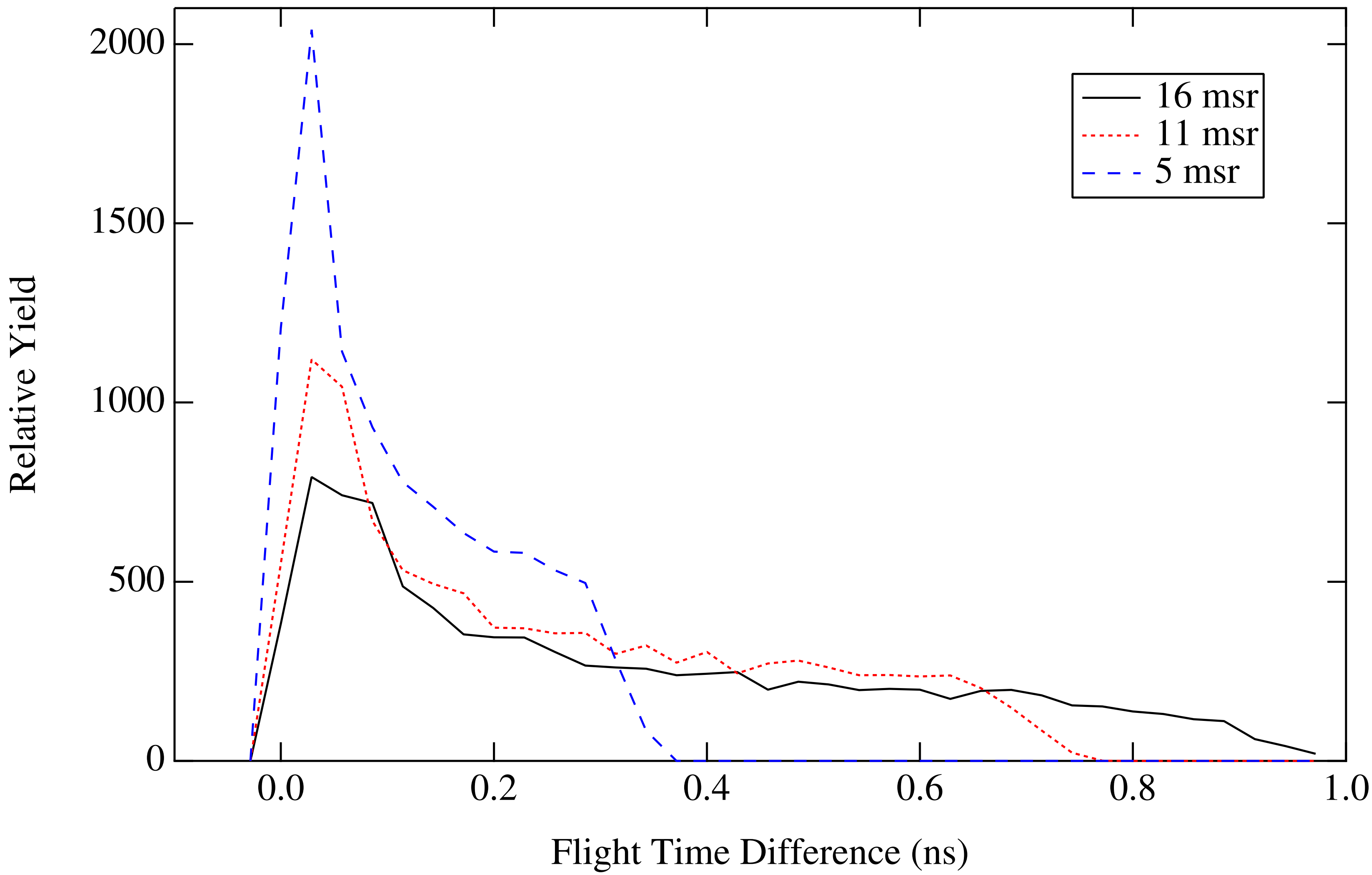
Length = 9.04 m target to focal plane

Mass Spectrum



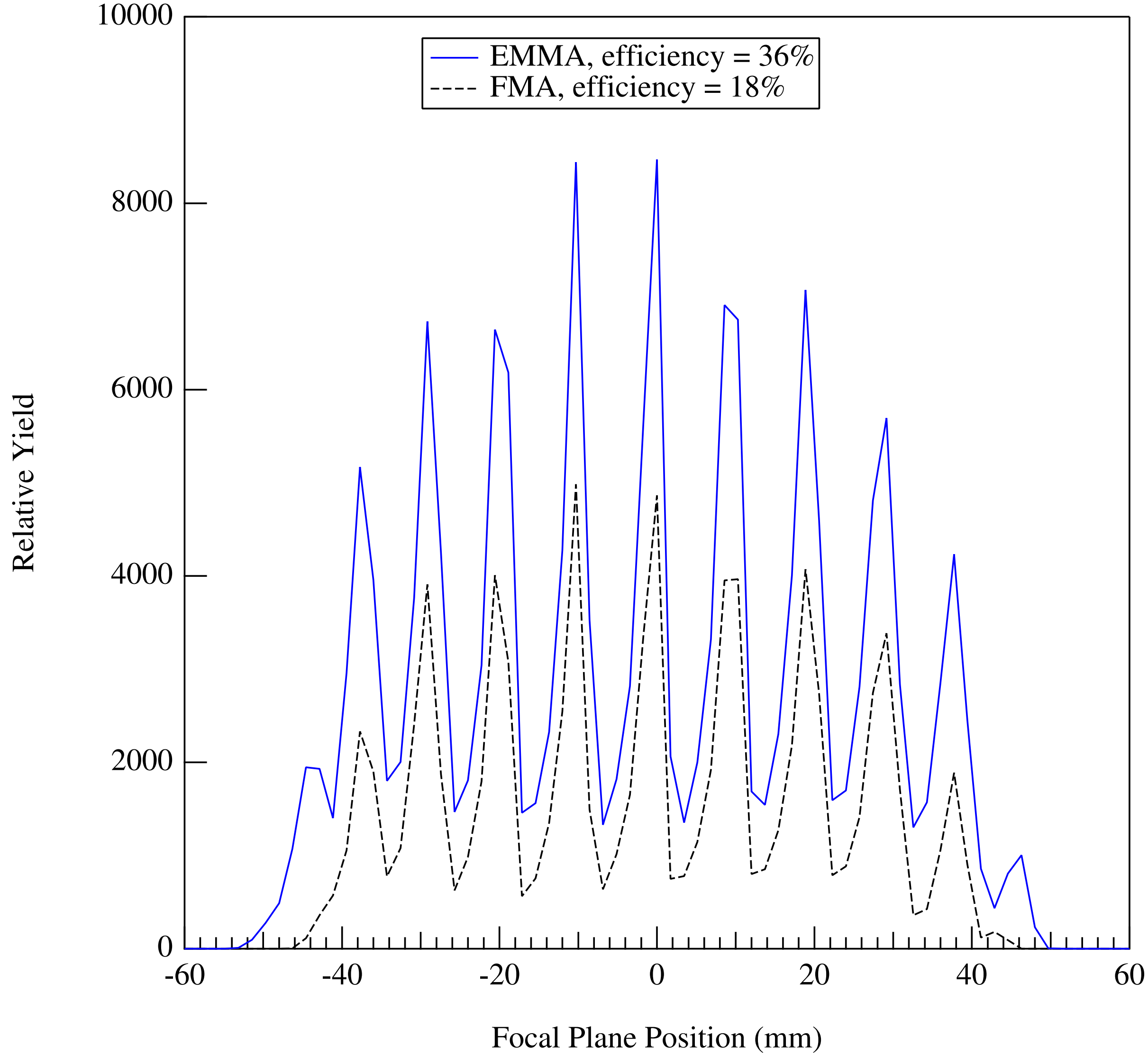
Uniform spreads of ± 3° by ± 3° (11 msr), ± 10% ΔE/E, ± 0.5 mm beam spot in both directions

Time Profile



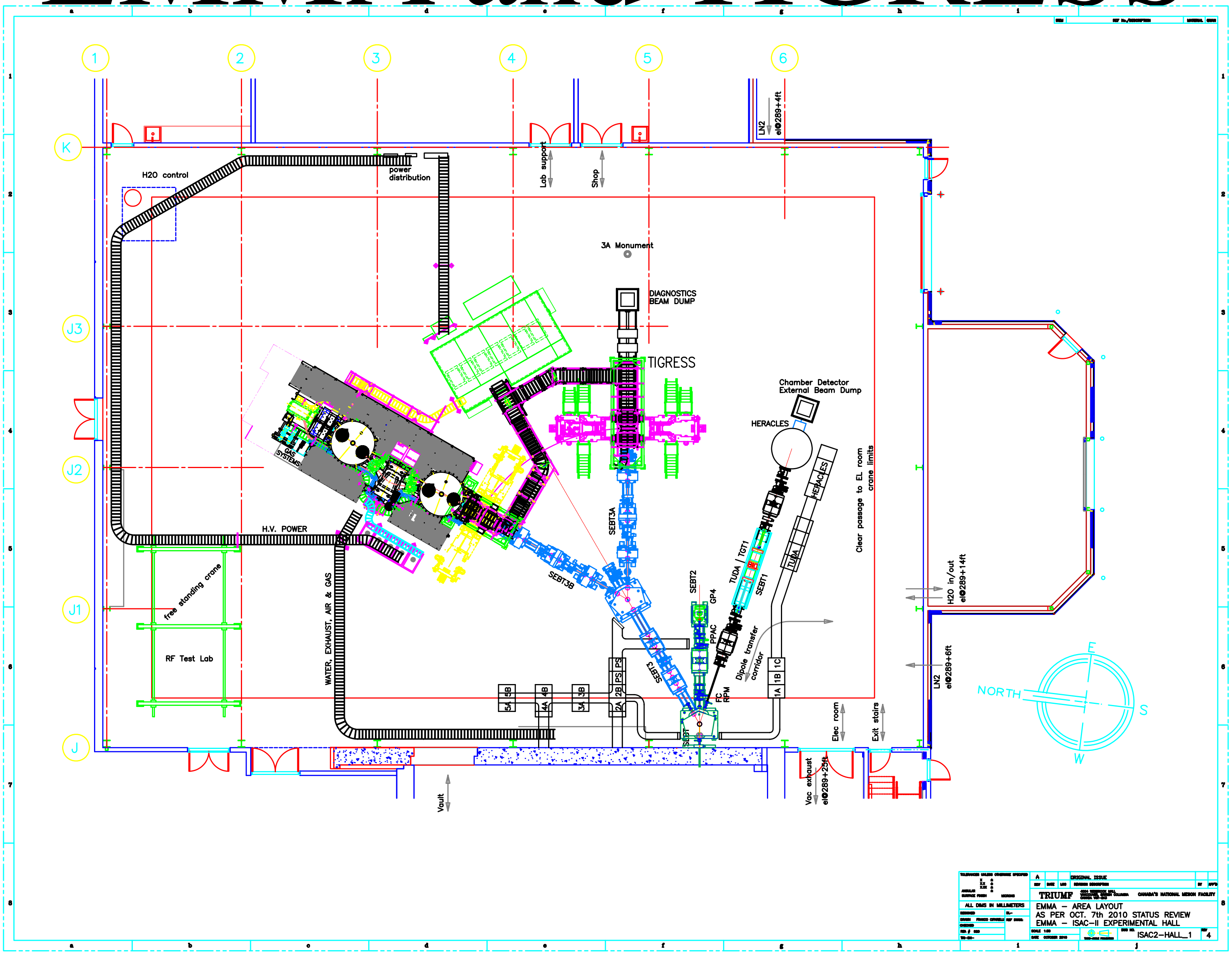
Flight time of 1 μs for central trajectory (0.4 A MeV)

EMMA-FMA Comparison



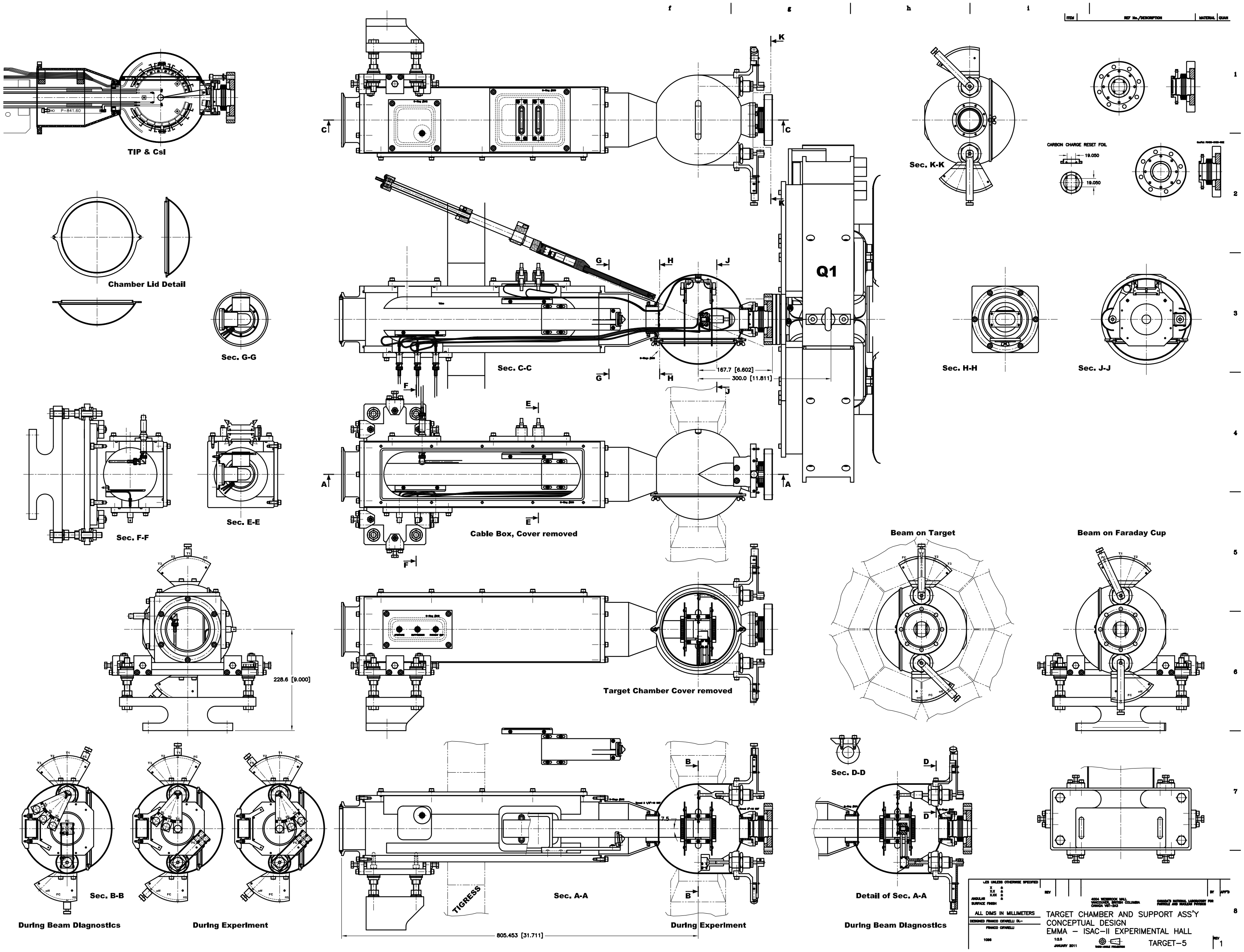
11 masses centred about A = 100, q = 20; 1.8 A MeV; Uniform spreads of ± 10% ΔE/E and 30 msr (± 5°)

EMMA and TIGRESS

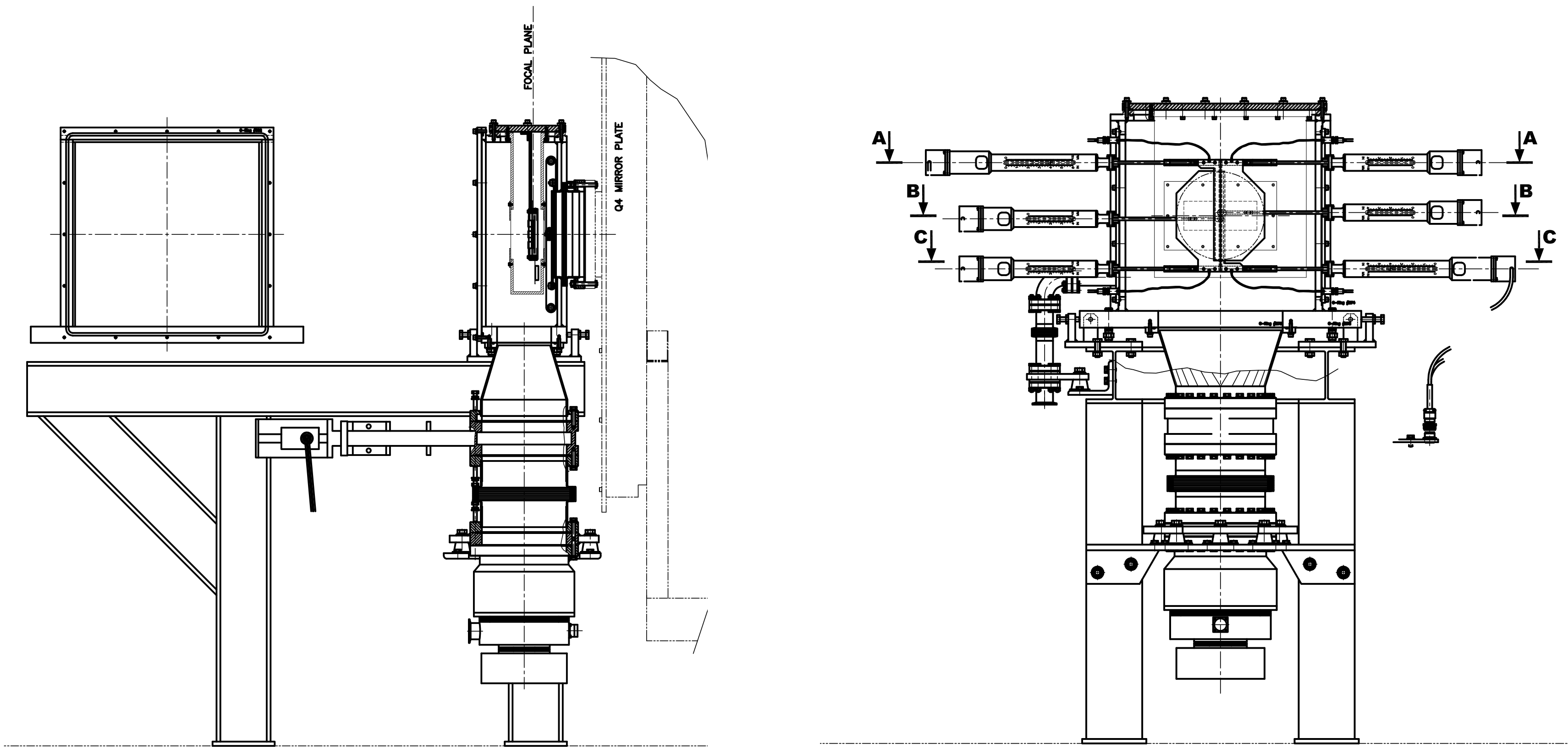


TIGRESS placed in front of EMMA or alone

Target Chamber

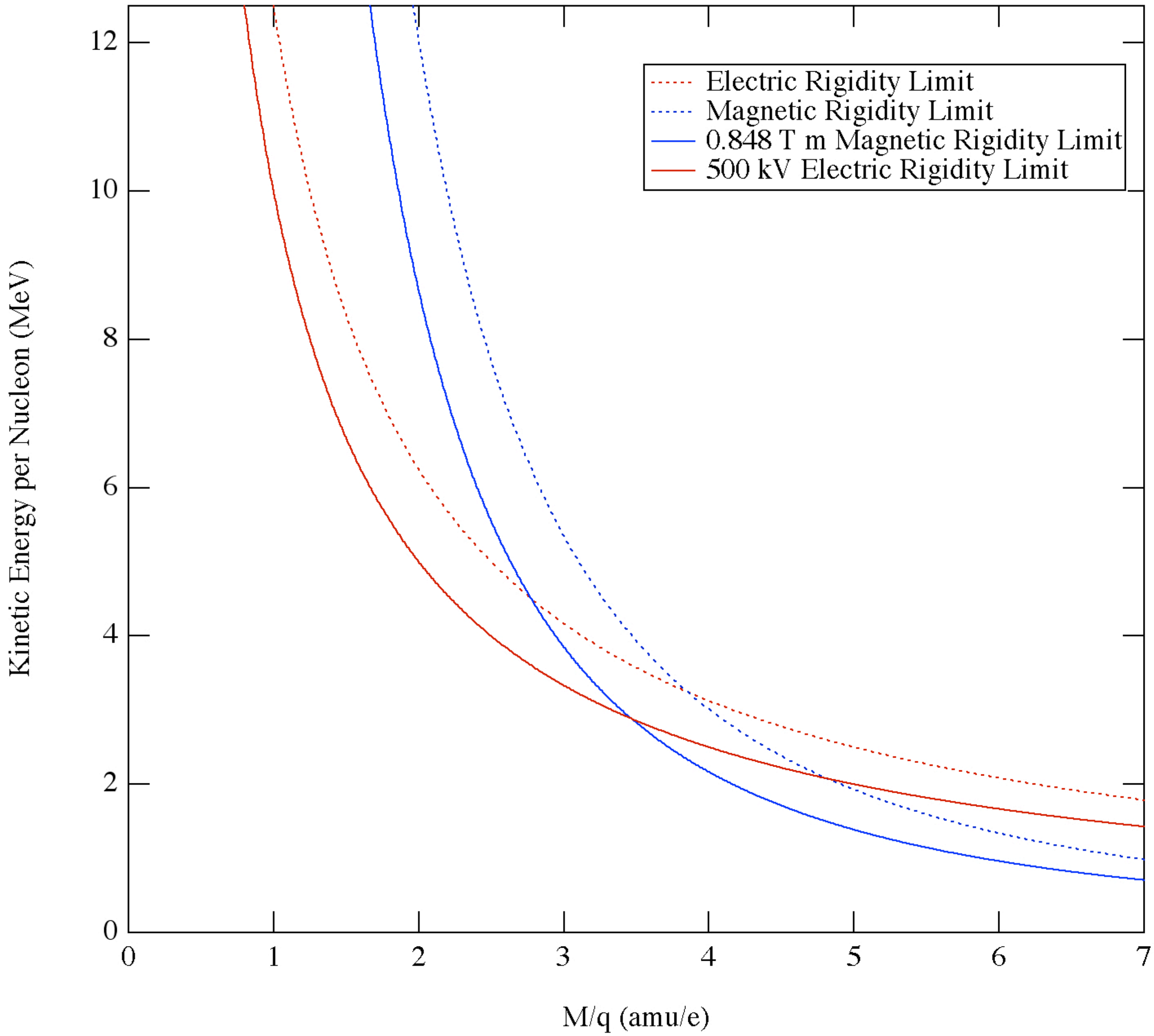


Focal Plane



PGAC, Ionisation Chamber, DSSD

Rigidity Limits



Beam Suppression

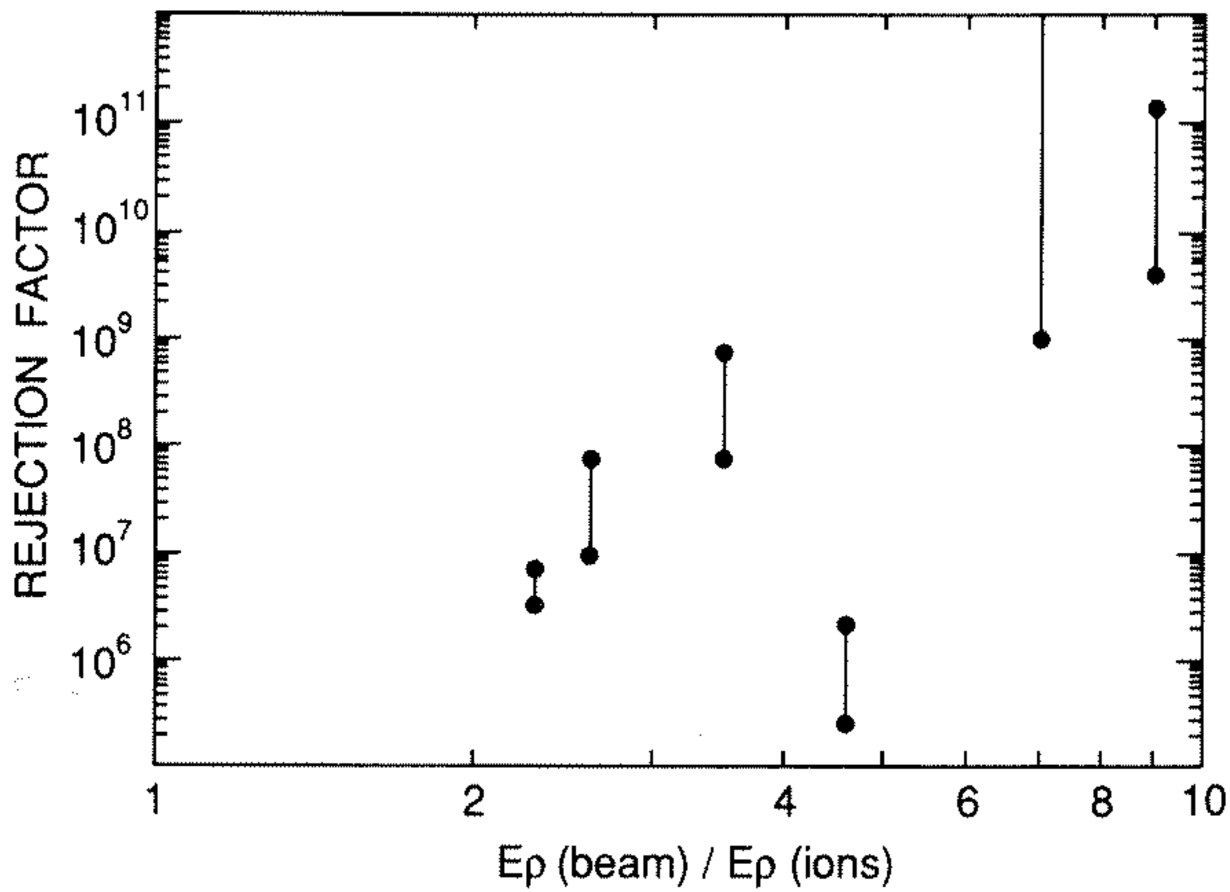
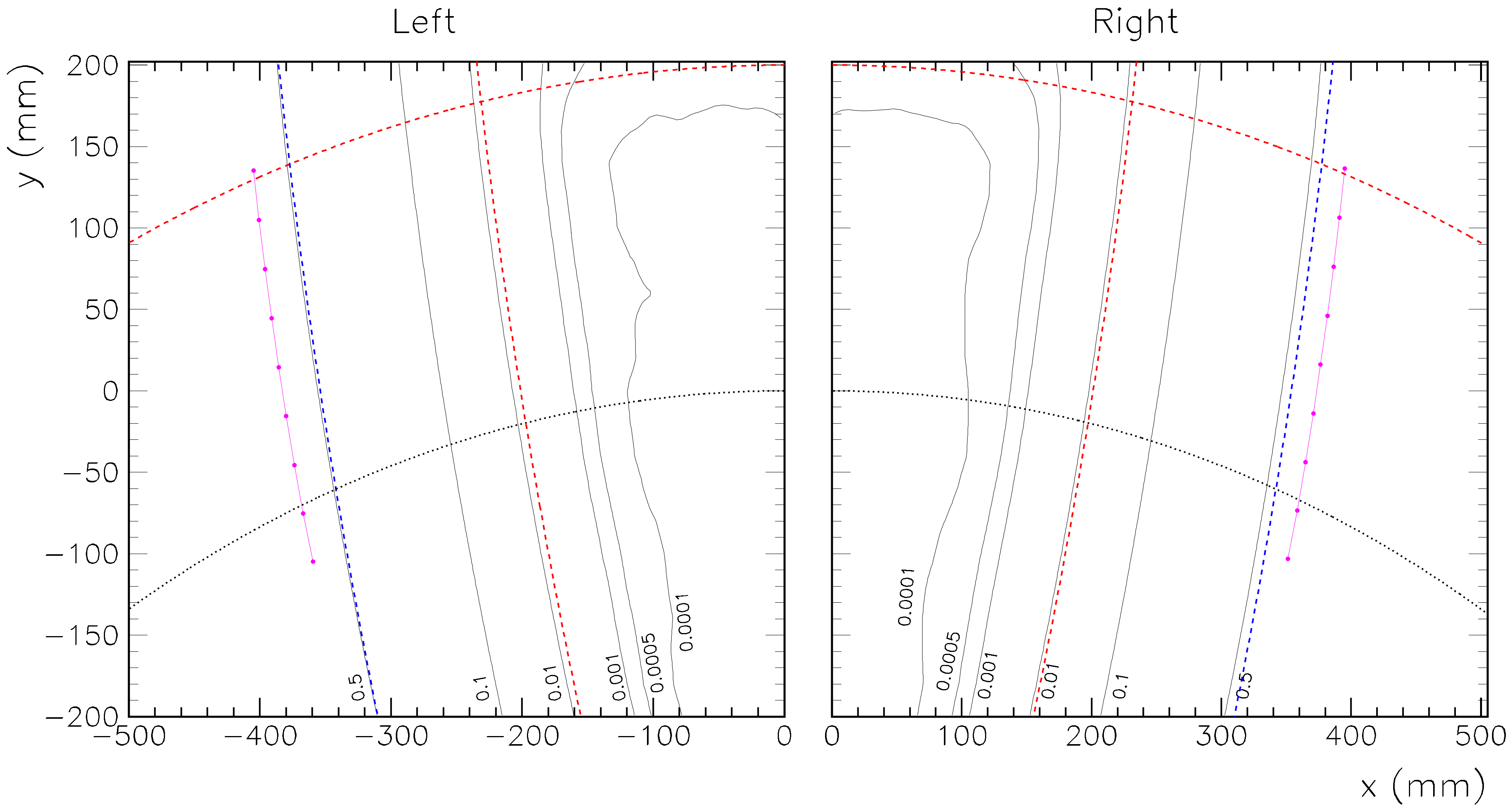


Fig. 10. Experimental beam rejection factor in day-to-day operation.

Magnet Map



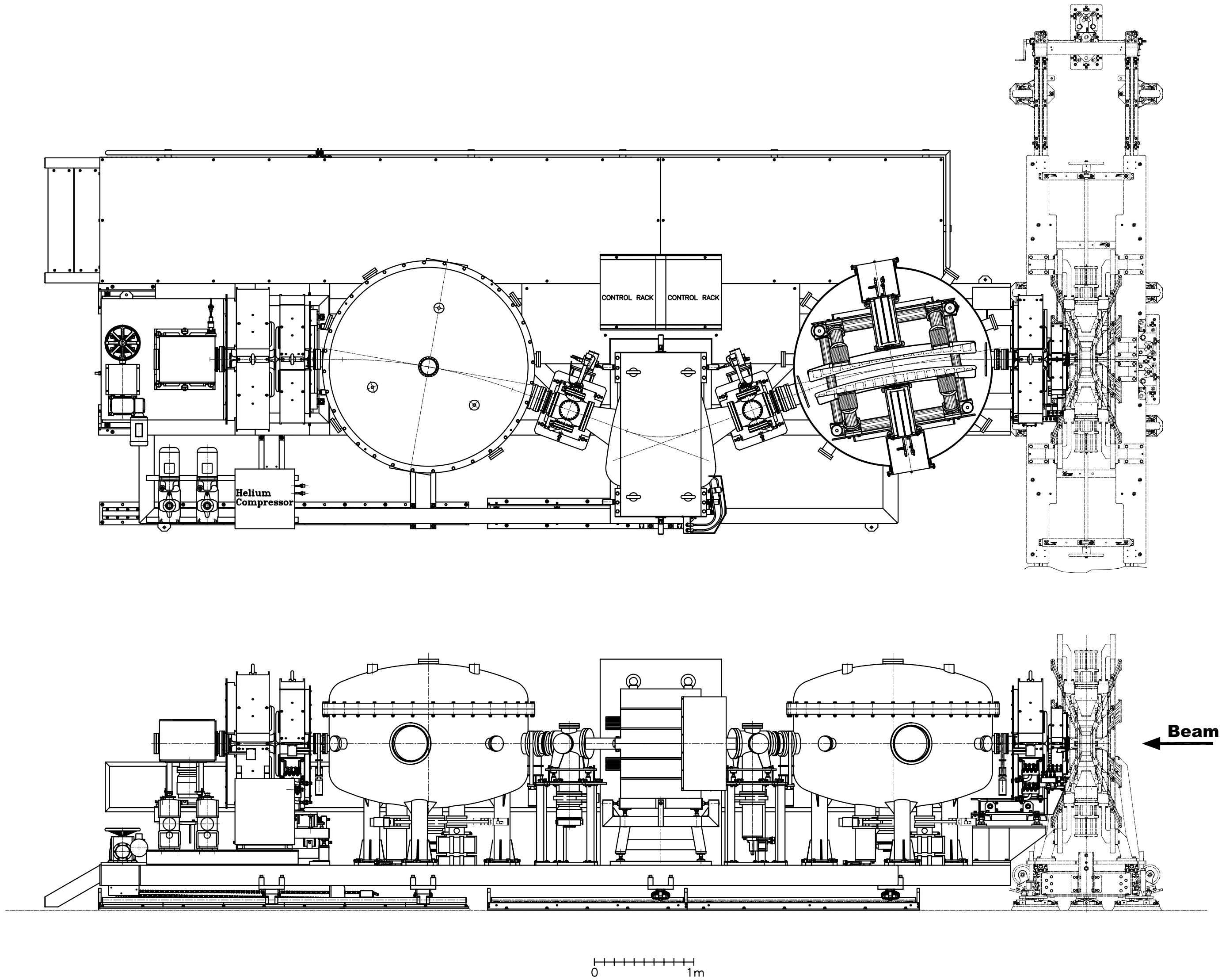
Left
Right
y (mm)
x (mm)
200
150
100
50
0
−50
−100
−150
−200
−500
−400
−300
−200
−100
0
100
200
300
400
500
0.5
0.1
0.01
0.001
0.0005
0.0001

“Driving the First Spike”

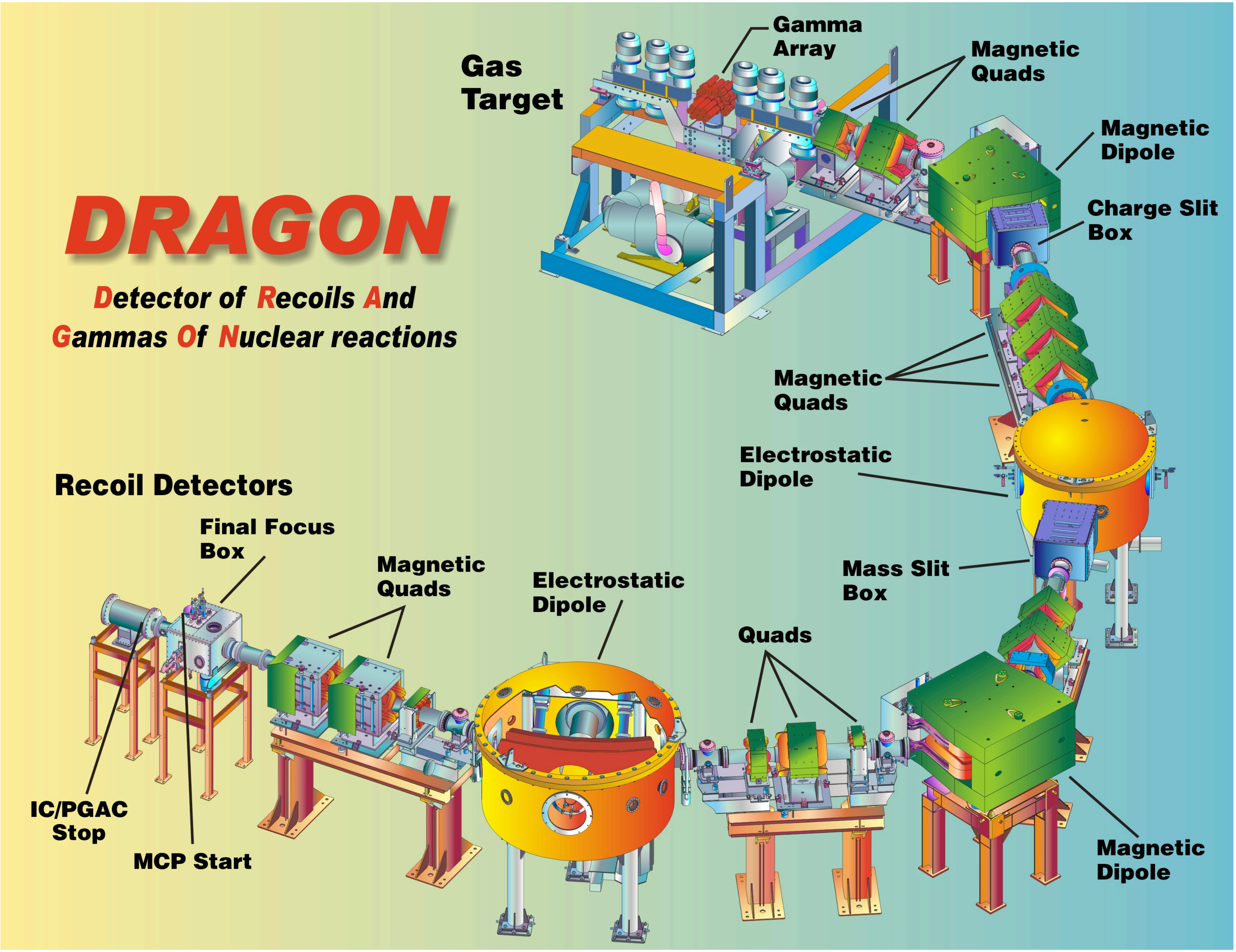
350 kV TRIUMF-engineered high voltage power supplies built and tested
Common support structure rails installed
TRIUMF-designed focal plane detectors to be built and tested in 2011
Delivery of large electromagnetic elements from Bruker expected in 2011

Current Status

Reference

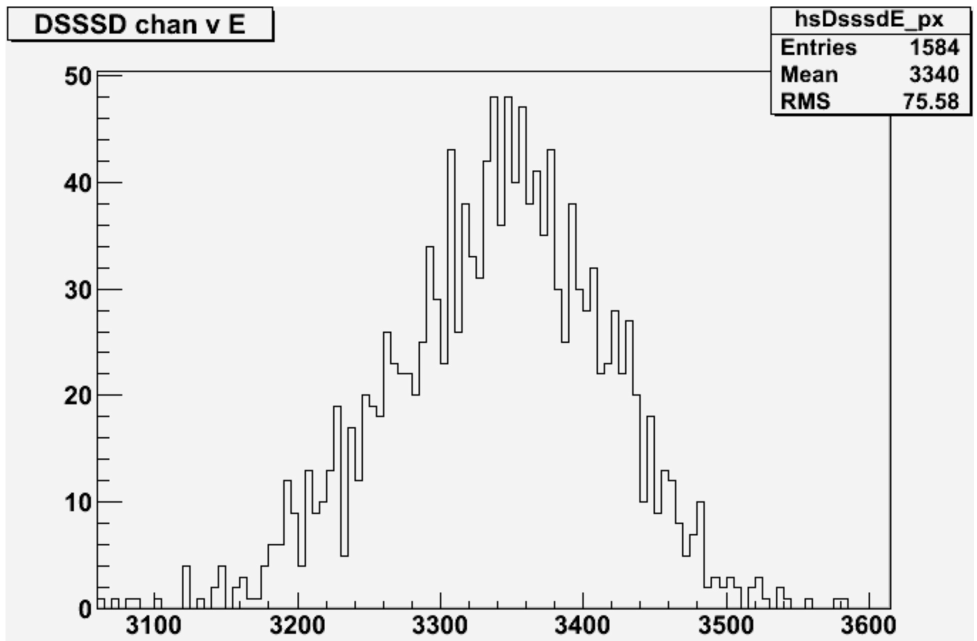


B. Davids and C. N. Davids, NIM A 544, 565 (2005)



DRAGON
Detector of Recoils And
Gammas Of Nuclear reactions
Gas Target
Gamma Array
Magnetic Quads
Magnetic Dipole
Charge Slit Box
Magnetic Quads
Electrostatic Dipole
Mass Slit Box
Quads
Magnetic Dipole
Electrostatic Dipole
Magnetic Quads
Final Focus Box
Recoil Detectors
IC/PGAC Stop
MCP Start

Measurement of $^{3}He(\alpha,\gamma)^{7}Be$ with DRAGON



- Bombarded ^{3}He gas target with 10^{17} α particles at E_{cm} = 2.8 MeV
- Focal Plane Si detector ^{7}Be recoil spectrum free from scattered beam
- Total lack of scattered beam implies beam rejection factor of at least 10^{17}
- This is a world record by at least 5 orders of magnitude
- Gas target density profile measured with $^{3}He(^{12}C,p)^{14}N$ reaction
- Measurements are ongoing