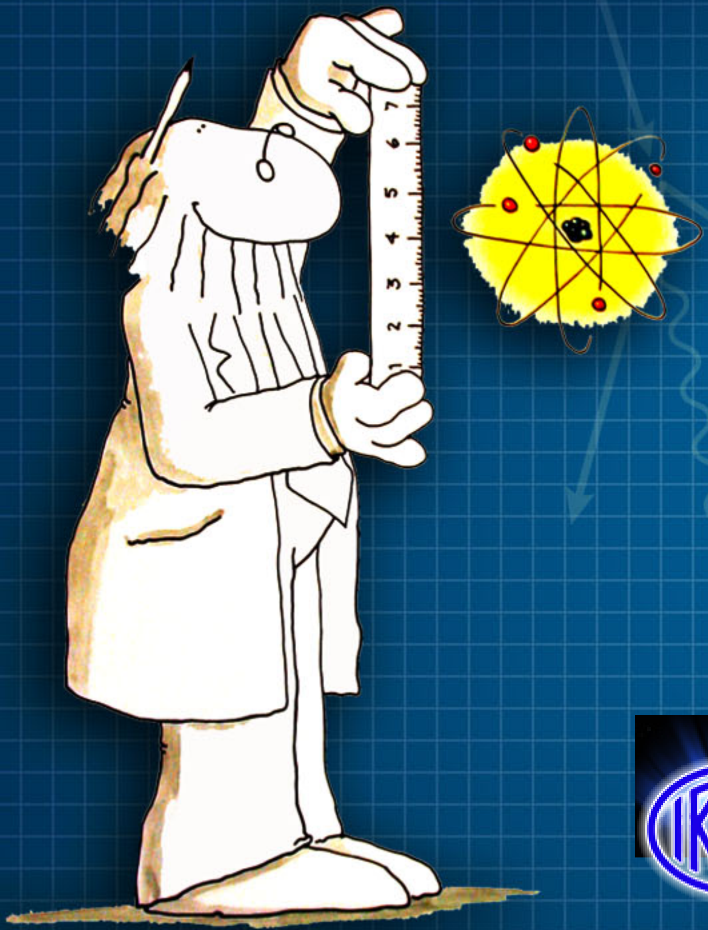


# Measurement of stopping powers using single electron counting

**Malcolm McEwen**

**Ionizing Radiation Standards**

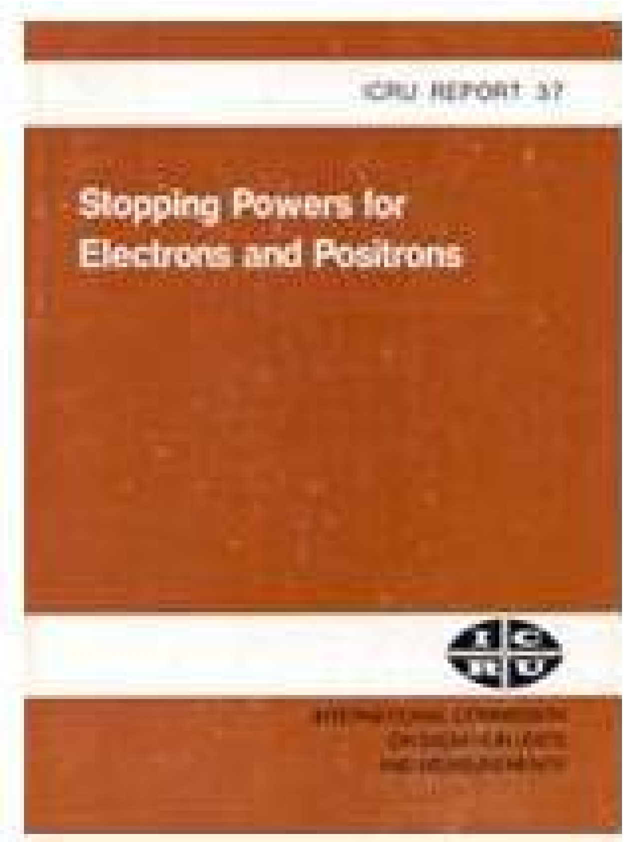
**National Research Council, Canada**

**27th April 2015**

**Council on Ionizing Radiation Measurements and Standards**

# The problem

- Stopping powers are essential data for radiation dosimetry
- Tabulated data are used in Monte Carlo codes and dose calculation algorithms, dose conversions, *etc*
- Experimental data are limited in scope and do not have requisite uncertainty to compare with the calculations and/or provide some validation




***Q: Can we obtain accurate experimental data to compare with the calculations?***

# What has been done previously?

- ❖ There have been a number of attempts over the years
- ❖ Two types of approach:
  - o Determination of absolute stopping powers
  - o Determination of stopping power ratios

Phys. Med. Biol., 1989, Vol. 34, No 12, 1863–1869. Printed in the UK

**Measurement of the total stopping power of 5.3 MeV electrons in polystyrene by means of electron beam absorption in ferrous sulphate solution**

H Feist† and U Müller‡
Physikalisch-Technische Bundesanstalt, D-3300 Braunschweig, Federal Republic of Germany

**Abstract.** The present paper describes how an experimental arrangement for the calibration of Fricke solution in terms of absorbed dose to water can be utilised to determine total, i.e. collisional and radiative, mass stopping power of high-energy electrons. As a first result the measurement of the total mass stopping power of polystyrene at about 5.3 MeV kinetic electron energy is presented in detail. Comparison of the obtained value with the corresponding result of recent theoretical computations shows agreement within the measurement uncertainty of about 1.2% (SD).

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Radiation Physics and Chemistry 68 (2003) 1017–1022
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**Use of a range scaling method to determine alanine/water stopping power ratios**

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[a] Ionizing Radiation Standards, National Research Council of Canada, Montreal Road, Ottawa, Canada K1A 0R6
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, UK

**Abstract**

A phantom composed of alanine dosimeter material has been constructed and depth–dose measurements made in a 10 MeV electron beam. The results have demonstrated the feasibility of using relative depth–dose measurements to determine stopping power ratios in materials of dosimetric interest. Experimental stopping power ratios for alanine dosimeter material and water agreed with the data of ICRU Report 37 within the uncertainty of the experiment (±1.2% at a 95% confidence level).


*Keywords:* Electron; Stopping power; Absorbed dose; Dosimetry; Alanine

# A tale of two standards laboratories (going back 20 years)

NPL
National Physical Laboratory

Measurement of the Stopping Power of Graphite

Malcolm R McEwen

National Physical Laboratory

MSc Radiation Physics

July 1993

University College London

National Research Council Canada

National Research Council Canada / Conseil national de recherches Canada

NRC·CNRC

Institute for National Measurement Standards / Institut des étalons nationaux de mesure

PhD Thesis

Accurate Measurements of the Collision Stopping Powers for 5 to 30 MeV Electrons

Miller S. MacPherson

September, 1998

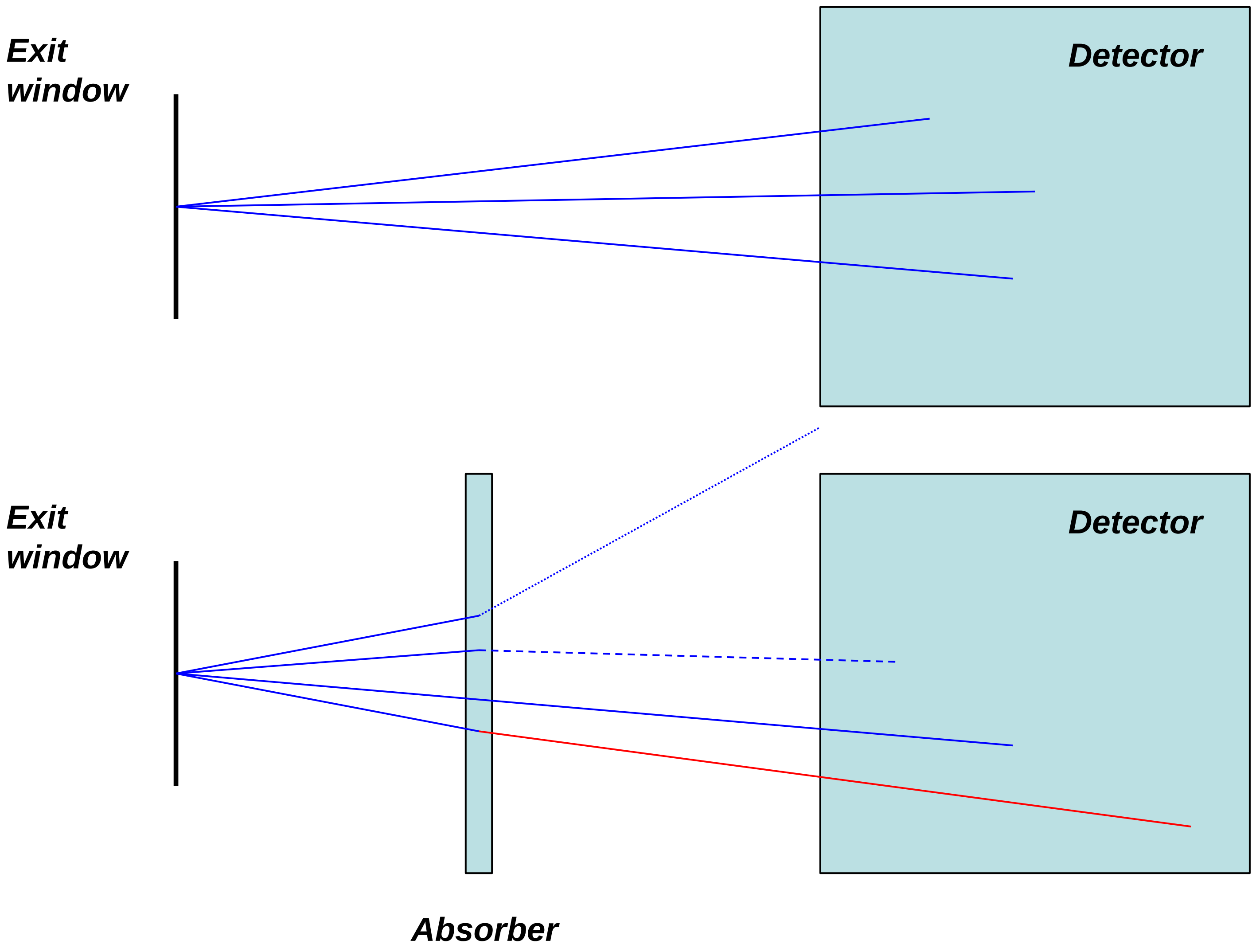
PIRS-0626

Results contained in this report are traceable to the national measurement standards of Canada.

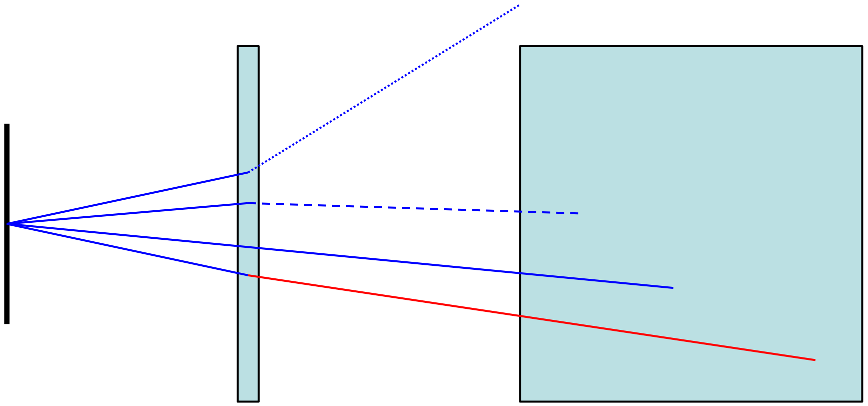
Les résultats contenus dans ce rapport sont traçables aux étalons nationaux de mesure du Canada.

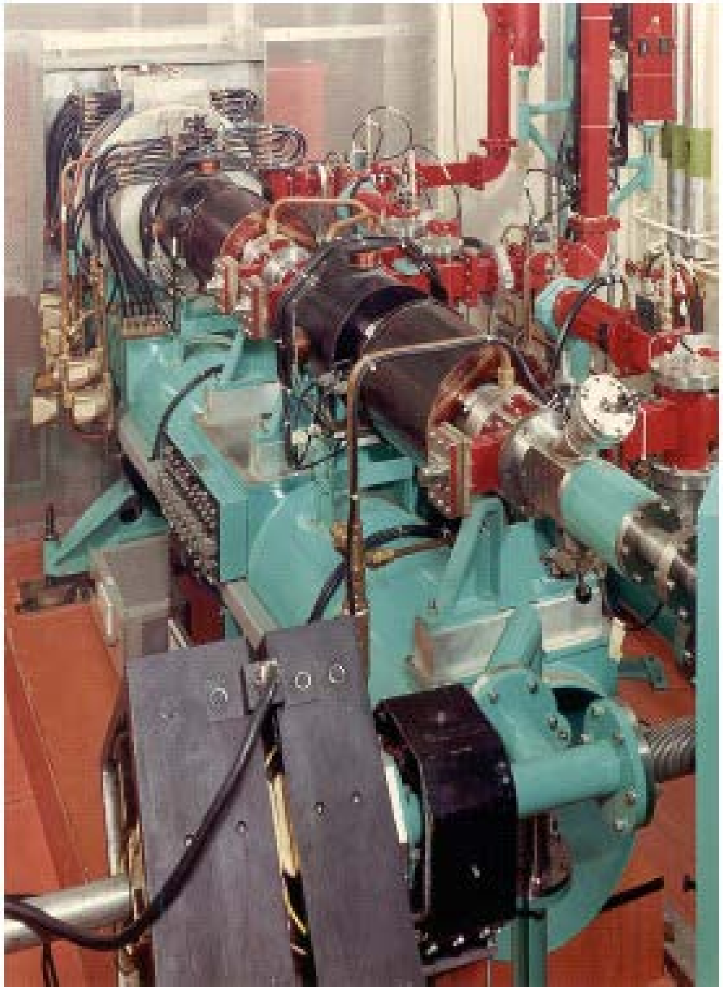
*These studies demonstrated that single-electron approach used at NRC was preferred*

# Basic principle



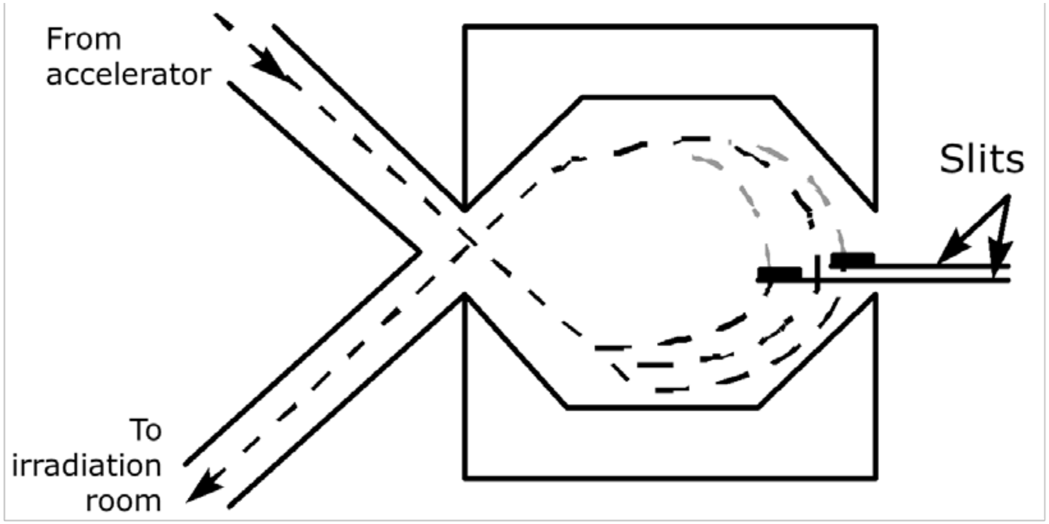
# Particle counting requires a particle source

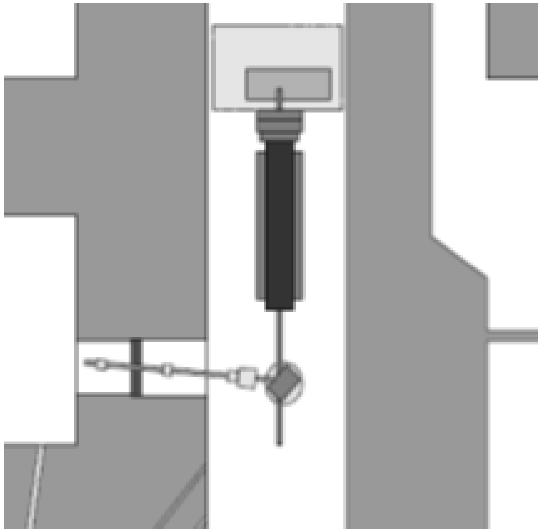




*Radiation Dynamics Ltd*
*research linac*
*3-20 MeV*
*Installed at NPL in 1974*

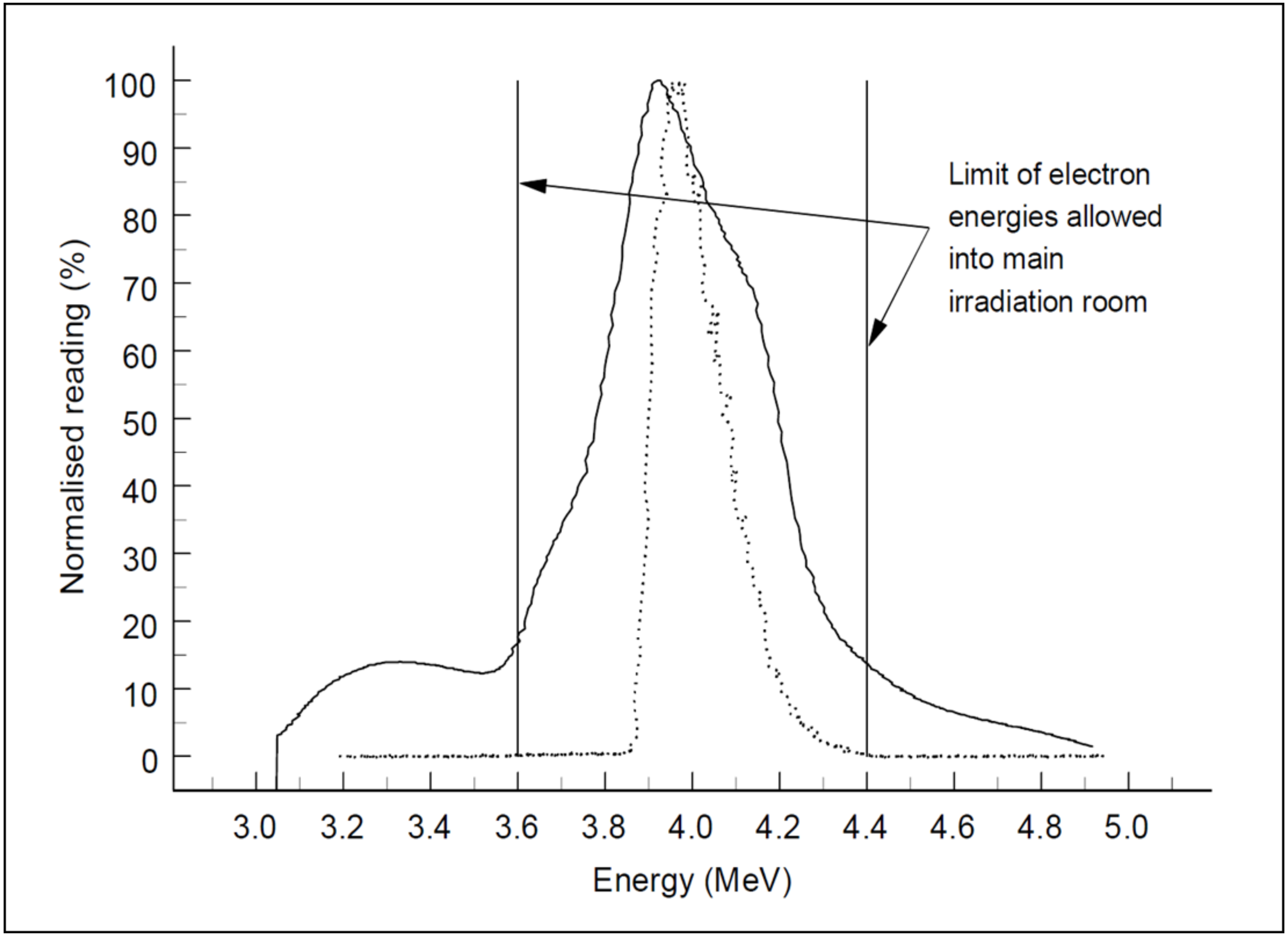
# Energy selection



- The linac employs a ‘pretzel’ achromatic bending magnet
- The different paths that different energy electrons take within the magnet allow precise energy selection using a pair of movable slits. Both the position (mean energy) and width (energy resolution) can be varied.
- A narrow slit width can also be scanned across the beam to determine the electron spectrum
- This design was used in the clinical RDL/ABB Dynaray linacs

# Electron spectrum - example

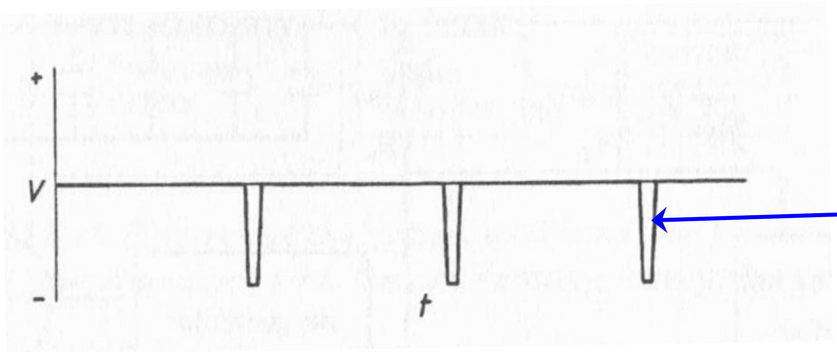



A lot of trial & error was needed to optimize the spectrum shape

Limits, due to slit edges ,can be varied down to < 100 keV

# How do you get the low beam current?

- Typical therapy electron beam current ~ 15 nA
- For a typical pulse width of 3 μs and PRF of 250 Hz this gives ~ $2 \times 10^8$ electrons per pulse
- Need, <u>on average</u>, less than 1 electron per pulse




Two electrons within the pulse can not be discriminated by the detector
A single particle is recorded with double the energy

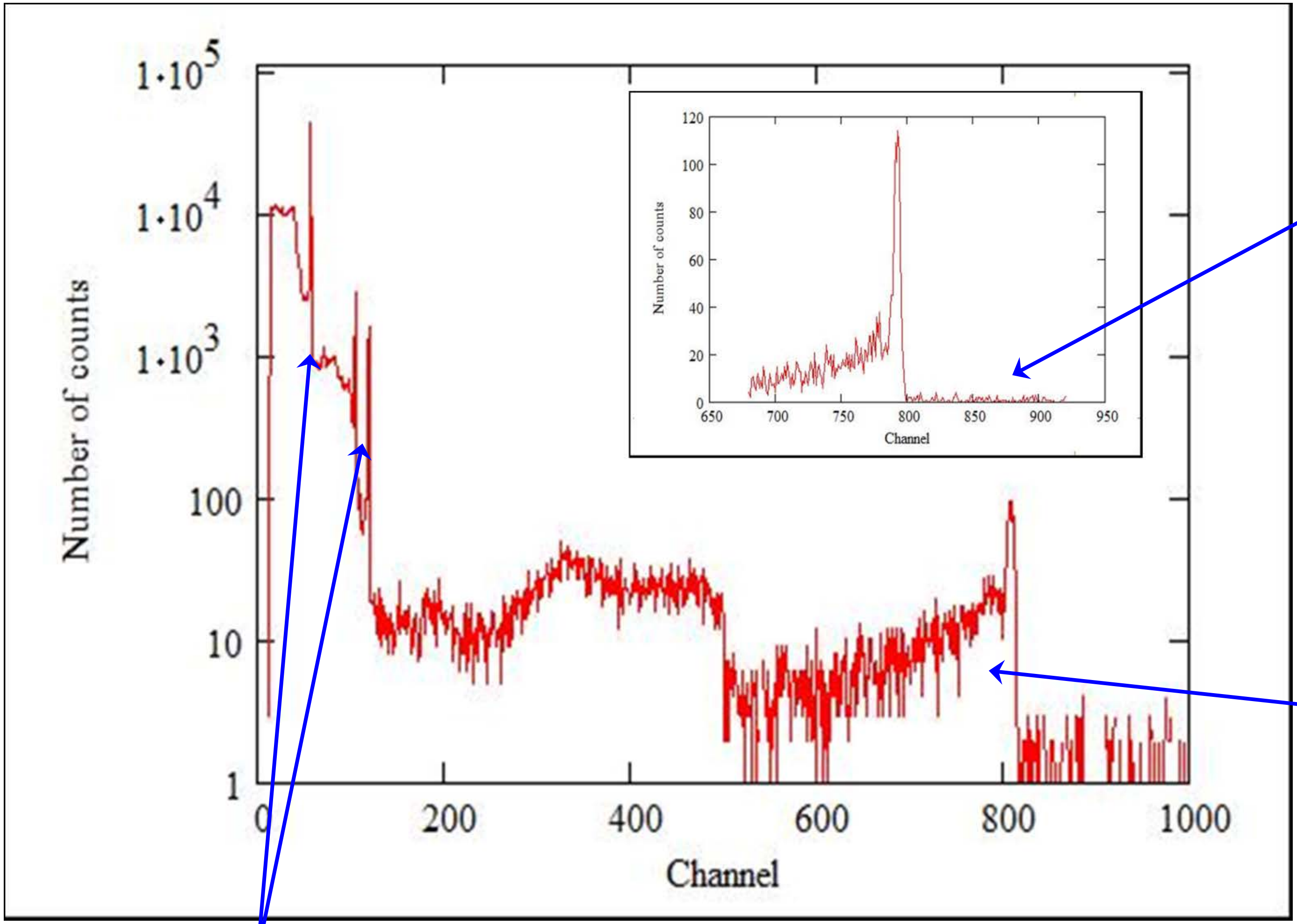
- Use a combination of reduced initial electron beam current, attenuators within the accelerating structure, and narrow transmission slit for the bending magnet

# Measuring the individual electrons

- Standard HPGe detector
- 1” thick, 1” radius parallel electrode design.
- For initial tests, cold finger design did allow placement right at exit window
- 1024-channel MCA

Not ideal but good enough to investigate systematics of experiment

# Results and detector calibration

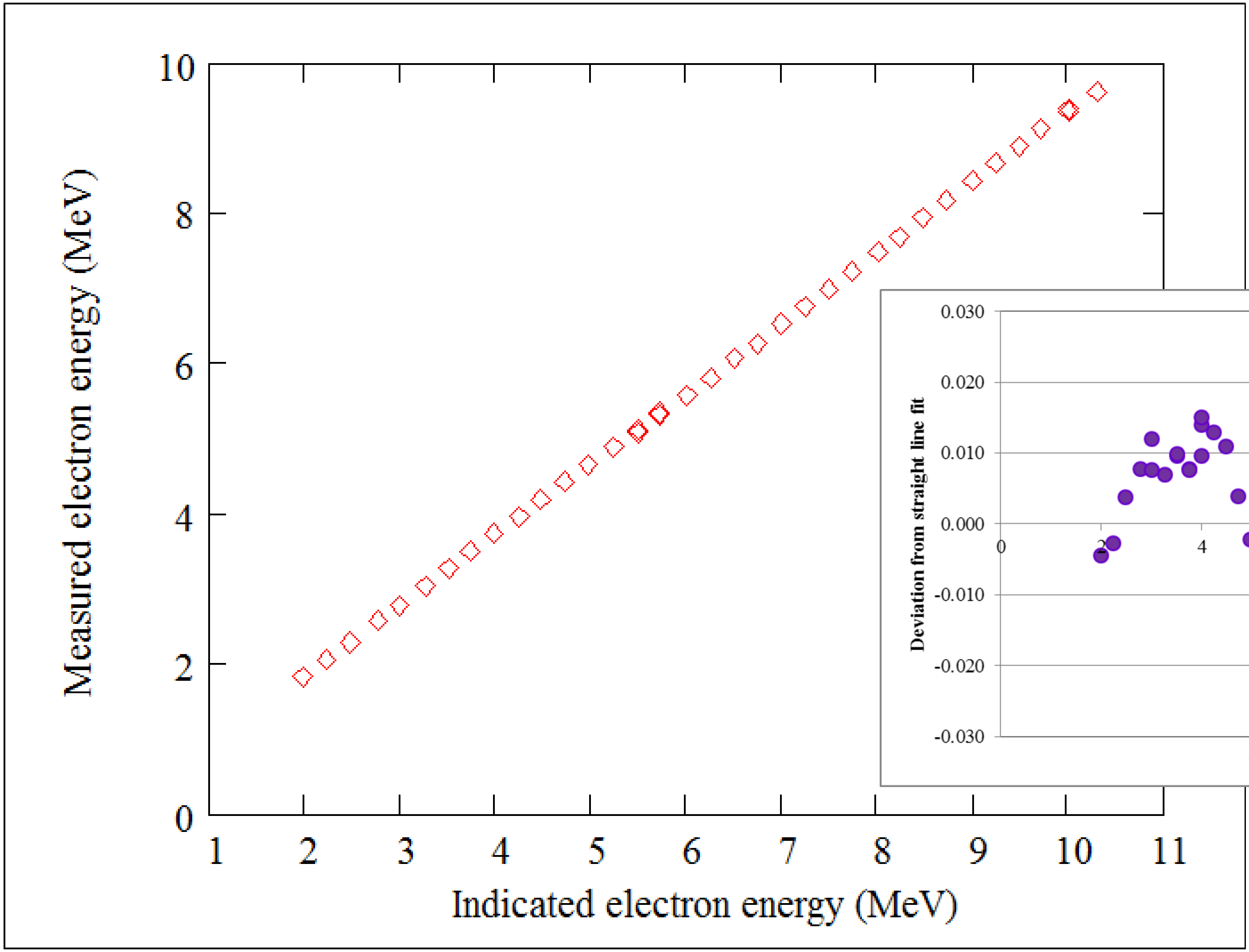


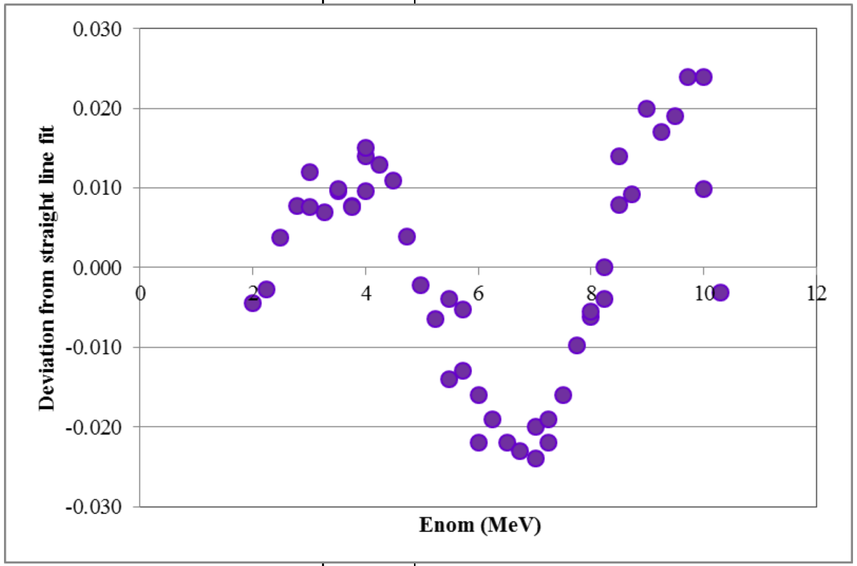

Little or no signal above expected maximum energy – no double counting

Total count rate from linac-sourced particles must be < PRF

Self-calibration – weak Cs-137 and Co-60 sources attached to side of detector housing

# Detector testing – energy calibration

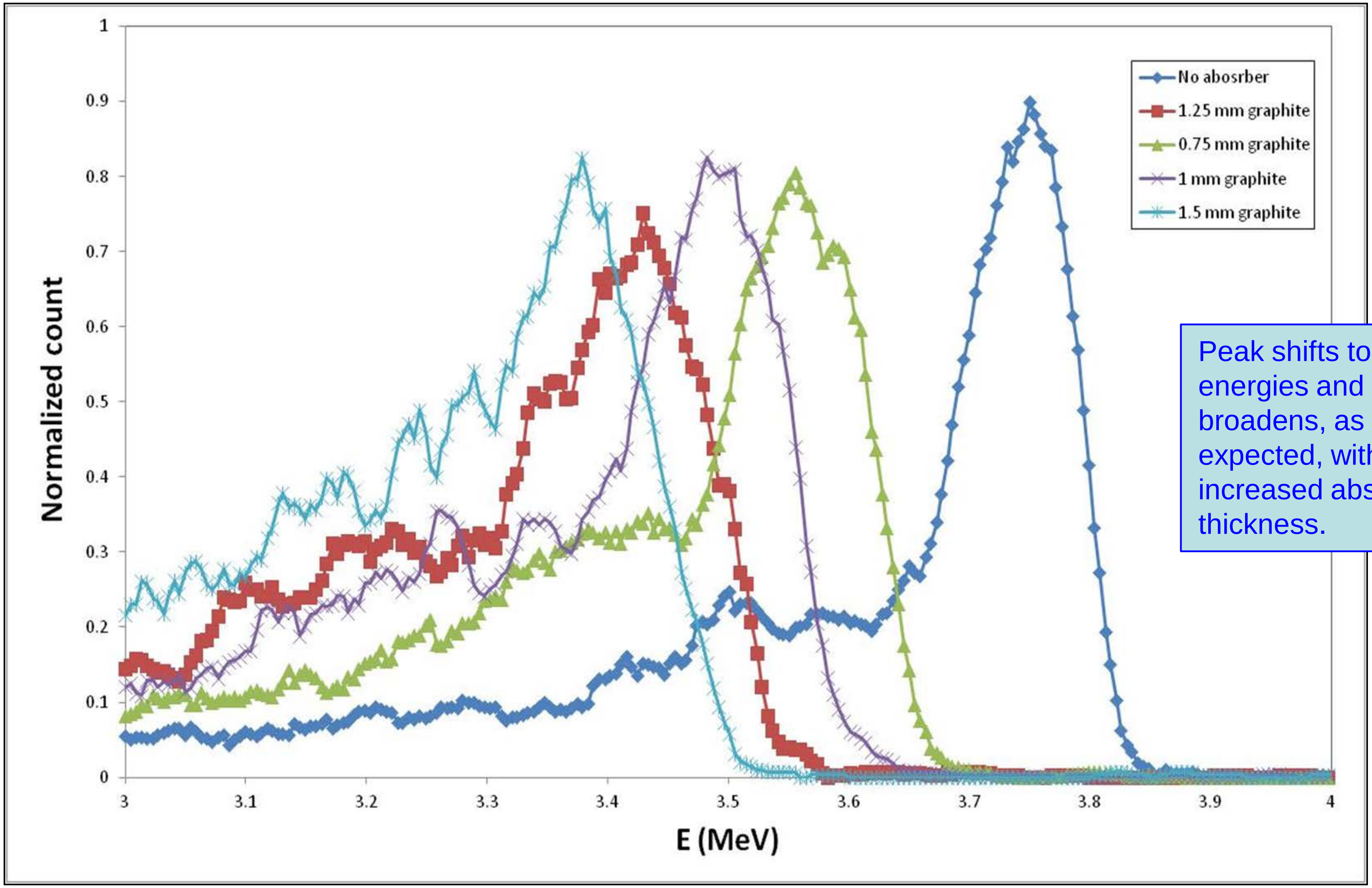



Repeatability at the 5 keV level

Non-linearity is due to magnet calibration, not HPGe

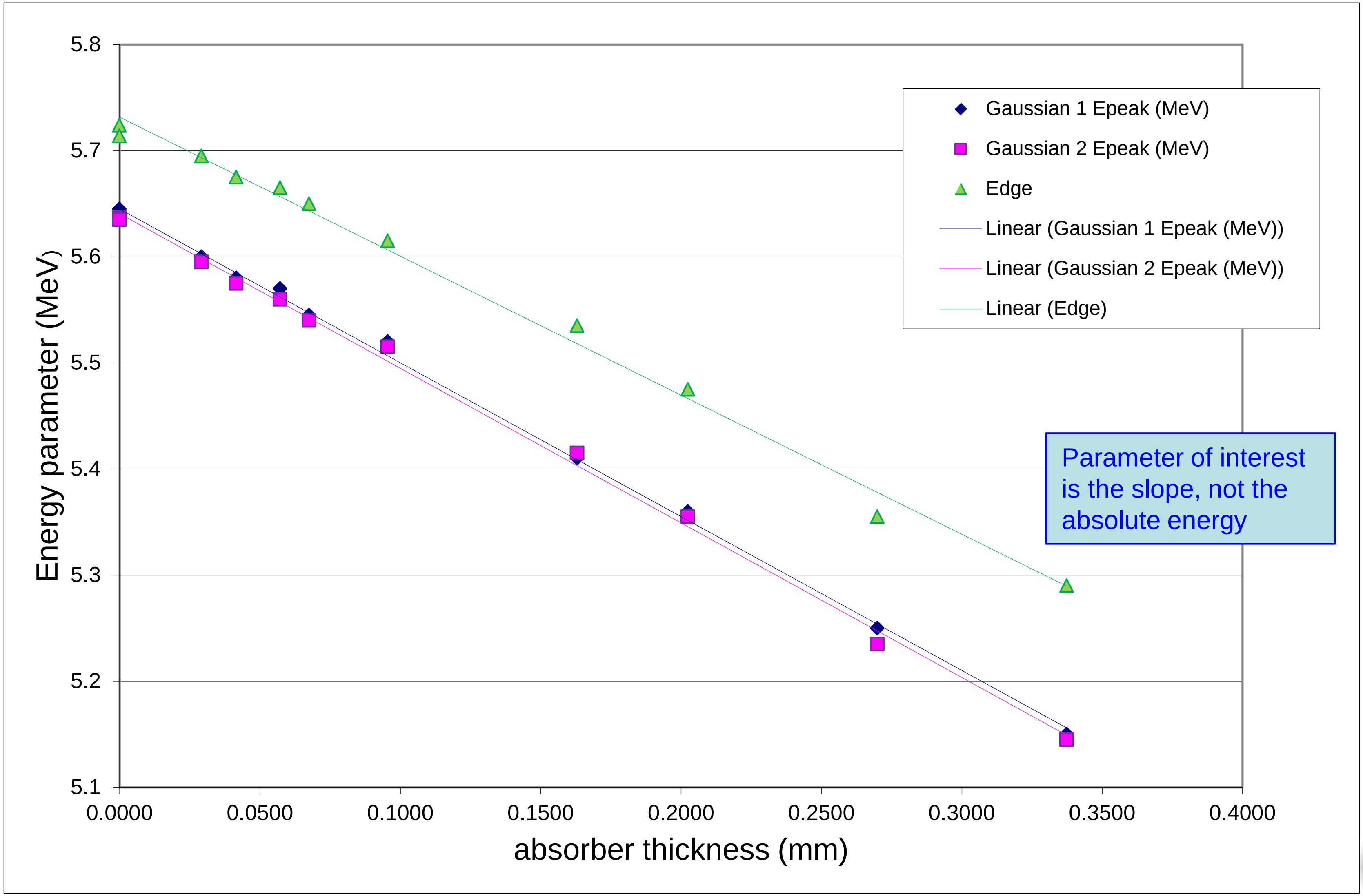
# Actual measurements



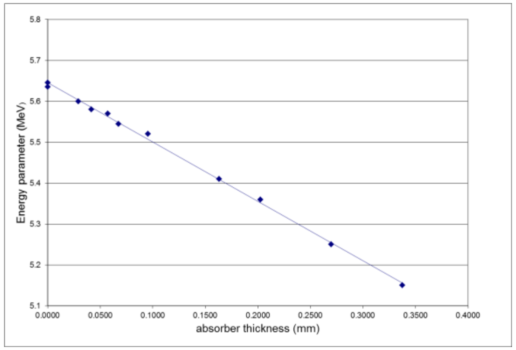

Peak shifts to lower energies and broadens, as expected, with increased absorber thickness.

10 – 20 minutes counting per point required to obtain at least 100 peak counts

# Analyzing the data – aluminium sheets



# Initial results




Gaussian fit to the high energy edge of the electron peak was found to be fairly robust and insensitive to energy losses due to detector geometry and degradation of spectrum.

> Repeatability in the measurement of electron energy was typically 5 keV.
> The standard uncertainty in the gradient dE/dt was in the range 1.0 % to 1.7 %.

Gradient of dE/dt obtained this way is NOT the stopping power as it ignores, by design, interactions that cause large energy losses (i.e., those that do not register in the ‘photopeak’).

Monte Carlo calculations could be used to reproduce the geometry and determine the equivalent gradient.

***Q: Is it possible to have a truly experimental determination of stopping powers?***

# Challenges

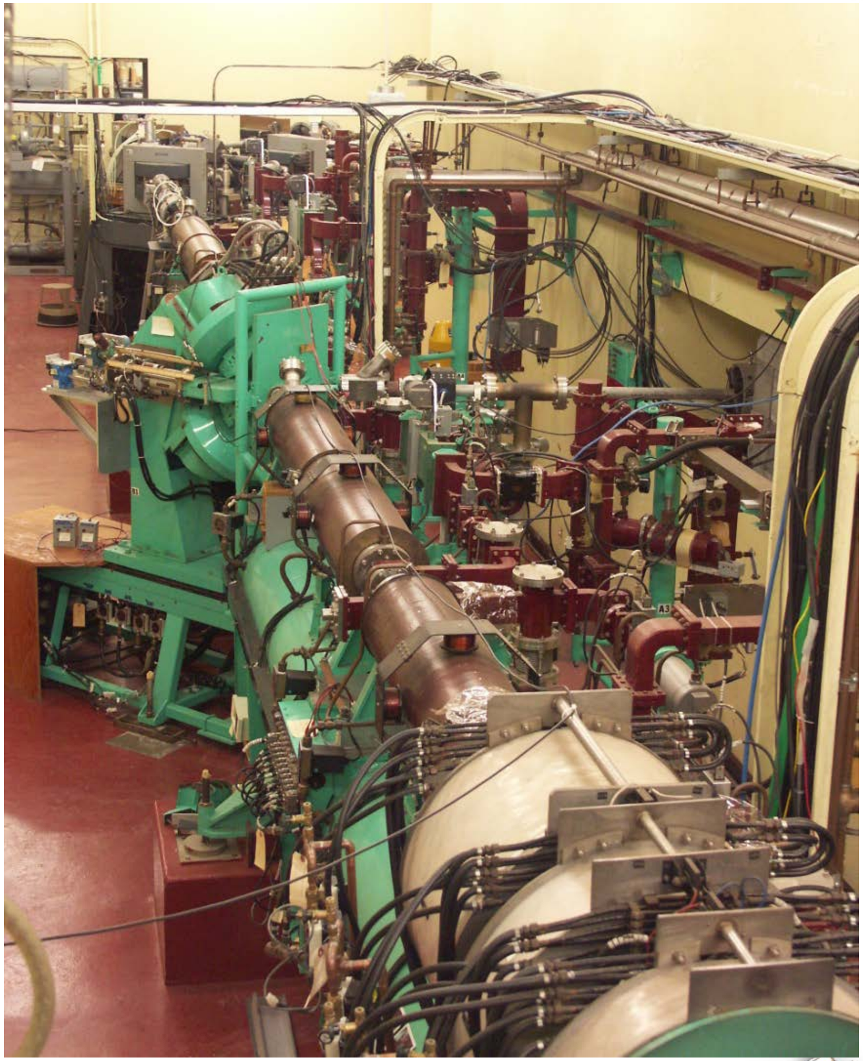
Three experimental limitations of the method were identified:

1. The resolution of the MCA was not enough for energies above 6 MeV to achieve the target uncertainty of 0.5 %.
2. The low energy of the calibration sources demand excellent linearity of the MCA.
3. The count rate was too low. Although the count rate is ultimately limited by the pulse-repetition-frequency of the linac (typically 200-400 cps) the detector geometry also has an impact.

# Next steps

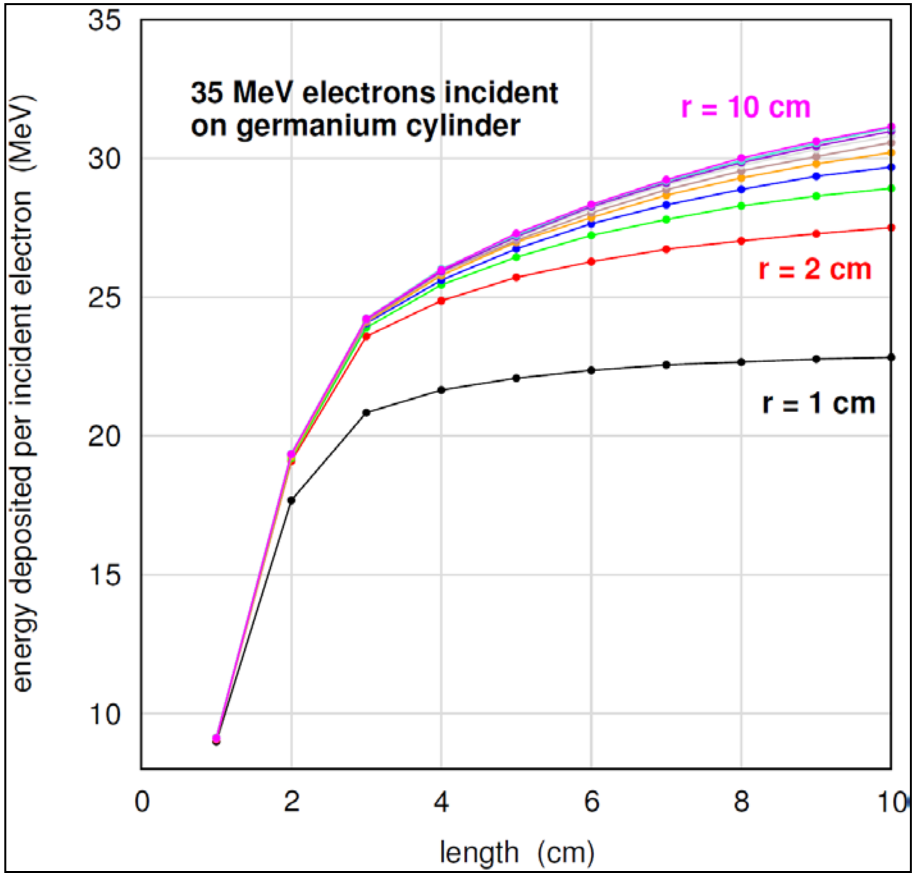
1. Higher spec MCA
2. Improved energy calibration using higher-energy photon sources.
3. Improve count rate and peak shape through use of a larger detector
4. Different linac!

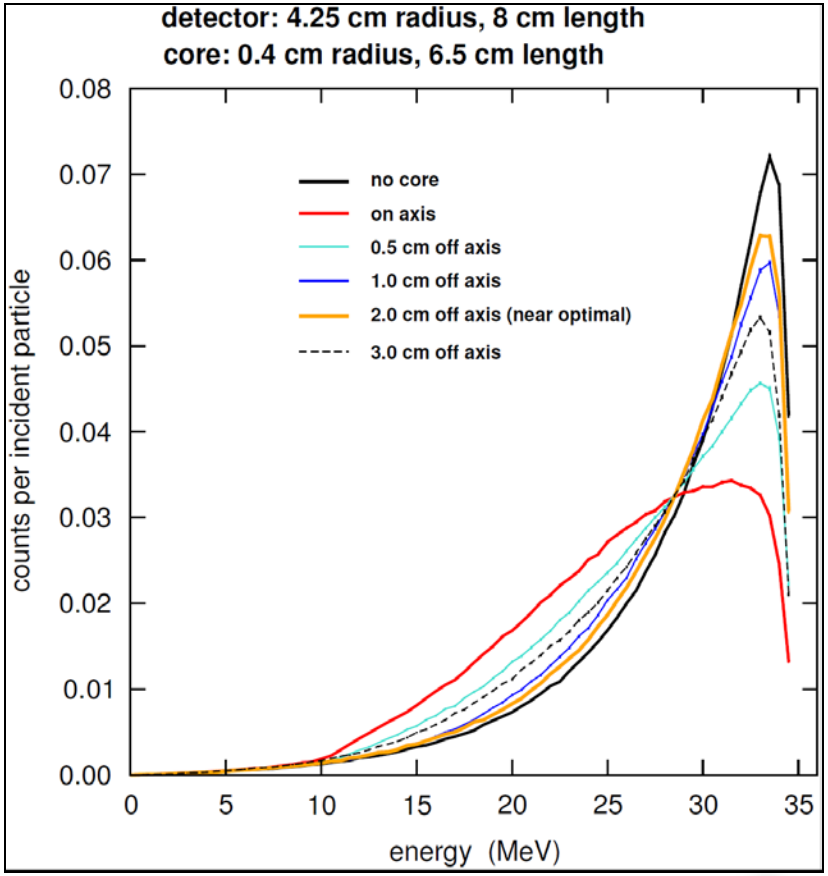
*Vickers Ltd research linac*
*3-40 MeV*
*Installed at NRC in 1968*



# Latest progress

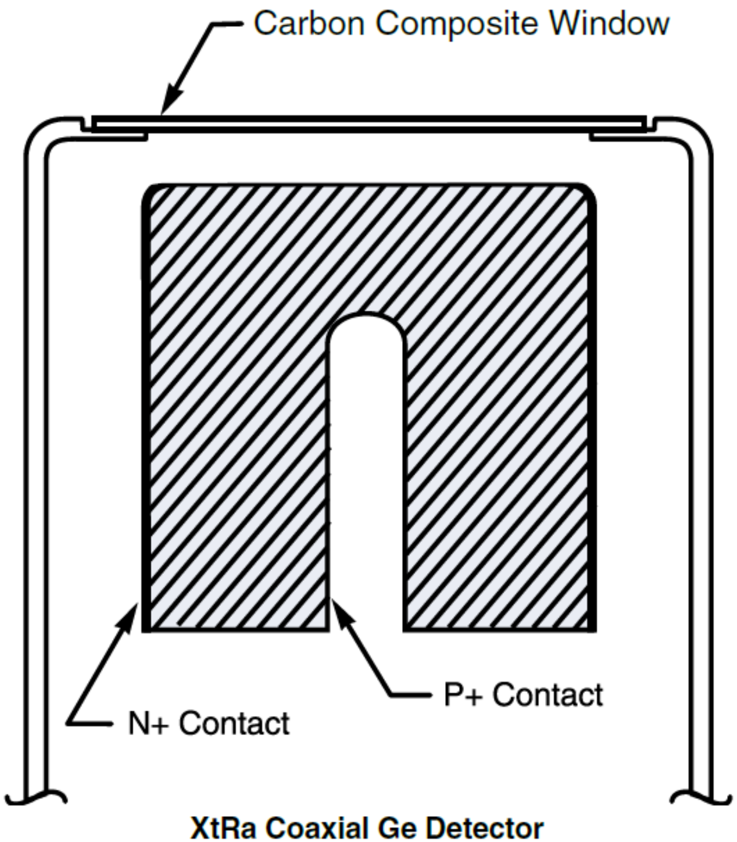
EGSnrc calculations used to find optimal crystal size for HPGe detector:



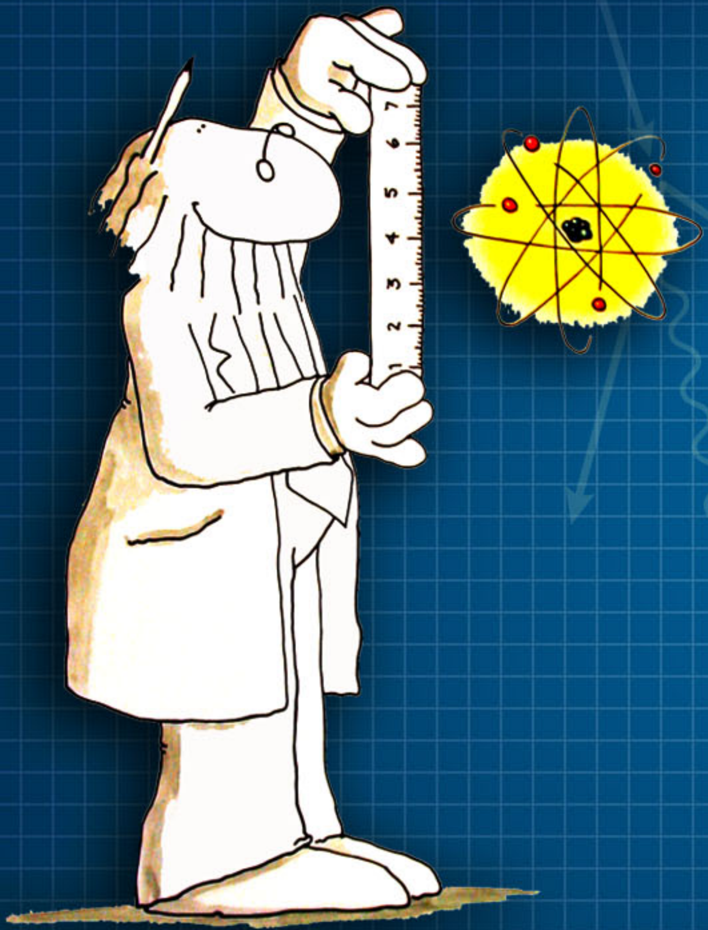



# Latest progress

Detector system being delivered to NRC this week (April 2015)




- Thin entrance window to minimize energy losses
- Very thin top electrode of known thickness (ditto)
- Large Ge volume (80% relative efficiency)
- Commissioning and testing due to being summer 2015
- Results to follow!!



# THANK YOU