Development of a spectrometry system for measurement of internal-pair studies

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Abstract

A new approach to studying excited 0^+ states is being introduced at iThemba LABS. It involves the study of low-lying electric monopole (E0) transitions which proceed via internal conversion (IC) and internal pair formation (IPF). Precise measurement of these processes require use of unique tools and techniques, such as an electron spectrometer. An electron spectrometer is currently under development at iThemba LABS, where optimization of its properties is being carried out both through measurements and simulations with the Geant4 toolkit.

Introduction

Electric monopole (E0) transitions are independent decay processes that compete with multipole transitions. However, compared to multipole transitions, much of the low-lying 0^+ excited state transitions identified thus far are still not very well understood. This is mainly due to the scarcity of experimental data. Moreover, measuring such weak transitions with high precision requires a unique set of tools and techniques. This work aims at firmly identifying and characterizing the nature of excited 0^+ states in nuclei by means of electron spectroscopy. Once fully operational the device will be used to study, among other nuclei, the ^{50}Ti nucleus where potential existence of admixtures of 0^+ excited states with 2^+, 3^+ and 4^+ states remain unresolved [3][4][2].

Main objectives

1. Refurbish the existing magnetic lens into a fully operational spectrometer.
2. Carry out simulations using the Geant4 toolkit to optimize the operation of the spectrometer.
3. Adapt a LEPS detector and use it in place of a SiLi detector to measure e^-/e^+ pairs.
4. Measure internal-pairs (e^-/e^+) in ^{50}Ti & study its microscopic properties.

Materials and methods

A Siegbahn-Kleinheinz dual lens that lay idle for years has been refurbished and was successfully commissioned using an alpha beam of 30 MeV on ^{70}Ge target in early October 2018 (see Fig. 1). It has six sections, with 12 layers of twenty-one windings each. It is operated by sweeping the current to create optimum momentum windows for respective e^-/e^+-pair energies of interest. A magnetic field grid mapped by the OPERA-3D package was imported into Geant4 simulations to aid the optimization and investigate the limitations of the device.

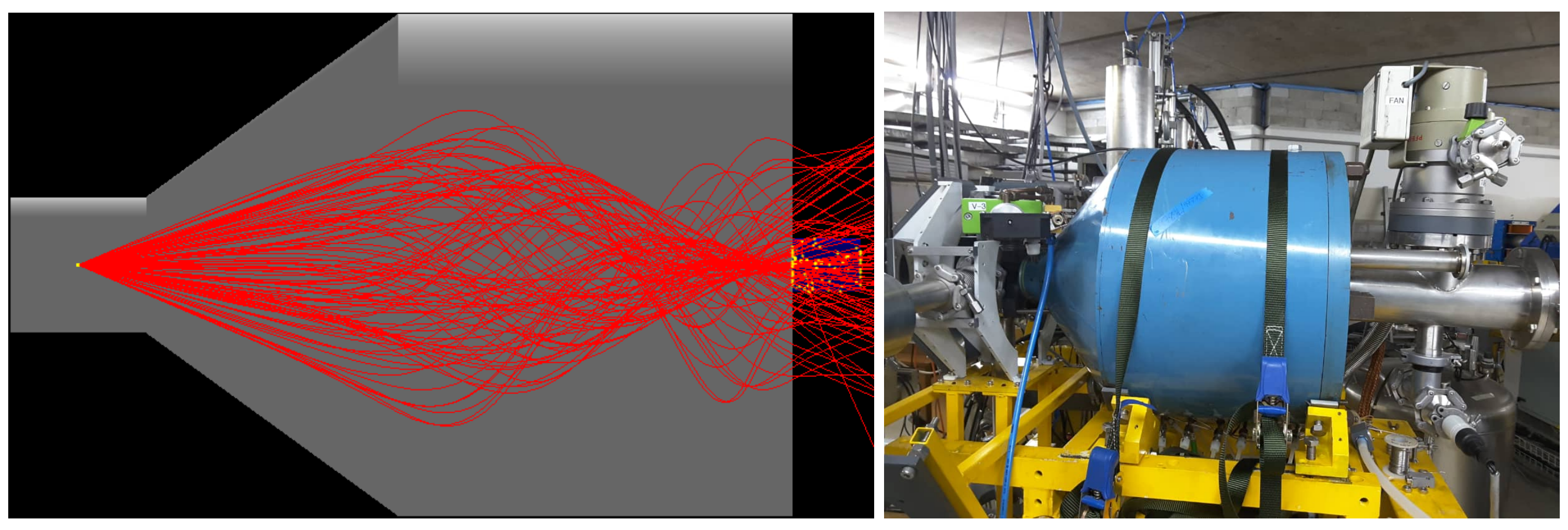

Figure 1: The electron spectrometer; electron trajectories under the influence of the magnetic field.

Electromagnetic transitions

Excited bound states normally decay by electromagnetic transitions, in which either Gamma-rays (multipole transitions) or CE or e^-/e^+-pairs (monopole transitions (E0)) are emitted. These are independent processes that compete based on the selection rules at play (see Fig. 2)[1].

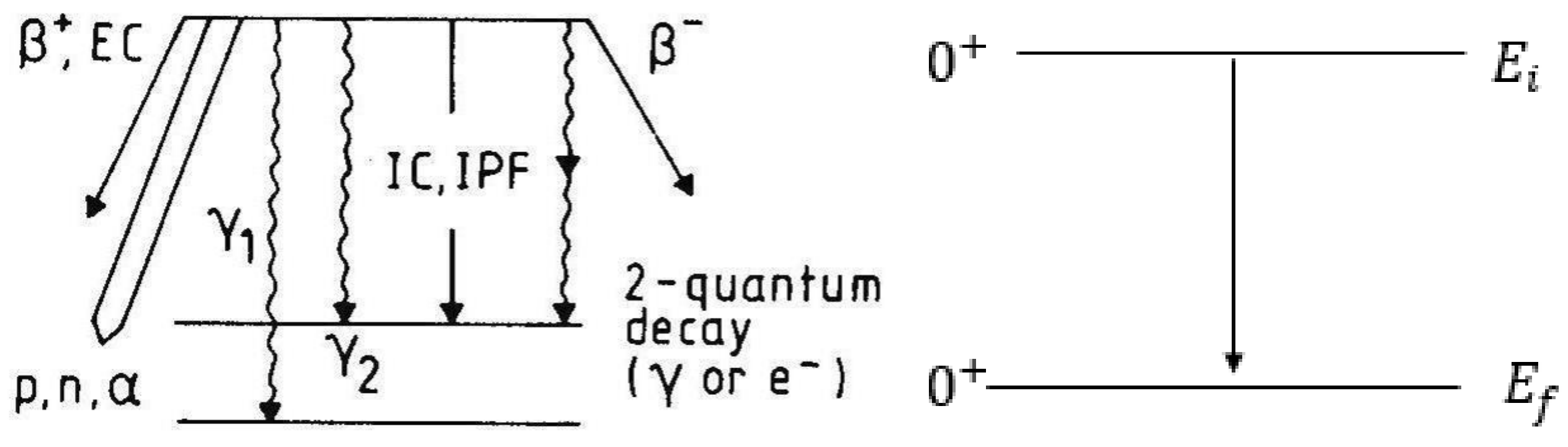

Figure 2: Competing decay modes of an excited nuclear state. IC, internal conversion; IPF, internal-pair formation; 2-quantum decay, higher-order process involving the emission of two quanta, & $0^+ \rightarrow 0^+$ transition.

The E0 transition probability is given by

$$W(i;\mathrm{E0}) = \Omega_i \rho^2 = \frac{1}{\tau_i} = \frac{\ln 2}{(T_{1/2})_i}, \tag{1}$$

$W(i;\mathrm{E0})$: absolute transition probability for the decay channel $i (= K, L, \ldots,$ or IPF),
Ω_i: electronic factor for channel i,
τ_i: partial lifetime that corresponds to the partial half-life $(T_{1/2})_i$, &
ρ^2: monopole transition strength (carrier of nuclear structure information).
And the monopole strength matrix element is given by

$$\rho = \left\langle 0_f^+ \middle| \sum_p \frac{r_p^2}{R^2} \middle| 0_i^+ \right\rangle \tag{2}$$

where r_p are radius vectors of the protons & $R = 1.2A^{1/3}$ fm, nuclear radius.

Simulations

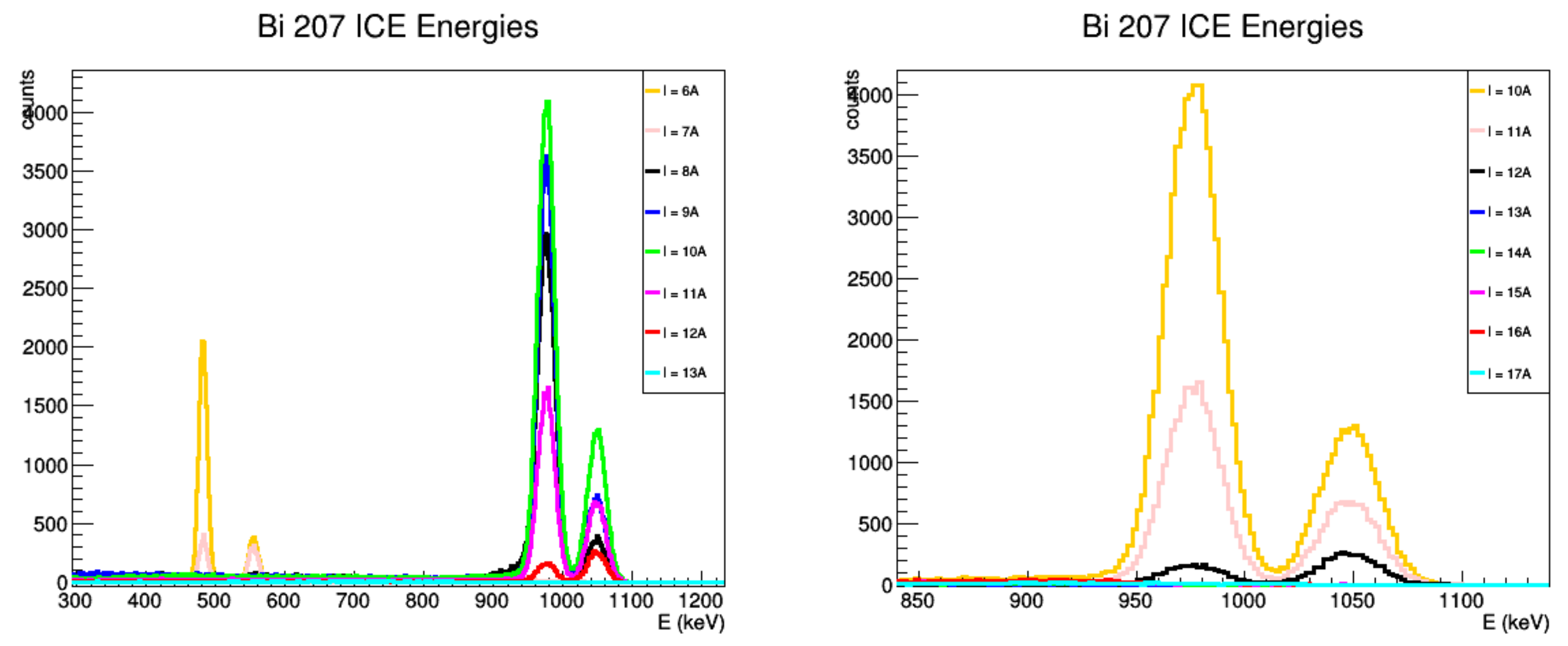

Figure 3: Electrons of given energies maximally transmitted by the corresponding magnetic field strengths.

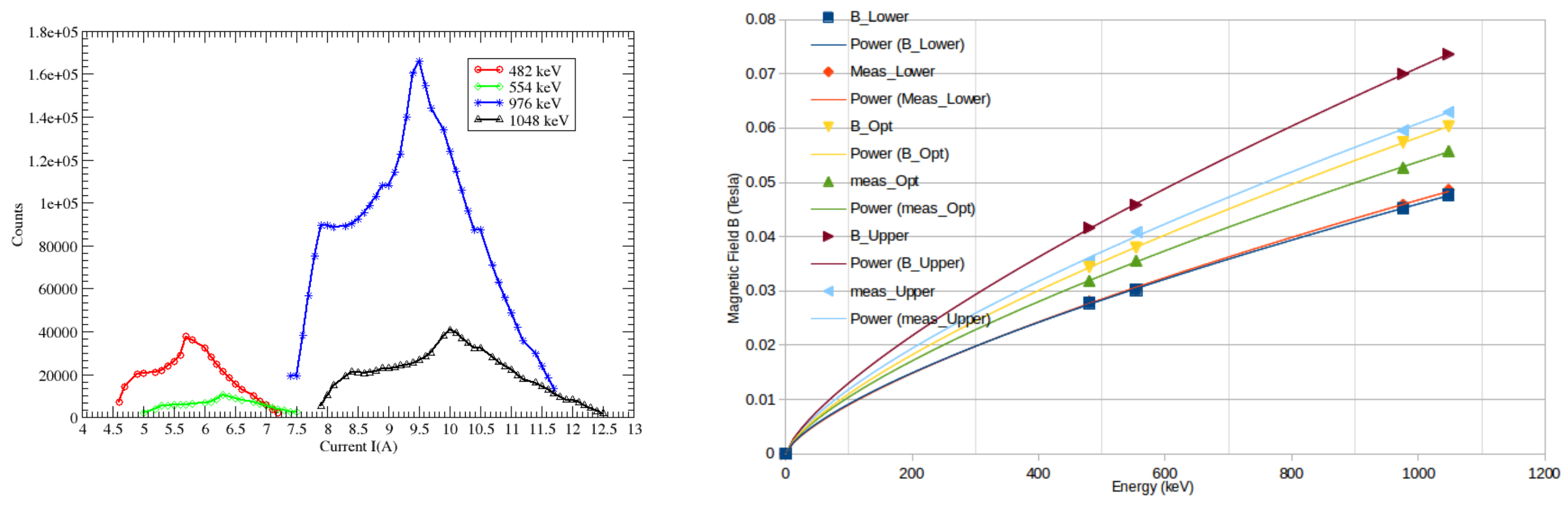

Figure 4: Momentum window for ^{207}Bi CEs, & the rigidity curve.

Re-adapting the LEPS detector

Figure 5: Setup to measure (also simulate) energy loss of electrons in LEPS detector.

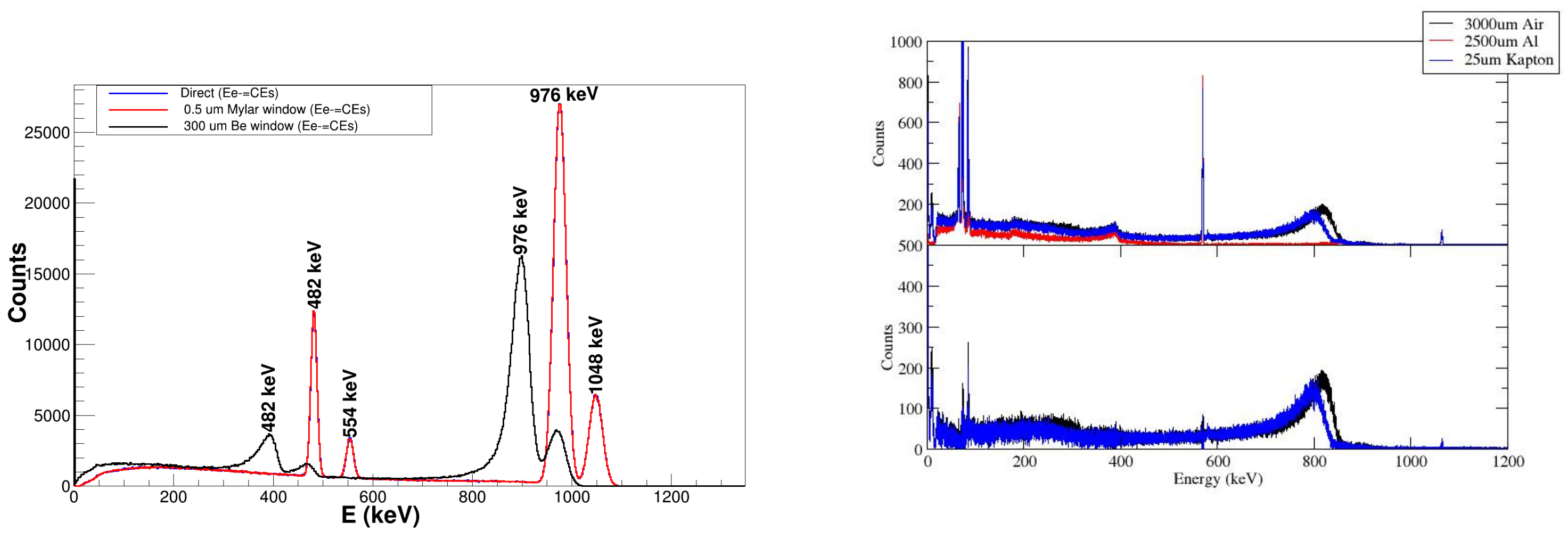

Figure 6: It Turns out the Be window in the LEPS causes e^- energy peaks to be shifted to lower energies.

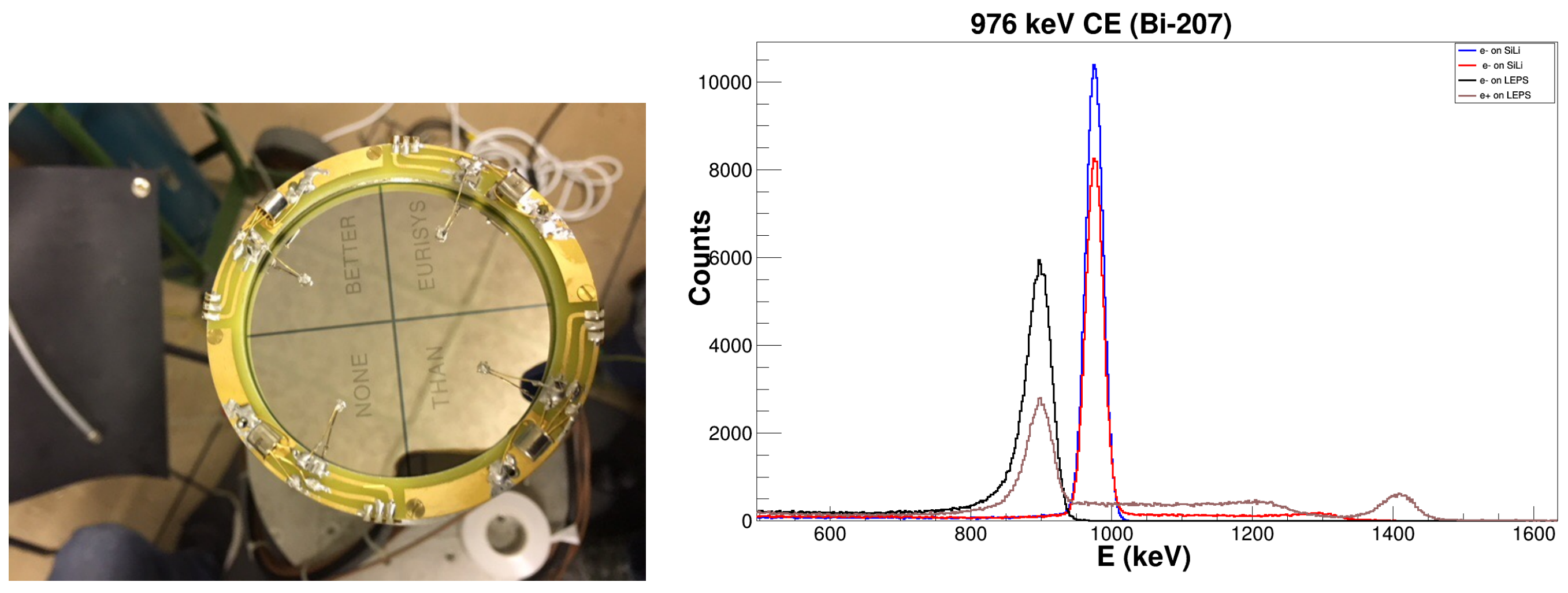

Figure 7: Encapsulating the LEPS detector with 0.5 μm mylar (in place of the 0.3 mm Be window).

Ongoing work

- Simulations on the use of the segmented LEPS detector in the spectrometer.
- The next thing to be done is to couple a re-adapted LEPS detector to the spectrometer (replacing the SiLi detector) and use the device to measure e^-/e^+ pairs.

References

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