

Reference fields for high energy neutron metrology

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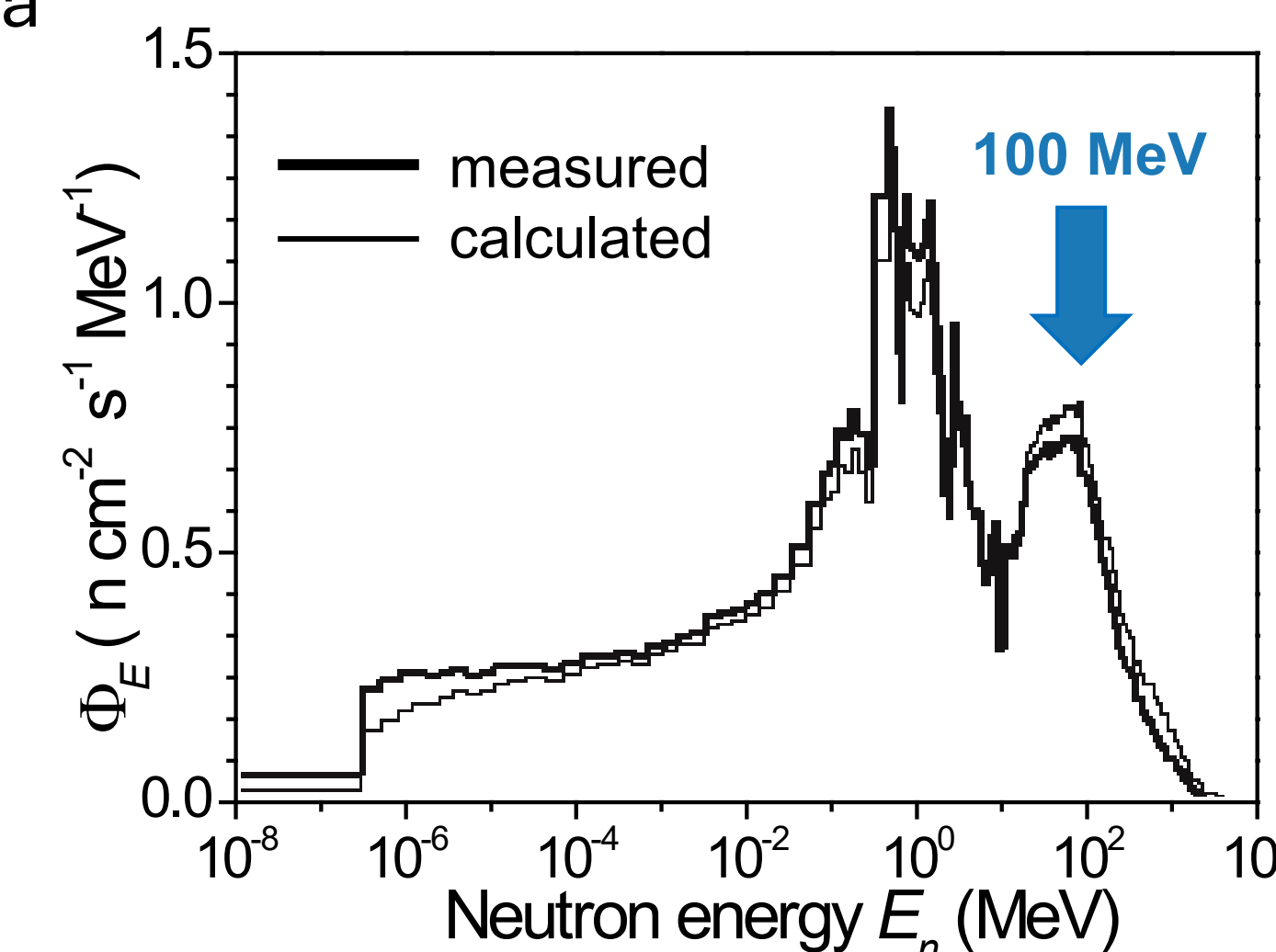
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Context

High energy neutron fields are produced naturally by galactic cosmic rays and solar energetic particles interacting with matter such as in spacecraft or the atmosphere (illustrated alongside at an altitude of 20 km), and artificially at high energy accelerator facilities for radiotherapy and research. Reliable measurement of such fields is essential in dosimetry for monitoring occupational exposure and patient safety, and requires instrumentation with traceability to internationally recognized reference standards, including quasi-monoenergetic, high energy neutron beams.

There are several facilities worldwide suitable for fast neutron metrology up to 20 MeV, with well-established reference standards and procedures (e.g. ISO-8529) for metrology and dosimetry.

Above 20 MeV few facilities exist, despite a growing interest and expressed need for high energy neutron metrology exceeding 100 MeV.

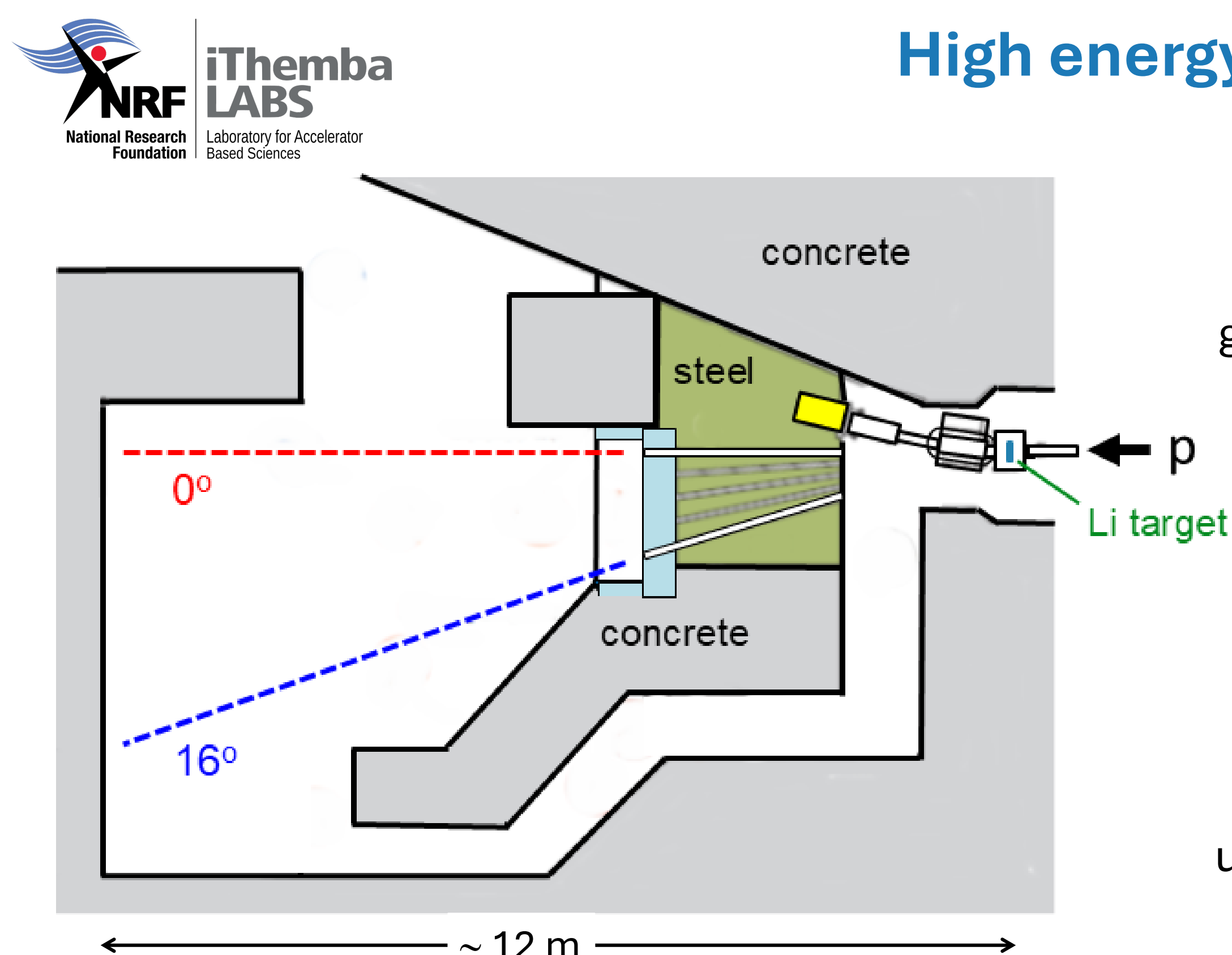


Adapted from Goldhagen *et al.* RPD **110** 387.

Challenges for high energy neutron metrology

- Very few facilities offering metrology beams above 20 MeV.
- No ISO standards above 20 MeV.
- Insufficient reference cross section data (e.g. for $^1\text{H}(n,n)^1\text{H}$ and $^{238}\text{U}(n,\text{fission})$).
- Many reaction channels of neutrons on ^{12}C with insufficient cross section data.
- Increased range of recoiling charged particles from neutron interaction in detector.
- Digital acquisition for neutron metrology not well established.

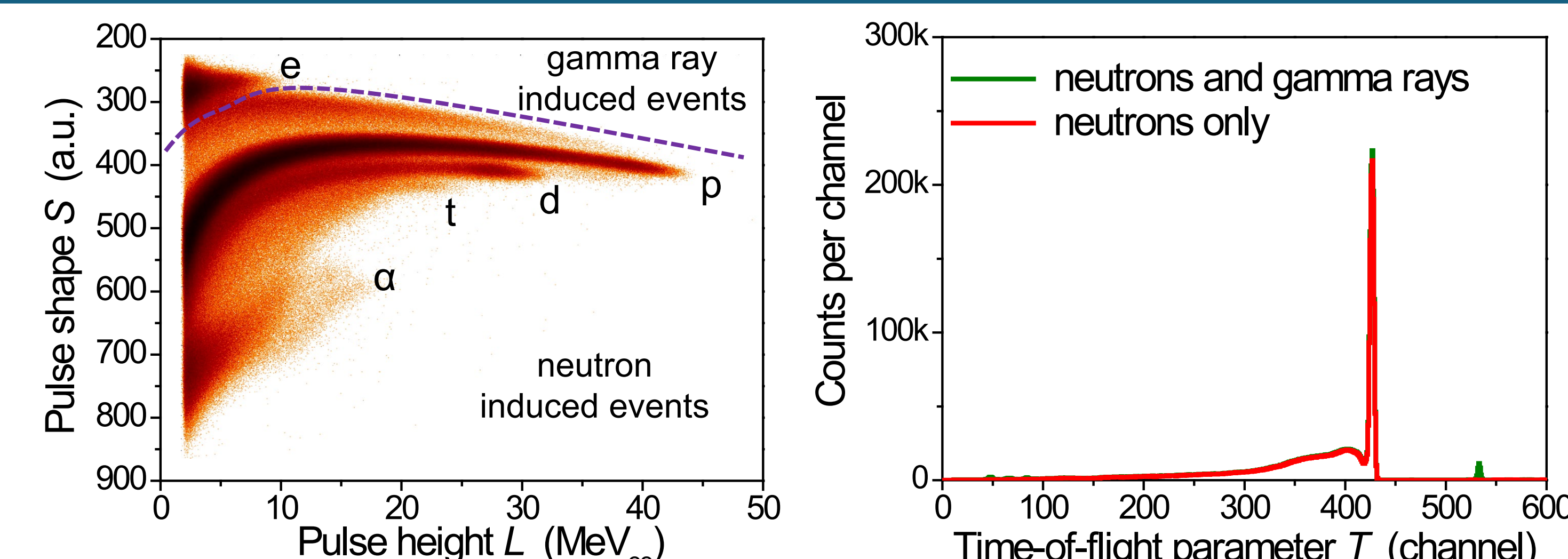
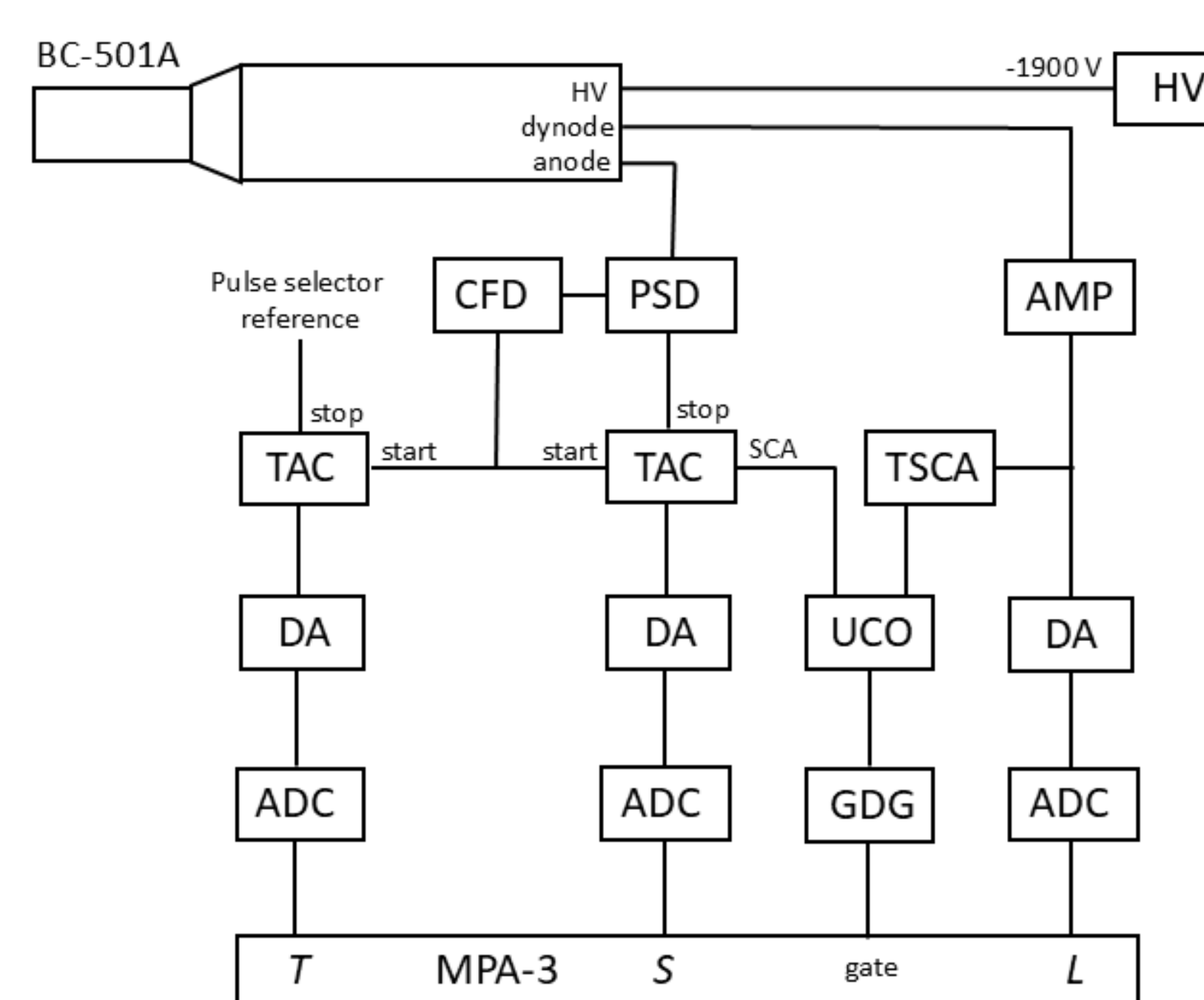
High energy neutron metrology at iThemba LABS South Africa



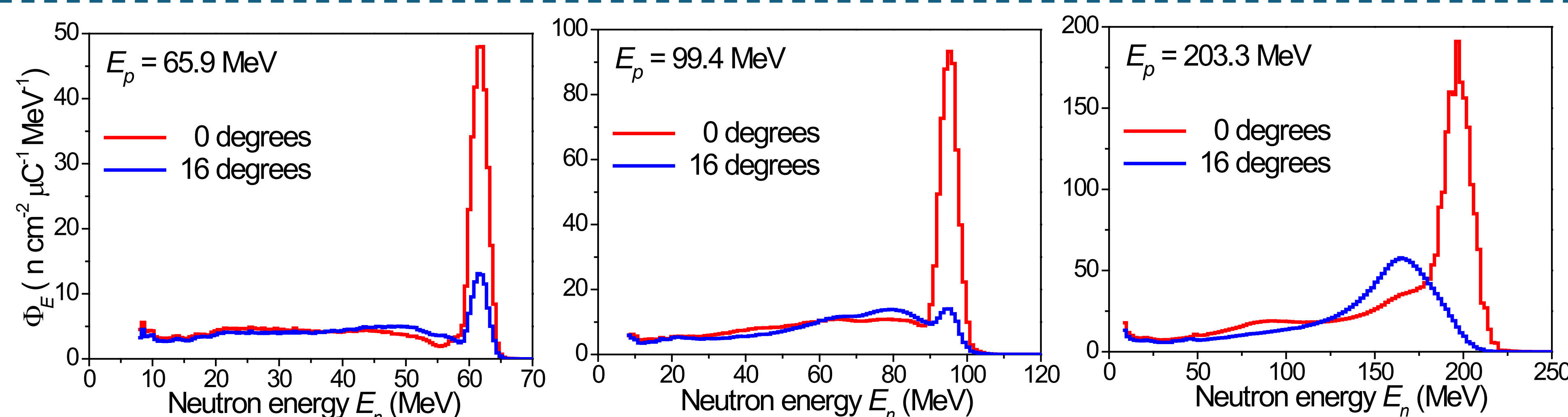
Nanosecond-pulsed proton beams from the $k = 200$ separated sector cyclotron are directed onto a natural lithium target. Neutrons and gamma rays produced via the $^7\text{Li}(p,n)^7\text{Be}$ reaction are collimated at 0° and 16° to the incident proton beam into a vault which has been designed to reduce low energy backgrounds.

Measurements of neutron energy spectra are typically made using the reference $2'' \times 4''$ BC-501A scintillator detector.

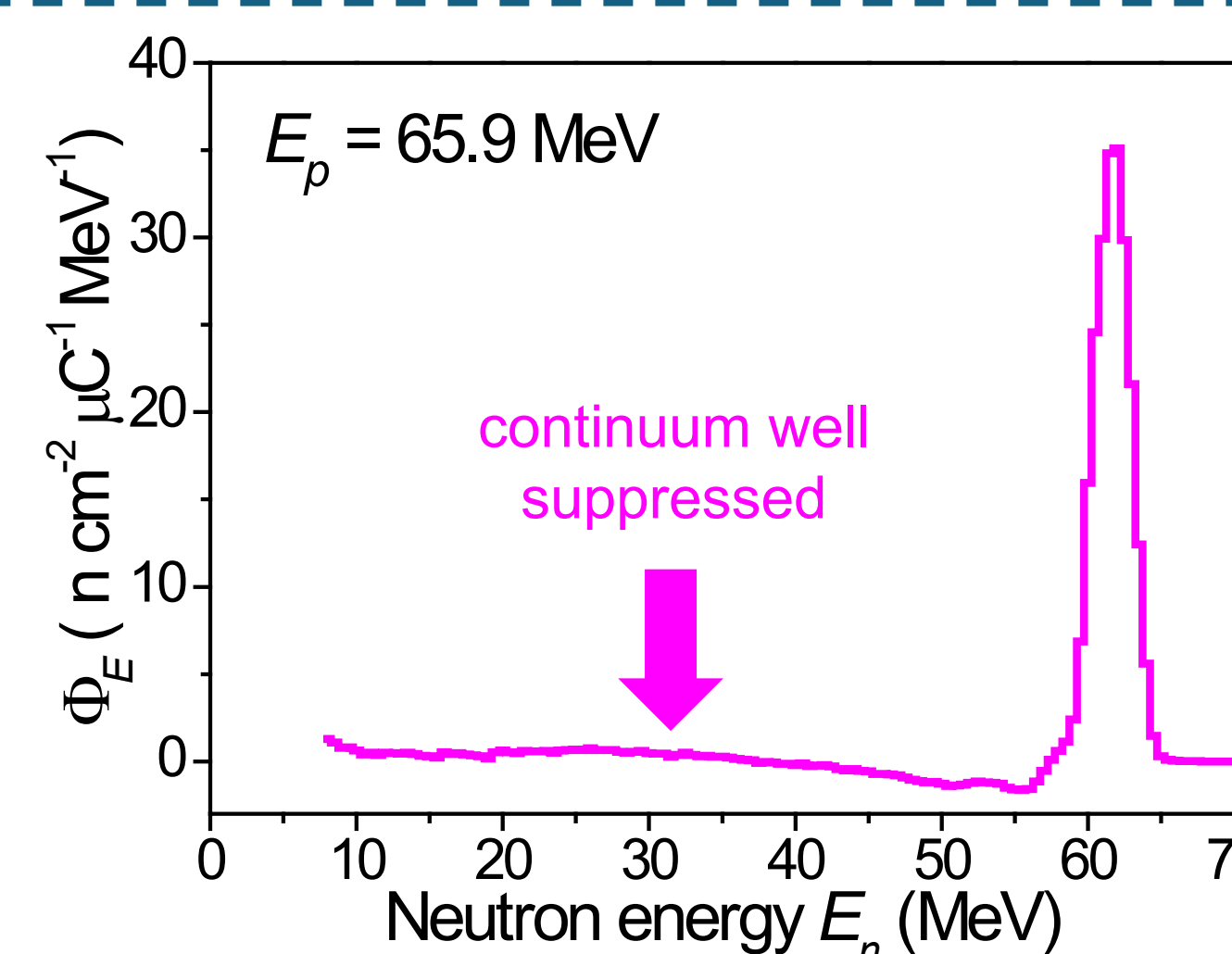
Data are recorded in coincidence in list mode using the standard NIM-based acquisition system: Time-of-flight T ; Pulse shape S ; Pulse height L .



Measurements with the BC-501A detector at 8.00 m at 0° for $E_p = 65.9$ MeV on a 8.0 mm $^{\text{nat}}\text{Li}$ target. **Pulse shape discrimination** (left) is used to separate (dashed line) events associated with the interactions of neutrons and gamma rays in the detector. Loci identified with recoiling electrons (e), protons (p), deuterons (d), tritons (t) and alpha particles (α) are evident. The **time-of-flight** spectrum (right) is shown with and without the neutron-gamma selection.

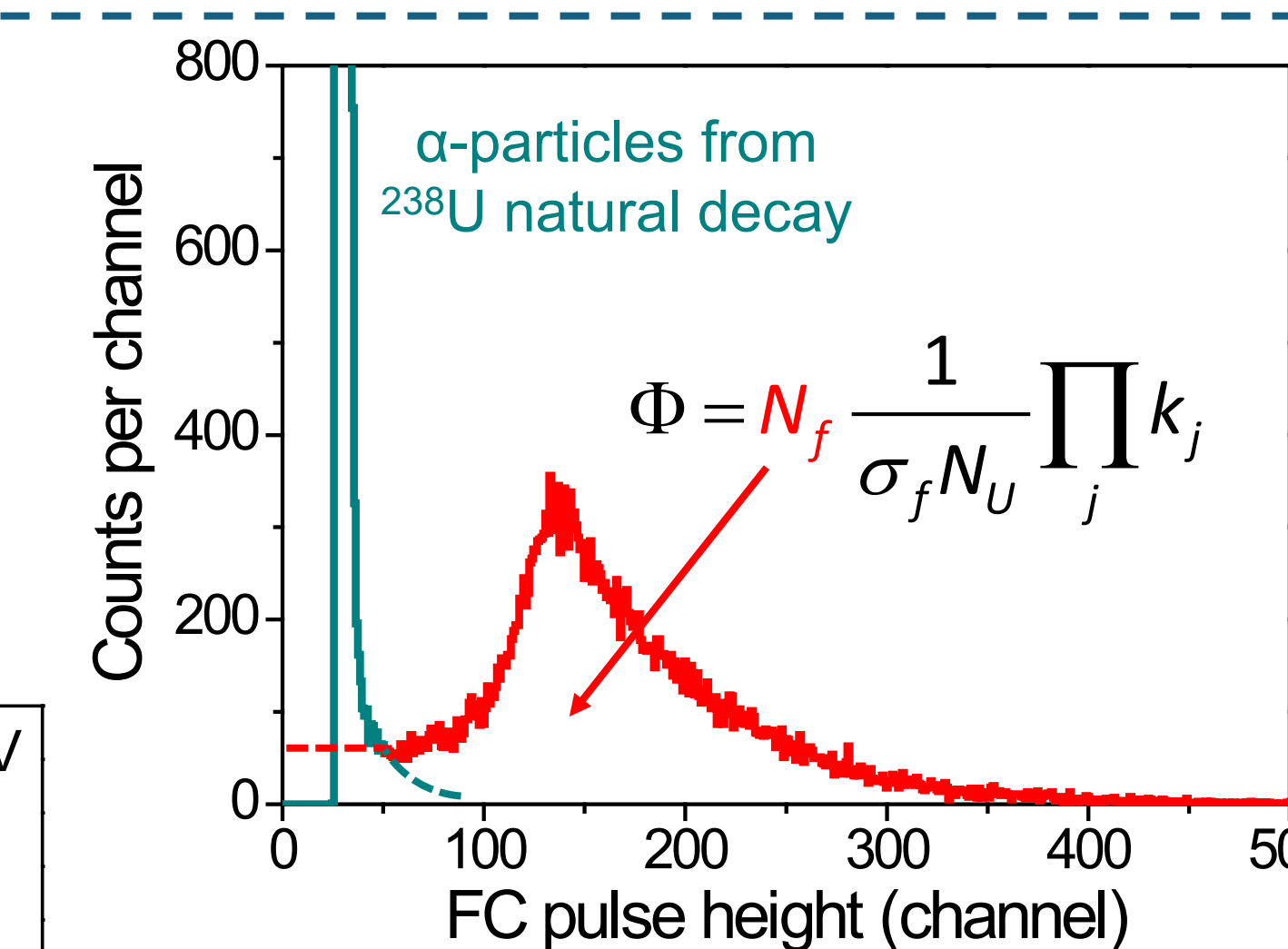
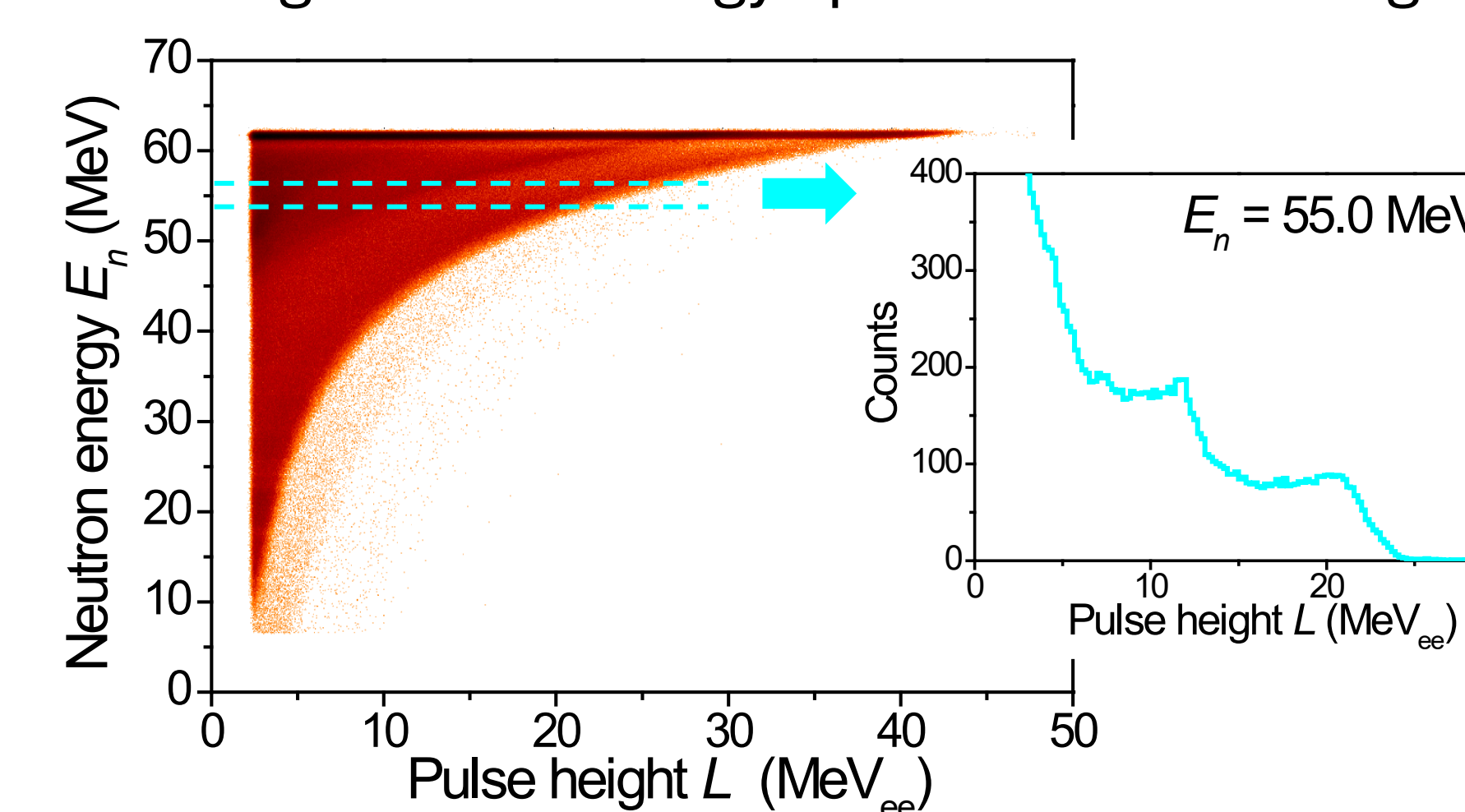


Neutron energy spectra measured via time-of-flight with the BC-501A detector at 8.00 m at both 0° and 16° for three proton beam energies and a 8.0 mm Li target, with a lower pulse height threshold of 2.5 MeV_{ee}, and adjusted for both detector efficiency and proton beam current. The peak is associated with the direct reaction and the broad continuum with the breakup of ^7Be .



The “difference” spectrum between 0° and 16° results in a nearly quasi-monoenergetic beam, when irradiations are made at both angles.

The full $E_n - L$ matrix (shown for $E_p = 65.9$ MeV) provides the data for selecting nearly monoenergetic pulse height (L) spectra as a function of neutron energy, which can be used for measuring neutron energy spectra via unfolding.



Neutron fluence Φ is measured relative to the $^{238}\text{U}(n, \text{fission})$ cross section σ_f using a ^{238}U ionization chamber with N_U ^{238}U atoms, where k_j are corrections.

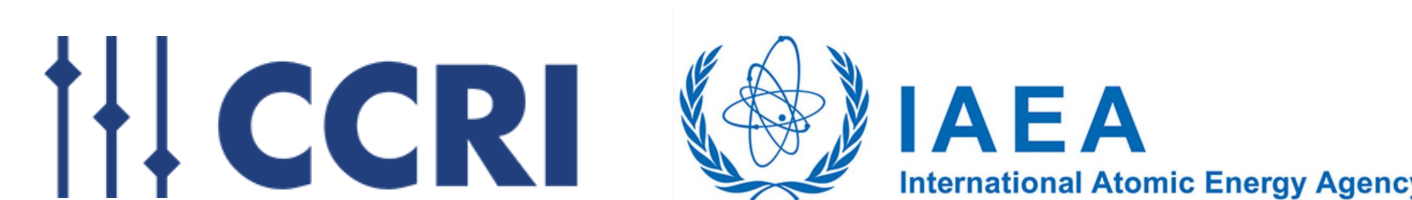
Science and Applications

- Production and study of accelerator-based neutron fields.
- Development and characterization of instrumentation for use out of the laboratory.
- Effects of high energy neutron radiation (biological and electronic).
- Cross section measurements for nuclear data.
- Fundamental physics.

Workshop: nBHEAM 2025

**Neutron Beams at High Energy:
Applications and Metrology**

7-8 July 2025, IAEA Headquarters, Vienna



Present status at iThemba LABS

The high energy neutron beam facility at iThemba LABS has been designated by the National Metrology Institute of South Africa, to be developed as a high energy neutron reference beam facility. A multi-institutional project is presently underway.

Designated institute(s)

iThemba Laboratory for Accelerator-Based Sciences ROR
For ionizing radiation: medium- and high-energy neutron measurements
(from 27 February 2015)
→ iThemba LABS
Somerset West

<https://www.bipm.org>

Credits

iTL: Zina Ndabeni.
UCT: Elizabeth Fairall,
Kutullo Maibane,
Miles Kidson.
PTB: Ralf Nolte,
Elisa Pirovano.