

Light output parameterization and calibration of CsI and LYSO scintillators operated at ACCULINNA-2 for detection of ions with $Z < 5$

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25th IEEE RT

1. Motivation

We investigated cluster structures in neutron-rich $^{10,12}\text{Be}$ via transfer reactions at ACCULINNA-2 [1] using CsI(Tl)/LYSO scintillators as the E -layer in ΔE - E telescopes. To address their nonlinear, (Z, A, E) -dependent light output, we parameterized the response and developed methods for ΔE -layer thickness measurement and ion separation. The results provide a calibration framework applicable to many experiments using CsI(Tl)/LYSO scintillators.

3. Method of calibration

1. Double-sided silicon strip detectors (DSSD) - thin ΔE layers

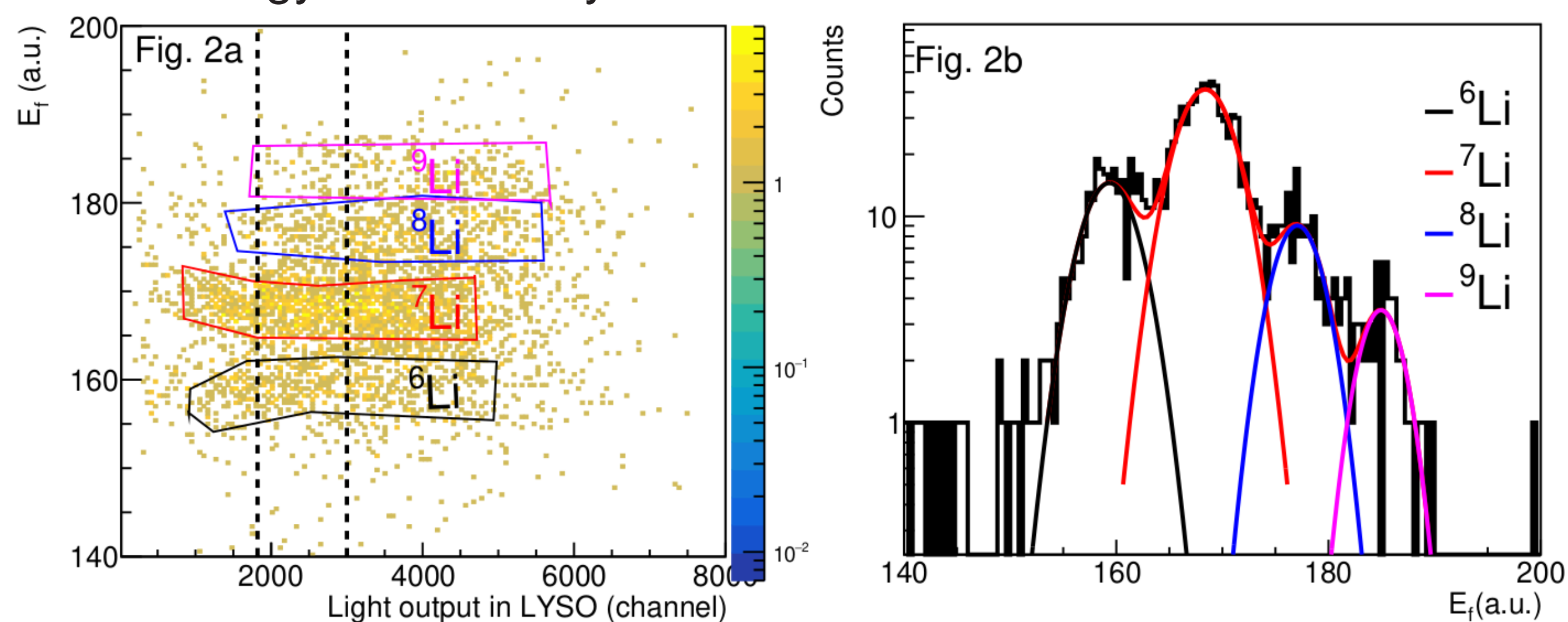
- **Linear calibration:** The DSSD response is linear in deposited energy. We calibrated each front and back strip using a ^{226}Ra α -source (5 lines in 4.8-7.6 MeV range); this calibration is applicable for all ions.
- **Thickness verification:** We determined the actual DSSD thickness by comparing the energy of elastically scattered beam ions (calculated from time-of-flight) with the energy measured in the DSSD.

2. CsI(Tl) and LYSO scintillators - thick E detectors

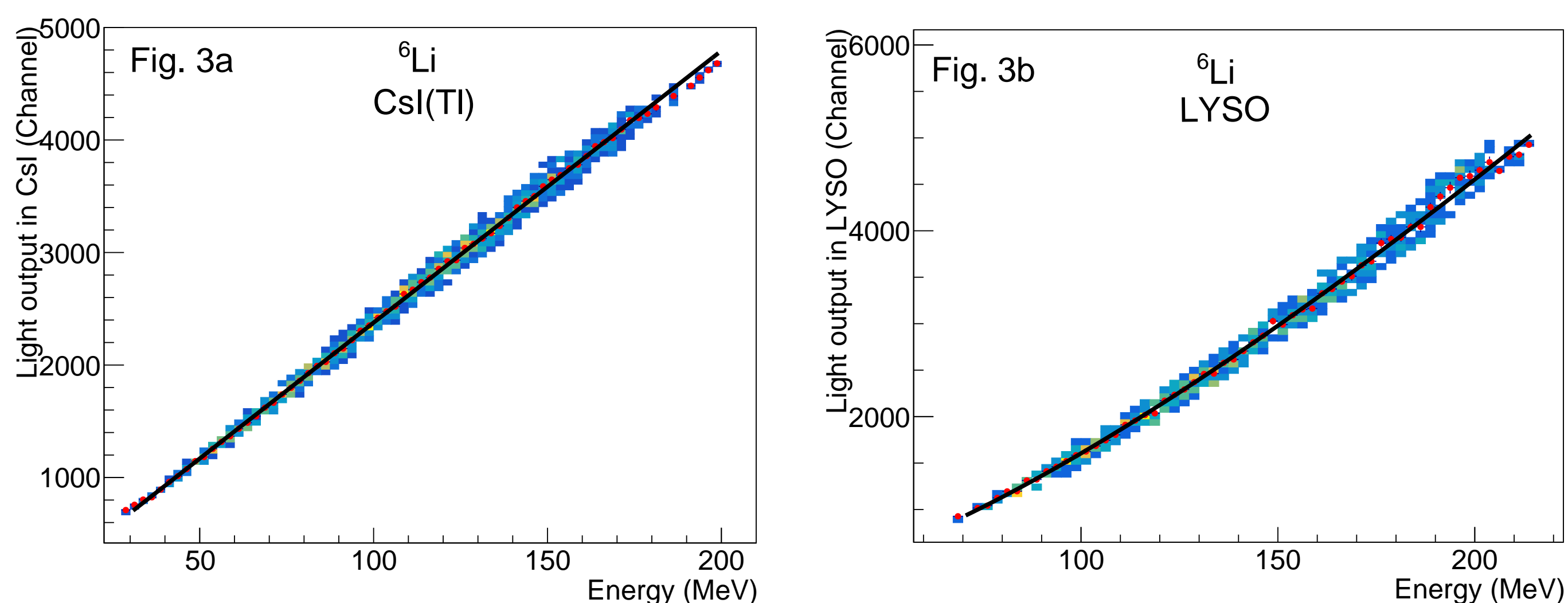
- **Nonlinear response:** Both scintillators exhibit light output that depends nonlinearly on particle type, energy, and stopping power (dE/dx). This necessitates isotope-specific calibration.
- **Particle identification:** CsI(Tl) clearly separates all isotopes (Fig.1a). LYSO, however, shows overlapping boundaries for He, Li, and Be isotopes (Fig.1b). To resolve them, we applied a straightening method [2] that defines a slowly energy-varying function E_f :

$$E_f = \sqrt{E_{\text{Si}} \cdot E_{\text{CsI/LYSO}} + a \cdot E_{\text{CsI/LYSO}}^2 + b \cdot E_{\text{Si}} - c / (E_{\text{CsI/LYSO}} + \text{off})^2} \quad (1)$$

where E_{Si} and $E_{\text{CsI/LYSO}}$ are the energy deposits in silicon and CsI(Tl)/LYSO scintillator detectors. The parameters a, b, c, off control the shape, slope, and low-energy non-linearity correction.



- **Isotope selection:** The straightening method of function (1) provided a quantitative and objective selection approach, and one straightening result is shown in Fig.2a, where its projection on E_f is shown in Fig.2b. The selection gates for different isotopes are done by the colored graphical cuts.



- **Energy reconstruction:** After selecting corresponding isotopes, the remaining energy, that is, the energy deposited in CsI(Tl)/LYSO detectors are reconstructed using calibrated ΔE in DSSD combined with range-energy relations from stopping-power databases (LISE++ [3]).

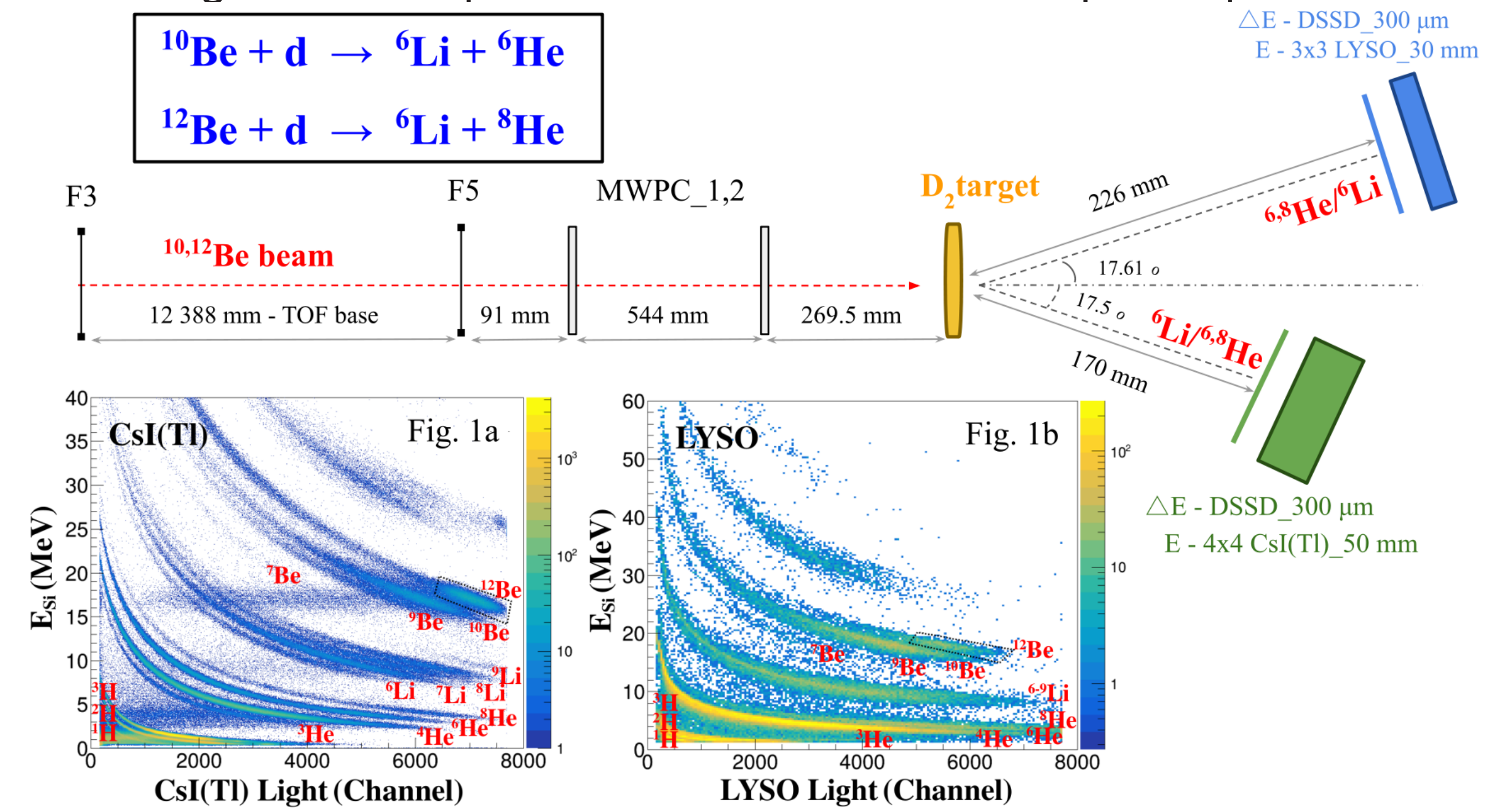
- **Light-output parameterization:** For $Z \geq 2$, we describe the nonlinear light output \mathcal{L} for each ion (in ADC values) as a function of energy E_0 [4]:

$$\mathcal{L} = a_0 \cdot E_0 - a_0 \cdot a_1 \cdot \ln(1 + E_0/a_1) + a_2 \quad (2)$$

where a_0 is the scaling factor dependent on quenching, a_1 is the nonlinear term, and a_2 is the offset.

2. Experimental setup

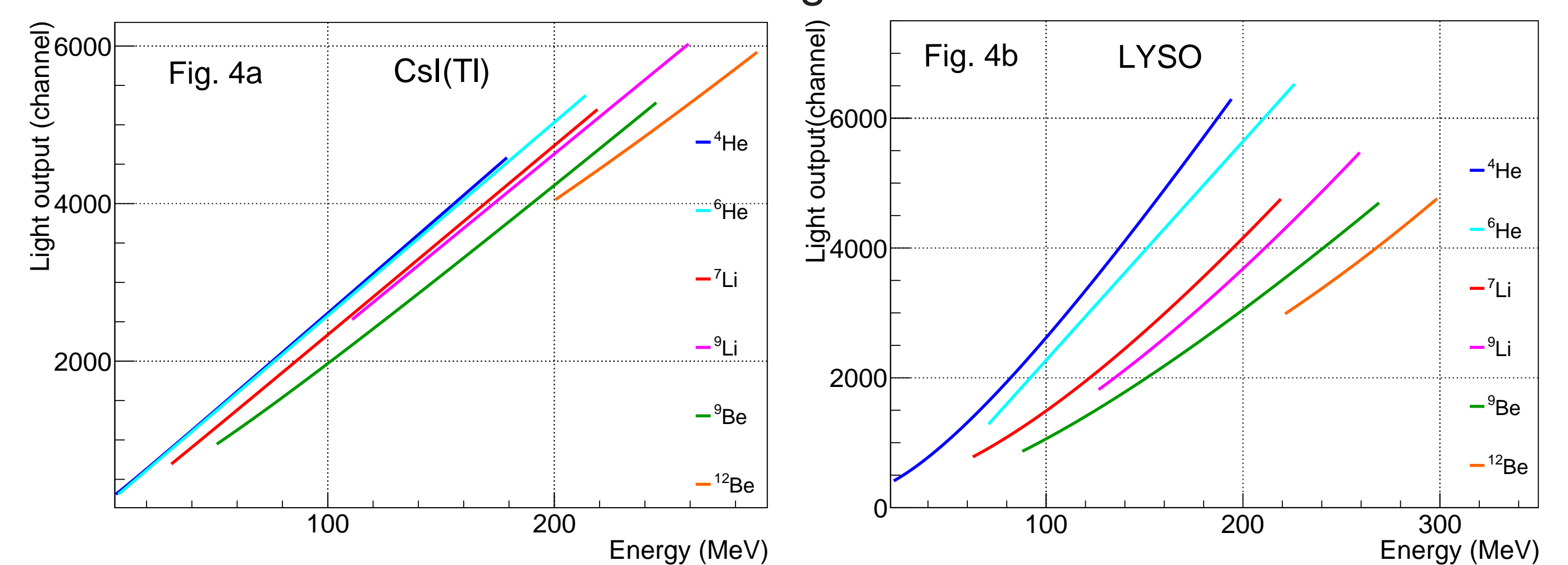
- Secondary $^{10,12}\text{Be}$ beams at 23 and 33 AMeV were produced via fragmentation of a 48.6 AMeV ^{18}O beam on a 2-mm Be target. The separator delivered ^{10}Be (78% purity, 5×10^5 pps) and ^{12}Be (87% purity, 1×10^5 pps). The secondary beam bombarded the physical target filled with cryogenic deuterium gas at a temperature of $\sim 25\text{K}$ and atmospheric pressure.



- The particle identification (PID) for ions registered by ΔE - E telescopes with DSSD-CsI(Tl) and DSSD-LYSO layers as shown in Fig.1a and 1b.
- Data extracted from this experiment was used to determine light-output response of CsI(Tl) and LYSO crystals for each sort of ions: $Z = 2$ ($^3,^4,^6,^8\text{He}$) ($10 \leq E \leq 250$), heavier isotopes $^6-^9\text{Li}$, $^7,^9,^{10,12}\text{Be}$ up to 300 MeV.

4. Results

- Both detectors show a nonlinear response, with heavier ions producing lower light output per deposited energy. LYSO shows stronger low-energy nonlinearity than CsI(Tl) but also larger isotope separation, making identification feasible with proper calibration and the straightening method described above. For ^{12}Be , it is difficult to draw firm conclusions due to limited statistics at low and intermediate energies.



\mathcal{L} -ratio	Energy (MeV)	Dell'Aquila [4]	Horn [5]	This work
$^6\text{Li}/^4\text{He}$	100	0.86	0.79	0.87
$^6\text{Li}/^4\text{He}$	150	0.89	0.83	0.92
$^7\text{Be}/^4\text{He}$	100	0.64	0.64	0.72
$^7\text{Be}/^4\text{He}$	150	0.74	0.69	0.80

- As energy increases from 100 to 150 MeV, our $^6\text{Li}/^4\text{He}$ and $^7\text{Be}/^4\text{He}$ ratios increase, consistent with reduced quenching at higher dE/dx . Our ratios are systematically higher than those reported in [4,5]. The discrepancies reflect differences in experimental conditions. For LYSO, no direct data comparison exists, highlighting the value of this calibration work.

5. Summary

- We presented an energy calibration method for CsI(Tl) and LYSO detectors using experimental data, demonstrated for ^3He to ^{12}Be ions. CsI(Tl) provided clear isotope separation (resolution $\sim 2.0\%$), while LYSO exhibits poorer resolution ($\sim 6.4\%$) at ~ 320 MeV,
- Implemented as a routine at ACCULINNA-2 facility, this addressed the insufficiently characterized response of LYSO to heavier ions ($Z > 1$) at low/intermediate energies - unlike the well-known response of CsI(Tl).

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[4] D. Dell'Aquila et al., Non-linearity effects on the light-output calibration of light charged particles in CsI(Tl) scintillator crystals, Nucl. Instrum. Methods Phys. Res. A **929** (2019).

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ACKNOWLEDGEMENT

