# DALI2+ at the RIKEN Nishina Center RIBF

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The utilization of large arrays of sensitive $\gamma$-ray detectors in combination with fast beams and a reaction target, is a powerful approach to interrogate nuclear structure.[1)] This technique, known as in-beam $\gamma$ ray spectroscopy and often in association with additional particle detectors, permits access to observables such as excited state energies, transition probabilities, exclusive and differential cross-sections, deformation lengths and parameters, state lifetimes and exclusive parallel momentum distributions. Highlights of RIKEN in-beam $\gamma$ ray spectroscopy results can be found in the references.[2–4)]

The Detector Array for Low Intensity Radiation (DALI) was constructed in 1995 for observing nuclear reactions with a low yield.[5)] DALI originally consisted of 60 $6 \times 6 \times 12$ cm$^3$ thallium-doped sodium iodide (NaI(Tl)) scintillators arranged around a reaction target to cover a large solid angle. The granularity of the detector array permitted a correction to the Doppler shifted $\gamma$-rays at RI beam velocities of $v/c \sim 0.3$.

DALI was supplemented with additional NaI(Tl) detectors up to a total of 186 in 2002[6)] and renamed DALI2. With the opening of the RIBF facility, where the RI beam velocities are $v/c \sim 0.6$, DALI2's greater angular resolution and detection efficiency was integral to its continuing success.

In the spring of 2017, DALI2 was further upgraded to DALI2+ by the inclusion of additional new detectors to the array, bringing the total to 226. Poorly performing older detectors were substituted. A rendering of the new arrangement is shown in Fig. 1. Additional support structures were fabricated to accommodate the new detectors. The simulated full-energy-peak efficiency (FEP) and inherent energy resolution of the DALI2 and DALI2+ configurations for various photon energies (in a centre-of-mass (CM) frame) are listed in Table 1. The beam pipe, shield, target thickness, beam velocity distribution and individual detector resolutions are not included in the simulations. The $\gamma$-rays are emitted isotropically in the CM frame and Doppler corrected. The small reduction in FEP efficiency of the DALI2+ configuration is a consequence of the reduced angular coverage. The smaller opening angles of the detectors lead to an increase in inherent energy resolution because of Doppler correction.

DALI2+ was employed for the first time for the third SEASTAR campaign.[7–9)] It surrounded the liquid hydrogen target of MINOS[10)] which was situated between BigRIPS[11)] and SAMURAI[12)] spectrometers.

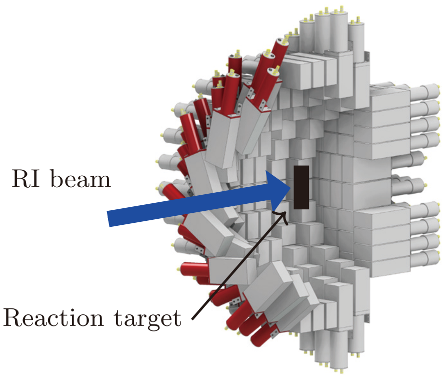


Fig. 1. A 3D rendering of the half sector of DALI2+.

Table 1. GEANT4 simulated FEP efficiencies and inherent energy resolution of the DALI2 and DALI2+ arrays. (without add-back / with 15 cm radius add-back[6)])

| | **v/c = 0** | **v/c = 0.6** | |
|---|---|---|---|
| **E$_\gamma$ (MeV)** | eff. (%) | eff. (%) | FWHM (keV) |
| *DALI2 & standard target position* | | | |
| 0.5 | 41/48 | 42/51 | 38/43 |
| 1.0 | 25/33 | 25/36 | 76/85 |
| 2.0 | 14/20 | 15/25 | 150/161 |
| *DALI2+ & standard target position* | | | |
| 0.5 | 37/43 | 40/48 | 38/43 |
| 1.0 | 22/29 | 24/34 | 76/85 |
| 2.0 | 13/19 | 15/23 | 139/155 |
| *DALI2+ & MINOS target position* | | | |
| 0.5 | 36/42 | 39/48 | 36/41 |
| 1.0 | 22/29 | 24/34 | 72/80 |
| 2.0 | 12/18 | 14/23 | 138/146 |

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