Study of the electromagnetic response of the ^{56}Fe nucleus by proton inelastic scattering

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Abstract

This work presents preliminary results from an experimental campaign conducted in October 2025 at the Research Center for Nuclear Physics, Osaka University. The experiment studied the inelastic scattering of high-energy protons (392 MeV) at very forward angles off ^{56}Fe nuclei. The scattered protons were measured with the high-resolution magnetic spectrometer "Grand Raiden".

Double-differential cross-sections for the (p,p') scattering process were obtained after correcting the ion-optical aberrations and subtracting the background. The photo-absorption cross-section and E1 strength function were deduced by the virtual photon method. The nuclear polarizability was calculated, and the exhaustion of the Thomas-Reiche-Kuhn sum rule was verified.

The preliminary results are compared with existing experimental data. These observables provide important constraints on nuclear response models, and are relevant for applications involving photonuclear reactions. They have direct applications to astrophysics, for instance, as nuclear physics inputs to models of ultra-high-energy cosmic rays propagation.

QUESTION

Can very-forward-angle (p,p′) scattering be used to infer the equivalent photo-absorption response of ^{56}Fe throughout the Isovector Giant Dipole Resonance (IVGDR) energy range?

PRELIMINARY RESULT

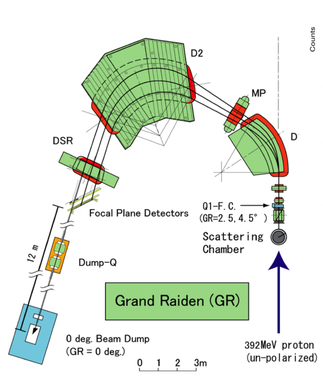
A preliminary equivalent photo-absorption cross-section was inferred across the measured IVGDR energy range by very forward (p,p') scattering.

1 Experimental method

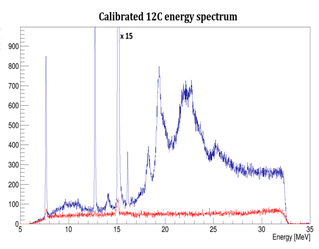
392 MeV protons · very forward angles · high-resolution spectrometry

1 measured DDCS → 2 corrections + background subtraction → 3 estimated QFS subtraction

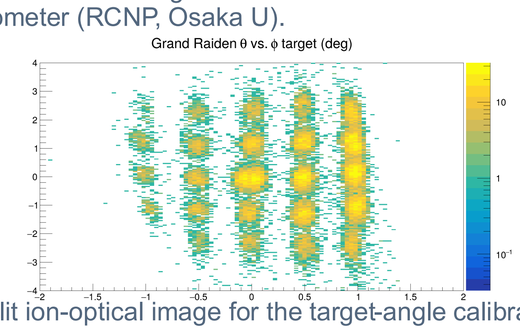
4 E1-dominant residual → 5 Virtual Photon Method → 6 equivalent photo-absorption response



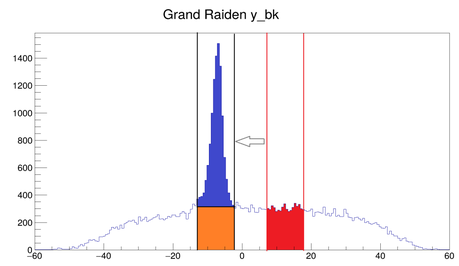
Grand Raiden magnetic spectrometer (RCNP, Osaka U).



Energy calibration with known ^{12}C resonances.



Sieve-slit ion-optical image for the target-angle calibration.



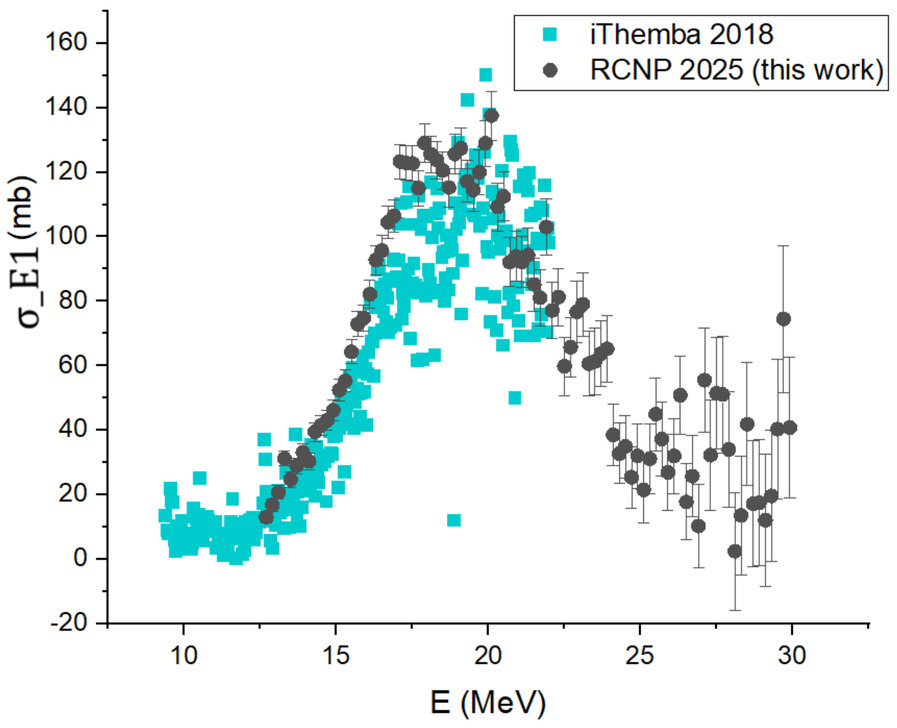
Instrumental background subtraction at 19–22 MeV. is distinct from the later estimated QFS subtraction.

2 Equivalent photo-absorption cross-section

PRELIMINARY INFERRED RESPONSE ACROSS THE MEASURED IVGDR RANGE

Peak ≈ 18.7 MeV

Estimated QFS subtraction · E1-dominant residual · Virtual Photon Method



Circles: this work (RCNP, 2025), preliminary inferred equivalent photo-absorption response after estimated QFS subtraction and an E1-dominant Virtual Photon Method treatment. Squares: normalized iThemba response from Jingo et al. (2018). Error bars shown for this work are statistical.

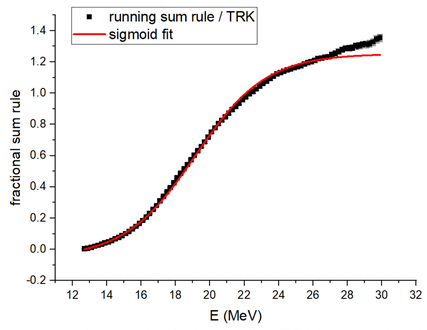
CROSS-FACILITY CONSISTENCY

RCNP and normalized iThemba results show consistent IVGDR-region centroids and cross-section magnitudes.

This cross-facility consistency supports the feasibility of using very-forward-angle (p,p′) scattering to infer the equivalent photo-absorption response across the whole IVGDR energy range.

3 Integrated observables

Thomas-Reiche-Kuhn (TRK) sum-rule exhaustion



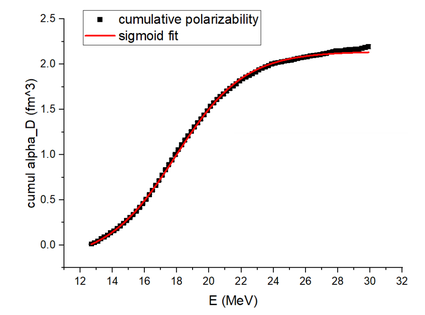
Running response integral relative to the TRK sum rule; the sigmoid fit supplies the extrapolated total.

≈ 1090 MeV mb
integrated strength
Based on sigmoid extrapolation

≈ 30.5%
TRK enhancement
Based on sigmoid extrapolation

Static electric-dipole polarizability

$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma_{E1}(E)}{E^2}\,\mathrm{d}E$$



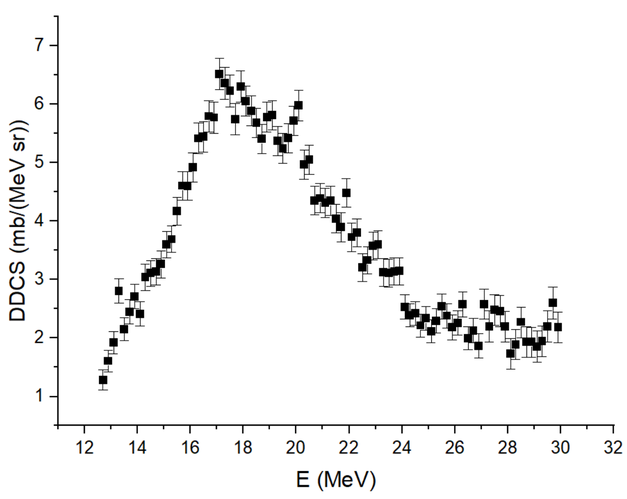
preliminary dipole polarizability
≈ 2.31 fm³
Based on sigmoid extrapolation

Literature total-response equivalent
2.23 ± 0.15 fm³
may include non-E1 strength

The preliminary value is likely overestimated; the literature total-response equivalent may include non-E1 strength.

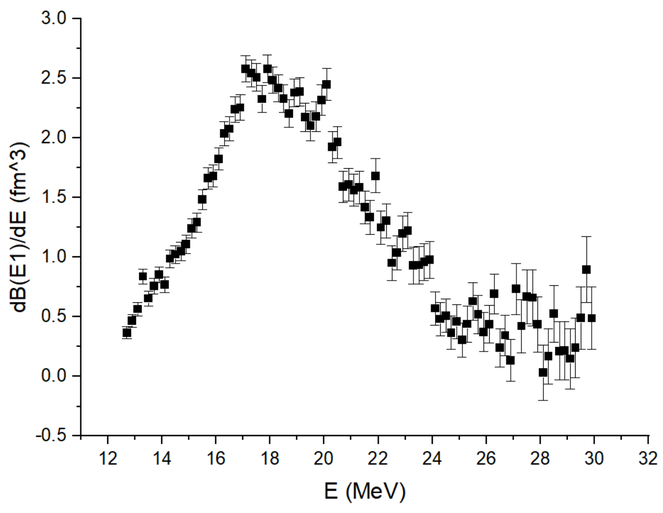
4 Double-differential cross-section 56Fe(p,p')

$$\frac{\mathrm{d}^2\sigma_C}{\mathrm{d}E\,\mathrm{d}\Omega} = \sum_{\pi L} \frac{1}{E} \frac{\mathrm{d}n_{\pi L}}{\mathrm{d}\Omega}\,\sigma_\gamma^{\pi L}(E)$$



DDCS for natural iron, averaged over the finite angular around zero degrees. Displayed uncertainties are statistical.

5 E1 strength function



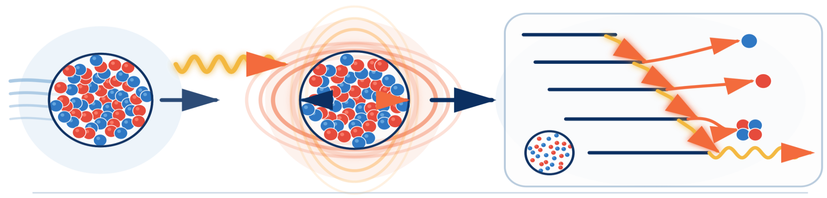
E1 strength deduced from the preliminary inferred equivalent response; displayed uncertainties are statistical.

6 Analysis status

- Natural-iron target; finite angular-window averaging.
- Estimated QFS subtraction; E1-dominant approximation; no completed multipole decomposition analysis (MDA).
- Statistical uncertainties are shown; model-dependent systematic uncertainties remain under evaluation.
- Data at non-zero scattering angles is not yet analysed.

7 Astroparticle physics relevance

^{56}Fe + boosted CMB photon → **IVGDR vibrational excitation** → **nuclear decay cascade**



Electromagnetic-response data provide nuclear inputs for photonuclear-interaction and ultra-high-energy cosmic-ray propagation models in astroparticle physics.

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References

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Figure sources

Thesis figures; Grand Raiden schematic adapted from RCNP. The response comparison includes this work (RCNP, 2025) and the normalized iThemba response from Jingo et al. (2018).

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