E1 and M1 strength in ^{58}Ni from (p,p')

TECHNISCHE UNIVERSITÄT DARMSTADT

SFB - Workshop

B04: Dipole response and neutron equation of state

Outline:

- Dipole strength
- Experiment at RCNP
- Peak-by-peak analysis
- Multipole decomposition analysis
- Summary and outlook

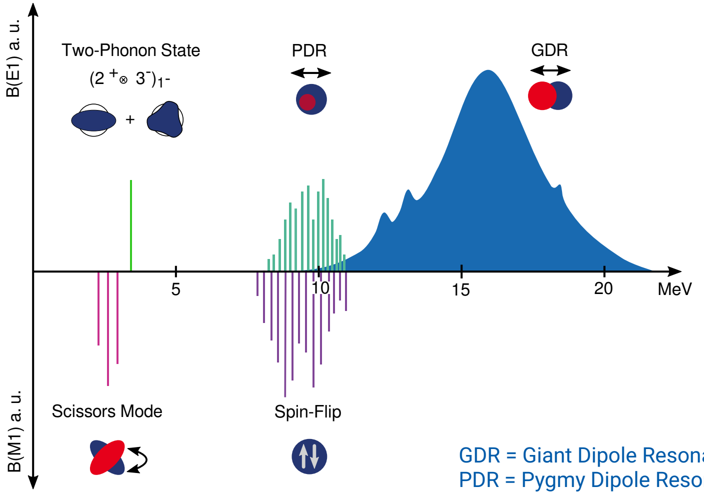
SFB 1245

Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)
Project-ID 279384907 - SFB 1245.

Projects in B04

- Total photoabsorption cross sections at NEPTUN
  - ^{48}Ca experiment planned for fall 2021
- Ab initio calculation of E1 response and polarizability
  - Extension to open-shell nuclei with $\pm$ 1 or 2 nucleons outside shell closures
- E1 (and M1) response and polarizability from (p,p') experiments at RCNP
  - Systematics of Sn isotopes completed
    S. Bassauer et al., Phys. Lett. B 810, 135804 (2020)
    S. Bassauer et al., Phys. Rev. C 102, 034327 (2020)
    M. Markova et al., Phys. Rev. Lett. (submitted)
  - Provide data for the theoretical development: ^{58}Ni discussed here

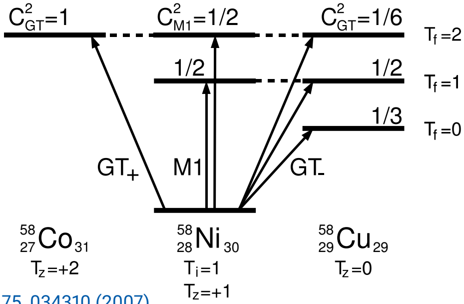
Dipole strength distribution



GDR = Giant Dipole Resonance
PDR = Pygmy Dipole Resonance

Magnetic dipole strength in (p,p')

- Low momentum transfer and proton energy $\approx 300\,\mathrm{MeV}$:
  - Isovector spin-flip M1 transitions favoured
  - Isospin analogue to Gamow-Teller transition



H.Fujita et al., Phys. Rev. C 75, 034310 (2007)

Magnetic dipole strength in (p,p')

- Unit cross section method

$$\frac{\mathrm{d}\sigma^{\mathrm{IV}}_{\mathrm{M1}}}{\mathrm{d}\Omega}(0^\circ) = \hat{\sigma}_{\mathrm{M1}} F_{\mathrm{M1}}(0^\circ, E_x) B^{\mathrm{IV}}(\mathrm{M1}_{\sigma\tau})$$

- Electromagnetic strength
  - Isoscalar contributions negligible
  - Pure spin excitation

$$B(\mathrm{M1}) \approx \frac{3}{2\pi}\left(\frac{g_s^{\mathrm{IV}}}{2}\right)^2 \cdot 2B^{\mathrm{IV}}(\mathrm{M1}_{\sigma\tau})$$

Electric dipole strength in (p,p’)

- Conversion to photoabsorption cross section
  - Virtual photon method

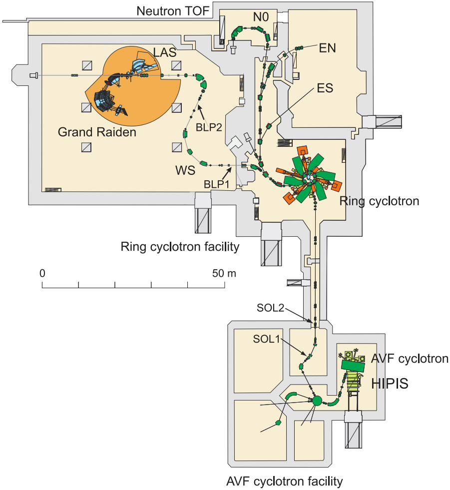
$$\frac{\mathrm{d}^2\sigma_{\mathrm{E1}}}{\mathrm{d}\Omega\mathrm{d}E} = \frac{1}{E}\frac{\mathrm{d}N_{\mathrm{E1}}}{\mathrm{d}\Omega}\sigma_{\mathrm{abs}}^{\mathrm{E1}}$$

- Dipole polarizability
  - Equation of state of neutron rich matter

$$\alpha_{\mathrm{D}} = \frac{\hbar c}{2\pi^2}\int \frac{\sigma_{\mathrm{abs}}^{\mathrm{E1}}}{E^2}\mathrm{d}E$$

Research Center for Nuclear Physics (RCNP)

- July 2005
- Proton beam energy
  $E_p = 295\,\text{MeV}$
- ^{58}Ni Target:
  $4\ \text{mg/cm}^2$

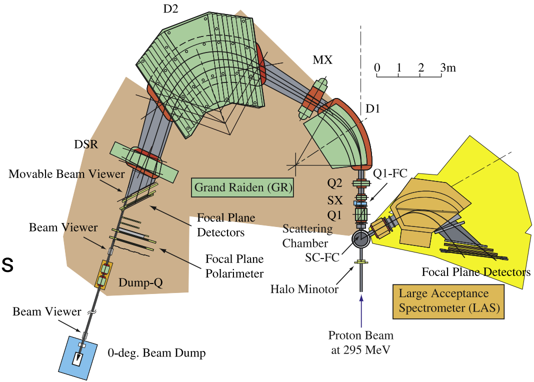


P. von Neumann-Cosel, A. Tamii
Eur. Phys. J. A 55, 110 (2019)

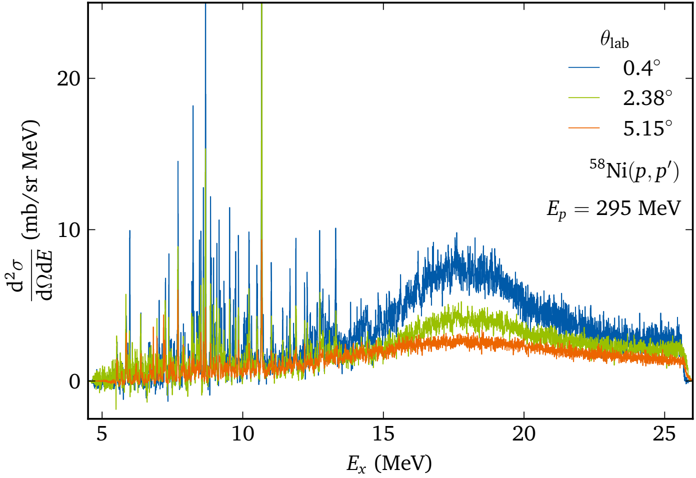
Grand Raiden Spectrometer

- Spectrometer angles: 0°, 2.5°, and 4.5°
- Raw data analysis: H. Matsubara, Dissertation, Osaka University (2010)
- Excitation energy spectra for seven scattering angles between 0.4° and 5.15°
- High energy resolution of 22 keV FWHM

Spectrometer setup at 0°

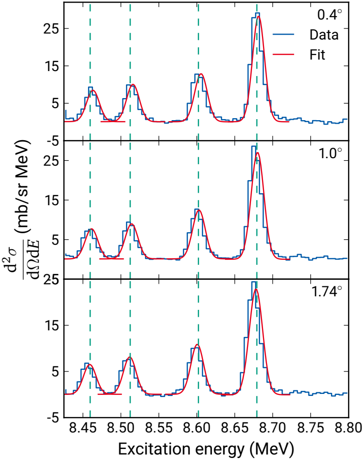


^{58}Ni Spectra



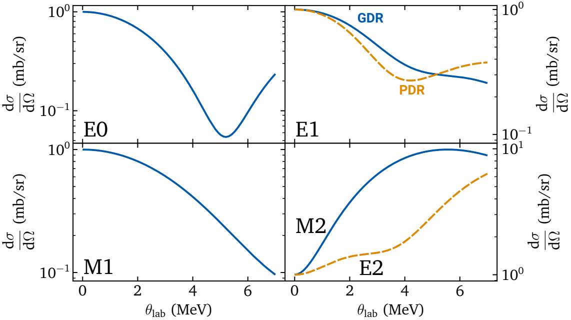
Peak-by-peak analysis

- Analysis of individual transitions between 5 MeV and 13.3 MeV
- Peak fitting with gaussians on linear background
- High level density
- In total 185 transitions
  - 147 present in at least five spectra



Peak-by-peak analysis
Multipolarities

- DWBA calculations
  V. Yu. Ponomarev (2019)
- Comparison to experimental angular distributions
- Identification of low energy E1 transitions difficult



Peak-by-peak analysis
Comparisons

- Identification of corresponding states in complementary experiments

$$\frac{|E_x^{(p,p')} - E_x^{\mathrm{Ref}}|}{\sqrt{u^2_{(p,p')}(E_x) + u^2_{\mathrm{Ref}}(E_x)}} \leq \sqrt{2}$$

- Nuclear resonance fluorescence (γ, γ'):
  F. Bauwens et al., Phys. Rev. C 62, 024302 (2000)
  M. Scheck et al., Phys. Rev. C 88, 044304 (2013)
  J. Sinclair, priv. comm. (2019)

  E1, M1

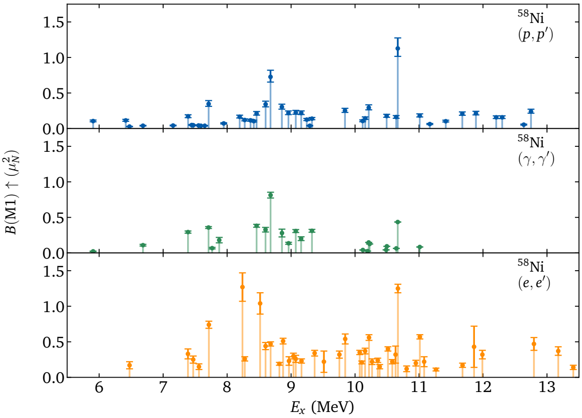
- Inelastic electron scattering (e, e') :
  W.Mettner et al., Nucl. Phys. A473, p. 160-178 (1987)

  M1, M2

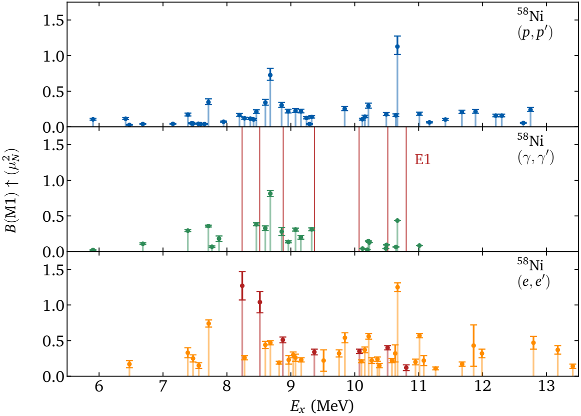
- (p, p') at 160 MeV + ^{58}Ni (^{3}He,t)^{58}Cu:
  H.Fujita et al., Phys. Rev. C 75, 034310 (2007)

  E1, IVSM1

Magnetic dipole strength distribution

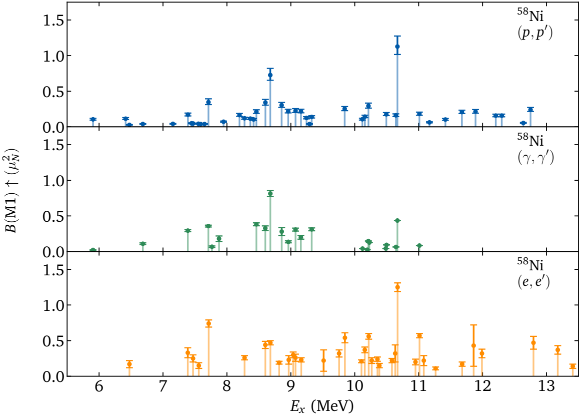


Magnetic dipole strength distribution



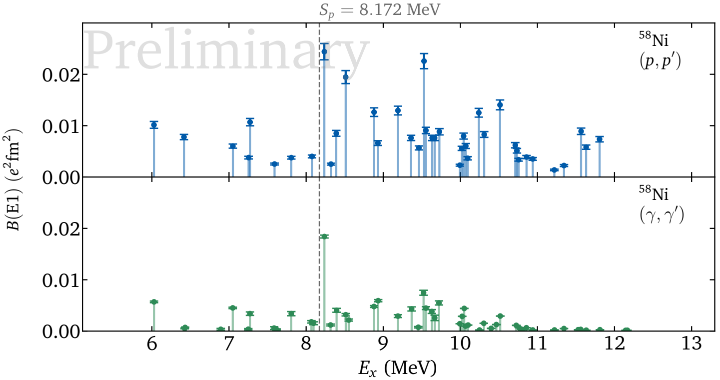
- For seven states: different parities given in (γ,γ') and (e,e')
- Unusual behaviour

Magnetic dipole strength distribution

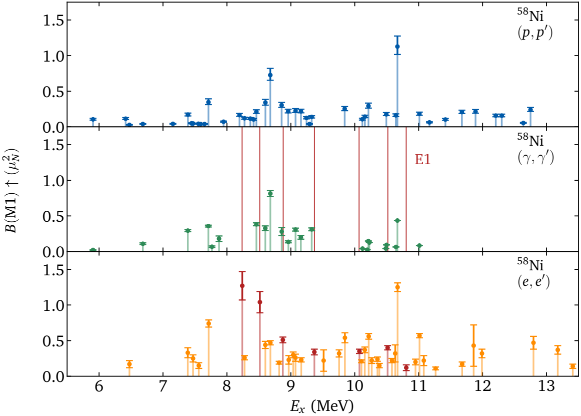


- (p, p') : Spin-M1
- Electromagnetic probes: spin and orbital contributions
- Decomposition with theoretical calculations from **B01**

Electric dipole strength distribution



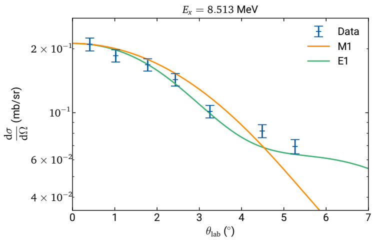
Magnetic dipole strength distribution

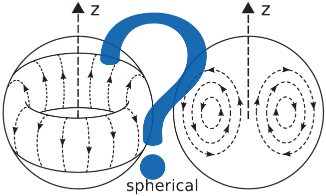


- ► For seven states: different parities given in (γ,γ') and (e,e')
- ► Unusual behaviour

Candidates for toroidal mode?

- E1-like angular distributions in (p, p')
- (e, e') Experiment:
  - Backward angles $93^\circ - 165^\circ$
  - Magnetic transitions (M1, M2)
- Unusual structure:
  - **?** Strong electric transverse components
  - **?** Candidates for toroidal dipole mode
  - Theoretical calculations from **A04**





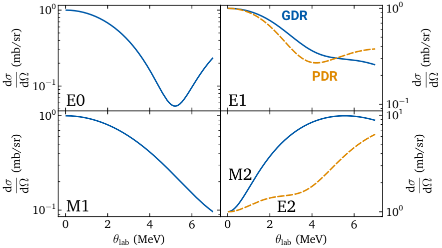
A.Repko et al., Eur. Phys. J. A 55, 242 (2019)

Multipole decomposition analysis

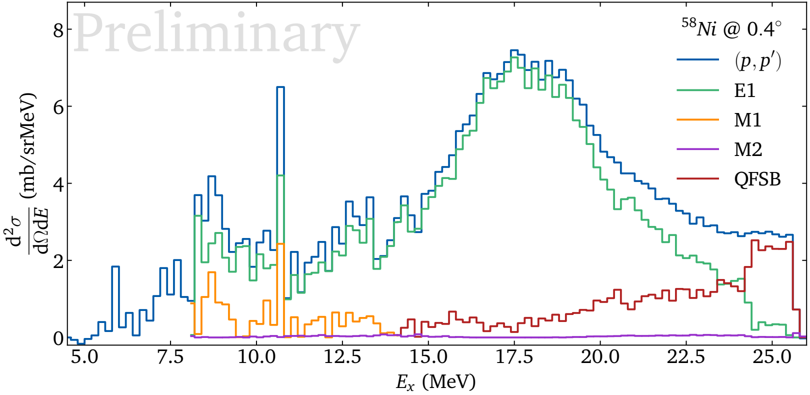
- Multipole decomposition analysis (MDA)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta_{\mathrm{cm}}, E_x)\bigg|_{\mathrm{Exp.}} = \sum_{J^\pi} a^{J^\pi} \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta_{\mathrm{cm}}, E_x, J^\pi)\bigg|_{\mathrm{DWBA}}$$

- Unresolved strength and GDR
- Electric dipole polarizability
- Theo. calculations within **B04**



Multipole decomposition analysis



Summary and outlook

- Analysis:
  - ✓ Peak-by-peak
  - ▷ MDA
- M1:
  - ✓ Detailed comparison of the strength distribution
  - ▷ Decomposition in spin and orbital contributions
- E1:
  - ▷ Further analysis of states with unusual properties
  - ▷ Electric dipole polarizability