Experiments with Real Photons at the S-DALINAC

Workshop on Gamma Strength and Level Density in Nuclear Physics and Nuclear Technology Dresden Rossendorf, 30.08.2010

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S-DALINAC

- **Superconducting Darmstadt Linear Accelerator**
- 10 MeV injector
- 40 MeV main linac
- 2 recirculations
- electron beam up to 130 MeV
- new: polarized source
S-DALINAC

Accelerator Hall

Experimental Hall

HIPS

NEPTUN

5 m
Outline

High Intensity Photon Setup HIPS

- Nuclear Resonance Fluorescence (NRF)
- self-absorption
- (activation: nuclear astrophysics)

Photon Tagger NEPTUN

- functional principle
- application areas
- summary
Principle of Nuclear Resonance Fluorescence

- NRF (nuclear resonance fluorescence): high-energy photons as probes
- low angular momentum transfer → only dipole und quadrupole transitions
- excitation is strength selective → spectroscopy despite high level density

Motivation

**Energy / MeV**

- **E1**
- **Strength**
- **Giant Dipole Resonance**
- **Pygmy Dipole Resonance**
- **Two Phonon State**

- $(\gamma,\gamma')$
- $S_n$
- $(\gamma,n)$
Motivation

- level energy
- angular momentum quantum number
- parity quantum number
- transition width
- cross section and transition strength

NRF measurements
High Intensity Photon Setup HIPS

- energy: up to 10 MeV
- current: up to 60 µA
- flux behind radiator: $10^6 \gamma/(\text{keV cm}^2 \text{ s})$
- flux at target position: $10^{4-5} \gamma/(\text{keV cm}^2 \text{ s})$
$^{140}$Ce @ 8 MeV – A Typical NRF Spectrum
Determination of Observables

- spin quantum number
  - angular distributions are different for $0\rightarrow 1\rightarrow 0$ and $0\rightarrow 2\rightarrow 0$ sequence
  - intensity ratio $w$ for two angles determines spin

- transition strength
  - measured peak area connected to transition strength
  - photon flux deduced with help of calibration target

- parity quantum number
  - Compton polarimetry (low analyzing power)
  - polarized photons in entrance channel
$^{94}$Mo at 8.7 MeV

![Graph showing B(E1) for $^{94}$Mo at 8.7 MeV energy. The graph includes E1-strength, probably E1-strength, sensitivity limit 130°, and sensitivity limit 90°. The x-axis represents energy in keV ranging from 3000 to 8000, and the y-axis represents $B(E1) / 10^{-3} e^{2} fm^{2}$. The graph displays various bars corresponding to different energies and strengths.]
$^{60}\text{Ni at 9.9 MeV}$

$B(E1) \left[ 10^{-3} \text{ e}^2 \text{ fm}^2 \right]$ vs. Energy [keV]

1 picture provided by Matthias Fritzsche
N = 82 Isotones

\begin{align*}
\text{\(^{136}\text{Xe}, Z=54\)} & \\
\text{\(^{138}\text{Ba}, Z=56\)} & \\
\text{\(^{140}\text{Ce}, Z=58\)} & \\
\text{\(^{142}\text{Nd}, Z=60\)} & \\
\text{\(^{144}\text{Sm}, Z=62\)} & \\
\end{align*}

\text{D. Savran et al, Phys. Rev. Lett. 100 (2008) 232501}

An Assumption

- NRF-experiments: \( I \propto \frac{\Gamma_0}{\Gamma} \)
- transition strength: \( B(E1) \propto \Gamma_0 \)
- assumption: \( \Gamma_0/\Gamma \approx 1 \)
  - in most cases no transitions in lower lying states observed
  - **but: are there many small transitions?**

- determine ground state transition width \( \Gamma_0 \) **absolutely** (and therefore the branching ratio to the ground state)
NRF principle

- excitation and decay scheme:

\[ \begin{align*}
E_j & \quad \Gamma_0 \\
\Gamma_0 & \quad \Gamma_0 \\
E_0 & \quad J_j \\
\Gamma_{j\rightarrow i} & \quad \Gamma_{i\rightarrow 0} \\
J_i & \quad J_0
\end{align*} \]

- several decay channels
- excitation process unambiguous
- analyse absorption spectrum
Interaction with Absorber

- atomic attenuation
- several processes
- contributes at each energy
- independent of $\Gamma_0$

- resonant absorption
- only at resonance energies
- depends on $\Gamma_0$

- pair production

- Compton effect

- photo effect

$\sigma_A \propto \Gamma_0 \cdot e^{-\left(\frac{E}{\Delta}\right)^2}$

absorption lines only a few eV wide!!
Principle of measurement and self absorption\(^1\)

\(^1\) F. R. Metzger, Prog. in Nucl. Phys. 7 (1959) 53

- **idea:** scatterer made of absorber material as „high-resolution detector“

**self absorption:** decrease of decays in scatterer because of resonant absorption

\[
R(\Gamma_0) = \frac{N_{\text{woA}} - f \cdot N_{\text{wA}}}{N_{\text{woA}}} = 1 - \frac{f \cdot N_{\text{wA}}}{N_{\text{woA}}}
\]

**f**

\[
f = \frac{N_{\text{std}}}{N_{\text{wA}}}
\]
Determination of the Groundstate Transition Width

- calculate $R$ as function of $\Gamma_0$
- self absorption $R_{\text{exp}}$ determined experimentally
- comparison of experiment and calculation gives groundstate transition width $\Gamma_0$
- NRF-measurement also gives $\Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$
- thus total transition width $\Gamma$ and branching ratio $\Gamma_0 / \Gamma$ to ground state can be determined
Measurement on $^{140}$Ce

- scatterer: 2 g $^{140}$Ce
- calibration target: 312 mg $^{11}$B
- absorber: 60 g CeO$_2$
- endpoint energy: 8 MeV
- about 4 days for each measurement

$R_{\text{exp}} = 0.55 (2)$

$R_{\text{exp}} = 0.16 (6)$
Groundstate Transition Widths

\[ \frac{\Gamma_0^2}{\Gamma} / \text{meV} \]

\[ \Gamma_0 / \text{meV} \]

30.08.2010 | Christopher Romig | Technische Universität Darmstadt | Institut für Kernphysik
Principle of Photon Tagging

- photons are produced by electrons emitting bremsstrahlung

- idea: determine energy of electron to deduce photon energy

- thin radiator: only one interaction + conservation of energy: $E_\gamma = E_0 - E_e$
NEPTUN Facility

- monoenergetic electrons provided by S-DALINAC
- radiator target: 10 µm Au, only one photon per electron

- clam-shell magnet
- focal plane (128 scintillating fibers attached to PMs)
NEPTUN Facility - Specifications

- energy range: $2 \text{ MeV} \leq E_\gamma \leq 20 \text{ MeV}$
- energy resolution: $\Delta E = 25 \text{ keV @ 10 MeV}$
- energy window: $\approx 2-3 \text{ MeV}$
- primary beam: $E_0 = 28 \text{ MeV}$
- photon intensity: $\approx 10^3 \text{ keV}^{-1}\text{s}^{-1}\text{cm}^{-2}$
- dominated by energy spread of the accelerator
- improvements are in progress

Measured tagging resolution at NEPTUN
Tagged Beam Profile

- Measured using a HPGe detector

Graph showing counts vs. \( E_\gamma / \text{keV} \) for fibers no. 1, no. 9, and no. 16.
Experiments @ NEPTUN

- NEPTUN (excitation energy)
- HPGGe (γ decay)
- ToF (n emission)
Summary

- HIPS
  - NRF measurements for investigation of
    - Pygmy Dipole Resonance (systematics?)
    - Two Phonon States
  - self absorption measurements for determination of
    - absolute transition widths and strengths, respectively
    - branching ratio to ground state
  - activation measurements for investigation of
    - reaction rates of branching nuclei
    - abundance distributions in nucleosynthesis

- NEPTUN
  - detector characterization
  - ($\gamma,\gamma$) reactions below and above threshold
  - ($\gamma,n$) reactions
Thank You for your attention!

Many thanks to...

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