Low-lying dipole strength in open and closed-shell nuclei and a new approach to its decay pattern

TECHNISCHE UNIVERSITÄT DARMSTADT

05/27/2013 – 4th Workshop on Nuclear Level Density and Gamma Strength, Oslo

C. Romig[1], J. Beller[1], M. Fritzsche[1], J. Isaak[2,3], N. Pietralla[1], D. Savran[2,3], M. Scheck[1], L. Schnorrenberger[1], K. Sonnabend[4], M. Zweidinger[1]

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4) Institut für Angewandte Physik, Goethe-Universität Frankfurt, Max-von-Laue-Straße 1, 60438 Frankfurt

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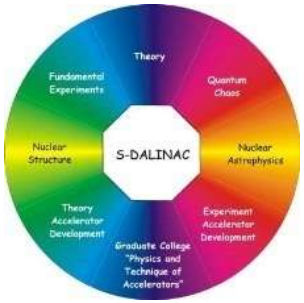

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Helmholtz Graduate School for Hadron and Ion Research

HIC for FAIR
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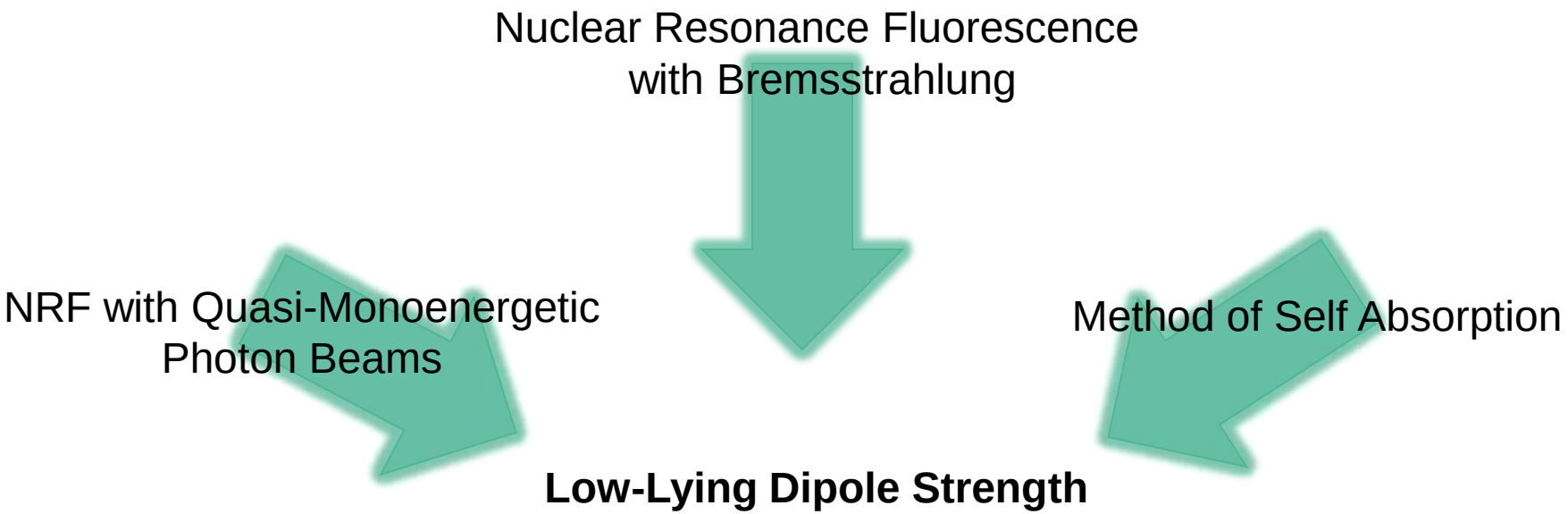
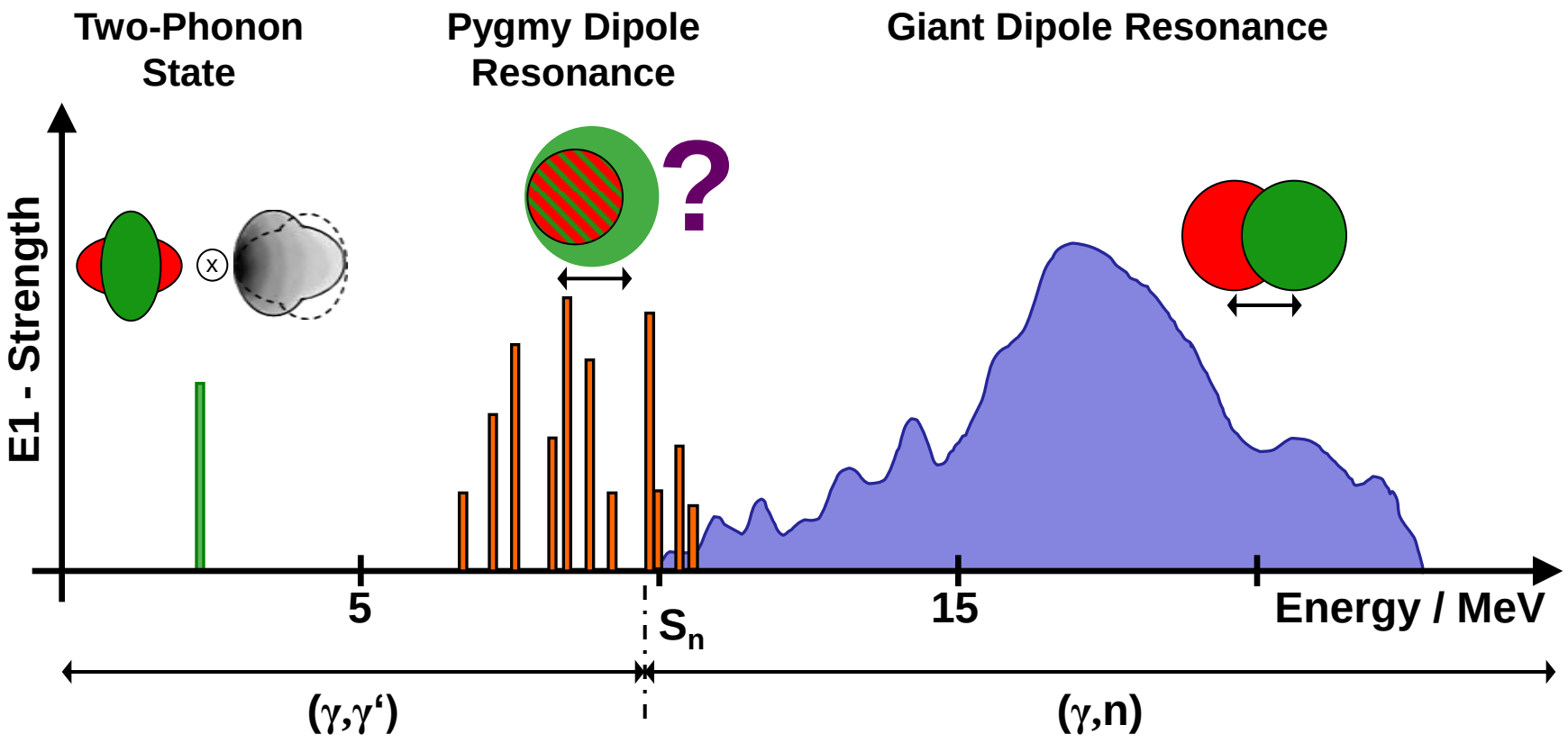
LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz

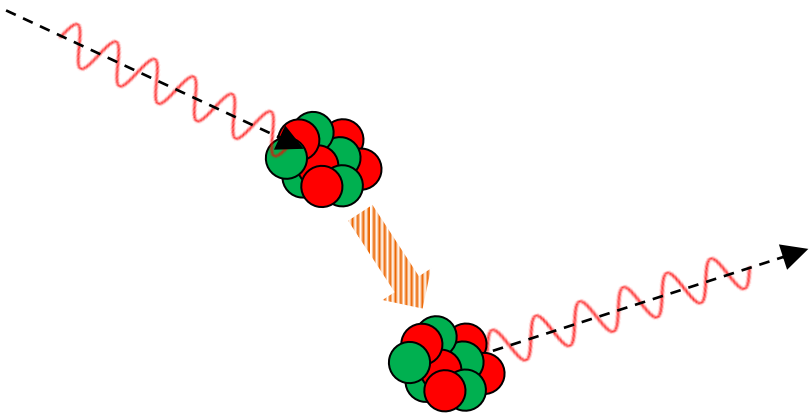
Outline

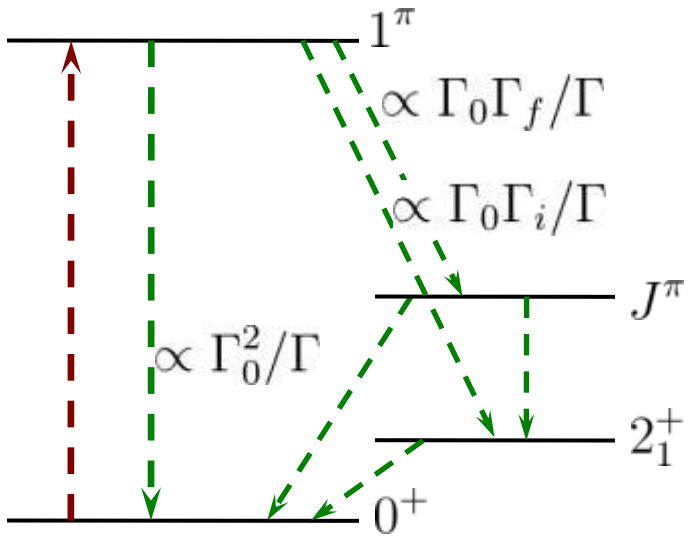

Nuclear Resonance Fluorescence
with Bremsstrahlung
NRF with Quasi-Monoenergetic
Photon Beams
Method of Self Absorption
Low-Lying Dipole Strength

E1-Response of spherical even-even nucleus



Principle of Nuclear Resonance Fluorescence[1]





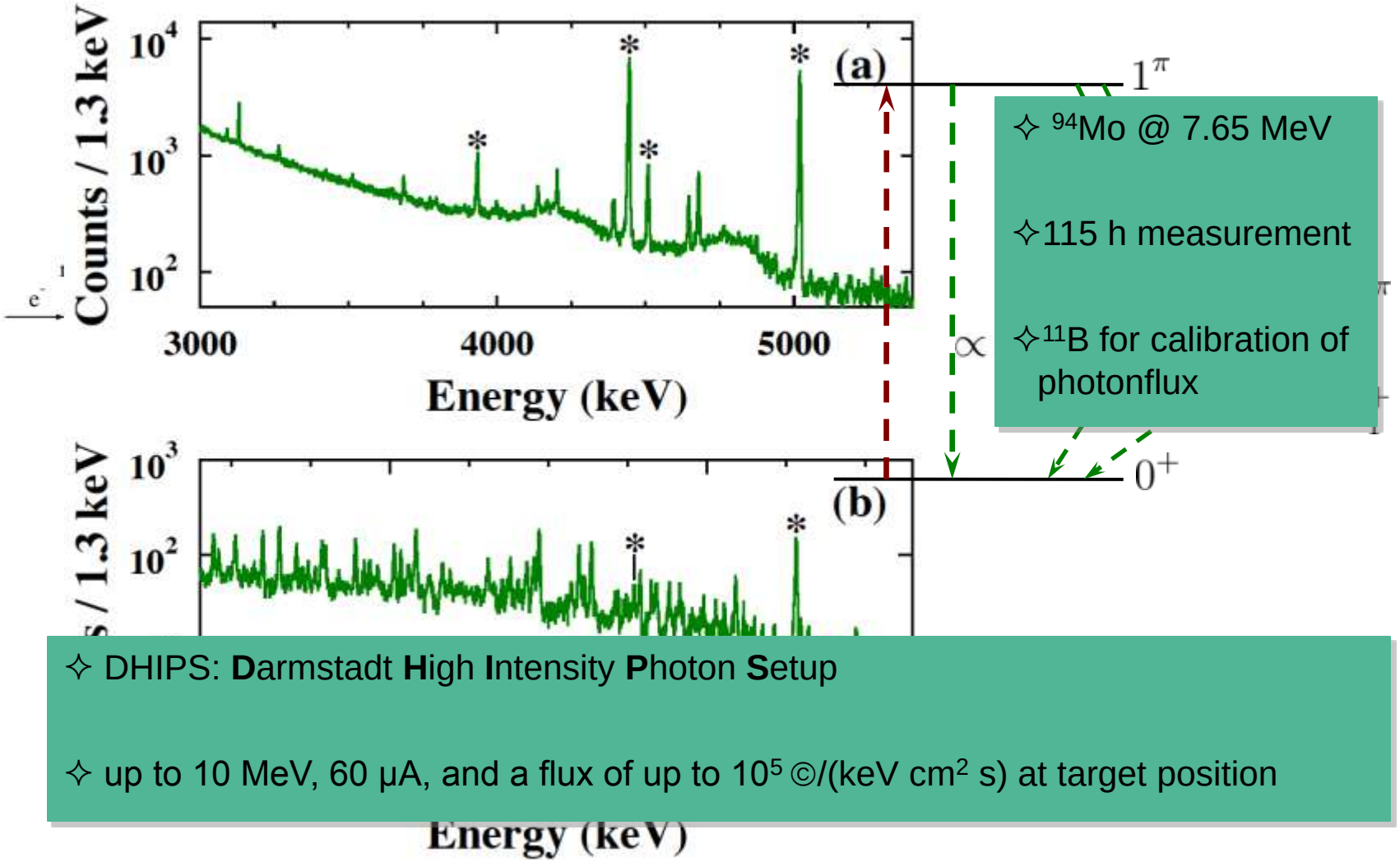
- ✧ NRF (**n**uclear **r**esonanc… …otons as probes
- ✧ low angular m… …excited states
- ✧ (model-indepen… …of quantum numbers an… …trengths

- ✧ B(E1) strength: $B(E1)\uparrow \propto \Gamma_0$
- ✧ NRF: sensitive to $\Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$

measure or ≈1

1) U. Kneissl, N. Pietralla, A. Zilges, J. Phys G: Nucl. Part. Phys. **32** (2006) R217

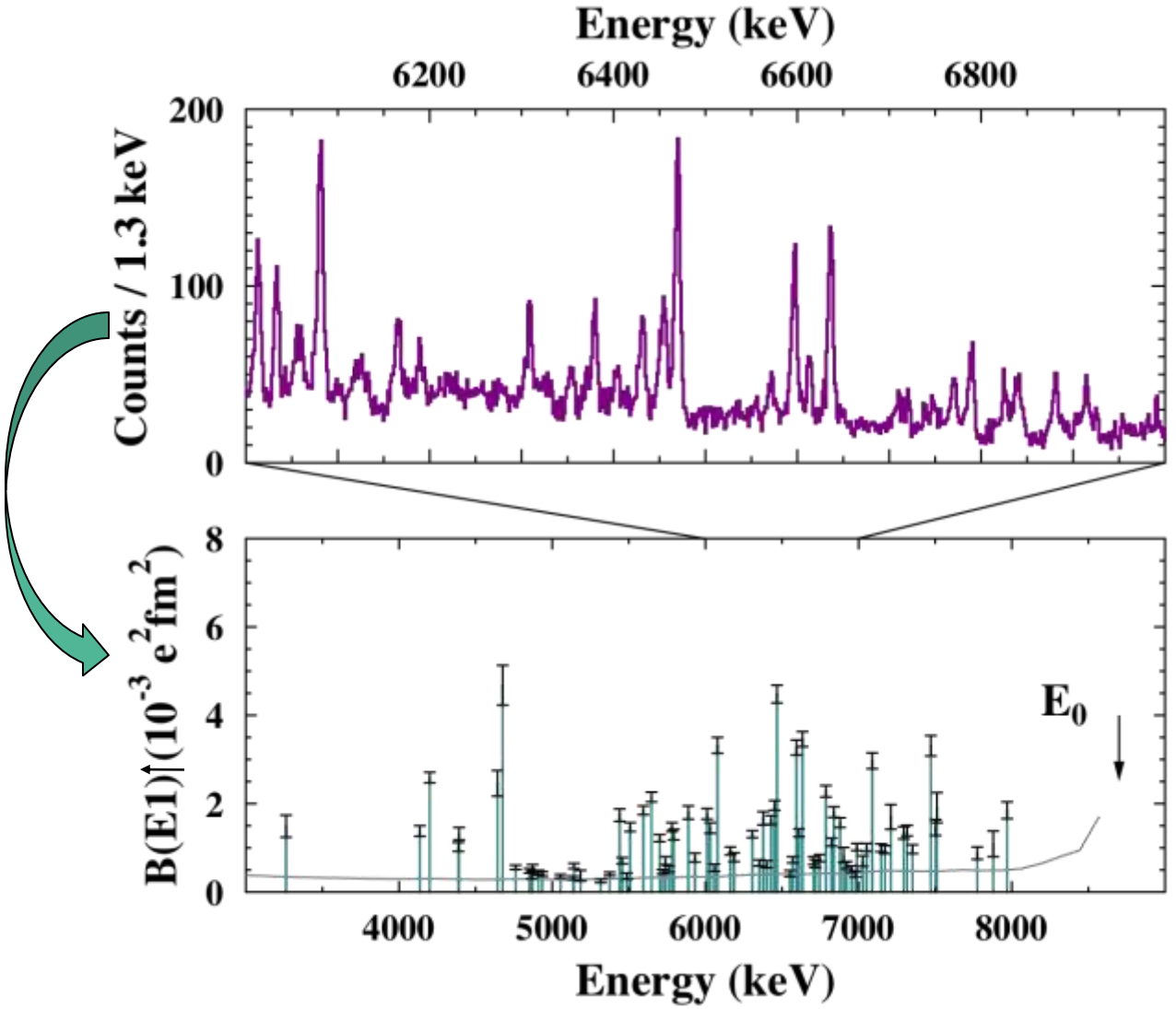
NRF @ DHIPS



- ^{94}Mo @ 7.65 MeV
- 115 h measurement
- ^{11}B for calibration of photonflux

- DHIPS: **D**armstadt **H**igh **I**ntensity **P**hoton **S**etup
- up to 10 MeV, 60 µA, and a flux of up to 10^5 ©/(keV cm^2 s) at target position

E1-Strength Distribution – ^{94}Mo

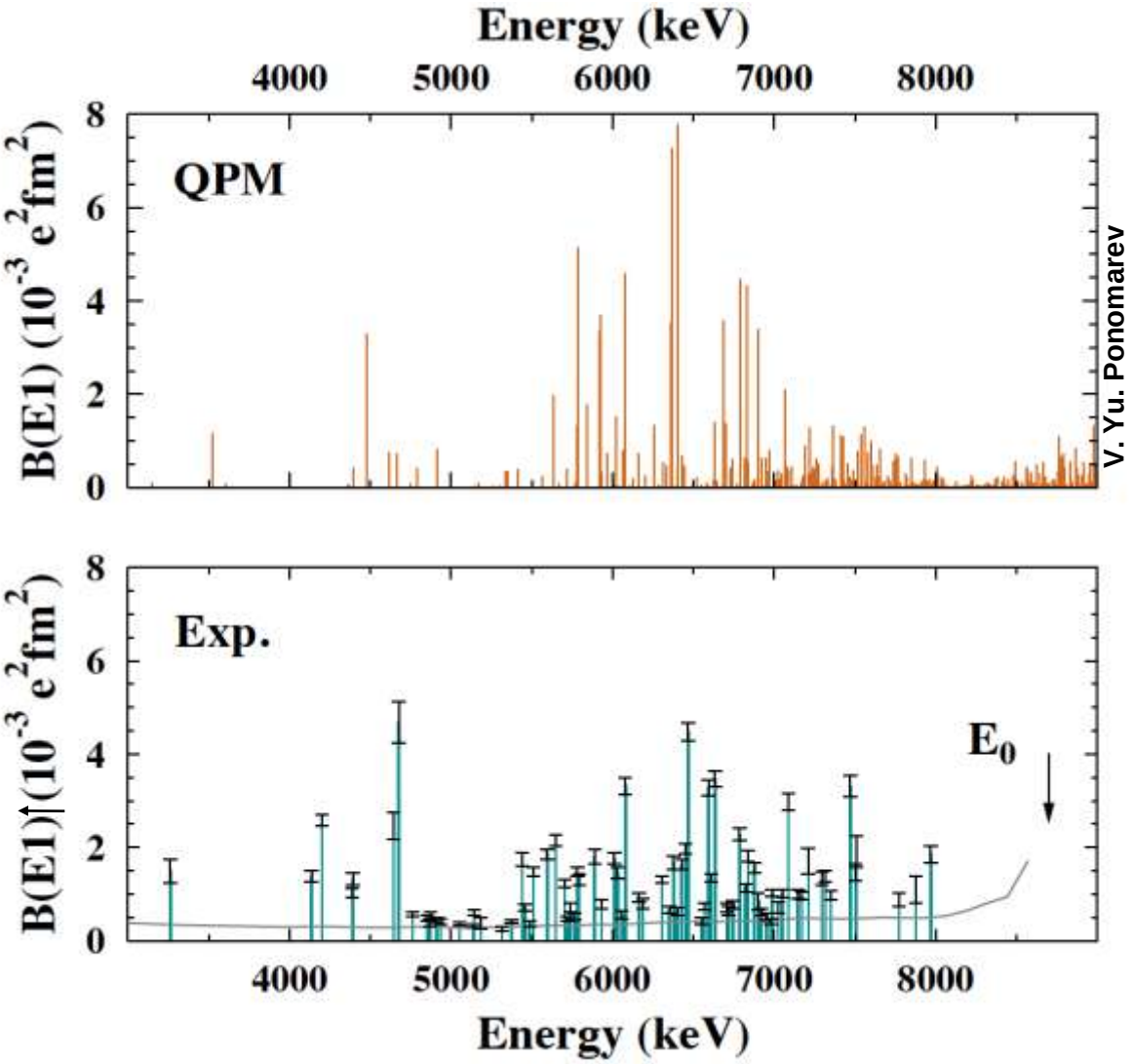


$$\frac{\Gamma_0^2}{\Gamma} \propto \frac{A}{N_\gamma \varepsilon \cdot N_T \cdot W}$$

$$\frac{\Gamma_0}{\Gamma} \approx 1$$

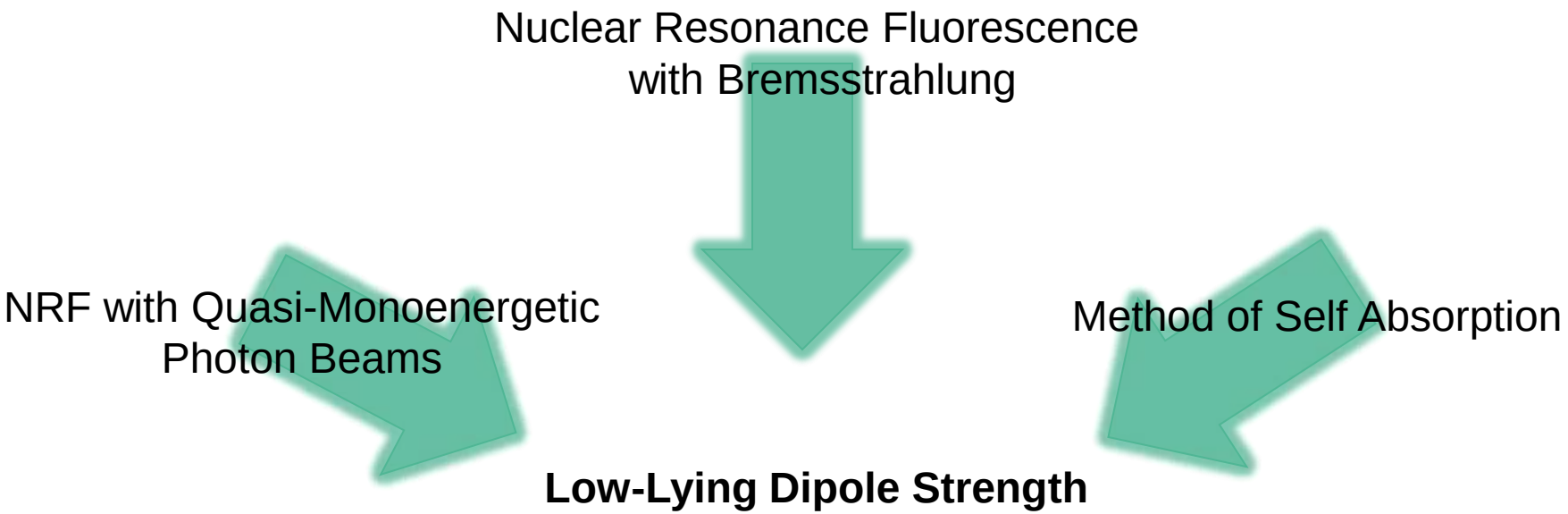
$$B(E1) \propto \Gamma_0$$

Comparison with QPM



- wave function includes one-, two-, and three-phonon configurations
- 219 1^- states up to 8 MeV
- 5 to 8 MeV: $106 \times 10^{-3}\ e^2fm^2$
- with sensitivity limit:
  66 1^- states
  $91 \times 10^{-3}\ e^2fm^2$
- 78 1^- states up to 8 MeV
- 5 to 8 MeV: $84(8) \times 10^{-3}\ e^2fm^2$

Outline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NRF @ HI©S

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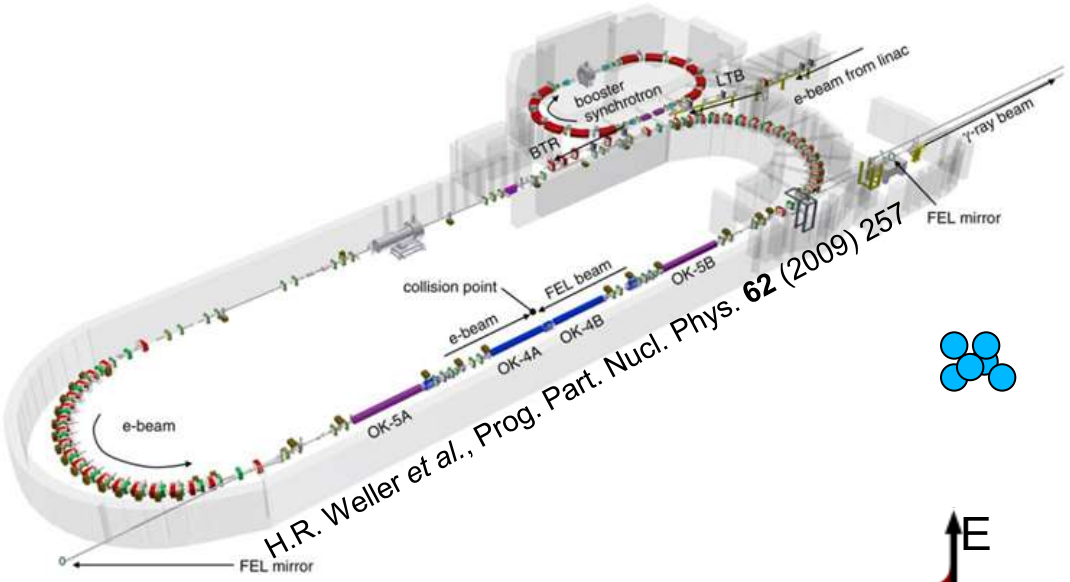
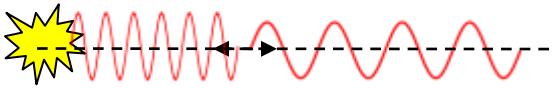
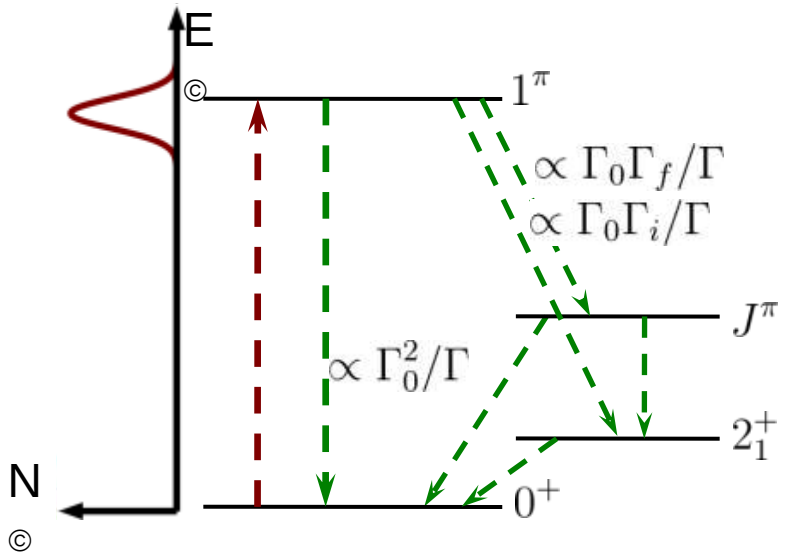


H.R. Weller *et al.*, Prog. Part. Nucl. Phys. **62** (2009) 257

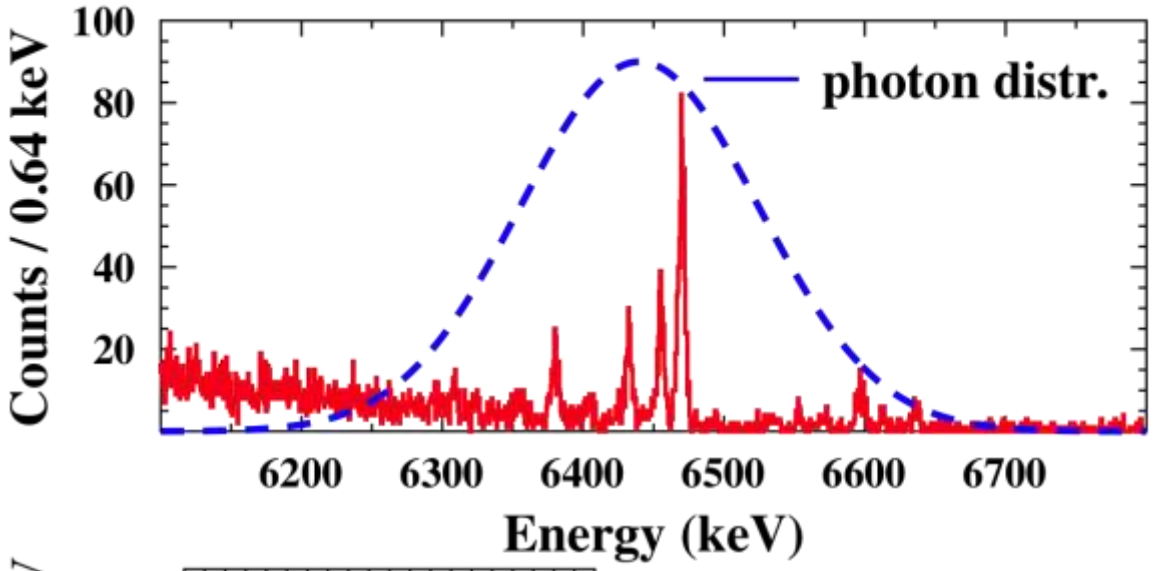
$$E_\gamma \simeq 4\gamma^2 E_{\mathrm{Photon}}$$

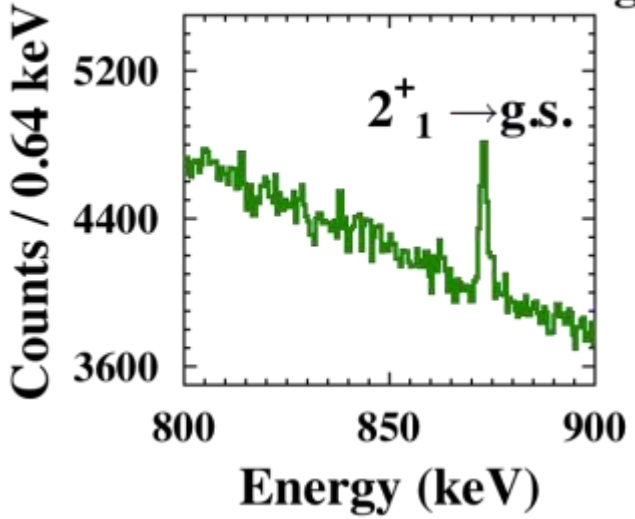


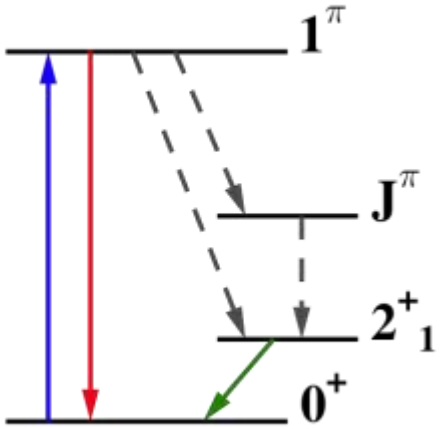
- ✧ quasi monoenergetic beam
- ✧ excitation only in narrow energy region



^{94}Mo @ HI©S

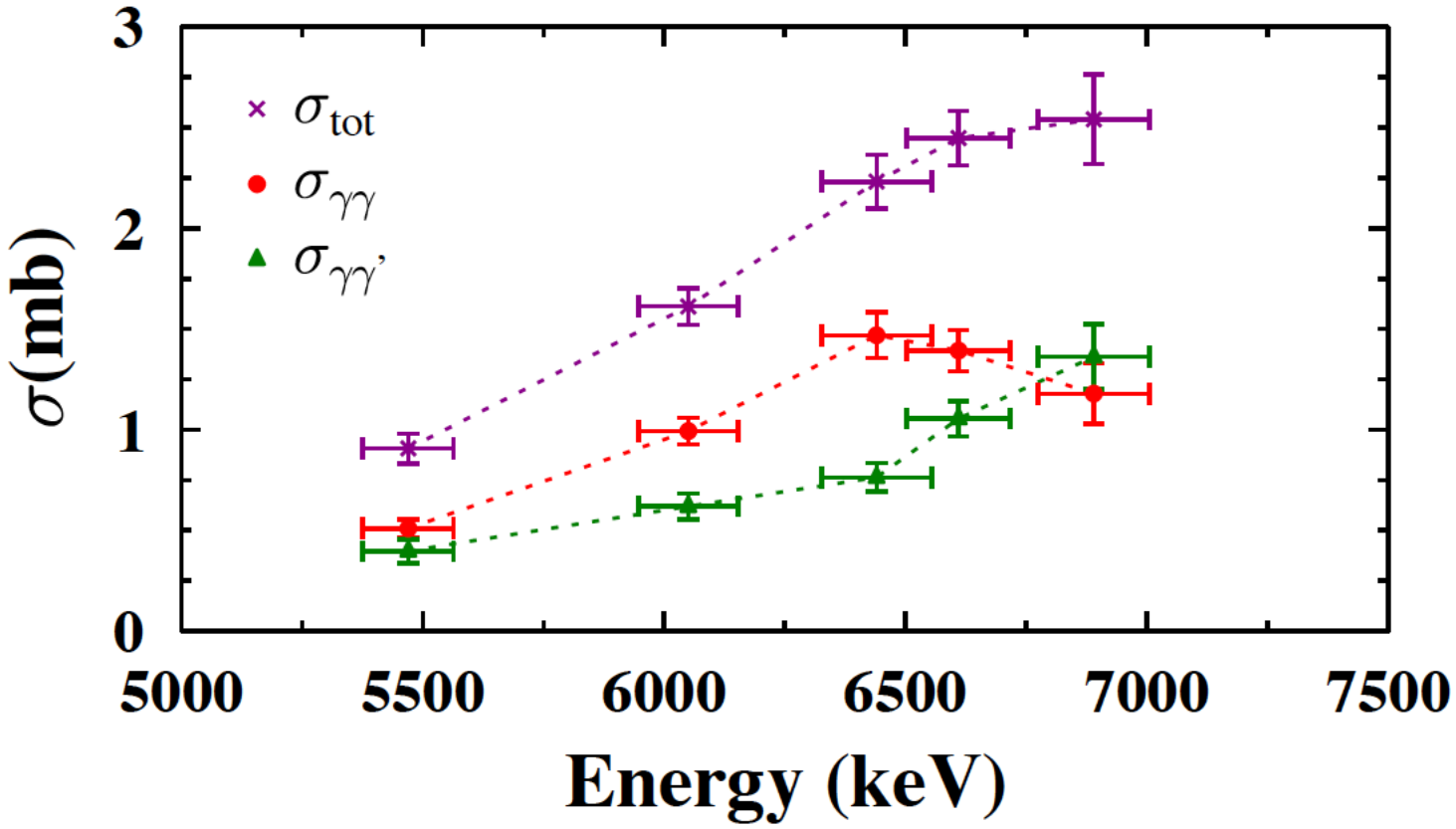






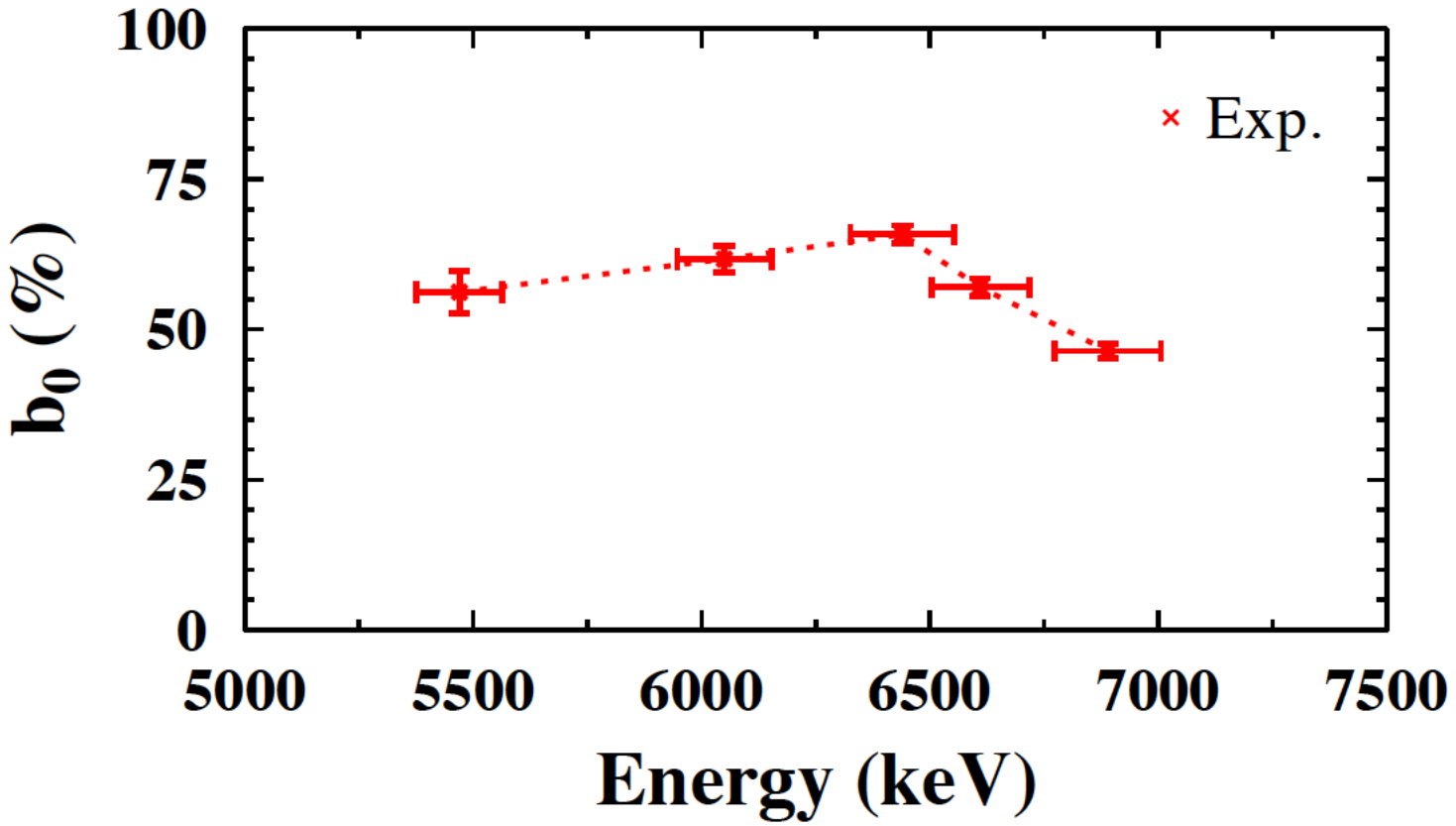
- ✧ incoming photons: excitation in narrow energy range
- ✧ „elastic“ decay (direct decay to gs)
- ✧ „inelastic“ decay (here: decay via 2^+_1)
- ✧ decay to intermediate states not observed

^{94}Mo @ HI©S – Mean Cross Sections



^{94}Mo @ HI©S – Mean Branching Ratio to GS

$$b_0 = \frac{N_{1\rightarrow \mathrm{gs}}}{N_{1\rightarrow \mathrm{gs}} + N_{2_1^+\rightarrow \mathrm{gs}}}$$



DICEBOX – Input for ^{94}Mo

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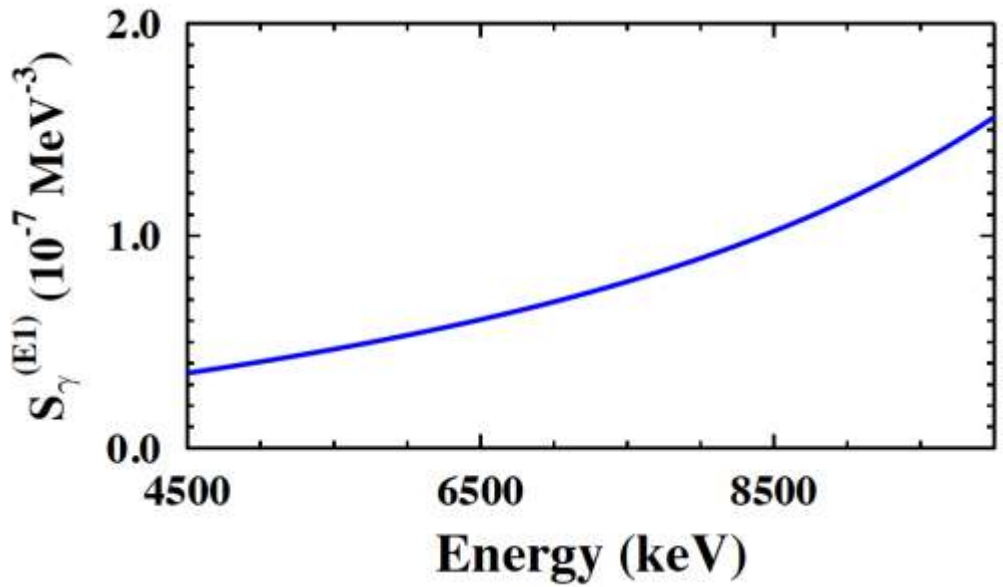
- level density: back-shifted Fermi gas model (a = 10.28 MeV^{-1}; E_1 = 0.73 MeV)

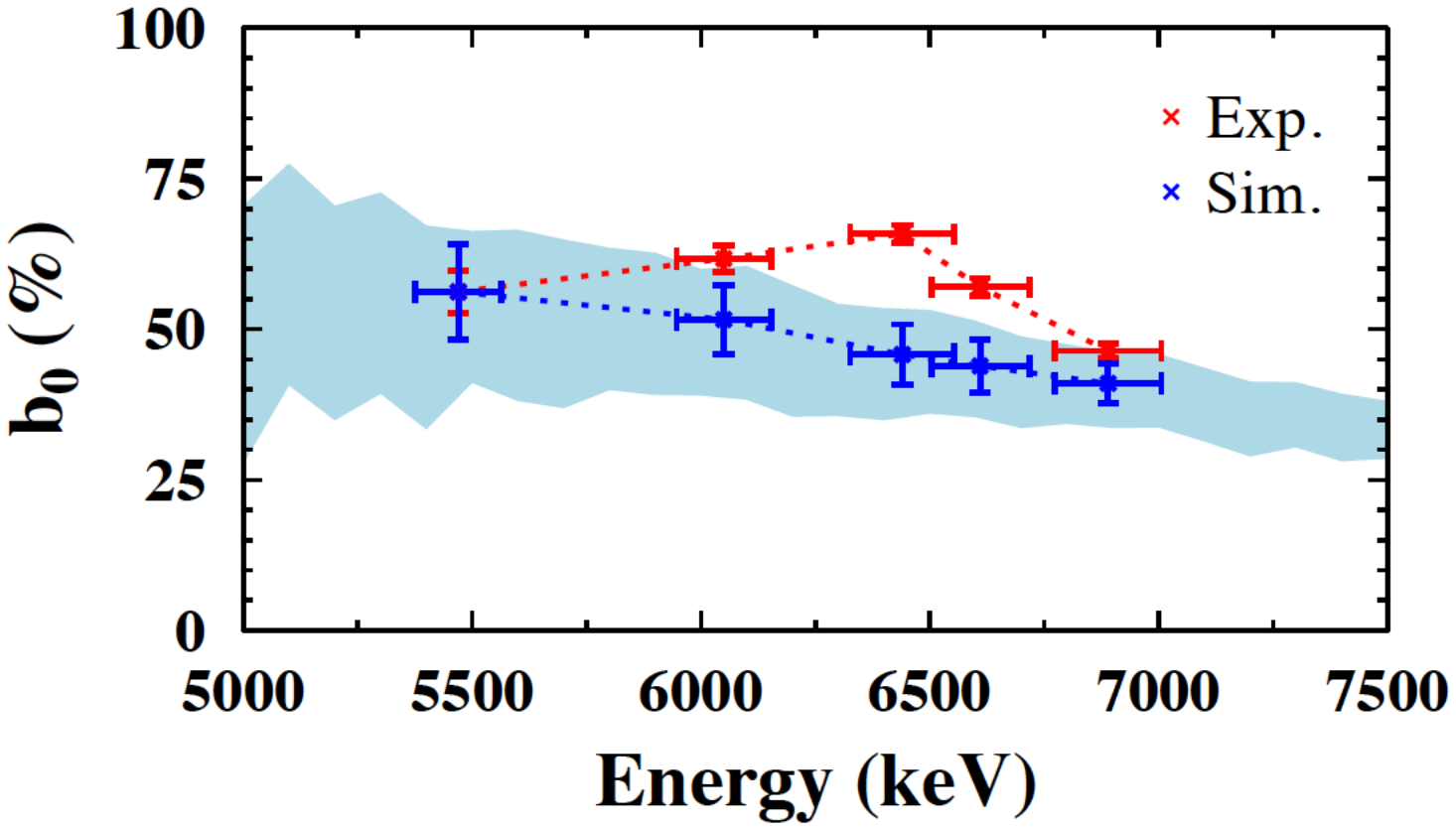
- photo-strength function: Lorentz parameterization for cross section (E1: fit to (©, n) data)

$$S_\gamma^{(E1)}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\cdot\frac{1}{E_\gamma}\cdot\sigma(E_\gamma;\sigma_0^{(E1)},E_0^{(E1)},\Gamma_0^{(E1)})$$



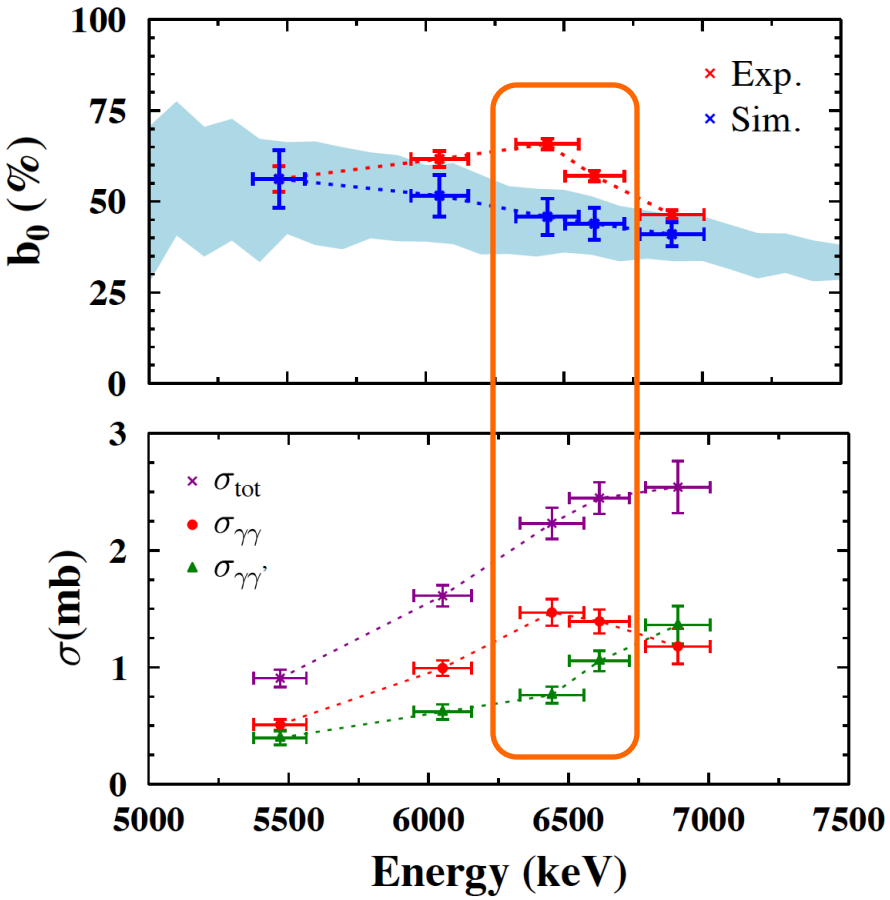
- photon flux distribution: from Duke measurements + 100 keV wide bins with constant flux

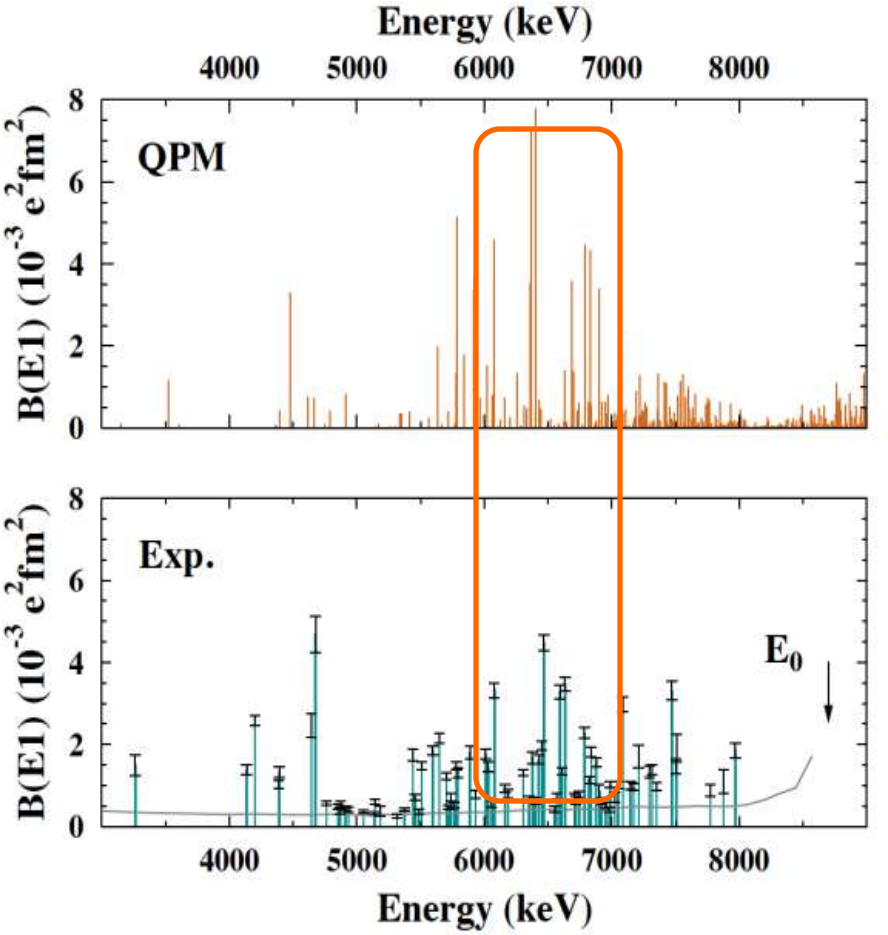
^{94}Mo @ HI©S – Mean Branching Ratio to GS



Evidence for Pygmy Dipole Resonance as structural feature?!

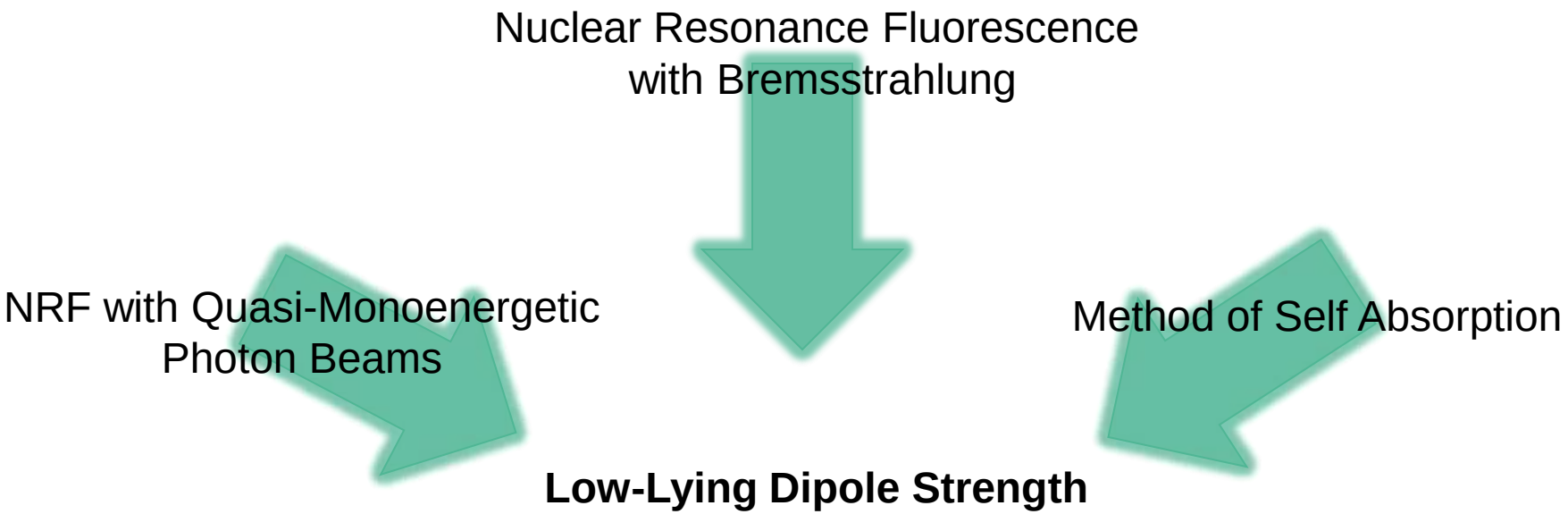
^{94}Mo @ HI©S – Mean Branching Ratio to GS





Evidence for Pygmy Dipole Resonance as structural feature?!

Outline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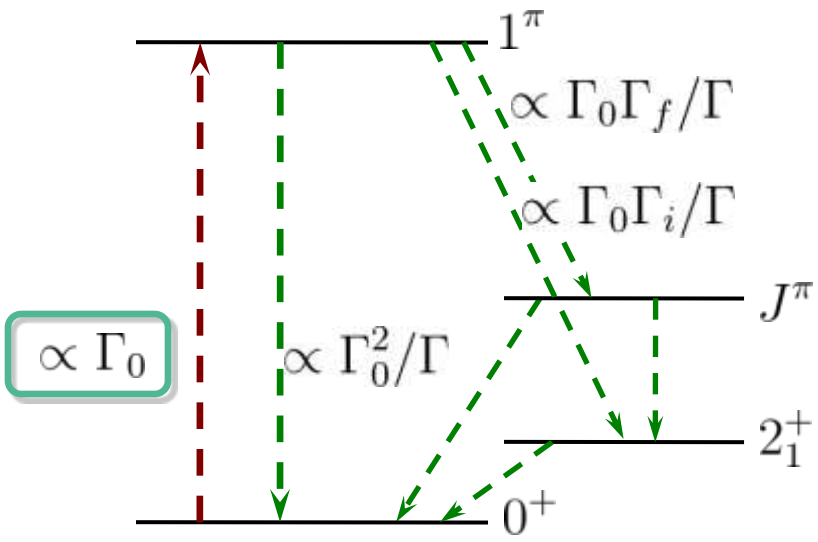
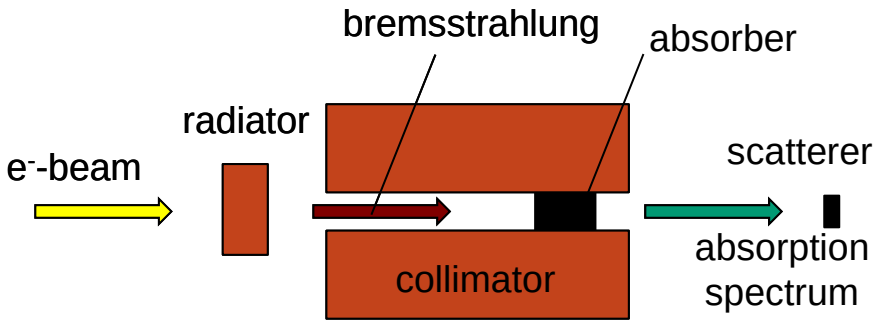
Investigation of Individual States



- NRF: sensitive to $\Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$
- several channels for decay process (but in most cases only ground-state transition observed)
- excitation process is unambigous and connected to absolute ground-state transition width Γ_0



Absorption Lines

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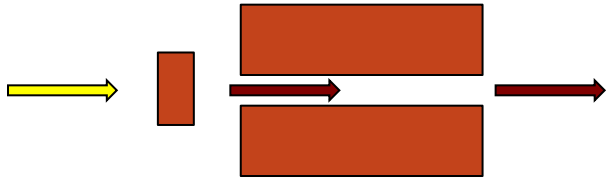
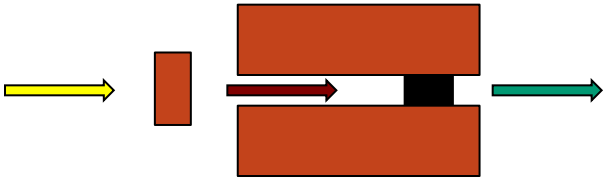
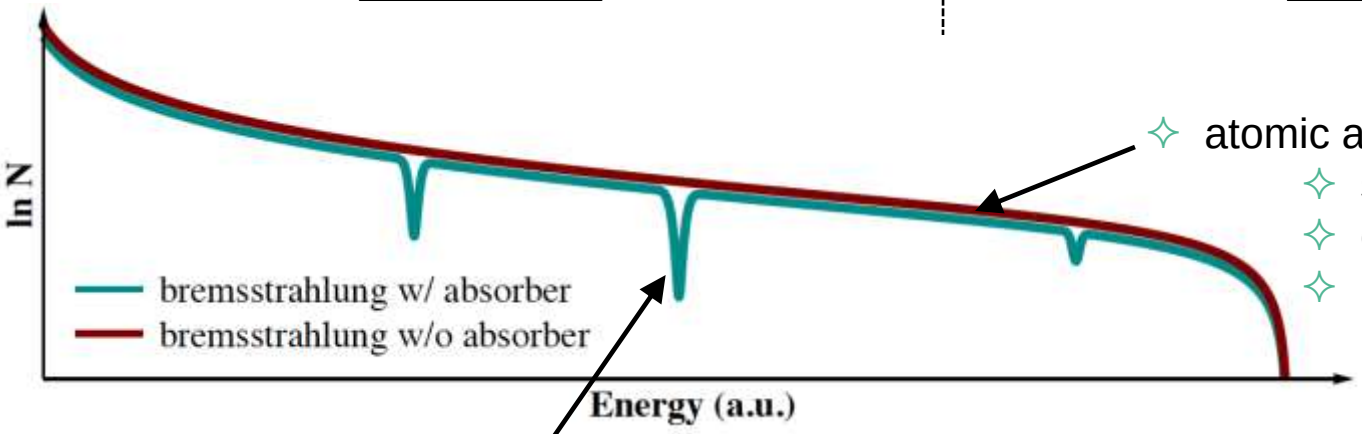
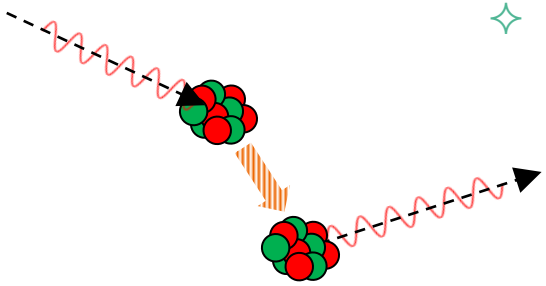
Absorption lines only a few eV wide!





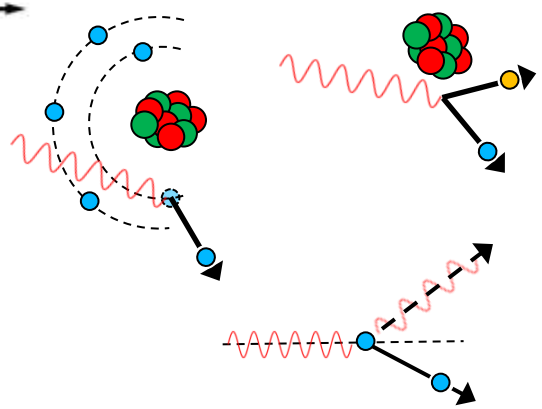


- atomic attenuation
  - several processes
  - contributes at each energy
  - independent of Γ_0



- resonant absorption
  - only at resonance energies
  - depends on Γ_0

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



Principle of Measurement and Self Absorption[1]

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

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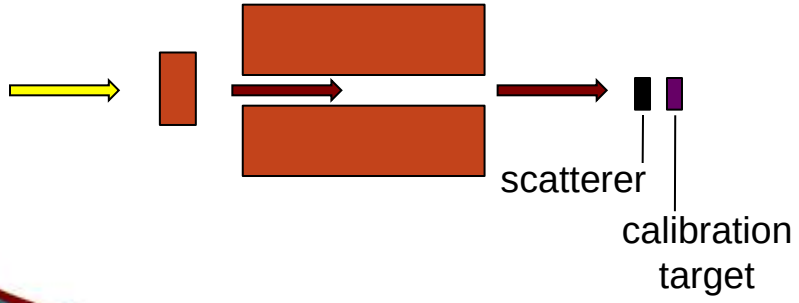
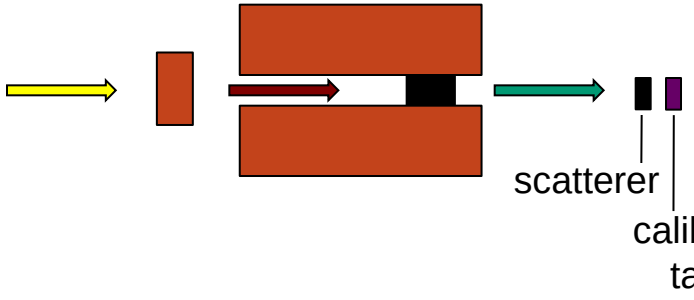
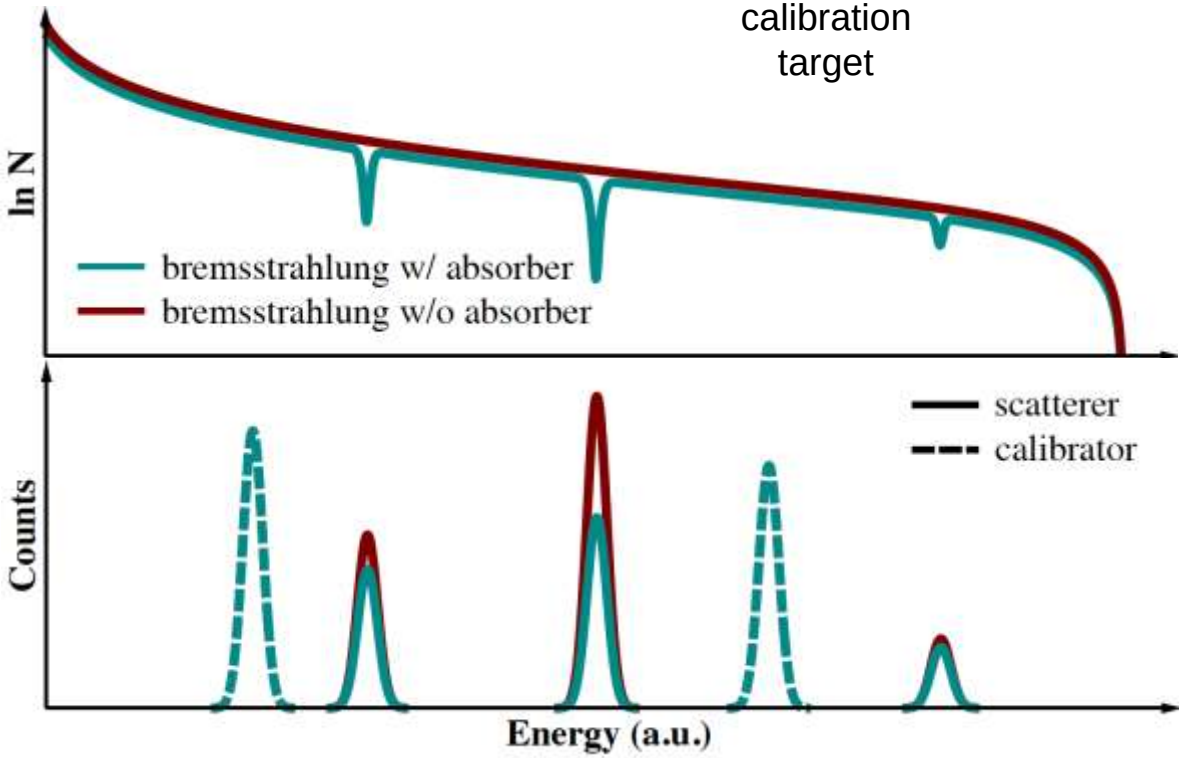
Use scatterer made of absorber material as „high-resolution detector“.







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

$$R(\Gamma_0) = \frac{N_{\mathrm{woA}} - f \cdot N_{\mathrm{wA}}}{N_{\mathrm{woA}}}$$

$$f = \frac{N^{\mathrm{std}}_{\mathrm{woA}}}{N^{\mathrm{std}}_{\mathrm{wA}}}$$

Determination of Ground-State Transition Width and Branching Ratio to the Ground State

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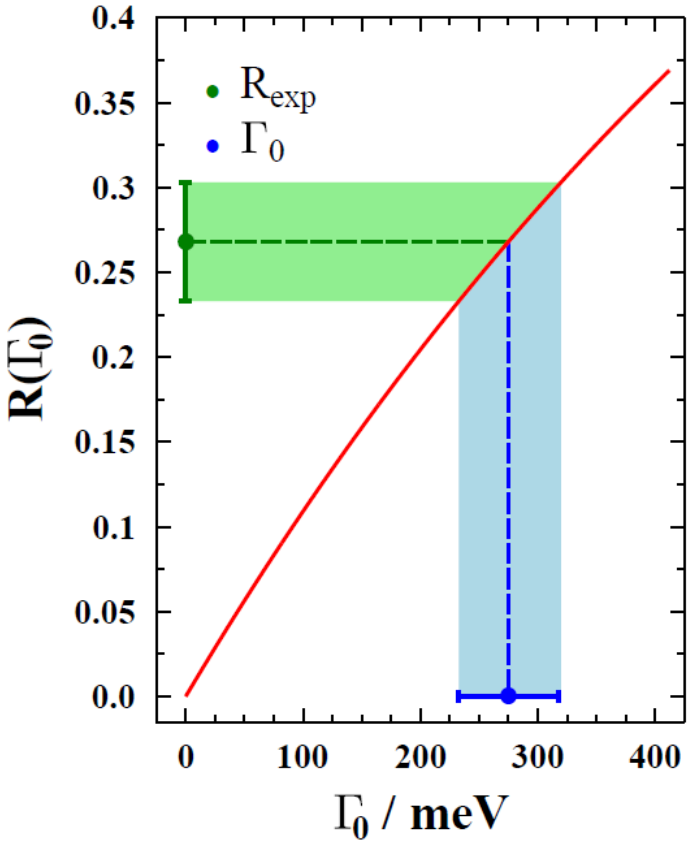
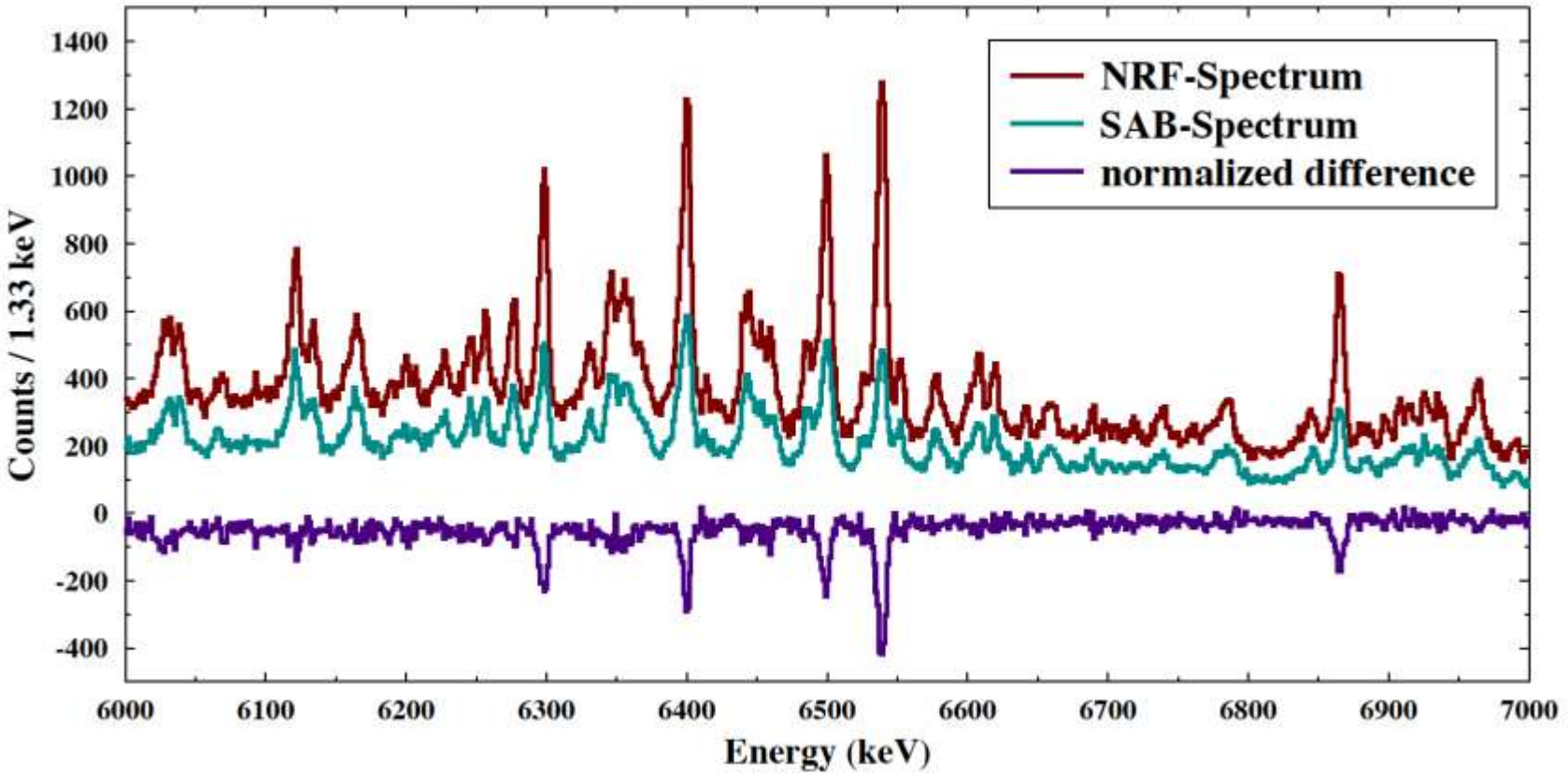
- calculate *R* as function of Γ_0
- self absorption R_{exp} determined experimentally
- comparison of experiment and calculation gives ground-state transition width Γ_0
- NRF-measurement gives $\Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$
- thus total transition width Γ and branching ratio Γ_0/Γ to ground state can be determined

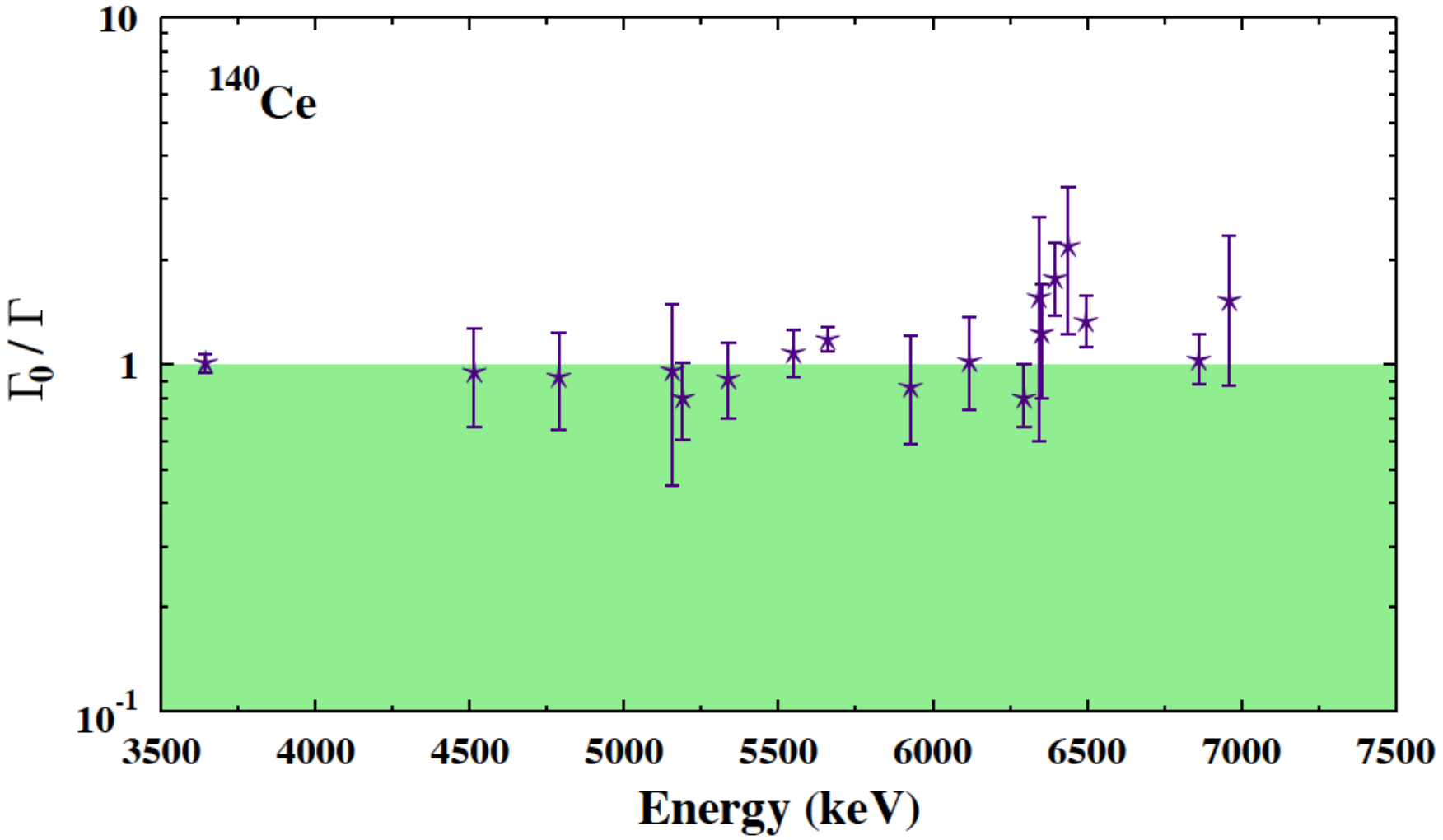


Measurement on ^{140}Ce

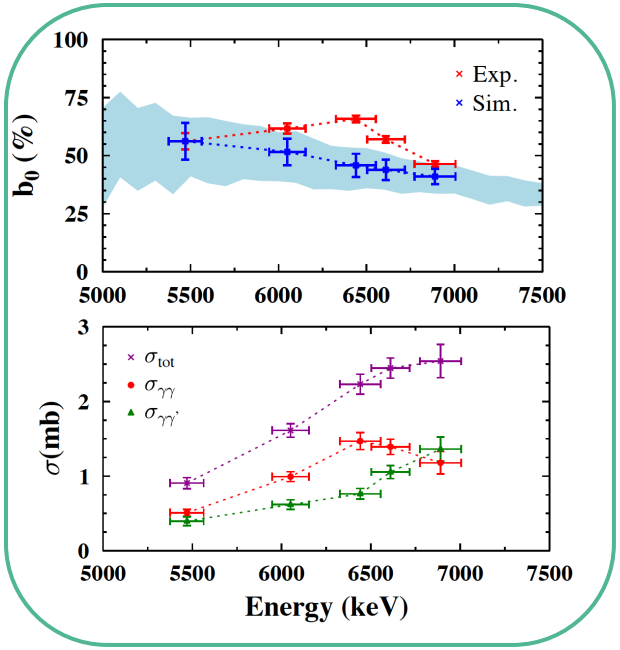
- scatterer: 2 g ^{140}Ce
- calibration target: 312 mg ^{11}B
- absorber: 60 g CeO_2 measurement
- endpoint energy: 8 MeV
- about 4 days for each measurement

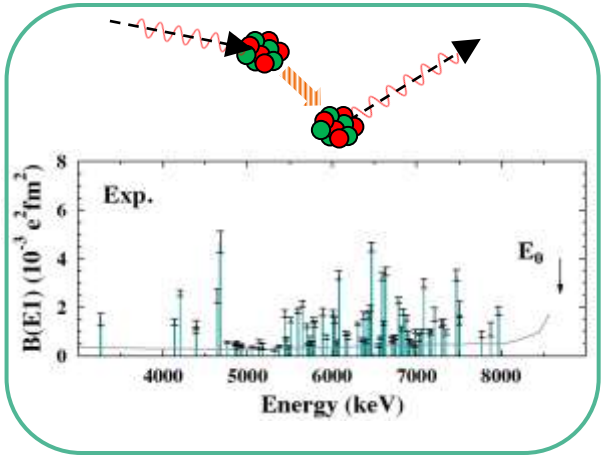


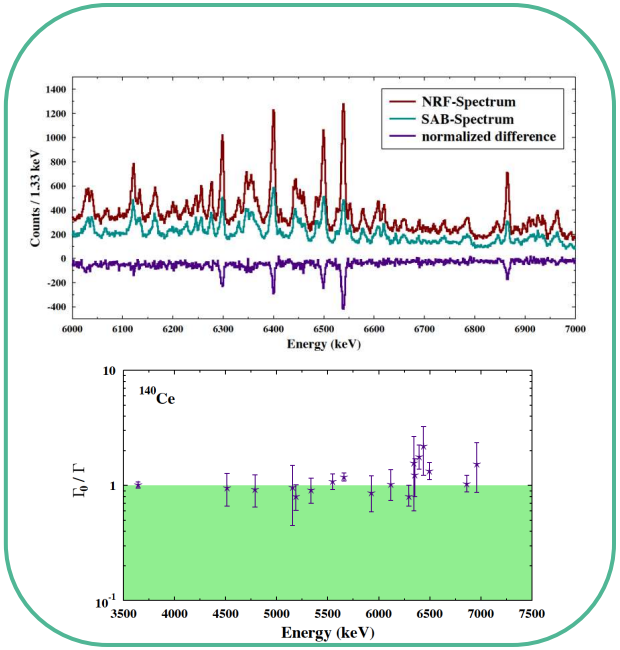
Results for ^{140}Ce



Conclusion







Low-Lying Dipole Strength

Thank you for your attention!

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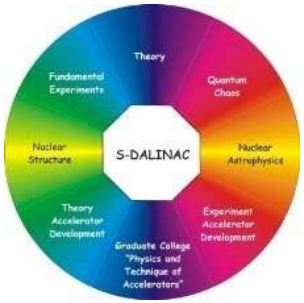

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LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz

^{60}Ni @ HI©S

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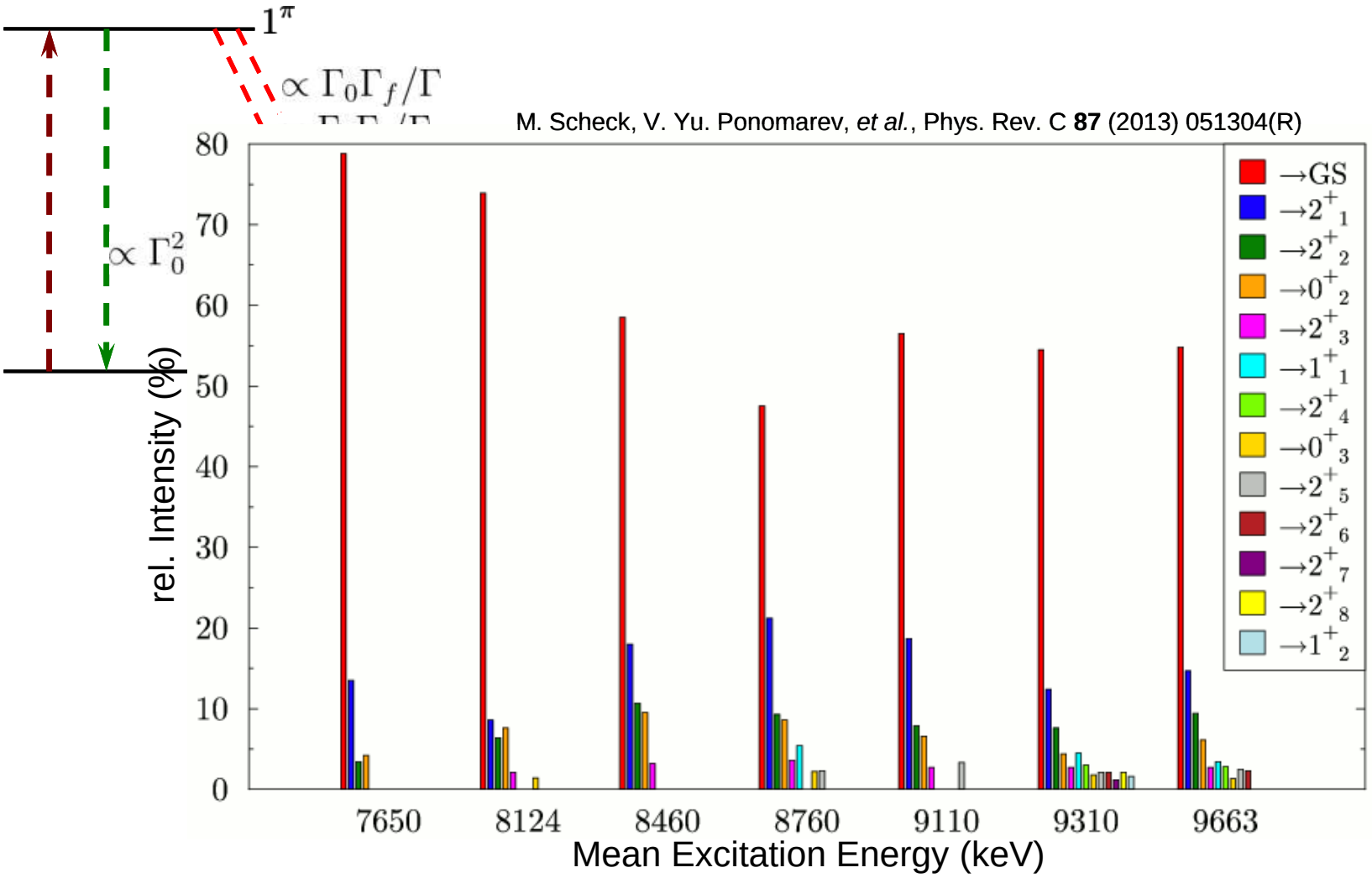

M. Scheck, V. Yu. Ponomarev, *et al.*, Phys. Rev. C **87** (2013) 051304(R)