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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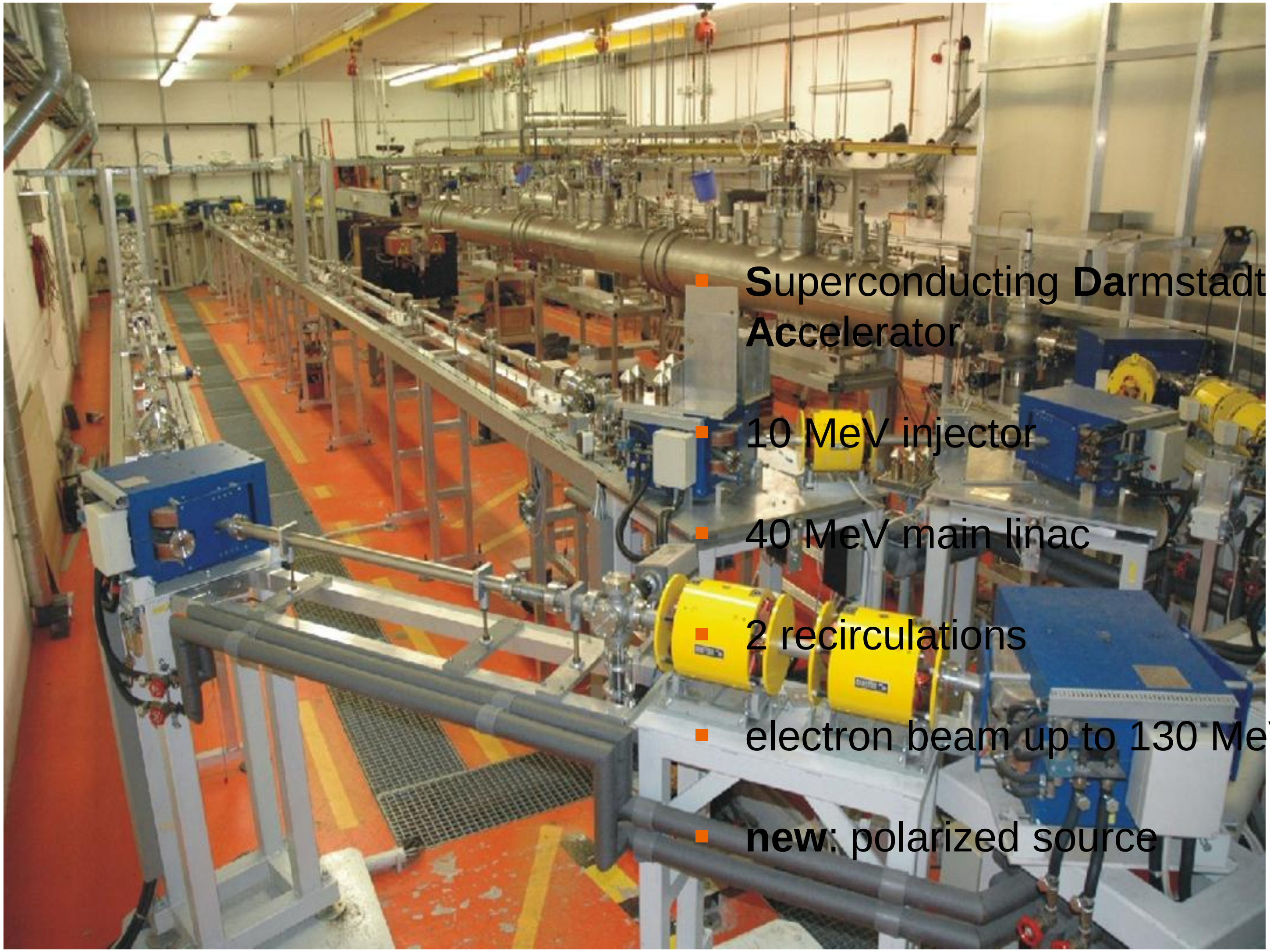
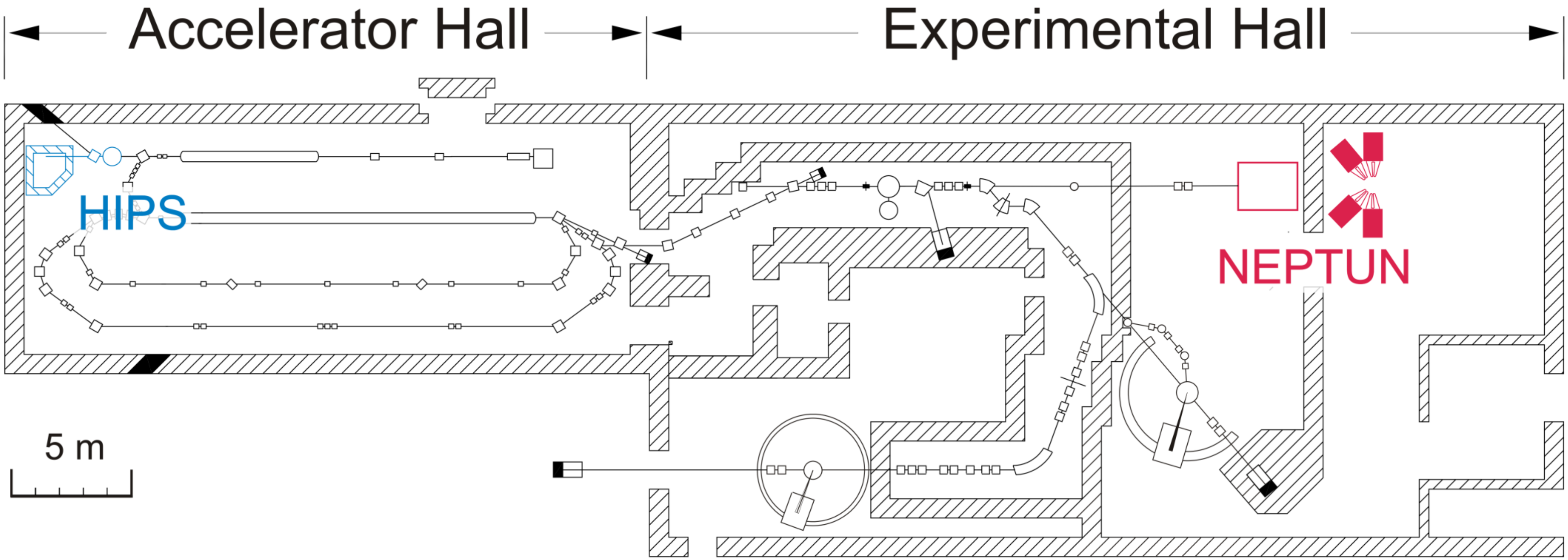
SFB 634

S-DALINAC



- **S**uperconducting **Da**rmstadt **Lin**ear **Ac**celerator
- 10 MeV injector
- 40 MeV main linac
- 2 recirculations
- electron beam up to 130 MeV
- **new**: polarized source

S-DALINAC



Outline

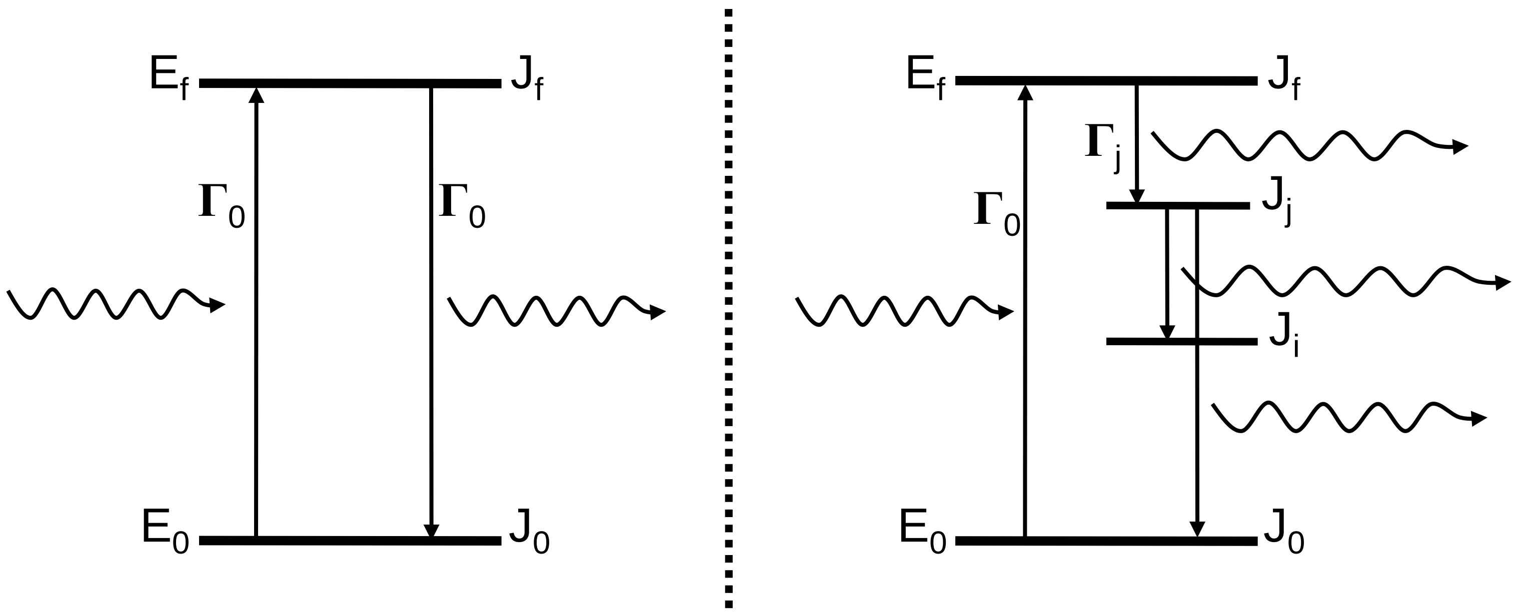
High Intensity
Photon Setup HIPS

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

Photon Tagger
NEPTUN

- functional principle
- application areas
- summary

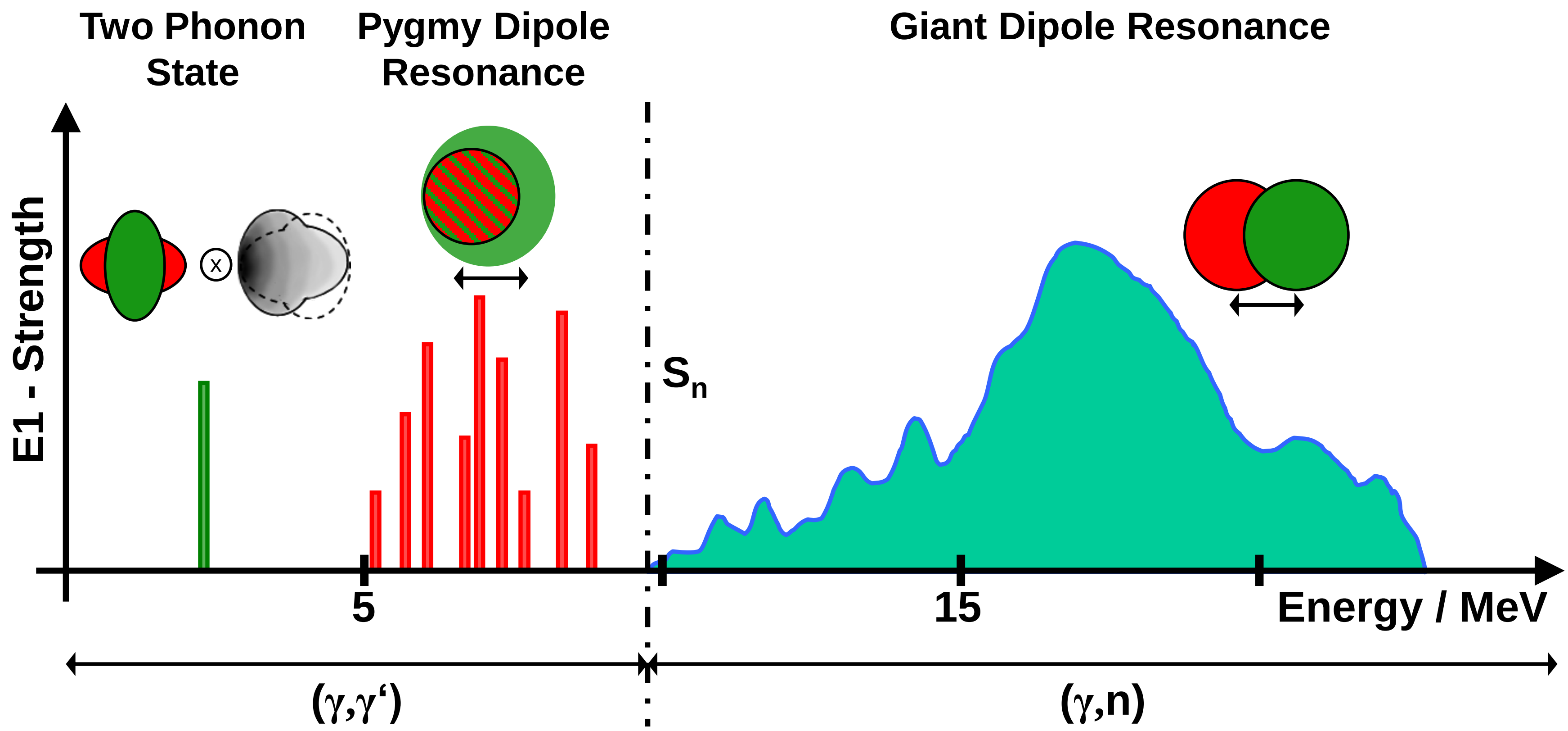
Principle of Nuclear Resonance Fluorescence[1]



- NRF (**n**uclear **r**esonance **f**luorescence[1]): high-energy photons as probes
- low angular momentum transfer → only dipole und quadrupole transitions
- excitation is strength selective → spectroscopy despite high level density

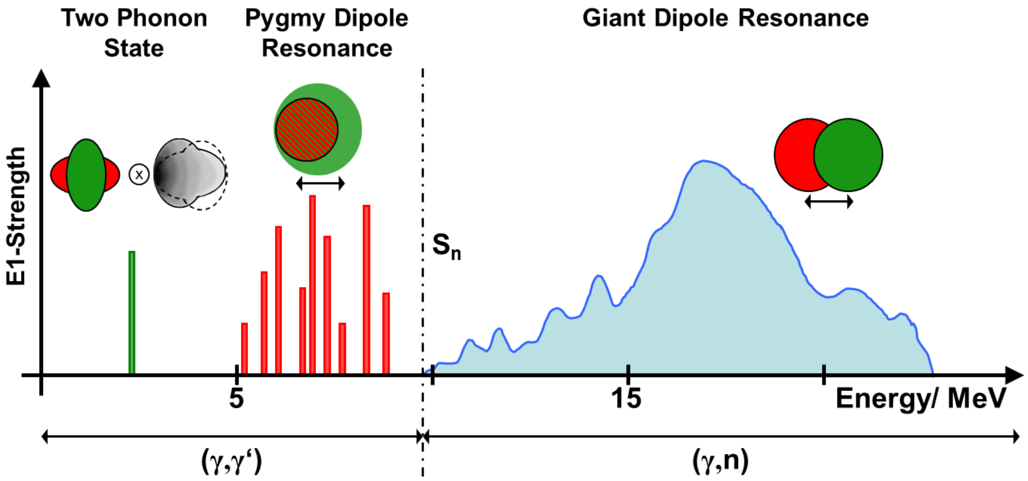
1 U. Kneissl, H.H. Pitz, A. Zilges, Prog. Part. Nucl. Phys. **37** (1996) 349

Motivation



Two Phonon State
Pygmy Dipole Resonance
Giant Dipole Resonance
E1 - Strength
x
S_n
5
15
Energy / MeV
(γ,γ‘)
(γ,n)

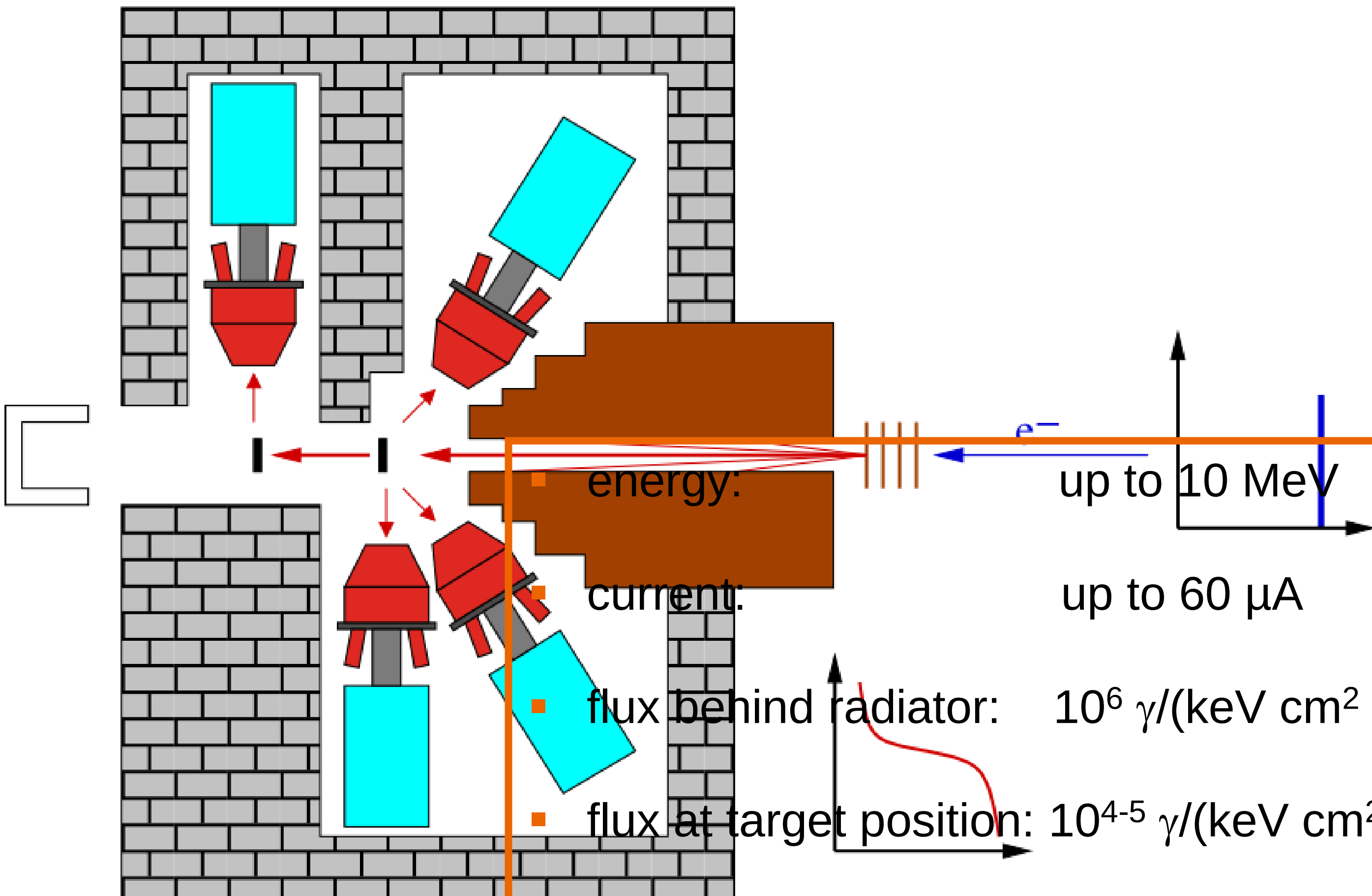
Motivation



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

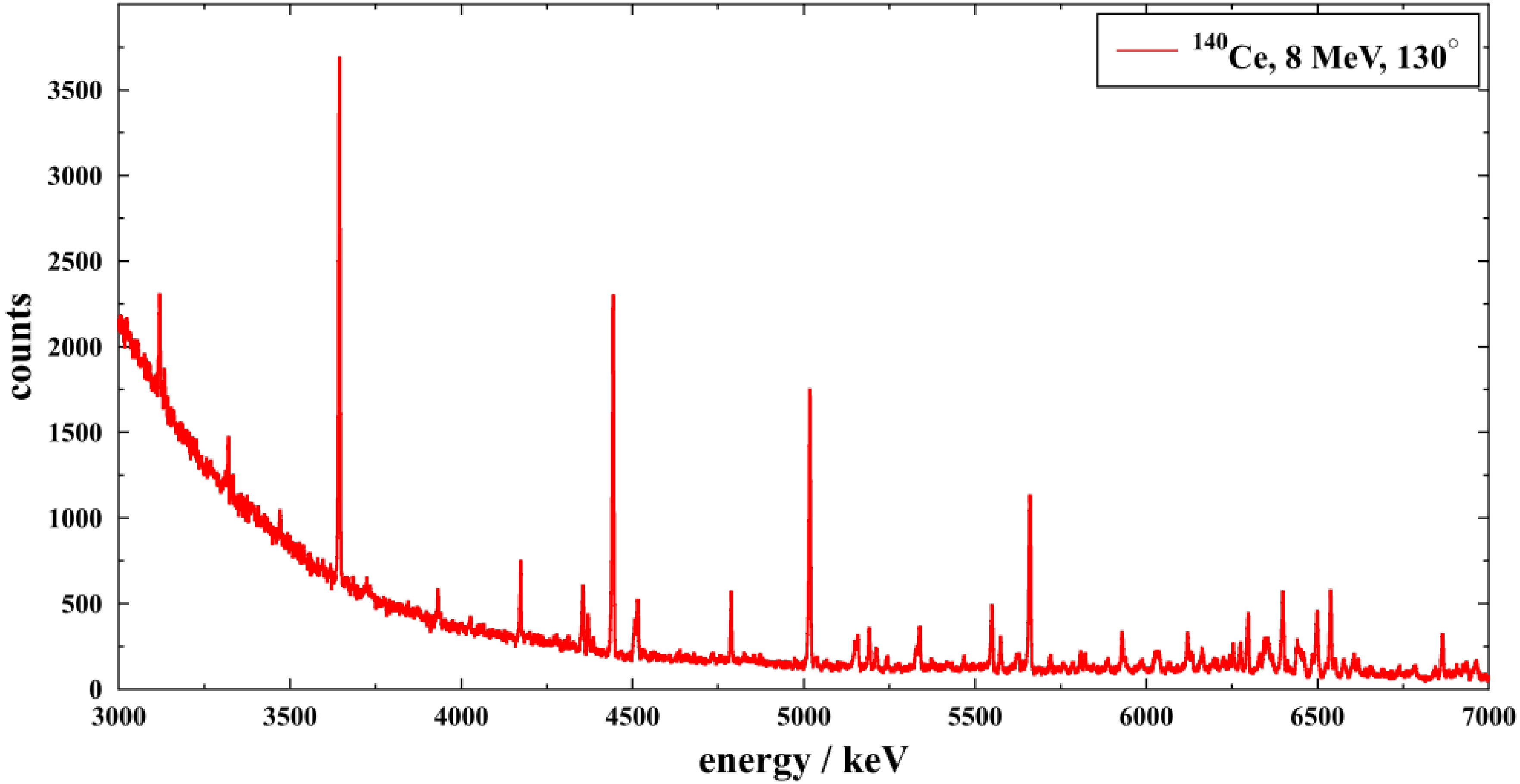
NRF measurements

High Intensity Photon Setup HIPS



- energy: up to 10 MeV
- current: up to 60 µA
- flux behind radiator: 10^{6} γ/(keV cm² s)
- flux at target position: 10^{4-5} γ/(keV cm² s)

^{140}Ce @ 8 MeV – A Typical NRF Spectrum



Determination of Observables

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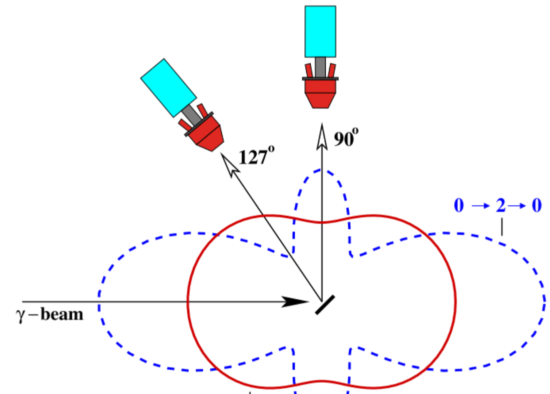
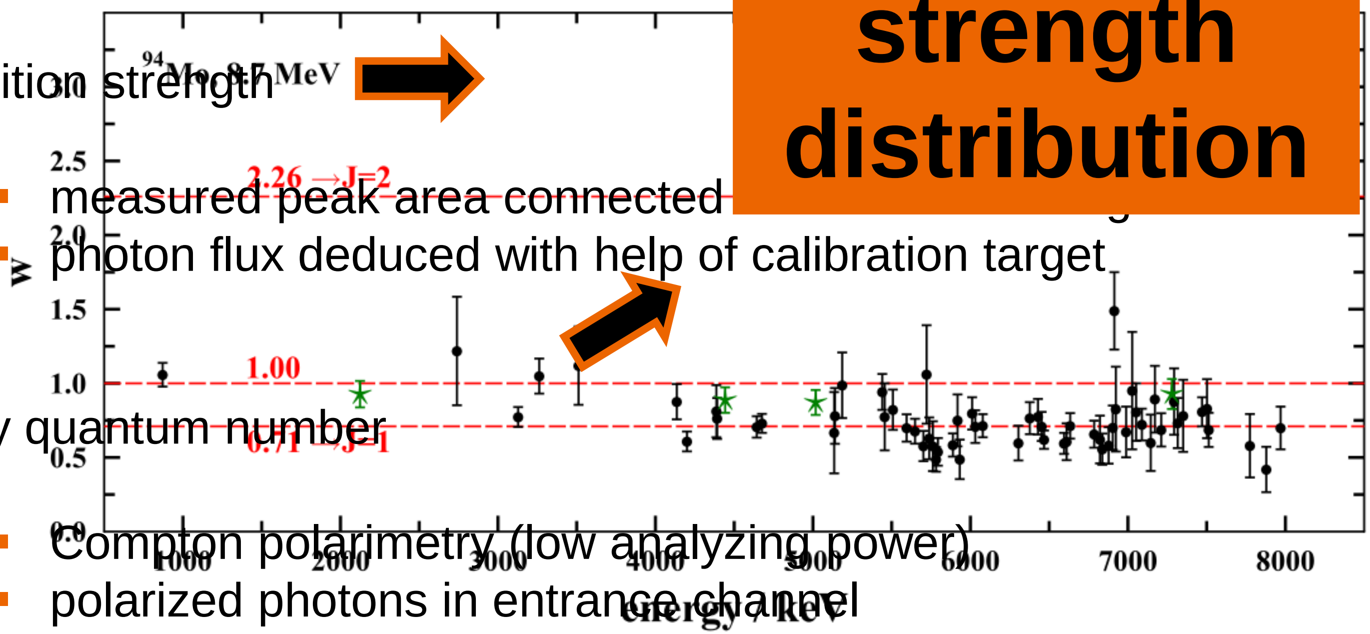
- spin quantum number
  - angular distributions are different for 0→1→0 and 0→2→0 sequence
  - intensity ratio *w* for two angles determines spin



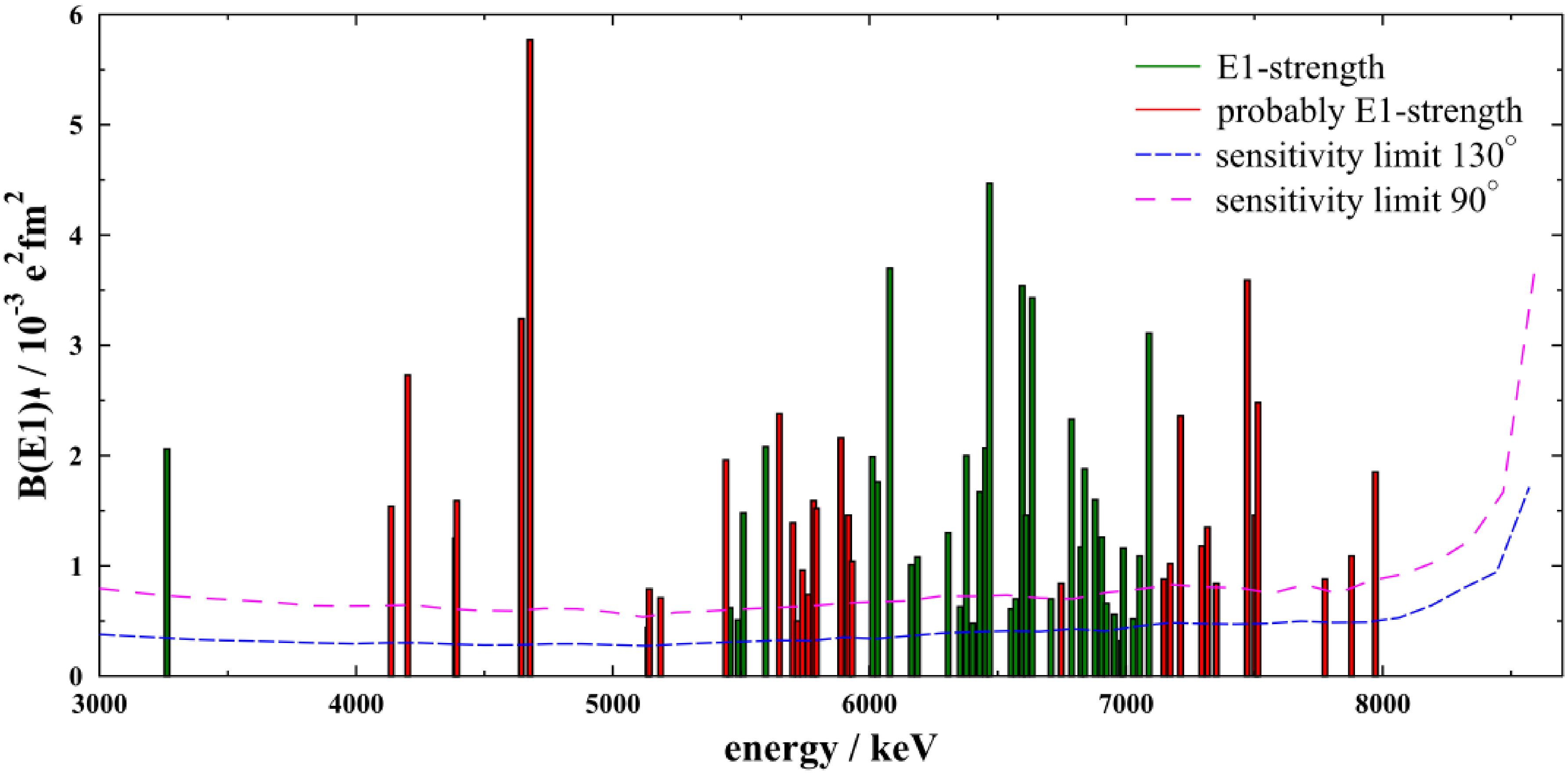
strength distribution

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

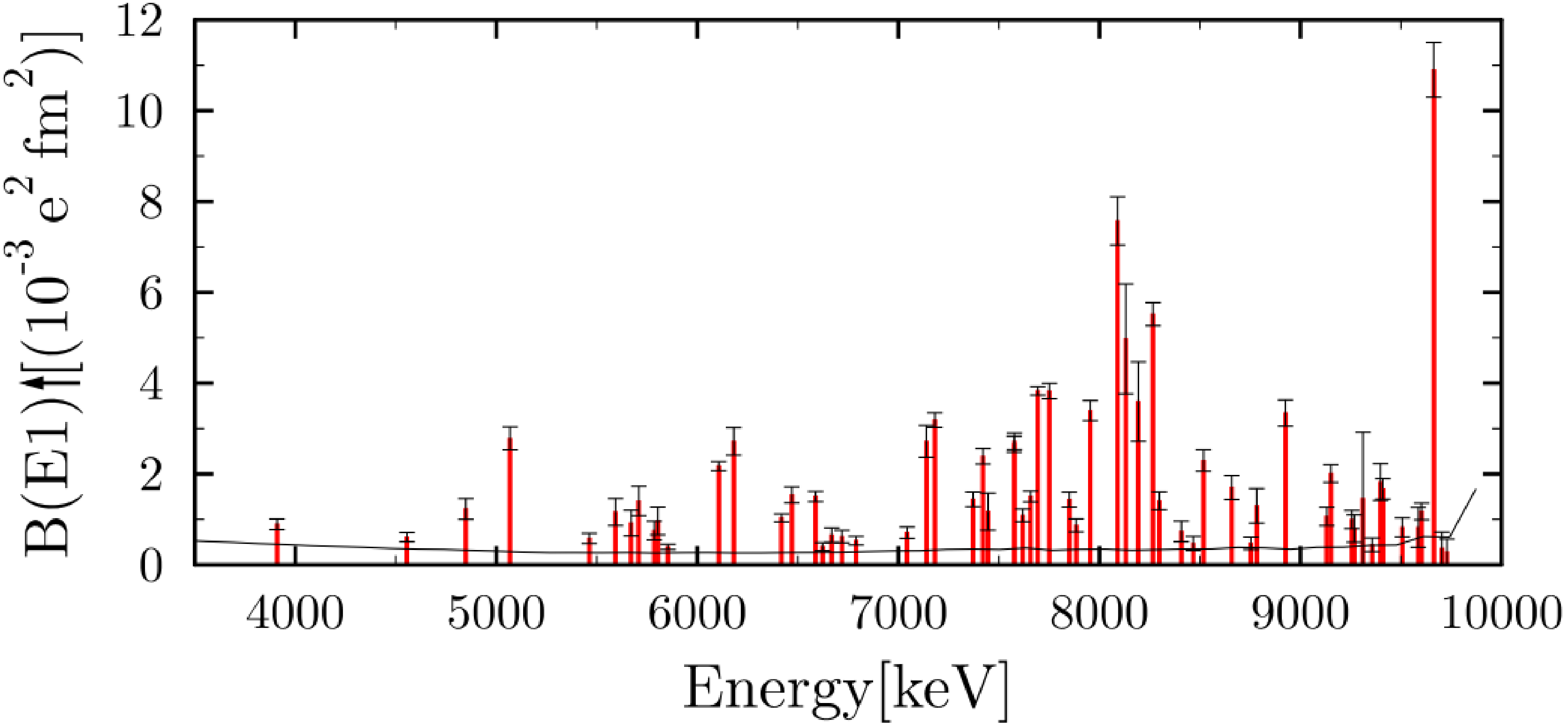


- parity quantum number
  - Compton polarimetry (low analyzing power)
  - polarized photons in entrance channel

^{94}Mo at 8.7 MeV

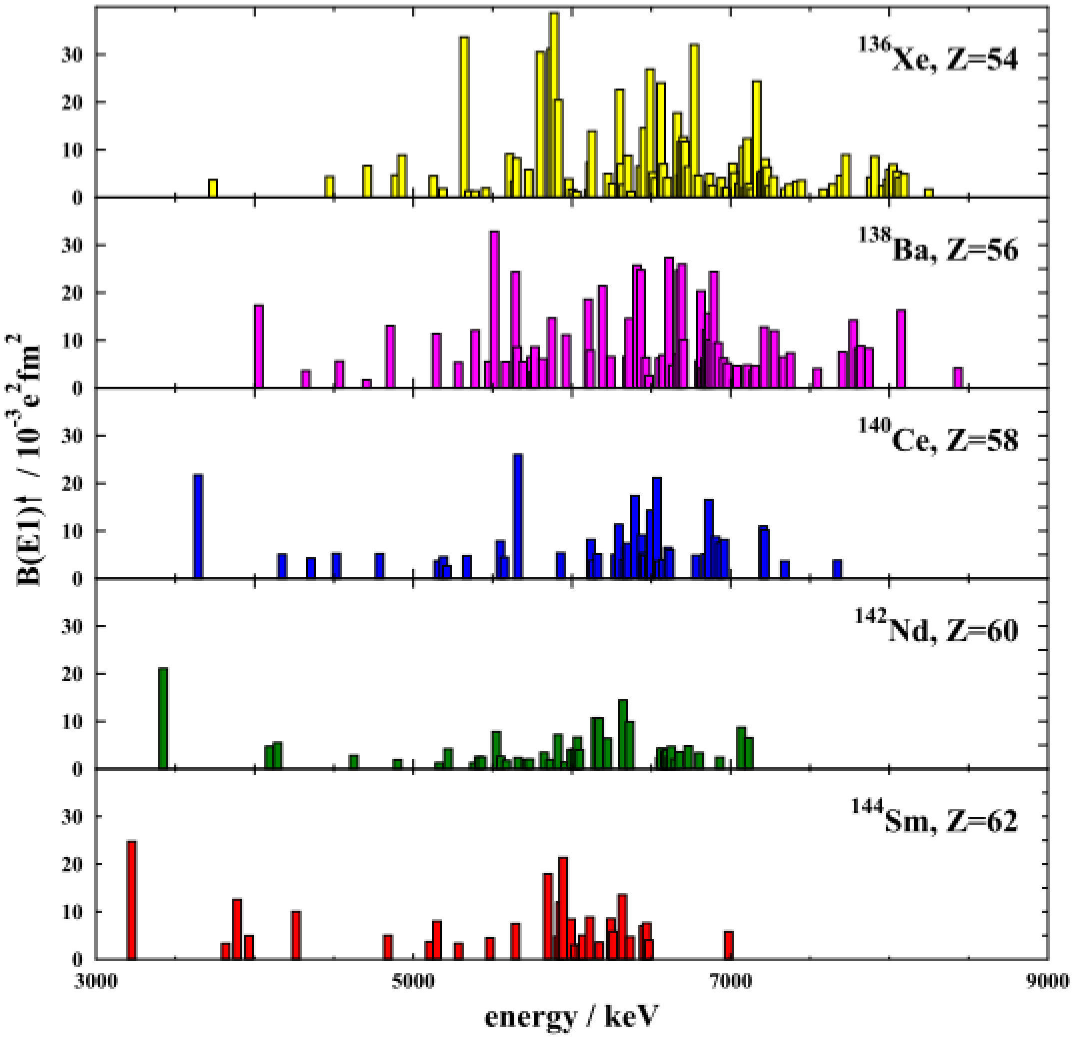


^{60}Ni at 9.9 MeV[1]



1 picture provided by Matthias Fritzsche

N = 82 Isotones



S. Volz et al, Nucl. Phys. **779 A** (2006) 1

D. Savran et al, Phys. Rev. Lett. **100** (2008) 232501

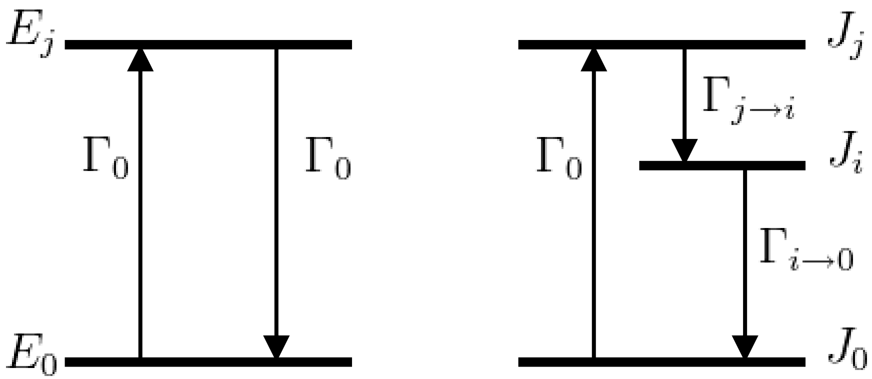
An Assumption

- NRF-experiments: $I \propto \Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$
- 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?**

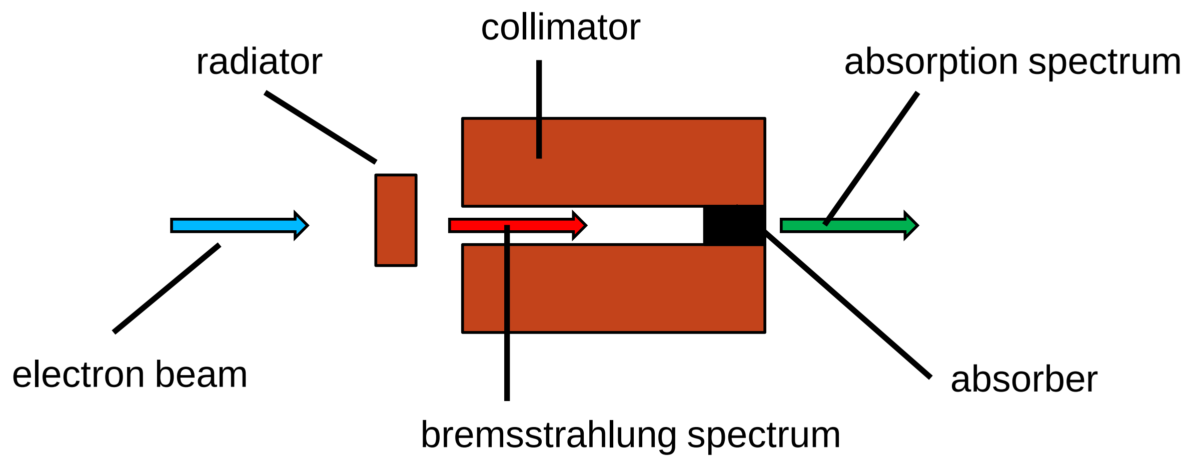
➢ **determine ground state transition width Γ_0 absolutly** (and therefore the branching ratio to the ground state)

NRF principle

- excitation and decay scheme:

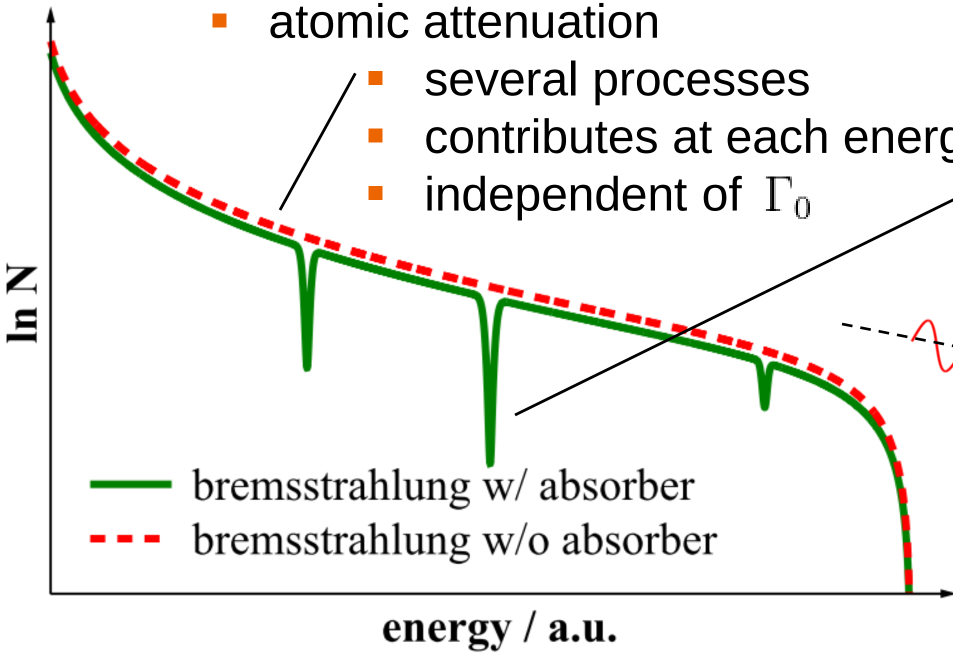


- several decay channels
- excitation process unambiguous
- ➢ analyse absorption spectrum



Interaction with Absorber

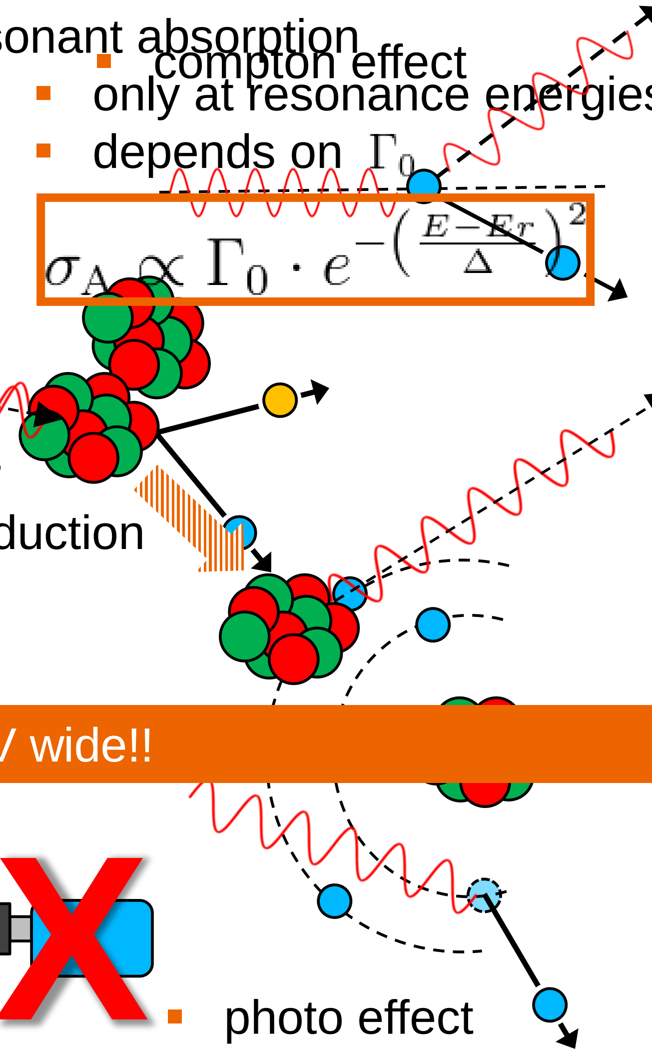
- atomic attenuation
  - several processes
  - contributes at each energy
  - independent of Γ_0



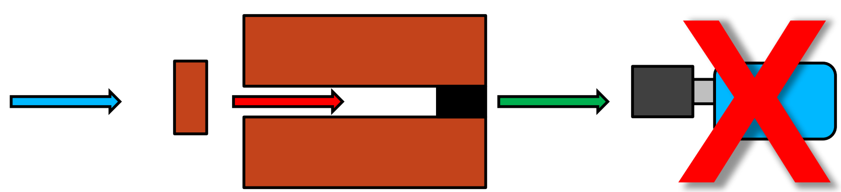
- resonant absorption
  - only at resonance energies
  - depends on Γ_0

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

- compton effect
- pair production
- photo effect



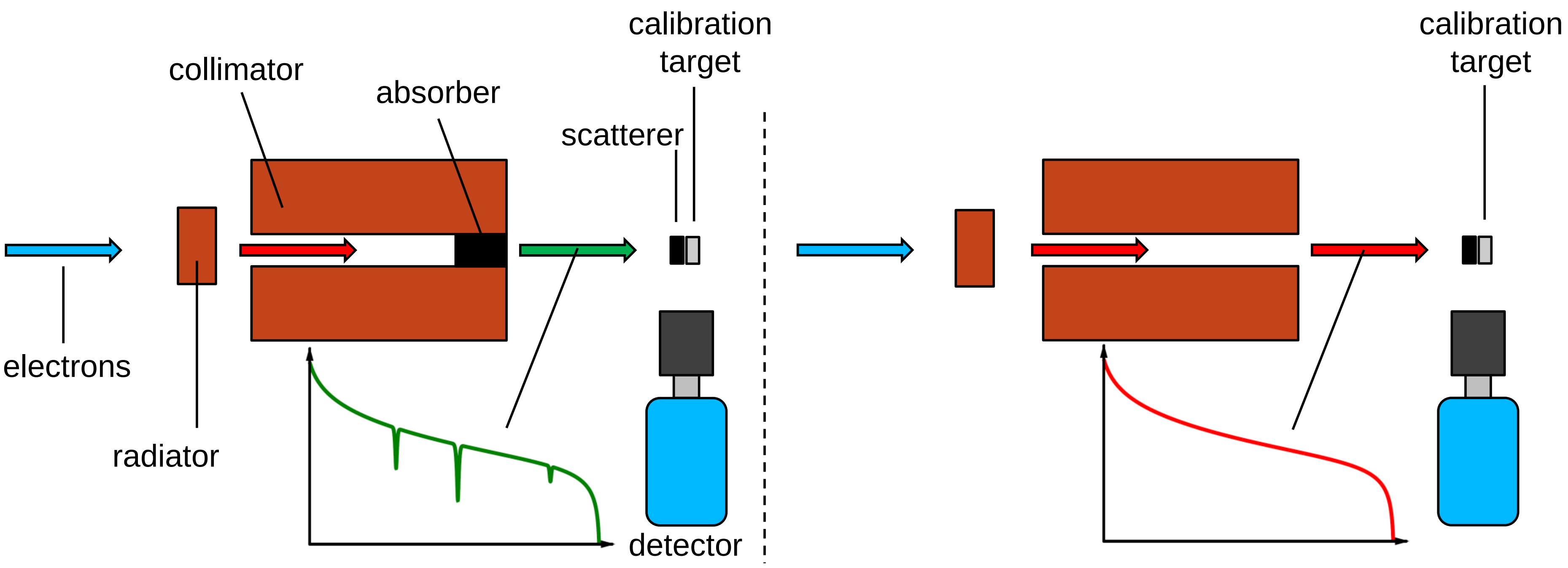
absorption lines only a few eV wide!!



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“

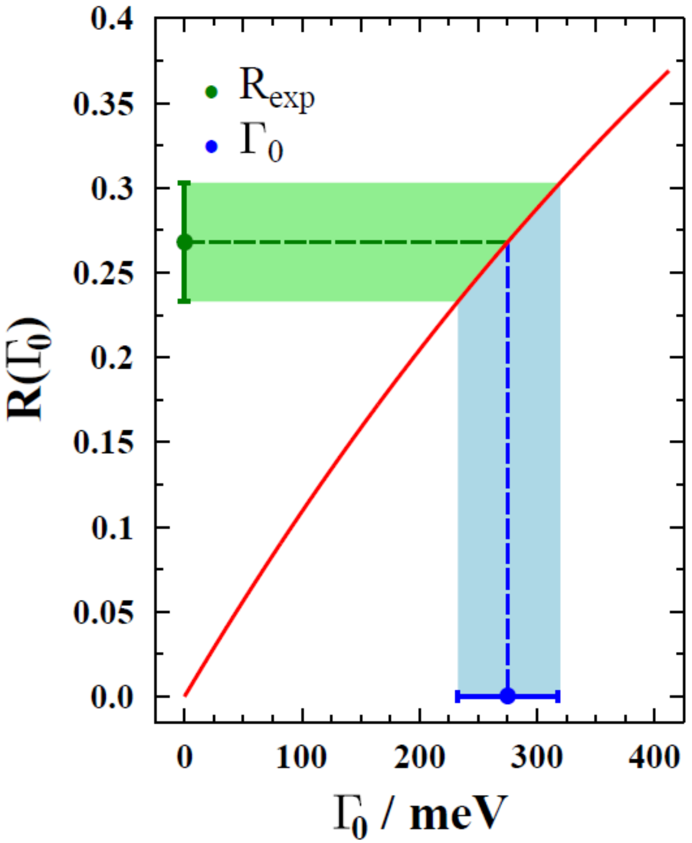


- self absorption: decrease of decays in scatterer because of resonant absorption

$$R(\Gamma_0) = \frac{\boxed{N_{\mathrm{woA}}} - \boxed{f} \cdot \boxed{N_{\mathrm{wA}}}}{\boxed{N_{\mathrm{woA}}}} = 1 - \frac{f \cdot N_{\mathrm{wA}}}{N_{\mathrm{woA}}} \qquad \boxed{f = \frac{N^{\mathrm{std}}_{\mathrm{woA}}}{N^{\mathrm{std}}_{\mathrm{wA}}}}$$

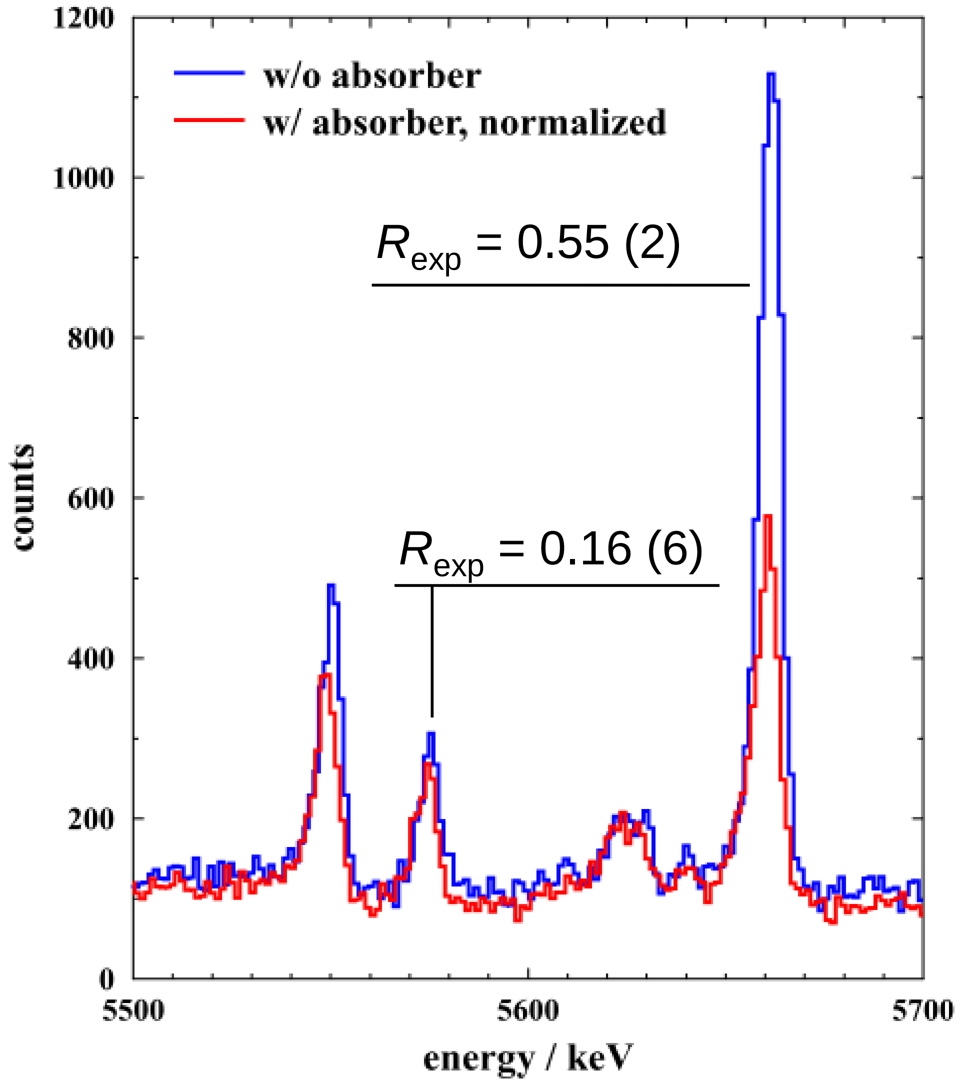
Determination of the Groundstate Transition Width

- calculate *R* as function of Γ_0
- self absorption R_{exp} determined experimentally
- comparison of experiment and calculation gives groundstate transition width Γ_0
- NRF-measurement also 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

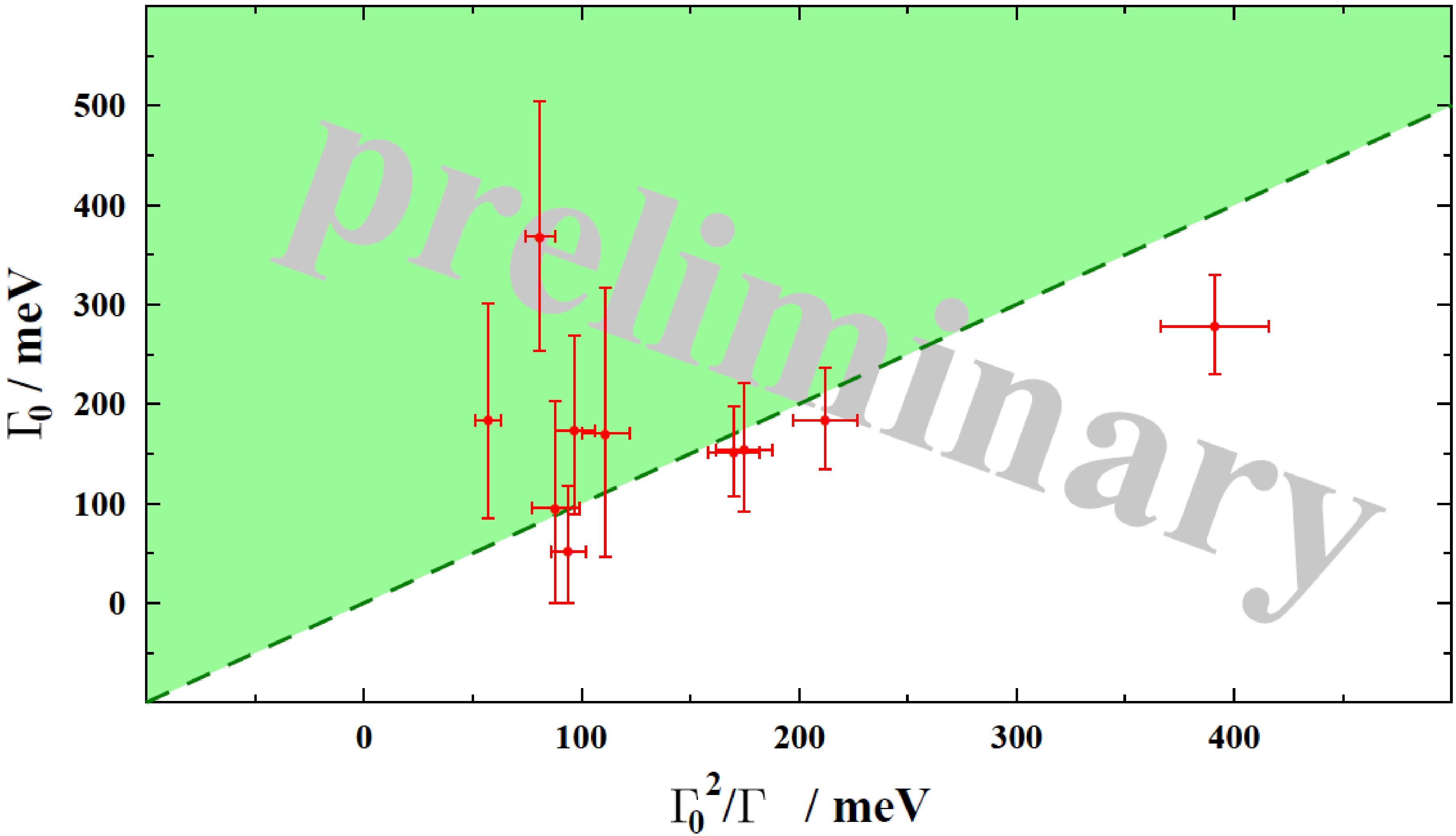


Measurement on ^{140}Ce

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

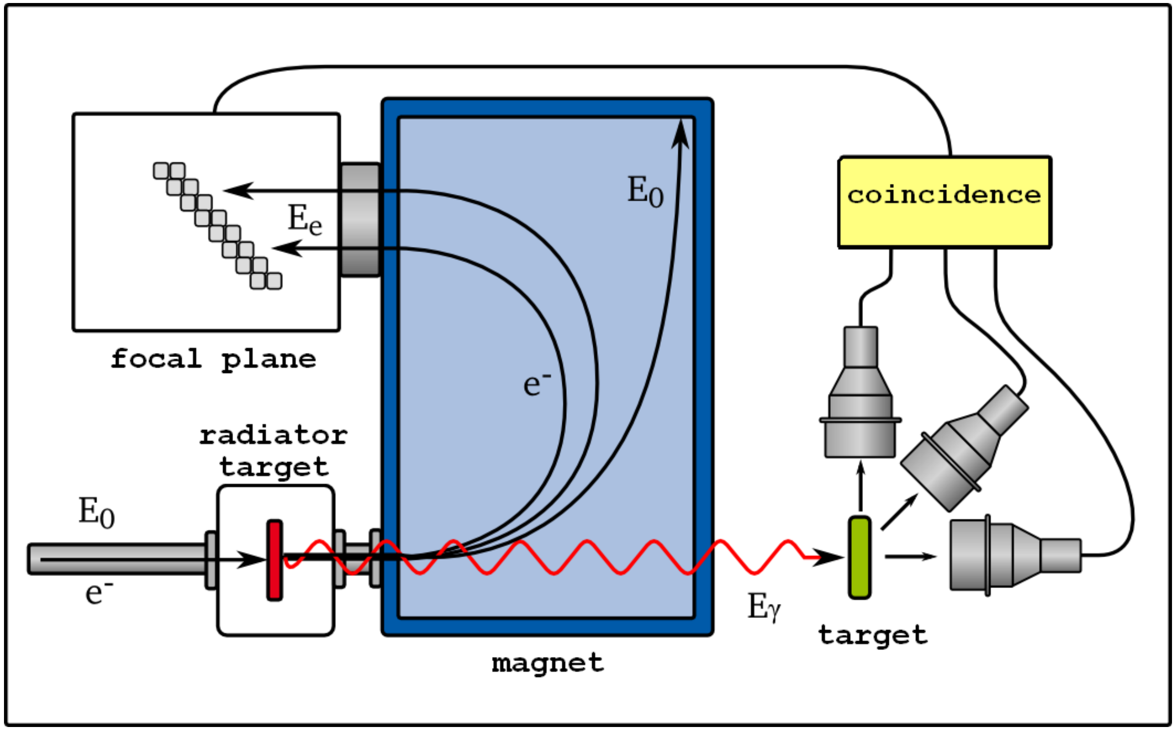


Groundstate Transition Widths



Principle of Photon Tagging

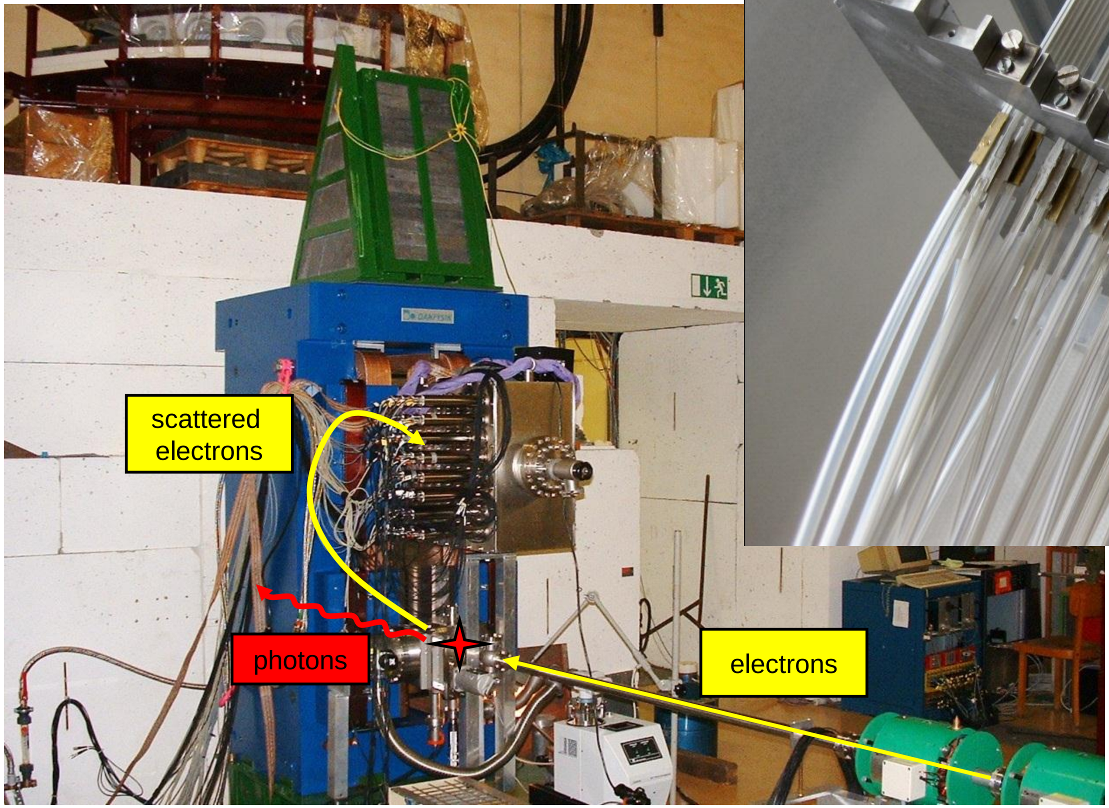
- photons are produced by electrons emitting bremsstrahlung
- idea: determine energy of electron to deduce photon energy
- thin radiator: only one interaction + conservation of energy: $E_\gamma = E_0 - E_e$

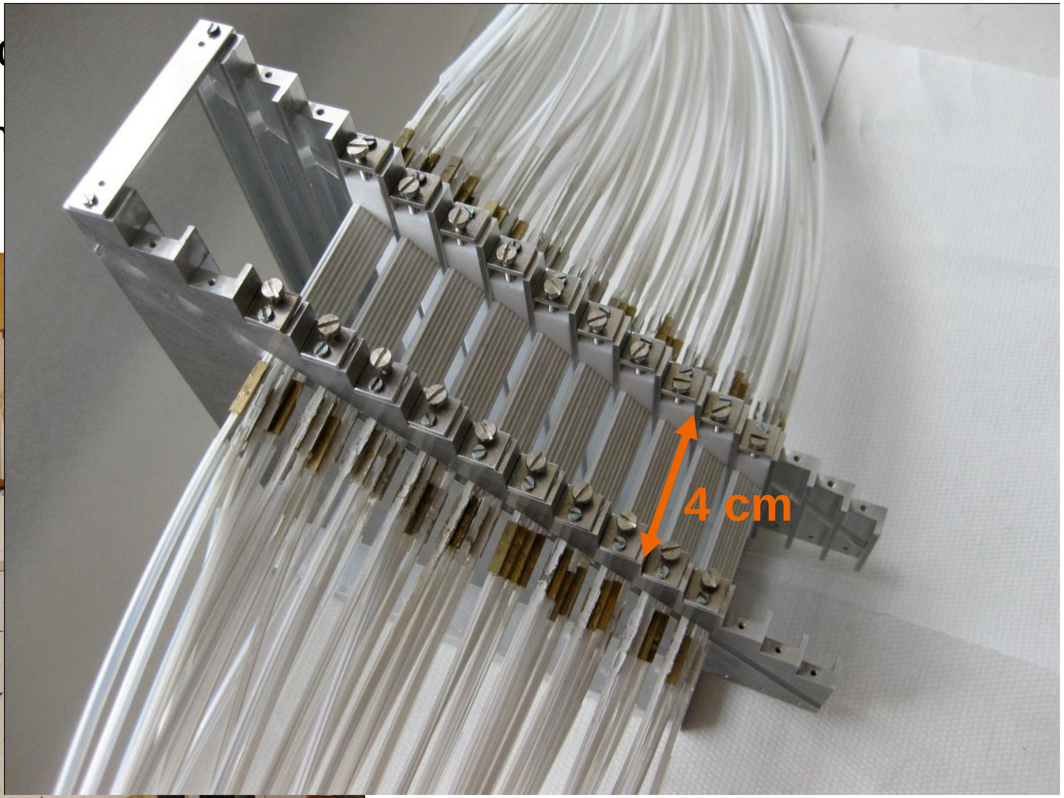


D. Savran et al., Nucl. Instr. and Meth. in Phys. Res. A **613** (2010) 232

NEPTUN Facility

- monoenergetic electrons provided
- radiator target: 10 µm Au, only or



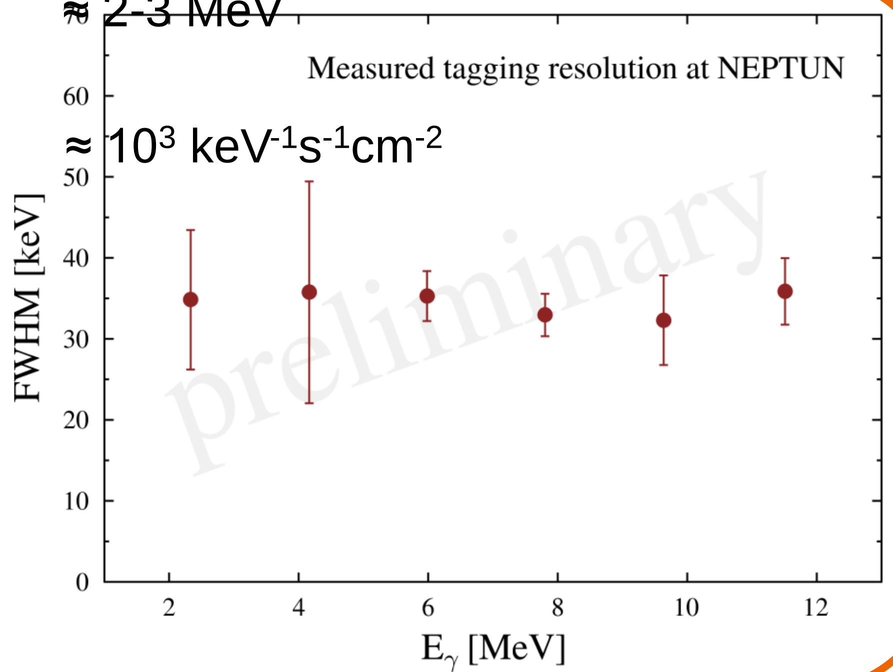


- clam-shell magnet
- focal plane (128 scintillating fibers attached to PMs)

NEPTUN Facility - Specifications

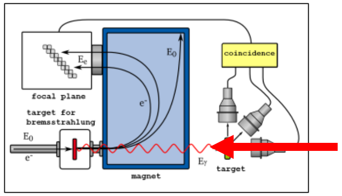
- energy range: 2 MeV ≤ E_γ ≤ 20 MeV
- energy resolution: ΔE = 25 keV @ 10 MeV
- energy window: ≈ 2-3 MeV
- photon intensity: ≈ 10^3 keV^{-1}s^{-1}cm^{-2}

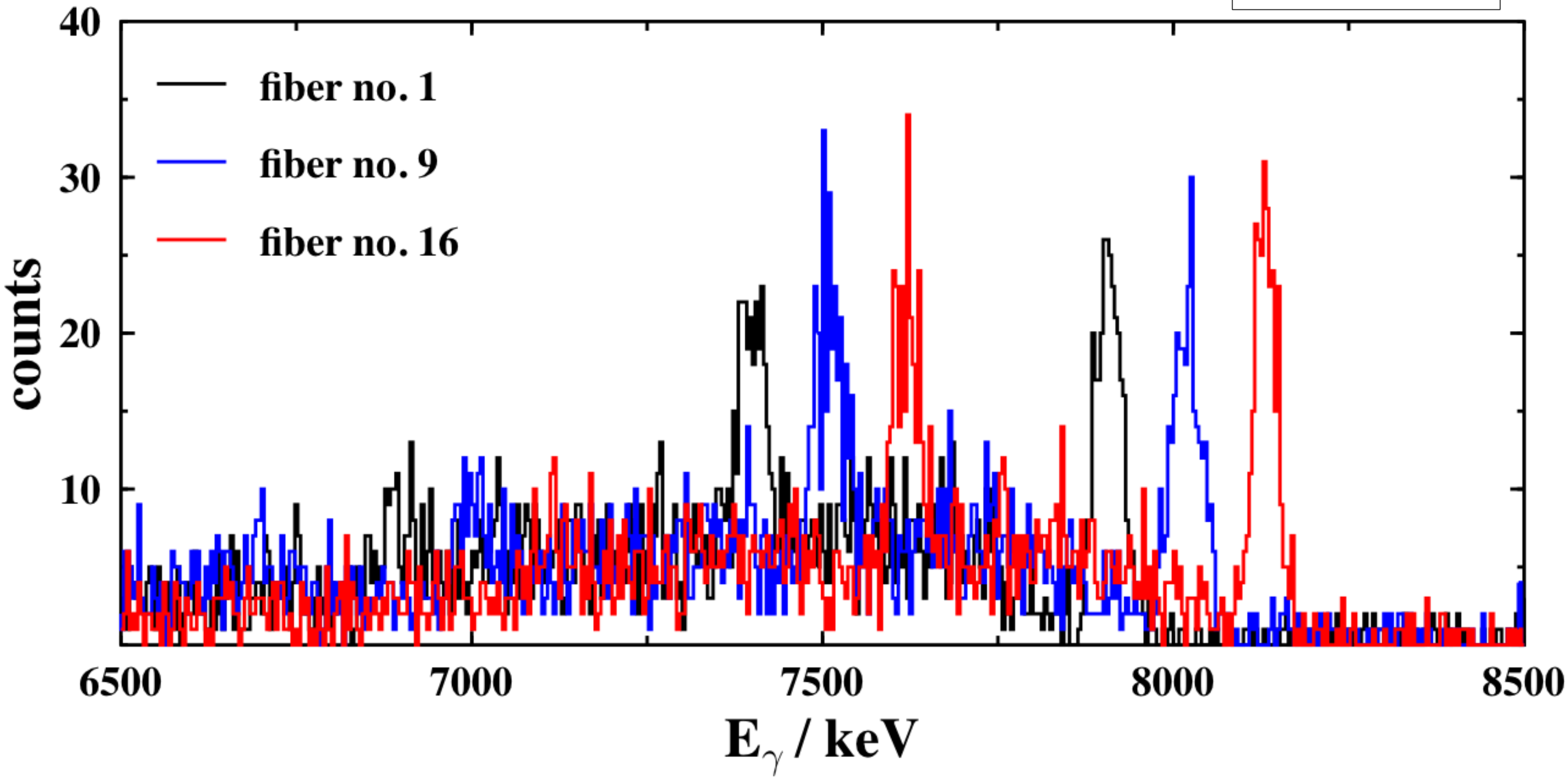
- primary beam: E_0 = 28 MeV
- dominated by energy spread of the accelerator
- improvements are in progress



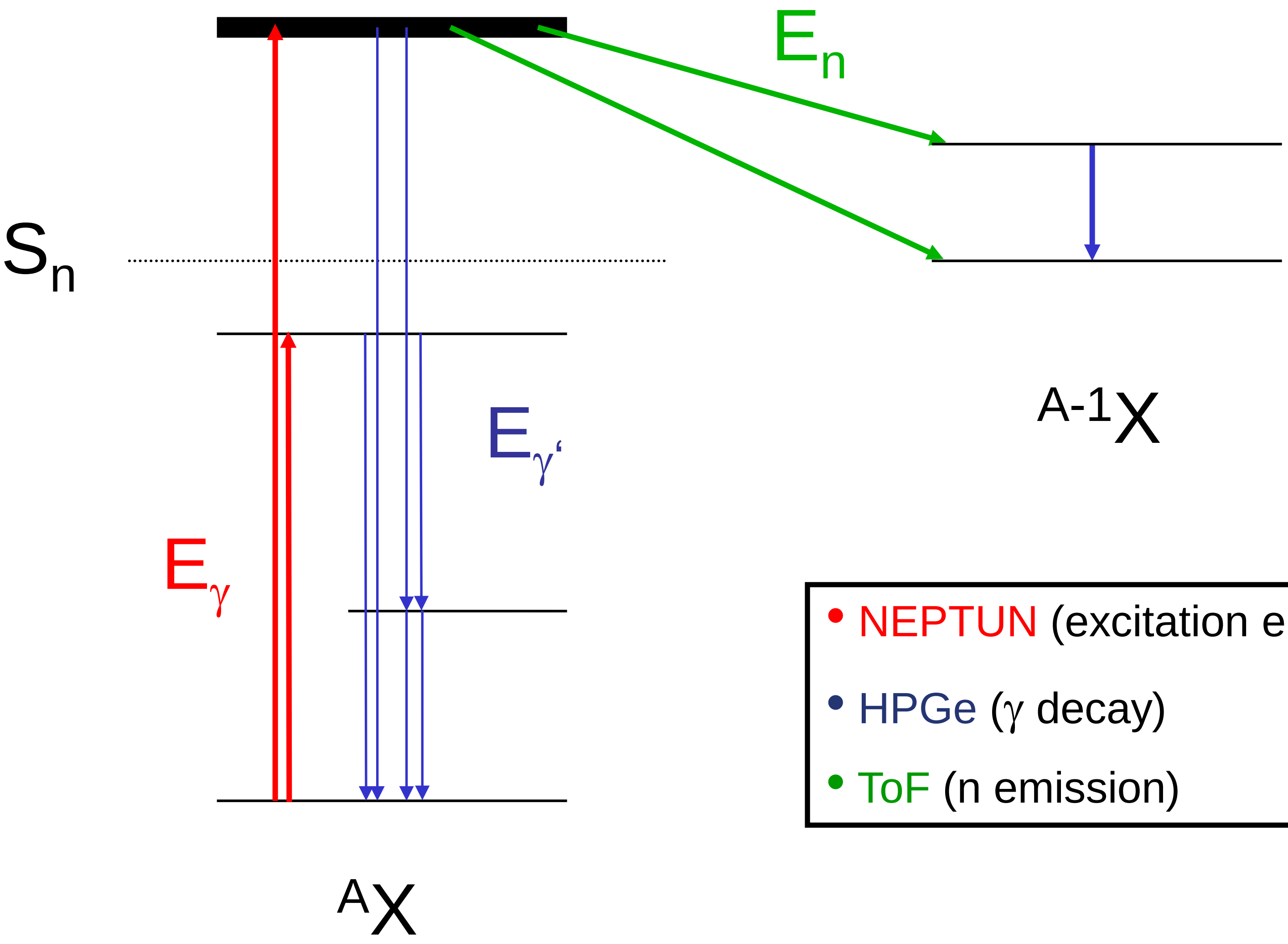
Tagged Beam Profile

- Measured using a HPGe detector





Experiments @ NEPTUN



- NEPTUN (excitation energy)
- HPGe (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
  - (γ,γ) reactions below and above threshold
  - (γ,n) reactions

Thank You…

Thank You for your attention!

Many thanks to…

**M. Fritzsche, J. Glorius, J. Isaak, B. Löher,
N. Pietralla, D. Savran, L. Schnorrenberger,
K. Sonnabend, C. Wälzlein, and M. Zweidinger**

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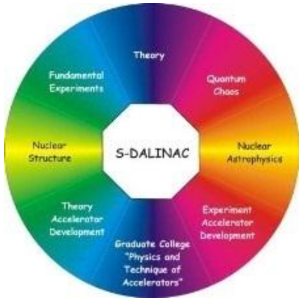

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

HIC for FAIR
Helmholtz International Center

LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz