Reaction studies for the astrophysical γ-process using in beam γ-ray spectroscopy

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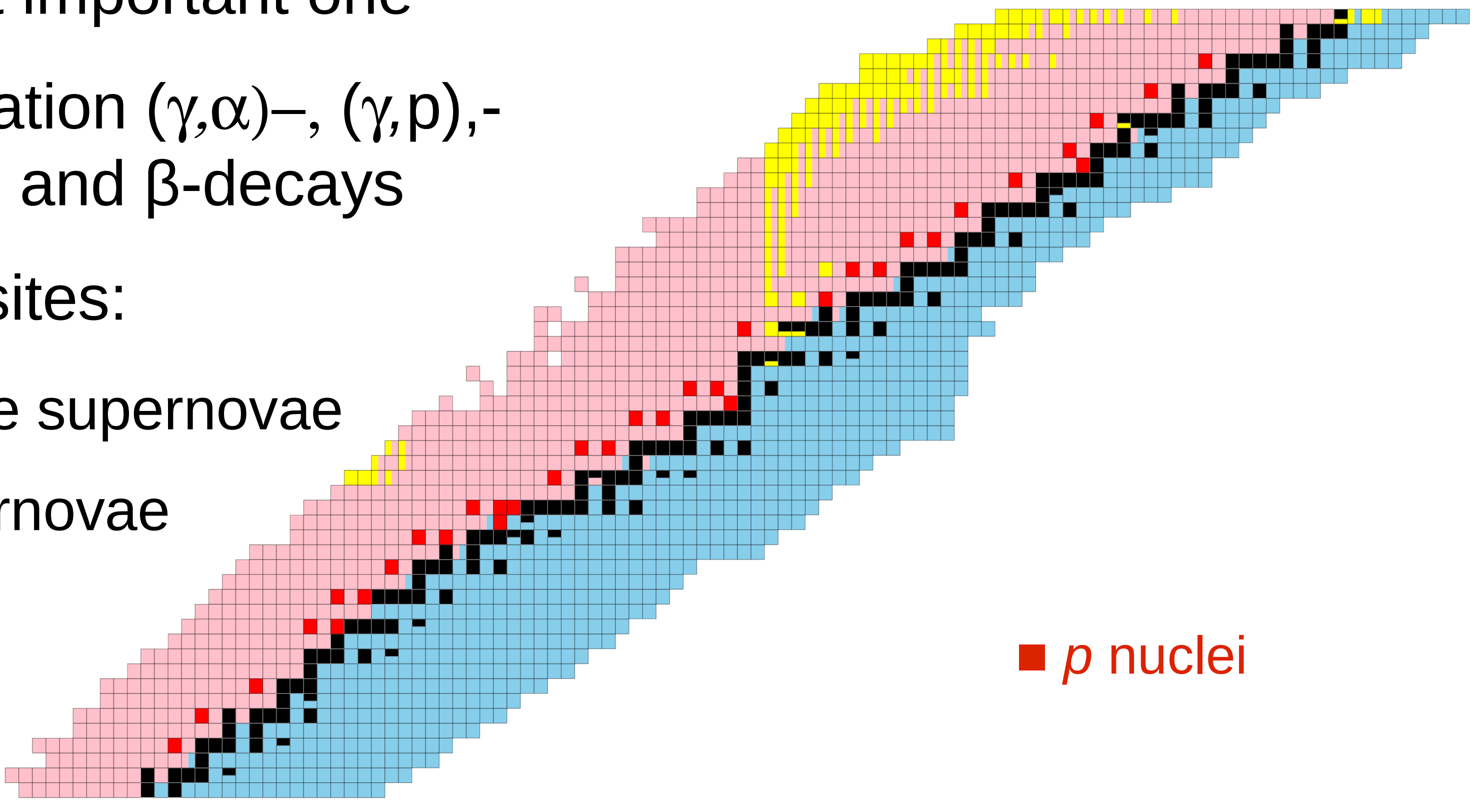
γ process

- 30-35 nuclides are produced by the *p* process
- γ process most important one
- Photodisintegration (γ,α)–, (γ,p),- (γ,n)- reactions and β-decays
- Astrophysical sites:
  - core-collapse supernovae
  - type Ia supernovae



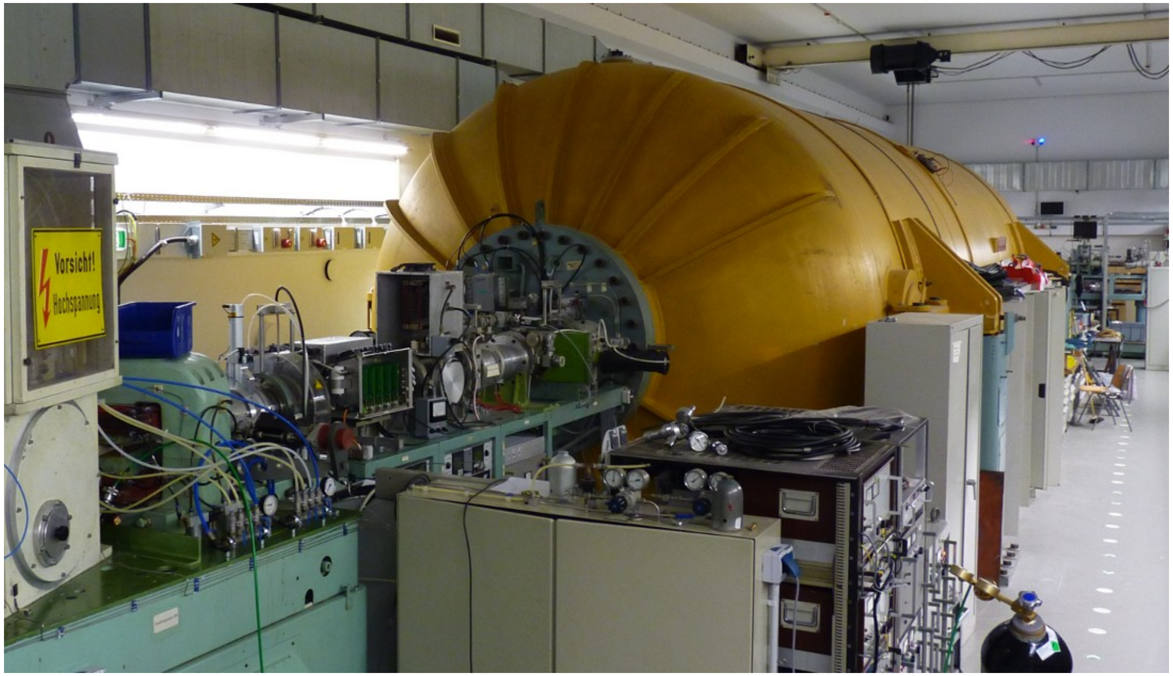
Motivation

- *p* nuclides around A≈100 are underestimated by network calculations
- Improvements *by narrowing down the possibilities* with measurements of reaction in this region
  - **^{85}Rb(p,γ)**
  - ^{89}Y(p,γ)
  - **^{112}Sn(α,γ)**

In-beam method with HPGe detectors

- **Advantages**
  - Detection of the prompt γ-quanta and the activation
  - Study of stable and radioactive reaction products
  - Determination of partial cross sections
- **Disadvantages**
  - Restricted geometry → low efficiency
  - High beam induced background
  - Limited beam current

Setup in Cologne

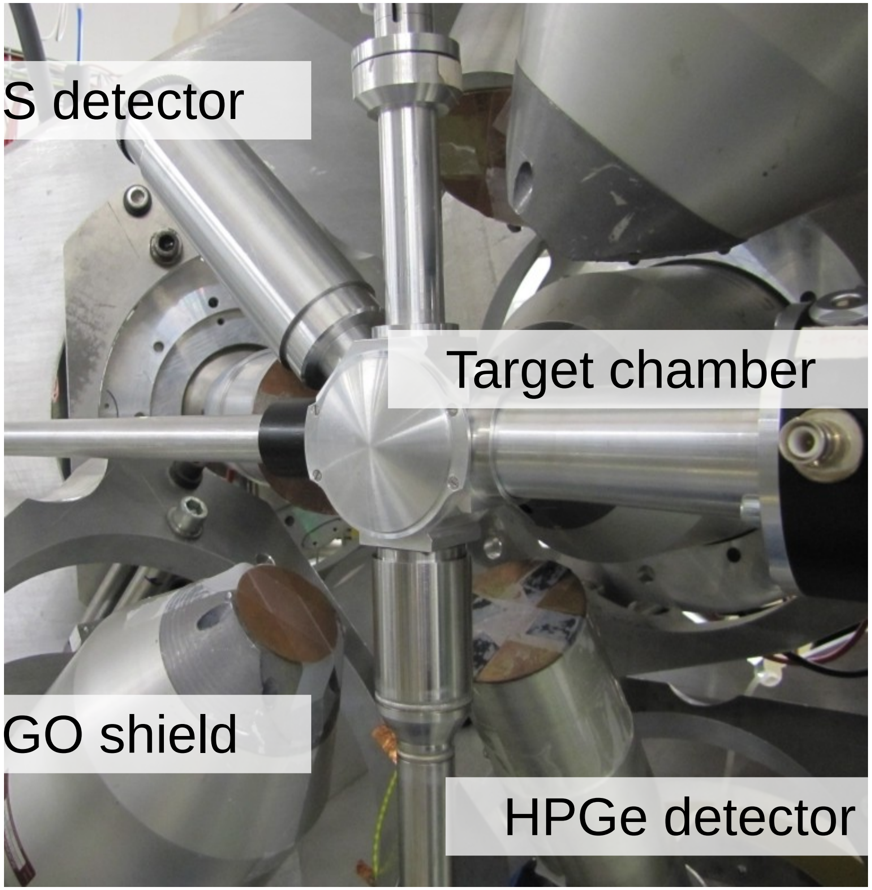


- 10 MV Tandem accelerator for various ions
- Beam intensities up to 10 µA (protons) and 1 µA (α-particles)
- Well defined beam energy (range of serveral keV)

Setup in Cologne

HORUS Spectrometer

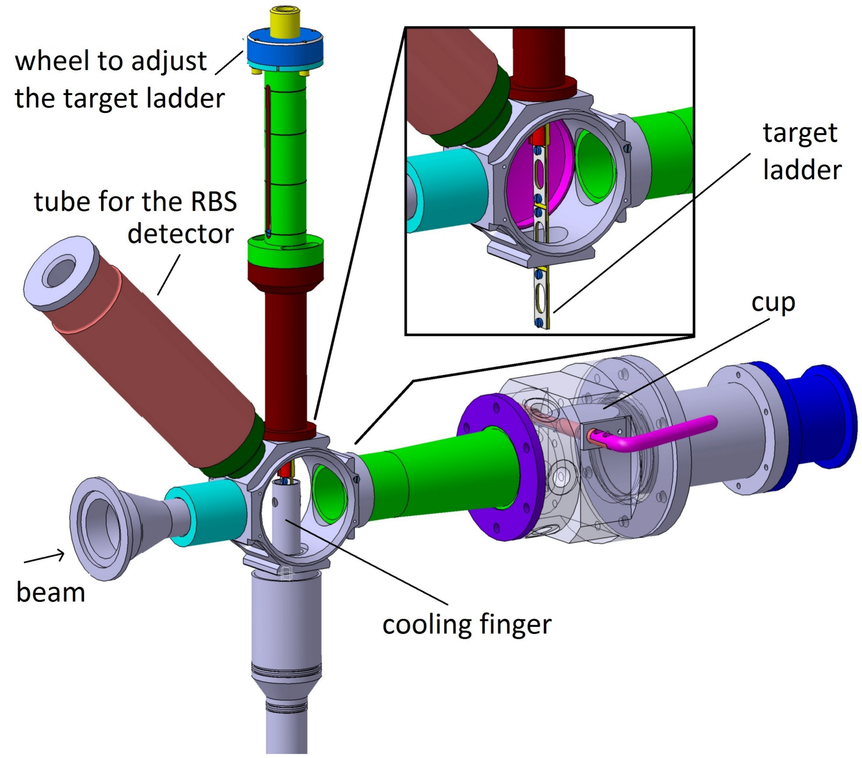
- Array of 13 HPGe detectors
- 5 angles realtiv to beam axis
- 5 of the detectors are equipped with BGO shields
- $\gamma\gamma$ coincidences possible
- Absolute photopeak efficiency 2 % @ 1332 keV



Setup in Cologne

Target chamber

- Build with aluminium and tantalum
- Cooling trap
- RBS detector
- Current read out at three positions (target, chamber, and cup)
- Supression of secondary electrons

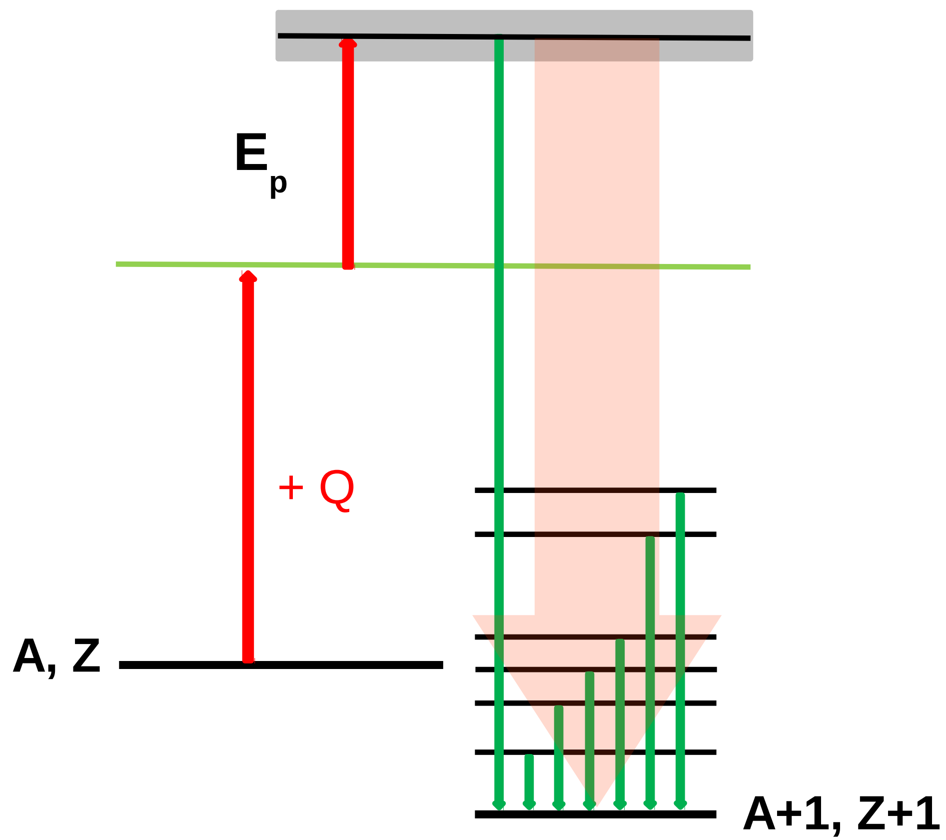


A. Sauerwein, PhD thesis 2013, IKP

Cross section

Transitions to the ground state

- Determination of the total cross section

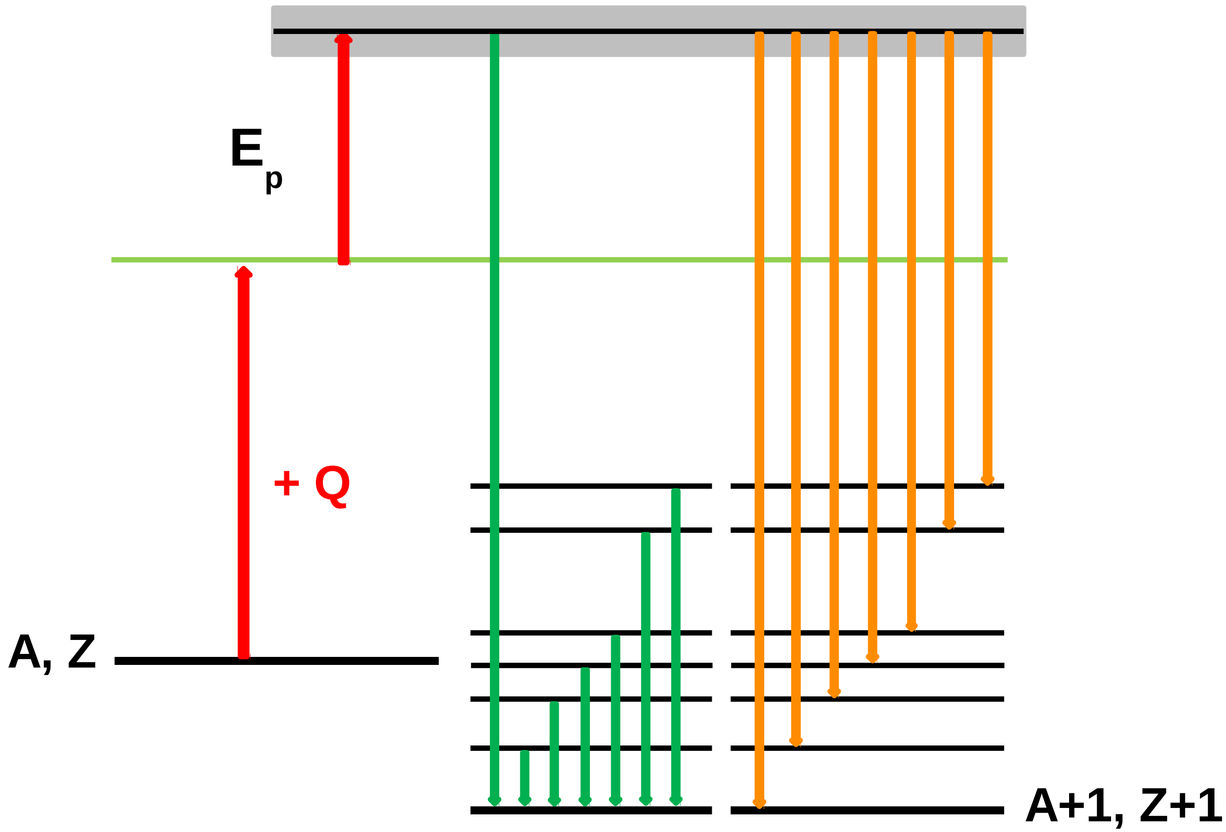


Transitions to the ground state

- Determination of the total cross section

De-excitation of the entry state

- Determination of partial cross sections



Total cross section determination

Test-measurement:

Determination of the total cross section of $^{85}Rb(p,\gamma)$ reaction at a proton energy of 4000 keV

$$\sigma = \frac{\text{Number of reactions}}{\text{Number of projectiles} \cdot \text{Number of target nuclei}}$$

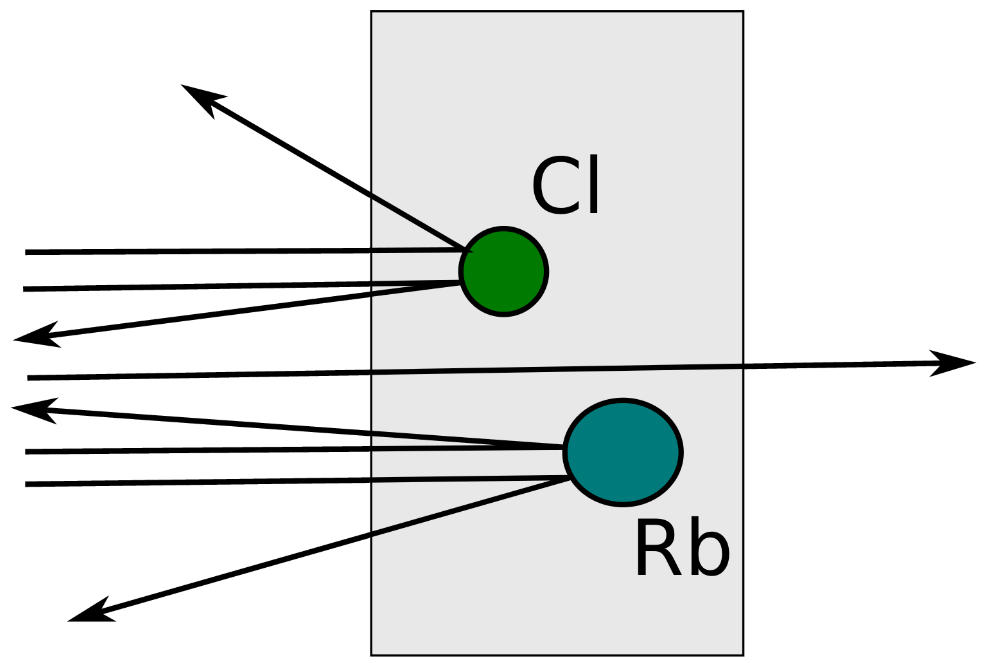
Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

Number of target nuclei

Rutherford Backscattering Spectrometry

- Ion beam on the target
- Detect the energy of the scattered ions
- Spectrum is unique.
  It depends on the beam energy, the composition and the **thickness** of the target



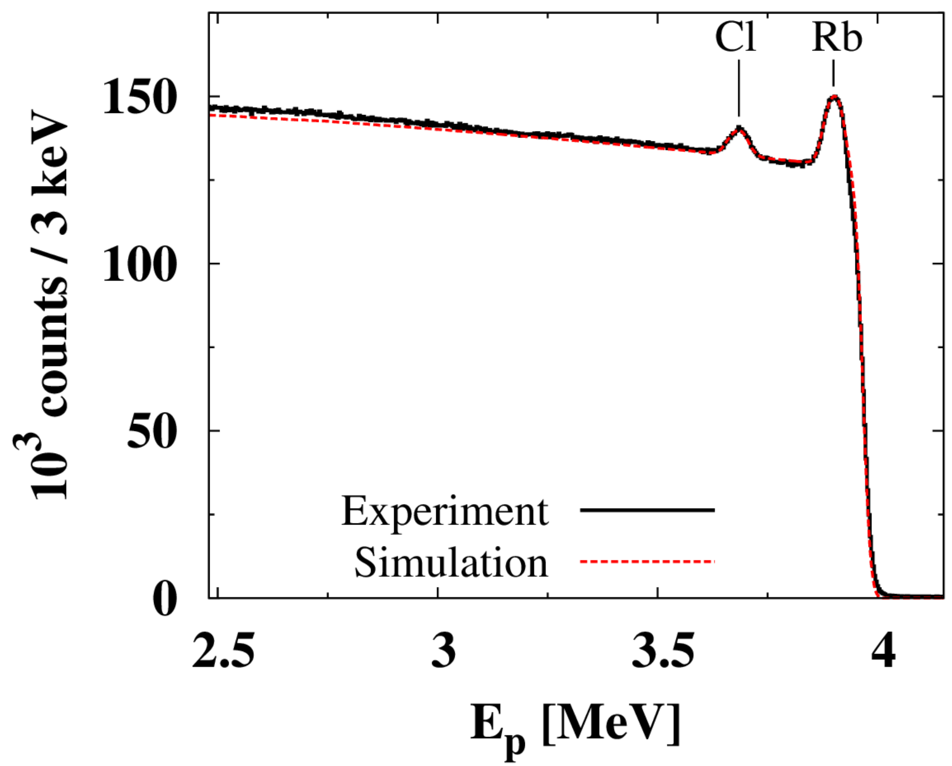
Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

Number of target nuclei

Simulating the Rutherford Backscattering Spectrum of the target

→ Thickness is the only free parameter



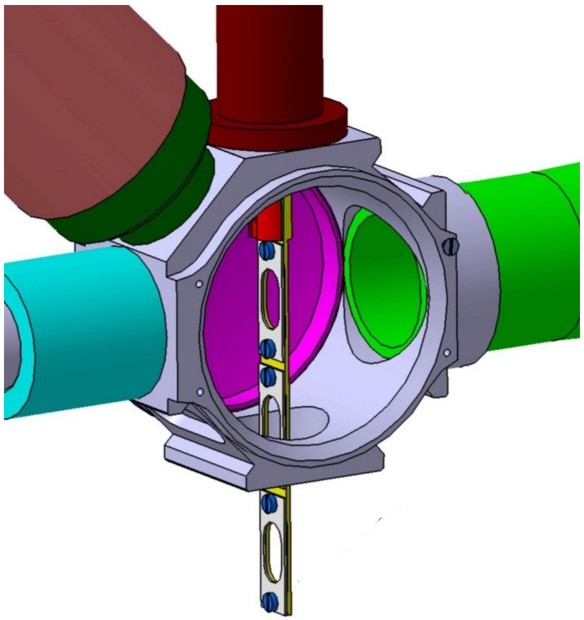
1.95(15)·10^{18} Rb nuclei / cm²

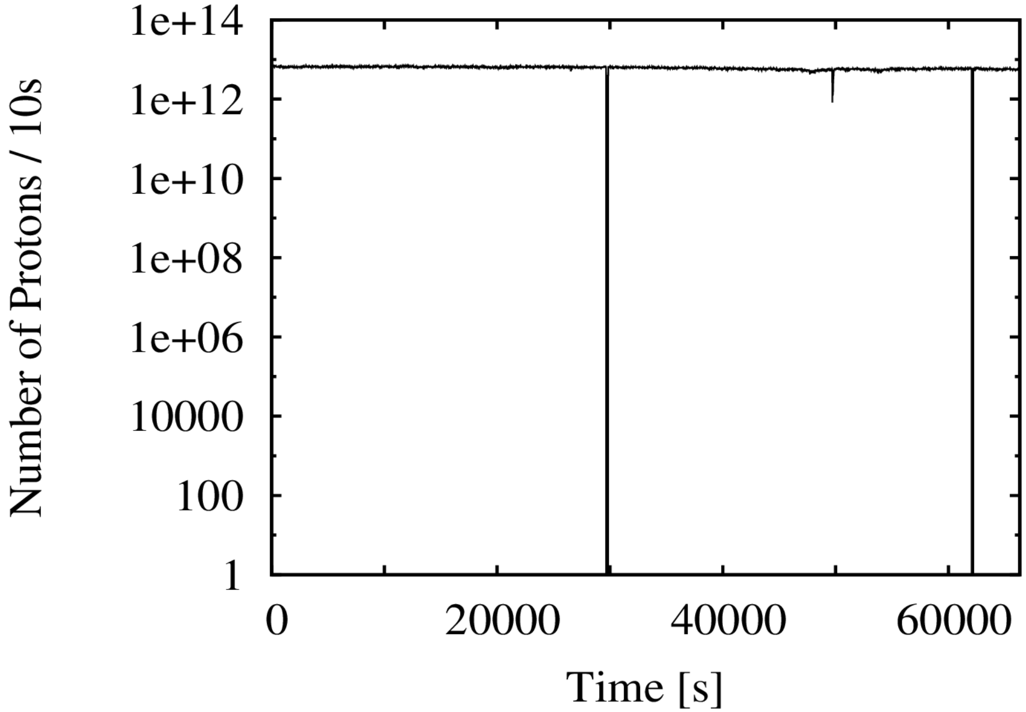
Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

Number of protons

- Current read out on the target and the target chamber





$6.1(1)\cdot10^{11}$ Protons / s

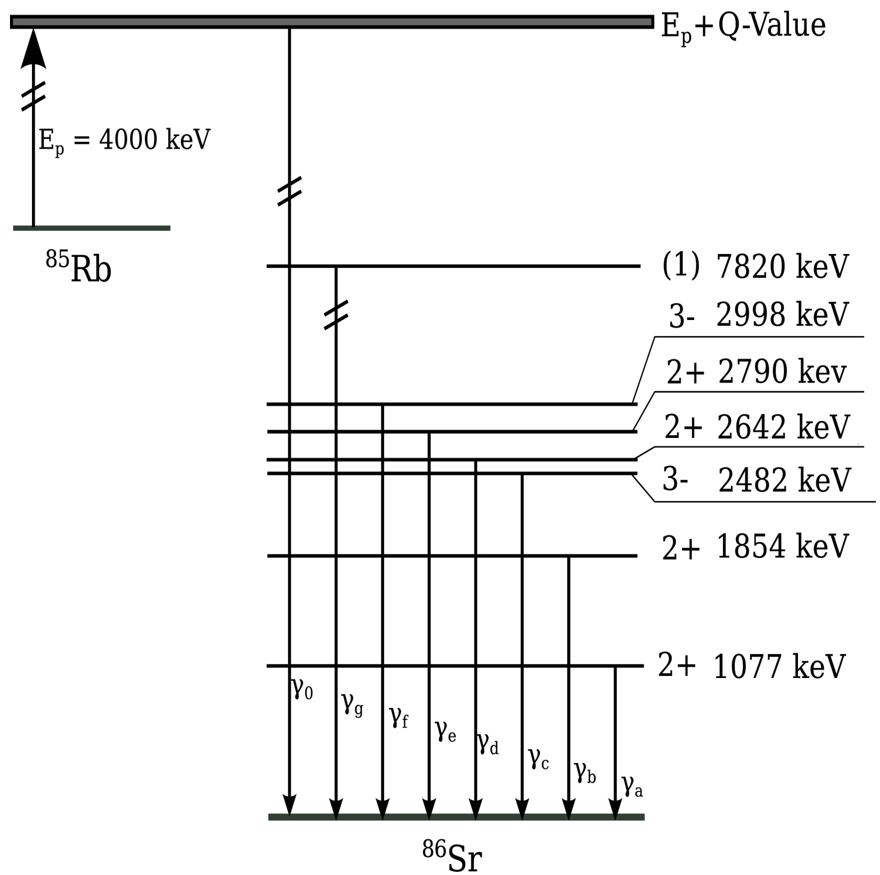
$\rightarrow 3.71(8)\cdot10^{16}$ Protons

Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

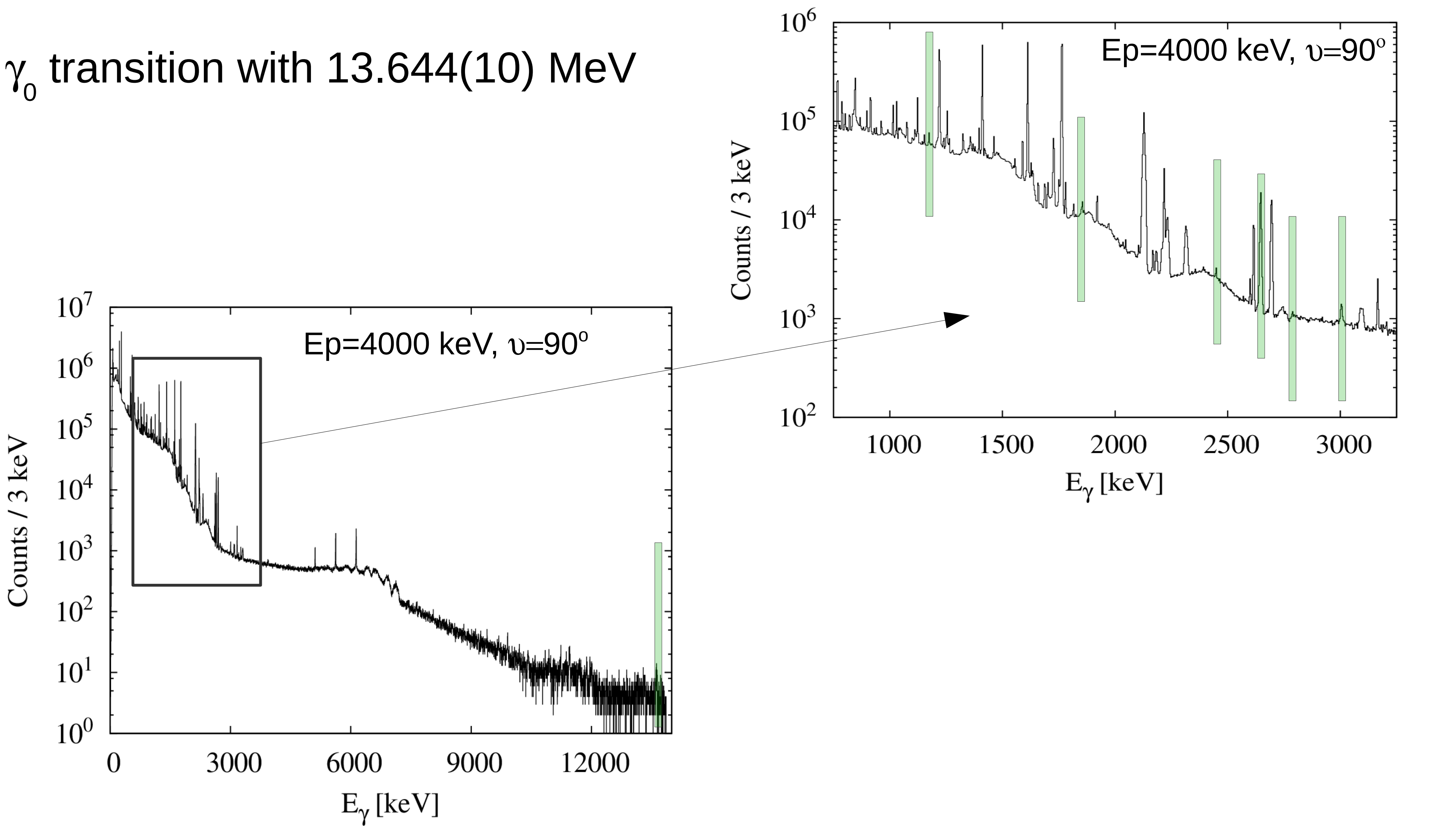
Number of reactions

Number of events in a full-enery peak that is caused by a ground state transition.



Total cross section determination

γ_0 transition with 13.644(10) MeV



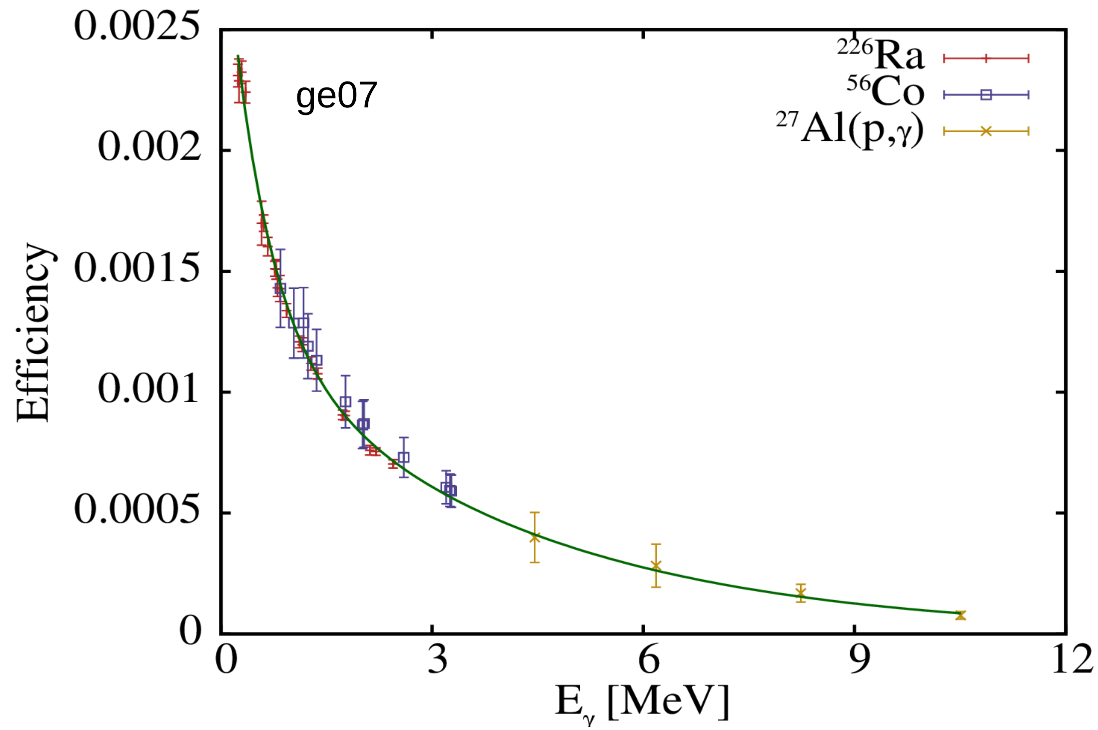
Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

← Number of reactions

- Determine the detector efficiency with ^{226}Ra, ^{56}Co and ^{27}Al(p,γ)
- ^{27}Al(p,γ)-resonance delivers values up to 10.5 MeV
- This resonance needs a exact proton energy of 3674.4 keV

→ Callibration of the proton beam is possible



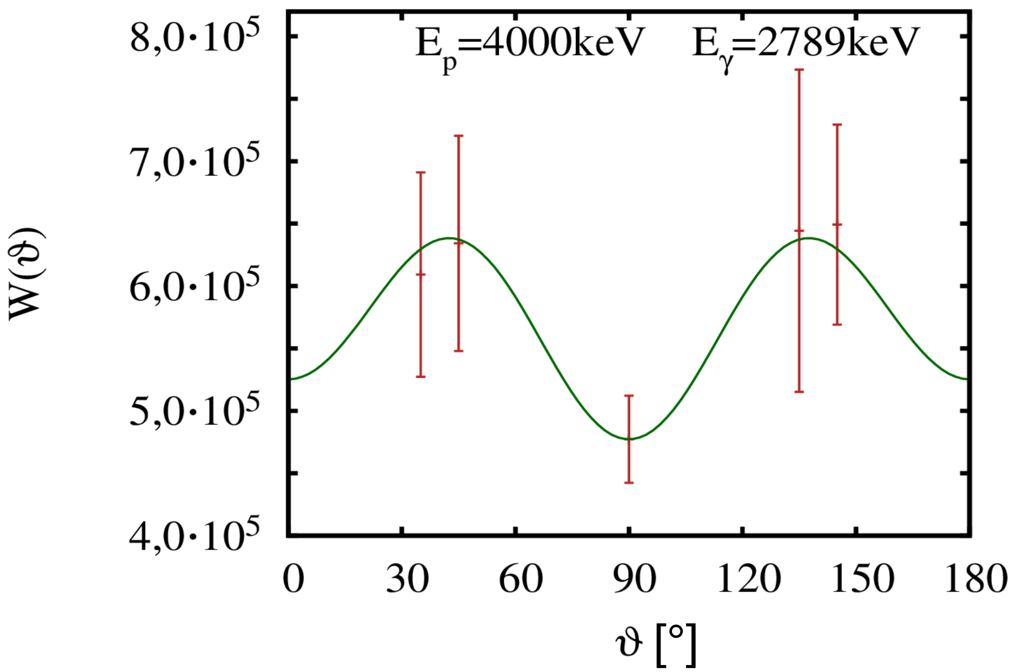
f(x)=a·exp(b·x)+c·exp(d·x)

Total cross section determination

$$\sigma = \frac{N_R}{N_P \cdot N_T}$$

← Number of reactions

- Consider deadtime
- Determine the angular distribution of the emitted γ-ray
  → Fit with Legendres polynoms



Total cross section determination

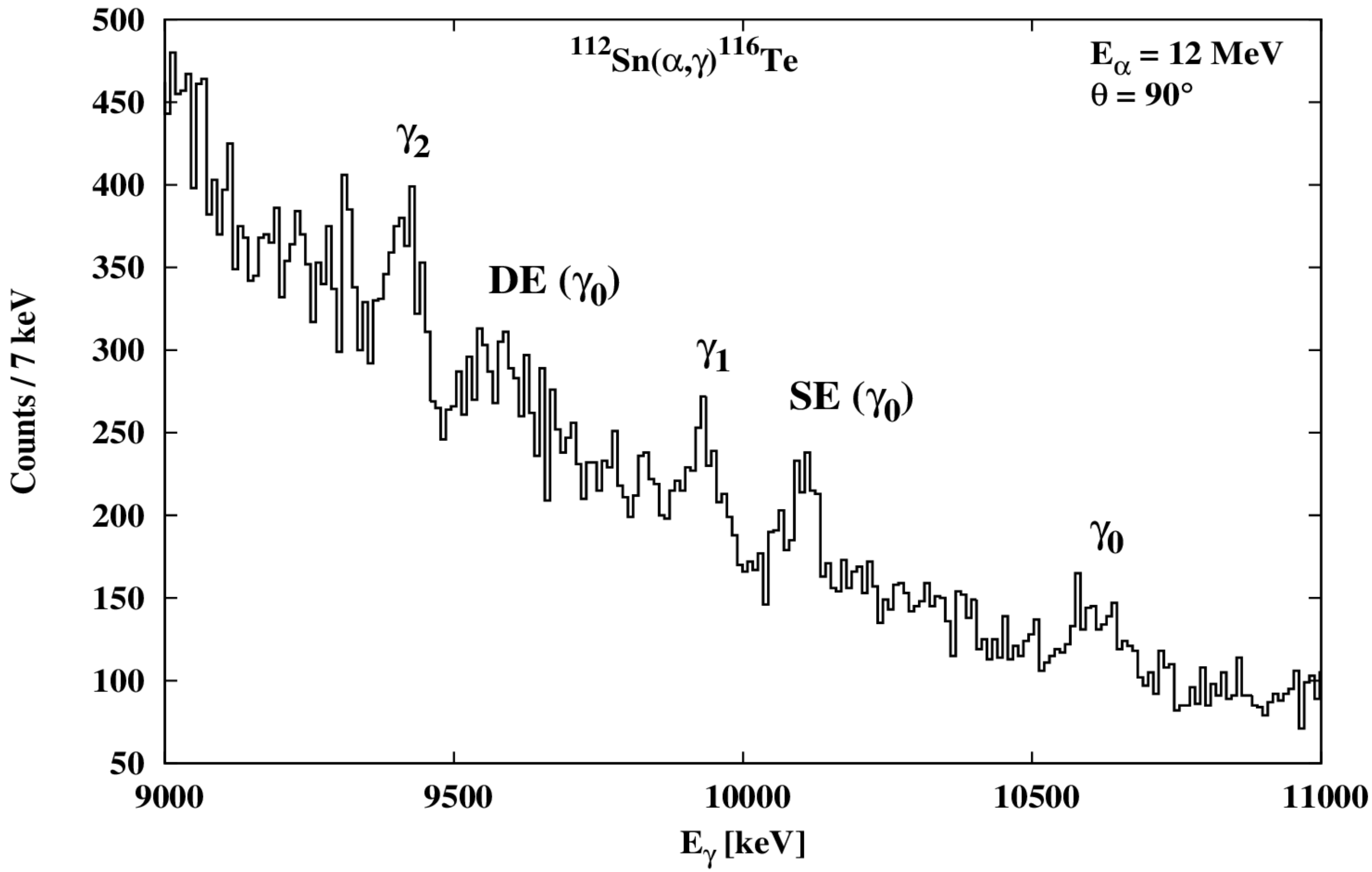
$$\sigma = \frac{N_R}{N_P \cdot N_T} = 6.52(92)\ \text{mb}$$

Only one proton energy was measured

→ Measurement at several proton energies in the near future

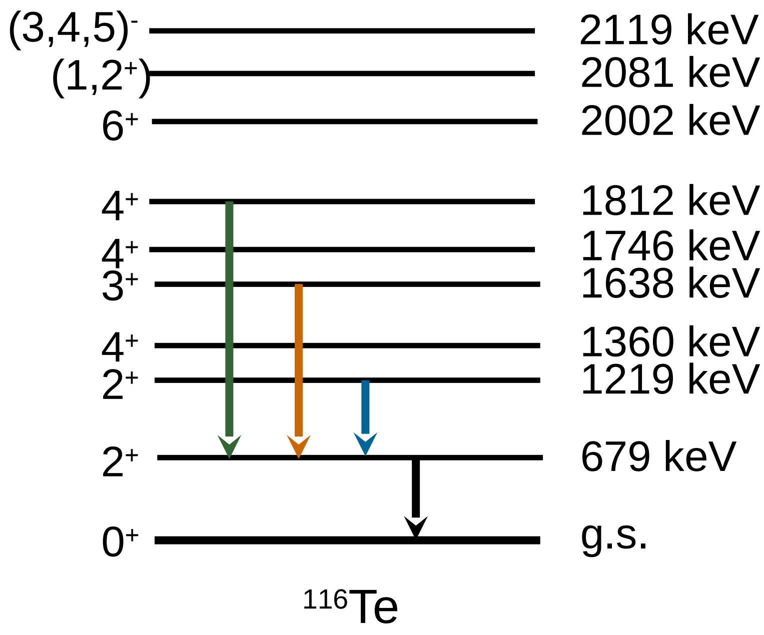
$^{112}Sn(\alpha,\gamma)^{116}Te$ in beam

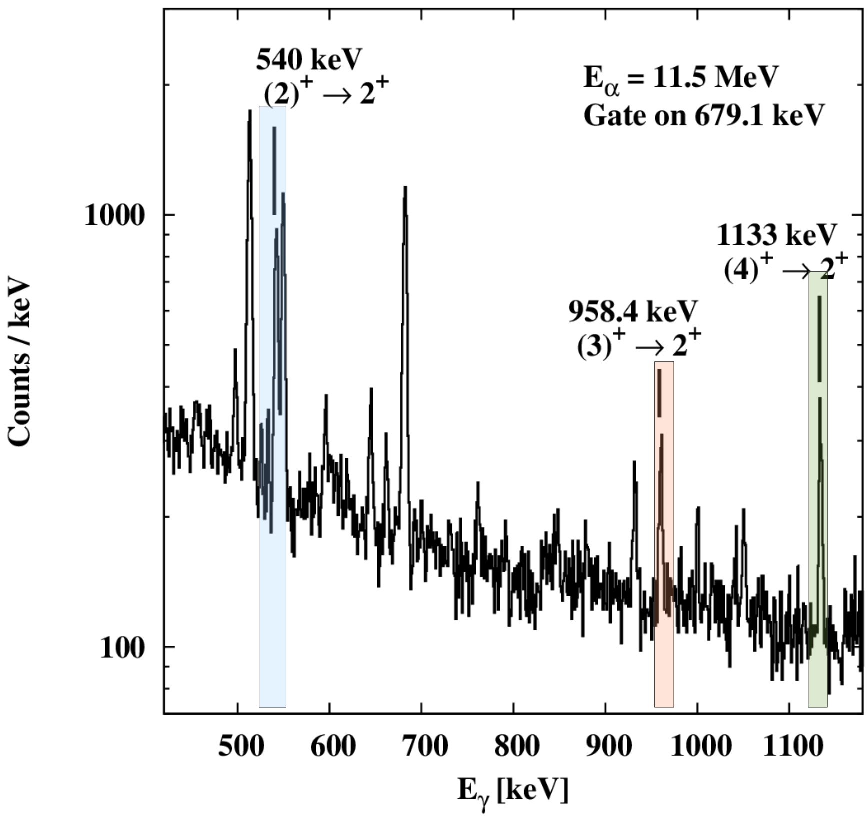
- E_α = 10.5 MeV, 11 MeV, 11.5 MeV, and 12 MeV
- Beam currents from 150 nA – 200 nA



Partial cross sections can be calculated!

$^{112}Sn(\alpha,\gamma)^{116}Te$





- Reaction product ^{116}Te is not well known
  → Improvement of nuclear structure physics with $\gamma\gamma$-coincidence

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Partial Cross sections