Experimental techniques to measure ion-induced cross sections and applications to the p process

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supported by DFG **(ZI 510/5-1 and INST 216/544-1)**

Ion-induced cross sections on heavy nuclei

Interesting energy range usually
way below the Coulomb barrier

↓

Typical cross sections in μb range

↓

- Maximize number of reactions
- Find efficient detection techniques

Maximize beam current

Low cross sections can partly be compensated by high beam currents, but the target has to withstand it.

In activation and AMS experiments one can separate reaction site and counting site.

A dedicated, high current, few MeV accelerator for protons and α‘s with excellent enery definition should be set up! (see ECOS/NuPECC report)

Find efficient detection techniques: Two-step experiments

Step 1: Induce the reaction of interest, e.g.
(p,γ), (α,γ), (α,n), ...

Step 2: Take the irradiated sample and analyze it

- using γ spectroscopy after β decay
- using fingerprints from other decay paths
- using Accelerator Mass Spectrometry (AMS)

Find efficient detection techniques: One-step (in-beam) experiments

Detect the ejectile in-beam after the reaction of interest, e.g. radiative capture (p,γ) or (α,γ), or the reaction product (recoiling compound nucleus)

- using 4π NaI summing crystals
- using high resolution HPGe arrays
- using recoil separators

Find efficient detection techniques: Experiments with radioactive ion beams

- Experiment is carried out in inverse kinematics

$$^{92}\mathrm{Mo}(p,\gamma)^{93}\mathrm{Tc} \rightarrow p(^{92}\mathrm{Mo},^{93}\mathrm{Tc})\gamma$$

- typically very low beam currents
- H or He gas (jet) target, plastic target
- in-beam oder two-step experiments (implantation)

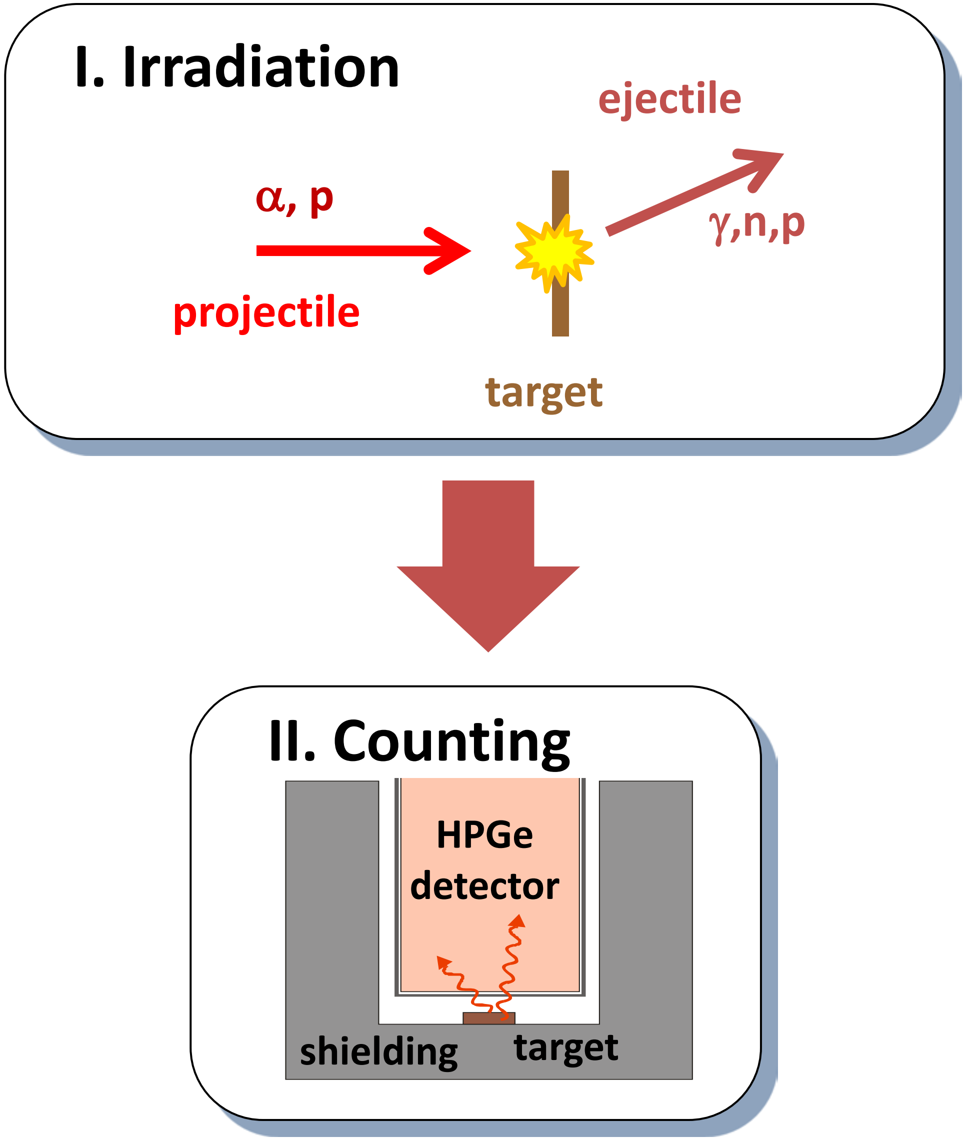
Find efficient detection techniques: Two-step experiments

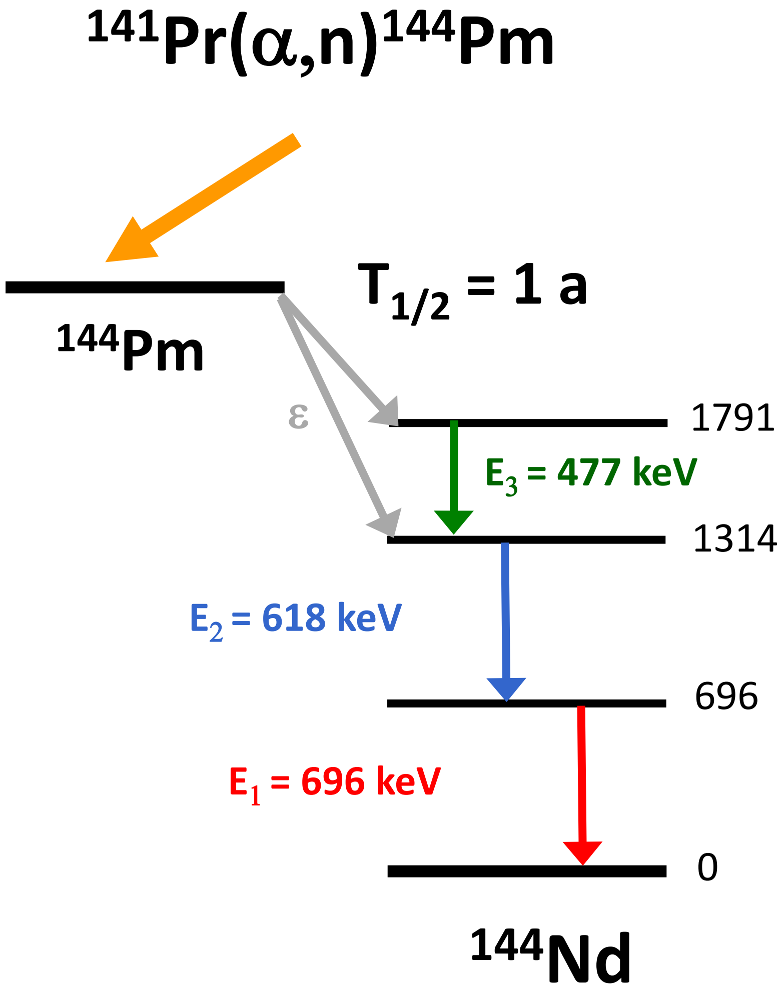
Step 1: Induce the reaction of interest, e.g.
(p,γ), (α,γ), (α,n), …

Step 2: Take the irradiated sample and analyze it

- using γ spectroscopy after β decay
- using fingerprints from other decay paths
- using Accelerator Mass Spectrometry (AMS)

Activation followed by γ spectroscopy



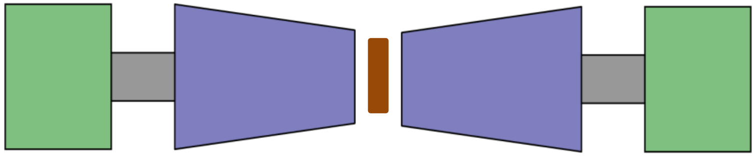


Activation followed by γ spectroscopy

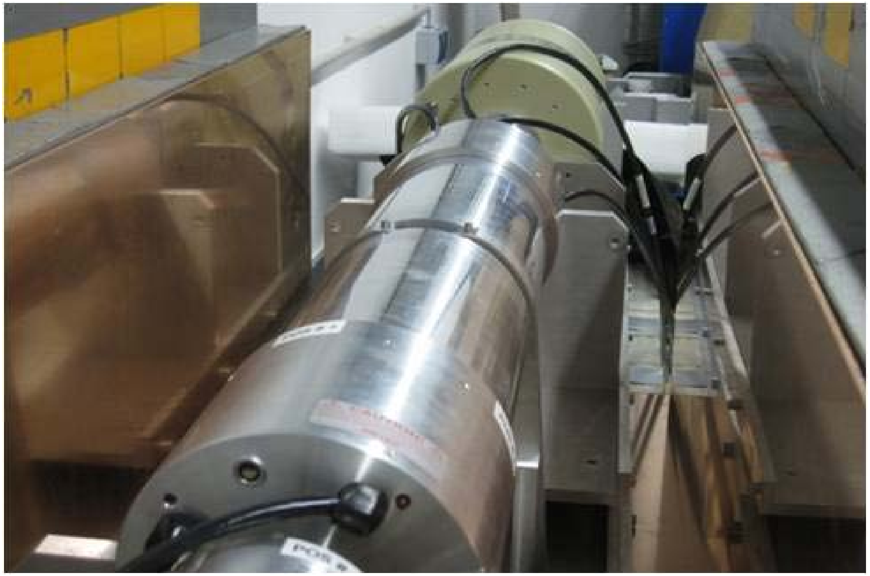
Irradiation @ PTB Braunschweig

He++ ions from TCC-CV28 cyclotron, energies between 11 and 15 MeV, ion current in μA range

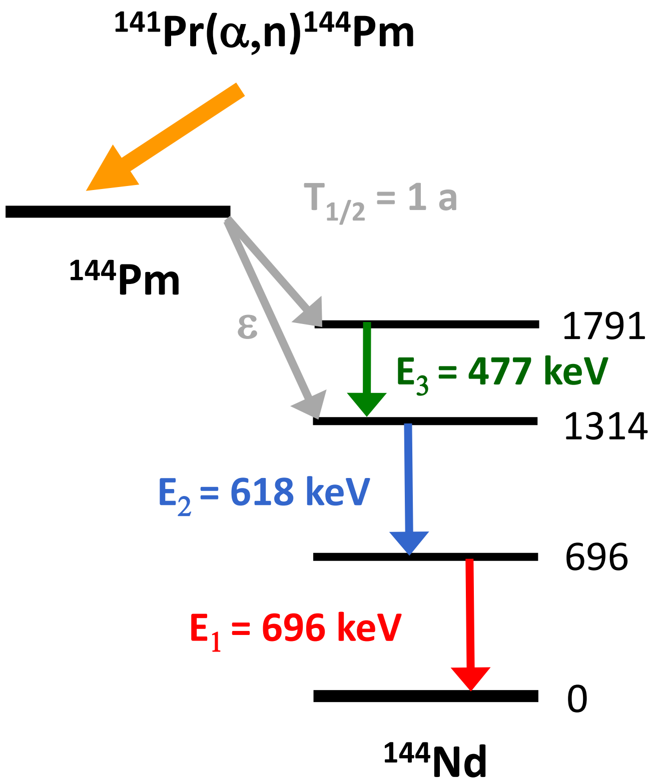
Counting @ IKP Köln:



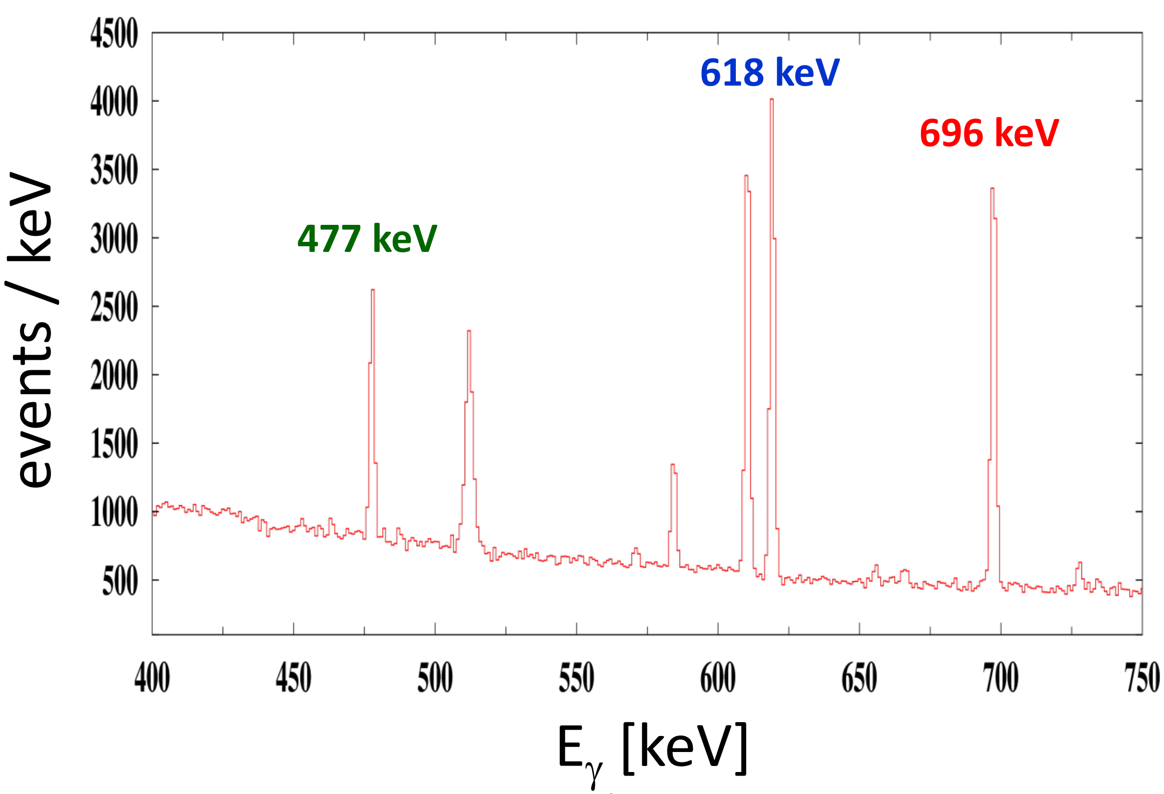
Two 100% Clover (4 detectors each) plus addback, shielded by BGO and passive shielding



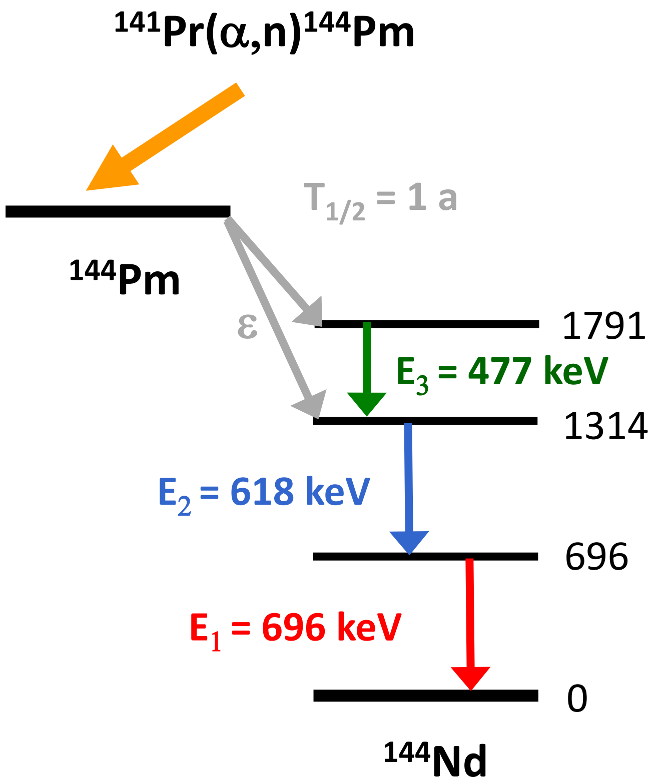
$^{141}Pr(\alpha,n)^{144}Pm$: Single spectrum after activation

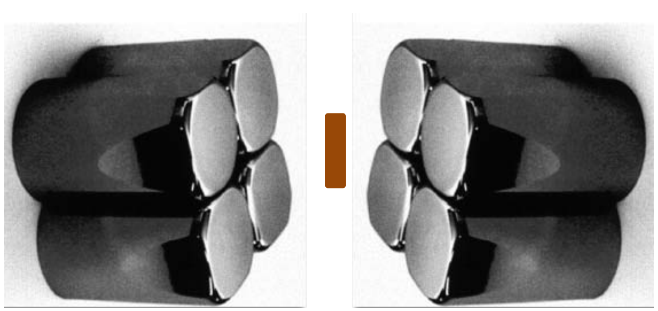


E_α=13.8 MeV @ PTB

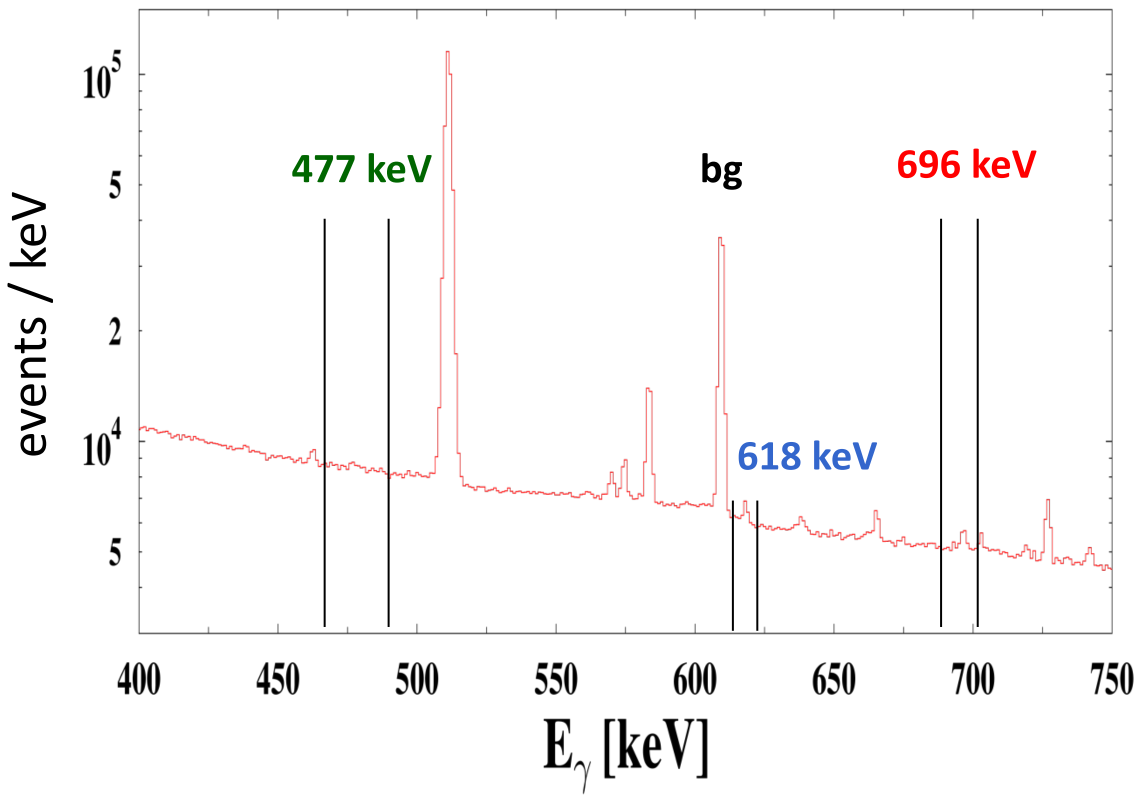


$^{141}Pr(\alpha,n)^{144}Pm$: Single spectrum after activation



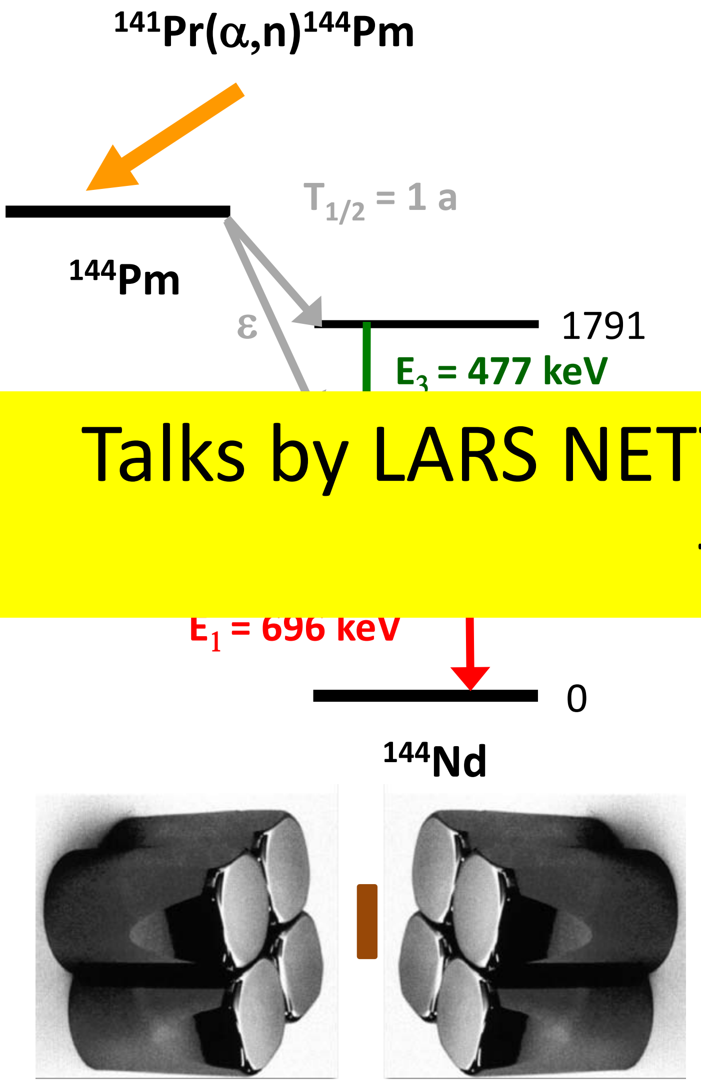


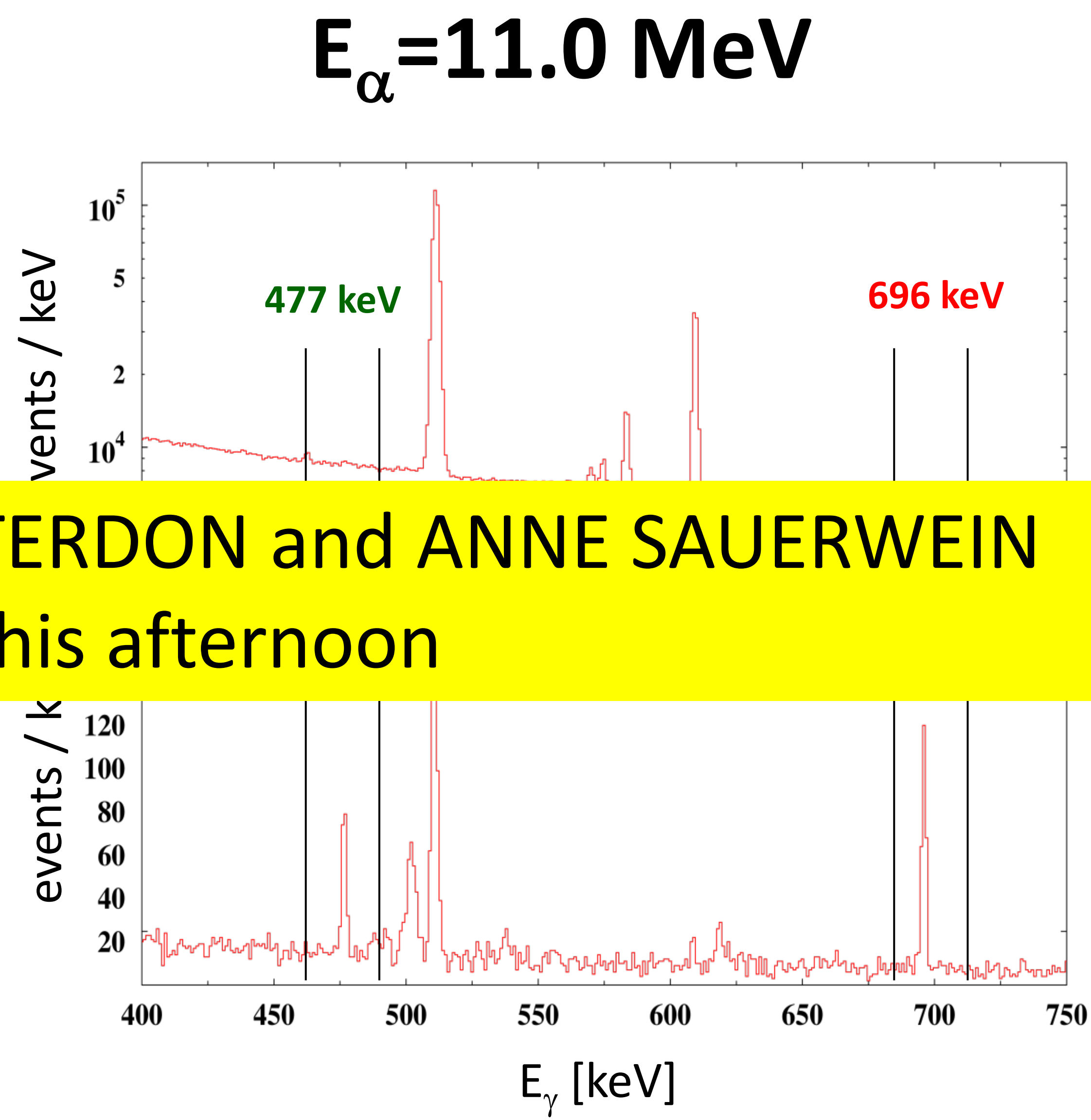
E_α=11.0 MeV @ PTB



A. Sauerwein et al., Phys. Rev. C 84 (2011) 045808

Coincidence between two Clover segments

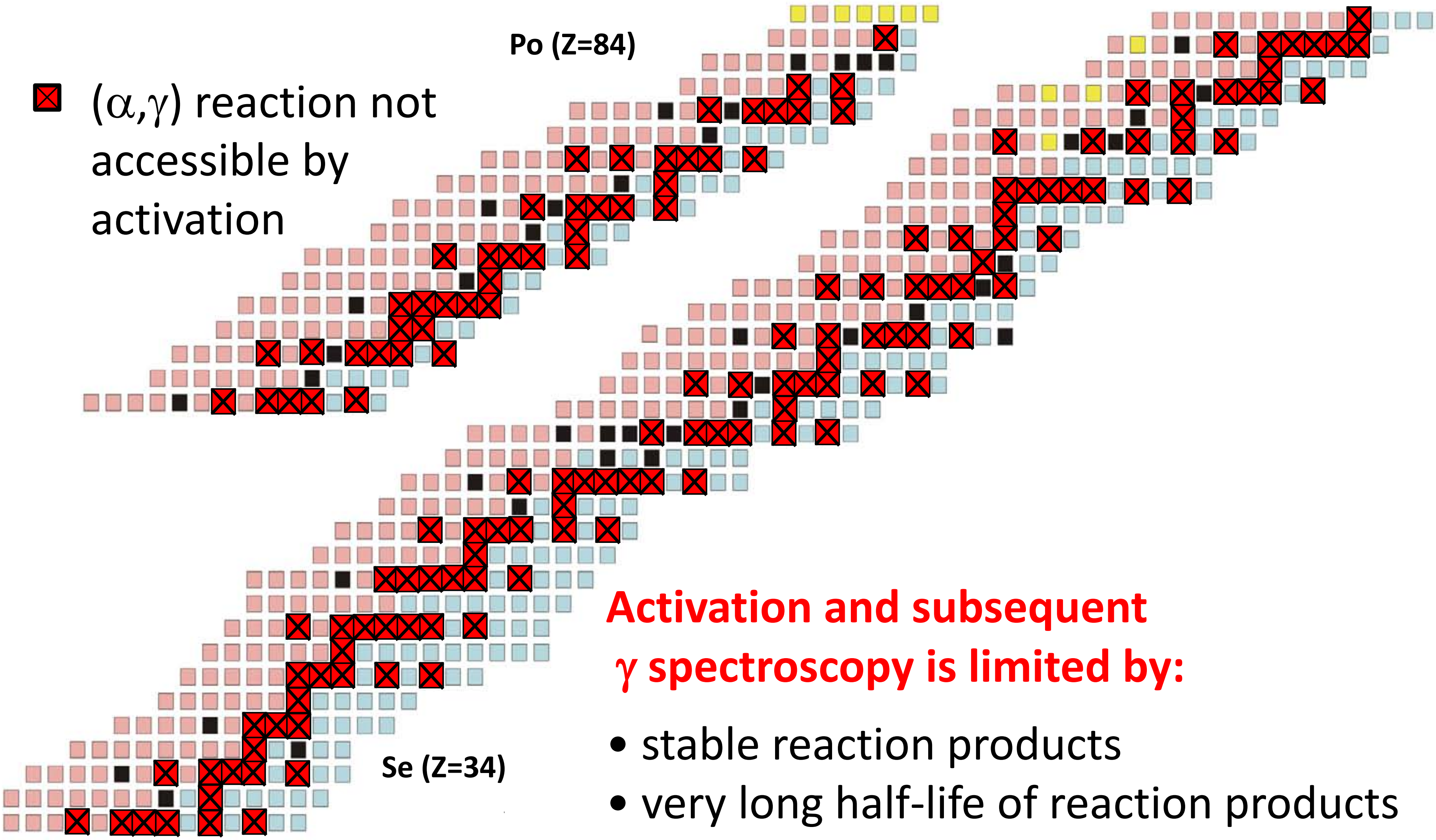




Talks by LARS NETTERDON and ANNE SAUERWEIN this afternoon

A. Sauerwein et al., Phys. Rev. C 84 (2011) 045808

Limitations of γ spectroscopy after irradiation



Activation and subsequent γ spectroscopy is limited by:

- stable reaction products
- very long half-life of reaction products
- weak γ intensities of radioactive decays

Find efficient detection techniques: Two-step experiments

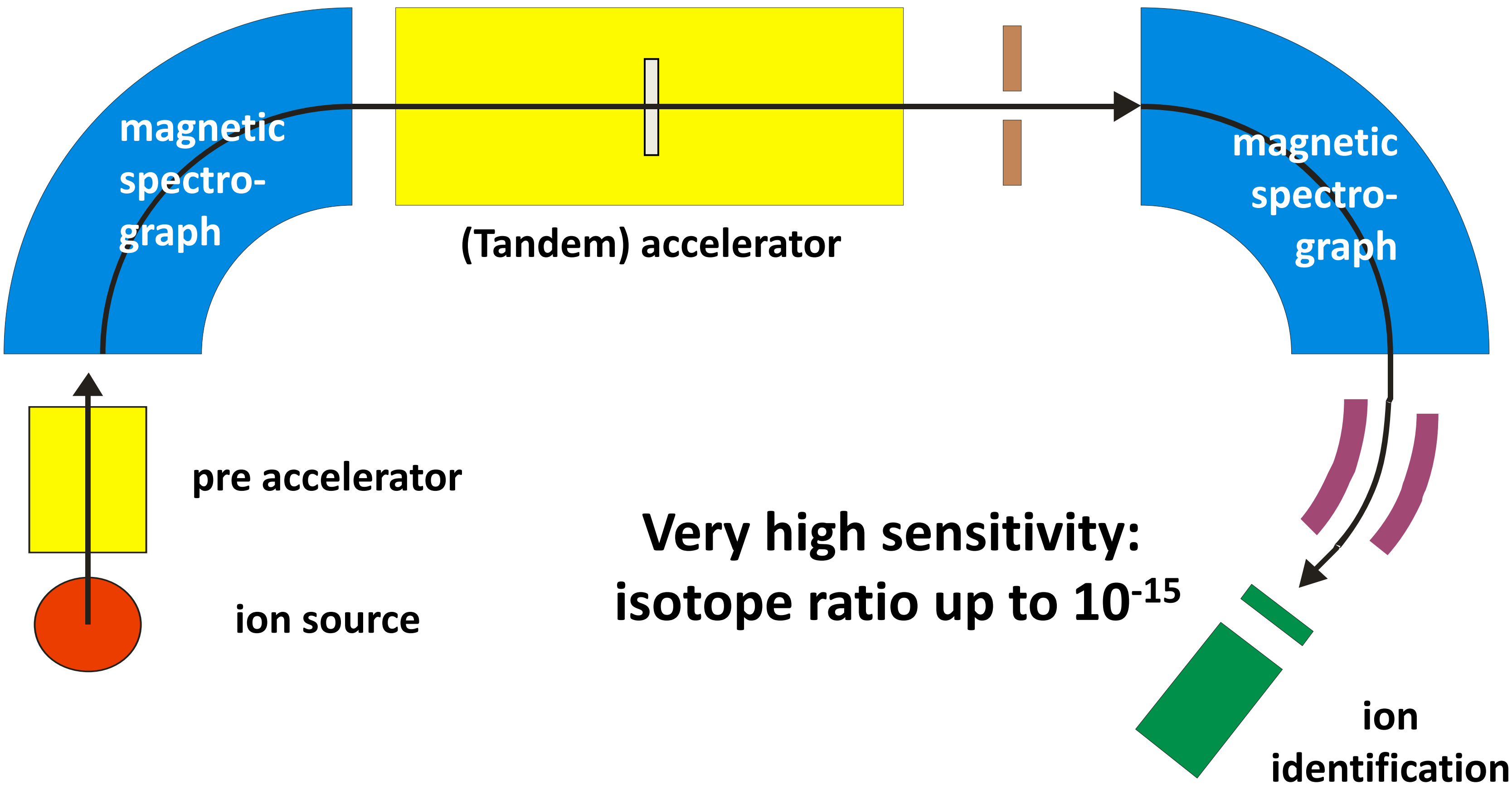
Step 1: Induce the reaction of interest, e.g.
(p,γ), (α,γ), (α,n), ...

Step 2: Take the irradiated sample and analyze it

- using γ spectroscopy after β decay
- using fingerprints from other decay paths
- using Accelerator Mass Spectrometry (AMS)

Accelerator Mass Spectrometry

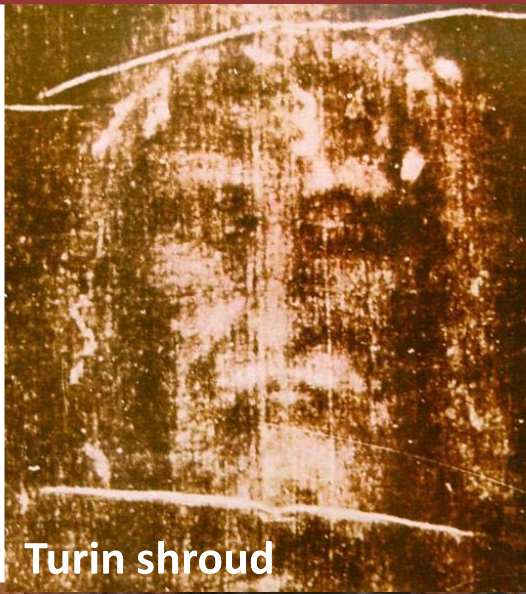
Identify the compound nuclei in the target after irradiation



Very high sensitivity:
isotope ratio up to 10^{-15}

Accelerator Mass Spectrometry

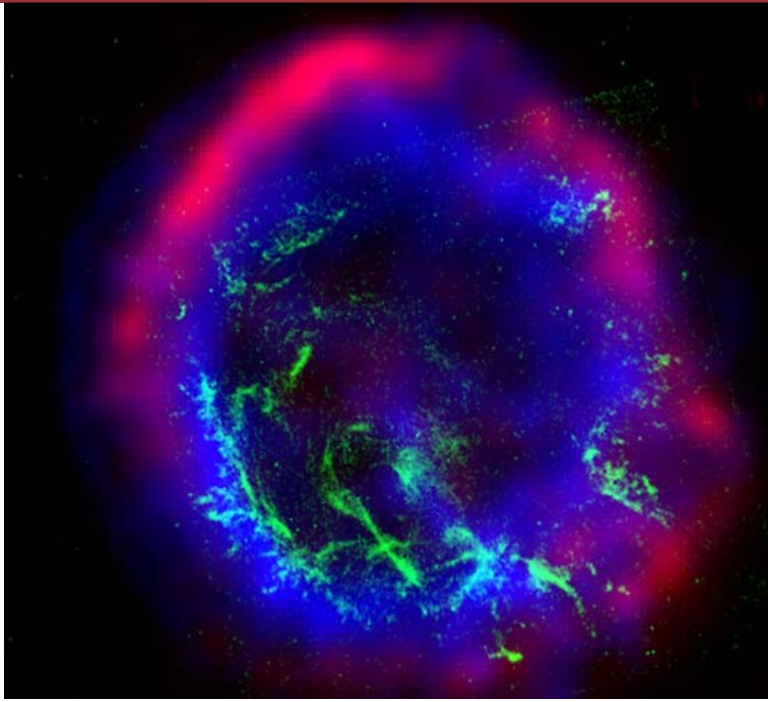
Typical application:
Detection of smallest amounts of ^{14}C
and/or of other cosmogenic nuclides
(e.g. ^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca, ^{129}I)



Accelerator Mass Spectrometry

But as well: Detection of nuclides produced in the laboratory

Problem: Each isotope to be measured needs development time for sample preparation and detection



Talk by MICHAEL PAUL
this afternoon

^{26}Mg(p,n)^{26}Al: M. Paul et al., PLB 94 (1980) 303 (^{26}Al is a cosmogenic nuclide)

^{40}Ca(α,γ)^{44}Ti: H. Nassar et al., PRL 96 (2006) 041102

CologneAMS

A new AMS facility at the IKP, University of Cologne

- Tandetron with 6 MV terminal voltage (no moving parts)
- standard isotopes: ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca, ^{129}I (geosciences, prehistory, protohistory)

SFB 806: Our way to europe

SPP 1158: Coordinated Antarctica research

- ample beam time for development and nuclear physics applications

DFG

Universität zu Köln

GFZ Helmholtz-Zentrum Potsdam

CologneAMS – a new option to measure small reaction cross sections

Ion source wheel , up to 200 probes

CologneAMS

CologneAMS – a new option to measure small reaction cross sections

- First ^{14}C test measurement: February 2011 (all specifications fulfilled)
- Start of standard operation: fall 2011

Find efficient detection techniques:
<u>One-step (in-beam) experiments</u>

Detect the ejectile in-beam after the reaction of interest, e.g. radiative capture (p,γ) or (α,γ) or the reaction product (recoiling compound nucleus)

- using 4π NaI summing crystals
- using high resolution HPGe arrays
- using recoil separators

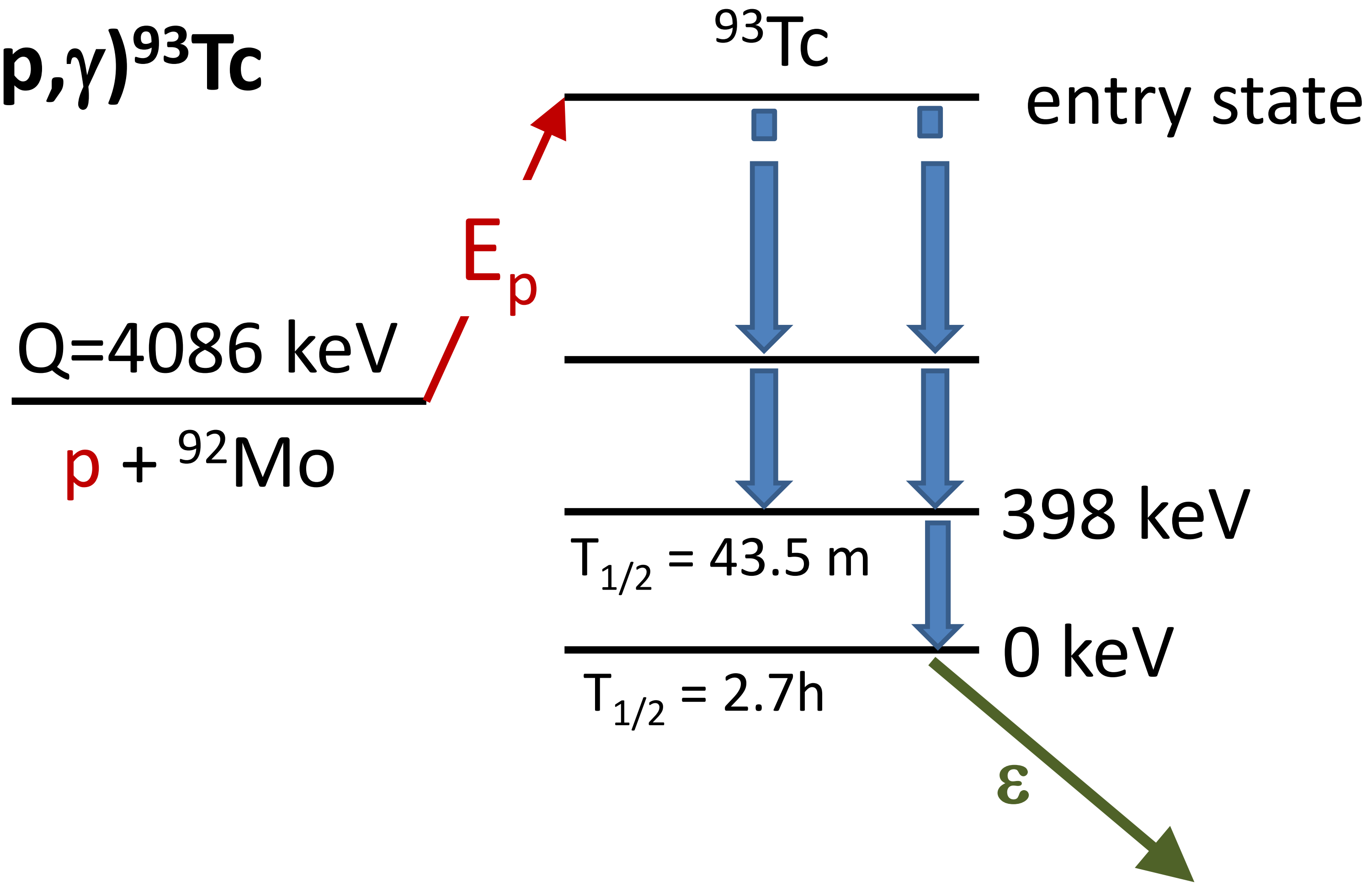
The HORUS array at IKP Köln

- **14 HPGe γ detectors** in close geometry
- Photopeak efficiency at 1332 keV: up to 5%
- Installed at 10 MV Tandem

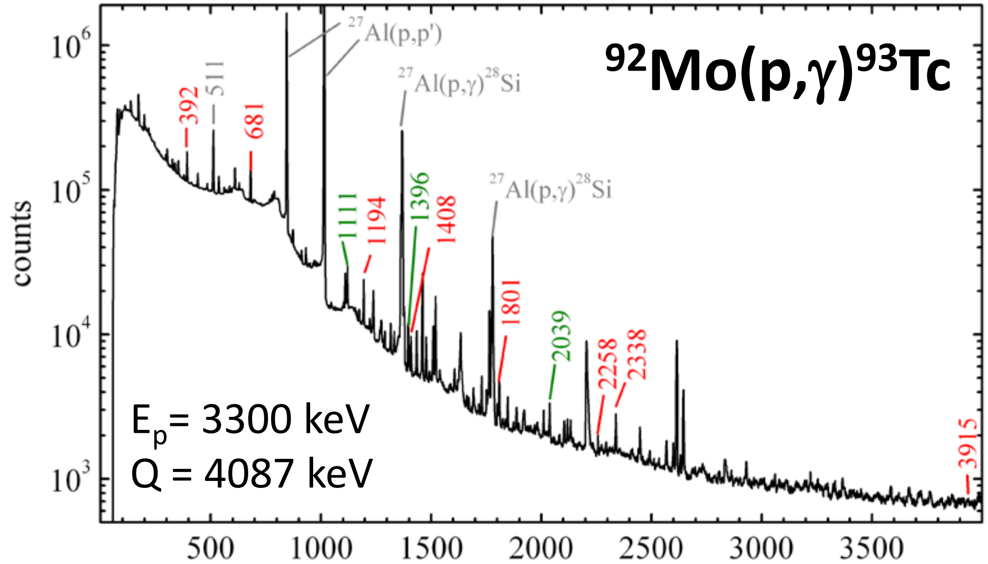
- High energy resolution to observe single transitions
- Adequate efficiency to study low cross sections
- Determination of angular distributions possible
- Coincidence technique to suppress background

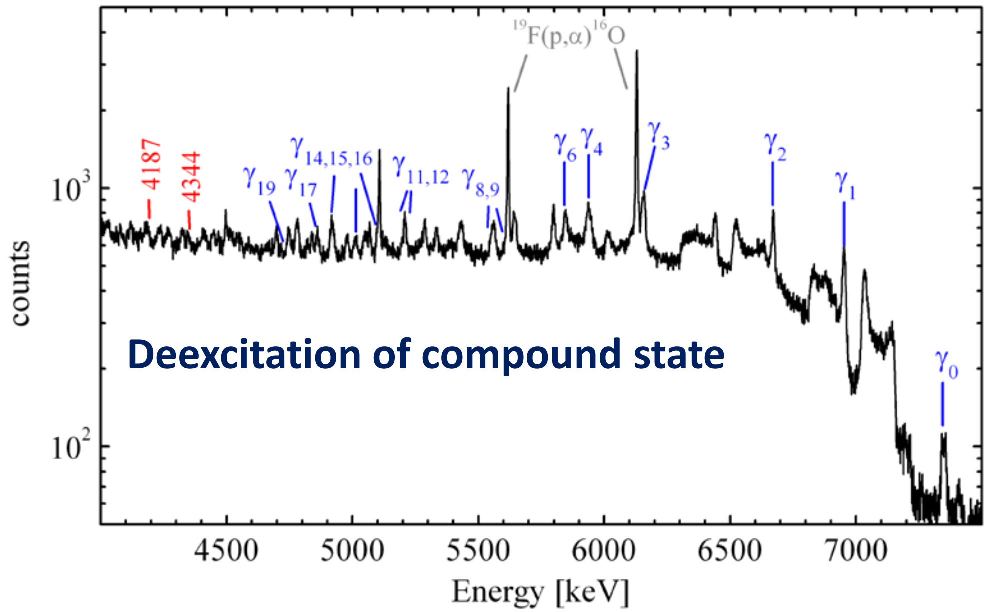
Experiments to study capture reactions

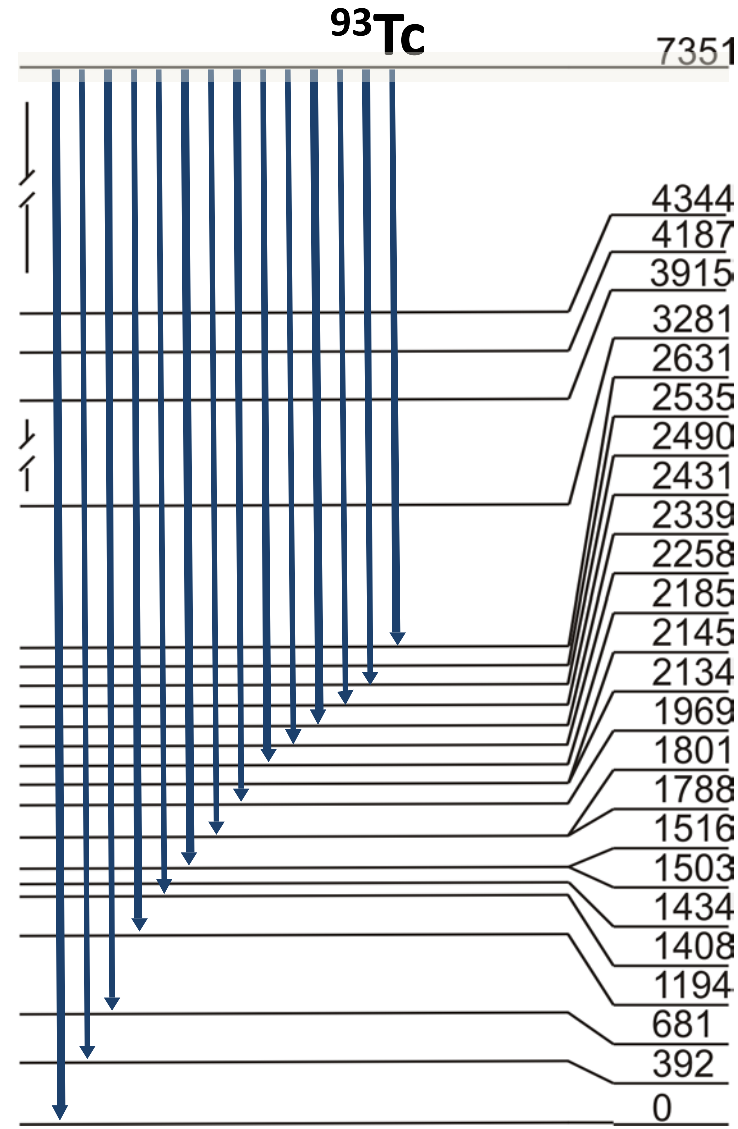
$^{92}Mo(p,\gamma)^{93}Tc$



Radiative proton capture on ^{92}Mo

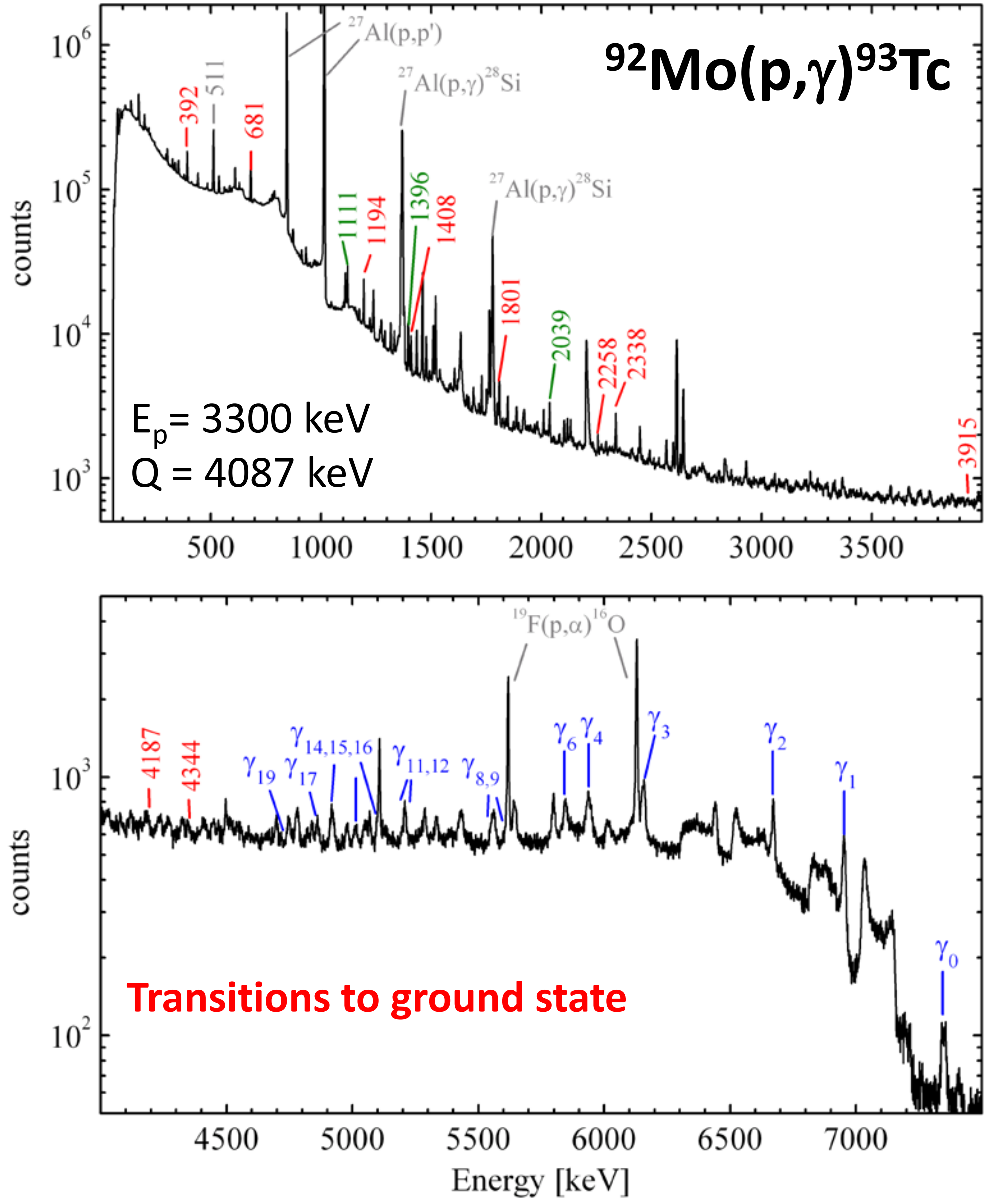


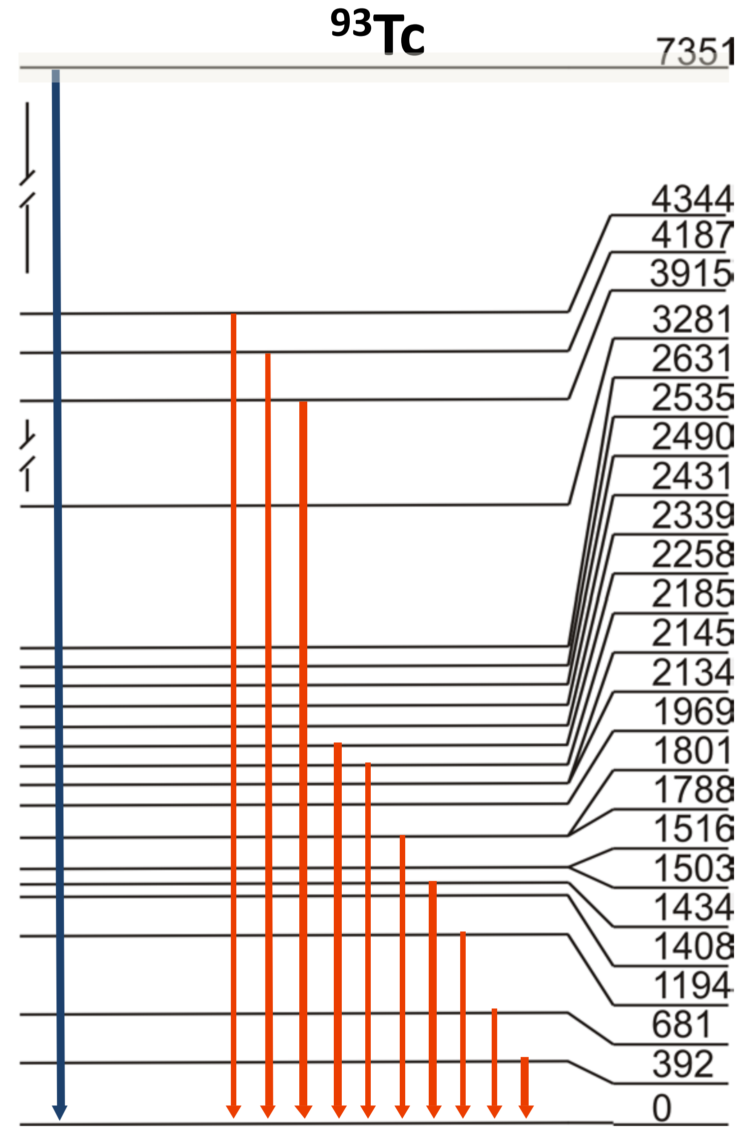




Partial cross sections

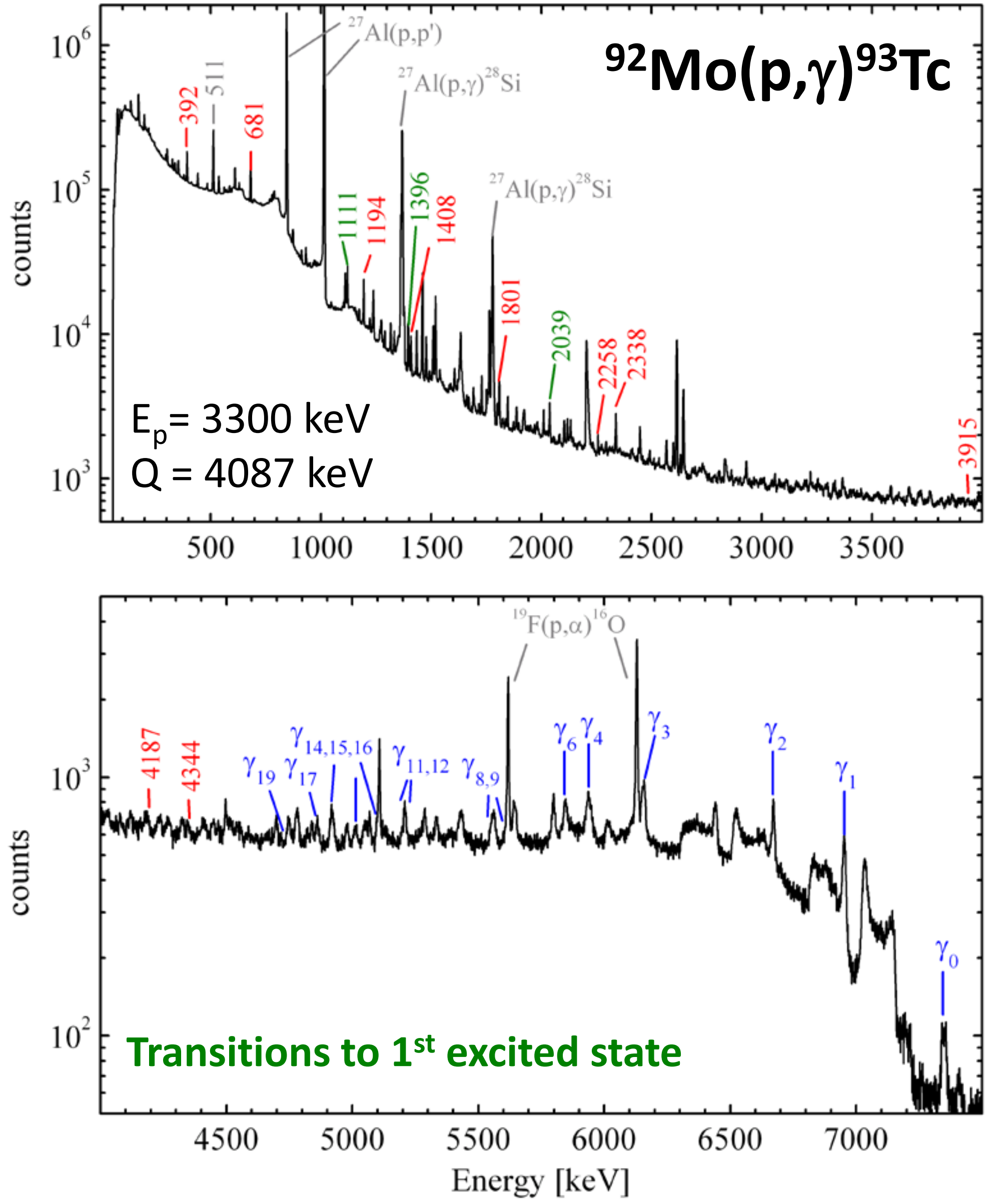
Radiative proton capture on ^{92}Mo

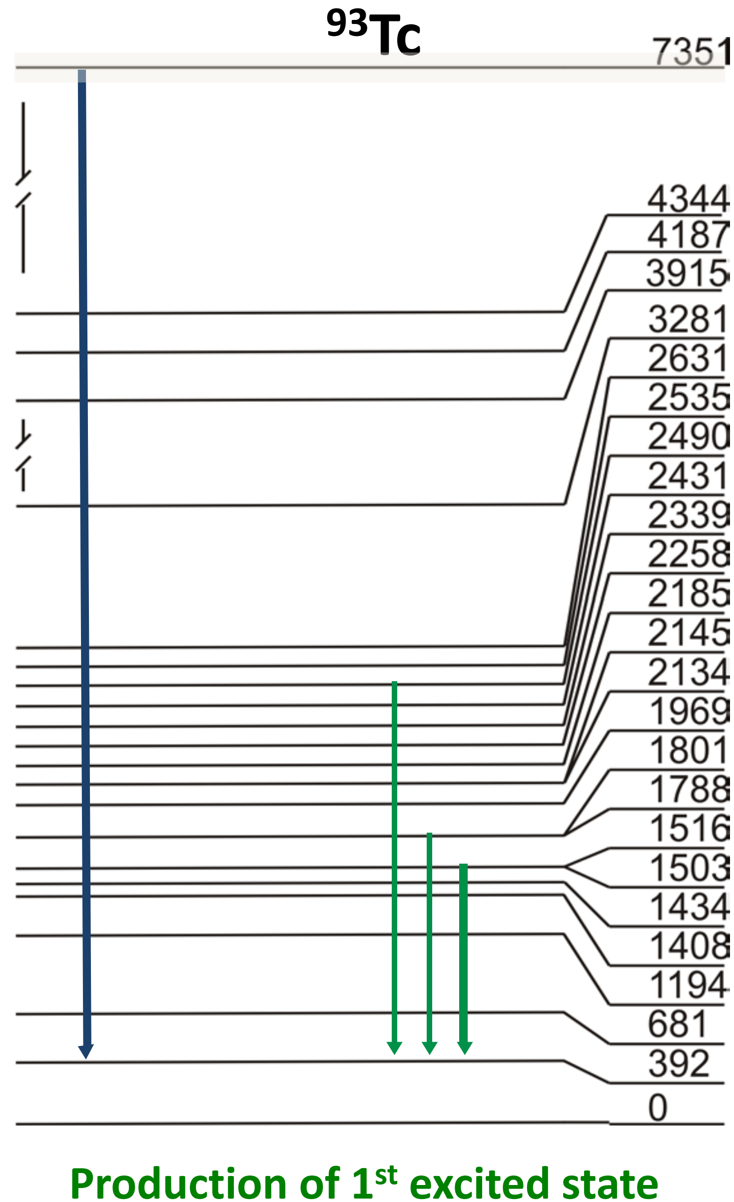




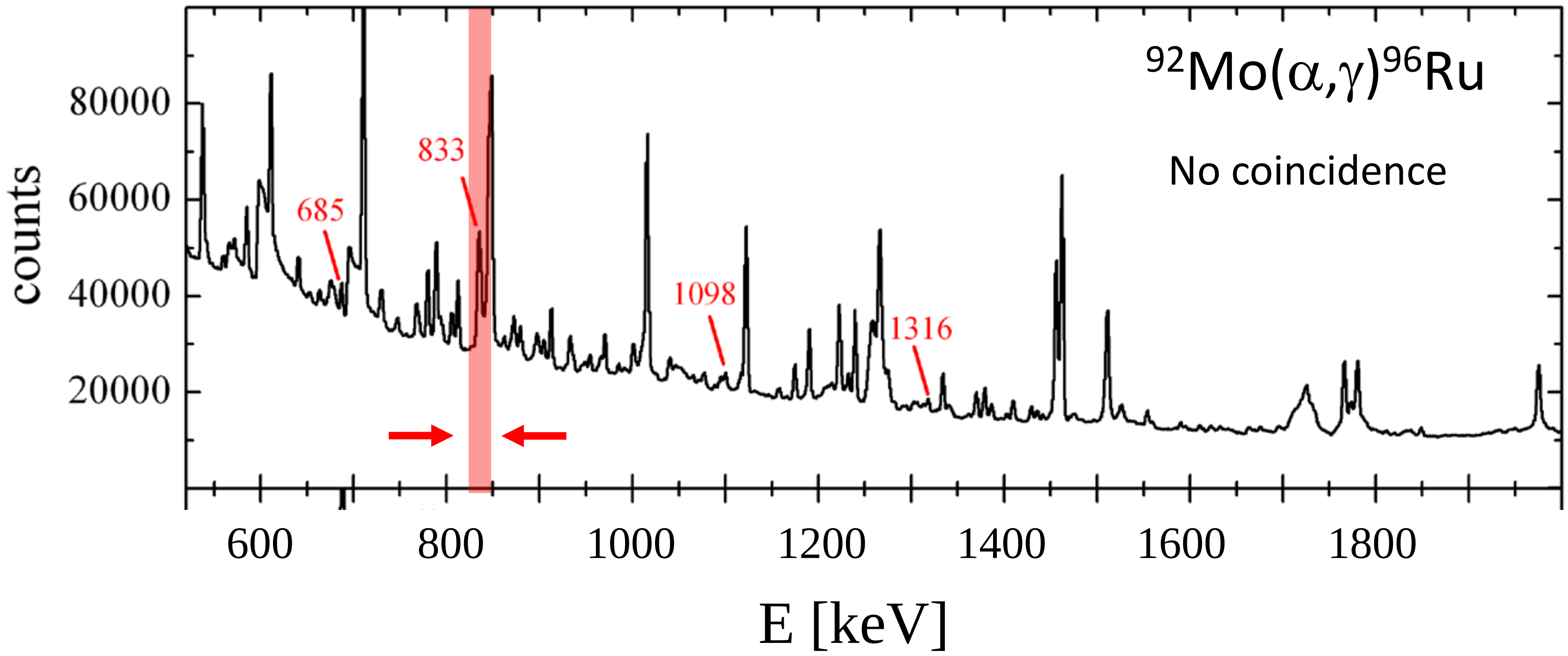
Total cross section

Radiative proton capture on ^{92}Mo

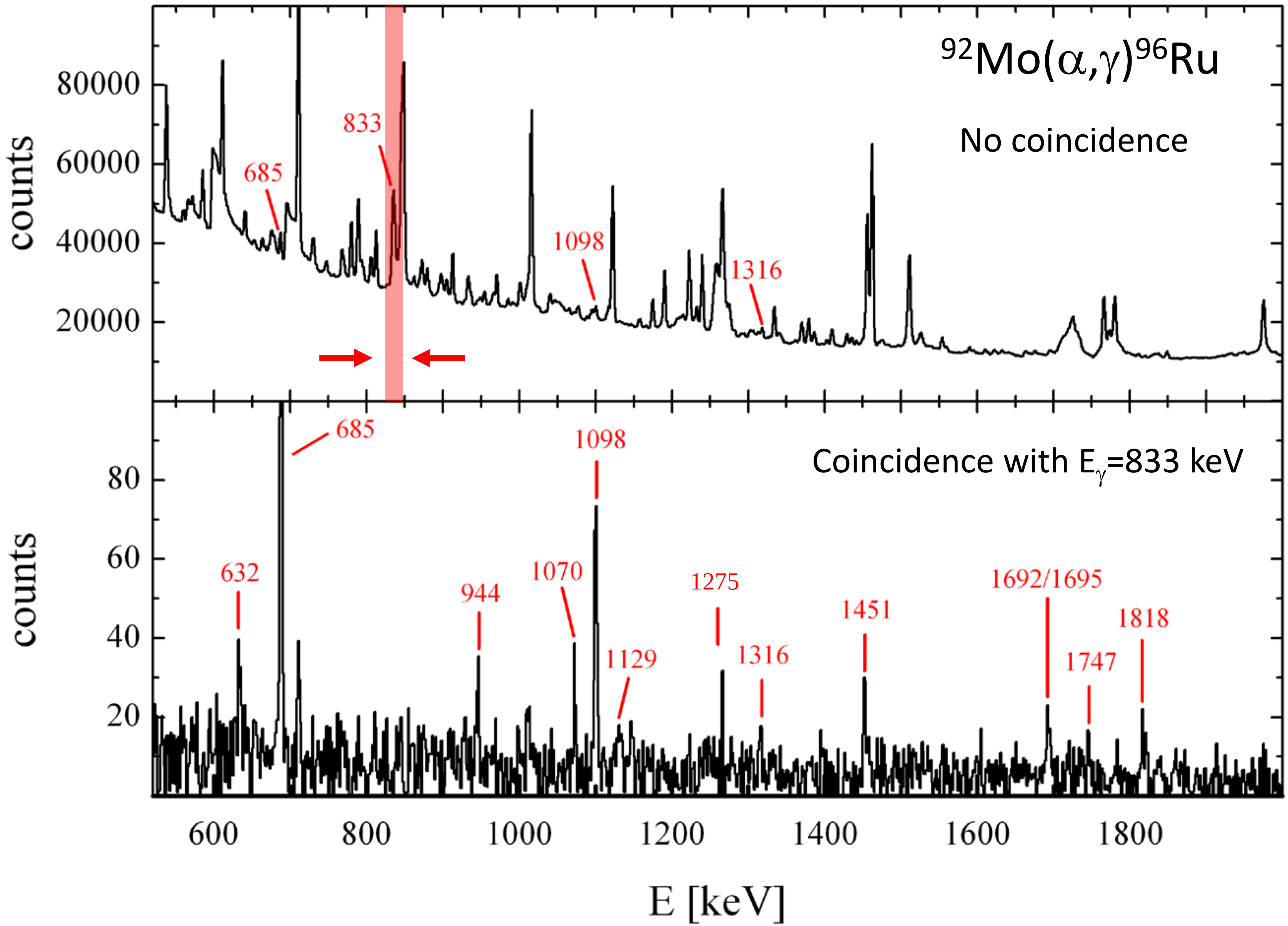




Background reduction using γ-γ coincidence techniques



Background reduction using γ-γ coincidence techniques



One-step (in-beam) experiments using high resolution HPGe arrays

Yields a wealth of information on

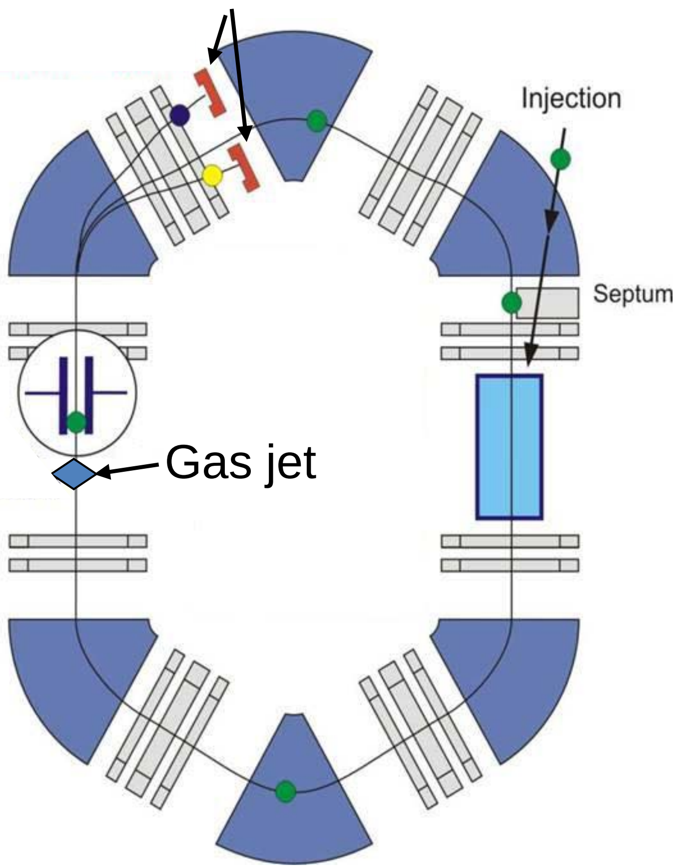
- partial and total cross sections
- gamma ray strength function
- structure of compound system

Talk by SOTIRIS
this afternoon

Find efficient detection techniques: <u>Experiments with radioactive ion beams</u>

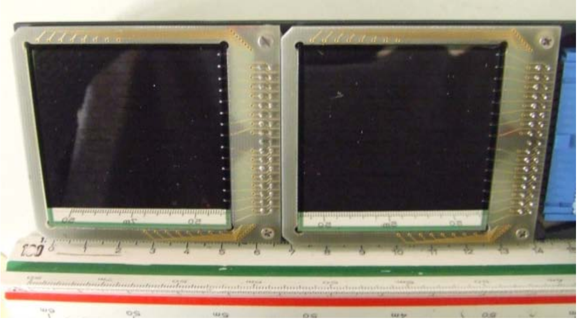
- Experiment is carried out in inverse kinematics
  → typically very low beam currents
- H or He gas (jet) target
- In-beam oder two-step experiments (implantation)

Experiment with radioactive ion beams @ ESR



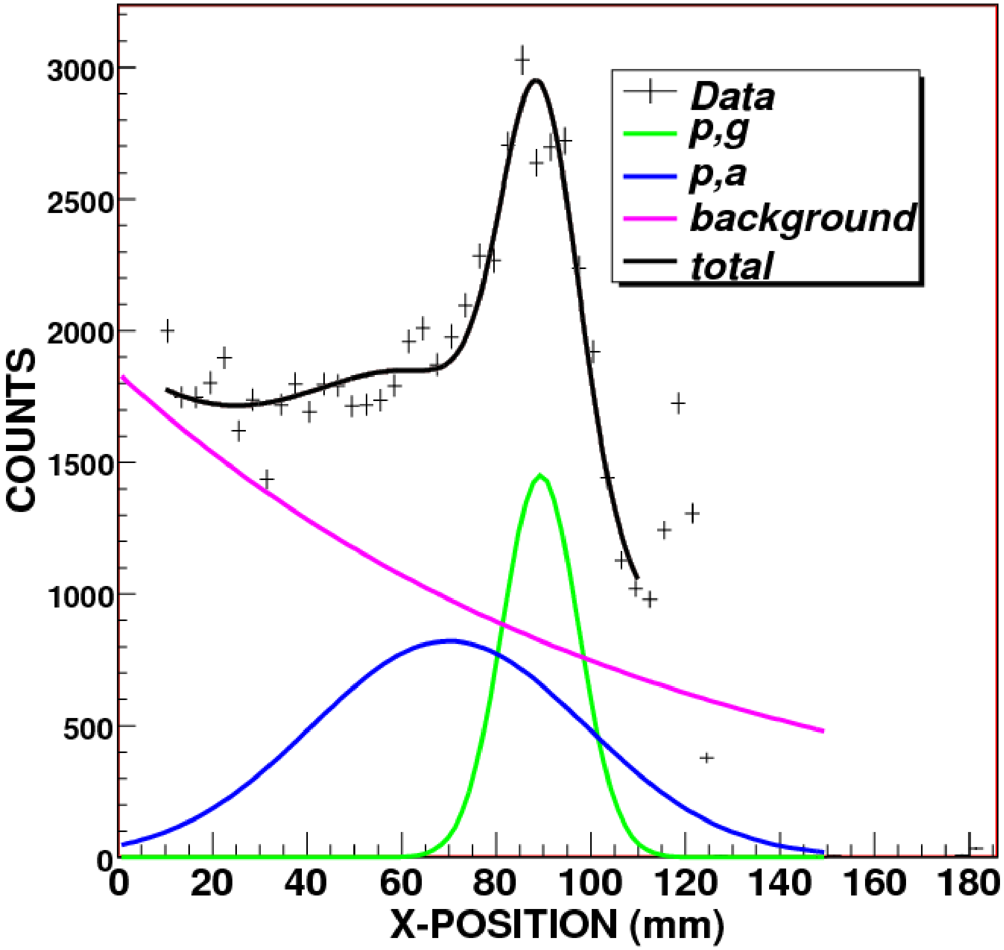
ESR@GSI

- radioactive ion beam injected in storage ring
- deceleration and cooling possible
- internal H or He gas jet target
- detection of ions with in-ring silicon strip detectors



Courtesy: M. Heil

Pilot experiment with stable beam: $^{96}Ru(p,\gamma)^{97}Rh$



Without (p,n) component – resulting in an upper limit for (p,γ)

$\sigma_{PG} < 4.0$ mb

Non-smoker: 3.5 mb

Courtesy: M. Heil

Experimental techniques to measure ion-induced cross sections and applications to the p process

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V. Foteinou, A. Lagoyannis, S. Harissopulos

INP Demokritos, Athens, Greece

H.W. Becker, D. Rogalla

Ruhruniversität Bochum

U. Giesen

PTB Braunschweig

supported by DFG **(ZI 510/5-1 and INST 216/544-1)**

Gamma-ray strength functions used in TALYS code

Brink-Axel standard Lorentzian

Generalized Lorentzian Kopecky-Uhl for E1 radiation

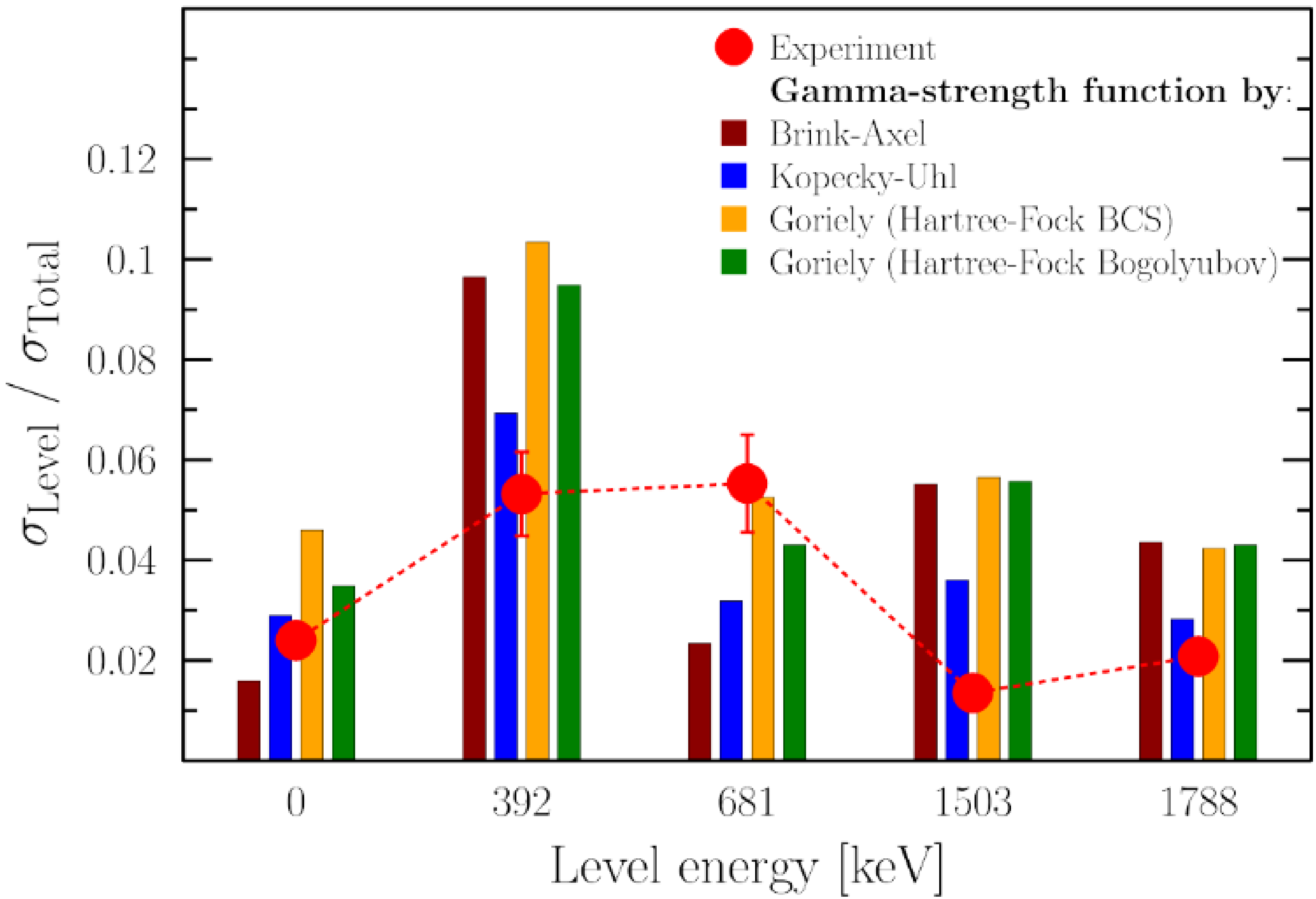
Hartree-Fock BCS tables for E1 radiation

Hartree-Fock-Bogolyubov tables for E1 radiation

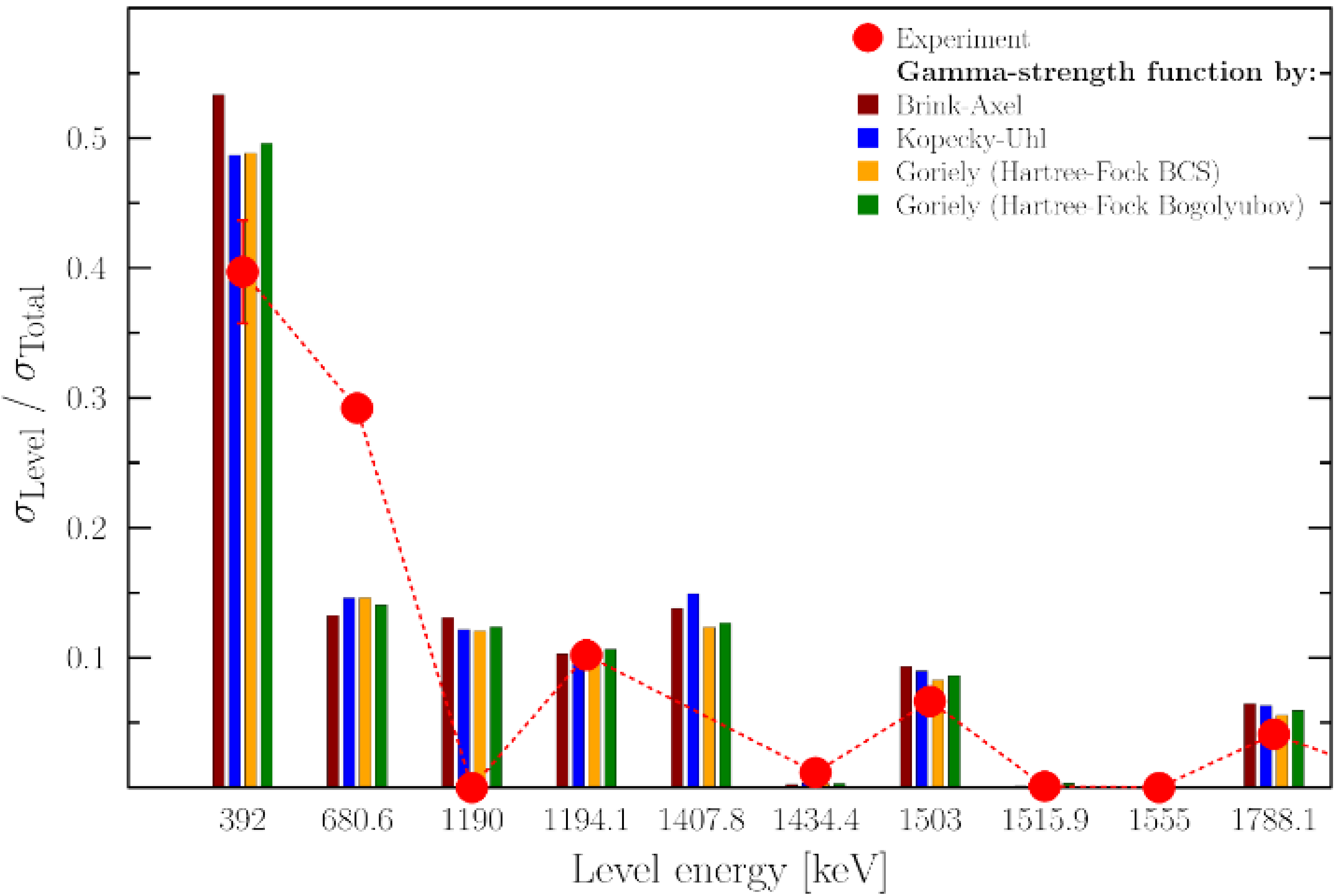
TALYS 1.2:

A. Koning, S. Hilaire, M. Duijvestijn

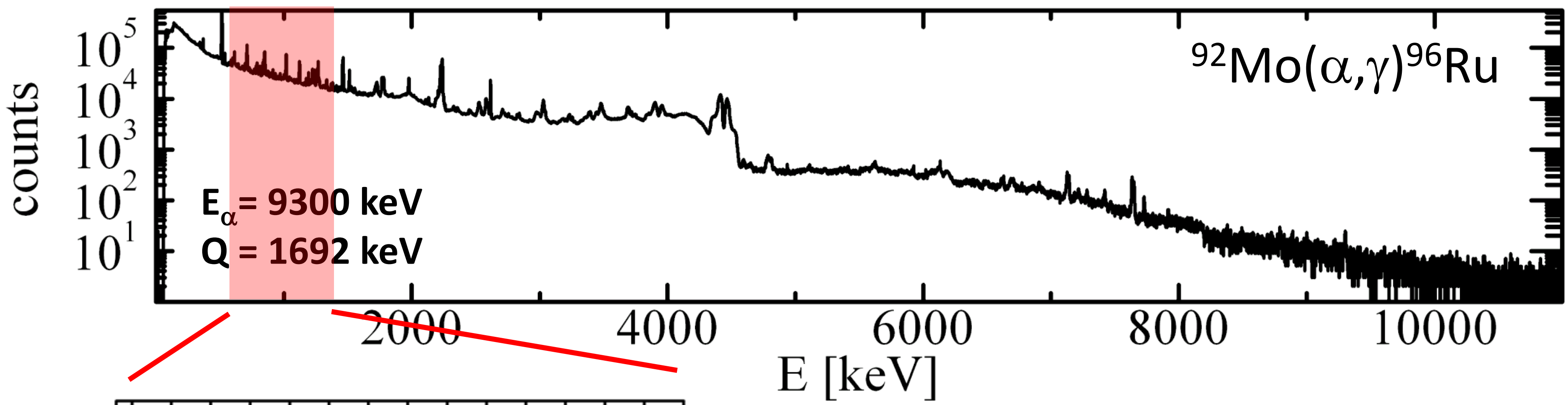
Partial cross sections for $^{92}Mo(p,\gamma)$

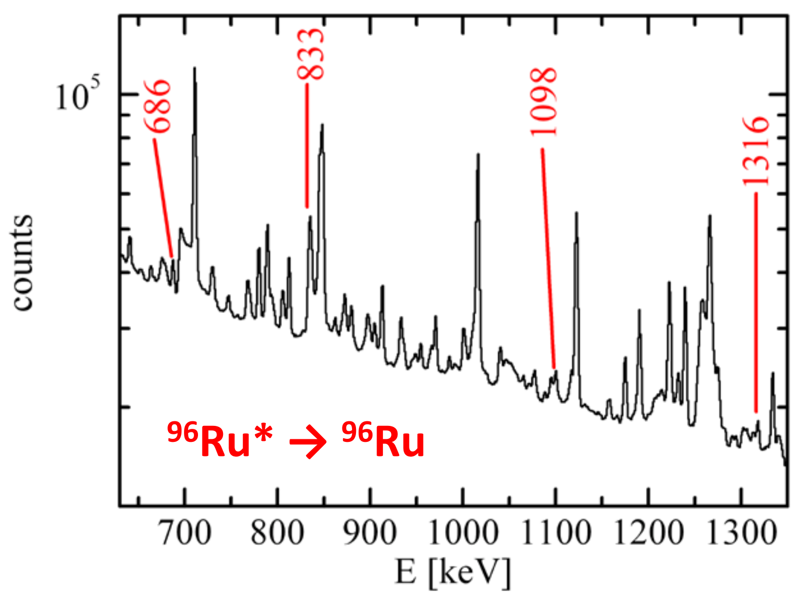


Population of levels in $^{92}Mo(p,\gamma)$



Radiative α capture: $^{92}Mo(\alpha,\gamma)$



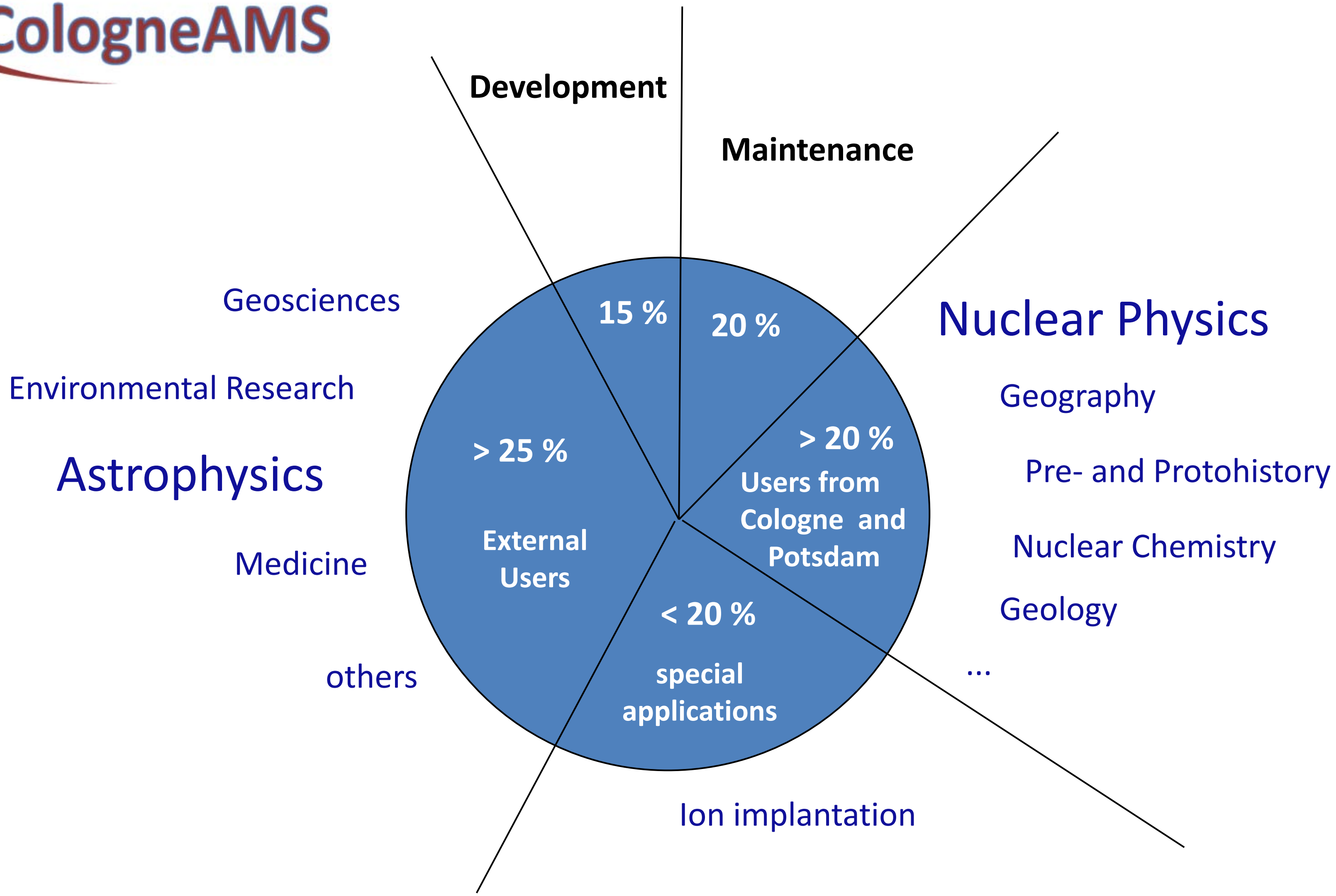


σ(experiment) = 382 ± 100 µb

σ(TALYS) = 422 µb

Beamtime distribution at CologneAMS

CologneAMS



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CologneAMS

Inauguration: October 1st, 2010

CologneAMS – a new option to measure small reaction cross sections

CologneAMS

Inside the Tandetron