Experiments to study optical-model potentials

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Astrophysics with modern small-scale accelerators

Physikzentrum Bad Honnef

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Member of the Bonn-Cologne Graduate School of Physics and Astronomy

Bonn-Cologne Graduate School of Physics and Astronomy

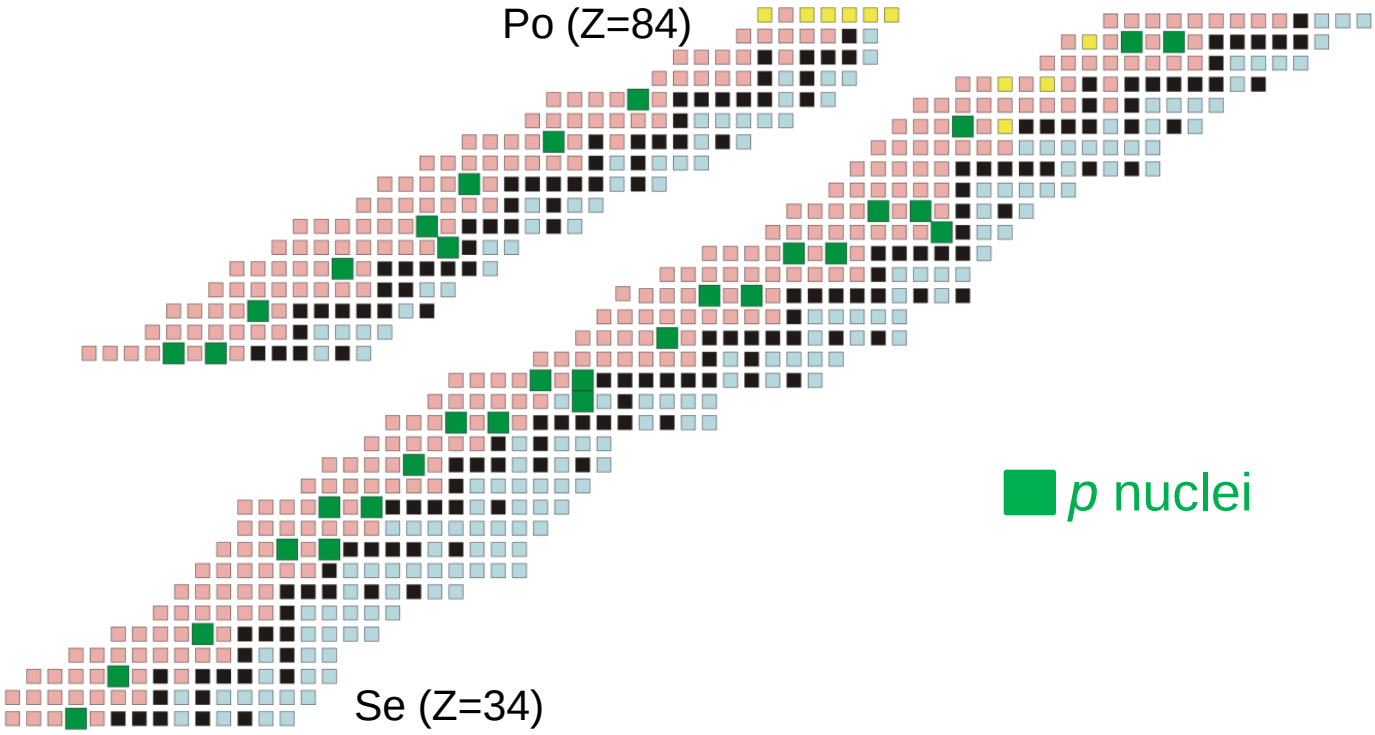
Outline

- *p* nuclei
- off-beam experiment (activation)
  - ^{141}Pr(α,n)^{144}Pm at PTB Braunschweig
- in-beam measurements with HPGe detectors
  - ^{74}Ge(p,γ)^{75}As at INP „Demokritos“ Athens
- summary

Some facts about the *p* nuclei…

p nuclei:

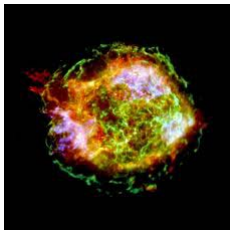
- proton-rich isotopes of some elements between Se and Hg
- not produced in the *s* or *r* process
- between 30 and 35 nuclei
- isotopic abundances ~ 0.1 – 1%

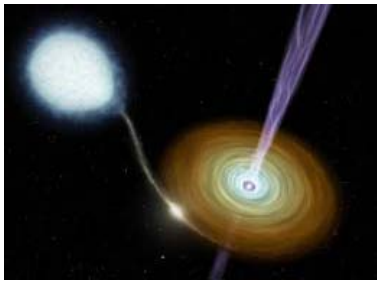


Some facts about the *p* nuclei…

nucleosynthesis of *p* nuclei:

- different *p* nuclei are produced by different processes in various astrophysical sites
- γ process (core-collapse supernovae (SN), Type Ia SN, subChandrasekhar SN)
- ν process (core-collapse SN)
- rp process (accreting binary system with compact object)
- pn process (subChandrasekhar SN)
- νp process (core-collapse SN)





reaction network:

- large network of reactions: Photodisintegrations, proton capture reactions, β decays, …
- ~ 20000 reactions
- ~ 2000 nuclei (mainly unstable)

Difficulties in the determination of reaction rates

- number of reactions too large to measure all of them
- many reactions on radioactive nuclei
  ➡ (currently) not measurable
- Gamow window located at low energies, often below Coulomb barrier
  ➡ small cross sections

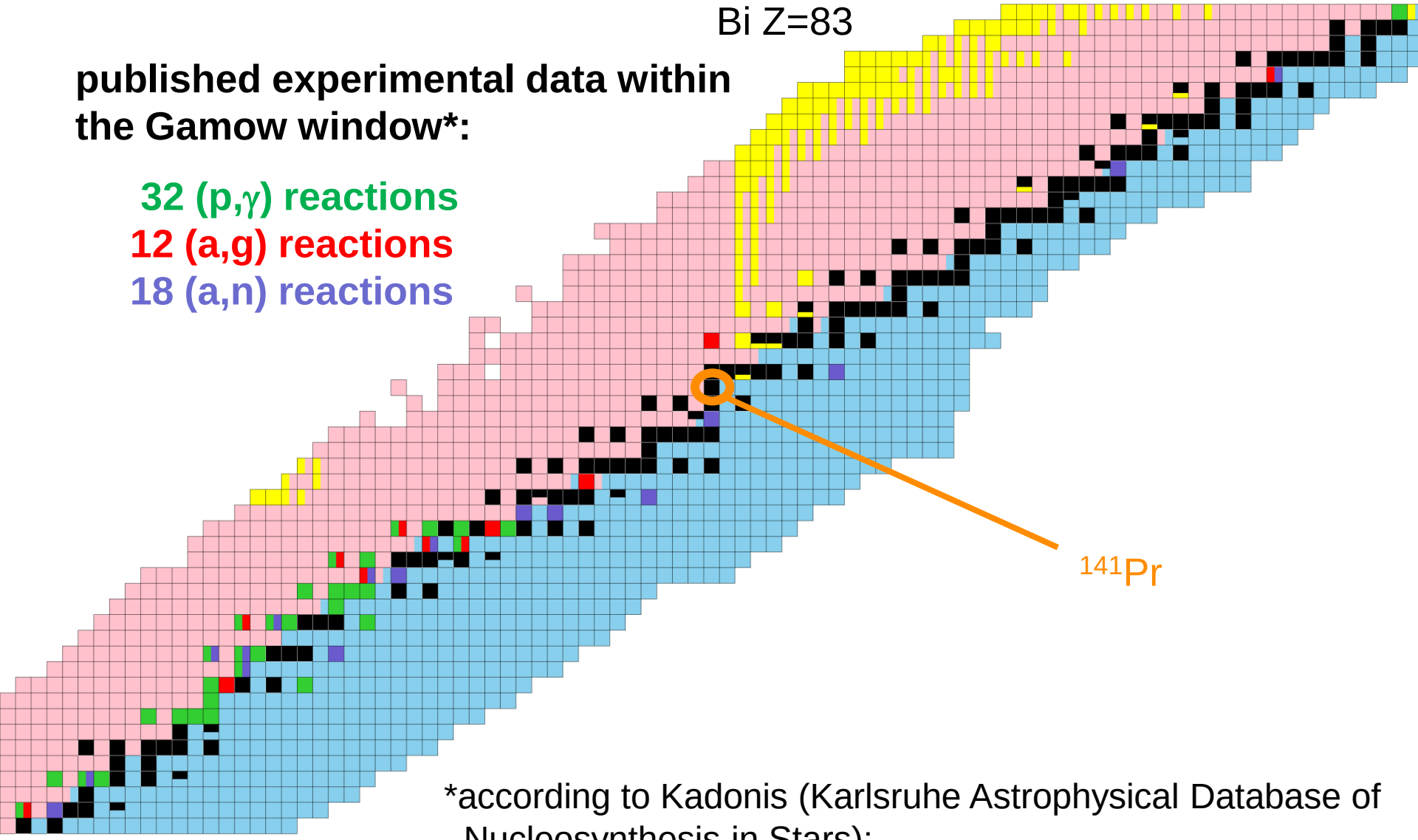
theoretical calculations necessary

- to calculate reaction rates, if no experimental data is available
- to extrapolate the data towards smaller energies, if experimental data is available above the Gamow window

improvement of nuclear models to calculate reaction rates

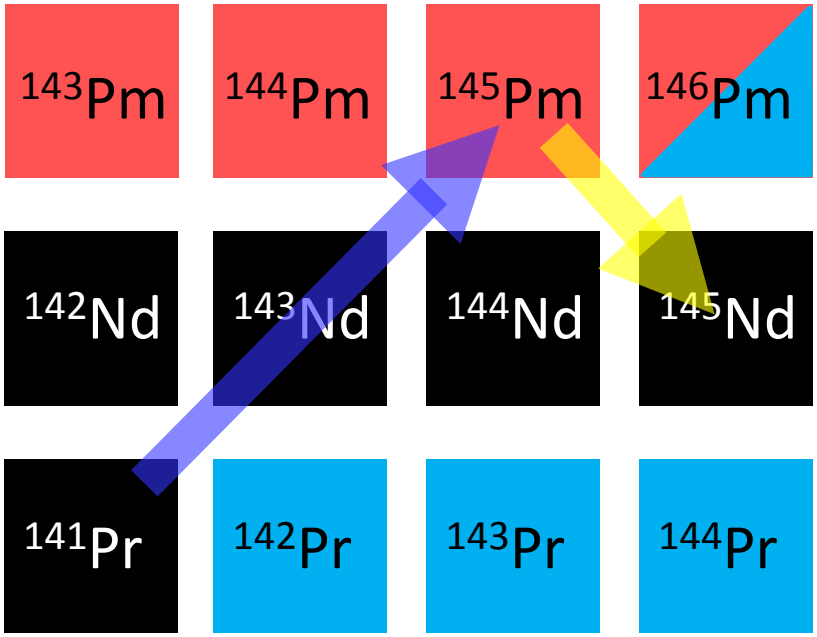
- nuclear masses
- properties of excited states
- nuclear level densities
- γ-strength functions
- optical model potentials (OMP)

Experimental situation for proton- & α-induced reactions



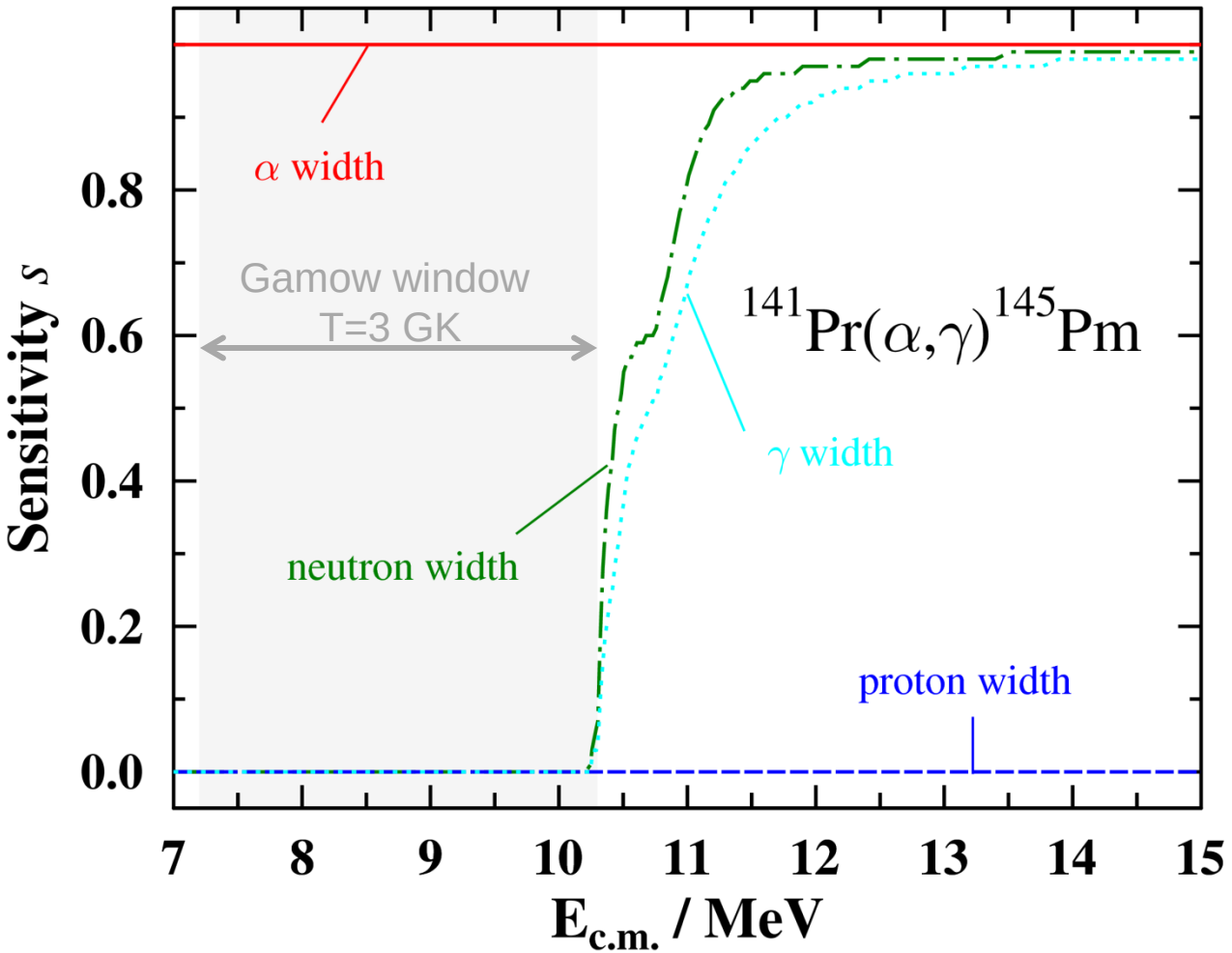
*according to Kadonis (Karlsruhe Astrophysical Database of Nucleosynthesis in Stars): http://www.kadonis.org (January 21st, 2012)

α+^{141}Pr optical model potential



- inside the star the reaction ^{145}Pm(γ,α)^{141}Pr takes place
- but stellar effects for reverse reaction ^{141}Pr(α,γ)^{145}Pm are smaller

Relevance of nuclear physics input of different reaction channels



- within the Gamow window: only sensitive to α width

➡ BUT:

^{141}Pr (α,γ) reaction hampered by small cross section and weak γ intensity in ^{145} Nd

➡ idea:

improvement of α+^{141}Pr OMP by ^{141}Pr(α,n) reaction

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

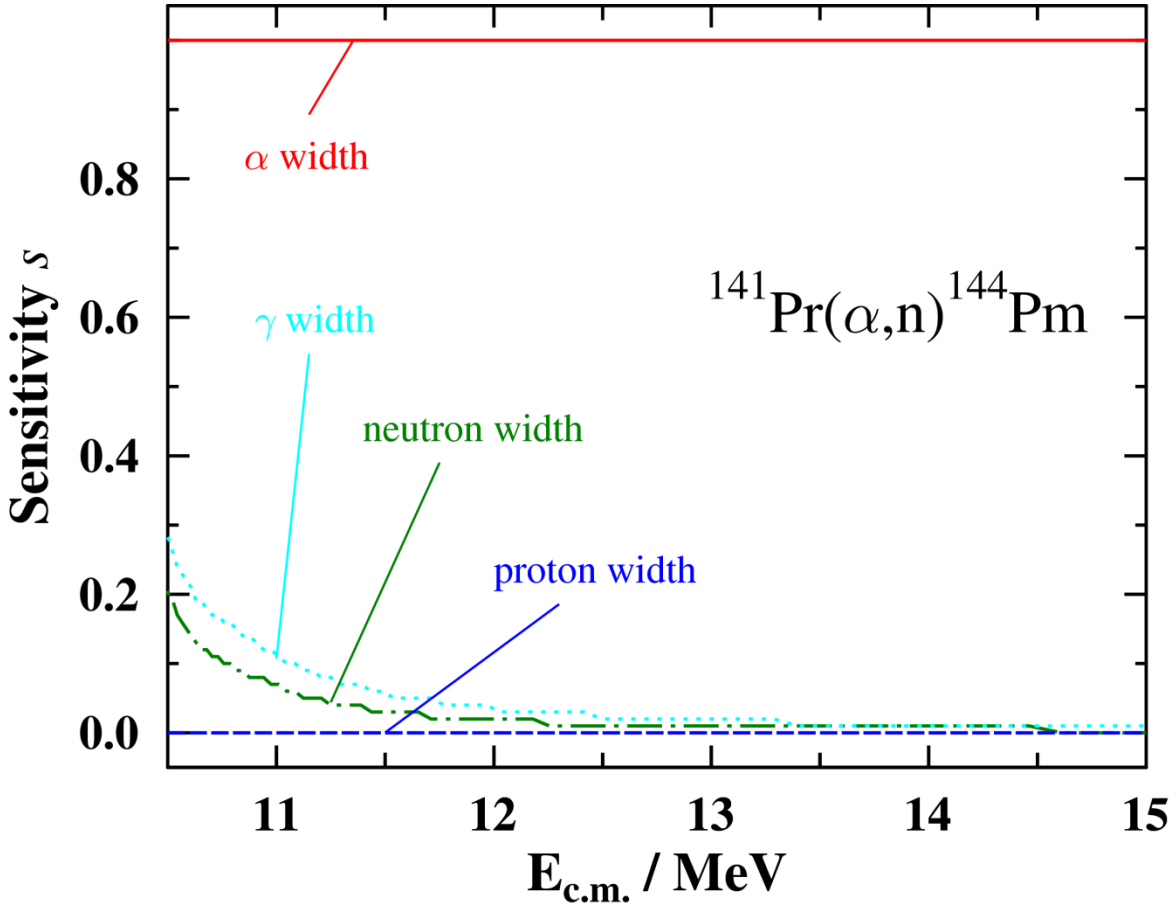
Calculated with SMARAGD Code version 0.8.3s (T. Rauscher)

Relevance of nuclear physics input of different reaction channels

except close to the (α,n) threshold the ^{141}Pr(α,n)-rate is sensitive to the α-nucleus OMP

experimental data improve the α-nucleus OMP

improvement of predictions of stellar ^{145}Pm(γ,α)^{141}Pr-rate



A. Sauerwein *et al.*,
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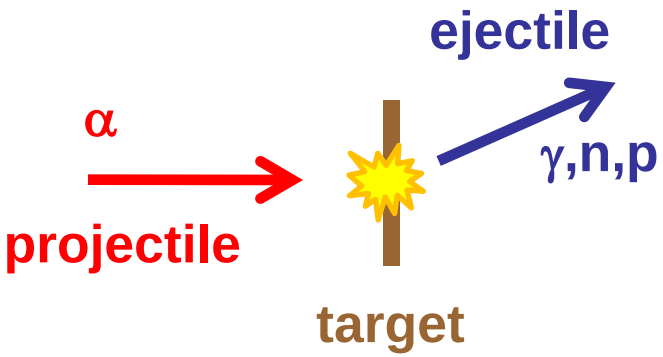
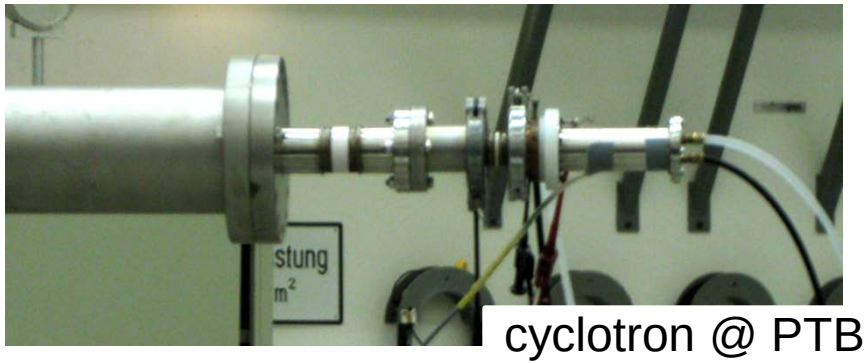
Activation experiments

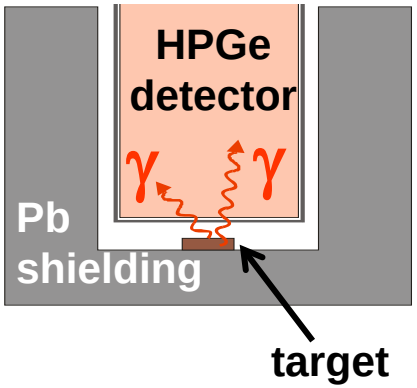
I. Activation





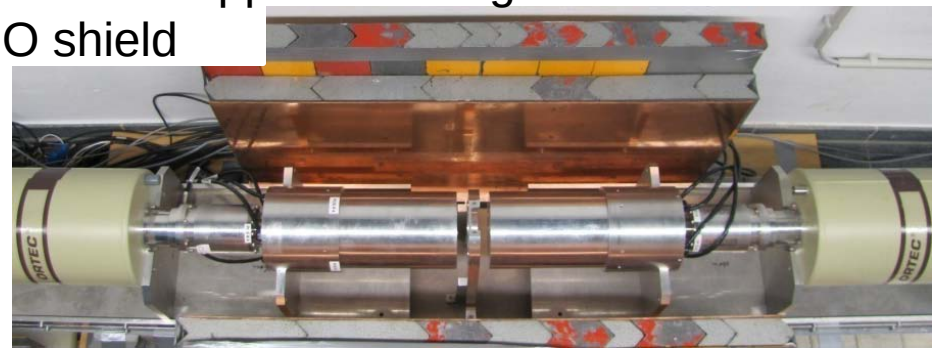
cyclotron @ PTB Braunschweig

II. Counting



Counting setup in Cologne:

- 2 HPGe Clover detectors (relative efficiency of 120% each)
- passive lead and copper shielding
- active BGO shield



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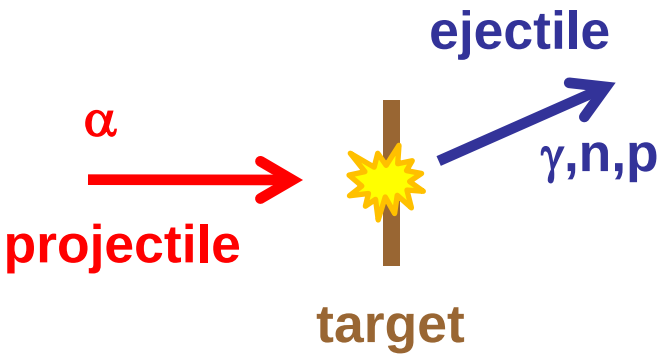

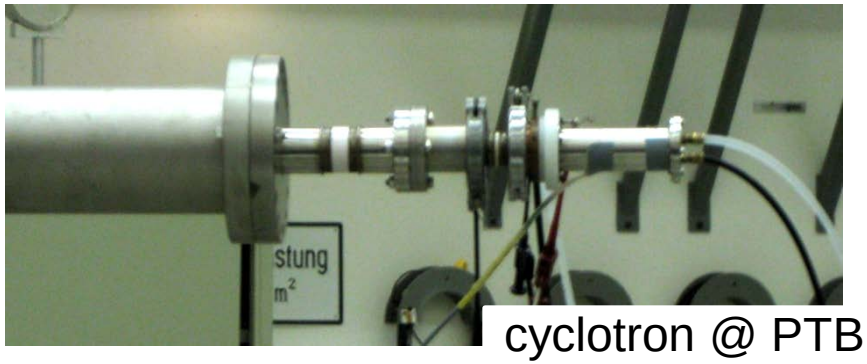

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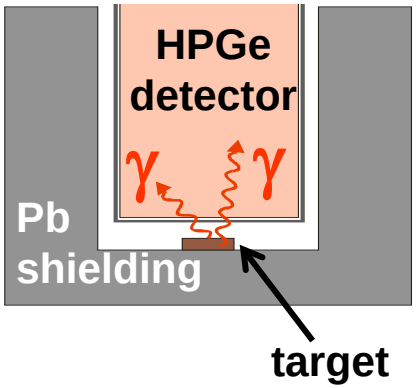

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G. Duchêne *et al*. NIM **A** 432 (1999) 90

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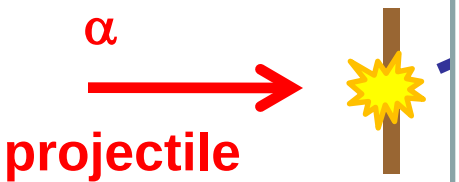
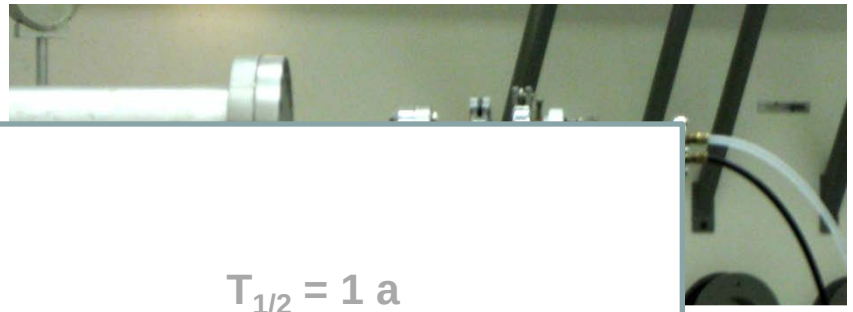
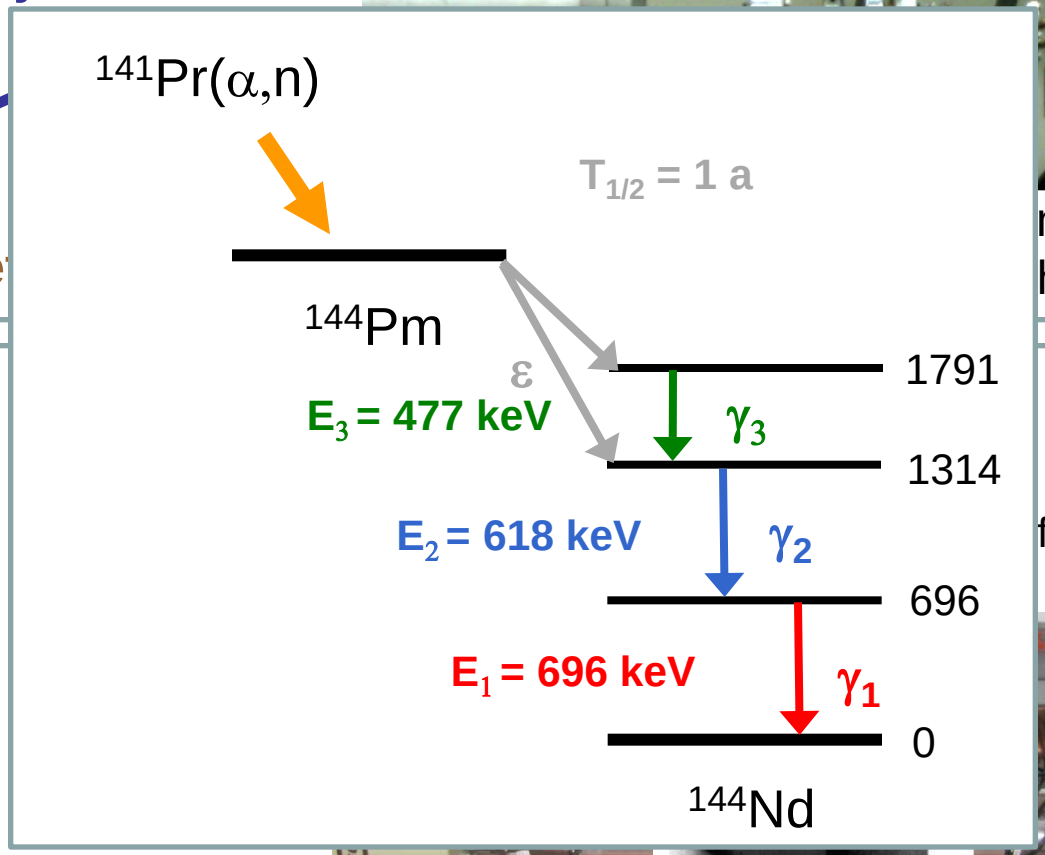




n @ PTB
hweig



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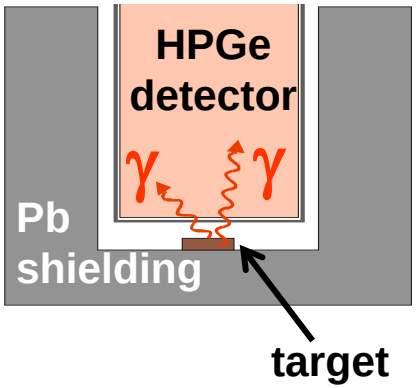

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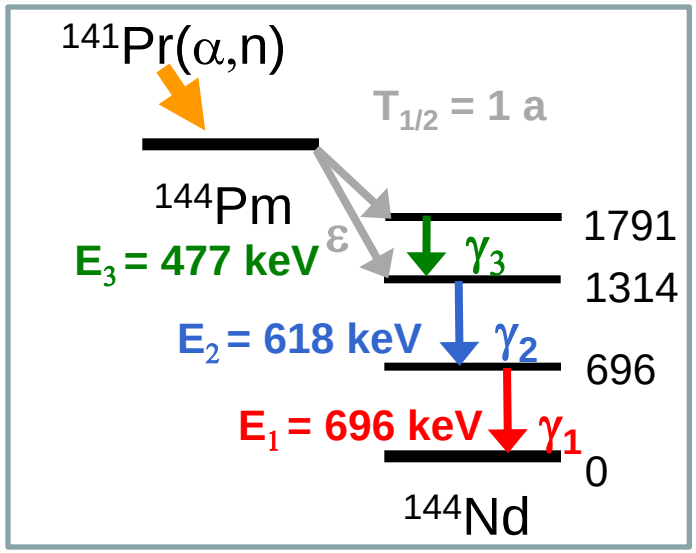
G. Duchêne *et al*. NIM **A** 432 (1999) 90

Experimental parameters and spectra

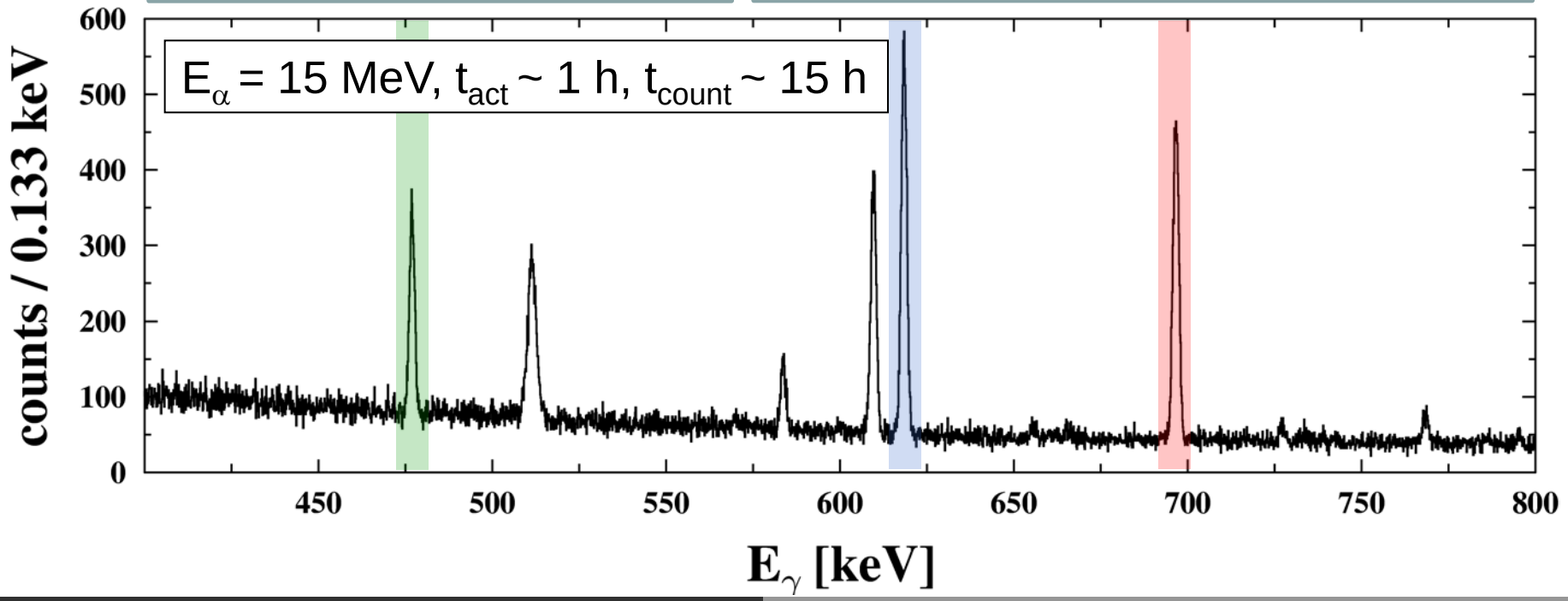


beam intensities up to 3.5 μA

α energies: 11, 11.4, 12, 12.6, 13.2, 13.8, 14.4, and 15 MeV

t_{act} : 1 - 17 h

t_{count} : 15 h - 40 d



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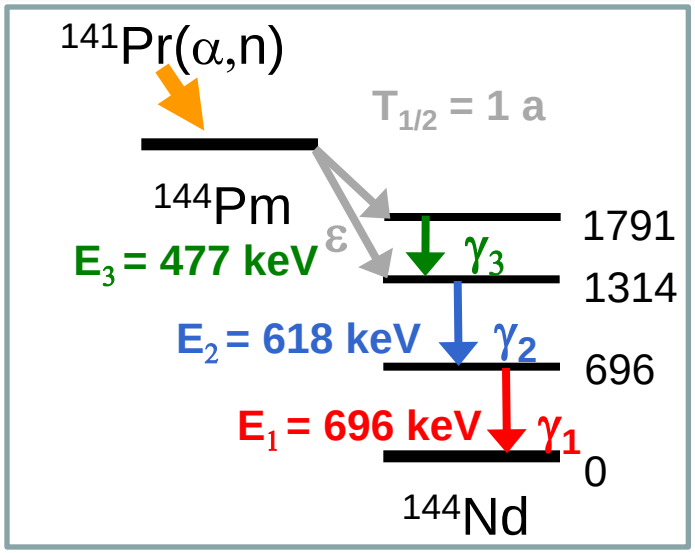

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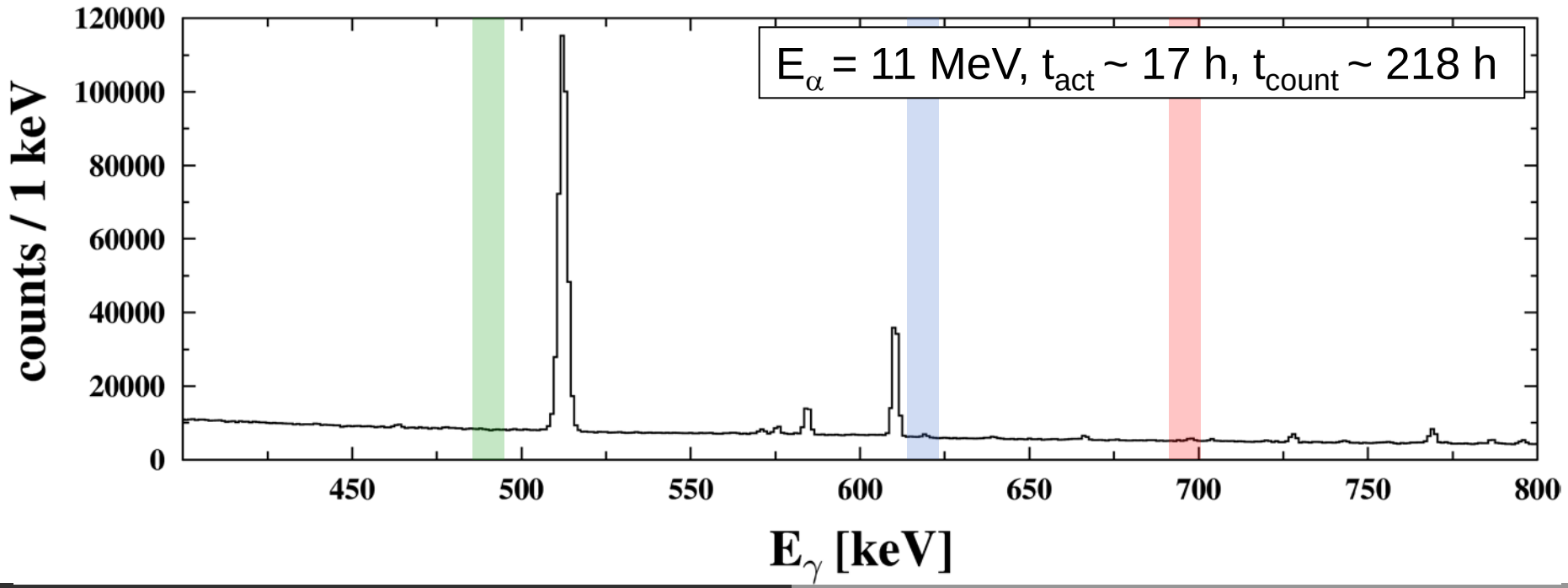

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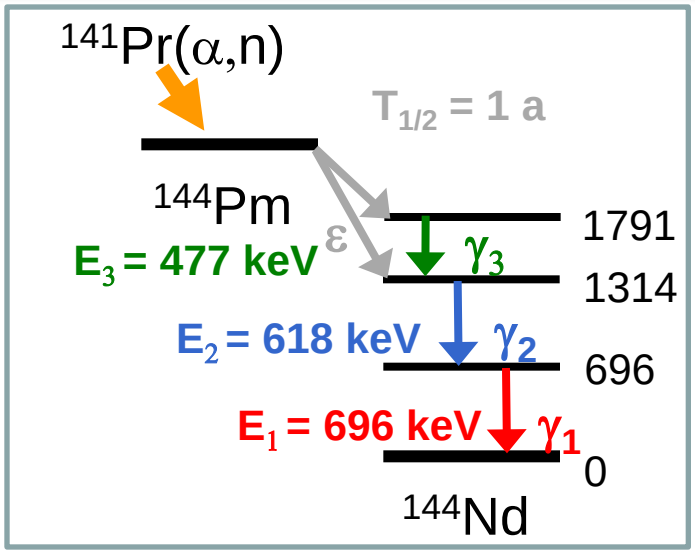

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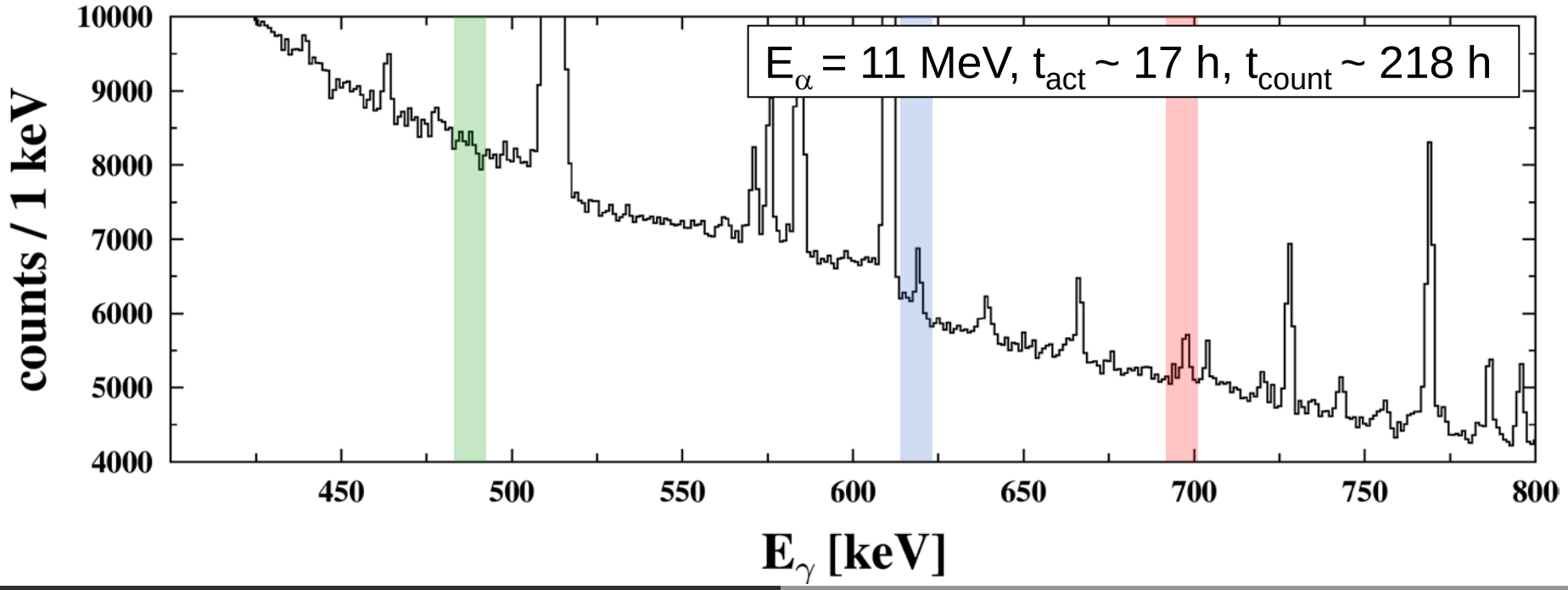
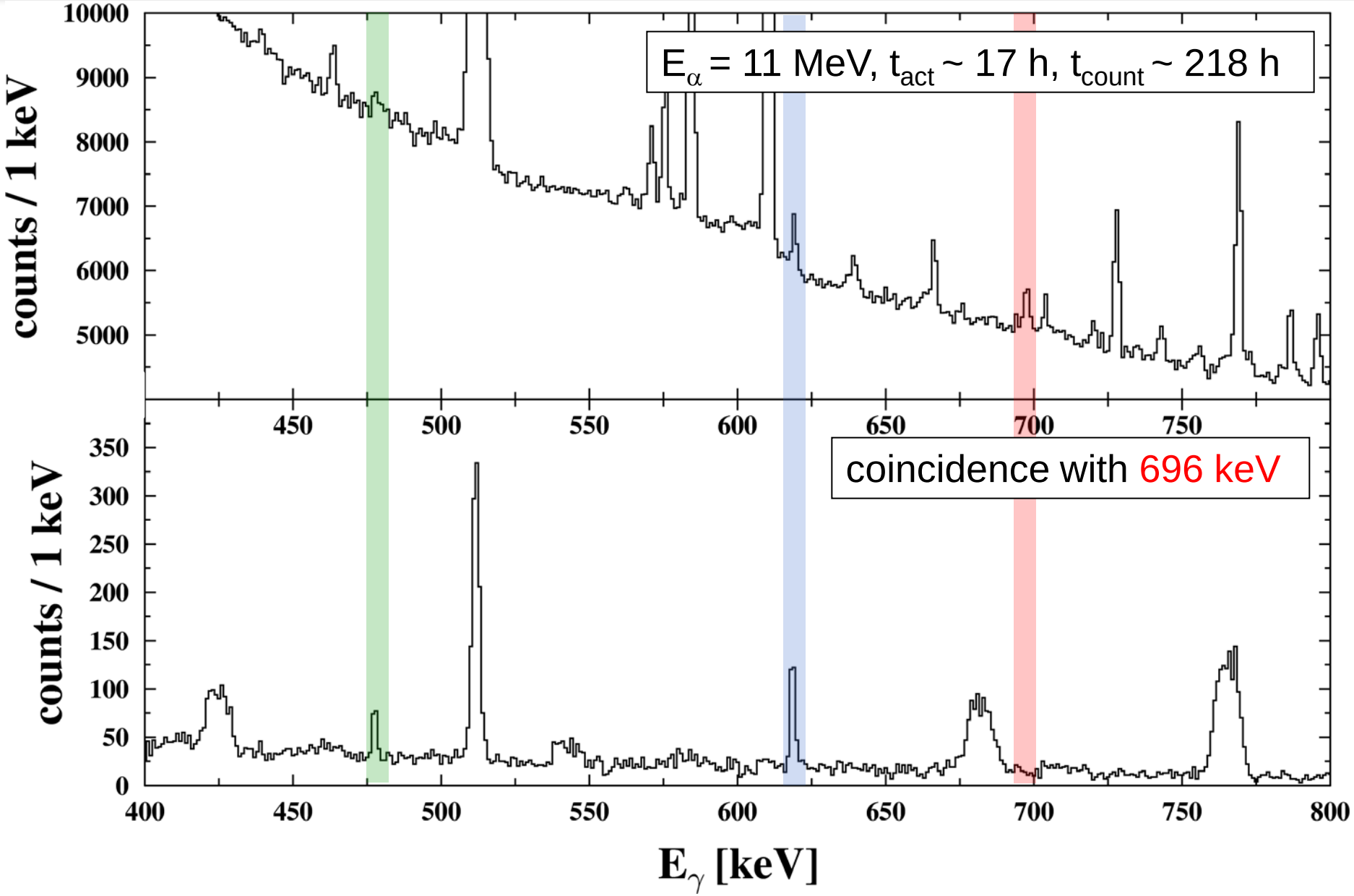


Comparison of single spectra and coincidence spectra



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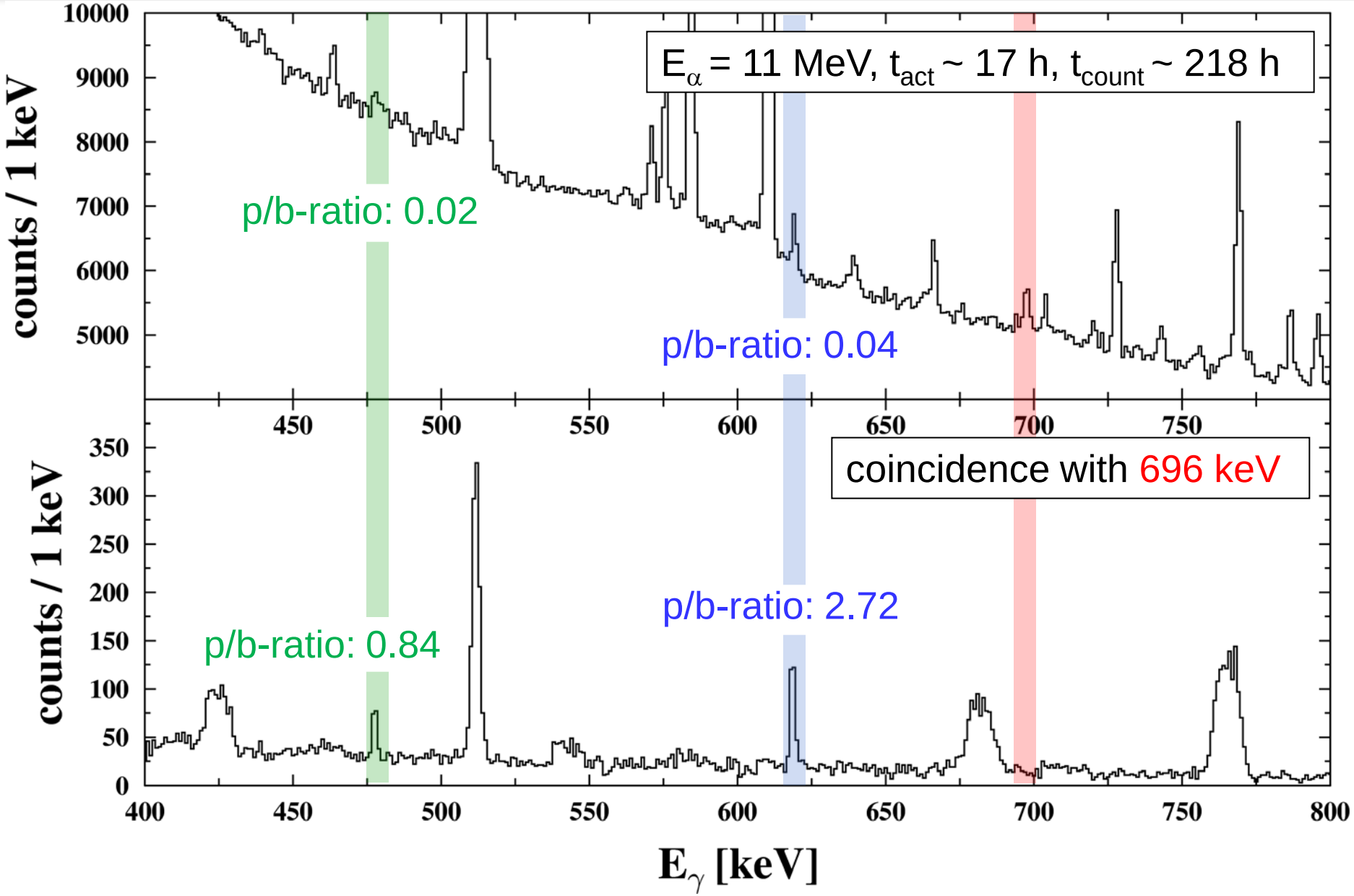
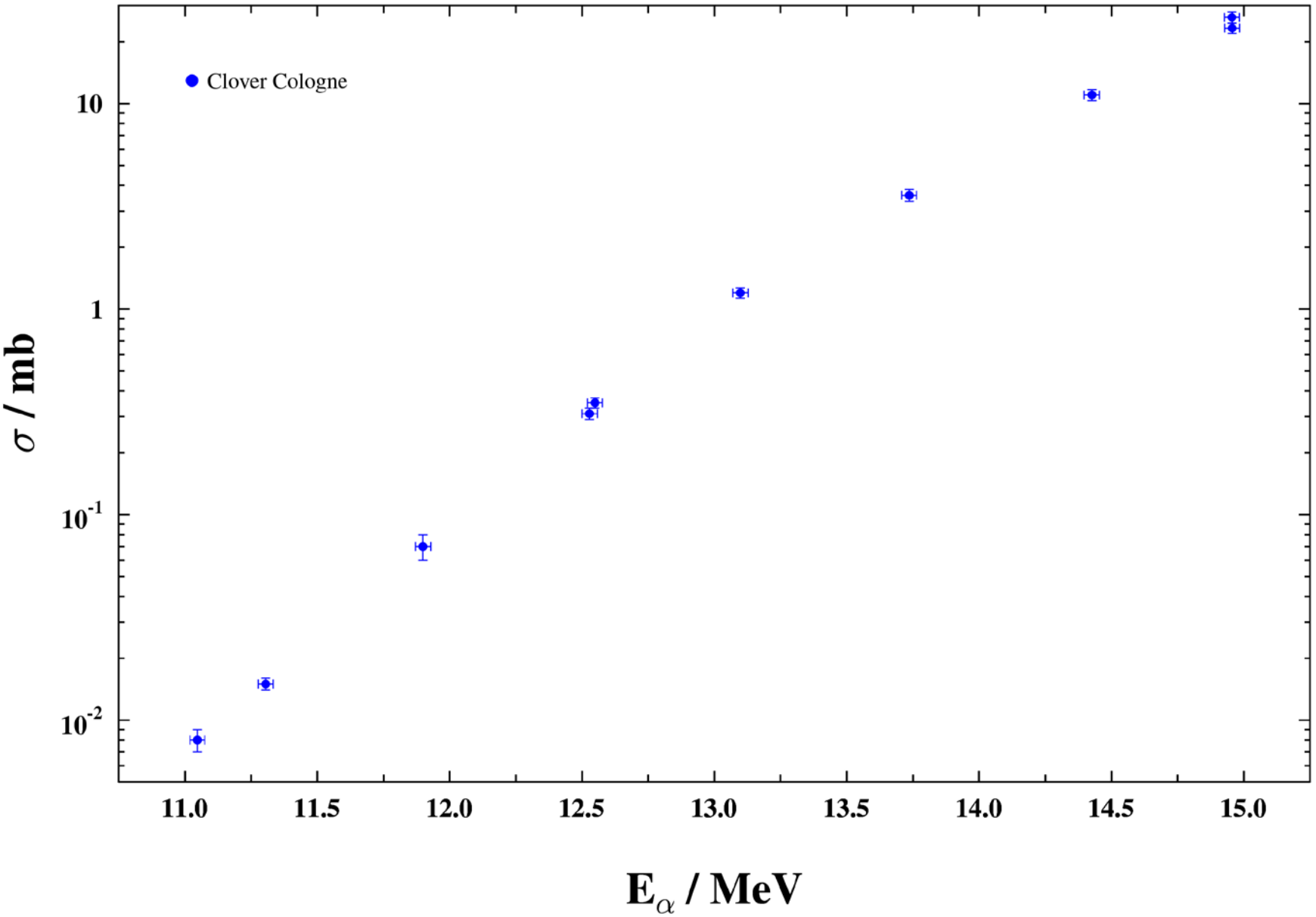


Consistency check of coincidence method



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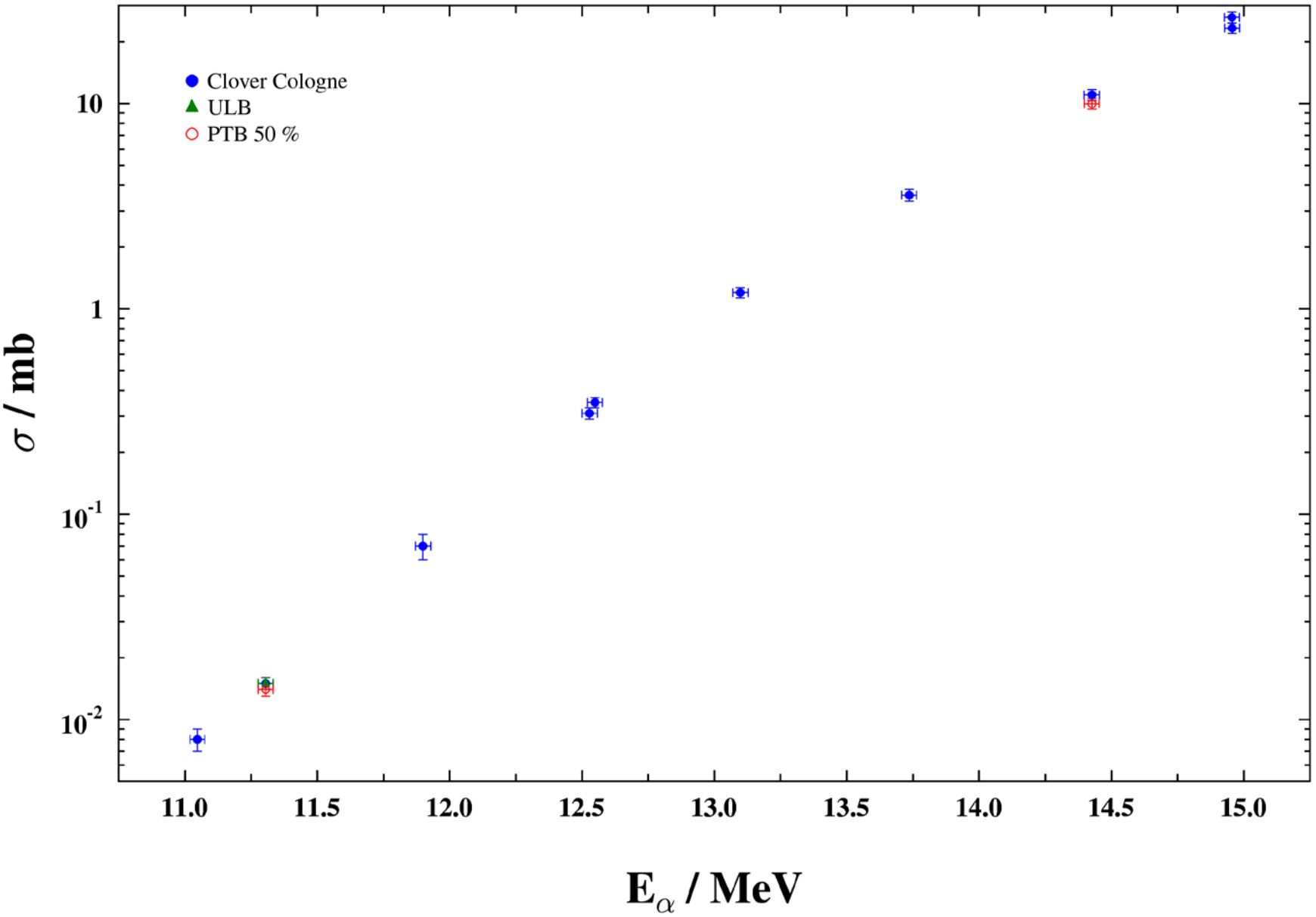

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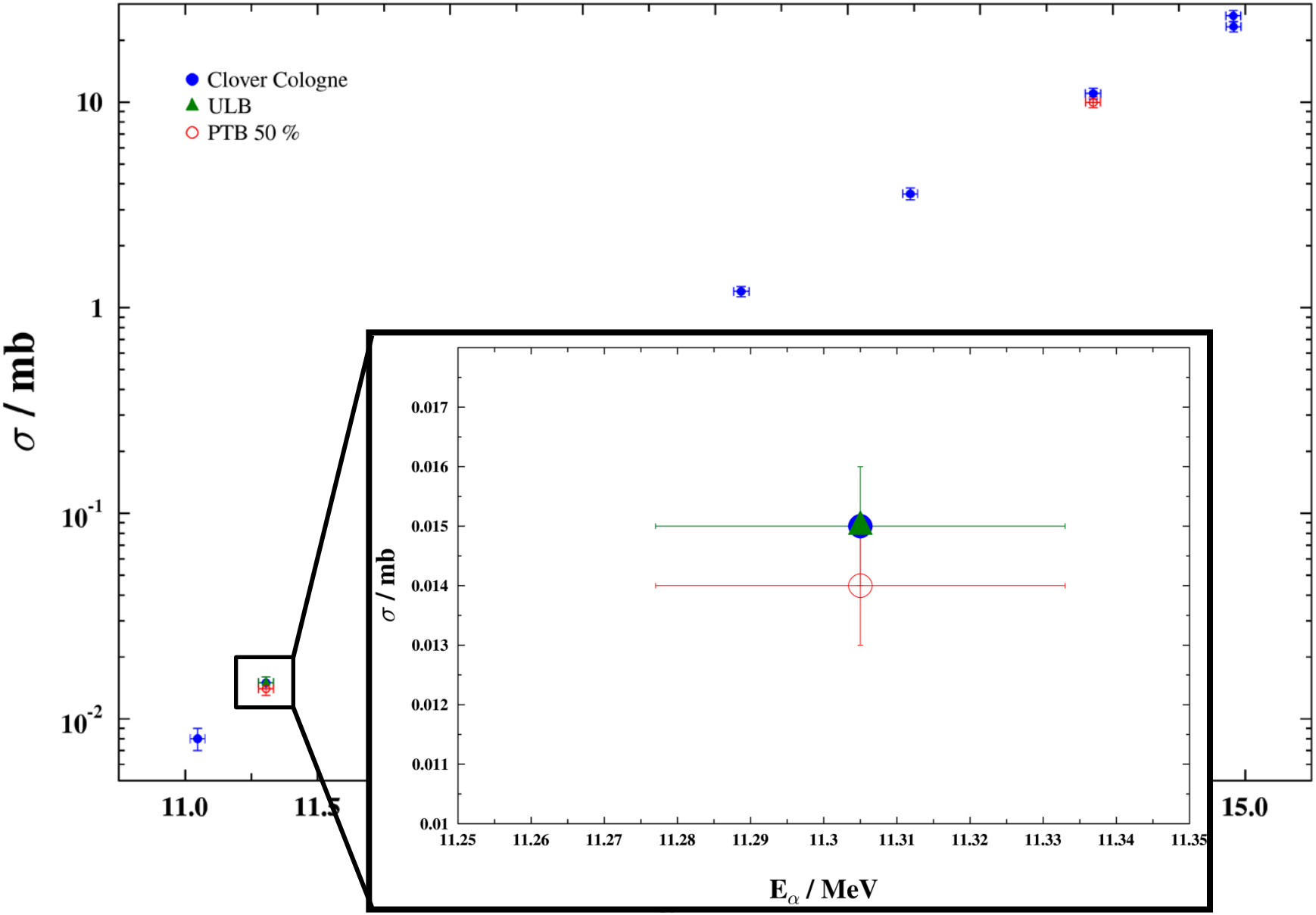

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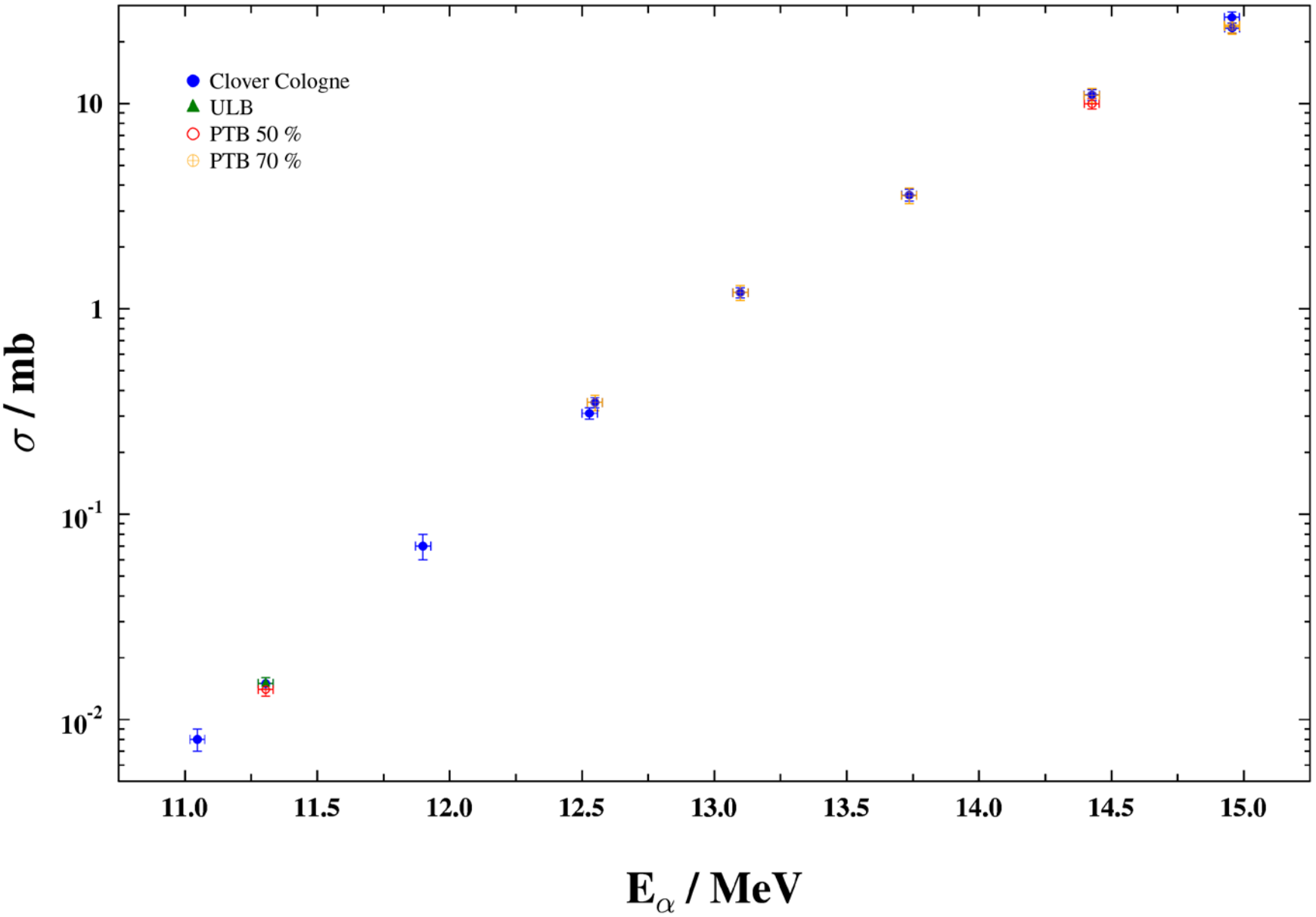

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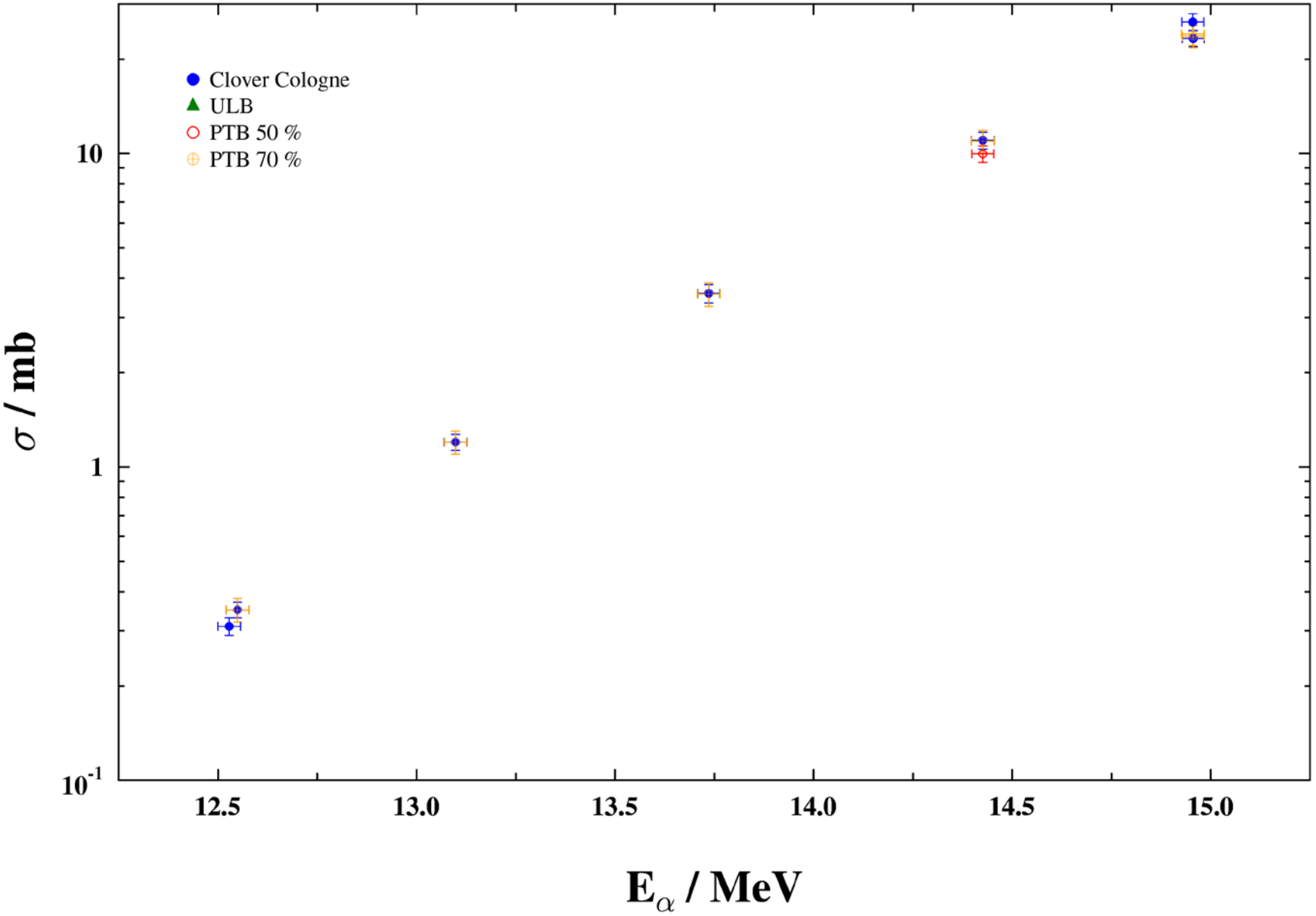

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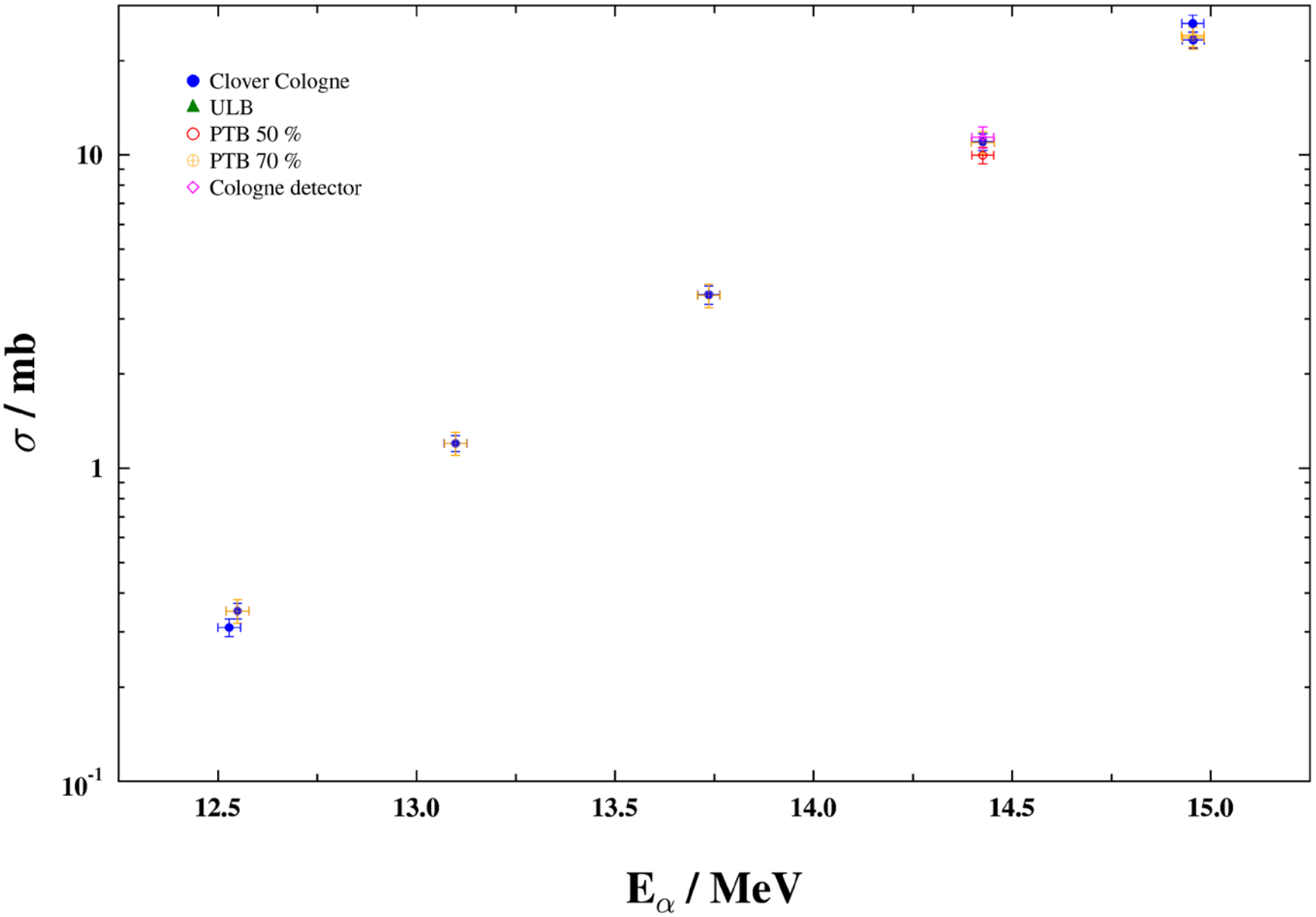
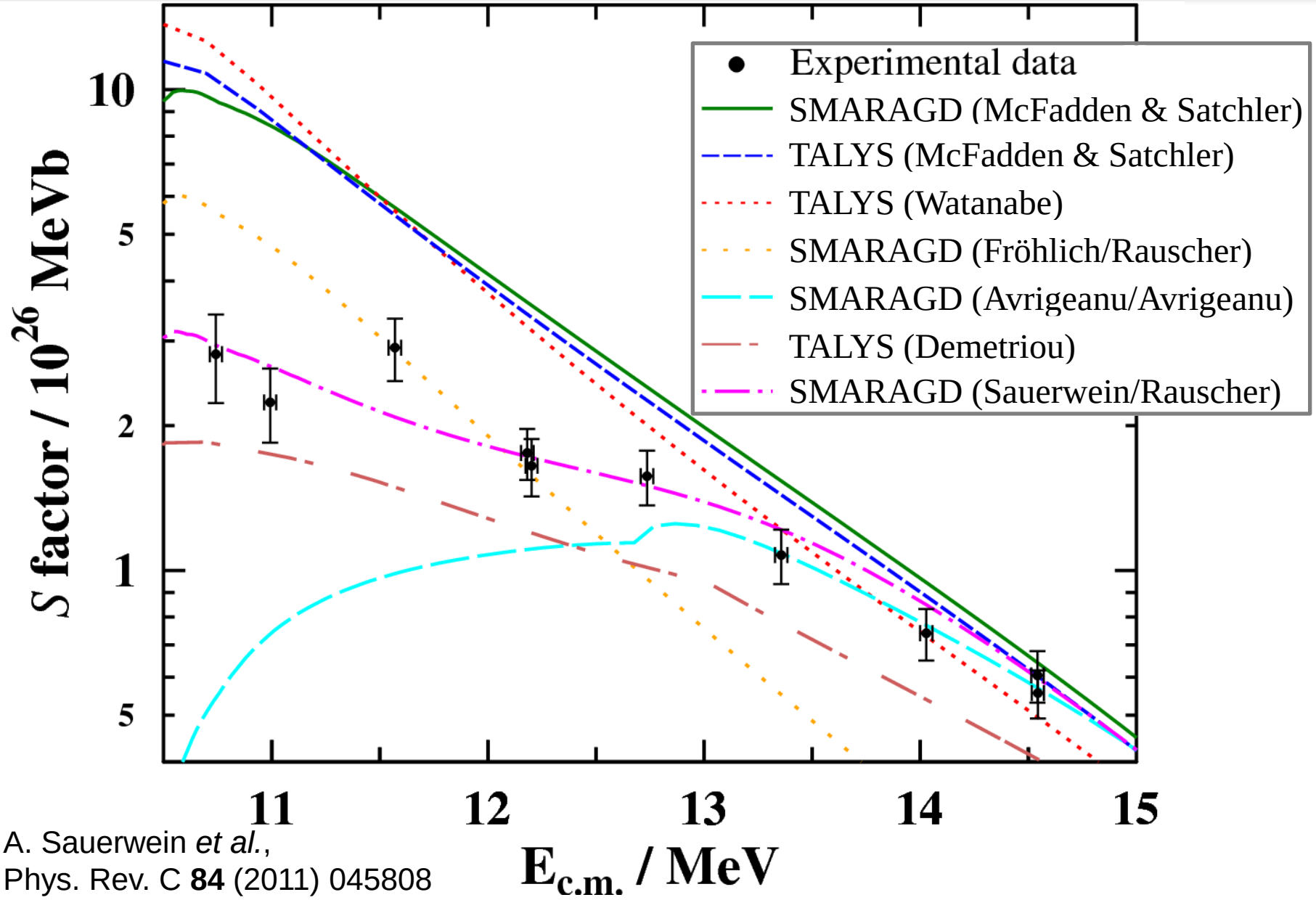
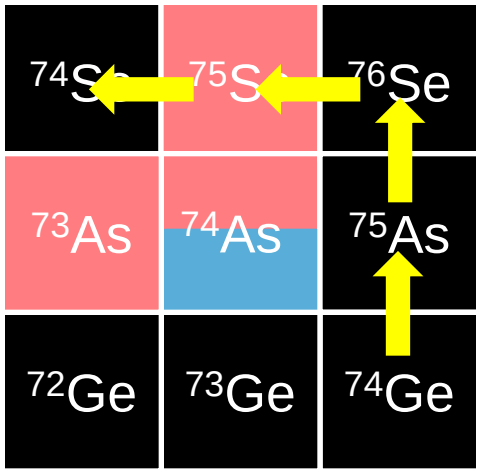


Results $^{141}Pr(\alpha,n)^{144}Pm$



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

Impact of ^{74}Ge(p,γ) on the *p*-process reaction flow

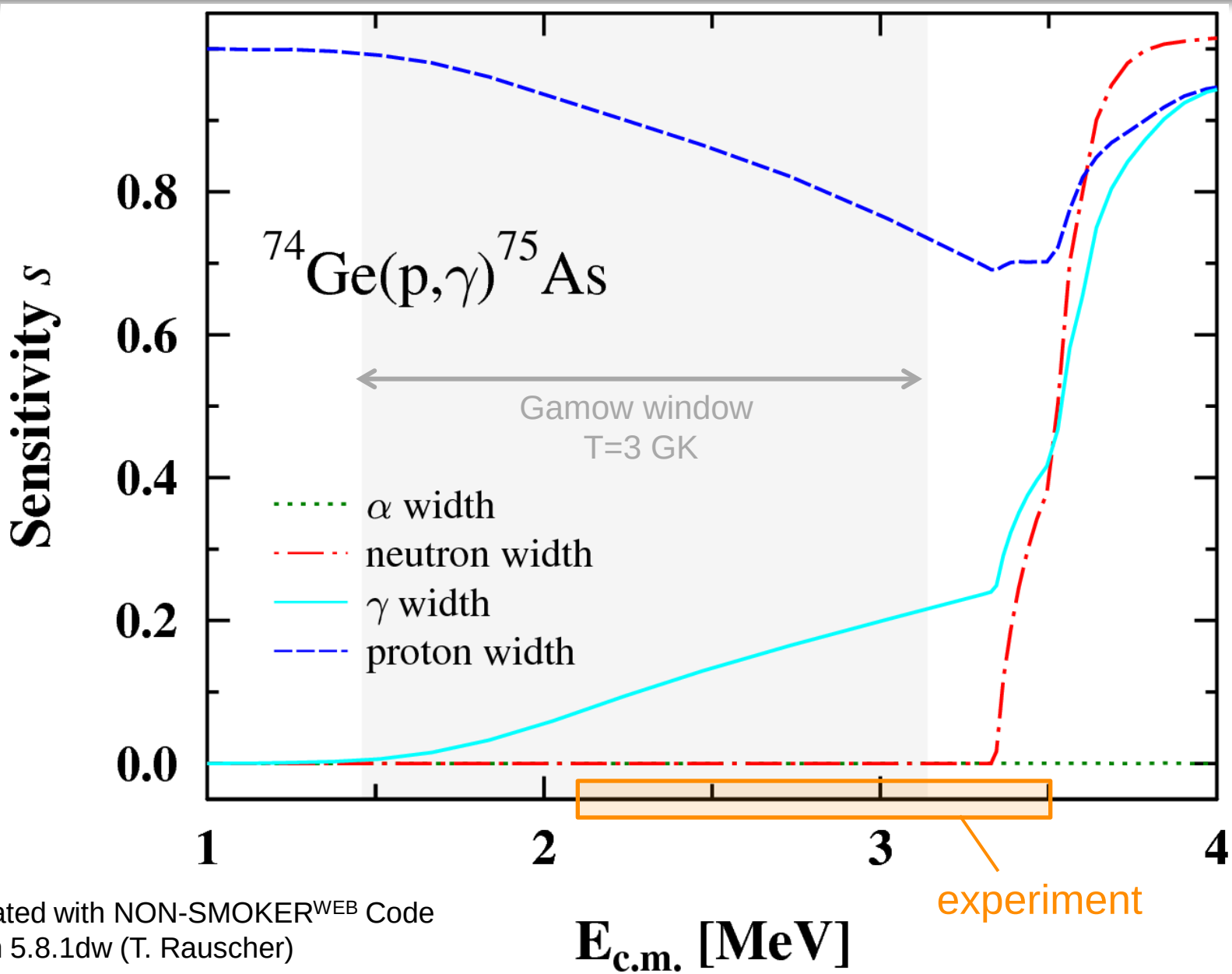


- abundance of ^{74}Se depends not only on the ^{74}Se(γ,p) rate
- can be produced by ^{74}Ge(p,γ)^{75}As(p,n)^{75}Se(γ,n)

direct impact of ^{74}Ge(p,γ) on final abundance of ^{74}Se

W. Rapp et al., APJ 653 (2006) 474

Relevance of nuclear physics input to the cross section

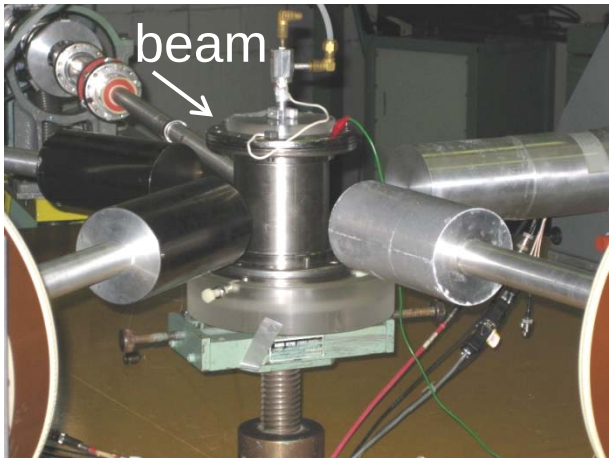


Calculated with NON-SMOKER^{WEB} Code version 5.8.1dw (T. Rauscher)

In-beam experiments with HPGe detectors

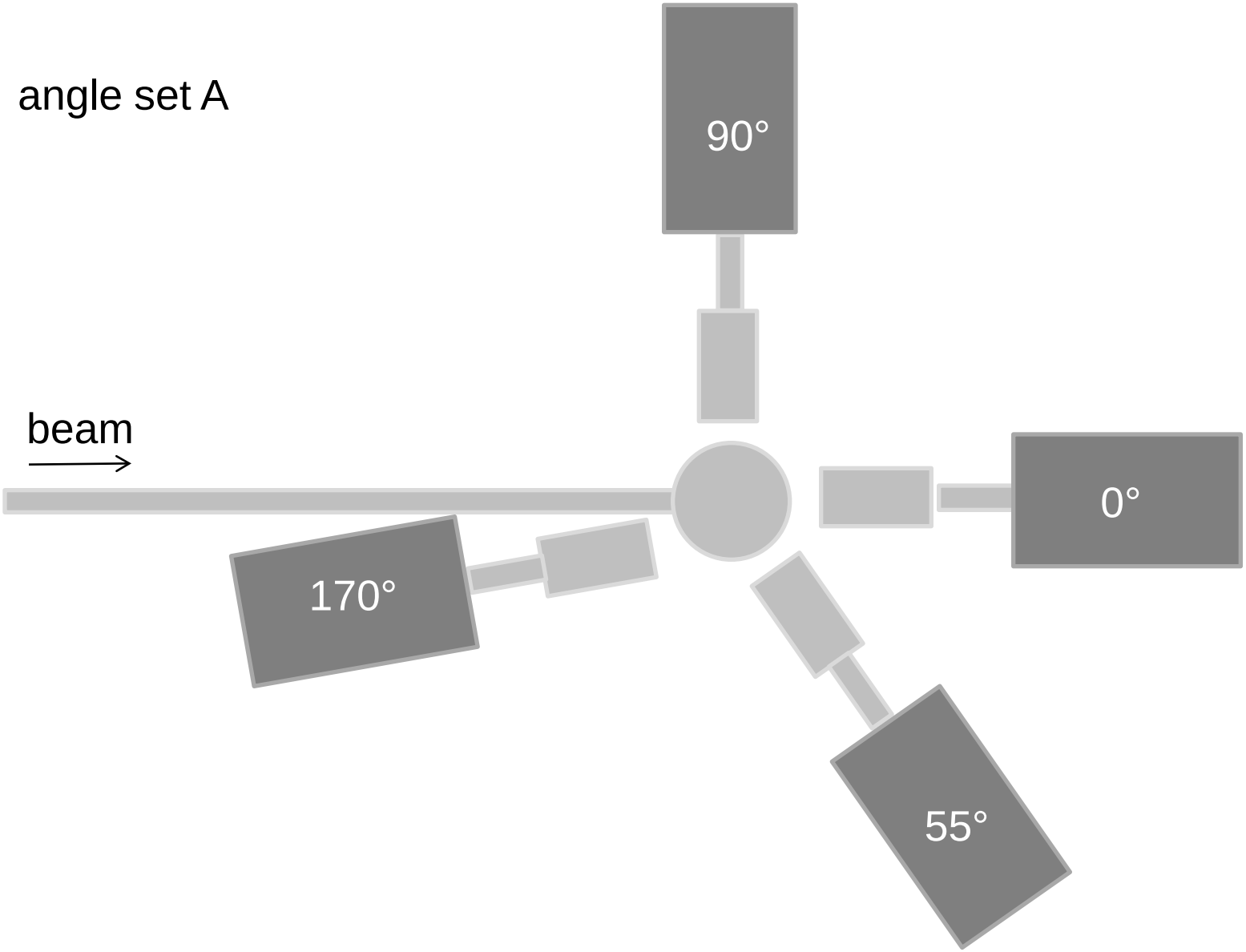
- detection of the prompt γ decays of the excited reaction products

Institute of Nuclear Physics NCSR „Demokritos“ Athens



- 5.5 MV Van de Graaff Tandem accelerator
- 4 HPGe detectors (relative efficiency of ~100 % each) under fixed angles on a turnable table
- each energy measured under two angle sets

Experimental method



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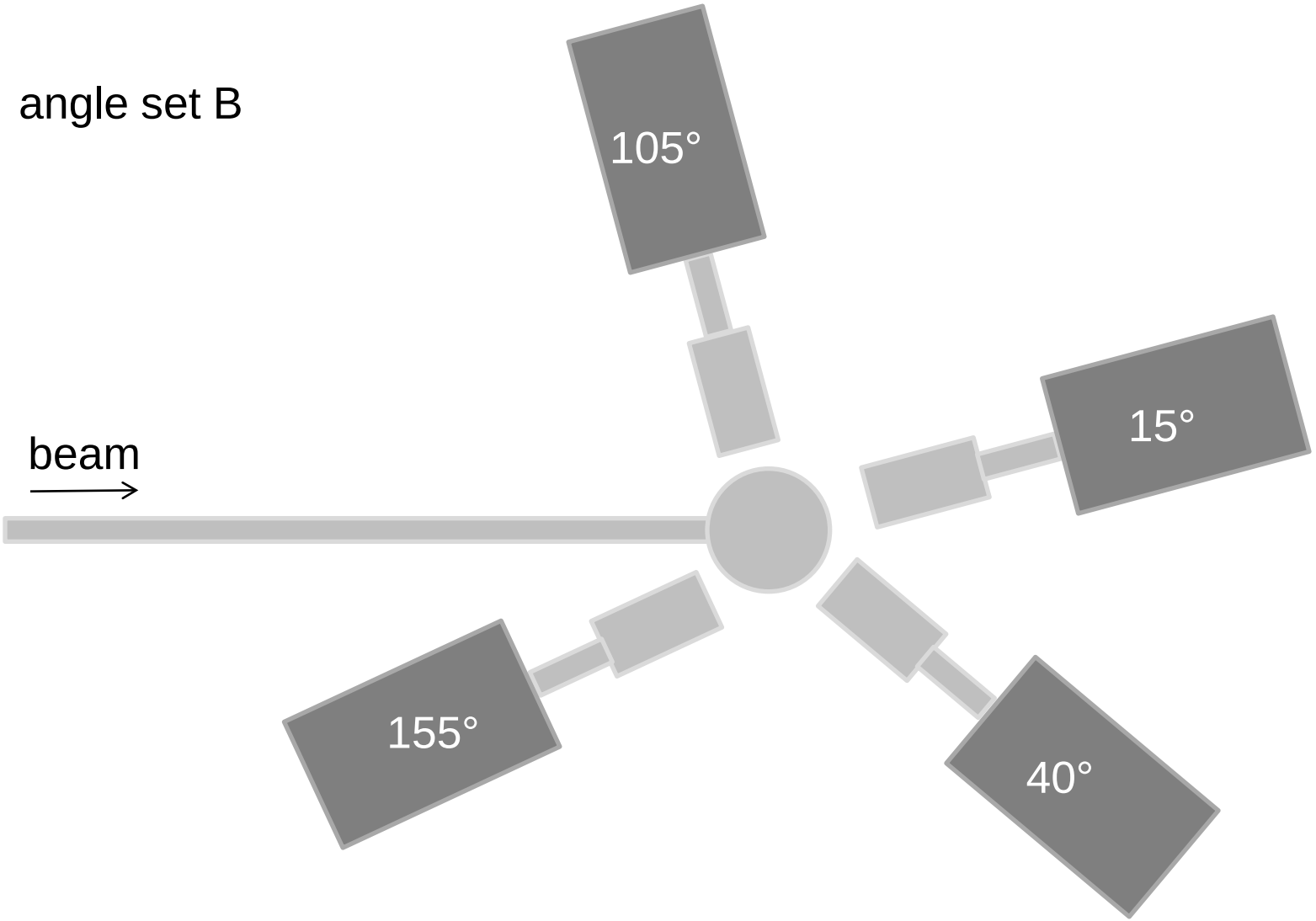
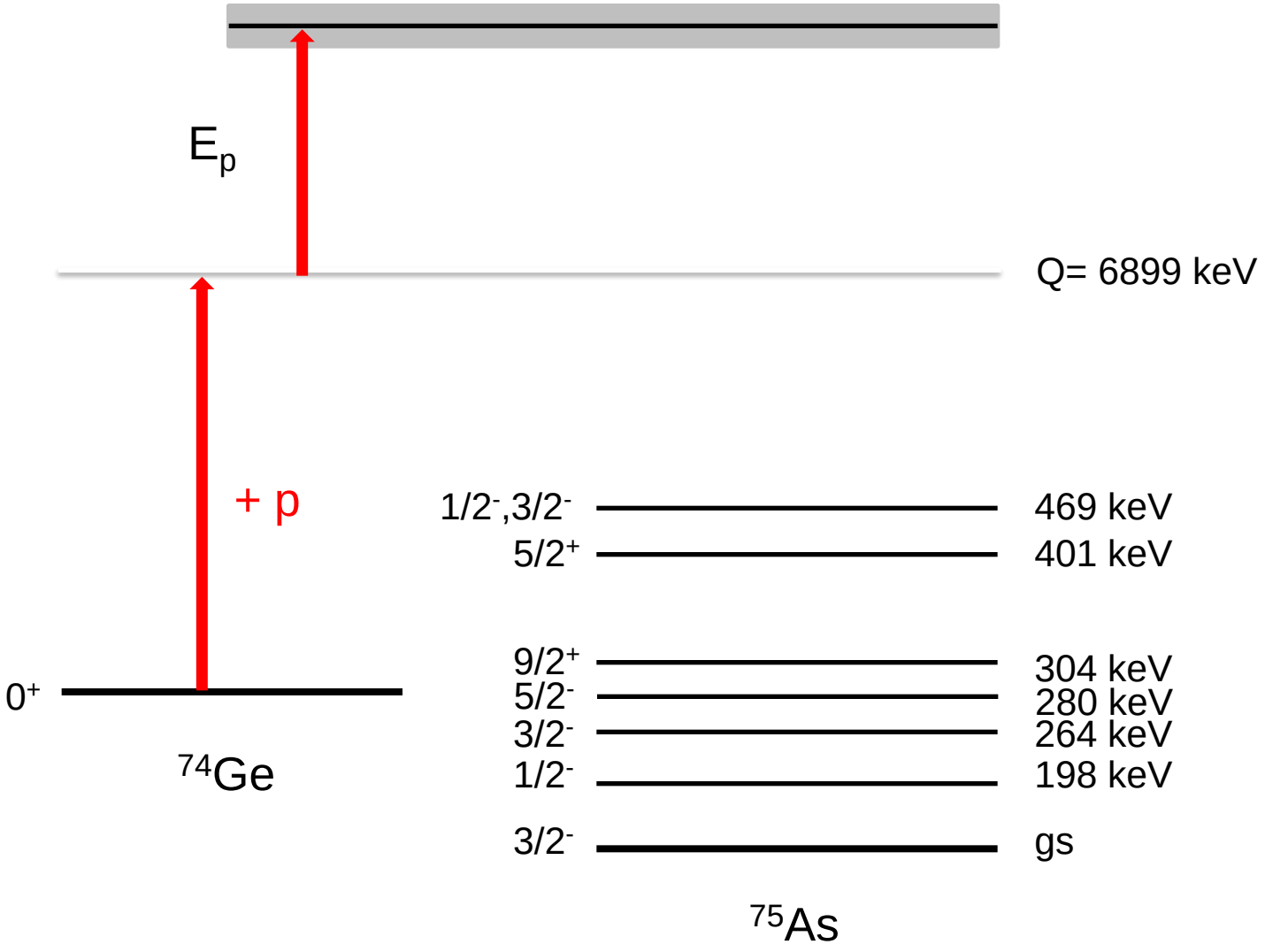
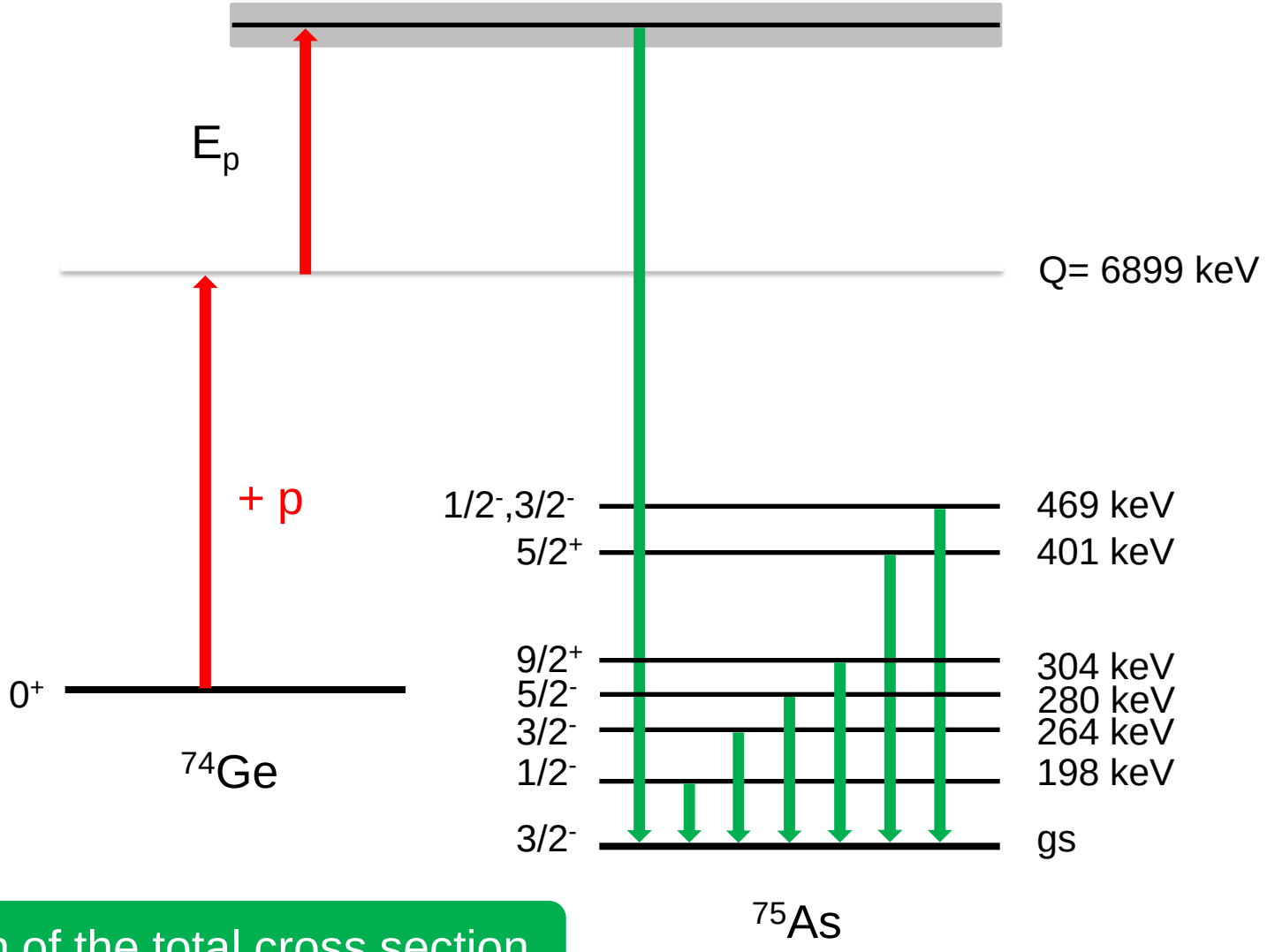


$^{74}Ge(p,\gamma)$


E_p
Q= 6899 keV
+ p
$1/2^-,3/2^-$
469 keV
$5/2^+$
401 keV
$9/2^+$
304 keV
$5/2^-$
280 keV
$3/2^-$
264 keV
$1/2^-$
198 keV
$3/2^-$
gs
0^+
^{74}Ge
^{75}As

$^{74}Ge(p,\gamma)$

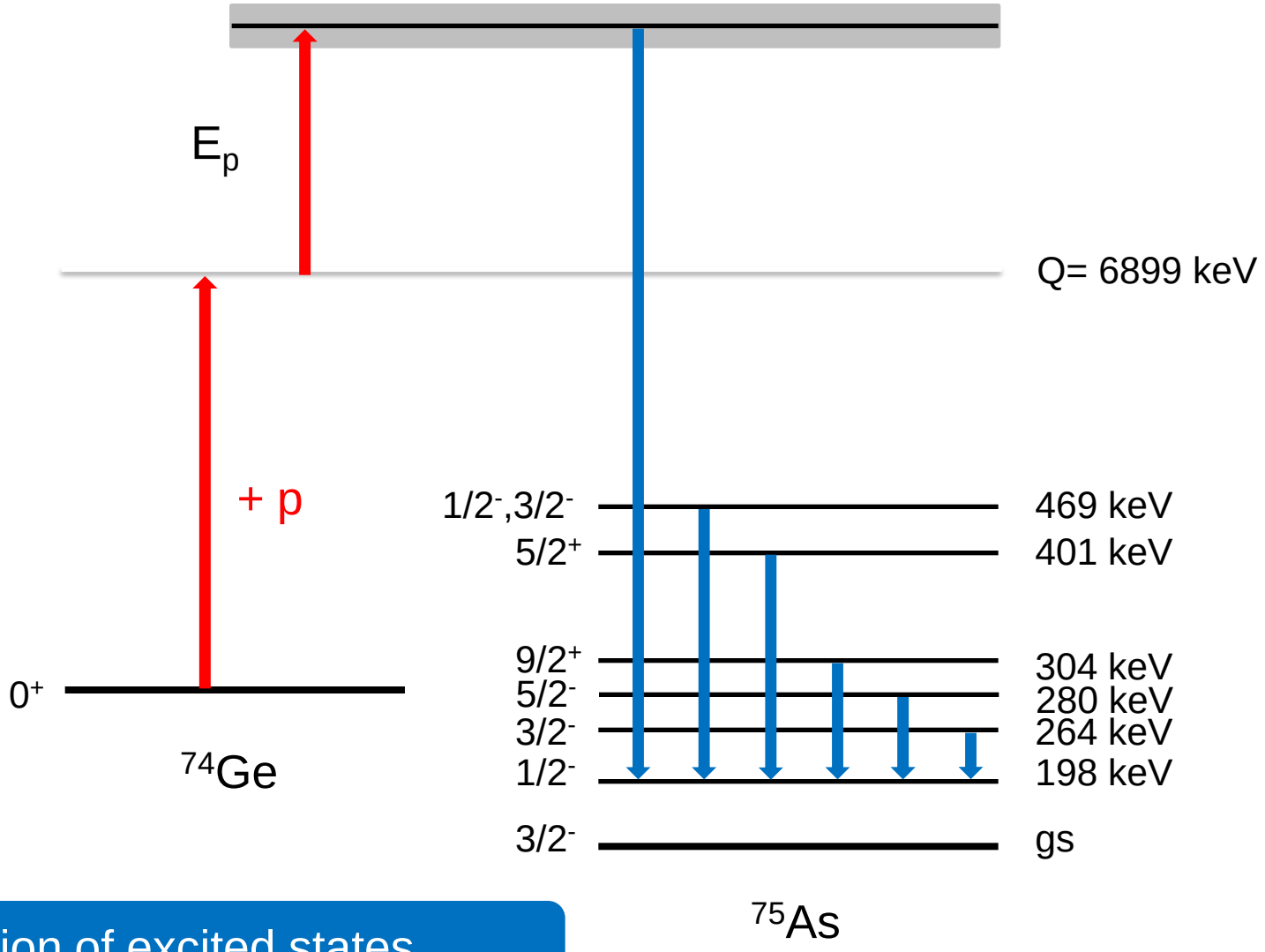
transitions to the ground state



determination of the total cross section

$^{74}Ge(p,\gamma)$

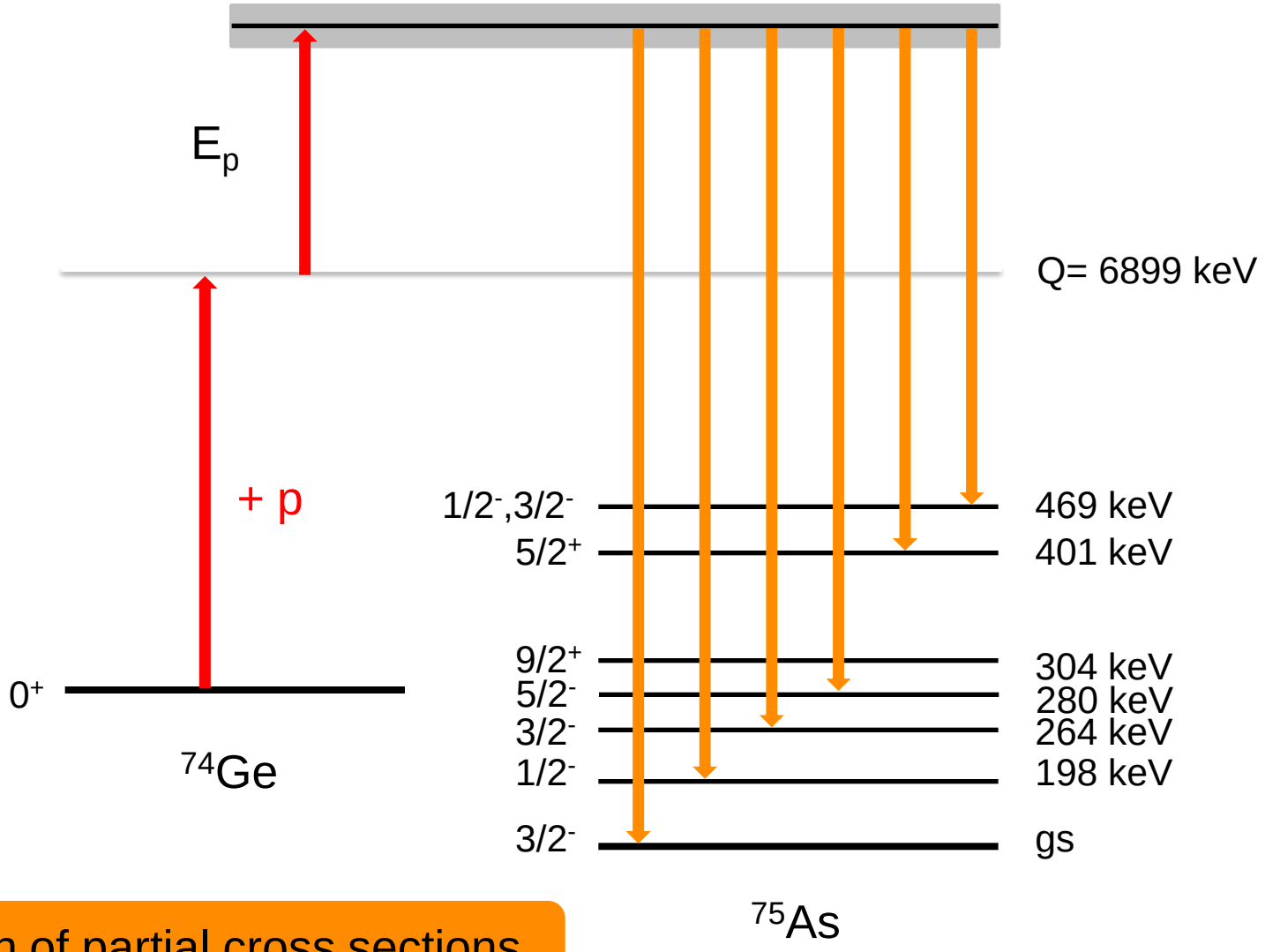
transitions to excited states



production of excited states

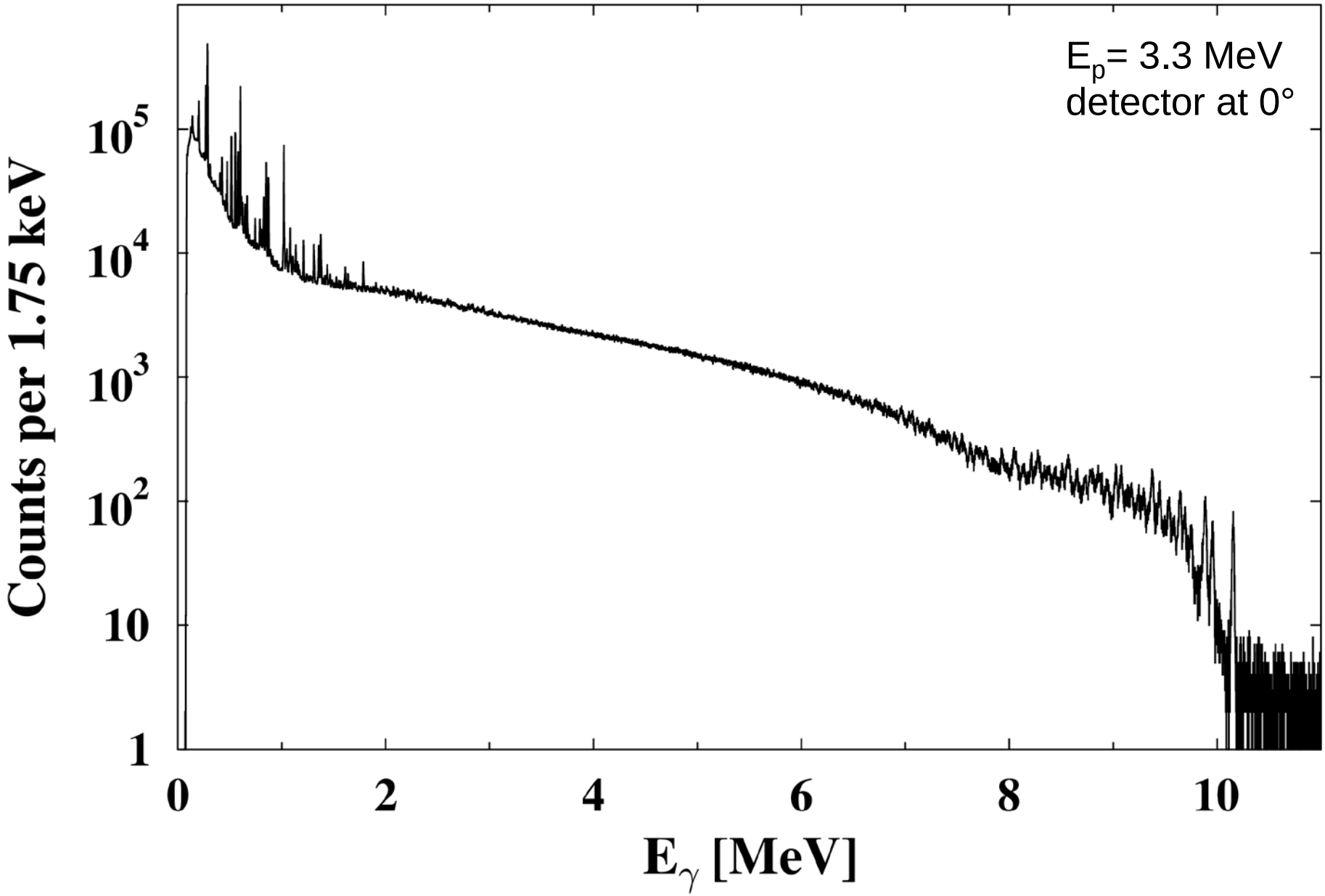
^{74}Ge(p,γ)

de-excitation of „entry state“



determination of partial cross sections

Spectrum $^{74}Ge(p,\gamma)^{75}As$



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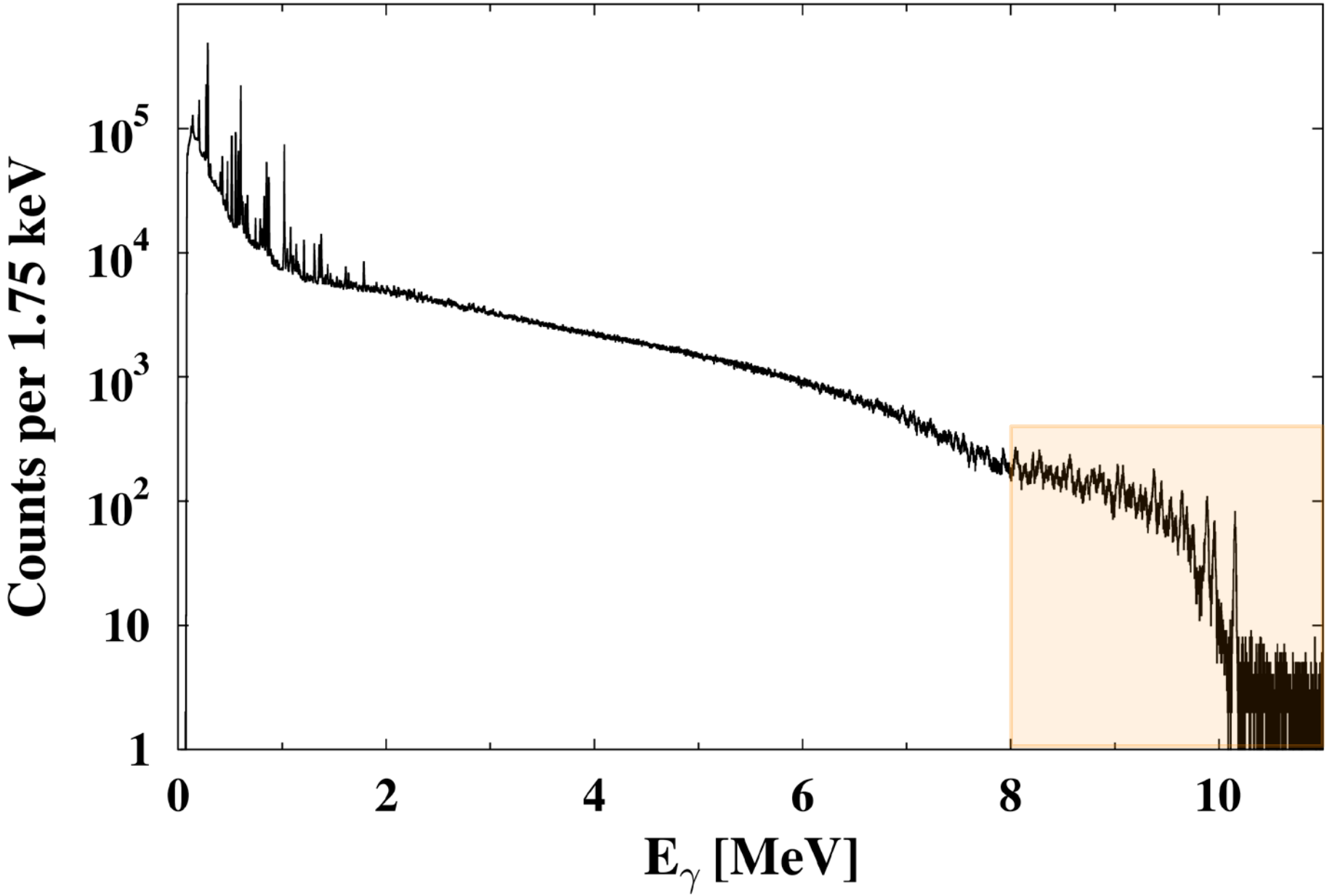

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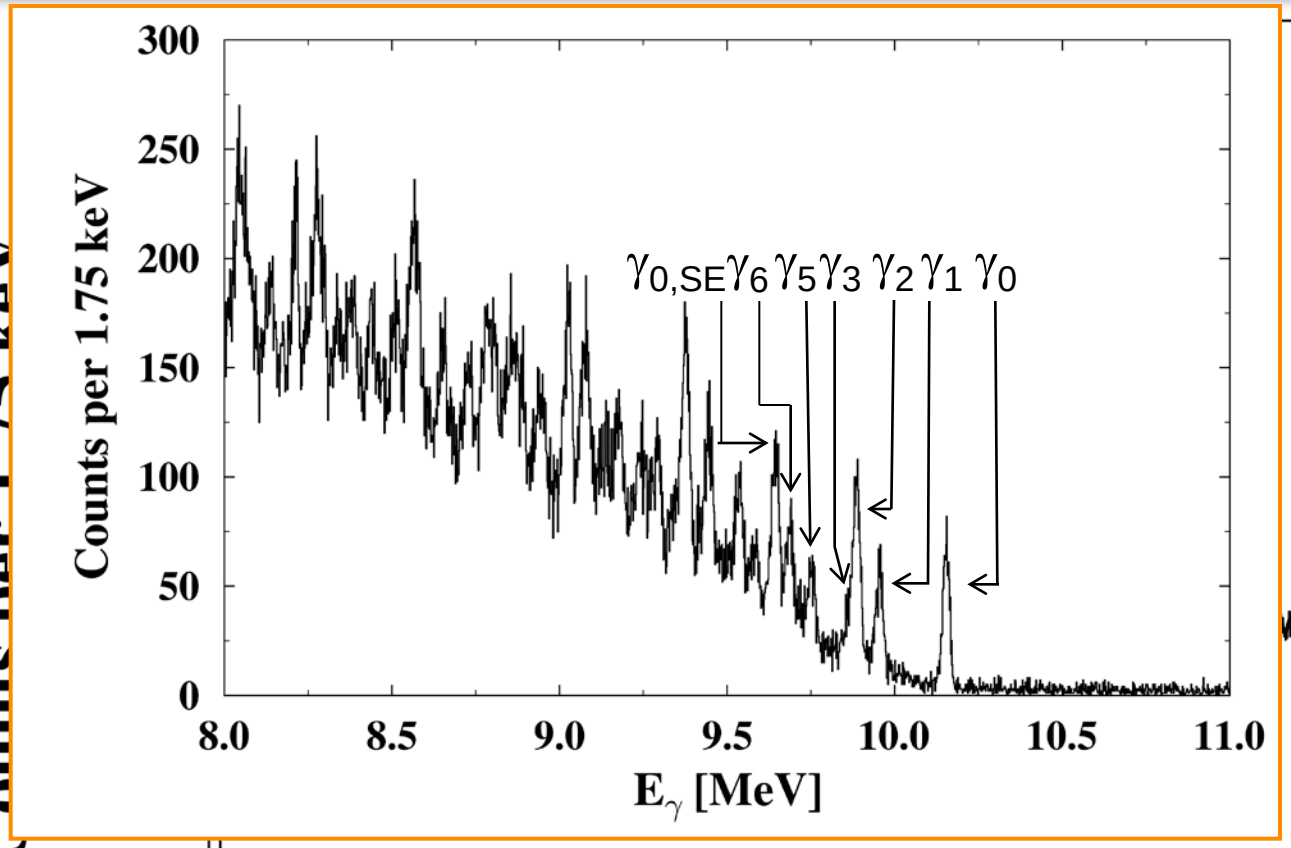
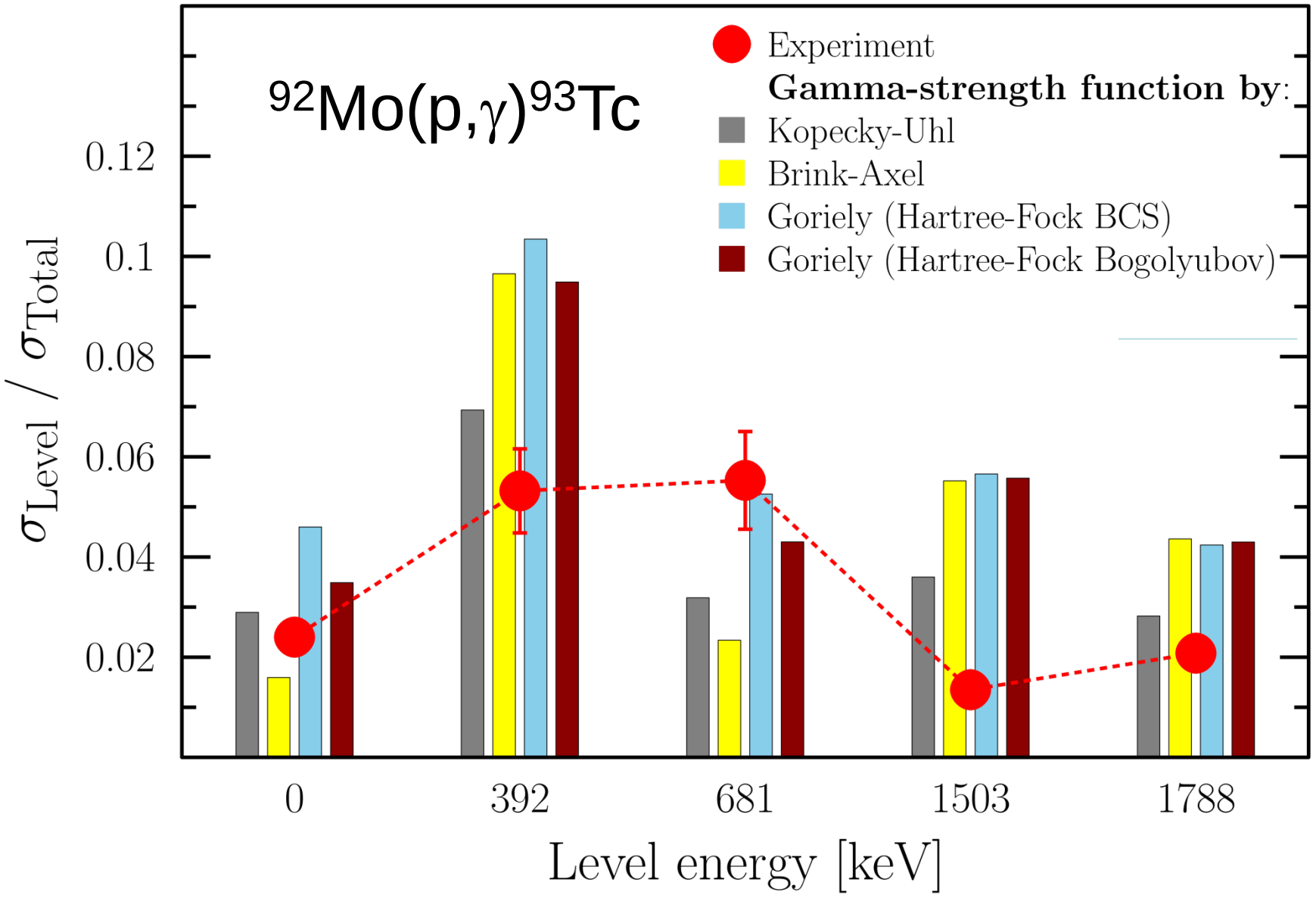


Partial cross sections ^{92}Mo(p,γ)



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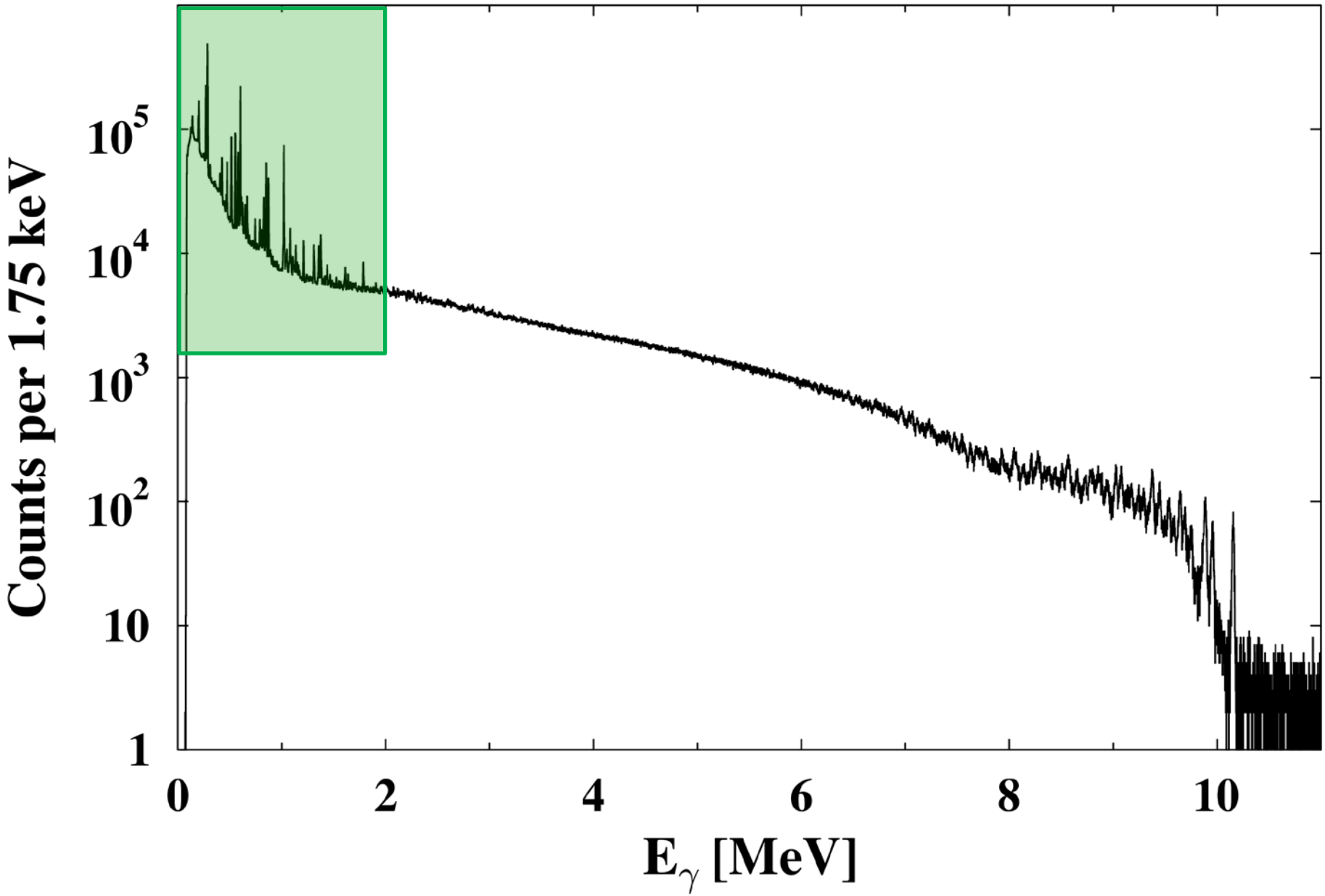
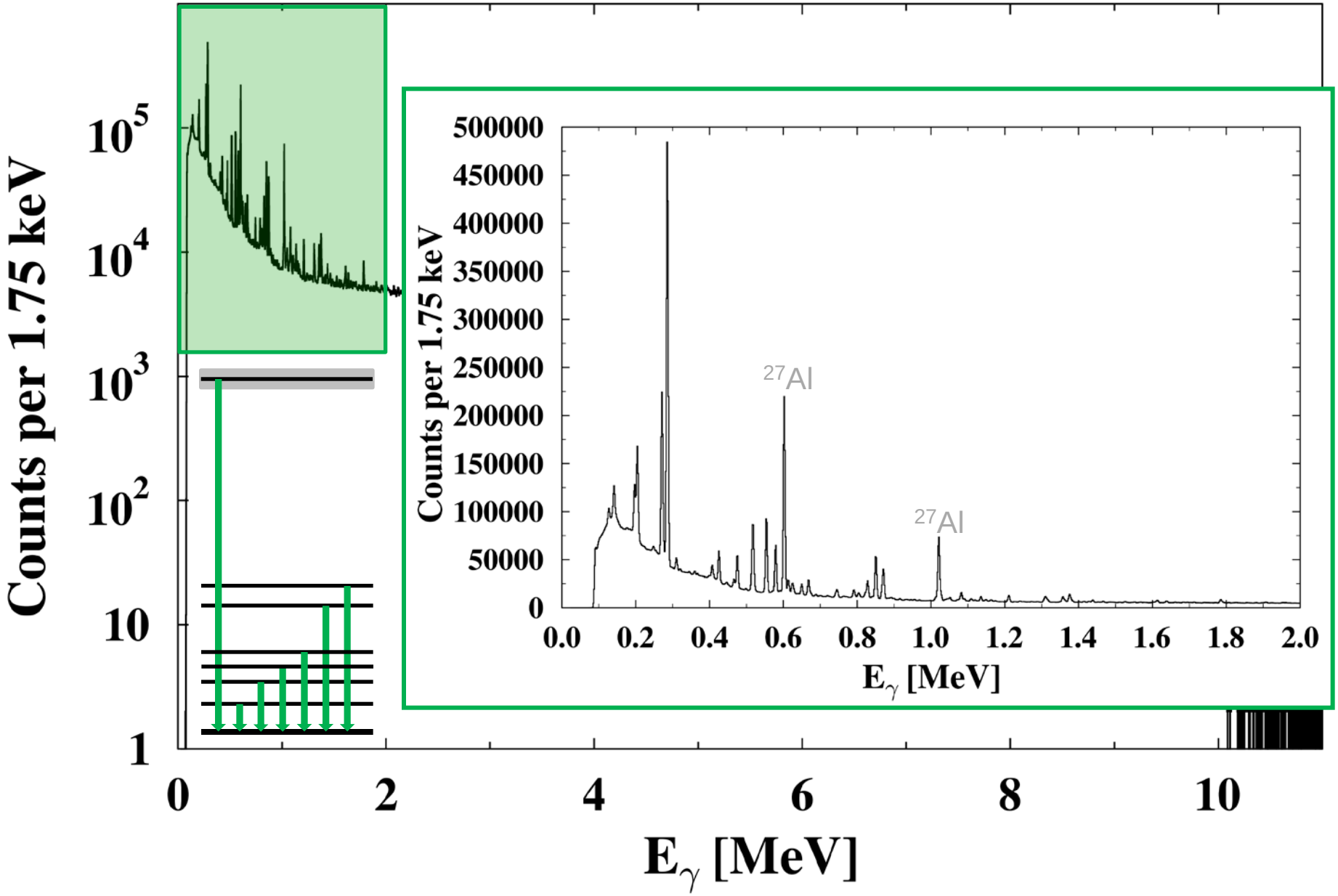
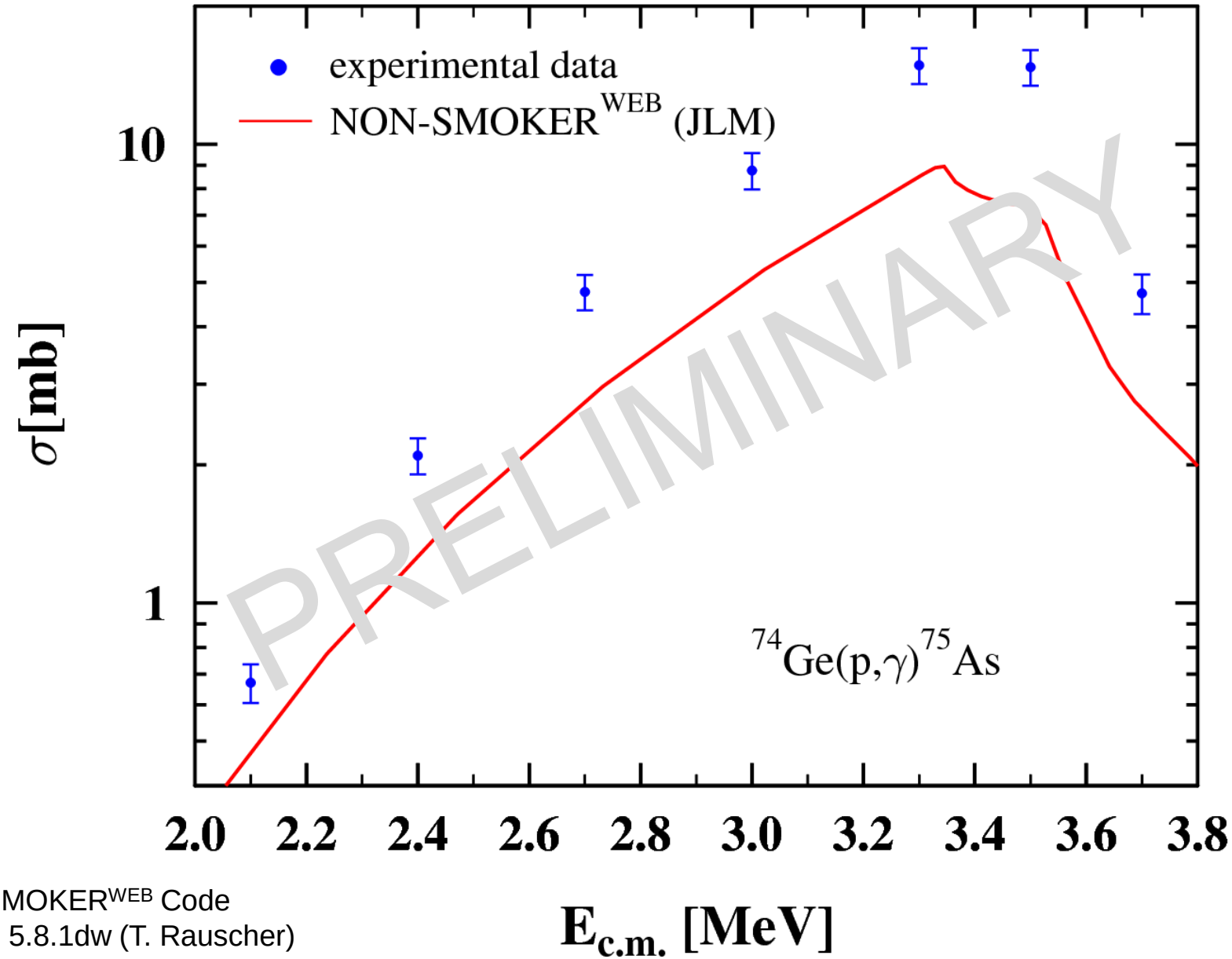


Spectrum $^{74}Ge(p,\gamma)^{75}As$



Preliminary results



NON-SMOKER^{WEB} Code
version 5.8.1dw (T. Rauscher)

Summary

$\gamma\gamma$-coincidence method with a clover-type HPGe detector

- used to determine absolute cross sections
- consistency checks with additional setups

➡ $^{141}Pr(\alpha,n)^{144}Pm$ has been measured at PTB Braunschweig

➡ a local potential was constructed

in-beam method with HPGe detectors

➡ $^{74}Ge(p,\gamma)^{75}As$ has been measured at INP Athens