In-beam and activation experiments for γ-process nucleosynthesis at the University of Cologne

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The γ process

- dominant reaction mechanism for *p* nuclei
- photodisintegration on *s* and *r* seed nuclei
- occurs in type Ia and type II supernovae
- complex network of thousands of reactions

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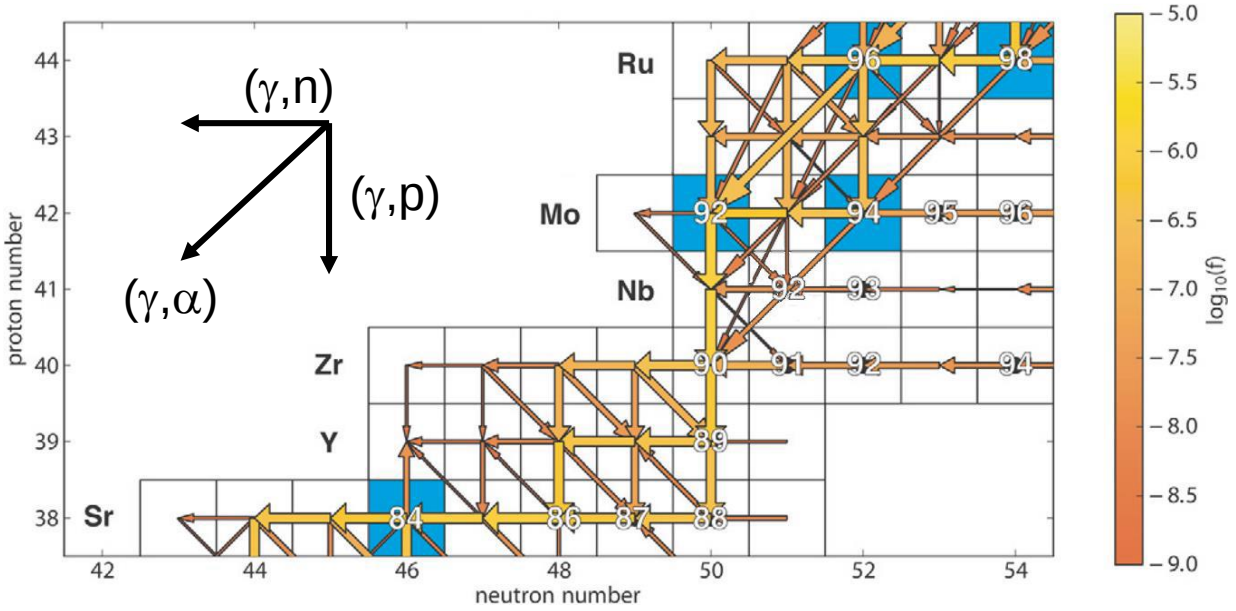

T. Rauscher *et al.*, Rep. Prog. Phys. **76** (2013) 066201

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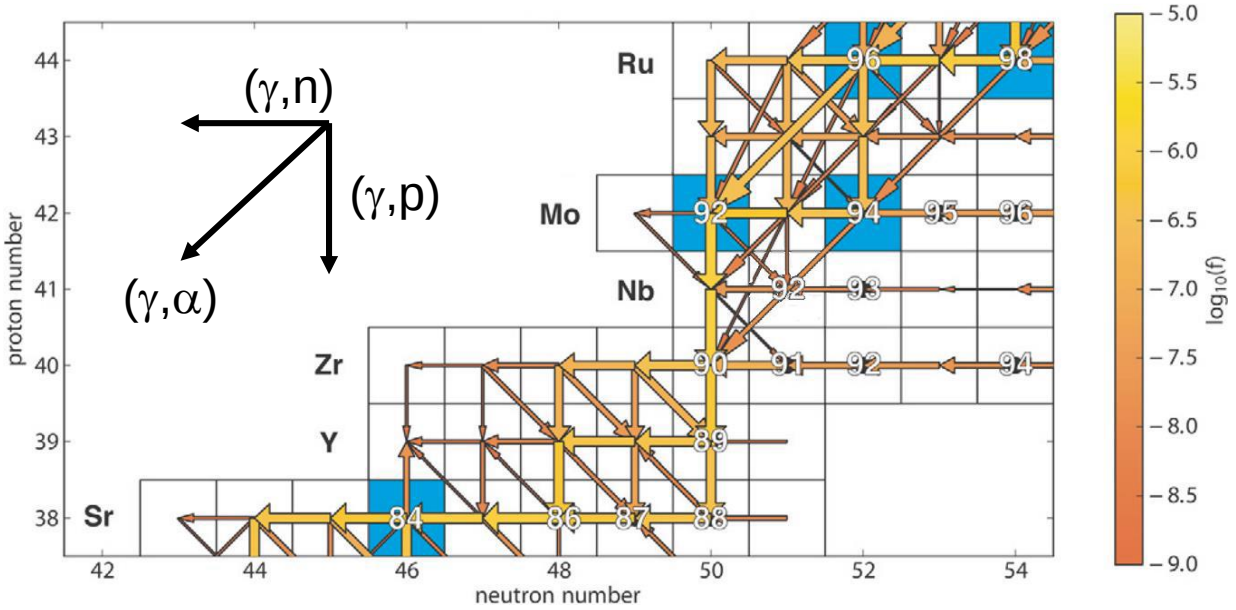

➡ reaction rates based on theory

➡ constrain input parameters experimentally

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Experimental setups in Cologne

10 MV FN tandem ion accelerator

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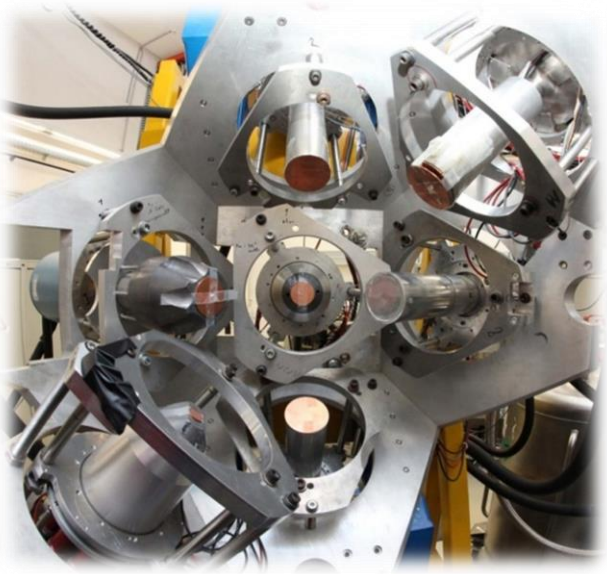
In-beam γ-ray spectroscopy



HORUS spectrometer

- 14 HPGe detectors
- 6 equipped with BGO shields
- angular distributions
- γγ coincidences

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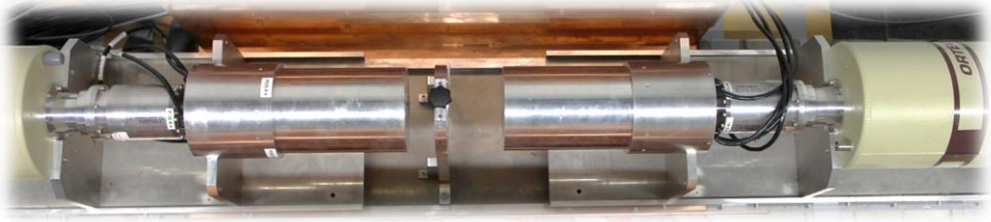
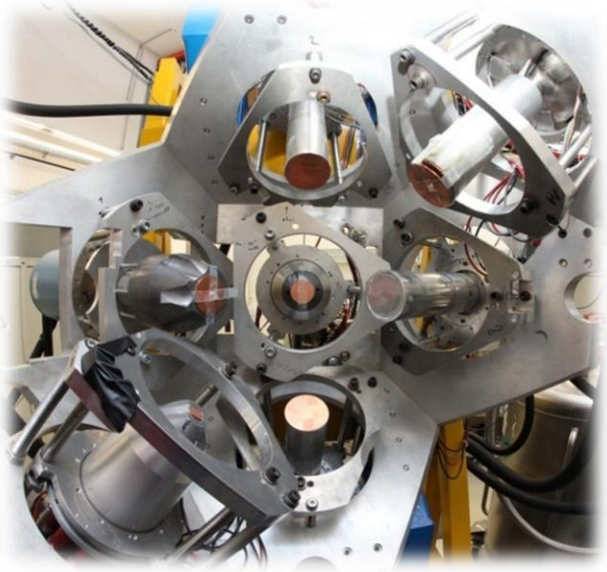
Activation experiments



Cologne Clover Counting Setup

- 2 HPGe Clover detectors
- passive Pb and Cu shielding
- total efficiency ≈ 7 % @ 1332 keV

In-beam γ-ray spectroscopy



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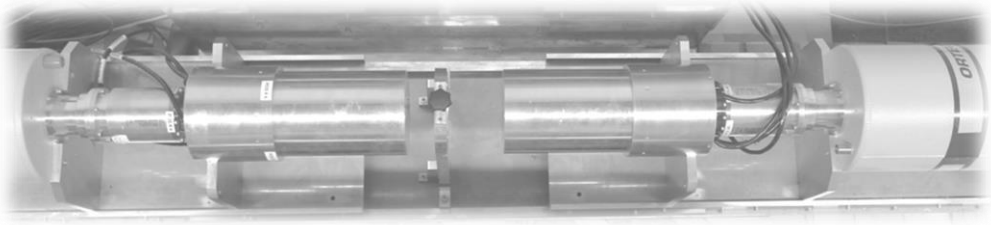

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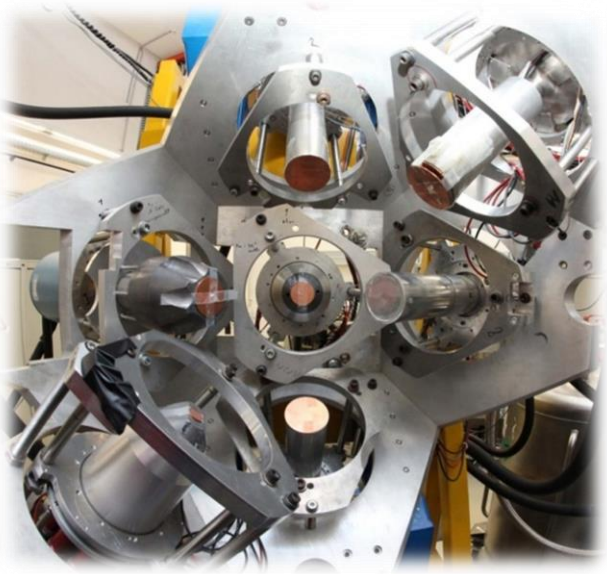

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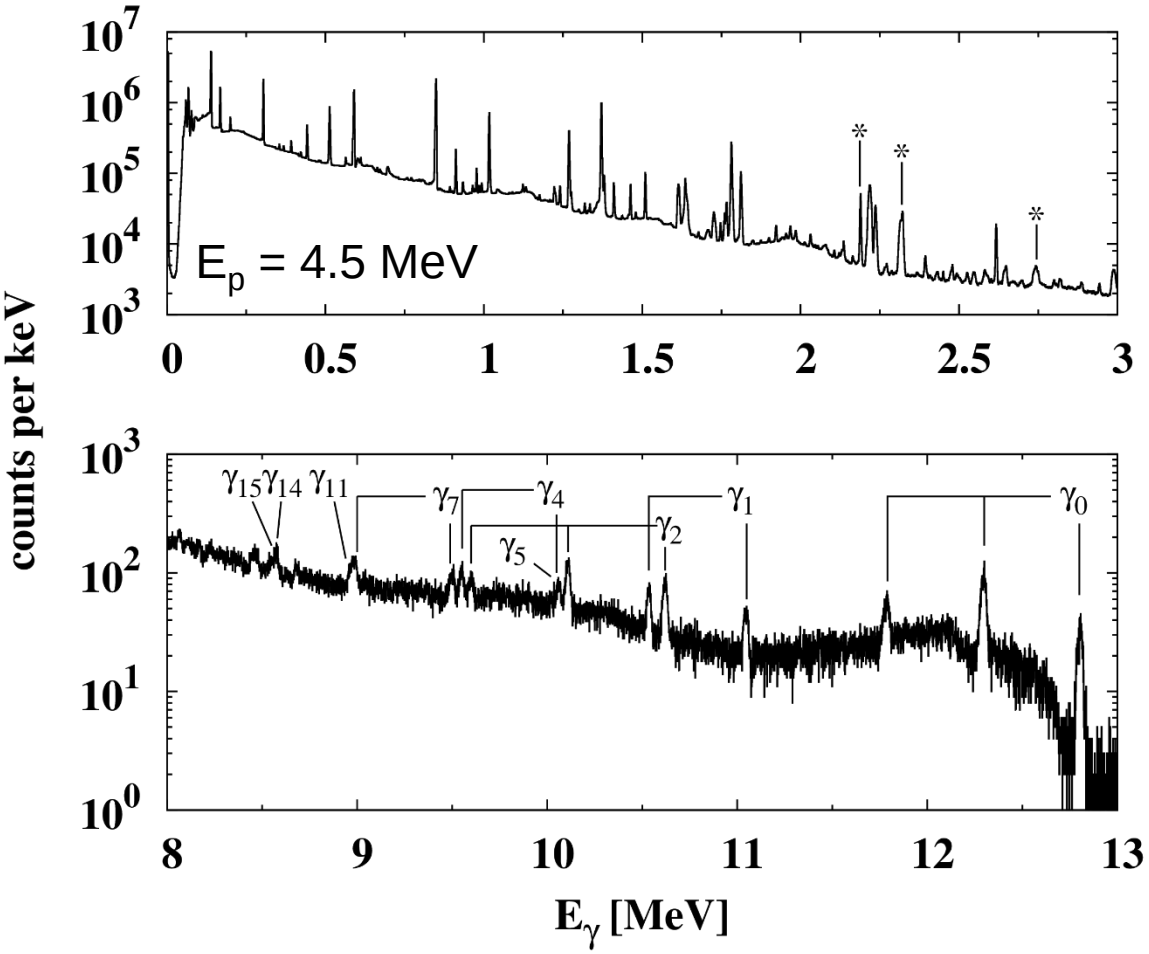
$^{89}Y(p,\gamma)^{90}Zr$ – Experimental details

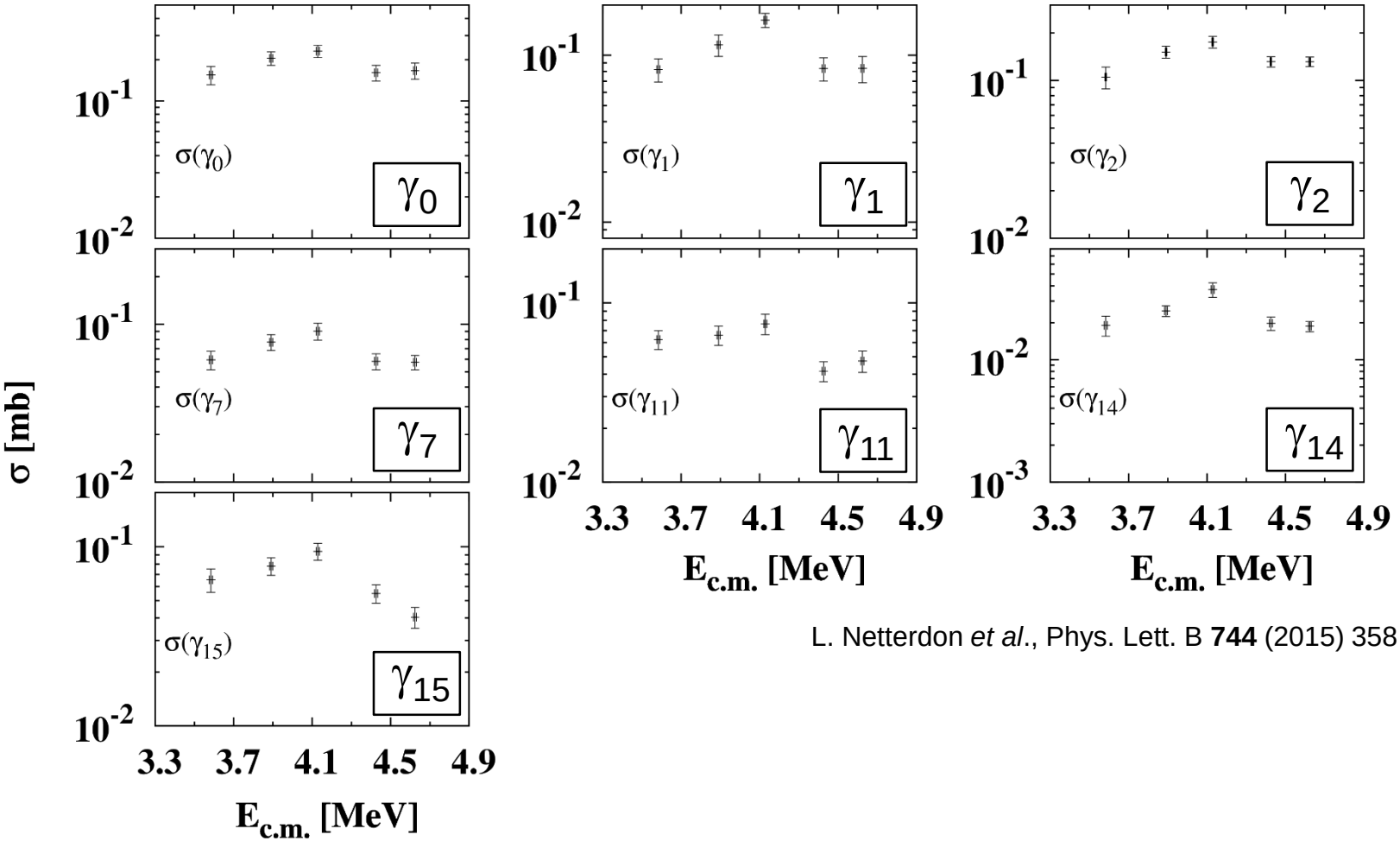


- E_p = 3.65 MeV – 4.7 MeV
- beam current ≈ 50 nA
- ^{nat}Y target ≈ 580 μg / cm^2
- five total cross-section values
- partial cross sections for population of seven 0^+ / 2^+ states

→ sensitive to *E*1 strength!

L. Netterdon *et al.*, Phys. Lett. B **744** (2015) 358

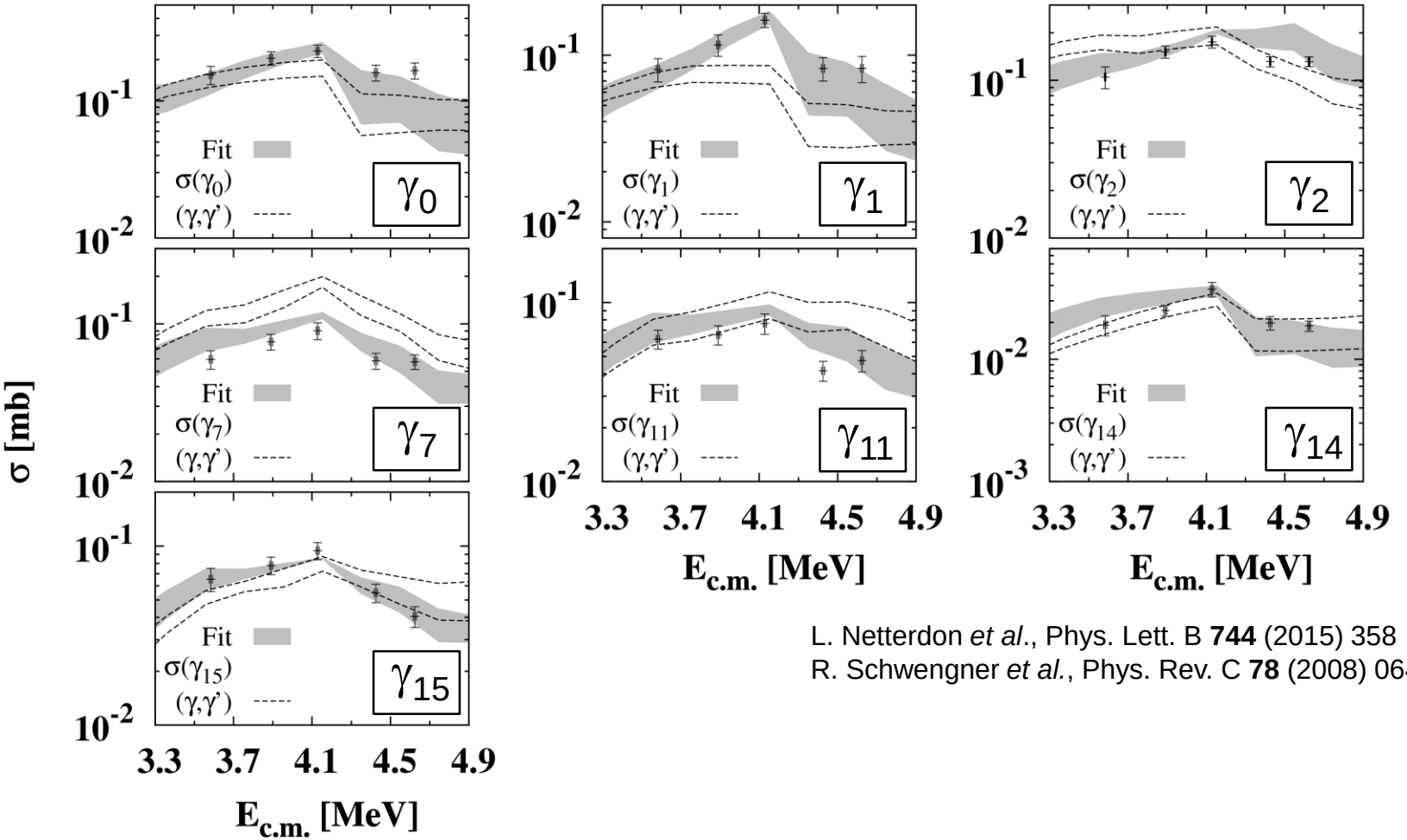
$^{89}Y(p,\gamma)\,^{90}Zr$ – Partial cross-sections



L. Netterdon *et al*., Phys. Lett. B **744** (2015) 358

- goal: describe partial cross sections with appropriate γ-ray strength function in statistical-model calculations

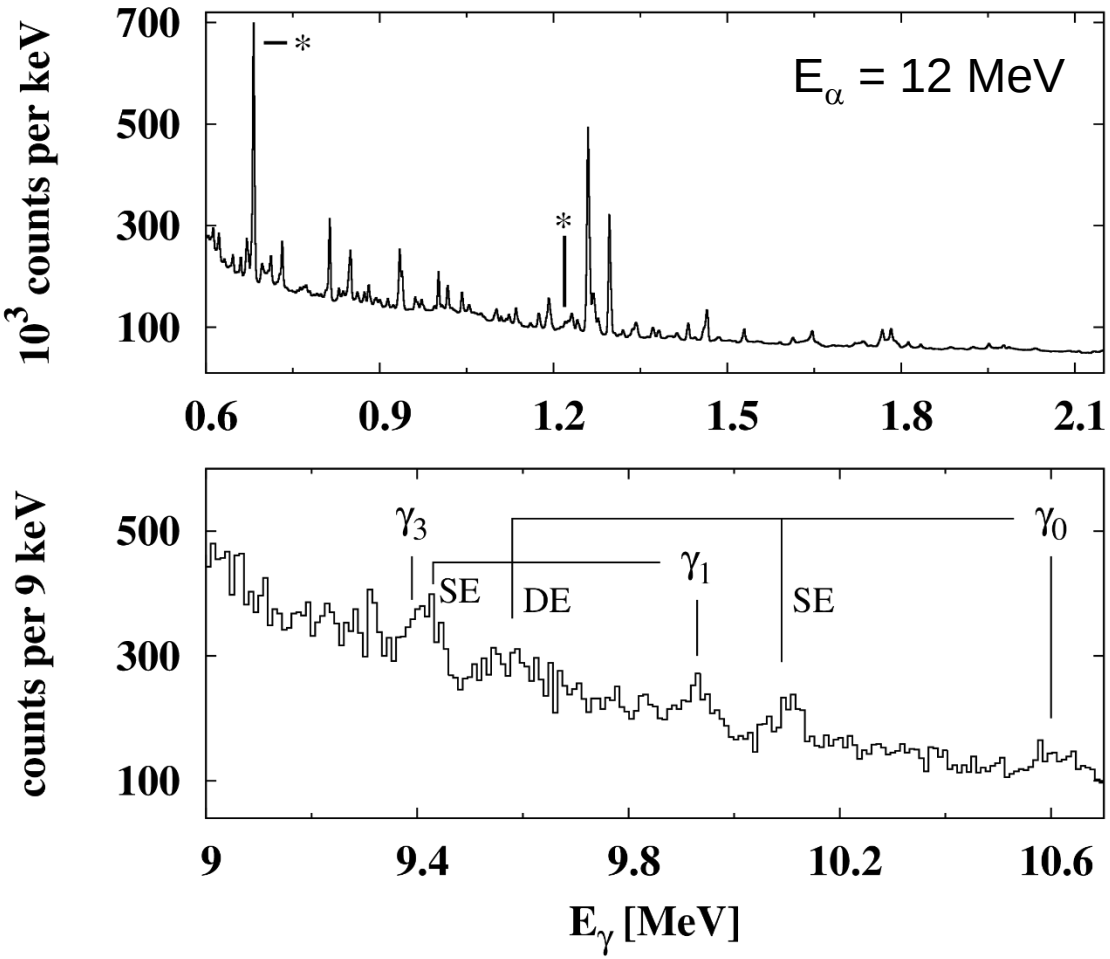
$^{89}Y(p,\gamma)\,^{90}Zr$ – Partial cross-sections



L. Netterdon *et al*., Phys. Lett. B **744** (2015) 358
R. Schwengner *et al.*, Phys. Rev. C **78** (2008) 064314

- γ-ray strength function fitted to reproduce partial cross sections

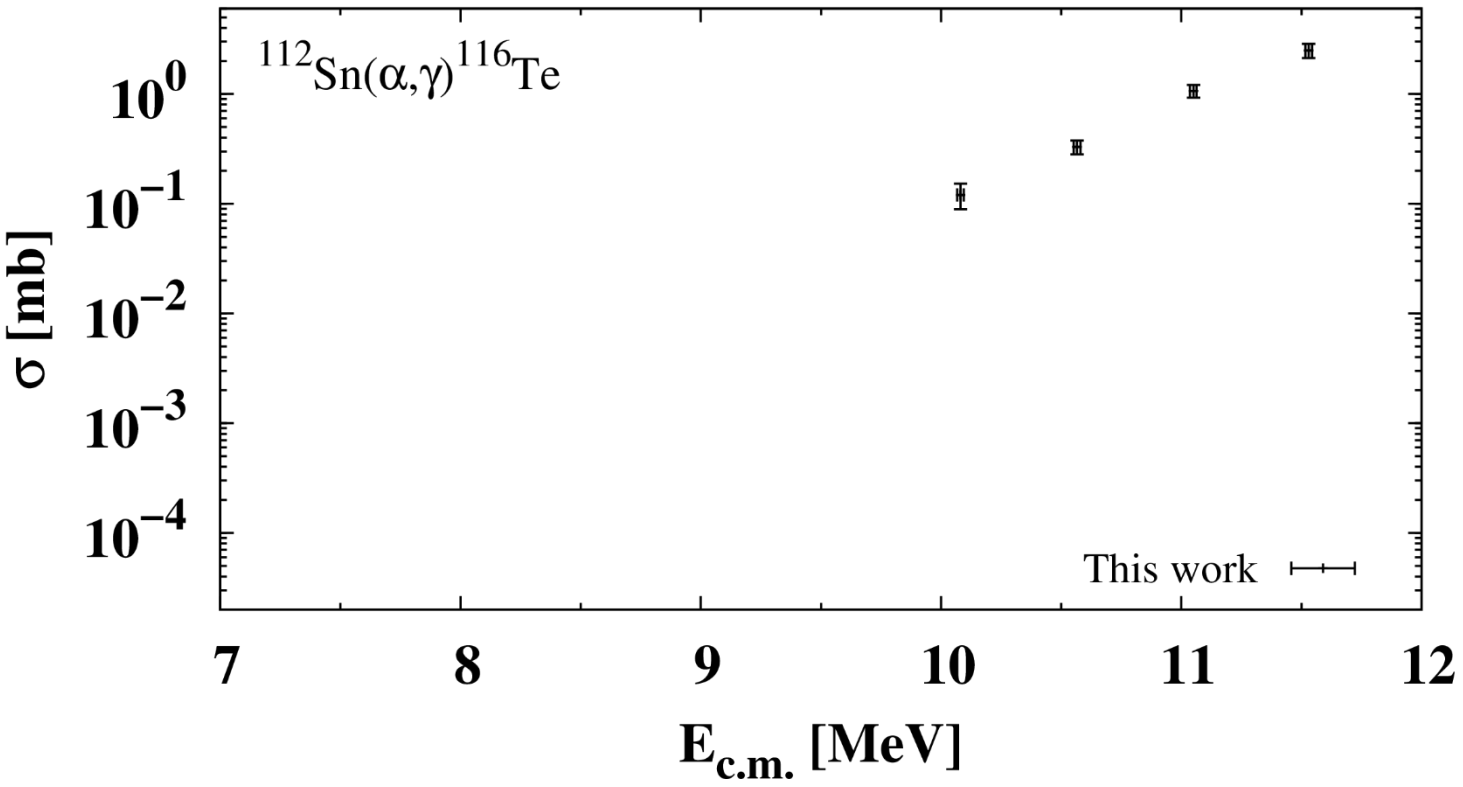
$^{112}Sn(\alpha,\gamma)^{116}Te$ – Experimental details



- E_α = 10.5 MeV – 12 MeV
- four total cross-section values
- beam current ≈ 80 nA – 240 nA
- ^{112}Sn target enriched to ≈ 85 %
- thickness ≈ 360 μg / cm^2
- partial cross-sections for population of three discrete states

L. Netterdon *et al*., Phys. Rev. C **91** (2015) 035801

^{112}Sn(α,γ) ^{116}Te – Total cross-section



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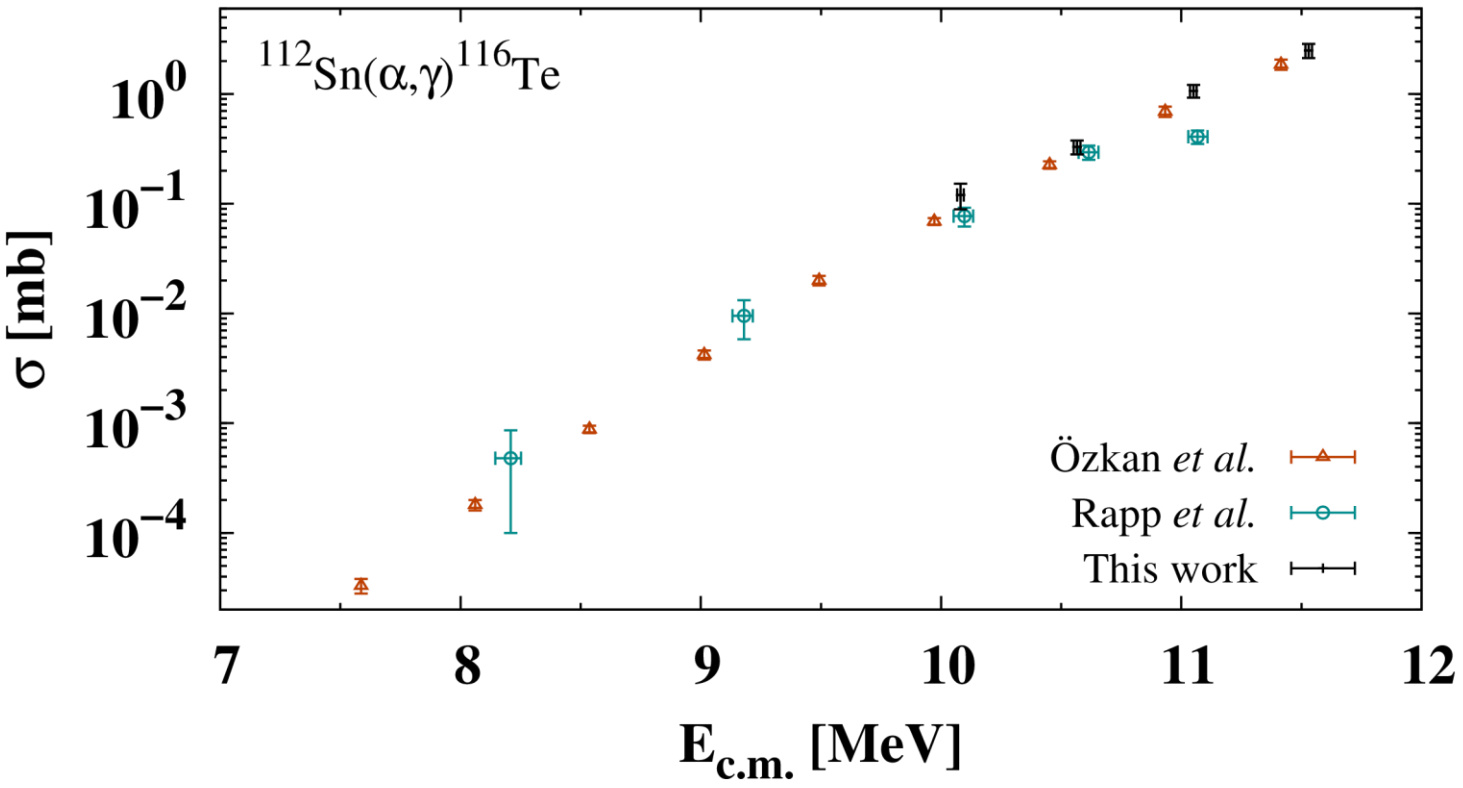

- very good agreement with previous activation measurements
  - (α,γ) reactions can be measured in-beam @ HORUS!

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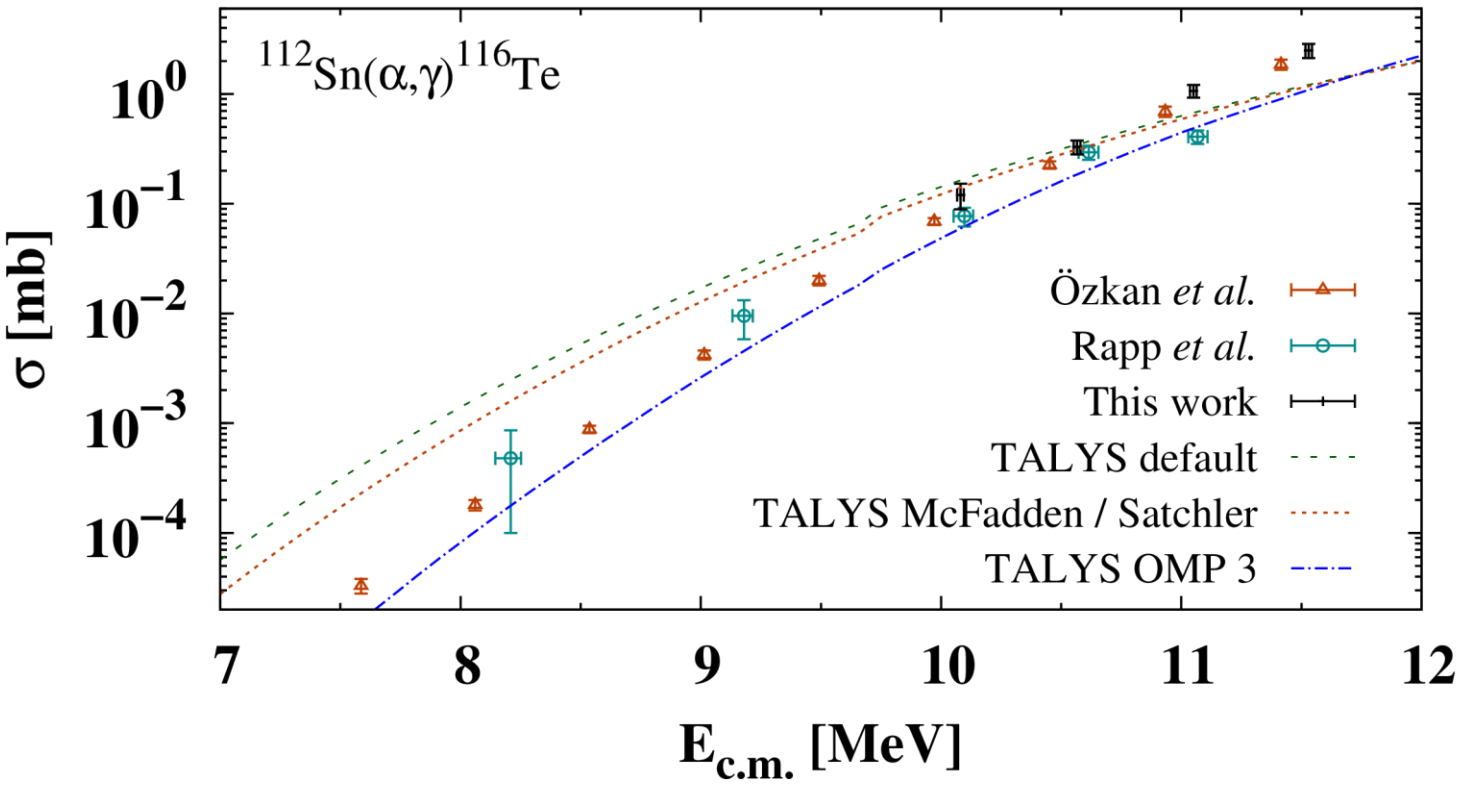

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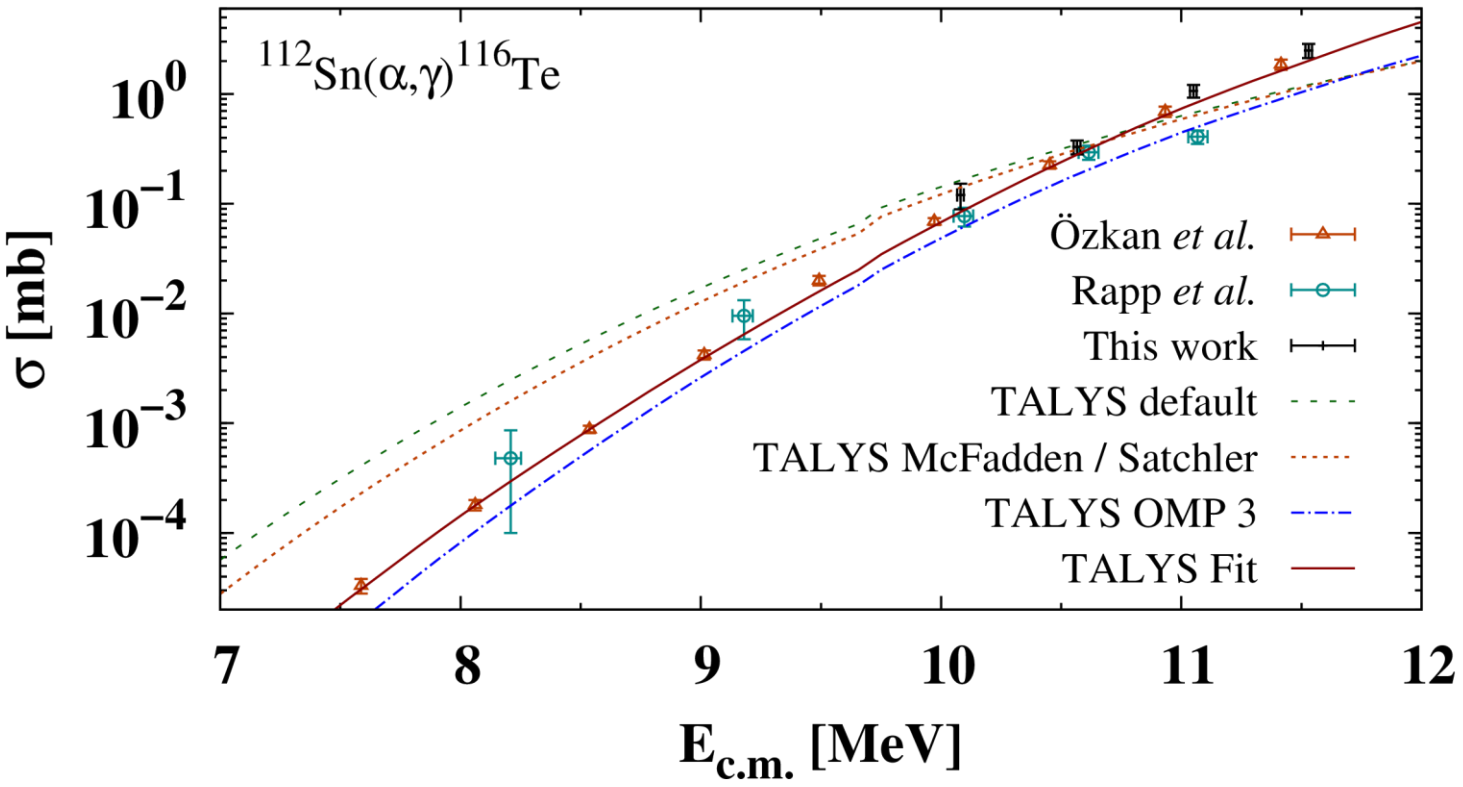
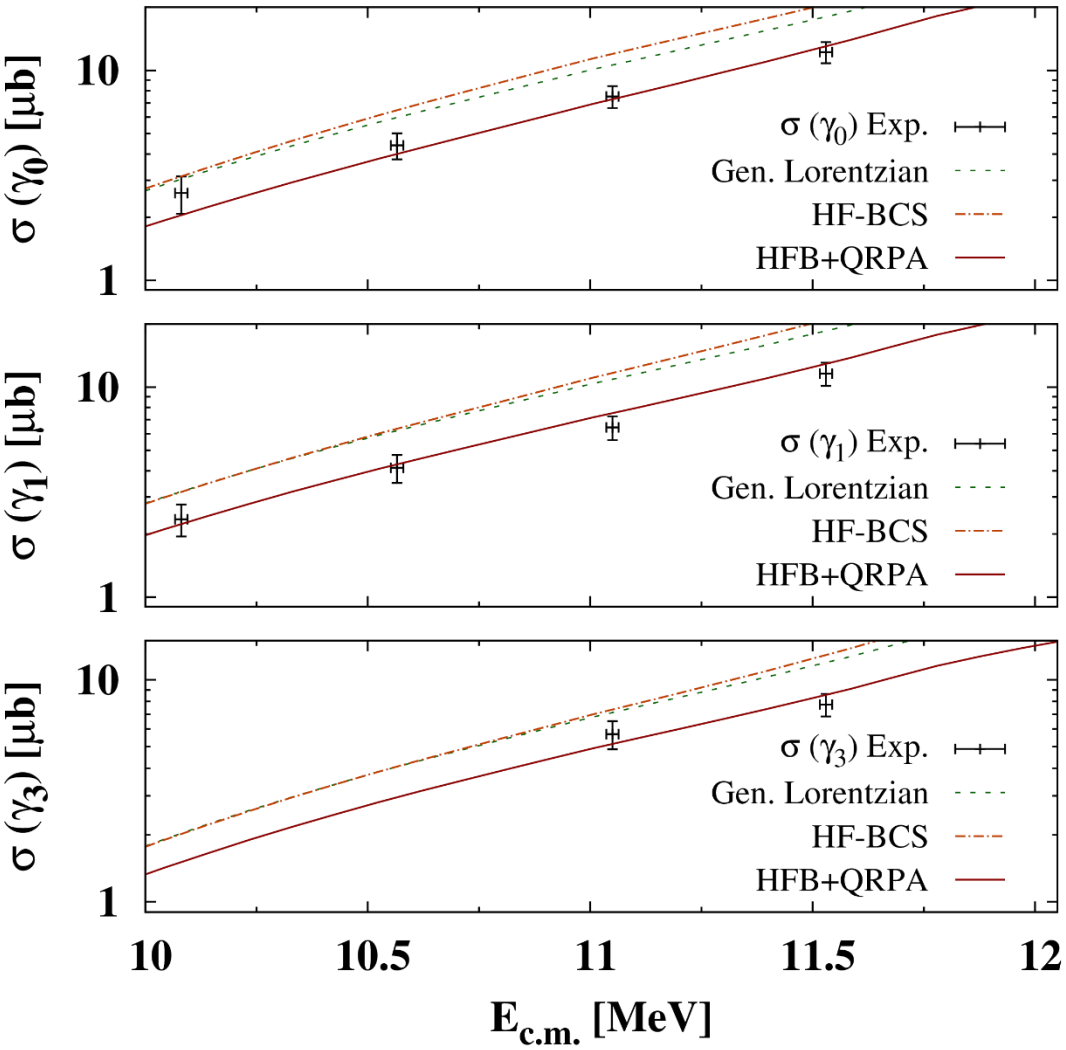


- very good agreement with previous activation measurements
  - (α,γ) reactions can be measured in-beam @ HORUS!
- standard α-OMPs fail to reproduce experimental data
- local adjustment necessary → partial cross-sections and other reactions?

L. Netterdon *et al.*, Phys. Rev. C **91** (2015) 035801

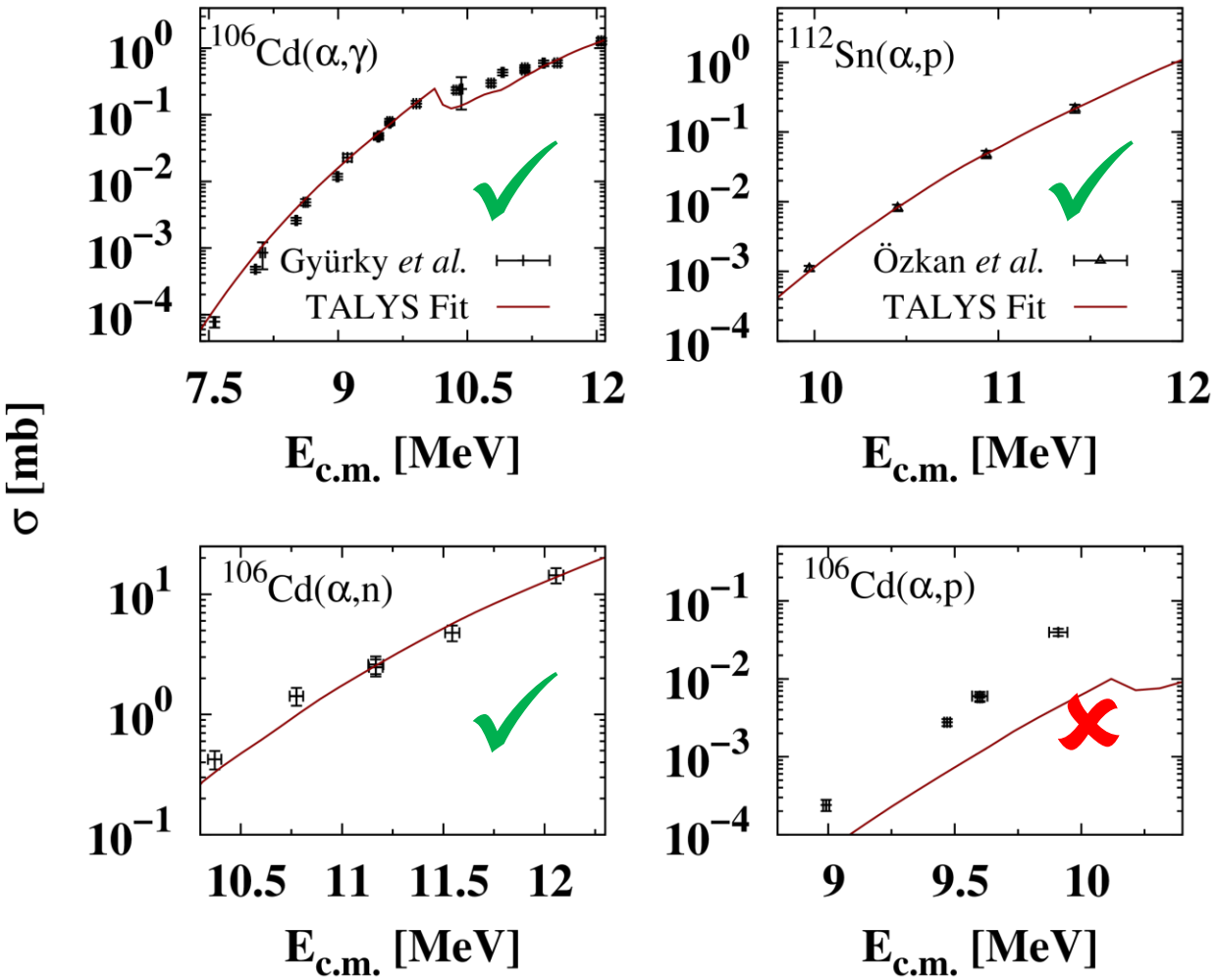
^{112}Sn(α,γ) ^{116}Te – Partial cross sections



- new experimental information
- allows constraint on γ-ray strength
- first time measured for an α-induced reaction!
- excellent agreement with microscopic model

L. Netterdon *et al*., Phys. Rev. C **91** (2015) 035801

Model applicability in Sn / Cd region



proton-shell closure in Sn?

L. Netterdon *et al.*, Phys. Rev. C **91** (2015) 035801
Gy. Gyürky *et al.*, Phys. Rev. C **74** (2006) 025805
N. Özkan *et al.*, Phys. Rev. C **75** (2007) 025801

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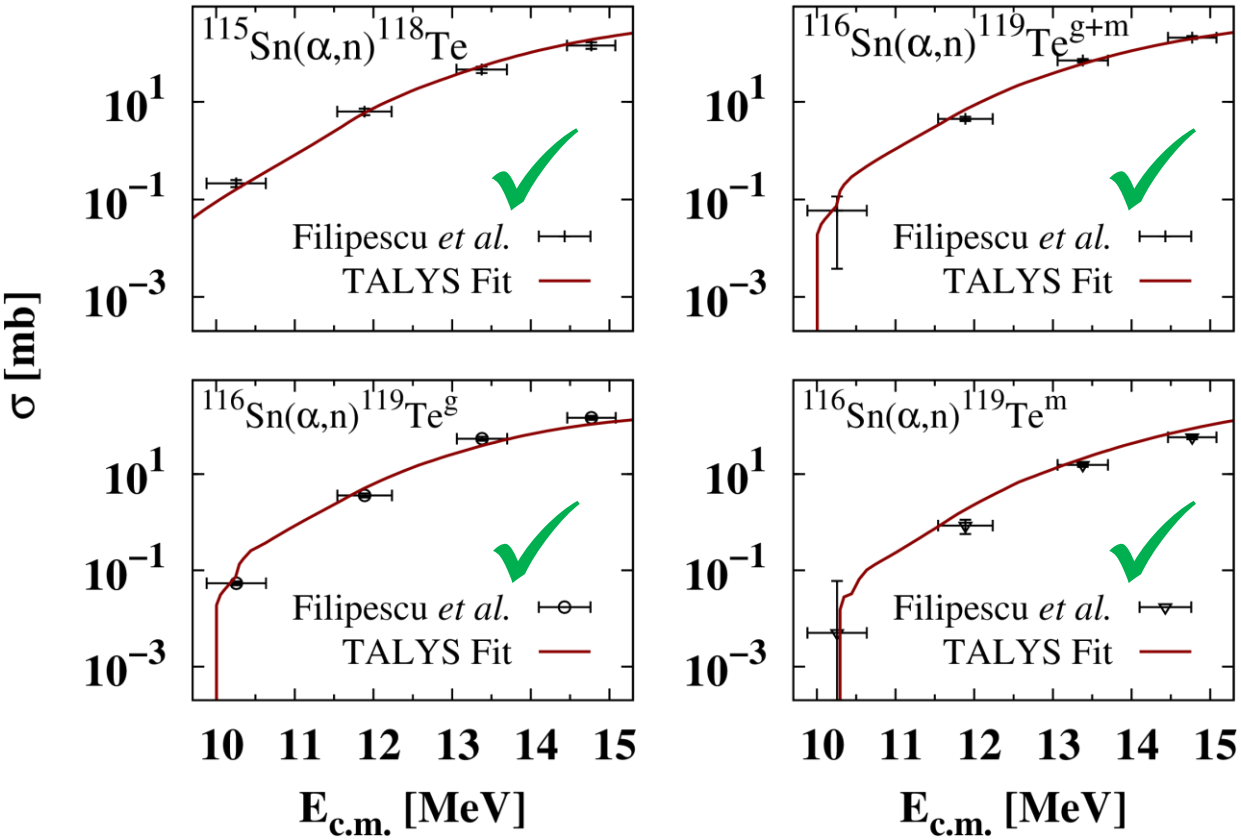
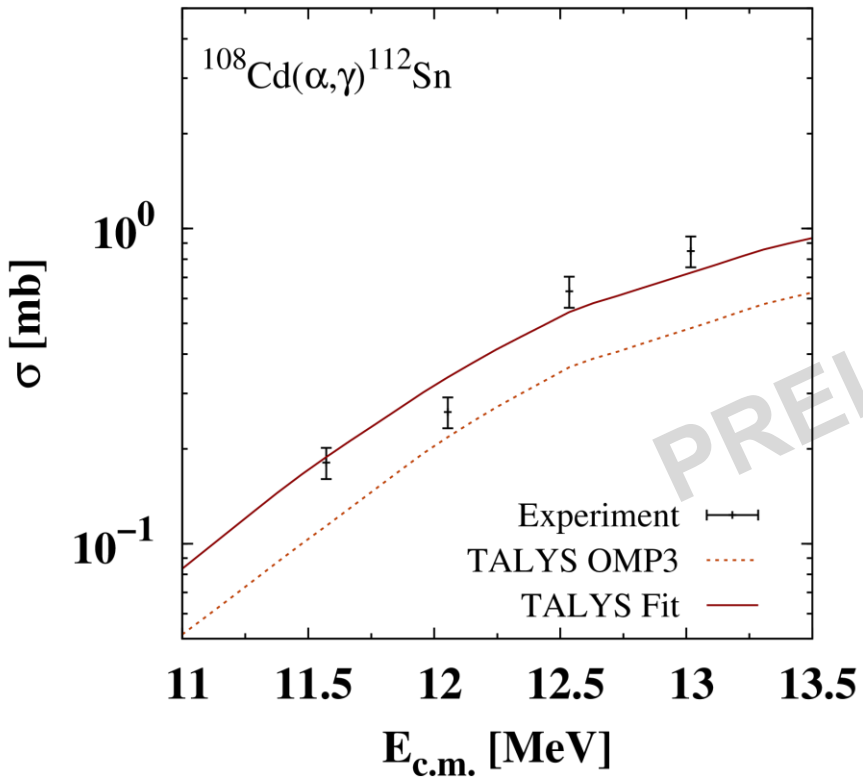
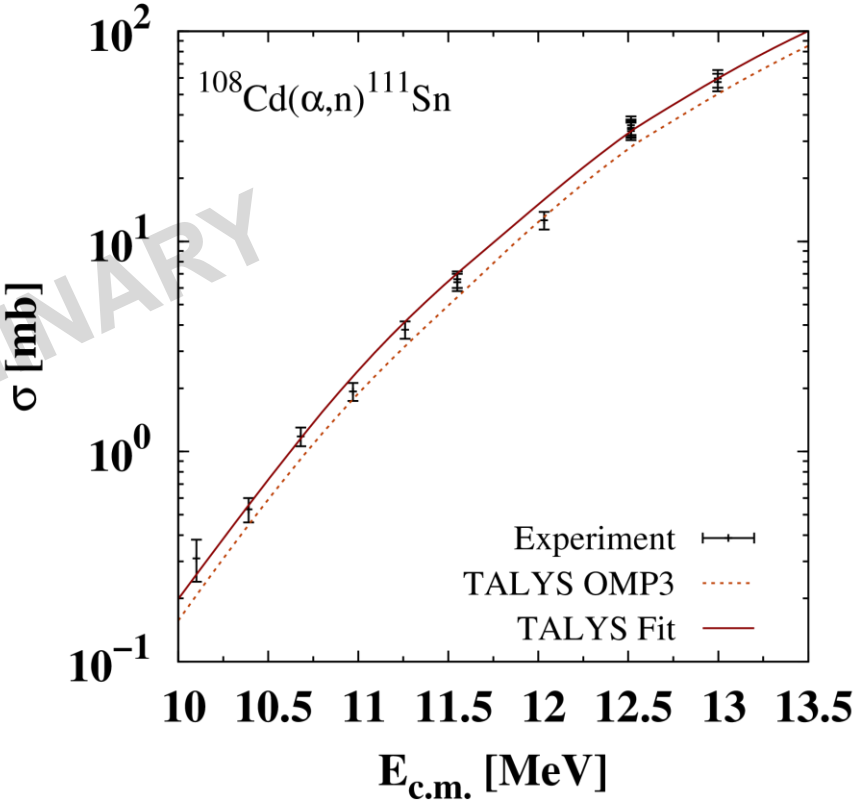


- presently found model well-suited for α-induced reactions in Sn / Cd region
- further experimental investigations are needed

L. Netterdon *et al.*, Phys. Rev. C **91** (2015) 035801
D. Filipescu *et al.*, Phys. Rev. C **83** (2011) 064609

Outlook: α-induced reactions in ^{108}Cd





- simultaneous measurement of (α,γ) and (α,n) cross sections
- ^{108}Cd(α,γ): 4 energies using in-beam technique
- ^{108}Cd(α,n): 10 energies with activation method
- good agreement with statistical-model predictions using parameters from ^{112}Sn(α,γ) measurement for <u>both</u> reactions

Summary

- γ-ray spectrometer HORUS and Cologne Clover Counting Setup for nuclear astrophysics experiments

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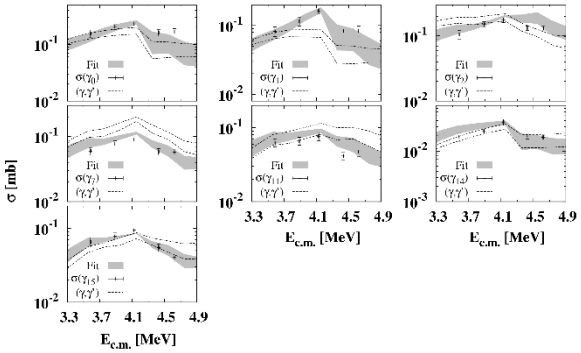
  - partial cross-sections to seven discrete states
  - extract γ-ray strength function in ^{90}Zr



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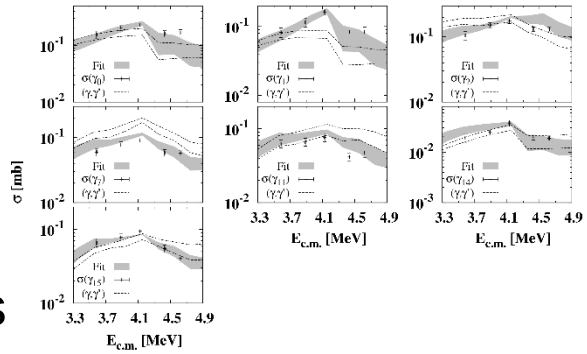
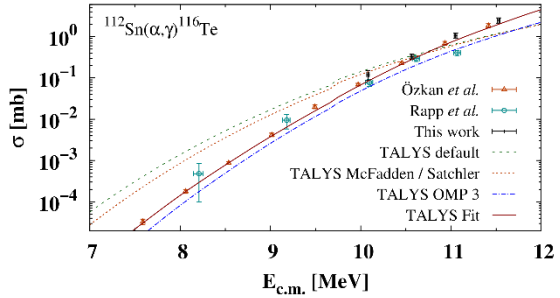
  - locally adopted model well-suited to describe various reactions in Sn / Cd region





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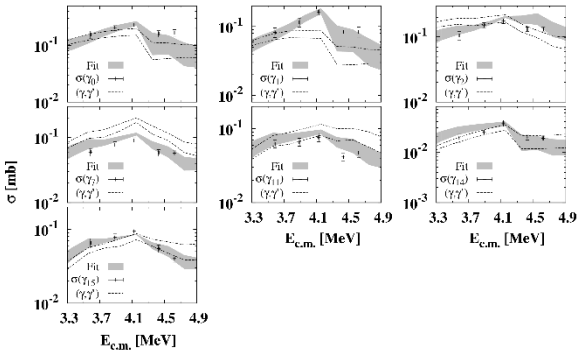
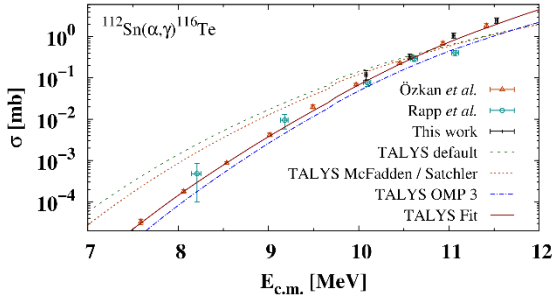
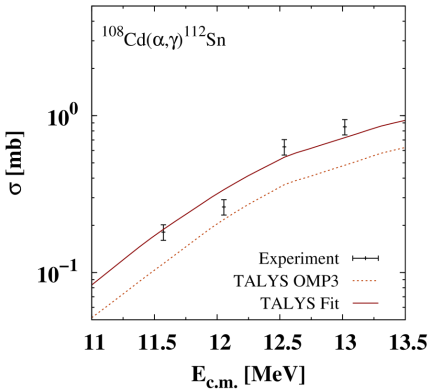
- α-induced reactions on ^{108}Cd via in-beam and activation technique → in progress







In-beam and activation experiments for γ-process nucleosynthesis

UoC

V. Derya, F. Heim, A. Hennig,
J. Mayer, S. G. Pickstone, S. Prill,
P. Scholz, M. Spieker, M. Weinert,
J. Wilhelmy, K. O. Zell, and A.Zilges

H.-W. Becker and
D. Rogalla

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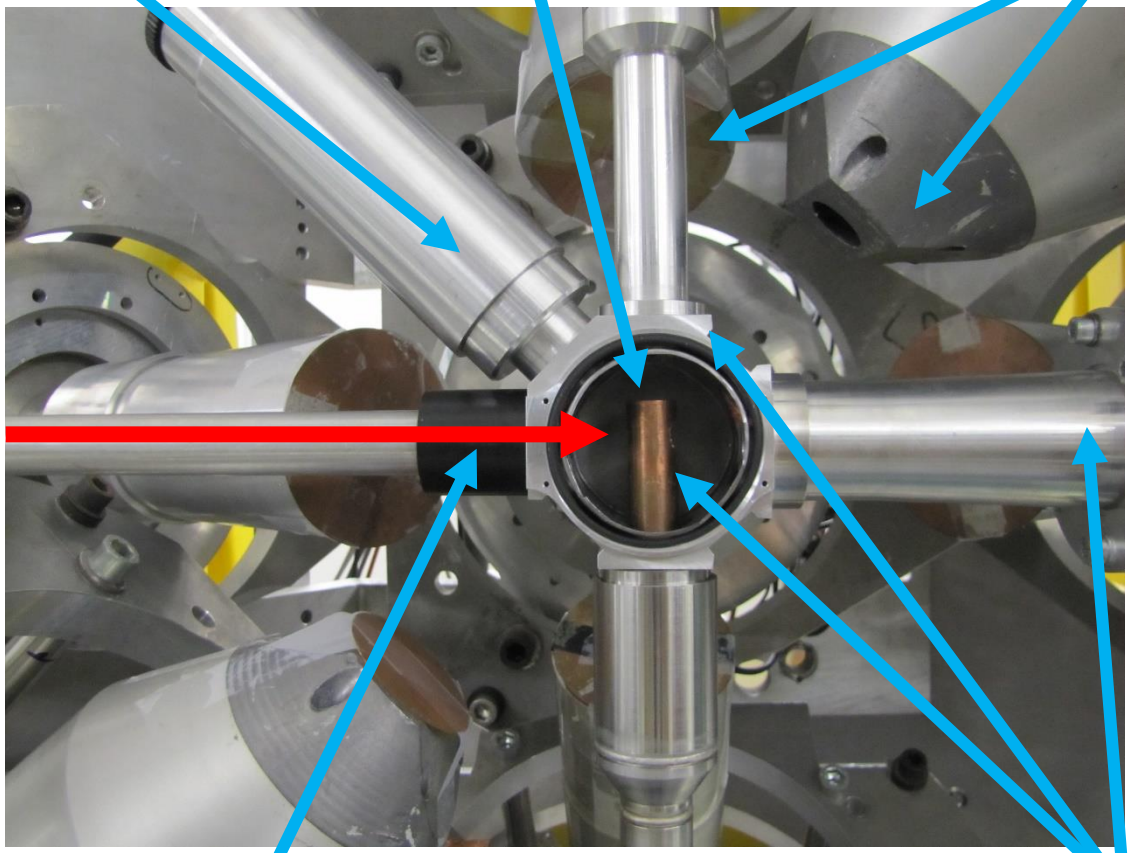
S. Goriely

Experimental setup in Cologne

RBS detector

cooling trap (LN_2)

HPGe (+BGO) detectors



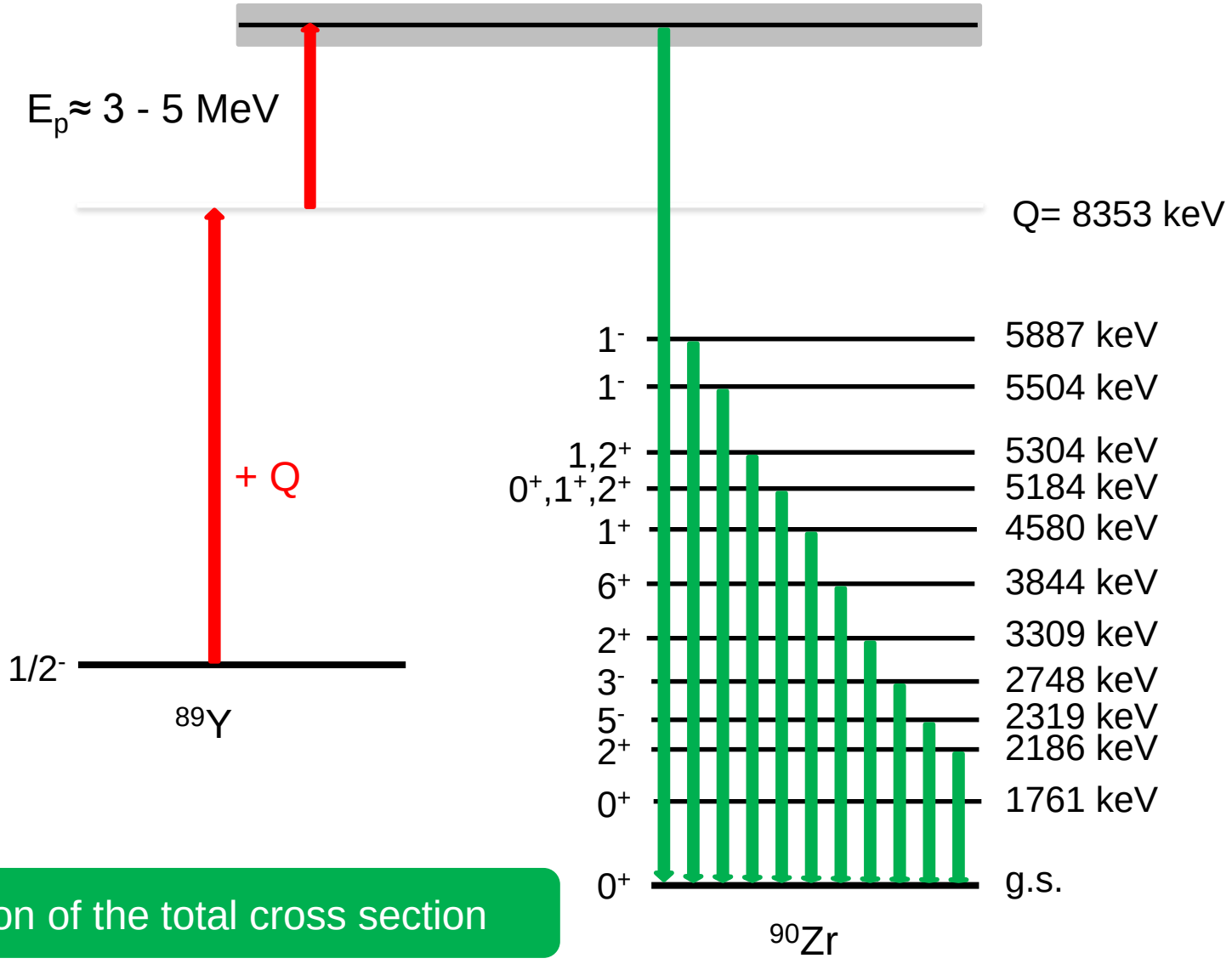
beam

suppression voltage
U_s = - 400 V

independent current read-out

L. Netterdon *et al.*, NIM **A 754** (2014) 94

$^{89}Y(p,\gamma)$ – In-beam method



determination of the total cross section

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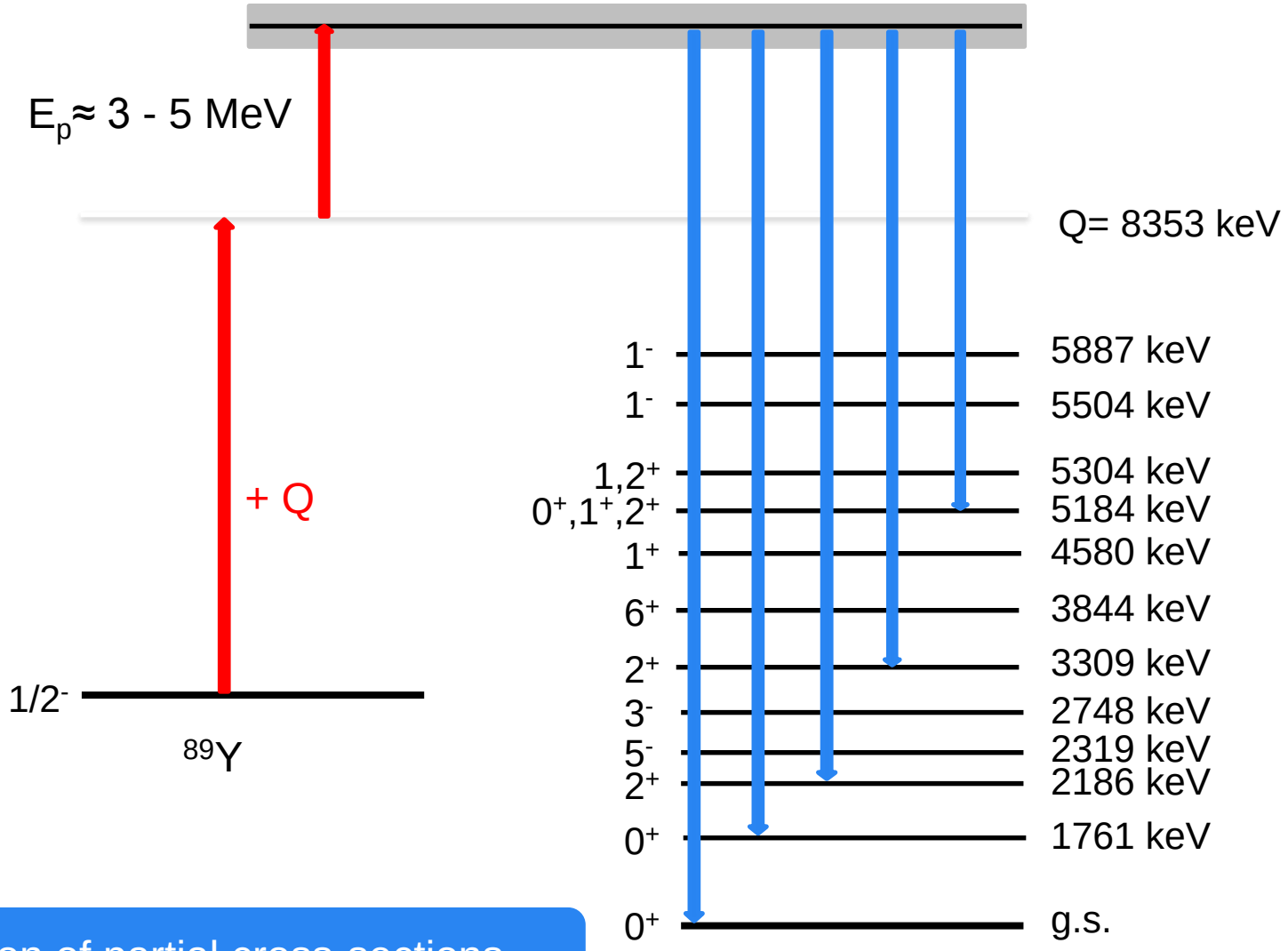
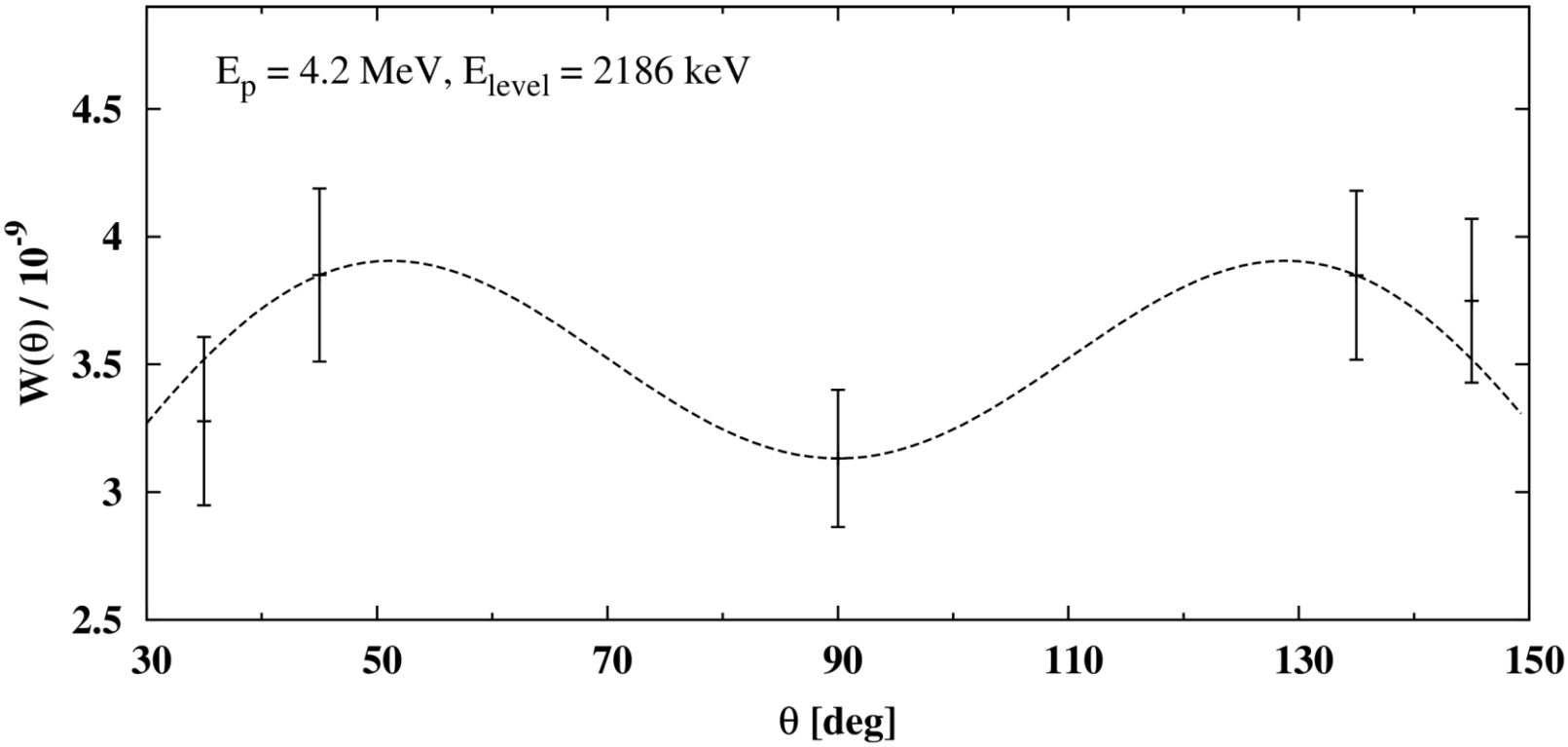


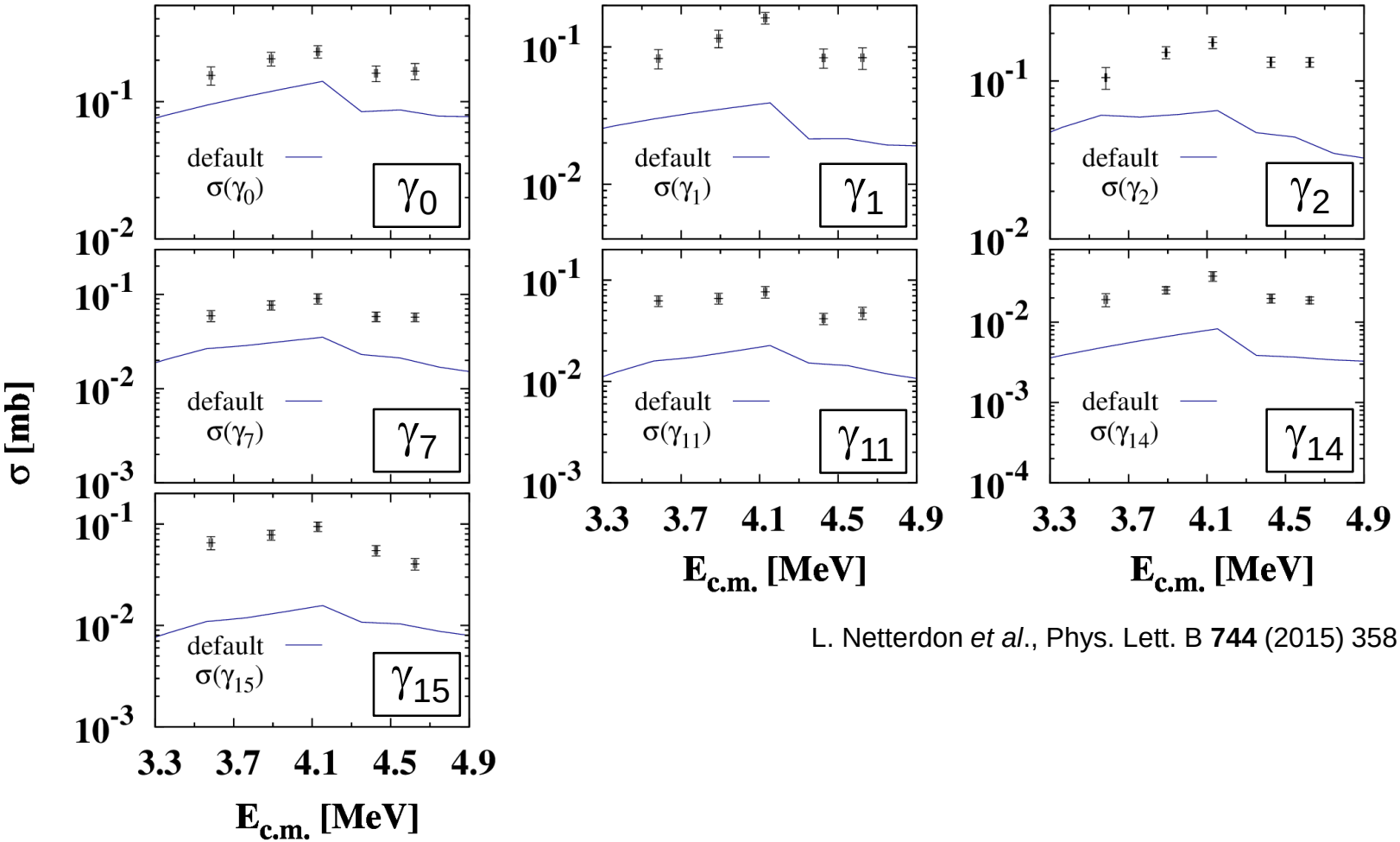
determination of partial cross-sections

^{89}Y(p,γ) – Angular distributions



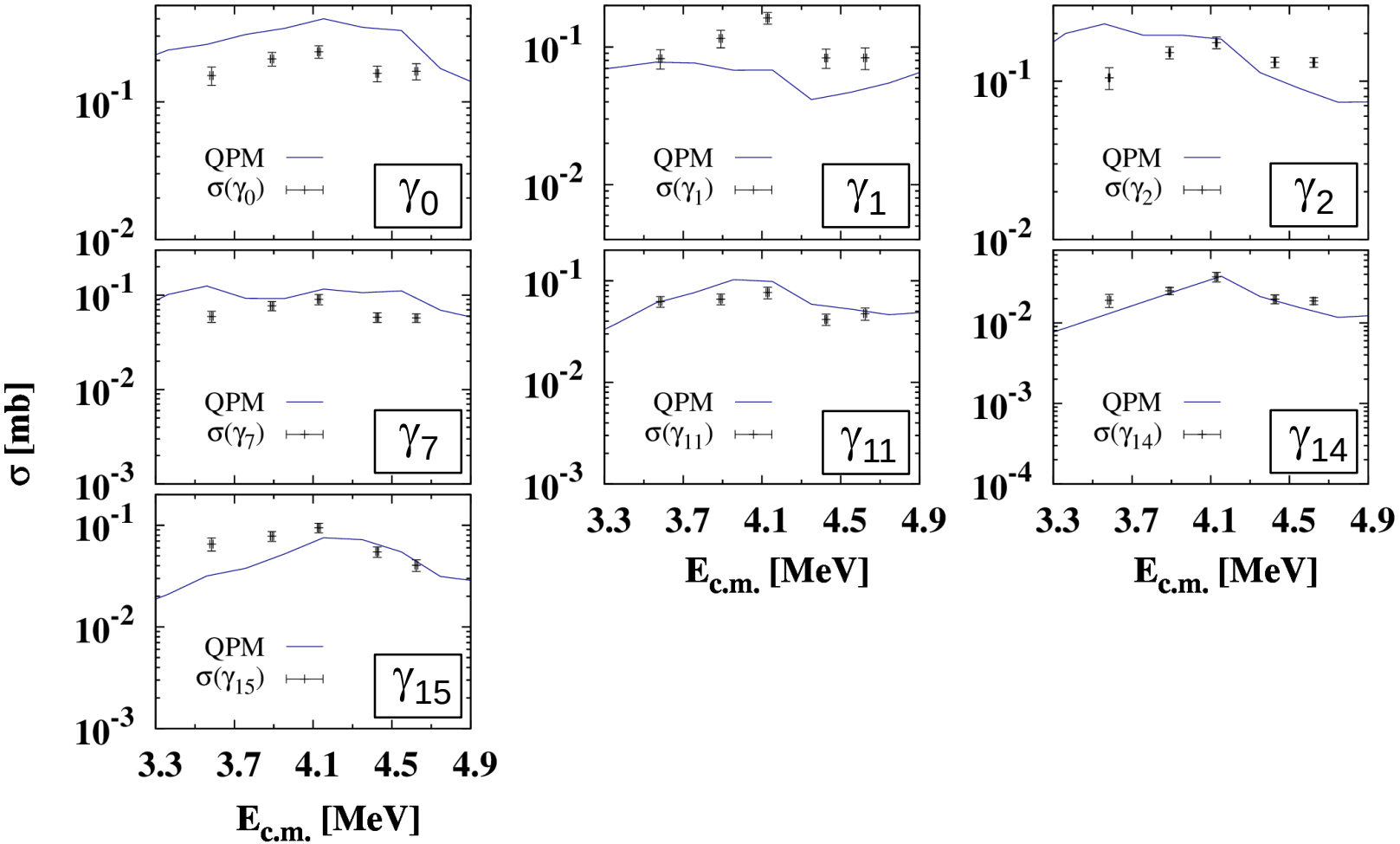
- measure reaction yield at 5 different angles relative to beam axis
- fit sum of Legendre polynomials
- obtain reaction yield in 4π

^{89}Y(p,γ) – Partial cross-sections

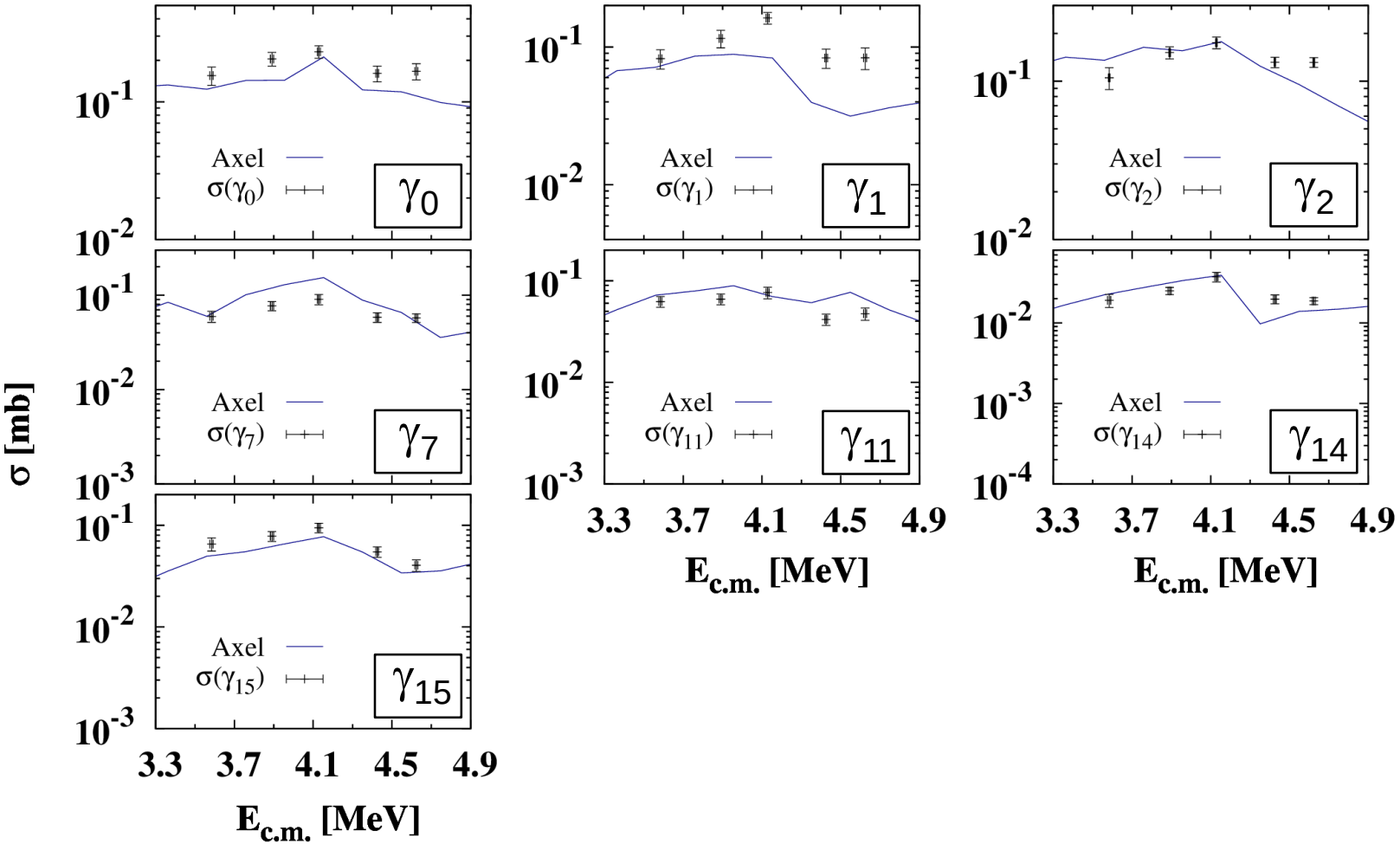


L. Netterdon *et al*., Phys. Lett. B **744** (2015) 358

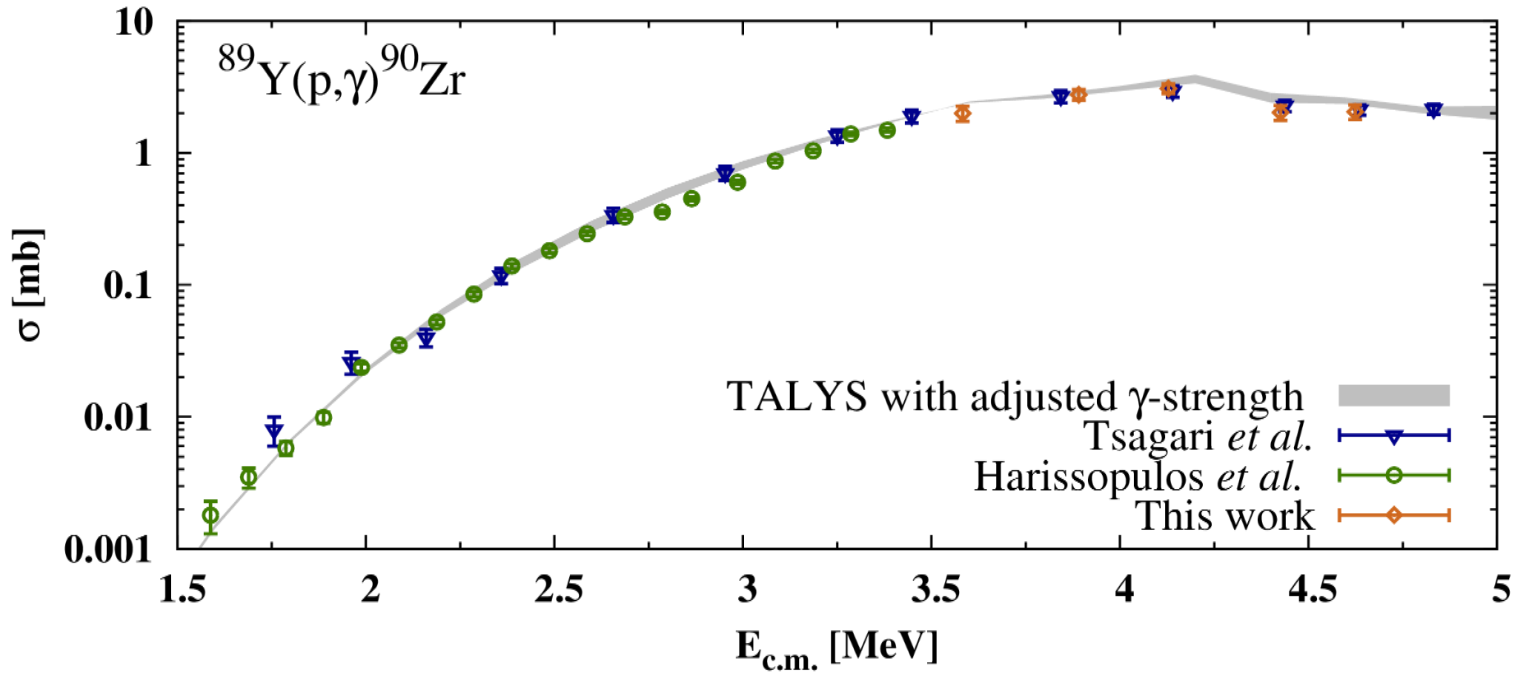
^{89}Y(p,γ) – Partial cross-sections QPM



^{89}Y(p,γ) – Partial cross-sections Axel *et al.*

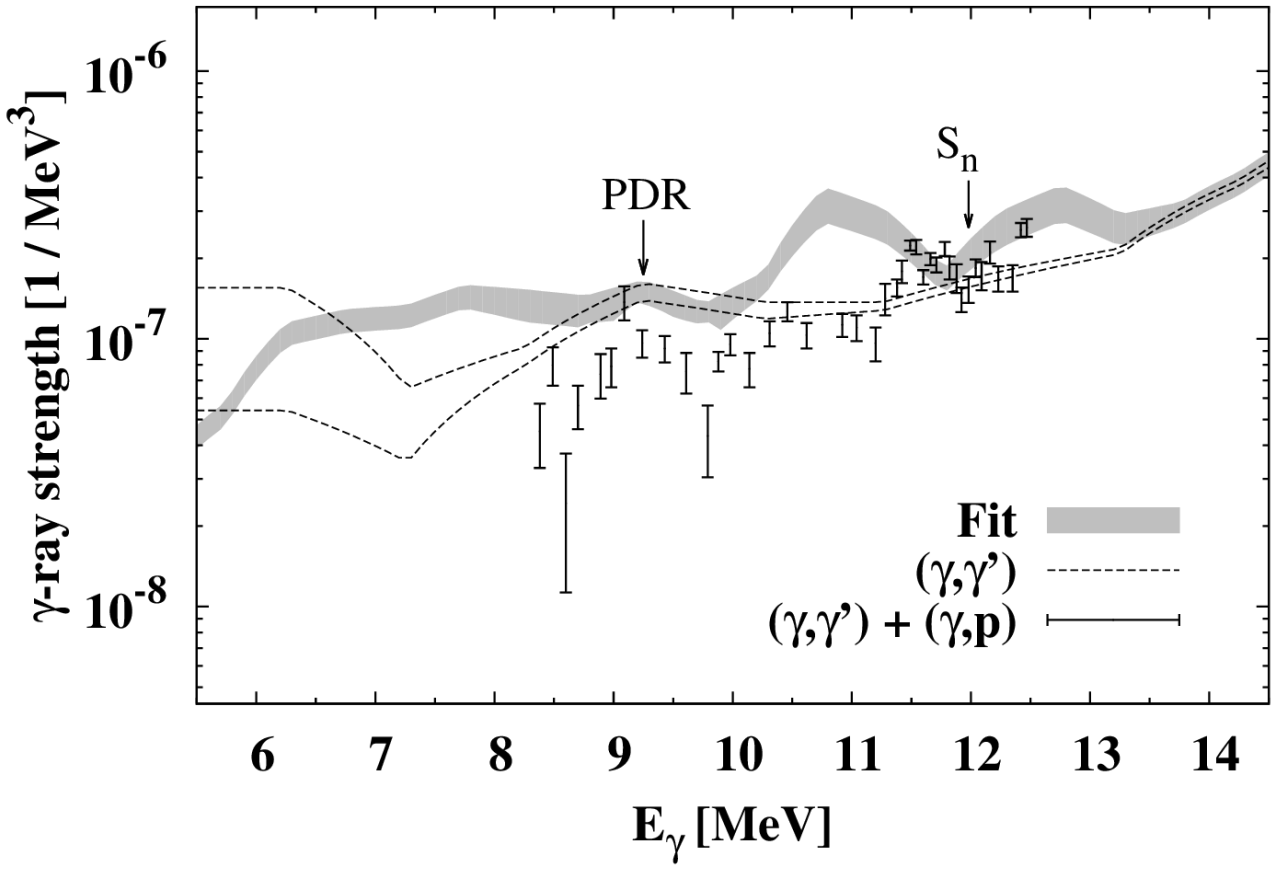


$^{89}Y(p,\gamma)\,^{90}Zr$ – Total cross-section



- excellent agreement of experimental data with previous measurements
- using adjusted γ-strength also reproduces total cross section

^{90}Zr – γ-ray strength function

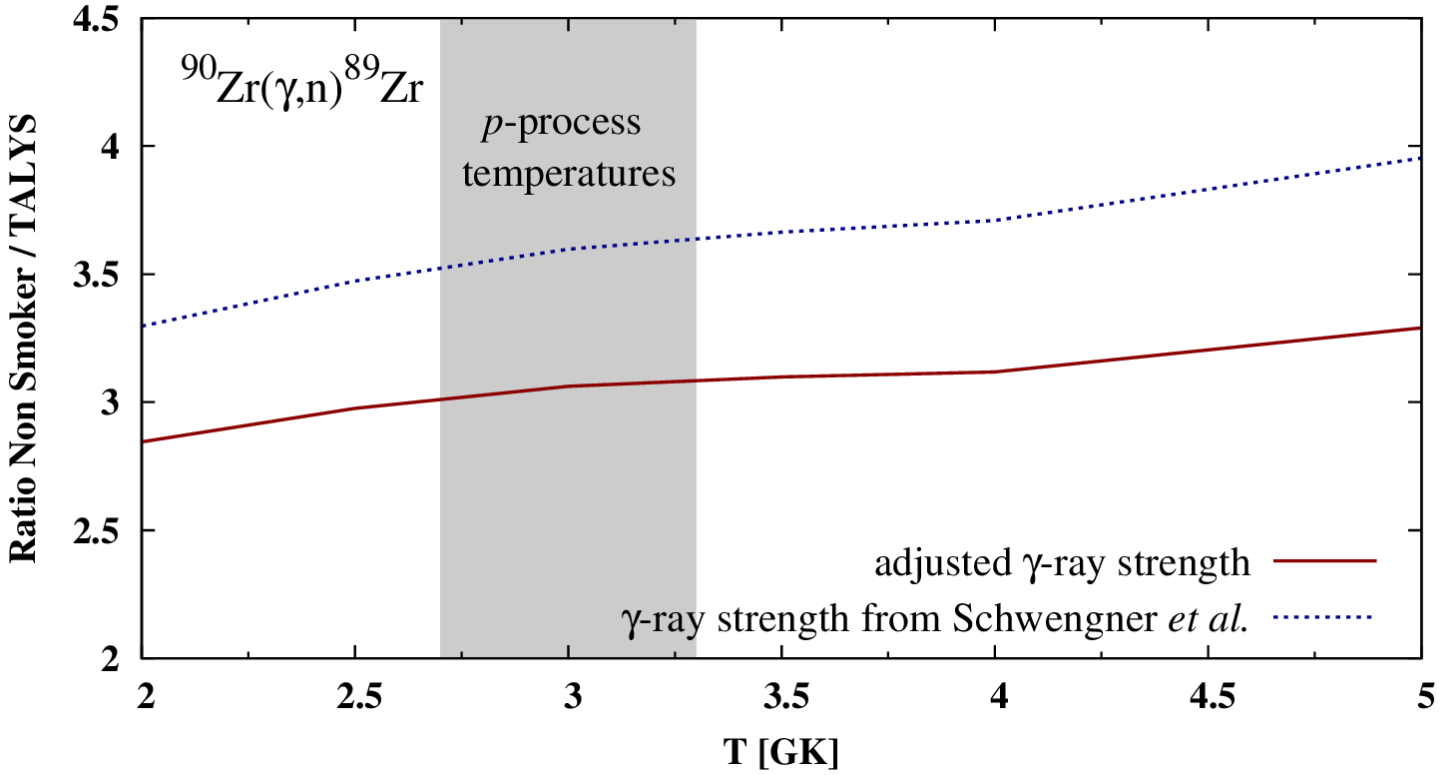


- location and strength of PDR is consistent
- where do deviations come from?

  → γ-branching ratios, dependence on nuclear temperature?

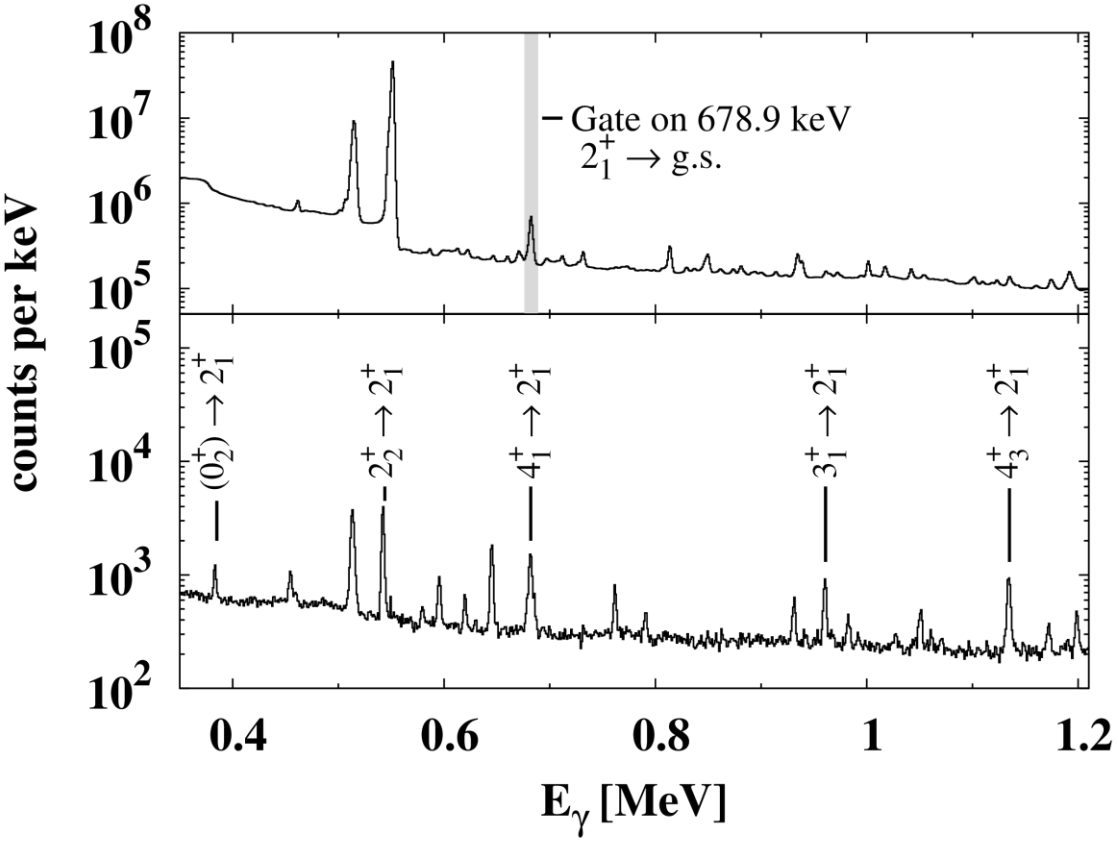
R. Schwengner *et al.*, Phys. Rev. C **78** (2008) 064314
P. Axel *et al.*, Phys. Rev. C **2** (1970) 689
L. Netterdon *et al.*, Phys. Lett. B **744** (2015) 358

Stellar reaction rate of ^{90}Zr(γ,n)



- comparison of stellar reaction rates with widely used Non Smoker code
- reaction rates with experimental γ-ray strength functions lower by about a factor of 3
- impact on solar abundance distribution of *p* nuclei (?)

^{112}Sn(α,γ) – $\gamma\gamma$-coincidences



- effective background reduction
- only three ground-state transitions available in literature
- reconstruction of experimentally known level scheme up to 16th excited state
- no evidence for further g.s. transitions found

L. Netterdon *et al*., Phys. Rev. C **91** (2015) 035801

^{92}Mo(p,γ) – Partial cross-sections