p-process nucleosynthesis: activation experiments

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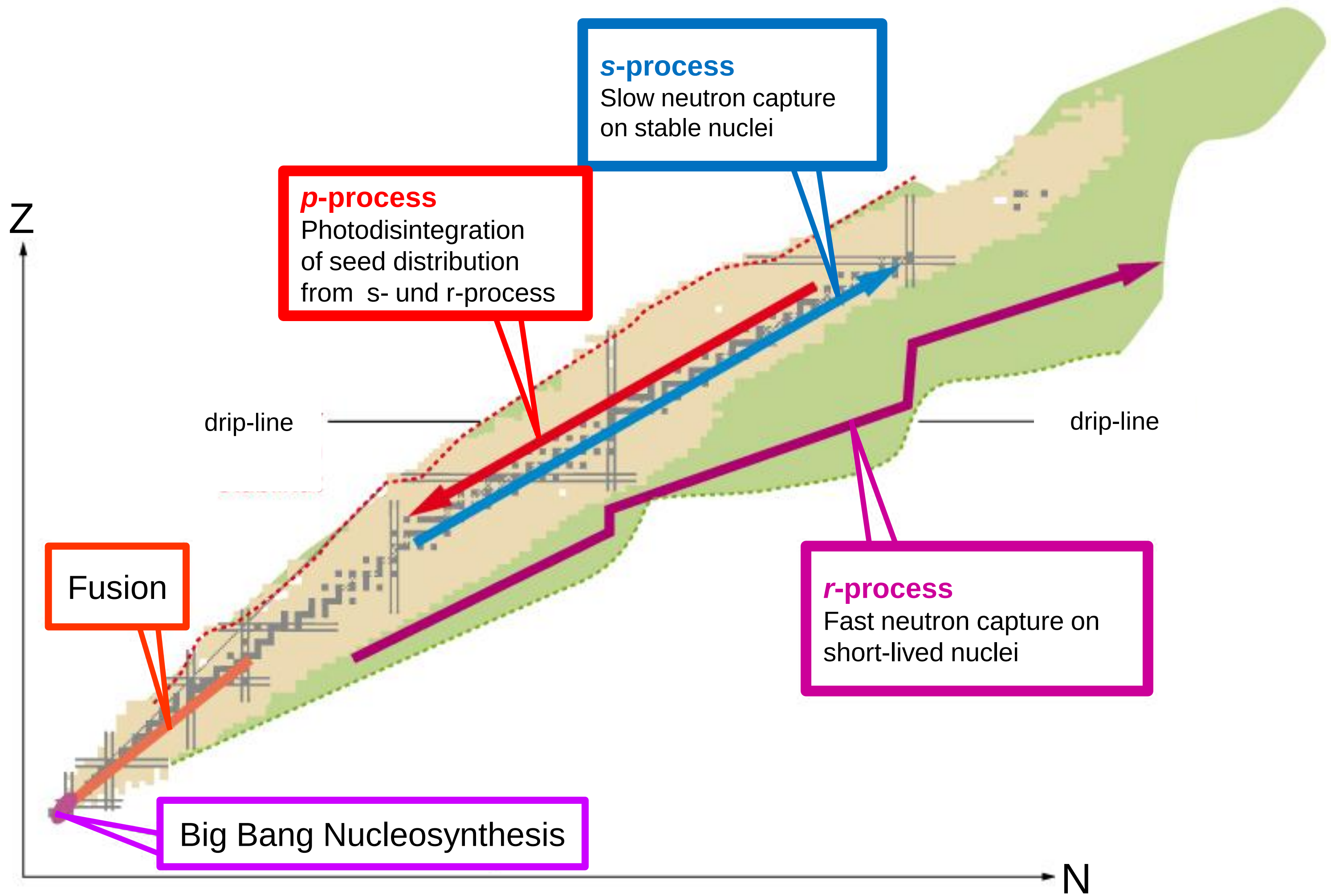
LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz

DAAD Deutscher Akademischer Austausch Dienst
German Academic Exchange Service

Outline

- introduction
- activation experiments
- preliminary results
- summary & outlook

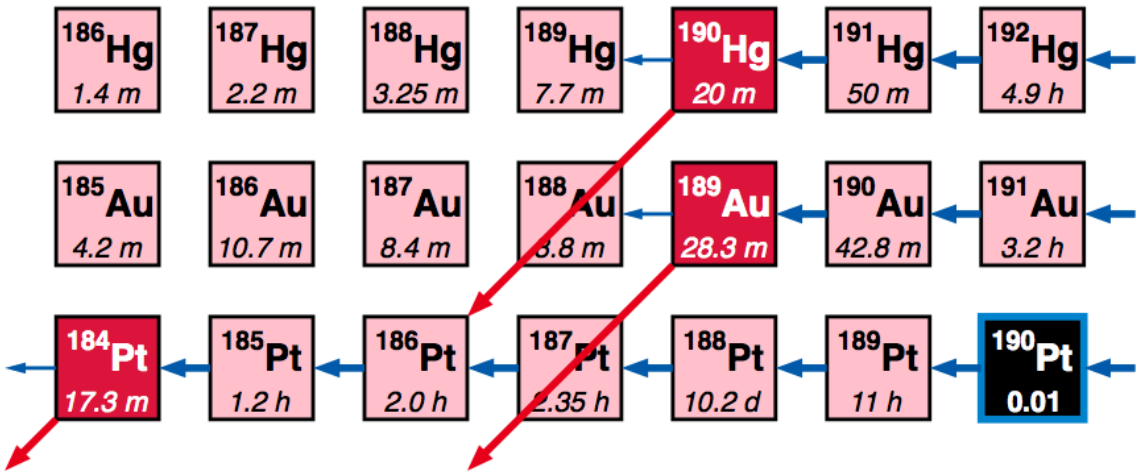
Nucleosynthesis of heavy elements



p-process

Starting point: seed distribution of *s*- and *r*-process

- (γ,n) reactions shift distribution to proton-rich isotopes
- (γ,α) and (γ,p) start to compete with (γ,n) reaction rates
- position of branching nuclei determines final p-abundances



Reaction network of *p*-process

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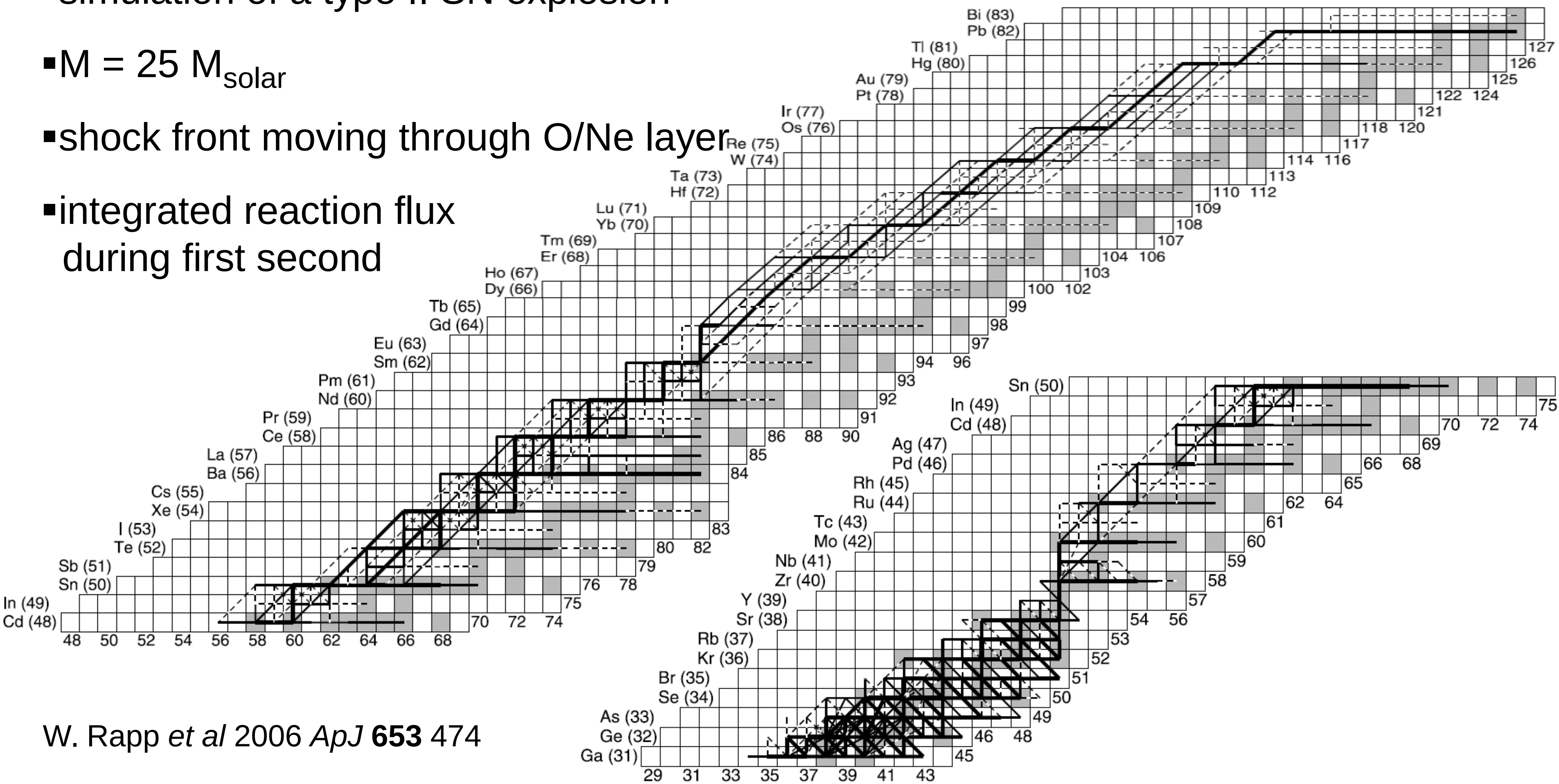
- simulation of a type II SN explosion
- M = 25 M_{solar}
- shock front moving through O/Ne layer
- integrated reaction flux during first second

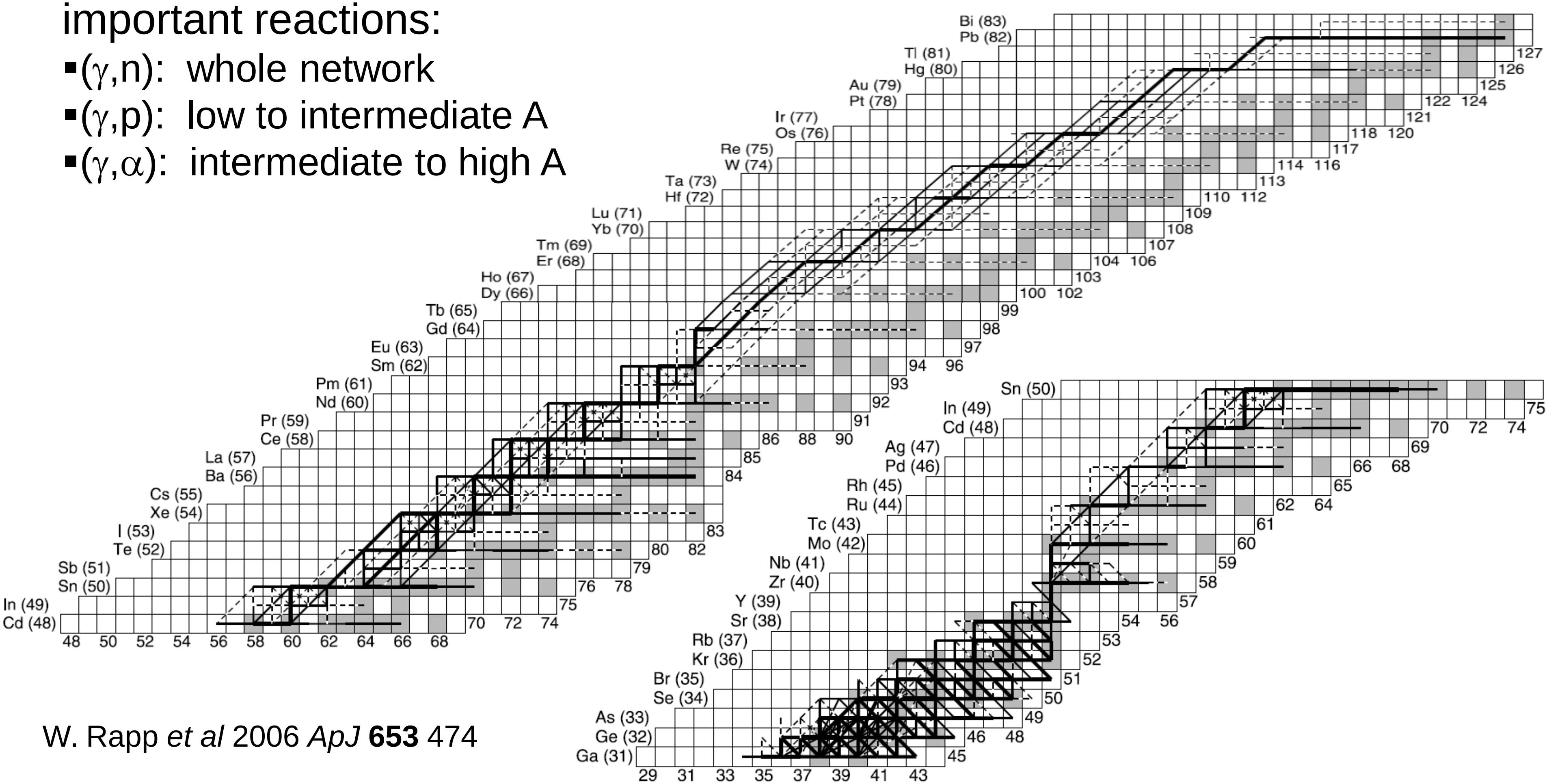


W. Rapp *et al* 2006 *ApJ* **653** 474

Reaction network of *p*-process

important reactions:

- (γ,n): whole network
- (γ,p): low to intermediate A
- (γ,α): intermediate to high A



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Reaction network of *p*-process

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- complex reaction network involving more than ten thousand reactions
- calculations need lot of physics input (reaction rates)
- rates cannot be measured for all reactions

→ calculation within the statistical Hauser-Feshbach model

- input parameters for statistical model codes:
  - optical potentials
  - γ-width
  - level densities
  - masses
- HF predictions have to be tested carefully by measurement

→ optimization of input parameters

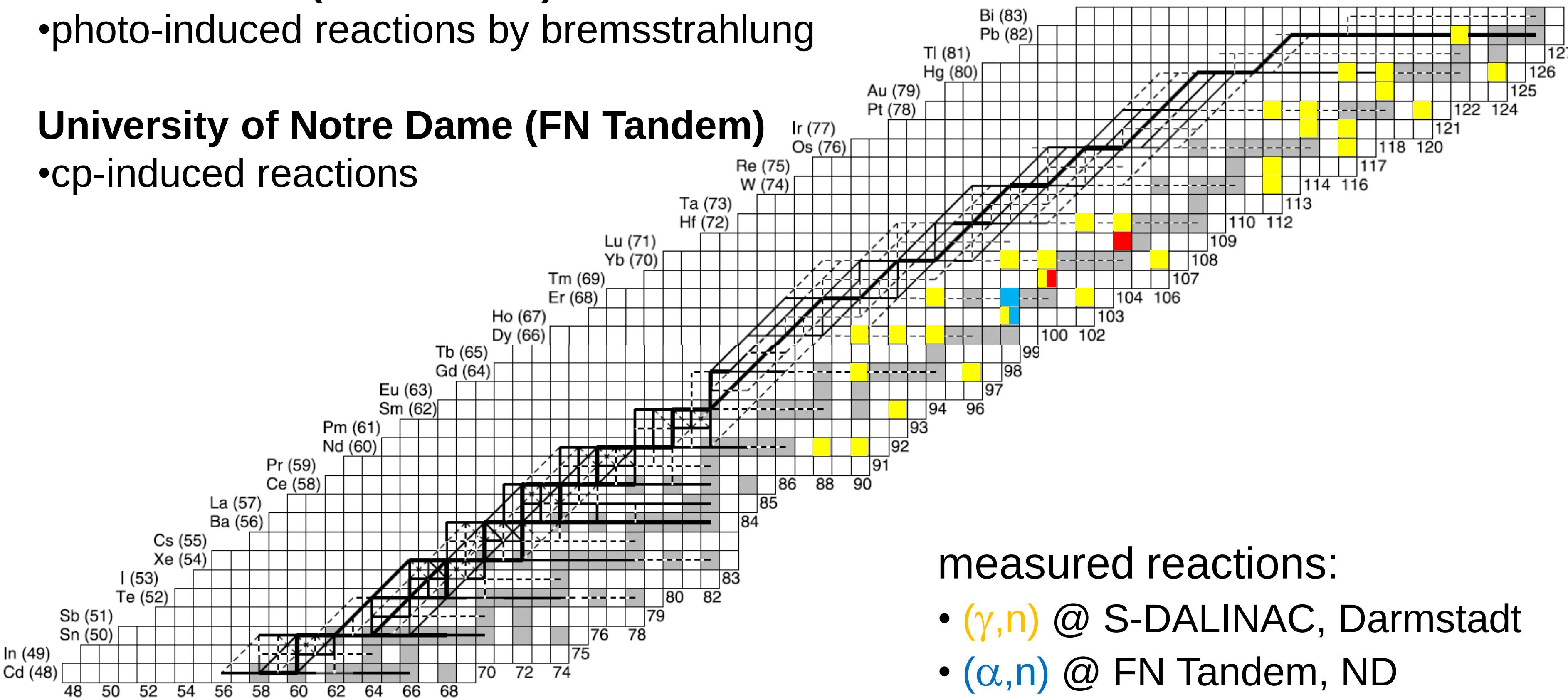
Measurements @ Darmstadt & Notre Dame

TU Darmstadt (S-DALINAC)

•photo-induced reactions by bremsstrahlung

University of Notre Dame (FN Tandem)

•cp-induced reactions



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measured reactions:

- (γ,n) @ S-DALINAC, Darmstadt
- (α,n) @ FN Tandem, ND
- (p,n) @ FN Tandem, ND

Calculations in the statistical HF model

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Compound nucleus theory

- entrance & exit channel are independent

$$\sigma_{\mathrm{HF}} \propto \sum_n (2J_n + 1) \frac{\langle \Gamma_{J_n}^{\mathrm{form}} \rangle \langle \Gamma_{J_n}^{\mathrm{dec}} \rangle}{\langle \Gamma_{J_n}^{\mathrm{dec,tot}} \rangle}$$

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Consequence for (α,n) & (p,n) reactions

- cp-width << n-width @ stellar temperatures (Coulomb supression)
- above n-separation energy: $\langle \Gamma_{J_n}^{\mathrm{dec,neutron}} \rangle \approx \langle \Gamma_{J_n}^{\mathrm{dec,tot}} \rangle$

➢ smallest width determines cross section

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- (α,n) & (p,n) reactions are not sensitive to neutron-width (sub-Coulomb)
- good possibility to test α- & p-nucleus optical potentials

Activation experiments

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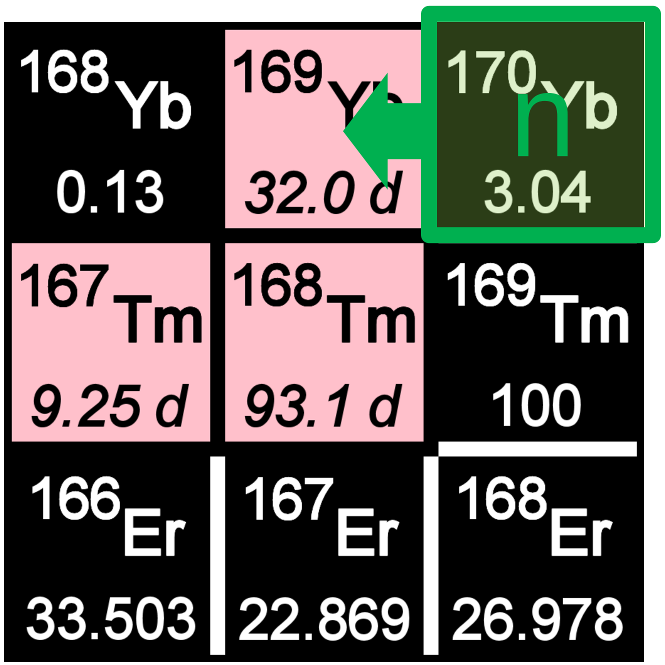
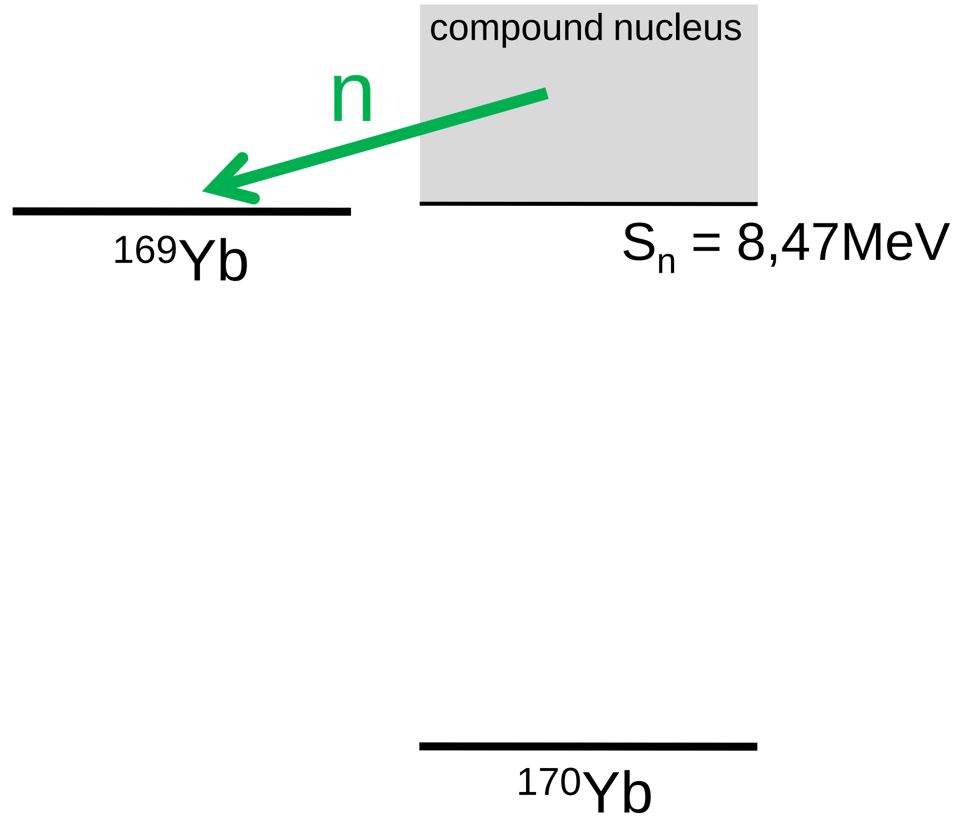
- 1 compound nucleus, 3 reactions
  - ➢ same exit channel





Activation experiments

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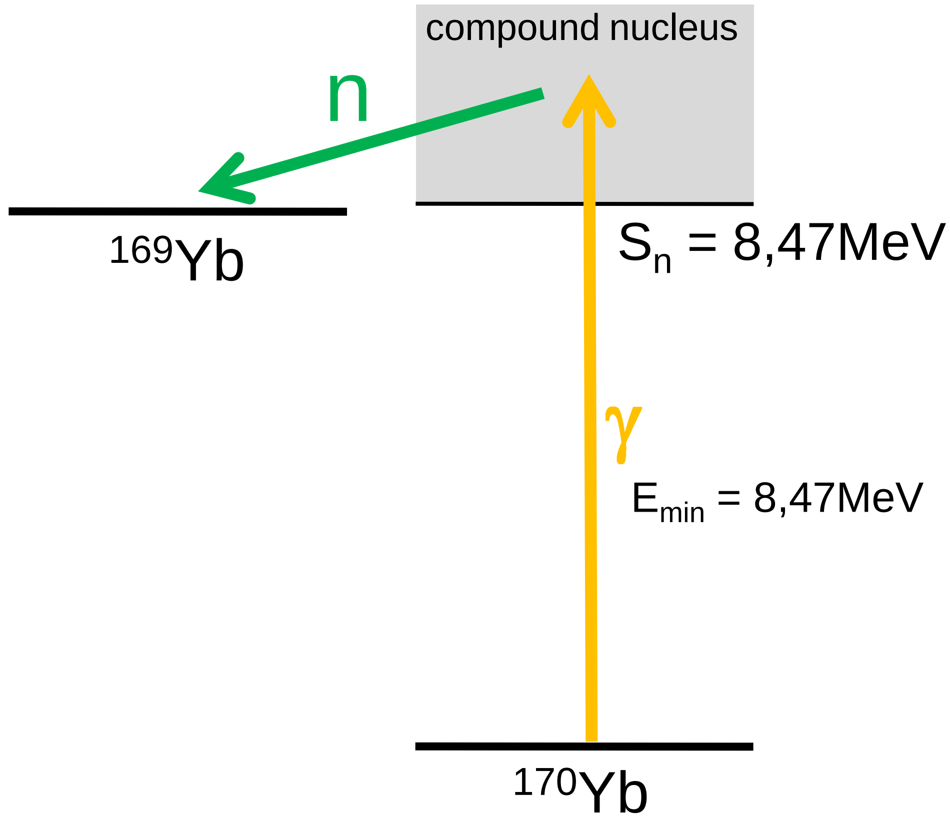
➢ same exit channel

^{168}Yb 0.13	^{169}Yb *32.0 d*	^{170}Yb 3.04 γ
^{167}Tm *9.25 d*	^{168}Tm *93.1 d*	^{169}Tm 100
^{166}Er 33.503	^{167}Er 22.869	^{168}Er 26.978



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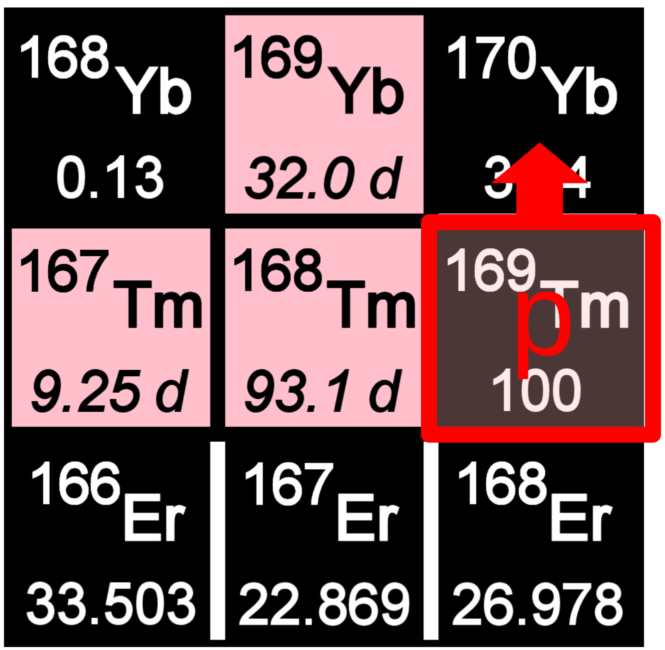

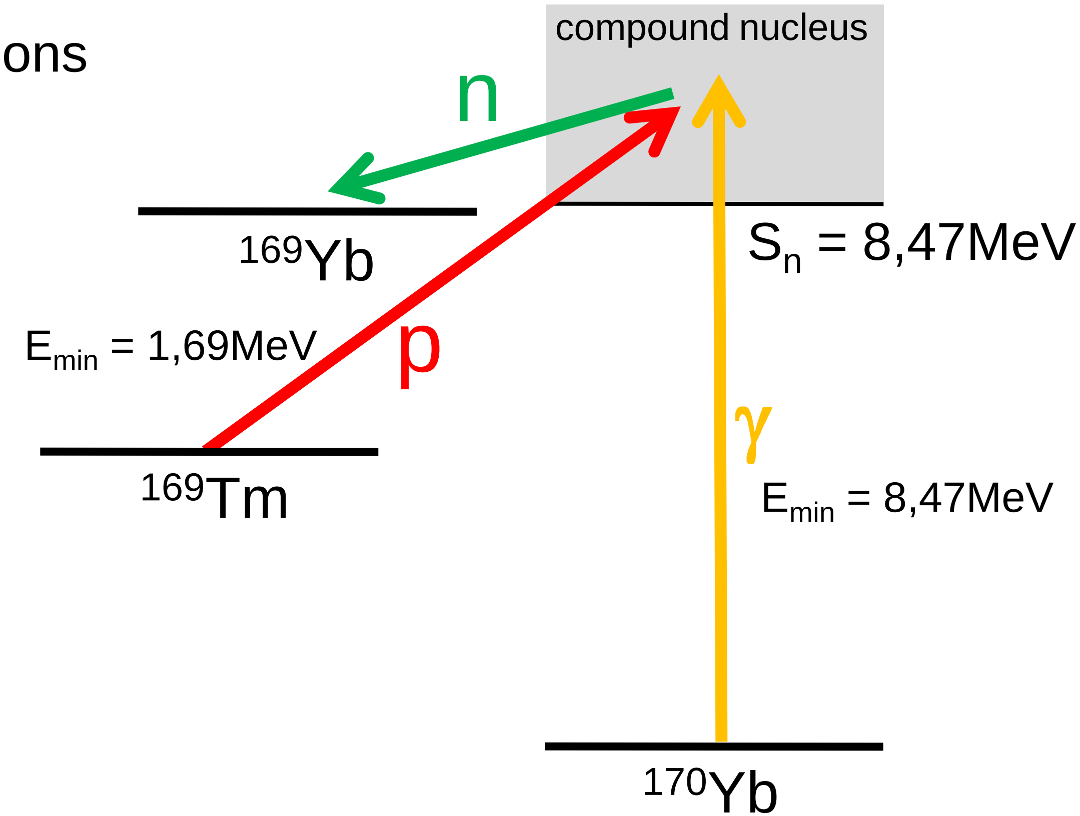

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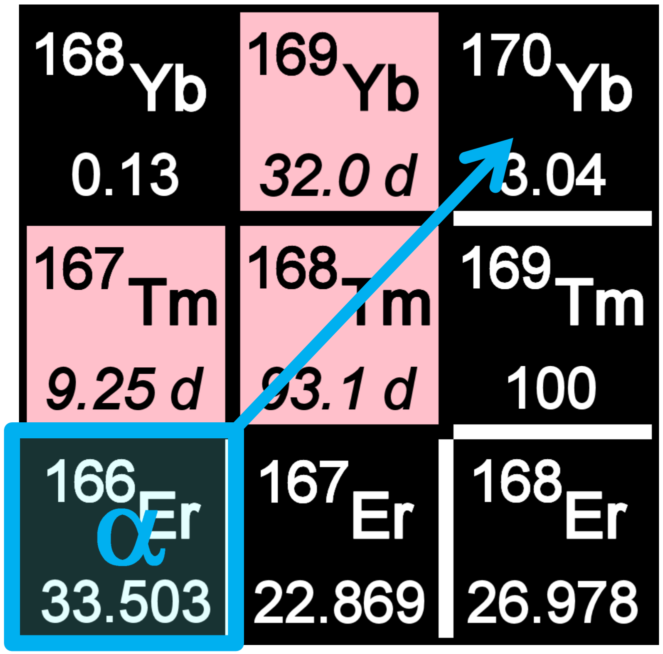

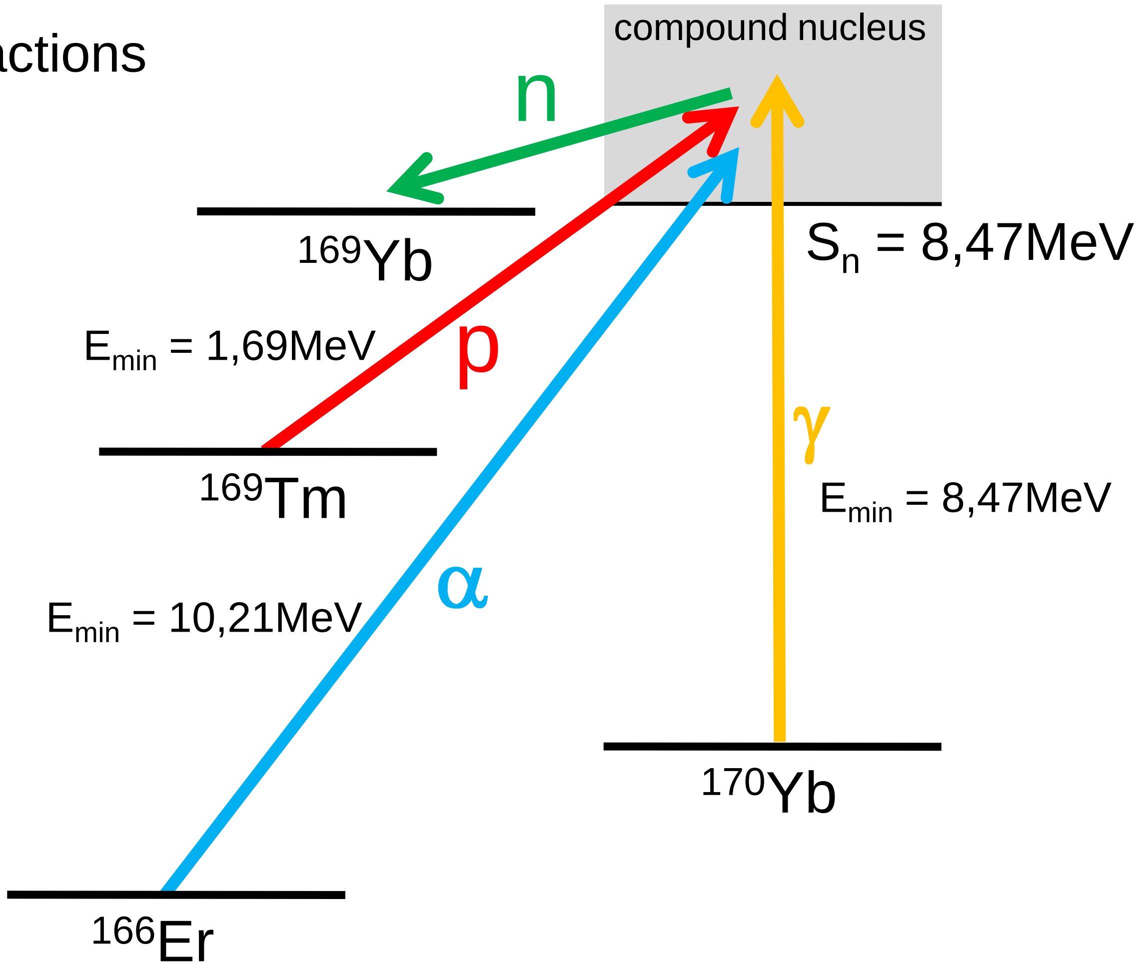

γ-spectroscopy of subsequent decay

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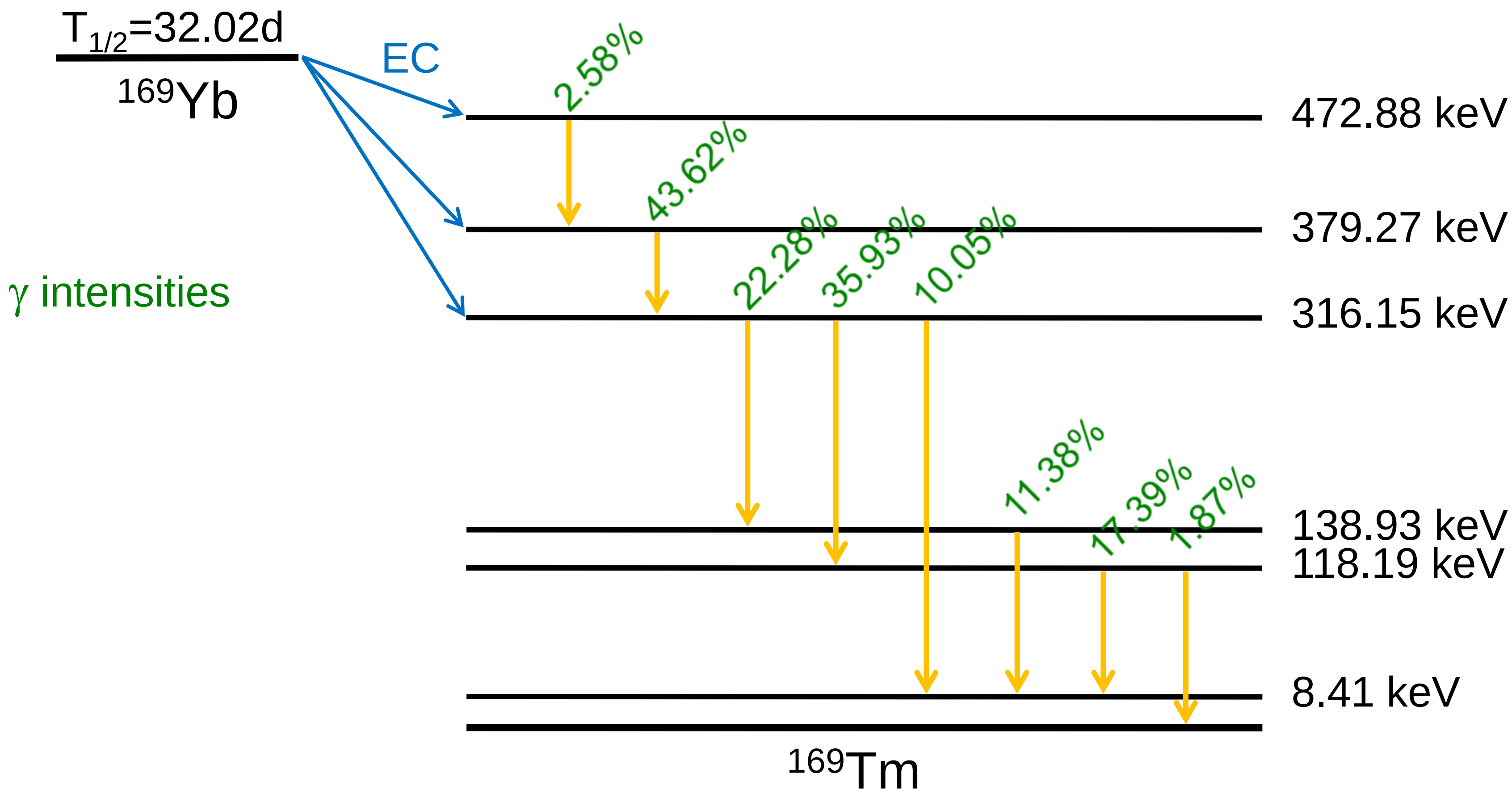
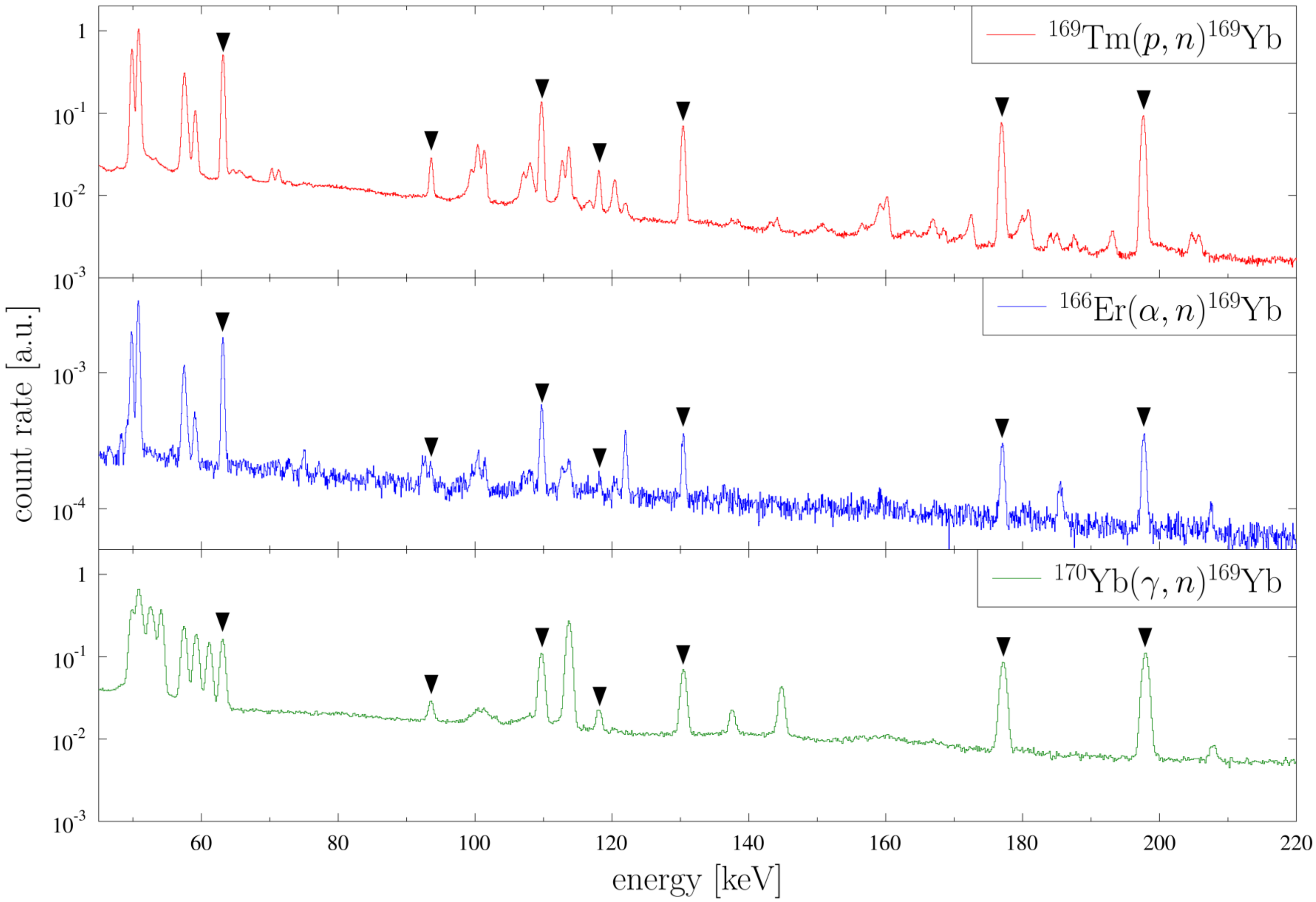


- ➢ equal systematic uncertainties influence all cross sections

www.nndc.bnl.gov/ensdf

γ-spectra



^{169}Tm$(p,n)^{169}$Yb
^{166}Er$(\alpha,n)^{169}$Yb
^{170}Yb$(\gamma,n)^{169}$Yb
count rate [a.u.]
energy [keV]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
60
80
100
120
140
160
180
200
220

Evaluation of data

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CP-induced reactions (monoenergetic beam)

- peak area directly proportional to cross section

$$Y_{\text{peak}} \propto \sigma\left(E\right)$$

➢ energy resolved cross section

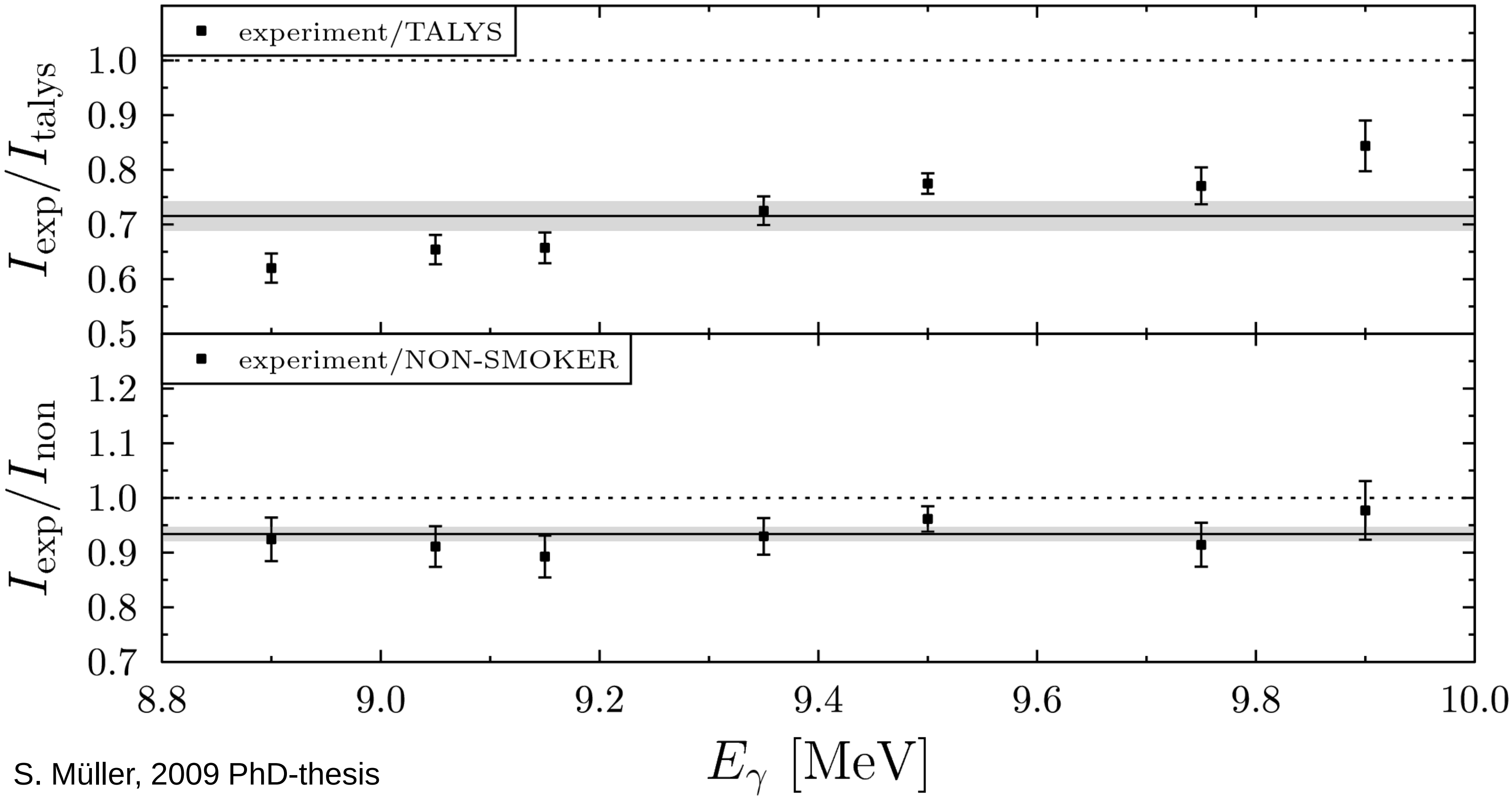
Photo-induced reactions (bremsstrahlung)

- peak area proportional to energy integrated cross section

$$Y_{\text{peak}} \propto \int_0^\infty \sigma\left(E\right) n_\gamma\left(E\right) dE$$

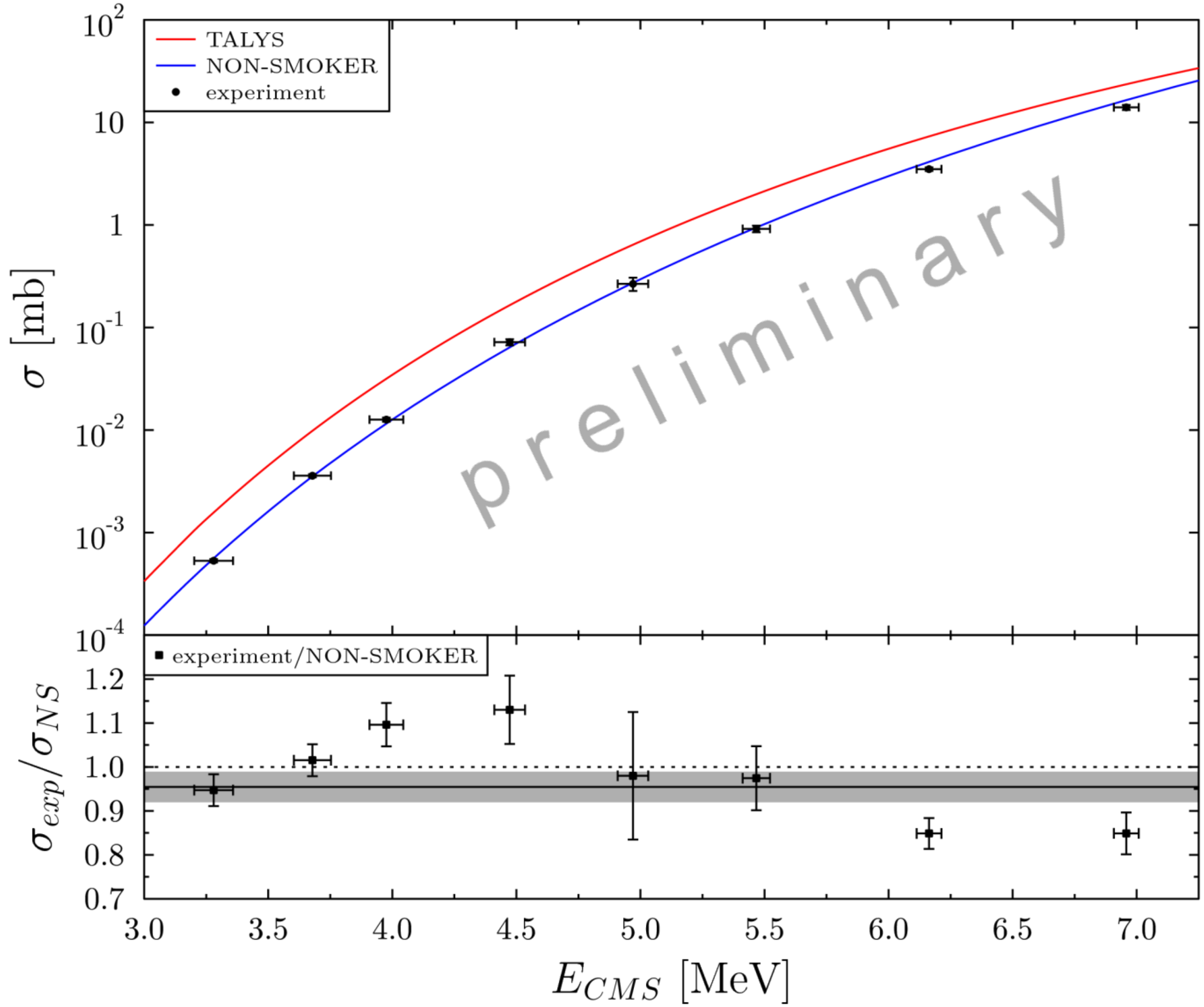
➢ energy integrated cross section

Preliminary results $^{170}Yb(\gamma,n)$

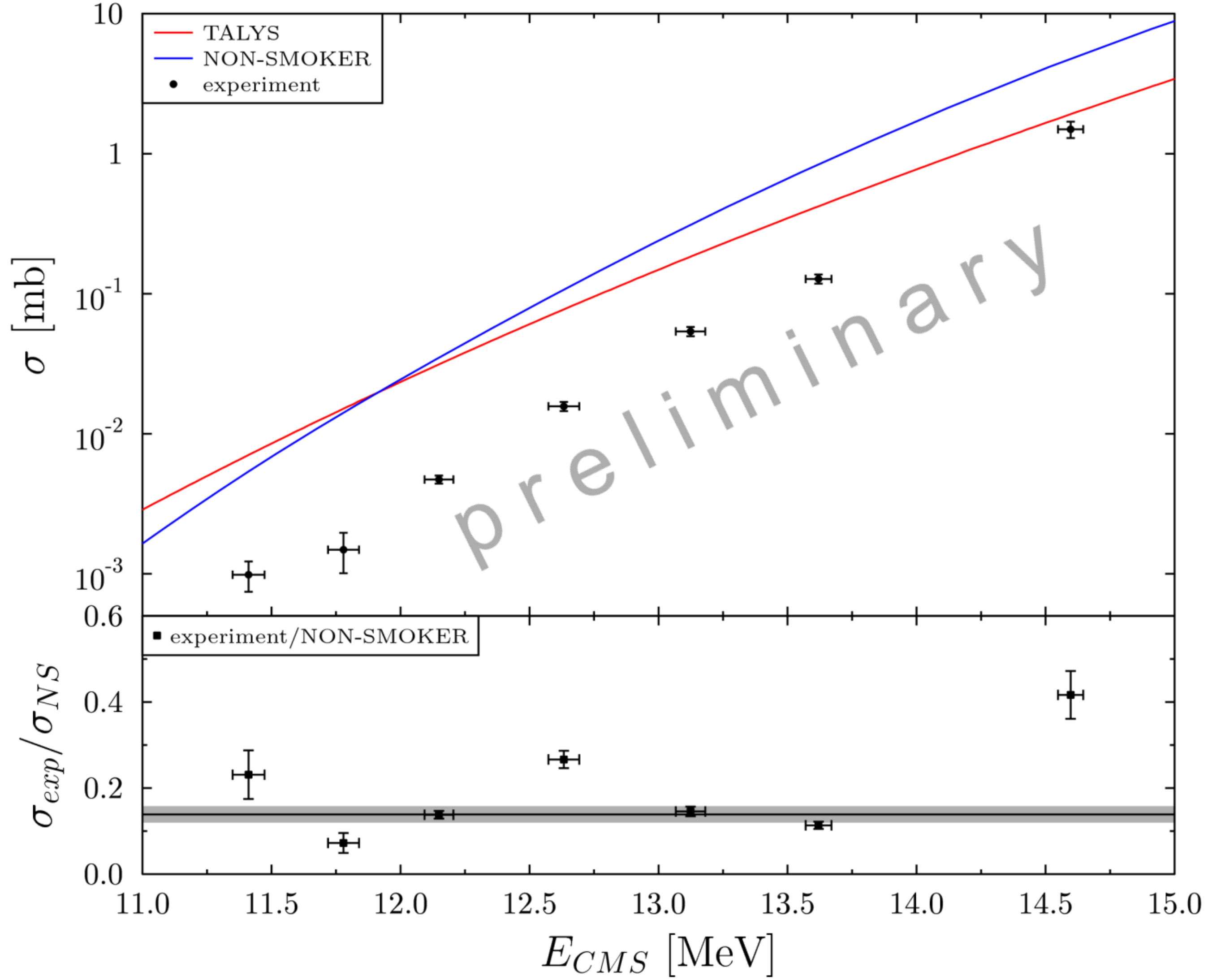


S. Müller, 2009 PhD-thesis

Preliminary results $^{169}Tm(p,n)$



Preliminary results $^{166}Er(\alpha,n)$



Summary

Probing statistical Hauser-Feshbach model

Three activation measurements

- production of one compound nucleus ^{170}Yb
- ^{170}Yb(γ,n) @ S-DALINAC, Darmstadt, Germany
- ^{166}Er(α,n) & ^{169}Tm(p,n) @ FN-TANDEM, University of Notre Dame, USA

Preliminary results compared to theory

- good description of ^{169}Tm(p,n) and ^{170}Yb(γ,n)
- deviation by a factor of 6 for ^{166}Er(α,n)

Outlook

Further evaluation of data

- correction for summing effects

Detailed comparison with HF predictions

- calculate XS with different HF codes (e.g. TALYS, NON-SMOKER)
- systematic variation of input parameters (optical potential)

Collect more experimental data

- cp-induced reactions in the rare earth region (x,n)
- ^{165}Ho(α,n) & ^{175}Lu(p,n)
- compare to recent results
- extend existing systematic studies

Thank you …

…for your attention!

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