Gamma-induced reactions in explosive nucleosynthesis

- **The p-process**
- **Direct measurements with photons**
- **„Indirect“ measurements: Optical potentials**
- **Outlook**

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from October 1st, 2007:

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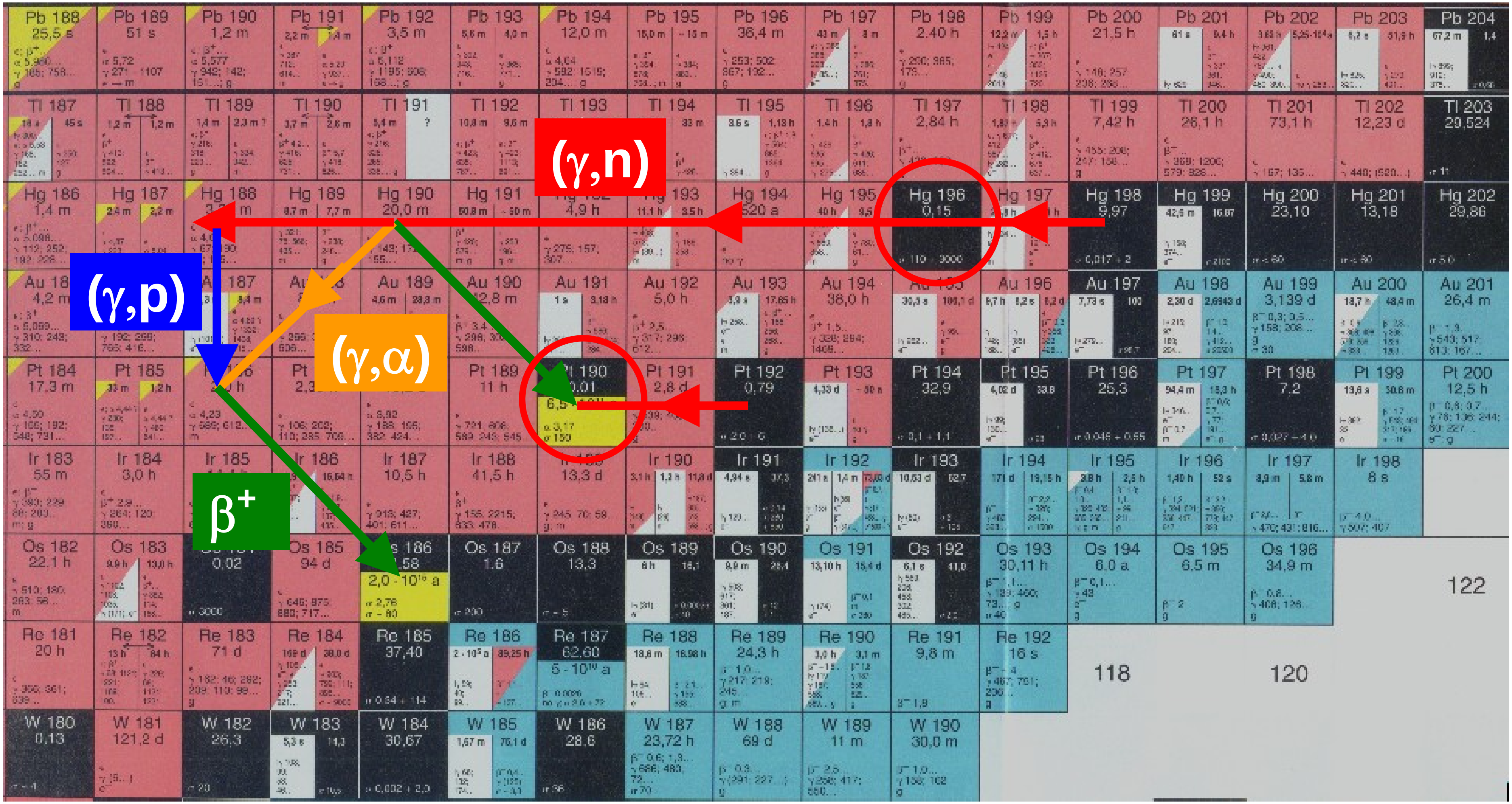
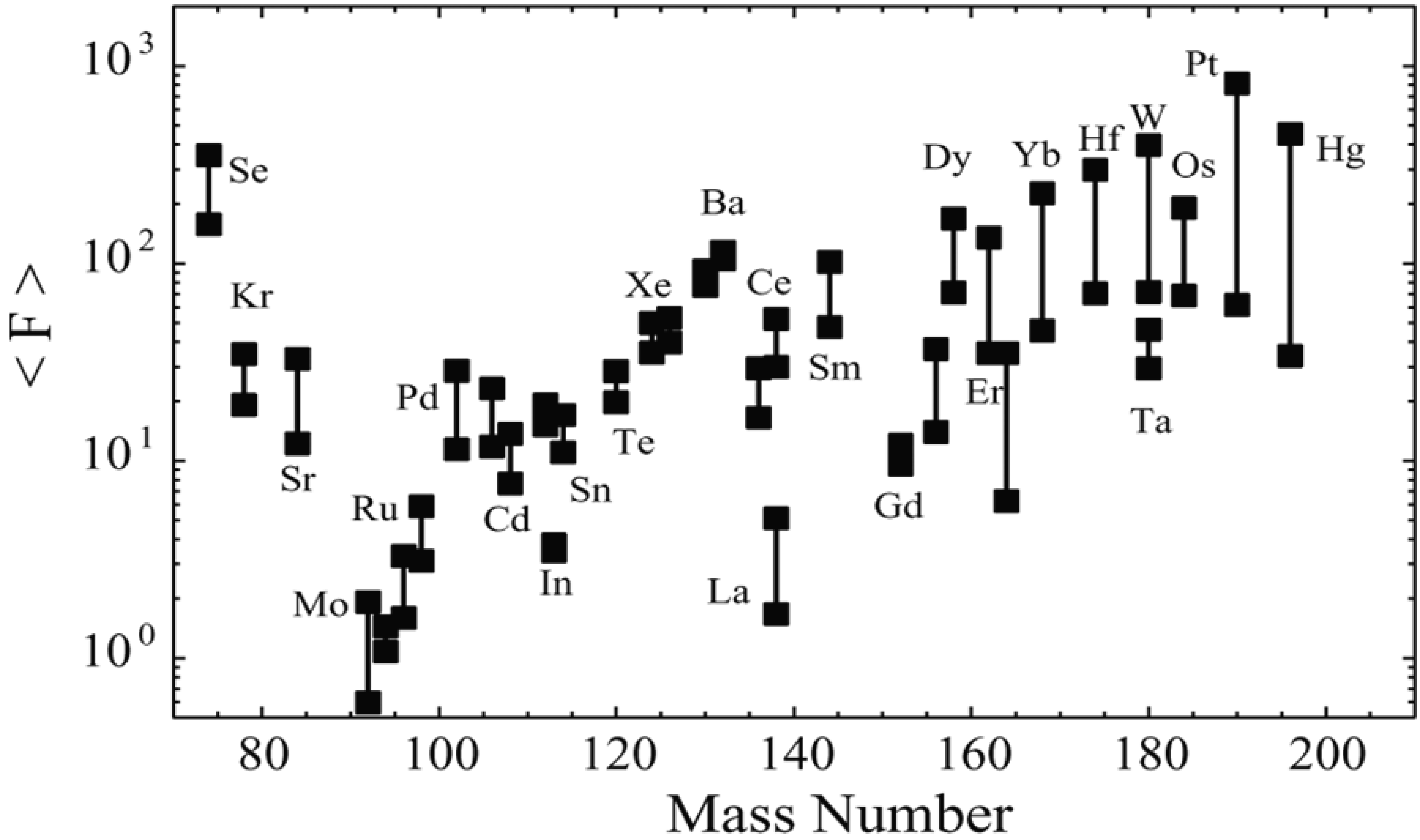
Universität zu Köln

The p-process: Nuclear reaction network



For lighter nuclei there may be competing reactions: (n,γ), (p,γ), (α,γ), νp-process

Abundance of p nuclei: Prediction vs. observation



M. Arnould and S. Goriely, Phys. Rep. ***384*** *(2003) 1*
S. Goriely et al., Astronomy & Astrophysics ***444*** *(2005) L1*

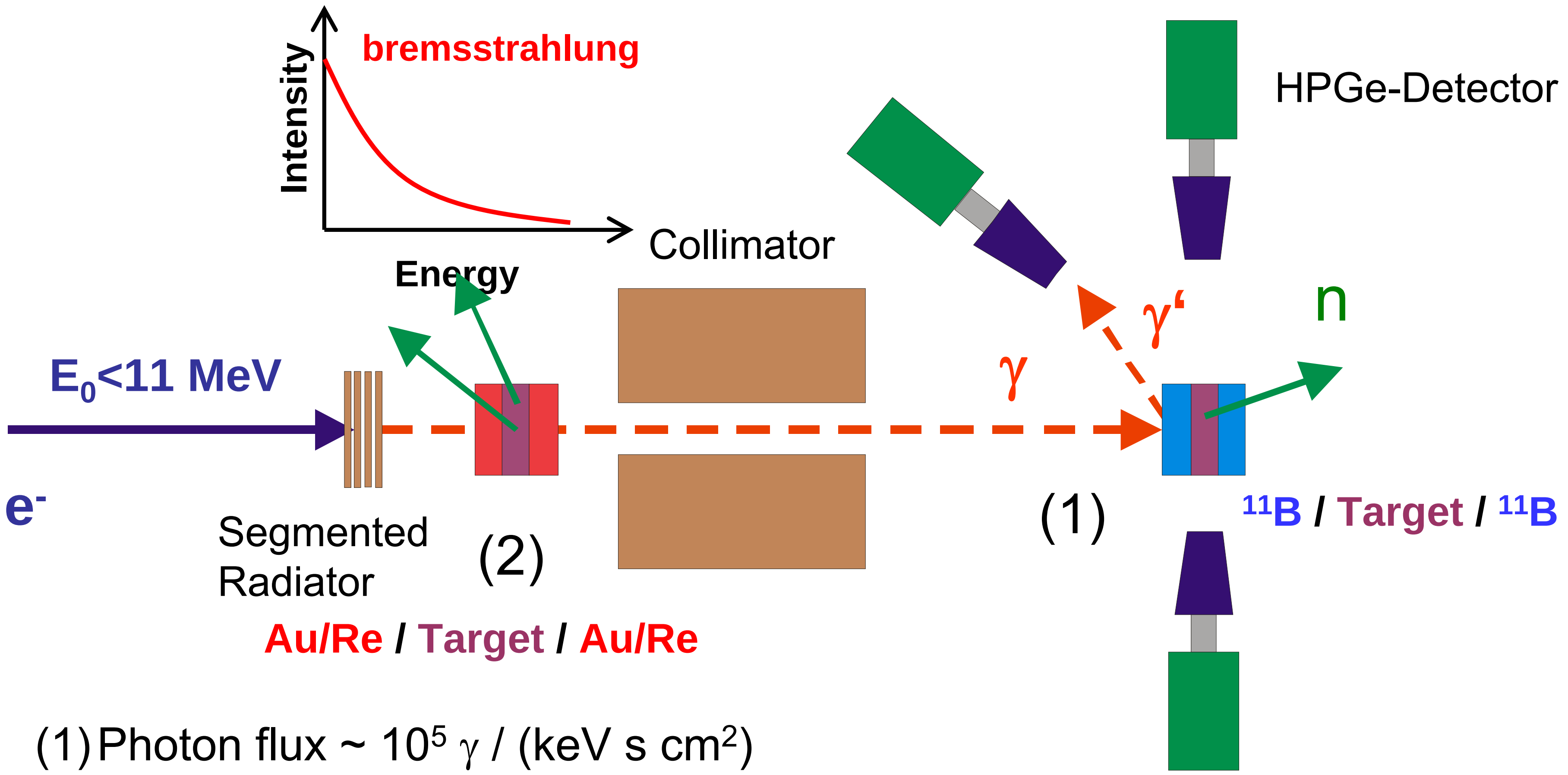
Nuclear Physics input for the p-process

- **Groundstate masses**
- **Properties of excited states**
- **Level densities**
- **Photoresponse (γ,γ'), (γ,n), (γ,α), (γ,p)**
- **Optical potentials (e.g. α – nucleus)**

Photon sources for direct measurements

- **Bremsstrahlung (untagged and tagged)**
  - **Production of a quasi-thermal spectrum**
  - **Photon Tagger System NEPTUN**
- **Laser Compton Backscattering**
  - **AIST at Tsukuba/Japan → next talk**
- **Virtual photons from Coulomb interaction**
  - SUPER**FRS/**NEU**LAND setup at GSI/**FAIR
    → talk by Konstanze Boretzky on Thursday

The photoactivation setup at S-DALINAC

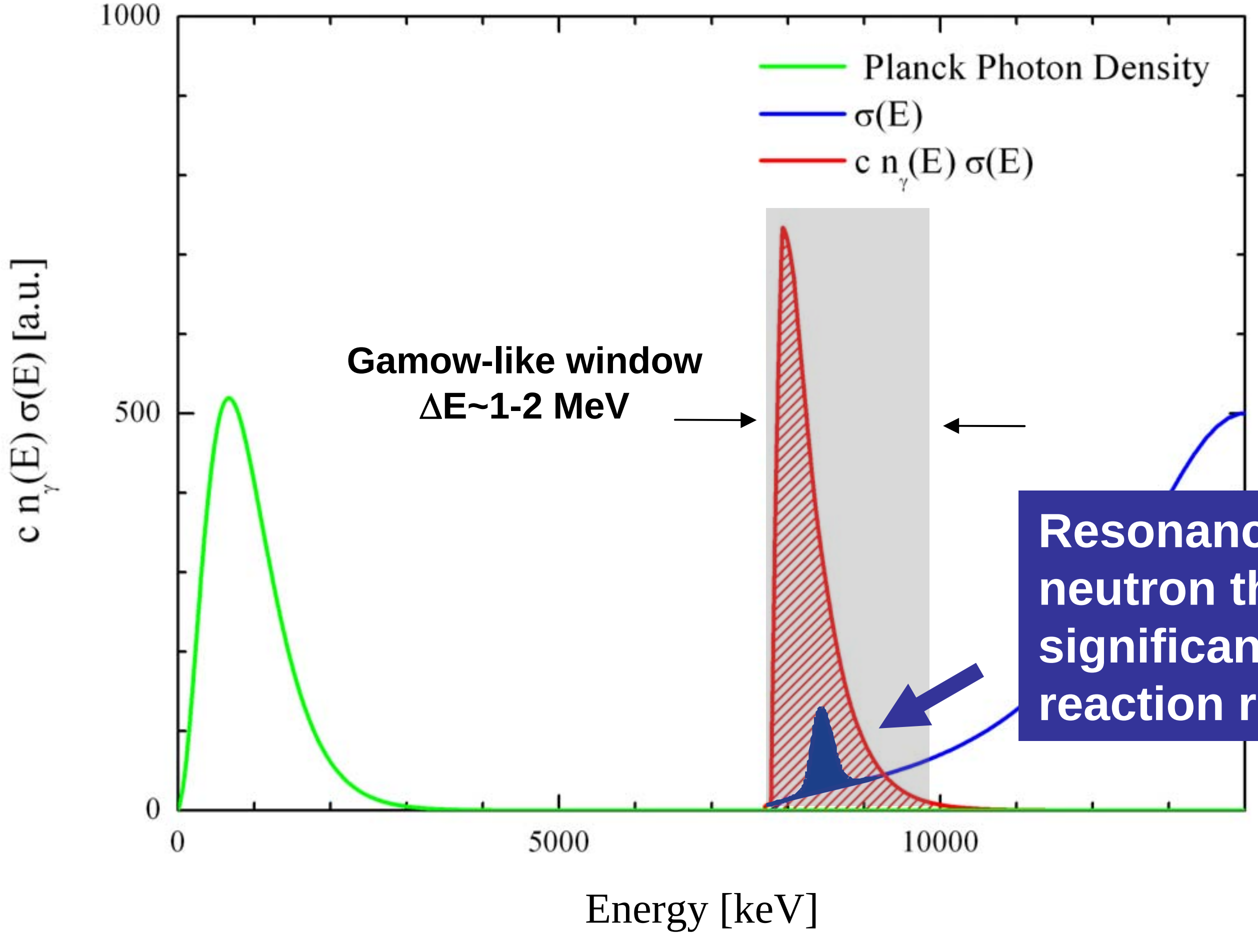


(1) Photon flux ~ 10^5 γ / (keV s cm^2)
Calibration of the photon flux via ^{11}B(γ,γ‘)

(2) Photon flux ~ 10^7 γ / (keV s cm^2)
Calibration of the photon flux via ^{197}Au(γ,n) and ^{187}Re(γ,n)

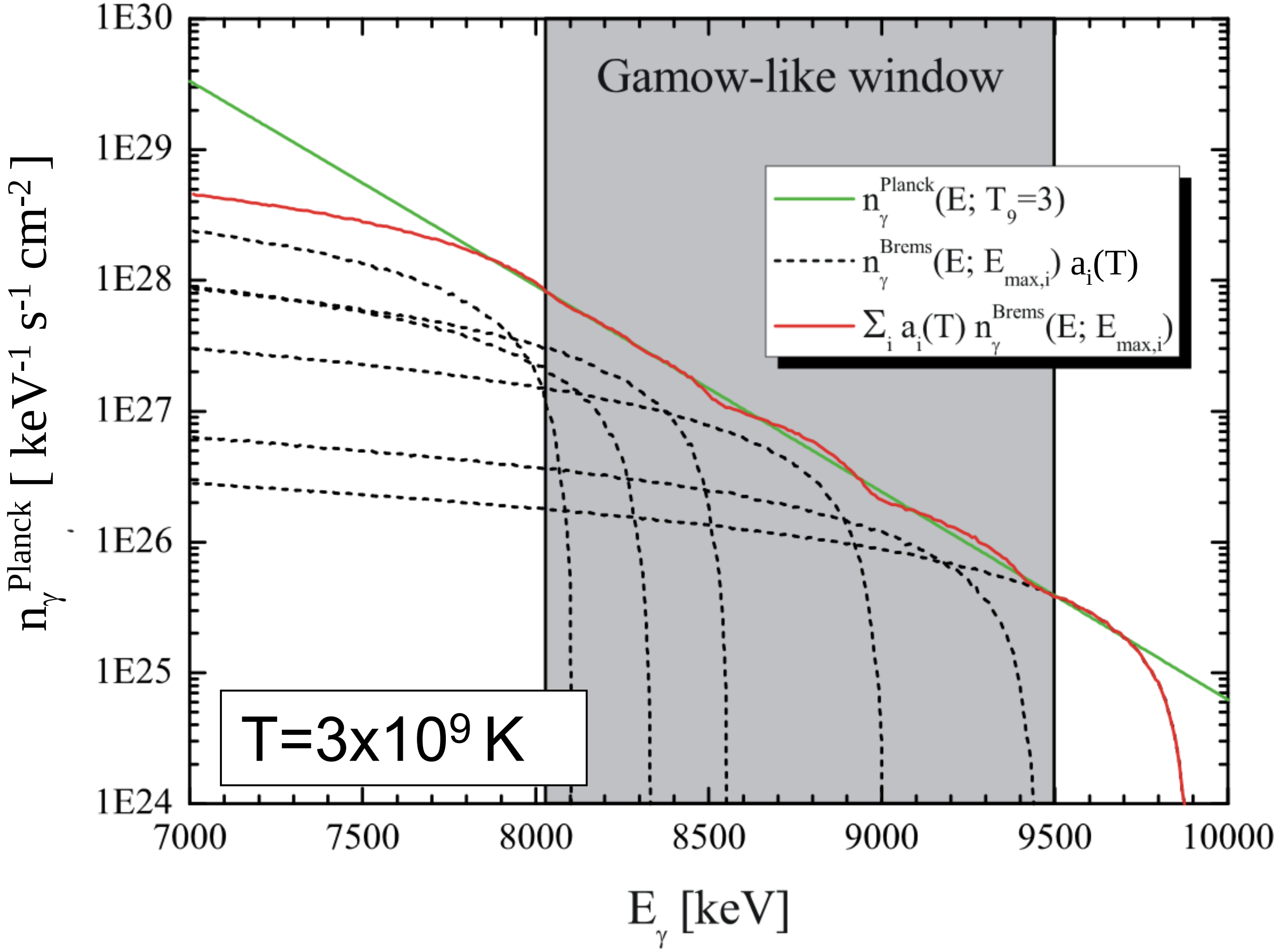
Energy region of interest: Gamow window for (γ,n)

Reaction rate: $$\lambda(T) = c \int n_\gamma(E)\, \sigma(E)\, dE$$



Resonance close to neutron threshold would significantly increase reaction rate

Production of a quasi-thermal spectrum



A. Z. *et al.*, Prog. Part. Nucl. Phys. 44 (2000) 39
P. Mohr *et al.*, Phys. Lett. B **488** (2000) 127

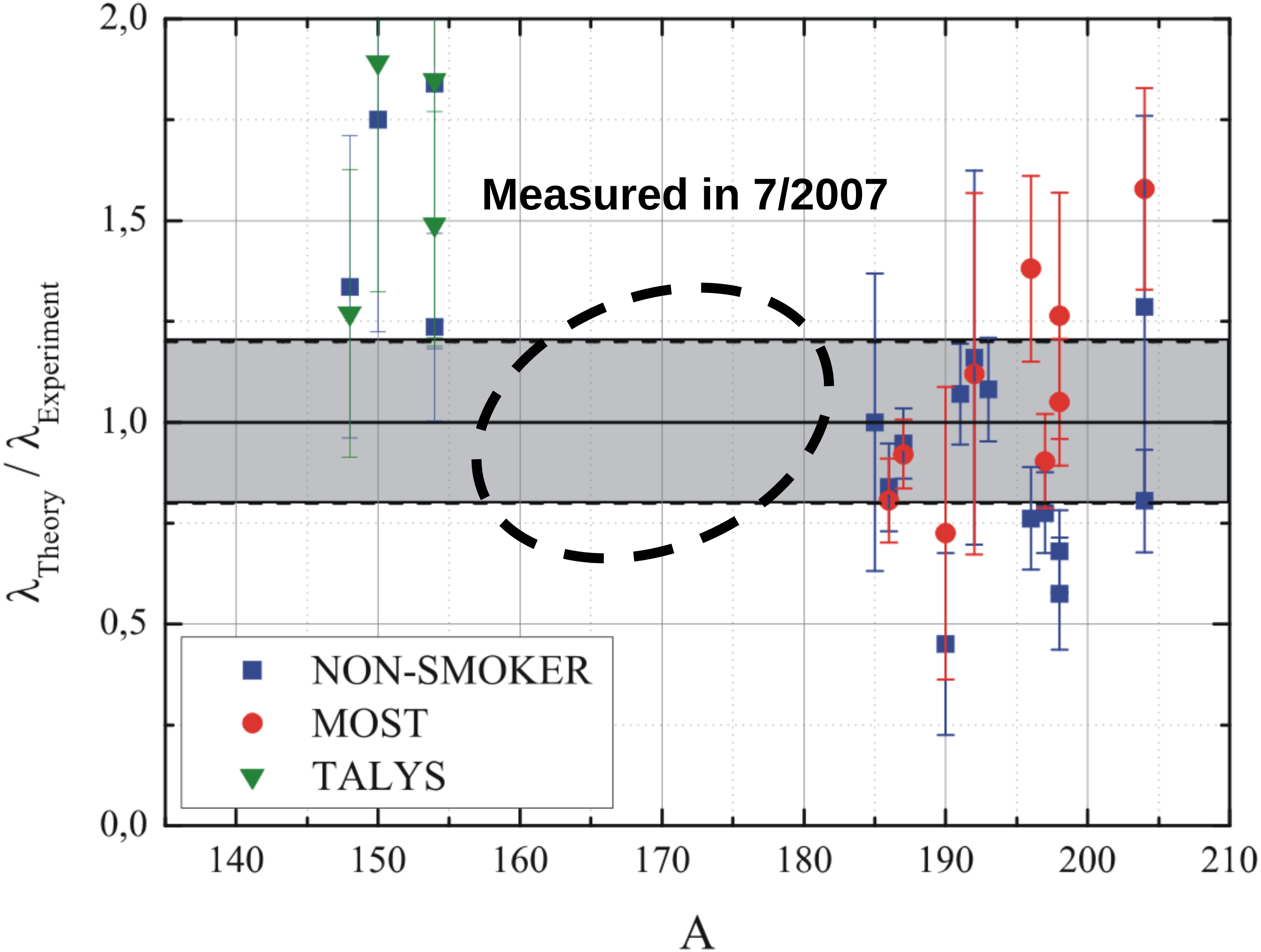
Groundstate reaction rates @ 2.5×10^9 K

Isotope	$\lambda_{exp,gs}$	Reference	$\lambda_{NONS,gs}$	$\lambda_{MOST,gs}$
^{186}W	310(40)	K. Sonnabend et al., ApJ 583 (2003) 506	260	250
^{185}Re	19(7)	S. Müller et al., Phys. Rev. C 73 (2006) 025804	19	44
^{187}Re	76(7)		72	70
^{190}Pt	0.4(2)	K. Vogt et al., Phys. Rev. C 63 (2001) 055802	0.18	0.29
^{192}Pt	0.5(2)		0.58	0.56
^{198}Pt	87(21)		50	110
^{197}Au	6.2(8)	K. Vogt et al., Nucl. Phys. A 707 (2002) 241	4.81	5.6
^{196}Hg	0.42(7)	K. Sonnabend et al., Phys. Rev. C 70 (2004) 035802	0.32	0.58
^{198}Hg	2.0(3)		1.36	2.1
^{204}Hg	57(21)		73.3	170
^{204}Pb	1.9(3)		1.53	3.0
^{191}Ir	4.3(5)	J. Hasper, submitted	4.6	-
^{193}Ir	13.5(16)		14.6	-

M. Arnould and S. Goriely, Phys. Rep. 384 (2003) 1

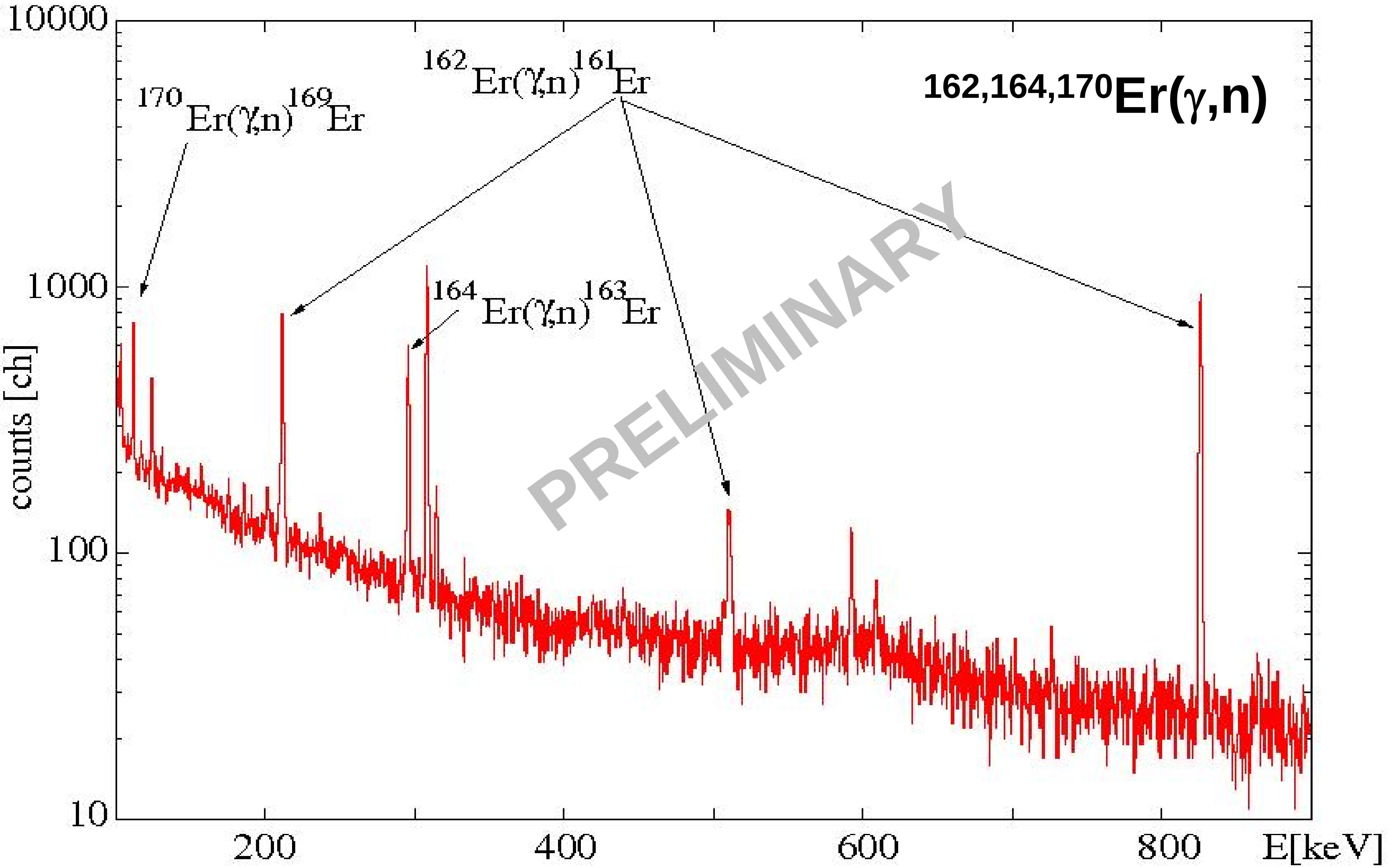
T. Rauscher and F.-K. Thielemann, ADNDT 75 (2000) 1

Groundstate reaction rates @ 2.5x10^{9}K



M. Arnould and S. Goriely, *Phys. Rep.* 384 (2003) 1
T. Rauscher and F.-K. Thielemann, *ADNDT* 75 (2000) 1
A. J. Koning et al., *AIP* 769 (2004) 1154

Photodissociation of Er isotopes



J. Hasper and S. Müller, priv. comm.

From integrated reaction rates to $\sigma(E)$

Untagged photons from bremsstrahlung measure always INTEGRATED reaction rates:

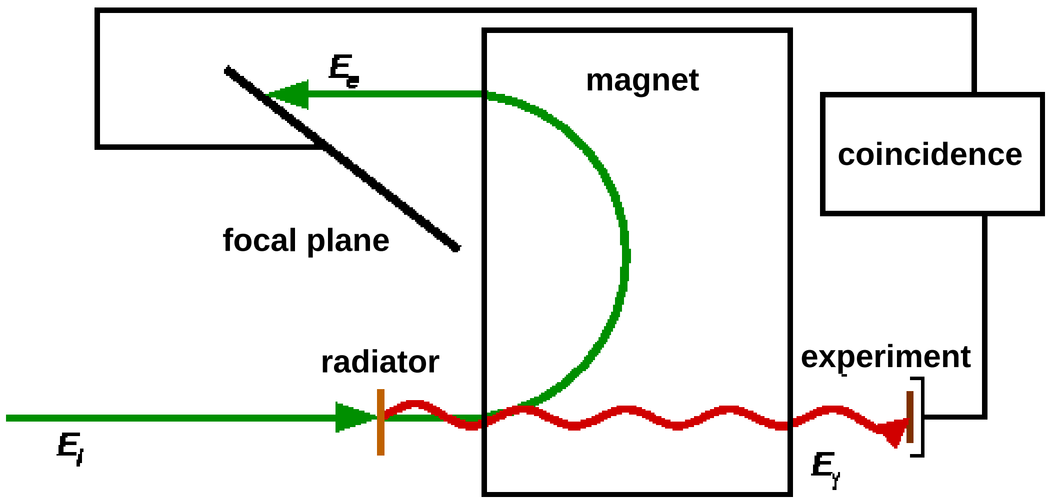
$$\lambda(T) = c \int n_\gamma(E)\,\sigma(E)\,dE$$

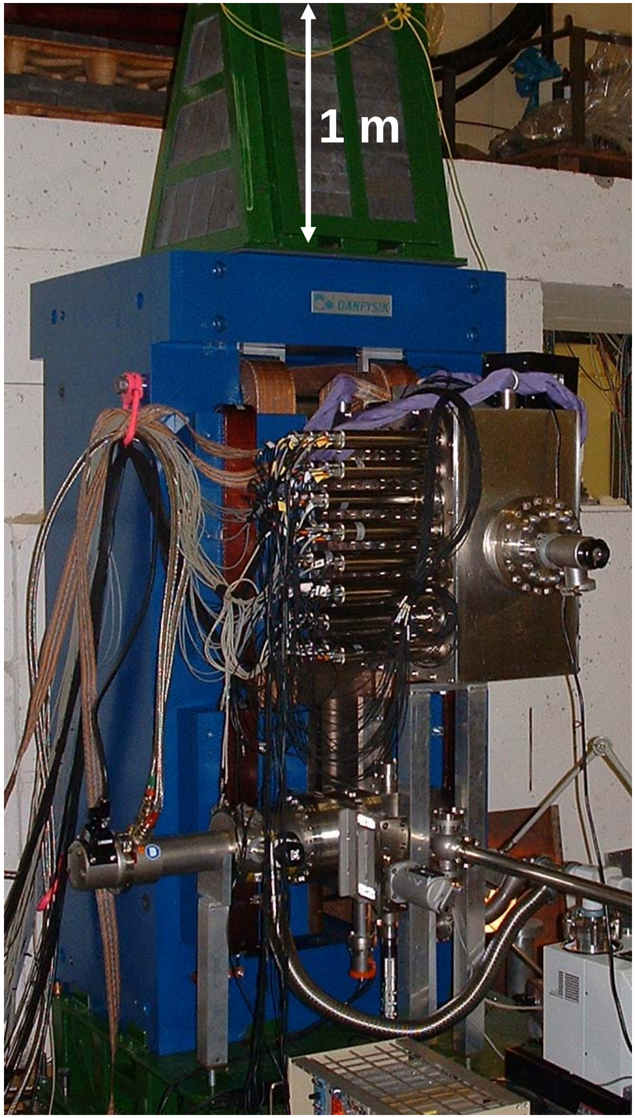
Additional information can be deduced from the shape of the cross section $\sigma(E\gamma)$

→ use photons with „known“ energy

- **Tagged bremsstrahlung photons**
- **Laser Compton Backscattering**

Photon tagger NEPTUN @ S-DALINAC





Energy range: 6 MeV ≤ E_γ ≤ 20 MeV

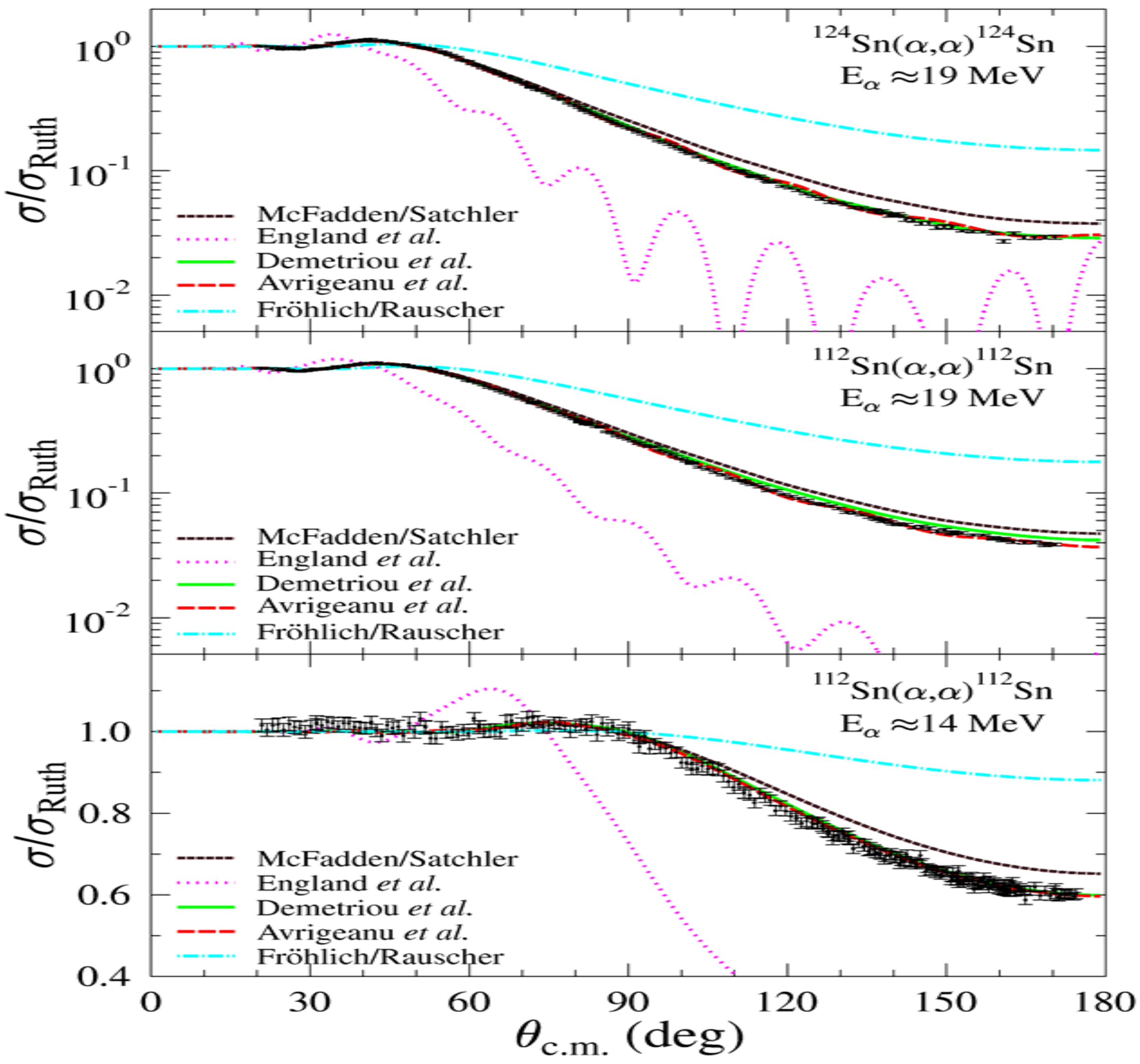
Energy resolution: ΔE = 25 keV @ 10 MeV

Photon intensity: ≈ 10^4 $keV^{-1}s^{-1}$

→ Measure (γ,γ‘), (γ,n), (γ,p), and (γ,α) cross sections

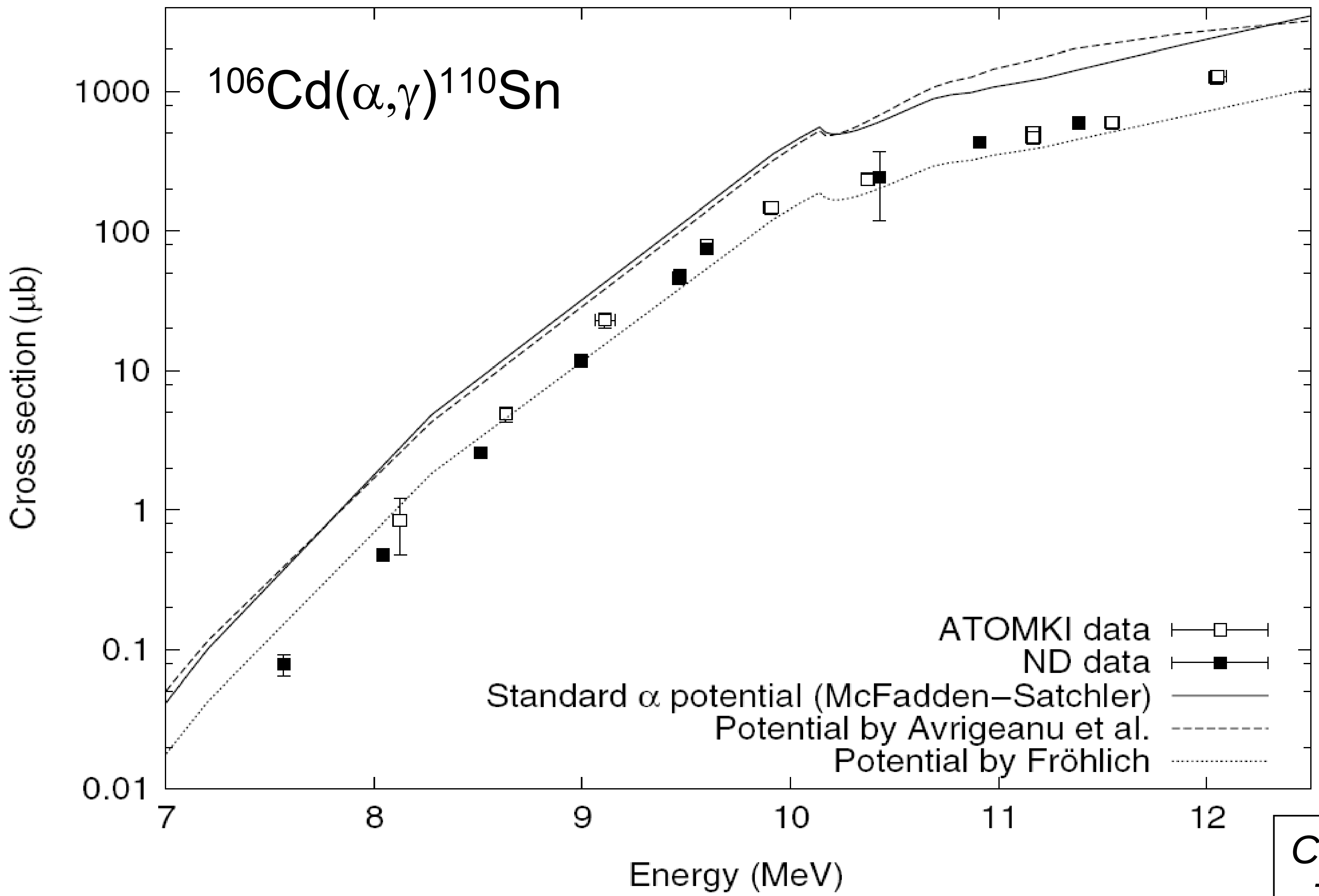
„Indirect" measurements: α-nucleus potentials

α – nucleus potential in Sn isotopes from (α,α)



*D. Galaviz et al., PRC **71** (2005) 065802*

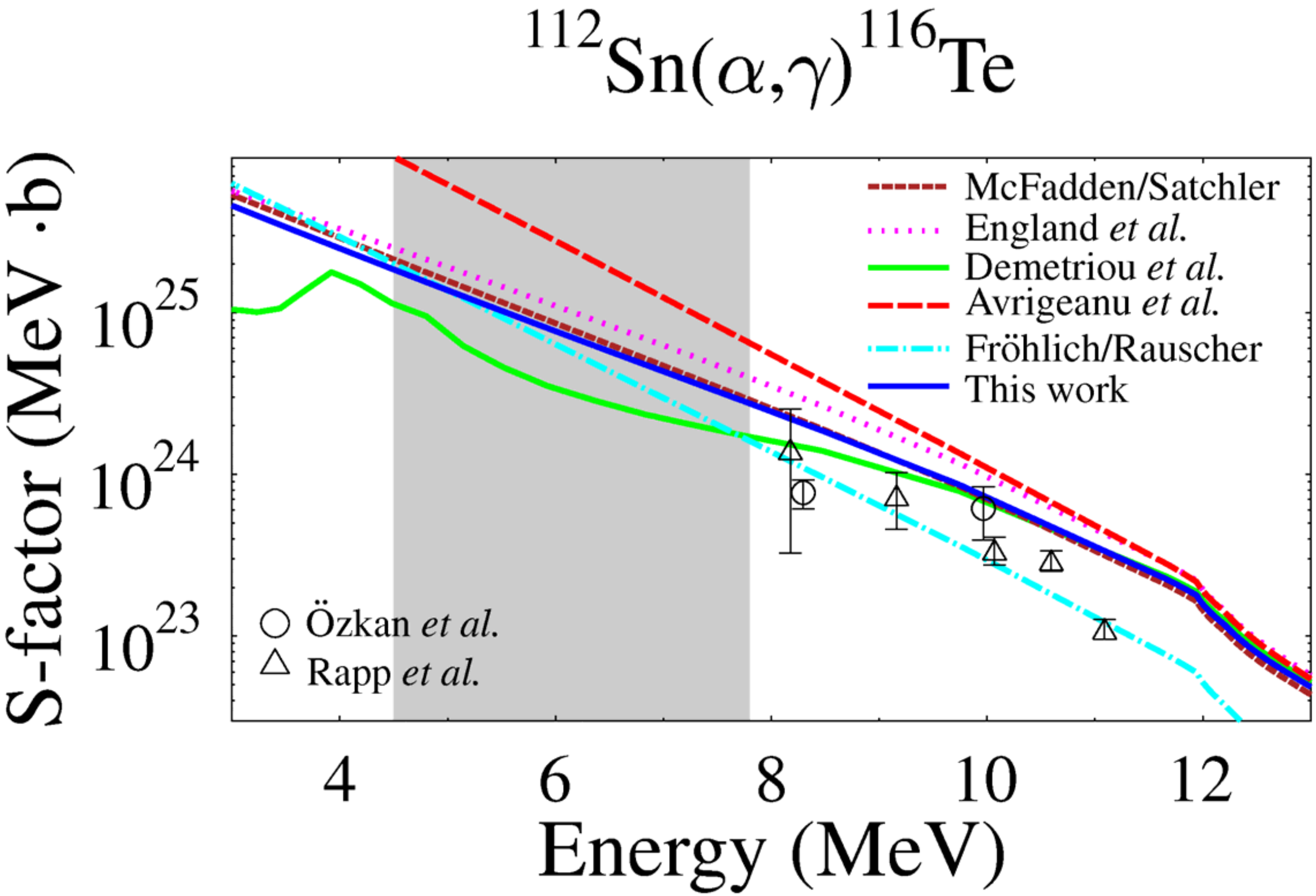
α - capture cross sections



Courtesy of Zs. Fülöp

ATOMKI – NOTRE DAME - Collaboration

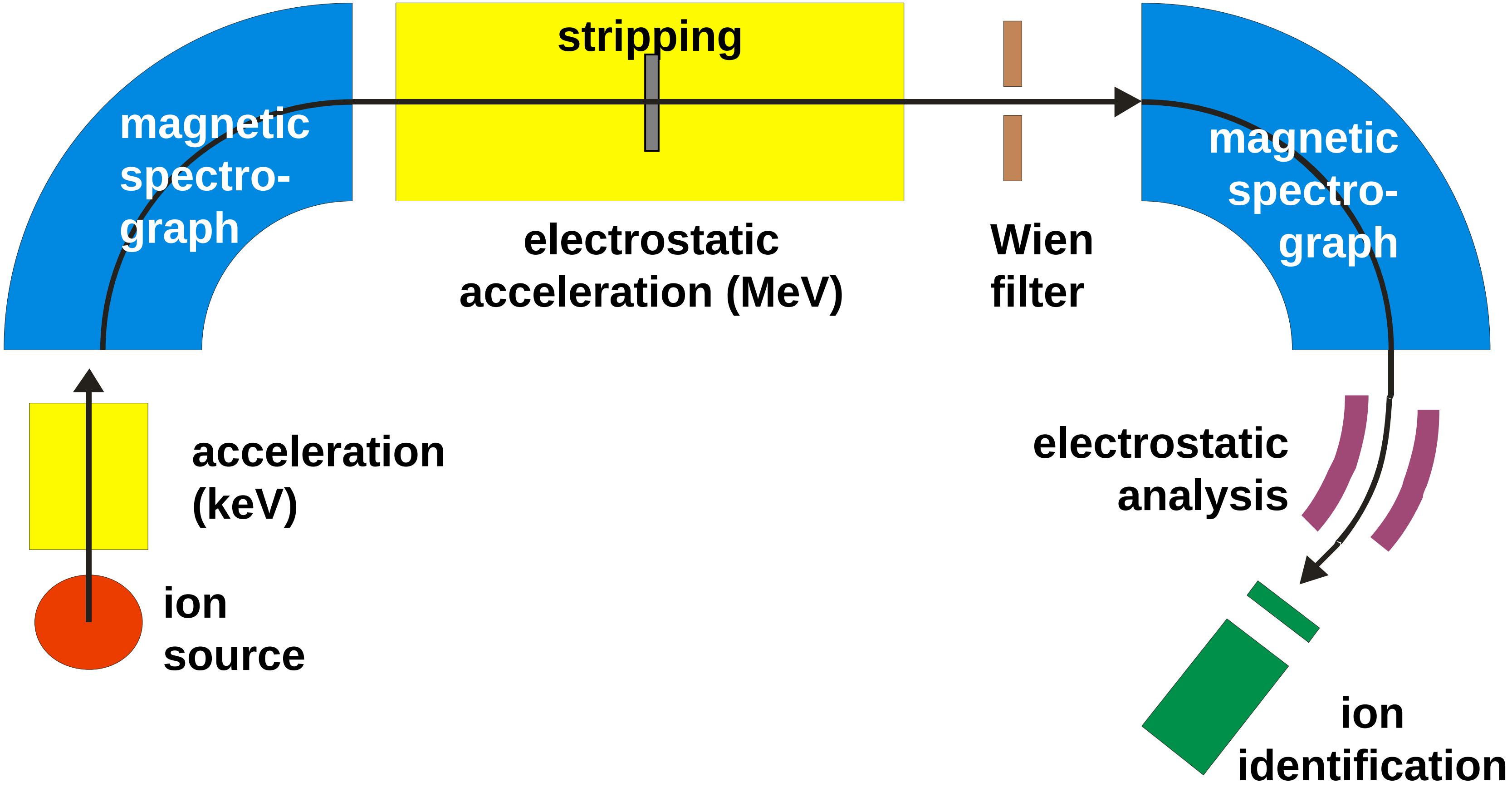
α - capture cross section



N. Özkan et al., PRC 75 (2007) 025801

*<u>Overview:</u> P.Demetriou, C. Grama, S. Goriely, NPA **707** (2002) 253*

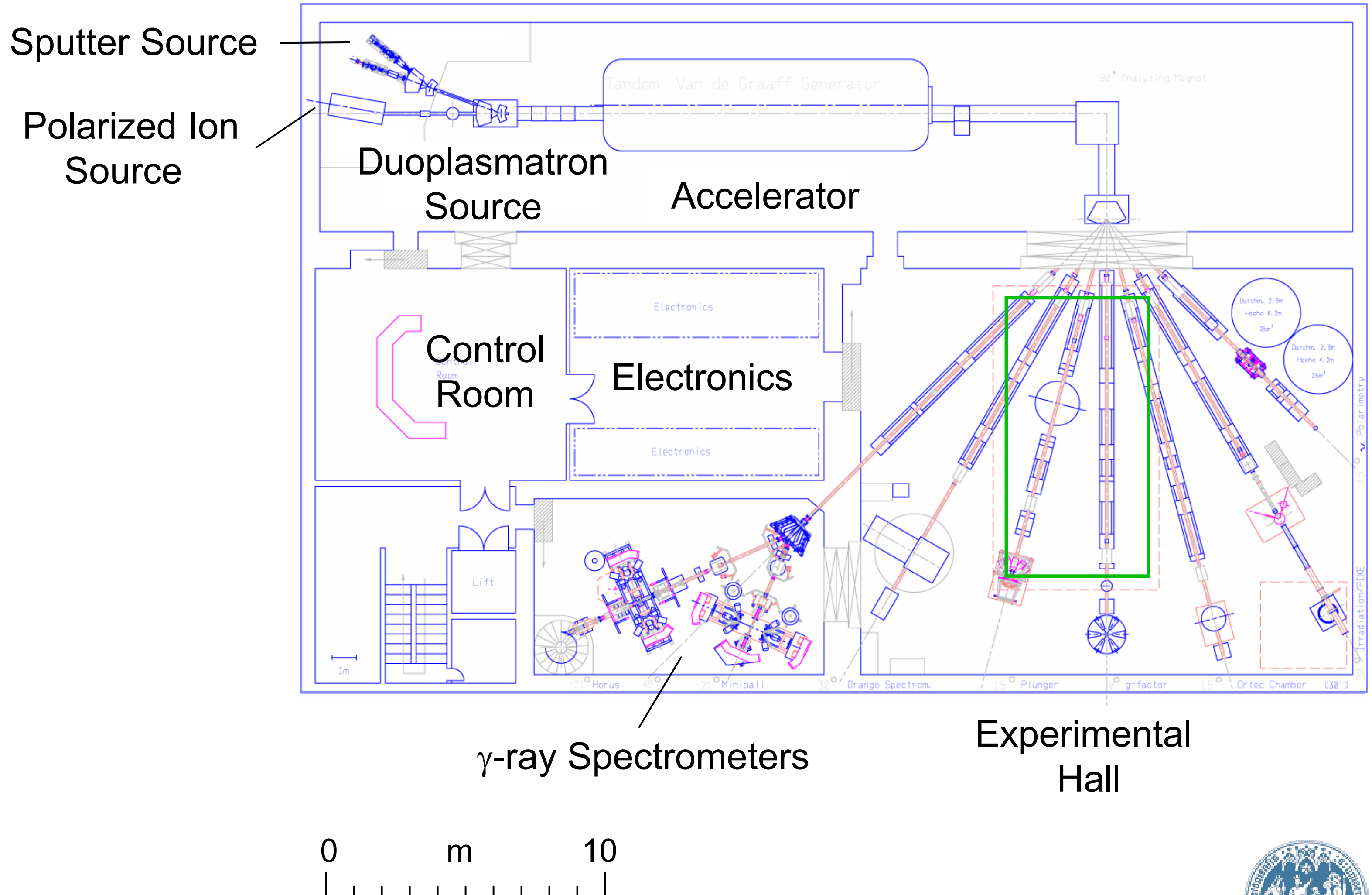
Accelerator Mass Spectrometry



High **sensitivity**: isotopic ratios down to 10^{-15}

High **efficiency**: amounts of 10^{5} nuclei

The existing 10 MV Tandem Accelerator (1st basement) Institute for Nuclear Physics, University of Cologne



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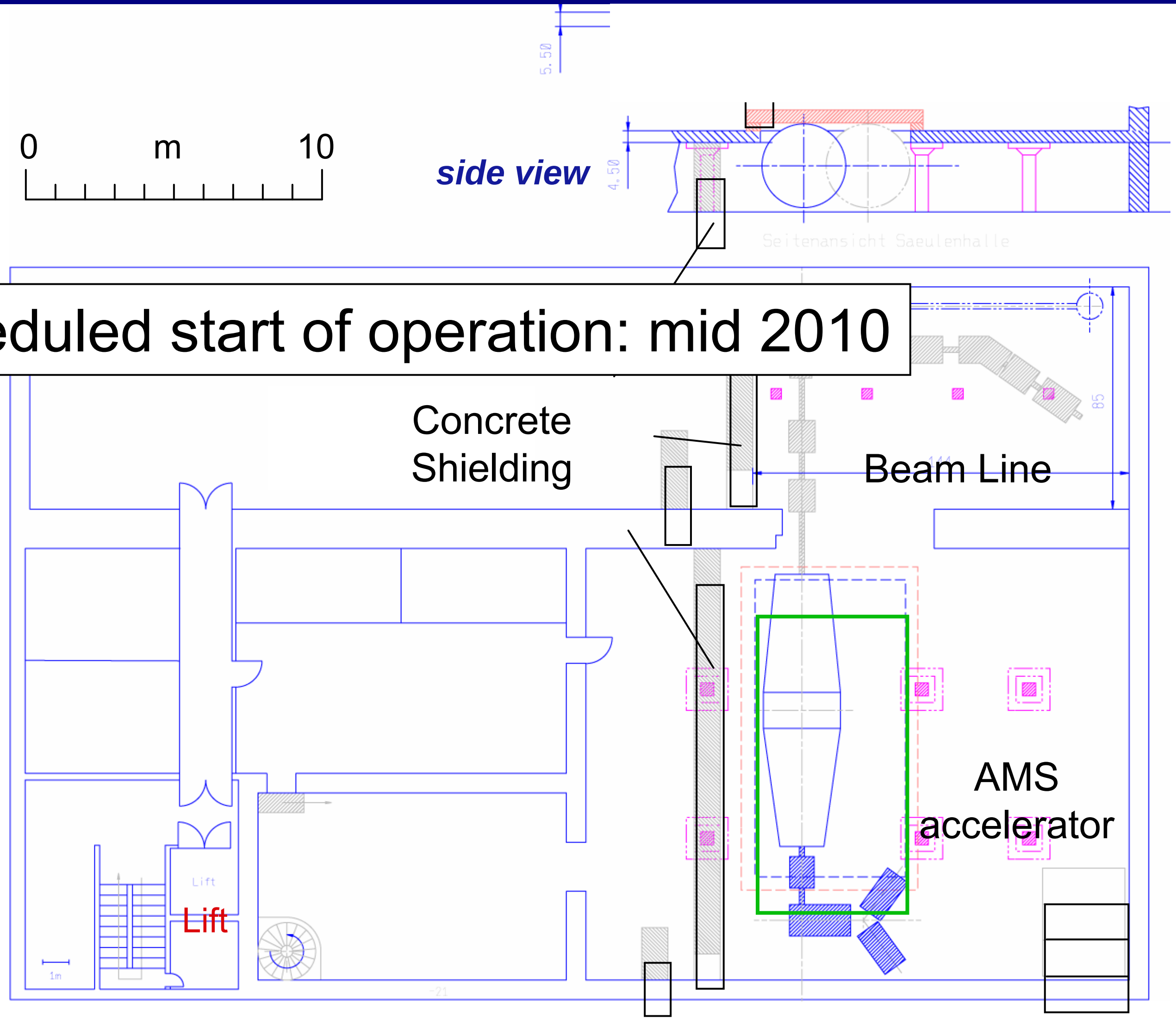
The new 6 MV Tandem AMS machine (2nd basement)



Scheduled start of operation: mid 2010

Funded by DFG and

University of Cologne

Gamma-induced reactions in explosive nucleosynthesis

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More information and references: www.zilges.de