

Photodissociation of neutron deficient nuclei

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- p -Process Nucleosynthesis

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- The Photoactivation Technique @ S-DALINAC

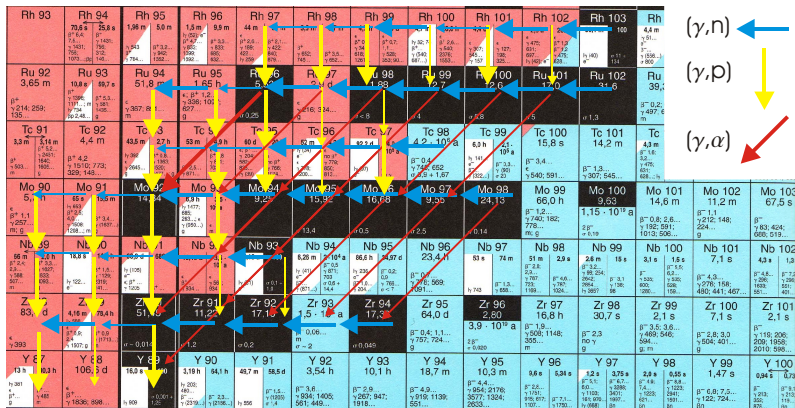
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- Coulomb Dissociation in Inverse Kinematics
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- p -Process Nucleosynthesis
- The Photoactivation Technique @ S-DALINAC
- Coulomb Dissociation in Inverse Kinematics @ LAND / GSI
- Summary & Outlook

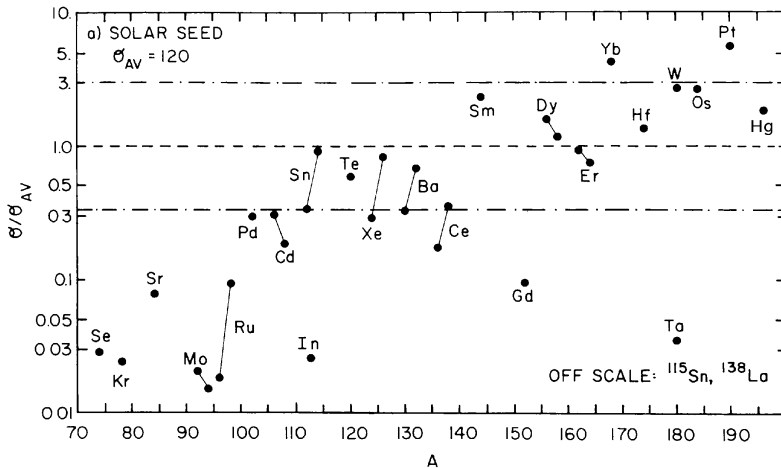
Reaction rates in the $A \approx 100$ region at $T_9 = 2.5$

Rh 93	Rh 94	Rh 95	Rh 96	Rh 97	Rh 98	Rh 99	Rh 100	Rh 101	Rh 102	Rh 103	Rh 104	Rh 105	Rh 106
70.6 s 1.431; 320; 75; 141; 1075; 186	25.8 s 1.401; 320; 141; 1075; 186	5.0 m 1.96 m; 5.0 m 1.543; 1.942; 1.794; 1.952	9.5 m 1.95 m; 9.5 m 1.959; 1.959; 1.959; 1.959; 1.959; 1.959	44 m; 31 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.5 m; 8.7 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.7 m; 26.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.4 d; 3.3 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	Rh 102 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	Rh 103 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	Rh 104 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	Rh 105 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	Rh 106 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Ru 92	Ru 93	Ru 95	Ru 96	Ru 97	Ru 98	Ru 99	Ru 100	Ru 101	Ru 102	Ru 103	Ru 104	Ru 105	
3.65 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	10.8 s; 59.7 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	51.8 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	1.66 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	5.52 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.9 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	1.68 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	12.7 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	12.6 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	17.0 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	31.6 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	39.35 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	18.7 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.44 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Tc 91	Tc 92	Tc 93	Tc 94	Tc 95	Tc 96	Tc 97	Tc 98	Tc 99	Tc 100	Tc 101	Tc 102	Tc 103	Tc 104
3.3 m; 3.14 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.4 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.7 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	5.3 m; 4.3 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	6.0 d; 2.0 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.0; 10.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	92.2 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	$4.2 \cdot 10^6$ a 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	6.9 h; 2.1; 10.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	15.8 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	14.2 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.3 m; 5.3 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	54.2 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	10.30 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Mo 90	Mo 91	Mo 92	Mo 93	Mo 94	Mo 95	Mo 96	Mo 97	Mo 98	Mo 99	Mo 100	Mo 101	Mo 102	Mo 103
5.7 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	14.84 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.9 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.9; 19.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	9.25 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	15.92 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	16.68 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	9.55 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	24.13 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	14.6 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	9.63 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	14.6 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	11.2 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	67.5 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Nb 89	Nb 90	Nb 91	Nb 92	Nb 93	Nb 94	Nb 95	Nb 96	Nb 97	Nb 98	Nb 99	Nb 100	Nb 101	Nb 102
6.6 m; 3.9 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	16.9 s; 14.0 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	80.9 d; 88.0 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	10.15 d; 2.4; 10.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	16.13 a; 100 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.10 ³ a 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	86.5 h; 34.97 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	23.4 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	63 s; 74 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	5.1 m; 2.9 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	15 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.1 s; 1.5 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	7.1 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	4.3 s; 1.3 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Zr 88	Zr 89	Zr 90	Zr 91	Zr 92	Zr 93	Zr 94	Zr 95	Zr 96	Zr 97	Zr 98	Zr 99	Zr 100	Zr 101
83.4 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	78.4 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	51.45 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	11.22 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	17.15 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	$1.5 \cdot 10^8$ a 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	17.38 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	64.0 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.80 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	16.8 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	30.7 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.99 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	7.1 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	2.1 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d
Y 87	Y 88	Y 89	Y 90	Y 91	Y 92	Y 93	Y 94	Y 95	Y 96	Y 97	Y 98	Y 99	Y 100
8.3 h; 86.3 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	106.6 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	100 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	6.1 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	58.5 d 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.54 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	10.1 h 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	18.7 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	10.3 m 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.5 s; 5.3 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	3.75 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	0.55 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	1.47 s 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d	0.94 s; 0.73 1.95 m; 4.7 h; 16 d 1.95 m; 4.7 h; 16 d

Reaction rates in the $A \approx 100$ region at $T_9 = 2.5$

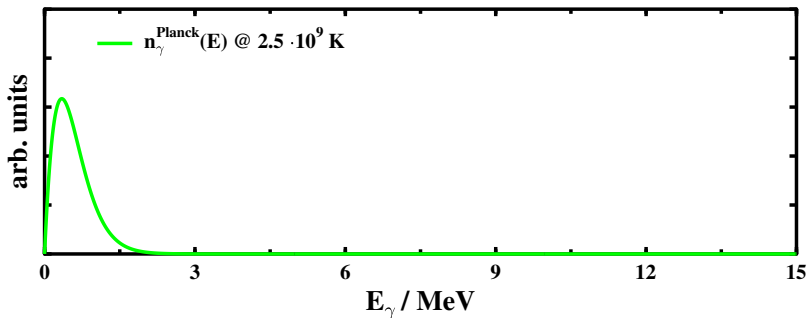


Overproduction factors



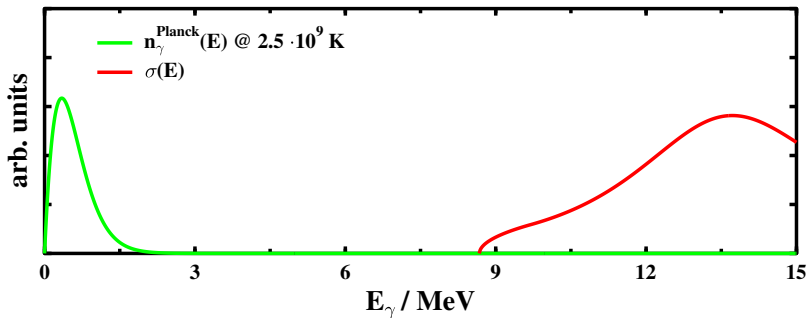
Gamow window for (γ, n) reactions

- Planck distribution: $n_{\gamma}^{\text{Planck}} dE = \frac{1}{\pi^2(\hbar c)^3} \frac{E^2}{\exp(E/kT)-1} dE$



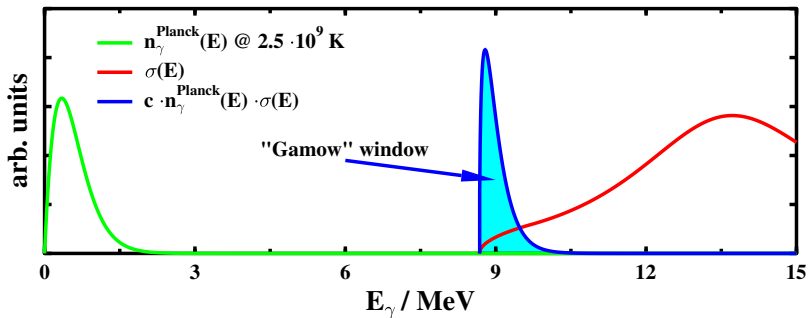
Gamow window for (γ, n) reactions

- Planck distribution: $n_{\gamma}^{\text{Planck}} dE = \frac{1}{\pi^2(\hbar c)^3} \frac{E^2}{\exp(E/kT)-1} dE$
- Cross section $\sigma(E)$ with typical threshold behaviour

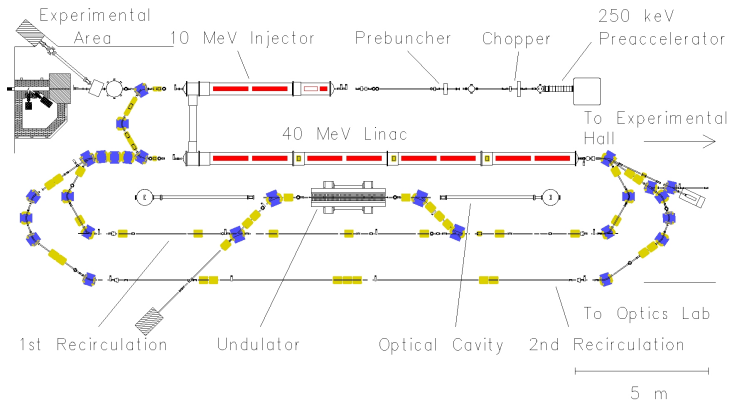


Gamow window for (γ, n) reactions

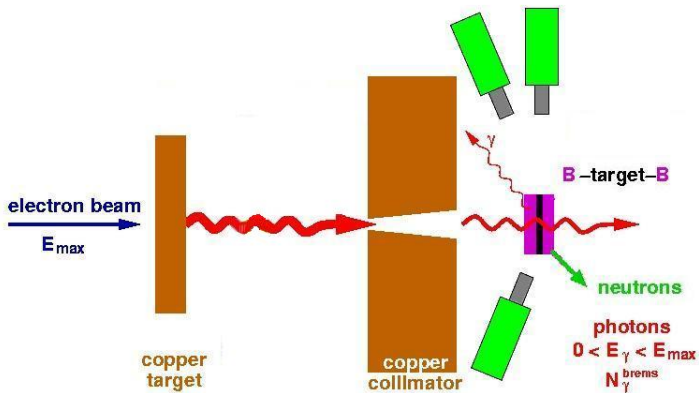
- Planck distribution: $n_{\gamma}^{\text{Planck}} dE = \frac{1}{\pi^2(\hbar c)^3} \frac{E^2}{\exp(E/kT)-1} dE$
- Cross section $\sigma(E)$ with typical threshold behaviour
- Reaction rate: $\lambda(T) = \int c \cdot n_{\gamma}^{\text{Planck}} \cdot \sigma(E) \cdot dE$



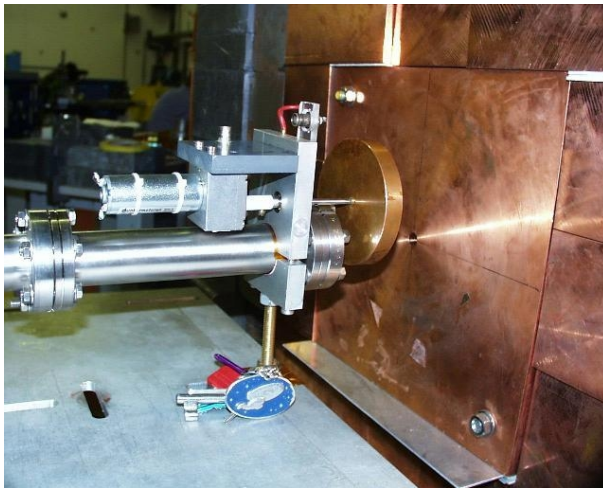
First step: Activation



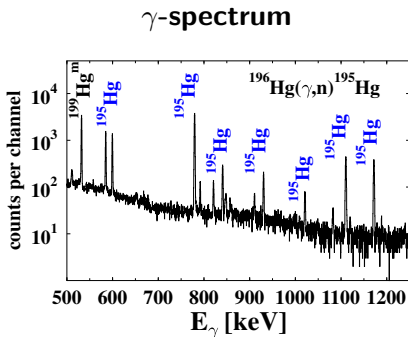
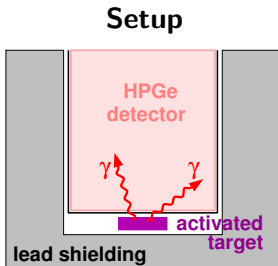
First step: Activation



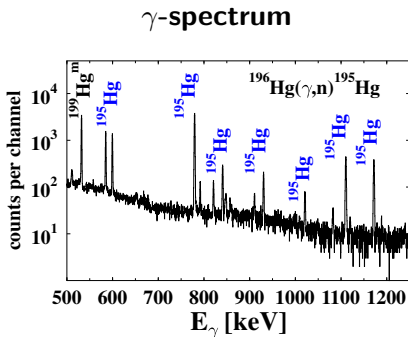
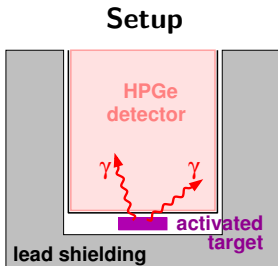
First step: Activation



Second step: γ -spectroscopy



Second step: γ -spectroscopy



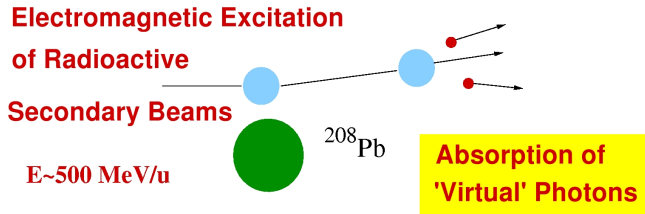
- Isotopic abundance of ^{196}Hg : 0.15%

Groundstate reaction rates at $T = 2.5 \cdot 10^9$ K

isotope	$\lambda_{\text{exp}} [s^{-1}]$	$\lambda_{\text{NONS}} [s^{-1}]$	$\lambda_{\text{MOST}} [s^{-1}]$
^{96}Zr	6.2 \pm 0.3	6.1	—
^{186}W	314 \pm 44	257	250
^{185}Re	19 \pm 9	12.8	—
^{187}Re	94 \pm 5	70.5	74.9
^{190}Pt	0.4 \pm 0.2	0.18	0.29
^{192}Pt	0.5 \pm 0.2	0.58	0.56
^{198}Pt	80 \pm 19	50	110
^{197}Au	6.2 \pm 0.8	4.8	5.6
^{196}Hg	0.42 \pm 0.07	0.32	0.58
^{198}Hg	2.0 \pm 0.3	1.4	2.1
^{204}Hg	57 \pm 9	73	170
^{204}Pb	1.9 \pm 0.3	1.5	3.0

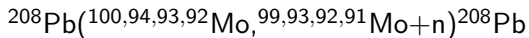
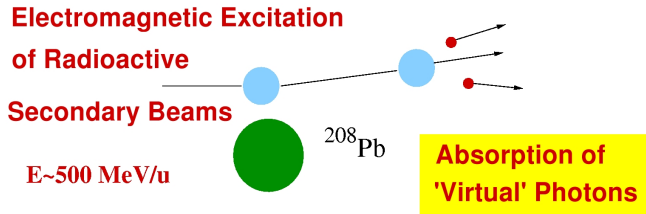
Photodissociation in inverse kinematics

real photons \rightarrow virtual photons

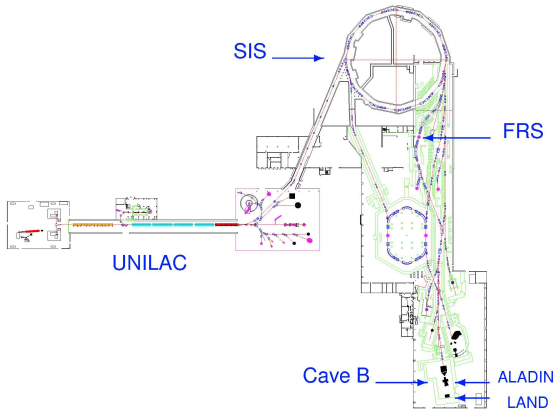


Photodissociation in inverse kinematics

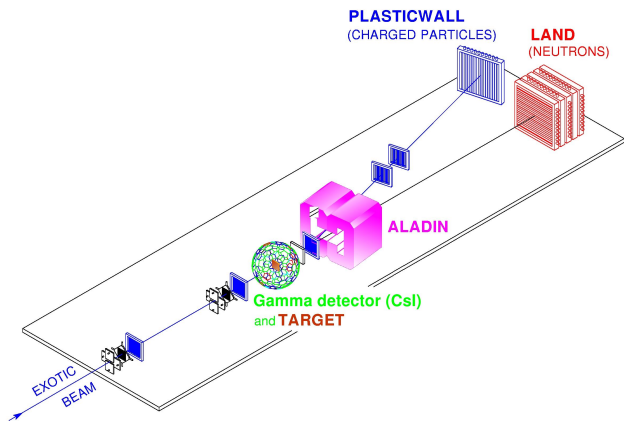
real photons \rightarrow virtual photons



The GSI Accelerator Facilities



Coulomb dissociation at GSI/LAND



- Photoactivation @ S-DALINAC

- Photoactivation @ S-DALINAC
- Coulomb Dissociation in Inverse Kinematics @ LAND / GSI

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- Experiments on $^{92,93,94,100}\text{Mo}$ @ LAND / GSI

- Photoactivation @ S-DALINAC
- Coulomb Dissociation in Inverse Kinematics @ LAND / GSI

- Experiments on $^{92,93,94,100}\text{Mo}$ @ LAND / GSI
- Photoactivation of ^{92}Mo @ ELBE

- Photoactivation @ S-DALINAC
- Coulomb Dissociation in Inverse Kinematics @ LAND / GSI

- Experiments on $^{92,93,94,100}\text{Mo}$ @ LAND / GSI
- Photoactivation of ^{92}Mo @ ELBE
- Photoactivation of ^{100}Mo @ S-DALINAC

Collaboration for Experiment S295

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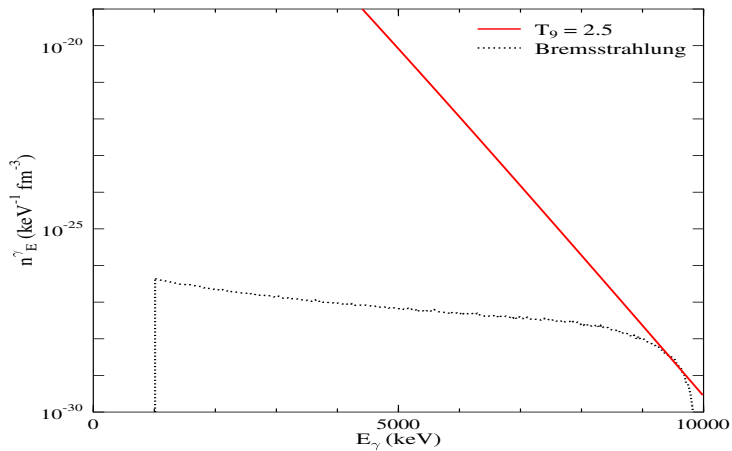
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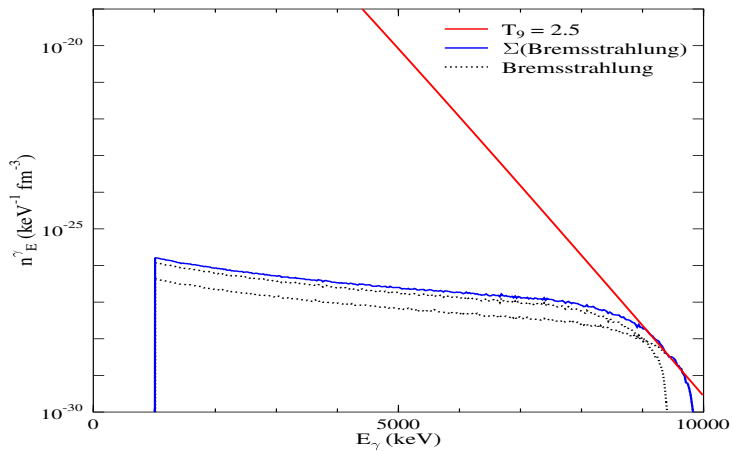
work supported by the DFG under contract SFB 634 and by BMBF

contact: *www.zilges.de*

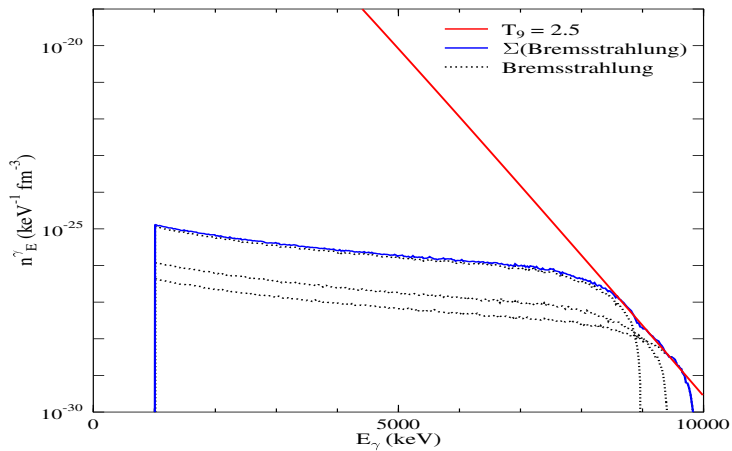
Direct determination of the reaction rate



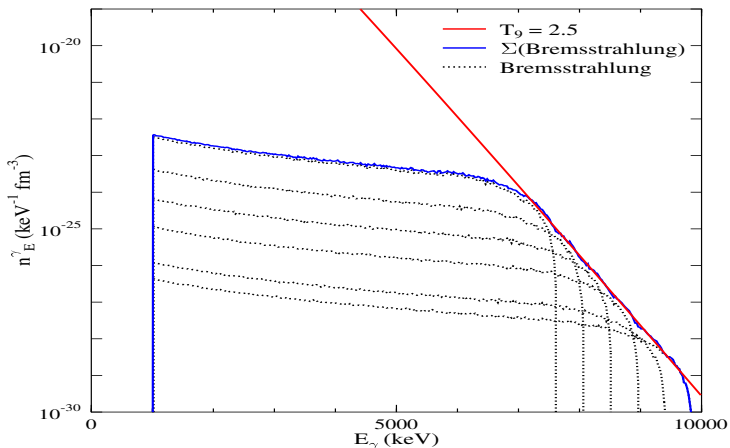
Direct determination of the reaction rate



Direct determination of the reaction rate



Direct determination of the reaction rate



- Reaction rate: $\lambda(T) \propto \sum a_i(T) \cdot Y_i$