The origin of the proton rare isotopes in nature

Status and Uncertainties of Nuclear-Reaction Rates

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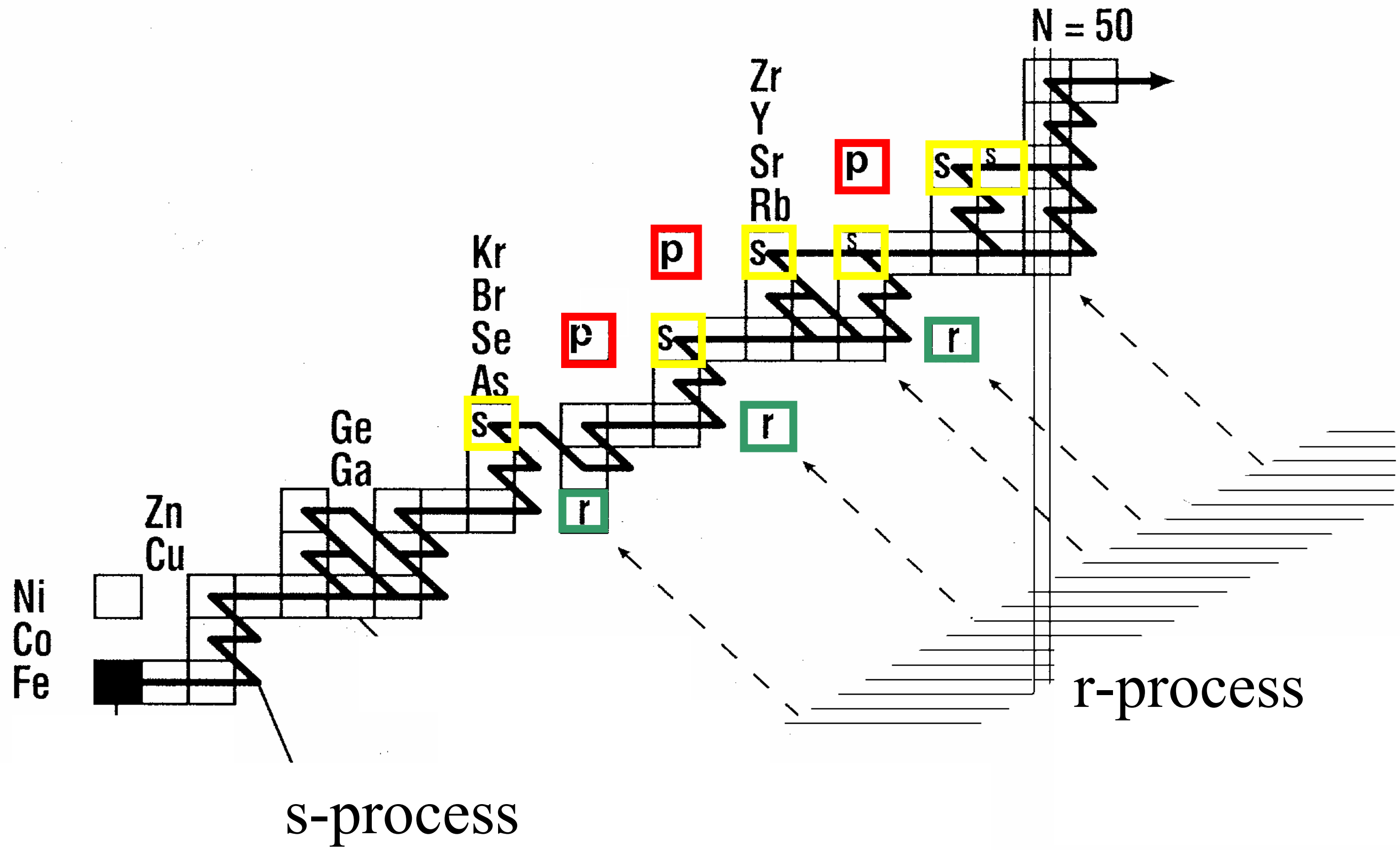
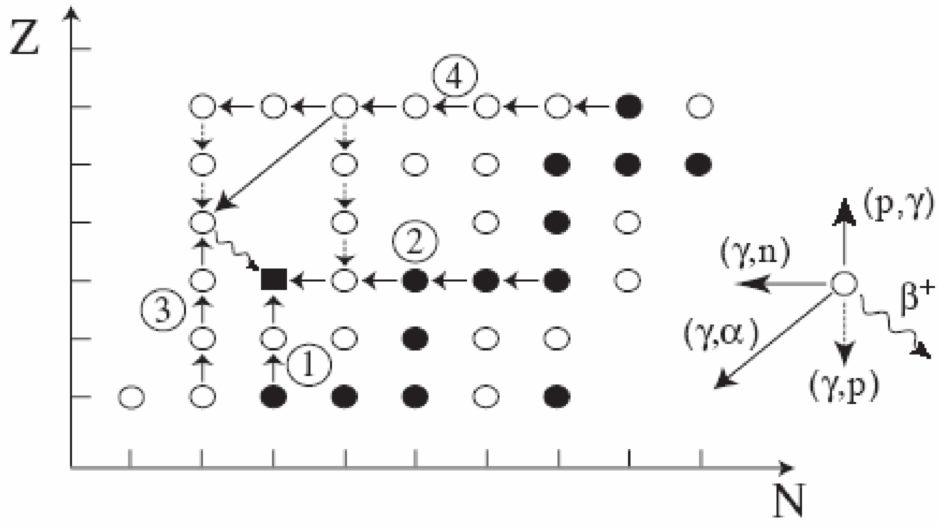
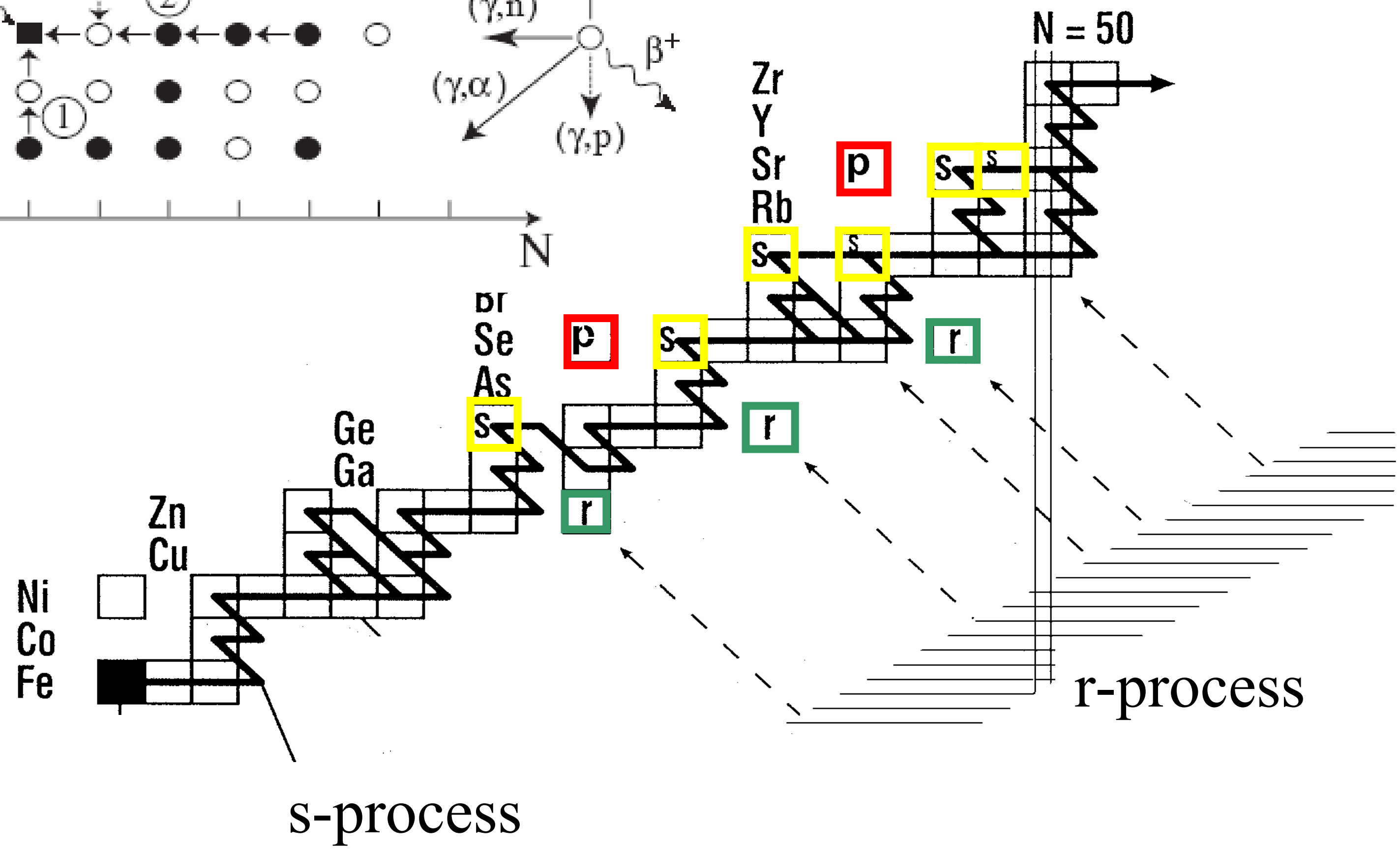
Out-line

- Overview Nucleosynthesis
- Observed Abundances
- Scenarios for p-Process
- Experimental Status
- Reaction Network
- Influence of Rates on the p-Abundances
- Conclusions

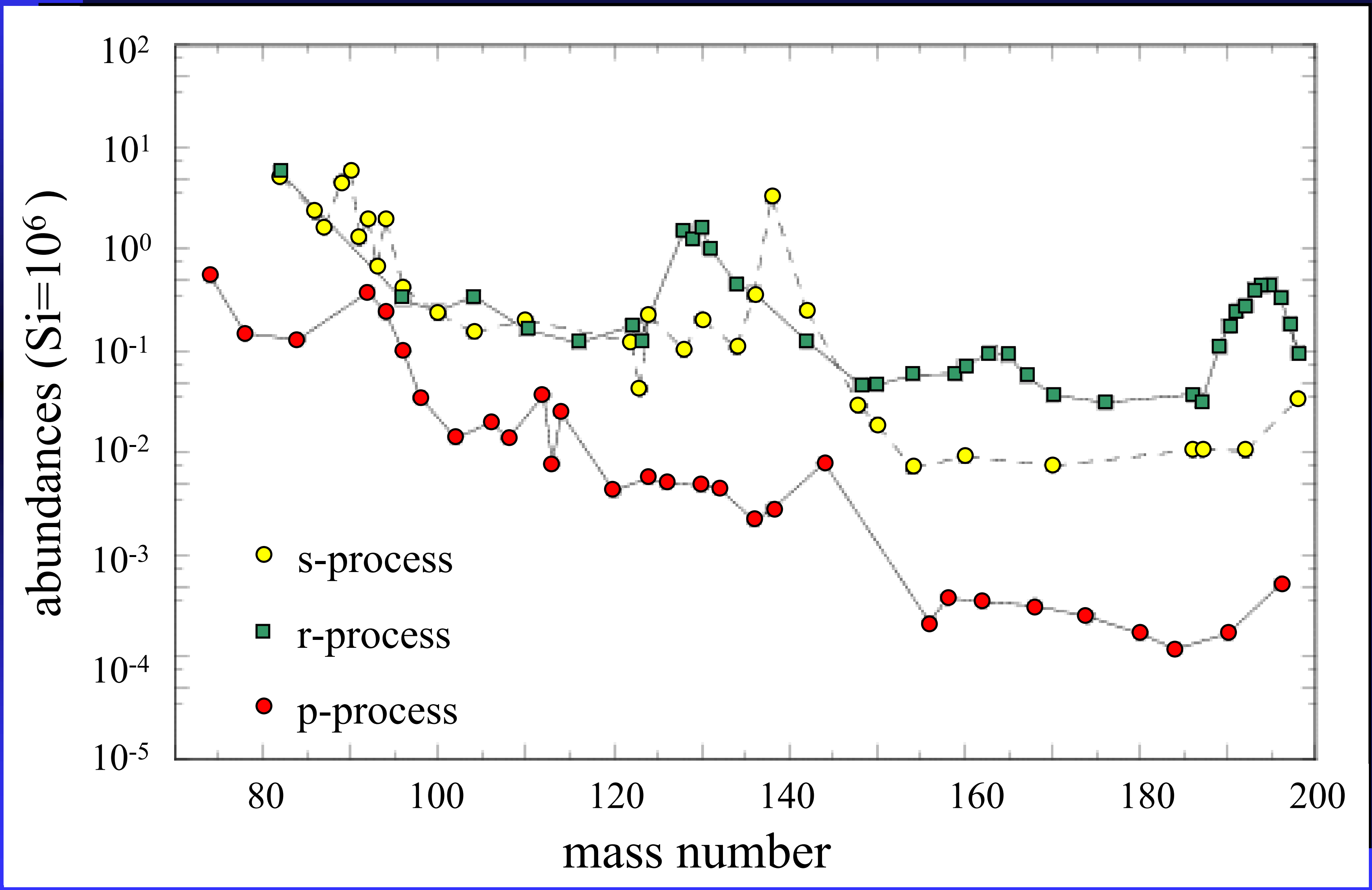
Overview Nucleosynthesis



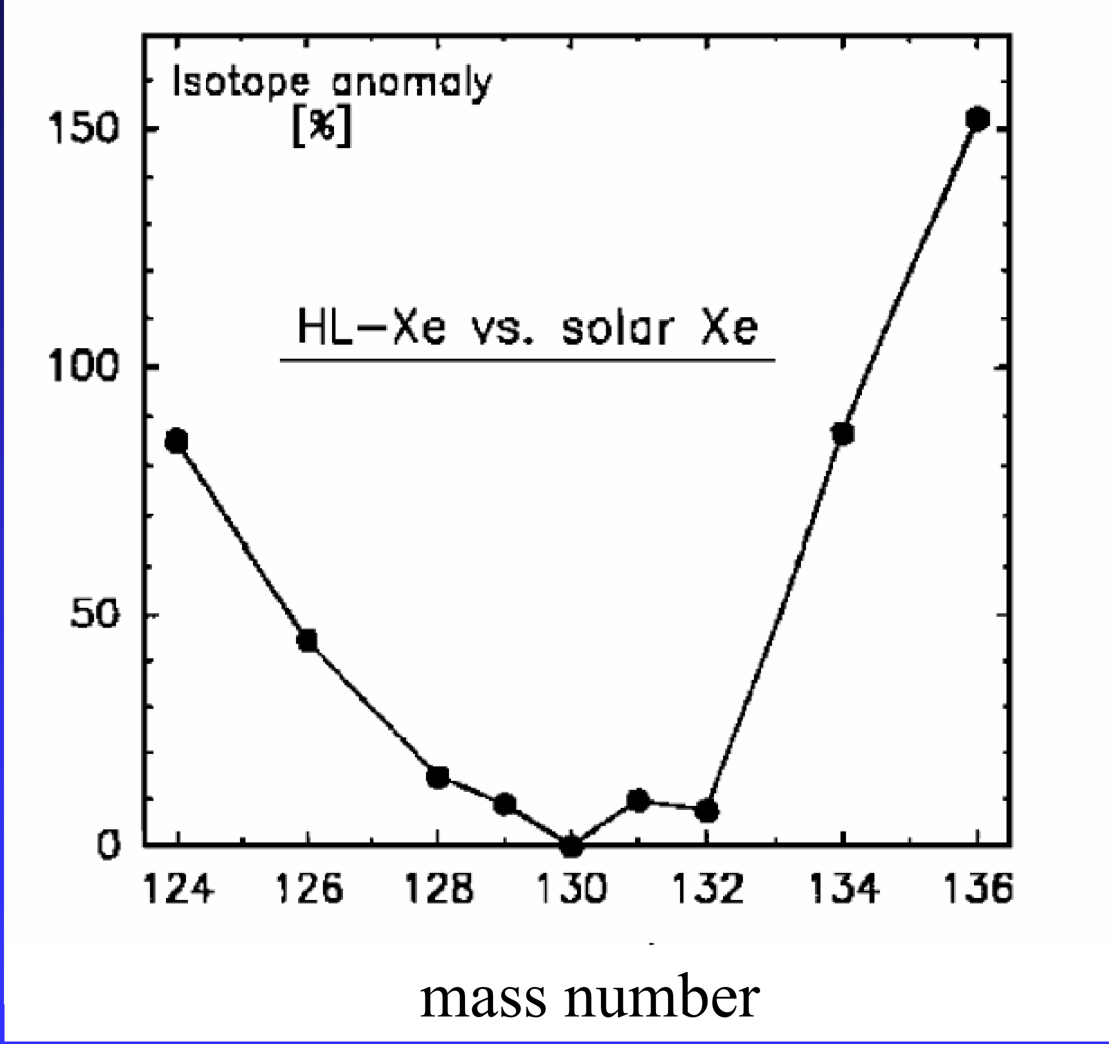

Z
N
4
2
3
1
(p,γ)
(γ,n)
β+
(γ,α)
(γ,p)


N = 50
Zr
Y
Sr
Rb
Se
As
Ge
Ga
Zn
Cu
Ni
Co
Fe
p
s
r
s-process
r-process

Observed Abundances



Isotopic anomalies



Scenarios for p-Process

Conditions

- Very hot enviroments T_9= 2 - 3
- Short time scale

Where ?

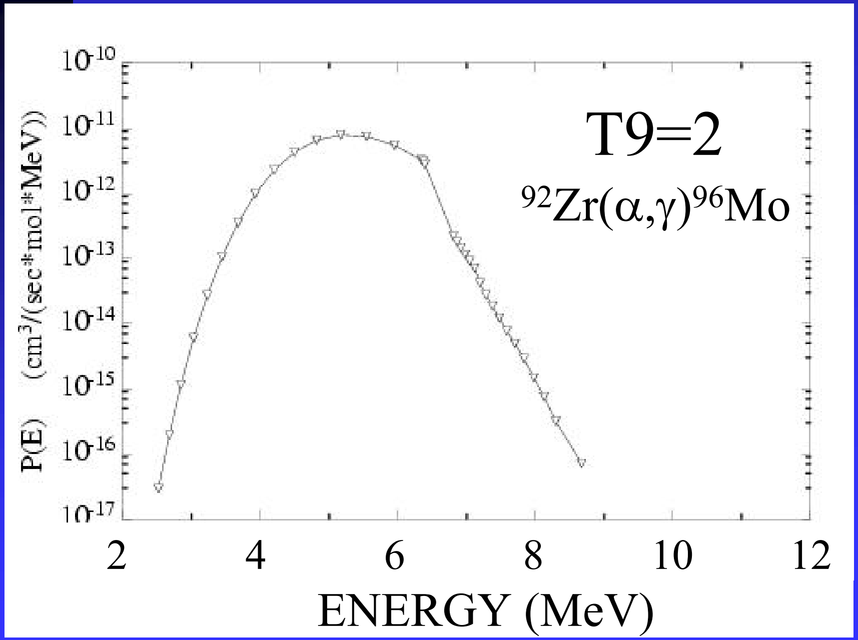
- Explosive massive stars (SN type II)
- Binary systems (nova, x-ray burster, SN type I)
- Accretion discs on compact objects (black holes)
- Othere scenarios: pre-type II SN production, PCSN, SSAD.

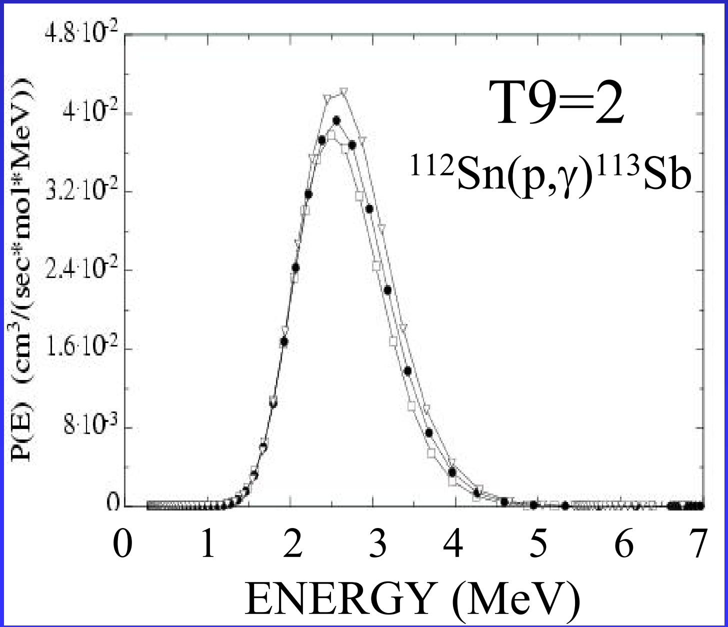
Reaction Energy and Gamov Peak

Rate:

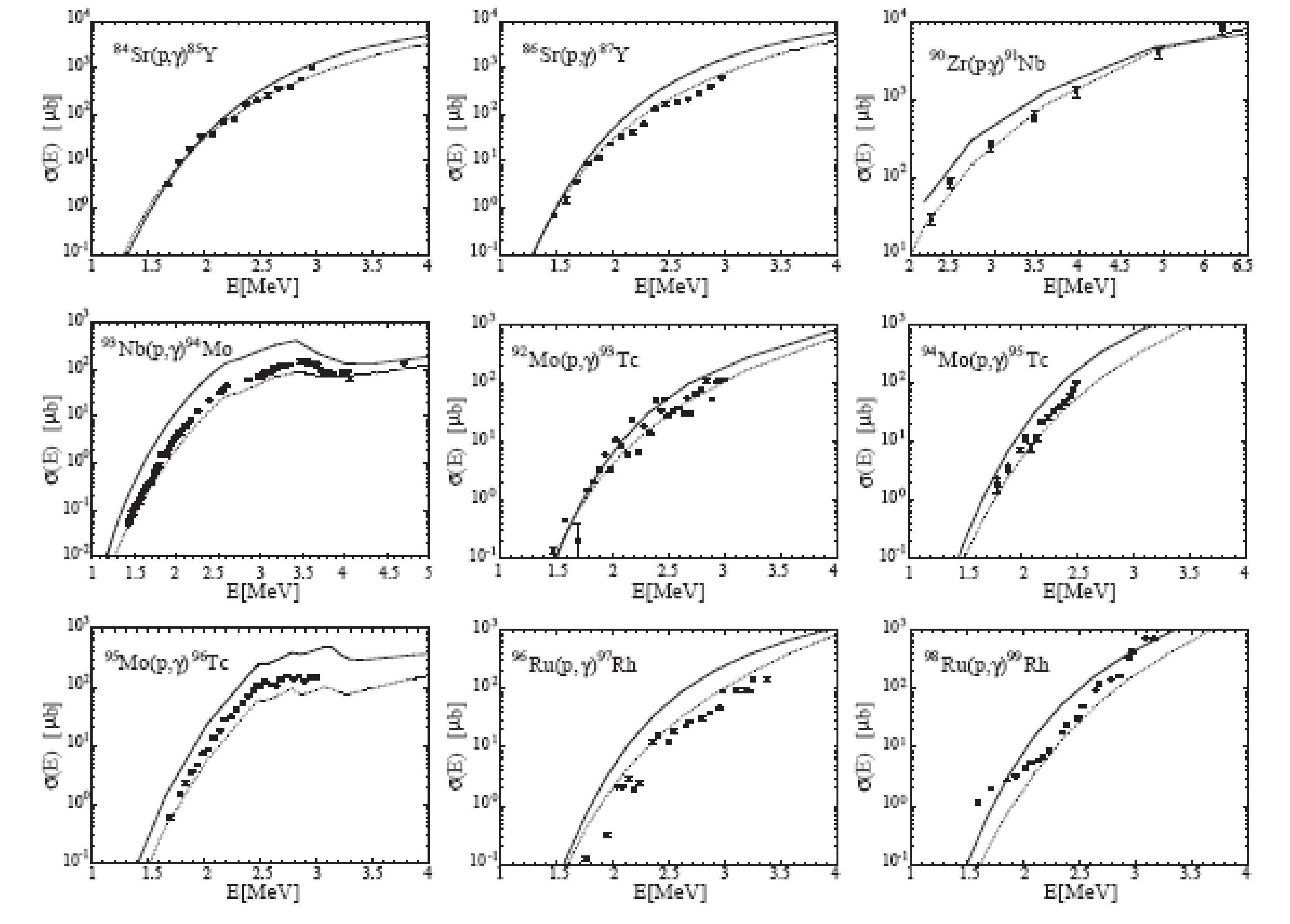
$$\langle \sigma \cdot v \rangle = \left(\frac{8}{\pi \cdot \mu} \right)^{1/2} \cdot \frac{1}{(k \cdot T)^{3/2}} \cdot \int_0^\infty \sigma(E) \cdot \exp\left(- \frac{E}{k \cdot T} \right) \cdot dE$$

- Penetrability
- Maxwell Boltzmann distribution





Status of (p,γ)-Experiments



Status of (α,γ)-Experiments

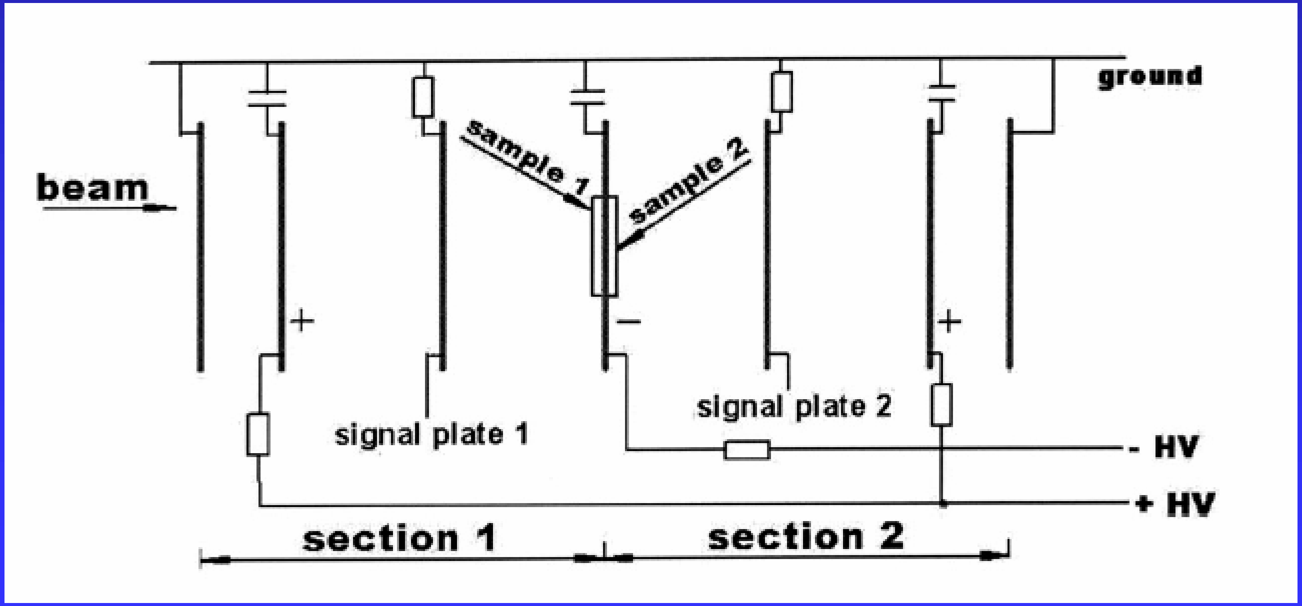
- Few experimental data on α-induced reactions.
- Measurements of ^{144}Sm(α,γ)-cross section showed a big difference to theory.
- Exp (n,α) rates for different isotopes shows:

  ^{143}Nd: exp.= NONSMOKER/2.7

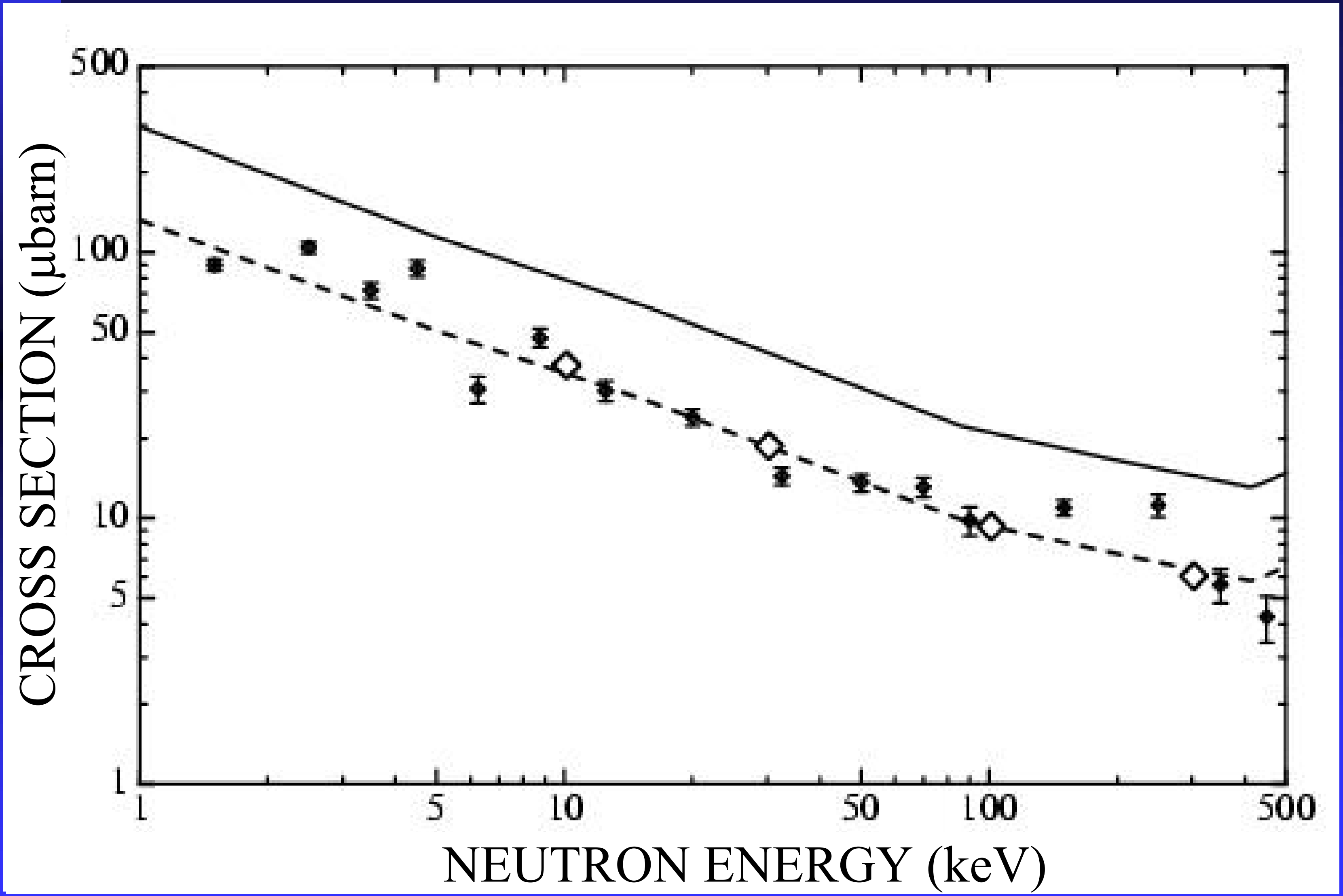
  ^{147}Sm: exp.=NONSMOKER/3.3
- α-induced reactions on ^{96}Ru result in exp.=theo./2

$^{95}Mo(n,\alpha)$-Experiment

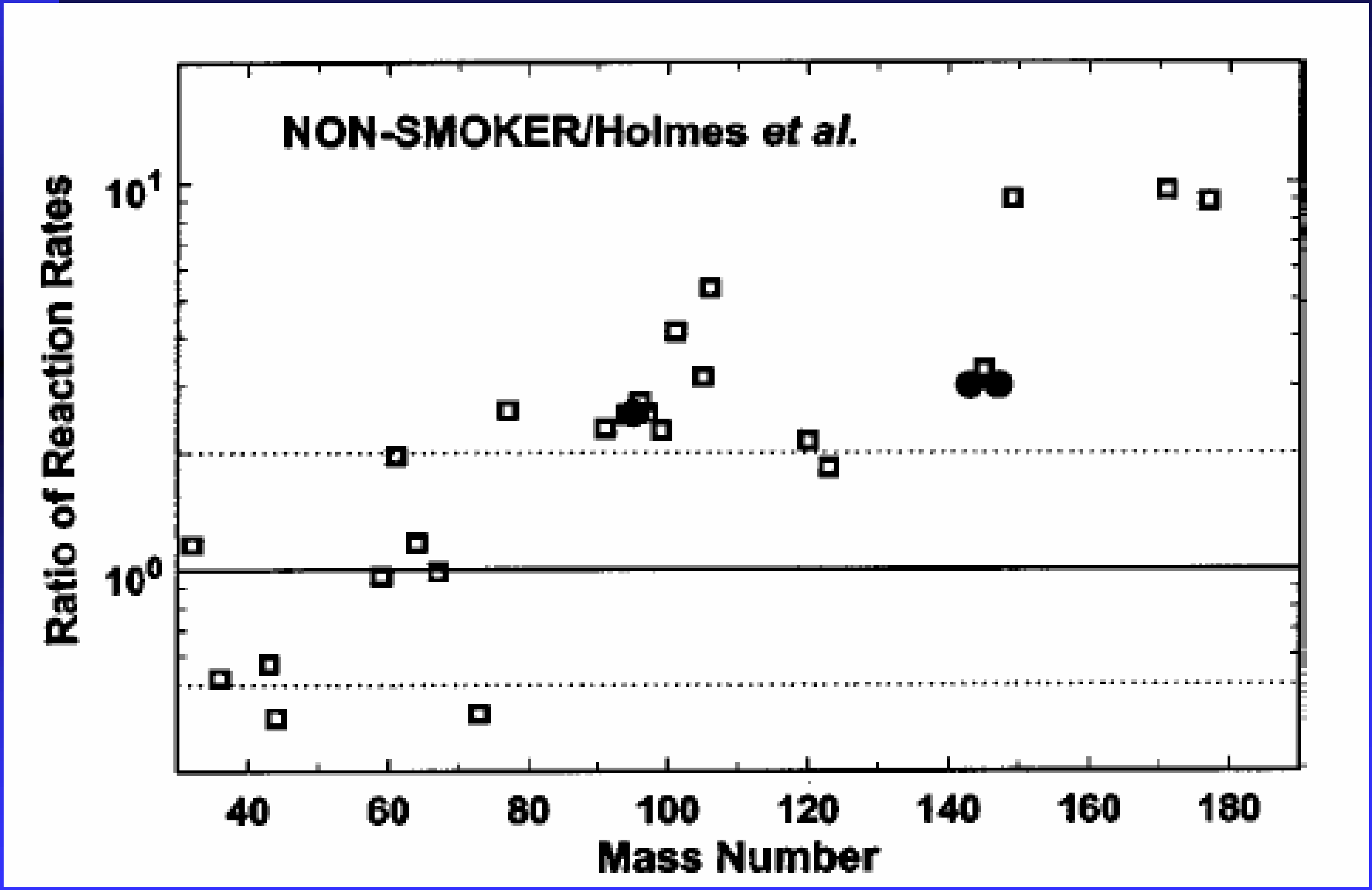
- Oak Ridge National Laboratory
  150 MeV e^--accalerator, 525 Hz, 8 ns, (γ,n)-reactions on Ta
- Energy calibration: time of flight method
- α-particles were detected using a CIC.



The $^{95}Mo(n,\alpha)$-cross section

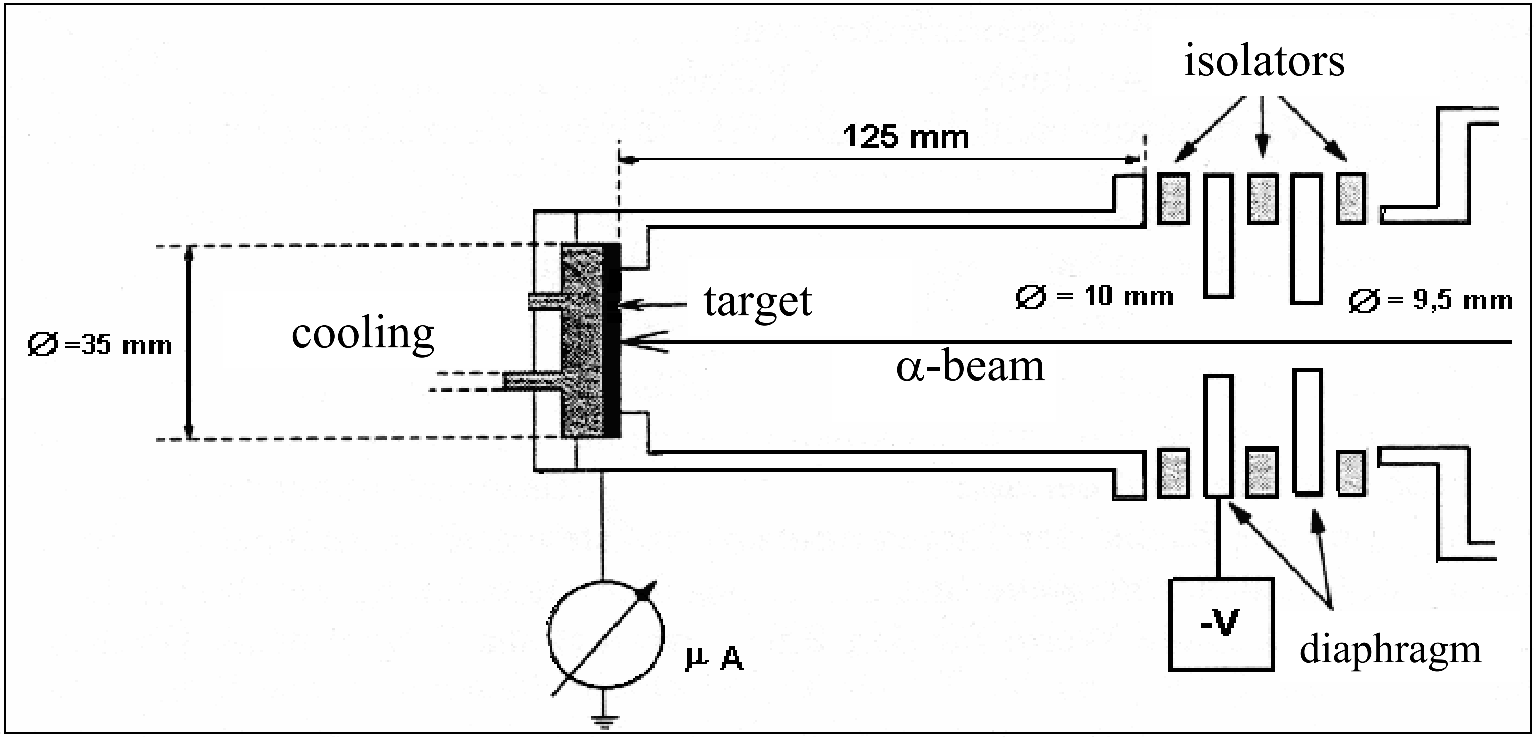


NON-SMOKER/Holmes

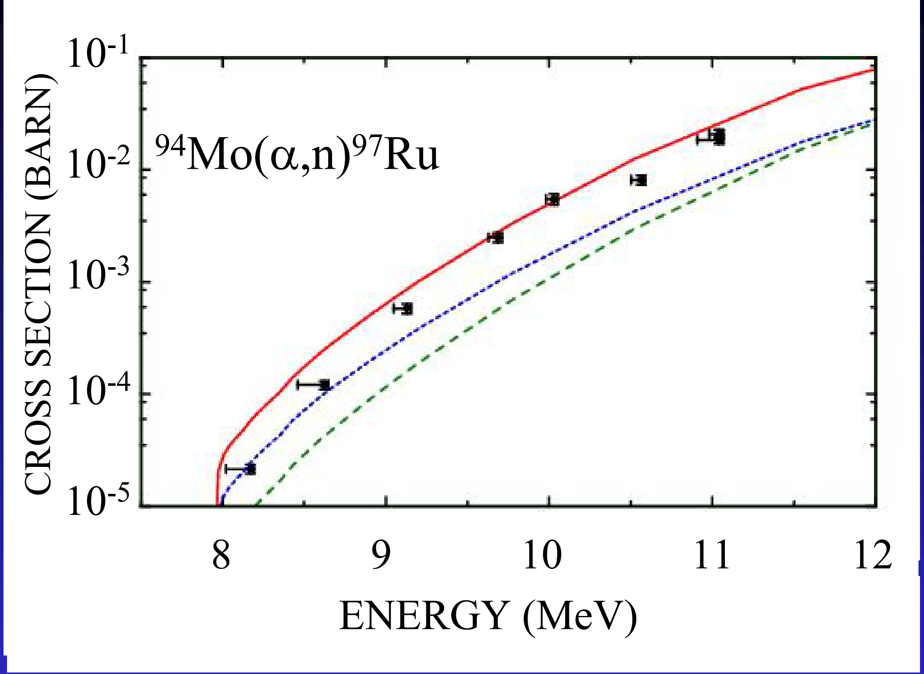


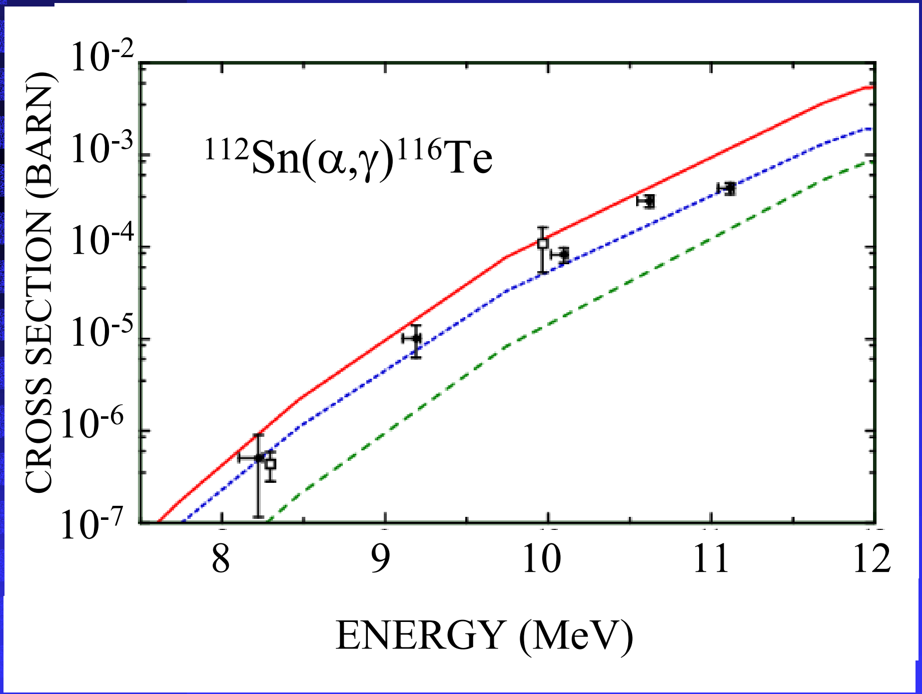
Activation-Experiments

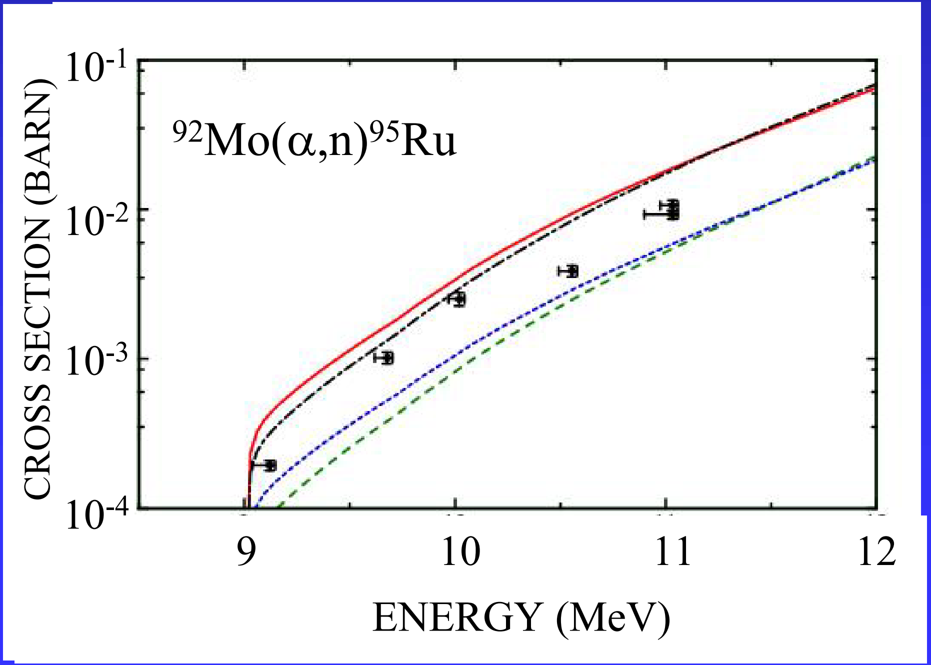
- 8 Mo & 7 Sn activations at the PTB (Germany)
  - E_α= 8 – 11 MeV
  - I_α= 5 – 7 μA
  - t_Mo= 25 min – 9 h; Δt= 30 s
  - t_Sn= 45 min – 4 h; Δt= 30 s



Results:


$^{94}Mo(\alpha,n)^{97}Ru$
CROSS SECTION (BARN)
ENERGY (MeV)


$^{112}Sn(\alpha,\gamma)^{116}Te$
CROSS SECTION (BARN)
ENERGY (MeV)


$^{92}Mo(\alpha,n)^{95}Ru$
CROSS SECTION (BARN)
ENERGY (MeV)

Potential parameters

Using SMOKER code and a χ^2-test

Wood-Saxon potential:

$$V(r) = -\frac{V_0}{1+\exp\left(\frac{r - r_r A^{1/3}}{a_r}\right)} - i\frac{W_0}{1+\exp\left(\frac{r - r_v A^{1/3}}{a_v}\right)}$$

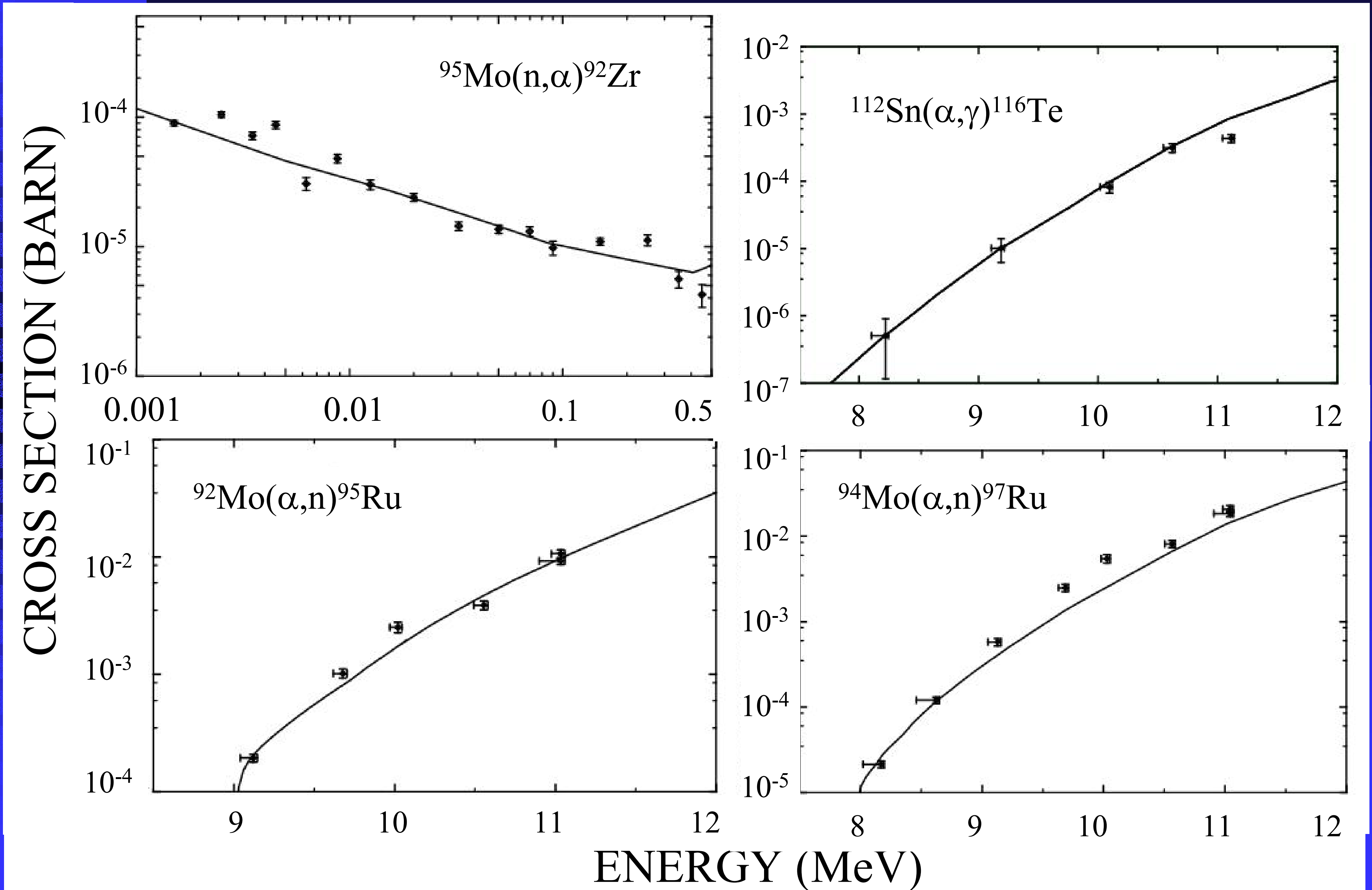
parameter	V_0	r_r	a_r	W_0	r_v	a_v
value	185.0 MeV	1.40 fm	0.52 fm	25,0 MeV	1.40 fm	0.52 fm

reaction	^{94}Mo(α,n)	^{92}Mo(α,n)	^{112}Sn(α,γ)	^{95}Mo(n,α)	sum
χ^2	27.0	104.0	107.5	146.4	385.0

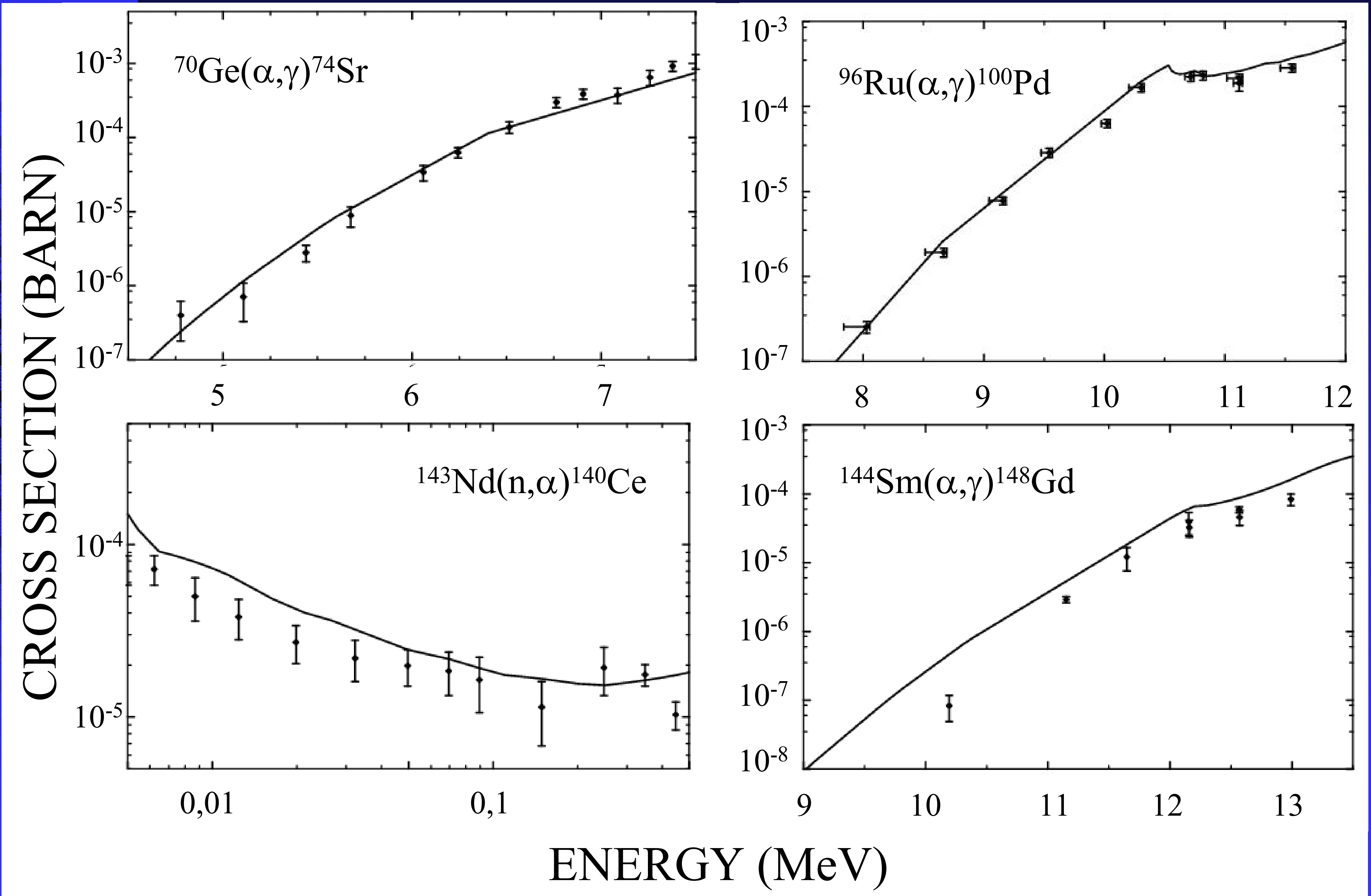
parameter	V_0	r_r	a_r	W_0	r_v	a_v
value	185.0 MeV	1.31 fm	0.52 fm	25,0 MeV	1.40 fm	0.52 fm

reaction	^{94}Mo(α,n)	^{92}Mo(α,n)	^{112}Sn(α,γ)	^{95}Mo(n,α)	sum
χ^2	11.4	4.0	9.1	4.9	29.4

New Potential Parameters



Independent experiments

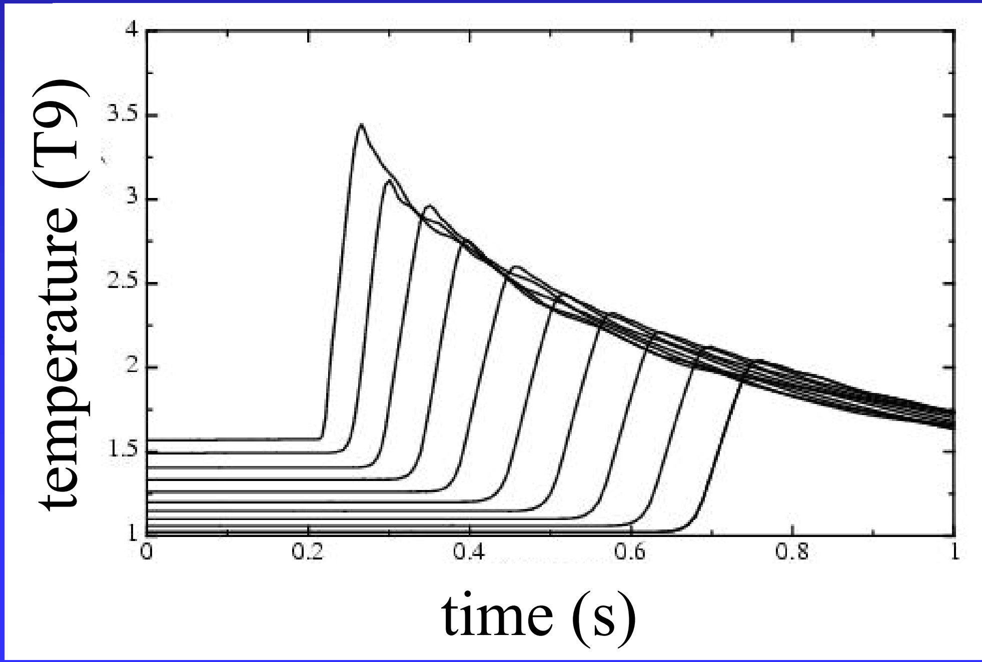


Network

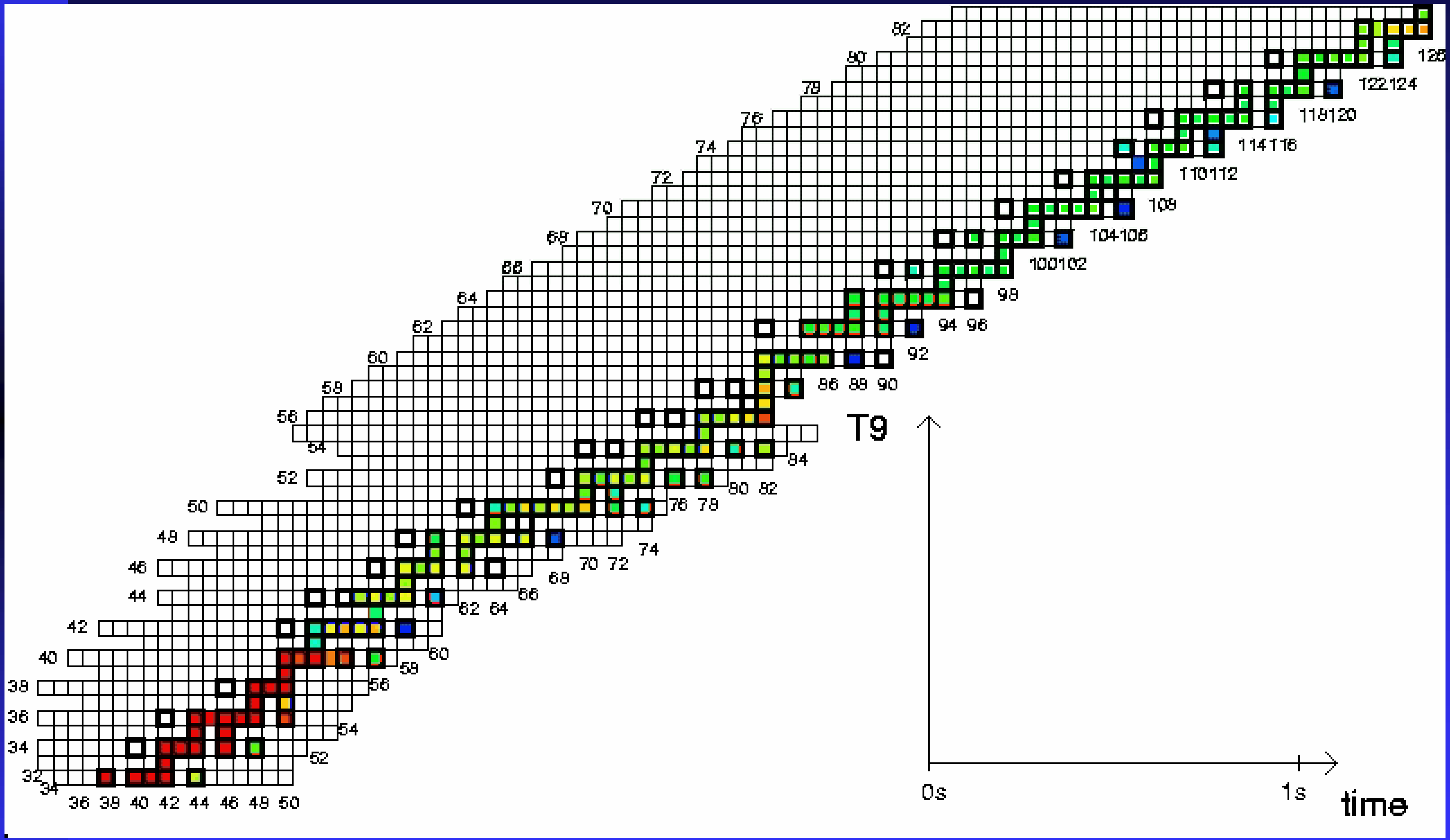
Extended a MSU network was used for x-ray burst. Simulated explosive O/Ne burning in a SN Type II.

Now:

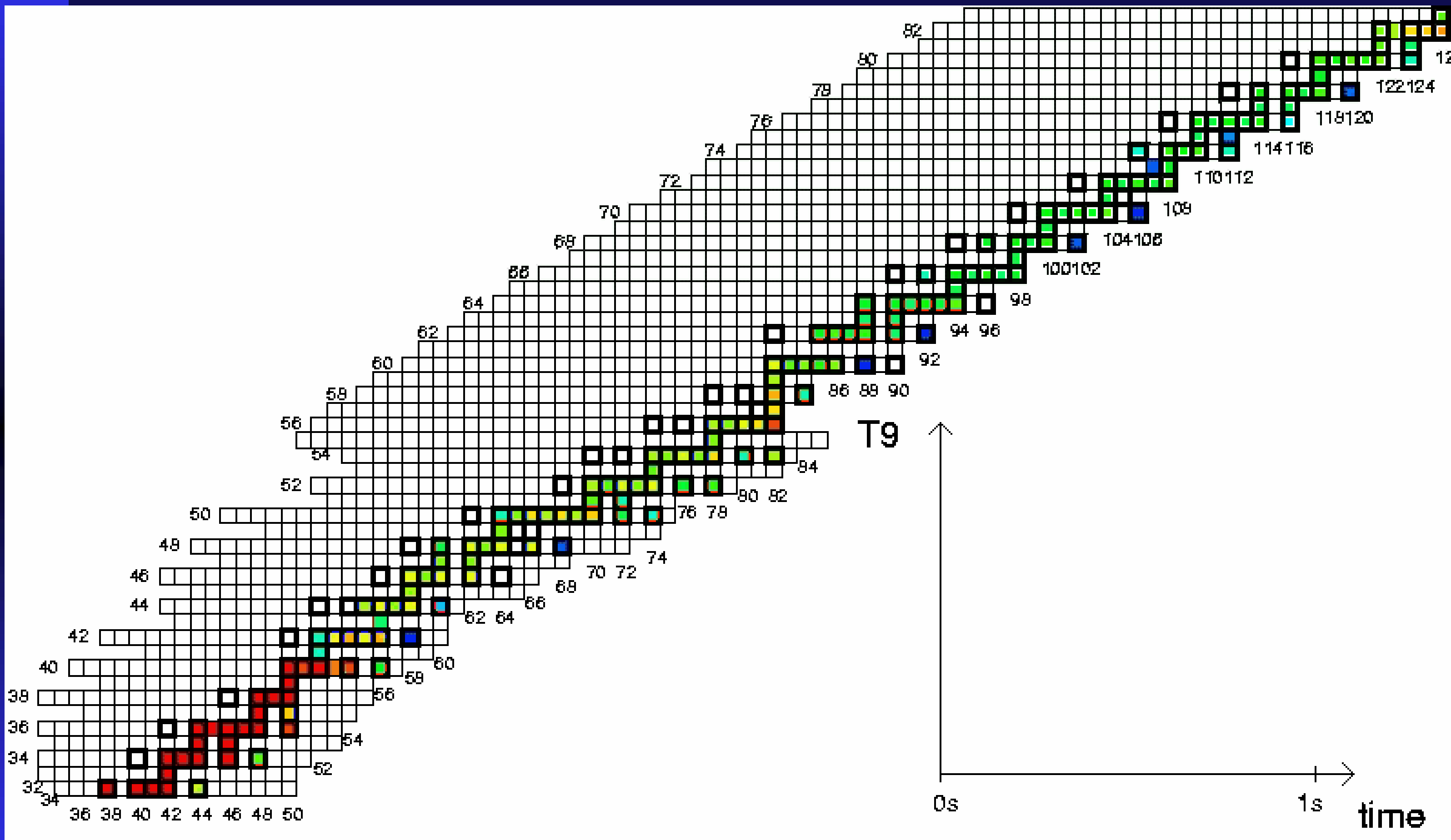
- 1814 nuclei
- ~15000 rates
- 10 layers



Network T_{9max}=3.1



Network $T_{9max}=2.4$



Some Definitions

- Overabundance factor

$$F_i = \frac{X_i}{X_{i\_Solar}}$$

- Produced mass of isotope i

$$\mathrm{m}_i(M) = \sum_{n \geq 1} \frac{1}{2} \times \left(X_{i,n} + X_{i,(n-1)}\right) \times \left(M_n - M_{n-1}\right)$$

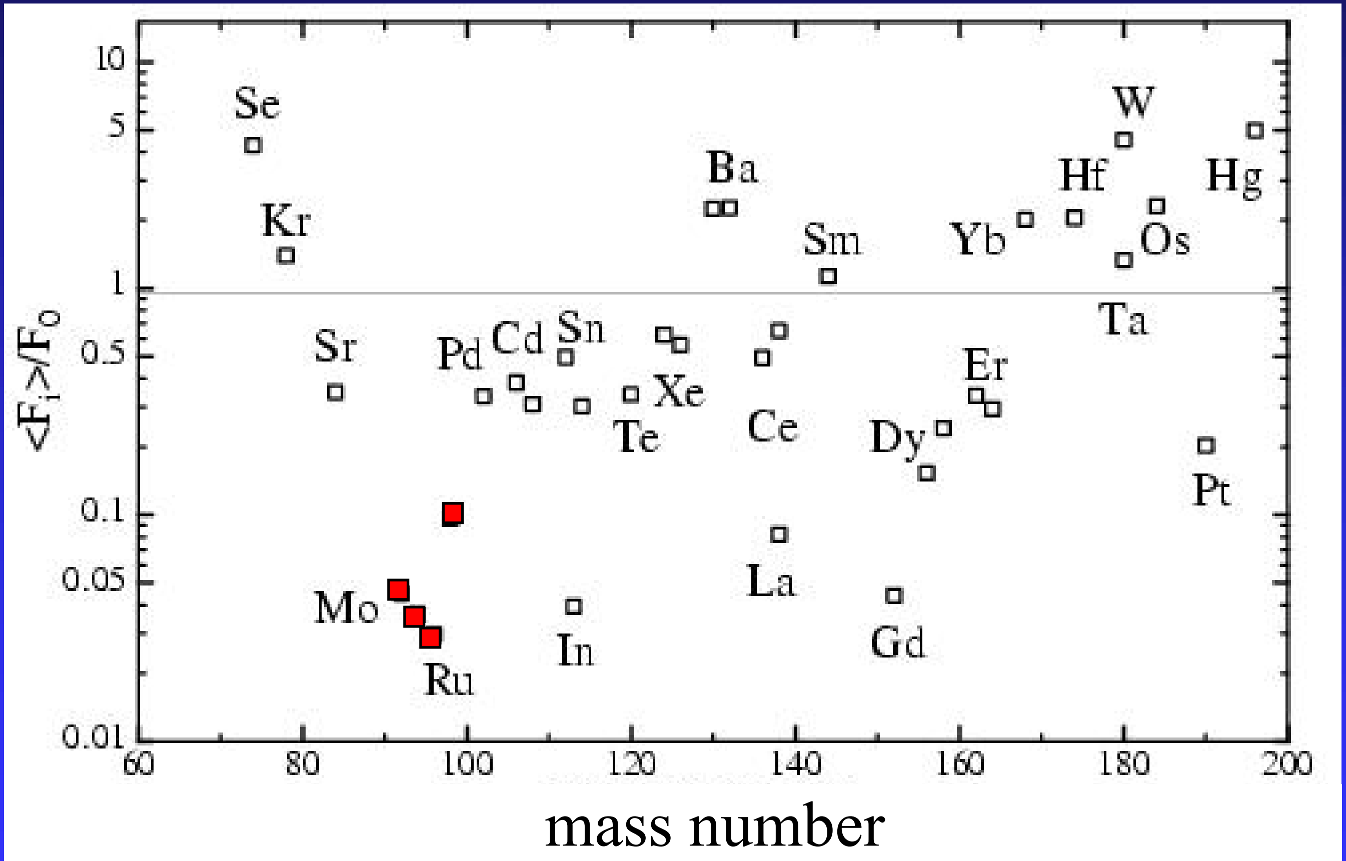
- Averaged overproduction factor for a isotope i.

$$\langle F_i \rangle = m_i(M) / \left(M_p(M) \times X_{i\_Solar}\right)$$

- Normalized overproduction factor

$$\frac{\langle F_i \rangle}{F_0} \qquad F_0 = \sum_i \langle F_i \rangle / 35$$

Normalized Overabundances

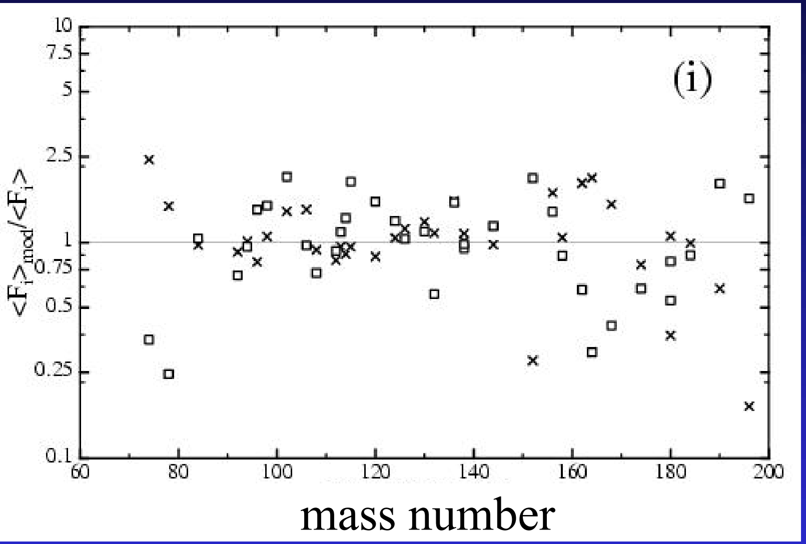


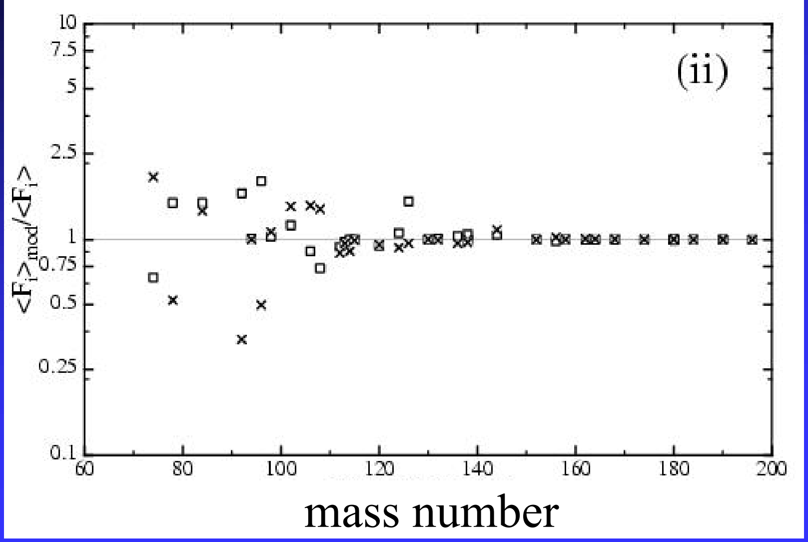
Influence of Rate Types

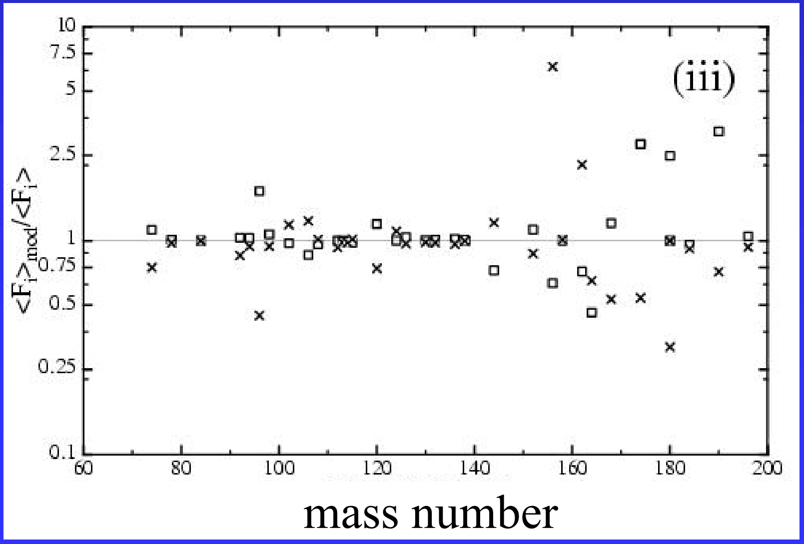
(i) neutron-rates

(ii) proton-rates

(iii) α-rates







Conclusions

- More experimental data are needed for
  α-induced rates (A>147).
- The (γ,p)-rates on p-nuclei (A<96) should be measured.
- The Mo and Ru problem is not a problem of rate uncertainty (n,p,α on A>56)
- Convection should be considered in the model.

interesting publications:

- M. Arnould, S. Goriely, Physical Reports 384 (2003) 1-84.
- W. Rapp, P. E. Koehler, F. Käppeler, and S. Raman Physical Review C, Volume 68, (2003) 015802.