Optical Model Potentials and Nuclear Level Densities for the nucleosynthetic p-process:

An experimentalist's point of view

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Optical Model Potentials (OMP), Nuclear Level Densities (NLD), and γ-ray strength functions are the basic "input" parameters in HF calculations

$$\sigma = \pi ƛ^2 \frac{1}{(2J_a+1)(2J_A+1)} \sum_{J^\pi} (2J+1) \frac{T_{aA}^{J^\pi} T_{Bb}^{J^\pi}}{\sum_i T_i^{J^\pi}}$$

γ Emission is described by the **Giant Dipole de-excitation (GDR)**

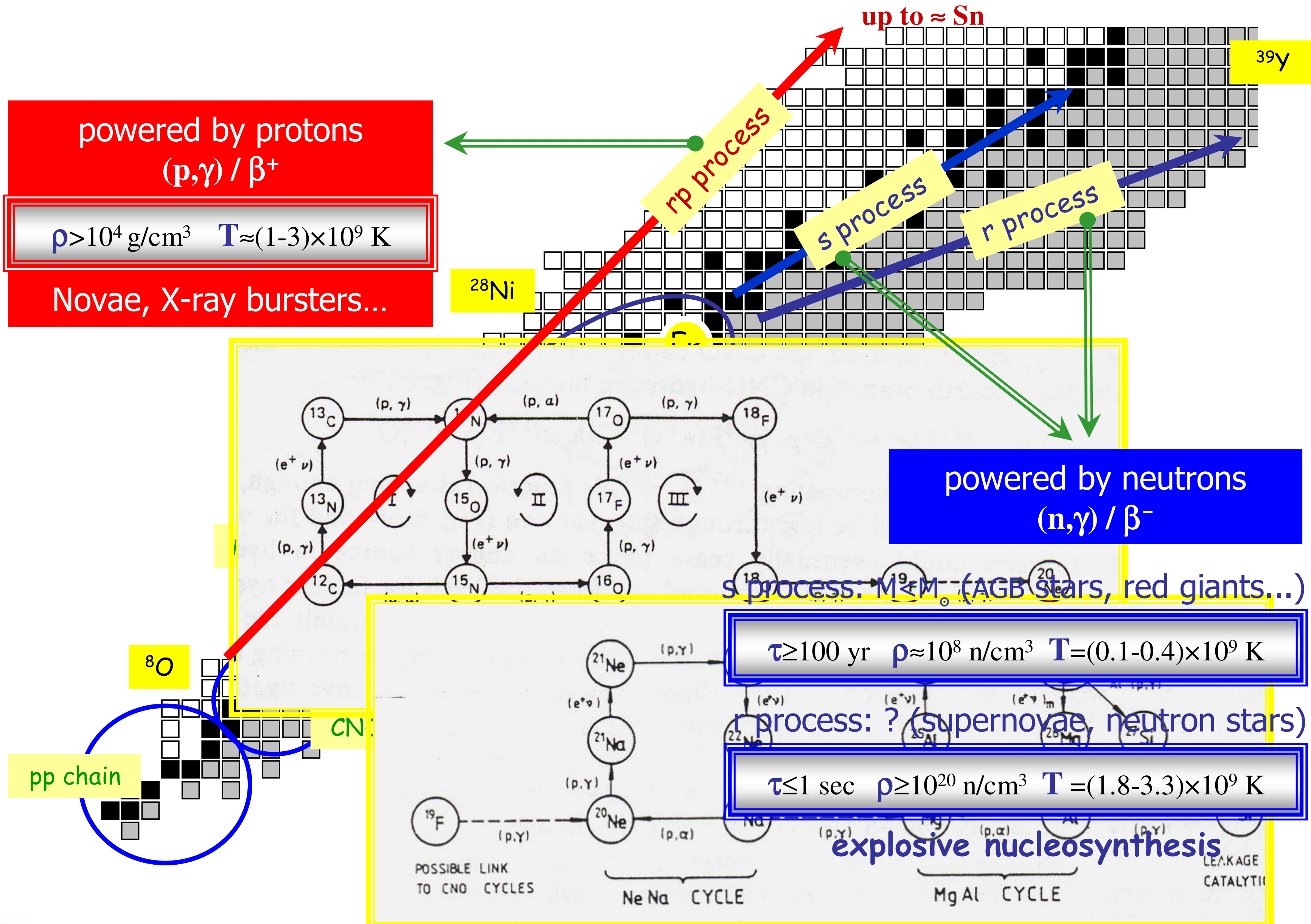
Particle emission: *T*s from **Optical Model Potentials (OMP)**

When CN is excited to continuum then ***T*s have to be averaged**

$$\overline{T}_{aA} = \sum_I \int \rho(E_a, I) T_{aA}^I(E_a)\, dE_a$$

Nuclear Level Density (NLD)

Capture reactions and Nucleosynthesis



powered by protons
(p,γ) / β^{+}

ρ>10^{4} g/cm^{3} T≈(1-3)×10^{9} K

Novae, X-ray bursters…

powered by neutrons
(n,γ) / β^{-}

s process: M<M$_{\odot}$ (AGB stars, red giants…)

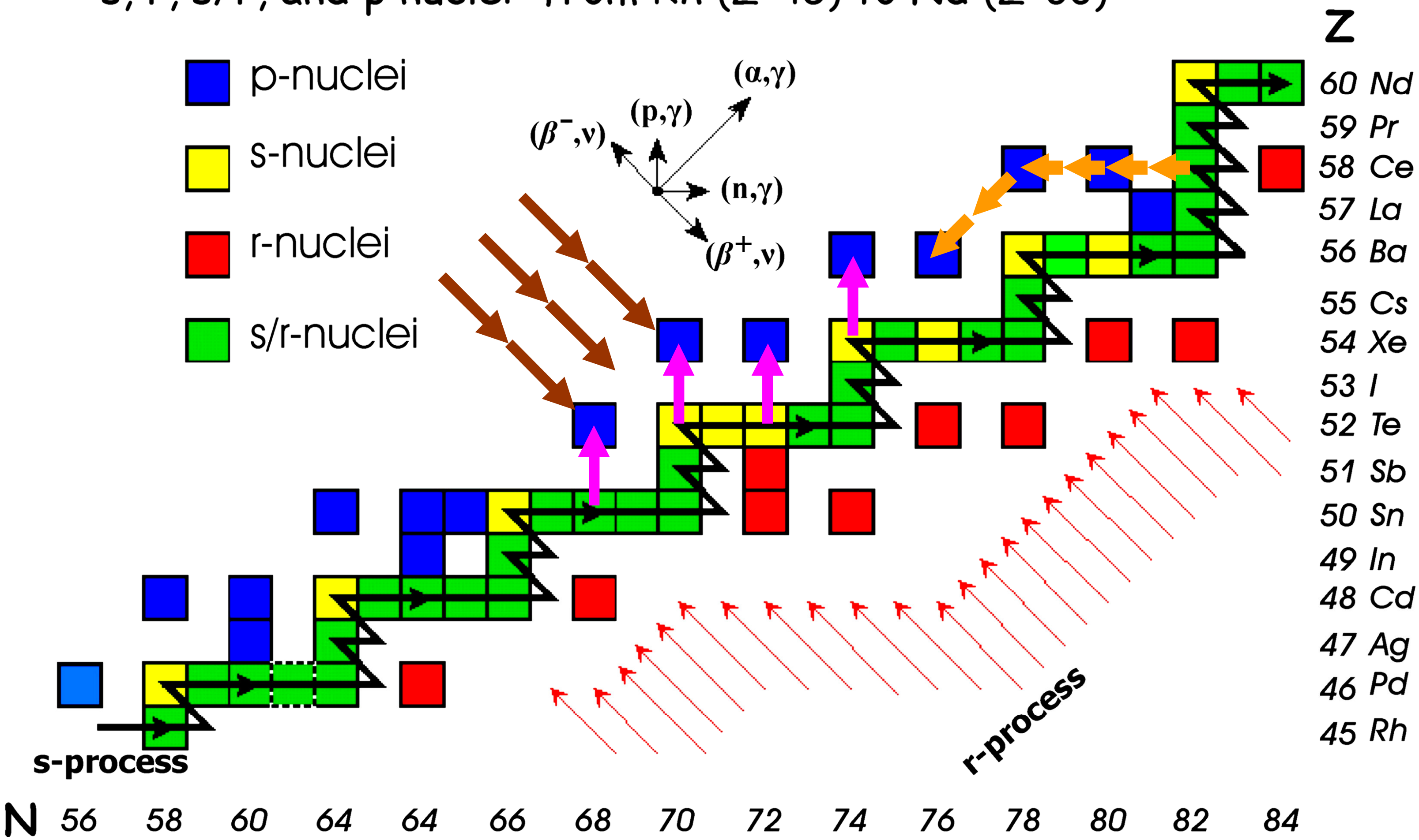
τ≥100 yr ρ≈10^{8} n/cm^{3} T=(0.1-0.4)×10^{9} K

r process: ? (supernovae, neutron stars)

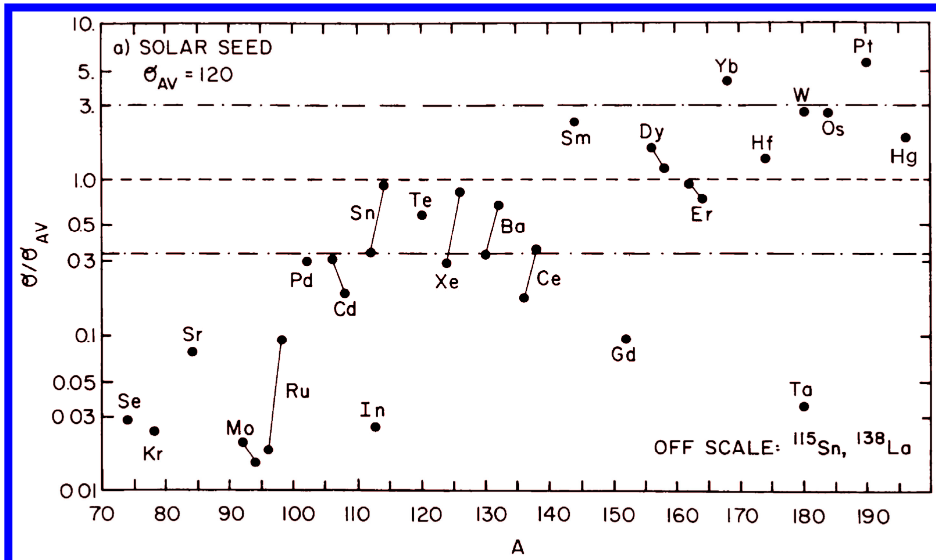
τ≤1 sec ρ≥10^{20} n/cm^{3} T =(1.8-3.3)×10^{9} K

explosive nucleosynthesis

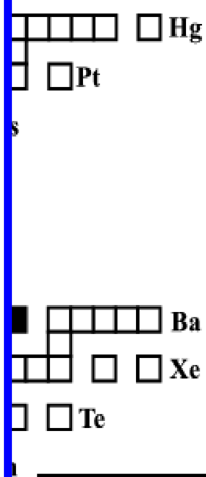
s, r, s/r, and p nuclei from Rh (Z=45) to Nd (Z=60)

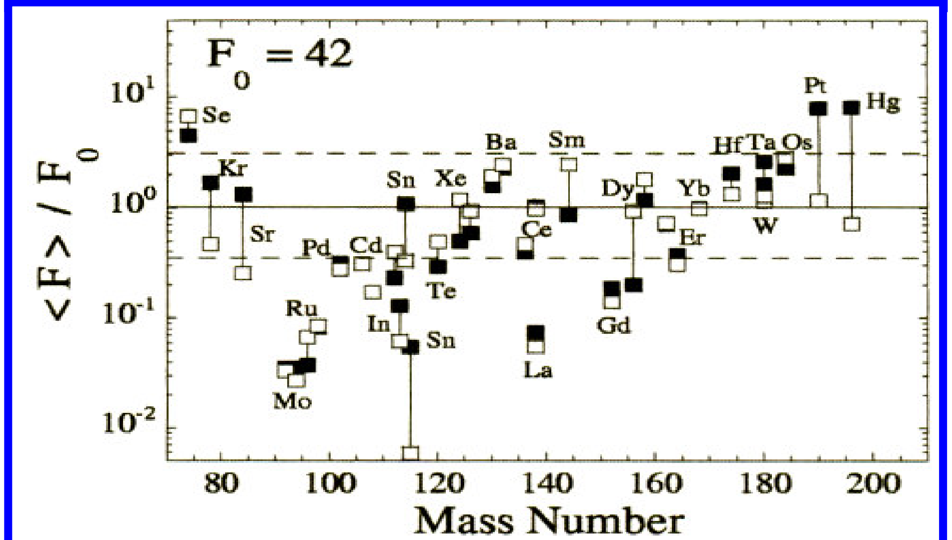


p-nuclei solar abundances



Woosley and Howard, Ap. J. Suppl. 36, 285 (1978)

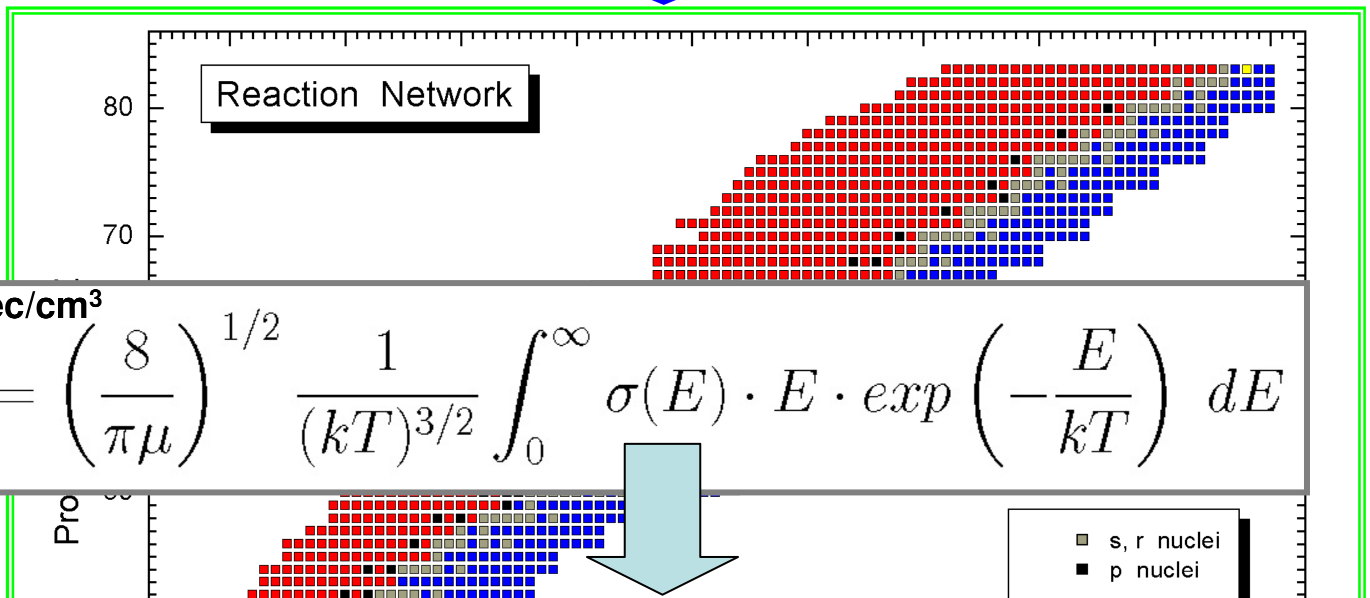




S. Goriely et al., A&A 375, 35 (2001)

p nucleus	(%)	p nucleus	(%)	p nucleus	(%)
74_Se	0.89	114_Sn	0.65	156_Dy	0.06
78_Kr	0.35	115_Sn	0.34	158_Dy	0.10
84_Sr	0.56	120_Te	0.096	162_Er	0.14
92_Mo	14.84	124_Xe	0.10	164_Er	1.61
94_Mo	9.25	126_Xe	0.09	168_Yb	0.13
96_Ru	5.52	130_Ba	0.106	174_Hf	0.162
98_Ru	1.88	132_Ba	0.101	180_Ta	0.012
102_Pd	1.02	138_La	0.09	180_W	0.13
106_Pd	1.25	136_Ce	0.19	184_Os	0.02
108_Cd	0.89	138_Ce	0.25	190_Pt	0.01
113_In	4.3	144_Sm	3.1	196_Hg	0.15
112_Sn	0.97	152_Gd	0.20	solar abundances	

"seed" abundances (s process) → reaction network → p-nuclei abundances (p process)



reactions/sec/cm^3

$$<\sigma v>=\left(\frac{8}{\pi\mu}\right)^{1/2}\frac{1}{(kT)^{3/2}}\int_0^\infty \sigma(E)\cdot E\cdot exp\left(-\frac{E}{kT}\right)\,dE$$

HAUSER-FESHBACH THEORY

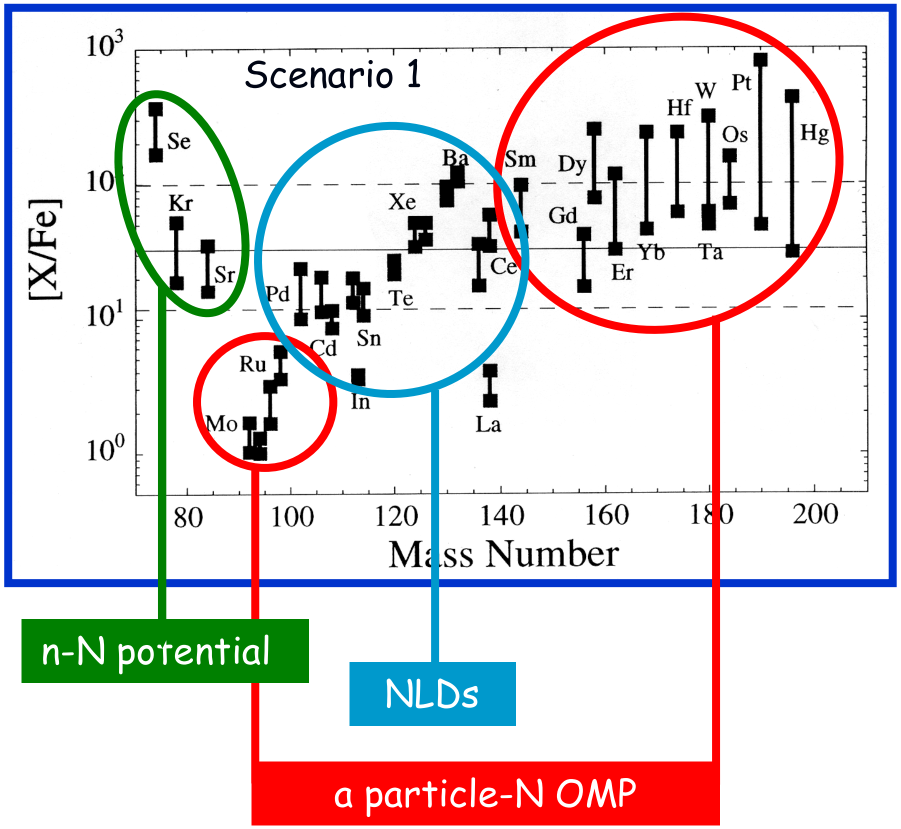
Optical Model Potentials - Nuclear Level Densities - γ-Ray Strengths

n, p, α-particles (32≤Z≤83 , 36≤N≤131)

p-process scenarios and nuclear physics uncertainties

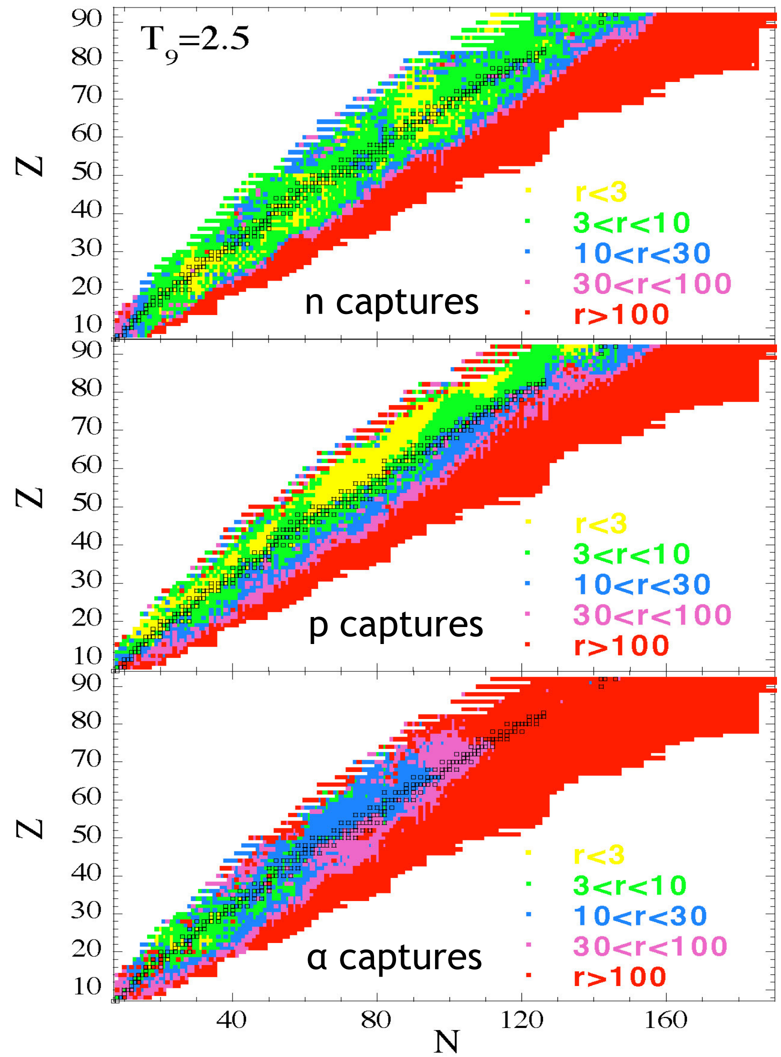
S. Goriely, ESF Workshop on p process, Vravron, Greece, 2002 - M. Arnould and S. Goriely Phys. Rep. 384, 1 (2003)

1. SN-II explosions
2. SN-Ia C-deflagration in Chandrasekhar-mass WD
3. He-detonation in Sub-Chandrasekhar-mass WD.



$$r := \langle\sigma\upsilon\rangle_{max.} / \langle\sigma\upsilon\rangle_{min.}$$

obtained with 14 different sets of nuclear ingredients (OMP, NLD, …) in HF calculations.



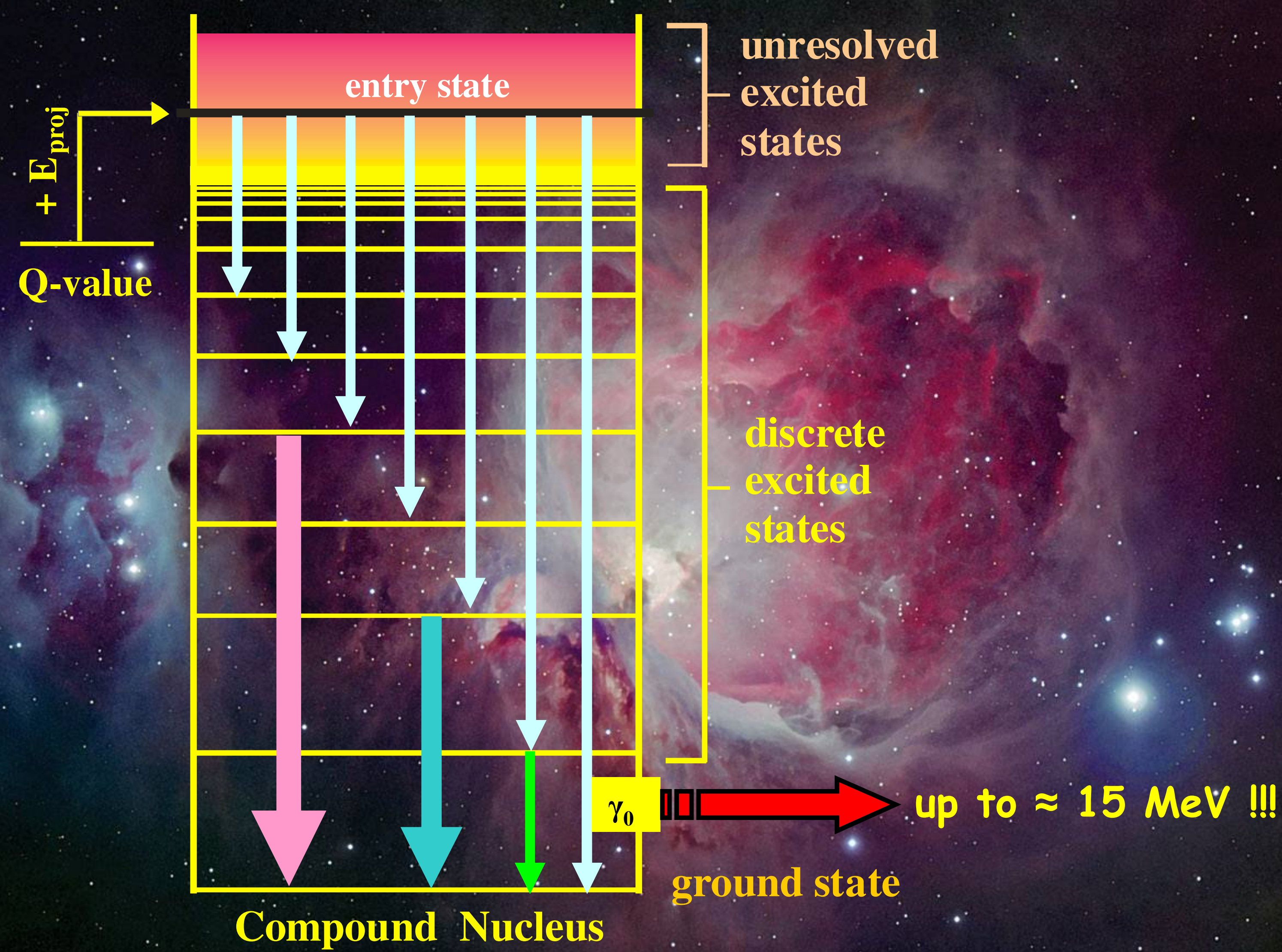
On top of any **ASTROPHYSICAL** (p-process) model improvements, it is of key importance to investigate the uncertainties in the **NUCLEAR** properties, and in particular, in the nuclear level densities (NLD), optical model potentials (OMP) and γ-ray strength functions entering the HF calculations.

- Systematic cross-section measurements of proton- and α-particle capture reactions at energies relevant to p process.
- So far 25 (p,γ) and 10 (α,γ) reaction cross sections were measured from Cu-65 up to Sb-123 at energies from 1.5 to 6 MeV (protons) or 7 to 12 MeV (α-particles)
- ACTIVATION as well as IN-BEAM measurements

γ-angular distributions ⟷ angle-integrated γ-fluxes

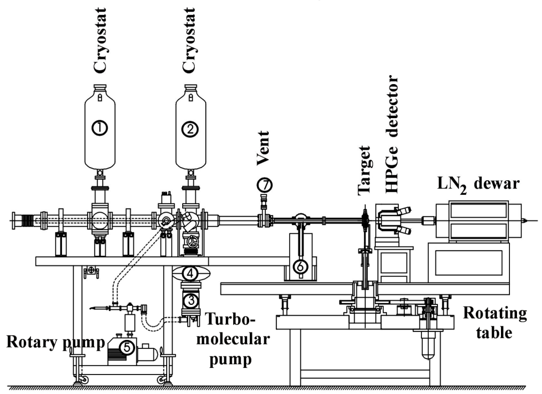
4π γ-summing method

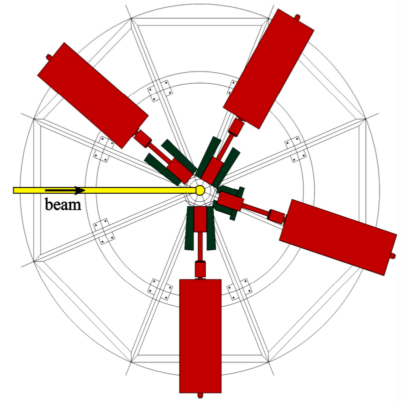
γ decay after compound nucleus formation



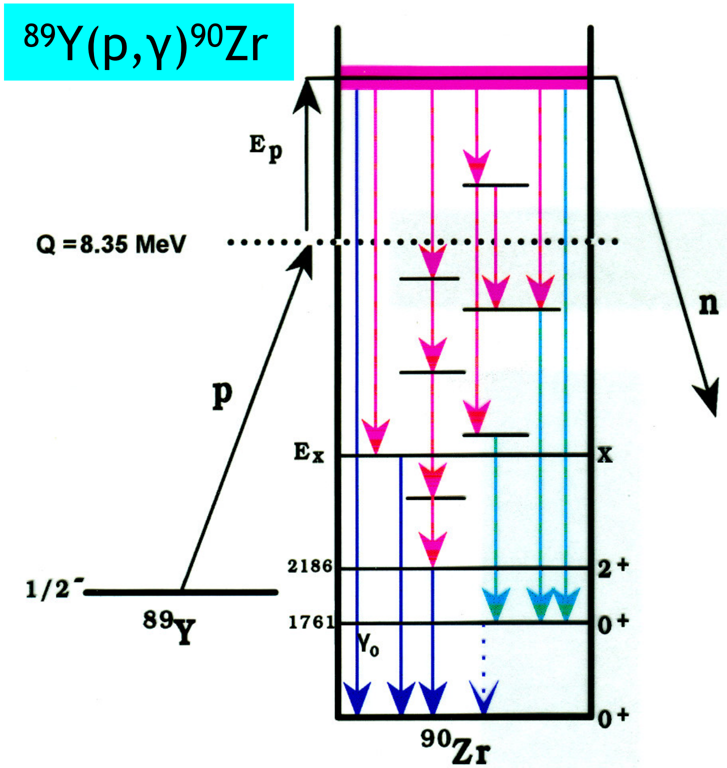
In-beam cross-section measurements of $^{89}Y(p,\gamma)^{90}Zr$

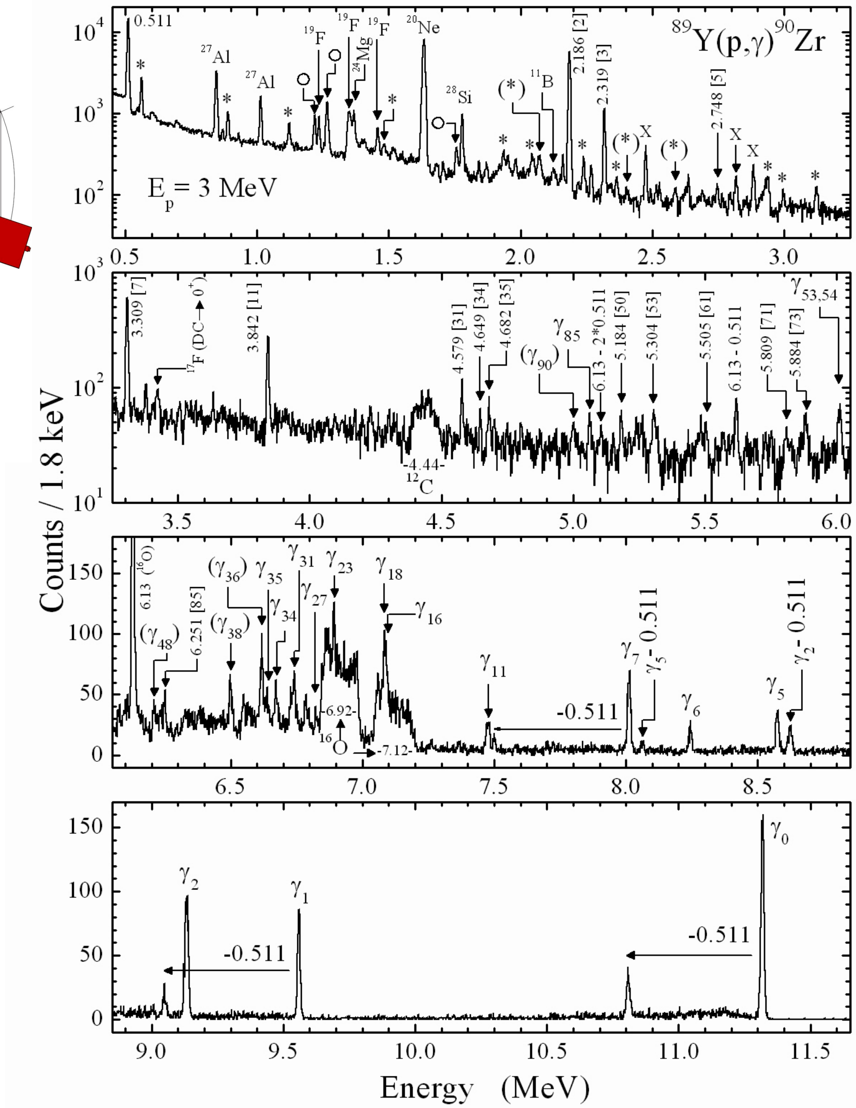
The 4xHPGe array @ IfS/Stuttgart



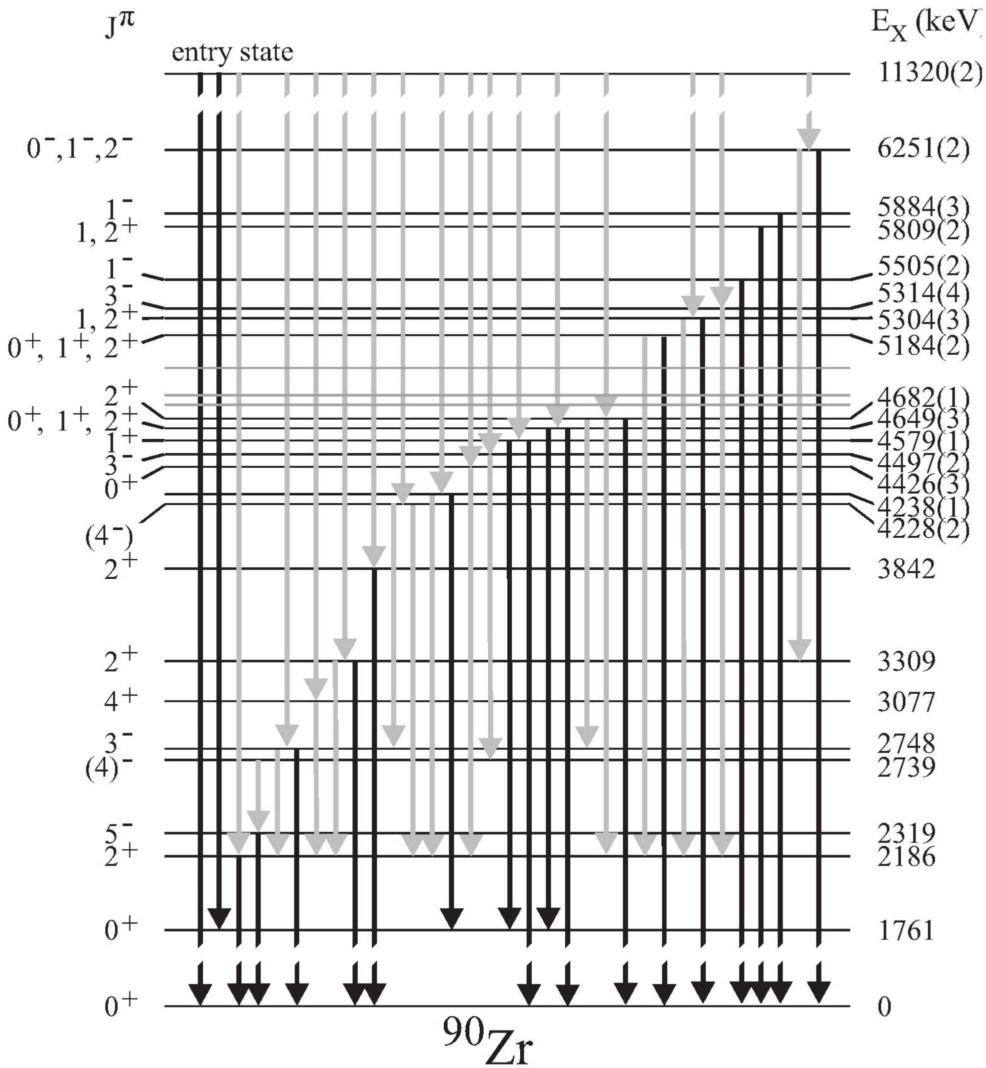


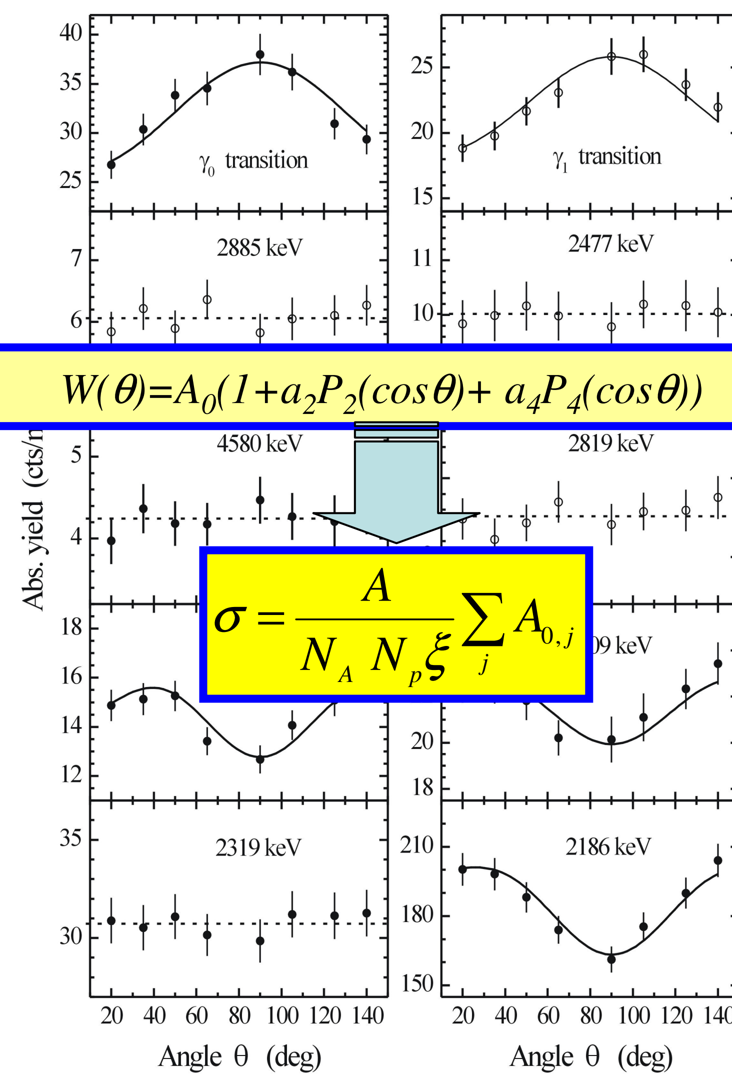
$^{89}Y(p,\gamma)^{90}Zr$





In-beam cross-section measurements of $^{89}Y(p,\gamma)^{90}Zr$

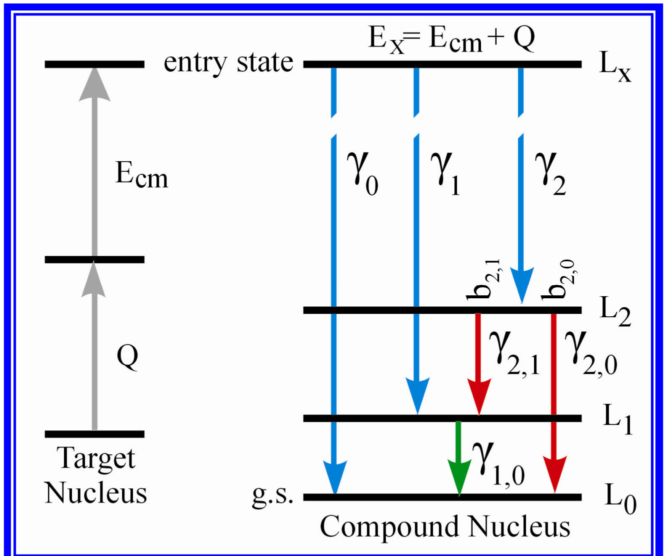


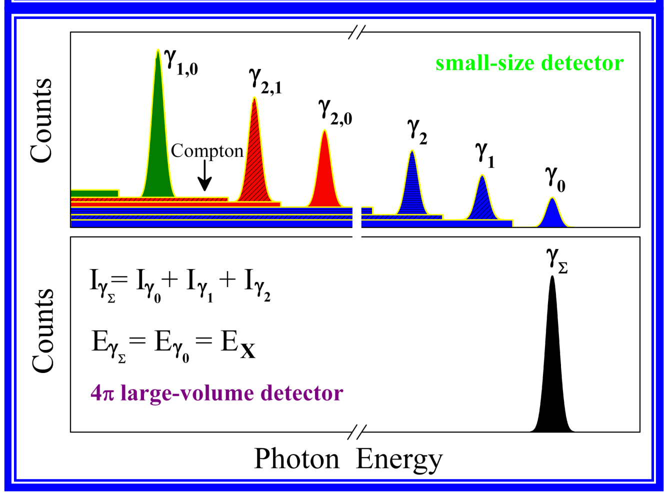


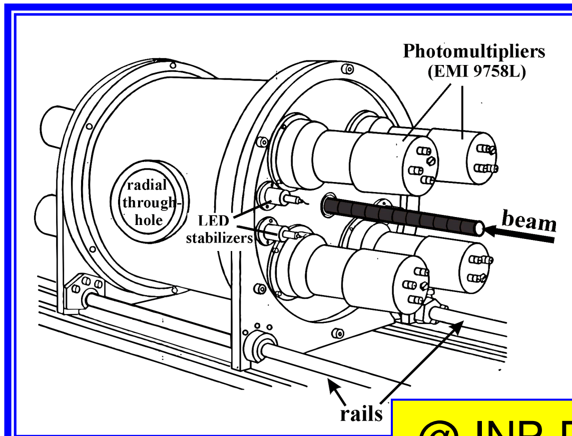
$$W(\theta)=A_0(1+a_2P_2(\cos\theta)+a_4P_4(\cos\theta))$$

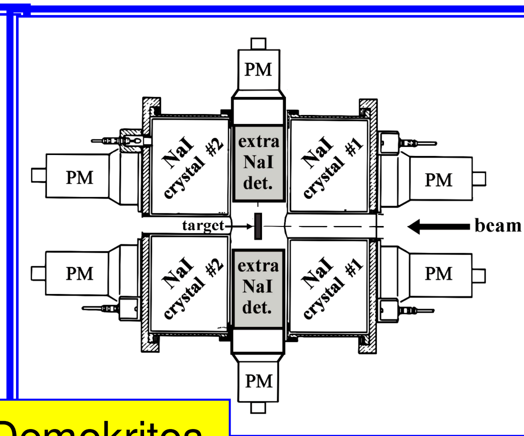
$$\sigma=\frac{A}{N_A\,N_p\xi}\sum_j A_{0,j}$$

The 4π γ-summing method



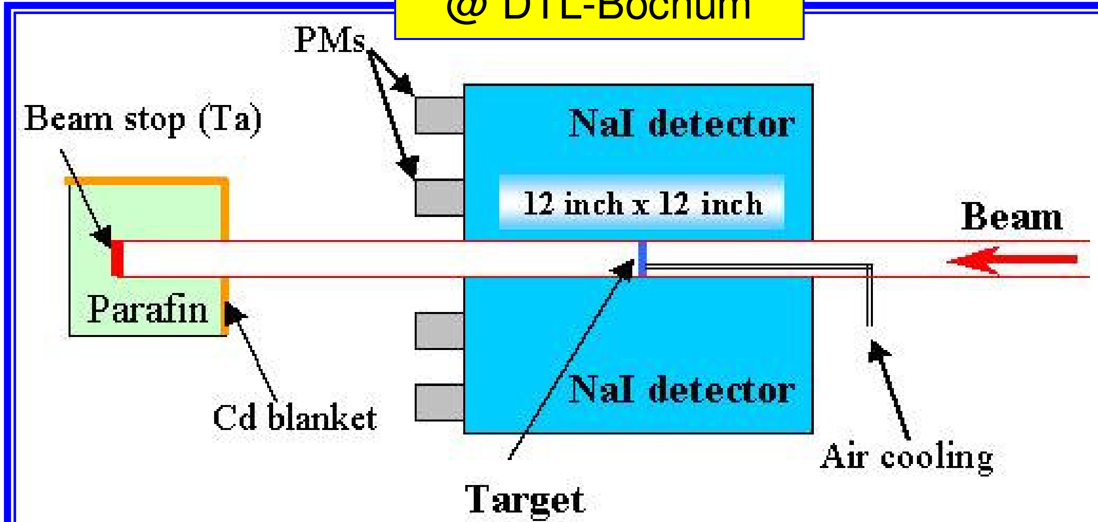




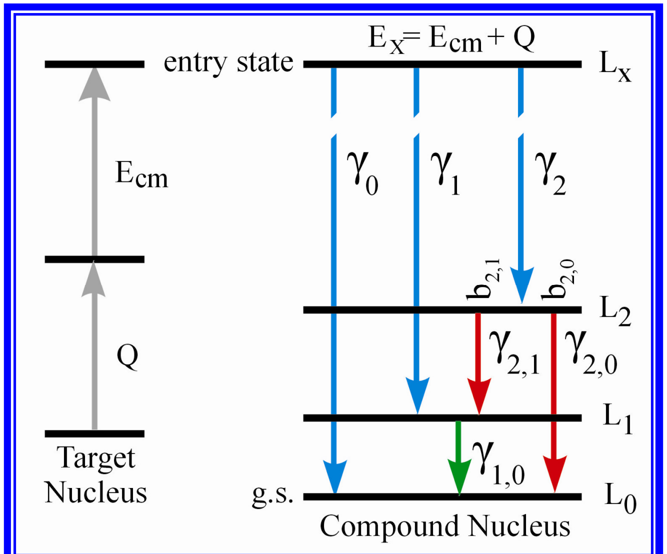


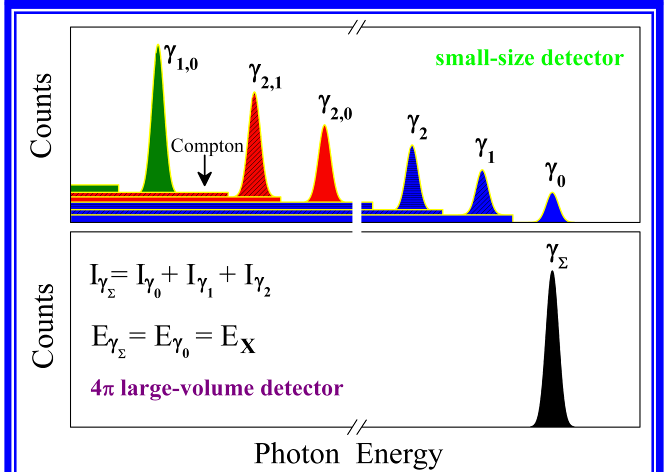
@ INP-Demokritos

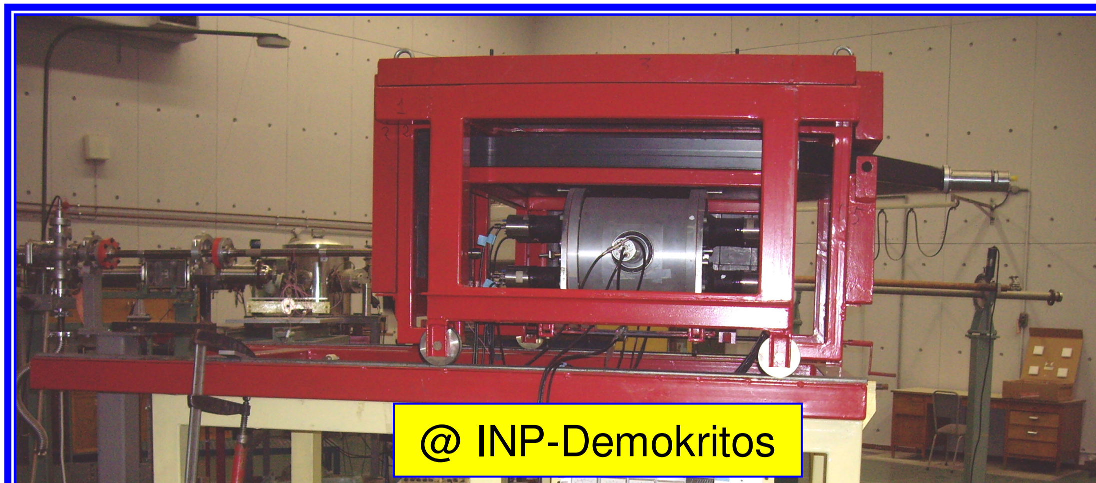
@ DTL-Bochum

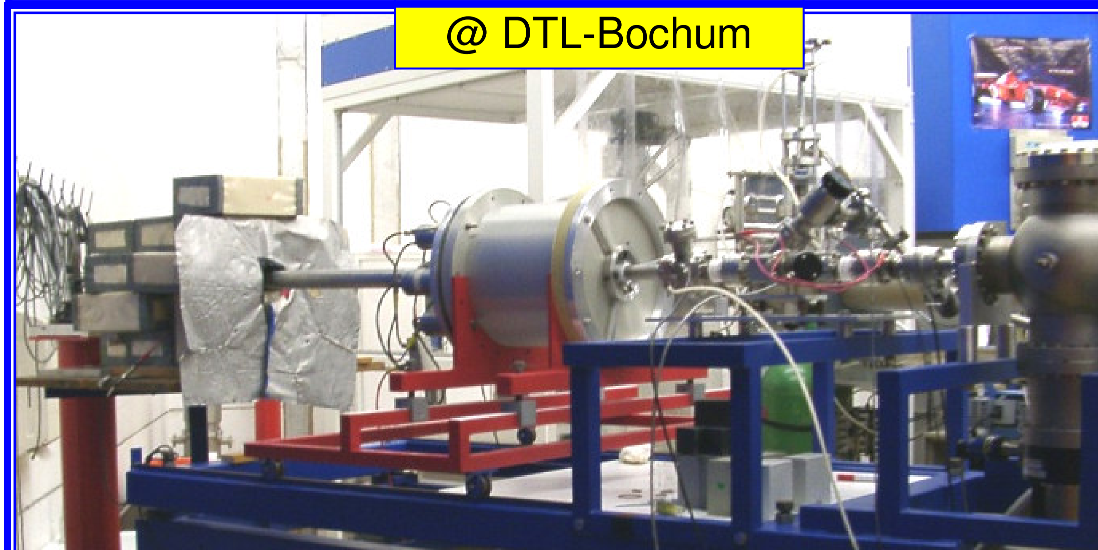


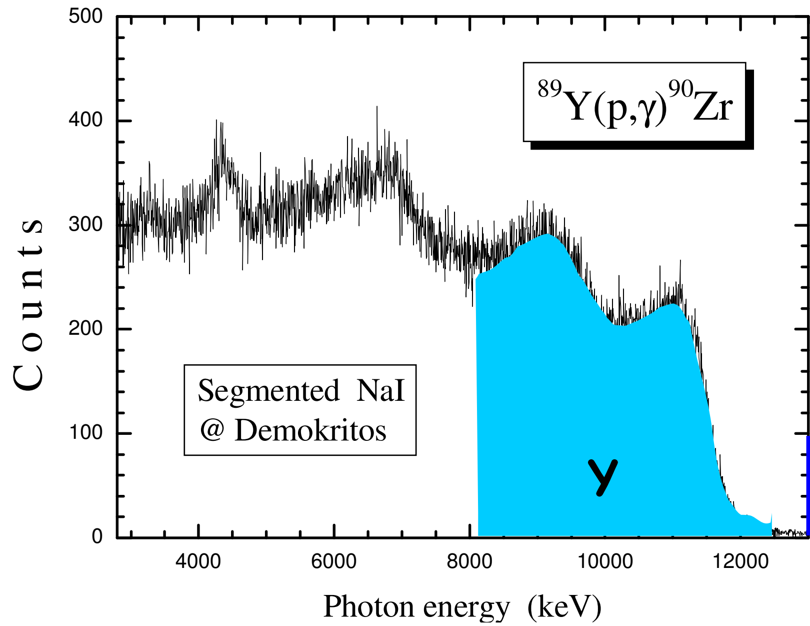
The 4π γ-summing method

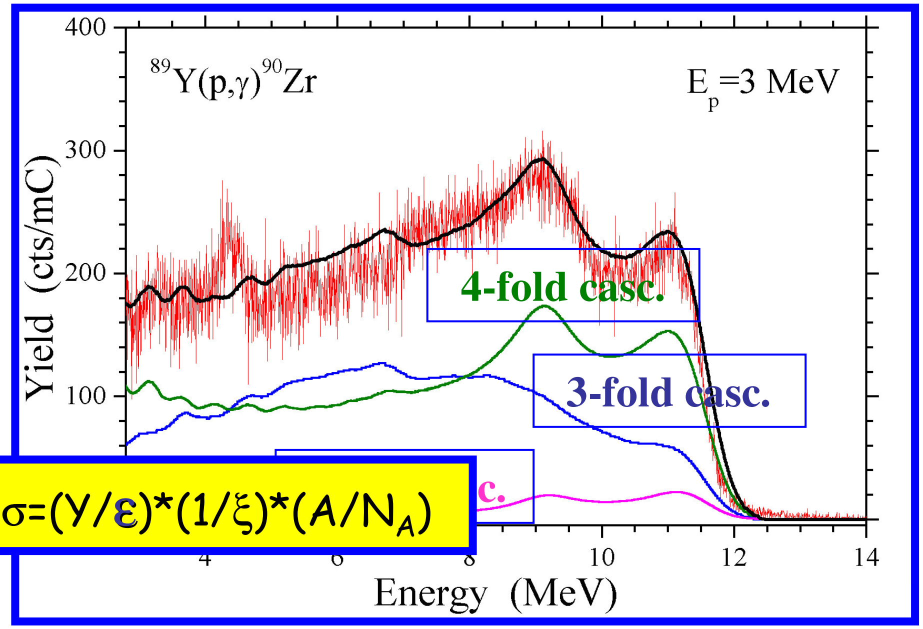






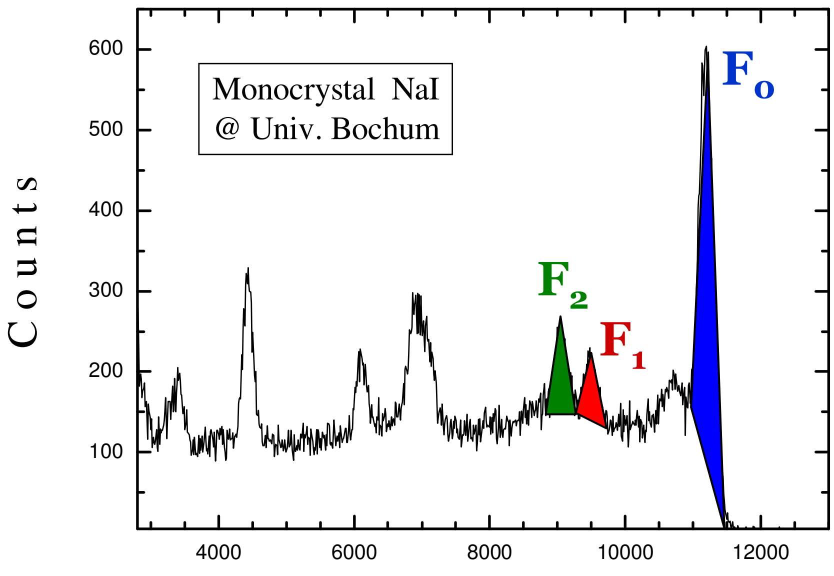


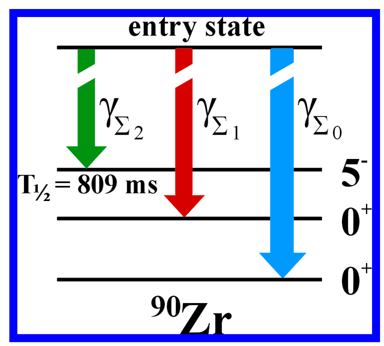




$$\sigma=(Y/\varepsilon)*(1/\xi)*(A/N_A)$$

P. Tsagari et al., PRC 015802, 2004





$$Y_0 = F_0 / (N_{proj} \times \varepsilon_0)$$

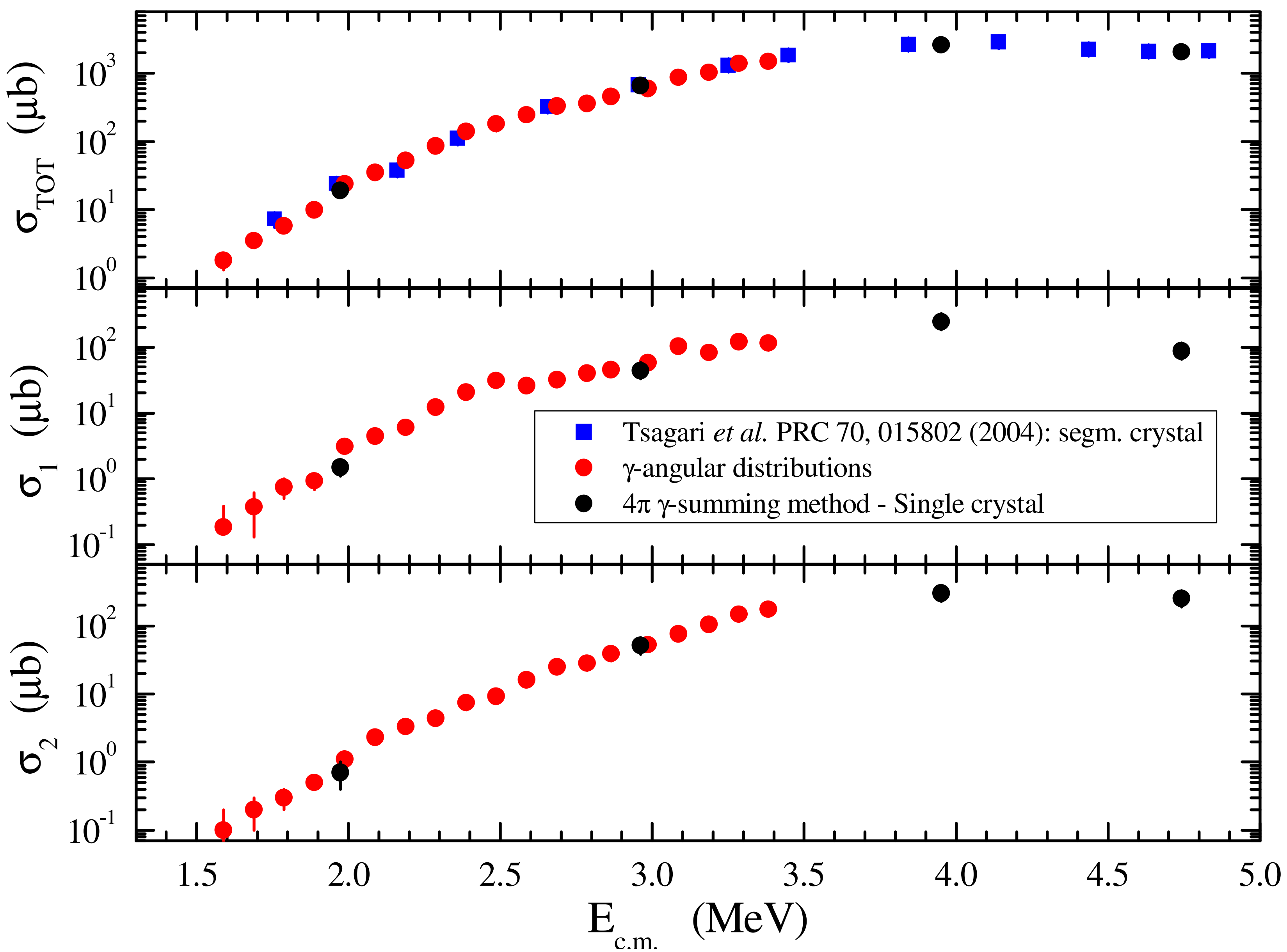
$$Y_1 = F_1 / (N_{proj} \times \varepsilon_1)$$

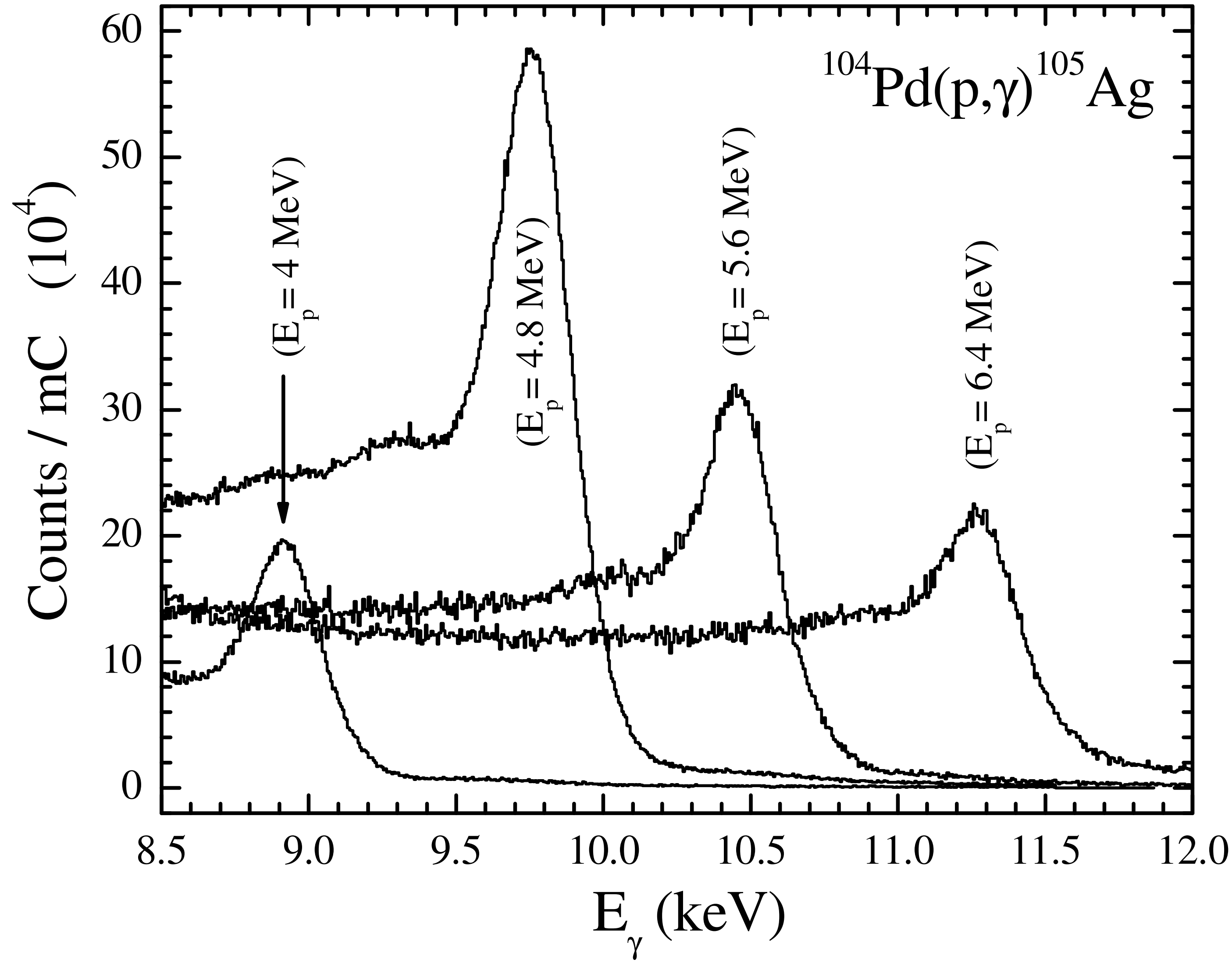
$$Y_2 = F_2 / (N_{proj} \times \varepsilon_2)$$

$$Y_{TOT} = Y_0 + Y_1 + Y_2$$

$$\sigma_{TOT} = (A/N_A)\ (Y_{TOT} / \xi)$$

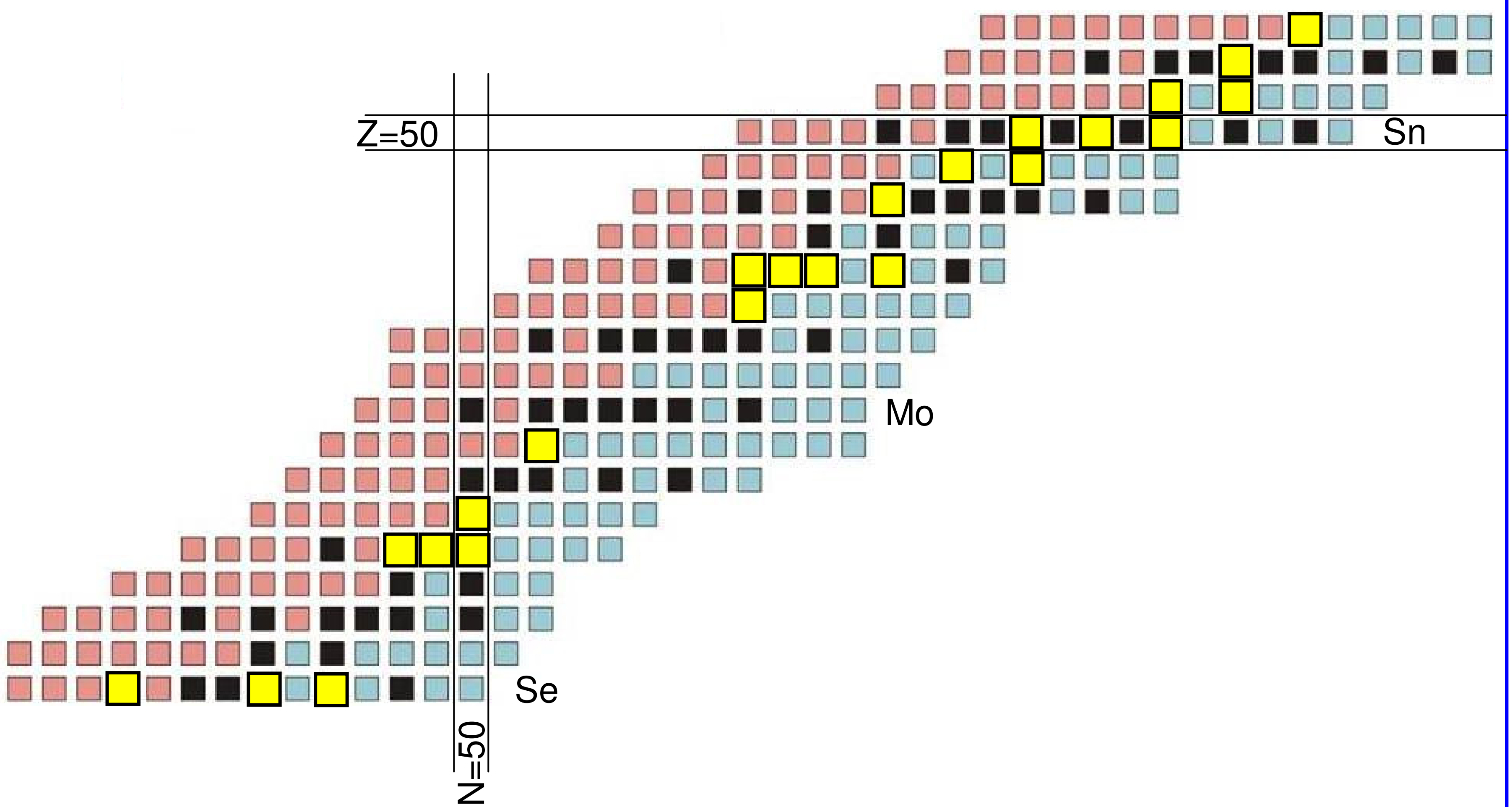
Angular distributions vs. 4π γ-summing method: $^{89}Y(p,\gamma)^{90}Zr$





104Pd(p,γ)105Ag
(Ep = 4 MeV)
(Ep = 4.8 MeV)
(Ep = 5.6 MeV)
(Ep = 6.4 MeV)
Counts / mC (10^4)
Eγ (keV)
0
10
20
30
40
50
60
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0

(p,γ) cross section systematics: Demokritos-Bochum-Stuttgart

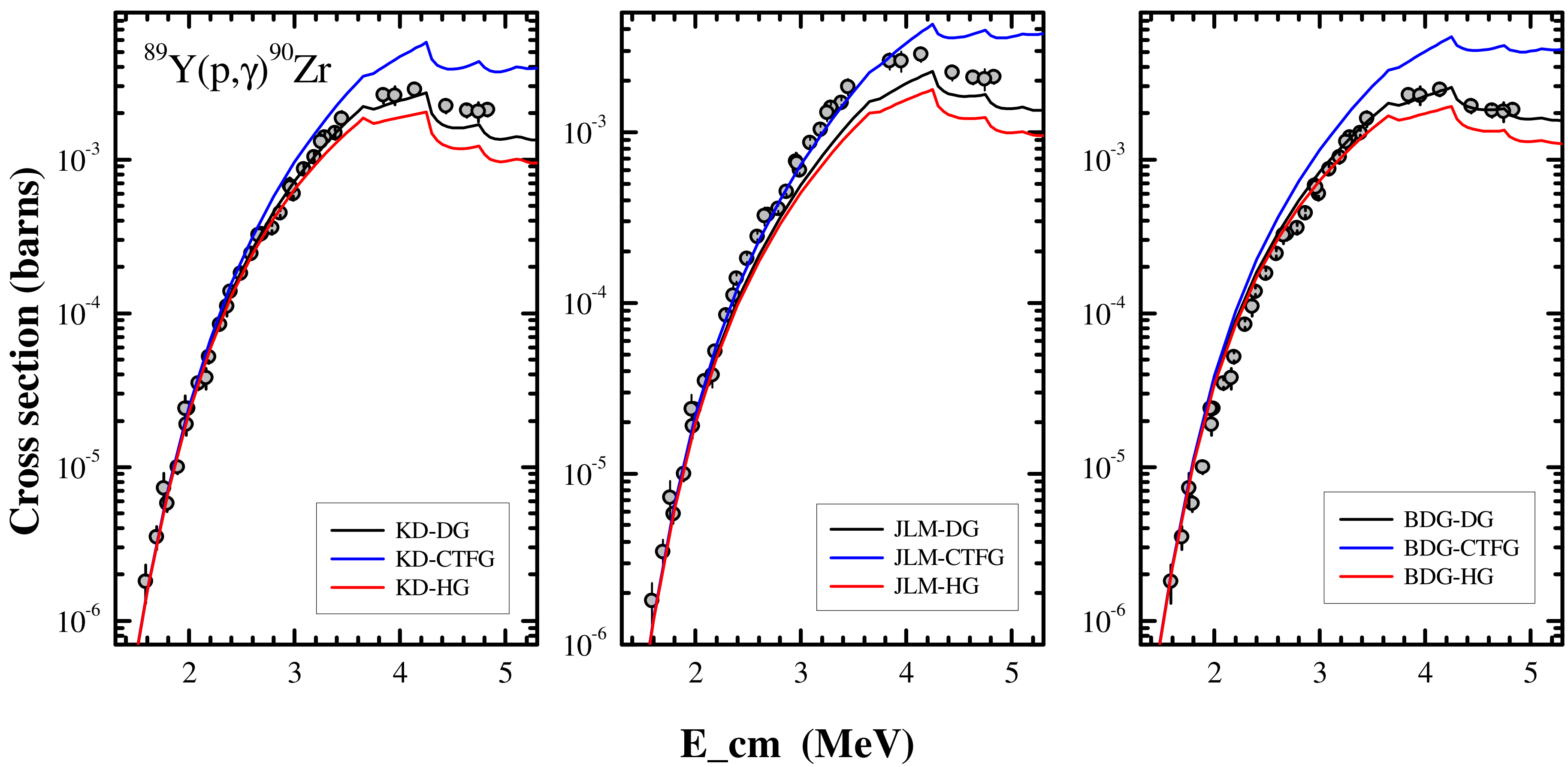


HF input parameters

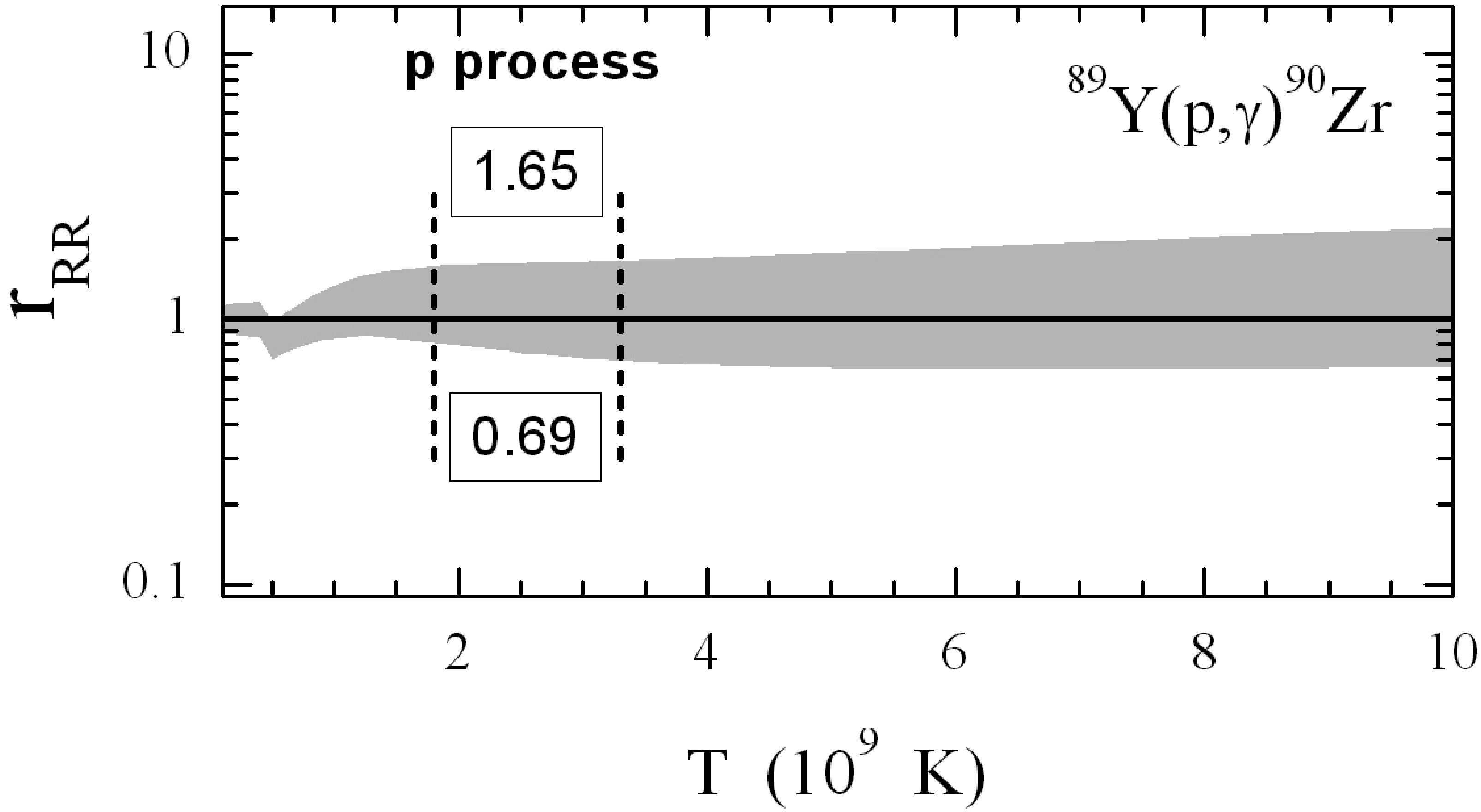
OMP : T_p	NLD : $\rho(U,J)$	γ-ray strength : T_γ
n-N (nucleon-Nucleus)		**E1 - transitions**
PHENOMENOLOGICAL	**PHENOMENOLOGICAL**	
Koning & Delaroche Nucl. Phys. A 713, 231 (2003)	**CTFG: (A.J. Koning et al.)** *Constant temperature formula at low T and Fermi Gas model at higher T* Proc. Int. Conf. on Nucl. Data Sci. Tech. ND2007, Nice, France, Apr. 2007 (http://dx.doi.org/10.1051/ndata:07767)	**Goriely** *(Modified Lorentzian)* Phys. Lett. B 436, 10 (1998) Parametrization of **Kopecky & Uhl** Phys. Rev. C 41, 1941 (1990) **Belgya et al.,** IAEA-Tecdoc-1506 / RIPL2.
MICROSCOPIC	**MICROSCOPIC**	**MICROSCOPIC**
Jeukenne et al. Phys. Rev. C 16, 80 (1977) **Bauge et al.** Phys. Rev. C 63, 024607 (2001)	**Demetriou & Goriely – HFBCS** Nucl. Phys. A 695, 95 (2001) *Combinatorial* **Hilaire & Goriely – HF** Nucl. Phys. A 779, 63 (2006)	**Goriely & Khan** Nucl. Phys. A 706, 217 (2002)
α-N (α-Nucleus)	**HF CODE used: TALYS 1.0** **A.J. Koning et al.** Proc. Int. Conf. on Nucl. Data Sci. Tech. ND2007, Nice, France, Apr. 2007 (http://dx.doi.org/10.1051/ndata:07767)	**M1 - transitions**
PHENOMENOLOGICAL		Parametrization of **Kopecky & Chrien** Nucl. Phys. A 468, 285 (1987)
Mann Hanford Eng. Rep. 1995		
SEMI-MICROSCOPIC		
Demetriou, Grama, Goriely *- double folding -* Nucl. Phys. A 707, 59 (2002)		

$^{89}Y(p,\gamma)^{90}Zr$: data vs. predictions

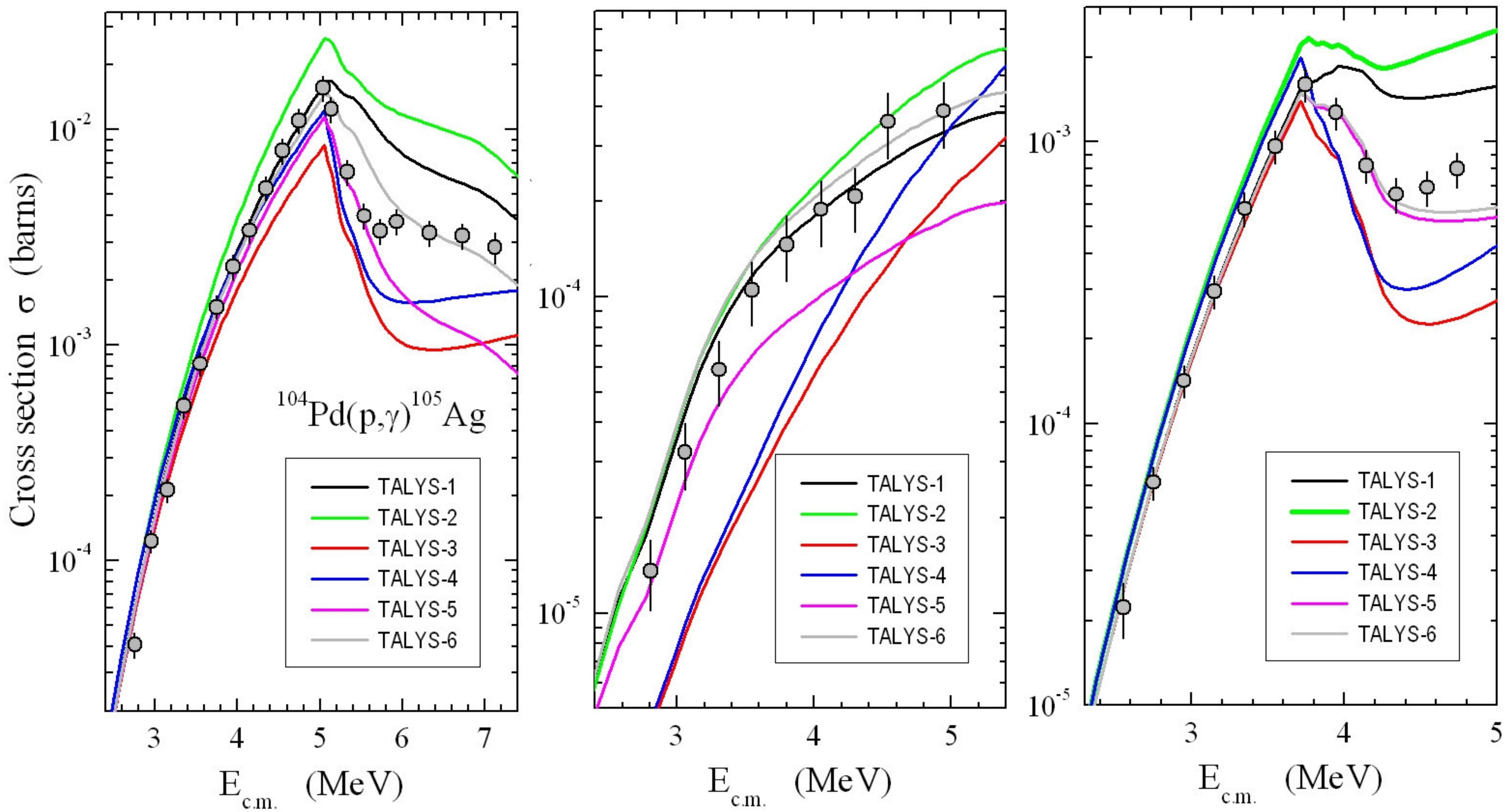
TALYS predictions: $^{89}Y(p,\gamma)^{90}Zr$



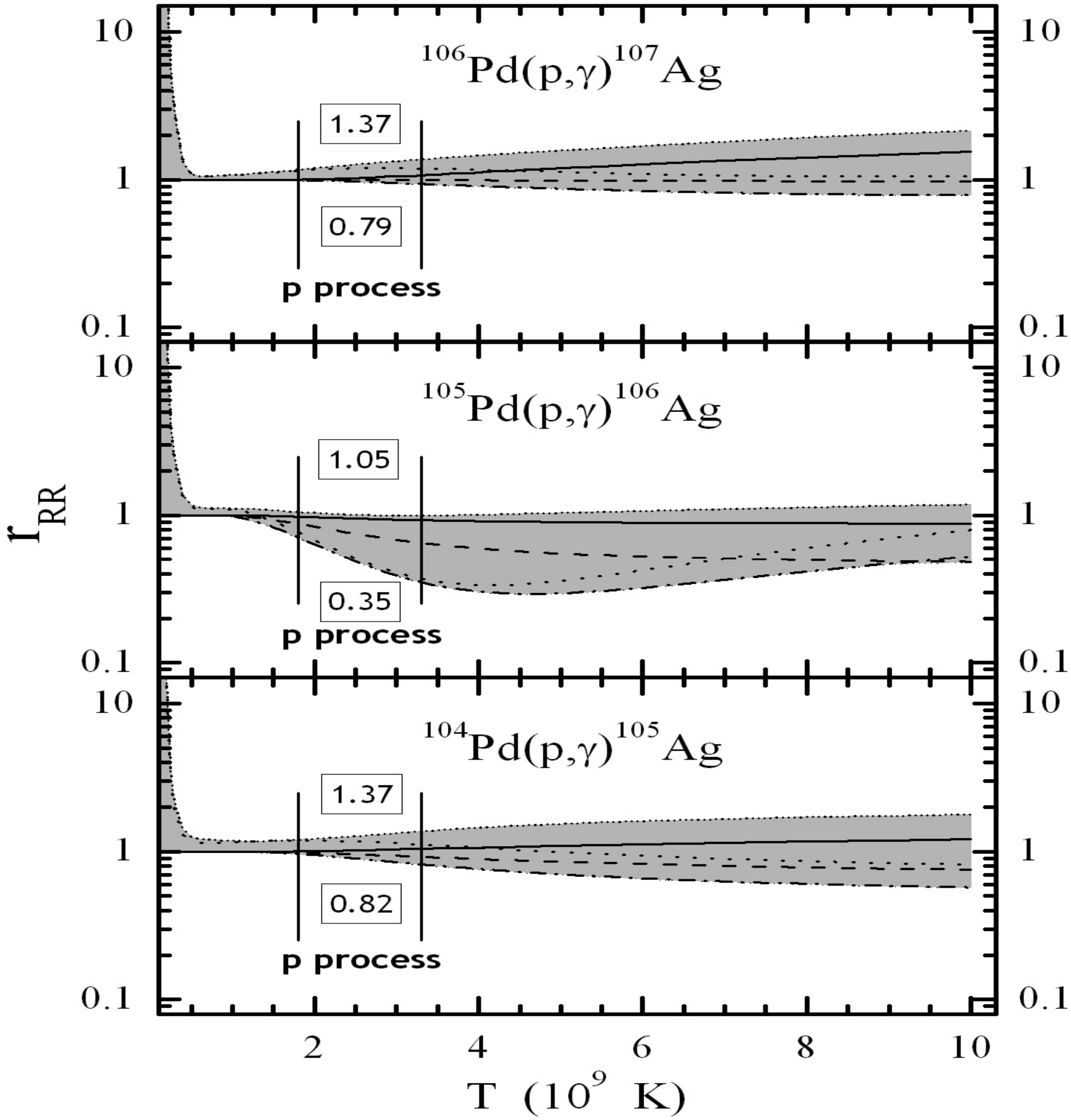
$^{89}Y(p,\gamma)^{90}Zr$ reaction rates



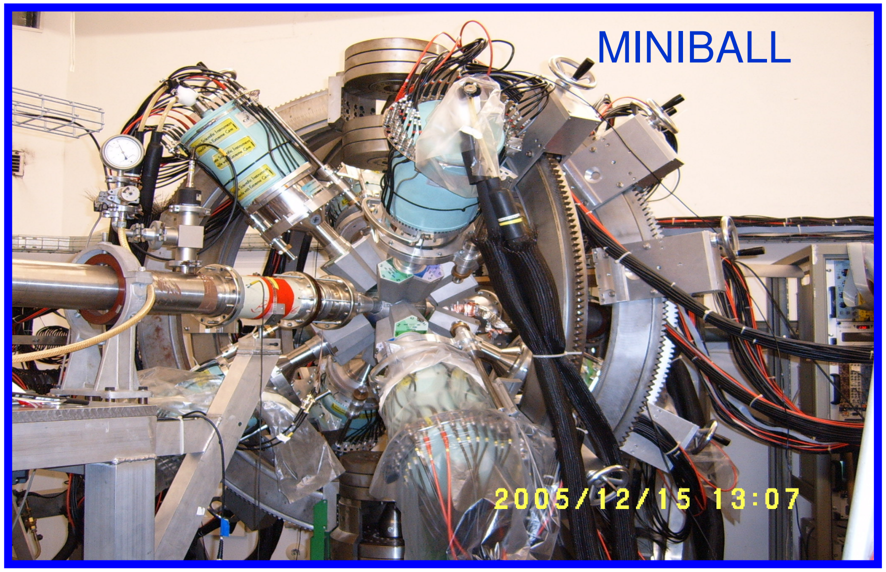
$^{104,\,105,\,106}$Pd(p,γ) cross sections: Data vs predictions

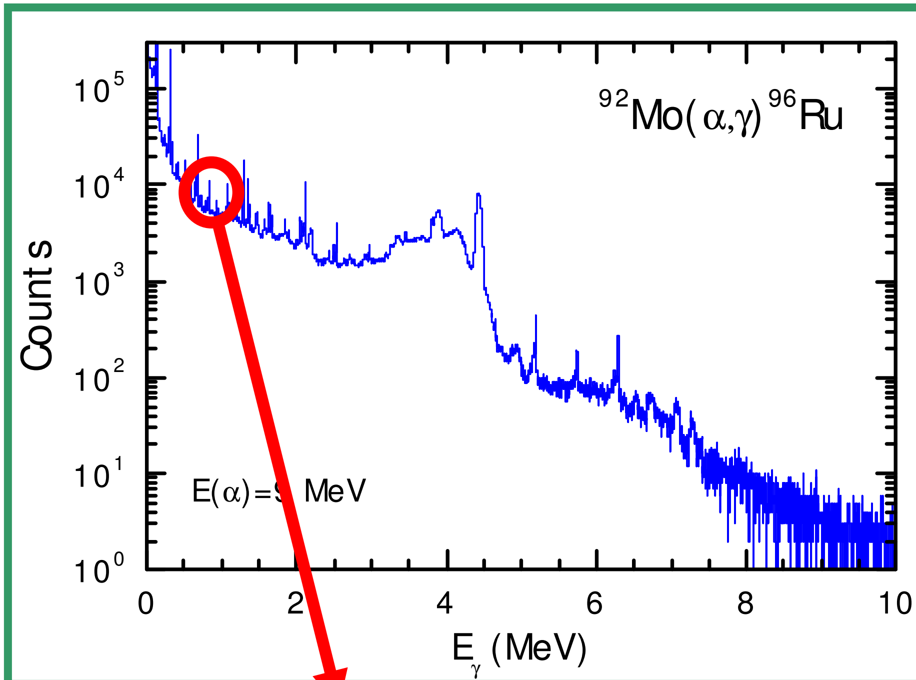


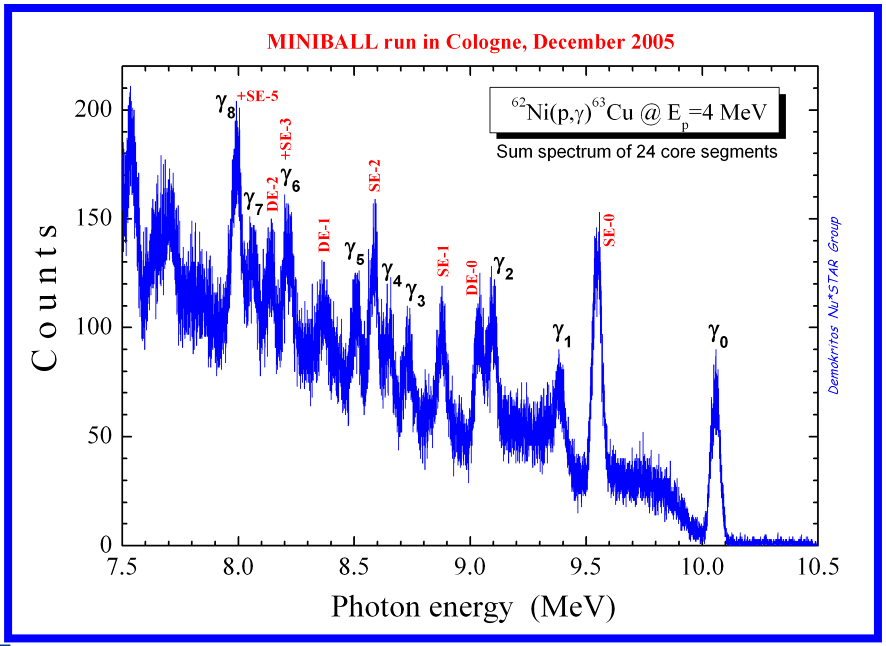
$^{104,\,105,\,106}$Pd(p,γ) reaction rates

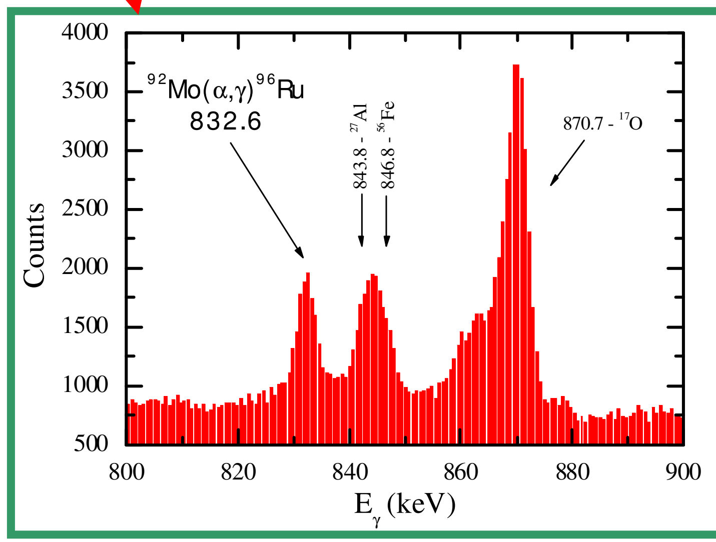


In-beam cross-section measurements of α-capture reactions

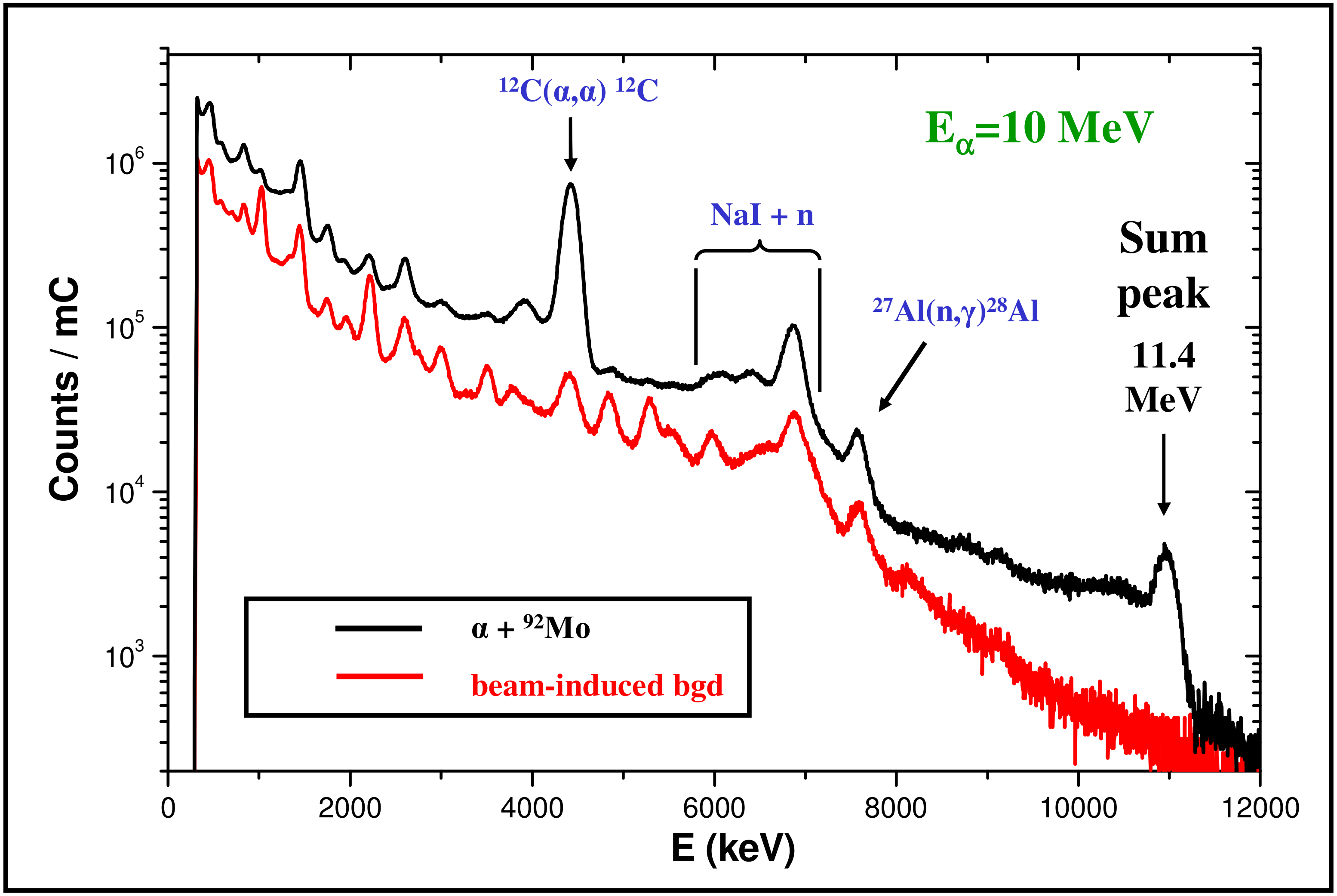




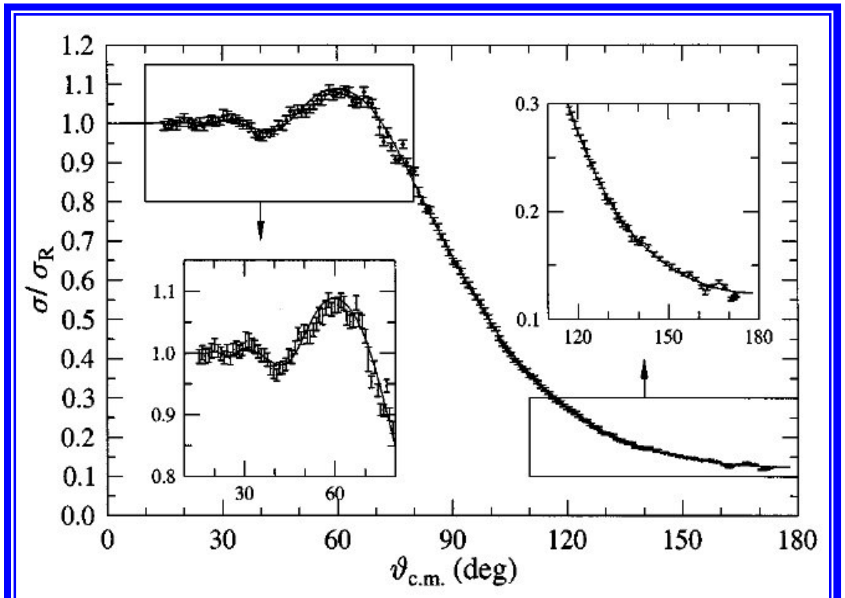




$^{92}Mo(\alpha,\gamma)^{96}Ru$ target thickness=398 μgr/cm² enrichment=97.7%

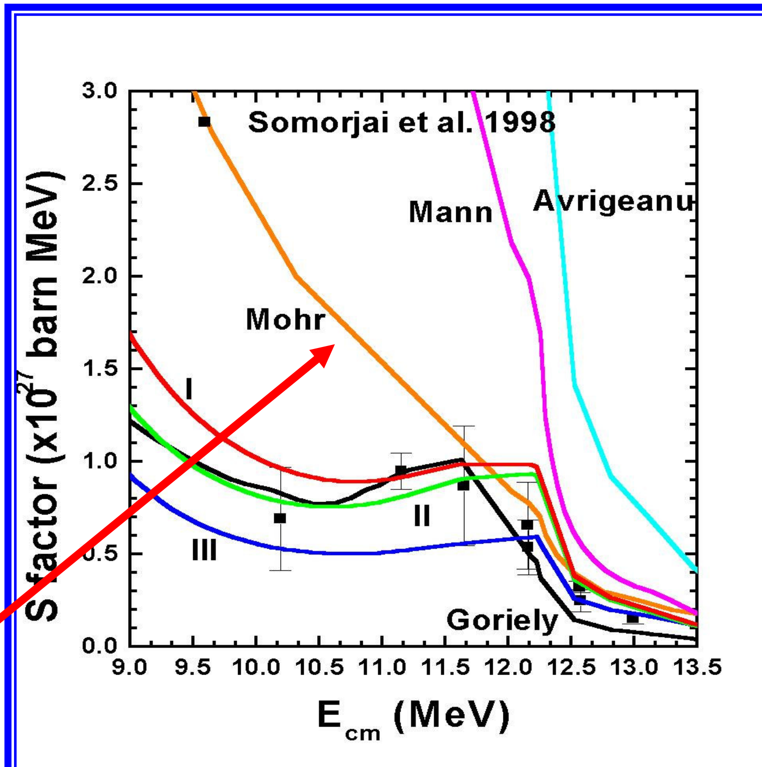


^{144}Sm(α,α)^{144}Sm
Local α-OMP @ 20 MeV



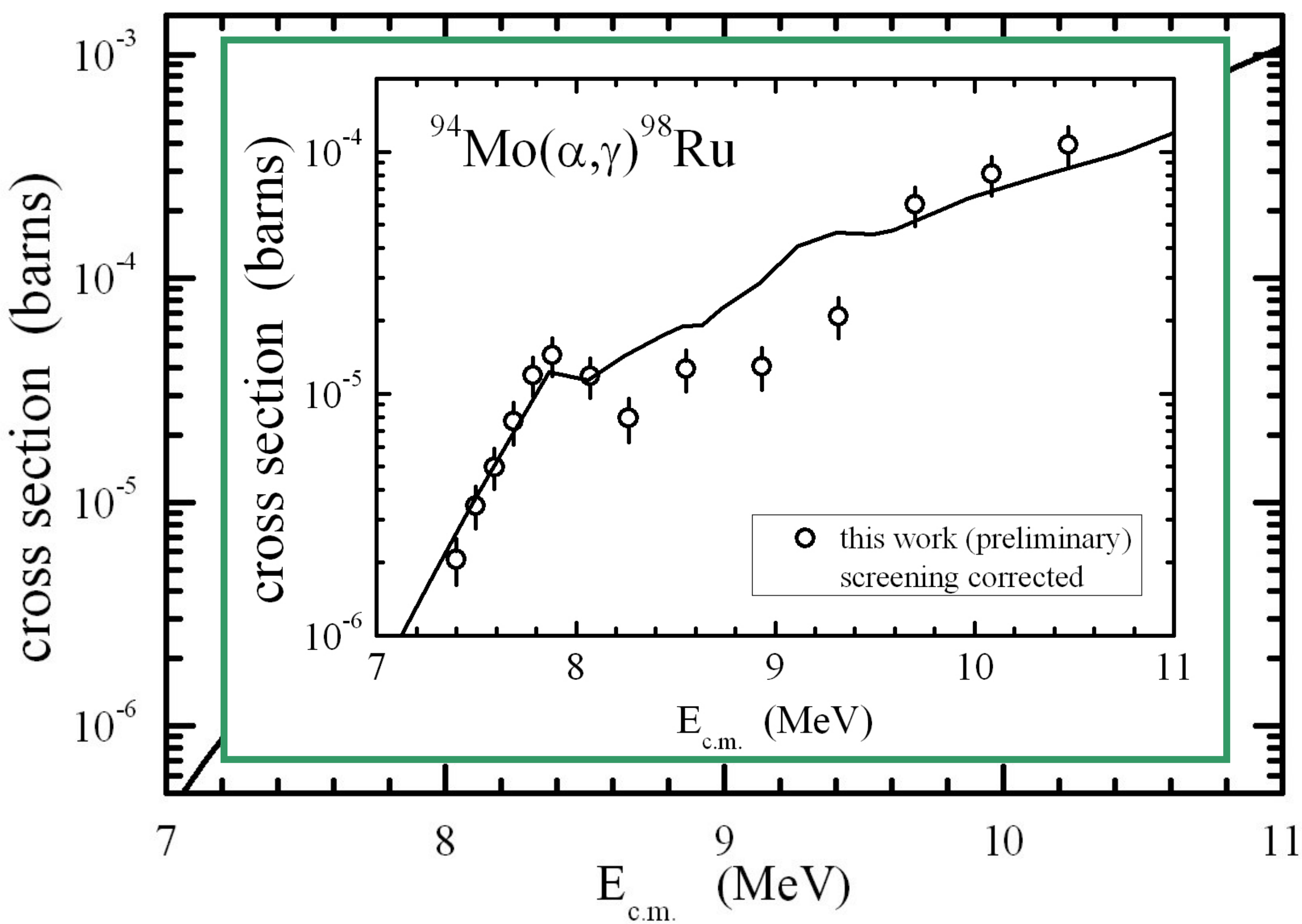
Mohr et al. PRC 55, 1523 (1997)

$S(E) = \sigma(E) \times E \times \exp(2\pi \times \eta(E))$
Demetriou et al, NPA 707, 253 (2002)



^{144}Sm(α,γ)^{148}Gd
Somorjai et al., A&A 333, 1112 (1998)

Mohr's Local α-OMP @ 20 MeV failed at sub-Coulomb energies


cross section (barns)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
7
8
9
10
11
$E_{c.m.}$ (MeV)
$^{94}Mo(\alpha,\gamma)^{98}Ru$
10^{-4}
10^{-5}
10^{-6}
this work (preliminary)
screening corrected

Nucl. Phys. A. 707, 253 (2002)

Improved global α-optical model potentials at low energies

P. Demetriou[a,*], C. Grama[b], S. Goriely[c]

$$U = V_c + V + iW + \Delta V$$

Real part V : double-fold

effective NN interaction:
M3Y -density dependent (Kobos e
projectile density:
n/p densities from elastic scatter
target density: Hartree-Fock theo

Imag. part W : Woods-S

Volume + Surface (ratio, da
geometry: r_W, a_W
Fermi-type energy depen
of imaginary potential dept
to el. scattering + reaction data

Correction ΔV : dispersive relations

DG² - OMP III
parameters adjusted to all alpha scattering and reaction data at low energies near Coulomb barrier

global potential

new data on alpha-capture
lpha elastic scattering

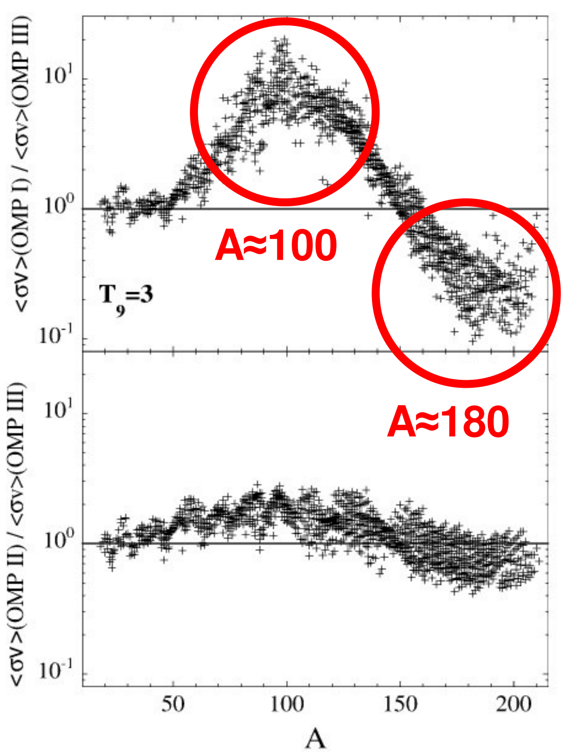
fitting (im. pot. depth):
vements (diffuseness)
dated global potential

y nuclear reactions and the optical potential: where do we stand?

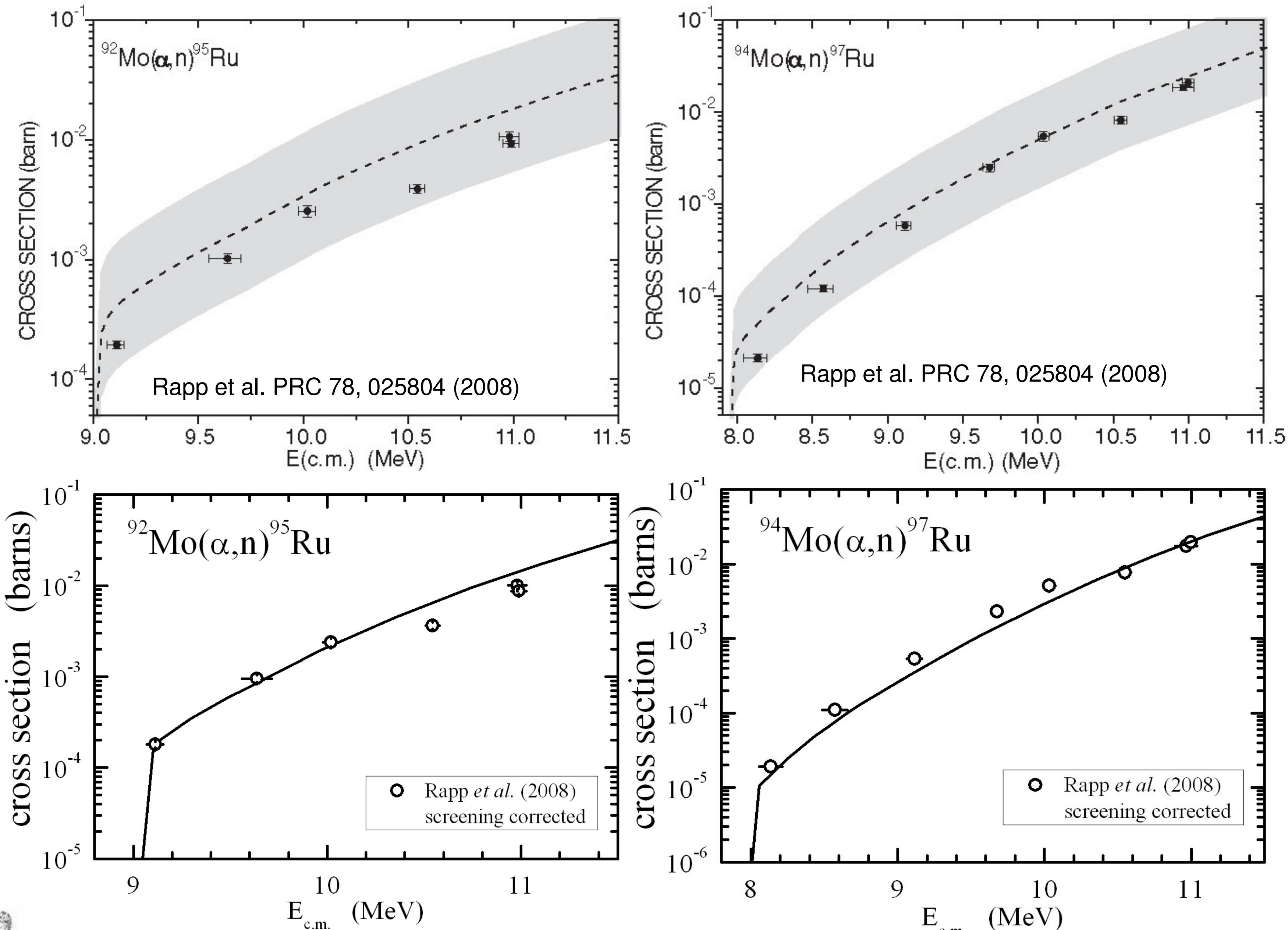
Demetriou and M. Axiotis

ymposium on Nuclear Physics, TOURS VI, AIP Conf. Proceedings, vol. 891, AIP, N.Y., 2007, p. 281.

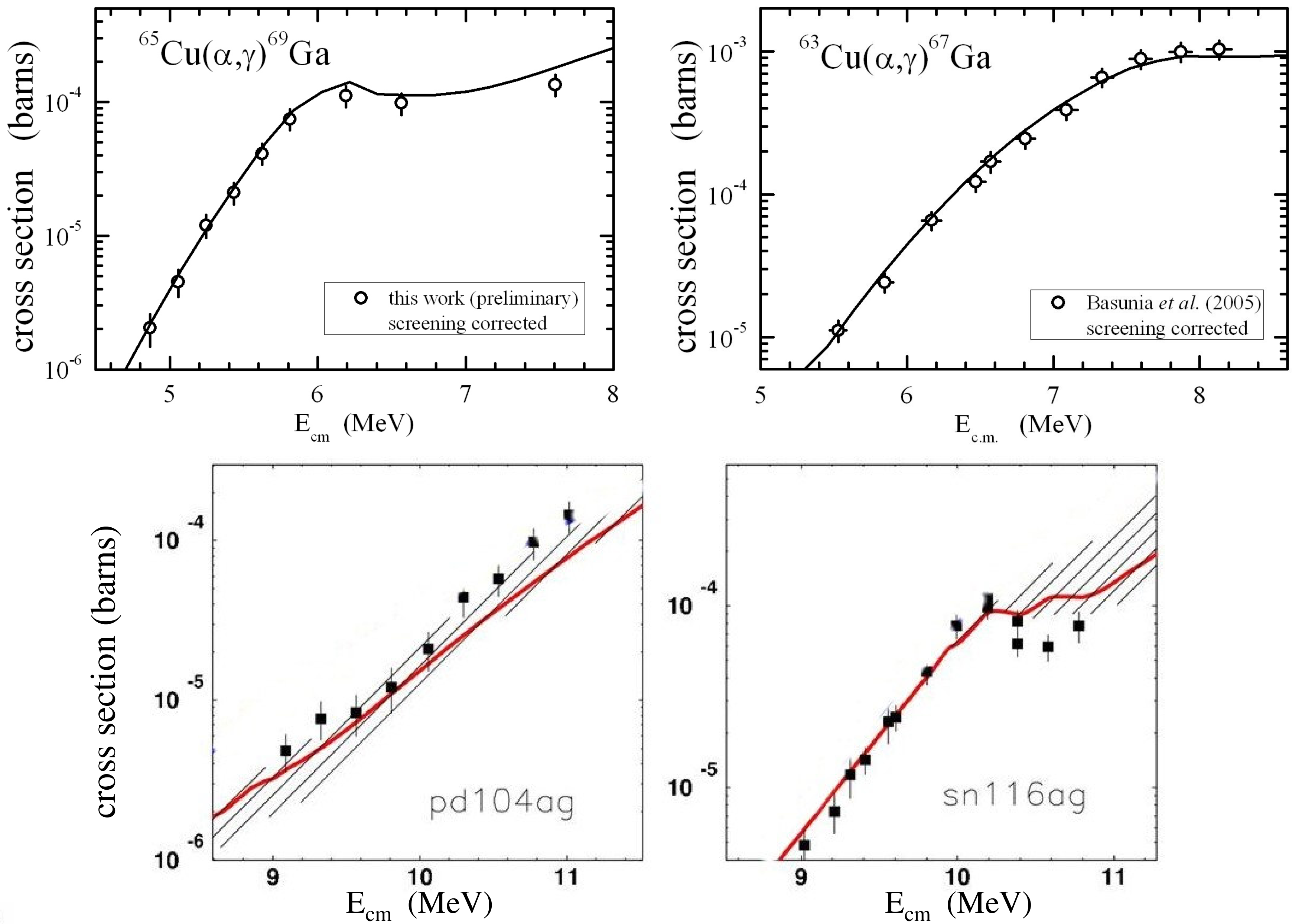
P. Demetriou, C. Grama, and S. Goriely, Nucl. Phys. A 707, 253 (2002)



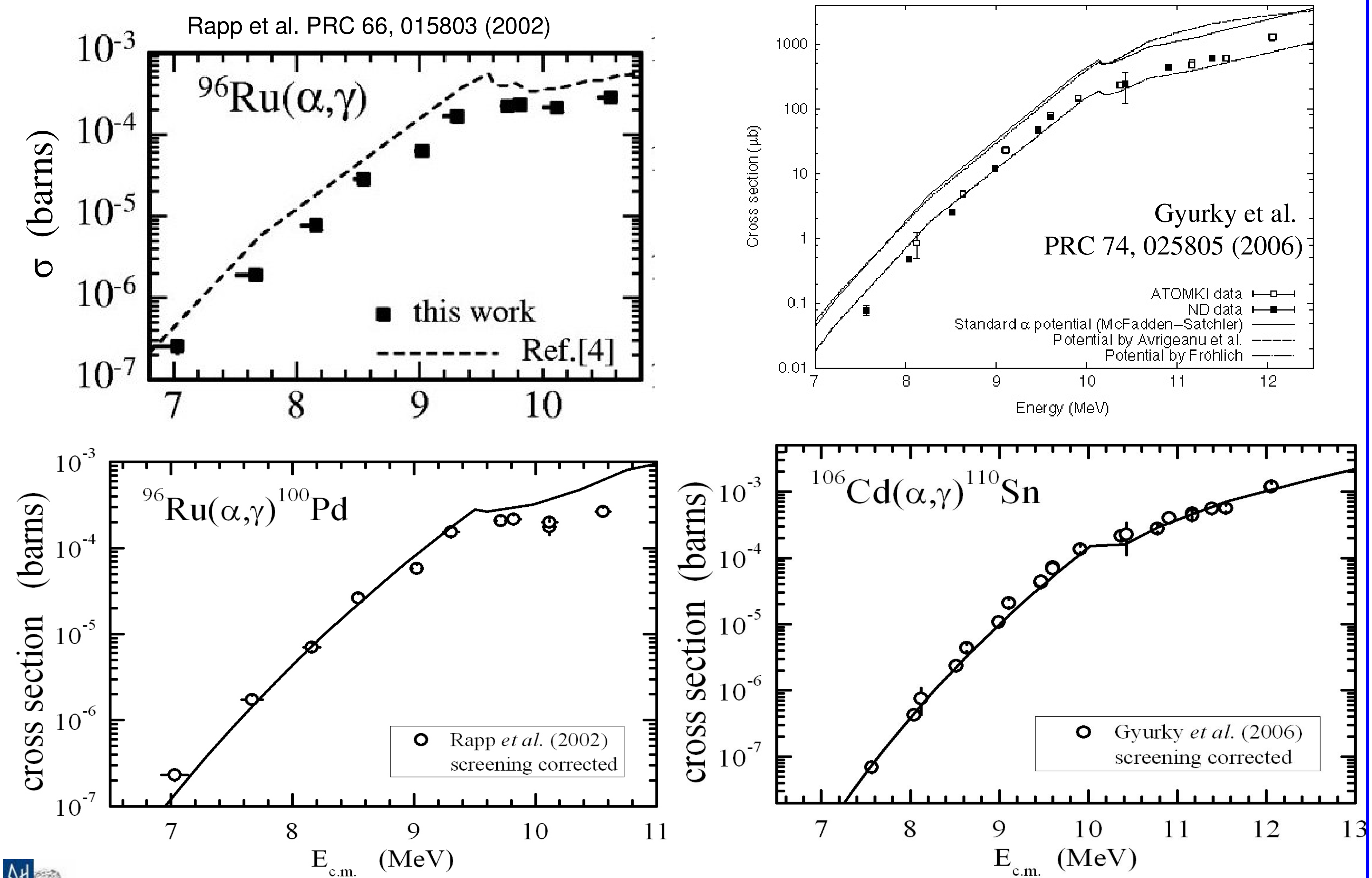
(α,γ) cross section measurements: $^{92}Mo(\alpha,\gamma)^{96}Ru$



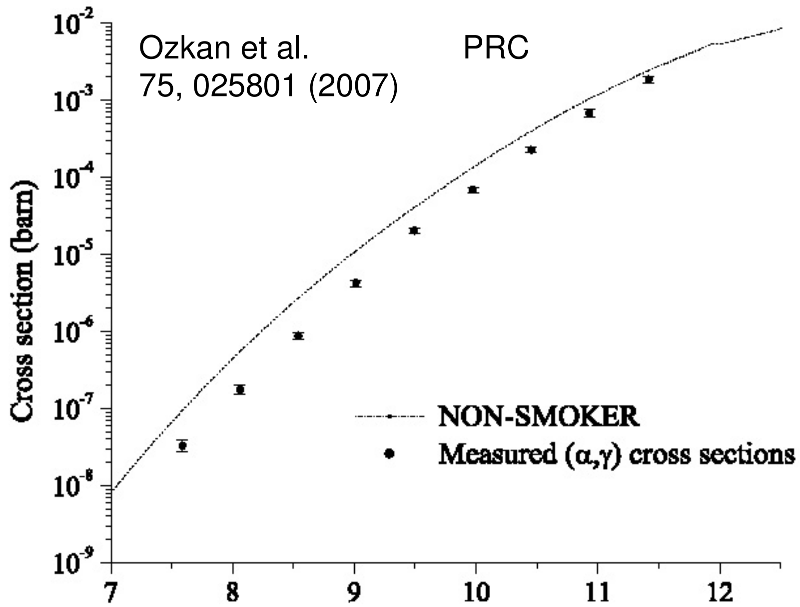
(α,γ) cross section measurements: $^{92}Mo(\alpha,\gamma)^{96}Ru$

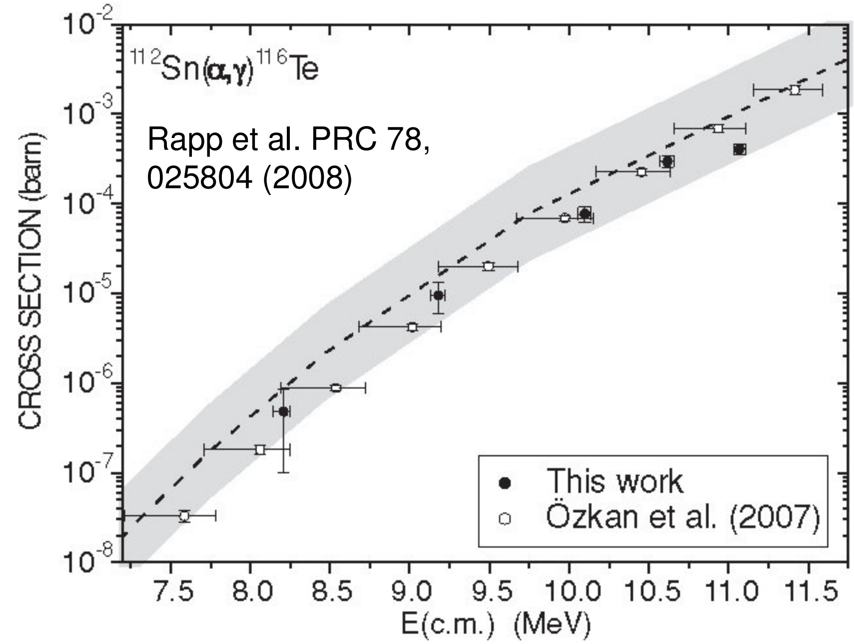


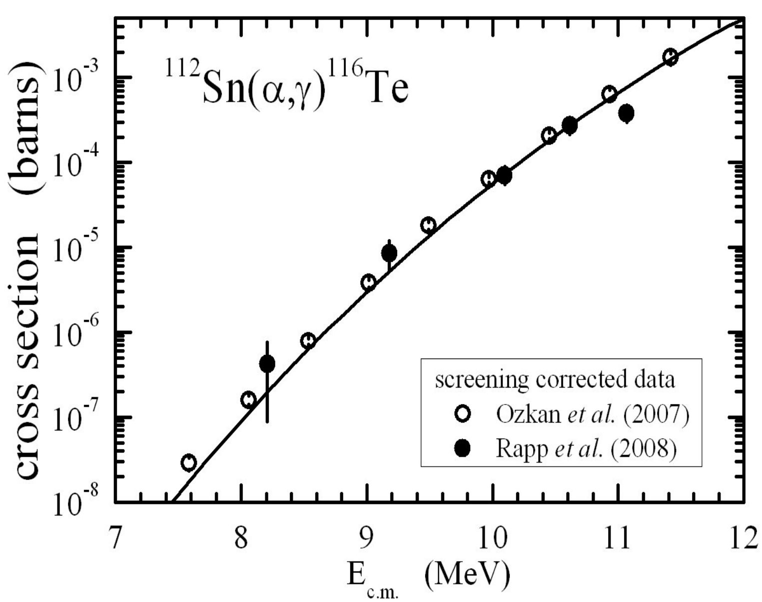
(α,γ) cross section measurements: $^{92}Mo(\alpha,\gamma)^{96}Ru$



(α,γ) cross section measurements: $^{92}Mo(\alpha,\gamma)^{96}Ru$







Some conclusions

- In most the (p,γ) cases, uncertainties affecting nuclear input (OMP, NLD) give rise to at most 40 to 50 % uncertainties in the reaction rates. No real affection of the p-process abundance calculations.

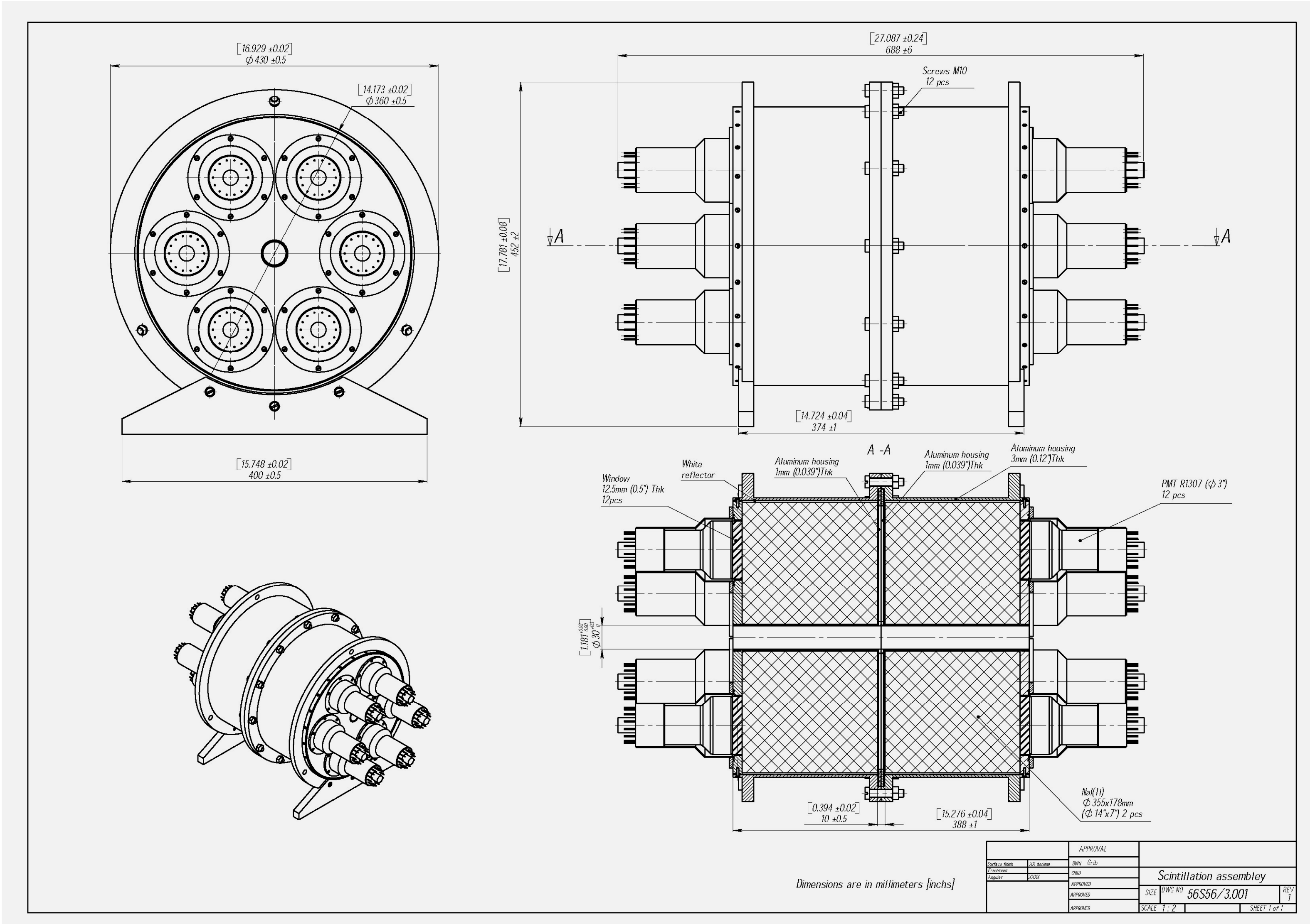
- The α-potential is (still) poorly known; Consequently, the astrophysical (α,γ) reaction rates obtained from HF calculations can be highly uncertain and abundance calculations may strongly be affected!

- HOWEVER, we began understanding the α-N potential thanks to the continuously increasing cross section database of α-induced reactions and elastic scattering data and the semi-microscopic DG^2 approach.

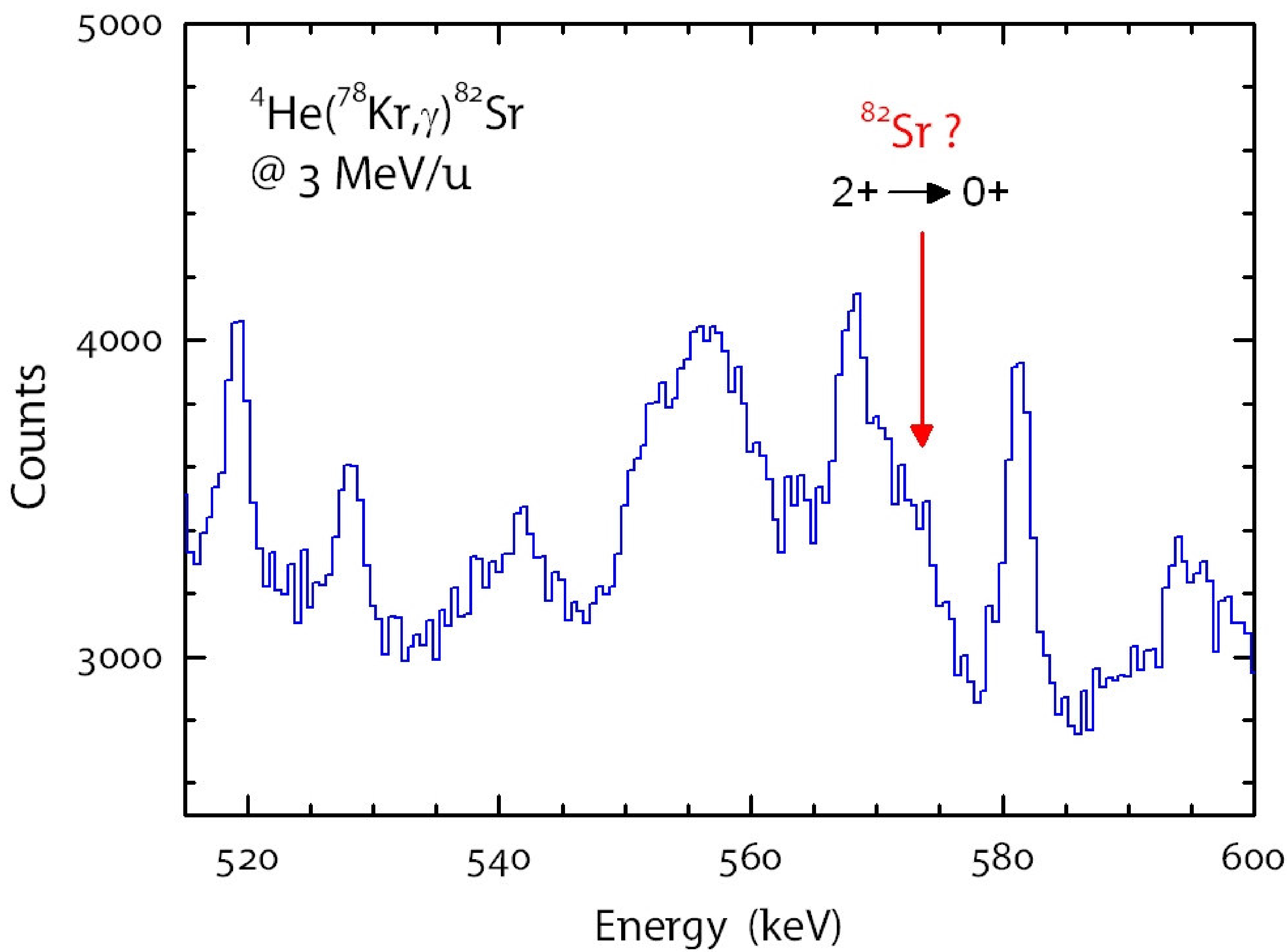
- Using the improved DG^2 α-OMP and the TALYS code we were able to reproduce almost all data up to the A≈100 (and ^{144}Sm). The next challenges are:
  1) To check the predictions of the DG^2 α-OMP at much higher masses.
  2) Move away from the valley of stability and test its reliability also there !

IMPROVED INSTRUMENTS AND METHODS ARE NECESSARY

New instruments



New approaches



Experienced Researcher and/or Post-doc positions in Experimental Nuclear Physics and Ion-Beam Applications

The TANDEM Accelerator Laboratory of the Institute of Nuclear Physics (INP) of the National Centre for Scientific Research (NCSR) "Demokritos", Athens, Greece, invites for applications for four (4) experienced researcher and/or post-doctoral positions in nuclear physics and applications of ion beams. The successful candidates will sign a contract for a maximum period of 30 months to work at the TANDEM Laboratory of INP for the LIBRA project that was funded recently by the EC within the FP7-Capacities-REGPOT program. The candidates will be given significant responsibility for the achievement of the LIBRA deliverables.

Ευχαριστω !

Thank you !

applications of ion-beams in materials analysis, or cultural heritage studies, or environmental monitoring, or ion-beam micro-machining, or biomedicine. First priority will be given to the candidate having experience with micro-beams.

4. [Code: LIBRA-P4] Nuclear Physicist or Astrophysicist holding (or be about to receive) a PhD degree in the theoretical study of nuclear reactions with relevance to nuclear astrophysics.

Applicants should send via e-mail a CV (with a list of publications, a brief description of their activities and the names of two referees) to Dr. Sotirios Harissopulos (E-mail: sharisop@inp.demokritos.gr). The deadline for applications is Monday, June 15, 2009. A review of applications will begin end of June 2009 and will remain open until the positions are filled. The salary range and starting date are negotiable.