Level densities and gamma Strength functions with the OSLO method

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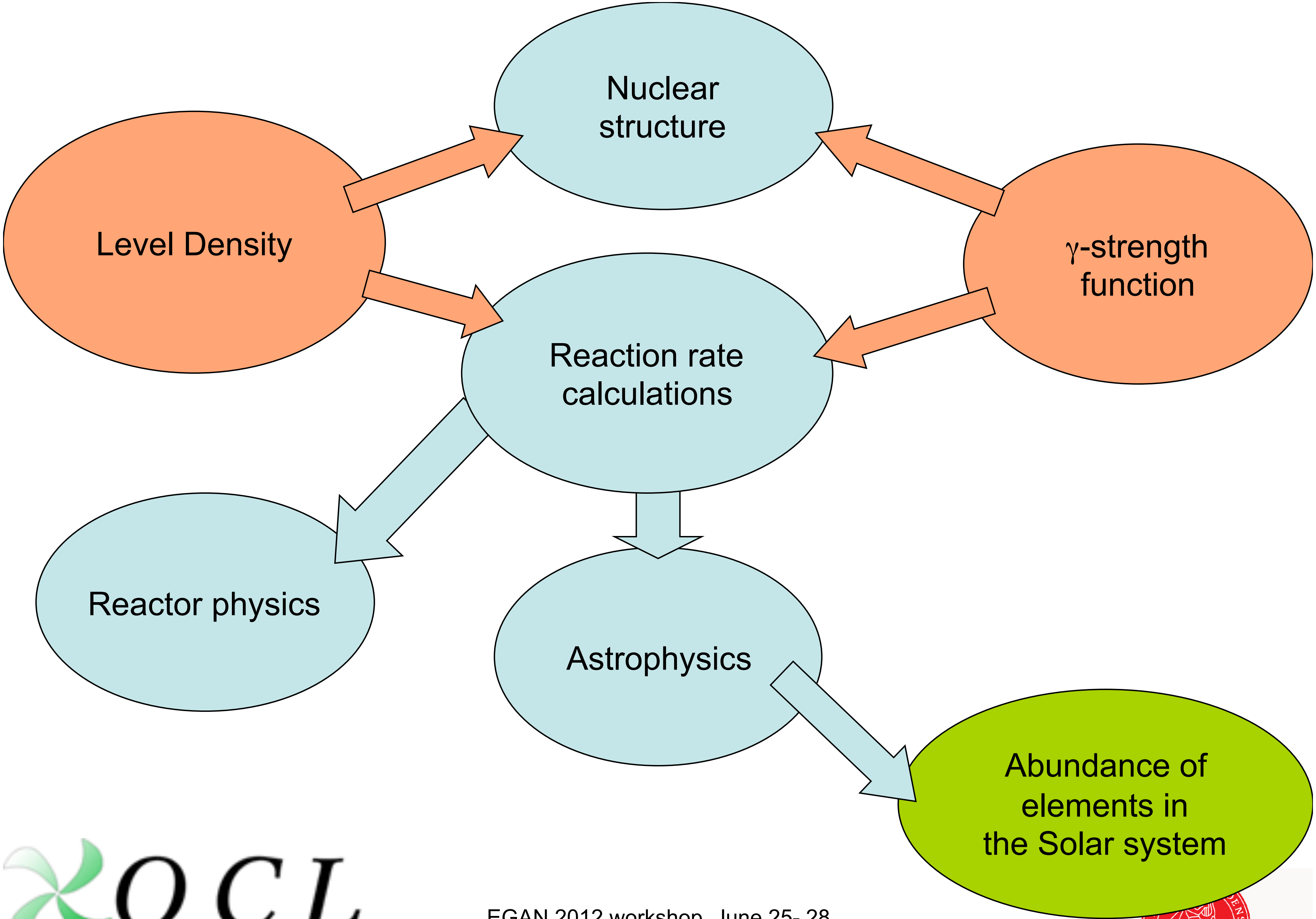
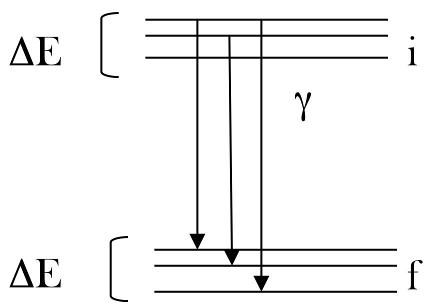
Today's Menu

- Aperitif: Motivation
- Entrée: Experimental setup and the "Oslo method"
- Plat principal: Level density and γ-strength functions results, effects of small resonances on (n,γ) cross section calculations.
- Dessert: Conclusions and future plans

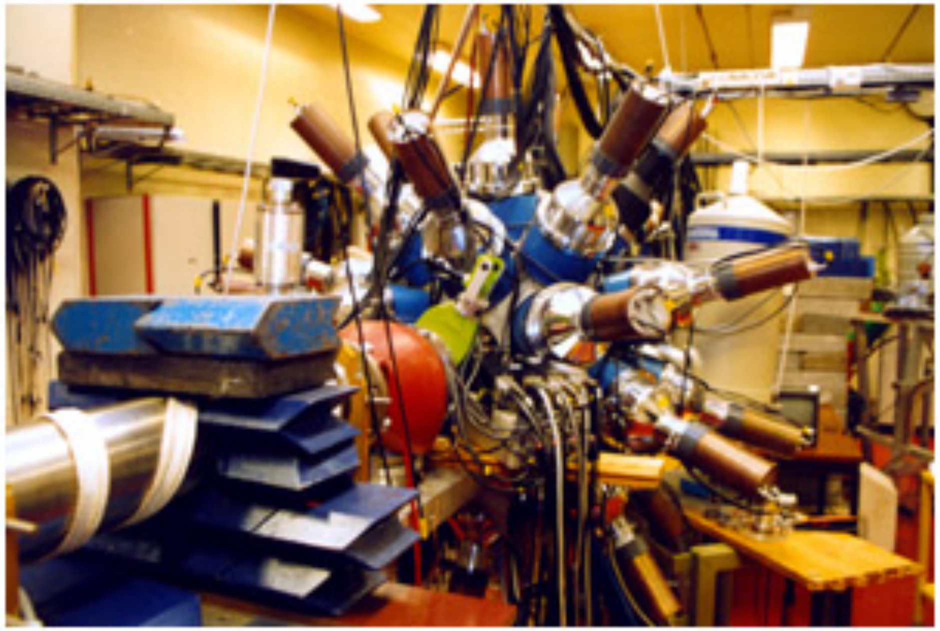

Nuclear structure
Level Density
γ-strength function
Reaction rate calculations
Reactor physics
Astrophysics
Abundance of elements in the Solar system

What is γ-ray strength functions?

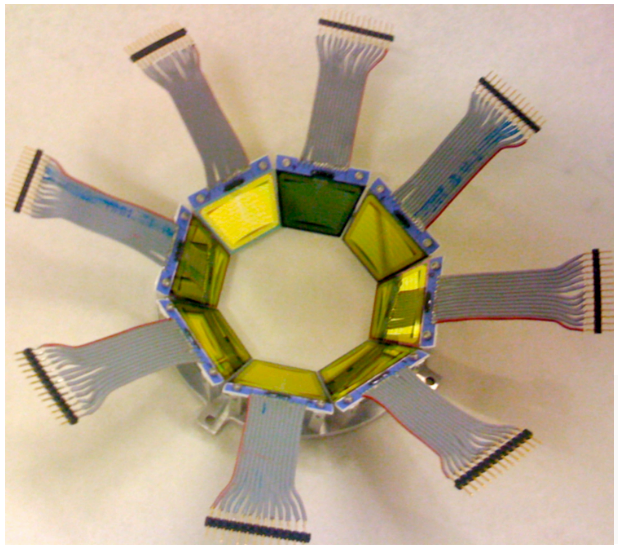
- A measure of the average, nuclear electromagnetic response determined by the nuclear structure and the available degrees of freedom
- Directly related to partial decay widths and reduced transition probabilities
- Fruitful concept in the quasi-continuum/continuum region



Experimental setup @ OCL



- Beam: p, d, 3He, α with energies up to 30-45 MeV
- Reactions: (^{3}He,$\alpha\gamma$), (^{3}He,^{3}He'γ), (p,p´γ), (d,pγ) and (p,tγ)
- CACTUS: 28 5" x 5" NaI(Tl), $\varepsilon \approx 15\%$ @ E_{γ}=1.33 MeV
- SiRi: 64 Si ΔE-E particle telescopes, $\Delta\theta \approx 2^{o}$
- Spin 2-6 ħ



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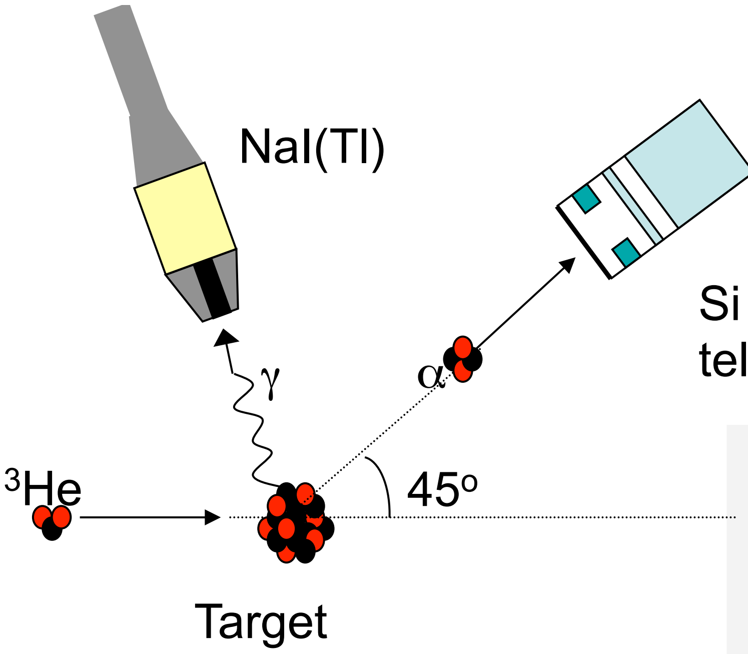
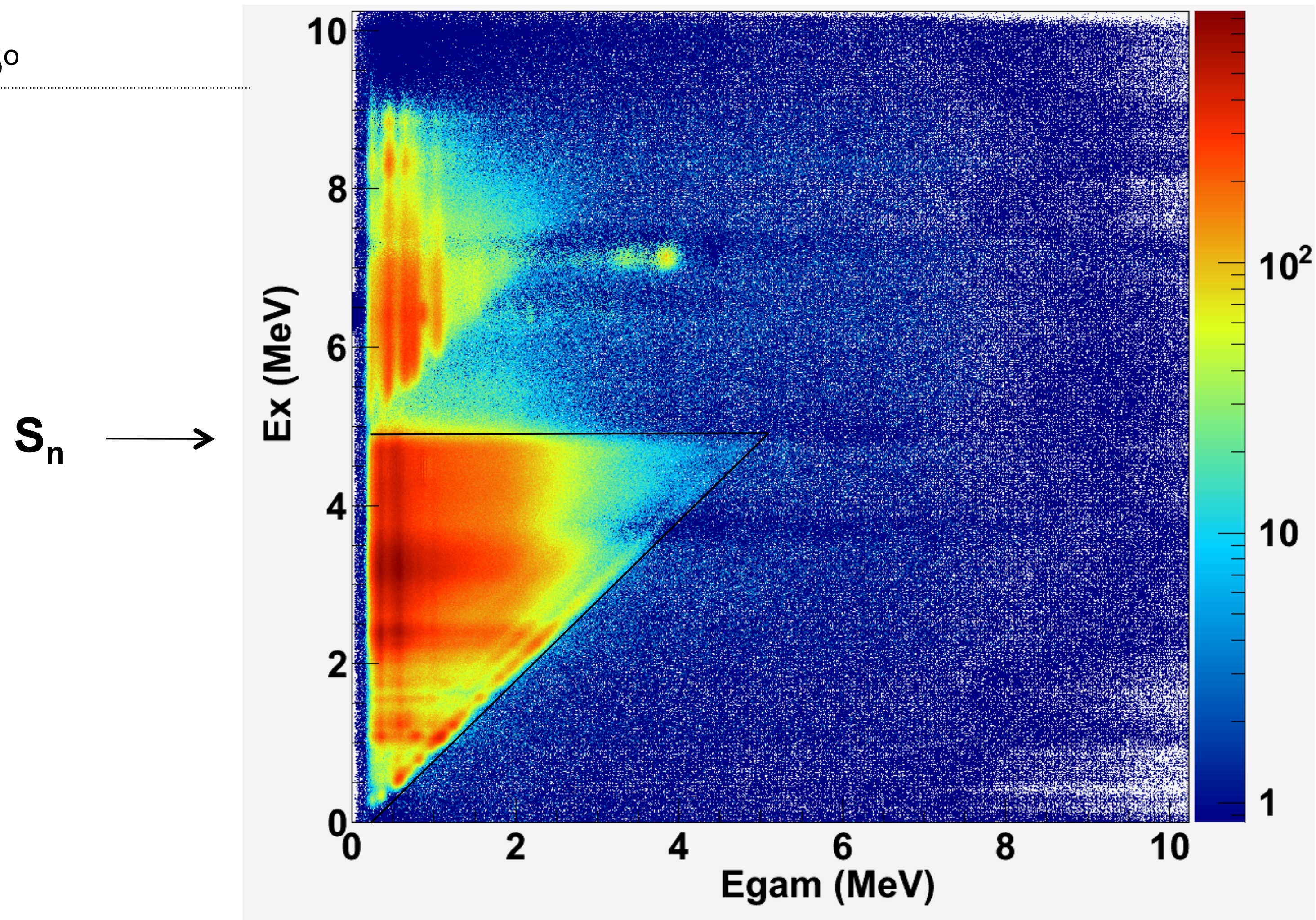
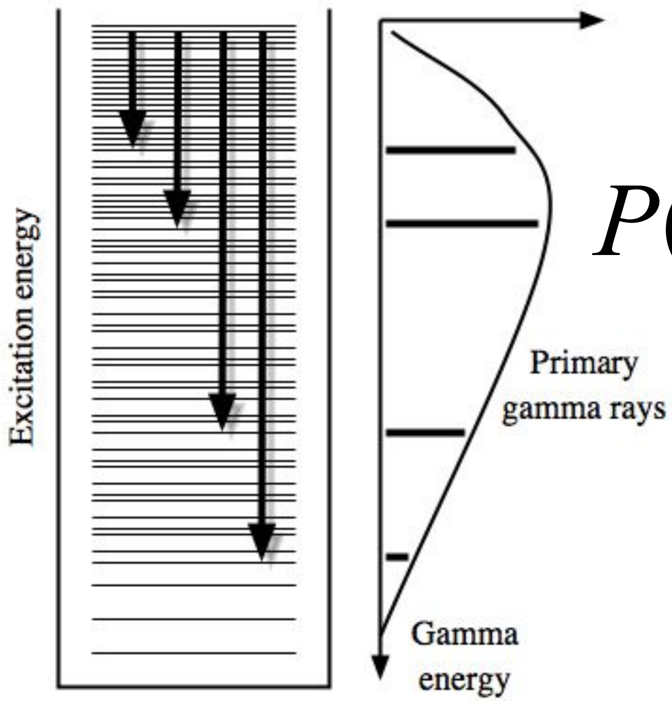

NaI(Tl)
Si ΔE-E
telescope
γ
α
^{3}He
45^o
Target

^{232}Th(d,p)


S_n
Ex (MeV)
Egam (MeV)
0
2
4
6
8
10
1
10
10^2

Isolating the primary gamma ray:



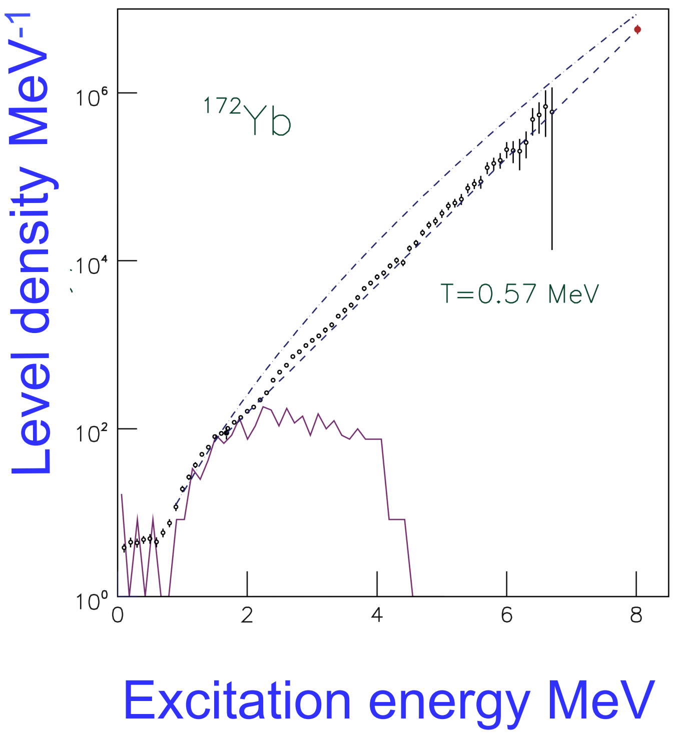
$$P(E_i, E_\gamma) \propto \rho(E_f) \cdot T(E_\gamma)$$

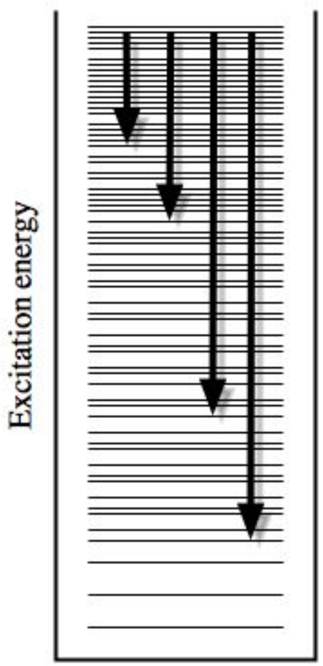
$$\mathcal{T}(E_\gamma) = 2\pi \sum_{XL} E_\gamma^{2L+1} f_{XL}(E_\gamma)$$

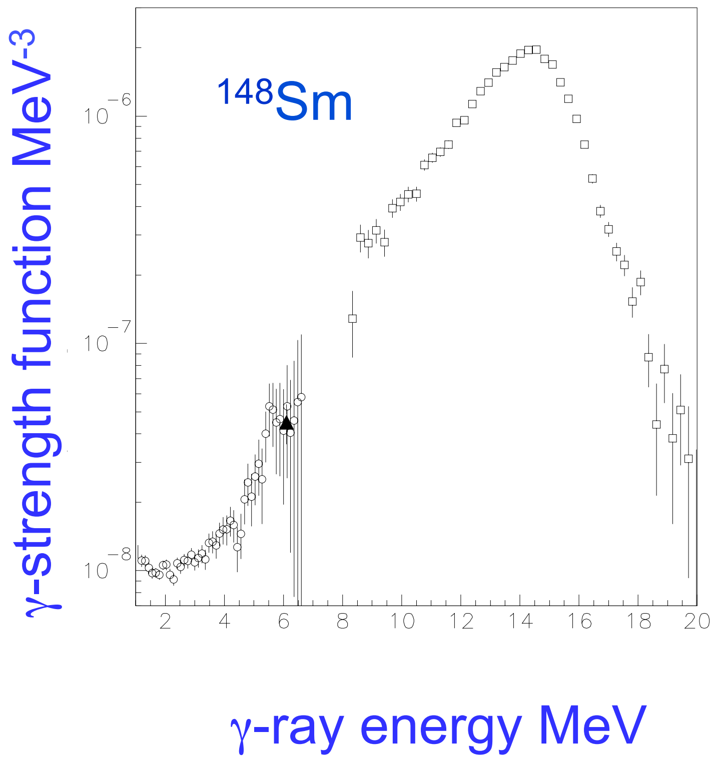
Assuming dominance of dipole radiation (*E1 and M1*)

$$f(E_\gamma) \simeq \frac{1}{2\pi} \frac{\mathcal{T}(E_\gamma)}{E_\gamma^3}$$

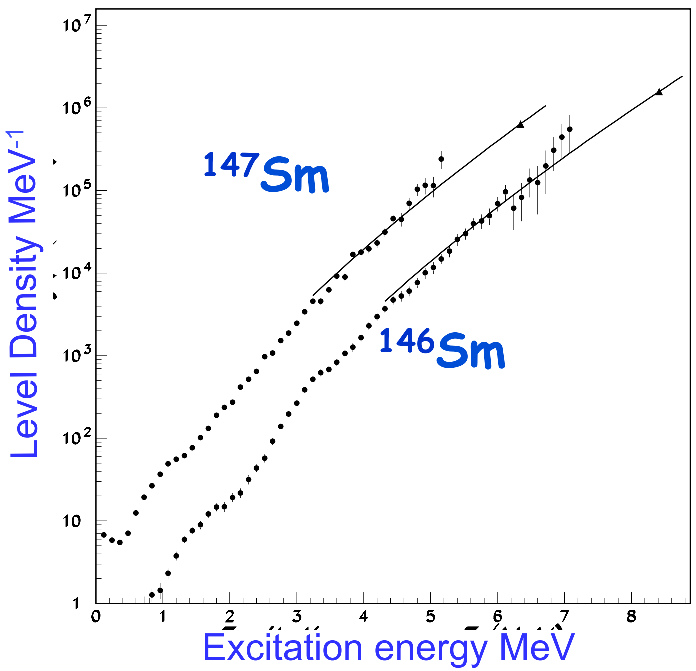
From the primary gamma spectra: functional form of level densities and γ strength functions

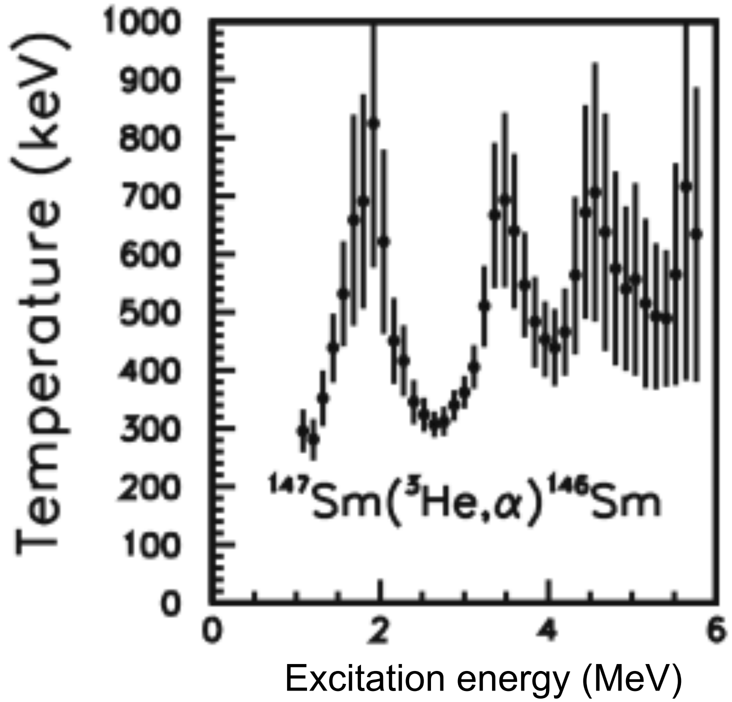






Thermodynamic properties of atomic nuclei

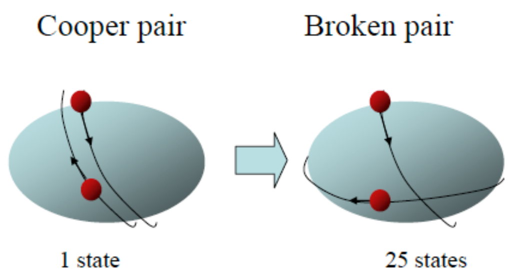




Level density ⇒ entropy ⇒ temperature

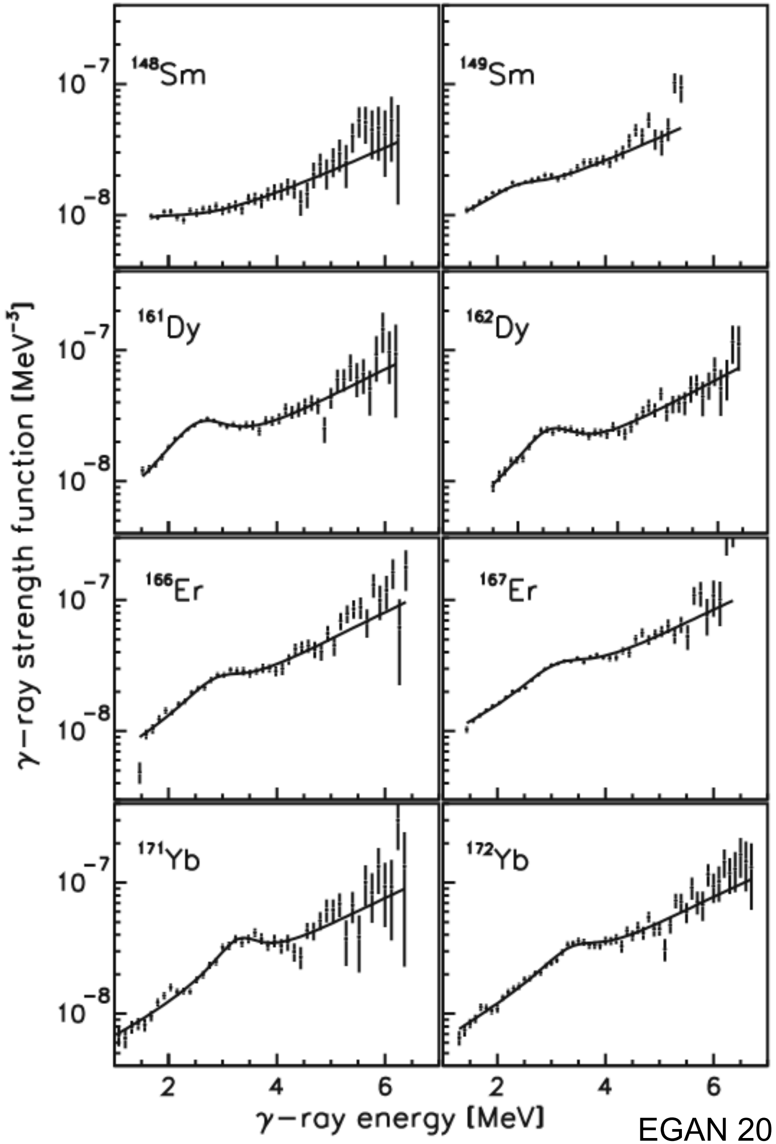
$$S(E) = k_B \ln\left[\rho(E)/\rho_0\right]$$

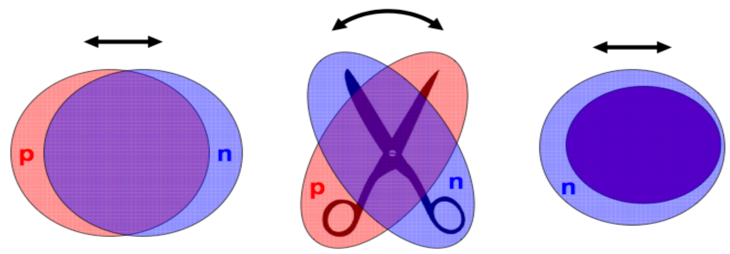
$$T(E) = \left(\frac{\partial S(E)}{\partial E}\right)_V^{-1}$$

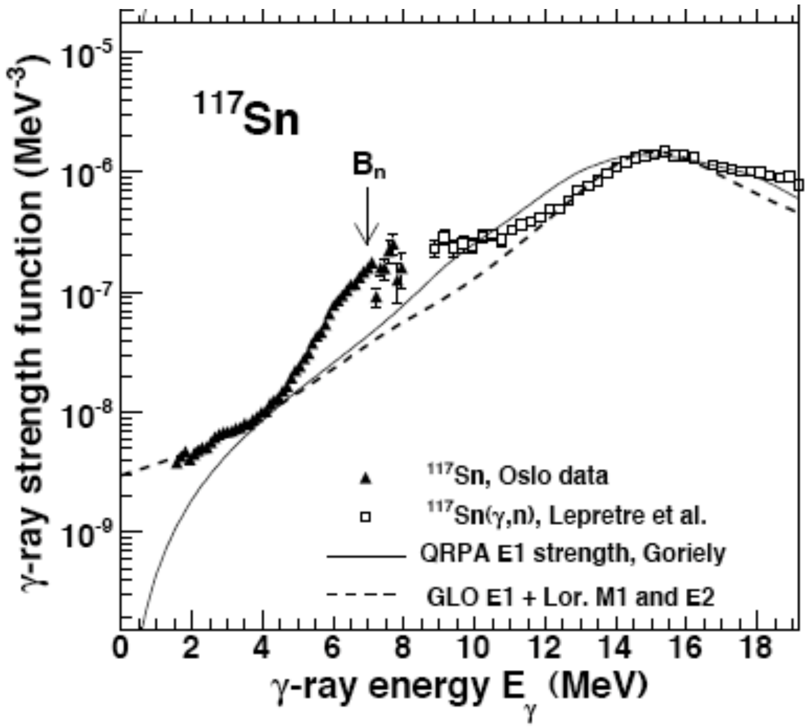


pairing phase transition

Small (Pygmy) resonances on the tail of the Giant Dipole Resonance



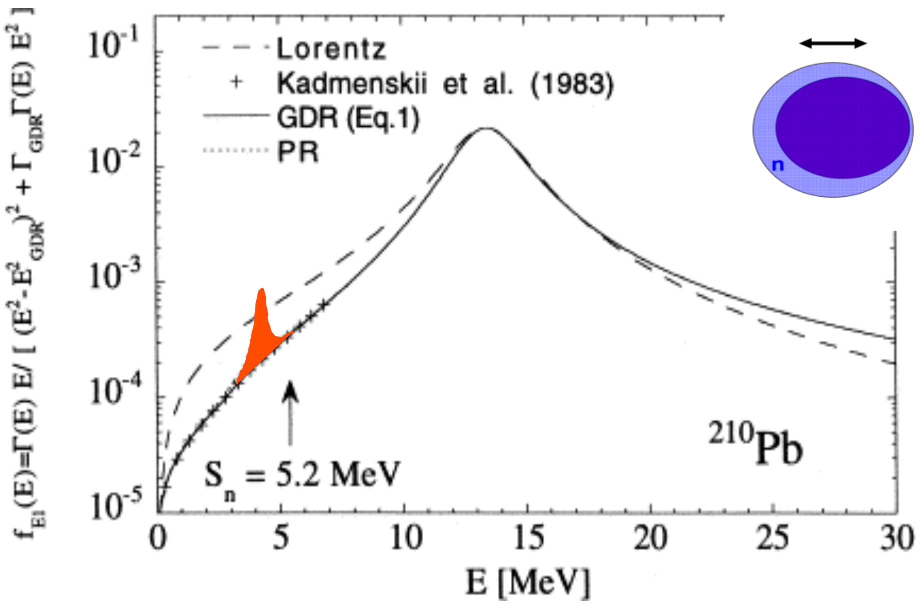




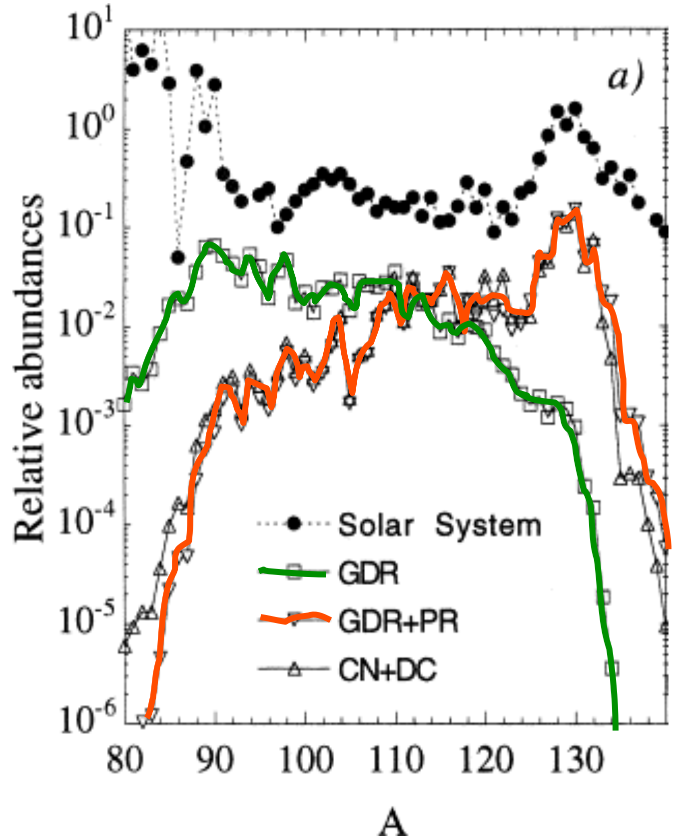
U.Agvaanluvsan et al. PRL(2009)

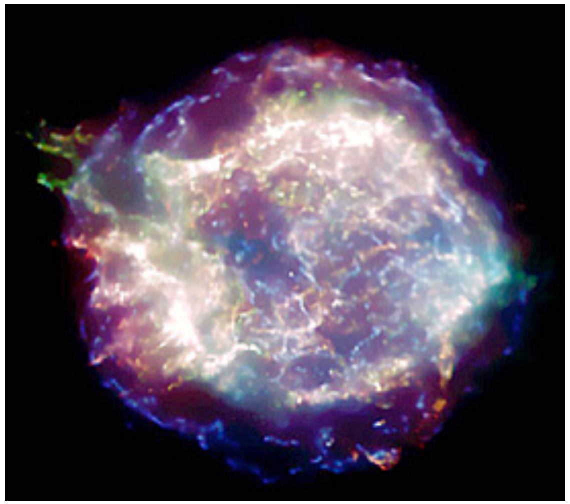
EGAN 2012 workshop June 25- 28

S.Siem et al. PRC(2002)



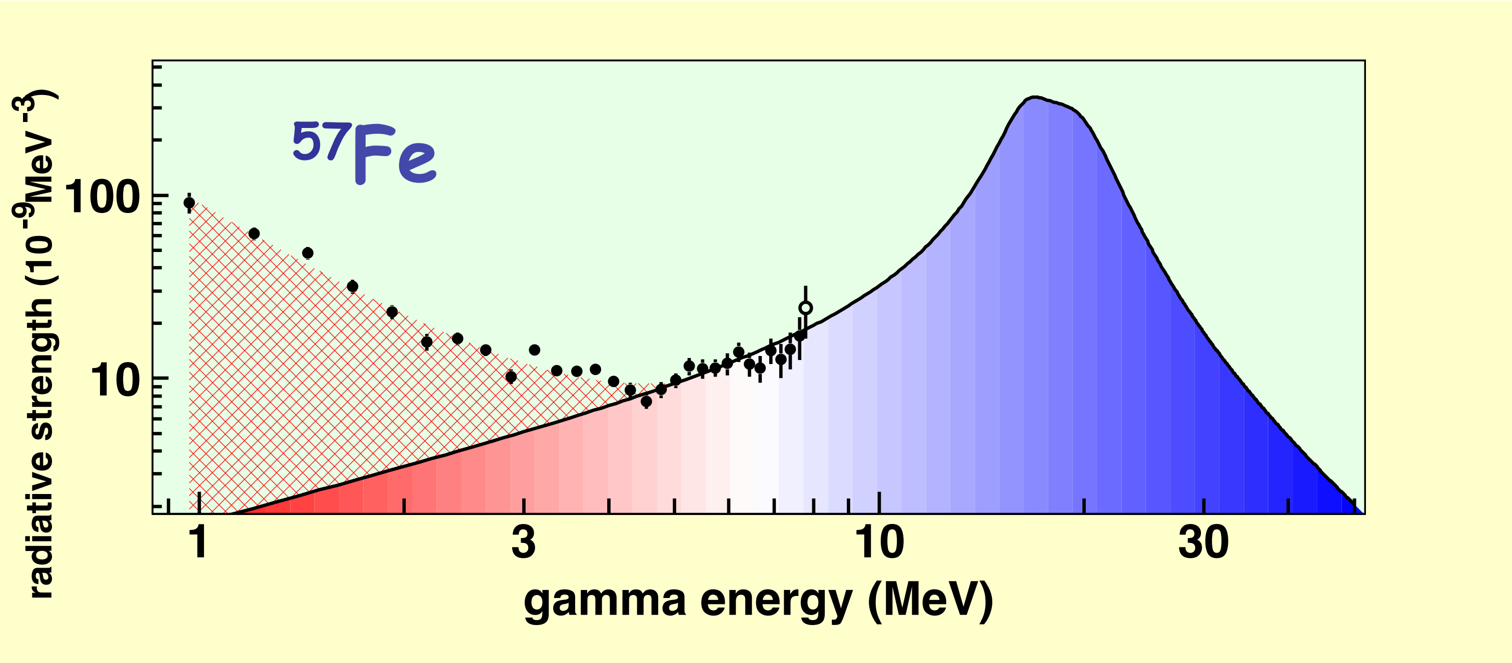
S. Goriely Phys. Lett. B 436 (1998)





Can small resonances in the strength function effect the results of abundance calculations?

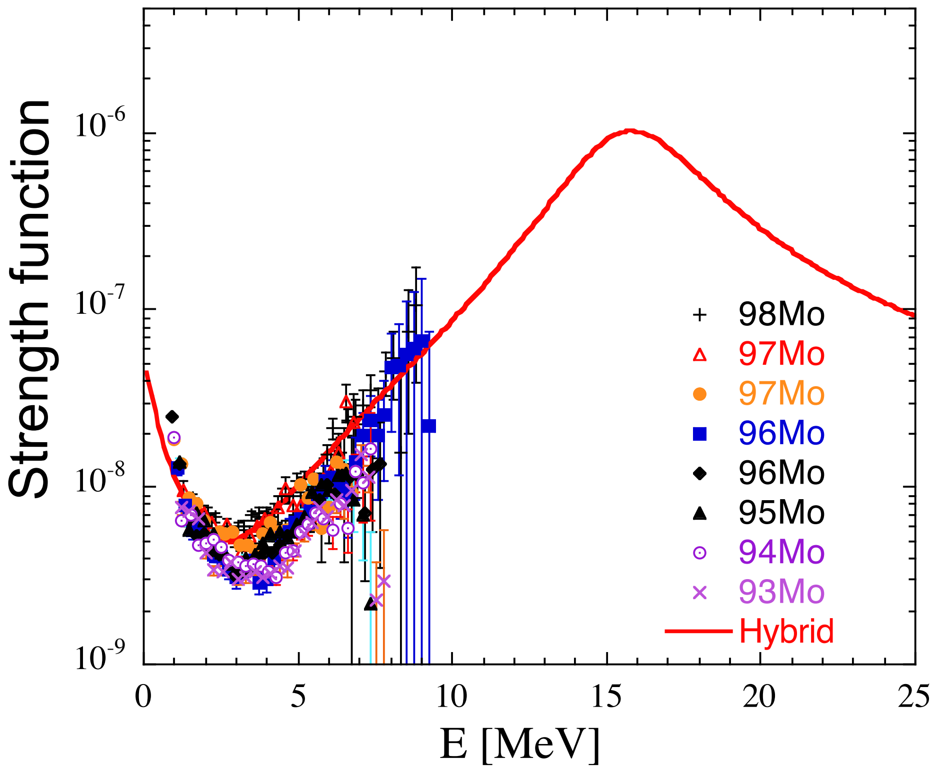
Low energy enhancement (upbend) of the strength function

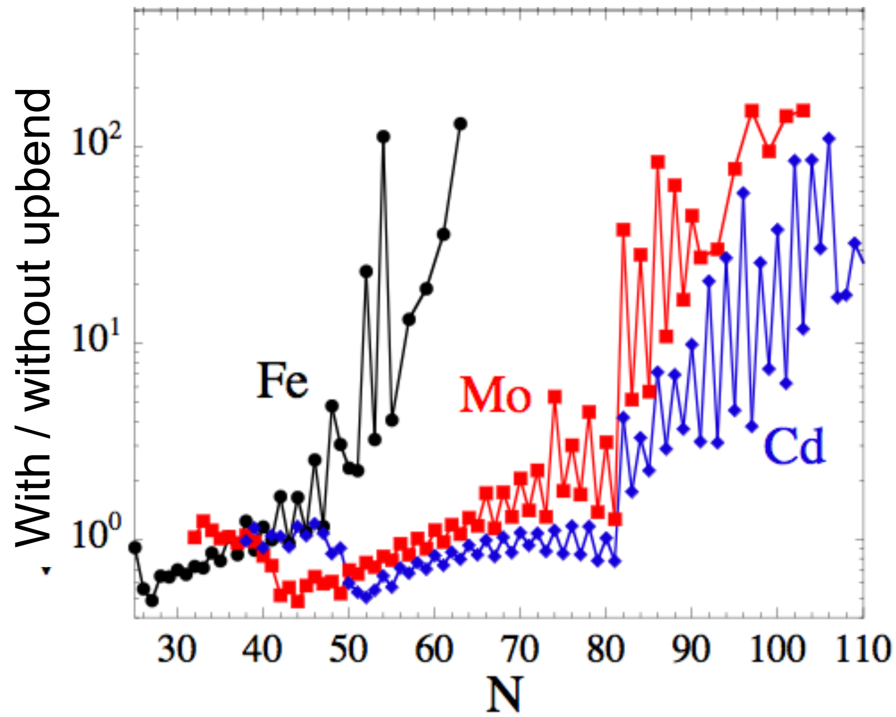


Totally unexpected and so far unexplained

How does this enhancement effect reaction cross sections?

How does the “upbend” affect neutron capture cross sections?





Assuming the strength functions of Mo isotopes all have the same energy trend

A.C.Larsen et al. PRC (2010)

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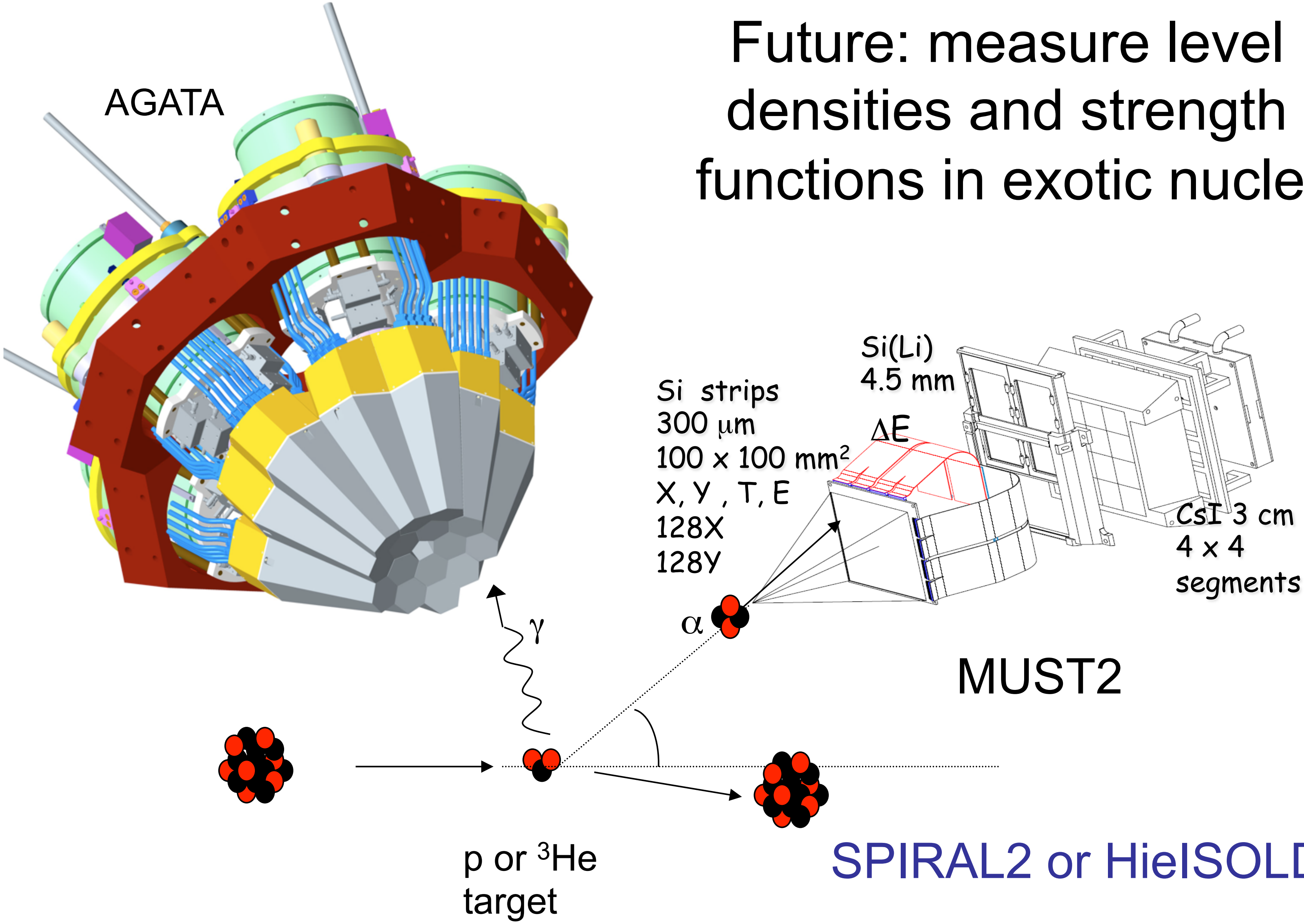
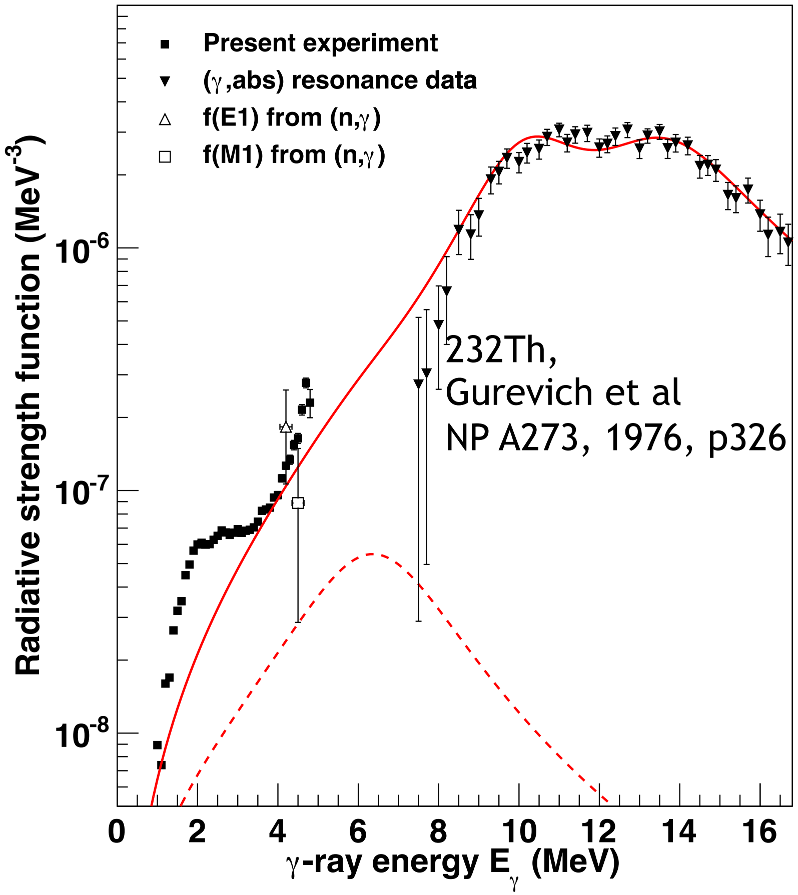
Future: measure level densities and strength functions in exotic nuclei



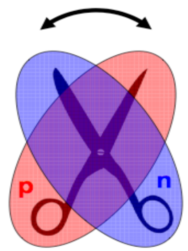
SPIRAL2 or HieISOLDE

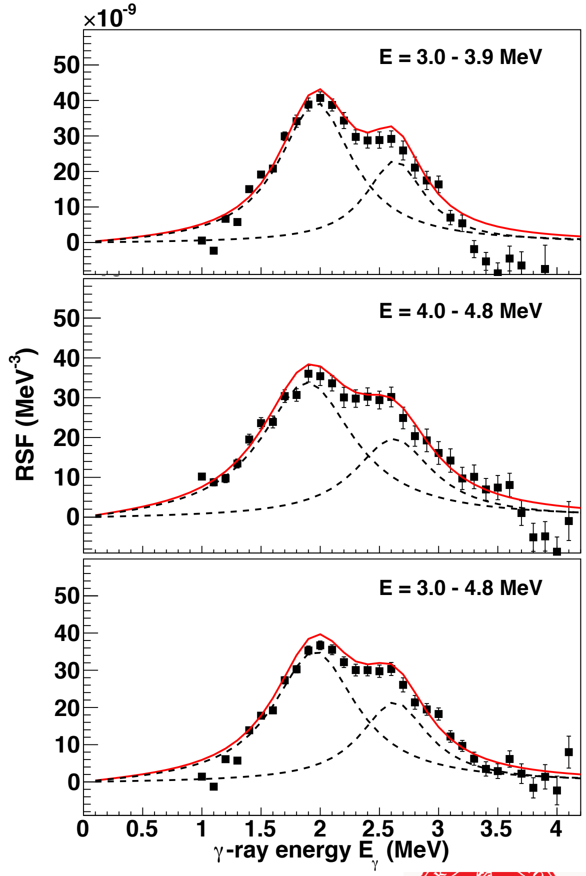
Nuclear data for reactor physics:
Level density and strength functions in the actinide region

$^{232}Th(d,p)^{233}Th$



Scissors mode?

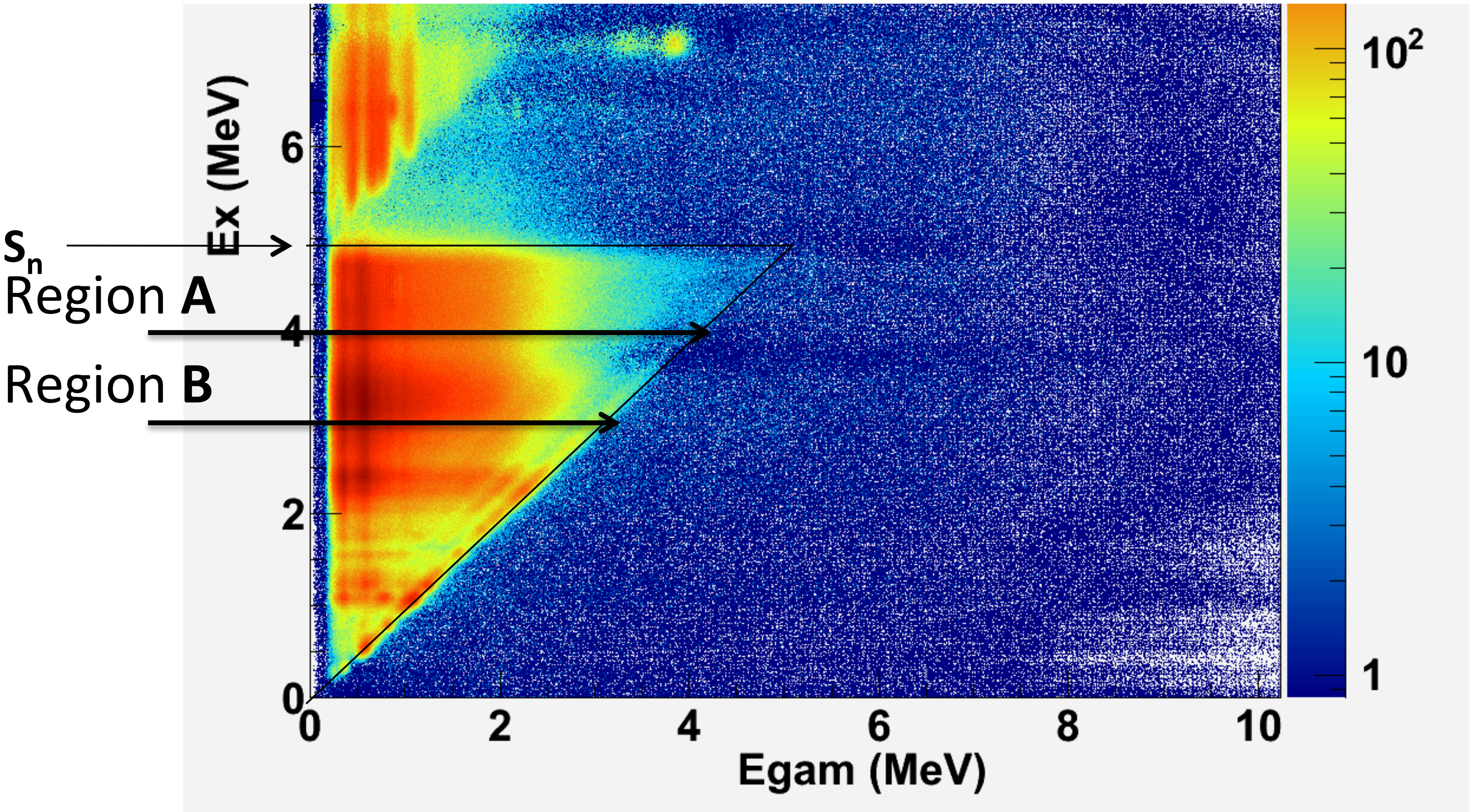


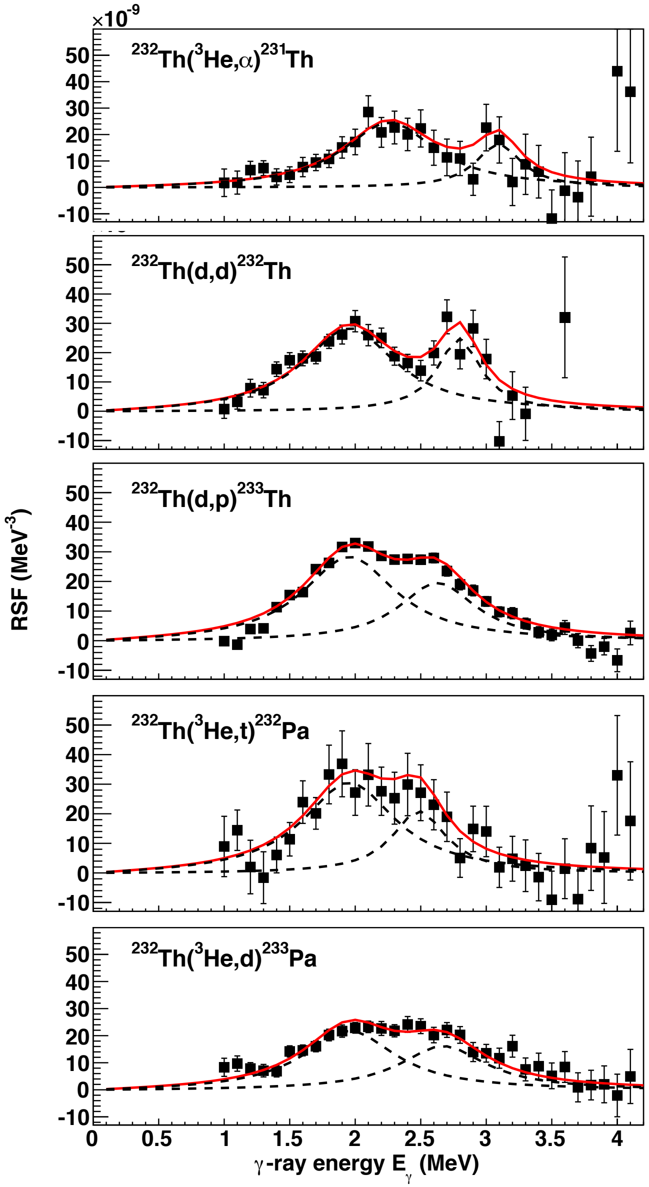


M. Guttormsen et al submitted PRL

Test of Brink-Axel:
Two statistical independent data sets

^{232}Th(d,p)





M. Guttormsen et al submitted PRL

- ➢ The scissor mode in actinides has huge strength of ~18 μ^2
- ➢ The strength is located lower Eγ ~2 – 2.5 MeV than for rare earth nuclei 2.5 – 3 MeV, indicating more softness

TABLE II: Scissors mode parameters (see text).

Nuclide	δ	ω_{M1} MeV	B_{M1} μ_N^2	$\omega_{M1}S_{-1}$ μ_N^2
^{231}Th	0.183	2.49(20)	11.2(30)	17.4
^{232}Th	0.192	2.23(20)	13.8(40)	15.8
^{233}Th	0.200	2.24(10)	15.3(20)	16.0
^{232}Pa	0.192	2.14(20)	14.7(40)	15.1
^{233}Pa	0.192	2.29(20)	12.7(30)	16.3

$$B_{M1} = \frac{9\hbar c}{32\pi^2}\left(\frac{\sigma\Gamma}{\omega_{M1}}\right),$$

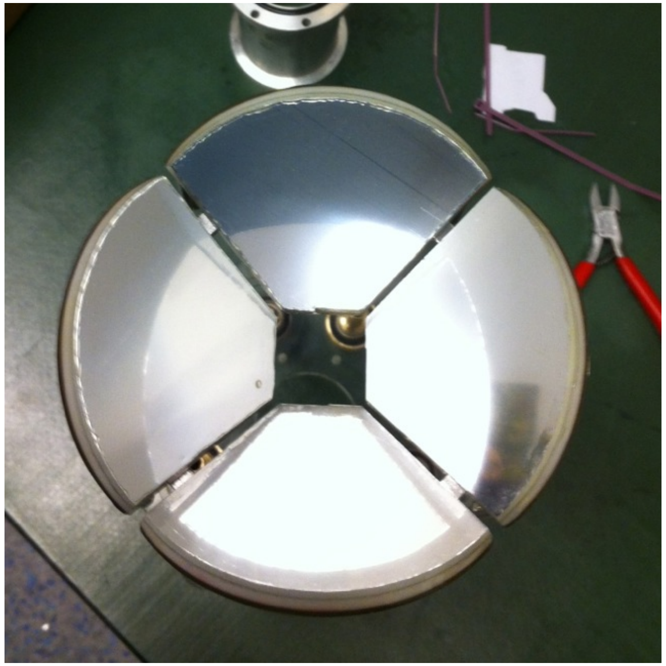
New PPAC fission detector

Buildt by Tamas Tornyi (Debrecen), on a stipend in Oslo.

Important for actinide studies

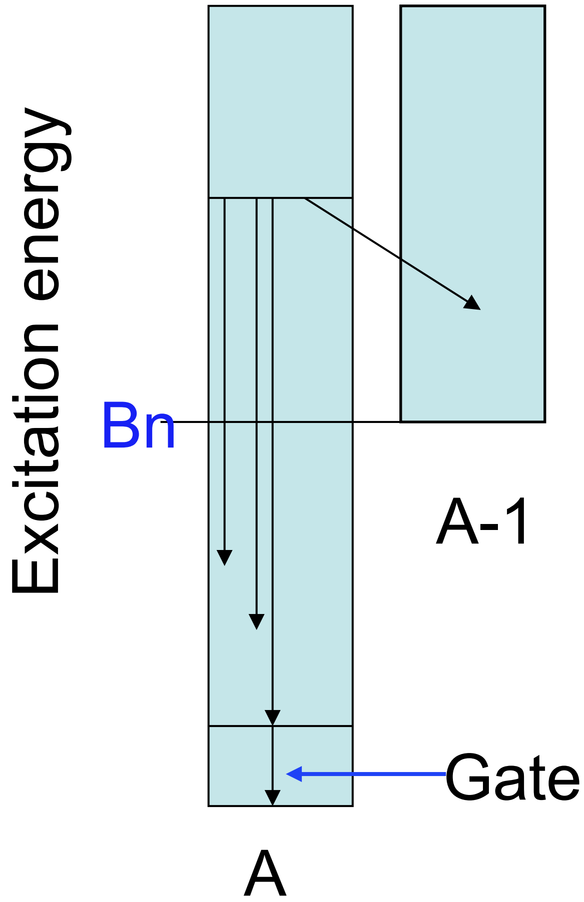
First experiment with PPAC detector:
^{237}Np(d,p) and ^{237}Np(3He, x) May 2012 (T. Tornyi PhD)
^{238}U(d,p) June 2012 (B.Jurado)

^{233}U exp September 2012 (S.J.Rose PhD)



Future plans:

Replace CACTUS detectors with LaBr3 detectors



- Better time and energy resolution
- high efficiency for high energy gamma rays.

- Extend Oslo method to Ex above Bn.

- Study competition between γ and particle decay.

- Study spin dependence of level density

- March 2012 exp in Oslo with 6 LaBr3 (3.5”x8”) barrowed from the Milano group, Thank you!

- We recieved funding for first 2 LaBr3 in 2012 ;-)

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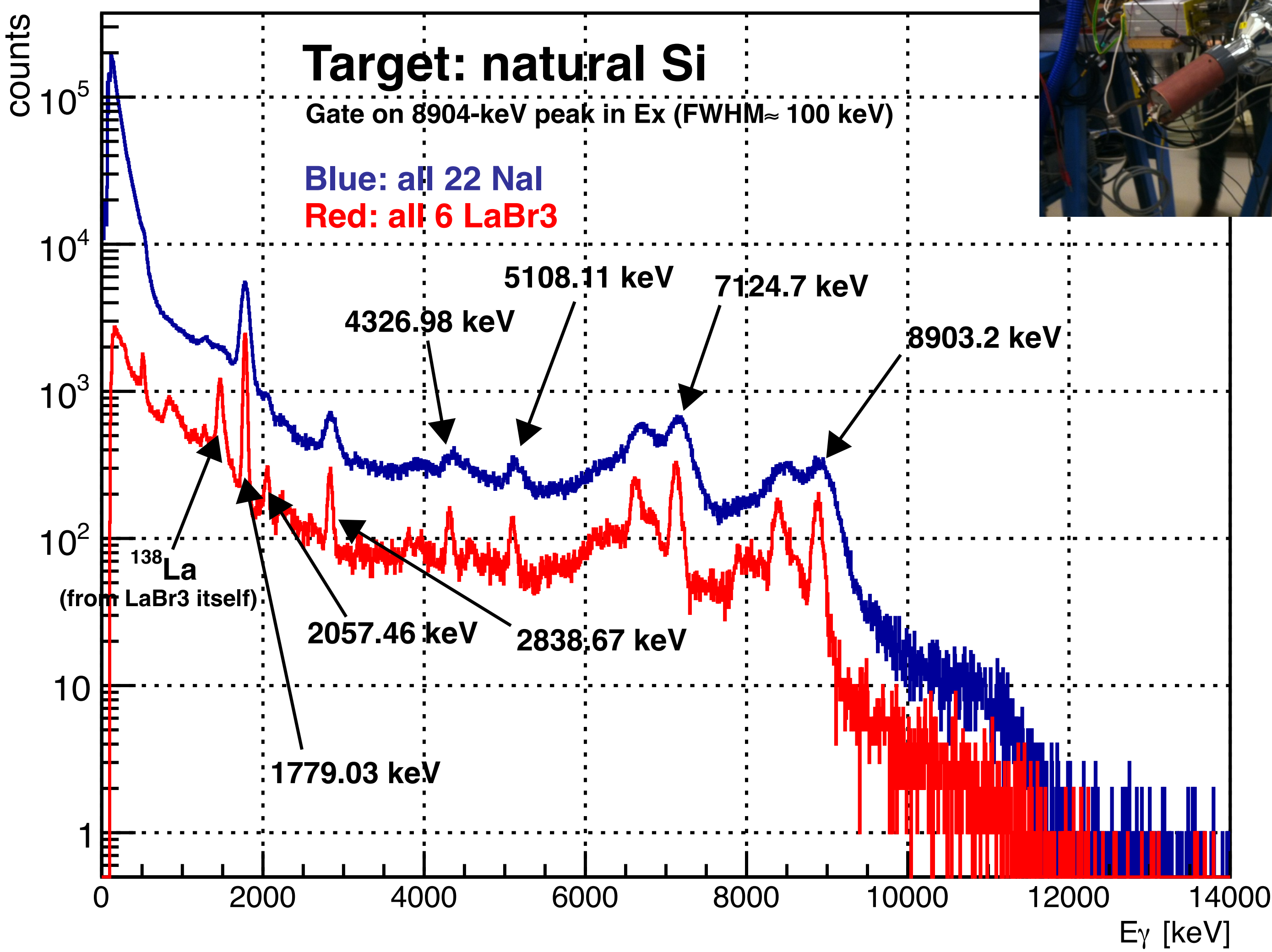
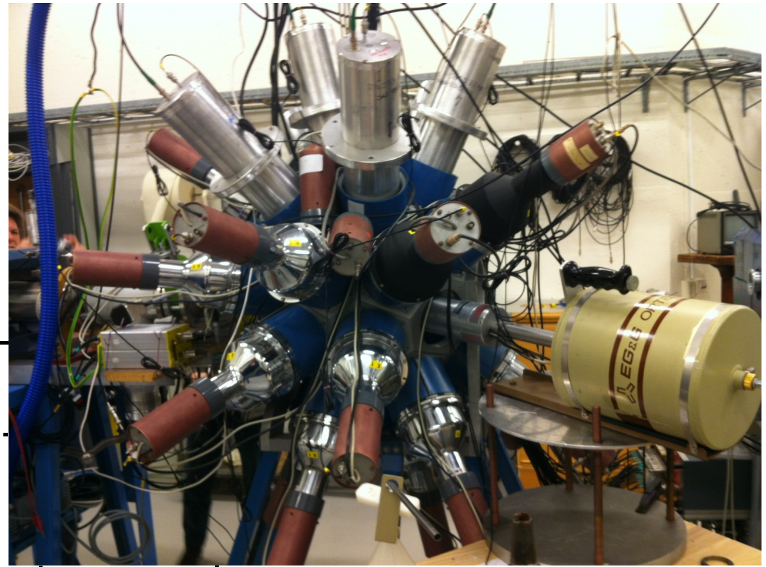
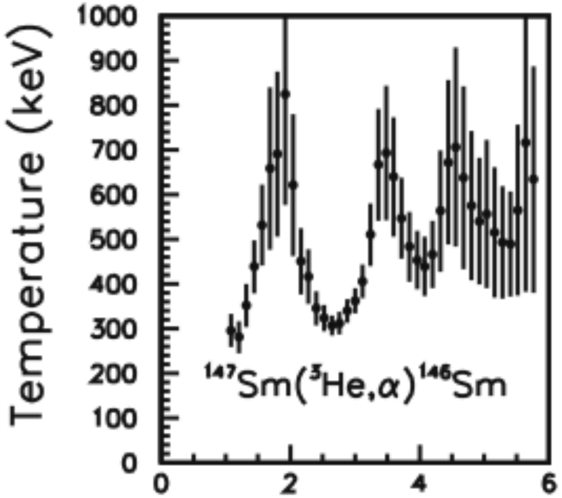
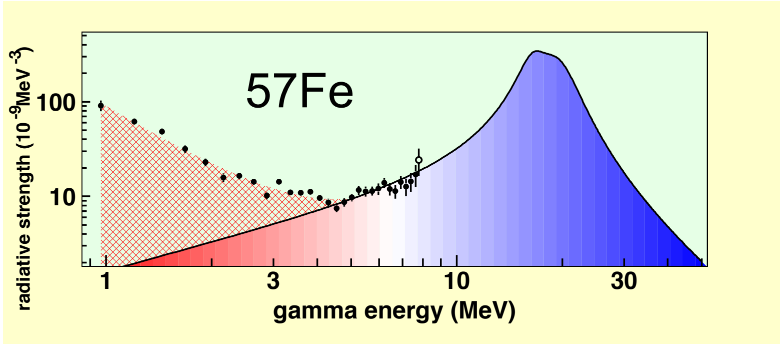
Example of difference in energy resolution:

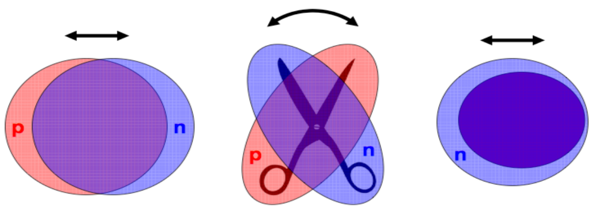


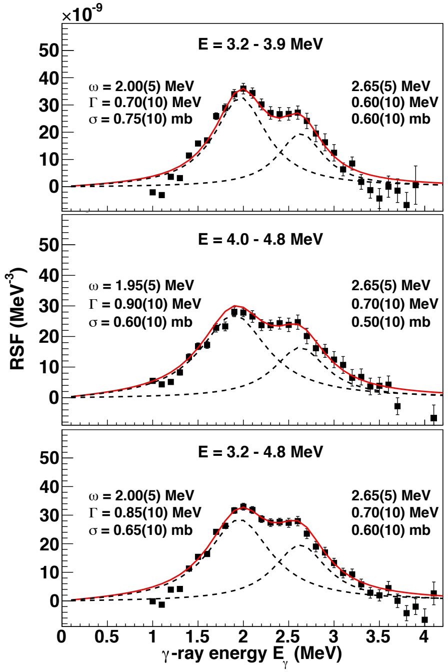


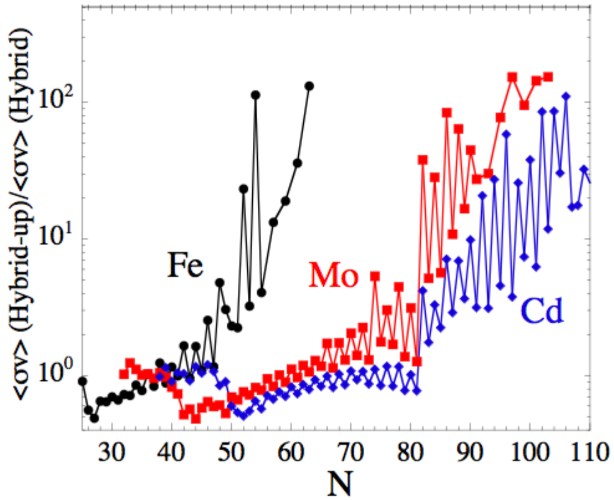
Summary


Temperature (keV)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
$^{147}Sm(^{3}He,\alpha)^{146}Sm$


57Fe
radiative strength ($10^{-9}MeV^{-3}$)
100
10
1
3
10
30
gamma energy (MeV)


p
n
p
n
n


$\times10^{-9}$
RSF (MeV^{-3})
E = 3.2 - 3.9 MeV
ω = 2.00(5) MeV
Γ = 0.70(10) MeV
σ = 0.75(10) mb
2.65(5) MeV
0.60(10) MeV
0.60(10) mb
E = 4.0 - 4.8 MeV
ω = 1.95(5) MeV
Γ = 0.90(10) MeV
σ = 0.60(10) mb
2.65(5) MeV
0.70(10) MeV
0.50(10) mb
E = 3.2 - 4.8 MeV
ω = 2.00(5) MeV
Γ = 0.85(10) MeV
σ = 0.65(10) mb
2.65(5) MeV
0.70(10) MeV
0.60(10) mb
0 0.5 1 1.5 2 2.5 3 3.5 4
γ-ray energy E_γ (MeV)


<σv> (Hybrid-up)/<σv> (Hybrid)
10^2
10^1
10^0
Fe
Mo
Cd
30 40 50 60 70 80 90 100 110
N


SAINT-GOBAIN
CRYSTALS

Future outlook and challenges:

- Ongoing analysis: $^{105-108}$Pd, ^{59,60}Ni, $^{90-92}$Zr, ^{105,106,111,112}Cd, ^{235}U, ^{237,238}Np, and ^{74}Ge
- What is the origin of the enhancement of low energy γ emission of exited nuclei.
- Impact of this enhancement/pygmy resonances on large network calculations of formation of elements in stars.
- Go to higher spin, investigate the level density as a function of both spin and temperature.
- Develop the Oslo method for inverse kinematics to study neutron rich exotic nuclei.

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Collaborators

- A.Bürger, F. Giacoppo, A.Görgen, M.Guttormsen, A.C.Larsen, H.T.Nyhus, J.Rekstad, T.Renstrøm, S.J.Rose, S.Siem, N.U.H.Syed, H.K.Toft, G.M.Tveten, T.Wiborg-Hagen, University of Oslo, Norway
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- G.Mitchell, North Carolina & TUNL, USA
- L.Bernstein, D.Bleuel, Lawrence Livermore NL, USA
- M.Wiedeking, iTemba labs South Africa
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- F. Gunsing, CEA Saclay, France
- M. Krticka, Charles University, Prague
- U. Agvaanluvsan, Stanford Univ./MonAme Scientific Research Center
- E. Algin, Eskisehir Osmangazi University

4th Workshop on Level Density and Gamma Strength

May 27—31, 2013

Welcome to Oslo!

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