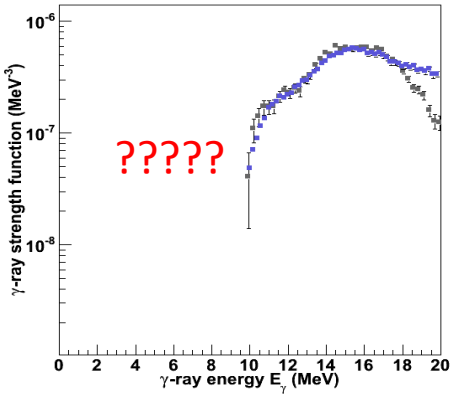
Low-energy enhancement in the γ-ray strength functions of ^{73,74}Ge

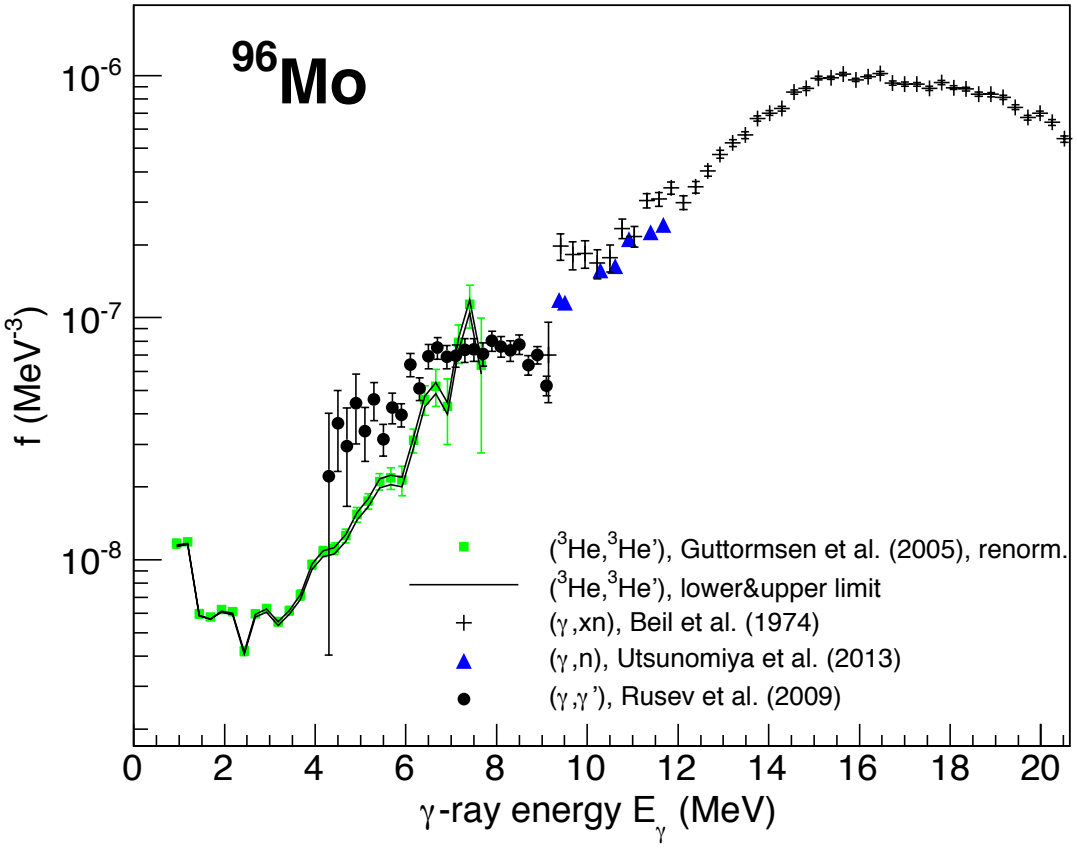


Therese Renstrøm

Oslo Cyclotron Laboratory,

University of Oslo

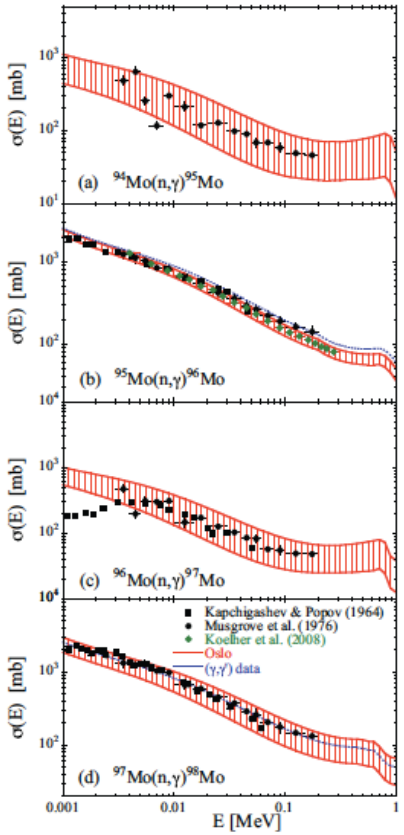
Many people measuring the same property…?

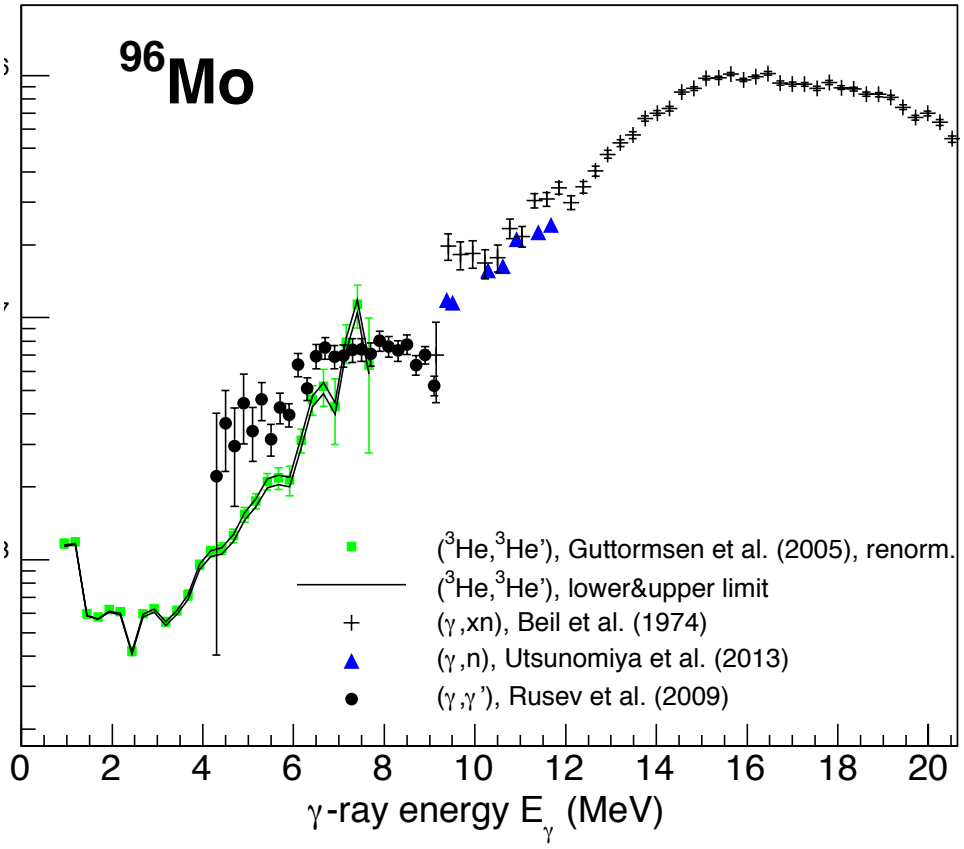


Updated version of famous graph, courtesy of Ann-Cecilie Larsen

Many people measuring the same property…?

H. Utsunomiya, Phys. Rev. C 88,015805 (2013)





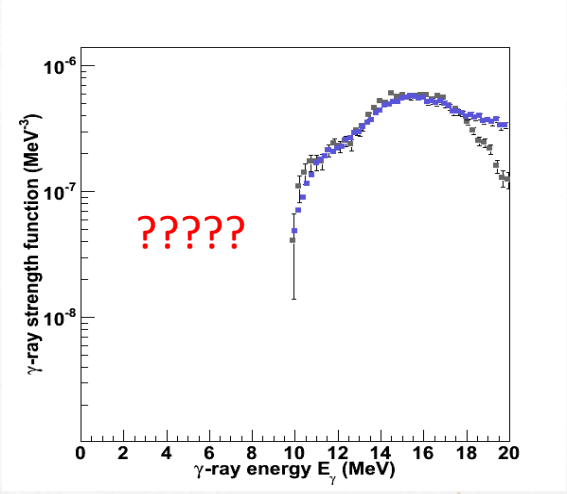
P. E. Koehler, Phys. Rev. C 88, 041305(R) (2013)
-New neutron resonance parameters, small uncertainties

Need for a new common case?

^{74}Ge

^{74}Ge(^{3}He, ^{3}He')
@OCL

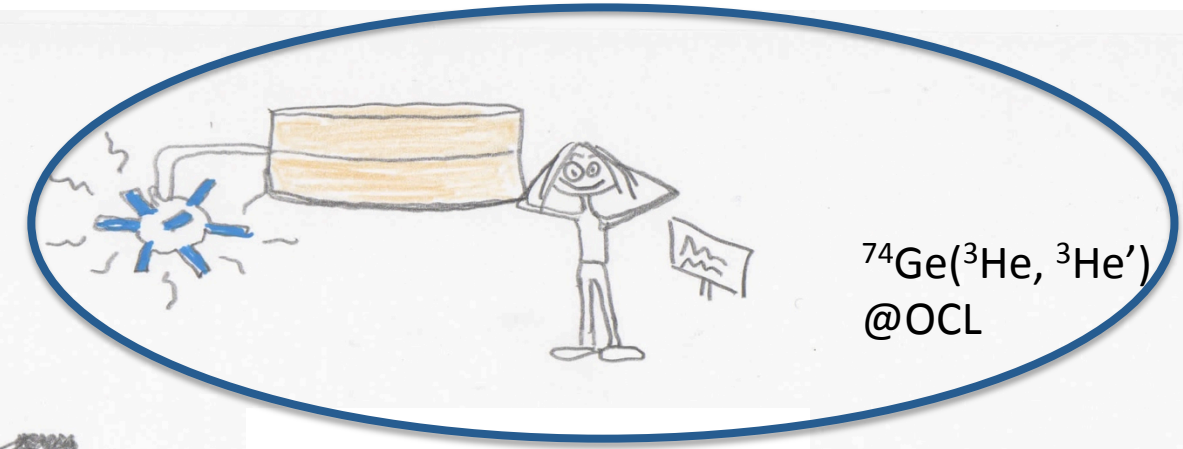
^{74}Ge(p,p')
@LLNL



^{74}Ge(γ,γ')
@ γELBE

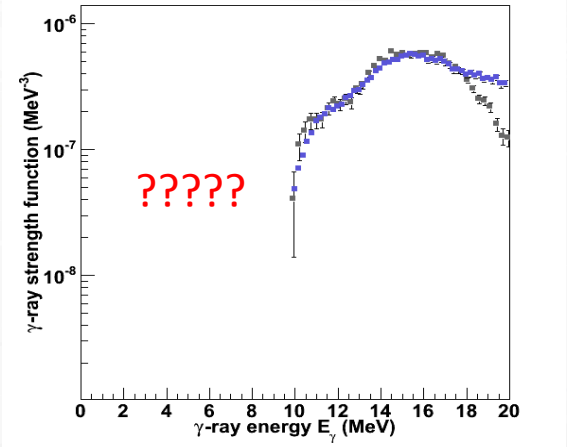
^{74}Ge(α, α')
@iThemba

^{74}Ge



^{74}Ge(^{3}He, ^{3}He')
@OCL

^{74}Ge(p,p')
@LLNL



^{74}Ge(γ,γ')
@ γELBE

^{74}Ge(α, α')
@iThemba

^{74}Ge

The first step is compilation

1. **Data sources**
   1. "Oslo method" ★
   2. (γ,γ') with Brehm ★
   3. (γ,γ') with HIGS
   4. Direct Reac.+ HPGe (DR-TSC) ★
   5. (n,γ) + statistical model
   6. (n,2γ)
   7. (γ,n) – Utsonomya ★
   8. (p,p'), (α,α')
   9. (e,e')
   10. (n,n')
   - Note: Many of these are inextricably linked with Level Density
2. **Database format**
3. **Evaluation methodology**
4. **New measurements/Benchmark**
5. **Understanding sources of discrepancies**

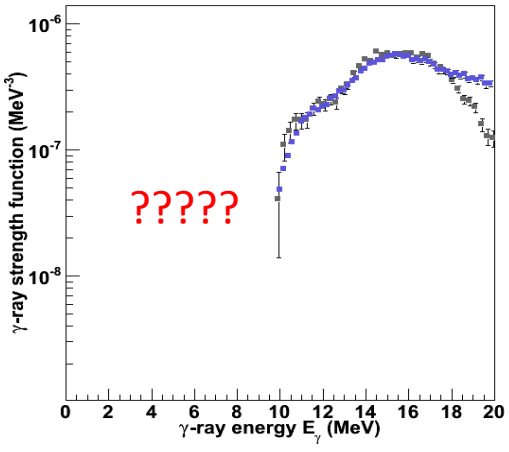
e, ^{3}He')

^{74}Ge(p,p')

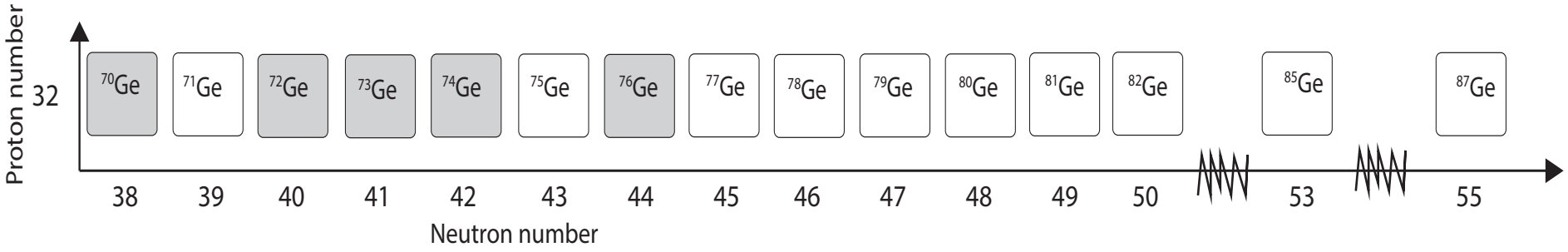
^{74}Ge(γ,γ')

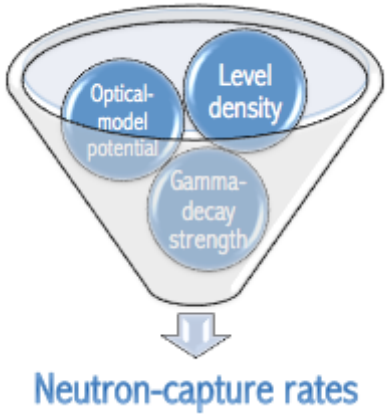
^{74}Ge(α, α')

Advantages by this type of joint effort:
- Timescale
- Communication
- Understanding of data analysis
- More FUN!



Why Germanium???

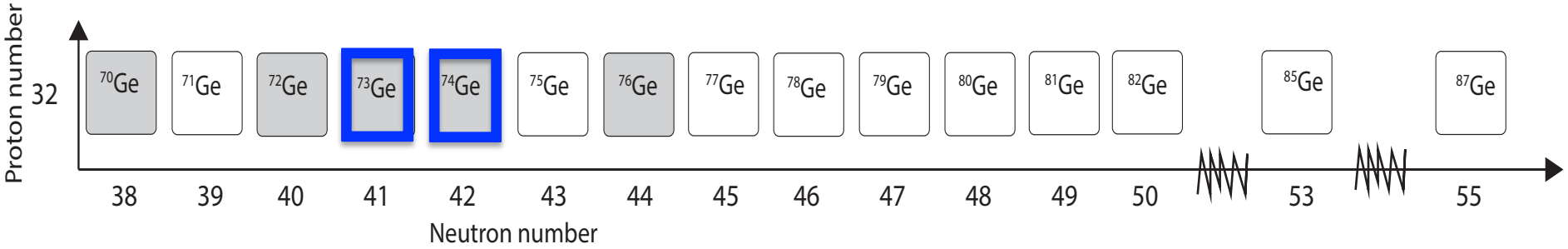


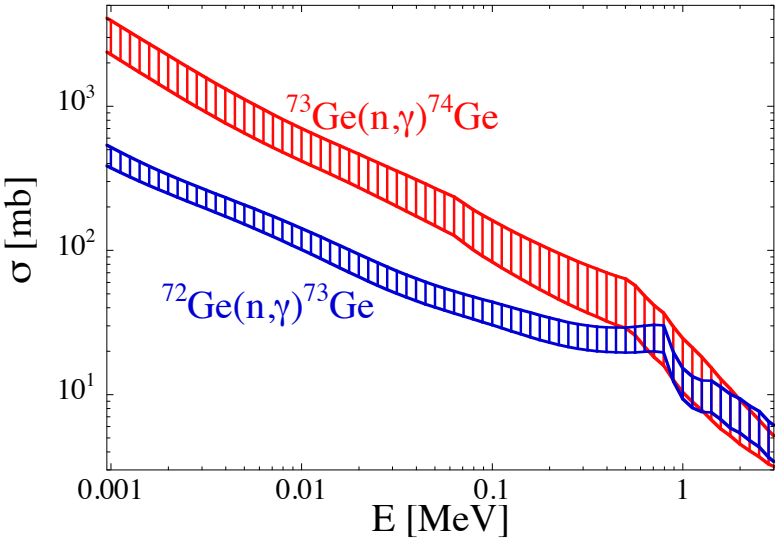


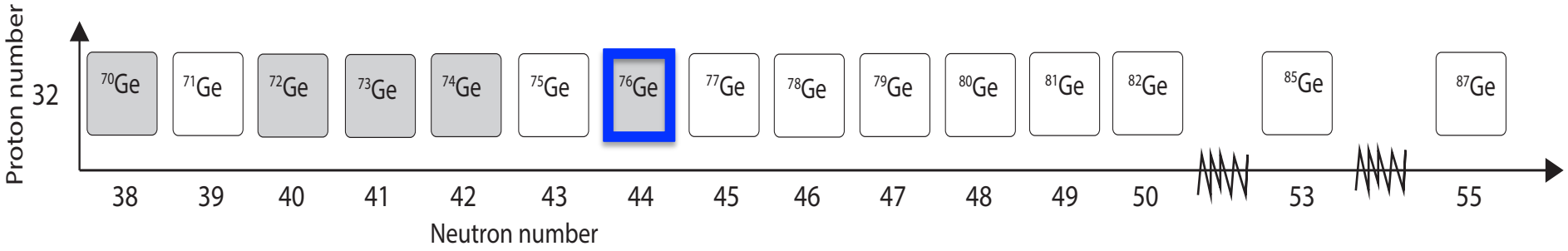
Level density and gamma-decay strength can be extracted using the Oslo-method

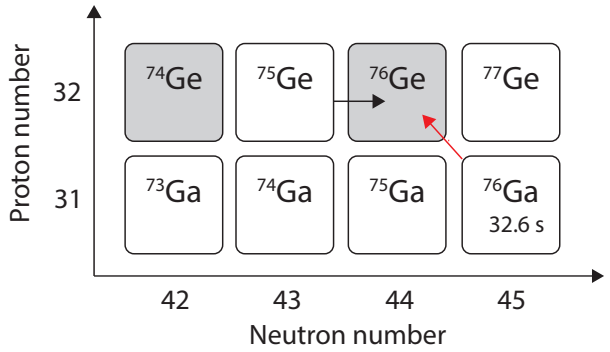
Figure courtesy of Ann-Cecilie Larsen

"Almost all of the (n,γ) cross sections of the 277 stable isotopes have been measured. The few exceptions are ^{17}O, ^{36,38}Ar, ^{40}K, ^{50}V, ^{70}Zn, ^{72,73}Ge, ^{77,82}Se, ^{98,99}Ru, ^{131}Xe, 138La, 158Dy, and 195Pt…", F. Käppeler et al., Rev. of Mod. Phys, 83, 2011

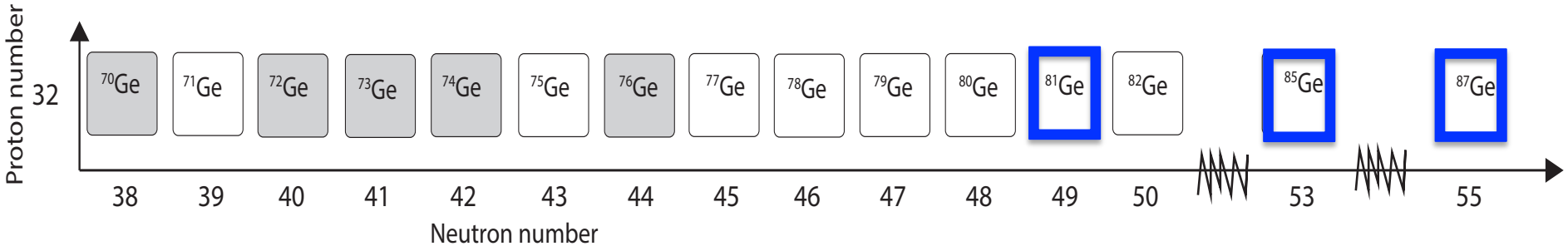


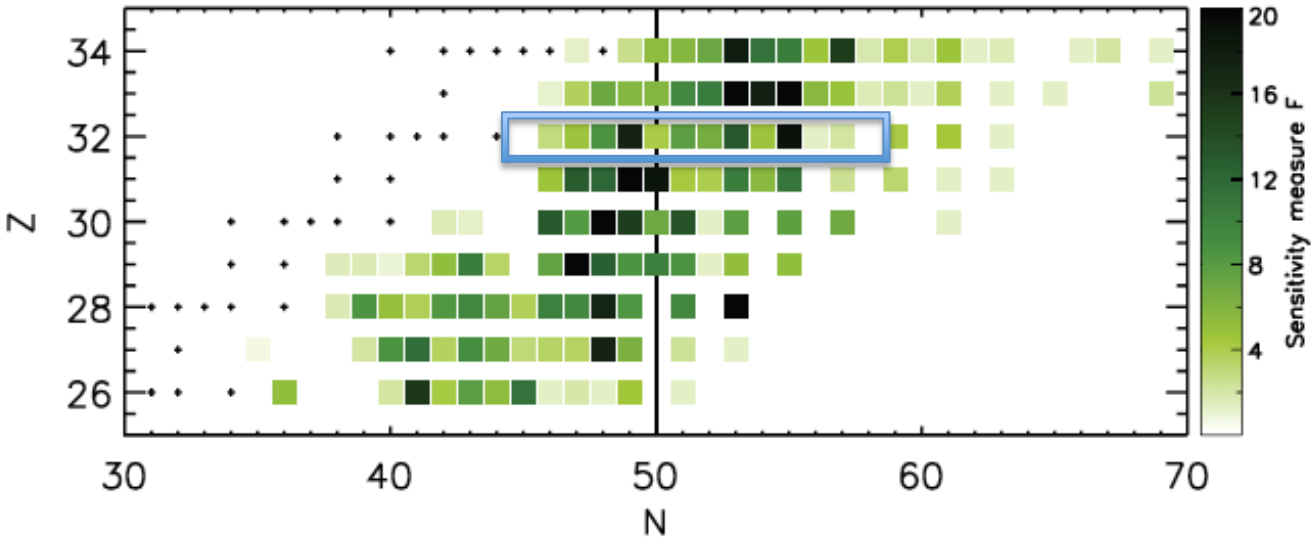






A. Spyrou, PRL **113**, 232502 (2014)





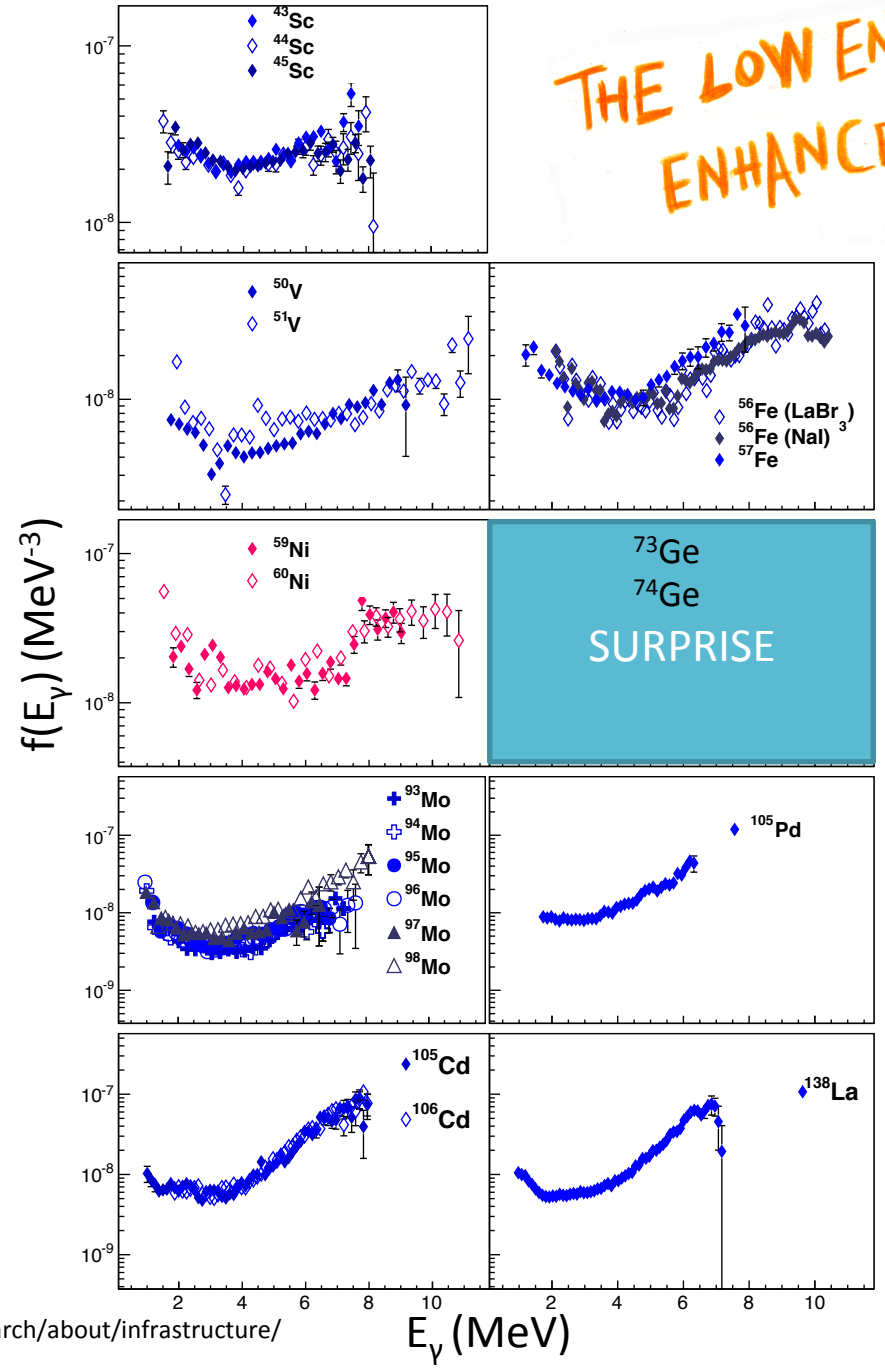
R. Surman, AIP Advances **4** , 041008 (2014)

THE LOW ENERGY ENHANCEMENTS...

Two theoretical explanations of the type:

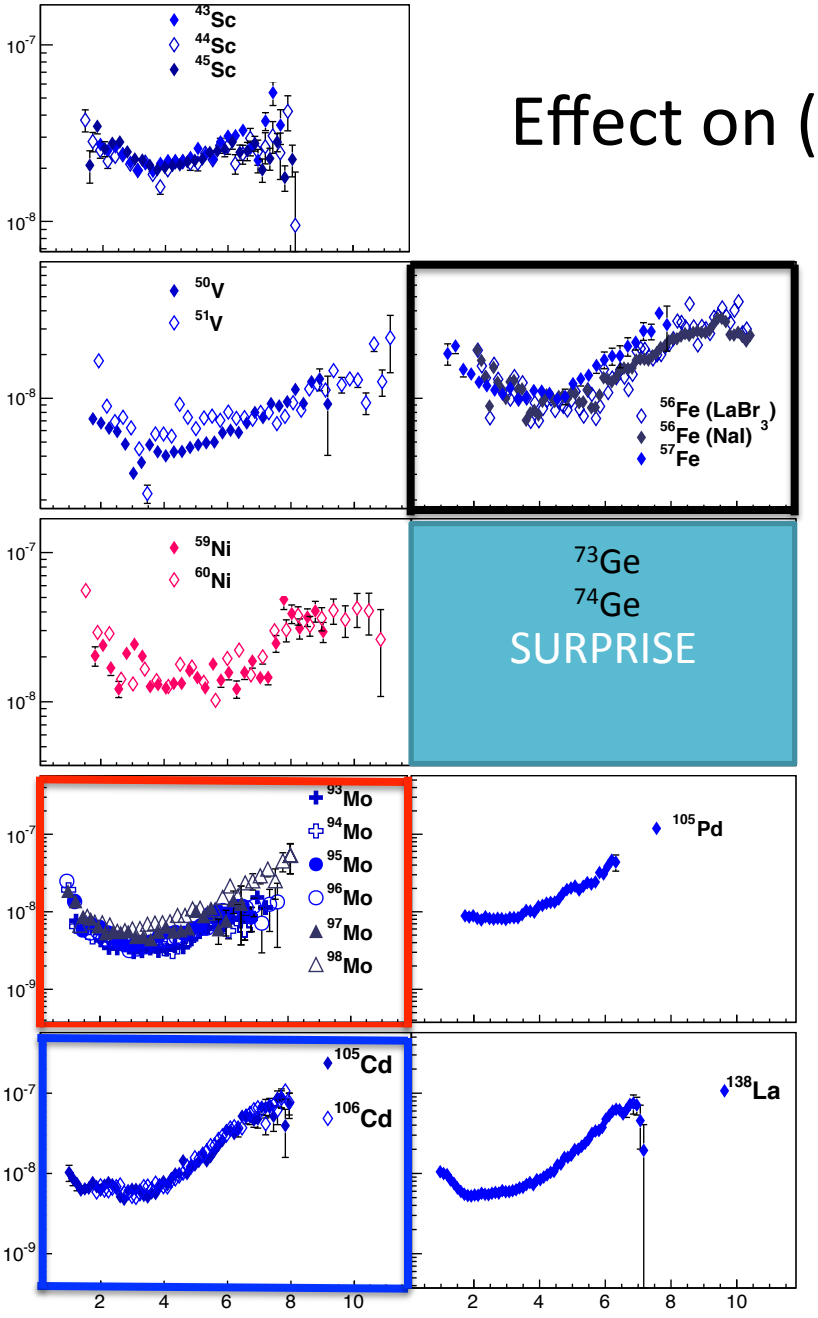
Argues for E1
E. Litvinova and N. Belov, Phys. Rev. C 88, 031302(R) (2013)

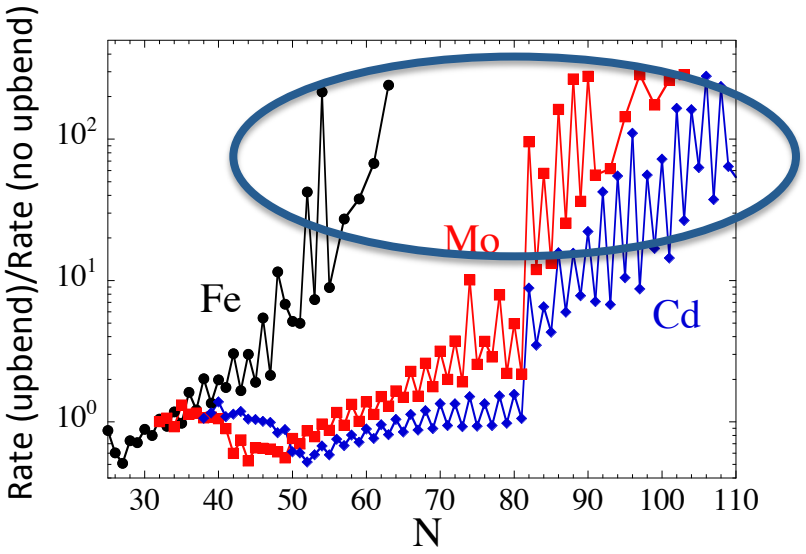
Argues for M1
R. Schwengner, S. Frauendorf, and A. C. Larsen, Phys. Rev. Lett. 111, 23504 (2013)



http://www.mn.uio.no/fysikk/english/research/about/infrastructure/OCL/nuclear-physics-research/compilation/

Effect on (n, γ) reaction rates





A. C. Larsen and S. Goriely, Phys. Rev. C 82, 014318 (2010)

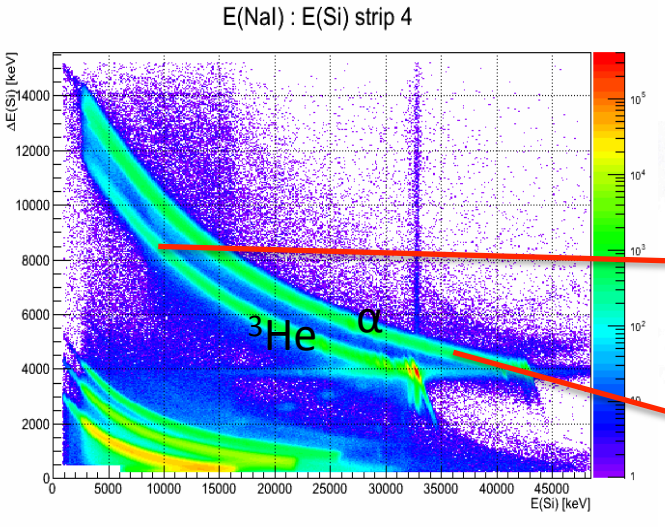
Two experiments below and above Sn

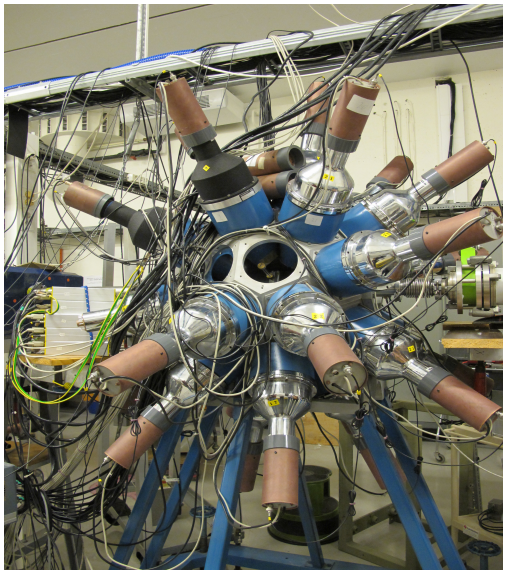
(^{3}He,^{3}He')

(^{3}He, α)

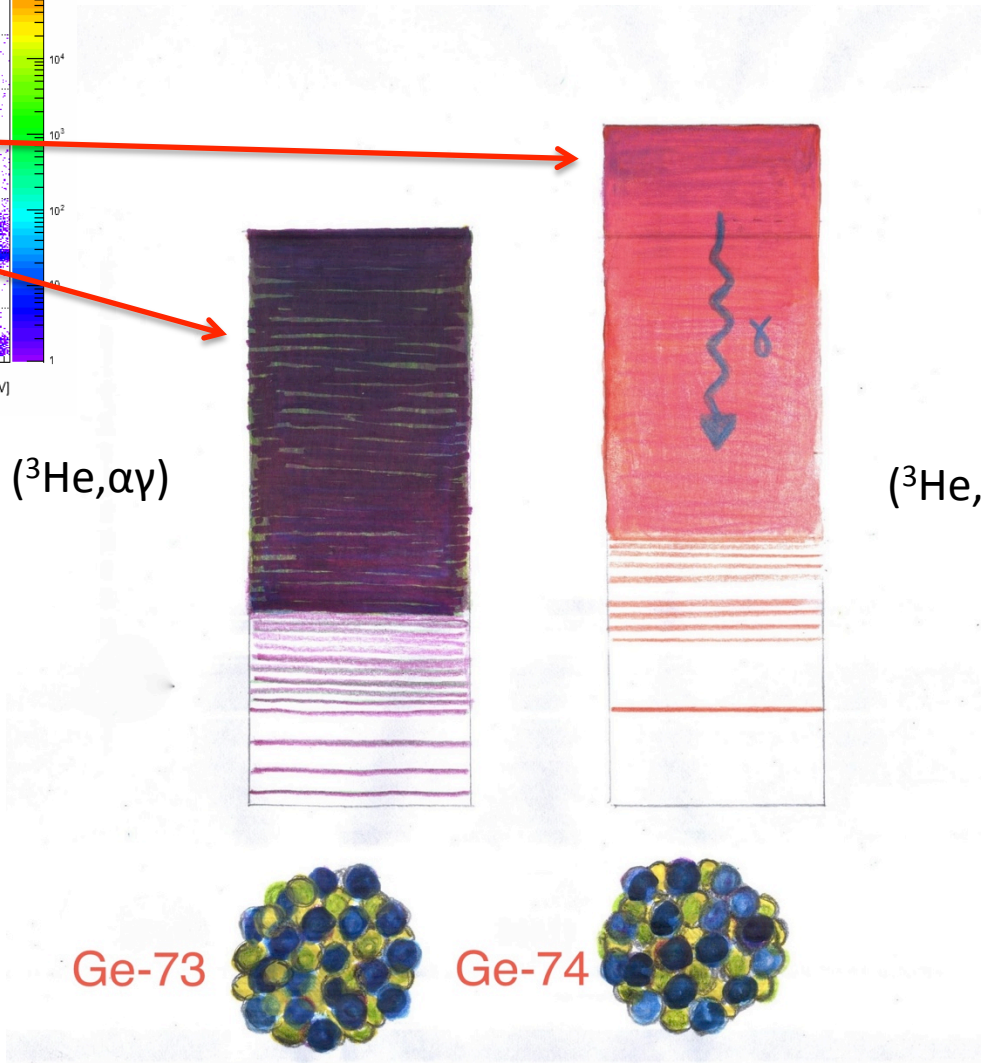
(γ, n)

^{74}Ge & bonus nucleus ^{73}Ge

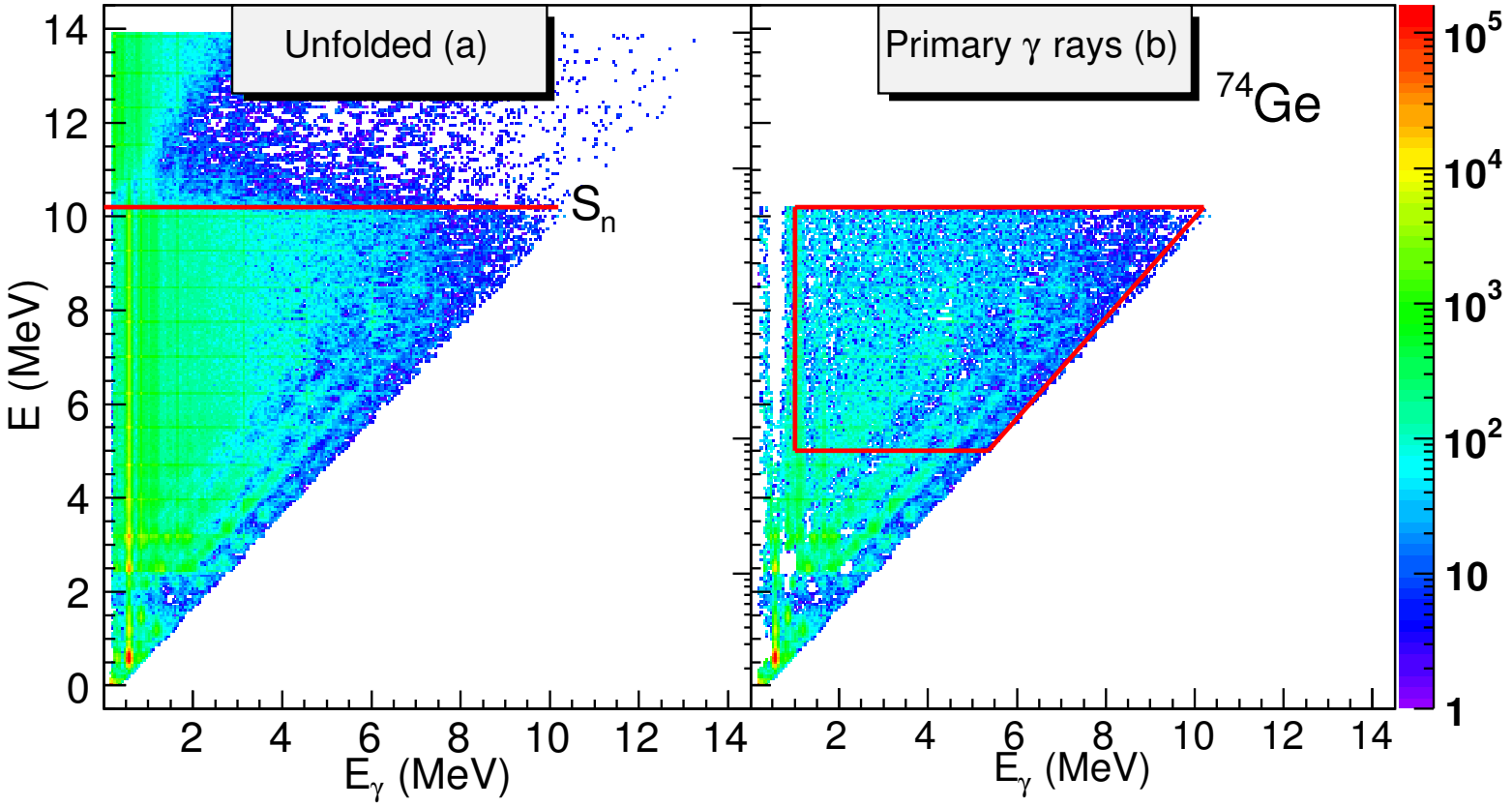




(^{3}He,αγ)



(^{3}He, ^{3}Heγ)


Unfolded (a)
Primary γ rays (b)
^{74}Ge
S_n
E (MeV)
E_γ (MeV)
E_γ (MeV)
0
2
4
6
8
10
12
14
10^5
10^4
10^3
10^2
10
1

Neutron resonance data

-discrepancies between the libraries

Atlas of N. Res. by S.F. Mughabghab

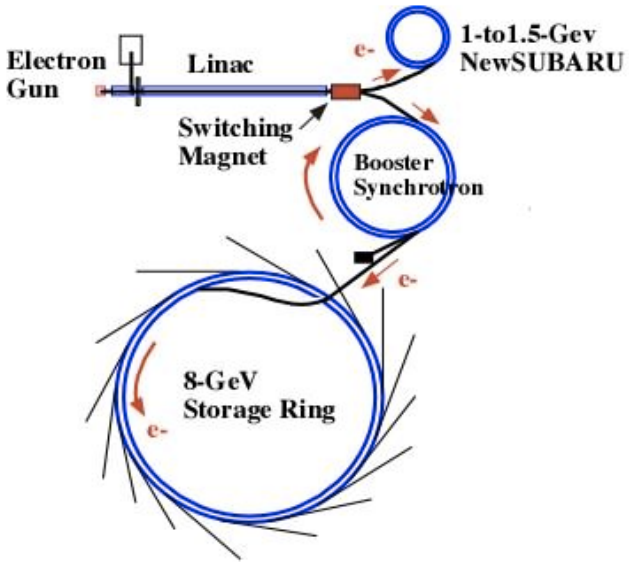
RIPL3

In the case of ^{73,74} Ge, s-wave spacings, **D**0 , are given in both Atlas of N. Res. by S.F. Mughabghab and RIPL. After careful consideration we have chosen to use an average value of the two proposed sets of **D**0 values and uncertainties. The two main reasons for this choice are:

1. For 73,74 Ge the **D**0 values from Atlas of N. Res. are larger by 38% and 60%, respectively, than the values given in RIPL3.
2. Atlas of N. Res. presents a table of measured resonanses giving a good transparency.

The experimental results that give the values listed in RIPL-3 are not presented in any peer-reviewed publication.

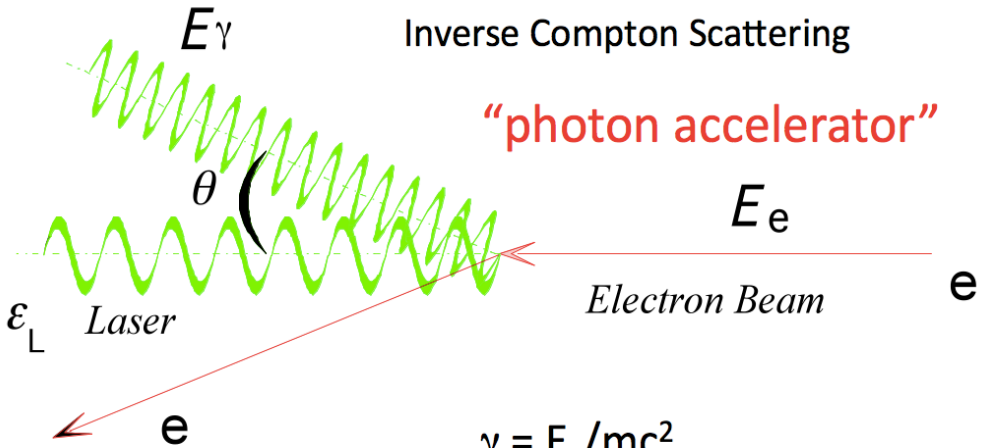
The photo-neutron experiment @NewSUBARU synchrotron radiation facility



Relativistic electrons on eV photons

Laser Compton backscattered
-ray beams are ideal because:

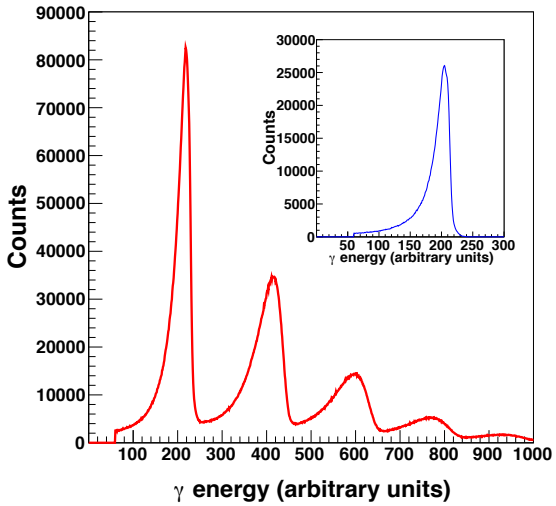
-Almost monochromatic
- Tunable energies



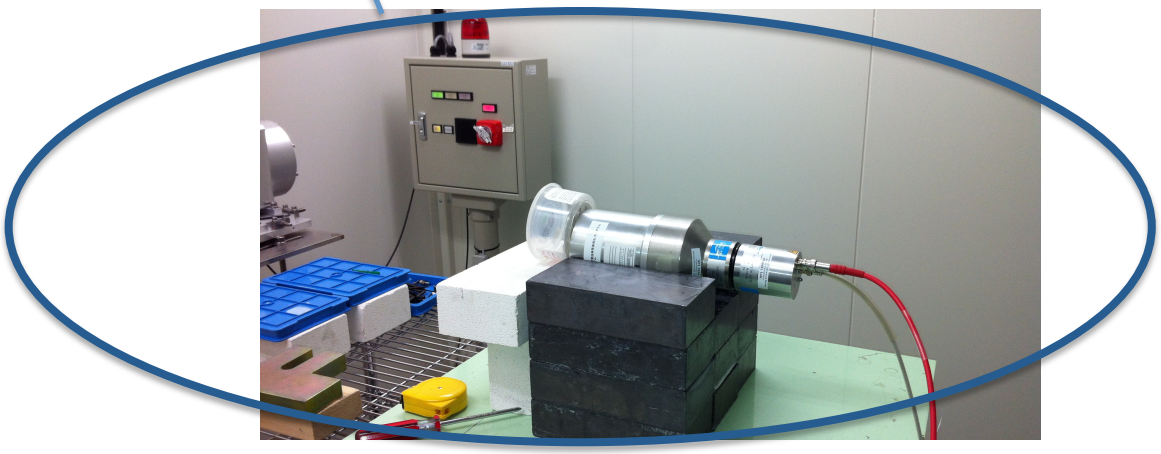
$\gamma = E_e/mc^2$

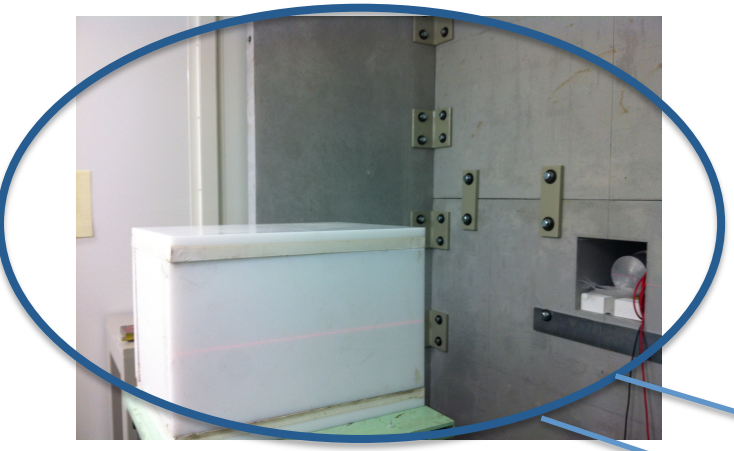
$$E_\gamma = \frac{4\gamma^2 \varepsilon_L}{1 + (\gamma\theta)^2 + 4\gamma\varepsilon_L/(mc^2)}$$

20 ^{3}He proportional counters

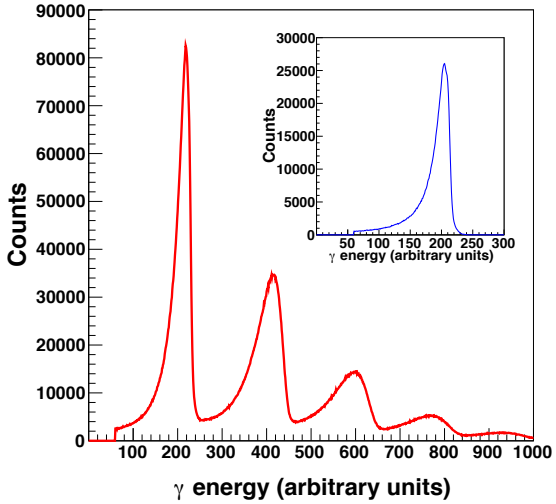


$$\int_{S_n}^{E_{\max}} n_\gamma(E_\gamma)\sigma(E_\gamma)dE_\gamma = \frac{N_n}{N_t N_\gamma \xi \varepsilon_n g}$$

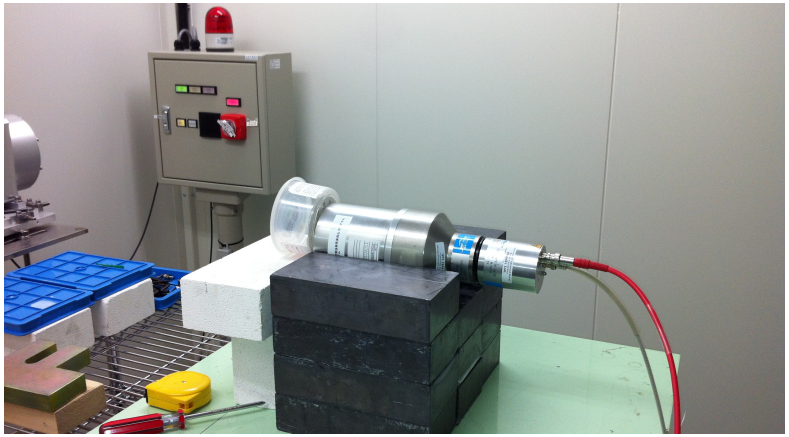




20 ^{3}He proportional counters

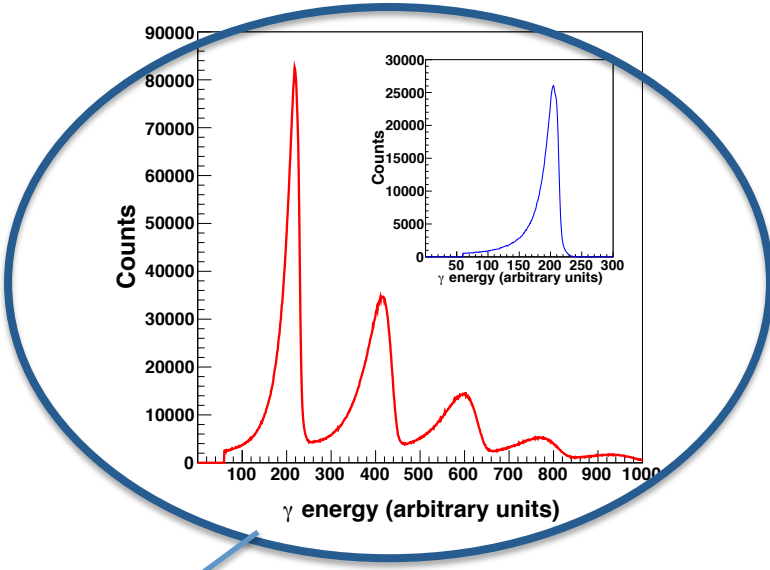


$$\int_{S_n}^{E_{\max}} n_\gamma(E_\gamma)\sigma(E_\gamma)dE_\gamma = \frac{N_n}{N_t N_\gamma \xi \varepsilon_n g}$$

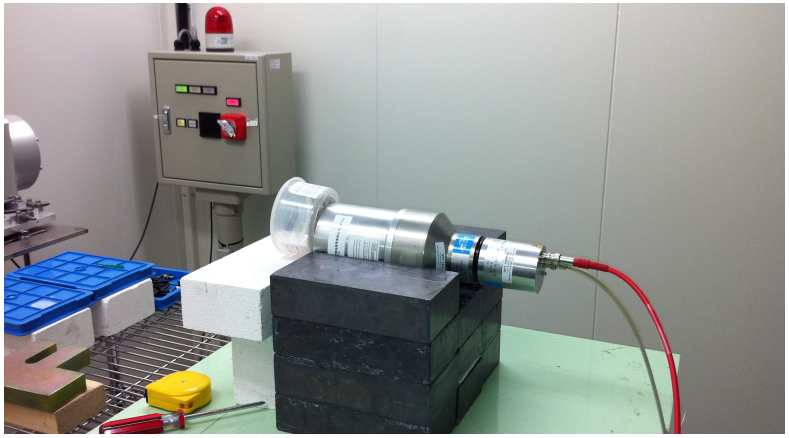


Solve integral using
Taylor expansion method

20 ^{3}He proportional counters

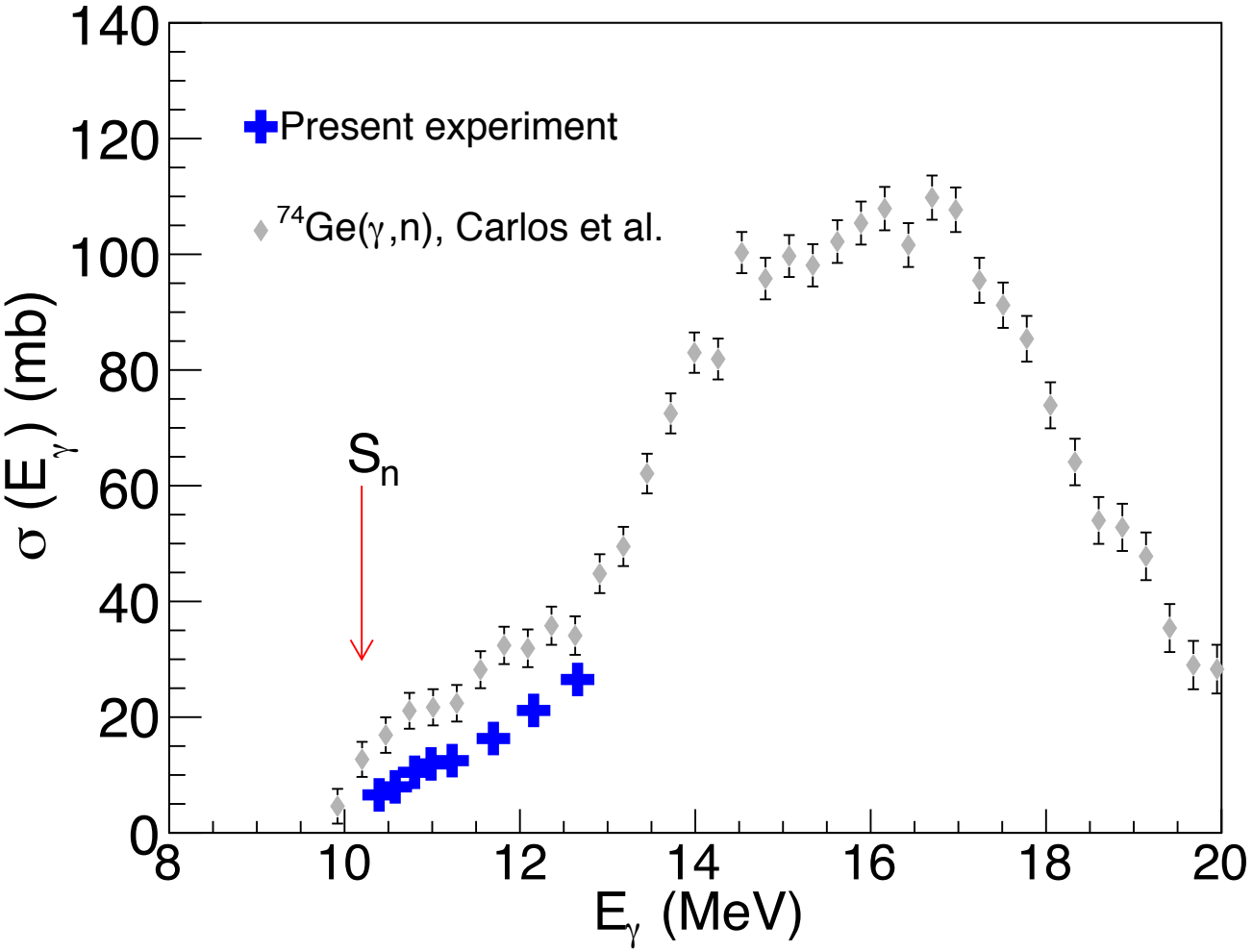


$$\int_{S_n}^{E_{\max}} n_\gamma(E_\gamma)\sigma(E_\gamma)dE_\gamma = \frac{N_n}{N_t N_\gamma \xi \varepsilon_n g}$$



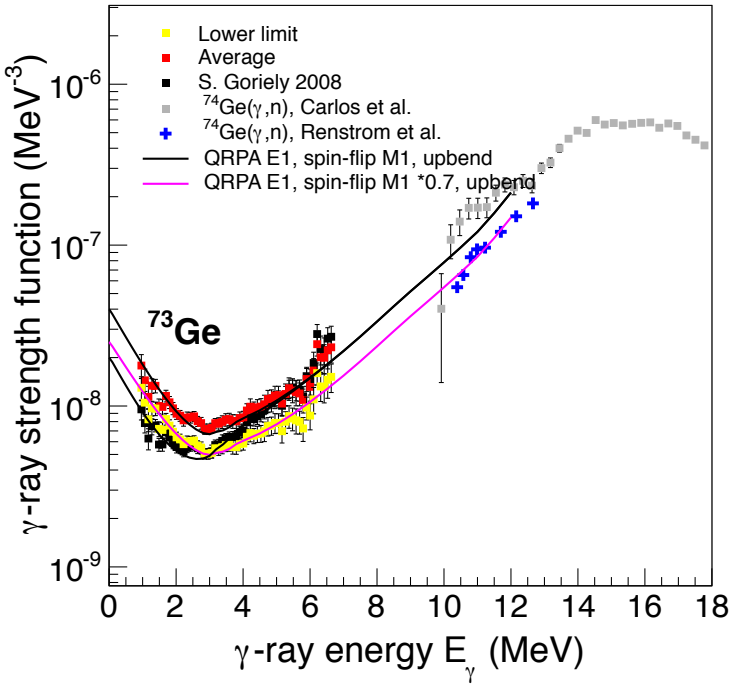
Solve integral using
Taylor expansion method

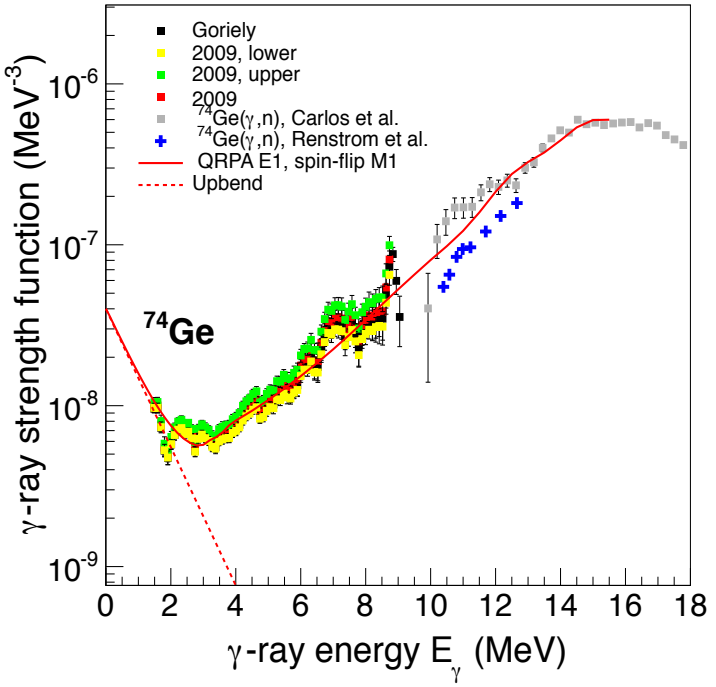
Photoneutron cross sections, ^{74}Ge

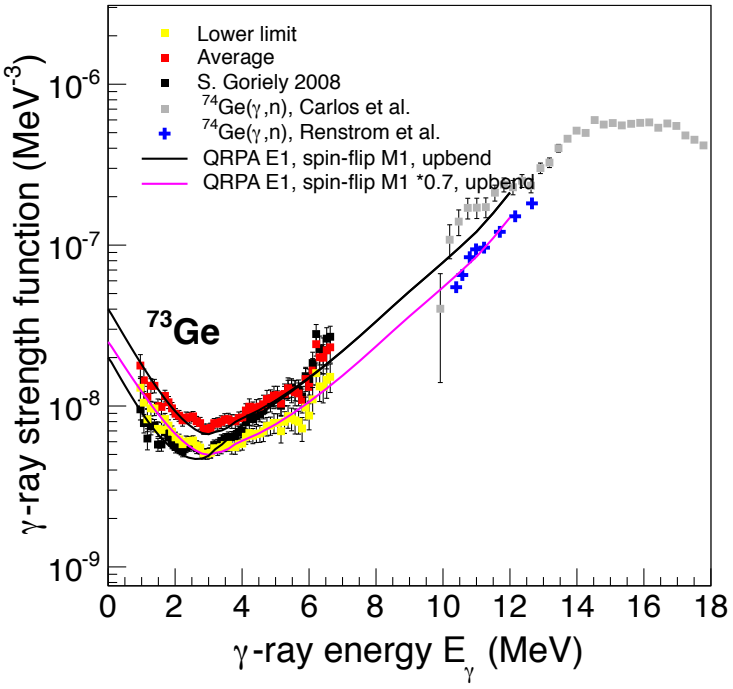


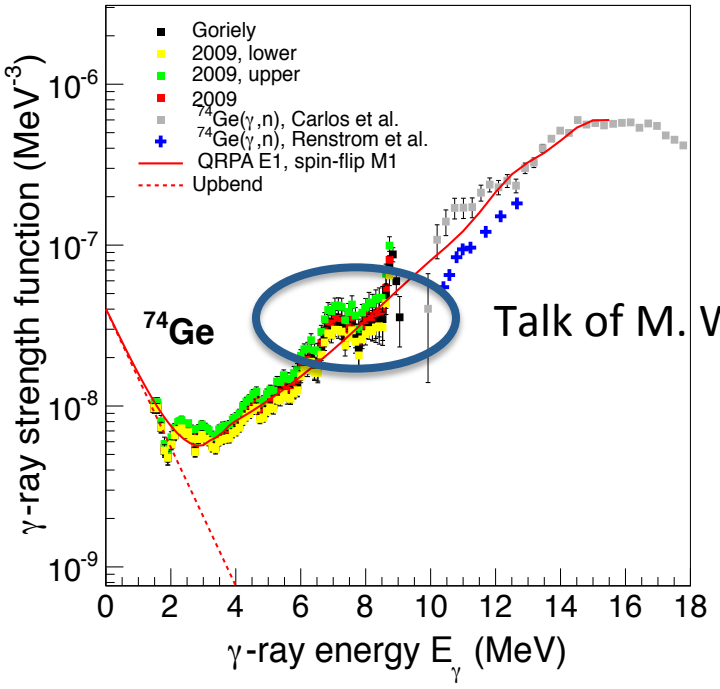
$$f\uparrow(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma(E_\gamma)}{E_\gamma}$$

Detailed balance $f\uparrow = f\downarrow$
(allows us to put it all together)



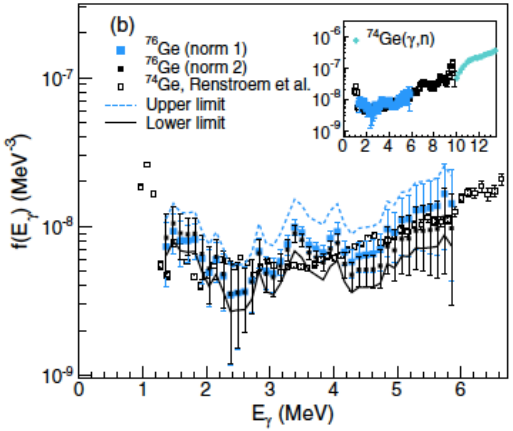




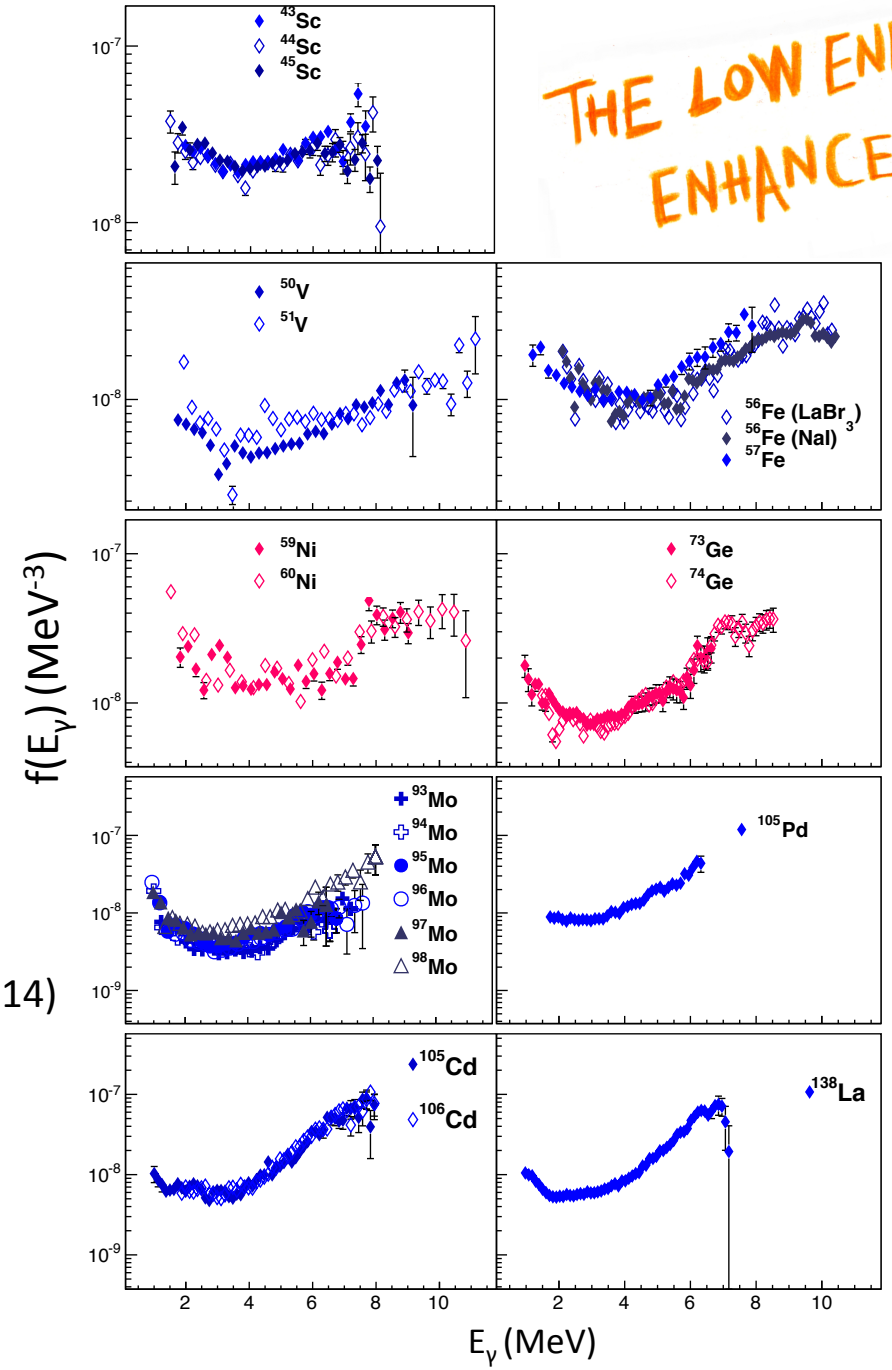


Talk of M. Wiedeking ☺

β-Oslo upbend

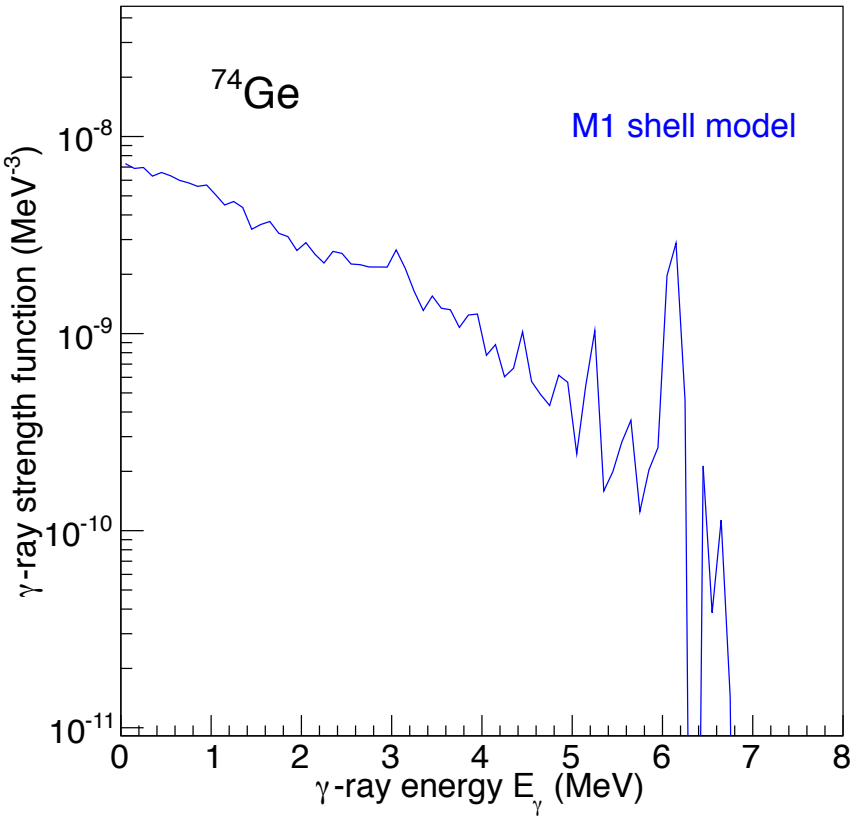


A. Spyrou, PRL **113**, 232502 (2014)



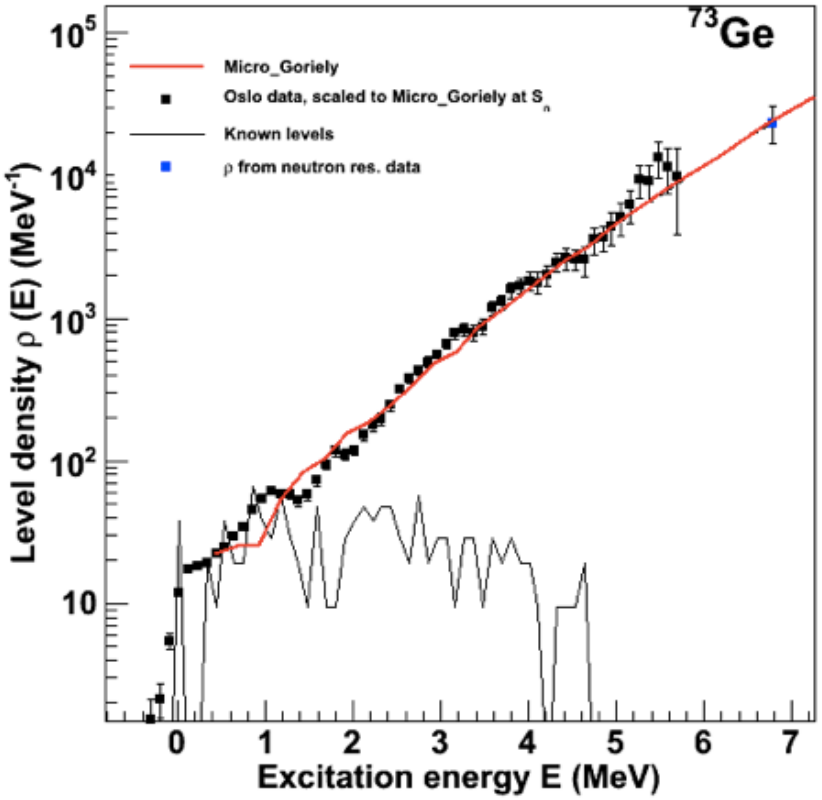
THE LOW ENERGY ENHANCEMENTS...

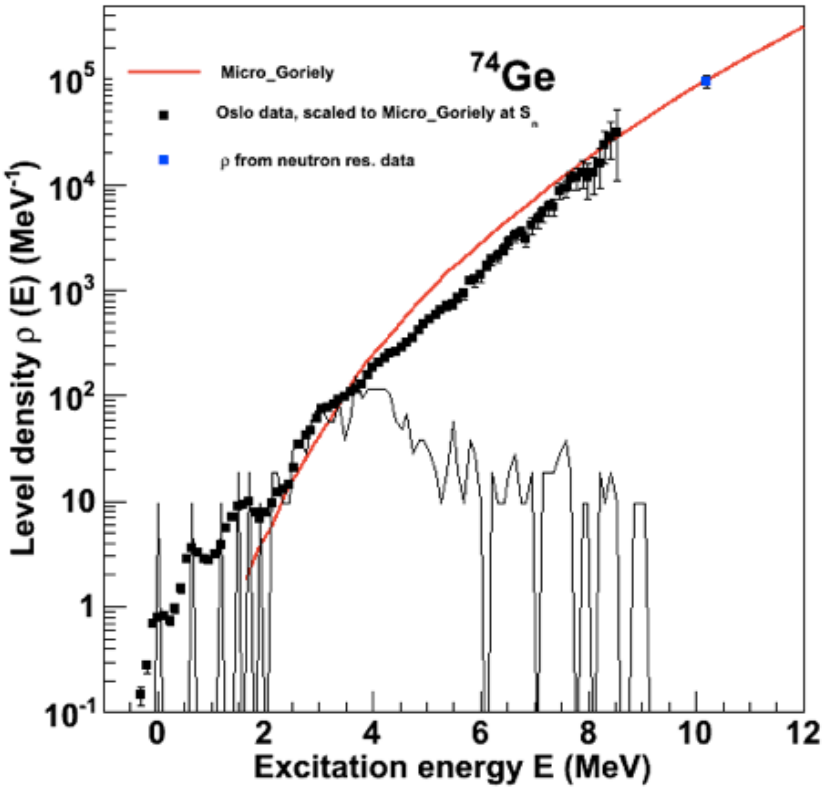
Shell-model calculations, ^{74}Ge



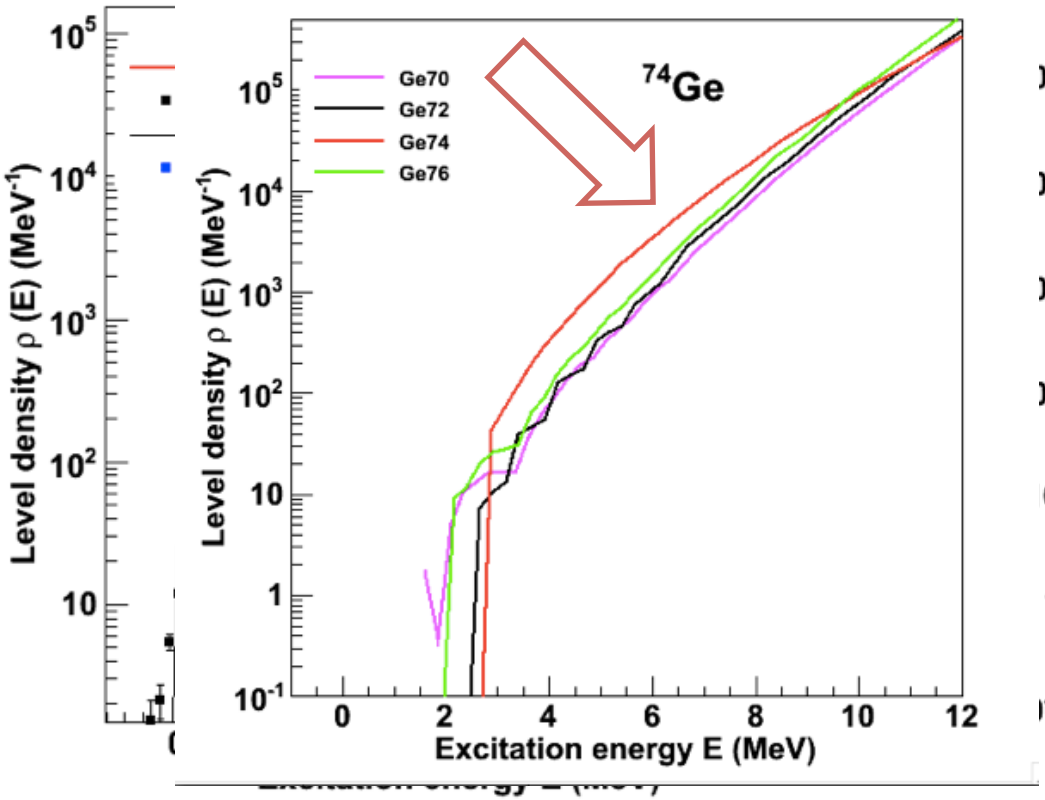
Talk of R. Schwengner

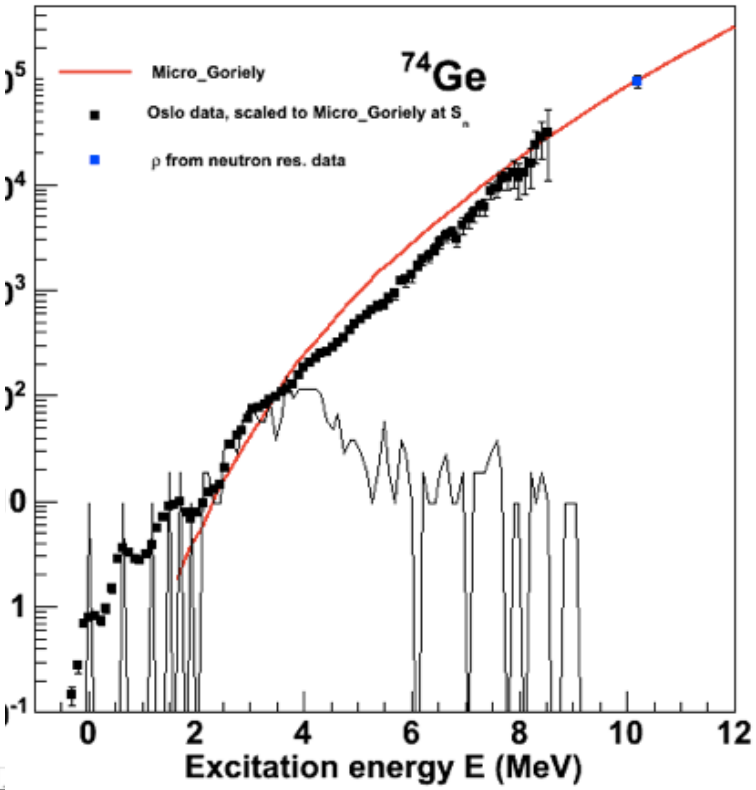
Level densities of ^{73,74}Ge



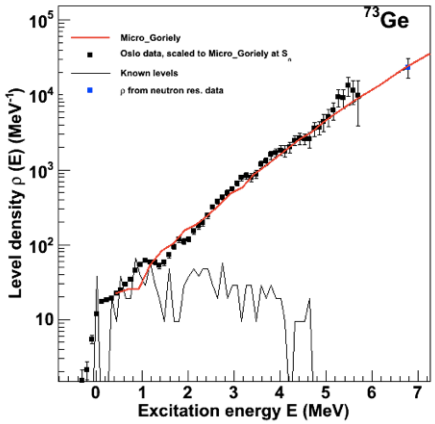


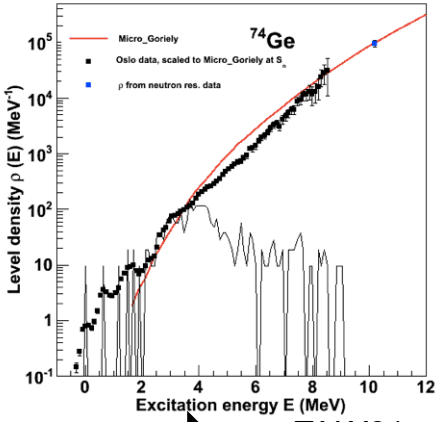
S. Goriely et al., Phys. Rev. C 78 064307, (2008)


Level density ρ (E) (MeV^{-1})
Ge70
Ge72
Ge74
Ge76
^{74}Ge
Excitation energy E (MeV)

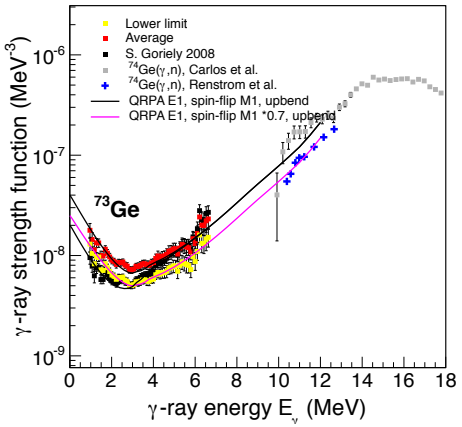

Micro_Goriely
^{74}Ge
Oslo data, scaled to Micro_Goriely at S$_n$
ρ from neutron res. data
Excitation energy E (MeV)

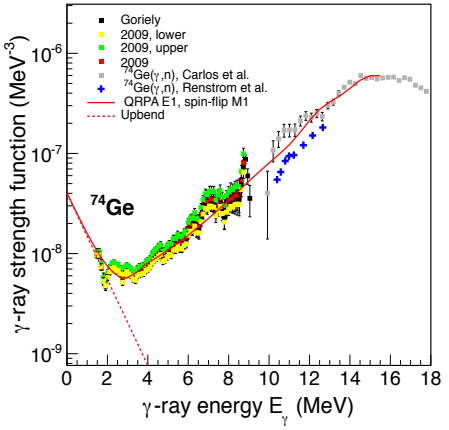
Constraining (n, γ)-cross sections

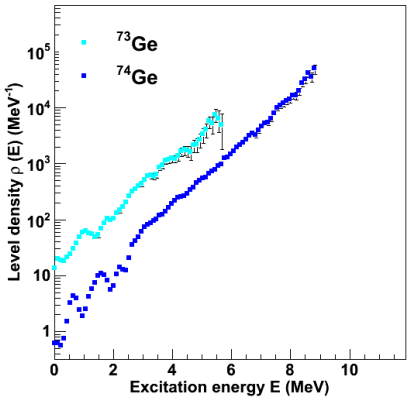




TALYS*



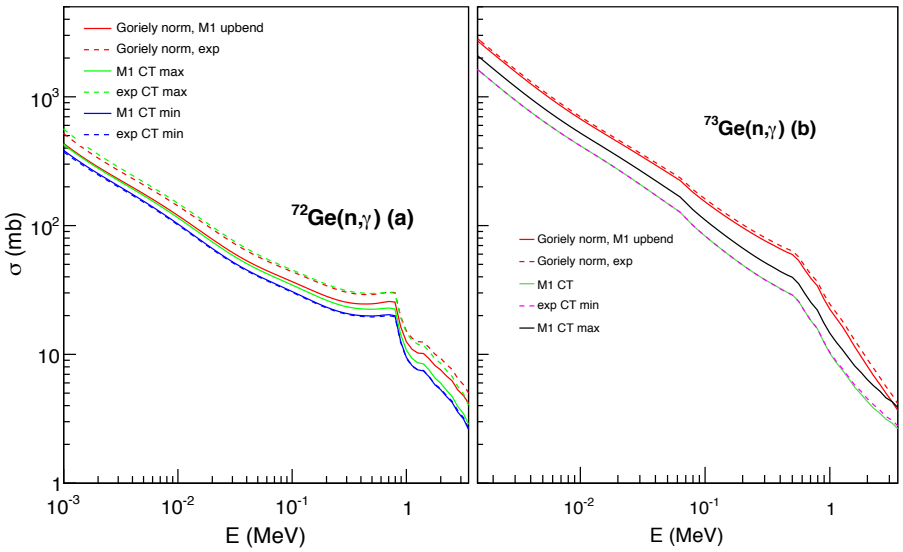


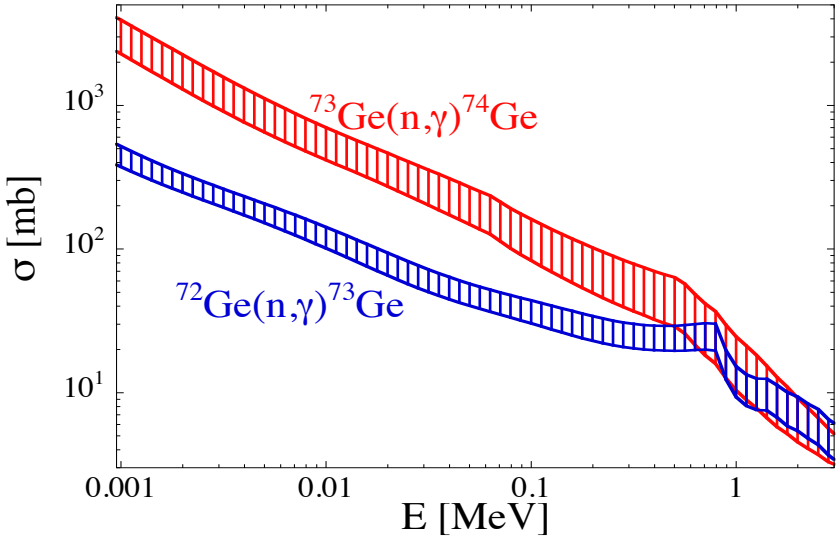


Neutron optical potential

*TALYS: Koning et al., http://www.talys.eu

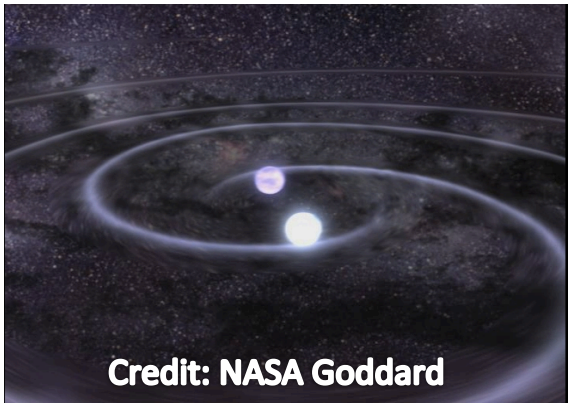
Using a variety of different inputs in TALYS

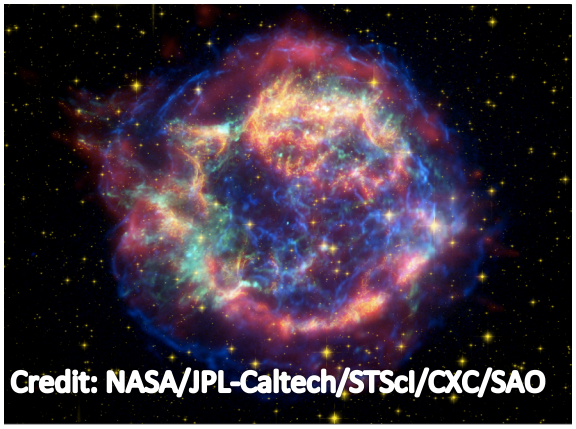


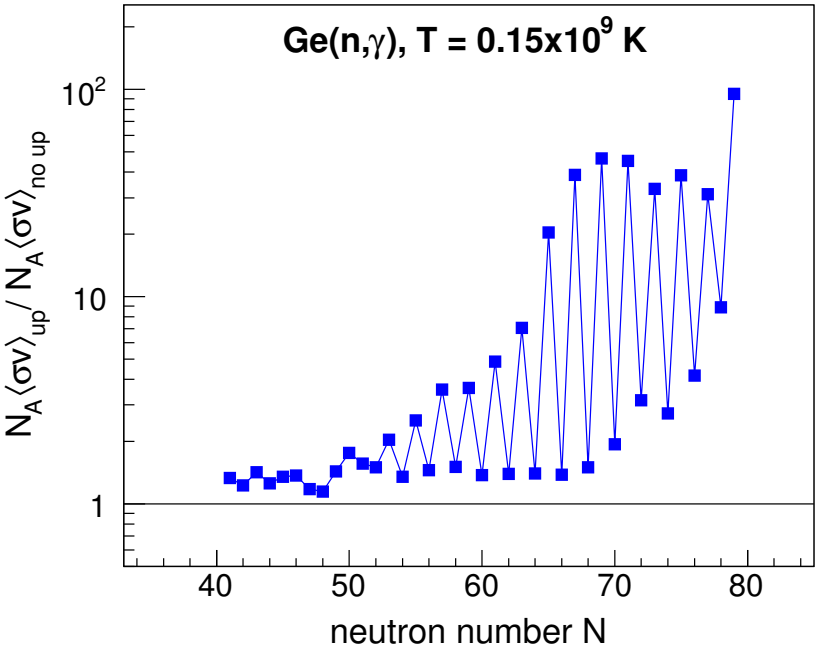


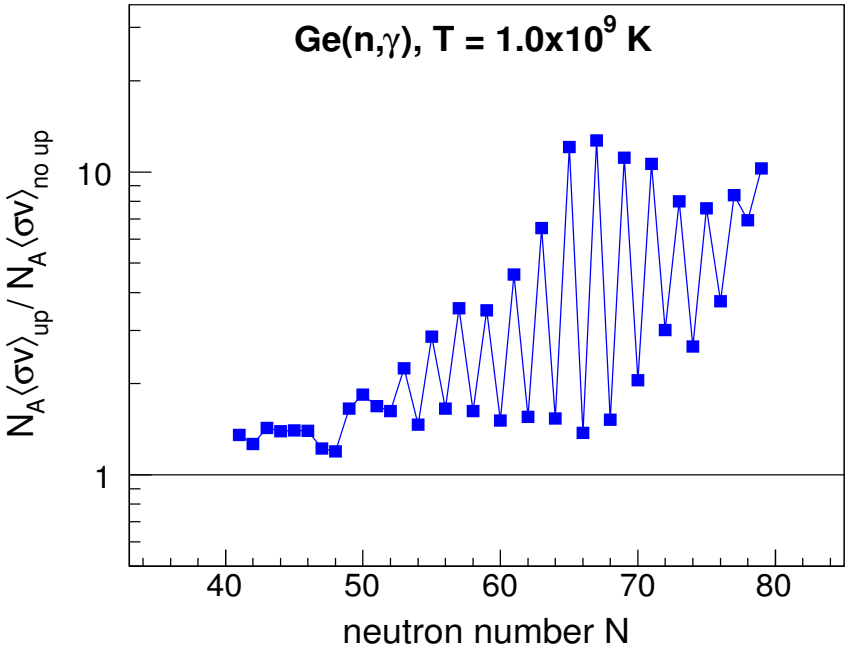
Maxwellian Average Cross Sections

Reaction	kT (keV)	MACS (mb) (new)	MACS(mb)*
^{72}Ge(n,γ)	30	66 (13)	73 (7)
^{73}Ge(n,γ)	30	294 (78)	243 (47)

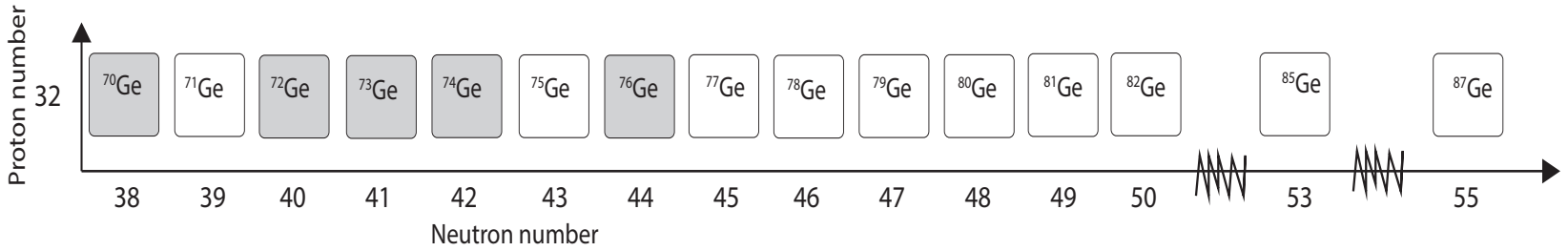

Credit: NASA Goddard


Credit: NASA/JPL-Caltech/STScI/CXC/SAO


Ge(n,γ), T = 0.15x10^9 K
10^2
10
1
40
50
60
70
80
neutron number N
N_A⟨σv⟩_up / N_A⟨σv⟩_no up


Ge(n,γ), T = 1.0x10^9 K
10
1
40
50
60
70
80
neutron number N
N_A⟨σv⟩_up / N_A⟨σv⟩_no up

The search for the upbend continues…



Beta-Oslo method on ^{78,80}Ge

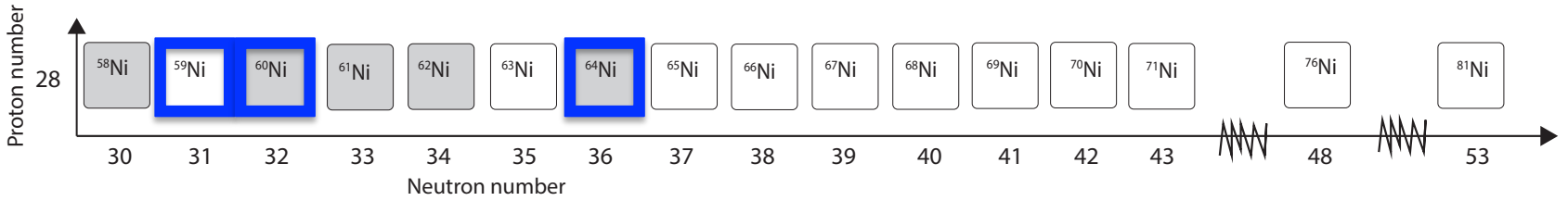
NSCL PAC 39 PROPOSAL

“Search for the upbend in neutron-rich Ge isotopes”

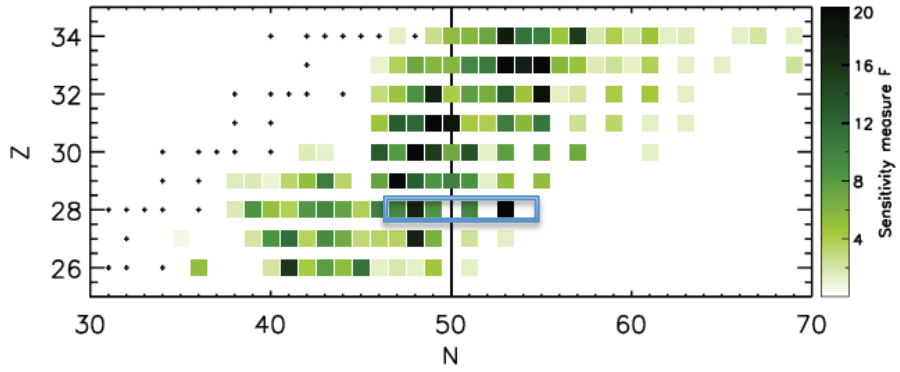
Spokespersons:

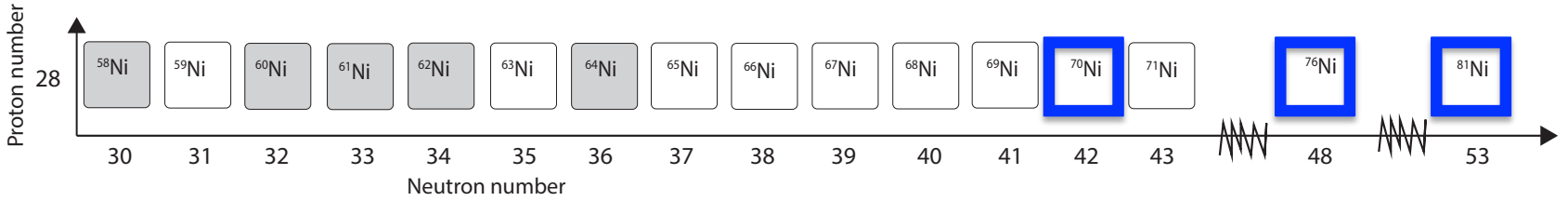
A. C. Larsen, M. Guttormsen, T. Renstrøm (University of Oslo, Norway)

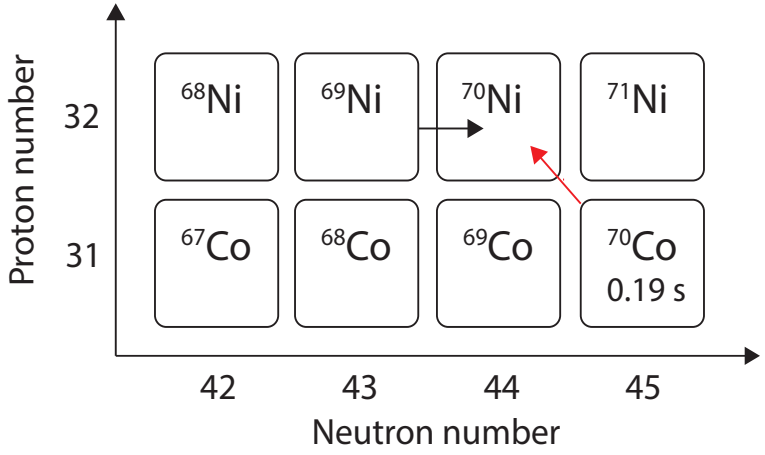
A sneek peek at the most neutron rich isotope analysed to date using the beta-Oslo method…



Experiments performed in Oslo,
γSF to be published.

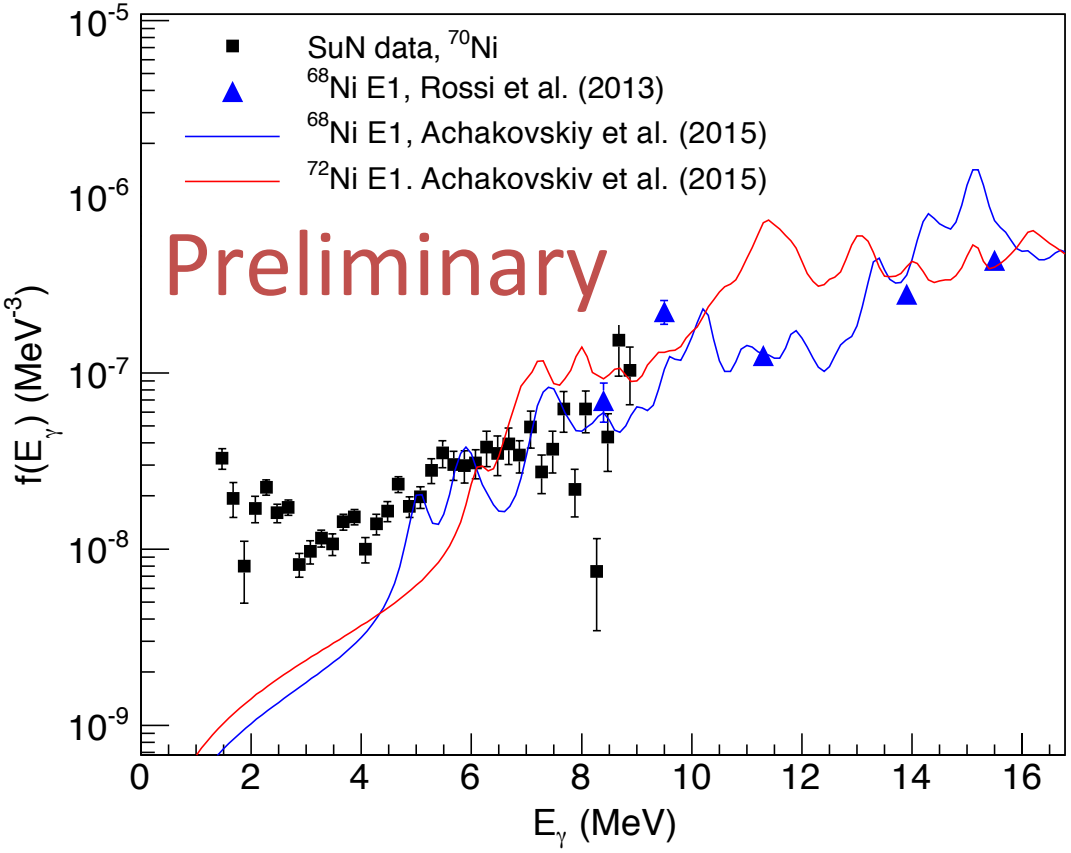






The β-Oslo method for ^{70}Ni

Discretionary beam time @ NSCL/MSU, February 2015;
^{70}Co beta-decaying into ^{70}Ni



[S.N. Liddick et al., in preparation]

Summary

- Strength functions of ^{73,74}Ge both show a low energy enhancement
- If this enhancement is there for more neutron-rich Ge-isotopes, it will strongly influence the (n, γ) reaction rates
- Shell-model calculations indicate that the upbend is of M1-type
- Good agreement between the photo-neutron data and the Oslo data

THANK YOU FOR LISTENING