

Statistical properties of warm nuclei:
Investigating the low-energy enhancement in the gamma strength function of
neutron-rich nuclei

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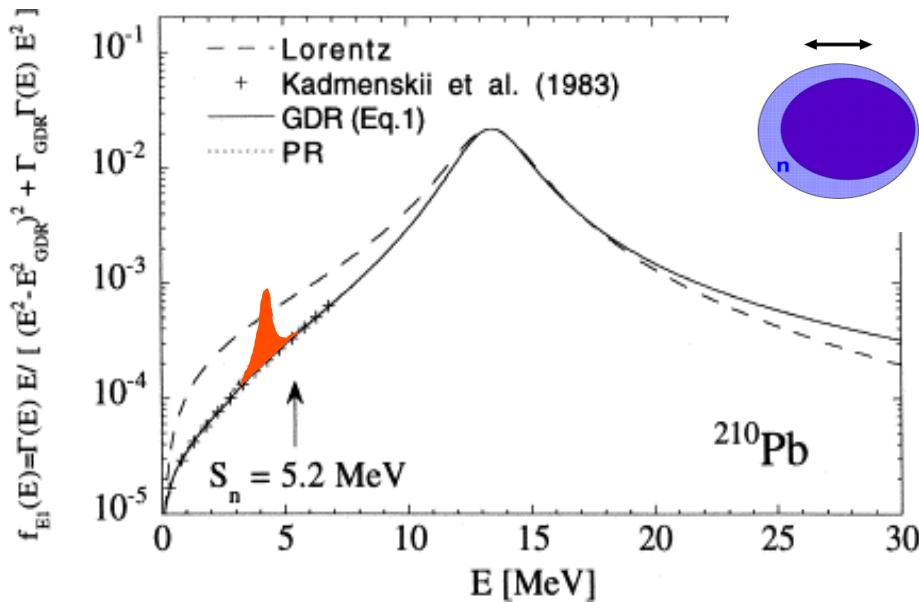
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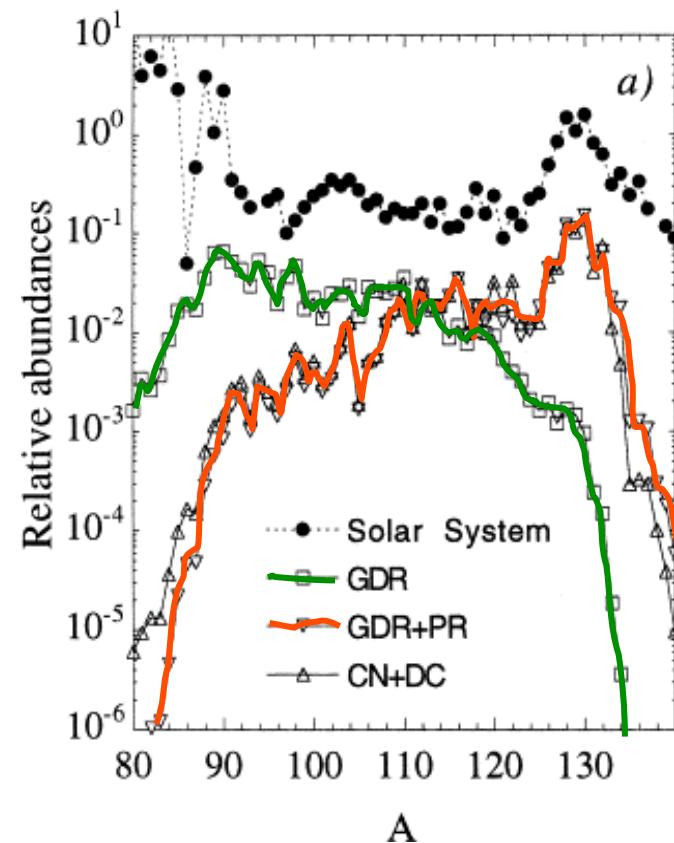
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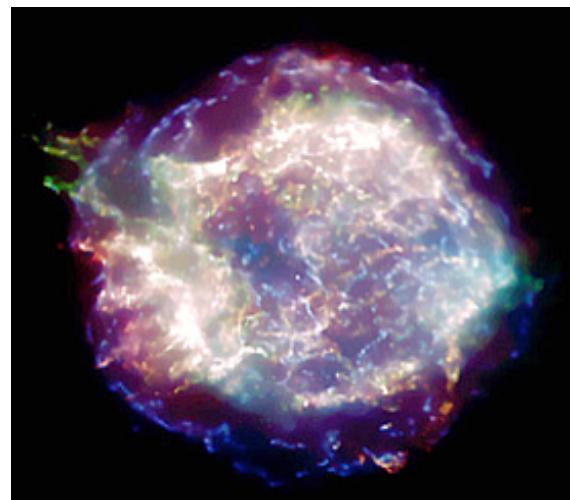
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S. Goriely Phys. Lett. B 436 (1998)

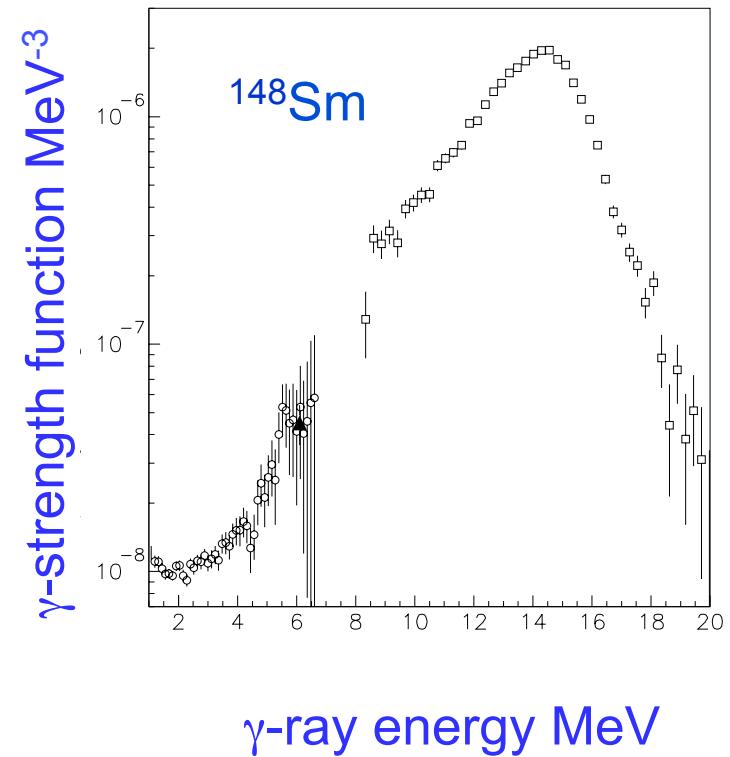
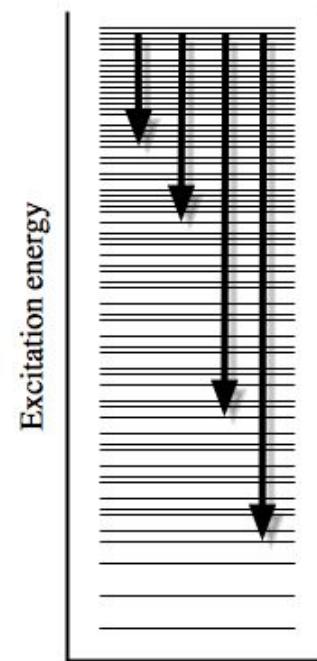
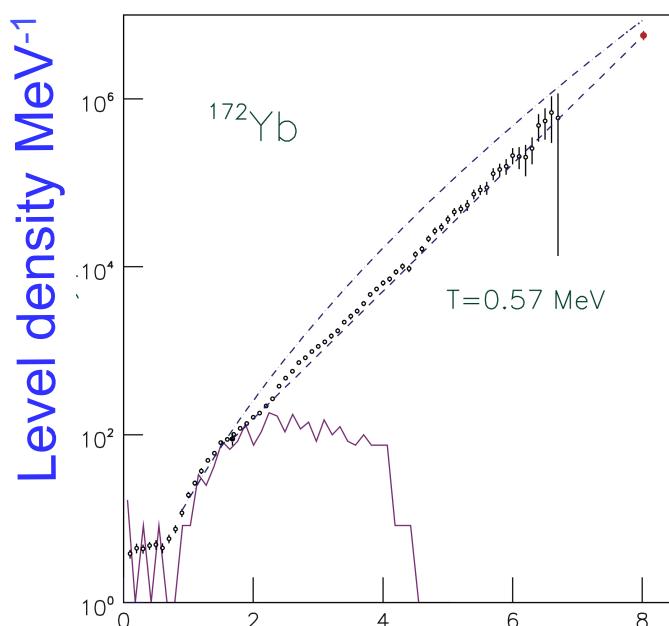


- Gamma strength functions important input in cross section calculations
- Small resonances in the strength function can effect the results of abundance calculations.
- We need more/better data on gamma strength functions, especially for exotic nuclei



Method A (The Oslo method)

Measure gamma-particle coincidences
isolate the primary gamma spectra

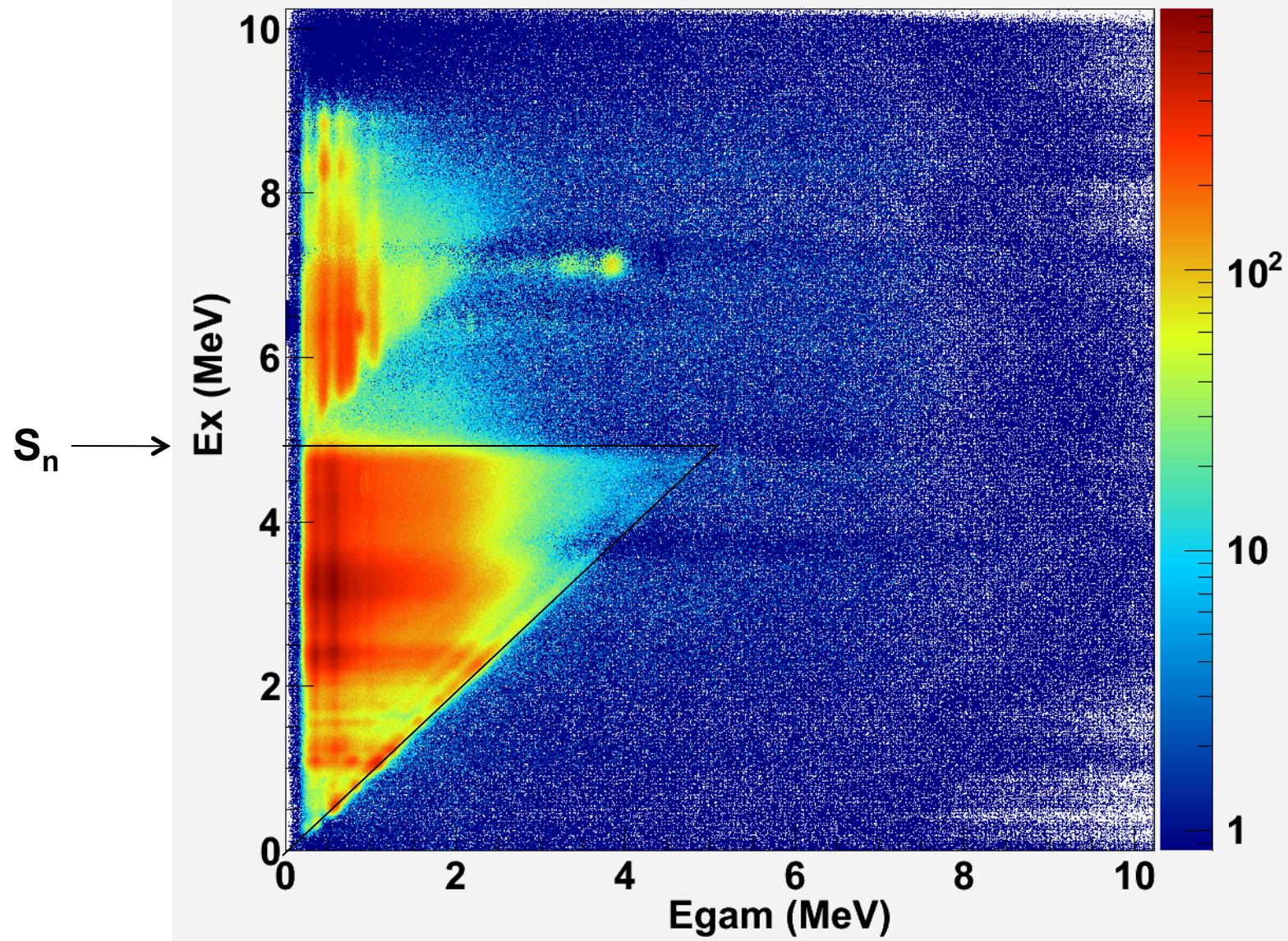


$$P(E_i, E_\gamma) \propto \rho(E_f) \cdot T(E_\gamma)$$

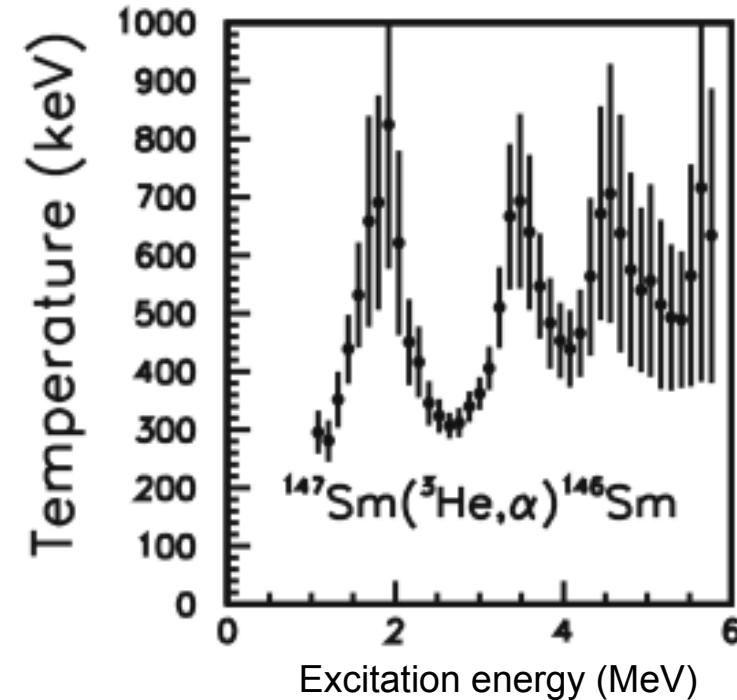
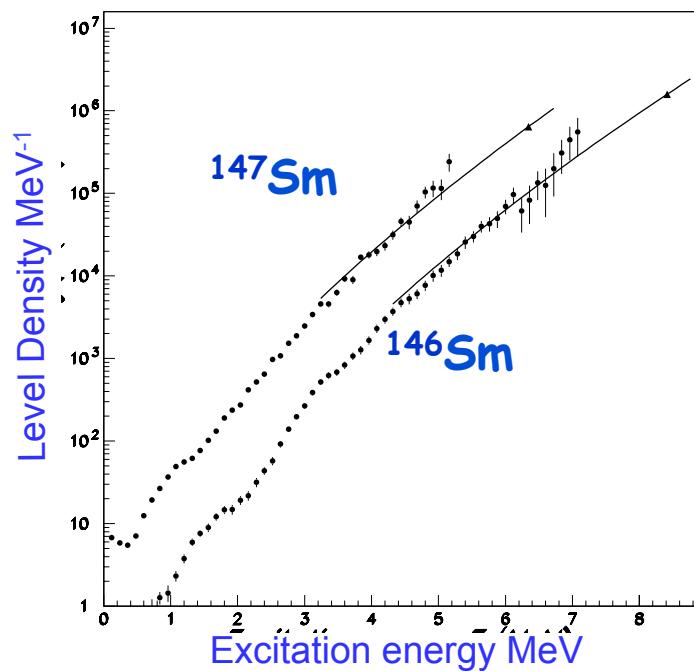


$^{232}\text{Th}(\text{d},\text{p})$

Egam-Ex



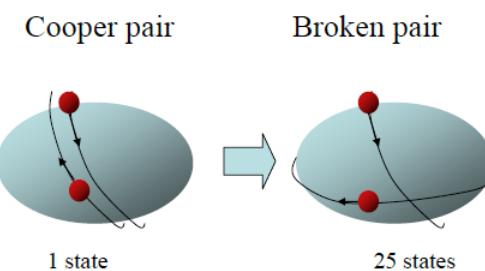
Thermodynamic properties of atomic nuclei



Level density \Rightarrow entropy \Rightarrow temperature

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

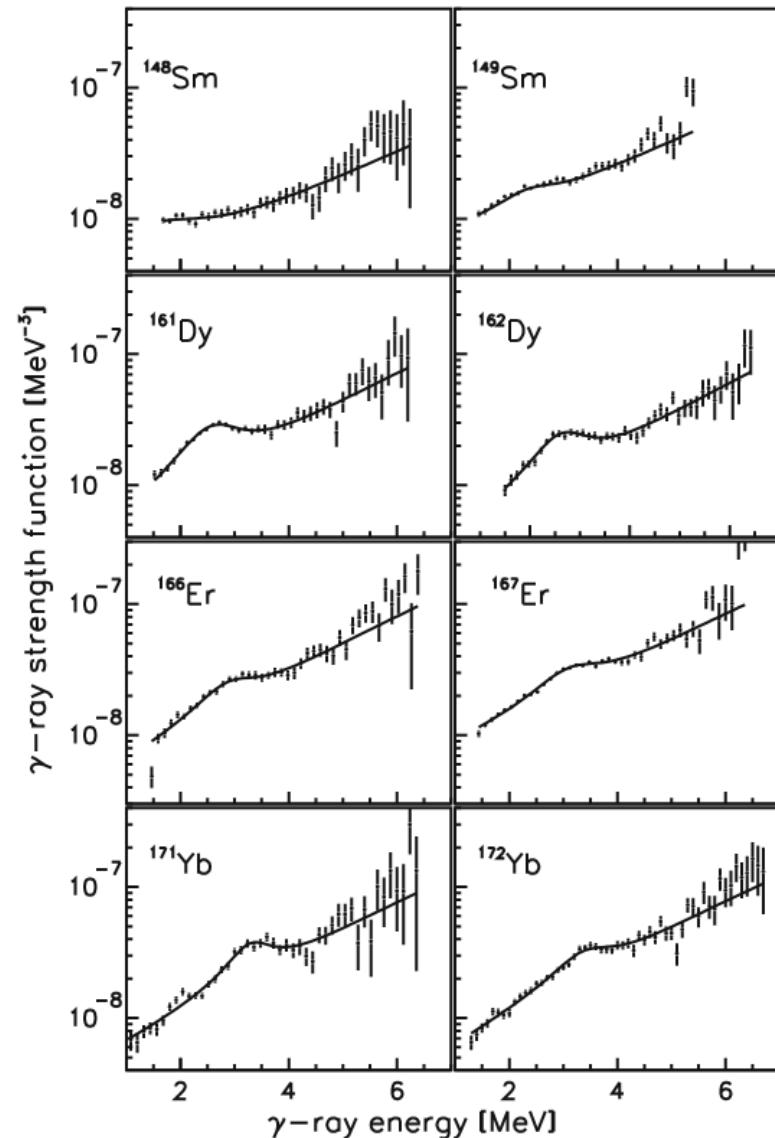
$$T(E) = \left(\frac{\partial S(E)}{\partial E} \right)_V^{-1}$$



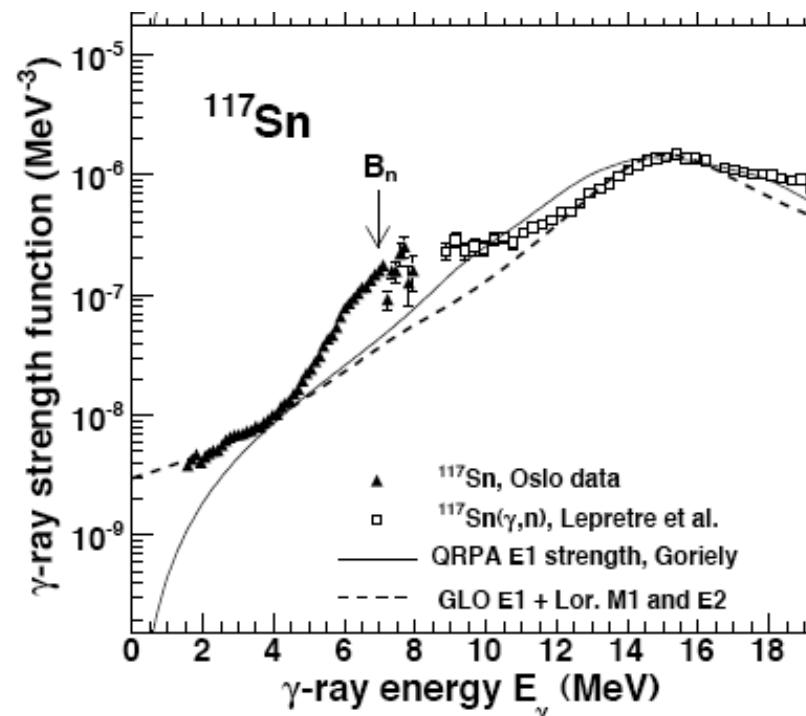
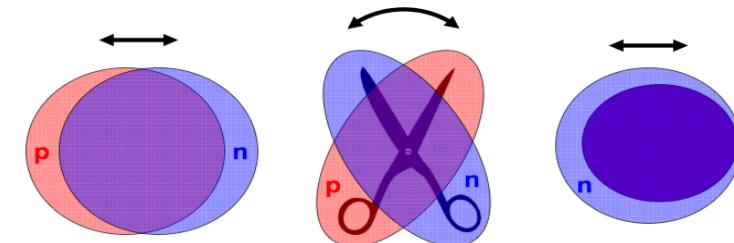
pairing phase transition



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



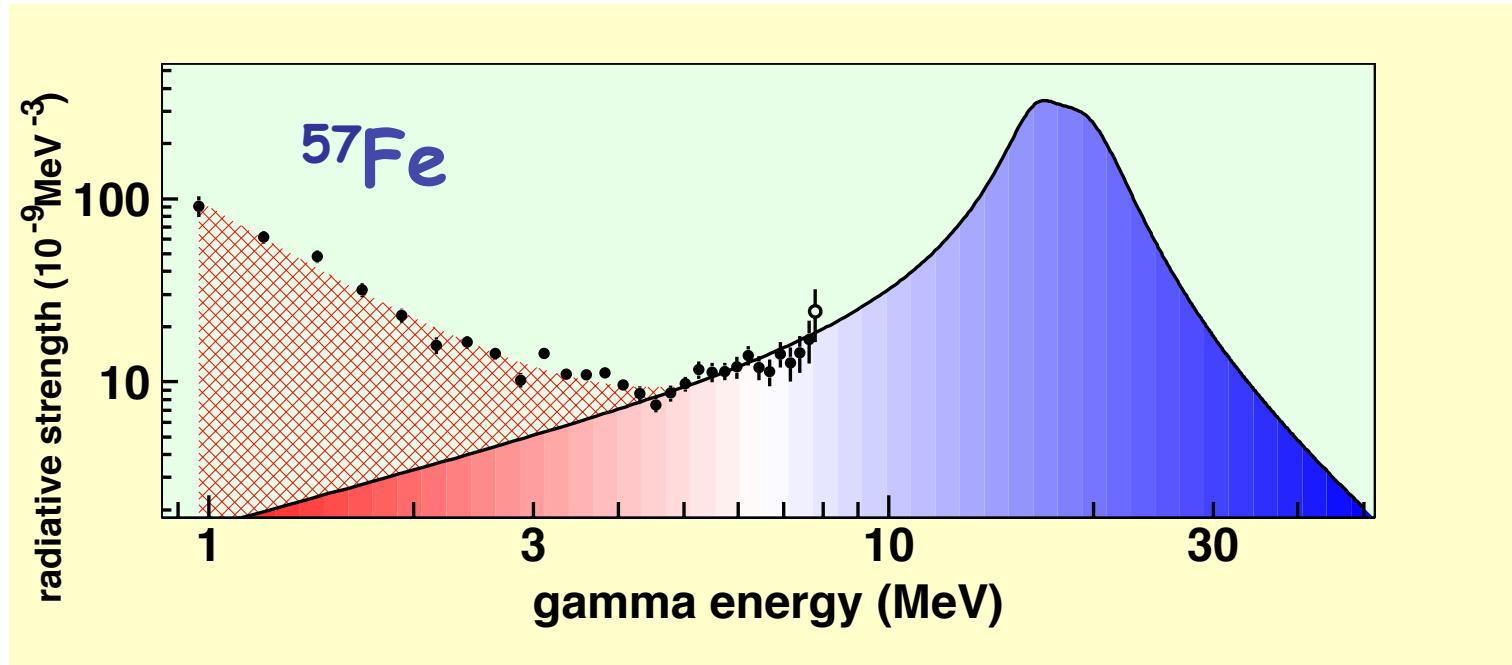
S.Siem et al. PRC(2002)



U.Agvaanluvsan et al.
PRL(2009)

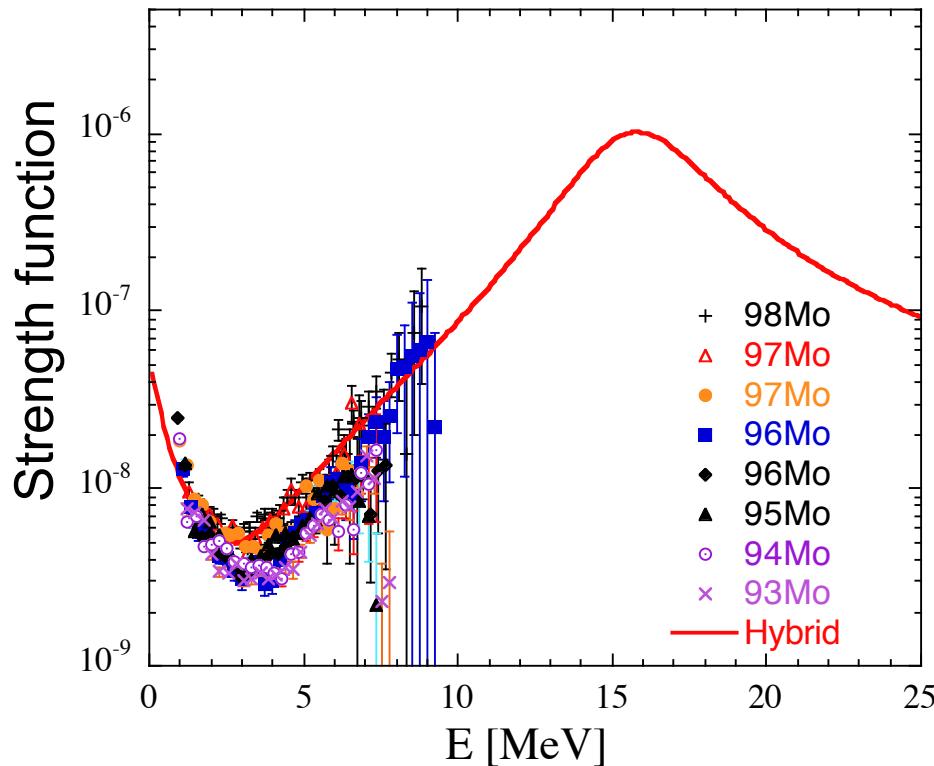


Low energy enhancement of the strength function

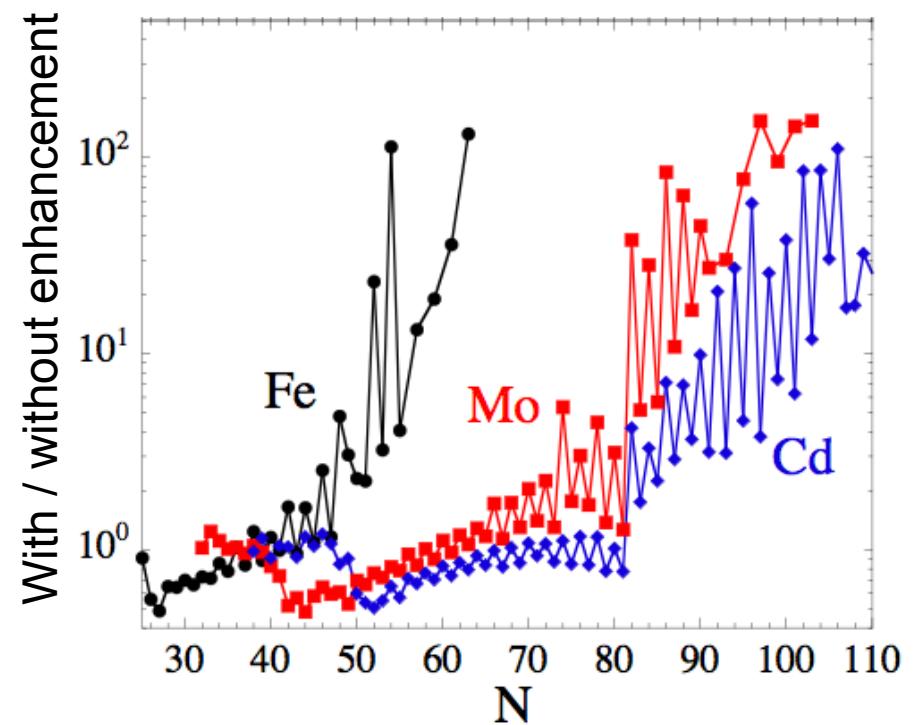


Totally unexpected and so far unexplained

How does the low energy enhancement effect neutron capture cross sections?



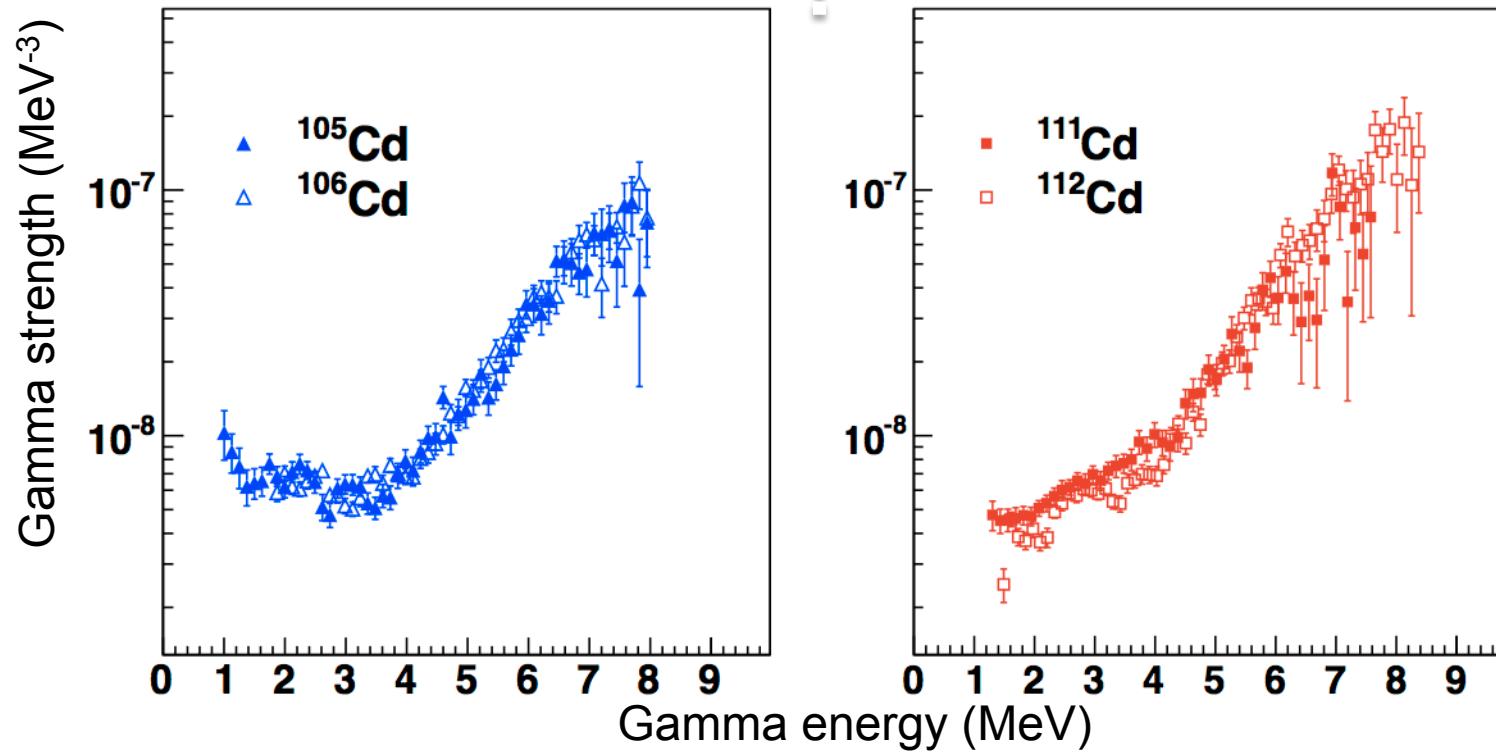
Assuming the strength functions of Mo isotopes all have the same energy trend



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

But will the enhancement also be there for neutron rich nuclei?
We need to measure it.

PRELIMINARY

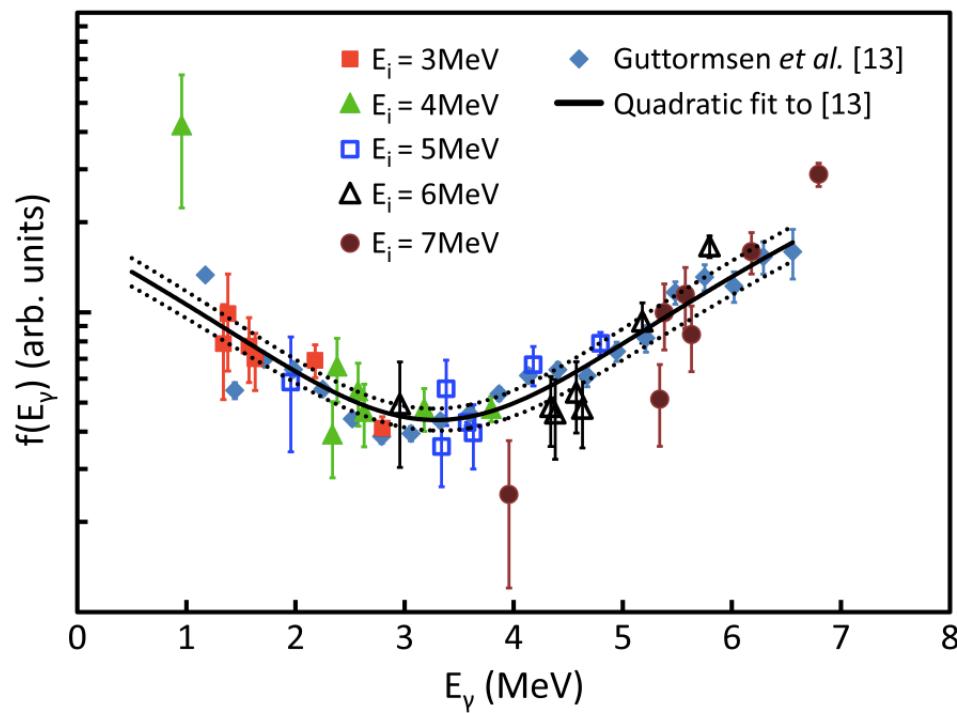


Many thanks to Cath Scholey @ JYFL for lending us the $^{106,112}\text{Cd}$ targets!



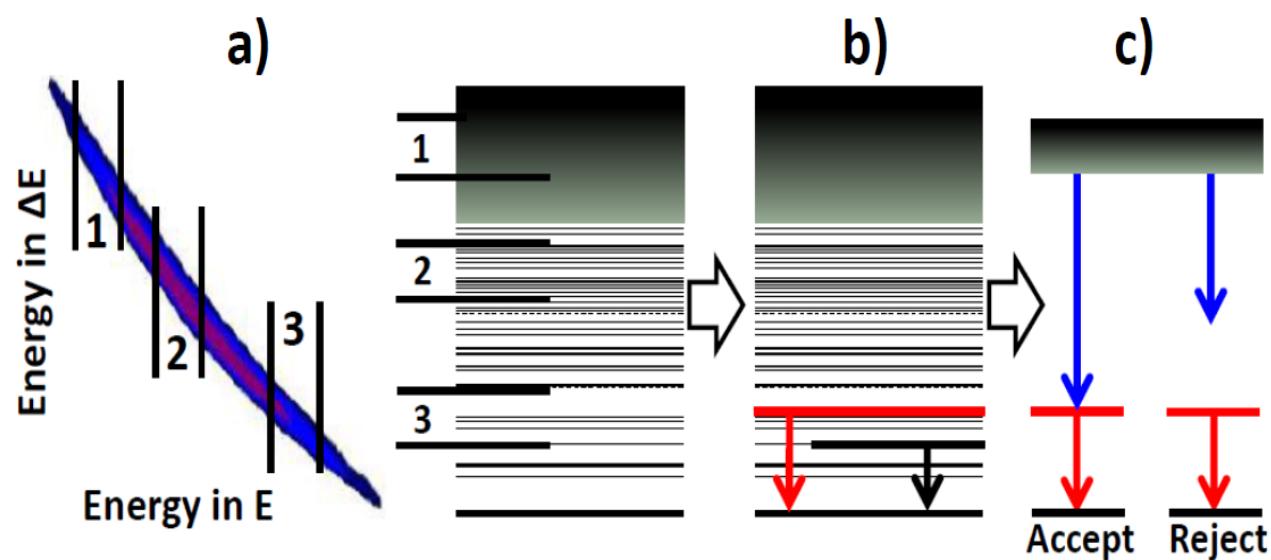
The low energy enhancement was recently confirmed in ^{95}Mo

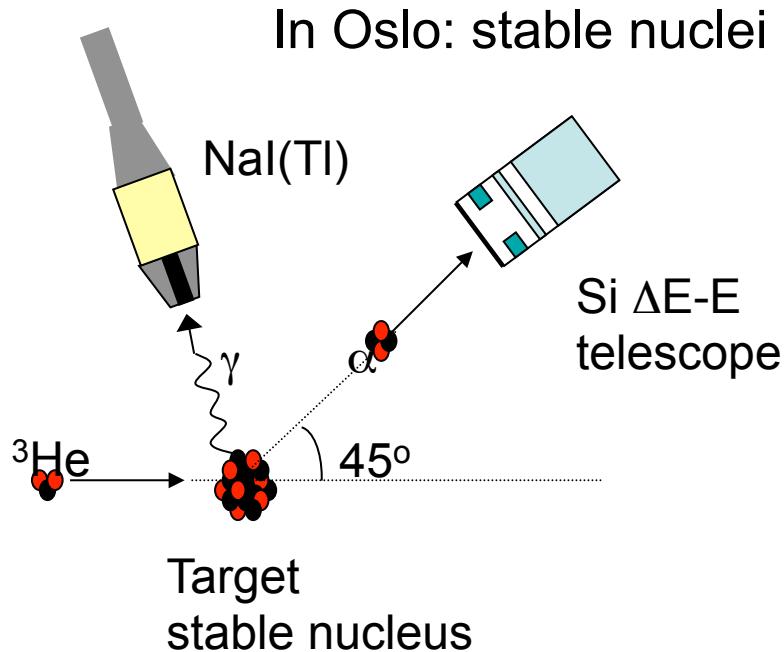
M. Wiedeking, L. A. Bernstein *et al.*, PRL 108, 162503 (2012)



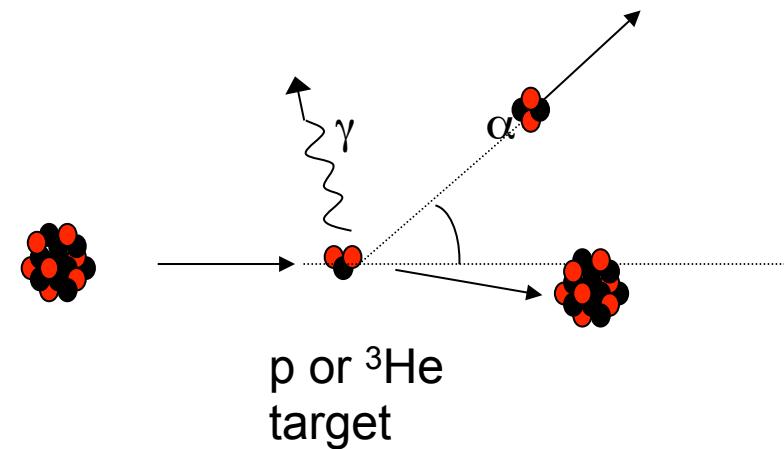
Proton- γ - γ correlations from the $^{94}\text{Mo}(\text{d},\text{p})^{95}\text{Mo}$ reaction
(experiment at Berkeley National Lab).
Ge detectors. Completely model-independent!

Method B (Wiedeking et al)





HIE-ISOLDE: Exotic beams,
using inverse kinematics



Conclusion:

want to measure the gamma strength function with two independent methods:

Method A (Oslo method)

Method B (Wiedeking et al.)

Well established for normal kinematics,
first time in inverse kinematics



Experimental details:

Beam purity: >95% important for the Oslo method.
Should be no problem (IS469 had >99% purity)

Beam: ^{66}Ni beam of 5,5 MeV/u
Intensity ca 1×10^7 pps at MINIBALL

Target: very thin 0.1 mg/cm² polyethylene, to minimize uncertainty in excitation energy from straggling/energy loss in target.

gamma detection: MINIBALL + Replace/add large volume LaBr₃(Ce) detectors (3,5 x 8") to have higher efficiency for high energy gamma rays. Ordering two in 2012. Expect to have 6 detectors by the time of the experiment.

charge particle detectors: Annular strip CD detector as Delta E + two QQQ2 E detectors

Shifts requested: 24 total (21 shifts of ^{66}Ni and 3 shifts for setup and calibrations)

The current proposal is a pilot (low risk experiment) based on the existing MINIBALL setup.

Future perspectives:

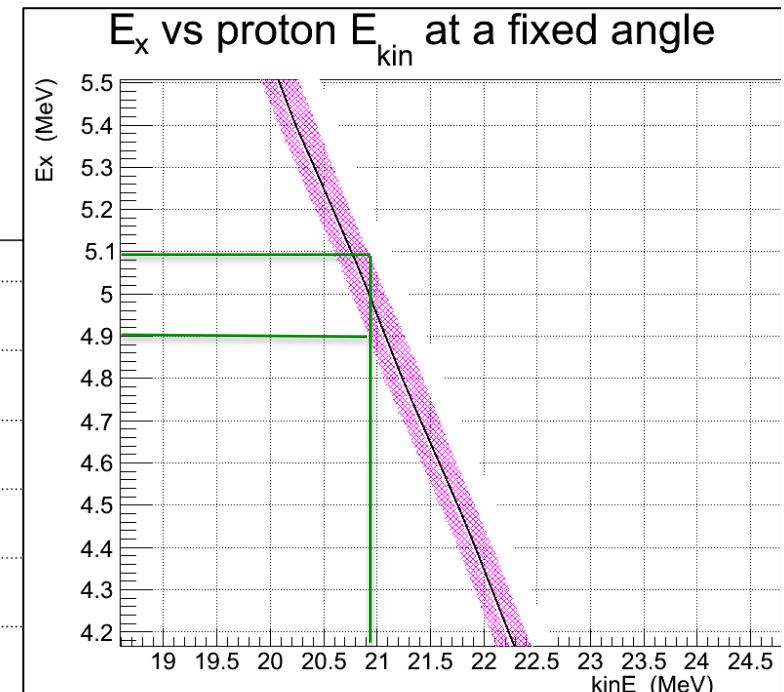
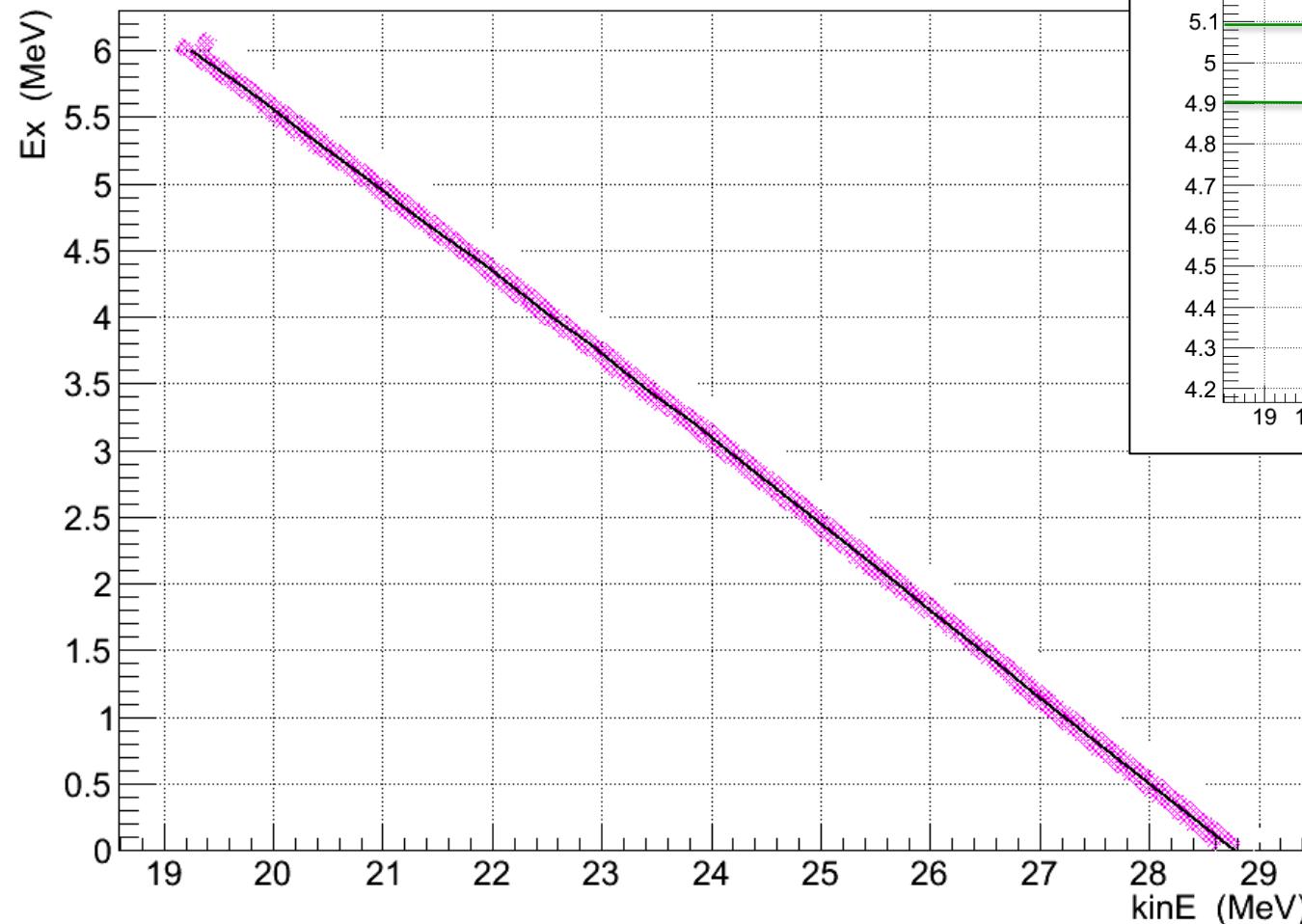
- would like higher beam energies
- and different reactions like (d,p) or (t,p)
- different beams
- would need a new dedicated setup/ charged particle detector

Extra slides

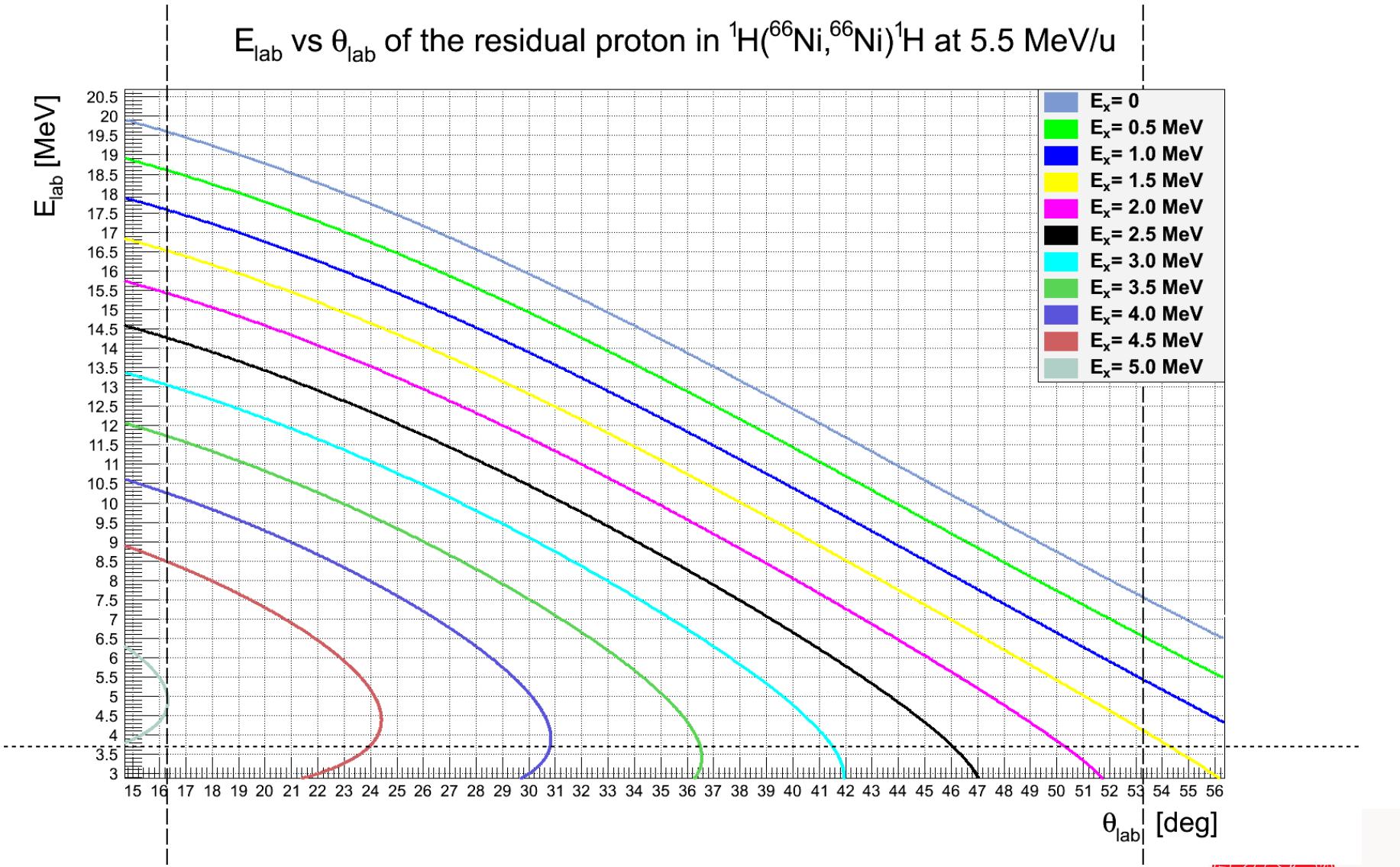


The uncertainty in the Excitation energy due to beam energy spread is +/- 100KeV

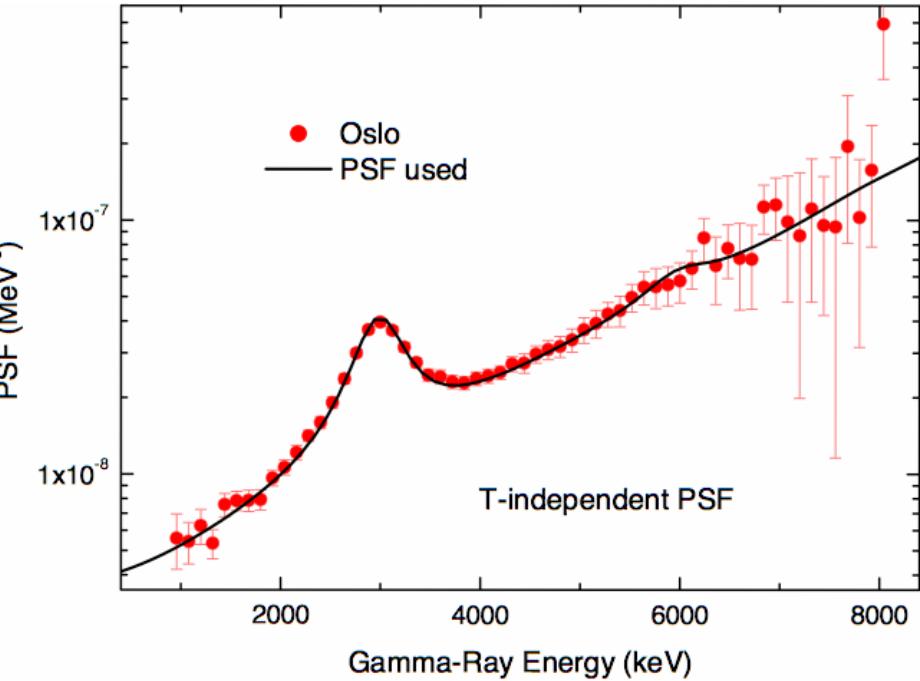
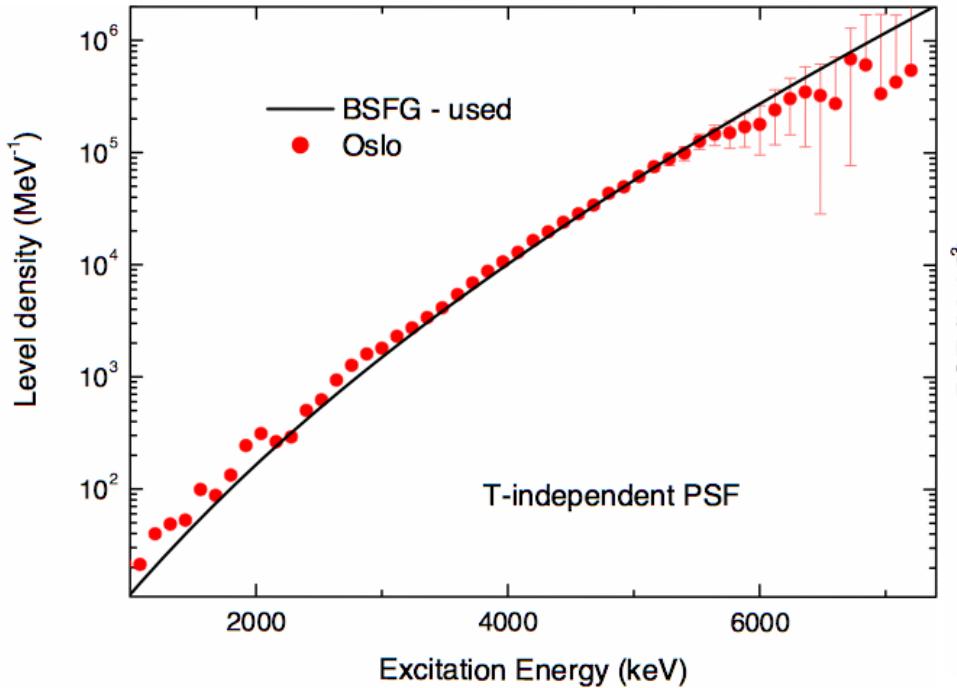
E_x vs proton E_{kin} at a fixed angle



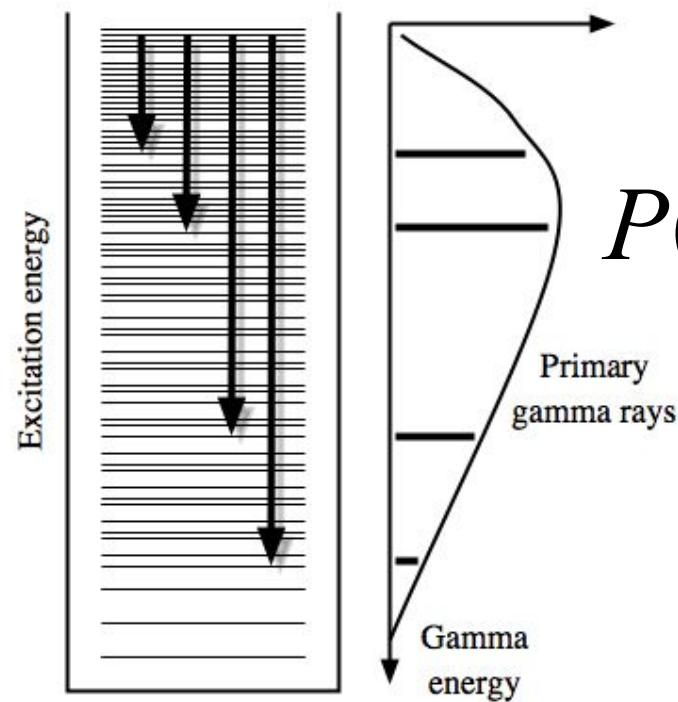
The angular resolution of the CD detector is causing the biggest uncertainty in the excitation energy..



Blind test of method



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*)

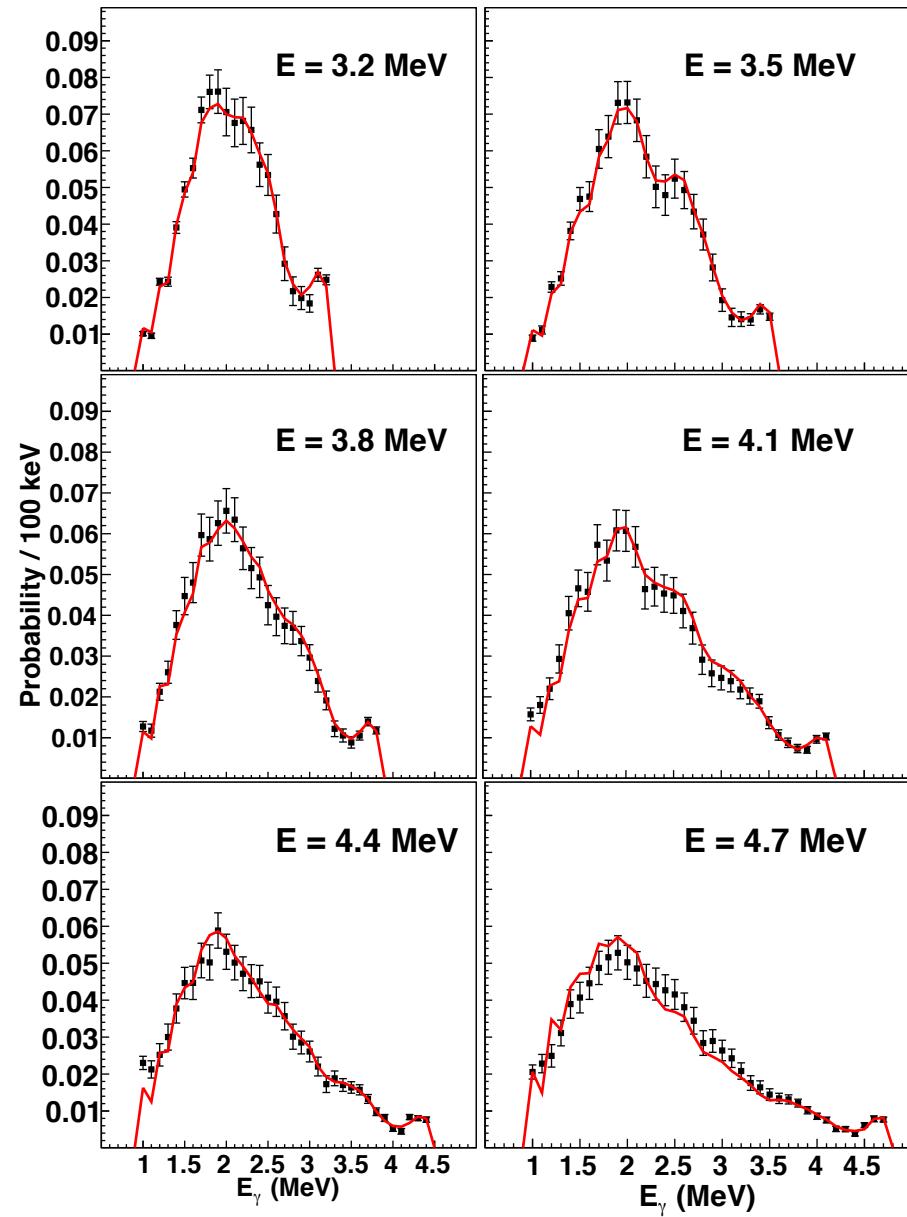
$$f(E_\gamma) \simeq \frac{1}{2\pi} \frac{\mathcal{T}(E_\gamma)}{E_\gamma^3}$$



How well does it really work?

$$P \sim \rho(E_f) \cdot f(E_\gamma) \cdot E_\gamma^3$$

^{233}Th -data



Charge breeding

The needed A/q can be found from $E_{\text{final}} = 2.9 + 14/(A/q)$ [MeV/u].

As the life times of the Ni-isotopes that have been produced at ISOLDE are long compared to the breeding time the loss in efficiency will originate from the losses in the charge breeding set up

In 2005 ^{68}Ni was charge bred to $A/q = 3.5$. In that case the total efficiency for the trapping efficiency, breeding efficiency into the required charge state and the transmission through REX was 3.5% This could give us a beam energy of 6.9 MeV/u, for ^{66}Ni .