Experimental study of level density and gamma-strength functions from compound nuclear reactions

Cross section of outgoing particles:

$$d\sigma(E) \sim \sigma_C(E) \frac{T_d(E')\rho_f(E^*)}{\sum_i T_{di}} dE$$

The particle transmission coefficients T are usually known from cross sections of inverse reactions (from optical model parameters).

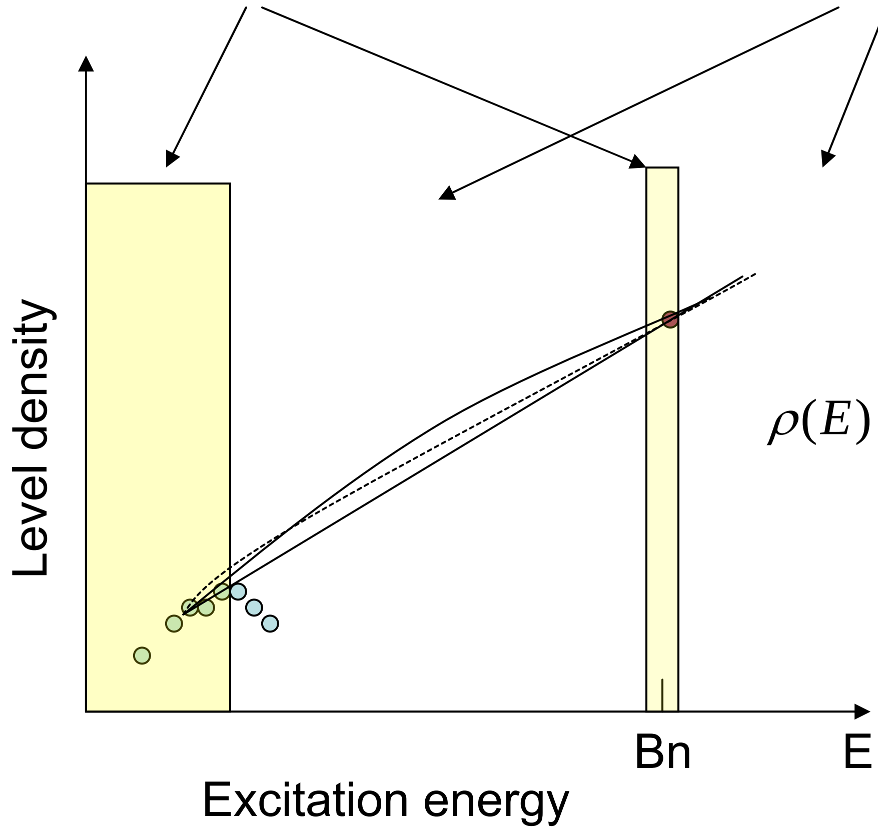
Level densities and
gamma-transmission coefficients
are most uncertain values !!!

How is nuclear level density estimated ?

Traditionally, for most of the nuclei, the level density is estimated on the basis of experimental information from low-lying discrete levels and neutron resonance spacing

Level density is known for most of the stable nuclei

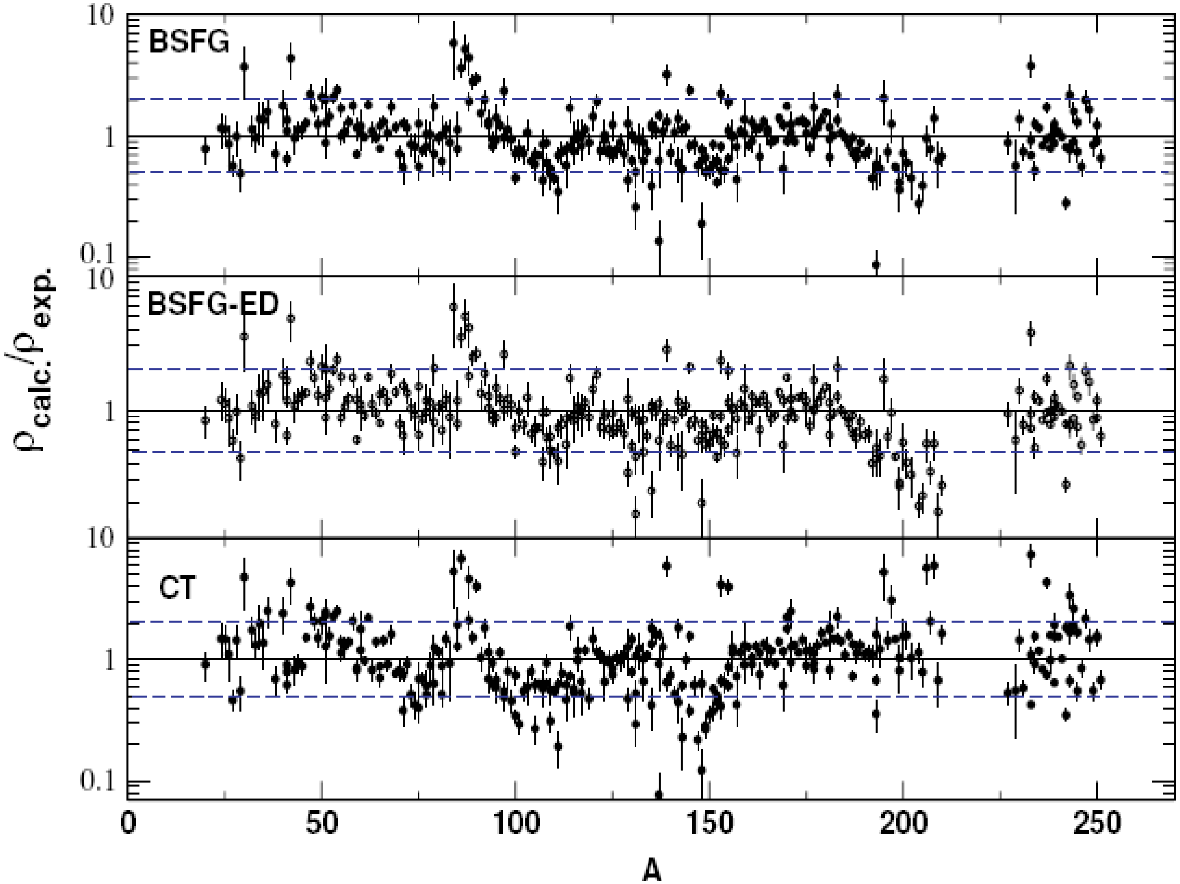
Level density is unknown for most of the nuclei



$$\rho(E) = \frac{\exp(2\sqrt{a(E-\delta)})}{12\sqrt{2}\sigma\, a^{1/4}(E-\delta)^{5/4}}$$

a, δ -parameters

σ = f(a, δ)



Test of the formulas proposed in the work for the LD at the neutron resonance energy. The dashed lines mark a difference by a factor of 2 between experimental and calculated values.

T.von Egidy, D.Bucurescu, Phys.Rev. C 72, 044311 (2005);

Additional problems:

1. spin cutoff parameter at neutron binding energy is not known
2. ratio of levels with negative and positive parities is not known
3. possible deviations of the shape of real level density from model functions used for interpolation

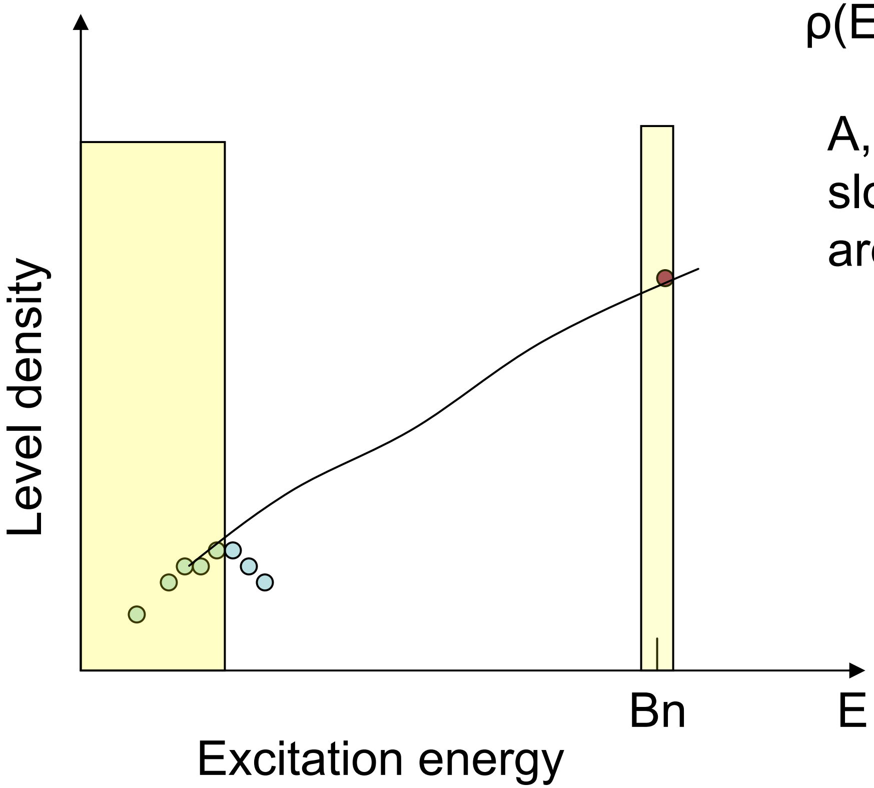
might lead to

extra uncertainties of total level densities

<u>We need to use some experimental techniques capable to measure the TOTAL level densities in the whole excitation region</u>

Oslo method

is based on the measurements of particle-gamma coincidences from (^{3}He, αγ) and (^{3}He, ^{3}Heγ) reactions



$\rho(E) = \rho'(E) \cdot A \cdot \exp(BE)$

A,B are uncertain, i.e. both slope and absolute numbers are uncertain

The level density from particle spectra of compound nuclear reactions

The concept:

$$d\sigma(E) \sim \sigma_C(E) \frac{T_d(E')\rho_f(E^*)}{\sum_i T_{di}} dE$$

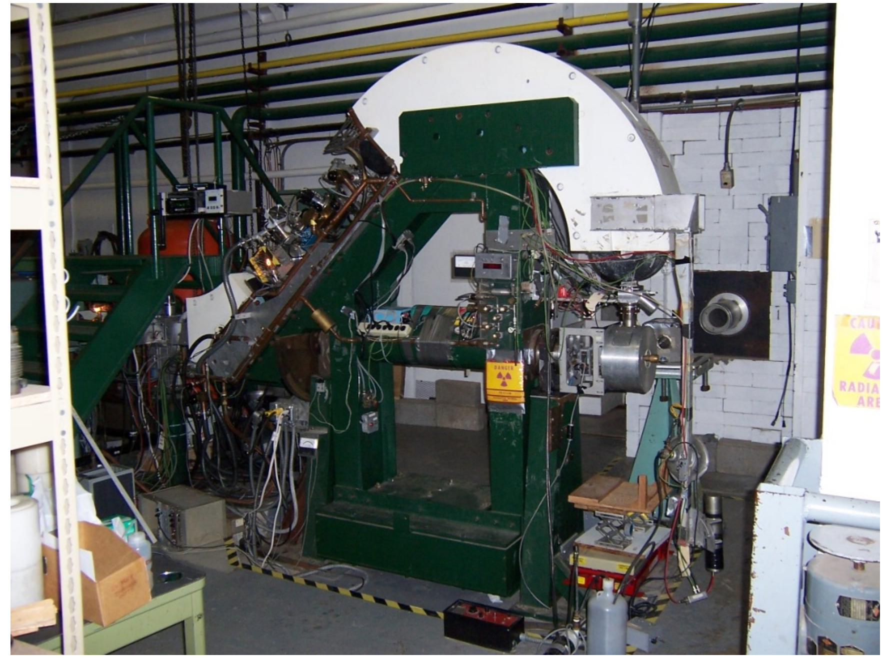
The problem :

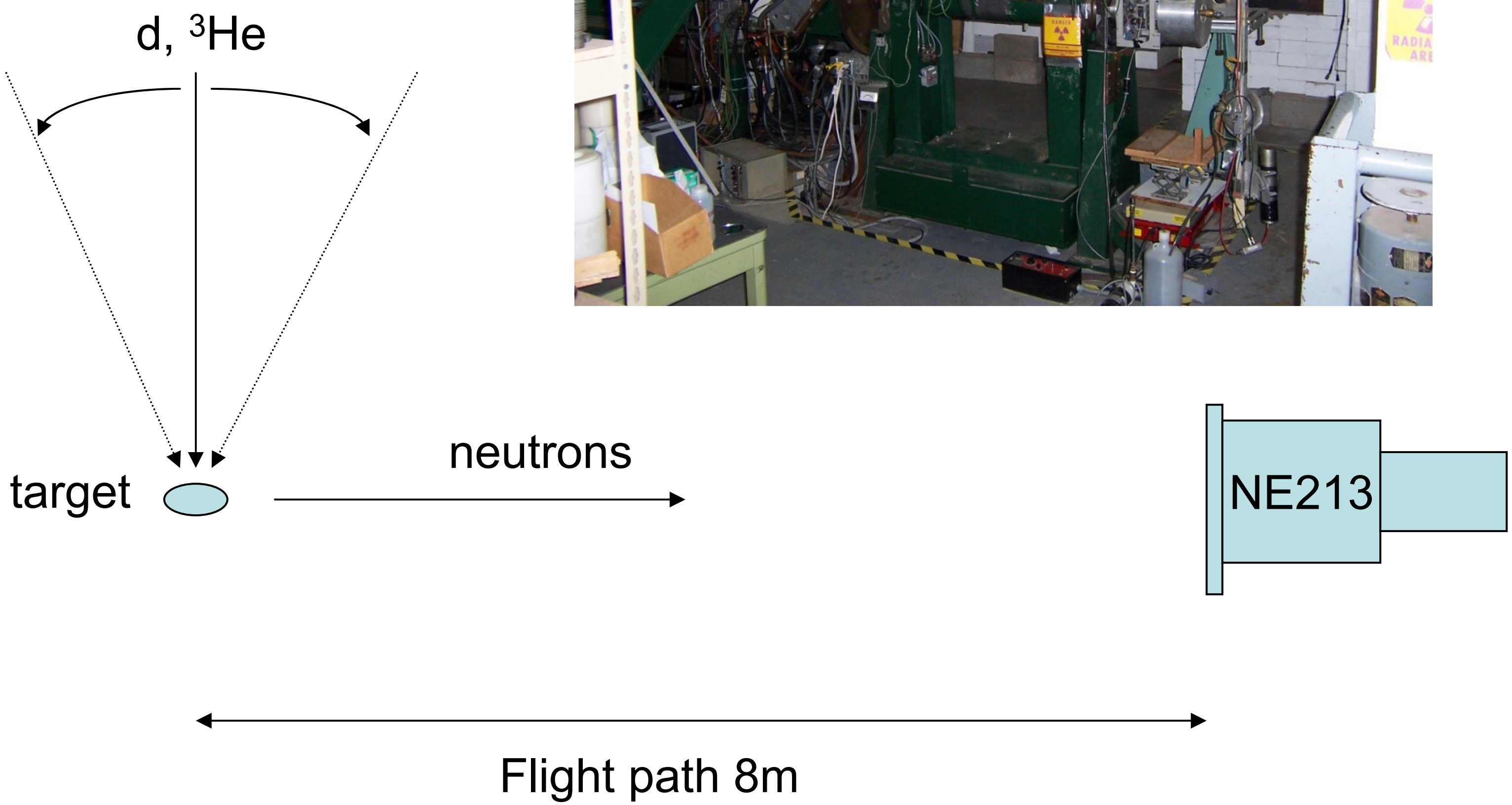
Make sure that the compound reaction mechanism dominates.

Possible solutions:

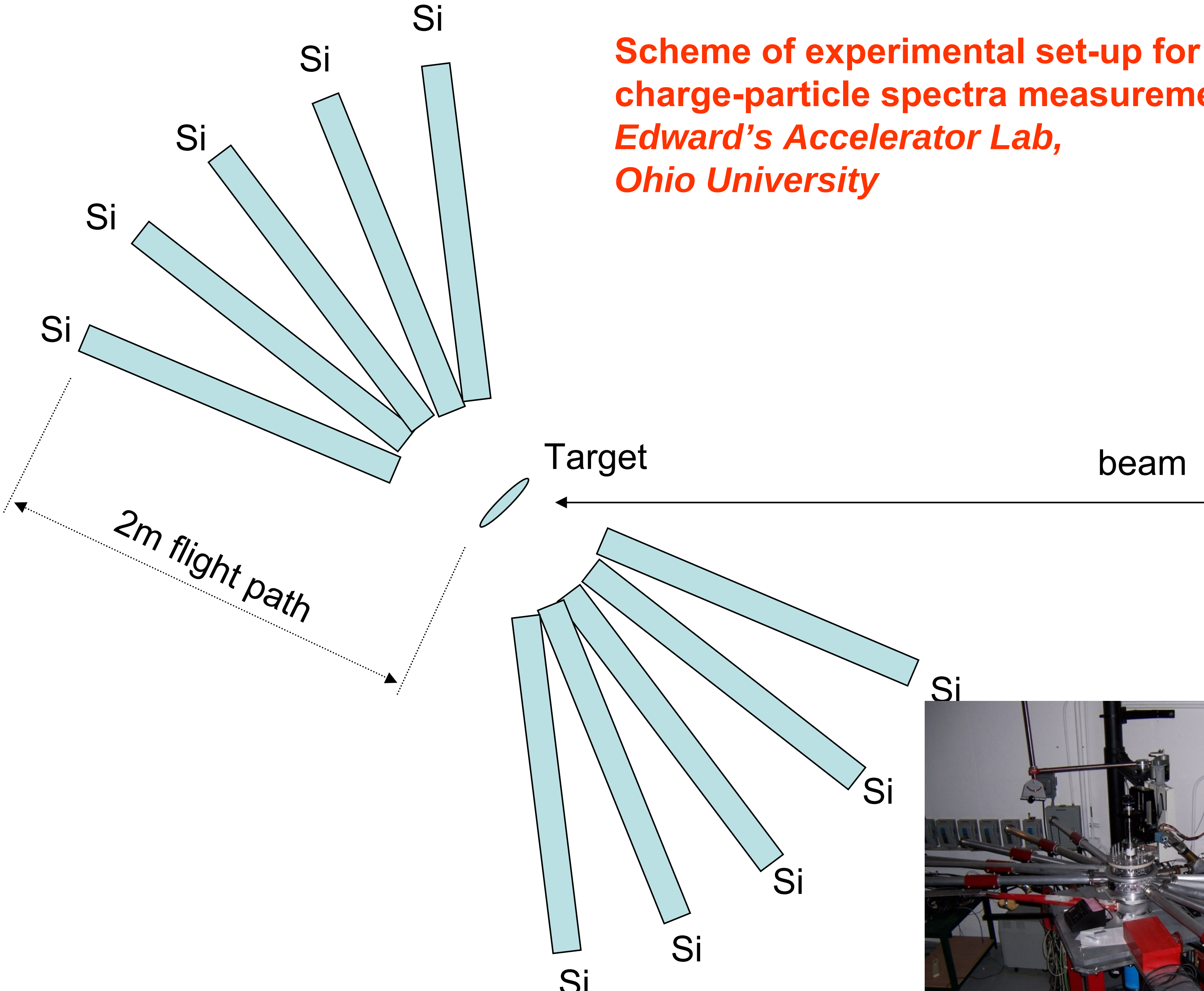
1. Select appropriate reactions (beam species, energies, targets).
2. Measure the outgoing particles at backward angles
3. Compare reactions with different targets and incoming species leading to the same final nuclei

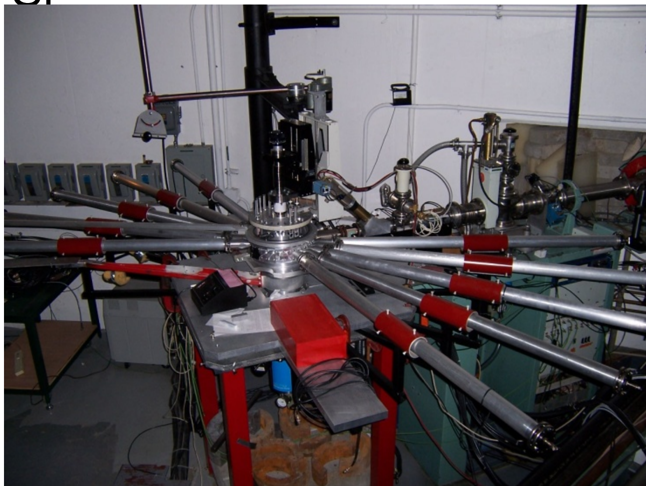
Swinger facility
at Edwards Lab.
Ohio University





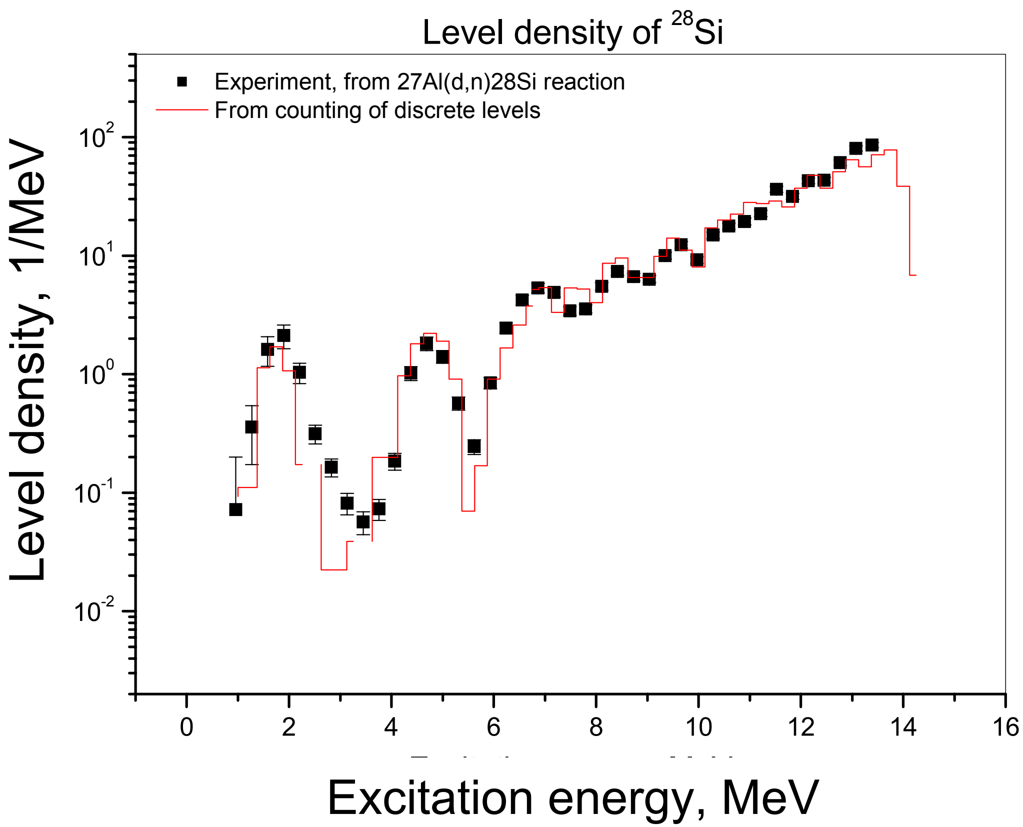
Scheme of experimental set-up for charge-particle spectra measurements
Edward’s Accelerator Lab,
Ohio University



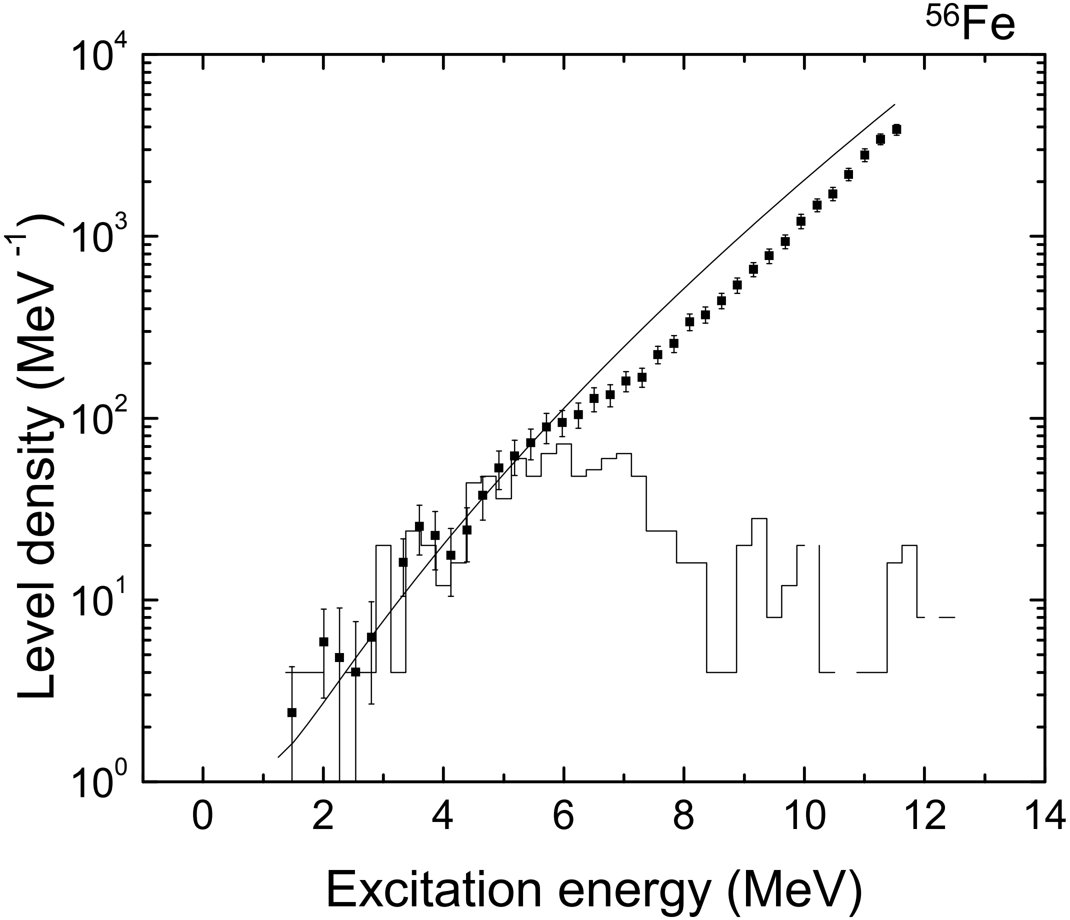


Experimental level densities from (d,n) reactions measured at Edwards Lab. of Ohio University

Testing the level density with $^{27}Al(d,n)^{28}Si$



$^{55}Mn(d,n)^{56}Fe$, E_d=7.5 MeV



Points are from our experiment, line – Fermi-gas model with parameters from systematics T.von Egidy, D.Bucurescu, Phys.Rev. C 72, 044311 (2005);

$^{55}Mn(d,n)^{56}Fe$, E_d=7.5 MeV

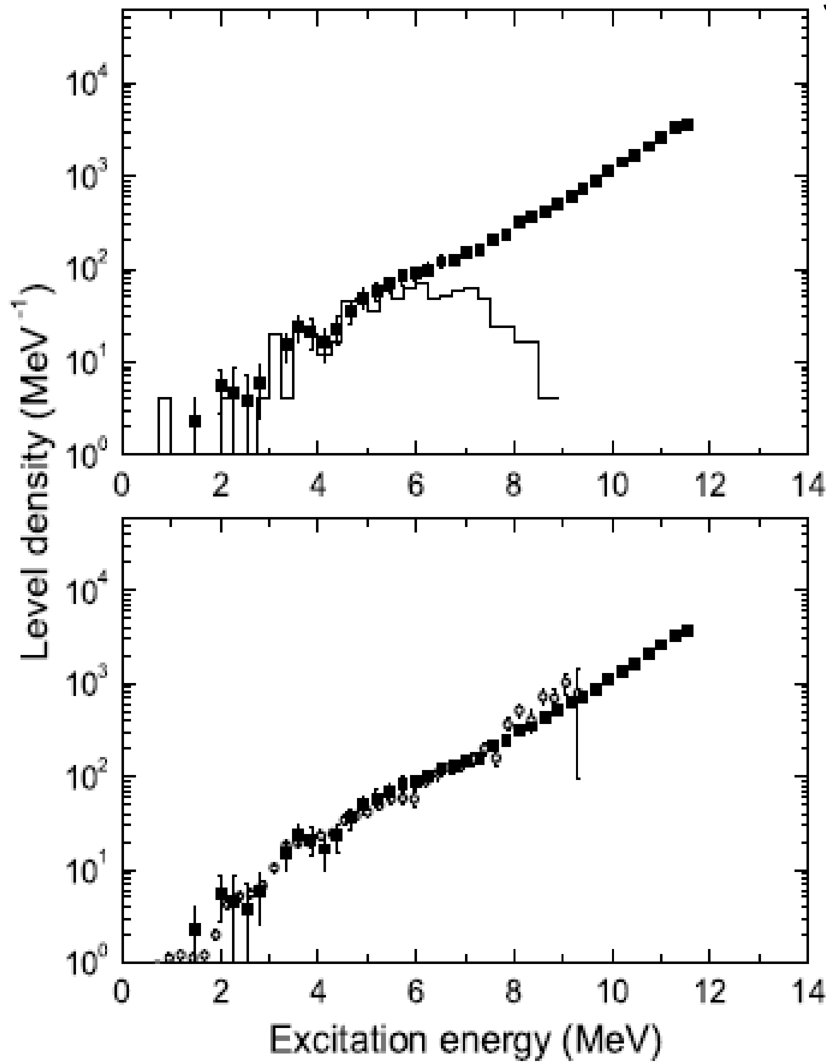
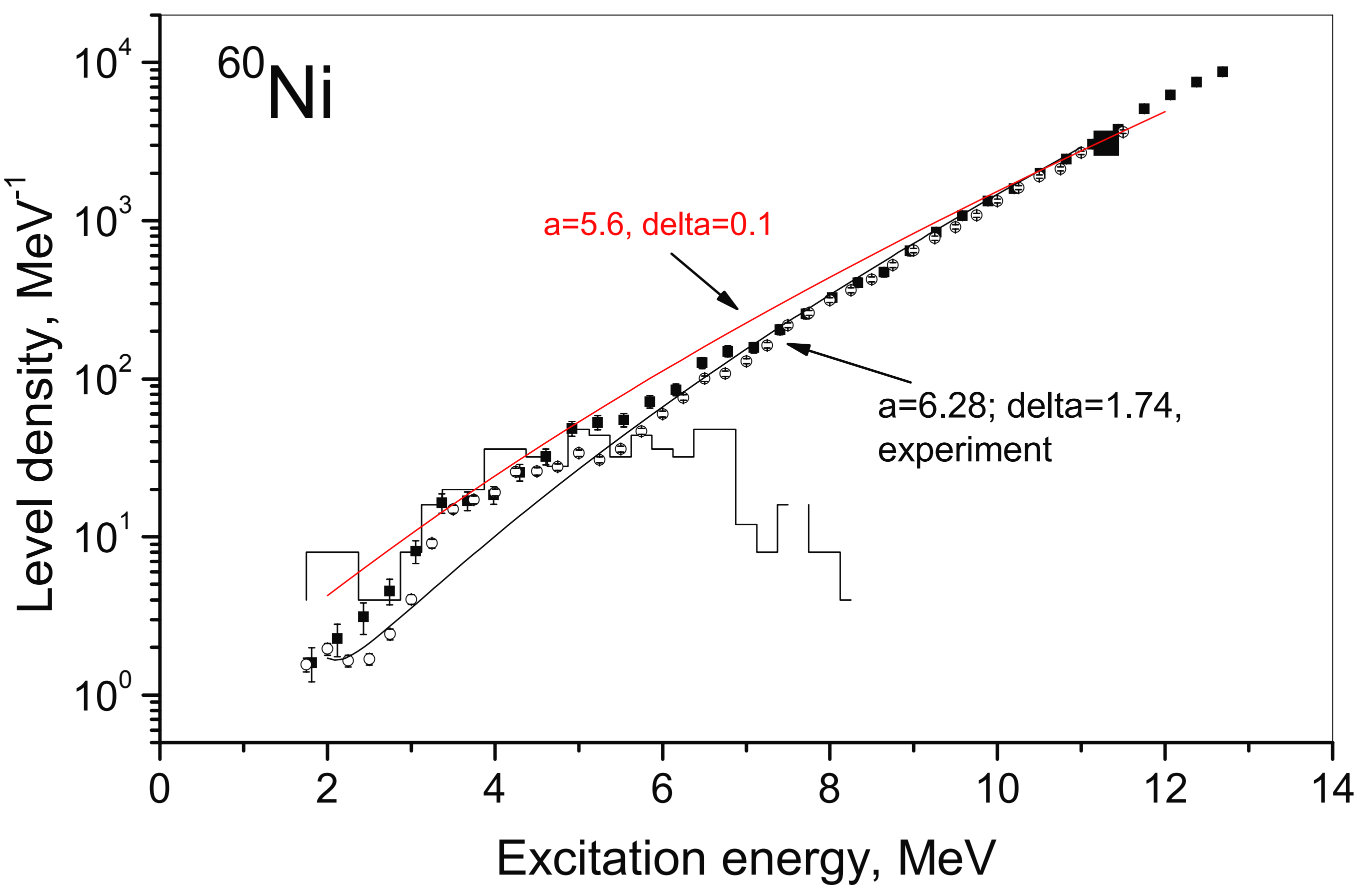


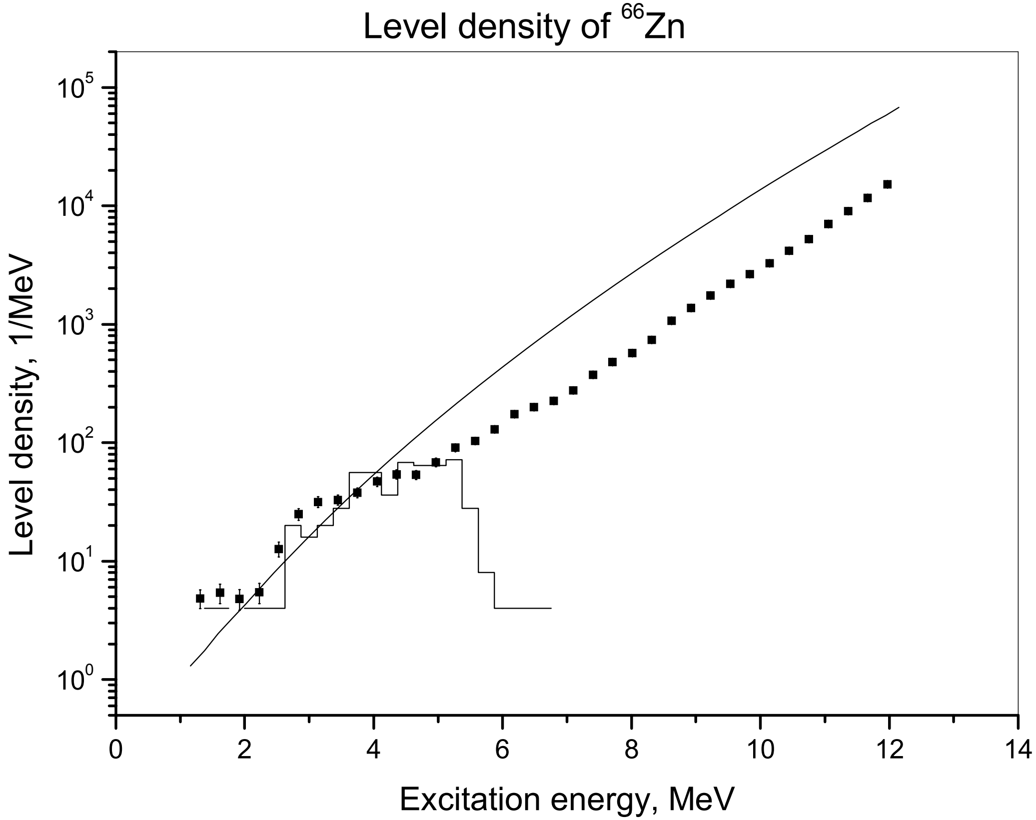
FIG. 3: The comparison of the NLD extracted from neutron evaporation spectra (full circles) with discrete NLD (upper panel) and with NLD (open circles) obtained from Oslo-type experiment (lower panel).

A.Voinov, S.Grimes et al
PRC 74, 014314 (2006)



Points are from our experiment, red line the the Fermi-gas model with parameters found from the fit to discrete levels and neutron resonance spacing, black line is the Fermi-gas model fit to experimental points

$^{65}Cu(d,n)^{66}Zn$, E_d=7.5 MeV

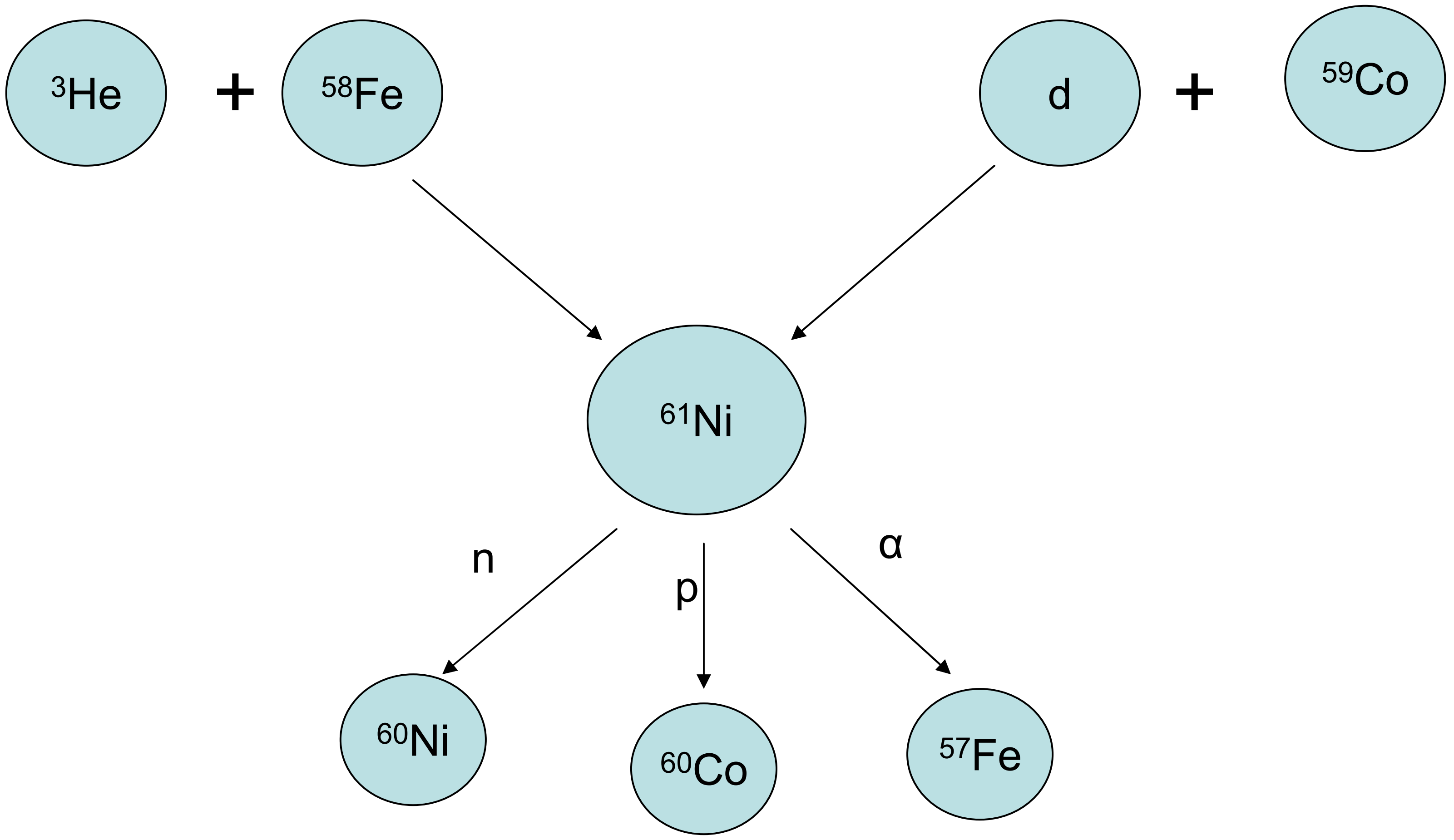


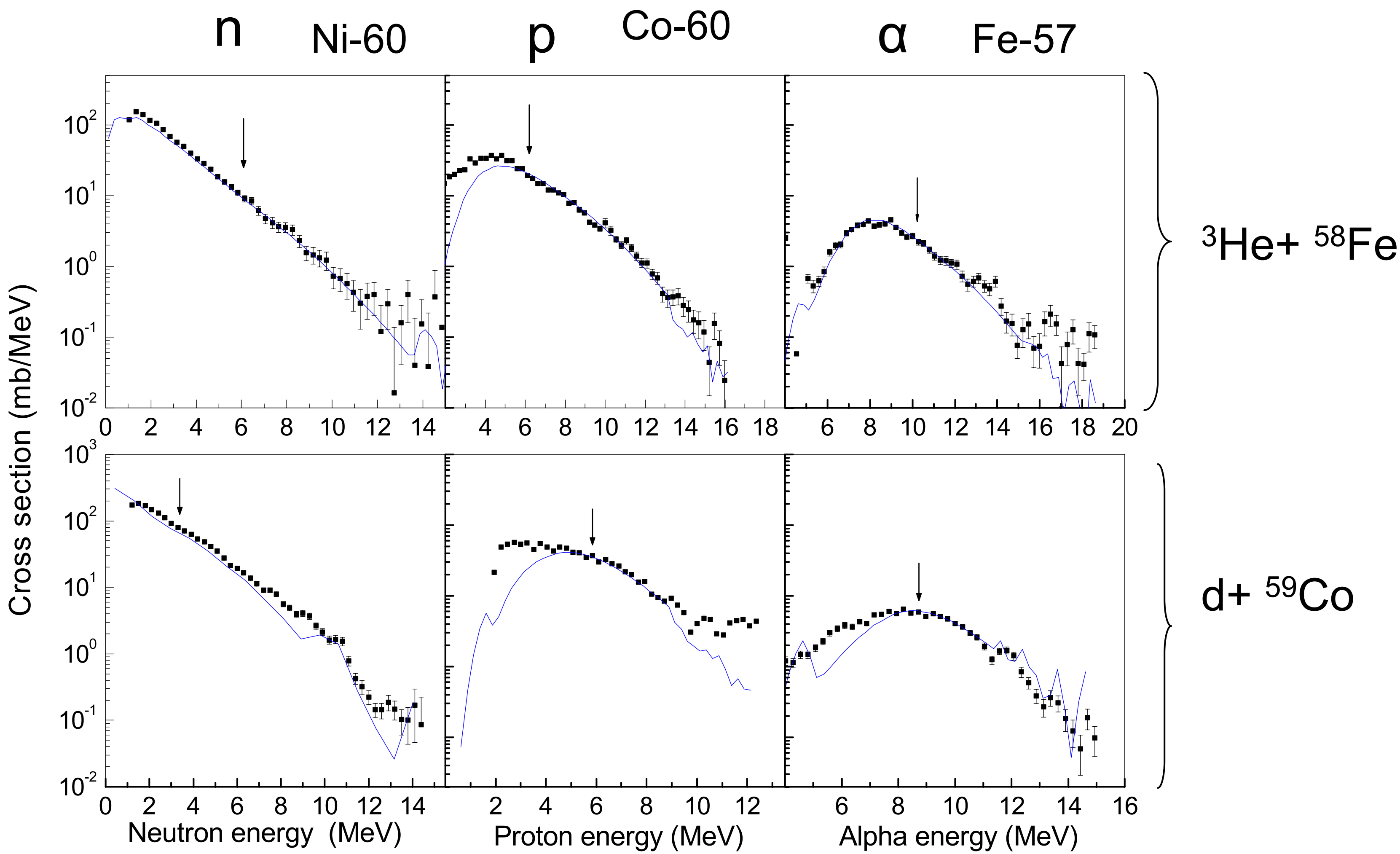
Main results from (d,n) experiments:

1. Neutron spectra measured at backward angles are suitable for level density determination.

2. For many nuclei we got different level densities (shape and absolute numbers) compared to predictions from level density estimations based on neutron resonance spacings

Reactions with deuterons and He-3





A.Voinov, S.Grimes et al, Phys. Rev. C 76, 044602 (2007)

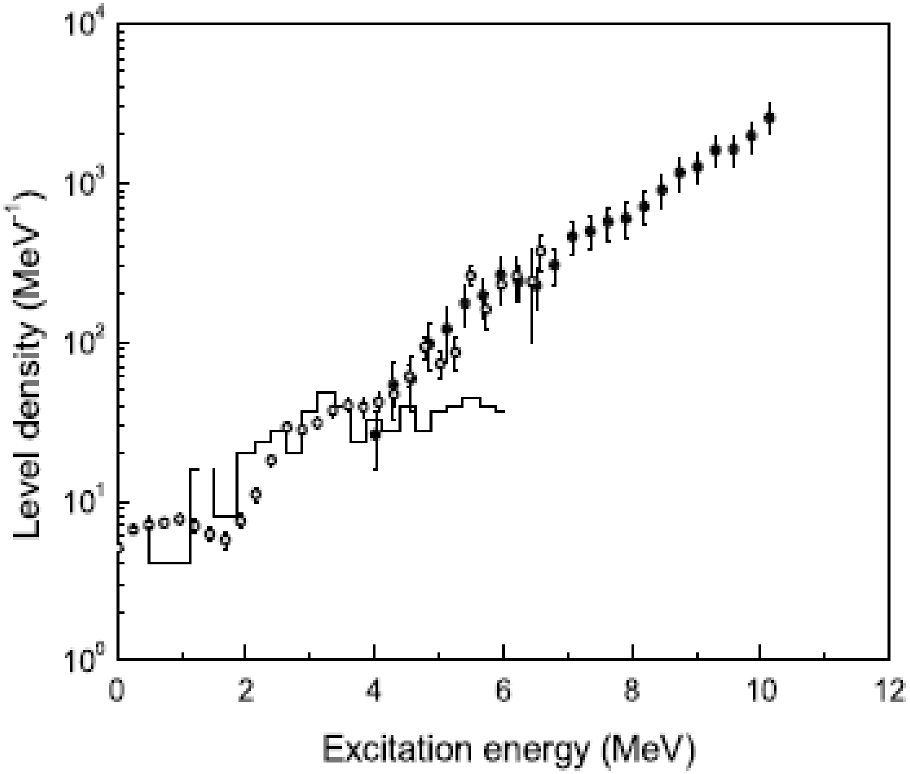
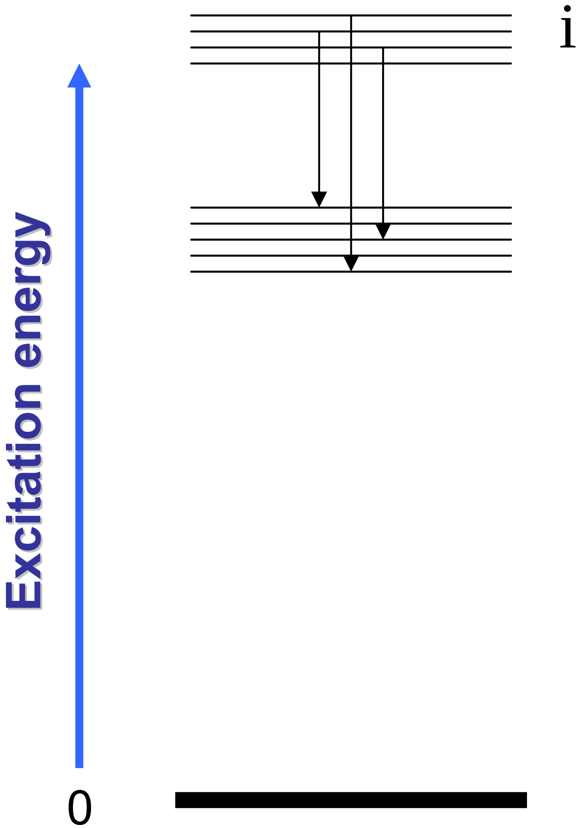
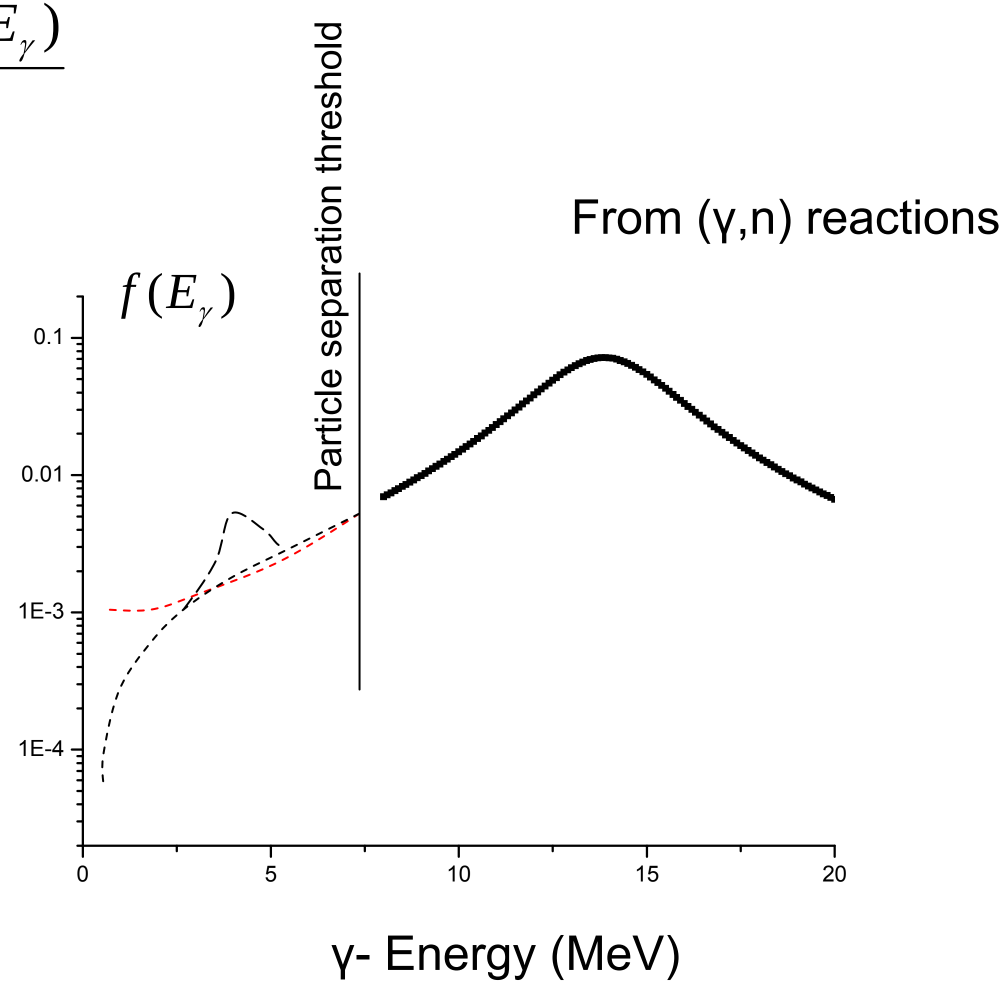


FIG. 5: The experimental level densities of ^{57}Fe nucleus. Filled points are present experimental values. Open points are data from Oslo experiment [9]. Histogram is density of discrete levels.

γ – strength function in continuum

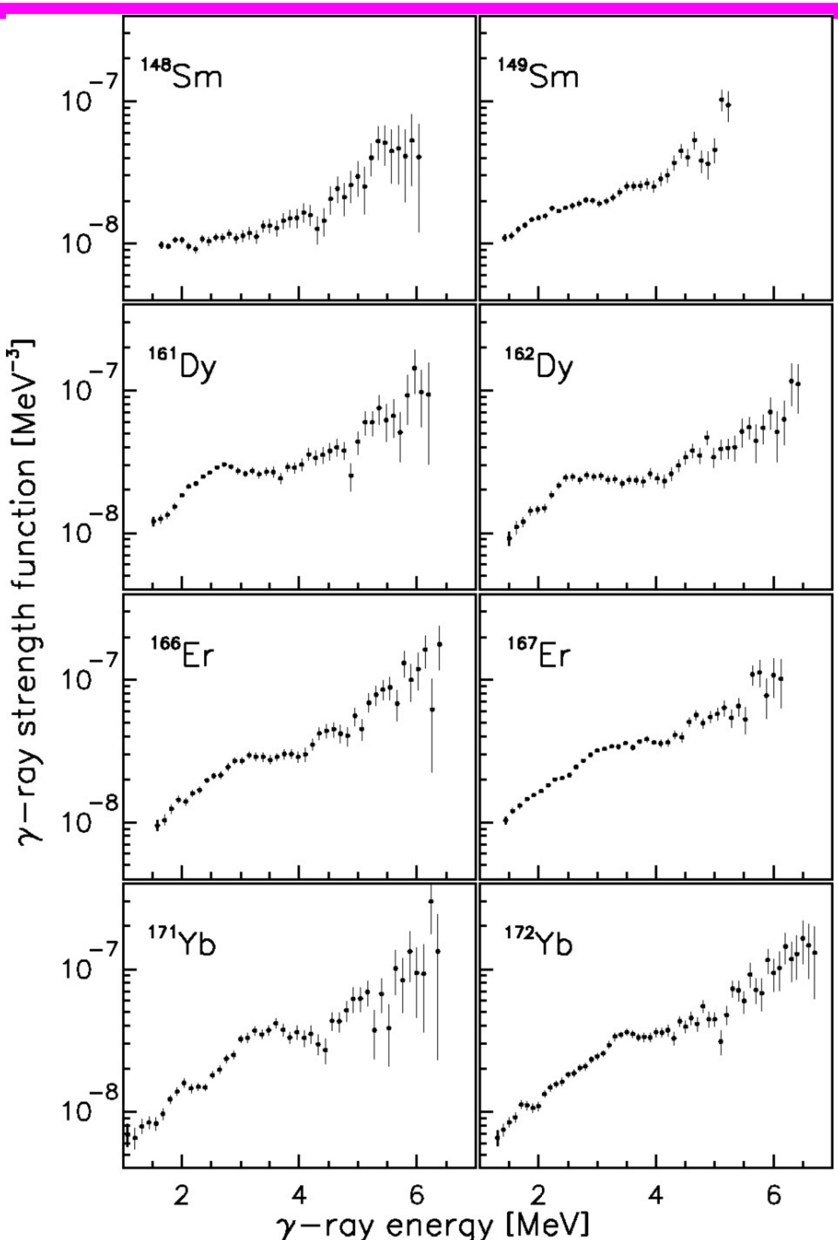
$$f(E_\gamma) = \frac{\Gamma(E_\gamma)}{E_\gamma^3 D_i} \sim \frac{\sigma_{\text{abs}}(E_\gamma)}{E_\gamma}$$



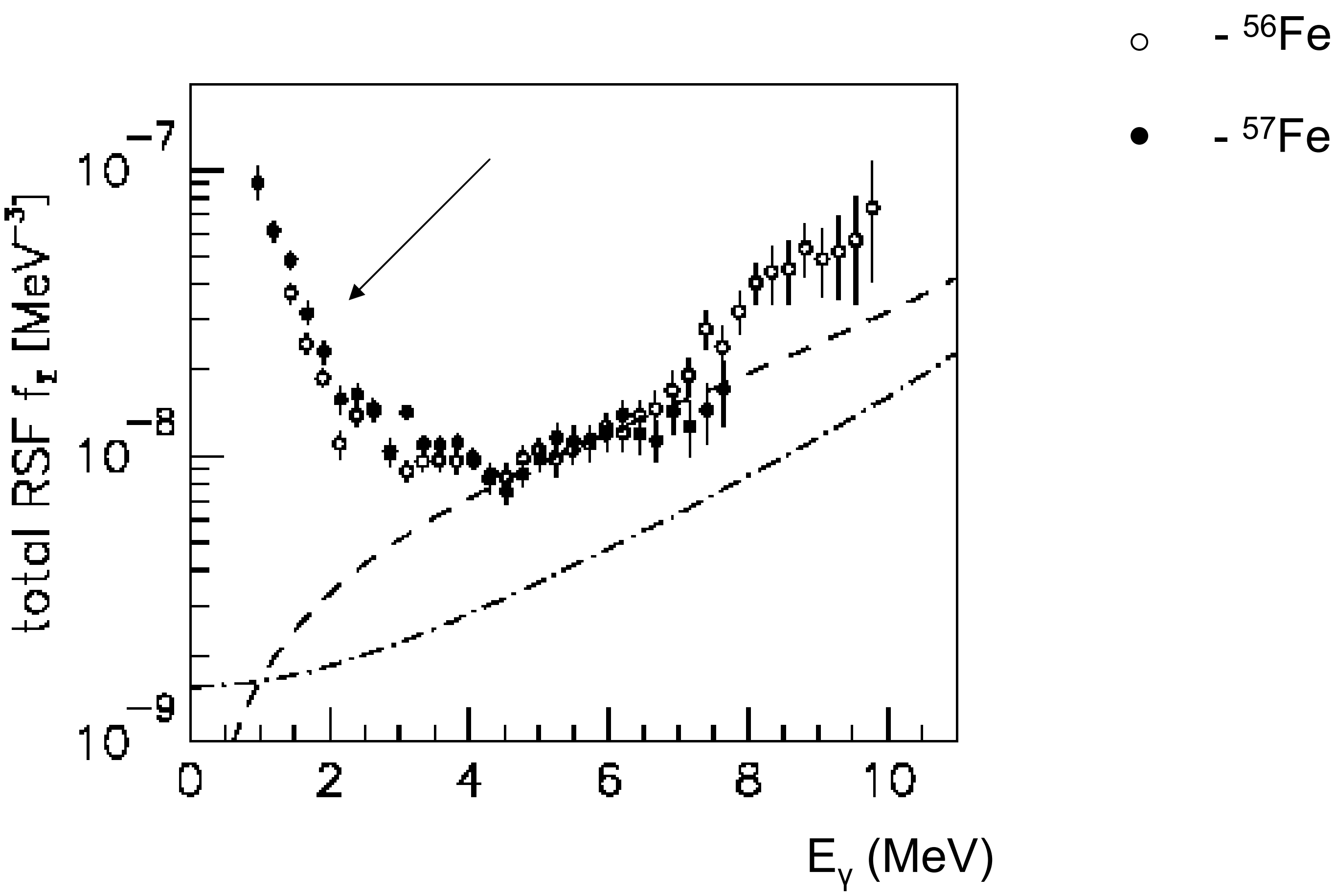


Some results of γ-strength functions for rare-earth nuclei

From Oslo Cyclotron Lab

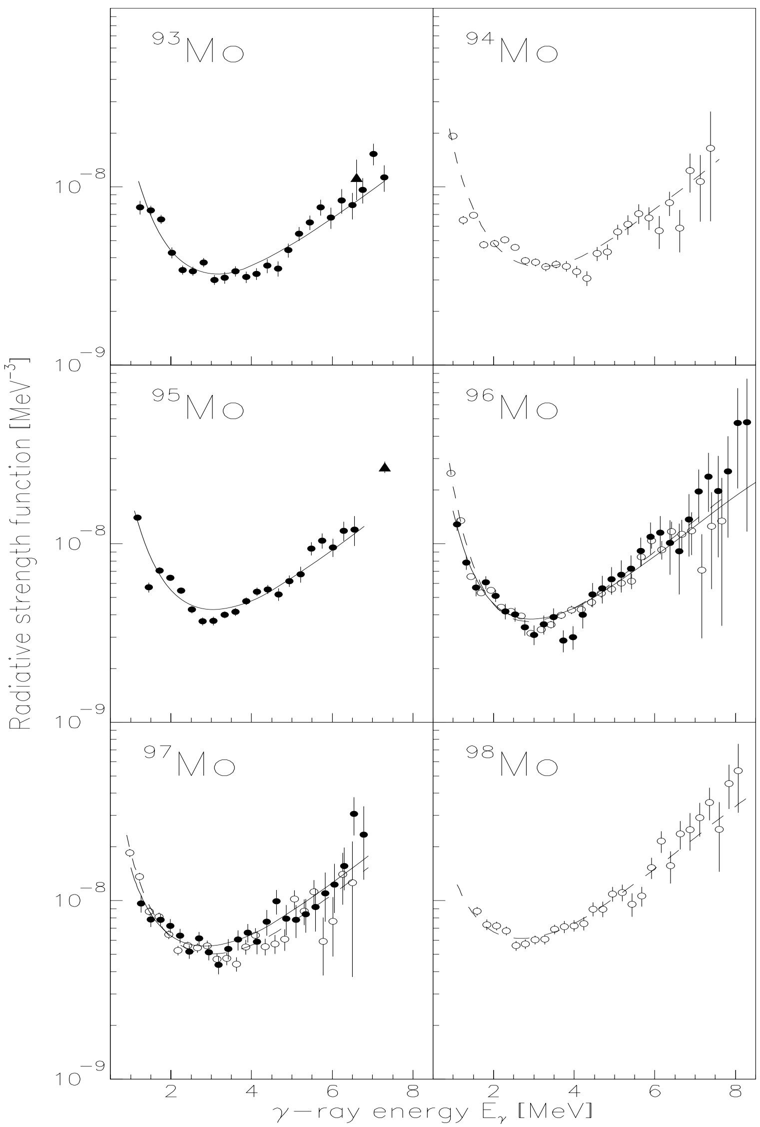


γ-strength function of iron isotopes
Low energy upbend phenomenon



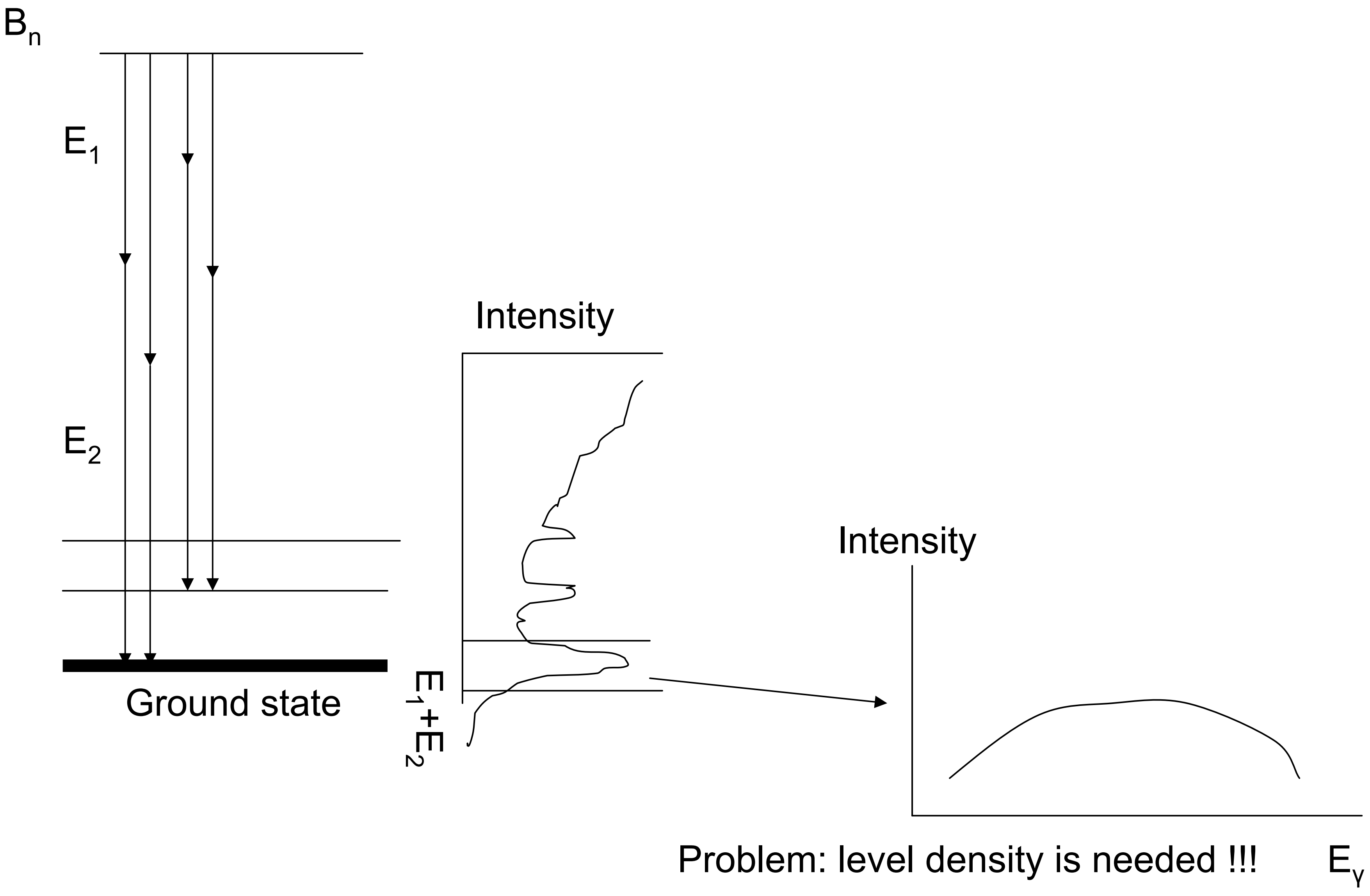
Phys.Rev.Lett. 93, 142504 (2004)

γ-strength function of molybdenum isotopes



M. Guttormsen et al, Phys. Rev. C, 71, 044307 (2005).

Method of two-step γ – cascades from neutron capture reactions



Problem: level density is needed !!!

Measurement of gamma-strength function at Edwards Lab. Of Ohio University

(p,2γ)
(d,n) } ⟶ Produce the same product nucleus

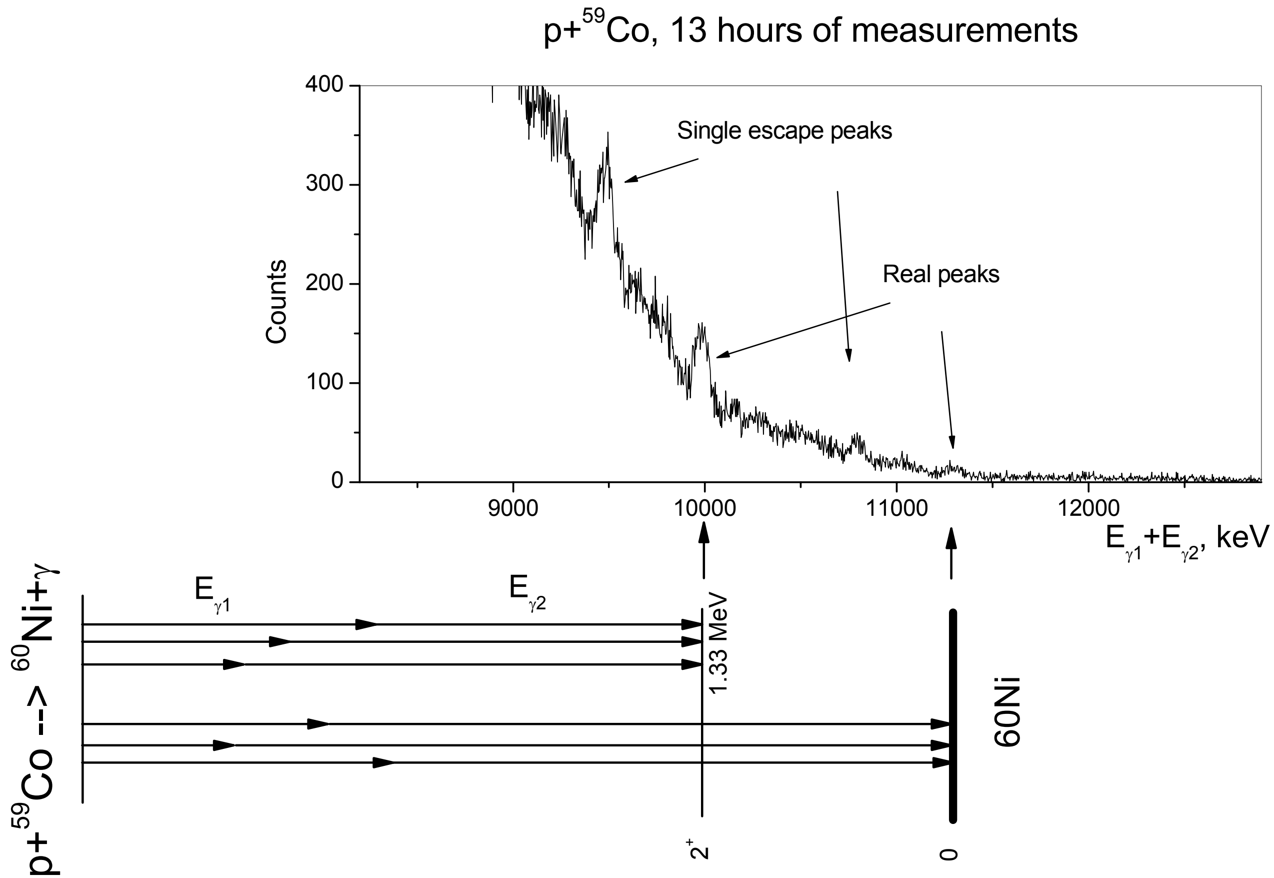
Strategy

1. We obtain a level density from neutron evaporation spectra.
2. We obtain a γ-strength function from 2γ- spectra

The first candidate is ^{59}Co(p,2γ) ^{60}Ni reaction at E_p=1.9 MeV

The level density of ^{60}Ni has already been measured
from ^{59}Co(d,n) ^{60}Ni reaction:

First results from $^{59}Co(p,2\gamma)$



Conclusions

- We have tools based on different experimental techniques to measure level density and gamma-strength functions

- Level density systematics based on neutron resonance data do not provide sufficient accuracy needed for increasing demands of cross section calculations.

- Total level densities can be obtained from particle evaporation spectra of CNR. Combination of different experimental techniques and type of reactions must be used to eliminate uncertainties connected to different reaction mechanisms.

- The gamma strength function bellow particle separation threshold is still poorly understood. It can be experimentally investigated with Oslo technique and technique based on measurements of cascades following the proton or neutron capture along with measurements of level densities from evaporation spectra of CNR.

Collaborators :

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