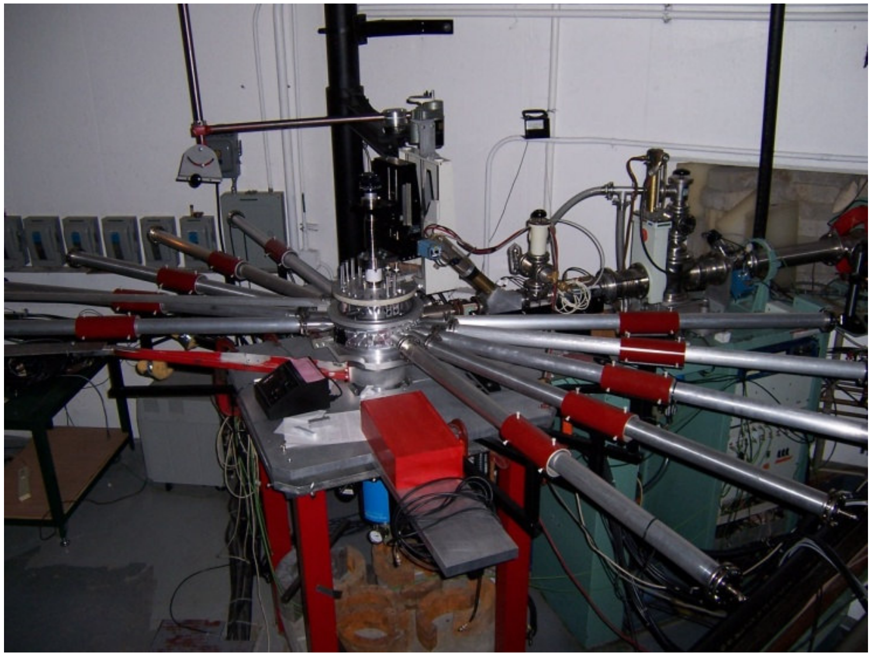
Level density and gamma-strength functions from compound nuclear reactions

Ohio University: *A.V. Voinov, S.M. Grimes, C.R.Brune, T. Massey* et al

Oslo University: *M. Guttormsen, A.C. Larsen, S.Siem* et al

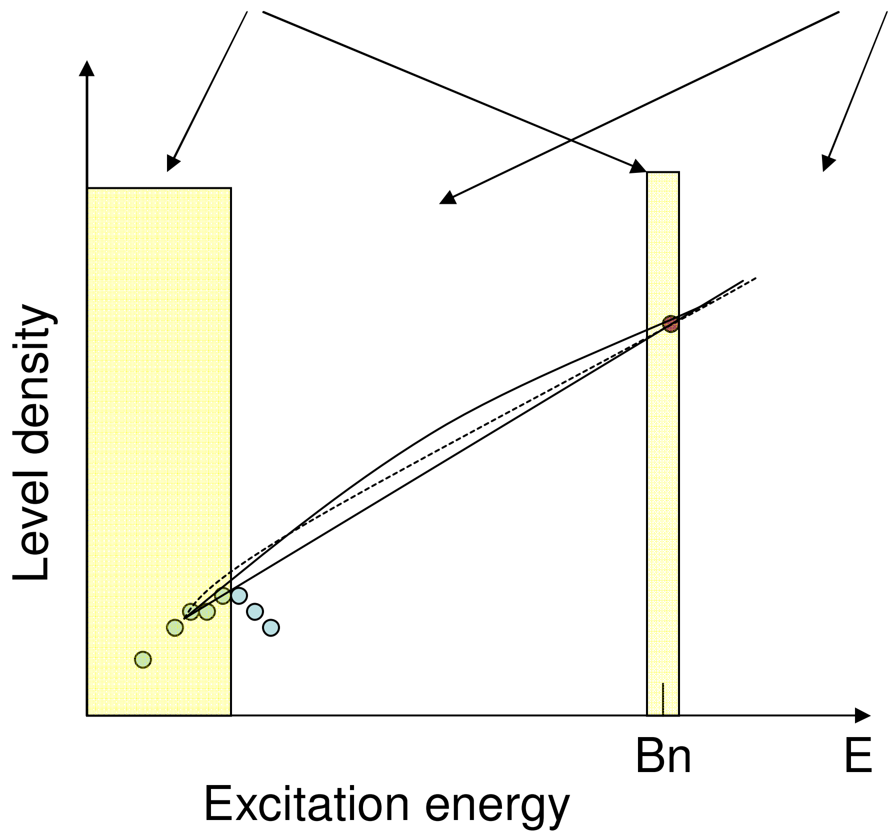


Nuclear level density

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



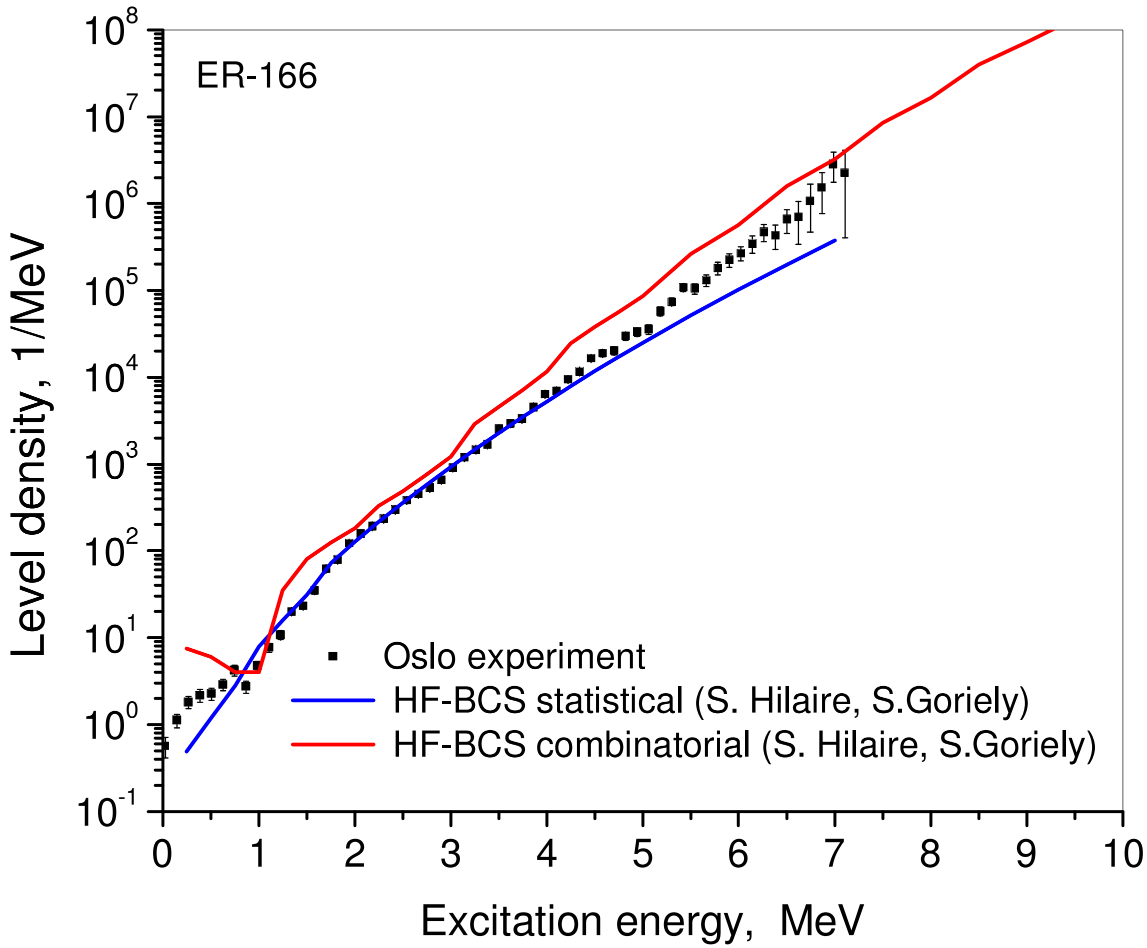
$$\rho(E) = \frac{\exp(2\sqrt{a(E-\delta)})}{12\sqrt{2}\sigma\, a^{1/4}(E-\delta)^{5/4}}$$

OR

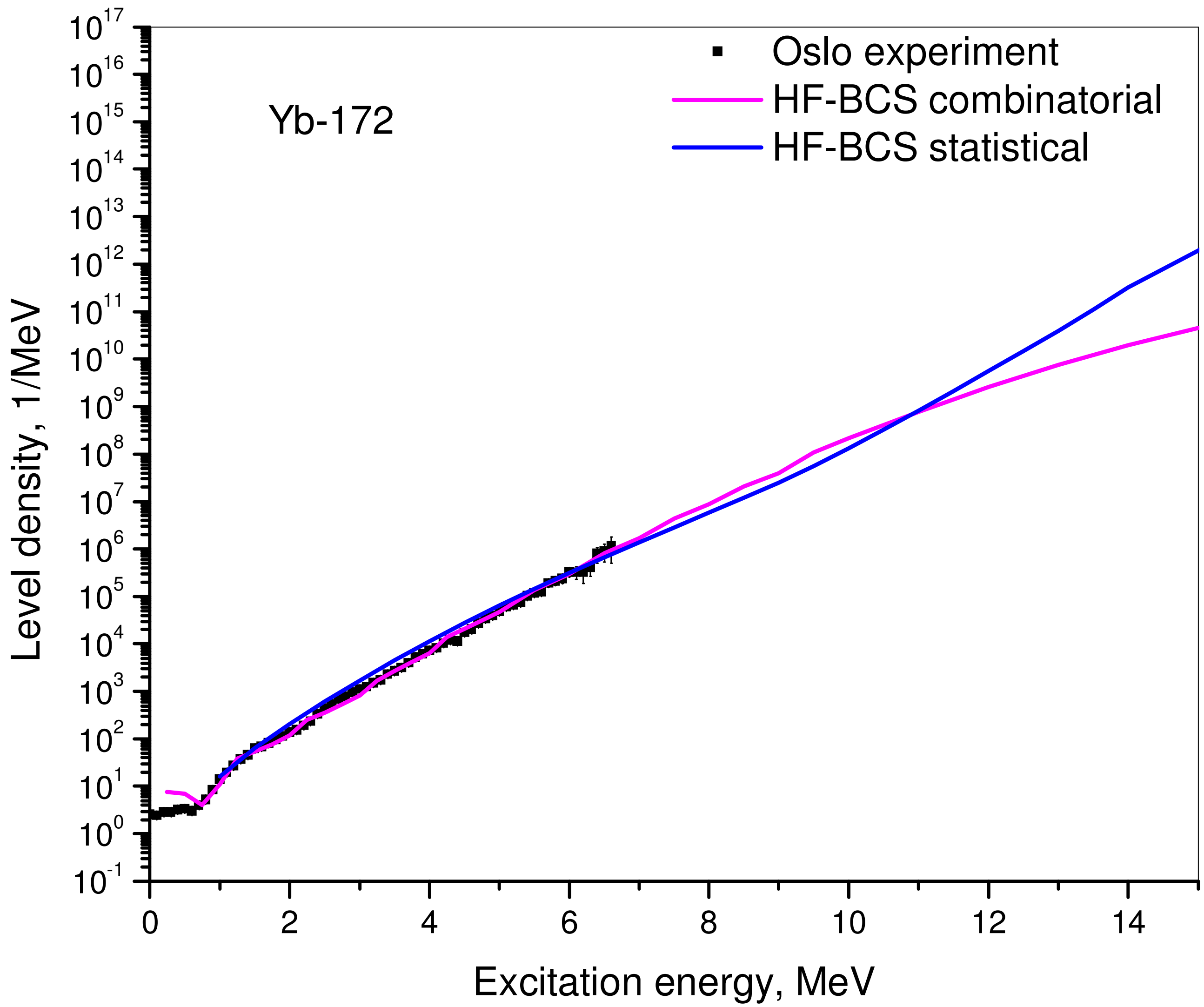
$$\rho(E) = \frac{\exp(\sqrt{(E-\delta)/T})}{T}$$

OR ?

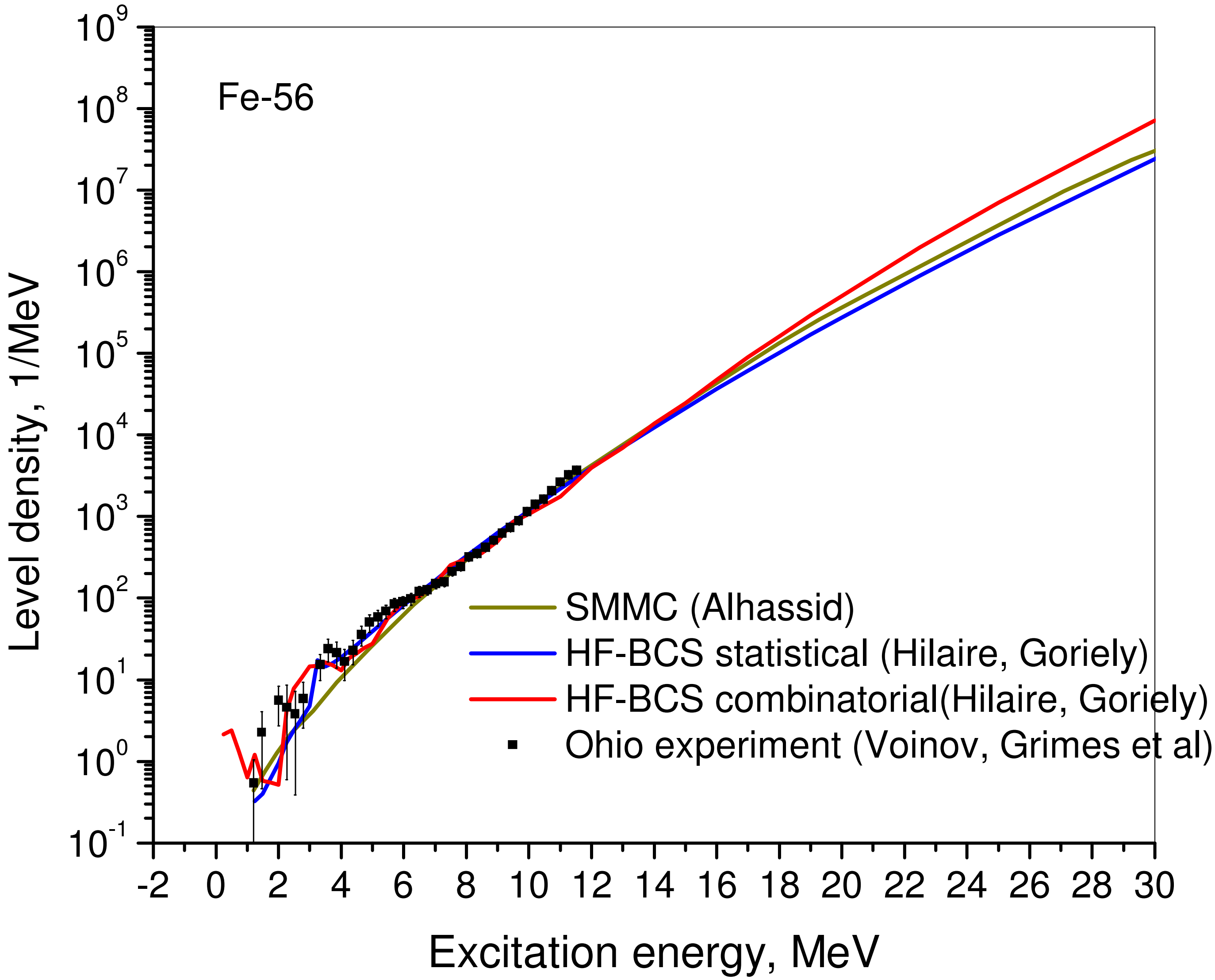
a, δ,T -parameters

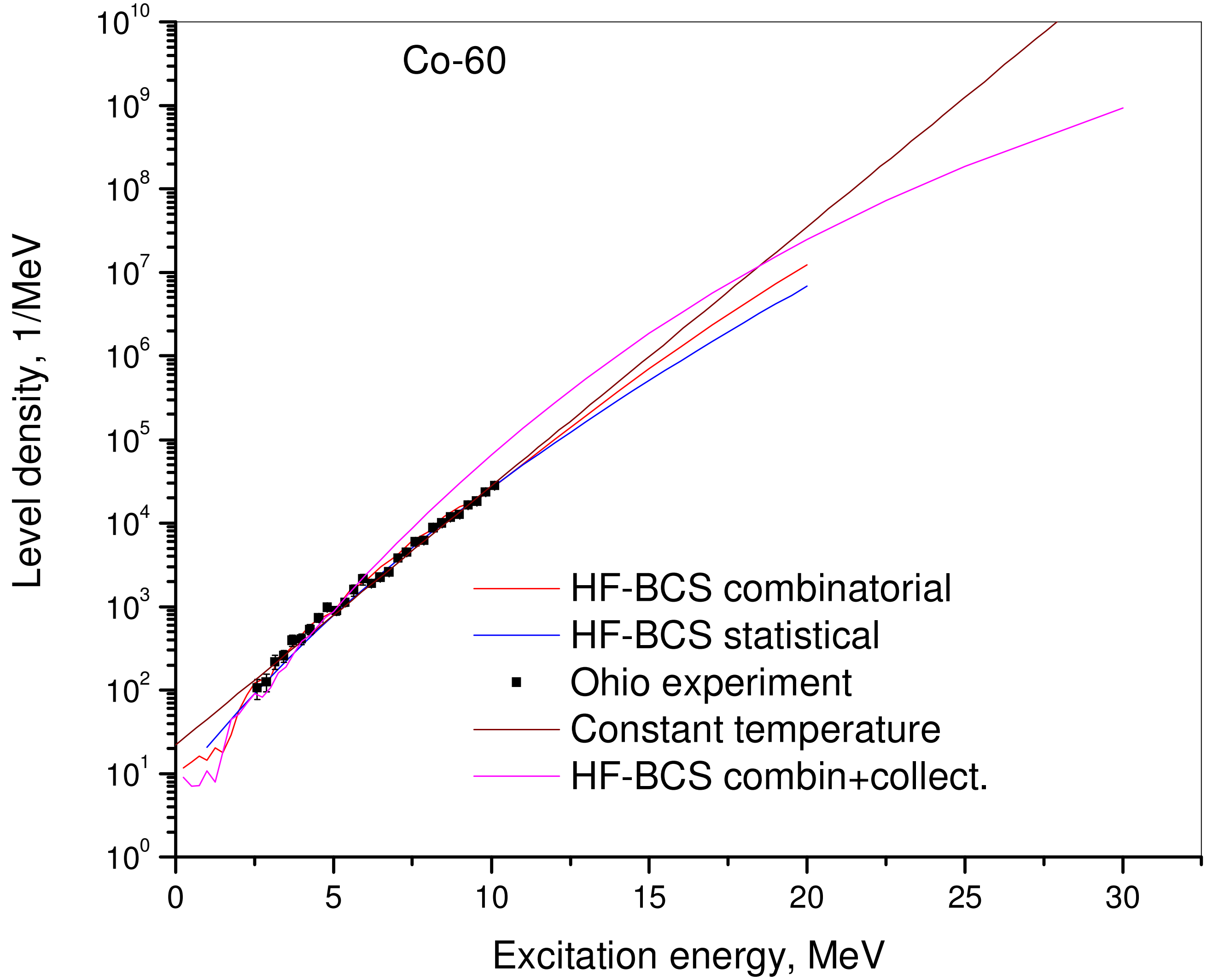


ER-166
Level density, 1/MeV
Excitation energy, MeV
Oslo experiment
HF-BCS statistical (S. Hilaire, S.Goriely)
HF-BCS combinatorial (S. Hilaire, S.Goriely)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0
1
2
3
4
5
6
7
8
9
10

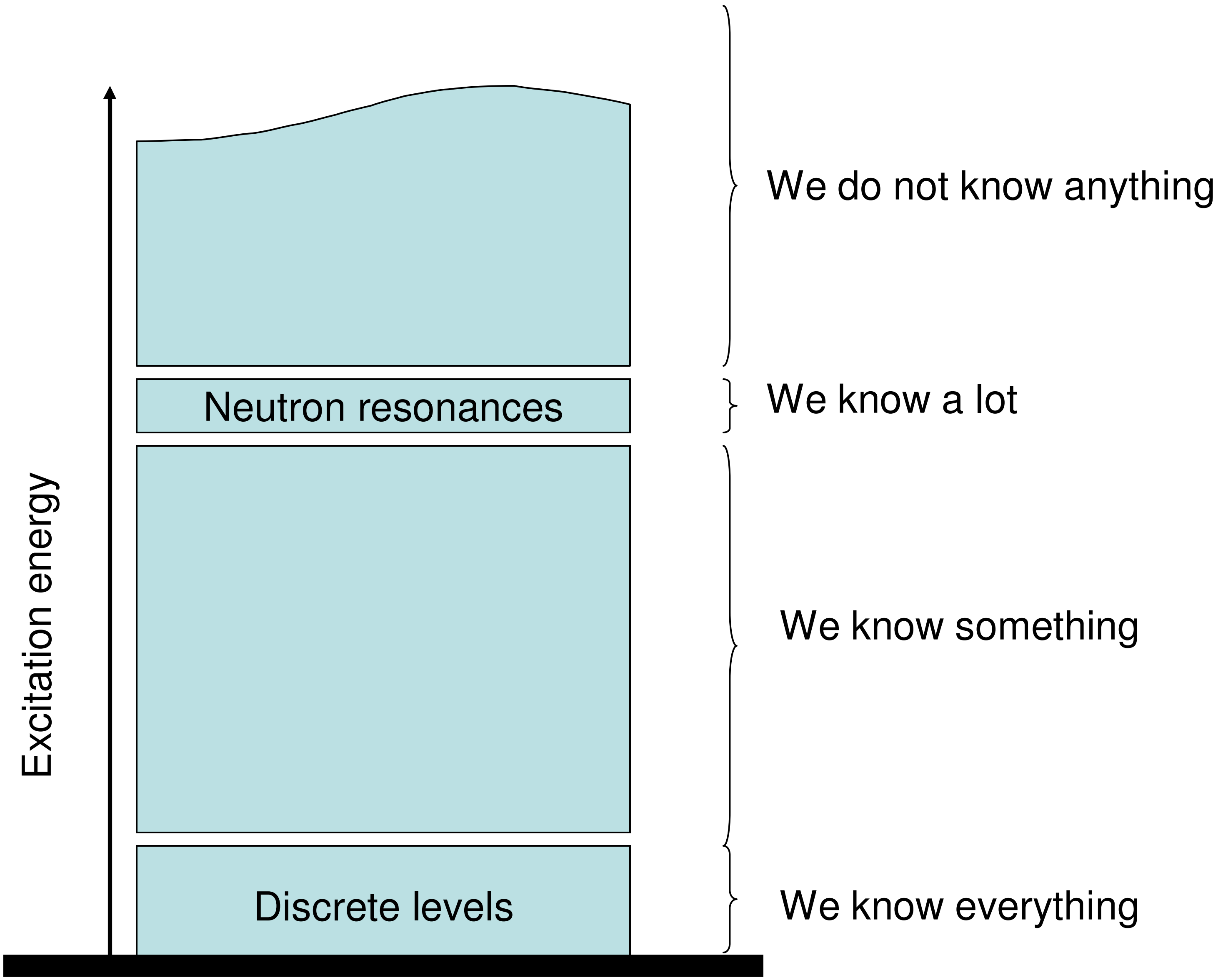


Yb-172
Oslo experiment
HF-BCS combinatorial
HF-BCS statistical
Level density, 1/MeV
Excitation energy, MeV
10^17
10^16
10^15
10^14
10^13
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0
2
4
6
8
10
12
14


Fe-56
Level density, 1/MeV
Excitation energy, MeV
SMMC (Alhassid)
HF-BCS statistical (Hilaire, Goriely)
HF-BCS combinatorial(Hilaire, Goriely)
Ohio experiment (Voinov, Grimes et al)



It is important to obtain the excitation energy dependence of level density from an experiment in a wide energy range



Excitation energy
Neutron resonances
Discrete levels
We do not know anything
We know a lot
We know something
We know everything

The level density from particle spectra of compound nuclear reactions

The concept:

$$d\sigma(E) \sim \sigma_C(E)\frac{T_{in}(E')\rho_f(E^*)}{\sum_i T_{out\,i}}dE$$

The problem :

Make sure that the compound reaction mechanism dominates.

Possible solutions:

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

$$\sigma_{(d,xn)}=\sigma_{dn}+\sigma_{(d,pn)}+\sigma_{(d,an)}+\ldots$$

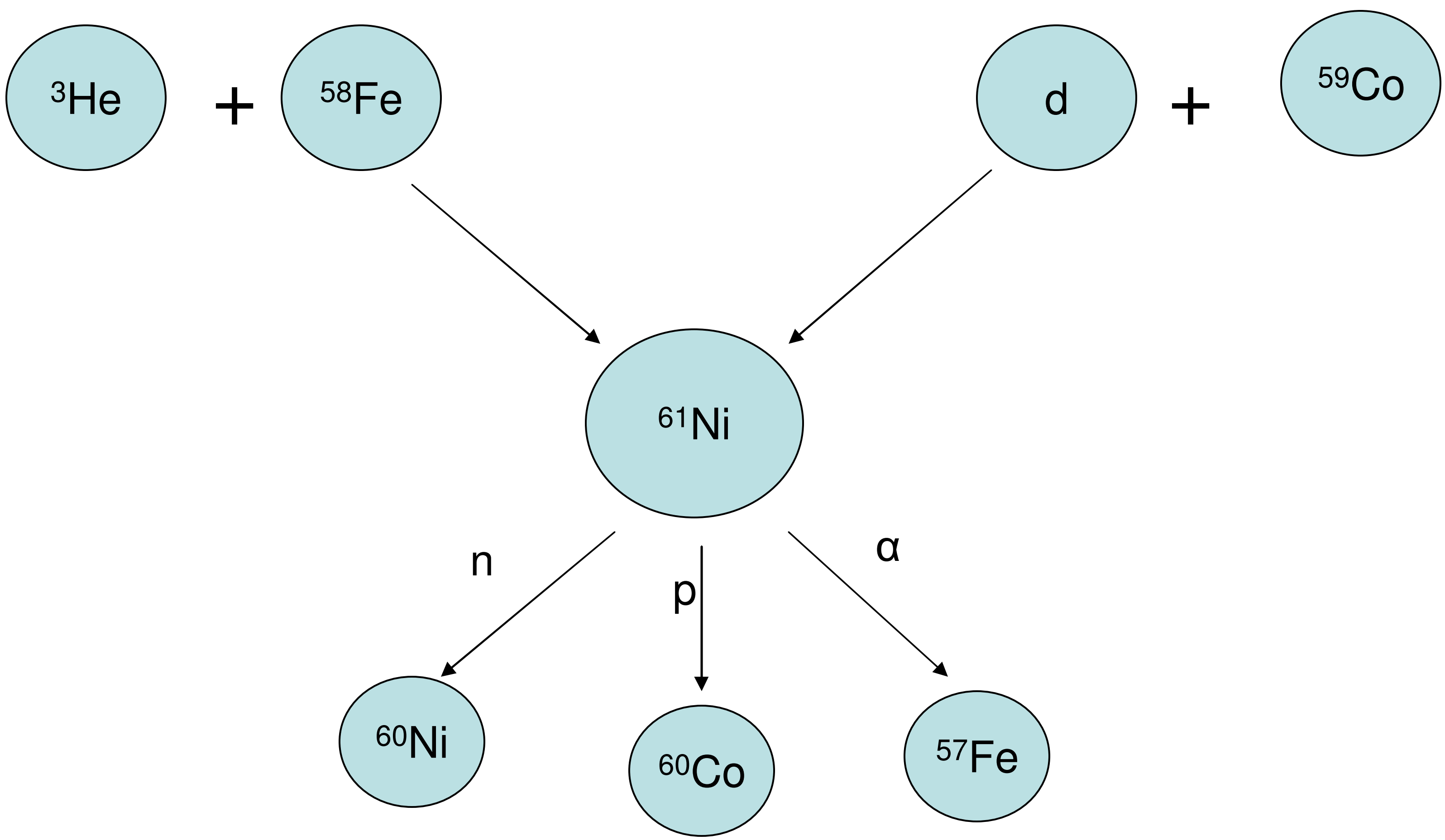
$$\sigma_{(d,xp)}=\sigma_{dp}+\sigma_{(d,np)}+\sigma_{(d,ap)}+\ldots$$

$$\sigma_{(d,xa)}=\sigma_{da}+\sigma_{(d,na)}+\sigma_{(d,pa)}+\ldots$$

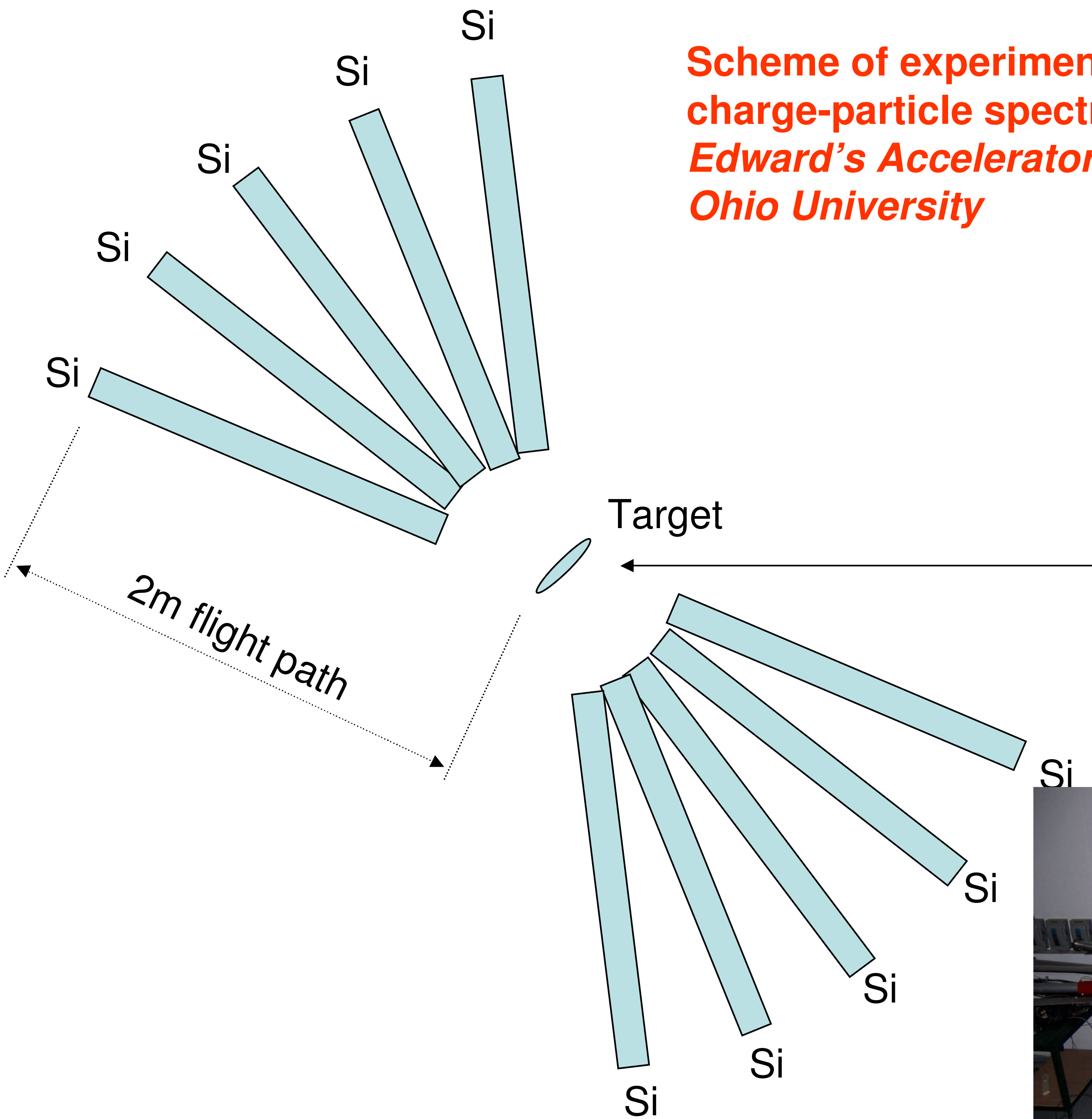
Traditional technique: measured only one type of outgoing particles, level density is determined below the particle separation threshold

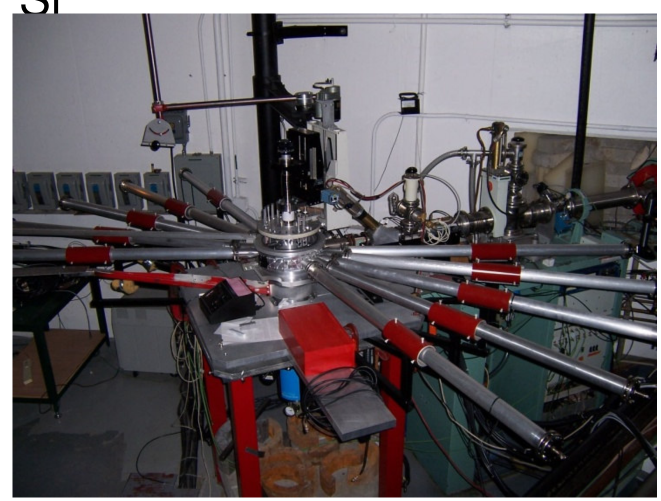
What we do: measure all type of outgoing particles, level density can be obtained below and above the particle separation threshold

Reactions with deuterons and He-3

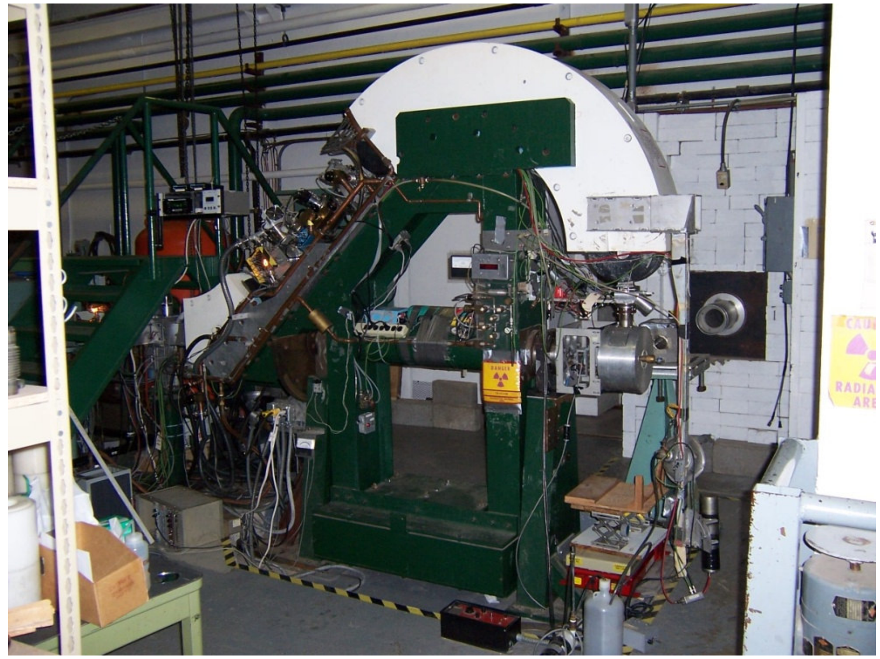


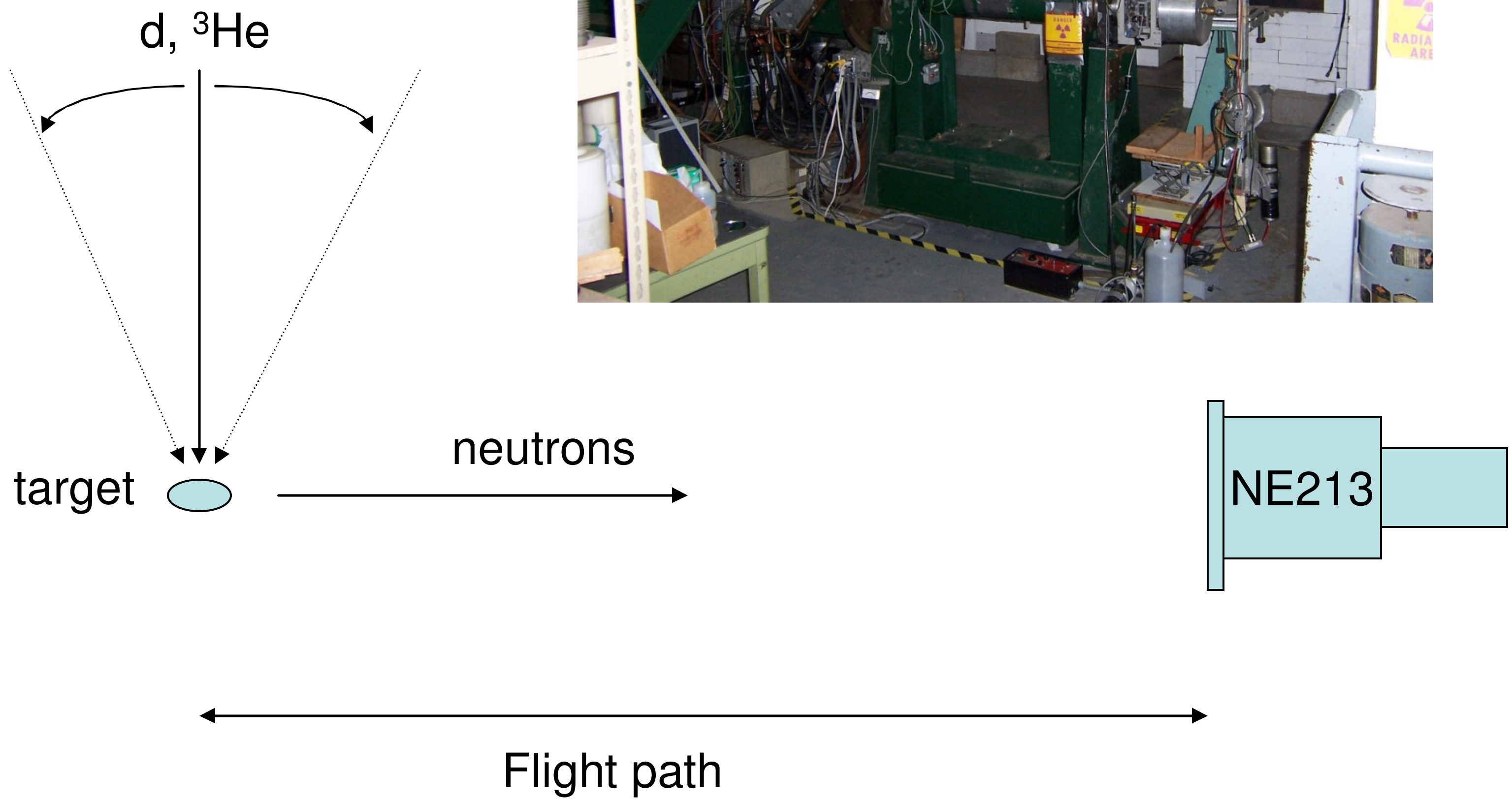
Scheme of experimental set-up for charge-particle spectra measurements
Edward's Accelerator Lab,
Ohio University





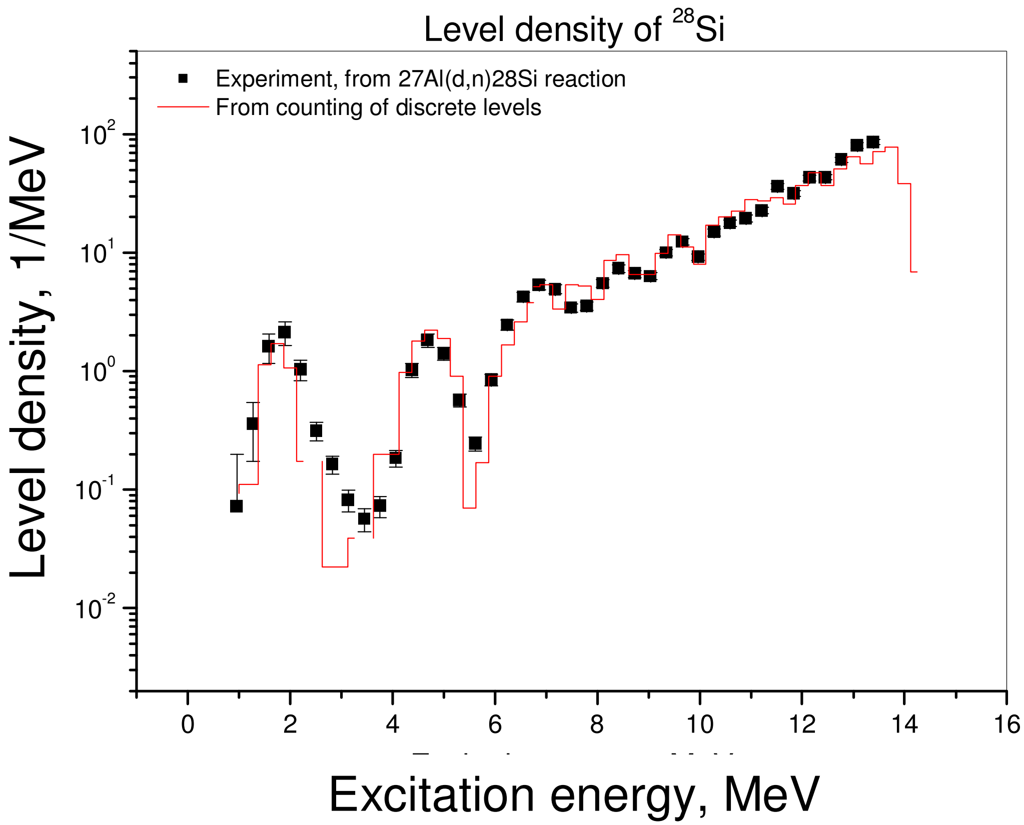
Swinger facility
at Edwards Lab.
Ohio University



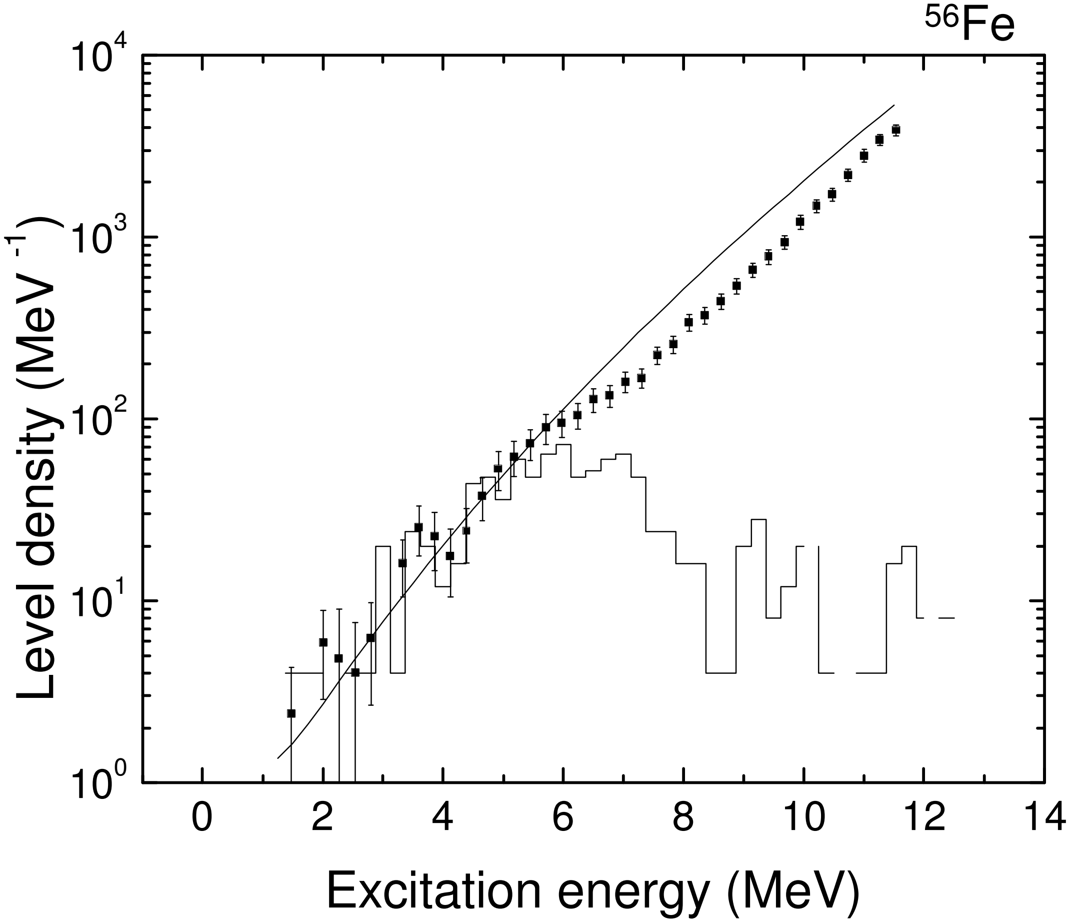


Experimental level densities measured at Edwards Lab. of Ohio University

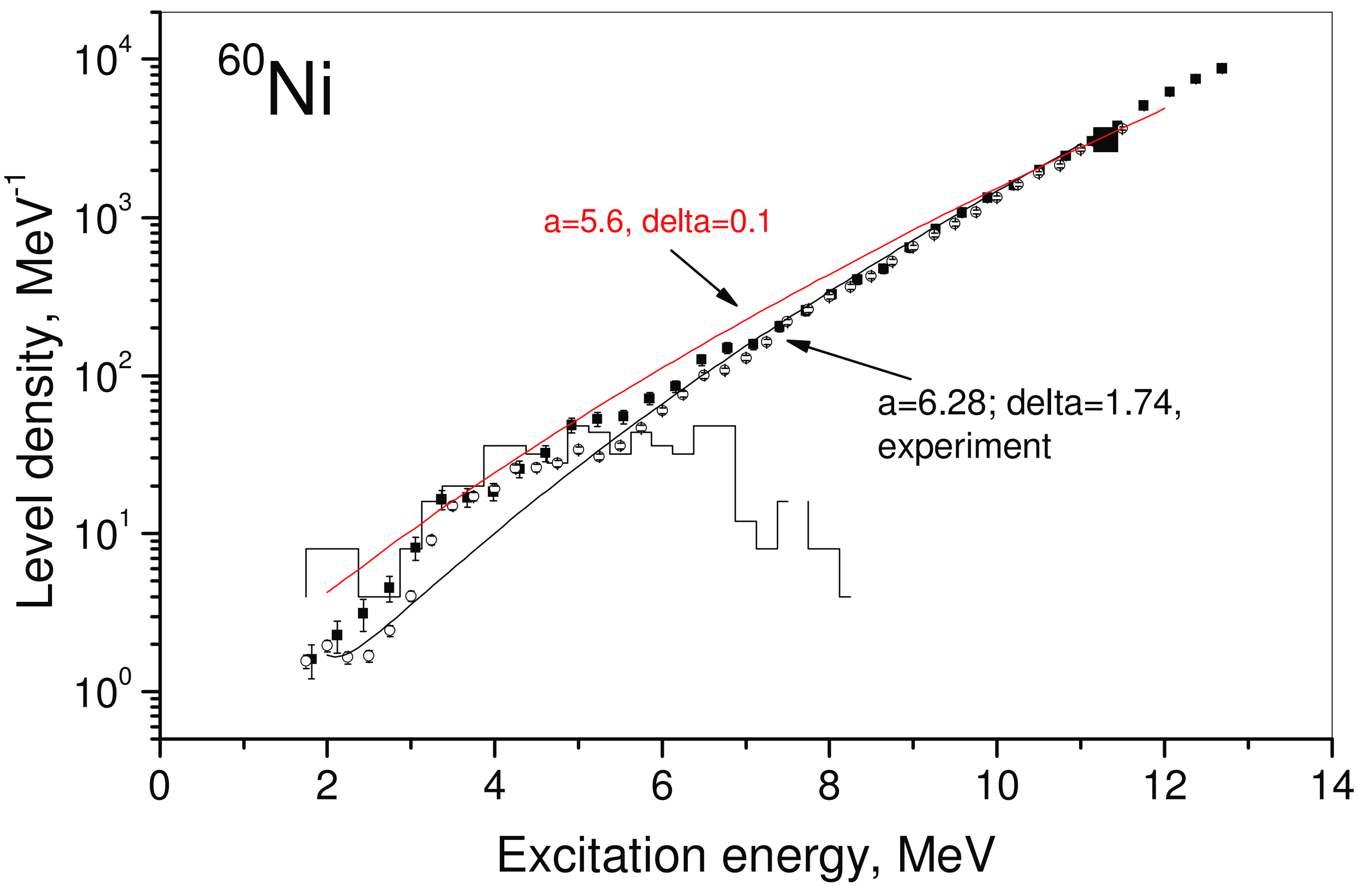
Testing the technique with $^{27}Al(d,n)^{28}Si$



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

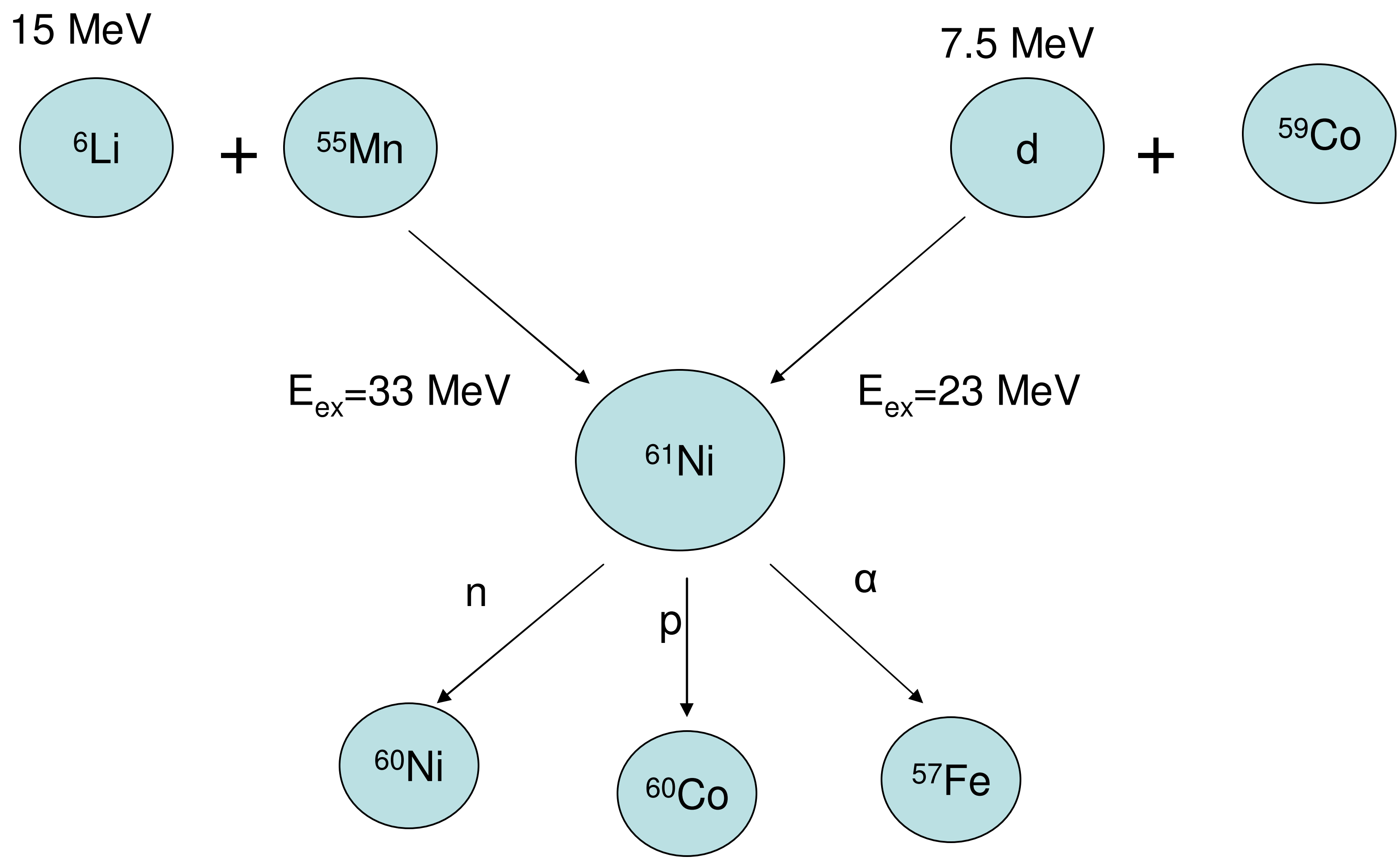


Points are from our experiment, line – Fermi-gas model with parameters from systematics T.von Egidy, D.Bucurescu, Phys.Rev. C 72, 044311 (2005);

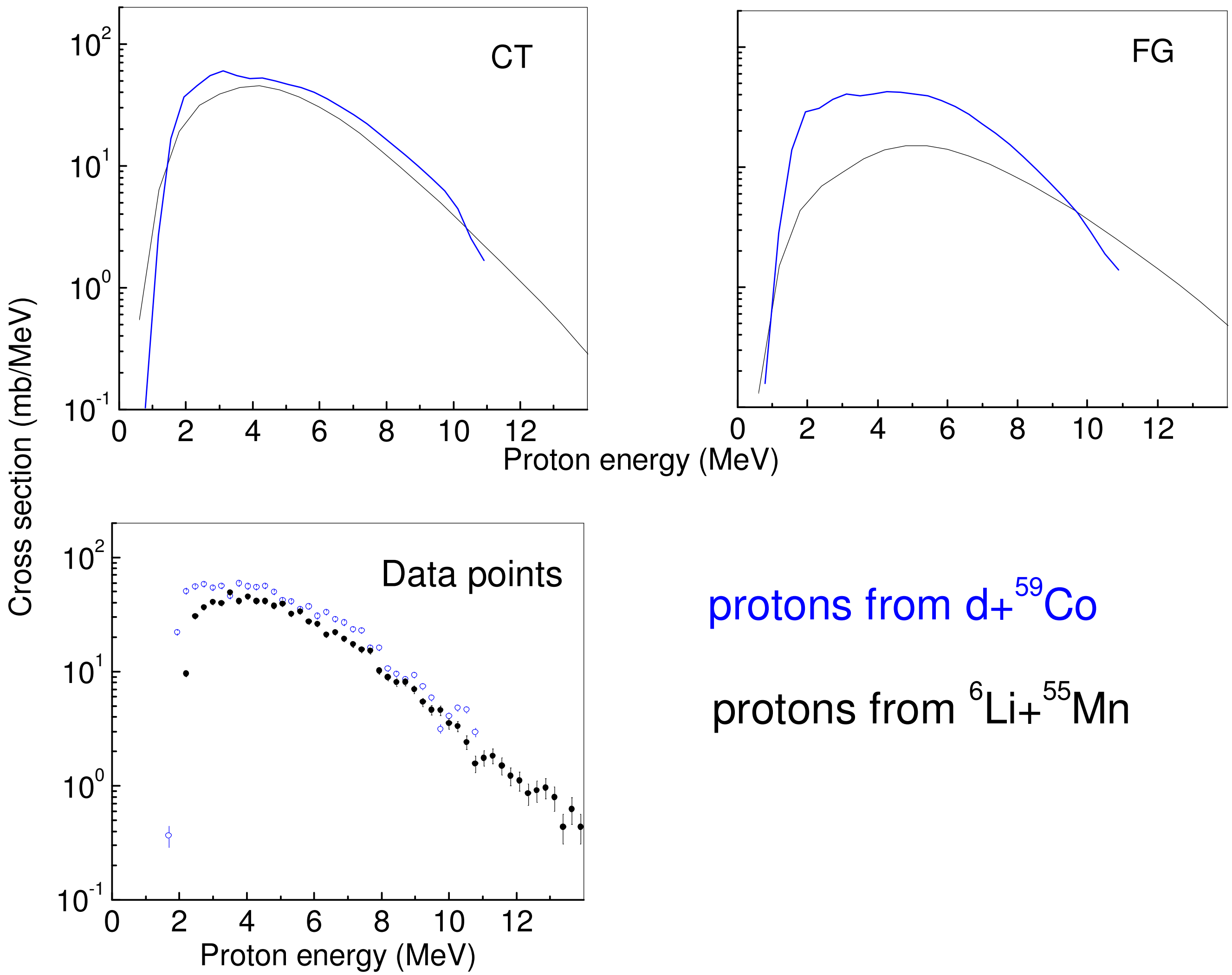


Points are from our experiment, red line is the Fermi-gas model with parameters found from the fit to discrete levels and neutron resonance spacing, black line is the Fermi-gas model fit to experimental points

Measurement of level density below and above the particle separation threshold

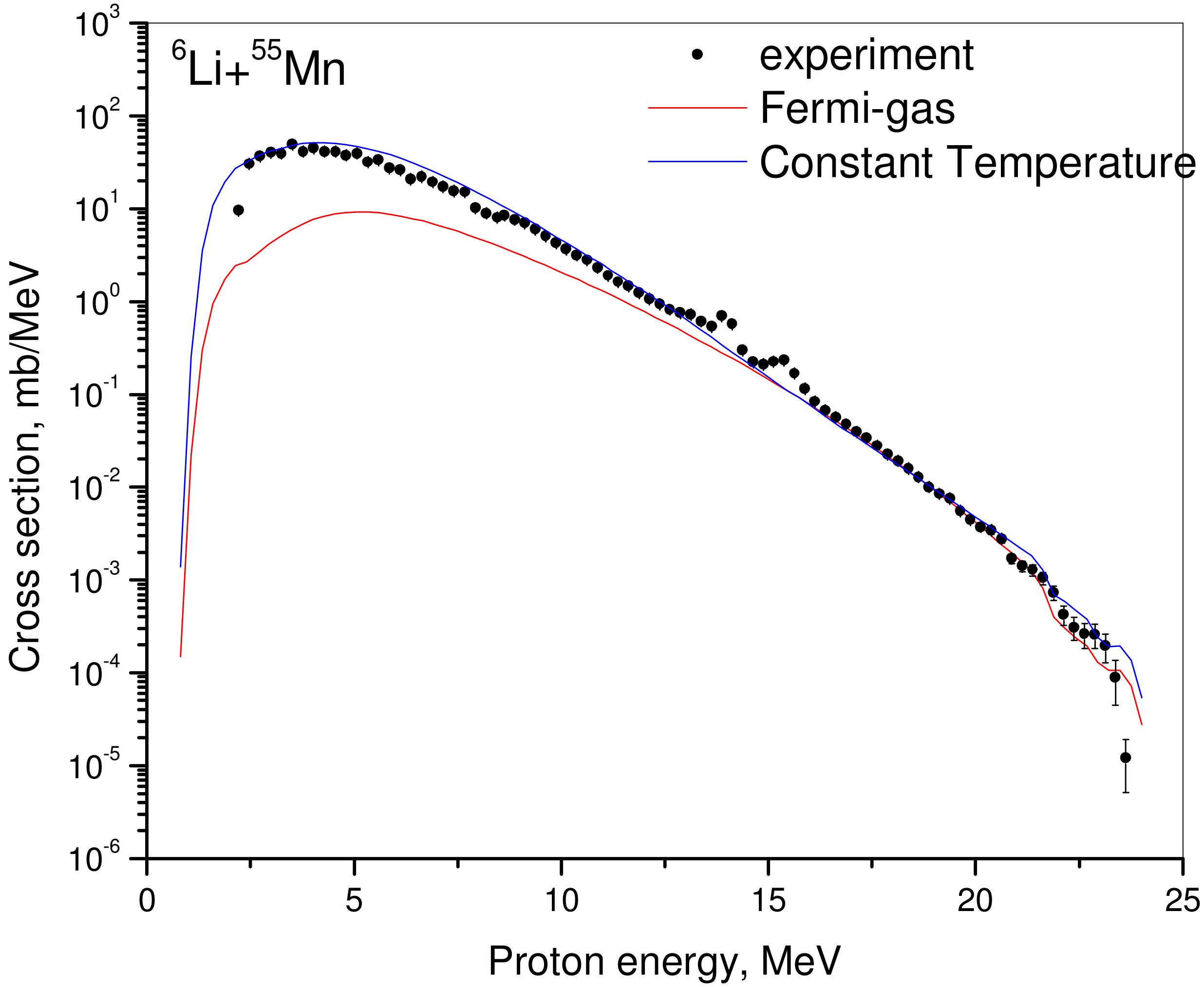


Empire calculations

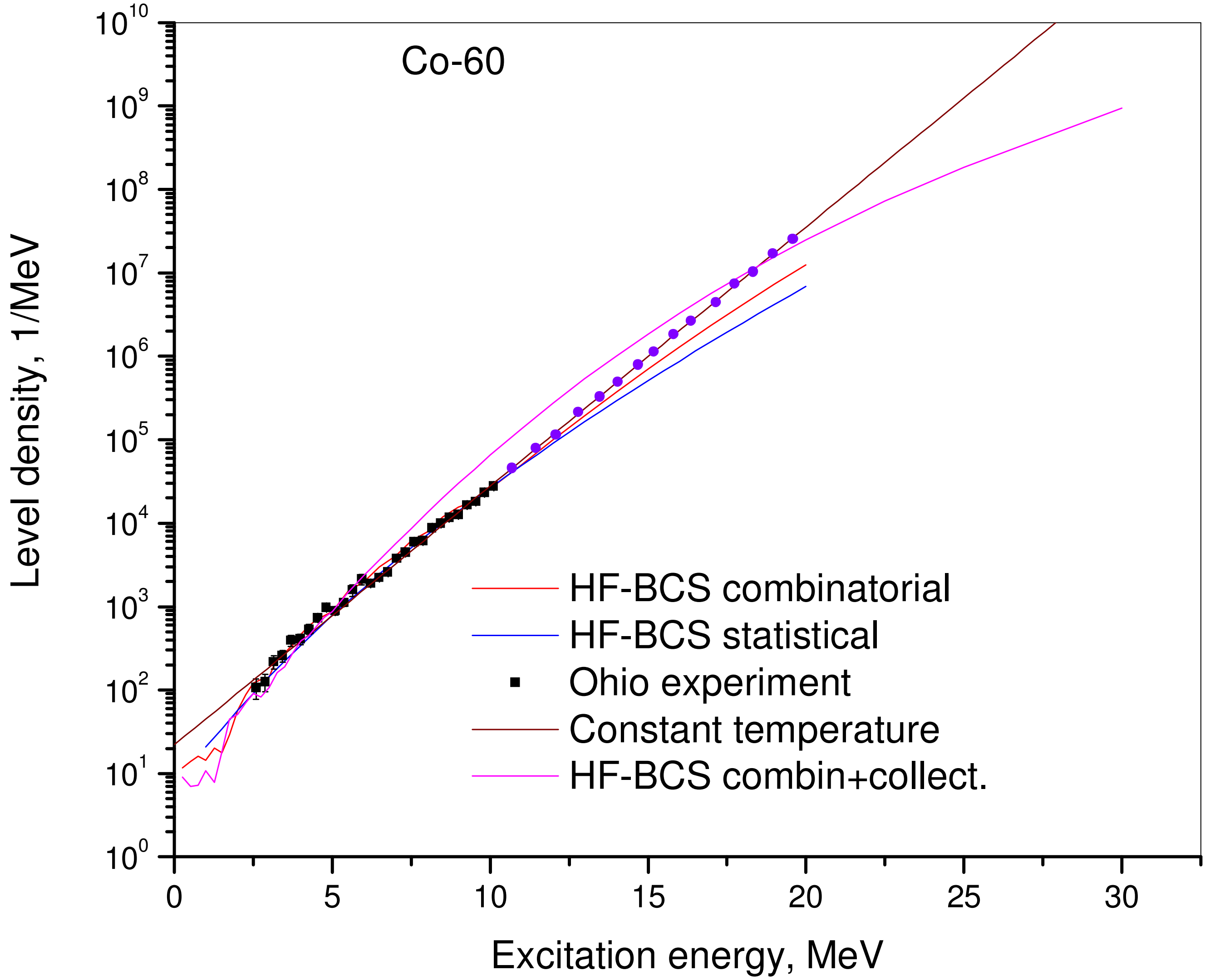


protons from d+^{59}Co

protons from ^{6}Li+^{55}Mn



$^{6}Li+^{55}Mn$
experiment
Fermi-gas
Constant Temperature
Cross section, mb/MeV
Proton energy, MeV

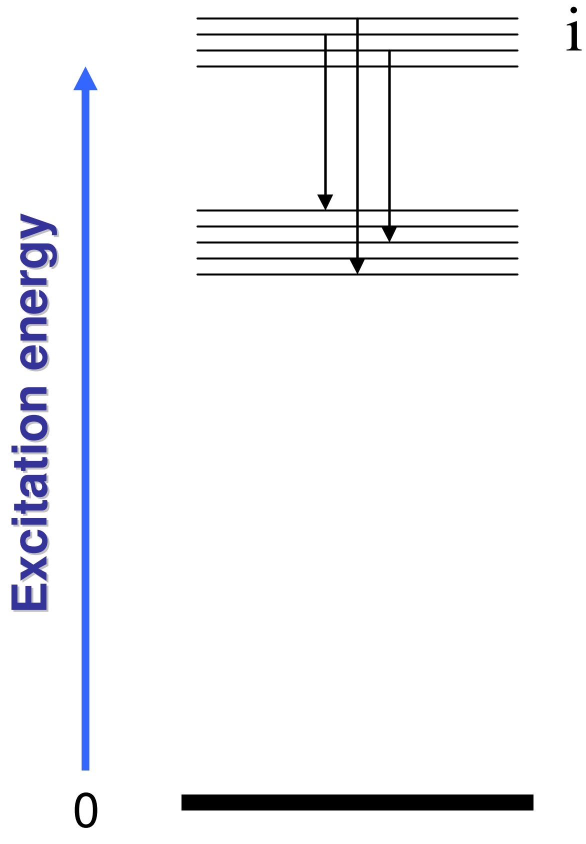


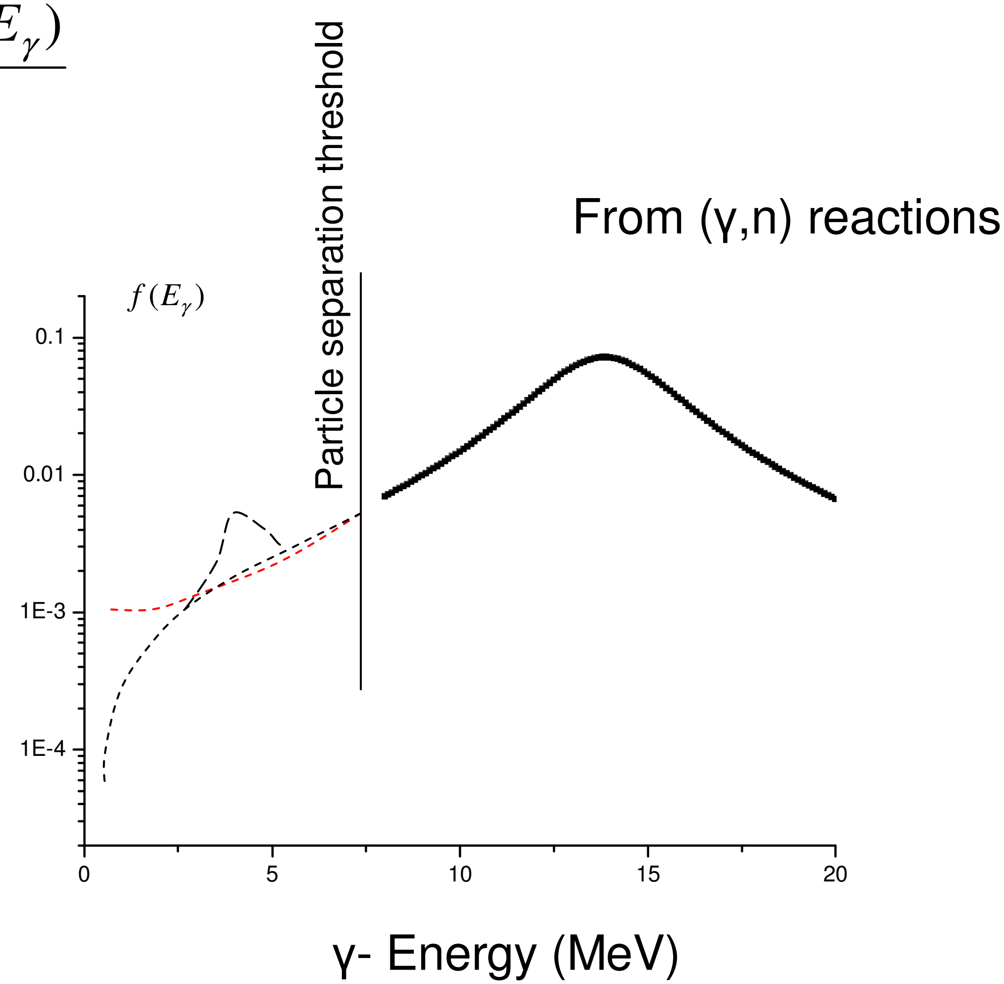
Co-60
Level density, 1/MeV
Excitation energy, MeV
HF-BCS combinatorial
HF-BCS statistical
Ohio experiment
Constant temperature
HF-BCS combin+collect.
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
0
5
10
15
20
25
30

1. It is necessary to get experimental data in a wide excitation energy interval including the energy range above the particle separation threshold.
2. It can be done experimentally by measuring all outgoing particles from compound nuclear reactions
3. The constant temperature model seems to be a good approximation for excitation energies far beyond the particle separation threshold (at least for some nuclei)

γ – strength function in continuum

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





Experimental techniques used to study gamma-strength functions below the particle separation threshold:

1. Continues gamma spectra from neutron capture reactions
2. Two-step cascades (TSC) following thermal neutron capture reactions (Dubna, Prague)
3. Set of gamma spectra at different initial energies (Oslo technique)
4. (gamma, gamma’)

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

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

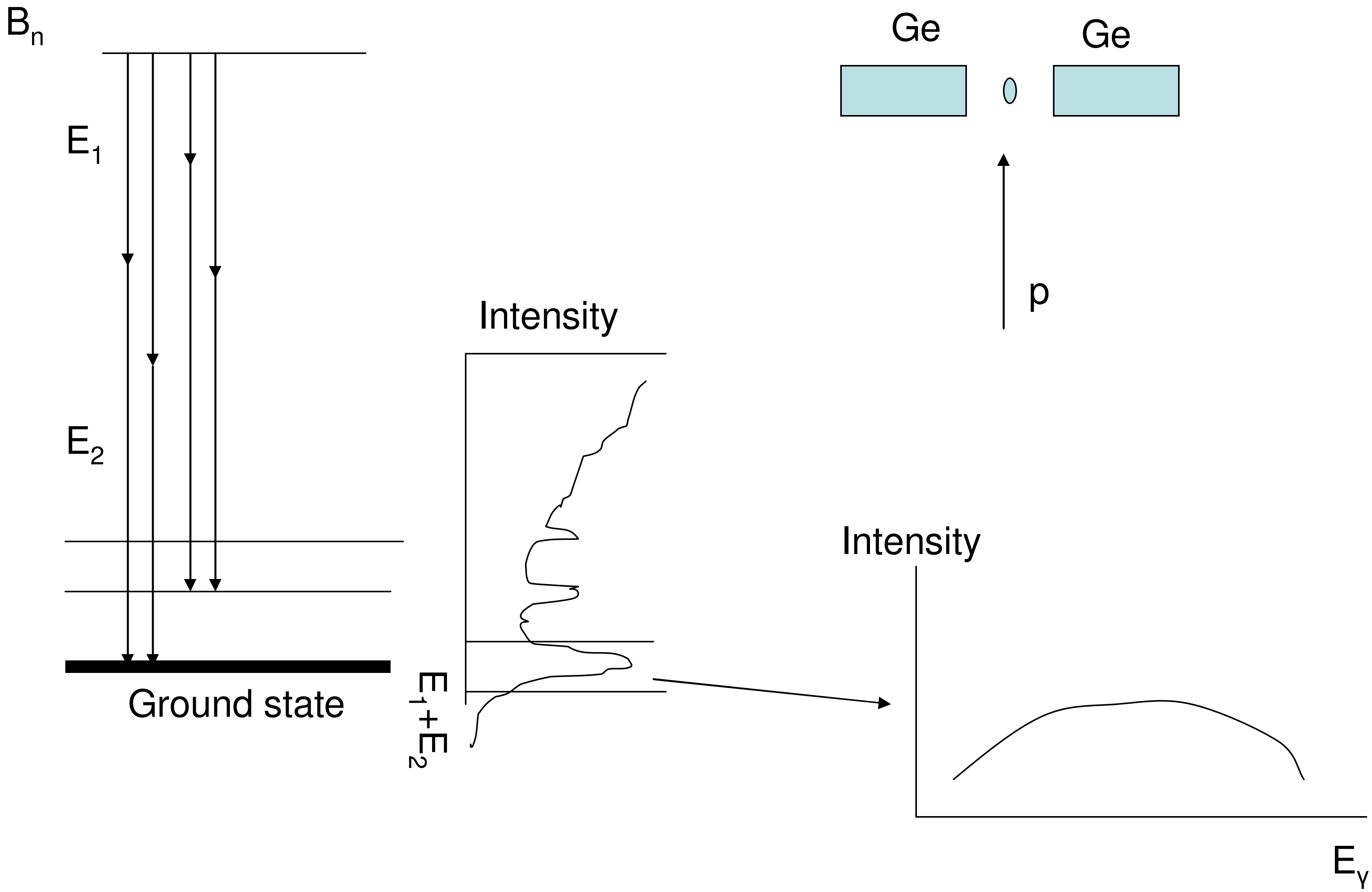
Idea

1 step: we obtain the level density from neutron evaporation spectra.
2 step: we obtain the γ-strength function from 2γ- spectra

The first candidate is ^{59}Co(p,2γ) ^{60}Ni reaction at E_p=1.85 MeV

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

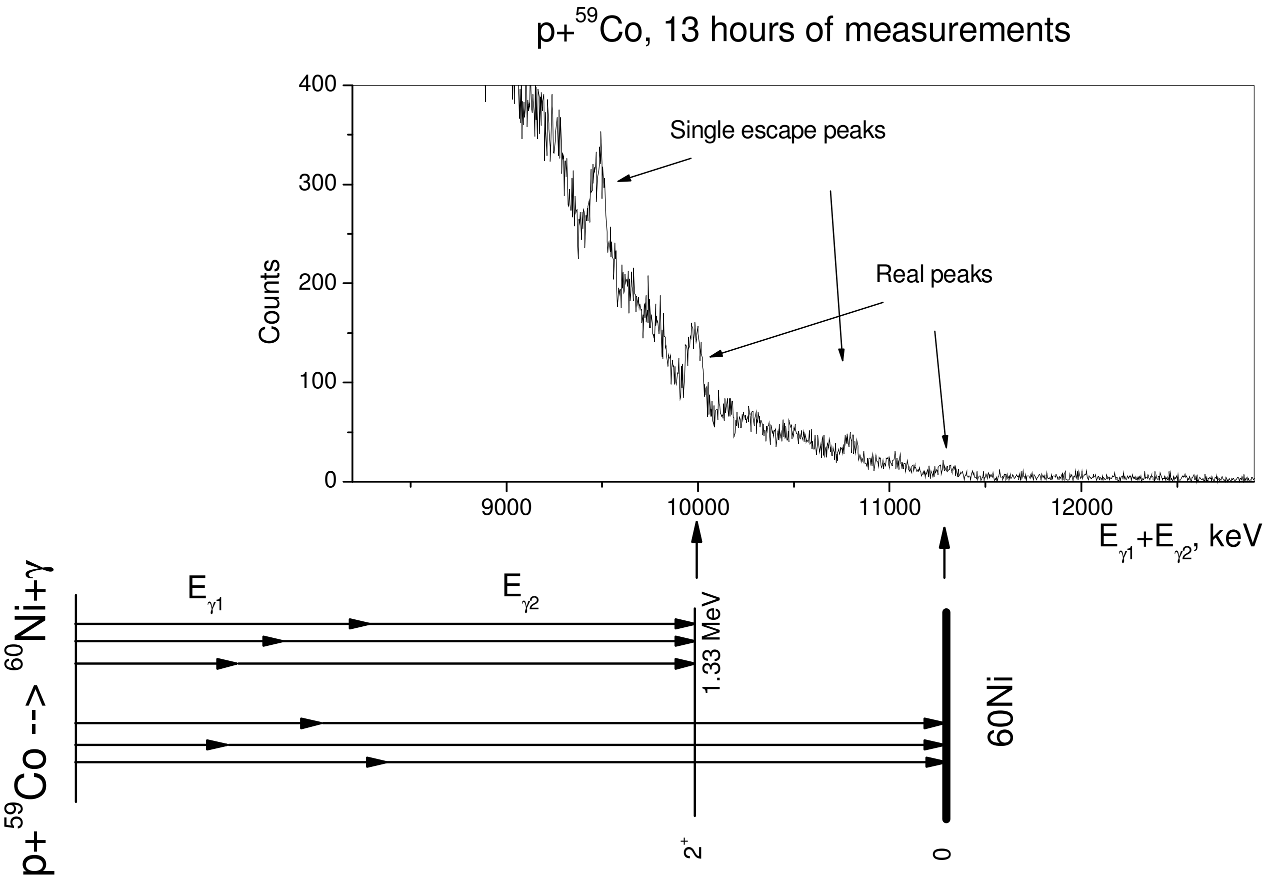
Two-step cascades from proton capture

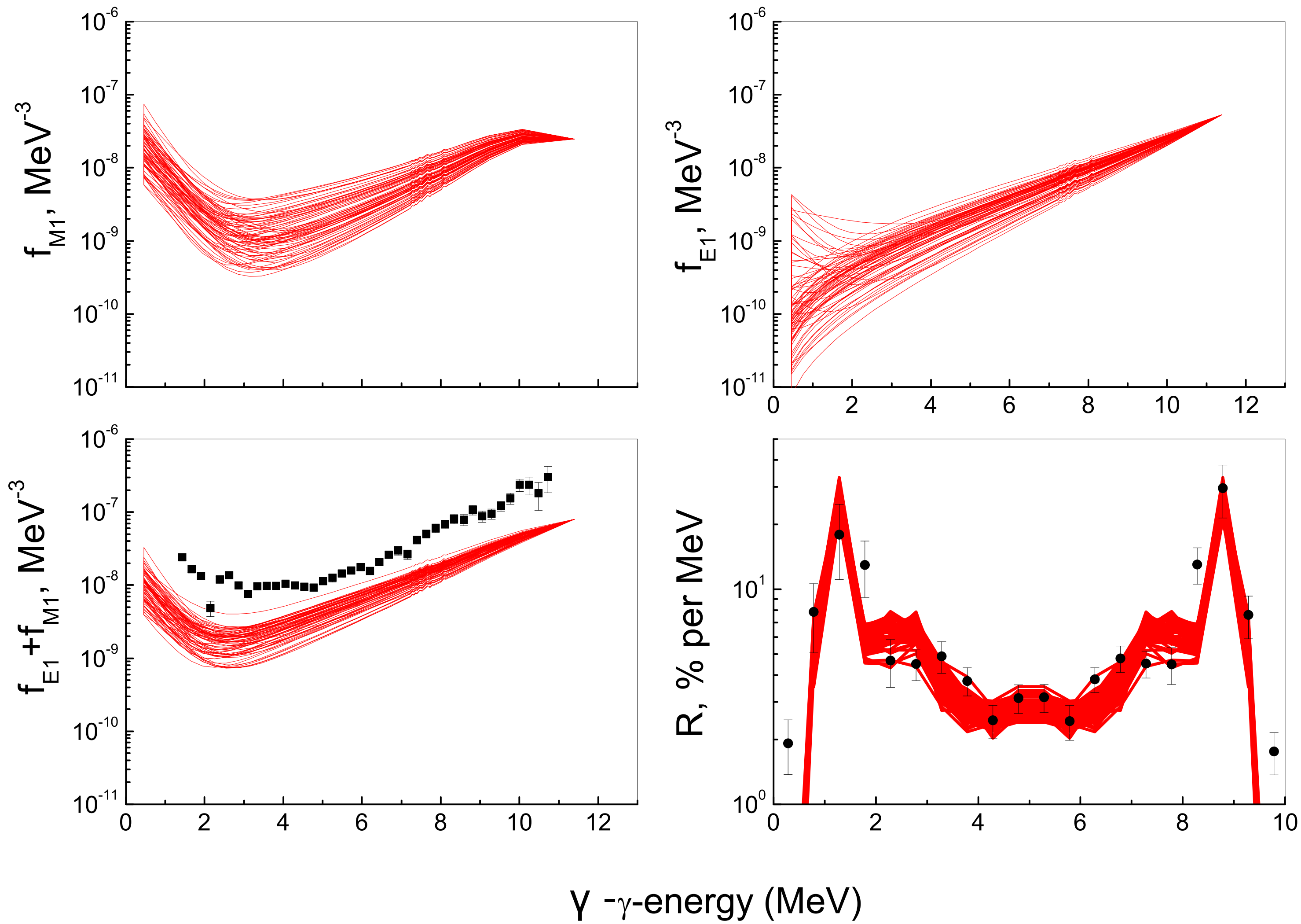


The difference for TSC technique between proton and thermal neutron capture reactions

	Neutron capture	Proton capture
Compound nuclear resonances excited	1 or 2	many, ~ 100
Porter-Thomas fluctuations	very strong	suppressed considerably
Quality of TSC spectra (peak resolution)	very good	Not so good
Absolute normalization of TSC intensity	~ 20%	~5%

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





f_{M1}, MeV^{-3}
f_{E1}, MeV^{-3}
$f_{E1}+f_{M1}$, MeV^{-3}
R, % per MeV
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{1}
10^{0}
0
2
4
6
8
10
12
γ -γ-energy (MeV)

Conclusions

Gamma strength function

Gamma strength function can be studied with combination of (p,2g) and (d,n) reactions. The low energy enhancement is supported by results of these experiments for the ^{60}Ni. The low energy enhancement has the preference to be of M1 type.