Level density and gamma-strength from different experimental technique

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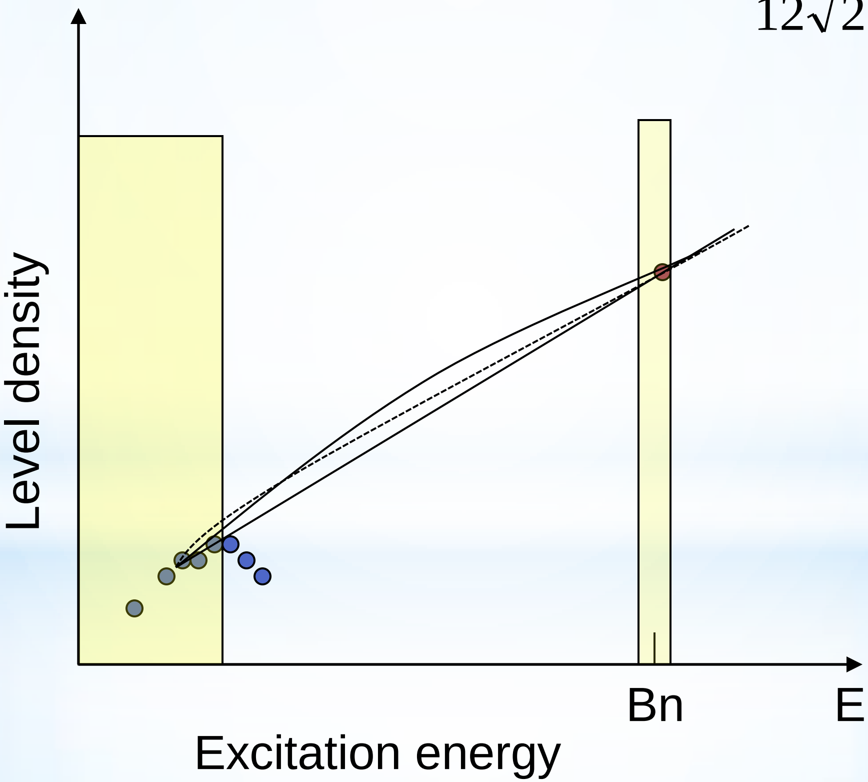
Nuclear level density

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

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



a, δ -parameters

σ = f(a, δ)

The total level density from particle spectra of compound nuclear reactions

<u>The concept:</u>

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

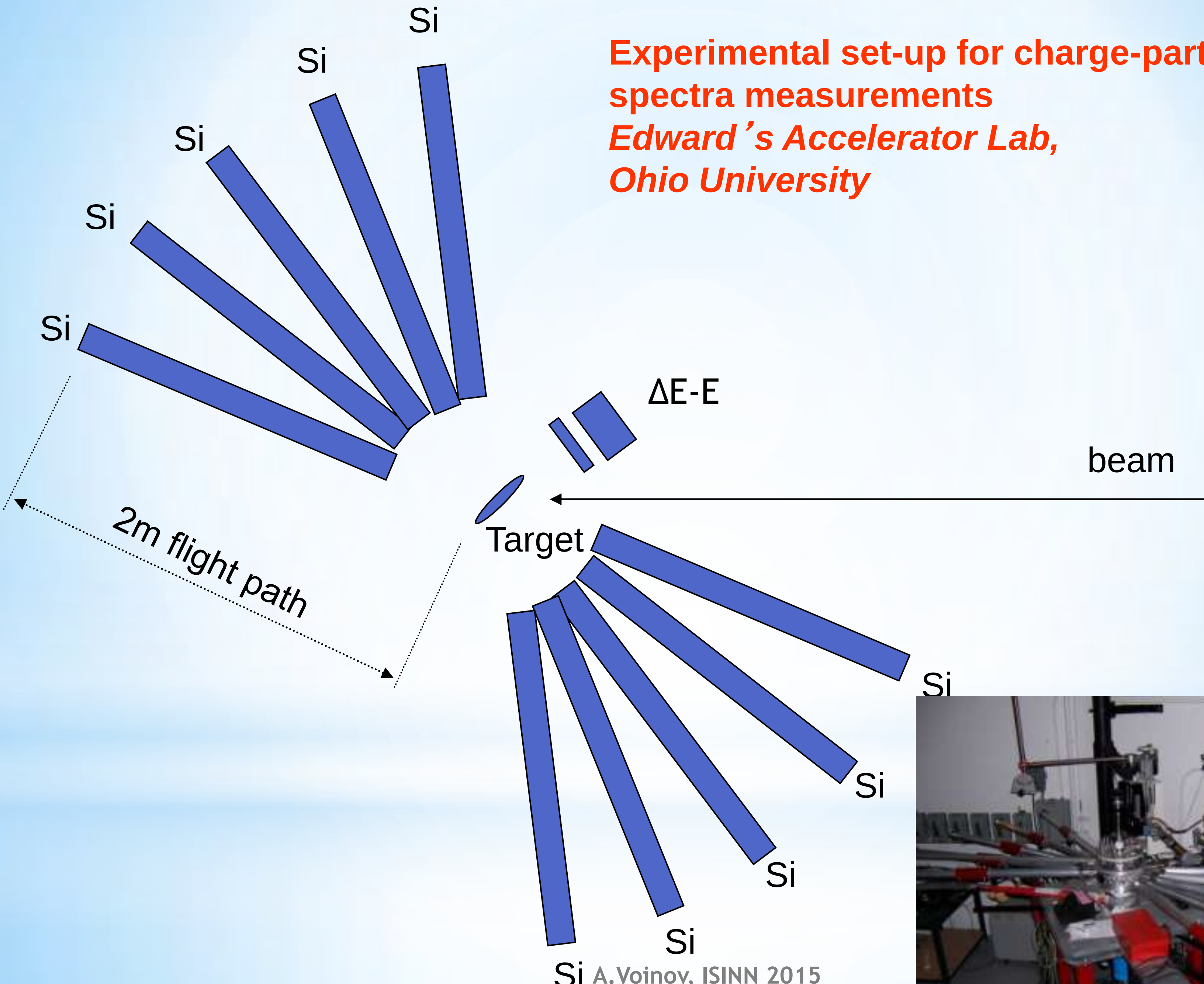
Make sure that the compound reaction mechanism dominates.

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

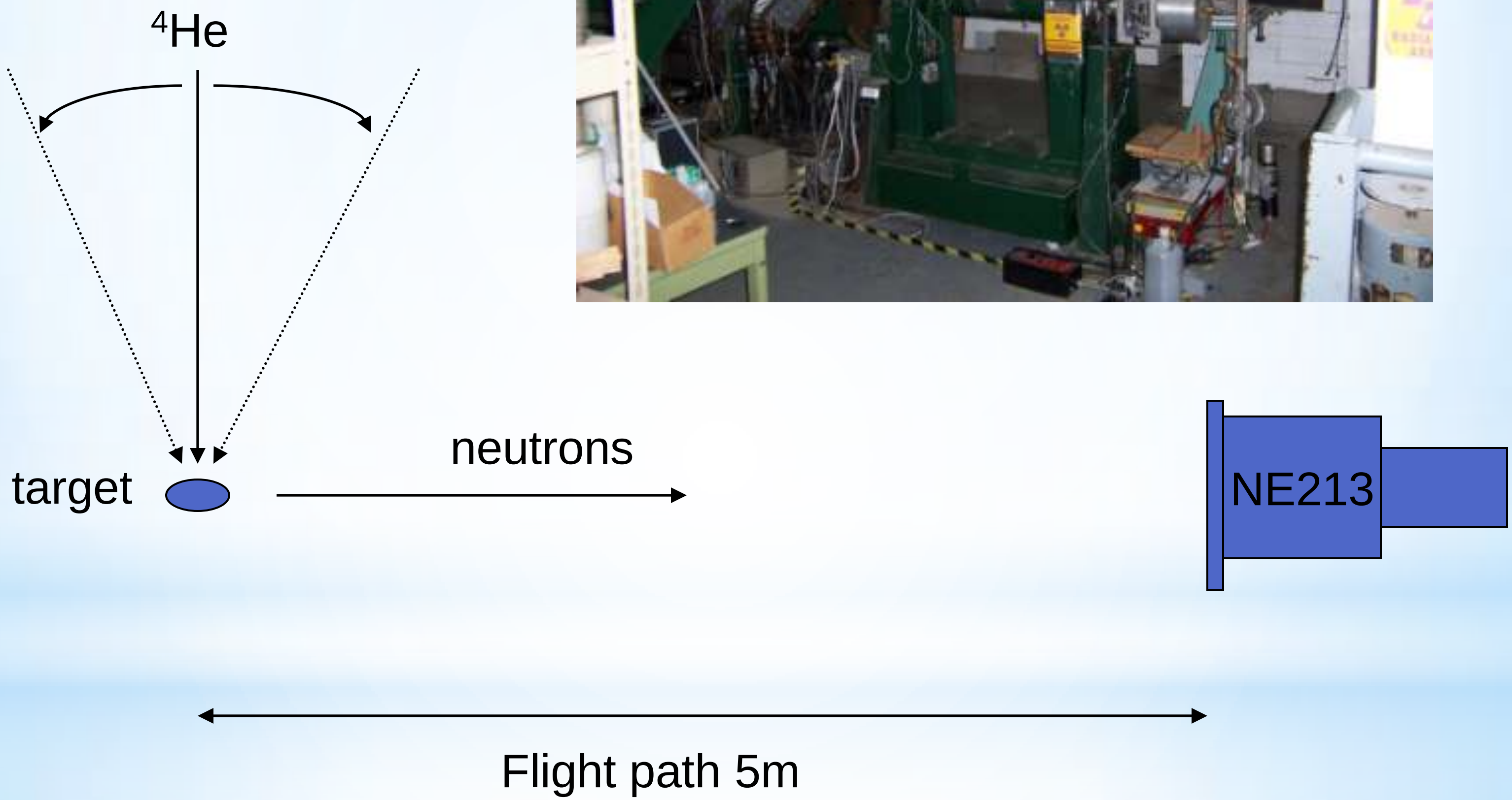
Experimental set-up for charge-particle spectra measurements

Edward's Accelerator Lab,

Ohio University

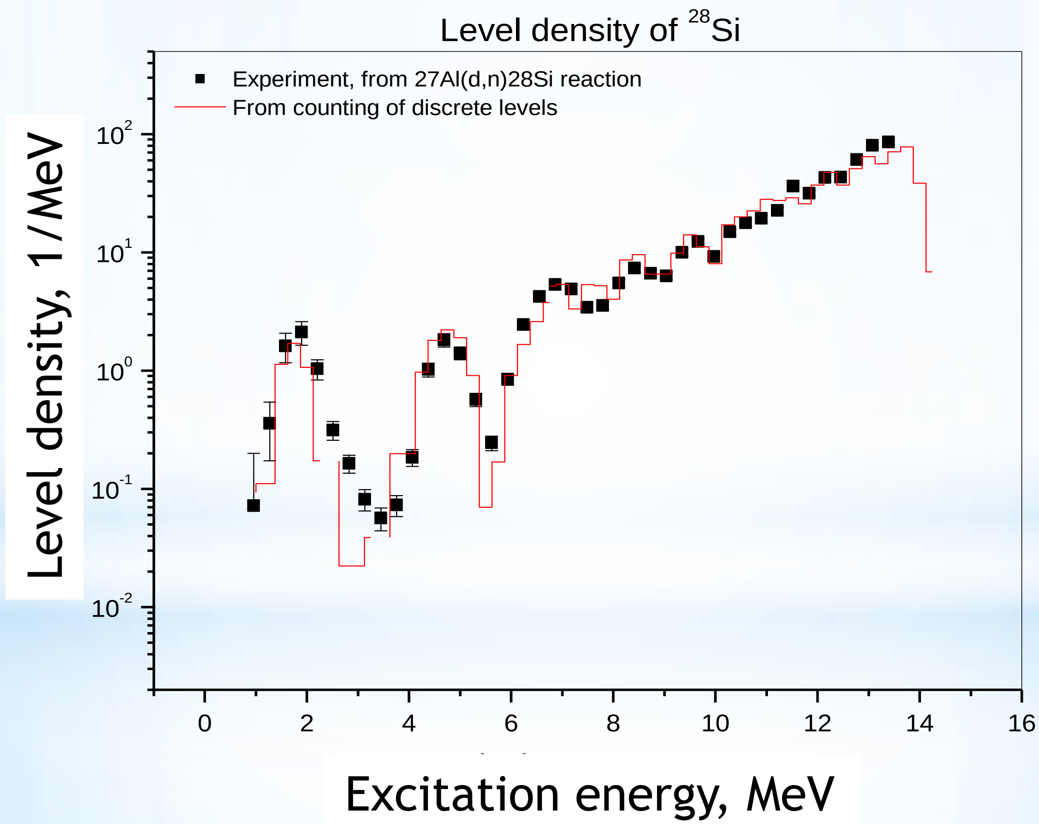


Swinger facility
at Edwards Lab.
Ohio University

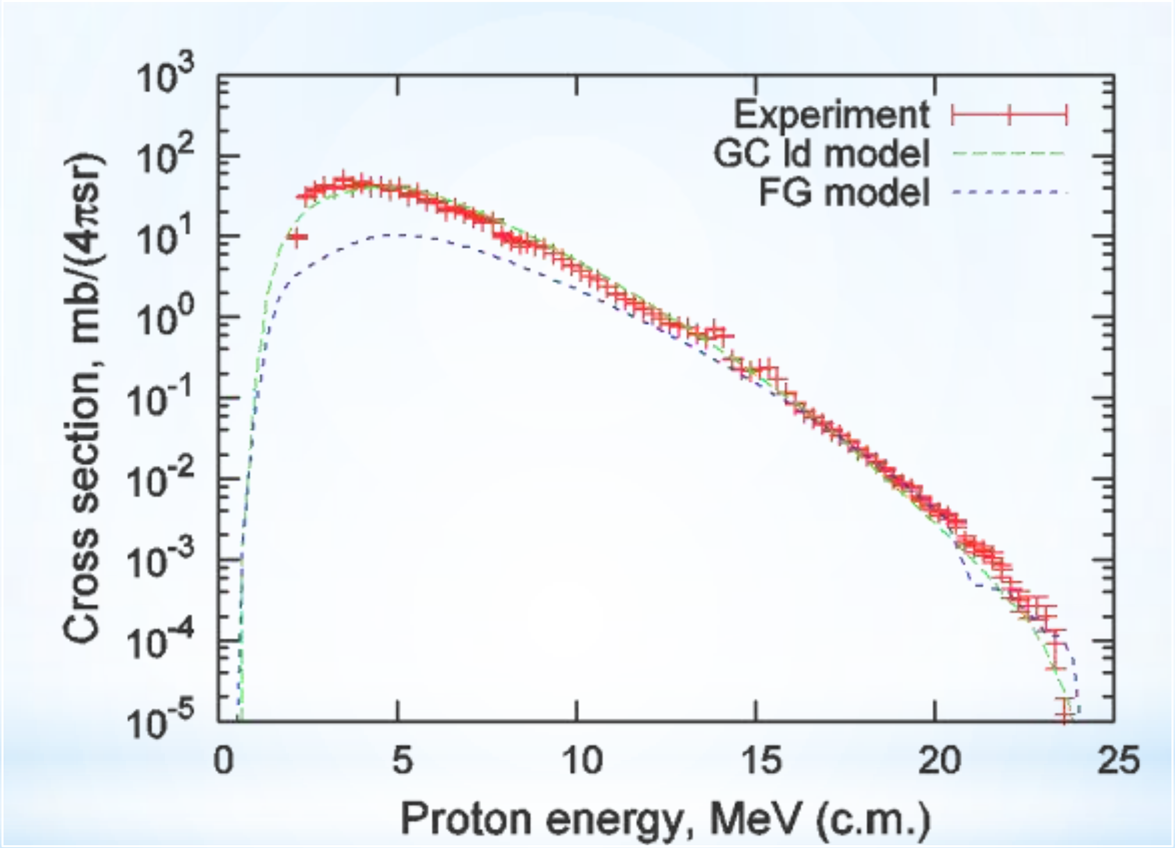


Experimental level densities measured at Edwards Lab. of Ohio University

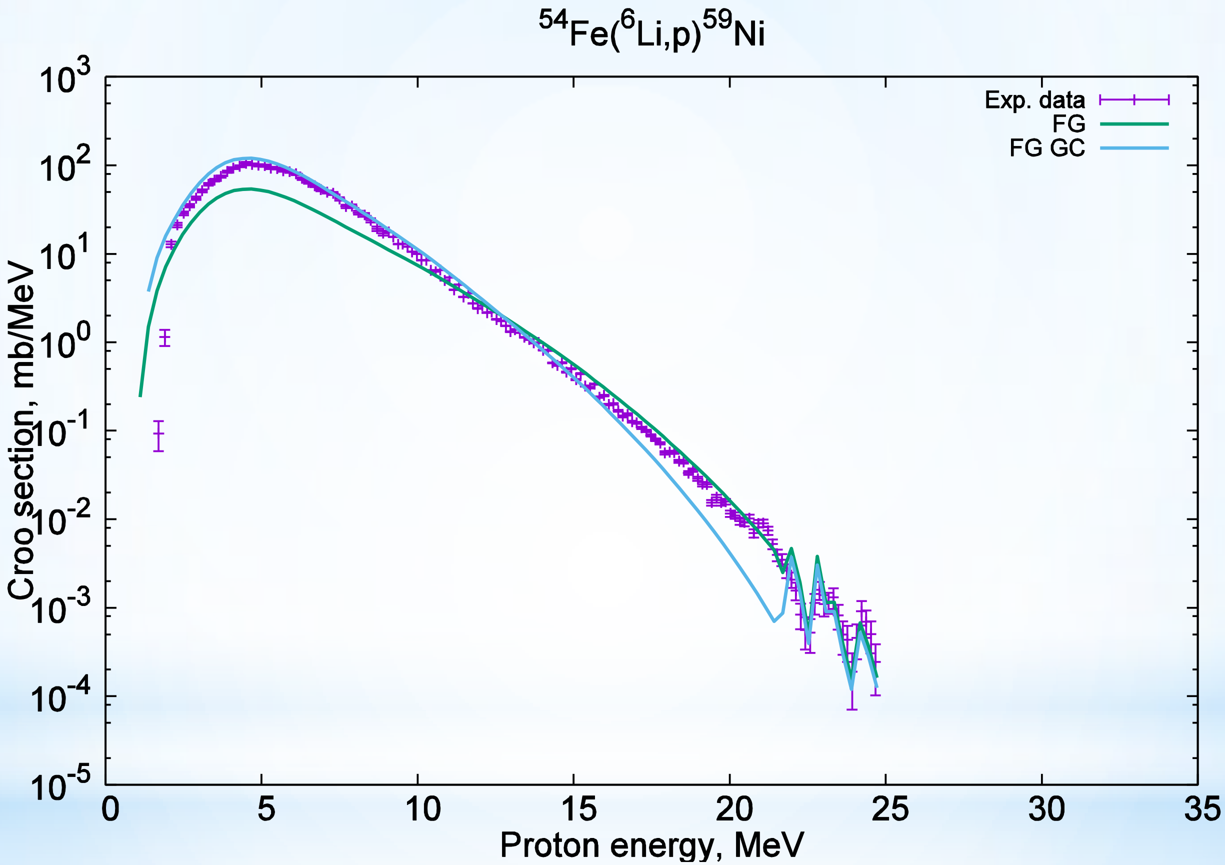
Testing the technique with $^{27}Al(d,n)^{28}Si$



$^{55}Mn(^{6}Li,p)$



Experiment
GC ld model
FG model
Cross section, mb/(4πsr)
Proton energy, MeV (c.m.)



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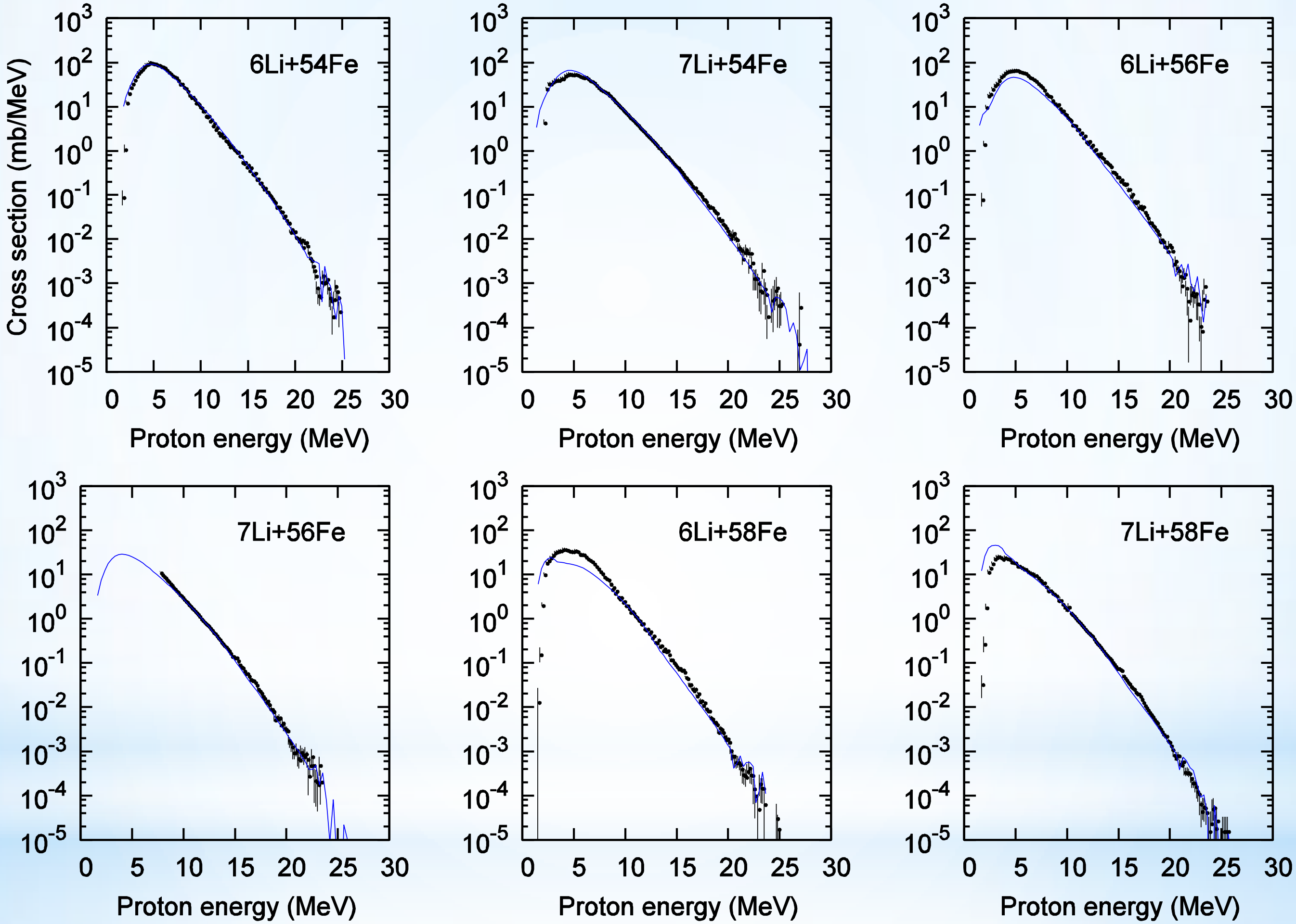
Proton evaporation spectra from $^{6,7}Li$ induced reactions on $^{54,56,58}Fe$. Constant temperature up to 12-16 MeV



Experimental spectra from Li induced reaction on irons confirm:

1. There is a transition region of excitation energy where parameter a should increase with U such that

$$T = \sqrt{\frac{U}{a(U)}} \approx const$$

2. Fermi-gas parameters obtained from simultaneously fitting both discrete levels and neutron resonance spacing work in the energy region up to the neutron separation energy only (T.von Egidy systematics)

3. Gilbert-Cameron model with a constant temperature level density at low energies and Fermi-gas at higher energies with parameter obtained with Ignatuyk or Iljinov systematics reproduce evaporation spectra better

Spin cutoff parameter

$$s = 0.0146 \times A^{5/3} \sqrt{\frac{U - d}{a}}$$

- Use the same parameters as in level density function

- Decouple parameters from level density parameters and determine them from different experimental technique

Spin cutoff σ from angular distribution of particles from compound nuclear reactions

T.Ericson and V. Strutinski, Nucl.Phys. 8, 284 (1958)

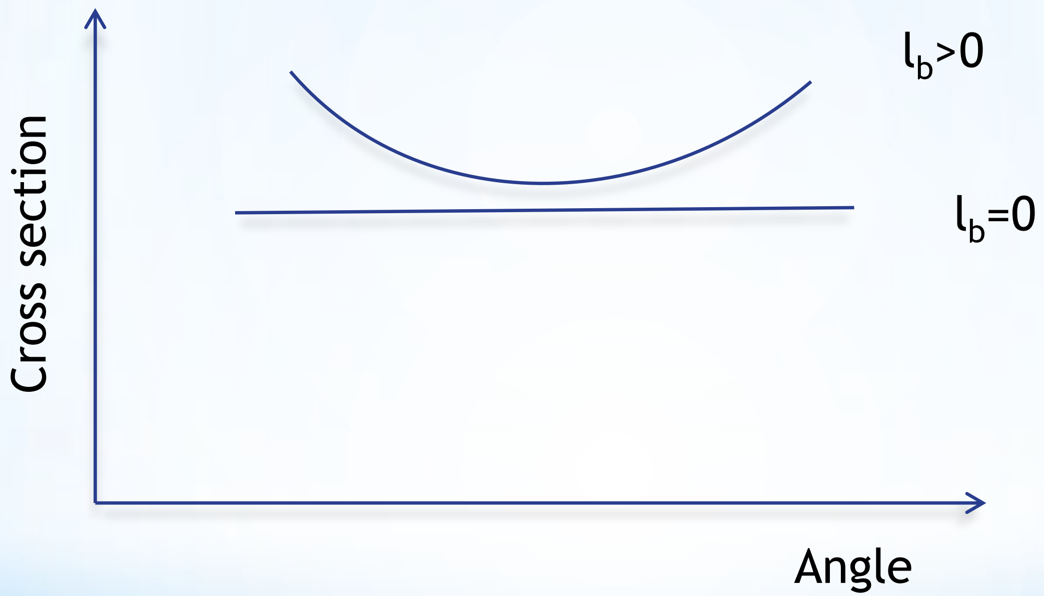
- Due to orbital momentum conservation, spin of compound nuclei tend to be aligned with orbital momentum of incoming particles

- Compound nucleus “remembers ” direction of incoming beam.

- Angular distributions become non-isotropic but symmetric about 90 degree

- Degree of anisotropy is determined by angular momenta of outgoing particles which are determined by spin distribution of residual nucleus

$a+A \longrightarrow C \longrightarrow B+b$



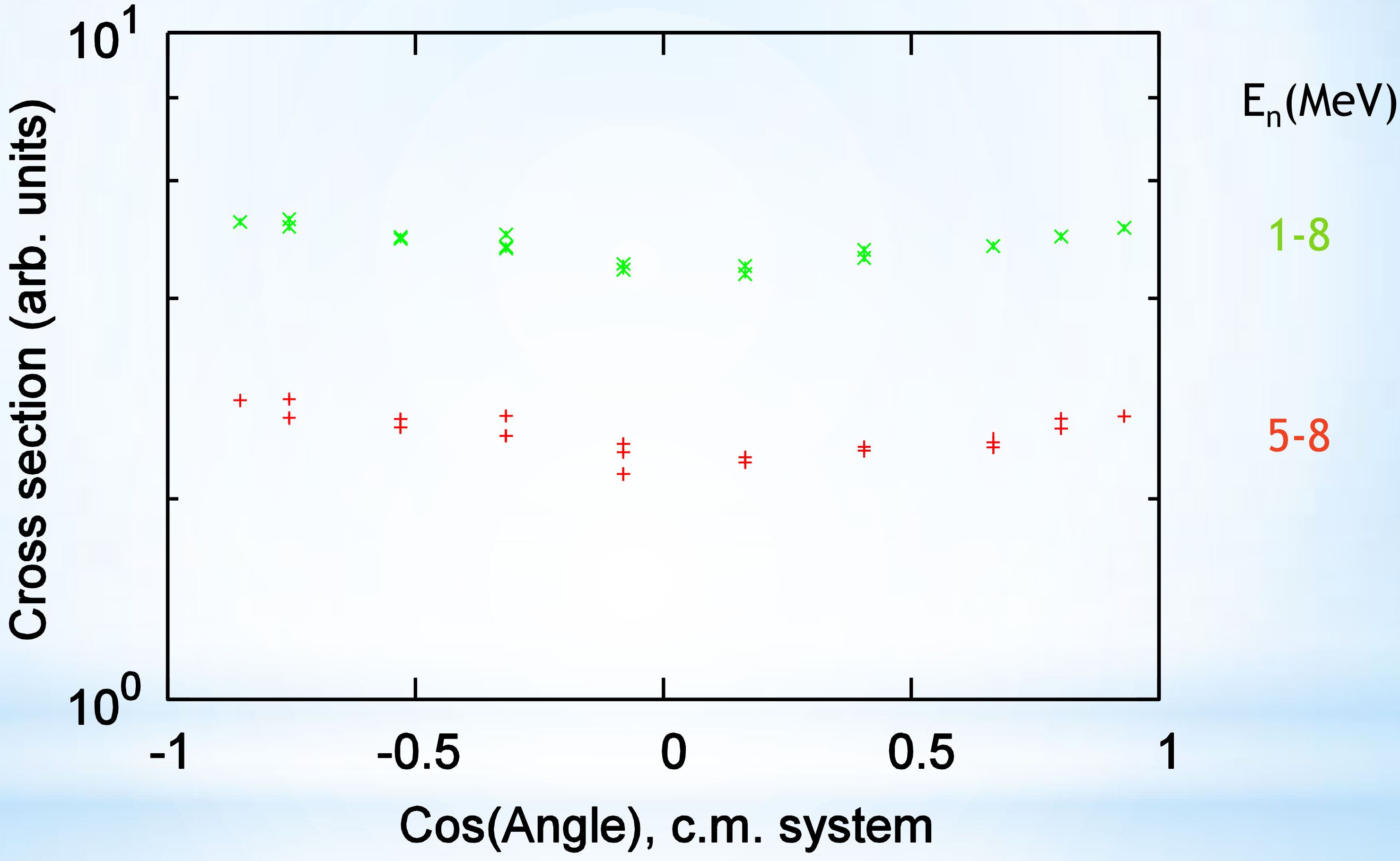
Orbital momenta are determined by spin of both compound C and residual nucleus B

Neutron angular distributions from $^{56}Fe(a,n)^{59}Ni$ reactions

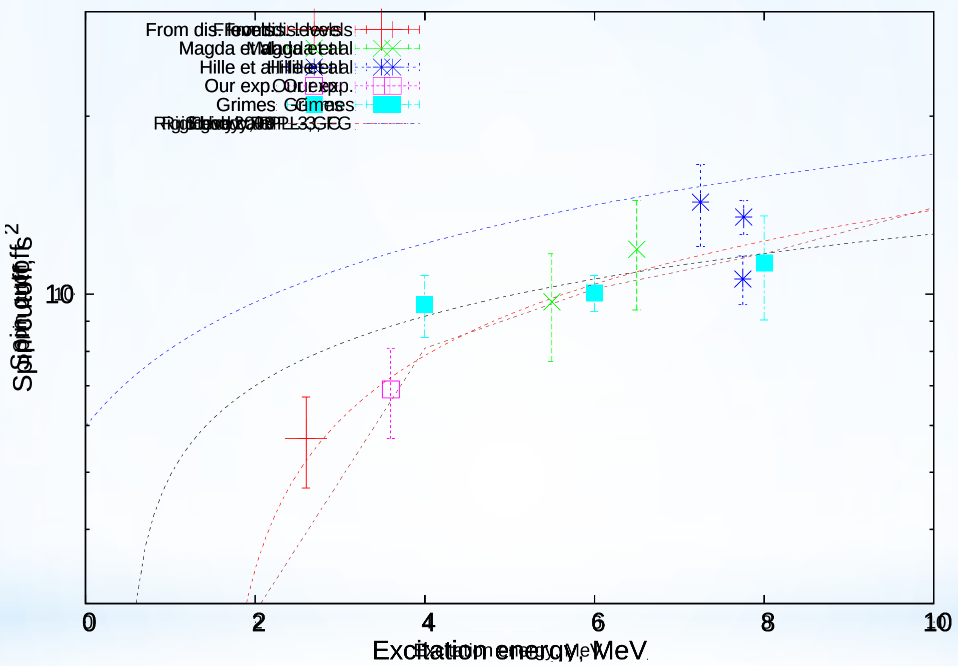
1. Experiment at Edwards Lab of Ohio University with 12 MeV alpha beam
2. P. Hille et al, Nucl.Phys. A232,157(1974)
3. M.T. Magda et al, Nucl.Phys. A140, 23(1970)
4. S.M. Grimes et al, PRC 10, 2373(1974)

Experimental neutron angular distributions have been analyzed with Hauser Feshbach code developed at Ohio University (S. Grimes).
The spin cutoff parameter has been adjusted to reproduce experimental angular distributions.

Preliminary neutron angular distributions from $^{56}Fe(\alpha,n)$ reaction (Ohio)



Spin cutoff parameter of 59Ni



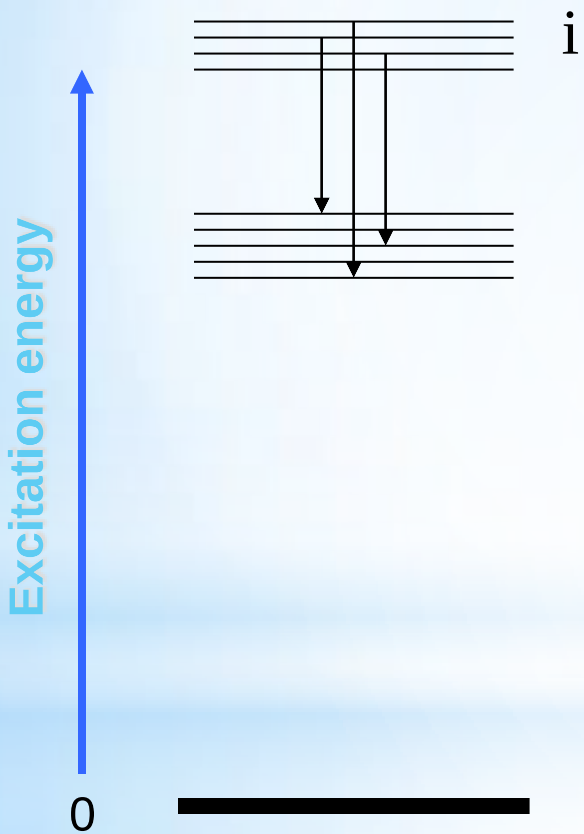
Conclusion

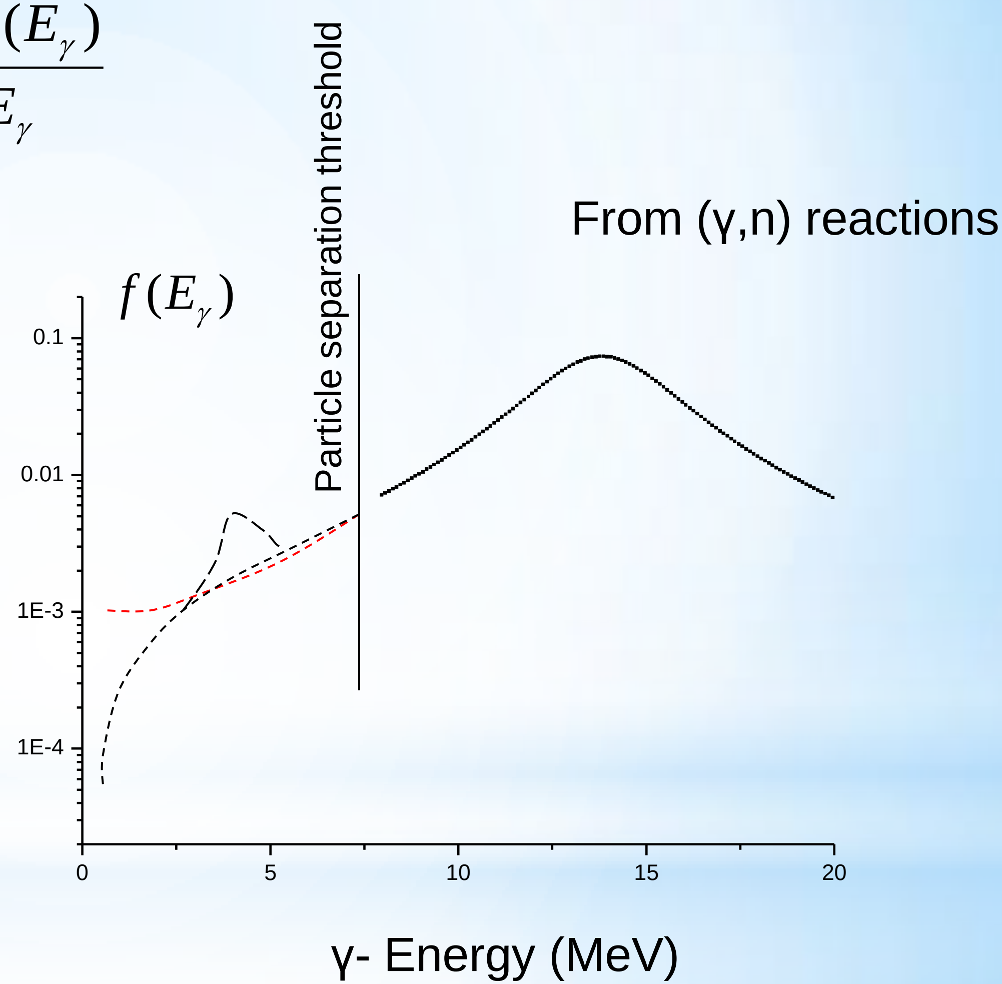
- Estimation of spin cutoff parameters from formula based on Fermi-gas model might lead to incorrect results. This formula might require different parameters from that obtained from analysis of a nuclear level density function.

- Spin cutoff parameter obtained from microscopical calculations appears to be more reliable.

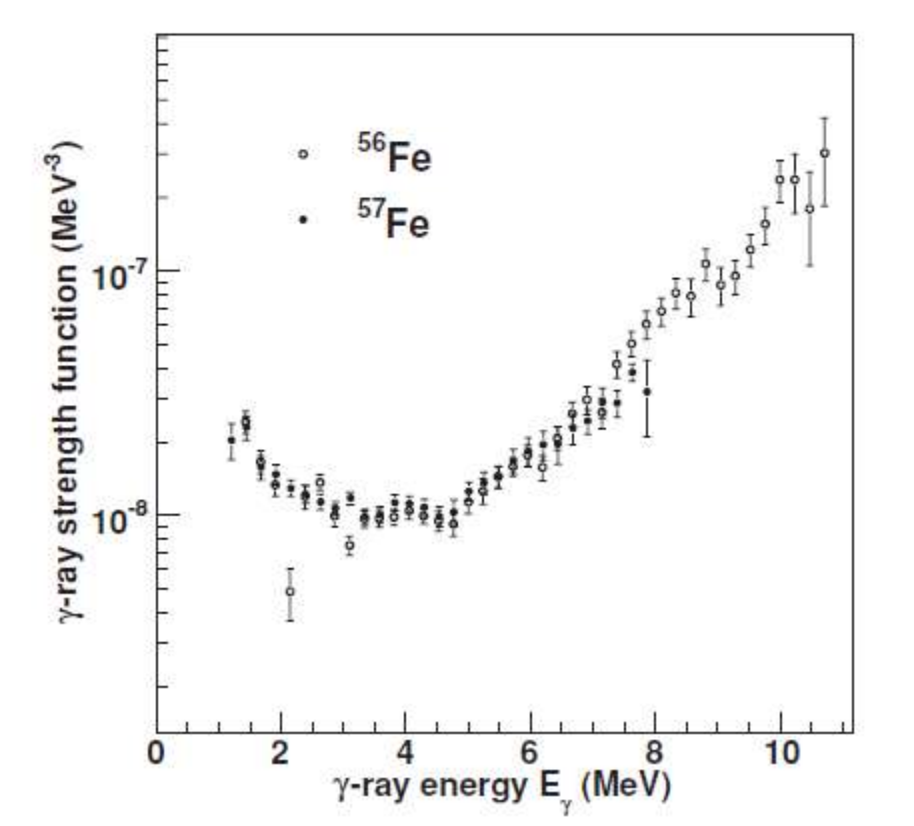
γ – strength function in continuum

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





γ-strength function from Oslo type of experiments
Low energy upbend phenomenon



○ - ^{56}Fe

● - ^{57}Fe

Problem of decomposition of the measured γ-strength into different multipolarities remains unsolved.

A.Voinov et al, Phys.Rev.Lett. 93, 142504 (2004)

Study of γ-strength function at Edwards Lab. of Ohio University

$^{55}Mn(p,2\gamma)^{56}Fe$

γ-strength of ^{56}Fe

$^{55}Mn(d,n)\,^{56}Fe$

Level density of ^{56}Fe

1. Level density are obtained from neutron evaporation spectra.
2. γ-strength function is analyzed from two-step cascade spectra

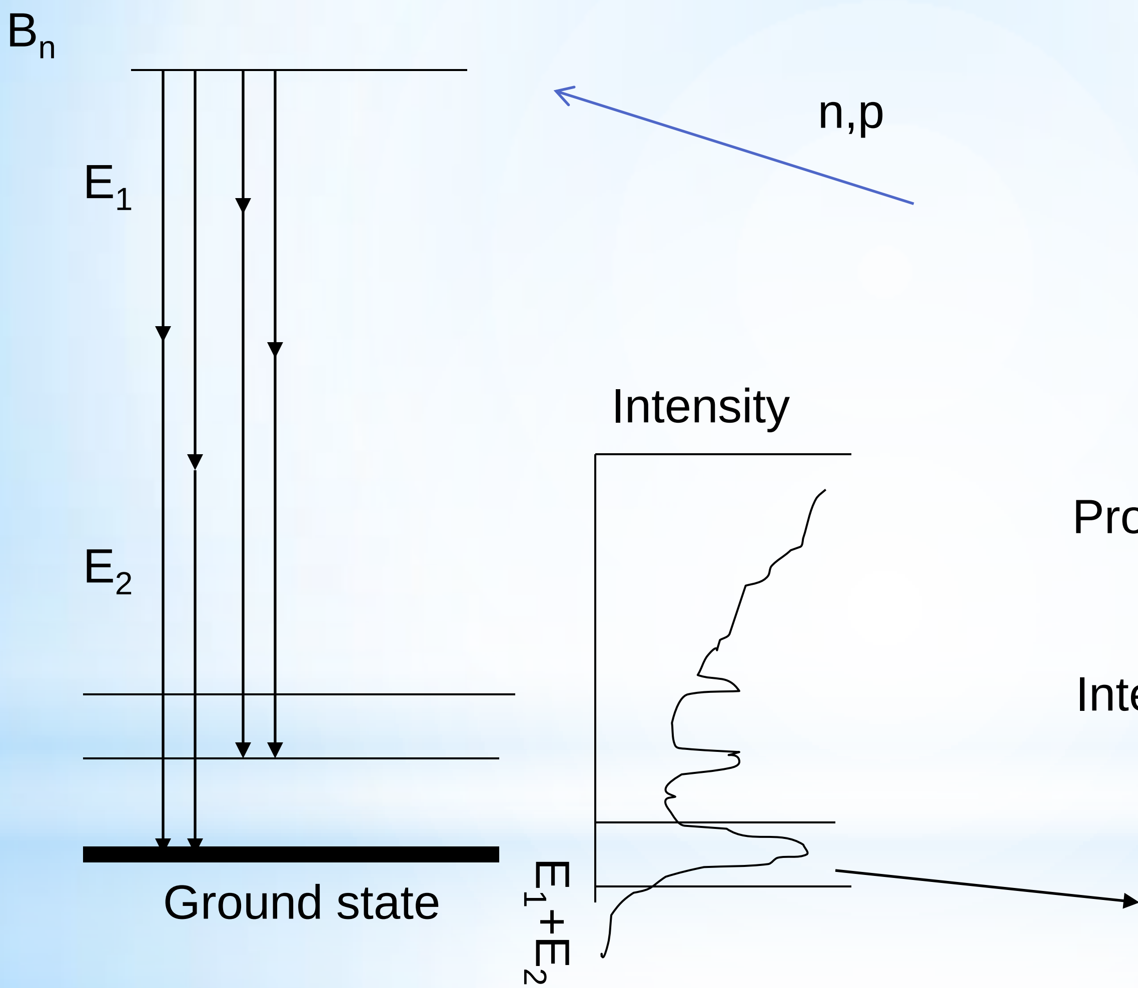
E_p=1.65 MeV

Idea of separation of the total E1+M1 strength into its E1 and M1 component

$f_{total} = f_{E1} + f_{M1}$ from Oslo experiment

$I_{\gamma\gamma} \sim f_{E1} f_{M1}$ from two-step cascade experiment

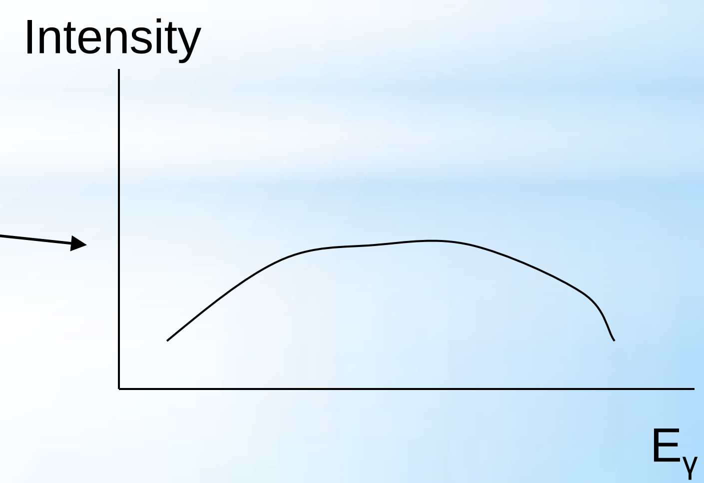
Method of two-step γ – cascades from capture reactions



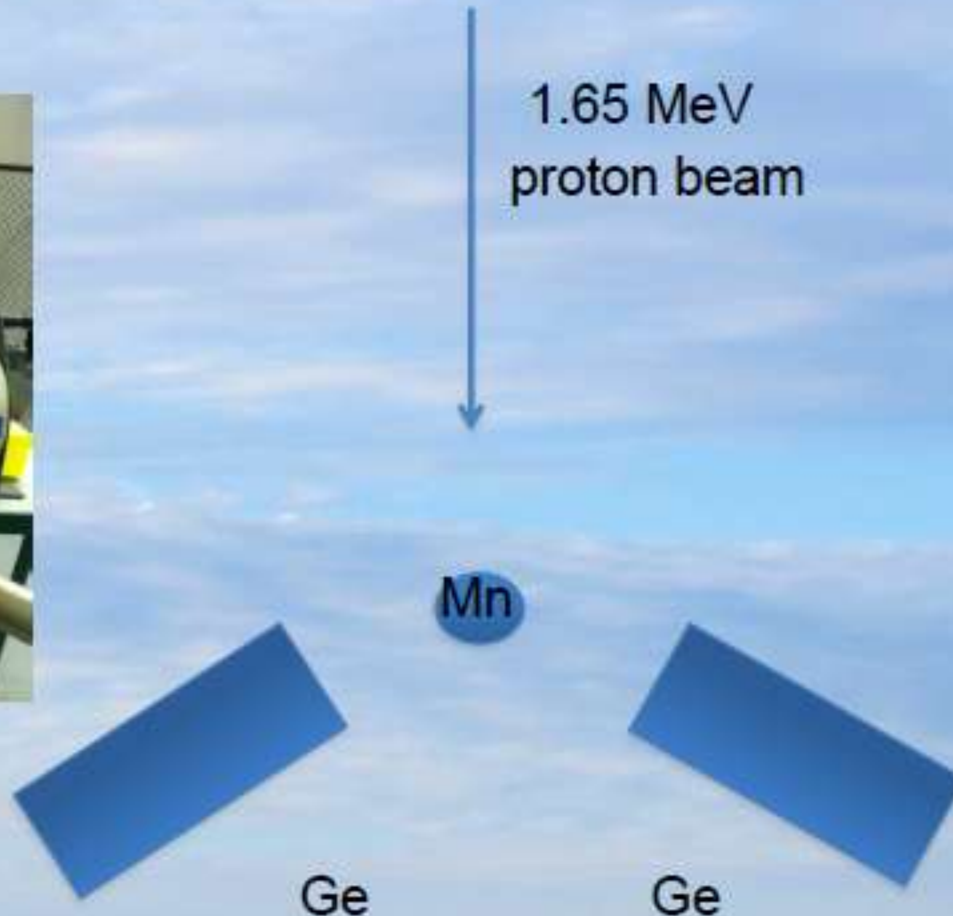
n-induced reactions:

A. Hoogenboom,
A. Sukhovoj,
F. Becvar

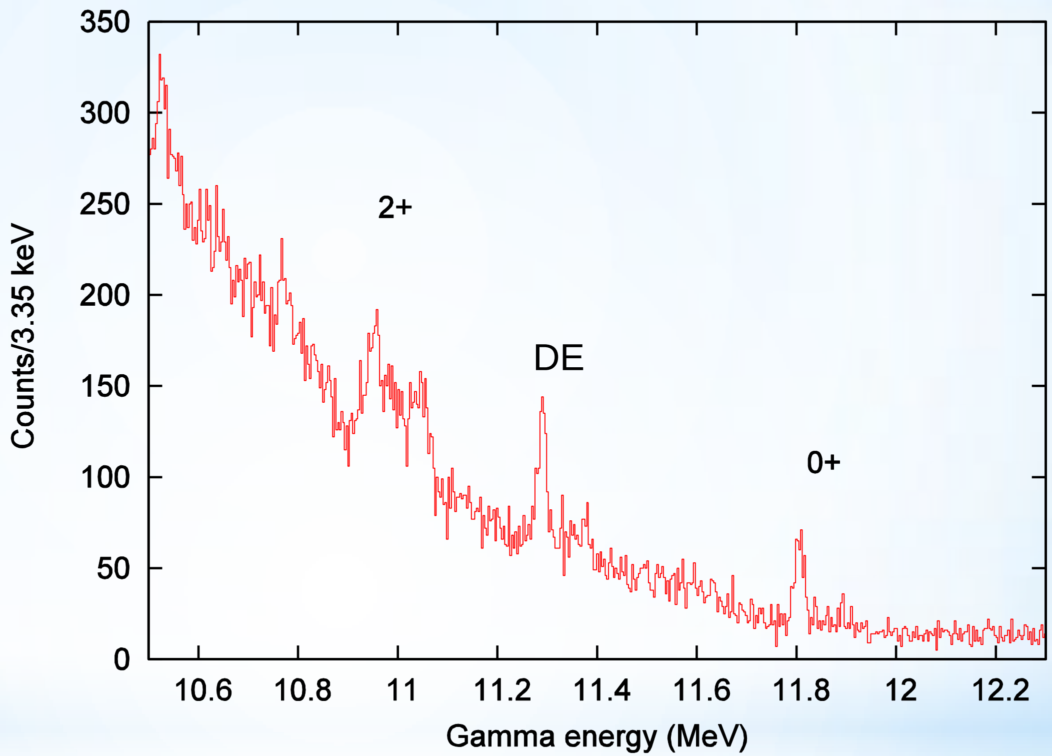
Problem: level density is needed !!!

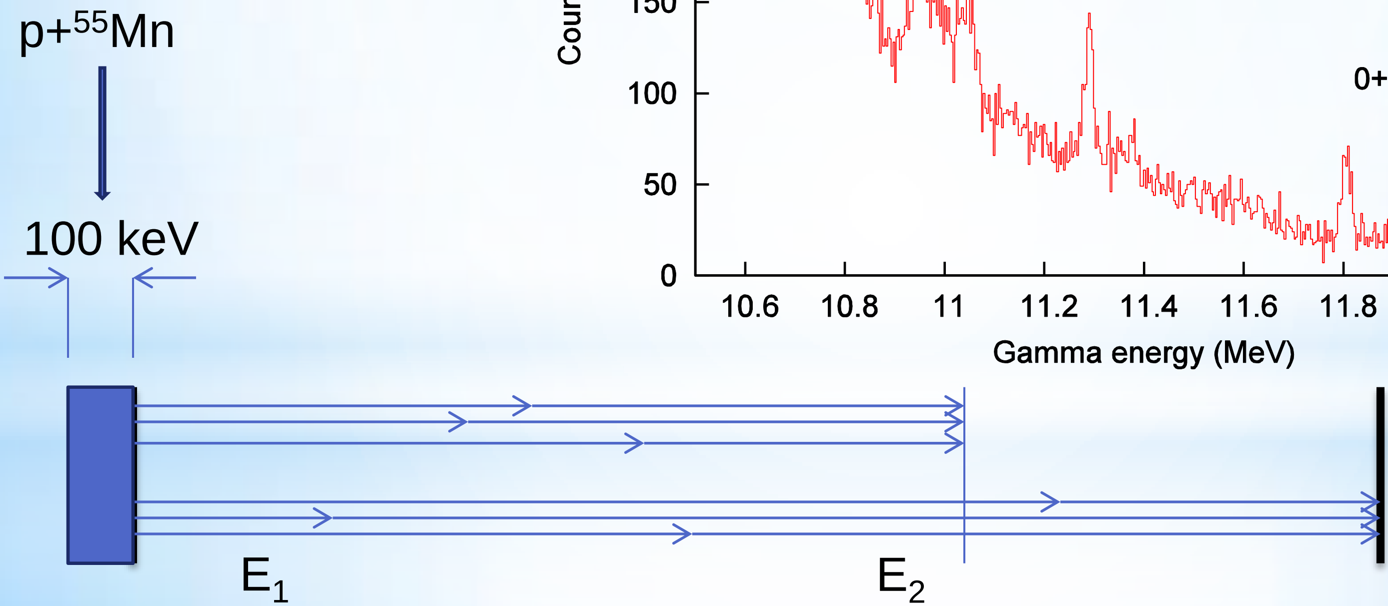


Experimental scheme



* Cascade γ-decay following (p+^{55}Mn) reaction

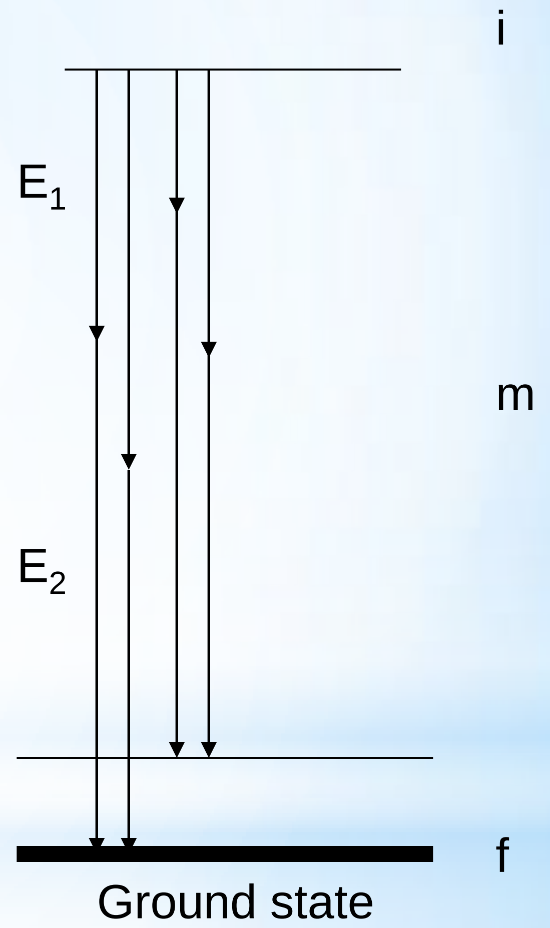




Calculations

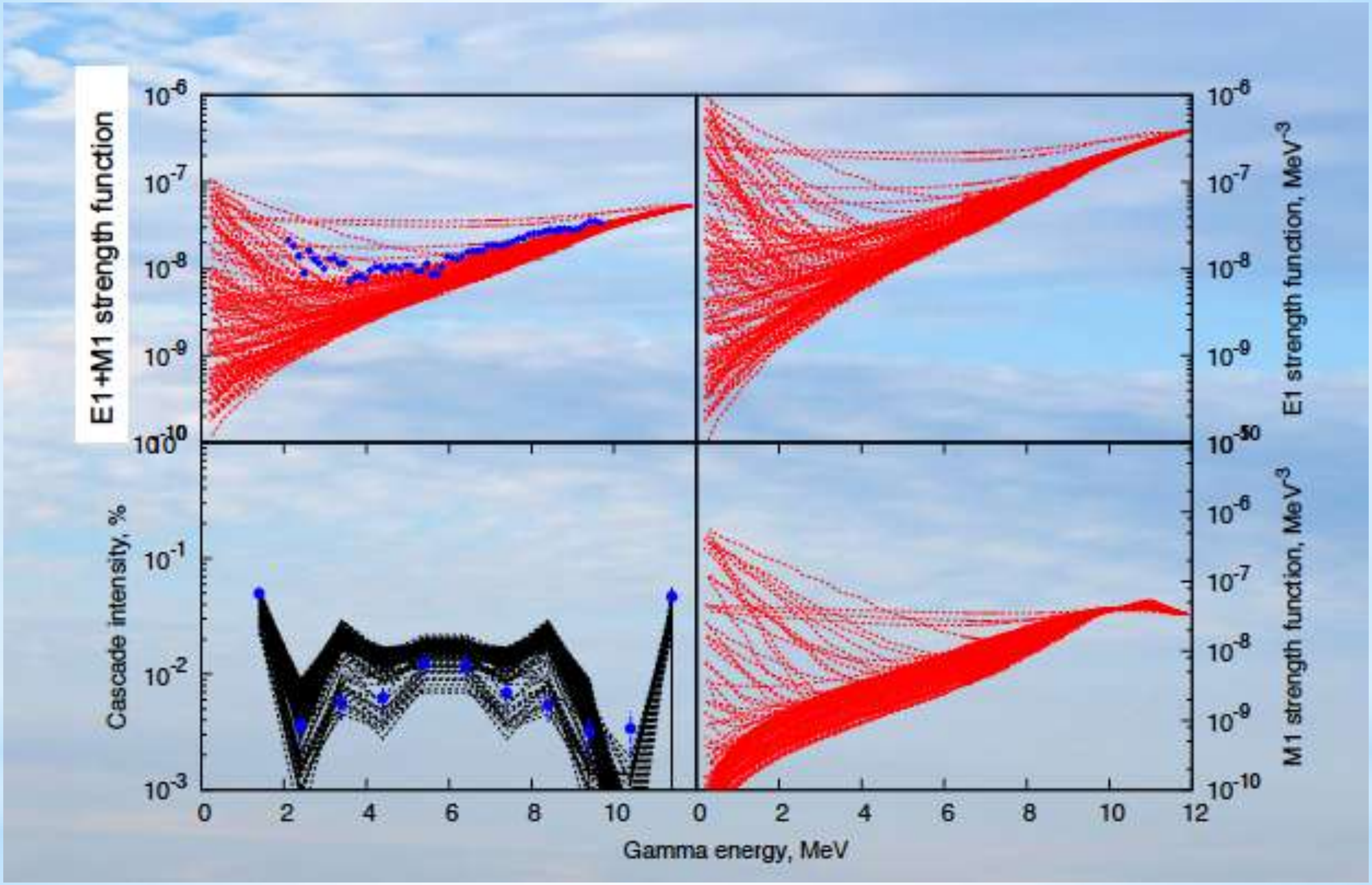
$$I_{if}(E_1,E_2) = \sum_{XL,XL',J^\pi_m} \frac{\Gamma^{XL}_{im}(E_1)}{\Gamma_i}\rho(E_m,J^\pi_m)\frac{\Gamma^{XL'}_{mf}(E_2)}{\Gamma_m} + \sum_{XL,XL',J^\pi_{m'}} \frac{\Gamma^{XL}_{im'}(E_2)}{\Gamma_i}\rho(E'_m,J^\pi_{m'})\frac{\Gamma^{XL'}_{m'f}(E_1)}{\Gamma_{m'}}$$

$$\Gamma^{XL}_{i\to m}(E_\gamma) = f_{XL}(E_\gamma)E_\gamma^{2L+1}D_i$$



Level density: from $^{55}Mn(d,n)^{56}Fe$ reaction

Initial spin distribution: optical model parameters, RIPL-3, A.J.Koning et al Nucl. Phys. A713, 231 (2003).



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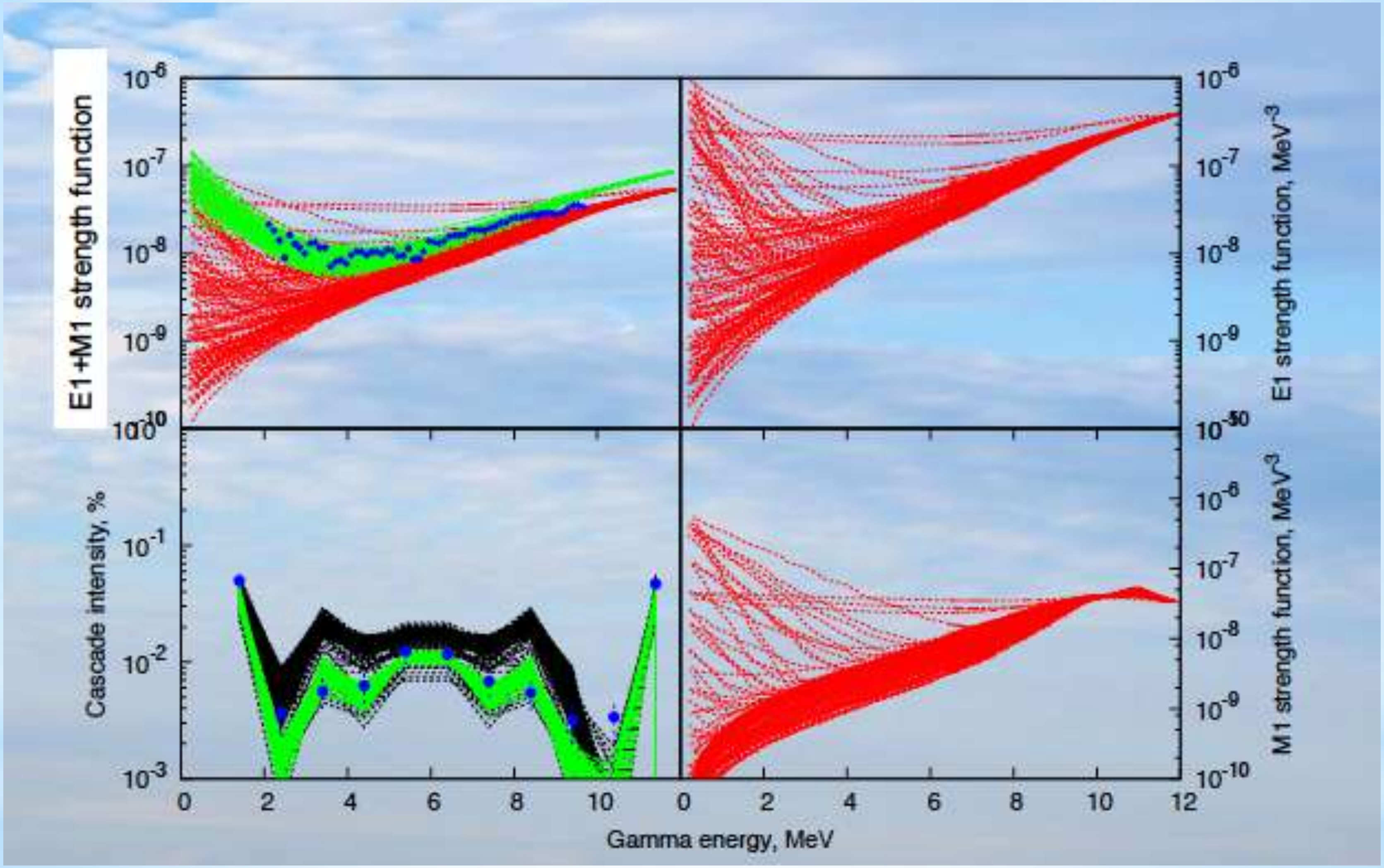
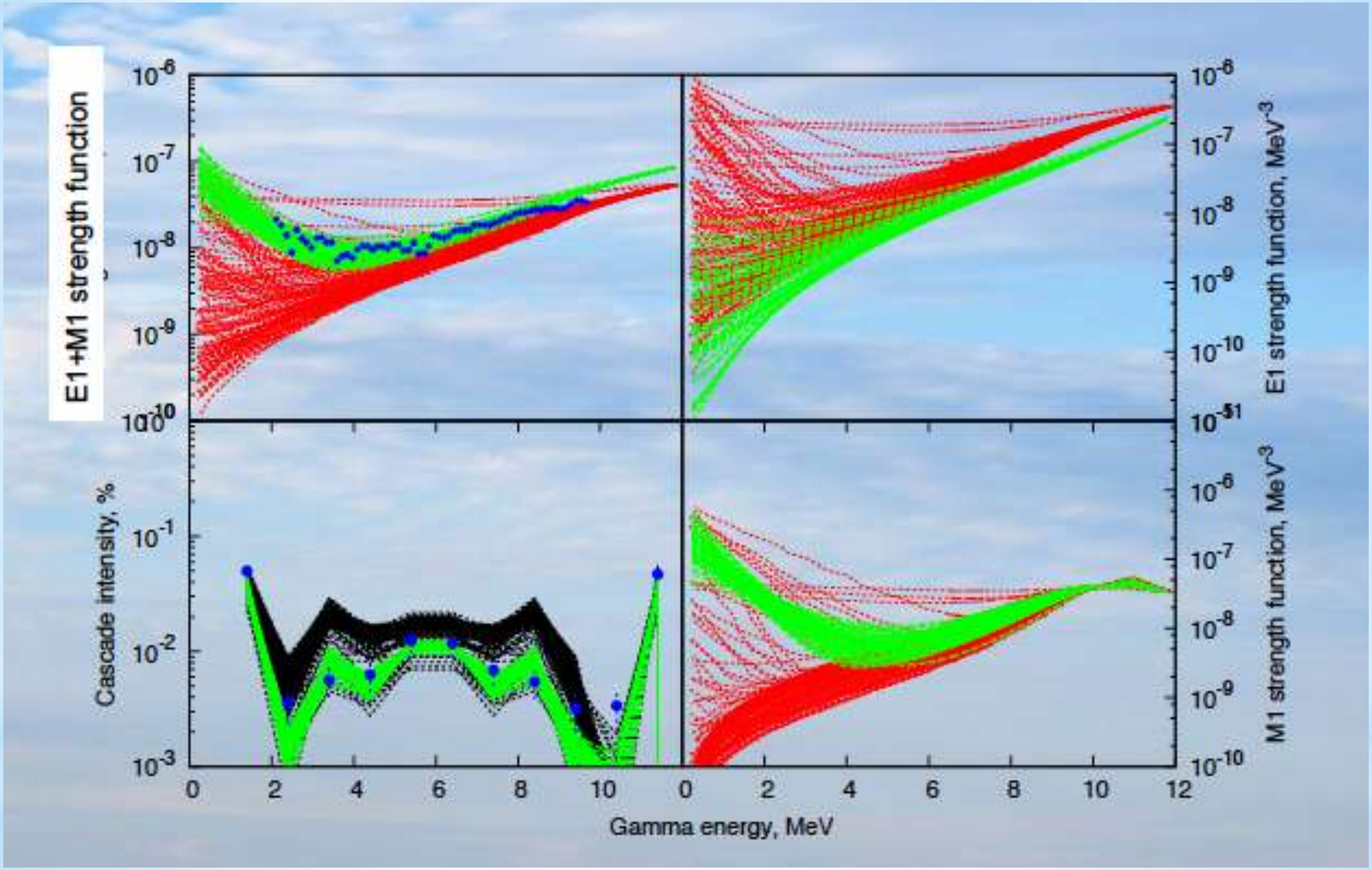


E1+M1 strength function
Cascade intensity, %
E1 strength function, MeV^{-3}
M1 strength function, MeV^{-3}
Gamma energy, MeV



E1+M1 strength function
E1 strength function, MeV^-3
Cascade intensity, %
M1 strength function, MeV^-3
Gamma energy, MeV

Conclusions

- The γ-strength function for 56Fe has been studied with combination of (p,2γ), (d,n) reactions and results from Oslo experiments.
- The decomposition of γ-strength into E1 and M1 components has been performed with simulations which support M1 low-energy enhancement.

Consistent with :

A. Voinov et al, Phys.Rev. C 81, 024319 (2010)	^{60}Ni
R. Schwengner et al, Phys.Rev.Lett. 111, 232504 (2013)	^{90}Zr, ^{94,95,96}Mo