Level densities, parameter systematics, and spin cutoff factors

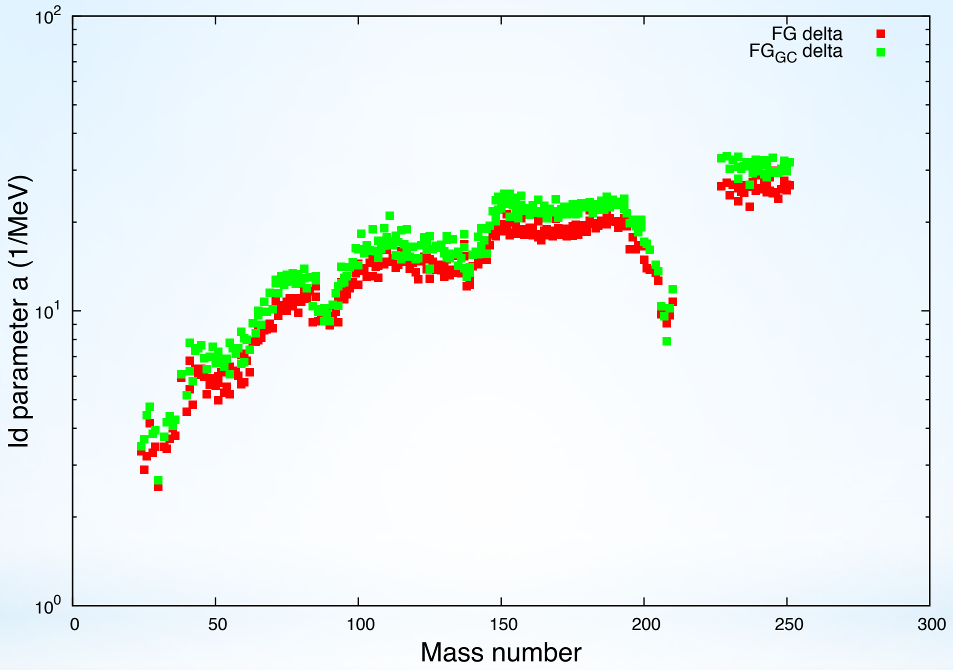
$$\rho(U) = \frac{\exp[2\sqrt{a(U - \delta)}]}{12\sqrt{2}\sigma a^{1/4}(U - \delta)^{5/4}}.$$

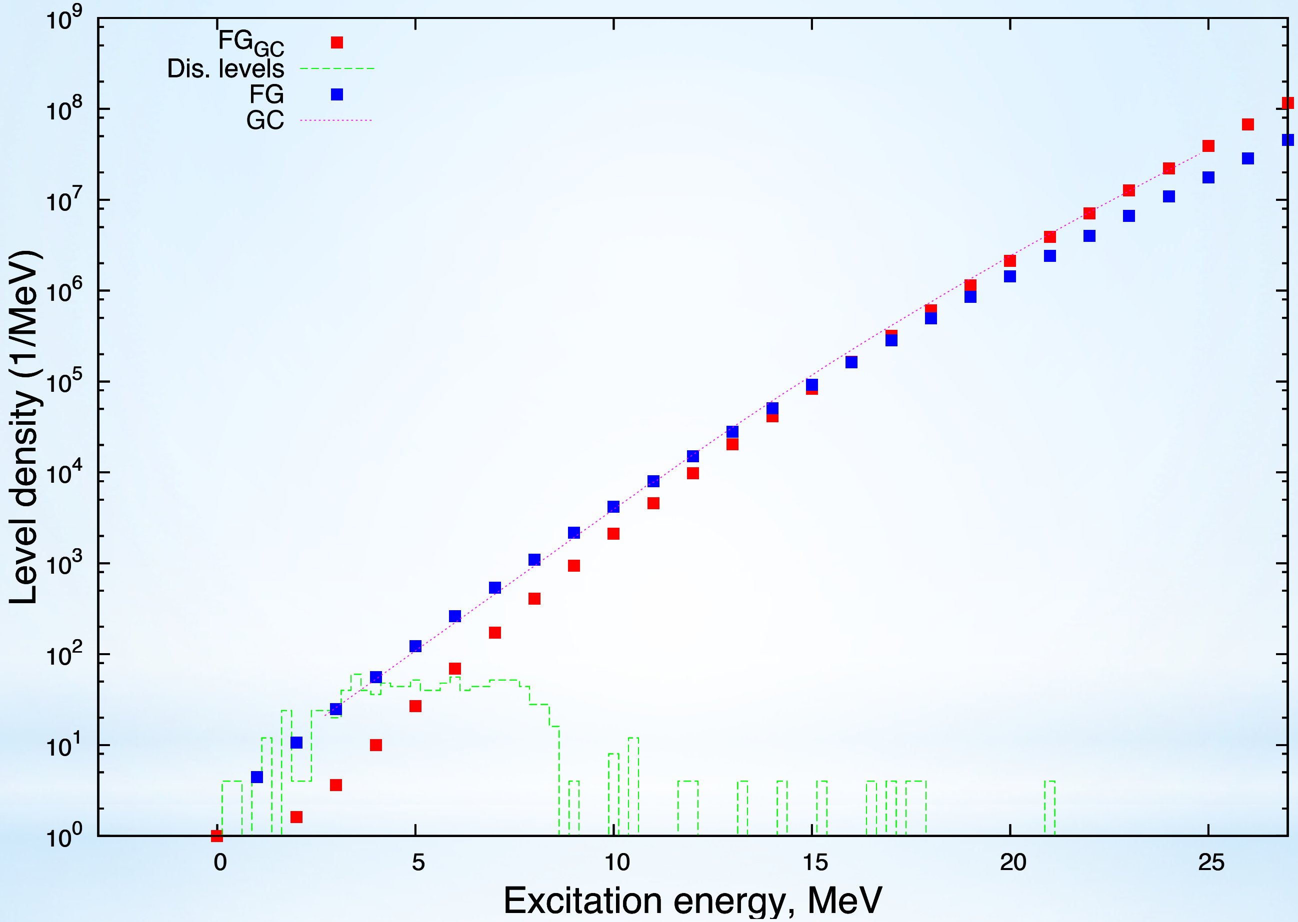
a from neutron resonance spacing

δ → from density of discrete levels (FG)

δ → $n12/\sqrt{A}$ from pairing, n=0,1 or 2 (FG_{GC})

Systematics of “a” parameter obtained with different δ





A.Voinov, Oslo workshop 2015

The total level density from particle spectra of compound nuclear reactions

The concept:

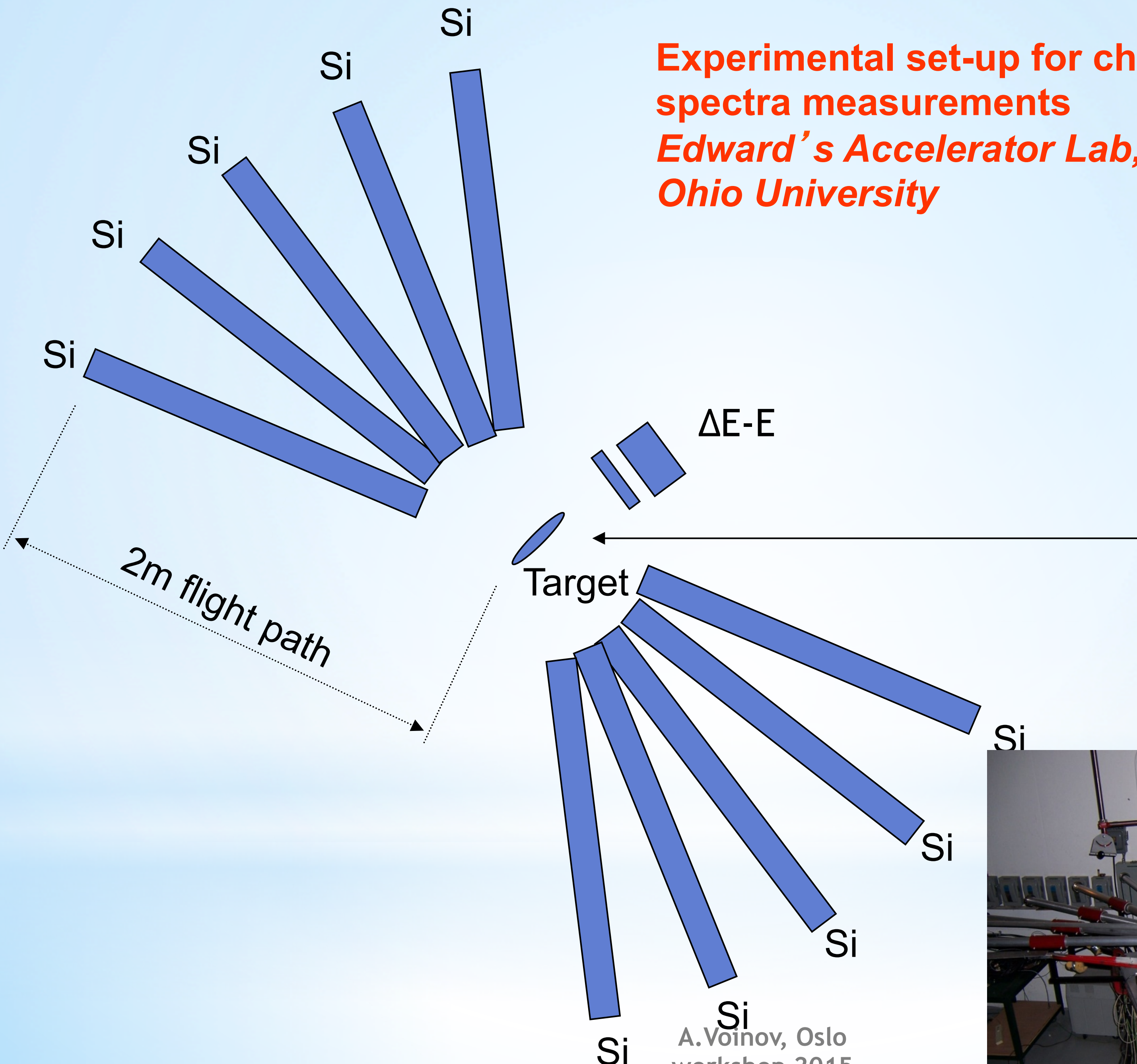
$$d\sigma(E) \sim \sigma_C(E)\frac{T_{in}(E')\rho_f(E^*)}{\sum_i \int T_i(E)\,dE}\,dE$$

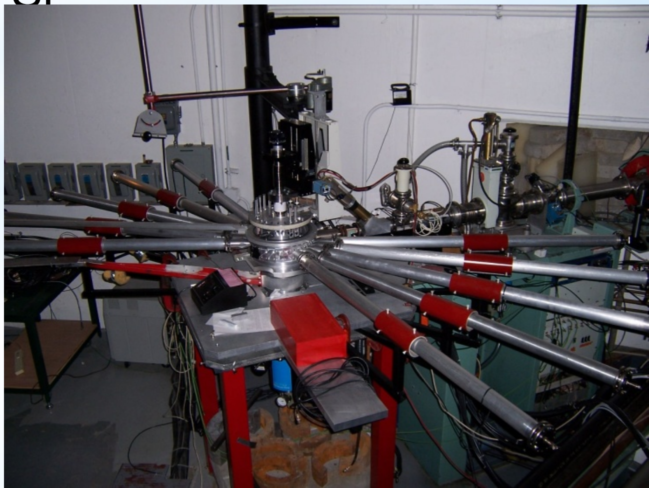
Make sure that the compound reaction mechanism dominates.

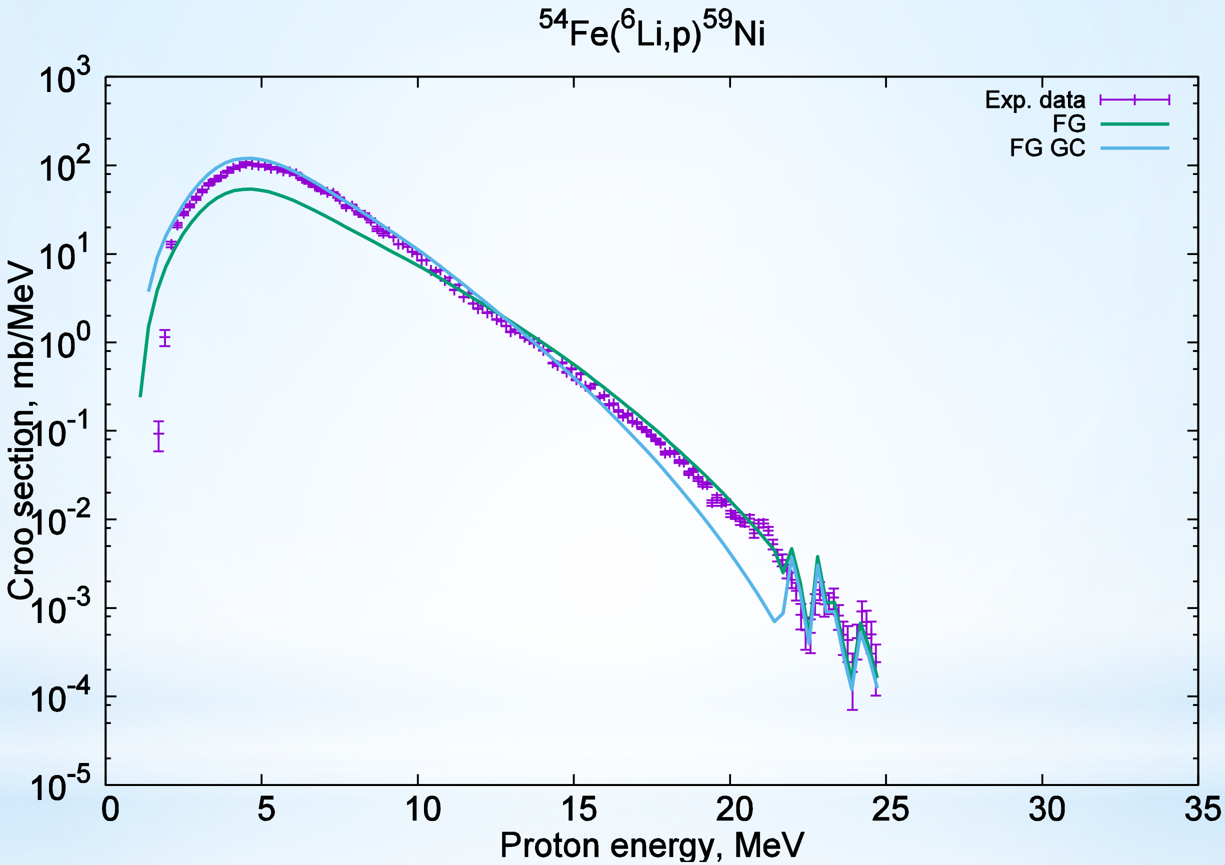
1. Select appropriate reactions (beam species, energies, targets).
2. Measure the outgoing particles at backward angles
3. Compare reactions with different targets and incoming species leading to the same final nuclei

Experimental set-up for charge-particle spectra measurements

Edward's Accelerator Lab, Ohio University

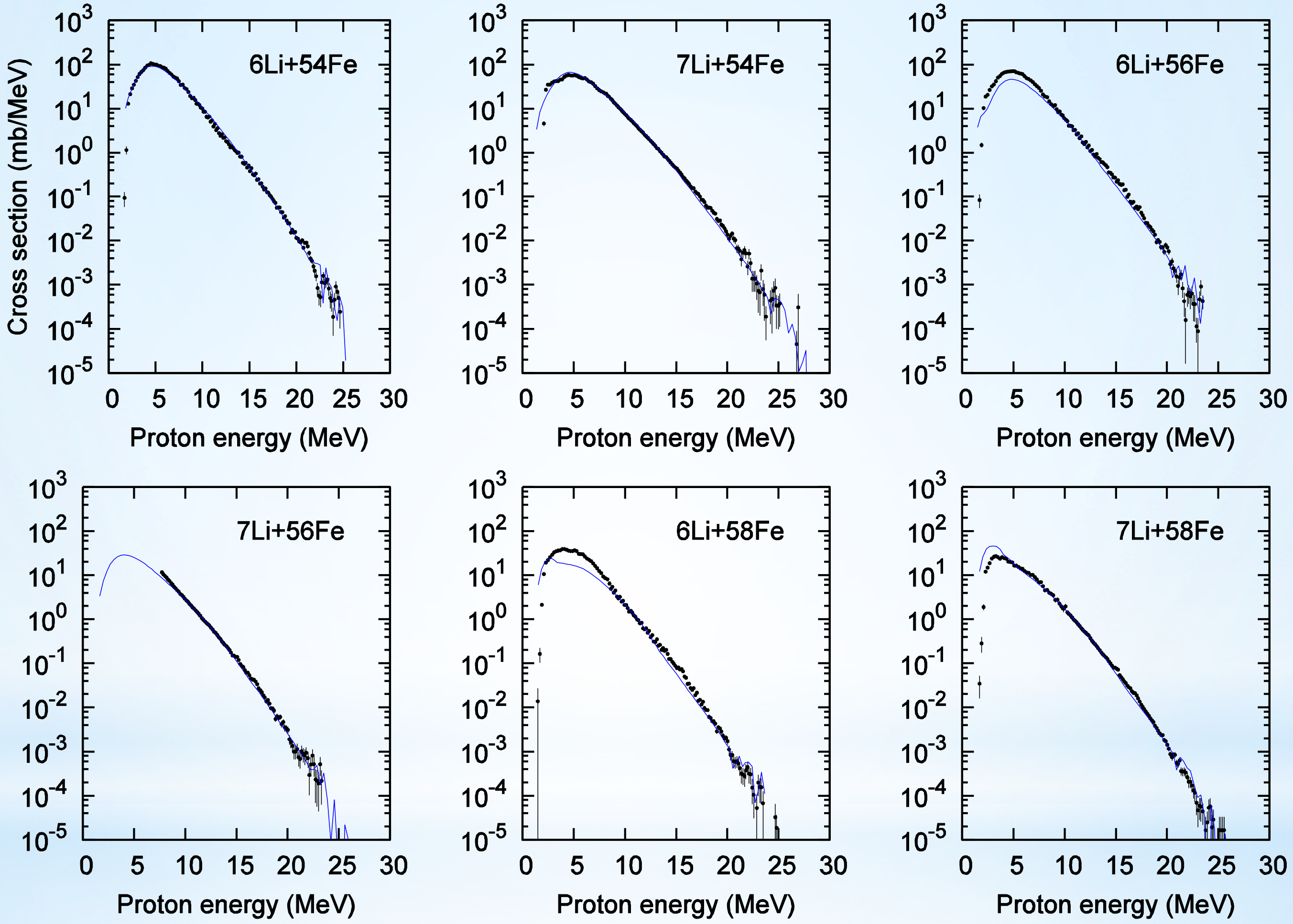




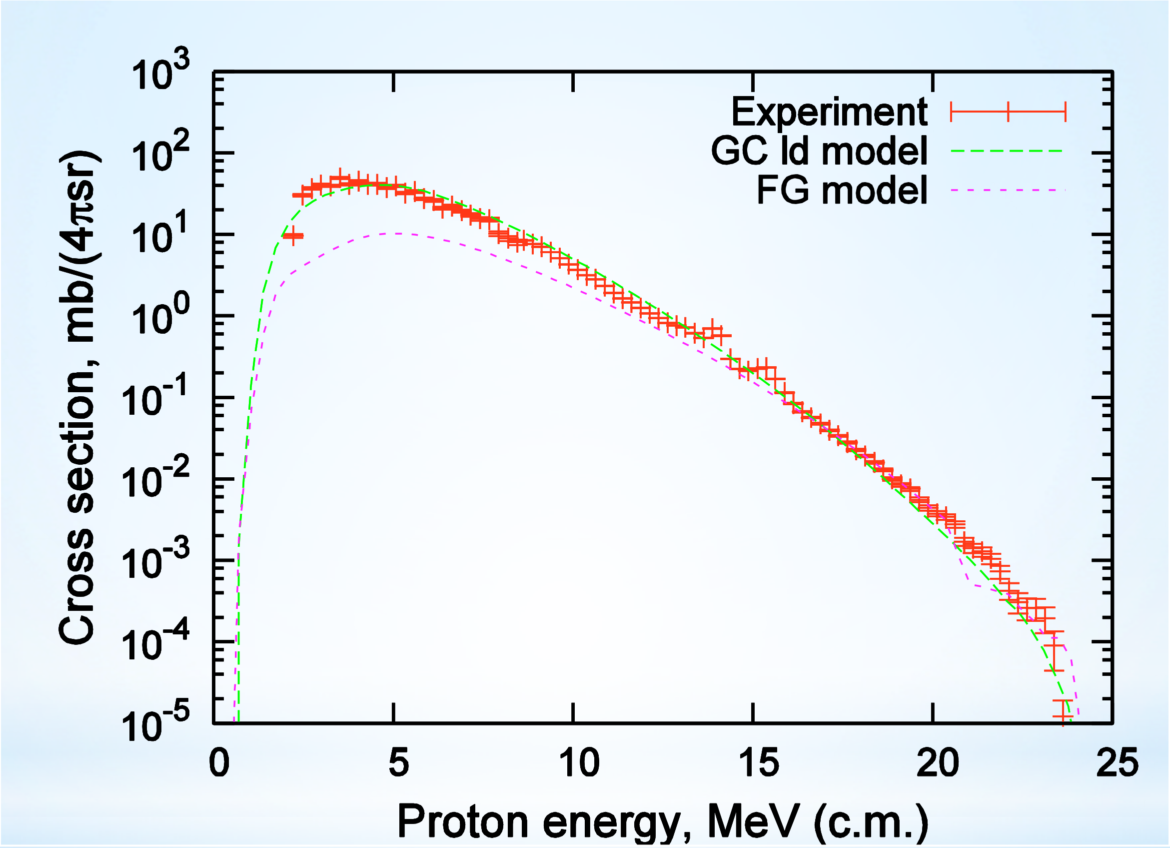


$^{54}Fe(^{6}Li,p)^{59}Ni$
Exp. data
FG
FG GC
Croo section, mb/MeV
Proton energy, MeV
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
5
10
15
20
25
30
35

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



55Mn(^{6}Li,p)



Experiment
GC ld model
FG model
Cross section, mb/(4πsr)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
0
5
10
15
20
25
Proton energy, MeV (c.m.)

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)

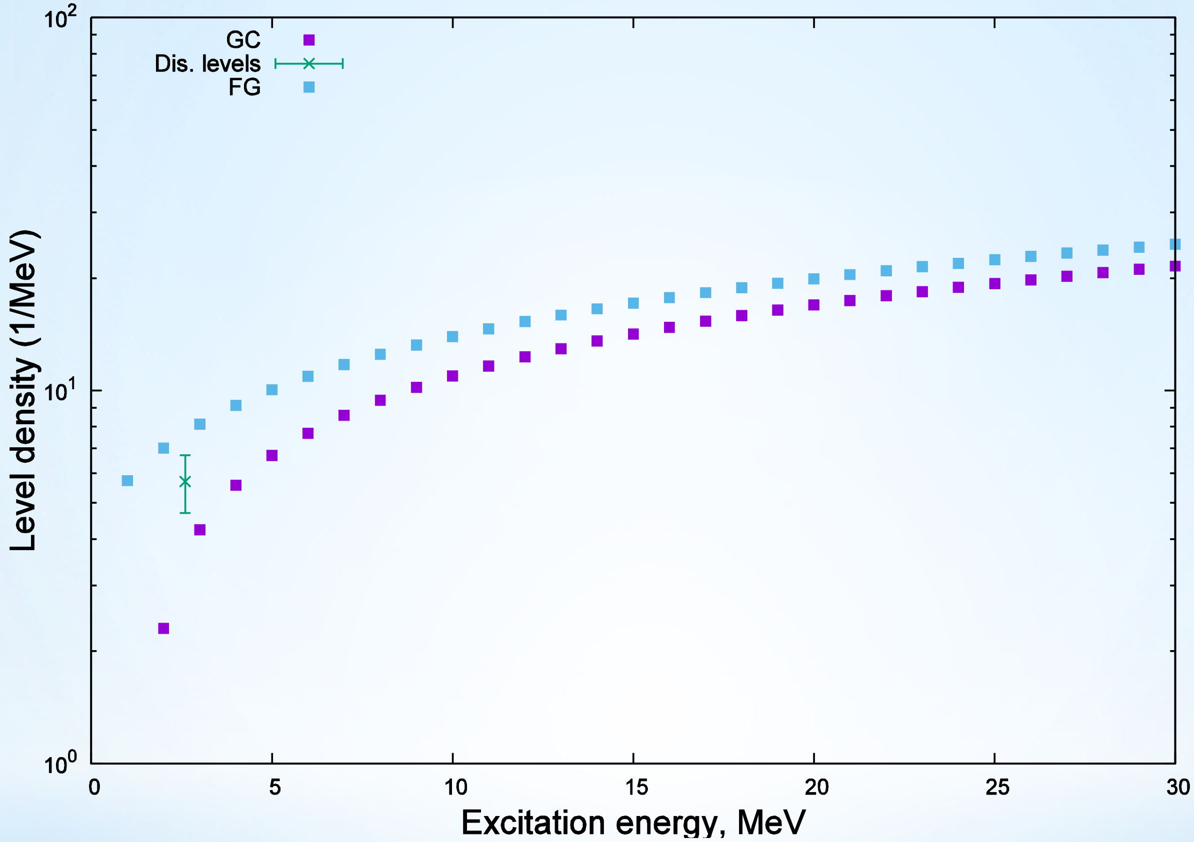
3. At higher excitation energies, parameter systematics obtained with (Ignatuyk, Iljinov systematics) reproduce evaporation spectra better

Spin cutoff parameter

$$\sigma = 0.0146 \cdot A^{5/3} \sqrt{\frac{U - \delta}{a}}$$

- Use the same parameters as in level density function

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



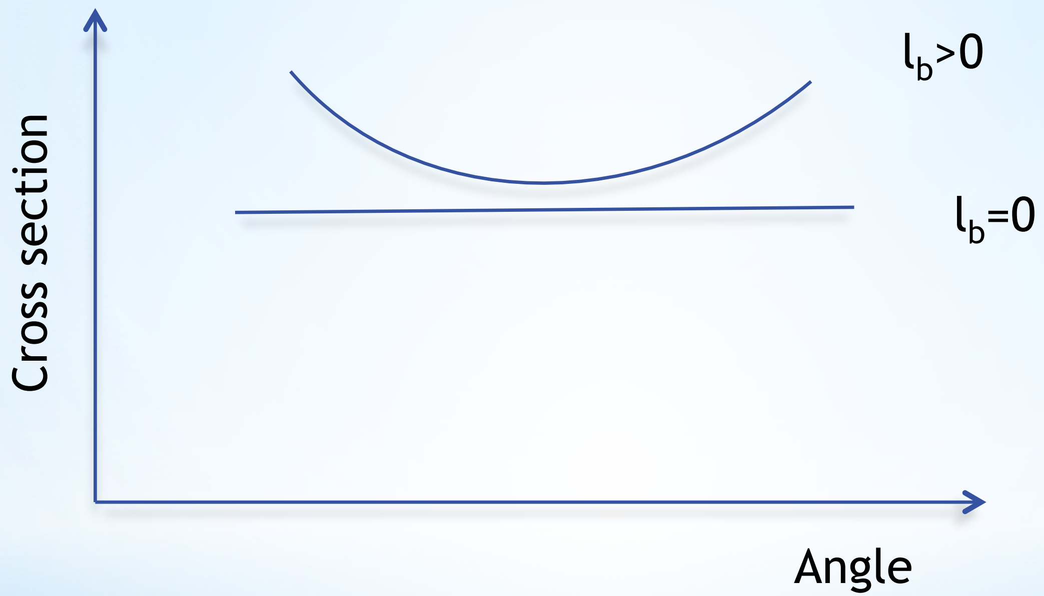
GC
Dis. levels
FG
Level density (1/MeV)
10^2
10^1
10^0
0
5
10
15
20
25
30
Excitation energy, MeV

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 → C → B+b



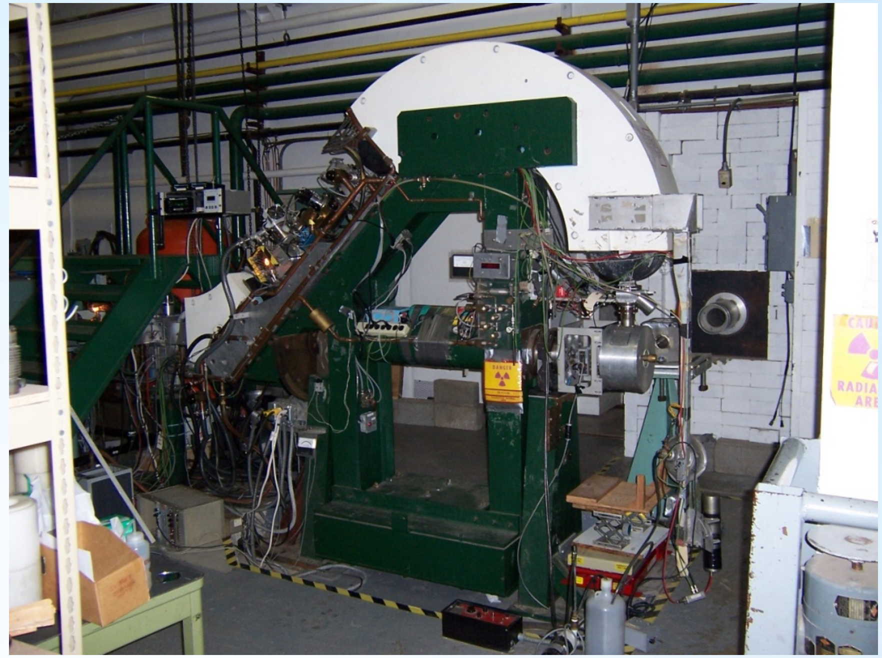
Orbital momenta are determined by spin of both compound C and residual nucleus B

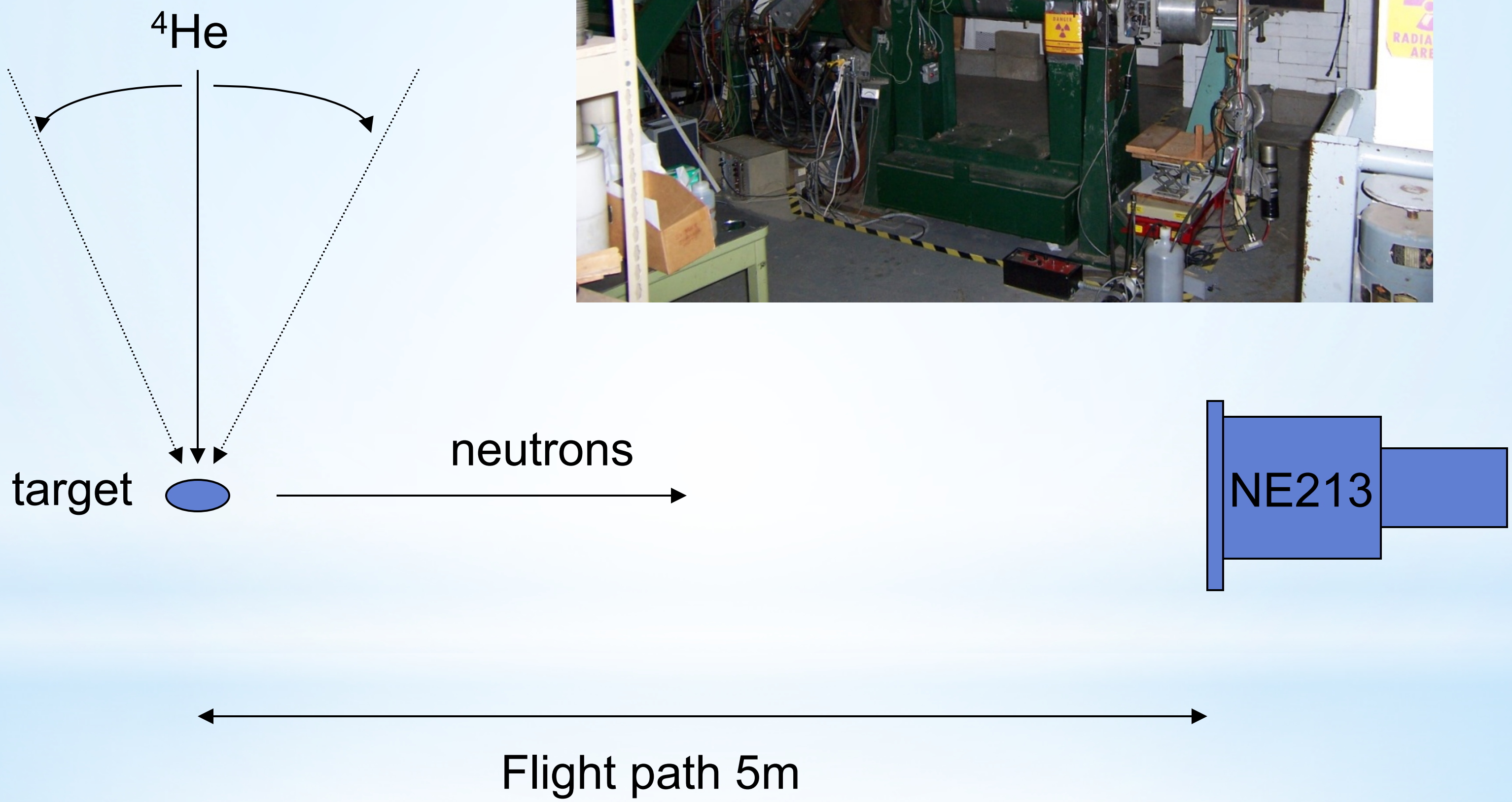
Neutron angular distributions from $^{56}Fe(a,n)^{59}Ni$ reactions

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)

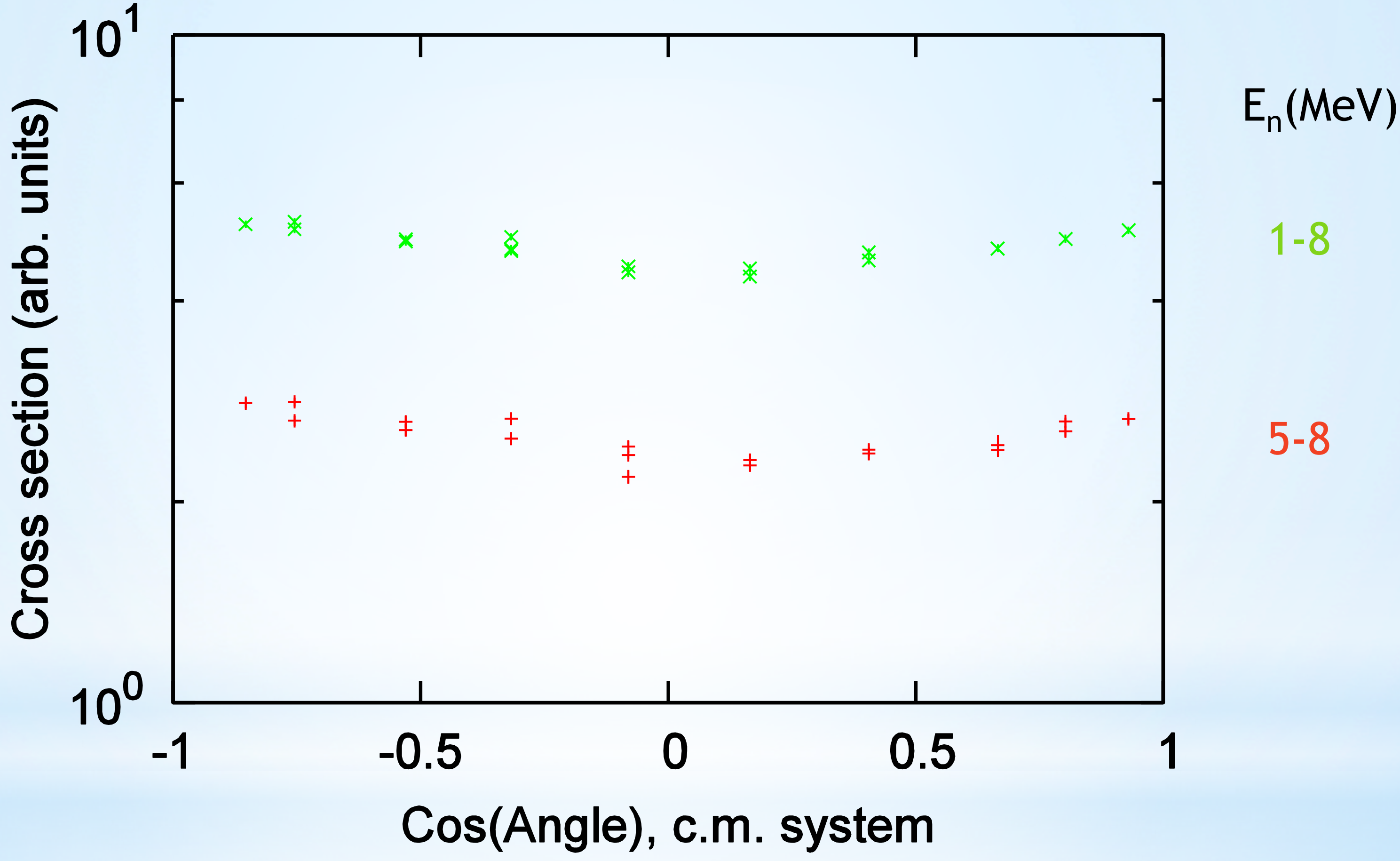
Experimental neutron angular distributions have been analyzed with Hauser Feshbach code developed at Ohio University (S. Grimes).
The spin cutoff parameter has been adjusted to reproduce experimental angular distributions.

Swinger facility
at Edwards Lab.
Ohio University

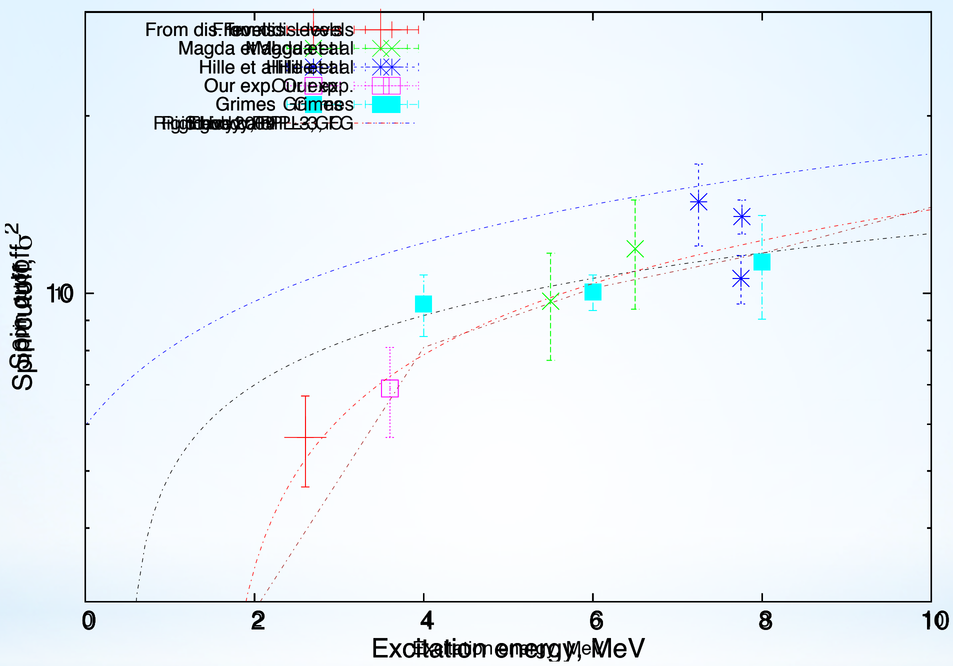




Preliminary neutron angular distributions from $^{56}Fe(\alpha,n)$ reaction (Ohio)



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.