Institute of Physics & Power Engineering

Current Status of the Problem of Cross Section Data for Ion Beam Analysis

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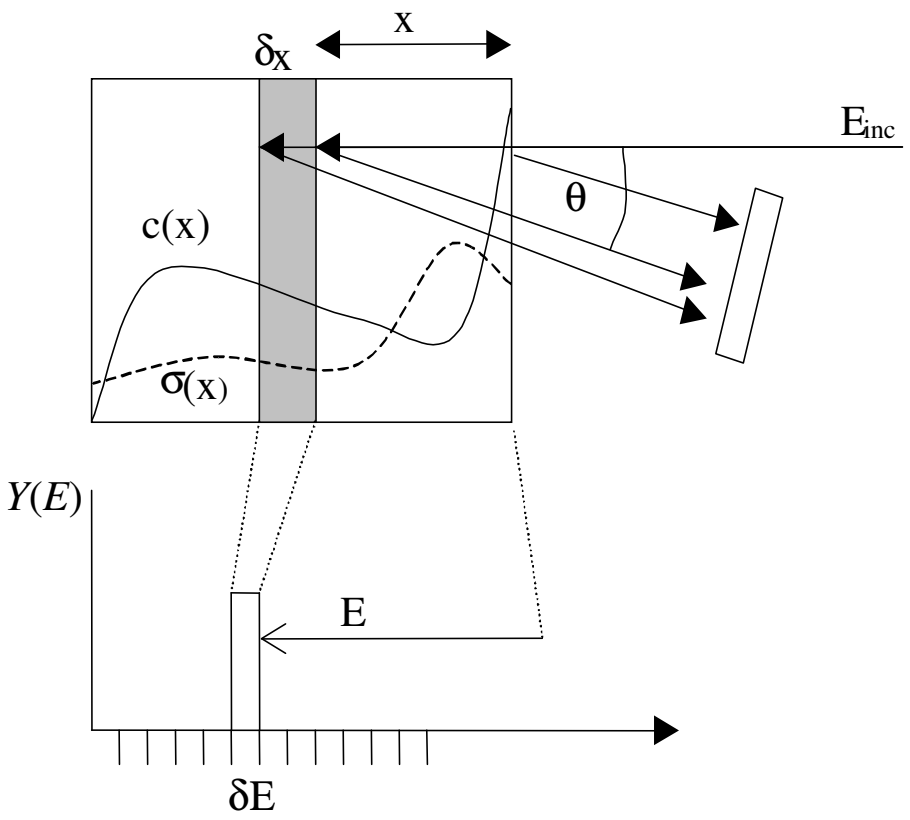
IBA Methods

Acronym		Interaction
PIXE	**P**article-**I**nduced **X**-ray **E**mission	Characteristic X-ray emission following ionization by the primary beam.
PIGE	**P**article-**I**nduced **G**amma **E**mission	Prompt gamma emission during ion beam irradiation
RBS	**R**utherford **B**ackscattering **S**pectrometry	Elastic scattering at backward angles
NRA	**N**uclear **R**eaction **A**nalysis	Nuclear reaction between incident beam and nuclei in the target, producing a light charged particle.
NRP or r-NRA	**N**uclear **R**esonance **P**rofiling, **r**esonant **N**uclear **R**eaction **A**nalysis	Exploitation of narrow nuclear resonances via scanning of the incident beam energy.
ERDA or FRS	**E**lastic **R**ecoil **D**etection **A**nalysis, **F**orward **R**ecoil **S**pectroscopy	Elastic recoil at forward angles, not necessarily Rutherford

Depth Profiling : Principle



- A channel of width δE at energy E in the spectrum corresponds to a slice of width dx at depth x in the sample, with E and δE being inversely related to x and δx through a linear combination of the stopping powers for the incident and outgoing particle
- The number of particles accumulated into that histogram bin is proportional to $c(x)$, δx, and $\sigma(E_x)$, where E_x is the energy of the incident beam when it gets to depth x.

$$Y_i(E) = \int_0^{\infty} \frac{N_0 c(x)\sigma(\varphi, E_1)\delta\Omega}{S(E')\left[\frac{-1}{\cos(\varphi+\theta)} + \frac{1}{\cos(\theta)}\frac{kS(E_1)}{S(kE_1)}\right]} \frac{1}{1.06\Gamma(x)} \exp\left(-\frac{(E'-E)^2}{0.36\Gamma^2(x)}\right) dE'$$

What nuclear data are needed for IBA?

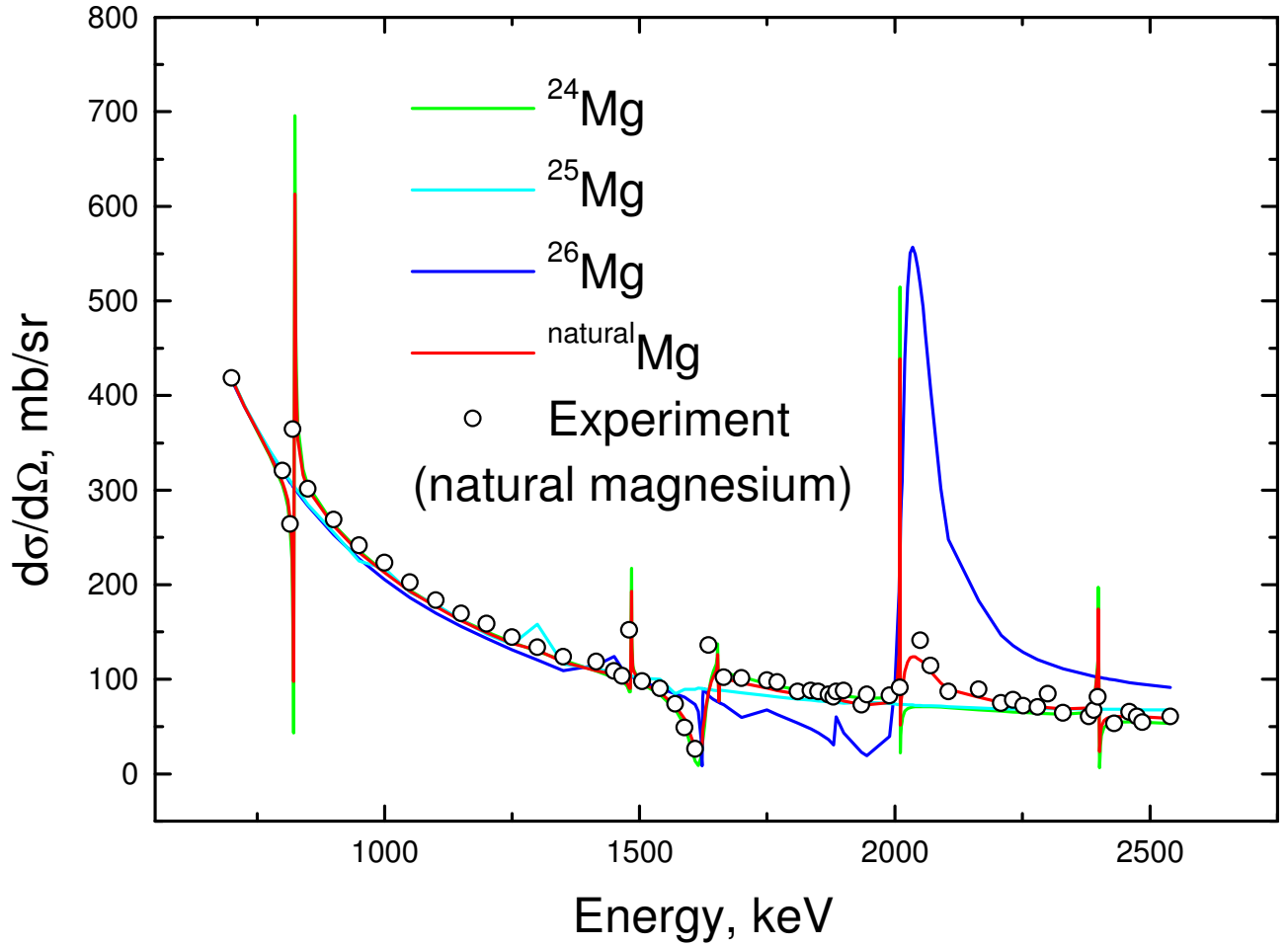
Differential cross sections $d\sigma(E)/d\Omega$ for:

- elastic scattering of light ions (p, d, ^{4}He, ^{7}Li,…)
- nuclear reactions induced by p, d, ^{4}He, ^{3}He in the energy range of 0.5÷10 MeV

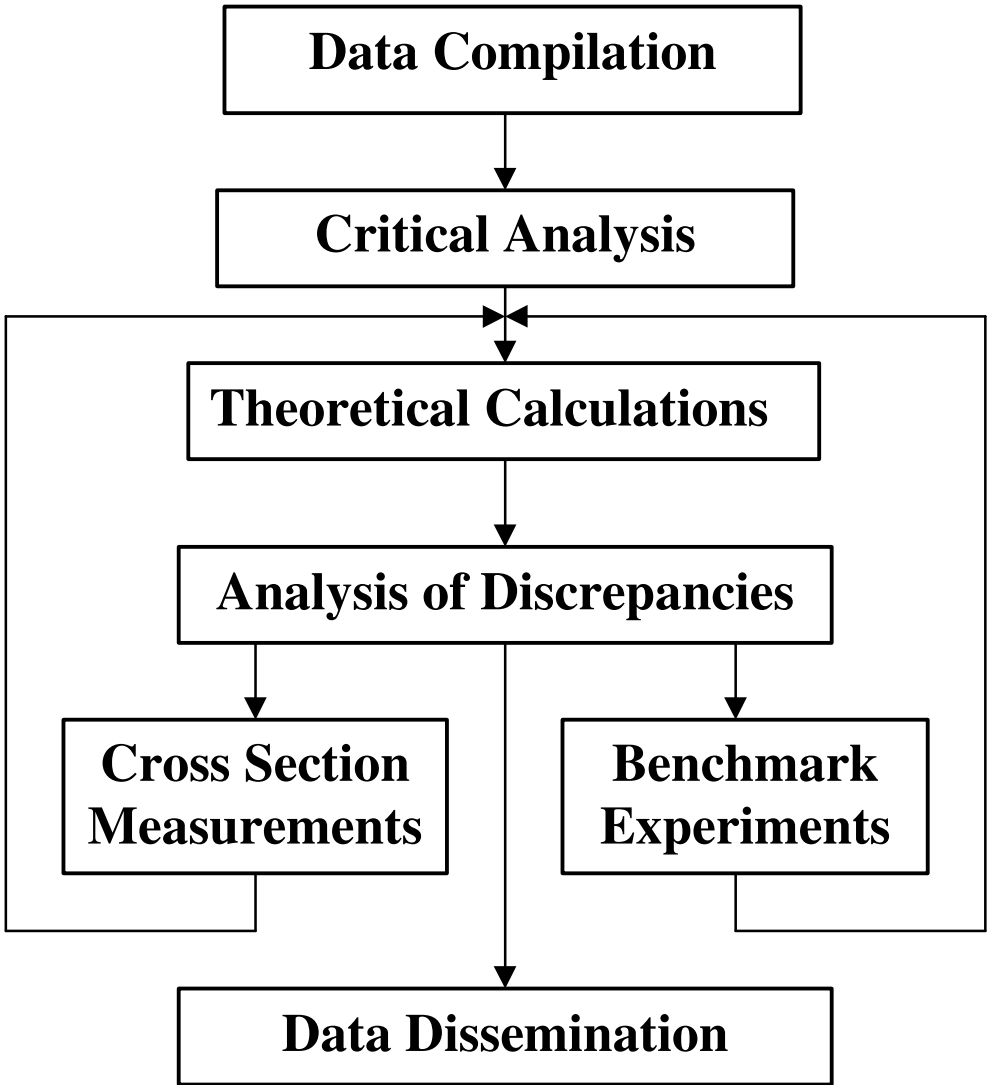
Distinctive feature of the nuclear data for IBA (as compared with other applications)

- IBA uses differential cross sections rather than total ones – data for different angles are needed
- IBA employs data mainly for elements of natural abundance rather than for separated isotopes – data acquired in nuclear physics studies are often not sufficient

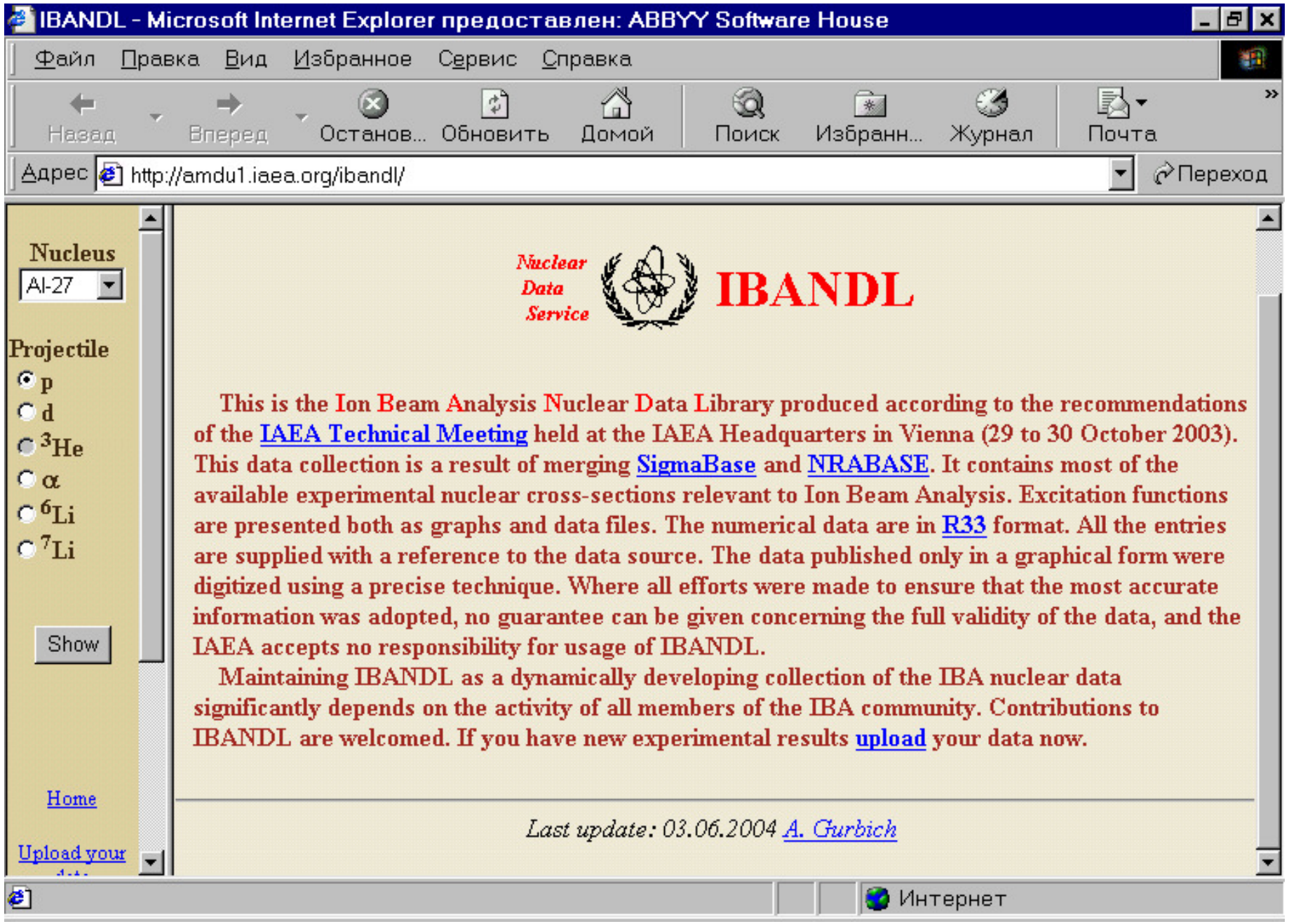
The difference between cross sections for separate isotopes and for an element of natural abundance



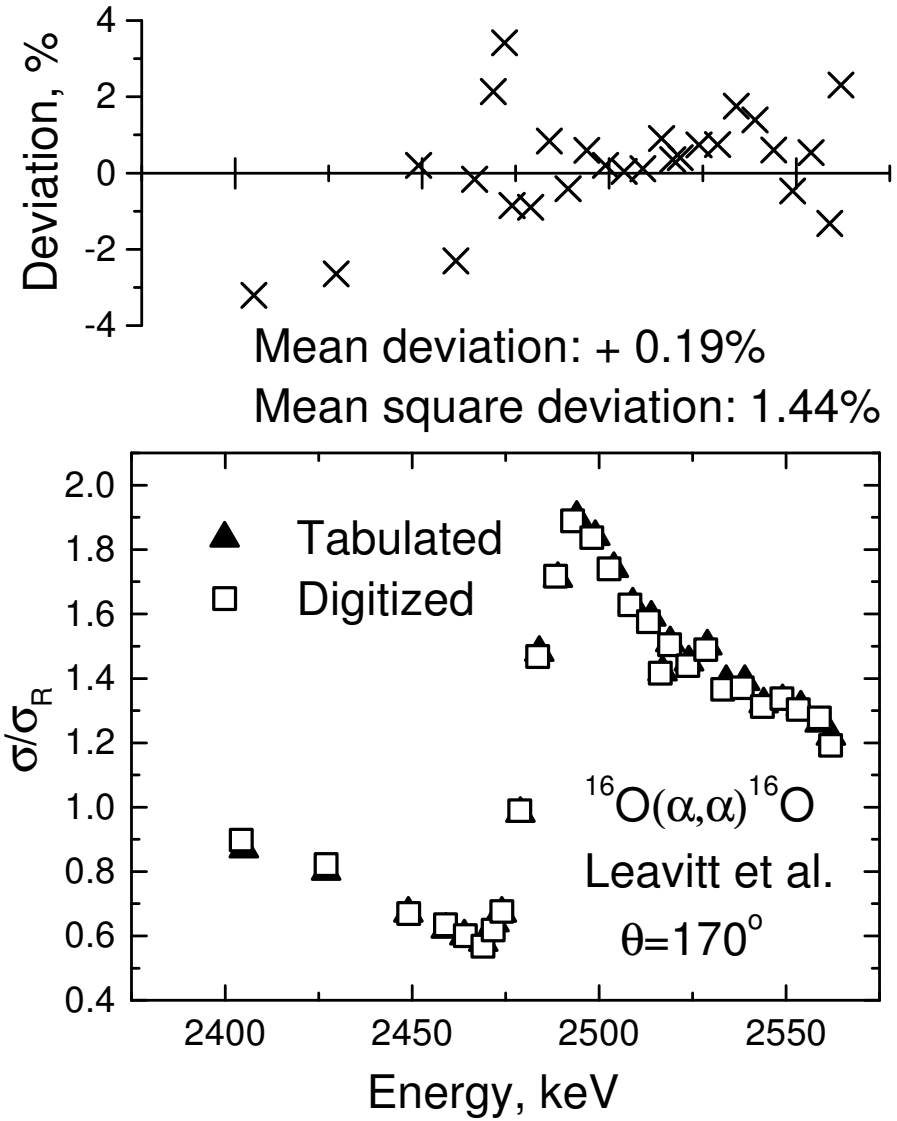
Evaluation


Data Compilation
Critical Analysis
Theoretical Calculations
Analysis of Discrepancies
Cross Section Measurements
Benchmark Experiments
Data Dissemination

Compilation

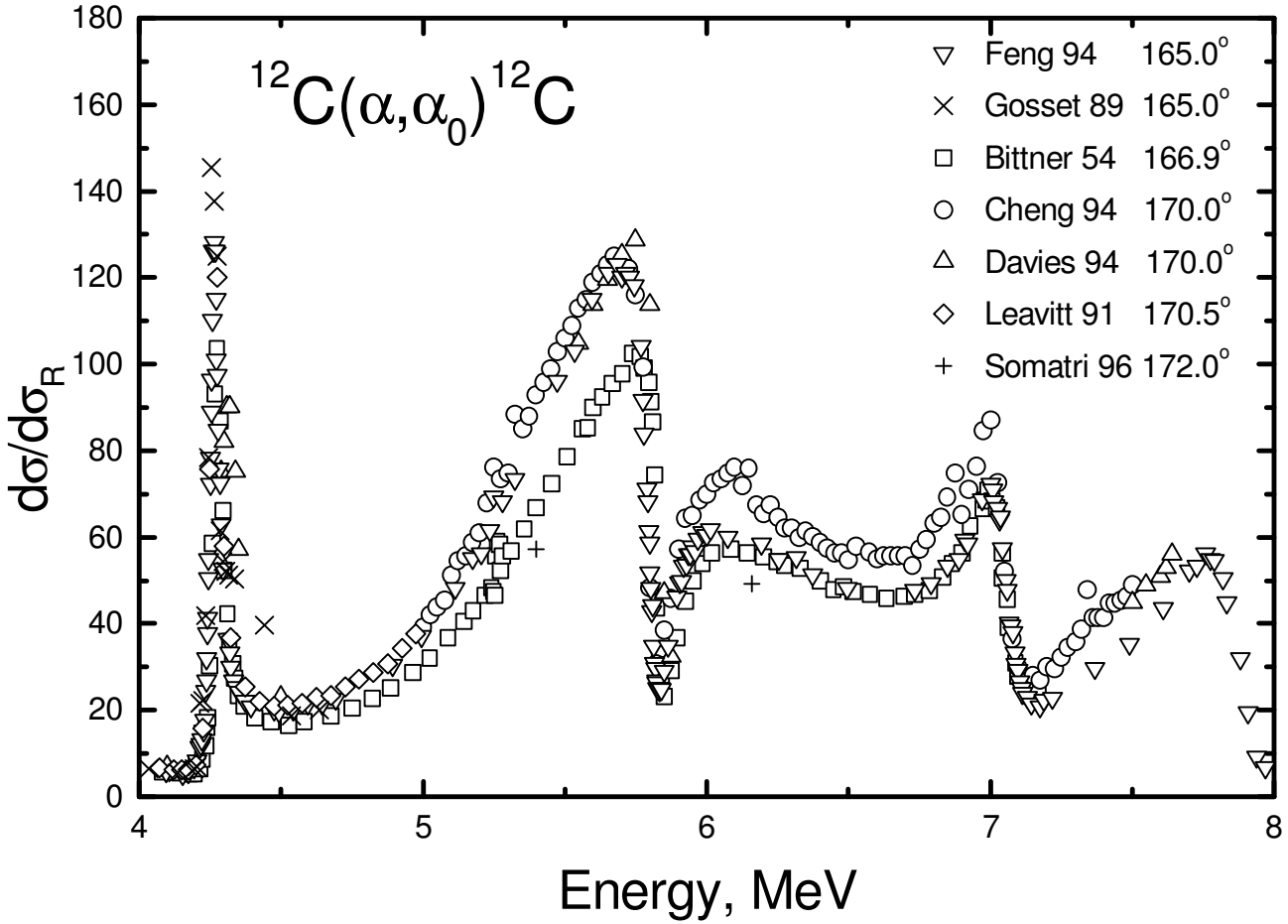


How accurate is digitizing?



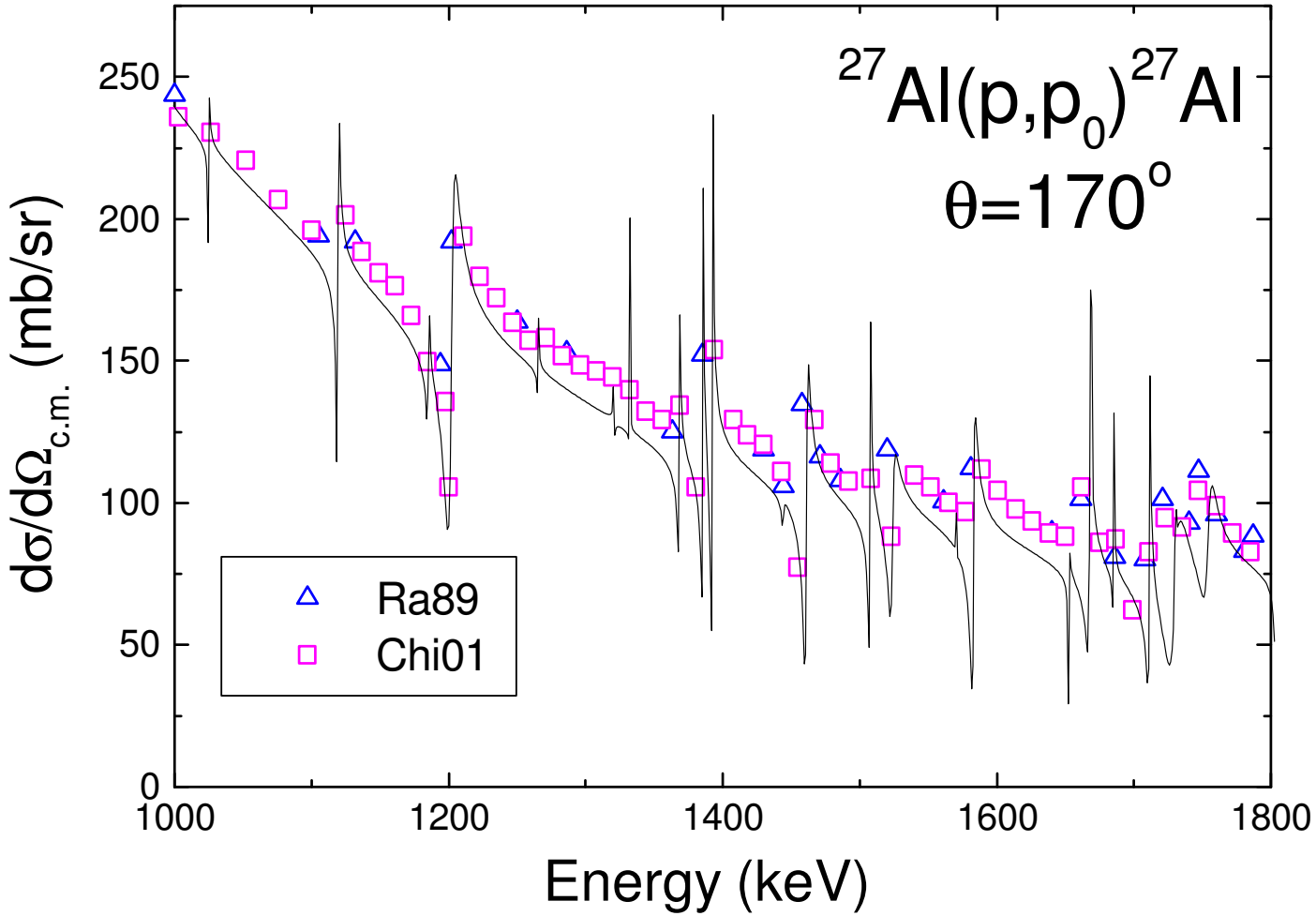
THE REASONS WHY EVALUATION IS NEEDED

Reason 1: because of discrepancies between results of different measurements



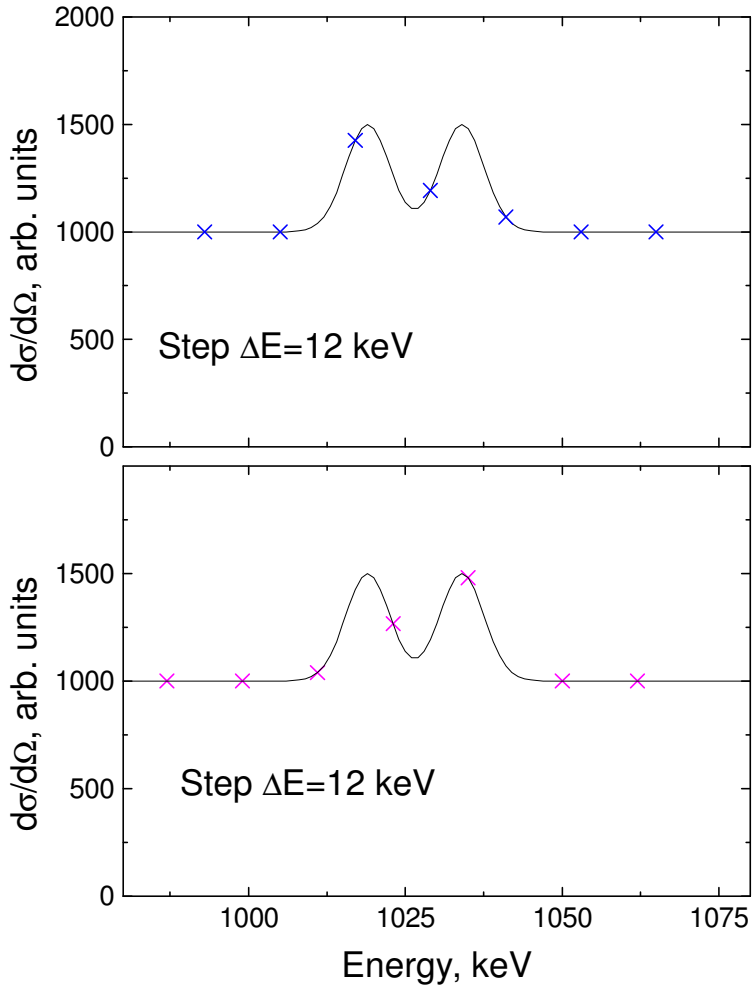
THE REASONS WHY EVALUATION IS NEEDED

Reason 2: because cross section may has a fine structure missed in some measurements



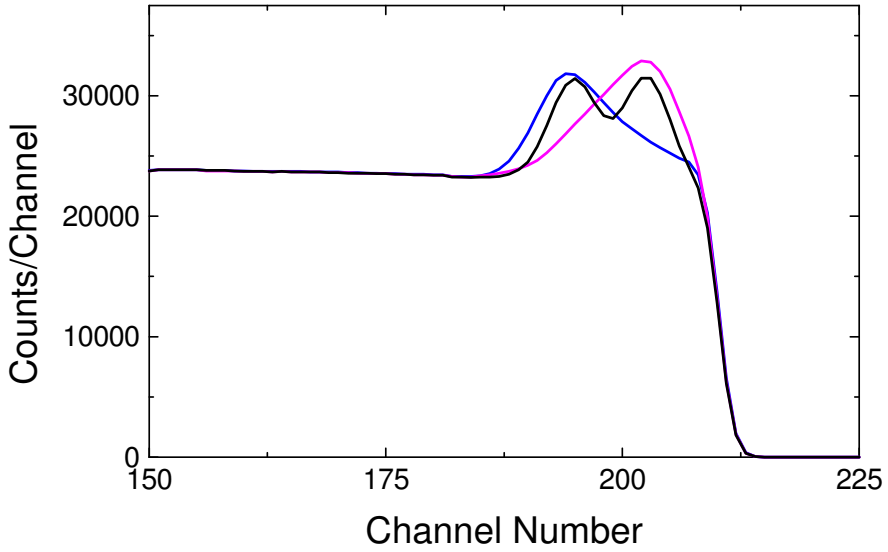
WHY IS A FINE STRUCTURE ESSENTIAL?

Suppose "true" cross section is as shown by a solid line and two measurements with 12 keV step are made, the measured points in the two sets being shifted by 6 keV



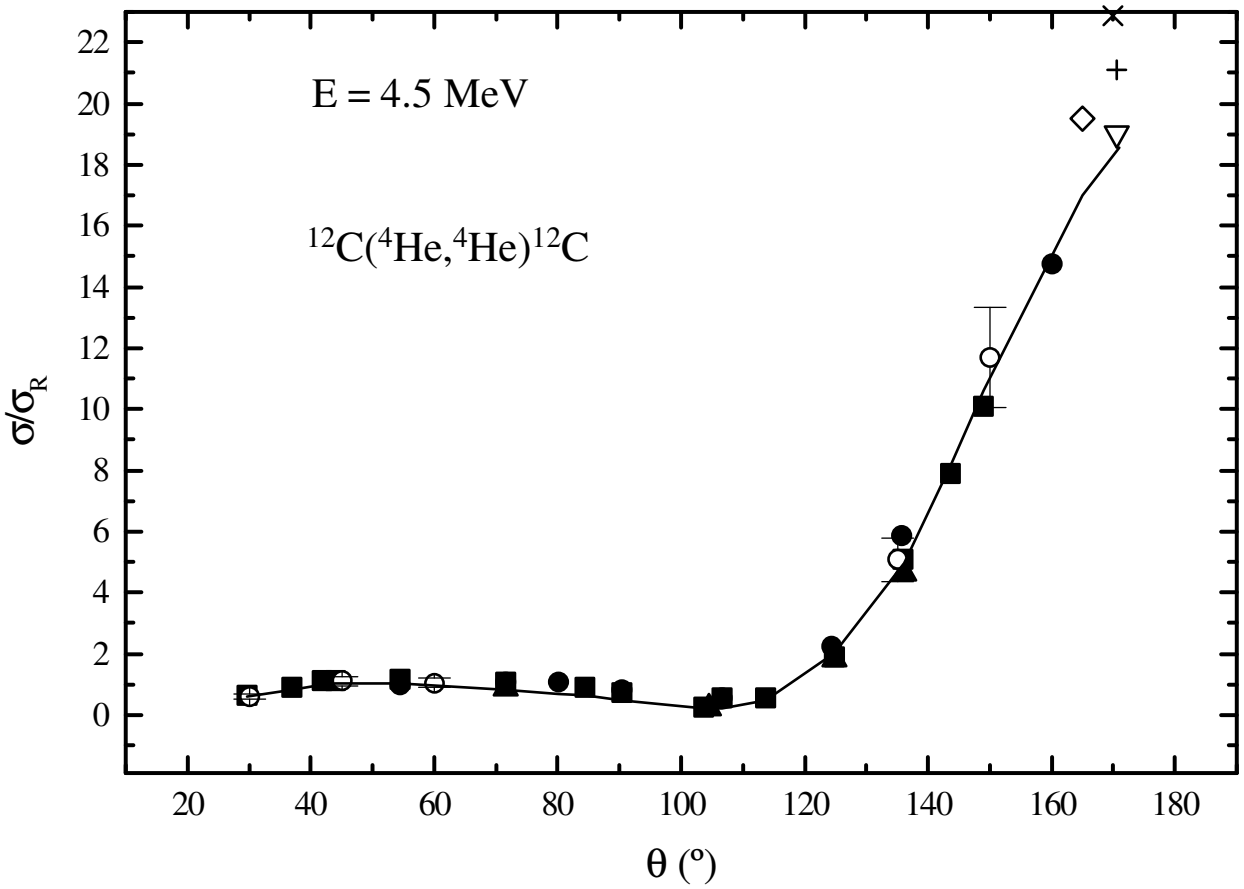
Simulated EBS spectra

Black line – simulation with "true" cross section, blue and magenta – simulation with sparse point cross section measurements

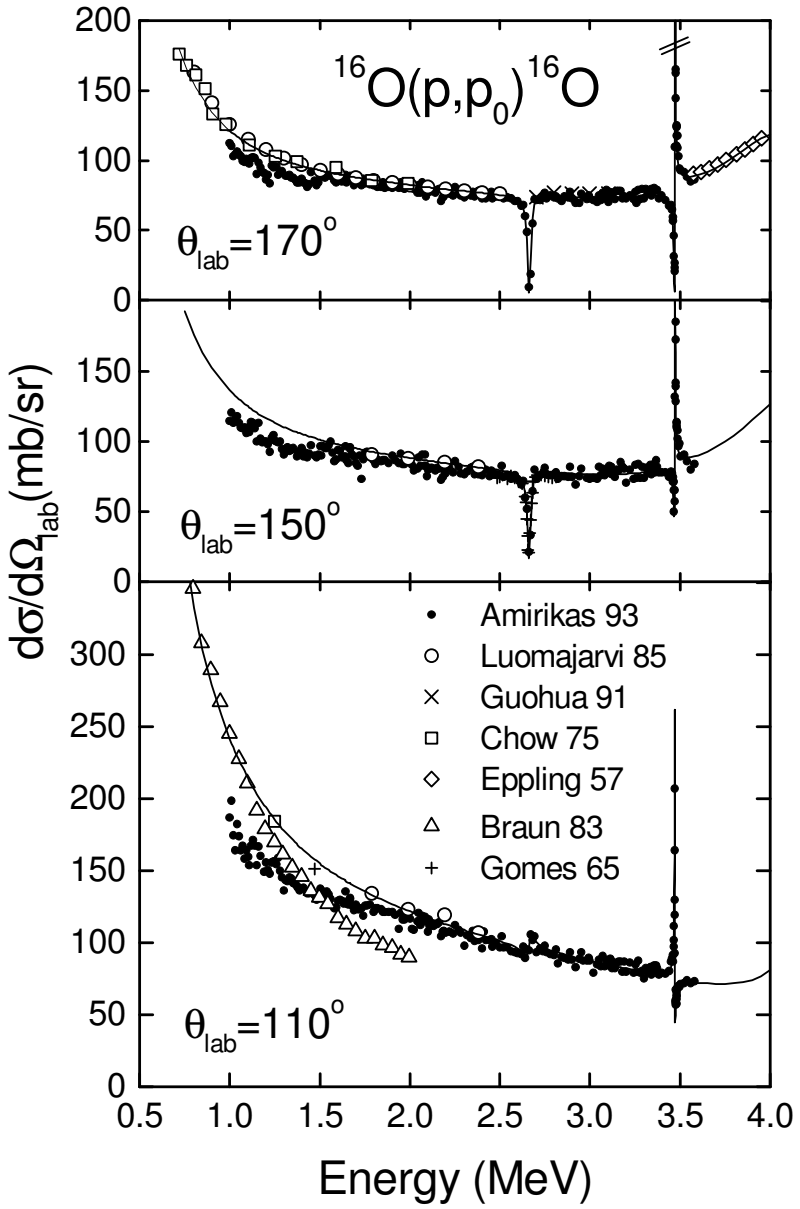


THE REASONS WHY EVALUATION IS NEEDED

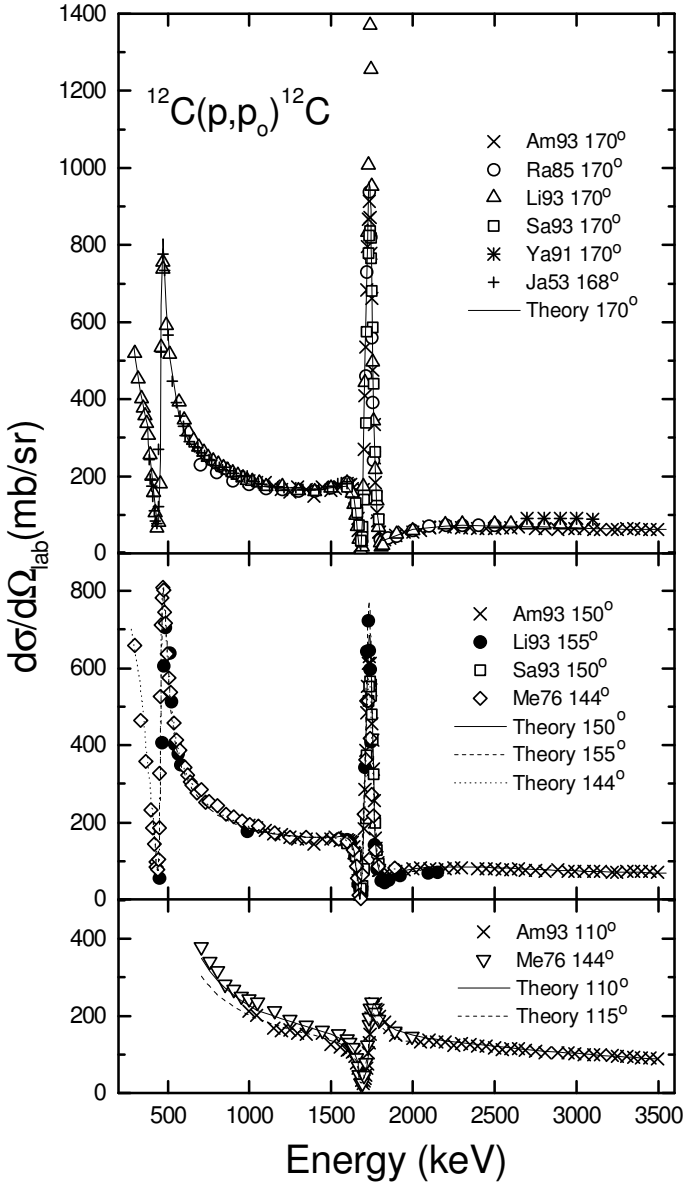
Reason 3: because cross section may have a strong dependence on angle.



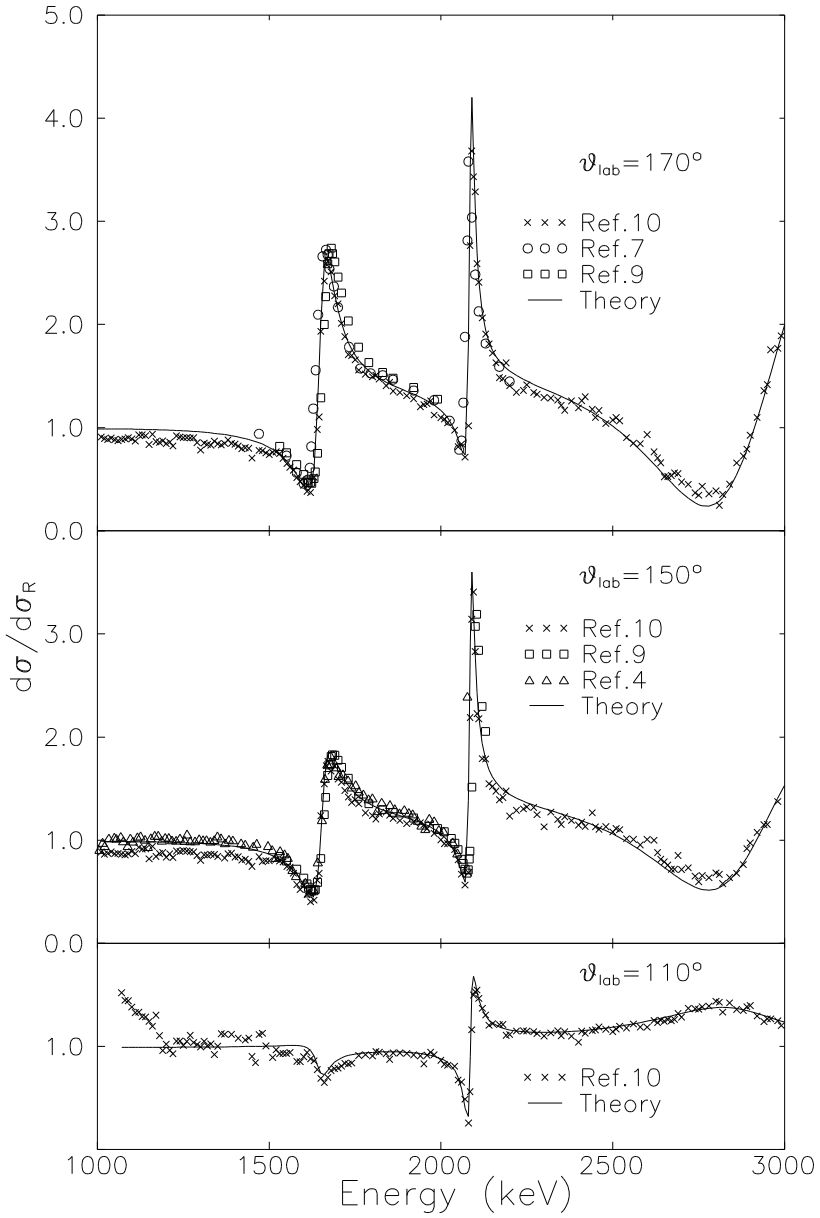
Evaluation of the proton elastic scattering from oxygen



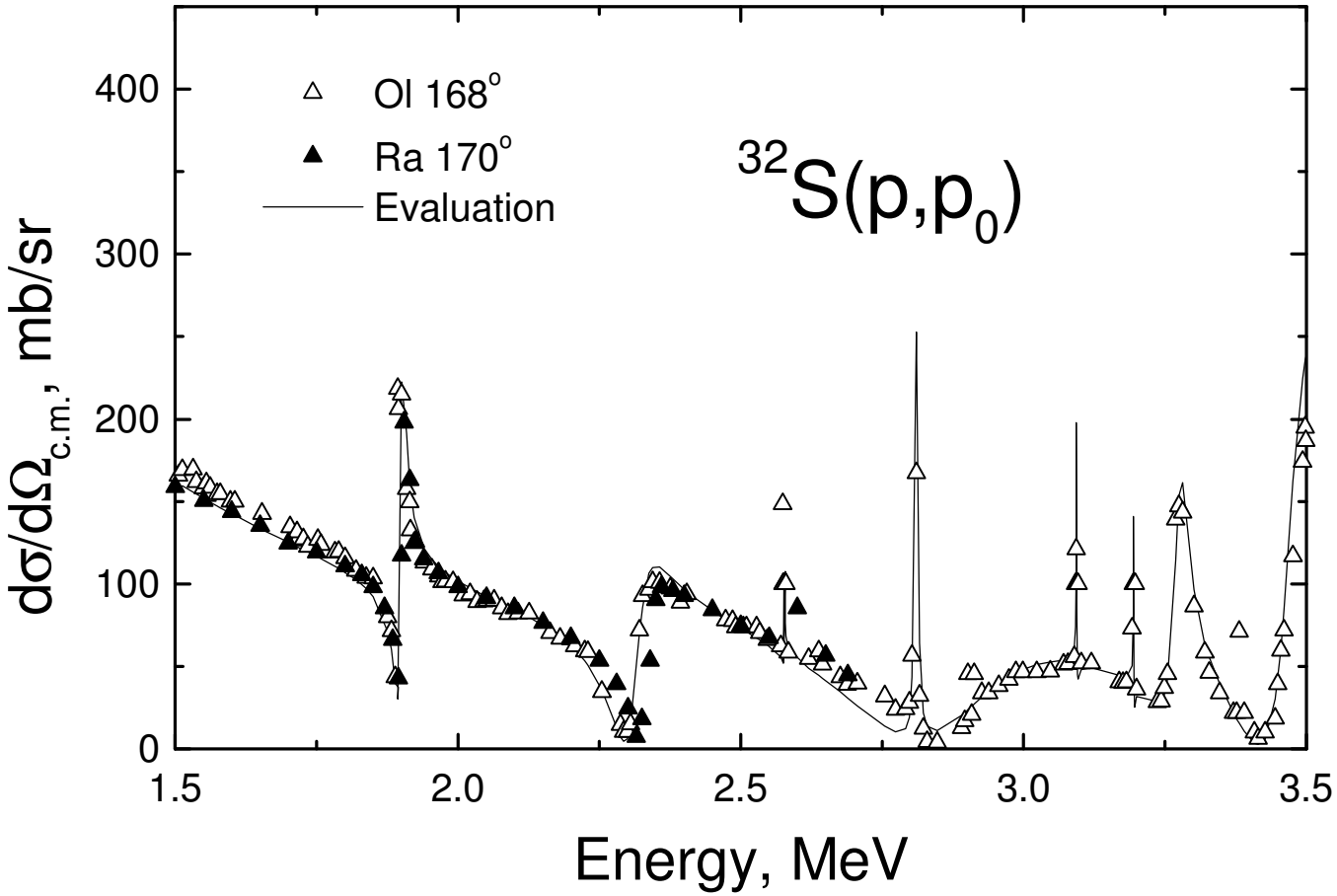
Evaluation of the proton elastic scattering from carbon



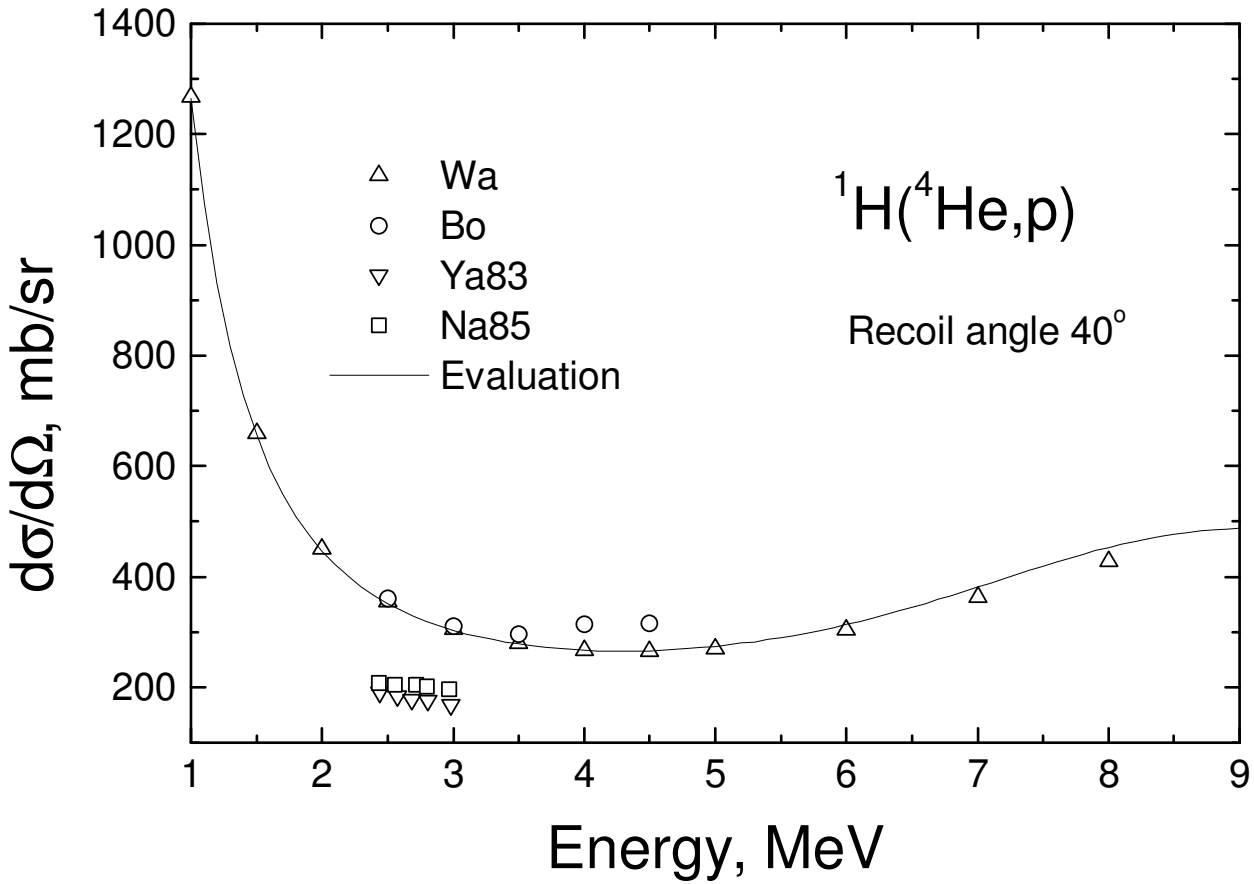
Evaluation of the proton elastic scattering from silicon



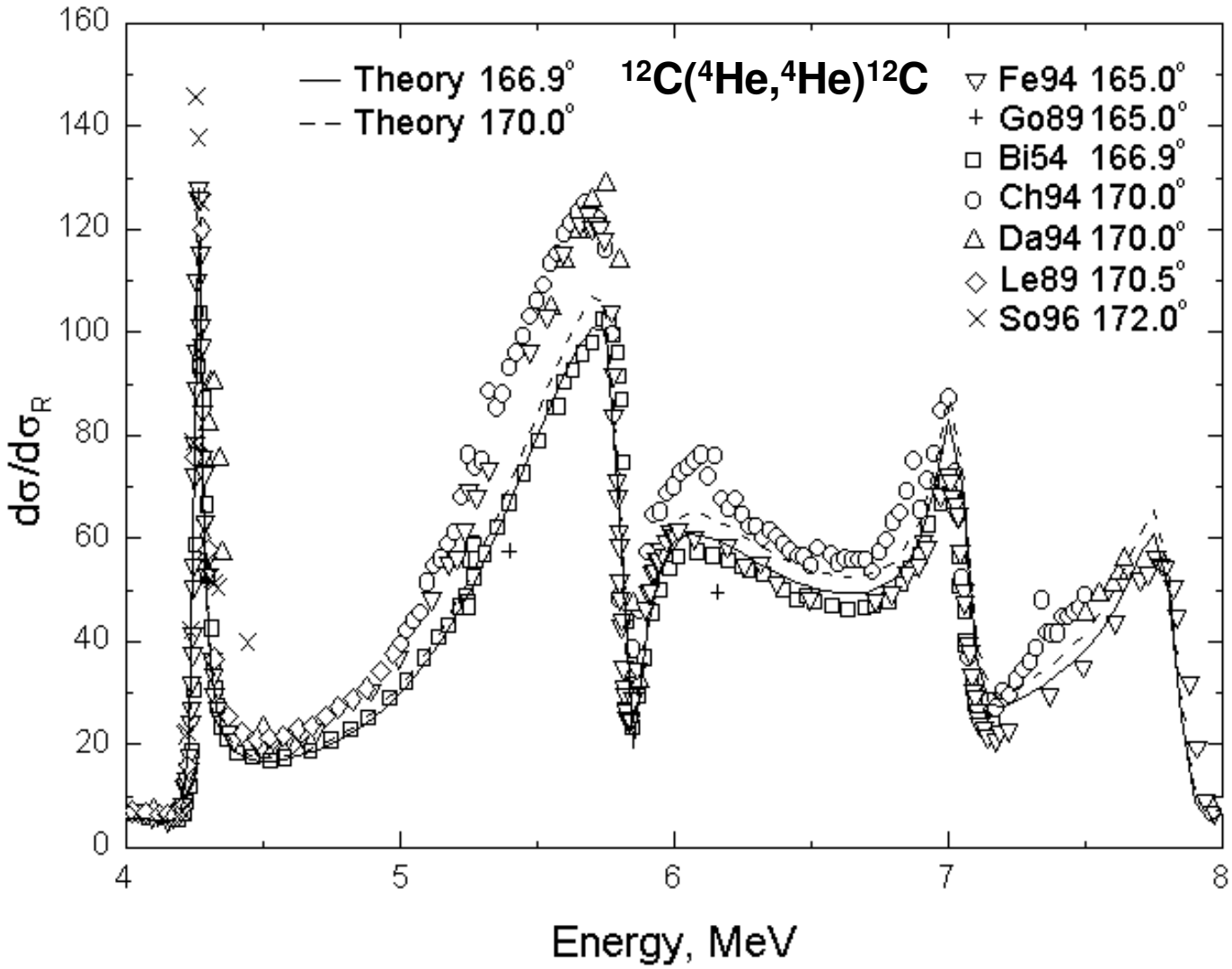
Evaluation of the proton elastic scattering from sulfur



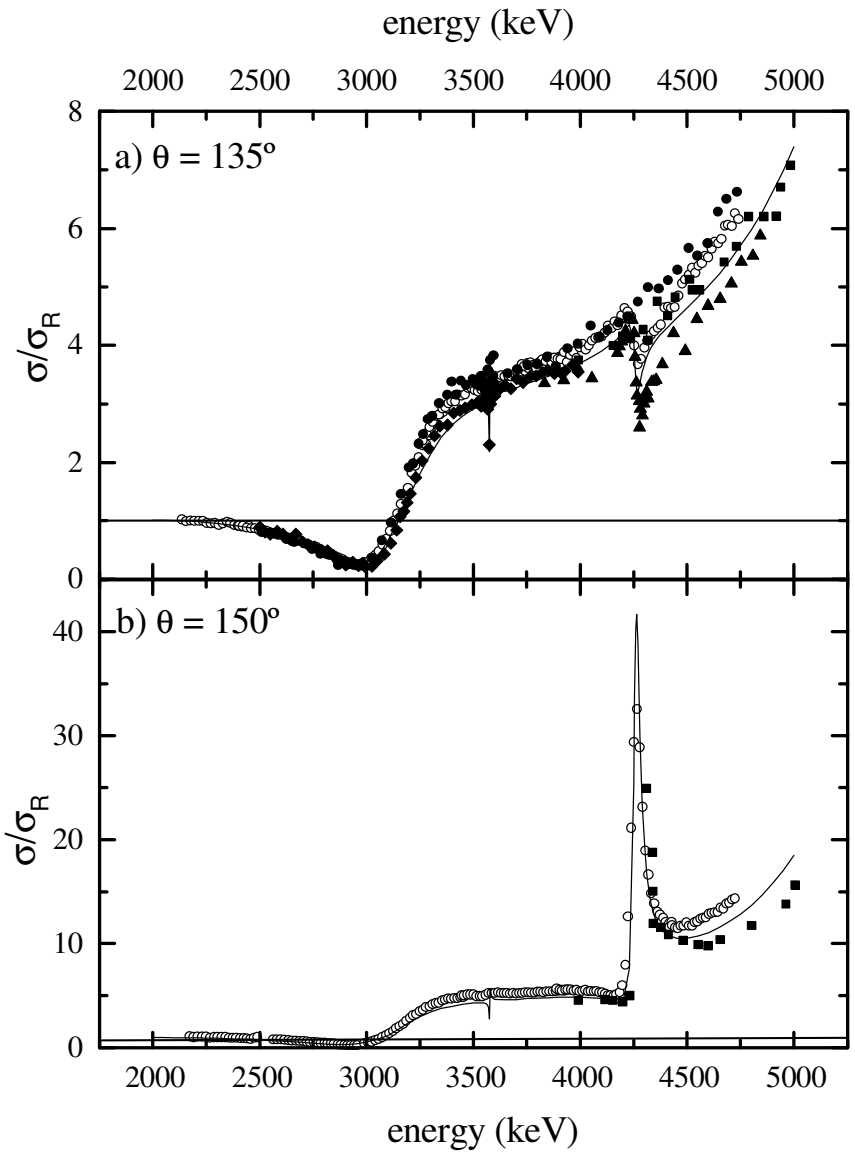
Evaluation of the $^{4}He+^{1}H$ recoil cross section



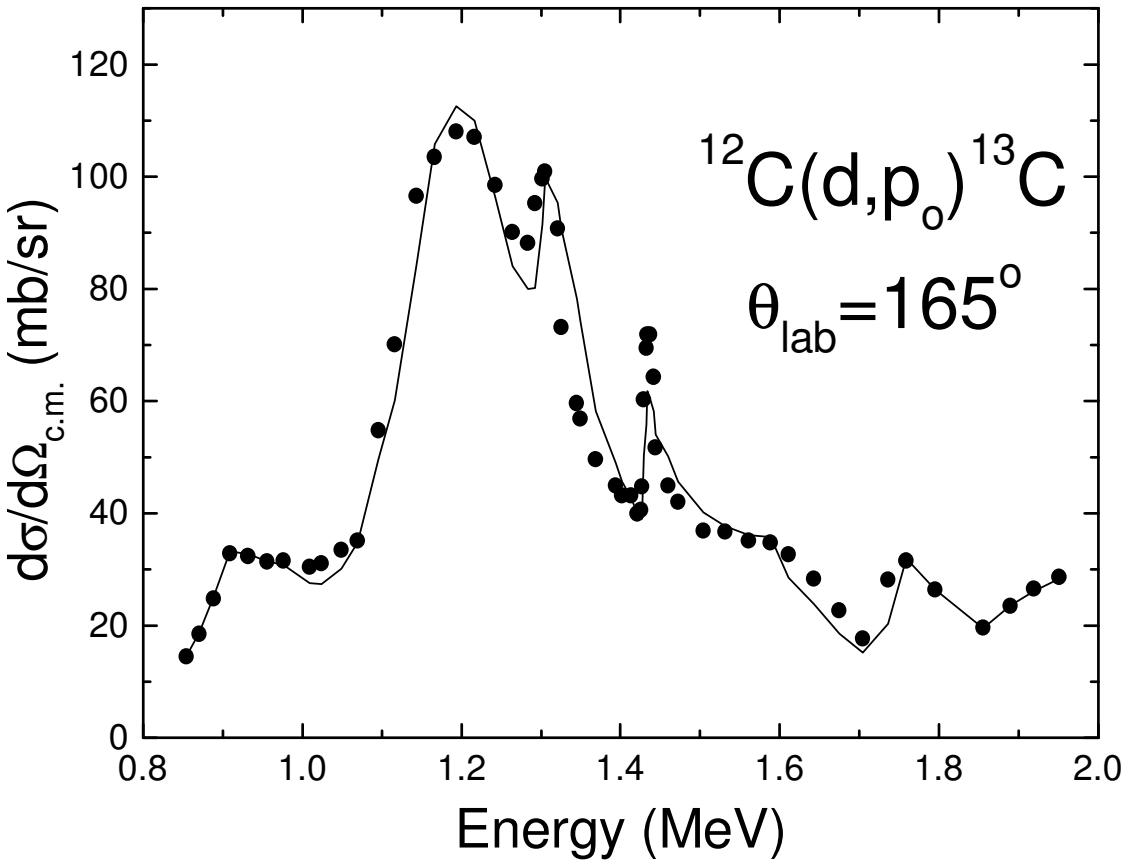
Evaluation of the alpha elastic scattering from carbon



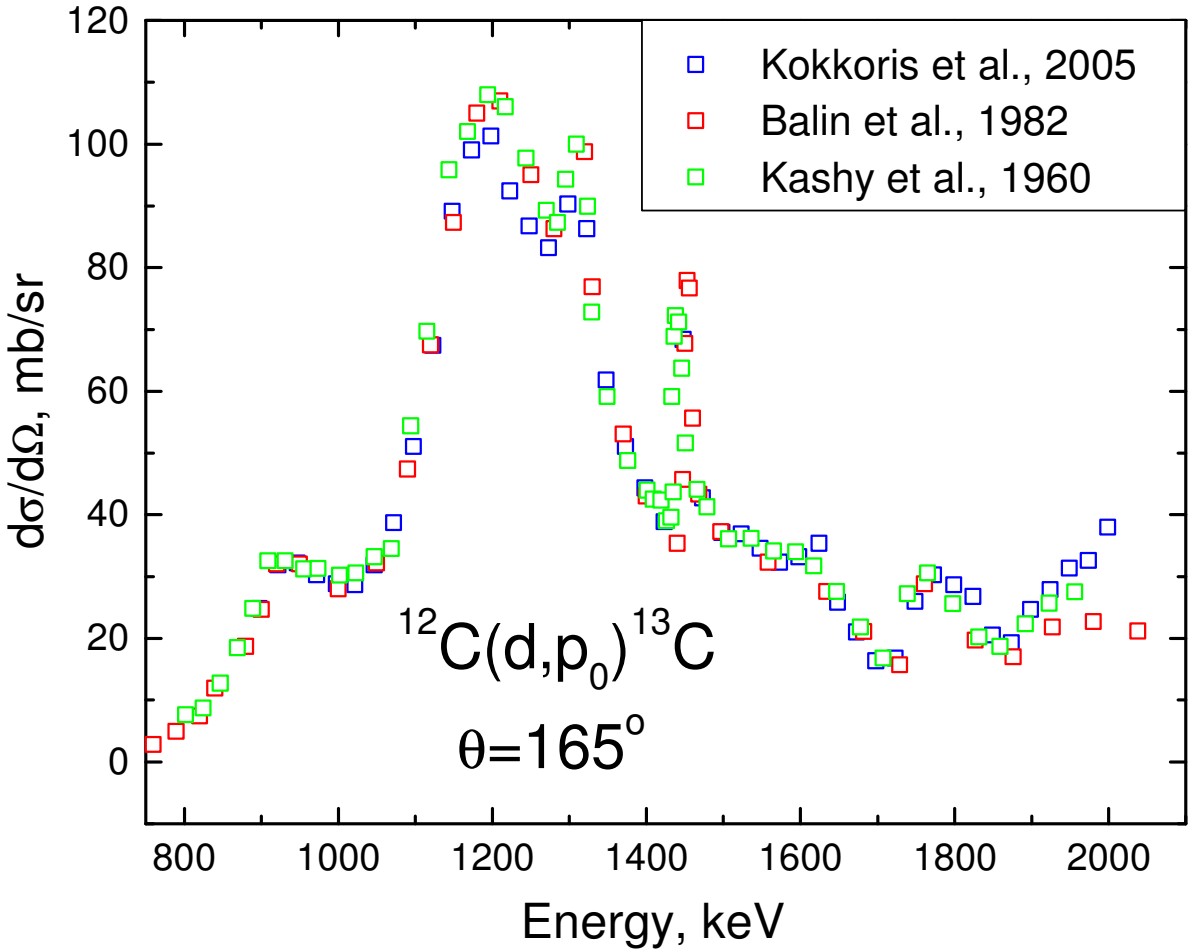
Evaluation of the alpha elastic scattering from carbon



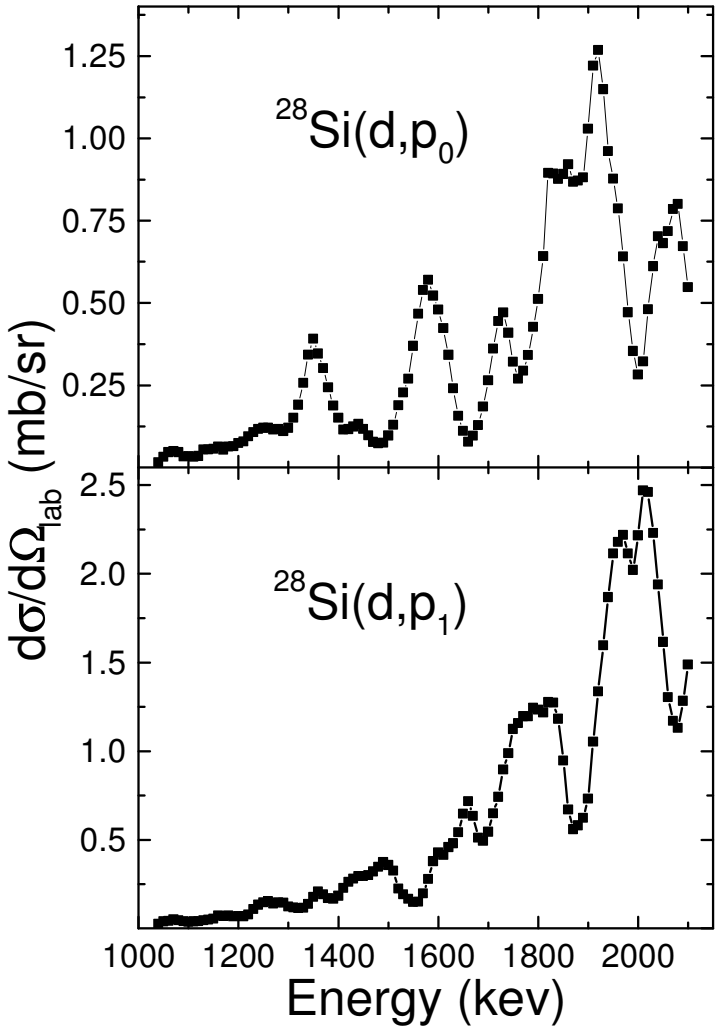
Differential cross section of the $^{12}C(d,p)^{13}C$ reaction



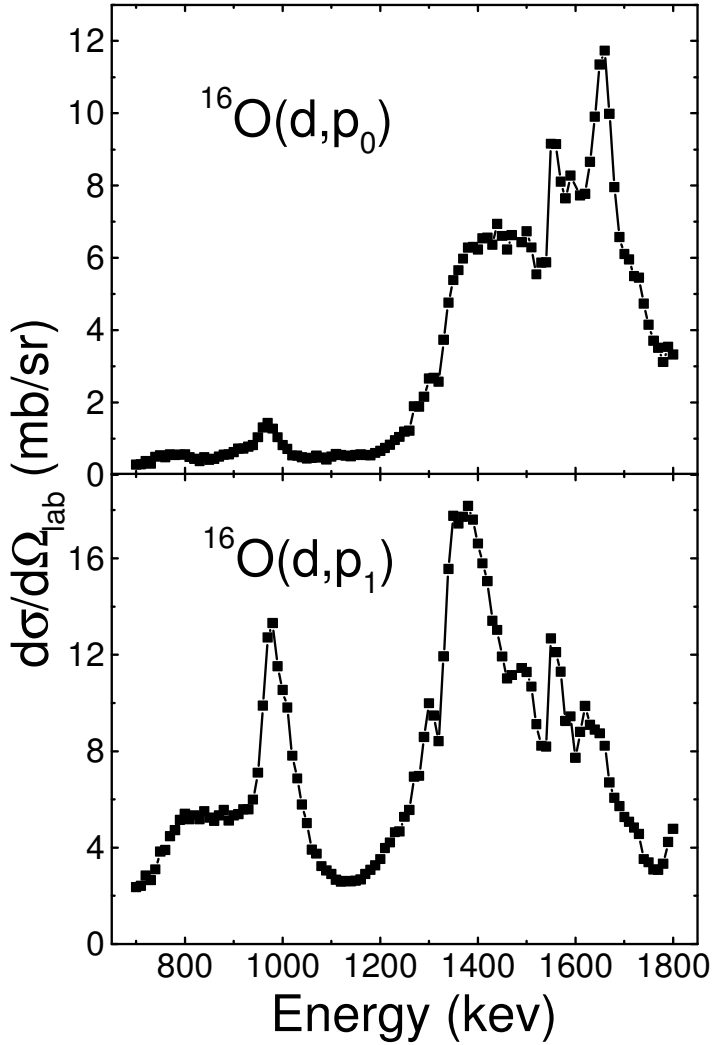
Differential cross section of the $^{12}C(d,p)^{13}C$ reaction



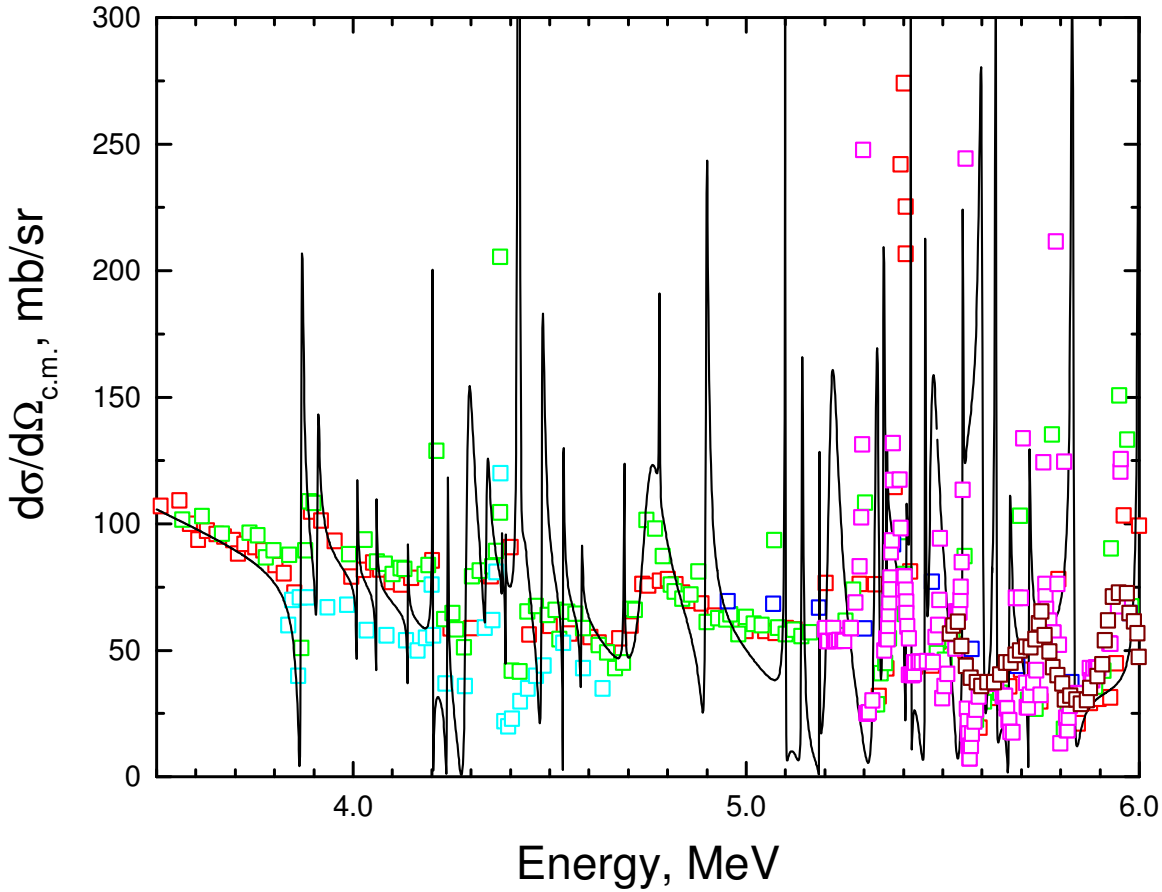
Differential cross section of the $^{16}O(d,p)^{17}O$ reaction



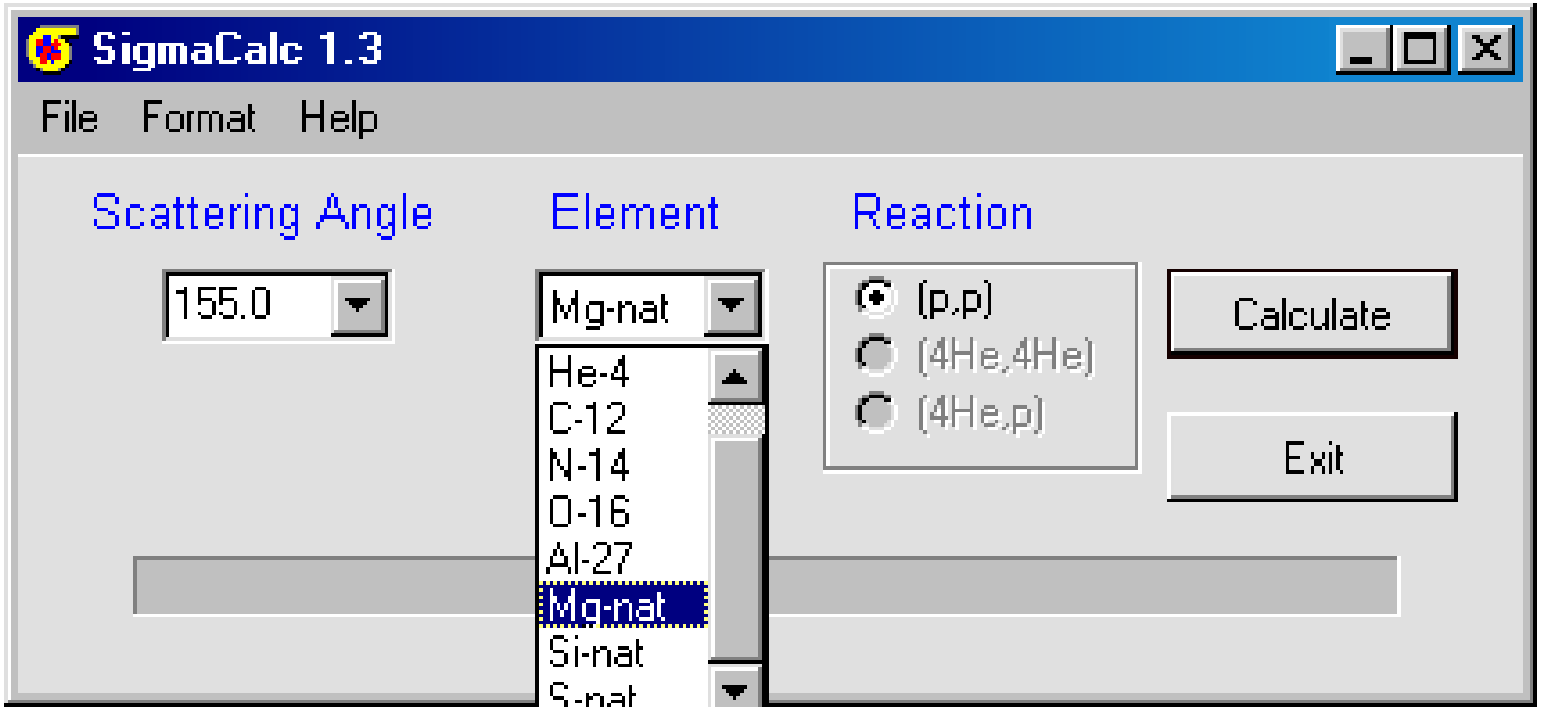
Differential cross section of the $^{28}Si(d,p)^{29}Si$ reaction



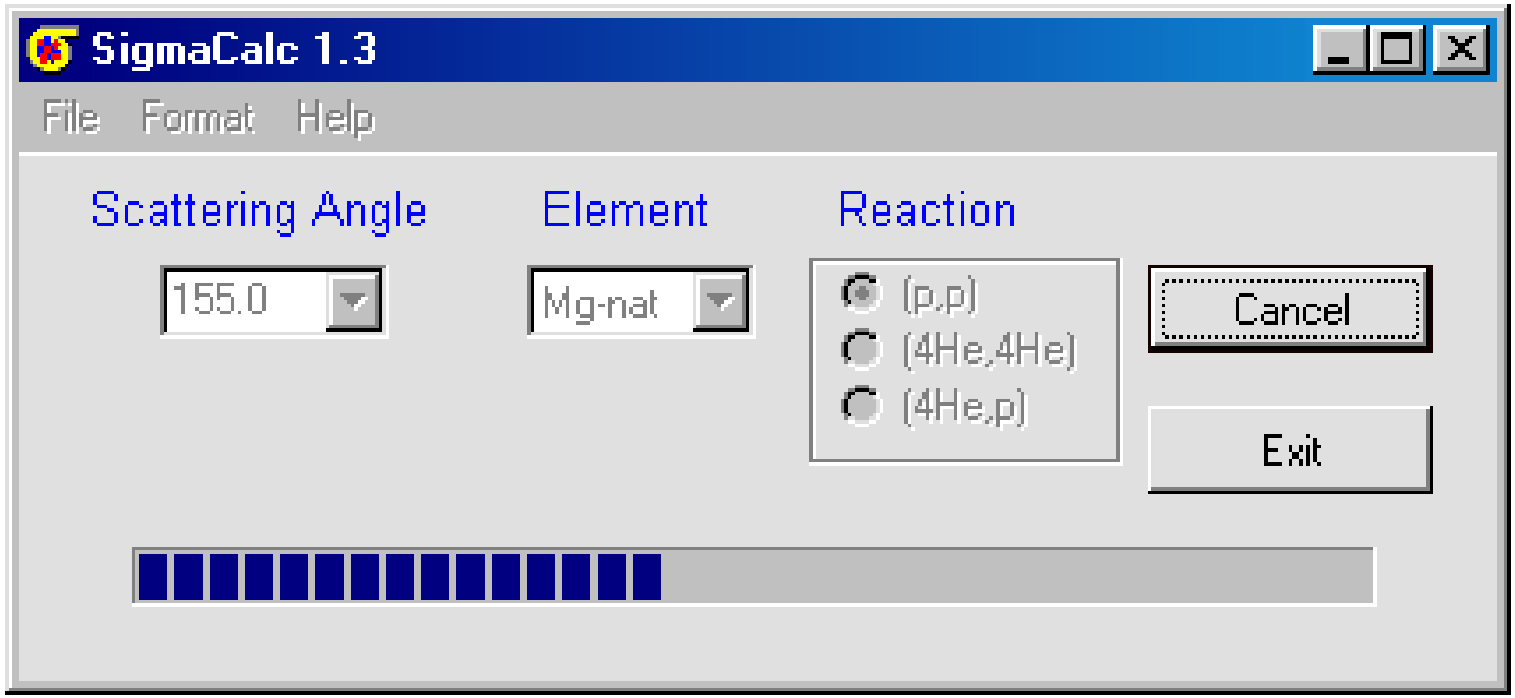
The differential cross section for alpha elastic scattering from silicon



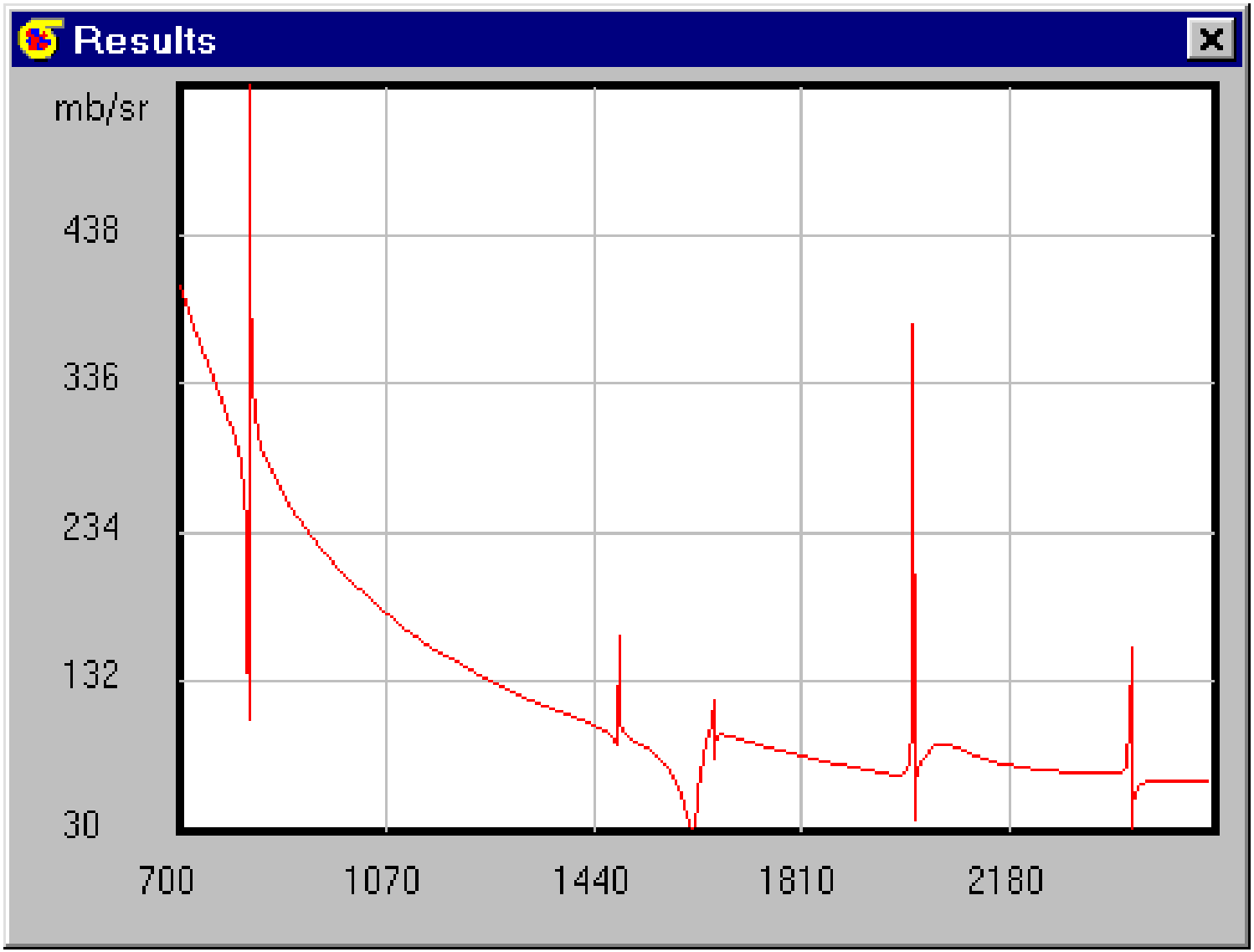
SigmaCalc CROSS SECTION CALCULATOR



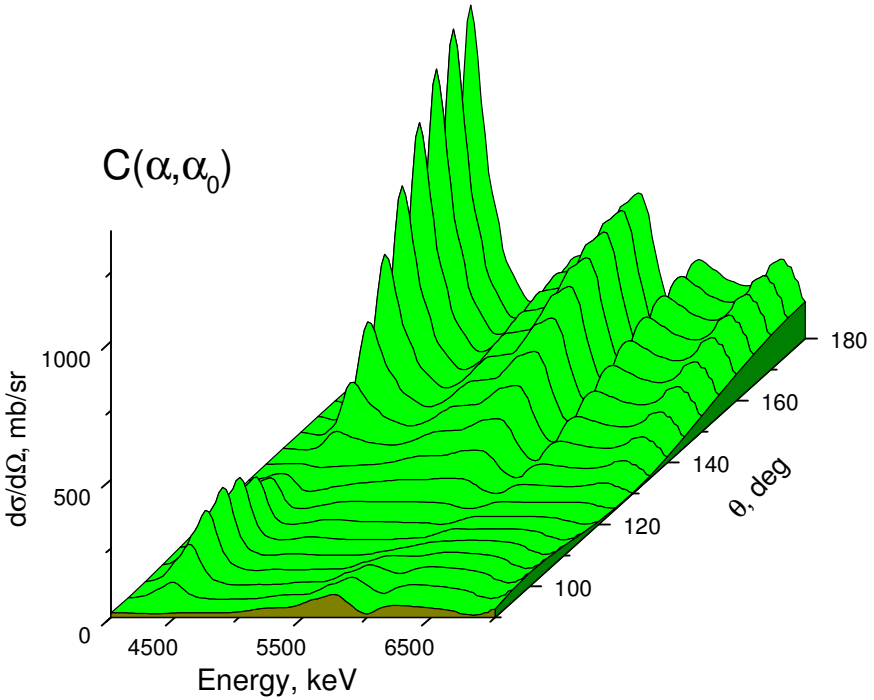
Calculations are based on S- and R-matrix theories. As far as the optimal set of parameters has been found excitation functions for analytical purposes can be calculated for any scattering angle with reliability exceeding that for any individual measurement.

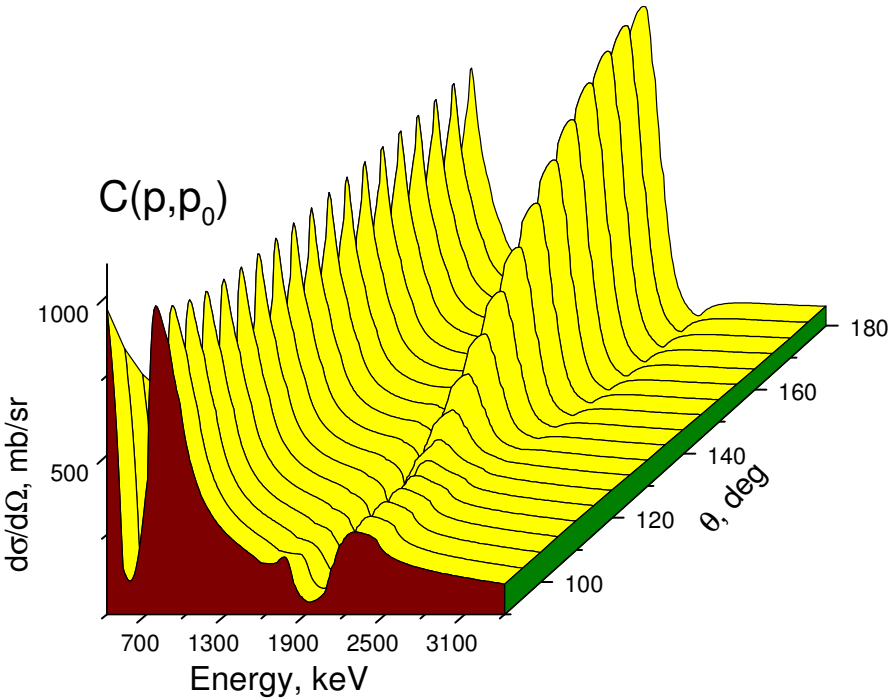


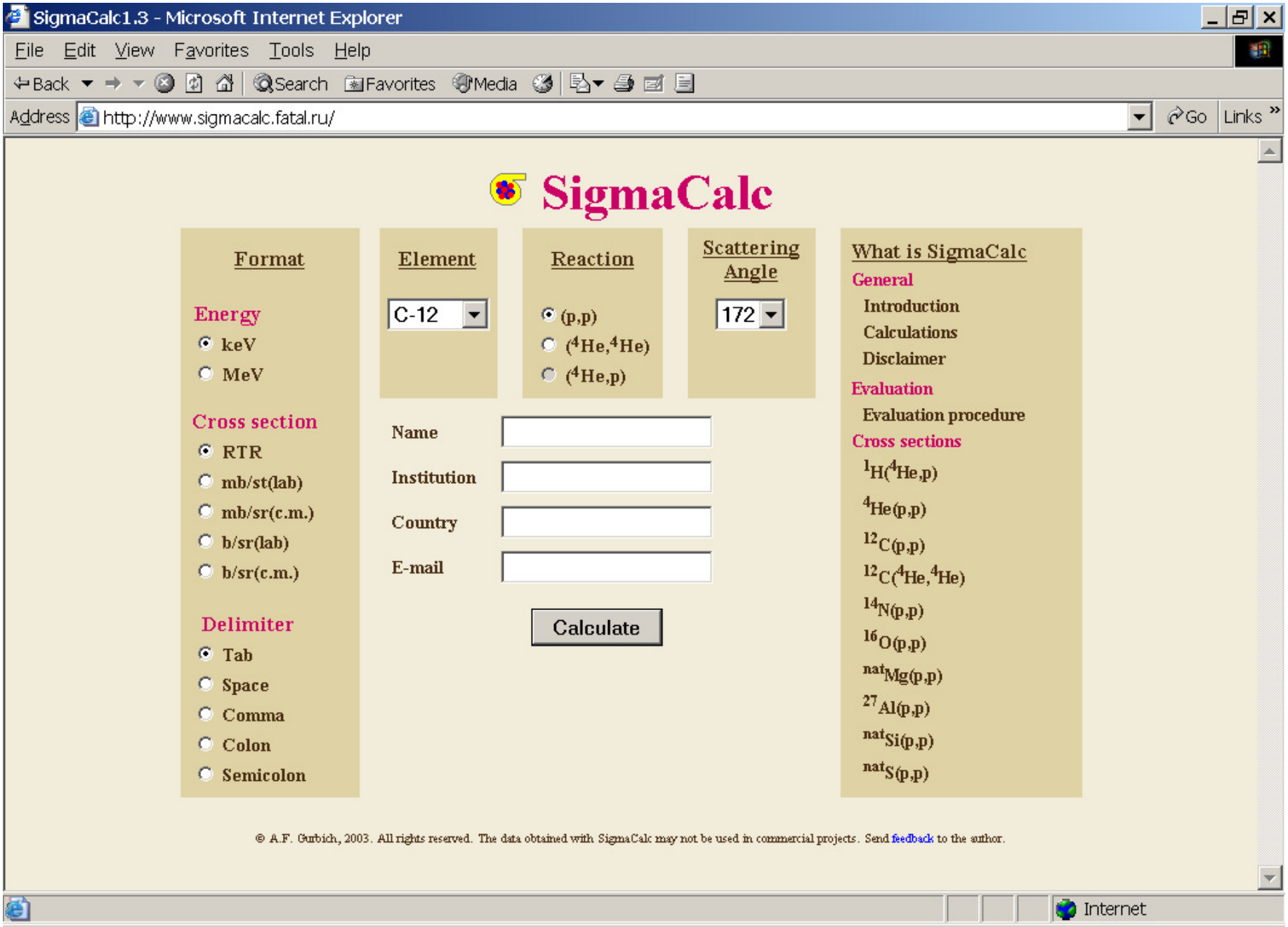
Results are presented both in tabular and graphical forms.



When the cross section has been evaluated it can be calculated for any scattering angle



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4He(p,p)
12C(p,p)
12C(4He,4He)
14N(p,p)
16O(p,p)
natMg(p,p)
27Al(p,p)
natSi(p,p)
natS(p,p)
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Internet

SUMMING UP

PRESENT STATUS OF THE PROBLEM:

- **RAW MEASURED DATA HAVE BEEN COMPILED IN ION BEAM ANALYSIS NUCLEAR DATA LIBRARY IBANDL**
- **SOME OF THE DATA HAVE BEEN EVALUTED AND ARE PROVIDED BY SigmaCalc CALCULATOR**

NEEDS OF THE IBA COMMUNITY:

- **RECOMMENDED DIFFERENTIAL CROSS SECTIONS FOR ALL REACTIONS OF INTEREST TO ION BEAM ANALYSIS AVAILABLE IN ELECTRONIC FORM**

CONCLUSIONS

- The compilation of the IBA related cross sections is in a good condition.
- New cross section measurements are needed in many cases.
- The work to evaluate the IBA cross sections should be continued.
- Further progress in resolving the problem of the nuclear data for IBA is expected due to establishing of a Coordinated Research Project (CRP) by the IAEA NDS.