CERN/SCC/77-2
1 March 1977

PROPOSAL TO THE SCC

STUDIES OF BINARY FISSION OF MEDIUM-HEAVY NUCLEI INDUCED BY 600 MeV PROTONS

LUND[1]- OSLO[2] COLLABORATION

G Andersson[1], M Areskoug[1], H-Å Gustafsson[1],
G Hyltén[1], E Hagebø[2], B Schrøder[1]

1 INTRODUCTION

The descriptions of the fission process are at present based on the macroscopic-microscopic method /1/. In this approach the smooth part of the total nuclear energy is represented by some macroscopic theory, eg the liquid drop model, and the remaining oscillations, shell corrections, are evaluated with a single-particle model. As a first step in the calculations a parameterization is chosen which can describe the nuclear shapes involved in the transition from the spherical ground state to the scission configuration of two touching fragments. The nuclear potential energy of deformation is then calculated with a macroscopic model and the saddle point separating the ground state and the scission point is located. At the saddle point the deformation energy constitutes the macroscopic contribution to the fission barrier.

Fig. 1 shows the fission barrier heights for nuclei along the line of beta-stability calculated with three different macroscopic models. These are the liquid drop model (LDM)/2/, the modified liquid drop model (MLDM) /3/ and the droplet model (DM)/4/. The differences between the models are mainly to be found in the evaluation of the nuclear surface energy. For masses in the region above approximately 170 amu, where most experimental work has been performed, the theories agree. With decreasing mass, differences between the barrier heights appear, and experimental fission cross sections in the mass region $A \approx 80 - 140$ can be used to single out the most relevant description of the surface energy.

The circles shown in fig. 1 indicate for each theory the approximate location of the so-called Businaro-Gallone point. Above this point the symmetric saddle is instable only towards fission, but below it becomes instable against two degrees of freedom, ie fission and mass-asymmetry. Below the Businaro-Gallone point the fragment mass-distribution is supposed to be highly asymmetric and above symmetric. The point has not been located experimentally, nor has its existence been proved.

We propose to determine the fission cross sections and fragment mass-distributions in medium-heavy elements ($65 \lesssim A \lesssim 165$) in order to provide experimental data required in connection with theories of average nuclear properties. During the last two years we have been involved in such a study at the CERN proton synchro-cyclotron. We hope to complete this experiment (LUND-OSLO COLLABORATION, SC53) in the summer 1977. Below we will briefly discuss some of the results obtained sofar for medium-heavy elements. We have found the synchro-cyclotron at CERN, with its high duty factor and stable conditions over long running periods, to be most suitable for the proposed experiment. The experimental equipment used in SC53 has to be improved, however, in order to increase counting rates and to obtain a better mass resolution. The existing relevant experimental information will be described in Section 2, the proposed experimental technique outlined in Section 3 and, finally, the proposed programme is given in Section 4.

2 EXPERIMENTAL INFORMATION

Fig. 2 shows nuclear fissilities, defined as the ratio of the fission cross section to the total inelastic reaction cross section, obtained with protons of energies 600 MeV /5-7/ and 1 GeV /8/. Two experimental techniques were used, mica track detectors /5,6/ and silicon surface-barrier detectors /7,8/. From the fission barrier heights in fig. 1, one would expect a fissility minimum around $Z^2/A=18$. Kotov et al. /8/ report a minimum at $Z^2/A=28$, whereas we observe an indication of a minimum around $Z^2/A=24$ /7/. This latter value coincide with earlier photofission data, see eg Ref./7/. The discrepancy at Tb ($Z^2/A=26.5$) between the two counter experiments /7,8/ is probably connected with the indentification of true binary events in the presence of a large background of accidental coincidences. Another source of error is to be found in the transformation of measured yields into differential cross sections. The original colinearity between complementary fission fragments is smoothed out due to the distribution of imparted linear momentum in the cascade and due to broadening caused by the subsequent particle evaporation before and after fission. The resulting in-plane angular distribution for Ag is shown in fig. 3 /7/. There is also a similar out-of-plane distribution, at present estimated, and the two distributions has to be taken into account when calculating the differential cross sections. An analysis of the in-plane distribution may yield the imparted linear momentum parallell to the proton beam direction and the imparted excitation energy in the cascade. The first quantity is needed when transforming differential cross sections into total fission cross sections, and the second is used in the fission-spallation competition calculations performed to obtain fission barrier heights from measured fissility values. At present we are engaged in such calculations.

Fig. 4 shows the fission cross sections of ^{238}U in the proton energy range 0.45 to 3 GeV obtained with different experimental techniques. The figure serves as an illustration of the difficulties involved in cross section determinations even if the fissility is high.

Fig. 5 shows the distribution of mass ratios of fission fragments from Ag, La and Tb /7/. The observed behaviour is quite unexpected. In the cases of Tb and Ag we obtain no mass ratios greater than 4, but for La values as high as 10 are observed. Without the Ag result one would from the broad La distribution have suggested the occurence of the Businaro-Gallone point just below La in agreement with the MLDM theory /3/. There is agreement between the total translational kinetic energy obtained /7/ and the predicted values for all three elements /13/.

In the proposed experiment we want to extend the earlier measurements /7/ to the mass range below Ag and to include more elements in the already studied mass range. In order to do this our experimental equipment will be changed to increase counting rates and mass resolution.

3 EXPERIMENTAL TECHNIQUES

Fig. 6 shows a schematic drawing of the proposed detector-target arrangement. The main differences compared to the present apparatus (SC53) is a new start-detector, which will permit five times larger solid angles and five times better mass resolution, and the inclusion of a dE gas ionization chamber. Apart from distances s_i and angles θ_i, six pulseheights will be measured. In the silicon surface-barrier detectors (SSBD) the signals X_1 and X_2 are proportional to the energies E_1 and E_2-dE_2, respectively. From the measured times-of-flight, $X_4 \sim T_1$ and $X_5 \sim T_2-T_1(s_{11}/s_1)$, the velocities v_1 and v_2 are obtained permitting the masses M_1 and M_2 to be calculated.

Stop signals for the flight time measurements are taken from the SSBD detectors. The common start signal is obtained from a thin carbon foil, from which electrons are evaporated on the passage of a heavy ion. These electrons are accelerated towards a pair of Channel Electron Multiplier Plates (CEMP) with a gain of about 10^7. The time resolution obtainable with this configuration is approximately 200 ps for alpha-particles and somewhat better for fission fragments /14/. At present (SC53) we use a similar start-detector with a Channel Electron Multiplier tube (CEM) with a typical time resolution of about 1 ns. With a typical E/M value of 1 MeV/amu (velocity about 1 cm/ns) the mass resolution with the CEMP will be about 5 per cent.

When extending the experiment towards lower target elements it becomes increasingly difficult to separate fission fragments from other reaction products. The pulseheight X_6 from the CEMP, proportional to the number of electrons emitted from the carbon foil, and the pulseheight X_5 from the ioniztion chamber will faciliate this discrimination. The sensitive part of the gas ionization chamber is about 10 cm long and we will use a gasmixture (10% methane, 90% argon) with a pressure of about 20 torr.

The electronics (not shown) are mainly commercial available (ORTEC) NIM units. It will be brought to CERN from Lund and Oslo as will the detectors, targets and scattering chamber. At present (SC53) we have access during experimental runs to a computer HP 21XX with pheripheral equipment and to a CAMAC crate with controller.

In the proposed experiment we request from CERN the following equipment if possible:

(i) a computer HP 21XX with Tektronix terminal, magnetic tape station and lineprinter

(ii) a CAMAC crate with controller type A

(iii) electronics:

1	AD811	EGG	8-channel peak reading ADC
1	335	LRS	Quad amplifier
1	428	LRS	Quad linear fan-in/fan-out
1	429	LRS	Logic fan-in/fan-out
2	S424F	EGG	Quad Scalers
5			NIM Bin and Power Supplies

As we hope to have one member of the collaboration continously stationed at CERN we would prefer to have access to the above mentioned equipment also outside experimental runs. The demand of computing time is at present foreseen to be small as most of the time-consuming analysis is planned to be performed at our home institutes. As a visiting group we do not ask for any direct financial support, apart from the requests stated above, from CERN although it naturally would be wellcomed.

At present (SC53) we are housed in countingroom CO4 and the scattering chamber is placed in UR2 just in front of the ISOLDE target region. We ask that these locations will be made accessible also for the proposed experiment.

4 SCIENTIFIC PROGRAMME

We propose to study the binary fission process in about 8 elements ranging from Cu to Ho. For each element we will measure

(i) in-plane and out-of-plane angular distributions

(ii) at the most probable angle $\langle\theta_2\rangle$, compare fig. 3, additional data will be taken to improve statistics

(iii) the variation of the differential cross section in a limited angular region ($30^\circ \lesssim \theta_1 \lesssim 130^\circ$).

From these experimental data we will obtain:

a) total fission cross sections

b) differential fission cross sections in a limited angular interval

c) the fragment mass-, velocity- and energy distributions

d) the total translational kinetic energy

e) the linear momentum and excitation energy imparted by the cascade

f) the total mass loss in the cascade and evaporation

It will then be possible to provide experimental data required in the theories of average nuclear properties, especially the fissility and mass distribution for different medium-heavy elements.

For this programme we ask for 30 shifts for test runs and 120 shifts for data-taking. The estimate is based on the same excellent duty-factor as SC provides at present, ie better than 50 per cent. The required beam intensity is about $2 \cdot 10^{11}$ protons per second and we thus can use only a small fraction of the total intensity available. We can thus share the beam with other groups.

A prefered preliminary distribution in time of the requested shifts would be: The present experiment (SC53) will be completed in May 1977 and the new equipment built and tested during the autumn 1977 at our home institutes. We would thus be ready for the test-shifts in January and February 1978, whereafter the data-taking could start. These shifts we ask for in eight groups of approximately 15 shifts each. A couple of days before each running period we would prefer to have one or two shifts for tests, modifications and calibrations. Such a procedure will be possible, at least in principle, with the new beam layout at the SC. We would prefer to complete the experiment around the summer 1979.

REFERENCES

/1/ M Brack *et al.*, Rev Mod Phys **44**(1972)320

/2/ W D Myers and W J Swiatecki, Ark Fys **36**(1967)343

/3/ H J Krappe and J R Nix, Proceedings of the Third International Atomic Energy Agency Symposium on the Physics and Chemistry of Fission, Rochester, New York, 1973, Vol. I, p. 159

/4/ W D Myers and W J Swiatecki, Ann Phys (N.Y.) **84**(1974)186; W D Myers, Nuclear Data Tables **17**(1976)411

/5/ J Hudis and S Katcoff, Phys Rev **C13**(1976)1961

/6/ R Brandt *et al.*, CERN 71-2, Yellow Report

/7/ G Andersson *et al.*, Phys Letters **64**(1976)B421; unpublished results of LUND-OSLO COLLABORATION

/8/ A A Kotov *et al.*, Sov J Nucl Phys **19**(1974)385; Sov J Nucl Phys **20**(1975)251; G E Solyakin private communication

/9/ A K Lavrukhina and L D Krasavina, Atomnaya Energiya **2**(1957)27

/10/ N S Ivanova, Zh Eksper Teor Fiz **31**(1956)413

/11/ V A Konshin *et al.*, Yadernaya Fizika **7**(1968)1187

/12/ J Hudis and S Katcoff, Phys Rev **180**(1969)1122

/13/ K T R Davies *et al.*, Phys Rev **C13**(1976)2385

/14/ B Sundqvist *et al.*, to appear in IEEE Trans Nucl Sci; G Gabor *et al.*, Nucl Instr Meth **130**(1975)65

/15/ G Friedlander, Proceedings of the Salzburg Conference on the Physics and Chemistry of Nuclear Fission, Salzburg, 1965, IAEA Vienna 1965, Vol. II, p. 265

FIGURE CAPTIONS

Fig. 1 The macroscopic fission barrier heights for nuclei along the line of beta-stability. The results of the three different theories are shown:

LDM liquid drop model /2/
MLDM modified liquid drop model /3/
DM droplet model /4/

The circles indicate the positions of the Businaro-Gallone points in the theories.

Fig. 2 Nuclear fissilities obtained in proton-induced fission. The experiments were performed with mica track detectors (▪ E_p= 600 MeV /5/, ▽ E_p= 590 MeV /6/) and with silicon surface-barrier detectors (● E_p= 600 MeV /7/, ○ E_p= 1 GeV /8/).

Fig. 3 Angular correlation between fission fragments from Ag obtained with silicon surface-barrier detectors at E_p= 600 MeV /7/.

Fig. 4 Fission cross sections for ^{238}U in the proton energy range 0.45 to 3.0 GeV. The experimental methods used were

radiochemistry + /9/, ✳ /15/
nuclear emulsions △ /10/
glass track detectors ◇ /11/
mica track detectors ▪ /5/, ▽ /6/, □ /12/
silicon surface-barrier detectors ● /7/, ○ /8/.

Fig. 5 The distributions of the mass ratios M_1/M_2 for Ag, La and Tb obtained with silicon surface-barrier detectors at E_p= 600 MeV /7/. The M_1/M_2 scale divisions are 1.0-1.6, 1.6-2.5, 2.5-4.0, 4.0-6.3, 6.3-10.0. The distributions are normalized to the same area. Error bars give the statistical errors.

Fig. 6 Proposed experimental set-up. See the text for details.

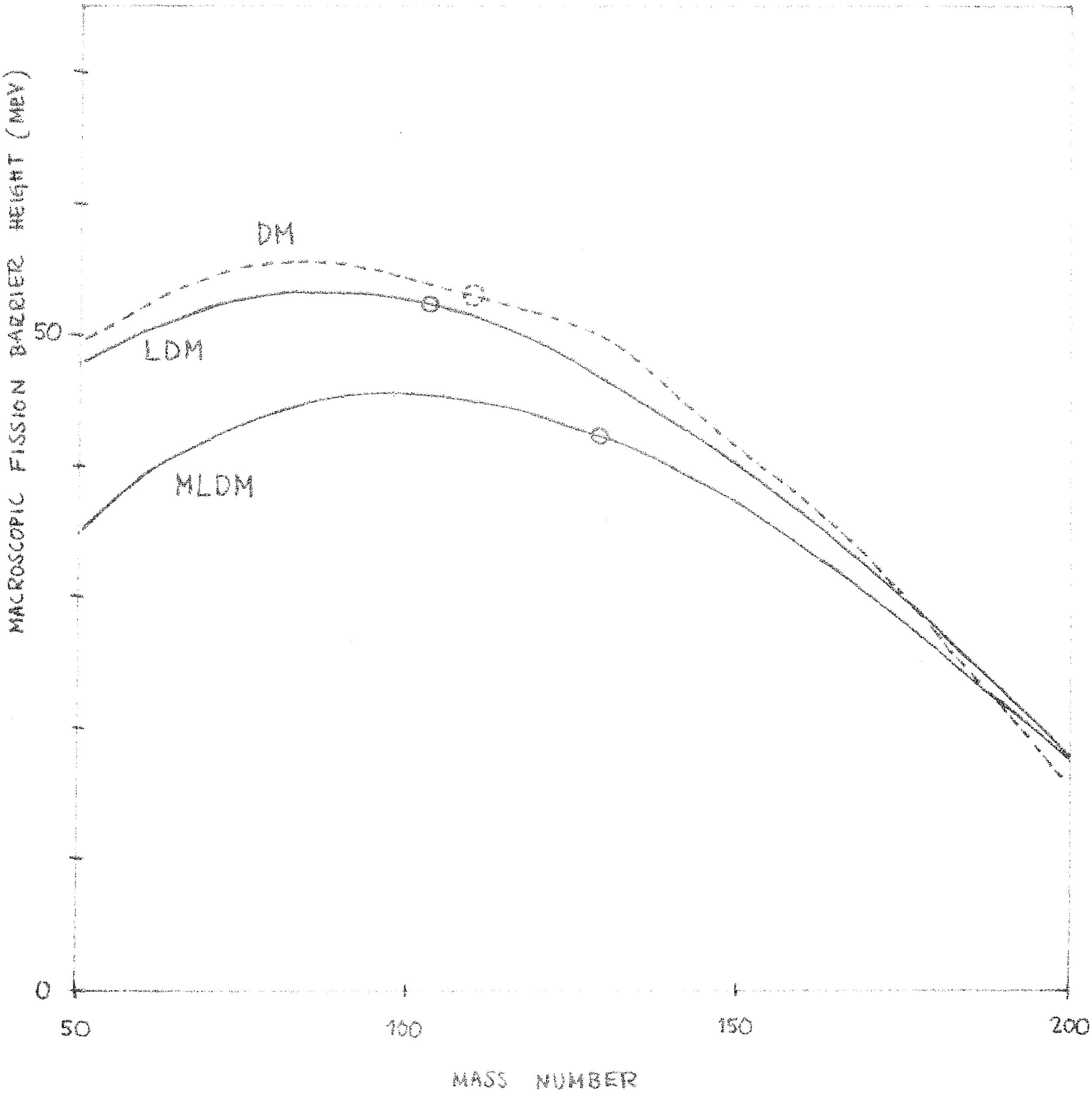
MACROSCOPIC FISSION BARRIER HEIGHT (MeV)
MASS NUMBER
0
50
50
100
150
200
DM
LDM
MLDM

Fig. 1

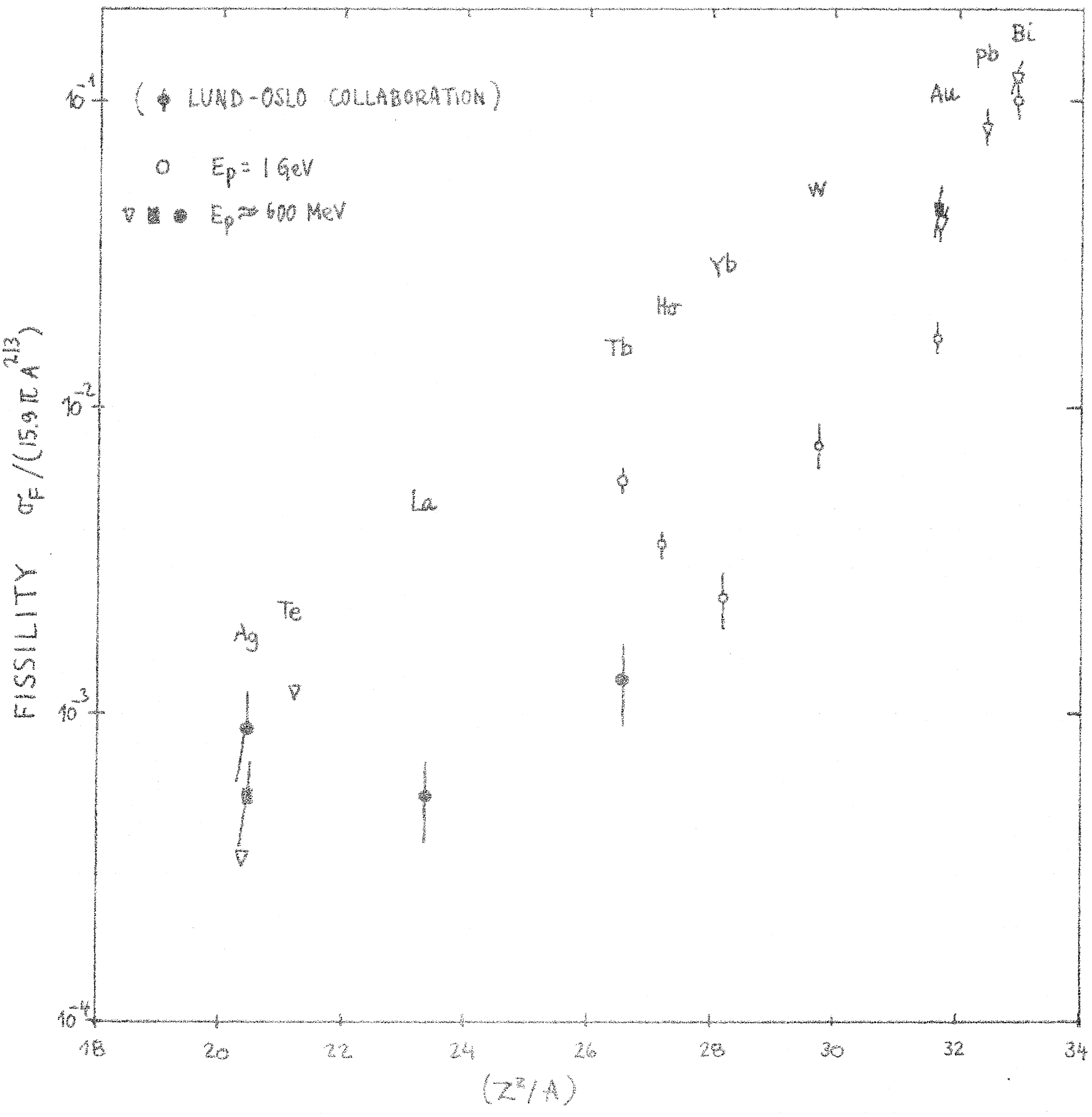
(ɸ LUND-OSLO COLLABORATION)
o Ep = 1 GeV
▿ ■ ● Ep ≈ 600 MeV
FISSILITY σF / (15.9 π A^2/3)
10^-1
10^-2
10^-3
10^-4
18
20
22
24
26
28
30
32
34
(Z²/A)
Ag
Te
La
Tb
Ho
Yb
W
Au
Pb
Bi

Fig. 2

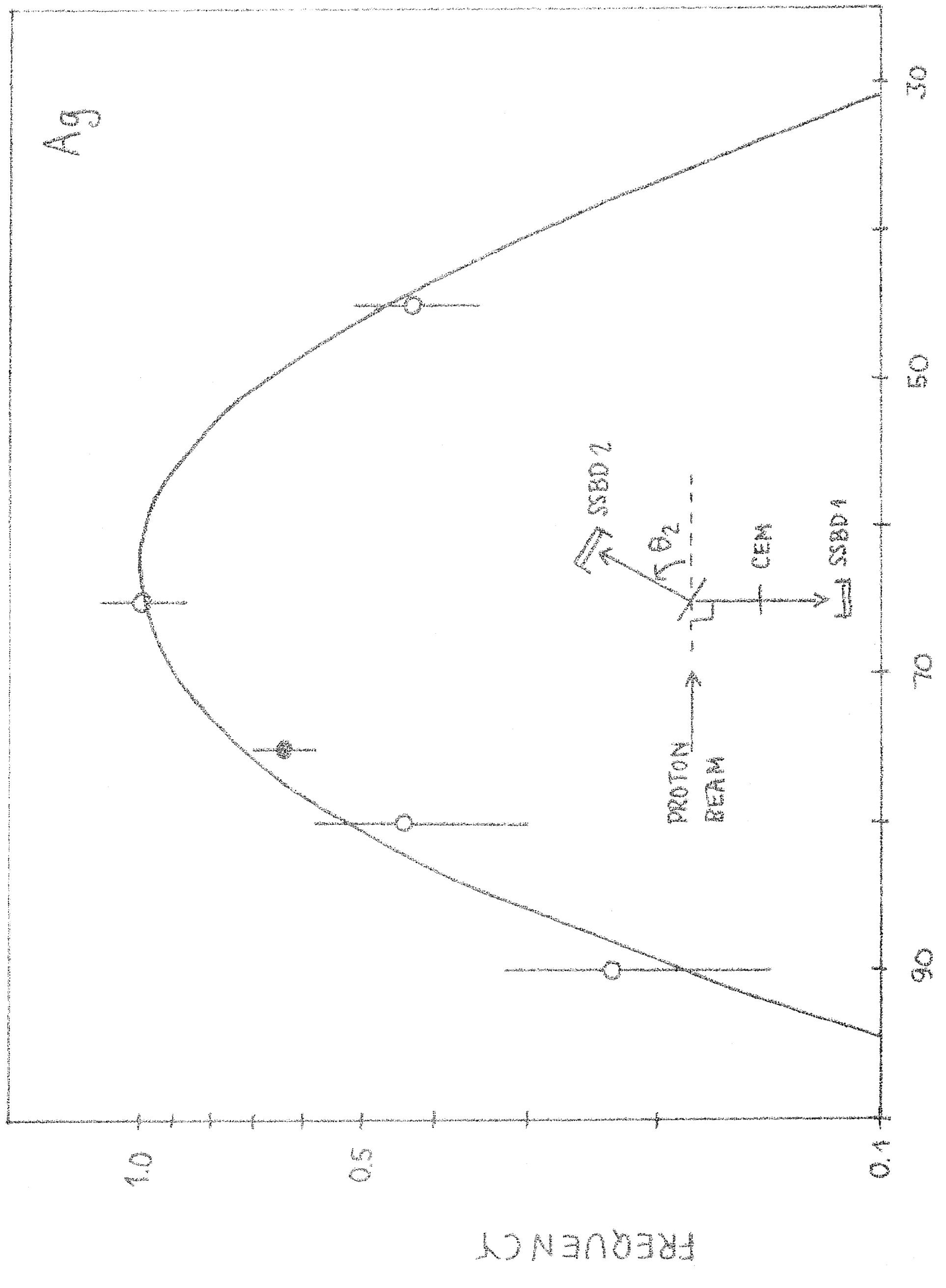
Ag
FREQUENCY
1.0
0.5
0.1
90
70
50
30
θ_2
PROTON BEAM
SSBD 2
θ_2
CEM
SSBD 1

Fig. 6

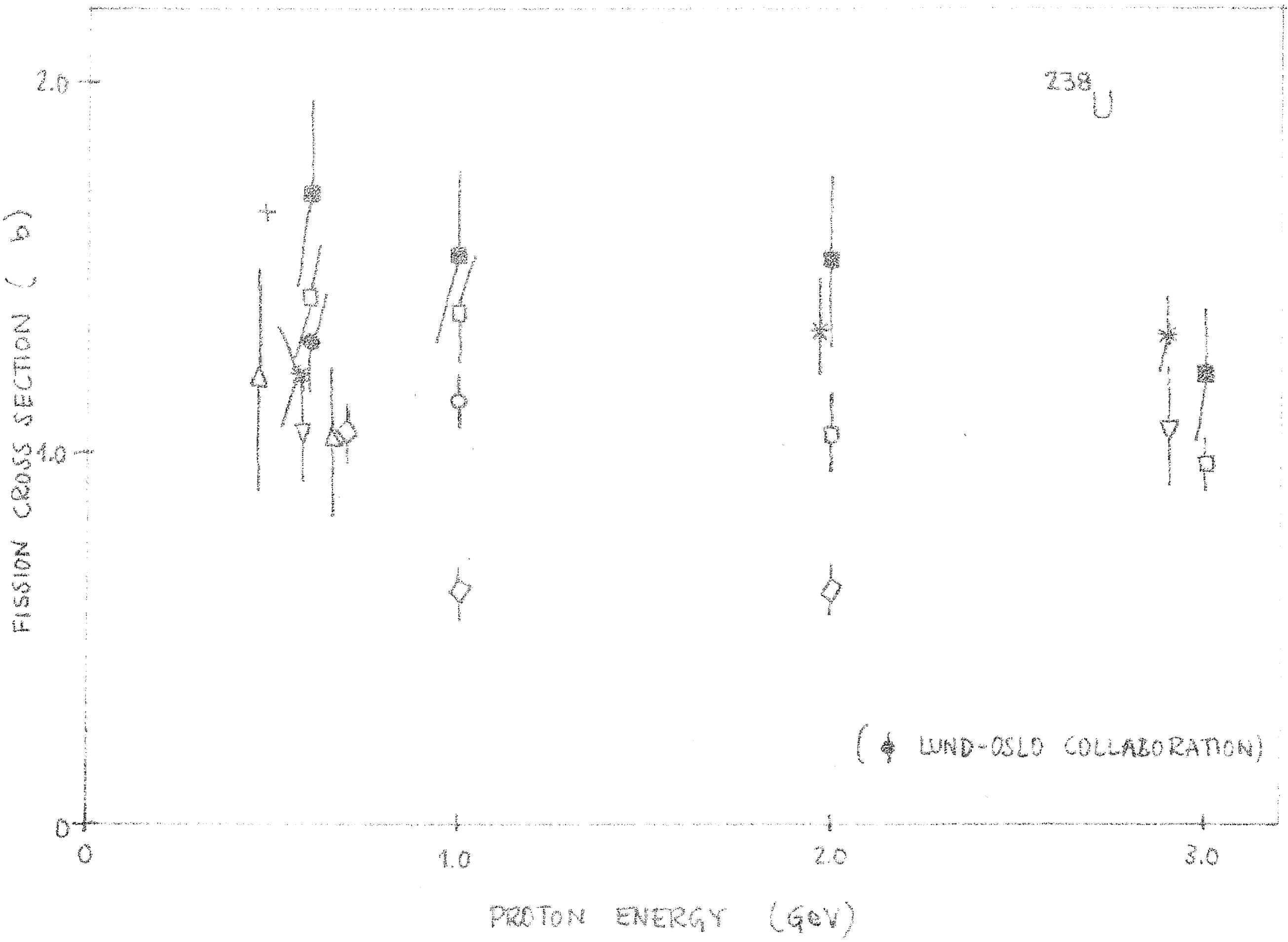
2.0
1.0
0
FISSION CROSS SECTION (b)
238U
(◆ LUND-OSLO COLLABORATION)
0
1.0
2.0
3.0
PROTON ENERGY (GeV)

Fig. 4

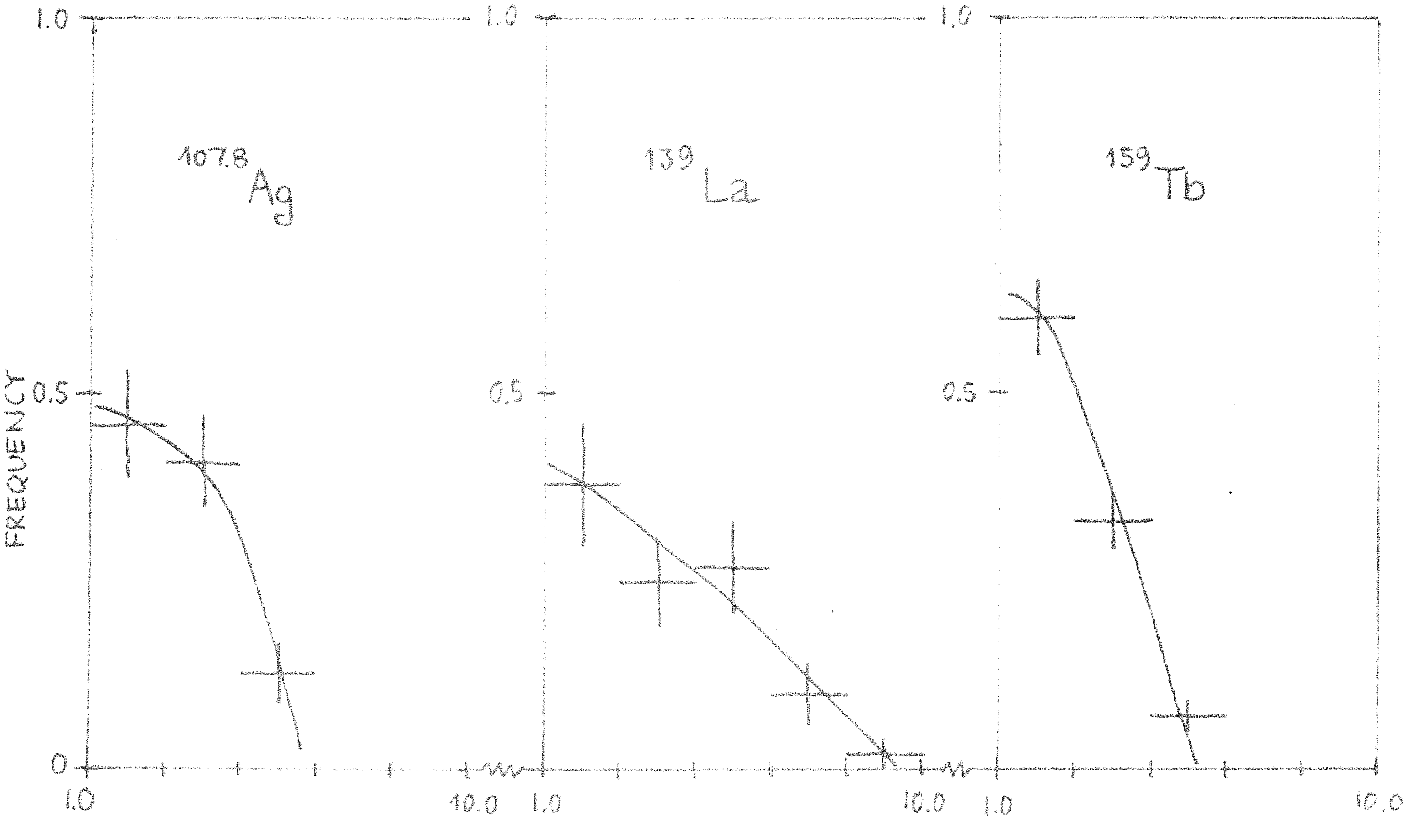
1.0
0.5
0
FREQUENCY
107.8Ag
1.0
10.0
M1/M2
1.0
0.5
139La
1.0
10.0
M1/M2
1.0
0.5
159Tb
1.0
10.0
M1/M2

Fig. 5

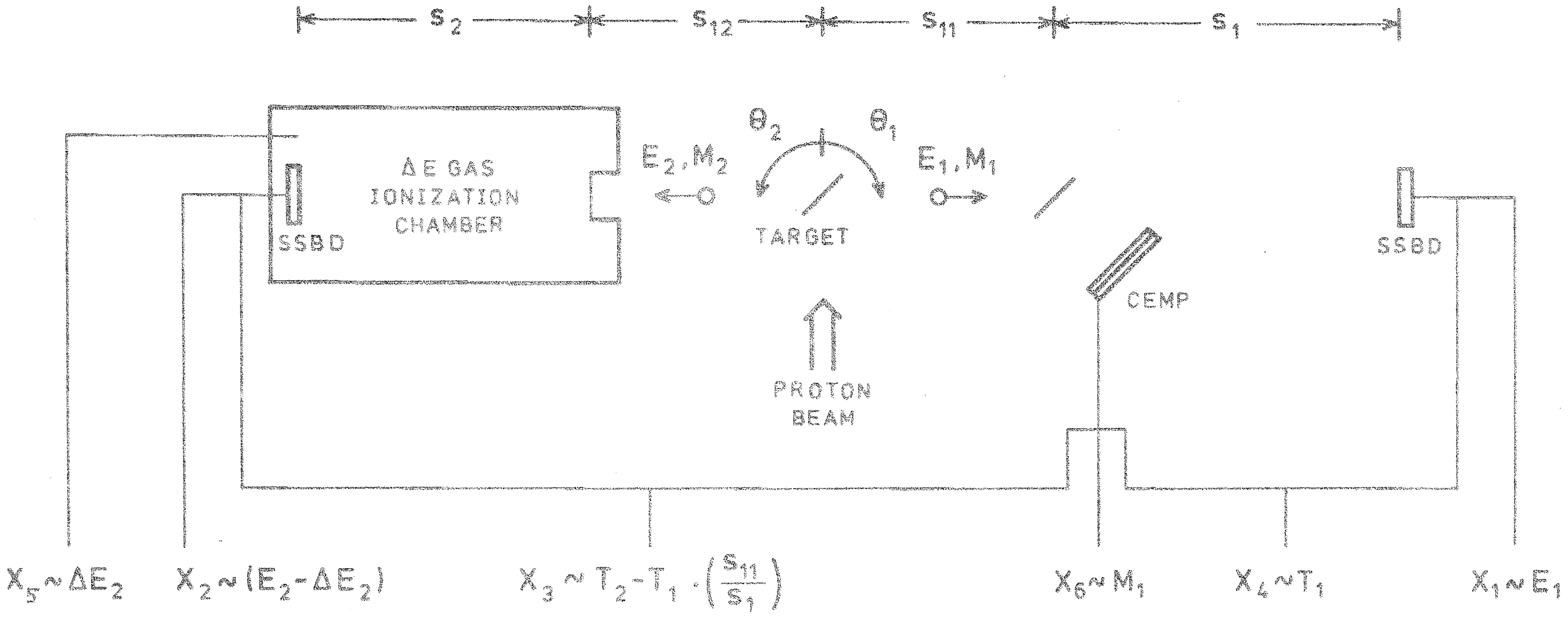
s_2
s_12
s_11
s_1
ΔE GAS IONIZATION CHAMBER
SSBD
E_2, M_2
θ_2
θ_1
TARGET
E_1, M_1
CEMP
SSBD
PROTON BEAM
X_5 ~ ΔE_2
X_2 ~ (E_2 - ΔE_2)
X_3 ~ T_2 - T_1 · (s_11 / s_1)
X_6 ~ M_1
X_4 ~ T_1
X_1 ~ E_1

Fig. 6