Fusion-Fission process for heavy systems
Opportunities with high intensity beams from VECC

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Plan of my talk :

01. The presentation is focused with the low energy end of the VECC super-conducting cyclotron.

02. Scattering chamber, Charged particle detector array, Large area gas detector array, neutron time of flight (TOF) array and 4-Pi multiplicity detector.

03. Fission time scale measurements (for heavy systems) - SHE

04. Fission mass and cross section measurements for heavy systems.

05. Fusion barrier distributions for super-heavy elements.

1. Formation of super heavy nucleus.

2. Two step process : (a) Survive Quasifission and lead to Compact Compound nucleus : (b) CN has to survive fission competition.

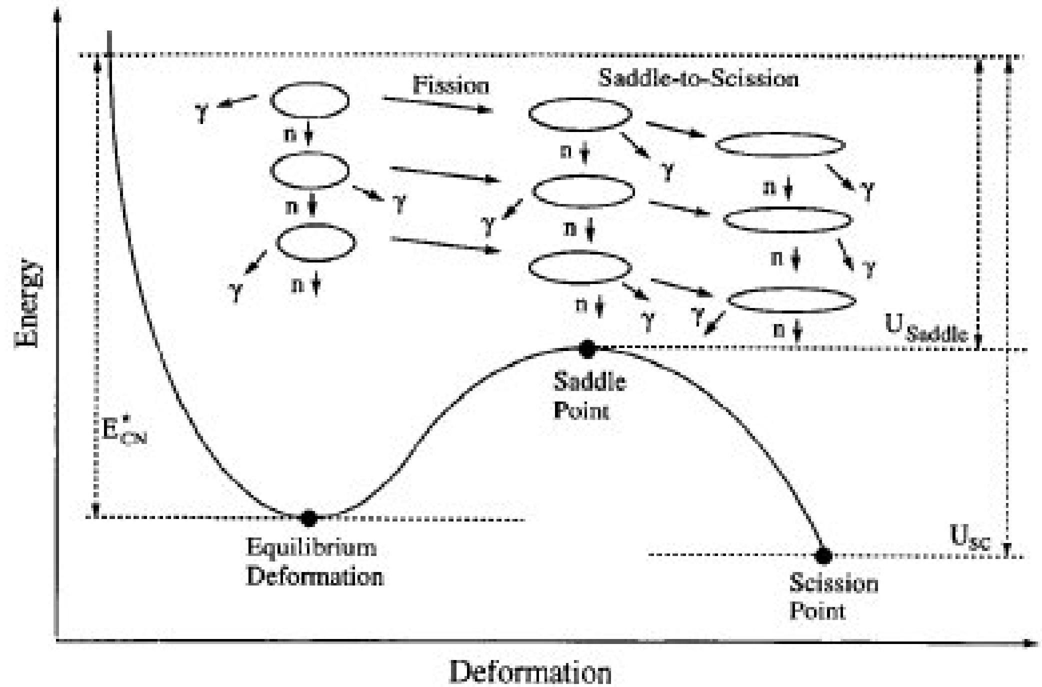
3. CN+NCN Process. NCN process: Fast fission, Quasifission, Pre-eq fission etc. All NCN process combined we call QUASIFISSION.

4. The optimum selection of target and projectile is necessary to maximize the formation probability of super-heavy nuclei.

5. Measurement of fission fragment angular distribution, mass distribution and mass energy co-relation helps in distinguishing NCN processes.

6. To optimize Super-heavy production we have to take care of (a) entrance Channel (b) Shell effect (c) deformation of enetrance channel (d) Neutron rich projectile

7. Time scale measurement can give important information about NCN process.

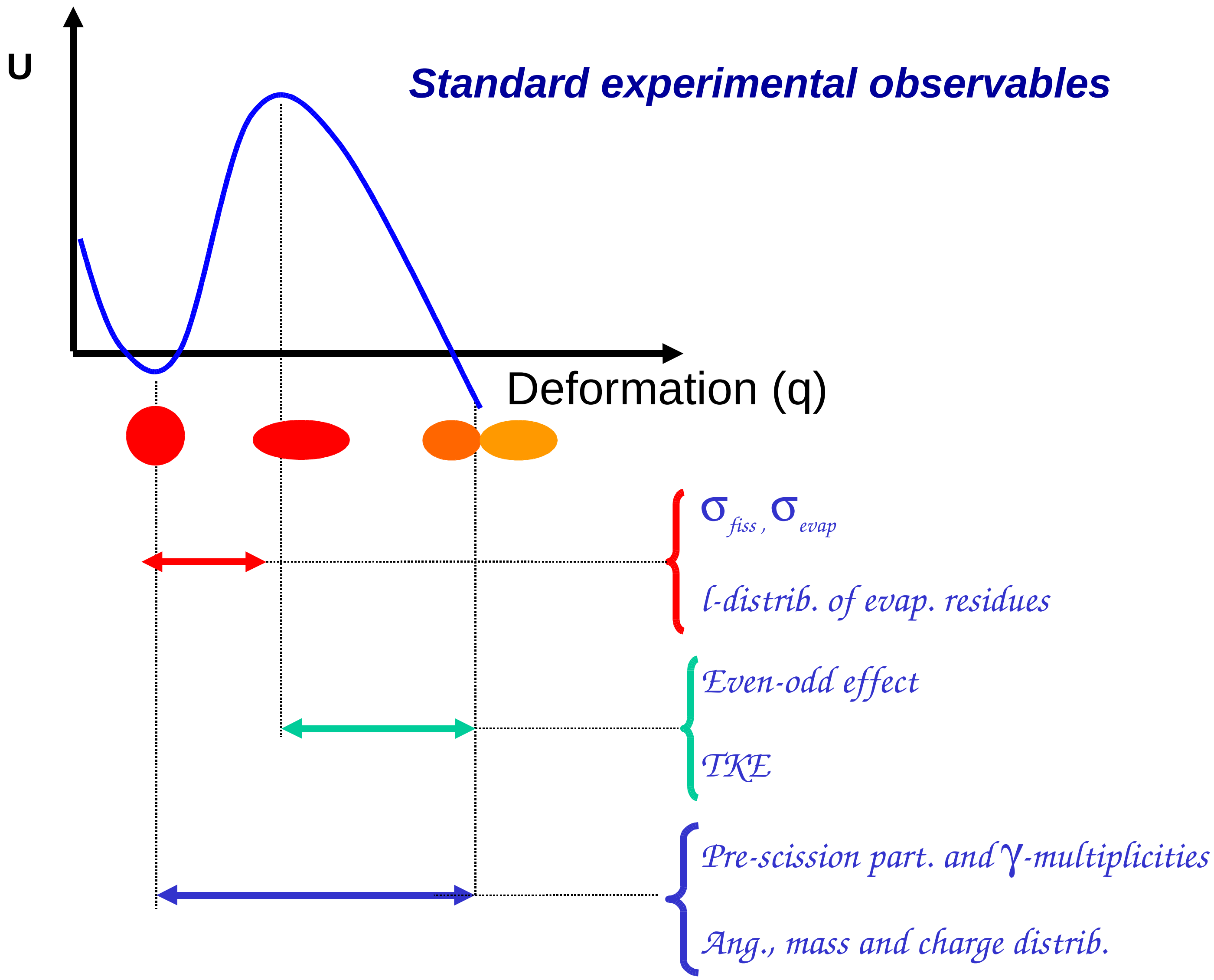


A Statistical Fission Width $\Gamma^{BW} = h \times R^{BW}$

The time for the whole fission process in Bohr-Wheeler approach is simply given by the fission rate and by the dynamical evaluation between saddle and scission points.

What observables we get in Fission Process?

Standard experimental observables



Fission time has two components:

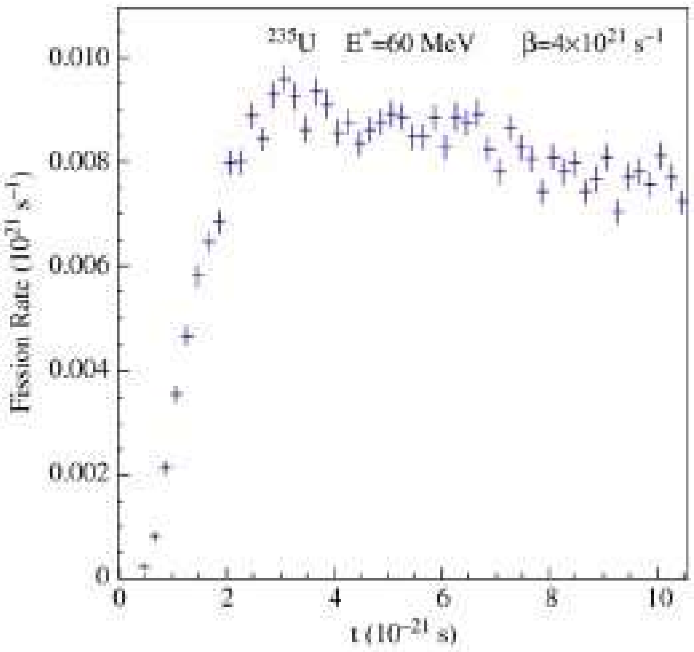
1. Time needed by the nucleus to pass over the saddle point.
2. The deformation time from the saddle up to the scission point.

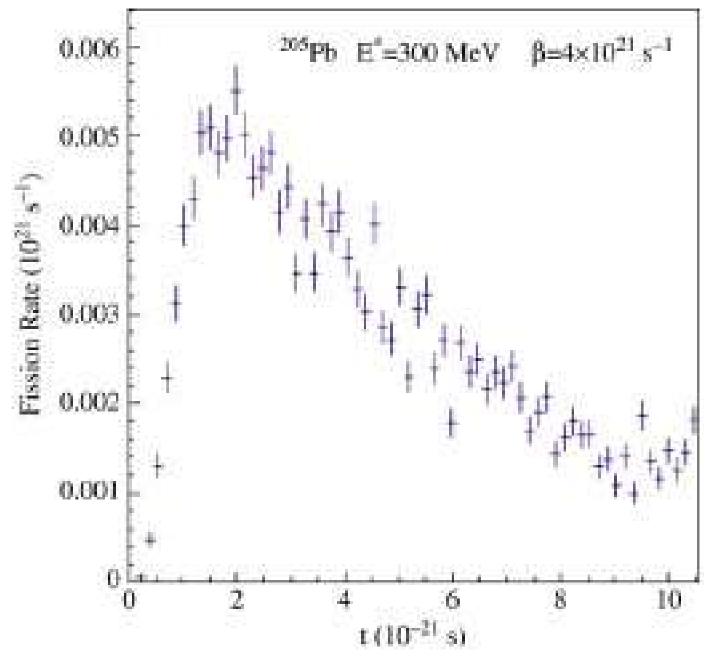
(a) Transient time:
Diffusion from the equilibrium configuration to the saddle point takes over a finite transition time due to nuclear viscosity effects and therefore the fission width rises to a final quasistationary value over a finite time.

(b) Passage over the saddle point (Statistical Time):
The time needed to pass the saddle point is much longer on average than the transient time. Very few nuclei will survive against fission at much longer time.

(c) The saddle to scission time is detetmined through the models reproducing observavbles sensitive to the whole process. Due to the large deformation reached at the scision point the level density, binding energies and kinetic energy of the fragments, emitted particles plays an important role.

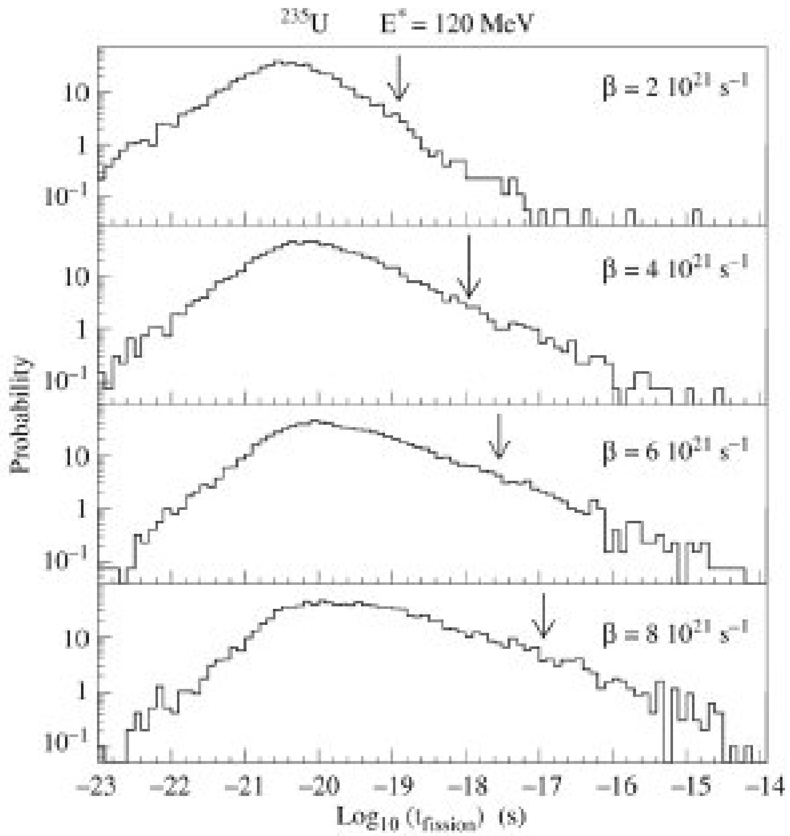
Fission Time Scale Measurements.......



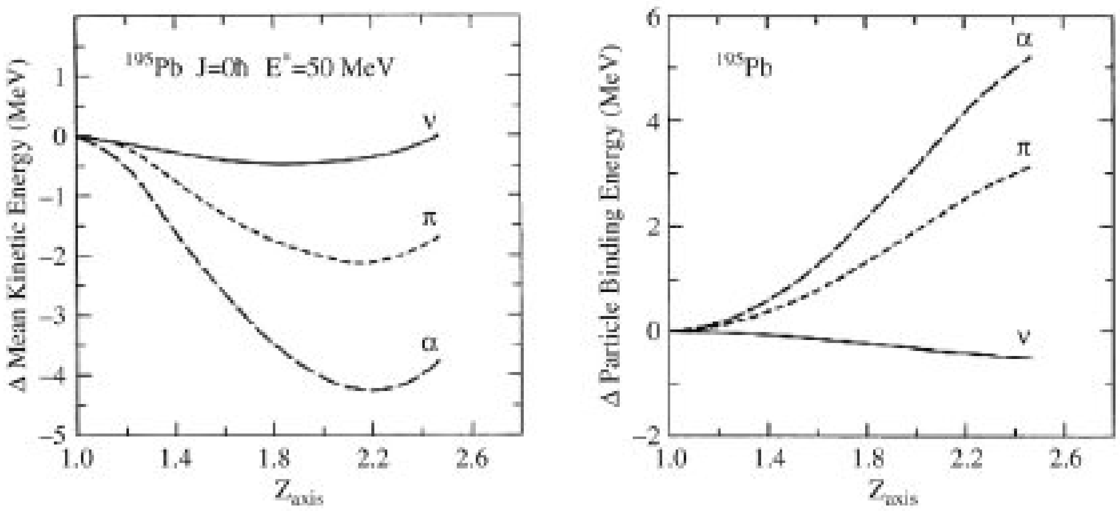


Time Evoluation for fission rates by CDSM code: Transient Time

Fission Time Scale Measurements.......



Fission time distributions (statistical time) for different friction coefficient

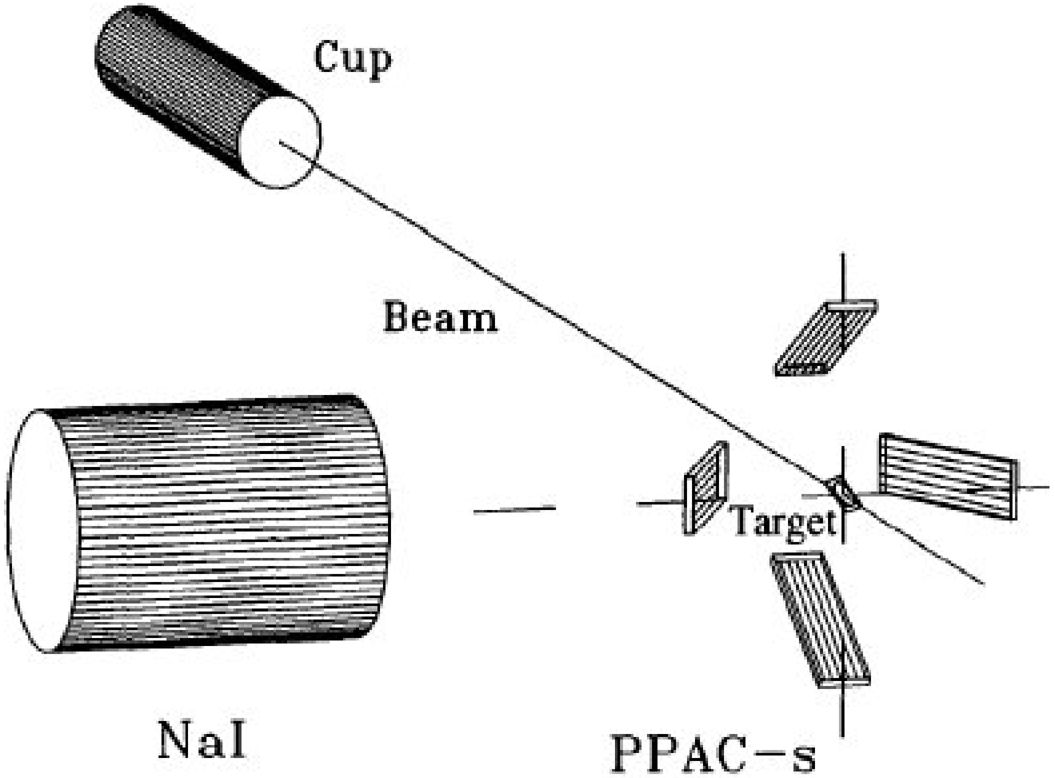


Change in the mean kinetic energy and binding energy for neutron, proton and alpha particle as a function of elongation Z axis along the symmetry axis

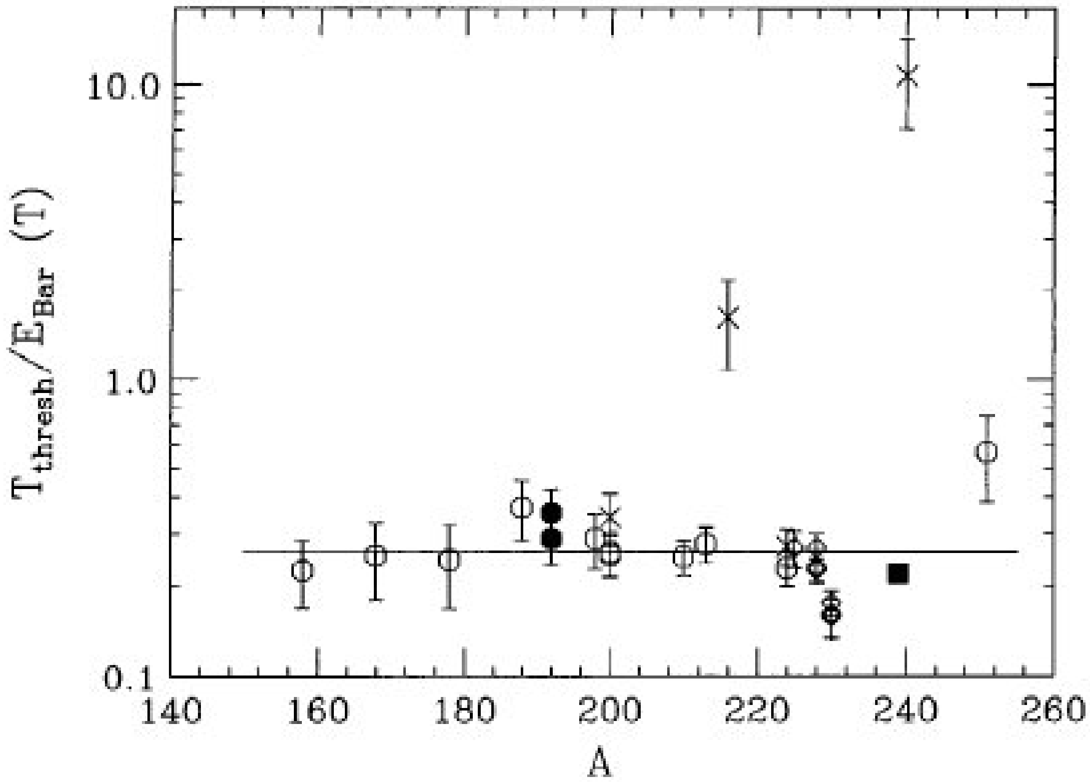
Lestone et al.

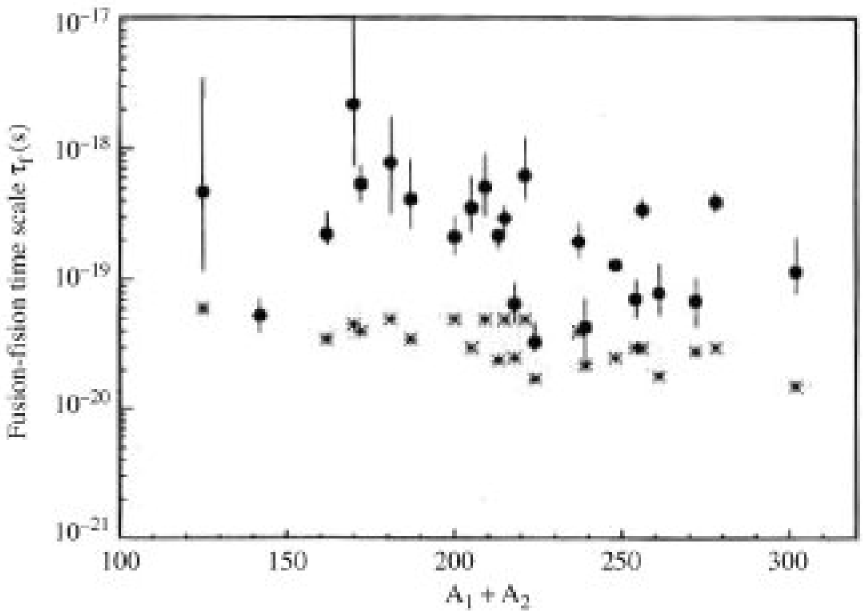
Pre-scission neutron multiplicity and GDR gamma Rays Measurements:

Early methods for fision time scale measurements: Neutrons are detected in coincidence with fission fragments. Neutron spectrum are fitted with three moving source fit with few parameters.

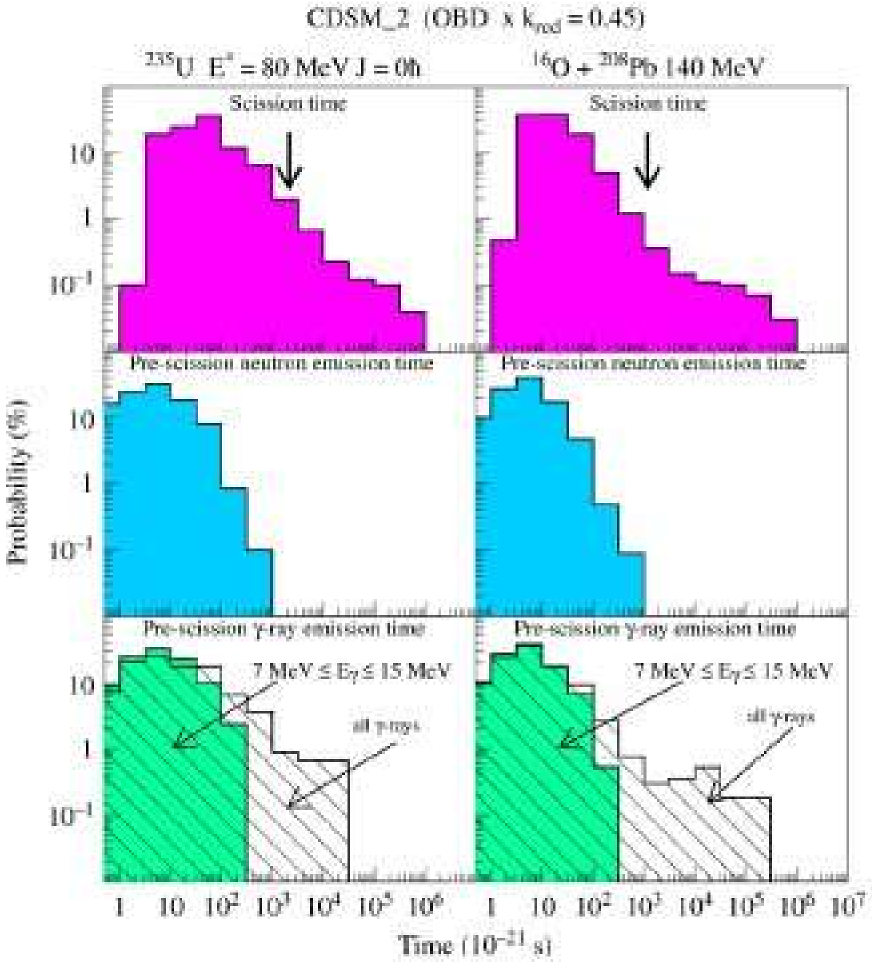


Onset of Dissipation





Comparision of the average fusion-fission times from pre-scission neutron multiplicities with (full points) or without (asterisks) dynamical effect.



Distribution of scission times (upper panel), neutrons emmited prior to scission (middle panel) and GDR- gamma-rays emitted prior to scission (lower panel)

Blocking Technique: Direct Technique

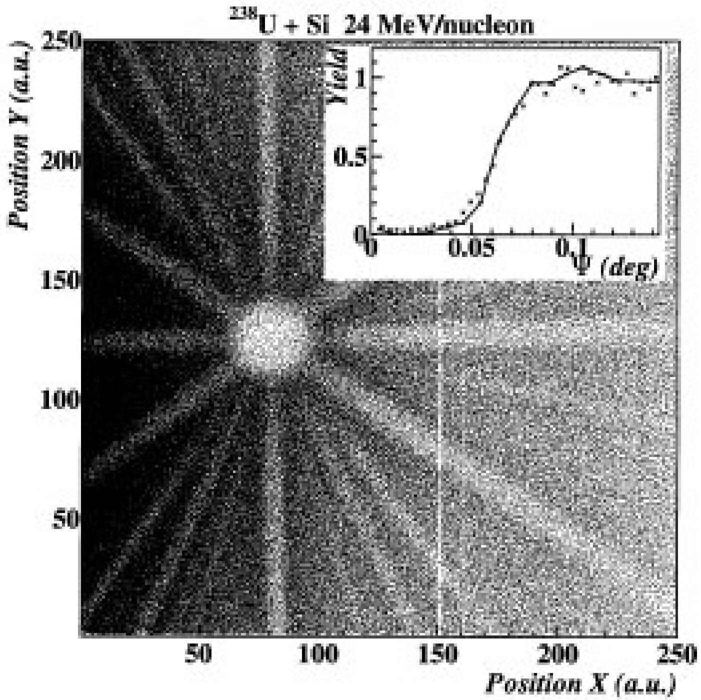
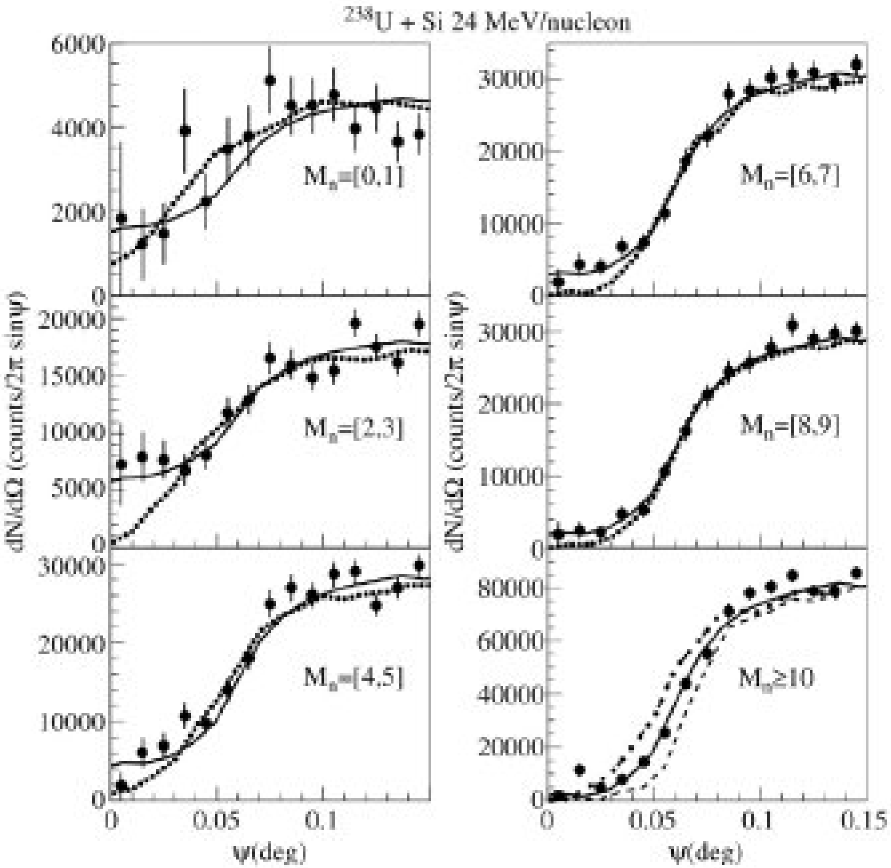
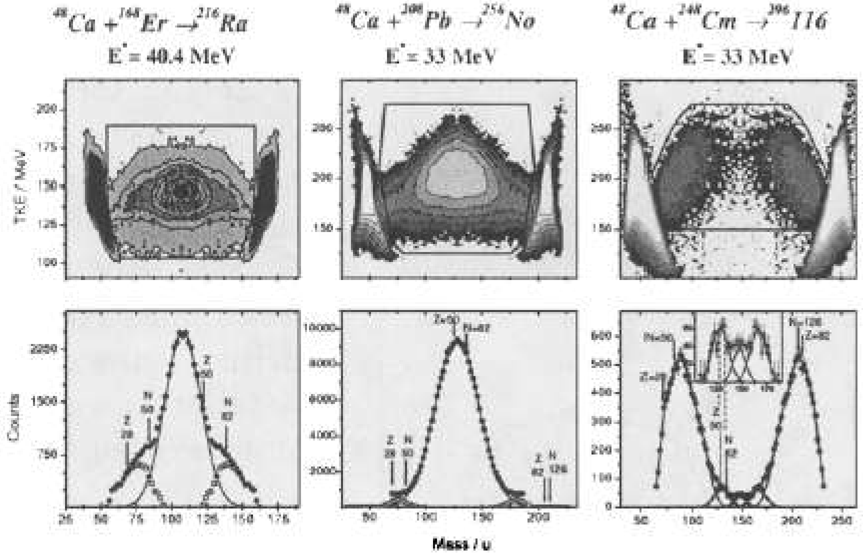


FIG. 1. Two-dimensional blocking pattern for elastically scattered nuclei. In the inset the one-dimensional blocking pattern integrated on the azimuthal angles from the center of the axial dip is presented. The full line is the result of a Monte Carlo simulation.



Blocking dips for fission fragments of uranium like nuclei. The dips are presented for different bins of measured total neutron multiplicity

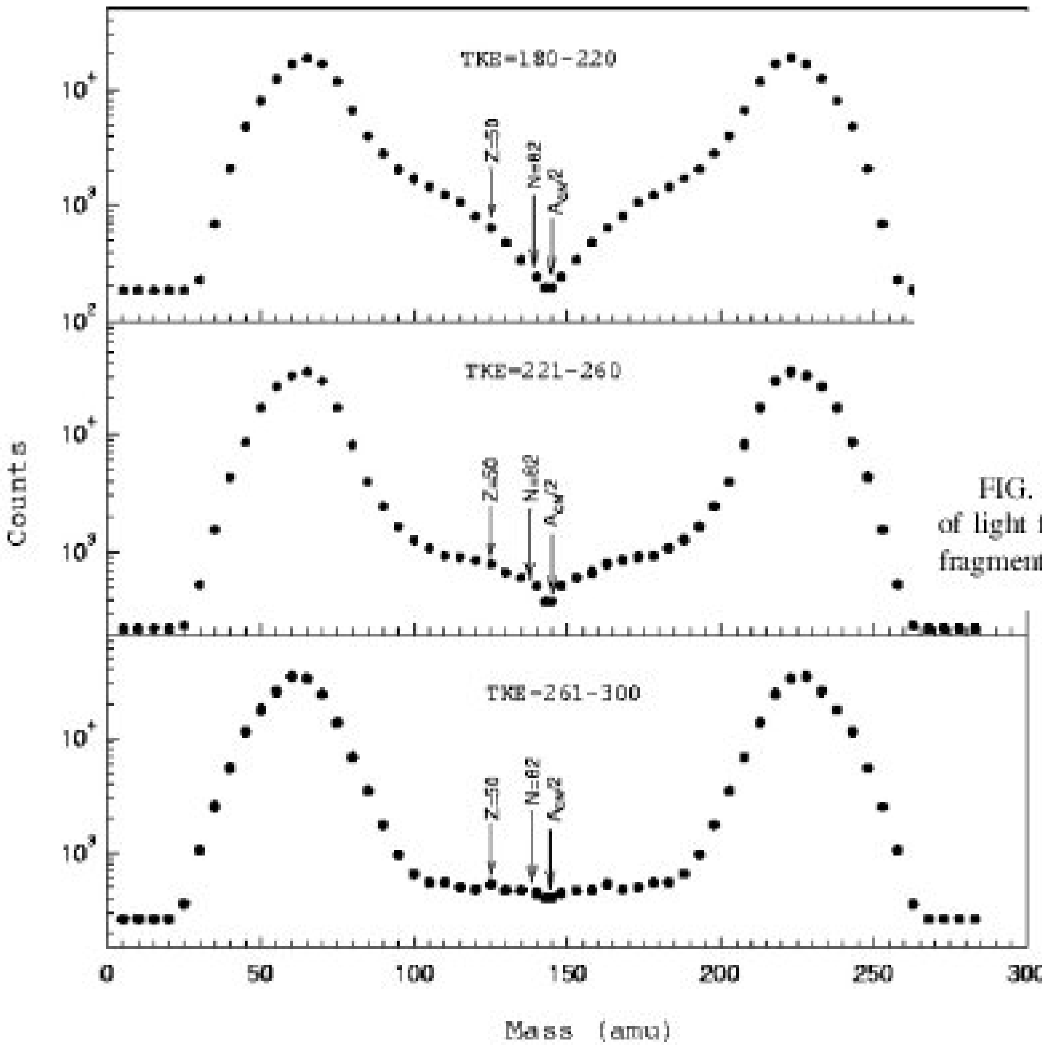
A rather short sensitivity limit 3 * 10-19 s was achived.



Two- dimensional matrices TKE-Mass (top Panels) and mass yields (bottom panels) of fission fragments of ^{216}Ra, ^{256}No, and Z=116 nuclei produced in the ^{48}Ca induced reaction.

Reactions	E_{lab} (MeV)	E^* (MeV)	$M_n^{A/2\pm20}$	M_n^{QF}
$^{48}Ca+^{208}Pb$	230	33	5.2 ± 0.7	3.1 ± 0.5
$^{48}Ca+^{238}U$	232	33	8.4 ± 1.2	4.9 ± 0.9
$^{48}Ca+^{244}Pu$	233	32	9.0 ± 1.2	4.6 ± 0.9
$^{48}Ca+^{248}Cm$	245	37	9.9 ± 1.4	5.6 ± 1.0

The measured value of neutrons in ^{48}Ca reaction.



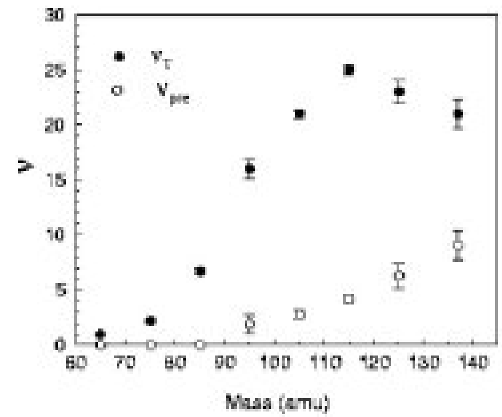


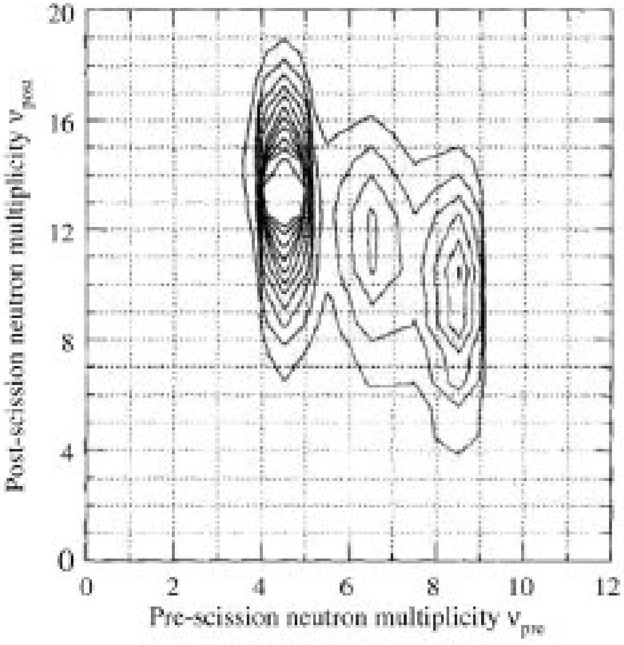
FIG. 6. Total and pre-scission neutron multiplicity as a function of light fragment mass A_{FF1} deduced from the fits to the measured fragment-neutron correlations.

Mass distribution for different TKE bins

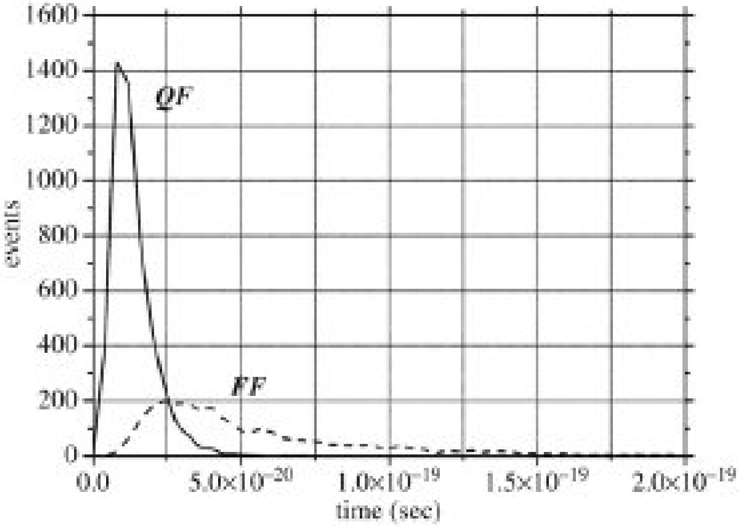
$^{56}Fe+^{232}Th$ Z=116

Time scale measured for symmetric component: much larger than Quasifission

DAEMON EXPERIMENT: Neutron Multiplicity distribution for $^{58}Ni+^{208}Pb$



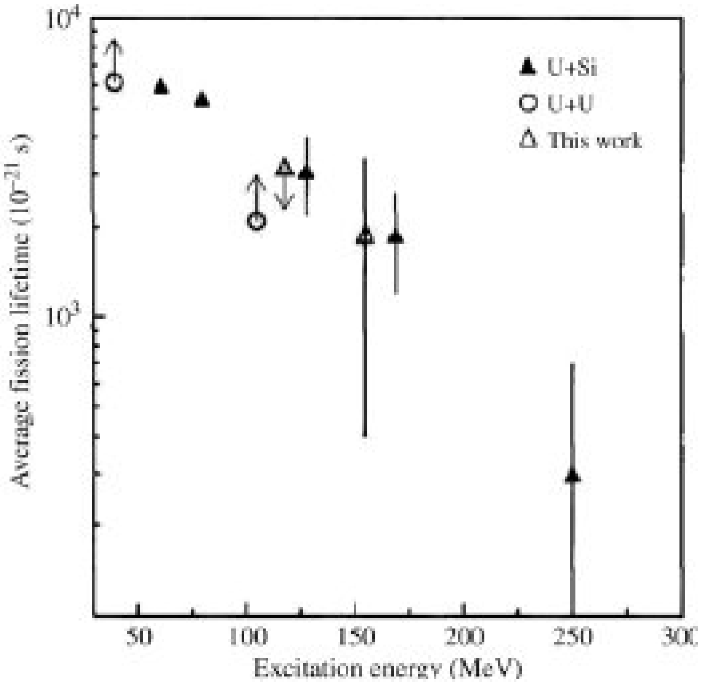
Back tracking procedure



Dynamical simulation

Atomic clock, Filling of K Vacancies

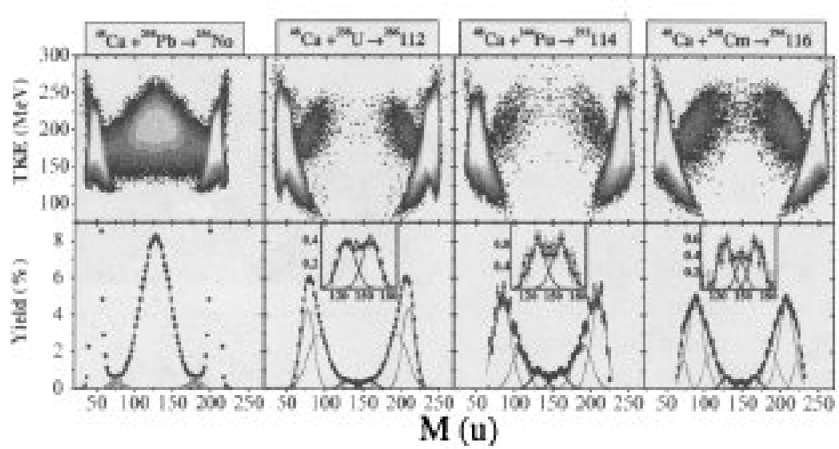
Fission fragments were measured in coincidence by gas detectors and X-rays by Germenium Detectors



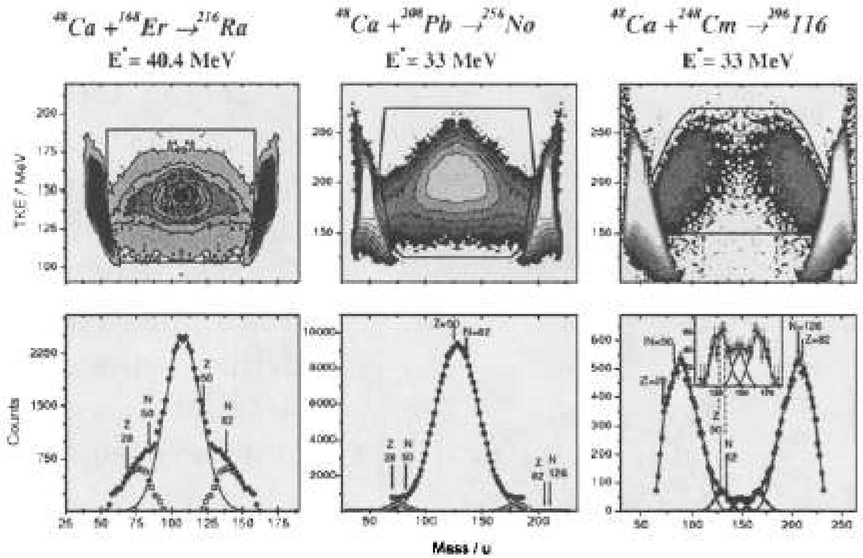
^{20}Ne(30MeV/A)+^{232}Th

This experiment could only estimate upper limits for the average scission times of Uranium nuclei ($T_{Scission}$ = 1.9 * 10^{-18}S)

A big oppertunities exists at VECC Super-conducting accelerator for such expts.

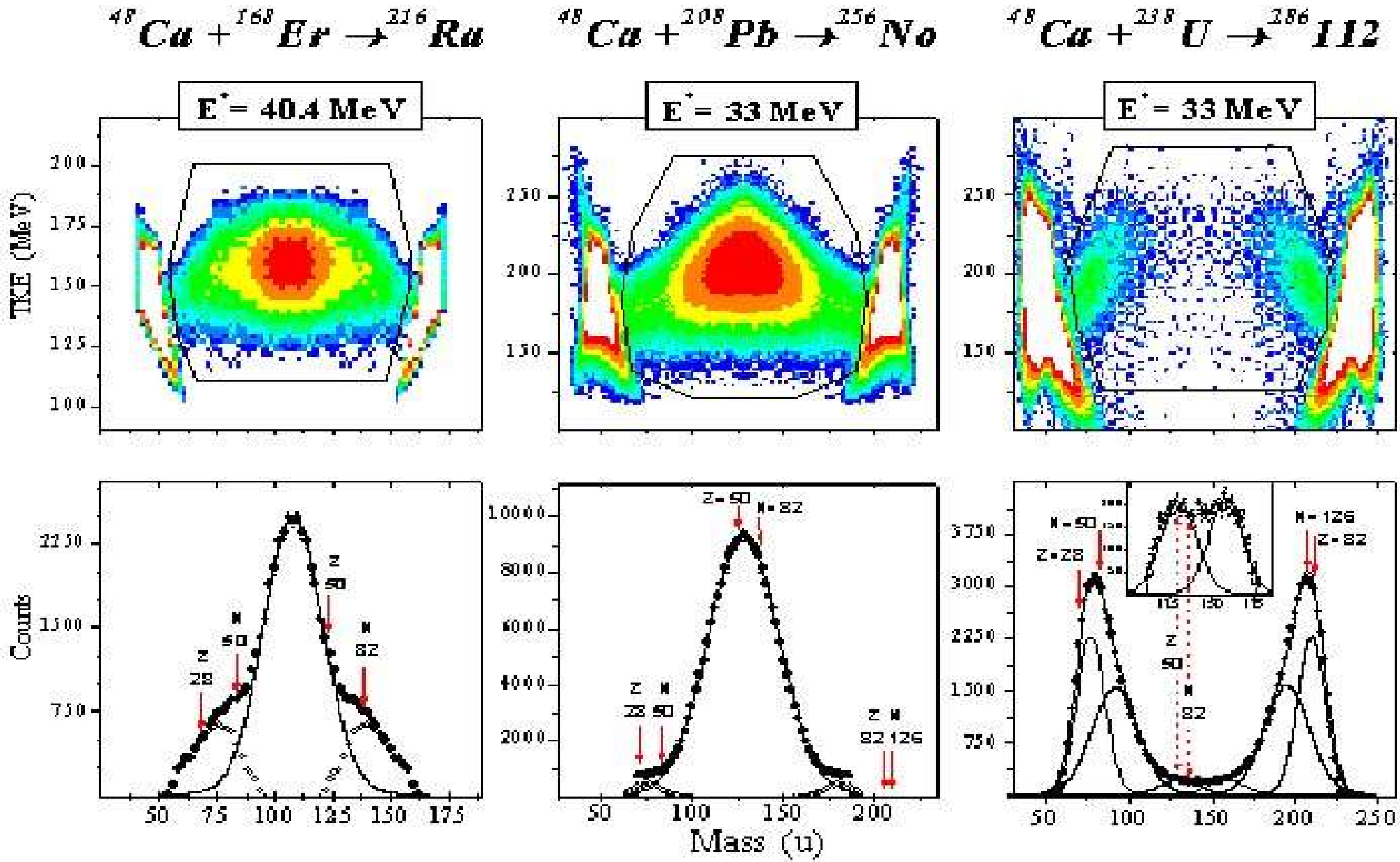


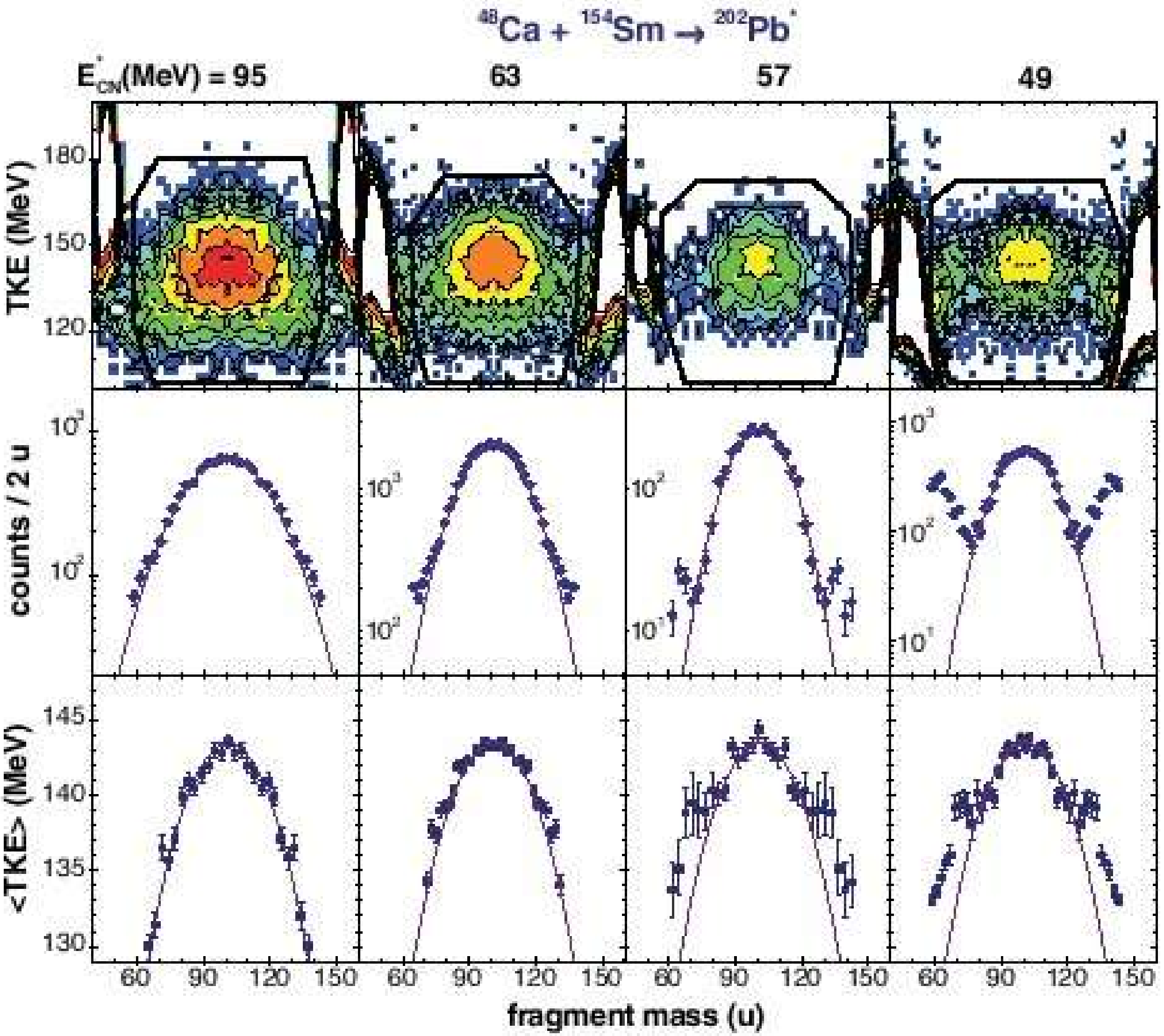
Two dimensional matrices TKE-Mass (Top panels) and mass yields (bottom pannels) of fission fragments of ^{256}No, $^{286}{}_{122}$, $^{292}{}_{114}$ and $^{296}{}_{116}$ nuclei produced in reactions with ^{48}Ca at the excitation energy E^*=33MeV

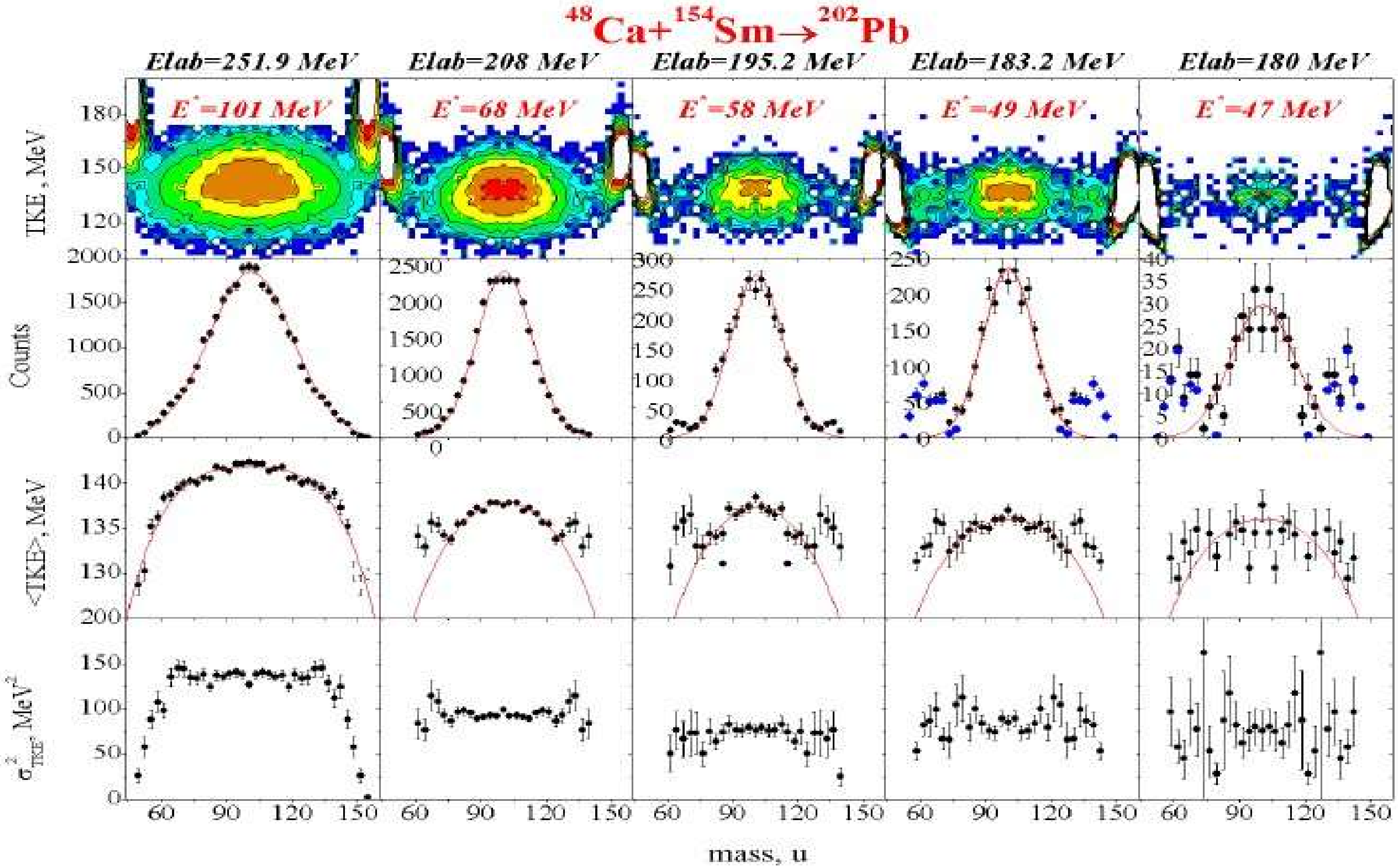


Two- dimensional matrices TKE-Mass (top Panels) and mass yields (bottom panels) of fission fragments of ^{216}Ra, ^{256}No, and Z=116 nuclei produced in the ^{48}Ca induced reaction.

Shell effect

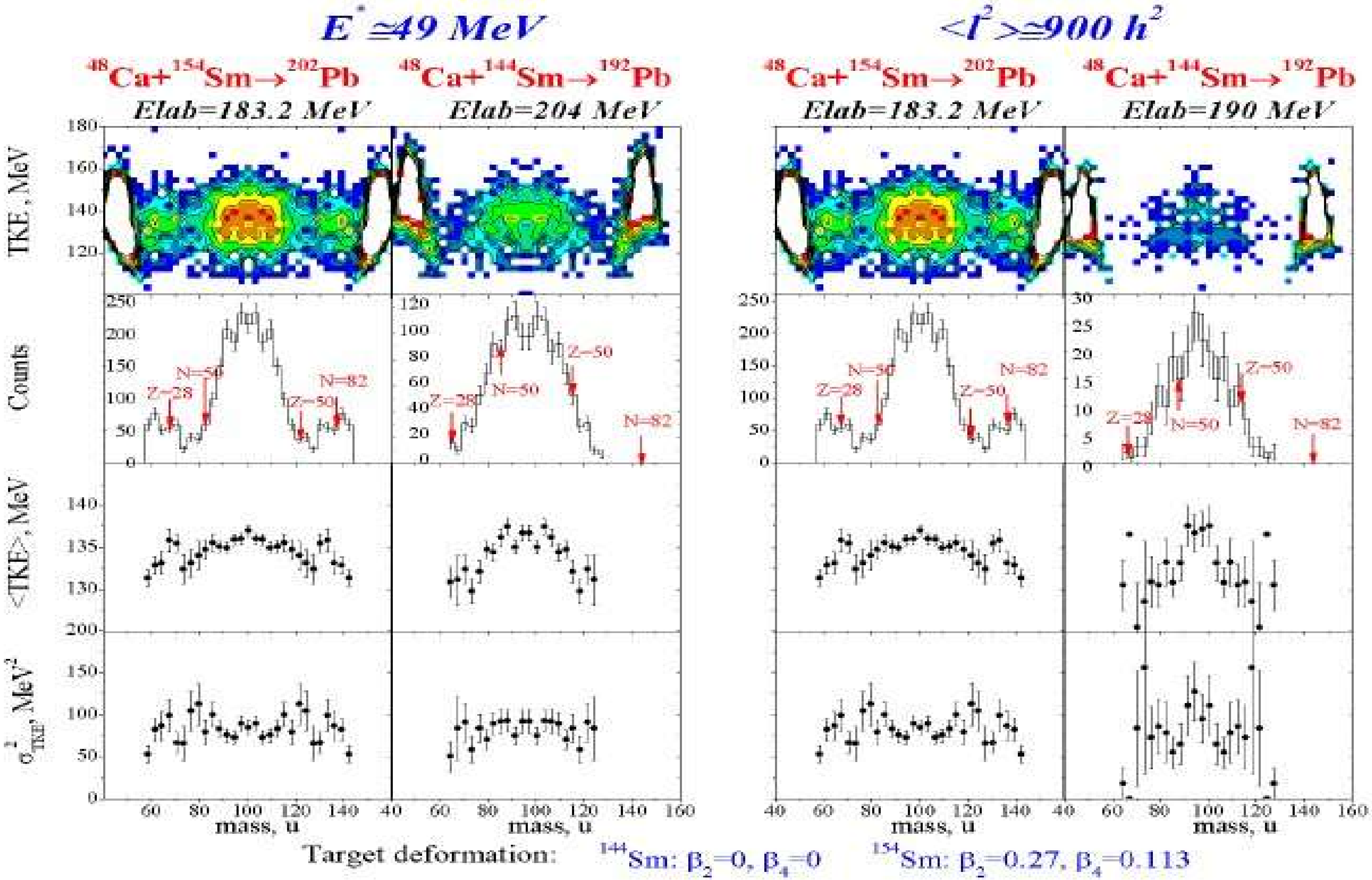



48Ca + 154Sm → 202Pb*
E*CN(MeV) = 95
63
57
49
TKE (MeV)
180
150
120
counts / 2 u
<TKE> (MeV)
145
140
135
130
60 90 120 150
fragment mass (u)



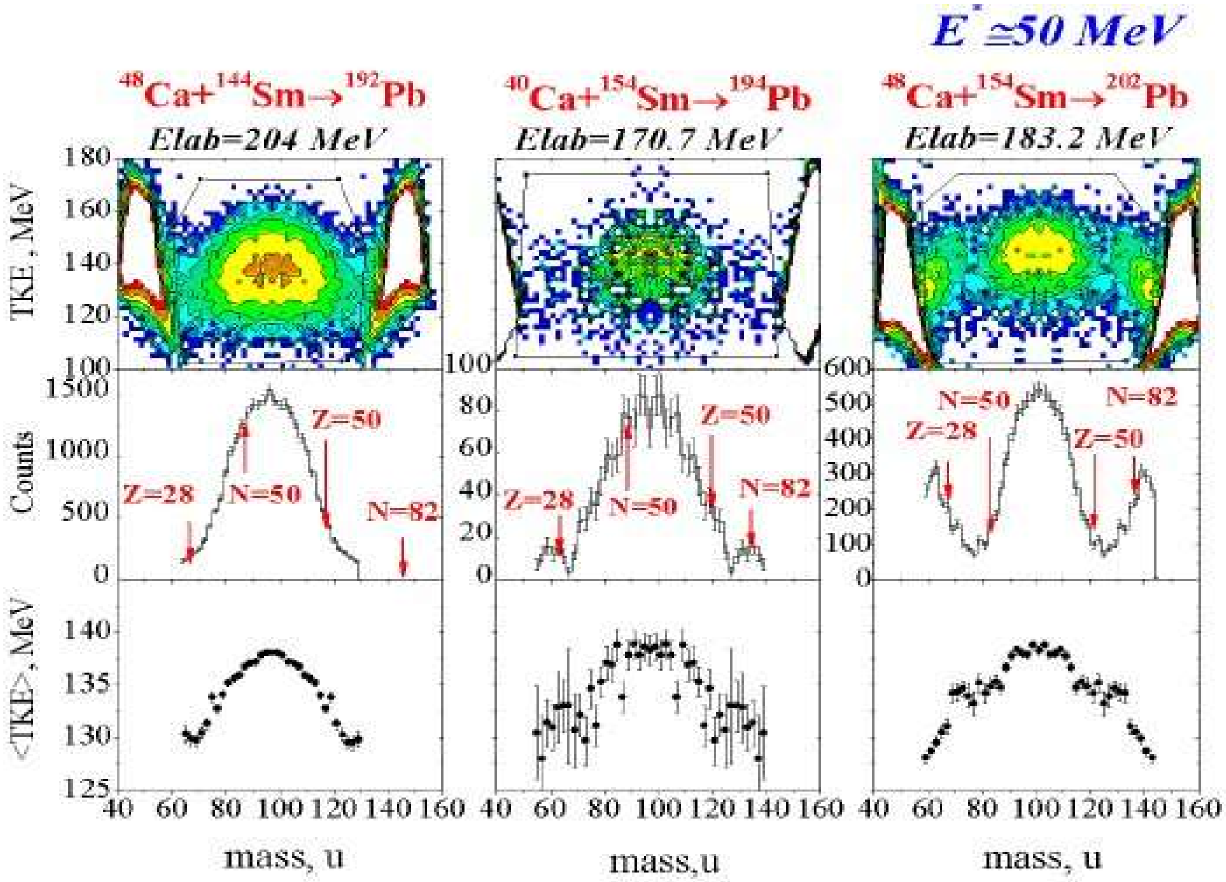
The relative yield of the asymmetric component increases with the decreasing E*

The effect of target deformation on quasi-fission



No evidence of asymmetric fission/QF in ^{48}Ca+ ^{144}Sm

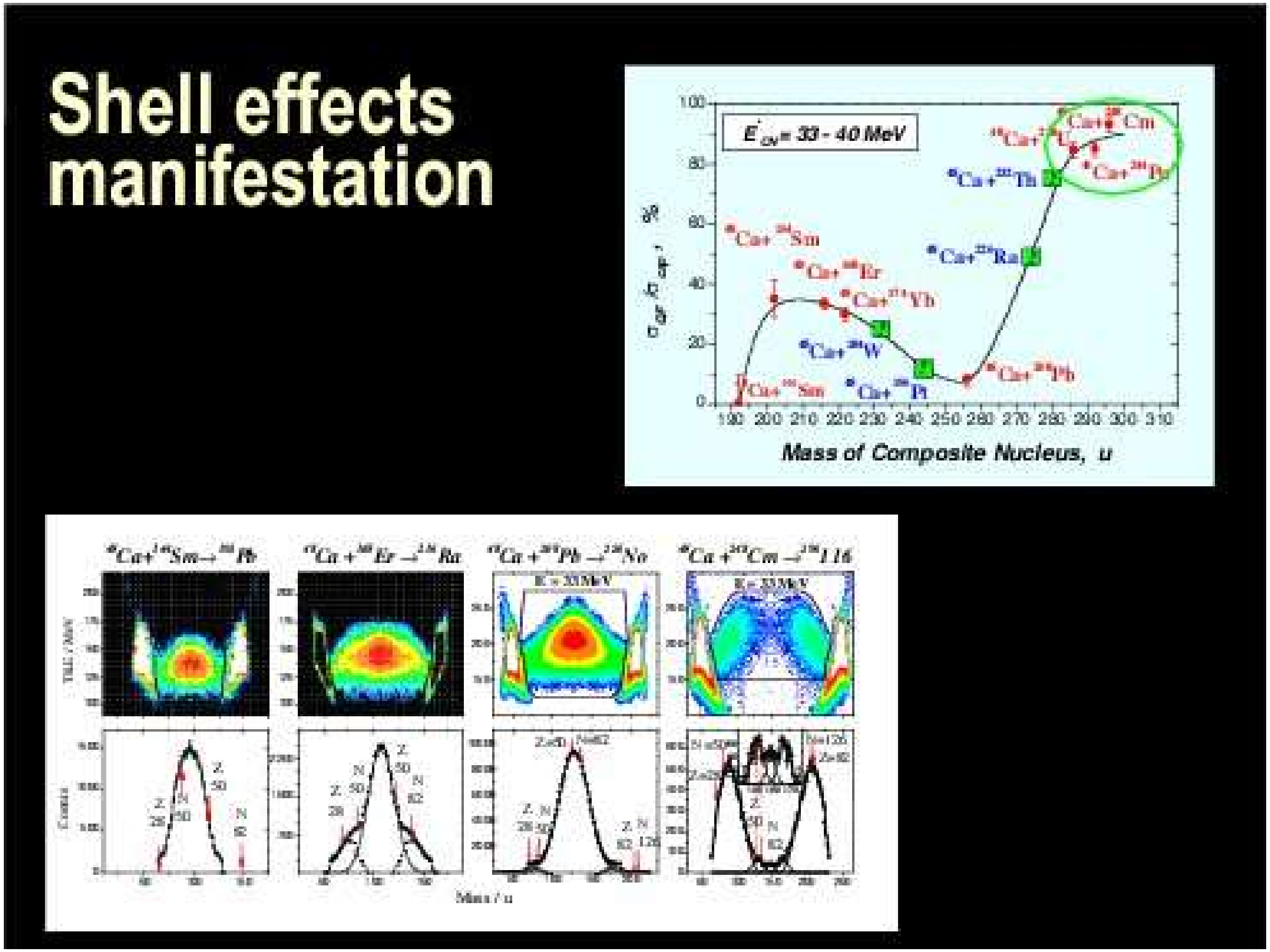
The effect of target deformation on quasi-fission



Target deformation: ^{144}Sm: $\beta_2=0$, $\beta_4=0$ ^{154}Sm: $\beta_2=0.27$, $\beta_4=0.113$

The target deformation favours the onset of asymmetric fission/QF

M.G. Itkis : NN-2006 Conference (RIO, BRAZIL)

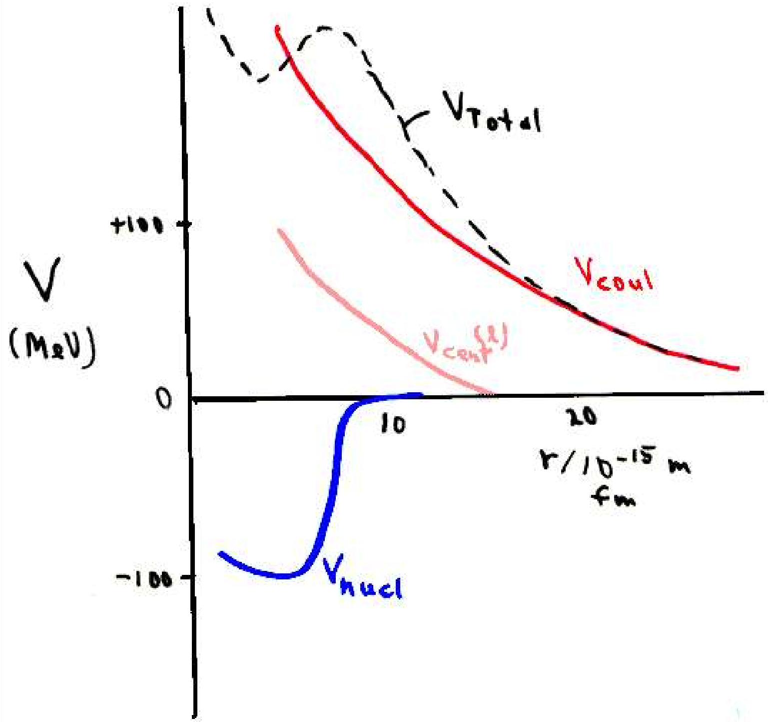


- Mass asymmetry: more symmetric systems lead to a large fusion hindrance also in a relatively light CN such as $^{202}Pb^{*}$ for high E* even at the low angular momenta populating ERs

- Shell effects: seem to play a role in the onset of QF

- Target deformation: deformed targets lead to wide barrier distributions, but the target deformation favours the onset of QF

NUCLEAR POTENTIAL



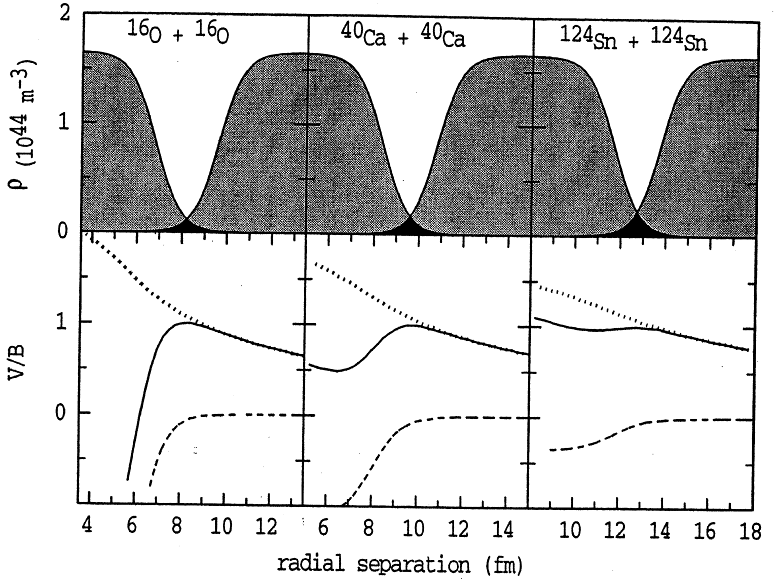


Figure 1 *Lower panels*: The Coulomb (*dotted lines*), the nuclear (*dashed lines*), and the total interaction potentials (*solid lines*), as a ratio to the fusion barrier energy B, for systems with charge products $Z_1Z_2 = 64$, 400, and 2500. The total potential is shown for orbital angular momentum $l = 0$ only. *Upper panels*: The corresponding nucleon density distributions at the barrier.

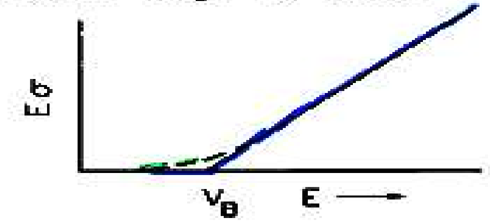
Why $\frac{d^2E\sigma}{dE^2}$ give barrier distribution ?

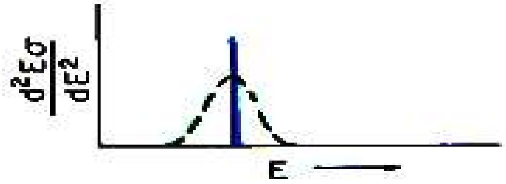
Consider single classical barrier in large $-\ell$ limit:

$\sigma = \pi R^2 (1 - V_B/E)$

$E\sigma = \pi R^2 (E - V_B)$ —

– – – Quantal penetration/ reflection



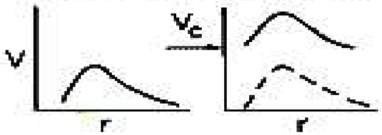


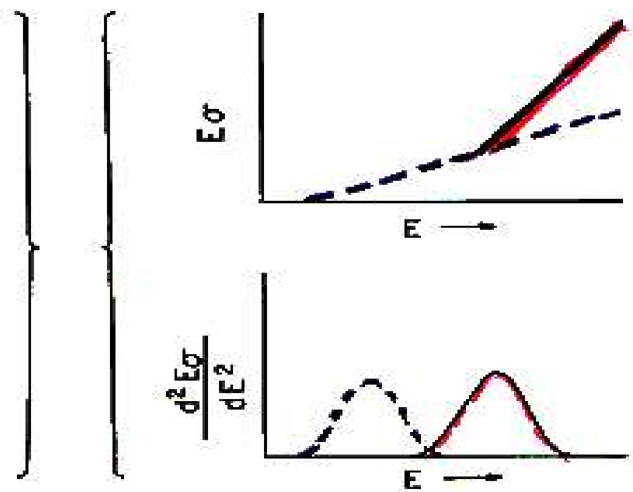
Now consider two barriers

Static Deformation

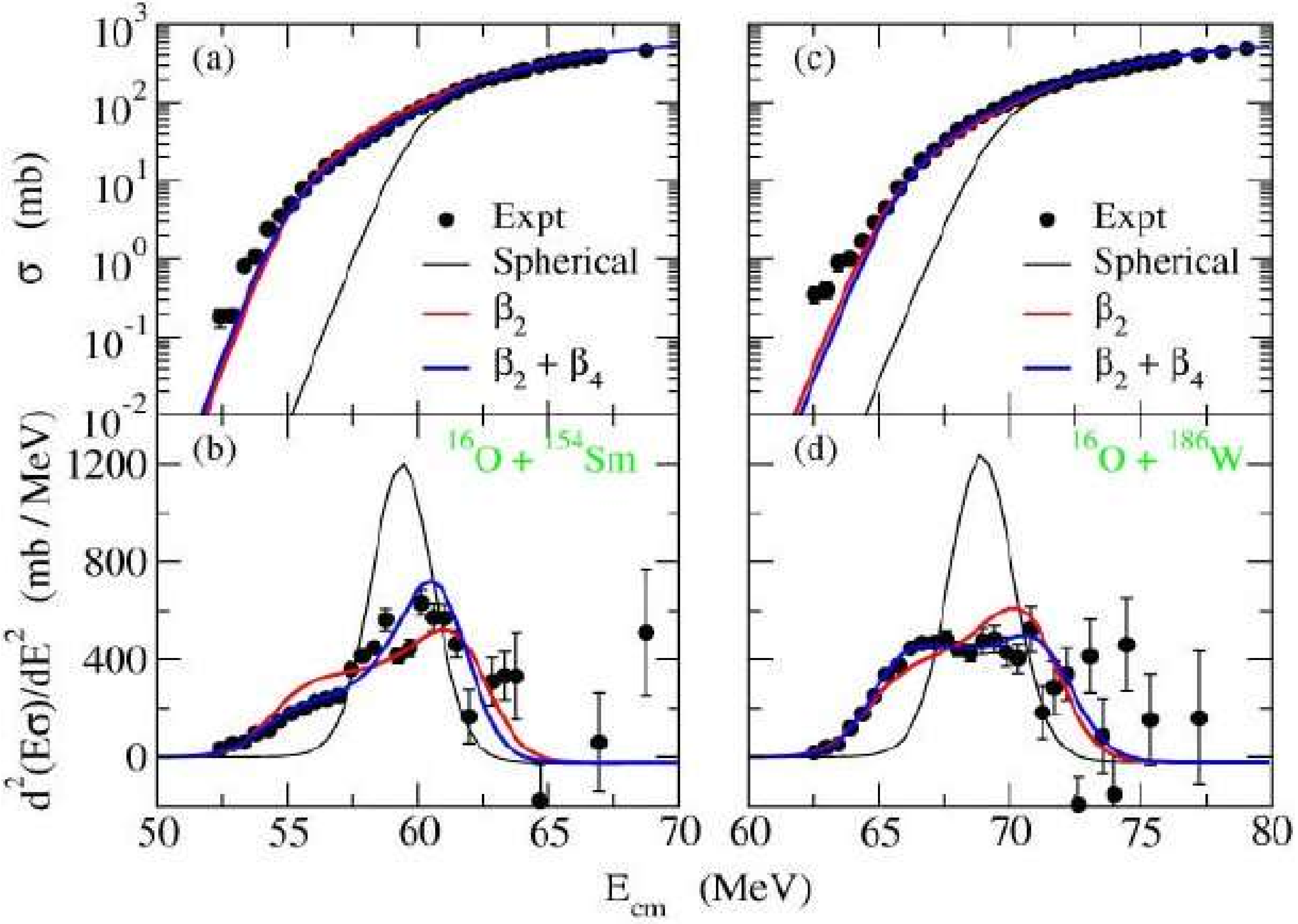
or

Coupling to internal degrees of freedom





Barrier Distributions



The Barrier position in fusion reaction: Is a key factor in the synthesis of Super-heavy nucleus.

C.B Distribution is also an important quantity to know the detail of the interaction potential in nucleus-nucleus collision

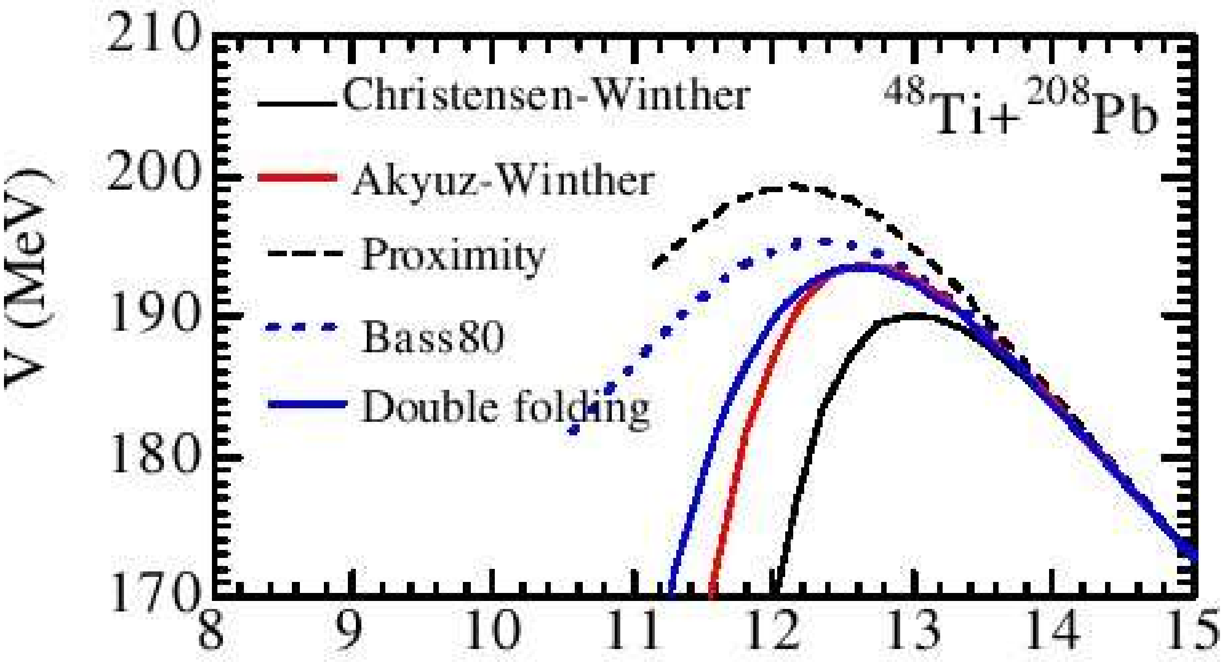
Several Methods and several nucleus-nucleus potentials have been proposed.

Bass barrier (Bass potential) has been frequently used to estimate the coulomb barrier height.

IS BASS POTENTIAL IS A CORRECT ONE ??????

Test Case $^{48}Ti+^{208}Pb$:

Theres is a need to experimentally determine barrier positions



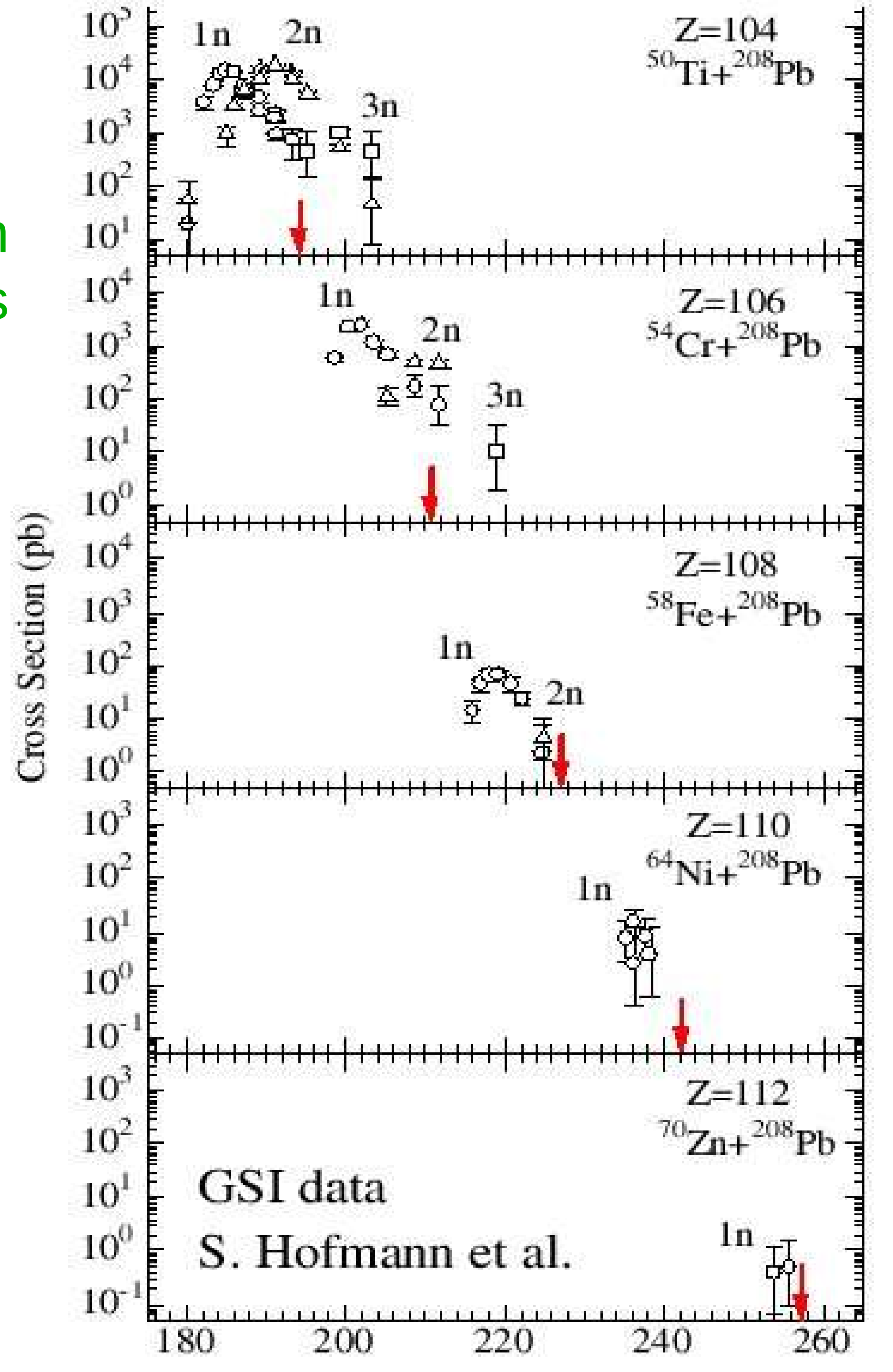
Why Barrier for SHE ??

The cross sections maximum for 1n channel for cold fusion reactions is located below the bass barrier.

How broadly does the fusion barrier distribute below the bass barrier.

One can get informations about nucleus- nucleus potential and inelastic couplings.

IT WILL HELP IN CALCULATING THE BOMBARDING ENERGY



Peculiarities of different systems:

Light Systems:

σ_{cap} ----> σ_{fus} ----> $\sigma_{ER} \equiv \sigma_{recoil}$

Ex: ^{40}Ca+^{90}Zr: Measure Recoils near zero degrees;RMS, HIRA, FMA, Electrostatic defelector, Velocity filter

Medium Systems:

σ_{cap} ----> σ_{fus} ----> $\sigma_{ER}+\sigma_{FF}$

Ex: ^{90}Zr+^{90}Zr:Measure recoils and FF and reconstruct σ_{cap} using statistical model code (HIVAP) : Fission fragment Detectors+ Zero degree devices, alpha counting etc.

Heavy Syetems:

σ_{cap} --->σ_{fus} ---->σ_{FF}

Ex: ^{16}O+^{238}U : Measure all Fission fragments...

Super Heavy: σ_{cap} ----> $\sigma_{Fus}+\sigma_{QF}+\sigma_{DI}$ ----> $\sigma_{ER}+\sigma_{QF}+\sigma_{FF}+\sigma_{DI}$

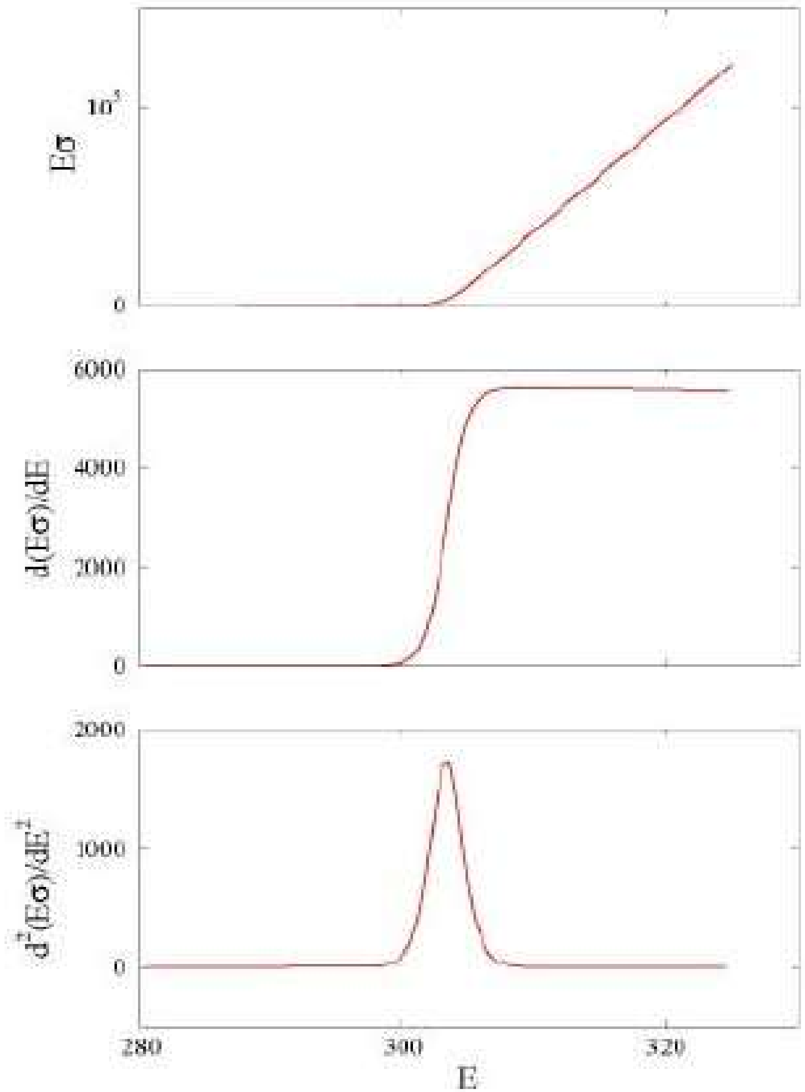
$\sigma_{ER}\approx 0$ for super heavy systems. Measure whatever you like (at all angles and at all energies of Interest)... Can you measure ?? Better to go Home..........

Or Come back after dinner and measure the reflected wave

σ_{QE}

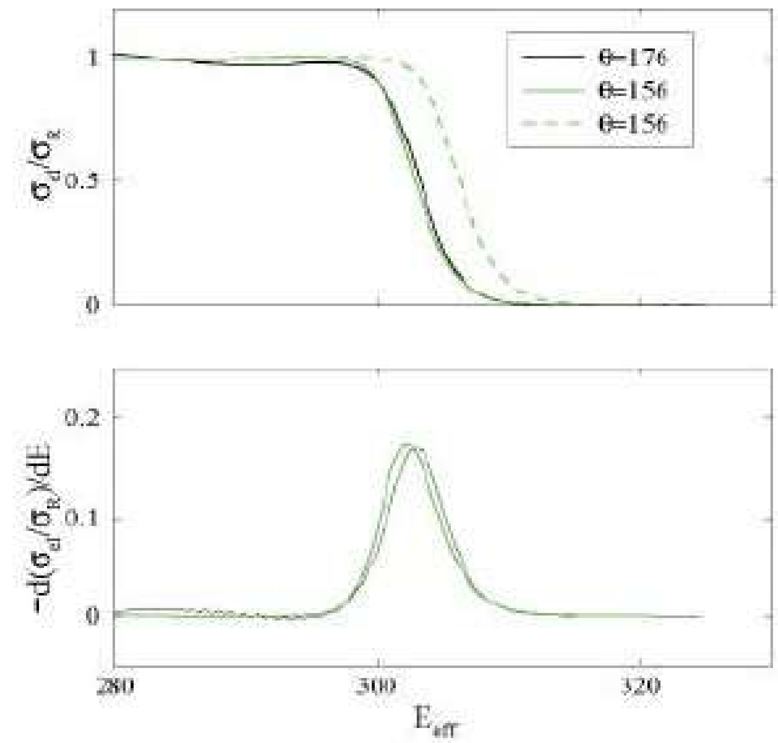
Some what related to transmitted wave

Fusion: $E\sigma=\pi R^2(E-B)$



QE: Everything not crossing the barrier

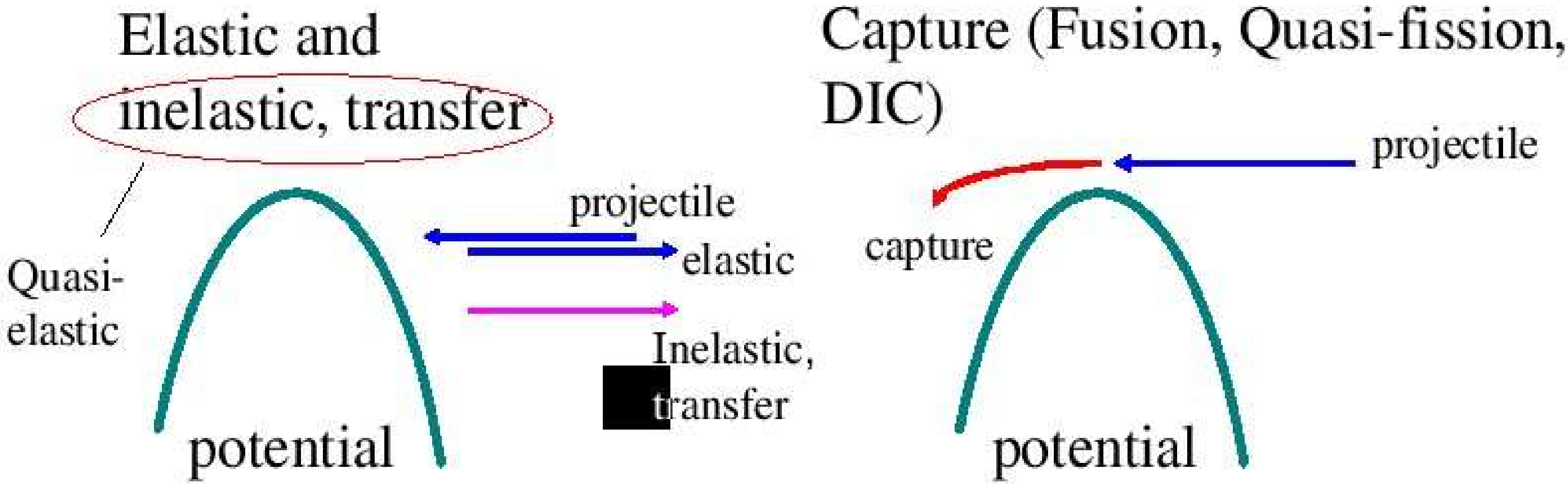
$E_{eff}=2E/(1+\text{cosec}(\theta/2))$



Barrier distribution is obtained by first derivative of cross sections for elastic and quasi-elastic events at back ward angles.

M.V. Andres et al. , Phys. Lett. 202B, 292 (1988).

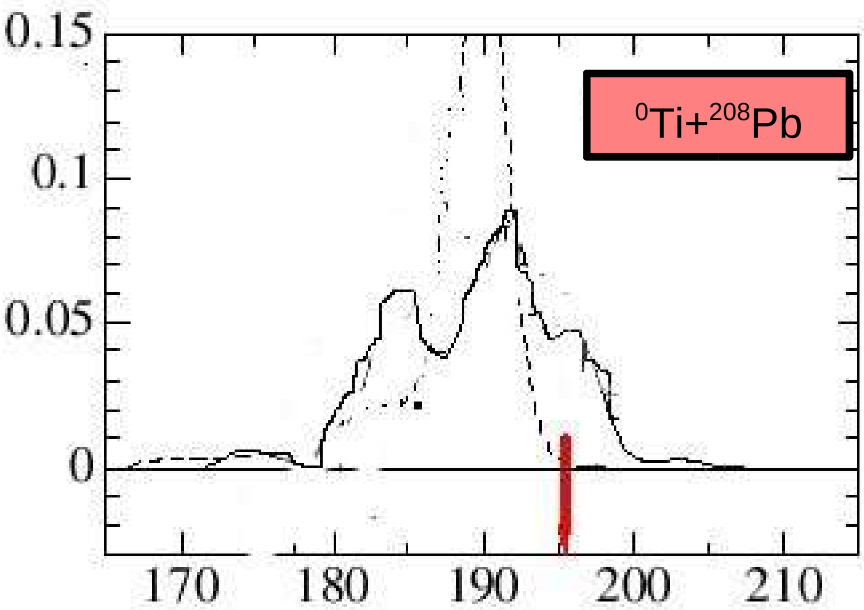
K. Hagino & N. Rowley : Phys. Rev C 69 054610 (2004).



180° back-scattering cross sections ⇨ sensitive to the angular momentum zero ($l = 0$) potential

This method is simple. For heavy system, fusion-fission, quasi-fission and deep-inelastic processes come into play.

Coupled Channel Calculation from scattering



^{208}Pb : $3^{-} \times 2$phonons

Projectiles: $2^{+} \times 1$phonon

Dashed lines: no-coupling,

Real part: a_0=0.69 fm, r_0=1.18 fm, V_0 : adjusted.

Imaginary part: a_w=0.4 fm, r_w=1.0 fm, V_w=30 MeV

r_c=1.1 fm

With the availability of the super conducting cyclotron with High Intensity beams a number of interesting target projectile combinations is possible (with Neutron rfich projectile like Ni, Cr, Kr etc..)

efforts for nImmediateew elements:

$^{86}Kr_{36}$+$^{208}Pb_{82}$--- An interesting case for super heavy

Z=118

Need for more high energy and high Intensity stable beam accelerators

Bright future for low energy nuclear physics with new Accelerators

Thank You