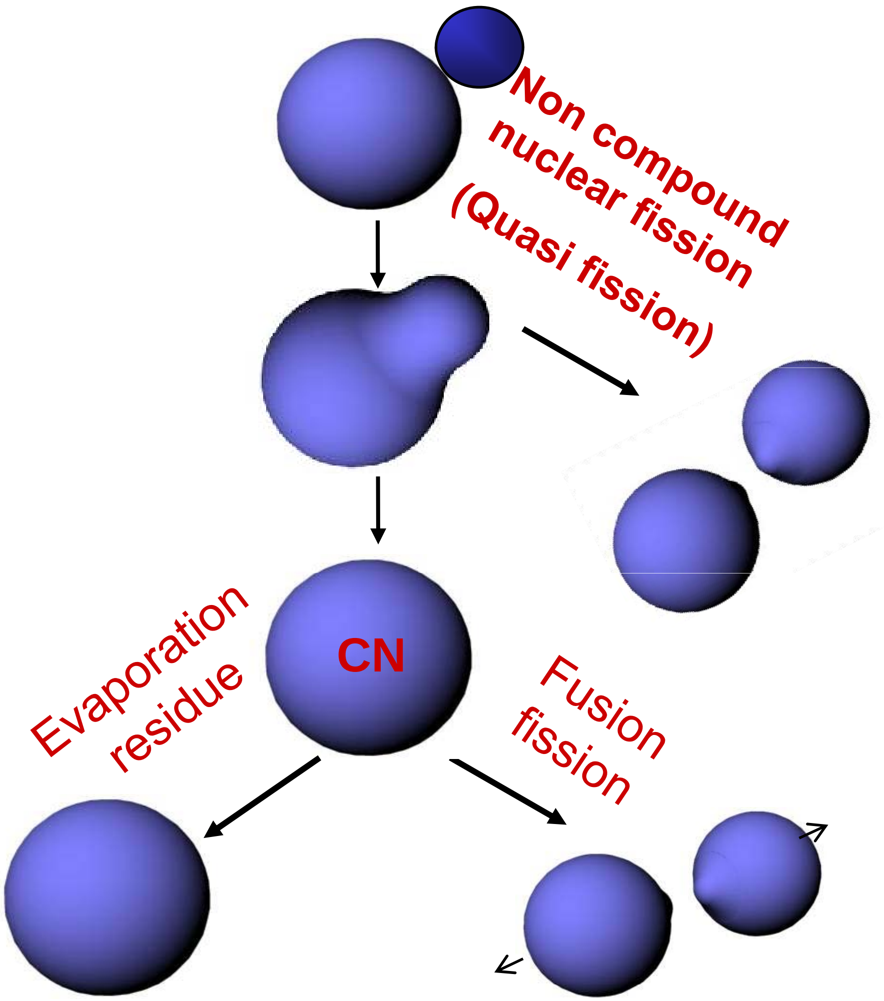
Fusion fission studies at Kolkata

Tilak Kumar Ghosh

Variable Energy Cyclotron Centre
Kolkata

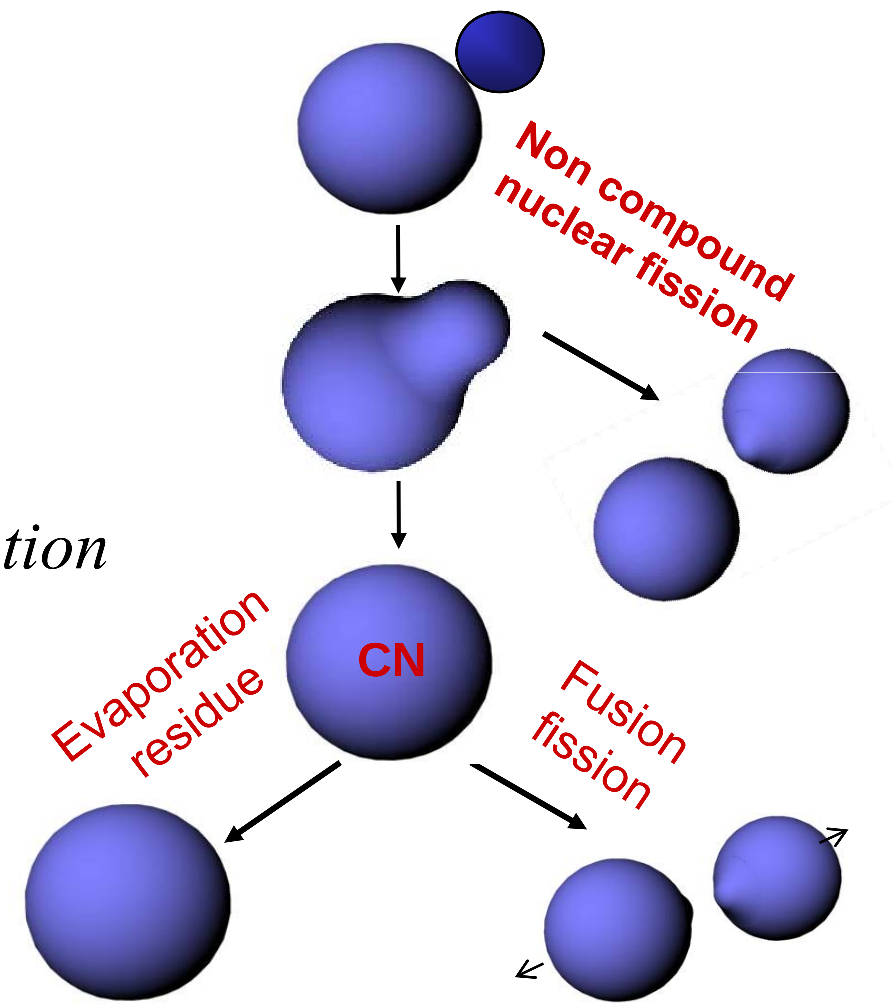
Physics Motivation

- *What influences fusion of two nuclei : what is the role of the target & projectile?*
- *How does the fusion process influence the subsequent evolution?*
- *Synthesis of super heavy elements: how it is affected by entrance channel dynamics?*



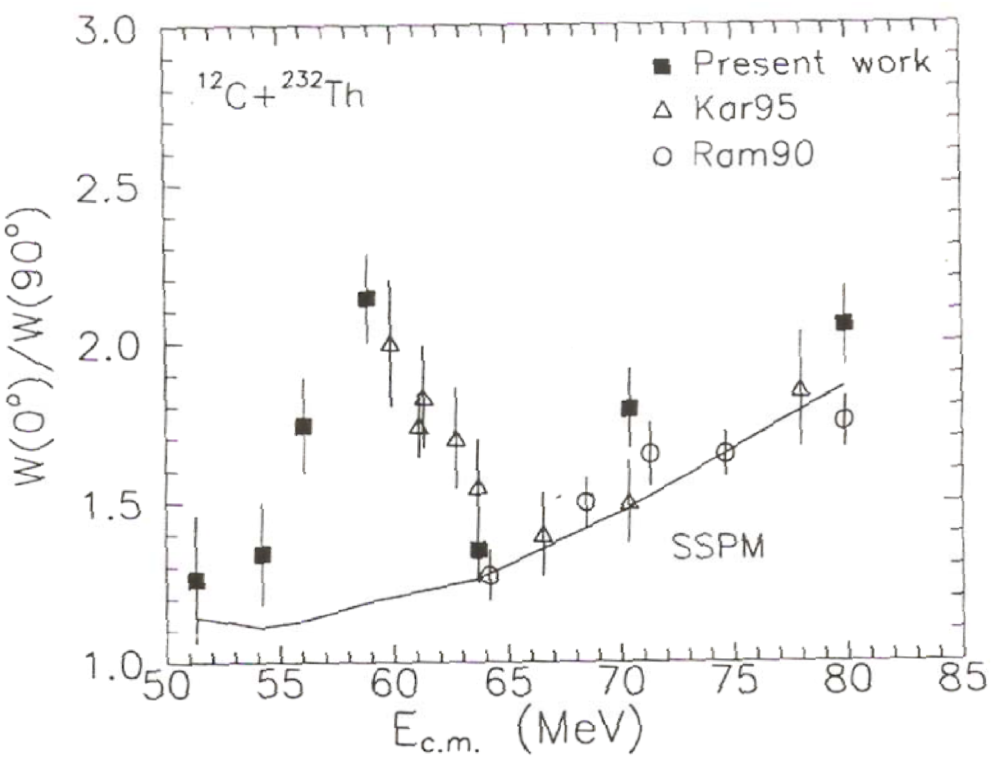
Experimental Probes

- *Study of evaporation residue (ER)*
- *Study of fragment angular distribution*



Fission fragment angular distribution

Puzzling features at near and sub-barrier energies



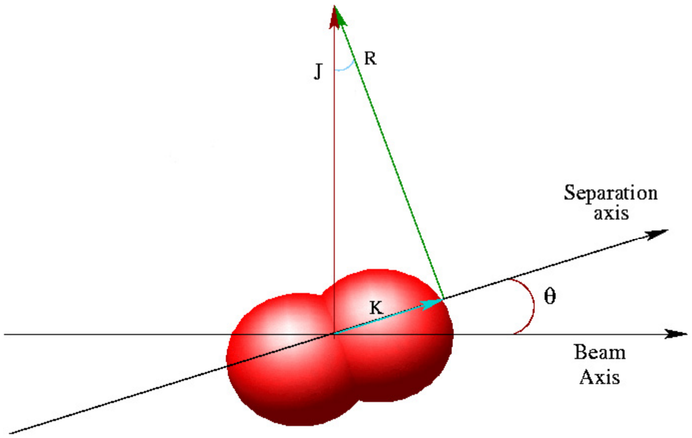
Angular anisotropies were found to be significantly larger than SSPM predictions

N. Majumdar, P. Bhattacharya et al., Phys. Rev. Lett 77, 5027 (R) (1996)
N. Majumdar, P. Bhattacharya et al., Phys. Rev. C 53, 544 (R) (1996)

Fission fragment angular distribution

Fragment angular anisotropy:

$$A = \frac{W(0^0)}{W(90^0)} = 1 + \frac{\langle J^2 \rangle}{4K_0^2}$$



- Broadening of the spin distribution due to couplings with Coulomb excited states

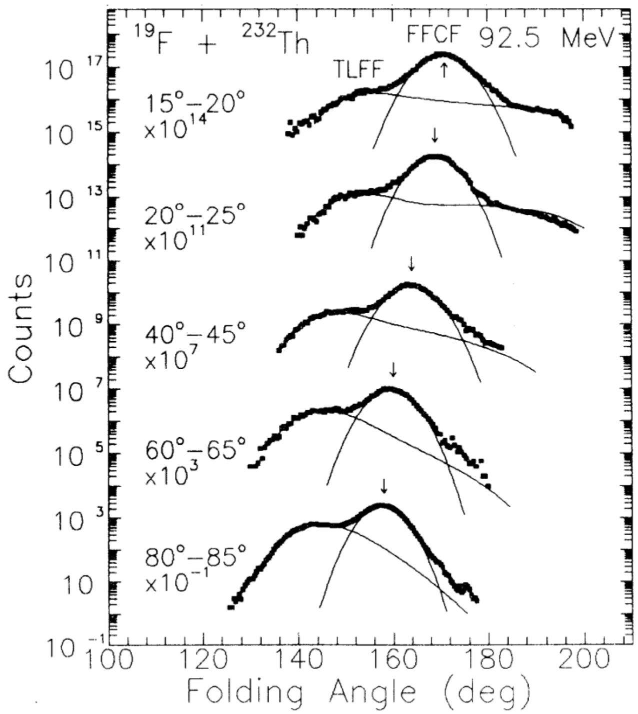
  - Ruled out from the fusion barrier distribution measurement

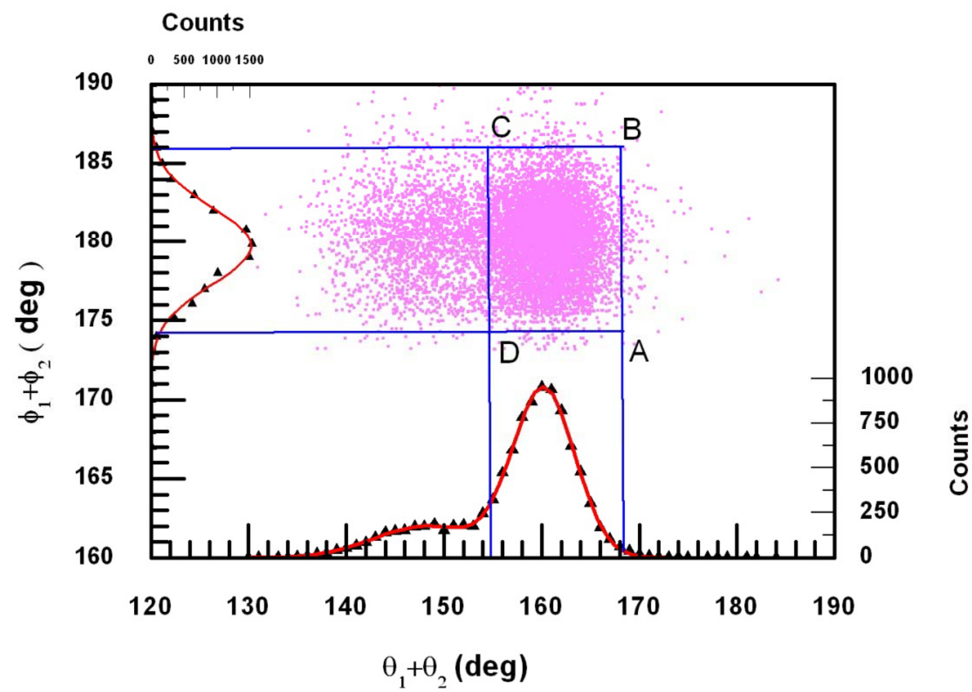
- Narrower K–distribution due to entrance channel memory

- Admixture of transfer fission?

Folding angle technique

Part of the projectile fuses with the target and the incompletely fused binary system undergoes fission

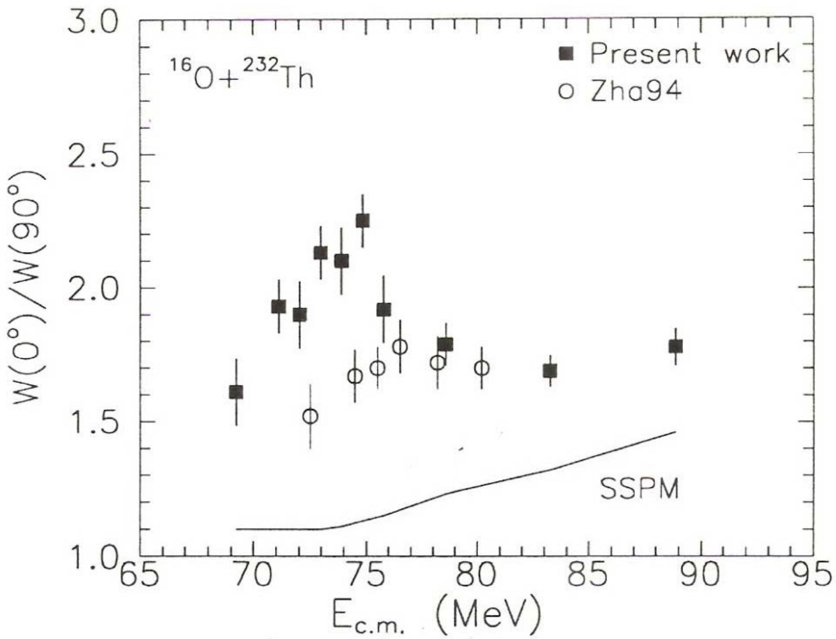


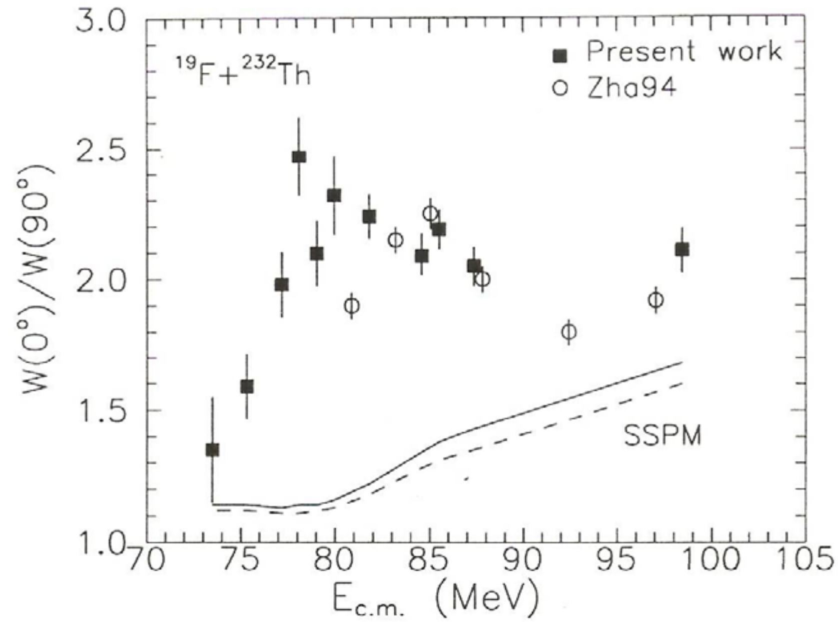


Separation of transfer induced fission channel

N. Majumdar, P. Bhattacharya et al., Phys. Rev. C 51, 3109 (1995)

Fission fragment angular distribution





- Narrower K–distribution due to entrance channel memory was responsible for increase in anisotropy

- Attributed to Quasi-fission or Pre-equilibrium fission.

N. Majumdar, P. Bhattacharya et al., Phys. Rev. C 51, 3109 (1995)
N. Majumdar, P. Bhattacharya et al., Phys. Rev. C 53, 544 (R) (1996)

Experimental probes to study Quasi fission

- *Study of evaporation residue (ER)*

  - ER cross section will be lower in case of QF

- *Study of fragment angular distribution*

  - Fragment anisotropy will be higher in case of QF

Contradictory results using two different probes…….

- ***Probe:*** *Angular distribution*

- Large angular anisotropy in the sub-barrier energy in reaction $^{16}O + ^{238}U$

⇨ *Presence of Quasi fission*

- ***Probe:*** *ER cross-section*

No hindrance of fusion was observed in the sub-coulomb barrier for the same reaction

⇨ *Absence of Quasi fission*

D. J. Hinde et al., Phys Rev Lett 74, 1295 (1995)

K. Nishio et al., Phys Rev Lett 93, 162701 (2004)

A New Probe

We proposed:

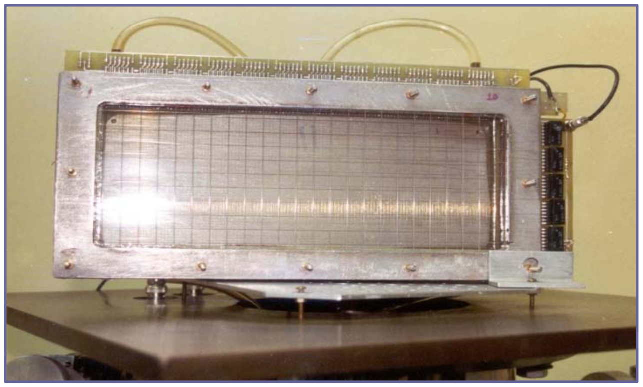
Accurate measurement of Mass Distributions can be used as a probe.

Variation of width of fragment mass distribution with excitation energies is a promising probe for studying quasi-fission

T.K. Ghosh,…..P.Bhattacharya et al., Phys. Rev. C 69, 031603 (R) (2004)
T.K. Ghosh,…..P.Bhattacharya et al., Phys. Rev. C 70, 011604 (R) (2004)

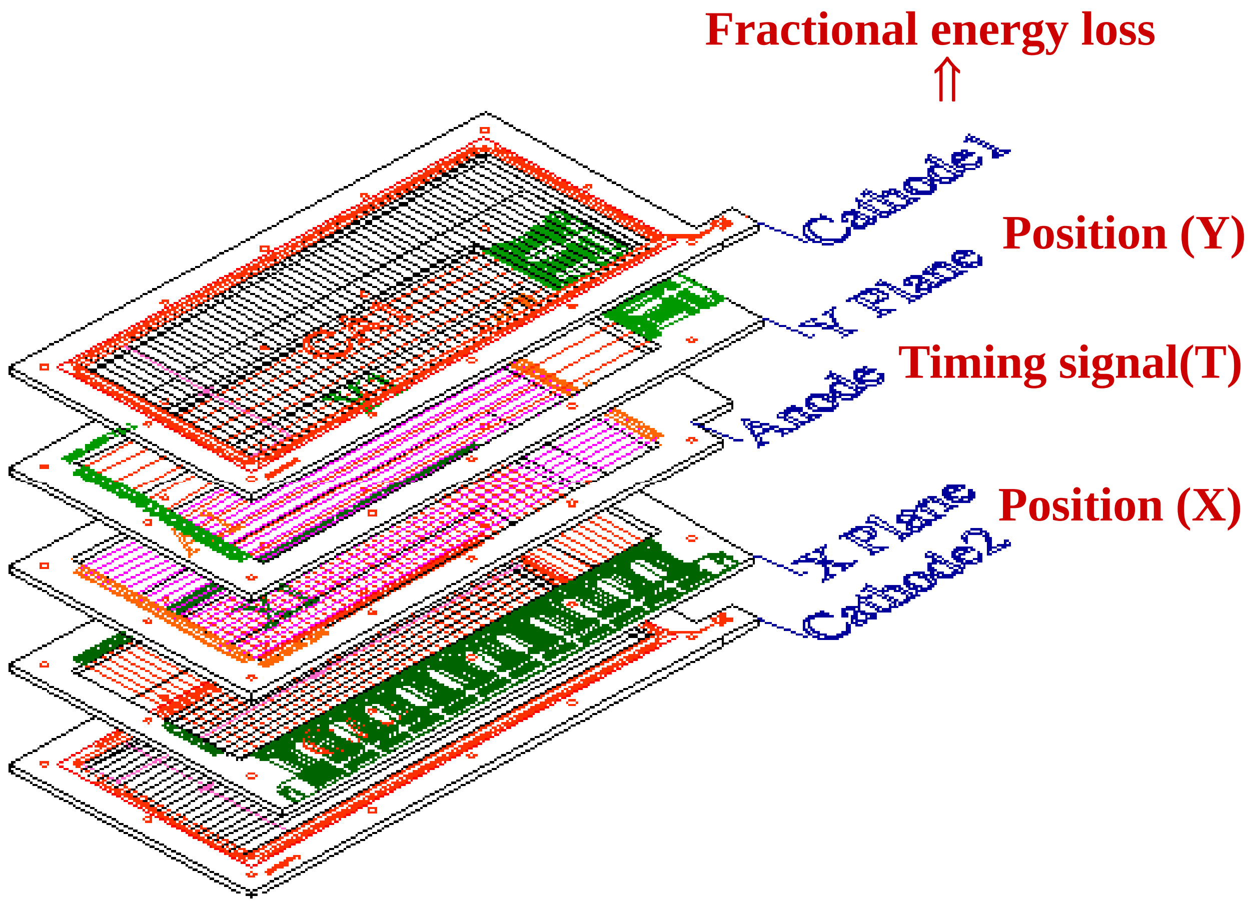
Detector for measurement

Position sensitive Multi Wire Proportional Counters (MWPC) were developed in the laboratory



Effective area:

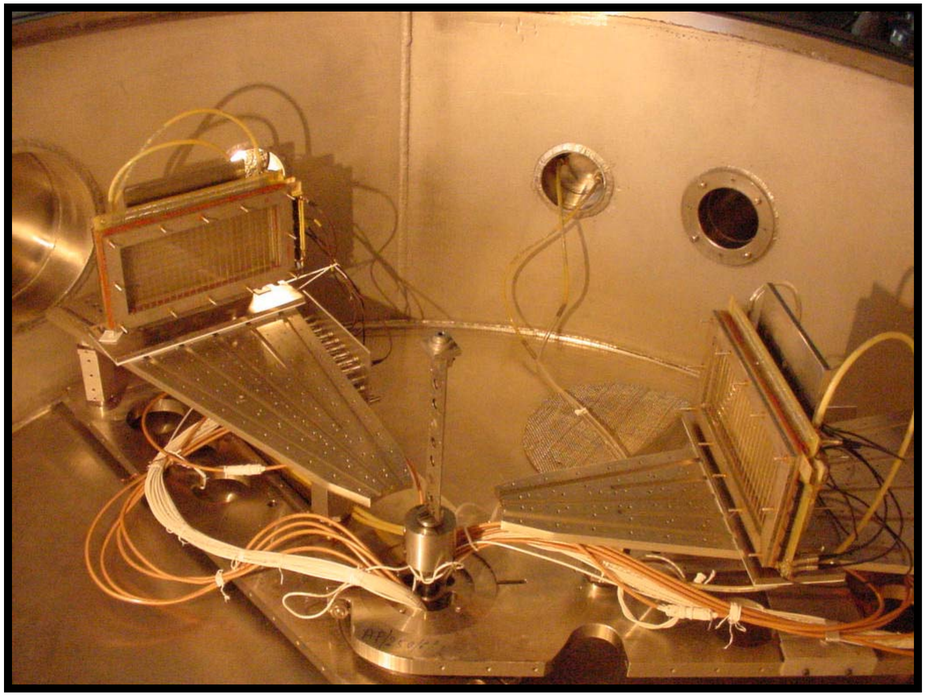
24 cm × 10 cm



T.K. Ghosh et al., Nucl. Instr. and Meth. A 540, 285 (2005)
P. Bhattacharya et al., Nucl. Instr. and Meth. A 276, 585 (1989)

Measurement Procedure

Experiments were carried out at the major accelerator facilities available in our country (VECC, BARC-TIFR, IUAC)



Flight path:

Forward detector: **56 cm**
Backward detector: **33 cm**

Angular coverage :

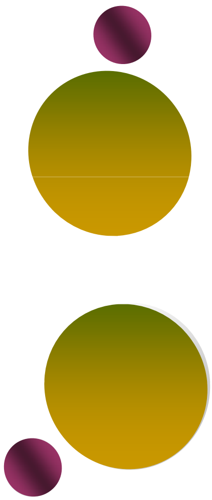
Forward detector : **25°**

Backward detector: **40°**

Efficient set-up for both mass and angular distribution measurement

Mass resolution ~ 4 amu

Role of target deformation on fusion fission

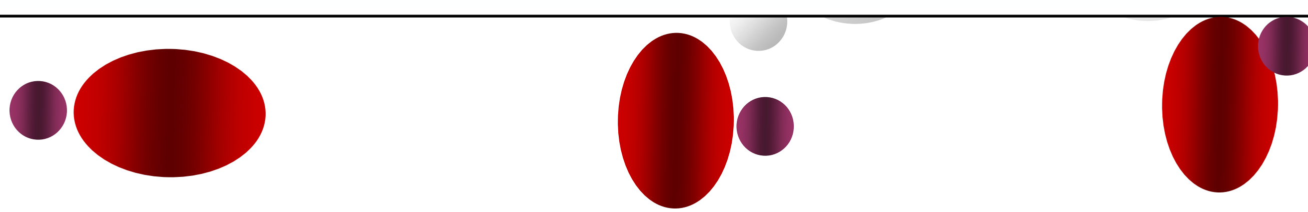


- ✓ ^{19}F + ^{209}Bi
- ✓ ^{16}O + ^{209}Bi

■ *^{209}Bi is a spherical nucleus*

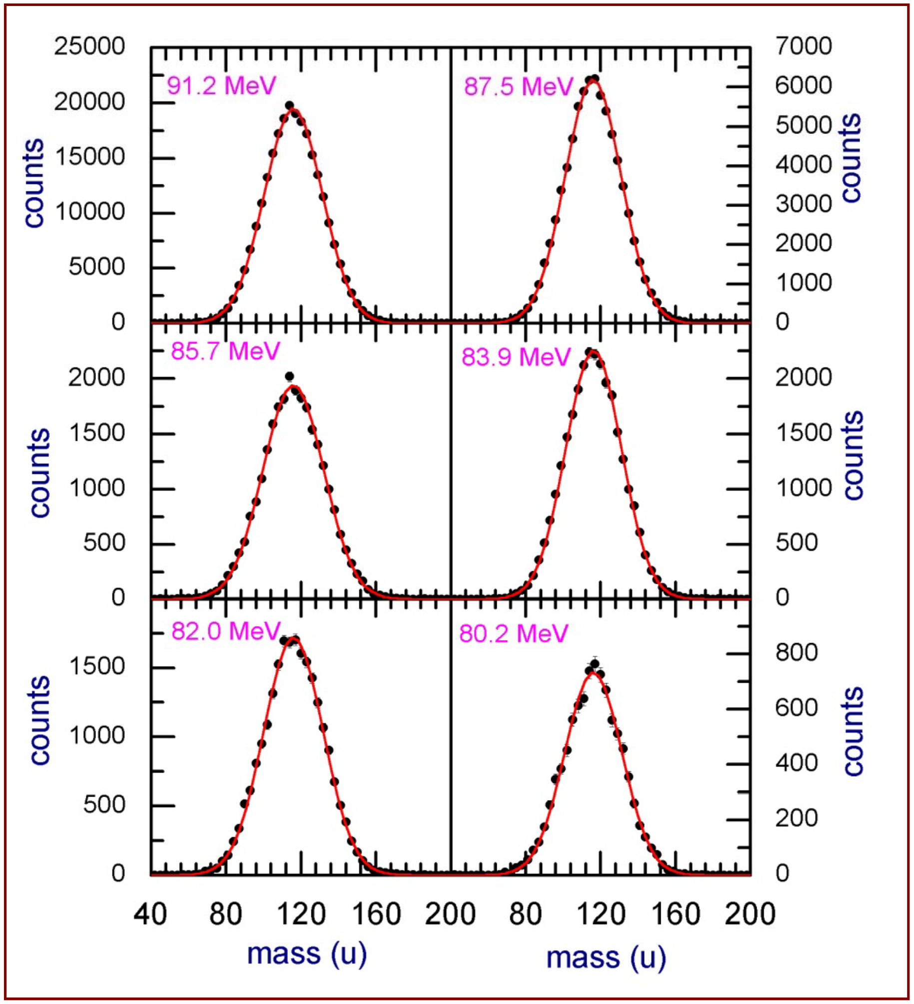
- ✓ ^{20}Ne + ^{232}Th
- ✓ ^{19}F + ^{232}Th
- ✓ ^{16}O + ^{232}Th
- ✓ ^{16}O + ^{238}U
- ✓ ^{12}C + ^{232}Th

■ *^{232}Th/^{238}U deformed nuclei*



Mass distribution: spherical target

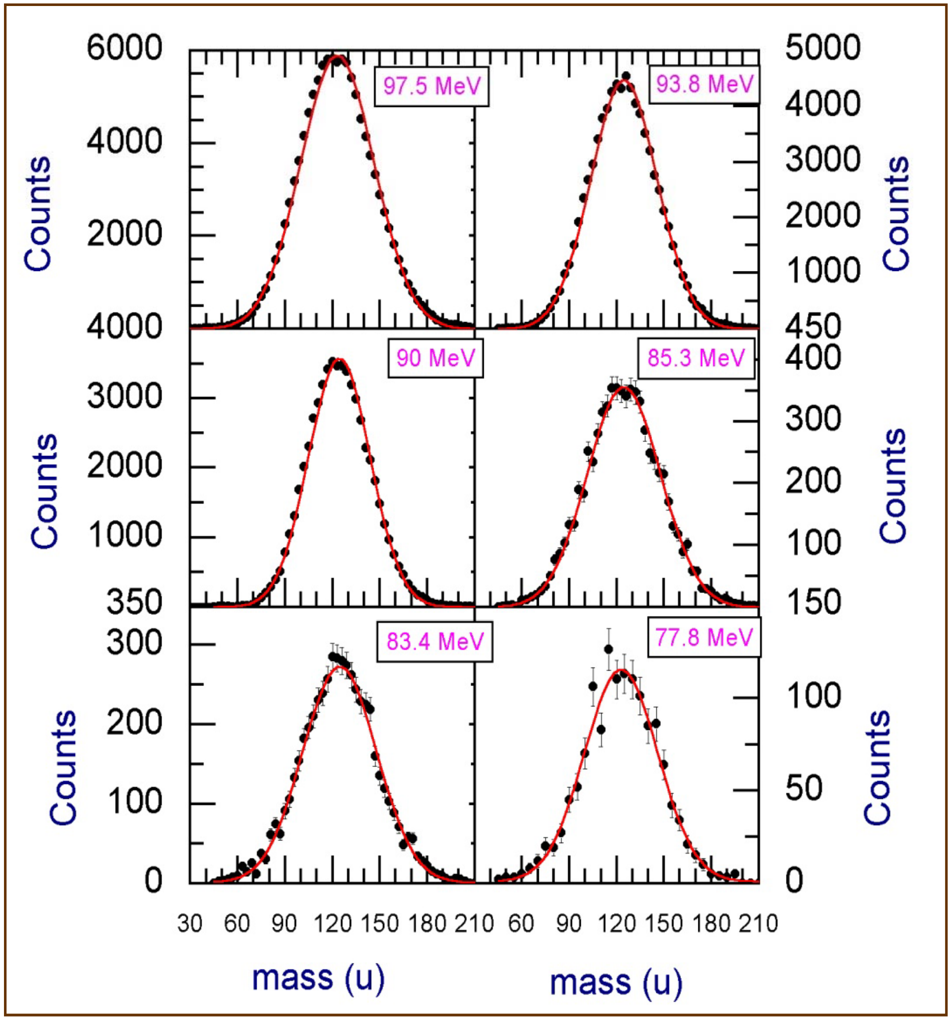
$^{19}F+^{209}Bi$



✓*Mass distributions are symmetric in shape peaking around* $A_{CN}/2$

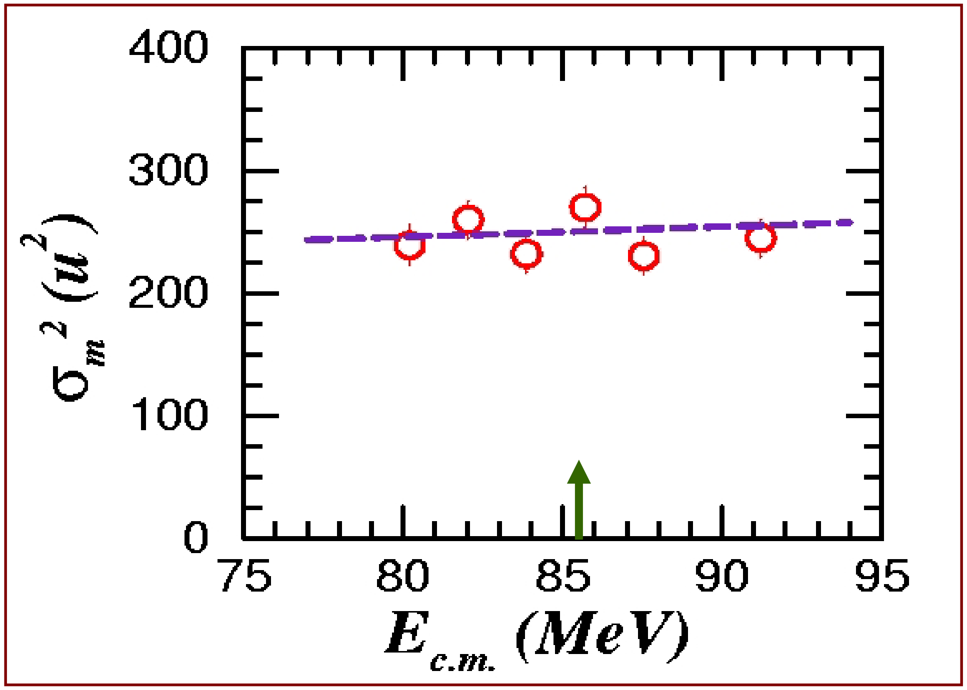
Mass distribution : deformed target

$^{19}F+^{232}Th$



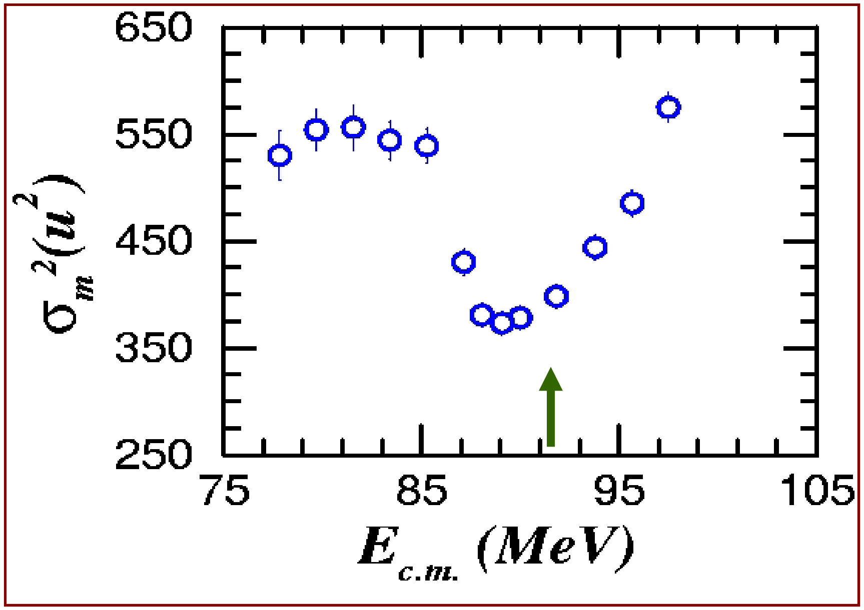
✓ *Mass distributions are symmetric in shape peaking around $A_{CN}/2$*

Variation of width of mass distribution



→ **monotonic increase**

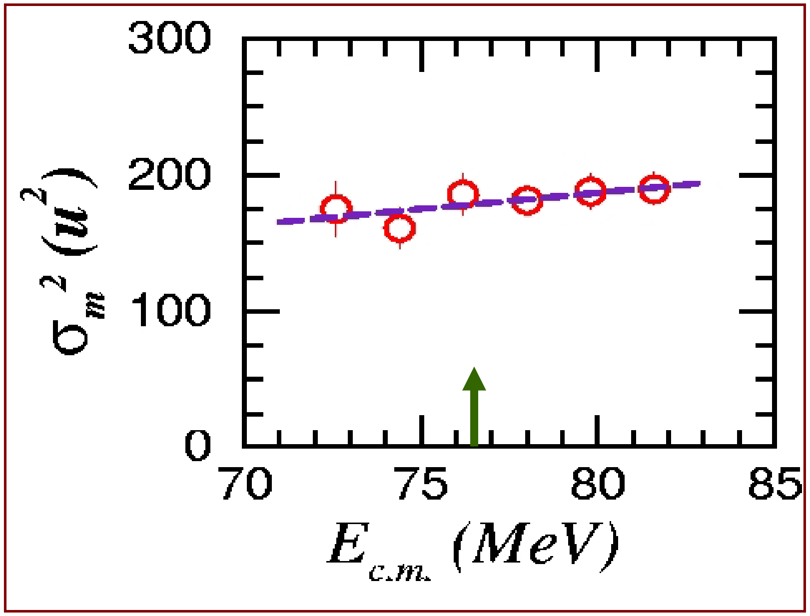
$^{19}F + ^{209}Bi$



anomalous !! → $^{19}F + ^{232}Th$

T. K. Ghosh et al., Phys Rev C 69, 031603(R) (2004)

Variation of width of mass distribution

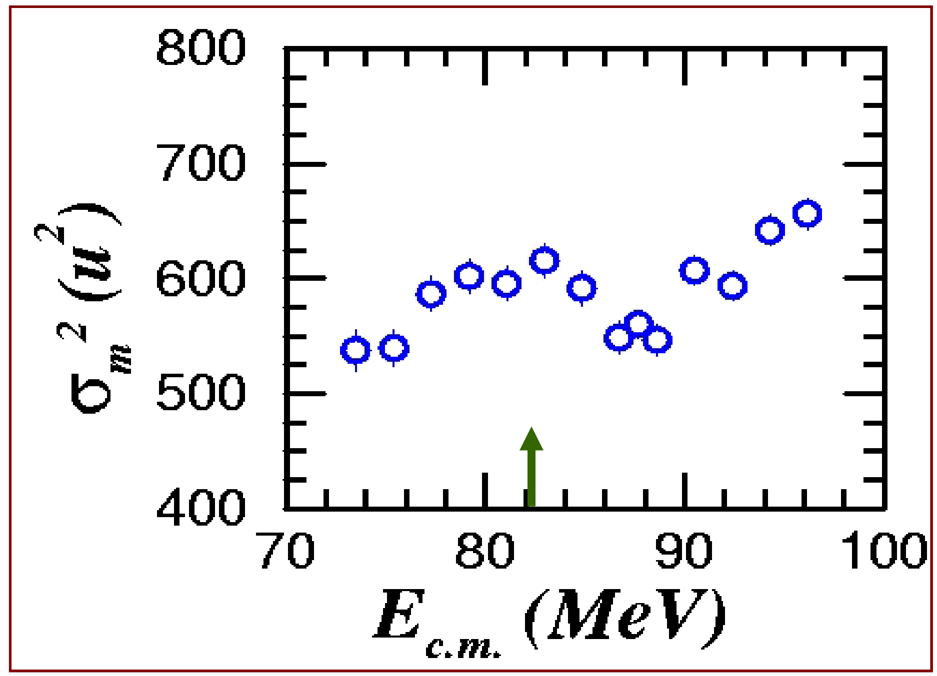


→ **monotonic increase**

$^{16}O+^{209}Bi$

anomalous !! →

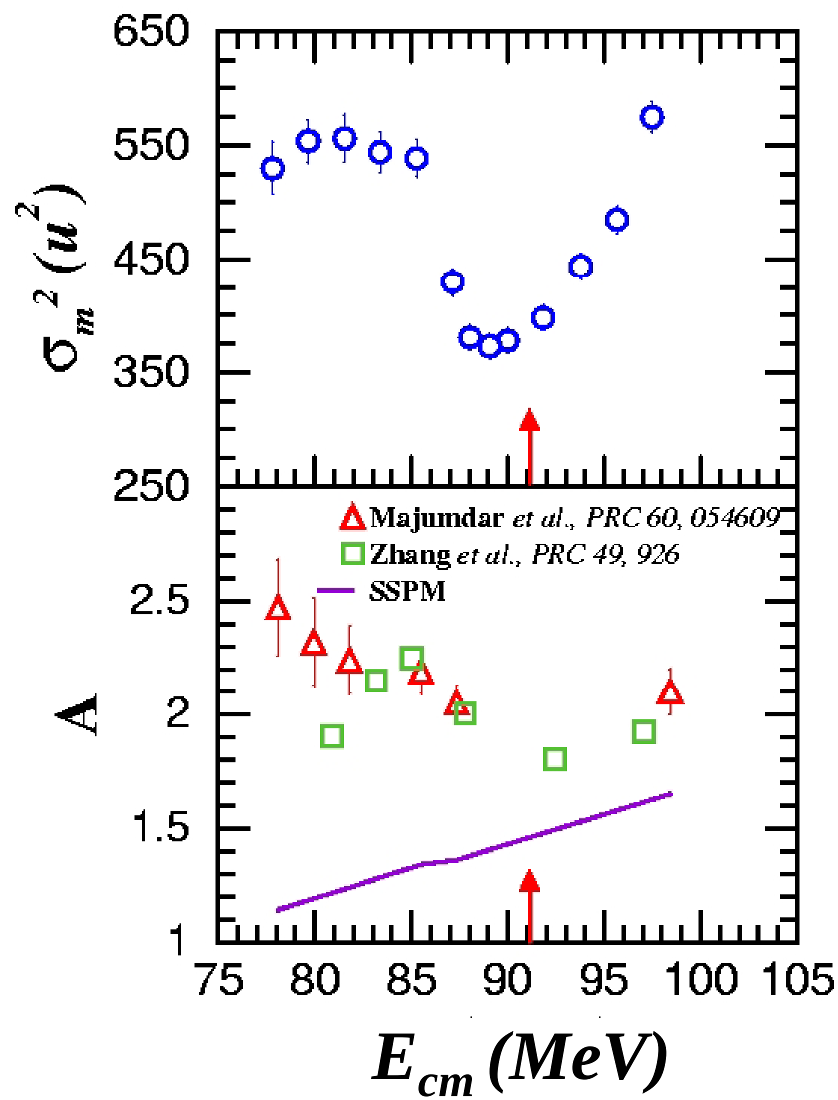
$^{16}O+^{232}Th$



T.K. Ghosh et al., Phys Rev C 70, 011604 (R) (2004)

$^{19}F+^{232}Th$

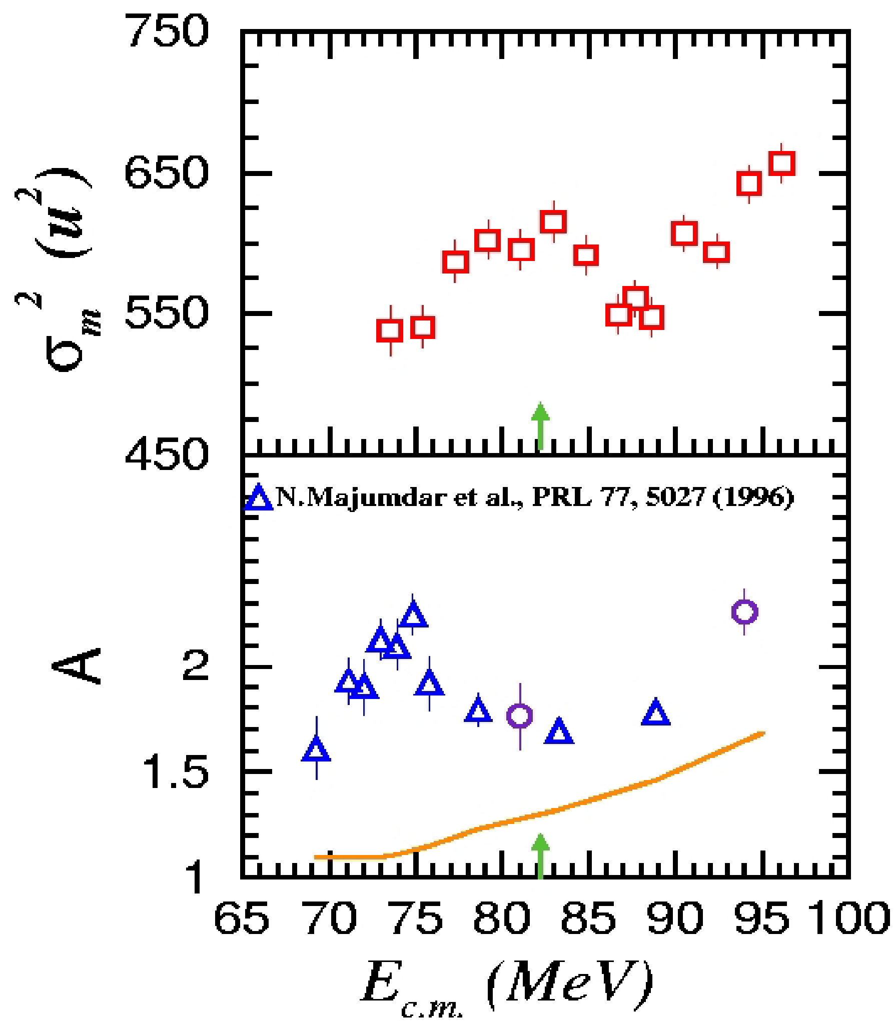
Anomalous increase in **width** of fragment mass distribution as well as **anisotropy** near the barrier



T.K. Ghosh et al., Phys. Rev. C 69, 031603 (R) (2004)
N. Majumdar et al., Phys. Rev. C 51, 3109 (1995)

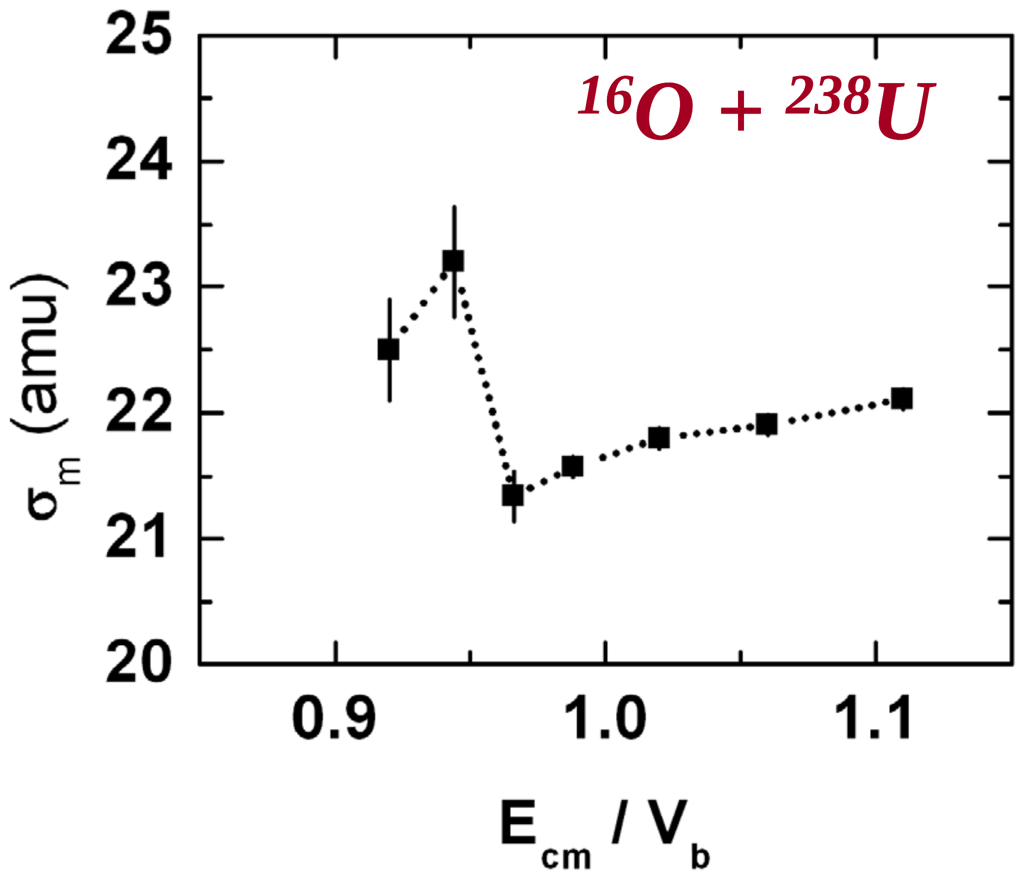
$^{16}O+^{232}Th$

Anomalous behaviour both in fragment mass and angular distributions near the Coulomb barrier.



T.K. Ghosh et al., Phys. Rev. C 69, 031603 (R) (2004)
N. Majumdar et al., Phys. Rev. Lett 77, 5027 (1996)

Mass distribution : A sensitive probe



Clear signature of quasi-fission in the sub-barrier for the reaction ***$^{16}O + ^{238}U$***

K. Banerjee, T.K. Ghosh et al; Phys. Rev. C 83, 024605 (2011)

Anomalous increase in width of mass distribution

Compound nucleus fission proceeds through mass symmetric fission barrier
→ *mass distribution is symmetric*

⇓

Width of the mass distribution is a smoothly varying function of the excitation energy

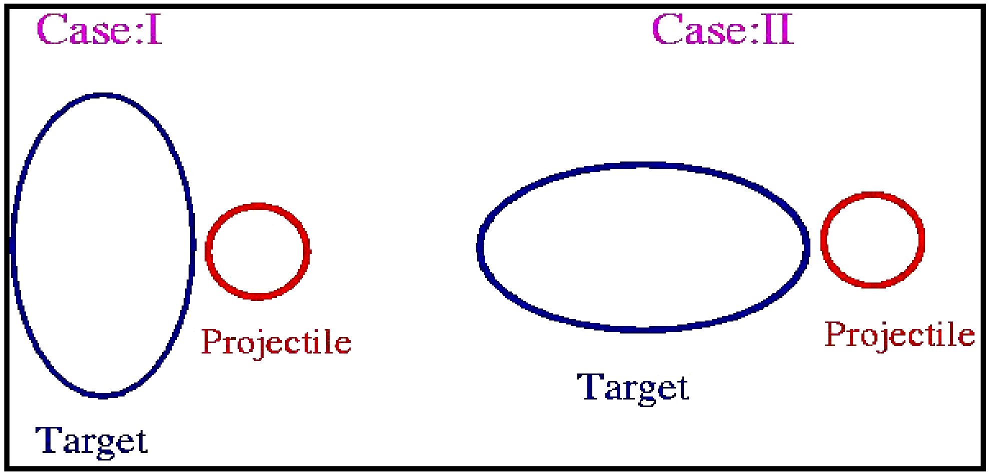
Quasi-fission proceeds through a mass asymmetric fission barrier

→ *fragment mass distribution is mass asymmetric or wider*

For a mixture of statistical and quasi-fission, the width of the mass distribution may get larger

T.K. Ghosh et al., Phys. Lett. B 627, 26 (2005)

Role of target deformation



Two different cases for the injection of the projectile at the tip and flattened side of the target.

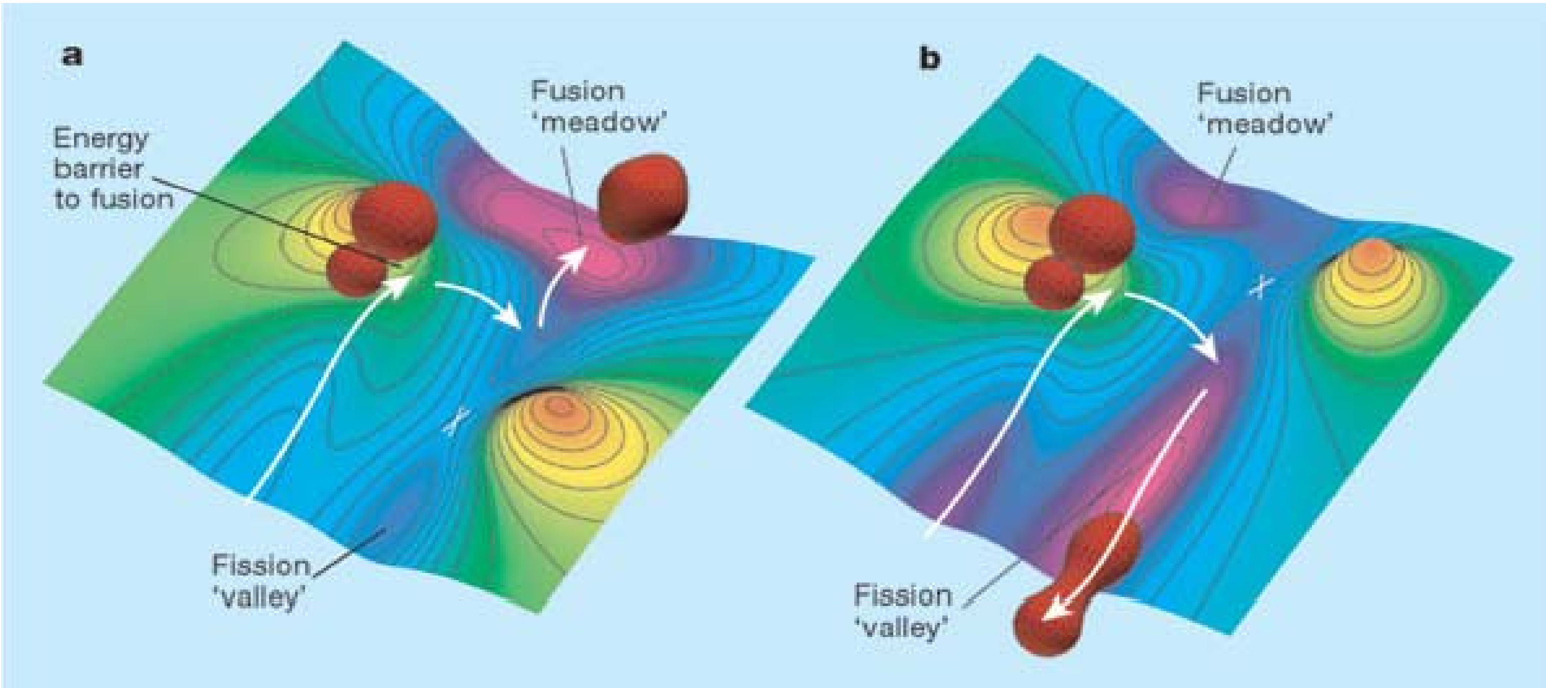
Orientation dependent Quasi-Fission

Contribution from Quasi fission?

- ***Spherical Target*** (^{209}Bi): ***No***
- ***Deformed Target*** (^{232}Th, ^{238}U): ***Yes***

T.K. Ghosh et al., arXiv:0809.2873v1
K. Banerjee, T.K. Ghosh et al; Phys. Rev. C 83, 024605 (2011)

Fission Valley

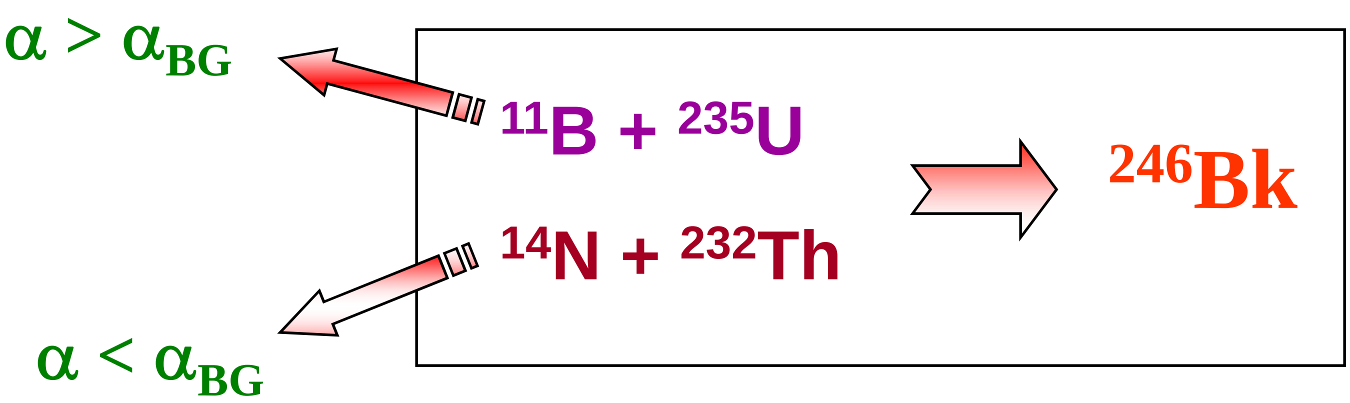


Nuclear shape evolution in a multi dimensional potential energy landscape

P. Moller and A.J.Seirk, Nature 422, 485 (2003)

Role of mass asymmetry

We populated the same compound nucleus at similar excitation energy



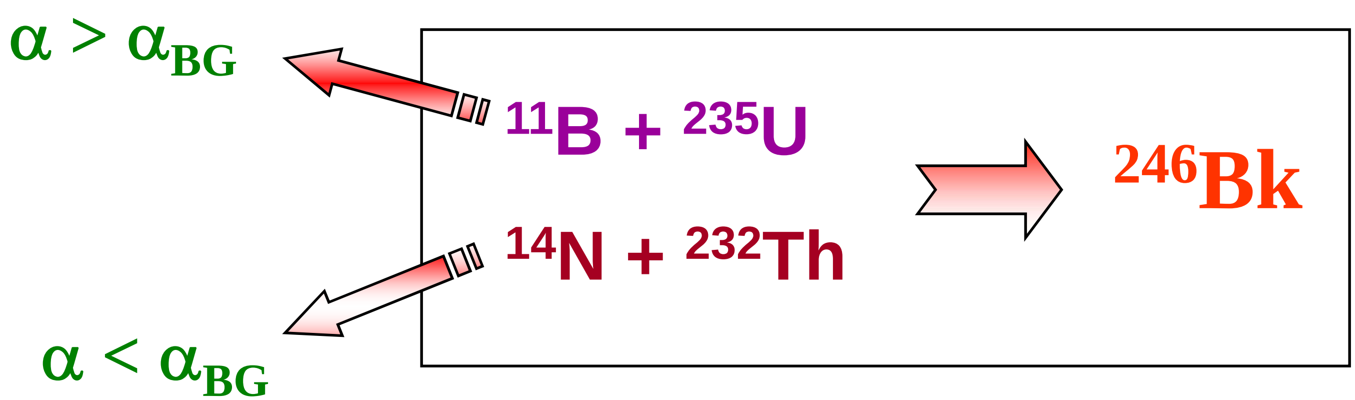
Mass asymmetry parameter: $\alpha = (M_t - M_p) / (M_t + M_p)$

α_{BG} → Businaro Gallone mass asymmetry parameter

T. K. Ghosh et al., Phys. Rev. C 79, 054607 (2009)

Role of entrance channel mass asymmetry

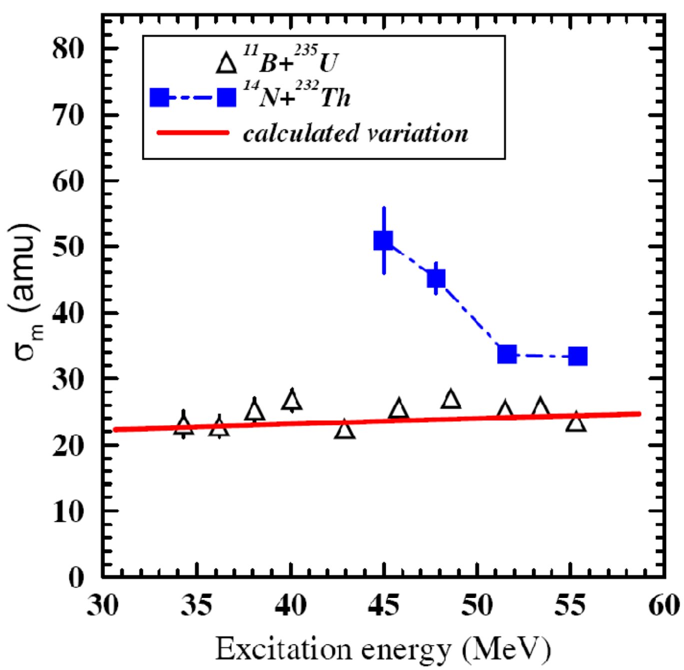
Targets nuclei are similarly deformed: initial configuration similar



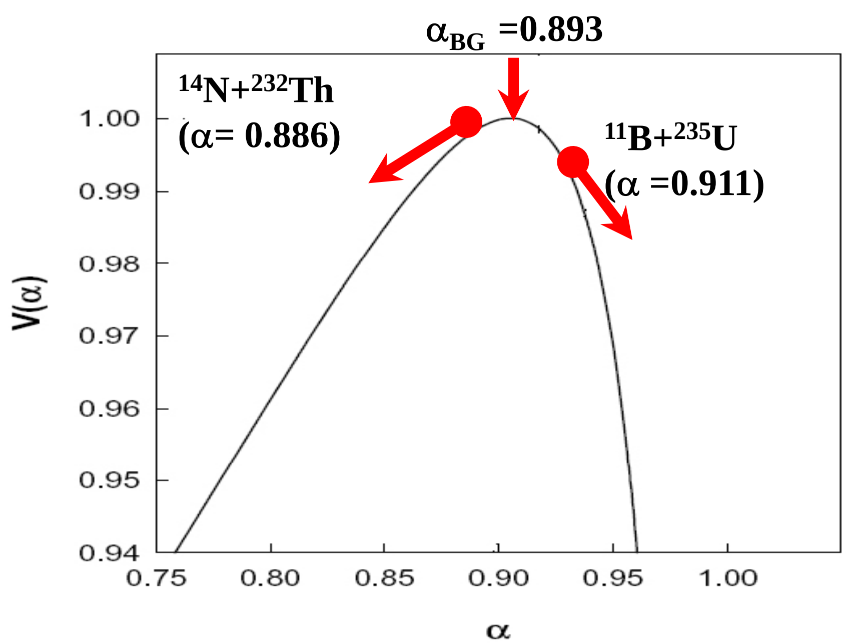
We expect quasi-fission in both the systems if the orientation dependent quasi-fission is the dominant reaction mechanism

But, we would expect quasi-fission only in $^{14}N + ^{232}Th$ and not in $^{11}B+^{235}U$ if the direction of mass flow drives the system to quasi-fission.

Role of mass asymmetry



Absence of quasi-fission in $^{11}B+^{235}U$



$$\sigma_m^2 = \frac{1}{k}\sqrt{\frac{E^*}{a}}$$

E*= *excitation energy at scission point*

a= *level density parameter*

k = *stiffness constant*

T. K. Ghosh et al., Phys. Rev. C 79, 054607 (2009)

Summary

- *Fission fragment angular distribution have been studied to understand the anomalous angular anisotropy near the Coulomb barrier energies using the major accelerator facilities in India*

- *Width of mass distributions is used as a tool to observe departure from normal fusion fission path*

- *Entrance channel mass asymmetry parameter play prominent role in fusion of two nuclei*

Collaborators

K. Banerjee, C. Bhattacharya, S. Bhattachrya, A. Dey, D. Gupta, S.Kundu,
G. Mukherjee, J.K. Meena, T. Rana, R. Pandey

VECC, Kolkata, India

P. Bhattacharya, S. Chattopadhyay, N. Majumdar, S. Pal, T. Sinha

SINP, Kolkata, India

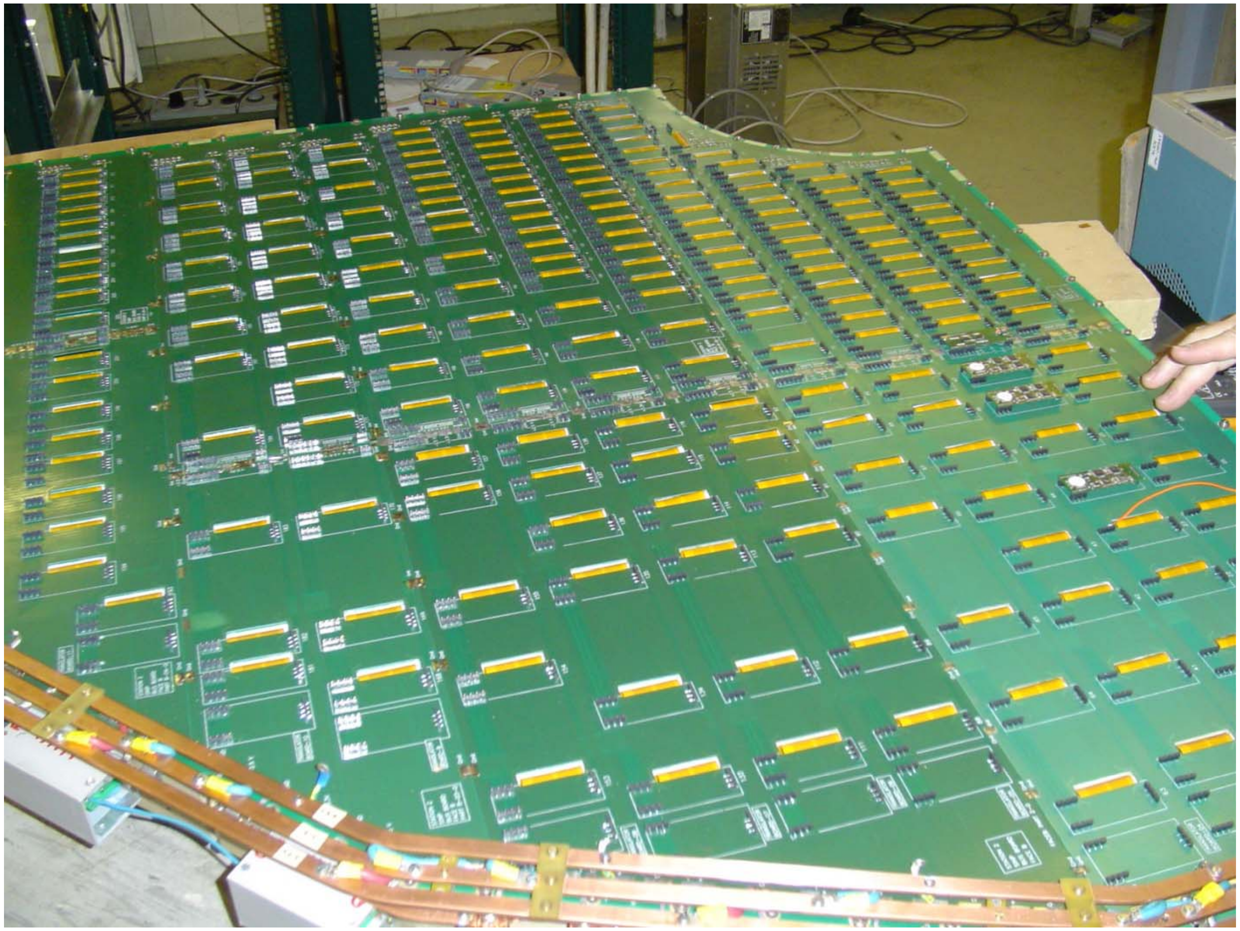
K.S. Golda, S.K. Dutta, P. Sugathan

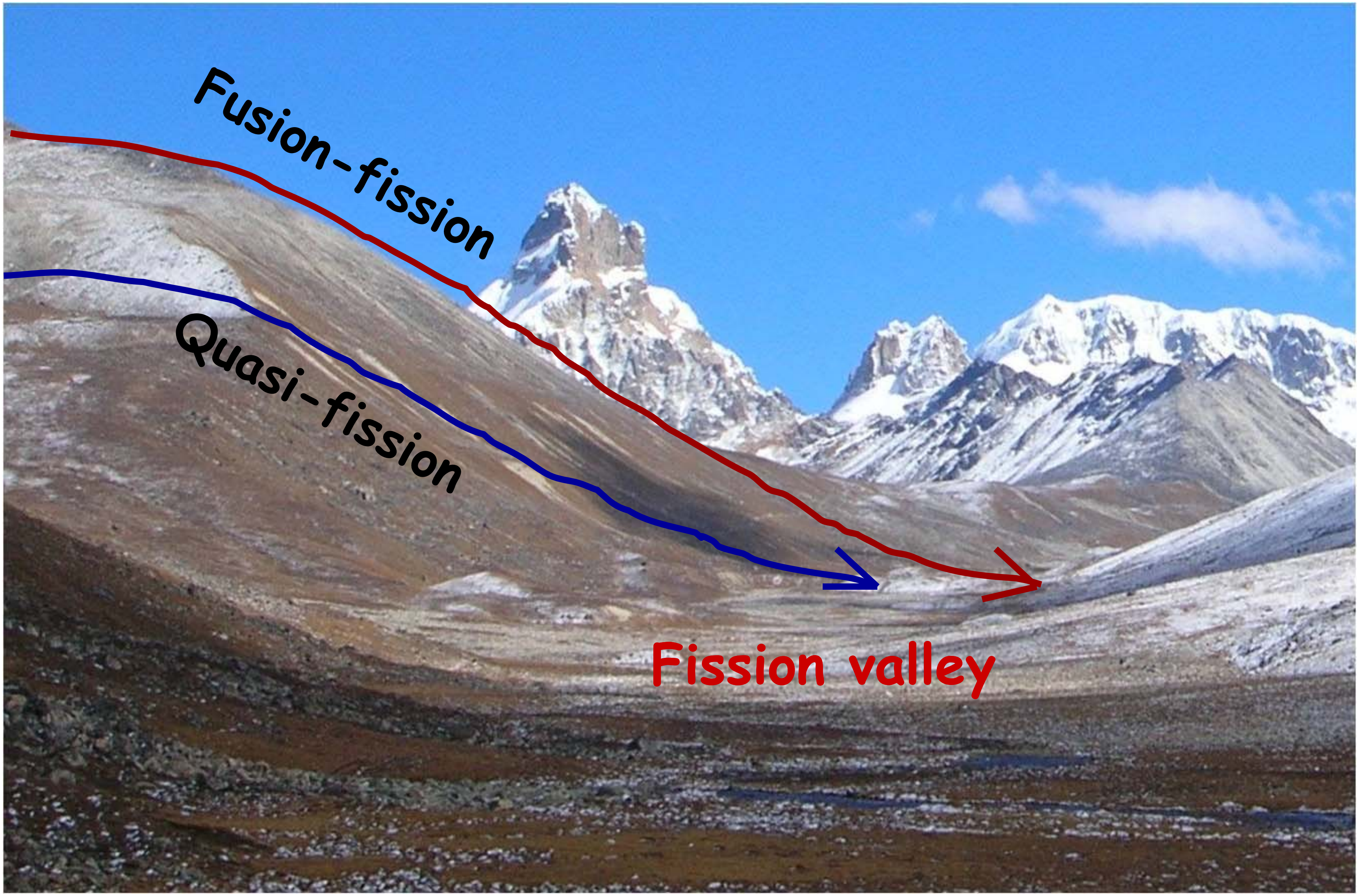
IUAC, New Delhi, India

D.C. Biswas, P.K. Sahu, A. Saxena

BARC, Mumbai, India

Spin off detector development





Yumesamdong (15,300 ft), North Sikkim, India

Mass Distribution Calculation

$$m_1 = \frac{(t_1 - t_2) - \delta t_0 + m_{CN}\frac{d_2}{p_2}}{\left(\frac{d_1}{p_1} + \frac{d_2}{p_2}\right)}$$

$$m_2 = m_{CN} - m_1$$

$$p_1 = \frac{m_{CN}V_{CN}}{cos\theta_1 + sin\theta_1 cot\theta_2}$$

$$p_2 = \frac{p_1 sin\theta_1}{sin\theta_2}$$

where m_1, $m_2 \Rightarrow$ *fragment masses*

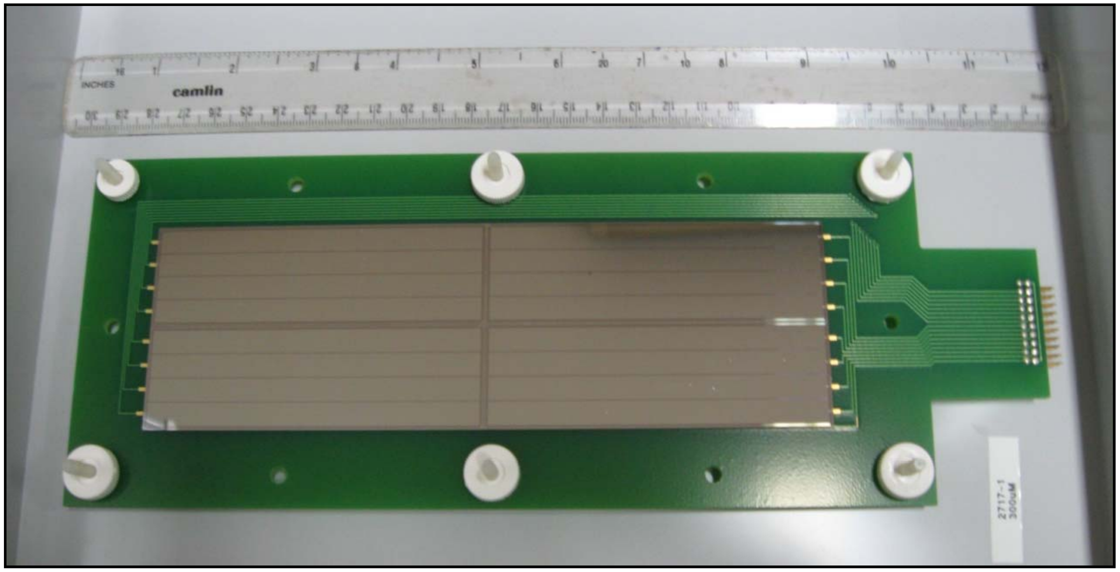
t_1, $t_2 \Rightarrow$ *flight times of the fragments for distances* d_1, d_2

p_1, $p_2 \Rightarrow$ *linear momentum in the lab. Frame*

δt_0= *difference of time zero*

T.K.Ghosh et al., Nucl. Instr. and Meth. A 540, 285 (2005)

New hybrid detector development



Segmented silicon detector

Hybrid gas detector