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21 Mar 2022, 00:10 → 25 Mar 2022, 17:05 Europe/Madrid
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Delving α and non-α structure beams induced incomplete fusion@ 4-7 MeV/A : A Role of Deformation

By

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Monday, 21 March, 22

Time 16:20

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Plan of presentation

Introduction

-What is CF/ICF….?

Motivation: need of measurements

-Why to study….?

Key Signatures

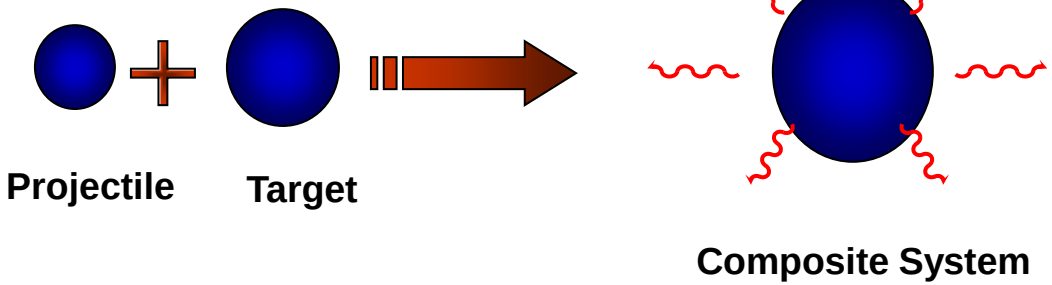
-How to study….?

Estimation of ICF and Role of deformation

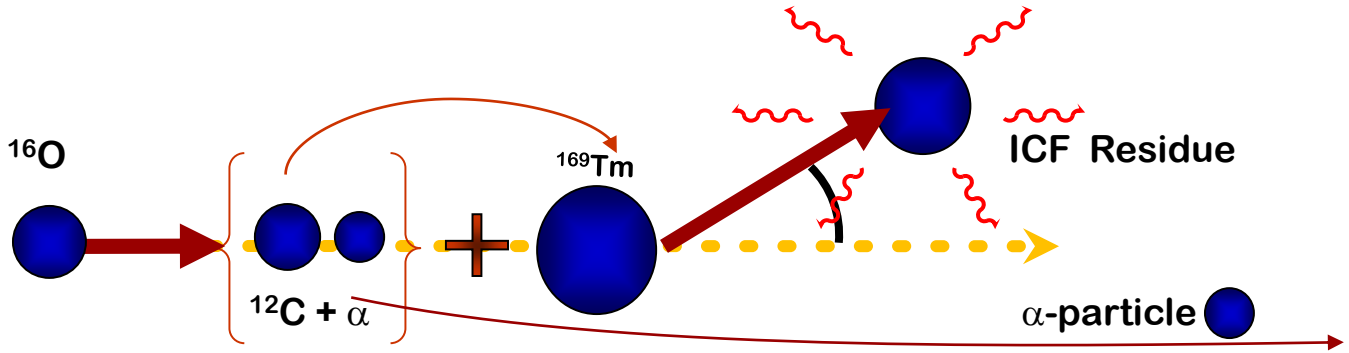
Conclusions…..

Introduction

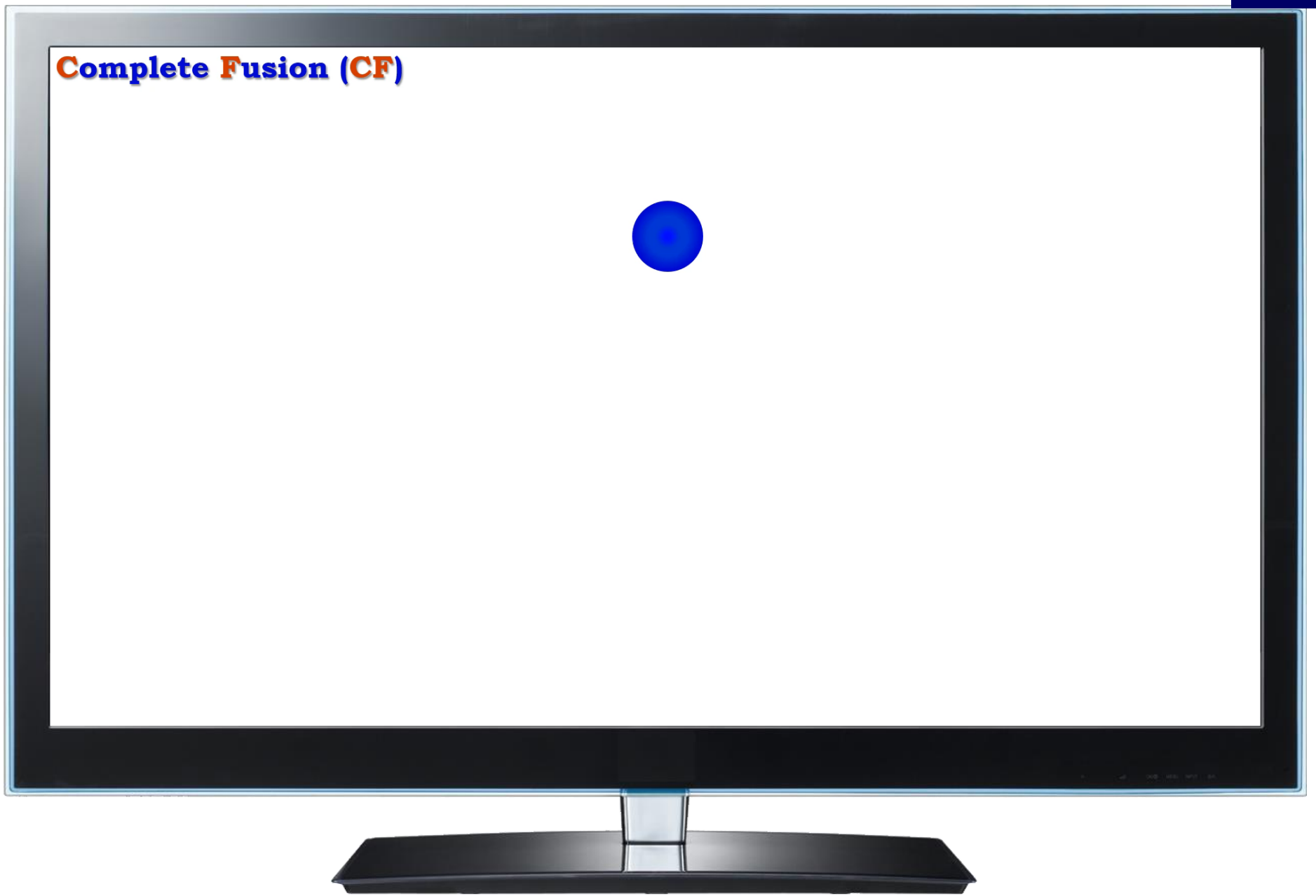
Complete Fusion (CF):-



In Complete Fusion (ICF):-



Animation



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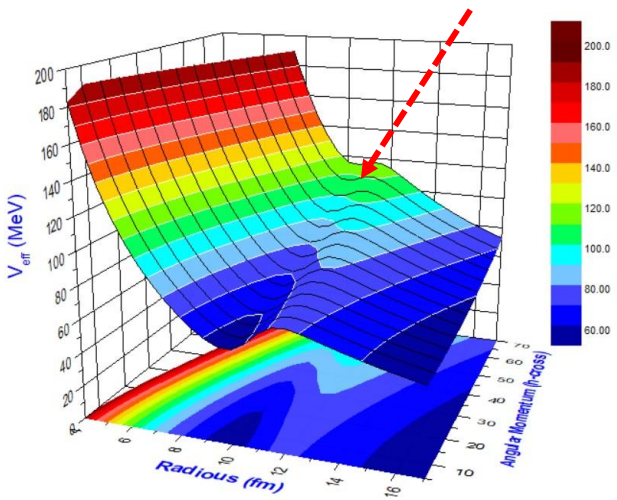
Introduction

$$V_{eff}(r) = V_c(r) + V_n(r) + V_{cent}(rel)$$

$$\frac{1}{4\pi\varepsilon_o}\frac{Z_P\, Z_T\, e^2}{r} \qquad \frac{V_o}{1+exp(\frac{r-R}{a})} \qquad \frac{\hbar^2}{2\mu}\frac{\ell(\ell+1)}{r^2}$$



$^{19}F+^{166}Er$

Effective potential verses relative separation between the ions and angular momentum imparted

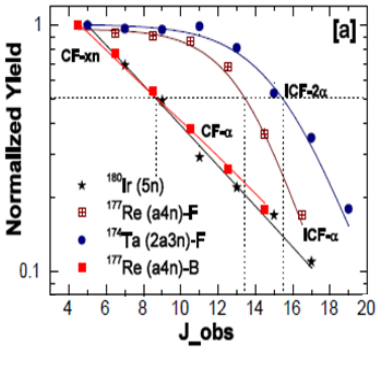
Characteristics of incomplete fusion (ICF)

- Only a fraction of the linear momentum is carried by ICF residues
- The ICF residues travel a smaller distance in the stopping medium.
- The residues populated by ICF, move at an angle w.r.t. the beam direction.
- The un-fused part of the incident ion moves in the forward direction
- The Spin distribution pattern of ICF residues distinctly different than for CF residues

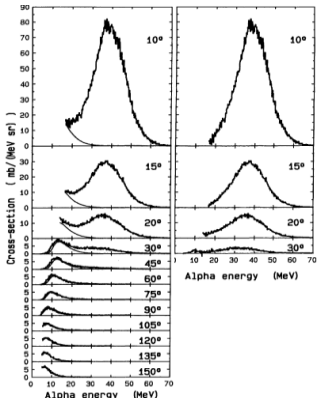
Key Signatures of ICFs

ICF may be studied via measurements of

- Energy & Angular distribution of emitted α-particles/ Projectile like fragments.
- Spin distribution of Residues
- Excitation functions of residues
- Recoil range distributions of the residues
- Angular distribution of residues



Spin Distribution of CF and ICF Residues



Angular Distribution of the Alpha Particles

Singh, *et al.*, Physics Letters B 671, 20 (2009)
Badran *et al.*, Eur. Phys. J. A 12 (2001) 317

Objective.....!

- **Degree of fusion of ICF – understanding of nuclear dynamics.....?.**
  - **Does ICF sensitive on projectile energy.....?-understand the threshold energy for ICF**
  - **Does mass asymmetry play any role in the underlying dynamics.....?.**
  - **In-put angular momentum multiplicity involved in ICF.....?.**
  - **Exciting to confirm the influence of ICF on CF at E/A =4-7 MeVA.**
  - **For high spin physics, ICF is a promising technique and will be intensively used.**
- **Experimental data for such reactions may be useful for the production of specific radioactive ion beams (RIBs).**
  - **More data is required to determine optimum-irradiation-conditions for producing radioactive isotopes of interest.**

Objective.....active area of investigations.!

- In the range of present energy of interest more and more reaction data as well as the modelling is required.....

- -To cater different possibilities of synthesizing the super heavy element (SHE).

- -In development of accelerator driven sub-critical systems (ADSS), Nuclear data are required as a function of energy materials of interest)

- -The cross section information of several different types of non-resonant and resonant reactions are important in nuclear astrophysics.

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Models for the ICF @ <10 MeV/A

- **Geometry Overlap**
  - B. G. Harvey and M. J. Murphy Phys. Lett. 130B (1983)373.
- **Microscopic Overlap**
  - Harvey et al, Phys., Nucl. Phys. A444 (1985)494.
- **Brack-up Fusion**
  -T. Udagawa and T. Tamura, Phys. Rev. Lett. 45 (1980)1311.
  -X-H Li , T Udagawa and T. Tamura, Phys. Rev. C (1984) 1985
  -A. K. Kerman and K. McVoy, Ann. Phys (N. Y.) 122, (1979)

- **SUM-RULE**
  -Wilczynski et al, Nucl. Phys. A 373 (1882)109.
  - Wilczynska et al, Phys. Rev. Lett. 42 (1979) 1599.

"NO THEORETICAL MODEL IS AVAILABLE FOR ICF DYNAMICS AT ENERGIES ≈4-7MEV/NUCLEON"

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Investigations done

..... Using ^{12}C and ^{16}O beams having α-Structure

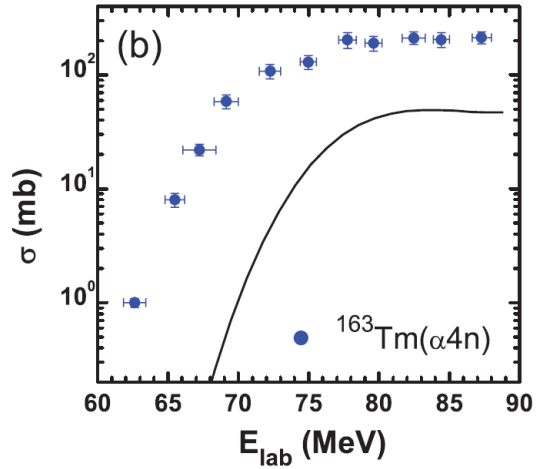
In order to explore some of the issues related to ICF dynamics, experiments have been carried out at Inter-University Accelerator center, New Delhi. Information of considerable value have been obtained from the measurements and a few systematics have been developed

Measurements carried out

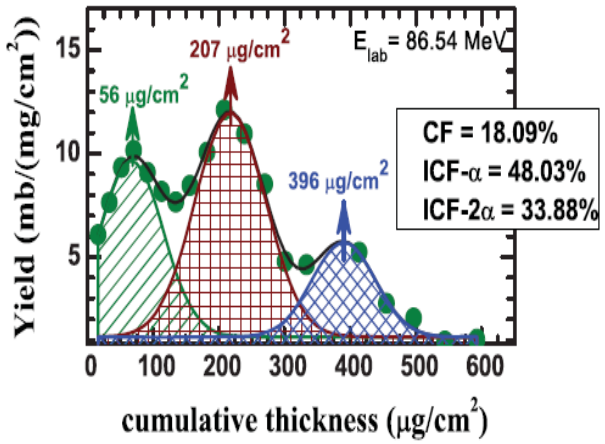
- Excitation functions: as an indication of ICF dynamics: influence of ICF on CF has been investigated as a function of projectile energy & mass asymmetry of interacting partners
- Forward recoil ranges: as a proof of fusion incompleteness Different LMT components have been observed, Relative contribution of CF and ICF have been deduced
- Angular distributions: to get the complementary information regarding ICF :- Disentangling of full and partial linear momentum transfer events
- Spin-distribution & feeding intensity profiles: to probe the entirely different entry state spin populations: Relatively large 'ℓ' values found to be contributed to ICF

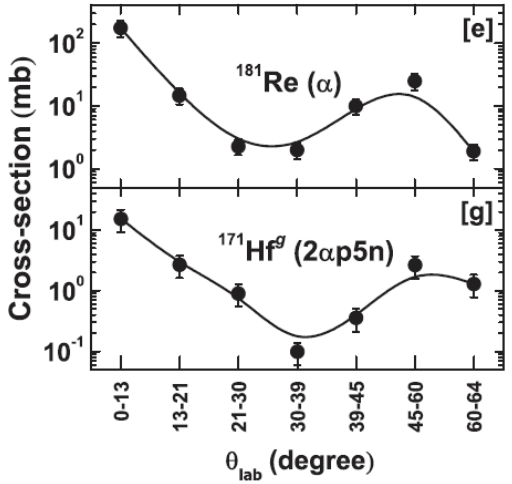
Gupta et al., Physical Review C80, 024613 (2009)
Yadav et. al., Physical Review C85, 034614 (2012)
Singh et al., Physics Letter B 67, 20(2009)

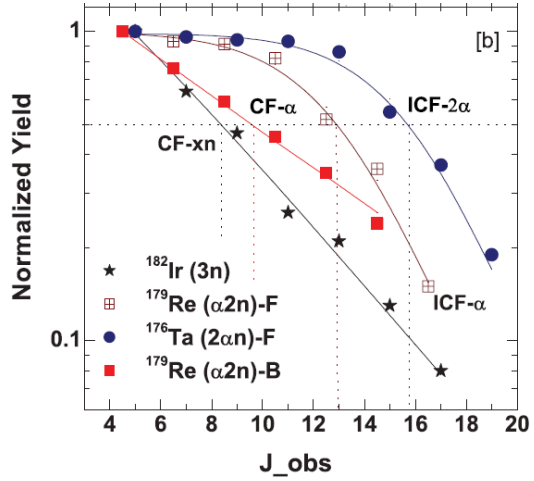
PHYSICAL REVIEW C **85**, 034614 (2012)



PHYSICAL REVIEW C 85, 064617 (2012)







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Investigations done

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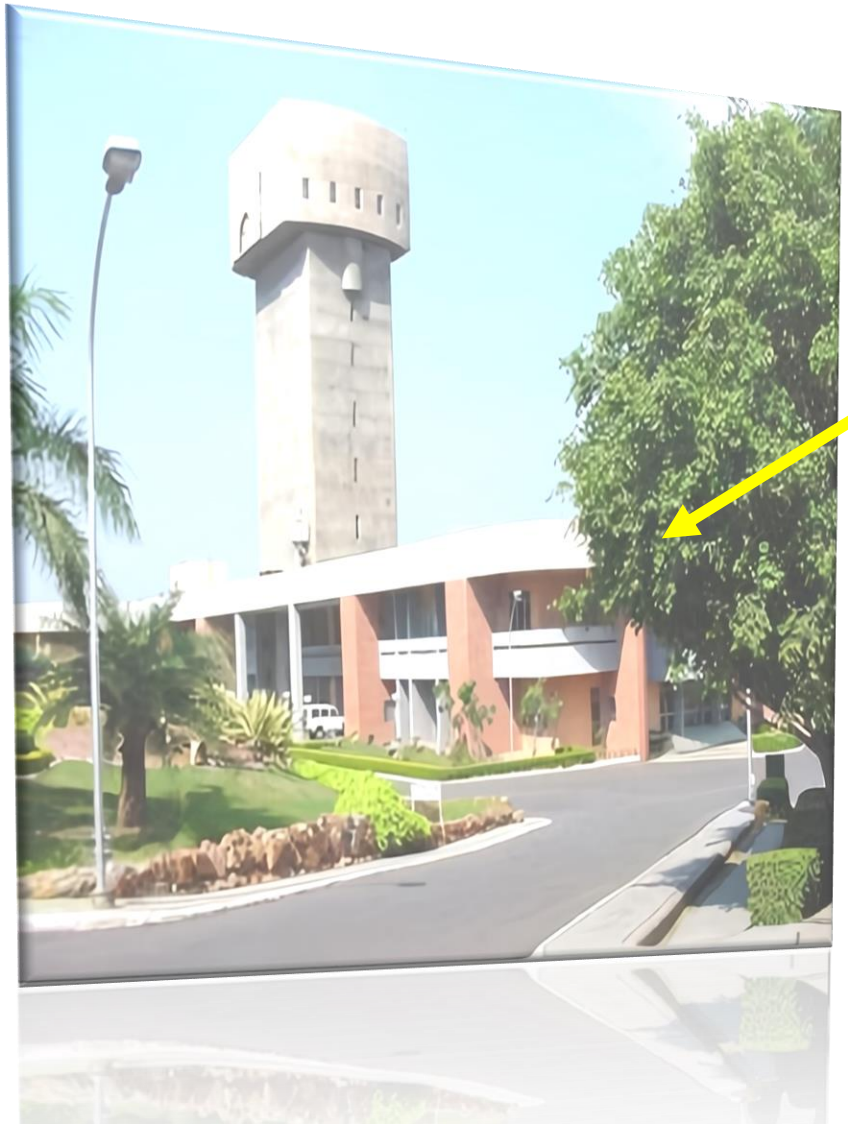
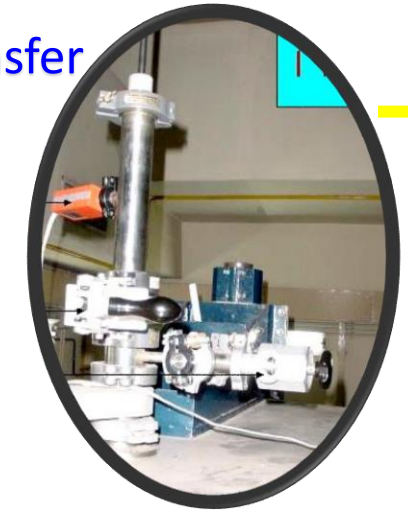
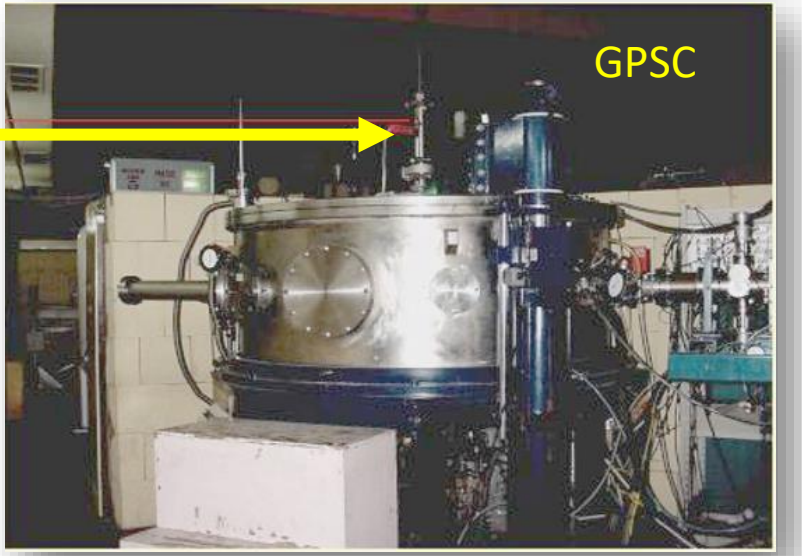


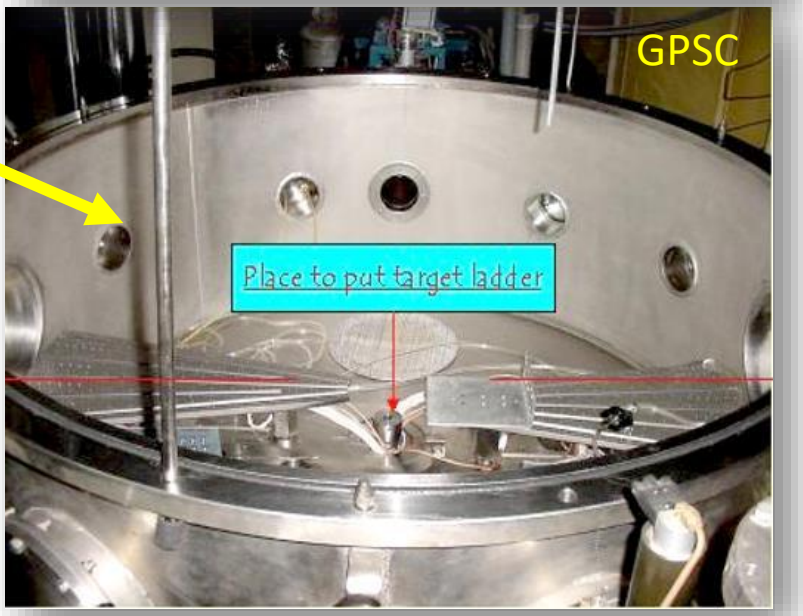
Inter University Accelerator Centre , IUAC New Delhi India

In Vacuum Transfer Facility





Inside view of GPSC



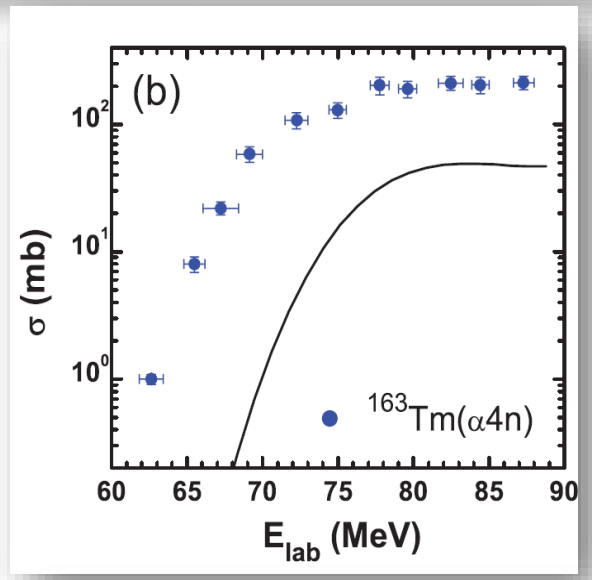
Estimation of ICF fraction

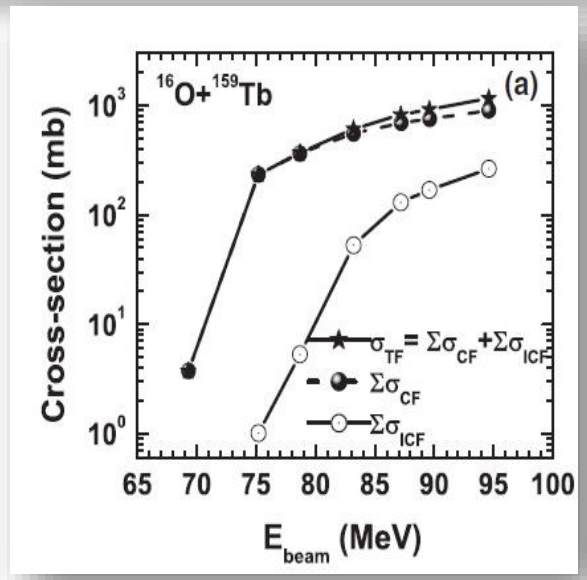
Estimation of ICF contribution

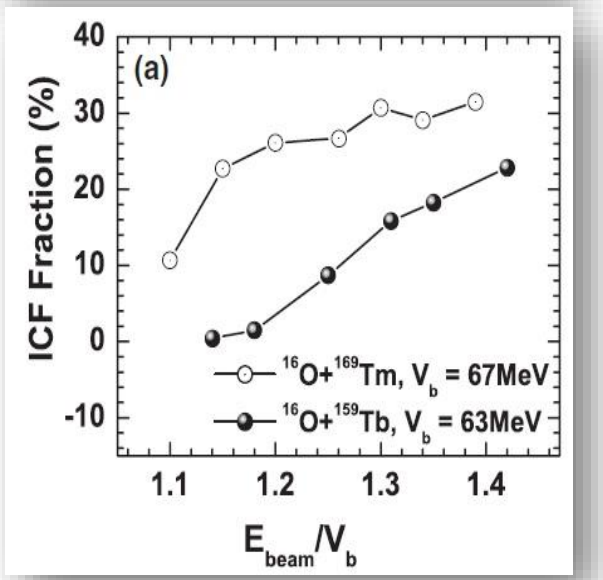
$$\Sigma\sigma_{\mathrm{ICF}} = \Sigma\sigma_{\mathrm{exp}} - \Sigma\sigma_{\mathrm{PACE4}}$$

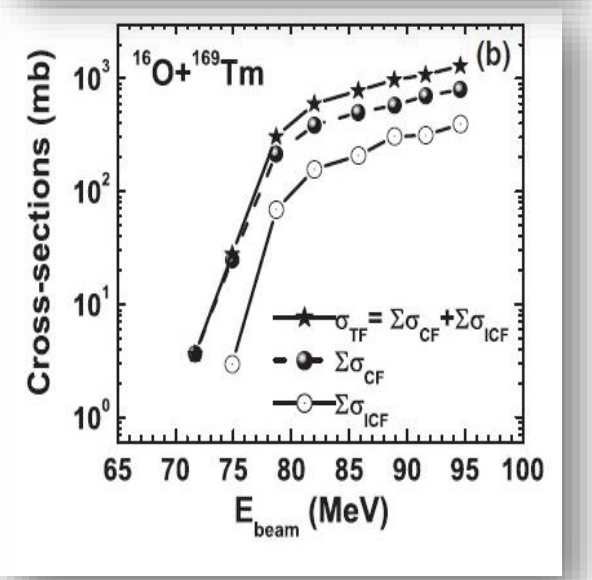
Estimation of ICF Fraction

$$F_{ICF}(\%) = \frac{\sigma_{ICF}}{\sigma_T} \times 100$$









Role of deformation

- Incomplete fusion is governed by the relative velocity ($v_{relative}$) of projectile i.e.,

$$V_{relative} = \sqrt{2(E_{cm} - V_b)/\mu}$$

Here;
V_b is the CB between the interacting partners,
$E_{c.m.}$ is the projectile energy in center of mass frame and
μ is the reduced mass of the projectile and target

- $F_{ICF}(\%)$ @ constant $V_{relative}$

S.No.	Projectile	Target			$F_{ICF}(\%)$*
		Atomic Number (Z)	Mass Number(A)	Deformation (β_2)	
1	^{12}C	49	115	0.08	4.84
2		65	159	0.271	10.6
3		69	169	0.295	13.45
4		71	175	0.287	17.9
5		73	181	0.269	13.45
6	^{16}O	41	93	0.053	5.97
7		49	115	0.08	13.61
8		45	103	0.18	11.47
9		65	159	0.271	22.96
10		67	165	0.293	28.27
11		69	169	0.295	30.16
12	^{19}F	65	159	0.271	28.91
13		69	169	0.295	33.53
14		71	175	0.287	32.89

*$F_{ICF}(\%)$@ $V_{relative}$=0.053c

Role of deformation

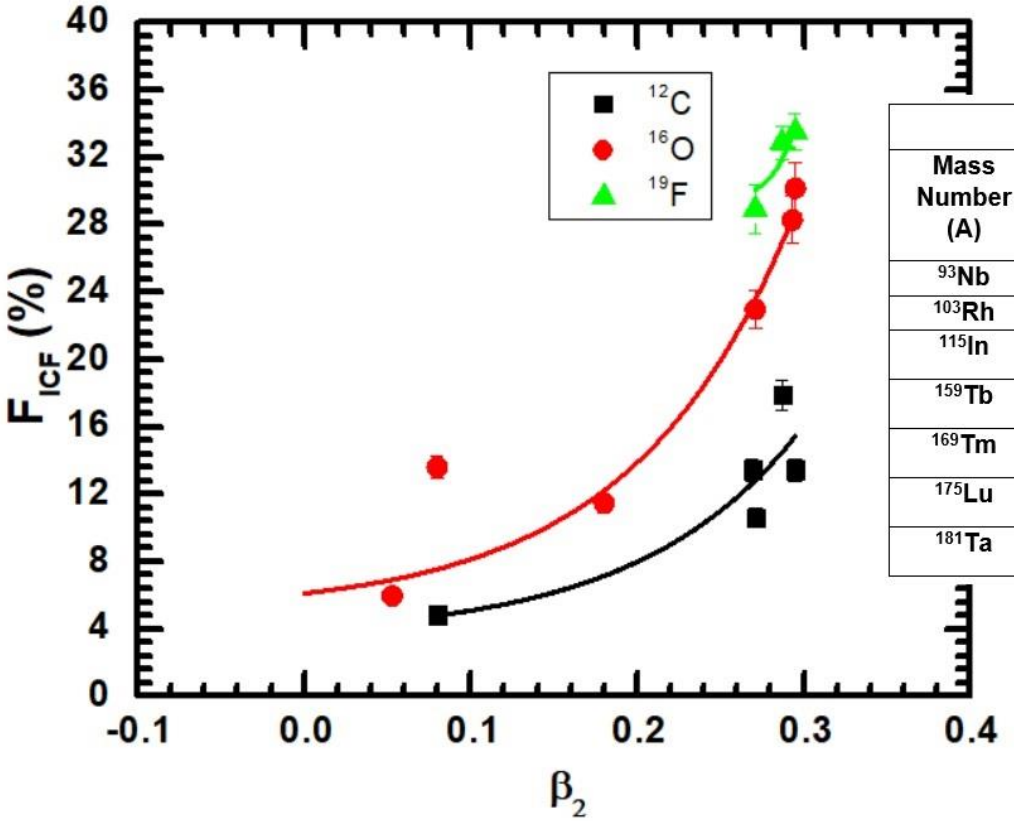
Fitting parameters

Beam	a	b
^{19}F	7.6	4.9
^{16}O	4.3	6.1
^{12}C	2.5	5.9

$$F_{ICF}(\%) = a \times \exp(b \times \beta_{2})$$

Where,
a and b are the fitting parameters and
β_2 is the deformation of the target nucleus

P. Moller, et al., Atomic data and Nuclear Data table 59, 185 (1995).



Target	
Mass Number (A)	Deformation Parameter (β_2)
^{93}Nb	0.053
^{103}Rh	0.18
^{115}In	0.08
^{159}Tb	0.271
^{169}Tm	0.295
^{175}Lu	0.287
^{181}Ta	0.269

F_{ICF} (%) as a function of target deformation parameter (β_2) for 14 systems ^{12}C,+X=(In, Tb, Ta, Tm,& Lu), ^{16}O+Y=(Nb, In, Rh, Tb, Ho and Tm) and ^{19}F+Z=(Lu, Ta &Tm) Lines are fit of the data

Summary and Future Plan

- The ICF Fraction is found to depend sensitively on deformation parameter β_2
- More data for several systems involving α-cluster and non α-cluster is required to have a proper empirical relation.
- The SUMRULE Model will be modified using the relation
- Further experiments are required to get more data to establish the empirical relation.

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Thanks