Quasi-Fission and Status of Super Heavy Element

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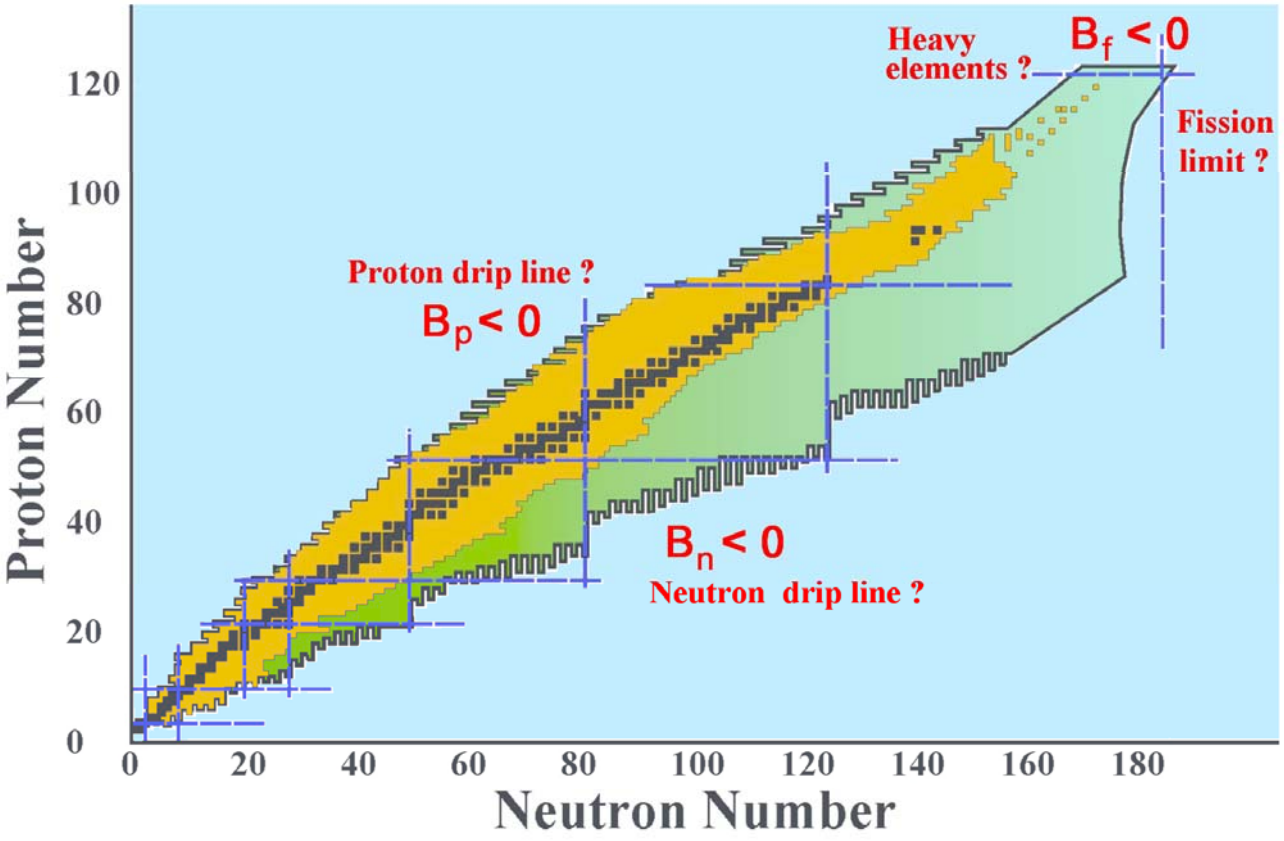
Plan of the talk

- *Introduction*
- *SHE and it's production routes*
- *Why study of quasi-fission is important?*
- *Experimental probes*
- *Facilities available at VECC*
- *Conclusion*

Where is the limits of the nuclear chart ?

Liquid drop Binding Energy :

$$B(Z,A) = a_v A - a_s A^{2/3} - a_c Z^2/A^{1/3} - a_{asy} (N-Z)^2/2A + a_\delta A^{-3/4}$$



Fissility parameter

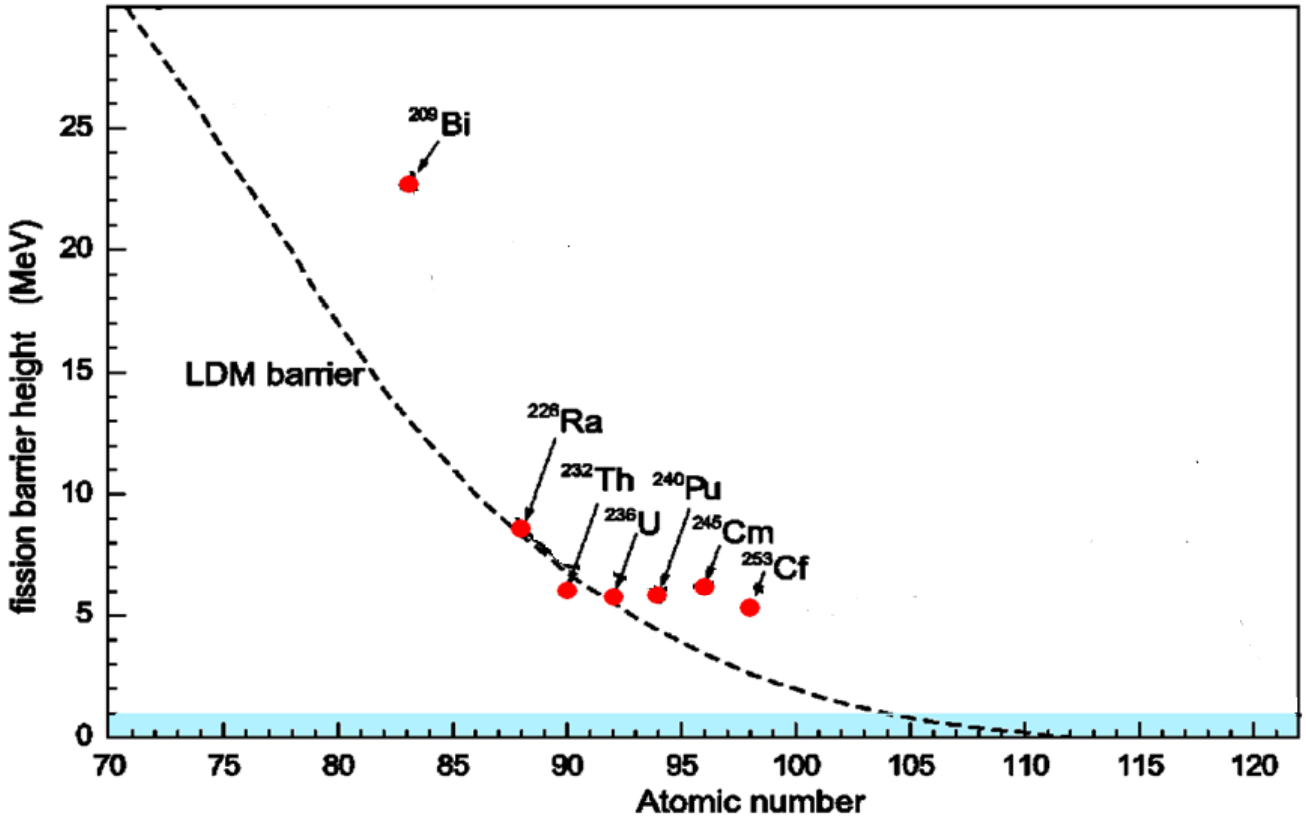
$$\chi = E_C(0)/2E_S(0)$$

Fission barrier

$$B_f = 0.7\ (1-\chi)^3.\ a_s.\ A^{2/3}$$

Nucleus with Z >104 will not exists since there is no barrier

Fission barrier

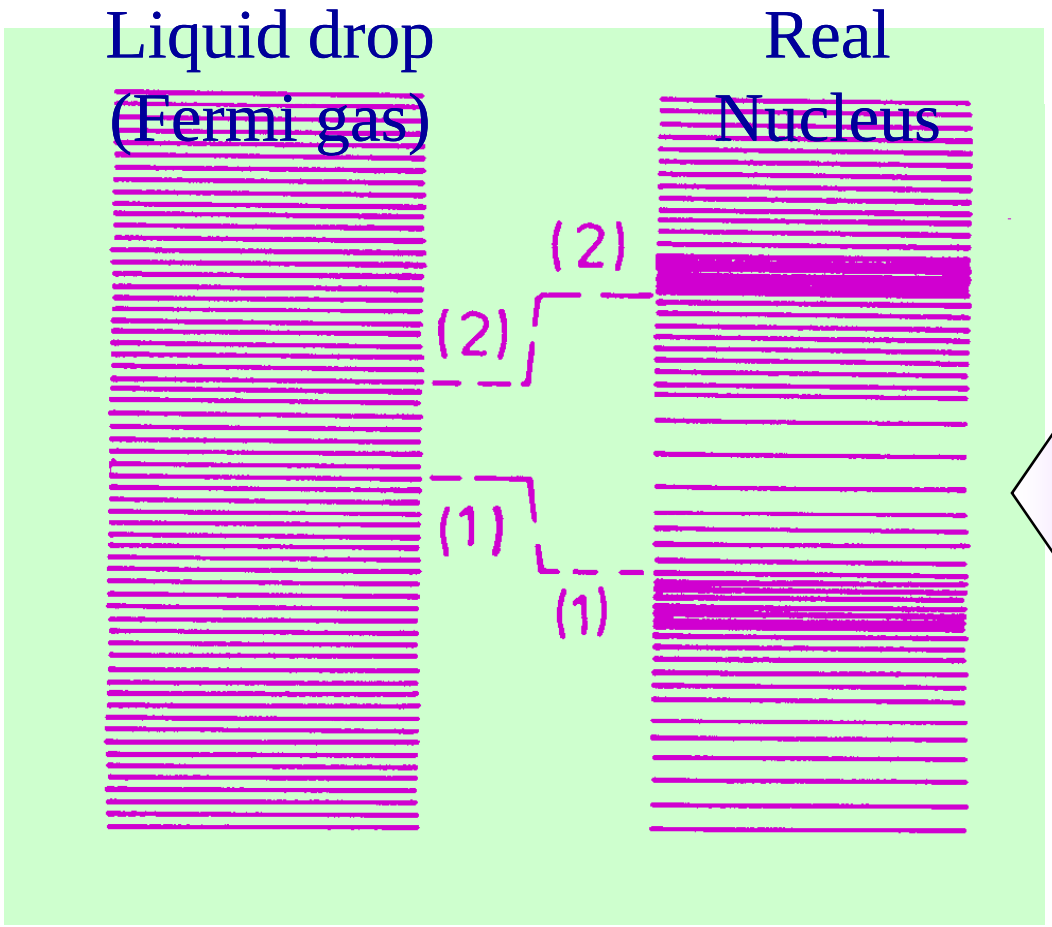


Measured barrier heights are much larger than liquid drop prediction

Itkis et al., Phys. Rev. C 65, 044602 (2002)

Shell effect

Stability arises from the shell structure



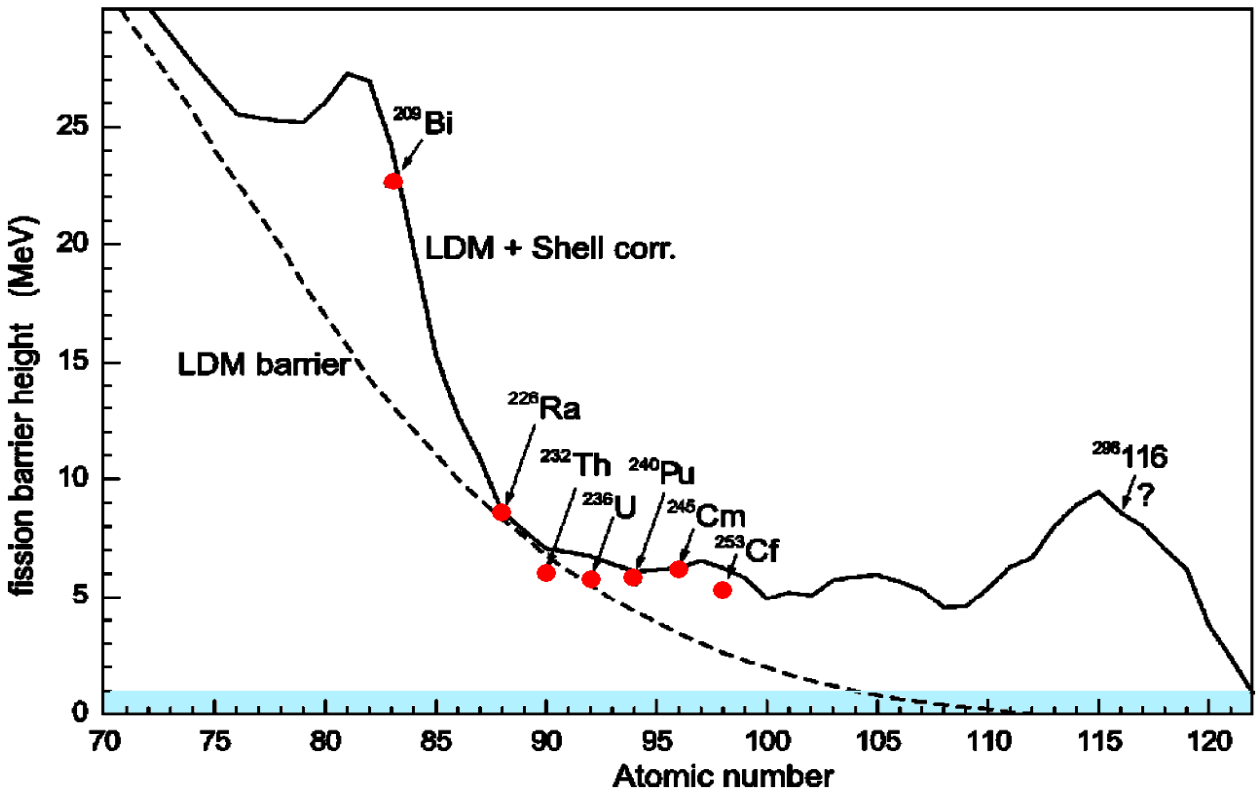
$$\mathbf{E = E_{LDM} + E_{SHELL}}$$

$$E_{SHELL} = \sum_{i=1}^{A} e_i - \langle E_{SHELL} \rangle$$

The nucleus is more tightly bound if the level density is small near Fermi surface

Nucleons occupy more tightly bound single particle states

Why does “SHE” exist?

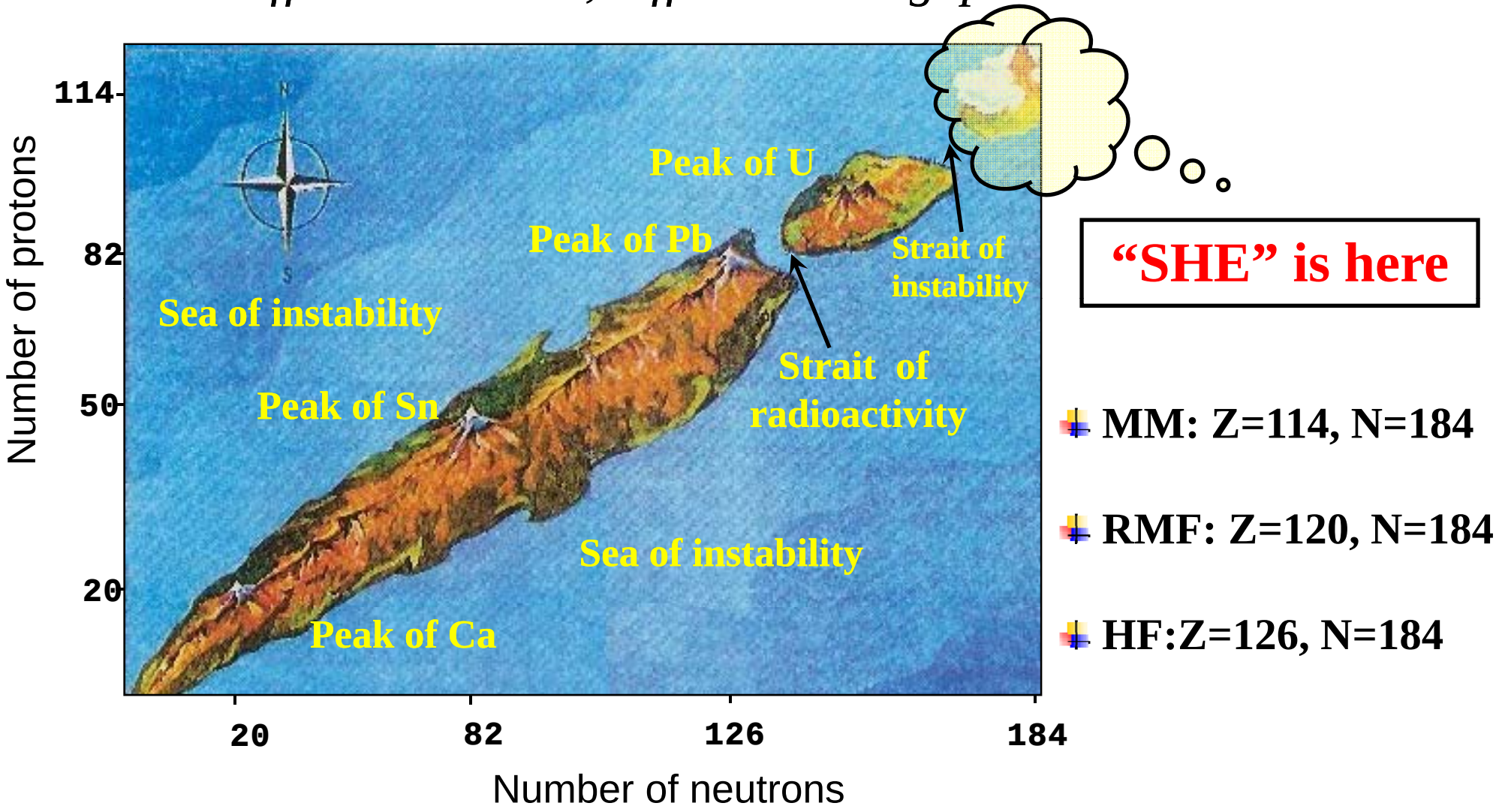


Regions of very low level density, quantum shell gaps, enhance the stability and heavy nuclei can develop a large “barrier” to decay

Itkis et al., Phys. Rev. C 65, 044602 (2002)

Where is the island of "SHE"?

Different theories, different shell gaps



- **MM: Z=114, N=184**
- **RMF: Z=120, N=184**
- **HF:Z=126, N=184**

From Geggeler, FLNR presentation (http://159.93.28.88/linkc/)

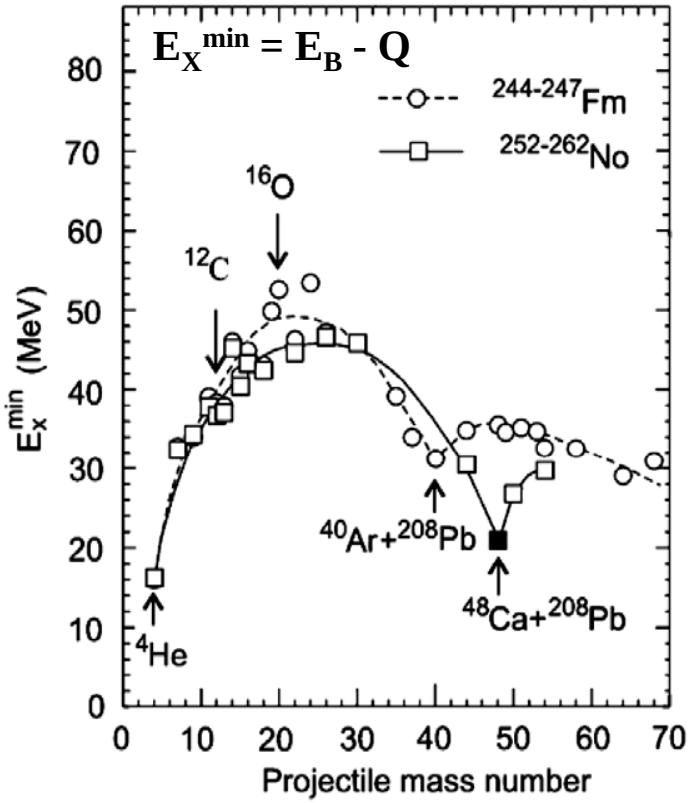
Production: Cold Fusion

Local minimum in excitation energy for ^{208}Pb target due to extra binding.

Production of super-heavy elements using

$^{208}Pb/^{209}Bi + {}^{50}Ti \ldots {}^{86}Kr$

***'Cold fusion'** as it generates the least excitation energy (15 - 20 MeV)*



- **Production of elements 107 to 112 using Cold fusion at GSI**
- Element 113 synthesized at **RIKEN**: Production cross-section of 55 Femto-barns

The dramatic drop of the production cross section with increasing Z practically excludes the continuation of such experiments for heavier elements

Production: Hot Fusion

Production of super-heavy elements using actinide targets:

^{238}U….^{249}Cf + ^{48}Ca

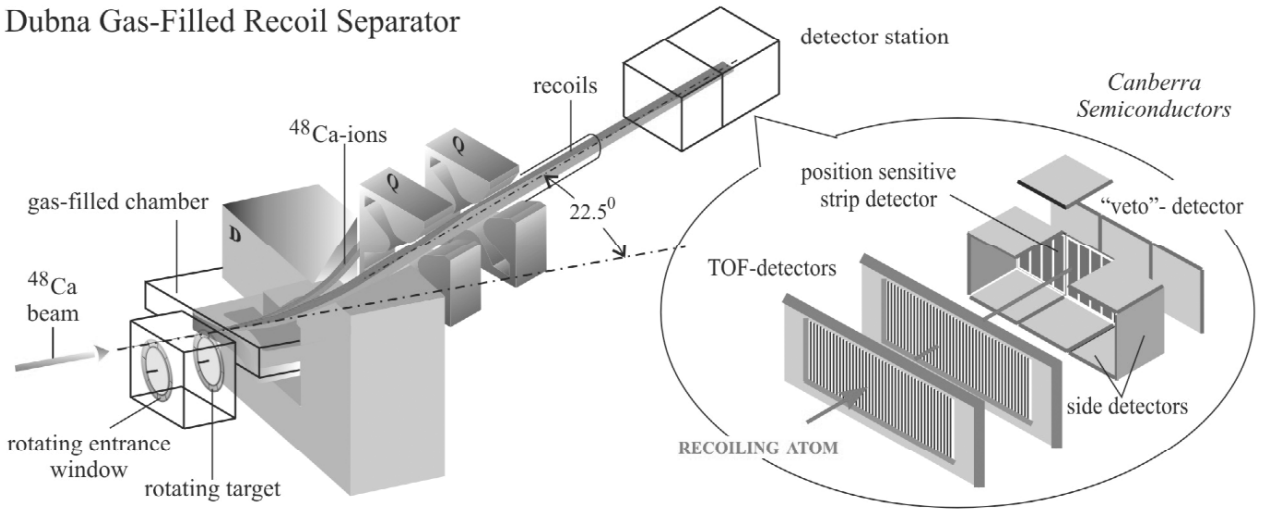
- *Higher excitation energy (E_x ~ 30 - 50 MeV) leads to emission of more neutrons (3n or more)*

- **Production of elements 112 to 118 using hot fusion at Dubna**

Discovery of the new element with Z=117, April, 2010

- One element was discovered in ^{48}Ca+ ^{249}Bk in 70 days experiment with Beam intensity ~ 50 microAmp

Detection



- Residues are separated in a separator and implanted in the focal plane detectors
- Prospective candidates are selected by time of flight and energy deposited
- Super-heavy residues decay by successive α-decay or spontaneous fission. Identification is by detecting successive α -decay chain and time correlation

Experimental status

Experiments to find SHE have been pursued mainly at three different places:

GSI (Germany), JINR (Russia), and RIKEN (Japan)

- **GSI:** alpha-decay chains were observed from super heavy nucleus $^{269}110$ and later on, from $^{270}108$, $^{272}111$, $^{277}112$

- **RIKEN:** discovered the $^{278}113$ SHE, and reconfirmed alpha decay chains from $^{271}110$, $^{272}111$ and $^{277}112$, observed earlier at GSI.

- **JINR:** Alpha decay chains of nuclei $^{294}118$, $^{293,292,291,290}116$, $^{288,287}115$, $^{289,288,287,286}114$, $^{284,283,282}113$, $^{285,283}112$, $^{280,279,278}111$, $^{276,275,274}109$, $^{275}108$, $^{272,270}107$, $^{271}106$ were detected

- JINR & US collaboration (ORNL & LLNL): Discovery of the new element $^{294,293}117$, in April, 2010

Scope in VECC

Synthesis experiments at VECC?

N☹

✓ *Beam energy near Coulomb barrier*

✗ *Large beam intensity (~ pμA) : thin target & small cross section*

✗ *Efficient residues identification : Fragment separator*

✗ *High detection efficiency*

Why the production cross section for SHE is small?

Quasi fission

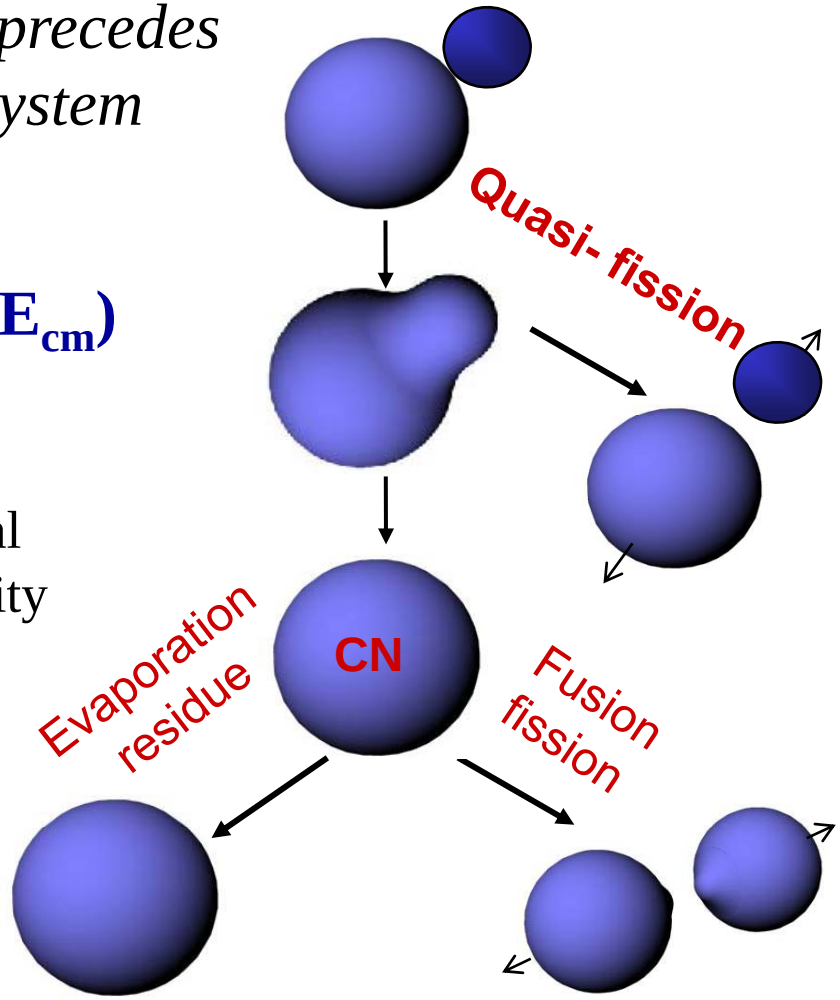
Quasi-fission is a fission-like process that precedes the formation of a compact mononuclear system

$$\sigma_{ER}(E_{cm}) = \sigma_{capture}(E_{cm}) \cdot P_{CN}(E_{cm}) \cdot P_{survival}(E_{cm})$$

Capture cross-section

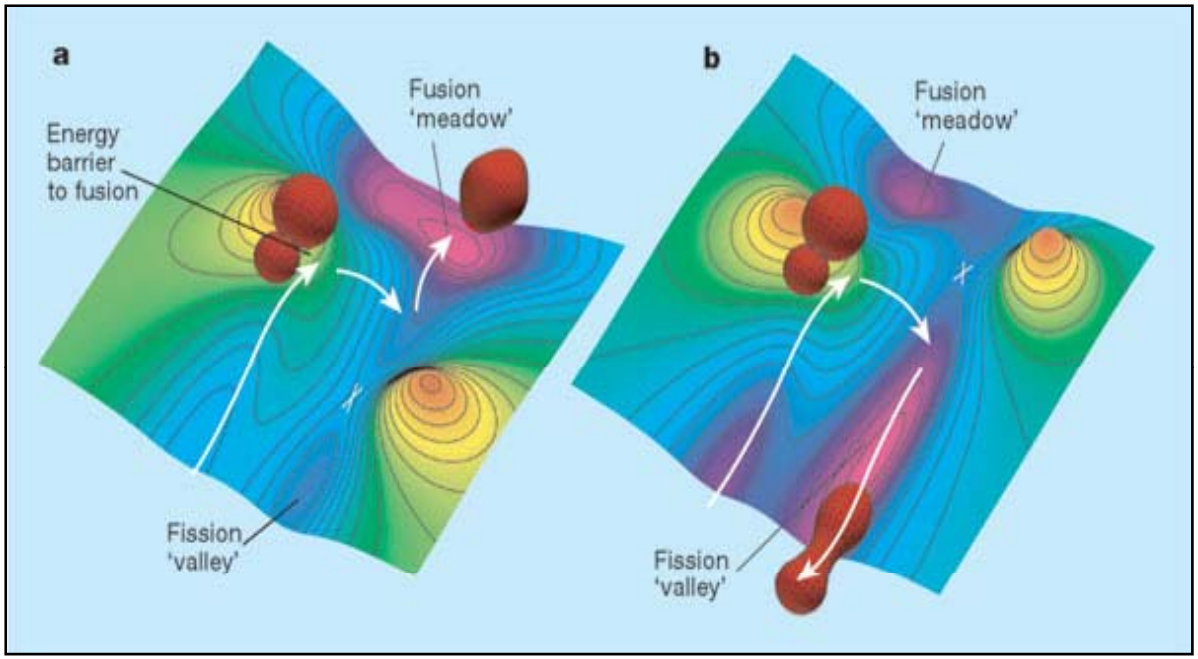
Probability of CN formation

Survival probability of CN



➢ For optimization of ER formation the challenge is to understand which parameters influence P_{CN}

Factors that may affect Quasi-fission



- ***Excitation energy***
- ***Angular momentum***
- ***Entrance channel mass asymmetry***
- ***Nucleus deformation and orientation***

Nuclear shape evolution in a multi-dimensional potential energy landscape plays the key role to determine the fission path

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

Experimental Probes to study Quasi fission

- *Study of evaporation residue (ER)*

- ER cross section will be hindered for QF

- *Study of fission fragment angular distribution*

- Large angular anisotropy for QF

- *Neutron multiplicity*

-Low pre-scission neutron multiplicity for QF

➢*Accurate measurement of width of mass distributions*

- More sensitive probe

T.K. Ghosh et al., Phys. Rev. C 69, 031603 (R) (2004)
T.K. Ghosh et al., Phys. Rev. C 70, 011604 (R) (2004)
K. Banerjee et al., Phys. Rev. C (in press) (2010)

Role of target deformation on Quasi fission

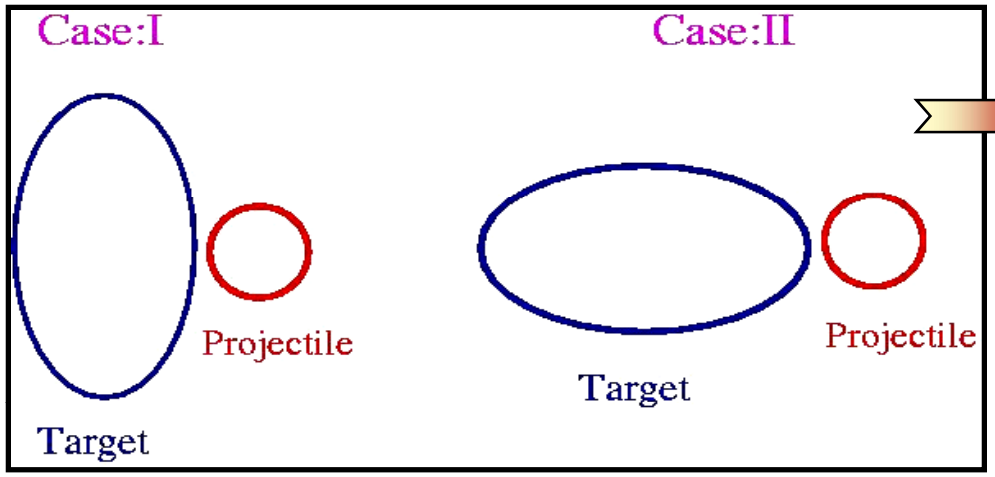
- ✓ $^{19}F + ^{209}Bi$
- ✓ $^{16}O + ^{209}Bi$

■ *^{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*

Role of target deformation



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

Contribution from Quasi fission?

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

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

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

K. Banerjee et al; Phys. Rev. C (in press) (2010)

Quasi-fission for more symmetric system

In our country, we didn't have an accelerator that could accelerate a projectile heavier than Fluorine/Neon to the Coulomb barrier energy when an actinide target is used !

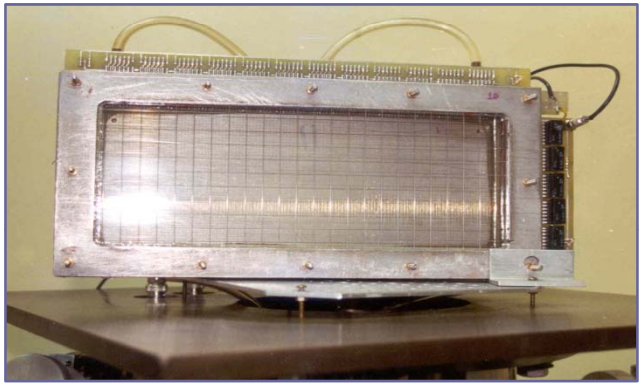
$^{84}Kr + {}^{198}Pt$
$^{74}Ge + {}^{208}Pb \Rightarrow {}^{282}(SHE)_{114}$
$^{40}Ca + {}^{242}Pu$

$^{80}Se + {}^{208}Pb$
$^{56}Fe + {}^{232}Th \Rightarrow {}^{288}(SHE)_{116}$

VECC machine will allow us, to reach the Coulomb barrier for more mass symmetric system

Instrumentation

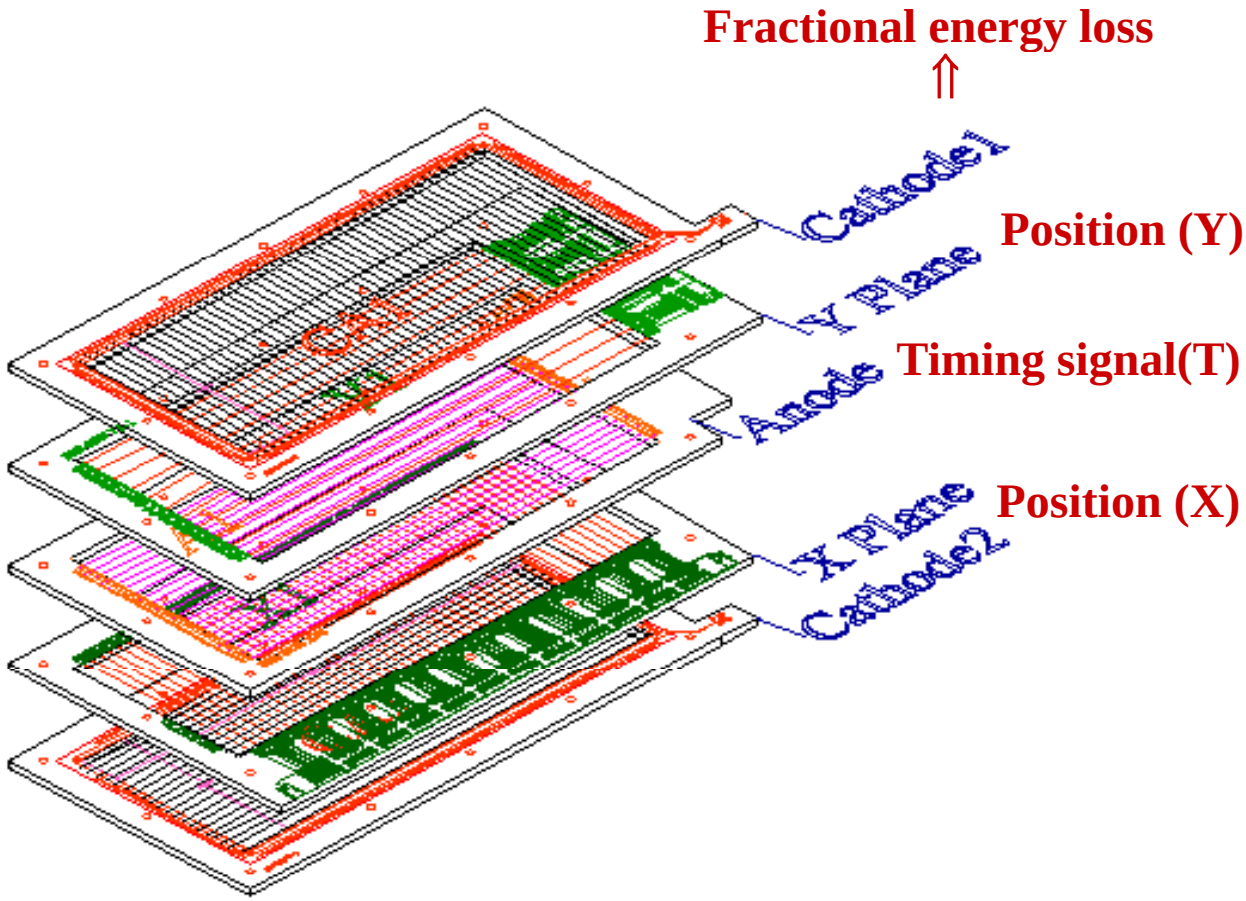
We have designed and fabricated Multi Wire Proportional Counters (MWPC) in our laboratory.



Effective area:

20 cm × 6 cm

24 cm × 10 cm



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

Facility at VECC

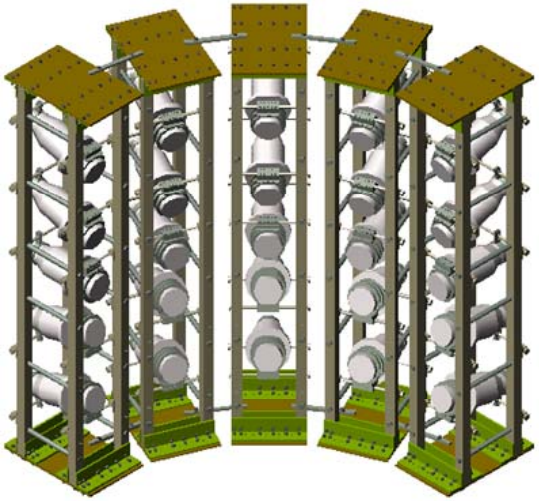
VECC scattering chamber

Dimension :
Diameter : 1 meter
Length: 2 meter long

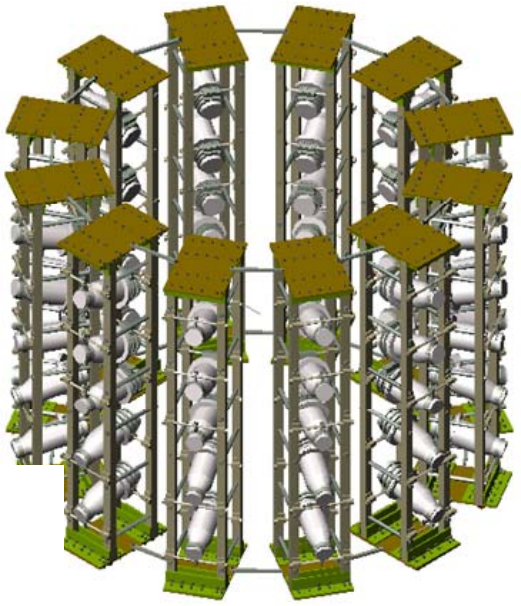
Large flight path -> ideal for mass measurement

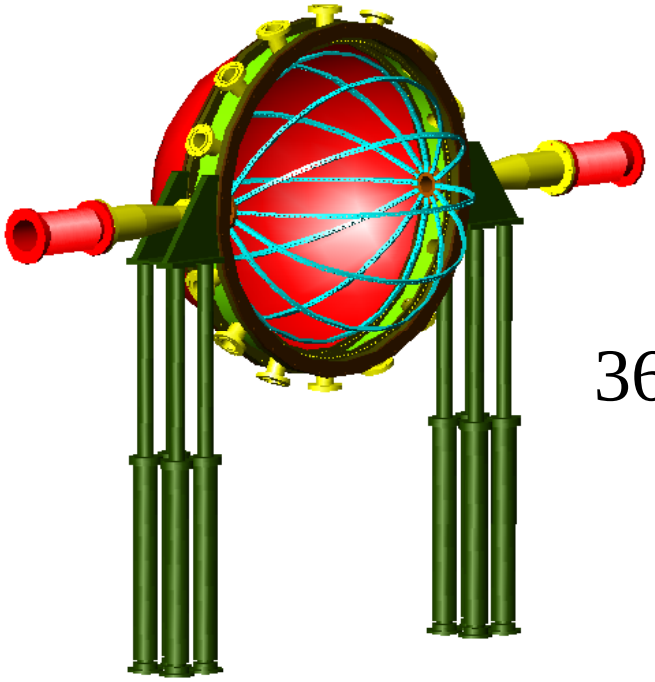
Expected mass resolution ~ 2 amu

VECC neutron array



Complete dismountable structure





Thin wall scattering chamber
Dia: 1 meter
Thickness: 3 mm
Flight path: 45 cm for FF

360 degree access for setup

Summary

- *New measurement of mass distributions of fission fragments can be carried out in order to understand the formation mechanism of heavy actinides and super heavy elements*

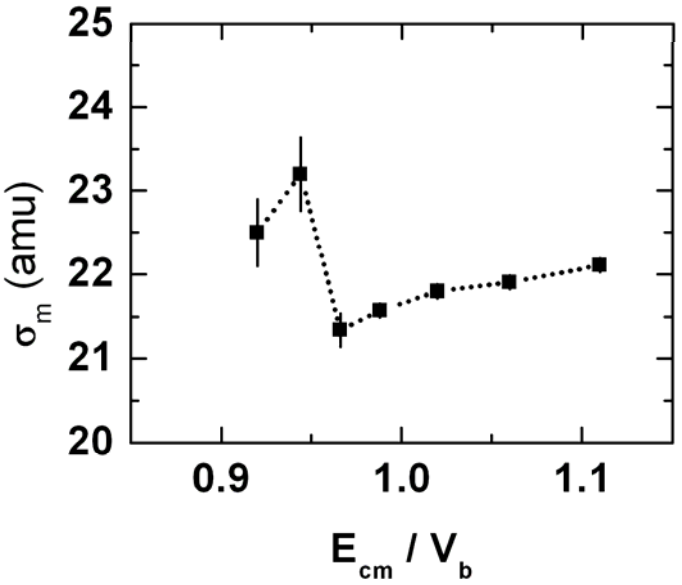
- *Effect of mass asymmetry and target deformation can be explored and dynamics of quasi-fission process can be studied*

Thank You

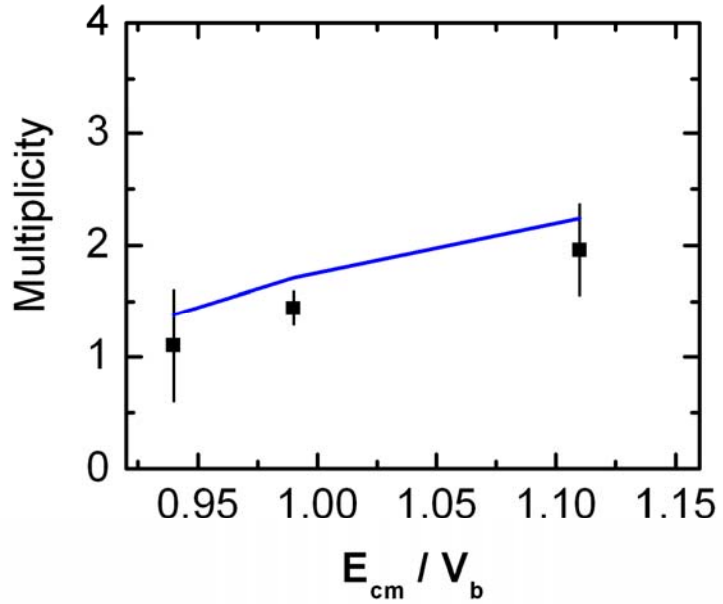
Mass distribution : A sensitive probe

- ***Probe:*** *Mass distribution*

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



- ***Probe:*** *Pre-scission neutron multiplicity*



Failed to detect quasi-fission

K. Banerjee et al; Phys. Rev. C (in press) (2010)