# Influence of exotic structure and weak binding of $^{6,8}He$ on reaction dynamics near the Coulomb barrier

Aradhana Shrivastava

Nuclear Physics Division

Bhabha Atomic Research Centre,

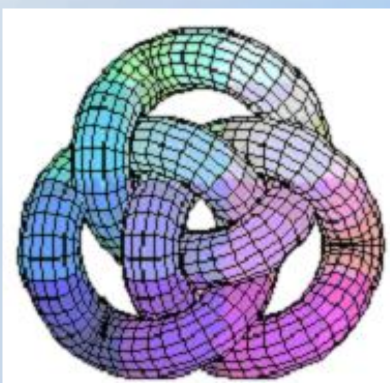
India

# Reactions with unstable nuclei

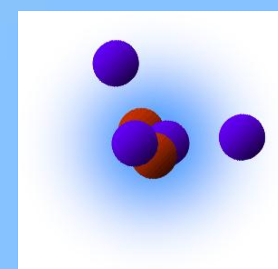
**Addition to Weak binding – large isospin**
**Exotic structure – Halos and skin**

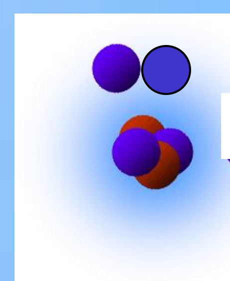
**Lightest Borromean Nuclei $^{6}He$**

**Inert $\alpha$ core, known $\alpha$-n interaction**



$^{4}He + n + n$
cigar



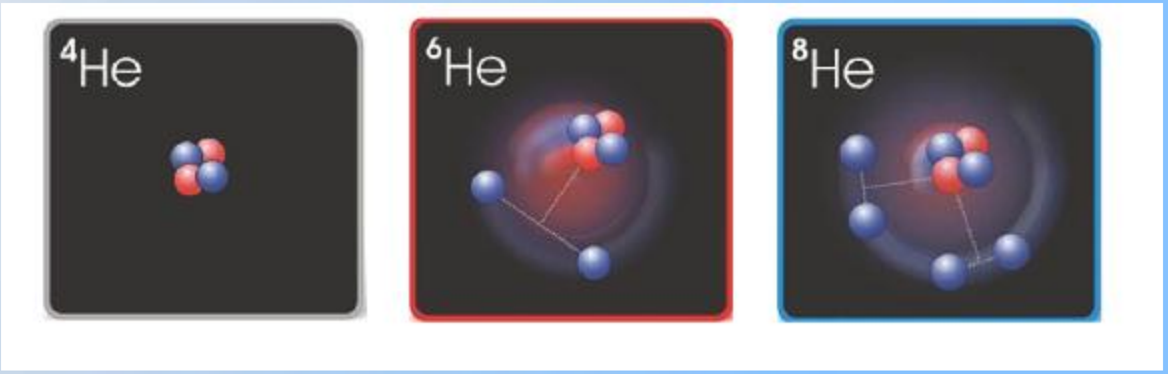


Di-neutron

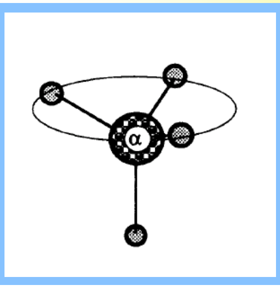
t + t

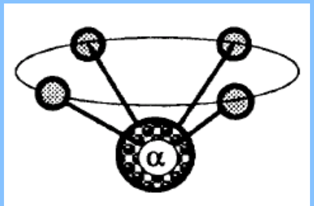
# He isotopic chain:

- Nucleon emission threshold from 20.5 MeV to 0.9 MeV
- $^{6}$He and $^{8}$He “Borromean” structures
- $^{8}$He : $^{4}$He + 4n $^{6}$He+2n (double Borromean)
- Charge radius of $^{6}$He > $^{8}$He,
- Neutron separation energy $^{6}$He < $^{8}$He




Neutrons in $^{8}$He




**$^{8}$He: largest N/Z ratio, strong di-neutron correlations**

**interesting case : interconnectivity of intrinsic structure with reaction dynamics**

# Challenges

**Low intensity ($10^5$ -$10^7$ pps) + beam decay + low coss-section + small signal to noise ratio:**
**Sensitivity**

**Separation of various processes leading to same reaction product:**
**Selectivity**

## Present Talk

**Sub-barrier fusion – most neutron rich nuclei $^{8}$He + $^{197}$Au**
**New off-beam technique : KX ray and gamma ray coincidence**

**Transfer, elastic, fusion and break up E> Vb**
**$^{6}$He+$^{65}$Cu : particle-neutron and gamma ray coincidence**
**$^{8}$He+$^{65}$Cu : Particle gamma ray coincidence**

**@ SPIRAL, GANIL**

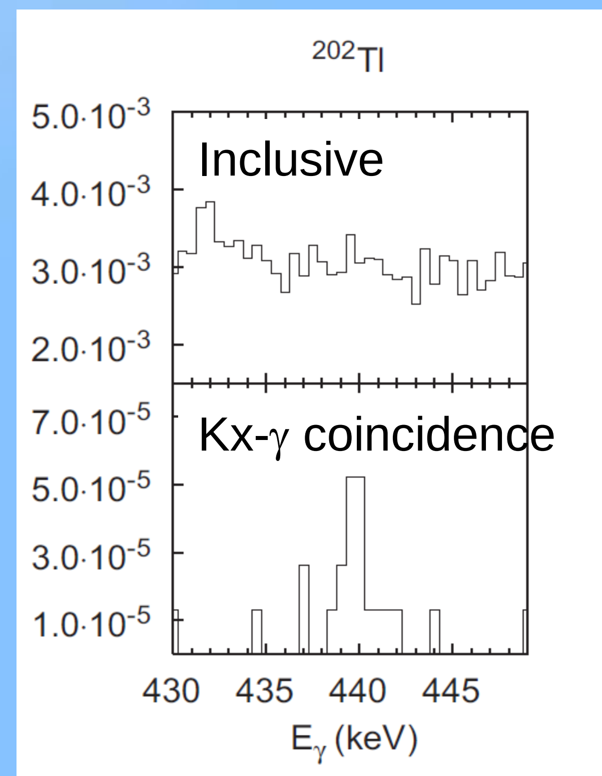
# New sensitive off-beam gamma spectroscopy Technique:

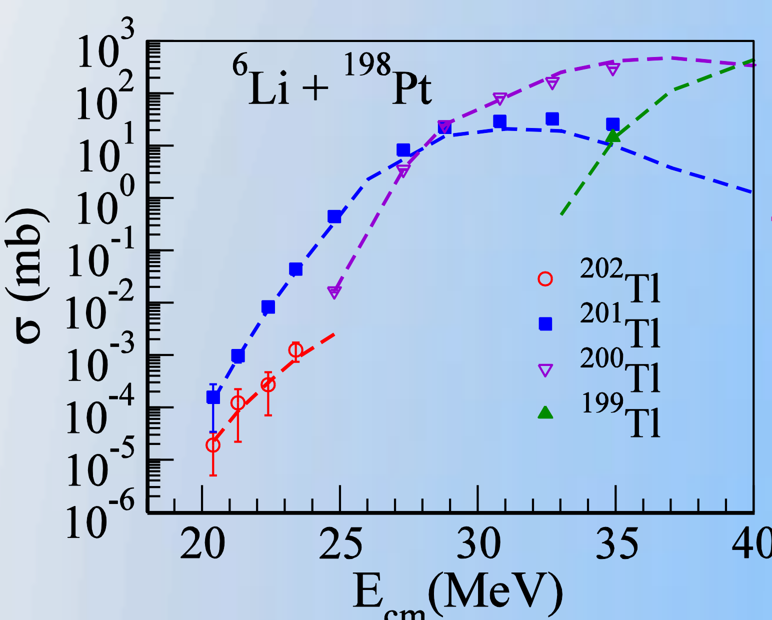
$^{8}He + ^{197}Au \rightarrow ^{205}Tl$

$^{6,7}Li$ beam from Mumbai Pelletron

$^{6,7}Li + ^{198}Pt \rightarrow ^{204,205}Tl$,

coincidence between characteristic KX rays and gamma rays of daughter nuclei of ERs




Lowest x-sec up to 20 nb

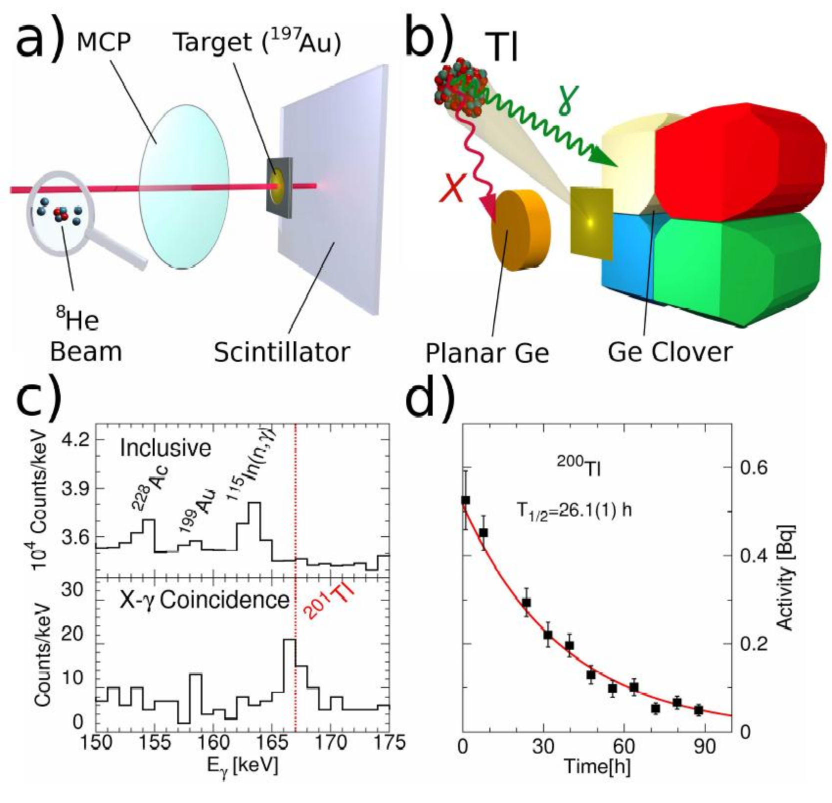
A. Shrivastava et al Phys. Rev. Letts 103(2009) 232702

# Tunneling of most neutron rich nuclei

**Primary beam: $^{13}C$ (75 MeV/A) on thick graphite,**
**Secondary beam: $^{8}He$, fully purified and reaccelerated at CIME**
**Target :$^{197}Au$ (6mg/cm$^2$) (stack $^{197}Au$ +Al)**

**Detection: sensitive off beam technique**

**$^{8}He$ ~4x10$^{5}$pps**

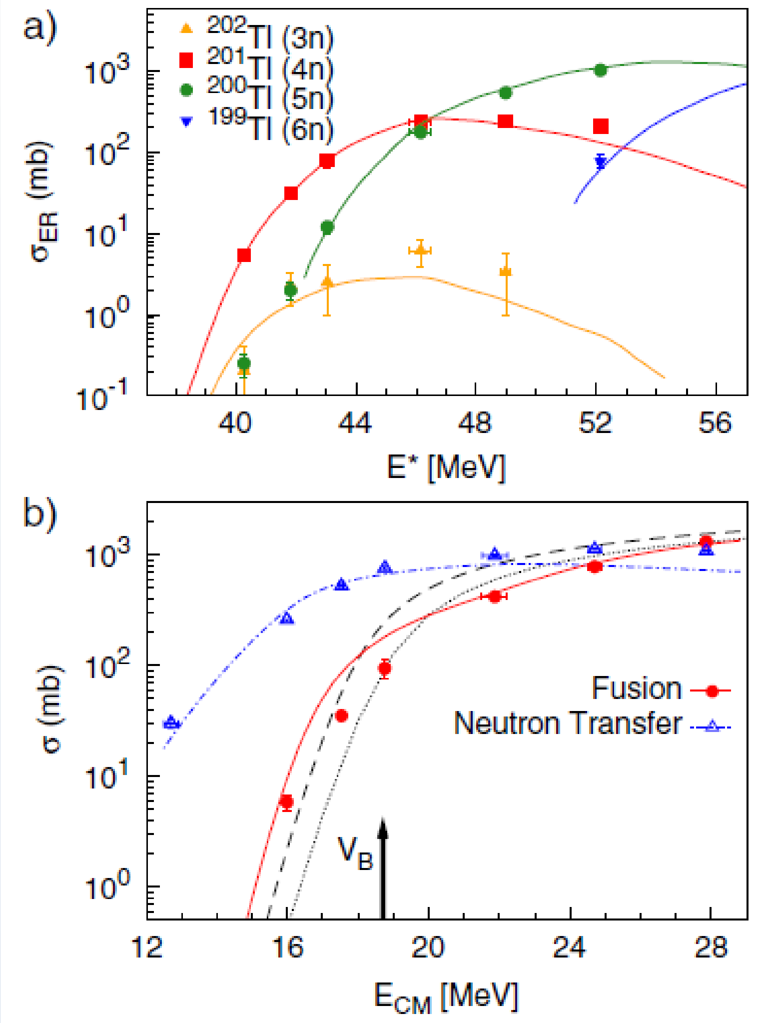



**X ray-gamma ray coinc**
**Fusion ERs $^{199}$-$^{202}$Tl**

**sensitivity**

**selectivity**

# Fusion and Neutron Transfer




**Evaporation residues from CN $^{205}$Tl**
**Accuracy similar to stable beams for low x-sec at sub-barrier: first time with low intensity RIB**

**Good agreement with statistical model calculation**

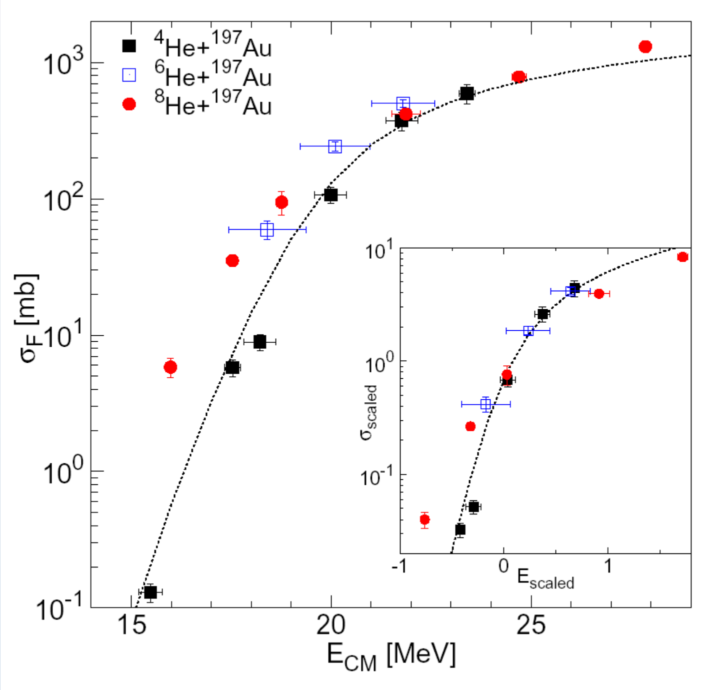
**1n,2n Transfer: $^{198,199}$Au**

**Transfer x-section larger than fusion**

**Couple channel calculations –1n,2n neutron transfer**

**A. Lemasson et al PRL 103, 232701 (2009)**

# Comparison of tunneling in He isotopes




**Adiabatic picture: fusion cross-section larger for more neutron rich isotope**

$\sigma_{fus}(^{6,8}He > \sigma_{fus}(^4He)$

$\sigma_{fus}$ $(^6He) \sim \sigma_{fus}(^8He)$

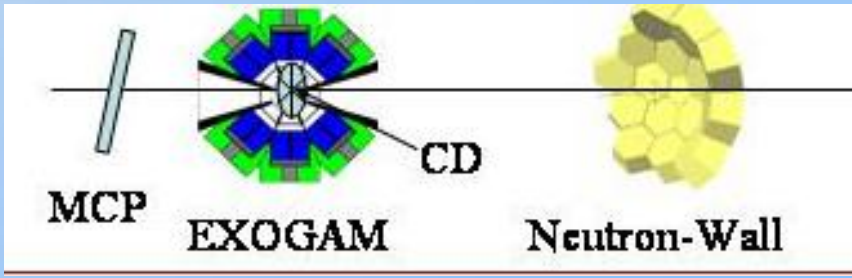
**$^8$He -easier to transfer excess neutron in peripheral reaction than to tunnel**

A. Lemasson et al PRL 103, 232701 (2009)

# Direct reaction & fusion measurement $^6$He + $^{65}$Cu

SPIRAL GANIL

$E_L$=23 MeV




**High Current 4.5x10$^7$ /sec $^6$He**
**Detector Arrays**

**Triple coincidence with RIB (p-n-γ)**

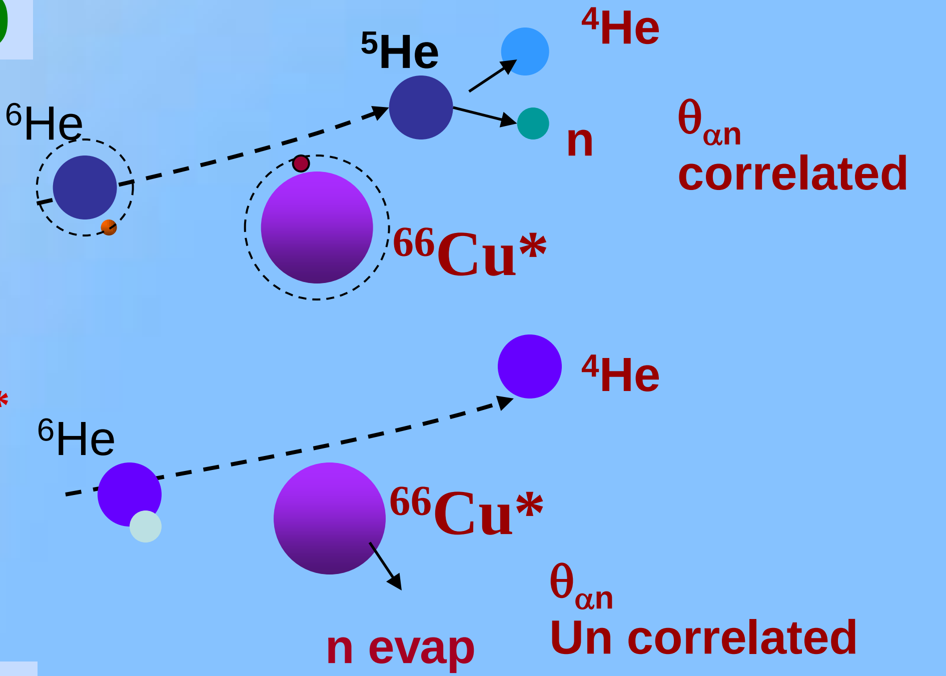
**1n and 2n transfer**

$^6$He+$^{65}$Cu

1n → $^5$He+ $^{66}$Cu*

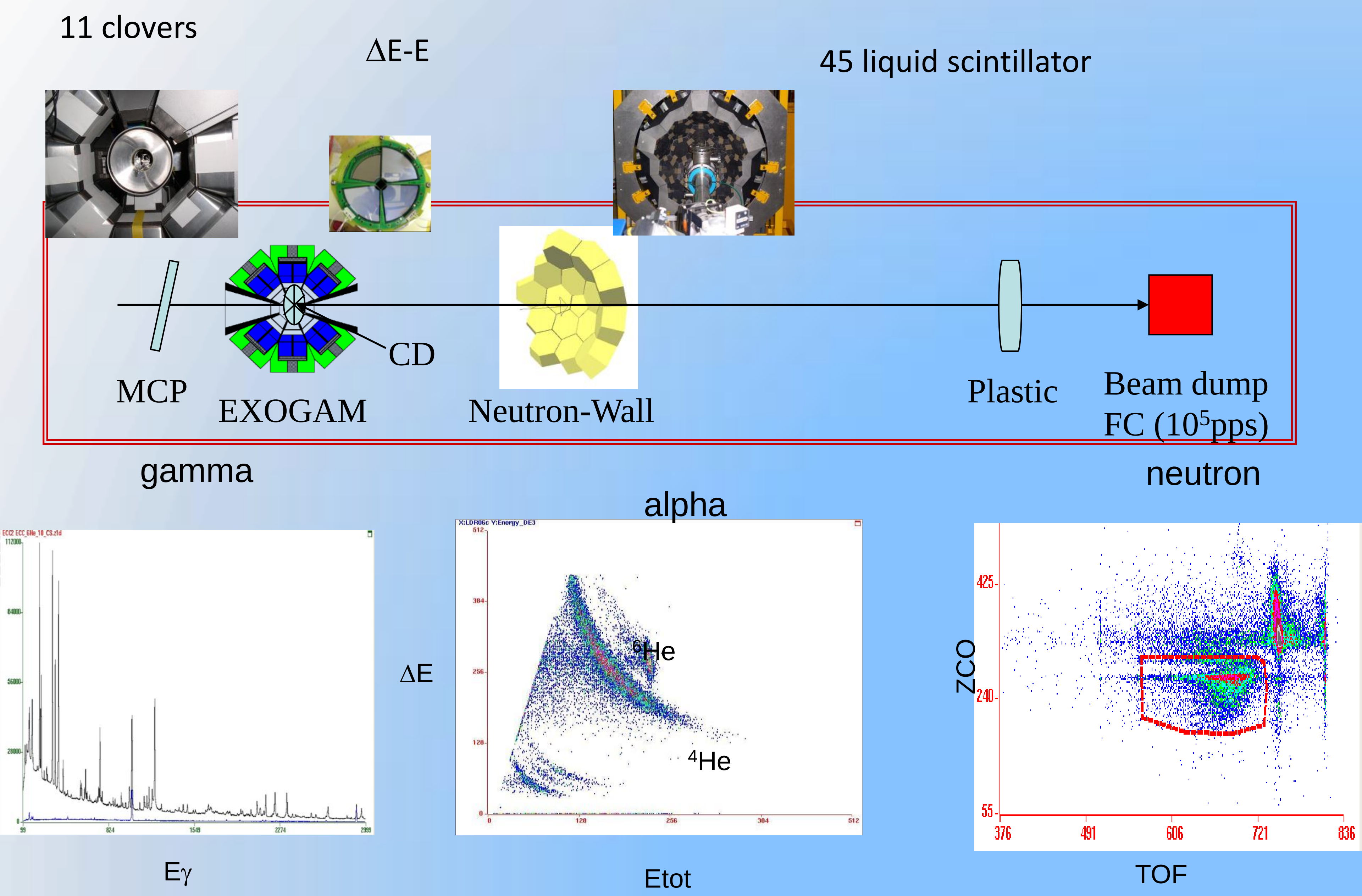
2n → $^4$He+($^{67}$Cu)*

$^4$He + γ($^{66}$Cu) + n

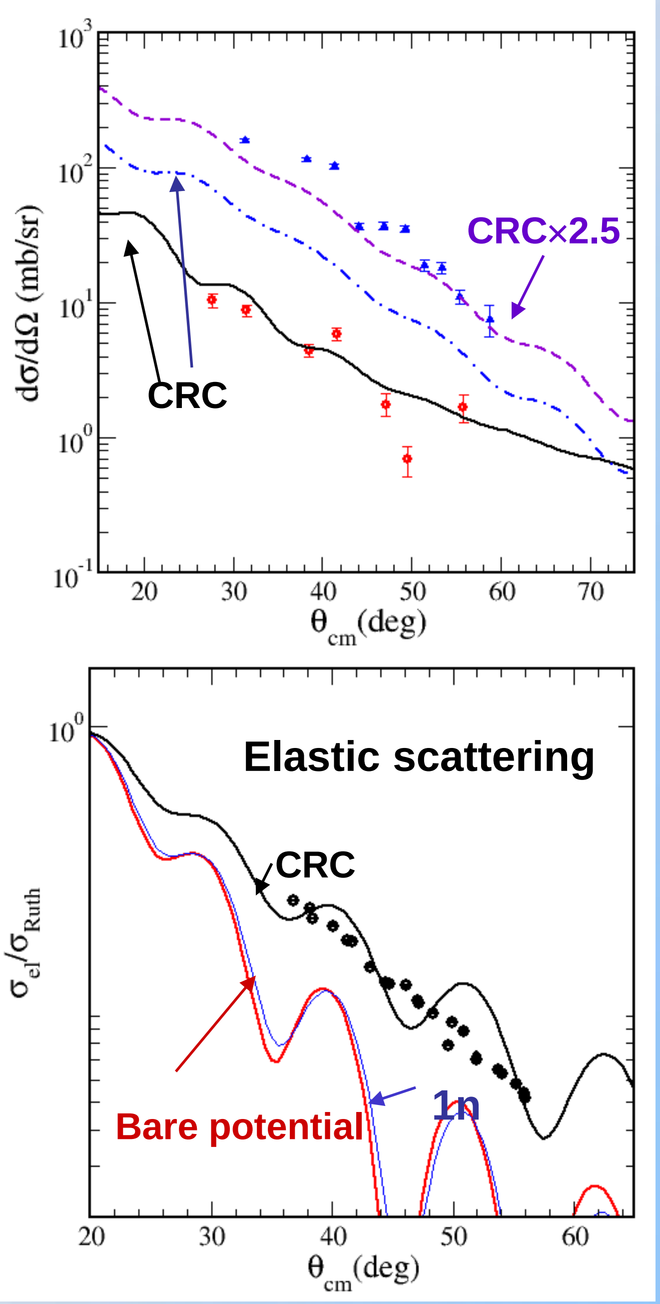



**Energy Angular correlations**
**To separate 1n /2n transfer**

# ***EXOGAM + Neutron-Wall + CD***



# Angular distribution



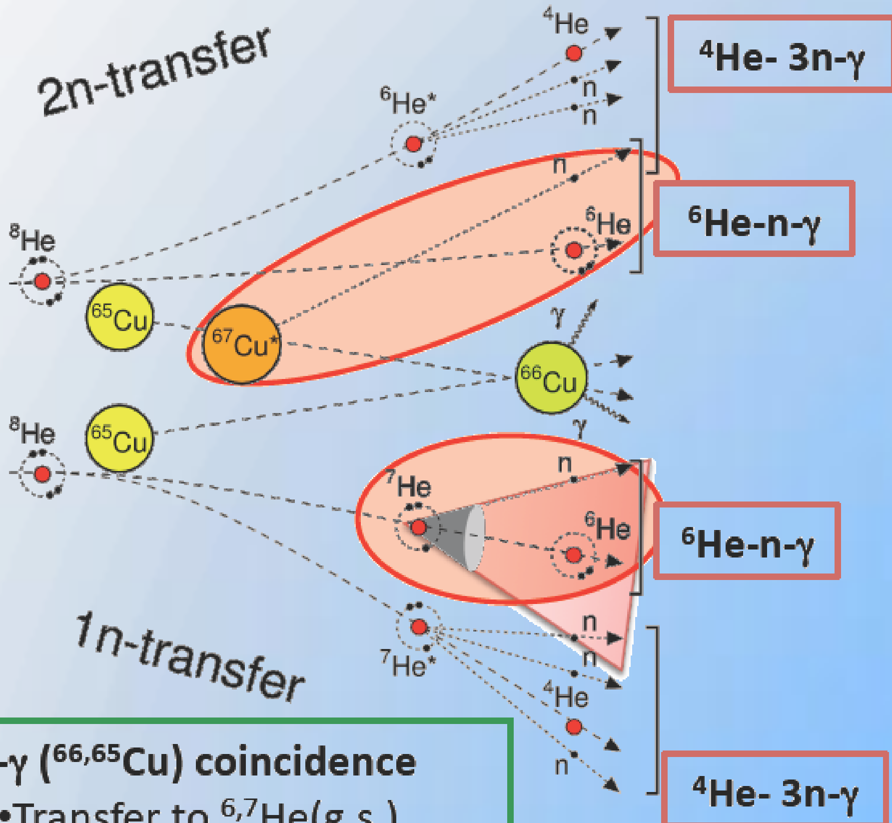


**2n transfer > 1n transfer naively – di neutron dominant**

- **CRC:**
- **coupling to nucleon transfer from $^{6}$He on elastic, transfer and fusion reactions is important**

A. Chatterjee et al. PRL , 101 (2008)032701

# Direct reaction & fusion measurement $^{8}$He + $^{65}$Cu




- **$^{6}$He-γ ($^{66,65}$Cu) coincidence**
  - ✚ •Transfer to $^{6,7}$He(g.s.)
- **$^{4}$He-γ ($^{66,65}$Cu) coincidence**
  - ✚ • Transfer to $^{6,7}$He*
  - ▬ • Compound Nucleus

= **1n+2n transfer angular distribution**

➢ Large 2n Q-value (+14.0 MeV)

transfer followed by n evaporation

**$^{67}$Cu does not survive**

Not possible to separate only with heavy residue γ-ray

1n and 2n transfer :

same final nuclei $^{6}$He-n-γ($^{66}$Cu)

➢Deconvolution 1n and 2n transfer:

- ✓kinematic correlation of $^{7}$He decay 6He+65Cu
- ✓Triples coincidences $^{6}$He-n-γ

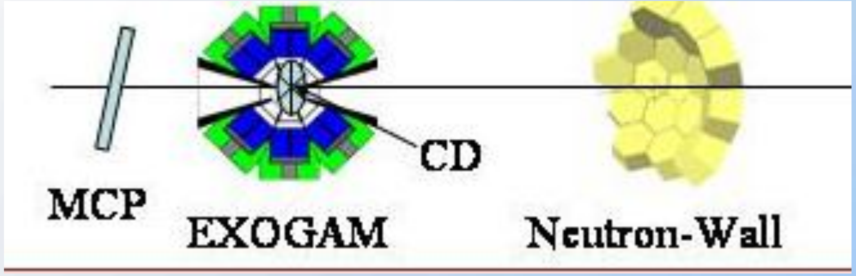
$^{6}$He+$^{65}$Cu : A. Chatterjee *et al.*, PRL **101** 32701 (2008)

- ✘ Low statistics
- ✘ Unbound excited states $^{6,7}$He*

Not possible to separate 1n and 2n transfer with this technique

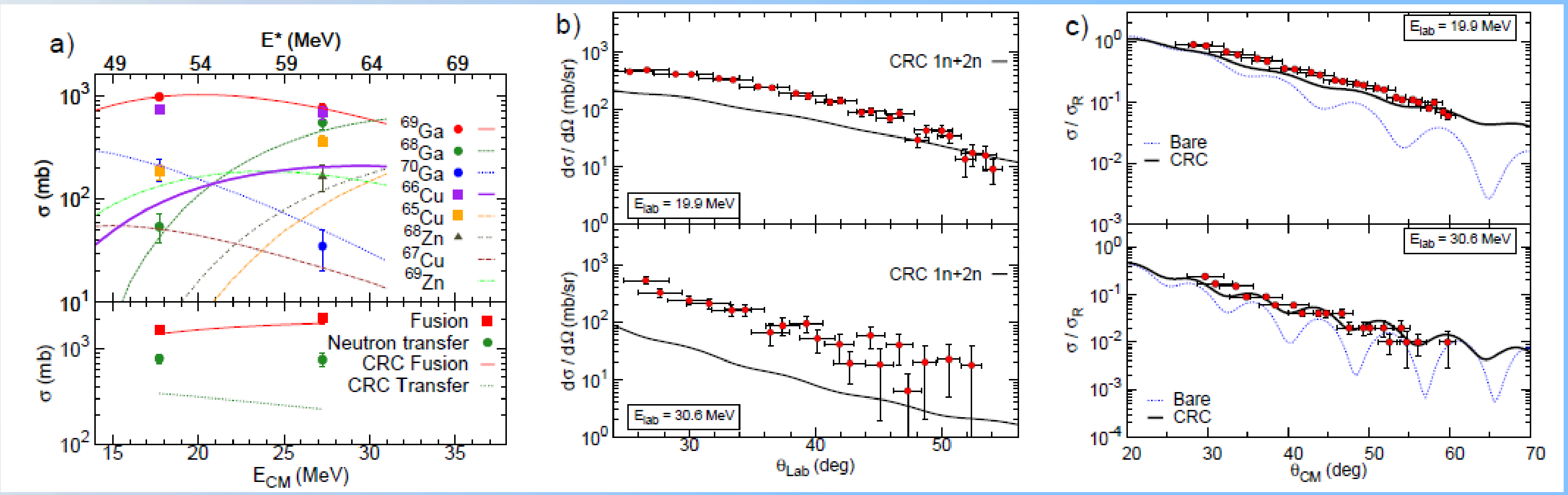
# Complete reaction studies $^{8}He+^{65}Cu$

**E= 19.9, 30 MeV**




**Elastic scattering ang dist: $^{8}He$**
**Transfer ang dist: $^{4,6}He+\gamma$ ($^{65,66}Cu$)**
**Fusion: inclusive gamma ERs**

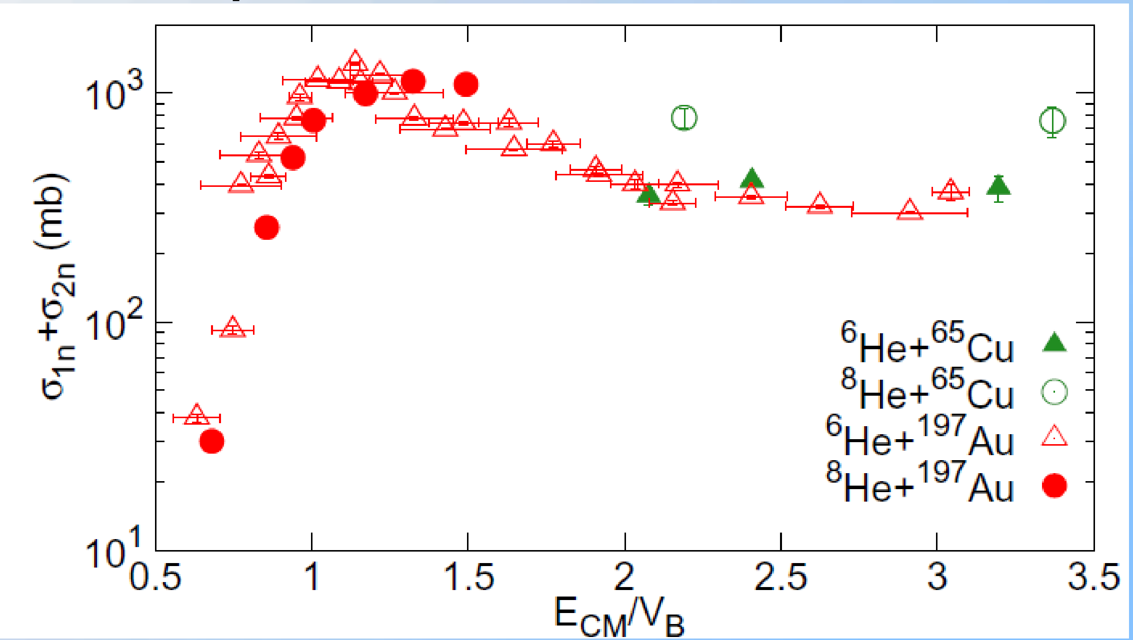
**Fusion, Transfer (1n+2n) Elastic scattering**




**CRC calculations: transfer coupling significant effect on elastic scattering**

**PRC 044,617(2010); PLB 697, 454 (2011)**

# Comparison of Neutron transfer $^{6,8}$He




**x-sec $^8$He> $^6$He at higher energies, both targets**
**- difference in geometry of valence neutrons in these isotopes, neutron correlations different in $^8$He and $^6$He**

**Dynamics of such processes with loosely bound neutrons is a subject of deeper theoretical studies.**

**PRC 044,617(2010); PLB 697, 454 (2011)**

# Summary

As accurate as with stable beams

**Experiment achievement with $10^5$ pps RIB:**
**New off-beam experimental technique to measure absolute fusion x-sec**

**transfer angular distributions from p– γ coincidences – $^{8}He+^{65}Cu$**

**1n and 2n transfer angular distributions from p– γ –n coincidences – $^{6}He+^{65}Cu$ : dominance of dineutron configuration**

**Reaction Mechanisms of $^{6,8}He$ around Vb**

**Dominant role of neutron(s) transfer**
**CRC calculations – significant effect on elastic scattering at E>Vb**

**Moderate enhancement in sub-barrier fusion**
**Similar behaviour of fusion x-section for $^{6}He$ and $^{8}He$ on $^{197}Au$**

# $^{8}He$ + $^{197}Au$,$^{65}Cu$ work

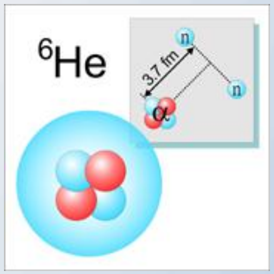
A. Navin, A. Lemasson, M. Rejmund, S. Bhattacharya, C. Schmitt, A. Chatterjee, K. Ramachandran, J. Nyberg, V. Nanal, R.G. Pillay,, I. Stefan, D. Bazin, Y. Blumenfeld, D. Beaumel, G. de France, M. Labiche, R. Lemmon, R. Raabe, J.A. Scarpaci, C. Simenel, C.Timis,N. Keely, V. Zelevinsky

GANIL; BARC, TIFR, VECC, Upsalla; MSU, IPN Orsay, Univ. of Surrey, Daresbury Lab, Univ of Leuven, CEA Saclay, NSCL MSU

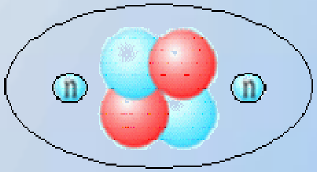
# THANK YOU

# Transfer Reactions with $^6$He

- Cluster structure $\alpha$ + 2n, t + t
- Where are the neutrons relative to each other : dineutron vs cigar




Phys. Rev. Lett. 93, 142501 (2004)



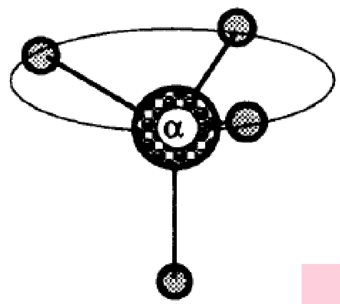

t + t found neglible
L. Giot et al PRC71(2005) 064311

Di-neutron more probable:
Yu Ts Oganessian et al PRL 82 (1999)
Y. L. Ye et al J. Phy. G 31(2005) S1647

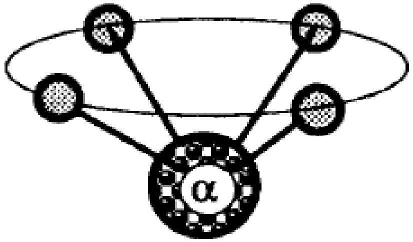
Near $V_B$ influence of n- transfer channel on reaction dynamics

Only study at E ~ Vb $^6$He+$^{209}$Bi
$\alpha$ –n coinc Total $\sigma$(2n) > $\sigma$(1n)
P. De. Young et al PRC71(2005) 05160

1*n* and 2*n* transfer <u>angular distribution</u> desired




# Neutrons in $^{8}$He




| | $^{4}$He | $^{6}$He | $^{8}$He |
|---|---|---|---|
| $S_n$(MeV) | 20.58 | 1.863 | 2.583 |
| $S_{2n}$(MeV) | | 0.973 | 2.138 |
| $\langle r^2 \rangle^{1/2}$ (fm) | 1.67(01) | 2.54(04) | 2.49(04) |

He anomaly

- <u>What is really determing the effect on fusion process</u>
- 4n skin/halo how will it be different viz vis $^{6}$He
- Effect on other channels elastic and transfer

**Is it possible to measure given the intensity?**
**$10^5$p/s**