Transfer reactions to probe structure of weakly bound ^{6}He, ^{7}Li around the Coulomb barrier

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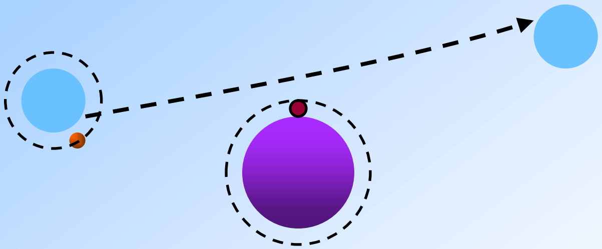
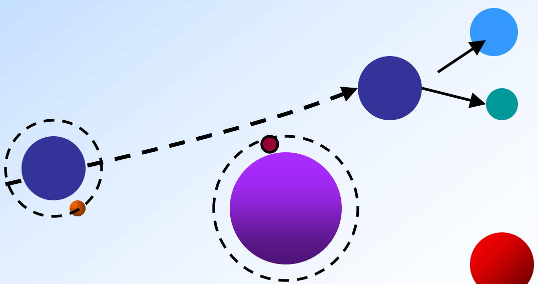
Transfer Reactions with weakly bound

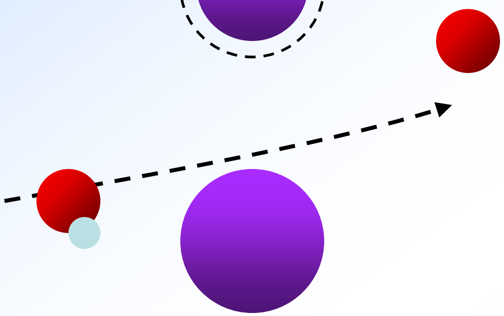
nucleon / cluster transfer



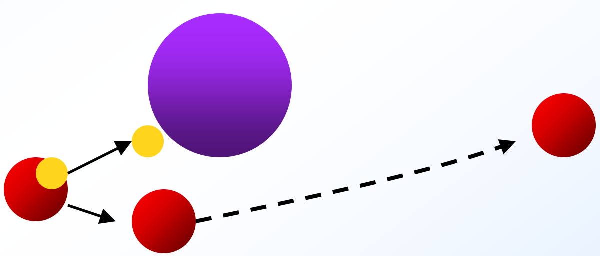
Projectile bound state to target bound state – like stable nuclei



Projectile bound state to target bound state "Ejectile unbound state"



Projectile bound state to Target continuum – decay like CN



Projectile continuum to Target continuum - Breakup Fusion/ incomplete fusion

Transfer reaction with weakly bound challenges

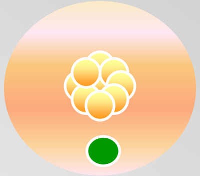
Experiment side: Need to distinguish various mechanisms leading to same reaction product

Theoretical front:
Correct treatment of coupling to Continuum for various processes

What can be learnt?

- **Cluster structure and Exotic shape spectroscopic factor**
- **spin parity of states in continuum**
- **At low energy around the Coulomb barrier coupling to transfer channels on elastic and fusion – complete reaction dynamics**

Lay out of the talk



1n transfer in weakly bound stable

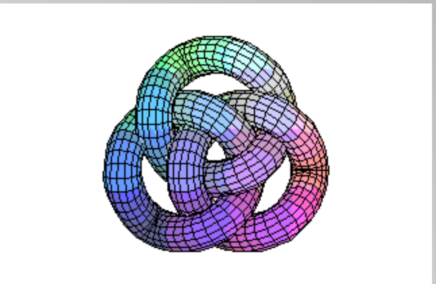
^{7}Li + ^{65}Cu Transfer followed by breakup

Mumbai Pelletron

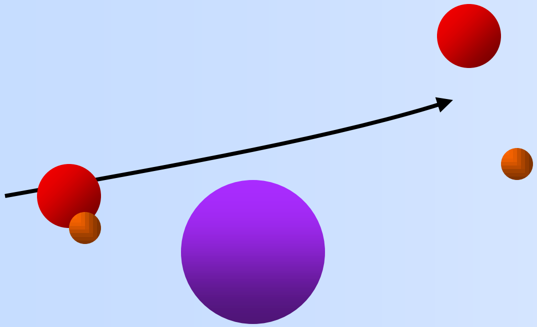
1n/2n transfer weakly bound unstable

^{6}He + ^{65}Cu neutron correlations in ^{6}He

SPIRAL GANIL



transfer-breakup mechanism in ^{7}Li + ^{65}Cu



To Study reactions leading to reaction products in unbound states

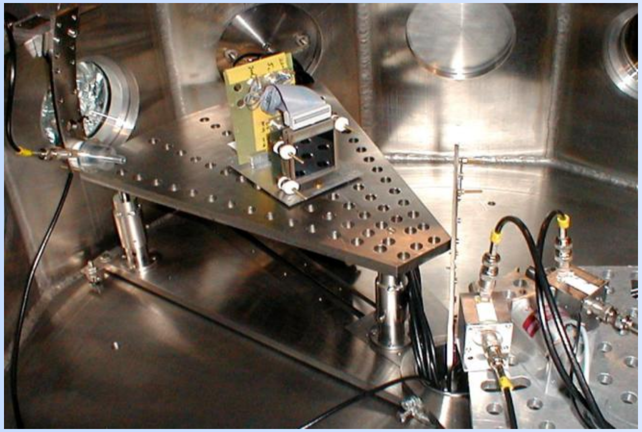
(a) **Projectile excitation to continuum – breakup**

(b) **Ejectile excitation to continuum – transfer-breakup**

Coincidence- Charged particle measurements ^{7}Li+^{65}Cu 25 MeV

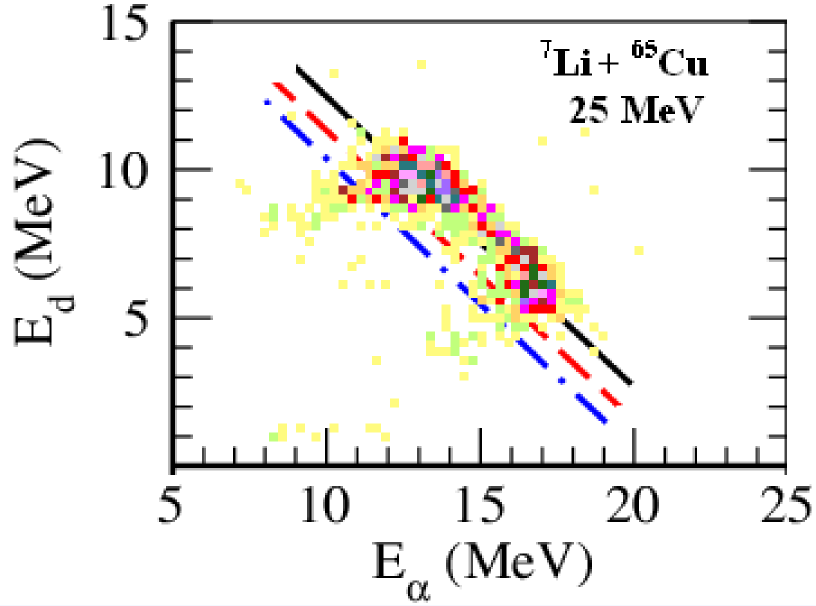
^{7}Li $\rightarrow \alpha + t$

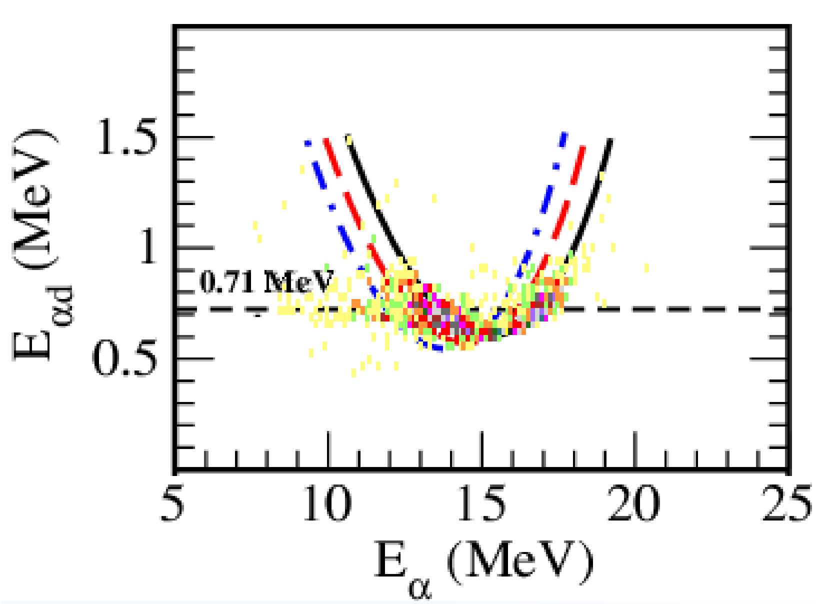
$\rightarrow \alpha + d + n$



Exclusive Charged particle measurements $^{7}Li+^{65}Cu$

α – d coincidence



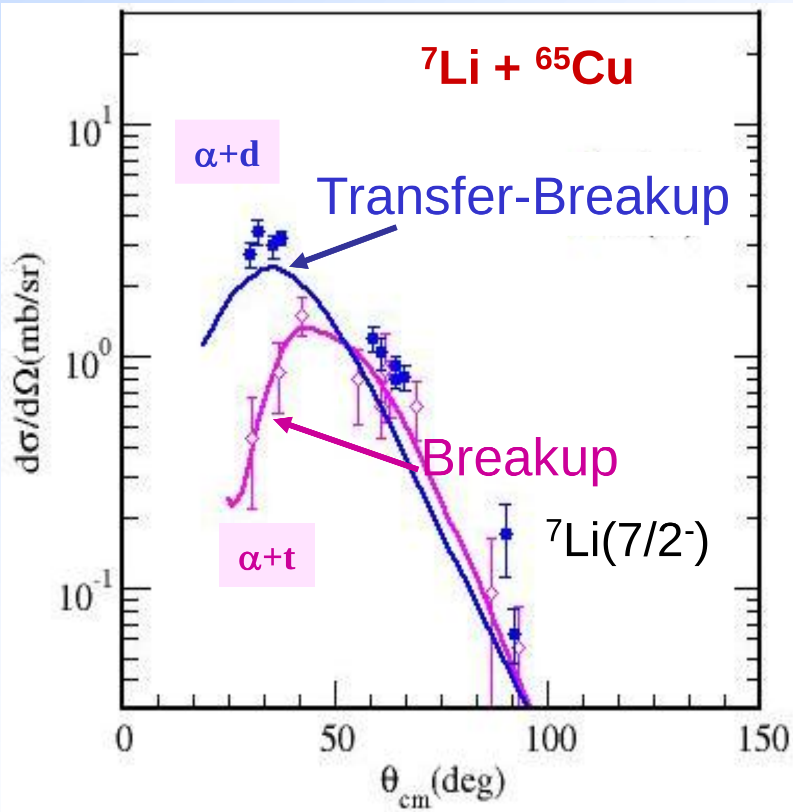


^{7}Li breakup → α + d +n

$E_{\alpha d}$ = 0.71 MeV

$^{6}Li(3^{+})$
↓
α + d

α-t vs. α -d coincidences



^{7}Li (α + t cluster)
σ (α + d) > σ (α + t)

neutron transfer followed by breakup

$^{7}Li + ^{65}Cu \rightarrow ^{6}Li(3^{+}) + ^{66}Cu$

$\downarrow$

$\alpha + d$

transfer followed by breakup > Direct breakup

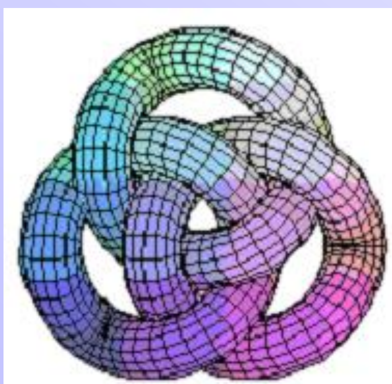
A. Shrivastava et al Phys.Letts.B 633 (2006)463

CCBA calculations
Transfer-Breakup
Direct transfer to 3^{+} of $^{6}Li^{*}$
followed by breakup to α+d ,
Final state interaction negligible

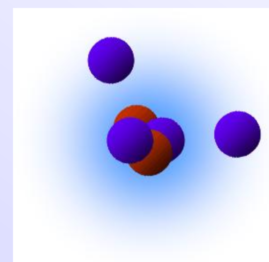
Transfer reactions with unstable nuclei

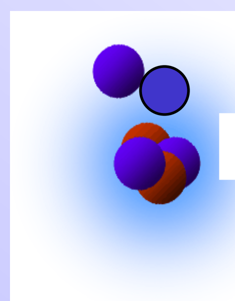
Addition to Weak binding – large isospin
Exotic structure – Halos and skins

Borromean Nucleus ^{6}He



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





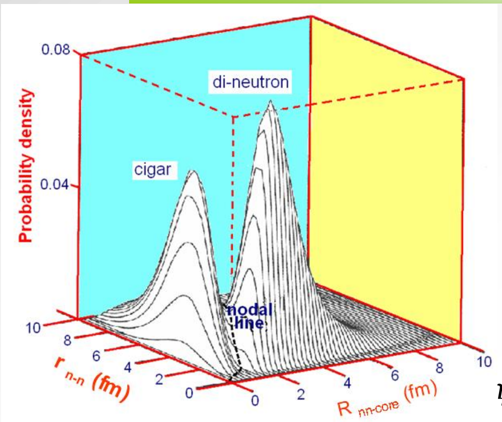
Di-neutron

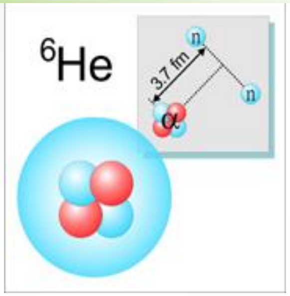
t + t

Transfer Reactions with ^{6}He

- **Cluster structure α + 2n, t + t**
- **Where are the neutrons relative to each other : dineutron vs cigar**
- **Influence of Coupling of n-transfer on reaction dynamics at low energies**

Spatial correlation between two neutrons





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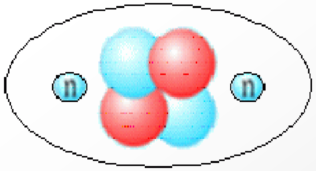


M. V. Zhukov Phys. Rep. 231 (1993) 151

Intuitively from $\sigma(2n)/\sigma(1n)$ -> spatial correlation

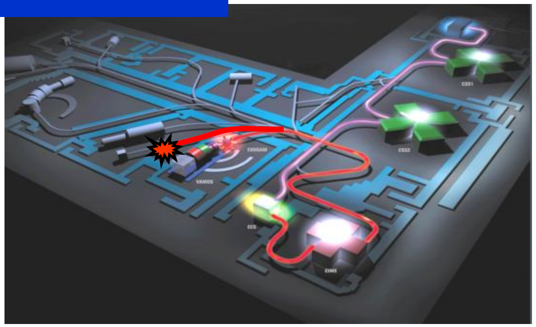
Only study at E ~ Vb $^{6}He+^{209}Bi$
$\sigma(2n)$ > $\sigma(1n)$ α-n coinc
P.de Young PRC71(2005) 05160

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

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

SPIRAL GANIL

E_L=23 MeV



High Current 4.5x10^{7} /sec ^{6}He
High efficiency detector array

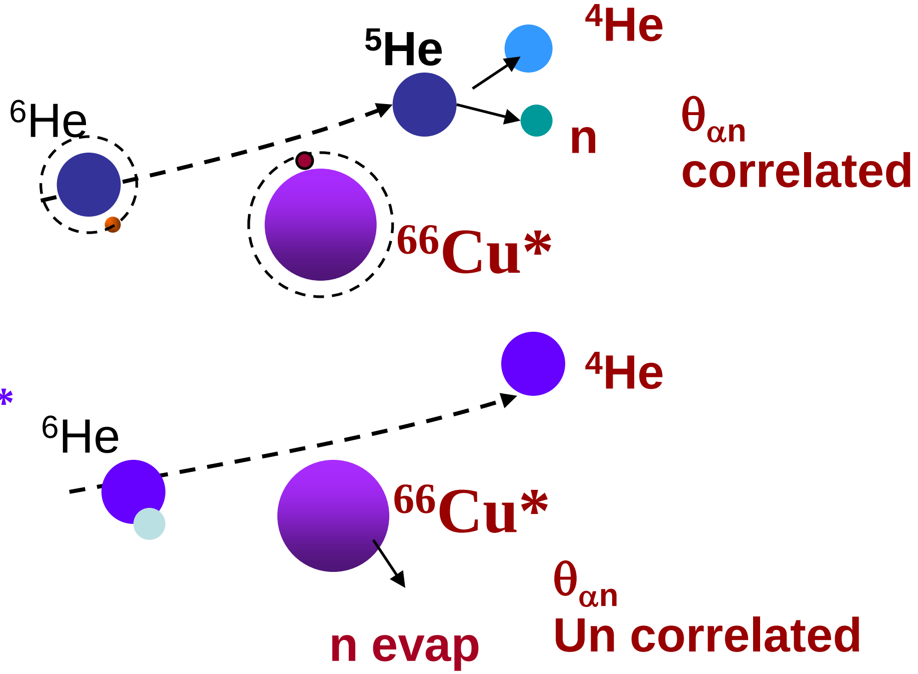
Triple coincidence measurement
p-γ-n correlations with RIB

1n and 2n transfer

$^{6}He+^{65}Cu$ —1n→ $^{5}He+ ^{66}Cu^{*}$

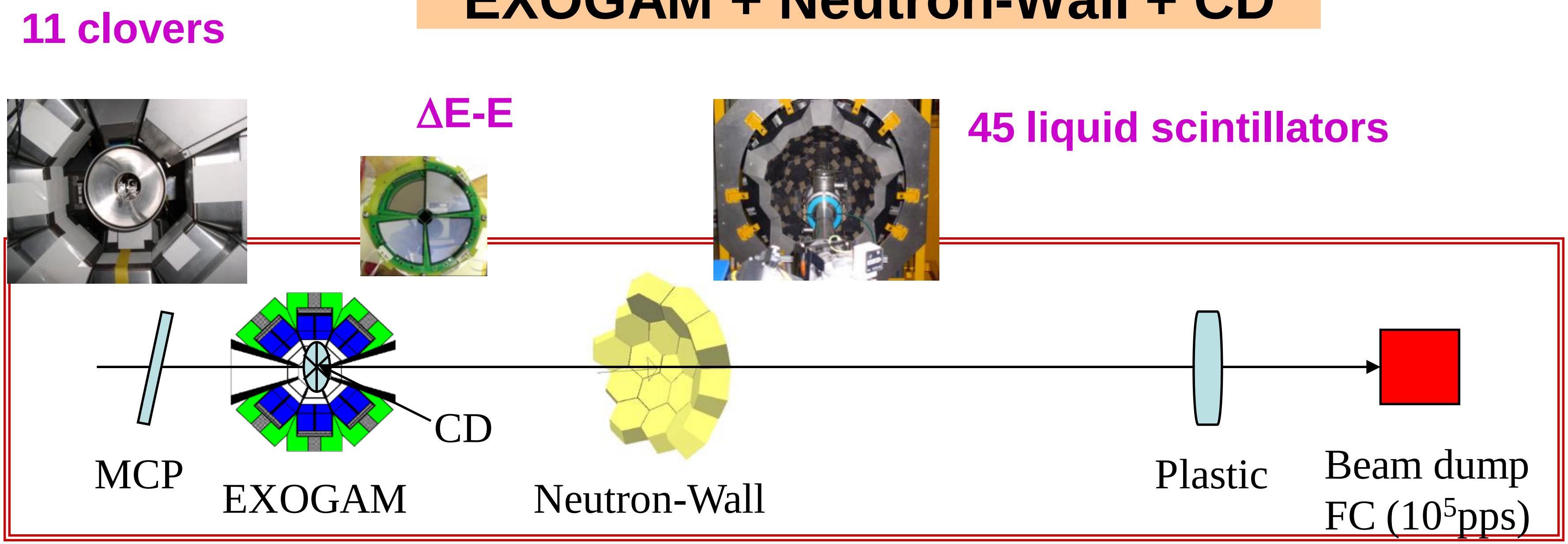
$^{6}He+^{65}Cu$ —2n→ $^{4}He+(^{67}Cu)^{*}$

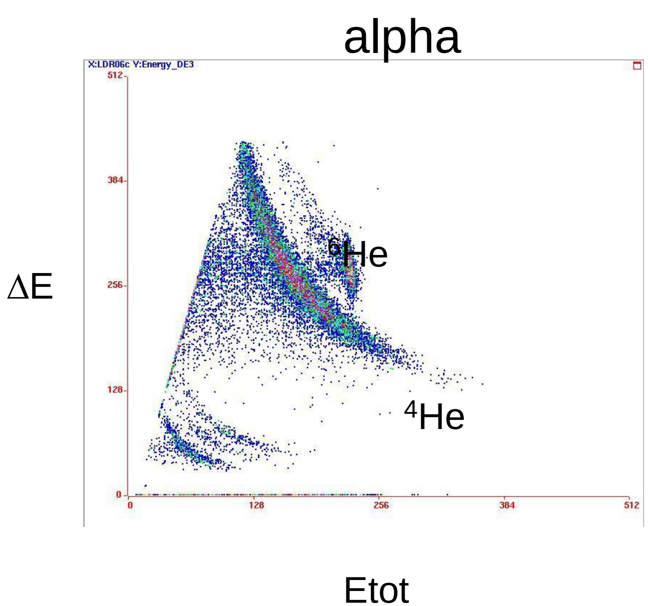
$^{4}He + \gamma(^{66}Cu) + n$

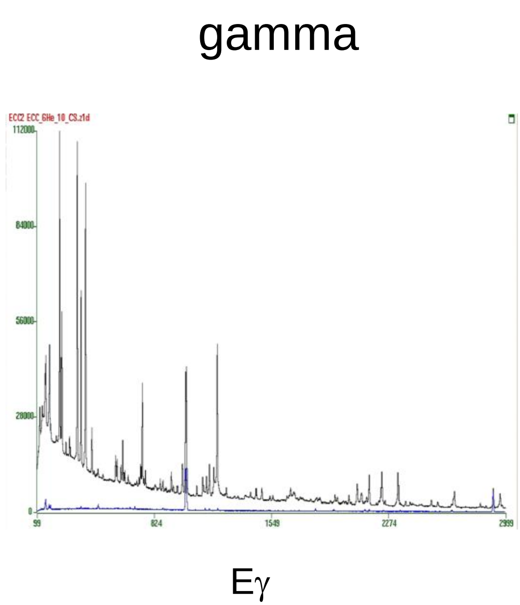


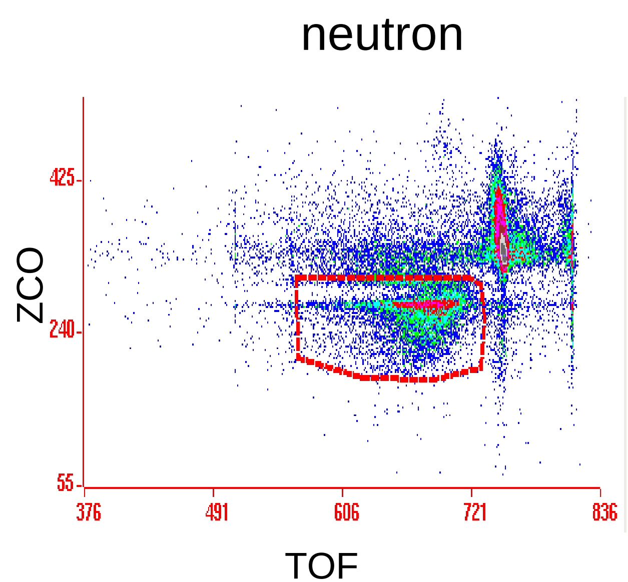
Energy Angular correlations
To separate 1n /2n transfer

EXOGAM + Neutron-Wall + CD



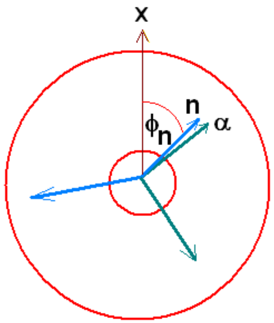






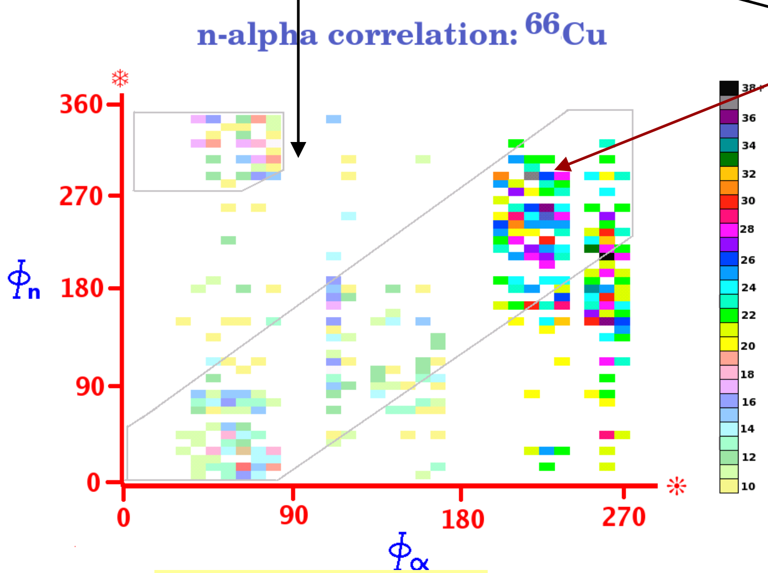
α –n angular Correlations – Laboratory angles

γ gate on ^{66}Cu

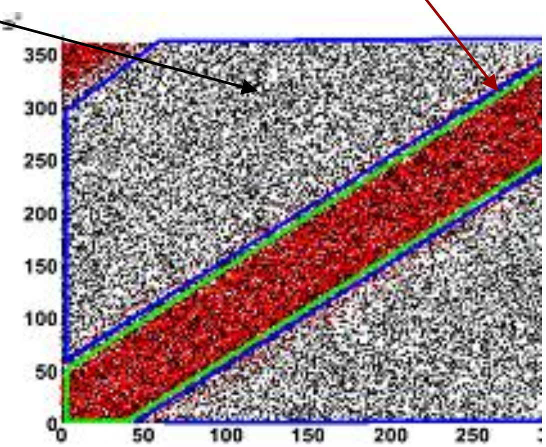


2n transfer
uncorrelated

1n transfer
correlated



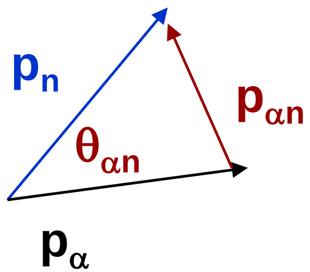
Experiment



Simulations

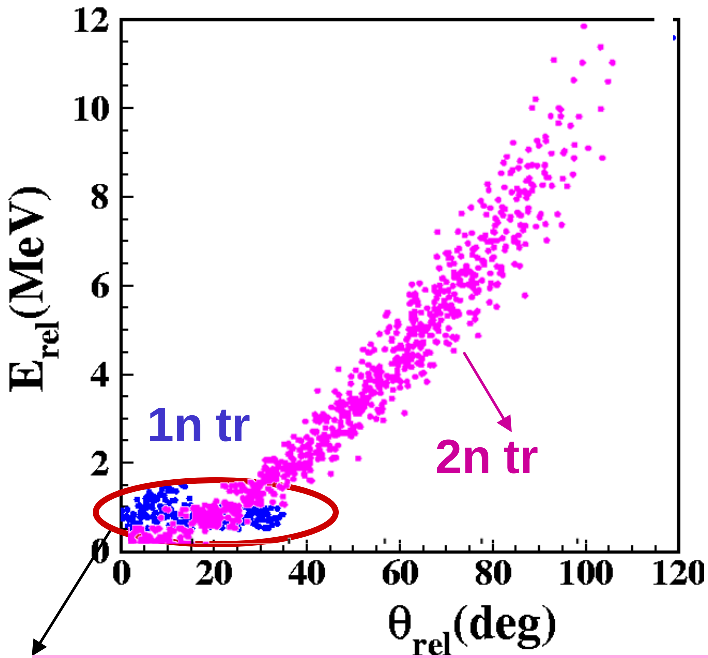
^{6}He+^{65}Cu → (1n) ^{5}He+ ^{66}Cu*

^{6}He+^{65}Cu → (2n) ^{4}He+(^{67}Cu)*



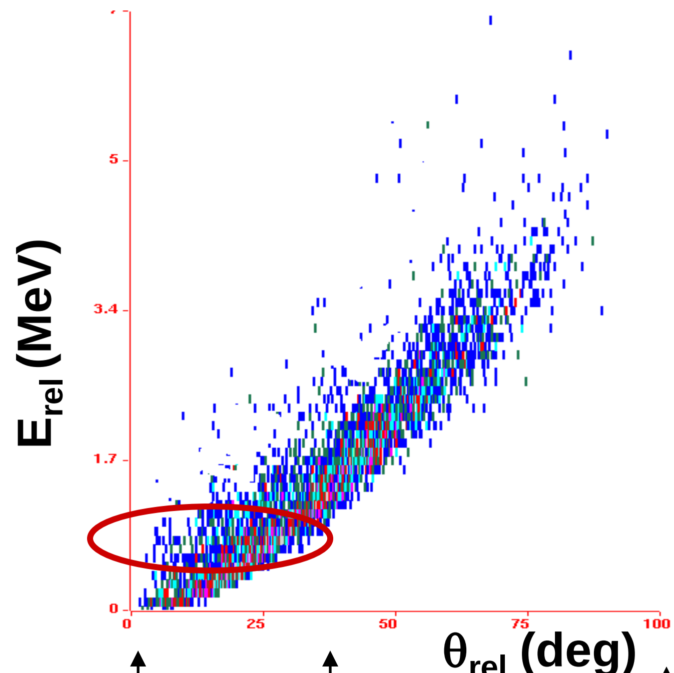
Relative energy vs relative angle between α and n

Simulation



^{5}He 3/2$^-$ 0.89 MeV, Γ = 600 keV

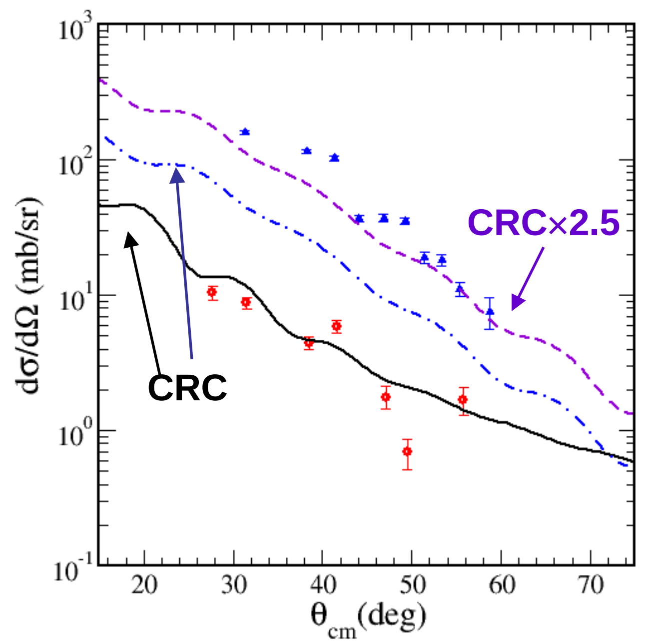
Experiment

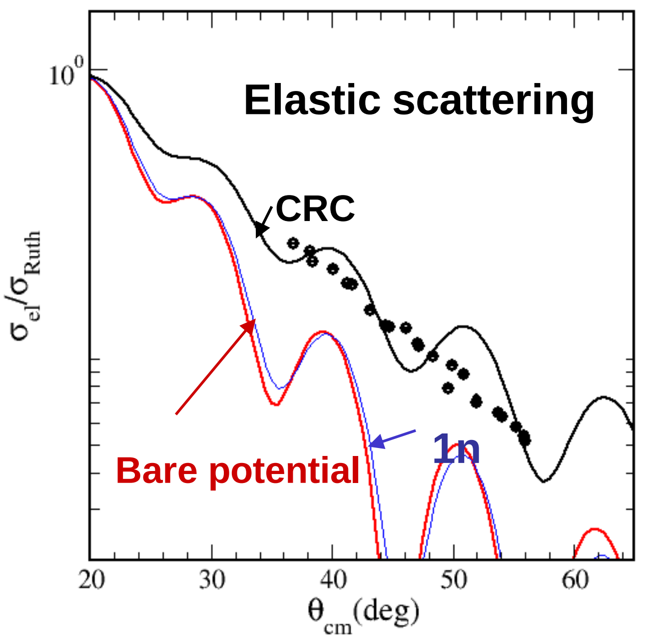


$\theta_{rel}<34^0$
1ntr + 2n tr

$\theta_{rel}>34^0$
Only 2ntr

Angular distribution





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

CRC calculations
Transfer
2n transfer - assumed pair transfer
Elastic :
strong effect of transfer coupling
Fusion
expt = 1375 ±220
CRC cal = 1655, 1614 and 1533 mb
(bare, 1n and 1n+2n calculations)

Summary

Weakly bound stable/unstable nuclei:

Evidence of transfer followed by break-up via coincidence measurement, explained by theory - $^{7}Li+^{65}Cu$

- **1n/2n transfer reactions - - $^{6}He + ^{65}Cu$,**

- ^{6}He spatial correlation of neutrons

2n transfer > 1n transfer

Di-neutron more probable

- CRC: coupling to neutron transfer in borromean nuclei on elastic, transfer and fusion reactions is important

Immediate future

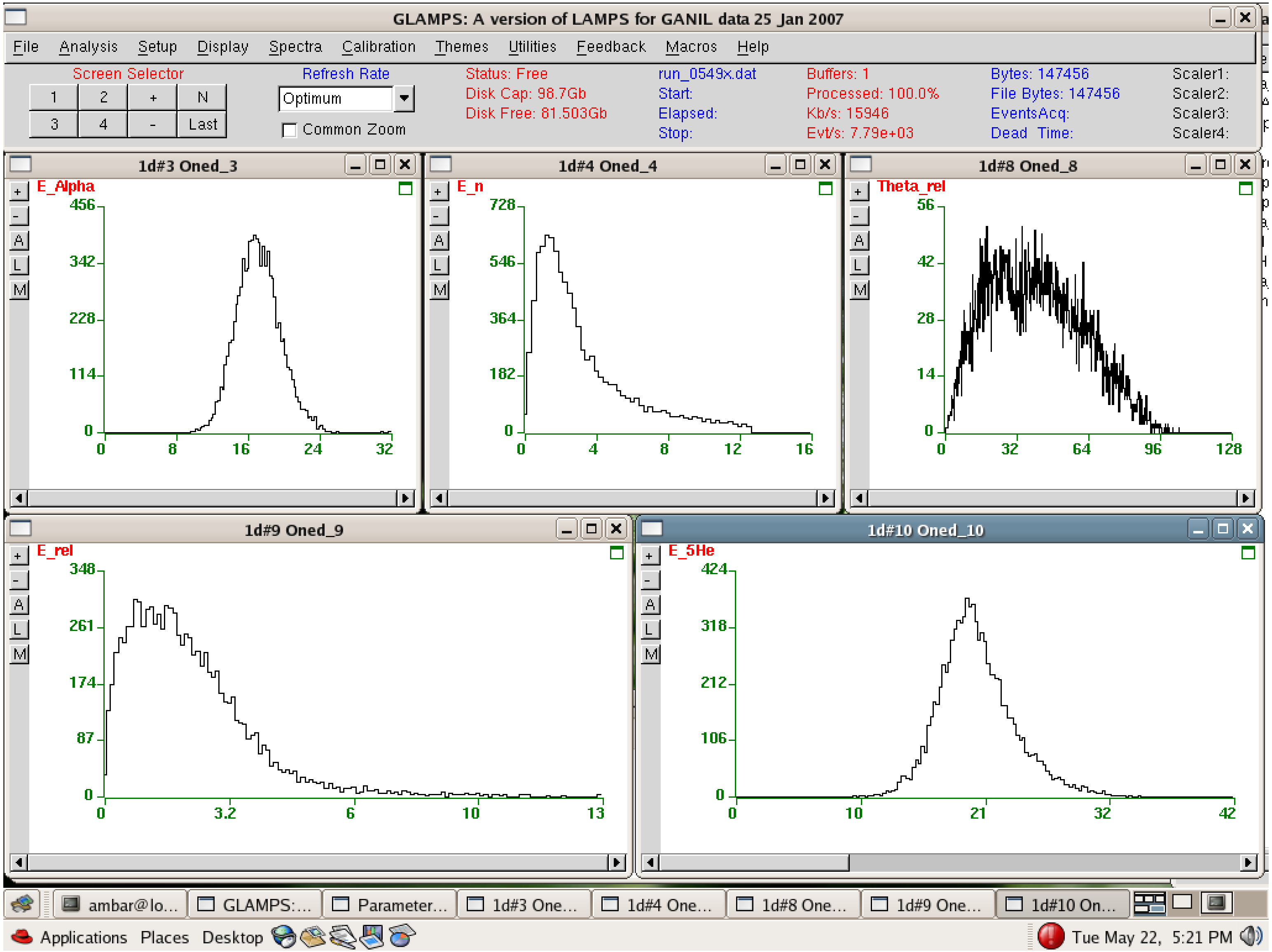
Direct and CN reactions with $^{8}He+^{197}Au$ around the barrier

Team

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

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

THANK YOU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Refresh Rate
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Elapsed:
Stop:
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1d#3 Oned_3
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1d#4 Oned_4
E_n
1d#8 Oned_8
Theta_rel
1d#9 Oned_9
E_rel
1d#10 Oned_10
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ambar@lo... GLAMPS:... Parameter... 1d#3 One... 1d#4 One... 1d#8 One... 1d#9 One... 1d#10 On...
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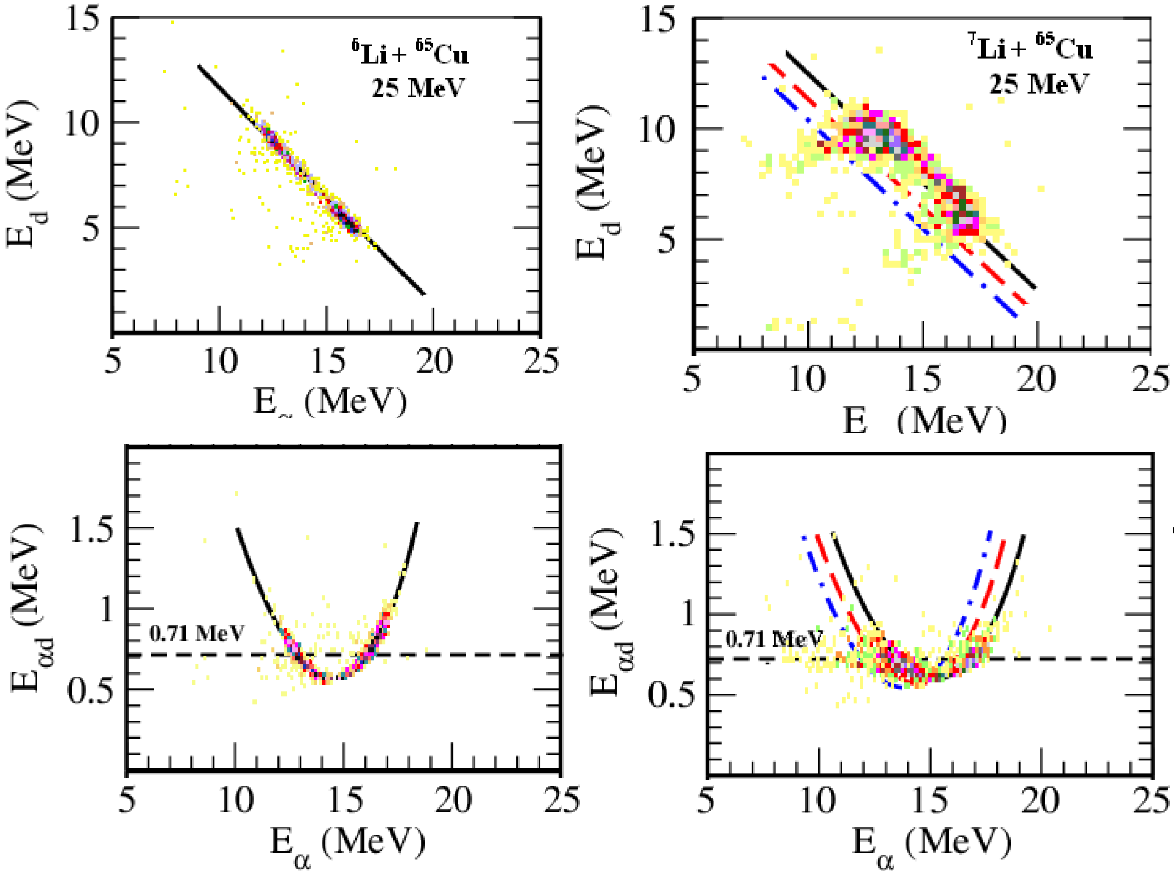
Tue May 22, 5:21 PM

Exclusive Charged particle measurements ^{6,7}Li+^{65}Cu 25 MeV

^{6}Li+^{65}Cu

α – d coincidences

^{7}Li+^{65}Cu



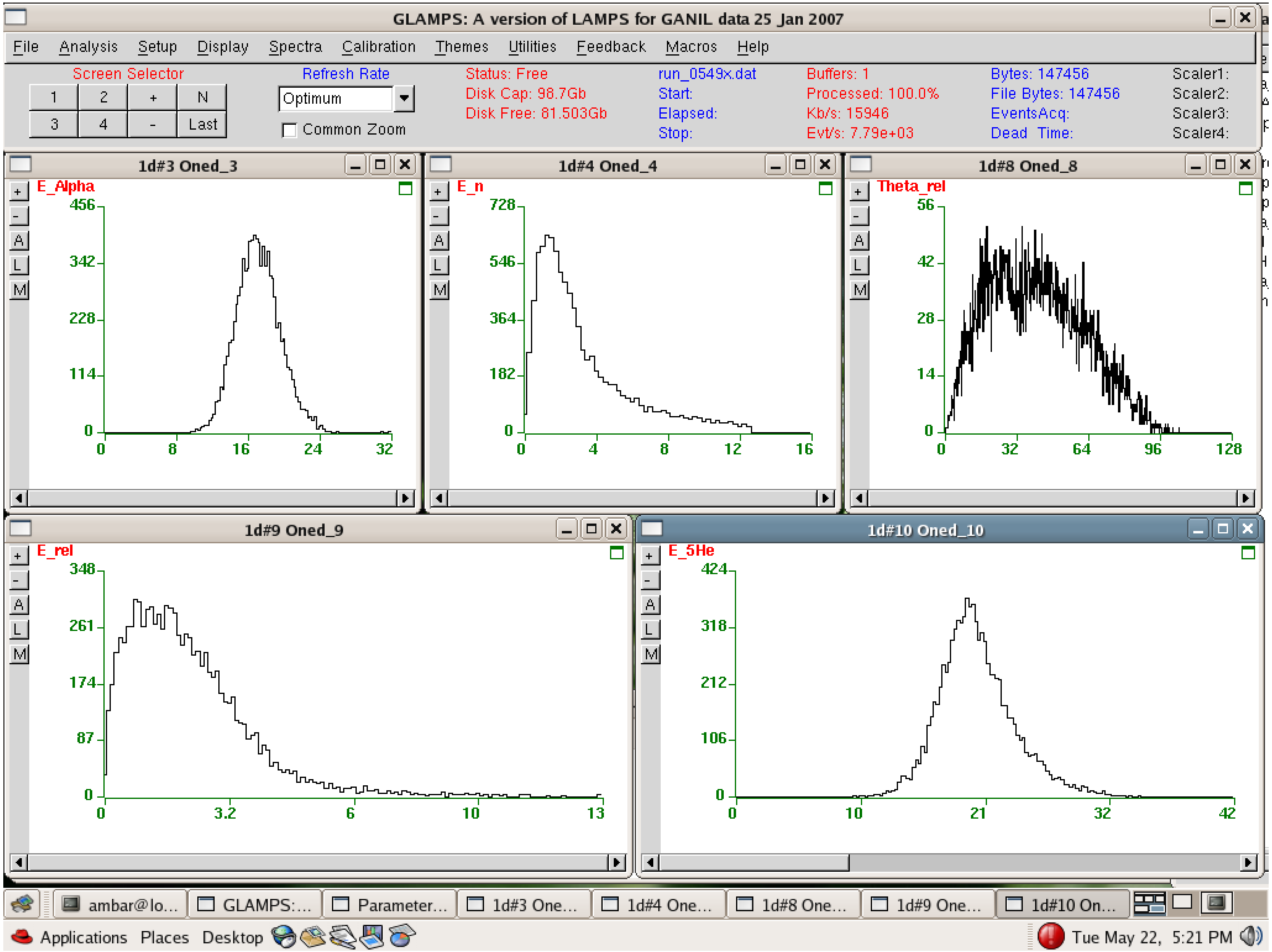
$E_{\alpha d}$ = E*(res) - breakup threshold
first resonance ^{6}Li(3^{+}) 2.186MeV

$E_{\alpha d}$ = 2.186 – 1.475 = 0.711 MeV

~~^{7}Li breakup→ α + d +n~~

Direct Break up
^{6}Li+^{65}Cu → ^{6}Li (3^{+})+^{65}Cu
↓
α + d
solid line :3 body kinematics

Transfer-Breakup
^{7}Li+^{65}Cu → ^{6}Li(3^{+}) + ^{66}Cu*
↓
α + d
3 body kinematics
^{66}Cu (gnd state),^{66}Cu (1.15MeV)
^{66}Cu(2.12 MeV)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EventsAcq:
Dead Time:
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Scaler2:
Scaler3:
Scaler4:
1d#3 Oned_3
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1d#4 Oned_4
E_n
1d#8 Oned_8
Theta_rel
1d#9 Oned_9
E_rel
1d#10 Oned_10
E_5He
Applications Places Desktop
Tue May 22, 5:21 PM

Literature

On Structure

6He – di-neutron, cigar, t + t

On strucutre+ reaction dynamics ~ VB

At low energy – transfer coupling, complete reaction measurement more alpha x-section

Kolata – only measurement 6he+209Bi

Medium mass - Identification difficult, angular distbn

Important to get better understanding in terms of

Calculations

Coupling to transfer very significant (more than BU)

– transfer coupling responsible for suppression in Fusion - Nick

disappearance of TA- Pakou

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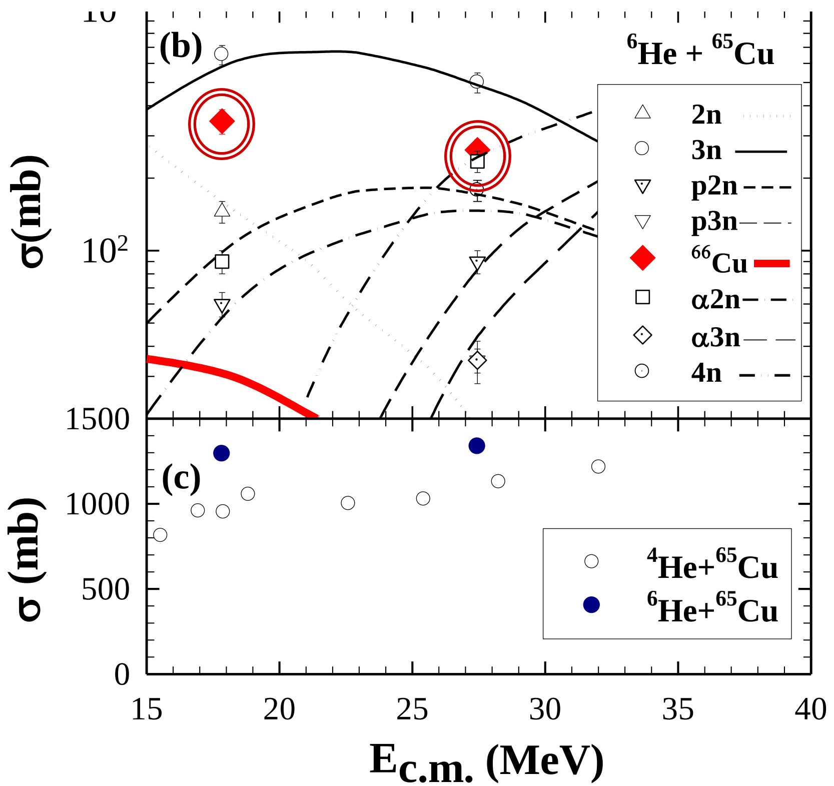
Transfer to continuum followed by evaporation



Good agreement for α + ^{65}Cu but
Large discrepancy in cross section
for <u>αn channel (^{66}Cu)</u> in ^{6}He + ^{65}Cu

p-γ coinc → provided direct evidence for large <u>TRANSFER (1n+2n)</u>
<u>(Same residue as from fusion)</u>

Phys Rev C 70 (2004)

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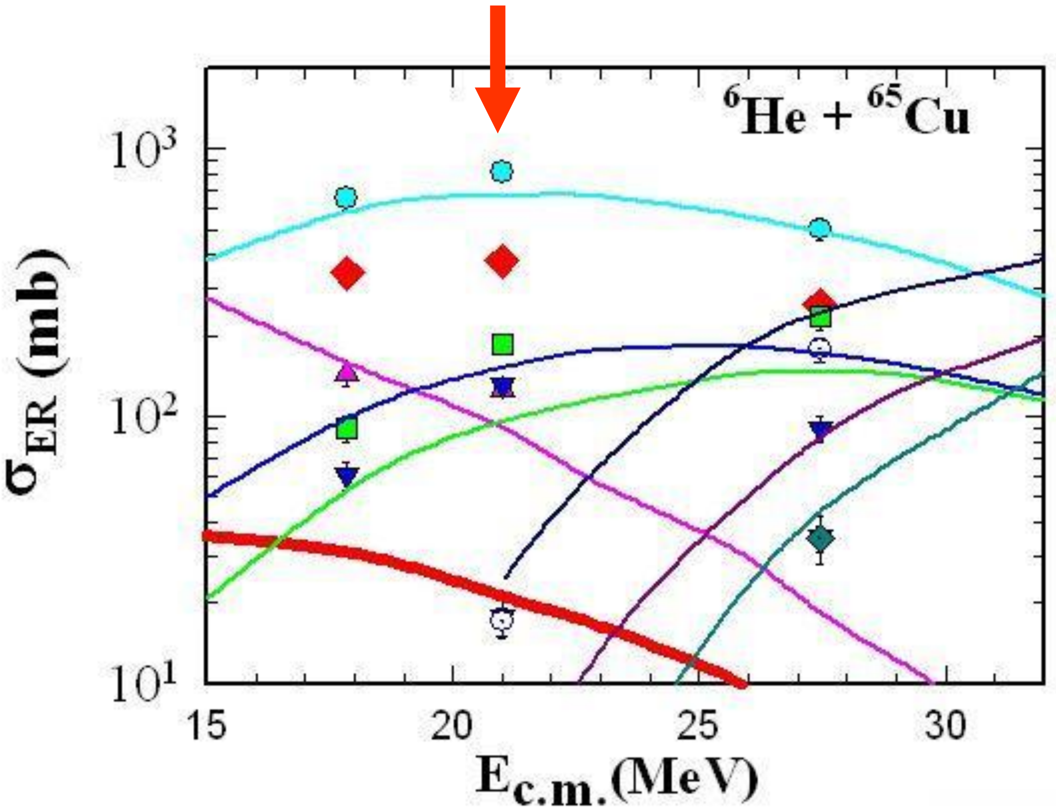
disappearance of TA- Pakou

Dear Aradhana,
Attached is the elastic scattering from the 1n transfer calculation.
The
effect of the 2n transfer is much larger than the 1n, although you should emphasise that the 2n transfer calculations are really only schematic and don't attempt to be realistic. They are merely meant to give an indication of what the effect could be. For the record, the total fusion cross sections for the bare, 1n and 1n+2n calculations are 1655, 1614 and 1533 mb, so the transfer couplings reduce the total fusion xsec, even for this energy which is well above the barrier (although here the effect is pretty small).
Nick.

Cross Sections



			σ (mb)
▲	2n	^{69}Ga	126
●	3n	^{68}Ga	816
○	4n	^{67}Ga	16.5
▼	p2n	^{68}Zn	132
▼	p3n	^{67}Zn	17.6
◆	αn	^{66}Cu	381
■	α2n	^{65}Cu	186
◆	α3n	^{64}Cu	0

^{6}He + ^{65}Cu → ^{71}Ga → ^{66}Cu + ^{4}He +n (Fusion Evaporation)

^{6}He + ^{65}Cu → ^{4}He + ^{67}Cu*→ ^{4}He + ^{66}Cu + n (2n transfer)

^{6}He + ^{65}Cu → ^{5}He + ^{66}Cu → ^{66}Cu + ^{4}He + n (1n transfer)

Extraction of Cross Sections

- 2n transfer cross section from 'outer region'
- Effective solid angle of neutron wall for 'outer region' taken into account
- 1n transfer cross section now obtained by subtracting the 2n transfer yield in the inner region
- Effective neutron solid angle for 'inner region' taken into account
- Neutron detector efficiencies taken into account on event by event basis
- Neutron detector effective solid angle for inner region determined by simulation