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Multi-neutron transfer in the scattering of ^{8}He at Coulomb barrier energies

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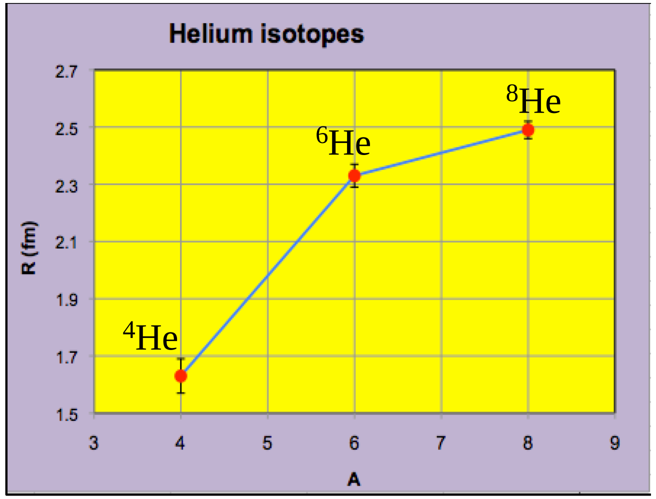
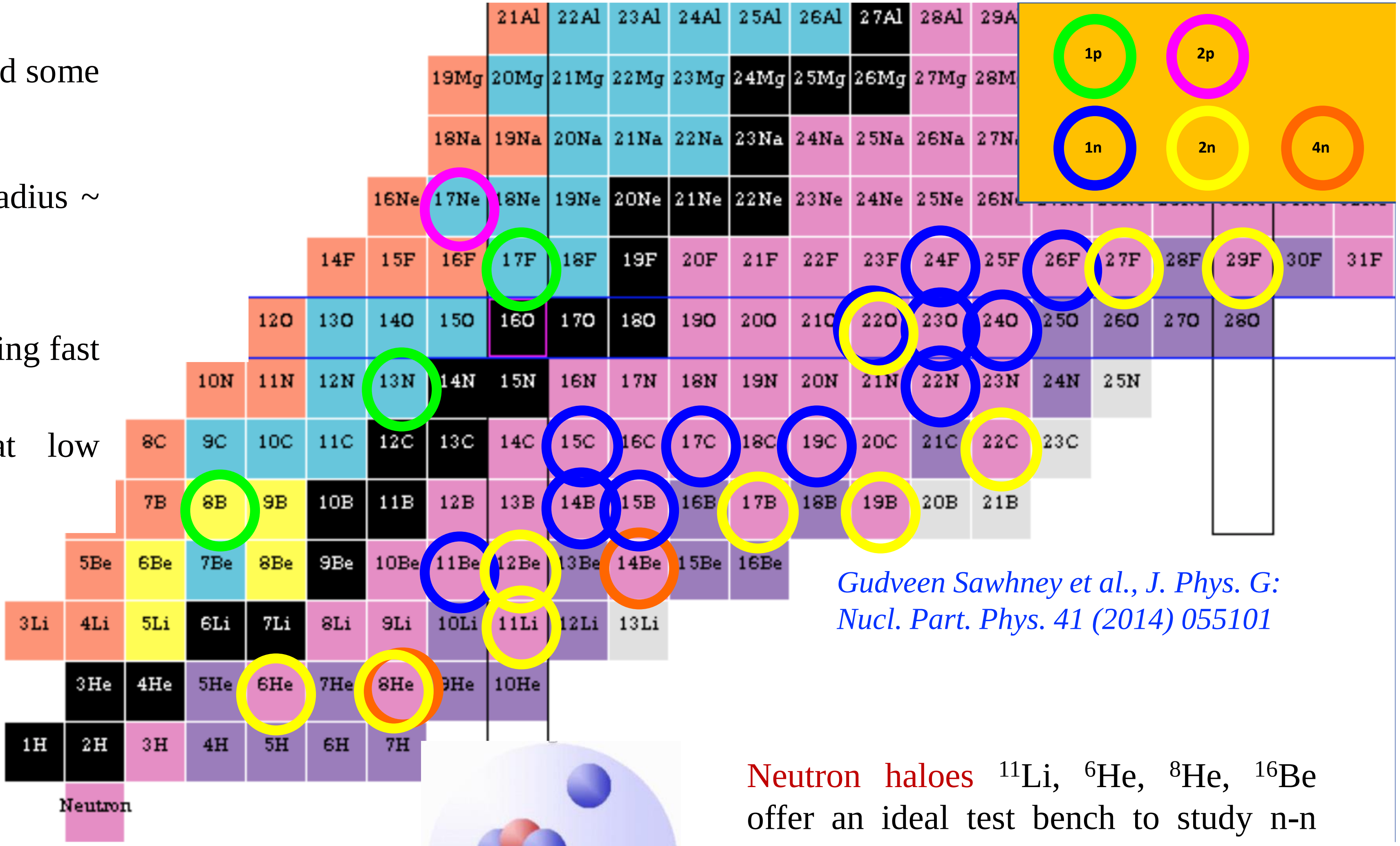
Halo nuclei

Exotic nuclear systems formed by a core and some weakly bound valence nucleons:

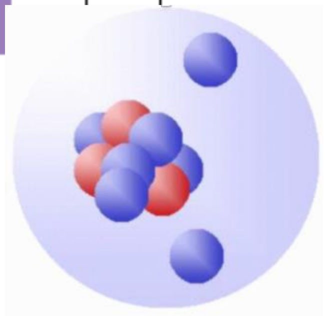
- Extended mass distribution and large radius ~ “halo”
- Large reaction cross sections
- Narrow momentum distributions following fast fragmentation reactions
- Concentration of dipole strength at low energies close to BU threshold



I. Tanihata, et al. Phys. Lett., B289:261, 1992.



Gudveen Sawhney et al., J. Phys. G: Nucl. Part. Phys. 41 (2014) 055101



Neutron haloes ^{11}Li, ^{6}He, ^{8}He, ^{16}Be offer an ideal test bench to study n-n correlations by measuring neutron transfer and breakup.

Searching for di-neutrons and tetra-neutrons

Scattering of ^{8}He +^{208}Pb at Coulomb barrier energies

- ^{8}He is the most neutron-rich bound nucleus, with a ratio of N/Z = 3 → excellent test bench for multi-neutron transfer.
- Spherical, well known double-magic target nucleus ^{208}Pb
- Coulomb barrier → large probability of neutron transfer
- Existing ^{6}He + ^{208}Pb elastic scattering data at similar incident energies ~ 22 MeV (Coulomb barrier).
- Comparing ^{6}He and ^{8}He scattering is interesting:

  → Rms. matter radii of ^{6}He and ^{8}He are very similar (2.33 fm, 2.49 fm), but they are halo and skin nuclei, respectively

  → Remove "geometrical" effects due to differences in size → better understanding of structure/dynamics of the reaction process

	S1n (MeV)	S2n (MeV)	Q1n (MeV)	Q2n (MeV)	SF(1n)	SF(2n)
^{6}He	0.973	1.771	+2.07	+8.15	1.6	1.0
^{8}He	2.140	2.574	+1.35	+6.98	2.9	1.0

N. Keeley et al., PLB 646, 222 (2007).
F. Skaza et al., PRC 73, 044301 (2006).
L.V. Chulkov et al., NPA 759, 43 (2005).

- S_{1n} and S_{2n}: higher in ^{8}He → smaller coupling to the continuum in ^{8}He ~ smaller breakup yield.
- Q_{1n} and Q_{2n}: 1n and 2n better Q-matched in ^{8}He ~ larger 1n and 2n transfer yield.
- SF(1n): higher in ^{8}He ~ larger 1n-transfer yield.
- SF(2n): Similar values ~ similar yields for 2n transfer.
- 4-neutron transfer. Unique mechanism for ^{8}He.

❖ Relative strength of the neutron transfer channels?
❖ Sequential or direct?
❖ Di-neutrons and tetra-neutrons?

Scattering of ^{8}He +^{208}Pb at 16 and 22 MeV

laboratoire commun CEA/DRF spiral2 CNRS/IN2P3

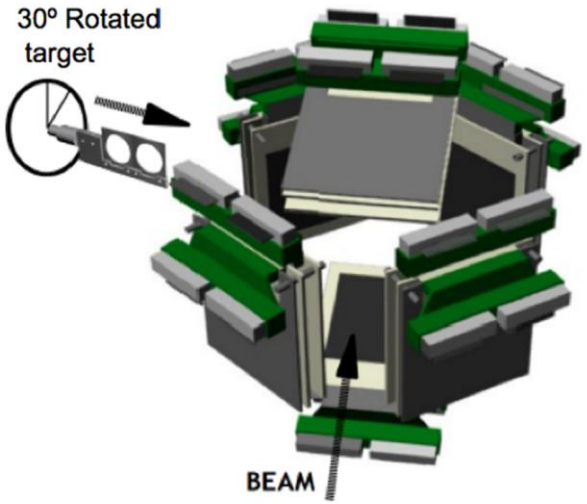
Caen, France

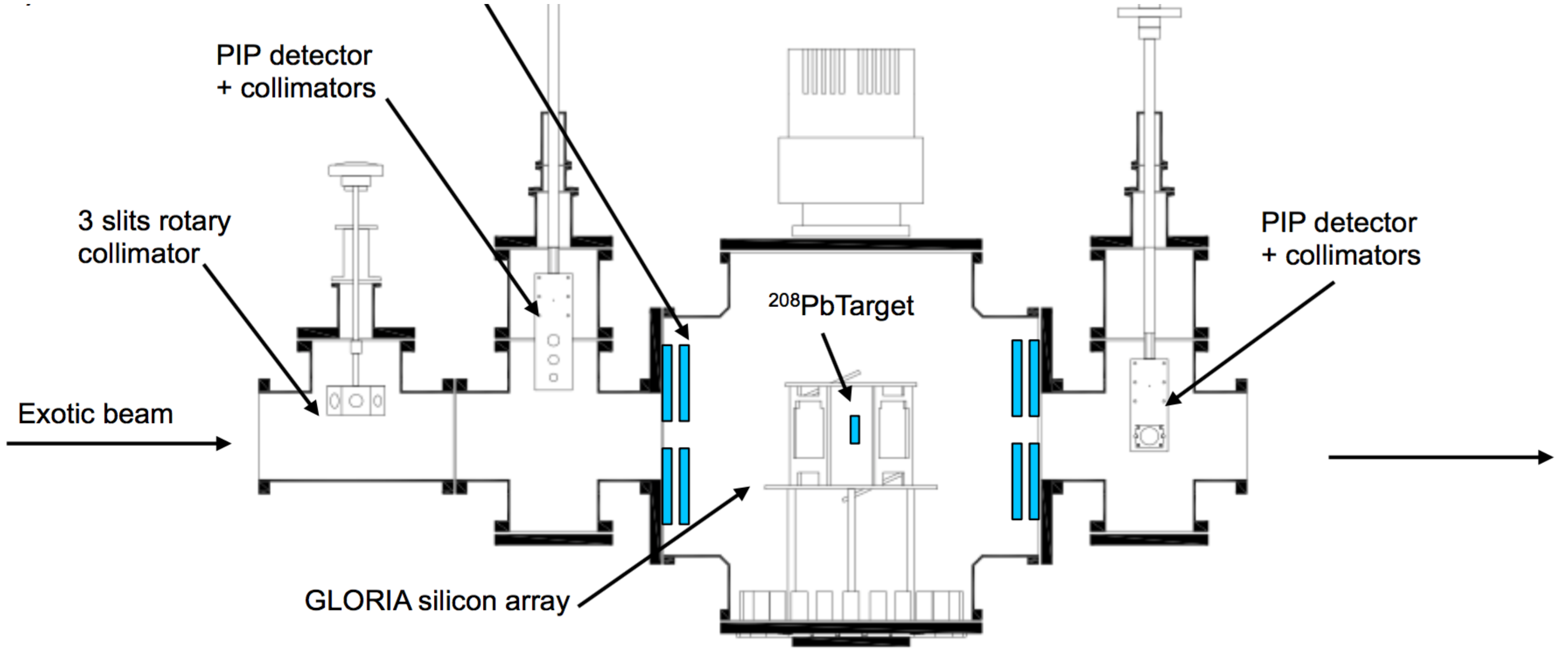
- Proposal E587S (2010)
- Measure the angular distribution of the elastic channel and the yields of ^{6}He and ^{4}He from 15° to 165° Lab.

GLObal ReactIon Array (GLORIA)

6 x DSSSD Si particle telescopes

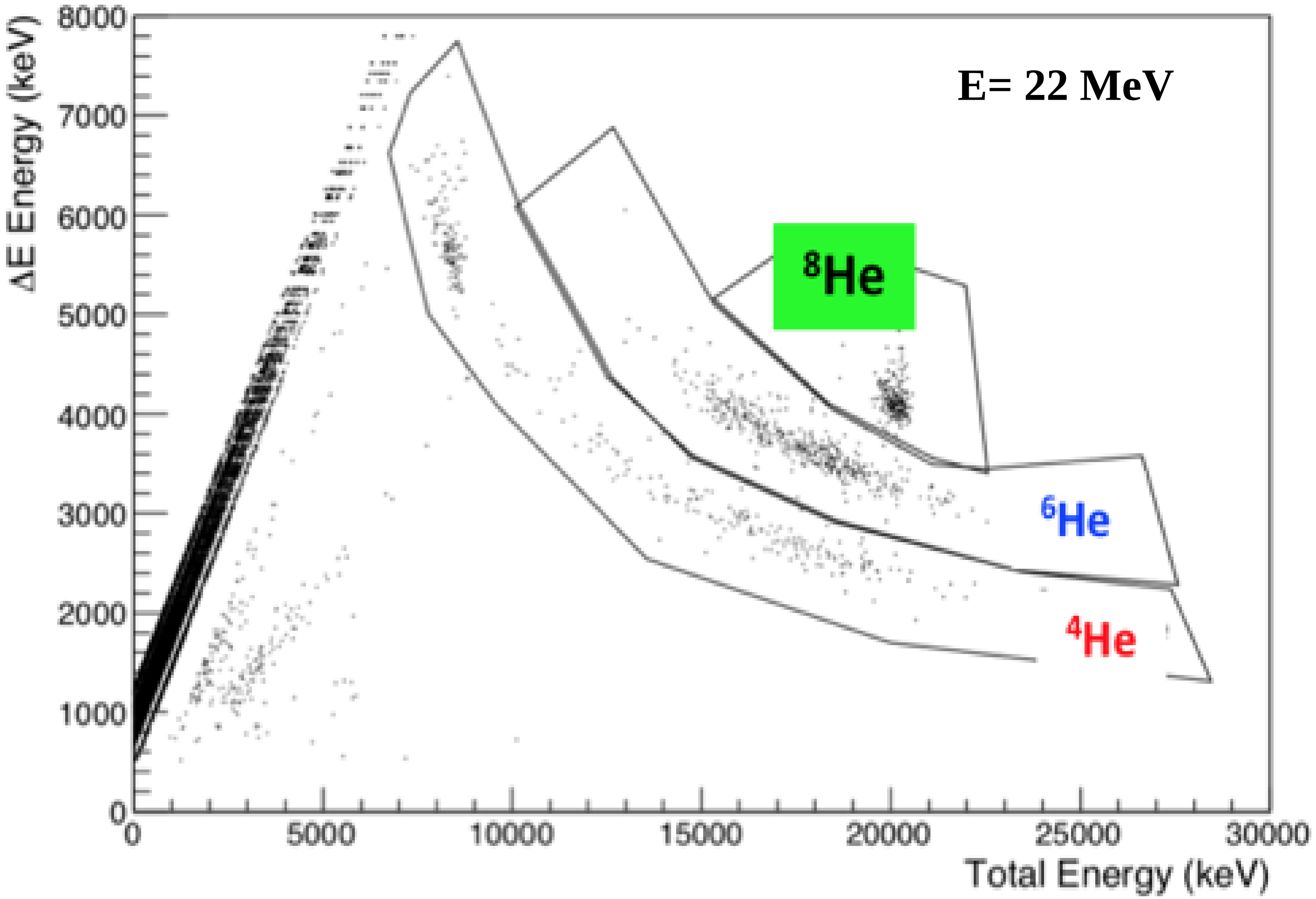
- 40 um DE & E, 1 mm
- Total solid angle: 26 %
- Angular range: 15 -165 deg.
- Angular res. ~ 3 deg.



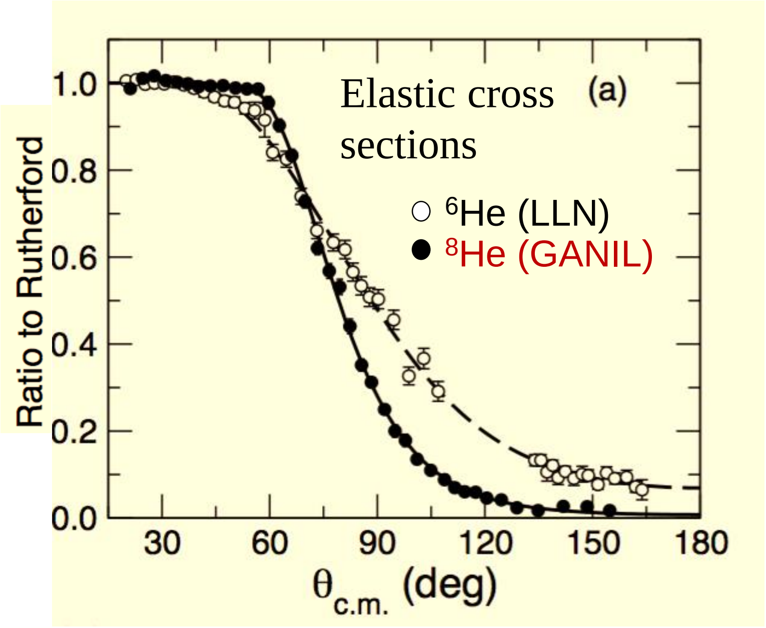


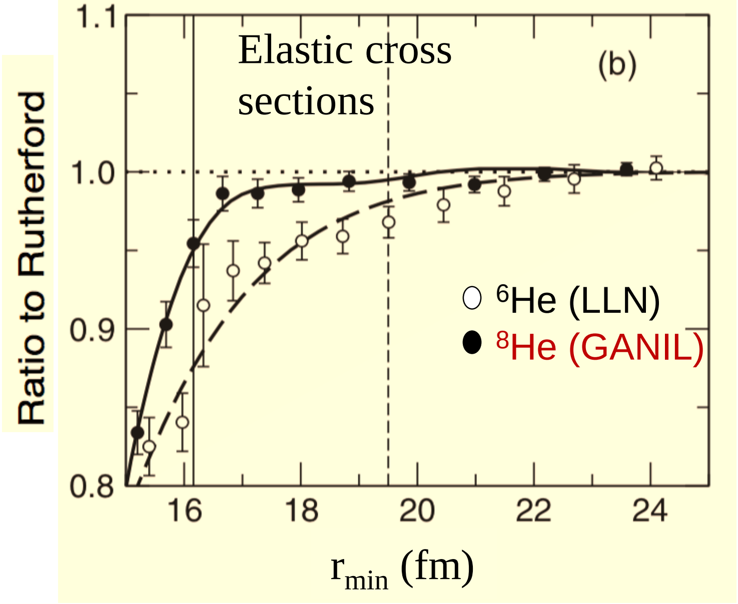
G. Marquínez-Durán et al. Nucl. Inst. Meth. A 755, 69 (2014).

Particle identification



Elastic cross sections





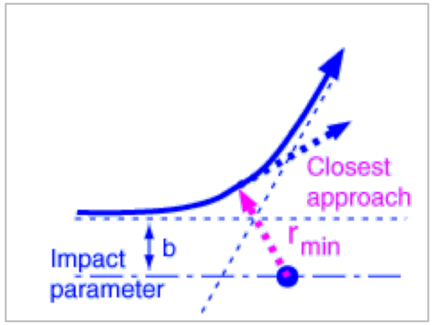
OM calculations: Vr, Wi Woods-Saxon

Projectile	V	r_V	a_V	W	r_W	a_W	σ_R (mb)
^{8}He	143.7	1.631	0.587	37.1	1.481	1.148	1529
^{6}He	147.4	1.237	0.618	19.8	1.090	1.766	1425

- Larger total reaction cross section for ^{8}He than for ^{6}He → **larger neutron transfer** as compared to ^{6}He.
- Consistent results of Z. Podolyák, et al., in ^{8}He + ^{208}Pb @ 26 MeV

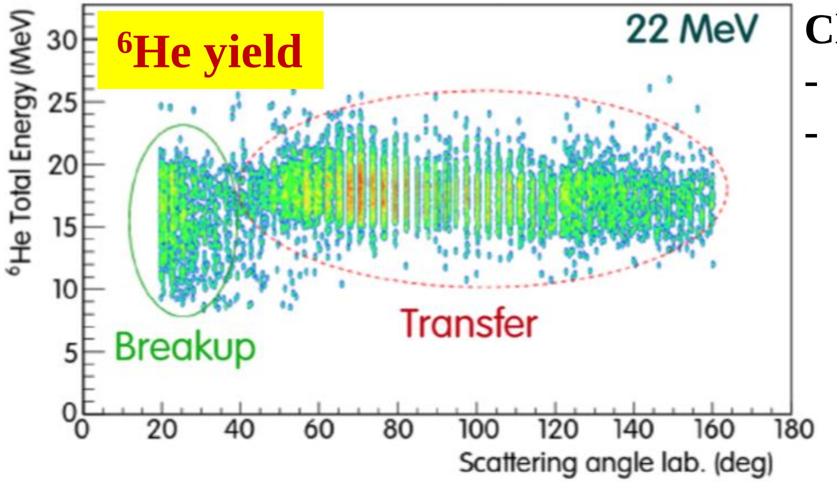
→ γ decay of low-spin states in ^{209}Pb → suggests strong one-neutron stripping process,

→ Strength comparable to fusion-evaporation channel ^{208}Pb(^{8}He,4n)^{212}Po



Z. Podolyák, et al., Nucl. Instr. Meth. A 511, 354 (2003).

^{4}He and ^{6}He yields

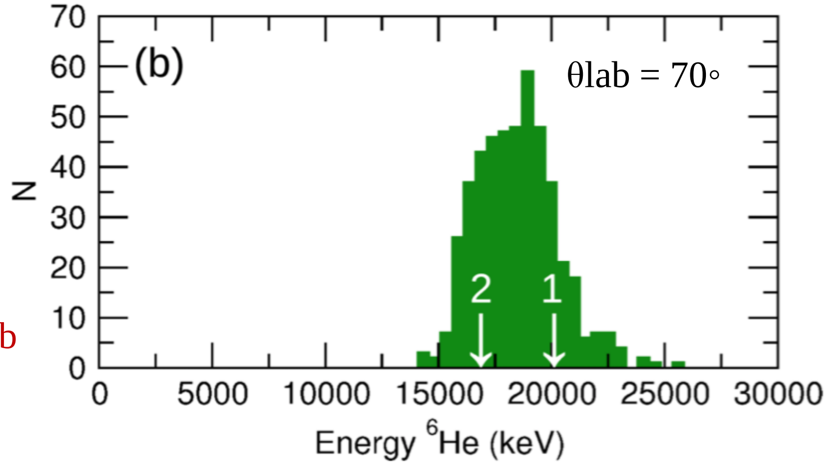


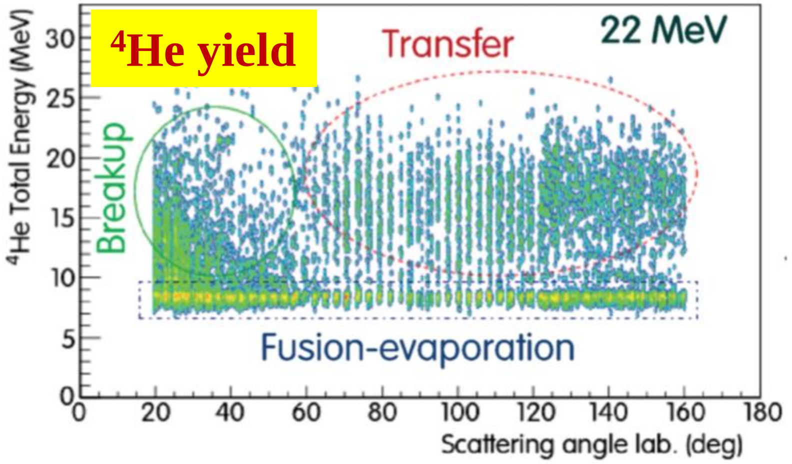
Clear separation between breakup/transfer

- 50∘ - 160∘ from neutron transfer reactions
- 20∘ - 40∘ , from ^{6}He → ^{4}He + 2n breakup

(1) 2n transfer: ^{208}Pb(^{8}He, ^{6}He)^{210}Pb
(2) 1n transfer: ^{208}Pb(^{8}He, ^{7}He → ^{6}He + n)^{209}Pb

"TRANSFER"



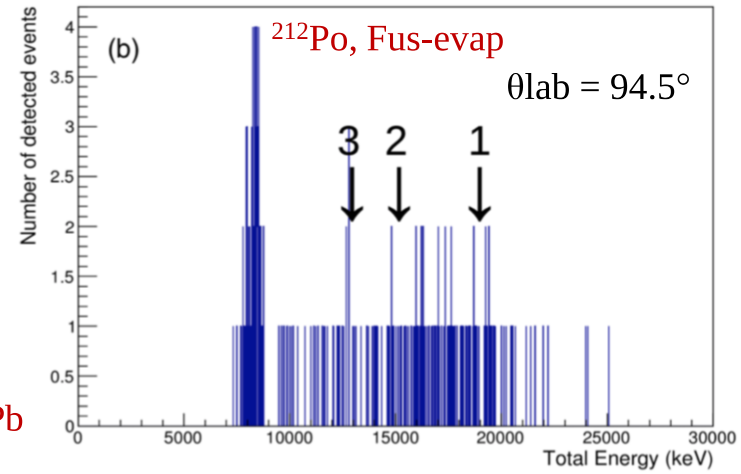


Moderate separation between breakup/transfer and fusion-evaporation

- α from fusion-evaporation events ^{212}Po
- 60∘ - 160∘ from neutron transfer reactions
- 20∘ - 40∘ , from ^{8}He → ^{4}He + 4n breakup

(1) 4n transfer: ^{208}Pb(^{8}He, ^{4}He)^{212}Pb
(2) 3n transfer: ^{208}Pb(^{8}He, ^{5}He → ^{4}He + n)^{211}Pb
(3) 2n transfer: ^{208}Pb(^{8}He, ^{6}He*1.8 → ^{4}He + 2n)^{210}Pb

"TRANSFER"

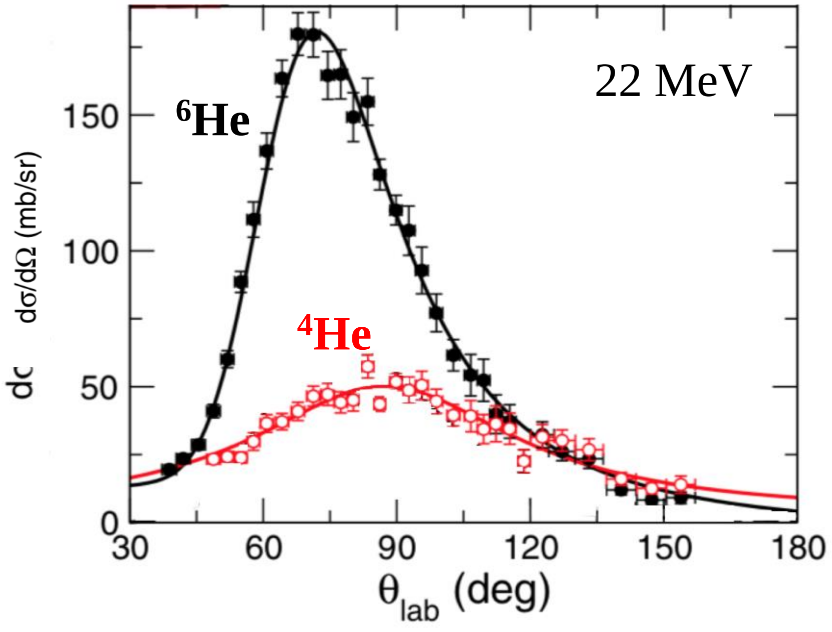


Kinematics consistent with neutron transfer channels

G. Marquínez-Durán et al., Phys. Rev. C ***98, 034615 (2018).***

Cross sections

^{6,4}He cross sections



^{6,4}He: The shape of the angular distributions consistent with a transfer reaction mechanism.

^{6}He:

- Competition of 1n and 2n transfer

^{4}He:

- Small spectroscopic factor for the ⟨^{8}He| ^{6}He$^*_{1.8}$ + 2n⟩ overlap → expected 3n or 4n transfer to ^{211}Pb and ^{212}Pb, respectively.

Reaction mechanisms

^{6}He

	Reaction	Q (MeV)	Q_{opt} (MeV)
2n transfer →	^{208}Pb(^{8}He, ^{6}He)^{210}Pb	+7.00	−0.8
1n transfer →	^{208}Pb(^{8}He, ^{7}He → ^{6}He + n)^{209}Pb	+1.40	−0.4
2n breakup →	^{208}Pb(^{8}He, ^{8}He* → ^{6}He + $2n$)^{208}Pb	−2.14	

^{4}He

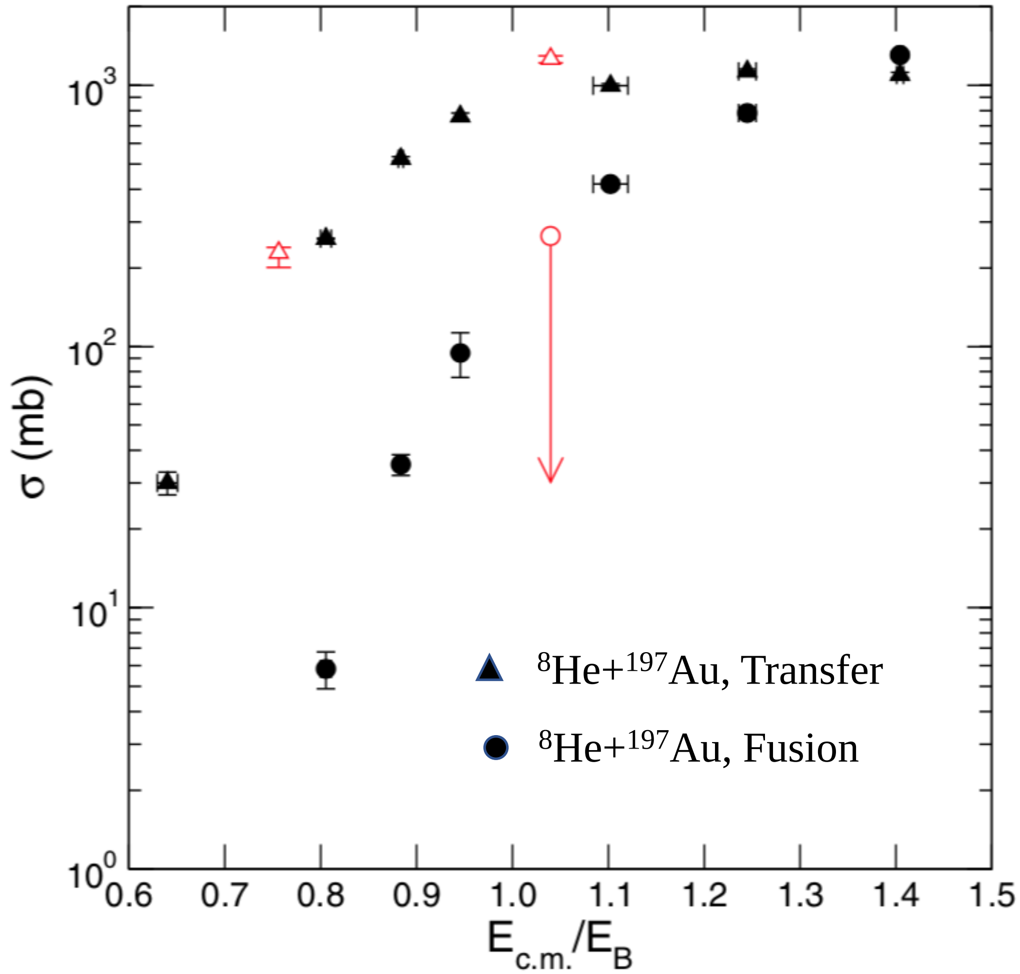
	Reaction	Q (MeV)	Q_{opt} (MeV)
4n transfer →	^{208}Pb(^{8}He, ^{4}He) ^{212}Pb	+14.99	−1.7
3n transfer →	^{208}Pb(^{8}He, ^{5}He → ^{4}He + n) ^{211}Pb	+9.12	−1.2
2n transfer →	^{208}Pb(^{8}He, ^{6}He$^*_{1.8}$ → ^{4}He + $2n$) ^{210}Pb	+5.20	−0.8
4n breakup →	^{208}Pb(^{8}He, ^{8}He* → ^{4}He + $4n$) ^{208}Pb	−3.11	
4n breakup →	^{208}Pb(^{8}He, ^{8}He* → (^{6}He$^*_{1.8}$ → ^{4}He + $2n$) + $2n$) ^{208}Pb	−3.94	

Total cross sections

E_{lab} (MeV)	$\sigma_{^6He}$ (mb)	$\sigma_{^4He}$ (mb)	σ_R (mb)
16	203^{+10}_{-28}	26 ± 5	254 ± 60
22	871 ± 31	393^{+10}_{-33}	1529 ± 40

Assume:

$\sigma_{Trans} = \sigma_{6He} + \sigma_{4He}$ $\sigma_{Fus} = \sigma_R - \sigma_{Trans}$



Good overall agreement between ^{8}He + ^{208}Pb and ^{8}He + ^{197}Au.

A. Lemasson, *et al.*, Phys. Lett. B **697**, 454 (2011).

A. Lemasson, *et al.*, Phys. Rev. Lett. **103**, 232701 (2009)

G. Marquínez-Durán *et al., Phys. Rev. C* ***98, 034615 (2018).***

→ Scattering of ^{8}He + ^{208}Pb dominated by transfer channels

Probing transfer of neutron clusters with Coulomb barrier reactions induced by ^{8}He

Objective. Measurement of the angular distributions of transfer cross sections for ^{6}He and ^{4}He yields in coincidence with neutrons and gammas, in the scattering of ^{8}He+^{208}Pb at the energy of 22 MeV.

I. Martel[1,2], N. Keeley[3], K. Kemper[4], K. Rusek[5], L. Acosta[6], L. Aguado[2], L. Barrón[6], J. Carpio[2], E. Chávez[6], A. Chbihi[7], C. García-Ramos[2], G. de Angelis[8], G. de France[7], N. Erduran[9], A. Gadea[10], A. Goasduff[8], J.A. Gómez-Galán[2], A. Gottardo[8], A. Illana[8], G. Jaworski[4], T. Kurtukian-Nieto[11], K. Mahata[12], F. Manchado de Sola[2], D. Marín-Lambarri[6], F.M. Marqués[13], M. Mazzocco[14], D. Mengoni[8], J. Nyberg[15], A.K. Orduz[7], M. Palacz[4], S. Pandit[12], V. Parkar[12], M. Pedro-Carrasco[2], Z. Poldoyak[16], R. Raabe[17], M. Renaud[17], A.M. Rodríguez-Pérez[2], F. Salguero[2], A.M. Sánchez-Benítez[19], M. Sánchez-Raya[2], J. Sánchez-Segovia[2], A. Shrivastava[12], N. Soic[20], D. Testov[8], J. Smallcombe[1], J.J. Valiente-Dobón[8], R. Wolski[18].

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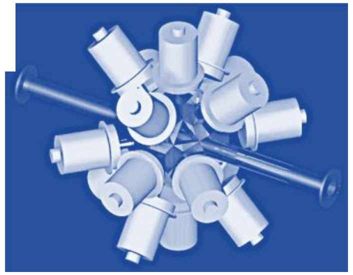
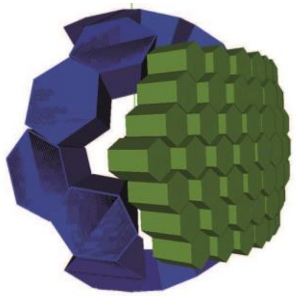
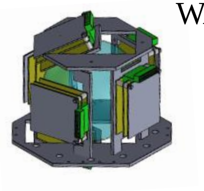


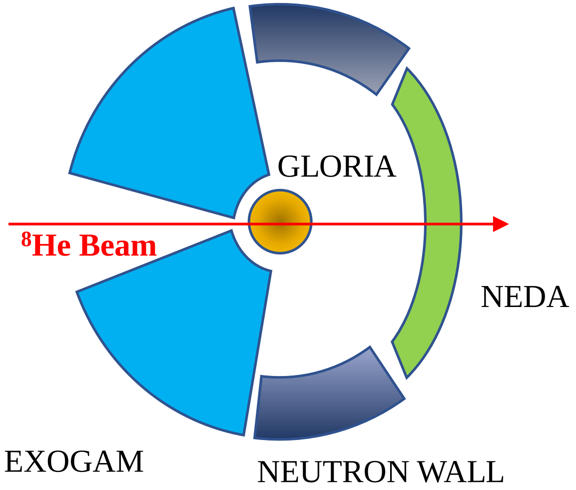
EXOGAM



NEDA +NEUTRON WALL



GLORIA



Summary and conclusions

- Sequential 1n-transfer to low-energy levels in ^{209}Pb seems to dominate the ^{6}He angular dsitribution.
- The data on ^{4}He is well reproduced by including a direct tetraneutron transfer component to highly excited states in ^{212}Pb.
- However, model uncertainties are too large to withdraw conclusive results.
- New proposal at SPIRAL1/GANIL to measure ^{6,4}He exclusive data in coincidence with gammas an neutrons.
- Everybody welcome to join the new proposal, just send me an email to imartel@uhu.es

Thanks!!