Andean School on Nuclear Physics in the 21st. Century

Fusion of the $^{8}B + ^{58}Ni$ proton-halo system

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Program

- Introduction
- Background
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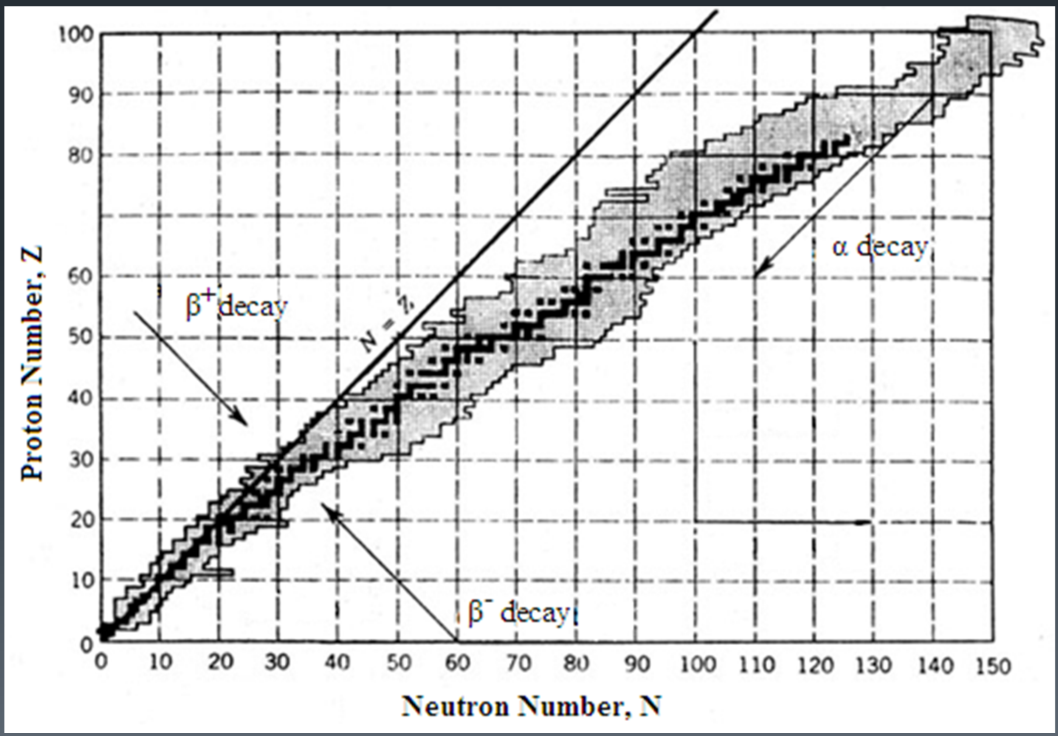
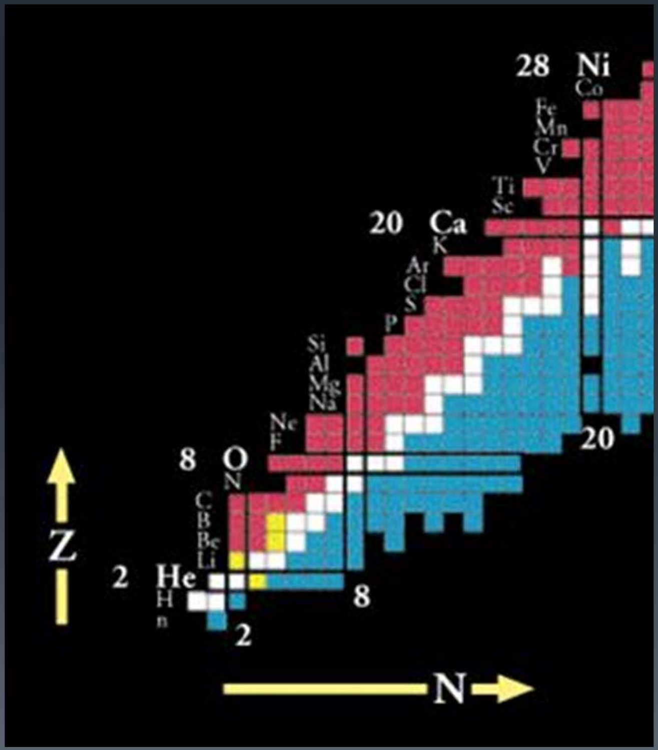
Introduction

- The elements found in nature mostly correspond to stable nuclei.
- Light stable nuclei approximately have N~Z.





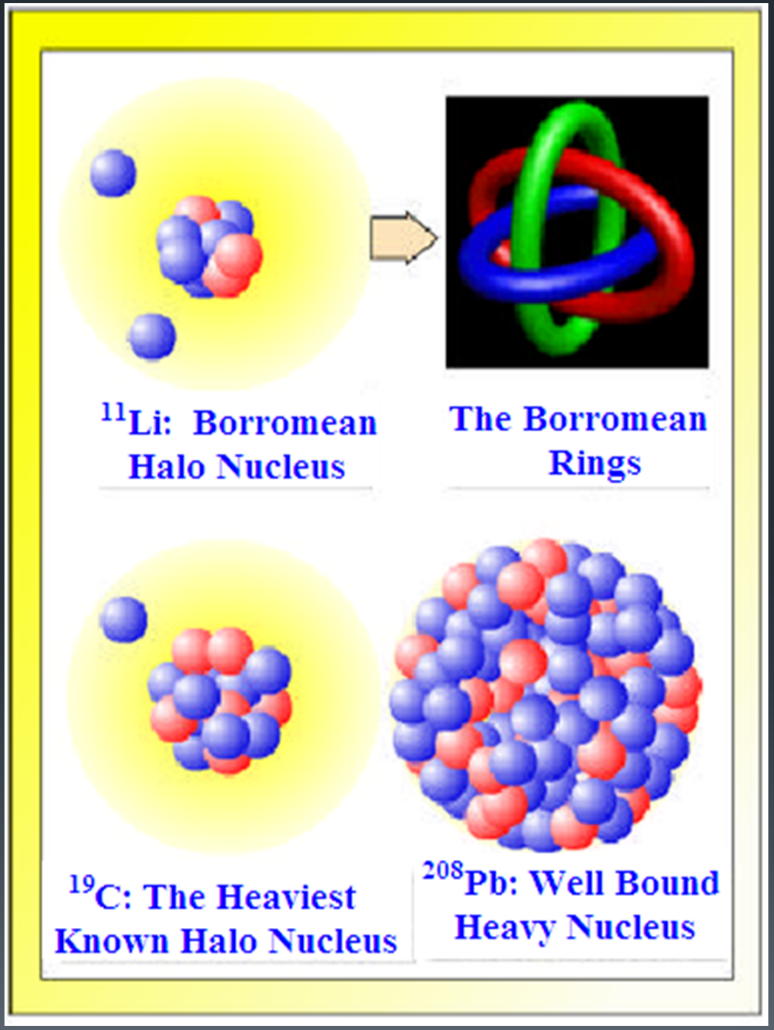
- Traditionally, nuclear experiments use stable beams.

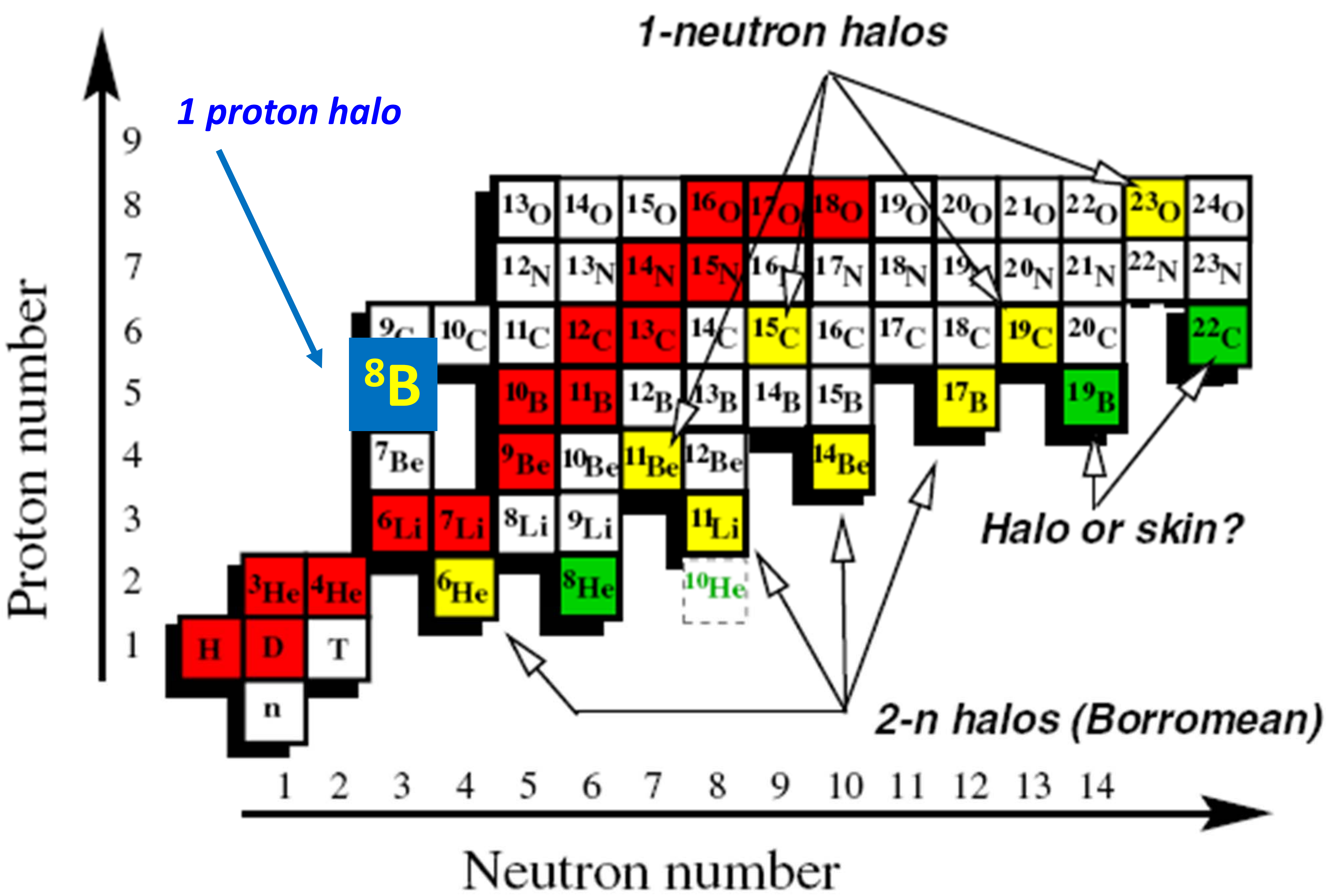
- However, research with radioactive ion beams has entered in the past two decades a new era with the advent of energetic beams of radioactive nuclei which can induce nuclear reactions.

- So now, it is possible to study a lot of nuclear exotic species.

Exotic properties of radioactive nuclei

- Unusual nucleonic composition.
- Isotopes with an excess of neutrons or protons.
- Might have a halo.
- Big dimensions compared to normal nuclei.
- Examples:
  - ^{11}Li which can be seen as a ^{9}Li core with two valence neutrons.
  - ^{6}He: ^{4}He core and two valence neutrons
  - ^{8}B: ^{7}Be core and a valence proton





1-neutron halos
1 proton halo
8B
Halo or skin?
2-n halos (Borromean)
Proton number
Neutron number

Radioactive Beam Facilities

1. TWINSOL - Notre Dame
2. FRIB - MSU
3. Argonne
4. HRIBF - Oak Ridge
5. Texas A&M
6. Berkeley
7. TRIUMF ISAC - Vancouver
8. RIBRAS - Sao Paulo
9. SIRIUS - Inglaterra
10. SPIRAL-II - GANIL
11. ARENAS - Louvain-la-Neuve
12. FAIR - GSI
13. MAFF - Munich
14. ISOLDE - CERN
15. EXCYPT - Catania
16. SPES - Legnaro
17. Dubna
18. NSC - Delhi
19. VECC - Calcuta
20. RIBF - Riken
21. Lanzhou
22. Beijing

Radioactive beams produced at Notre Dame

		^{8}C 0.2 MeV	^{9}C 0.13 s	^{10}C 19.3 s	^{11}C 20.3 m	^{12}C stable	^{13}C stable
		^{7}B 1.4 MeV	^{8}B 0.8 s	^{9}B 0.5 keV	^{10}B stable	^{11}B stable	^{12}B 0.02 s
		^{6}Be 0.1 MeV	^{7}Be 53.2 d	^{8}Be 5.6 eV	^{9}Be stable	^{10}Be 1.5×10^{6} a	^{11}Be 13.8 s
	^{4}Li 6.0 MeV	^{5}Li 1.5 MeV	^{6}Li stable	^{7}Li stable	^{8}Li 0.84 s	^{9}Li 0.18 s	
	^{3}He stable	^{4}He stable	^{5}He 0.6 MeV	^{6}He 0.8 s	^{7}He 0.2 MeV	^{8}He 0.12 s	
^{1}H stable	^{2}H stable	^{3}H 12.4 a					

Background

- ^{8}B has a very small proton separation energy of only 0.138 MeV and a $T_{1/2} = 0.8$ s.
- Guimarães *et al*., 2000, Kolata *et al*., 2001, Aguilera *et al*., 2009 have shown evidence that ^{8}B has a *proton halo.*
- These experiments and the comparison with models have shown a substantial enhancement in the reaction cross sections.

[1] V. Guimarães *et al*., Phys. Rev. Lett. **84**, 1862 (2000).
[2] J. J. Kolata *et al*., Phys. Rev. C **63**, 24616 (2001).
[3] E.F. Aguilera *et al*., Phys. Rev. C **79**, 021601(R) (2009).

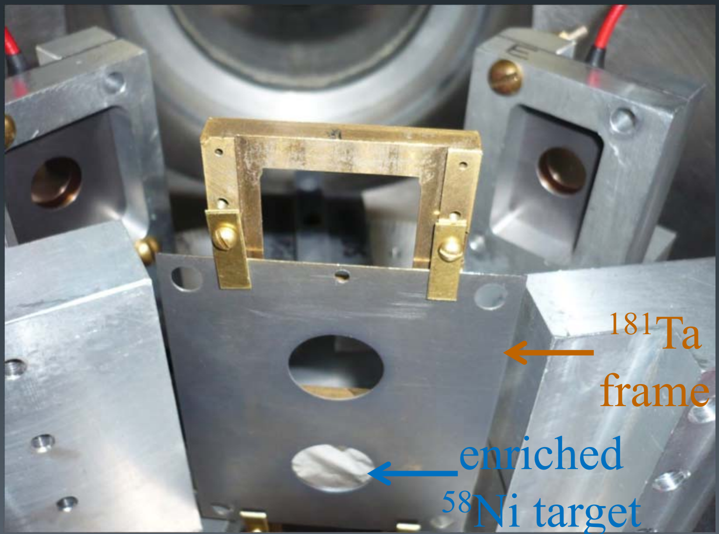
- In 2008, the Heavy Ion Group from Departamento de Aceleradores del Instituto Nacional de Investigaciones Nucleares (ININ) went to the Astronomy and Nuclear Structure Lab at the University of Notre Dame and performed an experiment.

- In this experiment the angular distribution of the evaporated products (protons) was measured in order to determine the fusion cross section of the $^{8}B+^{58}Ni$ system, around the Coulomb barrier.

Two different targets were used.

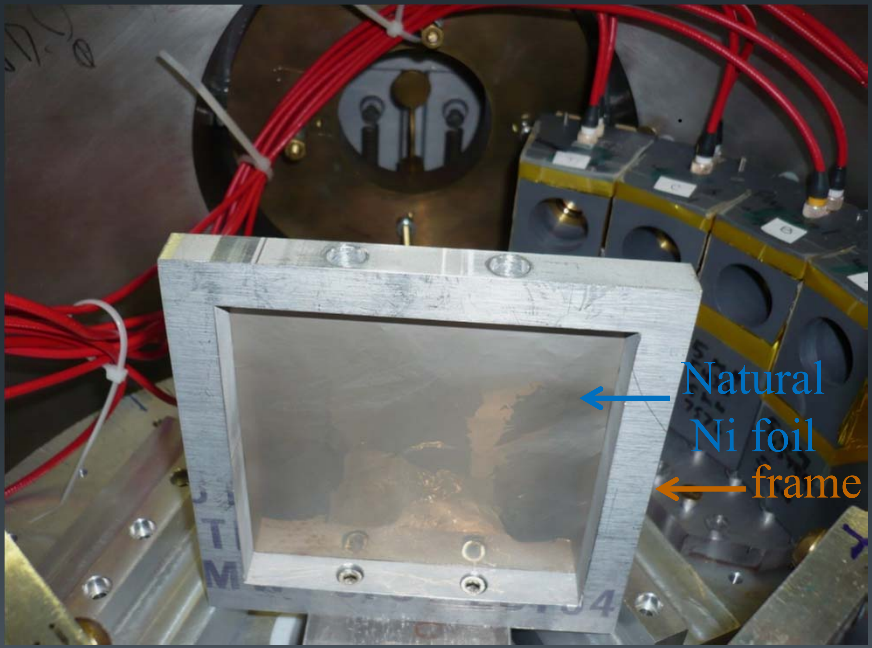
1) Enriched ^{58}Ni target (25 mm diameter) and a thickness of 0.7 mg/cm^2

This target was mounted on a ^{181}Ta frame.



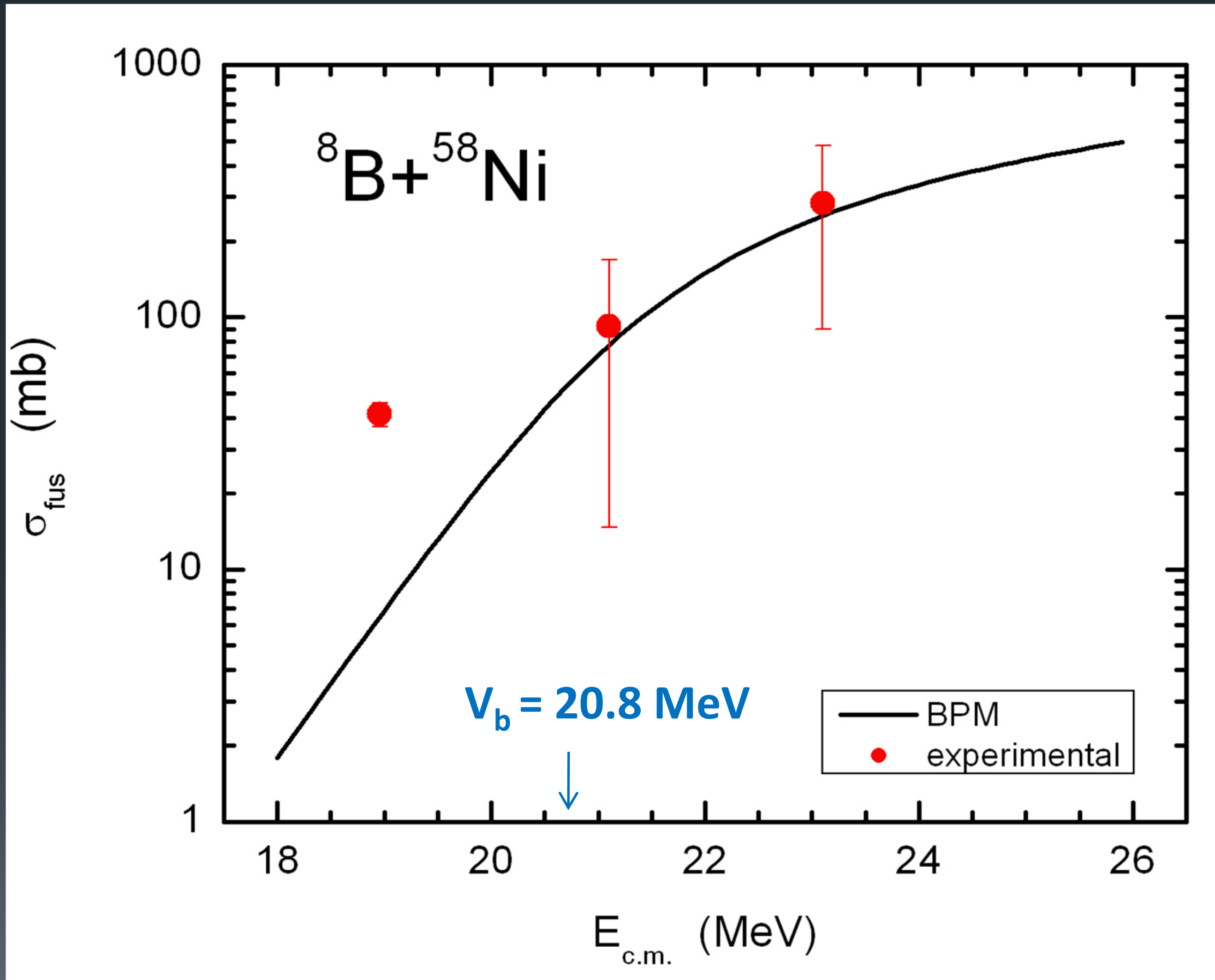
Measurements at $E_{c.m.}$ = 19.3, 21.2 and 23.2 MeV were made with the enriched ^{58}Ni target.

2) Natural Ni foil (13 cm x 13 cm square frame)



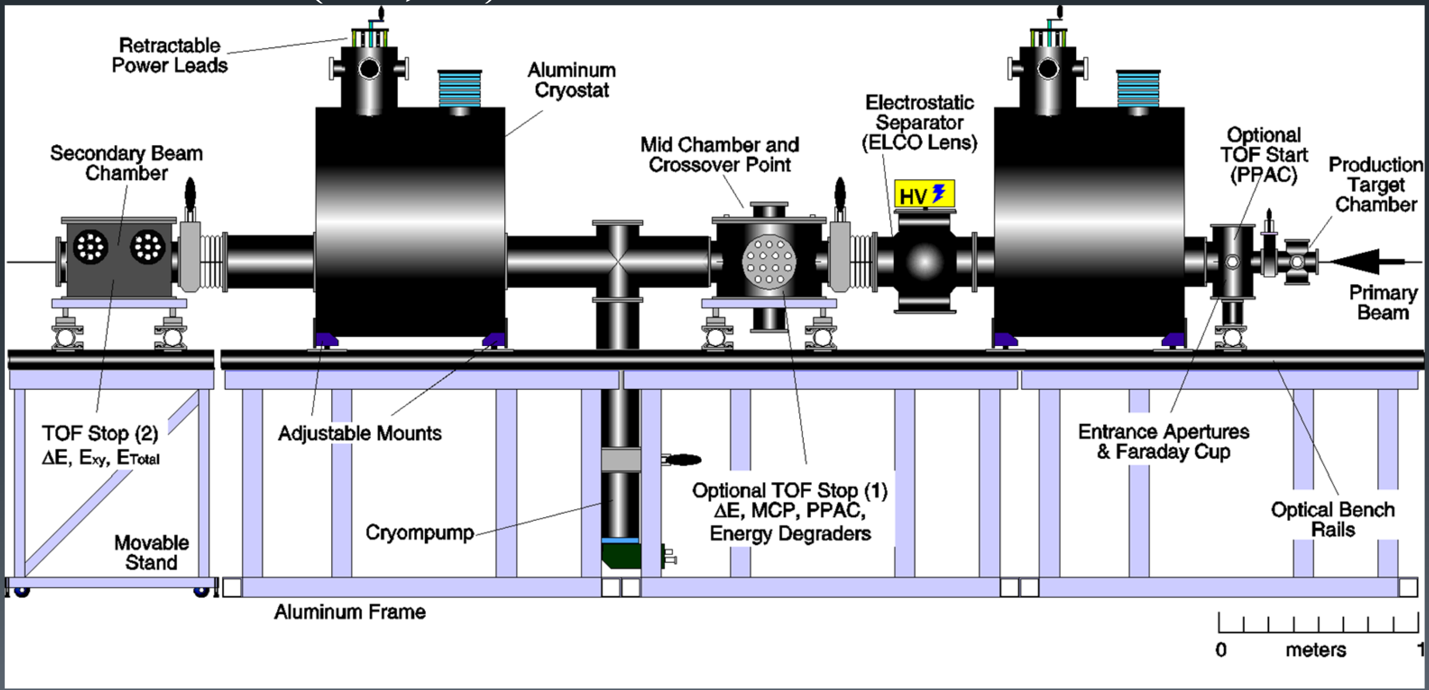
Because of lack of time this target was only bombarded at the lowest energy ($E_{c.m.}$ = 19.3 MeV).

Preliminary Results (2008)



Instruments and Methods

- Tandem Van de Graaff Accelerator and the TwinSol Facility of the Astronomy and Nuclear Structure Lab at the University of Notre Dame [4].
- ^{8}B radioactive beam is produced through a primary reaction: $^{3}He(^{6}Li,^{8}B)$



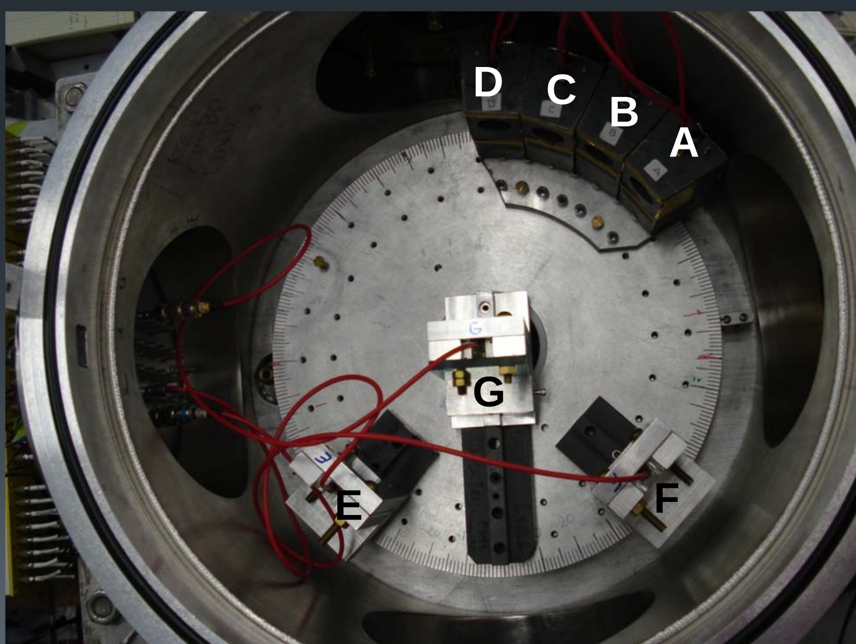
[4] M.Y. Lee *et al*., Nucl. Instrum. Methods Phys. Res., Sect. A **422**, 536 (1999).

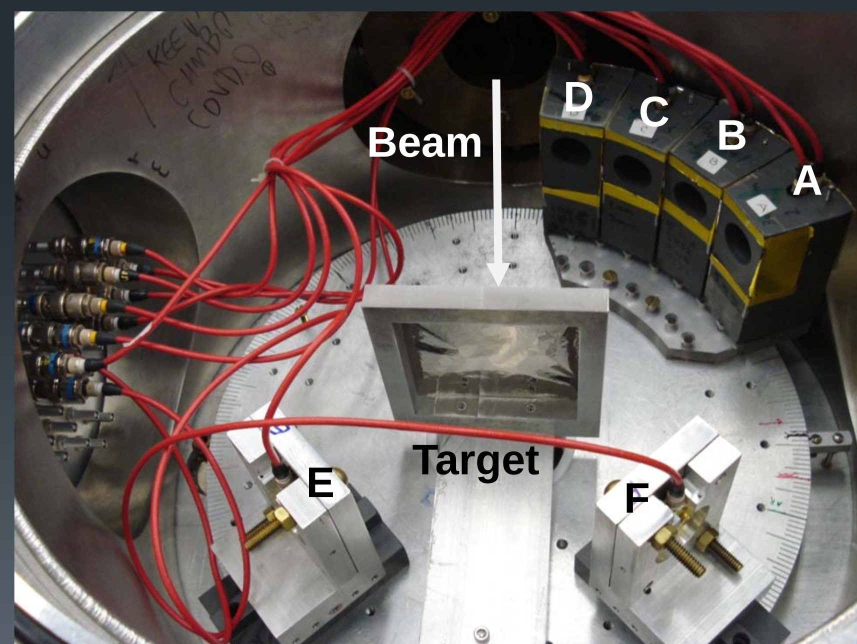
- The experiment was performed in four stages at different energies, using different secondary targets.

Stage	Target	[mg/cm^2]	$E_{c.m.}$ (MeV)
I	Natural Ni	1.4	23.4 25.6
II	^{58}Ni	0.9	22.1 23.7 25.0
III	^{58}Ni	0.7	21.2 23.2
	Natural Ni	5.6	19.3
IV	Natural Ni	2.2	20.1 22.1 23.8

Experimental Arrangement (2010)

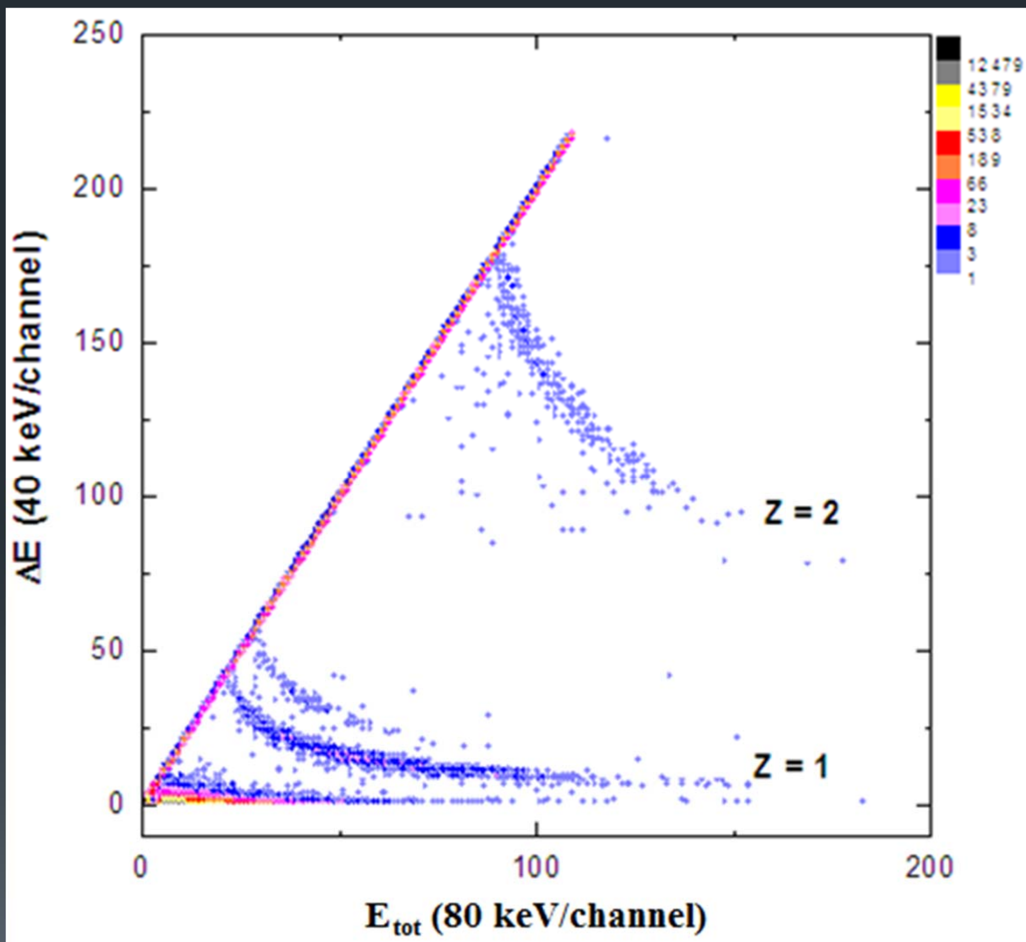
- 1 detector (G) placed at the position of the Ni target.
- 4 detectors E-ΔE (A,B,C,D) placed at 112.5º, 127.5º, 142.5º y 157.5º
- 2 monitors (E y F) placed at 45º



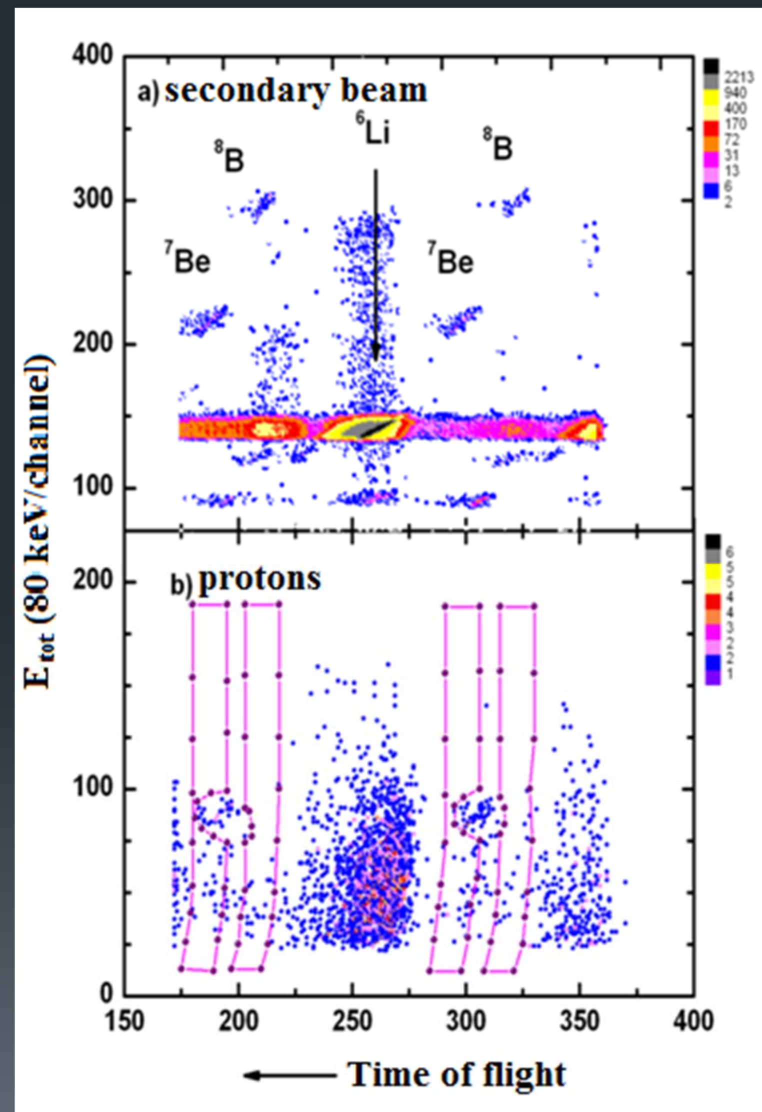


Detection Techniques

Telescope

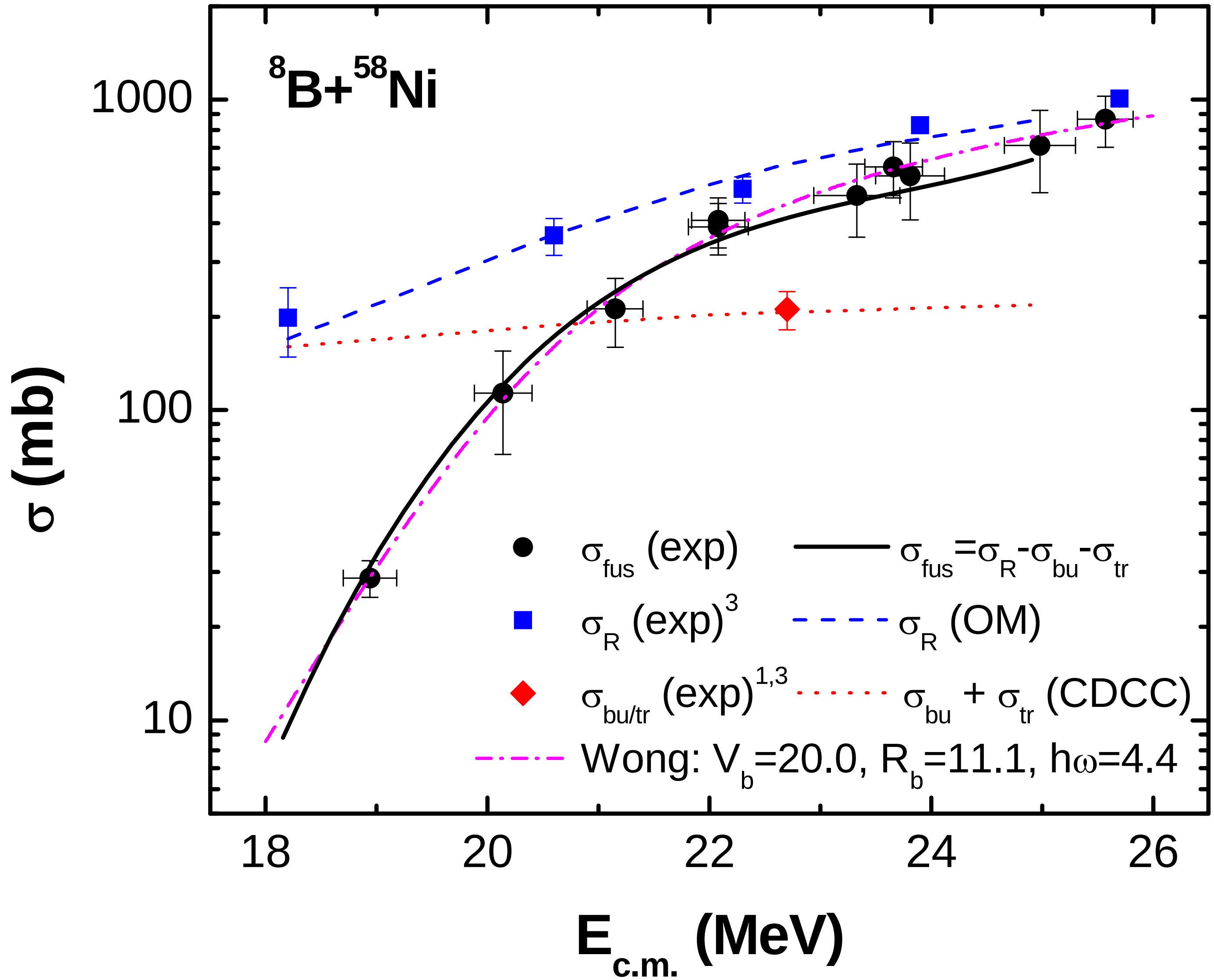


Time of flight



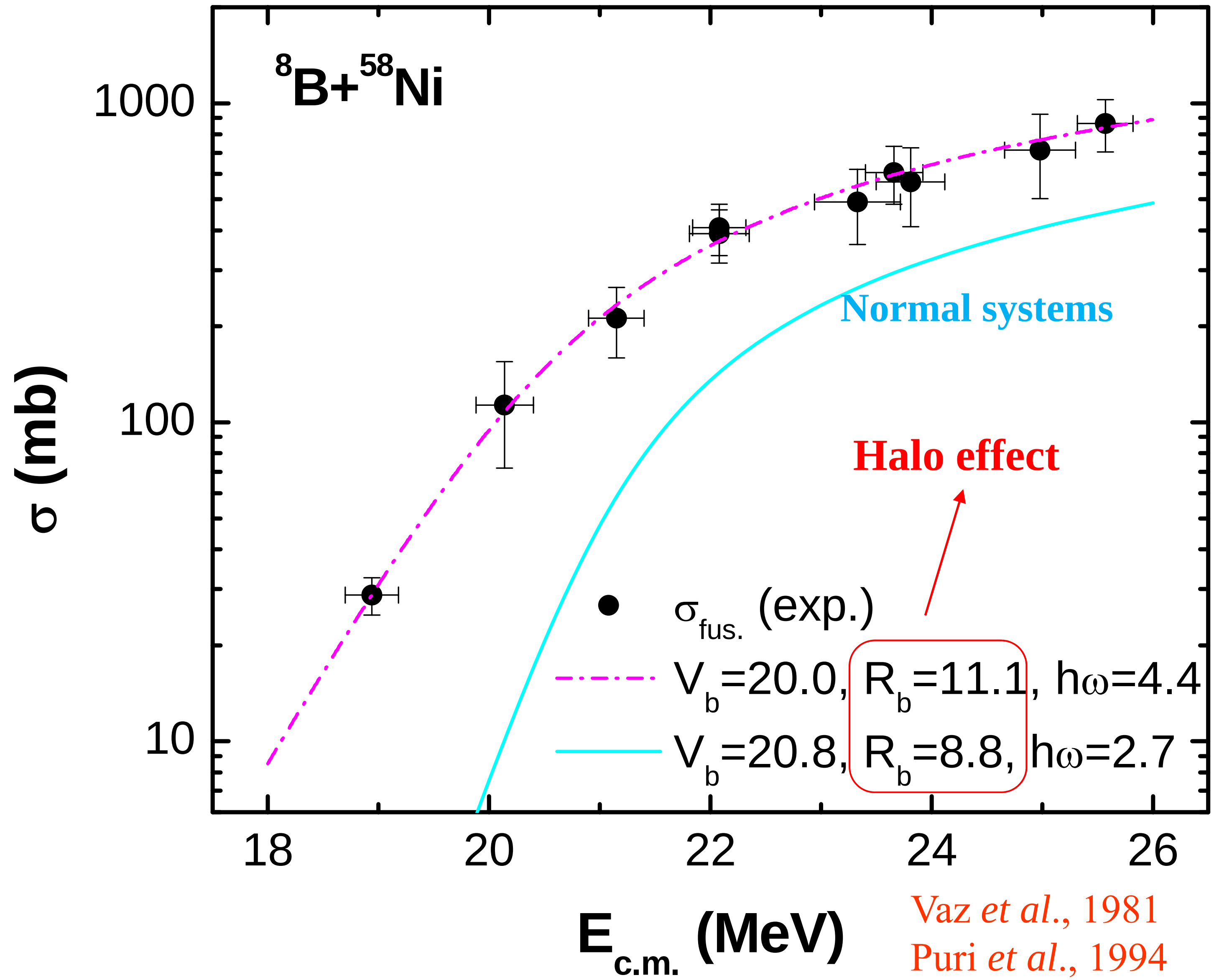
Results

E. F. Aguilera *et al.*, Phys. Rev. Lett. 107, 092701 (2011)



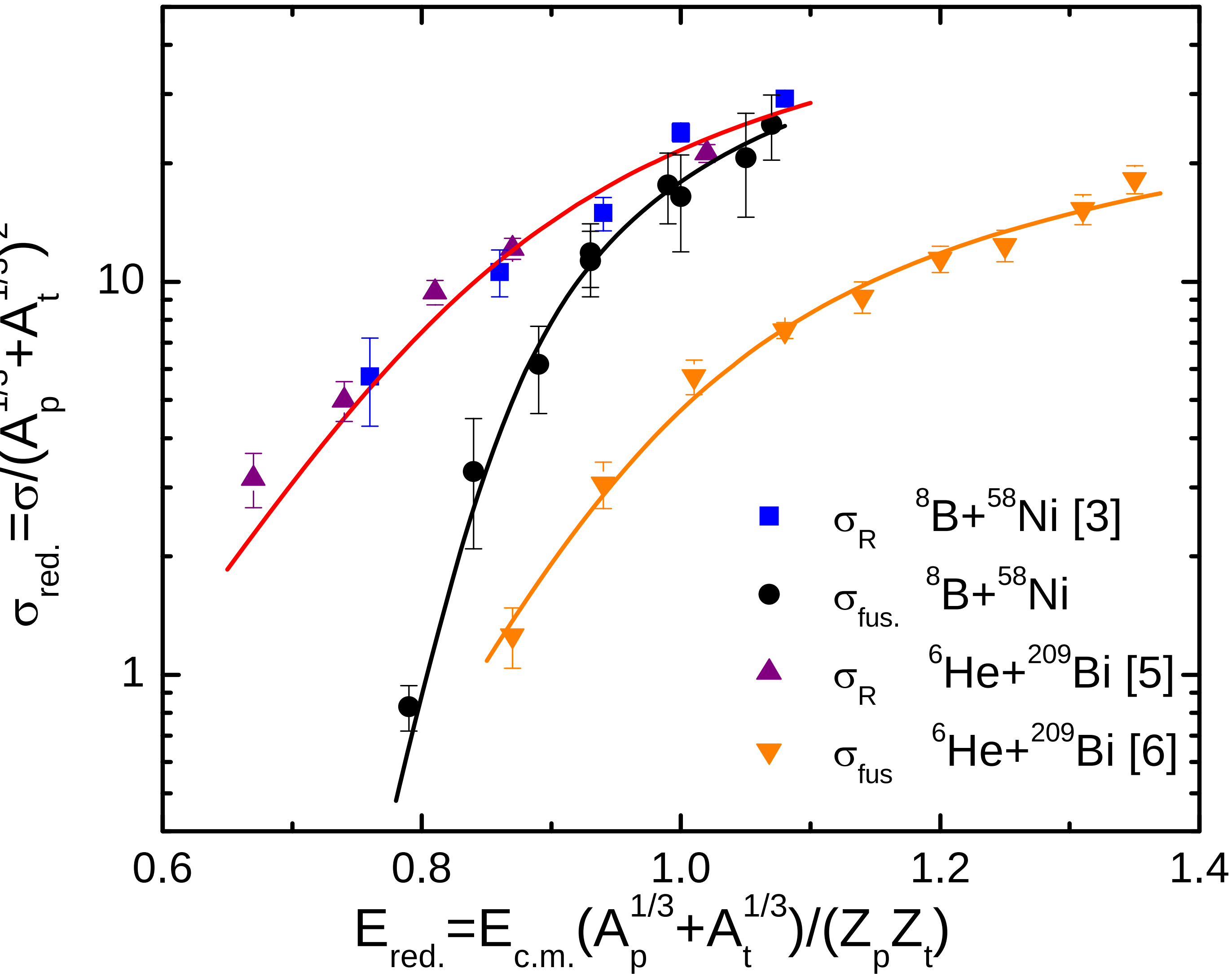
[1] V. Guimarães *et al.*, Phys. Rev. Lett. **84**, 1862 (2000).
[3] E.F. Aguilera *et al.*, Phys. Rev. C **79**, 021601(R) (2009).

Proton-halo Effects



Vaz *et al.*, 1981
Puri *et al.*, 1994

Proton vs. Neutron halo



[7] P. Amador-Valenzuela *et al.*, J. Phys.: Conf. Ser. **322**, 012007 (2011).
[8] E.F. Aguilera *et al.*, Phys. Rev. C **83**, 021601(R) (2011).

[3] E.F. Aguilera *et al.*, Phys. Rev. C **79**, 021601(R) (2009).
[5] E.F. Aguilera *et al.*, Phys. Rev. C **63**, 061603(R) (2001).
[6] J.J. Kolata *et al.*, Phys. Rev. Lett. **81**, 4580 (1998).

Conclusions

- The barrier radius inferred from the fusion data (11.1 fm) is 26% larger than that expected for normal systems, possibly indicating a strong static effect of the ^{8}B proton halo.

- The sum of the fusion and transfer or breakup channels exhausts the total reaction yield.

- It appears that the halo wave function enhances the transfer or breakup process for neutron-halo systems and the fusion yield for proton-halo systems.

- One might speculate that this difference results from the different role played by Coulomb polarization in the case of a charged rather than a neutral halo.

Thanks…

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Near-Barrier Fusion of the $^{8}B + ^{58}Ni$ Proton-Halo System

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Fusion cross sections were measured for the exotic proton-halo nucleus ^{8}B incident on a ^{58}Ni target at several energies near the Coulomb barrier. This is the first experiment to report on the fusion of a proton-halo nucleus. The resulting excitation function shows a striking enhancement with respect to expectations for normal projectiles. Evidence is presented that the sum of the fusion and breakup yields saturates the total reaction cross section.

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Evaporation protons from $^{8}B+^{58}Ni$ at near barrier energies

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Abstract. Yields of evaporated protons from the $^{8}B+^{58}Ni$ reaction are measured at backward angles, for several near barrier energies. Statistical model calculations using the code PACE are used to extrapolate the measurements to the whole angular region in order to get angle integrated cross sections. Fusion cross sections are deduced by using the calculated proton multiplicities. The obtained fusion excitation function shows a large enhancement as compared to BPM calculations using conventional barrier parameters.