Coulomb barrier scattering of the proton halo nucleus ^{17}Ne

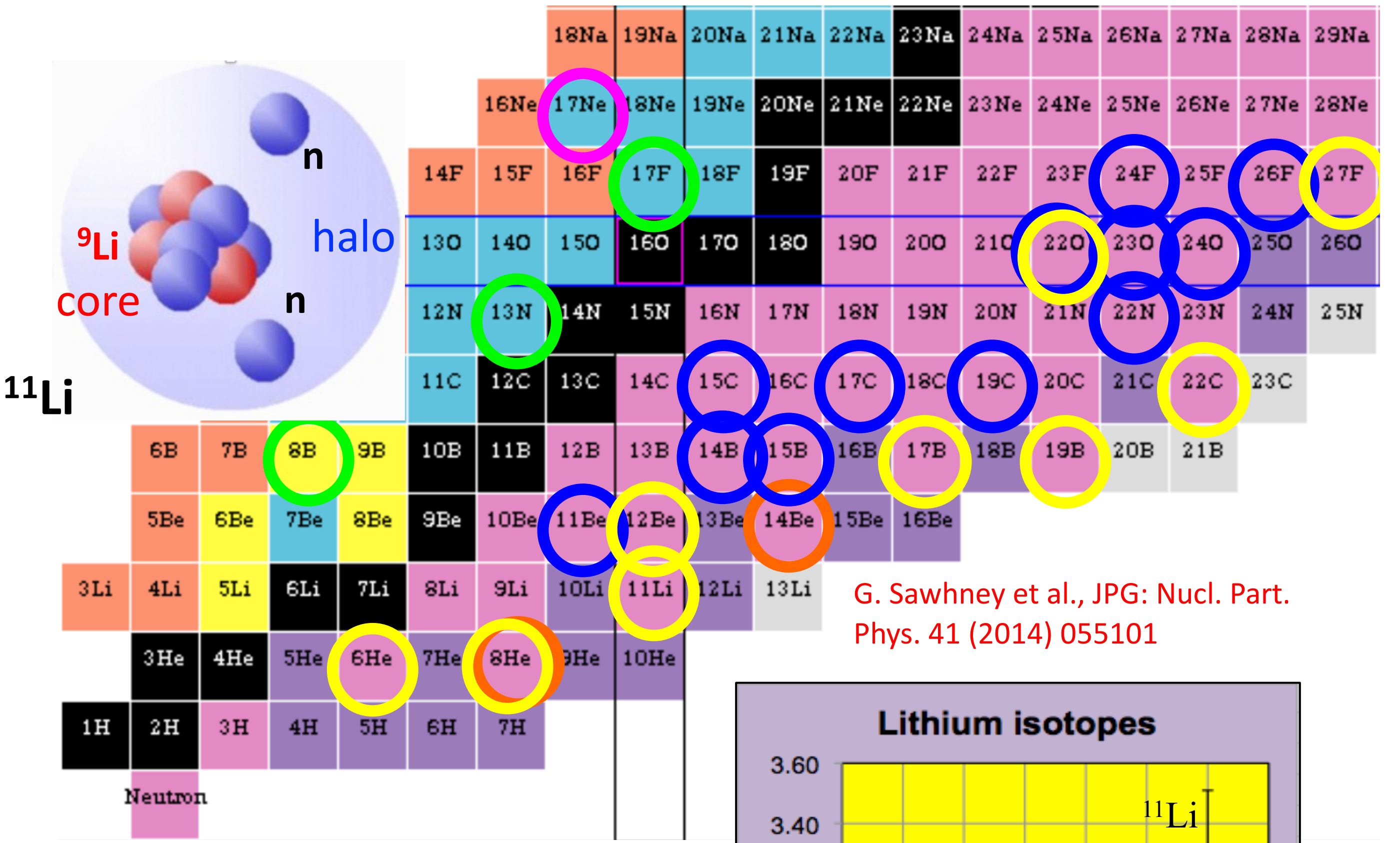
Ismael Martel

University of Huelva, Spain

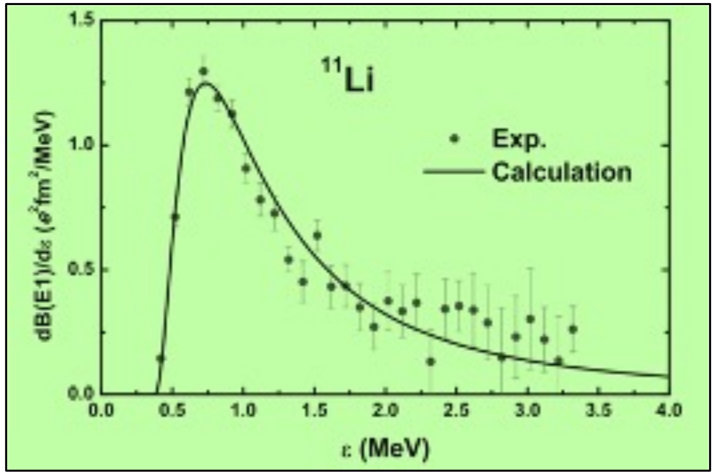
Halo nuclei

Exotic nuclear systems composed of a nuclear core and weakly bound valence nucleons

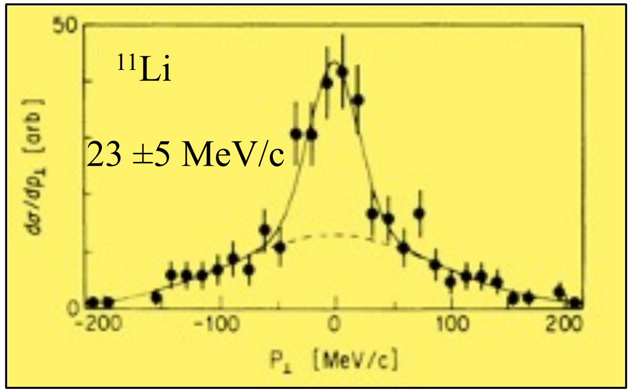
- Extended mass distribution
- Large rms radius ~ “halo”
- Large reaction cross sections
- Narrow momentum distributions of core/breakup
- Concentration of dipole strength at low energies close to the breakup threshold
- Halo → Borromean systems → none of the subsystems are bound
- Typical haloes: ^{11}Be (1n), ^{6}He(2n), ^{11}Li (2n), ^{8}B (1p), ^{17}Ne (2p)



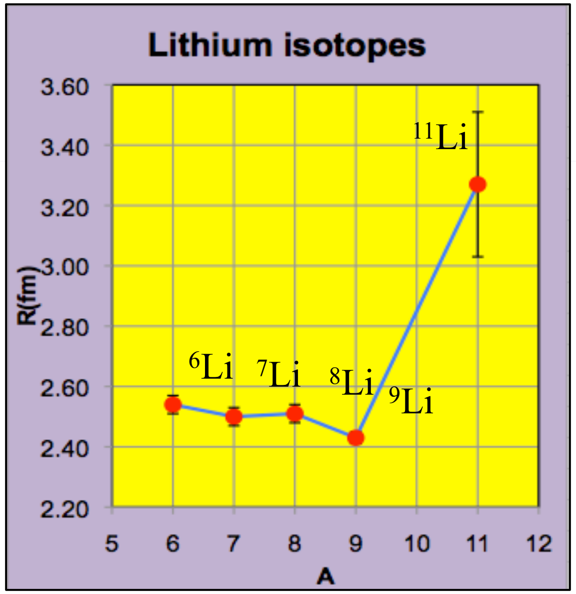
G. Sawhney et al., JPG: Nucl. Part. Phys. 41 (2014) 055101



T. Nakamura et al., Phys. Rev. Lett. 96, 252502 (2006). T. H. Kim et al., Jour. Kor. Phys. Soc. 73 (2018) 553.



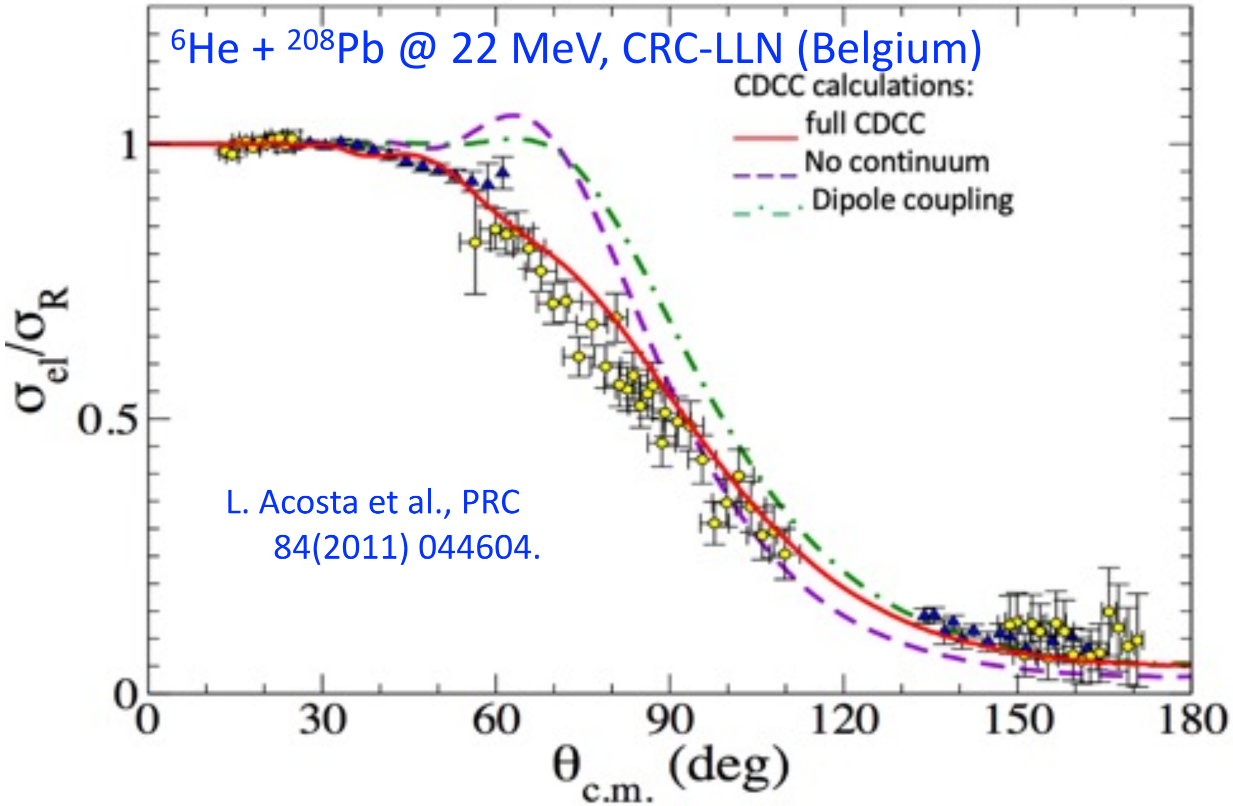
T. Kobayashi, et al. Phys. Rev. Lett. 60, 2599 (1988).

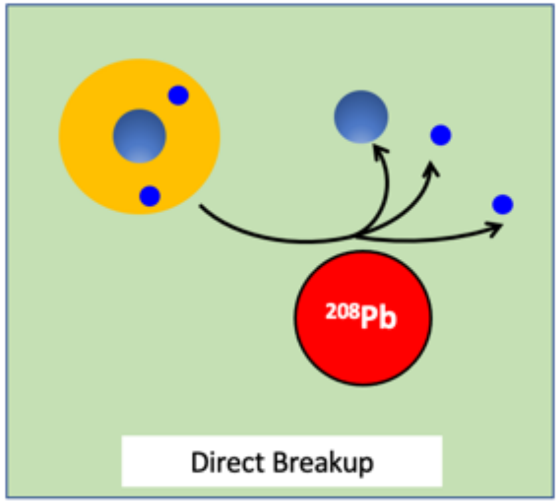


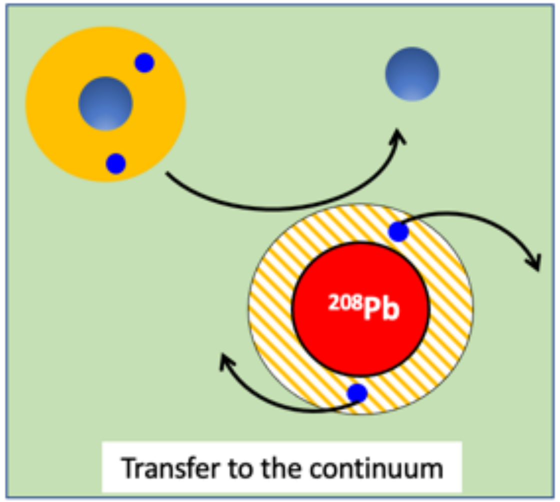
I. Tanihata et al., Phys. Rev. Lett. 55, 2676 (1985).

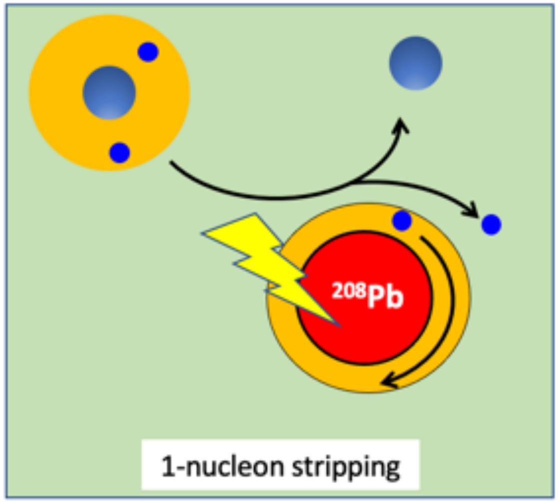
Coulomb barrier scattering

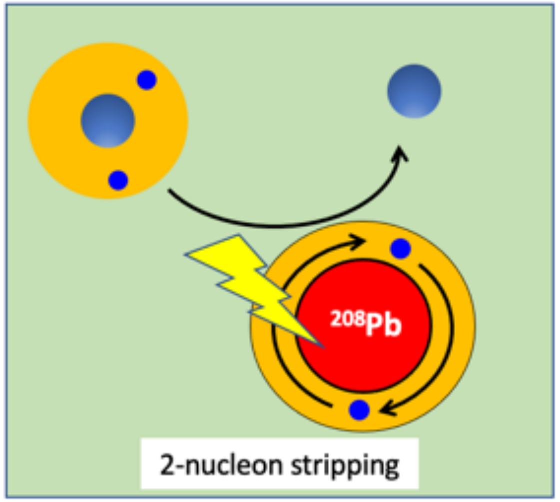
- Energies around Coulomb barrier-> Important coupling between elastic channel and inelastic, transfer, breakup and fusion.
- Halo: Low binding energy -> Coupling to the continuum
- Easily polarizable: forces between target and core/halo are different → distortion effects
- Dipole polarizability -> B(E1) -> large cross section for breakup.
- Nucleon transfer to the continuum
- Strong absorption in elastic channel ~ long range interactions
- Coulomb rainbow disappears!









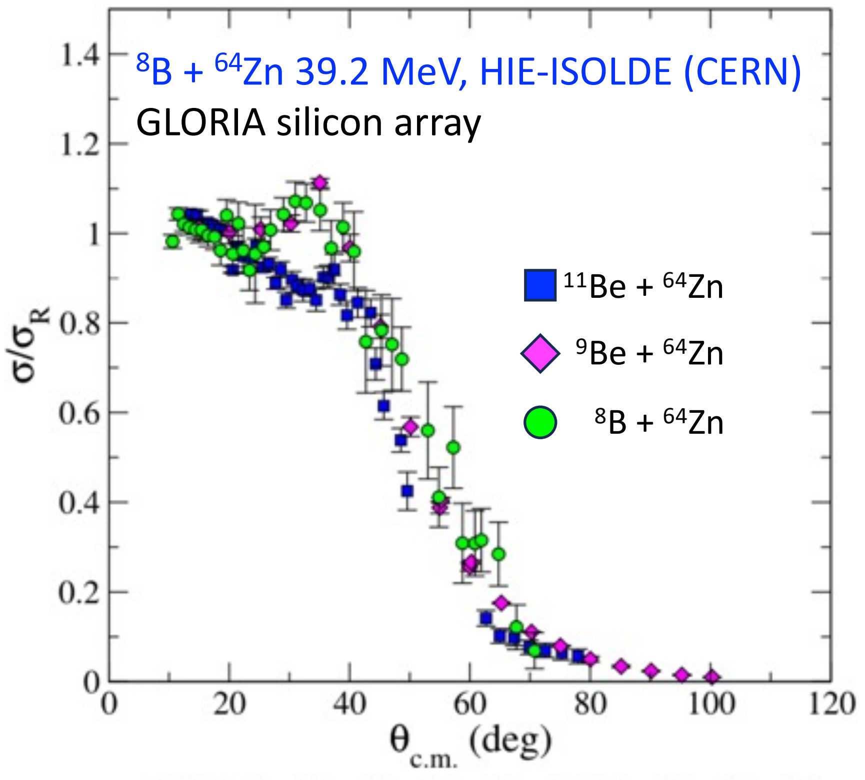


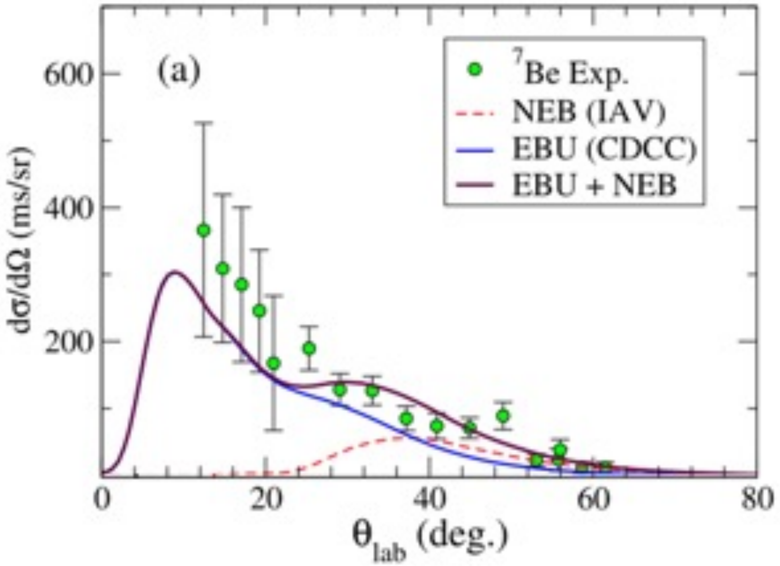
Proton halos

- Coulomb repulsion limits halo formation → only for ^{8}B(1p) and ^{17}Ne(2p) are known.
- Lack of experimental data at Coulomb barrier energies dynamics unknown
- ^{8}B(1p) is the most studied proton halo, Sp(^{8}B) = 136 keV only!
- Low energy measurements on ^{12}C, ^{27}Al, ^{58}Ni, ^{64}Zn, ^{120}Sn, and ^{208}Pb targets.
- In particular, for the system ^{8}B + ^{64}Zn,
  - Modest coupling of elastic scattering and breakup
  - Well described by OM and CDCC
  - Effects EBU + NEBU
  - Reaction cross sections are small, similar to the stable isotope ^{9}Be
  - The Coulomb Rainbow is present!!
- Complex couplings characteristic of the proton halo system
  - ✓ Higher effective Coulomb barrier Y. Kucuk and E. Aciksoz, EPJA 52(2016)98
  - ✓ Core "shading effect": the proton is "protected" by the core as it approaches the target, and the system breaks in the way out

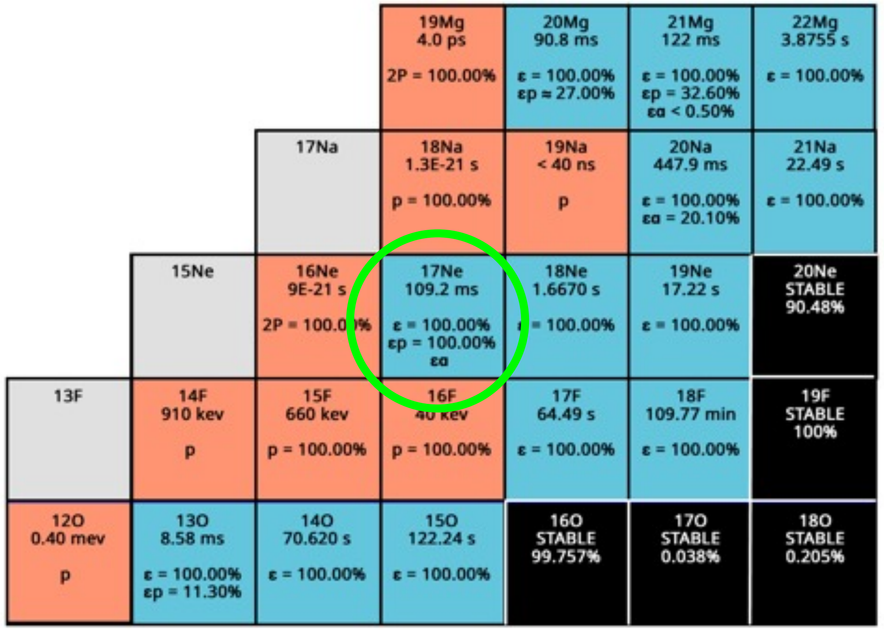
→ Recently demonstrated for **^{8}B + ^{120}Sn**

L. Yang et al., Nature Communications 13(2022)7193





What makes ^{17}Ne interesting?

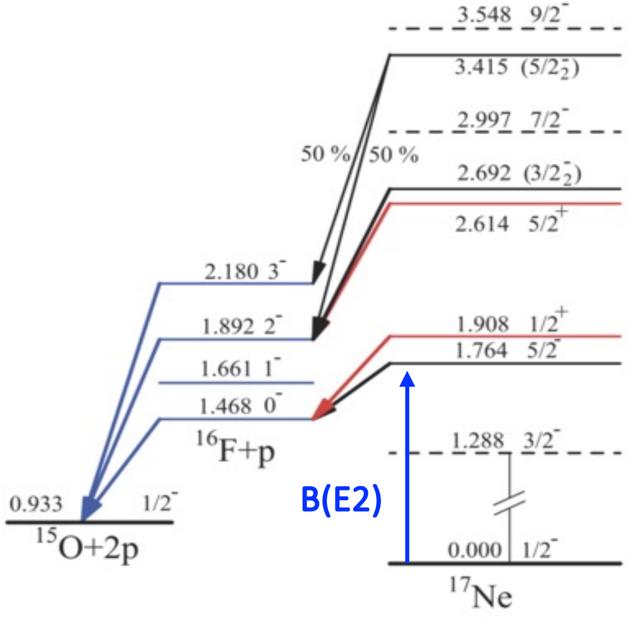


Candidate for a two-proton Borromean halo nucleus: ^{15}O core + two protons

- Dripline nucleus, S_{2p}=0.9 MeV & S_p=1.5 MeV
- Low lying dipole strength.
- No bound excited states.
- Narrow momentum distribution for 2p dissociation ~ 168 MeV/c
- Large matter radius.

The dynamics of ^{17}Ne at energies around the Coulomb barrier never measured before.

- Probe of B(E2;1/2− → 5/2−) → breakup
- Ground state mixing of (s1/2) (p3/2) (d5/2) configuration → probe halo
- Compare with data of ^{20}Ne + ^{208}Pb scattering at Coulomb barrier energies



s1/2 component		
R. Kanungo et al., EPJA 25(2005)327	J. Marganiec et al., PLB 759 (2016)200	C. Lehr et al., PLB 827(2022)136957
~ 20-65%	~ 25% or ~55%	~ 35%

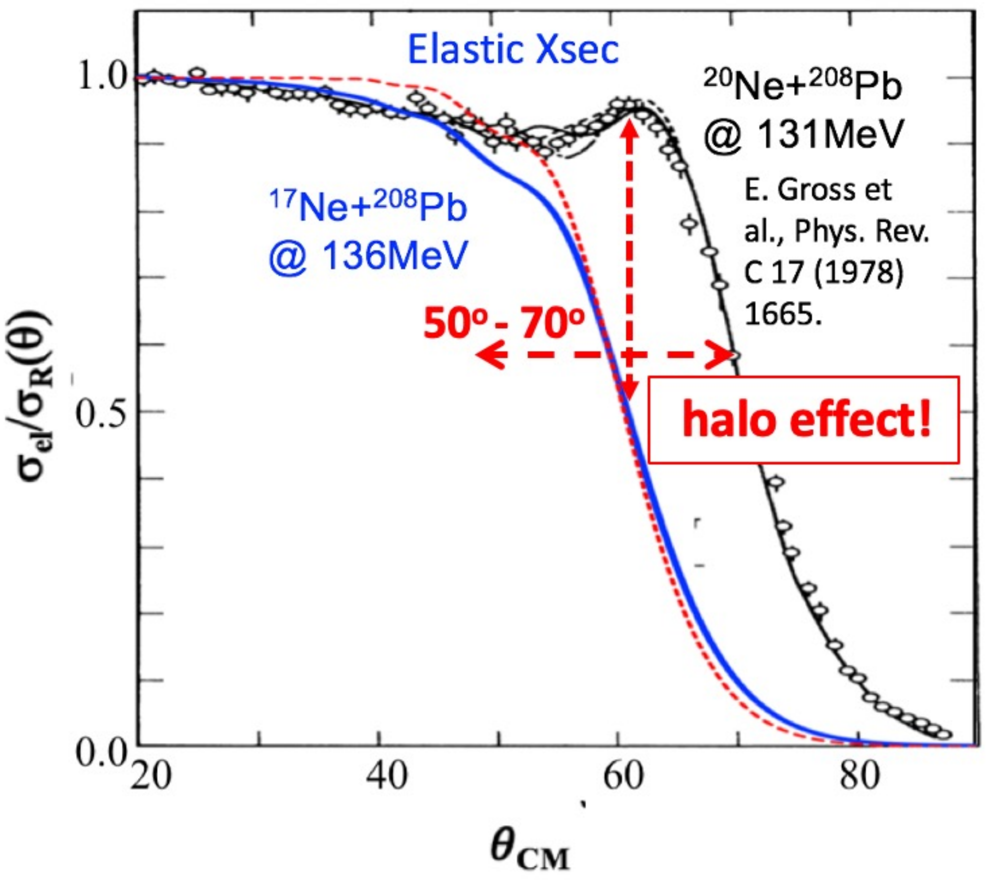
B(E2;1/2− → 5/2−) e2 fm4	
J. Marganiec et al., PLB 759 (2016)200	M.J. Chromik, et al., PRC66(2002)024313
90 ± 18	179± 26

J. Marganiec et al. Phys. Lett. B 759 (2016) 200–205

GANIL – SPIRAL1. Experiment E788S

Spokesperson: I. Martel, N. keeley, K. Rusek

- Scattering of $^{17}Ne + ^{208}Pb$ @ 136 MeV (Coulomb barrier ~ 125 MeV Lab) → ELASTIC and cross sections for ^{15}O production
- CDCC and CRC calculations (FRESCO) → dynamical effects of the 2p halo (Inert core of $^{15}O(1/2+)$ – Di-proton "halo" ^{2}He (0+))



- CRC: stripping cross section is very small & negligible effects in the dynamics.
- CDCC: coupling to the breakup channel gives strong effects.

→Large absorption on elastic θ ~ 50° – 70°.
→ Coulomb rainbow disappear.
→Large breakup Xsec, max. θ ~ 50°.

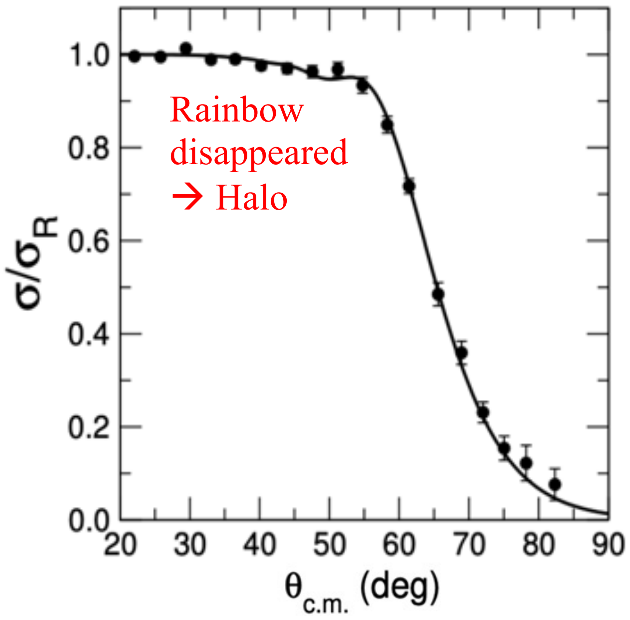
CDCC	
Total reaction [mb]	2327
Breakup [mb]	253

- 21 shifts of ^{17}Ne, E = 136 MeV (8 MeV/u)
- I ~ 2 x10^4 pps.
- Target thickness of 1,5 mg/cm^2.
- GLORIA silicon array.

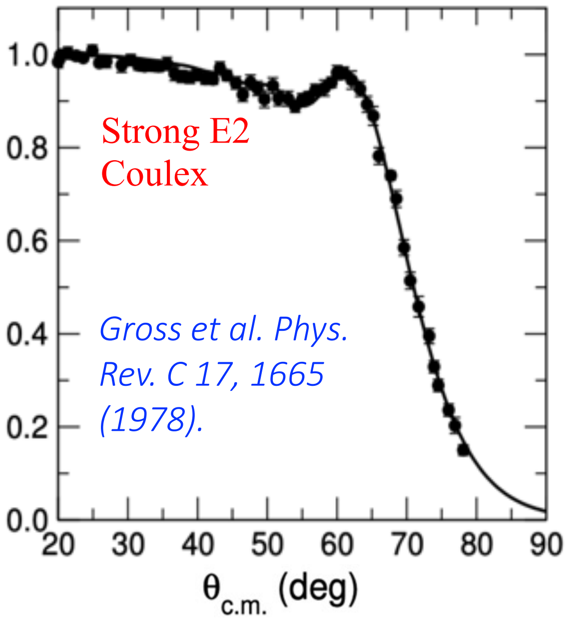
Elastic cross sections: Optical model analysis

J.D. Ovejas et al., PLB 843 (2023) 138007

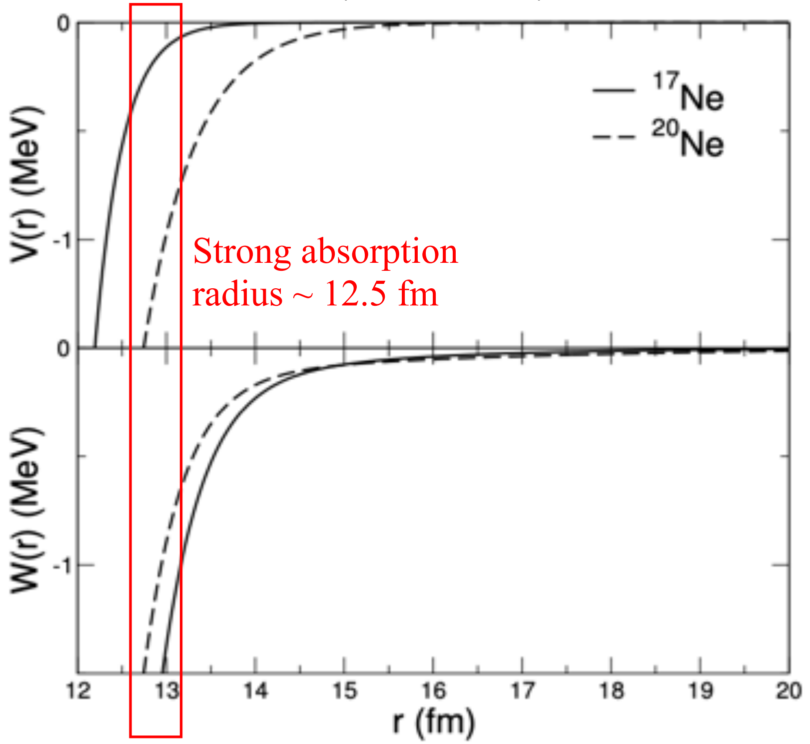
^{17}Ne + ^{208}Pb elastic @ 136 MeV



^{20}Ne + ^{208}Pb elastic @ 131 MeV



Best-fit optical model potentials

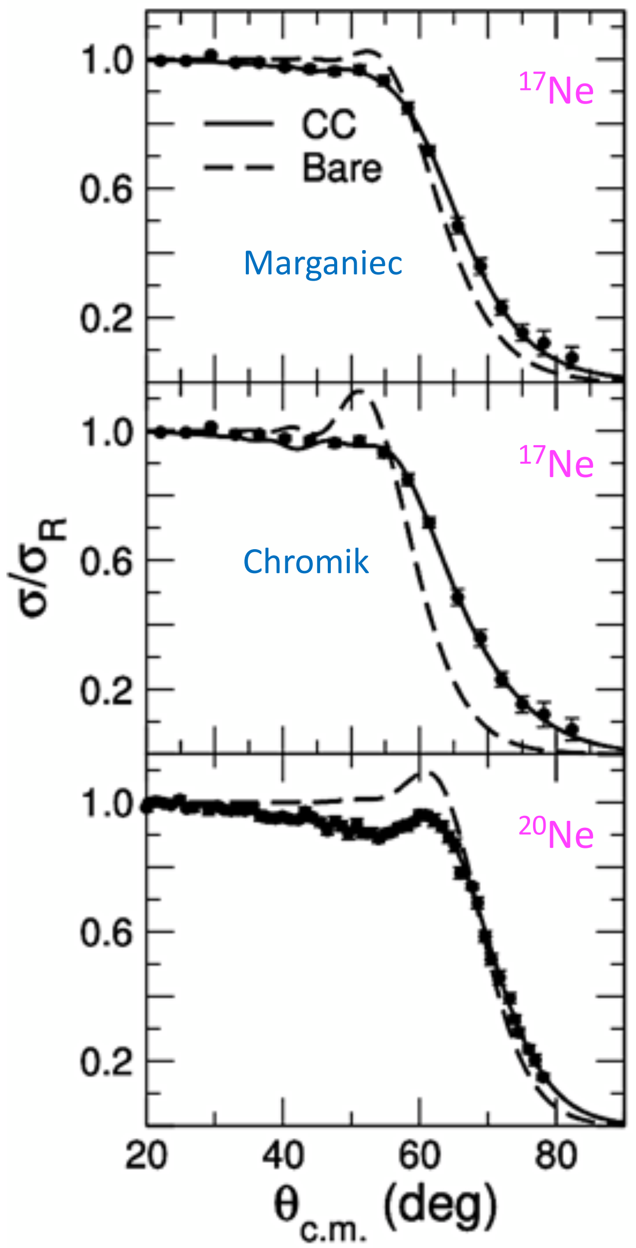


Woods-Saxon
- Real: Volume
- Imaginary: Volume plus derivative.

Polarisation potentials
- V(^{17}Ne) > V(^{20}Ne) → ^{17}Ne breakup
- W(^{17}Ne) < W(^{20}Ne) → E2-Coulex not as relevant

Projectile	V (MeV)	r_0 (fm)	a_0 (fm)	W (MeV)	r_W (fm)	a_W (fm)	W_D (MeV)	r_D (fm)	a_D (fm)
^{17}Ne	63.53	1.300	0.309	0.627	1.300	1.790	11.82	1.344	0.438
^{20}Ne	58.76	1.231	0.579	0.345	1.302	2.705	22.56	1.267	0.433

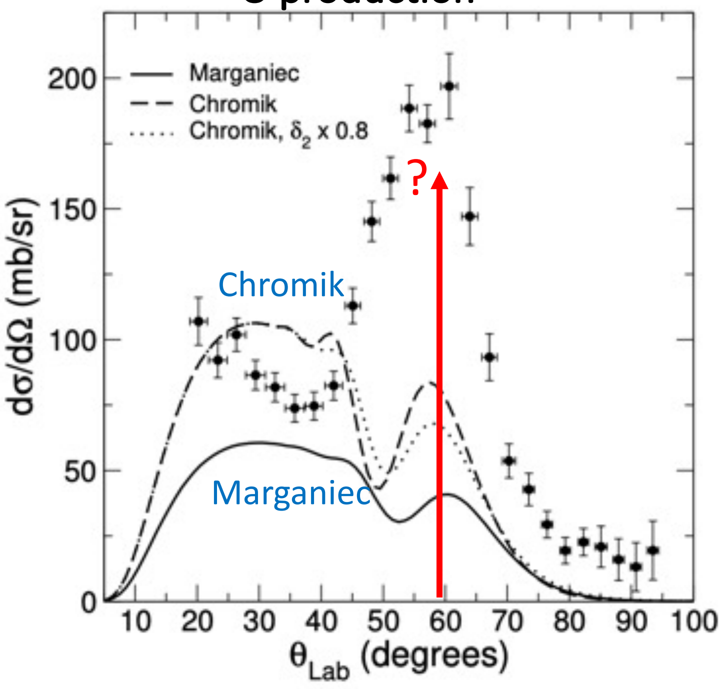
Coupled channel calculations



Rotational model

^{17}Ne	^{20}Ne
• couplings to $3/2^-_1$, $5/2^-_1$ (res.) • δ_2 -> ^{17}Ne charge radius; B(E2; $1/2^-_1 \rightarrow 5/2^-_1$) Marganiec / Chromik • Reorientation Reaction: 1903 mb Inelastic: 350 mb E2 coupling: 18% of total reac. xsec	• couplings to 2^+_1 level • δ_2 -> fit inelastic of Gross et al.; B(E2; $0^+_1 \rightarrow 2^+_1$) -> Raman et al. At. Data Nucl. Data Tables 78 (2001) 1. • Reorientation Reaction: 1968 mb Inelastic: 627 mb E2 coupling: 32% of total reac. xsec

^{15}O production



Conclusions

- Rainbow suppression. Reaction cross sections similar to stable ^{20}Ne.
- Probably E1 excitation of low-lying continuum ~ similar to ^{6}He → CDCC
- B(E2) values are critical; Chromik too large
- Peak ~ 55° Lab cannot be reproduced by CC calculations

Continuum Discretised Coupled channel calculations (Breakup)

N. Keeley, I. Martel, K. Rusek, K. Kemper. Phys. Rev. C (2023), in press.

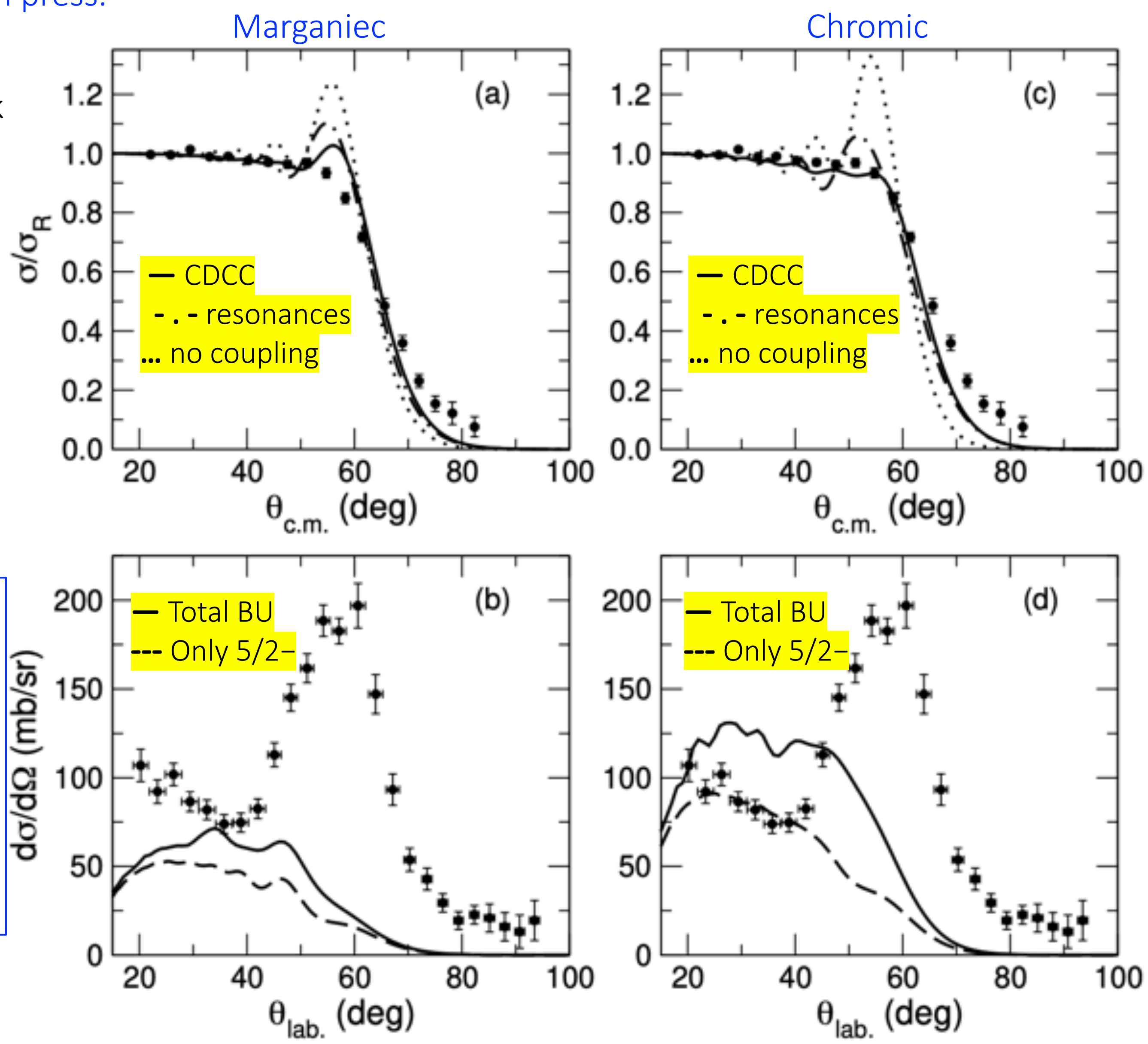
- Simple calculation using ^{15}O + ^{2}He cluster model.
- Binding potential → B(E2; 1/2− → 5/2−) Marganiec/ Chromik reproduce elastic data (M/C models).
- Check consistency with ^{15}O data.

Couplings

- 1.288-MeV 3/2− and 1.764-MeV 5/2− resonances
- L = 0, 1, 2 and 3 non-resonant continuum
- r0, a → B(E2; 1/2− → 5/2−) value
- V → binding energy
- ^{2}He + ^{208}Pb; 15O + 208Pb OM potentials
  → ^{4}He + ^{208}Pb; ^{16}O + ^{208}Pb

Conclusion

- ~ 50% of BU produced by 5/2− resonance
- BE2/Chromic-> overpredicts the ^{15}O distribution by 30–60% → excluded!
- BE2-> intermediate value between Chromic and Marganiec.
- CDCC calculations cannot reproduce the peak at θlab. ~ 55°

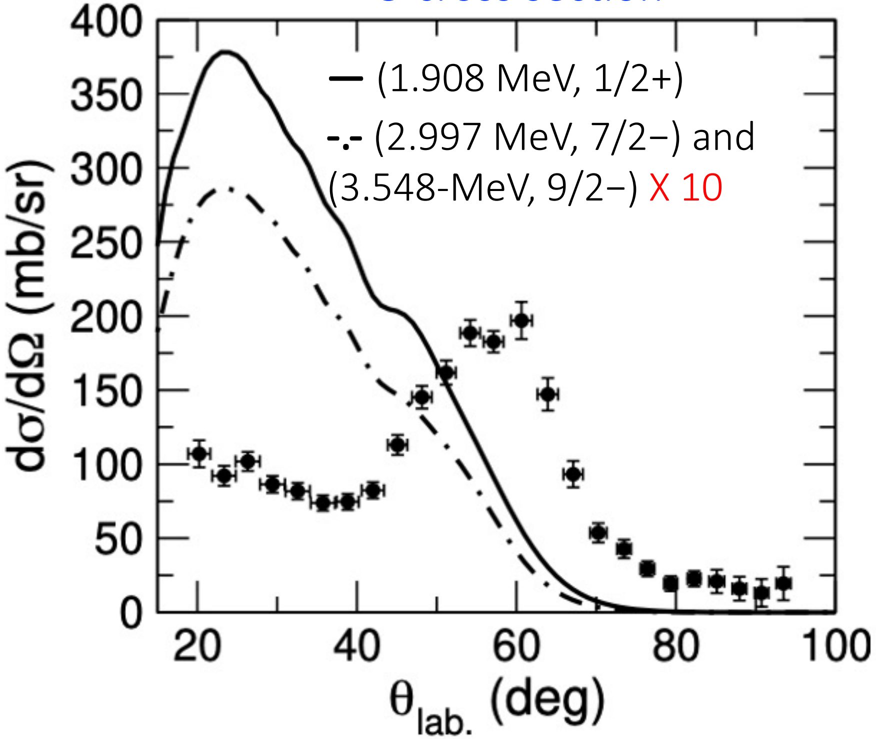


Origin of ^{15}O peak ~ 55° Lab?

N. Keeley, I. Martel, K. Rusek, K. Kemper. Phys. Rev. C (2023), in press.

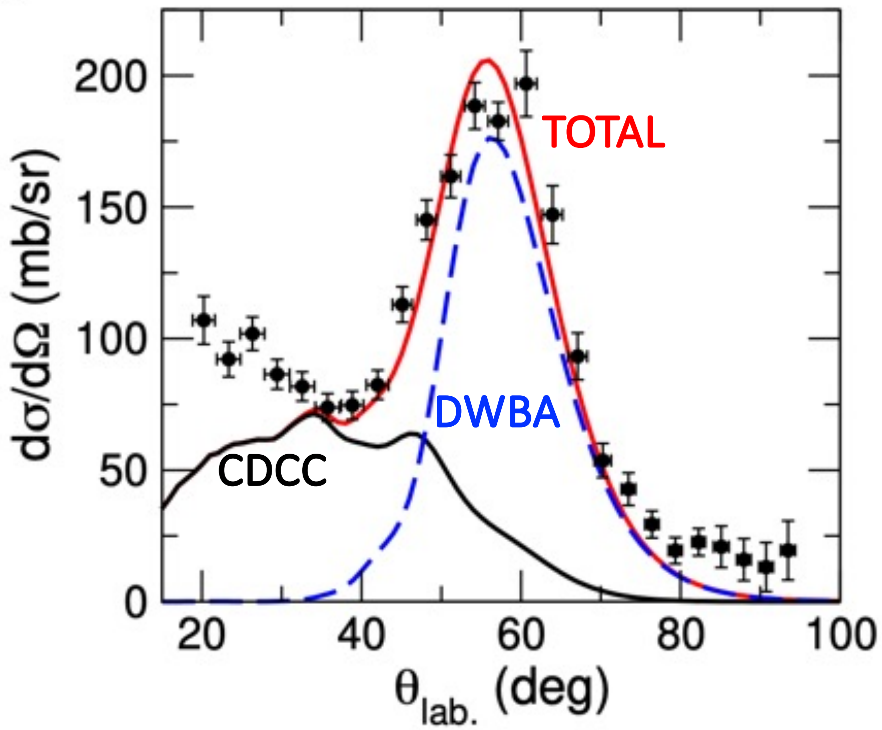
1. Missing resonant levels in CDCC calculation → (1.908 MeV, 1/2+) → too large contribution → failure of the model; (2.997 MeV, 7/2−) & (3.548, MeV 9/2−) → negligible
2. ^{15}O + ^{2}He cluster model too simplistic → Four body model, in progress
3. $^{13,14}O$ yield as contaminants of ^{15}O distribution → excluded due to Qval
4. 1p or 2p stripping process → 2p excluded due to Qvalue; 1p possible -> giant resonance in ^{209}Bi

^{15}O cross section



DWBA calculation
1p-stripping
^{209}Bi, (11 MeV, 5/2−), Γ = 0.4 MeV

^{15}O cross section



SUMMARY AND CONCLUSIONS

- Angular distributions for the elastic scattering and inclusive ^{15}O production cross sections of ^{17}Ne + ^{208}Pb at Coulomb barrier energies have been measured for the first time.
- The elastic data show a strong absorption pattern (no Coulomb rainbow) and suggests the presence of a halo in ^{17}Ne.
- The angular distribution of the cross section for ^{15}O production seems to be originated by a combination of breakup and 1p-striping through the giant resonance of ^{208}Bi at Ex~ 11 MeV.
- The data can be described by OM, CDCC and DWBA calculations.
- B(E2; 1/2− → 5/2−): the value of Marganiec et al. seems more consistent with the data, but it should be measured in a dedicated experiment.
- The reaction cross section is similar to the scattering of the stable isotope ^{20}Ne. Thus the system seems to present core-shading effects similar to the system ^{8}B+^{120}Sn.
- To probe this effect: new experiment with medium mass target like ^{64}Zn, where the Qval matching excludes the production of ^{15}O from 2p/1p channels.

^{17}Ne collaboration

Probing the dynamics of the two-proton haloes with the Coulomb-barrier scattering of ^{17}Ne

I. Martel[1], K. Rusek[2], N. Keeley[3], A. Chbihi[4], L. Acosta[10], L. Barrón[10], C. Borcea[19], M.J.G. Borge[17], J. Cederkall[9], N. Ceylan[6,1], E. Chávez[10], H. Dapo[6], A. Di Pietro[7], P. Figuera[7], C. García-Ramos[1],T. Kurtukian-Nieto, M. La Commara[12], G. La Rana[12], K. Mahata[14], F. Manchado de Sola[1], D. Marín-Lambarri[10], M. Mazzocco[11], A.K. Orduz[1], A. Pakou[5], S. Pandit[14] , C. Parascandolo[13], V. Parkar[14], D. Pierroutsakou[13], R. Raabe[8], M. Renaud[8], A.M. Rodríguez-Pérez[1], A.M. Sánchez-Benítez[15], J. Sánchez-Segovia[1], O. Sgouros[7], A. Shrivastava[14], F. Soramel[11], V. Soukeras[7], R. Sparta[7], N. Soic[20], O. Tengblad[17], R. Wolski[16], J. Yang[8].

1) Science and Technology Research Centre, University of Huelva, 21071 Huelva, Spain.
2) Heavy Ion Laboratory, University of Warsaw, Pasteura 5a, 02-093 Warsaw, Poland.
3) National Centre for Nuclear Research, ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland.
4) Grand Accélérateur National d'Ions Lourds. BP 55027 - 14076 CAEN, Cedex 05, France.
5) Department of Physics and HINP, The University of Ioannina, 45110 Ioannina, Greece.
6) Akdeniz University, Pinarbasi Mahallesi, 07070 Konyaalti, Antalya, Turkey.
7) INFN-Laboratori Nazionali del Sud, 95125 Catania, Italy.
8) Instituut voor Kern- en Stralingsfysica, B-3001 Heverlee, Belgium.
9) Physics Department, Lund University, Box 118, 221 Lund, Sweden.
10) Instituto de Física, UNAM, Ciudad de México, México.
11) University of Padova and INFN-Padova, Italy.
12) University of Napoli and INFN-Napoli, Italy.
13) INFN-Napoli, Italy.
14) Bhabha Atomic Research Centre, Mumbai – 400085 India.
15) Faculty of Experimental Sciences, University of Huelva, 21071 Huelva, Spain.
16) Henryk Niewodniczanski Institute of Nuclear Physics PAS, Cracow.
17) Instituto de Estructura de La Materia – CSIC. Serrano 113 bis, ES-28006 Madrid, Spain.
18) Centre Etudes Nucléaires de Bordeaux Gradignan, Chemin du Solarium, Gradignan F-33175, France.
19) IFIN-HH PO-BOX MG-6, 76900 Bucharest Magurele, Romania.
20) Rudjer Boskovic Institute, Bijenicka cesta 54, HR-10000 Zagreb, Croatia.

GANIL spiral2