EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Effects of the neutron halo in ^{15}C scattering at energies around the Coulomb barrier

(INTC-P-468)

Spokespersons: I. Martel, O. Tengblad

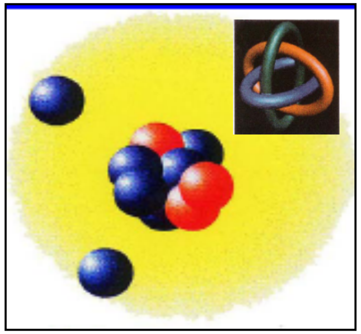
Local contact: Razvan Lica

Collaboration: IEM-CSIC (Madrid, Spain)-U. Lisboa (Portugal)- UNAM (México) – INFN (Catania, Italy)-U. Warsaw (Poland)-U. Belfast (UK)–NCNR (Otwock, Poland)-HINP (Ioanina, Greece) – U. Huelva (Spain) – IKS (Heverlee, Belgium)- RBI (Zagreb, Croatia) – HNINP (Crakow, Poland) – CERN (Geneva, Switzerland).

Halo Nuclei

<u>Common "Structural" properties</u>

- Rather inert core plus one or two barely unbound extra neutrons
- Extended neutron distribution, large "radius".→ "halo"
- Low binding energy
- Very few excited states –if any.



11Li → Borromean Halo

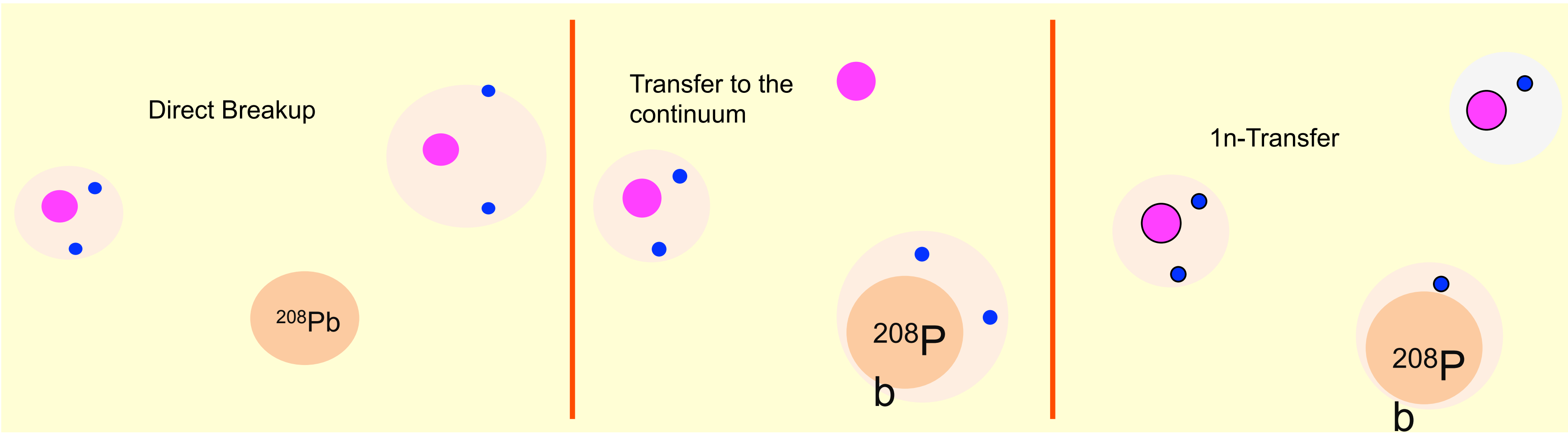
<u>Reaction properties at near-barrier energies:</u>

→ Strong absorption in elastic channel

→ Large cross section for fragmentation

→ They are easily polarizable:

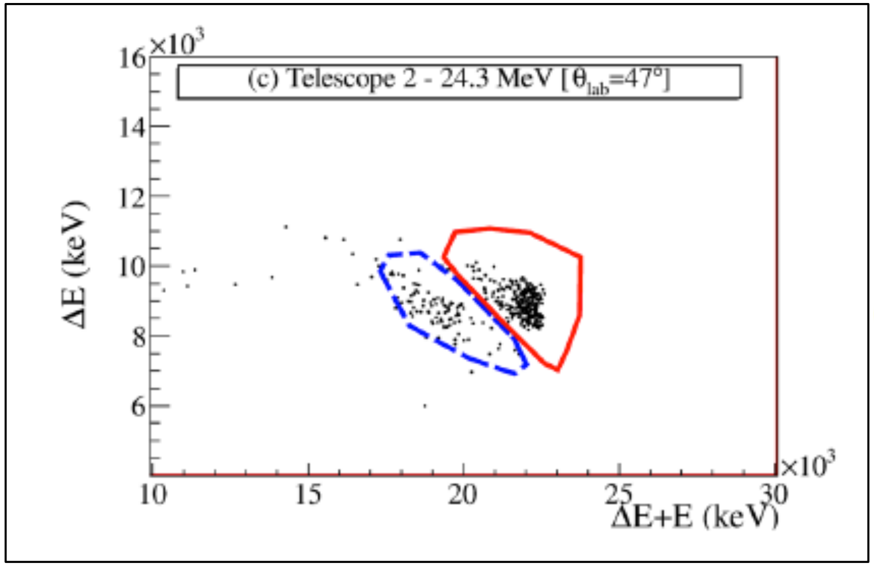
- In the scattering process the forces between target and core/ halo are different → distortion effects → e.g. Coulomb dipole polarizability

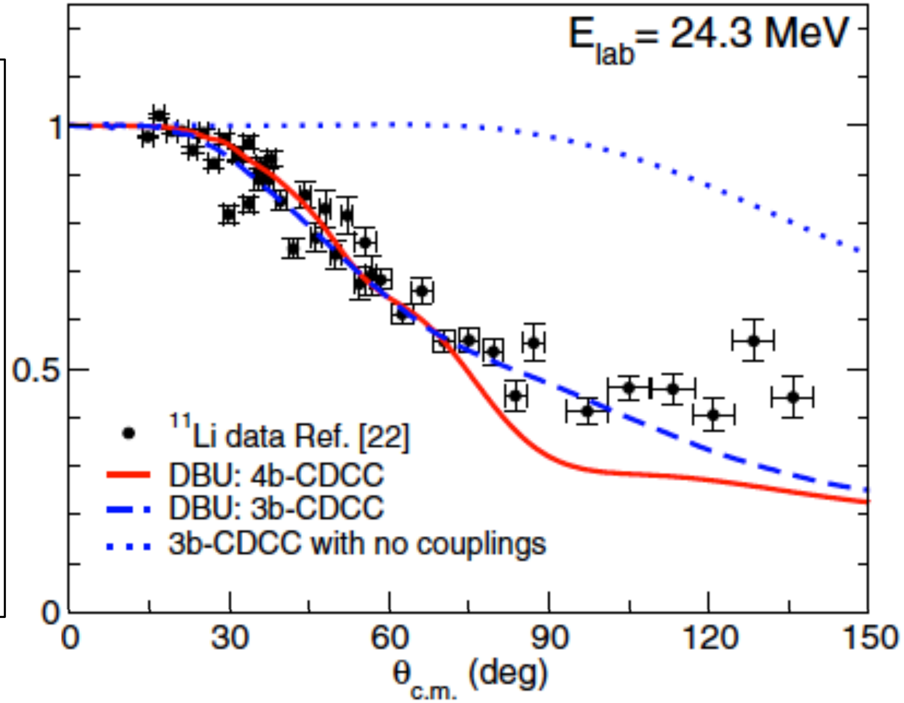


Experiment 1104 @ TRIUMF (Vancouver, Canada)

- Measure the elastic scattering of ^{11}Li on ^{208}Pb at energies below and above the Coulomb barrier (~ 27 MeV).
  - Energies : 2.2 MeV/u = 24.2 MeV
    2.7 MeV/u = 29.7 MeV
- Measure the inclusive break-up cross section by detecting ^{9}Li and α fragments.
- Average intensity on target 4,3 * 10^3 pps, ~ 25 Shifts; 1,9 mg/cm^2 ^{208}Pb

J. P. Fernández-García et al., PHYSICAL REVIEW C 92, 044608 (2015)





PRL **105,** 022701 (2010) PHYSICAL REVIEW LETTERS week ending 9 JULY 2010

Elastic Scattering and Reaction Mechanisms of the Halo Nucleus ^{11}Be around the Coulomb Barrier

A. Di Pietro,[1] G. Randisi,[1,2,*] V. Scuderi,[1,2] L. Acosta,[3] F. Amorini,[1,2] M. J. G. Borge,[4] P. Figuera,[1] M. Fisichella,[1,2] L. M. Fraile,[5,†] J. Gomez-Camacho,[6] H. Jeppesen,[5,‡] M. Lattuada,[1,2] I. Martel,[3] M. Milin,[7] A. Musumarra,[1,8] M. Papa,[1] M. G. Pellegriti,[1,2] F. Perez-Bernal,[3] R. Raabe,[9] F. Rizzo,[1,2] D. Santonocito,[1] G. Scalia,[1,2] O. Tengblad,[4] D. Torresi,[1,2] A. Maira Vidal,[4] D. Voulot,[5] F. Wenander,[5] and M. Zadro[10]

[1]*INFN–Laboratori Nazionali del Sud and Sezione di Catania, Catania, Italy*
[2]*Dipartimento di Fisica ed Astronomia, Universitá di Catania, Catania, Italy*
[3]*Departamento de Fisica Aplicada, Universidad de Huelva, Huelva, Spain*
[4]*Instituto de Estructura de la Materia CSIC, Madrid, Spain*
[5]*ISOLDE, CERN, CH-1211 Geneva 23, Switzerland*
[6]*Departamento de Fisica Atomica Molecular Nuclear, Universidad de Sevilla and Centro Nacional de Aceleradores, Sevilla, Spain*
[7]*Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia*
[8]*Dipartimento di Metodologie Fisiche e Chimiche per l'Ingegneria, Universitá di Catania, Catania, Italy*
[9]*Instituut voor Kern-en Stralingsfysica, Katholieke Universiteit, Leuven, Belgium*
[10]*Division of Experimental Physics, Ruđer Bošković Institute, Zagreb, Croatia*
(Received 7 March 2010; published 6 July 2010)

Collisions induced by ^{9,10,11}Be on a ^{64}Zn target at the same c.m. energy were studied. For the first time, strong effects of the ^{11}Be halo structure on elastic-scattering and reaction mechanisms at energies near the Coulomb barrier are evidenced experimentally. The elastic-scattering cross section of the ^{11}Be halo nucleus shows unusual behavior in the Coulomb-nuclear interference peak angular region. The extracted total-reaction cross section for the ^{11}Be collision is more than double the ones measured in the collisions induced by ^{9,10}Be. It is shown that such a strong enhancement of the total-reaction cross section with ^{11}Be is due to transfer and breakup processes.

DOI: 10.1103/PhysRevLett.105.022701 PACS numbers: 25.60.Bx, 25.70.Bc

REX-ISOLDE at CERN

^{11}Be + ^{64}Zn @ 24,5 MeV

The target was tilted at 45º to facilitate the measurement in the angular region around 90º.

Average intensity of 10^4 pps on target

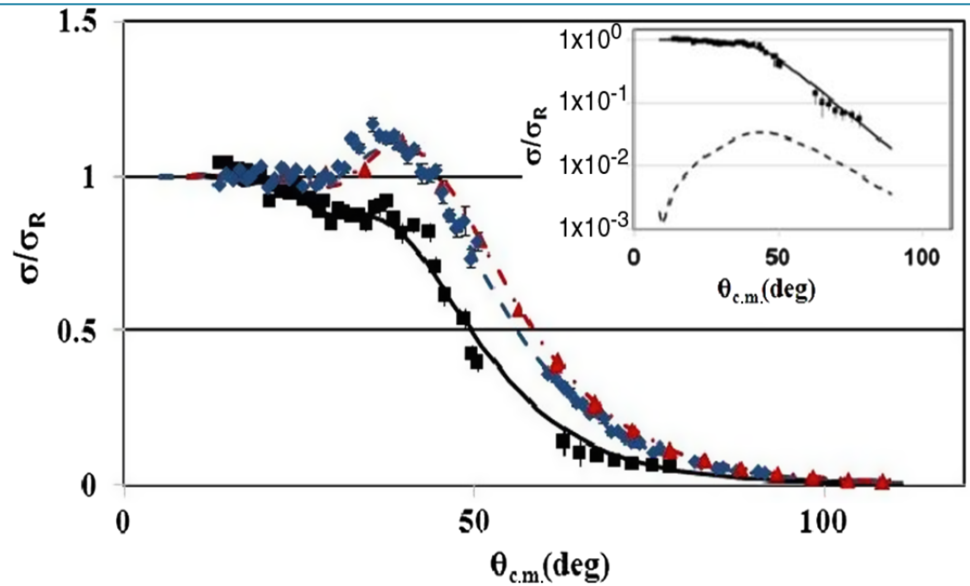


FIG. 1 (color online). Elastic-scattering angular distributions on ^{64}Zn: ^{9}Be (triangles), ^{10}Be (diamonds), and ^{11}Be (squares). The lines represent the OM calculations for ^{9}Be (dot-dashed line), ^{10}Be (dashed line), and ^{11}Be (full line). The inset shows the measured AD (symbols) and OM fit (full line) for the ^{11}Be + ^{64}Zn system together with the result of the calculation for the inelastic excitation of ($\frac{1}{2}^-$, $E_x = 0.32$ MeV, dashed line). The error bars are statistical for ^{10,11}Be and statistical + systematic for ^{9}Be on ^{64}Zn. See text for details.

What did we learn from these experiments?

- Long range absorption dominant in elastic scattering $\Rightarrow$ Suppress the rainbow in elastic cross sections.
- Long range absorption is produced by nuclear and Coulomb coupling to the continuum.
- Breakup mechanism is dominated by neutron transfer to the continuum.

Do these features occur in other halo nuclei ?

What makes ^{15}C interesting?

^{15}C have been studied by nuclear reactions at high energies (100 MeV/u).

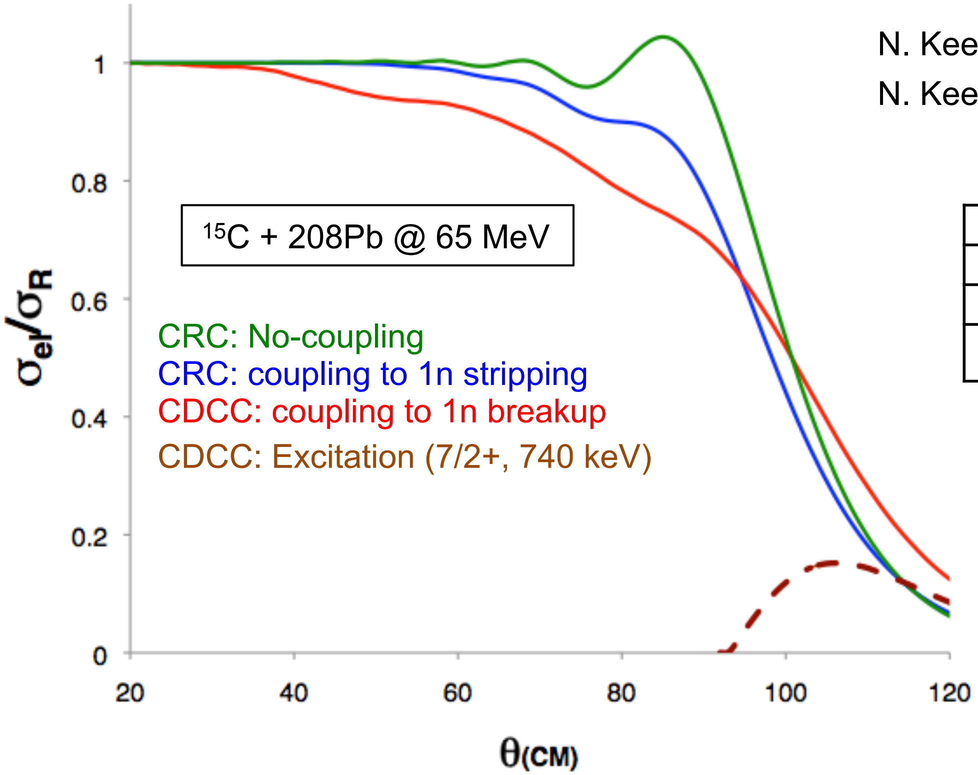
- narrow parallel momentum distributions of breakup (^{14}C + n)
- high reaction cross sections

→ **nuclear halo**

D. Bazin, et al. PRC 57(1998) 2156

Nucleus	Be target	Ta target
^{14}B	57 ± 2 MeV/c	48 ± 3 MeV/c
^{15}C	67 ± 3 MeV/c	67 ± 1 MeV/c
^{17}C	145 ± 5 MeV/c	
^{19}C	42 ± 4 MeV/c	41 ± 3 MeV/c

At low collision energies, ^{15}C scattering should be dominated by the competition between neutron transfer and breakup, and several theoretical studies has been carried out in the past: Coupled Reaction Channel calculations (CRC) and Continuum Discretized Coupled Channel Calculations (CDCC).



N. Keeley and N. Alamanos, Phys. Rev. C 75 (2007) 054610.

N. Keeley, K.W. Kemper and K. Rusek, Eur. Phys. J. A 50 (2014) 145.

CRC		CDCC	
Total reaction (mb)	927	Total reaction (mb)	1379
1-n stripping (mb)	265	Breakup (mb)	462
		Excitation(5/2+,740keV) (mb)	45

→Large effects due to ^{15}C halo!!

→Large difference 1n-stripping/breakup

❑ However, there are no data on ^{15}C scattering at low collision energies

Purpose of this experiment

Investigate the halo nature of ^{15}C and study the relevant reactions channels dominating the scattering with ^{208}Pb target of at energies around the Coulomb barrier.

Quantities to be measured: Angular distribution of ^{15}C (elastic/quasielastic scattering)

In addition (expected) angular distribution of ^{14}C fragments (1n transfer/breakup)

Target: ^{208}Pb target, doubly closed-shell nucleus, with large Z=82, well known structure and large separation energy between ground and first excited states.

Energy: 65 MeV (around the barrier)

Data analysis: CRC (1n-stripping), CDCC (breakup) + Polarization potentials.

What can we learn from this experiment?

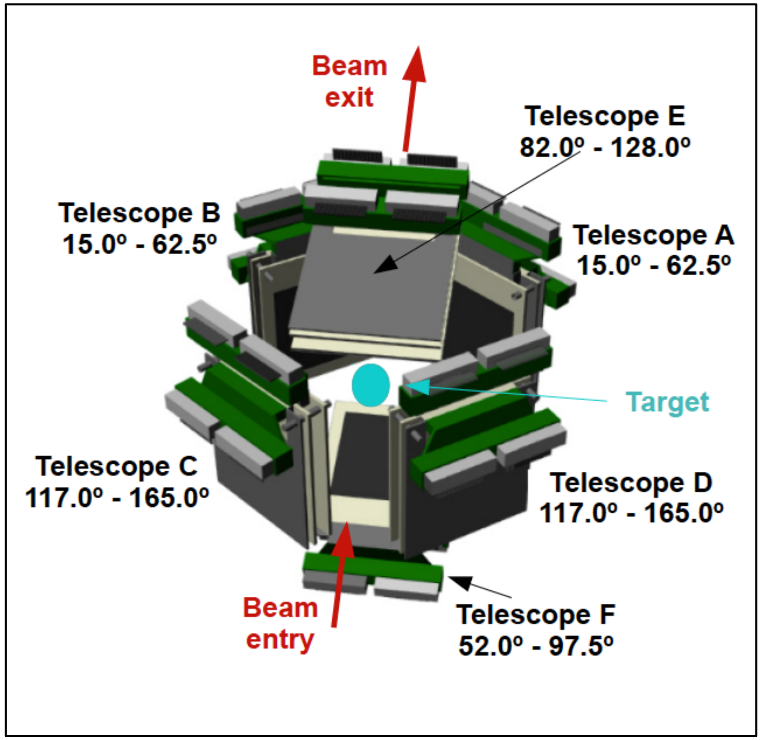
1. Long range absorption effects
2. OM nuclear potentials and total reaction cross section
3. Competition between neutron stripping and direct breakup
4. Coupling effects due to coulomb and nuclear potentials
5. Total reaction cross sections at Coulomb barrier energies
6. Total ^{14}C yields

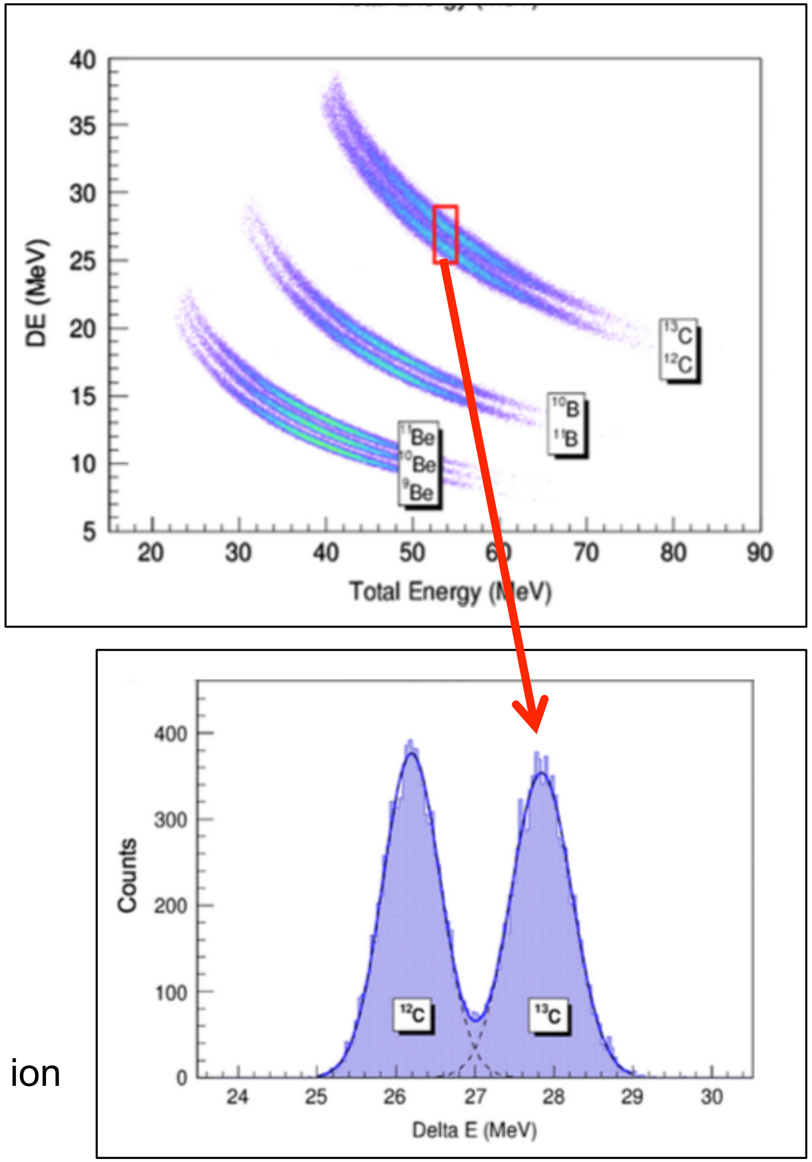
This would be the first dynamical study carried out so far for the halo nucleus ^{15}C at Coulomb barrier energies.

Experimental set-up

GLObal Reaction Array: GLORIA

G. Marquínez-Durán, Nucl. Inst. Meth. A755 (2014) 69.

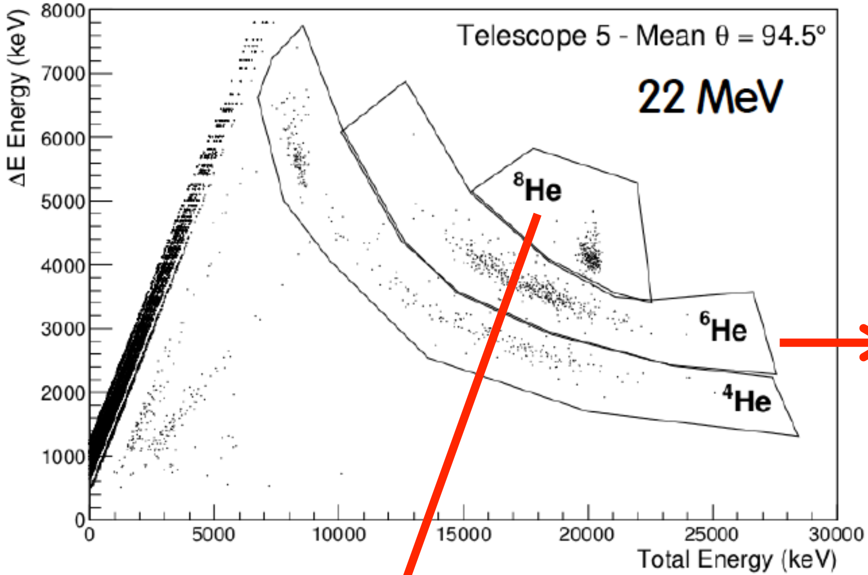


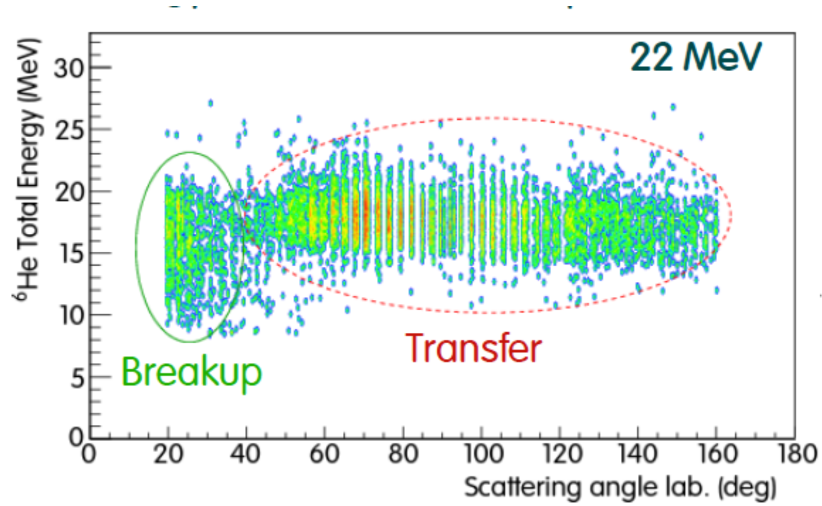


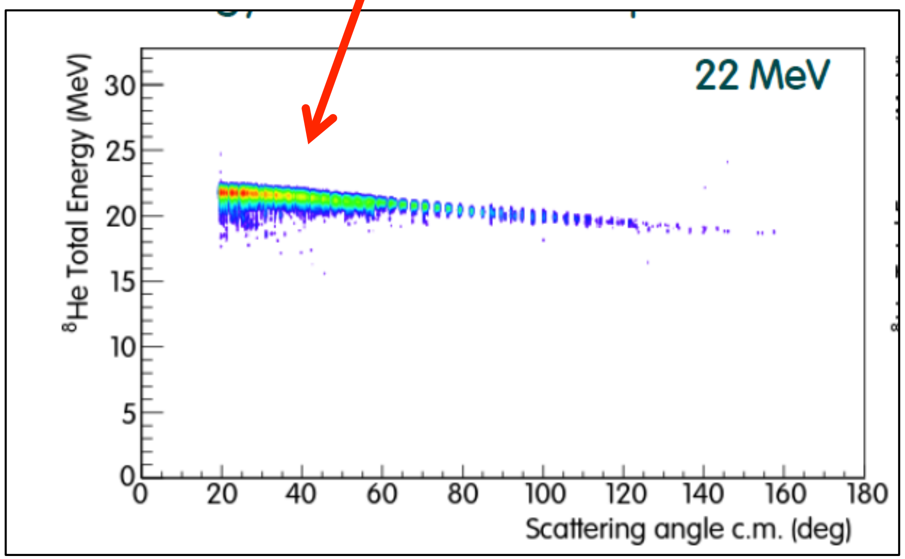
- 6 DSSSD particle telescopes (40mm, 1mm).
- Total solid angle = 26 %
-“Continuum” angular distributions between 15º-165º Lab.
- E_{res} ~30 keV

Montecarlo simulations for light ion detection

$^{8}He+^{208}Pb$ @ 22 MeV (GANIL, E587S)

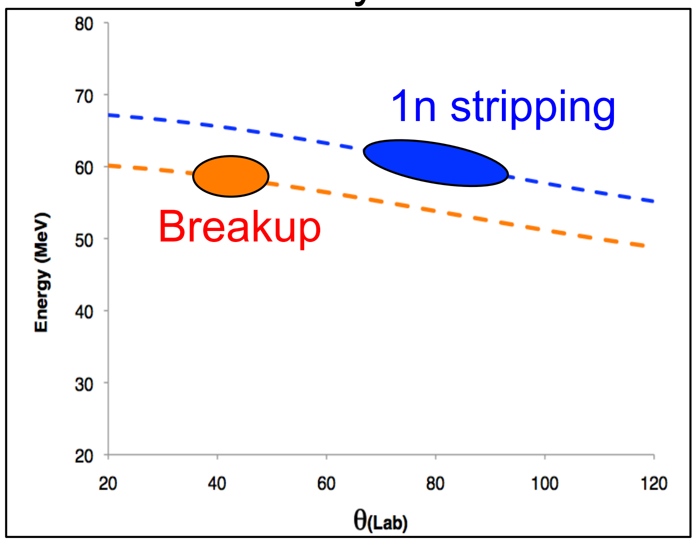






$^{15}C+^{208}Pb$ @ 65 MeV (Expected)

^{14}C yield



PREDICTIONS

Present situation (After TAC revision)

I=1,5 x 10^5 pps (primary target)
Transmission= 7,5%
I= 1,1x10^4 pps (on reaction target)
T=2 mg/cm2
$\Delta\theta$=3º
Request: 30 Shifts

Original proposal:

I=7,9 x 10^5 pps (primary target)
Transmission= 5%
I= 4,0x$10^{4\ pps}$ (on reaction target)
T=1,3 mg/cm2
$\Delta\theta$=3º
Request: 30 Shifts

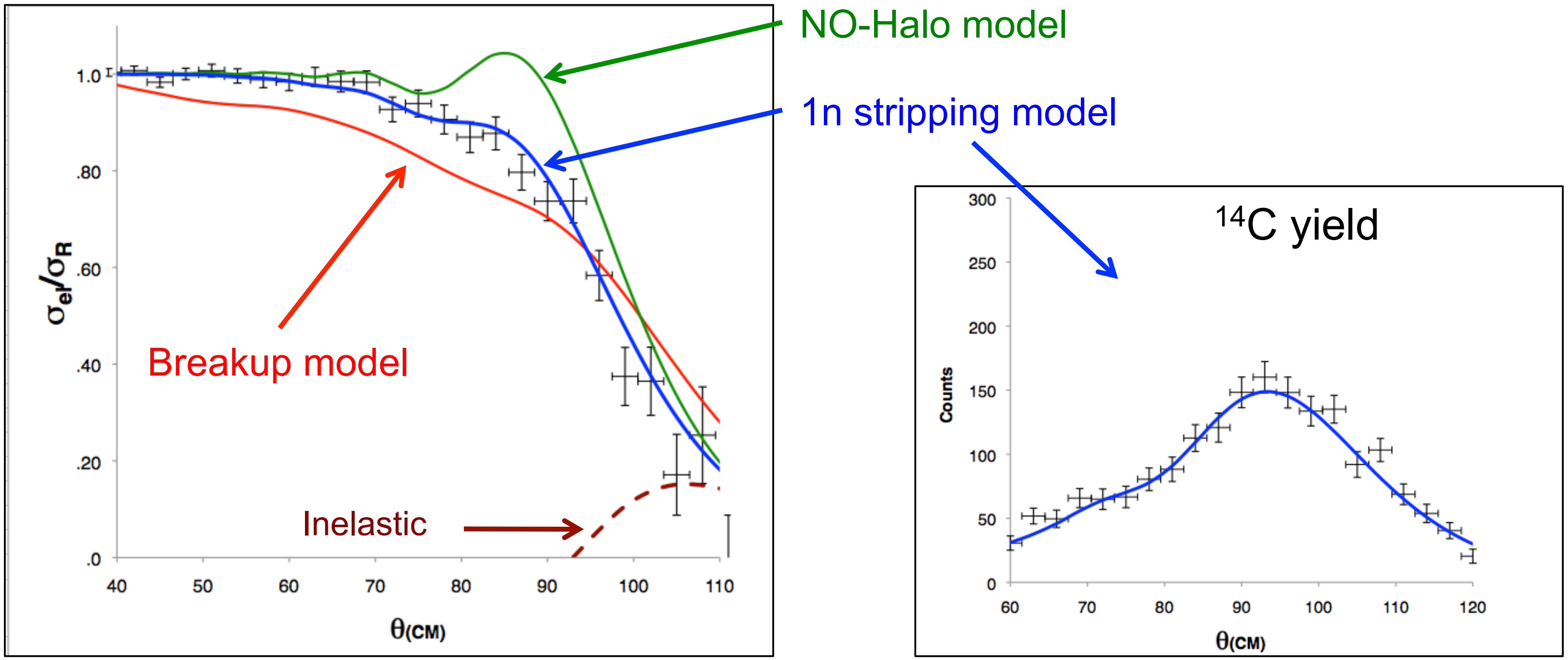
Expected yields at 65 MeV (30 shifts):

GLORIA: 25% efficiency Target: 2 mg/cm^2 ^{208}Pb σ_{el} (80º Lab) =450 mb/sr σ_{tran}(80º Lab) = 50 mb/sr

Y_{el} = 1027 events (3% uncertainty at 80º)

Y_{1n} = 122 events (9% uncertainty at 80º)

PREDICTIONS



Beam-time request

We request 30 shifts on 15C (5+) with A/Q=3 at a beam energy of 65 MeV (4,33 MeV/u).

ISOLDE ^{15}C production (CaO target, 1.4 GeV) ~ 1.5 x 10^5 pps (**Revised** Isolde Yields Data Base)

Transport, Charge breeding (REX-EBIS) and HIE-ISOLDE acceleration 7,5% → 1,1 x 10^4 pps at reaction target.

TAC Review

Modification of ^{15}C yield from of 7,9 x 10^5 pps to 1,5 x 10^4 pps at primary target.

-Revised beam transmission from 5% to 7,5%
-Increase target thickness from 1,3 mg/cm^2 to 2 mg/cm^2

Expected beam contaminant ^{15}N at a rate of 3,5 x 10^3 pps on target.

-^{15}N will be separated in silicon telescopes from Carbon isotopes
- Rutherford scattering (Eb=76 MeV, also check with OM calculation) → no effect on reaction channels
-^{15}N scattering will be measured (with no ^{15}C) between proton pulses, any background can be subtracted
- Low rate, no effect on DACQ
- Cross-check of detector setup and solid angles

Electrical installation.

- The XT02 reaction chamber is a semi-permanent installation that is being prepared to serve most of the reaction experiments to be performed at XT02.

- The electrical installations are being prepared, new cable trays have been installed, both on the Chamber support and around the XT02 experimental "footprint", so that all cabling reaches the electronic racks via these cable trays.

-The electronic racks have been installed and are professionally prepared with mains distribution.

-The experimental set-up will fit inside the reaction chamber.

-The safety control of the set-up is being prepared and should be performed by Sept. 2016.

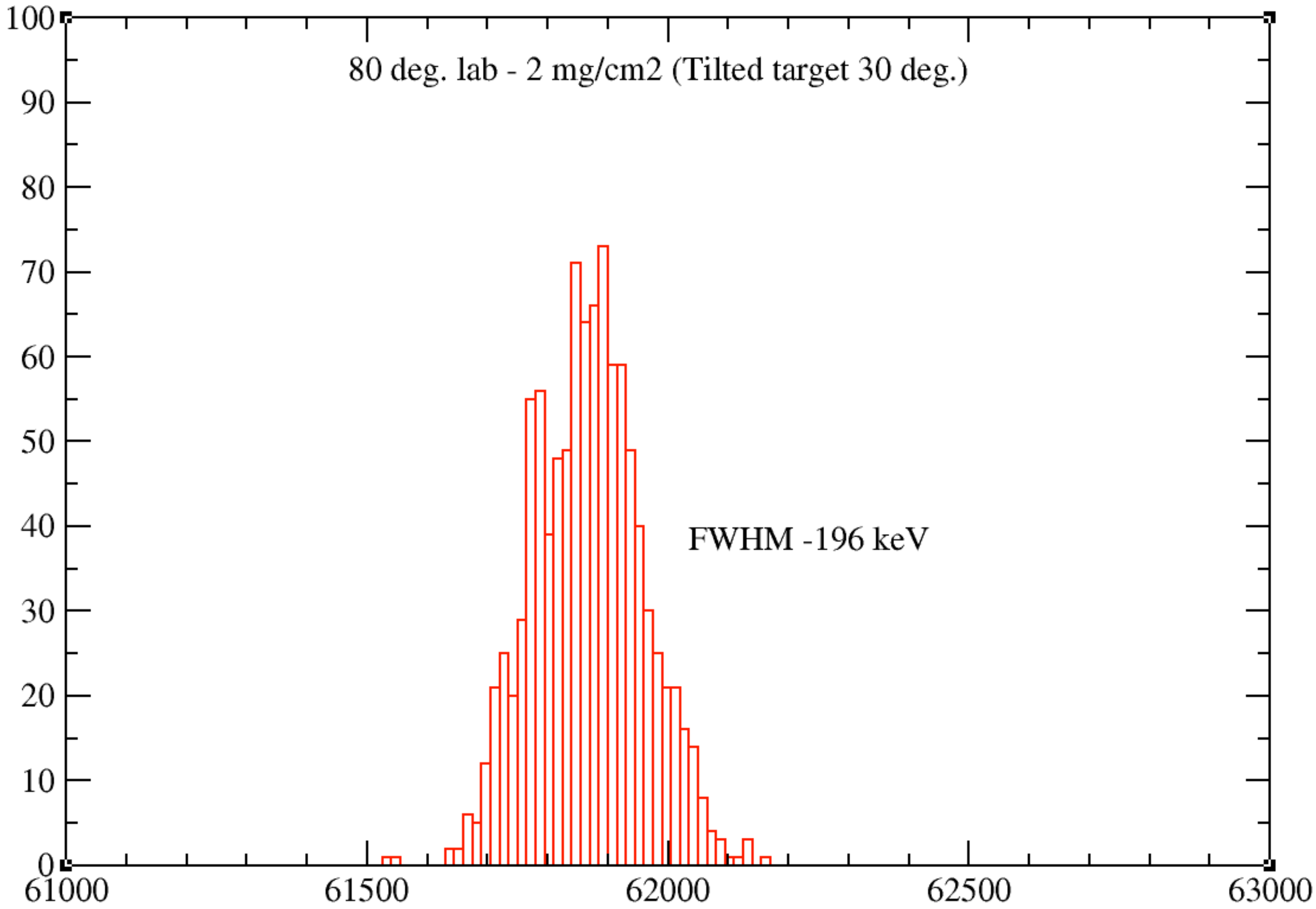
^{15}C Collaboration:

CERN – Huelva (Spain) – Madrid (Spain) – Warsaw (Poland) – Belfast (UK) – Leuven (Belgium) – Catania (Italy) –Zagreb (Croatia) – Ioannina (Greece) – Mexico (Mexico) – Cracow (Poland) – Aarhus (Denmark)

I. Martel[1,2], X. Aslanoglou[10] , L. A. Acosta[11], L. Barrón-Palos[11], MJG. Borge[1,3], T. Cap[5], E. Chávez-Lomelí[11], A. Di Pietro[8], P. Figuera[8], JP. Fernández[8], H.O.U. Fynbo[13], A. Huerta-Hernandez[11], N. Keeley[5], R. Kotak[6], M. Madurga[1], G. Marquínez-Durán[2], A. Pakou[10], K. Rusek[4], A.K. Orduz[2], R. Raabe[7], K. Riisager[13], N. Soic[9], O. Sgouros[10], A.M. Sánchez-Benítez[2], V. Soukeras[10], O. Tengblad[3], A. Trzcinska[4], M. Wolinska-Cichocka[4], R. Wolski[12]

1 PH Department, CERN, CH-1211 Geneva 23, Switzerland
2 University of Huelva, Avda Fuerzas Armadas sn, 21971 Huelva, Spain
3 Instituto de Estructura de La Materia – CSIC. Serrano 113 bis, ES-28006 Madrid, Spain
4 Srodowiskowe Laboratorium Ciężkich Jonów, Uniwersytet Warszawski, Pasteura 5A, 02-093 Warszawa, Poland
5 National Centre for Nuclear Research, ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland.
6 Astrophysics Research Centre, School of Mathematics and Physics, Queen's University Belfast, Belfast, County Antrim, BT7 1NN, United Kingdom
7 Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200d - bus 2418, B-3001 Heverlee, Belgium
8 INFN - Laboratori Nazionali del Sud, via S.Sofia 62, 95123 Catania, Italy
9 Rudjer Boskovic Institute, Bijenicka cesta 54, HR-10000 Zagreb, Croatia
10 Department of Physics and HINP, The University of Ioannina, Ioannina, Greece
11 Departamento de Física Experimental del Instituto de Física, Universidad Nacional Autónoma de México. Aptdo 20-364, México D. F. 01000, Mexico
12 Henryk Niewodniczanski Institute of Nuclear Physics PAS, Cracow, Poland
13 Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus, Denmark.

THANKS FOR YOUR ATTENTION!



Energy resolution dominated by HIE-ISOLDE LINAC ~1% beam energy
→ 650 keV