

IS619: Scattering of ^{15}C on ^{208}Pb at energies near the coulomb barrier

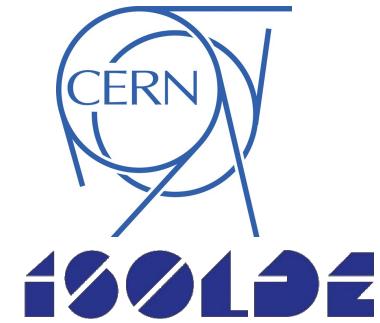
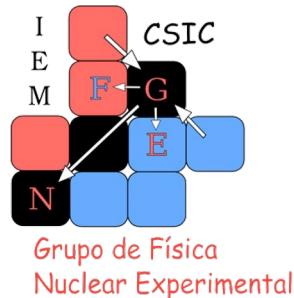
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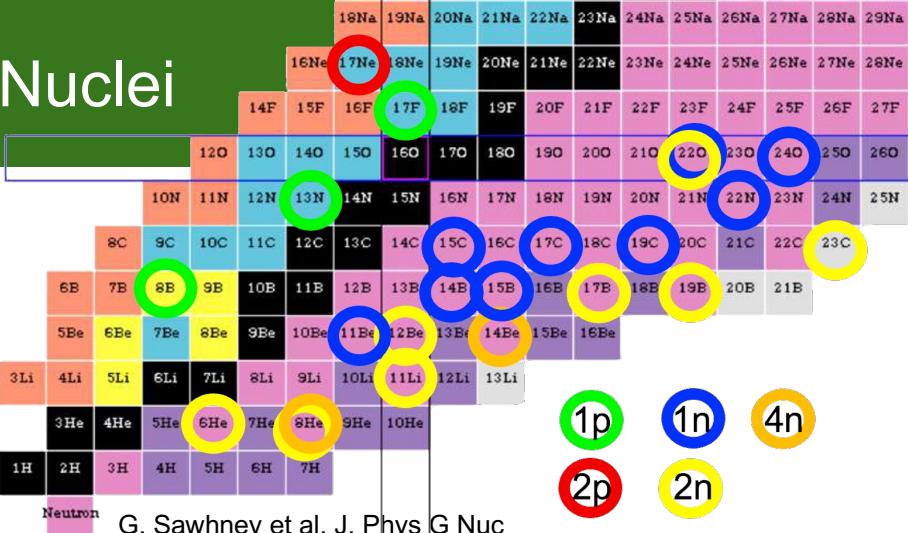
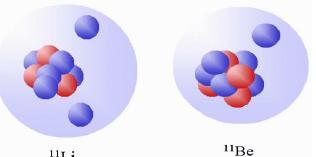
Universidad de Huelva



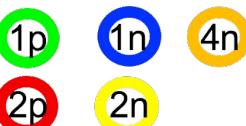
Halo Nuclei

The **nuclear halo** is a threshold effect arising from the very weak binding energy (0.1-1 MeV) of the outer nucleon(s)

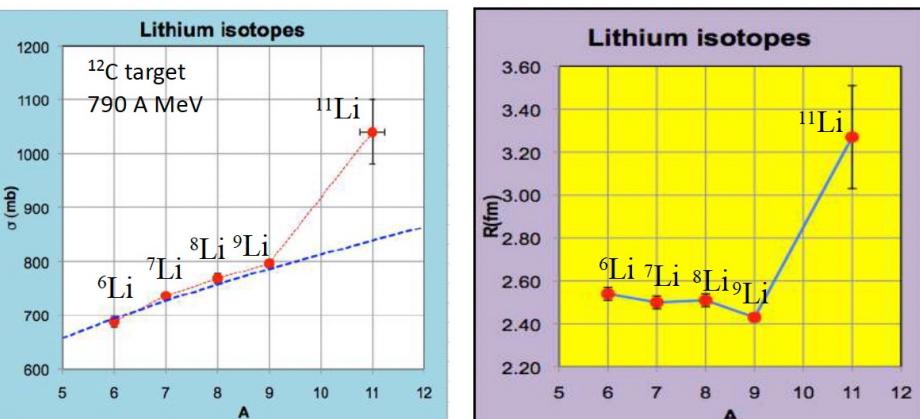
- Extended mass distribution
- Large reaction cross section
- Large rms radius
- Narrow momentum distribution of the fragments following breakup
- Concentration of $B(E1)$ close to Breakup threshold



G. Sawhney et al, J. Phys G Nuc part Phys 41 (2014) 055101



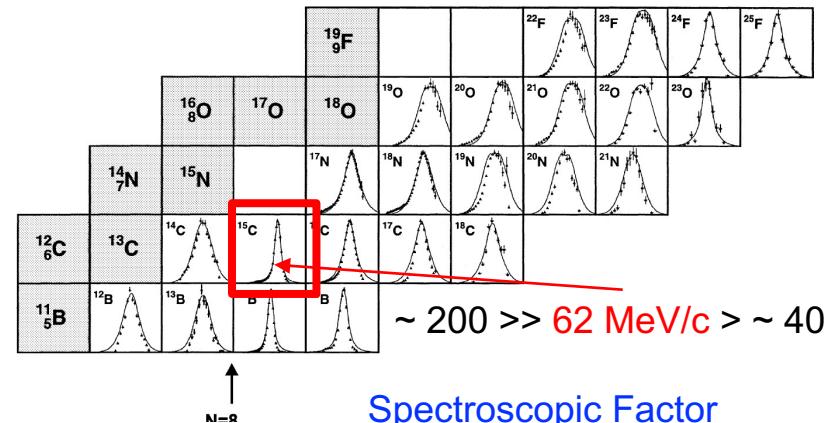
Tanihata, PRL 55 (1985)2676



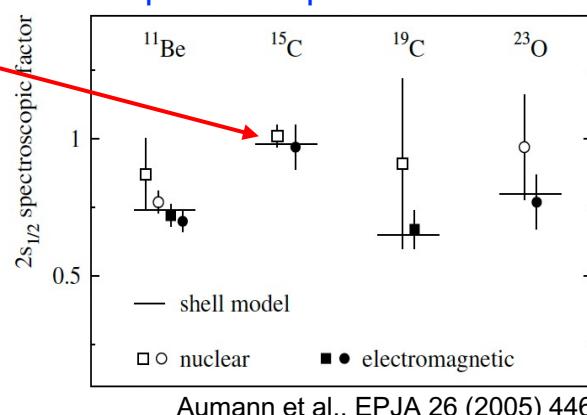
What makes ^{15}C ($T_{1/2} = 2.45\text{s}$) Interesting ?

- High energy experiments shows a **large total interaction cross section**
- Relatively **narrow longitudinal momentum distribution** of the fragments following break up.
- First excited state ($E = 740 \text{ keV}$)
- Ground state mainly $2s_{1/2}$
- Relatively **weakly bound**:

$$S_n = 1.2 \text{ MeV}; S_{2n} = 9.4 \text{ MeV}$$

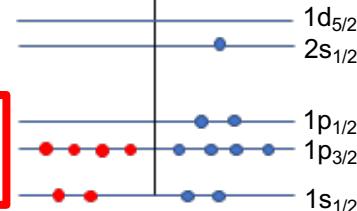


Spectroscopic Factor



Structure of ^{14}C core + 1n-halo
with a pure S-wave as ground state

Ozawa et al., NP A738 (2004) 38



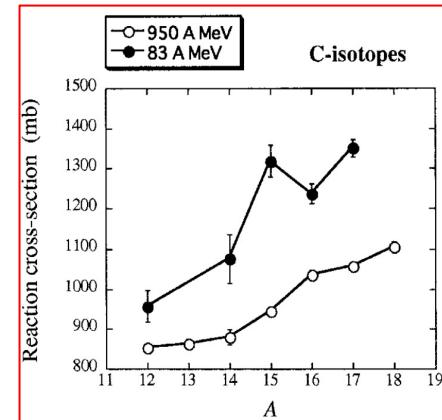
$^{15}\text{C} | \pi = \frac{1}{2}+$

^{15}C : Controversial 1n-halo

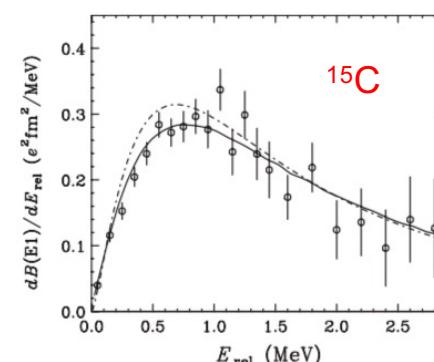
- Reaction cross section larger than $^{14,16}\text{C}$ at intermediate energies, but not at higher energies.
 - It seems that coupling increases when energy decreases
- $\text{B}(\text{E}1)$ deduced from coulomb breakup of ^{15}C on ^{208}Pb has a longer tail than ^{11}Be and smaller value of mean square radius.
- Nuclear matter radii and density were recently revisited

$$R_m = 2.59(5) \text{ fm} ; R_p = 2.37(3) \text{ fm} ; R_n = 2.73(8) \text{ fm} \rightarrow \delta_{np} = 0.36(9) \text{ fm}$$

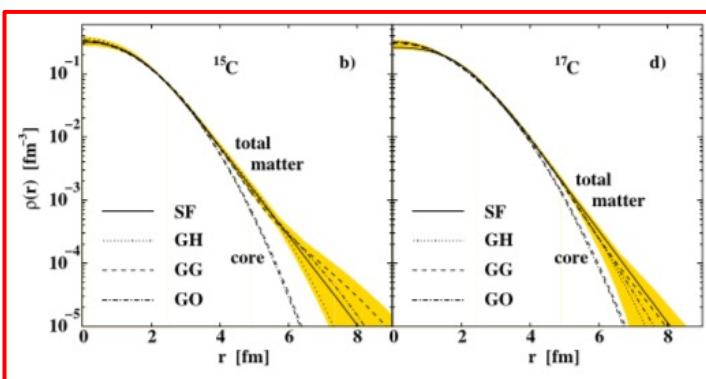
$$R_c = 2.41(5) \text{ fm} ; R_v = 4.36 (38) \text{ fm} \rightarrow \kappa = R_v / R_c = 1.81 \text{ (halo } \kappa > 2\text{)}$$



Ozawa et al.,
NP A738 (2004) 38



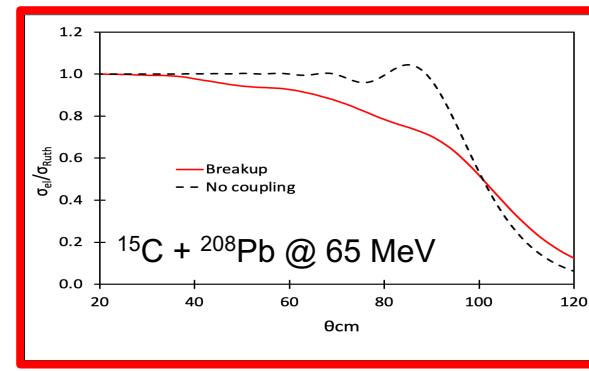
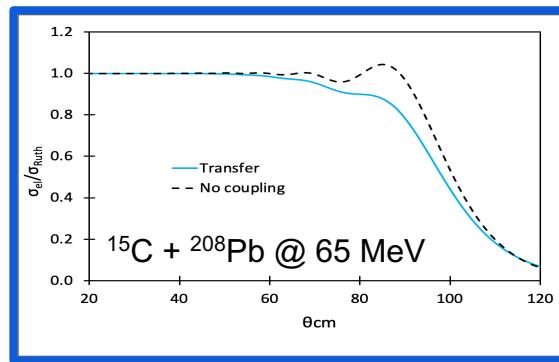
Nakamura et al., PRC 79 (2009) 035805



Dobrovolsky et al., NP A 1008 (2021) 122154

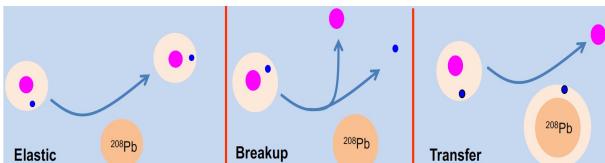
Coulomb Barrier Scattering of $^{15}\text{C} + ^{208}\text{Pb}$

- Reaction studies done at high energies all agree with a moderate halo structure for ^{15}C
- Which is the differential elastic cross section near Coulomb Barrier (E= 65 MeV)?**
- Predictions on the elastic scattering of $^{15}\text{C} + ^{208}\text{Pb}$ @ 65 MeV were done by Keeley et al. in the framework of CRC including 1n-stripping and CDCC including breakup



N. Keeley et al., PRC 75 (2007) 056610; EPJA 50 (2014) 145

Scattering dominated by the competition of 1n-stripping and breakup

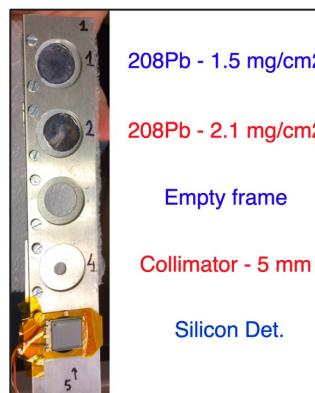
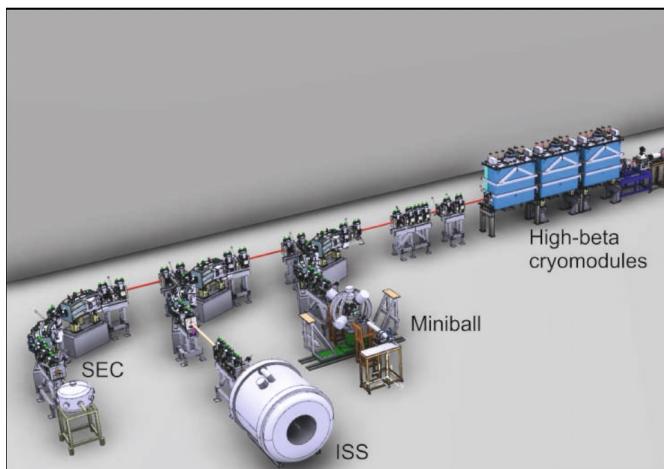


CRC/ 1n stripping		CDCC/ direct breakup	
Total reaction (mb)	927	Total reaction (mb)	1379
1-n stripping (mb)	265	Breakup (mb)	462 (33%)
(28%)		Excitation($5/2^+, 740\text{keV}$) (mb)	45

Coulomb Barrier Scattering of ^{15}C + ^{208}Pb

Experiment IS619 @ HIE-ISOLDE (CERN)

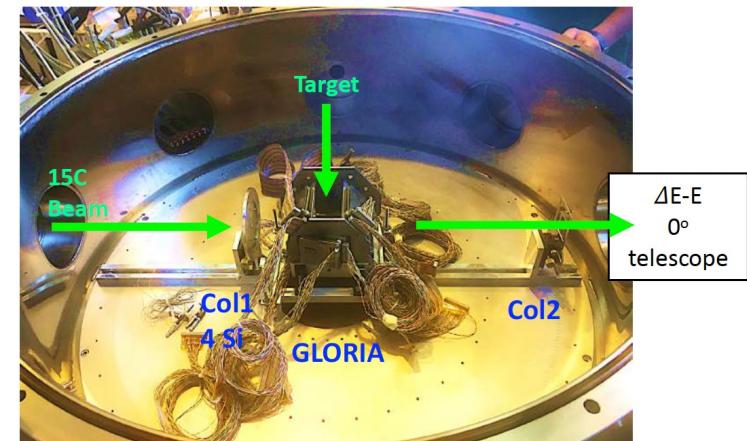
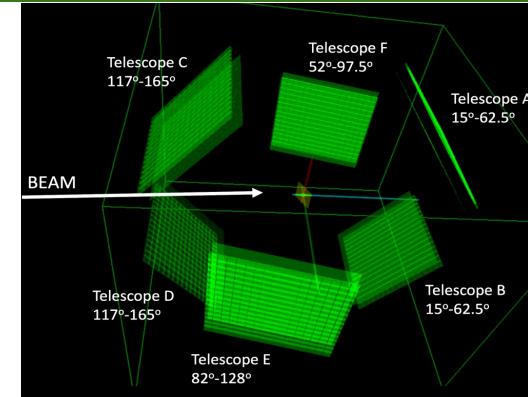
- **1×10^3 pps average ^{15}C at reaction point**
- $E = 4.37 \text{ MeV/u}$ (65.5 MeV) incoming ^{15}C (FWHM = 225 keV)
 - 65.43 MeV, after $75 \mu\text{g/cm}^2$ stripping C-foil
 - 64.56(23) MeV in the middle of the ^{208}Pb -foil
- **Cocktail beam of ^{15}N + ^{15}C :** $^{15}\text{C}/^{15}\text{N} \approx 1\text{-}3\%$
 - ^{15}N tightly bound @ this energy → use for monitoring and normalization



SEC: Scattering chamber

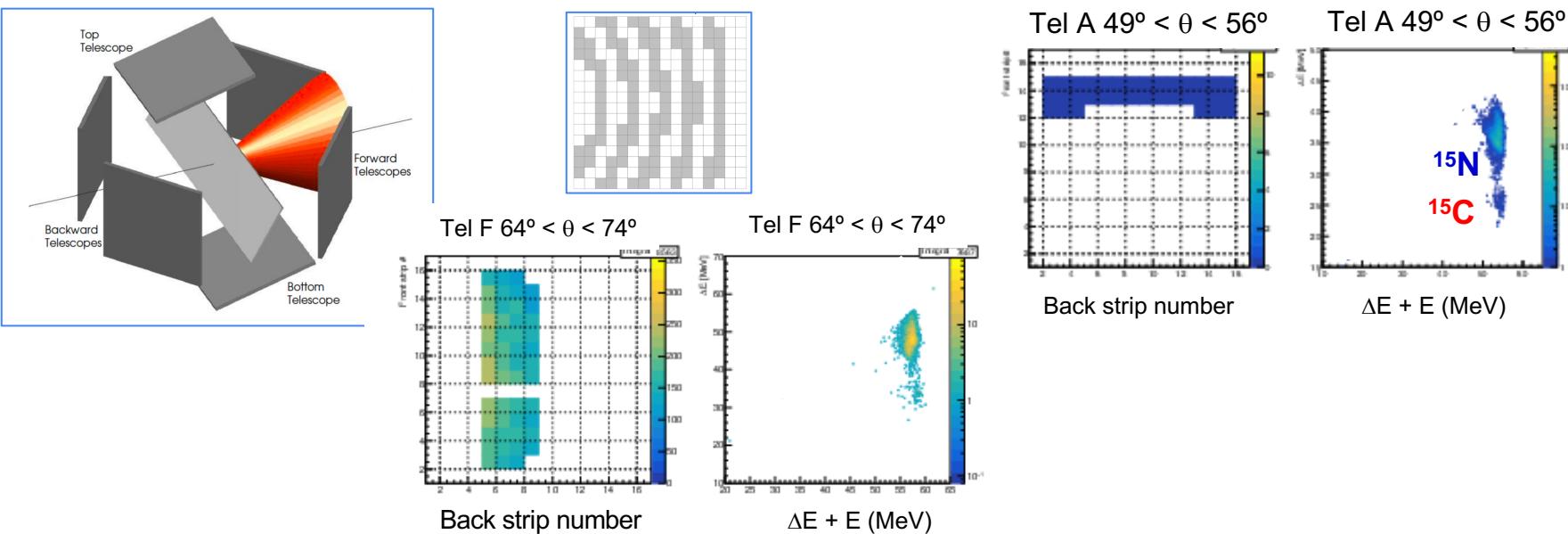
Experimental Setup

- Global Reaction Array **GLORIA**
(*NIM A 755 69-77 [2014]*)
 - 6 Si telescopes tangent to a 6 cm radius sphere
 - 40 μm (ΔE) + 1 mm (E) DSSDs in 256 pixels of $3 \times 3 \text{ mm}^2$
 - 2-3° angular resolution
 - Full angular coverage $\theta_{\text{LAB}} = 15^\circ - 165^\circ$
 - 25% geometric eff
 - ^{208}Pb targets 2.1 and 1.5 mg/cm^2 . 30° tilt.

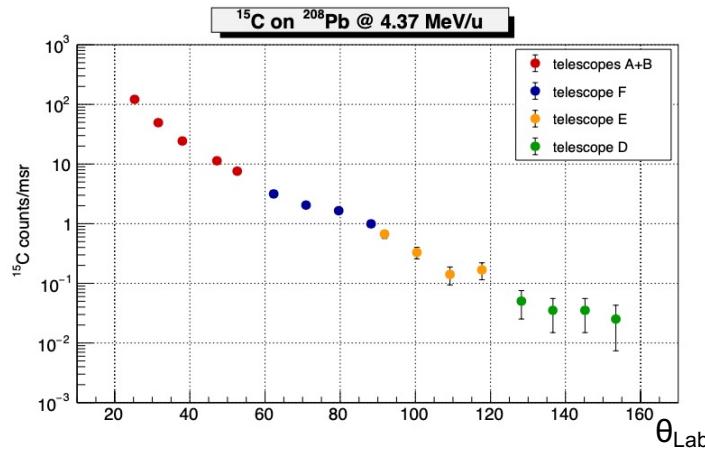


Data Analysis

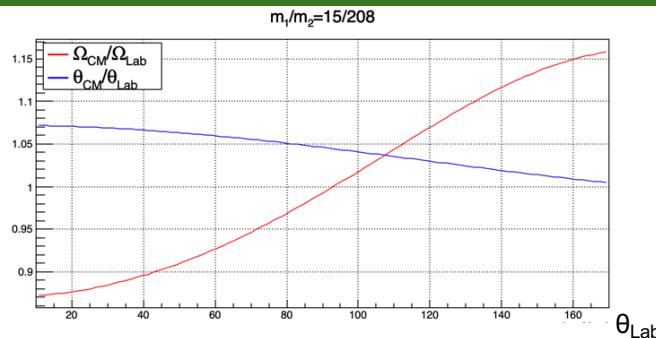
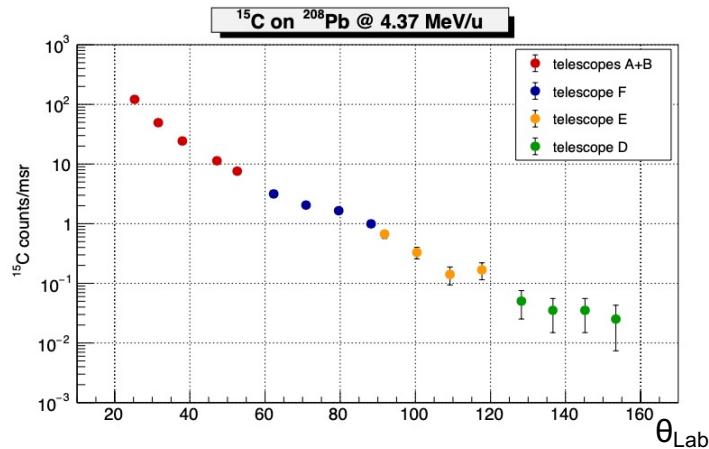
- In the $\Delta\theta$ sectors the same physics are expected (non-polarized beam) and minor effects of different energy losses happen, maximizing the statistics and reducing the errorbars.
- High granularity of DSSDs allows for grouping together pixels within a $\Delta\theta$ range.
- Telescope configuration allows for particle identification from 2D ($\Delta E - E_{TOT}$) plots.



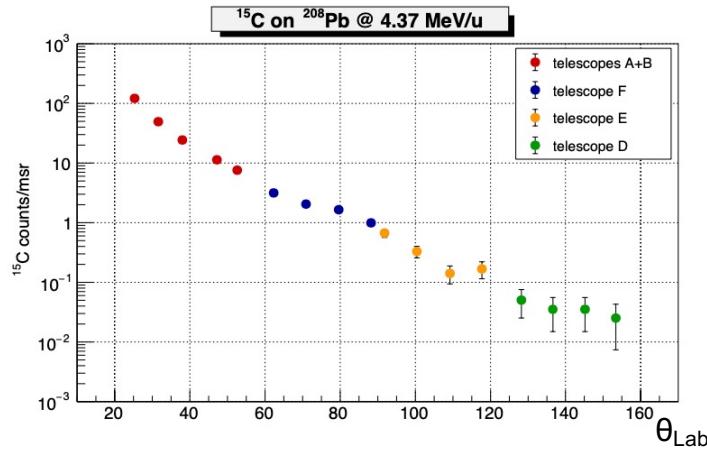
$^{15}\text{C} + ^{208}\text{Pb}$ Cross Section



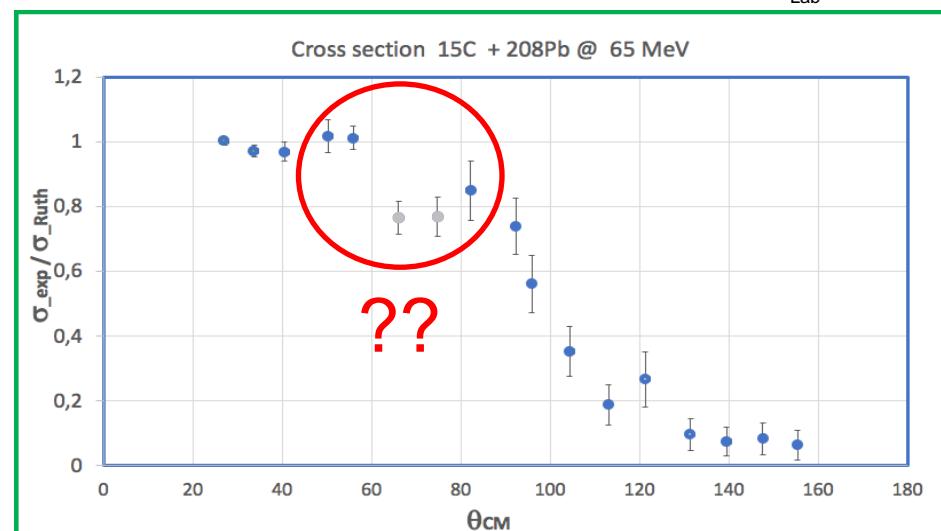
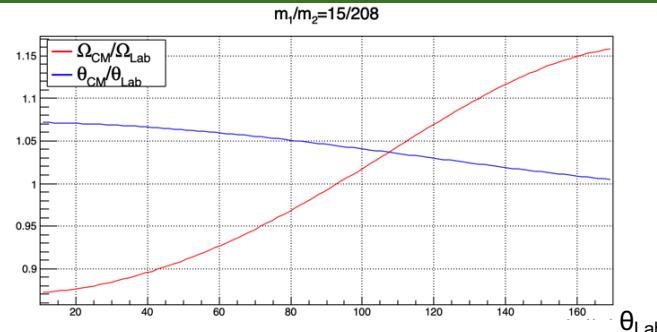
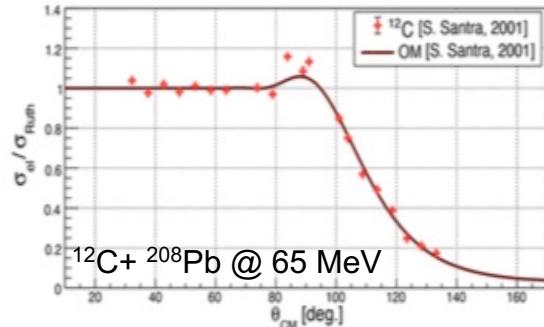
$^{15}\text{C} + ^{208}\text{Pb}$ Cross Section



$^{15}\text{C} + ^{208}\text{Pb}$ Cross Section



Santra et al., PRC 64 (2001) 024602

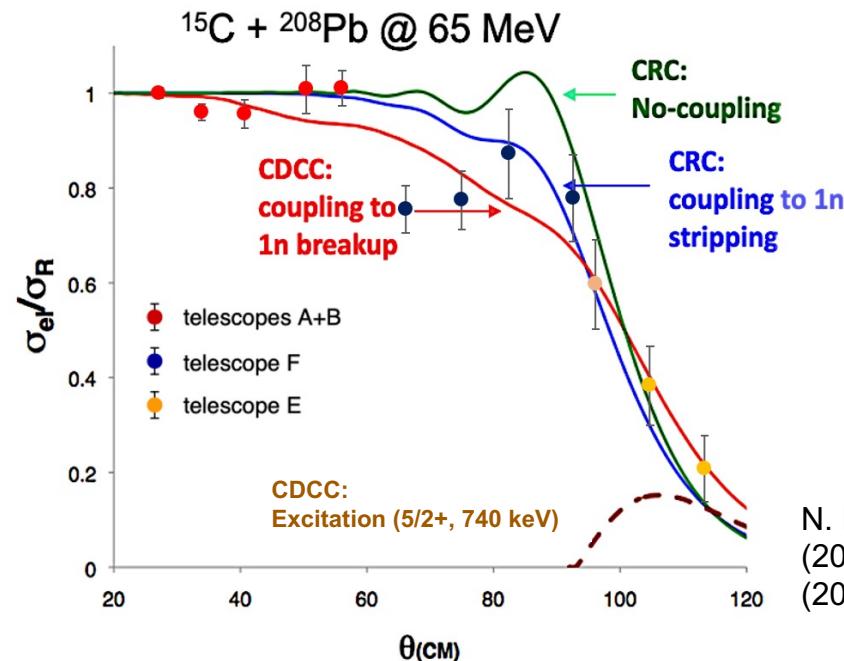


Comparison of Experimental results with Theory

The experimental angular distribution cross section of $^{15}\text{C} + ^{208}\text{Pb}$ @ 65 MeV are compared with the calculations done by Keeley et al., for the extreme case of no coupling and 1n-stripping within the coupled reaction channel and CDCC for no coupling and 1n breakup.

The experimental angular distribution of the elastic scattering near the Coulomb Barrier (~ 65 MeV) shows **strong couplings**.

The distribution favours the presence of **1n-stripping channel**.



N. Keenley et al., PRC 75
(2007) 056610; EPJA 50
(2014) 145

Summary & Outlook

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- We have performed the first study of the angular distribution of the elastic cross section of ^{15}C + ^{208}Pb @ 65 MeV at HIE-ISOLDE (CERN).
- ^{15}C nucleus is a border line halo case with relatively low binding energy, a moderate halo case.
- It constitutes a unique case where the last neutron is mainly in a $1\text{S}_{1/2}$ -wave state.
- Predictions on the scattering of $^{15}\text{C} + ^{208}\text{Pb}$ @ 65 MeV showed a scattering dominated by the competition of 1n-stripping and 1n-breakup.
- The preliminary experimental angular distribution of the elastic scattering near the Coulomb Barrier (~ 65 MeV) shows strong couplings and it favours the presence of 1n-stripping channel.
- Still studying the discontinuity between detectors A,B and F with ^{12}C and ^{15}N elastic scattering datasets.

The IS619 collaboration

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Thanks for your Attention

Channeling Effects

- **Channeling** through **Si lattice** in ΔE detectors leads to a smaller energy deposition.
- It happens in specific regions where the trajectory of the incident particle coincides with a channel of the detector wafer.
- The channeling of ^{15}N overlap with elastic of site of ^{15}C

