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-610, follow up of experiment IS699

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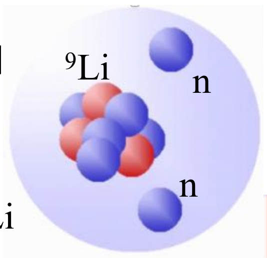
Local contact: Razvan Lica

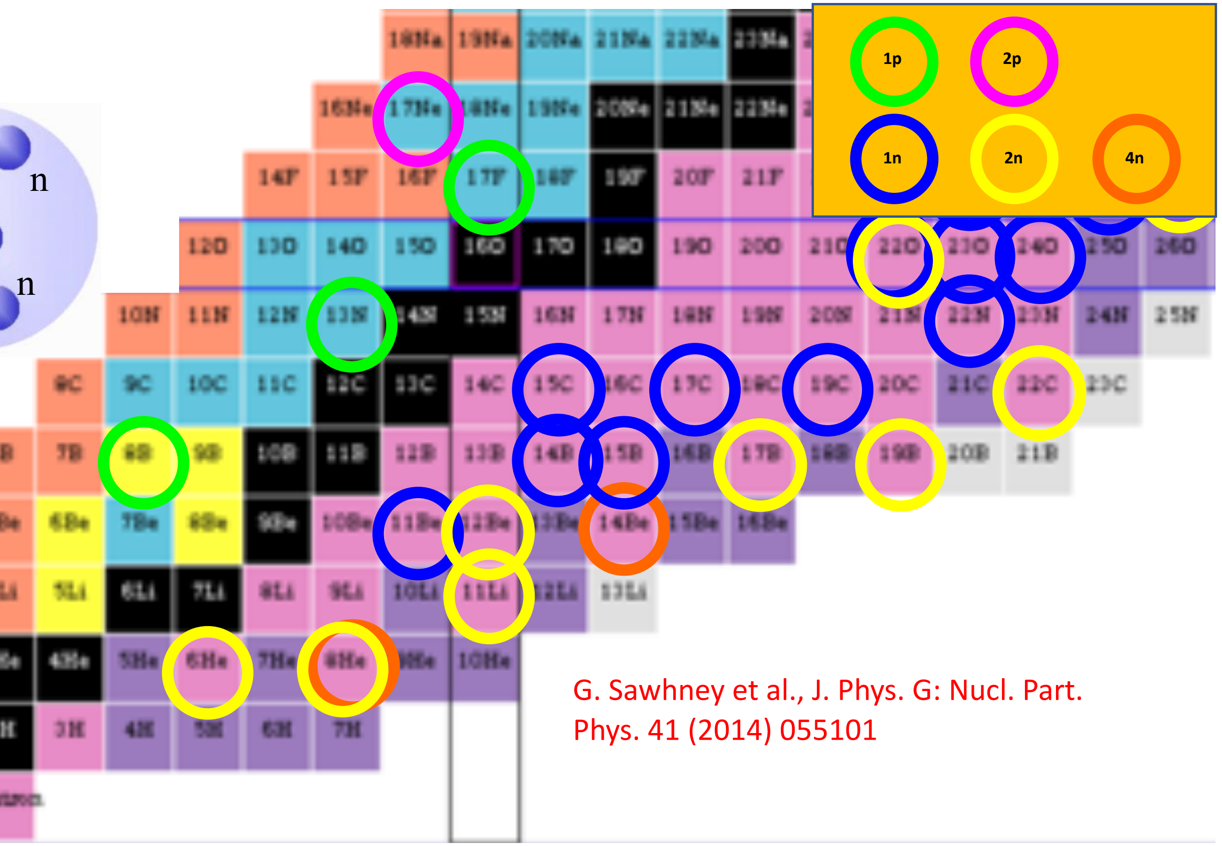
# Halo nuclei

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

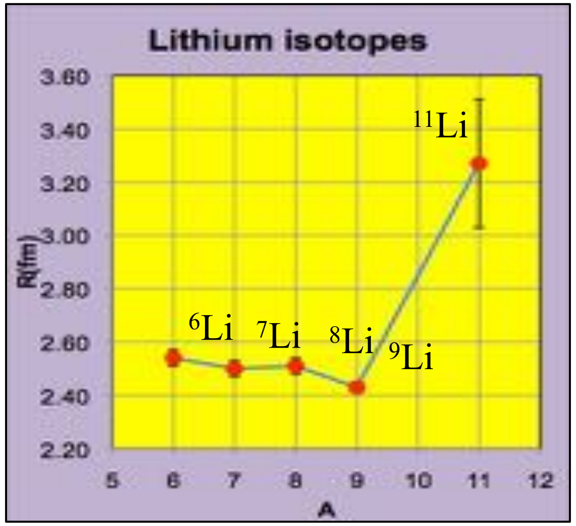
- Large matter radius ~ “halo”
- Large reaction cross sections
- Narrow momentum distributions
- Concentration of B(E1) close to BU threshold



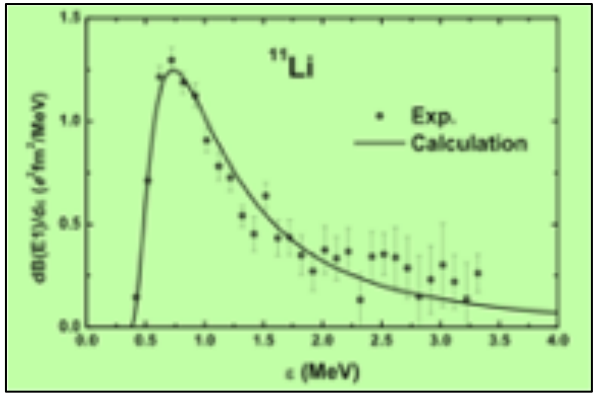

$^{11}$Li



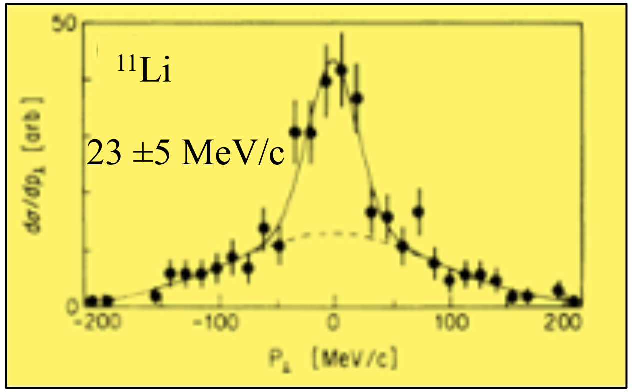

G. Sawhney et al., J. Phys. G: Nucl. Part. Phys. 41 (2014) 055101




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



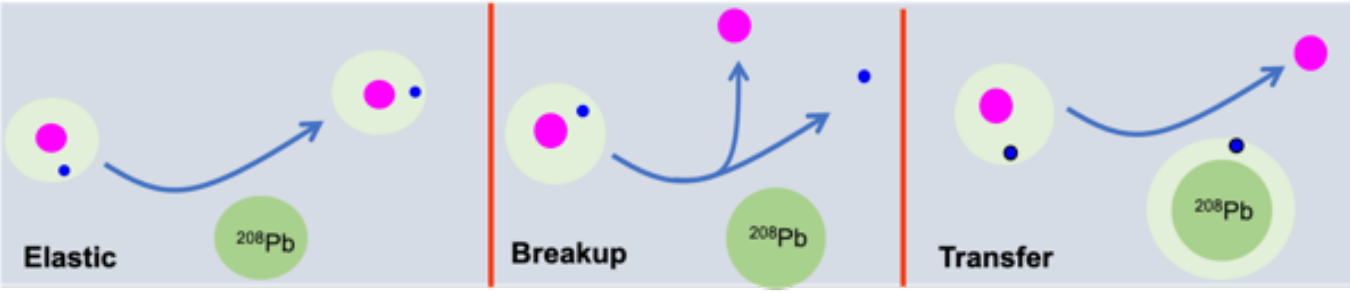

T. Nakamura et al., Phys. Rev. Lett. 96, 252502 (2006). T. H. Kim et al., Jour. Kor. Phys. Soc. 73 (2018) 553.




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

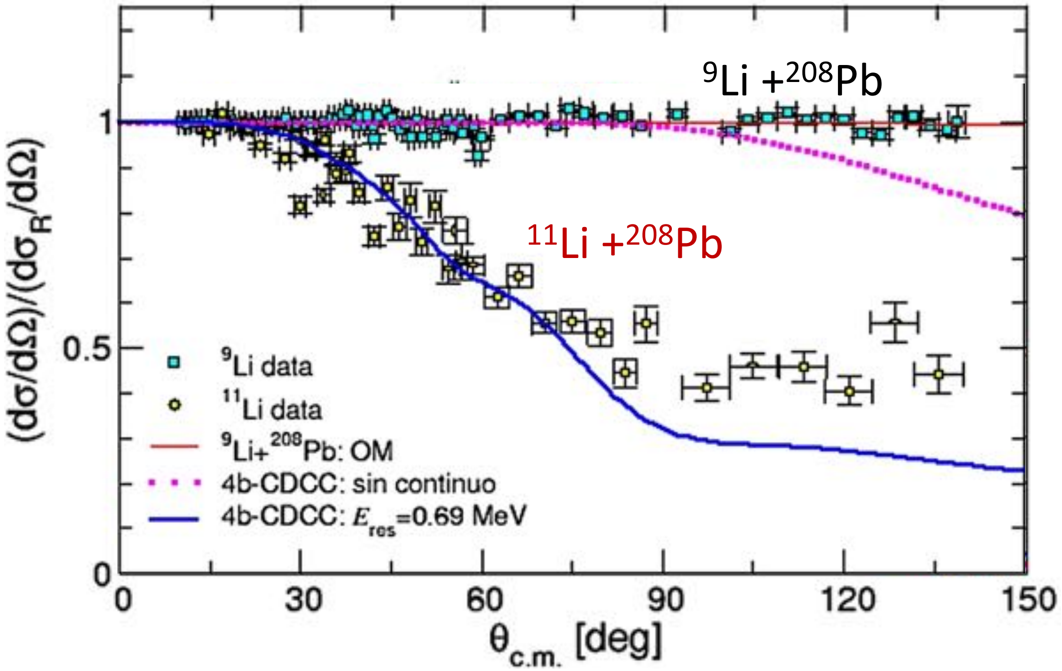
## Coulomb barrier scattering of halo nuclei

- Important coupling between relative motion and internal degrees of freedom.
- Strong effects on elastic angular distributions due to transfer, breakup and coupling to the continuum.




### Coulomb barrier scattering of $^{11}Li+^{208}Pb$, $E_{CM}$ = 23.1 MeV

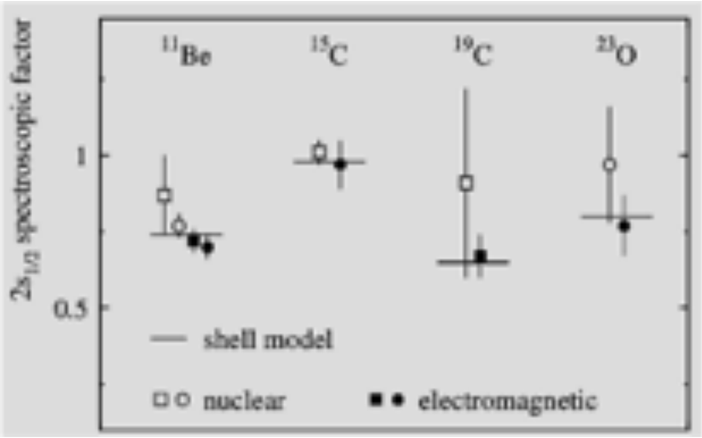
M. Cubero, et al. PRL 109, 262701 (2012)

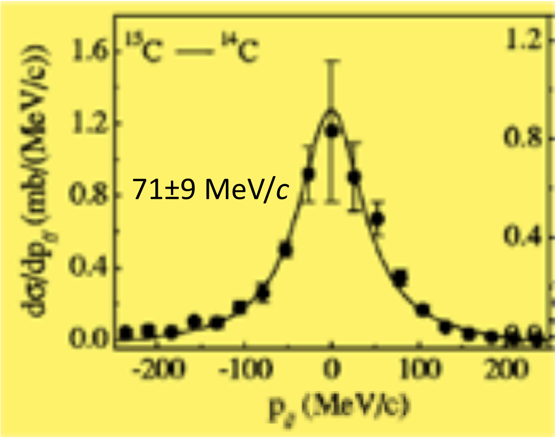



## What makes $^{15}C$ interesting?

- 1n-halo nucleus ($^{14}C$+n), $S_{1n}$=1.2 MeV.
- $^{15}C$ ($1/2^+$) has a bound excited state ($5/2^+$, 740 keV)
- Ground state characterized by $s_{1/2}$ sp-configuration.
  - **Only known case of a pure S-wave halo system**

**→ no data on reaction dynamics at Coulomb barrier energies**




T. Aumann, Eur. Phys. J. A 26, 441 (2005).

D. Q. Fang et al., Phys. Rev. C 69, 034613 (2004).

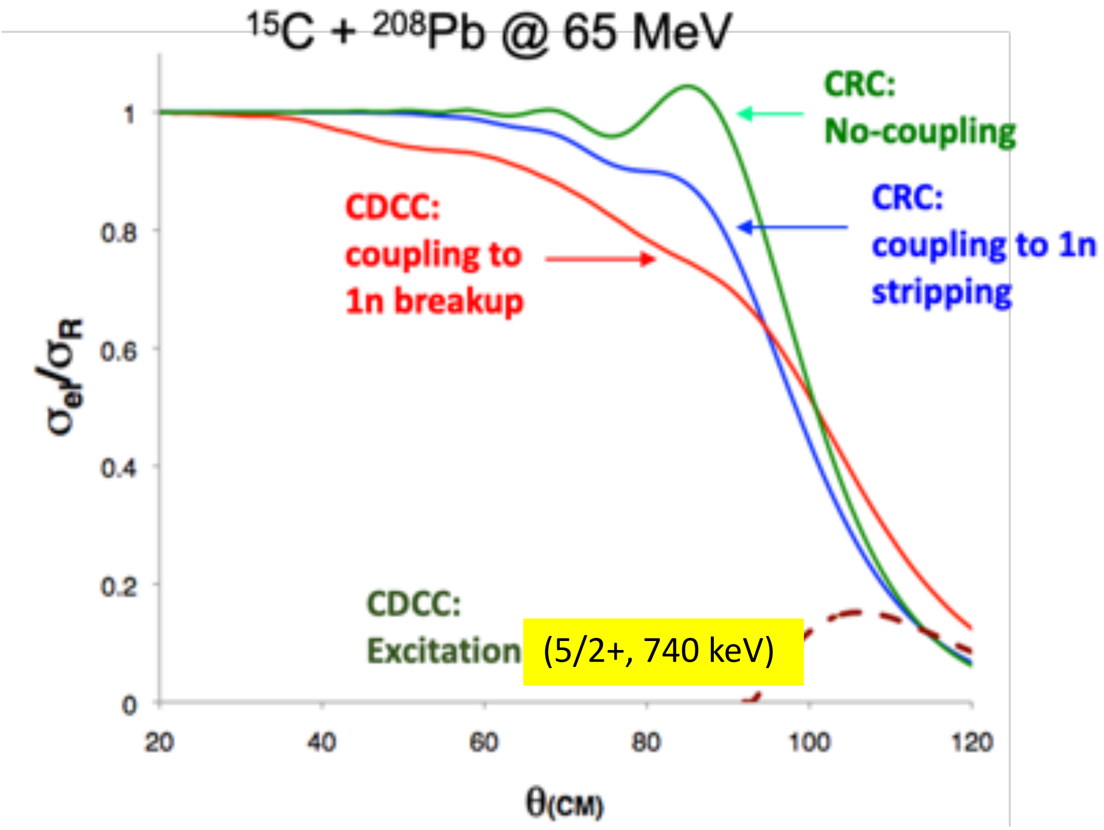
# Coulomb barrier scattering of $^{15}C$ + $^{208}Pb$

Theoretical calculations for the scattering of $^{15}C$+$^{208}Pb$ at Coulomb barrier ~ E= 65 MeV using Coupled Channel calculations.

- Dynamics dominated by the competition of 1n-stripping and breakup.
- Large influence of transfer/breakup on the angular distribution of elastic scattering.
- Weak influence of Inelastic (7/2+, 740 keV).

N. Keeley et al., Phys. Rev. C 75 (2007) 054610
N. Keeley et al., Eur. Phys. J. A 50 (2014) 145.

Angular distribution of the elastic cross section



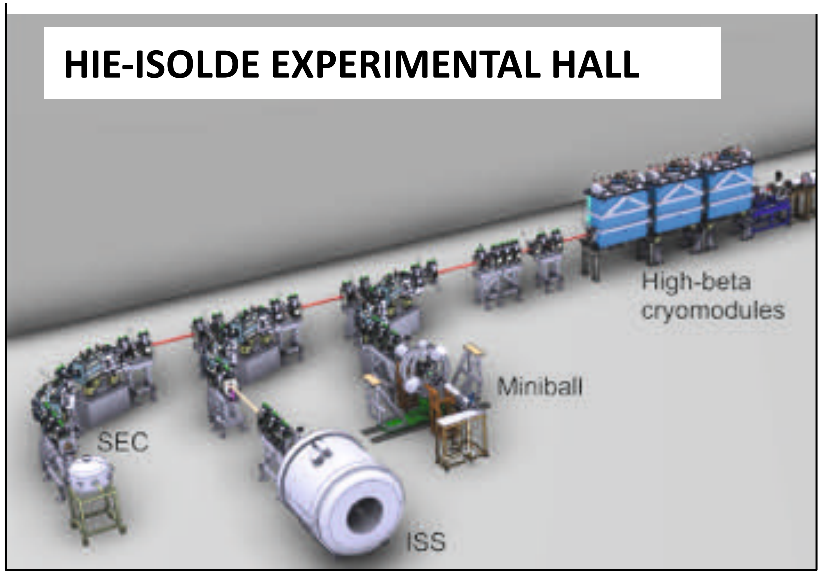
# Coulomb barrier scattering of $^{15}C$ + $^{208}Pb$

Experiment IS699 at HIE-ISOLDE (CERN, 2017)
I. Martel & O. Tengblad

- $^{15}C$ at E= 65 MeV
- CaO primary target
- 30 shifts, I= 1.1x$10^4$ pps on target
- $^{208}Pb$, 1.5 and 2.1 mg/cm$^2$.
- Beam impurity of $^{15}N$.

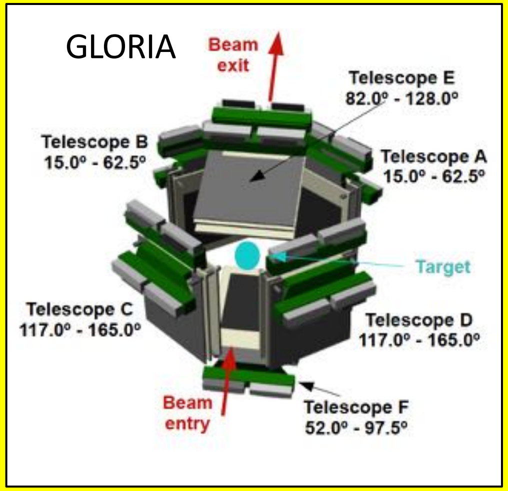
$^{15}N$ stable → monitoring and normalisation

## SEC: Scattering chamber, XT03 beam line




G. Marquínez-Durán, NIMA755 (2014)69.

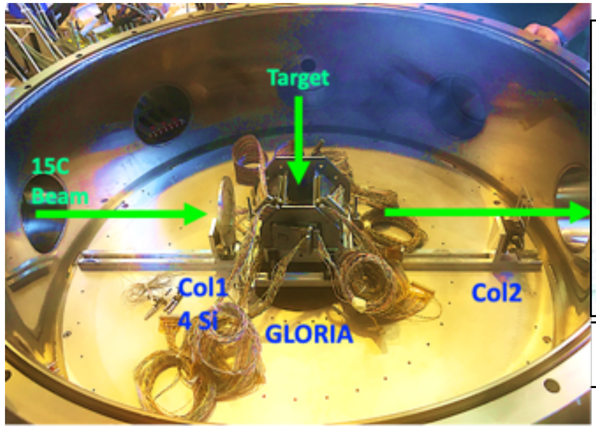
## GLORIA detector array

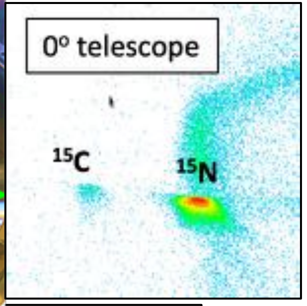



- 6 DSSSD particle telescopes
- 60 mm to target
- Total solid angle 26 %.
- Tilted target ~ 30°

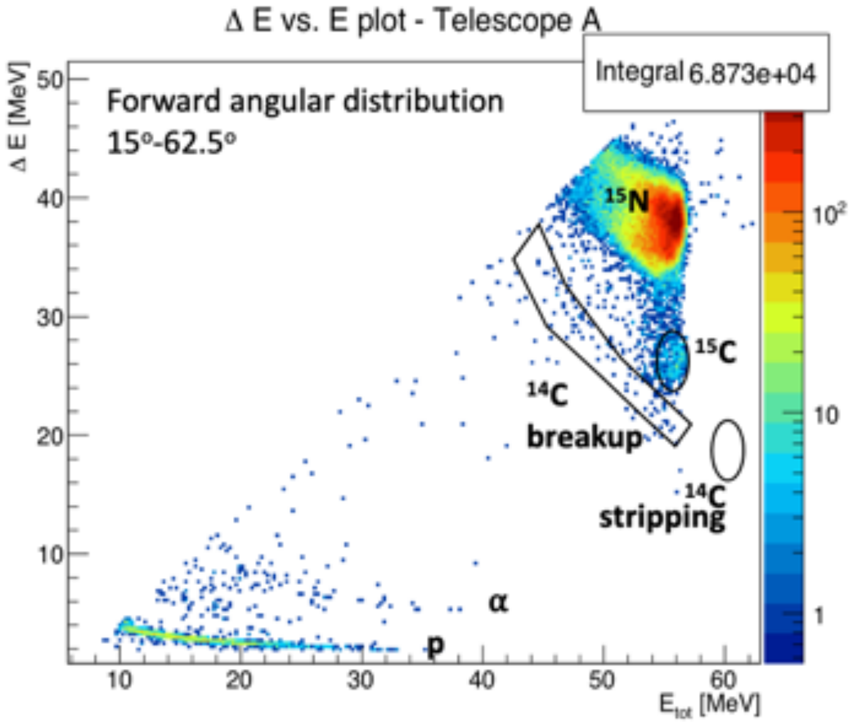
→ Full 15°-165° Lab.

## GLORIA setup in SEC




ΔE-E



# IS99-Experimental problems - analysis

- I ~ 1.5 x $10^3$ pps, about ~ 13% of request
- Thick lead target of 2.1 mg/$cm^2$ → energy resolution/PID.
- Diagnostic system and detector setup ~ 40%
- Channelling, crosstalk/charge sharing at front-back
- Missing strips/connectivity ~ 30%.
- Resulting statistics ~ 2% of expected!

→ Analysis rely on simulations.

→ Large uncertainty in angular distributions.

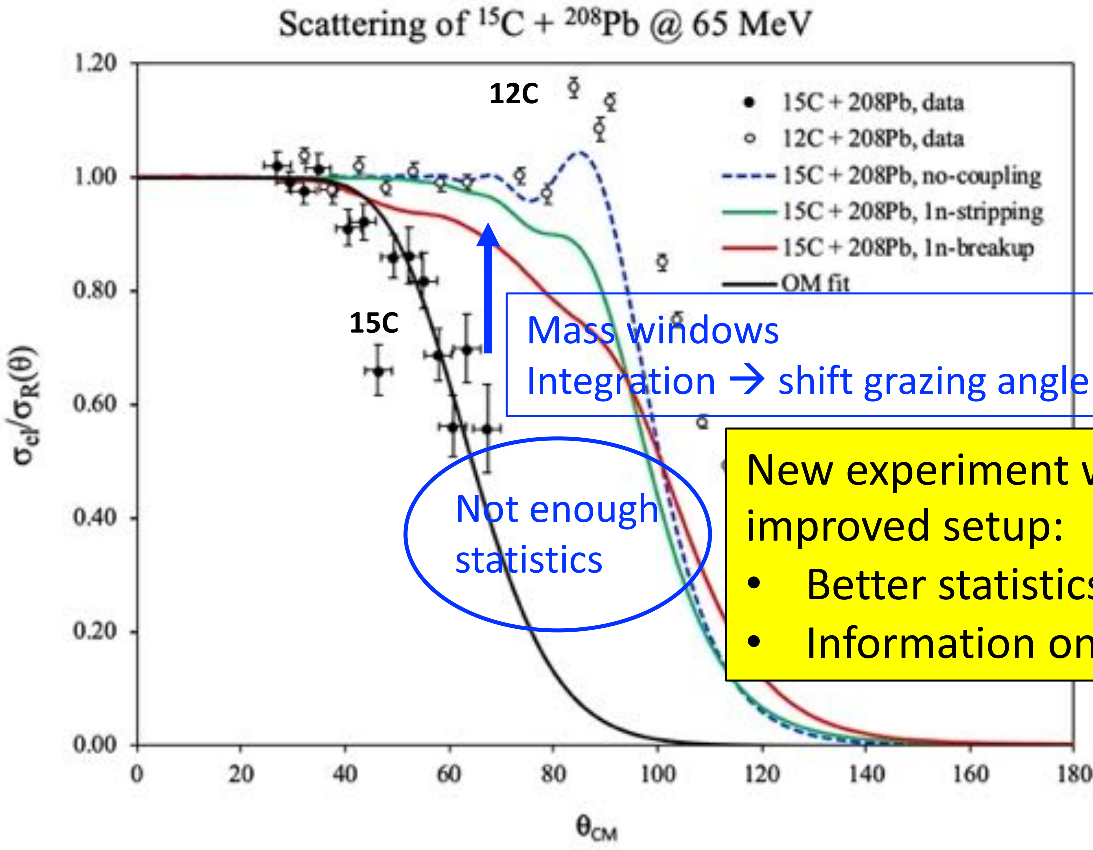
→ No possible to resolve breakup/striping

→ Found very strong absorption in elastic scattering

PhD students:
J. Díaz-Ovejas, Univ. Comp. Madrid.
Alexander Knyazev, Lund University.

## Angular distribution of elastic scattering

J D Ovejas et al 2020 J. Phys.: Conf. Ser. 1643 012095




New experiment with improved setup:
- Better statistics
- Information on dynamics

**OM parameters**

$^{15}$C → $a_w$= 1.5 fm (!!)

✓ Stable: $^{12}$C, $a_w$= 0.4 fm

✓ 2n-halo: $^6$He, $a_w$= 2 fm

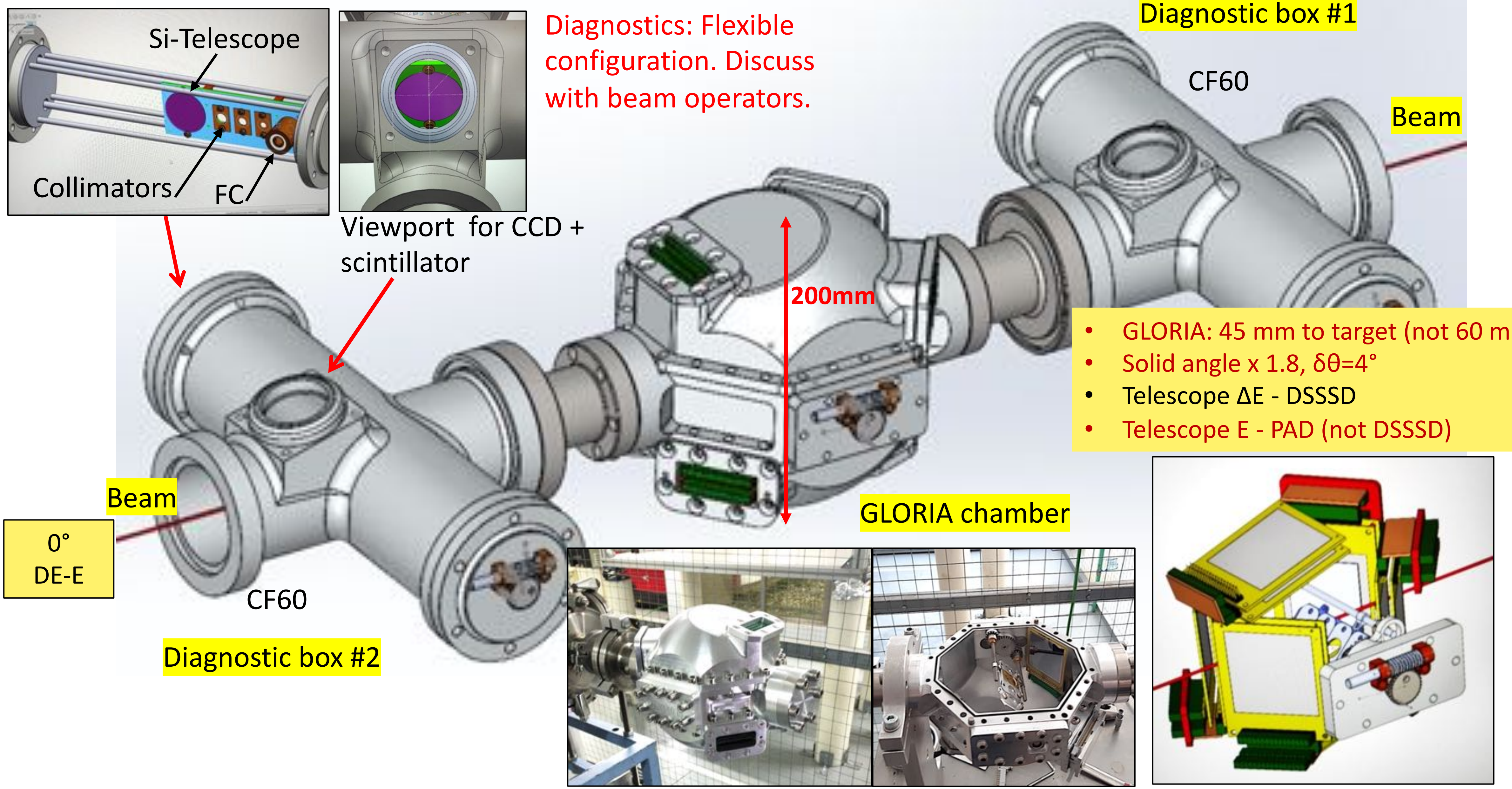
**Reaction cross sections**

$\sigma_{exp}(^{15}C)$ ~ 3000 mb → 8 x $\sigma_{exp}(^{12}C)$

✓ 3 x $\sigma_{th}$(1n-stripping)

✓ 2 x $\sigma_{th}$(1n-breakup)

# NEW GLORIA EXPERIMENTAL SETUP

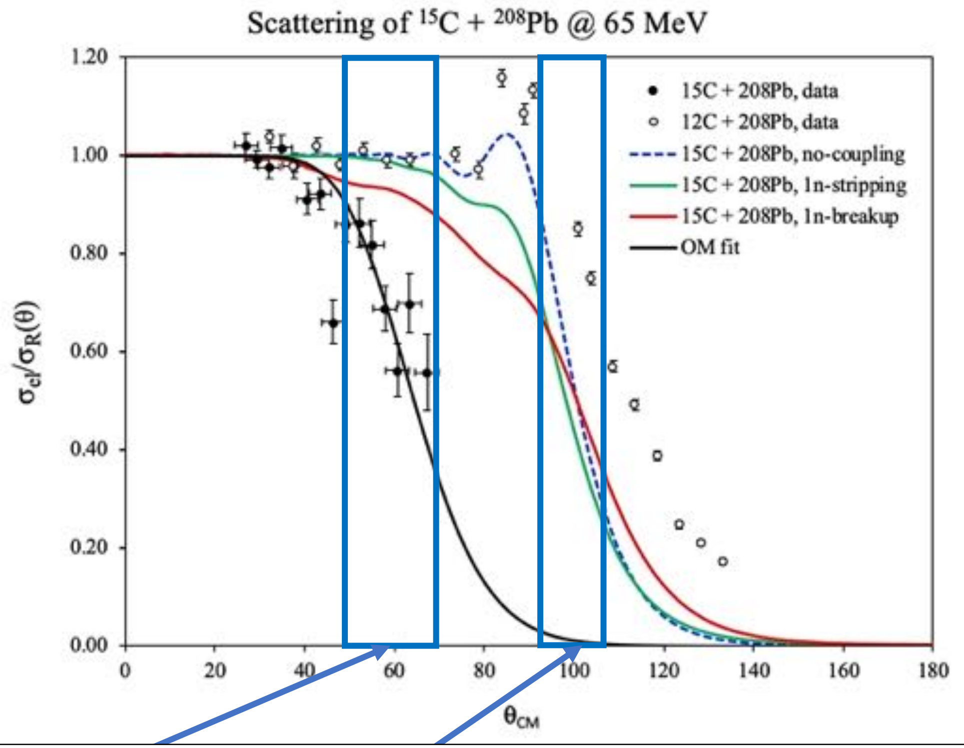



- GLORIA: 45 mm to target (not 60 mm)
- Solid angle x 1.8, $\delta\theta=4°$
- Telescope ΔE - DSSSD
- Telescope E - PAD (not DSSSD)

# BEAM TIME REQUEST

- Elastic ~ 5% uncertainty
- 24 shifts on $^{15}C^{5+}$, 65 MeV (4,3 MeV/u).
- 1 shift →primary target optimisation (CaO).
- 7% transport efficiency (previous experiment).
- $^{15}$C yield from CaO ~ 1.5 x $10^5$ pps → $10^4$ pps at reaction target.

  J.P. Ramos et al., NIMB 320 (2014) 83.
- GLORIA: ~ 2 x solid angle, PAD for E detectors, improved diagnostics
- $^{208}$Pb target of 1,3 mg/cm$^2$ thickness (1.1 mg/cm$^2$ tilted 35°).




| Counting rates | | | |
|---|---|---|---|
| Previous experiment | | | |
| θcm | σ (mb/sr) | Counts | Err (%) |
| 50° ± 2° | 2000 | 4000 | 1.5 |
| 60° ± 2° | 700 | 1600 | 2.5 |
| Theoretical calculations | | | |
| θcm | σ (mb/sr) | Counts | Err (%) |
| 100° ± 2° | 130 | 600 | 4.5 |

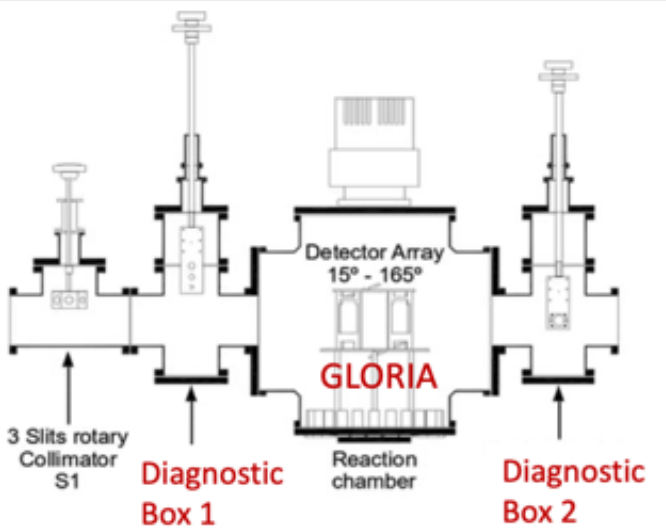
## TECHNICAL ADVISORY COMMITTEE

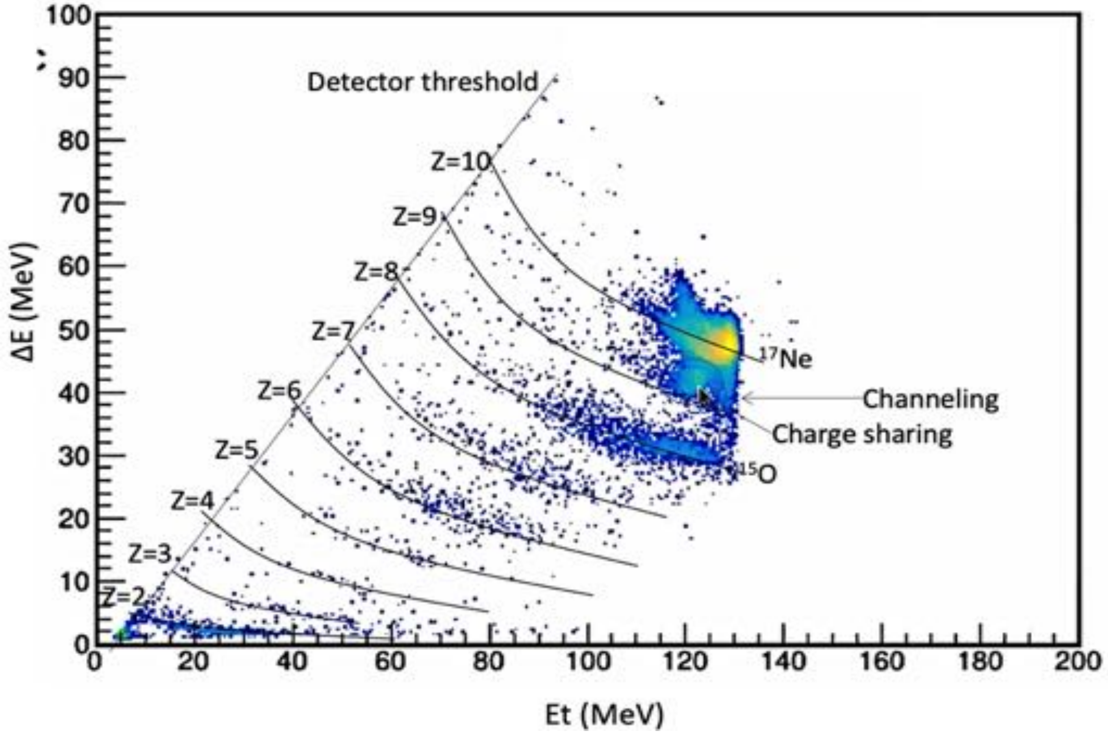
- Yield from nano-structured CaO is likely to be variable. A programme is underway to develop further production of isotopes from CaO. ✅
- Stripping foils will be needed to remove $^{15}$N. Will not be fully removed at these energies. ✅
- The experiment will require additional diagnostics to allow for better identification of the beam arriving to the setup. ✅

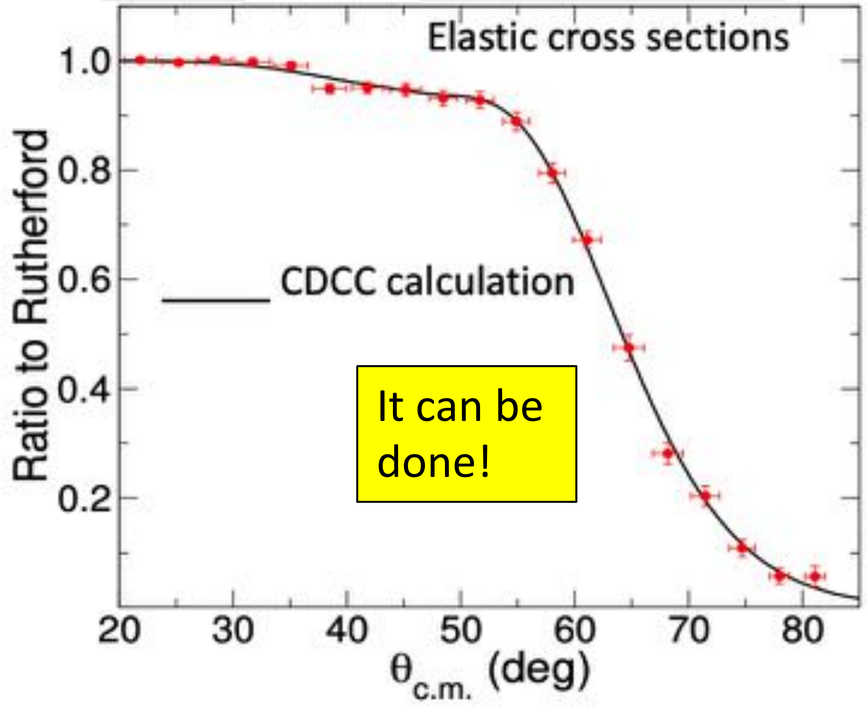
# RECENT EXPERIMENT $^{17}$Ne+$^{208}$Pb @ Coulomb barrier energy

- $^{17}$Ne+$^{208}$Pb @ 136 MeV (8 MeV/u)
- $^{208}$Pb target: 1.2 mg/cm2 and 1.3 mg/cm2
- I ~ 2 x $10^4$ pps (~25 shifts)
- GLORIA detector system
- E788S (2020)

Experimental setup



# Collaboration INTC-P-610

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

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**THANKS !**