ELASTIC SCATTERING OF ^{15}C ON HEAVY TARGETS NEAR THE COULOMB BARRIER

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on behalf the IS619 collaboration

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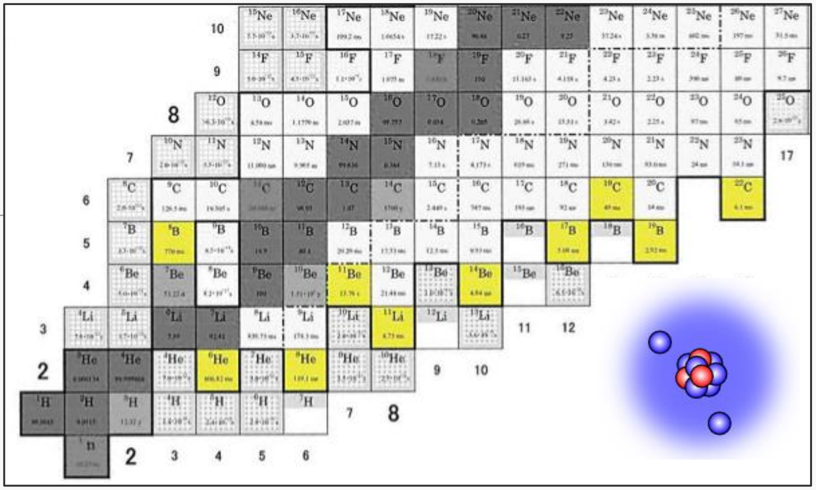
ISOLDE WORKSHOP
CERN, 6 December 2019

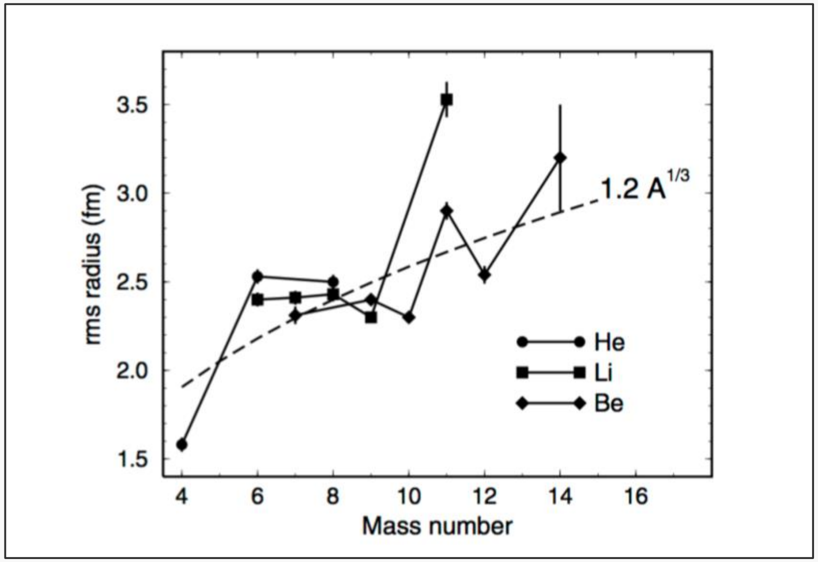
1. MOTIVATION

- Understanding the exotic **nuclear structure** in the light region of the nuclear chart.

- Observe and explain the effects of the nuclear structure on the **reaction dynamics**.

- Nuclear **halos**: reduced binding energy of last/two last valence nucleons (i.e. S_n or S_{2n} << 2 MeV) favours tunneling through the nuclear potential leading to an extended nuclear matter density to large distances.





Tanihata et al. Phys Rev Lett 55, 2676 (1985)
Hansen and Jonson. Europhys Lett 4, 409 (1987)

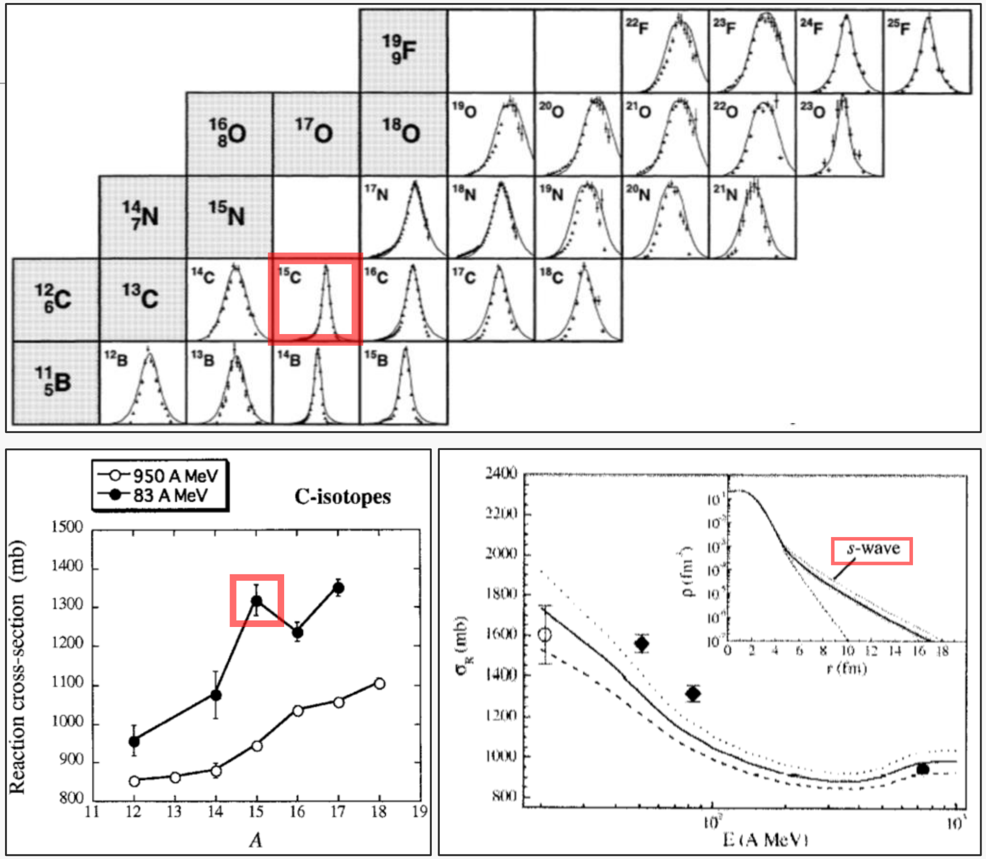
1. MOTIVATION

- For **^{15}C**, a high reaction cross section and a narrow longitudinal momentum distribution is found.

- An halo structure with a **pure s wave** as **ground state** and a ^{14}C core explains this features, despite the fact of having a relatively large separation energy S_n.

$S_n = 1218\ keV$

$S_{2n} = 9394\ keV$

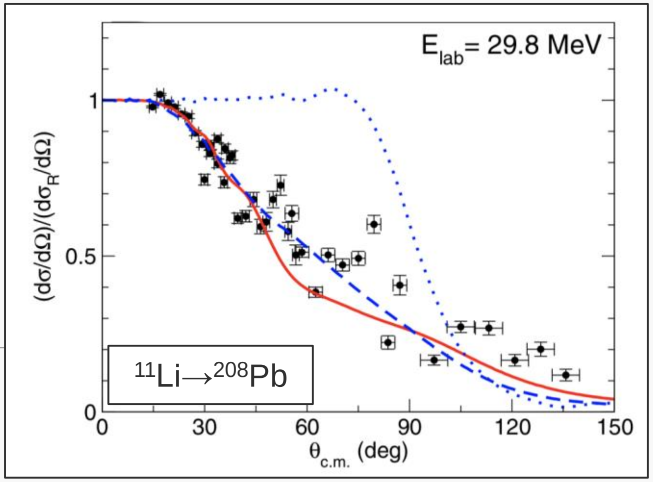


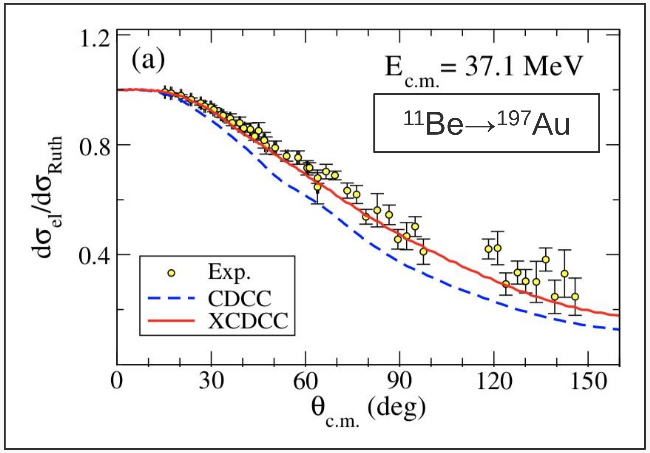
Ozawa. Nuc Phys A 738 38-44 (2004)

1. MOTIVATION

- **Previous experiments** have studied the halo effects on the near barrier **elastic scattering on heavy targets**.
- At **near barrier energies** of scattering the strong electromagnetic field of the reaction target induces a dipole polarization of the halo projectile.
- The structure effects manifest on the angular distribution of the elastic cross section.
- A strong absorption in the elastic channel and the suppression of the rainbow arising from the Fresnel interference in the Optical Model is found.

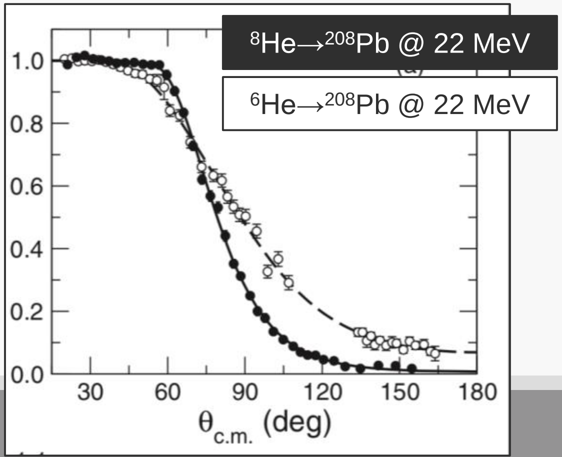
Cubero et al. PRL109 262701 (2012)





Pesudo et al. Phys Rev Lett 118 152502 (2017)

Marquinez-Duran et al. Phys Rev C 94 064618 (2016)



1. MOTIVATION

- All theses points led us to INTC-P-468.
- **IS619** at XT03 **HIE**-ISOLDE in August 2017.
- First low-energy dynamical study of ^{15}C.
- Aiming to elucidate the coupling between elastic, breakup and transfer channels due to the 1n halo structure and the effects of the continuum.
- The main goal is to measure the **angular distribution** of the **elastic channel** at an energy near the Coulomb barrier with a heavy target.
- Breakup/transfer/inelastic channels are desirable, though.

$$^{15}C + ^{208}Pb \rightarrow ^{15}C + ^{208}Pb \quad @ \quad E_{LAB}=4.37\ MeV/u$$

CERN-INTC-2016-025 / INTC-P-468
01/06/2016

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

31-May-2016

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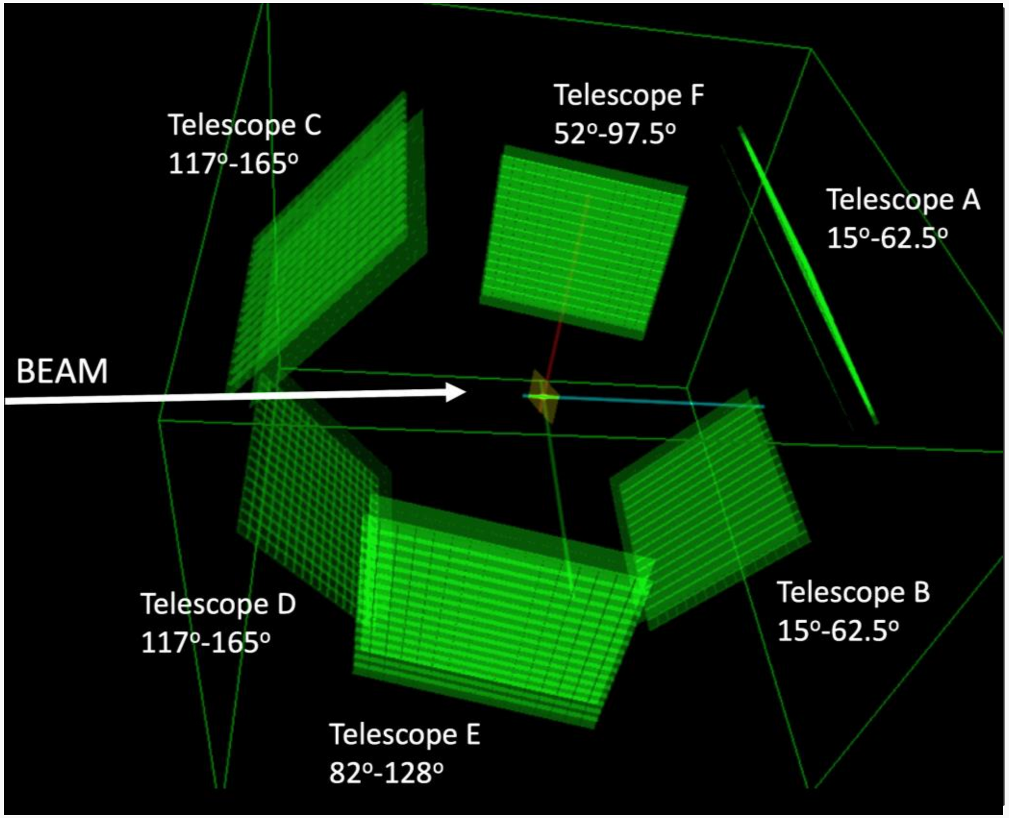
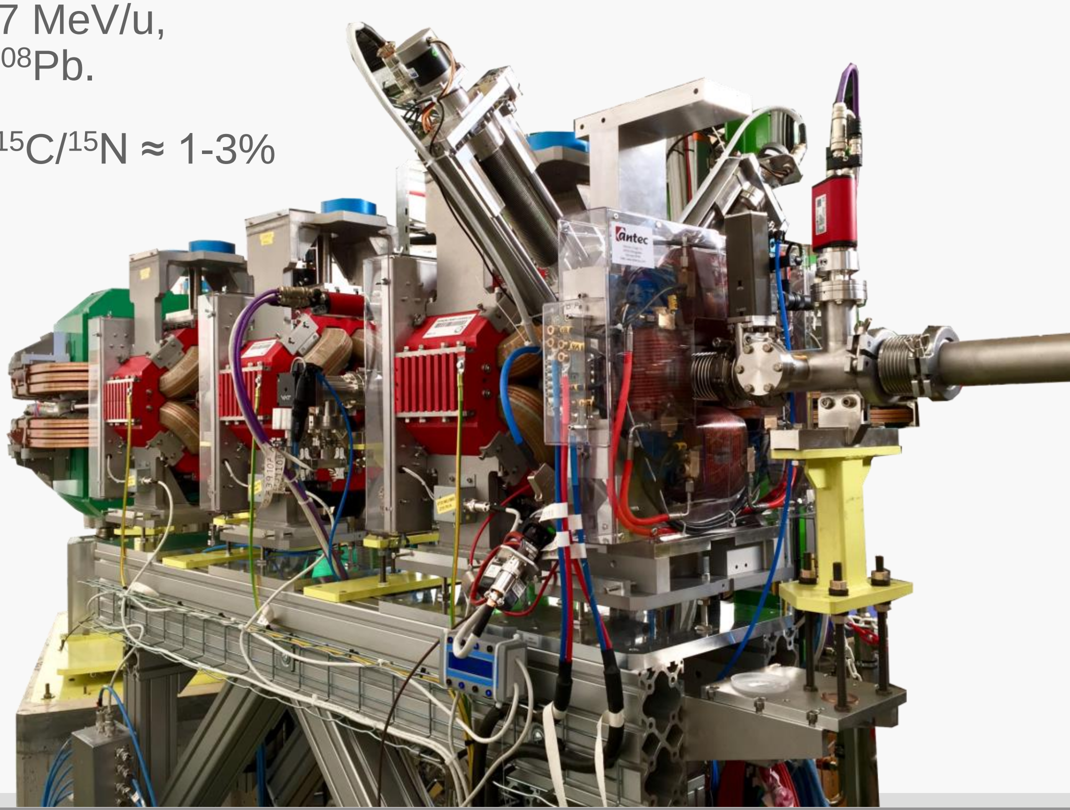
2. EXPERIMENTAL SETUP

- 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 tel. config.
- 50x50 cm^2 and 16x16 strips each DSSD ⟹ 256 pixels of 3x3 mm^2 and 2-3º angular res.
- 60 MeV dynamic range to detect A=15.
- **π** sr solid angle coverage (25% geometric eff.).
- θ_{LAB} from 15º to 165º in continuous way with overlapped regions between pairs of detectors.

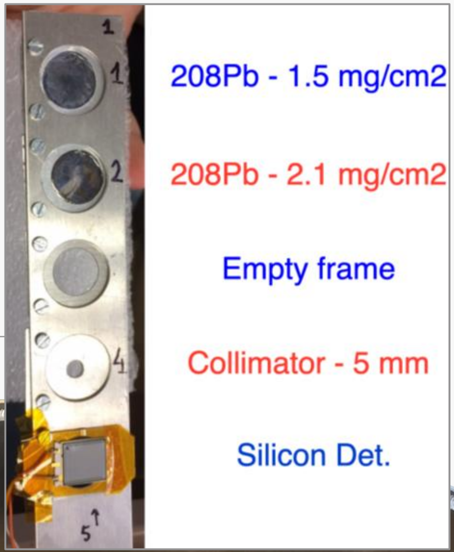


2. EXPERIMENTAL SETUP

- ^{15}C radioactive **beam** produced from 1.4 GeV proton pulses from PS booster impinging on a CaO primary/production target.
- Post-accelerated with A/q=3 up to 4.37 MeV/u, the Coulomb barrier for system ^{15}C + ^{208}Pb.
- ^{15}N present as contaminant in a ratio ^{15}C/^{15}N ≈ 1-3%
- Estimated ^{15}C yield ~ 10^3 pps
  (1.1· 10^4 pps requested)
- No other contaminants are observed with the 75 μg/cm^2 stripping foil.
- Cocktail beam ^{12}C + ^{15}N + ^{18}O at the same energy provides useful information for geometric/energetic calibration.



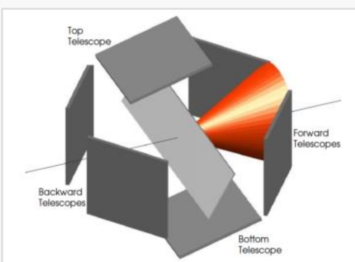
2. EXPERIMENTAL SETUP

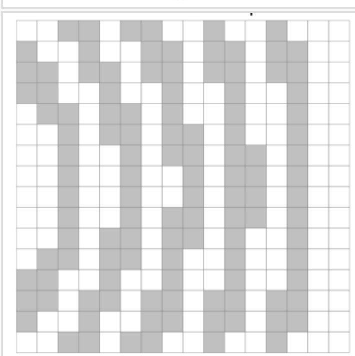


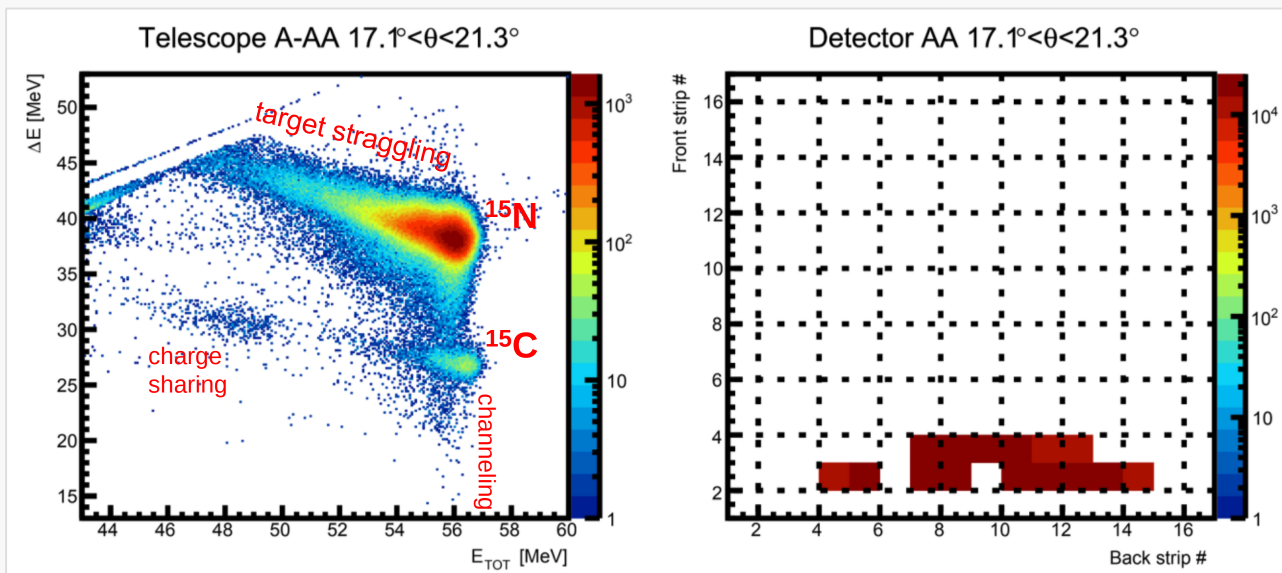
- ^{208}Pb **targets** 2.1 and 1.2 mg/cm^2. Purity ≈ 98%
- 30º tilt respect beam direction
  → no shadowing at 90º
  → assymetry in energy losses
- Thicker target
  → more straggling
  → higher reaction rate
- Thin target
  → better resolucion
  → less reactions

3. DATA ANALYSIS

- Telescope configuration allows for **particle identification** from 2D (ΔE-E_{TOT}) plots.
- High granularity of DSSDs allows for grouping together pixels within a $\Delta\theta$ range.
- 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.

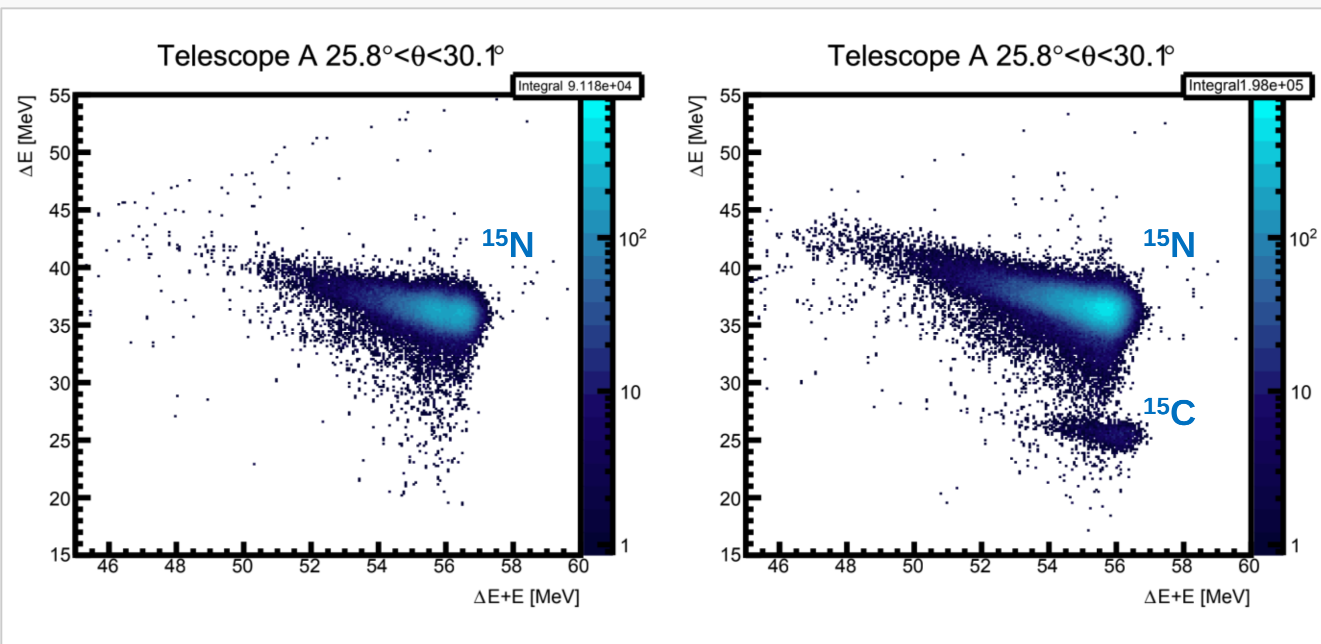


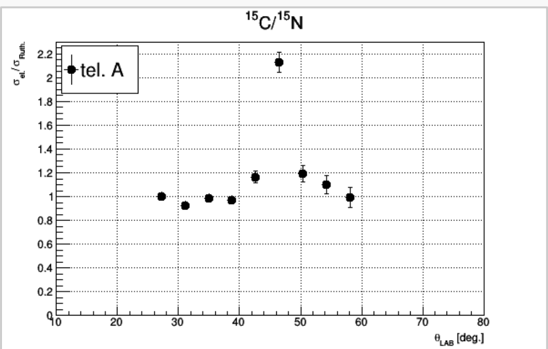


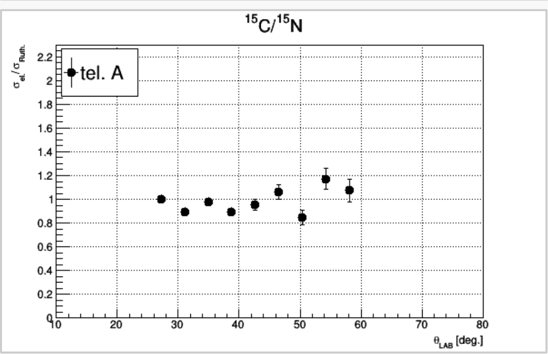


3. DATA ANALYSIS

- **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.

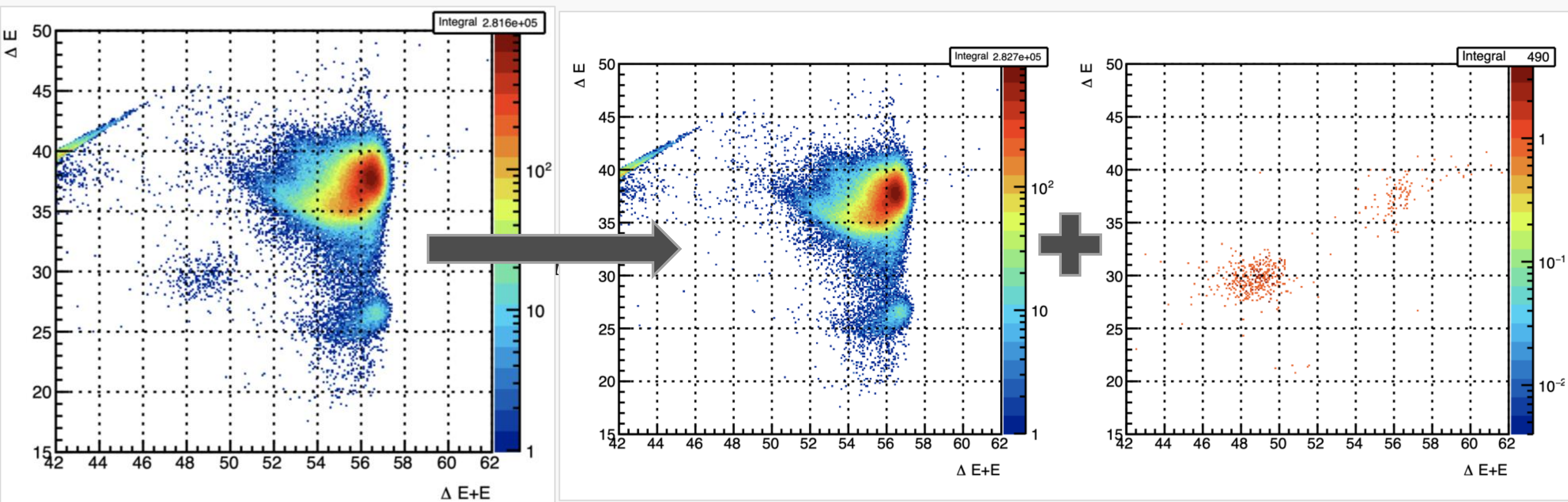






3. DATA ANALYSIS

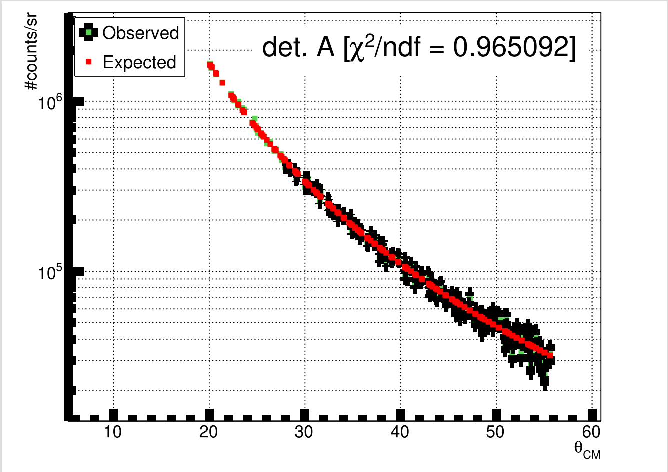
- High energy **charge sharing events** are demonstrated to create a well defined spot in the 2D plots.
- They appear even after setting a tolerance in the energy difference between the p- & n-sides of the DSSDs in a proportion close to 0.1% (<< fraction of inter-strip surface).
- They can be mainly isolated before doing any matching between the DSSDs sides.

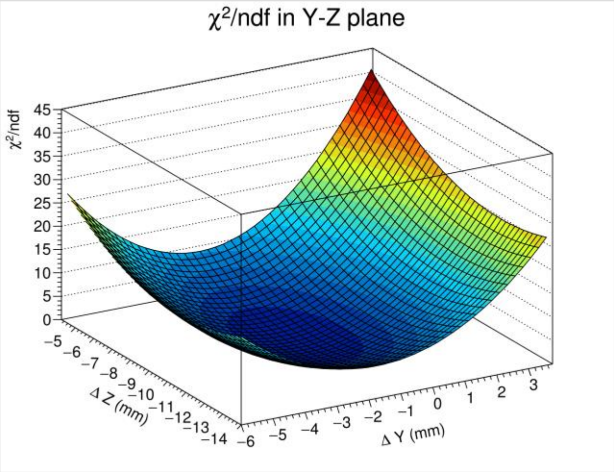


3. DATA ANALYSIS

- **Angle/solid angle determination** for every pixel is optimized with a χ^2 test.
- Optimal θ, φ and ΔΩ are chosen from the set of free parameters $(\overrightarrow{\boldsymbol{r}_{RP}}, I_N) = (x_{RP}, y_{RP}, z_{RP}, I_N)$ minimizing the χ^2/ndf when compared to the theoretical Rutherford cross section distribution.
- The loop happens to converge for several sets (z_{RP}, I_N), so the most feasible one is chosen according to the setup geometry and the intensity estimation by the ISOLDE beam team.

$^{15}N + ^{208}Pb \rightarrow ^{15}N + ^{208}Pb$





$$N_{Obs} = I_N \cdot t \cdot \sigma_{Pb} \cdot \frac{d\sigma_{Ruth}}{d\Omega} \cdot \Delta\Omega$$

$$\frac{d\sigma_{Ruth}}{d\Omega} = \left(\frac{Z_1 Z_2 \alpha \hbar c}{4E}\right)^2 \frac{1}{\sin^4(\theta_{CM}/2)}$$

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

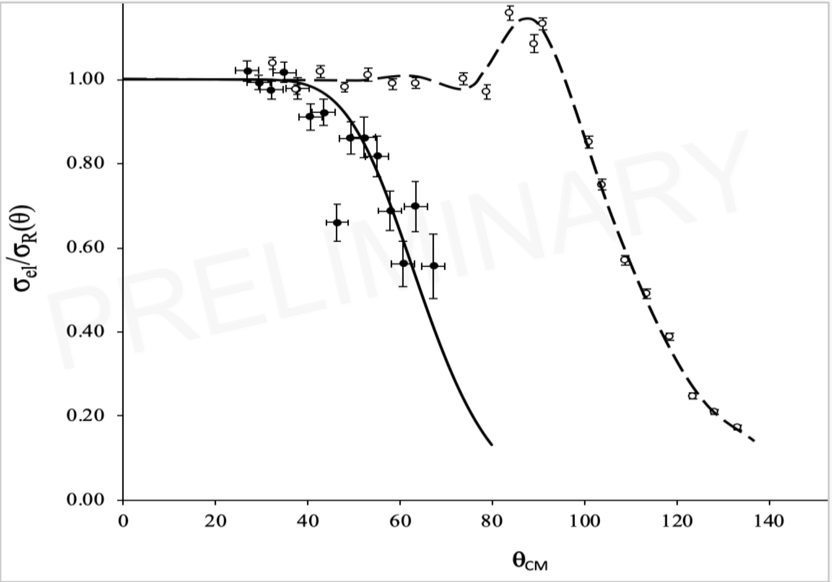
3. DATA ANALYSIS

- $\sigma_{el}(\theta)$ → Information on interactions governing relative motion.
- OM in terms of Woods-Saxon potentials to reproduce data.
- Data compared to ^{12}C scattering at same energy.
- Closest approach ~ 21 fm and σ_R = 3035 mb

	V_0 (MeV)	r_{r0} (fm)	a_{r0} (fm)	W_0 (MeV)	r_{i0} (fm)	a_{i0} (fm)
$^{15}C + ^{208}Pb$	32.90	1.256	0.560	22.10	1.256	1.560
$^{12}C + ^{208}Pb$	65.50	1.282	0.463	163.71	1.265	0.365

$^{12}C \rightarrow ^{208}Pb$ @ 65 MeV

Santra et al., Phys. Rev. C ***64*** *024602 (2001)*



$^{15}C \rightarrow ^{208}Pb$ @ 65 MeV

This work. To be published.

4. SUMMARY

- Angular distribution of the **elastic scattering of ^{15}C** on ^{208}Pb @ near barrier energy (4.37 MeV/u) has been **measured for the first time**.
- The experiment was carried out thanks to latest upgrade of **HIE-ISOLDE** in 2017 using the **GLORIA** experimental setup.
- It has been neccesary to consider **charge sharing** and **channeling** effects in the data analysis.
- A **geometrical optimization** of the angles/solid angles has been performed by a χ^2 test of the ^{15}N distribution.
- **Optical Model** calculations have been done to reproduce the overall trend of measured data.
- The **large imaginary diffuseness** suggests an extended neutron distribution.
- The strong absorption at already 50º could be due to the **unique s-wave nature** of the halo g.s.