IL NUOVO CIMENTO **45 C** (2022) 108
DOI 10.1393/ncc/i2022-22108-6

Communications: SIF Congress 2021

The Cryogenic TArgets for DIrect Reactions (CTADIR) project

M. Sedlak(1), A. Gottardo(1), A. Goasduff(1), R. Pengo(1),
F. Crespi(2)(3), I. Lombardo(4) and I. Zanon(1)

(1) *INFN, Laboratori Nazionali di Legnaro - Legnaro, Italy*
(2) *INFN, Sezione di Milano - Milano, Italy*
(3) *Università degli Studi di Milano - Milano, Italy*
(4) *INFN, Sezione di Catania - Catania, Italy*

received 31 January 2022

Summary. — The study of nuclei far from stability increasingly relies on measurements performed at exotic beam facilities. Direct reactions with exotic beams are a powerful tool to probe the single-particle degree of freedom of nuclear systems far from stability. However, the low intensity of exotic beams requires thick light targets to achieve the necessary luminosity. We present the project CTADIR, which aims at building a cryogenic ^{3,4}He target to be employed at the SPES exotic beam facility at Laboratori Nazionali di Legnaro.

1. – Direct reactions with exotic beams

Direct transfer reactions are a unique tool to study the single-particle structure of atomic nuclei [1,2]. While nuclear shells are not observables, cross section angular distributions of one-nucleon transfer reactions provide the overlap between the initial and final states of the reaction. Since this depends on the single-particle content of the wave functions, shell-structure information can be deduced when comparing data to a theoretical model.

Examples of the direct reactions exploited in nuclear structure studies are (^{4}He,^{3}He) or (^{3}He,d), where one neutron or one proton is added to a nucleus. They allow one to probe the proton and neutron single-particle structure, and have been widely used in the past with He beams on stable targets.

The development of exotic beams offers the opportunity to extend these studies in neutron-rich nuclei, but this requires to operate in the so-called inverse kinematics, with a heavy exotic beam impinging on light targets, for example ^{3,4}He. The ISOL facility SPES at LNL can produce beams of exotic nuclei in the ^{132}Sn and ^{78}Ni regions at energies of 10–15 MeV/u, which are well matched with proton-adding (^{3}He,d) reaction Q-values in these neutron-rich regions. The typical reaction cross section can be of the order of several mbarn, which make measurements feasible with a beam intensity as low as 10^4 particle per second (pps), if the target has a scattering center density larger than

10^{20} at/cm^2. Also neutron-adding (^{4}He,^{3}He) reactions have favorable cross sections at the beam energies provided by the SPES facility: this will help to study neutron shells around the $N = 50$ and $N = 132$ shell-closure. Cross sections will also be of the order of few mbarn. Compared to the more used (d,p) neutron transfer reactions, the (^{4}He,^{3}He) reaction can populate both single-particle and core-coupled states, also favoring larger angular momenta. This is an advantage in the doubly-magic ^{132}Sn region, where high-j orbitals are present [3].

Finally, inelastic scattering of a neutron-rich beam on a ^{4}He target allows one to study the Pygmy Dipole Resonance isoscalar components. These are of paramount importance in understanding the low-energy electric dipole response in neutron-rich nuclei in relation to its origin from the oscillations of a neutron-rich "skin" against a more proton-neutron balanced core [4].

2. – The CTADIR project

The goal of the Cryogenic Targets for Direct Reactions (CTADIR) research project [5] is the construction of cryogenic targets for the study of direct nuclear reactions with the exotic beams produced by the upcoming SPES facility at LNL. The beams of exotic isotopes produced by SPES will be employed to induce the aforementioned transfer reactions with target nuclei or for inelastic scattering experiments. Only two He cryogenic targets had been constructed so far for use in nuclear physics at low energies ($\sim$10 MeV/u): the HeCTOr project [6] and the present one. The CTADIR project has three research units: INFN, the University of Padua and the University of Milan. The INFN-LNL in particular is in charge of developing a cryogenic target for ^{3,4}He, designed to be coupled with compact-geometry detector arrays such as AGATA or GRIT. In order to achieve He target thickness of 10^{20} at/cm^2 within a very limited space available when used with the detector arrays, the cryogenic target has to be kept at temperatures $<$10 K.

3. – The cryogenic target

The body of the cryogenic target is made out of aluminum (Al) alloy. Two special laser-welded transitions Al/Stainless steel (SS) were designed to be able to connect the SS capillary pipes for the gas supply to the gas cell of the target. The helium gas is confined within two 3.8 μm thick Havar windows with a diameter of 10 mm. The tightness between the helium gas and the vacuum is achieved by pressing each Havar window onto the indium seal housed in the "V" shape groove. The target is anchored to a copper cold finger attached to the second stage of the RDE-418D4 two-stage Gifford-McMahon cryocooler as shown in fig. 1. This cryocooler can operate at different orientations and positions, working with the same principle as the cryopumps: the thermodynamic cycles are obtained by a physical displacer that moves the helium gas back and forth. The cryocooler with a second-stage capacity of 1.8 W at 4 K is connected to a 7 kW water-cooled compressor unit.

A copper thermal shield (see fig. 1), attached to the first stage of the cryocooler, is present in order to reduce the radiation heat load from the detectors, which surround the target. The target casing was designed to allow for the detection of the reaction products in the total angle of 140° on both sides of the target. With such geometry we calculate that the heat load on the target is less than 2 W at 9–12 K, which is compatible with the cryocooler.

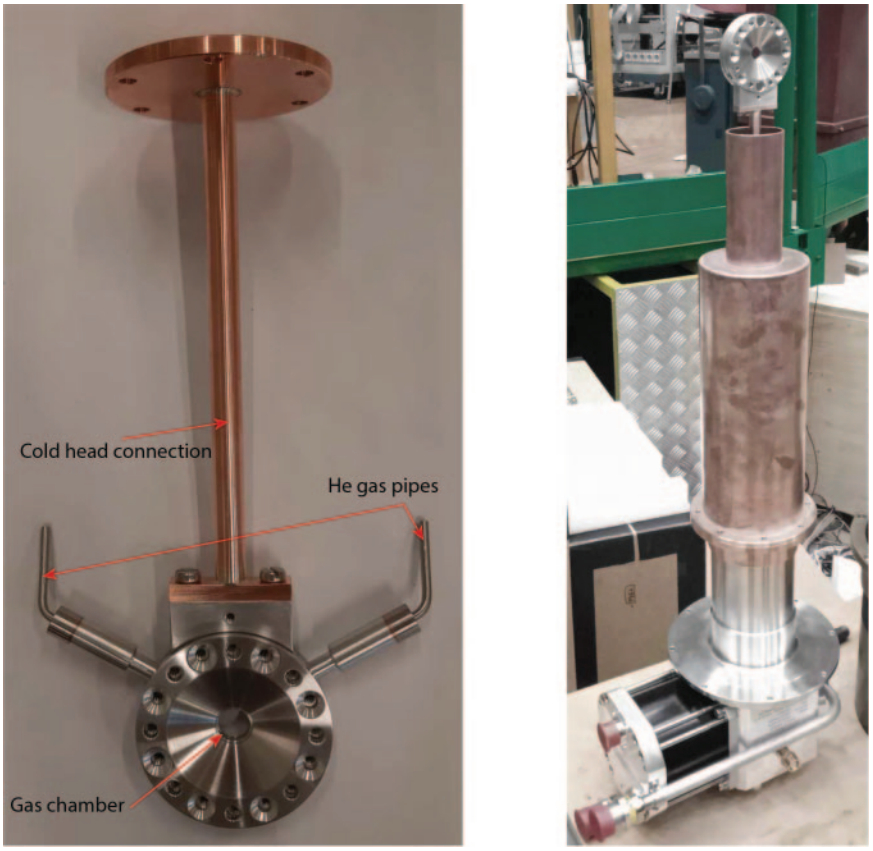

Fig. 1. – Photographs of the CTADIR cryogenic target assembly. Left: the CTADIR target detached from the cryocooler and without Havar windows. Right: the target casing is connected to the cryocooler with the thermal shield.

The temperature of the target will be regulated by a cryogenic temperature controller with a temperature sensor and a heater programmable for closed loop temperature control in proportional-integral-derivative (PID) mode. The homogeneity of the cooled target, from its center to the periphery, with He gas pressure of 1 bar and the temperature range 9 K to 10 K will be around 18%.

4. – Current status and future plans

All mechanical parts of the cryogenic target have been delivered. The assembly of the target without Havar windows is shown in fig. 1. The vacuum tightness test was performed together with gas and electrical feedthroughs and gas pipes connected to the vacuum chamber. The vacuum level of 10^{-7} mbar was achieved in the vacuum chamber with the target at room temperature. The test of the cooling system with and without pressurised He gas is scheduled to be performed in the upcoming weeks.

An experiment with the goal of commissioning and characterisation of the CTADIR cryogenic target was proposed to PAC at INFN-LNL. We proposed to study elastic scattering processes of protons and alpha particles on ^{4}He gas cooled to cryogenic temperatures (8–9 K). The silicon-detector arrays, GalTRACE [7], will be employed for

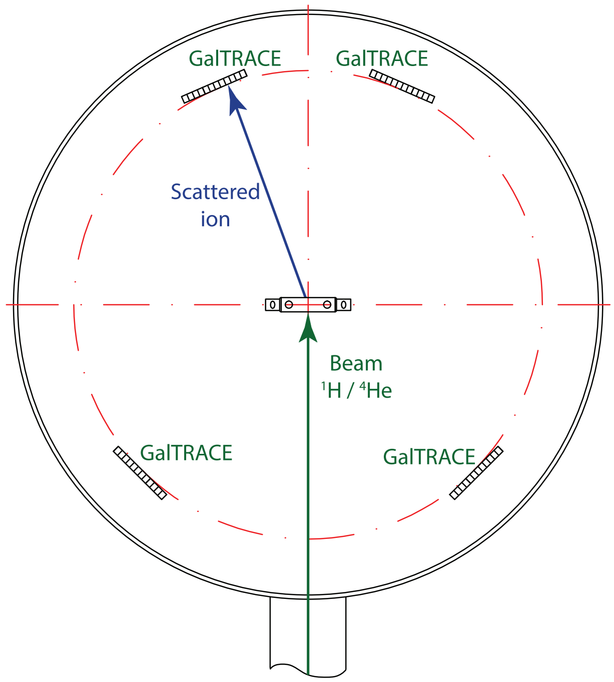

Fig. 2. – Schematic view of the proposed experiment for the cryogenic target commissioning. The arrangement of the target, TRACE detectors and incoming beam is shown.

particle detection and identification. Each detector has 12×5 segments with the size of $4 \times 4\,\text{mm}^2$. In the experiment, the proton beam, delivered by the CN accelerator, will be used to characterize the homogeneity of the target and ^{4}He beam for comparison of the measured and calculated values for scattered particles and the ice formation in time will be evaluated. The experimental set up is depicted in fig. 2. After successful commissioning, the target will be available to users for experiments with detector arrays such as AGATA or GRIT.

* * *

We acknowledge financial support from the Italian MUR PRIN 2017 call for funding, the CTADIR project-2017P8KMFT [8]. We also acknowledge the work of the technical office and mechanical workshop of LNL.

REFERENCES

[1] Kay B. P., Schiffer J. P. and Freeman S. J., *Phys. Rev. Lett.*, **111** (2013) 042502.
[2] Burgunder G. *et al.*, *Phys. Rev. Lett.*, **112** (2014) 042502.
[3] Bingham C. R. and Hillis D. L., *Phys. Rev. C*, **8** (1973) 729.
[4] Lanza E. G., Vitturi A., Litvinova E. and Savran D., *Phys. Rev. C*, **89** (2014) 041601(R).
[5] Goasduff A. *et al.*, *LNL Annu. Rep.*, **262** (2021) 41.
[6] Galtarossa F. *et al.*, *Nucl. Instrum. Methods A*, **1018** (2021) 165830.
[7] Zanon I. *et al.*, *LNL Annu. Rep.*, **259** (2020) 63.
[8] PRIN web portal, `https://prin.mur.gov.it/`.