Sub-barrier fusion of Si+Si system: does the deformation of ^{28}Si play a role?

Giulia Colucci, Department of Physics and Astronomy, Padova, Italy

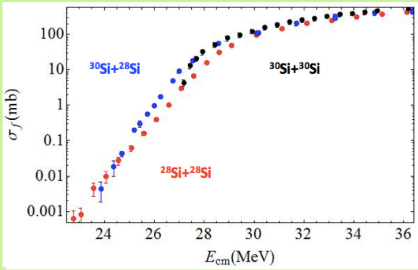
G. Montagnoli[1], A.M. Stefanini[2], D. Bourgin[3], P. Colovic[4], L. Corradi[2], M. Faggian[1], E. Fioretto[2], F. Galtarossa[2,5], F. Haas[3], M. Mazzocco[1], F. Scarlassara[1], C. Stefanini[1], E. Strano[1], M. Urbani[1], G.L. Zhang[1,6]

[1] Dip. di Fisica e Astronomia, Univ. di Padova, INFN, Sez. di Padova, I-35131 Padova, Italy; [2] INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro (Padova), Italy; [3] IPHC, CNRS-IN2P3, Universit́e de Strasbourg, F-67037 Strasbourg Cedex 2, France; [4] Ruder Bošković Institute, HR-10002 Zagreb, Croatia; [5] Dipartimento di Fisica e Scienze della Terra, Univ. di Ferrara, Ferrara, Italy; [6] School of Physics and Nucl. Energy Engineering, Beihang University, Beijing 100191, China

The aim

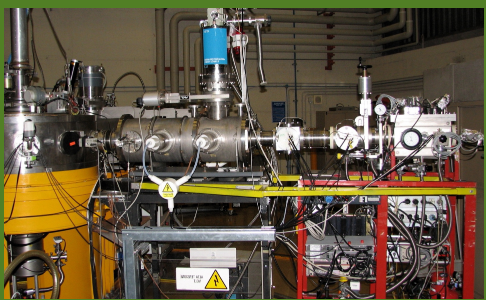
Fusion reactions are very important in the understanding of the nuclear structure of reacting nuclei. In particular, an important tool used in order to reveal this sensitivity is the comparison of data for neighboring isotopes.
A comparison between the isotopes of Si has not been possible in the past because of the lack of experimental data below 4 mb for the system ^{30}Si+^{30}Si.

The ^{30}Si beam has been provided by the XTU Tandem accelerator of the Laboratori Nazionali di Legnaro (LNL) of INFN, in the energy range 47-100 MeV.
The targets were 50 µg/cm³ evaporations of ^{30}Si onto 30 µg/cm³ carbon backings.

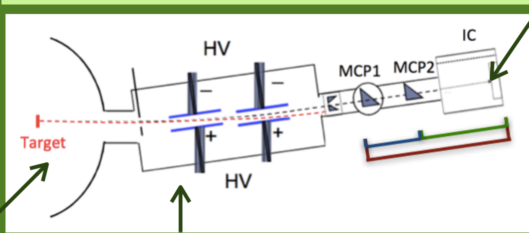


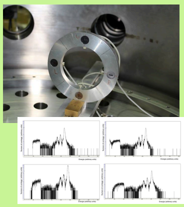
What makes so interesting the study of ^{30}Si+^{30}Si is the different shape of the ^{28}Si nucleus, which is deformed, with respect to the spherical ^{30}Si, and also the absence of positive Q-values for transfer channels. Indeed, these two properties allow to consider the only coupling of the vibrational states, neglecting the rotational ones which instead are strongly present in the deformed nucleus ^{28}Si.
This difference has a remarkable impact on the energy dependence of fusion cross sections at sub-barrier energies for the two symmetric systems.

The experimental set-up : PISOLO



The fusion-evaporation residues were detected by using a set-up at LNL which allows fast and reliable measurements of relative and absolute cross sections.





THE MONITORS

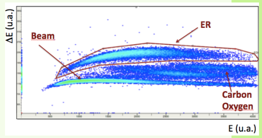
The reaction chamber is in sliding seal which allows to perform angular distributions . Four silicon detectors are placed symmetrically around the beam direction and used to monitor the beam and normalize to the Mott scattering cross section.

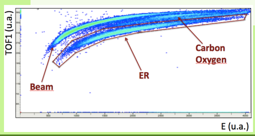
ELECTROSTATIC DEFLECTOR

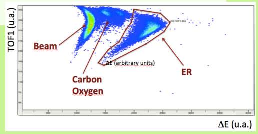
The electrostatic deflector assures the separation of residues from the transmitted beam and consists in two pairs of movable electrodes . Exploiting the different electrical rigidity of the residues and of the beam particles, it blocks the primary beam with a rejection factor around 10^{8}.

TELESCOPE TOF-E-ΔE

The E-TOF-ΔE telescope allows the detection of residues. It is made up of two microchannel plates detectors MCP, a transverse field ionization chamber, which measures the energy loss ΔE, and a silicon detector placed in the same gas volume of the chamber.
The silicon detector measures the residual energy of the evaporation residues and provides both the trigger for data acquisition and the start signal for the time of flight.
This configuration allows to consider three times of flight, which correspond to two different distances between the two MCP and the silicon detector, and to the distance between the two MCP.



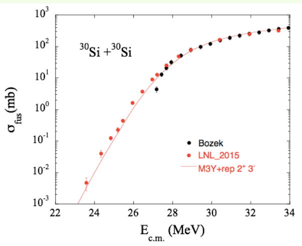




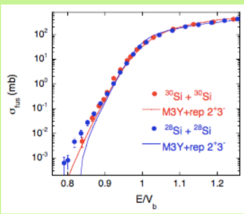
Results

EXCITATION FUNCTION

The experiment has allowed to extend the excitation function down to 3.5 mb.
A coupled-channel (CC) analysis of the sub-barrier excitation function has been performed, using the M3Y+repulsion potential. The coupling to the quadrupole 2^+ state of ^{30}Si at E_x = 2.235 MeV has been included, as well as the 3^- state at 5.488 MeV. The resulting excitation function seems to reproduce very well the trend of the experimental data. The statistical uncertainties are 1-2% at high energies and increase at sub-barrier energies to 10-20%. The systematic errors are estimated to be 7-8%, mainly due to the deflector transmission.

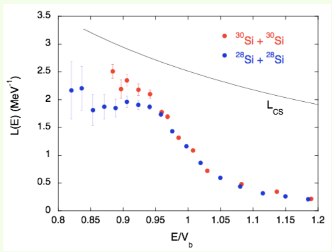


The comparison of the excitation function of the two symmetric system shows a different trend at energies below the coulomb barrier.



HINDRANCE

In order to investigate the presence of the fusion hindrance in the ^{30}Si+^{30}Si system, the logarithmic derivative L(E) has been calculated. L_{CS}(E) is the slope expected for a constant astrophysical S factor.
The L(E) obtained by previous fusion data of ^{28}Si+^{28}Si [1] is shown. No intersection between the L(E) and the curve L_{CS}(E) takes place, which confirms the absence of hindrance for the energy range measured in this experiment.

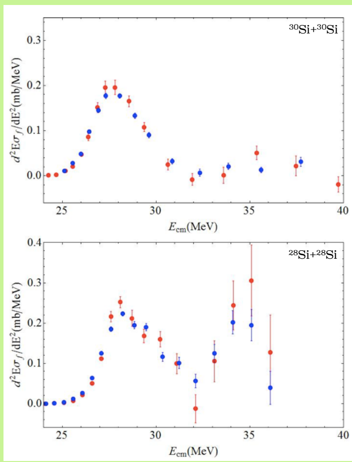


The comparison highlights a different behavior of the two systems. Indeed, the slope for ^{30}Si+^{30}Si increases steadily below the barrier whereas for ^{28}Si+^{28}Si it remains lower and more flat at the lowest measured energies.

These dissimilar behaviours might arise from the different structures of the two nuclei (^{28}Si has an oblate deformation while ^{30}Si is spherical). The comparison with detailed theoretical calculations is necessary to confirm this hypothesis.

BARRIER DISTRIBUTION

The barrier distribution have been obtained using the three-point difference formula, with two different energy steps of 1.0 MeV and 1.5 MeV.
In both cases a double peak structure shows up but only for the ^{28}Si+^{28}Si system the high-energy peak is stronger and closer to the low-energy one.



[1] G. Montagnoli et al., Phys. Rev. C 90 (2014) 044608.