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A supersonic jet target for the cross section measurement of the $^{12}C(\alpha,\gamma)^{16}O$ reaction with the recoil mass separator ERNA

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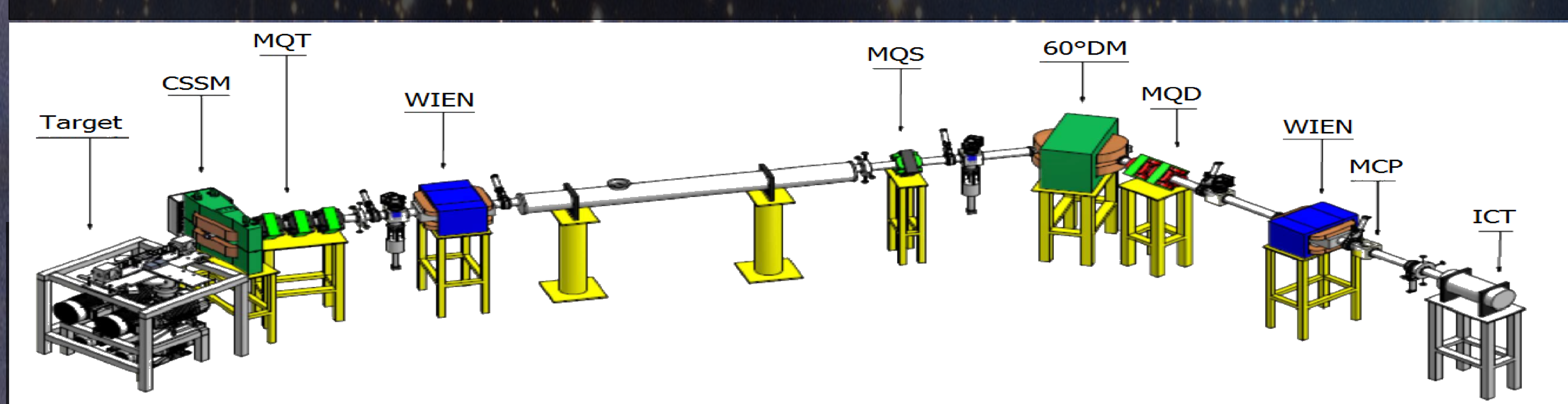
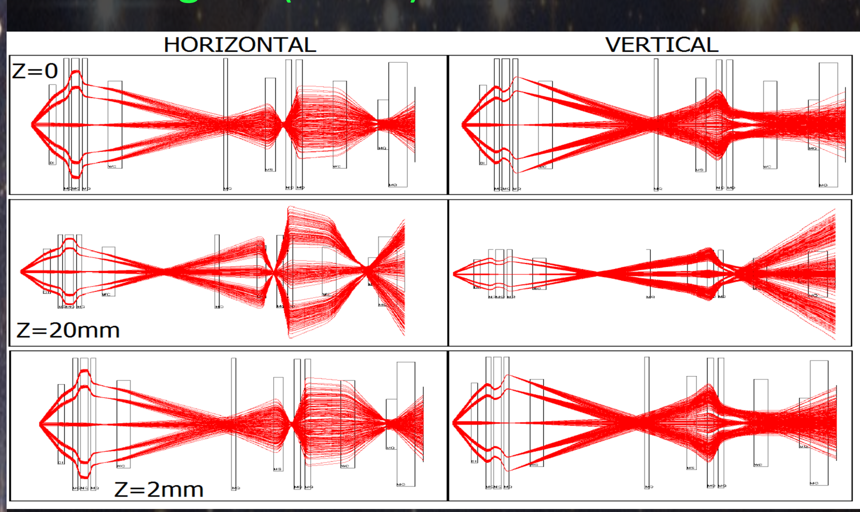
Abstract

$^{12}C(\alpha,\gamma)^{16}O$ plays a key-role in the determination of the C/O ratio at the end of stellar Carbon burning. Since stellar models predict an exceptional sensitivity of the following stellar evolution and nucleosynthesis on that parameter, the reaction cross section of $^{12}C(\alpha,\gamma)^{16}O$ must be determined with the precision of about 10% at the relevant Gamow E_0 = 300 keV. The ERNA (European Recoil mass separator for Nuclear Astrophysics) collaboration could measure, for the first time, the total cross section of $^{12}C(\alpha,\gamma)^{16}O$ by means of the direct detection of the ^{16}O ions produced in the reaction down to a an energy E_{cm} = 1.9 MeV. To extend the measurement at lower energy, it is necessary to limit the extension of the He gas target. This can be achieved using a supersonic jet, where the oblique shock waves and expansion fans formed at its boundaries confine the gas, that can be efficiently collected using a catcher. A test version of such system has been realized and experimentally characterized as a bench mark for a full numerical simulations using FV (Finite Volume) method.

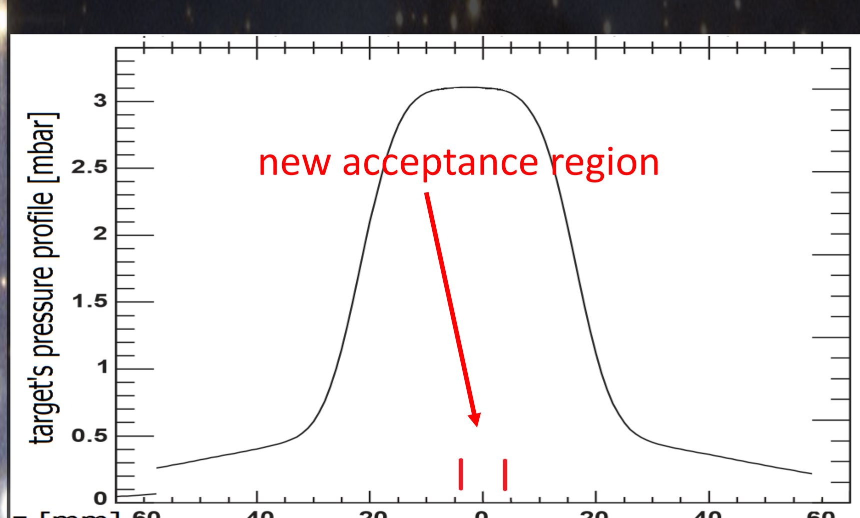
1. Introduction



The European Recoil Separator for Nuclear Astrophysics (ERNA) already measured the $^{12}C(\alpha,\gamma)^{16}O$ reaction cross section with a precision of 10% in the energy range [1.9;4.9] MeV. It's extrapolation at the Gamow energy E_0=300 keV suffers of ambiguity that a new campaign of measurements at lower energy can dispel. To be performed, ERNA need a new magnet (CSSM).

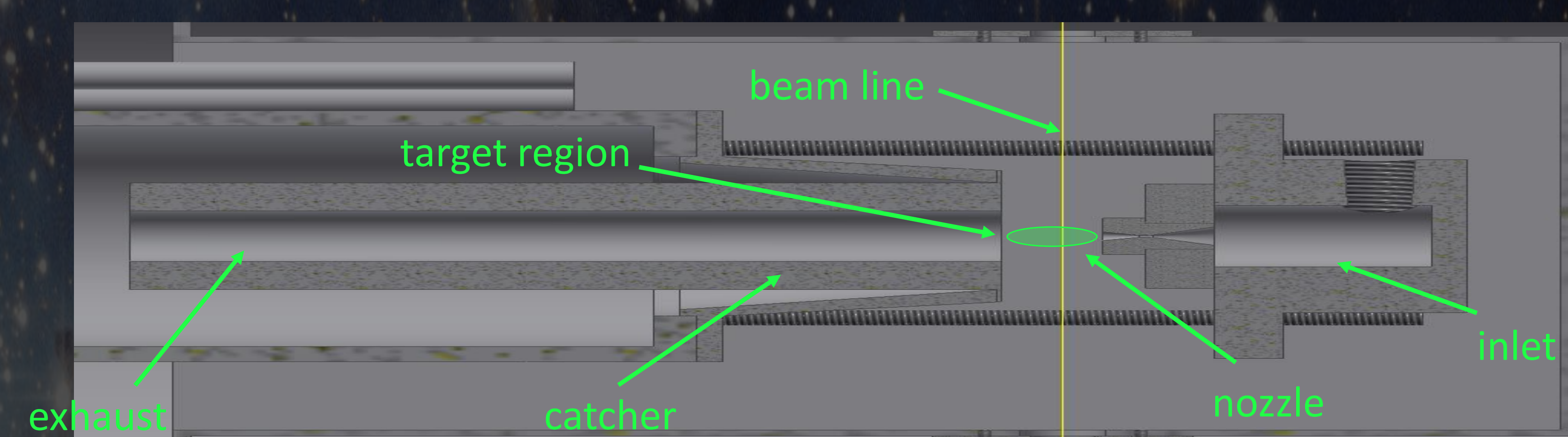


Simulations on the reaction products optic (COSY) has been performed tuning properly virtual elements of ERNA (up). The full acceptance region overlaps no more with the target itself (middle). Only the ^{16}O ions at a distance of max 2 mm from the target centre can be collected (down). A shorter target have to replace the present windowless gas target.



ERNA present target is about 40 mm long. Its reduction can be possible only lowering the He inlet pressure. This in turn could reduces dramatically target's thickness that is not desirable since the expected low reaction cross section (few pbarn). A supersonic jet gas target can solve the problem with its high density (~10^{18}atoms/cm^2) and high confinement (few mm).

2. A supersonic jet target



Using the setup shown above a supersonic jet can be formed. Injecting gas by the inlet it expands through the DeLaval nozzle and it's collected by the catcher that drive it into the vacuum system. Gas flow is controlled by the means of a flow controller. The target region is the one in which the gas expands and is aligned with the beam line.

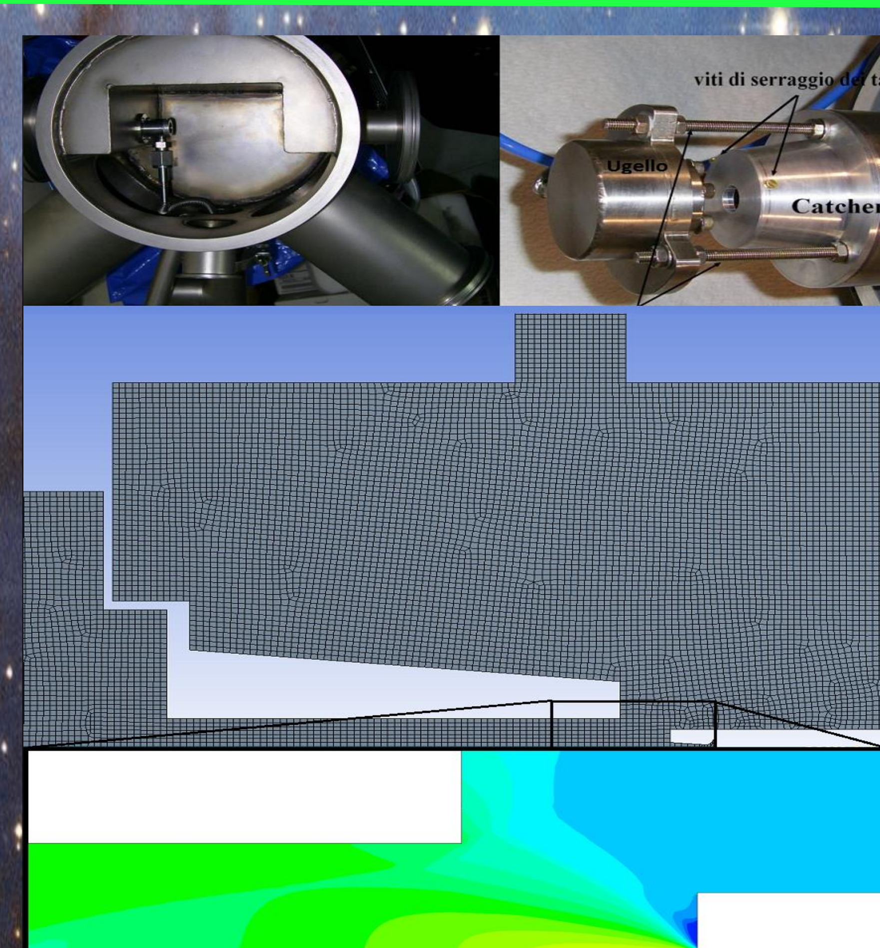
3. Target characterization

In order to characterize the target, a measure of its thickness by the mean of energy loss and ERDA was performed. In the first the energy loss of a 6 MeV C^{3+} beam through the target was measured and the profile reconstructed through an energy loss analysis. In the second the target's α-particle Rutherford scattered was acquired at 75.3°. Two main configuration have been used in both methods:

- Position dependent: a thin portion of the beam was selected by 1 mm in diameter collimator. In this way different points of the target was intercepted and analysed;
- Pressure dependent: several inlet jet pressure was used.

The two configurations was used both separately and mixed to have a more complete overview of the jet.

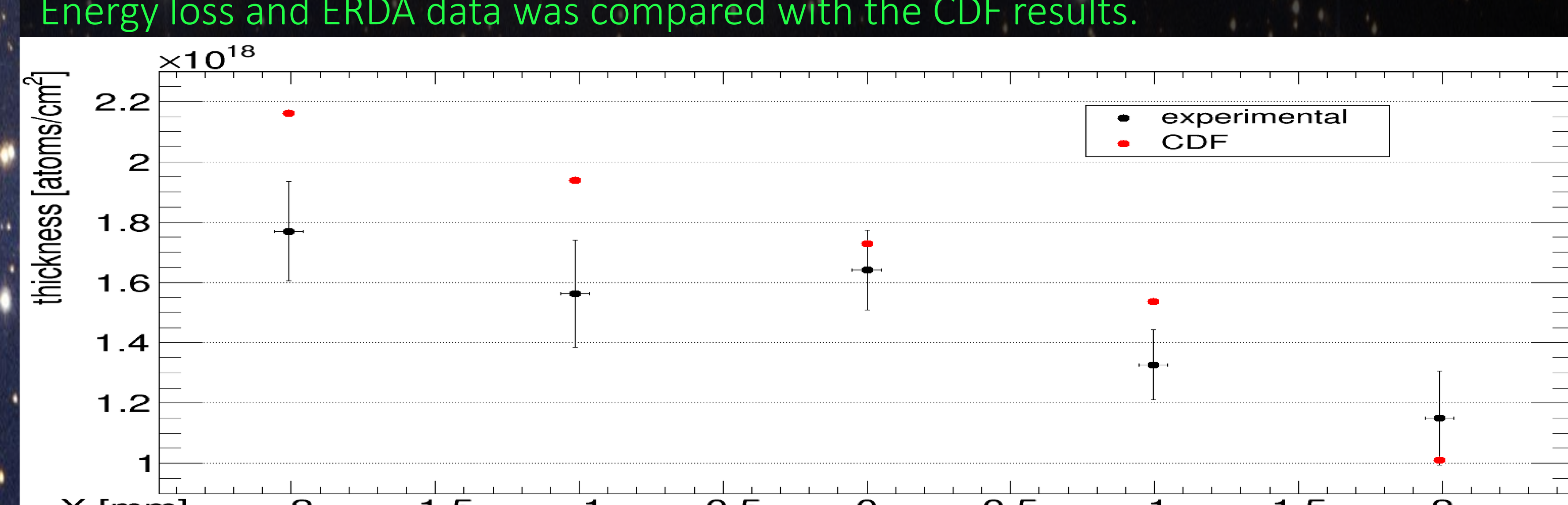
4. Computational Fluid Dynamic (CFD)



Since the complexity of the problem, an analysis tool was developed basing on Finite Volume commercial software ANSYS Fluent. In this environment, the setup (above) was reduced with a 2D axial symmetric approximation and a mesh in which evaluate the problem was set up (middle). The balance equation for energy, mass and entropy was evaluated with a κ-ε turbulence method (below). A 3D was reconstructed from the resulting density field and finally the target thickness evaluated.

5. Comparison

Energy loss and ERDA data was compared with the CDF results.



Their agreement allowed us to use the CDF to develop a thicker and smaller target.

6. Outlooks

The test jet is too broad and the setup is not able to collect all of its gas, even if several arrangements was attempted. This limitations has been overcome by the design of a confinement cell which should grant the optimal pressure for jet expansion and a post stripper gas for the collection of the ^{16}O in ERNA.