Development of a tracking detector to study the $^{12}C(\alpha,\gamma)^{16}O$ reaction

†J. G. Duarte[1,2], A. Di Leva[2,3], L. Gialanella[1,2], M. Romoli[2,3], R. Buompane[1,2], A. D'Onofrio[1,2], L. R. Gasques[1,2], G. Imbriani[1,2], E. L. Morales-Gallegos[1,5], G. Porzio[1,2], D. Rapagnani[6,7], F. Terrasi[1,2], A. Anastasio[2], A. Boiano[2]

[1]Dipartimento di Matematica e Fisica, Seconda Università degli Studi di Napoli, Caserta, Italia; [2]INFN, Sezione di Napoli, Napoli, Italia; [3]Dipartimento di Fisica, Università degli Studi di Napoli Federico II, Napoli, Italia; [4]Department of Nuclear Physics, University of Sao Paulo, Sao Paulo, Brazil; [5]SUPA, School of Physics and Astronomy, University of Edinburgh, Edinburgh, UK; [6]Dipartimento di Fisica e Geologia, Università degli Studi di Perugia, Perugia, Italia; [7]INFN, Sezione di Perugia, Perugia, Italia

ABSTRACT

Stellar model calculations are extremely sensitive to the rate of $^{12}C(\alpha,\gamma)^{16}O$. Although great efforts were devoted to decrease the uncertainty in the extrapolations, more precise data are needed to provide a good input to the stellar models. The required precision for the rate of $^{12}C(\alpha,\gamma)^{16}O$ is about 10% [Woosley, 2003]. The available data indicate that the cross section of $^{12}C(\alpha,\gamma)^{16}O$ at E_0 = 300 keV is dominated by E1 and E2 radiative capture processes into the ^{16}O ground state, where the main contribution to the capture cross section is given by two subthreshold states with J^π = 1− and 2+ at E_{level} = 7.12 and 6.92 MeV, respectively. Since the measurement of Dyer and Barnes in 1974 [Dyer, 1974], the E1 and E2 contributions have been determined by measuring the γ-rays from the ^{16}O-recoils. Some of the experiments conducted to date performed coincidence between γ-rays and ^{16}O-recoils to reduce background. In one case [Schurmann, 2005] it was possible to measure the total cross section by the detection of recoils using the RMS (Recoil Mass Separator) ERNA (European Recoil mass separator for Nuclear Astrophysics). In the case of a RMS, an additional constrain to the γ-ray data can be the measurement of the angular distribution of the recoils. Monte Carlo simulations together with the simulation of the beam transport through ERNA have shown that it could be possible to determine the E1 and E2 contributions by the analyses of the angular distribution of the recoils at the end of the RMS. In order to achieve that, a two stage tracking detector is being developed at CIRCE (Center for Isotopic Research on the Cultural and Environmental heritage), Caserta, where ERNA was moved in 2009. The first stage is a modification of the existing MCP detector [Di Leva, 2008], that will be made position sensitive. The second stage is a parallel grid position sensitive detector that will be placed inside of the existing Ionization Chamber Telescope [Rogalla, 1999]. The detector development will be described and the expected physics outcome presented.

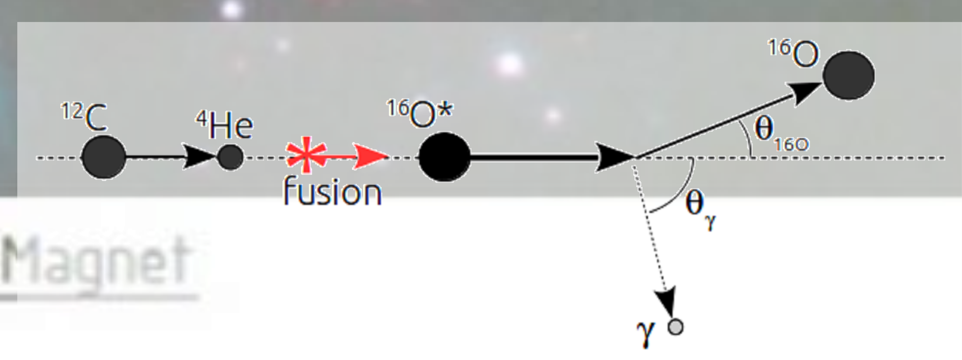
γ-ray angular distribution

From [Dyer, 1974], [Gialanella, 2001] and [Assunçao, 2006], and considering Q_k=1 for simplicity, one can derive the following relations:

$$W_{E1}(\theta_\gamma) = \tfrac{9}{2} sin^2(\theta_\gamma)|A_1|^2 \,;\, W_{E2}(\theta_\gamma) = \frac{315\sigma_{E2}}{14\sigma_{E1}} sin^2(\theta_\gamma)cos^2(\theta_\gamma)|A_1|^2 \,;\, W_{E1E2}(\theta_\gamma) = 45\sqrt{\frac{\sigma_{E2}}{5\sigma_{E1}}}cos\phi_{12} sin^2(\theta_\gamma)\cos(\theta_\gamma)|A_1|^2 \,;\, W(\theta_\gamma) = W'(\theta_\gamma)|A_1|^2$$

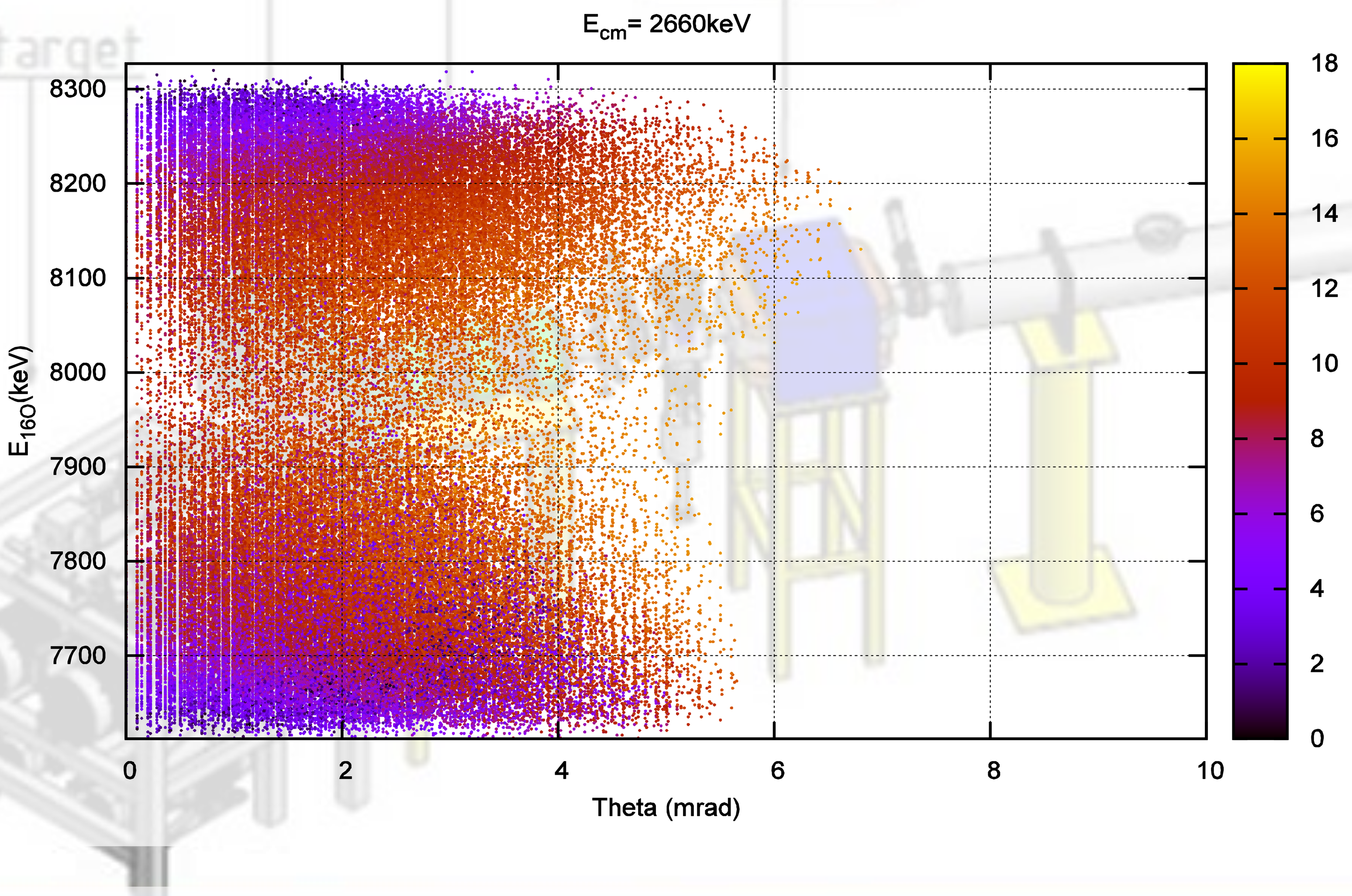
Angular and energy distributions of recoils

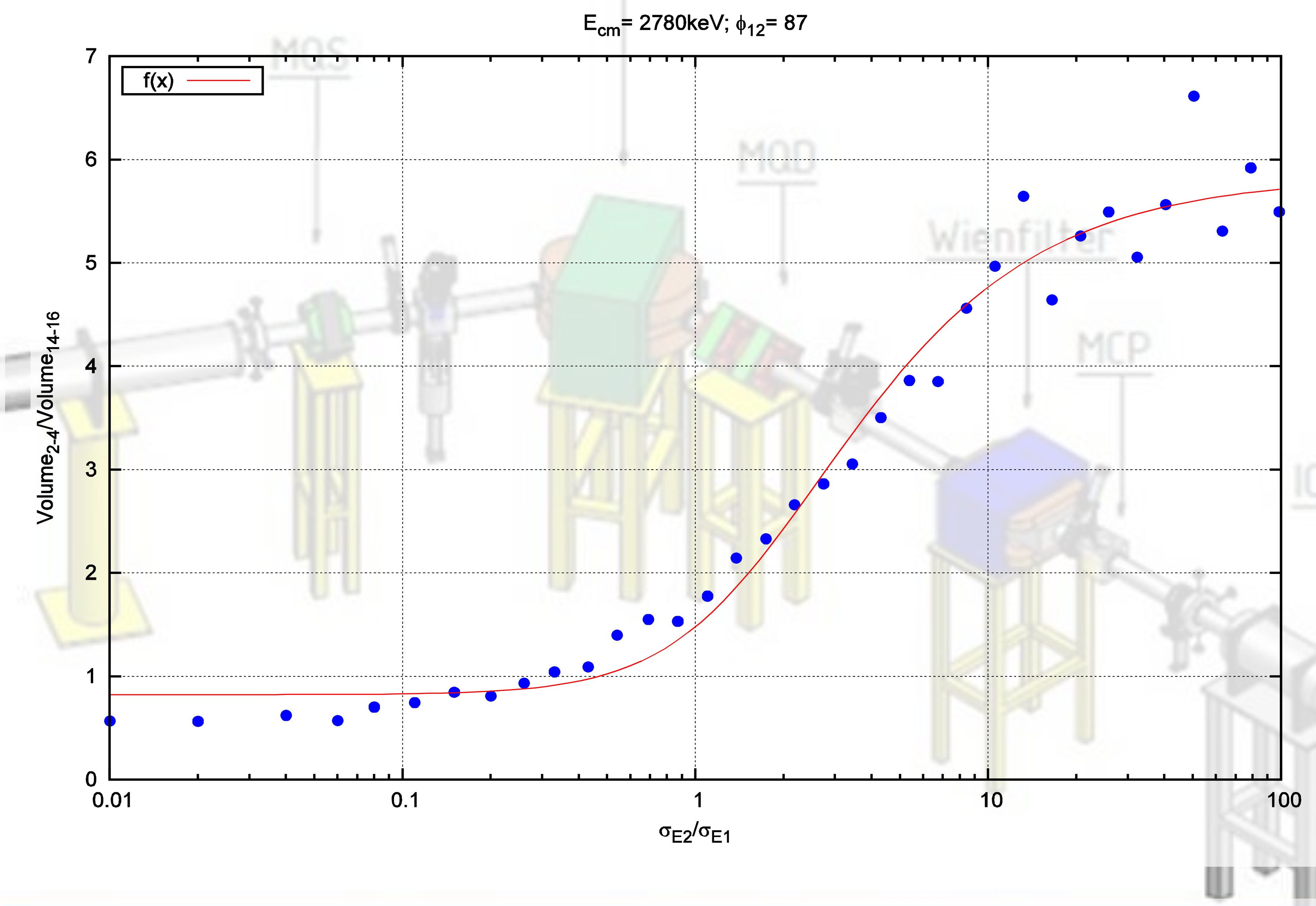
$$\theta_{16O} = arctan\left(\frac{E_\gamma \sin(\theta_\gamma)}{\sqrt{2c^2E^{12C}_{lab}m_{12C}} - E_\gamma\cos(\theta_\gamma)}\right);\quad E_\gamma = E^*_{16O}\left(\frac{1}{1-\sqrt{\frac{2m_{12C}E^{12C}_{lab}}{(m_{16O}c)^2}}\cos(\theta_\gamma)}\right);\quad E^{16O}_K = \frac{\left(\sqrt{2c^2E^{12C}_{lab}m_{12C}} - E_\gamma\cos(\theta_\gamma)\right)^2}{2c^2m_{16O}cos^2(\theta_{16O})}$$



Monte Carlo simulations

We obtained the recoils distribution from random γ-rays , and performed beam transport calculations with COSY Infinity:

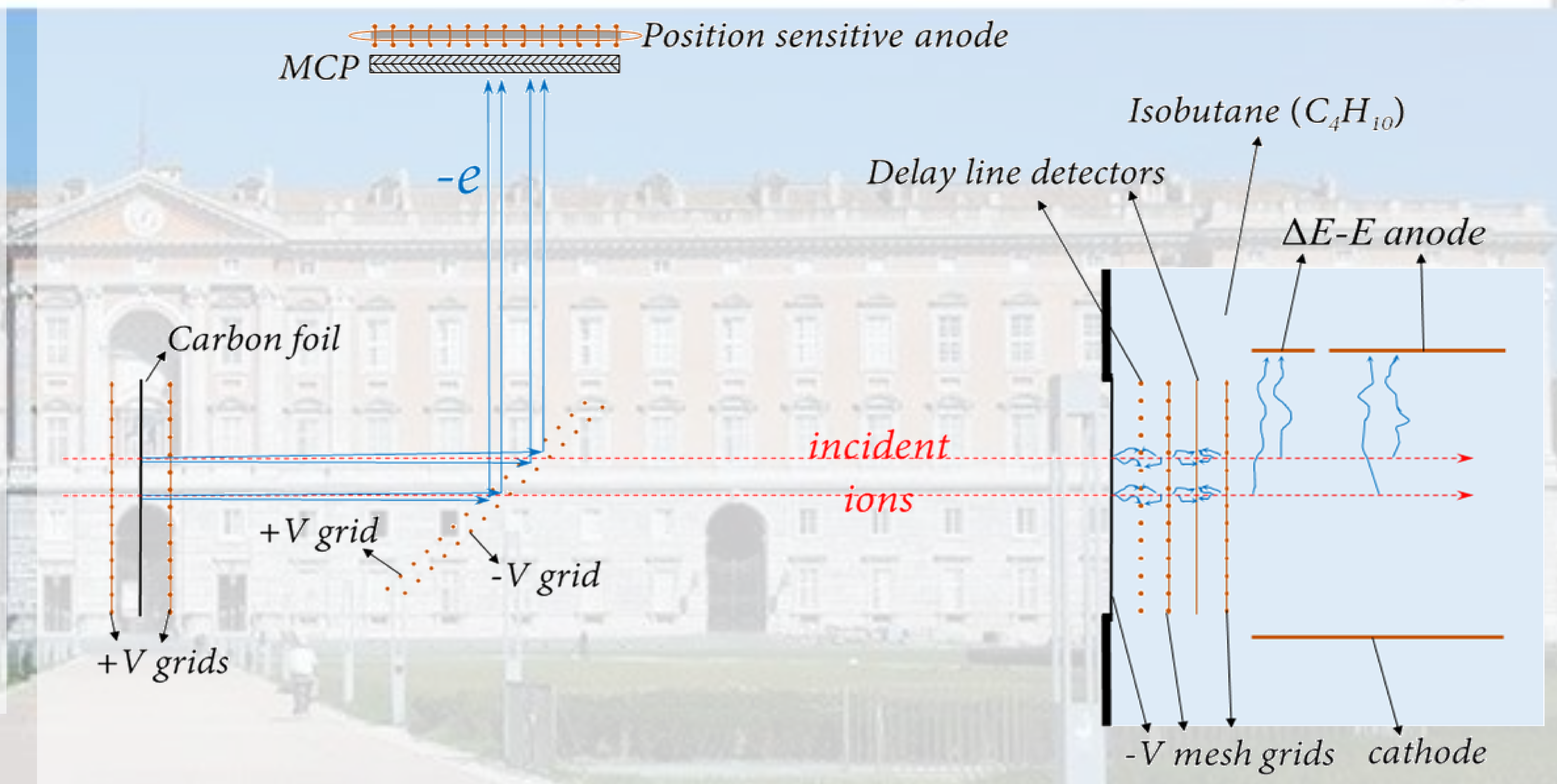




TRACKING DETECTOR

Step1) Replicate the mirror-MCP(pos. sen.) configuration;
Step2) Develop the parallel grid detectors;
Step3) Obtain two 2D spatial distributions along the central axis at the end of the ERNA line;
Step4) Calculate the final angular distribution of the recoils;
Step5) Retrieve the initial angular distribution of the recoils through a beam transport calculation;
Step6) Add an additional constrain to the γ-ray data;

Expected features: *Angular resolution* < 0.2 mrad
Time resolution < 0.1 ns



† Presenter's email: jeremias.duarte@na.infn.it

[Gialanella, 2001] The European Physical Journal A, 11:357-370; [Assunçao, 2006] Physical Review C, 73:055801.

[Woosley, 2003] Nuclear Physics A, 718:3c–12c; [Dyer, 1974] Nuclear Physics A, 233:495–520; [Schurmann, 2005] Eur. Phys. J. A, 26:301–305; [Di Leva, 2008] NIM A, 595:381–390; [Rogalla, 1999] NIM A, 437:266–273.