The ERNA experiment: recent achievements and perspectives

- **Raffaele Buompane**

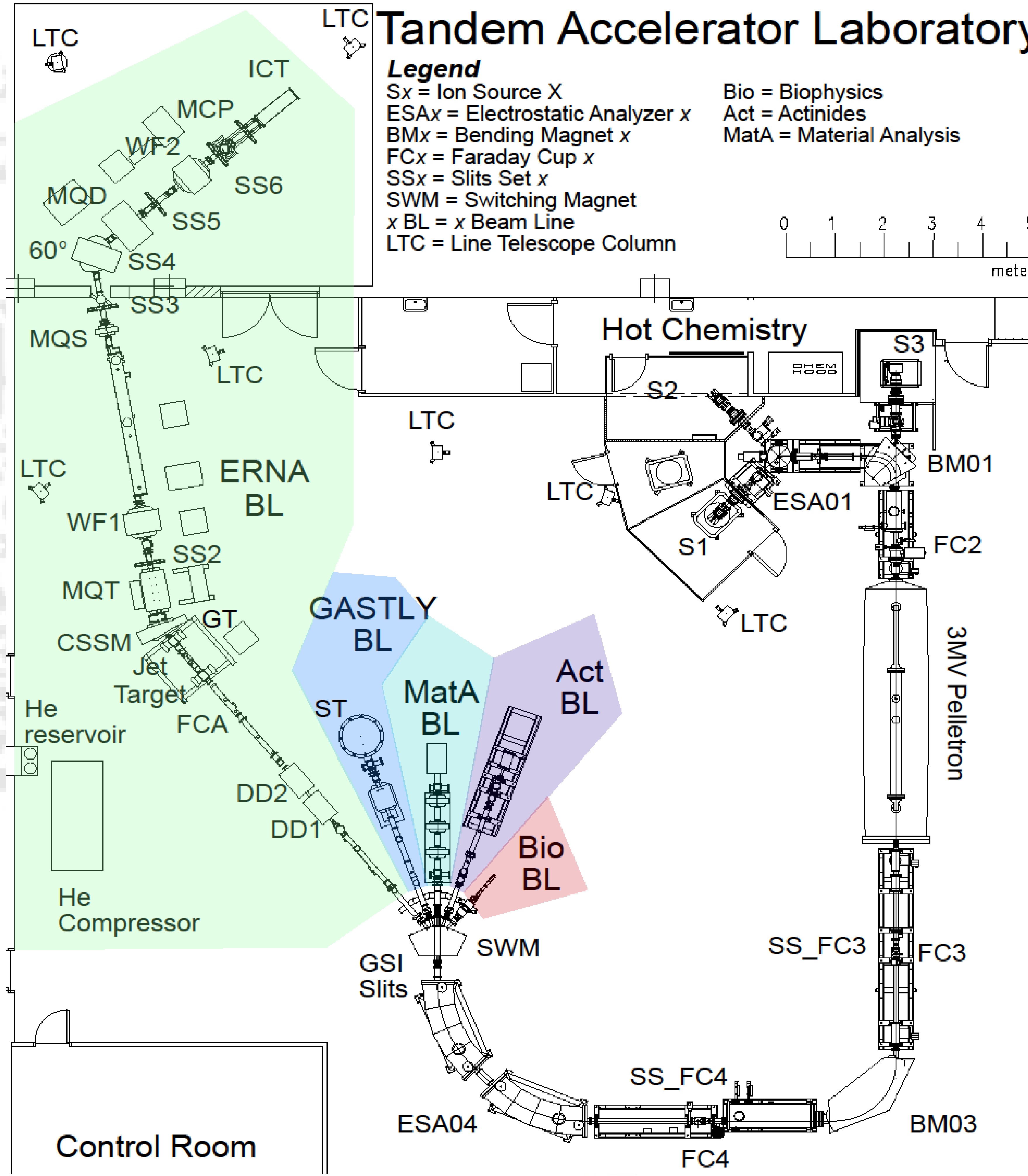
- Università degli Studi della Campania “Luigi Vanvitelli” and INFN Naples

Lepton Interactions with Nucleons and Nuclei - Marciana 2023

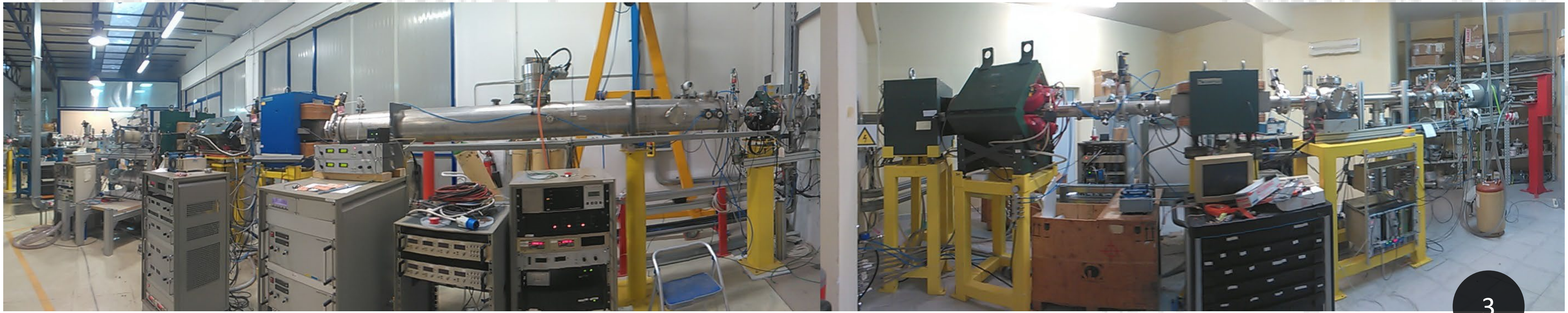
ERNA@CIRCE

ERNA RMS was developed at the 4MV Dynamitron Tandem Laboratorium of the Ruhr-Universität Bochum (Germany). Measurements of $^{3}He(\alpha, \gamma)^{7}Be$ successfully performed $^{12}C(\alpha, \gamma)^{16}O$ at Bochum.

In 2009, ERNA was moved to the Tandem Accelerator Laboratory of the CIRCE (Center for Isotopic Research on Cultural and Environmental heritage), at University of Campania.



ERNA@CIRCE



GASTLY - GAs-Silicon Two-Layer sYstem

Eur. Phys. J. A (2018) 54: 142

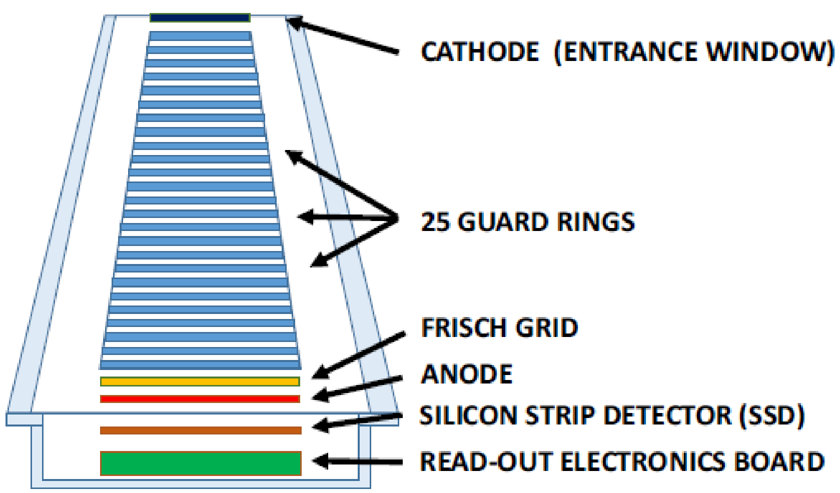
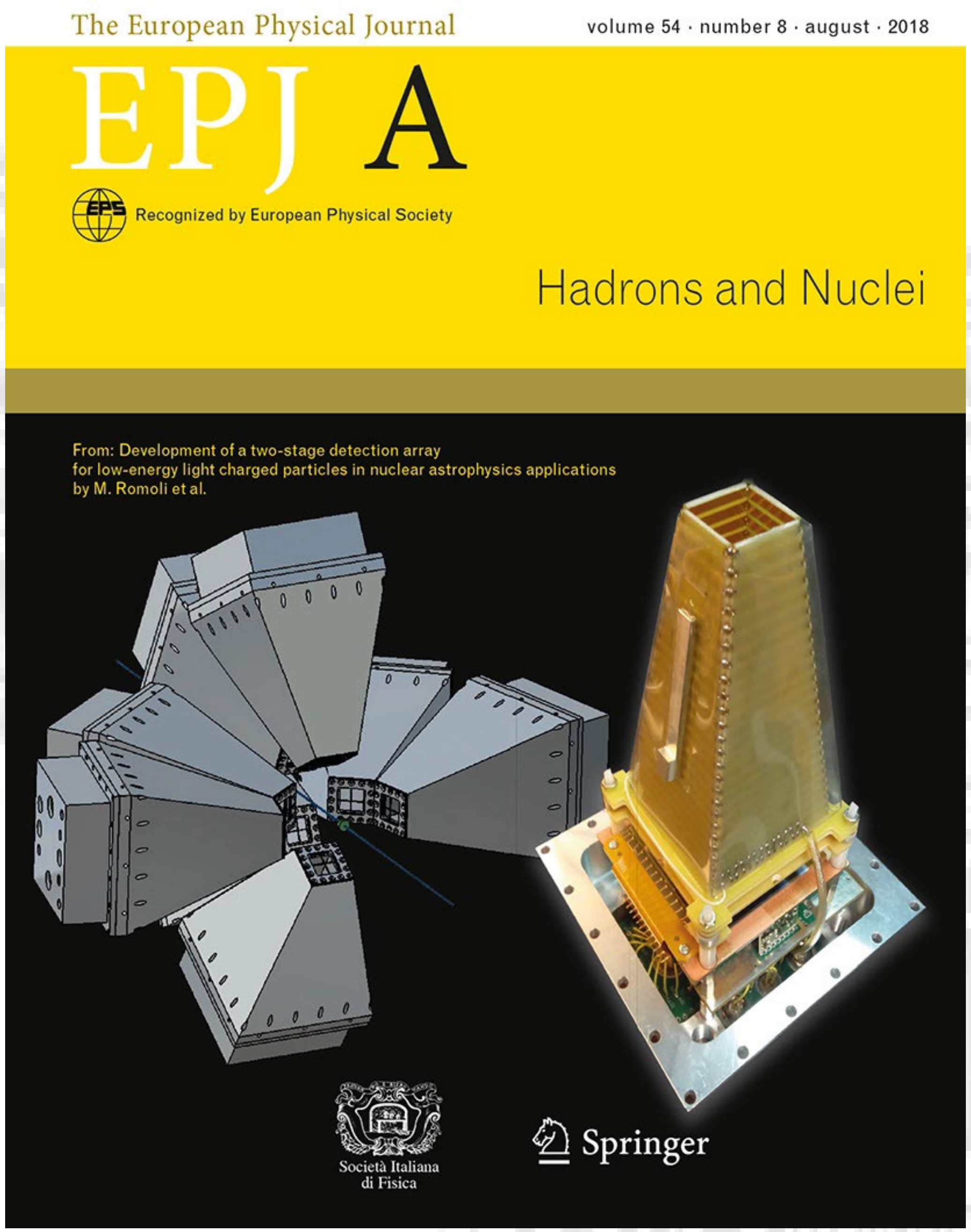


Fig. 2. Schematic cross-sectional view of a GASTLY module. Key components of the ionisation chamber are indicated. Both the ionisation chamber and the silicon strip detector are contained within an aluminium housing shaped as a truncated pyramidal structure with square section.



Devoted to study reaction with charged particle in the exit channel.
Good angular resolution ($\Delta\theta = 1.0° - 1.5°$) thanks the 16 Strips Silicon Detector used as residual energy detector.

GASTLY - GAs-Silicon Two-Layer sYstem

- Advanced burnings
  - $^{12}C(^{12}C,p)^{23}Na$ and $^{12}C(^{12}C,\alpha)^{20}Ne$
  - $^{12}C(^{16}O,p)^{27}Al$ and $^{12}C(^{16}O,\alpha)^{24}Mg$

Eur. Phys. J. A (2018) **54**: 132

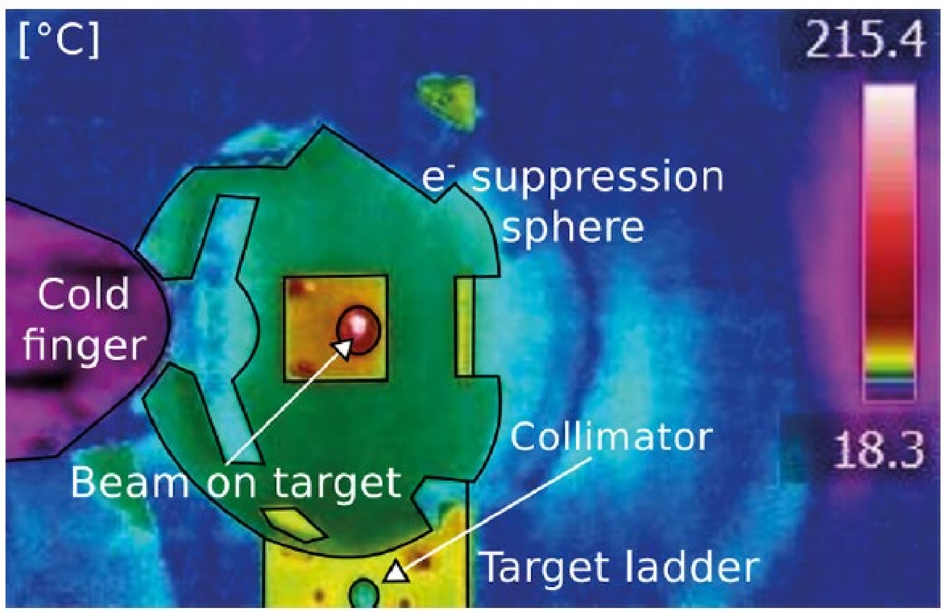


Fig. 1. Tone coded image of the HOPG target taken with the thermo-camera under beam bombardment with a $^{12}C^{3+}$ beam at laboratory energy $E = 8$ MeV. Contour lines have been added for clarity. Note that the temperature scale shown on the right side is only correct for carbon due to the emissivity value setted on the camera.

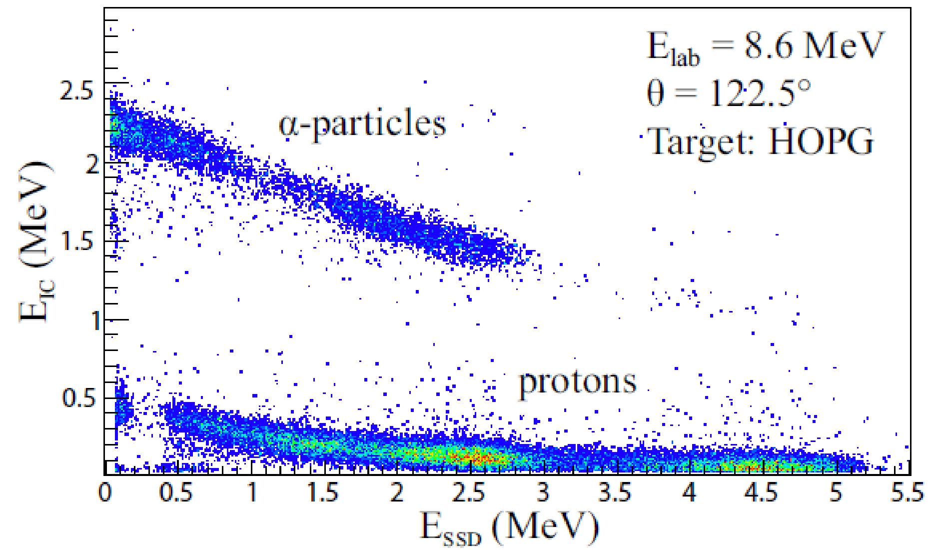


Fig. 9. E_{IC} *vs.* E_{SSD} matrix for the $^{12}C + ^{12}C$ fusion reaction. Distinct loci corresponding to protons and α-particles from the $^{12}C(^{12}C,p)^{23}Na$ and $^{12}C(^{12}C,\alpha)^{20}Ne$ reactions, respectively, can be clearly identified.

Eur. Phys. J. A (2018) **54**: 142

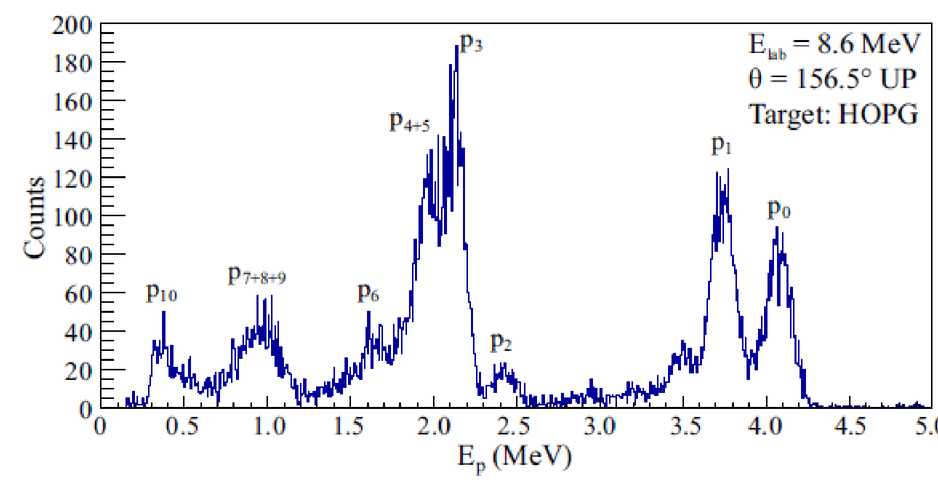
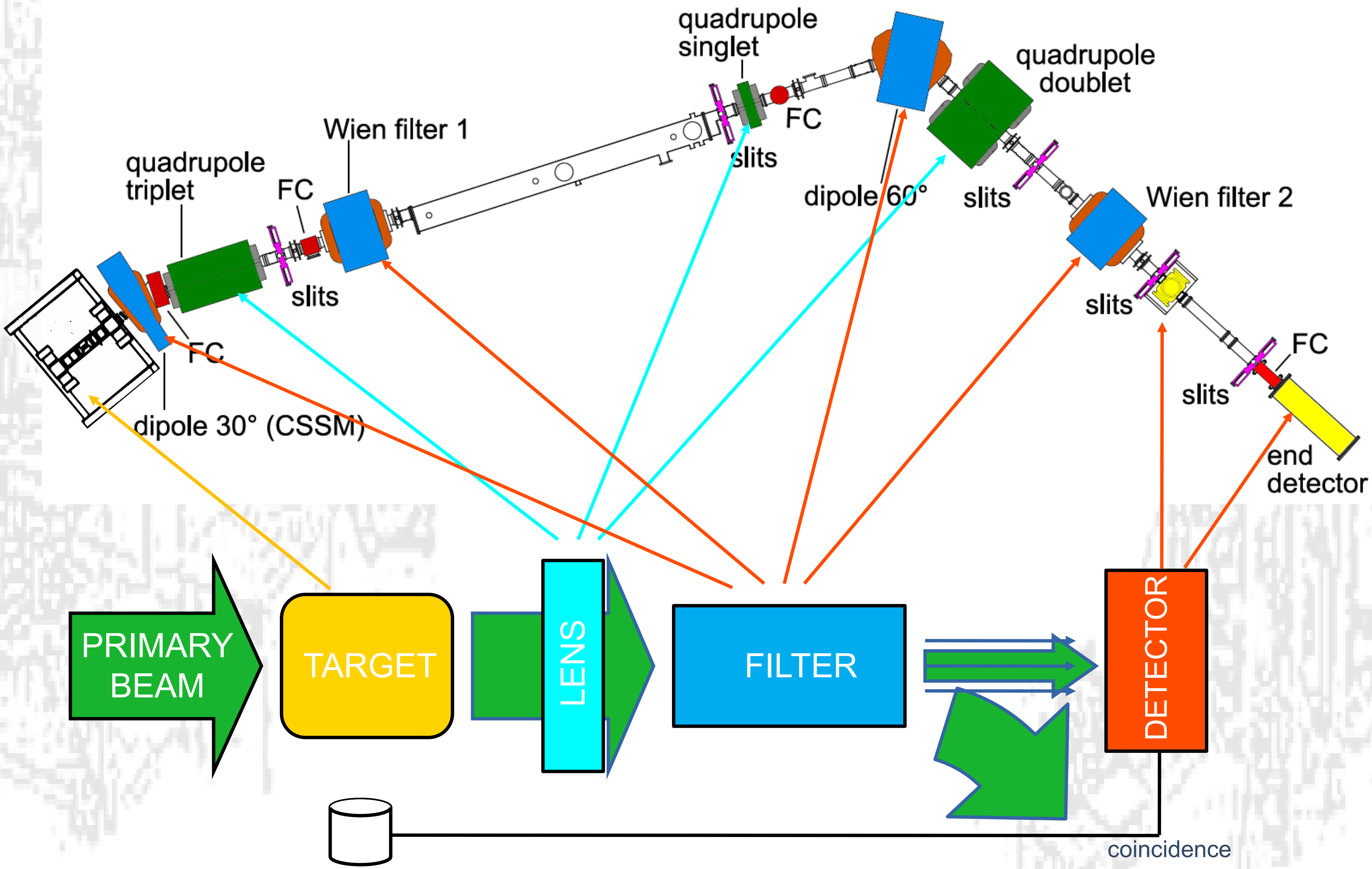
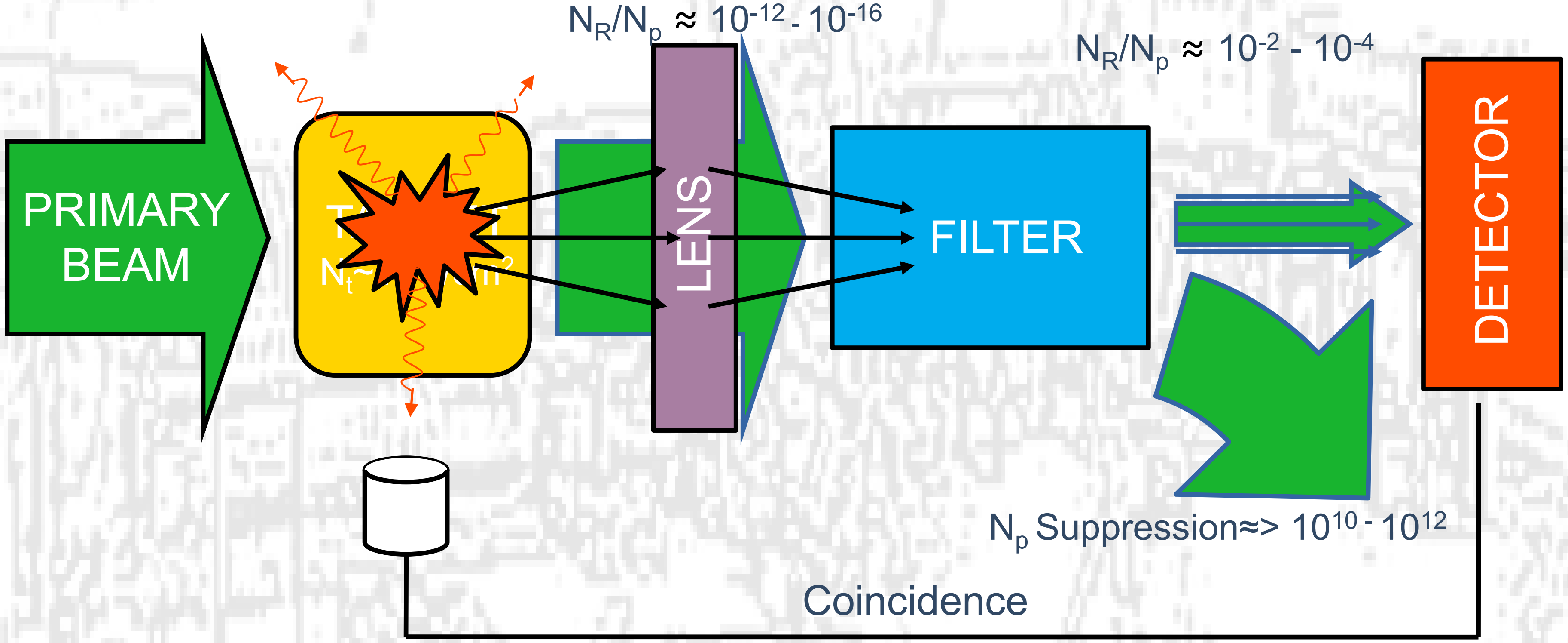


Fig. 10. Proton energy spectrum from the $^{12}C + ^{12}C$ fusion reaction, obtained as x-projection of the proton locus in the E_{IC} *vs.* E_{SSD} matrix.

ERNA - European Recoil for Nuclear Astrophysics

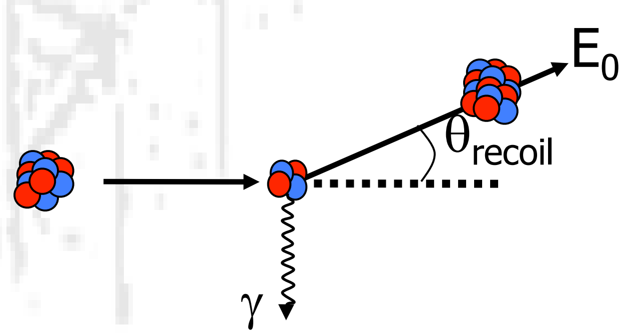


Separators principle



$\theta_\gamma = 90°$

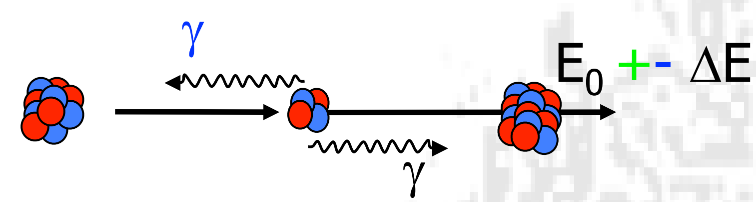
Full angular broadening



$$\theta_{recoil} \approx \arctan(\Delta p/p) = \arctan\left(\frac{E\gamma/C}{p_{recoil}}\right)$$

$\theta_\gamma = 0° / 180°$

Full energy broadening



$$\Delta E/E_0 \approx 2\,\Delta p/p = 2\,\frac{E\gamma/C}{p_{recoil}}$$

Cross section determination

RMS

Final Detector

Cross Section

$$N_\mathrm{r} = N_\mathrm{b} \cdot T_\mathrm{RMS} \cdot \Phi_{q_\mathrm{r}} \cdot \epsilon \cdot \int_{E_\mathrm{b} - \Delta E_\mathrm{b}}^{E_\mathrm{b}} \sigma(E) \cdot \frac{1}{\mathrm{d}E / \mathrm{d}N_\mathrm{t}} \mathrm{d}E$$

Beam

Charge State

Energy Loss

Target

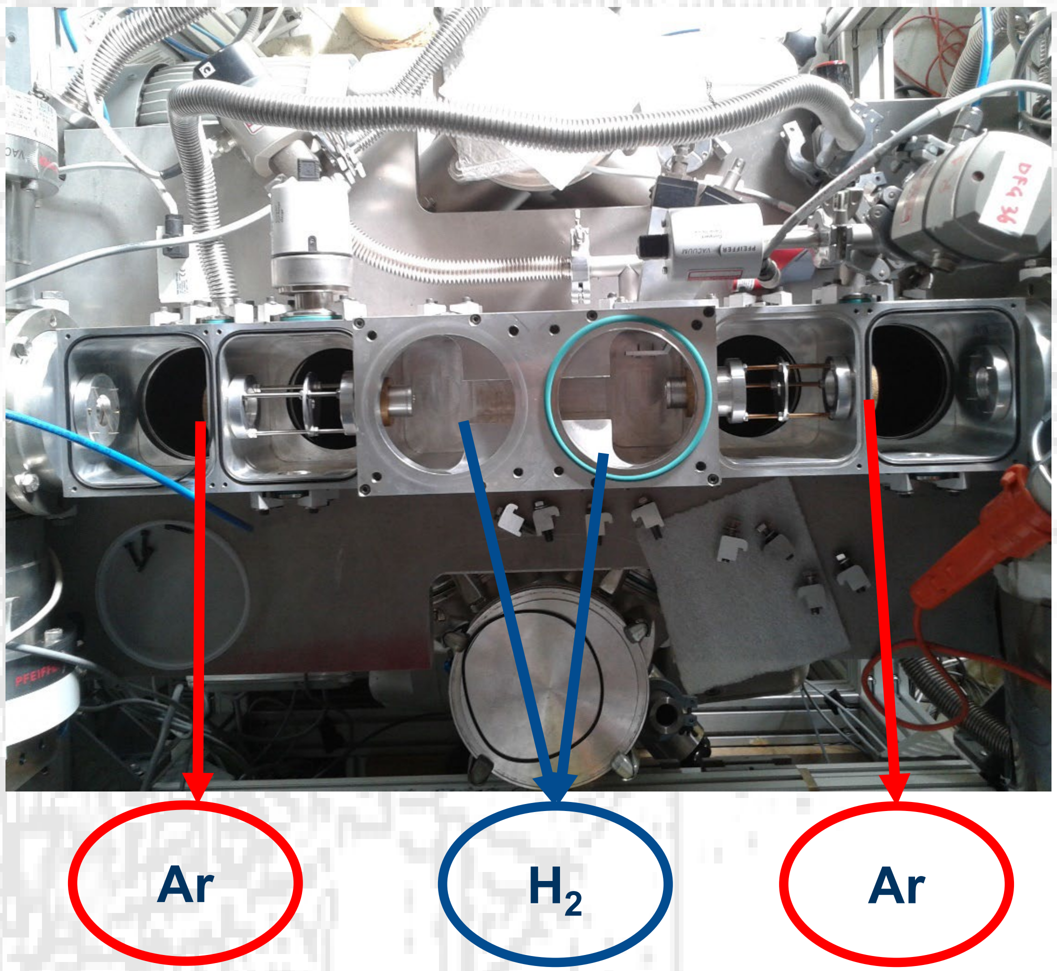
Typical uncertainty budget

Counting statistics	2-10%
Number of projectiles	1%
Transmission	1%
Charge state probability	2%
Target thickness	5%
Detection efficiency	0.5-2%

Recent achievements

Extended gas target

^{1}H configuration



Target density n = 7.22 ± 0.15 · 10^{18} at/cm^2 at 4.9 mbar
Target effective length 29.8 cm

D. Schürmann et al., Eur. Phys. J. A (2013) **49**: 80

^{4}He configuration

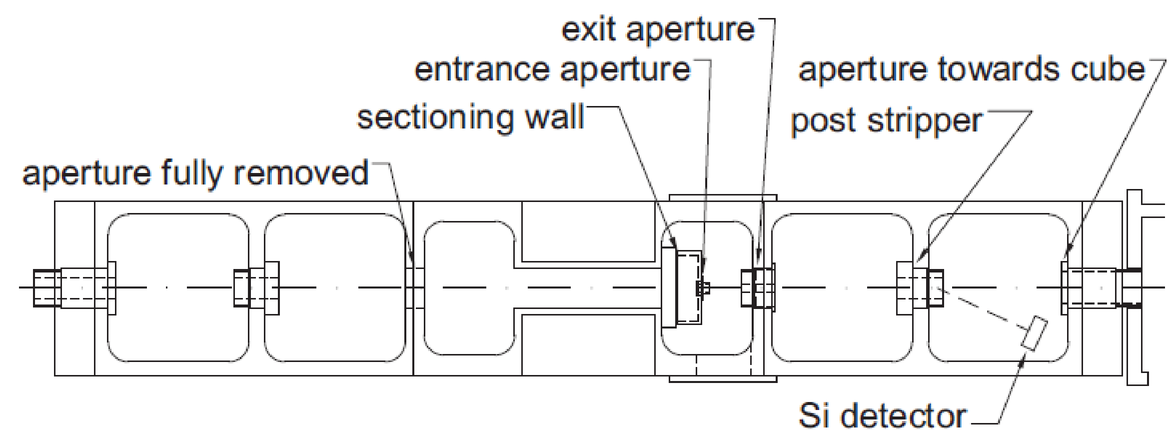


FIG. 2. Schematic top view of the modifications to the extended gas target chamber. The beam direction is from left to right. The relevant parts discussed in the text are indicated; for further details see Ref. [20].

Target density n = 0.54 ± 0.03 · 10^{18} at/cm^2 at 4.0 mbar
Target effective length 6 cm

Di Leva et al. PRC 95, 045803 (2017)

$^{15}N(\alpha,\gamma)^{19}F$

PHYSICAL REVIEW C **95**, 045803 (2017)

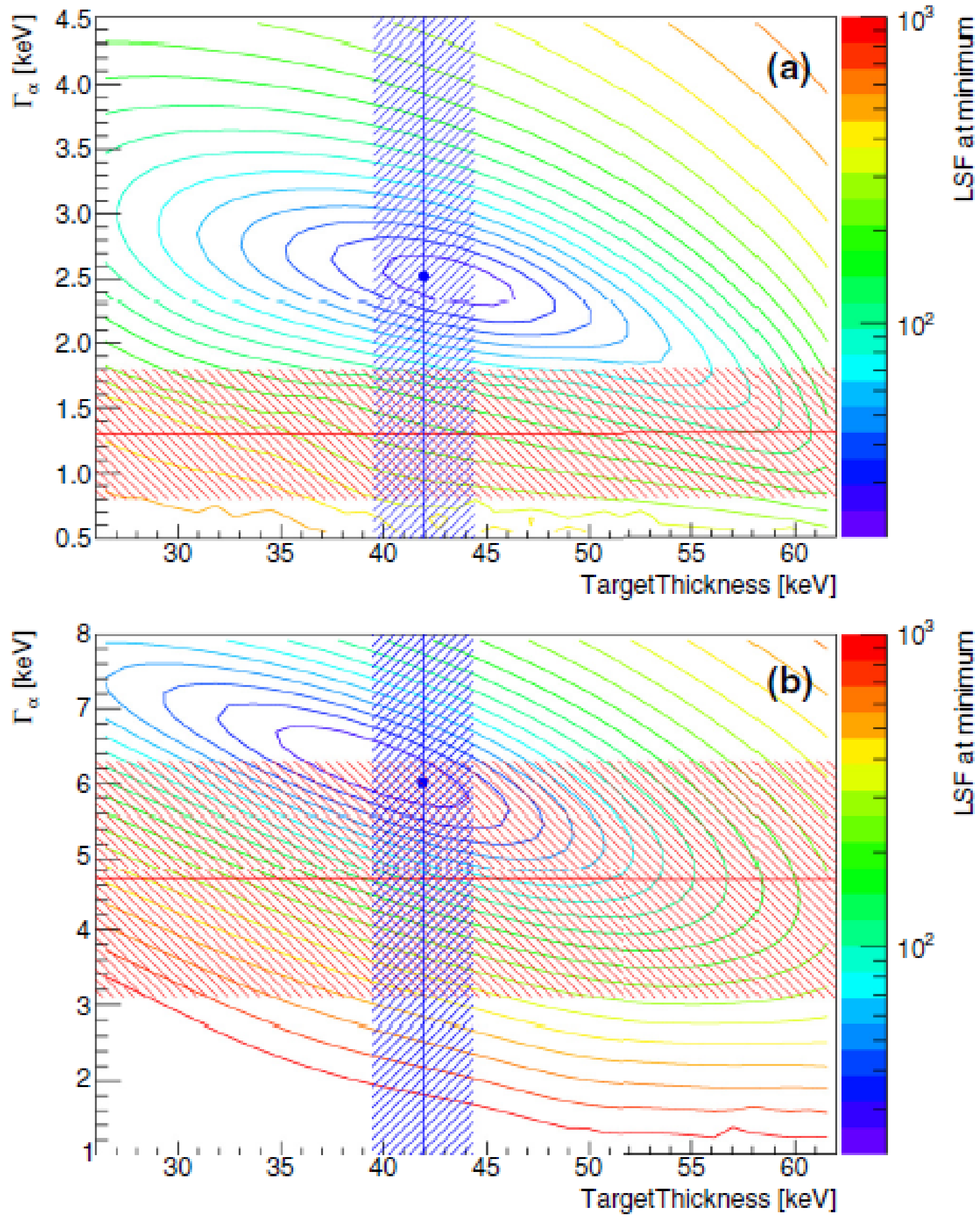


FIG. 9. LSF minima contour plots, as a function of the target thickness and Γ_α, for the 1.323 and 1.487 MeV resonances, panels (a) and (b), respectively. The vertical line is the experimentally determined target thickness and the shaded area its uncertainty. Horizontal lines are literature values of Γ_α and shaded area their uncertainties. The dots indicate the best fit values.

PHYSICAL REVIEW C **95**, 045803 (2017)

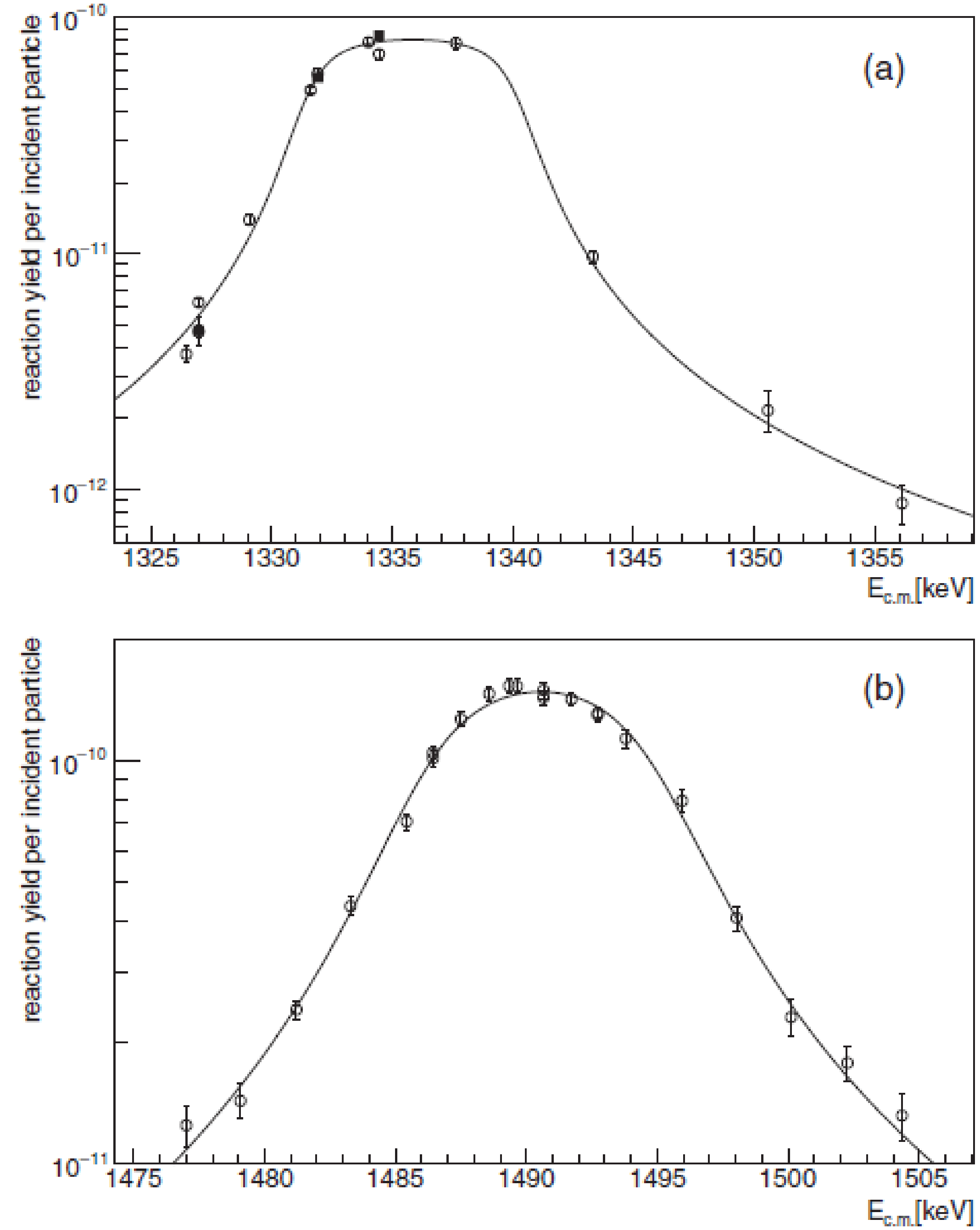
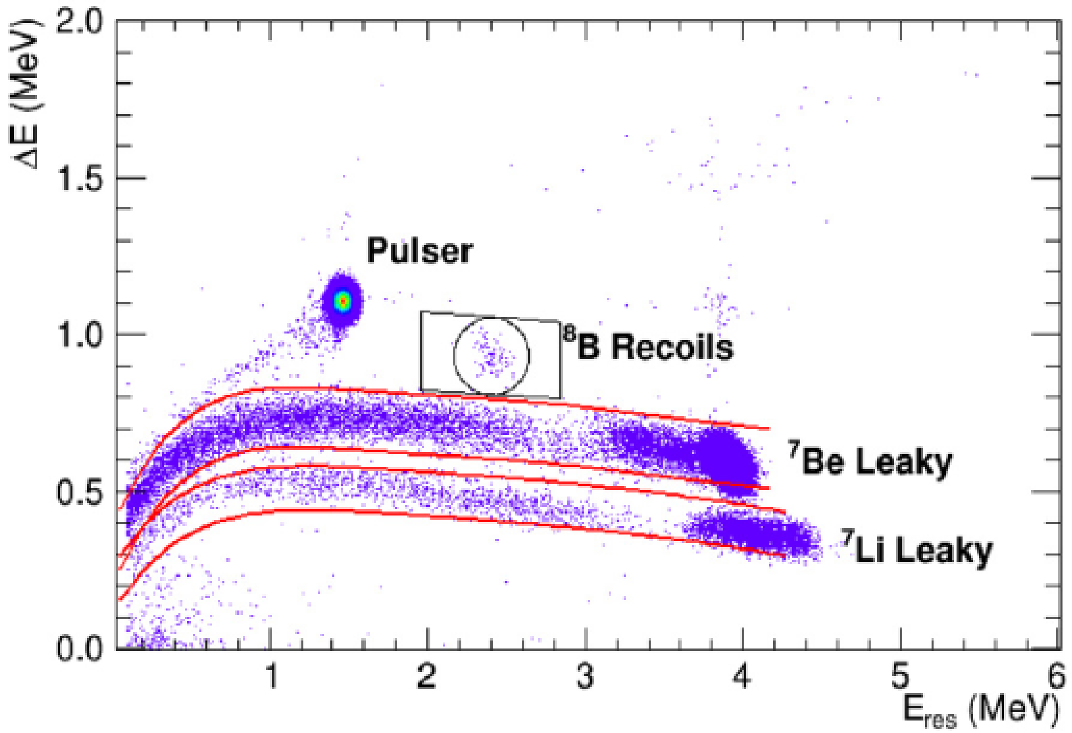
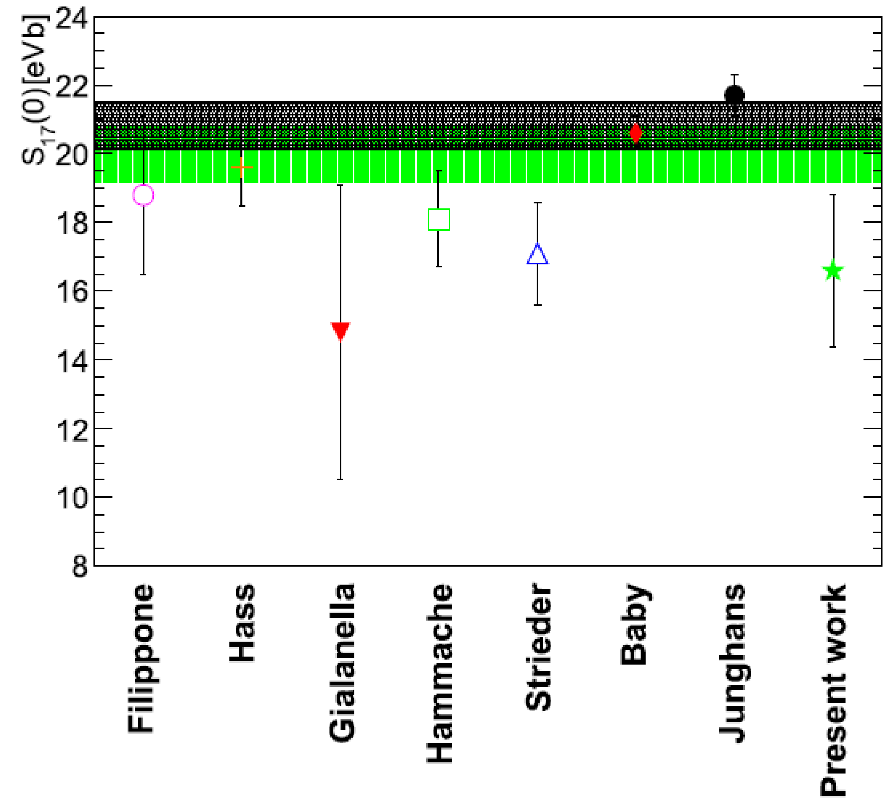


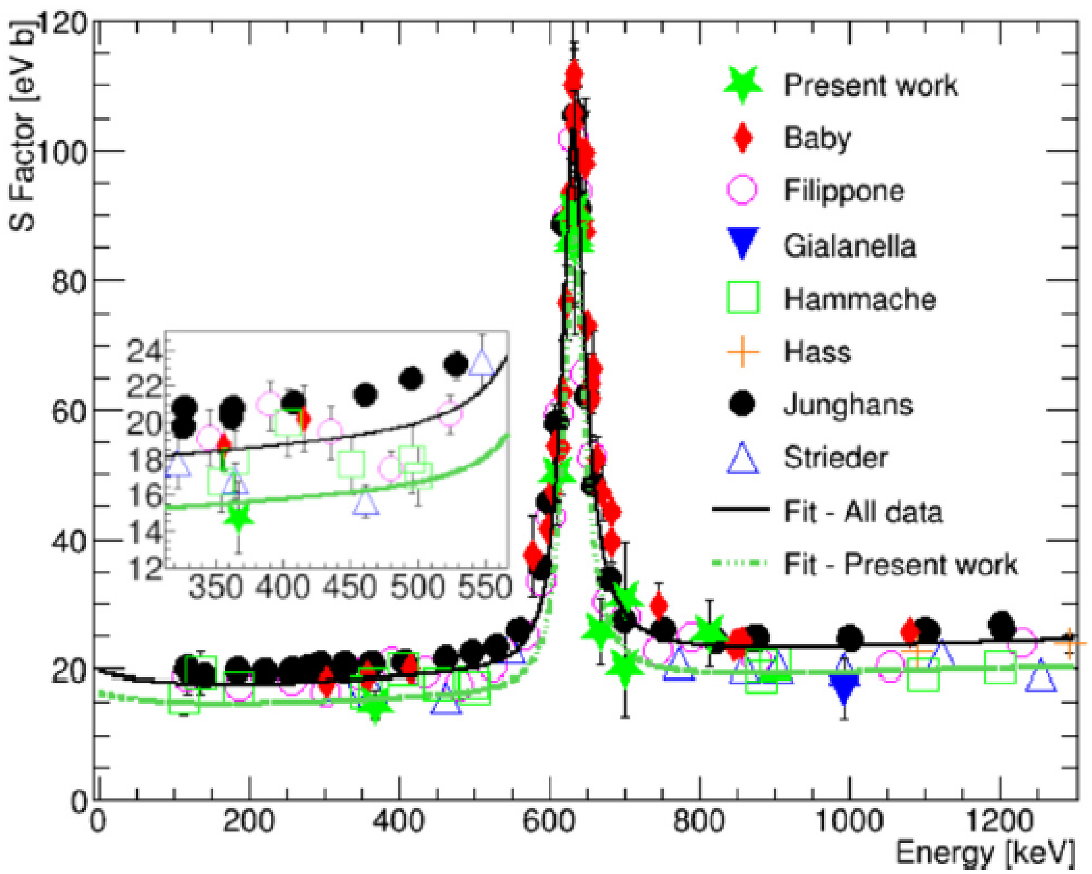
FIG. 8. Reaction yield per incident projectile observed for the two broad resonances at 1323 and 1487 keV, panels (a) and (b) respectively. Open circles and filled squares indicate measurements of recoils in the 4+ and 3+ charge states, respectively.

$^7Be(p,\gamma)^8B$

Physics Letters B 824 (2022) 136819







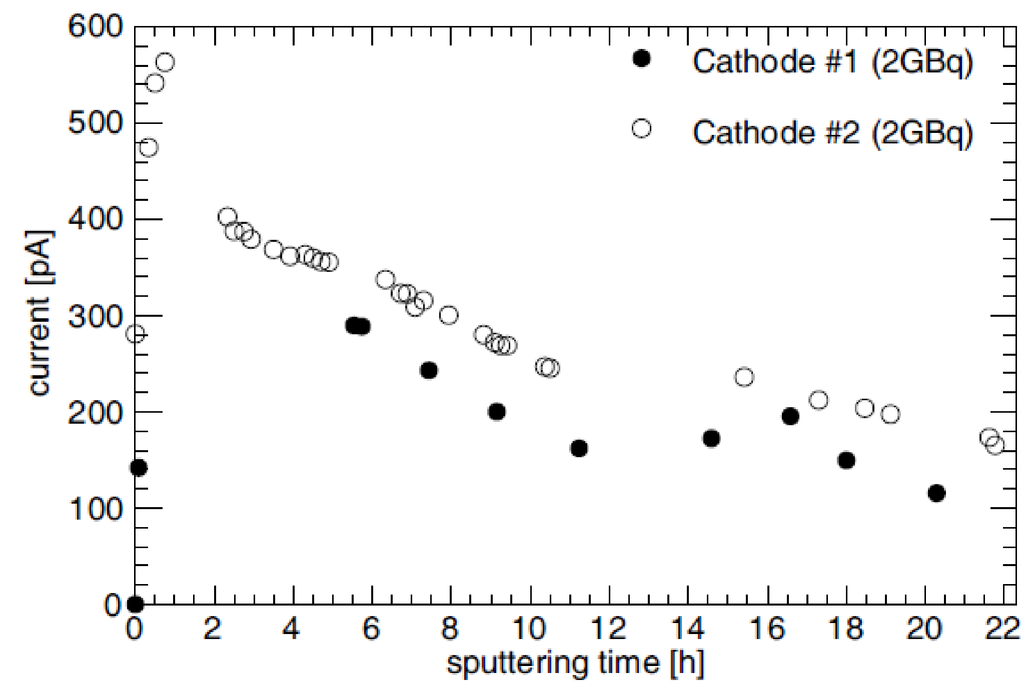


Fig. 9. $^7Be^{2+}$ beam current intensity at $E_b = 5.385$ MeV as a function of time for cathodes with an activity of about 2 GBq.

Ongoing measurements

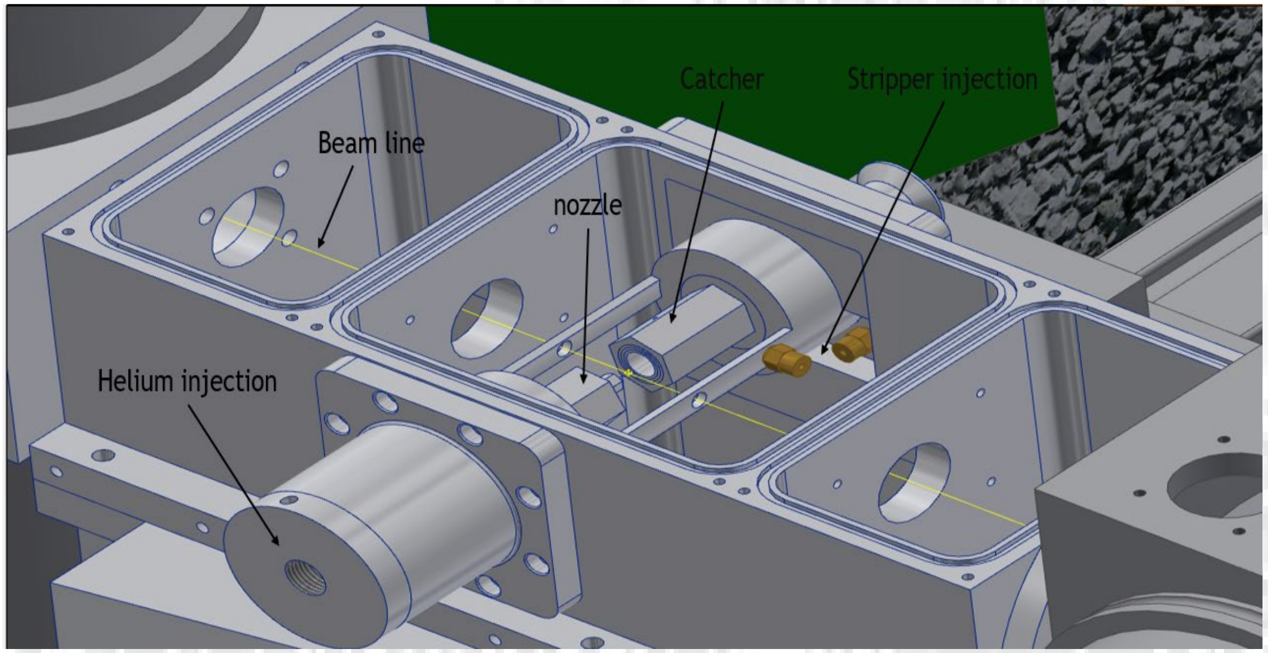
$^{12}C(\alpha,\gamma)^{16}O$

The measurements in Bochum was performed up to lower limit at E_{cm} = 1.9 MeV because of the background.

ERNA RMS has been updated to push down the measurement energy range:

- ✓ Charge State Selction Magnet (CSSM) -> Mitigate the background down to E_{cm}=1 MeV
- ✓ ^{4}He Supersonic Jet Target -> Improve the Transmission
- ✓ NaI gamma array detector -> Measurement of angular distribution
- ✓ ToF-Detector -> Improve the recoil identification

Recirculated ^{4}He Supersonic Jet Target



Target thickness = $(1.73 \pm 0.06) \times 10^{18} \frac{atoms}{cm^2}$

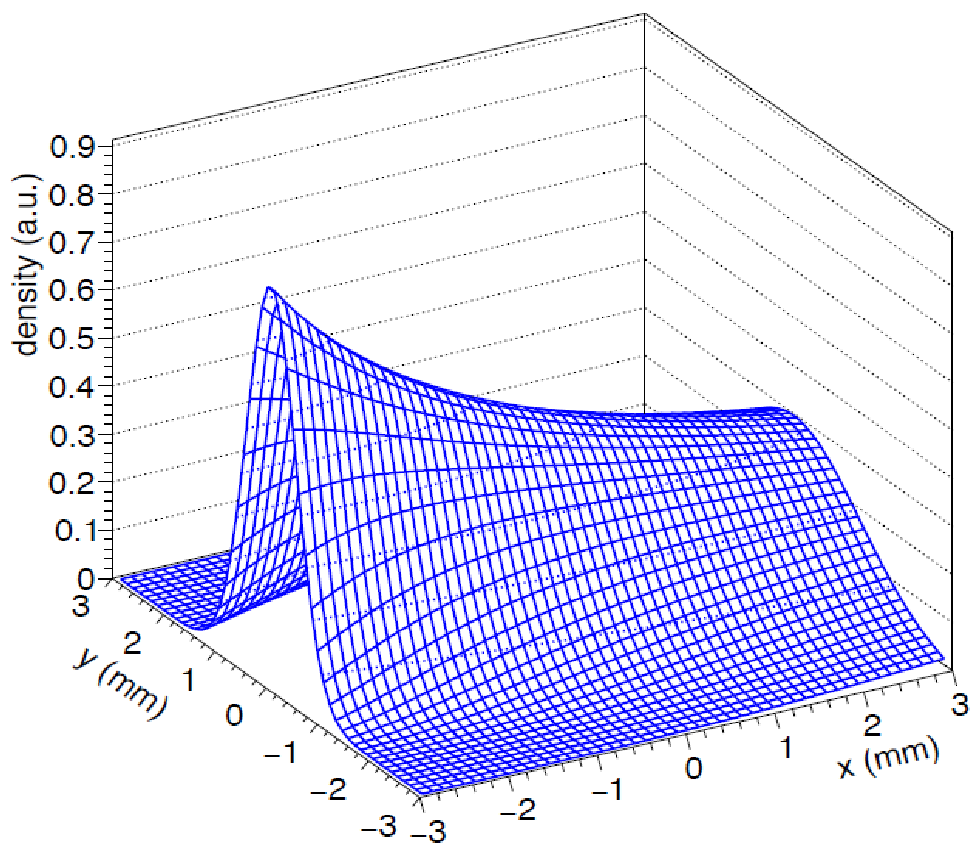
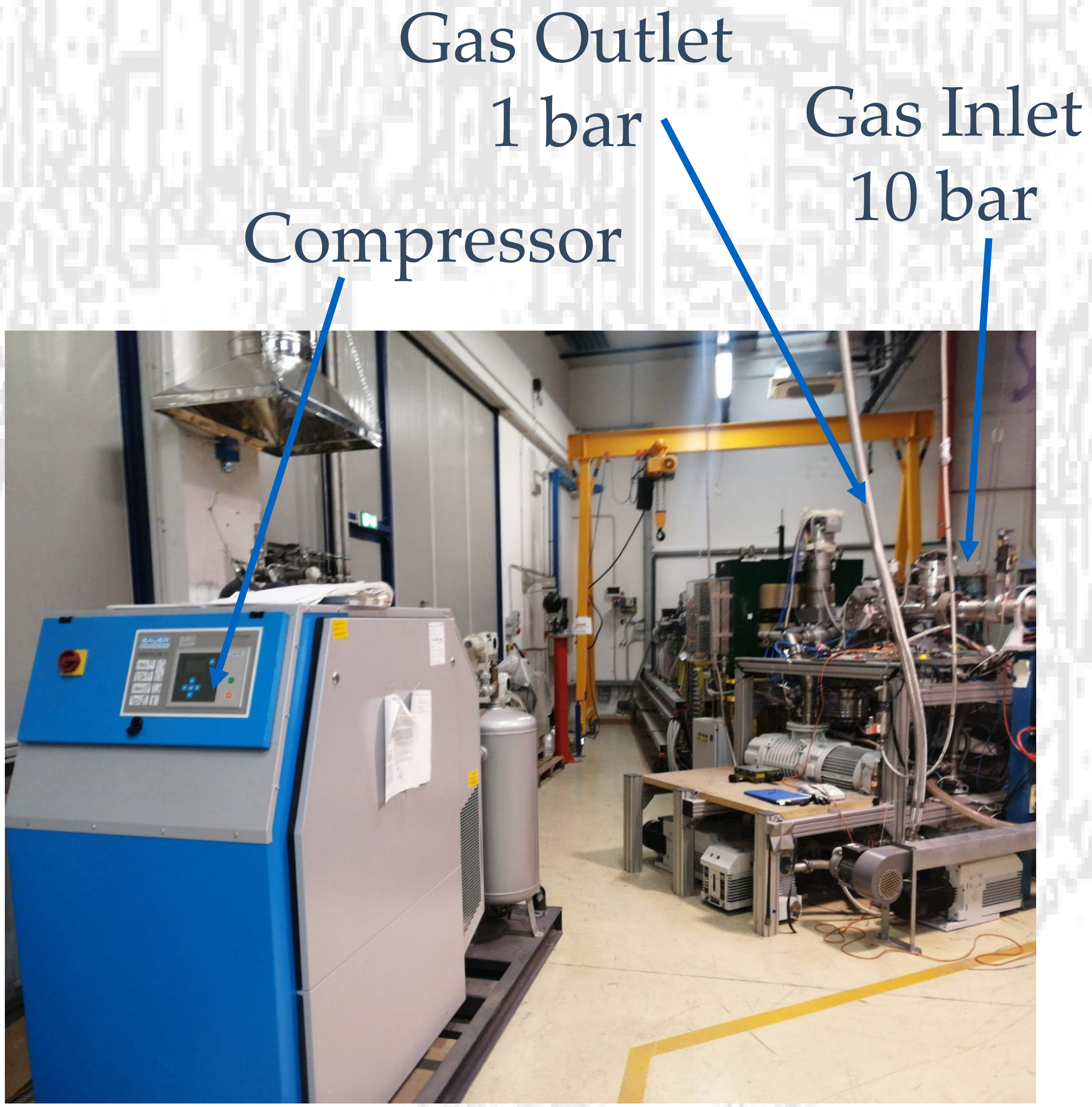


Figure 3.9: Jet profile obtained from scan measurement.

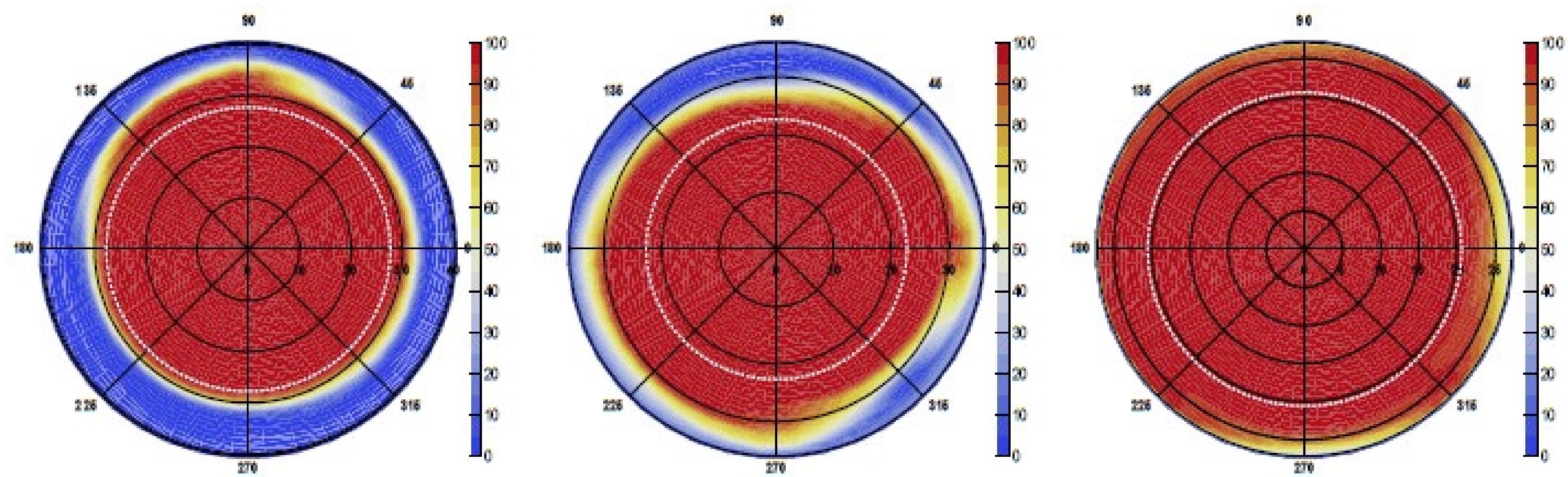


$^{12}C(\alpha,\gamma)^{16}O$ Acceptance

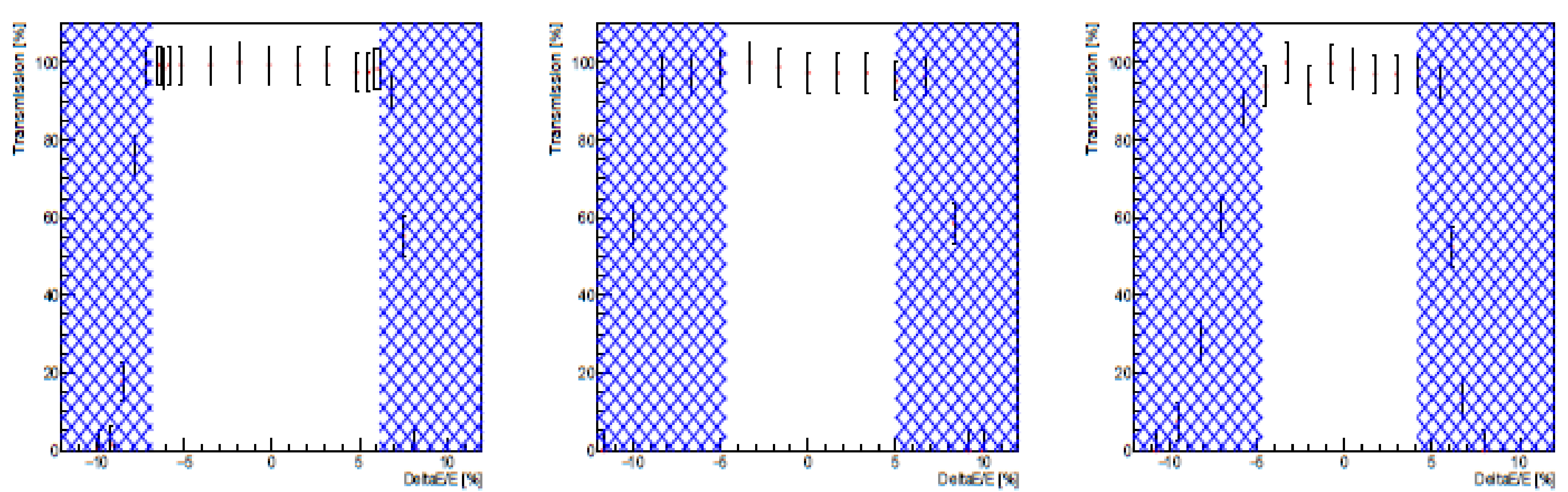
ERNA commissioning completed at

1 MeV 2 MeV 2.68 MeV

Angular

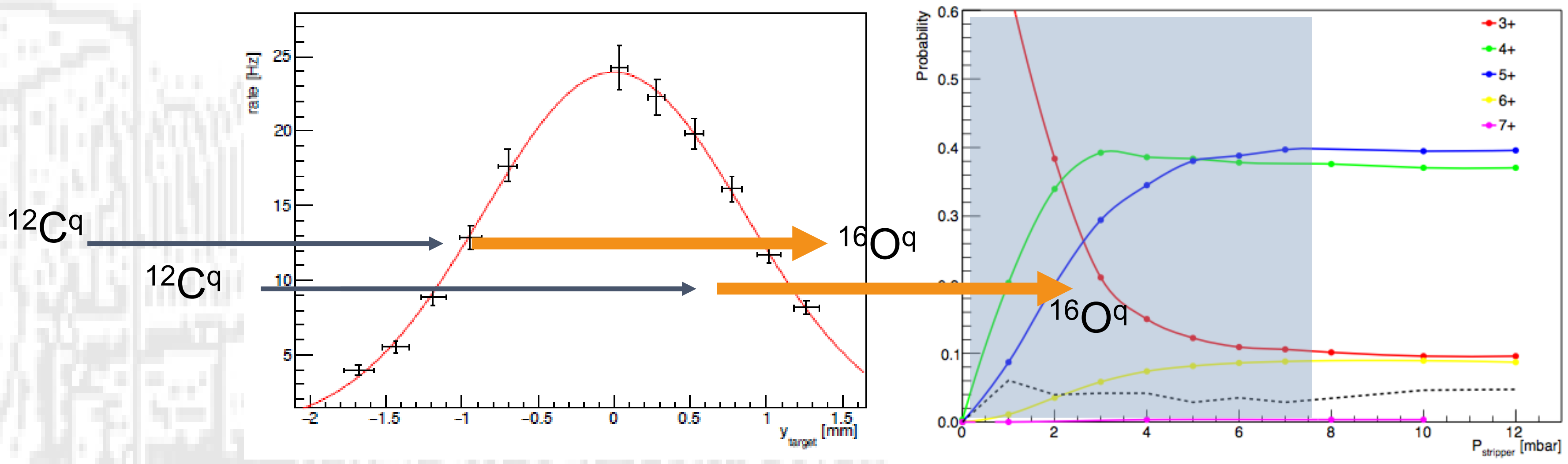


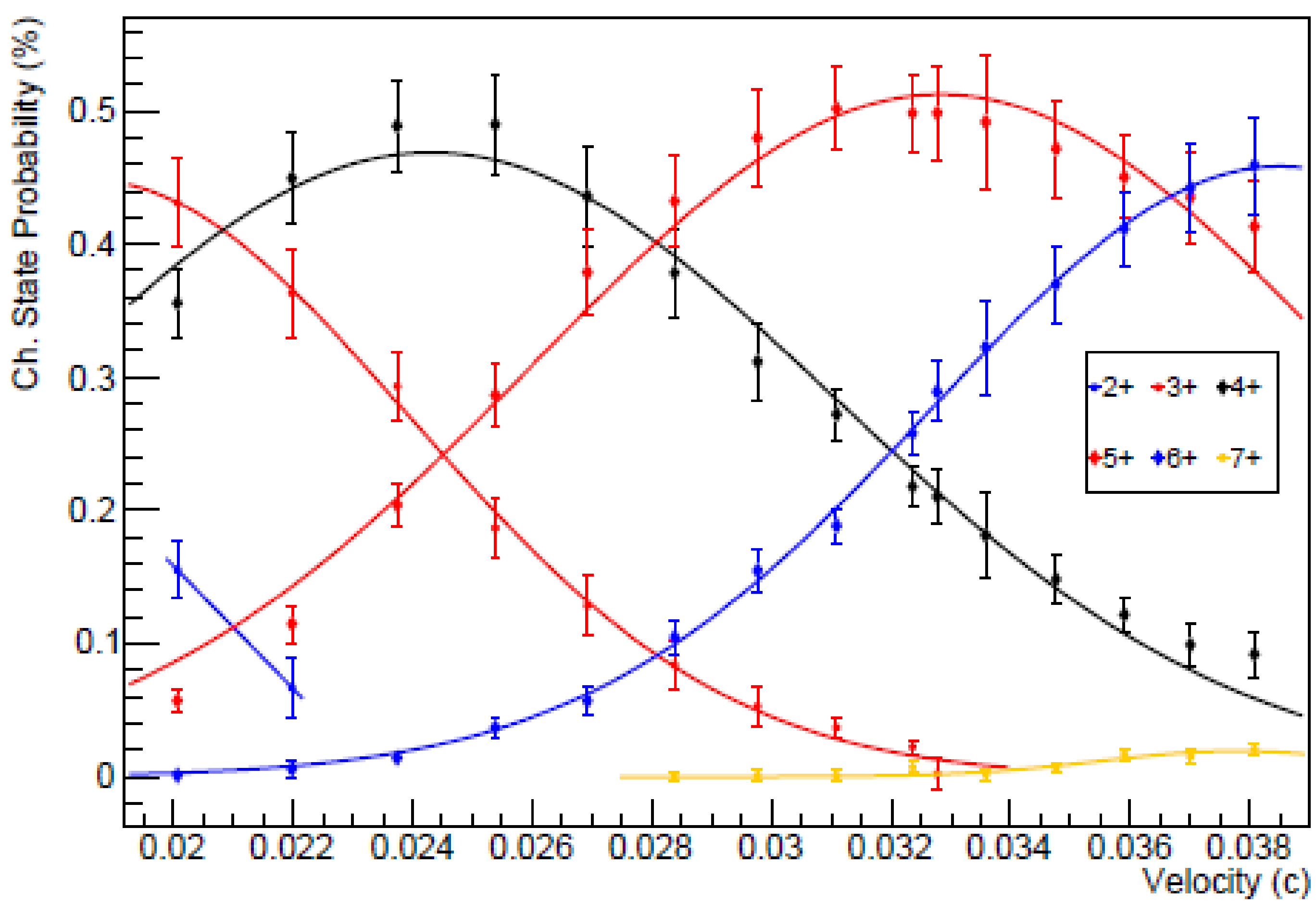
Energy



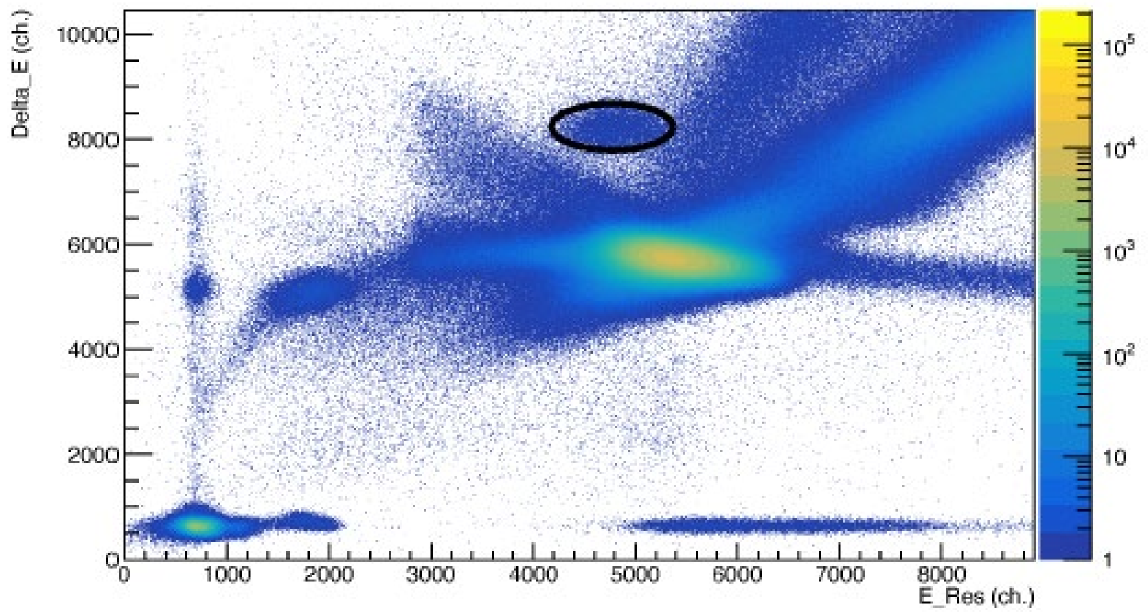
$^{12}C(\alpha,\gamma)^{16}O$ Charge states probability

^{4}He gas jet target   Ar gas post-stripper





$^{12}C(\alpha,\gamma)^{16}O$ Recoils identification

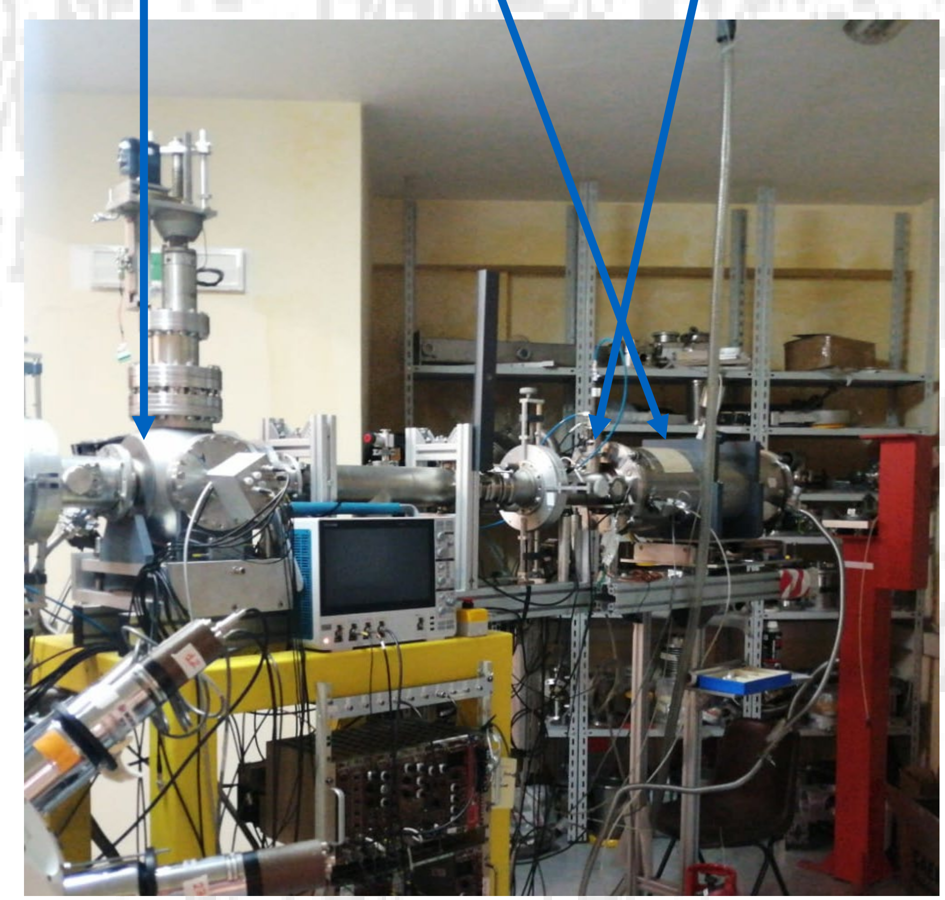


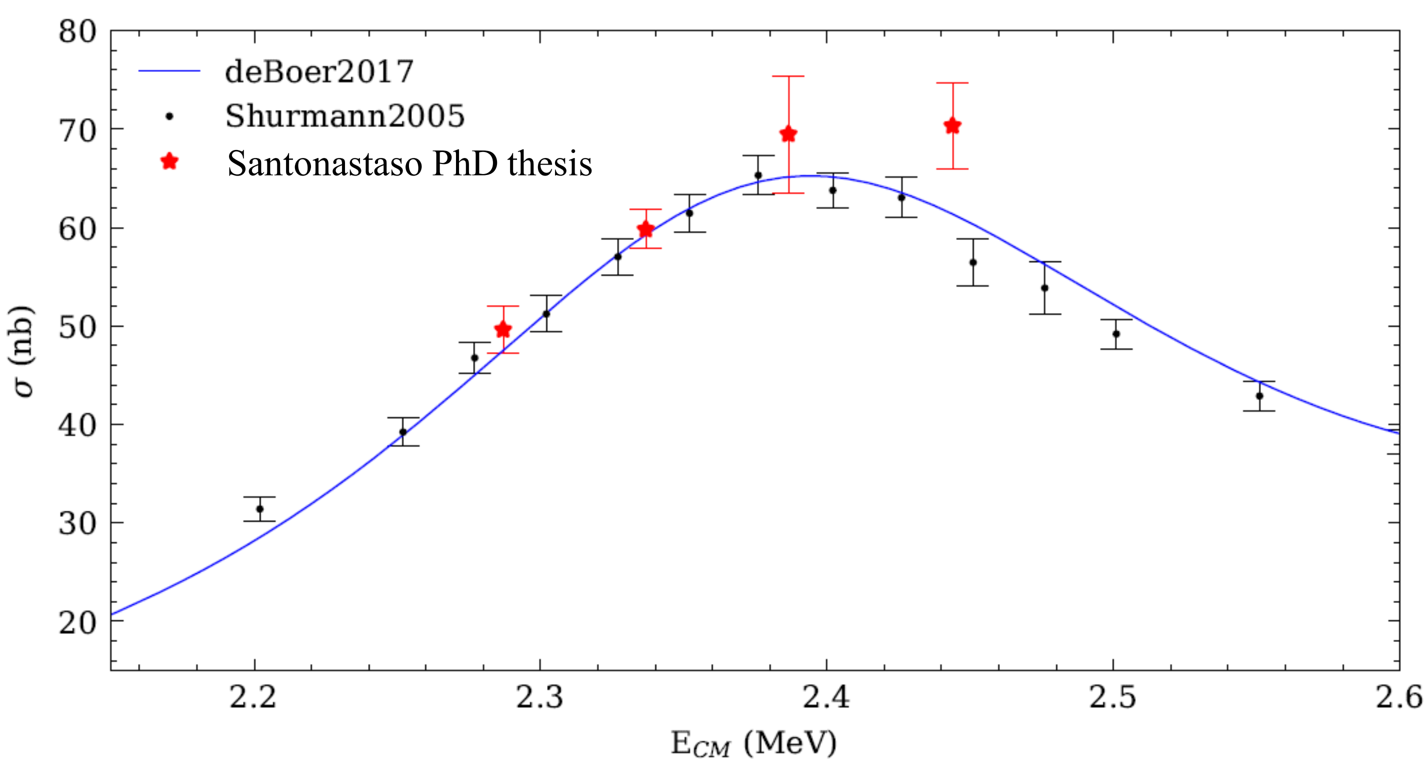
Measurement matrix at E_{cm} = 2.44 MeV. The ellipse corresponds to the ROI of the ^{16}O

ICT ΔE-E telescope

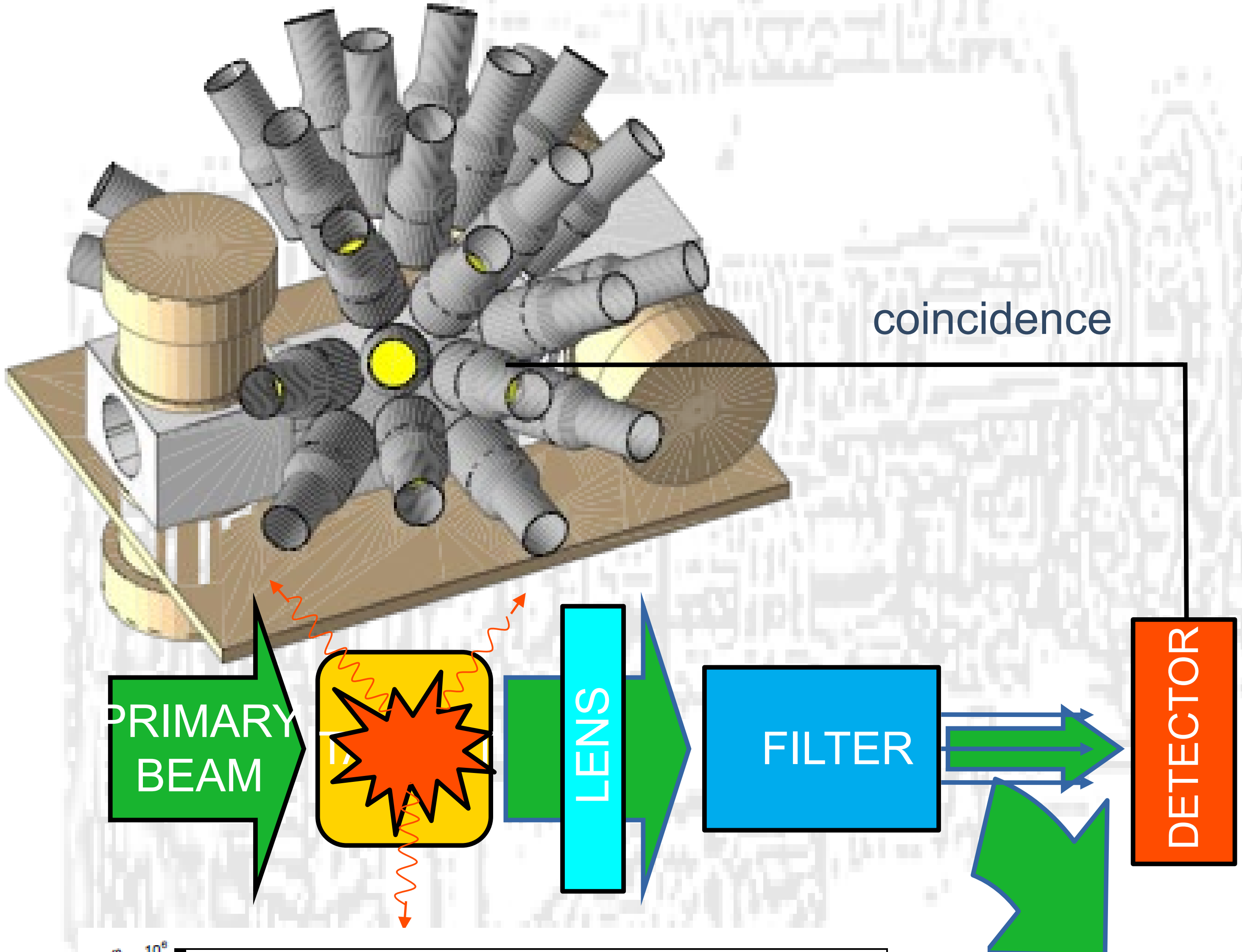
MCP ToF Start

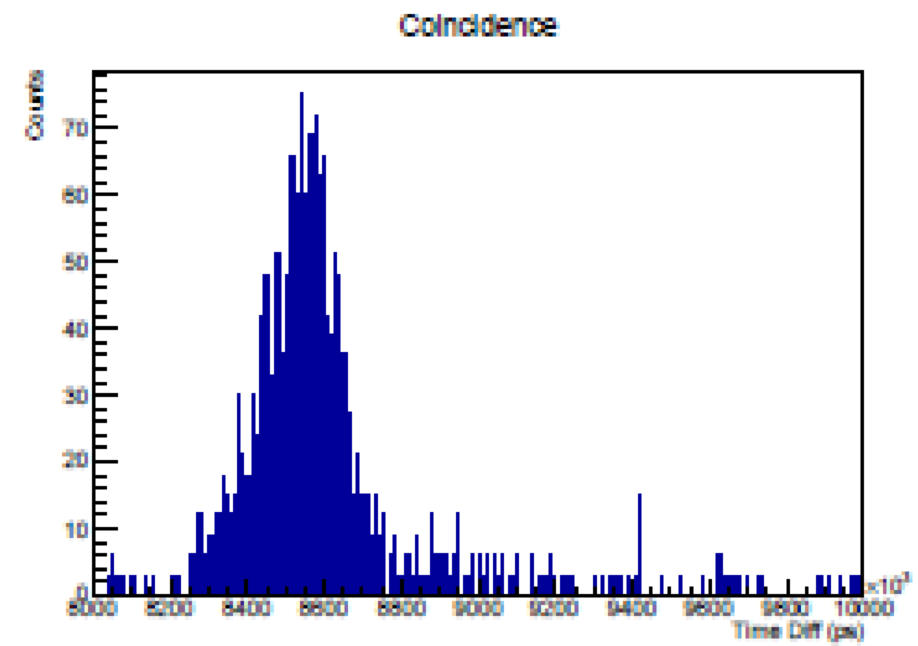
Parallel Grid ToF Stop

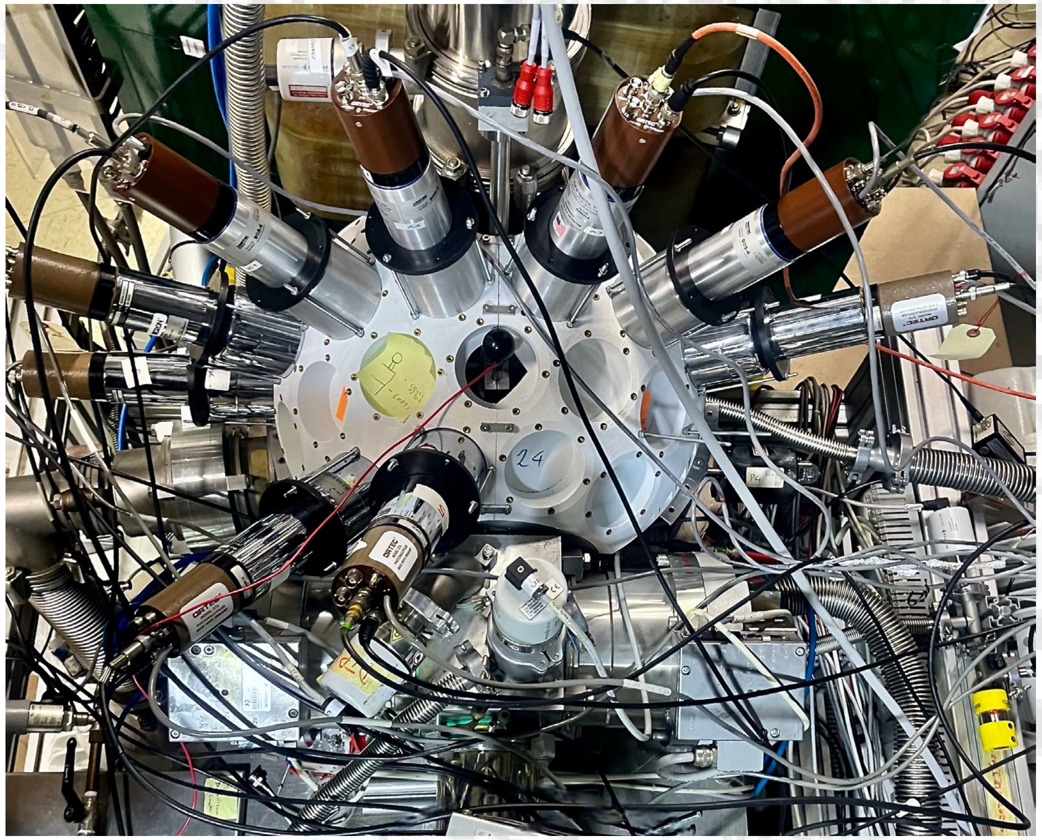


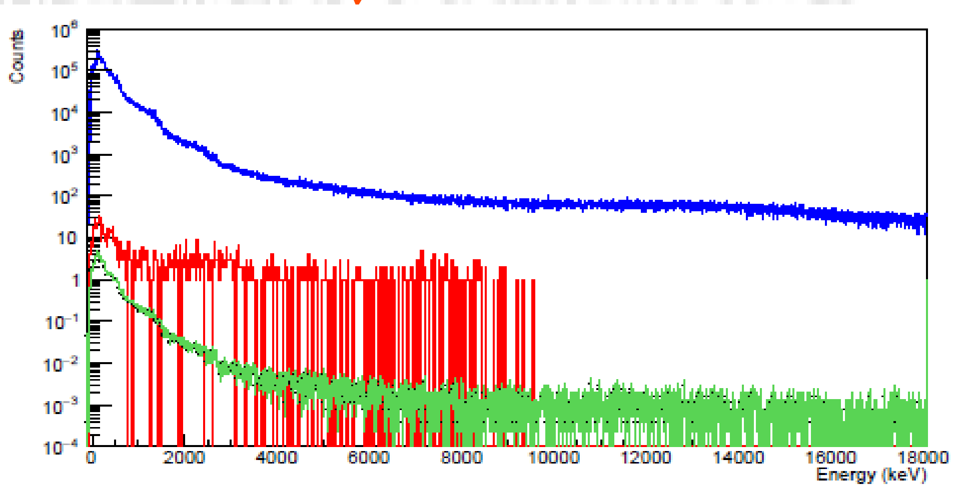


NaI γ-ray detection array









The reduced extension of the target offers the possibility for angular distribution measurements. Thanks to this system it is possible to distinguish the E1, E2 and cascades contributions to the cross section.

Summary

Recent achievement

- $^{15}N(\alpha,\gamma)^{19}F$ measured resonance width at 1323 and 1487 keV
- ^{7}Be Beam
  - $^{7}Be(p,\gamma)^{8}B$ measured in the energy range E_{cm} = 300 – 800 keV

Measurement ongoing

- $^{12}C(\alpha,\gamma)^{16}O$
  - Commissioning completed in the range of interest
  - Total Cross section in the energy range E_{cm} = 1.0 – 2.7 MeV
  - Angular distribution by NaI γ-ray detector array
- $^{7}Be(p,\gamma)^{8}B$ at E_{cm}> 1 MeV
- ^{7}Be Ionized Half Life (ASBeST PRIN project).

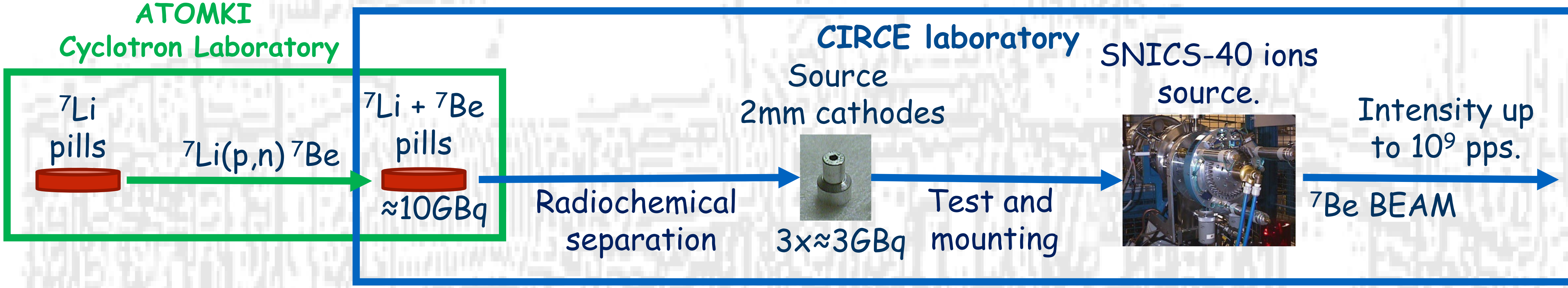
Analysis ongoing

- $^{12}C(^{12}C,p)^{23}Na$ and $^{12}C(^{12}C,\alpha)^{20}Ne$ - Angular distribution analysis
- $^{12}C(^{16}O,p)^{27}Al$ and $^{12}C(^{16}O,\alpha)^{24}Mg$ - Total cross section analysis

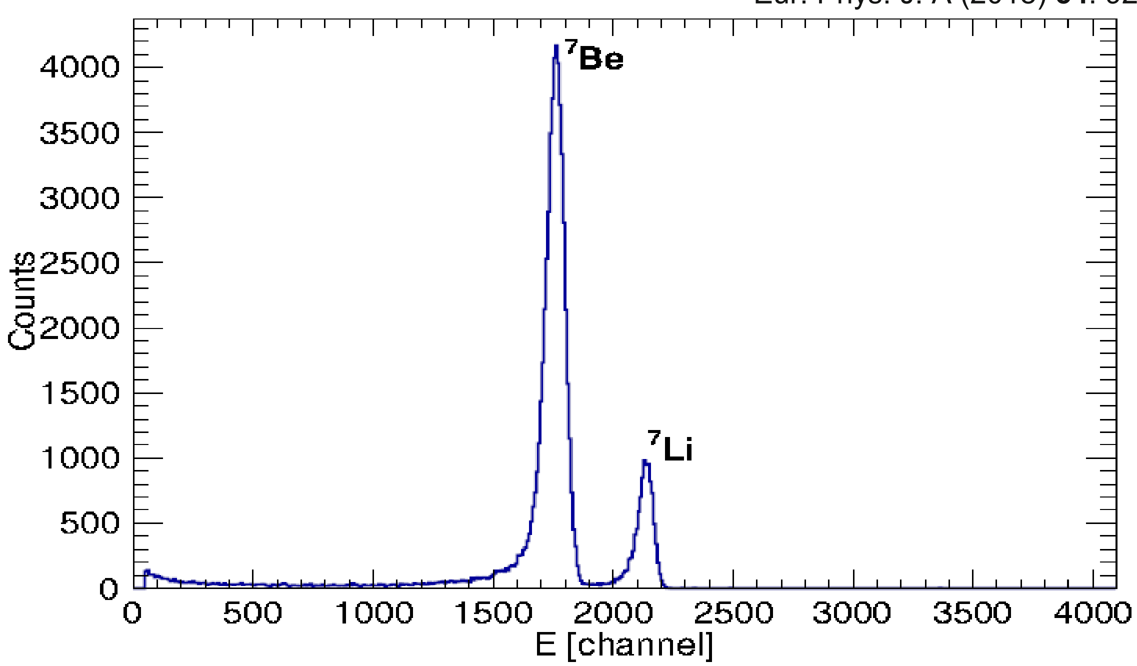
Thank you for your attention

$^{7}Be(p,\gamma)^{8}B$

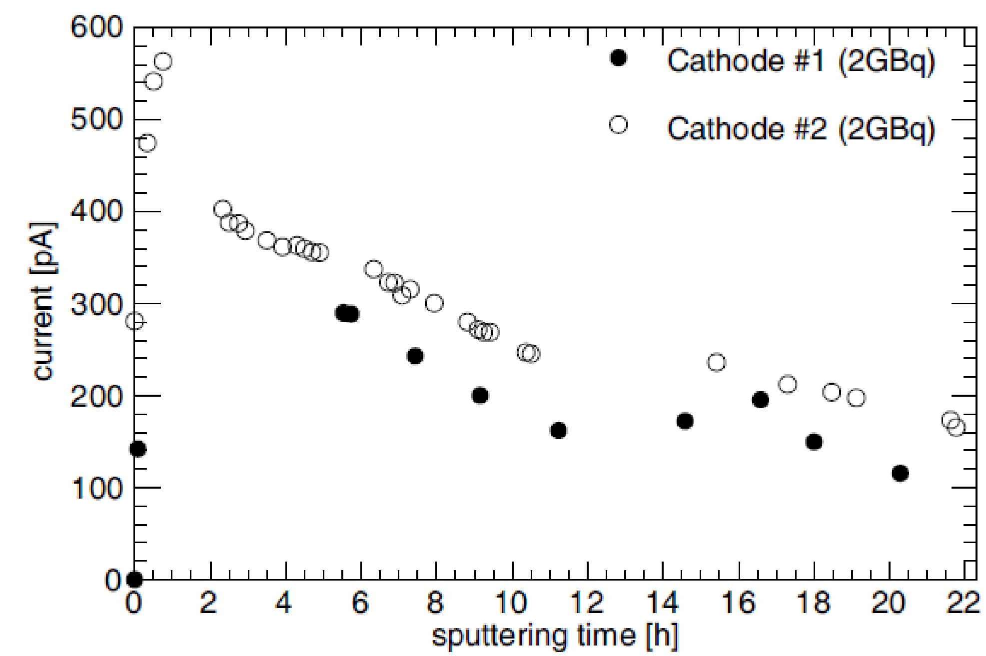
^{7}Be beam



Eur. Phys. J. A (2018) **54**: 92



The number of incident projectiles, including lithium contamination, is monitored on line through elastic scattering.



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