GRAN SASSO SCIENCE INSTITUTE

Towards $^{14}N(p,\gamma)^{15}O$ reaction measurement at LUNA-MV

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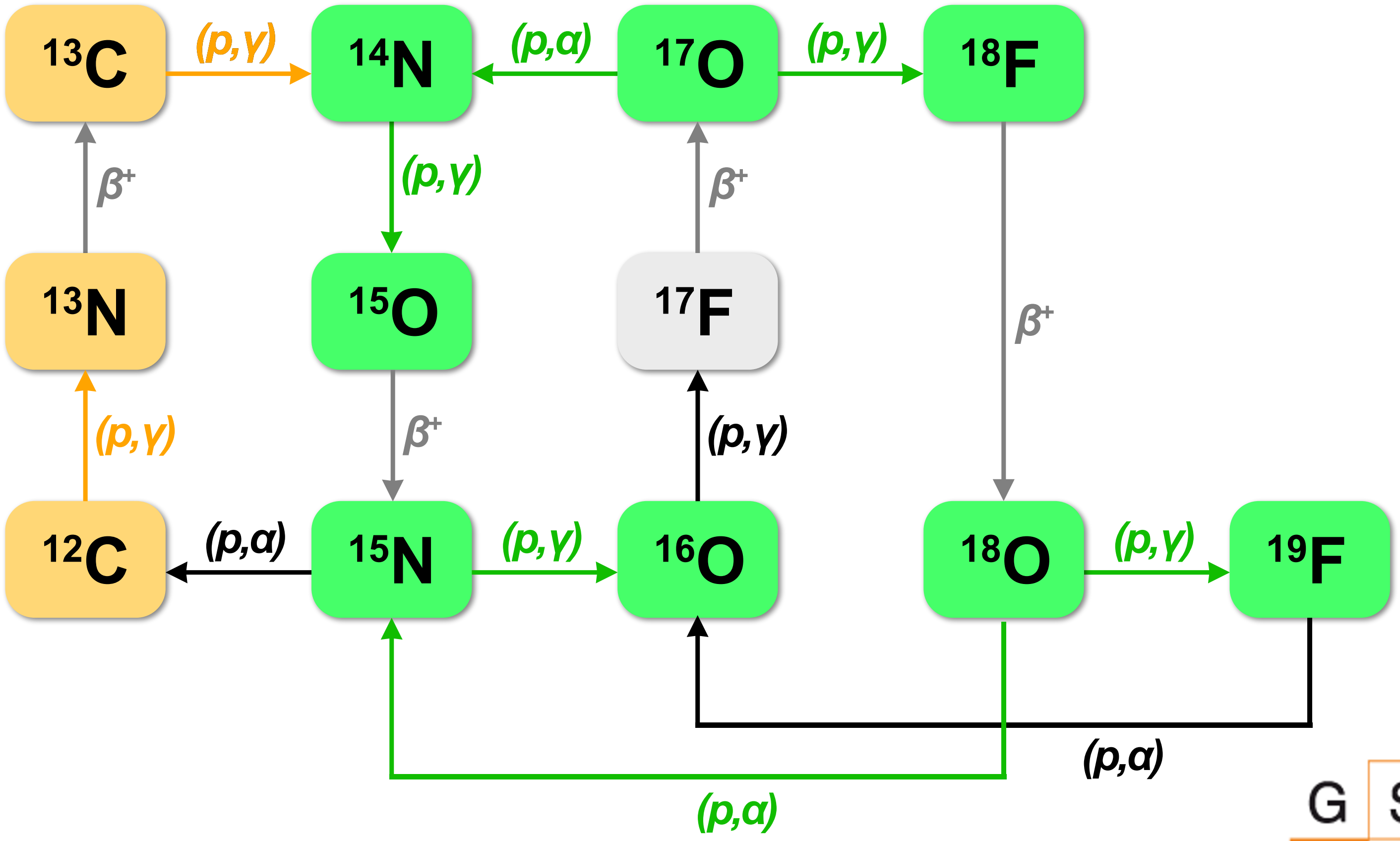
INFN LNGS

LUNA

The $^{14}N(p,\gamma)^{15}O$ and the CNO cycle

- The CNO Cycle is the main source of energy generation in massive main-sequence stars, accounts for ~1% in the Sun.
- The $^{14}N(p,\gamma)^{15}O$ is the slowest reaction of the CNO, controls its speed and energy production rate.



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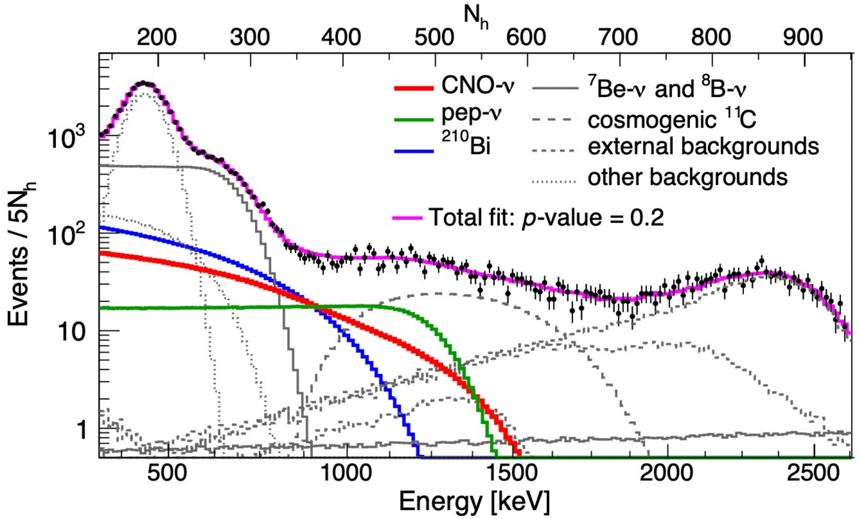
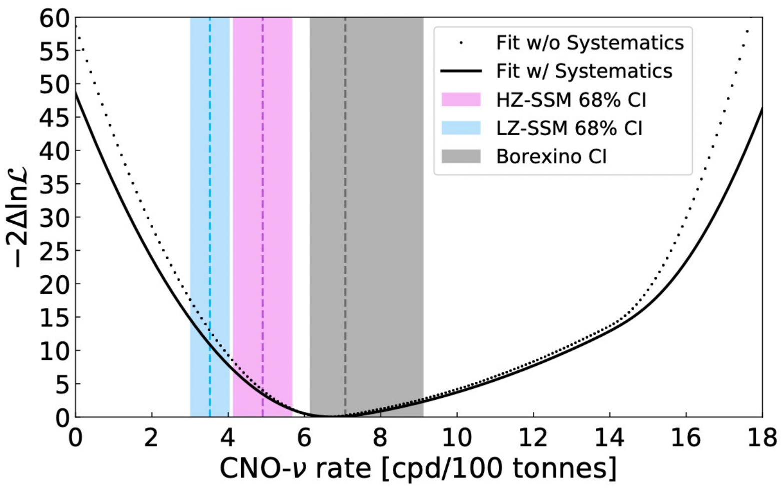
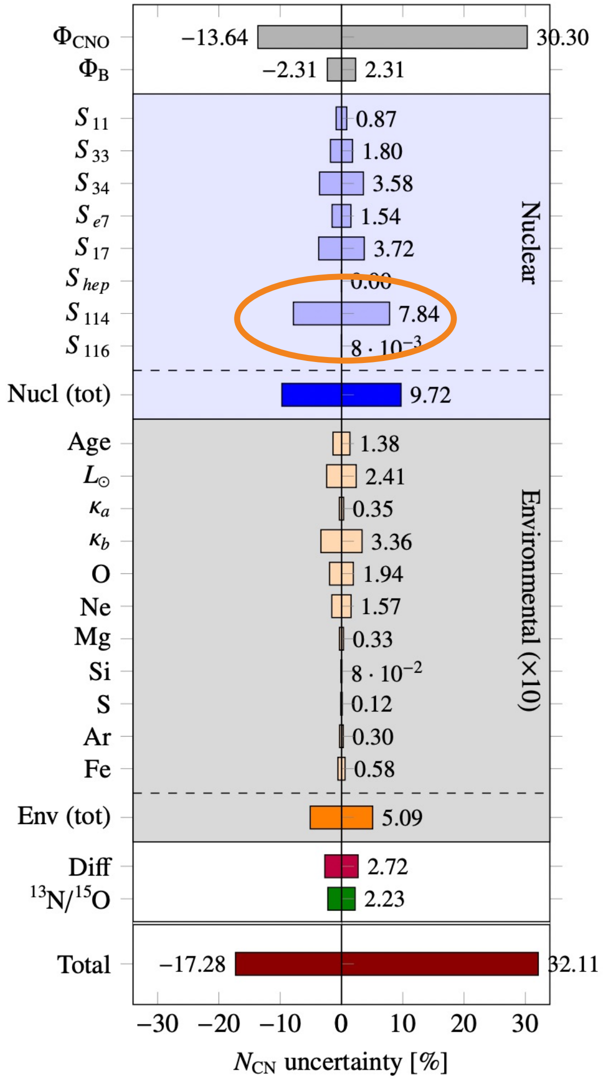
The $^{14}N(p,\gamma)^{15}O$ and the CNO cycle

- Solar CNO neutrino flux recently detected for the first time by Borexino (2020). → Solar metallicity probe.
- The result of Borexino disfavours "low metallicity" SSM prediction, but large uncertainties still remains. After CNO Flux itself, biggest contribution to the uncertainty budget from $^{14}N(p,\gamma)^{15}O$ cross section.

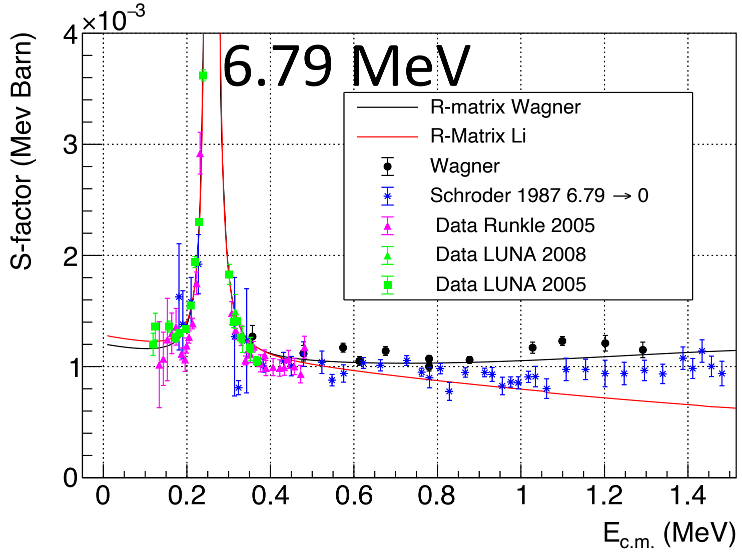


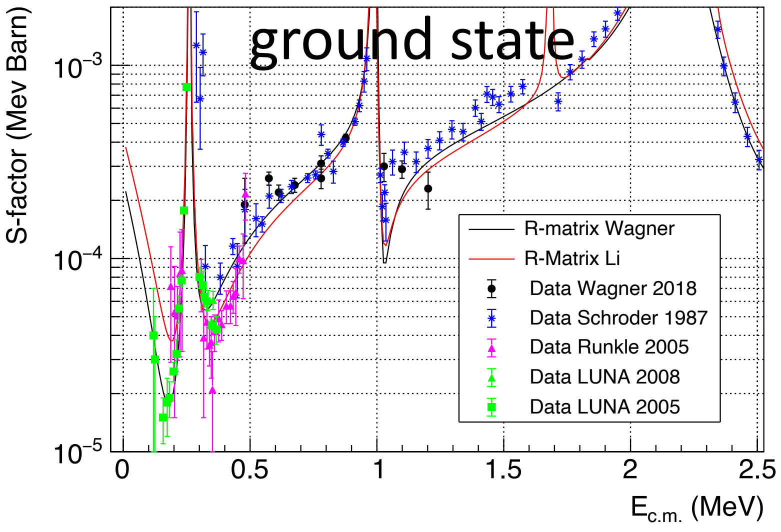


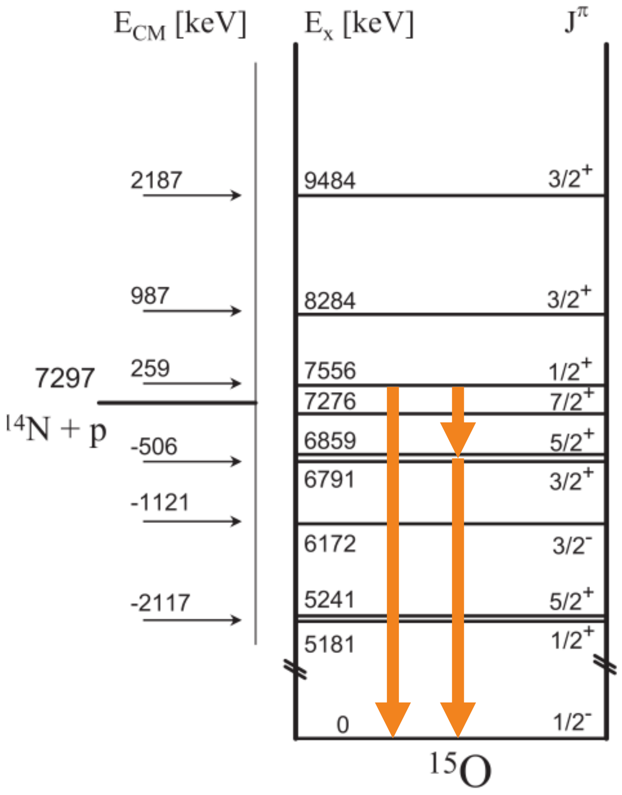


Uncertainties in $^{14}N(p,\gamma)^{15}O$ cross section determination: The role of nuclear structure

- Most important transitions contributing to the total capture: 6.79 MeV excited state, g.s of ^{15}O
- Secondary transitions: 6.17, 5.24, 7.28, 6.86, 5.18 MeV
- R-matrix analysis fails to provide a consistent view of both high and low energy data, why?







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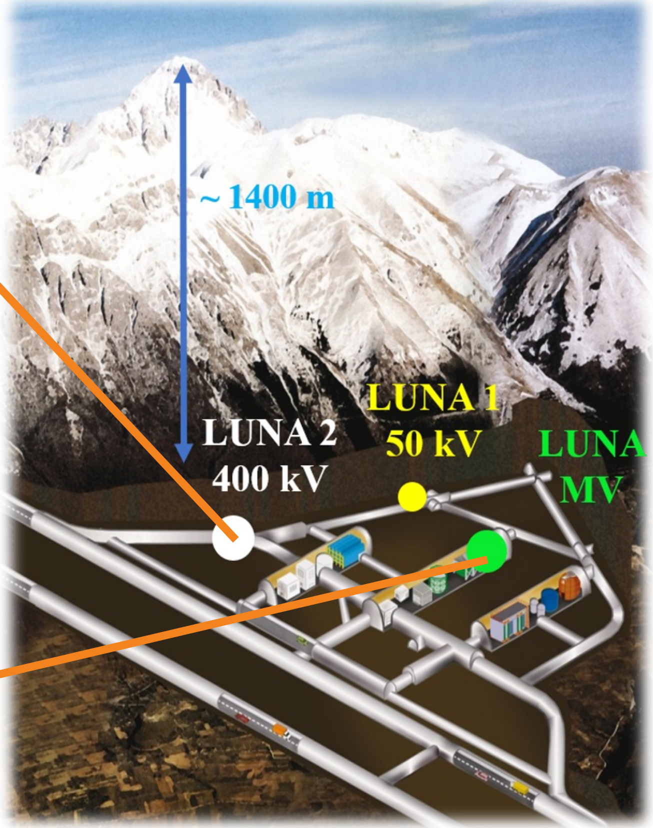
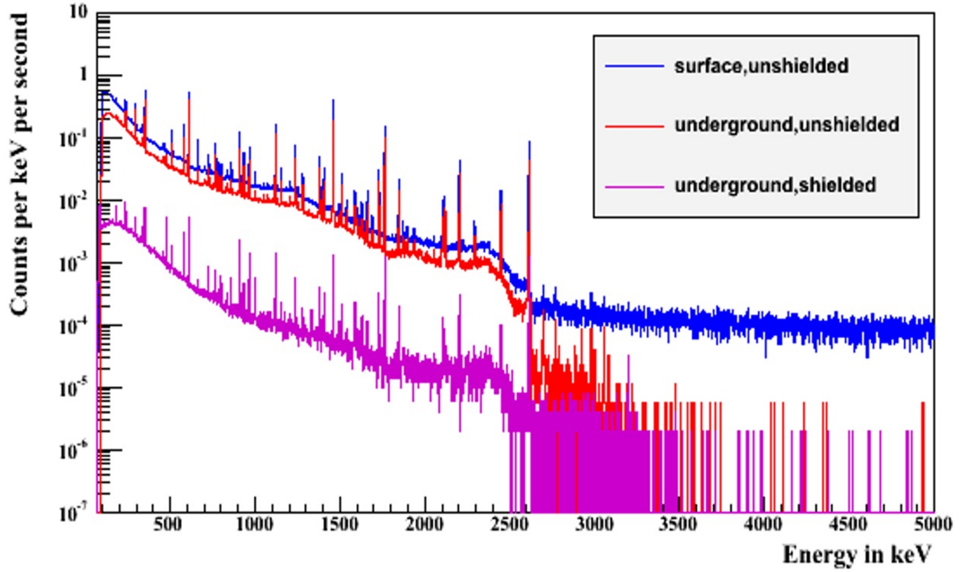
Underground Nuclear Astrophysics at LUNA





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The accelerator system for the LUNA-MV project

- Energy range 0.3-3.5 MeV
- H^+,He^+,$^{12}C^+$,$^{12}C^{++}$
- High current, energy stability below 10^{-5}, uninterrupted operation time >24h
- Scientific program:
  - $^{14}N(p,\gamma)^{15}O$
  - $^{12}C+^{12}C$, $^{22}Ne(\alpha,n)^{25}Mg$, $^{13}C(\alpha,n)^{16}O$ ...

Ion specie	Beam Intensity (eμA)	
	TV range 0.3 MV–0.5 MV	TV range 0.5–3.5MV
$^1H^+$	500	1000
$^4He^+$	300	500
$^{12}C^+$	100	150
$^{12}C^{+2}$	60	100

Beam intensity on target at different terminal voltage.

Sen, A. *et al.* (2019) 'A high intensity, high stability 3.5 MV Singletron™ accelerator', *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 450, pp. 390–395. doi:10.1016/j.nimb.2018.09.016.

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Towards $^{14}N(p,\gamma)^{15}O$ measurement @ LUNA-MV

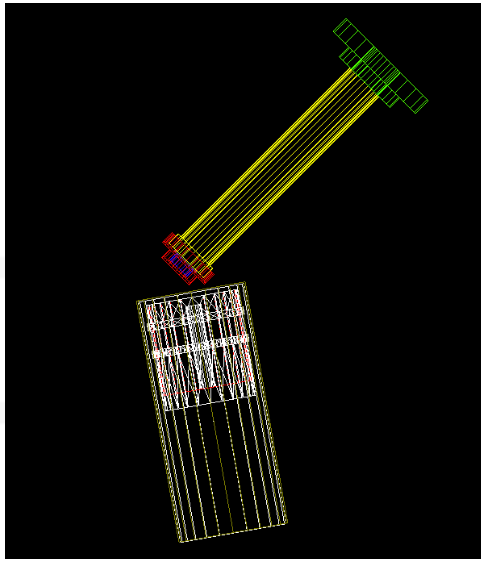
- Low background measurement over a wide-energy range, in order to address the existing issues in the extrapolations
- Angular distribution
- Measuring weaker transitions
- Pilot LUNA-MV project
  → Verifing the performance of the accelerator

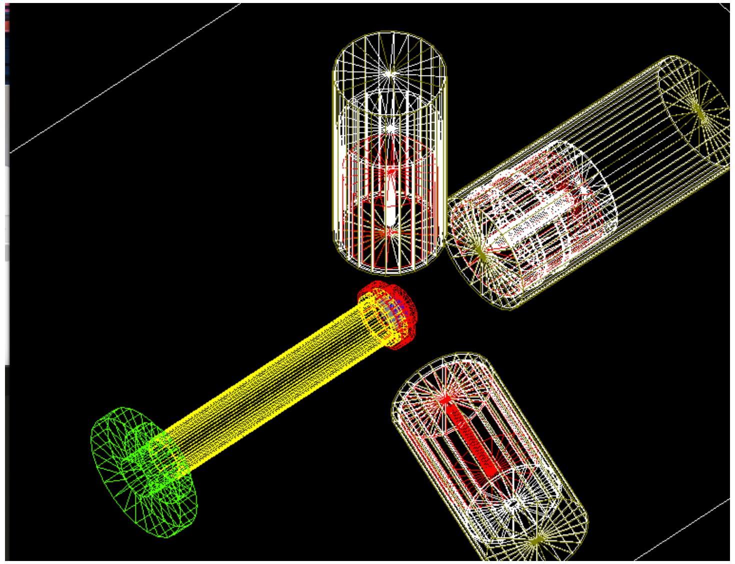
Towards $^{14}N(p,\gamma)^{15}O$ measurement @ LUNA-MV

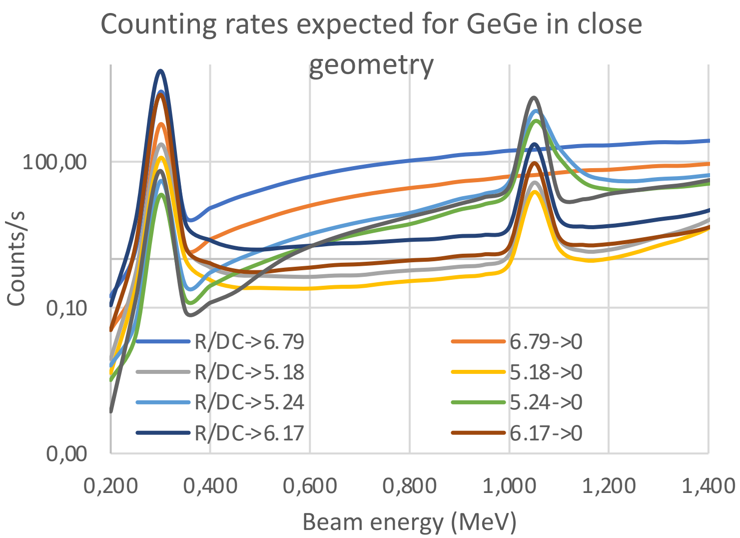
- Simulations and measurement planning
- Target production
- Target characterization
  - Atomki Tandetron
  - Luna-400
- Setup design and costruction

Simulations and measurement planning

- Angular distribution setup + Excitation function in close geometry simulated with Geant4.
- 3 HPGe detectors with ~120% relative efficiency
- Detectors at 10 cm from target, angles covered: 0°,45°,90°,135°...







Beam time (h) to 3%, down to 250 keV, primary trans.

Transition	0 deg	90 deg
6.79	6.2	0.7
5.18	27.1	25.0
g.s (+ summing-in)	37.6	33. 6

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Solid Targets production

Sputtered targets

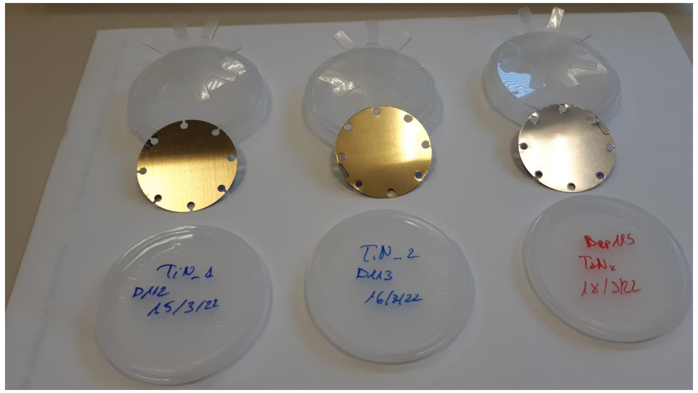
(Matteo campostrini, Valentino Rigato @ **LNL, Italy**):

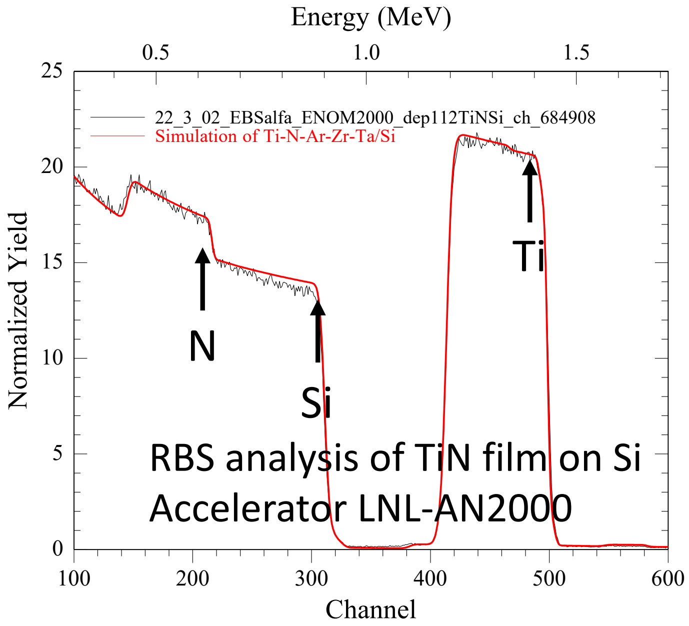
- Thin films on Ta backing produced using Reactive Magnetron Sputtering
- TiN or Me_xN_y , with Me= Ta, Nb, Zr on Ta backing.
- Sputtered TiN targets already proved to be durable and withstand well irradiation with high beam intensities.
- Higher Z metals promise reduction of the beam induced background.

  → Issues at higher energies with Ti(p,γ), Ti(p,n)

- 4 targets produced

Characterization → RBS, NRRA



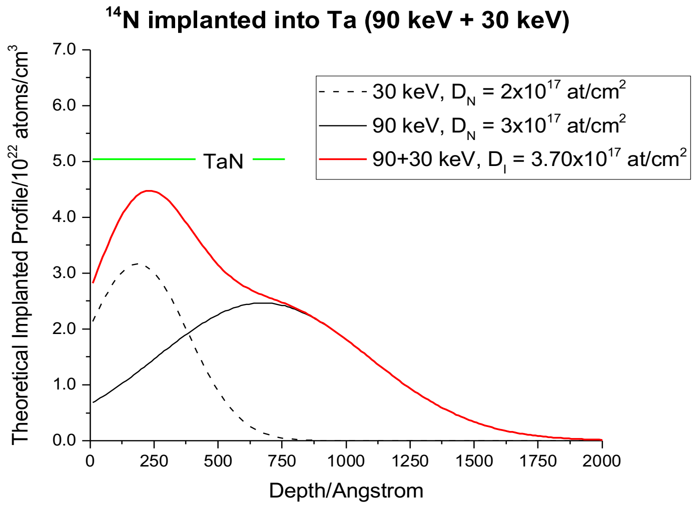


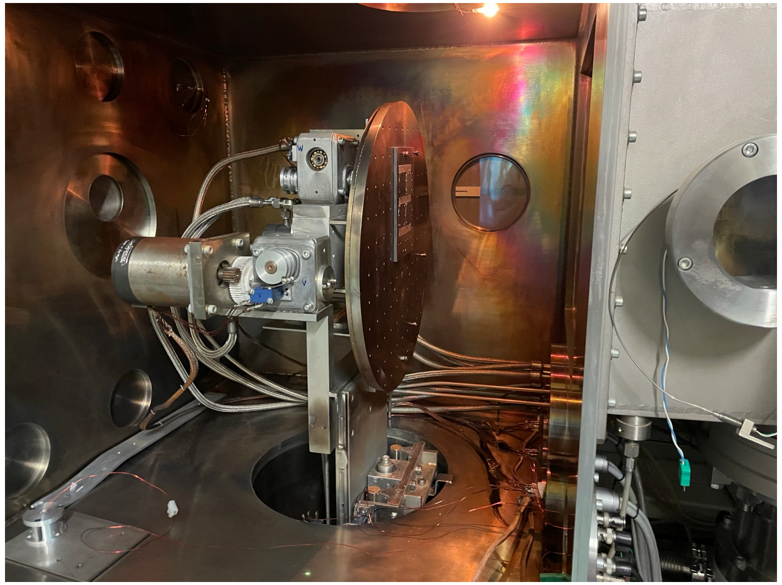
Solid Targets production

Implanted targets

(João Cruz @ **IST, Lisbon** - Under **RADIATE Transnational Access**):

- ^{14}N on Tantalum
- Isotopically pure
- Ta_xN_y → Higher beam energy reachable, lower Beam Induced Background (^{15}N(p,$\alpha\gamma$) an issue at higher energies..)





- 4 targets produced

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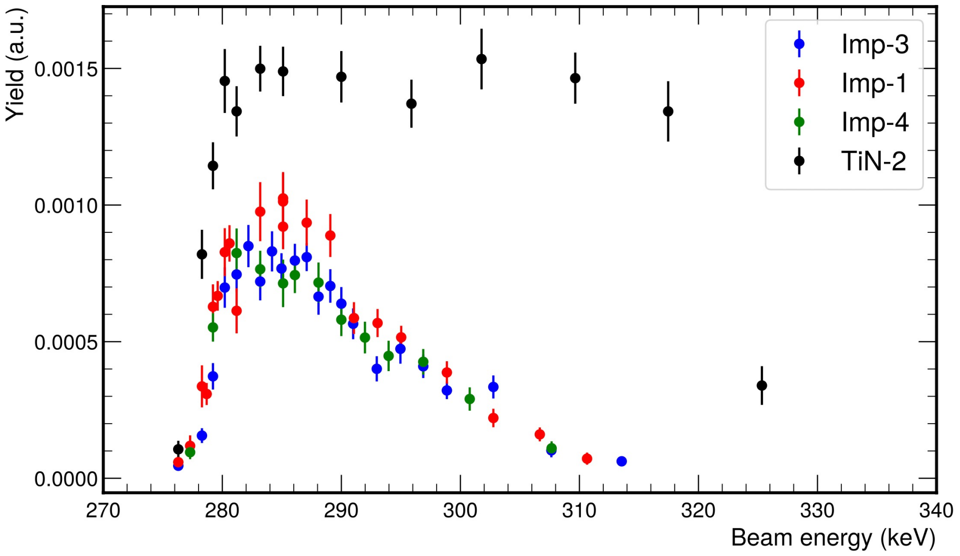
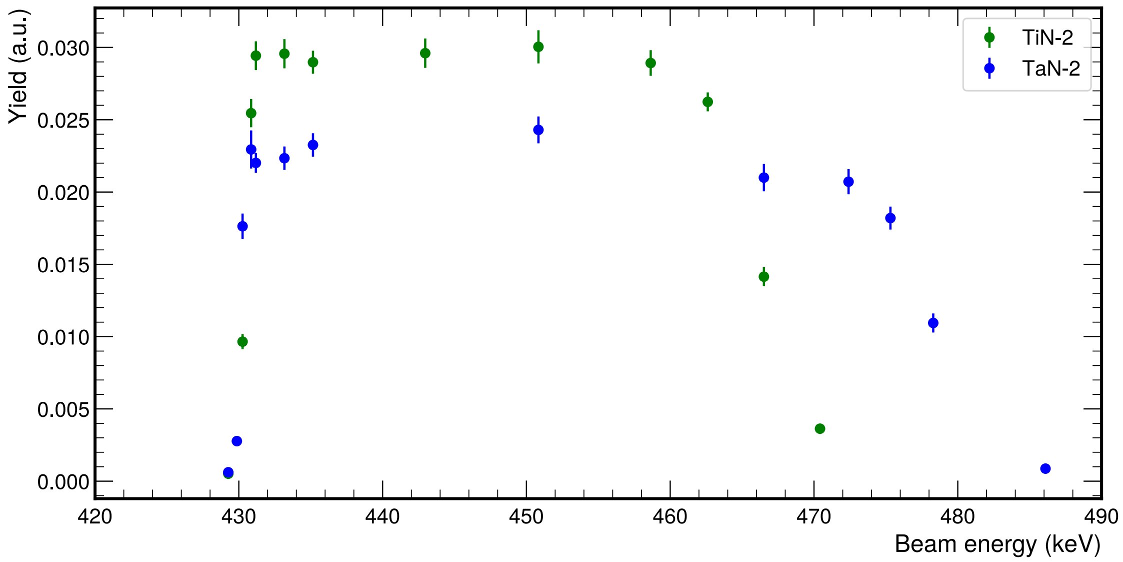
Solid Targets characterization

- Characterization campaigns performed to study target thickness, stability and beam-induced background.
- Atomki Tandetron, Hungary:
  - **278 keV ^{14}N** resonance scan
  - **429 keV ^{15}N** resonance scan





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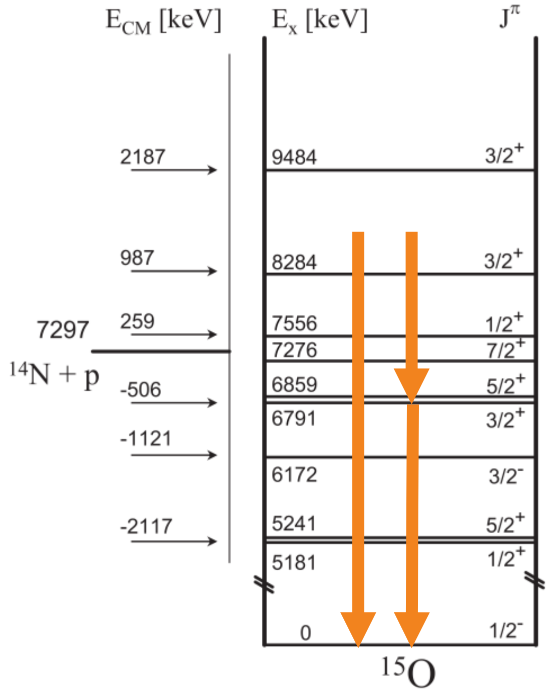
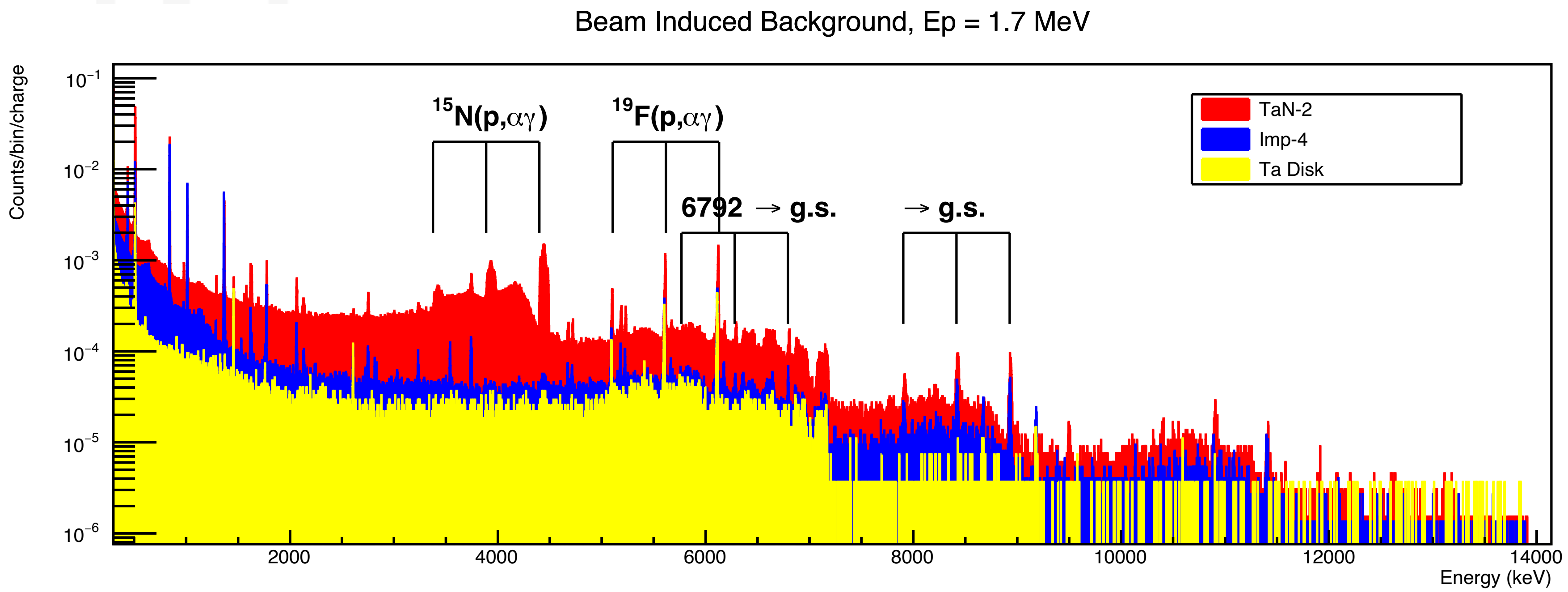
Solid Targets characterization

- Characterization campaigns performed to study target thickness, stability and beam-induced background.
- Atomki Tandetron, Hungary:
  - **Beam induced background runs at 1.7 MeV**: Implanted and sputtered targets vs. Ta Backing

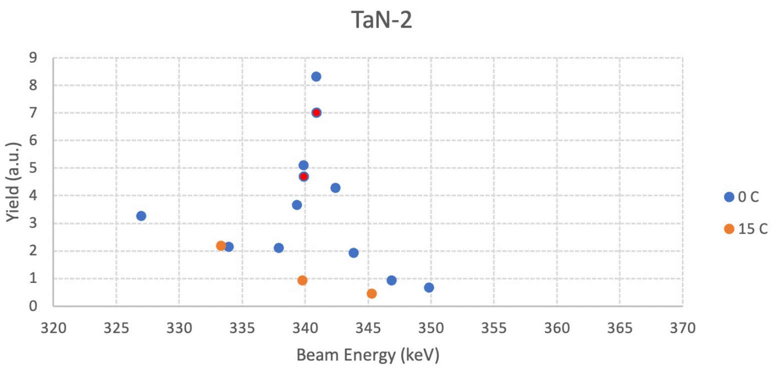




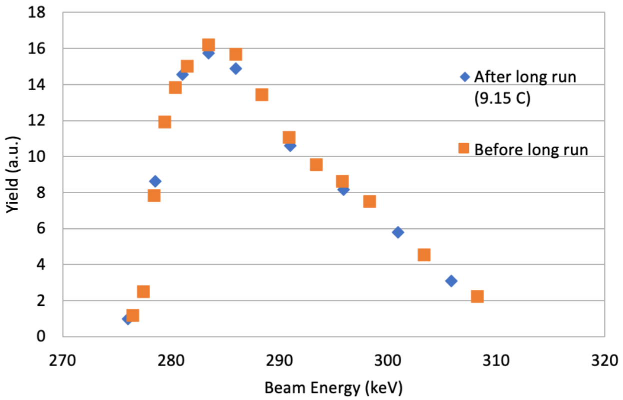
Solid Targets characterization

- Characterization campaigns performed to study target thickness, stability and beam-induced background.
- LUNA-400, LNGS, BGO Setup:
  - **278 keV ^{14}N** resonance scan
  - **340 keV ^{19}F** resonance
  - **Long Run** to test target stability

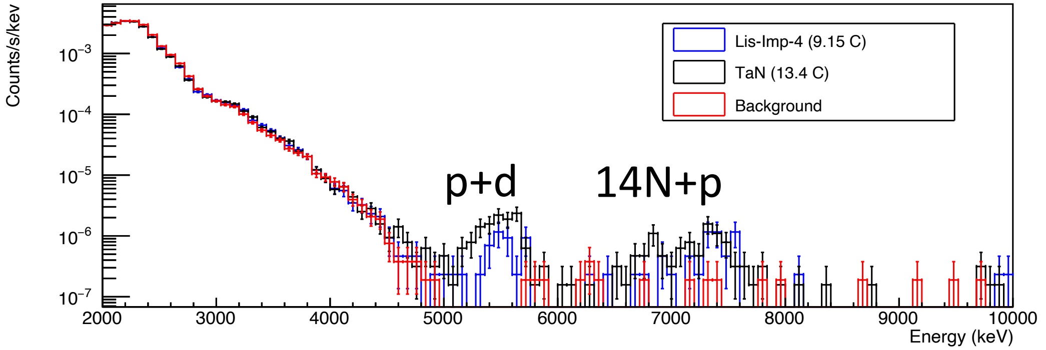
19F yield before and after irradiation



Implanted profile before and after irradiation



4π BGO Sum Spectrum, E_p=100 keV



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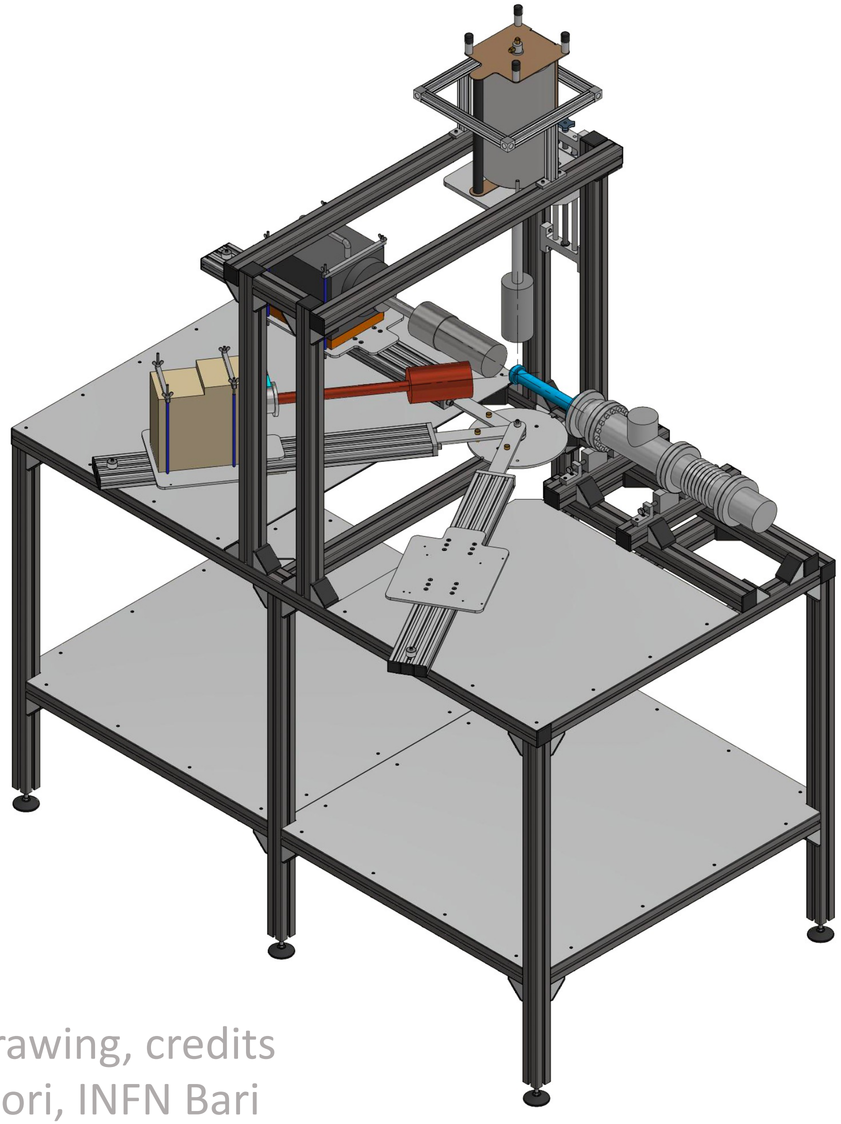
Setup design

- The support structure for the beamline and the detectors will be designed and constructed in collaboration with Bari INFN Mechanical Workshop



preliminary CAD drawing, credits M.Mongelli, C.Pastori, INFN Bari

Outlook

- With the installation phase near conclusion, the accelerator facility is expected to achieve operational readiness by early 2023, scientific commissioning and data taking will follow.
- A renewed measurement of the $^{14}N(p,\gamma)^{15}O$ will provide high-quality data over a wide energy range to address the existing issues between low energy data and higher-energy extrapolation.

Thank you for your attention!