LUNA: present and future of Nuclear Astrophysics at LNGS

GSSI Science Fair
24 February 2025

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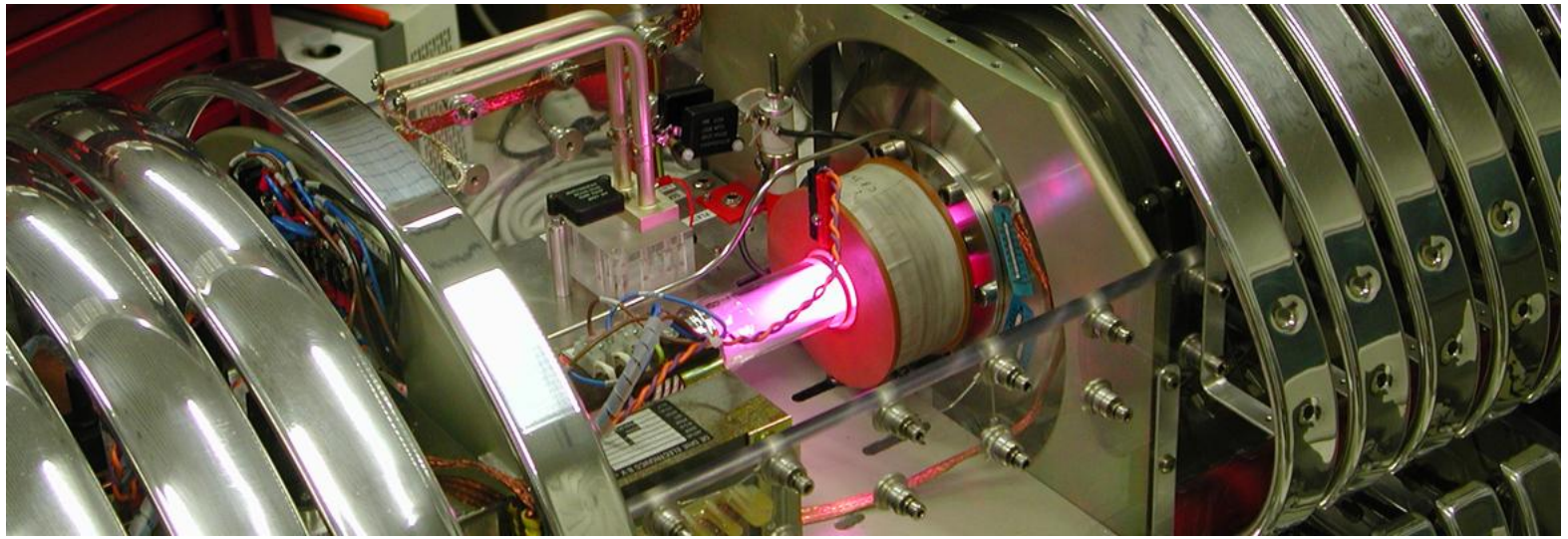
INFN - Laboratori Nazionali del Gran Sasso

LUNA
Laboratory for Underground
Nuclear Astrophysics



has been the only underground accelerator for nuclear astrophysics for over 30 years

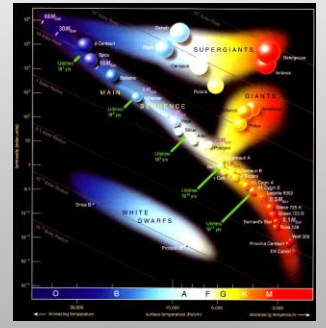
measures **nuclear cross sections** impacting

solar physics (solar neutrinos)
cosmological model (baryon density)
big bang nucleosynthesis (BBN)
stellar nucleosynthesis (H, He, C burning)

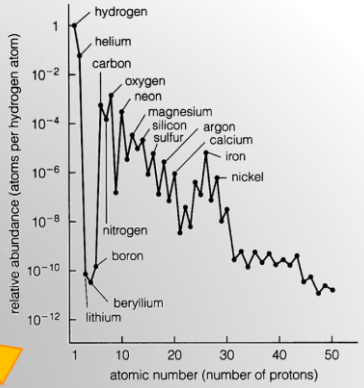
LUNA

Laboratory for Underground Nuclear Astrophysics

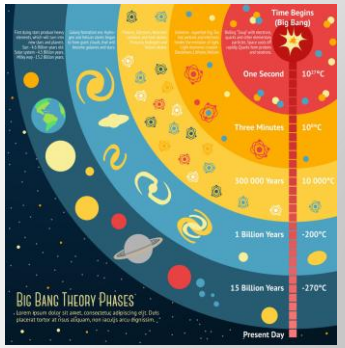
Stellar evolution



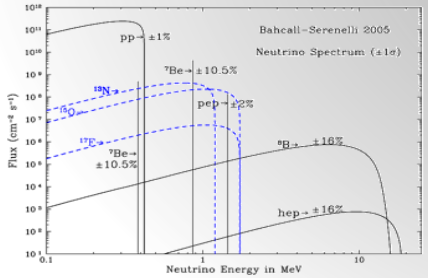
Nucleosynthesis



Evolution of early universe

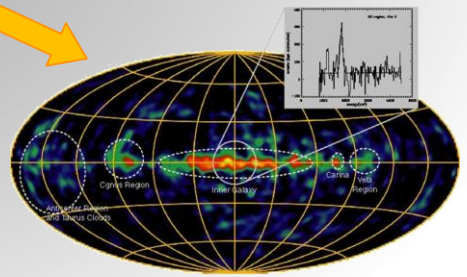


Nuclear cross sections



Solar neutrinos

Solar system



(Oberlack et al., 1996; Pluschke et al., 2001)

Astronomy

How do such nuclear reactions take place?

The energy of nuclei in a plasma follows a **Maxwell-Boltzmann distribution**

the **cross section** falls faster than exponentially as the energy decreases

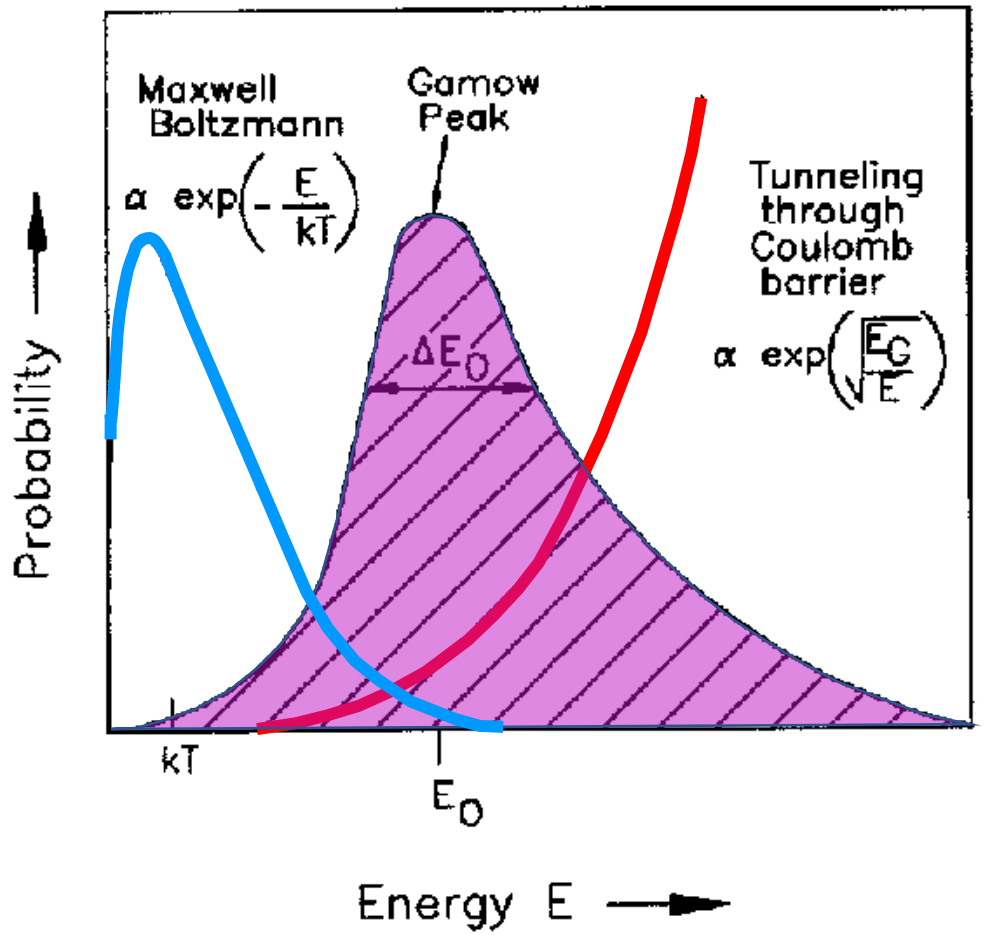
Consider a **reaction**

$$A + B \rightarrow C + D$$

The reaction rate is given by

$$\langle r \rangle = N_A N_B \int_0^\infty \phi(v)\, \sigma(v)\, v\, dv$$

The **Gamow peak** defines the relevant energy range for this reaction to occur



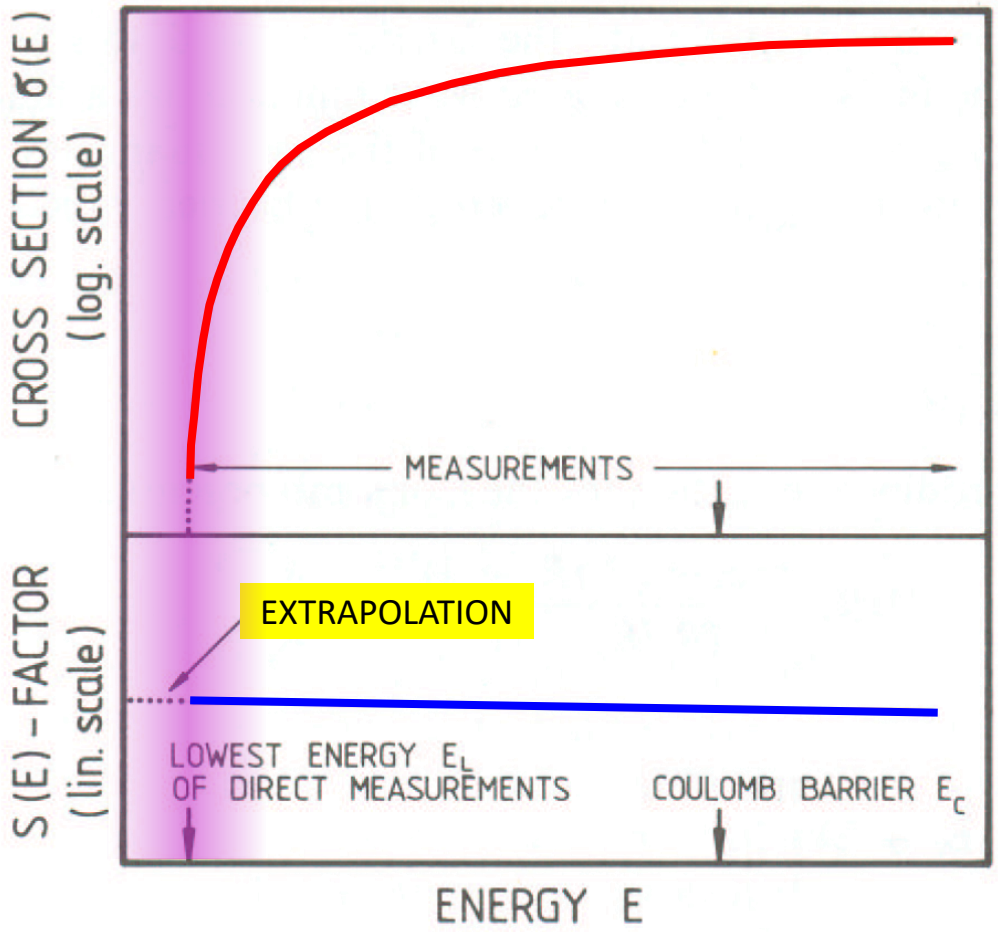
Low energy leads to small cross section…

Below a certain energy, the counting rate is too low and the cosmic-ray induced background prevents the direct measurement of the cross section

Introducing the **astrophysical S-factor S(E)** and factorizing the **Coulomb interaction term** apart:

$$\sigma(E) = \frac{1}{E} e^{-2\pi\eta} S(E)$$

it is possible to measure the cross section at high energy and extrapolate the astrophysical factor *S(E)* in the interesting energy range (Gamow window)



…small cross section leads to rare events…

Below a certain energy, the counting rate is too low and the cosmic-ray induced background prevents the direct measurement of the cross section

Introducing the **astrophysical S-factor S(E)** and factorizing the **Coulomb interaction term** apart:

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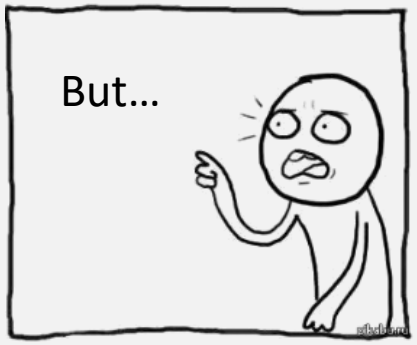
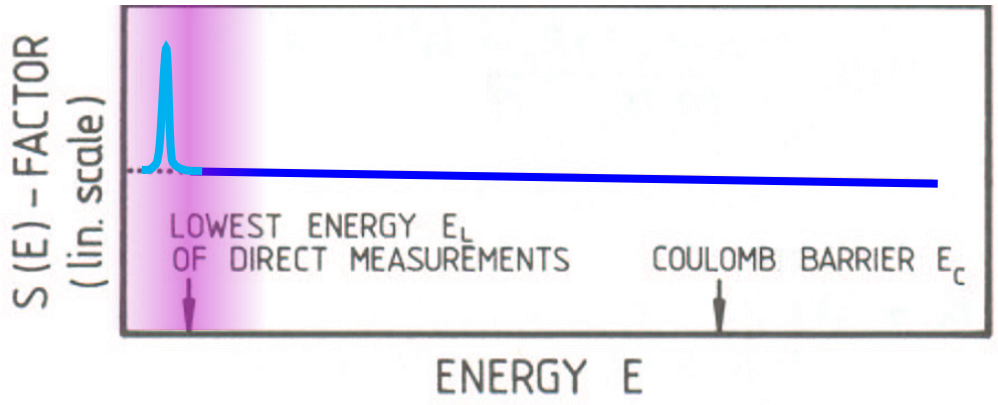
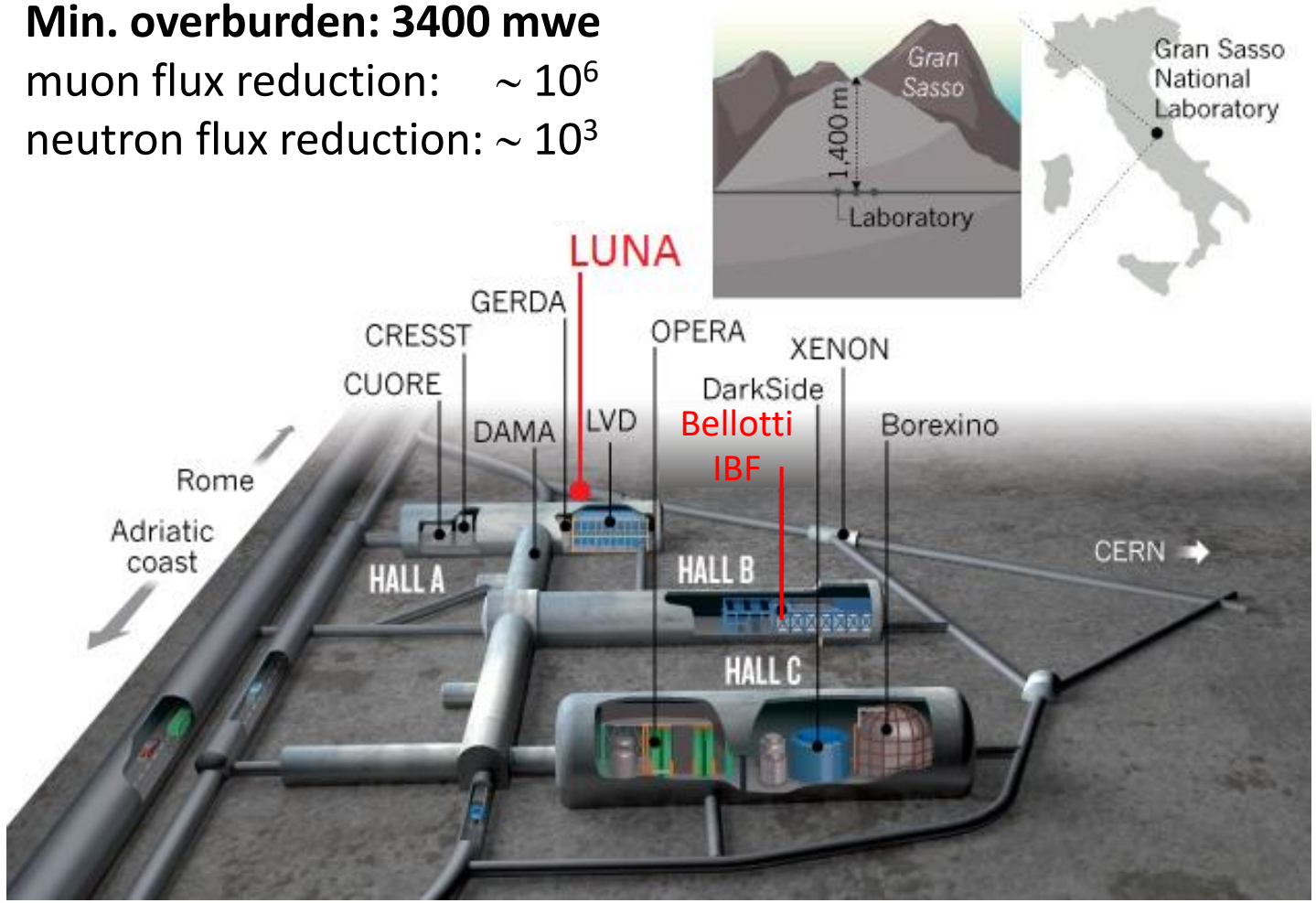


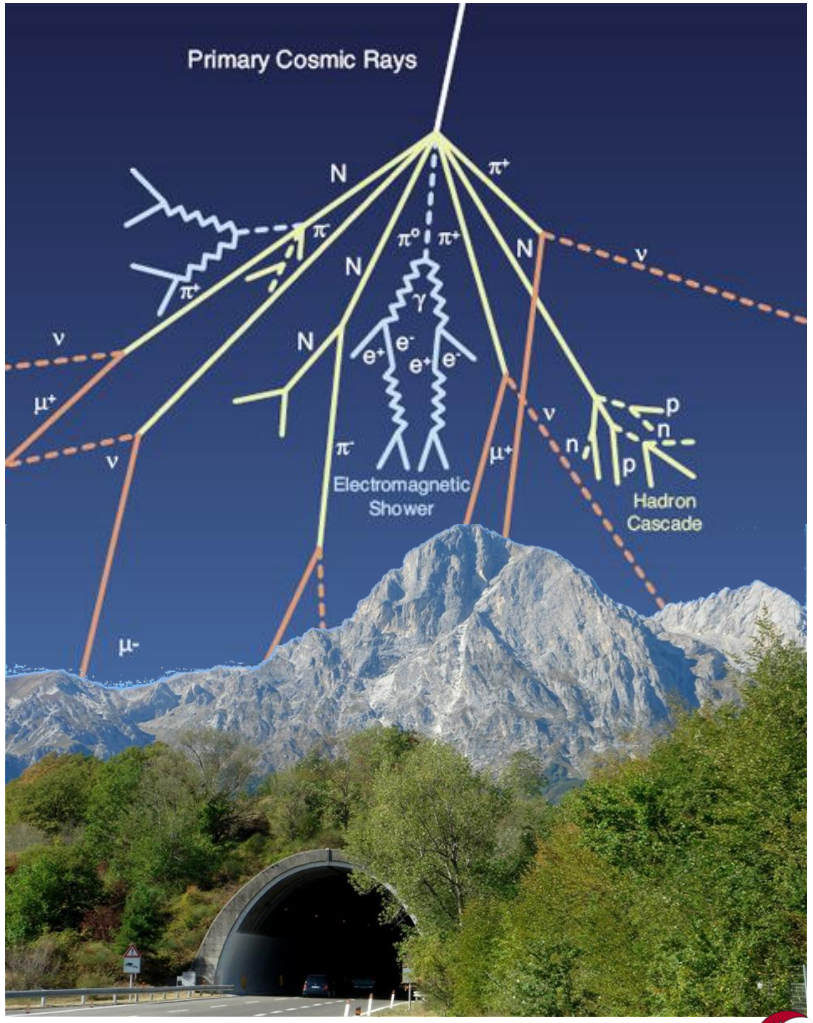
unexpected low-energy resonances may be present in the extrapolation region!



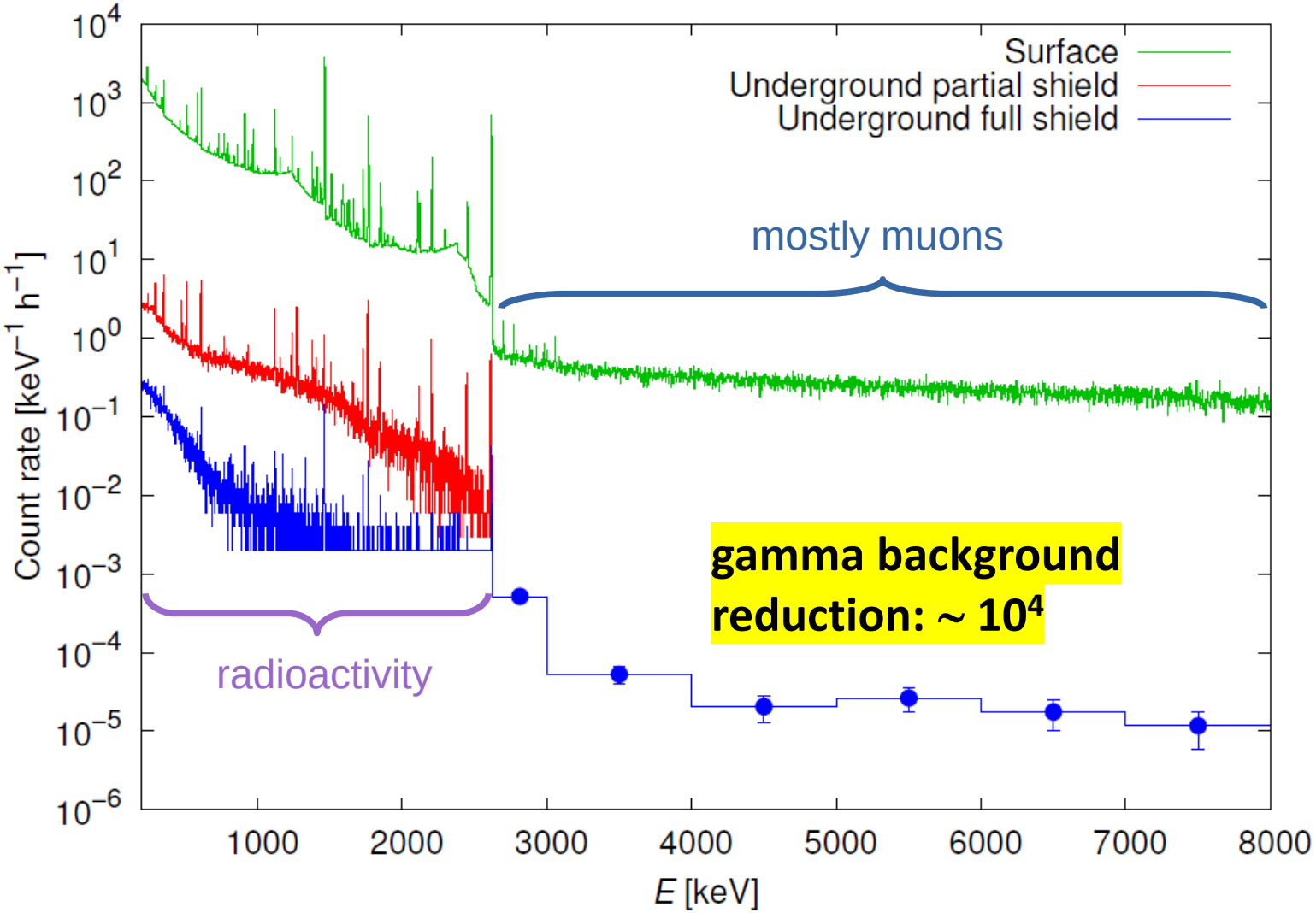
The Gran Sasso National Laboratory (LNGS)

Min. overburden: 3400 mwe
muon flux reduction: ~ 10^6
neutron flux reduction: ~ 10^3



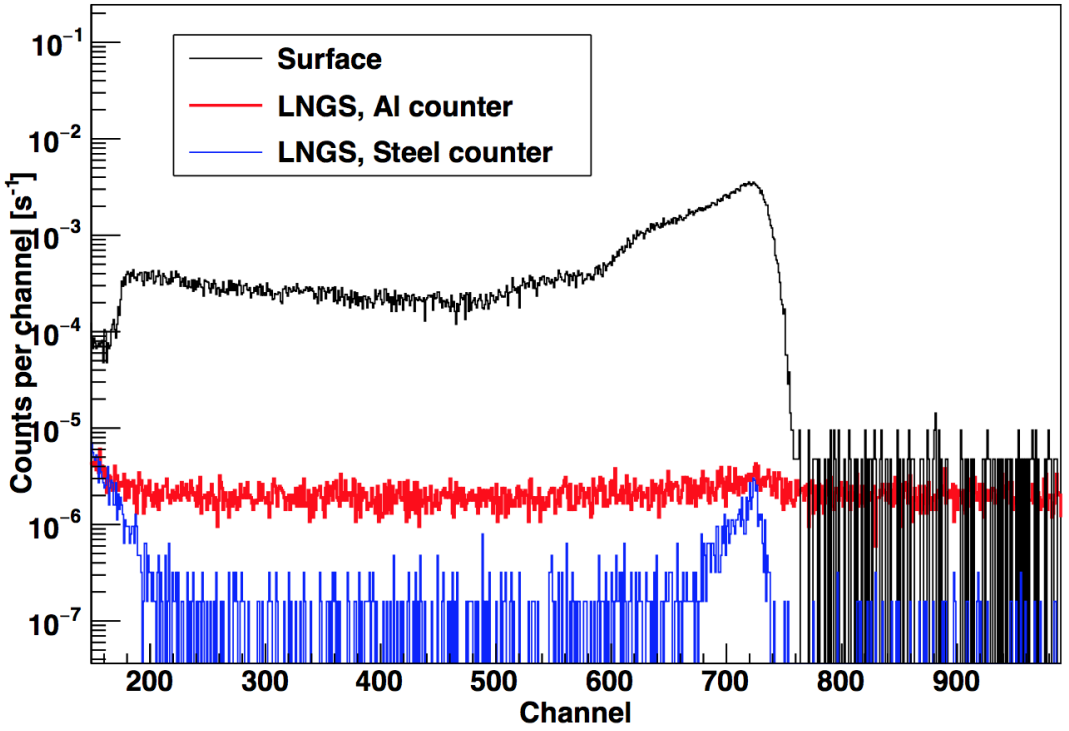


Gamma background reduction @ LNGS

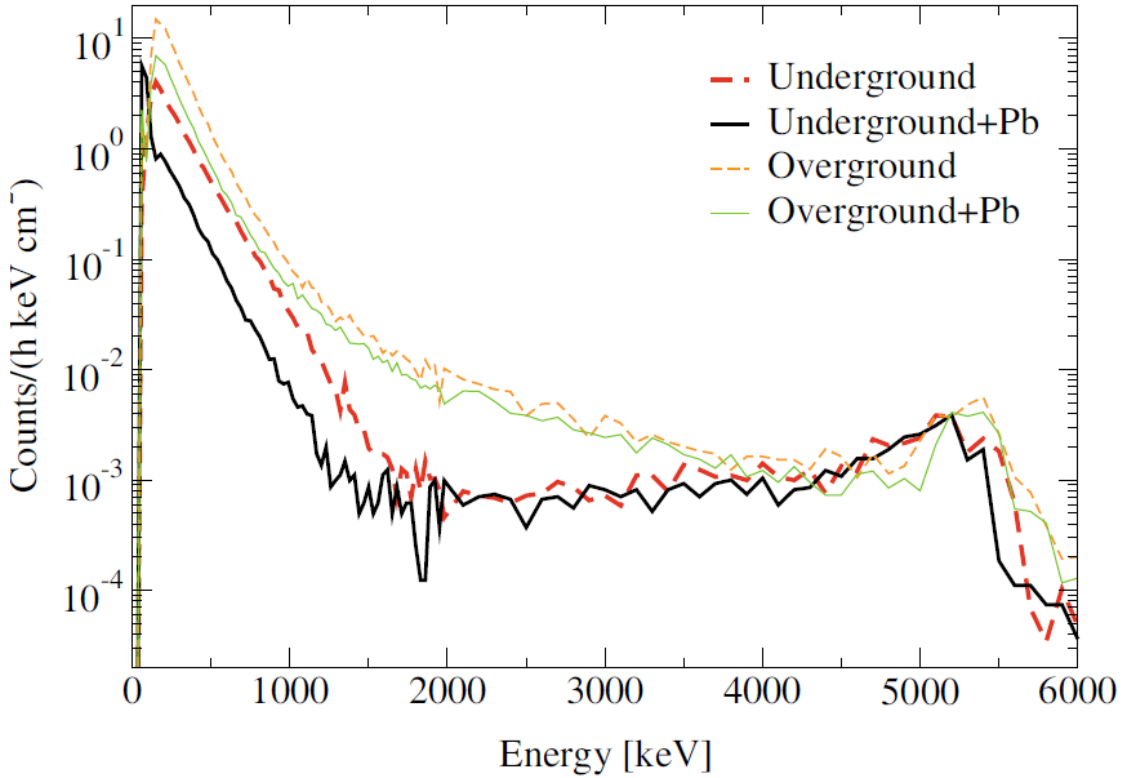


Particle background reduction @ LNGS

Neutrons

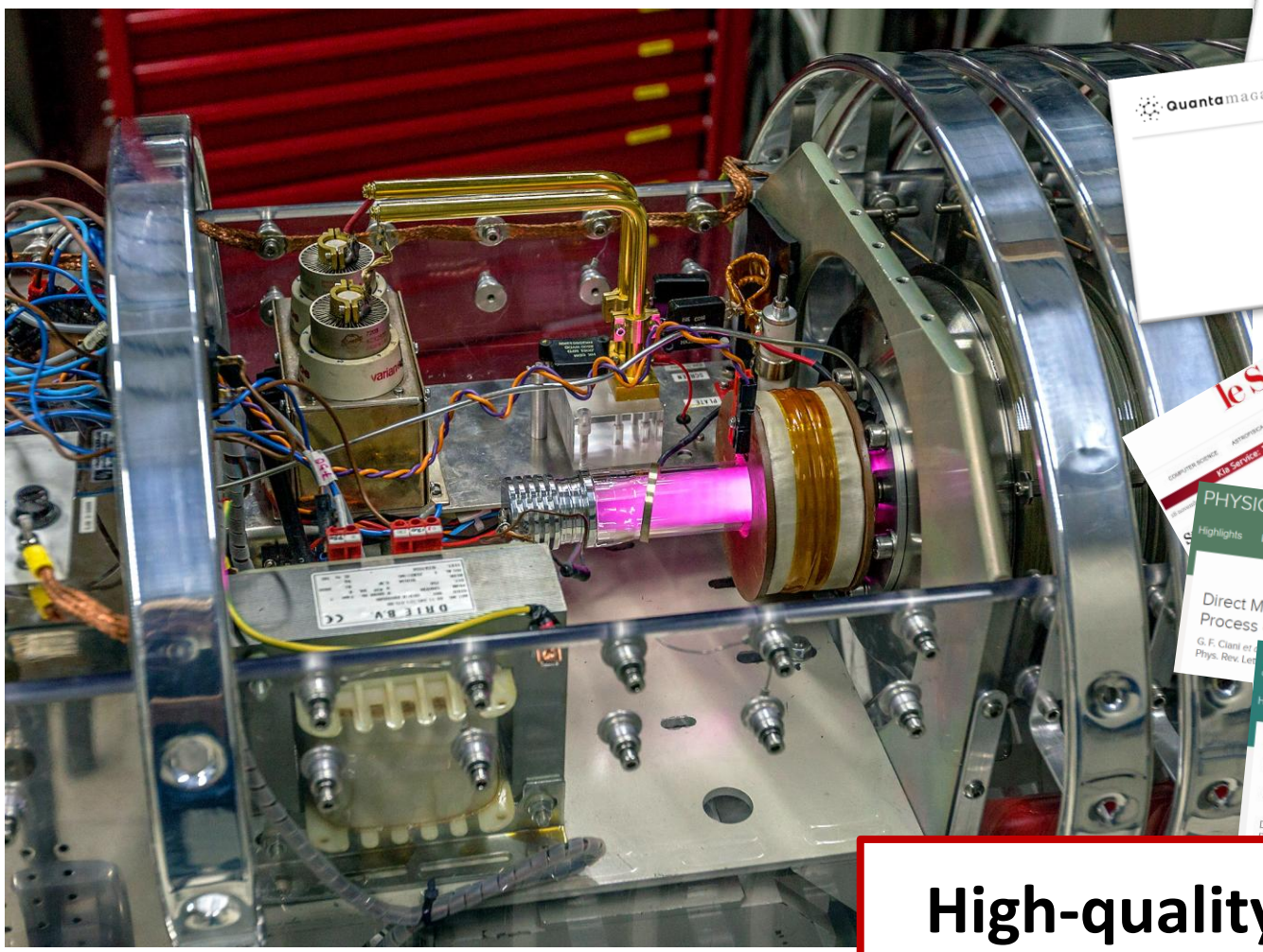


Charged particles



LUNA 400 kV

84 papers in 30 years
(2.8 papers/year)



High-quality scientific output and fallout

LUNA @ Bellotti Ion Beam Facility

Scientific program

LUNA will aim to shed light on the **advanced stages of stellar nucleosynthesis** using the new LUNA-MV accelerator at the Ion Beam Facility of LNGS

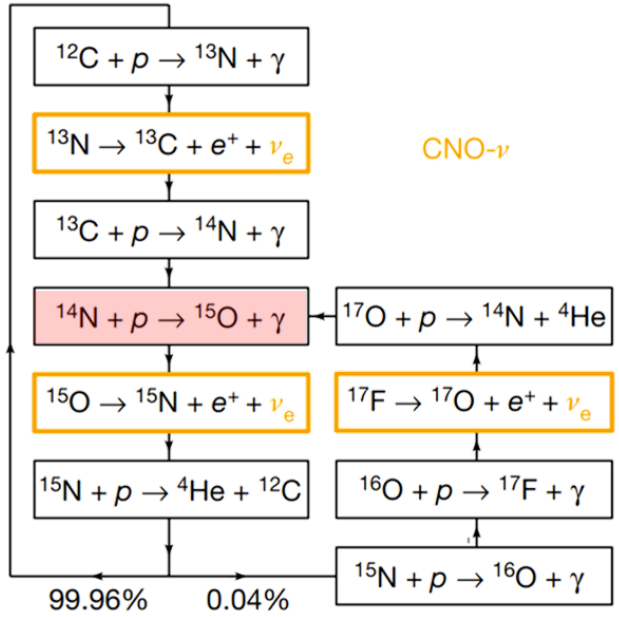
^{14}N(p,γ)^{15}O: bottleneck of the CNO cycle

^{22}Ne(α,n)^{25}Mg: neutron source for the s-process in AGB and massive stars

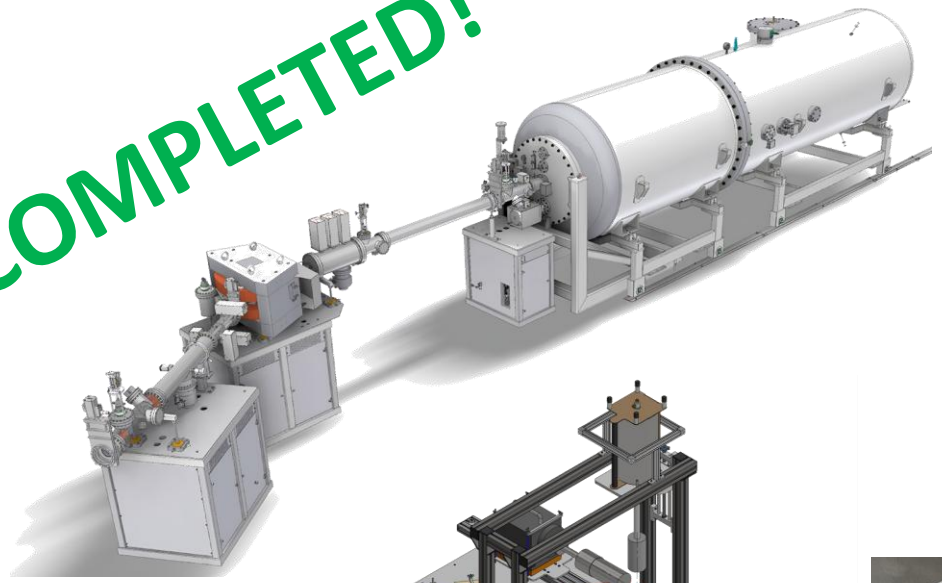
^{12}C+^{12}C: trigger of C burning in the stars

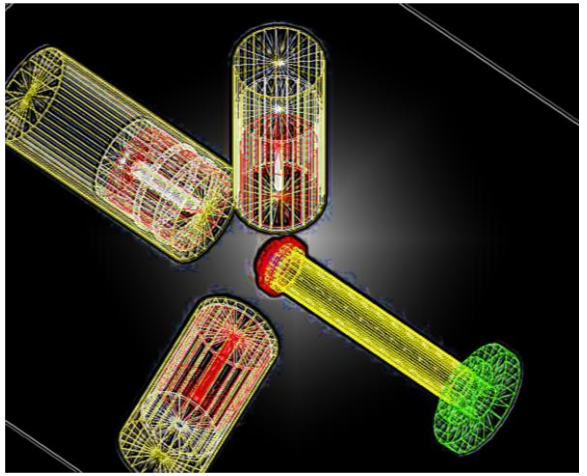
Lots of activities going on at LNGS!

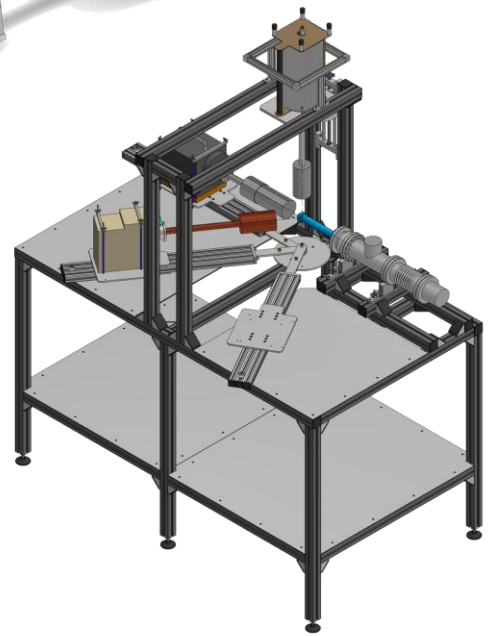
$^{14}N(p,\gamma)^{15}O$: bottleneck of the CNO cycle



COMPLETED!







PhD student on this topic

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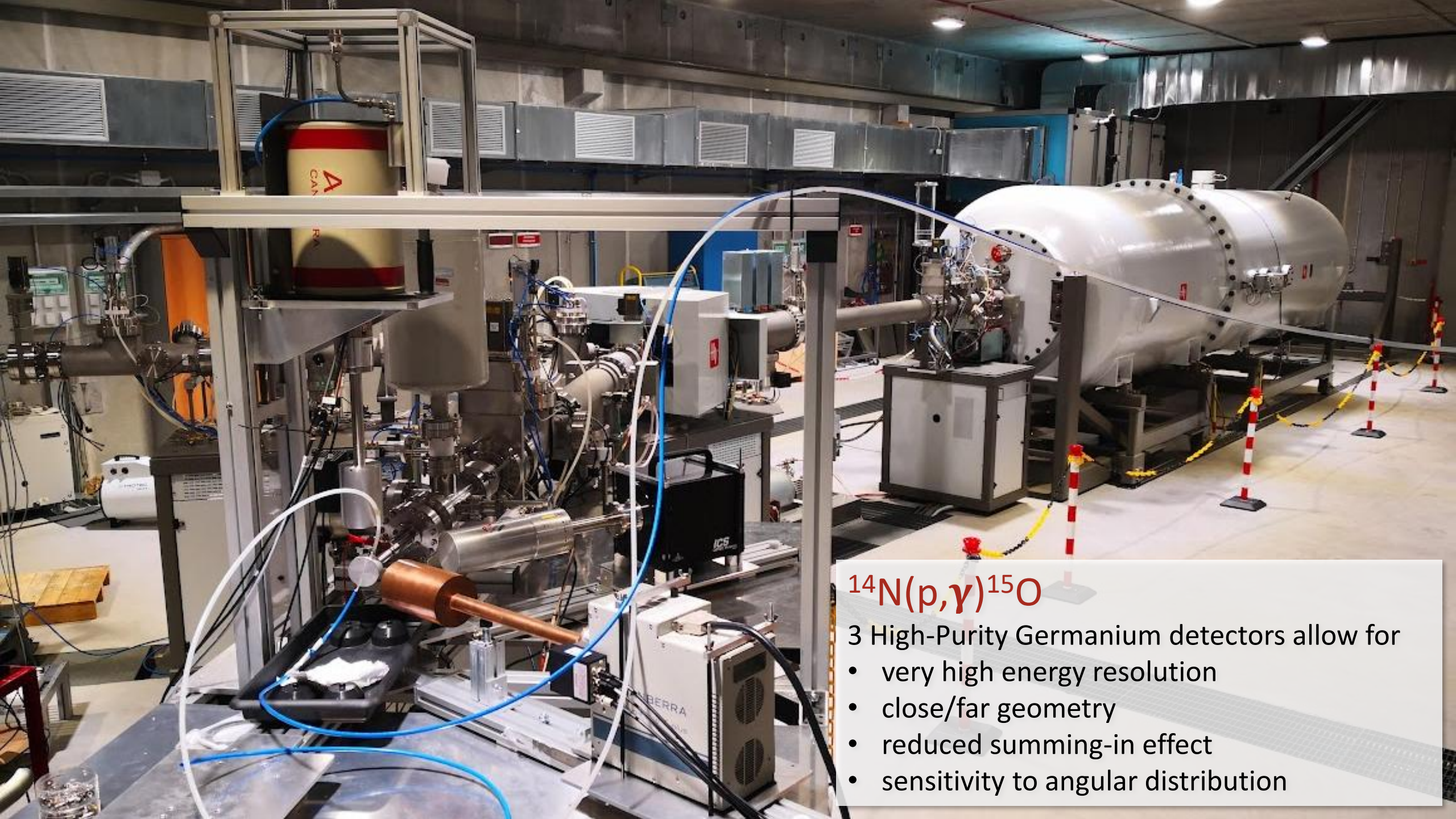
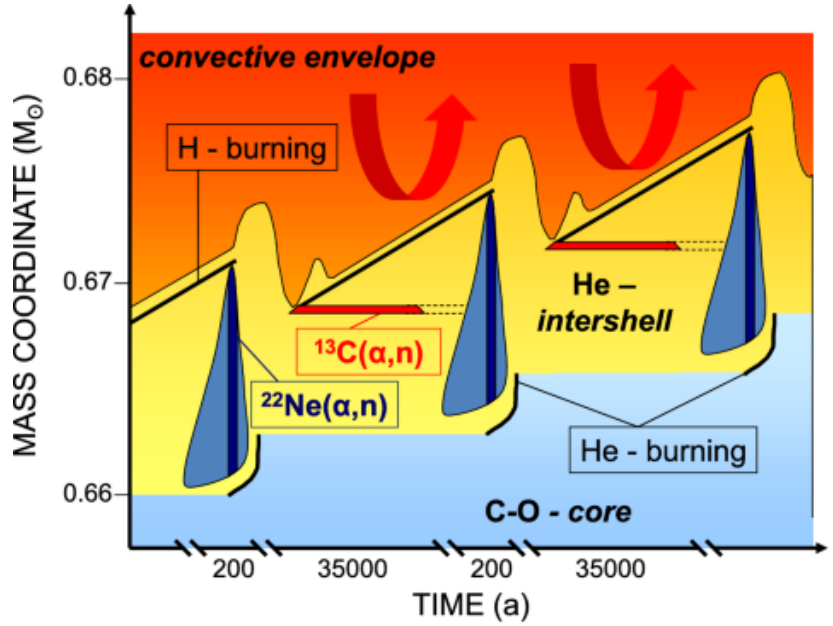


$^{14}N(p,\gamma)^{15}O$

3 High-Purity Germanium detectors allow for

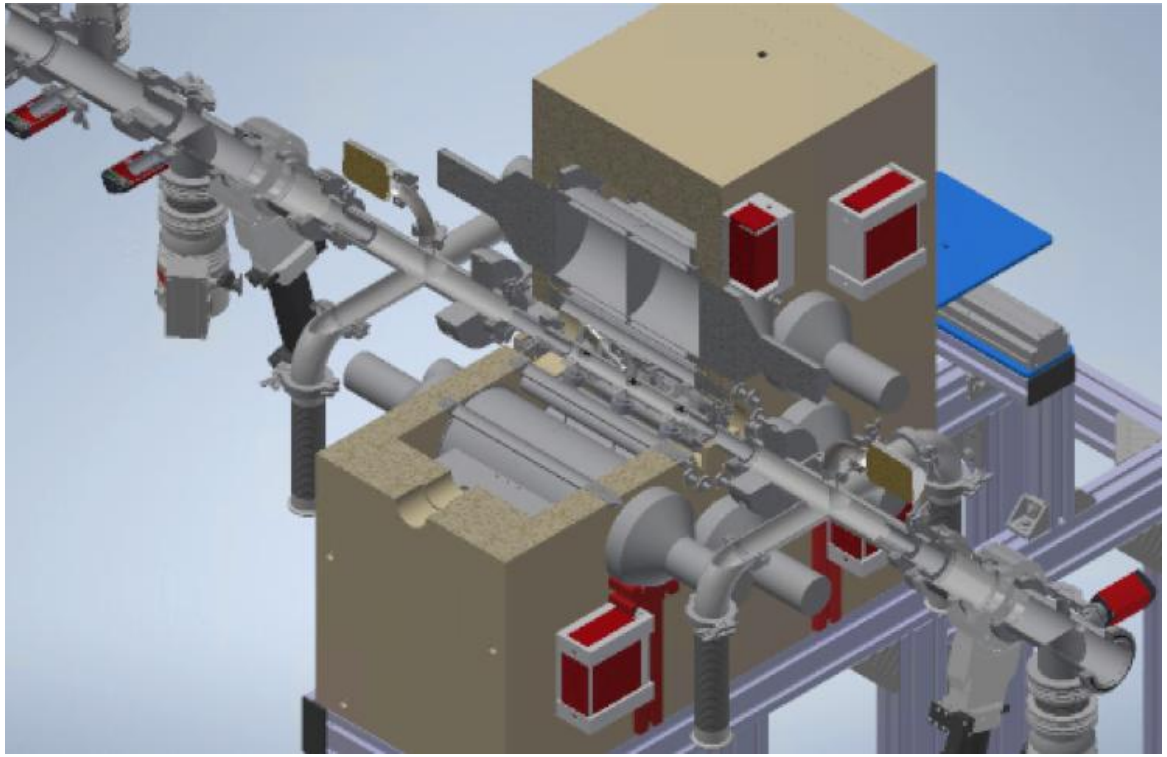
- very high energy resolution
- close/far geometry
- reduced summing-in effect
- sensitivity to angular distribution

$^{22}Ne(\alpha,n)^{25}Mg$: neutron source for the s-process



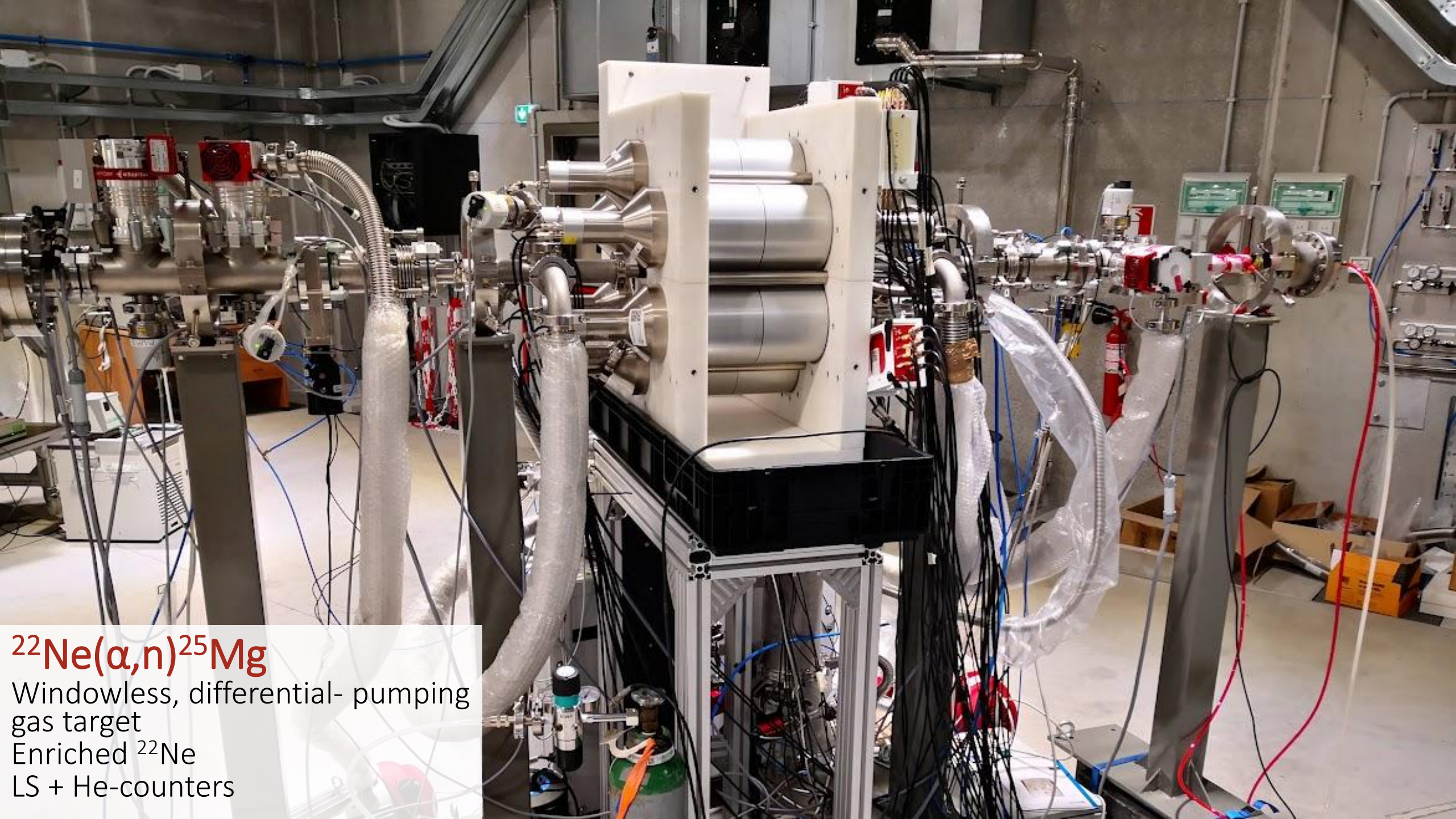
^{3}He + LS neutron detector (high efficiency + spectrometry)

Windowless, differential pumping gas target with RBS beam current reading



ERC starting grant

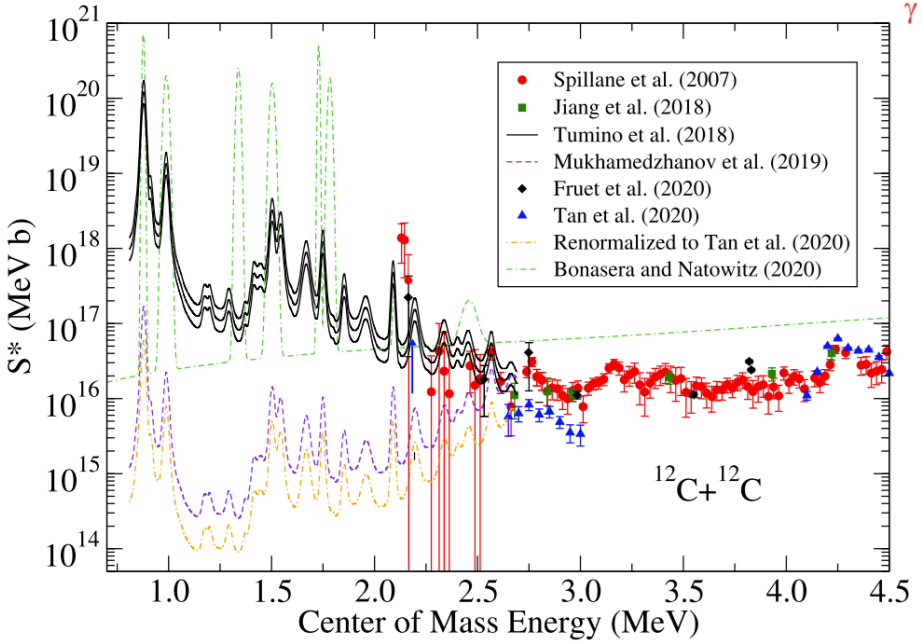
Andreas Best
(UNINA)



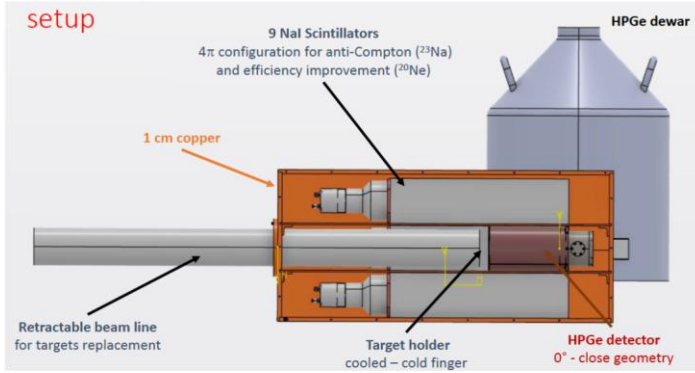
$^{22}Ne(\alpha,n)^{25}Mg$

Windowless, differential- pumping gas target
Enriched ^{22}Ne
LS + He-counters

$^{12}C+^{12}C$: trigger of C burning in the stars



γ measurement setup



PhD student on this topic

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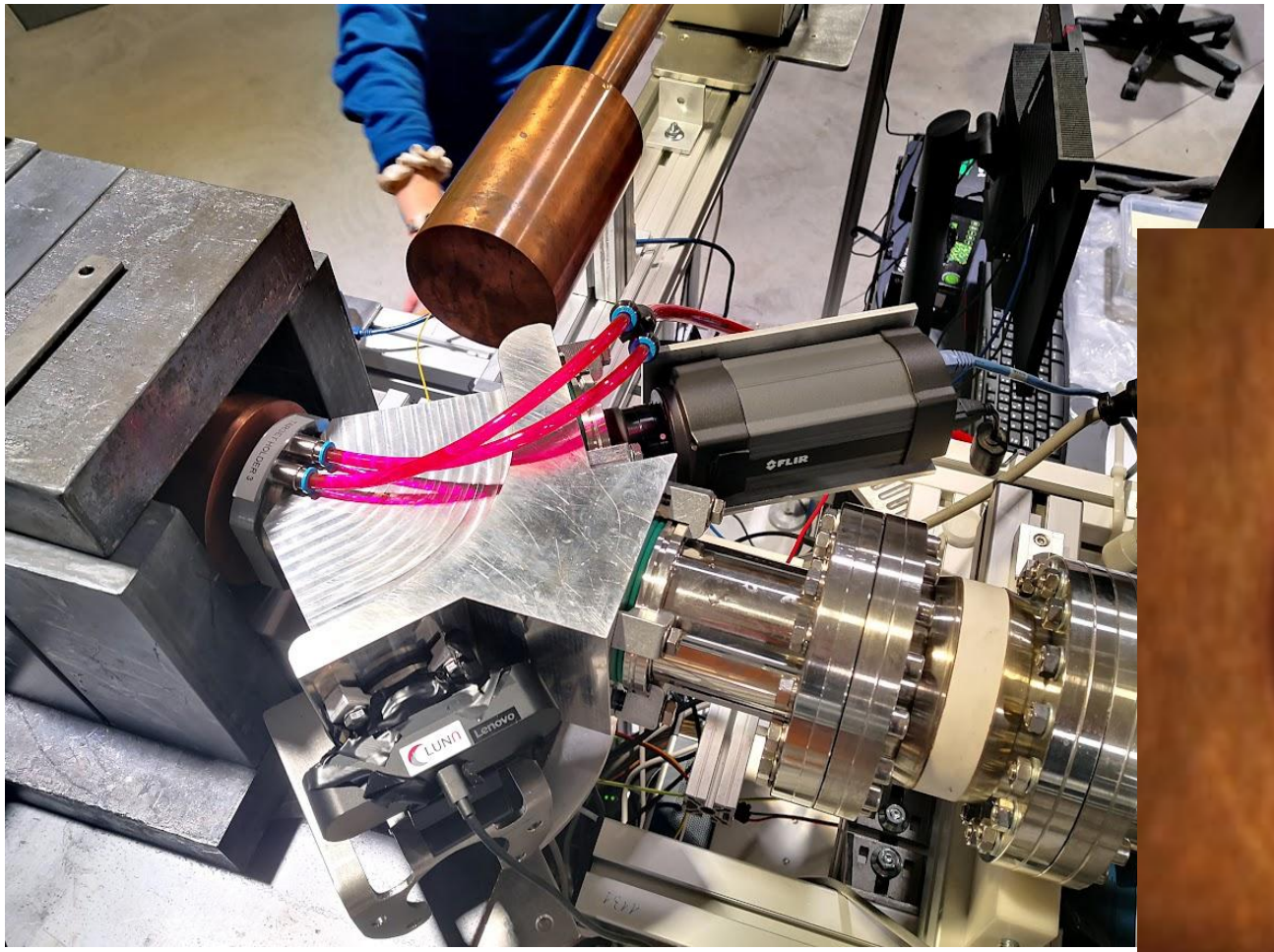
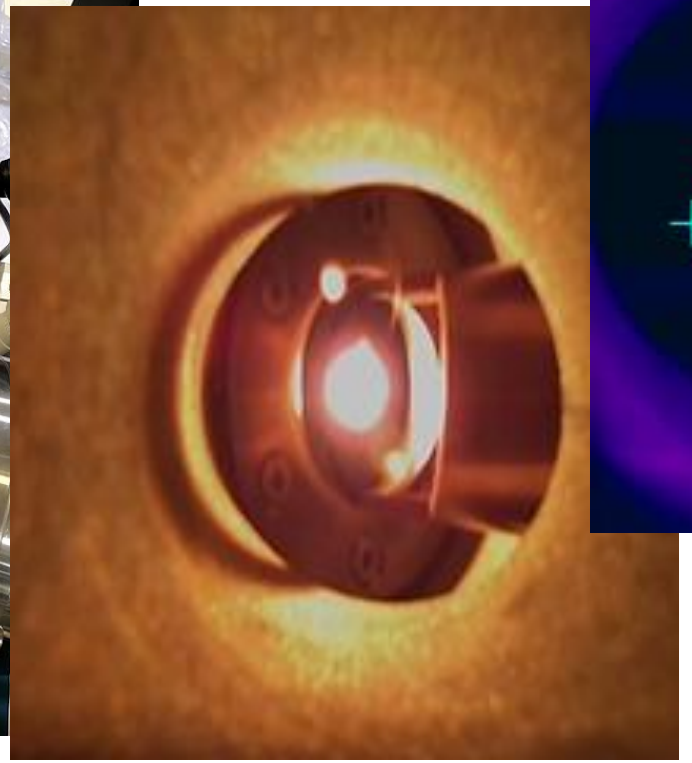
Beam line and shielding installed last week

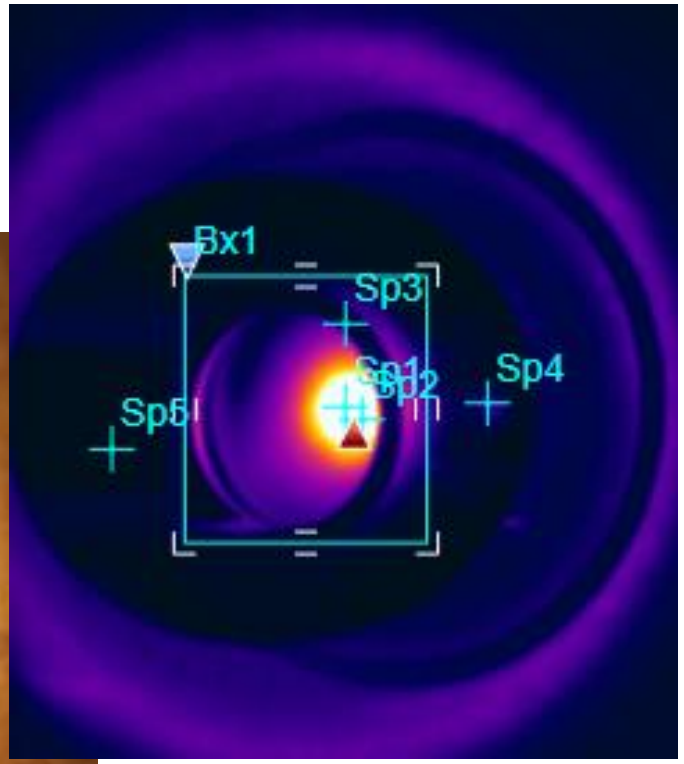
Data taking will start in April (sources)

Beam on target in May/June

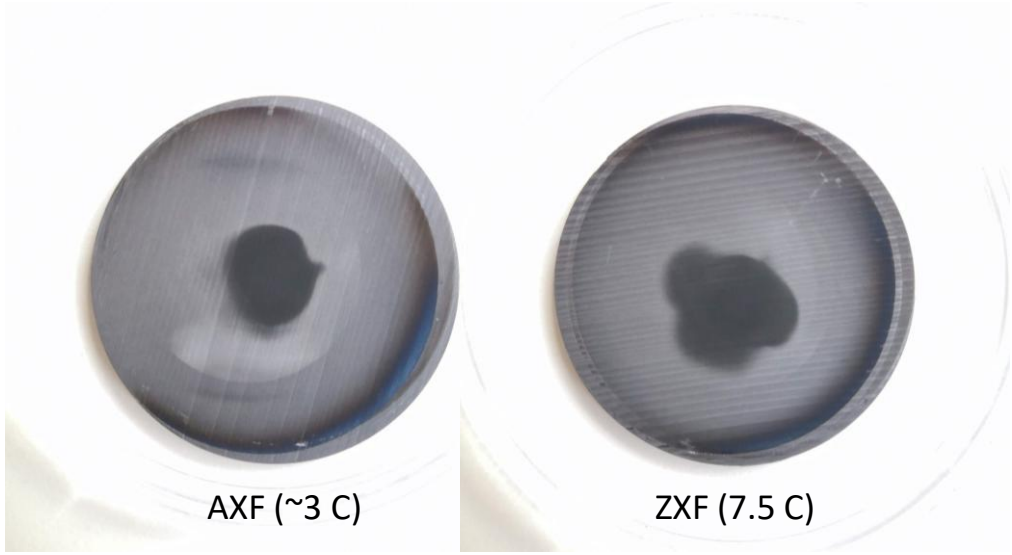
$^{12}C+^{12}C$: tests on targets

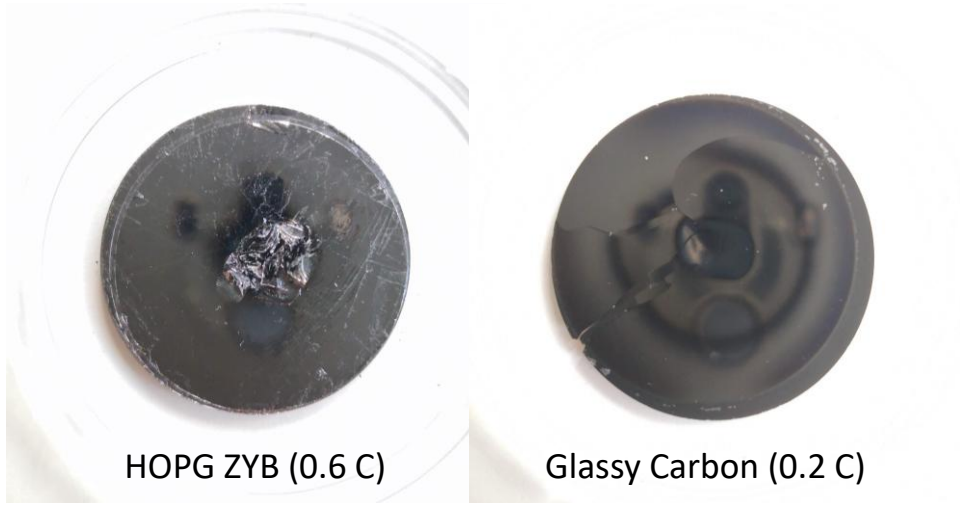


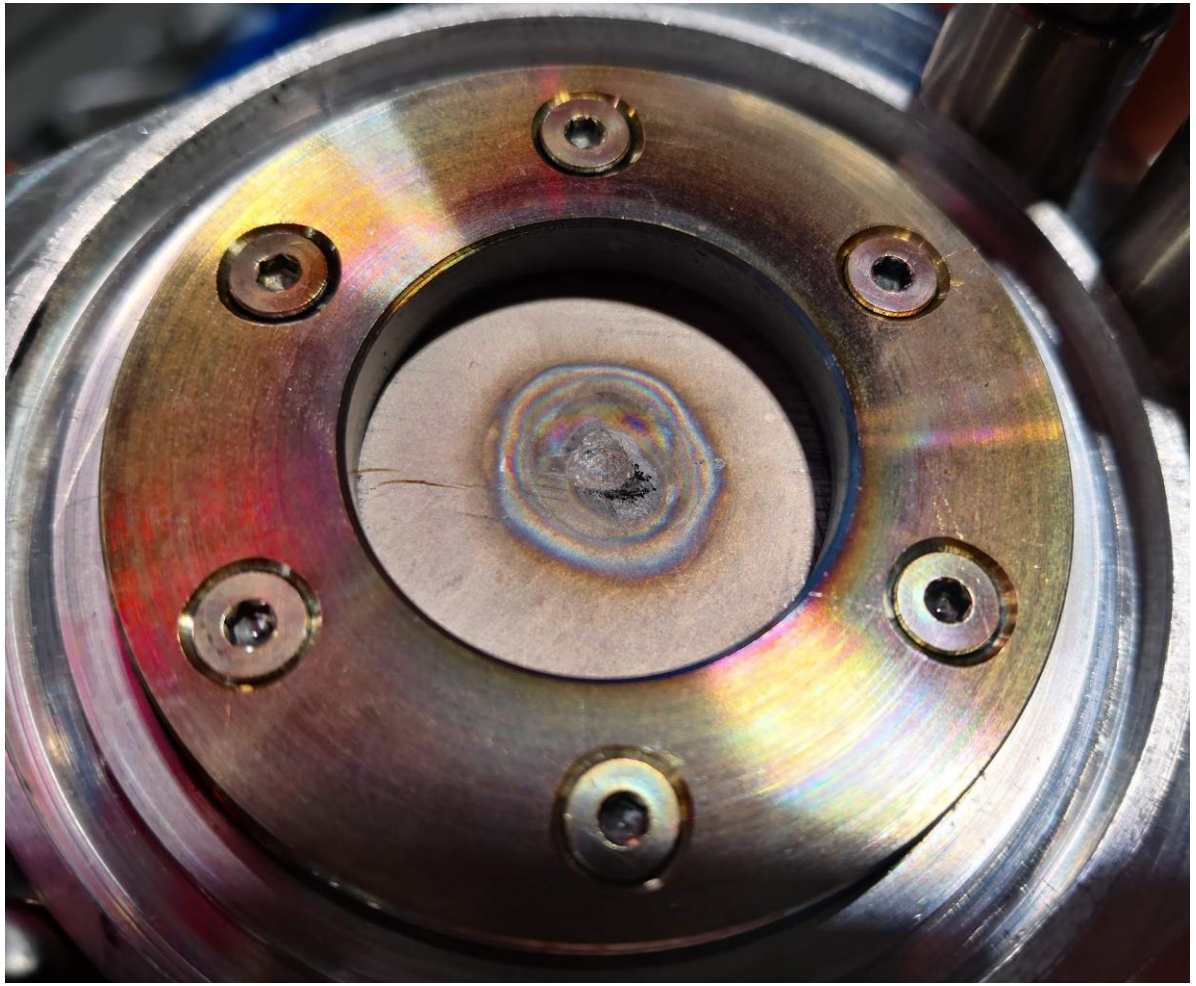




$^{12}C+^{12}C$: tests on targets







The LUNA collaboration

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People on site

Interested? Come talk to us!

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Dipali Basak

Donatello Ciccotti

Poster

Riccardo Gesué

Massimo Orsini