

The LUNA-MV project at Gran Sasso Laboratory

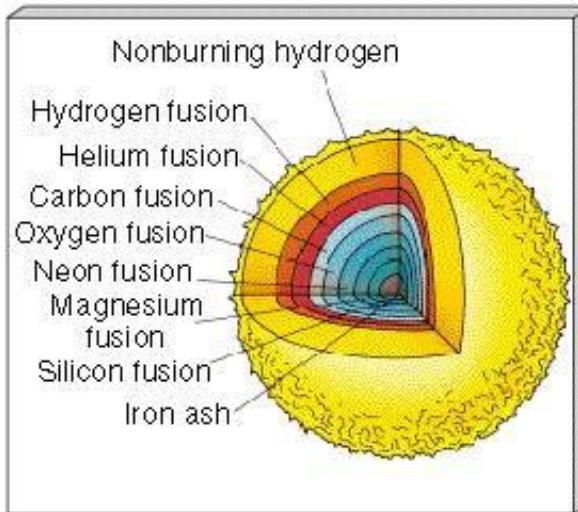
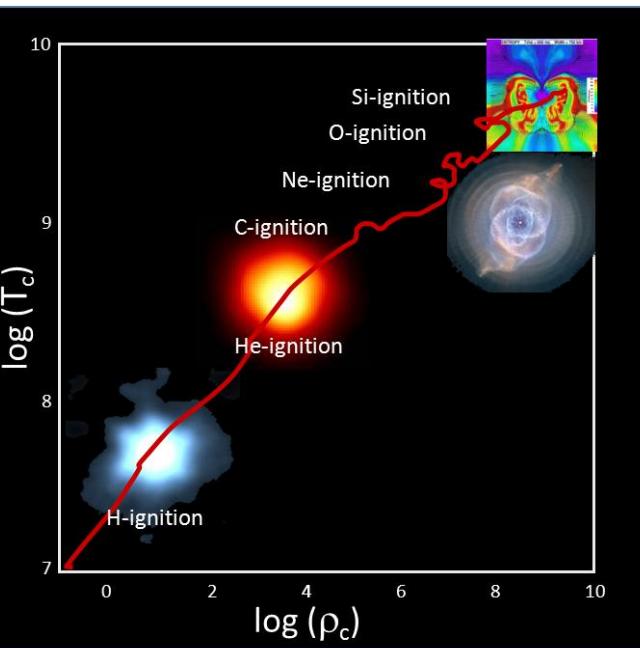
Alessandra Guglielmetti

Universita' degli Studi di Milano and
INFN, Milano, ITALY

Outline:

- Nuclear Fusion reactions in stars: why measuring their cross section?
- Why going underground: the LUNA experiment
- The LUNA-MV project

Why studying nuclear fusion reaction cross sections?



- Stars are powered by nuclear reactions
- Among the key parameters (chemical composition, opacity, etc.) to model stars, reaction cross sections play an important role

- They determine the origin of elements in the cosmos, stellar evolution and dynamic

- Many reactions ask for high precision data.

Sun

Luminosity = $2 \cdot 10^{39}$ MeV/s

Q-value (H burning) = 26.73 MeV

Reaction rate = $10^{38} s^{-1}$

Laboratory

$$R_{\text{lab}} = N_p N_t \sigma \varepsilon$$

N_p = number of projectile ions $\approx 10^{14}$ pps ($100 \mu A$ $q=1^+$)

N_t = number of target atoms $\approx 10^{19}$ at/cm 2

σ = cross section = 10^{-15} barn (at astrophysical energies)

ε = efficiency $\approx 100\%$ for charged particles
1% for gamma rays

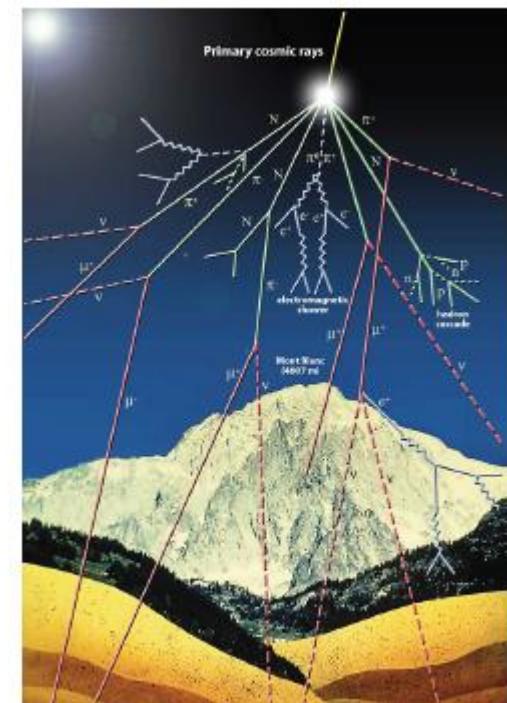
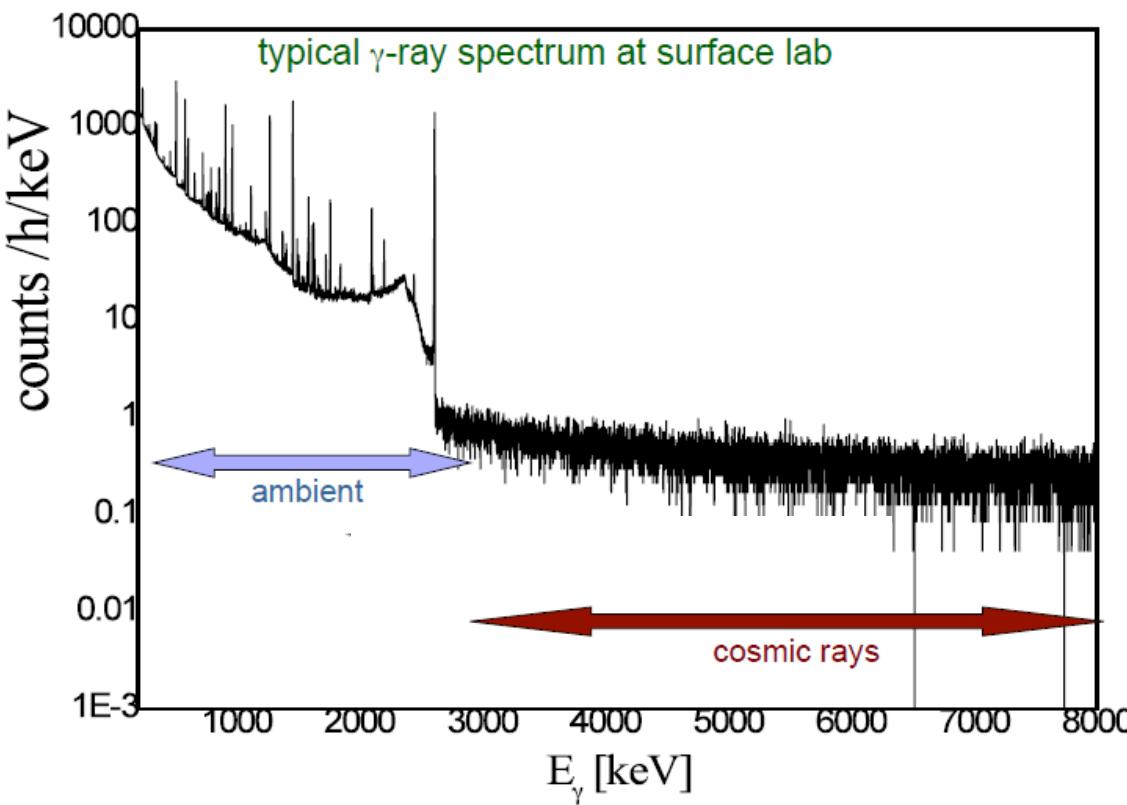
$R_{\text{lab}} \approx 0.3\text{-}30$ counts/year

$$R_{\text{lab}} > B_{\text{beam induced}} + B_{\text{env}} + B_{\text{cosmic}}$$

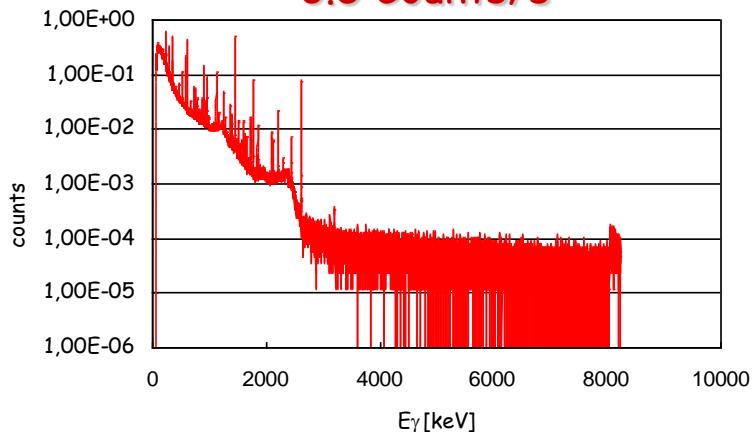
$B_{\text{beam induced}}$: reactions with impurities in the target
reactions on beam collimators/apertures

B_{env} : natural radioactivity mainly from U and Th chains

B_{cosmic} : mainly muons

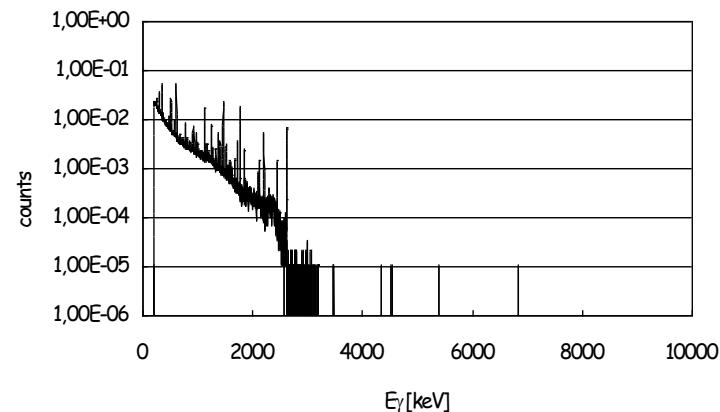


$3\text{MeV} < E_{\gamma} < 8\text{MeV}$:
0.5 Counts/s



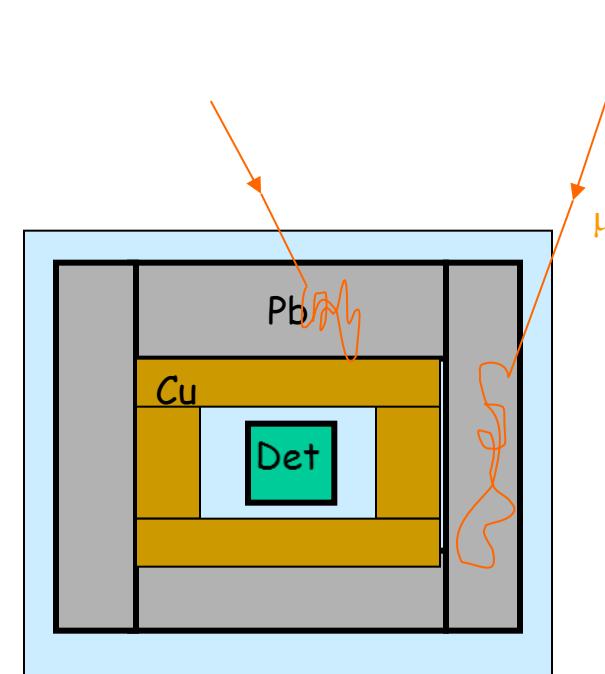
HpGe
GOING
UNDERGROUND

$3\text{MeV} < E_{\gamma} < 8\text{MeV}$
0.0002 Counts/s



$E_{\gamma} < 3\text{MeV} \rightarrow$ passive shielding for environmental background radiation

underground passive shielding is more effective since μ flux, that create secondary γ 's in the shield, is suppressed





Laboratory for Underground Nuclear Astrophysics

LNGS

(1400 m rock shielding \equiv 4000 m w.e.)

LUNA MV
(2012->...)

LUNA 1
(1992-2001)
50 kV

LUNA 2
(2000->...)
400 kV

Radiation

Muons
Neutrons

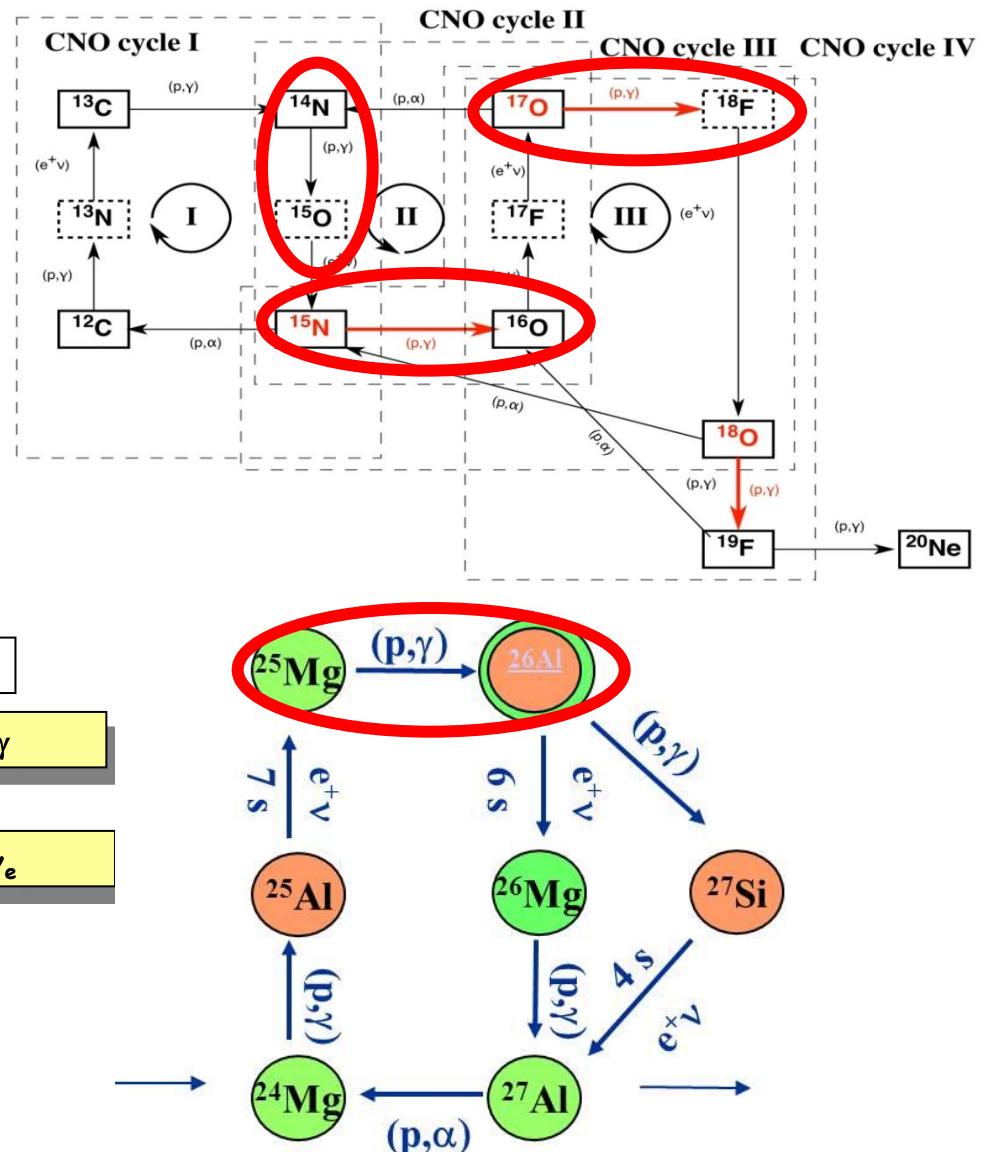
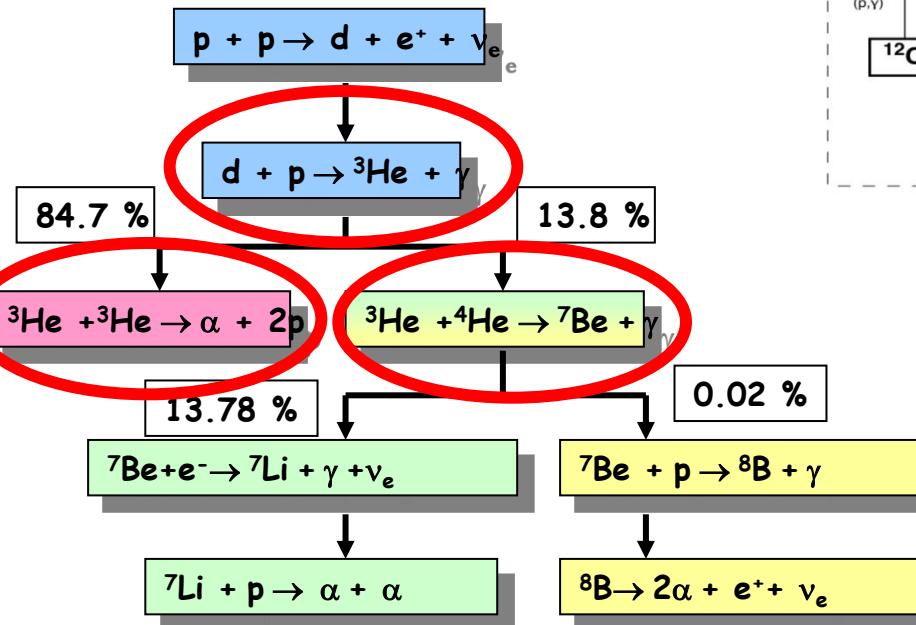
10^{-6}
 10^{-3}

LNGS/surface

Hydrogen burning

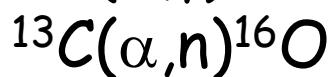


pp chain



LUNA MV Project

April 2007: a Letter of Intent (LoI) was presented to the LNGS Scientific Committee (SC) containing key reactions of the He burning and neutron sources for the s-process:



(α, γ) reactions on $^{14,15}\text{N}$ and ^{18}O

These reactions are relevant at higher temperatures (larger energies) than reactions belonging to the hydrogen-burning studied so far at LUNA

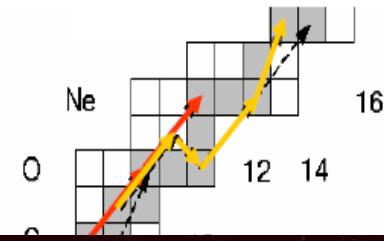


Higher energy machine \rightarrow 3.5 MV single ended positive ion accelerator

$^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ - Holy Grail of Nuclear Astrophysics

Stellar Helium burning in Red Giant Stars

the He burning is ignited on the ^4He and ^{14}N ashes of the preceding hydrogen burning phase (pp and CNO)



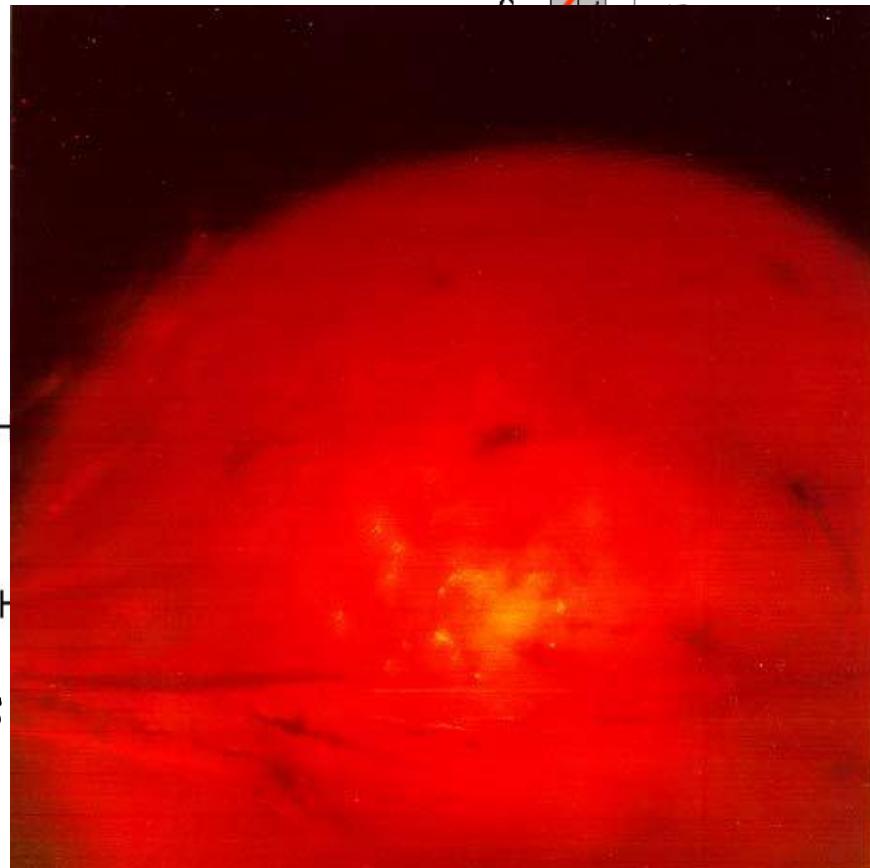
➤ Carbon
we are made of !

➤ ~~relevant~~ questions:
Evolution path and time scale
of Helium burning
~~consequences~~

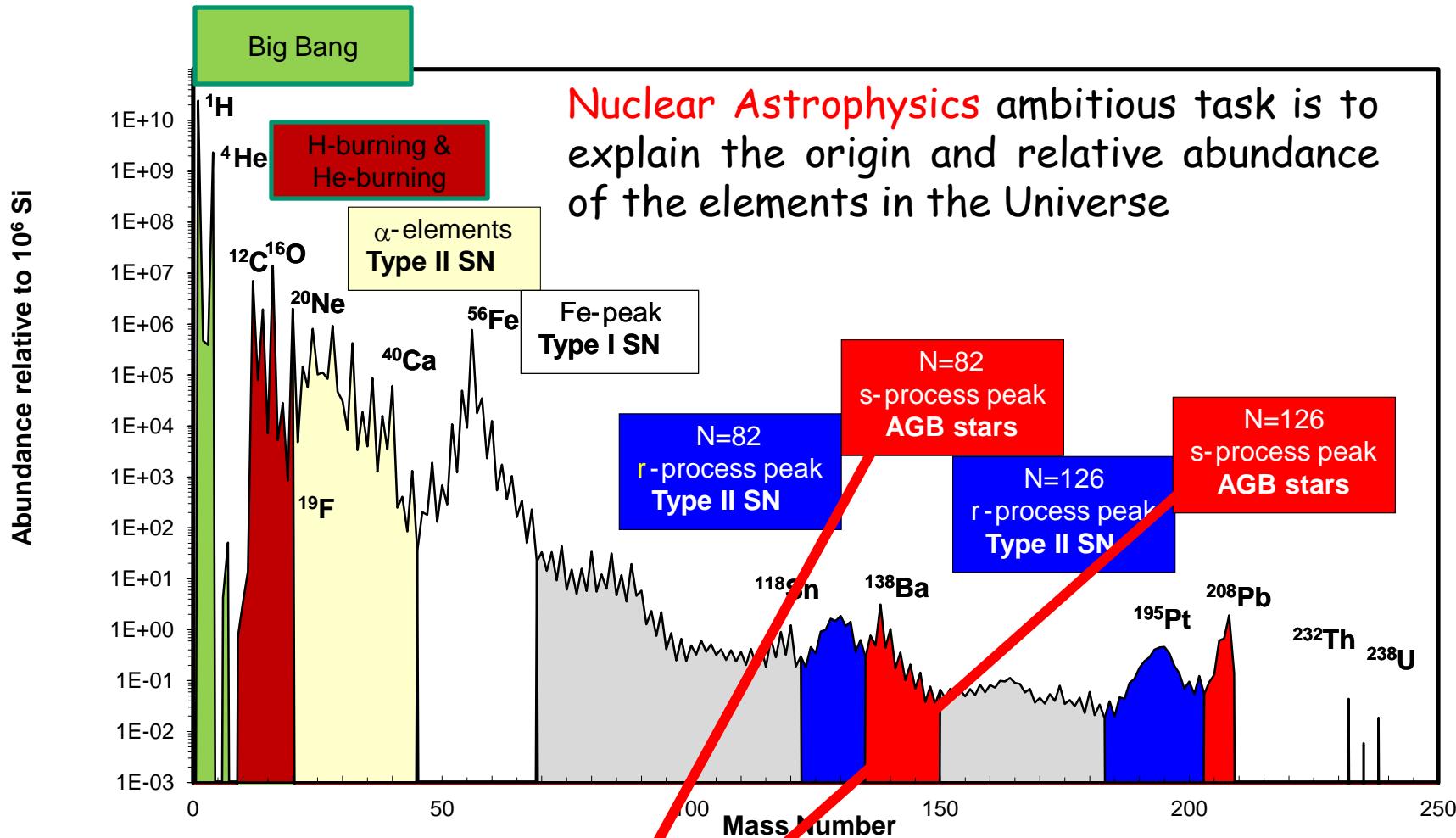
$^4\text{He}(2\alpha, \gamma)^{12}\text{C}(\alpha, \gamma)^{16}\text{O}(\alpha, \gamma)^{20}\text{Ne}$

- late stellar evolution
- composition of C/O White dwarfs
- Supernova type I explosion
- Neutron sources for s process
- Supernova type II nucleosynthesis

$^{14}\text{N}(\alpha, \gamma)^{18}\text{F}(\beta+\nu)^{18}\text{O}(\alpha, \gamma)^{22}\text{Ne}(\alpha, n)^{22}\text{Ne}(\alpha, \gamma)$



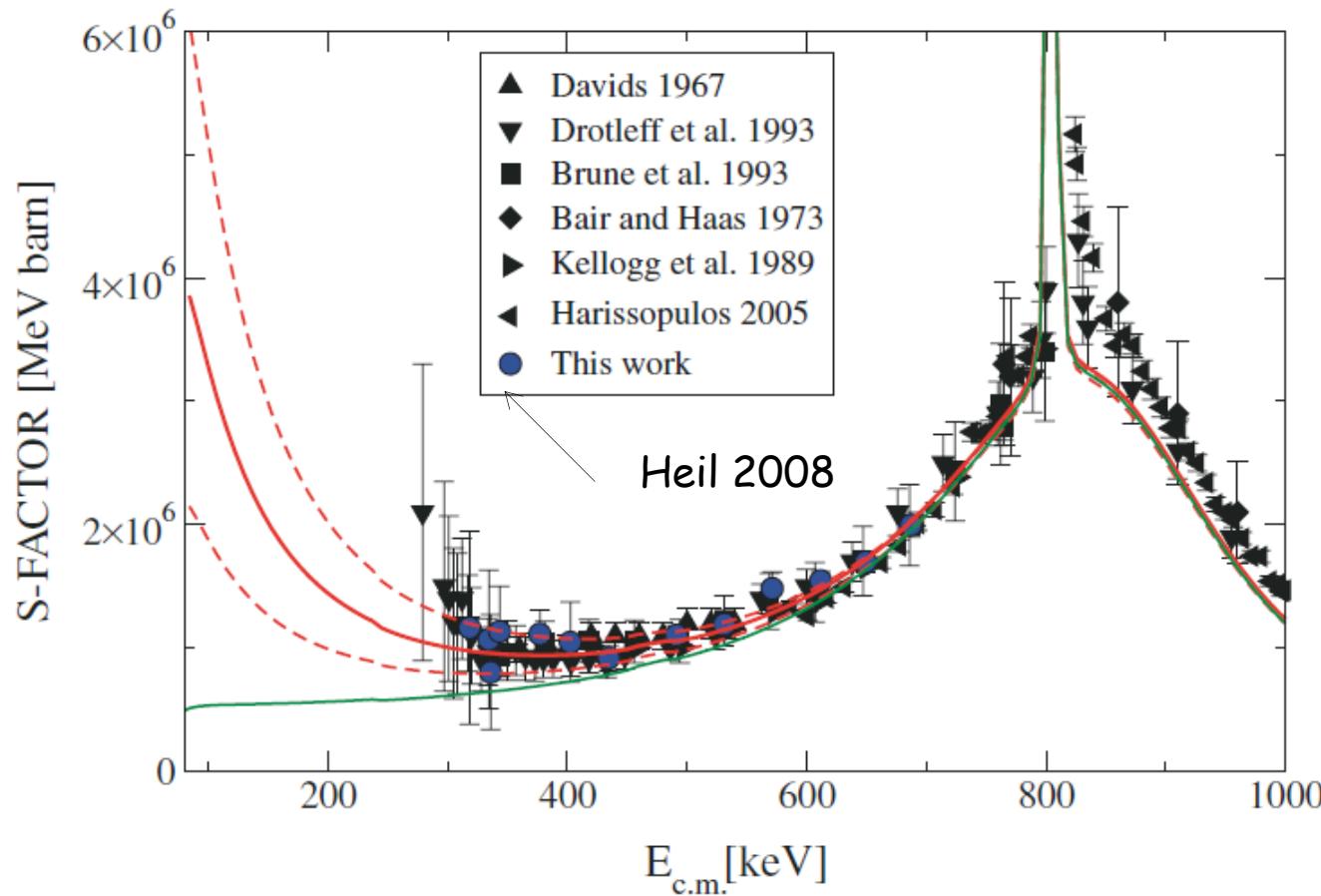
Element abundances in the solar system



n source reactions

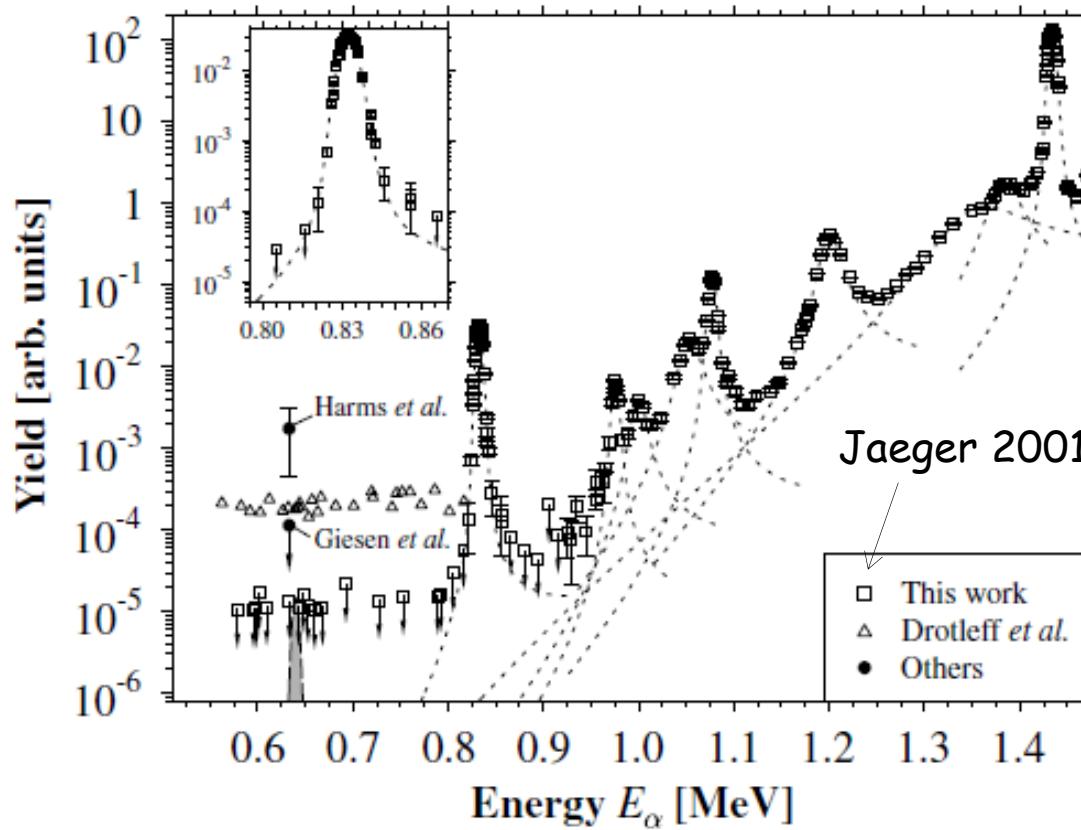
Nuclear Astrophysics ambitious task is to explain the origin and relative abundance of the elements in the Universe

$^{13}\text{C}(\alpha, \text{n})^{16}\text{O}$ experimental status of the art



Big uncertainties in the R-matrix extrapolations. Presence of subthreshold resonances
LUNAMV range: 350-800 keV alpha beam $\rightarrow E_n=2-3$ MeV

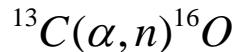
$^{22}\text{Ne}(\alpha, n)^{16}\text{O}$ experimental status of the art



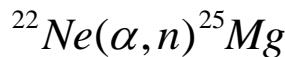
Unmeasured resonance at $E=635$ keV \rightarrow big uncertainties in the reaction rate.

LUNAMV range 600-1000 keV alpha beam \rightarrow $E_n=50-450$ keV

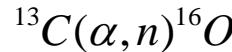
Estimate on LUNA MV n-production rate (100% efficiency)



a beam intensity: 200 μA
Target: ^{13}C , $2 \cdot 10^{17}\text{at/cm}^2$ (99% ^{13}C enriched)
Beam energy(lab) ≤ 0.8 MeV

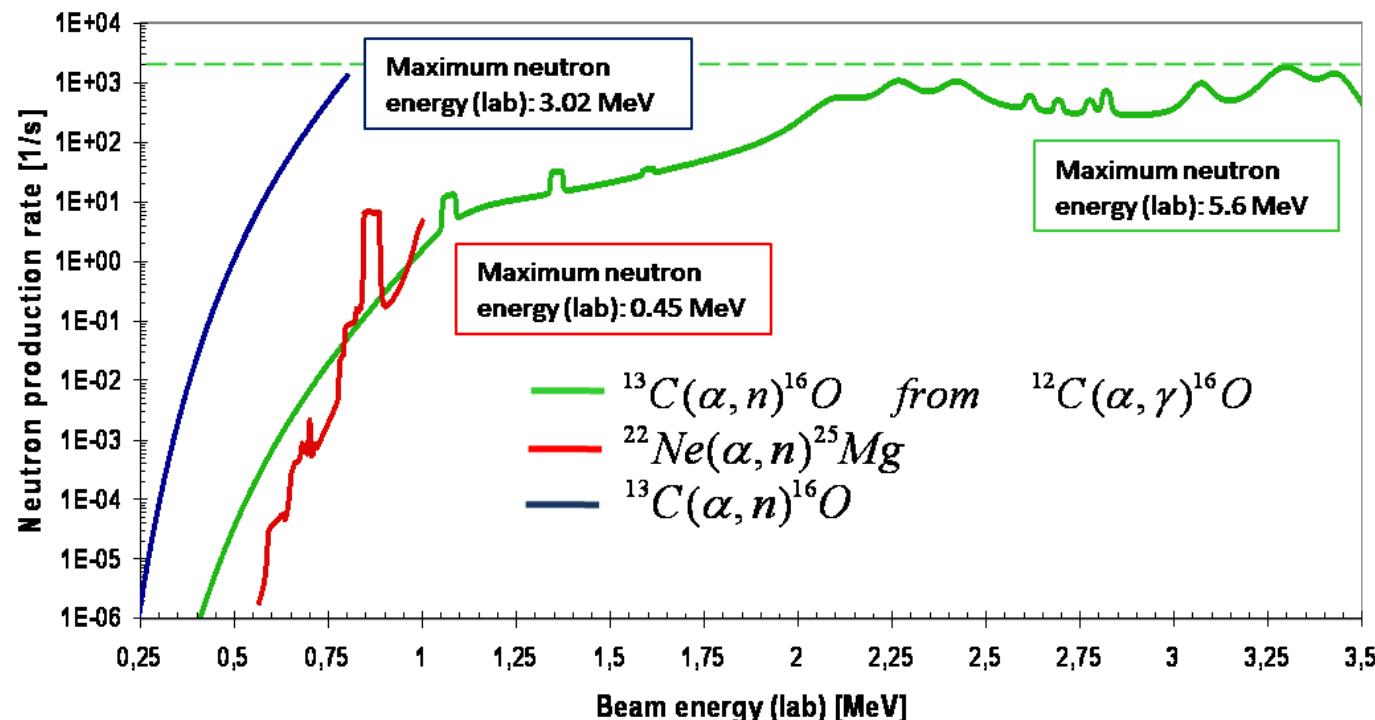


a beam intensity: 200 μA
Target: ^{22}Ne , $1 \cdot 10^{18}\text{at/cm}^2$
Beam energy(lab) ≤ 1.0 MeV



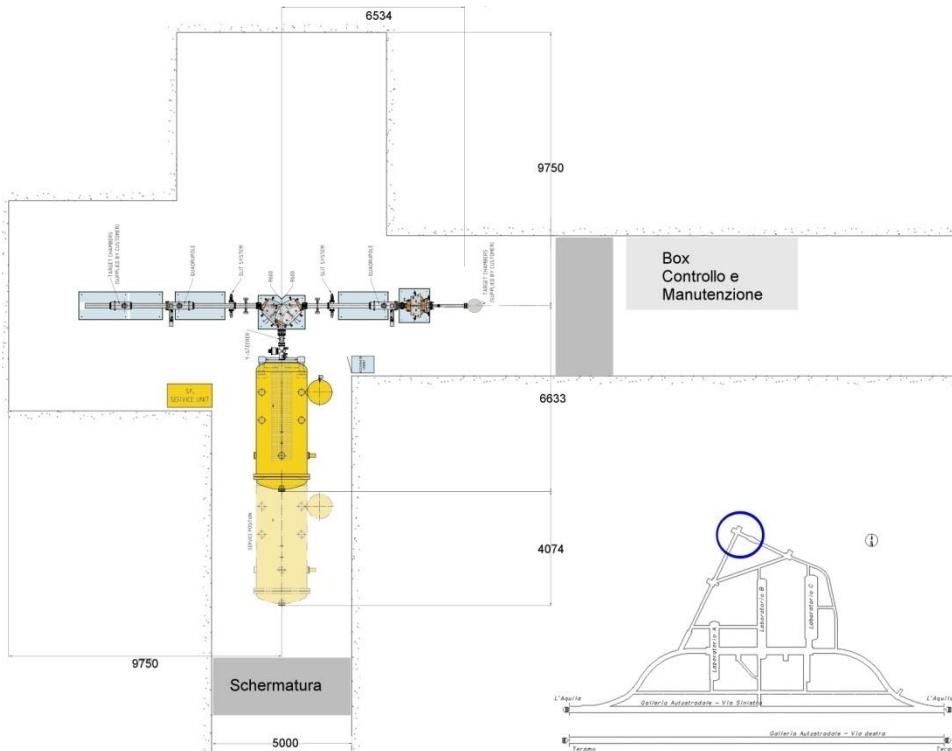
from $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$

a beam intensity: 200 μA
Target: ^{13}C , $1 \cdot 10^{18}\text{at/cm}^2$ ($^{13}\text{C}/^{12}\text{C} = 10^{-5}$)
Beam energy(lab) ≤ 3.5 MeV



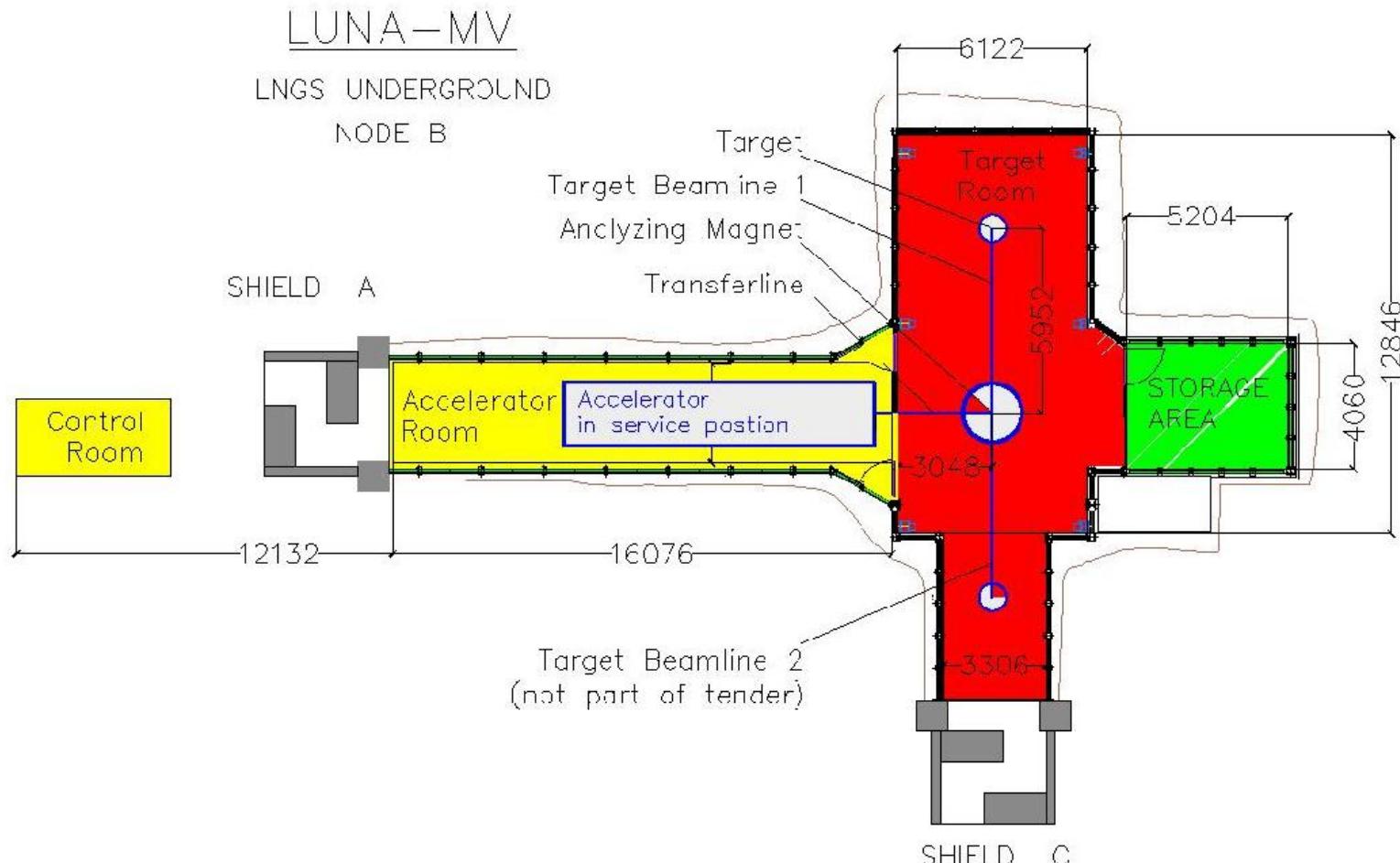
Maximum rate 2000 n/s. Minimum rate very low....

Location at the "B node" of a 3.5 MV single-ended positive ion accelerator



A complete refurbishment of the site is necessary

The accelerator will be a single ended machine capable to produce intense ($200\mu\text{A}$) alpha beams. Well defined beam energy (low ripple and long term drift)



The red area will be covered with HDPE(5%Li) panels

"Progetto Premiale LUNA -MV"

Special Project financed from the Italian Research Ministry
with 2.805 Millions of Euros in 2012

Schedule:

2012-2013 Hall preparation- Tender for the accelerator-
Shielding

2014 Beam lines R&D- Infrastructures

2015 Accelerator installation - Beam lines construction-
Detectors installation

2016 Calibration of the apparatus and first tests of beam on
target

A new request for 2013 has just been submitted

The new LUNA MV collaboration is "under construction"

THE LUNA COLLABORATION

Laboratori Nazionali del Gran Sasso

A.Formicola, M.Junker

Helmoltz-Zentrum Dresden-Rossendorf, Germany

M. Anders, D. Bemmerer, Z. Elekes

INFN, Padova, Italy

C. Broggini, A. Caciolli, R. De Palo, R. Menegazzo, C. Rossi Alvarez

INFN, Roma 1, Italy

C. Gustavino

Institute of Nuclear Research (ATOMKI), Debrecen, Hungary

Zs.Fülöp, Gy. Gyurky, E.Somorjai, T. Szucs

Osservatorio Astronomico di Collurania, Teramo, and INFN, Napoli, Italy

O. Straniero

Ruhr-Universität Bochum, Bochum, Germany

C.Rolfs, F.Strieder, H.P.Trautvetter

Seconda Università di Napoli, Caserta, and INFN, Napoli, Italy

F.Terrasi

Università di Genova and INFN, Genova, Italy

F. Cavanna, P.Corvisiero, P.Prati

Università di Milano and INFN, Milano, Italy

C. Bruno, A.Guglielmetti, D. Trezzi

Università di Napoli ''Federico II'', and INFN, Napoli, Italy

A.Di Leva, G.Imbriani, V.Roca

Università di Torino and INFN, Torino, Italy

G.Gervino

University of Edinburgh

M. Aliotta, T. Davinson, D. Scott