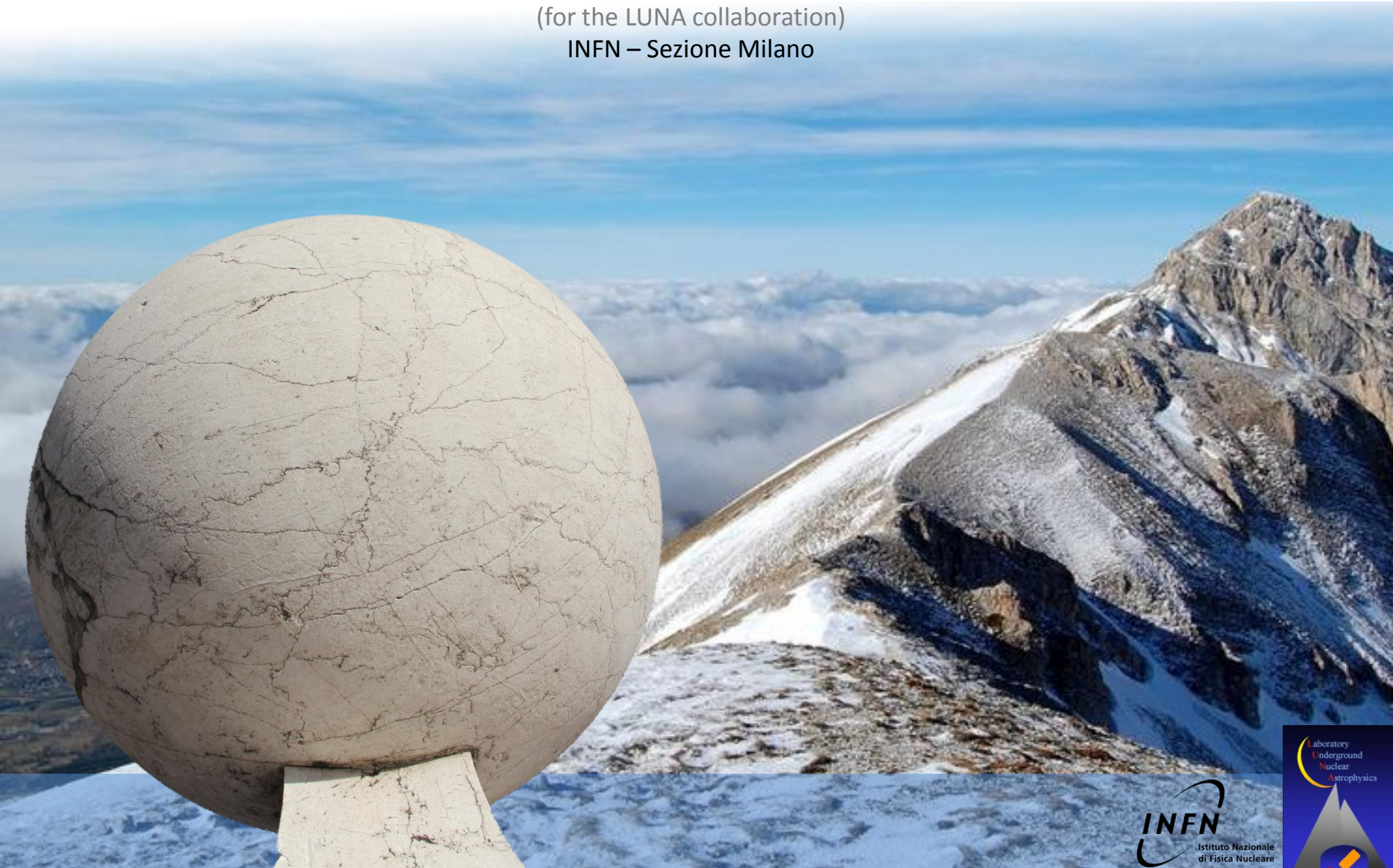
LUNA: Laboratory for Underground Nuclear Astrophysics

D. Trezzi
(for the LUNA collaboration)
INFN – Sezione Milano



Overview: Nuclear Astrophysics

LUNA (**L**aboratory for **U**nderground **N**uclear **A**strophysics)

- Fusion reactions that take place inside the stars
- Fusion reactions that in the past dominated the Big Bang Nucleosyntesis (BBN).

Nuclear fusion cross sections can be factorized like:

$$\sigma(E) = \frac{1}{E} S(E) P(E)$$

Quantum nature of the interaction

Astrophysical factor

Coulomb barrier penetration probability

$$P(E) = e^{-31.29 Z_1 Z_2 \sqrt{\frac{\mu}{E}}}$$

Gamow factor

$H^2(\alpha,\gamma)^6Li$

BBN energy range: 30-300 keV

Extimated cross section: 20 **pb**

LOW CROSS SECTION MEANS LOW BACKGROUND

Overview: Why an underground laboratory?

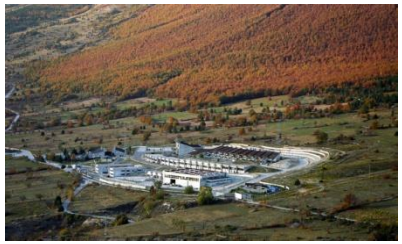
Low background laboratory: music for our detectors…

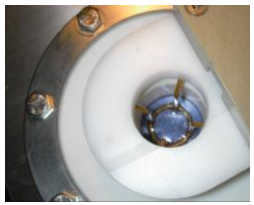
In order to record a thermonuclear direct fusion event at low energy, given the low value of its cross section, we need:

Minimize & Understand

$$R_{lab} \geq B_{cosmic} + B_{environment} + B_{BIB}$$

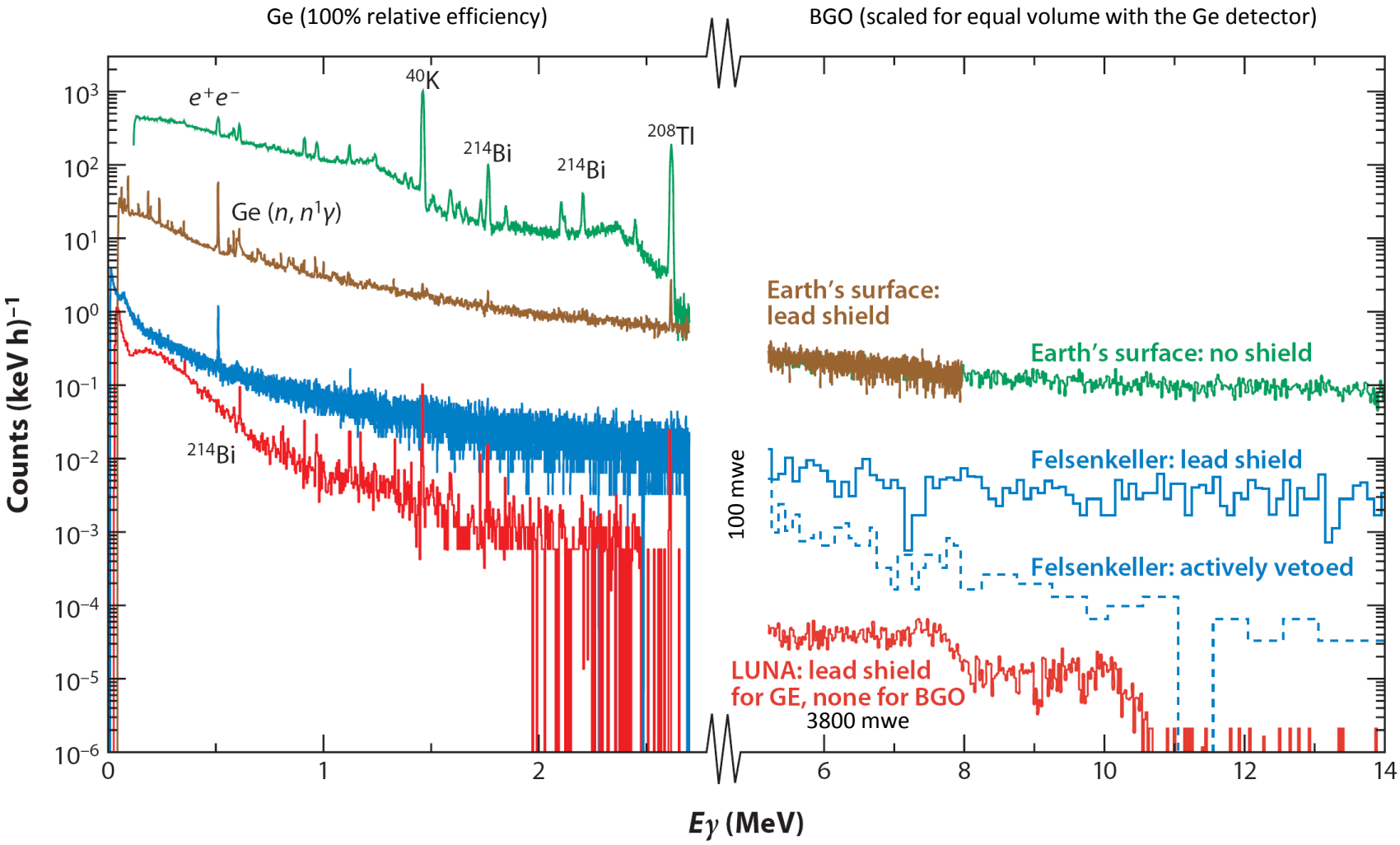
- B_{cosmic}: Cosmic ray induced events → **GOING UNDERGROUND**
- $B_{environment}$: Environmental radioactivity events → SHIELDING
- B_{BIB}: Beam induced background events from impurities in beam and target → HIGH PURITY TARGETS & MC SIMULATIONS





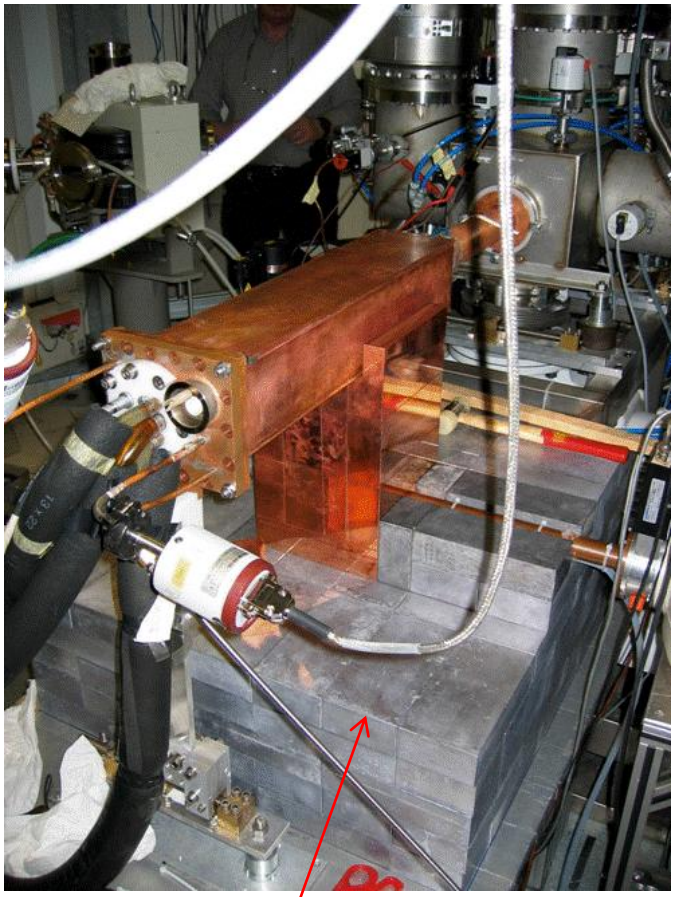
LUNA is located inside the LNGS. This is the largest underground laboratory in the world for experiments of nuclear astrophysics.

Overview: Why an underground laboratory?



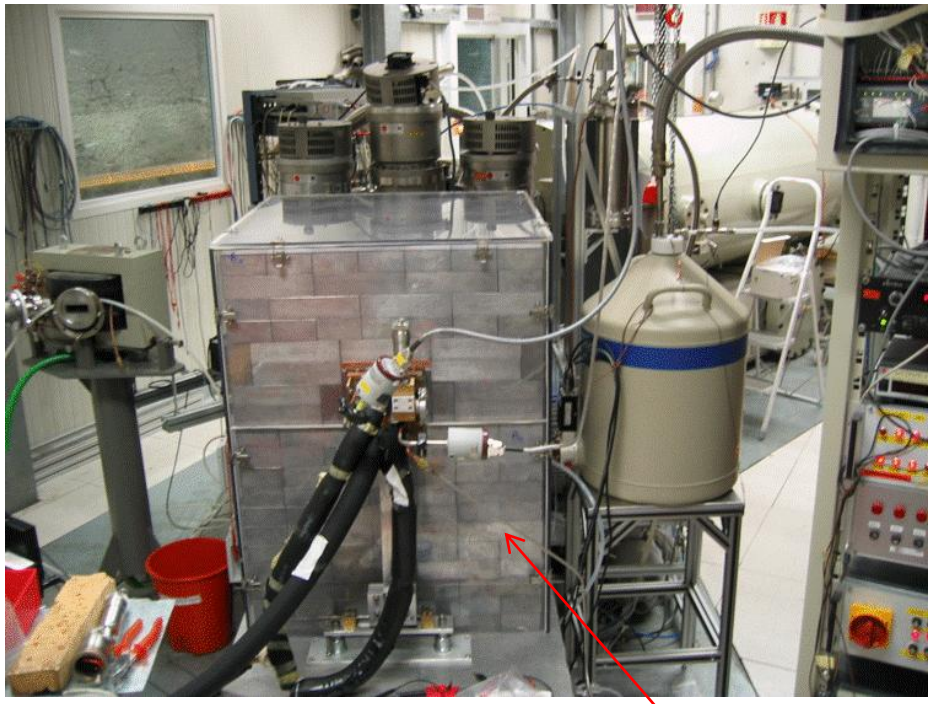
C. Broggini et al., Annu. Rev. Nucl. Part. Sci. 2010. 60: 53-73

How to reduce the environmental Background at LUNA



Lead castle

(Cosmic rays) and environmental radiation background reduction



Anti-Radon Box (N_2 flushing)

^{222}Rn (& daughter) suppression

Actual Situation $B_{environment}$:

^{228}Ac (911 keV) 98.0 counts/day

^{208}Tl (583 keV) 110.0 counts/day

^{208}Tl (2614 keV) 74.1 counts/day

^{214}Bi (609 keV) 132.4 counts/day

Natural Background stability is frequently monitored

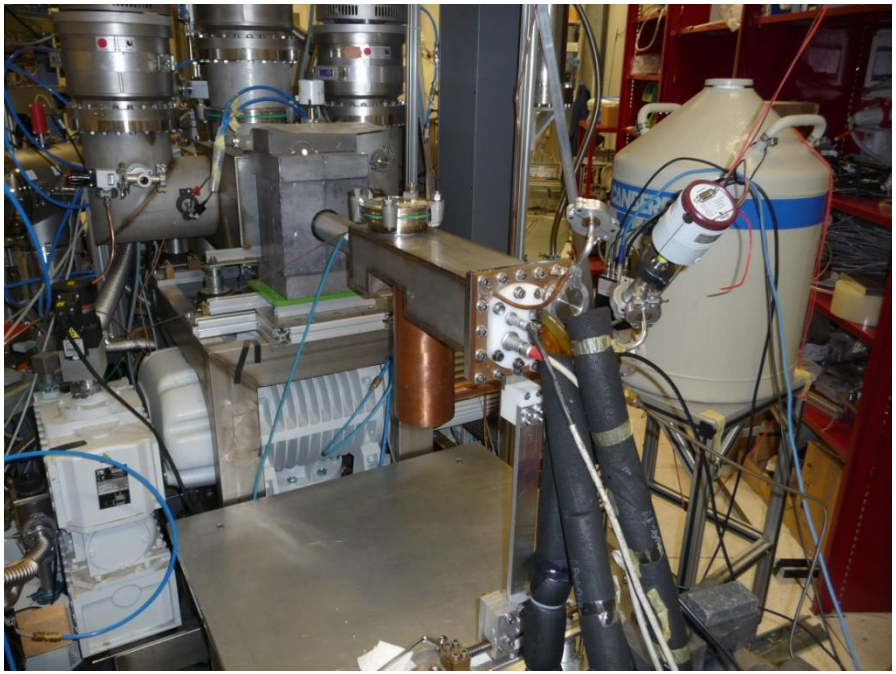
Nuclear fusion reactions at low energies: direct measurements

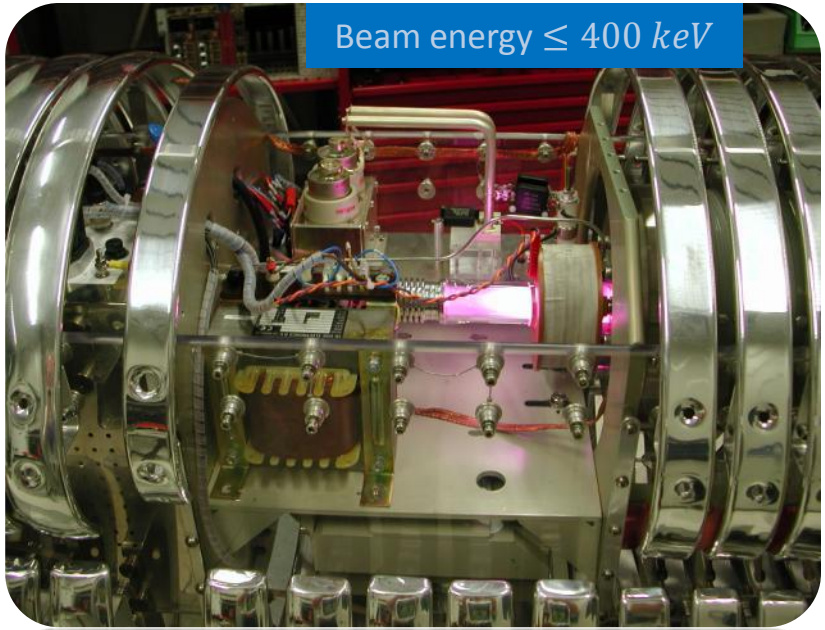
Nuclear fusion cross sections strongly depends on the energy:

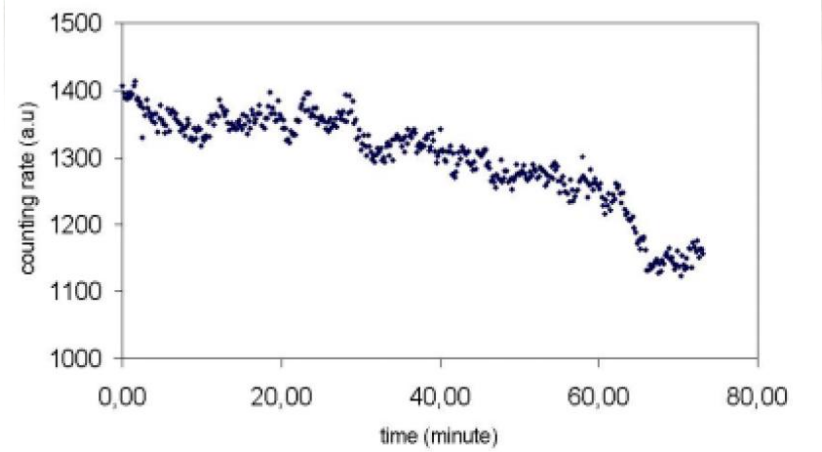
- Low energy spread (70 eV);
- High stability during time(5 eV/h).

Low cross sections mean low counting rates:

- High intensity (p@500 μA, α@250 μA);
- High efficiency detectors (4π BGO, array of Si det)







LNGS Annual Report 2000

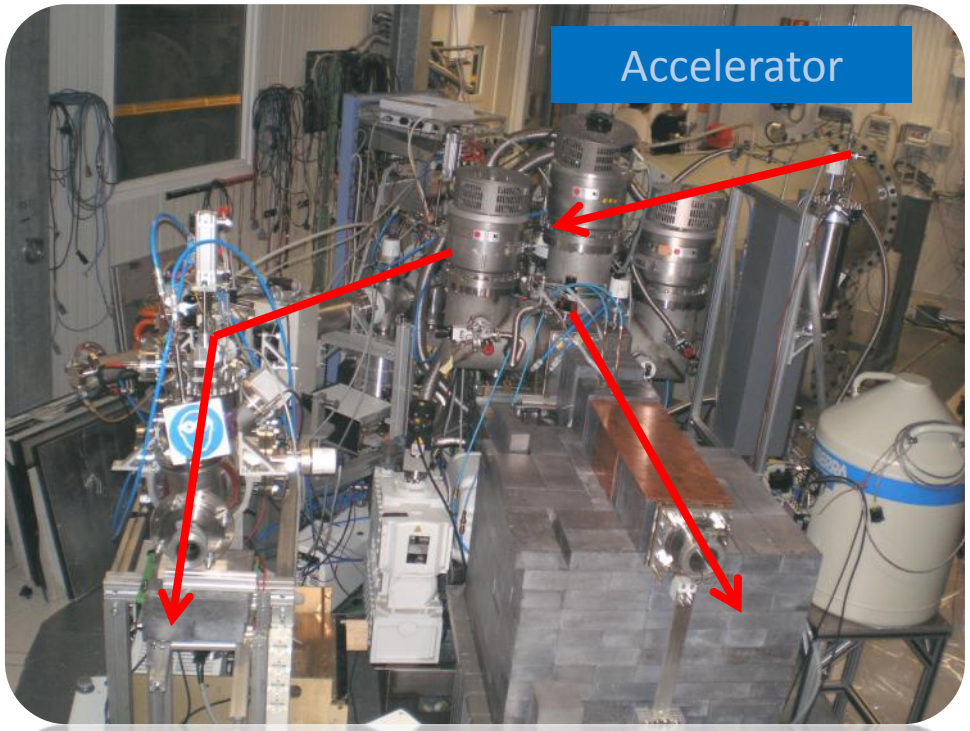
Solid and Gas Targets

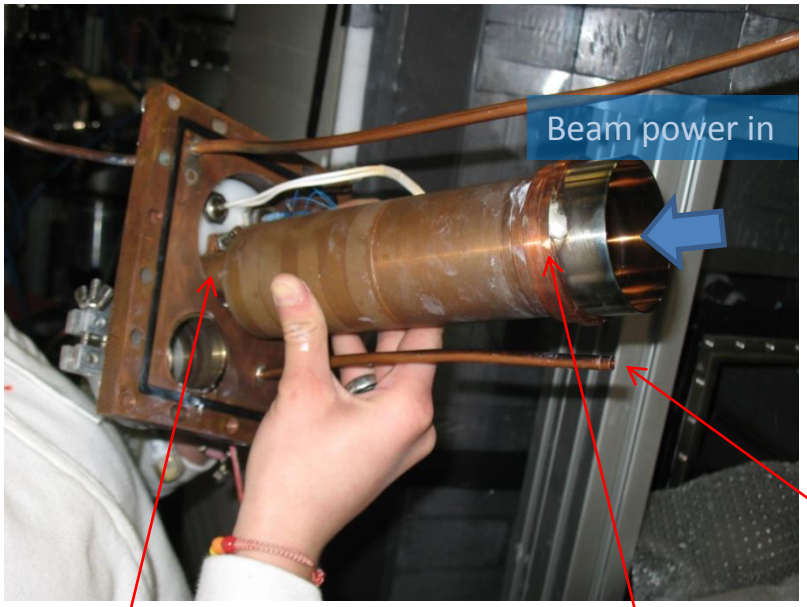
Targets at LUNA:

- Solid target (@ LNGS)
- Windowless gas target

Current measurement:

- Faraday cup (solid target)
- Calorimeter (gas target)





Now at LUNA:

- $^{17}O(p,\alpha)^{14}N$ (solid)
- $^{2}H(\alpha,\gamma)^{6}Li$ (gas)

Just completed: $^{17}O(p,\gamma)^{18}F$ [solid]

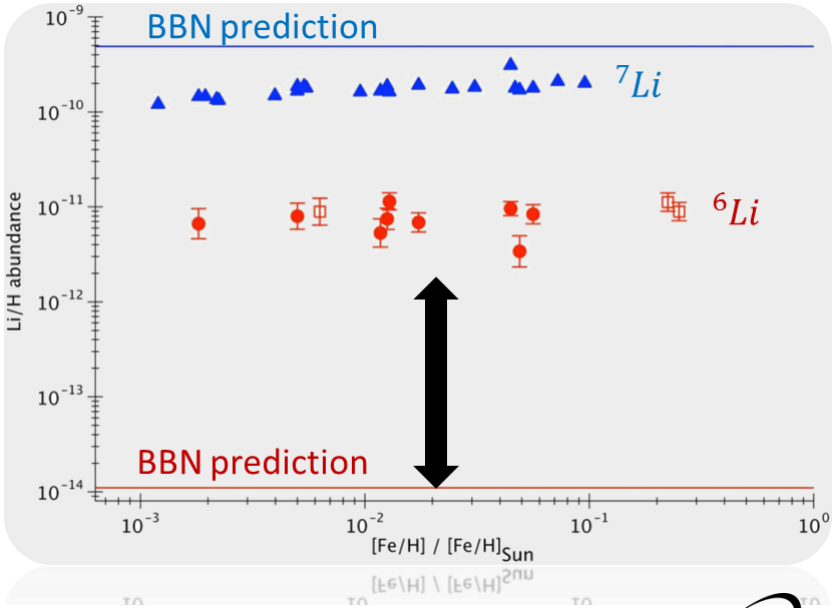
Near future: $^{22}Ne(p,\gamma)^{23}Na$ [gas]

$^2H(\alpha,\gamma)^6Li$ reaction: The Astrophysical point of view.

* Star that contain elements heavier than H or He

The amount of ^6Li measured in metal poor* stars is unexpectedly large compared to BBN predictions:

- Astrophysical problem
  - ^6Li results are at the borderline of being clear detections;
  - New Physics beyond the Standard Model.
- Nuclear problem
  - No direct measurements of the $^2H(\alpha,\gamma)^6Li$ cross section at the BBN energy region.

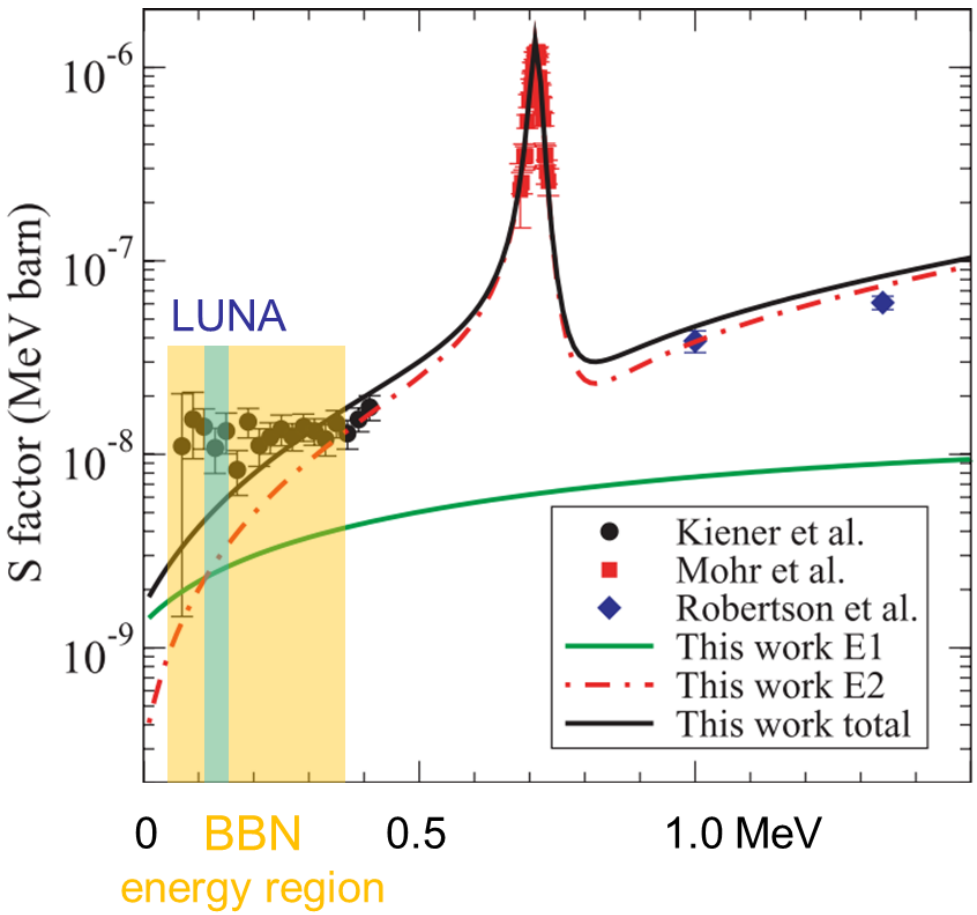


$H^2(\alpha,\gamma)^6Li$
BBN energy range: 30-300 keV
Extimated cross section: 20 **pb**

→ LUNA maximum energy in the CMS is about 130 keV
→ In the past LUNA measured similar cross section values

$^2H(\alpha,\gamma)^6Li$ has been measured at LUNA

$^2H(\alpha,\gamma)^6Li$ reaction: The actual Nuclear data



Direct measurements at:

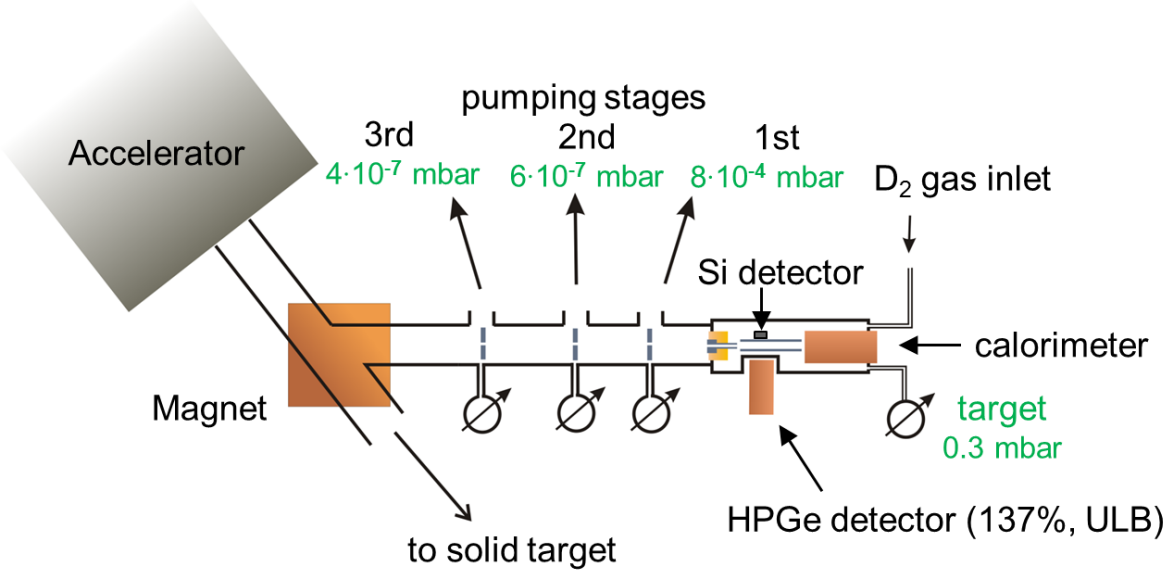
- $E > 1\ MeV$ [Robertson et al. 1991]
- Around the $0.7\ MeV$ resonance [Mohr et al. 1996]

Recent indirect measurements in the BBN energy region:

- Hammache et al. @ GSI [high Coulomb breakup]

GSI work provided *upper limits* due to the nuclear breakup contribution

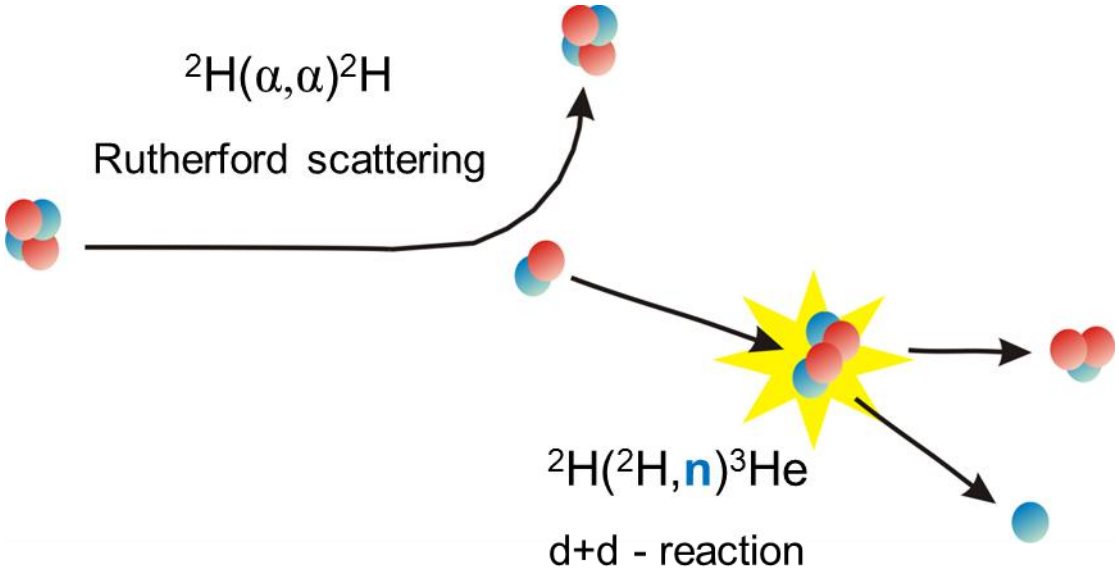
$^2H(\alpha,\gamma)^6Li$ reaction @ LUNA: the apparatus



- Deuterium at 0.3 mbar
- α beam (280 keV, 400 keV)
- Maximum current 250 μA

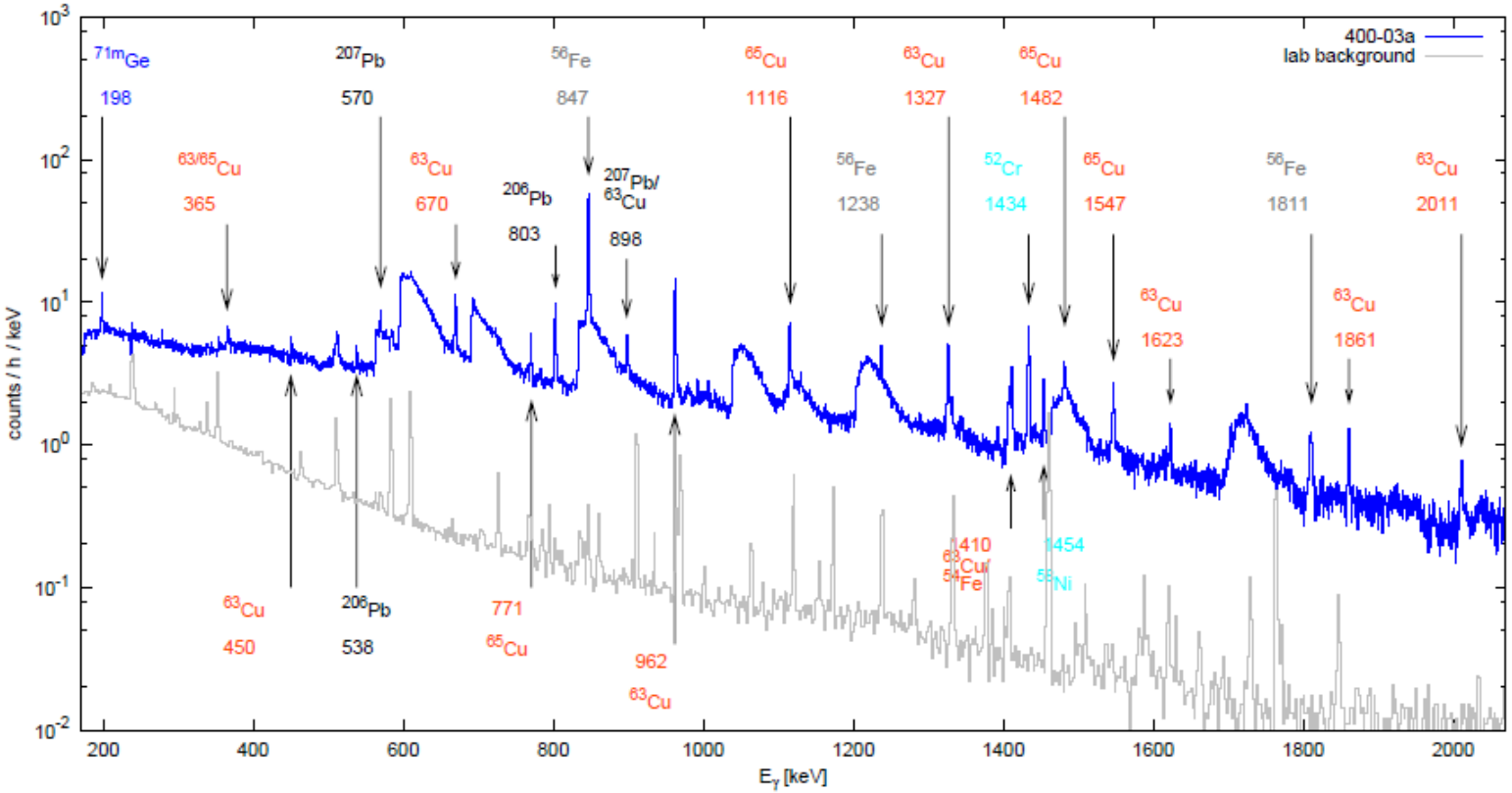
Why a Silicon Detector?

One of the main source of the BIB is the $d(d,n)^3He + (n,n'\gamma)$ reaction on surrounding materials (Pb, Cu and Ge)



$d(d,p)t$ reaction with similar cross section as monitor of the neutron production

$^{2}H(\alpha,\gamma)^{6}Li$ reaction @ LUNA: the Beam Induced Background (BIB)

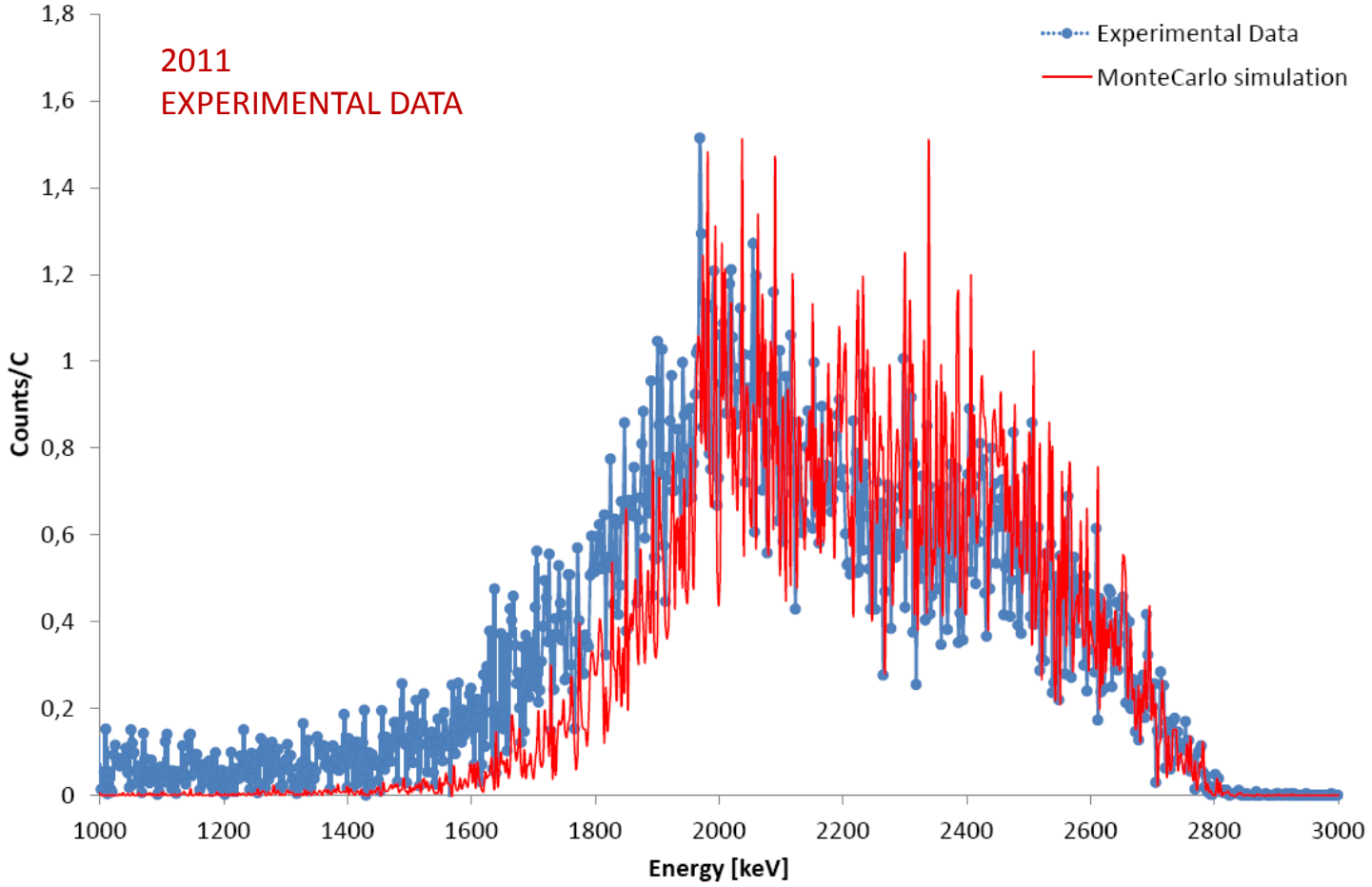


The BIB is the main contribution to the global Background

(also in the $^{2}H(\alpha,\gamma)^{6}Li$ ROI)

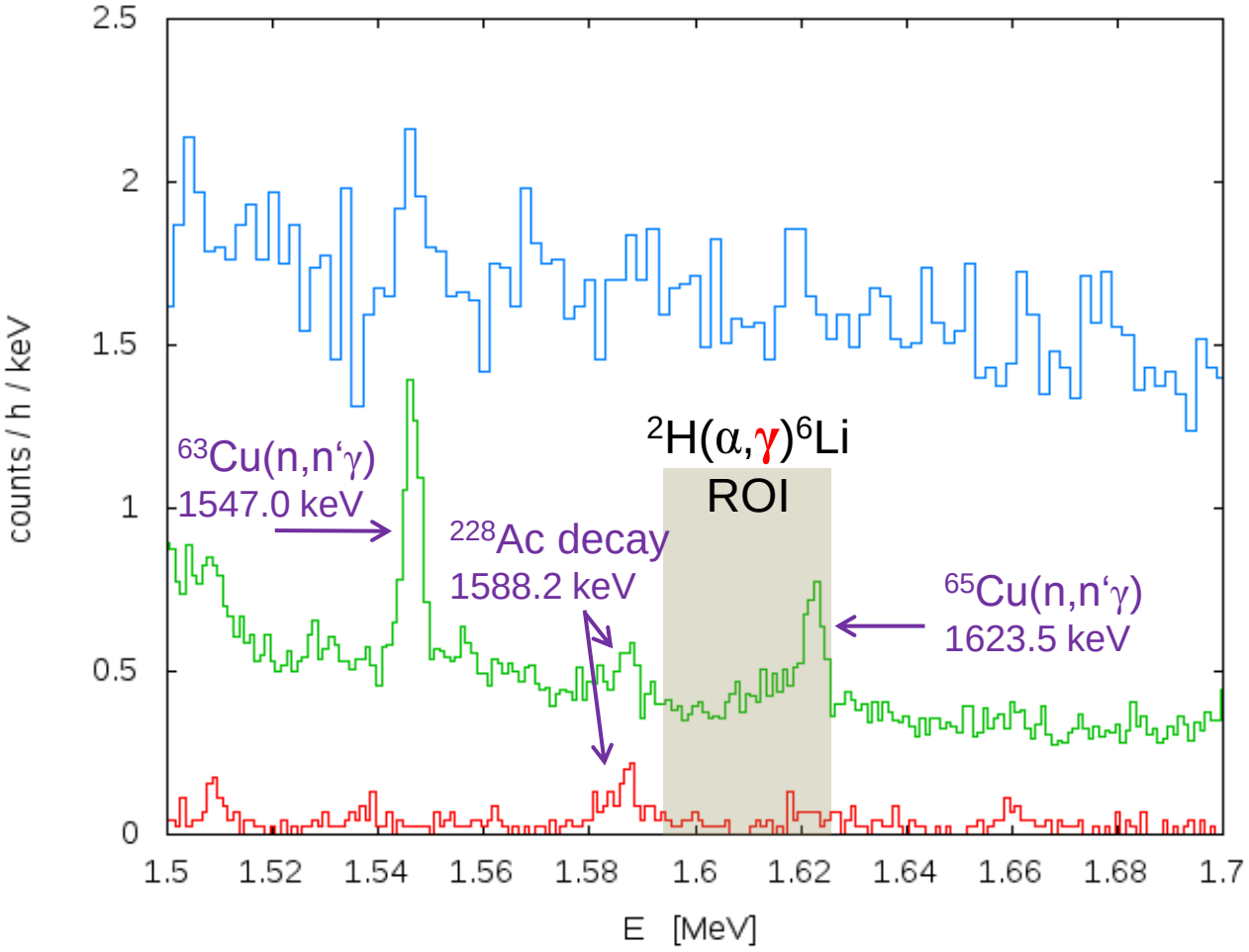
- Control the neutron production by measuring protons with the silicon detector
  (stability of the BIB → implantation of deuterium)
- Understanding the BIB by using Monte Carlo simulations

$^{2}H(\alpha,\gamma)^{6}Li$ reaction @ LUNA: the Beam Induced Background (BIB)



The silicon preliminary data are in agreement with the Geant3 Monte Carlo simulations

$^{2}H(\alpha,\gamma)^{6}Li$ reaction @ LUNA: 2010-2011 experimental data



Natural background at the Earth's surface

^{4}He beam and D_2 gas

Natural background at LUNA

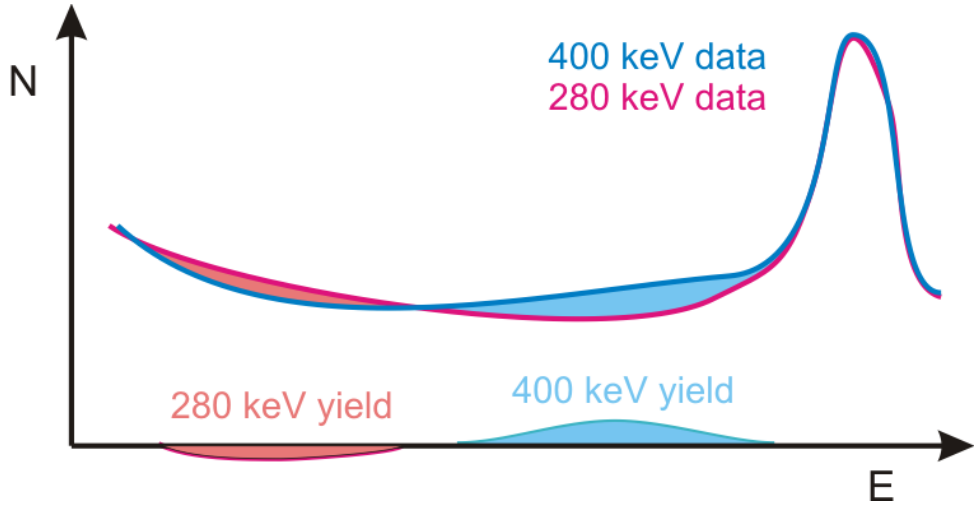
With about 200 hours of acquisition NO signal was evident (2010-2011 data)

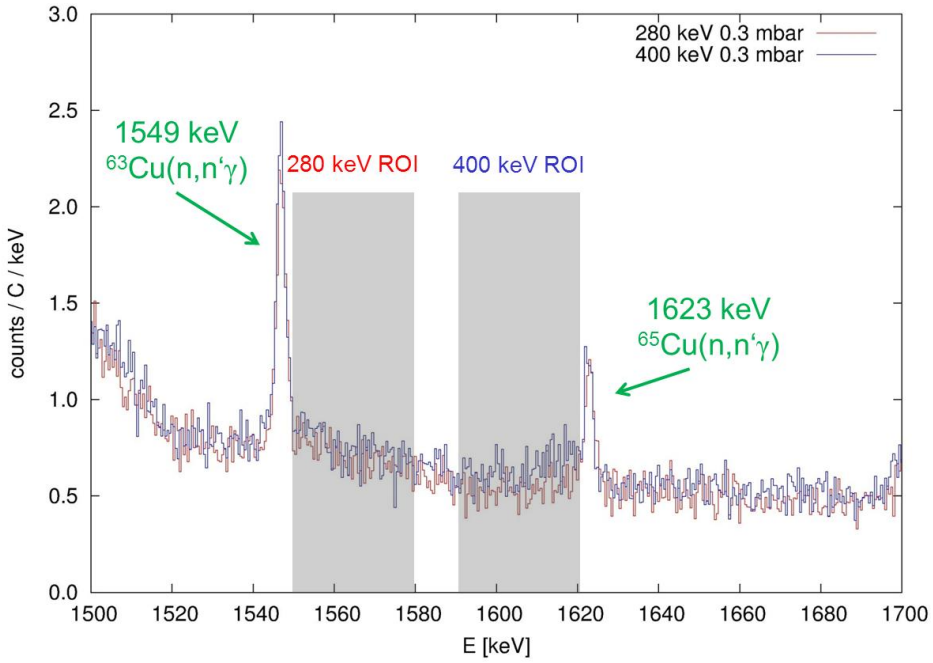
2011-2012: a new strategy

$^2H(\alpha,\gamma)^6Li$ reaction @ LUNA: the BIB subtraction approach

Analysis' strategy:

- Measure the $^2H(\alpha,\gamma)^6Li$ reaction @ 280 keV (LAB)
- Measure the $^2H(\alpha,\gamma)^6Li$ reaction @ 400 keV (LAB)
- Normalize the spectra to the same background
- Subtract the two spectra





400 keV ROI: [1589.6 … 1621.5] keV
280 keV ROI: [1549.7 … 1580.6] keV

Data analysis is in progress…
new results probably before the end of 2012

grazie per l'attenzione

thank you for your attention

Laboratori Nazionali del Gran Sasso, INFN, ASSERGI
A. Formicola, M. Junker
Forschungszentrum Dresden - Rossendorf, Germany
M. Anders, D. Bemmerer, Z. Elekes, M. L. Menzel
INFN, Padova, Italy
C. Broggini, A. Caciolli, R. Depalo, R. Menegazzo, C. Rossi Alvarez
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 Roma 1
C. Gustavino
Università di Milano and INFN, Milano, Italy
A. Guglielmetti, C. Bruno, M. Campeggio, 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 and D. Scott