Laboratory
Underground
Nuclear
Astrophysics

The $D(^4He,\gamma)^6Li$ reaction at LUNA and the Big Bang Nucleosynthesis

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For the LUNA collaboration

- The Big Bang Nucleosynthesis
- The Lithium problem
- The $D(^4He,\gamma)^6Li$ measurement at LUNA
- Conclusions

LUNA Vs BBN

In the standard scenario, the primordial abundance of light elements depends ONLY on:

- Barionic density ω_b (measured by CMB experiments at the level of %)
- Standard Model (τ_n, ν, α..)
- Nuclear astrophysics, i.e. cross sections of nuclear reactions in the BBN chain

The LUNA measurements are performed at LNGS, with the unique accelerator in the world operating underground.

Here, the background induced by cosmic rays is orders of magnitude lower than outside. The Low background at LNGS makes possible to study Nuclear reactions well below the coulomb barrier.

In particular, the BBN reactions can be studied in the region of interest, giving a direct experimental footing to calculate the abundances of primordial isotopes.

Already measured by LUNA:

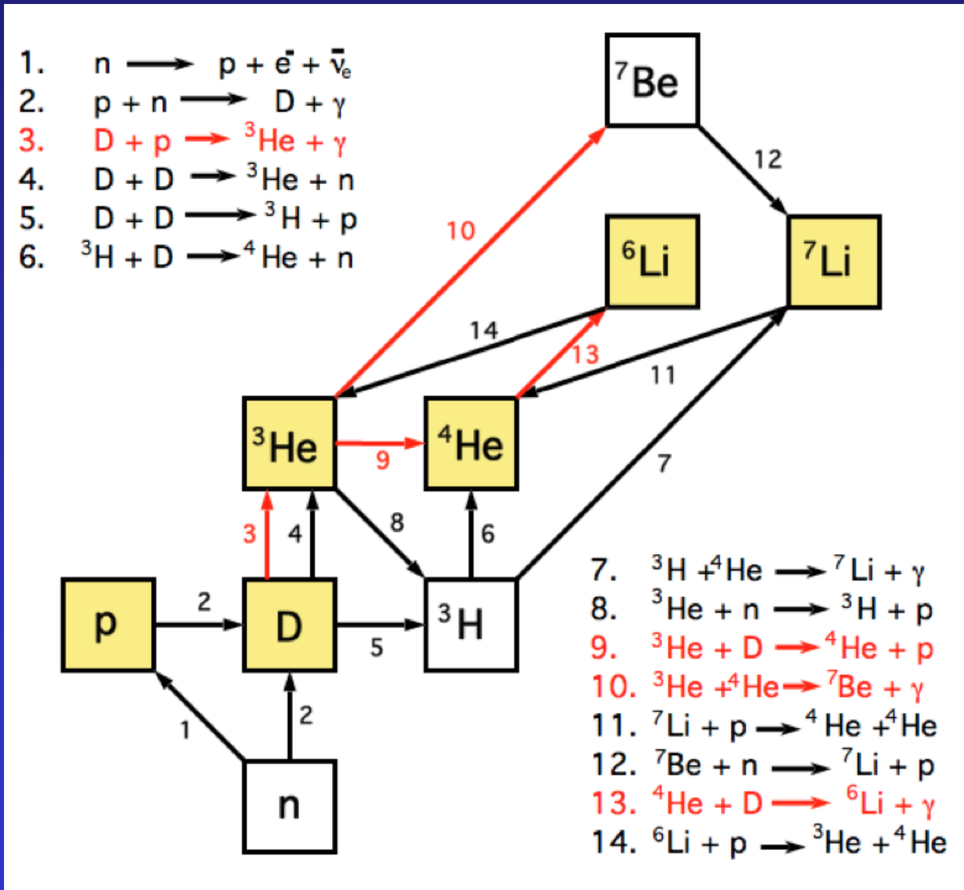
$P(D,\gamma)^3He$ (Deuterium abundance)

$^3He(^4He,g)^7Be$ (^7Li abundance)

$^3He(D,p)^4He$ (^3He abundance)

This talk:

$D(^4He,\gamma)^6Li$ (^6Li abundance)



The Lithium Problem(s)

Basic Concepts to unfold primordial abundances

•Observation of a set of primitive objects (born when the Universe was young)

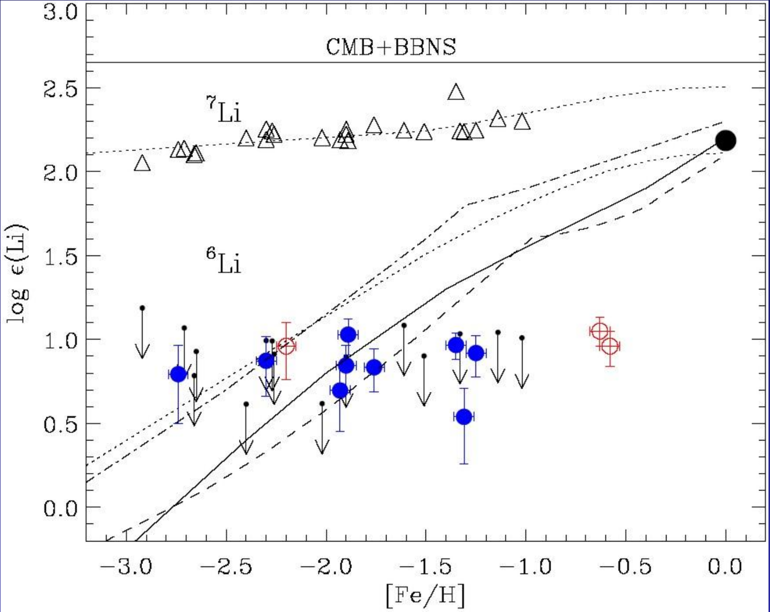
•Extrapolate to zero metallicity:

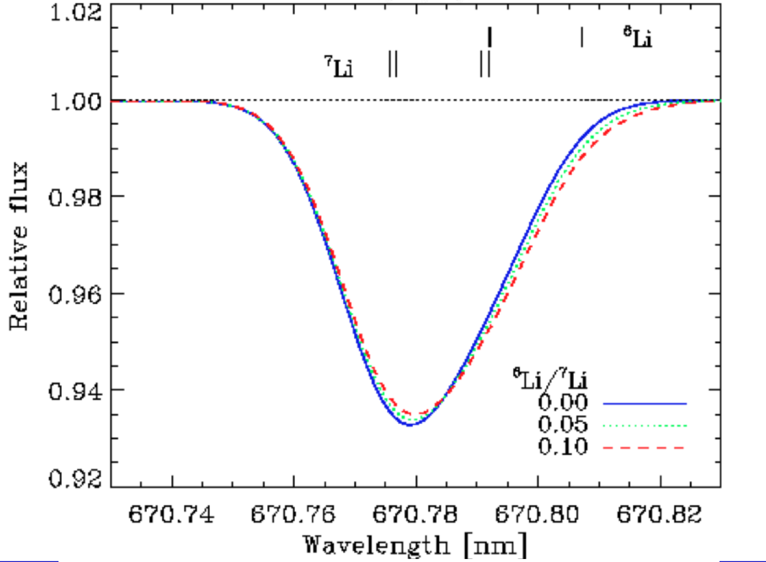
Fe/H, O/H, Si/H -----> 0

Lithium observations

•^{7}Li primordial abundance: observation of the absorption line at the surface of metal-poor stars in the halo of our Galaxy

•^{6}Li abundance : observation of the asymmetry of the ^{7}Li absorption line.





Line strength: ^{7}Li abundance
Line Profile: ^{6}Li/^{7}Li ratio

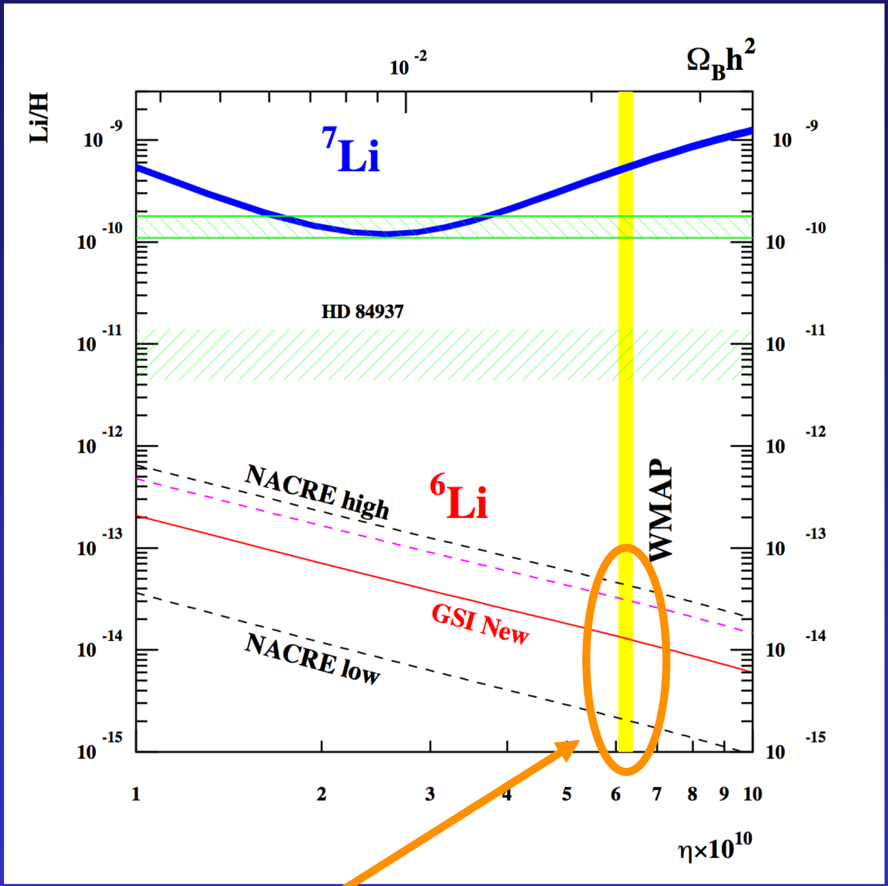
The Lithium Problem(s)

Observational Results:

•Observed ^{7}Li abundance is 2-3 times lower than foreseen (Spite Plateau): Well established "^{7}Li problem".

•Claim of a ^{6}Li abundance orders of magnitude higher than expected (Asplund 2006)

•However, the existence of a "Second Lithium problem" is presently debated, because convective motions on the stellar surface can give an asymmetry of the absorption line, mimicking the presence of ^{6}Li.



Uncertainty from D(^{4}He,γ)^{6}Li

For more details: "Lithium in the Cosmos", 27-29 february, Paris

$D(^4He,\gamma)^6Li$

The claimed ^6Li abundance in metal-poor stars is very large (Asplund et al. 2006) compared to BBN predictions (NACRE compilation). Possible reasons are:

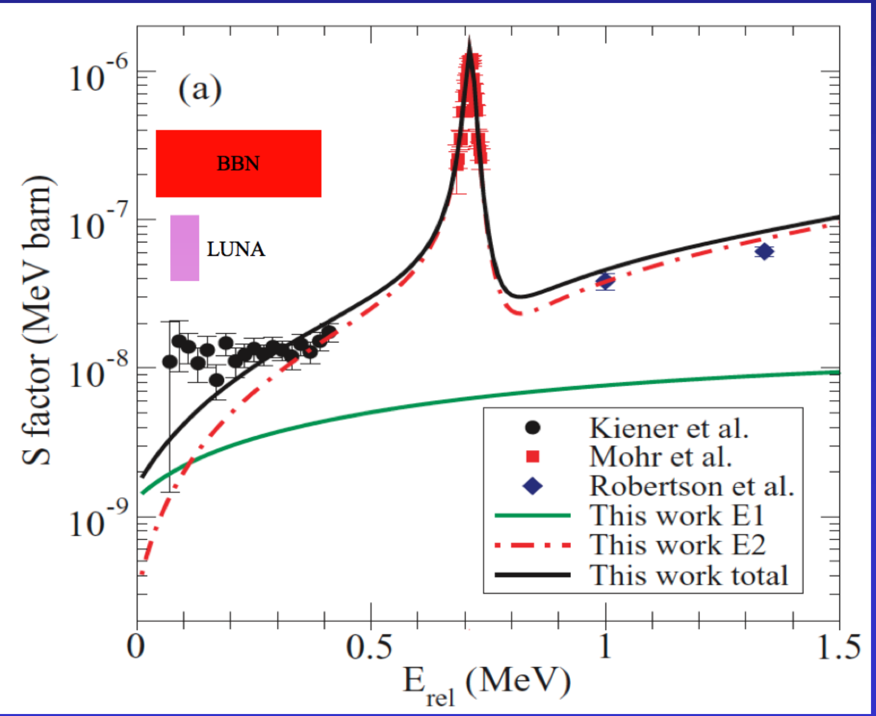
- Systematics in the ^6Li observation in the metal-poor stars
- Unknown ^6Li sources older than the birth of the galaxy
- New physics, i.e. sparticle annihilation/decay (Jedamzik2004), long lived sparticles (Kusakabe2010),…
- …Lack of the knowledge of the $D(^4He,\gamma)^6Li$ reaction.

IN FACT:

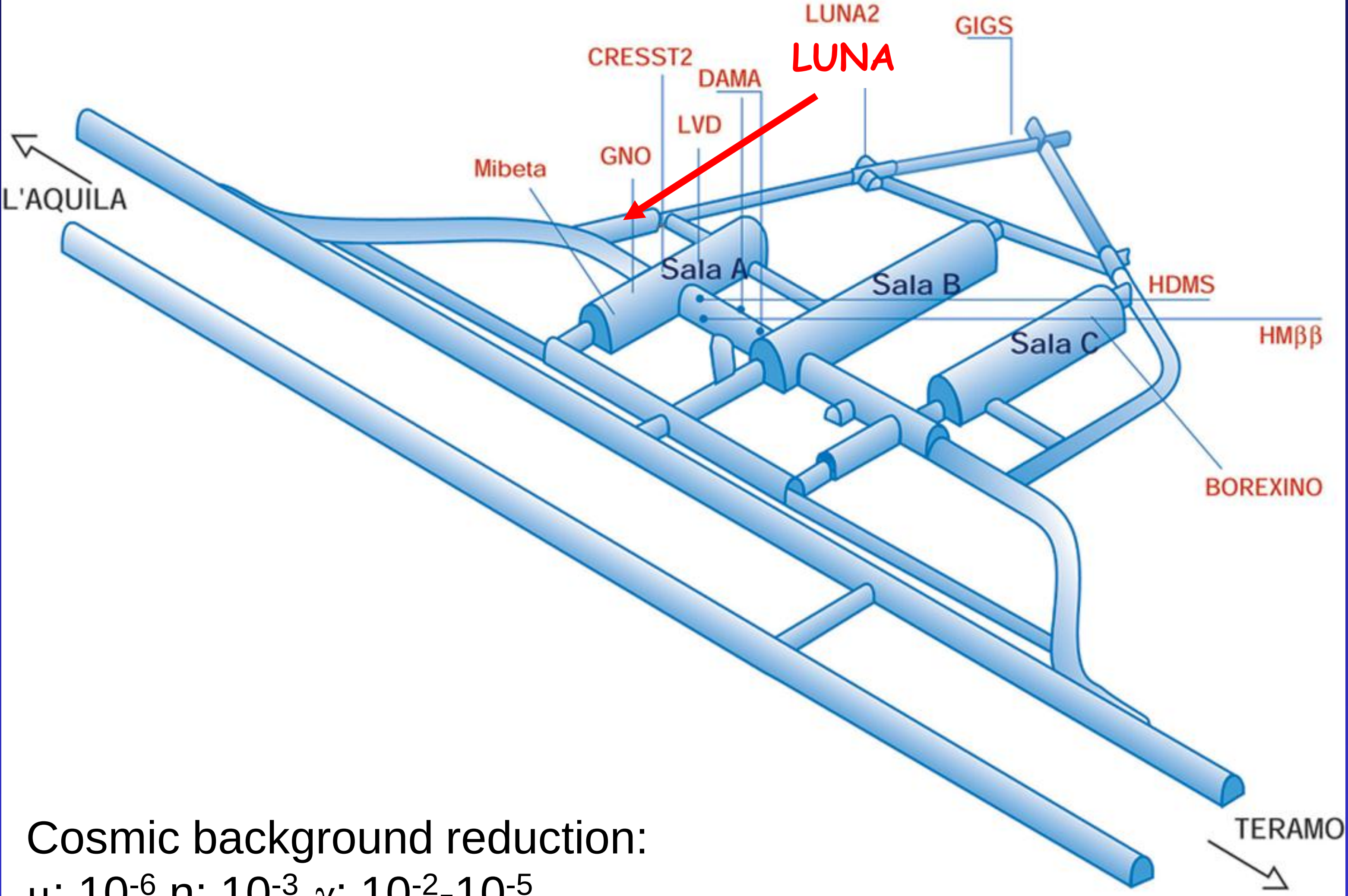
NO DIRECT MEASUREMENTS in the BBN energy region in literature (large uncertainty due to extrapolation)

INDIRECT coulomb dissociation measurements (Kiener91, Hammache2010) are not reliable because the nuclear part is dominant.

FOR THE FIRST TIME, the $D(^4He,\gamma)^6Li$ reaction has been studied at low energy ($80<E_{cm}(keV)<130$), well inside the BBN energy region $50<E(keV)<400$.

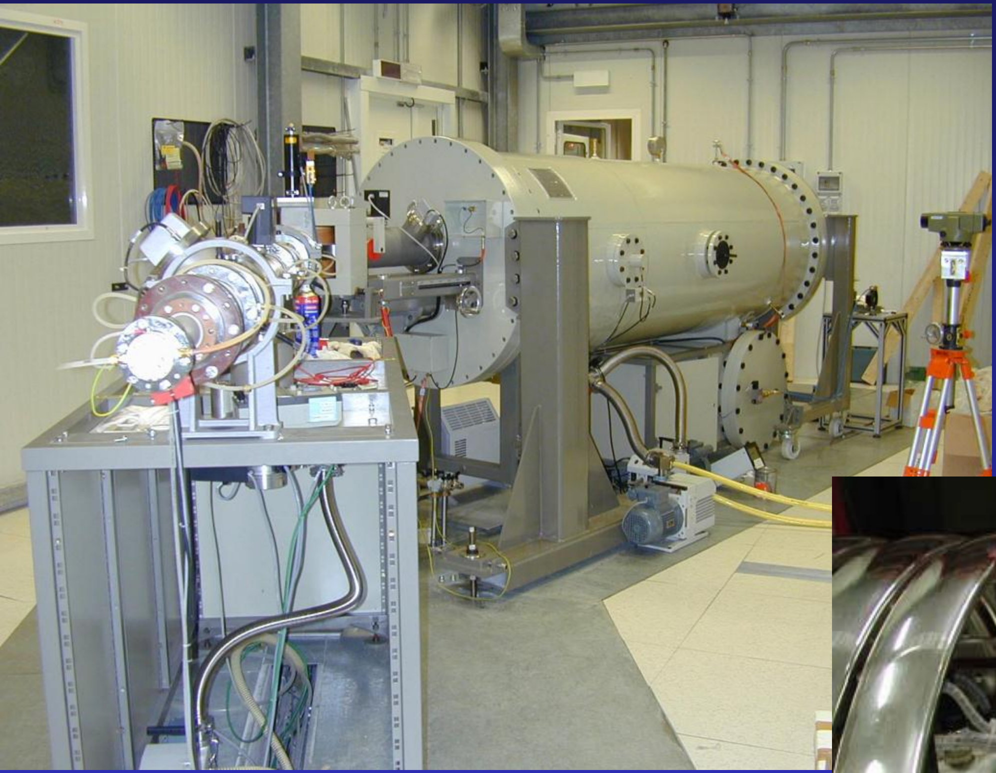


Gran Sasso National Laboratory (LNGS)



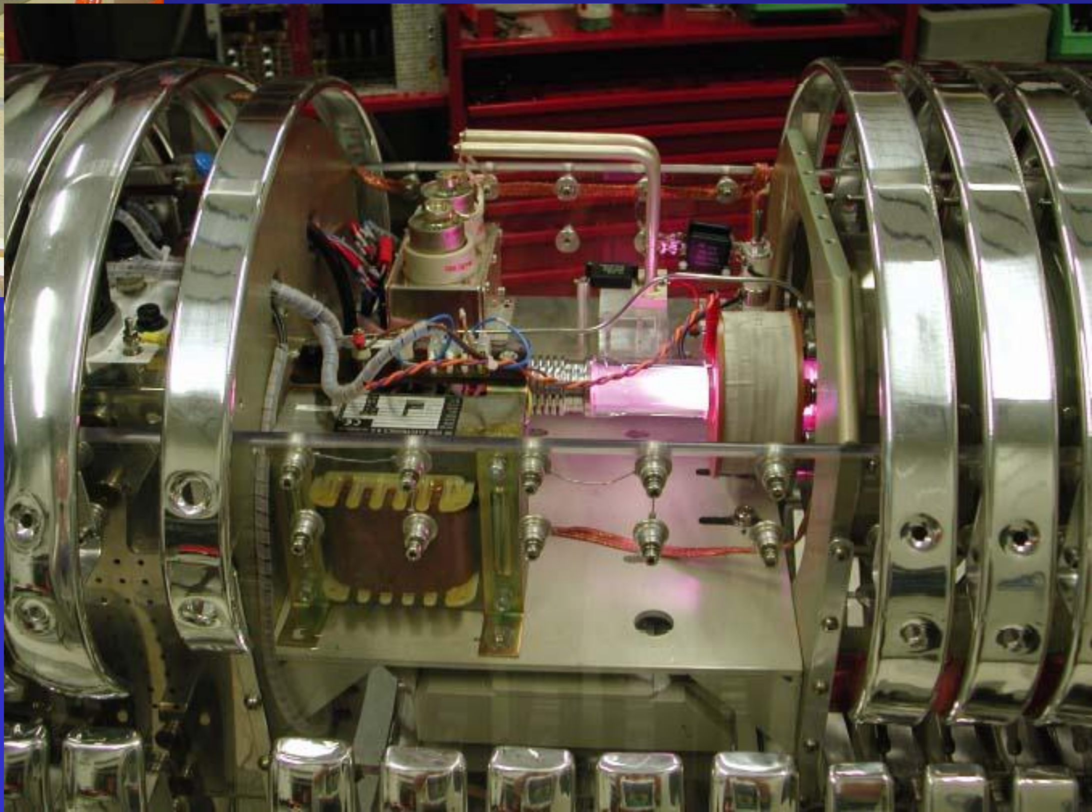
Cosmic background reduction:
μ: 10^{-6} n: 10^{-3} γ: 10^{-2}-10^{-5}

The LUNA (400 kV) accelerator



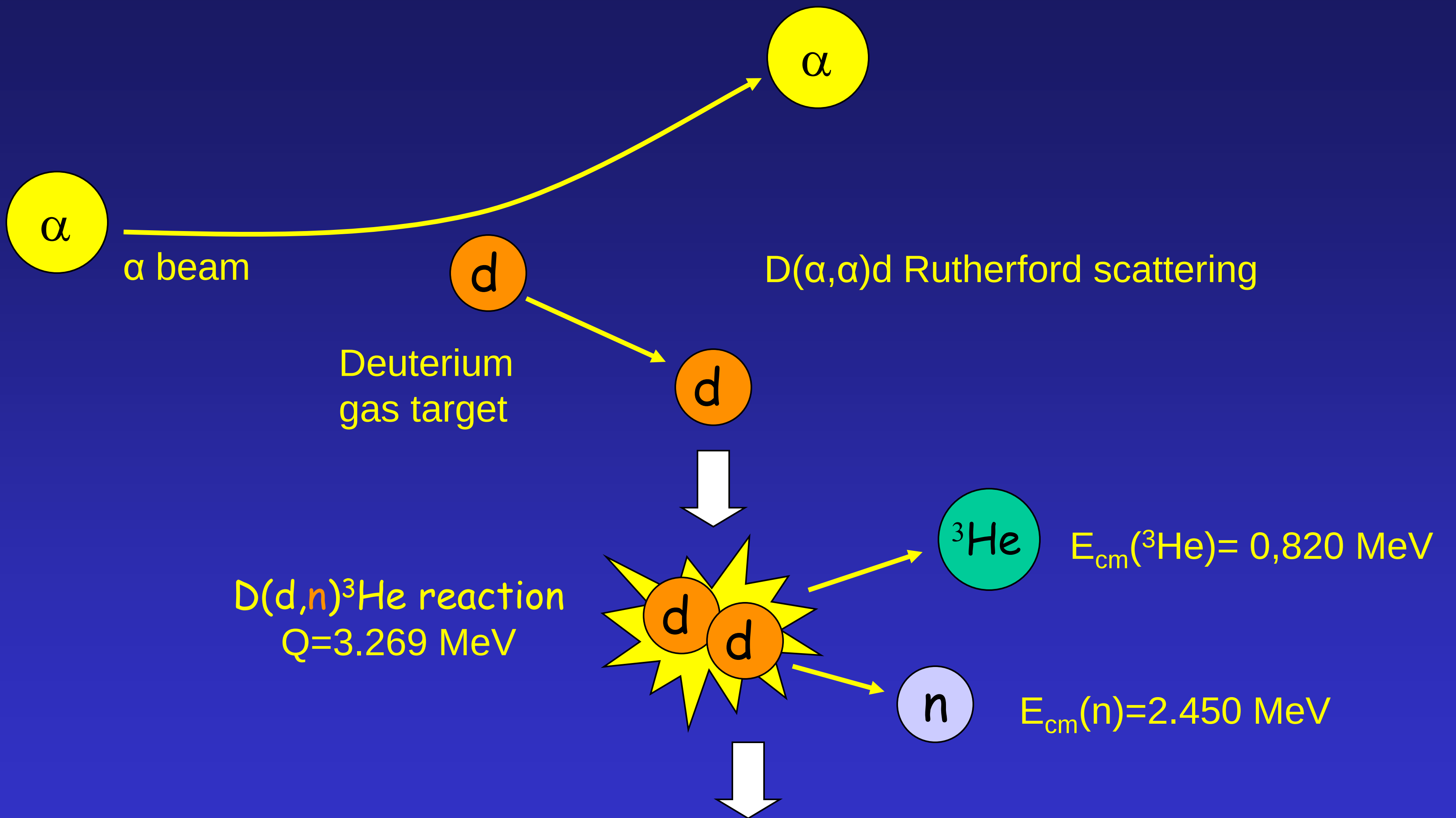
Voltage Range: 50-400 kV
Output Current: 1 mA (@ 400 kV)
Absolute Energy error: ±300 eV
Beam energy spread: <100 eV
Long term stability (1 h) : 5 eV
Terminal Voltage ripple: 5 Vpp

A. Formicola et al., NIMA 527 (2004) 471.



$^{14}N(p,\gamma)^{15}O$
$^{3}He(^{4}He,\gamma)^{7}Be$
$^{25}Mg(p,\gamma)^{26}Al$
$^{15}N(p,\gamma)^{16}O$
$^{17}O(p,\gamma)^{18}F$
$D(^{4}He,\gamma)^{6}Li$
$^{22}Ne(p,\gamma)^{23}Na$

Beam Induced Background origin

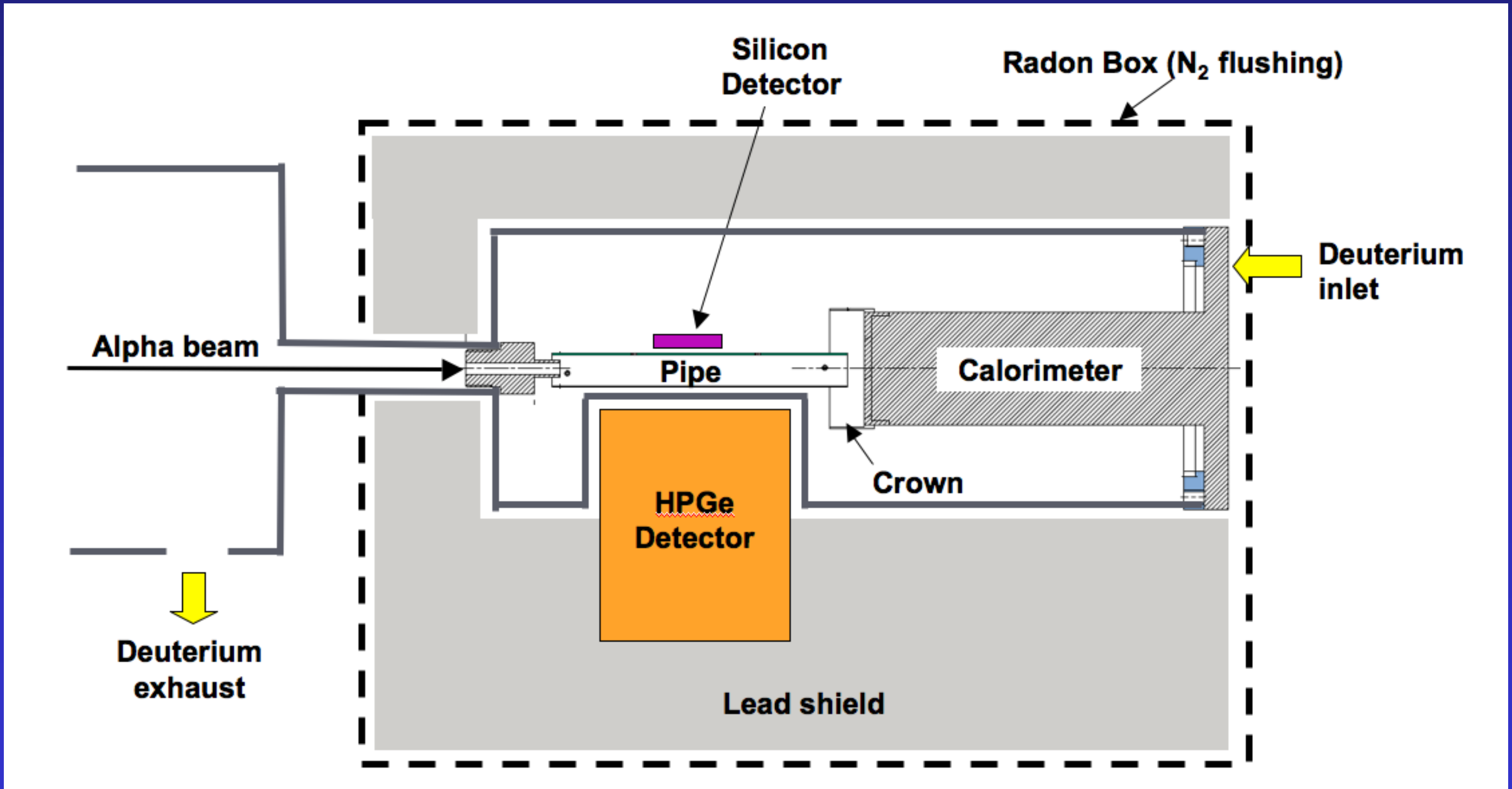


(n,n'γ) reaction on the surrounding materials (lead, steel, copper and germanium).

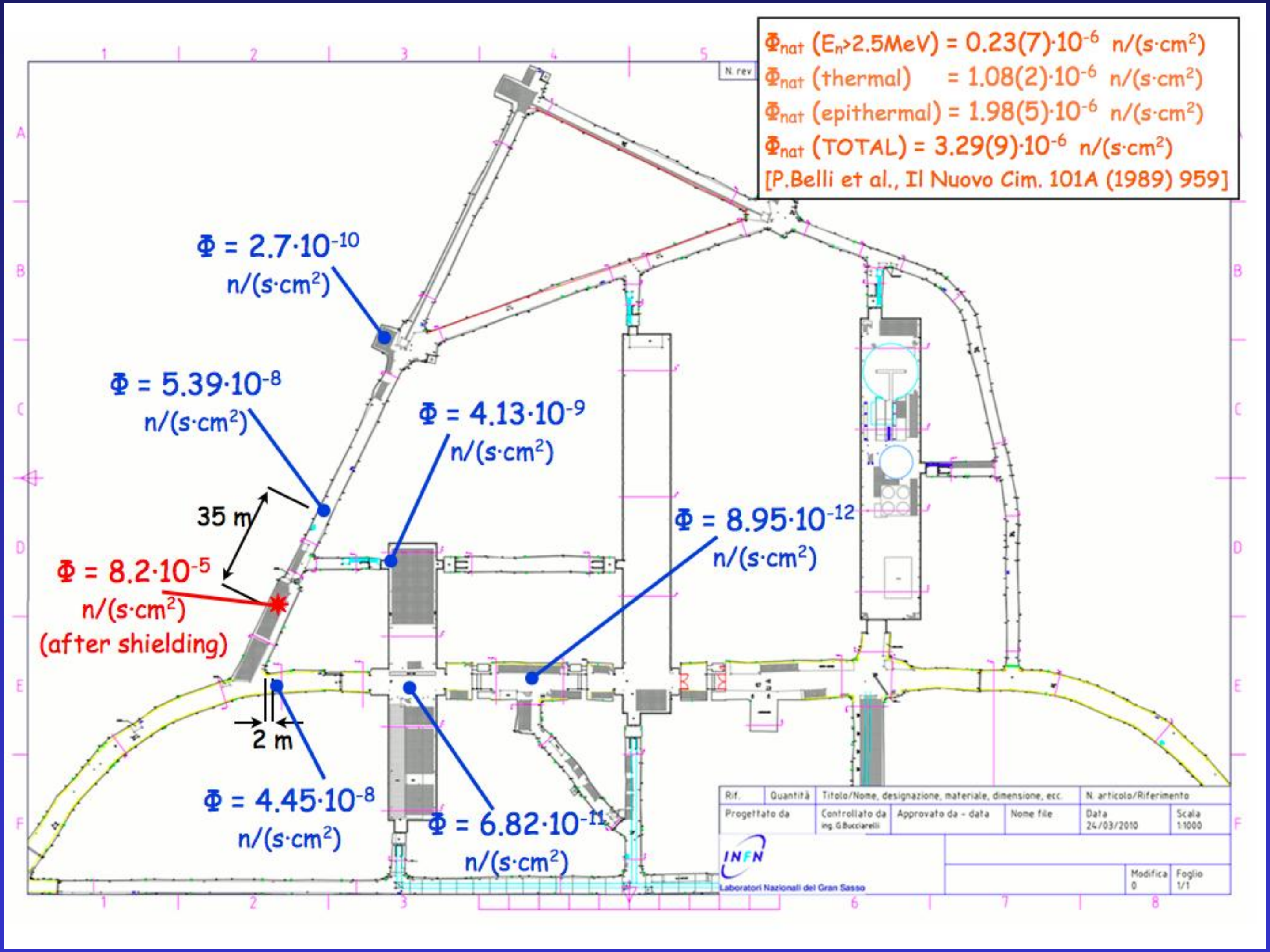
γ-ray background in the RoI for the D(α,γ)^{6}Li DC transition (≈1.6 MeV)

$D(^4He,\gamma)^6Li$ set-up

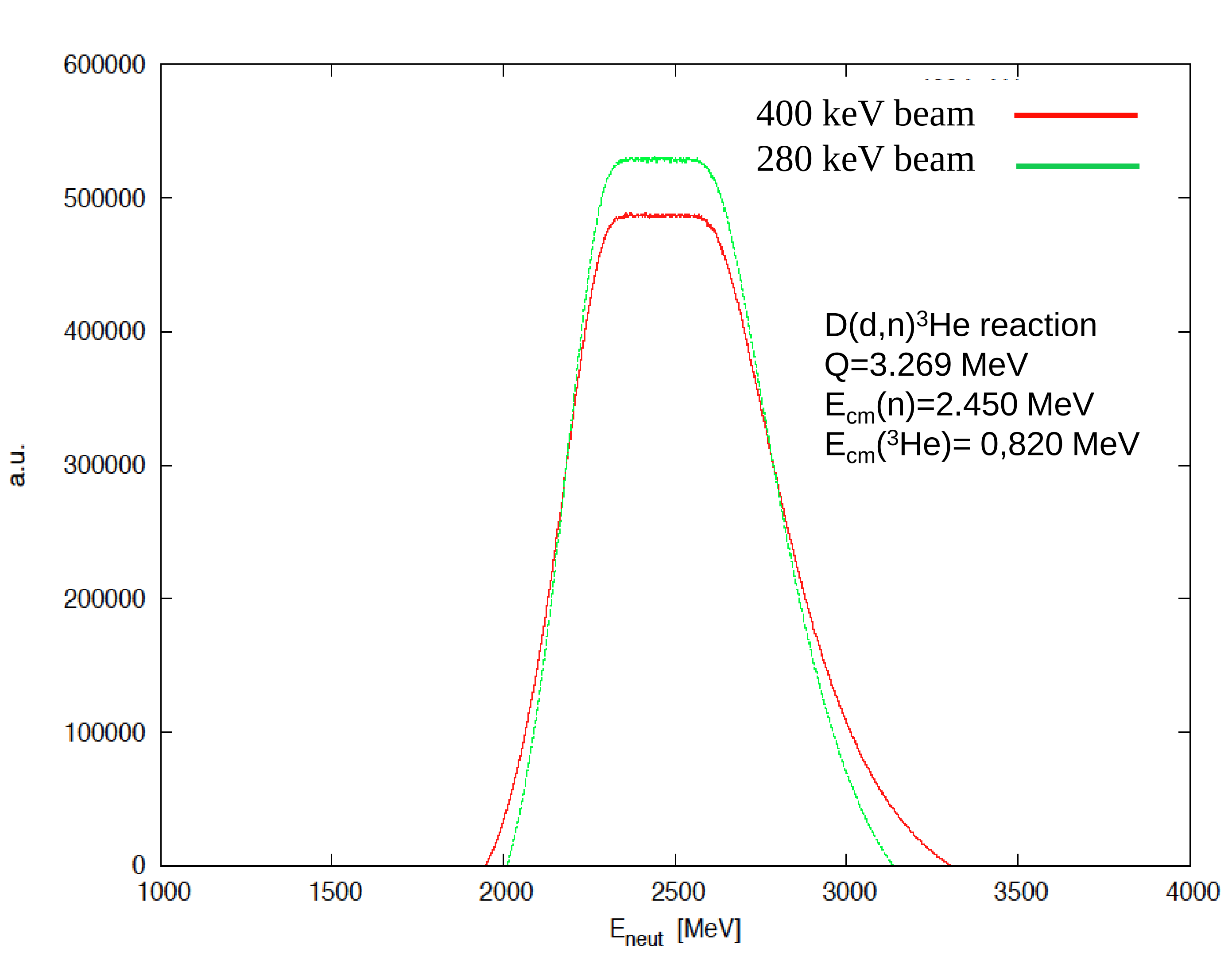
- Germanium detector close to the beam line to increase the detection efficiency
- Target length optimized
- Pipe to reduce the path of scattered deuterium, to minimize the $D(d,n)^3He$ reaction yield
- Copper removal
- Silicon detector to monitor the neutron production through the $D(d,p)^3H$ protons
- Lead, Radon Box to reduce and stabilize Natural Background



Neutron flux inside LNGS (GEANT simulation)



Neutron energy spectra



Signal/Noise estimation

Energy (keV)	Signal (counts/day@300uA)	Noise (counts/day@300uA) 35 keV window	N/S
240	4,8	900	189
280	10	731	70
360	25,8	620	23,7
400	37	670	18

Long measurement time needed.
No hope to see the D(〈 ,γ)^{6}Li signal at low beam energies

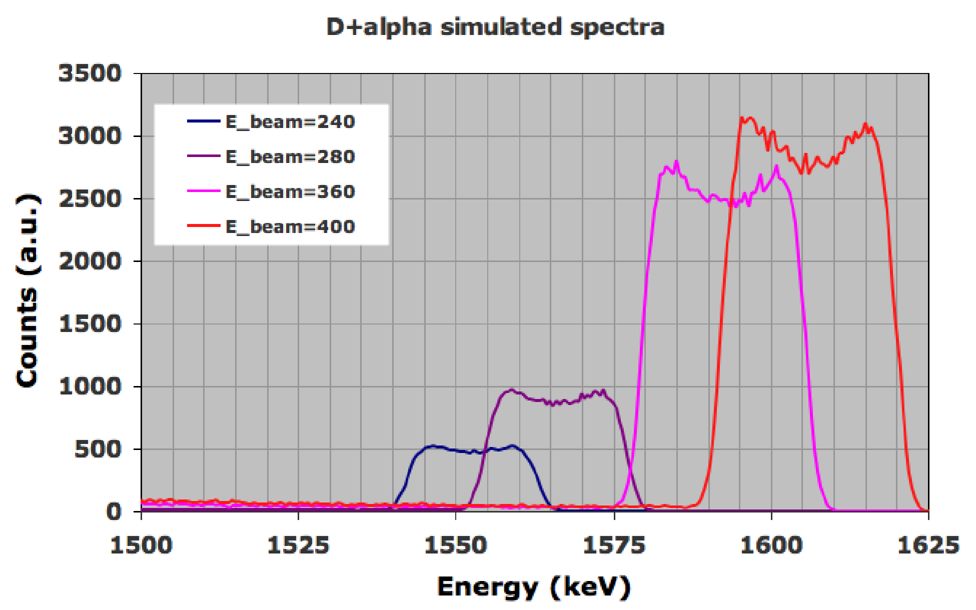
Measurement strategy:

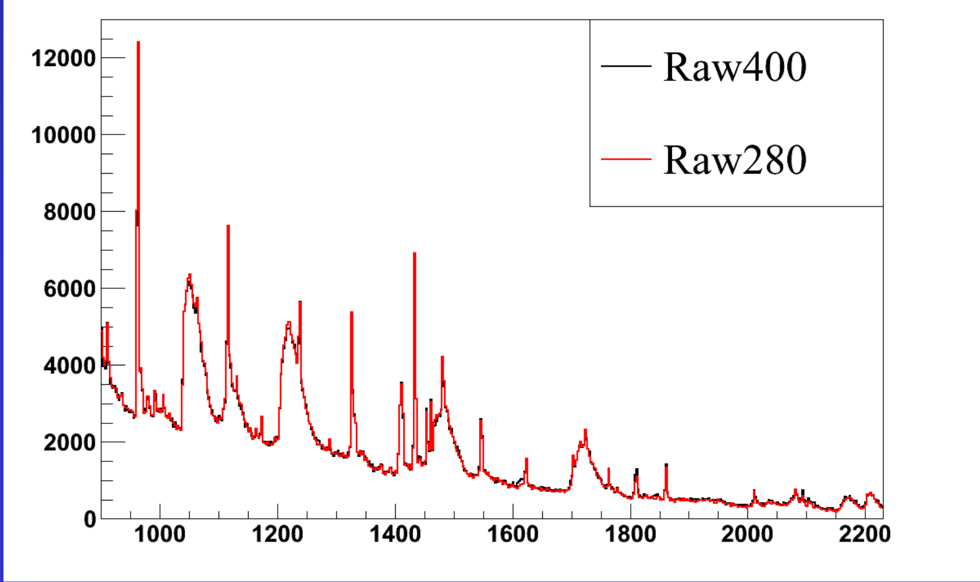
-The Energy of γ's coming from D+alpha reaction strongly depends on the beam energy, through the following relationship:

-Instead, the spectral shape of Background induced by neutron weakly depends on the α-beam energy.

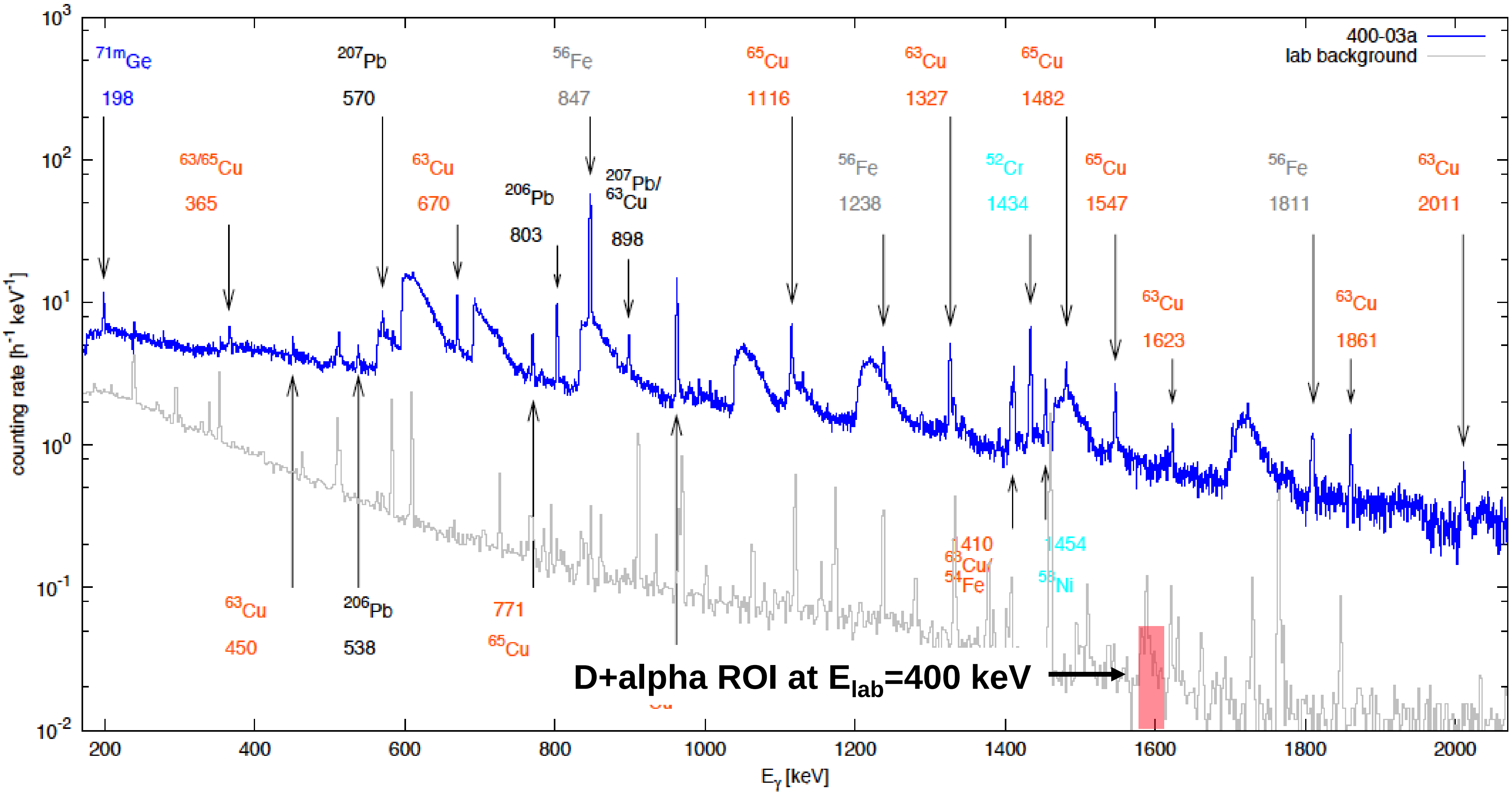
1. Measurement with E_{beam}=400 keV on D_2 target. The Ge spectrum is mainly due to the background induced by neutrons. The $D(\alpha,\gamma)^6Li$ signal is expected in a well defined energy region (1592-1620 keV) .
2. Same as 1., but with E_{beam}=280 keV. The background is essentially the same as before, while the gammas from the $D(\alpha,\gamma)^6Li$ reaction are shifted to 1555-1578 keV.

D(α,γ)^{6}Li Signal is obtained by subtracting the two spectra

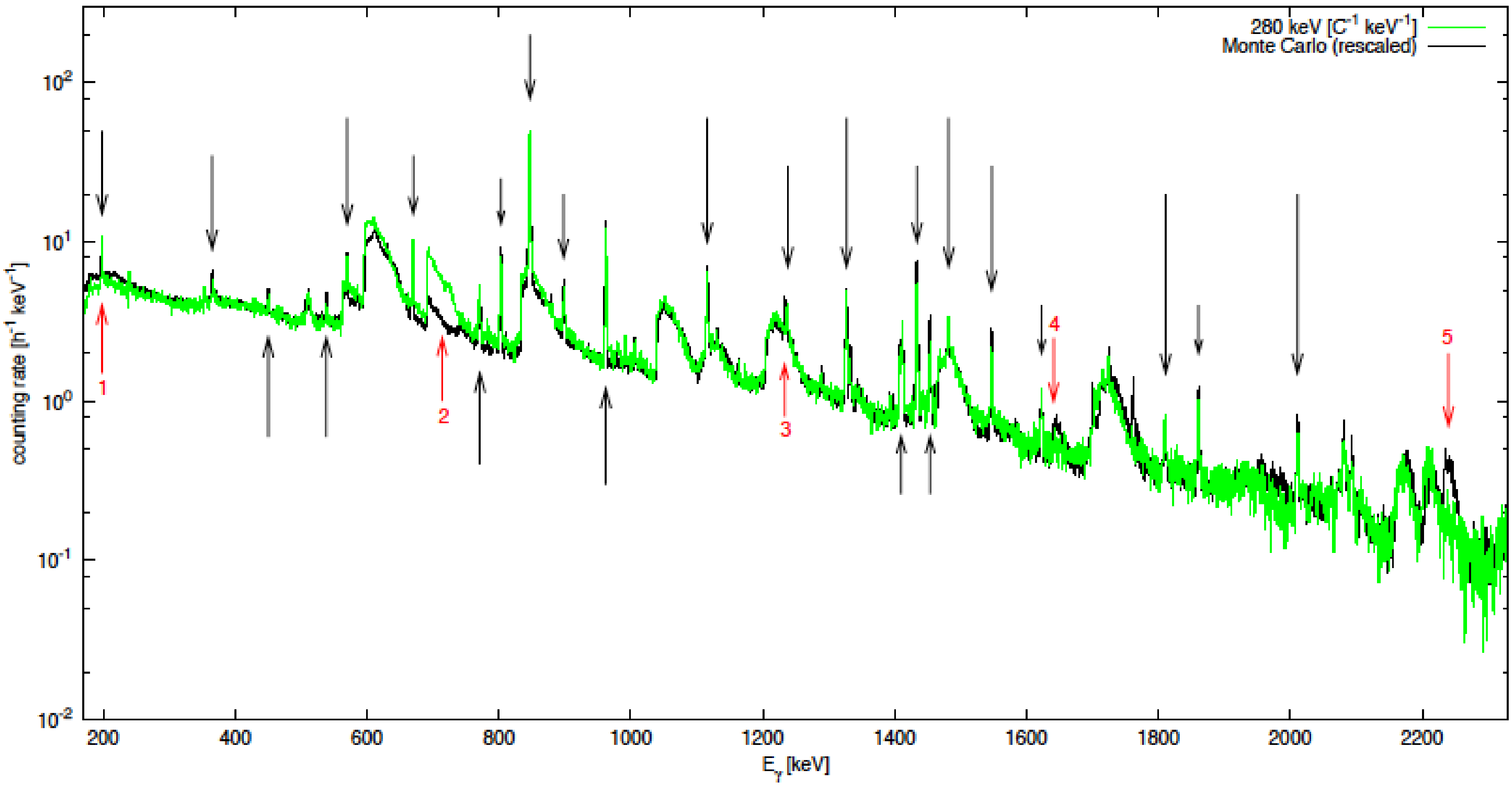




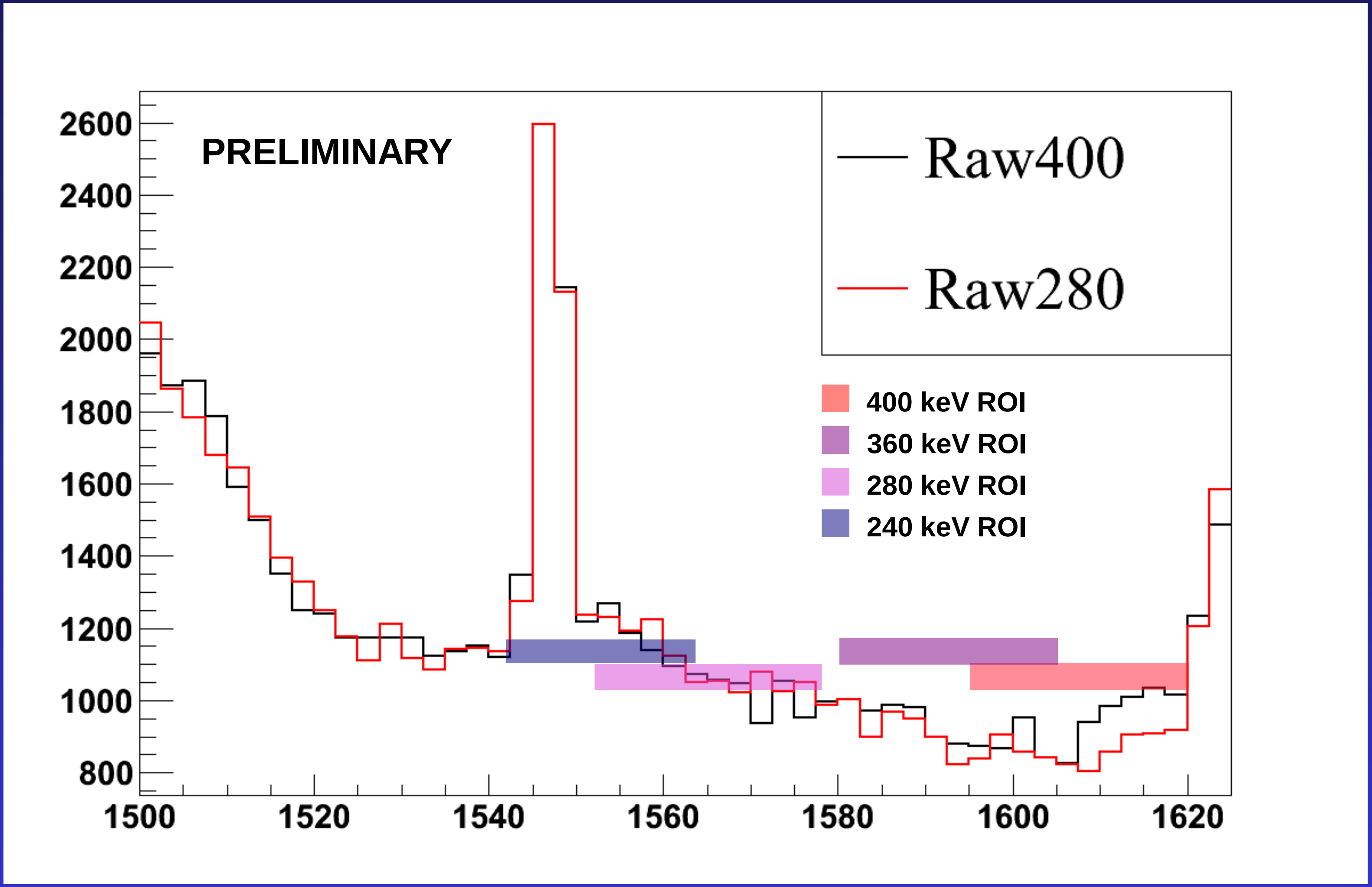
Beam Induced Background and Natural Background



Beam Induced Background Vs GEANT simulation

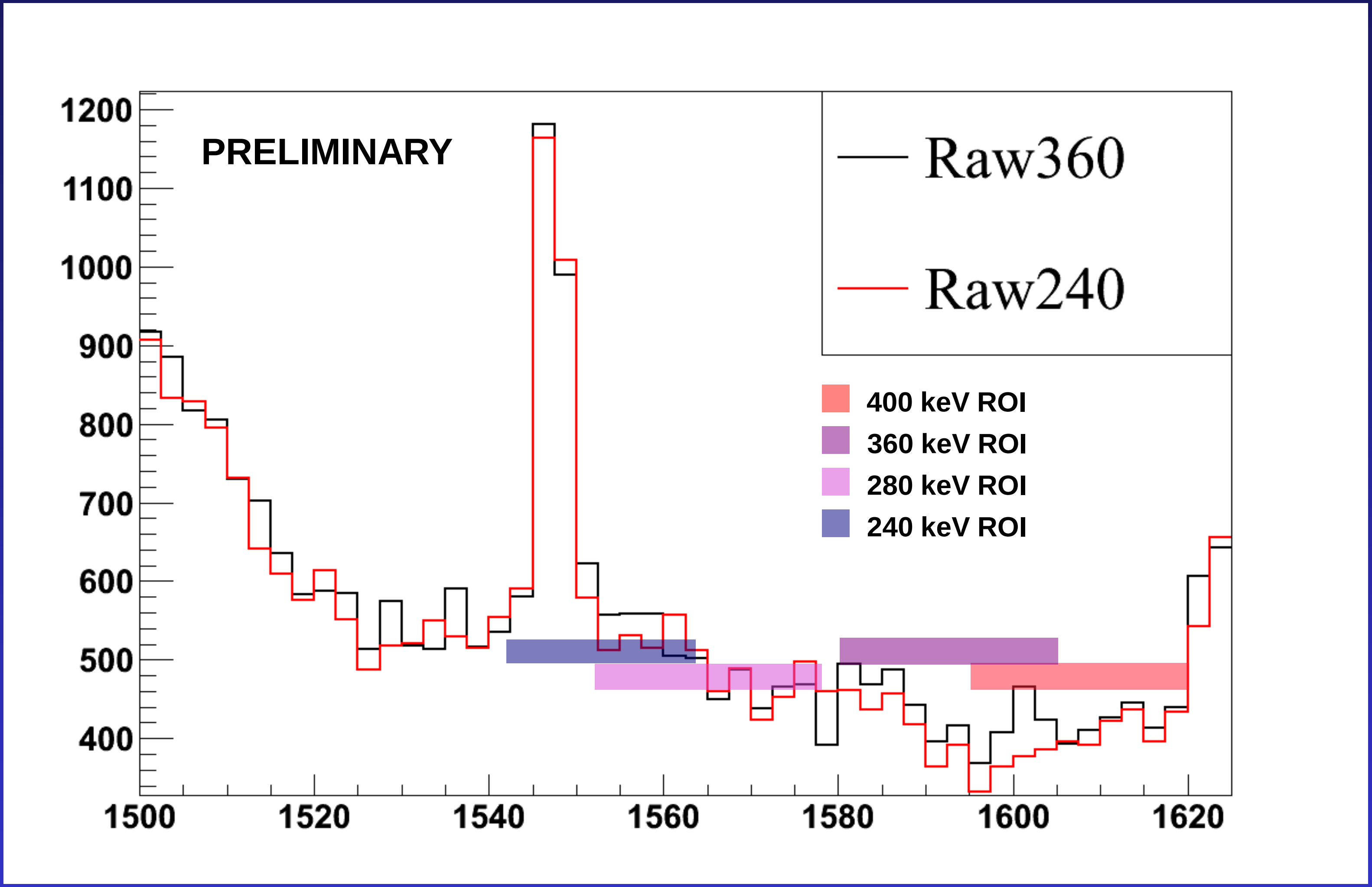


Some result (E_{lab}=400/280 keV)



400 keV: T=18,2 days; <P>=0,306 mbar; Q=514
280 keV: T=20,5 days; <P>=0,308 mbar; Q=539
Counting excess observed to the E_{lab}=400 keV ROI (red band)

Some result (E_{lab}=360/240 keV)



360 keV: T=8,55 days; <P>=0,300 mbar; Q=252
240 keV: T=9,07 days; <P>=0,300 mbar; Q=211
Counting excess shifted to the E_{lab}=360 keV ROI (violet band)

Conclusion

The LUNA measurement exclude a nuclear solution for the ^{6}Li problem. The observation of a “huge” amount of ^{6}Li in metal-poor stars must be explained in a different way (systematics in the ^{6}Li observation, unknown ^{6}Li sources older than galaxies, new physics…).

For the first time, the D(α,γ)^{6}Li reaction has been studied at BBN energies. The LUNA measurement provides a direct experimental footing to calculate the ^{6}Li primordial abundance.

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THANK YOU!