Study of the $^{2}H(p,\gamma)^{3}He$ reaction in the BigBang Nucleosynthesis energy range at LUNA

V. Mossa (for the LUNA collaboration)

viviana.mossa@ba.infn.it

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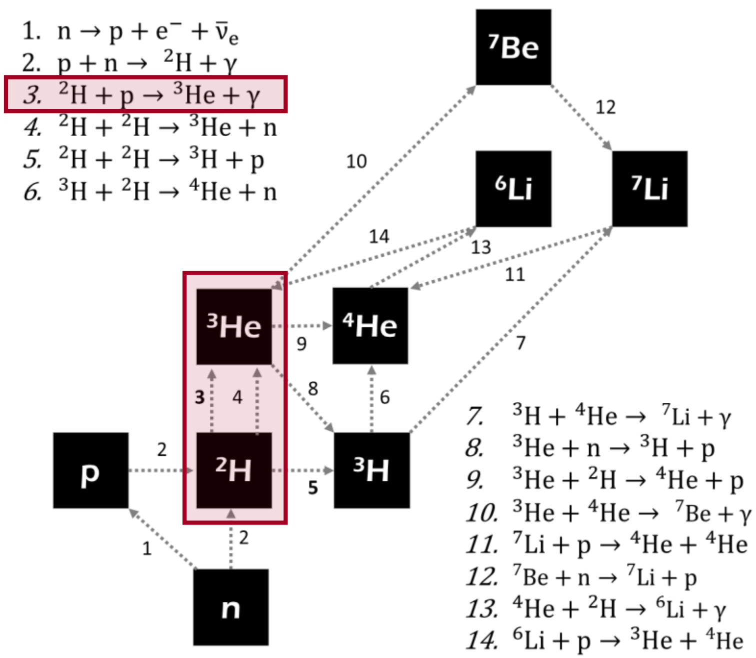
- Physics motivation for a new $^{2}H(p,\gamma)^{3}He$ measurement at BBN energies
- The $^{2}H(p,\gamma)^{3}He$ reaction at LUNA
- I phase: the BGO setup
- II phase (on going maesurements): the HPGe setup
- Preliminary results
- Conclusions



PRIMORDIAL ABUNDANCE OF ^{2}H:

- Direct measurements: observation of absorption lines in DLA system

$$\left[\frac{D}{H}\right]_{OBS} = (2.547 \pm 0.033) \cdot 10^{-5}$$

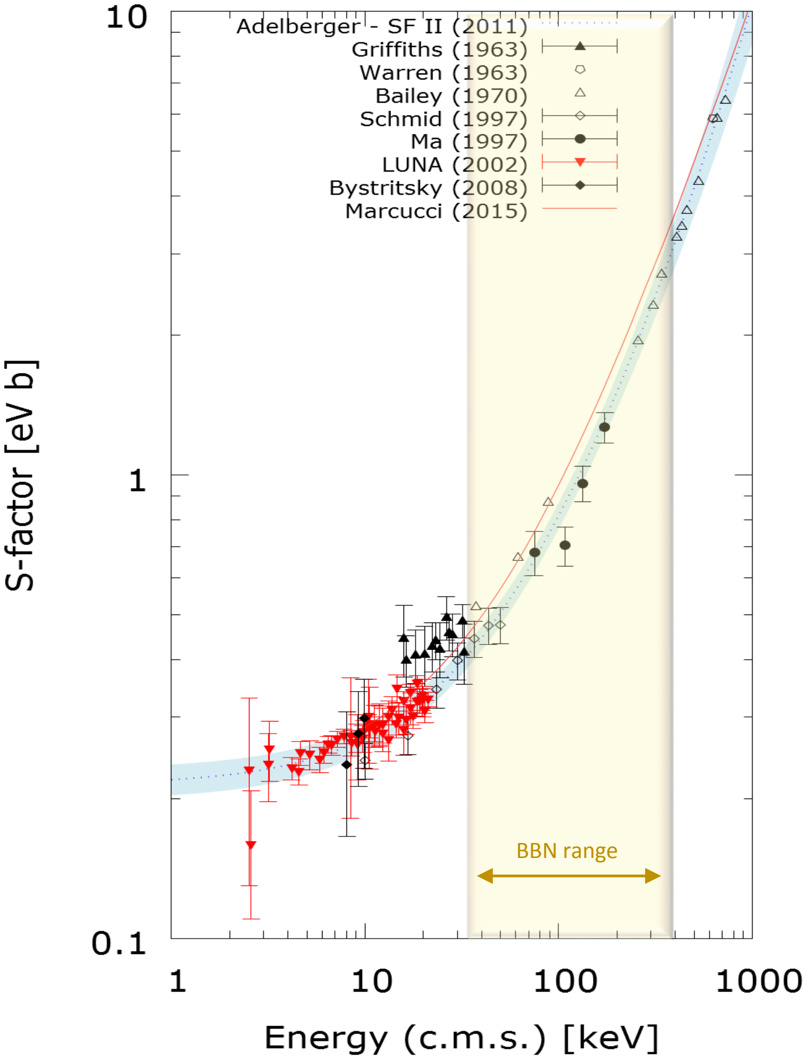
*R. Cooke at al., ApJ. 781 (2016) 31;

- BBN theory: from the cosmological parameters and the cross sections of the processes involved in ^{2}H creation and destruction

$$\left[\frac{D}{H}\right]_{BBN} = (2.65 \pm 0.07) \cdot 10^{-5}$$

*E. Di Valentino et al., Phys. Rev. D 90 (2014) 023543

Interest in a new $^{2}H(p,\gamma)^{3}He$ measurement

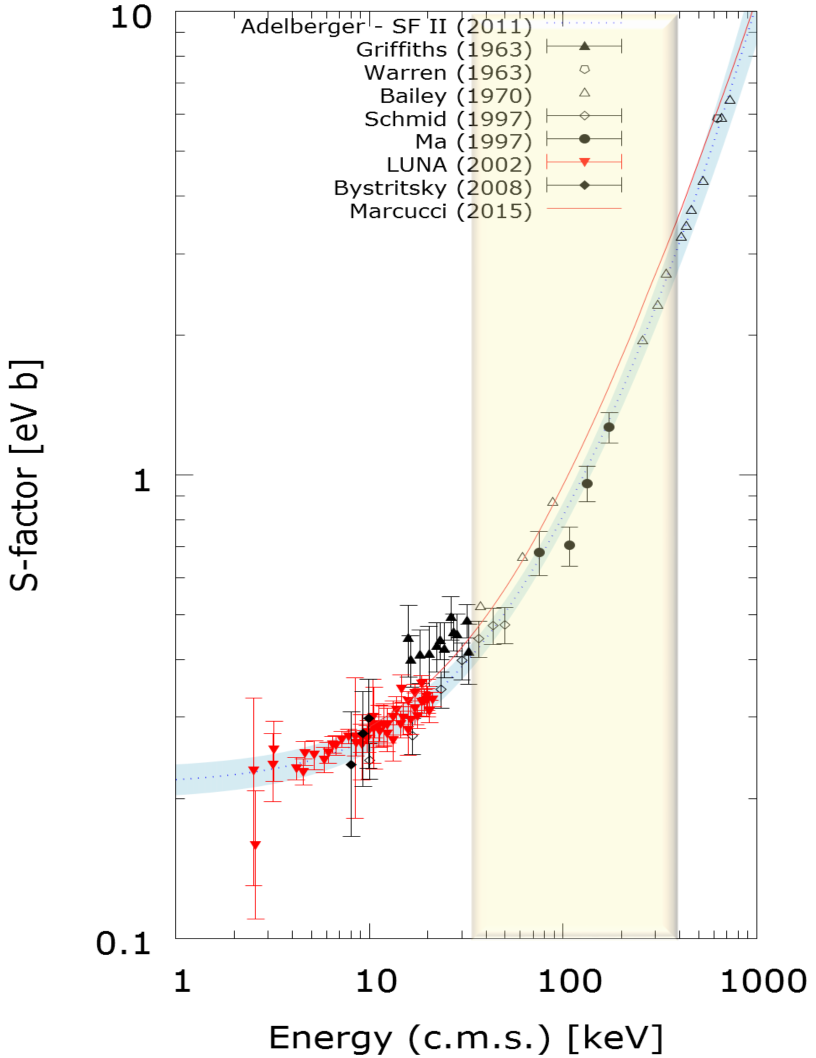


The error budget of computed abundance of deuterium is mainly due to the d(p,γ)^{3}He reaction

Reaction	$\sigma_{^2H/H} \times 10^5$
$p(n,\gamma)^2$H	± 0.002
$d(p,\gamma)^3$He	± 0.062
$d(d,n)^3$He	± 0.020
$d(d,p)^3$H	± 0.013

*E. Di Valentino et al., Phys. Rev. D 90 (2014) 023543

- Precise low energy data coming from LUNA 50 kV
- Only a single dataset is currently available at the BBN energy range with a systematic error of 9%
- No perfect agreement with recent «Ab-initio» calculations



The $^2H(p,\gamma)^3He$ reaction is of high interest also in theoretical nuclear physics, in particular for what concern "ab-initio" modelling, as light nuclei are involved in this process

There is a maximum discrepancy of 15% between theoretical predictions (red line) and the best fit of experimental data (blue band)

**Marcucci 2016 Phys. Rev. Lett.*
**Adelberger 2011 Rev. Mod. Phys.*

The difference between theory and the data let some author to adopt the theoretical curve or the S-factor value obtained from measurement.

BBN provides a precise estimate of Baryon density Ω_b, through the comparison of $(D/H)_{BBN}$ and $(D/H)_{obs}$:

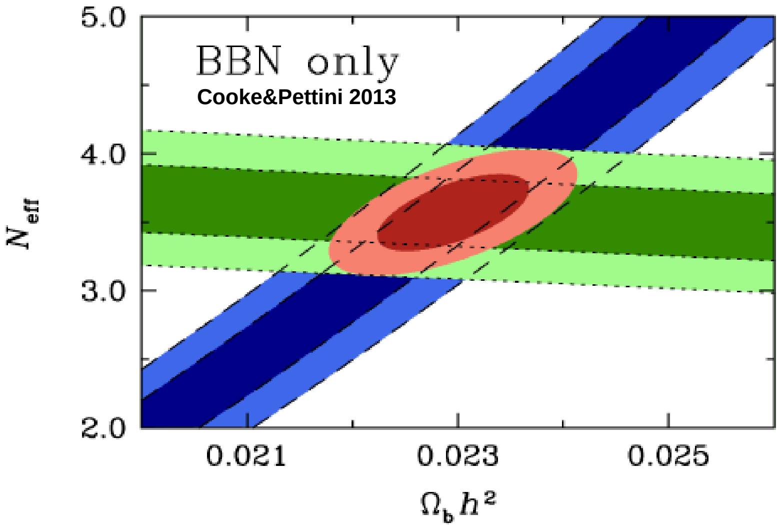
Assuming the Standard Model

- $100\Omega_{b,0}h^2$(CMB)= 2.22 ± 0.02 (PLANCK 2015)

d(p,γ)^{3}He data fit

- $100\Omega_{b,0}h^2$(BBN)= 2.20 ± 0.04 ± 0.02 (Cooke 2013)

D/H observations

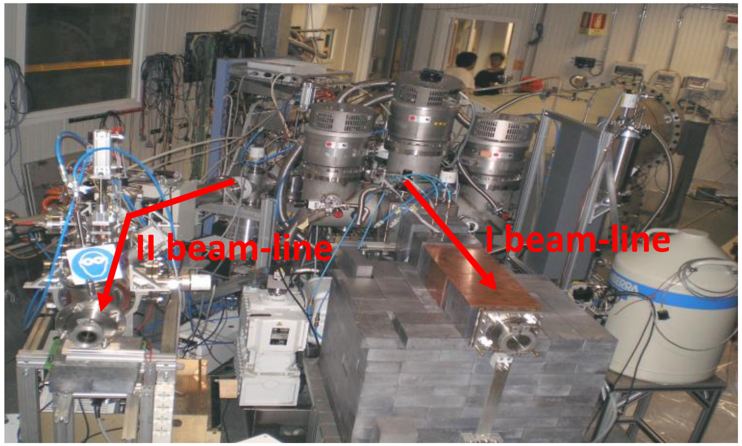


Measurement goal:

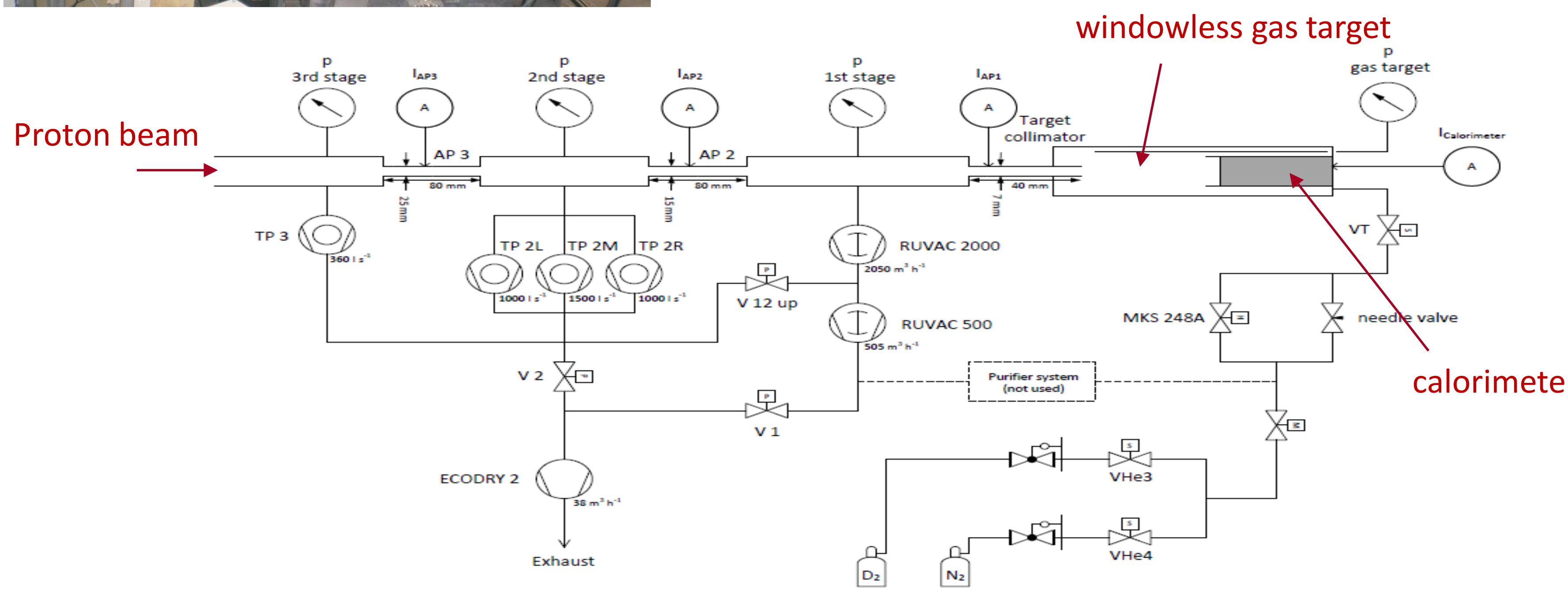
- Cross section measurement at 30keV<E_{cm}<300keV with ~5% accuracy
- Differential cross section measurement

Physics:

1. Cosmology: measurement of Ω_b
2. Cosmology : measurement of N_{eff}
3. Nuclear physics: comparison of data with "ab initio" predictions

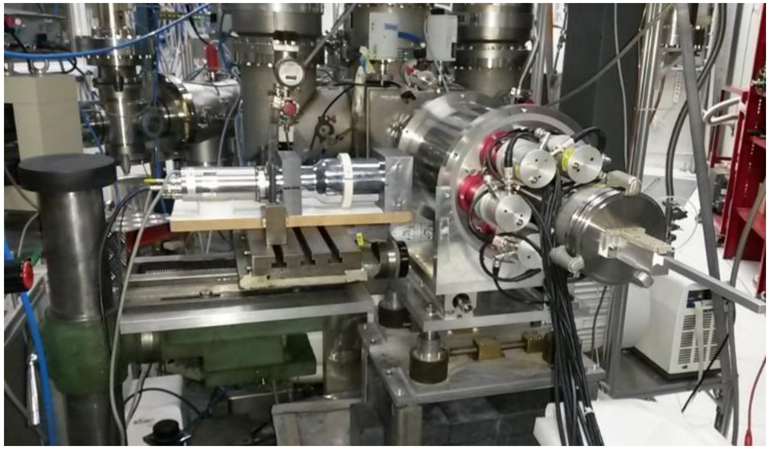


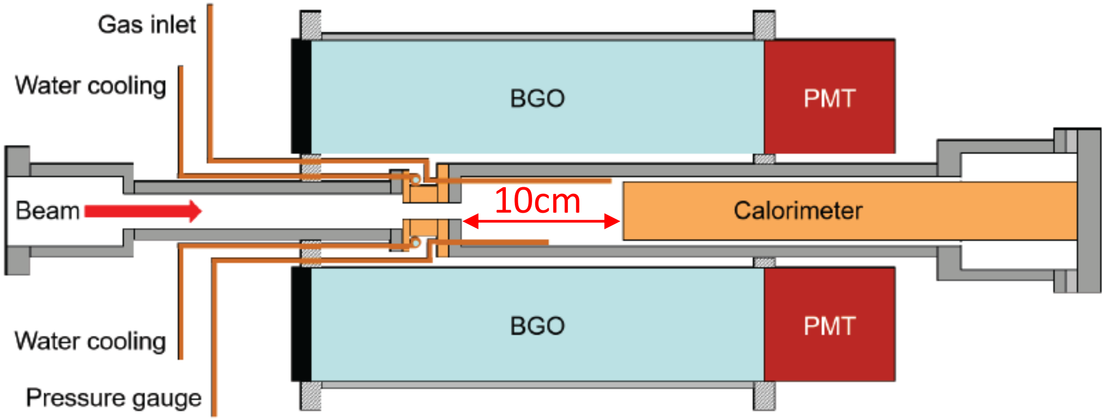
- Accelerator LUNA 400 kV
  - High current $I_p \cong 300\ \mu A$
  - E_{beam}=[50 – 400] keV
  - Long term stability ≈ 5eV/h
  - Energy spread ≈ 70 eV
- 2 beam-lines:
  - I beam-line: gas target
  - II beam-line: solid target



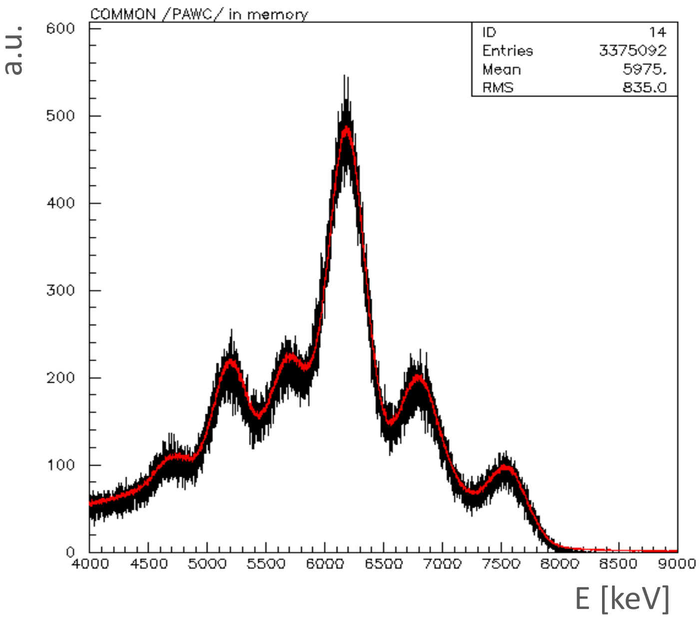
I phase: the BGO setup

- $E_{beam} \sim 50 - 300\ keV$
- Energy resolution in the total absorption peak ~ 8%
- $\sim 4\pi$ geometry
- High detection efficiency for 5.5 MeV γ-rays ~ 62%



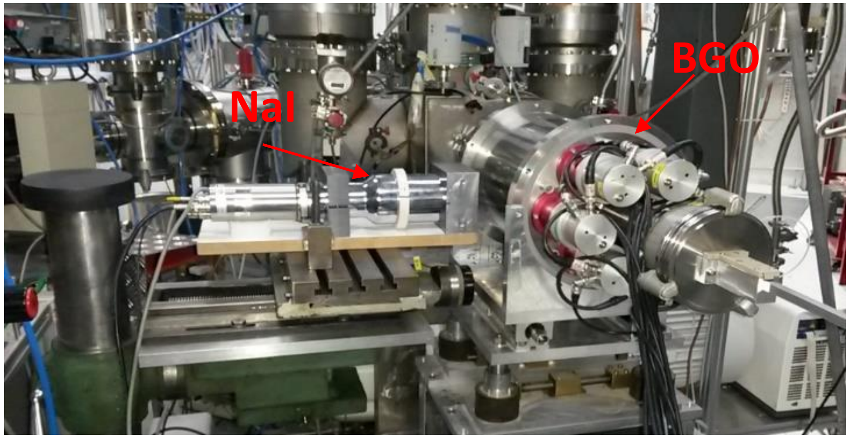


Efficiency calibration obtained with Monte Carlo simulations verified with radioactive sources (^{137}Cs, ^{60}Co, ^{88}Y) at low energy and with the resonant reaction $^{14}N(p,\gamma)^{15}O$ at high energy



Good agreement between experimental data and Geant4 simulation:

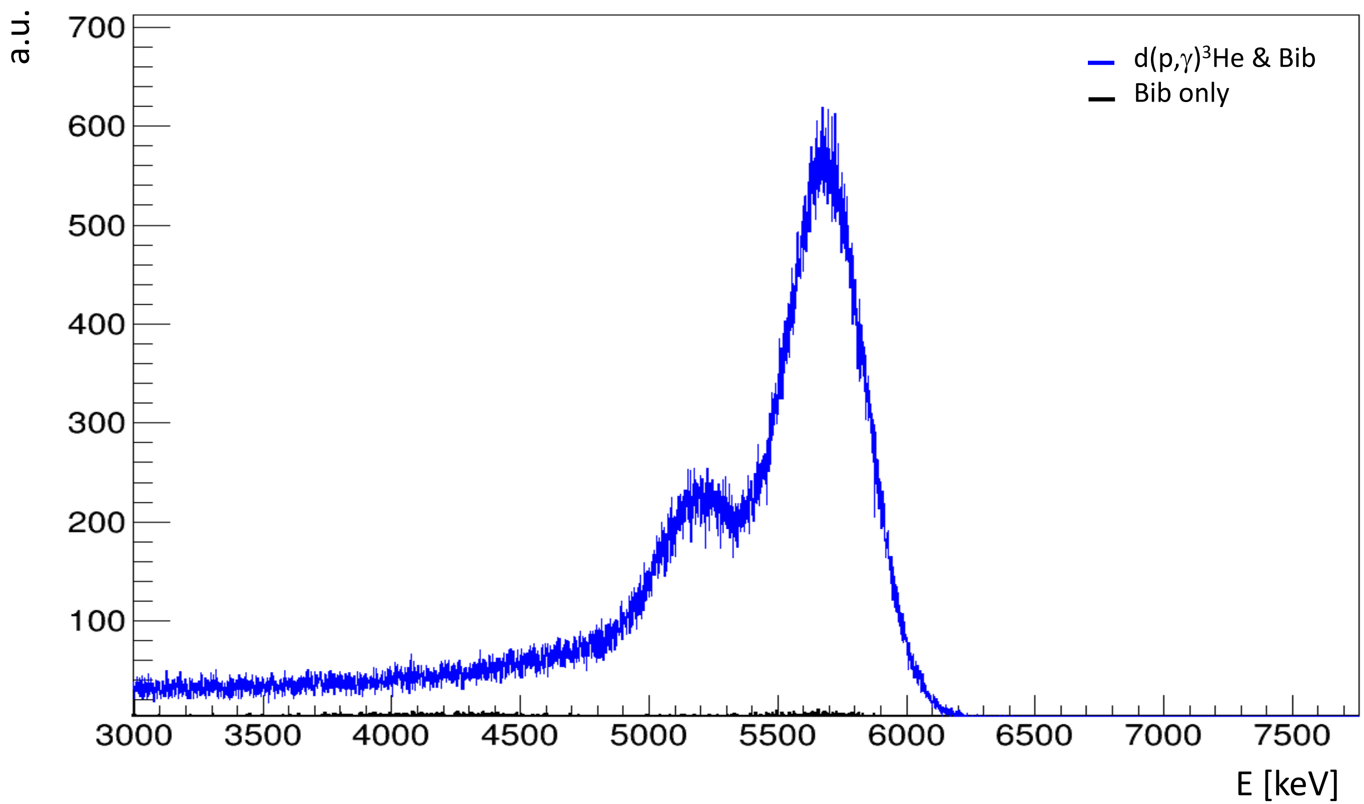
- $^{14}N(p,\gamma)^{15}O$ reaction



In order to reduce the systematic error, the resonance position has been identified coupling the BGO with a collimated NaI

- d(p,γ)^{3}He run
- Beam induced background run in vacuum at the same proton energy

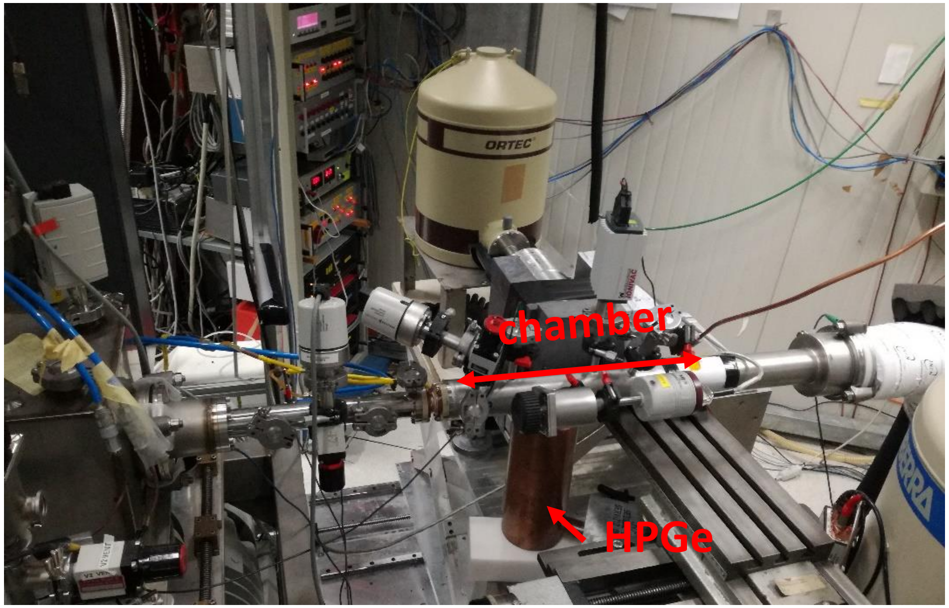
E_p=150 keV

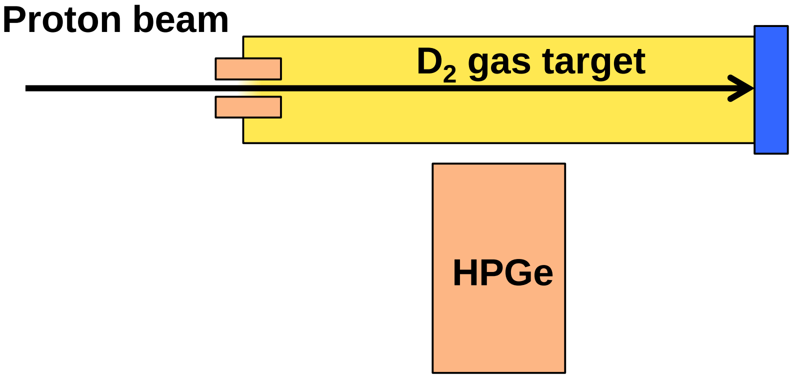


Data analysis is on going to extrapolate the S-factor and to evaluate the systematics

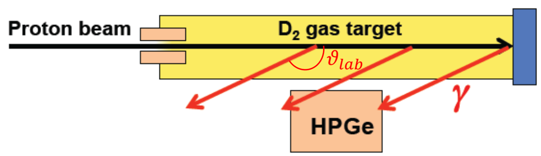
II phase: the HPGe setup

- High energy resolution in the total absorption peak < 0.10%
- Possibility of performing angular distribution measurements with extended gas target (33 cm)

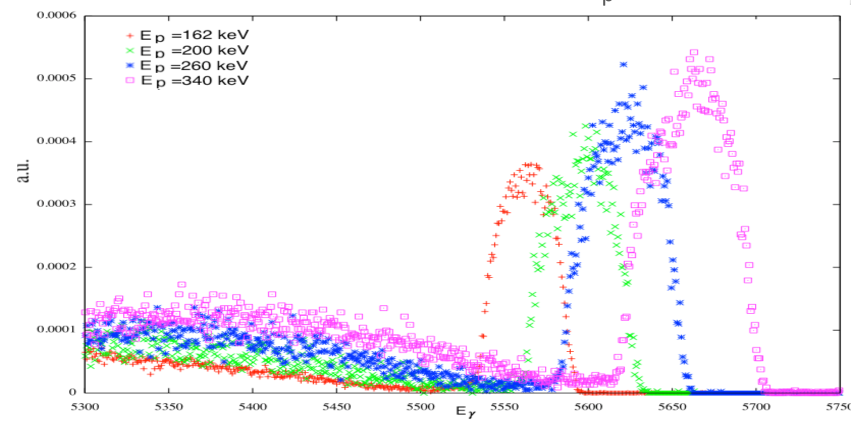




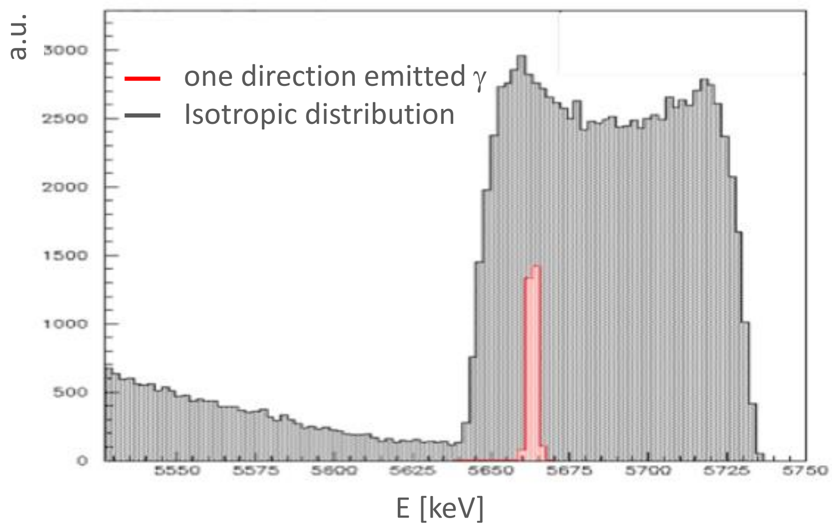
$$E_\gamma = \frac{m_p^2 + m_d^2 - m_{3He}^2 + 2E_p \cdot m_d}{2 \cdot (E_p + m_d - p_p \cos(\vartheta_{lab}))}$$



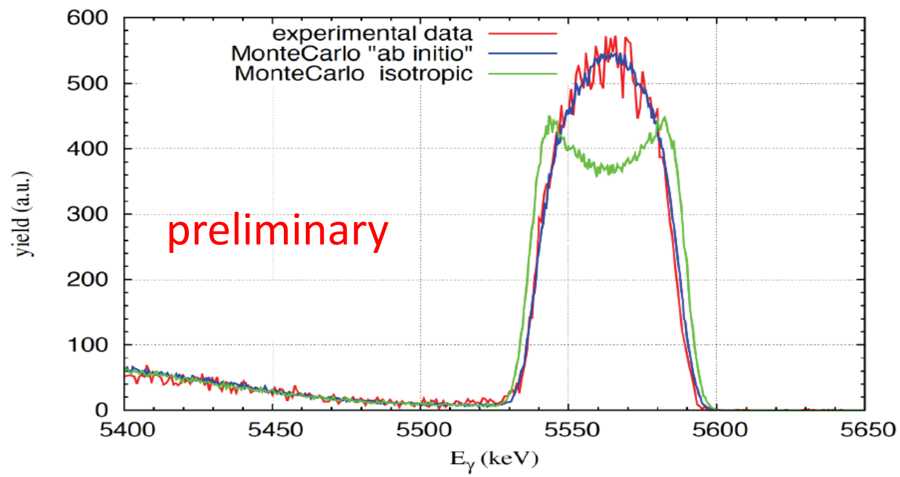
Dependence on E_p



Simulated angular distribution



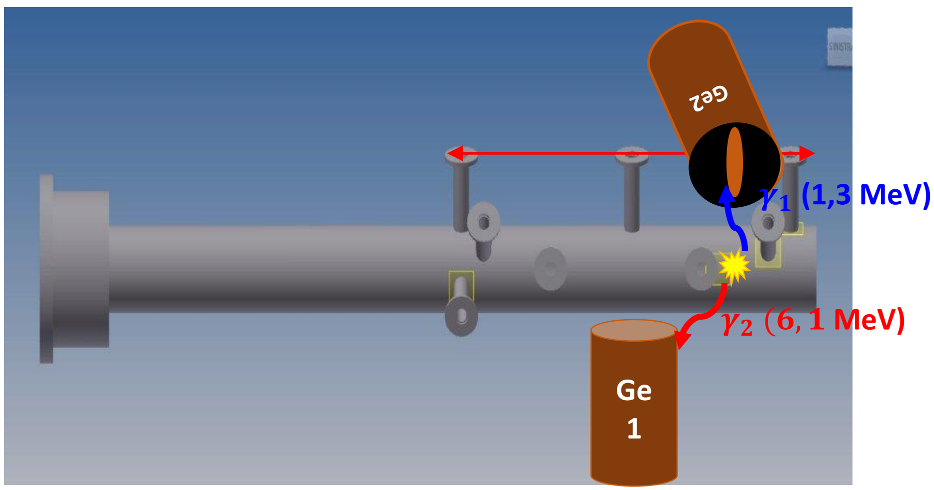
Comparison data/simulation

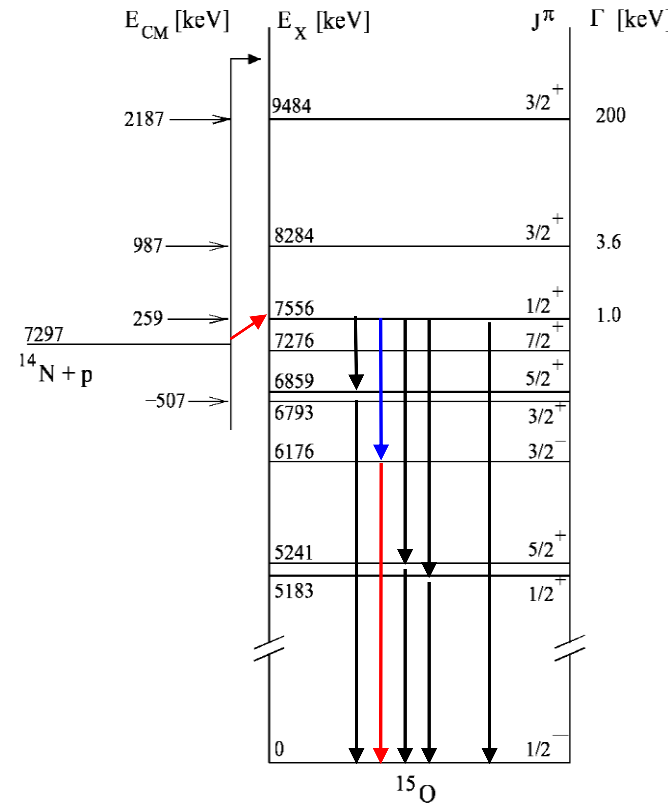


The set up is sensitive to the angular distribution

Efficiency calibration → coincidence between two γ rays emitted in cascade (decay γ–γ angular correlation is well known) :

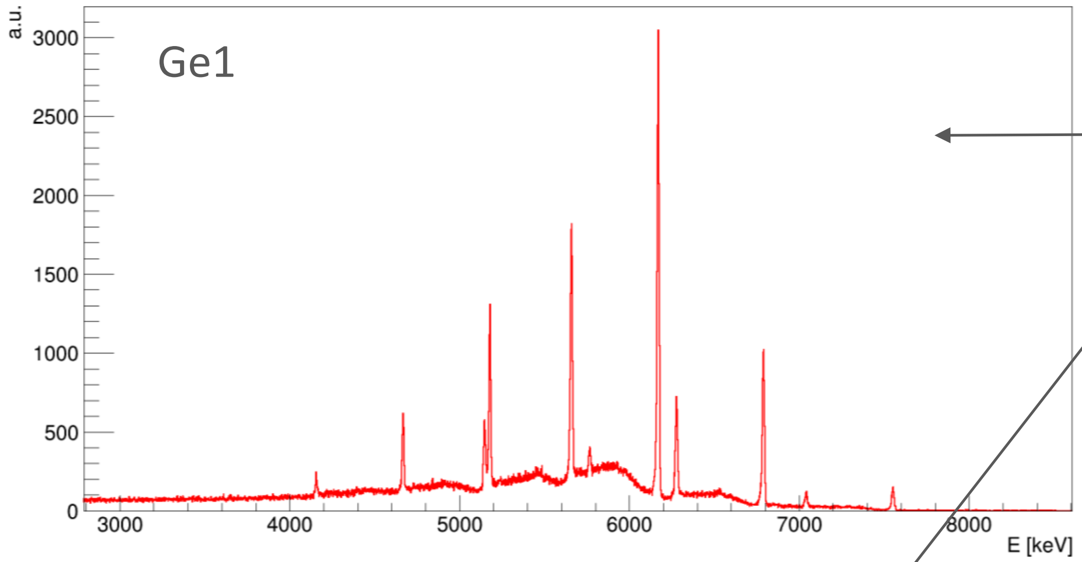
- ^{60}Co radioactive sources at low energy
- $^{14}N(p,\gamma)^{15}O$ on the E_R=259 keV resonance



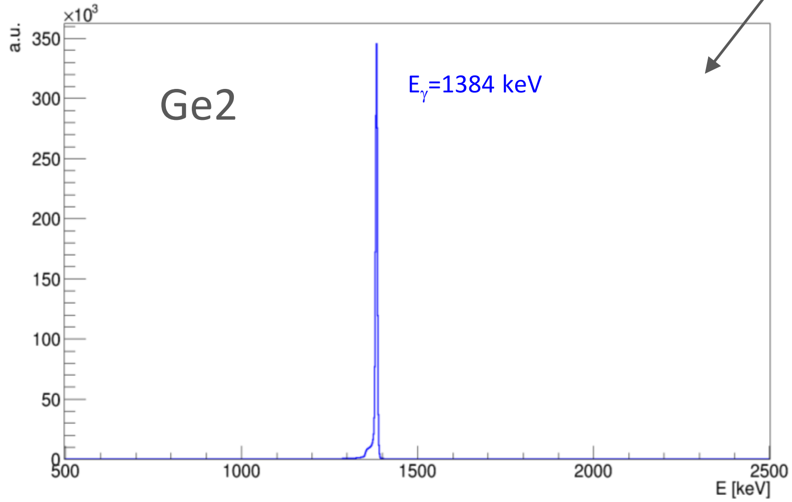


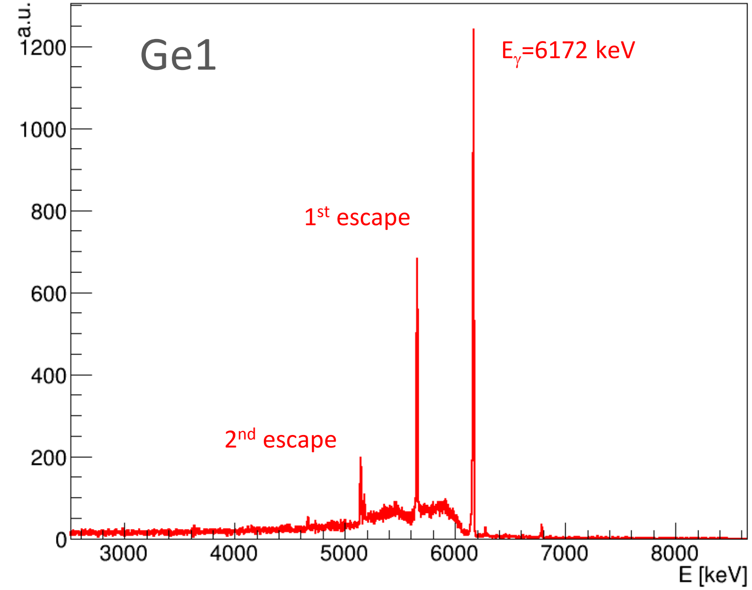
Eγ (keV)	Branching (%)
5181+2375 (14N)	17.1±0.2 (1.2%)
5241+2315	0.6±0.3 (50%)
6172+1384	57.8±0.3 (0.5%)
6791+765	22.9±0.3 (1.3%)
7556+0	1.6±0.1 (6.2%)

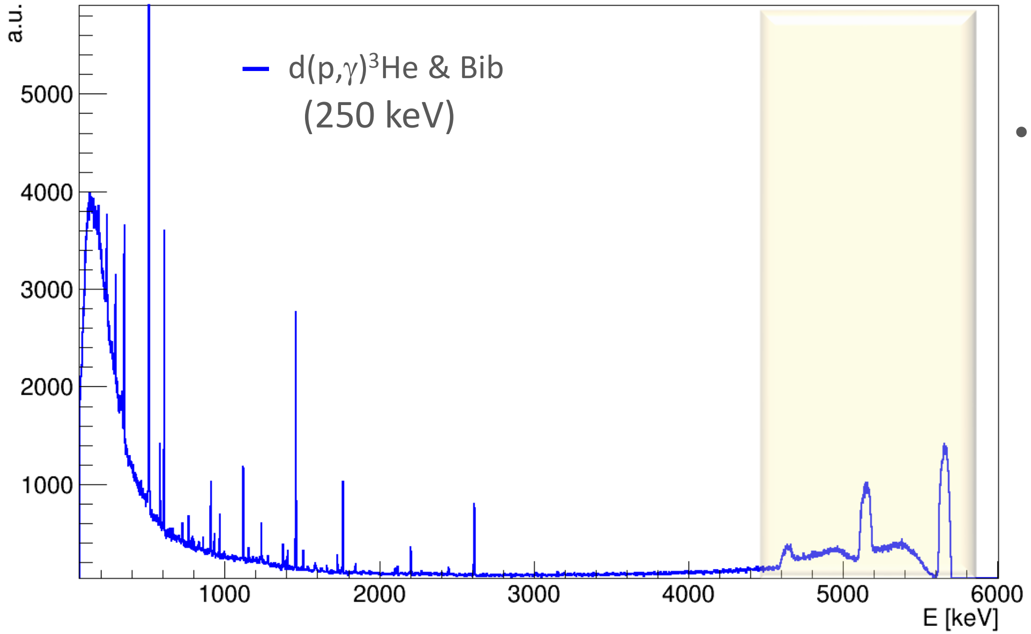
$$\varepsilon = \frac{N_{Ge1}}{N_{Ge2}}$$



- Ge1 $^{14}N(p,\gamma)^{15}O$ inclusive spectrum
- Ge1 and Ge2 coincidence spectra

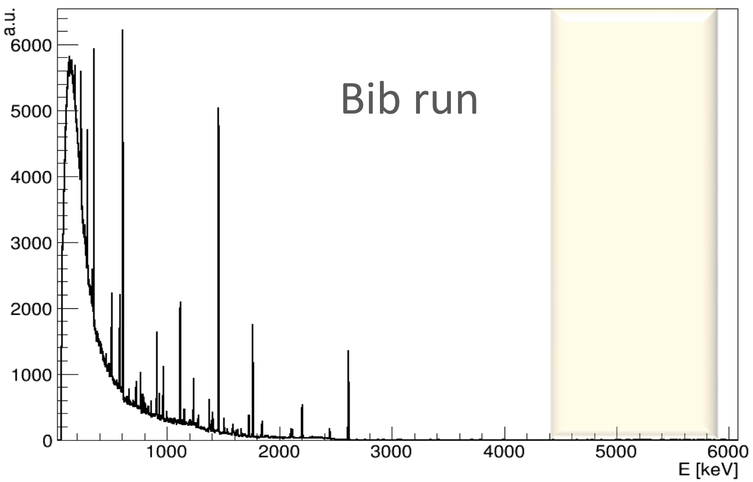






- d(p,γ)^{3}He run at 0.3 mbar of pressure inside the chamber

- Beam induced background run in ^{3}He



Data taking on going!

- High precision $^{2}H(p,\gamma)^{3}He$ cross section data in BBN energy range can put constraints on cosmological parameters
- As light nuclei are involved in this process, the $^{2}H(p,\gamma)^{3}He$ reaction is of high interest also for theoretical nuclear physics ab-initio calculations
- BGO data taking completed and data analysis on going
- HPGe data taking on going
- The data we are currently collecting [30 - 300 keV] together with those previously acquired at LUNA 50 kV [2.5 - 22 keV] will provide a complete data set with high accuracy in a wide energy range