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

V. Mossa (for the LUNA collaboration)

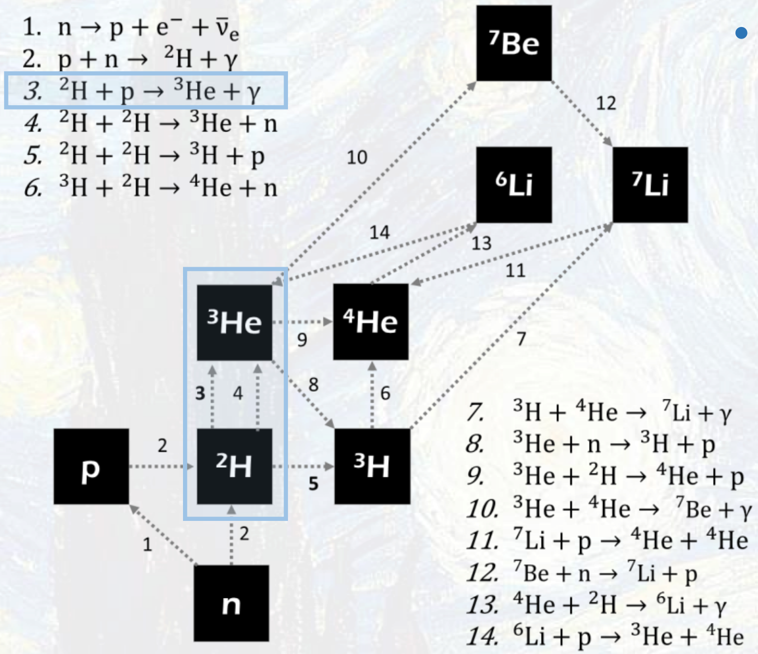
viviana.mossa@ba.infn.it

Terzo Incontro Nazionale di Fisica Nucleare – INFN2016,
14-16 Novembre 2016 – Laboratori Nazionali di Frascati

Outlook

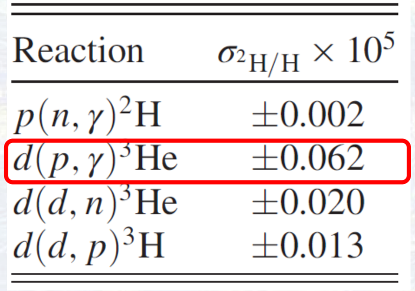
- Interest in the $^{2}H(p,\gamma)^{3}He$ measurement at BBN energies
- The $^{2}H(p,\gamma)^{3}He$ reaction at LUNA
- I phase and preliminary results: the BGO setup
- II phase: the HPGe setup
- Conclusions

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



1. $n \rightarrow p + e^{-} + \bar{\nu}_e$
2. $p + n \rightarrow {}^{2}H + \gamma$
3. ${}^{2}H + p \rightarrow {}^{3}He + \gamma$
4. ${}^{2}H + {}^{2}H \rightarrow {}^{3}He + n$
5. ${}^{2}H + {}^{2}H \rightarrow {}^{3}H + p$
6. ${}^{3}H + {}^{2}H \rightarrow {}^{4}He + n$
7. ${}^{3}H + {}^{4}He \rightarrow {}^{7}Li + \gamma$
8. ${}^{3}He + n \rightarrow {}^{3}H + p$
9. ${}^{3}He + {}^{2}H \rightarrow {}^{4}He + p$
10. ${}^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$
11. ${}^{7}Li + p \rightarrow {}^{4}He + {}^{4}He$
12. ${}^{7}Be + n \rightarrow {}^{7}Li + p$
13. ${}^{4}He + {}^{2}H \rightarrow {}^{6}Li + \gamma$
14. ${}^{6}Li + p \rightarrow {}^{3}He + {}^{4}He$

Knowing:
- the cosmological parameters
- the cross section of the processes responsible for ^{2}H creation and destruction



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

Present uncertainty is 10%

Primordial deuterium abundance can be calculated

BBN results can be compared with astronomical observations:

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

$$\left[\frac{D}{H}\right]_{OBS} = (2.53 \pm 0.04) \cdot 10^{-5}$$

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

Alternatively, from the measured deuterium abundance and the cross section of the nuclear reactions (measured with low uncertainty 3-5%)
→ the cosmological parameters such as the baryon density Ω_b and the number of neutrino families N_{eff} can be obtained and compared with cosmological measurements
Di Valentino et al, Phys. Rev. D 90 (2014) 023543

As an example, assuming the number of neutrino families $N_{eff}=3$:

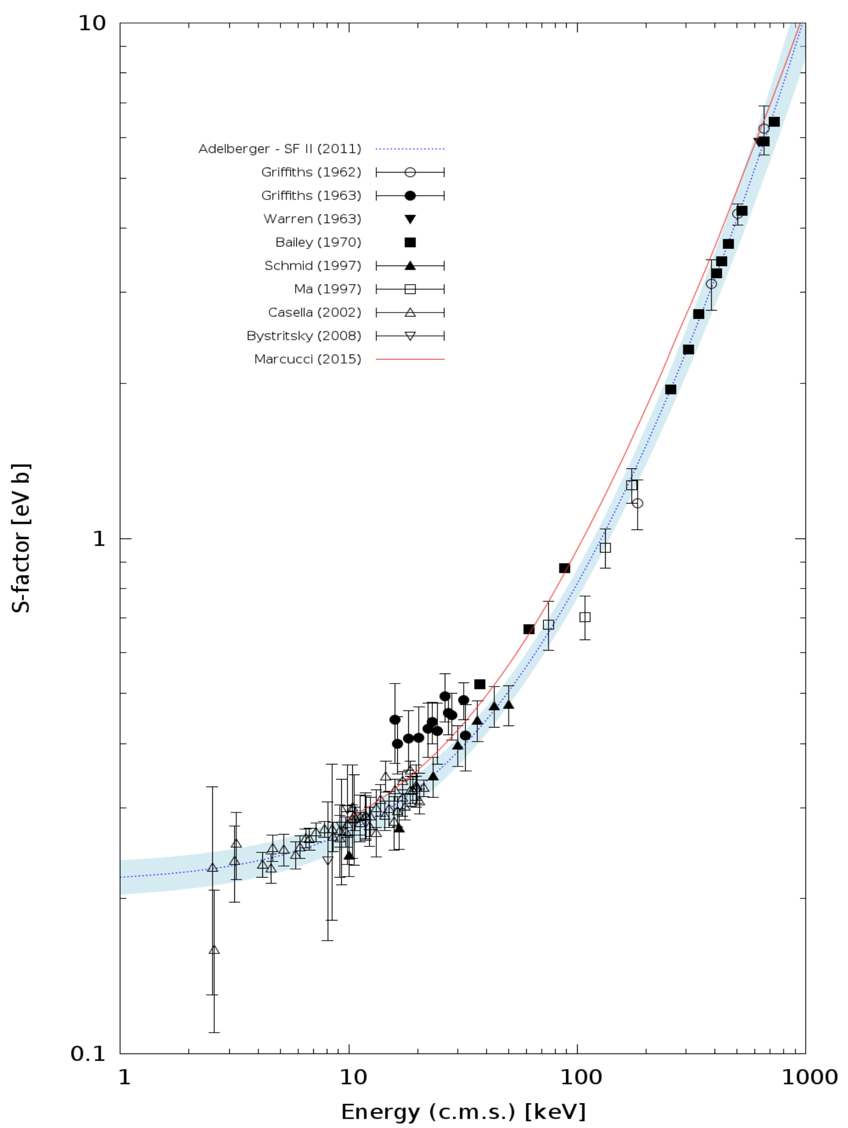
Astronomical Observations

Nuclear Physics → to be improved!

$$100\ \Omega_{b,0}h^2(D/H) = 2.20 \pm 0.02 \pm 0.04\ (Cooke\ 2014)$$
$$100\ \Omega_{b,0}h^2(CMB) = 2.20 \pm 0.03\ (PLANCK\ 2015)$$

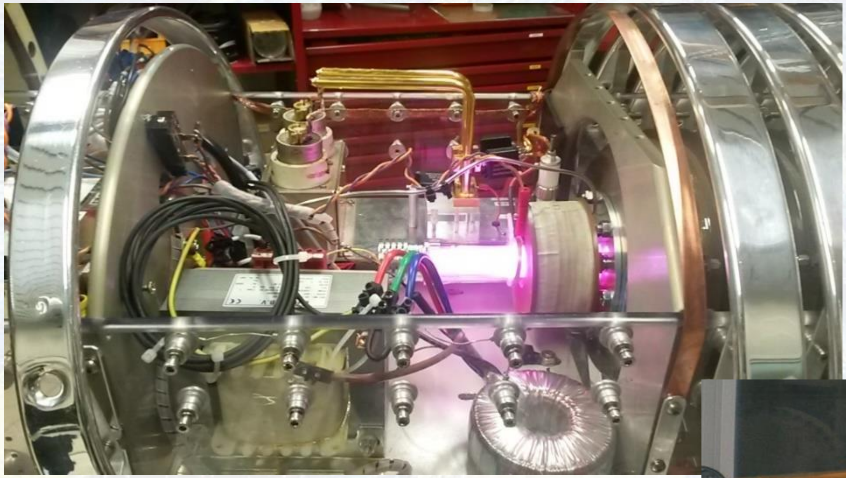
A measurement of the p+d reaction cross section is thus desiderable with a 3-5% accuracy in the energy range 10 keV < E_{cm} < 300 keV

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



As light nuclei are involved in this process, the $^{2}\mathrm{H}(\mathrm{p},\gamma)^{3}\mathrm{He}$ reaction is of high interest also in theoretical nuclear physics, in particular for what concern “ab-initio" modelling → low uncertainty in measured cross section is needed

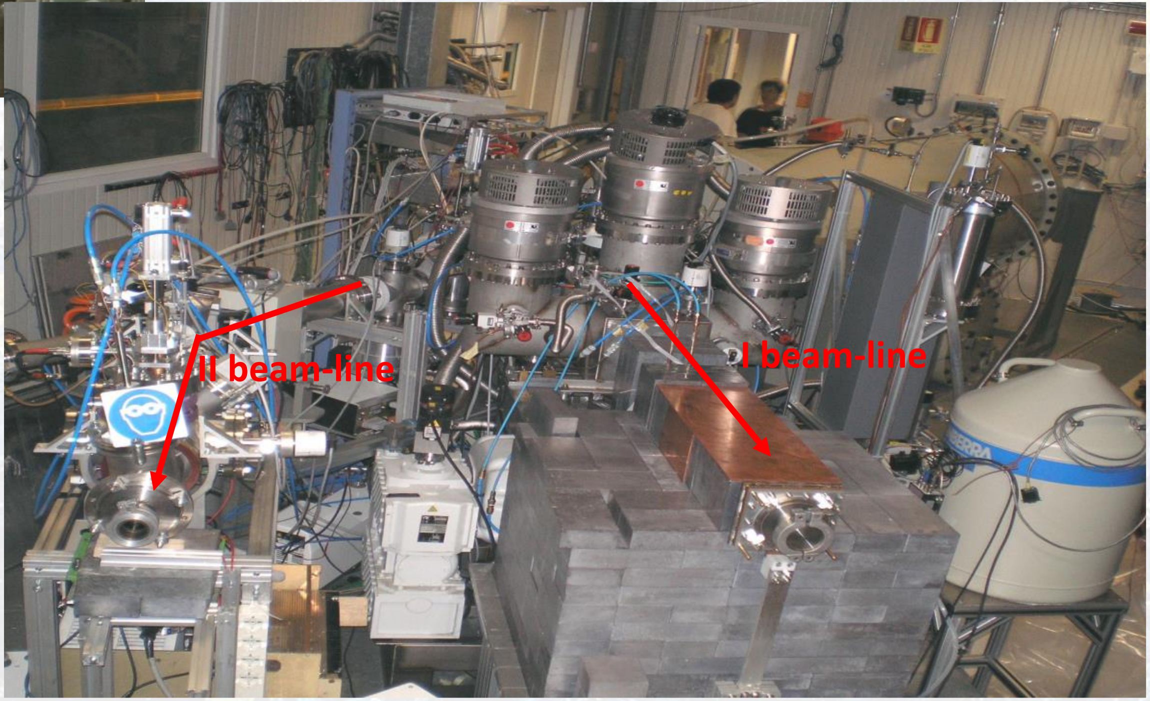
The ^{2}H(p,γ)^{3}He reaction at BBN energies at LUNA



Accelerator LUNA 400 kV

- High current $I_p \cong 500\ \mu A$
- E_{beam}=[50 – 400] keV
- Long term stability ≈ 5eV/h
- Energy spread ≈ 70 eV

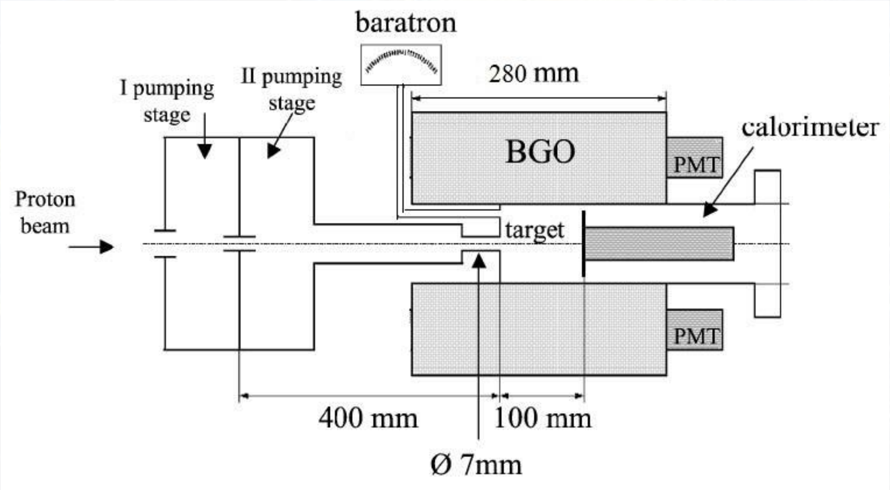
- I beam-line: windowless gas target. ^{2}H reference pressure = 0.3 mbar
- II beam-line: solid target

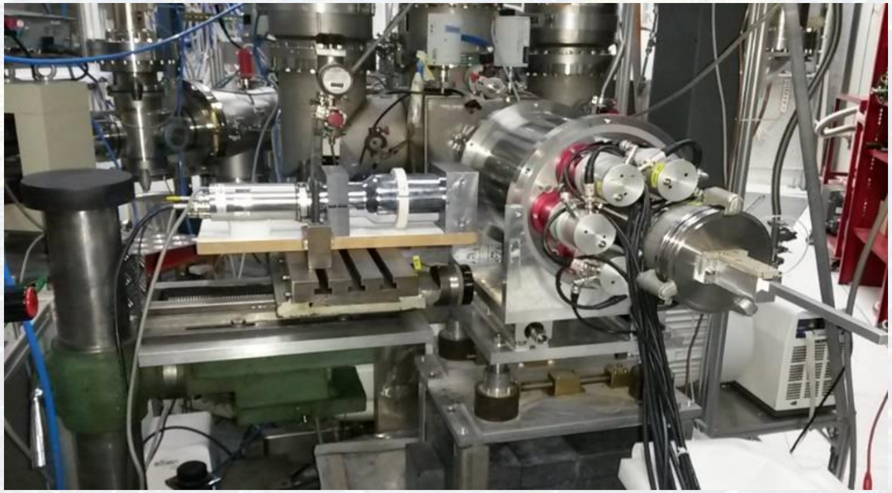


$^{2}H(p,\gamma)^{3}He$ measurement at LUNA

I phase: the BGO setup

- $E_{beam} \sim 50 - 400\ keV$
- 4π geometry → poor angular distribution sensitivity → only total cross section
- Energy resolution in the total absorption peak ~ 8%
- High detection efficiency for 5.5 MeV γ-rays ~ 60% → low energy measurements

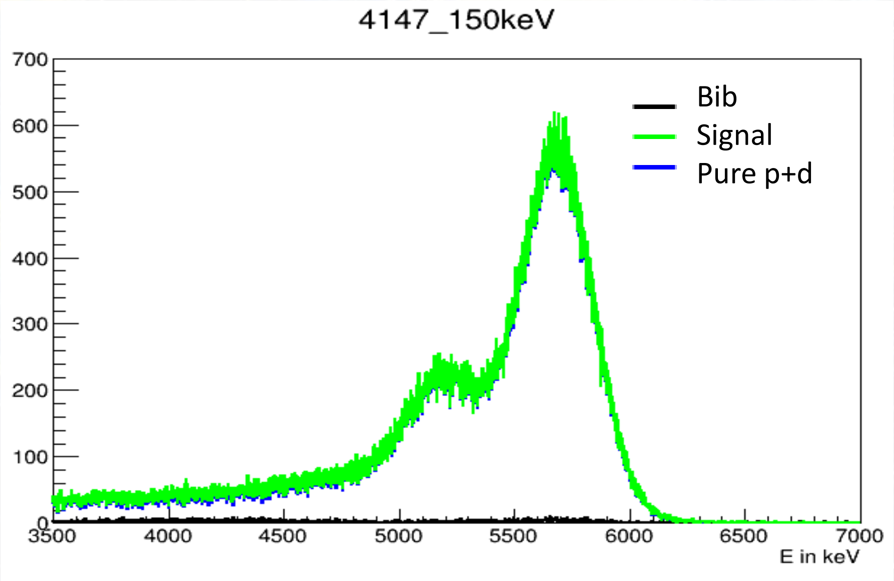


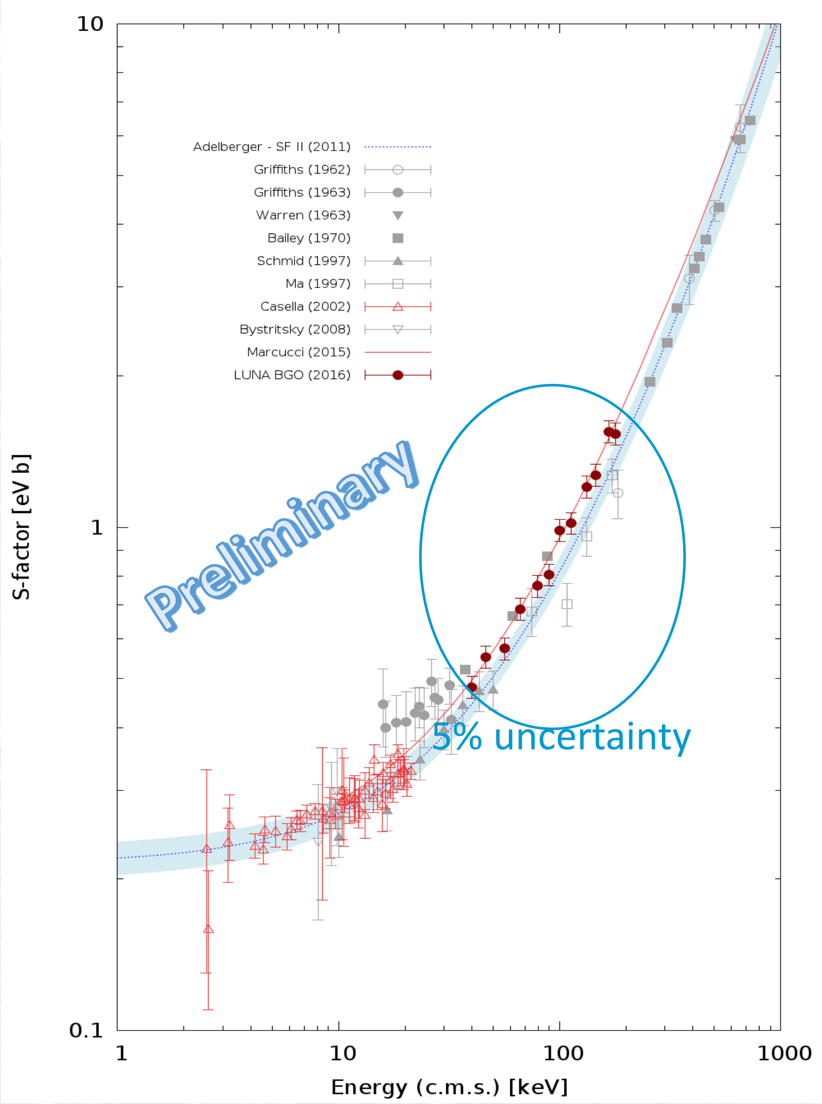


$^{2}H(p,\gamma)^{3}He$ measurement at LUNA

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

- Huge Bib due to $^{19}F(p,\alpha\gamma)^{16}O$ reaction for E_{cm}>200 keV

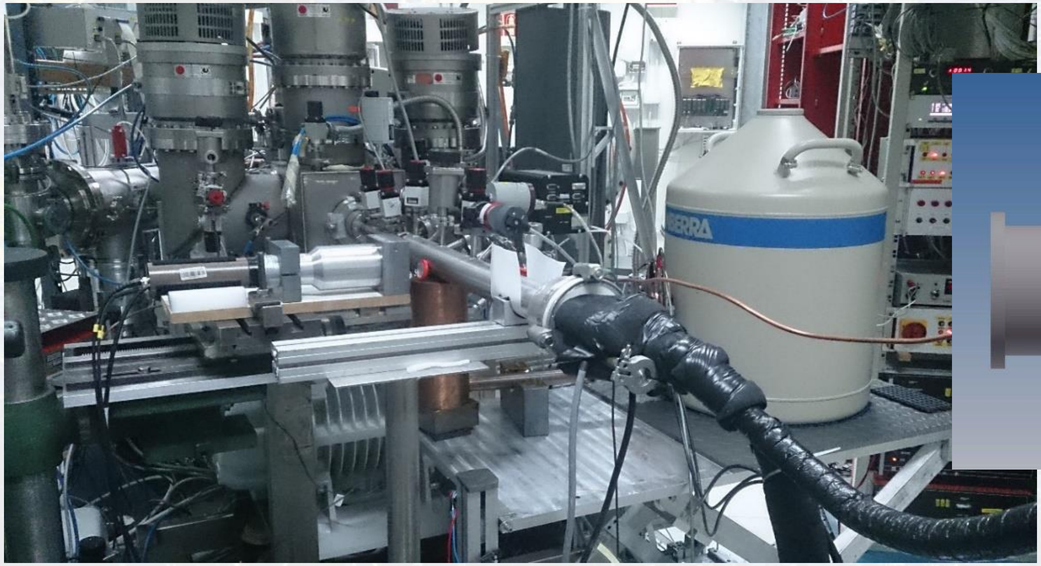


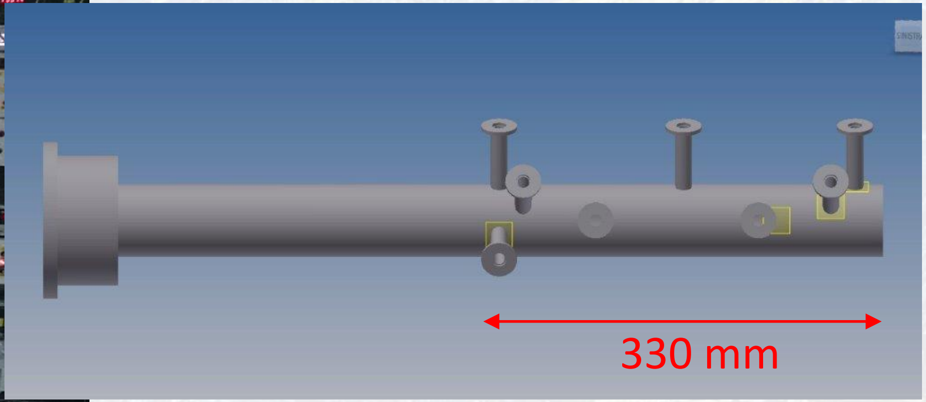


Next measurement- in progress

II phase: the HPGe setup

- $E_{beam} \sim 150 - 400\ keV$
- High energy resolution in the total absorption peak $\sim 0{,}08\%$
- Possibility of performing angular distribution measurements with extended gas target
- Detection efficiency for 5.5 MeV γ-rays $\sim 0{,}35\%$ → no low energy measurements





Conclusions

- High precision $^{2}H(p, \gamma)^{3}He$ cross section data in BBN energy range can confirm astronomical observations and/or 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
- The data we are currently acquiring together with those previously acquired at LUNA 50 kV will provide a complete data set with high accuracy in a wide energy range (0 - 267 keV)

Thanks for your attention!

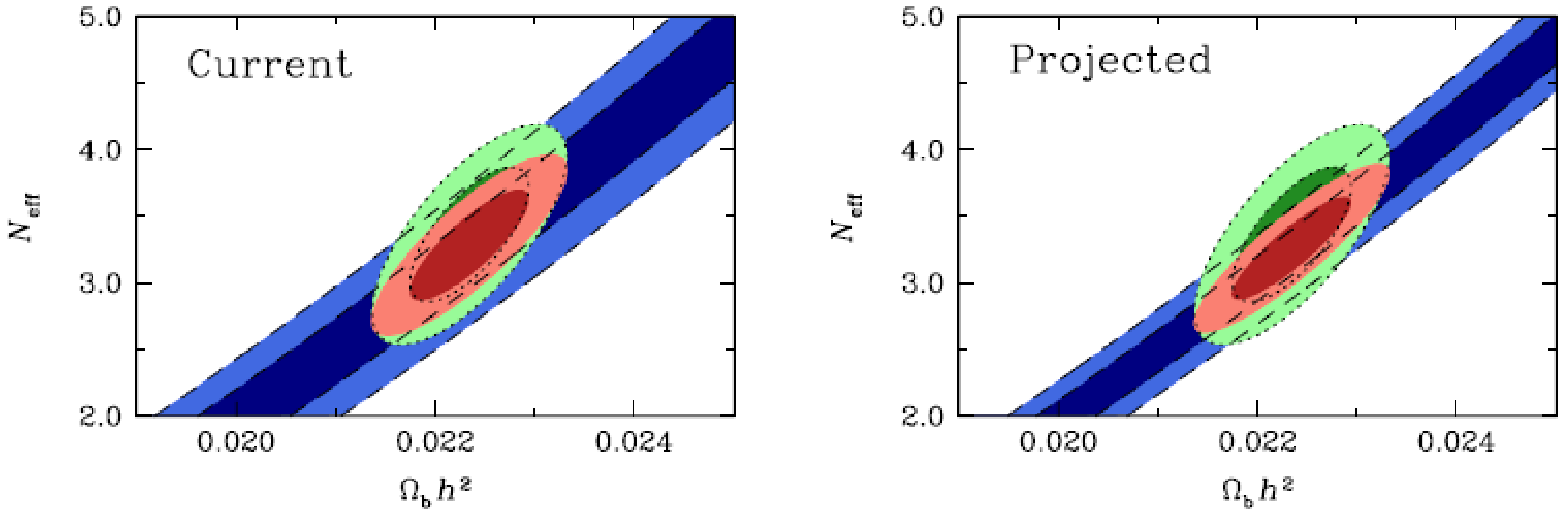


FIG. 6.— The 1σ and 2σ confidence contours (dark and light shades respectively) for $N_{\rm eff}$ and $\Omega_{b,0}\,h^2$ derived from the primordial deuterium abundance (blue), the CMB (green), and the combined confidence contours (red). The left panel illustrates the current situation, while the right panel shows the effect of reducing the uncertainty in the conversion from $({\rm D/H})_{\rm p}$ to $\Omega_{b,0}\,h^2$ by a factor of two (see discussion in Section 4.2). Dashed and dotted lines indicate the hidden contour lines for BBN and CMB bounds respectively.

Cooke etal.2014