New measurement of the $^{2}H(p,\gamma)^{3}He$ reaction at Felsenkeller underground lab

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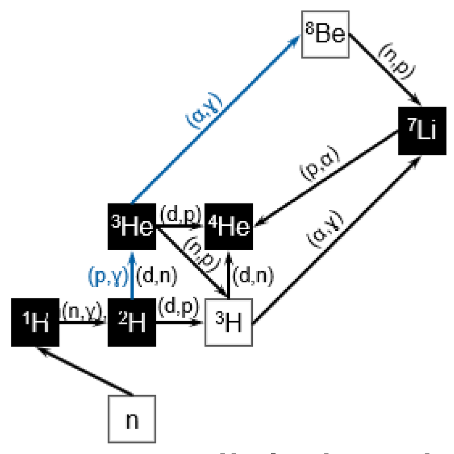
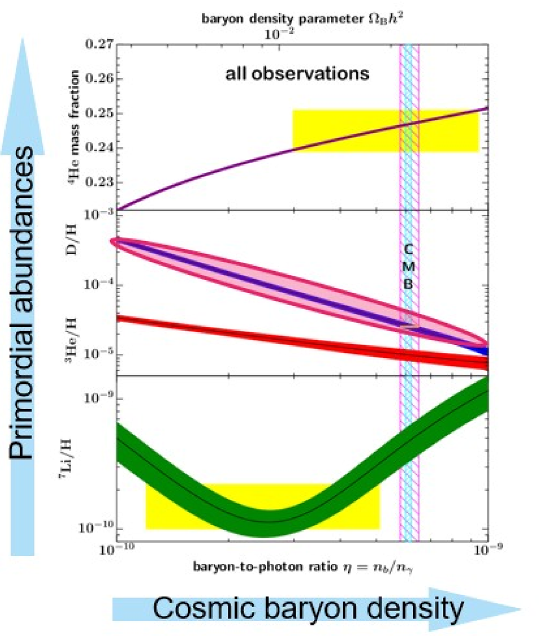
Abstract

The primordial deuterium abundance can be used to probe the cosmological baryon density. The $^{2}H(p,\gamma)^{3}He$ reaction is responsible for deuterium destruction during Big Bang Nucleosynthesis (BBN) and plays a crucial role in determining its abundance. This reaction was previously measured at BBN energies by the LUNA collaboration using a windowless gas target system, covering a proton beam energy range of 50–400 keV. However, measurements at higher energies using solid targets indicate an extrapolated cross-section that is 10 % higher. To reduce the tension between low- and high-energy data, a new measurement of the $^{2}H(p,\gamma)^{3}He$ reaction was performed at the Felsenkeller shallow-underground laboratory in Dresden, covering a proton beam energy range of 300–1200 keV, with partial overlap with both data sets. The reaction was studied using a solid target setup and multiple HPGe detectors positioned around the target, providing both cross-section and angular distribution data. The latter provides additional constraints for improving ab initio calculations.

Motivation

Big Bang Nucleosynthesis (BBN)





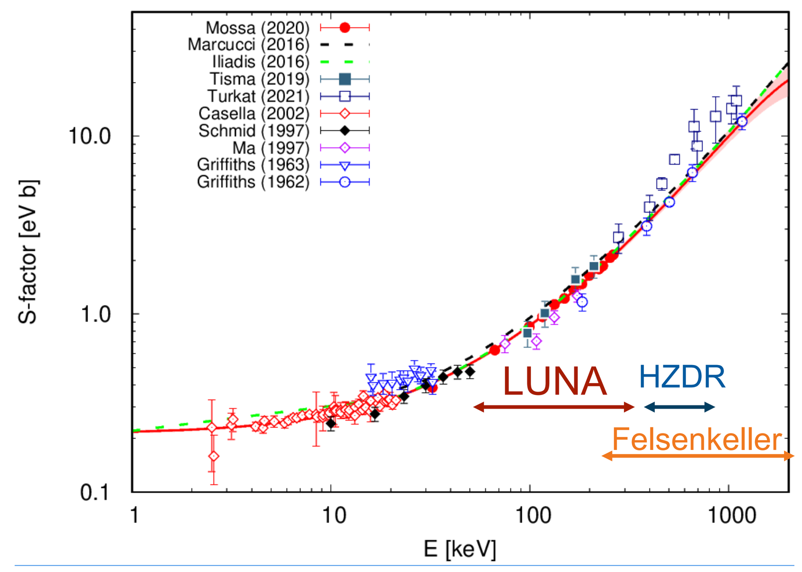
The promordial abundance depens only on:

- Baryon density: $\Omega_b h^2$
- Particle Physics: N_{eff}..,
- Nuclear astrophysics: Cross sections of relevant processes at BBN energies

State of the art

For many years $^{2}H(p,\gamma)^{3}He$ reaction has governed the uncertainty on the primordial deuterium abundance.

- The BBN energy range measured by LUNA, <3% uncertainty
  - $\Omega_B h^2|_{CMB}$ = (2236 ± 15) × 10^{-5}
  - $\Omega_B h^2|_{BBN,\ LUNA}$ [10] = (2233 ± 36) × 10^{-5}
- High energy data at E_p = 400-800 keV at HZDR



Felsenkeller GOAL

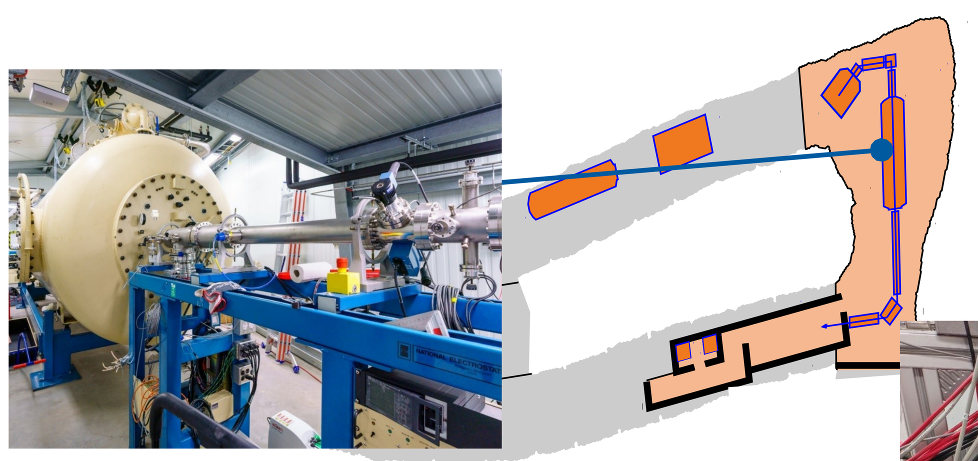
- Angular distribution measurements at E_p = 300 – 1200 keV
- Cross-section data at E_p = 300 – 1200 keV (overlap LUNA-HZDR data)

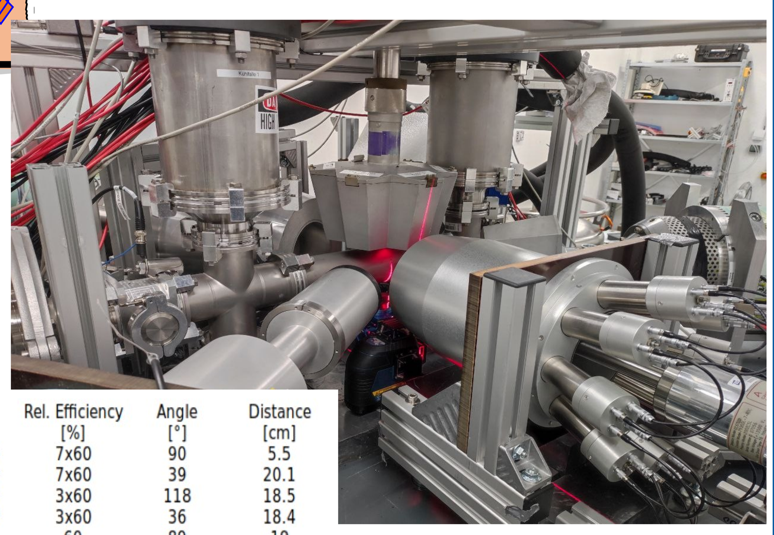
Experimental setup

5 MV Felsenkeller accelerator

ChETEC-INFRA supported

- ^{2}H, ^{4}He RF beams
- ^{12}C, ^{16}O, and other beams
- Beam current up to 30 uA



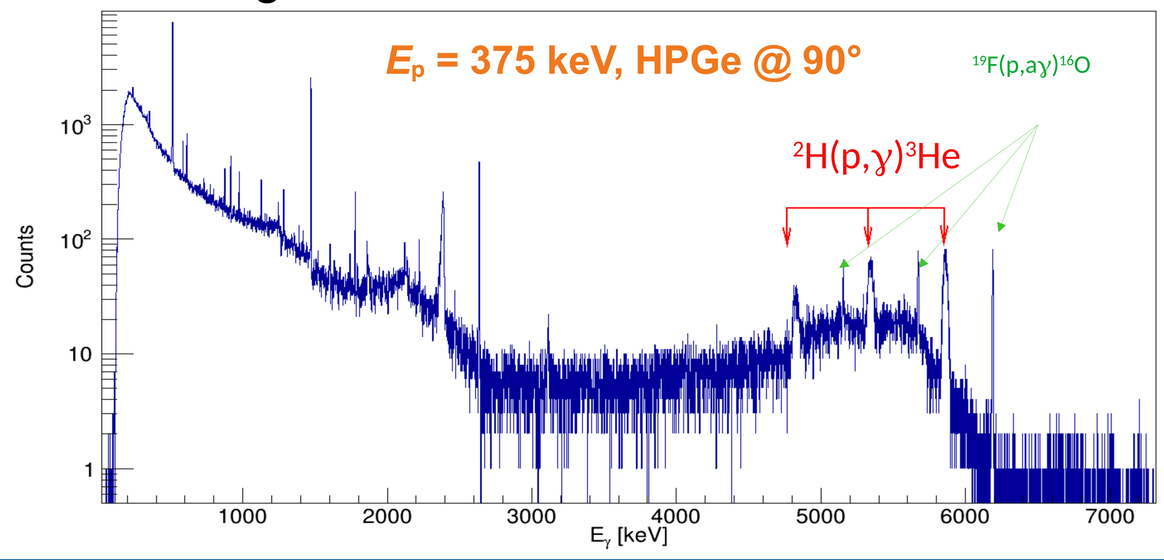


- Proton beam from 5MV accelerator
- Solid water cooled ZrD_2 targets
- 21 HPGe detectors

Detector ID	Type	Rel. Efficiency [%]	Angle [°]	Distance [cm]
EB18	7 cluster	7x60	90	5.5
EB17	7 cluster	7x60	39	20.1
MB1	3 cluster	3x60	118	18.5
MB2	3 cluster	3x60	36	18.4
Can60	single	60	89	19
Ron100	single	100	143.5	15.5

Data taking and analysis

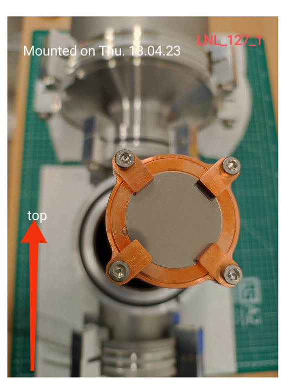
- Detection efficiency using standard sourses, $^{27}Al(p,\gamma)^{28}Si$ reaction at 992 keV resonance and Monte Carlo simulations
- High statistics run at E_p = 300 – 1200 keV with 50 keV step
- Reference run at E_p = 608 keV before and after each energy
- Beam induced background runs

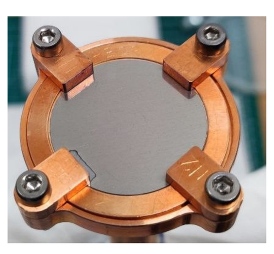


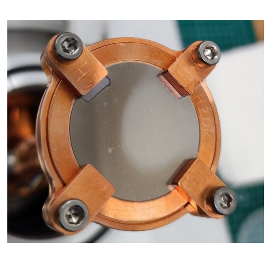
Preliminary results and outlook

Target analysis

Before irradiation **After irradiation**

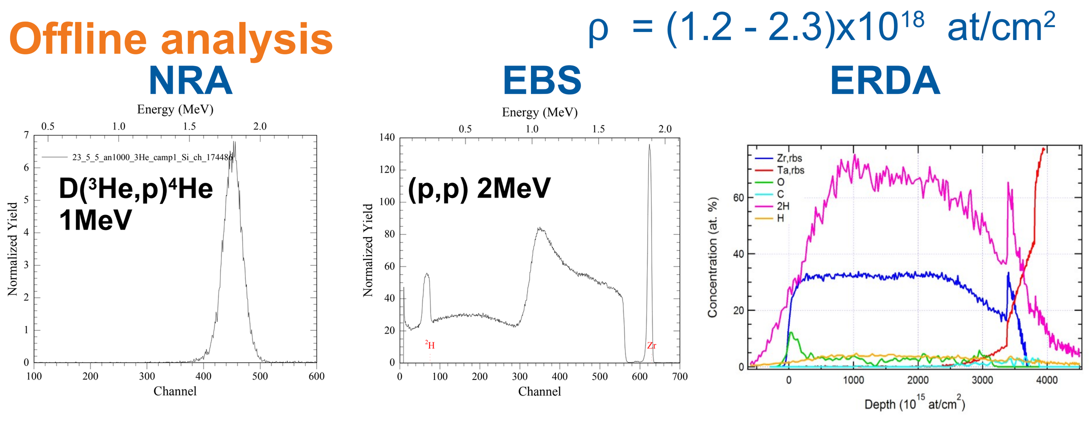




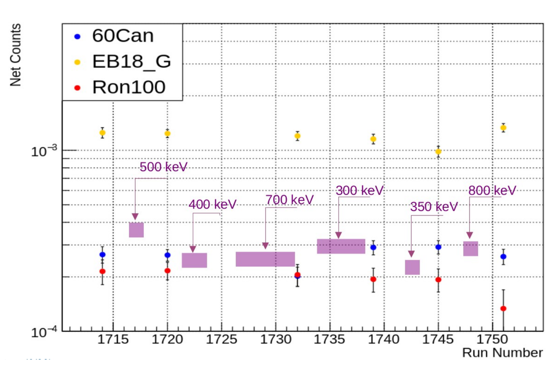


Offline analysis

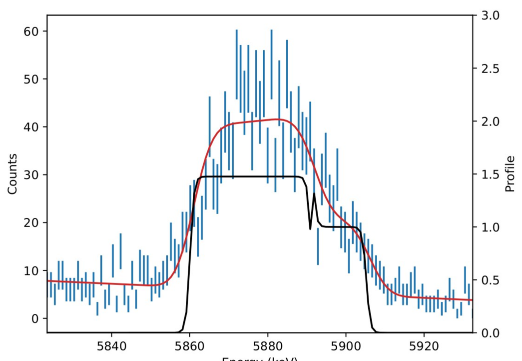
ρ = (1.2 - 2.3)x10^{18} at/cm^2



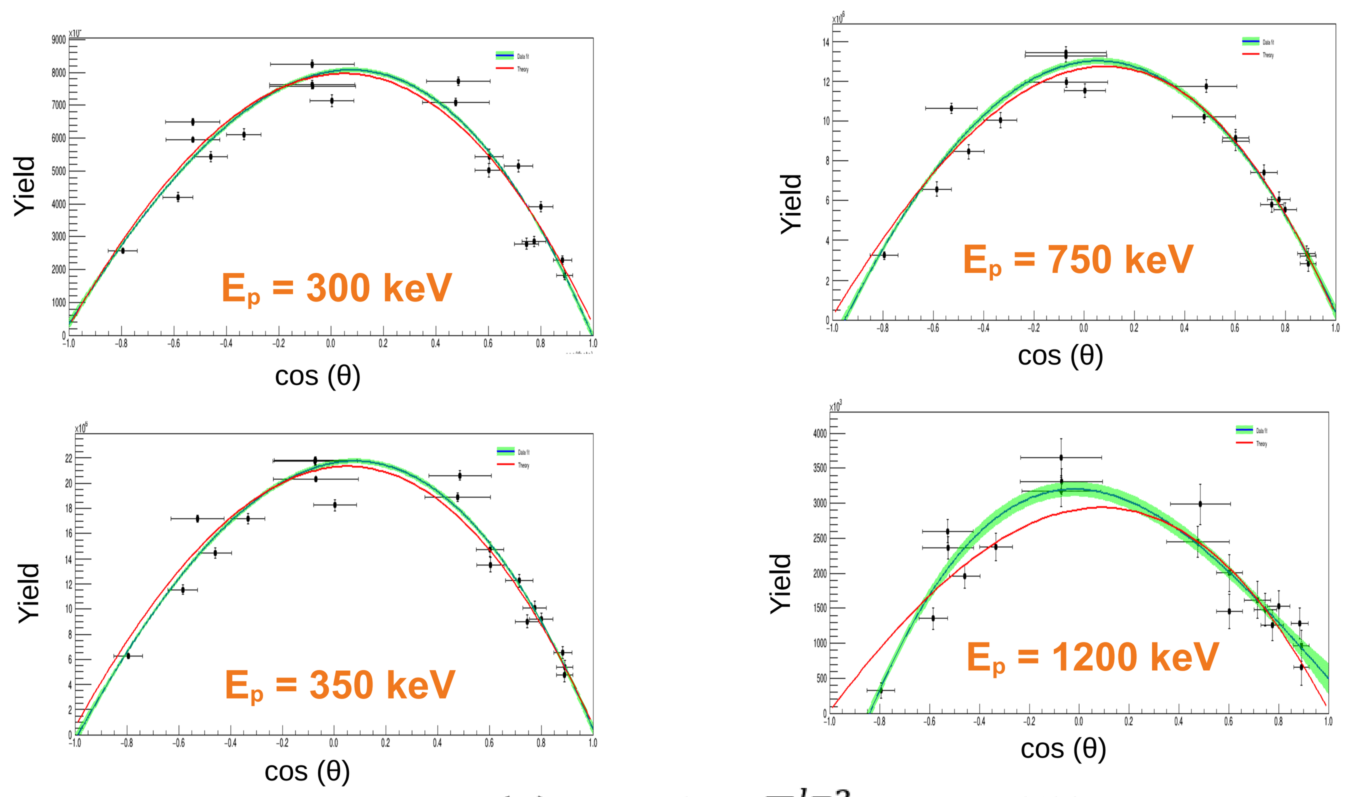
In beam analysis
Reference run at 608 keV



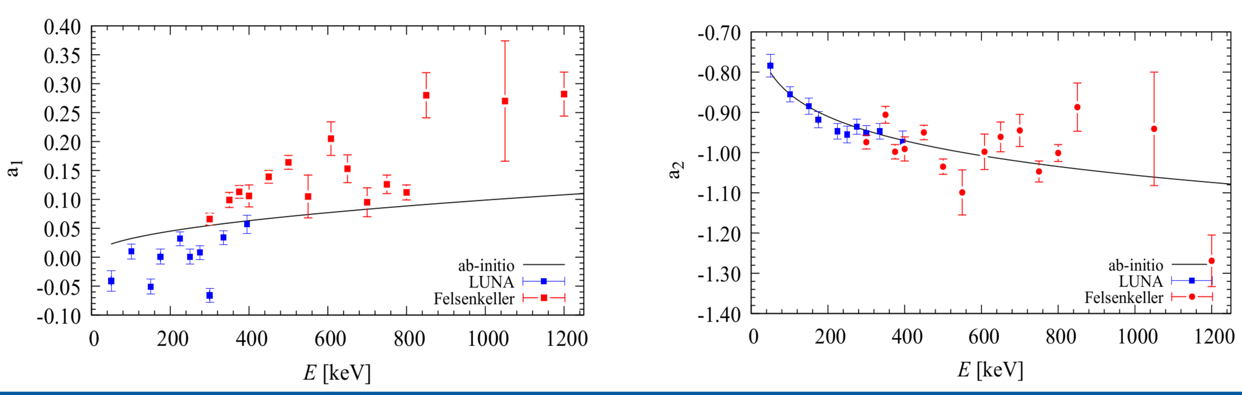
Offline analysis
Peak Shape Analysis



Angular distributions



$$W(\theta) = a_o\,(1 + \sum_{l=1}^{l=3} a_l P_l \cos(\theta))$$



Preliminary S-factor