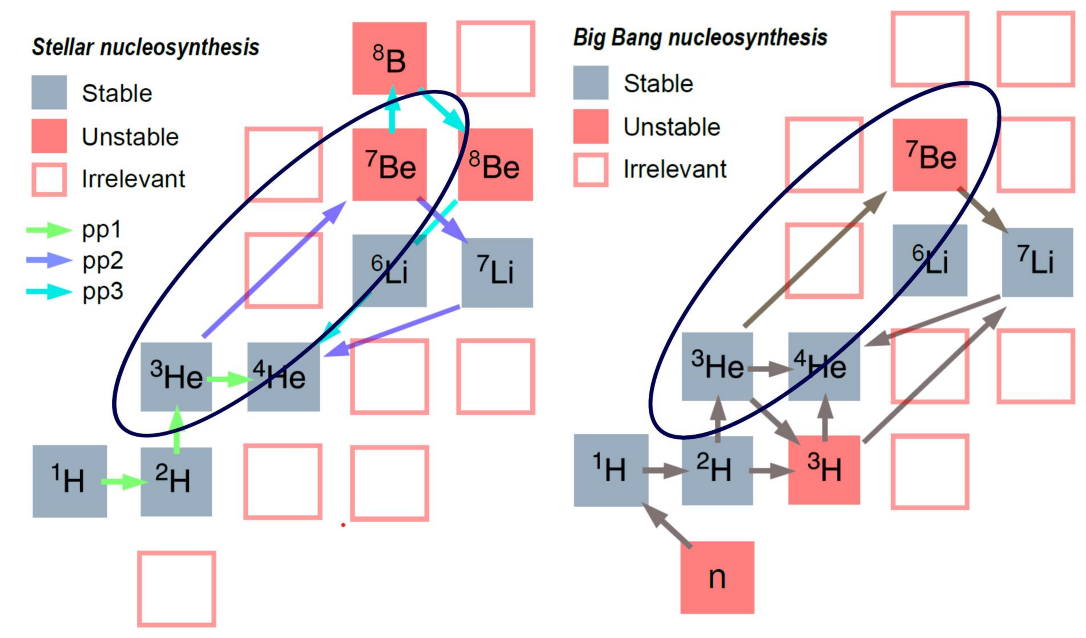
Gamma-ray angular distribution of the $^3He(\alpha,\gamma)^7Be$-reaction

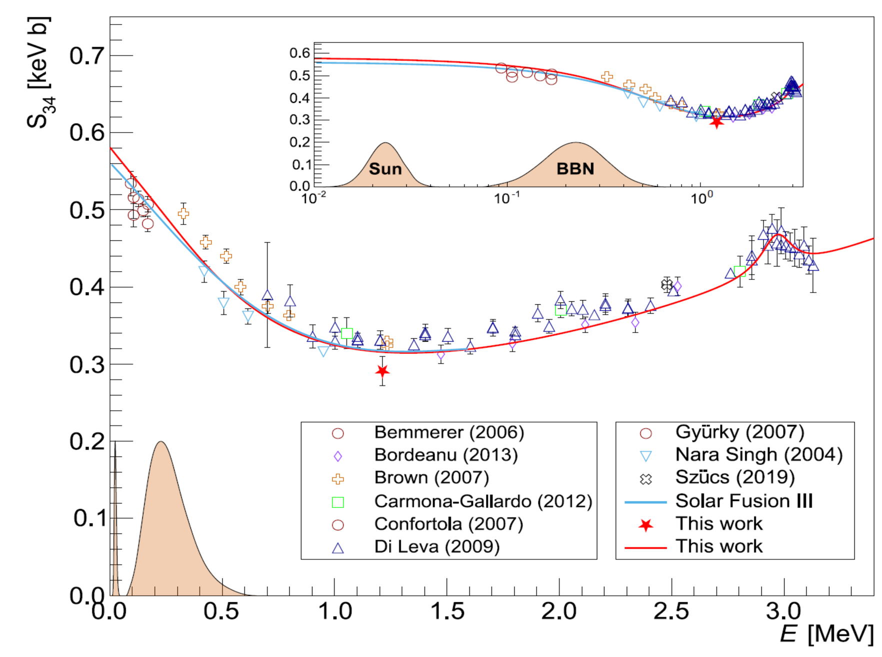
Peter Hempel[1,2], S. Turkat[2], D. Bemmerer[1], K. M. Nollett[3], X. Zhang[4]

[1] Helmholtz-Zentrum Dresden-Rossendorf (HZDR), 01328 Dresden, Germany
[2] Technische Universität Dresden, 01069 Dresden, Germany
[3] Department of Physics, San Diego State University, San Diego, CA 92182, USA
[4] Facility for Rare Isotope Beams, Michigan State University, East Lansing MI, 48824, USA

The $^3He(\alpha,\gamma)^7Be$ reaction plays a significant role in Big Bang nucleosynthesis, as well as in stellar hydrogen burning. It affects the nucleosynthesis of primordial ^7Li, as well as the theoretical prediction of solar ^7Be and ^8B neutrino fluxes. A measurement of its γ-ray angular distribution was performed using the 5 MV Pelletron accelerator at the Felsenkeller shallow-underground laboratory in Dresden (Germany). A ^4He beam was used to irradiate solid ^3He implanted targets. The prompt γ-rays were detected using more than 20 HPGe crystals surrounding the setup. The data is compared with new predicted angular distributions from a hybrid theory that blends cluster-based effective field theory and phenomenological approach.

$^3He(\alpha,\gamma)^7Be$ – Stellar hydrogen burning and Big Bang nucleosynthesis

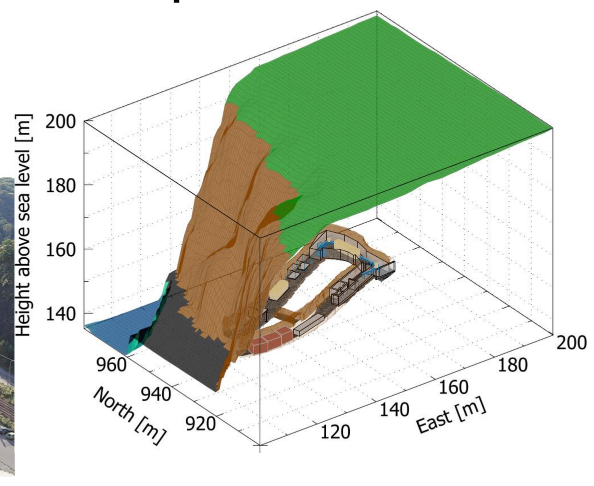




Aim: angular distribution for E_{CM} between 450 – 1200 keV, S-Factor at 1213 keV by activation analysis, comparison to hybrid theory

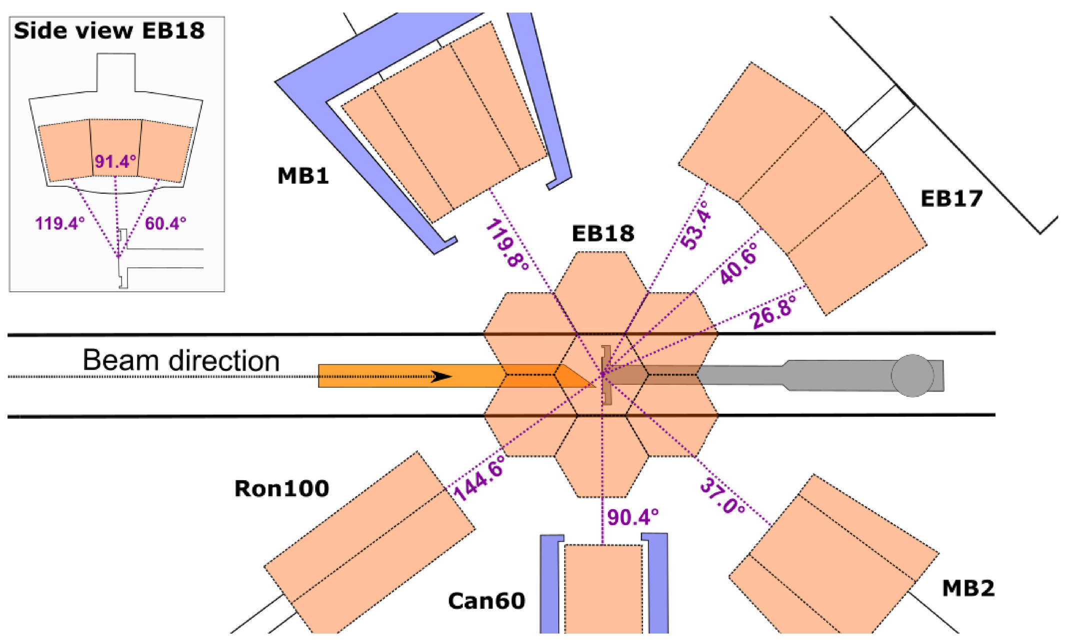
Felsenkeller laboratory

- Located in Dresden (Germany)
- 45 m of rock overburden
- α-beam provided by 5 MV Pelletron accelerator
- Beam intensity: 10 – 20 µA



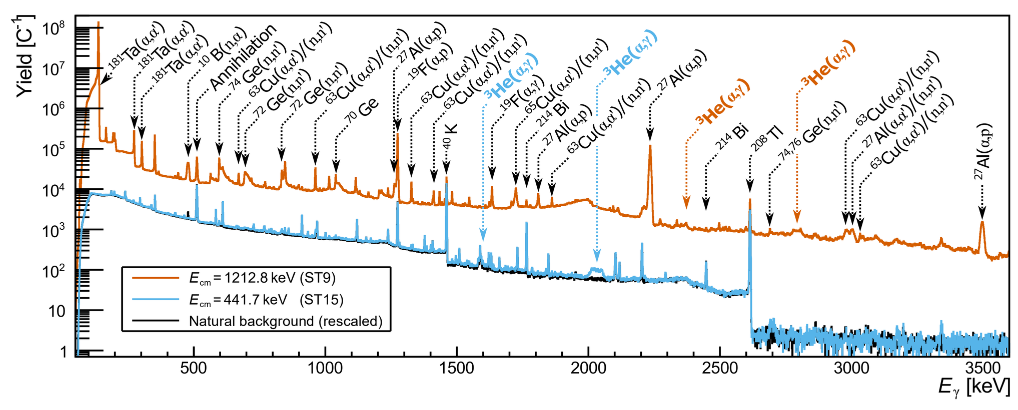
Experimental Setup

- > 20 HPGe crystals
- Target: solid, ^3He implanted in Ta
- Geant4 model of target holder, detector setup and beam spot



Prompt γ-ray spectrum

- Prompt γ-ray and background (scaled) pulse height spectra of the EB18 detector at 90° for E_{CM} = 1212 keV and E_{CM} = 442 keV
- The background contains components of both the natural and beam induced background



Legendre Polynomials

- Angular distribution W(cos ϑ) expressed in Legendre Polynomials P_l(cos ϑ)

$$\varepsilon = \int \mathrm{d}(\cos\vartheta)\,\frac{\mathrm{d}\varepsilon}{\mathrm{d}(\cos\vartheta)}\cdot W(\cos\vartheta)$$

$$= \sum_{l=0}^{2} a_l \int \mathrm{d}(\cos\vartheta)\,\frac{\mathrm{d}\varepsilon}{\mathrm{d}(\cos\vartheta)}\cdot P_l(\cos\vartheta)$$

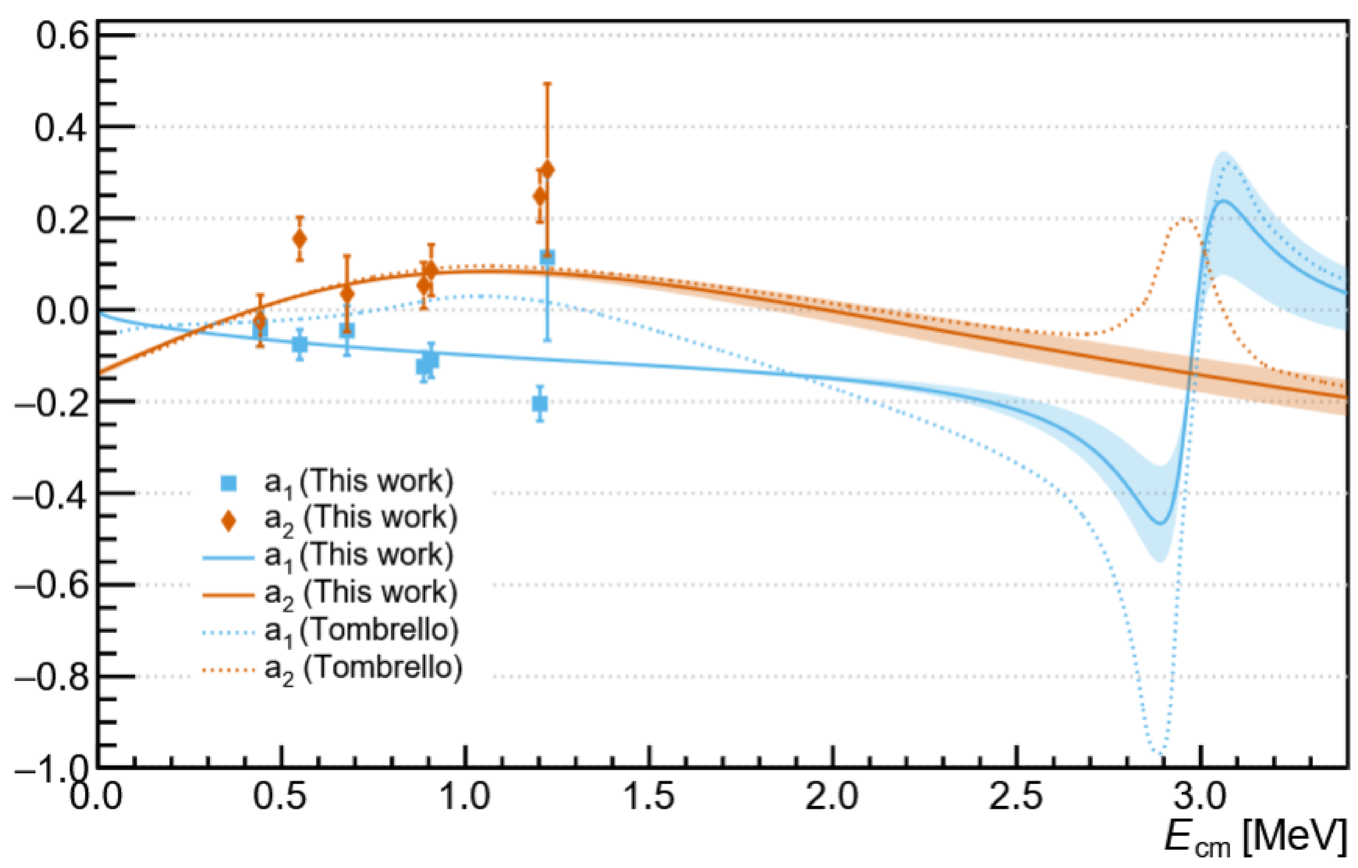
$$= \sum_{l=0}^{2} a_l \cdot \eta_l$$

- η_l is calculated from Geant4-simulations
- Bayesian analysis of the experimental data

Hybrid Theory

- Consider E1, M1 and E2 multipoles
- E1: EFT framework [2] with theoretical parameter ranges from SF-III [1], dominates $S_{34}(0)$ up to E_{CM} = 2 MeV
- E2, M1: phenomenological approach inspired by previous clusterbased EFT studies [2]
- Legendre polynomials:
  - a_1: Interference E1 – M1 and E1 – E2
  - a_2: E1 multipole ($S_{34}(0) \leftrightarrow a_2$)

Angular Distribution

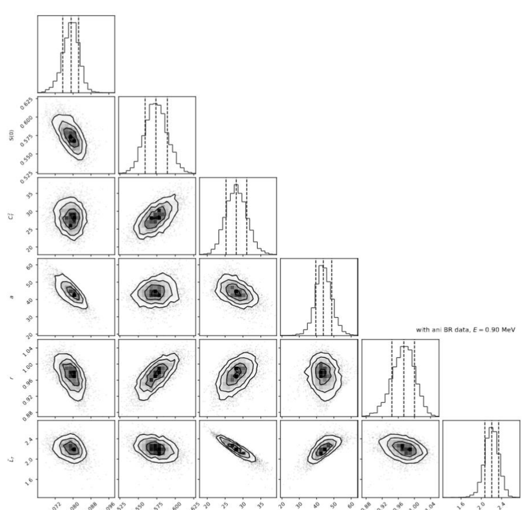


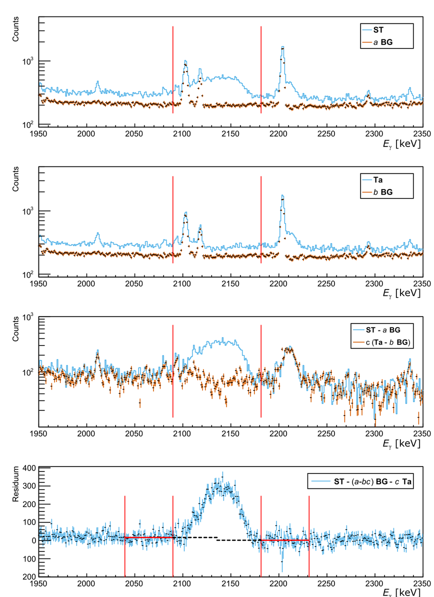
- Forward/backward anisotropy a_1 in agreement with theory
- Discrepancy between a_2 and theory for highest energy (E_{CM} = 1212 keV)
- Expect large changes of a_1 around resonance at 3 MeV

Activation analysis

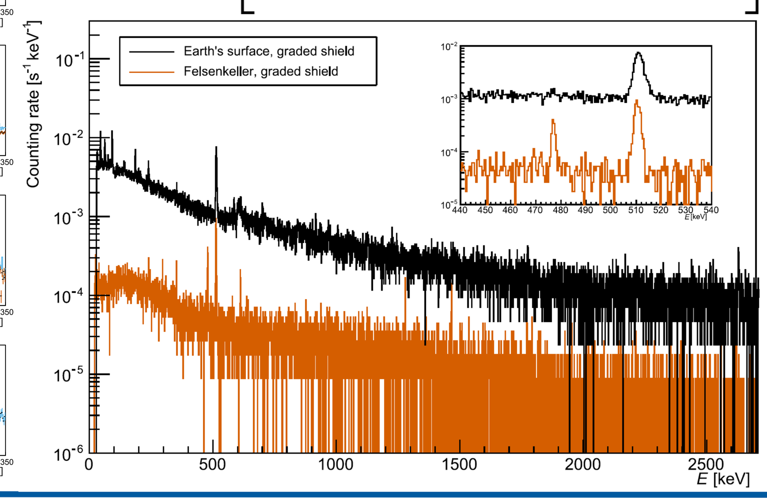
- Performed at the HZDR Ion Beam Center (activation) and at Felsenkeller (counting)
- Areal ^3He density: relative to $^3He(d,p)^4He$ using a Silicon surface barrier detector

Additional material





$$\mathcal{L} = \sum_k \ln\left[\frac{1}{\sqrt{2\pi}\,\mathrm{d}N_k} e^{-\frac{1}{2}\left(\frac{N_k - N_k^{model}}{\mathrm{d}N_k}\right)^2}\right]$$



[1] B. Acharya, M. Aliotta, A. B. Balantekin, D. Bemmerer, C. A. Bertulani, A. Best, C. R. Brune, R. Buompane, et al., arXiv e-prints , arXiv:2405.06470 (2024), Review of Modern Physics.

[2] X. Zhang, K. M. Nollett, and D. R. Phillips, J. Phys. G47, 054002 (2020), 1909.07287.

Institute of Radiation Physics · Nuclear Physics Division · Felsenkeller

M. Sc. Peter Hempel · p.hempel@hzdr.de · www.hzdr.de