

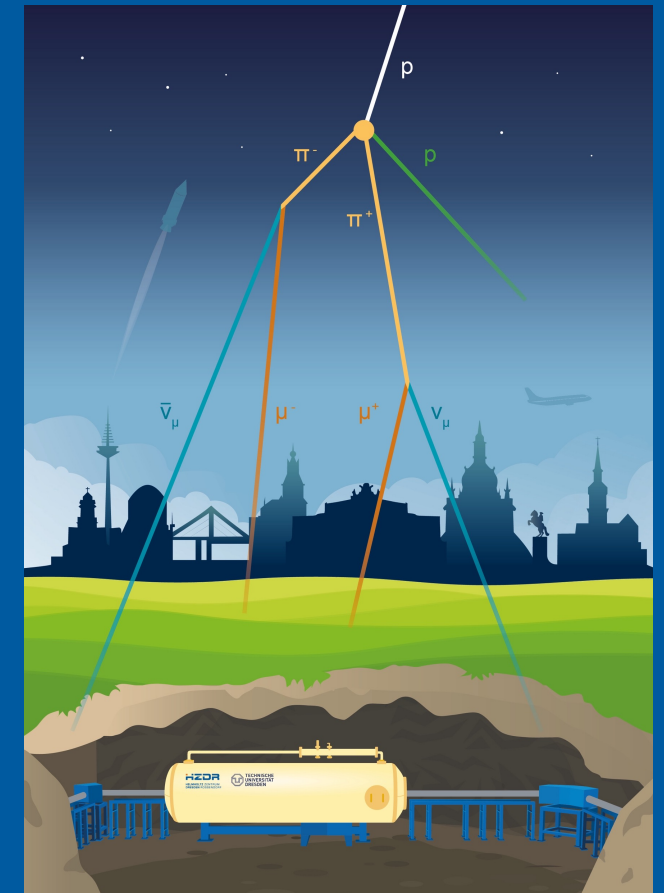


Felsenkeller lab for nuclear astrophysics and LUNANOVA ERC project

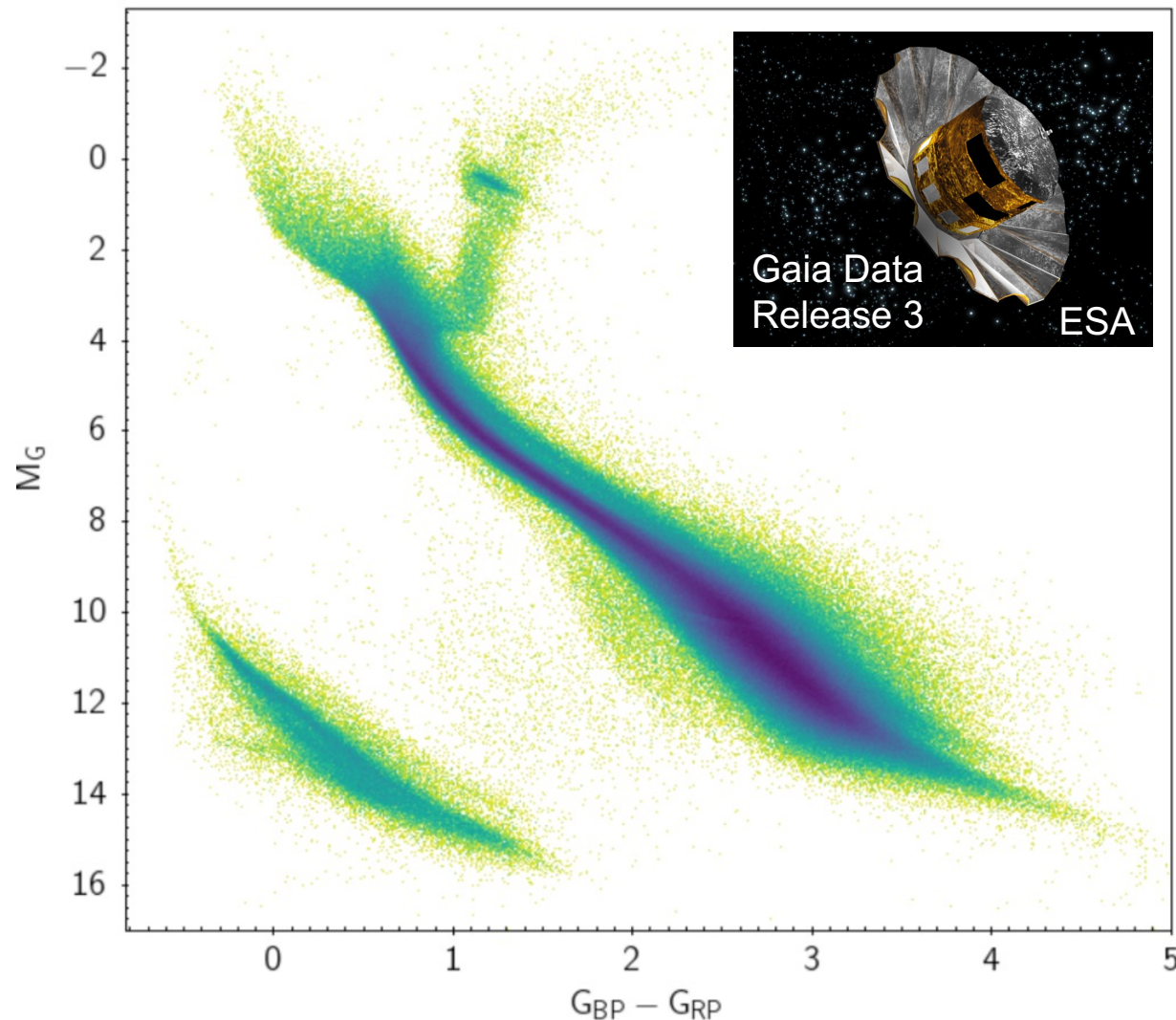
*Helmholtz Matter in the Universe Days
GSI Darmstadt, 19.10.2026*

Daniel Bemmerer
Helmholtz-Zentrum Dresden-Rossendorf

Institute of Radiation Physics · Nuclear Physics Division · Prof. Dr. Daniel Bemmerer · d.bemmerer@hzdr.de · www.hzdr.de/felsenkeller

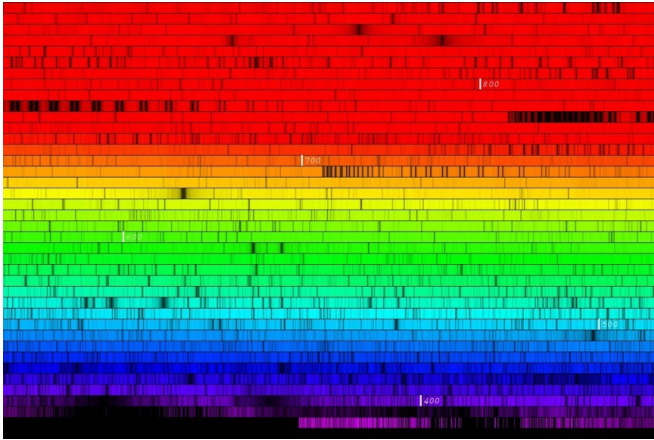


The Sun as foundation science



- ~ 10^9 individual stars with measurements of color, temperature, luminosity, (composition)
- ~ 10^3 stars with accurate, precise, (model) independent mass determinations
...selective club: eclipsing binaries
- 1 star with accurate, precise, (model) independent age determination, radius and mass, elemental abundances

Foundation science: Solar spectrum, solar elemental abundances



Solar envelope is convective

→ hydrodynamic models

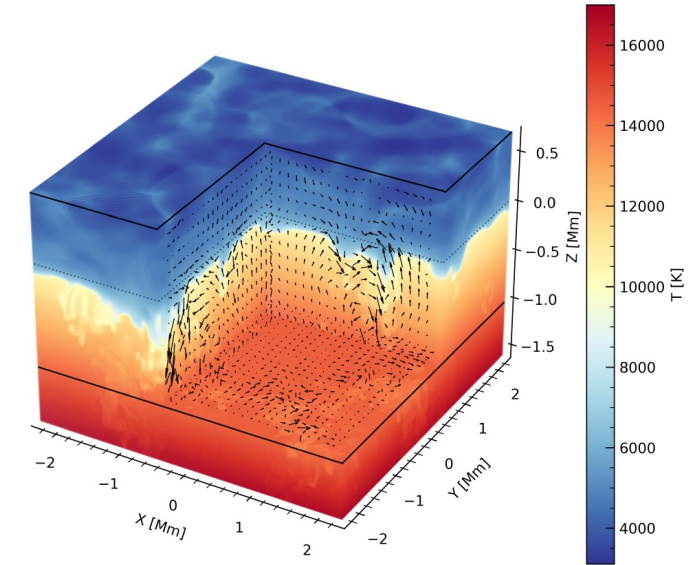
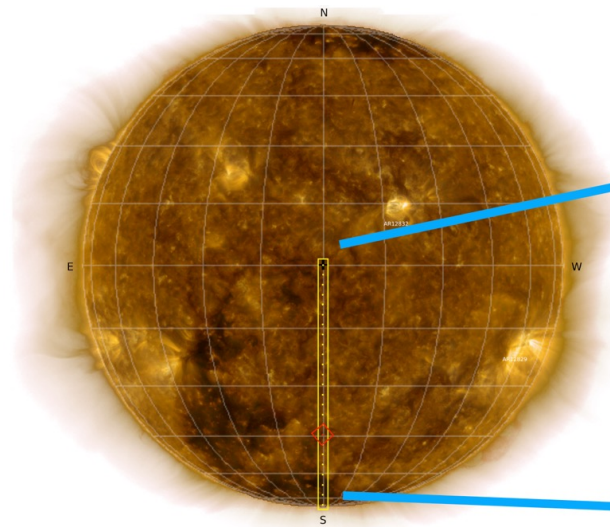
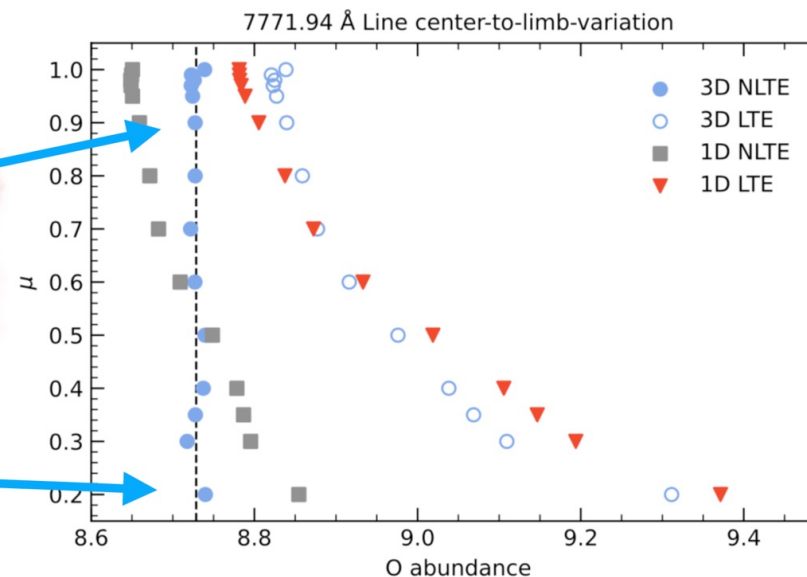
→ 3D atmosphere model

Model atmosphere

→ detailed radiative transfer - NLTE

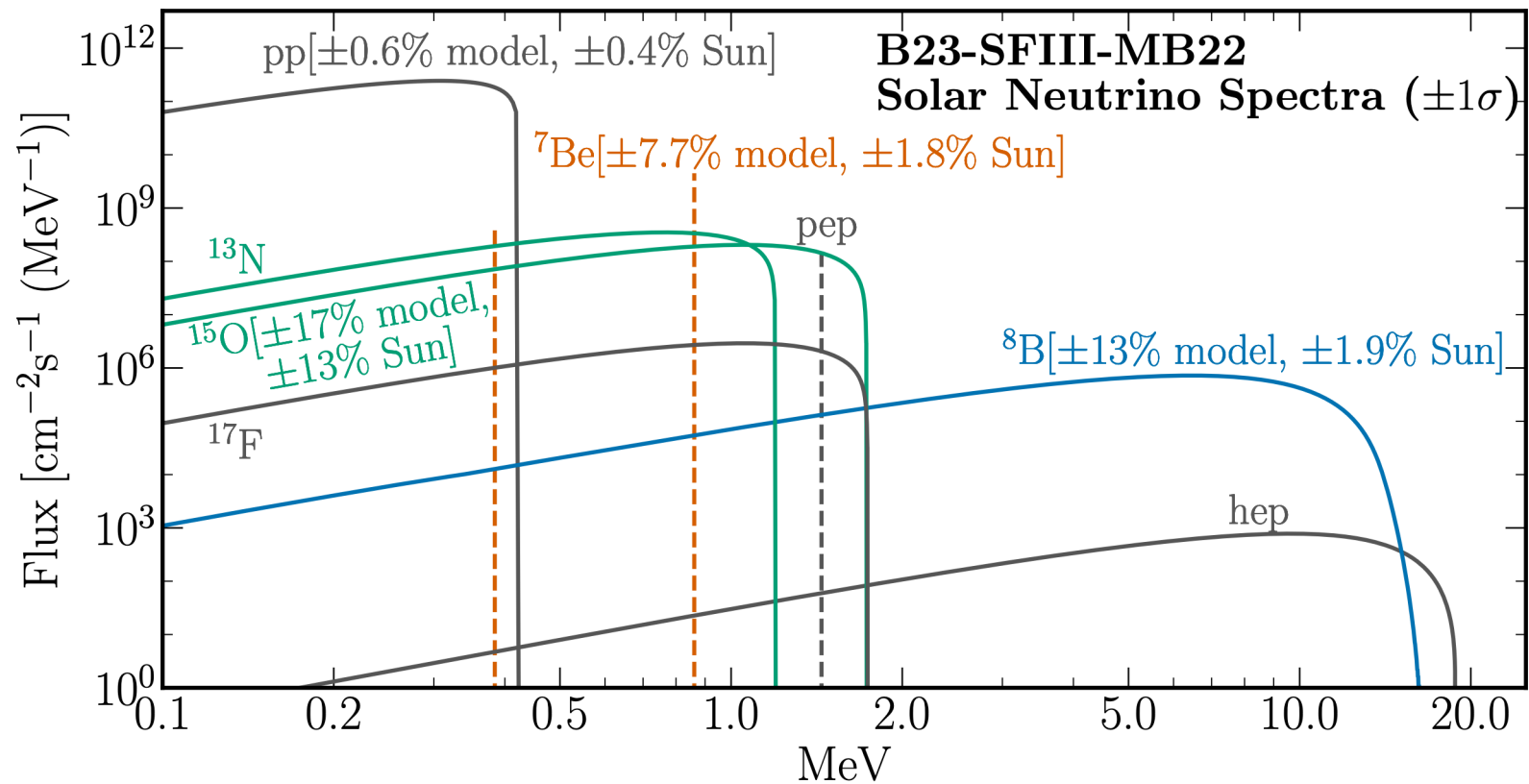
→ determination of abundances

→ spatially resolved spectroscopy



Pietrow, Hoppe, Bergemann et al. 2023
Bergemann, Hoppe, et al. 2021

Solar neutrino energy spectrum from the standard solar model



SSM model ν fluxes...

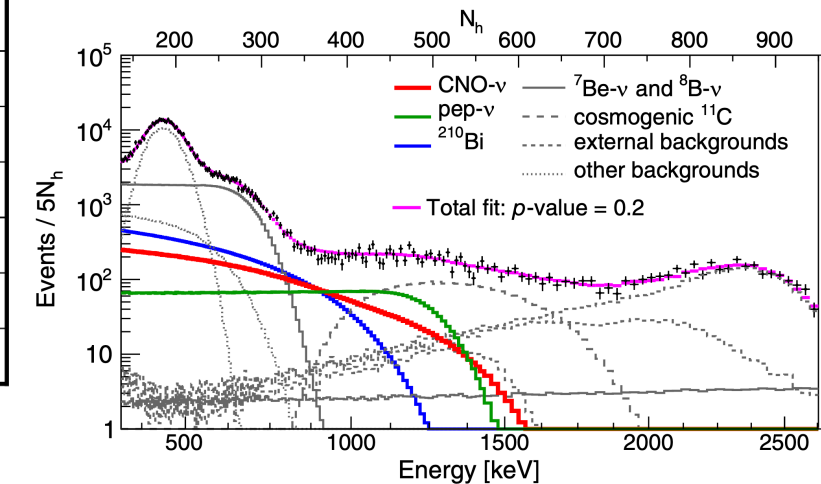
$\nu(\text{pp})$	$\pm 0.6\%$
$\nu(^{7}\text{Be})$	$\pm 7.7\%$
$\nu(^{8}\text{B})$	$\pm 13\%$
$\nu(^{13}\text{N}+^{15}\text{O})$	$\pm 17\%$

Model not precise

and data

$\nu(\text{pp})$	$\pm 0.4\%$
$\nu(^{7}\text{Be})$	$\pm 1.8\%$
$\nu(^{8}\text{B})$	$\pm 1.9\%$
$\nu(^{13}\text{N}+^{15}\text{O})$	$\pm 13\%$

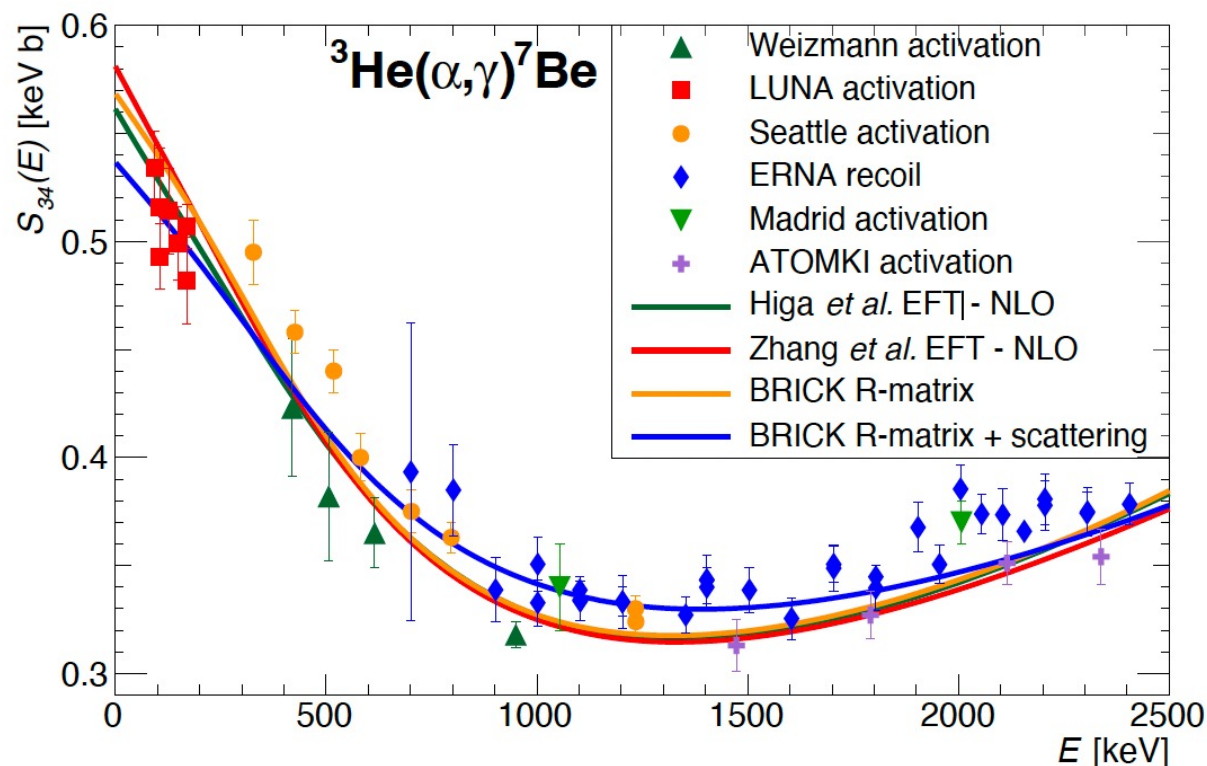
Data precise



Borexino (2023)

Model uncertainties >> experimental uncertainties!

$^3\text{He}(\alpha,\gamma)^7\text{Be}$ – pp-II chain



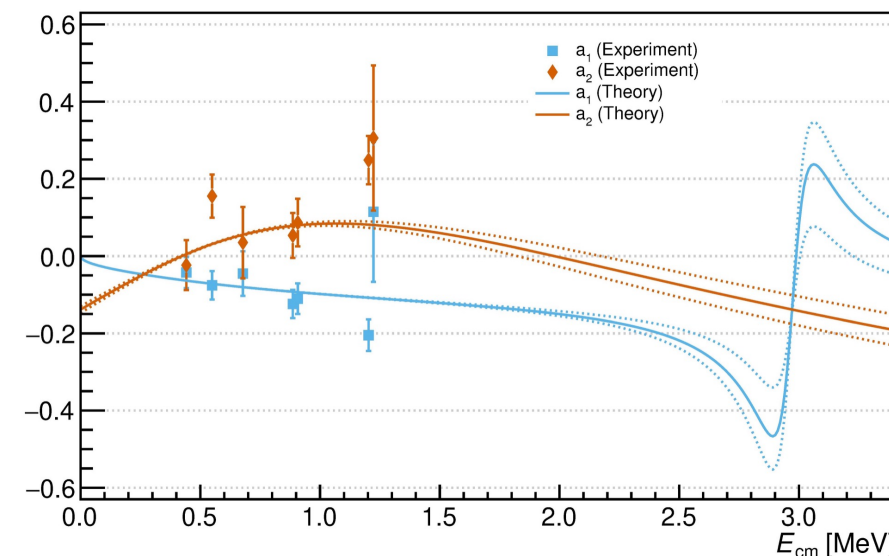
Evaluated S-factor normalization, 5.1% precision:

$$S_{34}(0) = (0.561 \pm 0.018_{\text{expt}} \pm 0.022_{\text{theor}}) \text{ keV b}$$

Rev. Mod. Phys. 97, 035002 (2025)

Community recommendations for future work:

- ♦ γ -ray angular distribution data
- ♦ Further development of *ab initio* techniques.
- ♦ Study of the S-factor over a wide energy range, 50-1500 keV.
- ♦ Elastic scattering data below 2 MeV



S. Turkat *et al.*, Phys. Rev. C in press



European Research Council
Established by the European Commission

LUNANOVA

Laboratory **U**nderground for **N**uclear **A**strophysics
New **O**bservatory for Solar Neutrino Reactions



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Helmholtz-Zentrum Dresden-
Rossendorf (HZDR), Germany

Alba Formicola (PI)
Istituto Nazionale di Fisica
Nucleare (INFN), Italy



Heraeus Workshop on Interdisciplinary Physics of the Sun, June 2025

Aldo Serenelli (PI)
Instituto de Ciencias del
Espacio (ICE-CSIC), Spain

Gianluca Imbriani (PI)
Università degli studi di
Napoli Federico II, Italy

...ERC Synergy Grant, 01.09.2026 – 31.08.2032, 14 M€



LUNANOVA objective....

Model ν fluxes...

♦ $\nu(\text{pp})$	$\pm 0.6\%$	$\pm 0.4\%$
♦ $\nu(^7\text{Be})$	$\pm 7.7\%$	$\pm 1.8\%$
♦ $\nu(^8\text{B})$	$\pm 13\%$	$\pm 1.9\%$
♦ $\nu(^{13}\text{N}+^{15}\text{O})$	$\pm 17\%$	$\pm 13\%$

Model not precise

and data

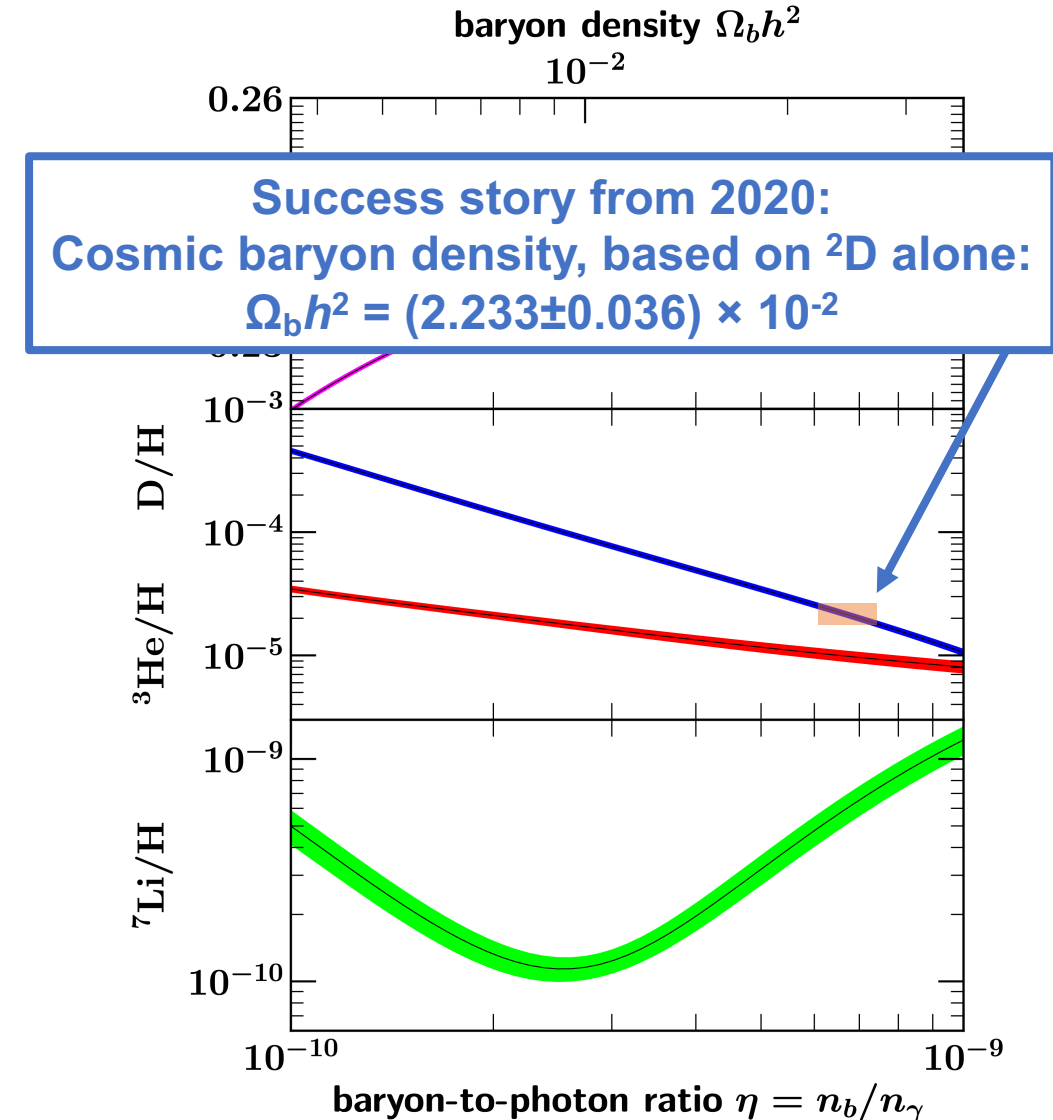
Data precise

Remove nuclear physics uncertainties from the Sun.

LUNANOVA tools:

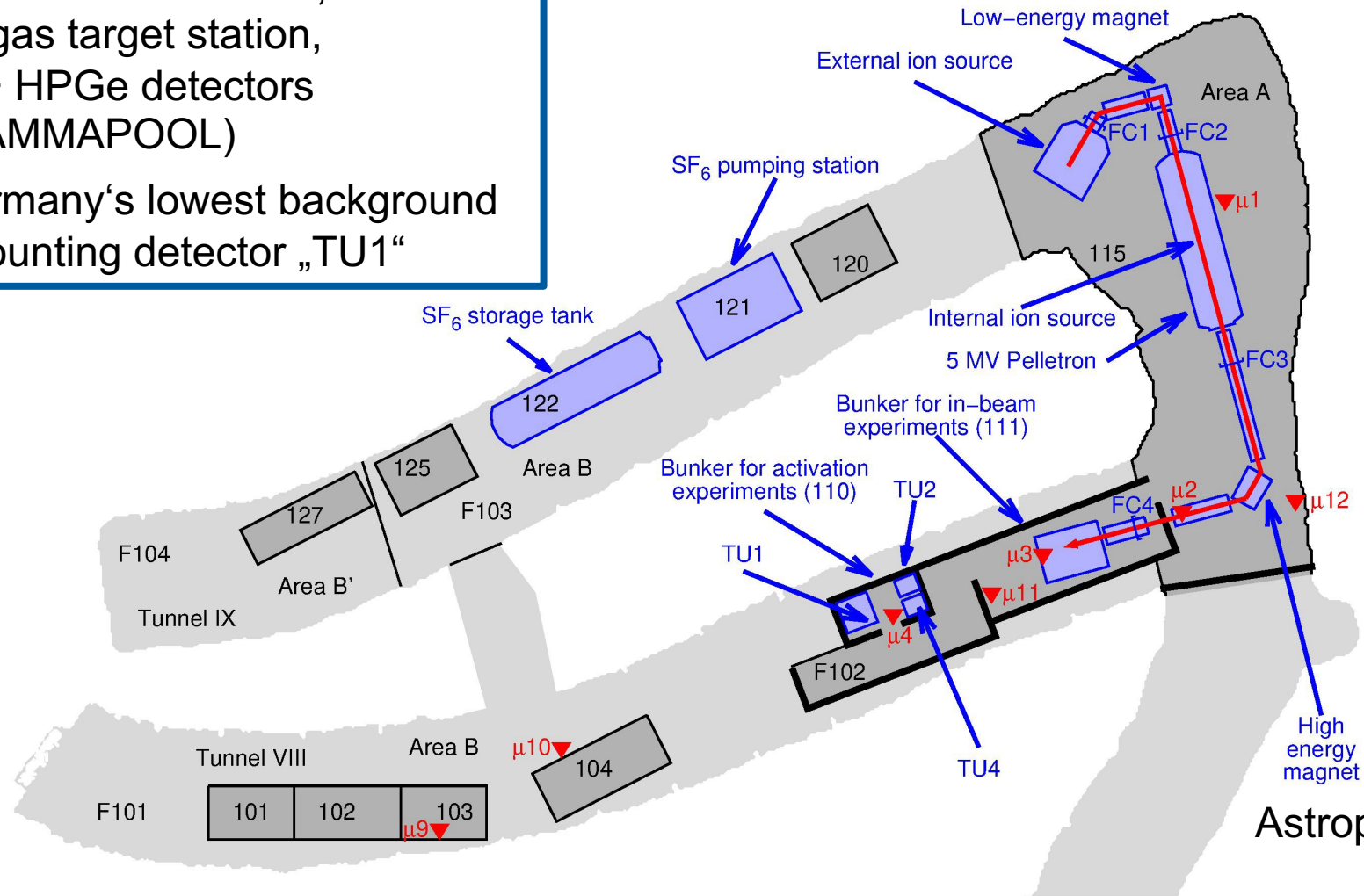
- ♦ New 600 kV LUNANOVA accelerator @ Gran Sasso
- ♦ Experiments at Felsenkeller, CRYRING, *et al.*
- ♦ Theory support
- ♦ New solar model

....and why it might work



Felsenkeller underground lab, HZDR & TU Dresden

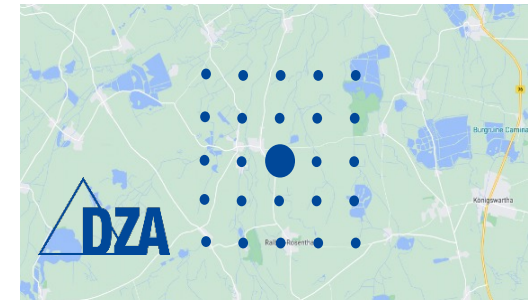
- 5 MV ion accelerator, jet gas target station, 20+ HPGe detectors (GAMMAPOOL)
- Germany's lowest background γ -counting detector „TU1“



Astropart. Phys. 148, 102816 (2023)
Eur. Phys. J. A 61, 19 (2025)

Felsenkeller lab, science program

- ♦ **Solar fusion experiments** – LUNANOVA (2026-2032)
Helmholtz cross-links to CRYRING (local ion source), JUNO, potentially HIBEF
- ♦ **Helium burning experiments** – HEARTS (Eliana Masha, 2026-2031, next talk)
...towards the Holy Grail of Nuclear Astrophysics, $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$
again, cross-links to CRYRING
- ♦ **User-driven experiments**, evaluated every six months by a facility advisory board
Carbon burning (Sandrine Courtin *et al.*, Uni Strasbourg)
p-process (Daniel Galaviz *et al.*, Uni Lisbon)
Big Bang (Marialuisa Aliotta *et al.*, Uni Edinburgh)
s-process (Ranjan Sariyal *et al.*, Institute for Basic Science, Korea)
(...fill in your own project here!)
- ♦ **Outlook within Deutsches Zentrum für Astrophysik (DZA)**
Low Seismic Lab, 200 m deep, site selection process starting now
400 m² cavern for nuclear astrophysics included (Experimentierbereich 2)

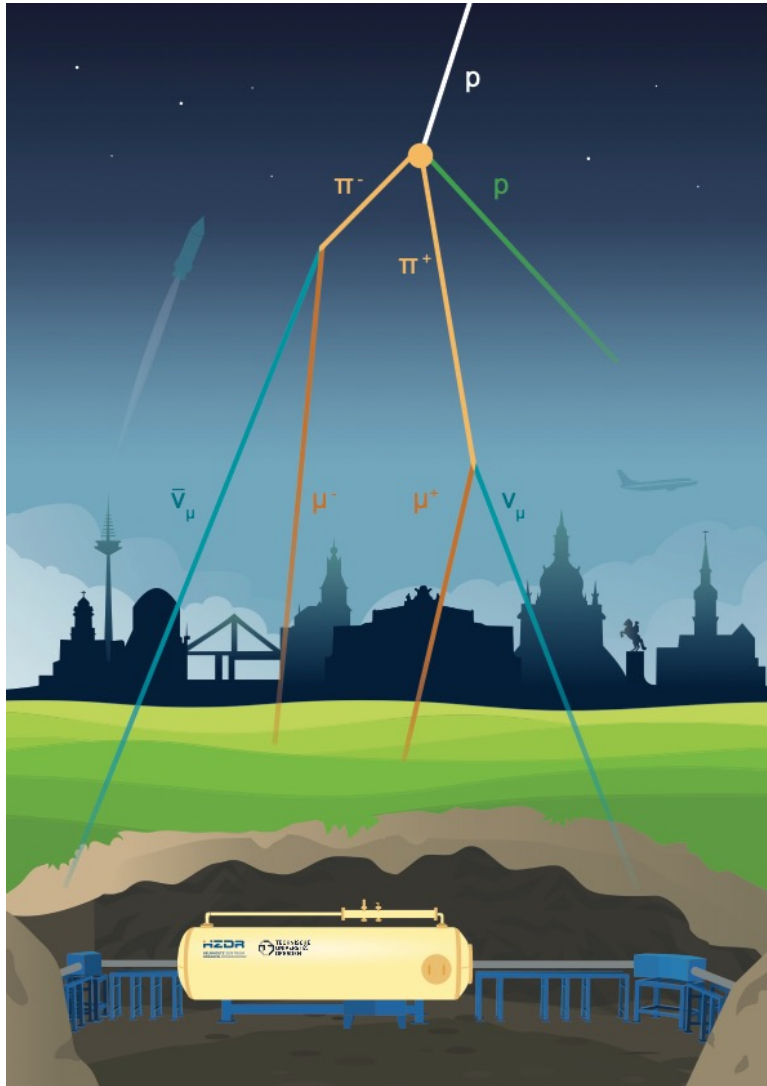
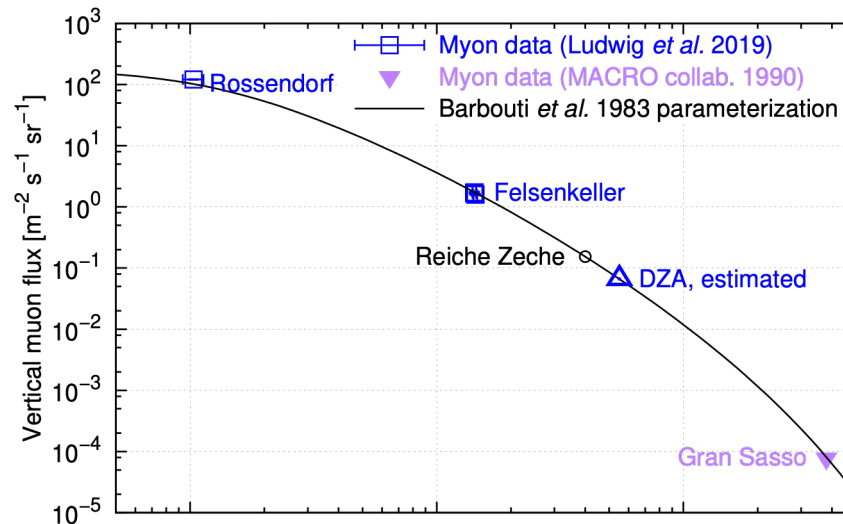
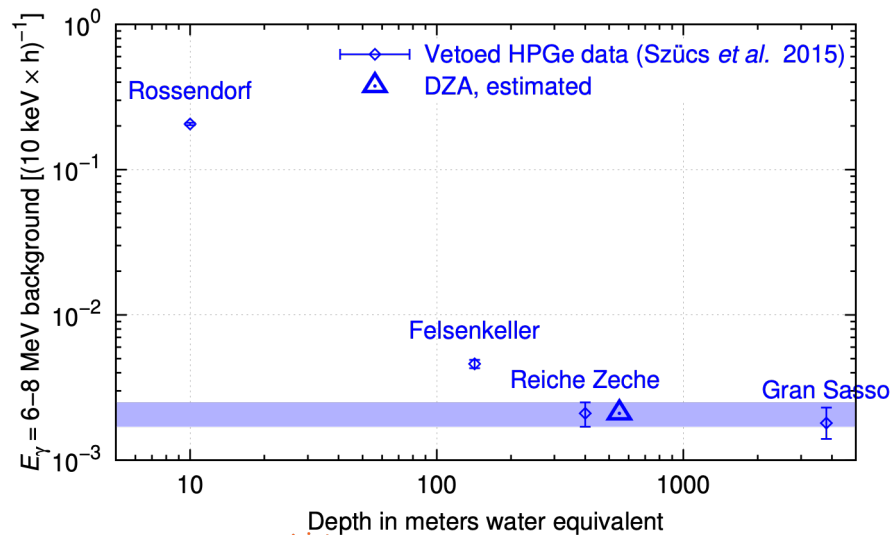
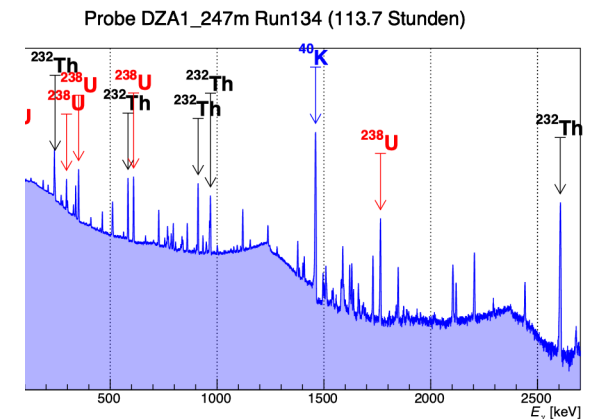


Felsenkeller lab, HZDR and TU Dresden, and LUNANOVA

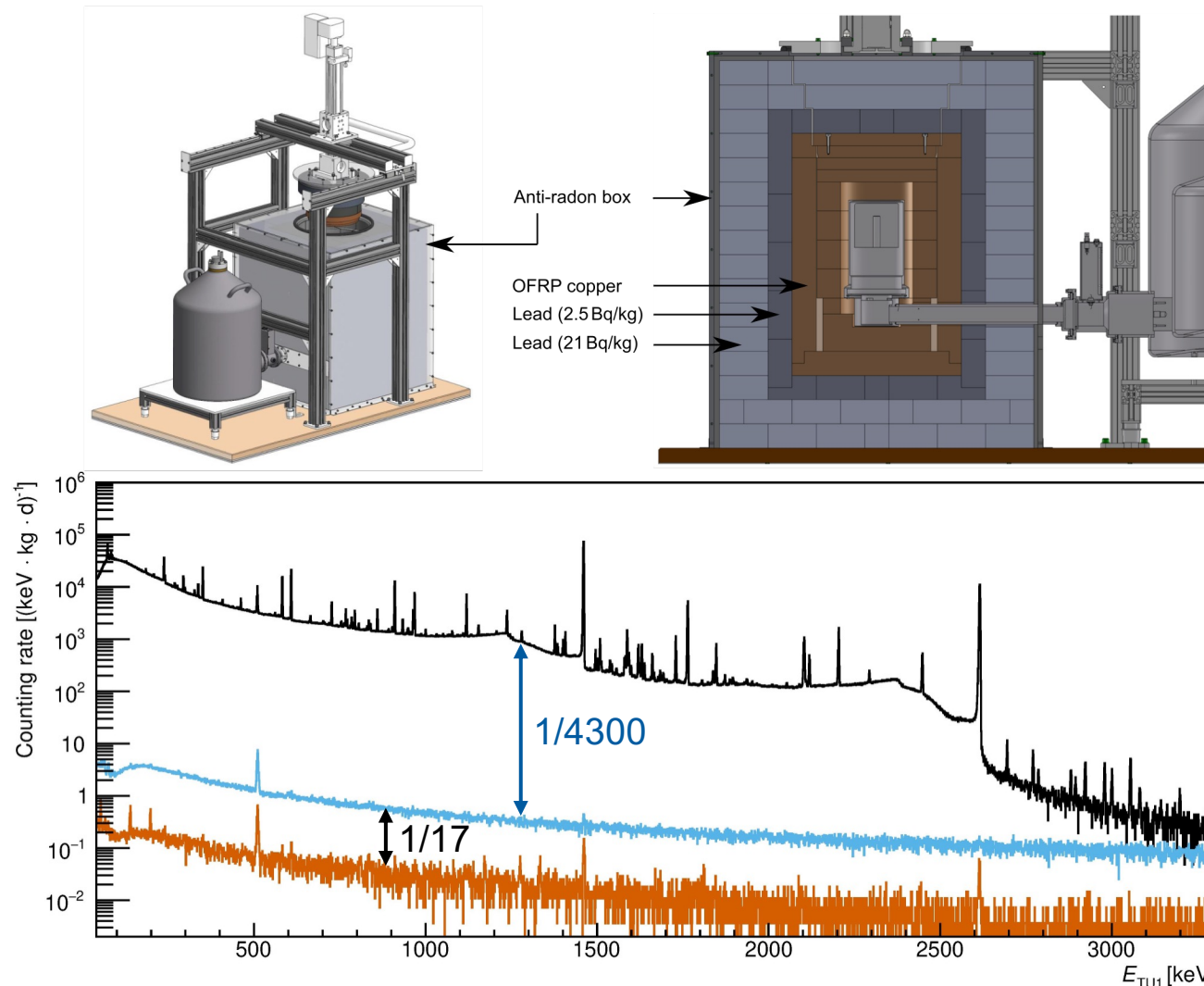
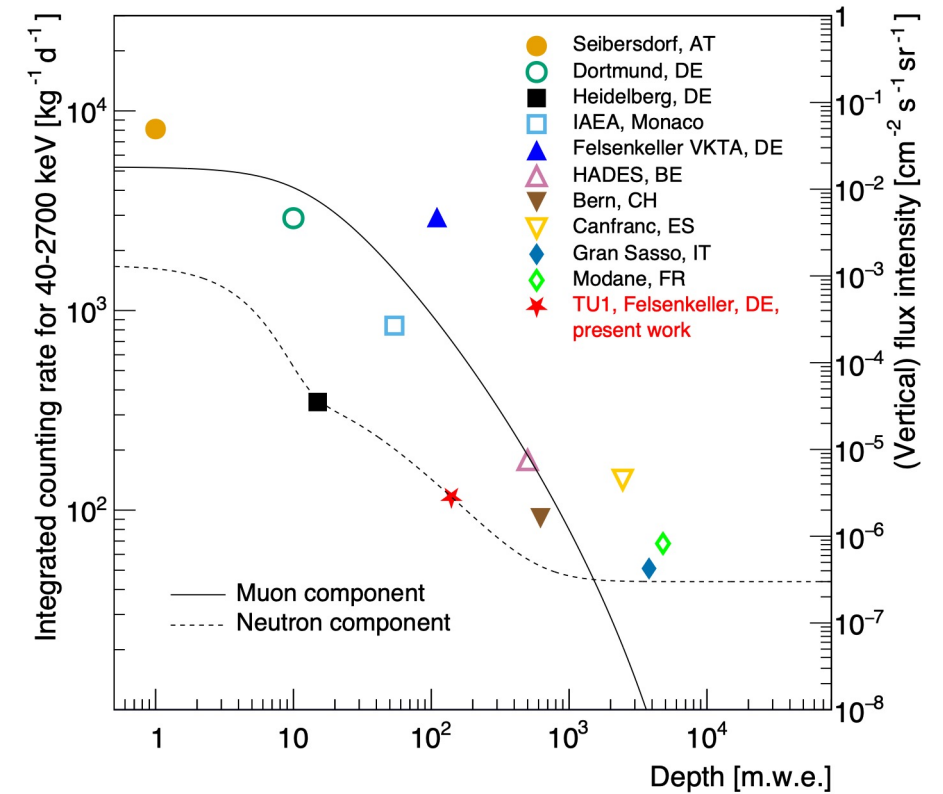


- ◆ Solar fusion – LUNANOVA (2026-2032)
- ◆ Helium burning – HEARTS (Eliana Masha)
- ◆ User-driven experiments
- ◆ Deutsches Zentrum für Astrophysik (DZA)

DZA Low Seismic Lab, at the „sweet spot“ for nuclear astrophysics

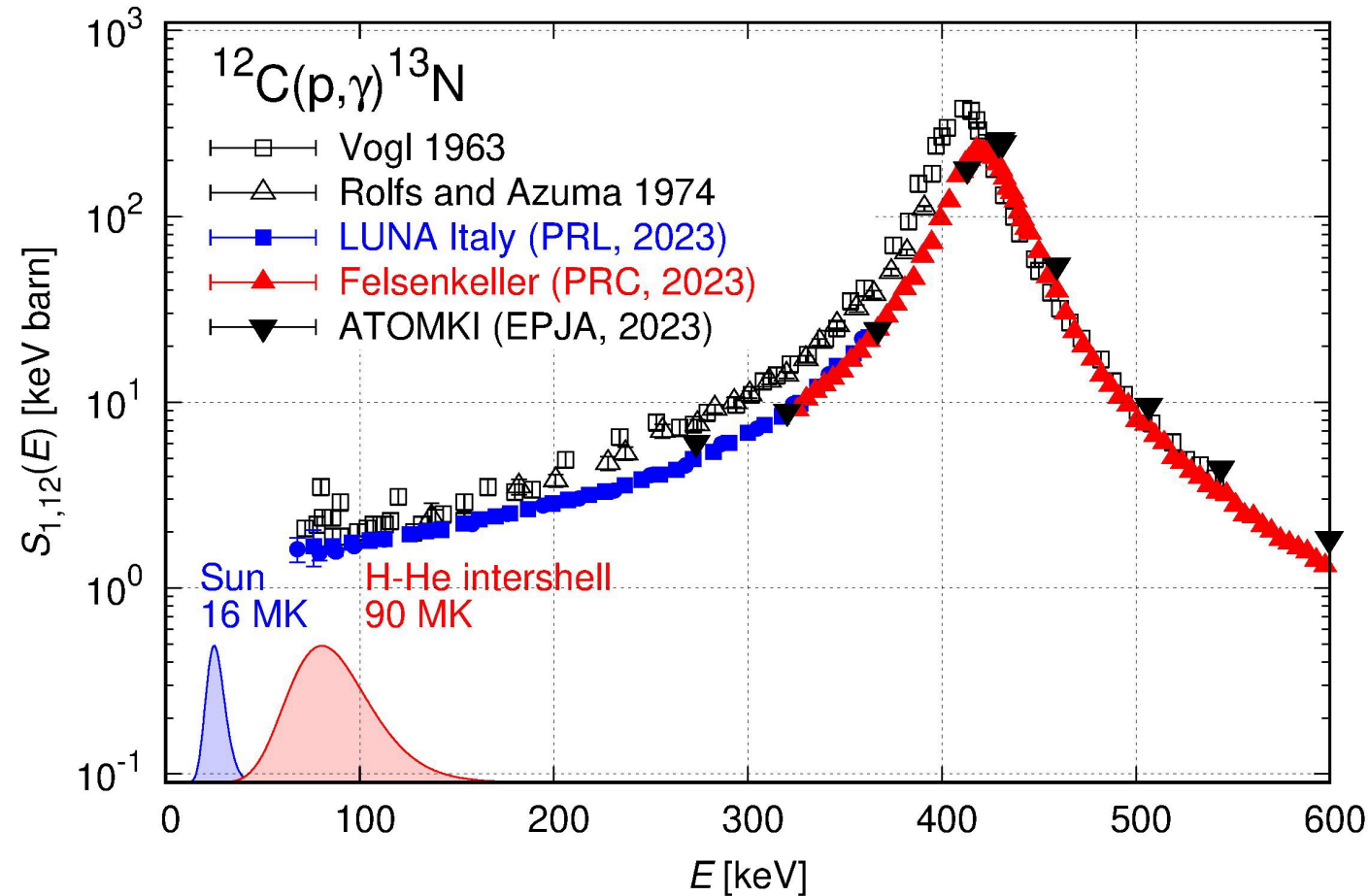
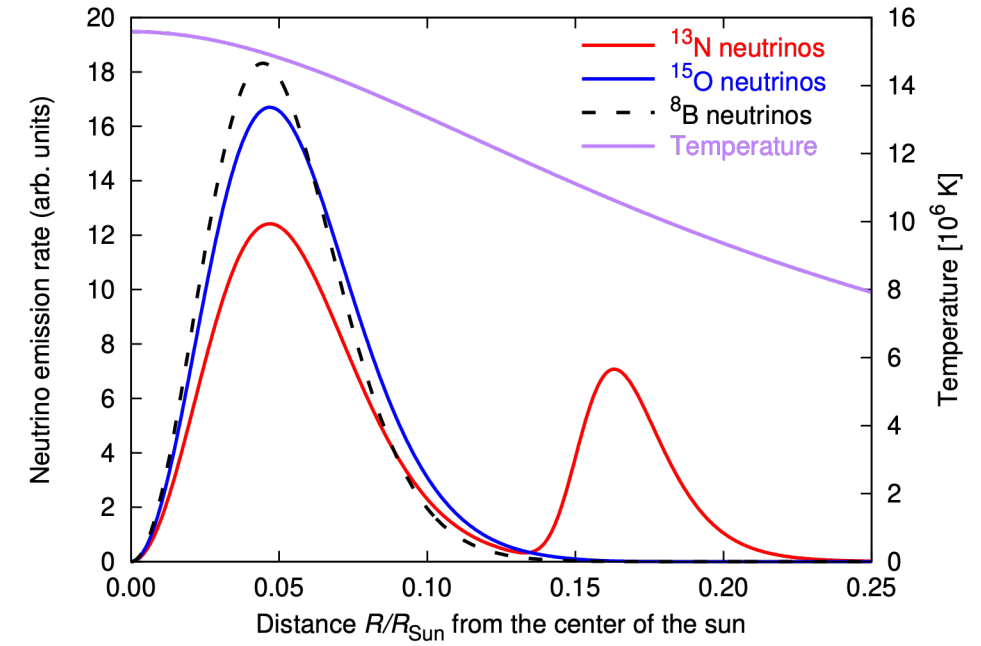


Germany's most sensitive radioactivity measurement setup "TU1"

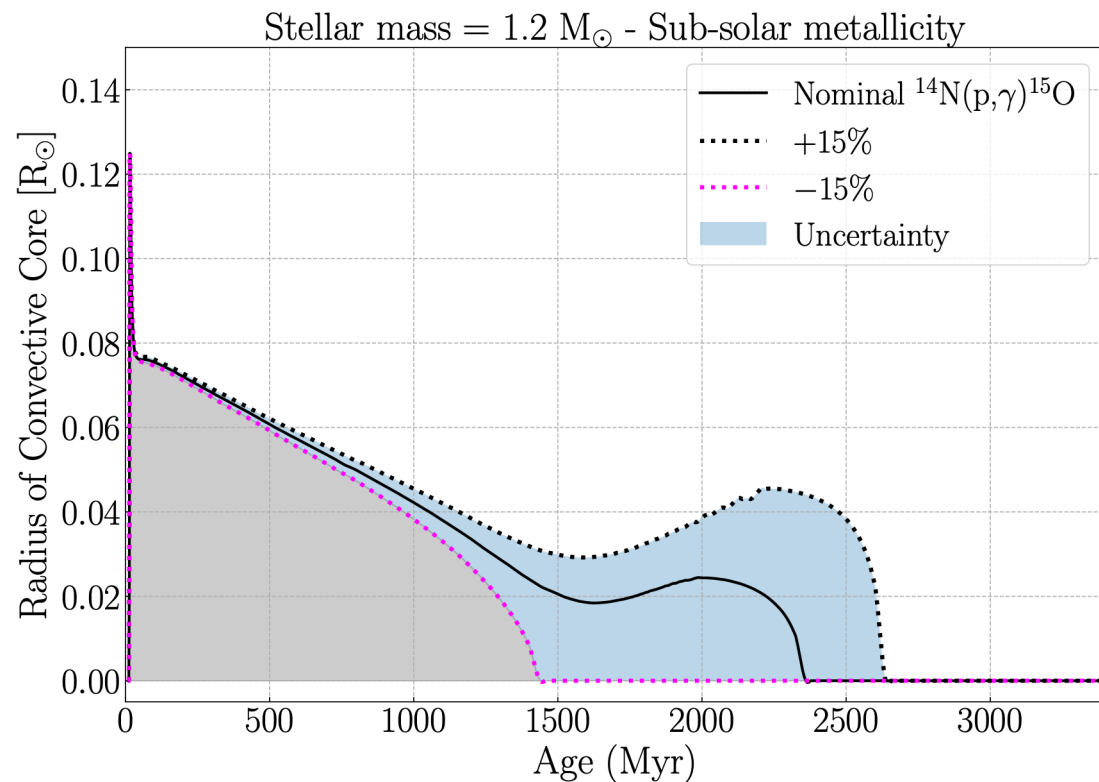
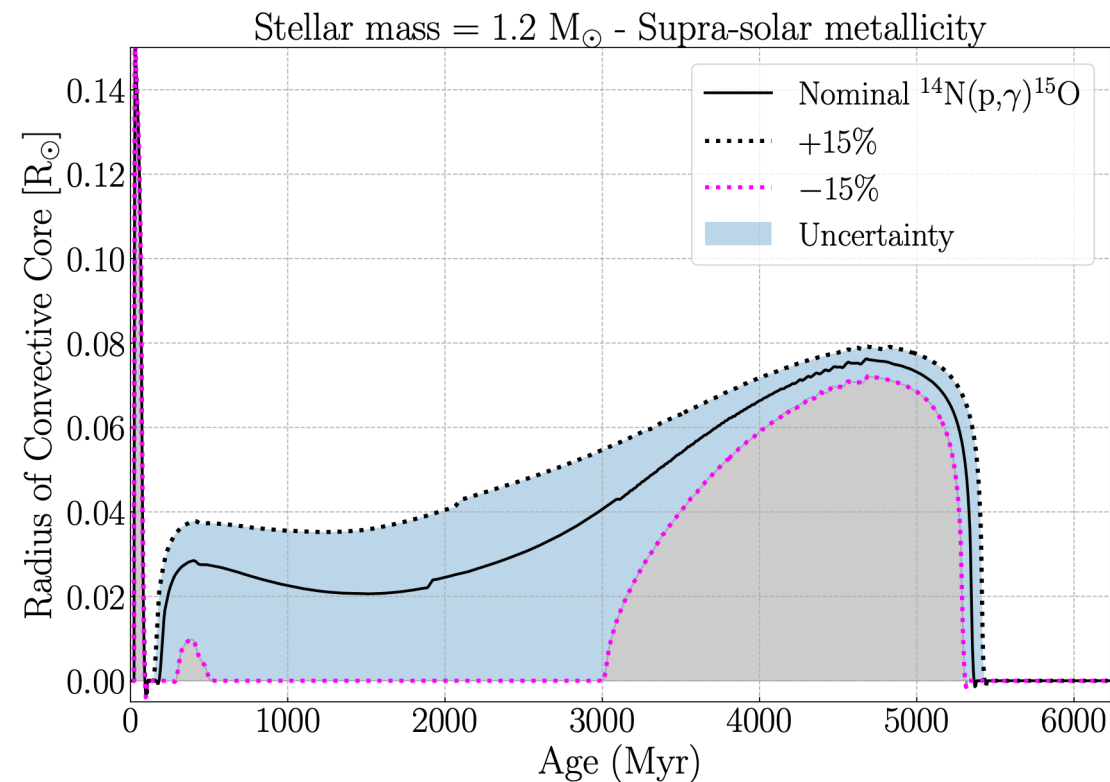


Steffen Turkat, Kai Zuber *et al.*,
Astropart. Phys. 148 (2023) 102816

Study of the $^{12}\text{C}(p,\gamma)^{13}\text{N}$ reaction in Italy, Hungary, Germany

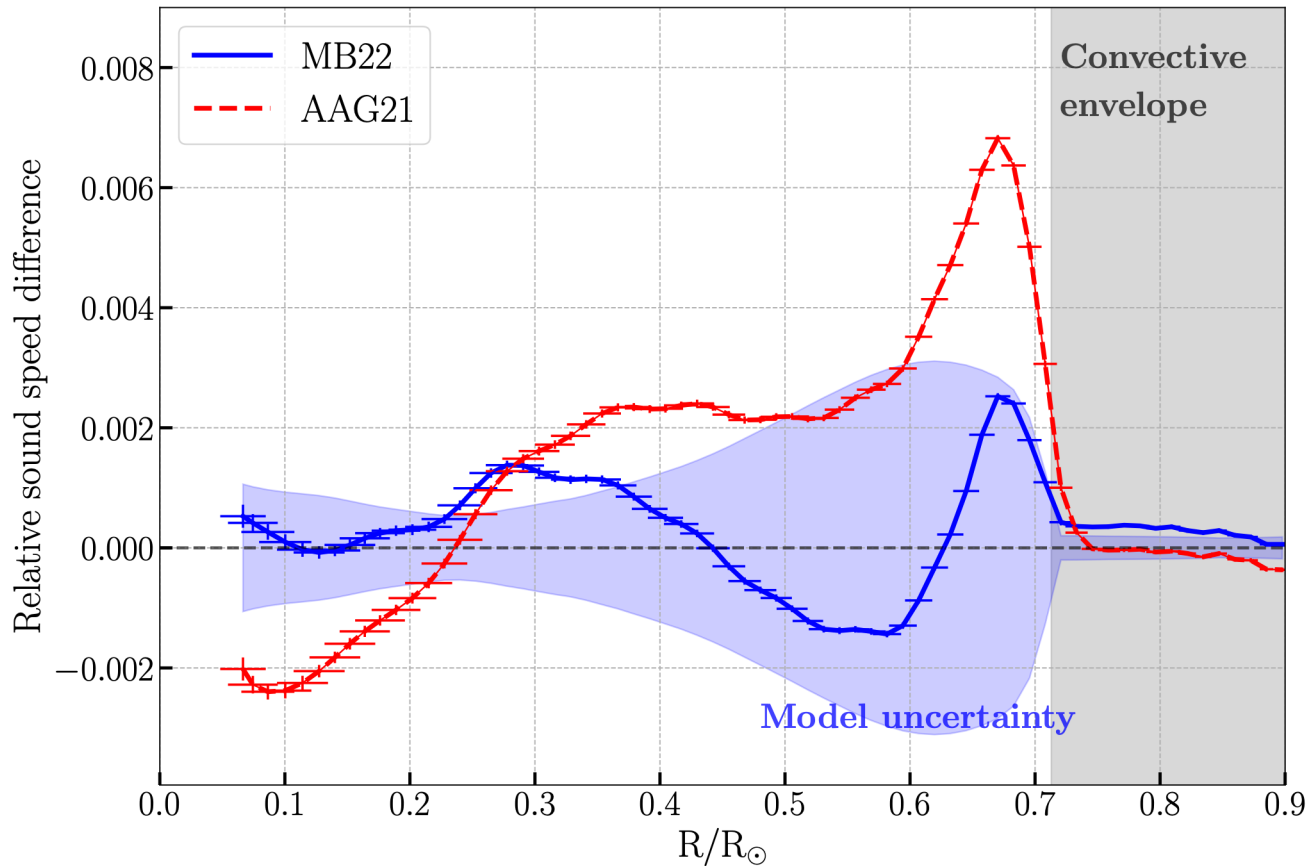


Impact of CNO cycle rate for solar-like stars – convective cores



Nuclear cross section vs hydrodynamics (convection and overshooting)

Helioseismology, the study of acoustic oscillations in the Sun



Model	$R_{CZ}/R_{\odot}$	Y_S	$\langle \delta c/c \rangle$	Y_{ini}	Z_{ini}
MB22-phot	0.7123	0.2439	0.0010	0.2734	0.0176
AAG21	0.7197	0.2343	0.0027	0.2638	0.0155
GS98	0.7122	0.2425	0.0010	0.2718	0.0187
Solar	0.713 ± 0.001	0.2485 ± 0.0035			

$$\nabla T^4 \propto \kappa$$

↑
Temperature T

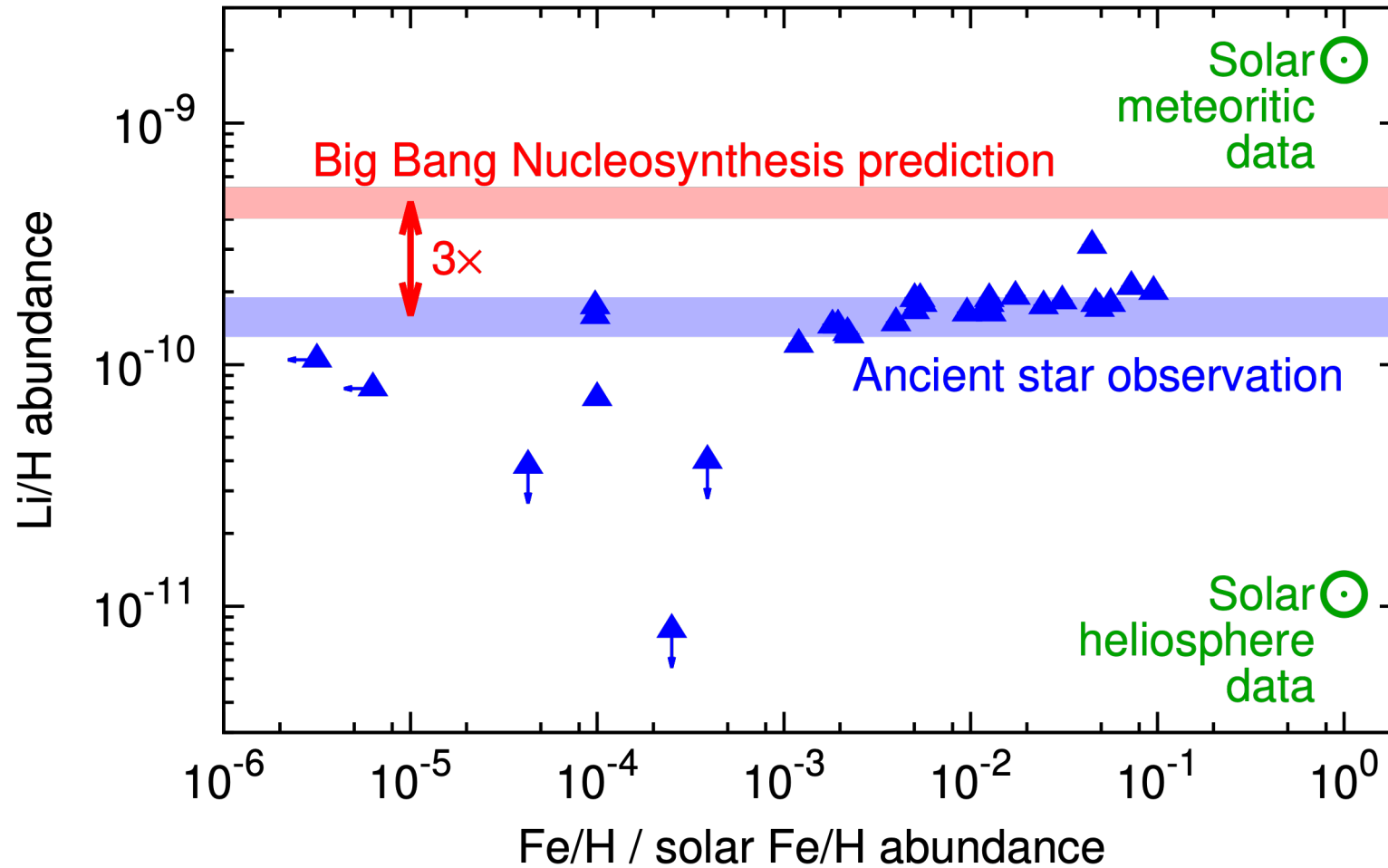
Radiative opacity κ

$$c^2 \propto T/\mu$$

↑
Sound speed c

Molar mass μ
(elemental composition)

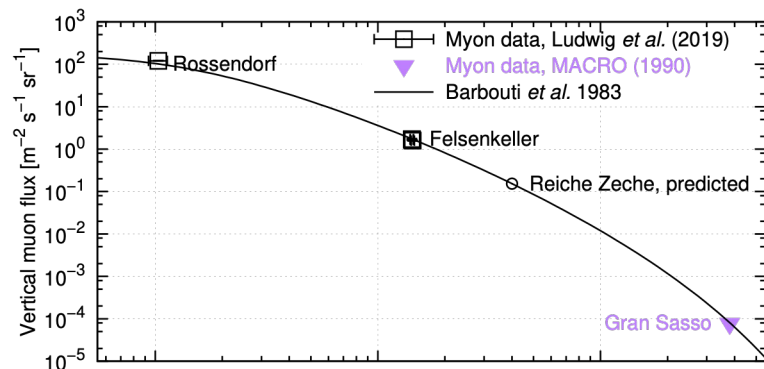
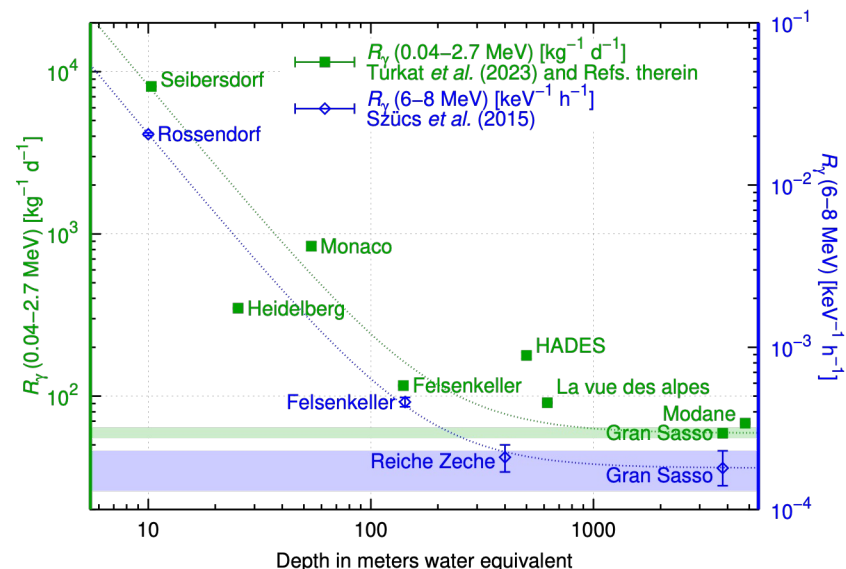
${}^7\text{Be}$ and ${}^7\text{Li}$ – wide scope for future study



Felsenkeller: Studying low cross sections with low background

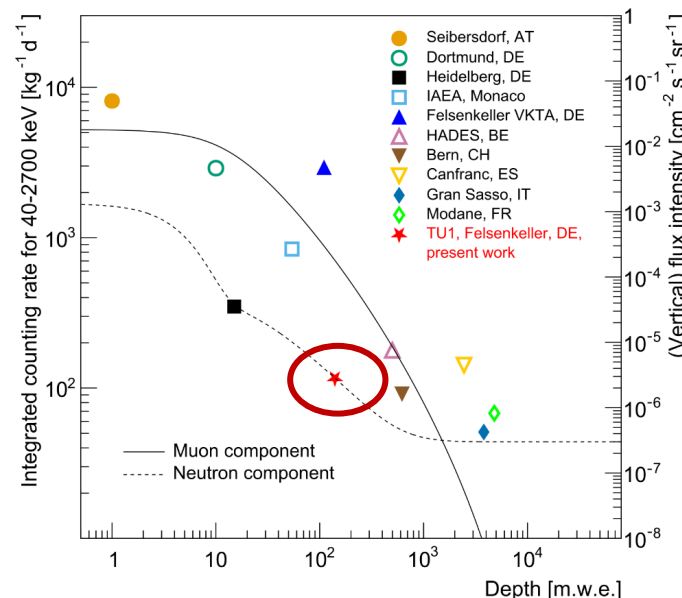
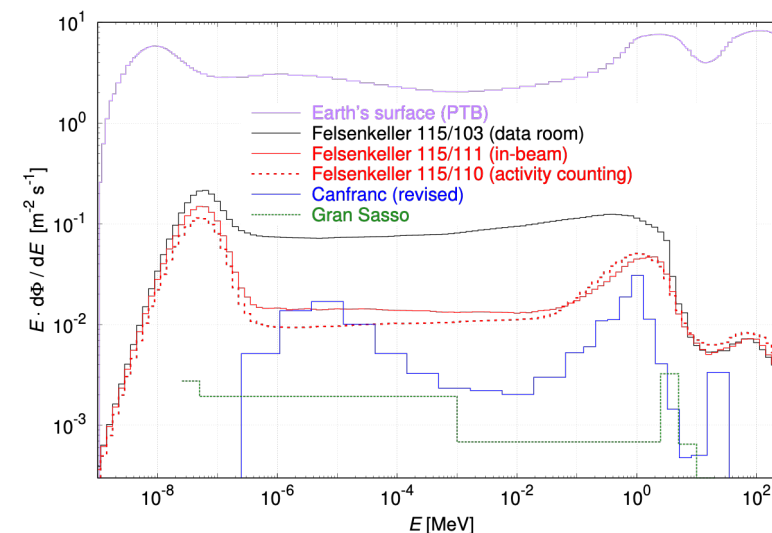
40× lower muon background

Astropart. Phys. 112, 24 (2019)



200× lower neutron background

Phys. Rev. D 101, 123027 (2020)



100× lower γ -background

Eur. Phys. J. A 51, 33 (2015)

Astropart. Phys. 148, 102816 (2023)

Eur. Phys. J. A 61, 19 (2025)