This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008324 (ChETEC-INFRA).

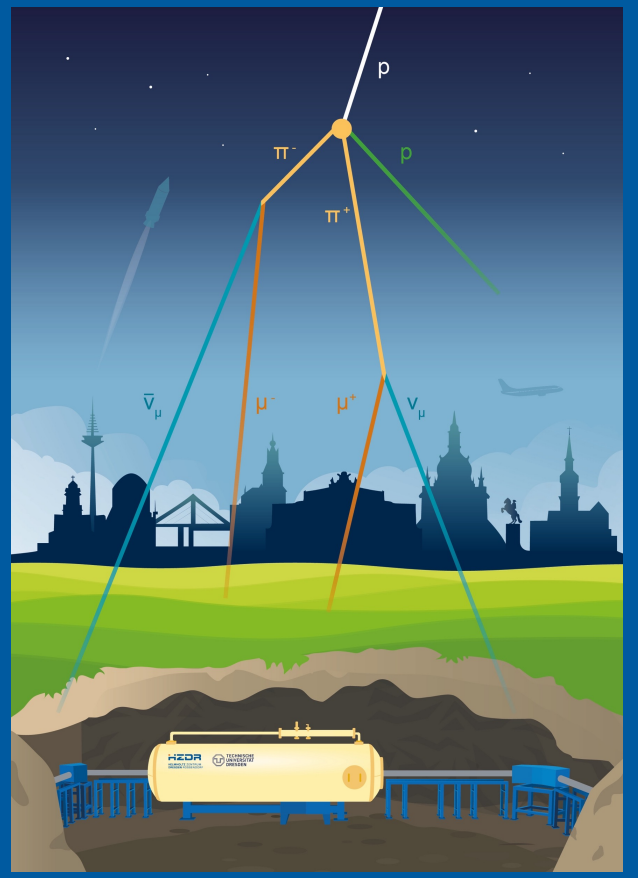
Nuclear astrophysics: The Felsenkeller lab in Dresden

German-Georgian Science Bridge

Dresden, 21.08.2025

Prof. Dr. Daniel Bemmerer

Helmholtz-Zentrum Dresden-Rossendorf



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

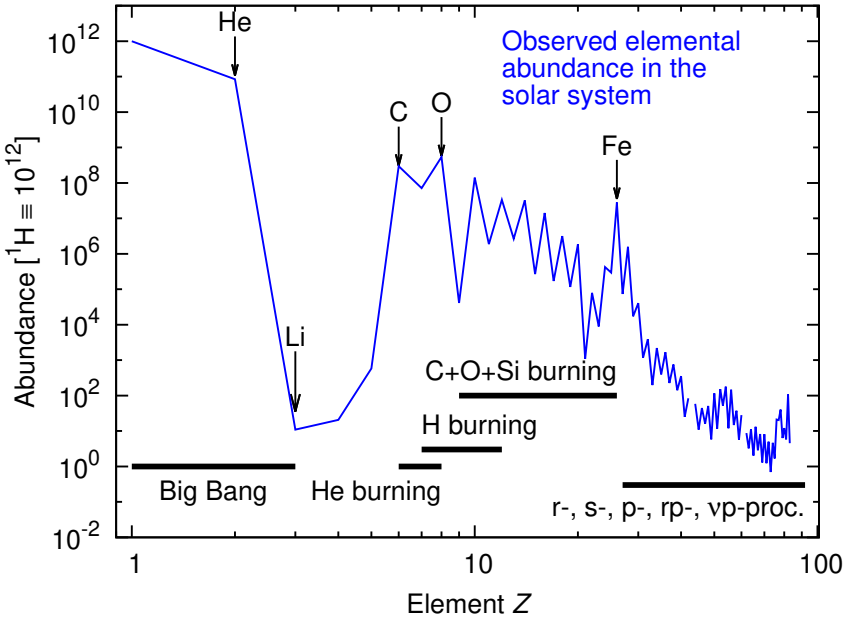
Nuclear astrophysics: The Felsenkeller lab in Dresden

H															He
Li	Be									B	C	N	O	F	Ne
Na	Mg									Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

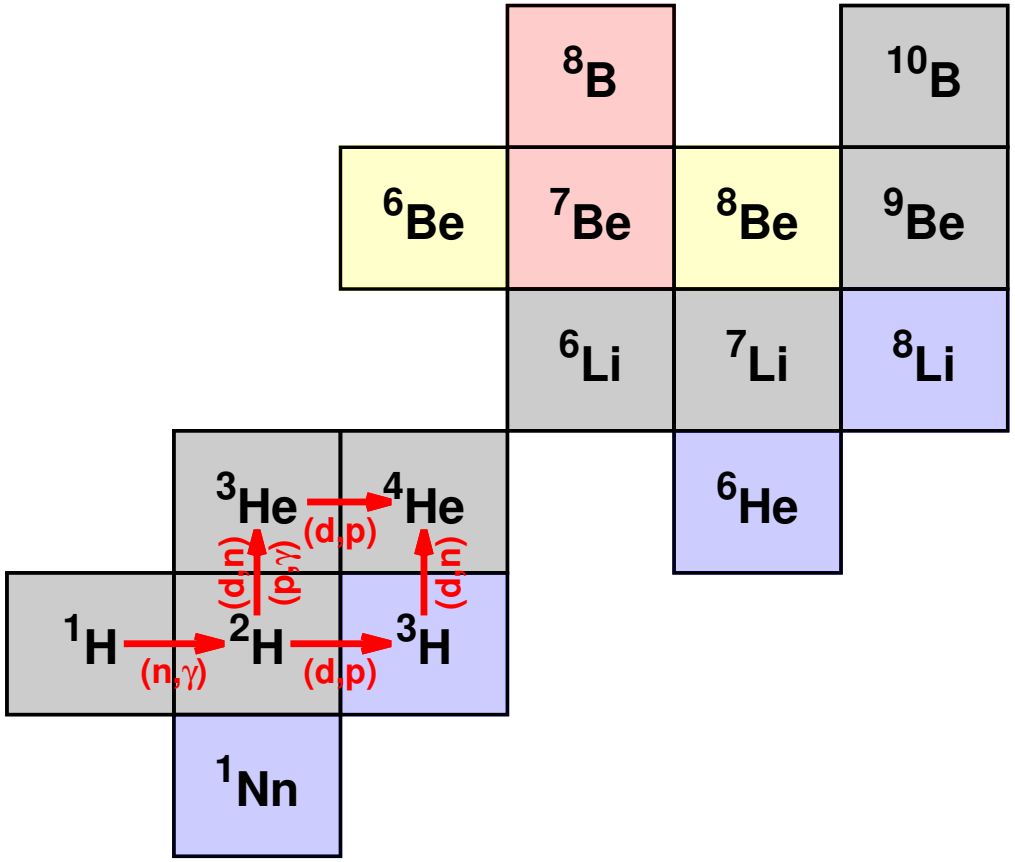
Big Bang
Cosmic
Stellar
r-process
s-process

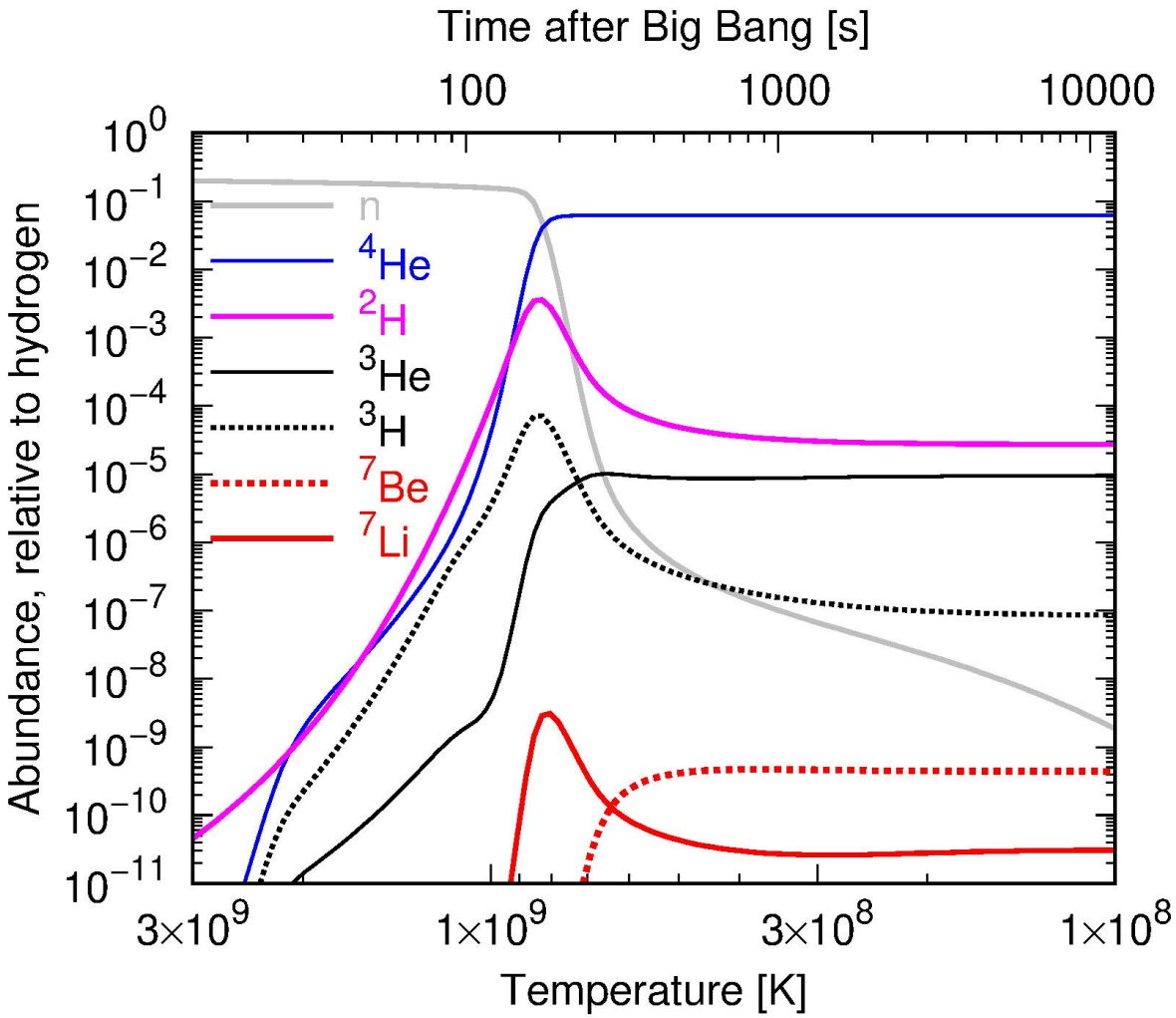
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

Further contributions: p-, i-, rp-, ν-processes



Big Bang Nucleosynthesis (BBN) and ^{2}H (D) as a cosmological probe





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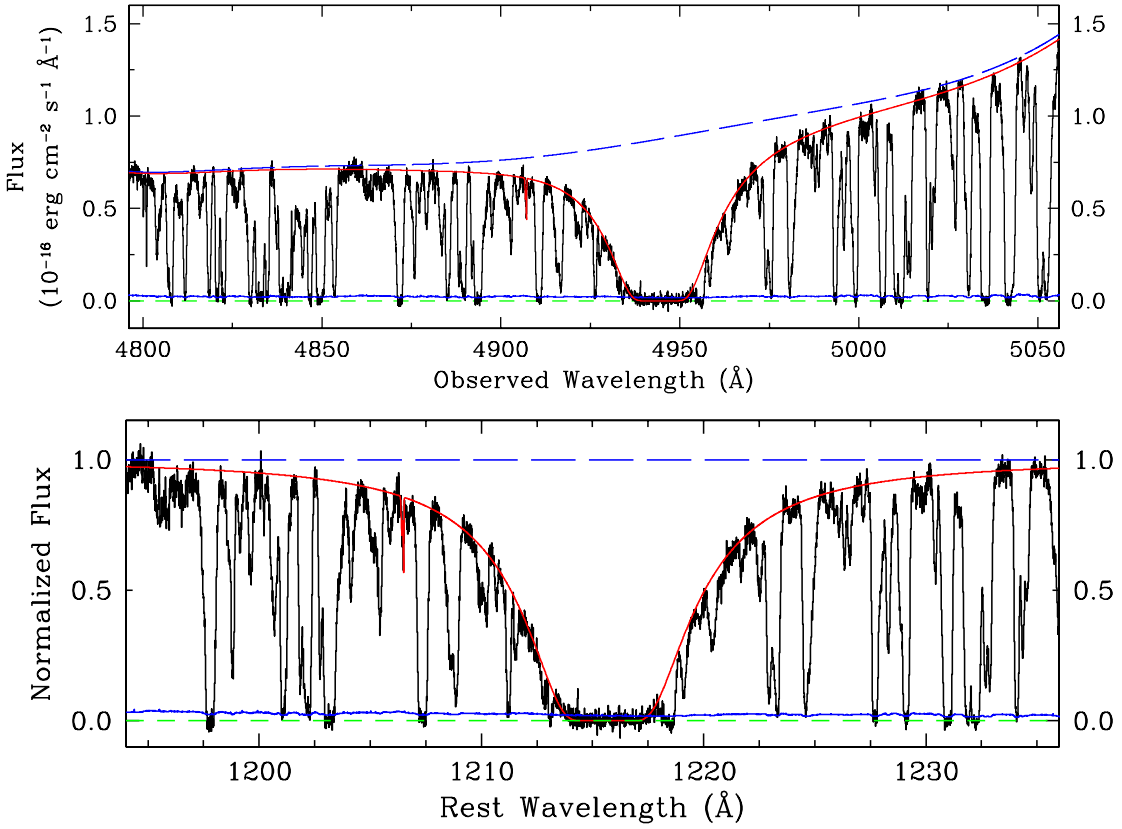
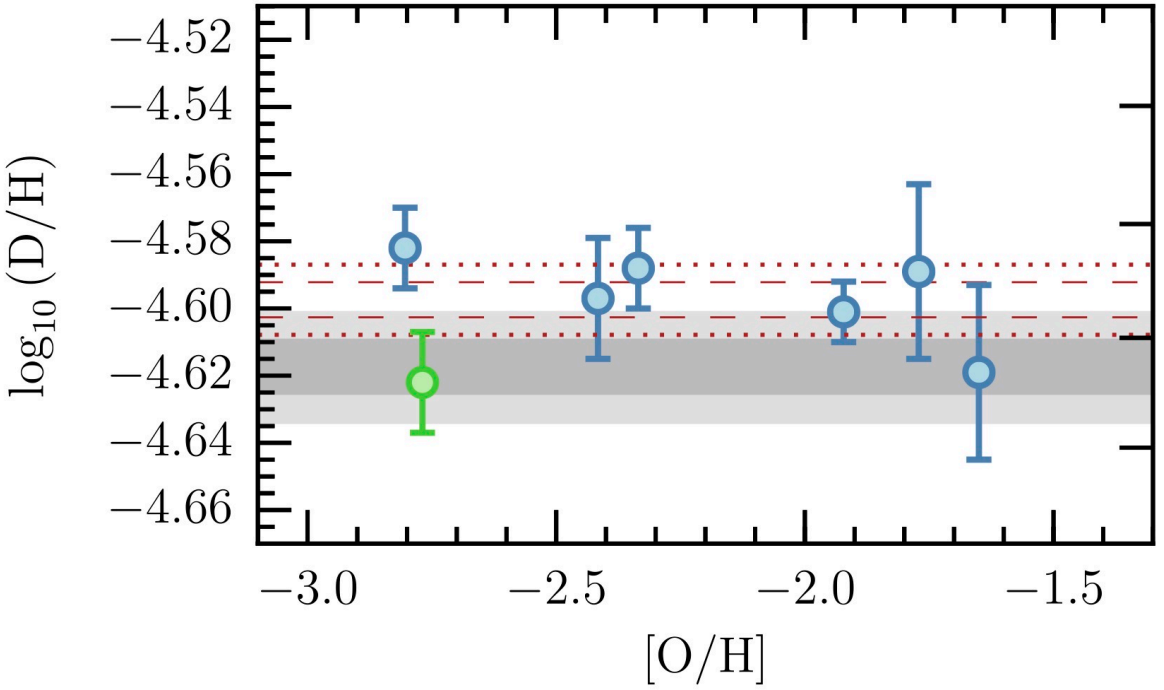
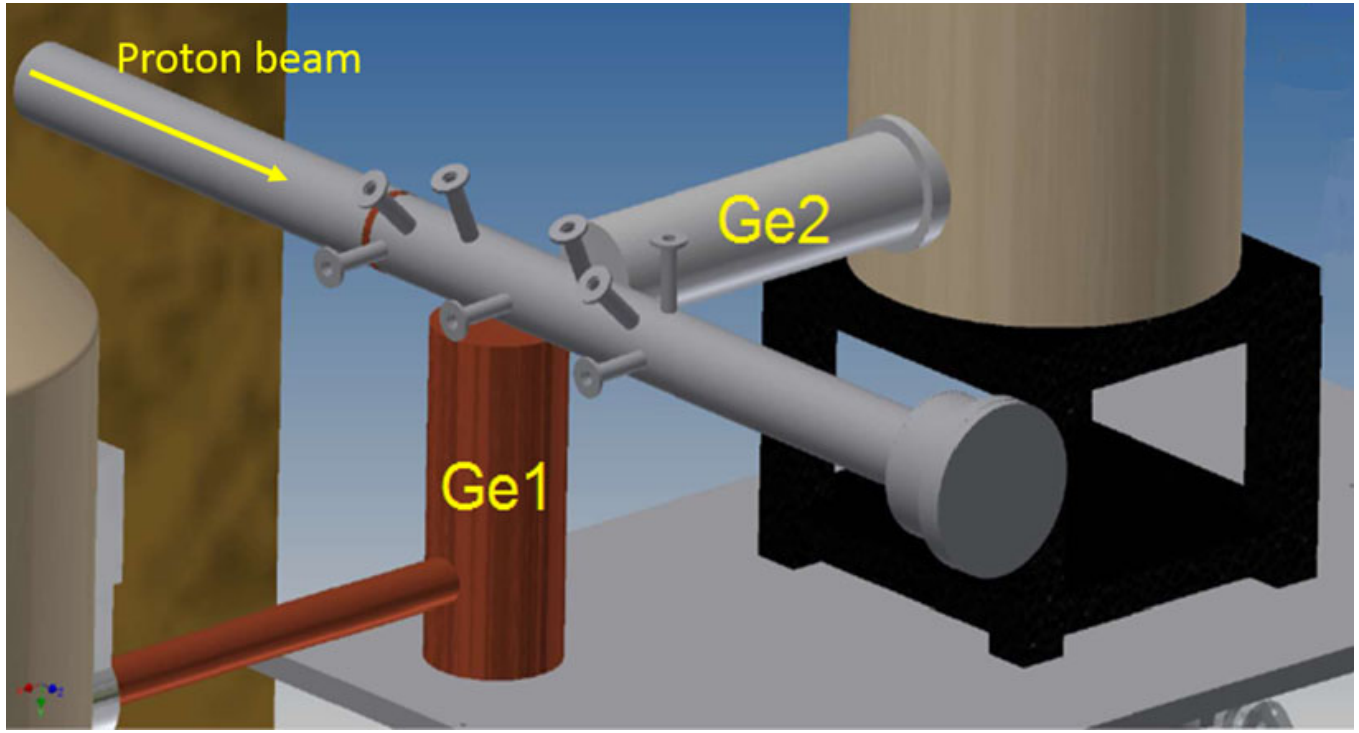




Astronomical ^{2}H observations:
Cooke *et al*. ApJ 855, 102 (2018)

Big Bang Nucleosynthesis (BBN) and ^{2}H (D) as a cosmological probe



Mossa *et al.* (LUNA), Nature 587, 210 (2020)
K. Stöckel *et al.* (LUNA), Phys. Rev. C 110, L032801 (2024)

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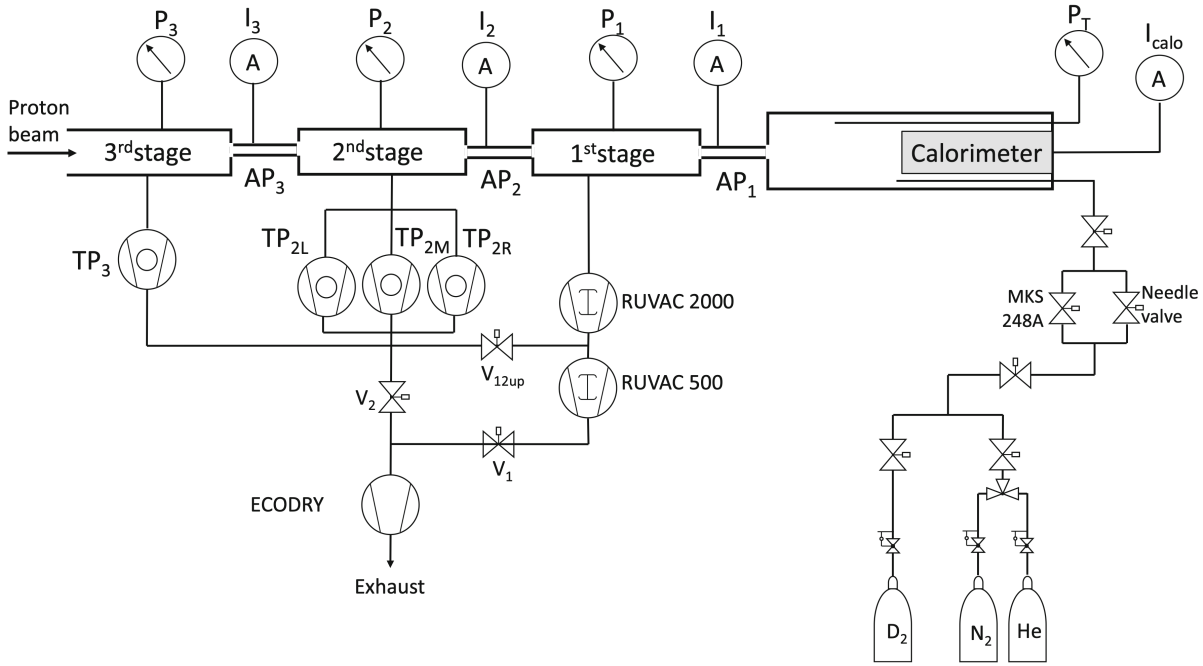

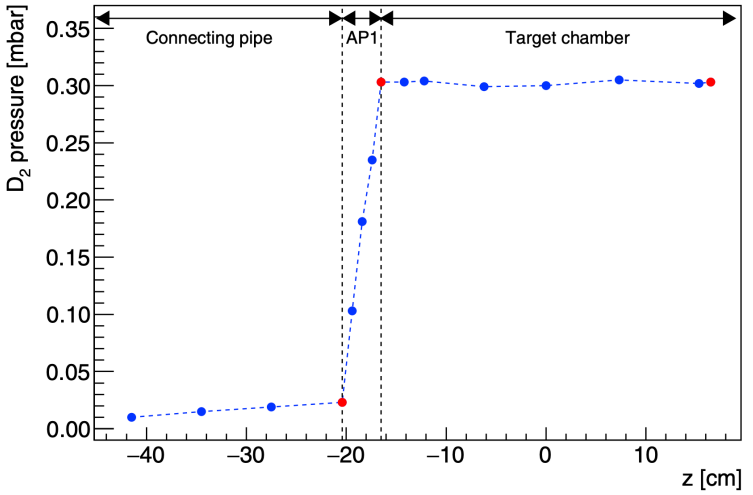

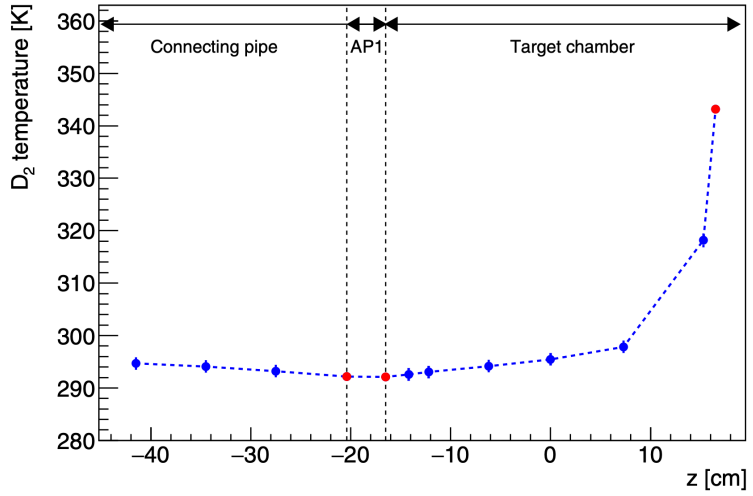

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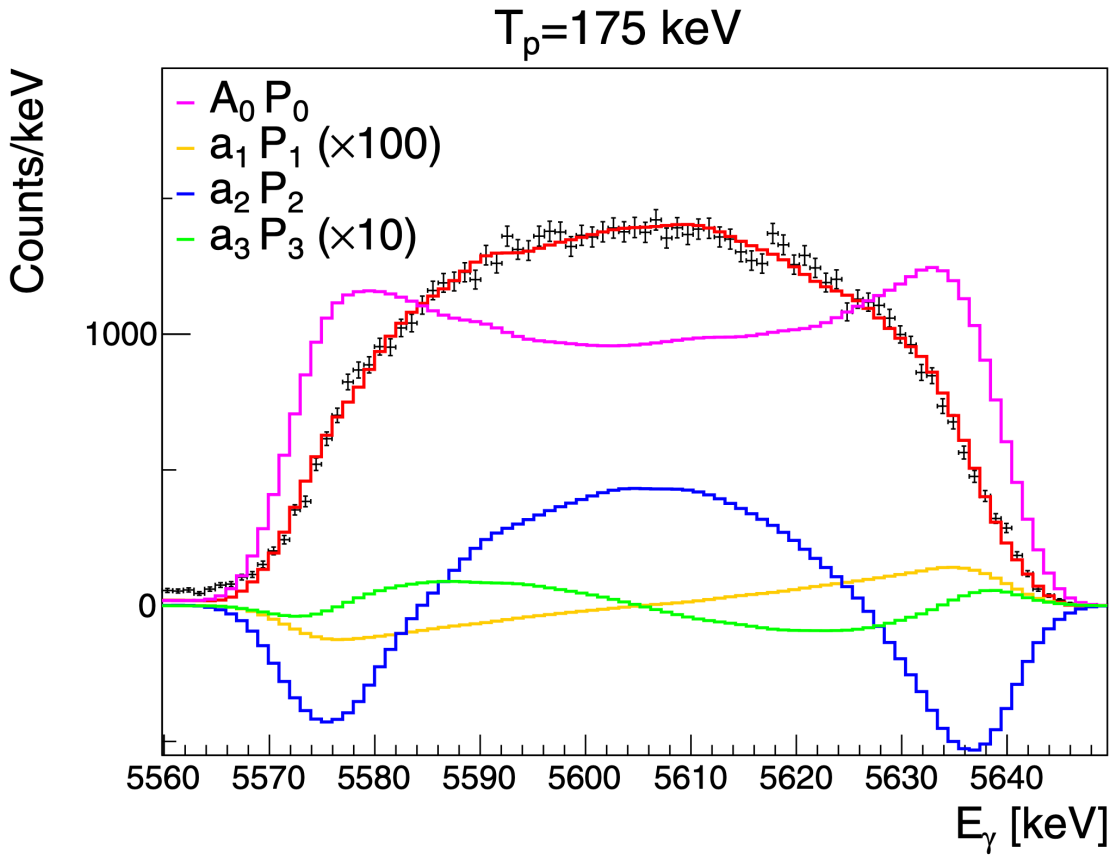
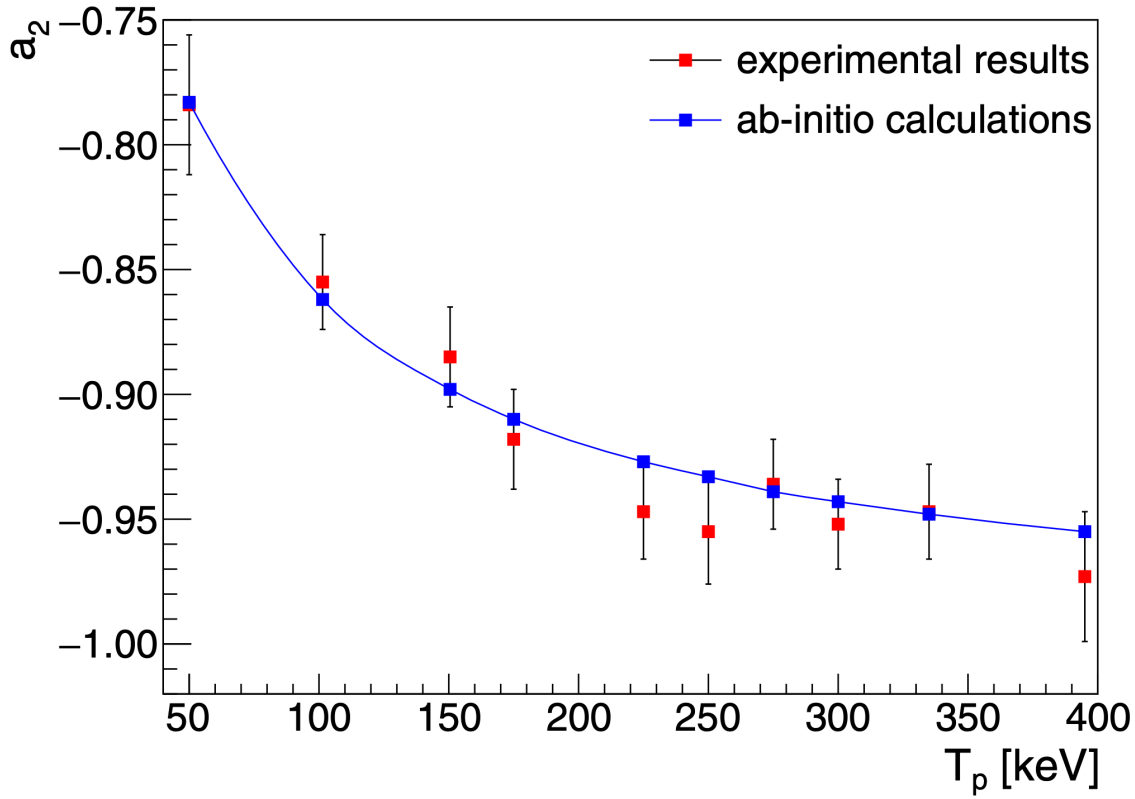
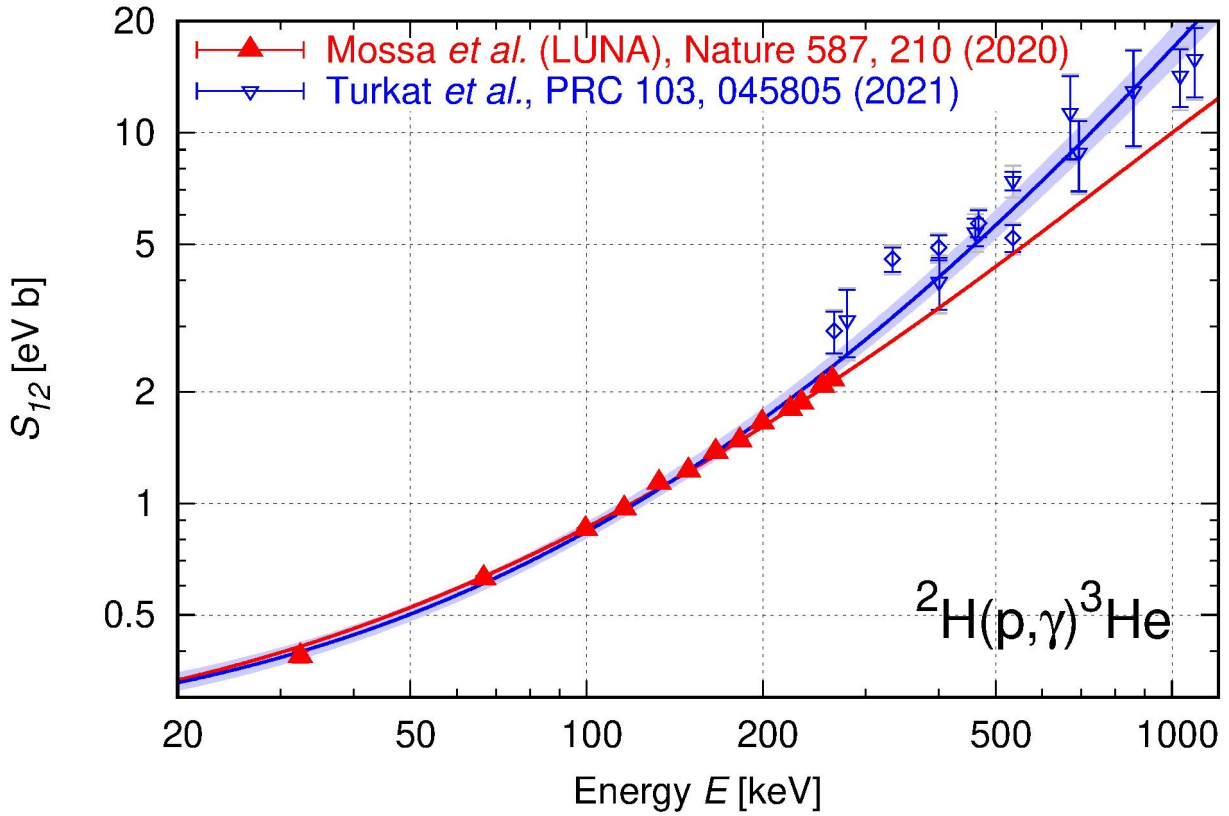




Mossa *et al.* (LUNA), Nature 587, 210 (2020)
K. Stöckel *et al.* (LUNA), Phys. Rev. C 110, L032801 (2024)

Big Bang Nucleosynthesis (BBN) and ^{2}H (D) as a cosmological probe

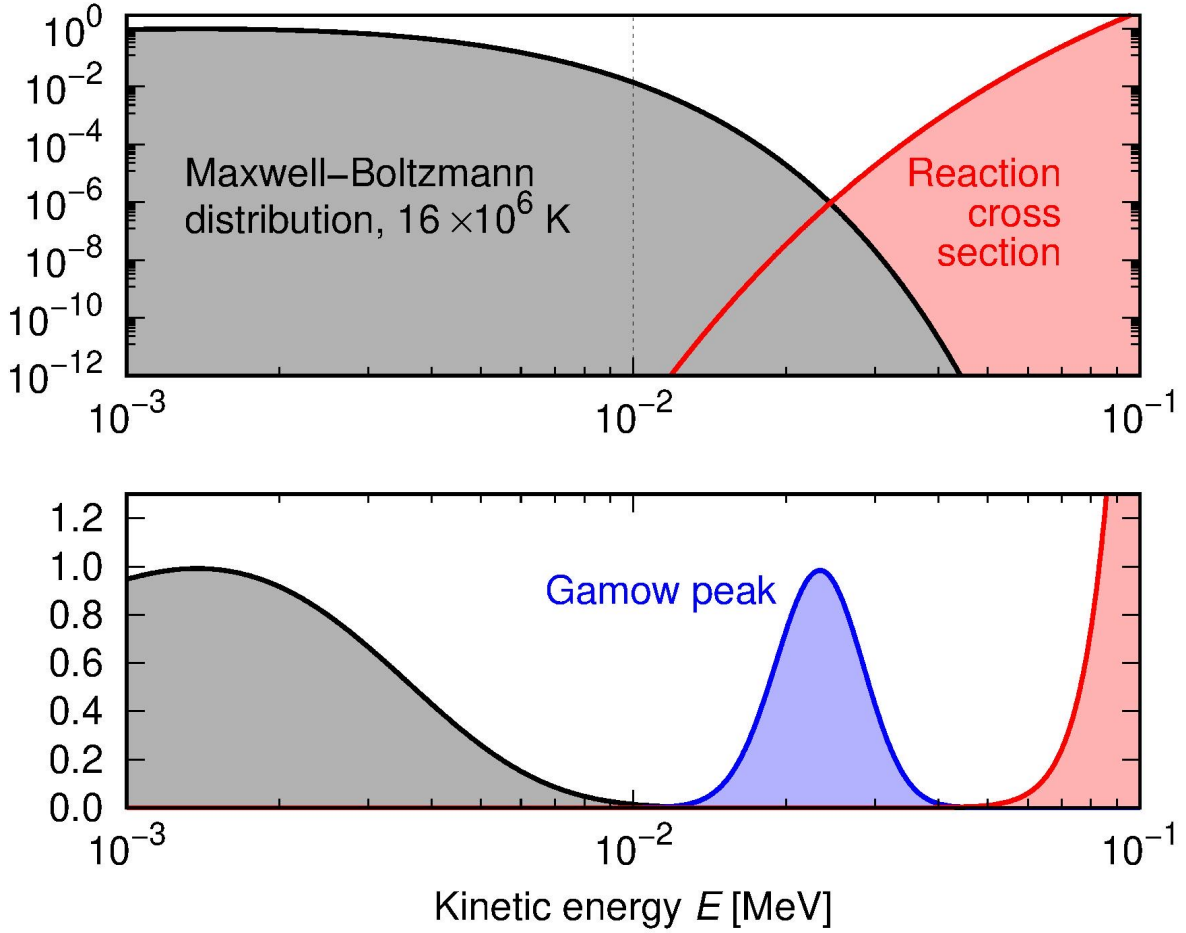
$$S_{12}(E) = \sigma(E) \times E \times \exp\left(Z_1 Z_2 \alpha \sqrt{\frac{\mu c^2}{2E}}\right)$$



Using ^{2}H from BBN to determine the cosmic baryon density:

$$\Omega_b h^2 = 0.02271 \pm 0.00062 \quad \text{BBN, before new LUNA data}$$
$$\Omega_b h^2 = 0.02233 \pm 0.00036 \quad \text{BBN, including new LUNA data}$$
$$\Omega_b h^2 = 0.02236 \pm 0.00015 \quad \text{Cosmic Microwave Background}$$

Maxwell Boltzmann versus tunneling probability



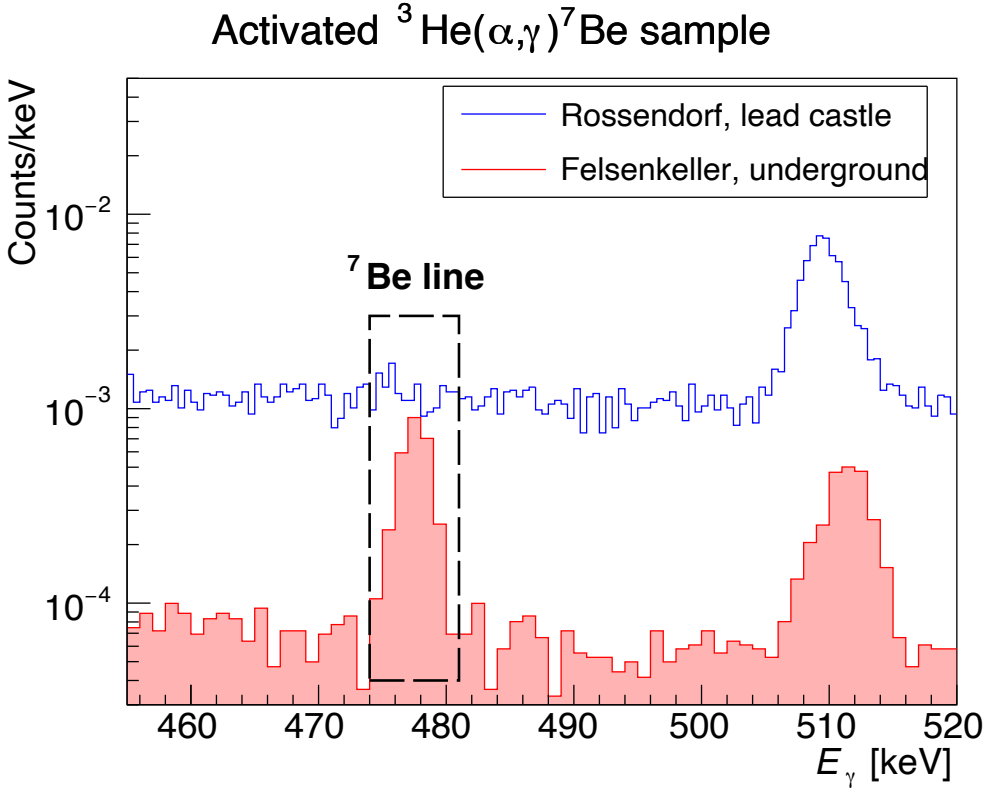
Sensitive, underground experiments needed

$$\frac{E^{\frac{1}{2}}}{T^{\frac{3}{2}}} \exp\left[-\frac{E}{k_{\mathrm{B}}T}\right]$$

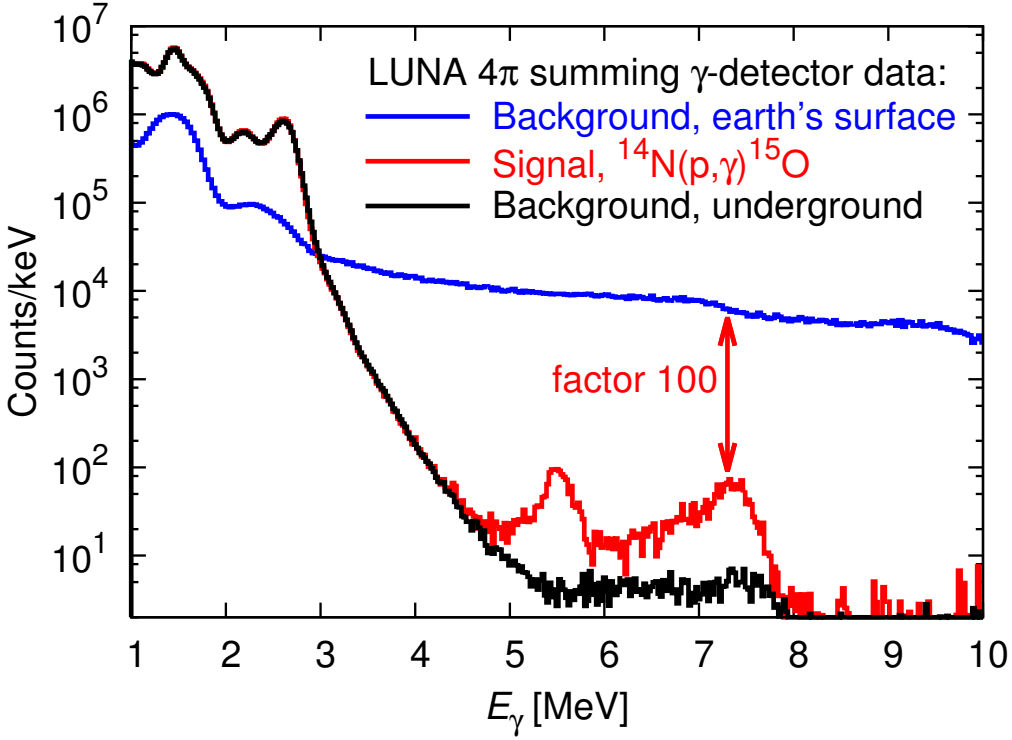
$$N_{\mathrm{A}}\langle\sigma v\rangle \propto \int_0^{\infty} \exp\left[-\frac{E}{k_{\mathrm{B}}T}\right] \exp\left[-\frac{b}{\sqrt{E}}\right] S(E)\,dE$$

$$\frac{S(E)}{E} \exp\left[-\frac{b}{\sqrt{E}}\right]$$

Measuring very small cross sections, two examples



Felsenkeller Dresden



LUNA, below the Gran Sasso mountain, Italy

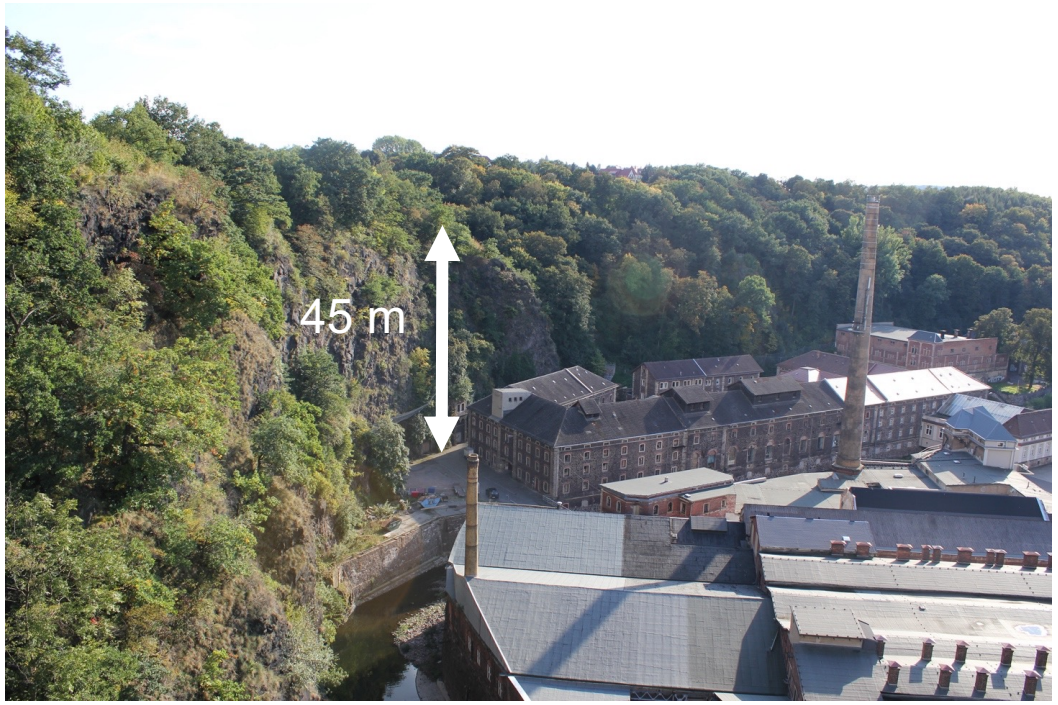
Dresden Felsenkeller underground lab, below 45 m of rock

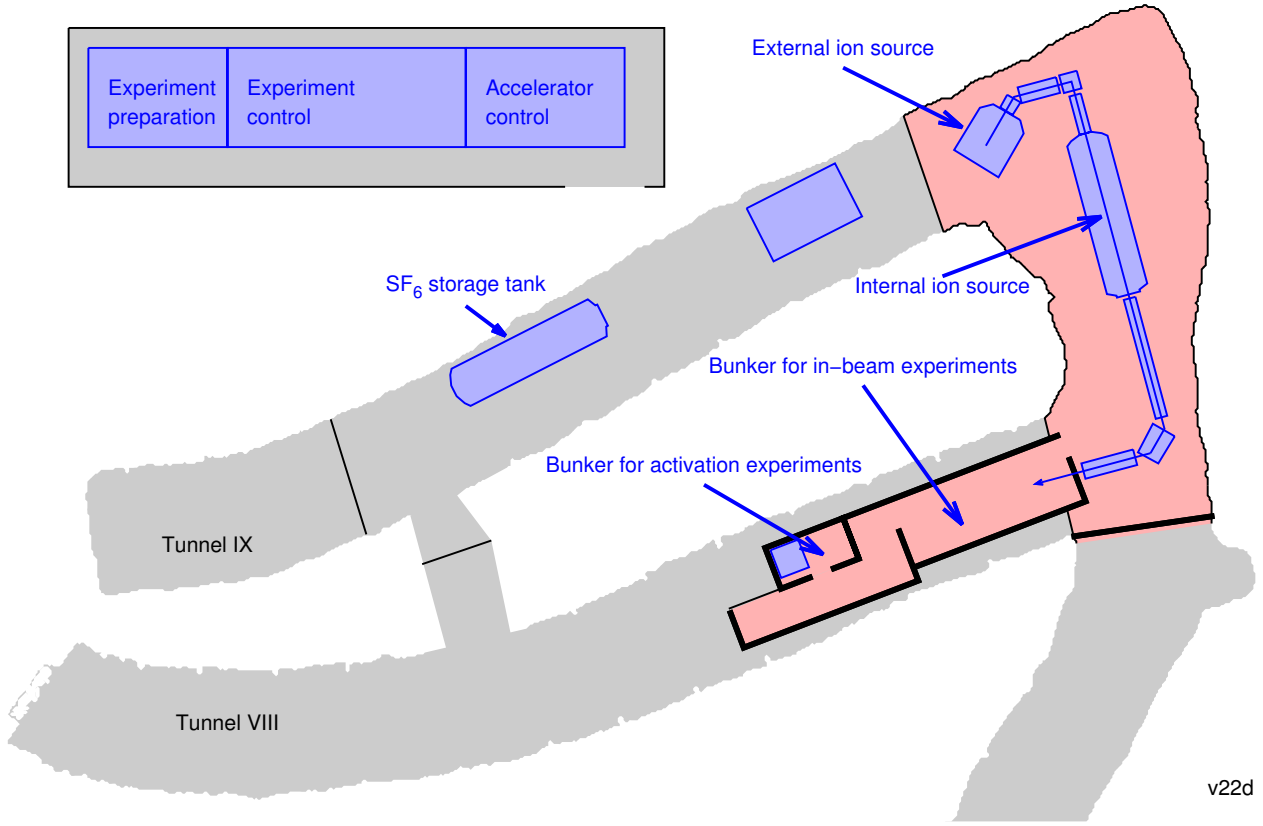
Joint effort HZDR – TU Dresden

- Investment by TU Dresden (Kai Zuber *et al.*) and HZDR (Daniel Bemmerer *et al.*)
- Day to day operations by HZDR

Two main instruments

- **HZDR:** 5 MV Pelletron, 30 µA beams of $^{1}H^{+}$, $^{4}He^{+}$, $^{12}C^{+}$, ...
- **TU Dresden:** 163% ultra-low-background HPGe detector for offline radioactivity measurements

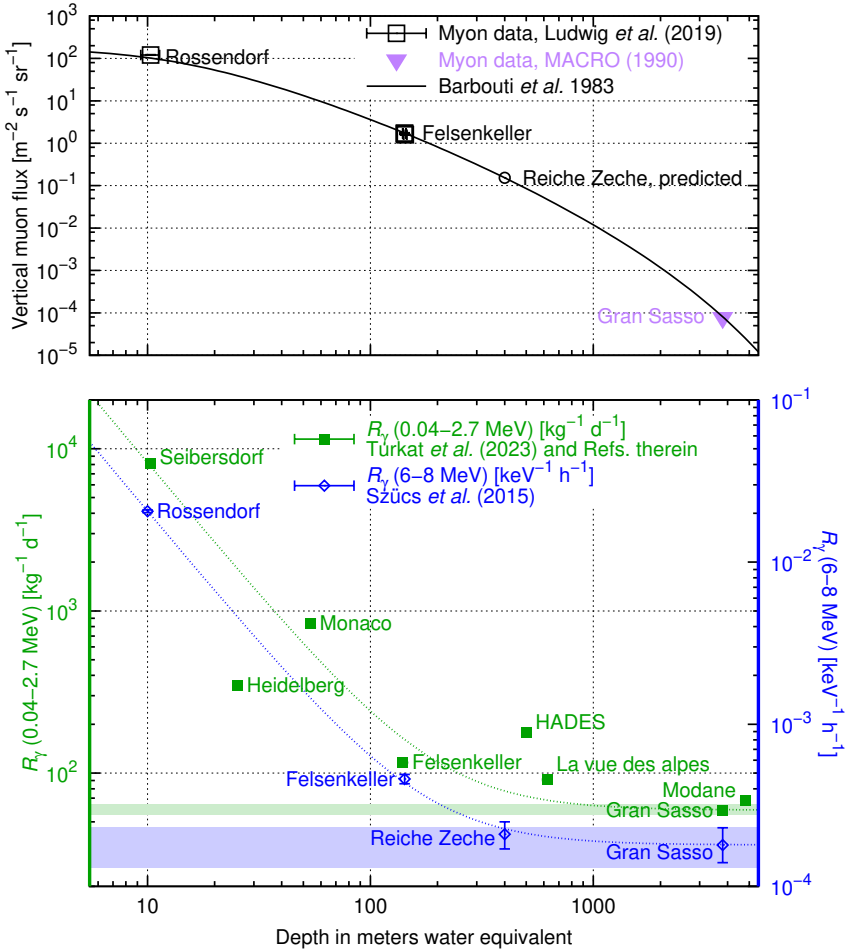




Felsenkeller: Studying low cross sections with low background

40× lower muon background

Astropart. Phys. 112, 24 (2019)

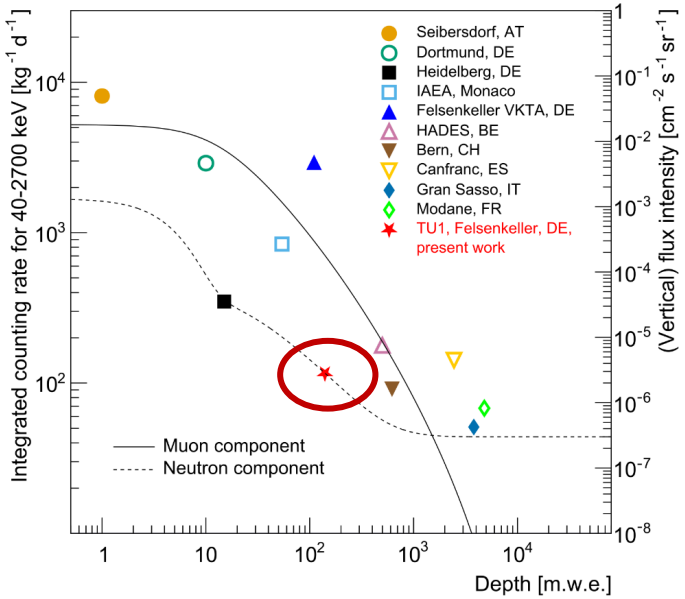


100× lower γ-background

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

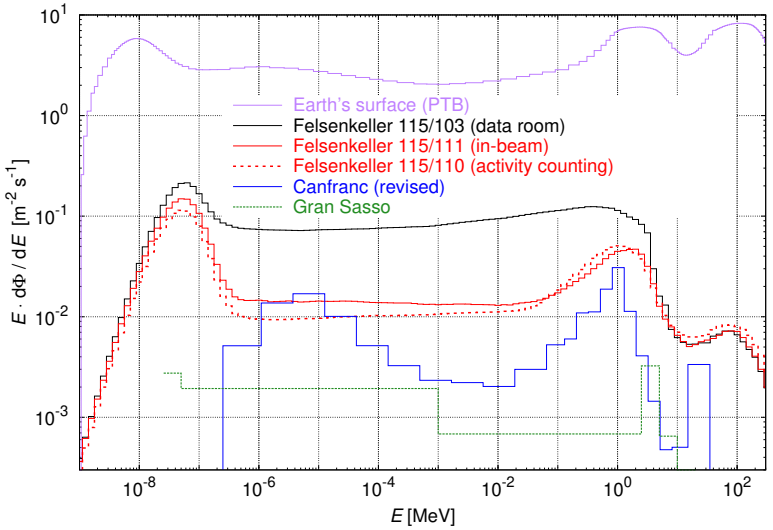
Astropart. Phys. 148, 102816 (2023)

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

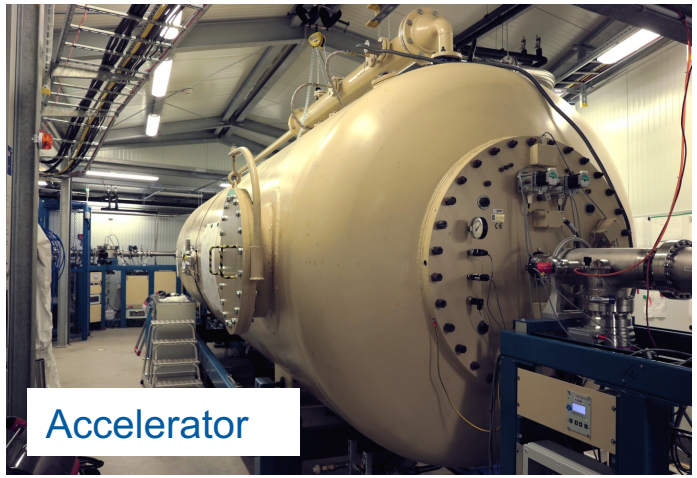


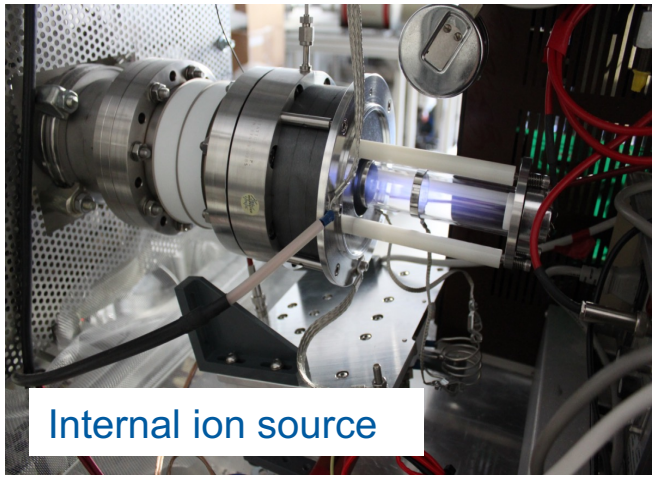
200× lower neutron background

Phys. Rev. D 101, 123027 (2020)

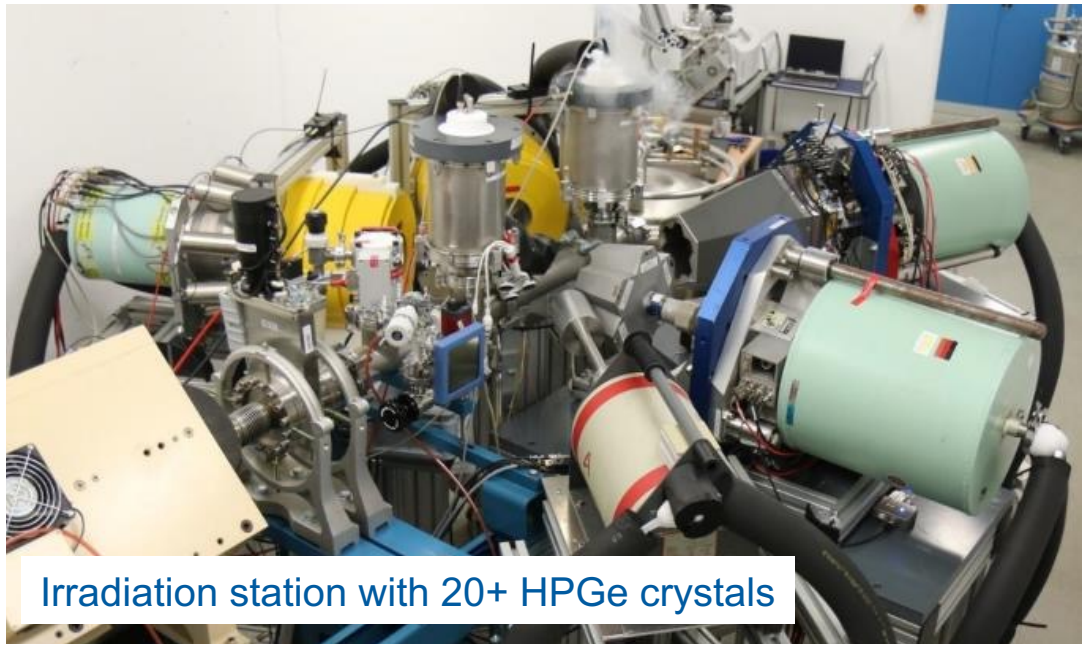


Felsenkeller 5 MV underground ion accelerator


Accelerator


Internal ion source


External ion source

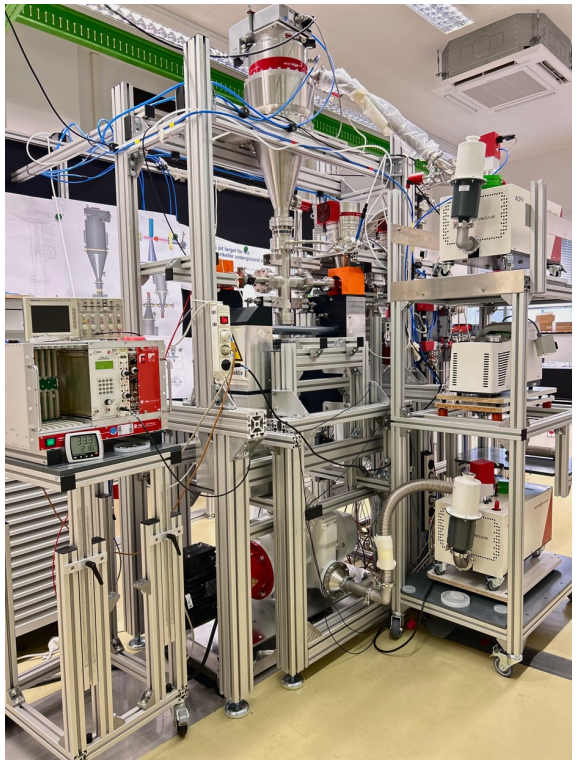

Irradiation station with 20+ HPGe crystals

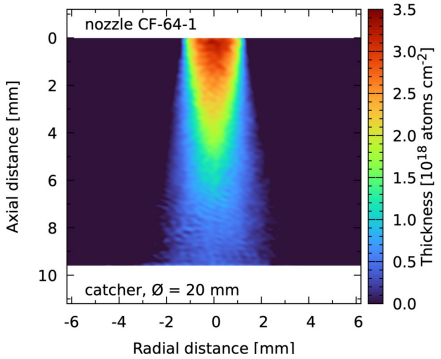
5 MV accelerator (0.4-3.8 MV), two alternative ion sources

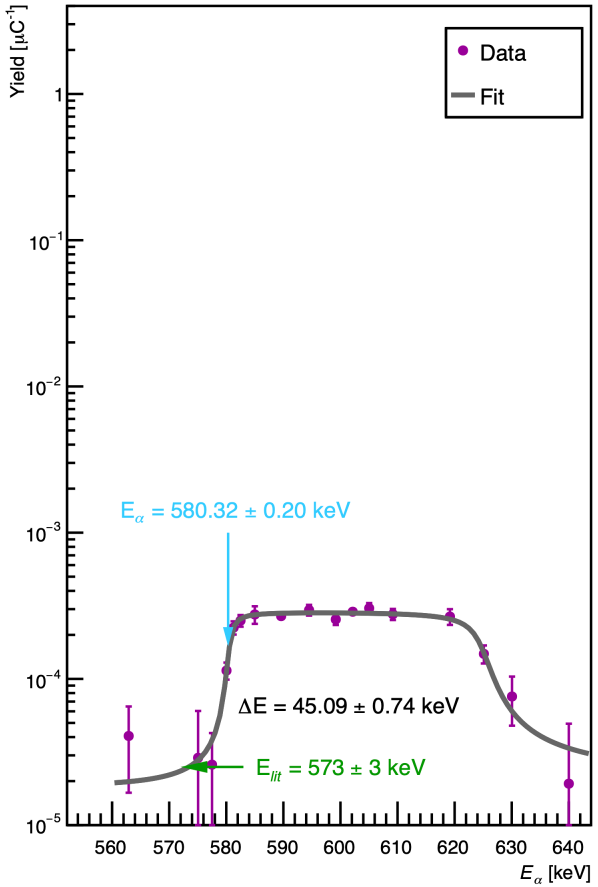
- Internal RF ion source: 30 μA ^{1}H, ^{4}He
- SNICS sputter ion source: 30 μA ^{12}C

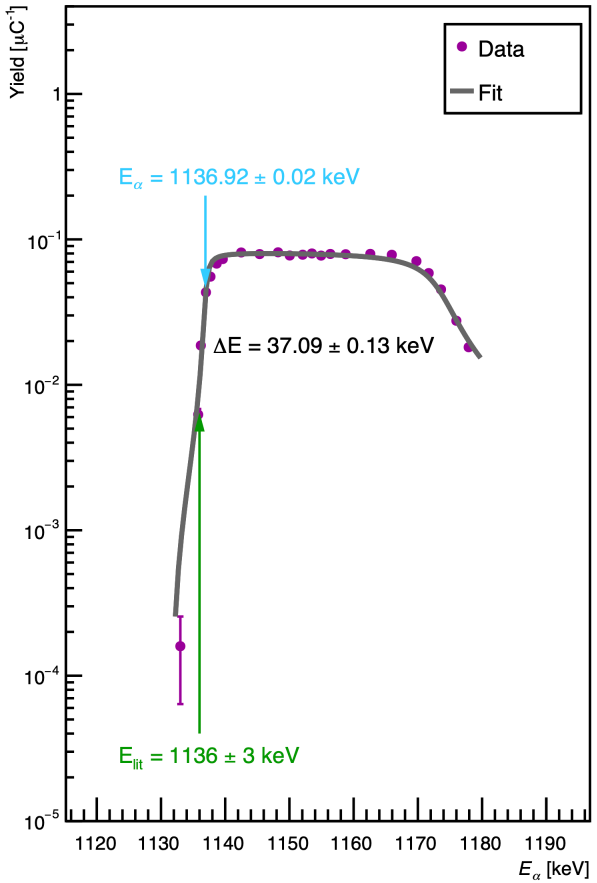
- 24 hour operation permitted even without operator
- Personnel is allowed at target while beam is on
- Control and counting rooms at surface
- EU-supported transnational access 2021-2025

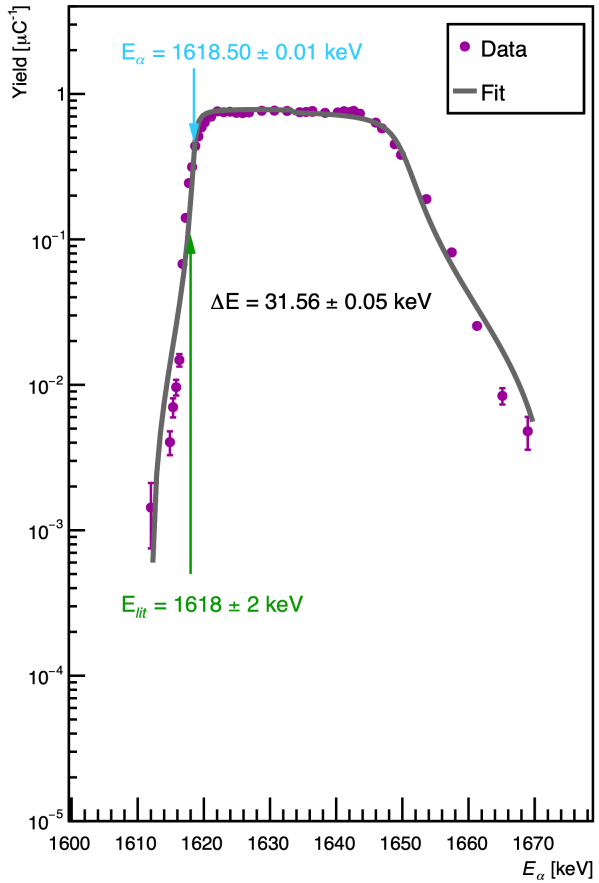
Jet gas target system at Felsenkeller



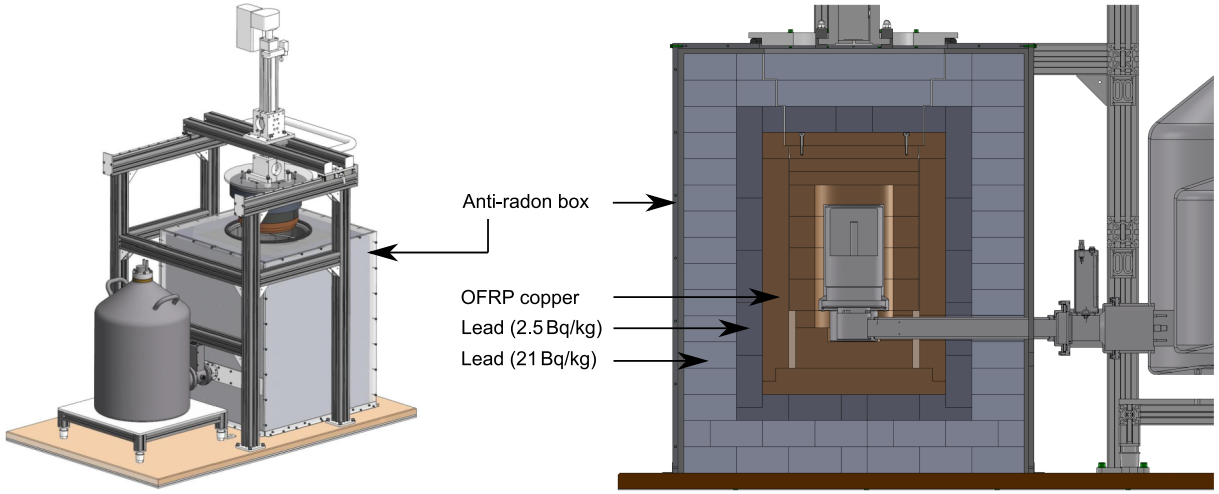


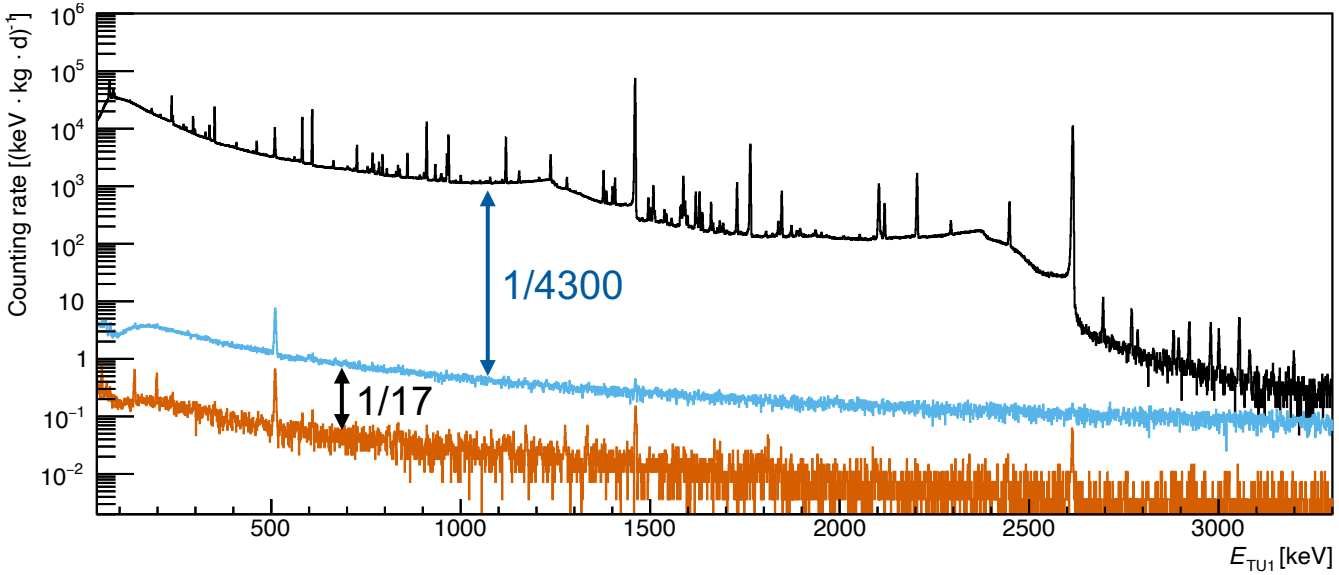


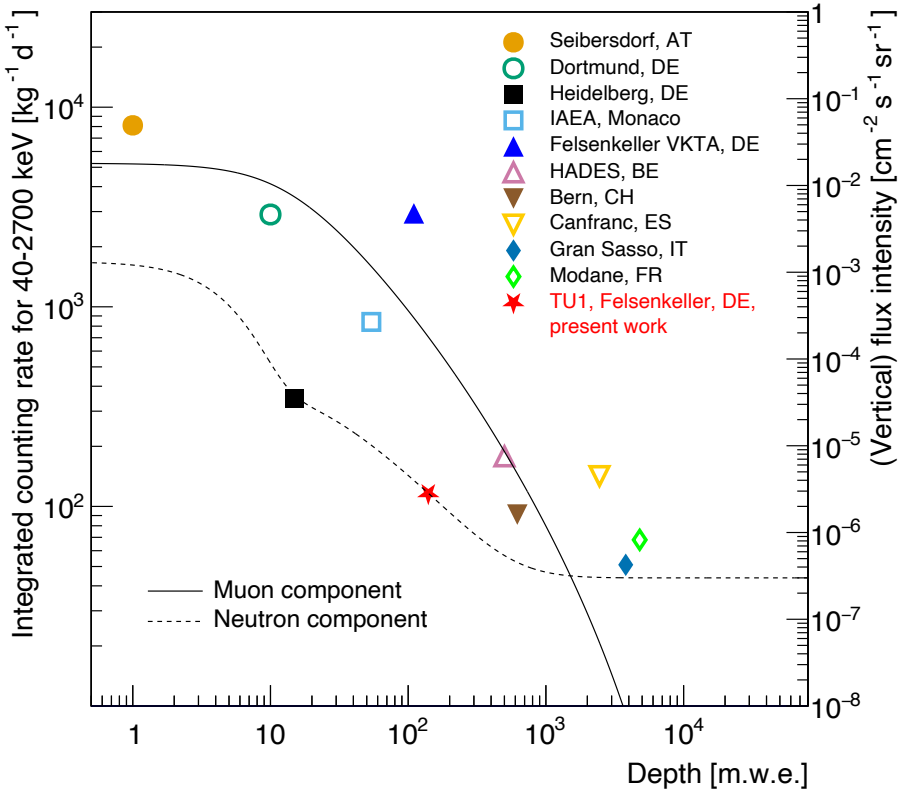




Germany‘s most sensitive radioactivity measurement setup “TU1”







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

The periodic table: Hydrostatic stellar burning

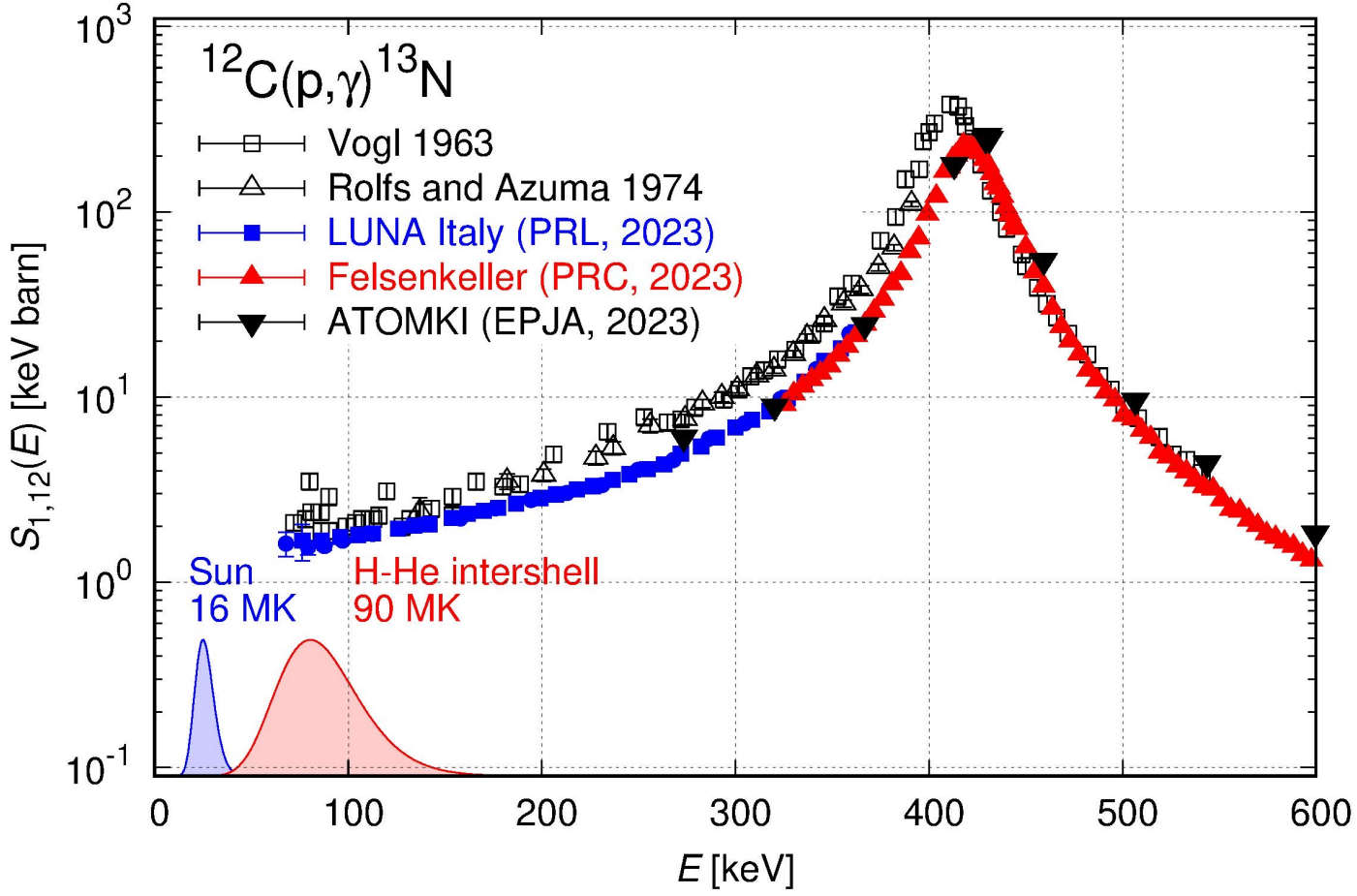
H															He
Li	Be									B	C	N	O	F	Ne
Na	Mg									Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

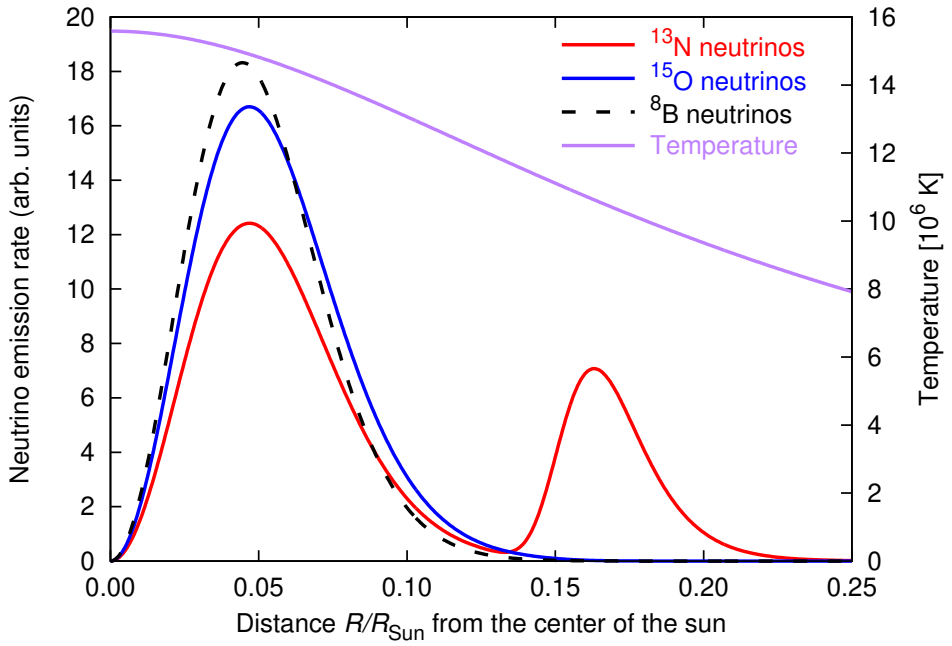
Big Bang

Stellar

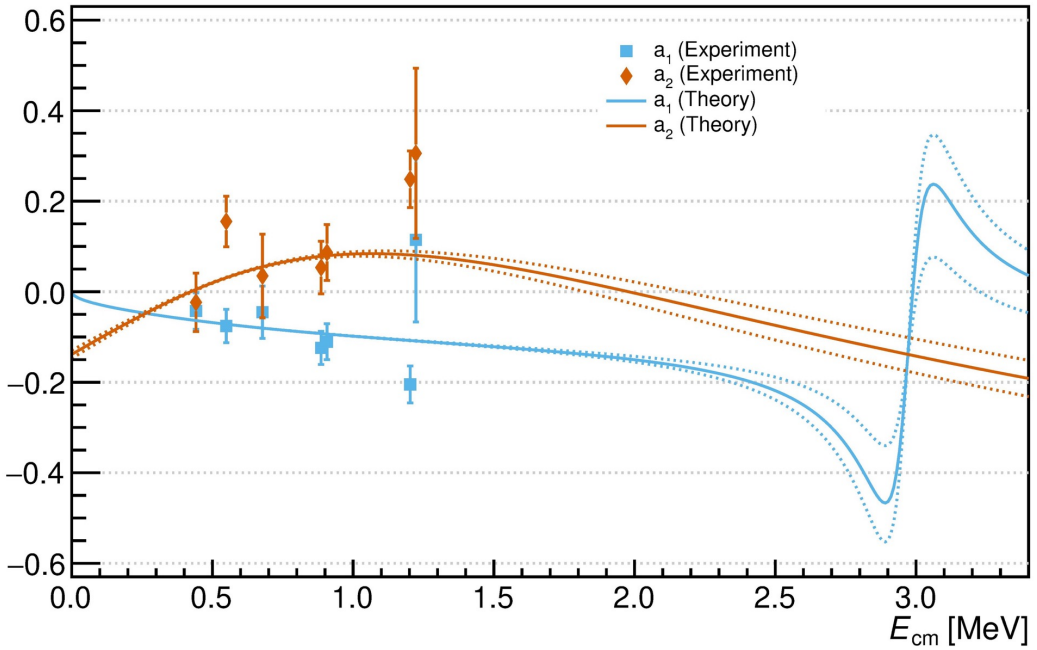
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

Study of the $^{12}C(p,\gamma)^{13}N$ reaction at Felsenkeller and at LUNA



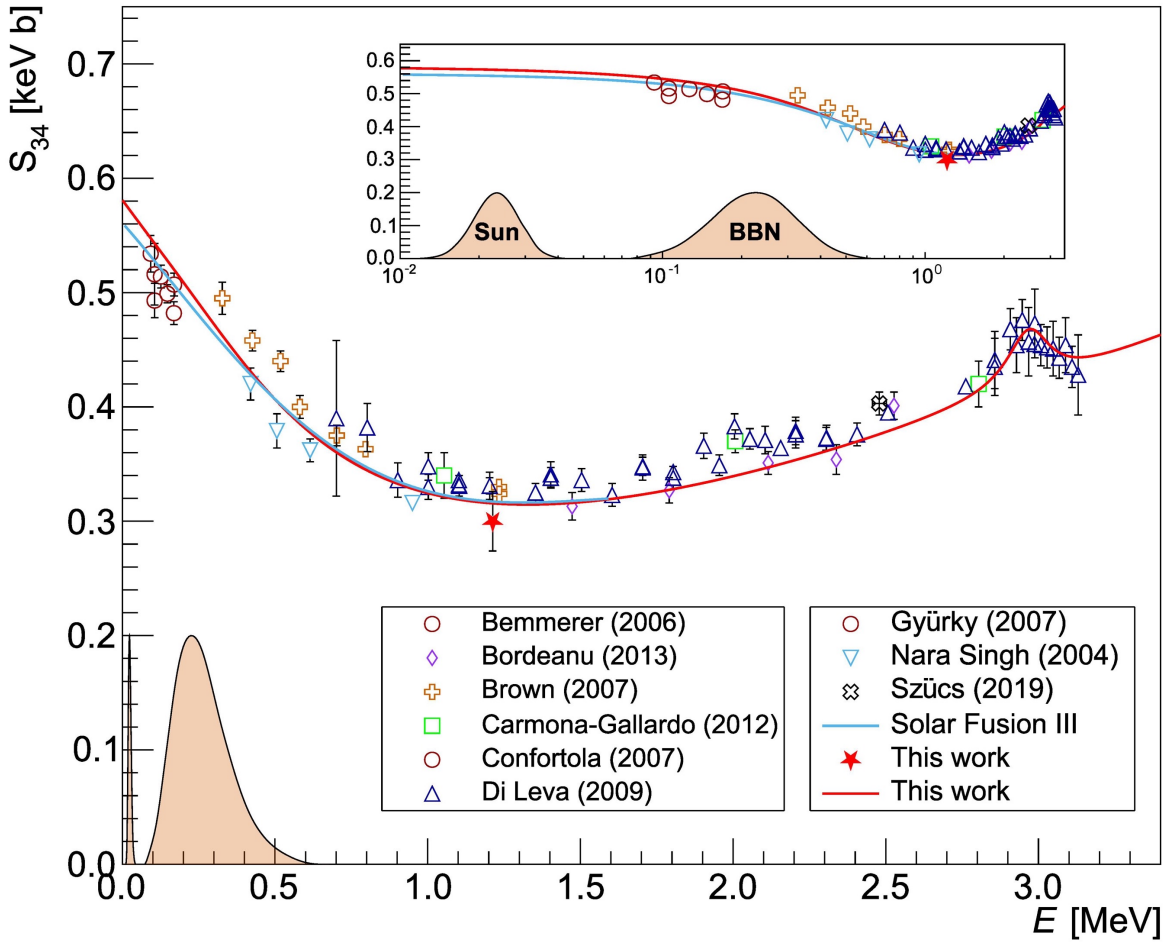


Study of the ^{3}He(α,γ)^{7}Be γ-ray angular distribution at Felsenkeller

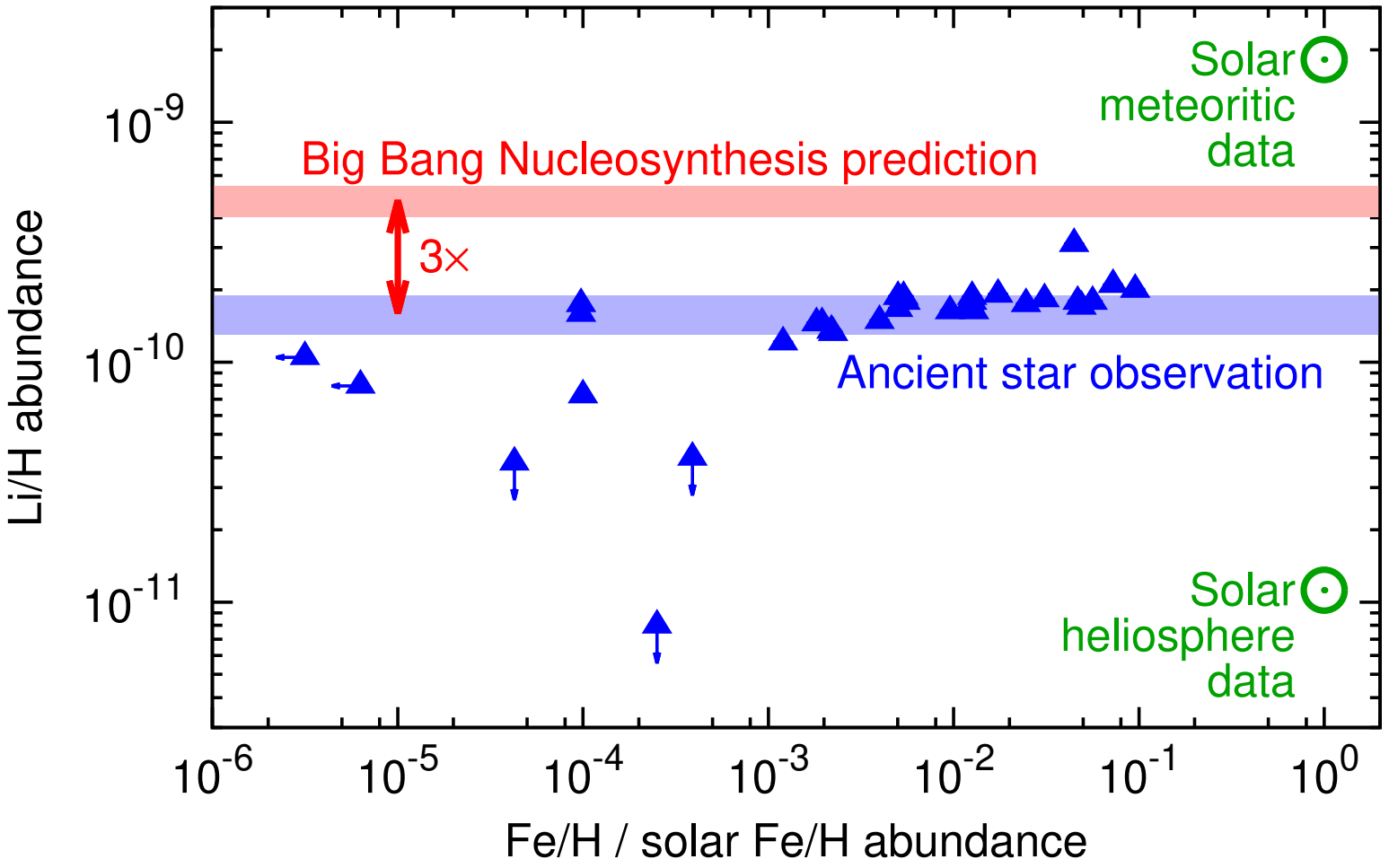


$$\frac{d\sigma}{d\Omega_{\text{c.m.}}} = A_0\left(1+\sum_{l=1}^{3} a_l P_l(\cos\theta_{\text{c.m.}})\right)$$

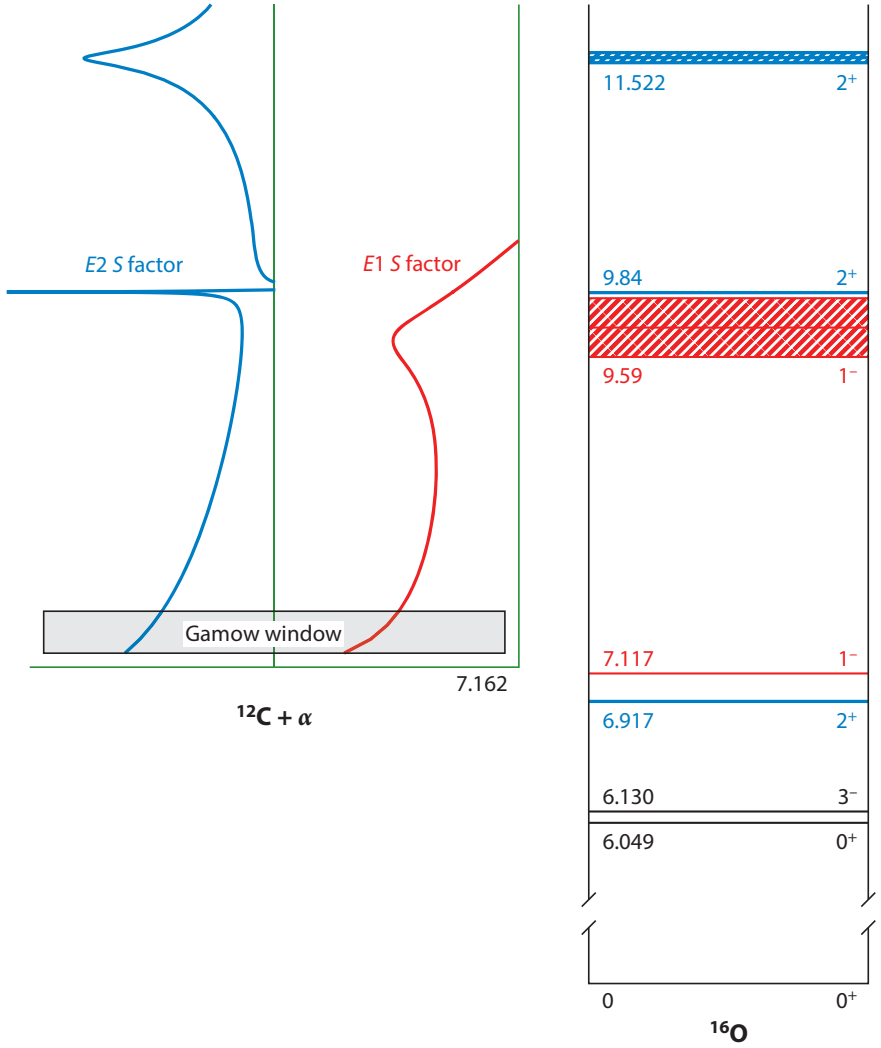
$$= A_0\left(1+\sum_{l=1}^{3} a_l P_l(E_\gamma)\right).$$

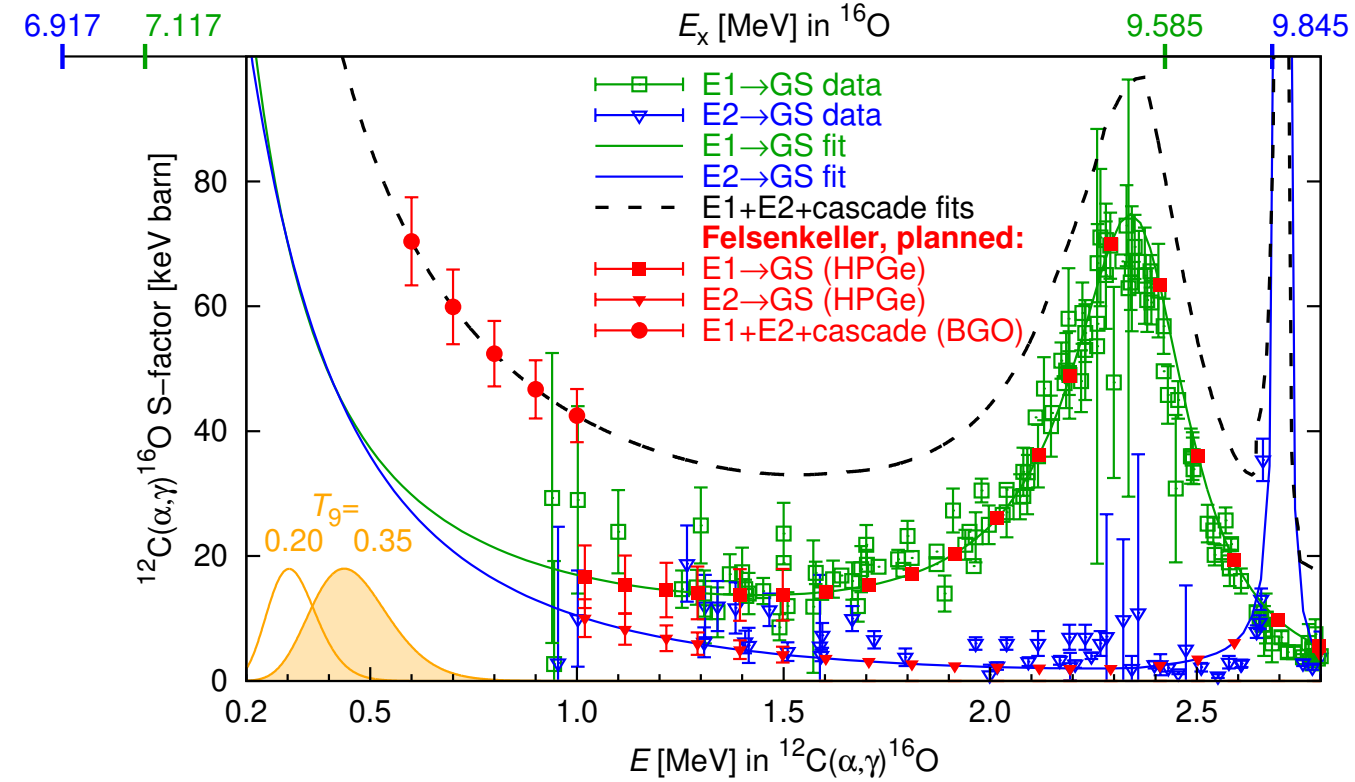


^{7}Be and ^{7}Li – wide scope for future study



Science outlook for Felsenkeller... The long-term goal





- Study of the “holy grail” reaction

Acknowledgments for Felsenkeller

Kai Zuber

The Felsenkeller team

Funding

- Helmholtz NAVI, DTS, MML, ERC-RA
- DFG, DAAD
- TU Dresden Excellence Initiative funds (K. Zuber), DFG Großgerät (K. Zuber)
- European Union ChETEC-INFRA

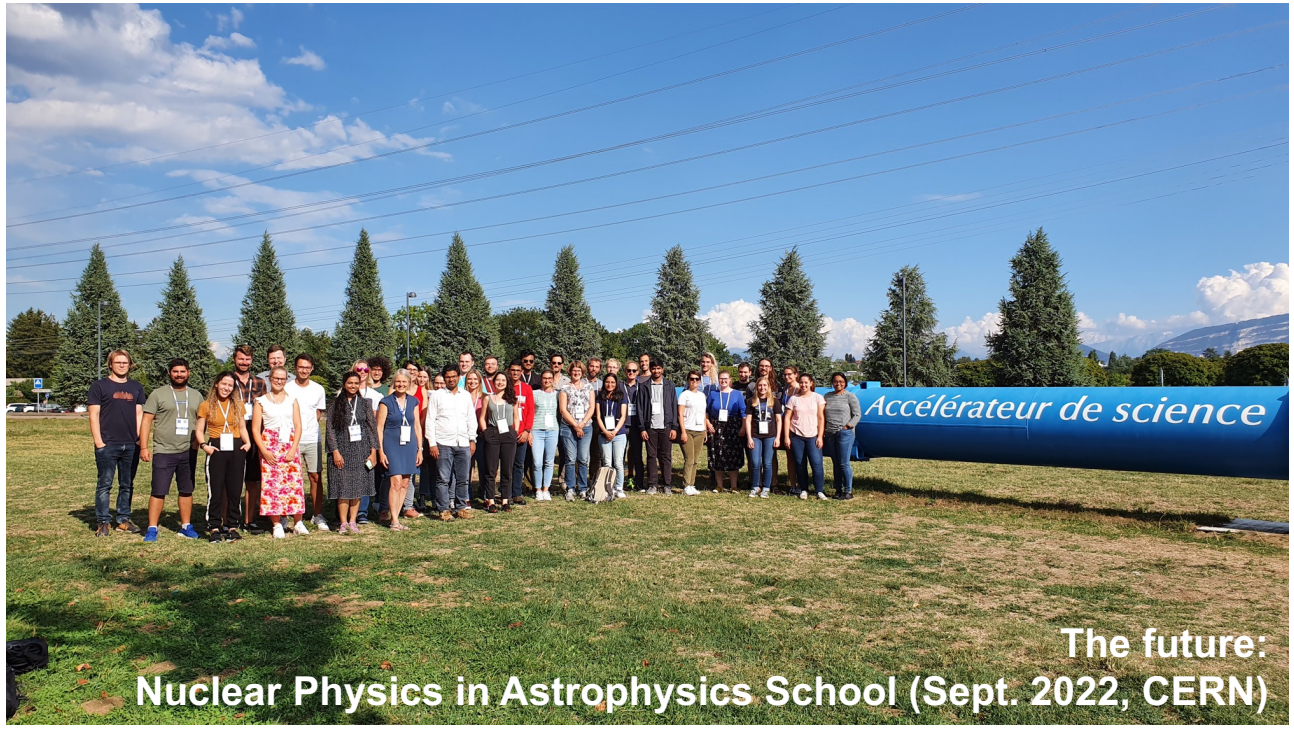
First beam 04.07.2019, T. Kajita

Tom Cowan

HZDR nuclear physics, HZDR ion beam ctr
LUNA & ChETEC-INFRA collaborations
...and many more!

ChETEC-INFRA EU project for nuclear astrophysics [ketek-infra]

The present:
General Assembly (June 2022, Padova)

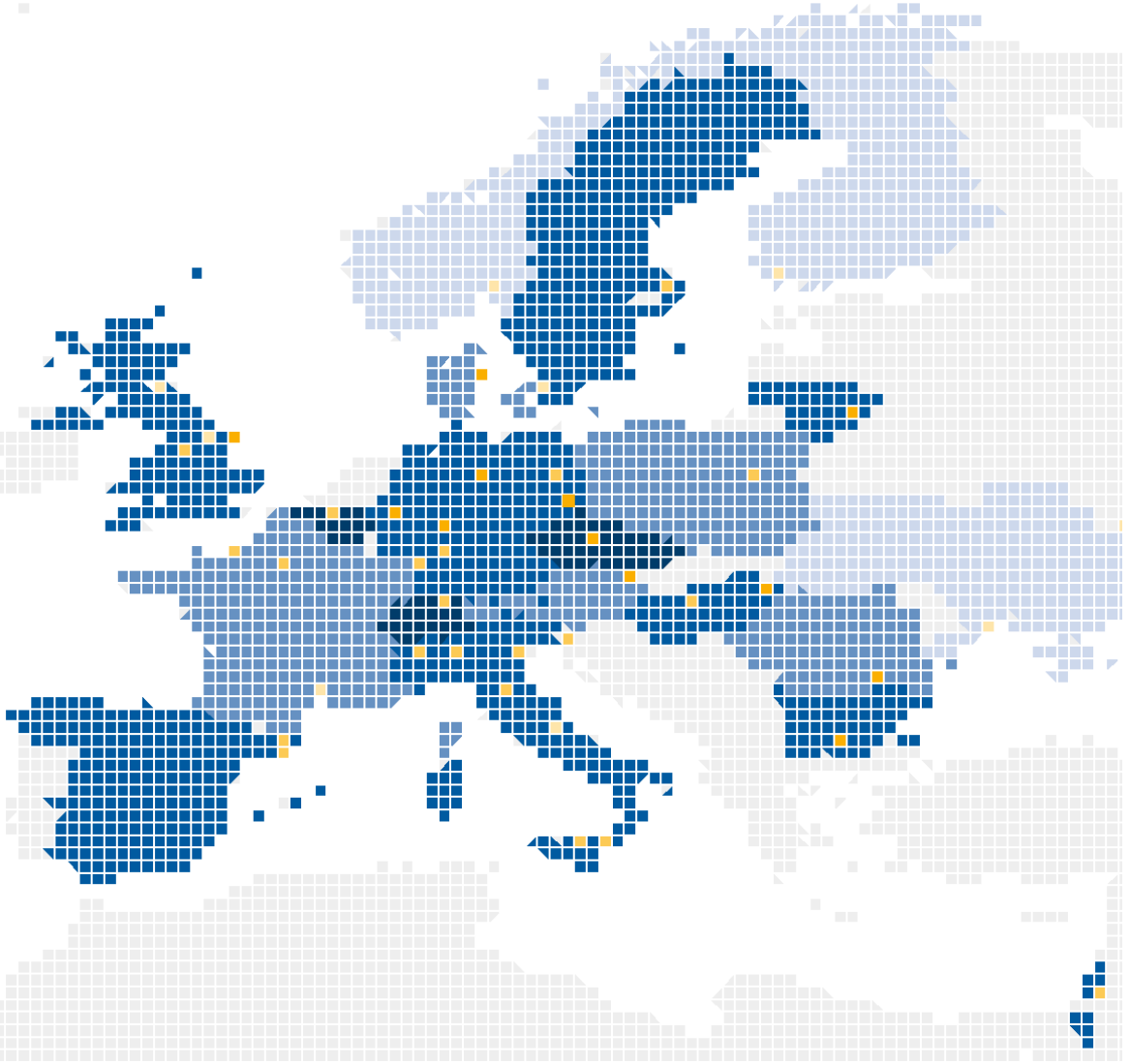


The future:
Nuclear Physics in Astrophysics School (Sept. 2022, CERN)

https://www.chetec-infra.eu

- **Starting Community** of research infrastructures
- **32 partners** in 17 EU+ countries
- 2021 – 2025
- 5 M€ support by EU

31 partners in ChETEC-INFRA



14 research infrastructures made accessible by ChETEC-INFRA

HZDR Felsenkeller Underground / DE

HZDR DREAMS AMS / DE

Vienna University VERA AMS / AT

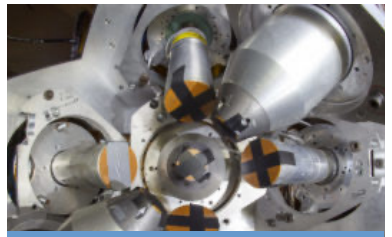
IANAO National Astronomical Observatory / BG

ASU Perek Telescope / CZ

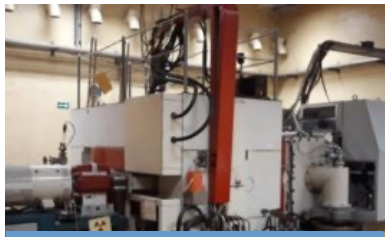
Nordic Optical Telescope La Palma / ES (Arhus / DK)

Frankfurt University van de Graaf n-source / DE

PTB Ion Accelerator Facility / DE



University of Cologne 10 MV Tandem / DE



ATOMKI Cyclotron / HU

laboratories

supercomputers

telescopes

Vilnius University Moletai Astronical Observatory / LT

IFIN-HH 3 MV Tandetron accelerator / RO

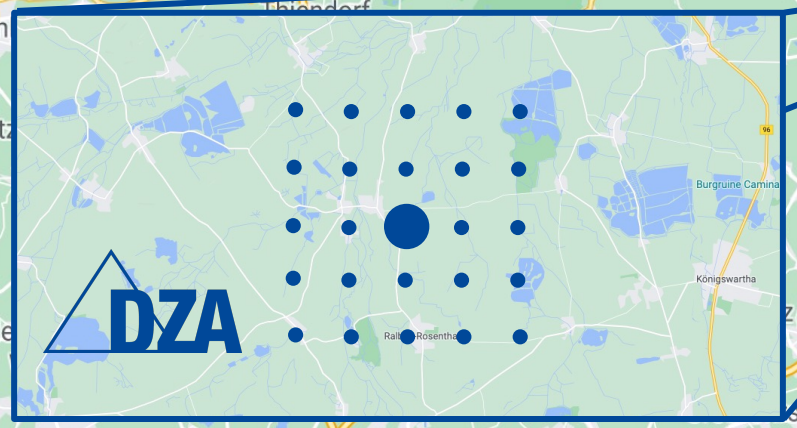
Hull University VIPER cluster

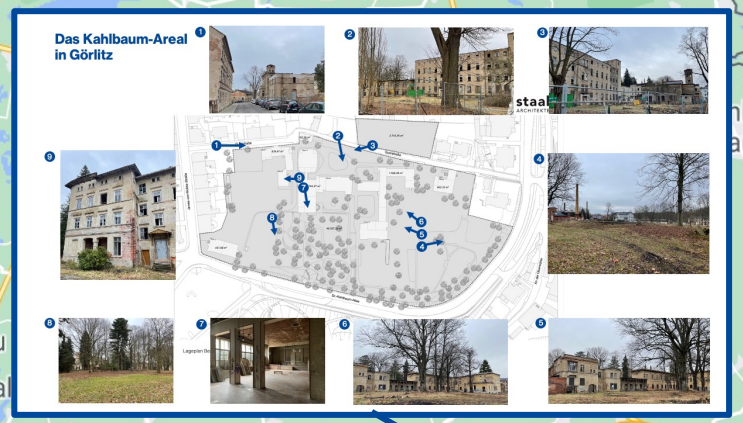
Bellotti IBF, IT
Underground ion accelerator

Courtesy Christian Stegmann / DESY

Eine Region für Astrophysik, Technologie und Digitalisierung

Möglicher Standort des Einstein-Teleskop mit dem unterirdischen Low-Seismic-Lab





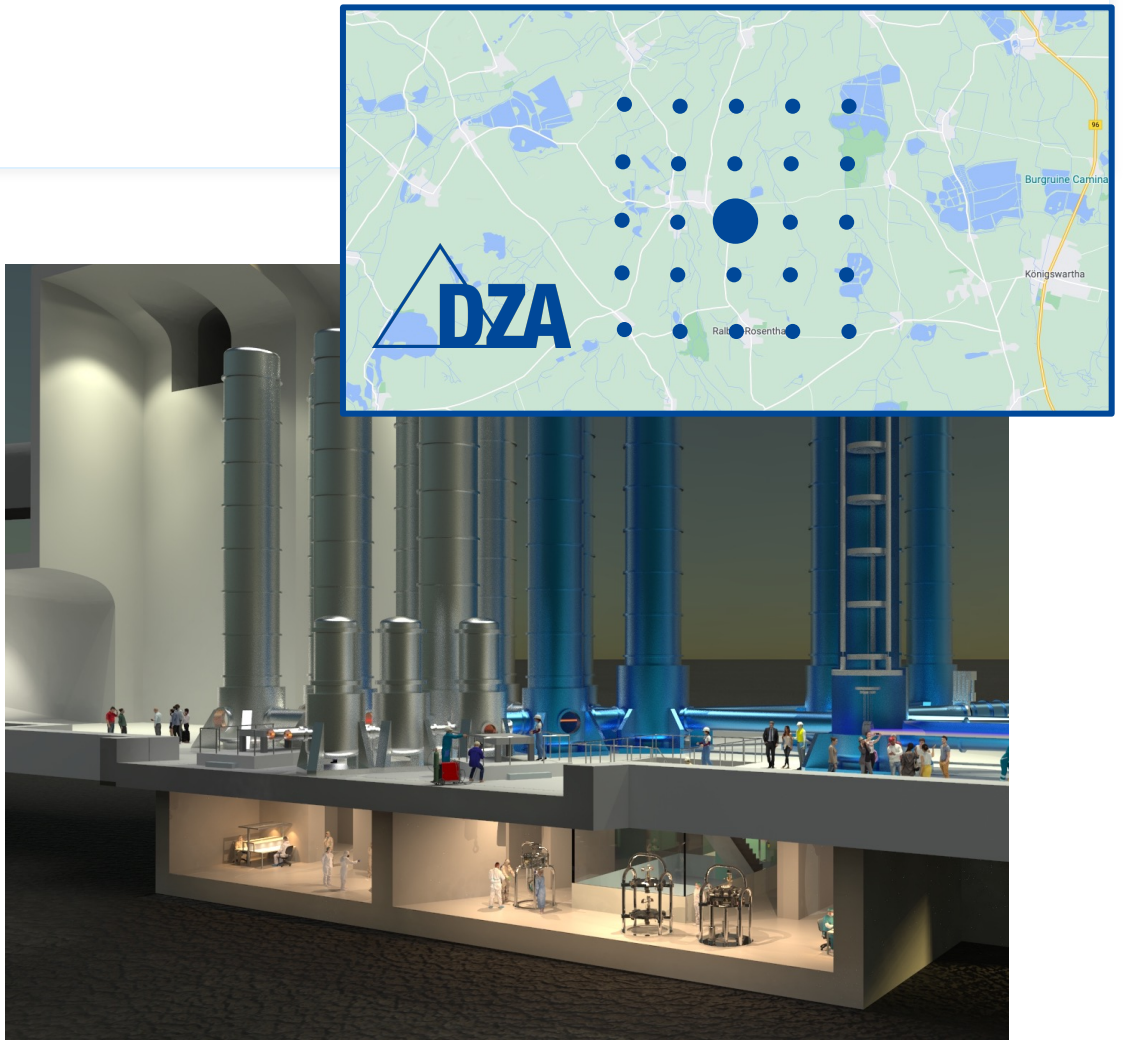
Ein Zentrum für Astrophysik mit fortschrittlicher Computertechnik und Technologieentwicklung

DZA

TECHNISCHE UNIVERSITÄT DRESDEN

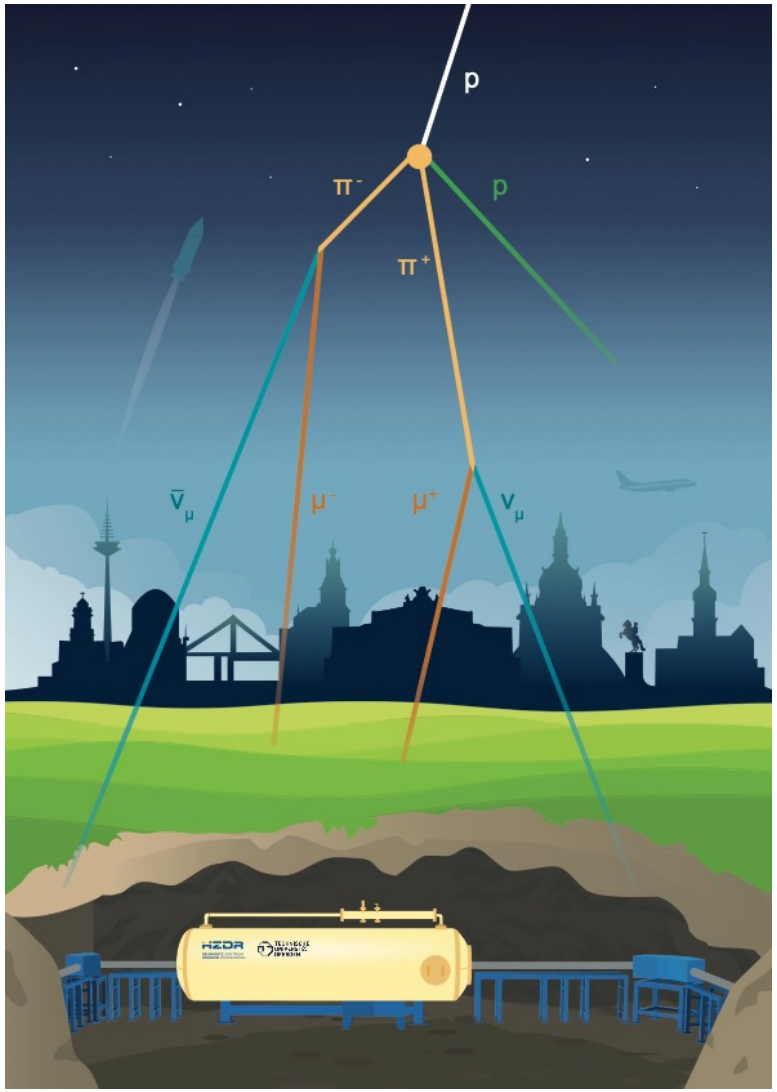
Das Low-Seismic-Lab

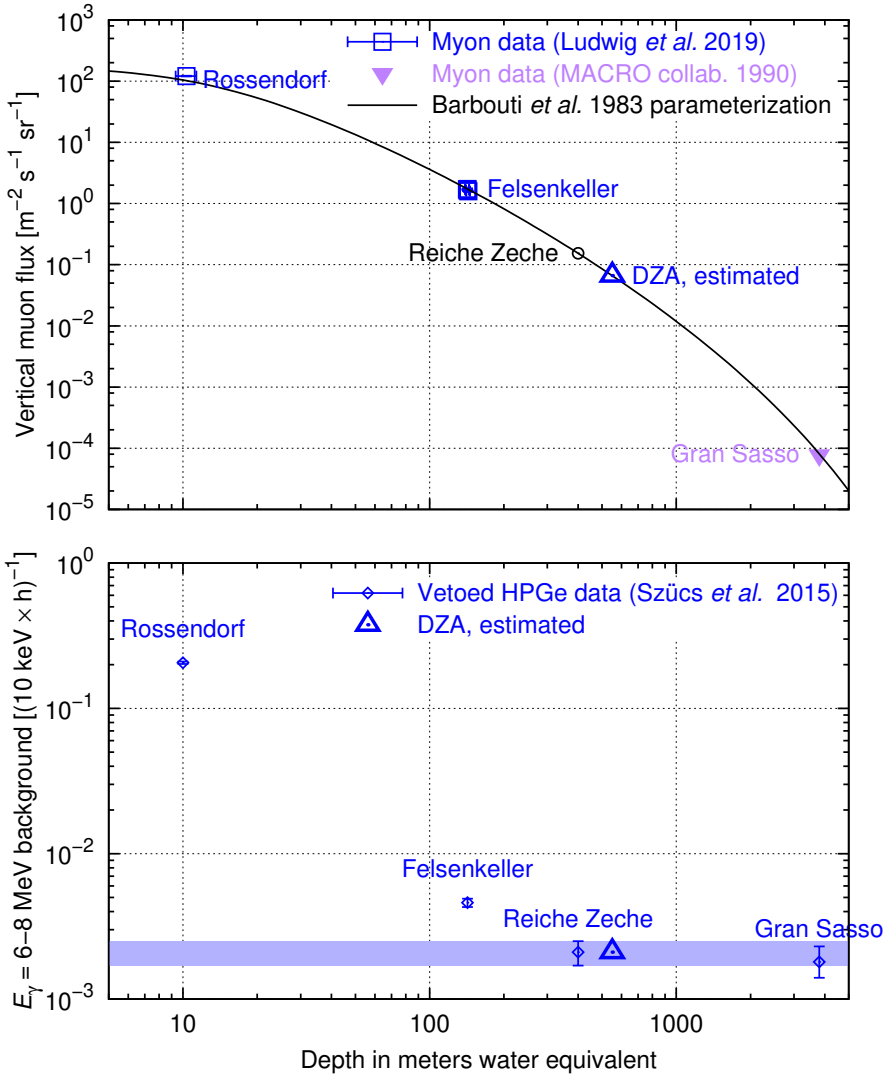
- Technologieentwicklung für die Gravitationswellenastronomie
- Adaptive seismische Rauschunterdrückung
- Sub-Nanometer-Mikroskopie und Photolithographie
- Astrophysik mit Beschleunigern

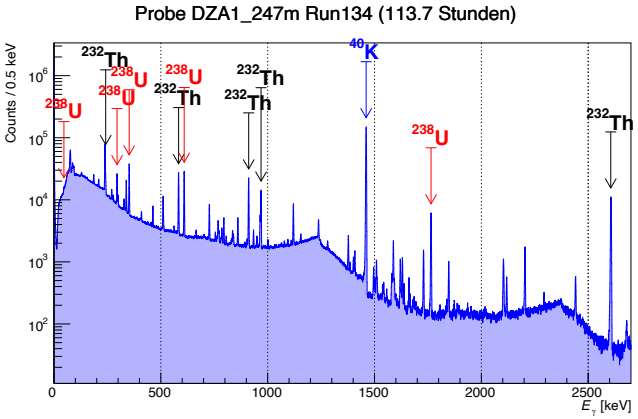


Courtesy Christian Stegmann / DESY

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







Nuclear astrophysics: The Felsenkeller lab in Dresden

H															He
Li	Be									B	C	N	O	F	Ne
Na	Mg									Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Big Bang
Cosmic
Stellar
r-process
s-process

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

Further contributions: p-, i-, rp-, ν-processes