



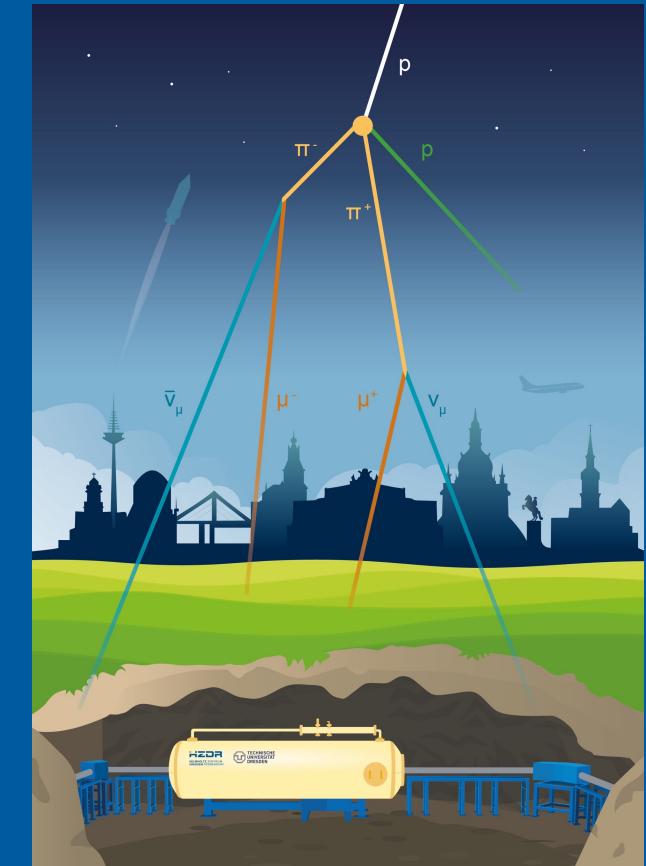
This project has received funding from
the European Union's Horizon 2020
research and innovation programme
under grant agreement No 101008324
(ChETEC-INFRA).



Nuclear astrophysics: The Felsenkeller lab in Dresden

German-Georgian Science Bridge
Dresden, 21.08.2025

Prof. Dr. Daniel Bemmerer
Helmholtz-Zentrum Dresden-Rossendorf



Nuclear astrophysics: The Felsenkeller lab in Dresden

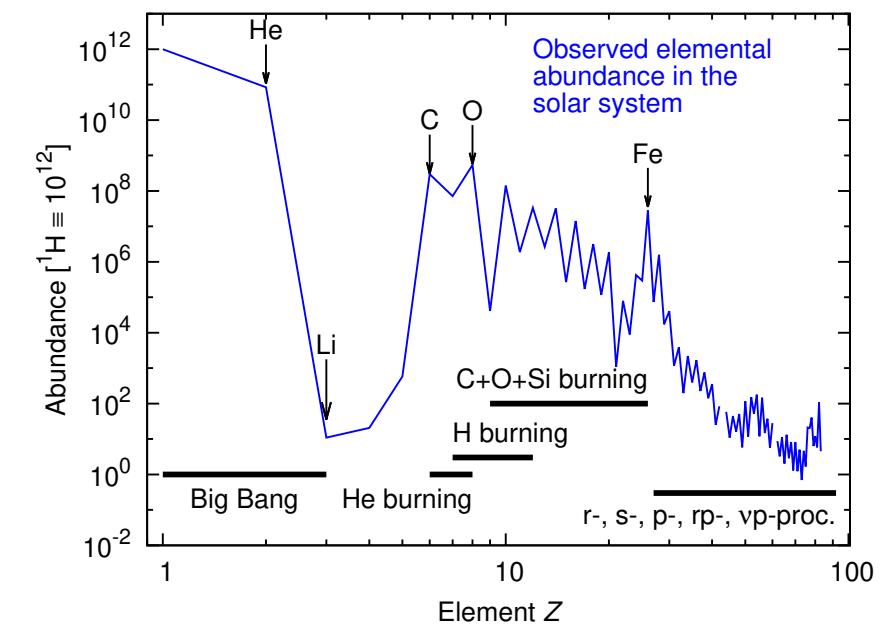
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Li	Be	
Na	Mg	
K	Ca	Sc
Rb	Sr	Y
Cs	Ba	La
Fr	Ra	Ac

He		
B	C	N
Al	Si	P
Si	S	Cl
O		F
Ne		Ar
He		
Ti	V	Cr
Mn	Fe	Co
Ni	Cu	Zn
Ga	Ge	
As	Se	Br
Se		Kr
Br		
Kr		
Zr	Nb	Mo
Tc	Ru	Rh
Pd	Ag	Cd
In	Sn	
Sn	Sb	Te
Sb	Te	I
Te		Xe
I		
Xe		
Hf	Ta	W
Re	Os	Ir
Pt	Au	Hg
Tl	Pb	
Pb	Bi	Po
Bi	Po	At
Po	At	Rn
At		
Rn		

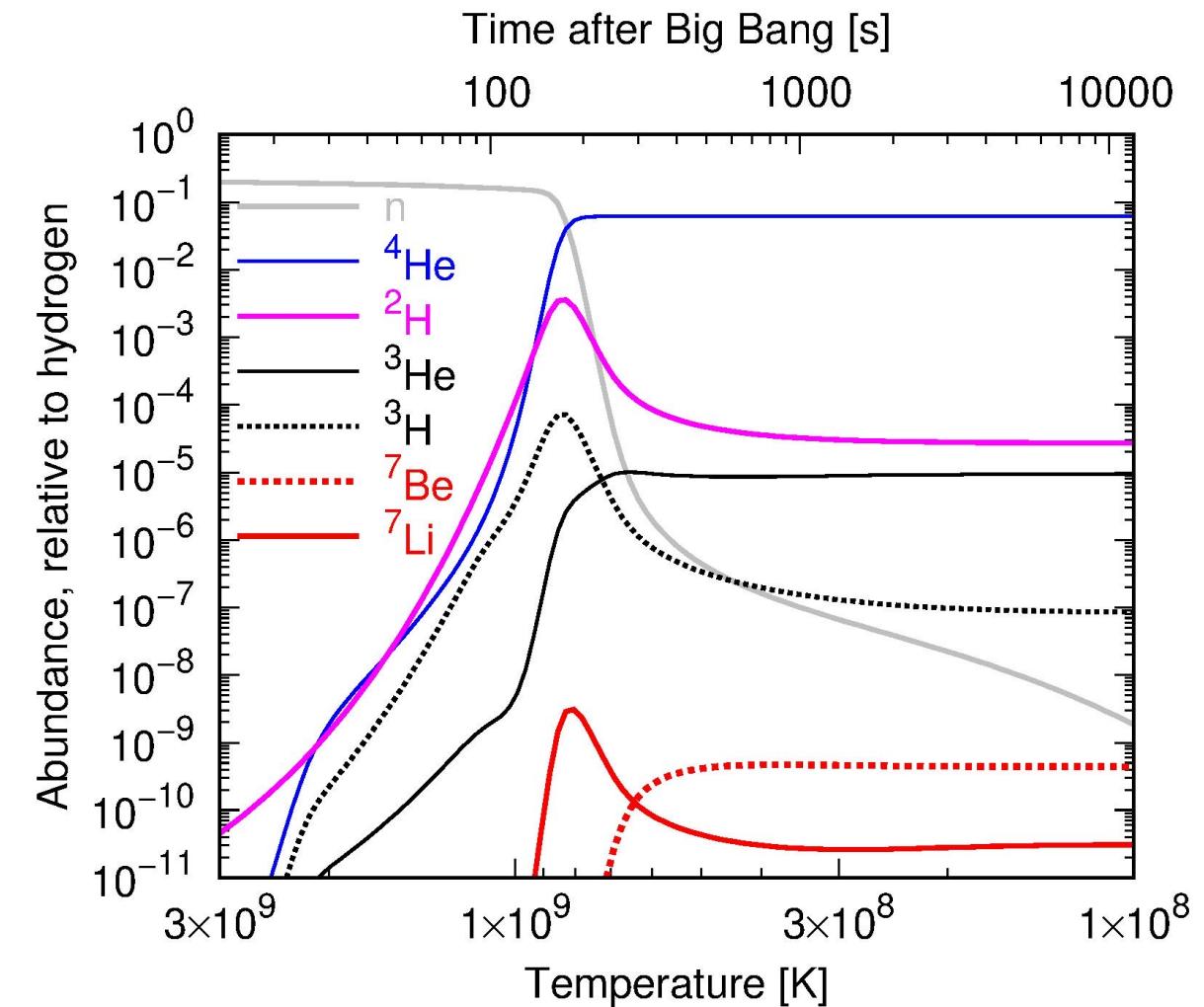
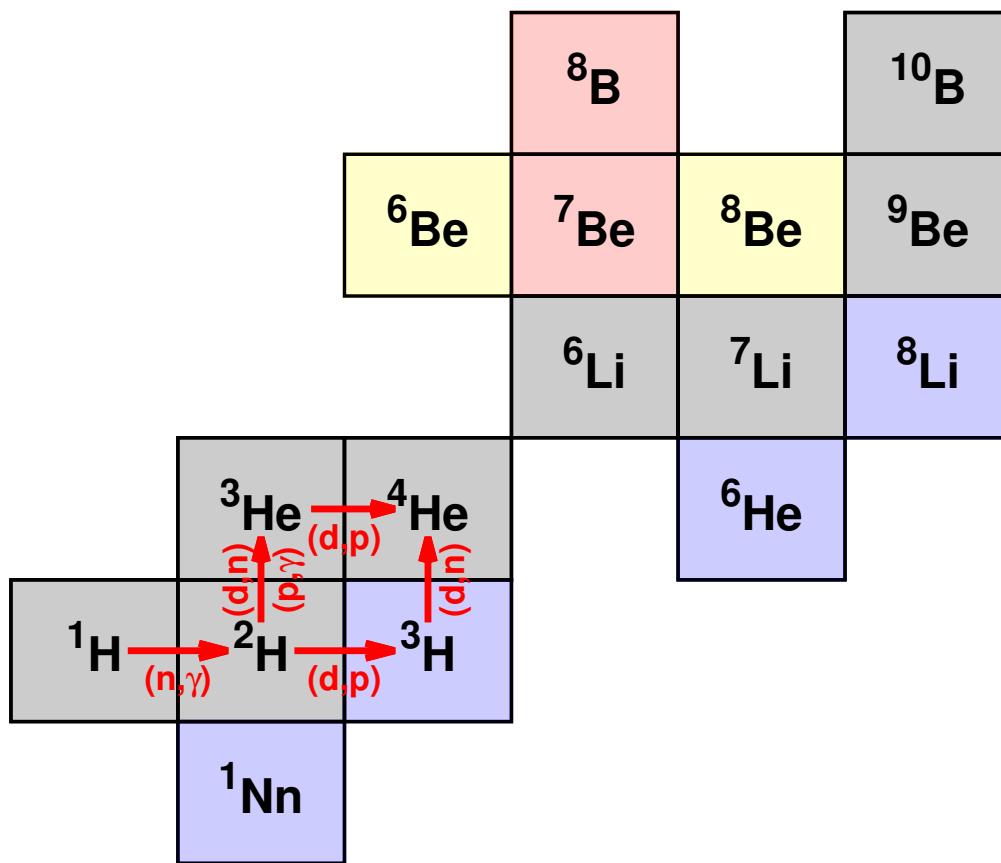
Big Bang
Cosmic
Stellar
r-process
s-process

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

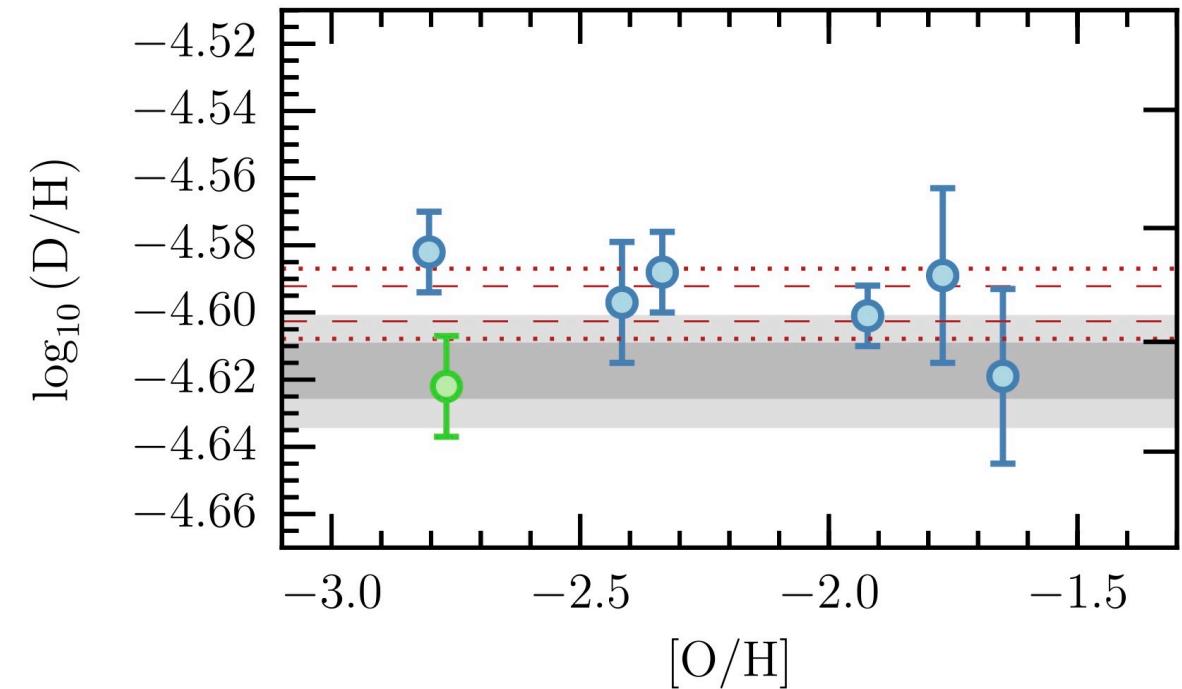
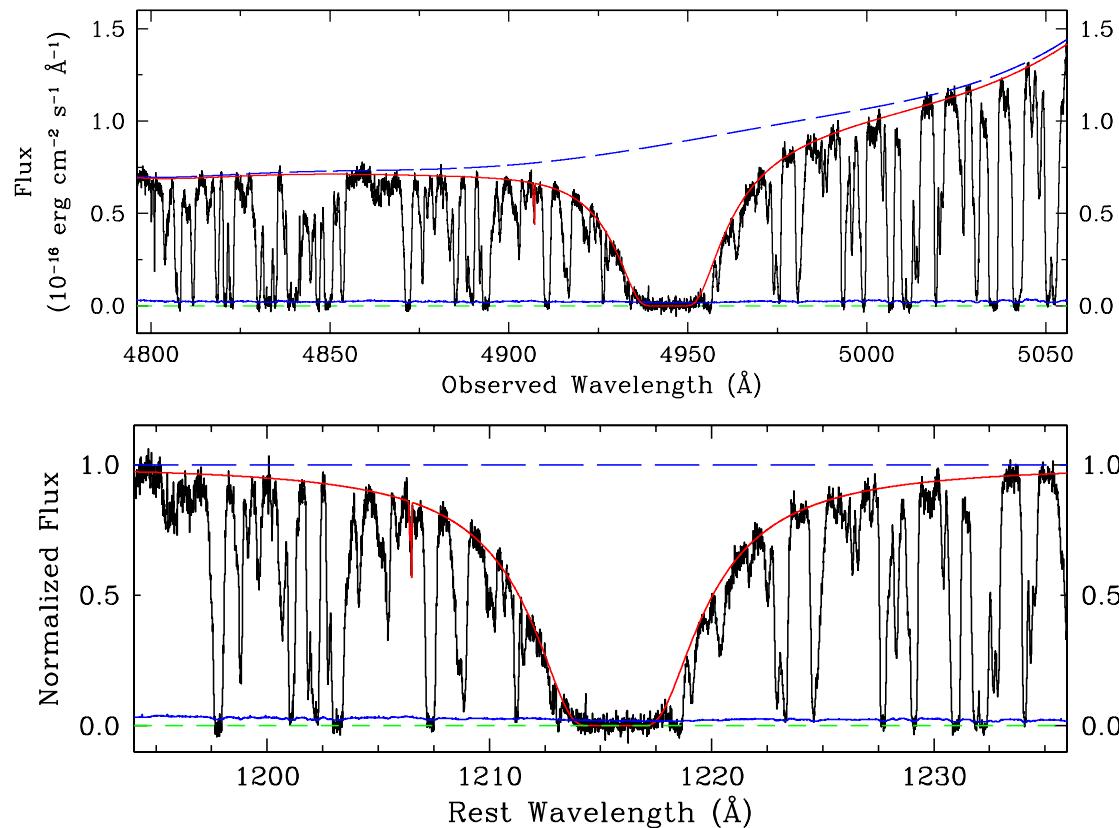
Further contributions: p-, i-, rp-, v-processes



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

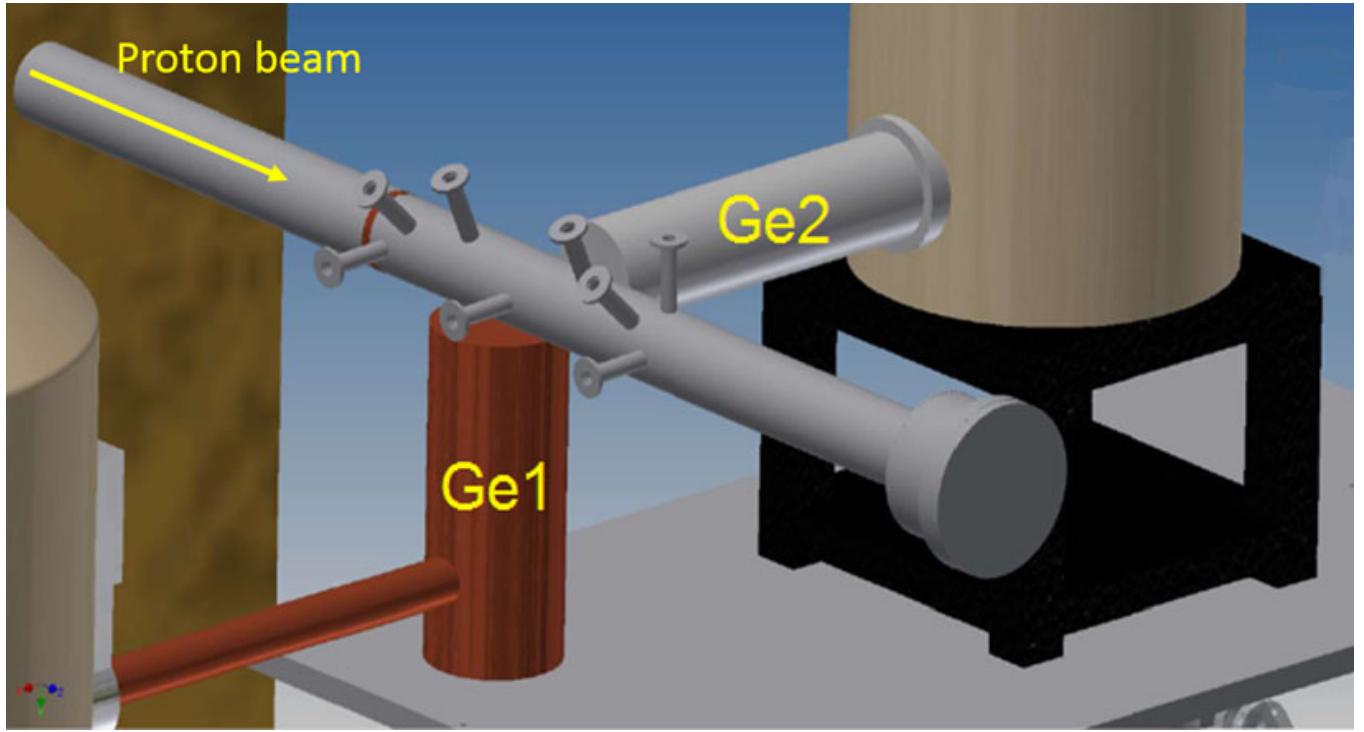


Big Bang Nucleosynthesis (BBN) and ^2H (D) as a cosmological probe



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

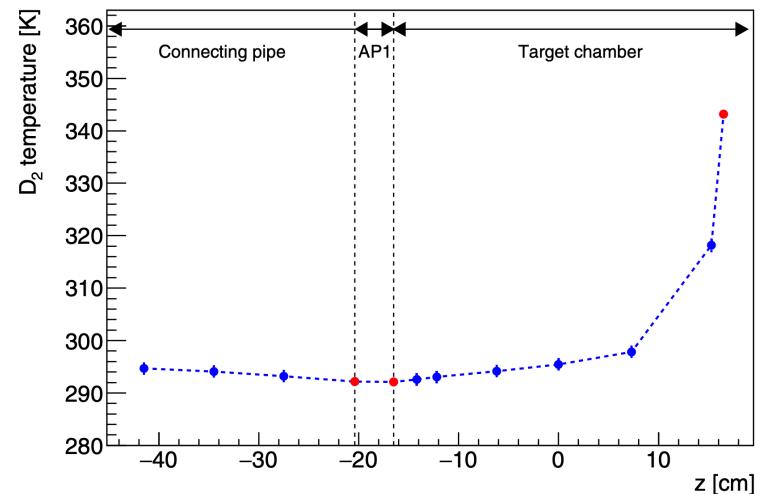
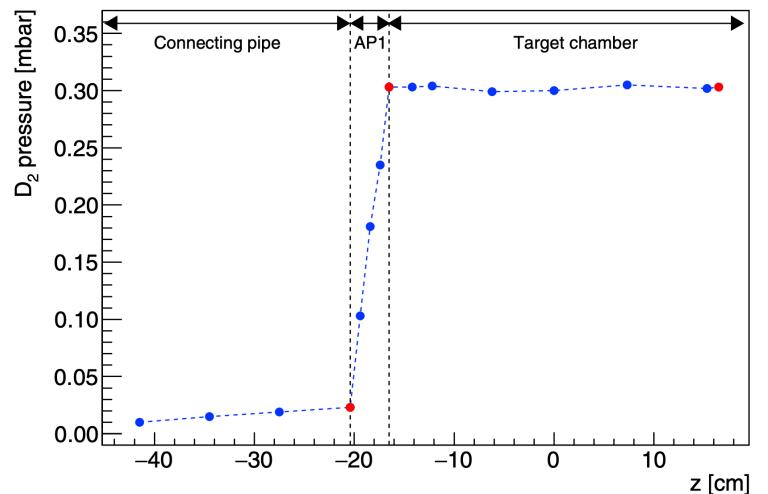
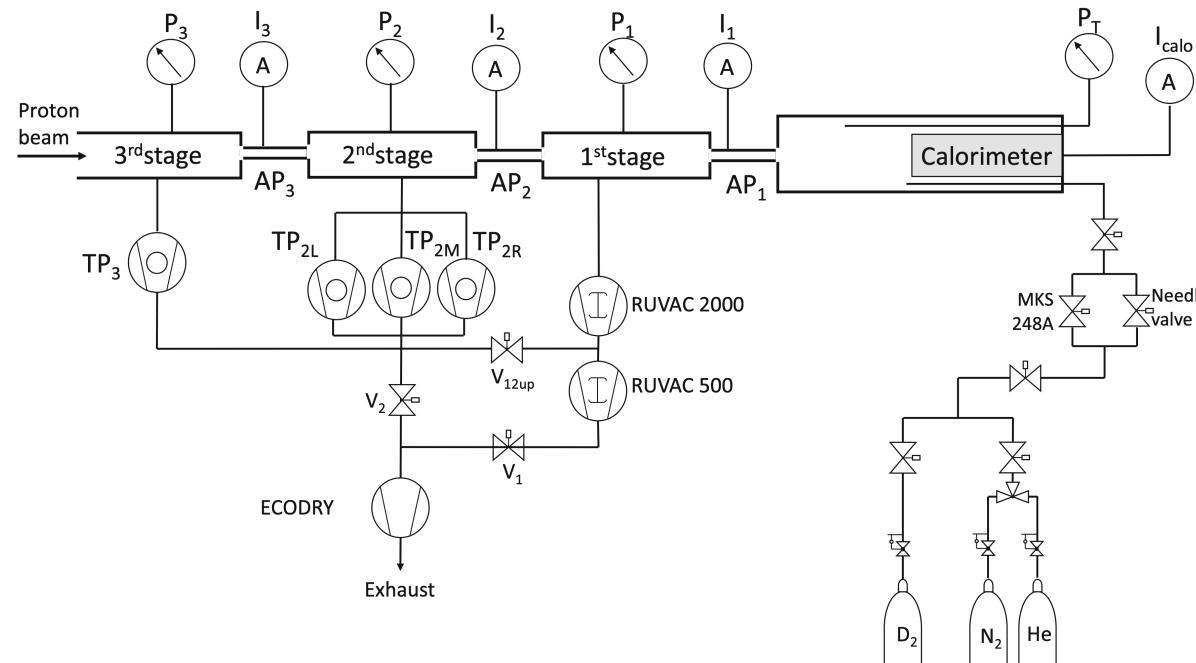
Big Bang Nucleosynthesis (BBN) and ^2H (D) as a cosmological probe



Mossa *et al.* (LUNA), Nature 587, 210 (2020)

K. Stöckel *et al.* (LUNA), Phys. Rev. C 110, L032801 (2024)

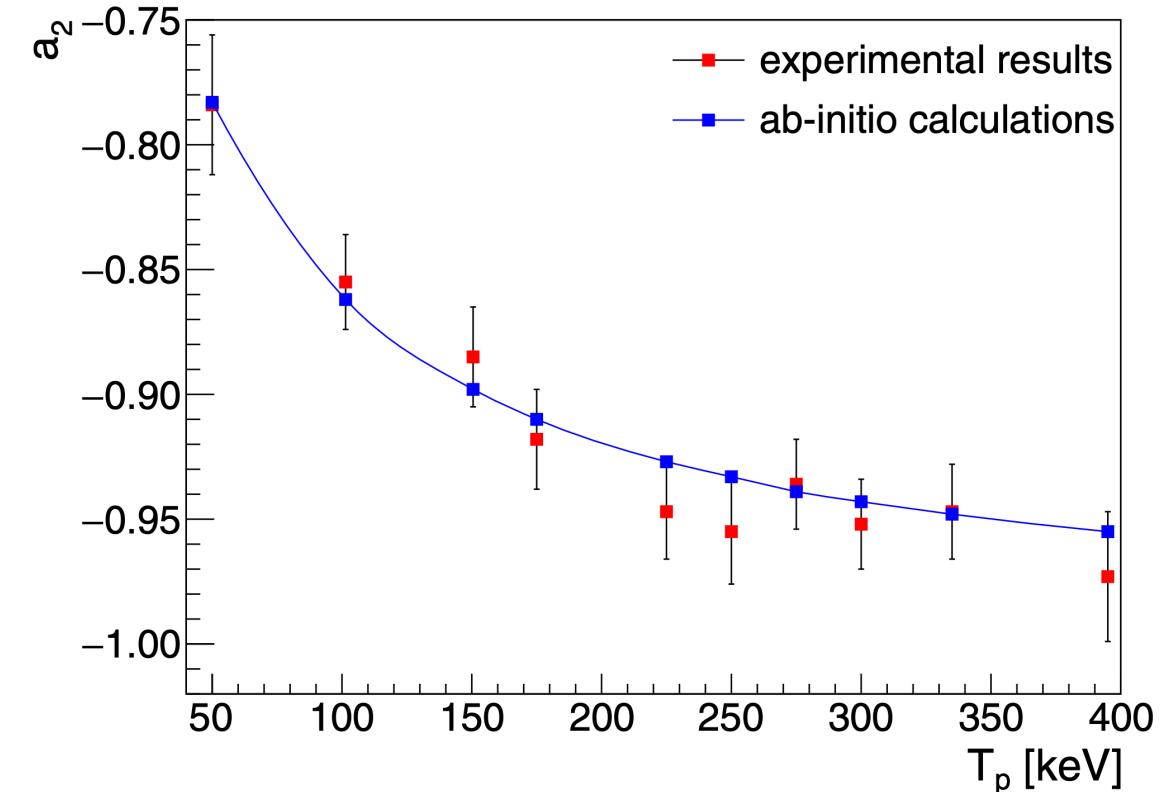
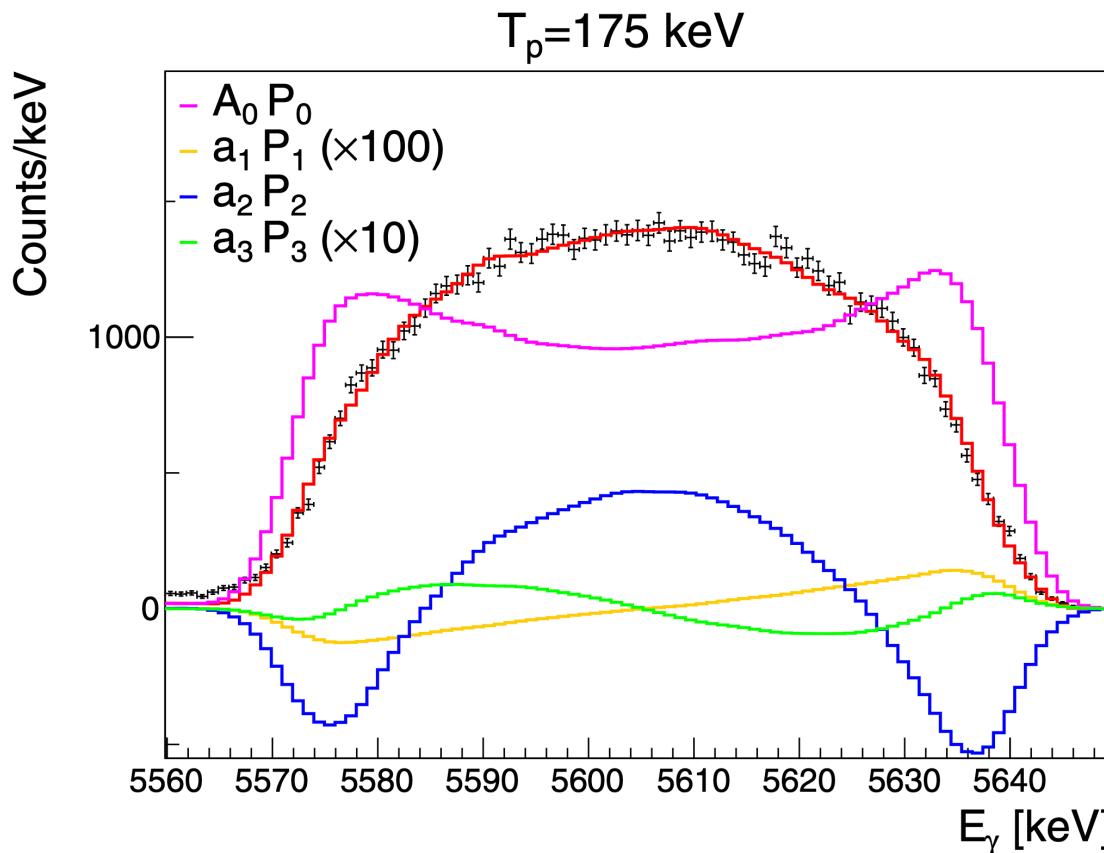
Big Bang Nucleosynthesis (BBN) and ^2H (D) as a cosmological probe



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

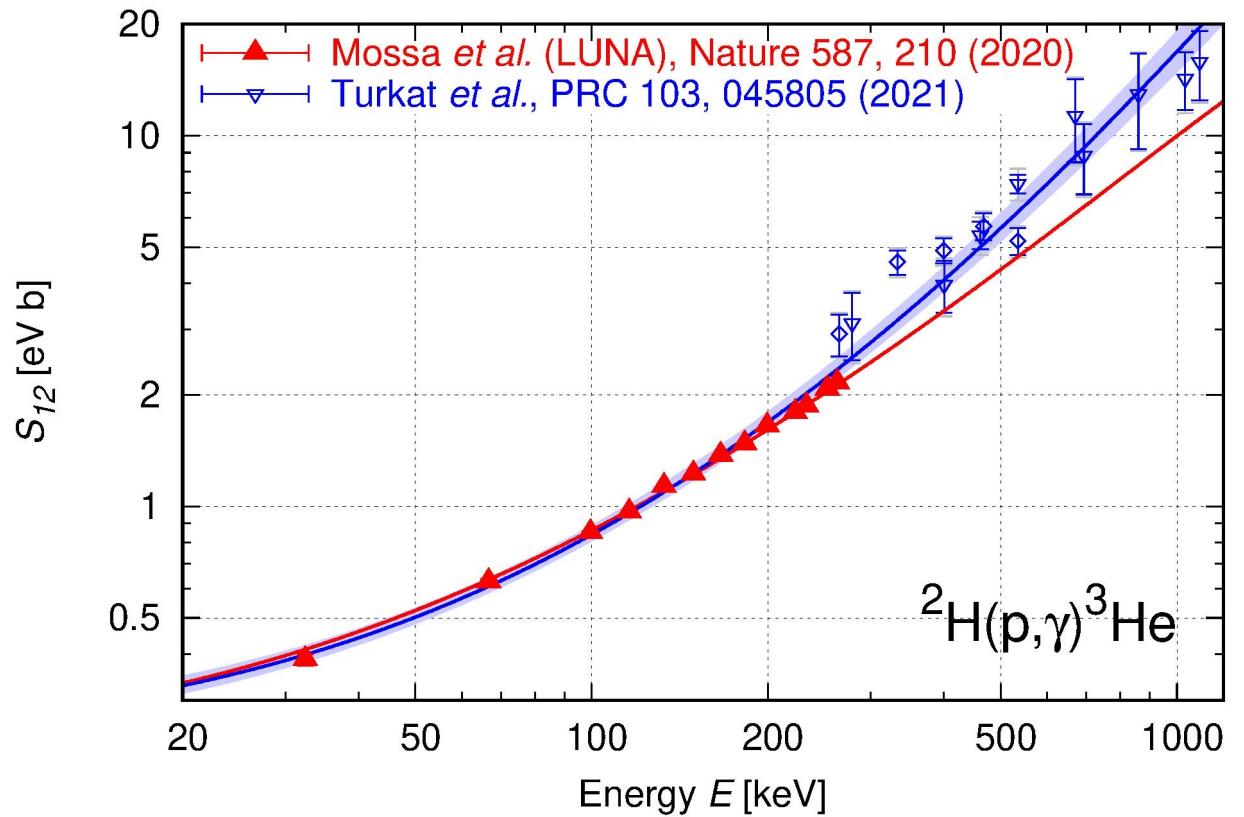


Mossa *et al.* (LUNA), Nature 587, 210 (2020)

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

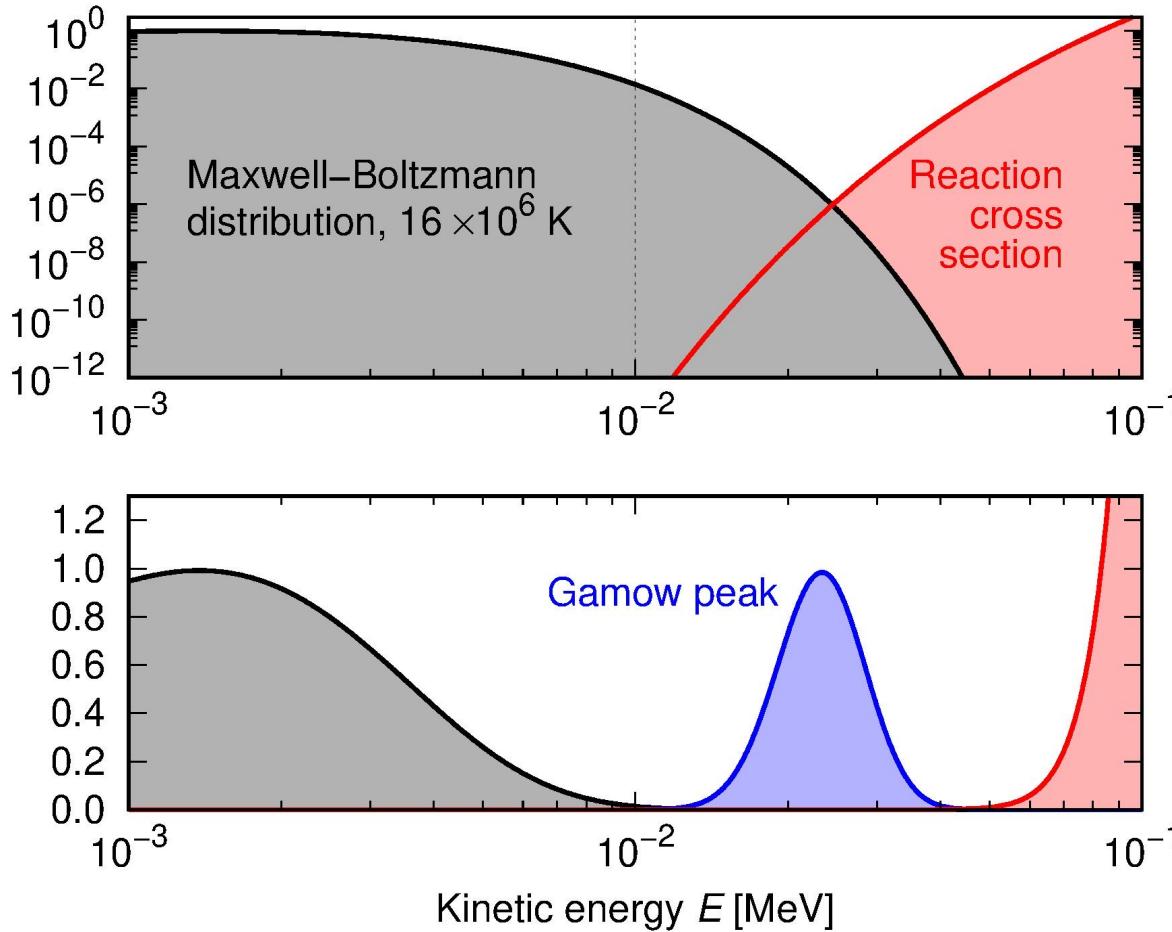
$$S_{12}(E) = \sigma(E) \times E \times \exp \left(Z_1 Z_2 \alpha \sqrt{\frac{\mu c^2}{2E}} \right)$$



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

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

Maxwell Boltzmann versus tunneling probability



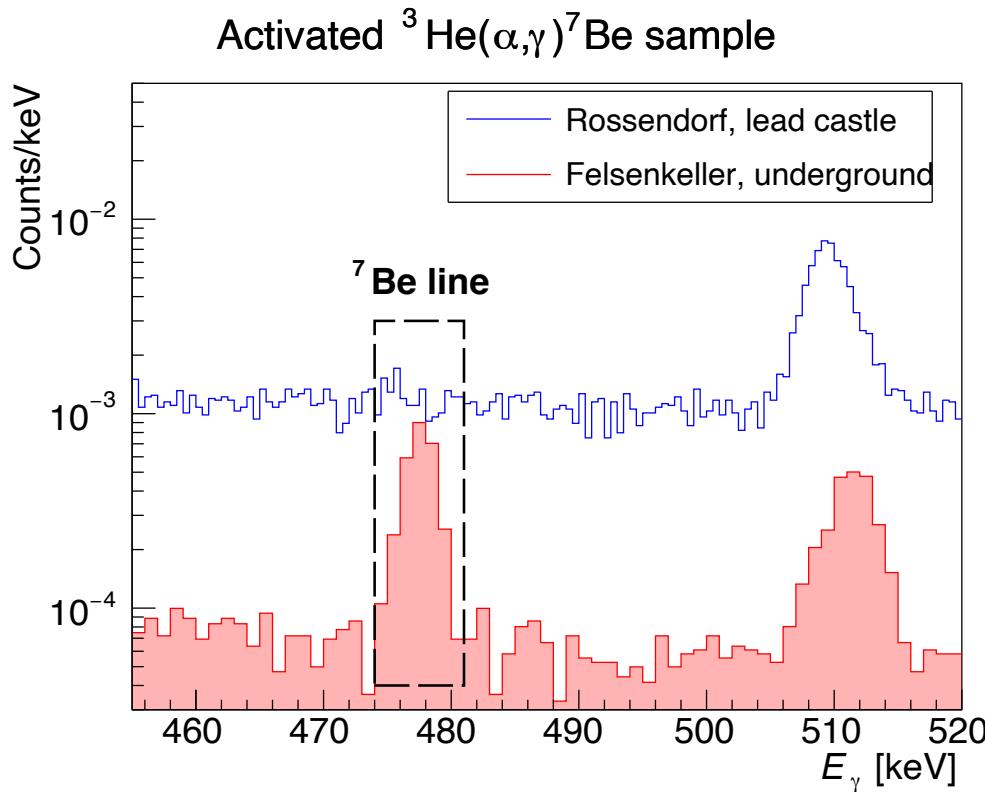
Sensitive,
underground
experiments needed

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

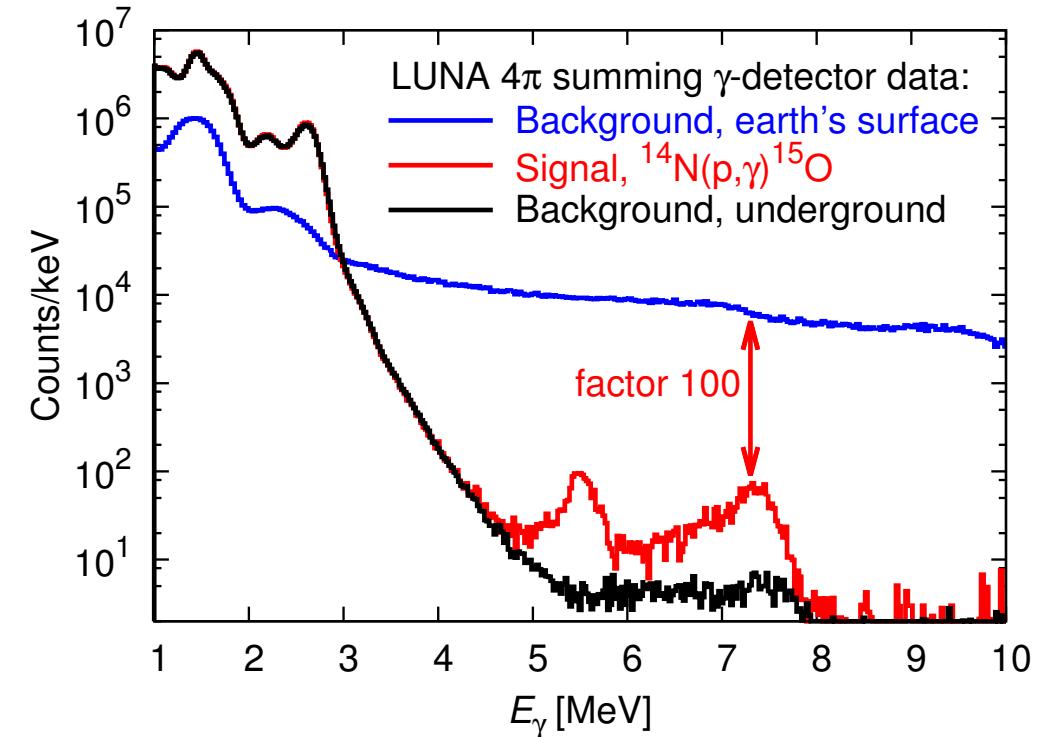
$$N_A \langle \sigma v \rangle \propto \int_0^{\infty} \exp\left[-\frac{E}{k_B T}\right] \exp\left[-\frac{b}{\sqrt{E}}\right] S(E) dE$$

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

Measuring very small cross sections, two examples



Felsenkeller Dresden



LUNA, below the Gran Sasso mountain, Italy

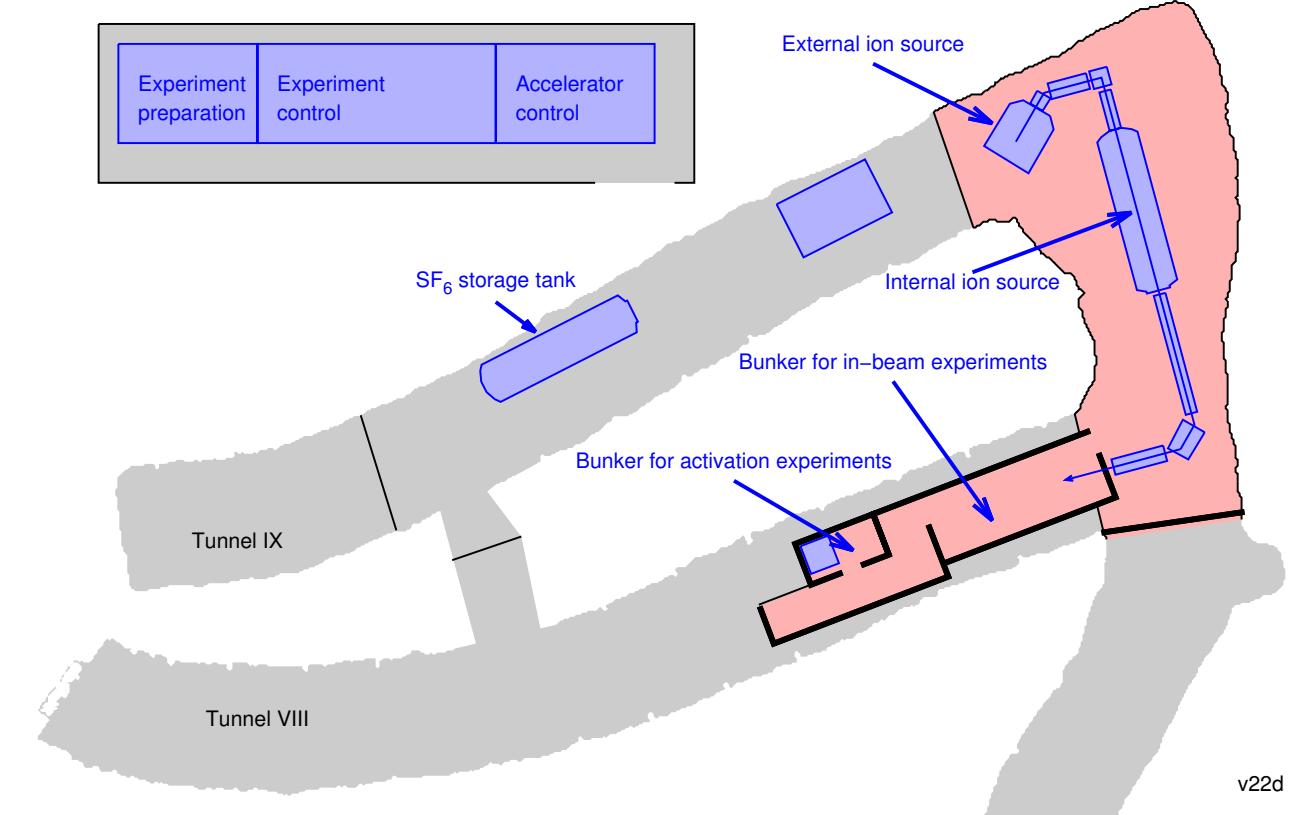
Dresden Felsenkeller underground lab, below 45 m of rock

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

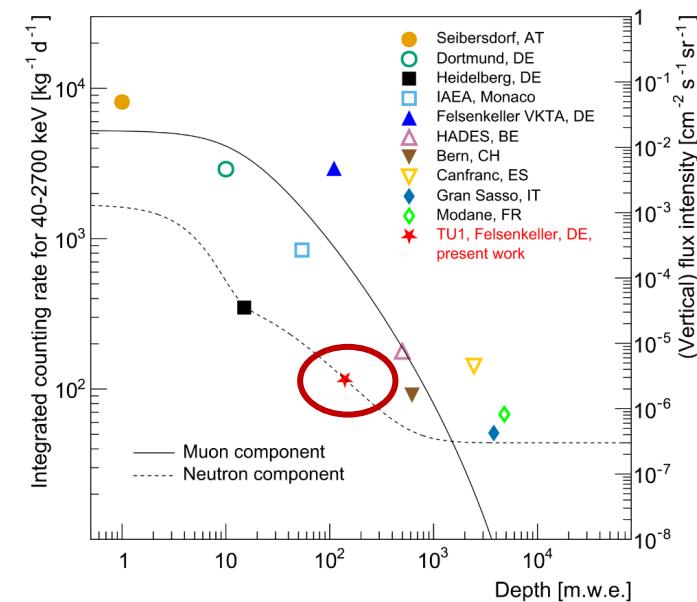
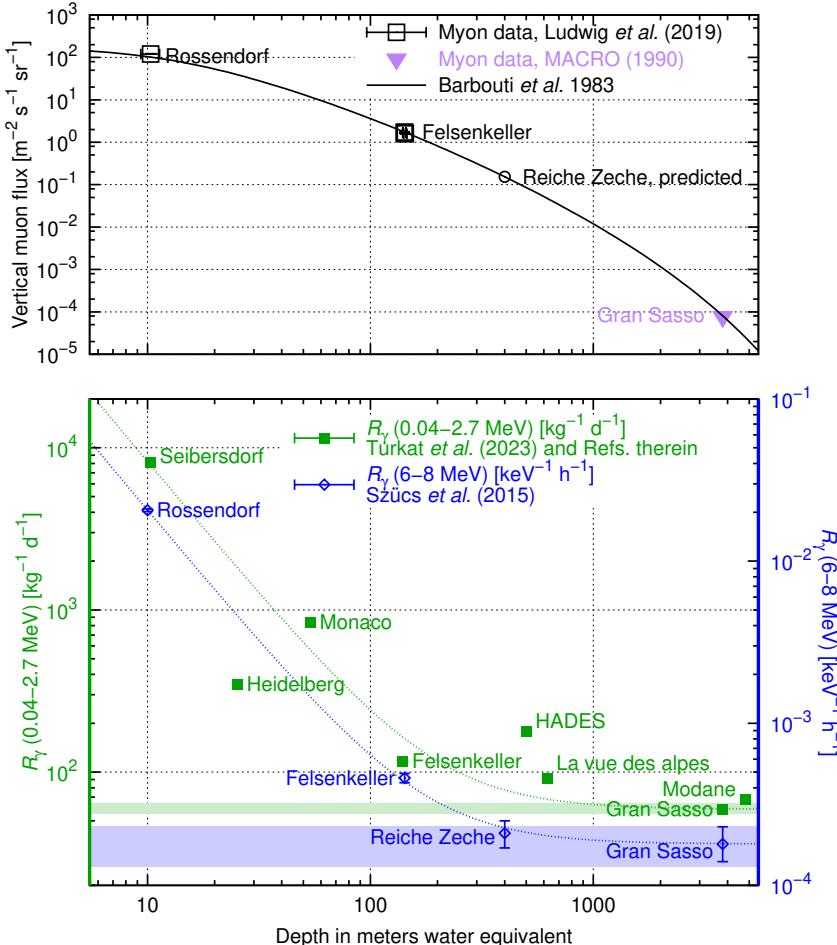
Two main instruments

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

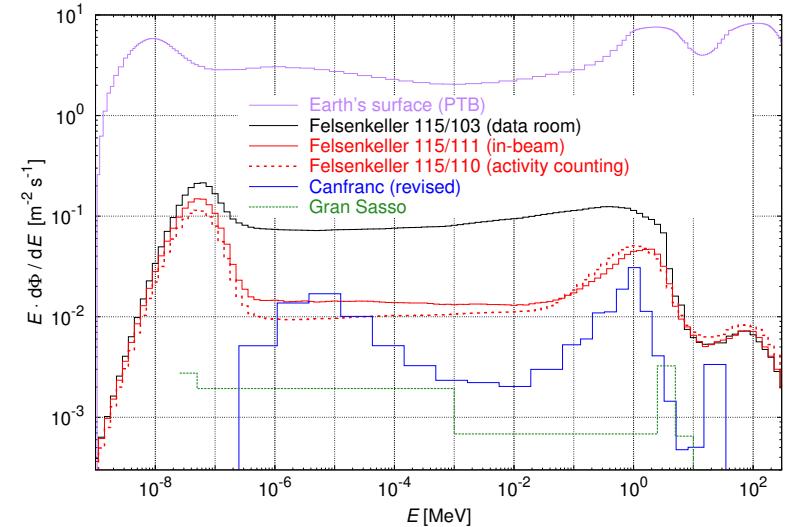


Felsenkeller: Studying low cross sections with low background

40× lower muon background
Astropart. Phys. 112, 24 (2019)

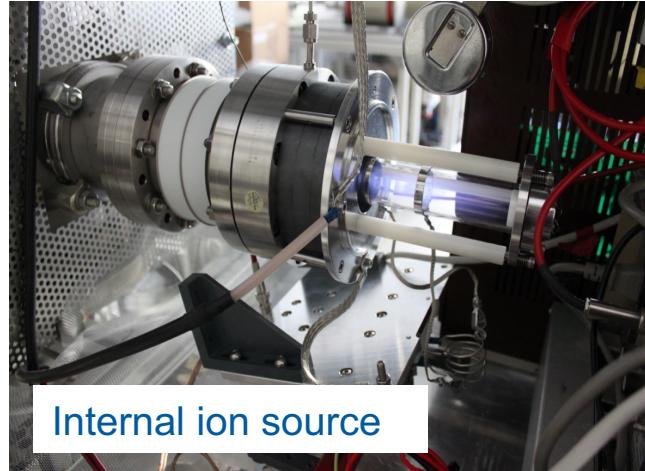


200× lower neutron background
Phys. Rev. D 101, 123027 (2020)



100× lower γ -background
Eur. Phys. J. A 51, 33 (2015)
Astropart. Phys. 148, 102816 (2023)
Eur. Phys. J. A 61, 19 (2025)

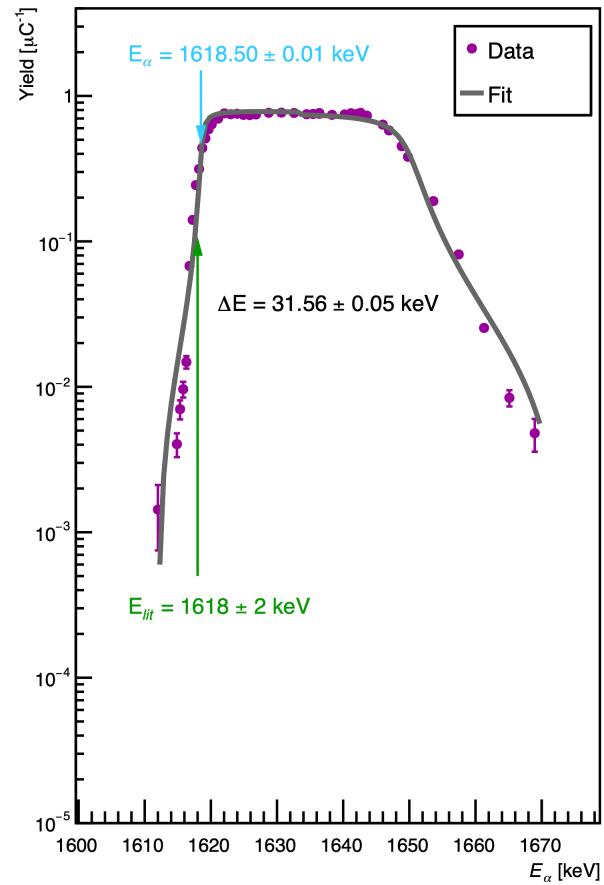
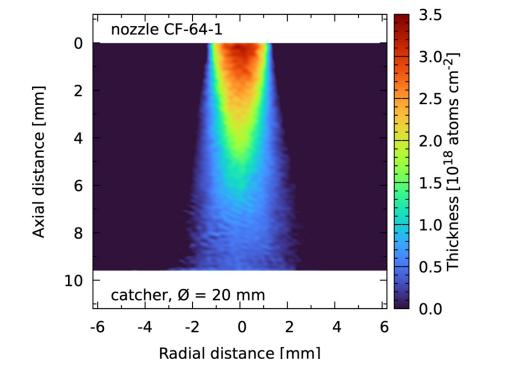
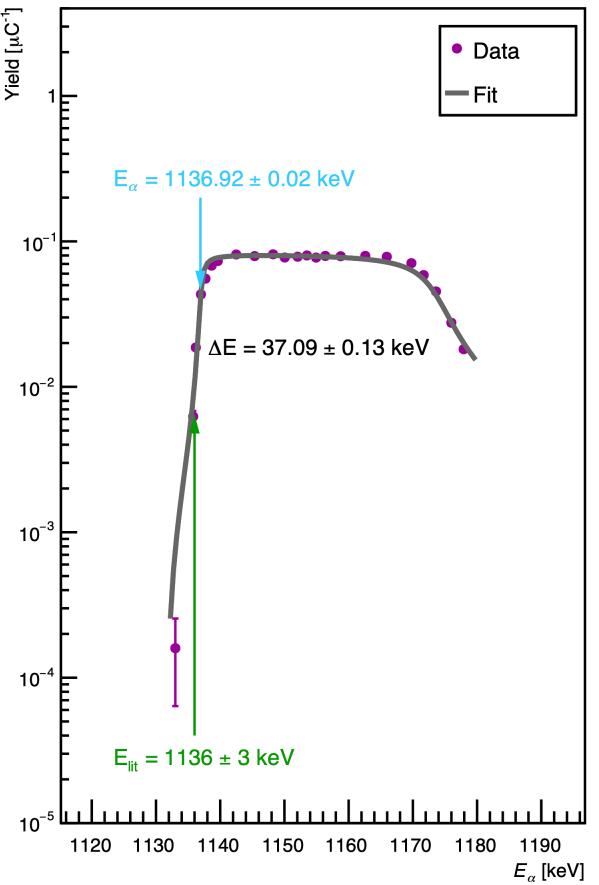
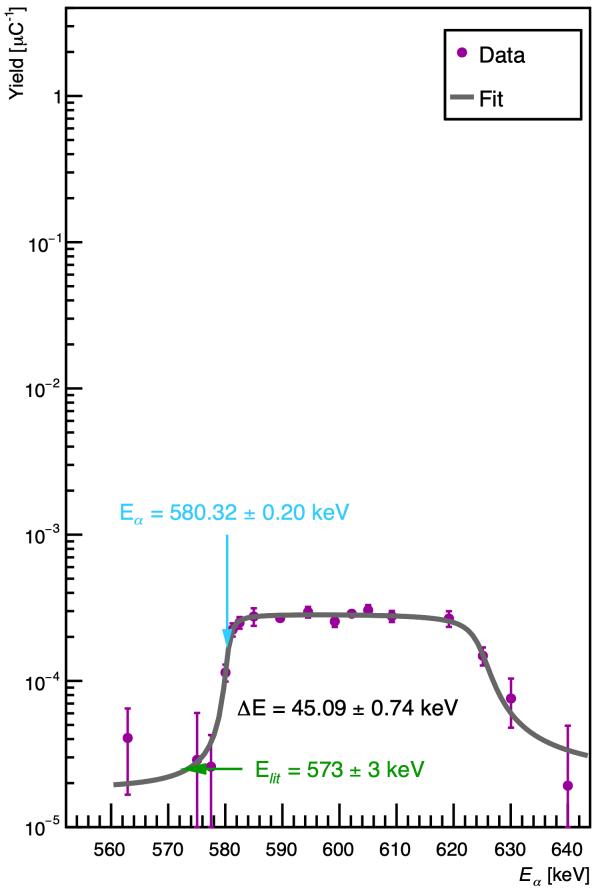
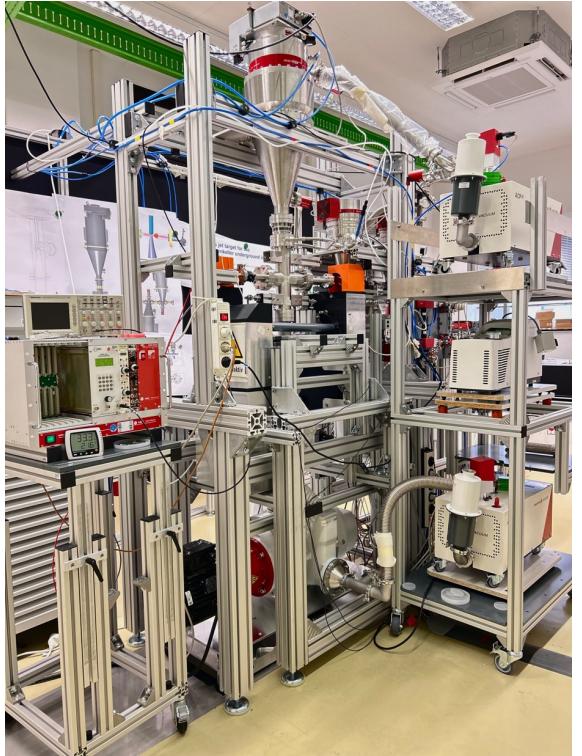
Felsenkeller 5 MV underground ion accelerator



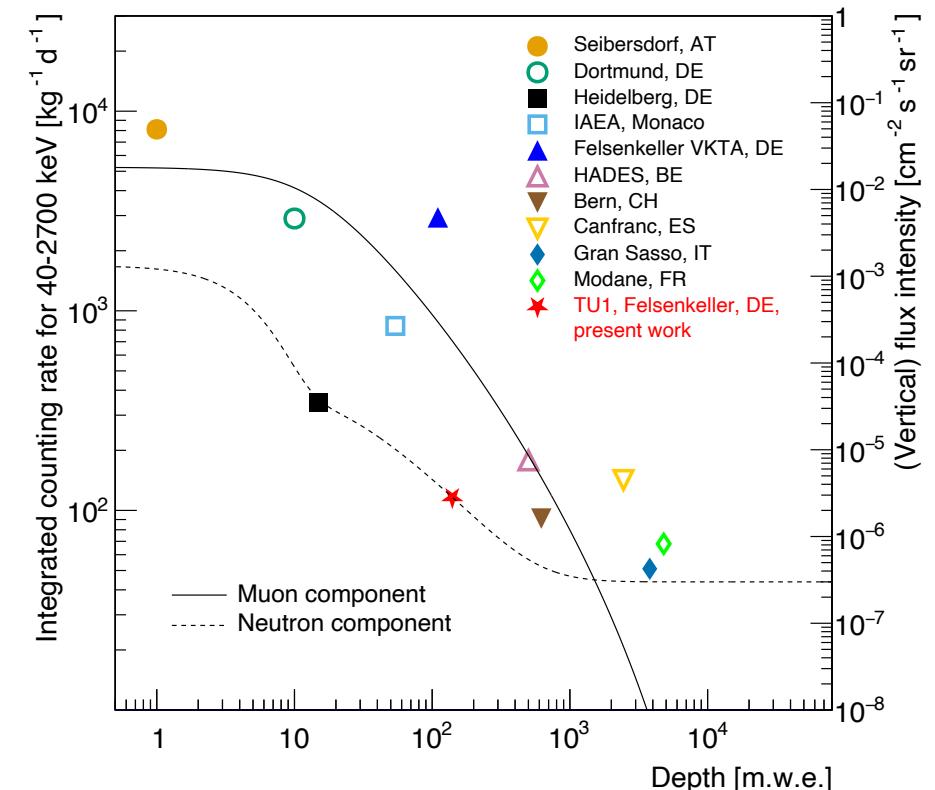
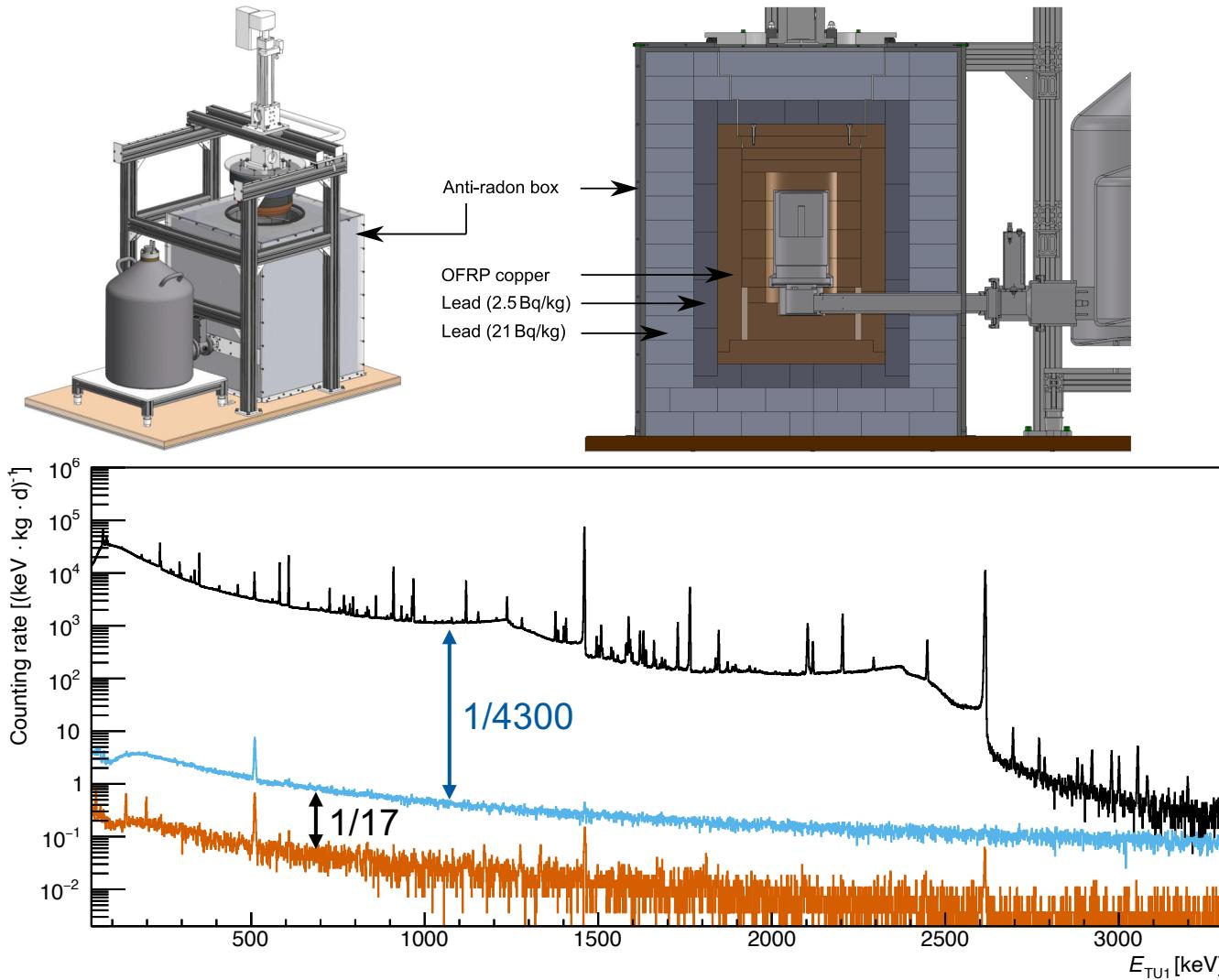
5 MV accelerator (0.4-3.8 MV), two alternative ion sources

- Internal RF ion source: $30 \mu\text{A} \text{ }^1\text{H}, \text{ }^4\text{He}$
- SNICS sputter ion source: $30 \mu\text{A} \text{ }^{12}\text{C}$
- 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

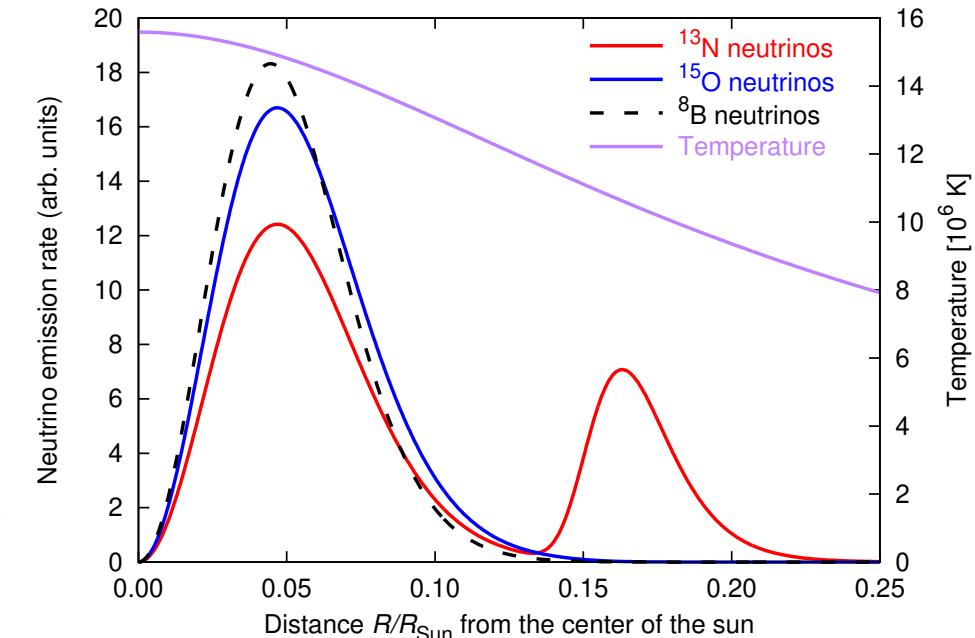
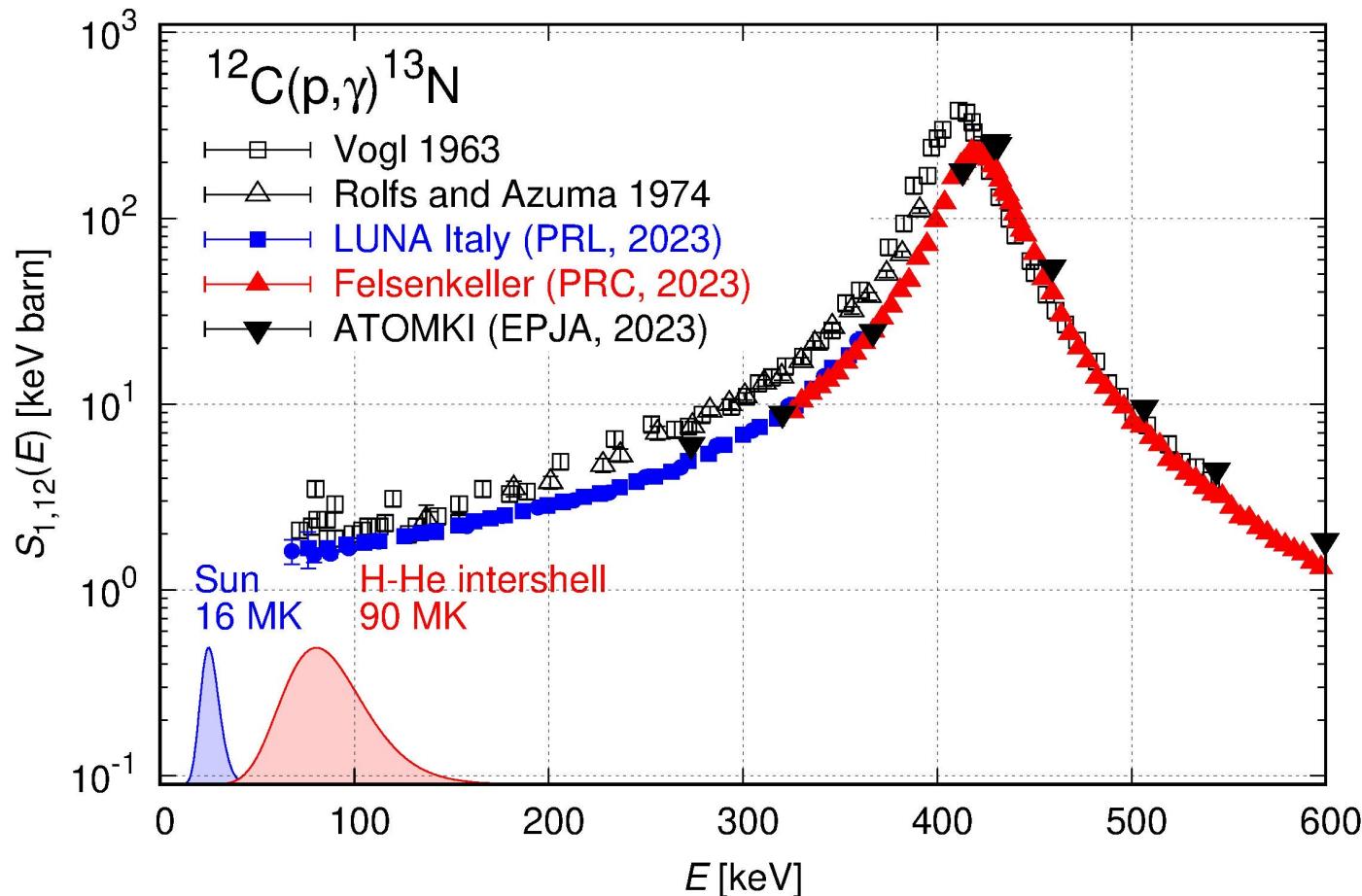
H		
Li	Be	
Na	Mg	
K	Ca	Sc
Rb	Sr	Y
Cs	Ba	La
Fr	Ra	Ac

														He
B	C	N	O	F	Ne									
Al	Si	P	S	Cl	Ar									
Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn

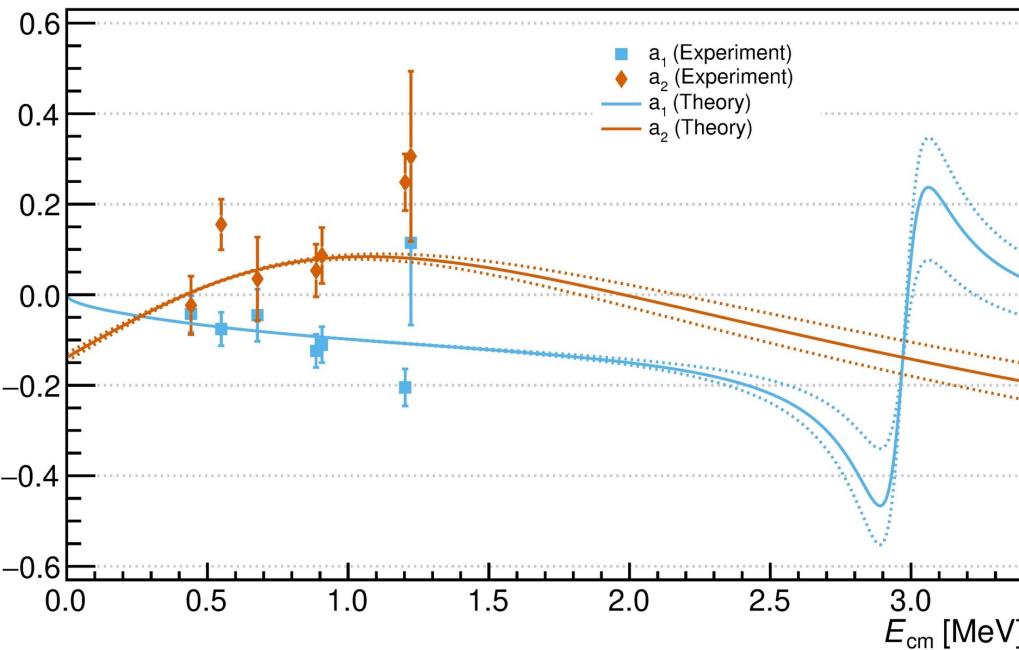
Big Bang
Stellar

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

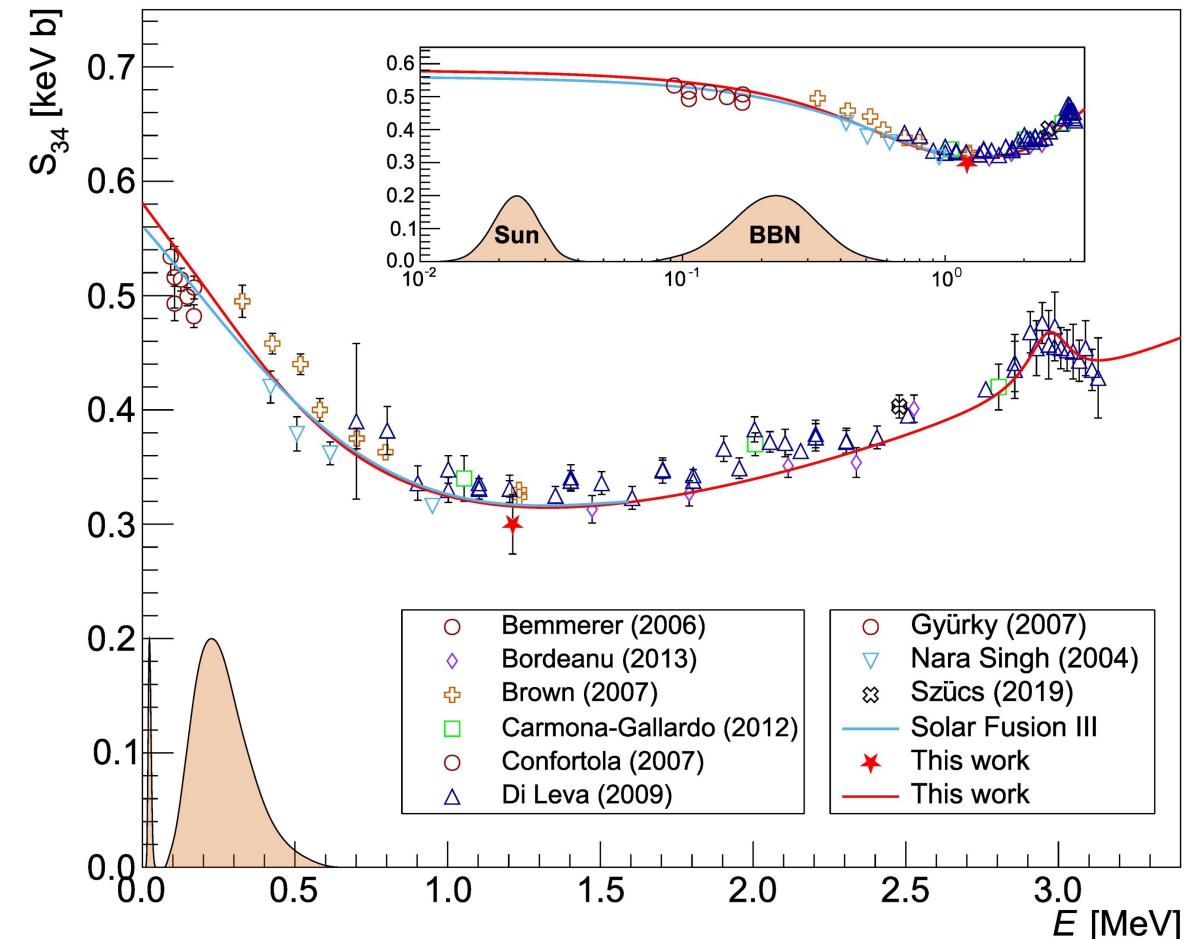
Study of the $^{12}\text{C}(\text{p},\gamma)^{13}\text{N}$ reaction at Felsenkeller and at LUNA



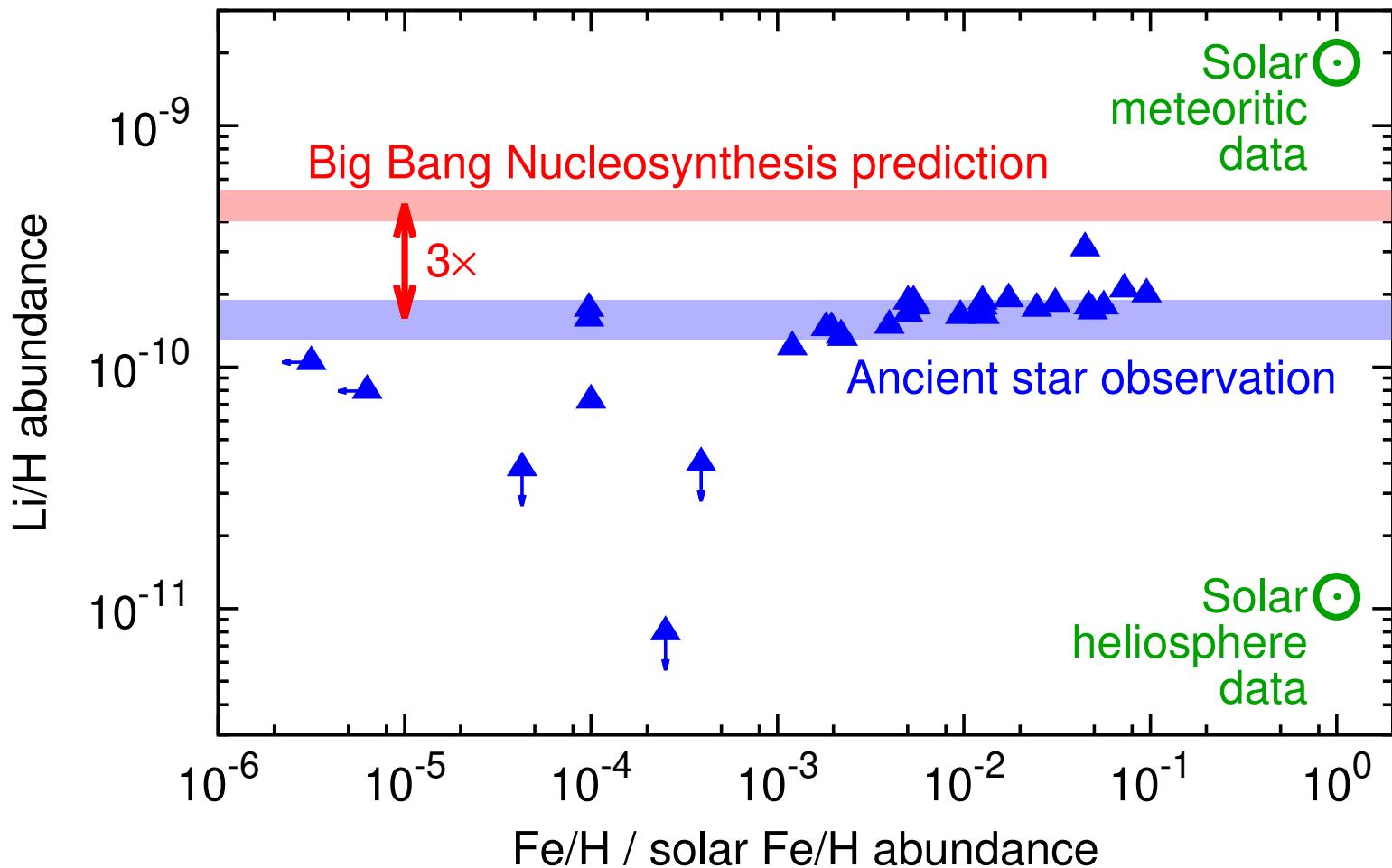
Study of the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ γ -ray angular distribution at Felsenkeller



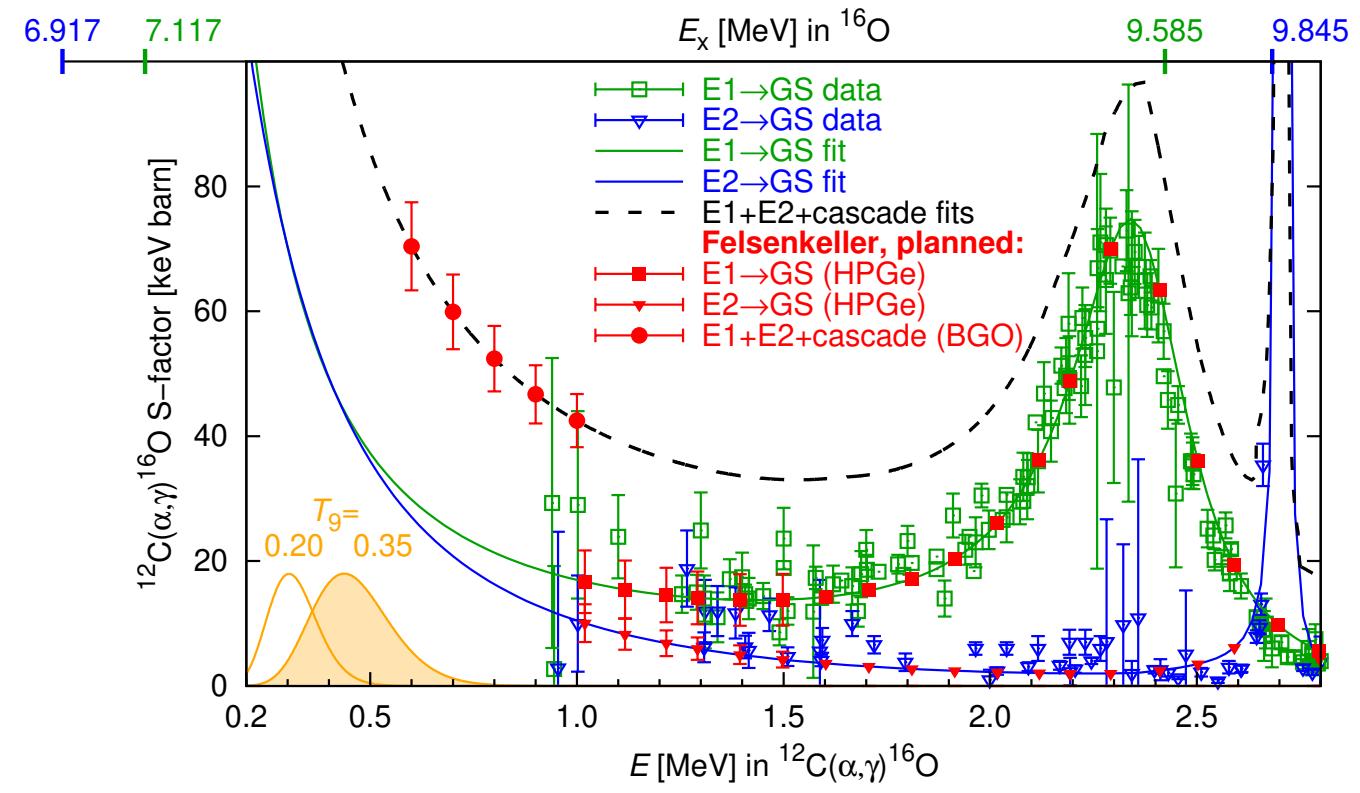
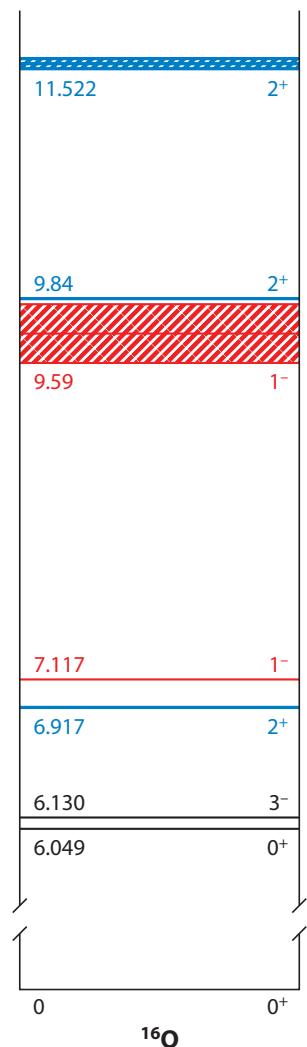
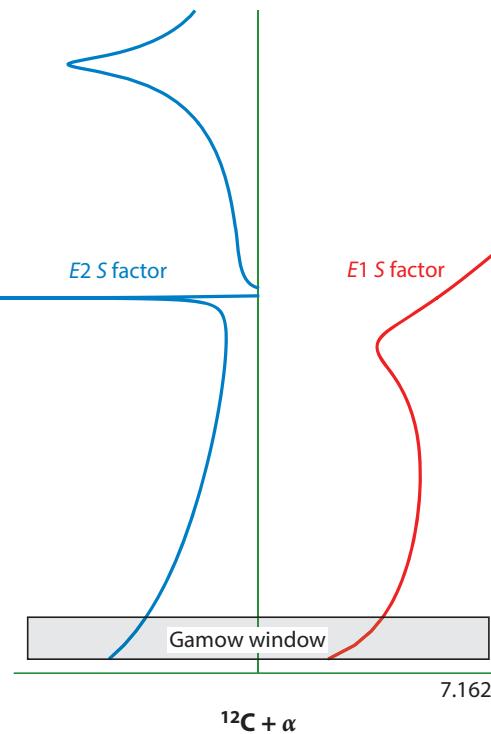
$$\begin{aligned} \frac{d\sigma}{d\Omega_{\text{c.m.}}} &= A_0 \left(1 + \sum_{l=1}^3 a_l P_l(\cos \theta_{\text{c.m.}}) \right) \\ &= A_0 \left(1 + \sum_{l=1}^3 a_l P_l(E_\gamma) \right). \end{aligned}$$



^7Be and ^7Li – 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



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



HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF



Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut



Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK



universität
wien



AARHUS UNIVERSITY



Leibniz-Institut für
Astrophysik Potsdam



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האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM



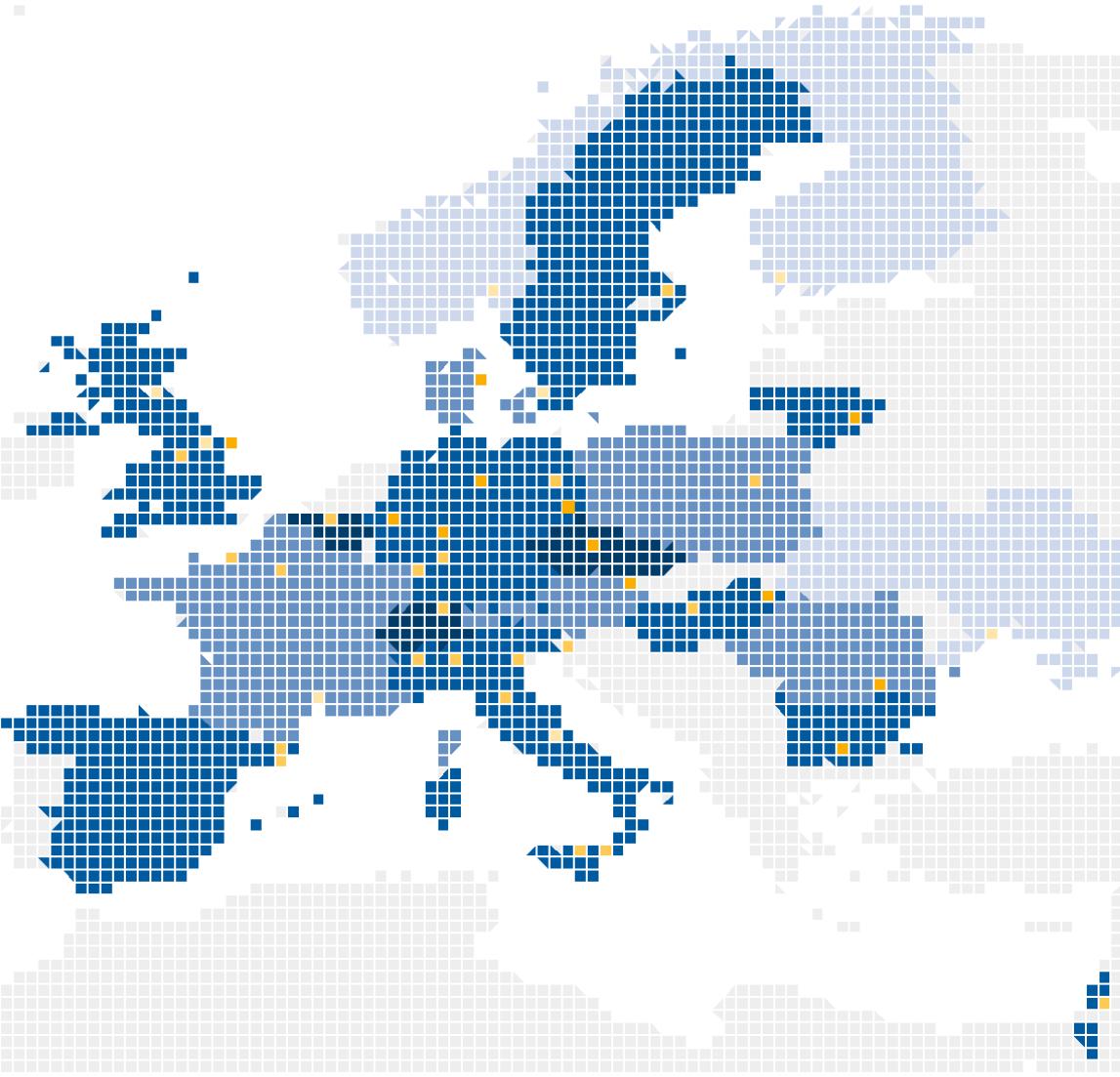
UNIVERSITÀ
DEGLI STUDI
DI MILANO



Horia Hulubei National Institute for R&D
in Physics and Nuclear Engineering



ETH zürich



UNIVERSITÉ
LIBRE
DE BRUXELLES



Institut Pluridisciplinaire
Hubert Curien
STRASBOURG



БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ



laboratoire commun CEA/DRF CNRS/IN2P3



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INNOVATION CAMPUS



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



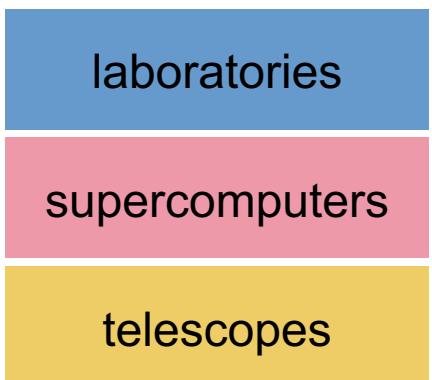
PTB Ion Accelerator Facility /
DE



University of Cologne
10 MV Tandem / DE



ATOMKI
Cyclotron / HU



Vilnius University Moletai
Astronomical Observatory / LT



IFIN-HH 3 MV Tandetron
accelerator / RO



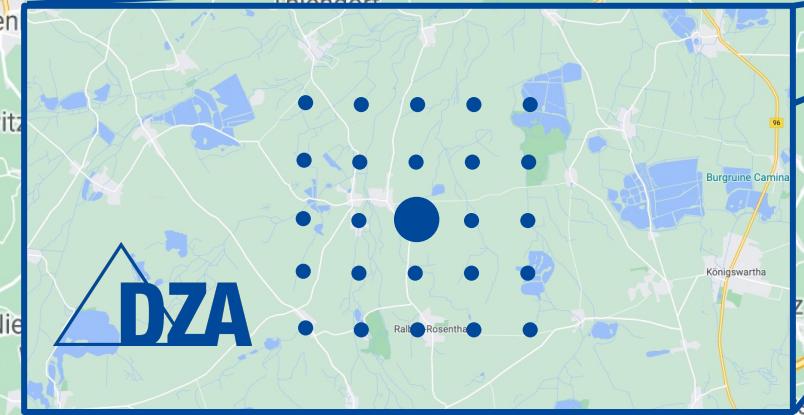
Hull University
VIPER cluster



Bellotti IBF, IT
Underground ion accelerator

Eine Region für Astrophysik, Technologie und Digitalisierung

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



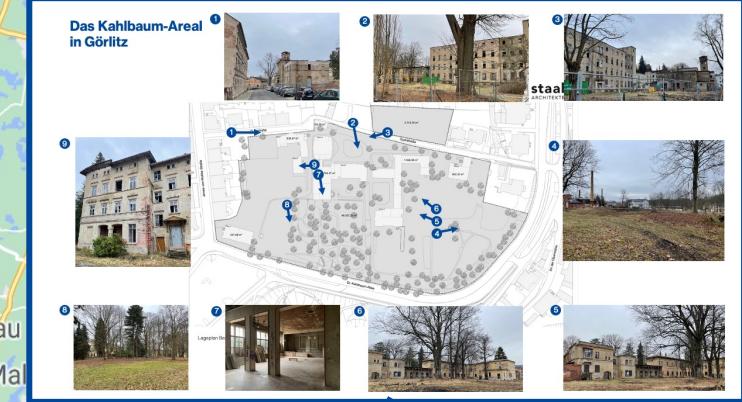
TECHNISCHE
UNIVERSITÄT
DRESDEN

21.08.2025

Nuclear astrophysics and the Felsenkeller lab
Dürrröhrsdorf-Dittersbach



Ein Zentrum für Astrophysik mit fortschrittlicher Computertechnik und Technologieentwicklung



27



Wymiar



Bad Muskau

Gablenz

Trebendorf

Elsterheide

Spreeta

Scipkau

Semmerberg

Hohenleipisch

Amtshaus

Elsterwerda

Plessa

Ortrand

Königsbrucker Heide

Grünewald

Bernsdorf

Oßling

Wittichenau

Lohsa

Boxberg/Oberlausitz

Rietsch

Boxberg/Oberlausitz

Hamburg/Lausitz

Pińsk

Reichenbach/Oberlausitz

Markersdorf

Görlitz

Hennersdorf

Lagów

Ujazd

Czernowice

Liw

Reichenbach/Oberlausitz

Marker

Weißenberg

Kubischütz

Hochkirch

Bautzen

Croswitz

Kamenz

Elstra

Bischofswerda

Neukirch/Lausitz

Wilthen

Cunewalde

Sohland an der Spree

Neustadt in Sachsen

Kottmar

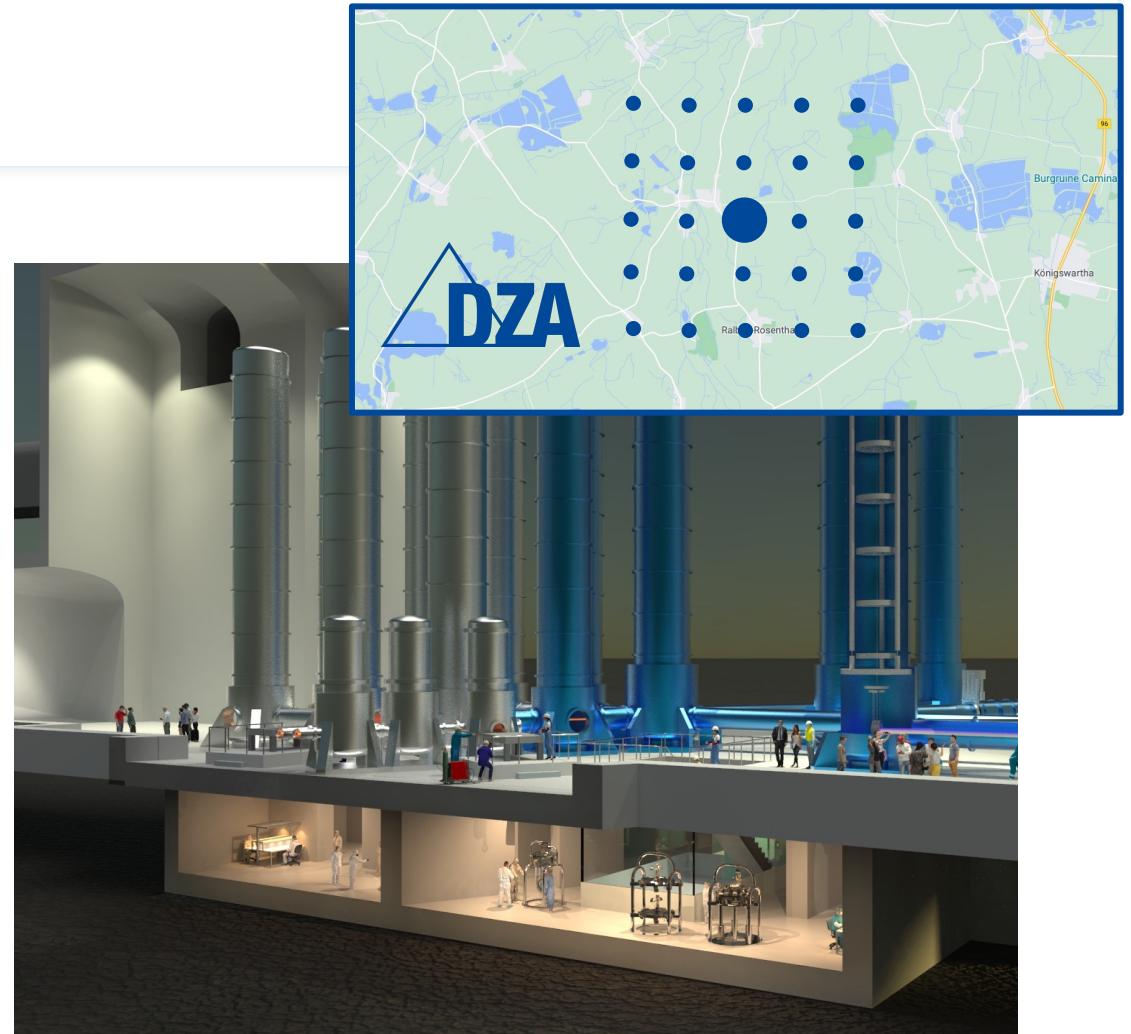
Herrnhut

Ostritz

Seidenberg

Das Low-Seismic-Lab

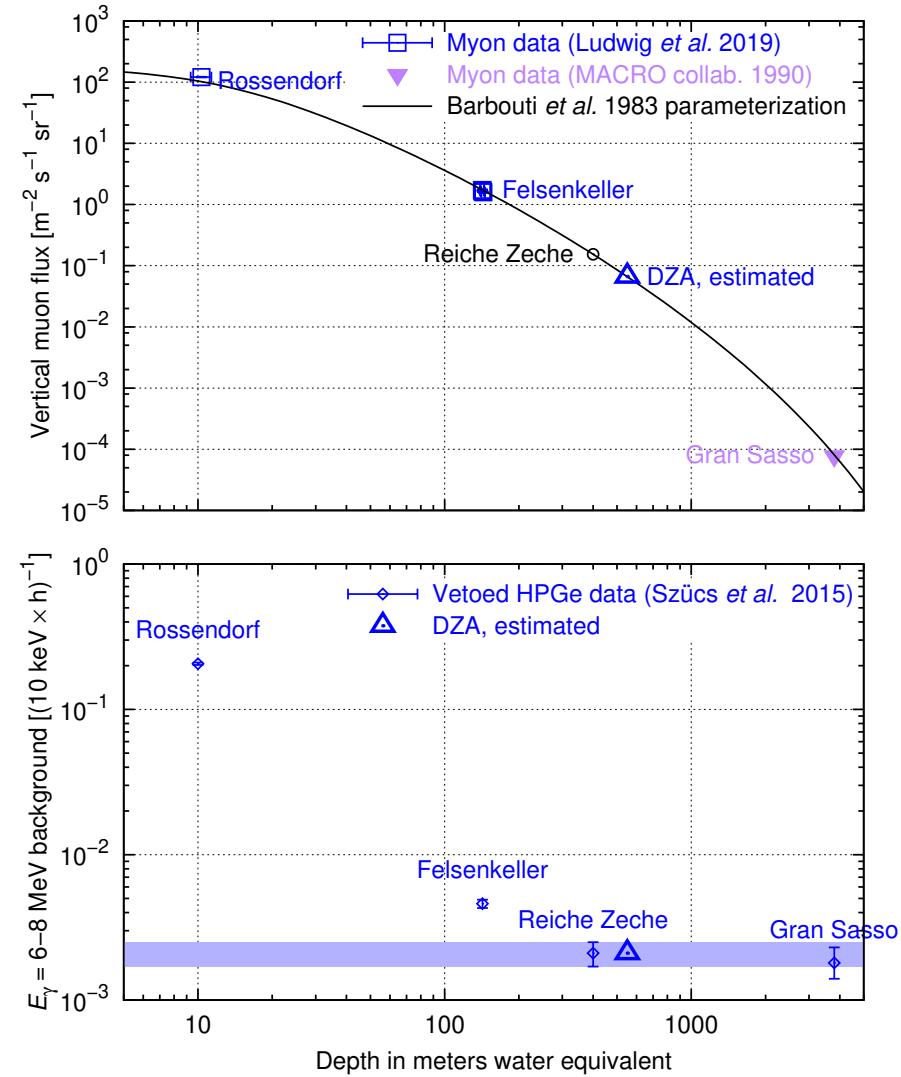
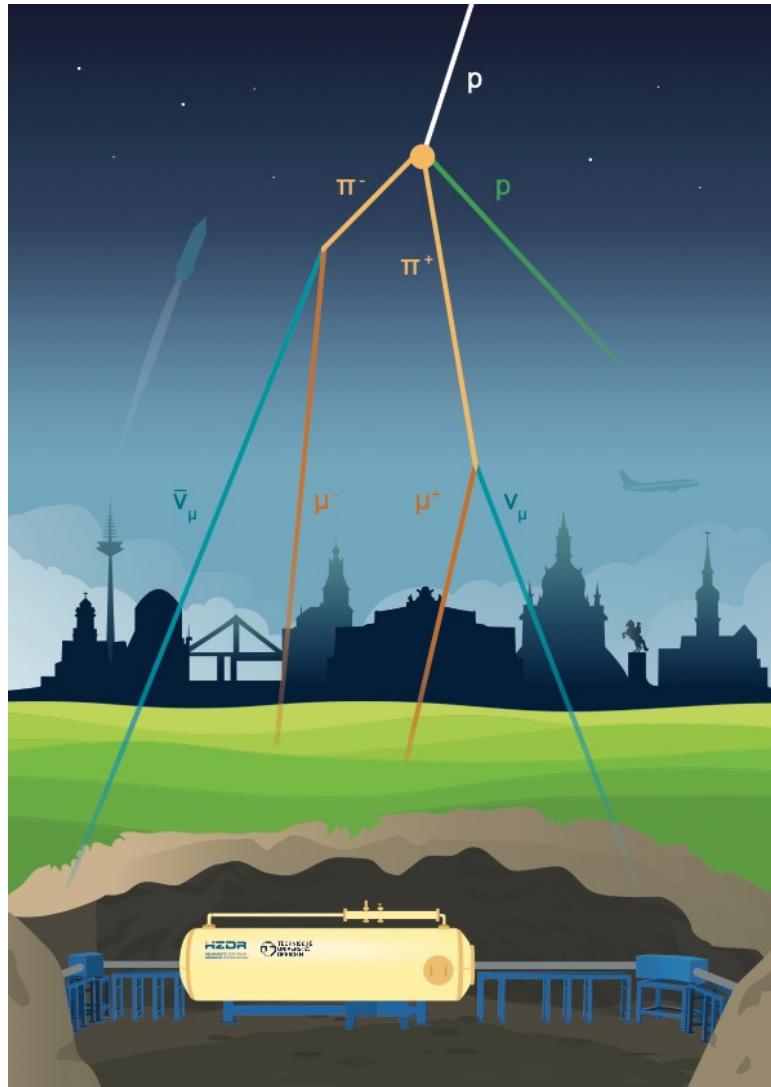
- Technologieentwicklung für die Gravitationswellenastronomie
- Adaptive seismische Rauschunterdrückung
- Sub-Nanometer-Mikroskopie und Photolithographie
- Astrophysik mit Beschleunigern



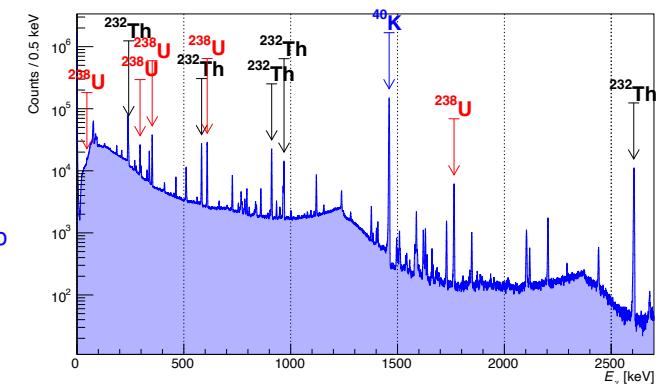
Courtesy Christian Stegmann / DESY

21.08.2020 Nuclear astrophysics and the Felsenkeller lab

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



Probe DZA1_247m Run134 (113.7 Stunden)



Nuclear astrophysics: The Felsenkeller lab in Dresden

H										He
Li		Be								
Na	Mg									
K	Ca	Sc								
Rb	Sr	Y								
Cs	Ba	La								
Fr	Ra	Ac								

										He
Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge
Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn
Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb
									Bi	Po
									At	Rn

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-, v-processes

