Underground Accelerators and the Dresden Felsenkeller

Nuclear Astrophysics Experiments in Germany

Workshop on Nuclear Astrophysics in Germany

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HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Underground accelerators and the Dresden Felsenkeller

LUNA 0.4 MV underground accelerator, Italy:

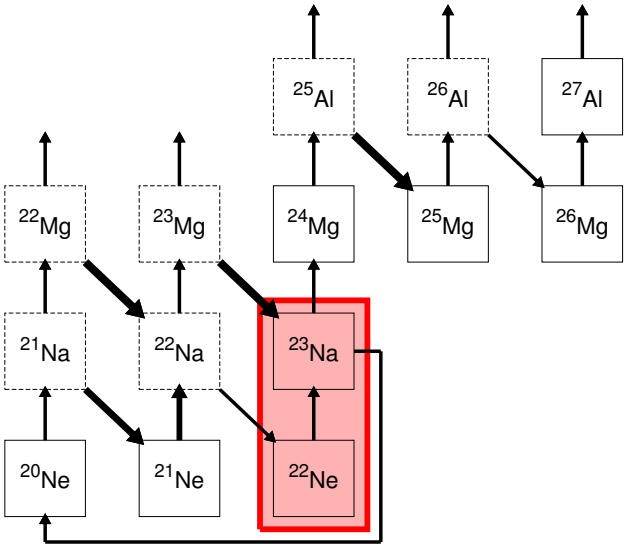
- New data on the $^{22}Ne(p,\gamma)^{23}Na$ reaction, relevant for hydrogen shell burning
- Big Bang nucleosynthesis and the $^{2}H(p,\gamma)^{3}He$ reaction

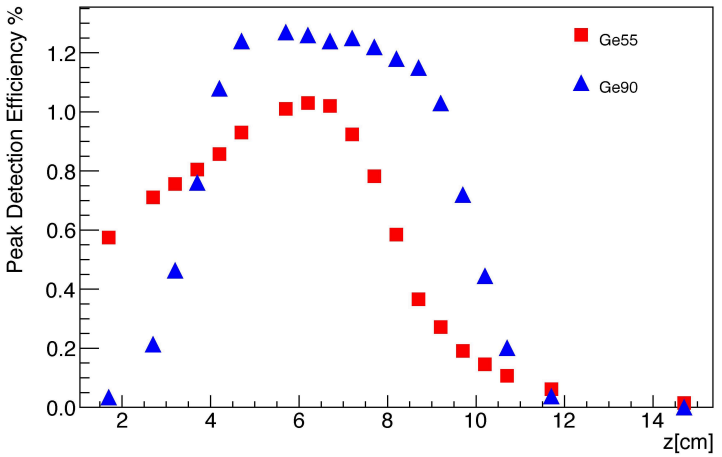
Future Felsenkeller 5 MV underground accelerator, Dresden/Germany:

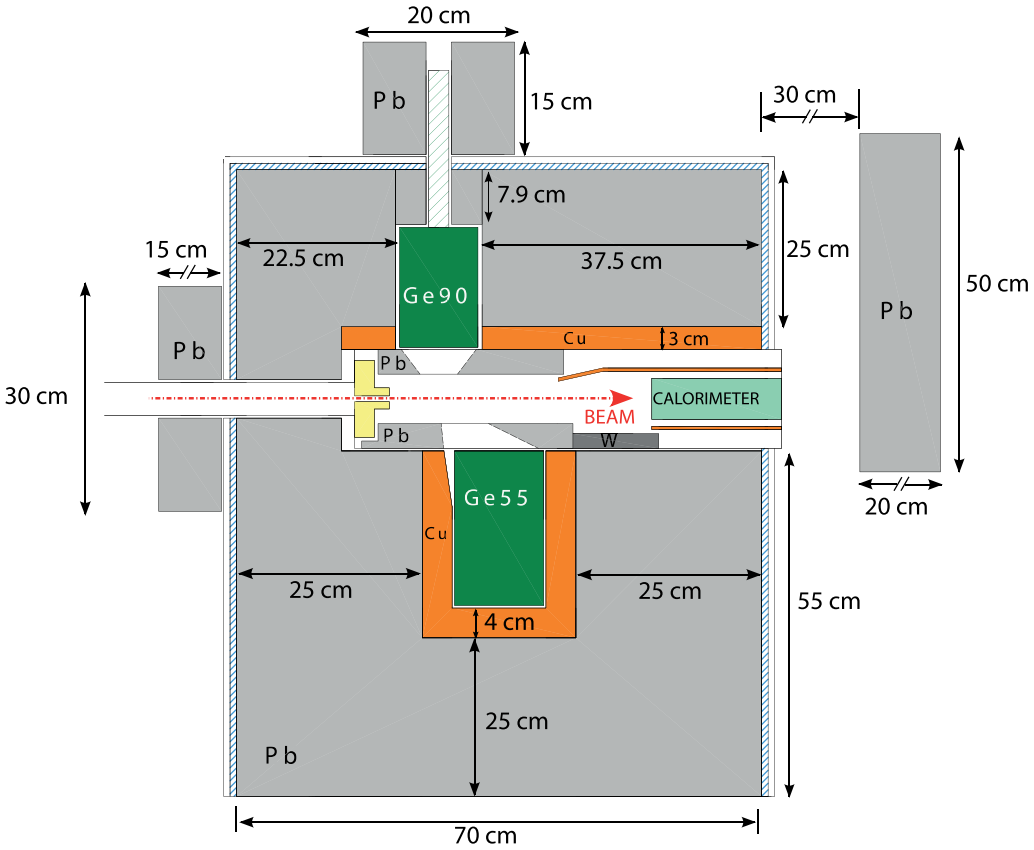
- Background studies
- Status

Experimental Nuclear Astrophysics in Germany, an attempt at an overview

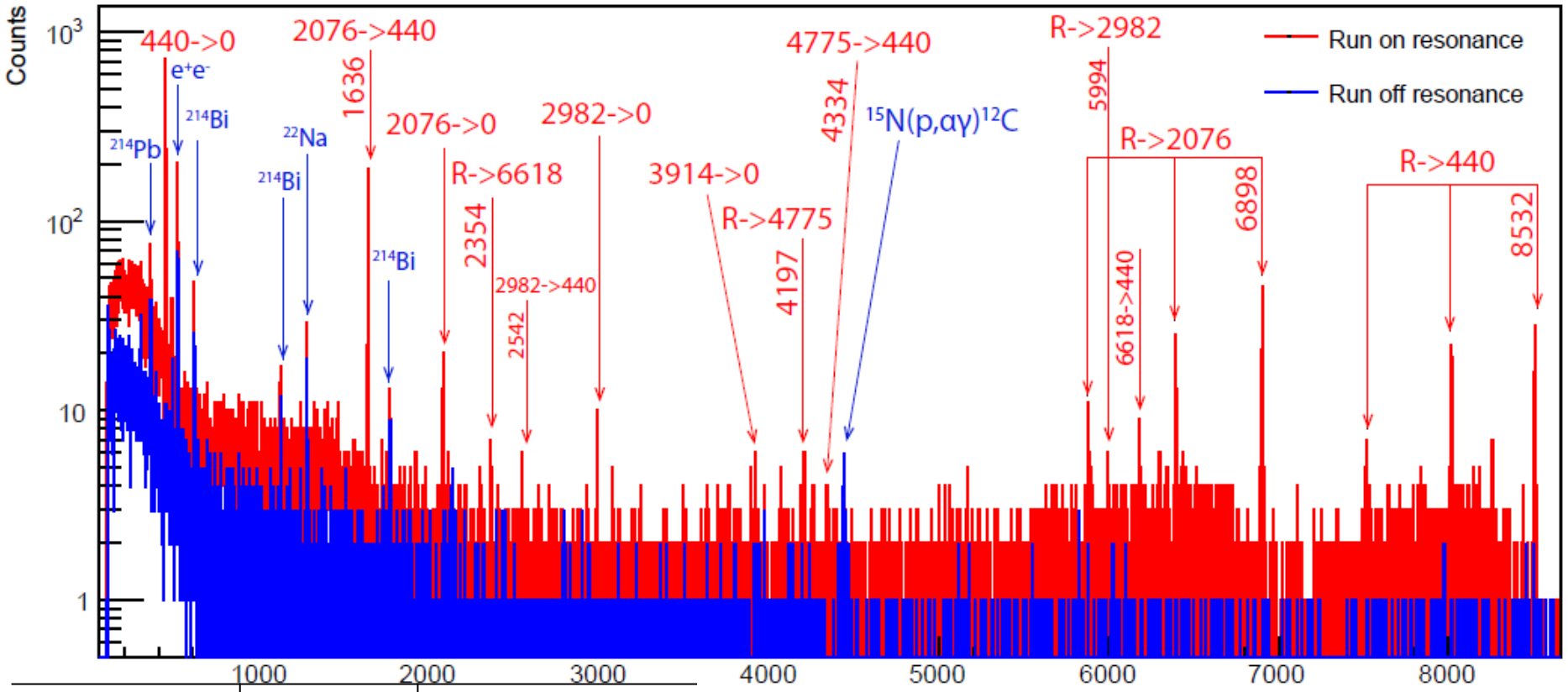
$^{22}Ne(p,\gamma)^{23}Na$ at LUNA, Gran Sasso, Italy





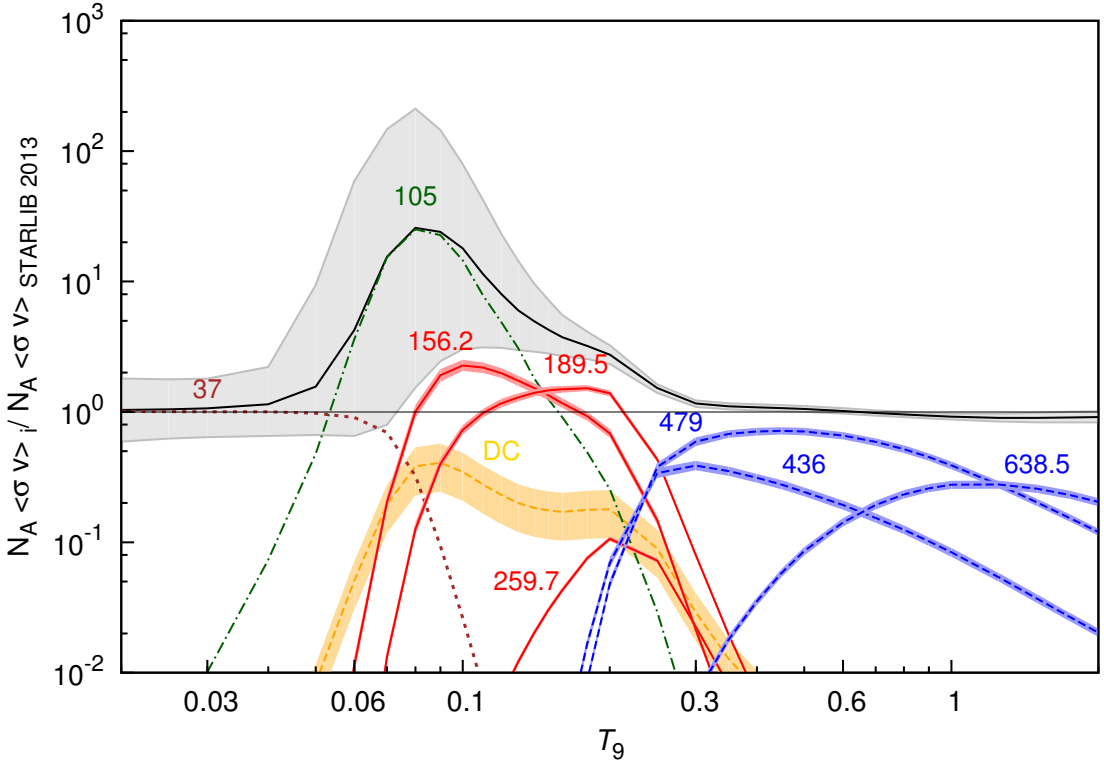


$^{22}Ne(p,\gamma)^{23}Na$ resonance at E_{res}^{lab} = 189.5 keV



γ-transition	E_γ [keV]	Branching [%]
R→440	8532	43.8 ± 1.0
R→2076	6898	47.7 ± 0.9
R→2982	5994	3.8 ± 0.5
R→4775	4197	1.9 ± 0.3
R→6618	2354	2.8 ± 0.2

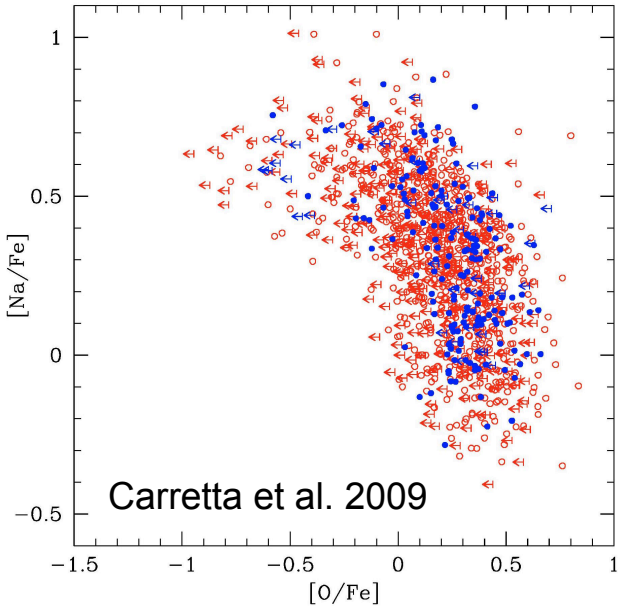
$^{22}Ne(p,\gamma)^{23}Na$, astrophysical reaction rate



Rate enhanced by more than a factor of 10!

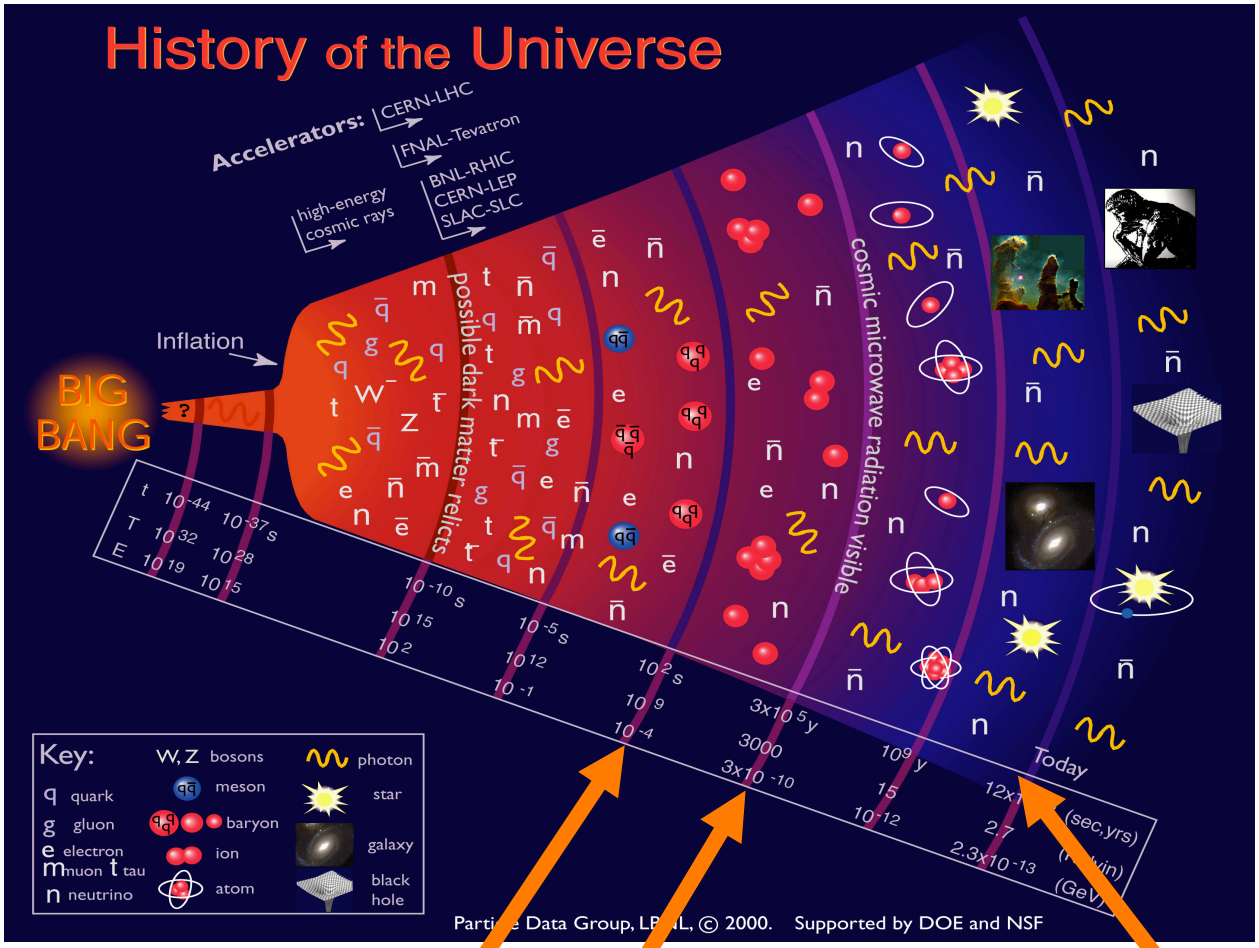
F. Cavanna *et al.*, Phys. Rev. Lett. 115, 252501 (2015)

Might help explain Na-O anticorrelation in globular clusters



Resonance energy [keV]	LUNA strength [μeV]	Previous indirect strength [μeV]
156.2	0.148 ± 0.007	0.0092 ± 0.0037
189.5	1.87 ± 0.06	≤ 2.6
259.7	6.89 ± 0.16	≤ 0.13

Three tools of observational cosmology

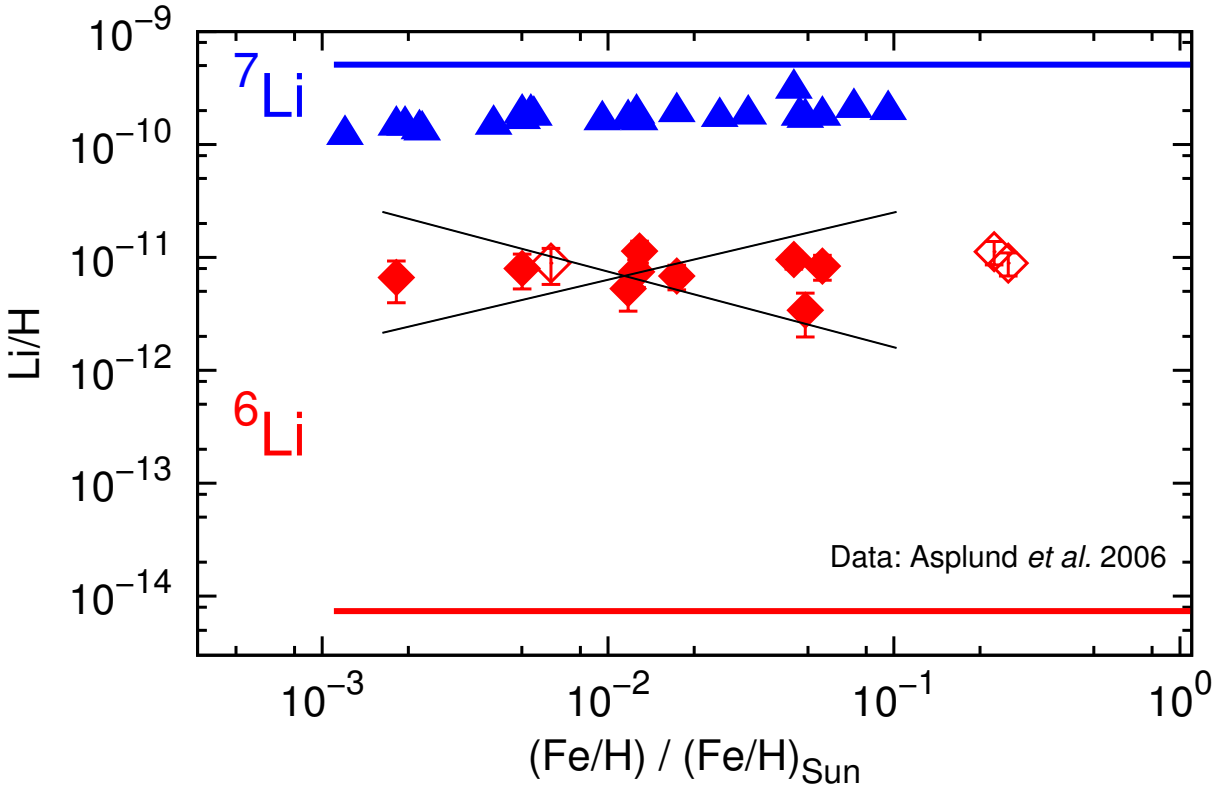


BBN, Big Bang Nucleosynthesis

CMB, Cosmic micro-wave background

SN Ia, type Ia supernovae

Observed nuclide abundance: BBN ^{7}Li and the “Spite plateau”

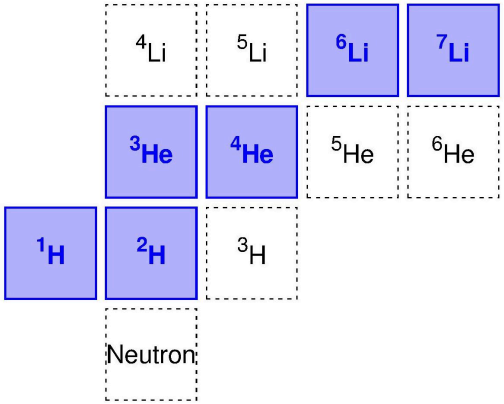


^{7}Li: ^{3}He(α,γ)^{7}Be

Phys. Rev. Lett. 97, 122502 (2006)

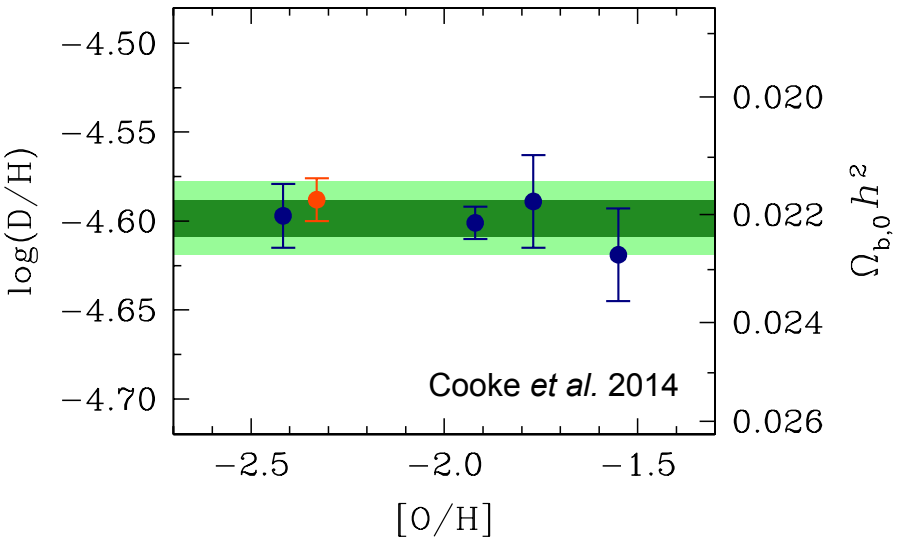
^{6}Li: ^{2}H(α,γ)^{6}Li

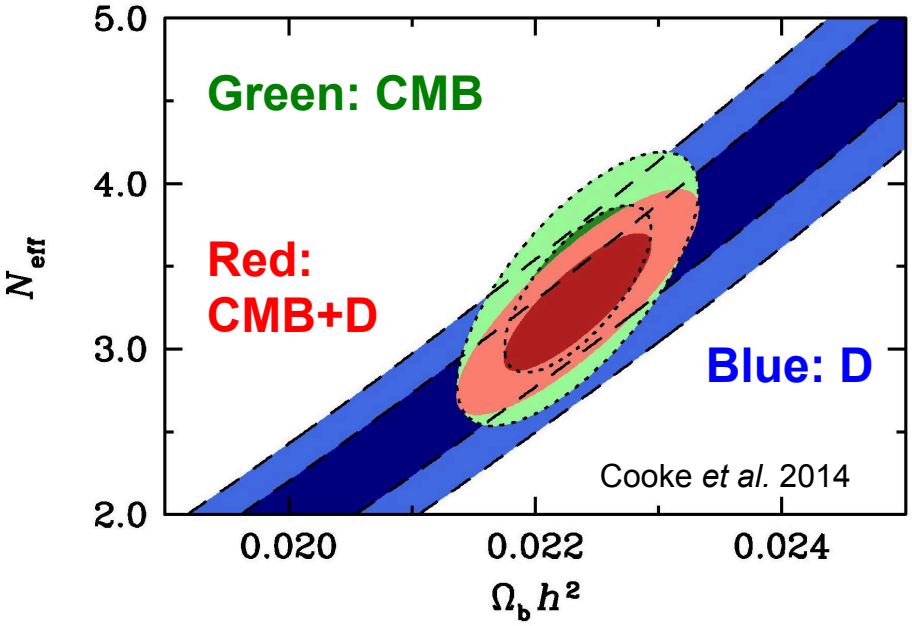
Phys. Rev. Lett. 113, 042501 (2014)



- CMB-based predictions for ^{7}Li and ^{6}Li now use direct experimental cross section data.
- What about deuterium from the Big Bang?

Big Bang abundance of deuterium

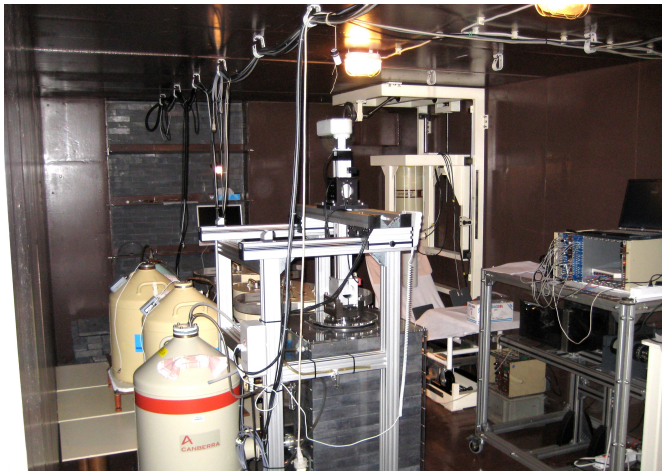


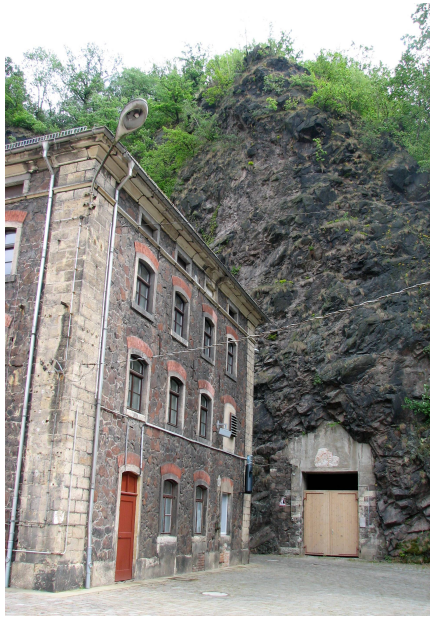


- Observations of primordial deuterium now report 1.5% precision!
- Deuterium has the potential to probe cosmological parameters, independently from the microwave background!
- Current limitation: $^2H(p,\gamma)^3He$ reaction rate, under study at LUNA.

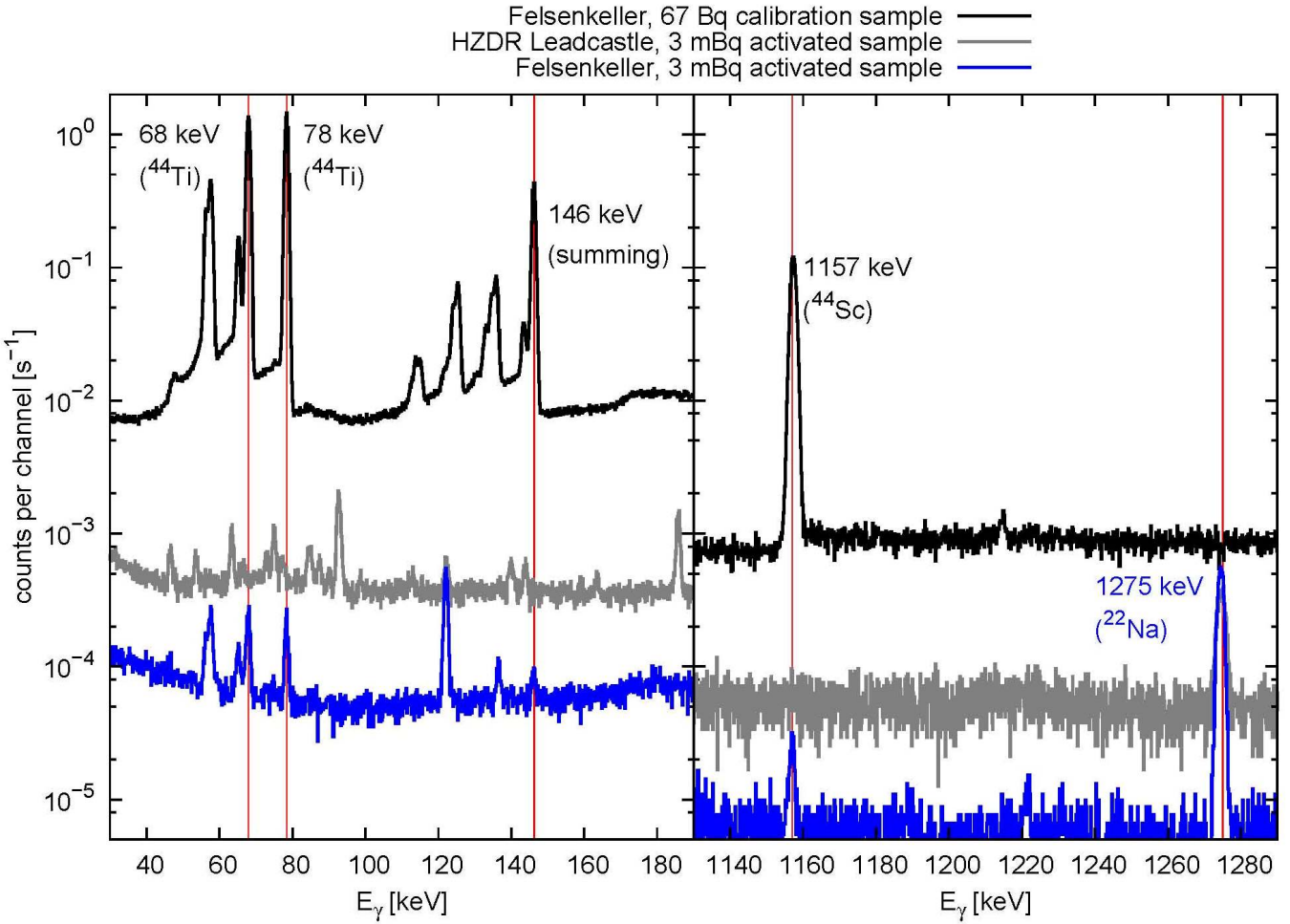
Dresden Felsenkeller, below 47 m of rock

- γ-counting facility for analytics, established 1982
- Deepest underground γ-counting lab in Germany
- Contract enabling scientific use (since 2009)
- 4 km from TU Dresden, and from city center
- 25 km from HZDR Rossendorf campus

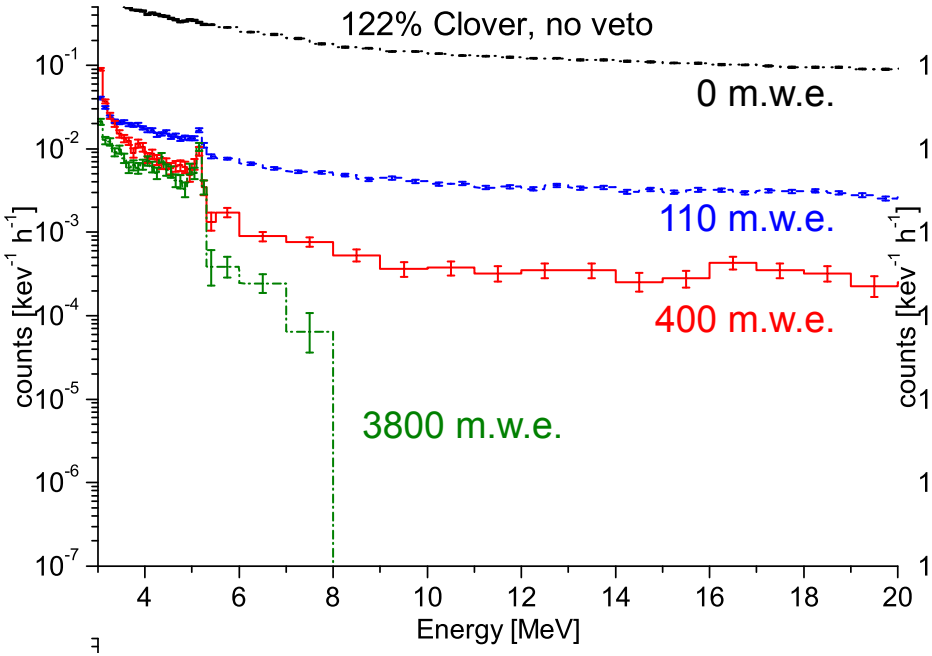


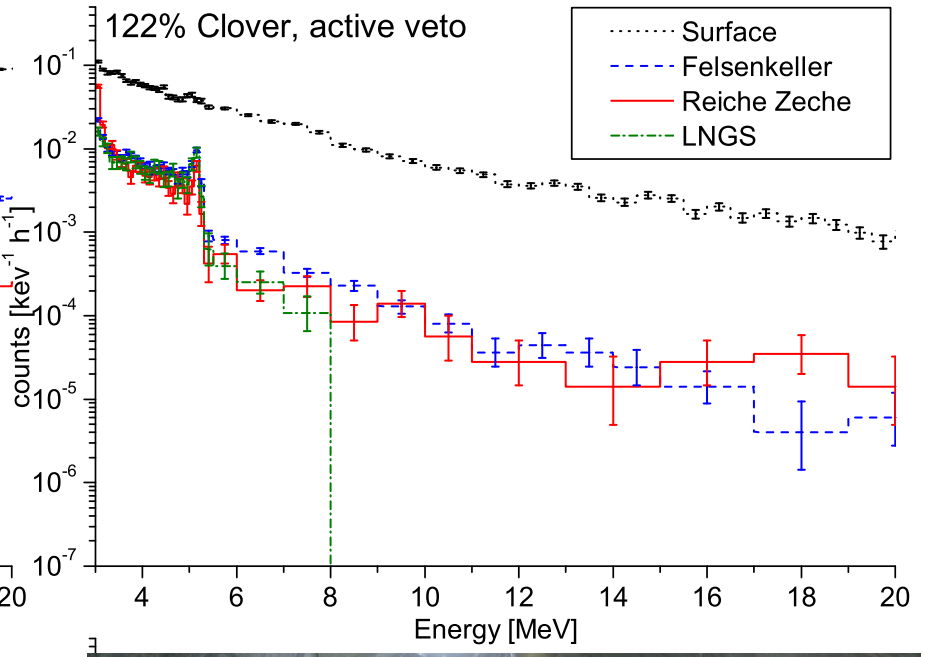


^{44}Ti production study:
Konrad Schmidt *et al.*
Phys. Rev. C 88, 025803 (2013)
Phys. Rev. C 89, 045802 (2014)

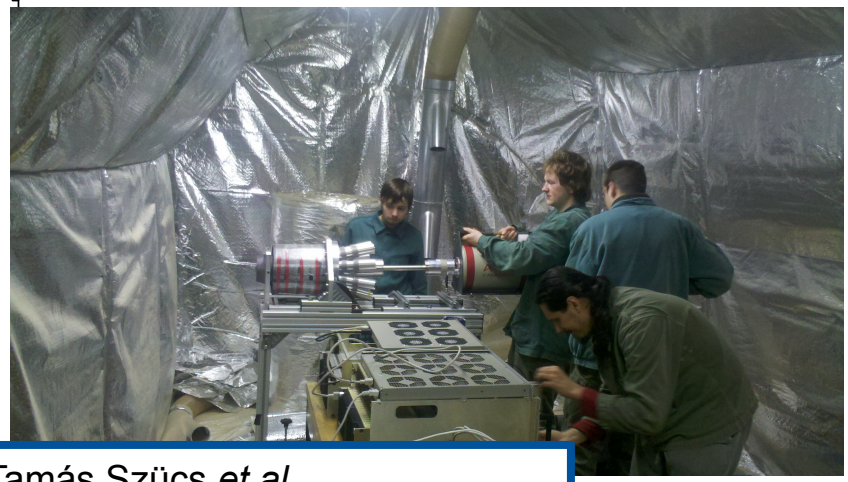


Background in γ-detectors (HPGe with active veto)





- One and the same HPGe detector (Eurisys Clover with active veto) used subsequently at different laboratories
- Background rate at 6-8 MeV γ-ray energy only a factor of 3 higher at Felsenkeller (110 m.w.e.) than at Gran Sasso
- Explanation: active veto suppresses remaining muon-induced effects



Tamás Szücs *et al.*
Eur. Phys. J. A 48, 8 (2012)
Eur. Phys. J. A 51, 33 (2015)

12 year old 5 MV Pelletron system from York/UK

- Spin-off company of York University doing ^{14}C analyses by accelerator mass spectrometry
- Magnets, beamline, pumps, fully digital control

- MC-SNICS sputter ion source (C^- and H^- ions)
- 250 µA upcharge current (double pellet chains)
- ➔ Well-suited for low-energy nuclear astrophysics

- Purchased by HZDR, brought to Dresden

12 July 2012: Still assembled, in York

24 July 2012: Loading of components in York

30 July 2012: Unloading of last component in Dresden

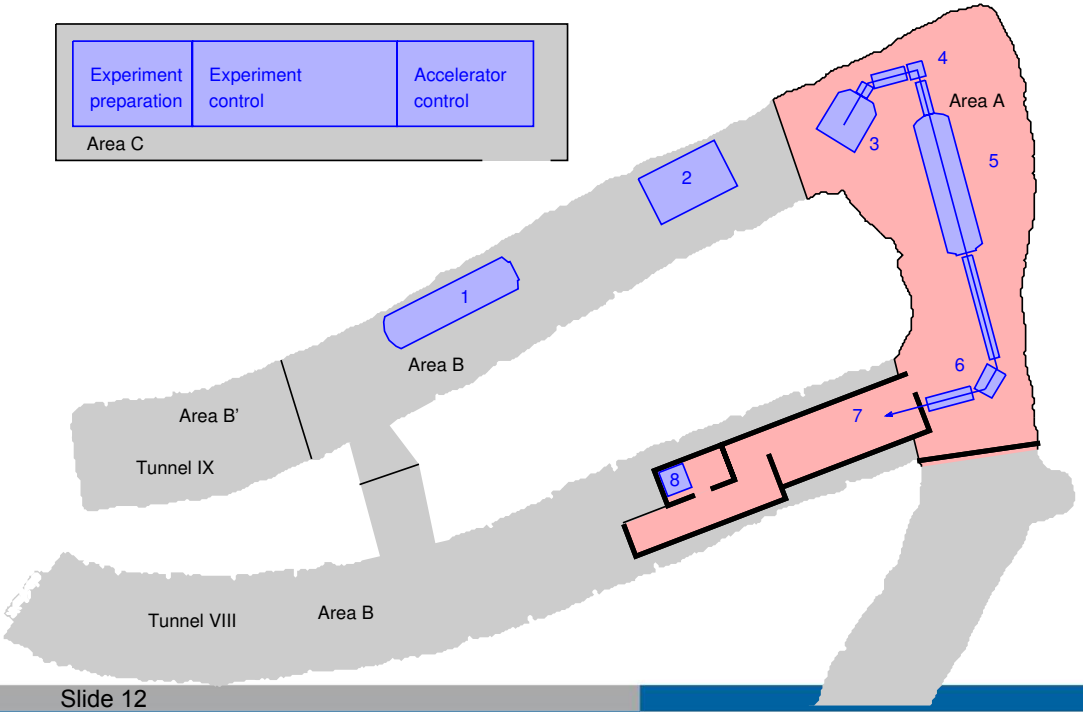
Felsenkeller status

Total investment needed+funded
- Purchase of 5 MV Pelletron (spent)
- Construction (TU Dresden, Excellence Initiative „support the best“, K. Zuber)
- Planning, infrastructure (HZDR)

Technical capabilities
- 5 MV tandem with single-ended option
- $^{1}H^{+}$, $^{4}He^{+}$, $^{12}C^{+}$ beams
- Background almost as deep underground

Running cost will be covered by HZDR
- Rent for the tunnel
- Electricity, liquid nitrogen
- 1 scientist and 1 engineer

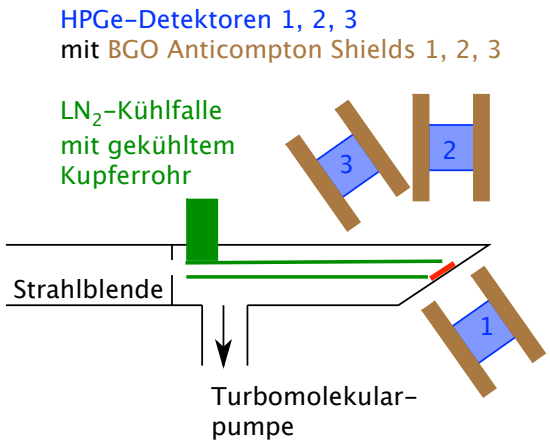
Construction ongoing August 2016 – August 2017
- Old floor has been removed, tunnel ceiling safety work underway
- Concrete-pouring from December 2016
- Opening of the facility September 2017



Experimentelle Nukleare Astrophysik Unter Tage
ENAUT collaboration at Felsenkeller accelerator, Dresden

Uni Köln (Prof. Andreas Zilges)
- $^{40}Ca(\alpha,\gamma)^{44}Ti$ reaction for ^{44}Ti nucleosynthesis
- HPGe detector #1, with μ veto

TU Dresden (Prof. Kai Zuber)
- $^{12}C(p,\gamma)^{13}N$ reaction, for solar neutrinos and ^{13}C production in AGB stars
- Solid target chamber



TU München (Prof. Shawn Bishop)
- $^{40}Ca(\alpha,\gamma)^{44}Ti$ reaction for ^{44}Ti nucleosynthesis
- HPGe detector #2, with μ veto

Uni Frankfurt (Prof. René Reifarth)
- $^{22}Ne(\alpha,\gamma)^{26}Mg$ reaction, competitor to the s-process neutron source $^{22}Ne(\alpha,n)^{25}Mg$
- List mode DAQ, electronics

+ HZDR (host lab)
- HPGe detector #3, with μ veto

TECHNISCHE UNIVERSITÄT DRESDEN
DRESDEN concept
HZDR

Experimental Nuclear Astrophysics in Germany: Facilities

GSI Darmstadt and FAIR

Cologne University

- 10 MV tandem, γ-ray spectroscopy
- 6 MV accelerator mass spectrometry

TU Darmstadt

- S-DALINAC electron beam

HZDR Dresden

- Felsenkeller 5 MV underground accelerator
- 6 MV tandem: accelerator mass spectrometry, ion beam analysis
- 3 MV tandem: in-beam γ-ray spectroscopy, activation
- 40 kV, 200 kV, 500 kV implanters
- DT neutron generator (TU Dresden), neutron time of flight
- 40 MeV electron beam ELBE
- 200 MeV proton beam Oncoray

Frankfurt University

- FRANZ neutron source

TU Munich 17 MV Tandem

- Q3D spectrograph, ion beam analysis
- Accelerator mass spectrometry

Experimental Nuclear Astrophysics in Germany: Institutions and main topics

GSI Darmstadt and FAIR

- Astrophysical r-process, including all of the below groups

Cologne University

- Astrophysical p-process

TU Darmstadt

- S-DALINAC experiments

HZDR Dresden

- H-, He-, C-burning, Big Bang nucleosynthesis
- ^{44}Ti nucleosynthesis

Frankfurt University

- Astrophysical s-process

TU Munich

- Nova nucleosynthesis
- ^{60}Fe and supernovae

Nuclear Astrophysics Experiments in Germany, and Felsenkeller laboratory Dresden

- Nuclear Astrophysics experiments are necessary to understand nucleosynthesis, and possibly even stellar structure
- Experimental results can be surprising!
- The Felsenkeller underground accelerator will provide a unique low-background capability for low-background experiments in nuclear astrophysics.
- There is a viable landscape of experimental nuclear astrophysics facilities, and of experimental nuclear astrophysics groups, in Germany