The Dresden Felsenkeller:

A shallow underground option for accelerator-based nuclear astrophysics

LUNA-MV round table, Assergi 10.-11.02.2011

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HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Mitglied der Helmholtz-Gemeinschaft

A possible accelerator in the Dresden Felsenkeller

- Science case
- γ-ray background
- Feasibility
- Status

Dresden, Germany

- 505,000 people, capital of Saxony region
- Semiconductor industry, “Dresdner Stollen” cake
- City center destroyed in 1945, now largely rebuilt (Zwinger Castle 1950’s, Church of Our Lady 2005, Royal Castle almost done)
- “La Firenze dell’Elba”
  Italian architects contributed in 1700’s
- Technical University (founded 1961), 36,000 students
- HZDR = Helmholtz-Zentrum Dresden-Rossendorf *(formerly FZD)*
  - One of 16 national laboratories (GSI, DESY, KIT...)
  - 800 staff
  - 60 M€ budget + 20 M€ projects
  1. Research with Photons, Neutrons, and Ions
  2. New Materials
  3. Cancer Research
  4. Nuclear Safety Research

HZDR campus in Dresden-Rossendorf

6 MV Tandetron (AMS)
3 MV Tandetron
40+200+500 kV implanters
2 MV van de Graaff

ELBE 40 MeV e$^-$ linac
DRACO 150 TW laser
D+T neutron generator

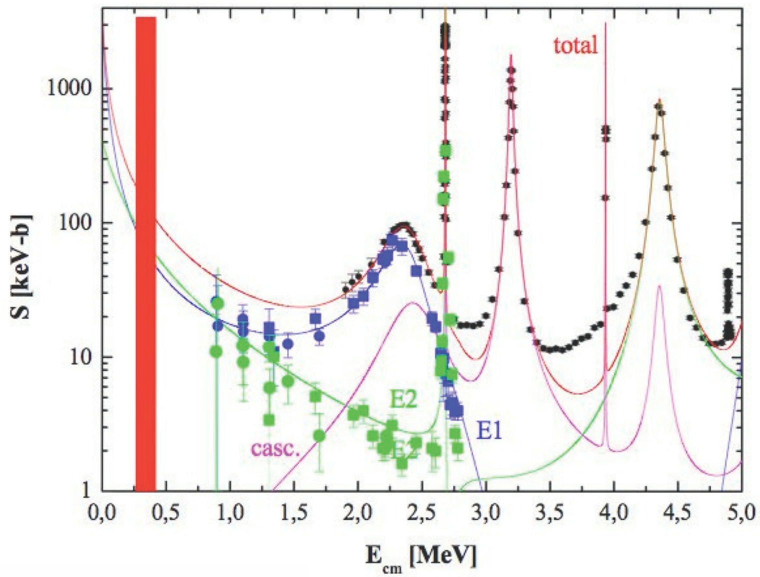
50 M€ upgrade underway

DRESDEN concept

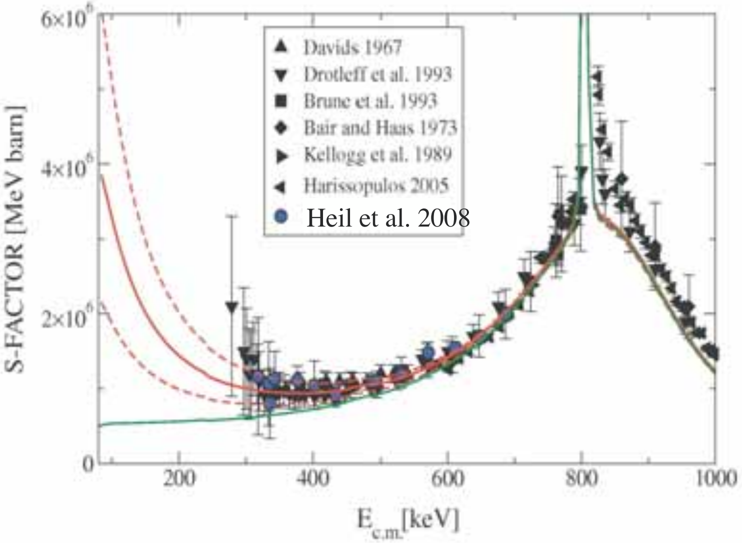
HZDR

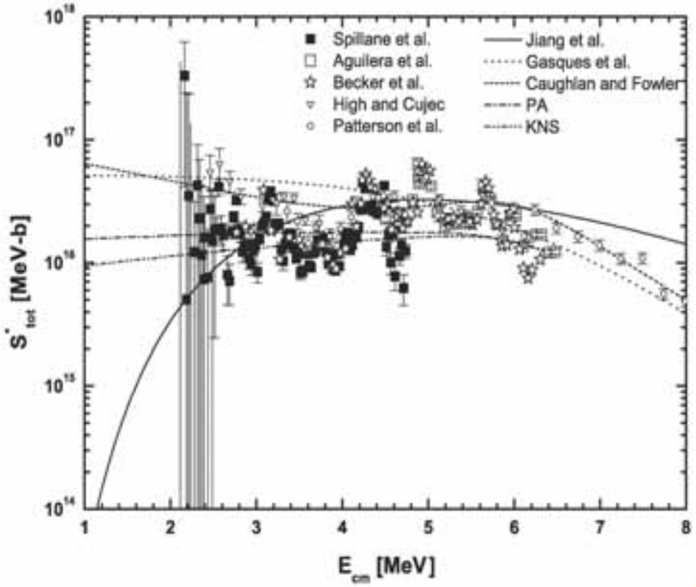
Science case for a higher-energy accelerator underground (1)

Helium burning
- $^{12}C(\alpha,\gamma)^{16}O$
- $^{14}N(\alpha,\gamma)^{18}F$
- $^{15}N(\alpha,\gamma)^{19}F$
- $^{18}O(\alpha,\gamma)^{22}Ne$



Neutron sources for the s-process
- $^{13}C(\alpha,n)^{16}O$
- $^{22}Ne(\alpha,n)^{25}Mg$



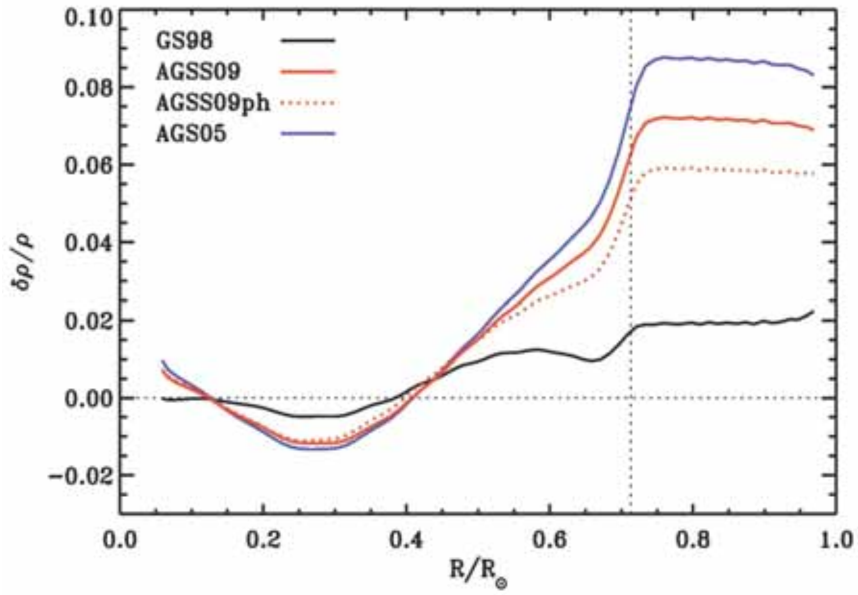


Carbon burning
- $^{12}C(^{12}C,\alpha)^{20}Ne$

DRESDEN concept

HZDR

Science case for a higher-energy accelerator underground (2)

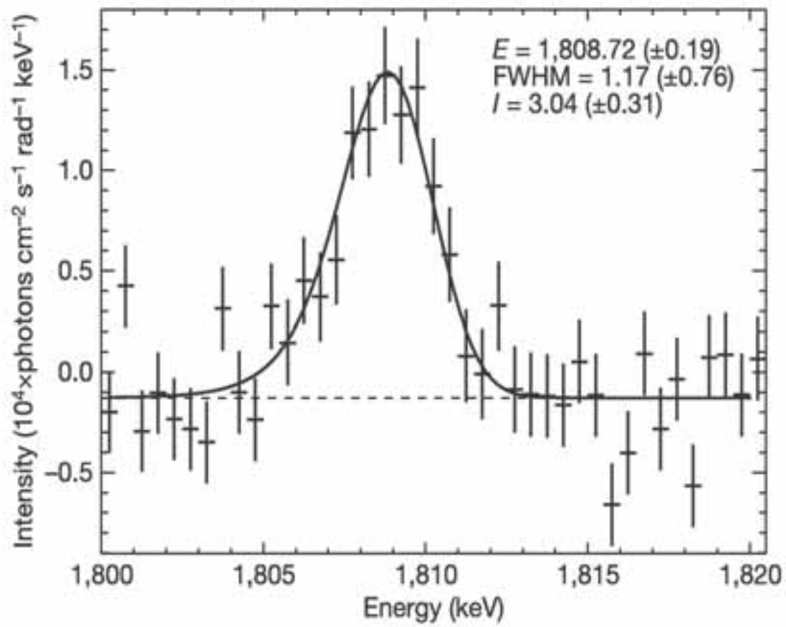


Solar composition problem

- $^{3}He(\alpha,\gamma)^{7}Be$, E>0.4 MeV
- $^{14}N(p,\gamma)^{15}O$, E>0.4 MeV

Radionuclides seen in space based observatories

- ^{26}Al, ^{44}Ti, ^{60}Fe

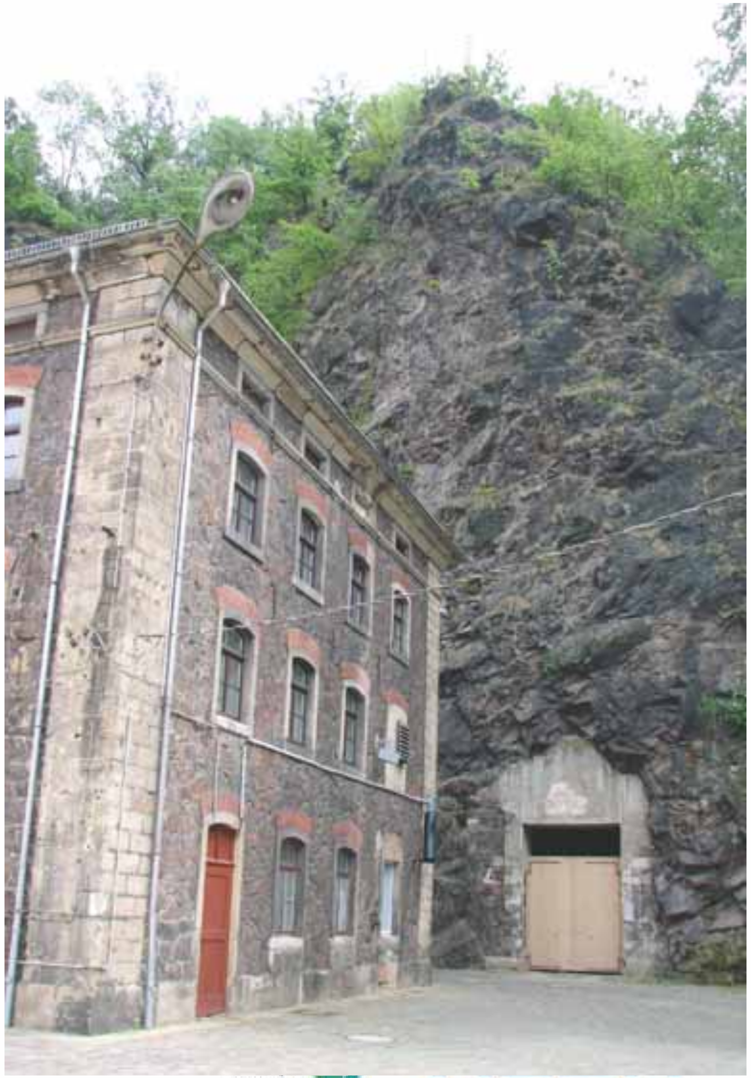


Applied physics

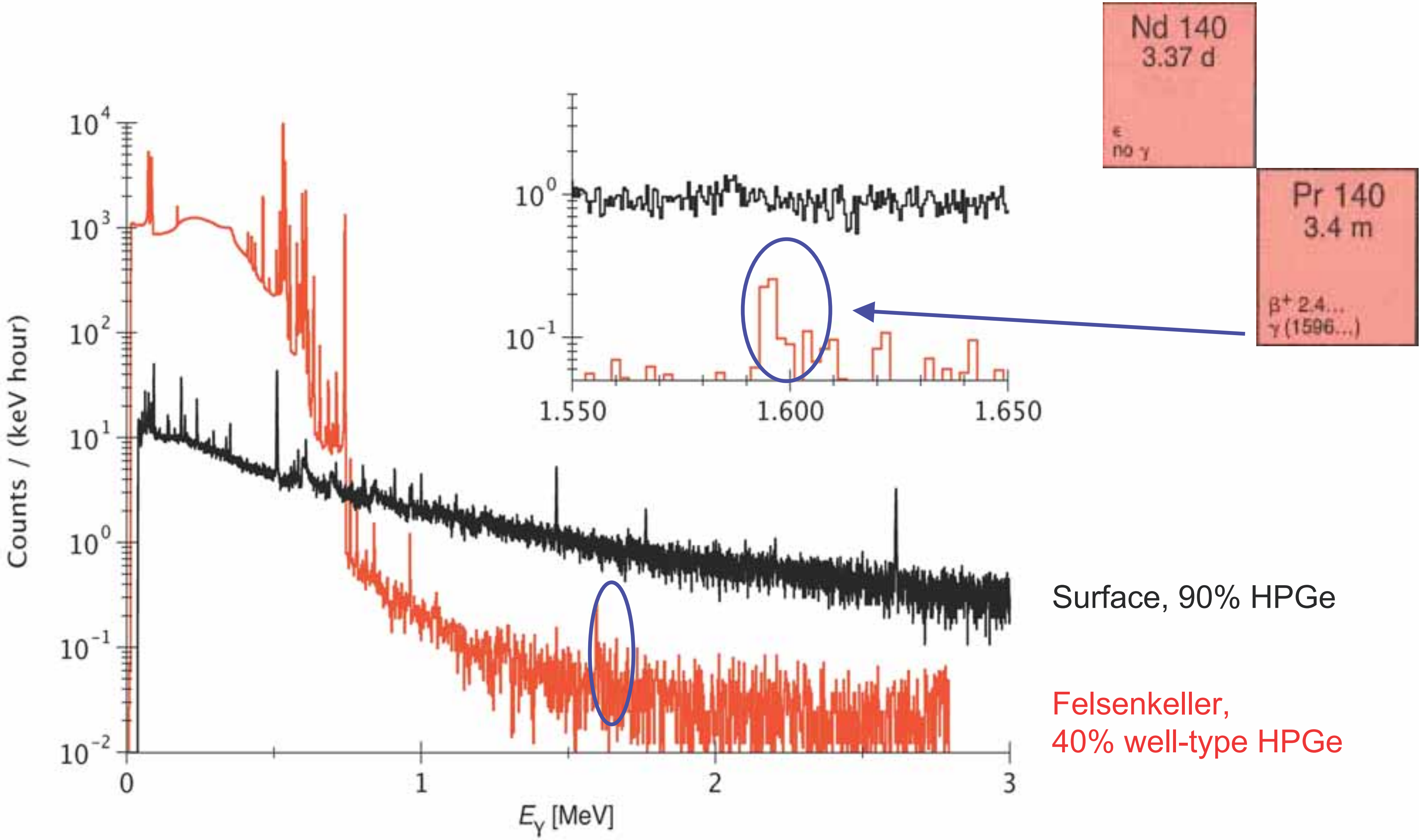
- $^{1}H(^{15}N,\alpha\gamma)^{12}C$, hydrogen depth profiling

Dresden underground laboratory: Felsenkeller, below 47 m of rock

- γ-counting facility for analytics, established 1982
  founding member of CELLAR collaboration
- 10 HPGe detectors
- Since 2009, contract enabling scientific use of Felsenkeller by HZDR and TU Dresden
- Several active Masters+PhD theses using Felsenkeller
- 5 km from TU Dresden, 25 km from HZDR campus

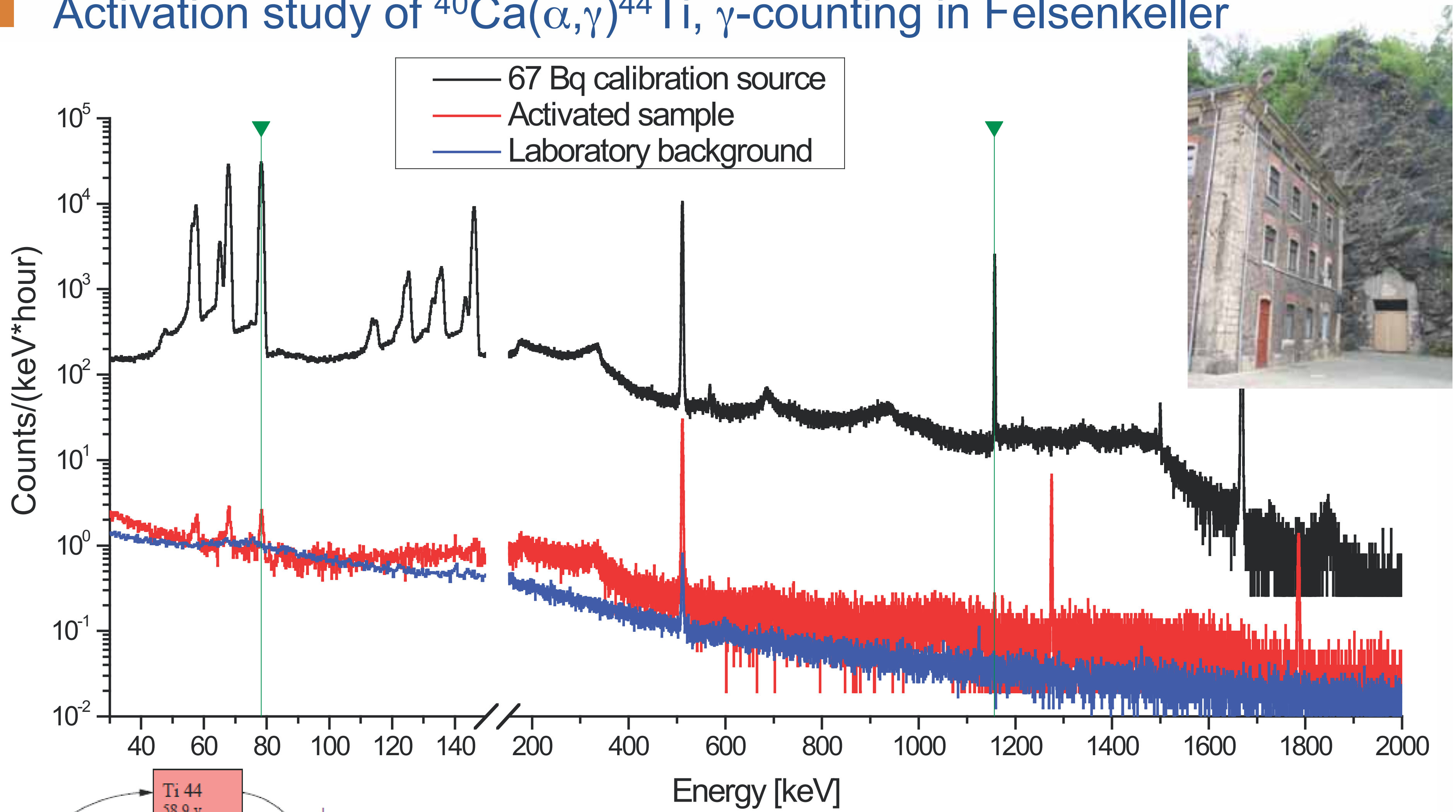


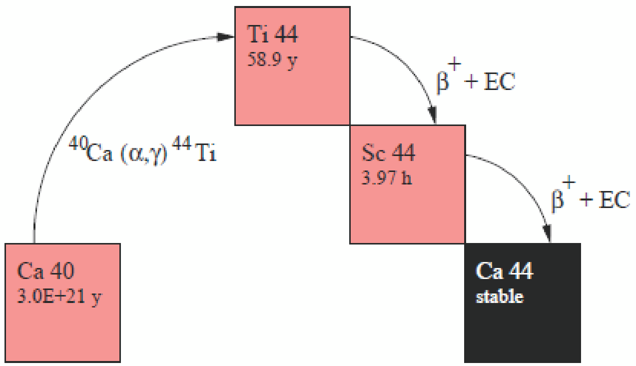
Photoactivation study at Felsenkeller: $^{144}Sm(\gamma,\alpha)^{140}Nd(EC)^{140}Pr$



C. Nair et al., Phys. Rev. C 81, 055806 (2010)

Activation study of $^{40}Ca(\alpha,\gamma)^{44}Ti$, γ-counting in Felsenkeller





K. Schmidt, Master's thesis TU Dresden (2011)

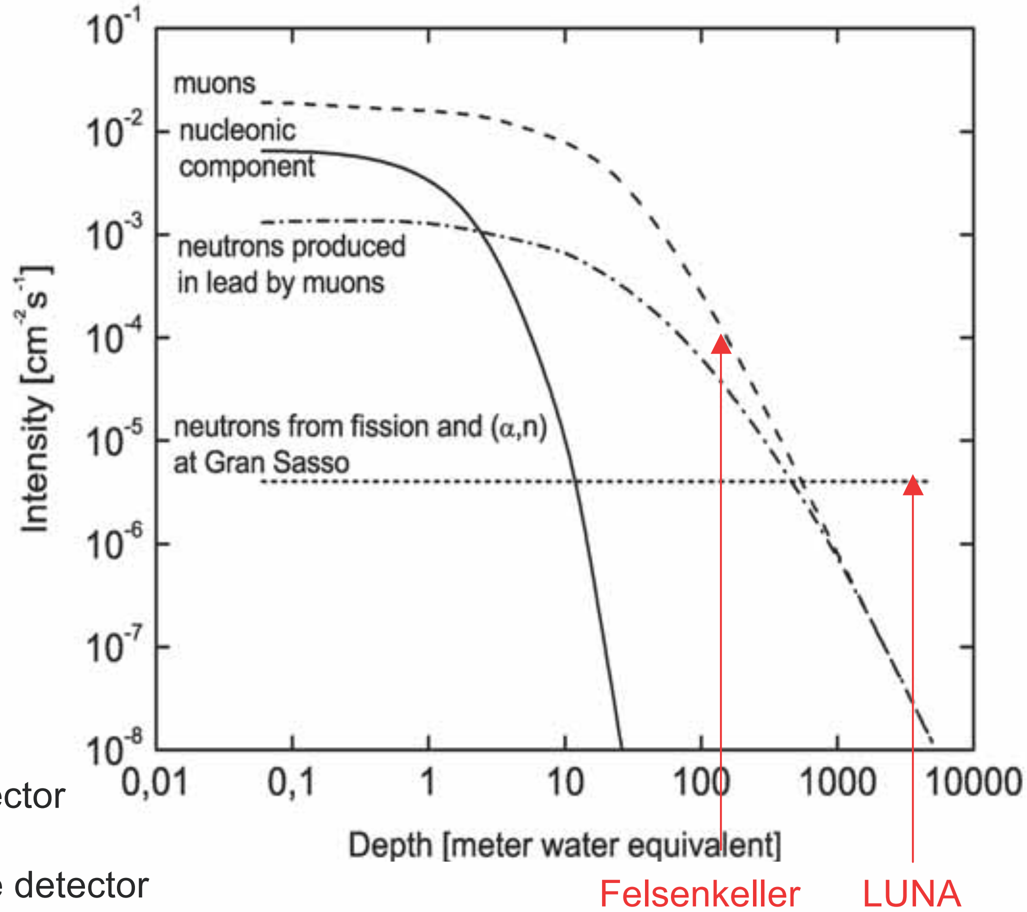
Laboratory background in γ-ray detectors underground

Benchmark: LUNA, detailed in three papers:

1. Unshielded HPGe (plus large BGO):
   D. Bemmerer et al.,
   Eur. Phys. J. A 24, 313 (2005)

2. Shielded HPGe:
   A. Caciolli et al.,
   Eur. Phys. J. A 39, 179 (2009)

3. HPGe with active shield:
   T. Szücs et al.,
   Eur. Phys. J. A 44, 513 (2010)



The issues are:

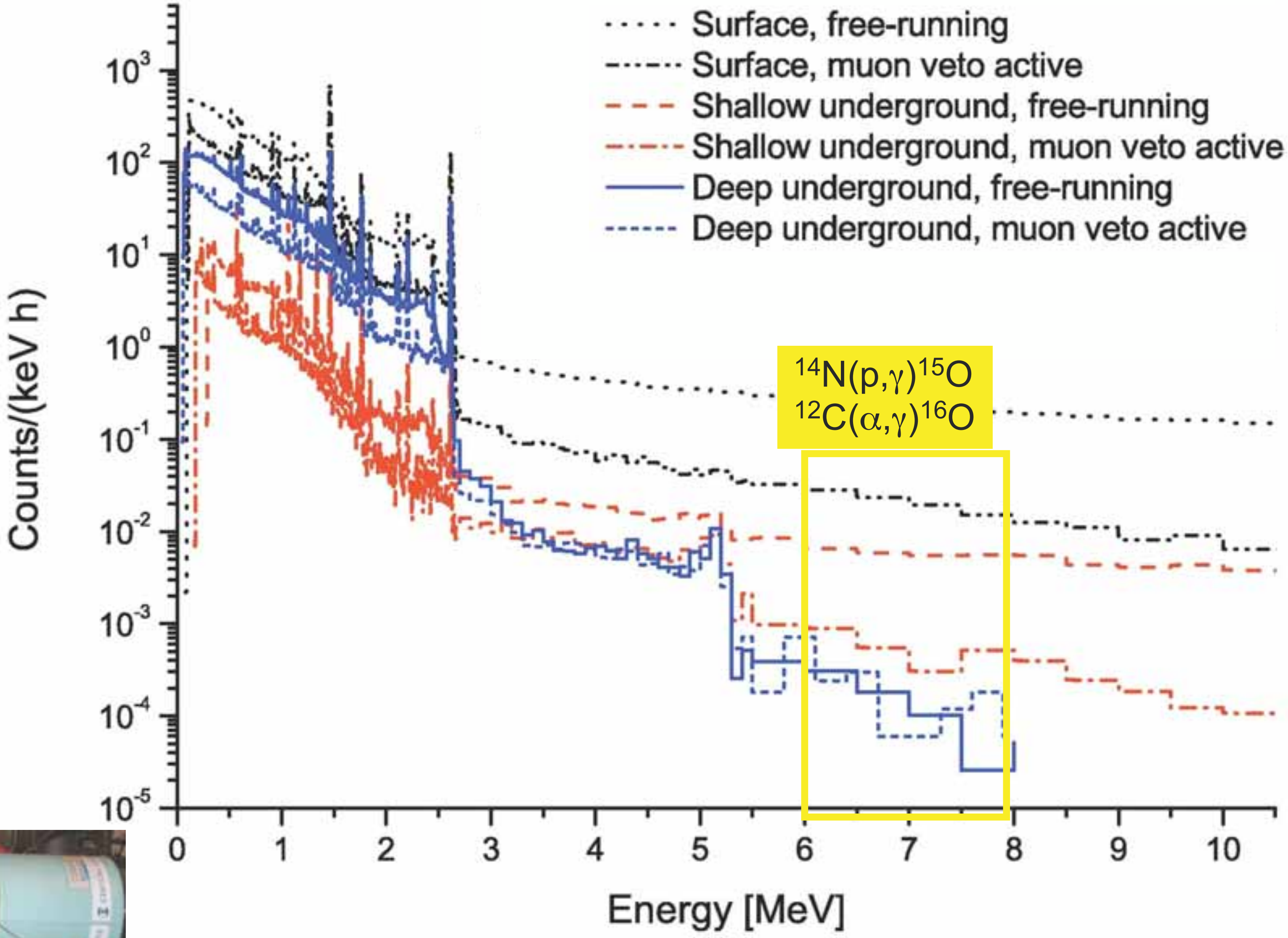
- Interaction of cosmic-ray nucleons in the detector
  →10m rock
- Energy loss of passing/stopping muons in the detector
  →active shield
- Neutrons generated by (α,n) reactions from natural radioactivity in the walls
  →Pb/Fe shield
- Neutrons generated by muons in the passive shield
  →1000m rock

γ-background comparison in a "traveling" HPGe detector, combining rock overburden with active shield (muon veto)

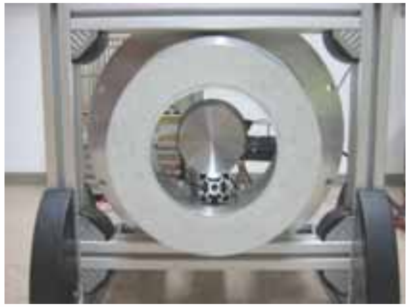
CLOVER HPGe detector, with BGO anticompton shield

+at LUNA
T. Szücs et al., Eur. Phys. J. A 44, 513 (2010)

+at Felsenkeller

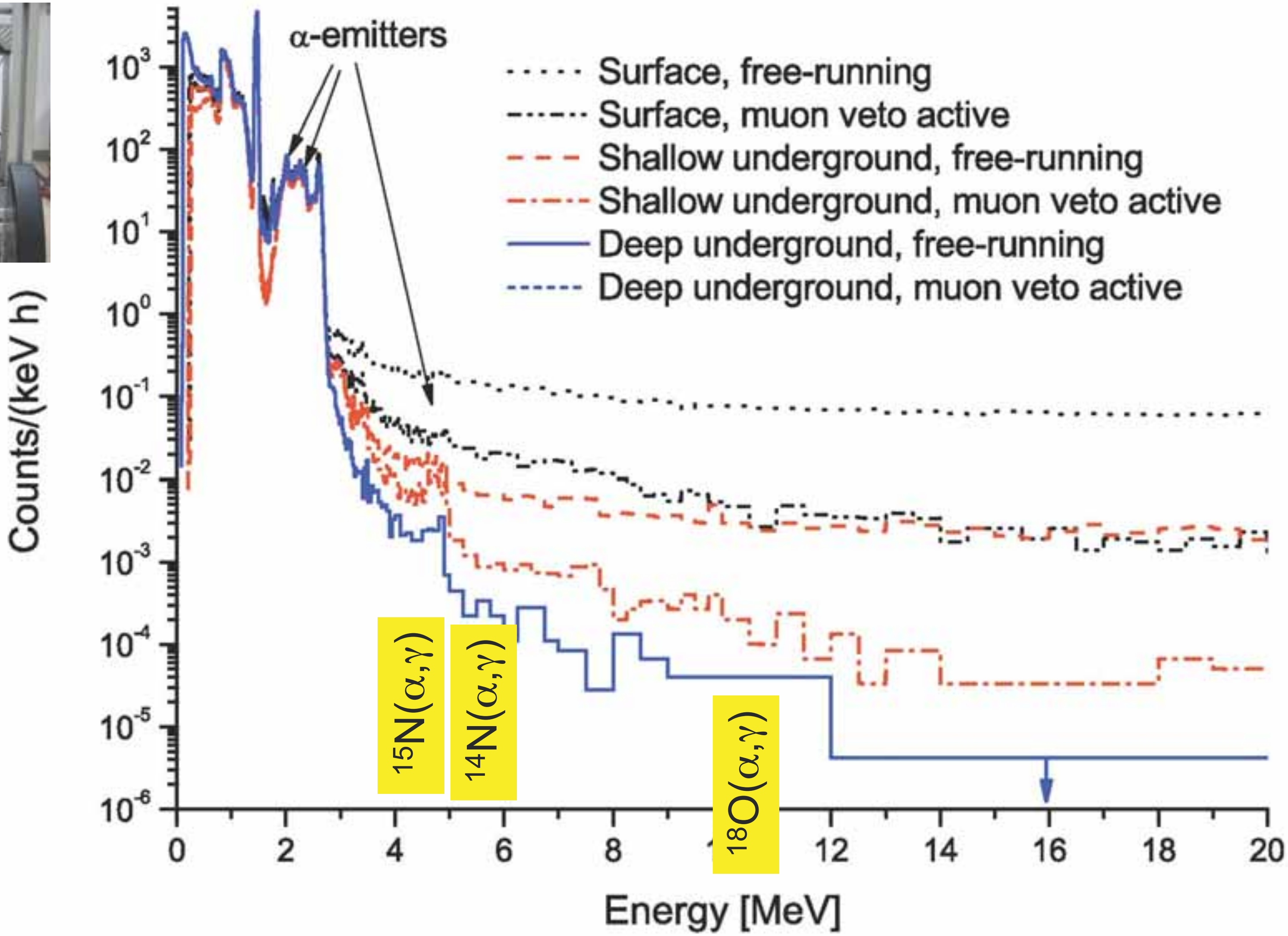


γ-background comparison in a “traveling” $LaBr_3$ detector, combining rock overburden with active shield (muon veto)

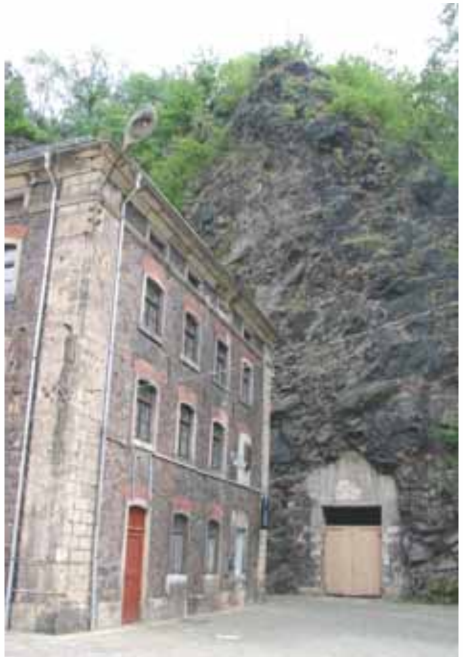


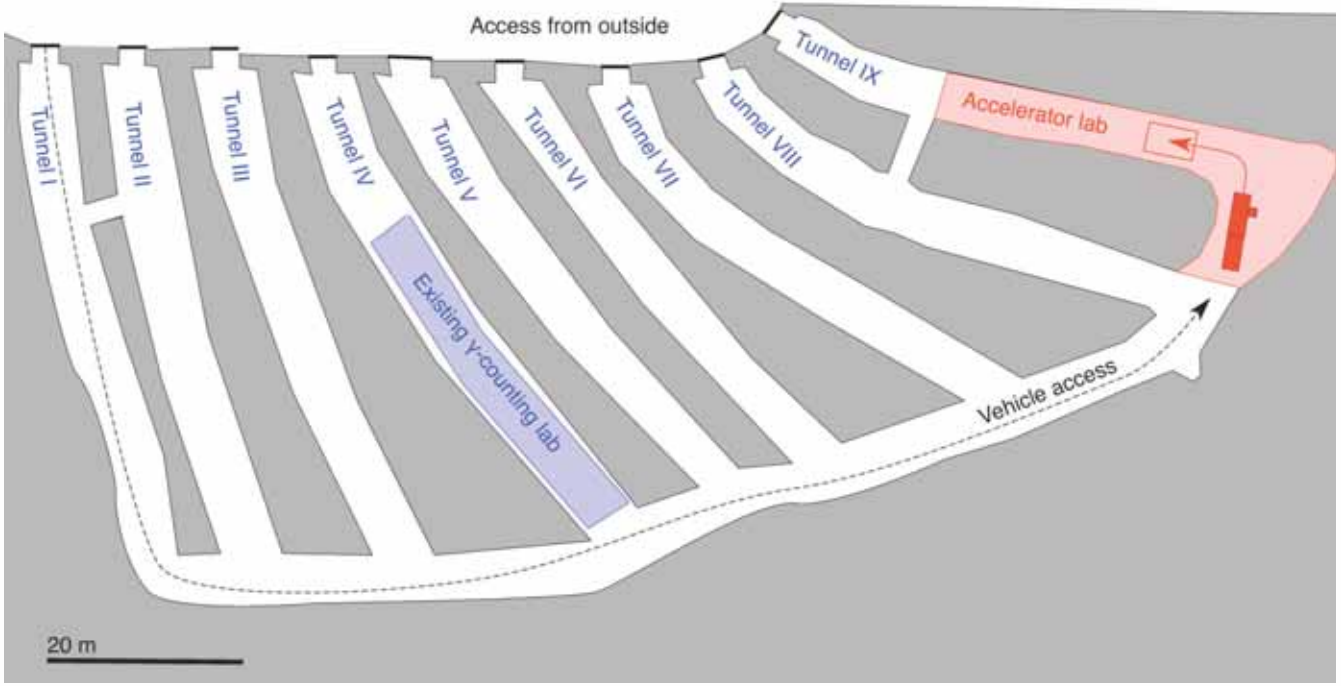
$LaBr_3$ detector, inside BGO active shield

2010 at LNGS and at Felsenkeller



Felsenkeller, possible site for an accelerator





- Tunnels exist since the 1850's, currently used for storing sausage skins, truck parking, etc.
- Inside Dresden city limits, trucks can drive in, technicians available at HZDR
- Startup possible with a used accelerator (3 MV, 0.1 mA α-beam, ion source on HV terminal)
- International user facility, fulfilling mission statement of HZDR parent organization Helmholtz

Pros and cons, possible accelerator in Felsenkeller

Con

- Higher background than deep underground facilities
- Might be perceived as competition by deep-underground projects
- Limited nuclear astrophysics community in Dresden

Pro

- No holes need to be dug (or pumped dry)
- No dark-matter search nearby
- Background only 3-10 times worse than LUNA
- Comparatively economical
- Students can come from local university by bicycle
- Experience+engineers for accelerator problems available at HZDR
- Related facilities at Dresden: DT-Generator, ELBE, ion beam center, AMS
- Part of a staged approach, may actually help more complex+expensive projects gather speed
- Active, and young German+European nuclear astrophysics community
- Science complementary with other upcoming facilities (FAIR, FRANZ)

The European perspective

- 1st Workshop on "Underground nuclear-reaction experiments for astrophysics and applications", Dresden/Germany April 2010: *30 participants from 8 countries, all projects represented*
  `http://www.hzdr.de/felsenkeller`
  "Due to the extensive science programme, the long running time per experiment, and the number of researchers involved (...), most participants see it necessary to call for at least two European underground facilities to be realized. (...) A consensus emerged that all facilities should be as open as possible to the community (...). The observational and computational astrophysicists should be included at the earliest stage, helping drive and define the science agenda and creating the added value of multidisciplinarity (...)".

- NuPECC Long Range Plan 2010, released on 8 December 2010:
  `http://www.nupecc.org`
  "An immediate, pressing issue is to select and construct the next generation of underground accelerator facilities. Europe was a pioneer in this field, but risks a loss of leadership to new initiatives in the USA. Providing an underground multi-MV accelerator facility is a high priority. There are a number of proposals being developed in Europe and it is vital that construction of one or more facilities starts as soon as possible."

- "Round Table LUNA-Megavolt at Gran Sasso", Gran Sasso/Italy 10.-11.02.2011

- 3rd workshop on "Underground nuclear-reaction experiments for astrophysics and applications" Canfranc/Spain, April 2012

Summary, a possible accelerator in the Dresden Felsenkeller

- Successful workshop in Dresden in April 2010
  - → suggestion for present workshop came up
  - → Next follow-ups: 2012 at Canfranc/Spain (L. Fraile), 2013 Boulby/UK (M. Aliotta)
- Rich science case
  - → recommendation from NuPECC for “one or more projects” to be started “as soon as possible”
- Combining shallow underground with active veto: background ~factor 3 worse than deep underground
- Staged approach is possible:
  fast+shallow accelerators help slower+deep underground accelerators
- Presently in discussions to obtain a used accelerator