Recent measurements from Felsenkeller shallow - underground laboratory

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18th Russbach School on Nuclear Astrophysics
Mar 12 – 18, 2023

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HZDR
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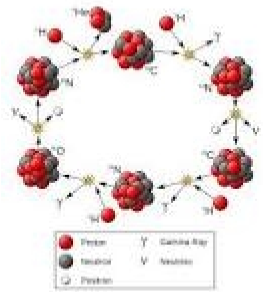
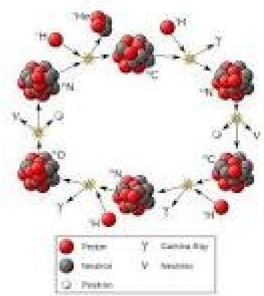
Felsenkeller laboratory

Felsenkeller laboratory



$^{12}C(p,\gamma)^{13}N$ reaction at energies above 400 keV

Felsenkeller laboratory



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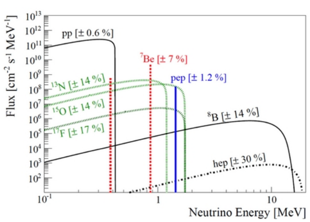
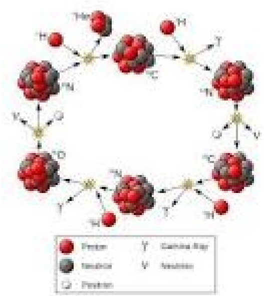
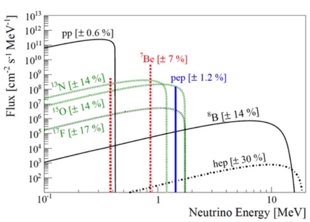


Solar neutrinos and $^{3}He(^{4}He,\gamma)^{7}Be$ reaction

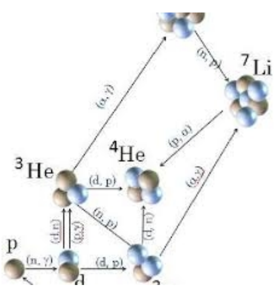
Felsenkeller laboratory



$^{12}C(p,\gamma)^{13}N$ reaction at energies above 400 keV

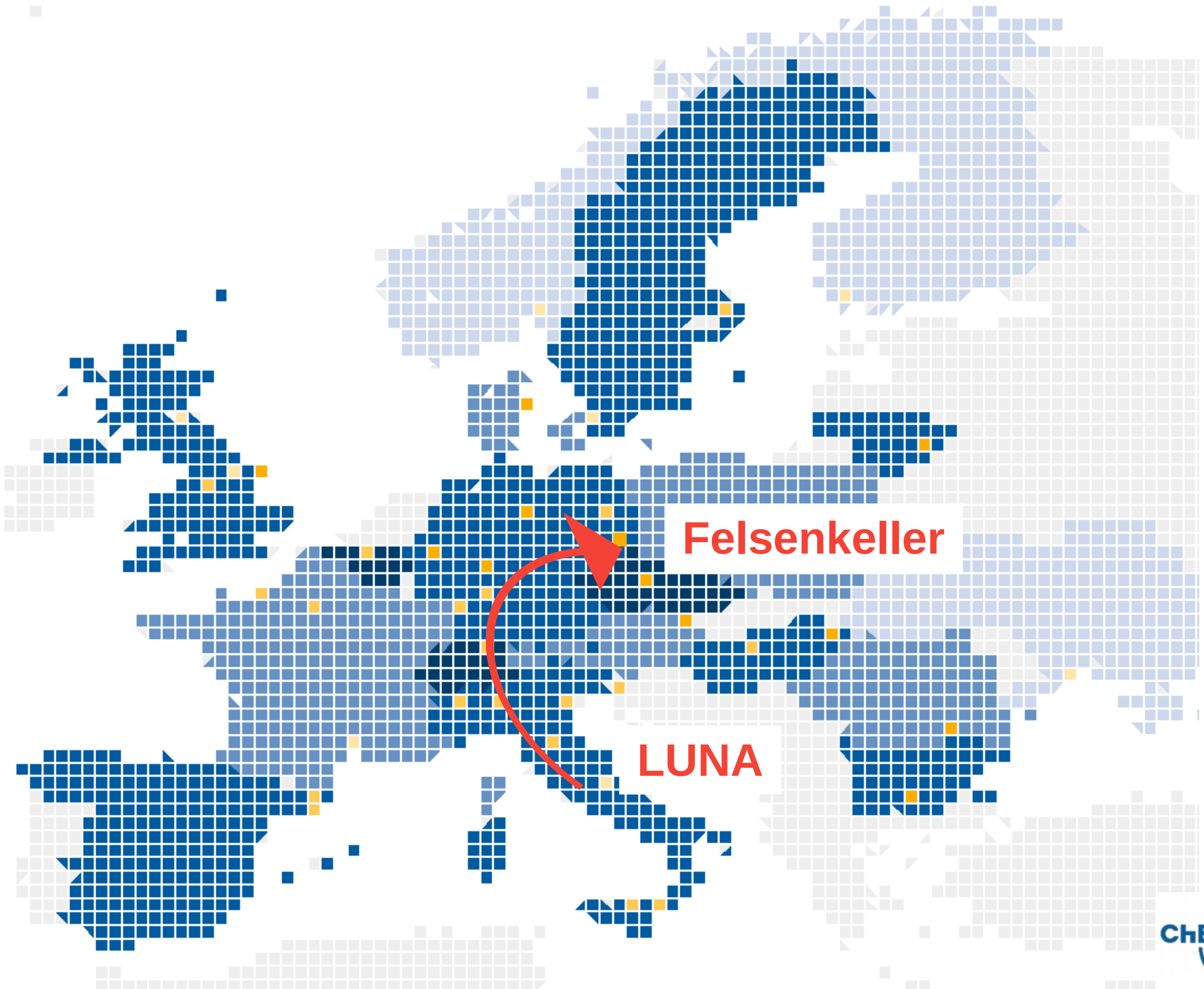


Solar neutrinos and $^{3}He(^{4}He,\gamma)^{7}Be$ reaction

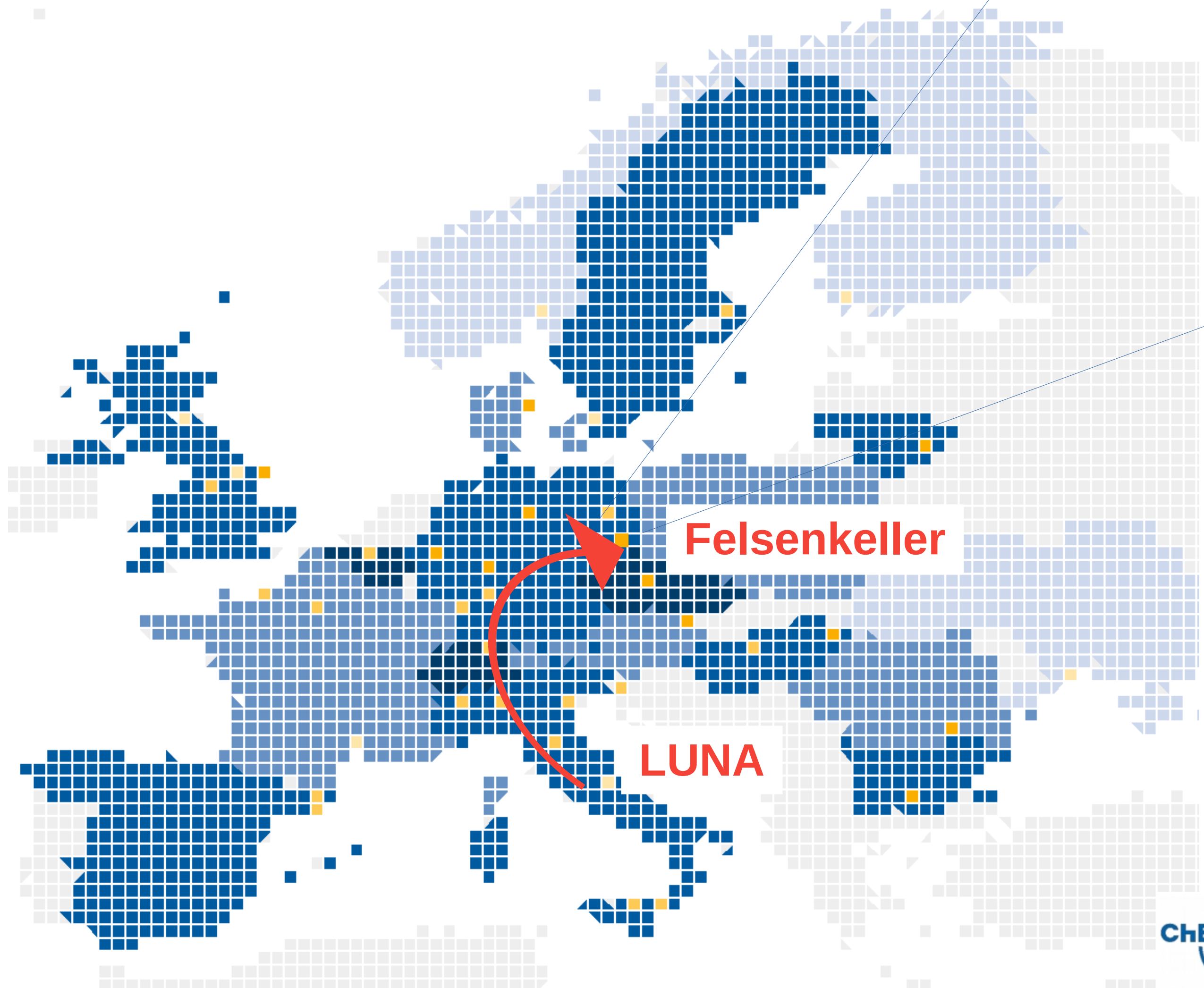


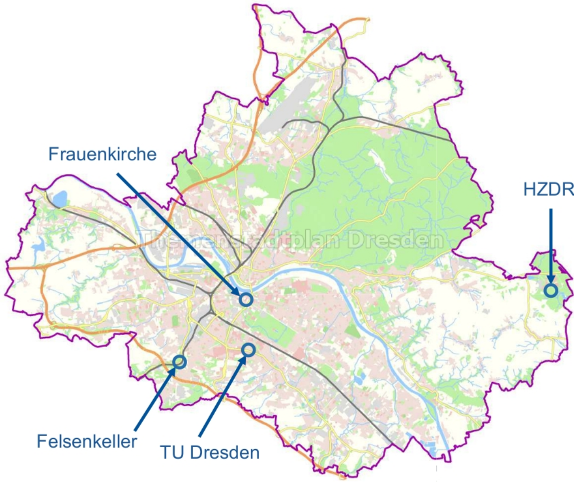
Big Bang Nucleosynthesis (BBN) and $^{2}H(p,\gamma)^{3}He$ reaction

Felsenkeller shallow-underground laboratory



Felsenkeller shallow-underground laboratory

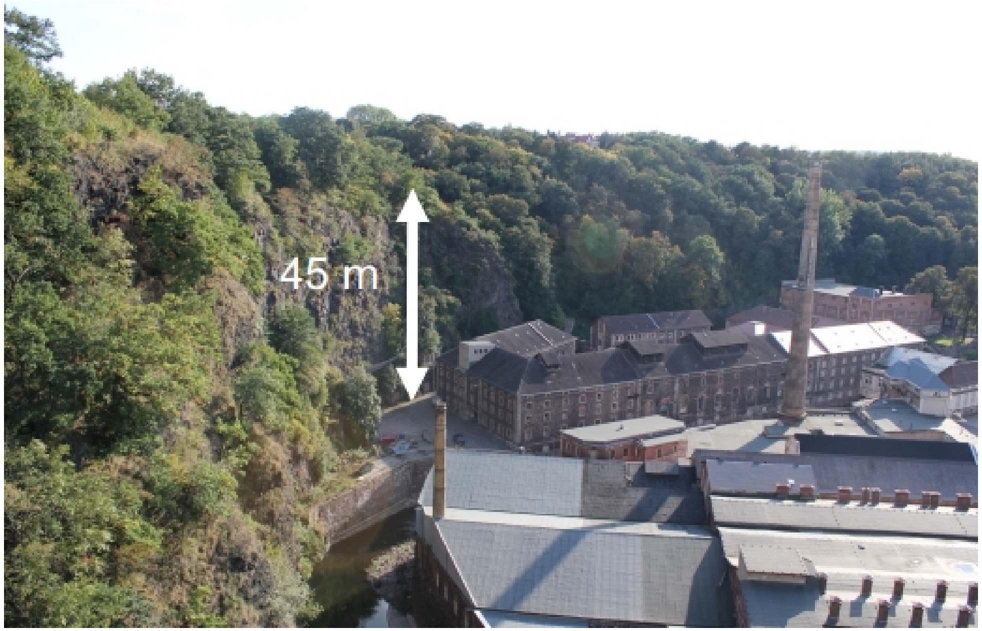


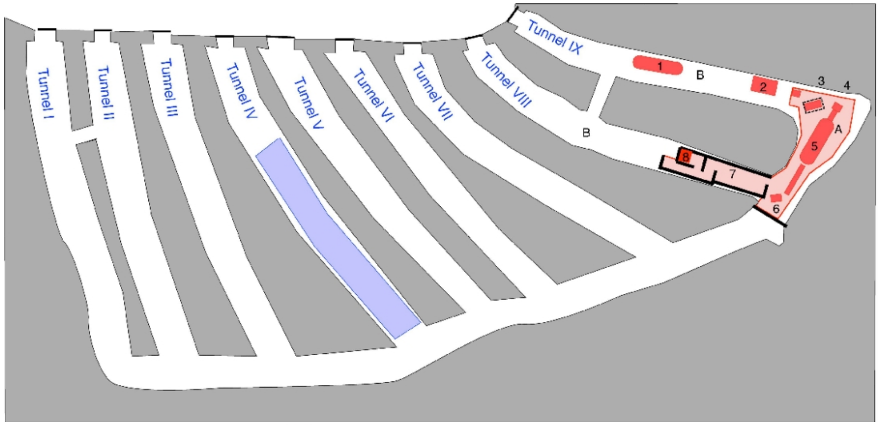


CHETEC INFRA DRESDEN concept HZDR

Felsenkeller shallow-underground laboratory

- Located in Dresden, Germany. Joint project:
  - TU Dresden (Prof. K. Zuber)
  - HZDR (Prof. D. Bemmerer)
- System of nine tunnels built for Felsenkeller brewery in 1859
- 24h beam operation permitted
- Surface offices / operator room
- Laboratory accessible with beam on target

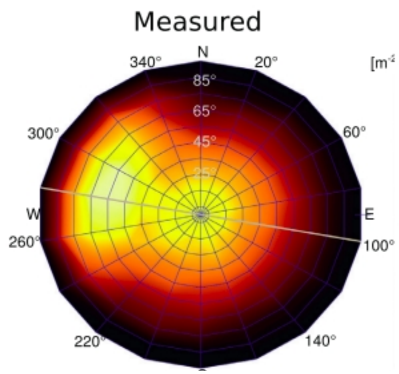


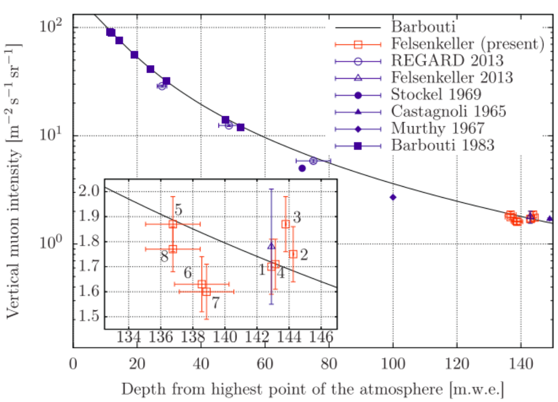


Felsenkeller shallow-underground laboratory

Background fully characterized

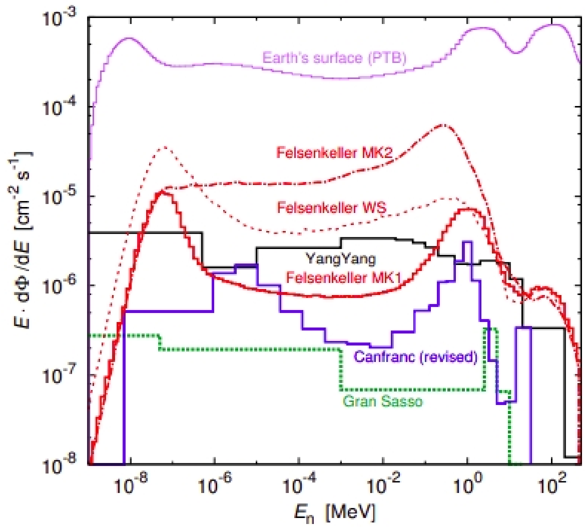
Muon flux: 40x reduced

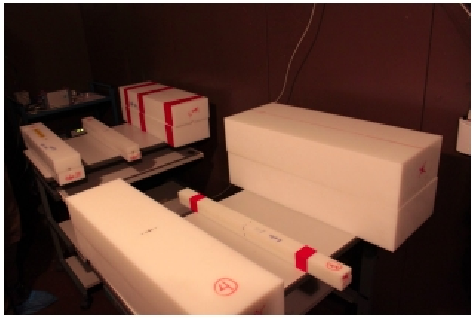




Astropart. Phys. 112, 24 (2019)

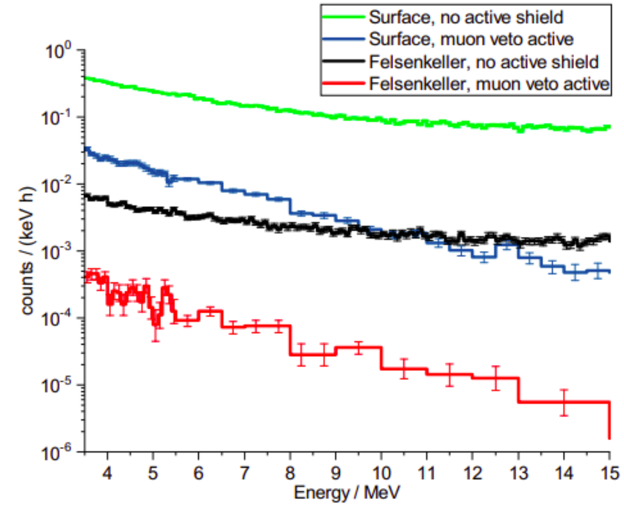
Neutron flux: 180x reduced





Phys. Rev. D 101, 123027 (2020)

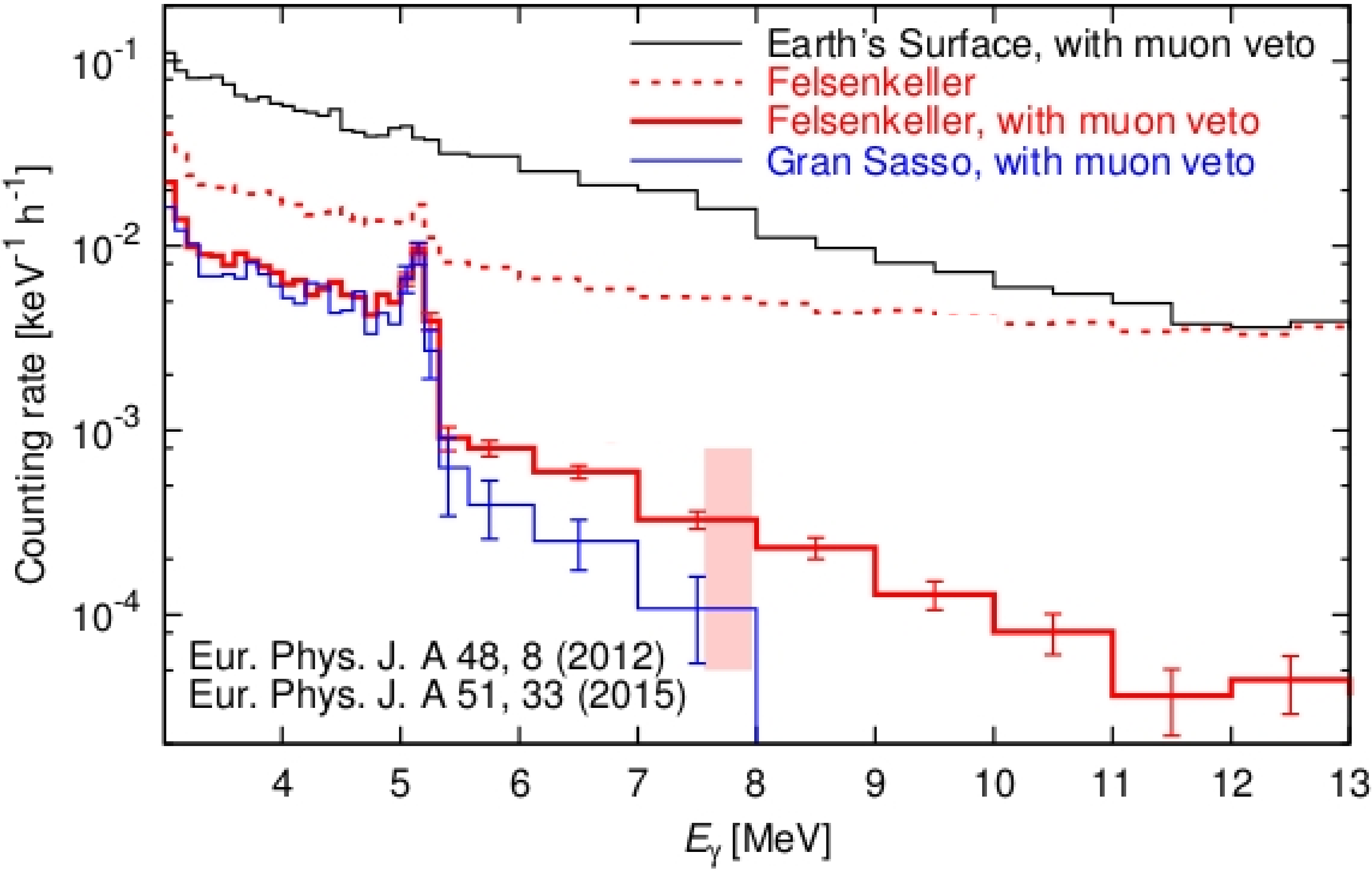
γ-ray background: 2500x reduced with muon veto



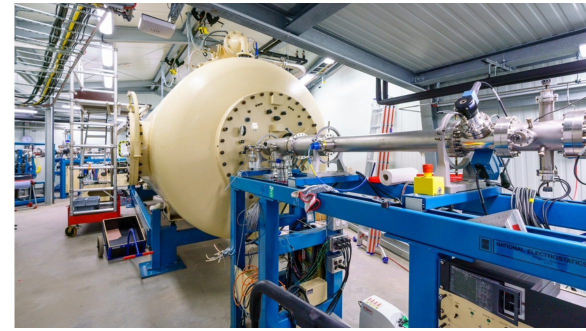
Eur. Phys. J. A 55, 174 (2019)

Felsenkeller shallow-underground laboratory

Background reduction compared with LUNA and surface lab

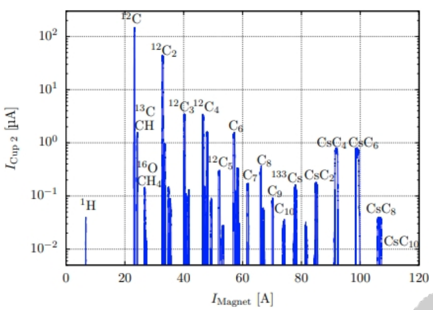


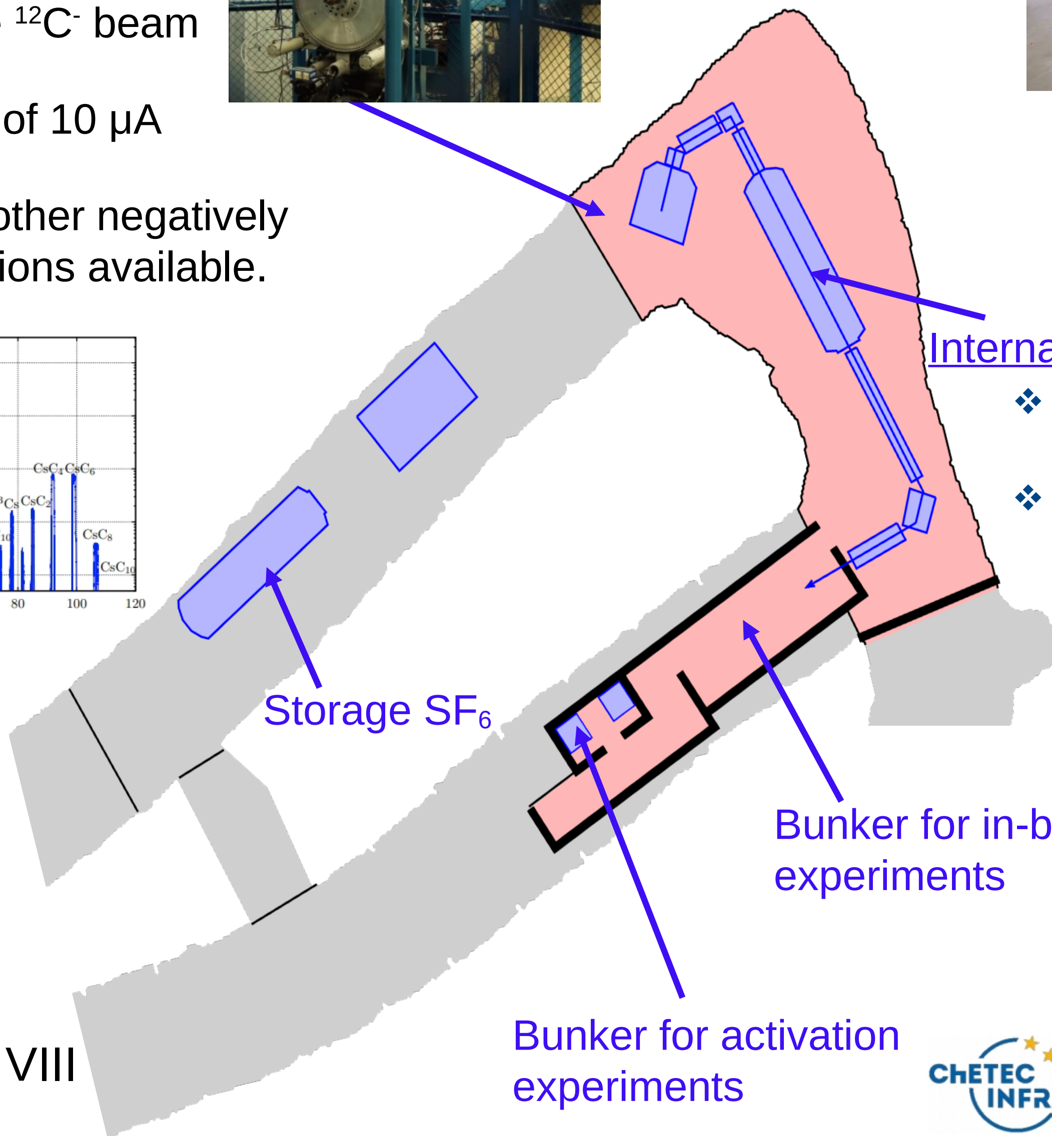
Felsenkeller shallow-underground laboratory



External ion-source

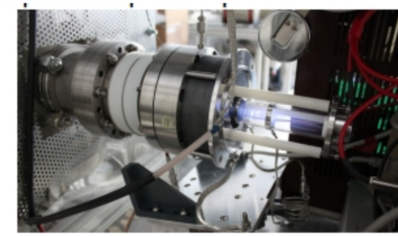
- Intensive $^{12}C^{-}$ beam
- Intensity of 10 μA
- Several other negatively charged ions available.





Internal radio frequency ion-source

- Intensive ^{2}H and ^{4}He beams
- Beam current up to 30 μA



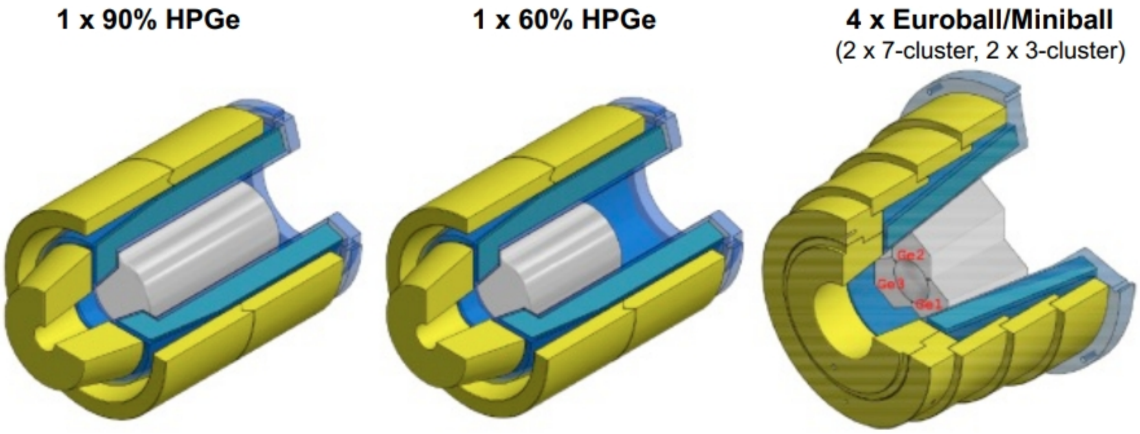
Felsenkeller as a User Facility

Beam time at the Felsenkeller is available for user proposals

ChETEC-INFRA Transnational Access facility: Recent project

Felsenkeller Scientific Advisory Board

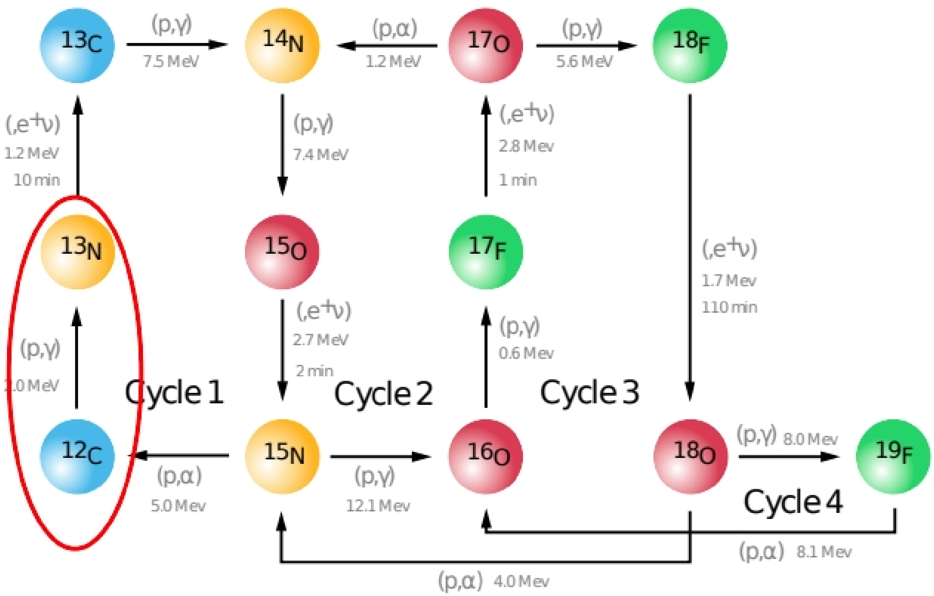
Available multiple High Purity Germanium detectors (with active and passive shielding and collimators)

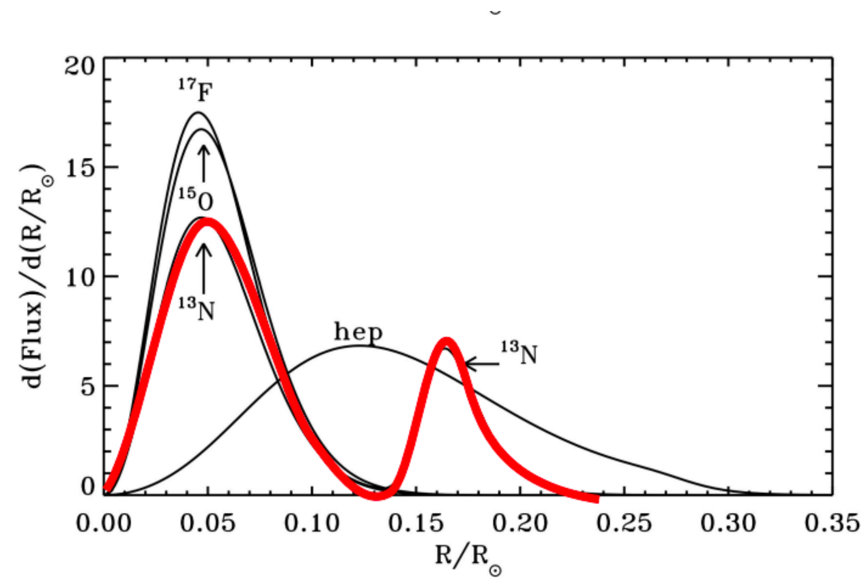


T. Szücs et al., Eur. Phys. J. A 55, 174, 2019

$^{12}C(p,\gamma)^{13}N$ reaction: Astrophysical motivation

The **$^{12}C(p,\gamma)^{13}N$** reaction one of the main sources of the solar CNO neutrino flux (Borexino data), through the beta-decay of ^{13}N





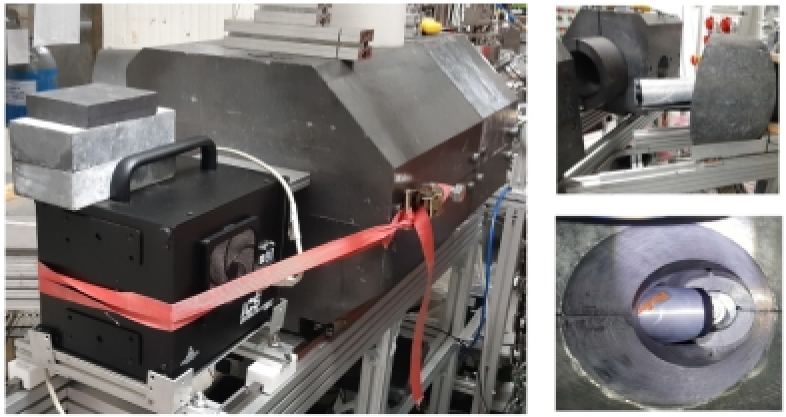
Bahcall *et al.* (2006)

The $^{12}C/^{13}C$ ratio is a significant indicator of nucleosynthesis and mixing processes during hydrogen burning in stars

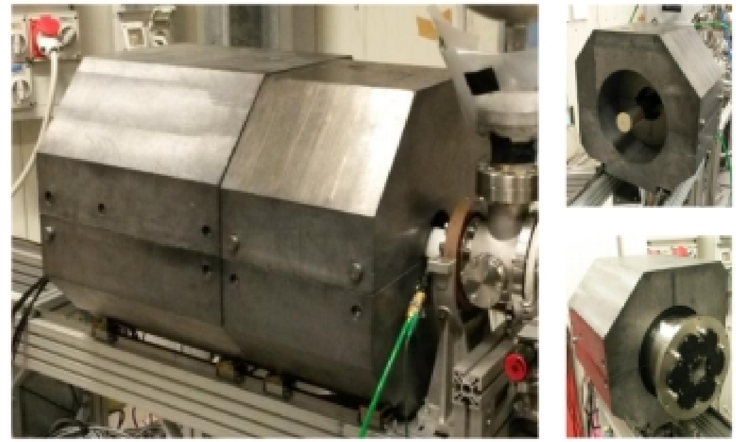
Deviations within and between models, simulations and experimental data

$^{12}C(p,\gamma)^{13}N$ reaction: low energy data

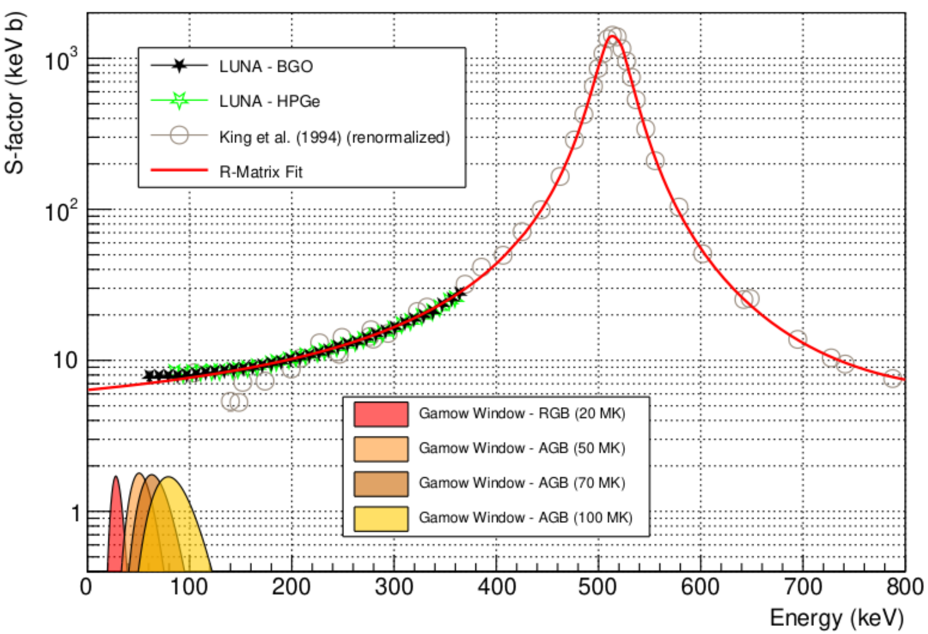
HPGe phase



BGO phase



More info: R. Depalo talk



LUNA data 25% lower than literature!

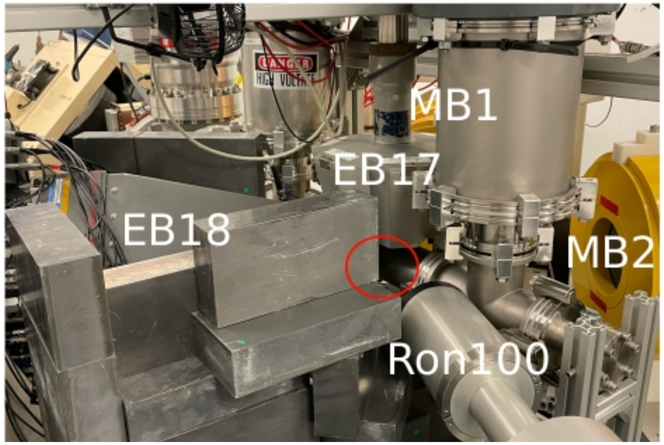
Skowronski *et al.* (2023) submitted

→ **High energy data nedeed!**

$^{12}C(p,\gamma)^{13}N$ reaction: Experimental setup

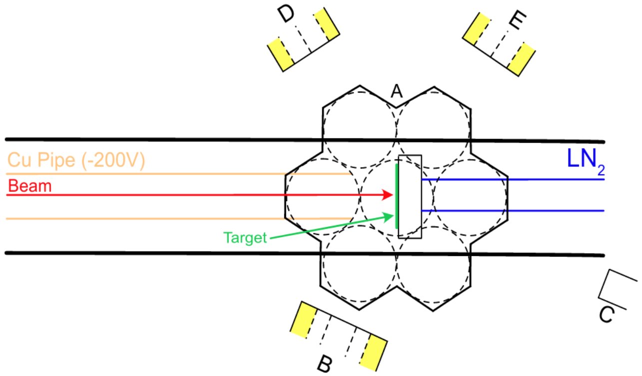
Detector	Crystals; rel. efficiency	Angle
EB17	$7 \times 60\%$	$90°$
EB18	$7 \times 60\%$	$114°$
MB1	$3 \times 60\%$	$122°$
MB2	$3 \times 60\%$	$55°$
Ron100	$1 \times 100\%$	$25°$

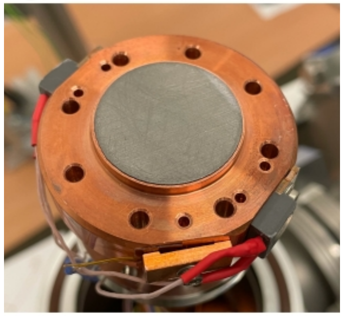
- Molecular proton beam (I = 16 μA)
- 21 HPGe detectors (four HPGe cluster + one single crystal)
- LN_2 target cooling.



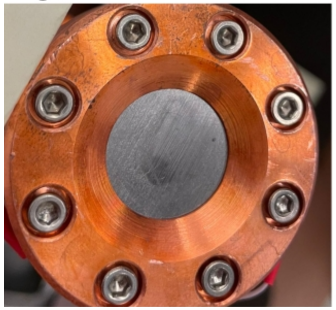
Targets

- carbon powder evaporated on Ta backing (Hungary)
- graphite targets (infinite thickness)





Before irradiation

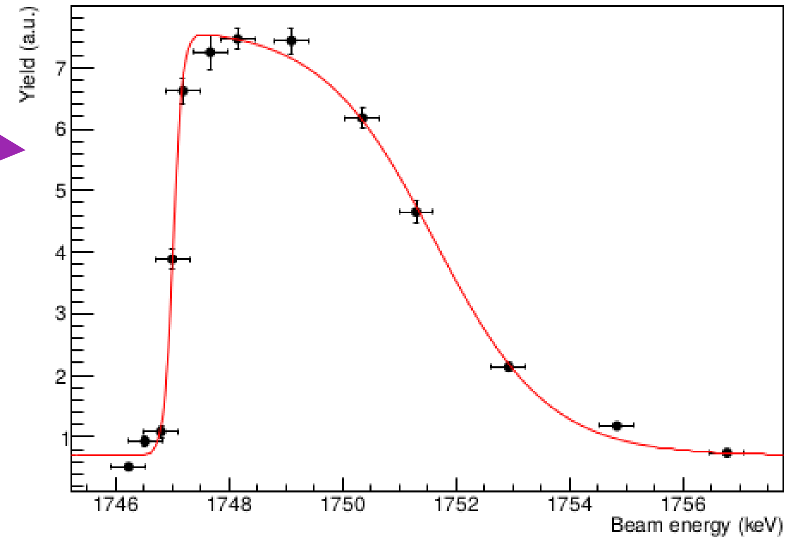


After irradiation

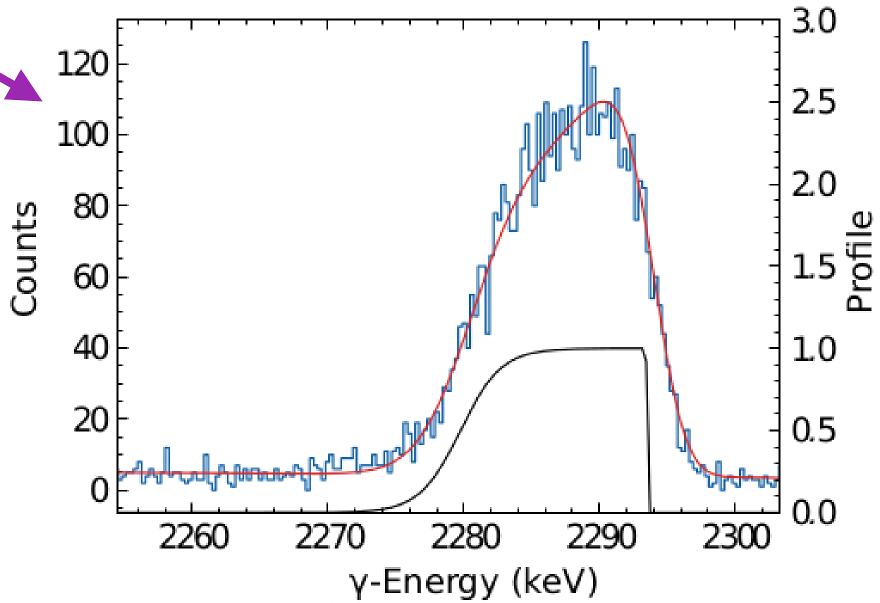
$^{12}C(p,\gamma)^{13}N$ reaction: Target characterization

- Resonance scan technique

  $^{13}C(p,\gamma)^{14}N$ resonance,
  E_r = 1747.6 keV $\omega\gamma$ = 7.3 ± 0.5 eV



- Peak shape analysis

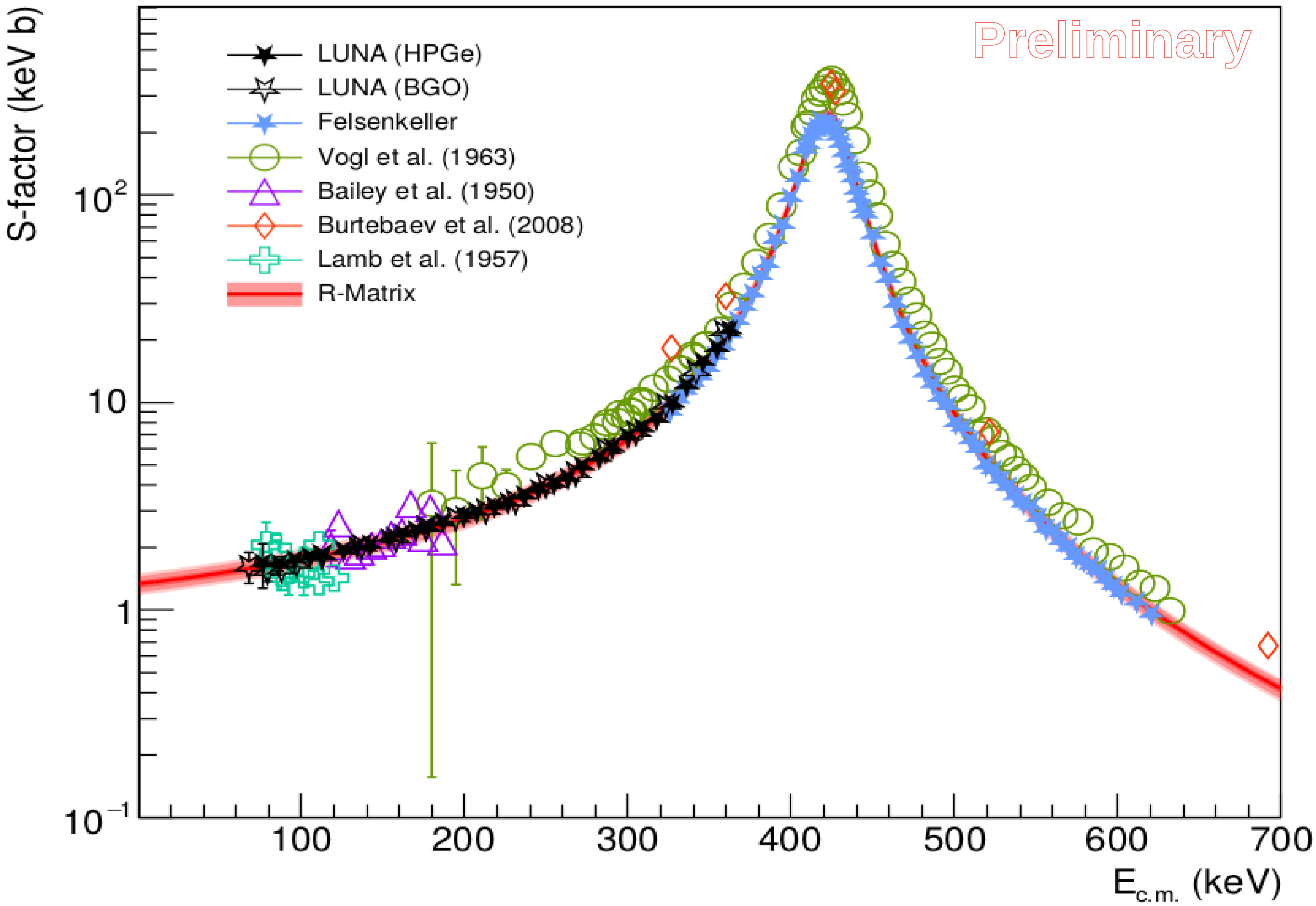


- Reference run at 380 keV

Target	Scan [keV]	PSA [keV]
12C_L1	13.3 ± 0.3	13.8 ± 0.4
12C_L4	15.8 ± 0.3	15.9 ± 0.2

ΔE for the different target and techniques

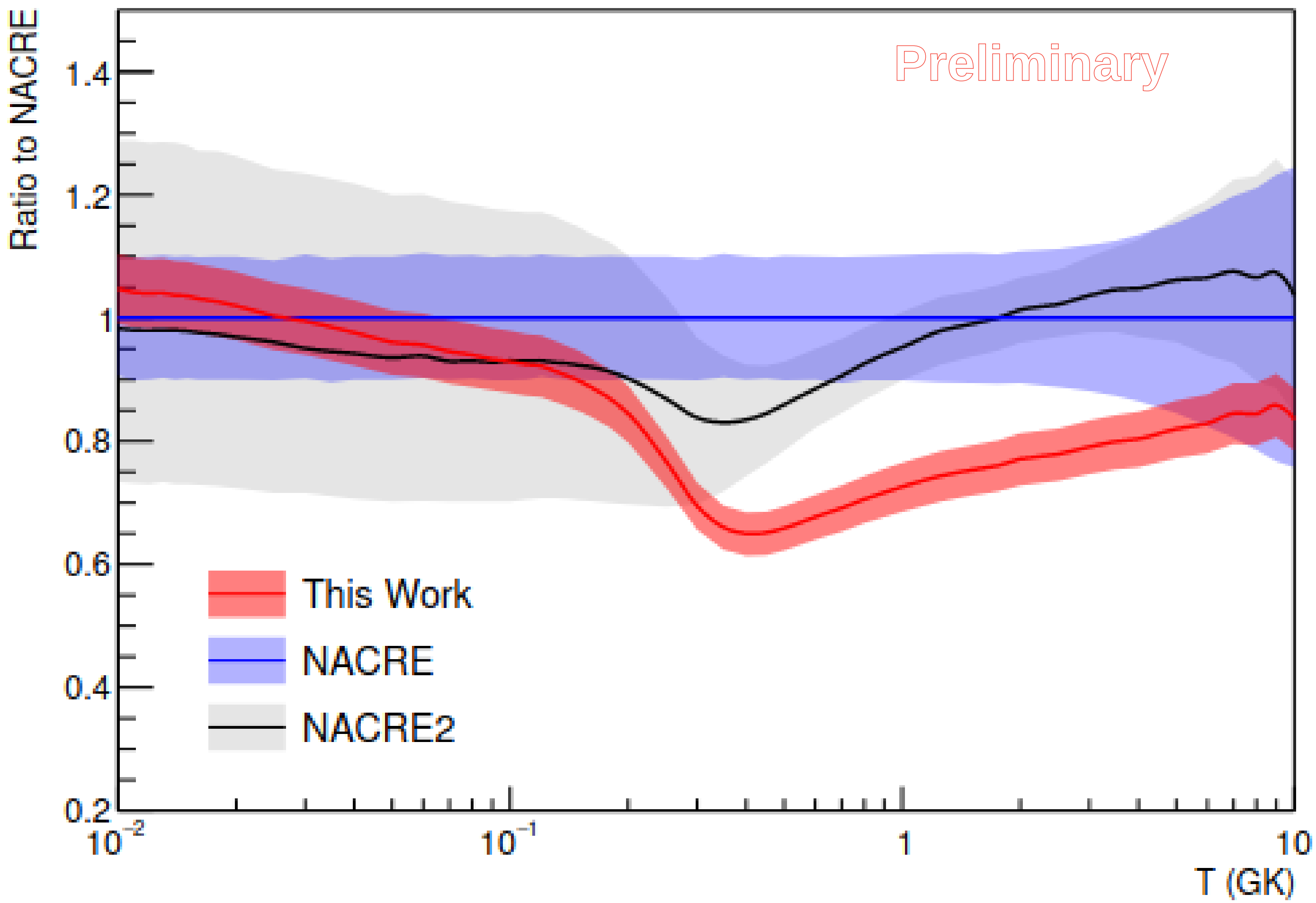
$^{12}C(p,\gamma)^{13}N$ reaction: Results



Felsenkeller S-factor show **25% discrepancy** with respect to the literature

Excellent agreement with low-energy LUNA data

$^{12}C(p,\gamma)^{13}N$ reaction: Results

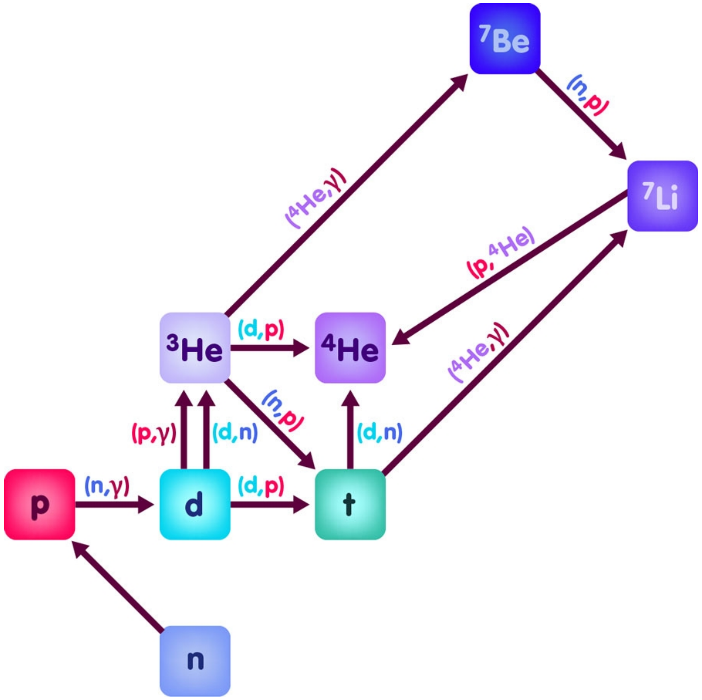


Reaction rate is consistently lower (20%-40%) at T > 0.3 GK suggesting a revision of the stellar model calculations for explosive H-burning.

$^{3}He(\alpha,\gamma)^{7}Be$ reaction

Big Bang Nucleosynthesis

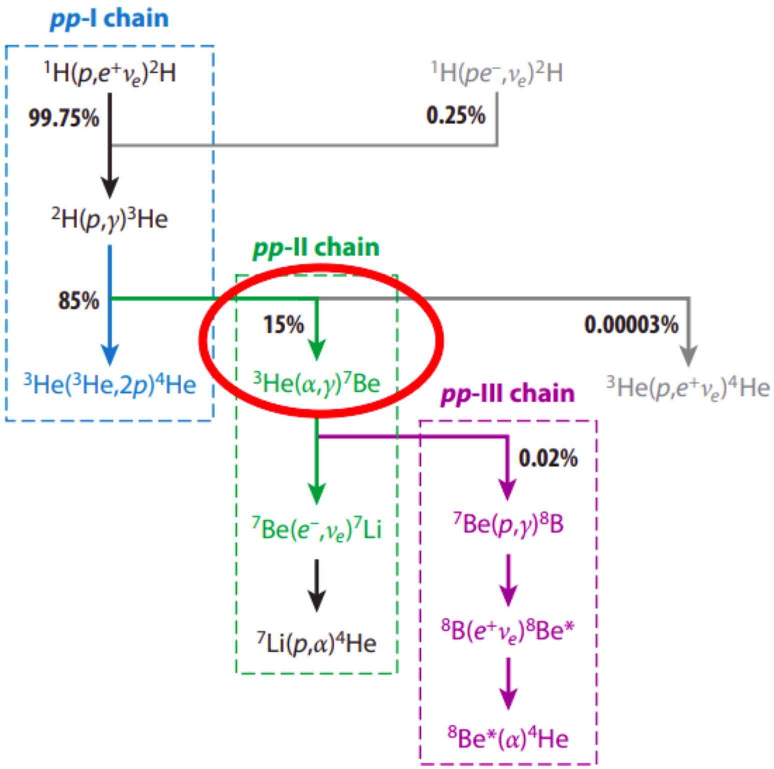
- 7Li production



$E_{BBN} \approx$ 160 – 380 keV

Hydrogen burning in the Sun

- Solar neutrino flux



$E_{Sun} \approx$ 19 - 30 keV

$^3He(\alpha,\gamma)^7Be$ reaction

Dominant Theoretical Error Sources for Neutrino Fluxes and the Main Characteristics of the SSM

Quant.	Dominant Theoretical Error Sources in %							
$\Phi(pp)$	$L_\odot$:	0.3	S_{34}:	0.3	κ:	0.2	Diff:	0.2
$\Phi(pep)$	κ:	0.5	$L_\odot$:	0.4	S_{34}:	0.4	S_{11}:	0.2
$\Phi(hep)$	S_{hep}:	30.2	S_{33}:	2.4	κ:	1.1	Diff:	0.5
$\Phi(^7Be)$	S_{34}:	4.1	κ:	3.8	S_{33}:	2.3	Diff:	1.9
$\Phi(^8B)$	κ:	7.3	S_{17}:	4.8	Diff:	4.0	S_{34}:	3.9
$\Phi(^{13}N)$	C:	10.0	S_{114}:	5.4	Diff:	4.8	κ:	3.9
$\Phi(^{15}O)$	C:	9.4	S_{114}:	7.9	Diff:	5.6	κ:	5.5
$\Phi(^{17}F)$	O:	12.6	S_{116}:	8.8	κ:	6.0	Diff:	6.0

Vinyoles *et al.*, Astrophys. J. (2017)

S_{34}: $^3He(\alpha,\gamma)^7Be$

S_{114}: $^{14}N(p,\gamma)^{15}O$

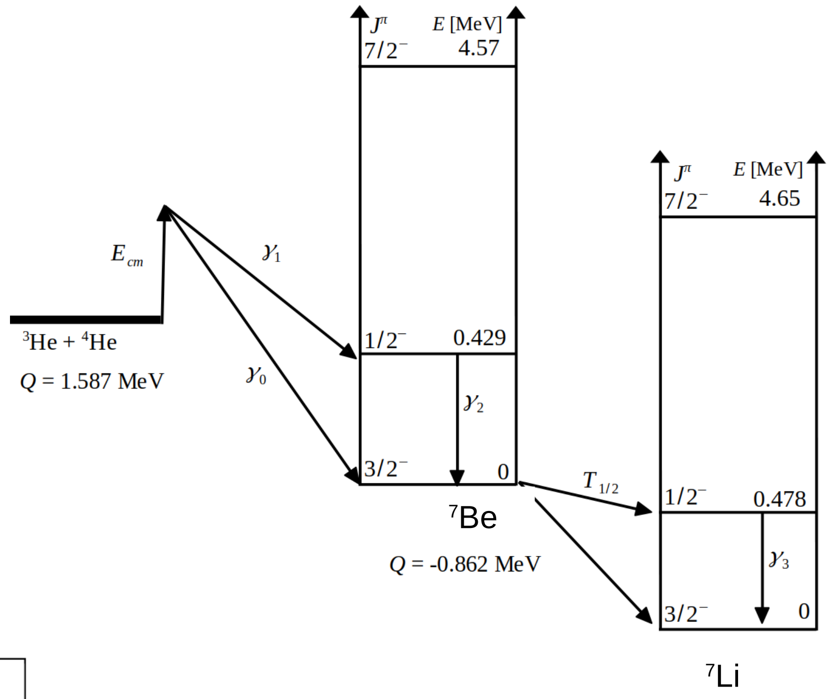
S_{17}: $^7Be(p,\gamma)^8B$

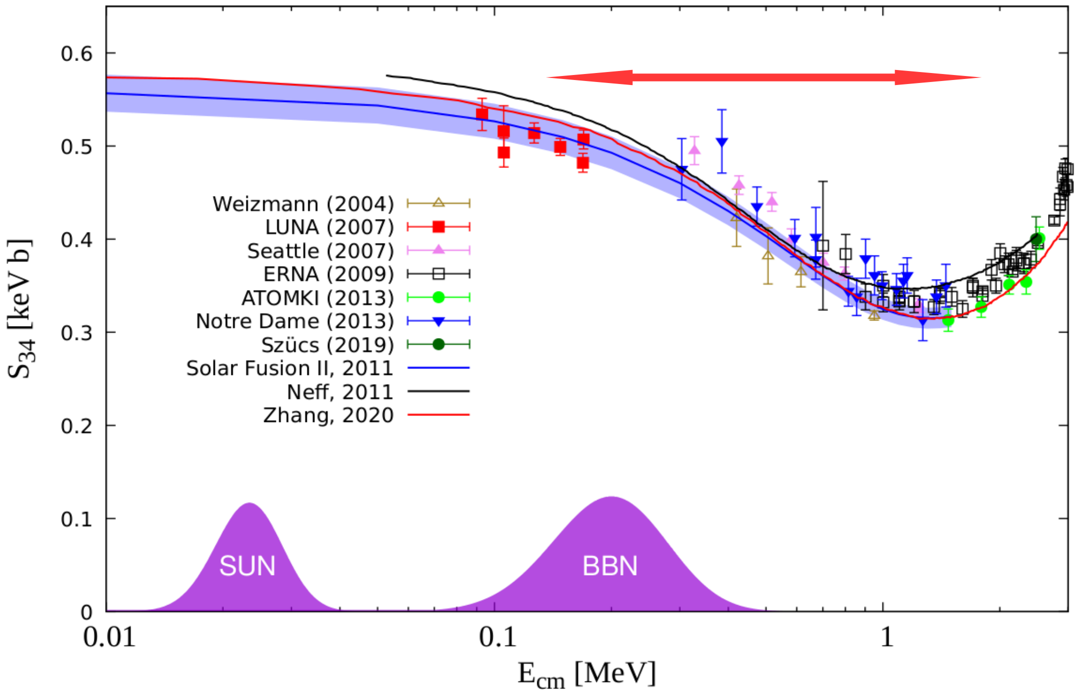
Neutrino flux data are more precise than the solar models!

$^3He(\alpha,\gamma)^7Be$ reaction

Current state of the art

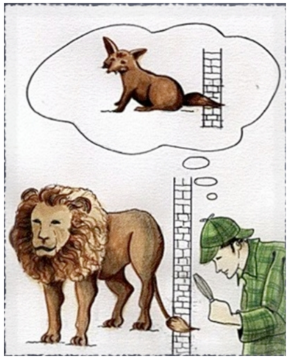
- Measuring directly the prompt γ-rays from the de-excitation into the ground state of ^7Be
- Activation analysis of the radioactive ^7Be at low-background counting facility
- Indirect approaches (See A. Tumino talk)





No data at E_{Sun}

S-factor extrapolations

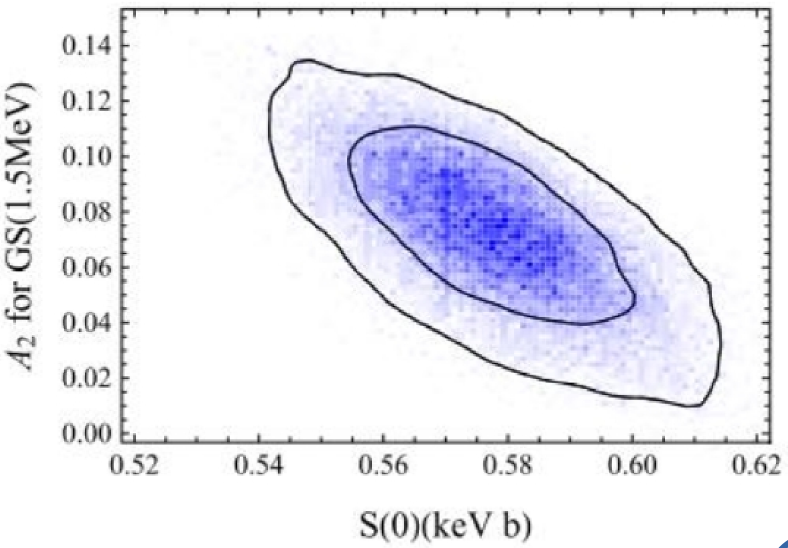


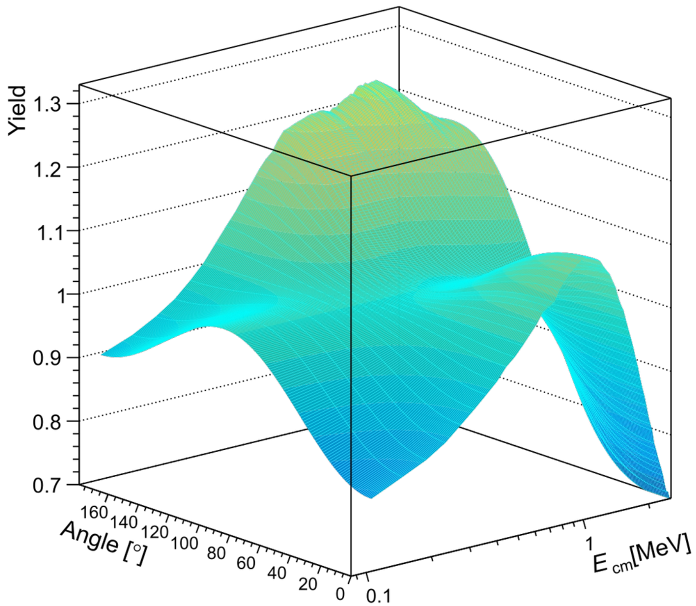
$^{3}He(\alpha,\gamma)^{7}Be$ reaction

Current state of the art: Theoretical studies shows correlation of the angular distribution coefficients with the extrapolated S(0)

Tombrello et al.,
Phys. Rev. 131, 2582 (1963)

$$\sigma^{i}(E,\theta) = \sigma^{i}(E)\,[1 + a_2^{i}(E)\,P_2(\cos\theta)]$$





Xilin Zhang et al 2020
J. Phys. G: Nucl. Part. Phys. 47 054002

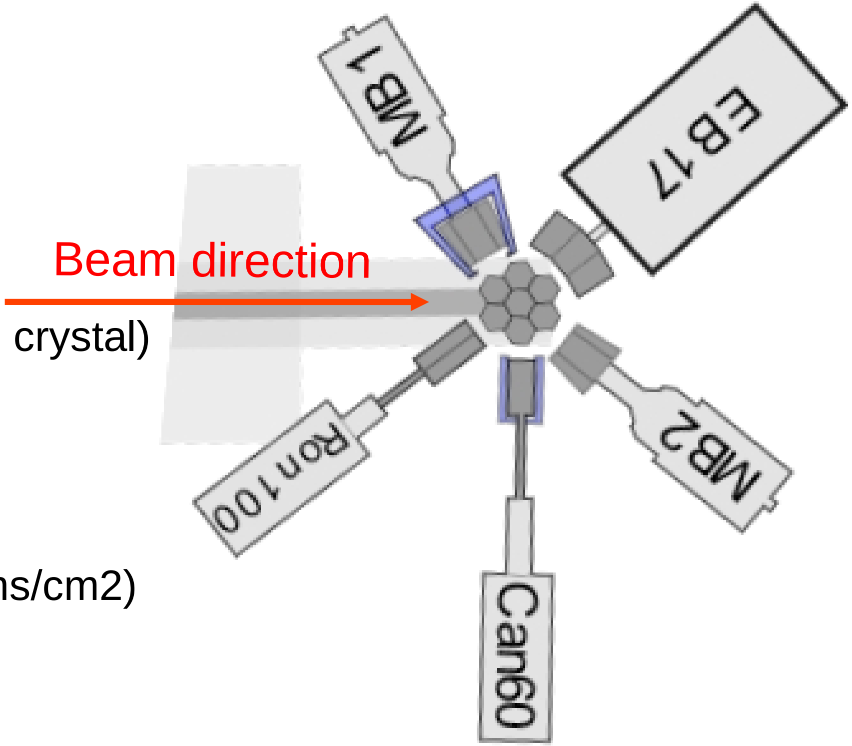
GOAL

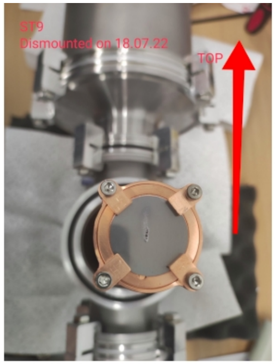
Direct angular distribution data needed!

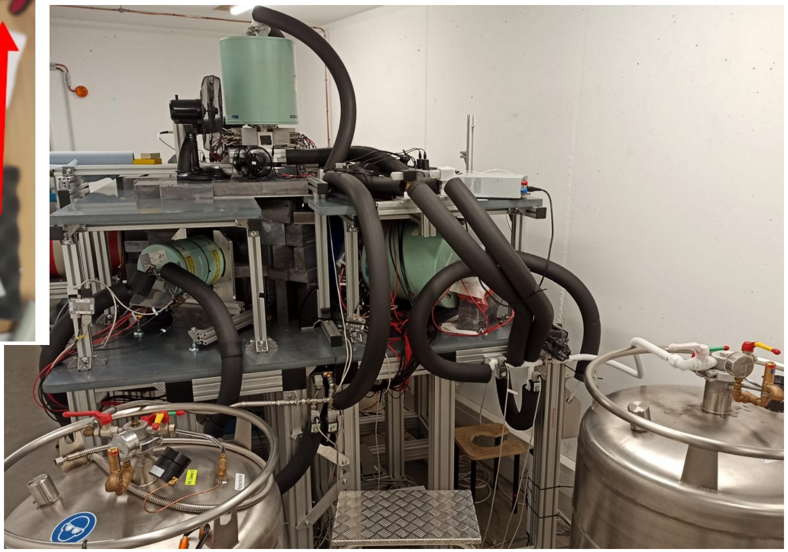
$^{3}He(\alpha,\gamma)^{7}Be$ reaction

Experiment: Solid target setup

- ^{4}He beam (I = 13-15 μA)
- 22 HPGe detectors (four HPGe cluster + 2 single crystal)
- LN_2 target cooling.
- Implanted ^{3}He target on Ta backing (2.7E17 atoms/cm2)
- Lead shielding for lab background reduction





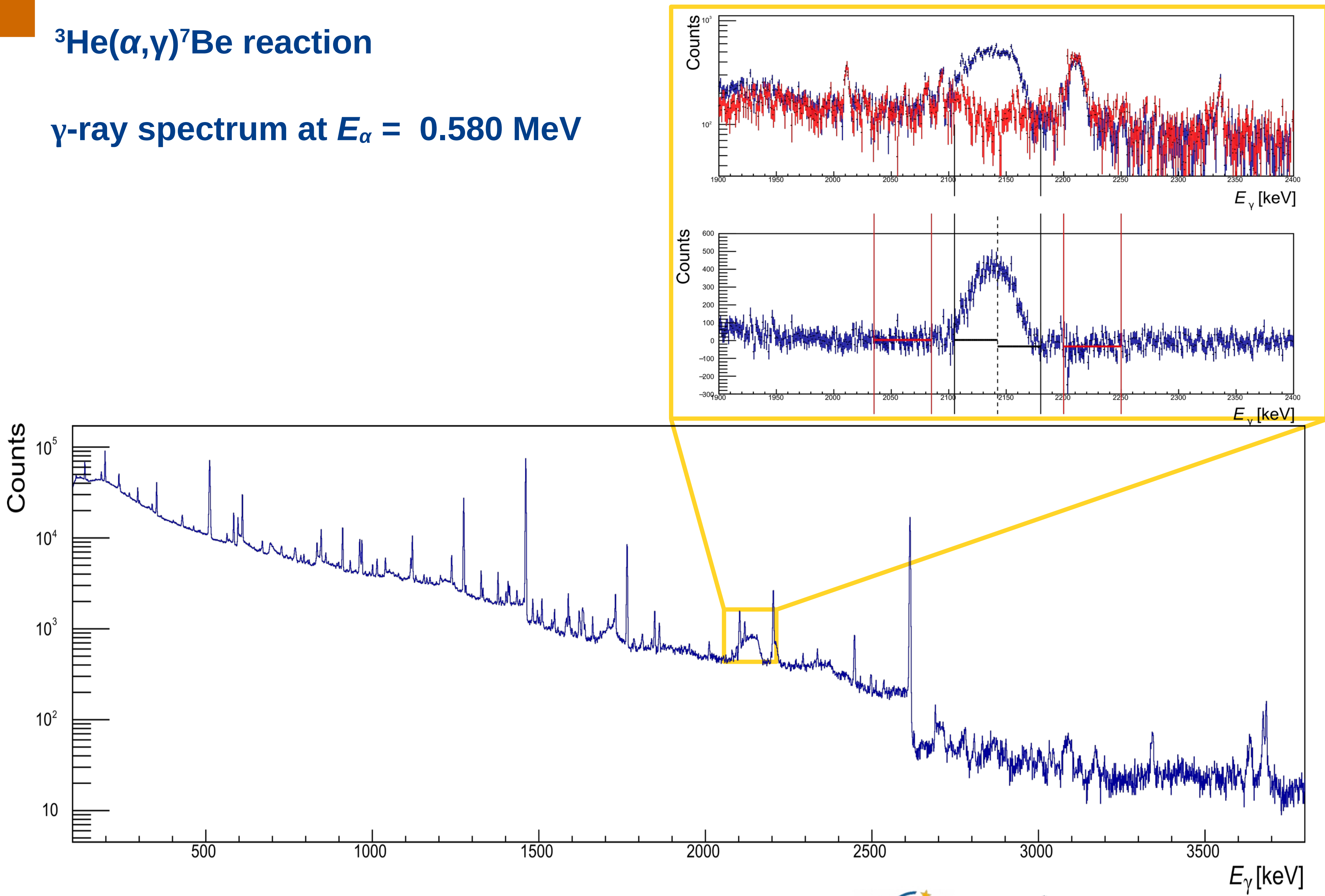


E_{α} = 0.470 MeV, 0.580 MeV, 0.92 MeV

θ = 36, 57, 90, 120 and 145 degree

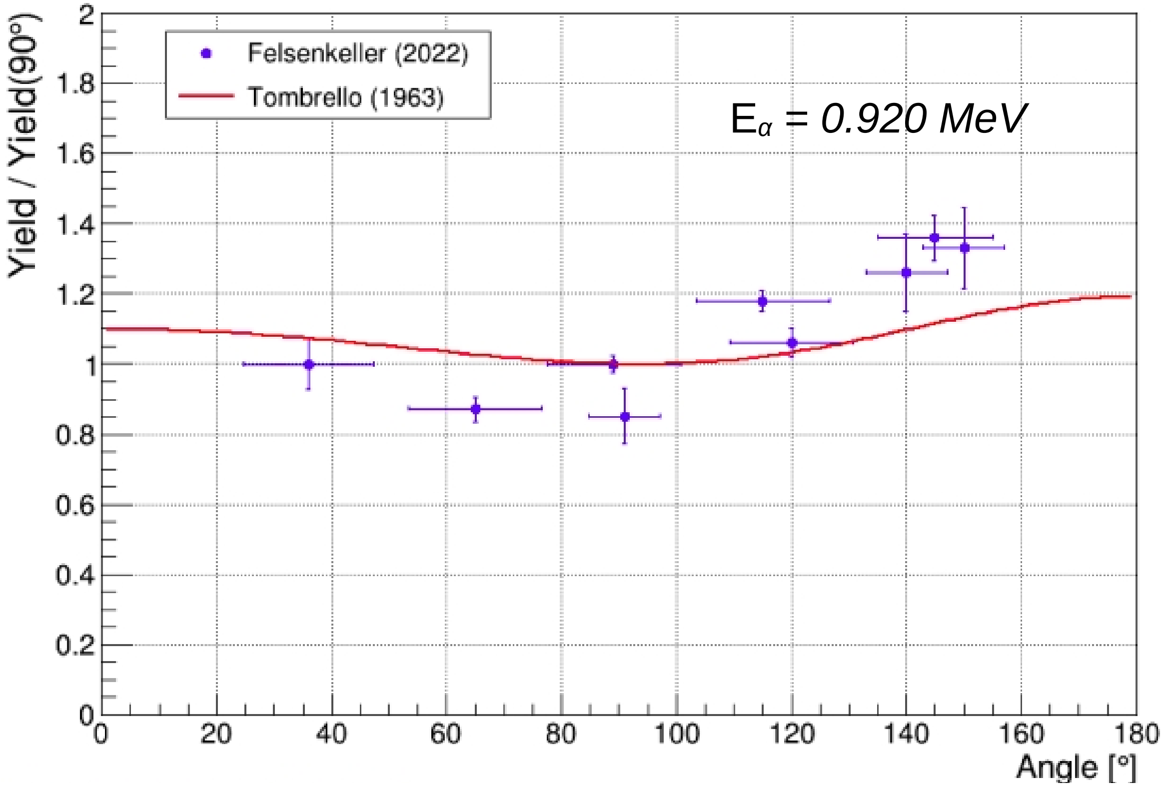
$^{3}He(\alpha,\gamma)^{7}Be$ reaction

γ-ray spectrum at E_α = 0.580 MeV



$^{3}He(\alpha,\gamma)^{7}Be$ reaction

Preliminary

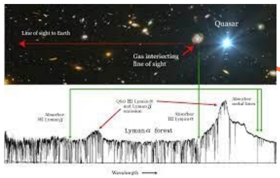


Analysis and last measurement still ongoing!!

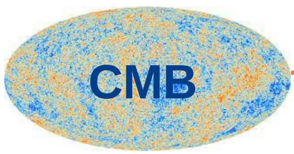
There seems a clear discrepancy with theory!
Forward and especially backward emission way more preferred!!

Big Bang Nucleosythesis: Why is important?

Primordial observations



X_i



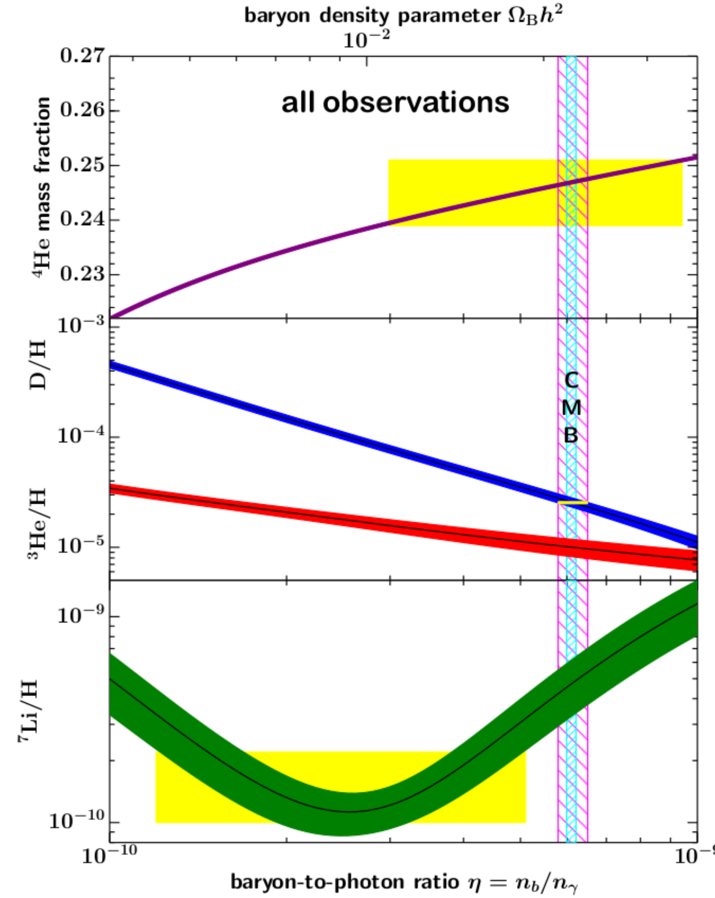
$\Omega_b h^2$

BBN

Termonuclear rates

Astroparticle

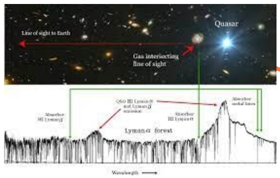
Nuclear astrophysics



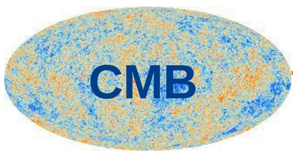
CheTEC INFRA   DRESDEN concept   HZDR

Big Bang Nucleosythesis: Why is important?

Primordial observations



X_i



$\Omega_b h^2$

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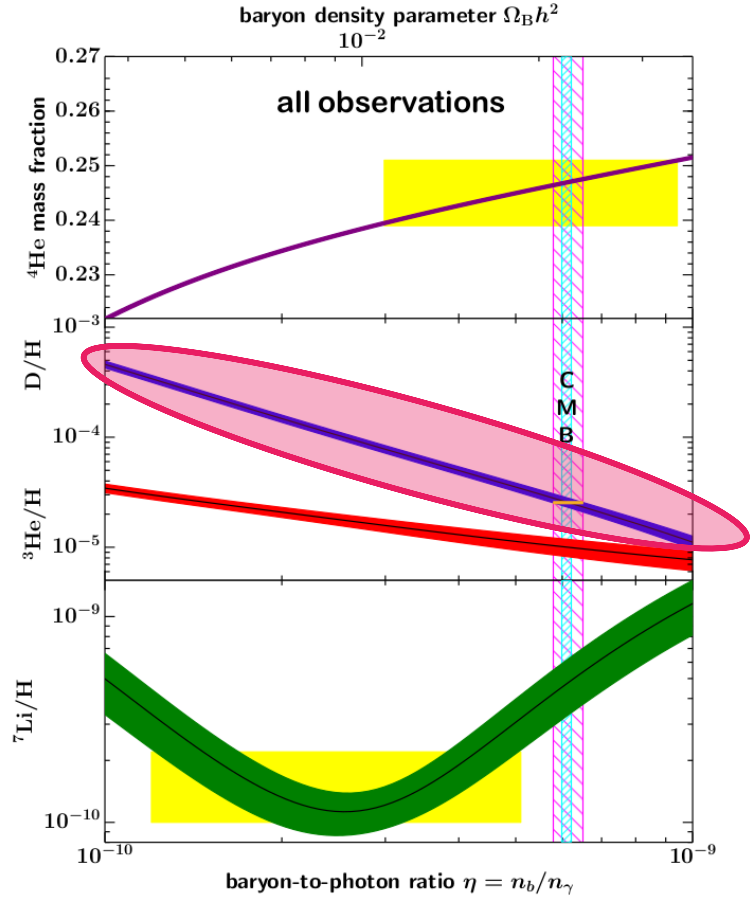


Strong Deuterium sensitivity to the cosmic baryon density!!!

Big Bang Nucleosythesis: $^2H(p,\gamma)^3He$ reaction

The primordial deuterium abudance [D/H] can be obtained by:

- Direct astronomical observation: [D/H] = $(2.527 \pm 0.030) \times 10^{-5}$

Cooke et al, APJ 855 (2018) 102

- From BBN theory knowing the cosmological parameters and nuclear cross sections: $[D/H]_1 = (2.439 \pm 0.052) \times 10^{-5}$, $[D/H]_2 = (2.587 \pm 0.055) \times 10^{-5}$

Planck 2018, A&A 641 (2020) A6

Reaction	$\Delta_{^2H/H} \cdot 10^5$
$p(n,\gamma)^2H$	$\pm$ 0.002
$^2H(p,\gamma)^3He$	$\pm$ 0.062
$^2H(^2H,n)^3He$	$\pm$ 0.020
$^2H(^2H,p)^3H$	$\pm$ 0.013

Valentino et al., PhyRevD 2014

For several years d+p needed!

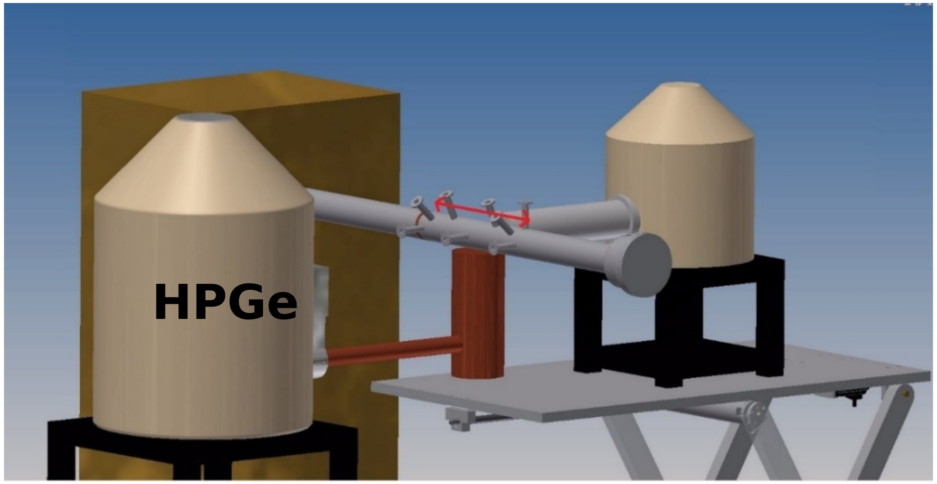
Comparing $[D/H]_{obs}$ with $[D/H]_{BBN}$ is possible to derive the barion density $\Omega_b h^2$ and/or number of neutrino species N_{eff}

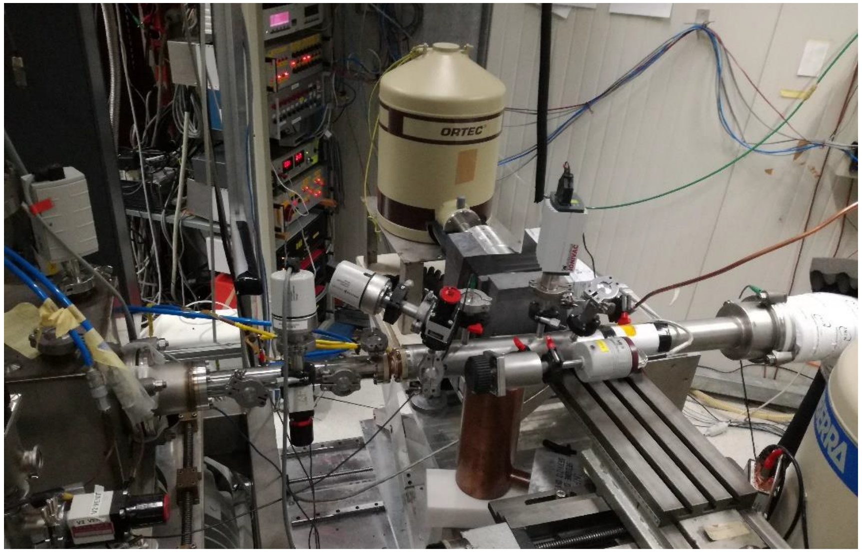
The $^{2}H(p,\gamma)^{3}He$ reaction

Direct measurement at BBN energies at LUNA laboratory (LNGS, Italy)

Measurement goal:

- Cross section measurement with ~3% accuracy
- E_{cm}= 30-300 keV



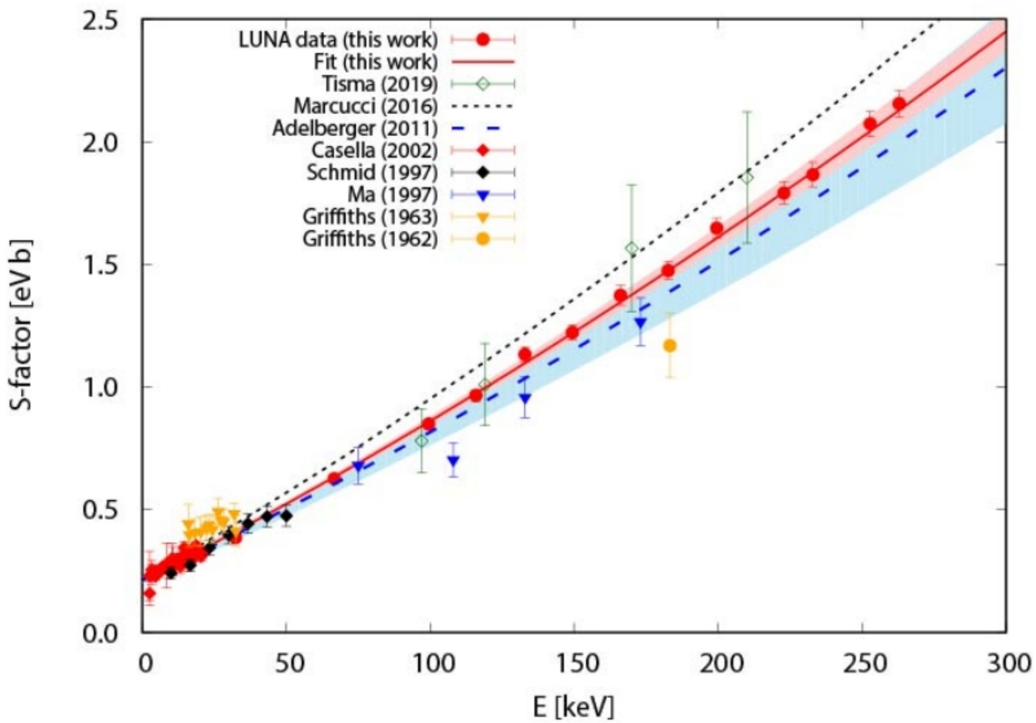


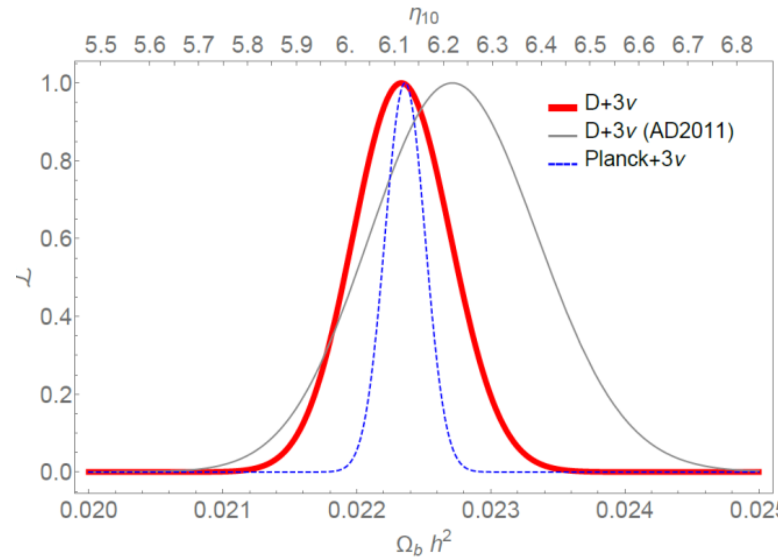
Extended windowless gas target setup

The $^2H(p,\gamma)^3He$ reaction

LUNA S-factor

Mossa *et al.* Nature volume 587, pages210–213 (2020)



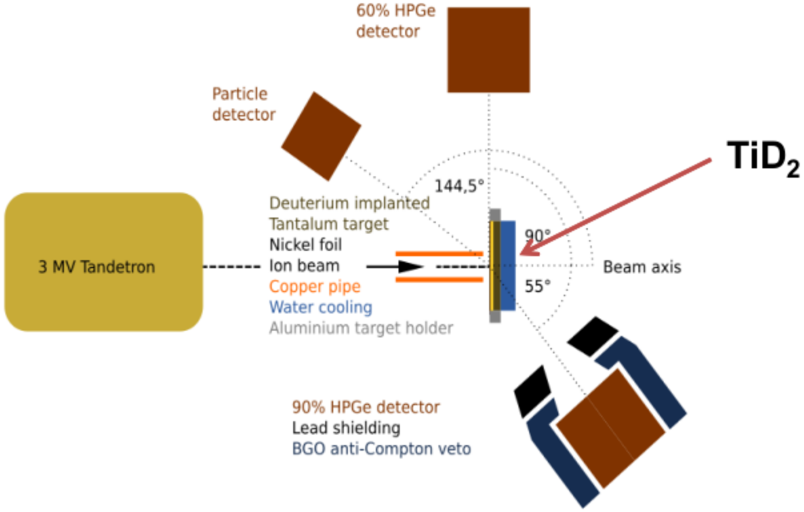


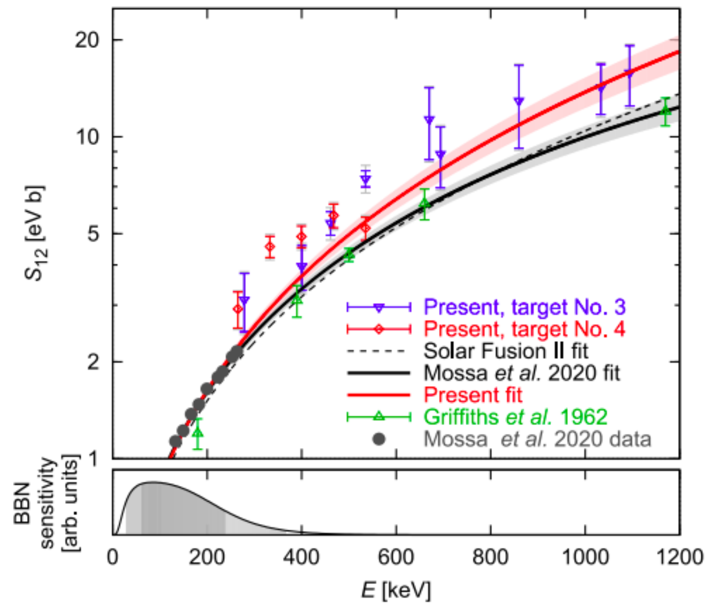
- BBN energy range fully covered, ~3% uncertainty
- Barion density from BBN in perfect agreement with Planck data
- Ab initio theory needs revision??

The $^2H(p,\gamma)^3He$ reaction

Turkat *et al. Phys. Rev. C 103, 045805 (2021)*

Direct measurement above 400 kV at HZDR





Main issues:

- Target composition and stability (TiD_2)
- Laboratory and beam induced background

- HZDR fit agrees within <1.2 % with LUNA fit in the BBN range
- For E_p > 400 keV (HZDR data) discrepancies of 10 % between LUNA and HZDR

LUNA - HZDR tension precision (?!) data above 400 keV are needed !

The $^2H(p,\gamma)^3He$ reaction

ChETEC-INFRA Transnational Access Proposal
Science Part (please upload as "Project Description" in GATE)

Measurement of the $^2H(p,\gamma)^3He$ reaction above 300 keV at Felsenkeller

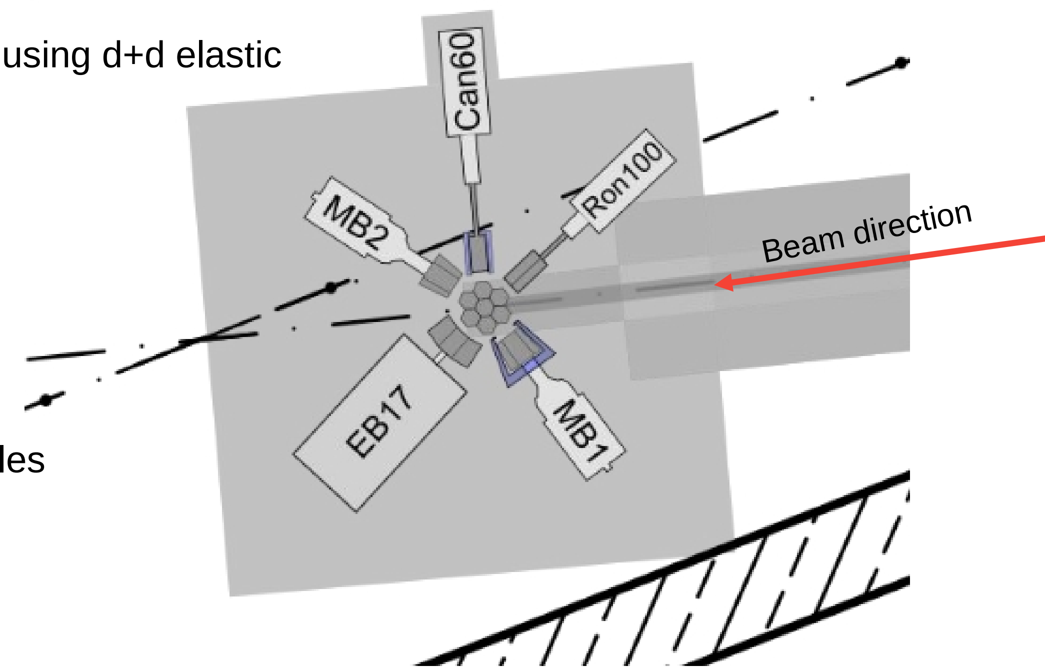
Spokesperson(s): A. Caciolli[1,2]

Felsenkeller Goal:

Overlap with the LUNA and new data in the energy range E_p = (400 – 1200) keV, angular distribution measurements

Solid target setup:

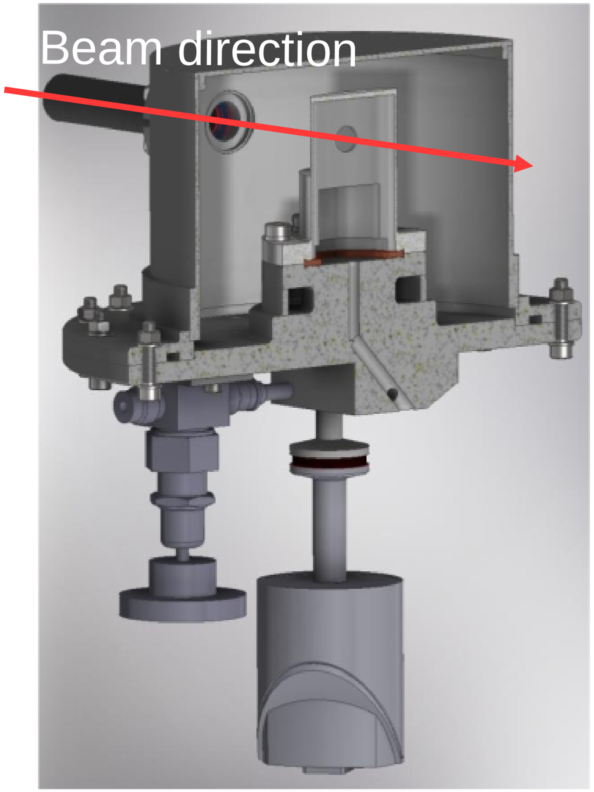
- ✓ ZrD_2 targets produced and characterized using d+d elastic scattering and ^3He+d at LNL
- ✓ TiD_2 target produced in Rossendorf
- ✓ ERDA analysis for targets
- ✓ Possible in beam analysis
- ✓ 21 HPGe detectors to cover different angles

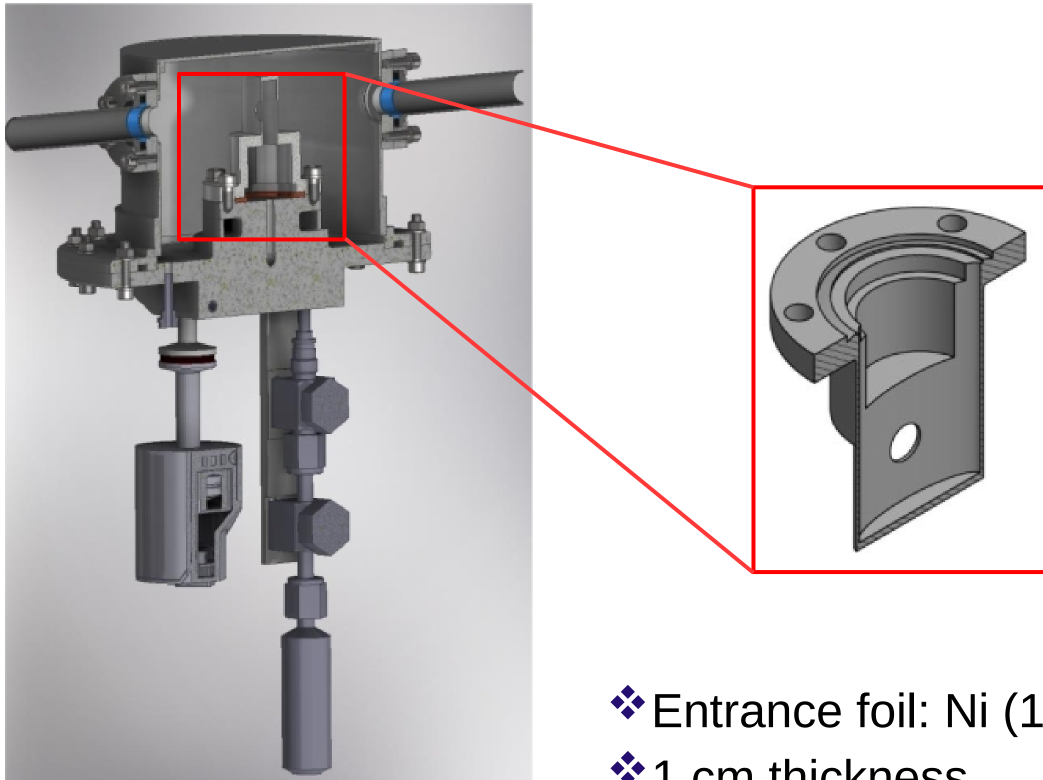


Data taking: Next April 2023!

Development gas targets at Felsenkeller

Gas-cell target



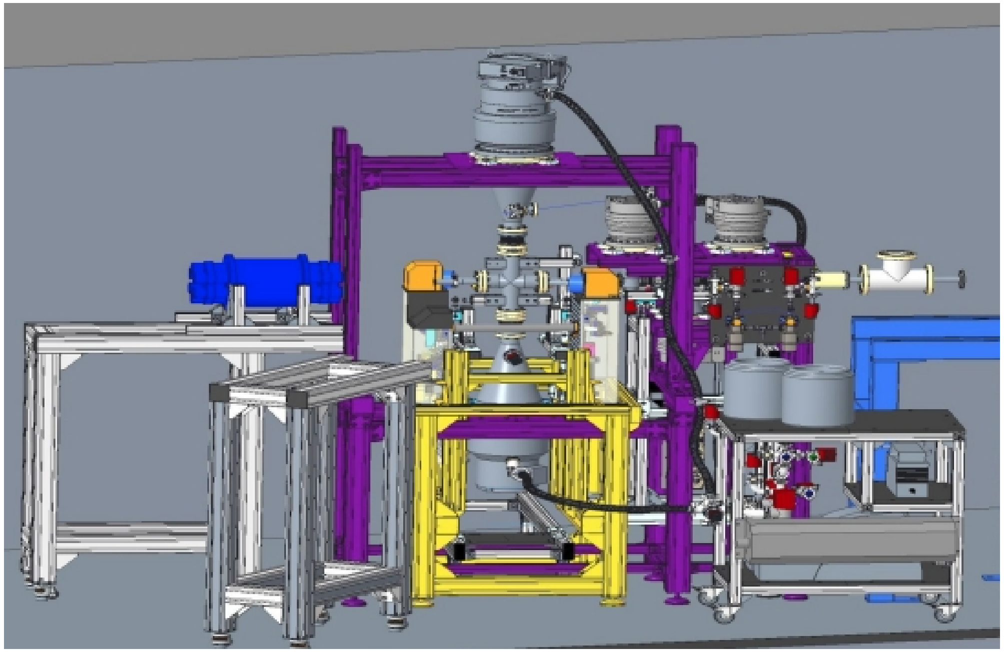


- One order of magnitude higher target thickness
- Target thickness can be monitored by pressure and temperature measurement
- Both angular and absolute cross section data!

- Entrance foil: Ni (1um (!))
- 1 cm thickness
- Exchangeable cell

Preliminary tests ongoing

Work in progress: Gas target (windowless and wall jet)

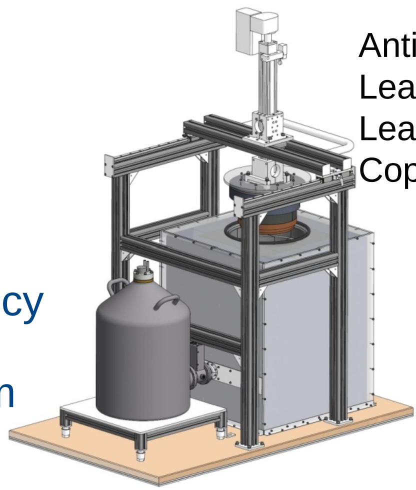


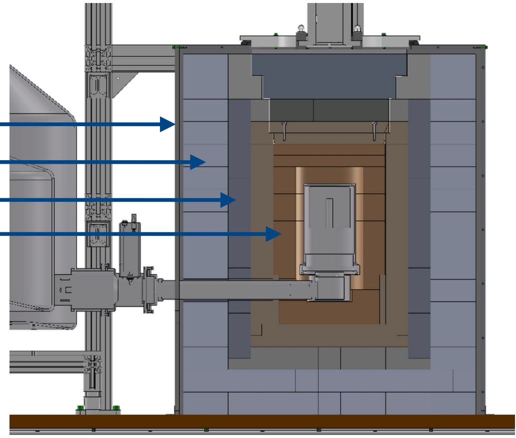
- 10^{18} cm^{-2} wall jet thickness based on JENSA@ MSU
- 10x10 mm^2 wall, 1 mm thick
- Target thickness measured by laser interferometry
- Windowless static gas target attached at the end (LUNA based)

Low-radiactivity measurements at Felsenkeller

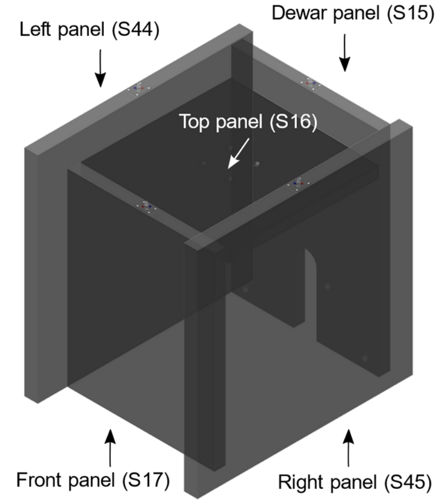
TU1 detector

- Canberra GX 150-250-R (ULB)
- HPGe with 163% relative efficiency
- Diameter: 90 mm, Length: 90 mm

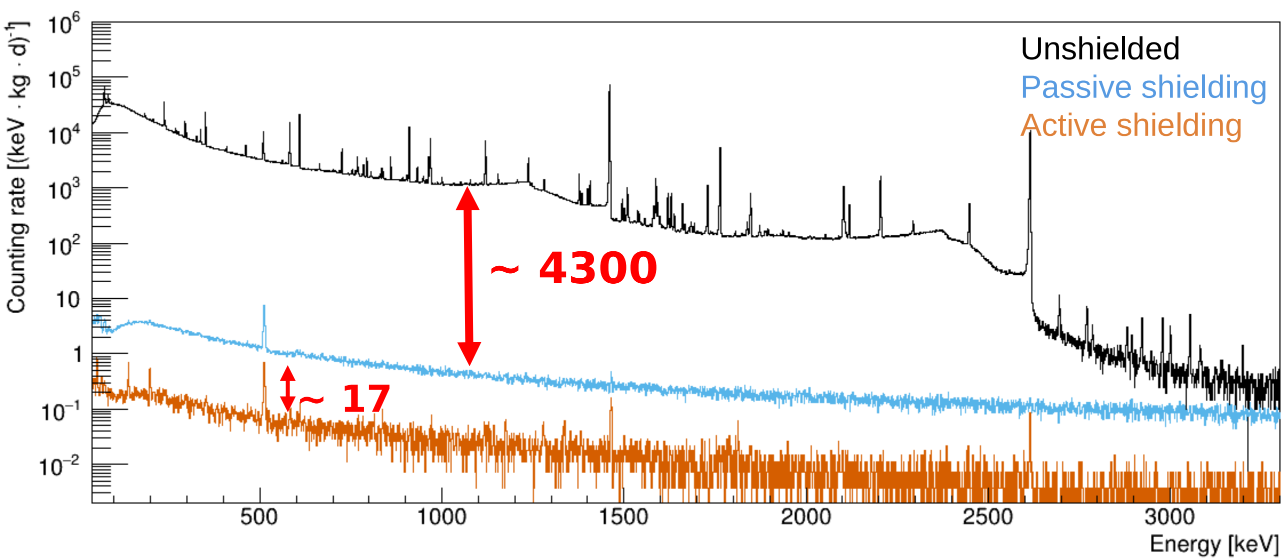




Passive shielding



Active shielding
Plastic muon veto detector

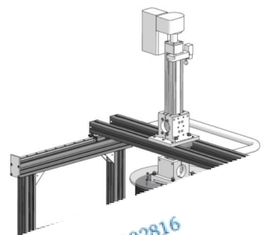


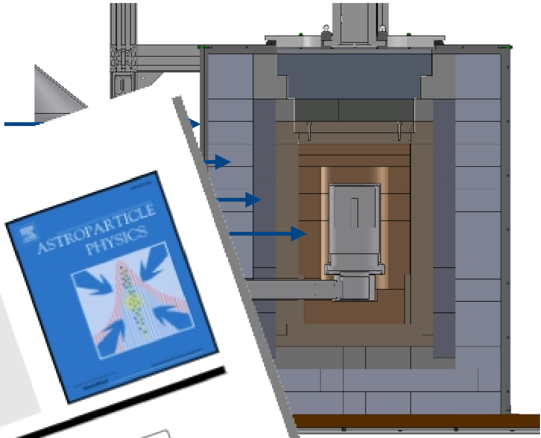
Mitglied der Helmholtz-Gemeinschaft

Low-radiactivity measurements at Felsenkeller

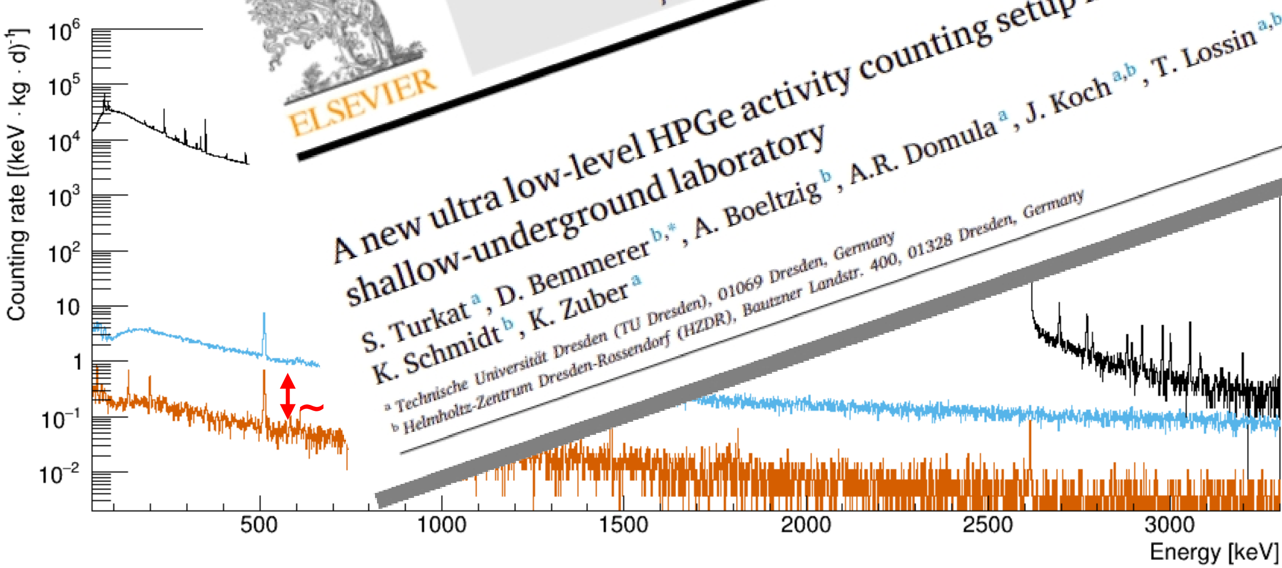
TU1 detector

- Canberra GX 150-250-R (ULB)
- HPGe with 163% relative effi...
- Diameter: 90 m...





...ve shielding



Astroparticle Physics 148 (2023) 102816

Contents lists available at ScienceDirect

Astroparticle Physics

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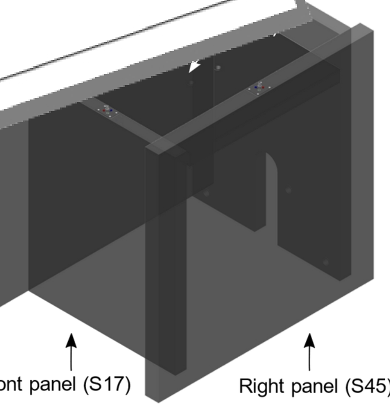
ASTROPARTICLE PHYSICS

Check for updates

A new ultra low-level HPGe activity counting setup in the Felsenkeller shallow-underground laboratory

S. Turkat [a], D. Bemmerer [b,*], A. Boeltzig [b], A.R. Domula [a], J. Koch [a,b], T. Lossin [a,b], M. Osswald [a,b], K. Schmidt [b], K. Zuber [a]

[a] Technische Universität Dresden (TU Dresden), 01069 Dresden, Germany
[b] Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstr. 400, 01328 Dresden, Germany



Active shielding
Plastic muon veto detector

CHETEC INFRA
DRESDEN concept
HZDR

Summary

- Felsenkeller in synergy with other facility/labs, beam time open for external proposals
- New data for the $^{12}C(p,\gamma)^{13}N$ reaction above 370 keV
- First angular measurement data for the $^{3}He(\alpha,\gamma)^{7}Be$ reaction
- Beam time at Felsenkeller open for external proposals (CheTEC INFRA proposal.
- New gas targets under study
- Unique HPGe detector for low background measurements at Felsenkeller