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# Cross section measurement of the $^{12}\text{C}(\text{p},\gamma)^{13}\text{N}$ reaction at the Felsenkeller underground ion accelerator

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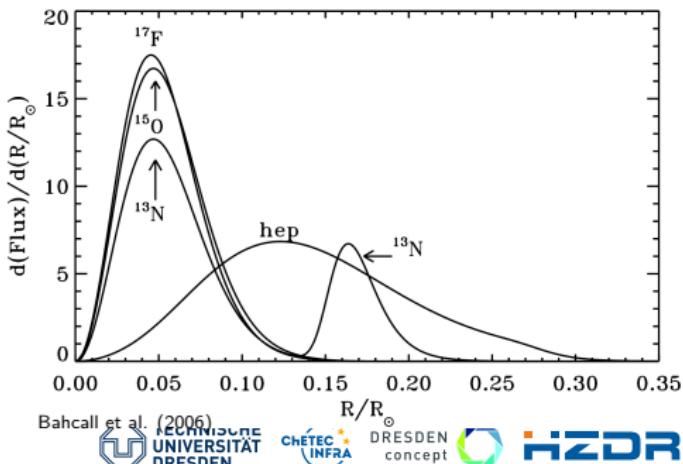
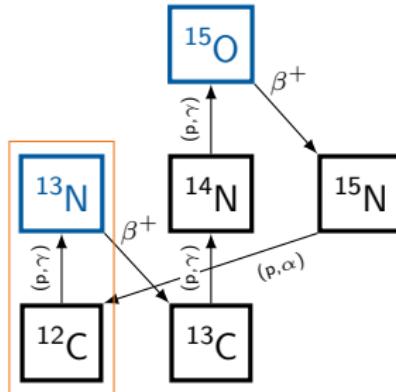
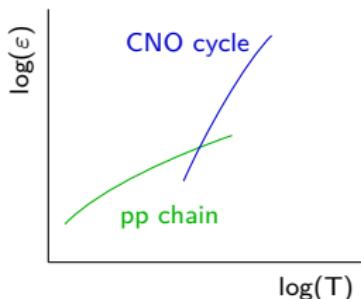
August 30, 2023



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

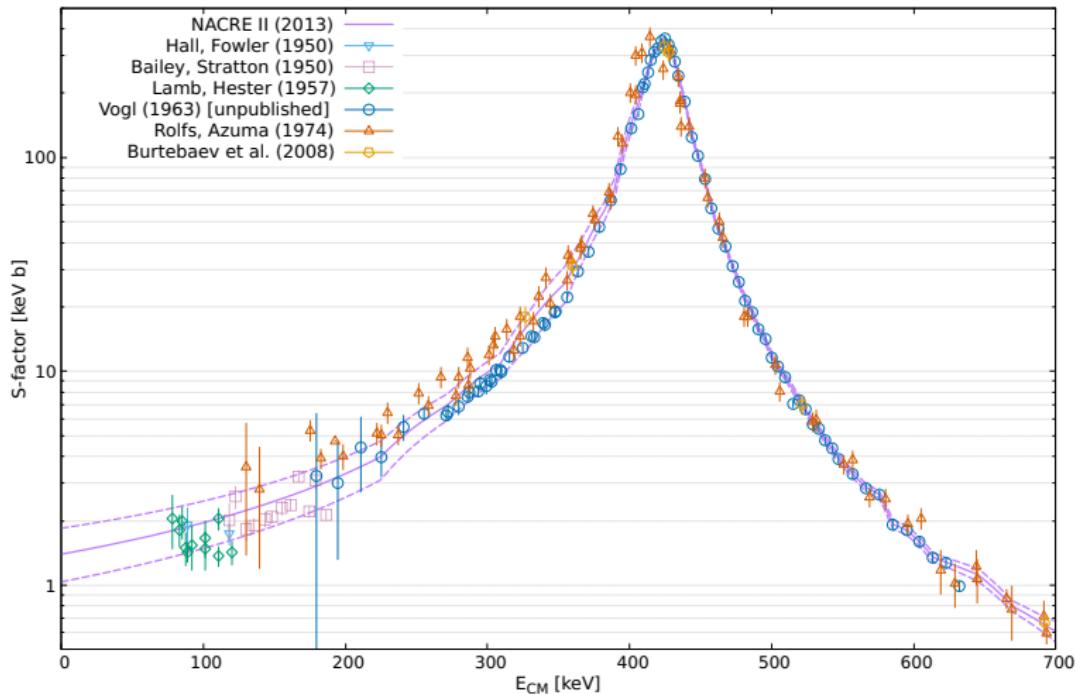
# The $^{12}\text{C}(\text{p}, \gamma)^{13}\text{N}$ reaction

- CNO cycle as dominant process in stars with  $T > 17 \cdot 10^6 \text{ K}$
- leading reaction in the burn-in phase of stars
- astrophysical scenarios:
  - $^{13}\text{N}$  neutrino emission
  - production of  $^{13}\text{C}$  for other reactions and  $^{12}\text{C}/^{13}\text{C}$  ratio



# State-of-the-art in 2022

- many studies 1950-1974, not well documented
- last consecutive study 1974



# 1st campaign: Felsenkeller

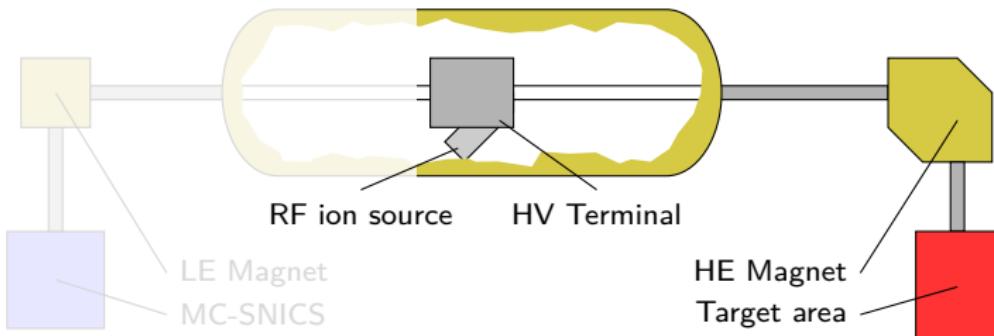
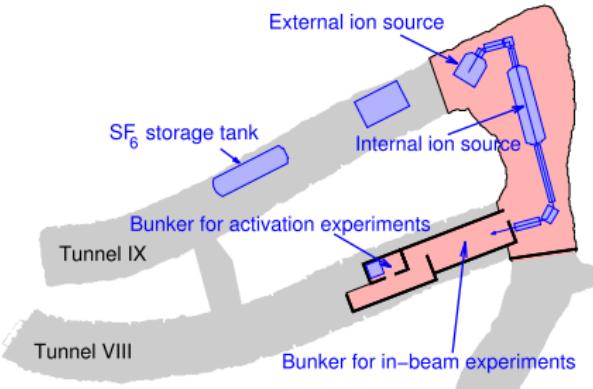
- Felsenkeller laboratory, located in Dresden, Germany
- shallow-underground with 45 m of rock overburden
- background fully characterized:
  - gamma-ray background for online and offline setup: Szücs (2015), Szücs (2019), Turkat (2023)
  - neutron flux and energy spectrum: Grieger (2020)
  - muon flux and angular distribution: Ludwig (2019)



→ see also: following talk by **Anup Yadav**  
poster by **Steffen Turkat**

# 1st campaign: Felsenkeller

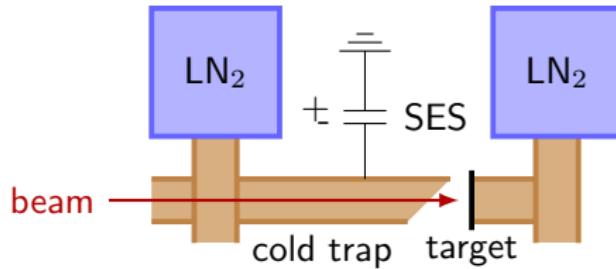
- molecular hydrogen beam from the internal RF ion source
- accelerator in single-ended mode used up to 1.8 MV
- $\text{H}_2^+$  beam intensity up to 15  $\mu\text{A}$



# 1st campaign: Felsenkeller

## Targets

- targets:
  - carbon powder evaporated on tantalum discs
  - graphite targets (infinite thickness)
- copper tube in front of target: cold trap and secondary electron suppression (SES)
- target cooling with LN<sub>2</sub> via copper rod
- 10<sup>-7</sup> mbar vacuum in target chamber



target before irradiation:



target after irradiation:

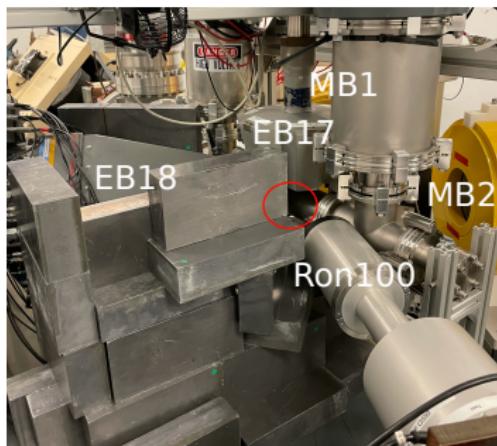


# 1st campaign: Felsenkeller

## Detectors

Detector	HPGe crystals; rel. efficiency	Angle (rel. to beam axis)
Ron100	$1 \times 100\%$	$25^\circ$
MB2	$3 \times 60\%$	$55^\circ$
EB17	$7 \times 60\%$	$90^\circ$
EB18	$7 \times 60\%$	$114^\circ$
MB1	$3 \times 60\%$	$122^\circ$

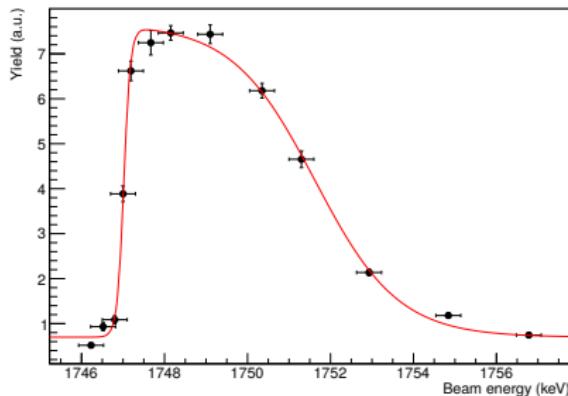
- close geometry (EB17) data used for cross section measurements
- all detectors used for angular distribution measurements



# 1st campaign: Felsenkeller

## Measurements

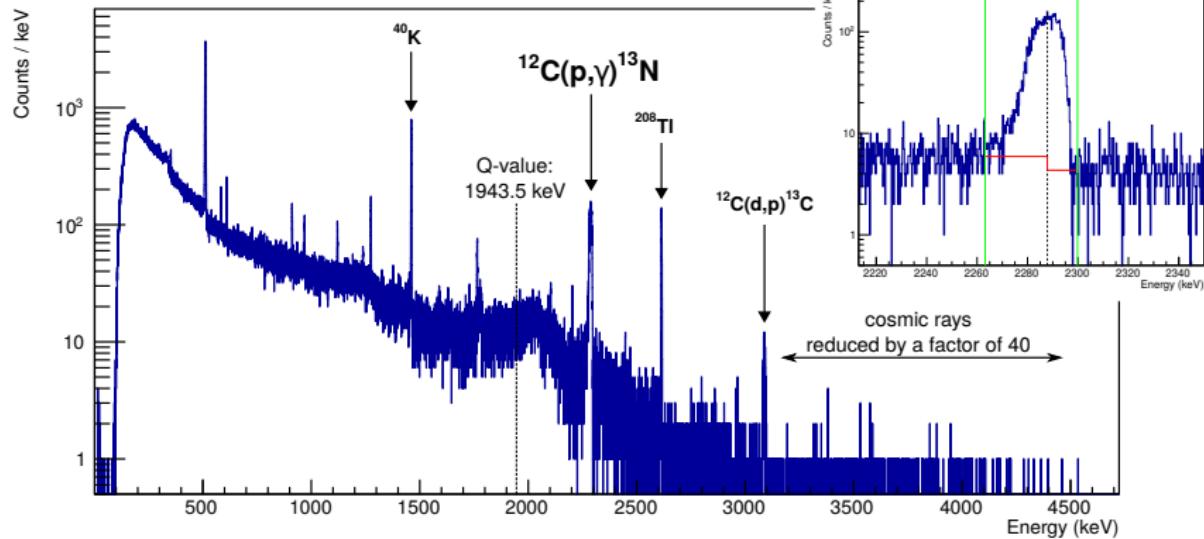
- efficiency calibration of detectors:
  - radioactive sources:  $^{137}\text{Cs}$ ,  $^{88}\text{Y}$ ,  $^{60}\text{Co}$  and  $^{22}\text{Na}$
  - resonance of the  $^{27}\text{Al}(p, \gamma)^{28}\text{Si}$  reaction at 992 keV
- measurements:
  - reference run each day/each target
  - monitor runs with the  $^{13}\text{C}(p, \gamma)^{14}\text{N}$  resonance
  - runs at 80 energies covering 330 to 640 keV



# 1st campaign: Felsenkeller

- one  $\gamma$ -ray from direct capture:  $E_\gamma \sim 2.2\text{--}2.5 \text{ MeV}$
- background:  $^{12}\text{C}(d,p)^{13}\text{C}$  observed (approx. 7 nA of D<sup>+</sup> in 10  $\mu\text{A}$  H<sub>2</sub><sup>+</sup>)
- low yield example (laboratory BG dominating)

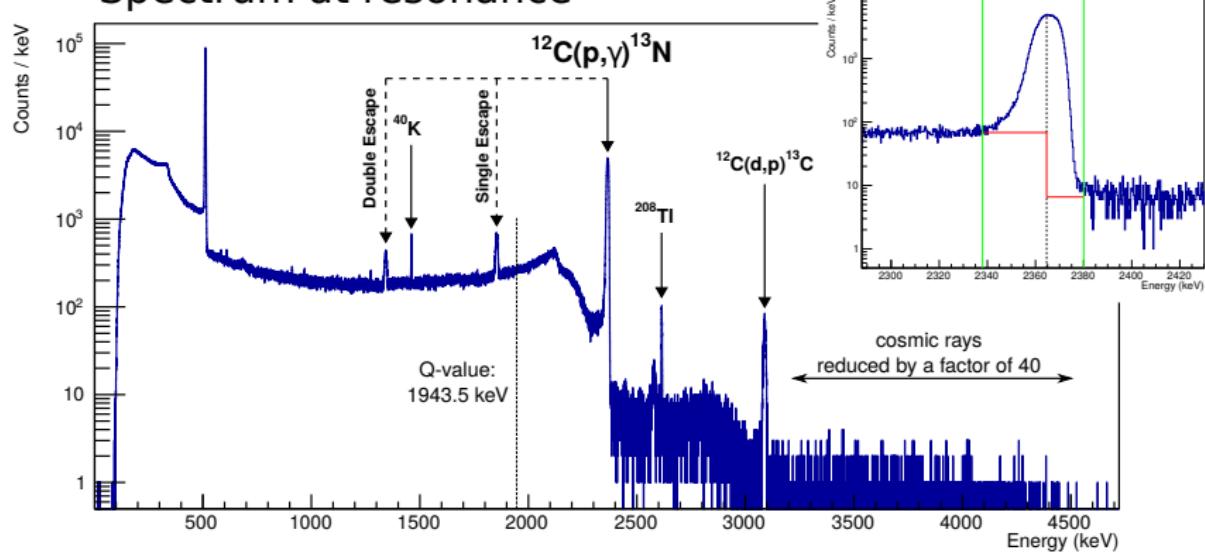
## Low yield spectrum



# 1st campaign: Felsenkeller

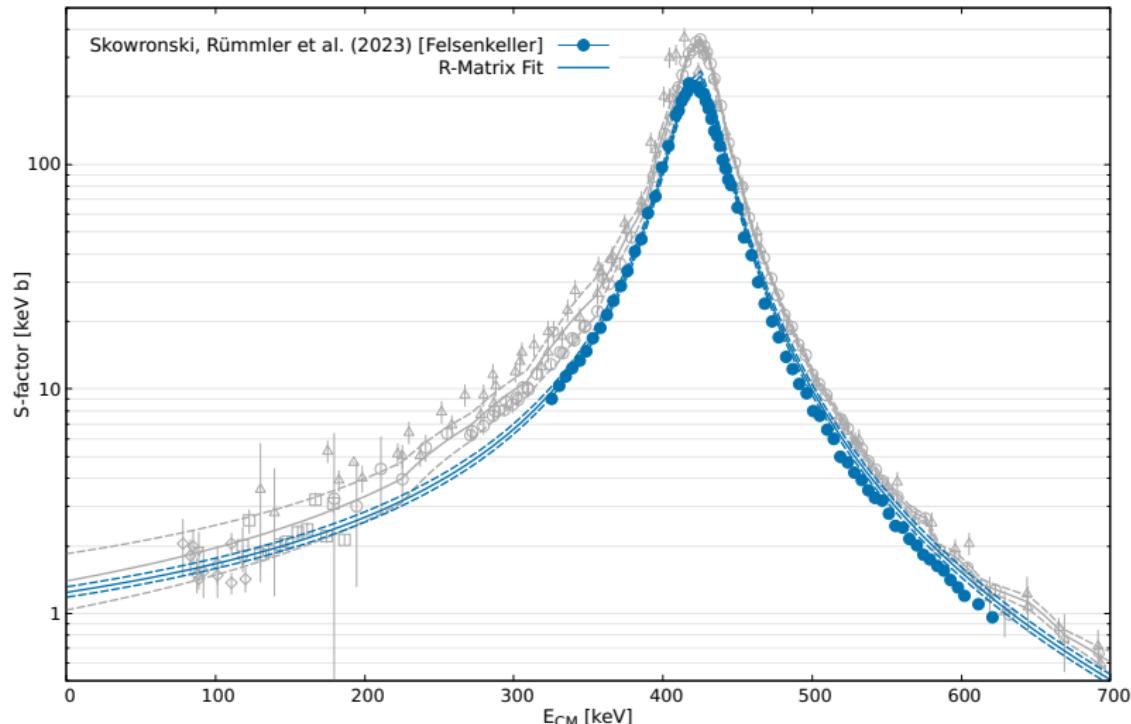
- high yield example (beam induced BG dominating)

## Spectrum at resonance



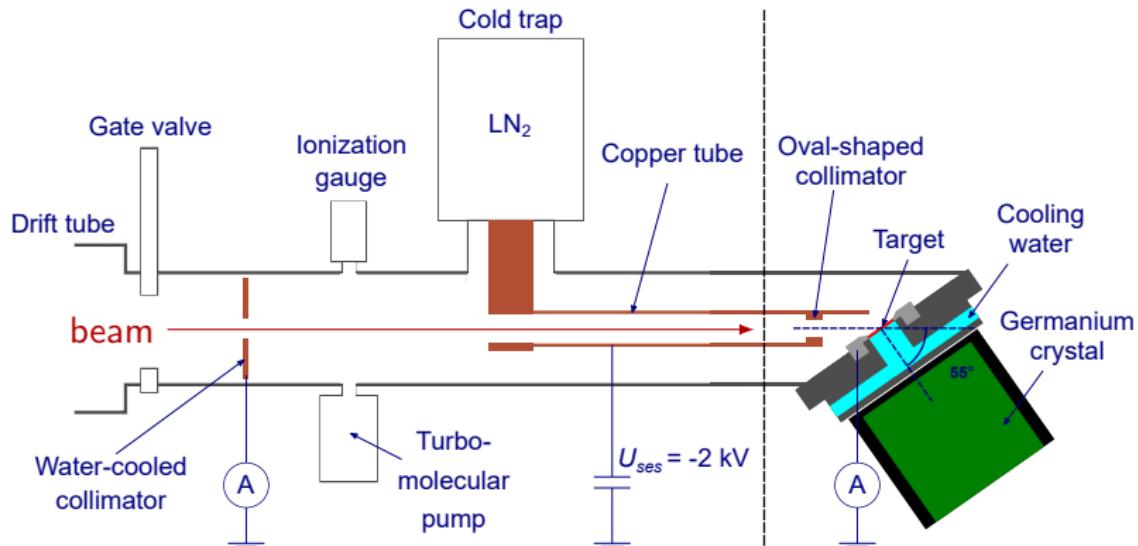
# 1st campaign: Felsenkeller

published results: Skowronski, Rümmler et al., Phys. Rev. C (2023)



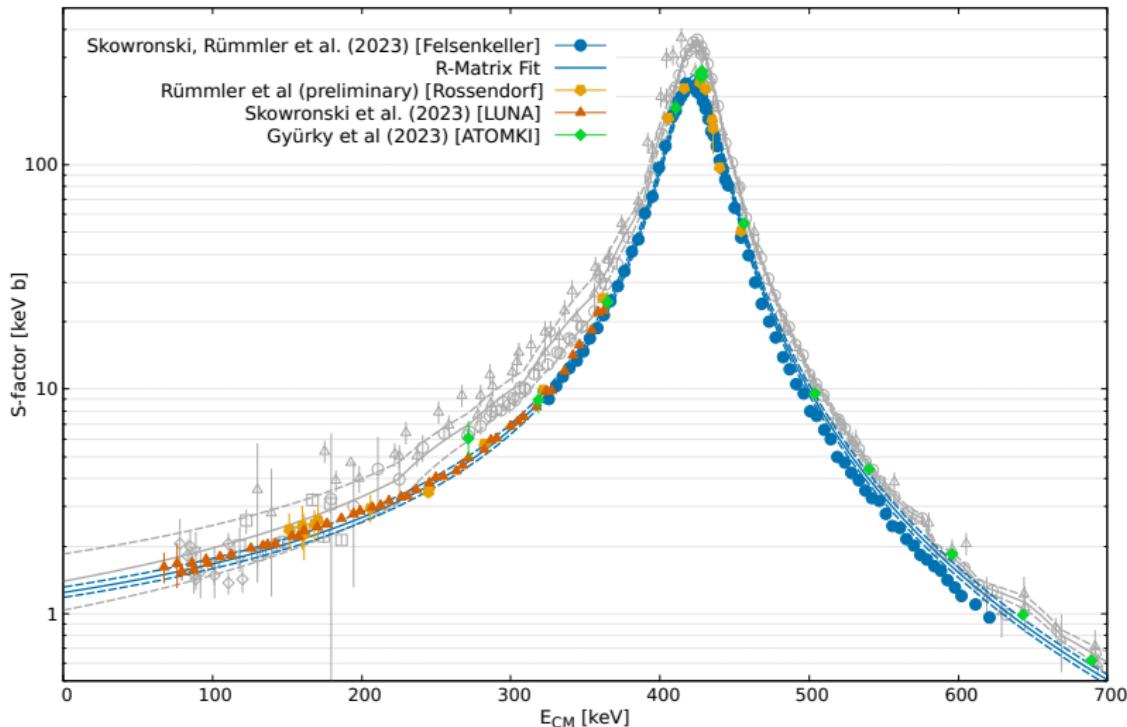
## 2nd campaign: Rossendorf (inverse kinematics)

- 3 MV Tandetron at Helmholtz-Zentrum Dresden-Rossendorf
- energy range:  $E_{CM} = 130 \text{ keV} - 450 \text{ keV}$
- inverse kinematics: carbon beam on hydrated targets
- lead shielding around target, additional plastic scintillation paddles



# Comparison of recent $^{12}\text{C}(\text{p}, \gamma)^{13}\text{N}$ measurements

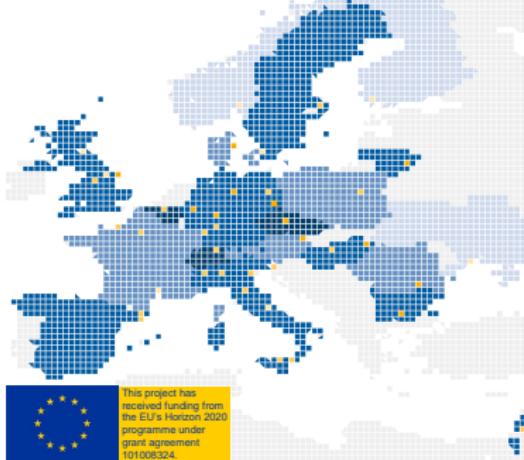
- further data: Skowronski et al. (2023) [LUNA], Gyürky et al. (2023) [ATOMKI]  
→ 25% lower reaction rate



# ChETEC-INFRA - Transnational Access



Chemical Elements as Tracers of the Evolution of the Cosmos – Infrastructures for Nuclear Astrophysics  
[ketek-infra]



EU supported access to 13 infrastructures



Felsenkeller, DE  
Underground ion accelerator



DREAMS, DE  
Accelerator Mass Spectrometry



VERA, AT  
Accelerator Mass Spectrometry



laboratories



supercomputer



telescopes



Rozhen, BG  
Ritchie-Chretien-Coudé telescope (2 m)



Perek, CZ  
2-m telescope



NOT, La Palma, ES  
Nordic Optical Telescope (2.56 m)



Frankfurt, DE  
Quasi-Maxwellian neutron generator



PIAF, DE  
Almost mono-energetic and 'white' neutrons



Cologne, DE  
10MV Tandem ion accelerator



ATOMKI, HU  
MGC-20 cyclotron for H,  $^2\text{H}$ ,  $^3\text{He}$ , and  $^4\text{He}$



Molétai, LT  
Ritchey-Chretien telescope (1.65 m)



IFIN-HH, RO  
Tandetron ion accelerators



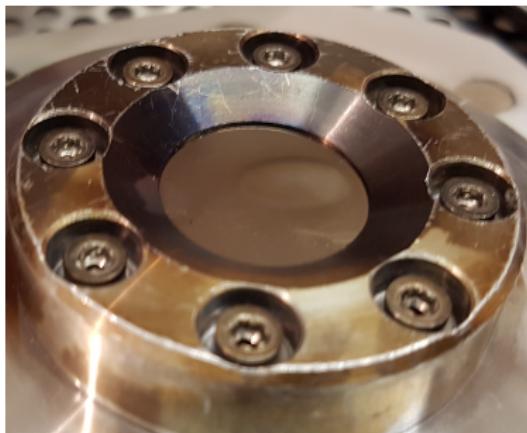
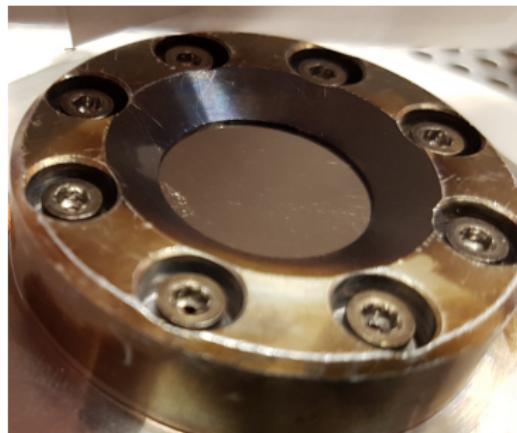
VIPER, UK  
High Performance Computing

# Backup slides

# 2nd campaign: Rossendorf (inverse kinematics)

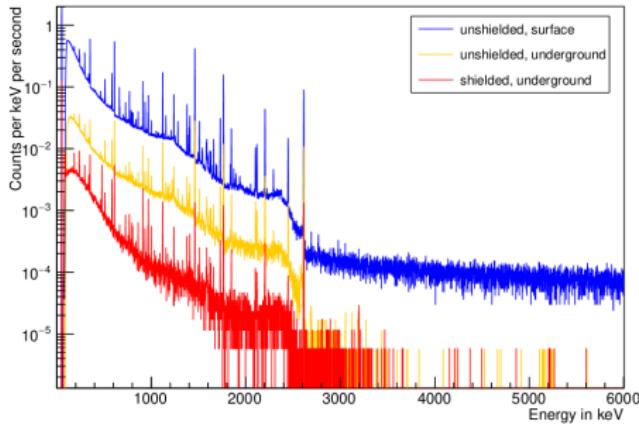
## Targets

- 220  $\mu\text{m}$  thick tantalum backings
- 100 nm or 200 nm titanium layer evaporated
- either hydrated (5 targets) or implanted (1 target)
- different energy points measured for each target
- (repeated) hydrogen scans (hydrogen profile, time stability) with nitrogen-beam for the  $^{15}\text{N}(\text{p}, \alpha\gamma)^{12}\text{C}$ -resonance



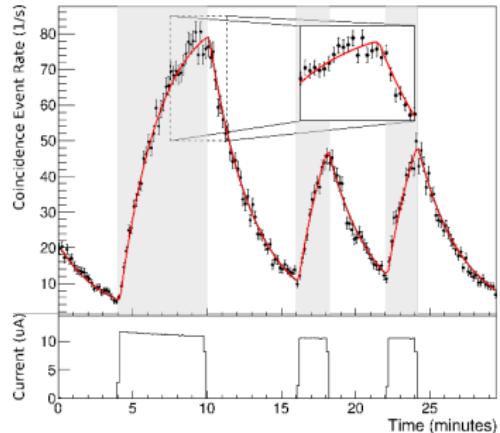
# LUNA campaign

- campaign at LUNA at Laboratori Nazionali del Gran Sasso (LNGS)
- deep-underground laboratory (3800 m.w.e.)
- 400 kV accelerator
- H<sup>+</sup>-beam with typical intensities of 300 μA
- energy range:  
 $E_{CM} = 130 \text{ keV} - 450 \text{ keV}$



# LUNA campaign

- targets: evaporated carbon on tantalum and graphite discs
- regular target characterization measurements
- two methods:
  - $\gamma$ -ray measurement with HPGe under  $0^\circ$  or  $55^\circ$
  - segmented  $4\pi$  BGO detector for activation measurement



- results accepted for publication in Phys. Rev. Lett.