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

Measurements of the ^{14,15}N(α, γ)^{18,19}F reactions and prospect for other He burning reactions at Felsenkeller

Eliana Masha

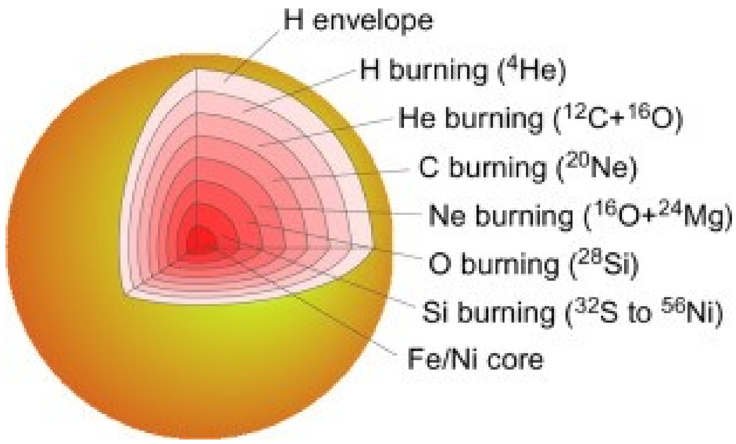
Helmholtz Zentrum Dresden-Rossendorf

EuNPC 2025
Caen, September 22-26, 2025

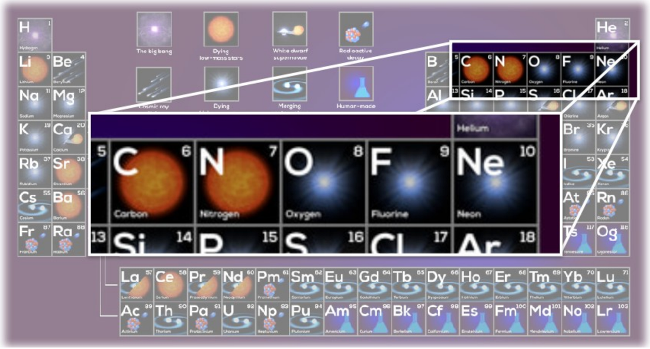
Helium burning as a key step in stellar nucleosynthesis

After hydrogen burning depletes the core, helium burning ignites under typical conditions of:

- Density: $10^2 - 10^4$ g/cm^2
- Temperature: $1 - 2\ 10^8$ K
- Sites: Red giant stars, Asymptotic Giant Branch (AGB) stars, massive stars, core-collapse supernova progenitors

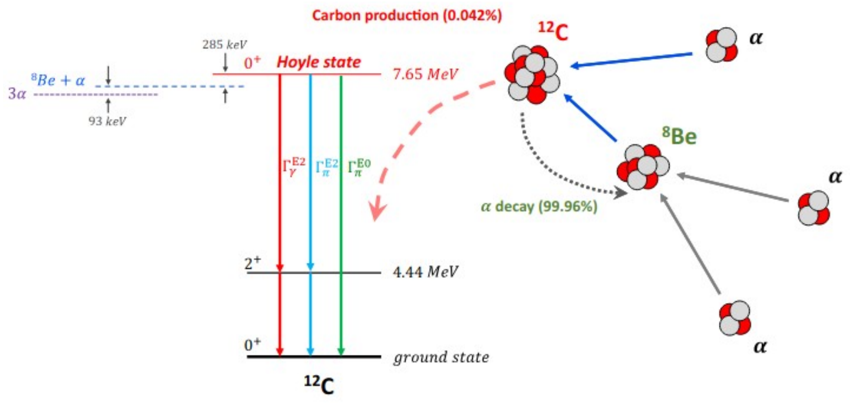


Helium burning is a cornerstone of stellar evolution and nucleosynthesis



Main Helium burning reactions

- 3α-process: $^{4}He(2\alpha, \gamma)^{12}C$
- $^{12}C(\alpha, \gamma)^{16}O$
- $^{4}N(\alpha,\gamma)^{18}F(\beta^{+}\nu)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$
- $^{14}N(\alpha,\gamma)^{18}F(\beta^{+}\nu)^{18}O(\alpha,\gamma)^{22}Ne$
- $^{16}O(\alpha,\gamma)^{20}Ne$
- $^{17}O(\alpha,\gamma)^{21}Ne$
- $^{19}F(\alpha, p)^{22}Ne$
- $^{18}F(\alpha, p)^{21}Ne$
- $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,\gamma/n)^{26,25}Mg$



Astrophysical motivation

- C/O ratio: sets conditions for later burning phases.
- F and Ne production/destruction: key for chemical evolution.
- Neutron sources (^{13}C,^{22}Ne+α): drive the s-process.
- Connects He burning to stellar yields and galactic abundances.

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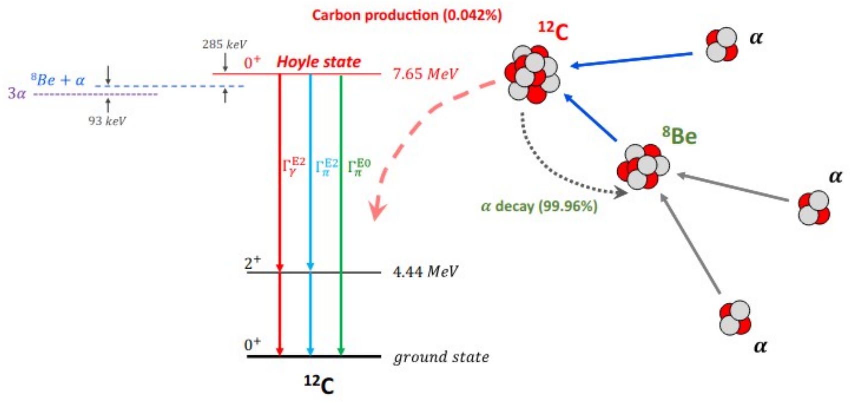

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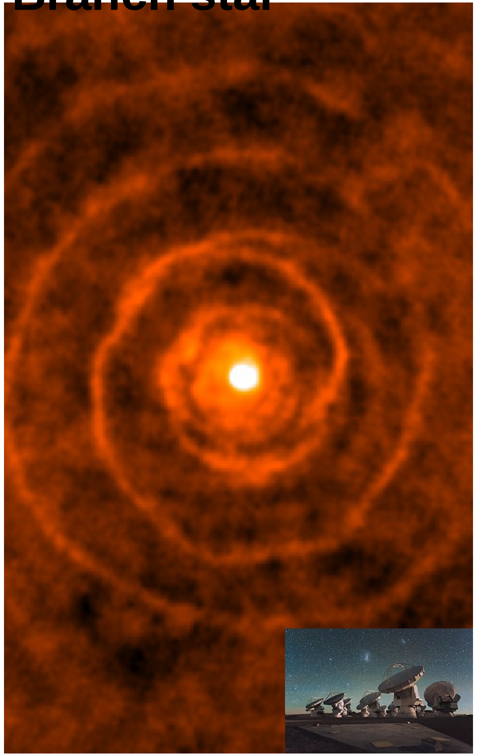
Most promising sources of Fluorine in stars

Type II Supernova

Credit: NASA, ESA, CSA, STScI, D. Milisavljevic, I. De Looze, T. Temim

James Webb Space Telescope Cold Side

Asymptotic Giant Branch star



Credit: Kim *et al.* Nature Astronomy (2017)

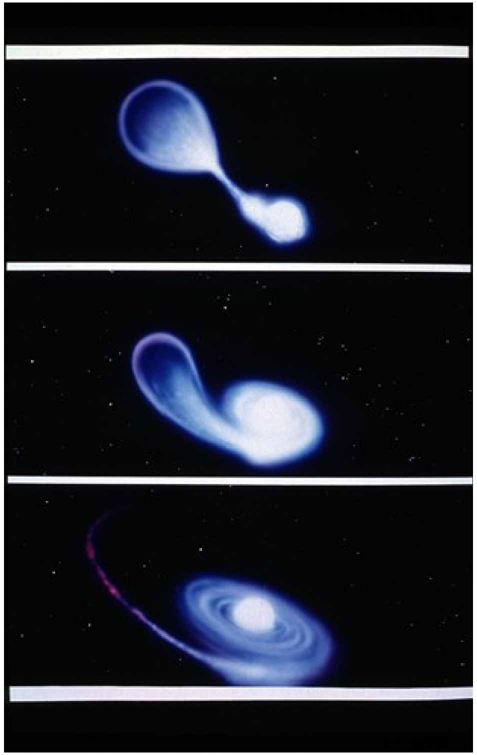
Atacama Large Millimeter /submillimeter Array (ALMA)

Wolf-Rayet star

Credit: NASA, ESA, CSA, STScI, Webb ERO Production Team

James Webb Space Telescope Hot Side

White Dwarf Merger



Credit: STScI, Dana Berry

Most promising sources of Fluorine in stars

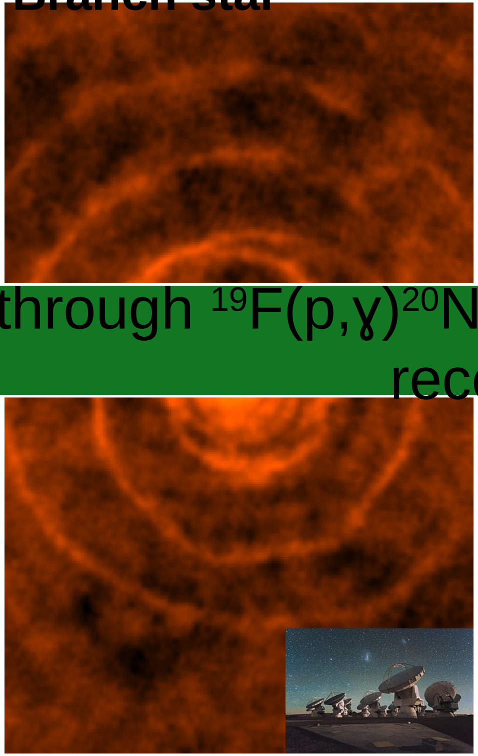
Type II Supernova

by neutrino spallation on ^{20}Ne

Credit: NASA, ESA, CSA, STScI, D. Milisavljevic, I. De Looze, T. Temim

James Webb Space Telescope Cold Side

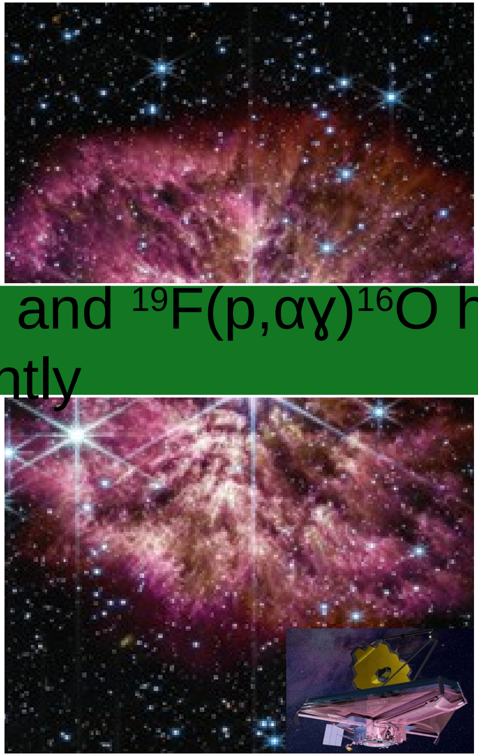
Asymptotic Giant Branch star



Credit: Kim *et al.* Nature Astronomy (2017)

Atacama Large Millimeter /submillimeter Array (ALMA)

Wolf-Rayet star



Credit: NASA, ESA, CSA, STScI, Webb ERO Production Team

James Webb Space Telescope Hot Side

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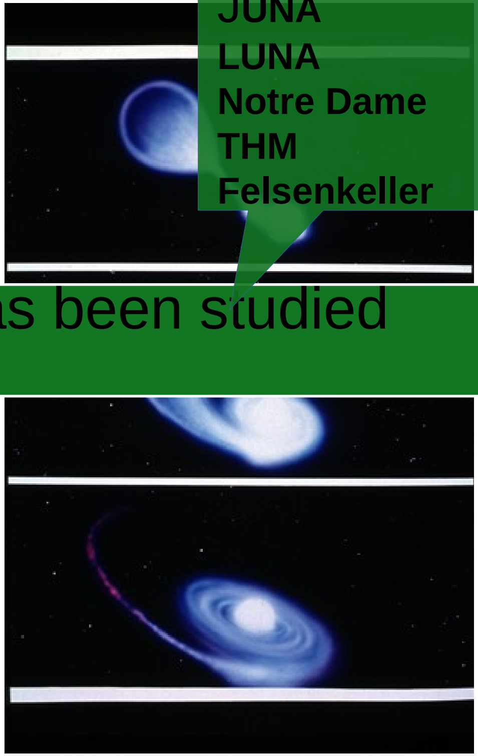

Credit: STScI, Dana Berry

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Notre Dame
THM
Felsenkeller

^{19}F destruction through ^{19}F(p,ɣ)^{20}Ne and ^{19}F(p,αɣ)^{16}O has been studied recently

Most promising sources of Fluorine in stars

Type II Supernova

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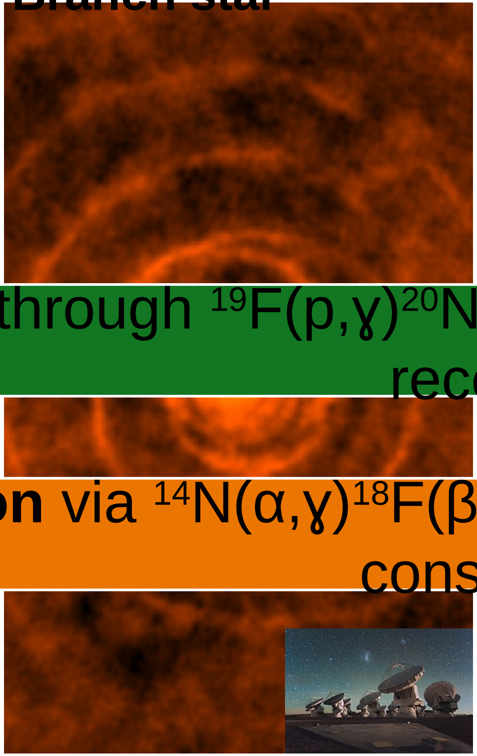
James Webb Space Telescope Cold Side

Asymptotic Giant Branch star



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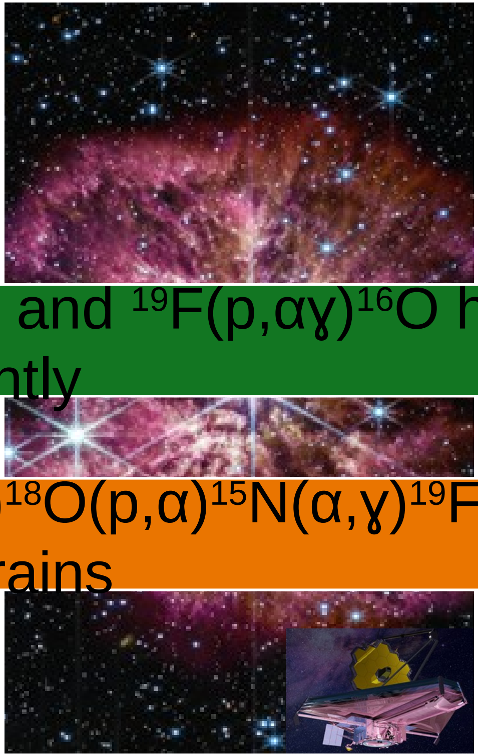
Atacama Large Millimeter /submillimeter Array (ALMA)

Wolf-Rayet star



Credit: NASA, ESA, CSA, STScI, Webb ERO Production Team

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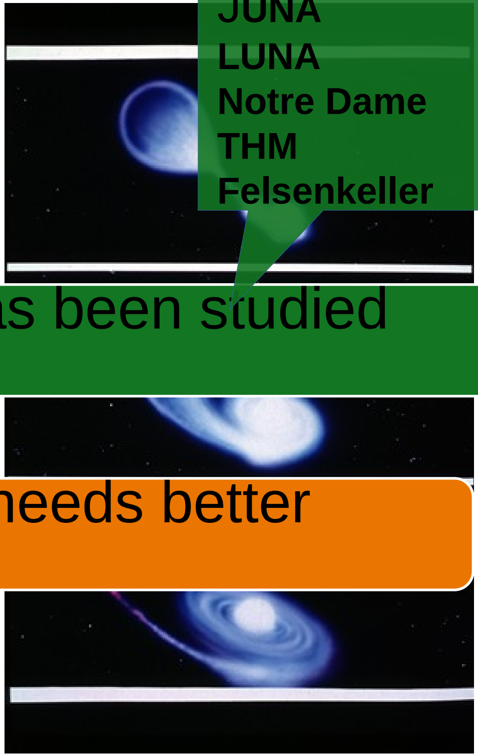

Credit: STScI, Dana Berry

JUNA
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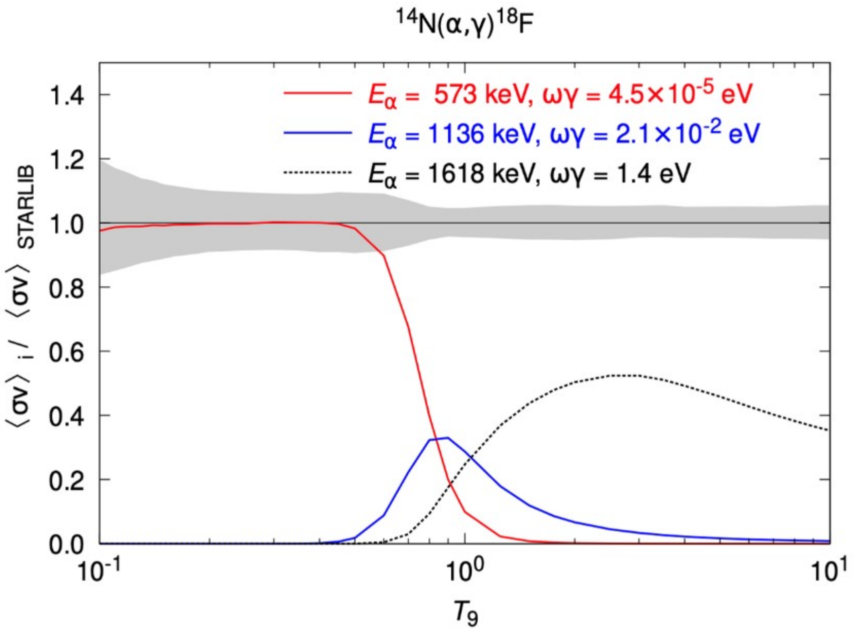
Felsenkeller

^{19}F destruction through ^{19}F(p,γ)^{20}Ne and ^{19}F(p,αγ)^{16}O has been studied recently

^{19}F production via ^{14}N(α,γ)^{18}F(β^{+})^{18}O(p,α)^{15}N(α,γ)^{19}F needs better constrains

$^{14}N(\alpha, \gamma)^{18}F$ reaction

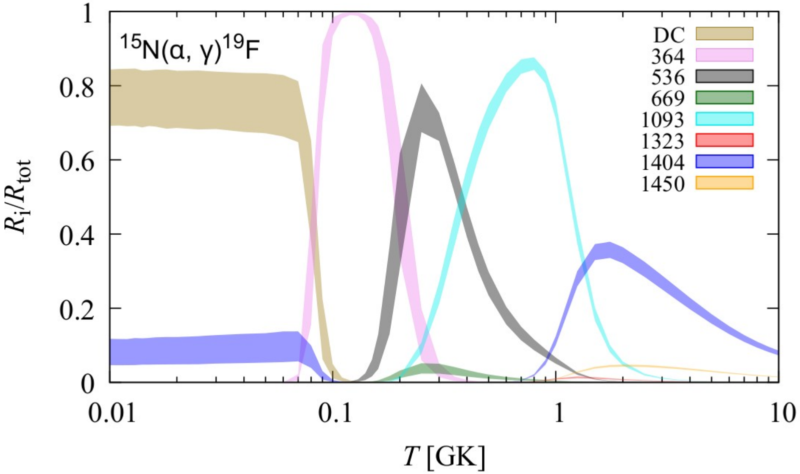
- Affects the production of ^{19}F
- Influence the synthesis of ^{22}Ne via $^{14}N(\alpha, \gamma)^{18}F(\beta^{\pm})^{18}O(\alpha, \gamma)^{22}Ne$, main neutron source in massive stars via the $^{22}Ne(\alpha, n)^{25}Mg$



Felsenkeller aim: Measurements of low-energy resonances (E_α= 0.4 – 1.6 MeV)

$^{15}N(\alpha, \gamma)^{19}F$ reaction

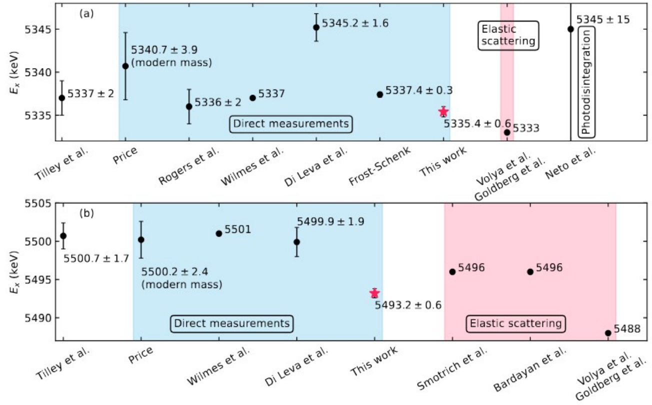
Total reaction rate is dominated by several resonances and the DC component



Resonances of interest >15% uncertainty

Cristallo et al. Astronomy&astrophysics 570 (2014) claims that:

- a strongly reduced **$^{15}N(\alpha,\gamma)^{19}F$** rate can match the observed ^{19}F
- *DC component contribution difficult to evaluate with the current exp. data*



Discrepancies in resonance energy and strength also at high energies E_r = 1.3 and 1.4 MeV *Fang et al., Phys. Rev. C 110, 025806 (2024)*

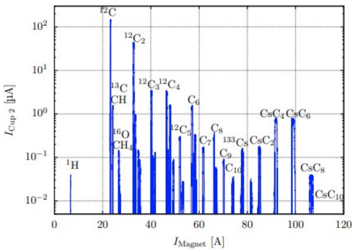
Felsenkeller aim: Measurements of the resonances < E_α = 1.8 MeV

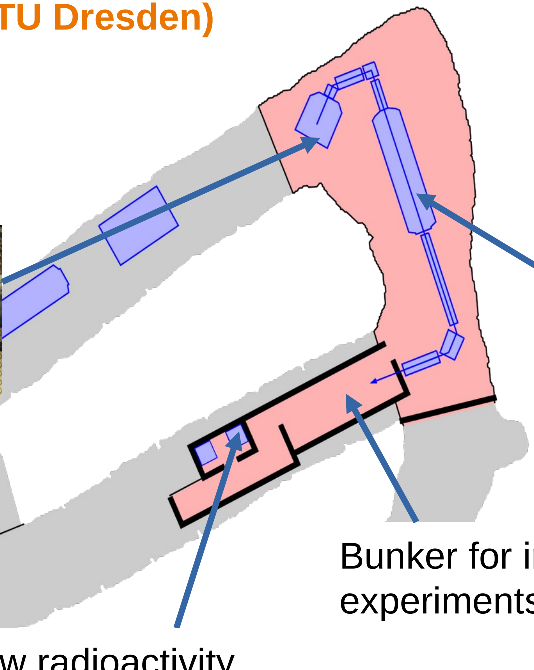
Felsenkeller underground lab

- One of the few underground labs for nuclear astrophysics worldwide
- Located in Dresden, Germany (HZDR + TU Dresden)
- Open facility for external proposals

External ion-source

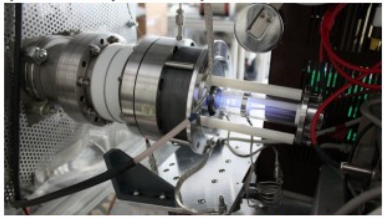
- Intensive ^{12}C beam
- Intensity of 20-30 μA
- Other negatively charged ions possible





Internal radio frequency ion-source

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



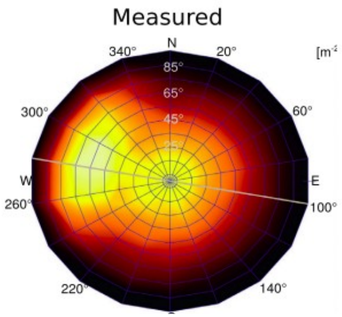
Bunker for in-beam experiments

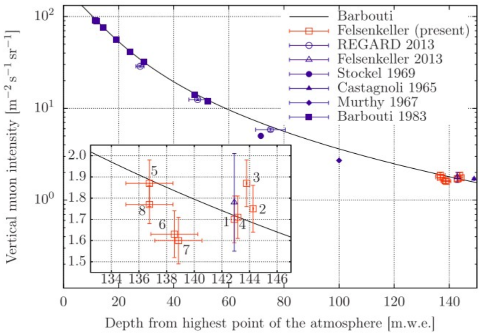
Low radioactivity measurements setup

ChETEC INFRA · Alexander von HUMBOLDT STIFTUNG · DRESDEN concept SCIENCE AND INNOVATION CAMPUS · HZDR

Felsenkeller underground lab

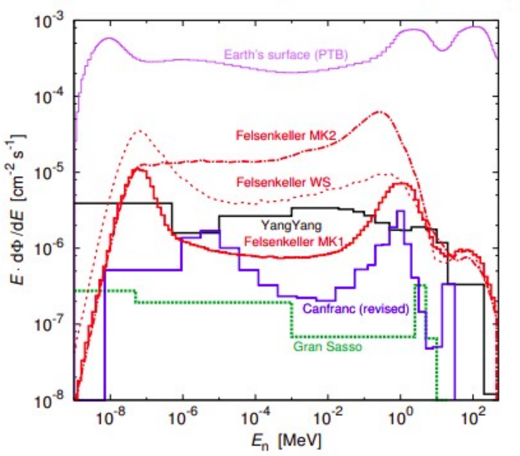
Muon flux: 40x reduced

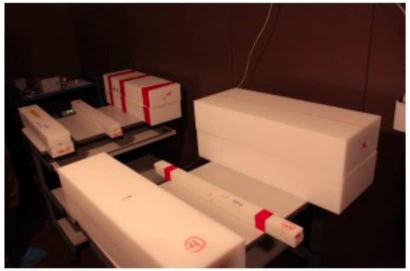




Astropart. Phys. 112, 24 (2019)

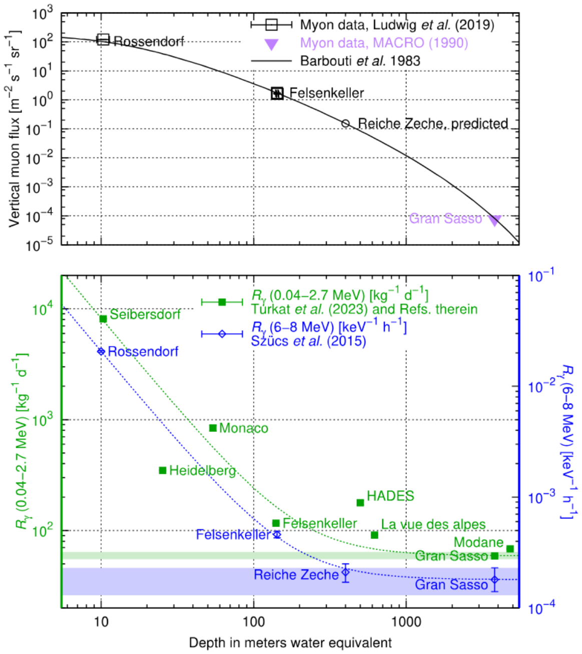
Neutron flux: 200x reduced





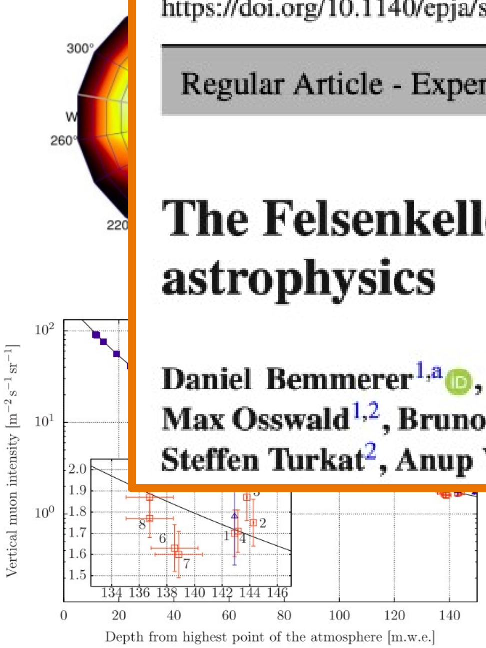
Phys. Rev. D.101, 123027 (2020)

γ-ray background: 100x lower



Felsenkeller underground lab

Muon flux: 40x reduced | **Neutron flux: 200x reduced** | **γ-ray background: 100x lower**



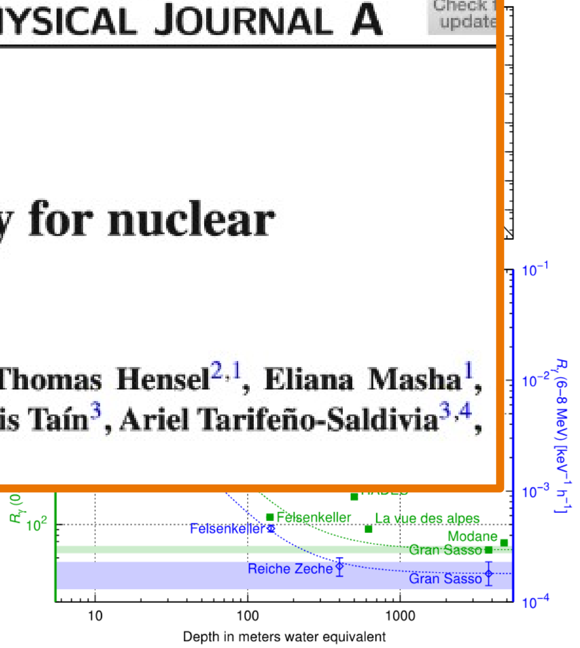
Eur. Phys. J. A (2025) 61:19
https://doi.org/10.1140/epja/s10050-025-01490-z

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Experimental Physics

The Felsenkeller shallow-underground laboratory for nuclear astrophysics

Daniel Bemmerer[1,a], Axel Boeltzig[1], Marcel Grieger[1], Katharina Gudat[1], Thomas Hensel[2,1], Eliana Masha[1], Max Osswald[1,2], Bruno Poser[1,2], Simon Rümmler[1,2], Konrad Schmidt[1], José Luis Taín[3], Ariel Tarifeño-Saldivia[3,4], Steffen Turkat[2], Anup Yadav[1,2], Kai Zuber[2]

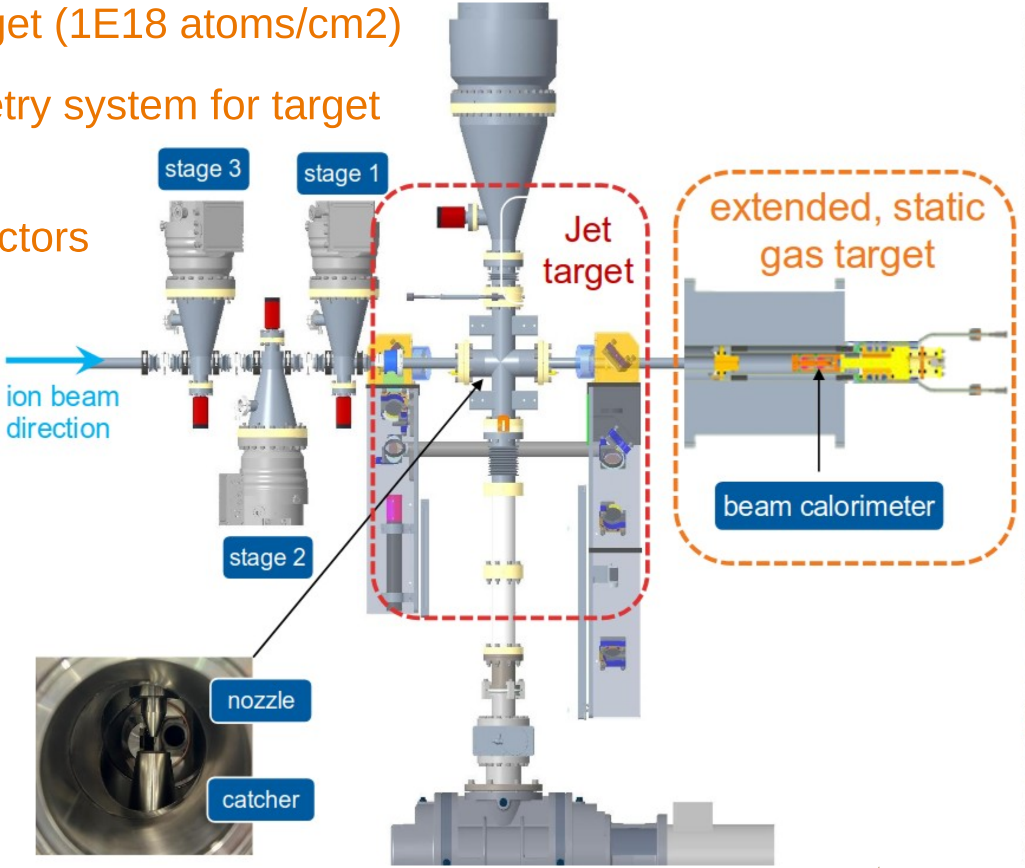


Phys. Rev. D.101, 123027 (2020)

Astropart. Phys. 112, 24 (2019)

$^{14}N(\alpha, \gamma)^{18}F$ reaction: Experimental setup

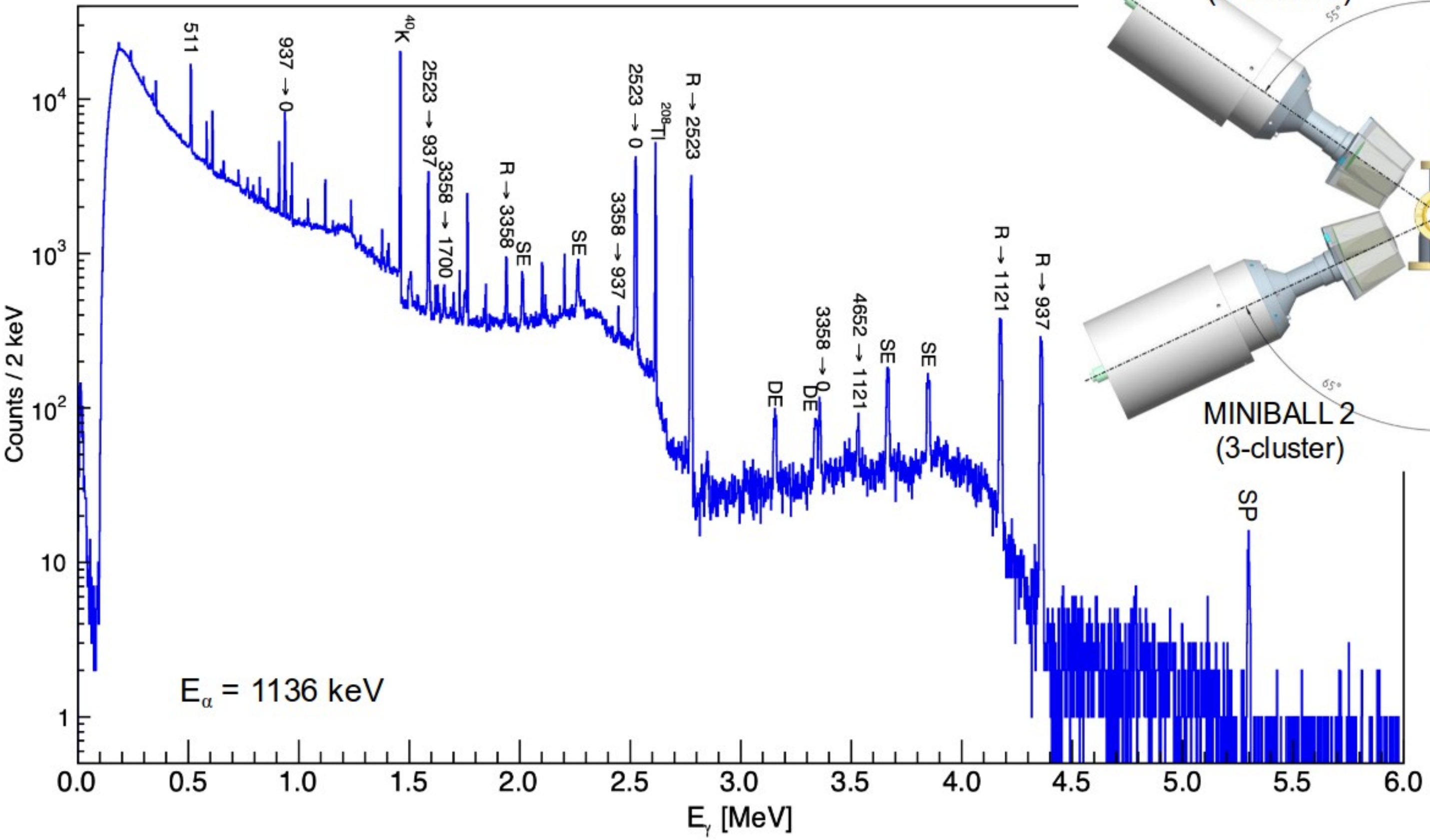
- Gas jet target (1E18 atoms/cm2)
- Interferometry system for target thickness
- HPGe detectors

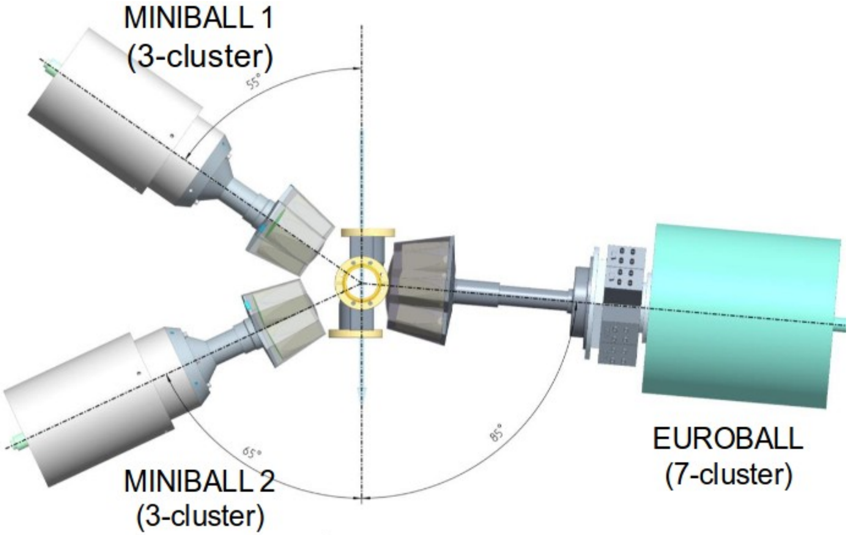


A. Yadav PhD project

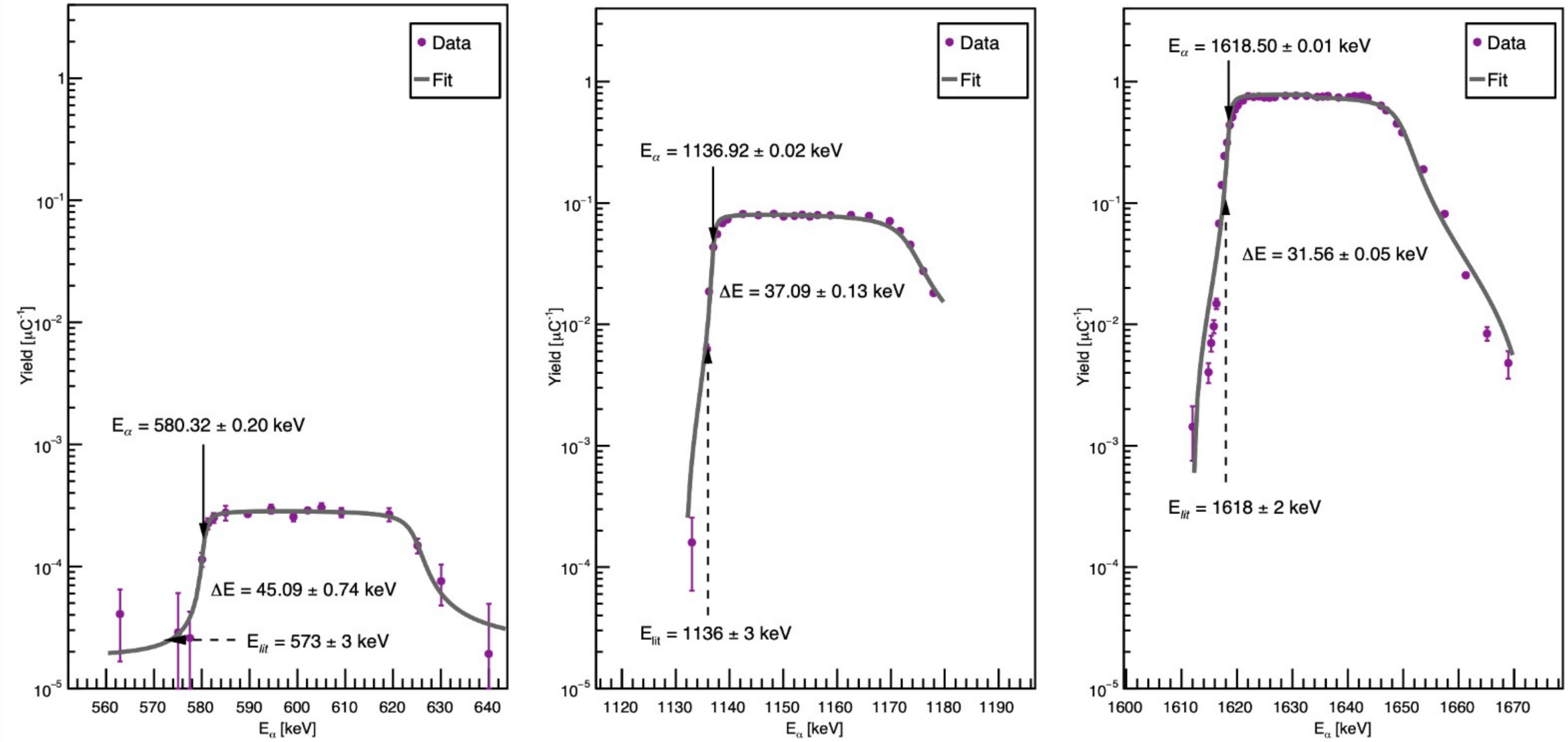
ChETEC-INFRA TA Project

$^{14}N(\alpha, \gamma)^{18}F$ reaction: γ-ray experimental spectrum





$^{14}N(\alpha, \gamma)^{18}F$ reaction: Resonance scans



$^{14}N(\alpha, \gamma)^{18}F$ reaction: Preliminary results

Resonance energy [keV]		Resonance strength $\omega\gamma$ [meV]	
this work	literature	this work	literature
580.3 ± 0.2[1]	573 ± 3	$4.6 \pm 0.3 \times 10^{-2}$	$4.6 \pm 0.3 \times 10^{-2}$
1136.9 ± 0.2[1]	1136 ± 3	$23.5 \pm 0.6 \times 10^{0}$	$21.1 \pm 0.3 \times 10^{0}$
1618.1 ± 0.1[1]	1618 ± 2	$4.55 \pm 0.07 \times 10^{2}$	$4.5 \pm 0.5 \times 10^{2}$

[1]statistical uncertainty only

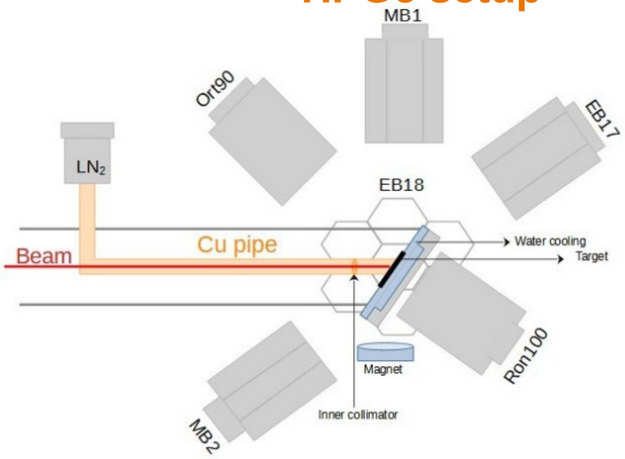
Final results, TRR, Branching ratios and angular distribution data under analysis

Stay tuned!

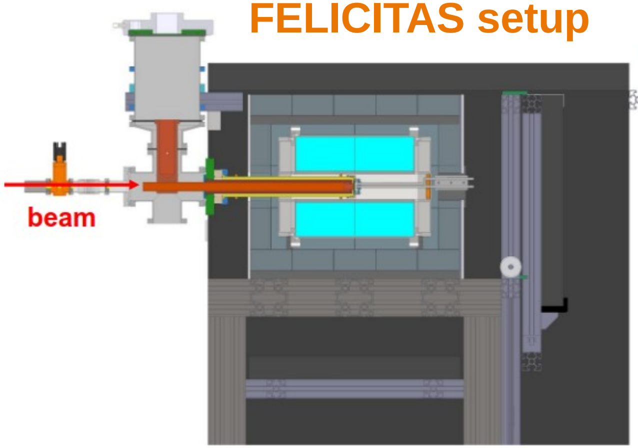
$^{15}N(\alpha, \gamma)^{19}F$ reaction: Experimental setup

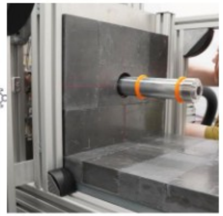
- Solid Ta^{15}N target (M. Campostrini, LNL)
- HPGe detection system for high energy resonances
- High efficiency 4π BGO detection system (FELICITAS) for low energy resonances
- Target stability: E_r= 1450 keV resonance

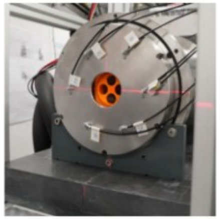
HPGe setup

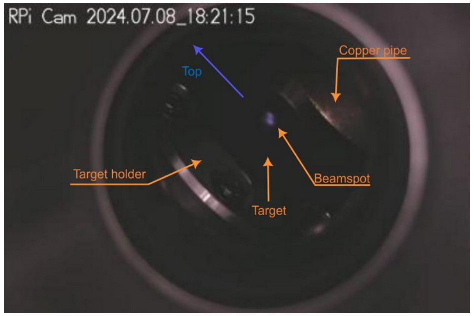


FELICITAS setup

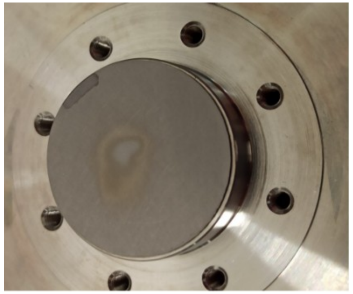








Optical camera during irradiation

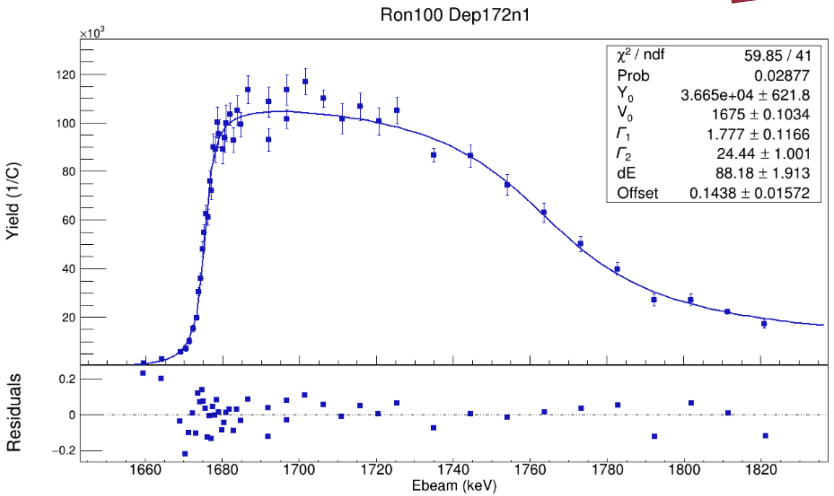


Target after irradiation

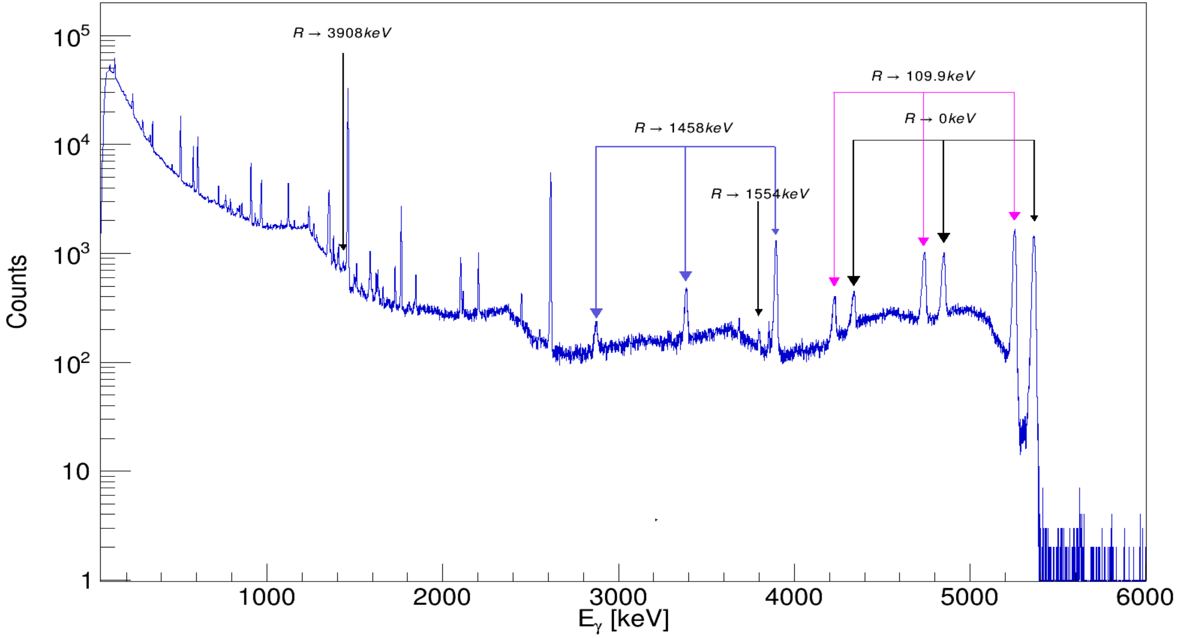
ChETEC-INFRA TA Project

$^{15}N(\alpha, \gamma)^{19}F$ reaction: Preliminary data

E_r = 1323 keV



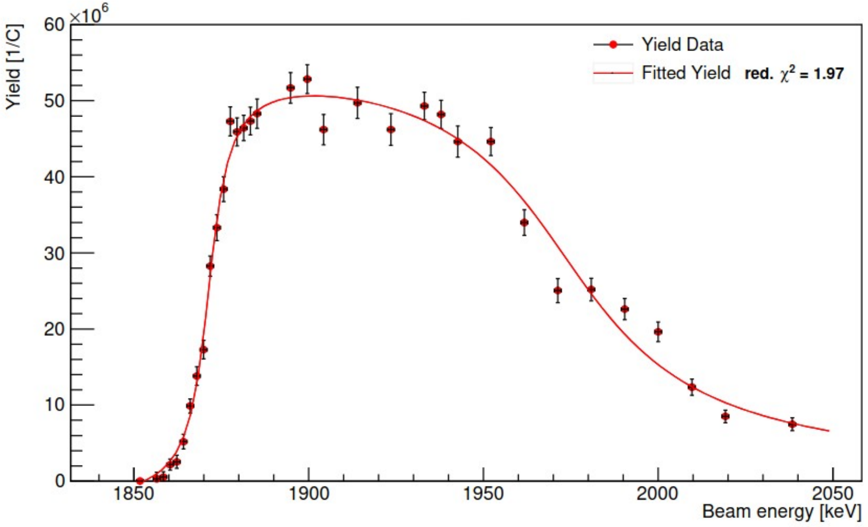
High statistics run on the top of the resonance

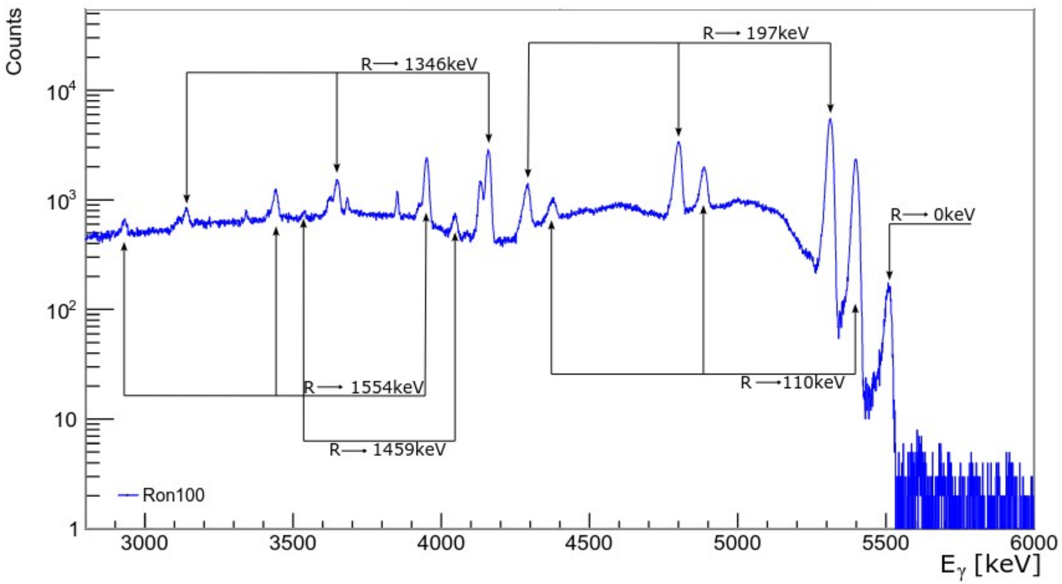


$^{15}N(\alpha, \gamma)^{19}F$ reaction: Preliminary data

E_r = 1487 keV

High statistics run on the top of the resonance





$^{15}N(\alpha, \gamma)^{19}F$ reaction: Preliminary results

	ERNA (2017)	Fang (2024)	Felsenkeller (2025)
E_X [keV]	5345.2 ±1.6	5335.4 ± 0.6	5336.1 ± 1.2
ωɣ [eV]	1.62±0.09	1.61±0.07	1.47 ± 0.08
E_X [keV]	5499.9 ±1.9	5493.2 ± 0.6	5491.1 ± 1.1
ωɣ [eV]	4.4±0.4	4.01±0.20	4.3 ± 0.3

Resonance scan + peak position approach

E_r = 1323 keV

E_r = 1487 keV

- Both experimental campaigns (HPGe and FELICITAS) have been completed, with a good statistics for all resonances with E_r>365 keV
- Analysis of resonance energies, strengths, and branching ratios and angular distribution is ongoing.

Summary and outlook

Felsenkeller underground lab

- Open facility for external users
- Beams: ^{12}C, ^{4}He, ^{2}H with intensities up to 20–30 μA
- Background reduced: muons ×40, neutrons ×200, γ ×100
- Main available setups: gas-jet target, solid targets

Ongoing and near future Helium burning program

- **^{14}N(α,γ)^{18}F**, **^{15}N(α,γ)^{19}F** experimental campaigns completed
- Final results, new TRR and astrophysics impact will follow
- ^{12}C(α,γ)^{16}O in direct and in inverse kinematics, with HPGe and with FELICITAS detector
- ^{18}O(α,γ)^{22}Ne measurements at E_r< 0.6MeV with solid or gas-target setup and FELICITAS detector

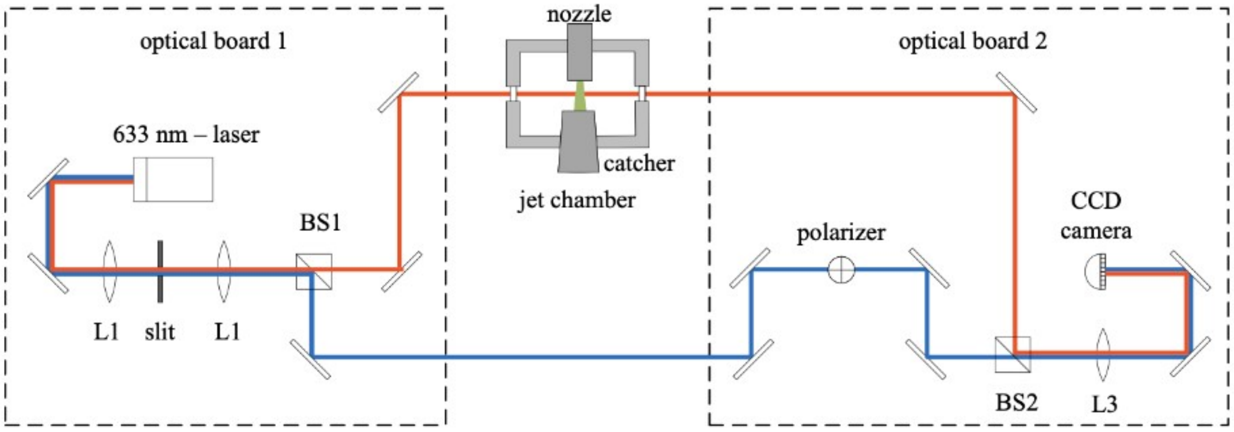
Felsenkeller team, June 2025

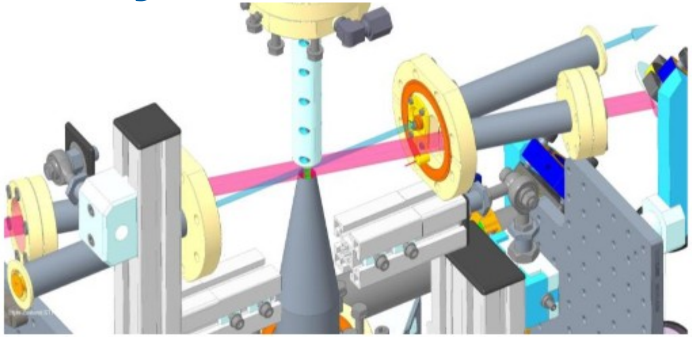
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008324 (ChETEC-INFRA).

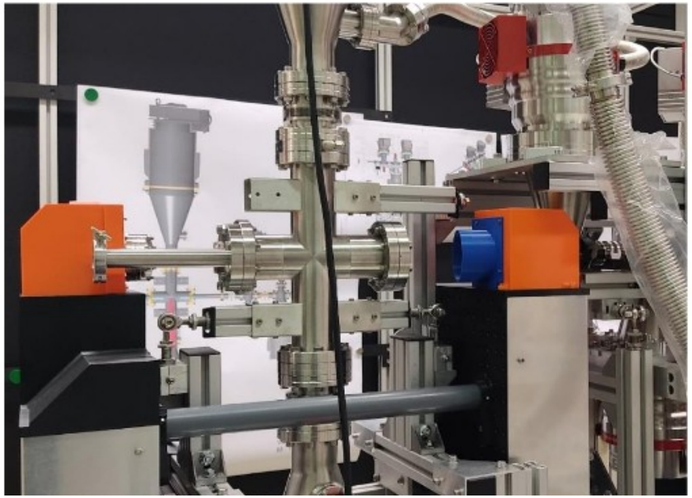
Backup

Gas-jet target thickness by laser interferometry

Mach-Zehnder Interferometer

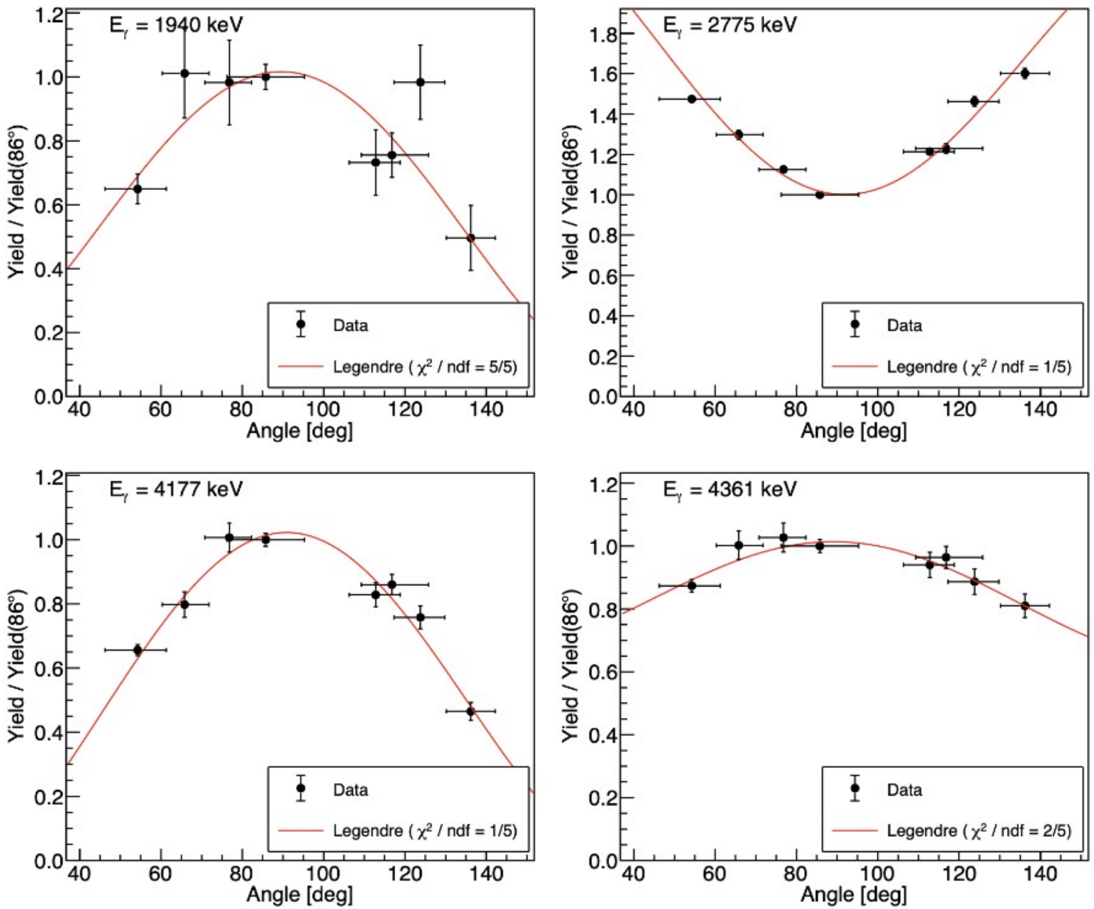






- Optical path length difference depends on:
  - Gas refractive index (for N_2: 1.0002985)
  - Density distribution
- Path length shift for N_2 (~ 110 nm

Angular distributions E_α = 1136 keV resonance



Angular distributions E_α = 1618 keV resonance