

How nuclear physics experiments shape our understanding of supernova γ -ray signatures

Thanassis Psaltis



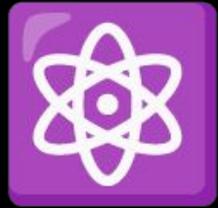
Saint Mary's
University

WNNPC 2026
February 13th, 2026



Crab Nebula (M1)

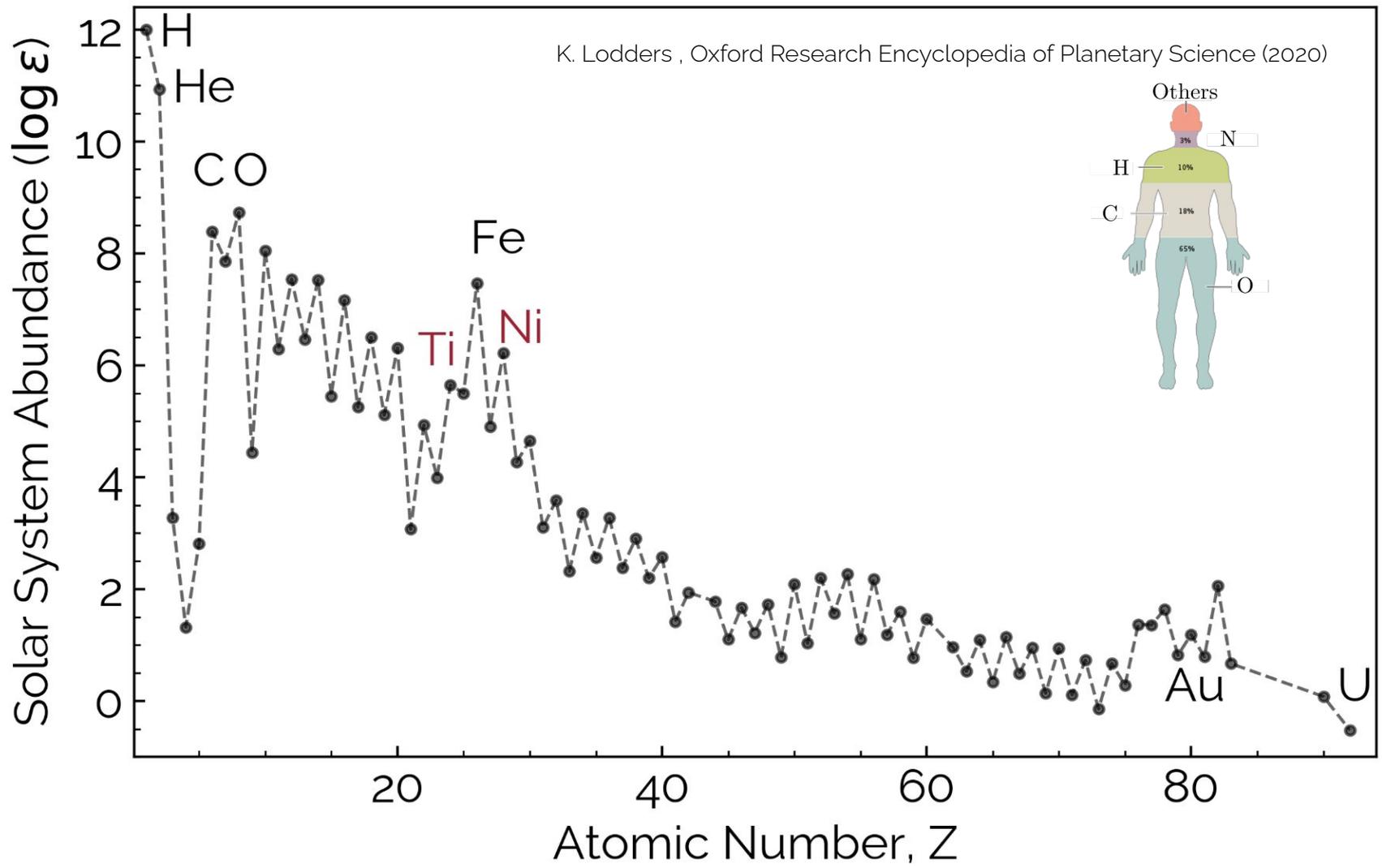
Image credit: NASA, ESA, CSA, STScI, T. Temim



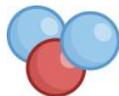
small + ✨ large

“The cosmic recipe” 🌌👨‍🍳





^1H (proton) ^2H (deuterium) ^3H (tritium)



Proton Number, Z



Hydrogen

Neutron Number, N



Uranium



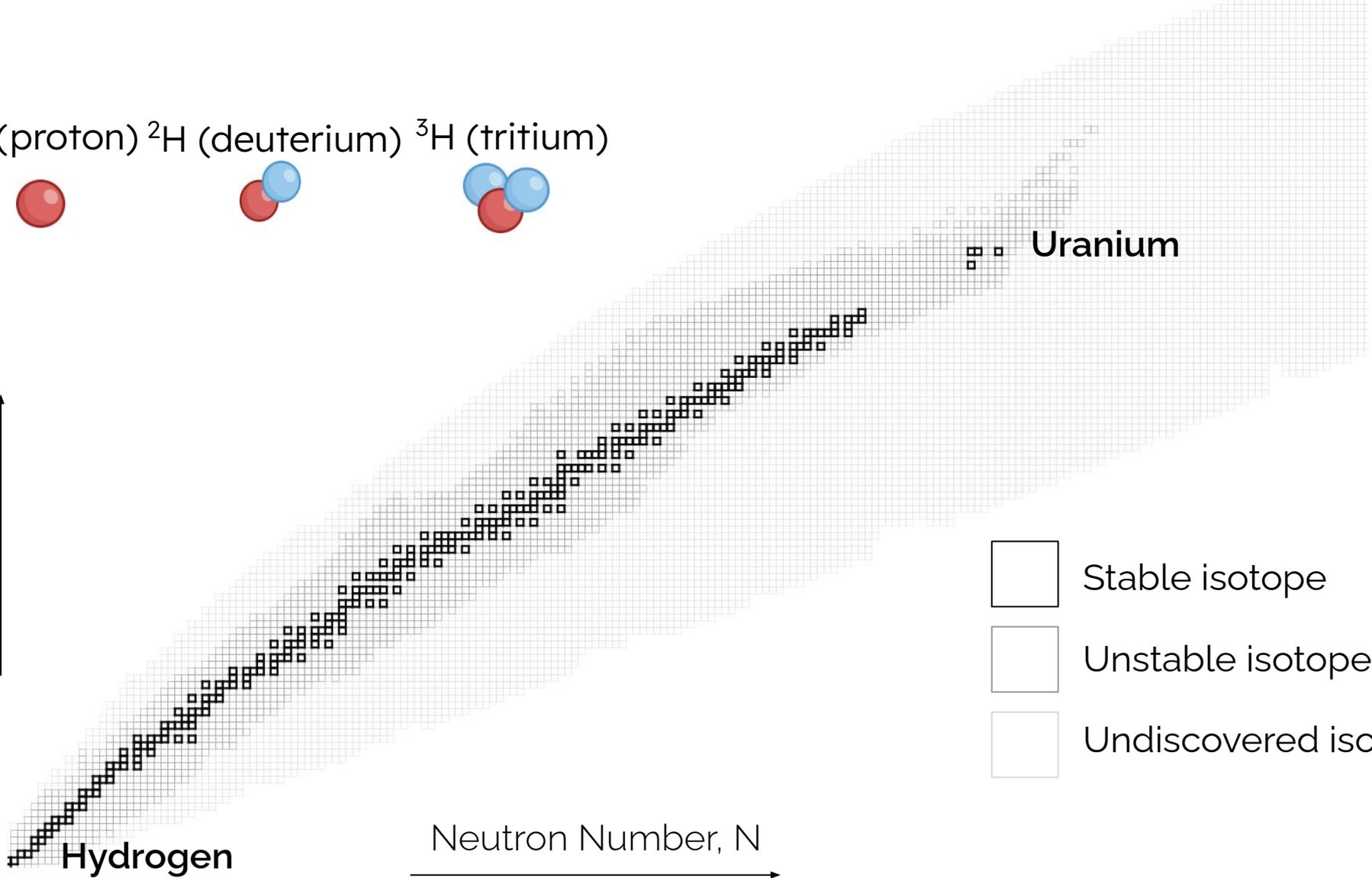
Stable isotope

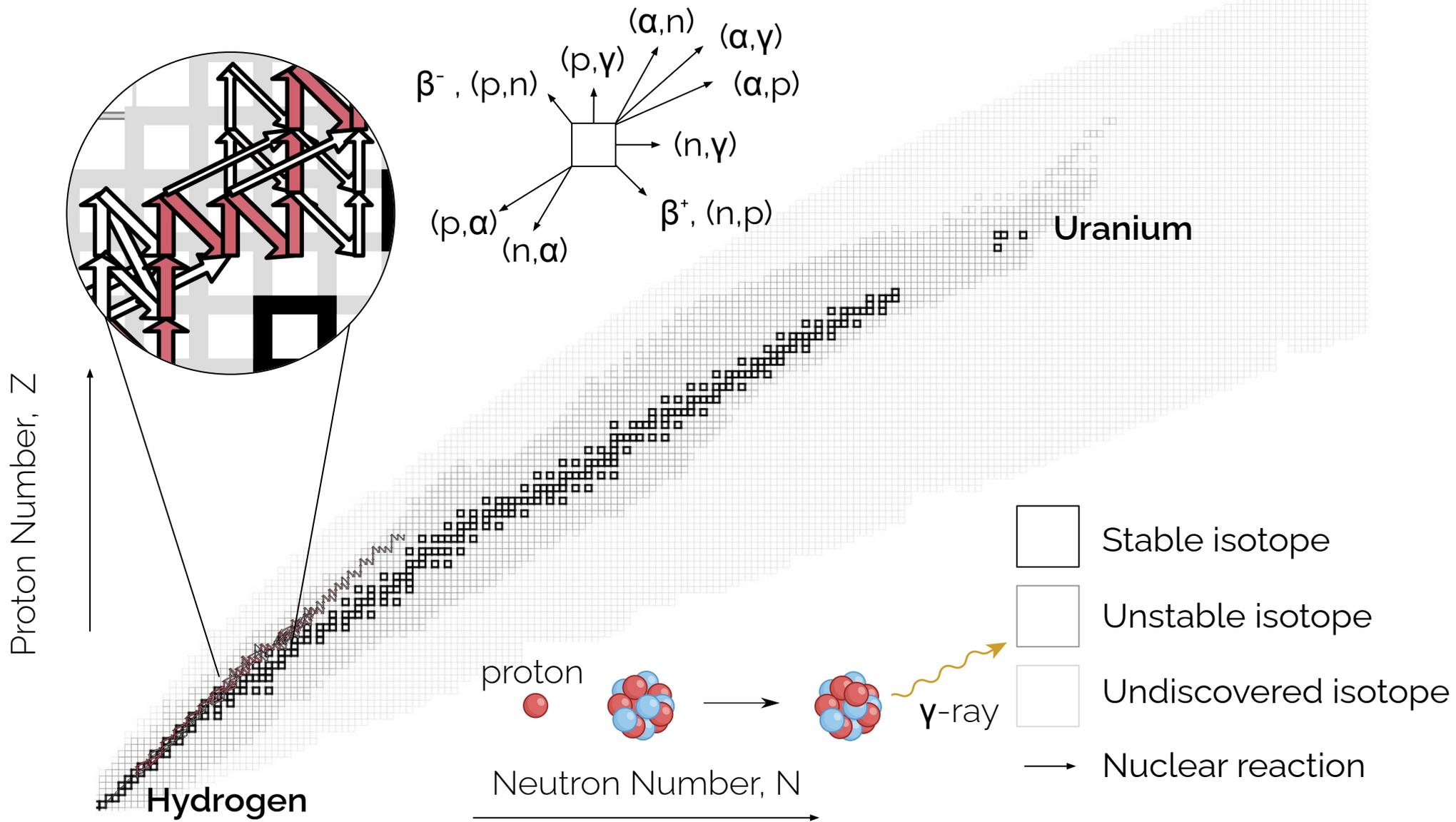


Unstable isotope

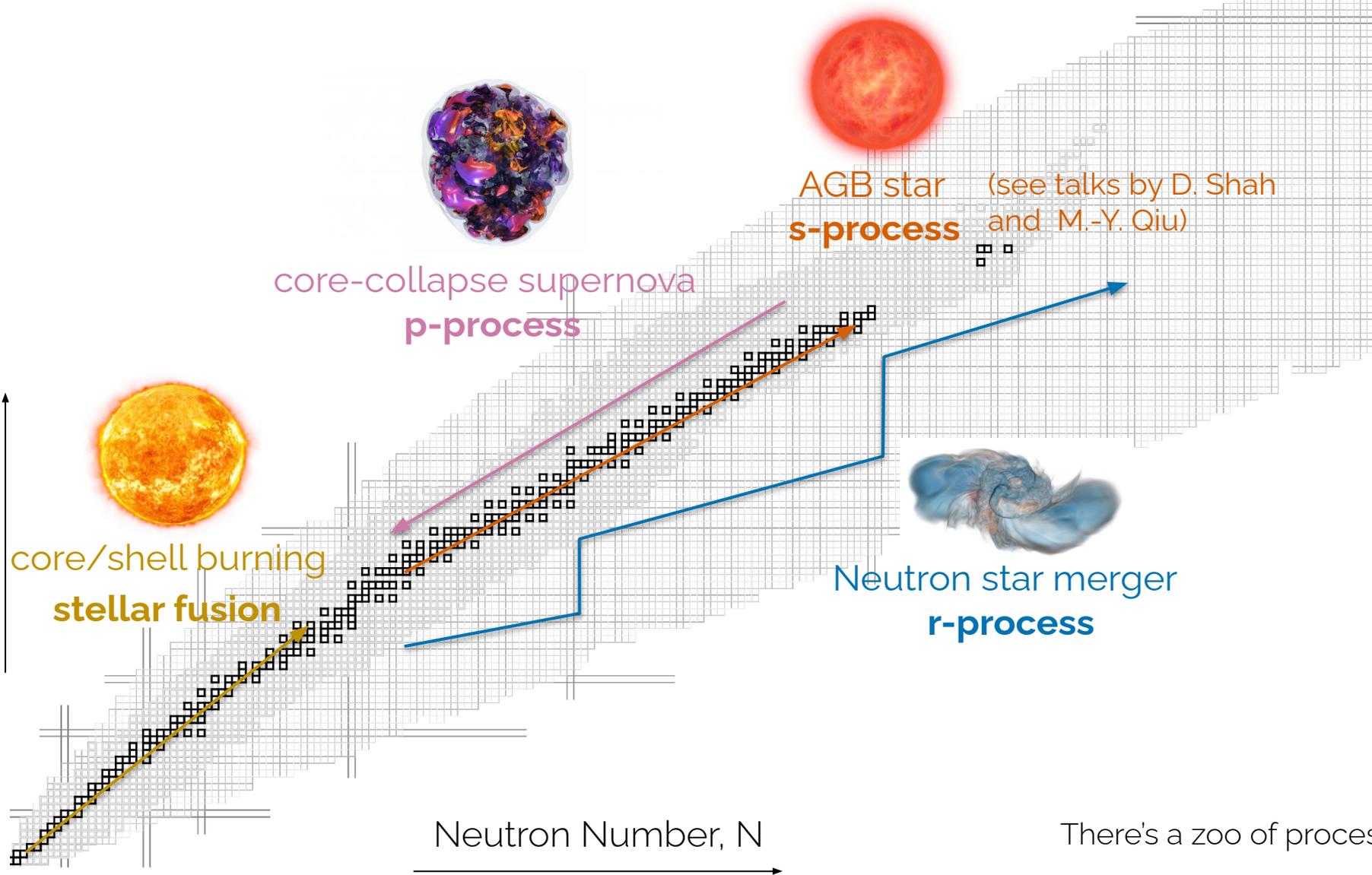


Undiscovered isotope





Proton Number, Z



Neutron Number, N

There's a zoo of processes...

Experimental Nuclear Physics

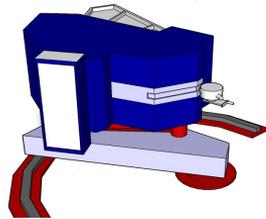
direct measurements using radioactive ion beams • stable ion beam experiments • recoil separators • charged-particle spectroscopy • indirect measurements • in-beam and activation γ -ray spectroscopy • thermonuclear reaction rate evaluation • active targets • magnetic spectrographs



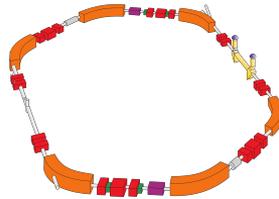
DRAGON (TRIUMF)



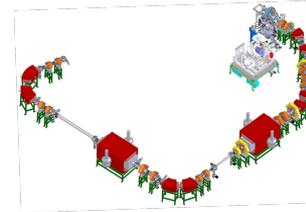
MUSIC (Argonne)



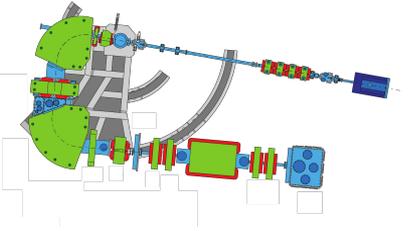
Enge Split-Pole (TUNL)



ESR (GSI)



SECAR (FRIB)



CRIB (CNS/RIKEN)

Experimental Nuclear Physics

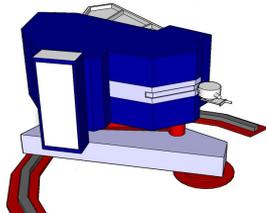
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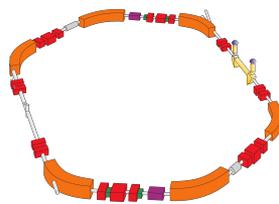
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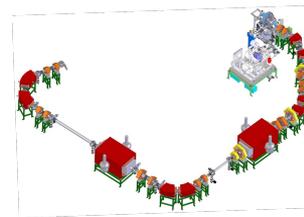
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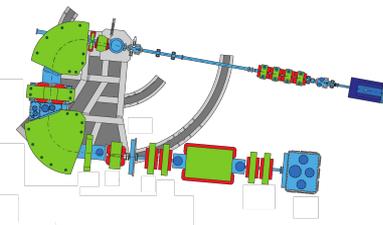
Enge Split-Pole (TUNL)



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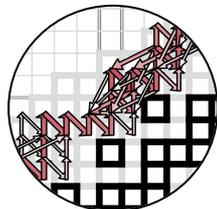
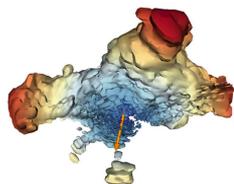
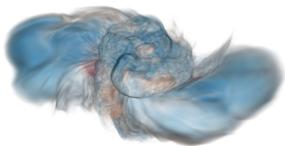
SECAR (FRIB)



CRIB (CNS/RIKEN)

Computational Astrophysics

core-collapse supernovae • nuclear sensitivity studies • classical novae • neutron star mergers • neutron star-white dwarf mergers • X-ray bursts • Galactic Chemical Evolution



Experimental Nuclear Physics

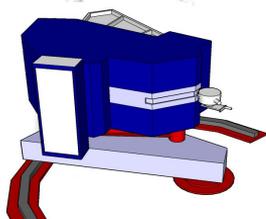
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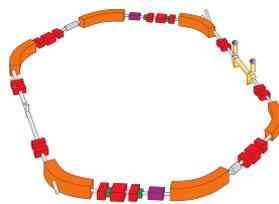
DRAGON (TRIUMF)



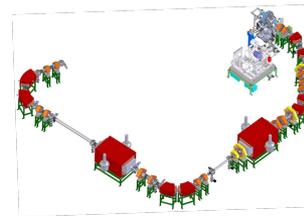
MUSIC (Argonne)



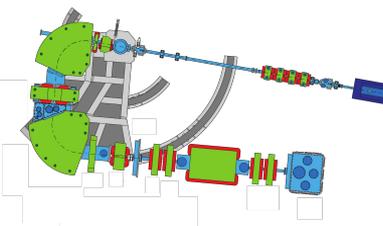
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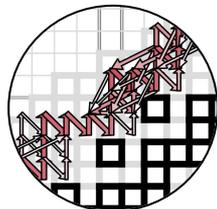
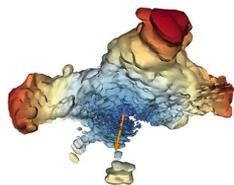
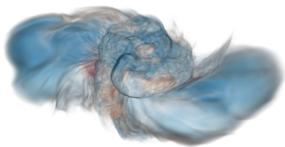
SECAR (FRIB)



CRIB (CNS/RIKEN)

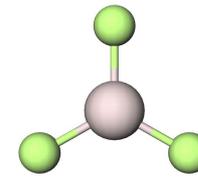
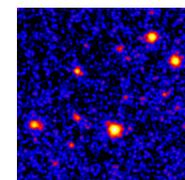
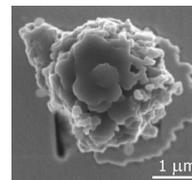
Computational Astrophysics

core-collapse supernovae • nuclear sensitivity studies • classical novae • neutron star mergers • neutron star-white dwarf mergers • X-ray bursts • Galactic Chemical Evolution



Observational Astronomy

metal-poor stars • presolar stardust grains • γ -rays • radioactive molecules



Experimental Nuclear Physics

How do nuclear properties like reaction rates and masses affect the production of elements?

Computational Astrophysics

How do nuclear vs. astrophysical uncertainties shape element production?

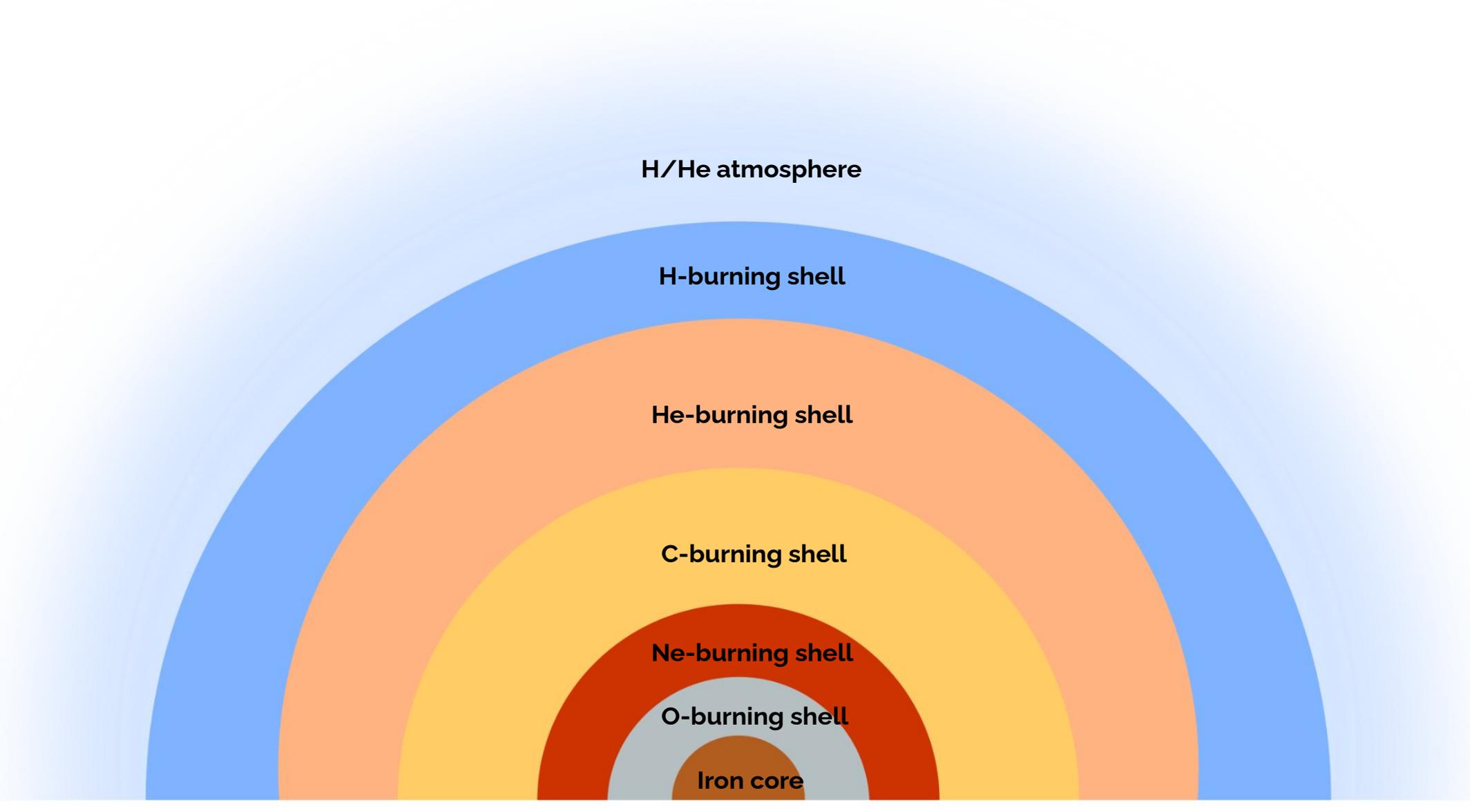
Observational Astronomy

What can observations tell us about the astrophysical sites of element production?



Crab Nebula (M1)

Image Credit: Burke-Gaffney Observatory (observatory.smu.ca)



A diagram showing the internal structure of a star as a series of concentric semi-circular shells. From the center outwards, the layers are: a small brown 'Iron core', a light blue 'O-burning shell', a dark red 'Ne-burning shell', a yellow 'C-burning shell', an orange 'He-burning shell', and a large blue 'H-burning shell'. The outermost region is labeled 'H/He atmosphere'.

H/He atmosphere

H-burning shell

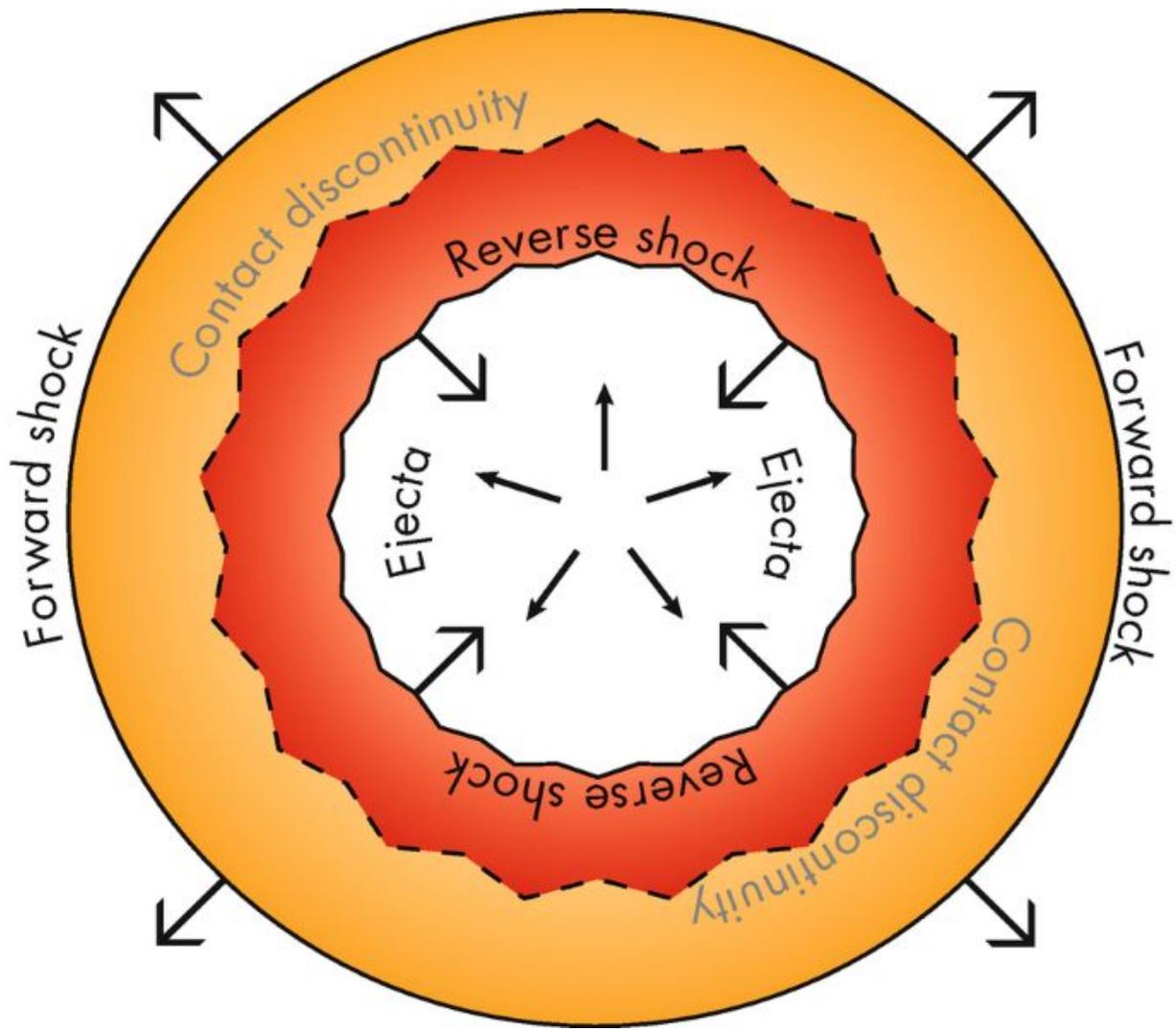
He-burning shell

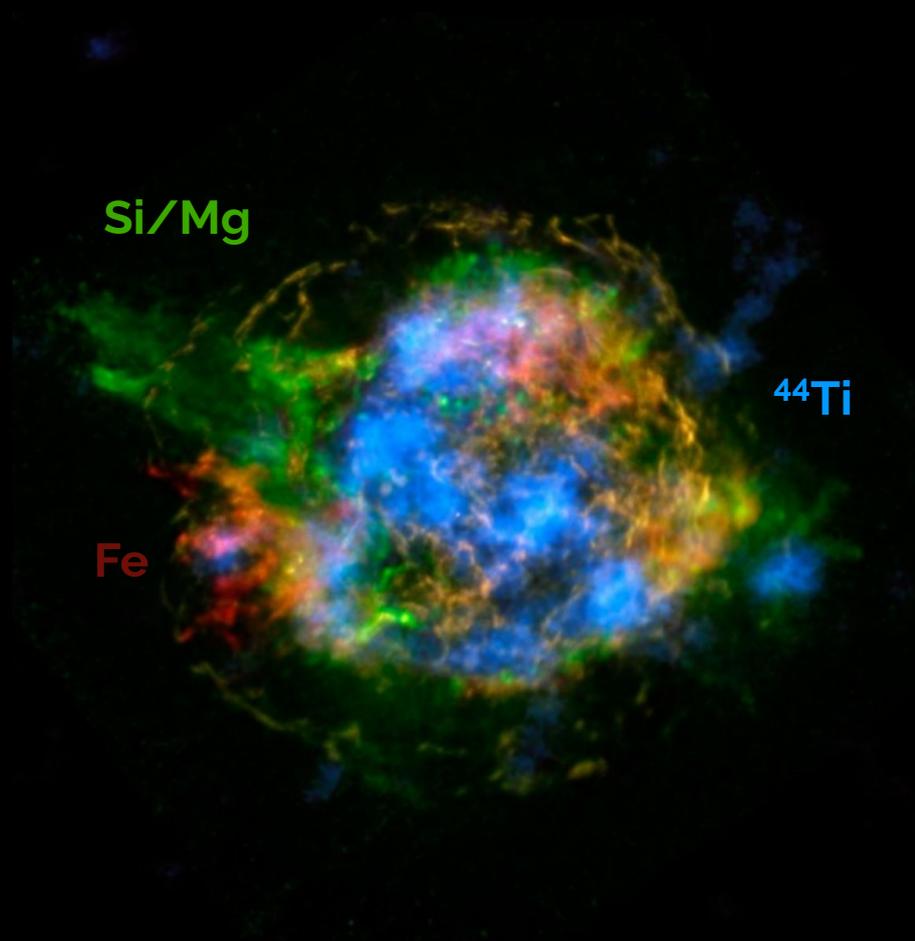
C-burning shell

Ne-burning shell

O-burning shell

Iron core



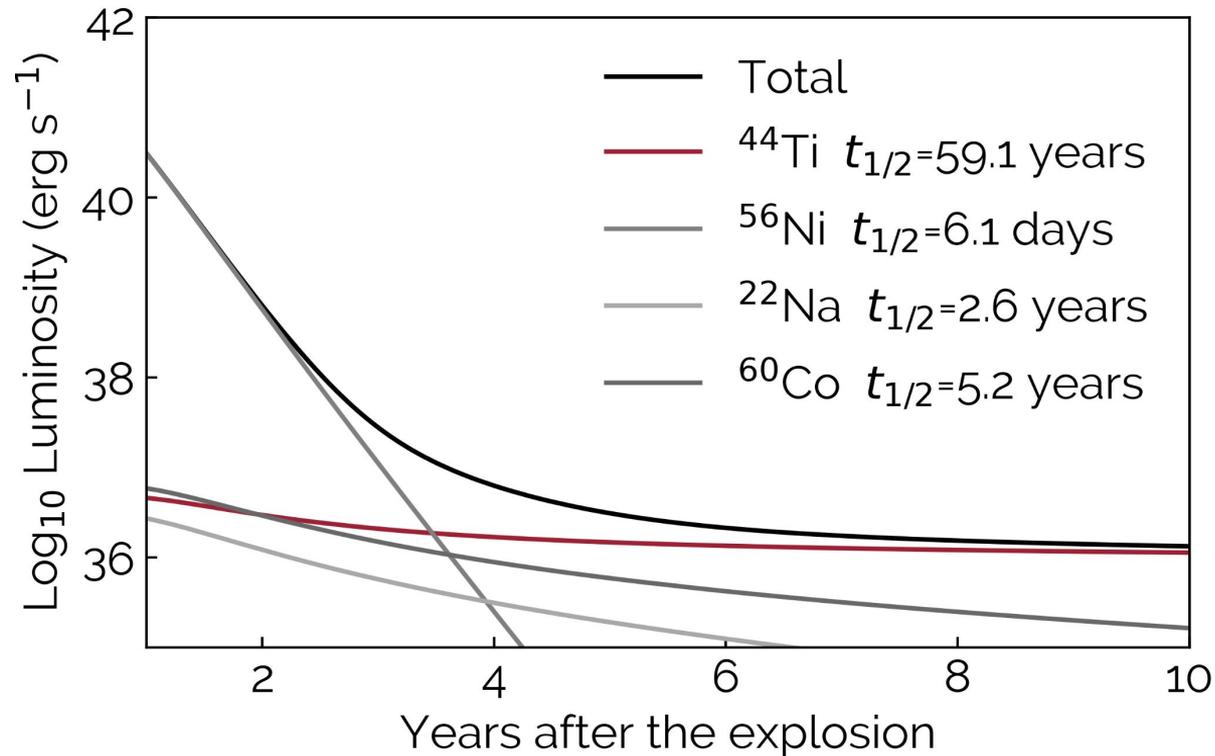


Si/Mg

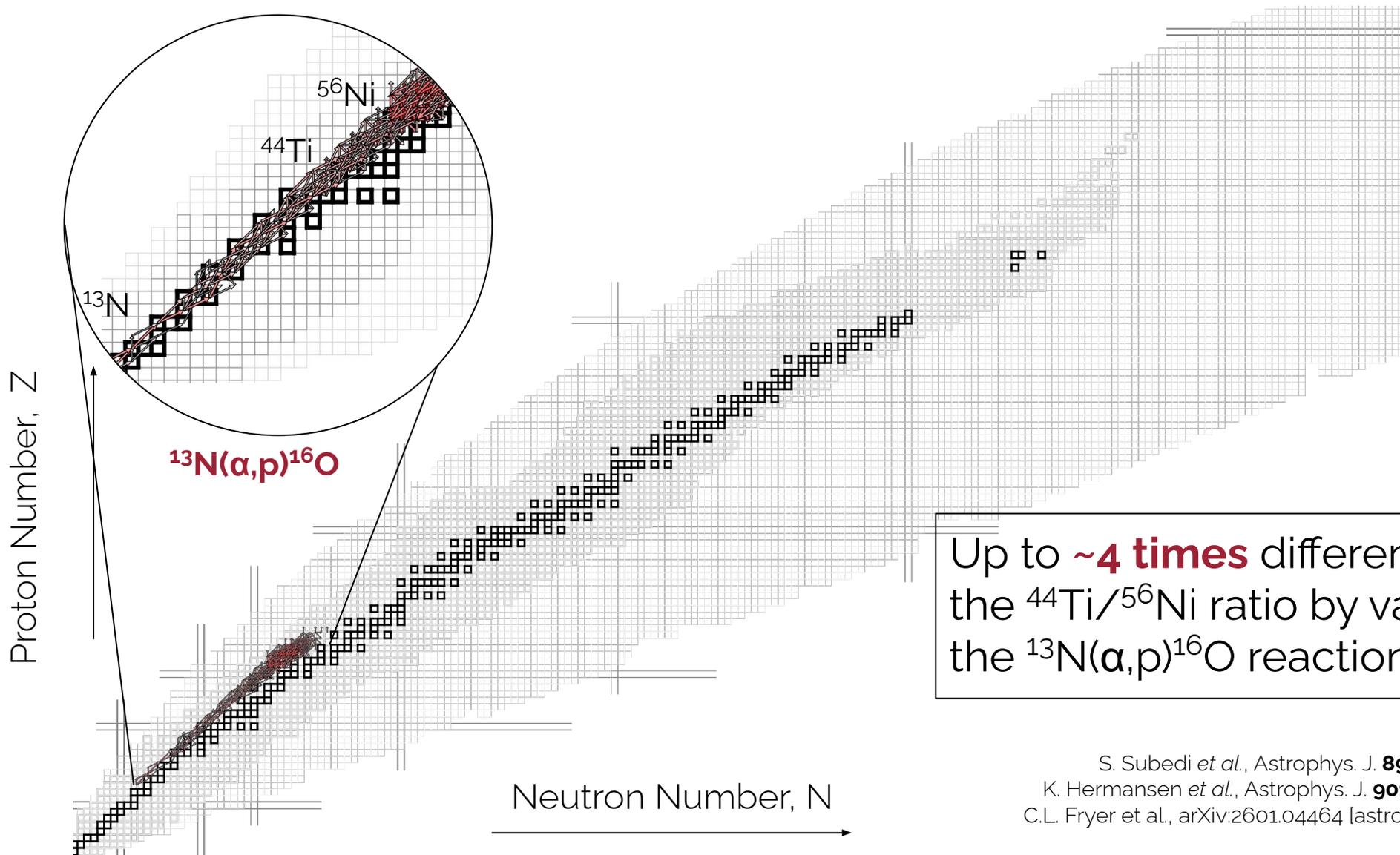
^{44}Ti

Fe

Radioactive isotopes power the core-collapse supernovae light curves



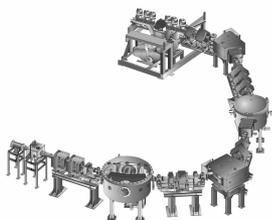
⁵⁶Ni and ⁴⁴Ti decays dominate the light curve at **early** and **late** times



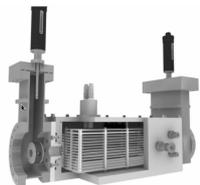
S. Subedi *et al.*, *Astrophys. J.* **898**, 5 (2020)
K. Hermansen *et al.*, *Astrophys. J.* **901**, 77 (2020)
C.L. Fryer *et al.*, arXiv:2601.04464 [astro-ph] (2026)

Experimental Nuclear Physics

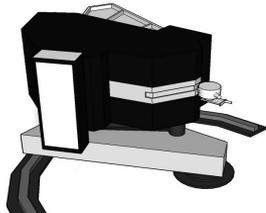
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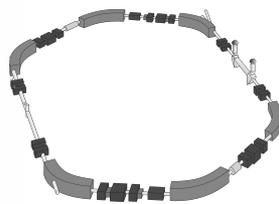
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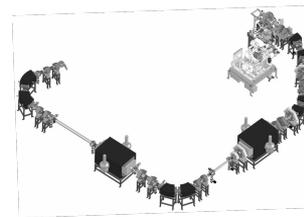
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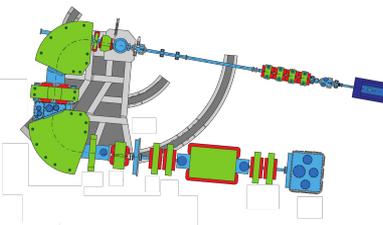
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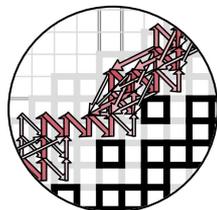
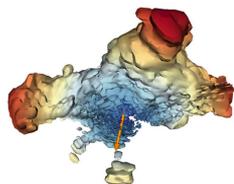
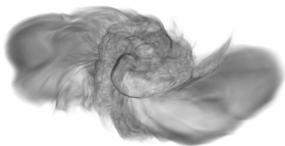
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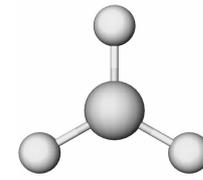
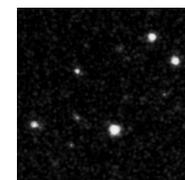
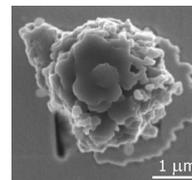
Computational Astrophysics

core-collapse supernovae • **nuclear sensitivity studies** • classical novae • neutron star mergers • neutron star-white dwarf mergers • X-ray bursts • Galactic Chemical Evolution



Observational Astronomy

metal-poor stars • presolar stardust grains • **γ -rays** • radioactive molecules

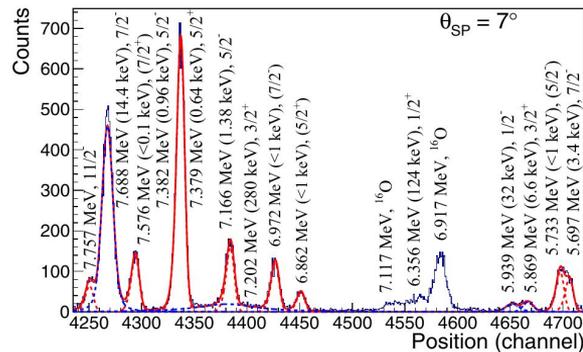
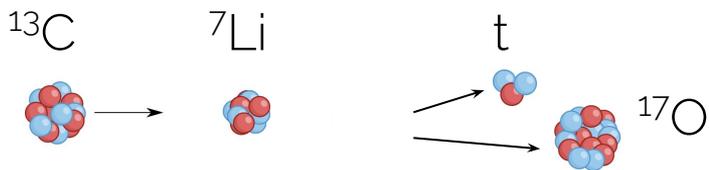


What has been done in the past?

1. Indirect measurement (IJCLab, Orsay, France)

A. Meyer *et al.*, Phys. Rev. C **102**, 035803 (2020)

- $^{13}\text{C}(^7\text{Li},t)^{17}\text{O}$ to study mirror states in ^{17}O
- Measurement of α -spectroscopic factors



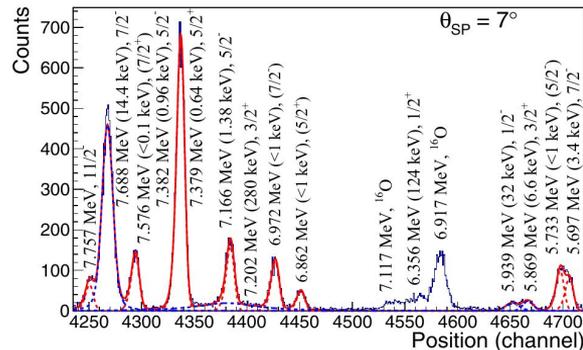
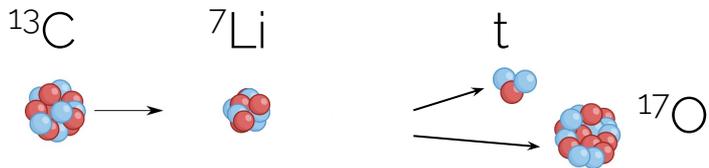
Focal plane spectrum

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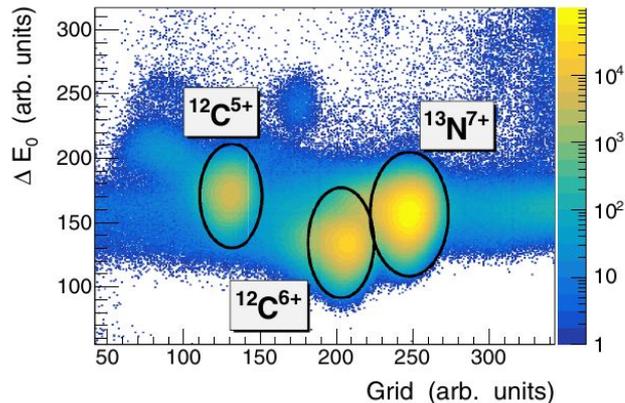
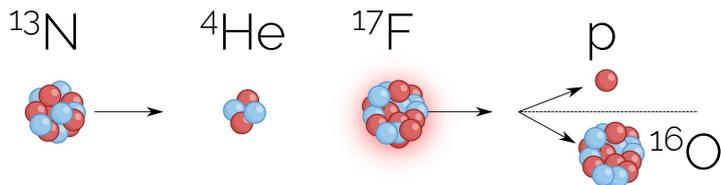


Focal plane spectrum

2. Direct measurement (Argonne, USA)

H. Jayatissa *et al.*, Phys. Rev. C **105**, L042802 (2022)

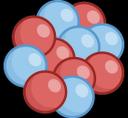
- ^{13}N beam (intensity $\sim 1000 \text{ s}^{-1}$) with 50% purity
- Measured the cross-section at $E_{\text{c.m.}} = 3.3\text{--}6.0 \text{ MeV}$

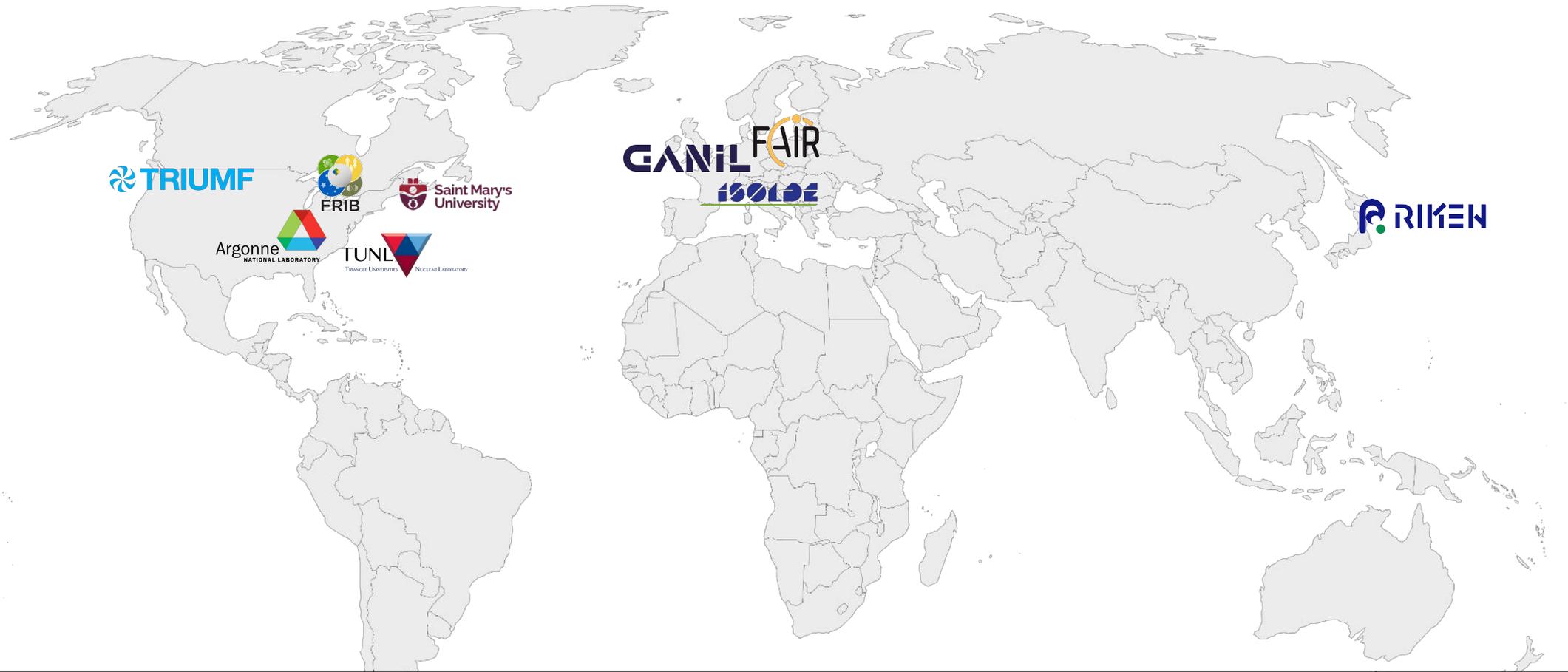


Particle Identification Plot

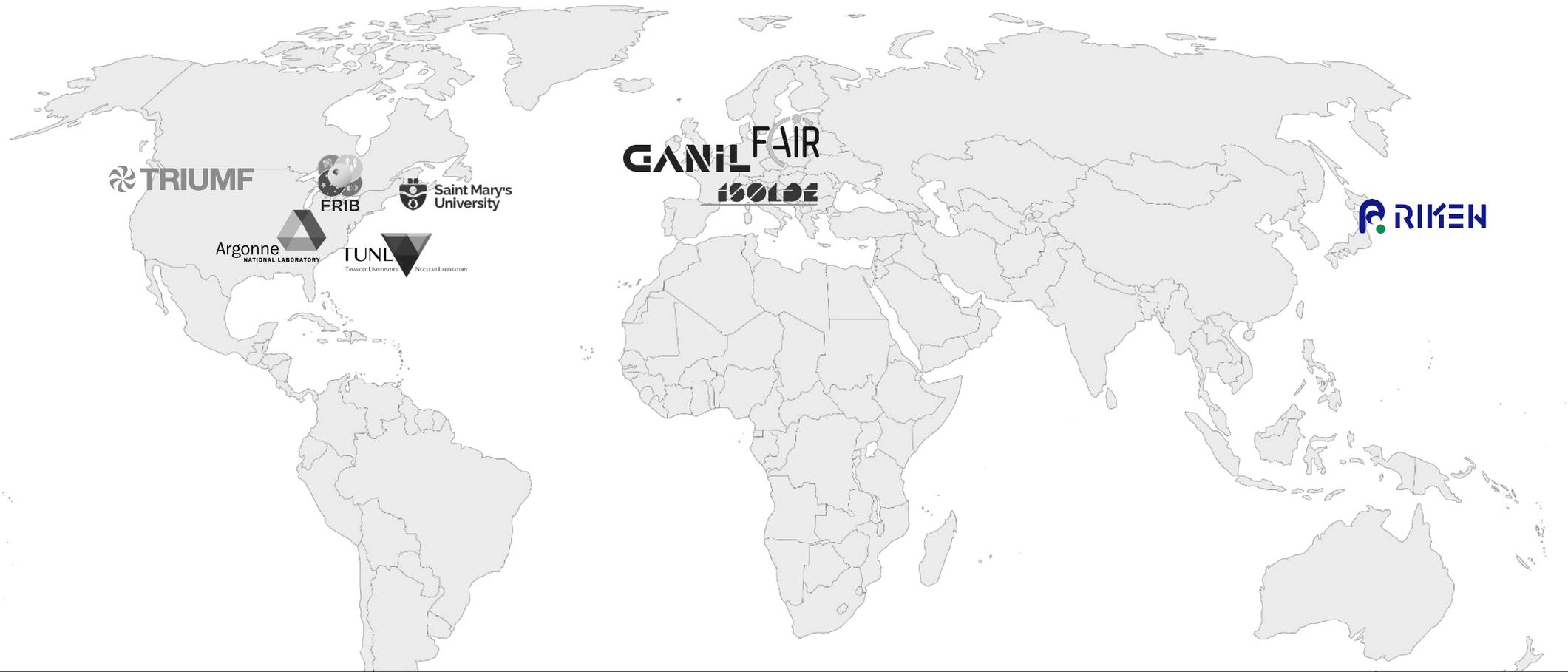
 Measure the $^{13}\text{N}(\alpha, p)^{16}\text{O}$ reaction directly using an intense radioactive ion beam

Ingredients for a nuclear reaction experiment:

- ion beam -  ^{13}N ($t_{1/2} \sim 10$ min)
- target
- detector (s)



Many opportunities worldwide for nuclear astrophysics research!



Many opportunities worldwide for nuclear astrophysics research!

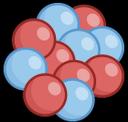
The collaboration

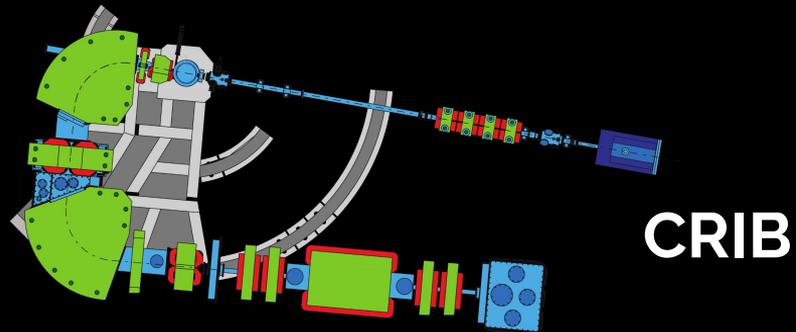
28 participants from 6 countries  (9 graduate students)

H. Yamaguchi, S. Hayakawa, K. Okawa, F.L. Liu, Q. Zhang
N. Imai, N. Kitamura, S. Hanai, S. Bae, J. Li, Y. Yamamoto (CNS) •
S. Ahn, S.M. Cha, G.M. Gu (CENS, IBS) • M. Lee, V. Beatty (TUNL) •
S. Kubono (RIKEN) • K.Y. Chae, C.H. Kim, S.H. Kim (Sungkyunkwan
University) • A. Kim, S. Do (CENuM) • E. Lopez-Saavedra (ANL) • N. Iwasa
(Tohoku U) • D. Kahl (FRIB) • M. Sferrazza (UBL) • M. La Cognata, M. La
Commara, R.G. Pizzone (INFN)



Ingredients for a nuclear reaction experiment:

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 **東武東上線のりば**
Tobu Tojo Line 车站 타는 곳

内科 整形外科
皮膚科 泌尿器科
東武リハバル

かとう内科クリニック
日曜診療・夜間急診科 予防検診・健康相談
〒114-8501 東京都荒川区西日暮里5-1-1
TEL: 03-3977-0222

4時25分 全車
5時30分 全車



原子番号

7

元素記号

N

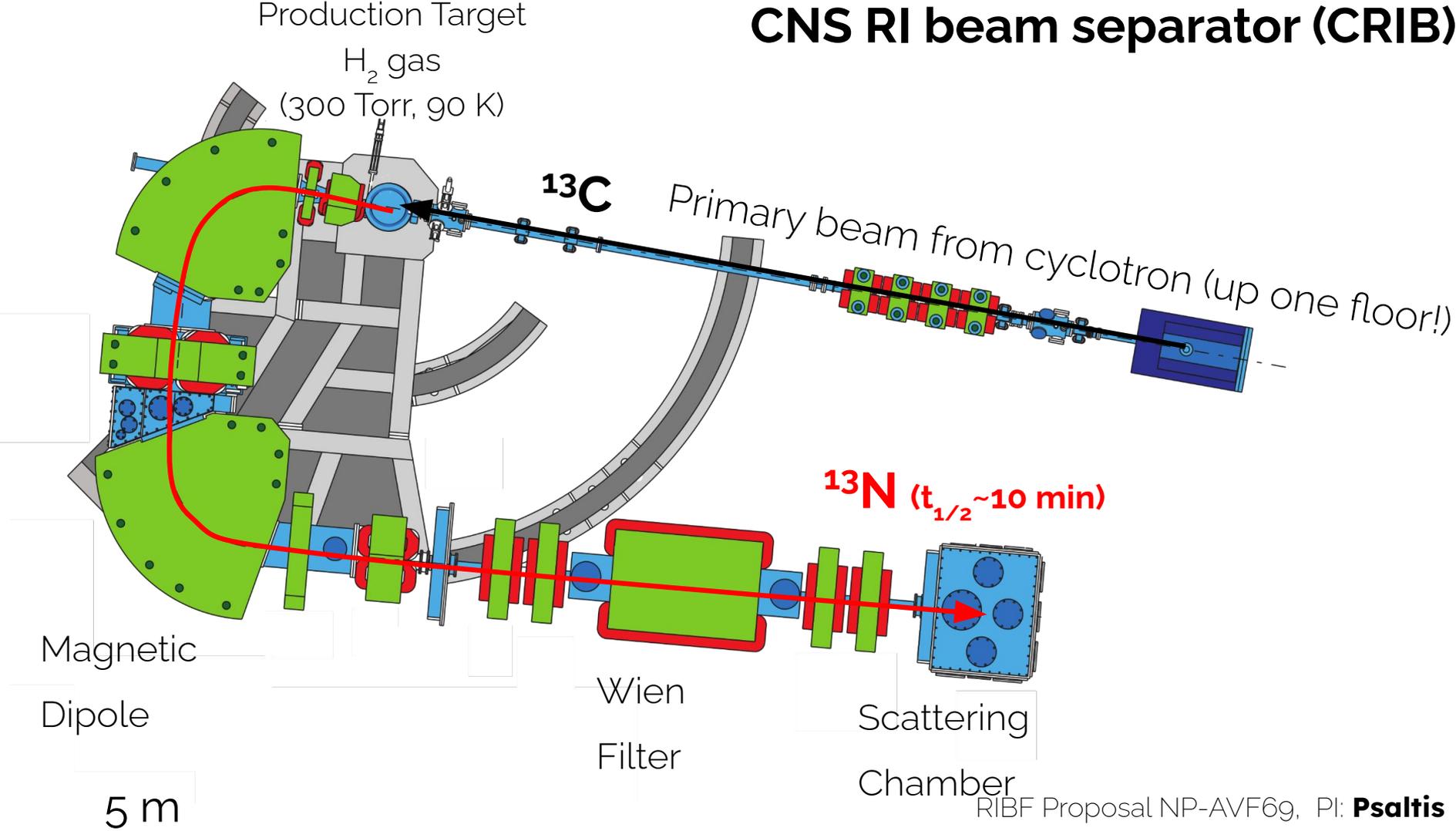
元素名 窒素

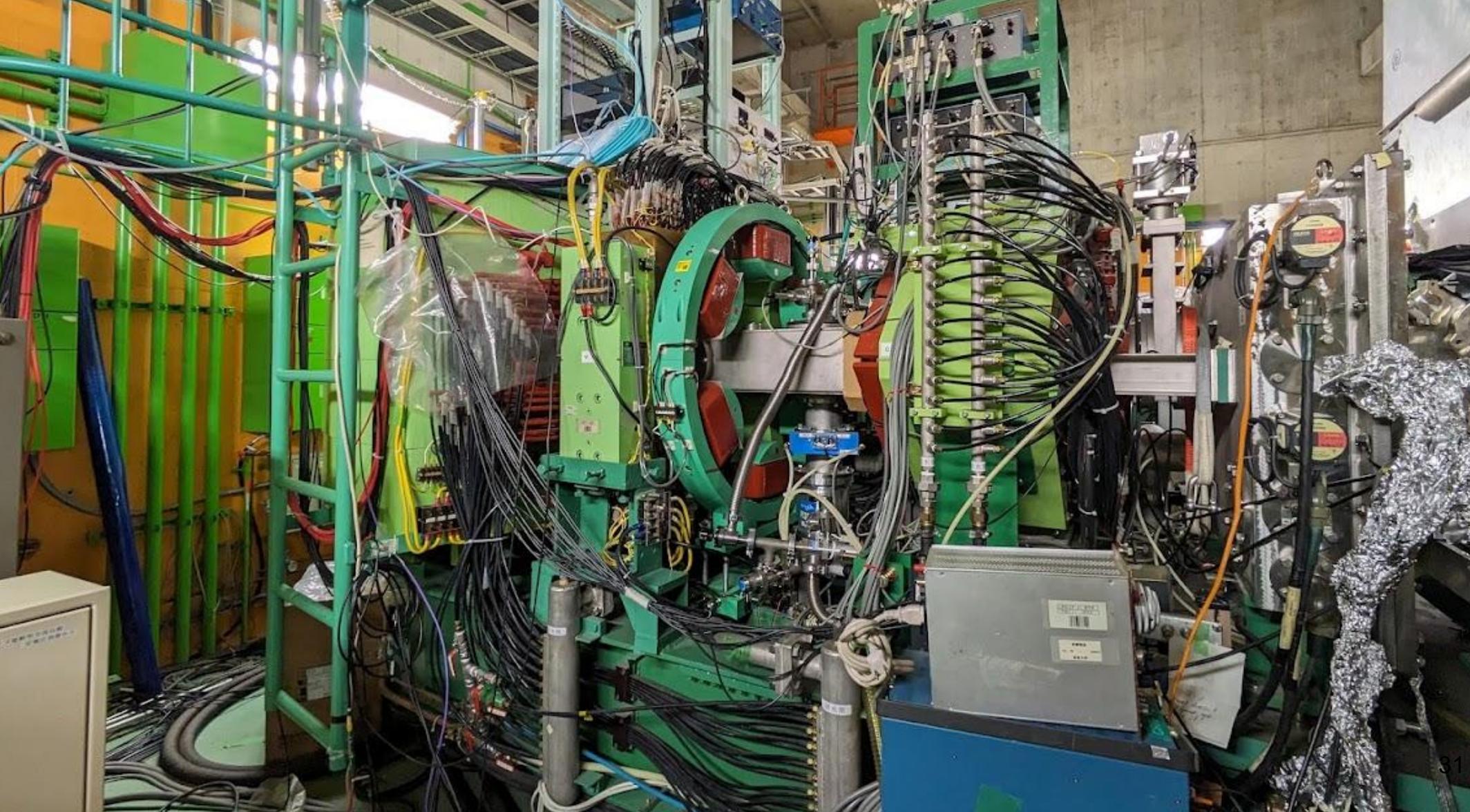
Nitrogen

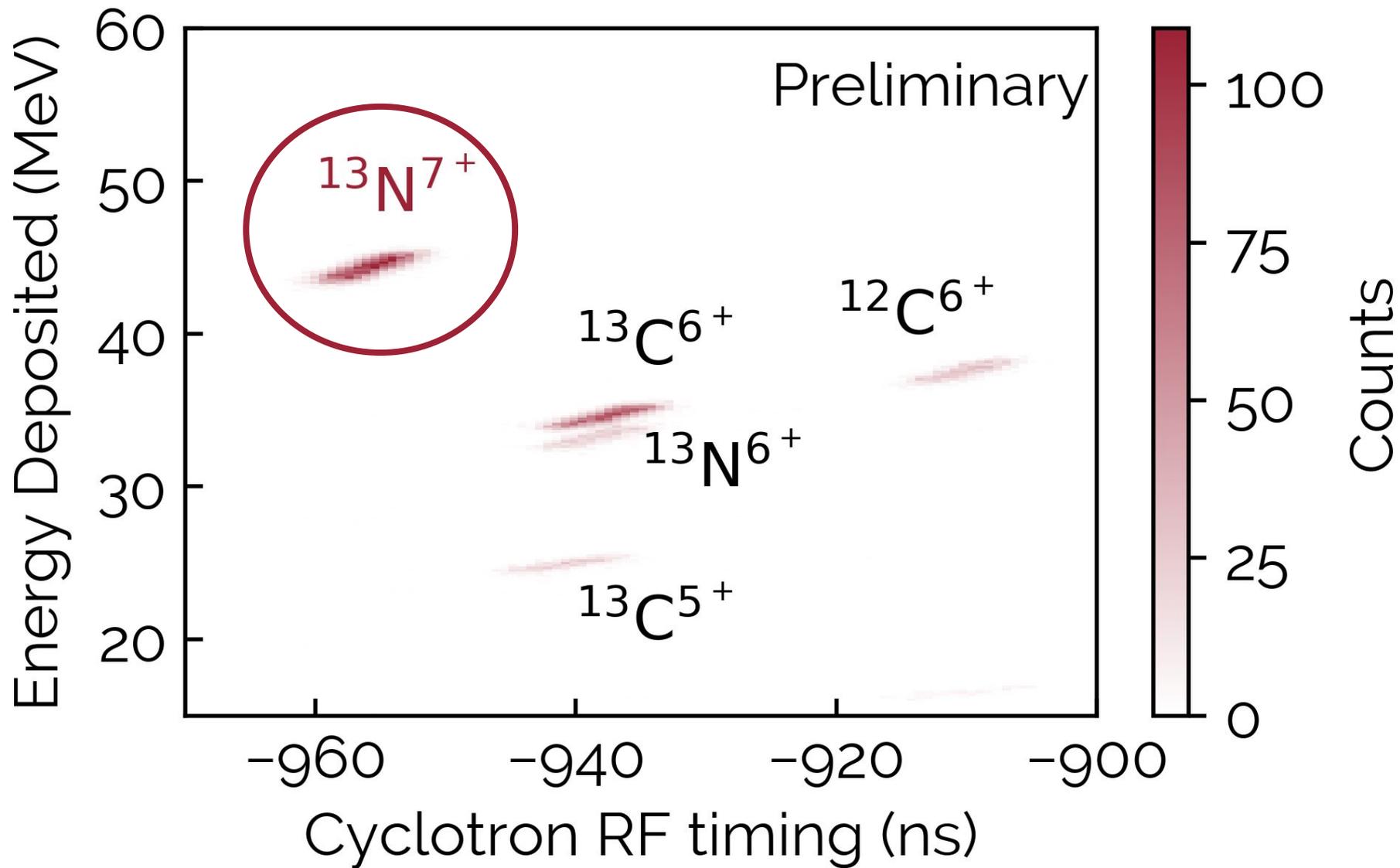
113番元素ニホニウム発見のまち

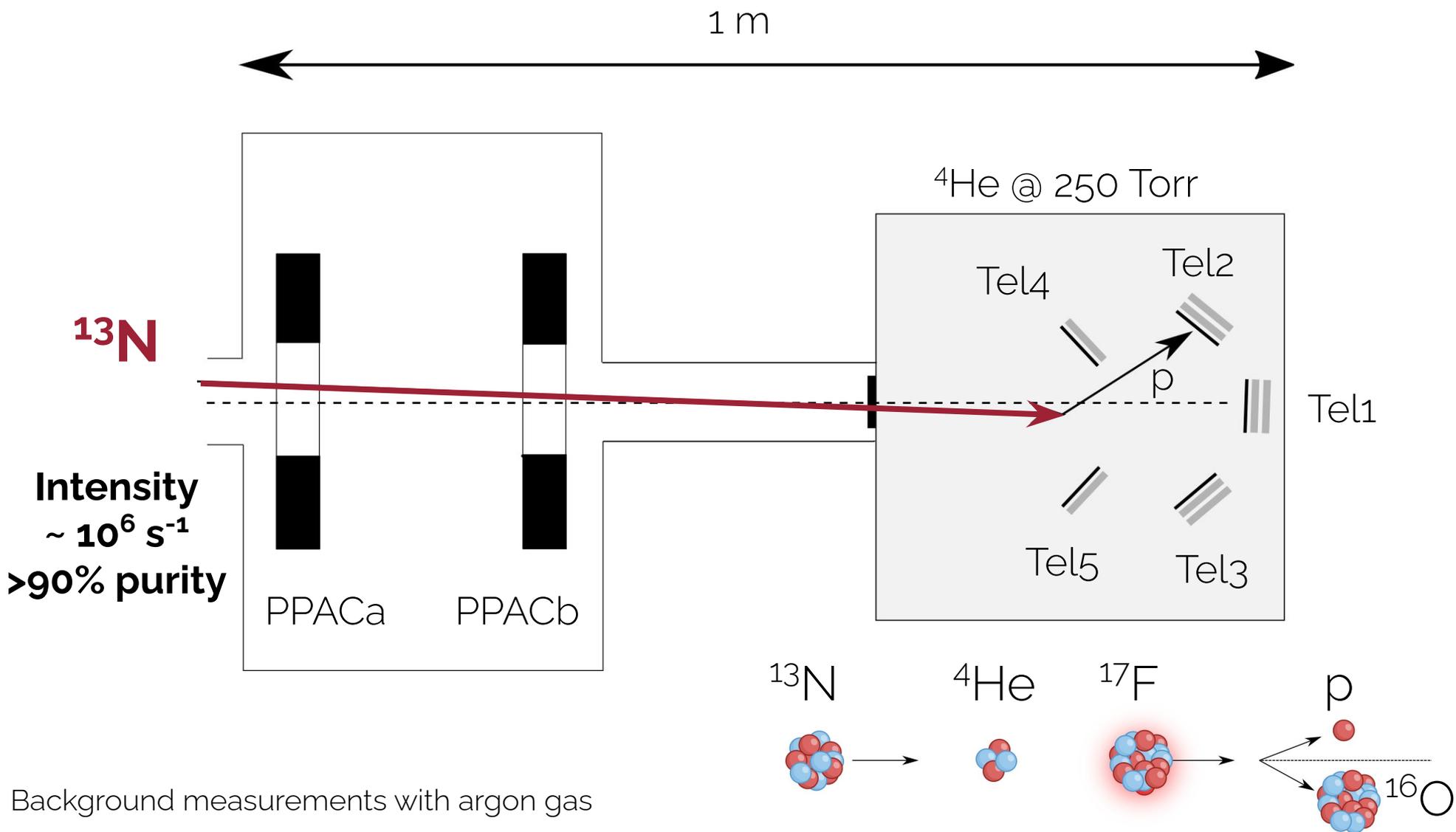
和光市

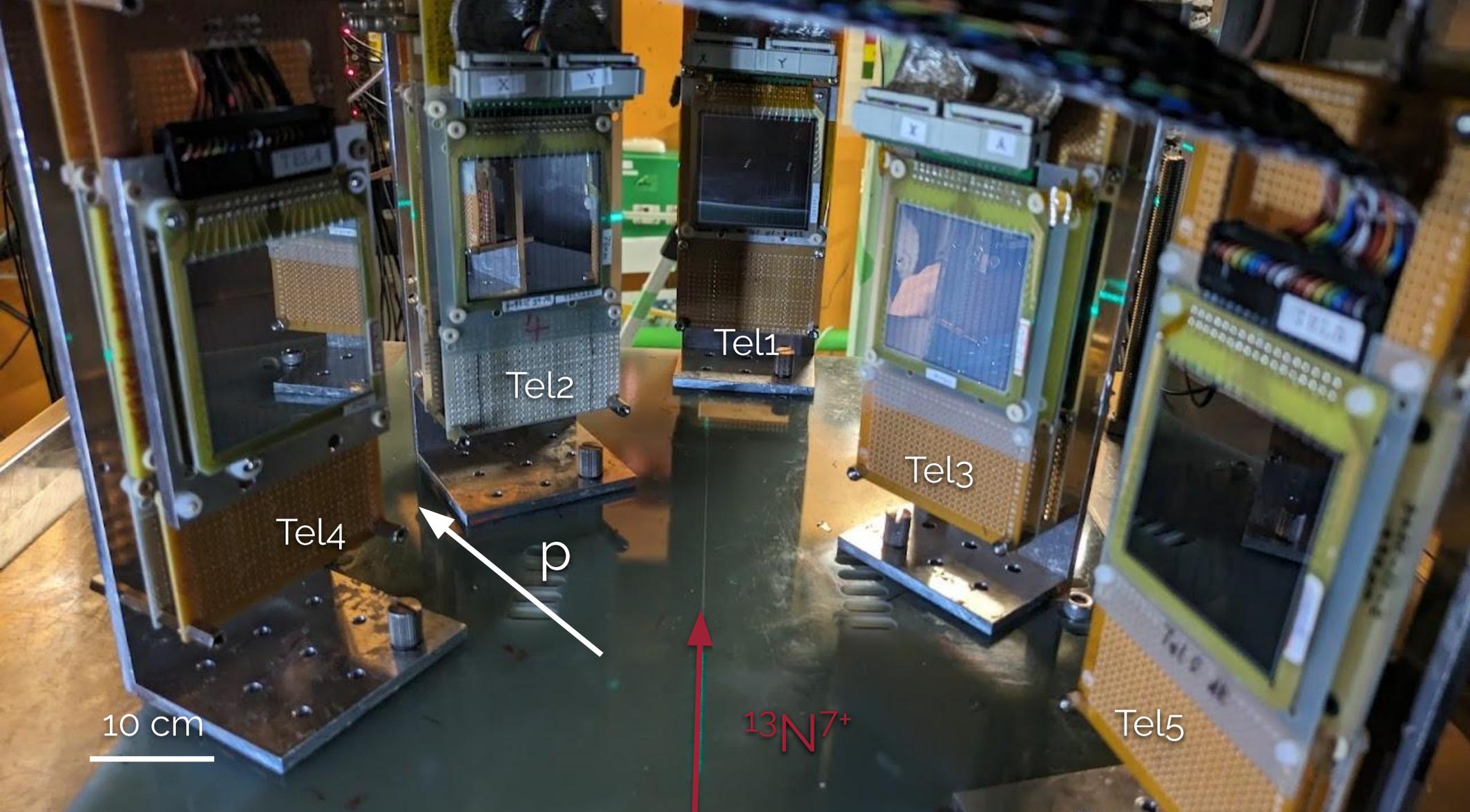
CNS RI beam separator (CRIB)











Tel2

Tel1

Tel3

Tel4

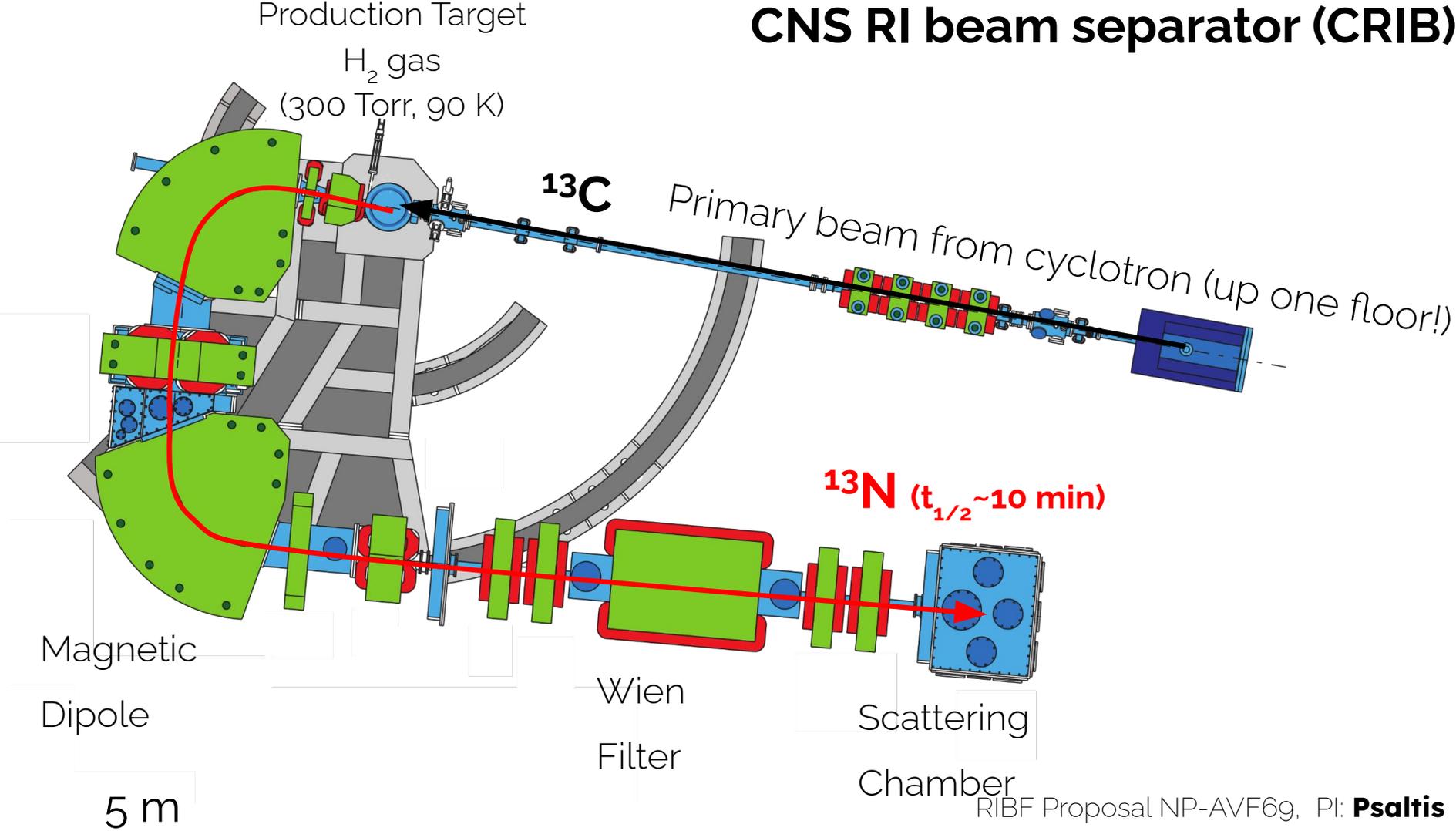
p

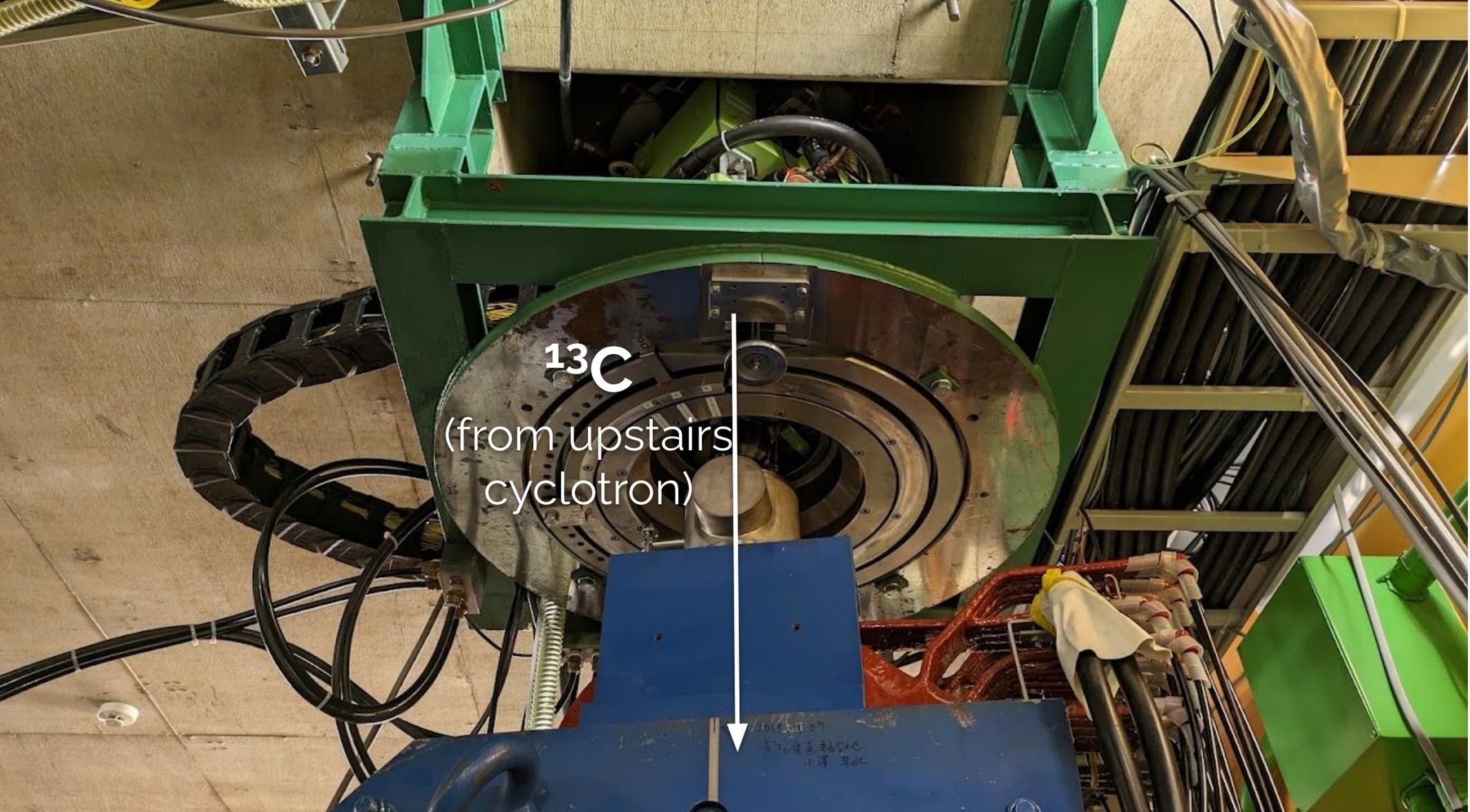
$^{13}\text{N}^{7+}$

Tel5

10 cm

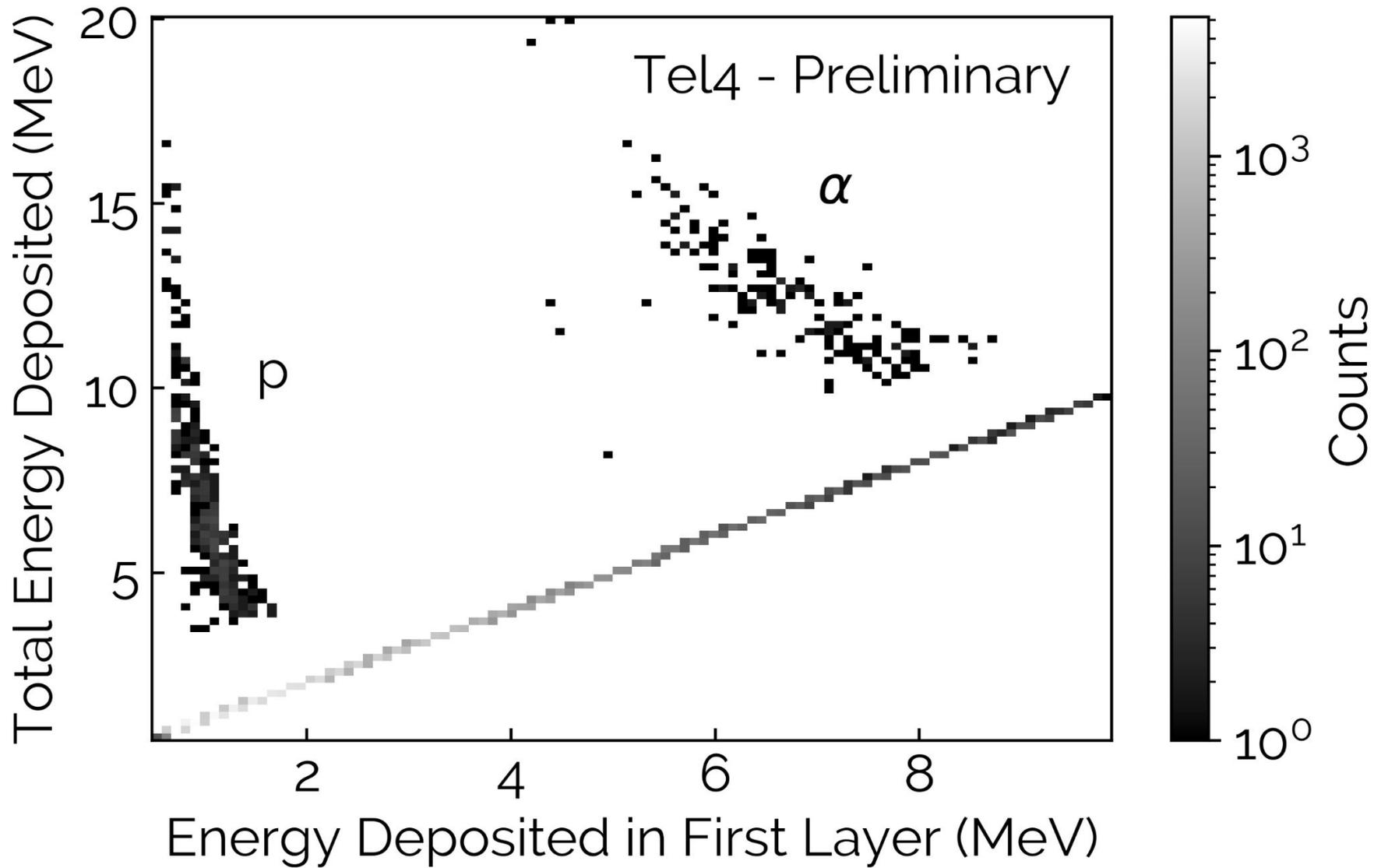
CNS RI beam separator (CRIB)





^{13}C
(from upstairs
cyclotron)

2012.04.07
13C 加速器
小澤 弘



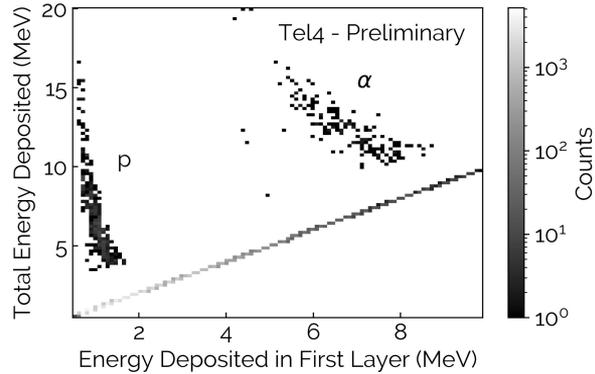


持ち出し
厳禁

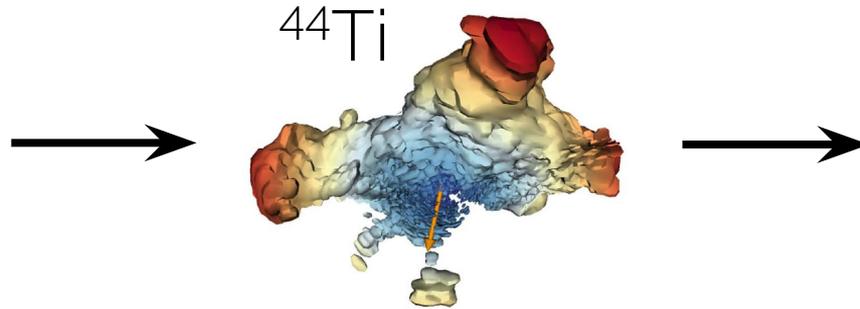
CAEN
Nuclear

ALGATE

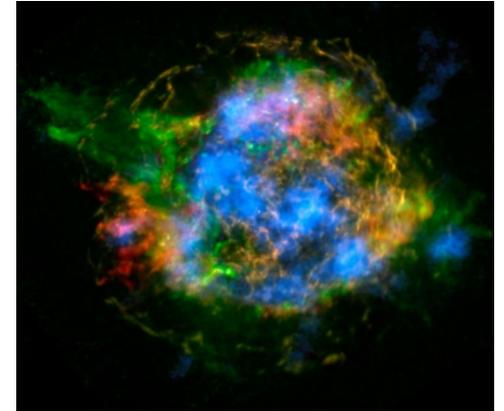
Future Directions



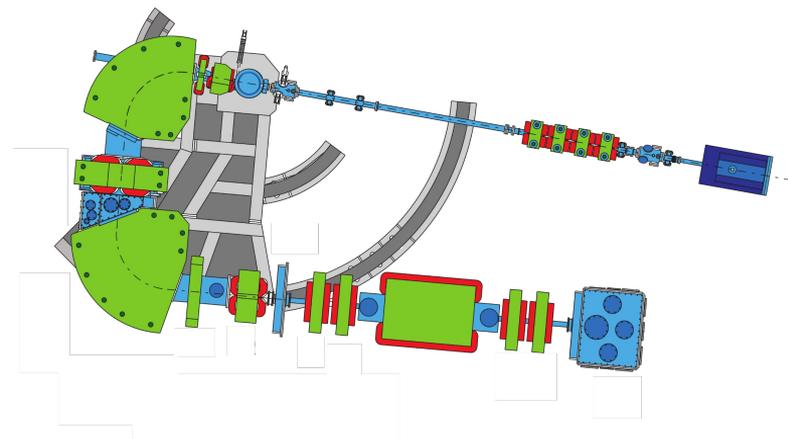
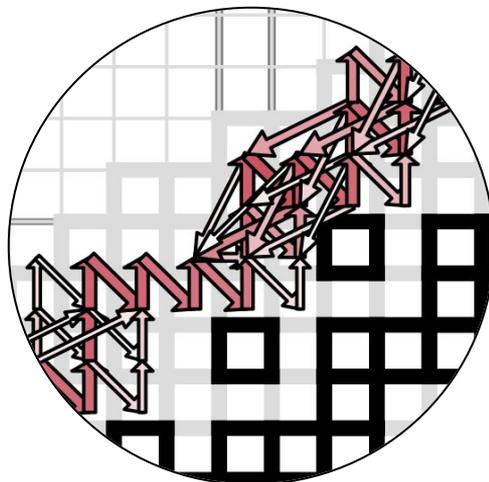
New $^{13}\text{N}(\alpha, p)^{16}\text{O}$
reaction rate



Updated simulation &
nucleosynthesis models



Conclusions & Outlook



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Multidisciplinary Research: Work on projects that bridge the gap between nuclear physics, stellar modeling & astronomy.

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Want to stay in touch? ✉️ thanassis.psaltis@smu.ca 🌐 <https://psaltisa.github.io>



Thank you for your attention!
ご清聴ありがとうございました。

陽子数

アルミニウム	Al	13	26.9815386	26.9815386
マグネシウム	Mg	12	24.304694	24.304694
ナトリウム	Na	11	22.98976928	22.98976928
ネオン	Ne	10	20.1797	20.1797
フッ素	F	9	18.9984032	18.9984032
酸素	O	8	15.999	15.999
窒素	N	7	14.006434	14.006434
炭素	C	6	12.0107	12.0107
ホウ素	B	5	10.811	10.811
ベリリウム	Be	4	9.0122	9.0122
リチウム	Li	3	6.941	6.941

