Constraining ^{44}Ti and ^{56}Ni yields via a direct ^{13}N(α,p)^{16}O measurement

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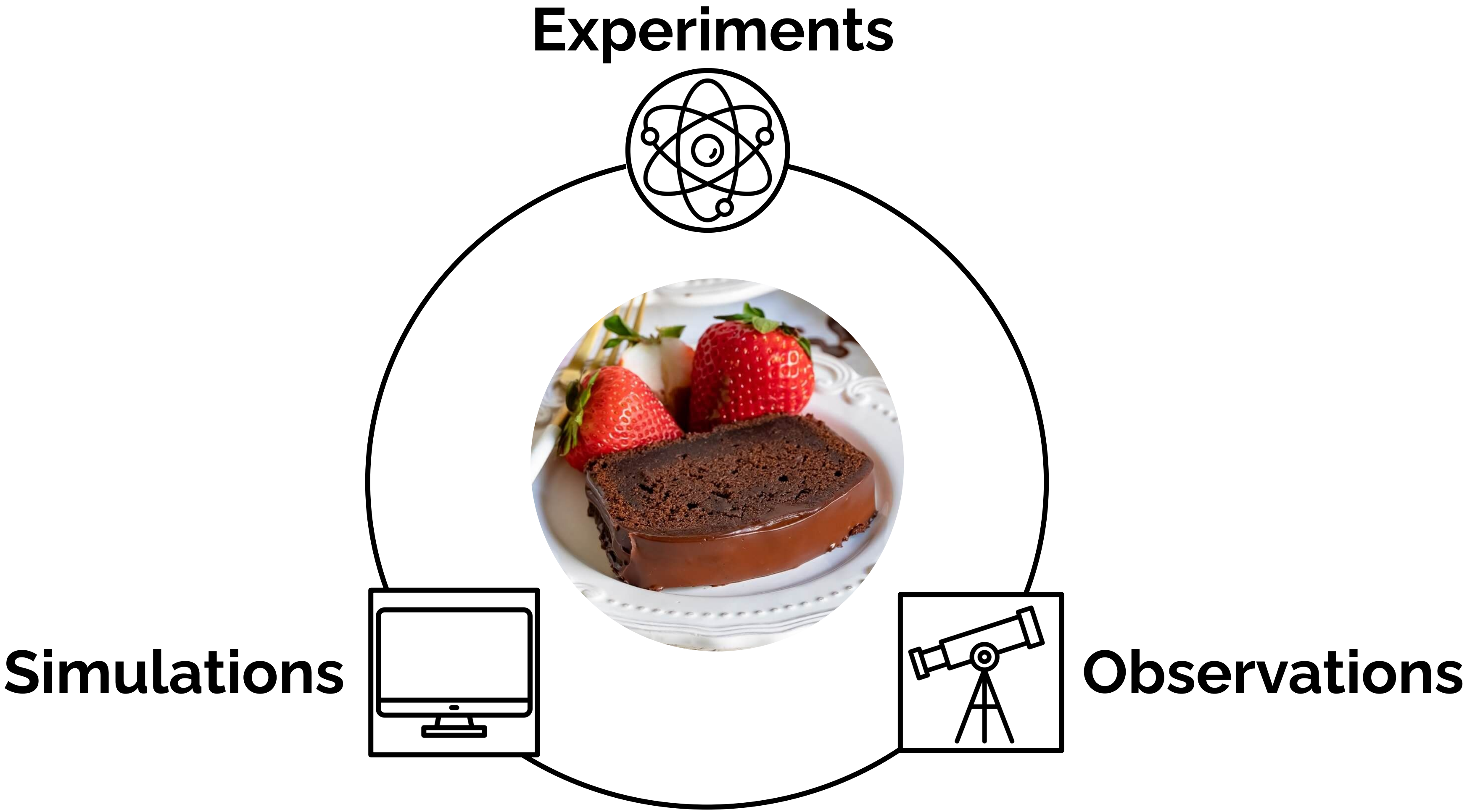
Saint Mary's University

Astrophysics with Radioactive Isotopes 2026
June 28th, 2026

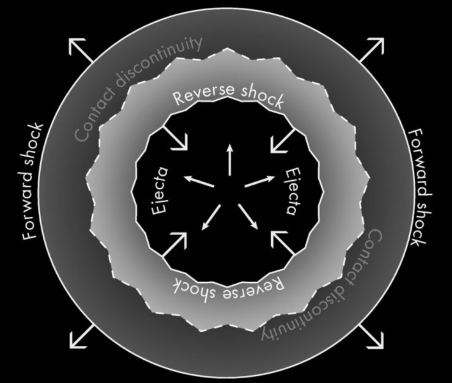
Cassiopeia A

Image credit: NASA, ESA, CSA, STScI

observed abundances = nuclear physics + astrophysical conditions



Our group uses radioactive ion beams to connect nuclear reactions with astronomical observables

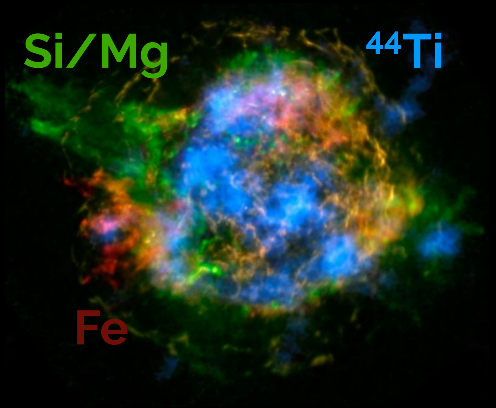


J. Vink, Physics and Evolution of Supernova Remnants (2020)

C.L. Fryer et al., arXiv:2601.04464 (2026)

See talks by C. Fryer, L. Boccioli, and R. Hatami

explosion dynamics

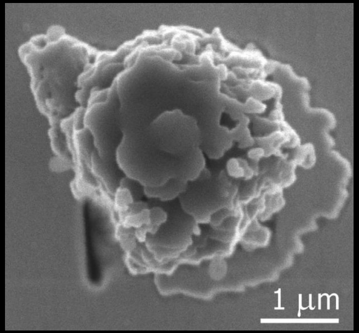


Cassiopeia A

B. W. Grefenstette *et al.*, Nature **506**, 339 (2014)

See talks by A. Jerkstrand and J. Issa

explosion remnants



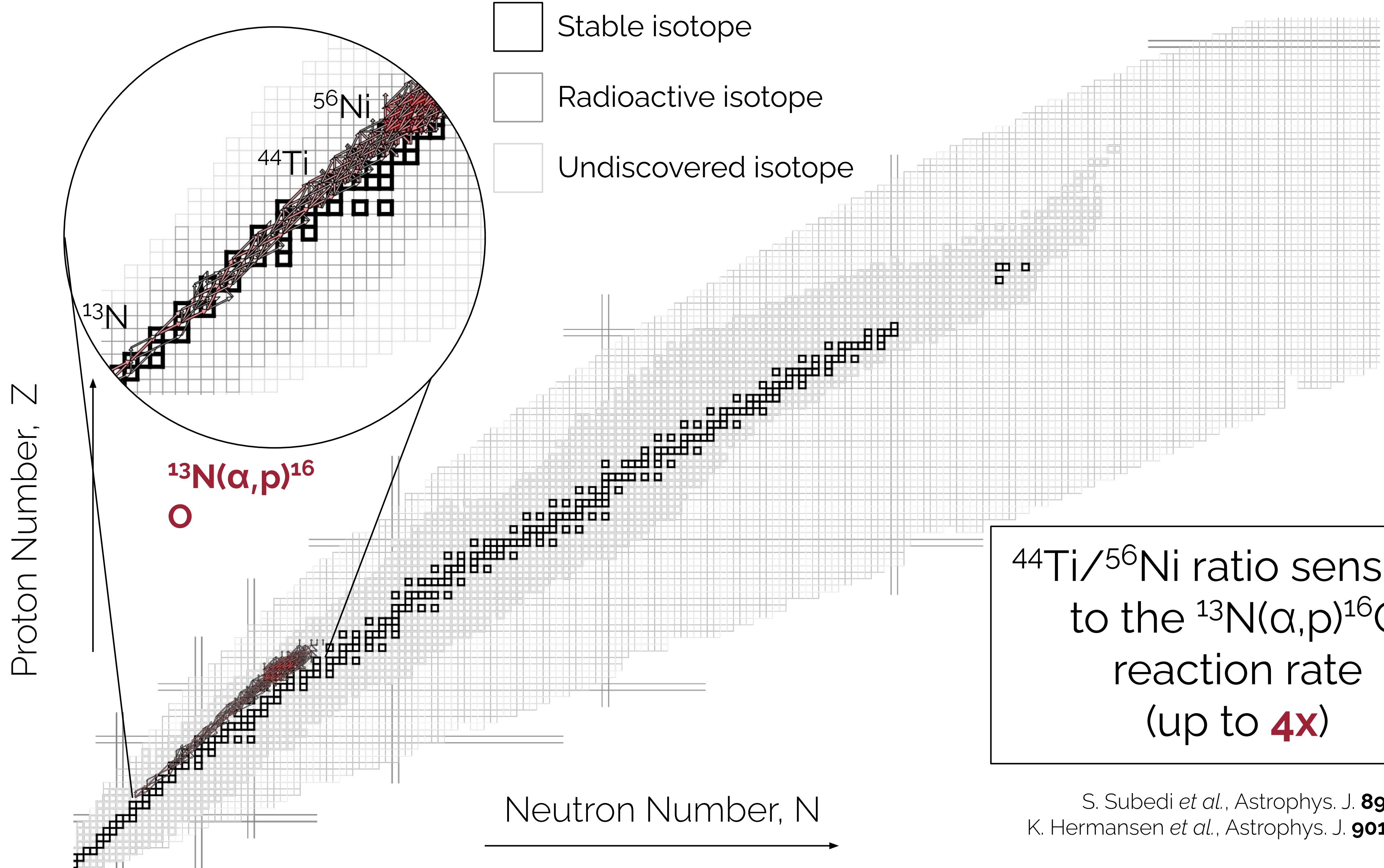
SiC grain

N. Liu *et al.*, Space Sci. Rev. **220**, 88 (2024)

See talks by N. Liu and G. Fowler

presolar grains

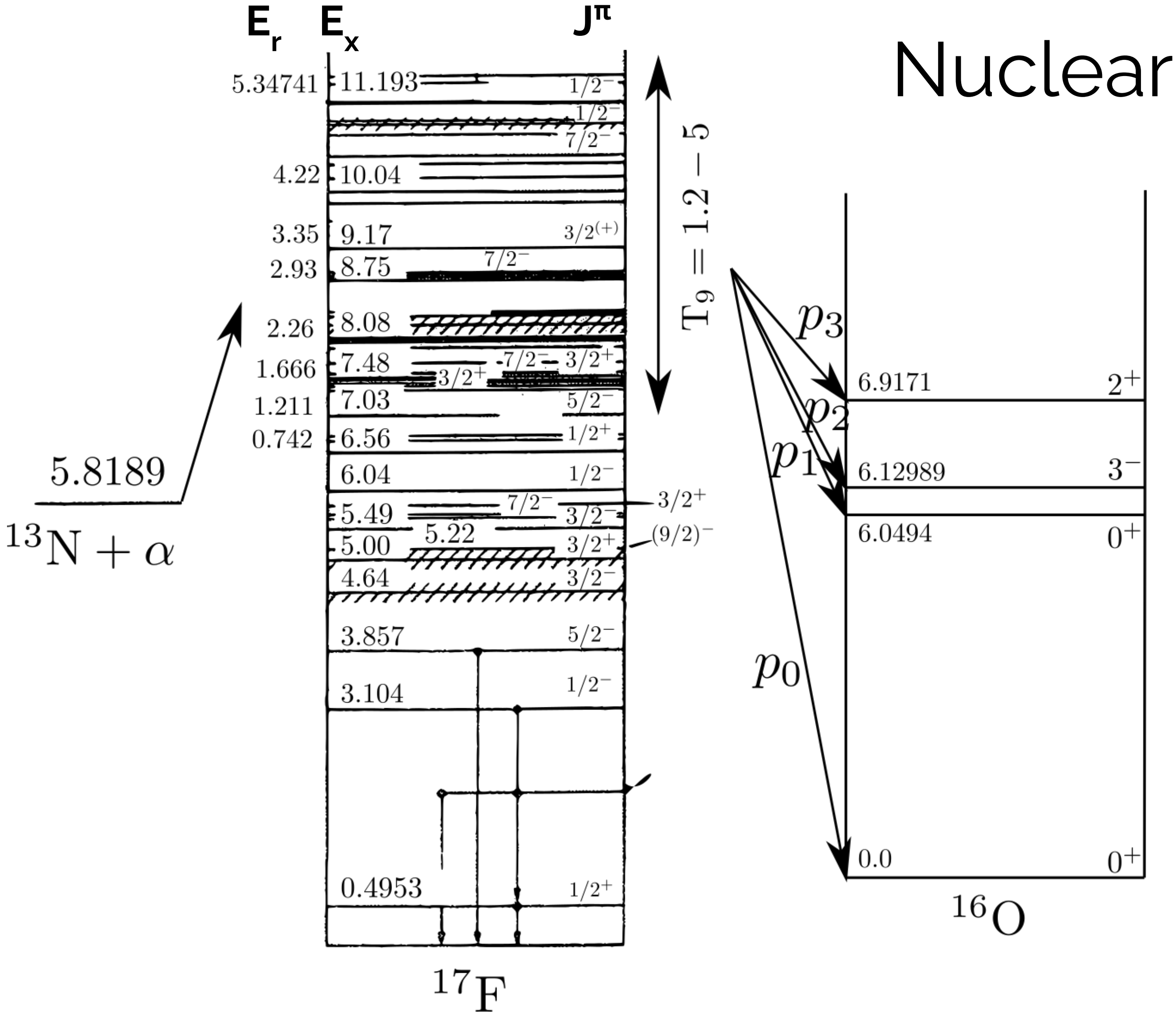
Radioactive isotopes are fingerprints of explosive nucleosynthesis

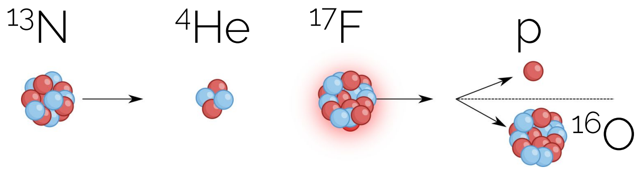


^{44}Ti/^{56}Ni ratio sensitive to the ^{13}N(α,p)^{16}O reaction rate (up to **4x**)

S. Subedi *et al.*, Astrophys. J. **898**, 5 (2020)
K. Hermansen *et al.*, Astrophys. J. **901**, 77 (2020)

Nuclear structure of ^{17}F



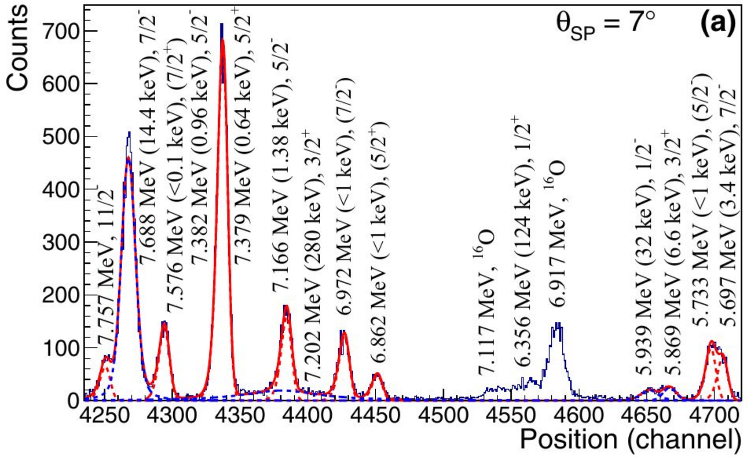


J. H. Kelley *et al.*, Nucl. Phys. A **564**, 1 (1993)
D.R. Tilley *et al.* revised manuscript (2018)

Previous work related to the $^{13}N(\alpha,p)^{16}O$ reaction

Pre-2020 the $^{13}N(\alpha,p)^{16}O$ reaction rate used was from CF88!

$^{13}C(^{7}Li,t)^{17}O$ to study mirror states in ^{17}F using the Tandem-ALTO Enge split-pole spectrograph.
α-spectroscopic factors were extracted using **DWBA** calculations.

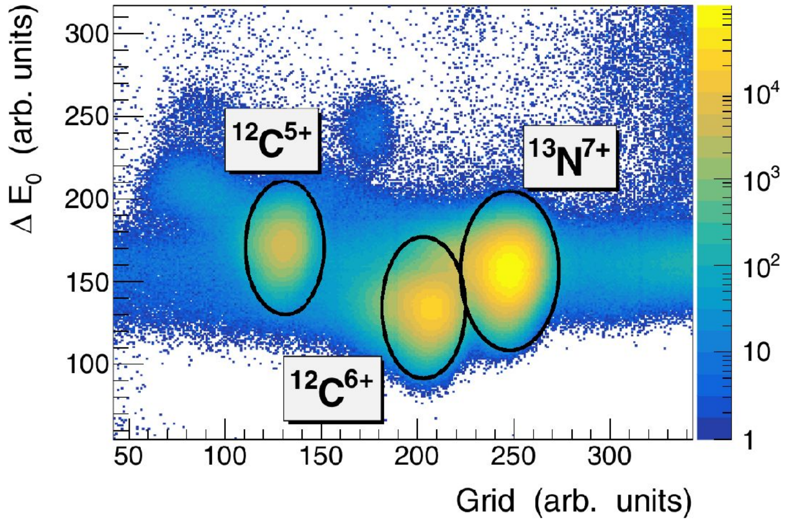


A. Meyer *et al.*, Phys. Rev. C **102**, 035803 (2020)

Previous work related to the $^{13}N(\alpha,p)^{16}O$ reaction

Pre-2020 the $^{13}N(\alpha,p)^{16}O$ reaction rate used was from CF88!

First direct measurement using MUSIC at Argonne. ^{13}N beam (**I ~ 10^3 s^{-1}**) and **50% purity**. Measured the cross-section at $E_{c.m.}$ = 3.3-6.0 MeV

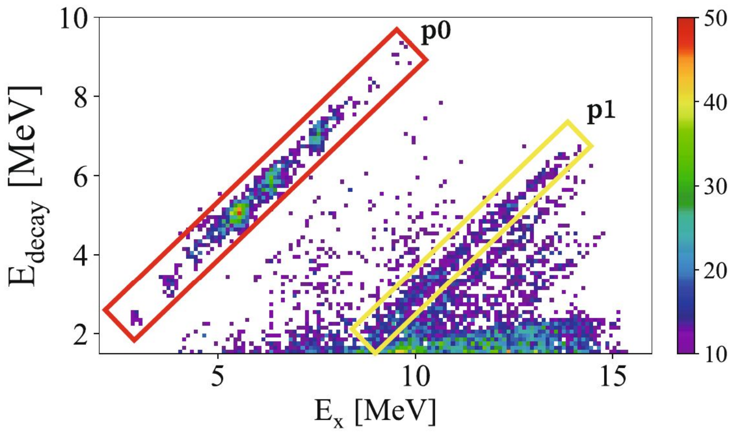


H. Jayatissa *et al.*,Phys. Rev. C **105**, L042802 (2022)

Previous work related to the $^{13}N(\alpha,p)^{16}O$ reaction

Pre-2020 the $^{13}N(\alpha,p)^{16}O$ reaction rate used was from CF88!

$^{19}F(p,t)^{17}F$ at the Tandem of Japan Atomic Energy Agency (JAEA) using using segmented silicon detectors (S3). Γ_α and Γ_p for levels in ^{17}F were extracted (E_x ~ 6-9.5 MeV)



S. Kim *et al.*, J. Korean Phys. Soc. (2026)

The Astrophysical Journal Supplement Series, 283:17 (115pp), 2026 March https://doi.org/10.3847/1538-4365/ae2bdc

The 2025 Evaluation of Experimental Thermonuclear Reaction Rates (ETR25)

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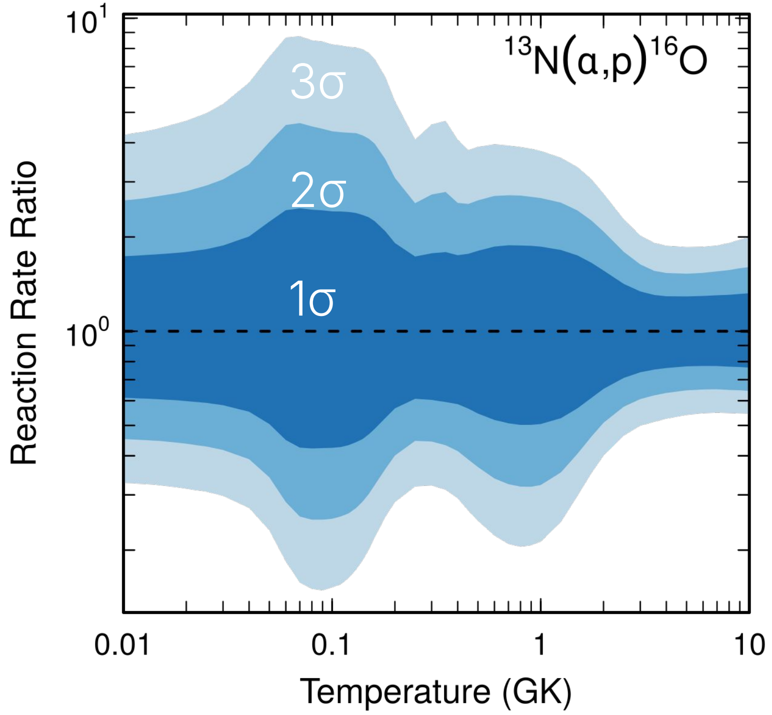
Abstract

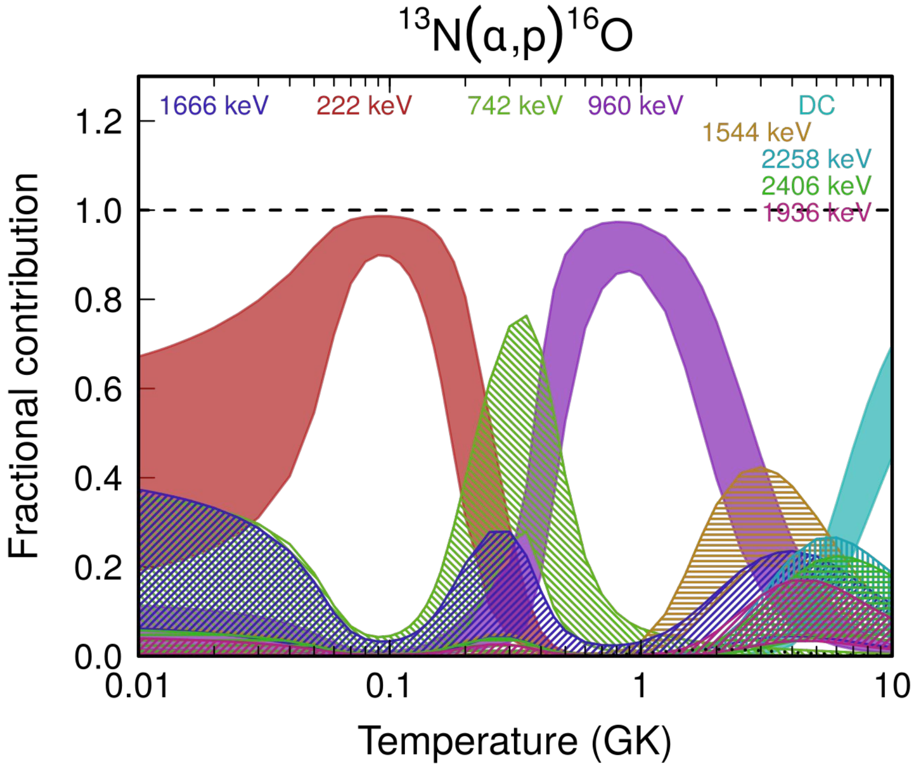
This work describes the formalism for estimating thermonuclear reaction rates for astrophysical applications, emphasizing modern statistical approaches such as Monte Carlo sampling and Bayesian models. We discuss related topics including the calculation of resonance energies from nuclear Q values, indirect estimates of particle partial widths, and matching of reaction rates at elevated temperatures to statistical model results. We have evaluated available experimental data on cross sections, resonance energies and strengths, partial widths, lifetimes, spin-parities, and spectroscopic factors. Based on these results, we have estimated numerical values of 78 experimental charged-particle thermonuclear reaction rates for target nuclei in the $A = 2$–40 mass region, for temperatures ranging from 1 MK to 10 GK. For each reaction, three rate values are provided: low, median, and high, corresponding to the 16th, 50th, and 84th percentiles, respectively, of the cumulative reaction rate probability density distribution. Additionally, we present the factor uncertainty of each rate at each temperature grid point. These results enable users to sample the reaction rate probability density in nucleosynthesis calculations, facilitating uncertainty estimates of nuclidic abundances. The rates presented here refer to their laboratory values. For use in stellar model simulations, these values need to be corrected for the effects of thermal excitations of the interacting nuclei. For each reaction, we include graphs that illustrate the fractional contributions to the overall reaction rate along with the associated uncertainty. These visuals are designed to assist both stellar modelers and nuclear experimentalists by identifying the primary sources of rate uncertainty at specific stellar temperatures. A graphical comparison with earlier Monte Carlo rates is also provided.

Unified Astronomy Thesaurus concepts: Nuclear astrophysics (1129)

ETR 25 C. Iliadis *et al.*, Astrophys. J. Supp. Ser. **283**, 17 (2026)
78 experimental thermonuclear reaction rates for A = 2 -40 nuclei, T =0.001-10 GK, with rigorous uncertainty quantification

Current status of the thermonuclear reaction rate





ETR 25 C. Iliadis *et al.*, Astrophys. J. Supp. Ser. **283**, 17 (2026)

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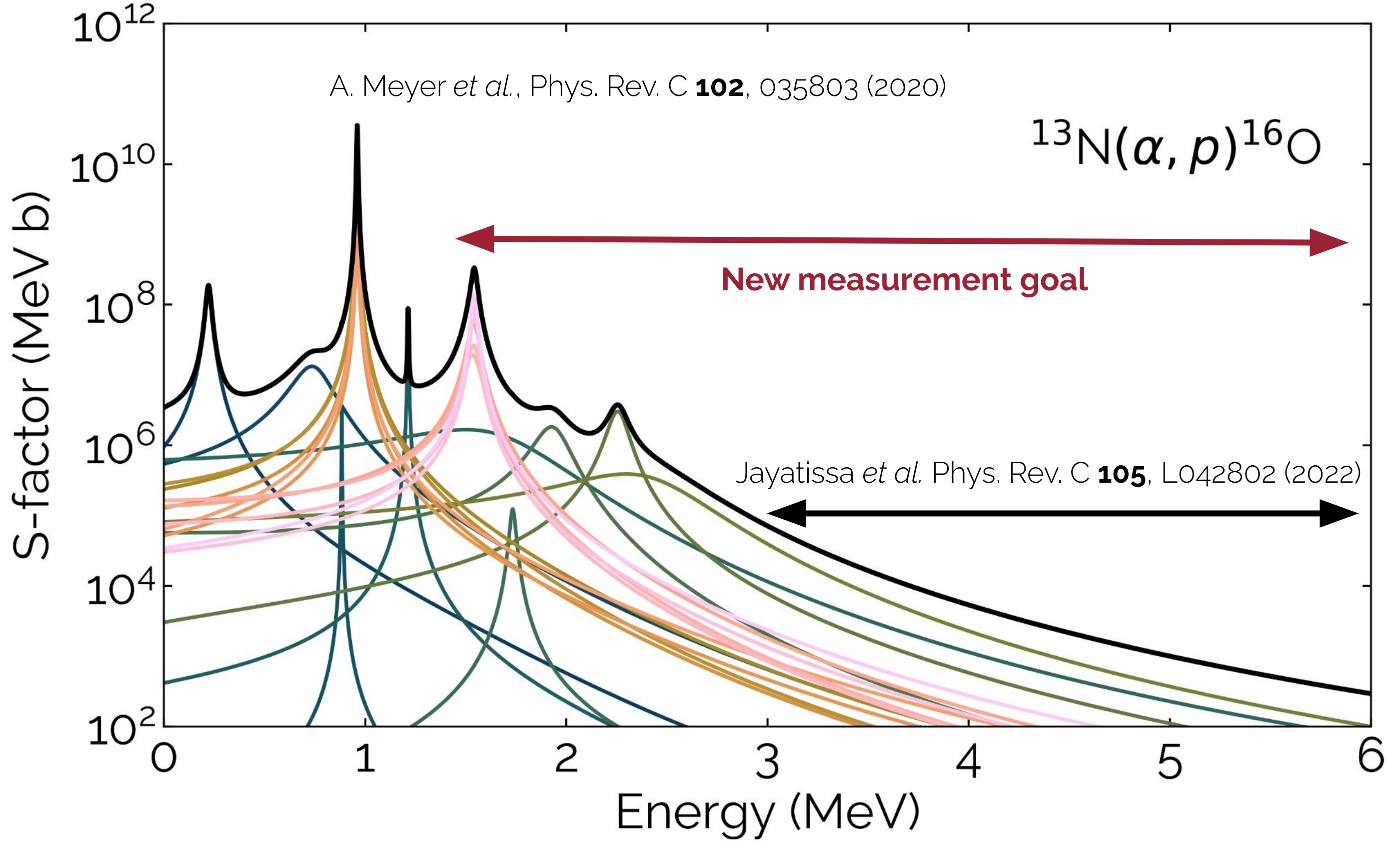
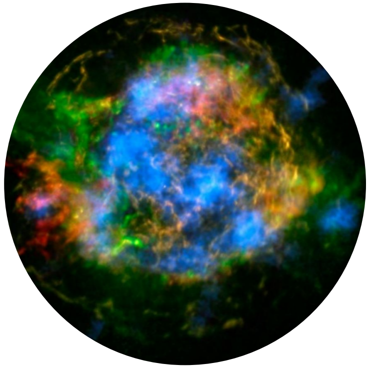
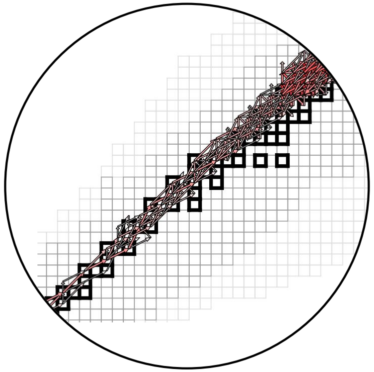


ETR 25 C. Iliadis *et al.*, Astrophys. J. Supp. Ser. **283**, 17 (2026)
78 experimental thermonuclear reaction rates for A = 2 -40 nuclei, T =0.001-10 GK, with rigorous uncertainty quantification

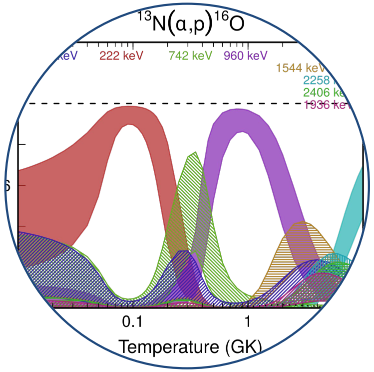
From observations to new experiments



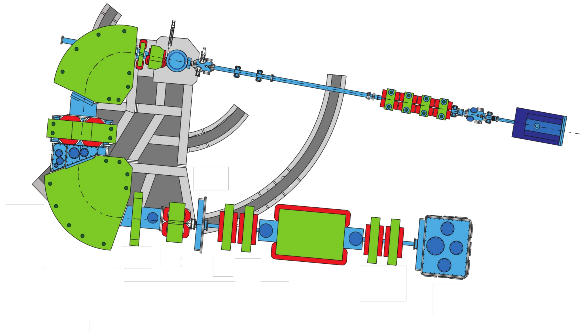
Observations



Sensitivity Studies

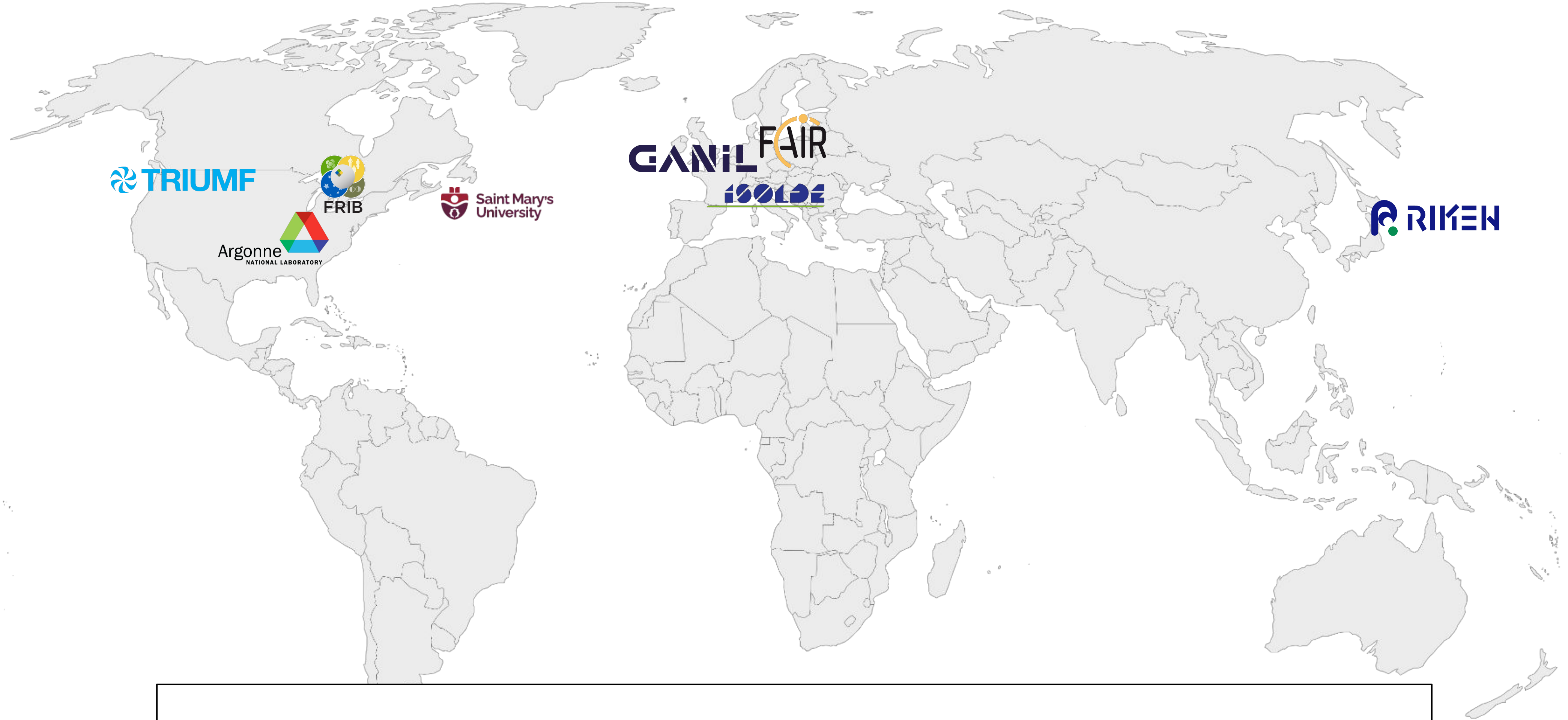


Reaction Rate Uncertainty



Need for new direct measurement (CRIB)

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



Building an international radioactive beam program

Building an international radioactive beam program

The collaboration

28 participants from **6** countries (9 graduate students)

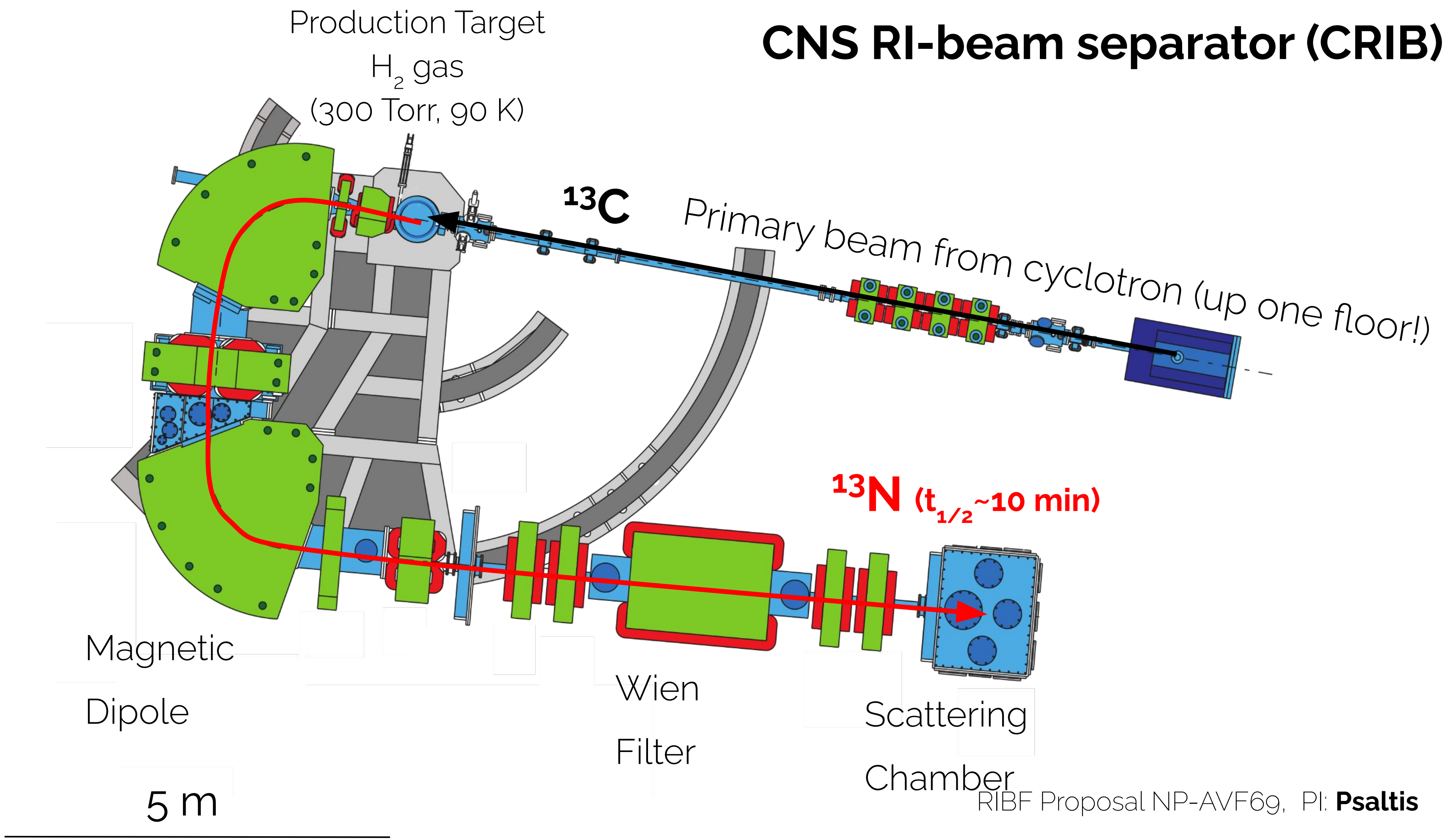
H. Yamaguchi, S. Hayakawa, K. Okawa, F.L. Liu, Q. Zhang
N. Imai, N. Kitamura, S. Hanai, S. Bae, J. Li , Y. Yamamoto (CNS) •
S. Ahn, S.M. Cha, G.M. Gu (CENS, IBS) • M. Lee, V. Beaty (TUNL) •
S. Kubono (RIKEN) • K.Y. Chae, C.H. Kim, S.H. Kim (Sungkyunkwan University) •
A. Kim, S. Do (CENuM) • E. Lopez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

Saint Mary's University
TUNL
Triangle Universities Nuclear Laboratory
NS
RIKEN NiSHiNA CENTER


TJ
東武東上線のりば
Tobu Tojo Line 车站 타는 곳
かとう内科クリニック
東急リバブル
03-3977-8222
IC
専用

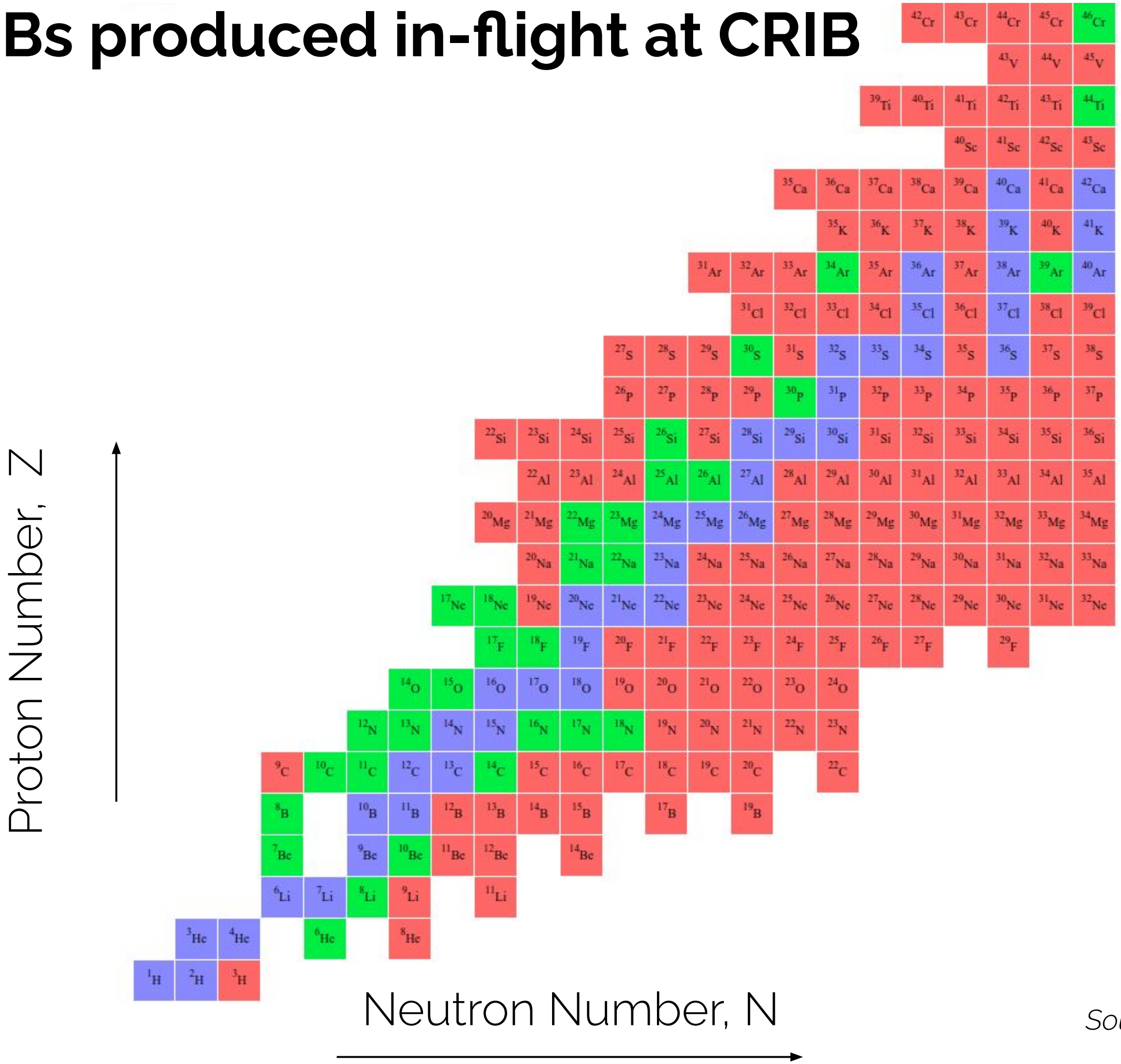

原子番号
7
元素記号
N
元素名
窒素
Nitrogen
113番元素ニホニウム発見のまち
和光市

CNS RI-beam separator (CRIB)



RIBF Proposal NP-AVF69, PI: **Psaltis**

RIBs produced in-flight at CRIB



- ^{A}X stable beam
- ^{A}X radioactive beam made in CRIB
- ^{A}X radioactive beam

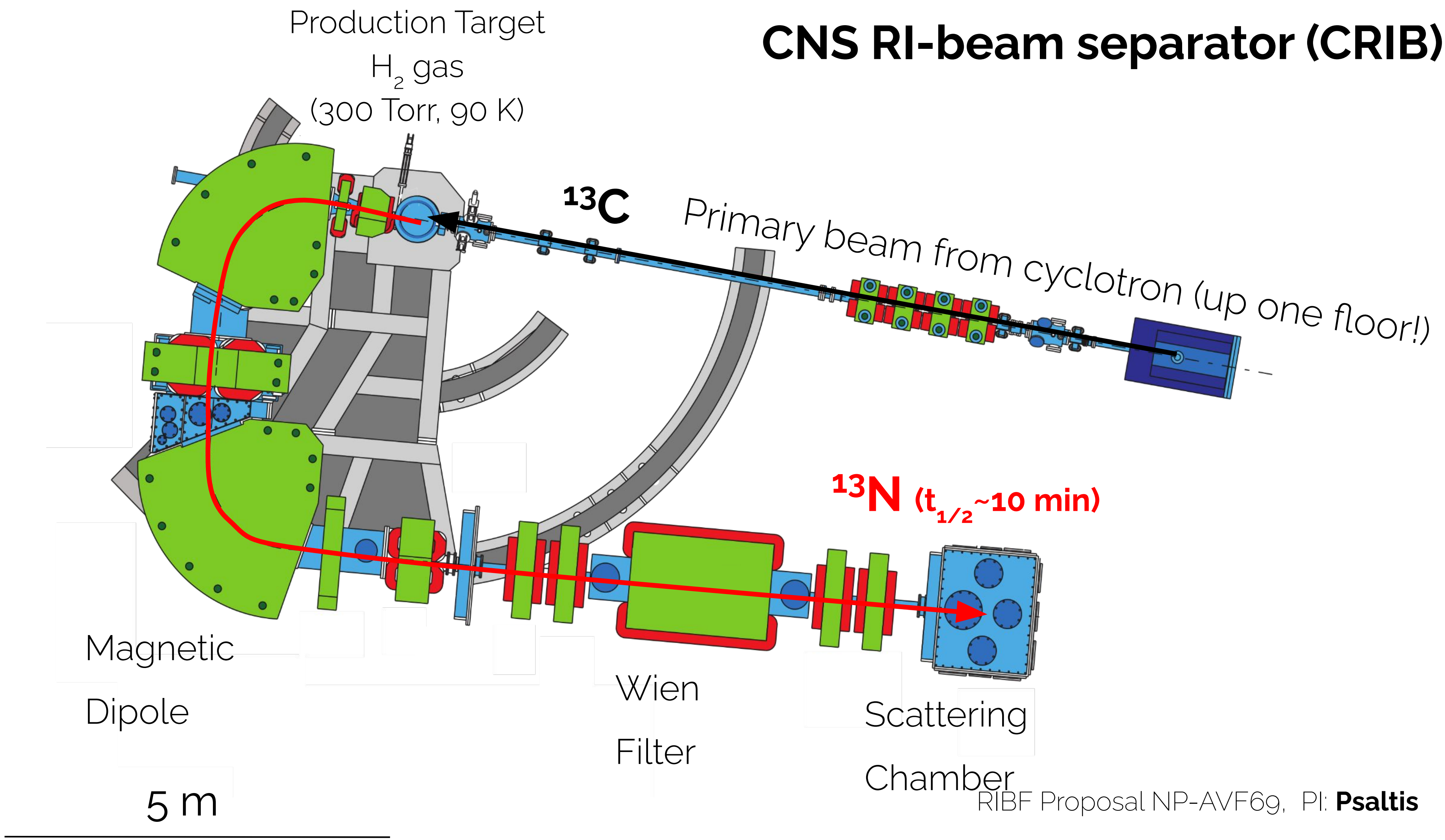
Hidetoshi Yamaguchi
(CNS/U Tokyo)

Some recent results

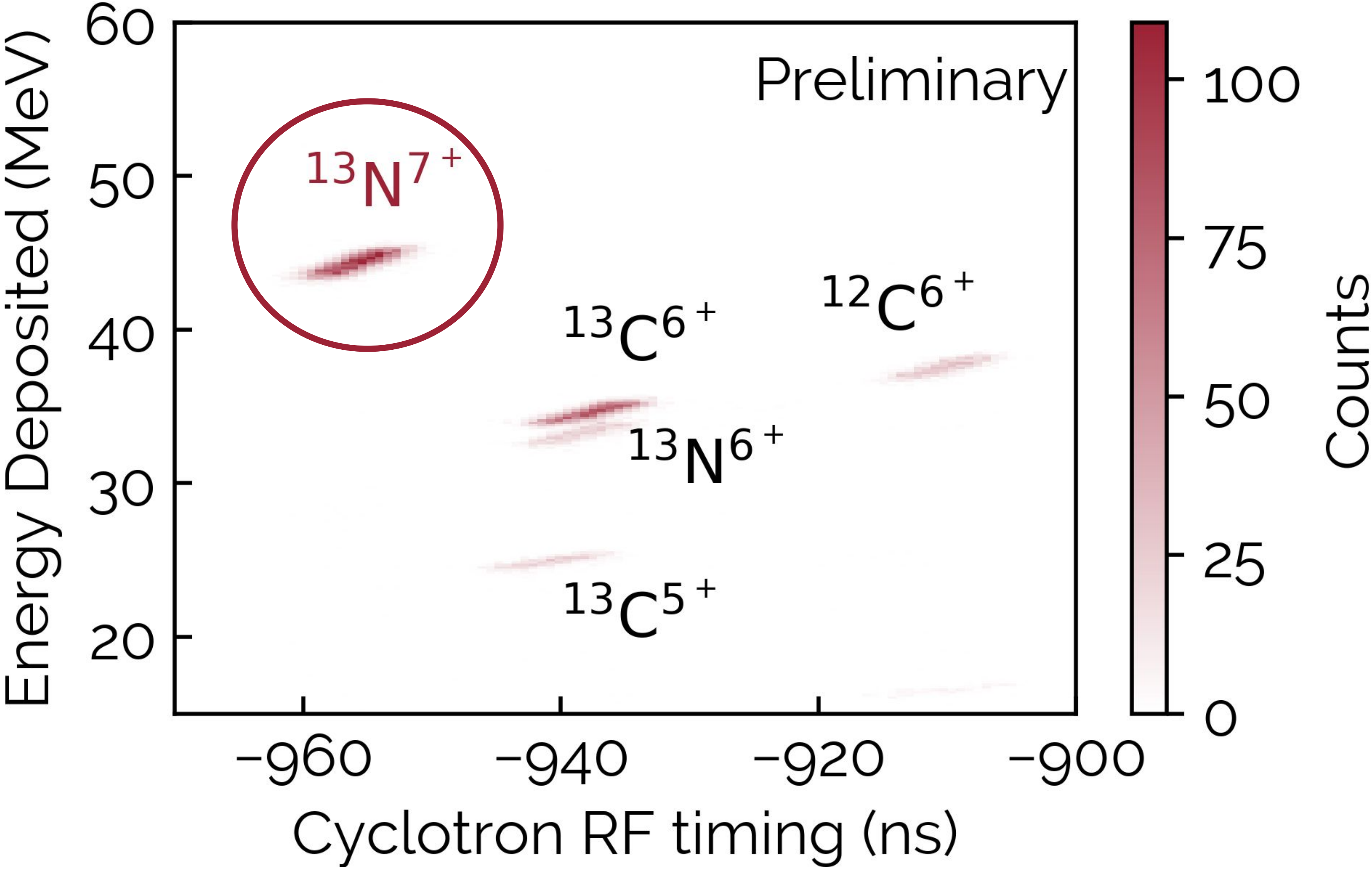
S. Hayakawa *et al.* Astrophys. J Lett. **915**, L13 (2021) **^{7}Be+n**
J. Hu *et al.*, Phys. Rev. Lett. **127**, 172701 (2021) **^{25}Al+p**
D. Kahl *et al.*, Phys. Rev. C **97**, 015802 (2018) **^{30}Si+α**
H. Yamaguchi et al., Phys. Rev. C **87**, 034303 (2013) **^{7}Be+α**

Source: cns.s.u-tokyo.ac.jp/crib/crib-new/beams-en/index.html

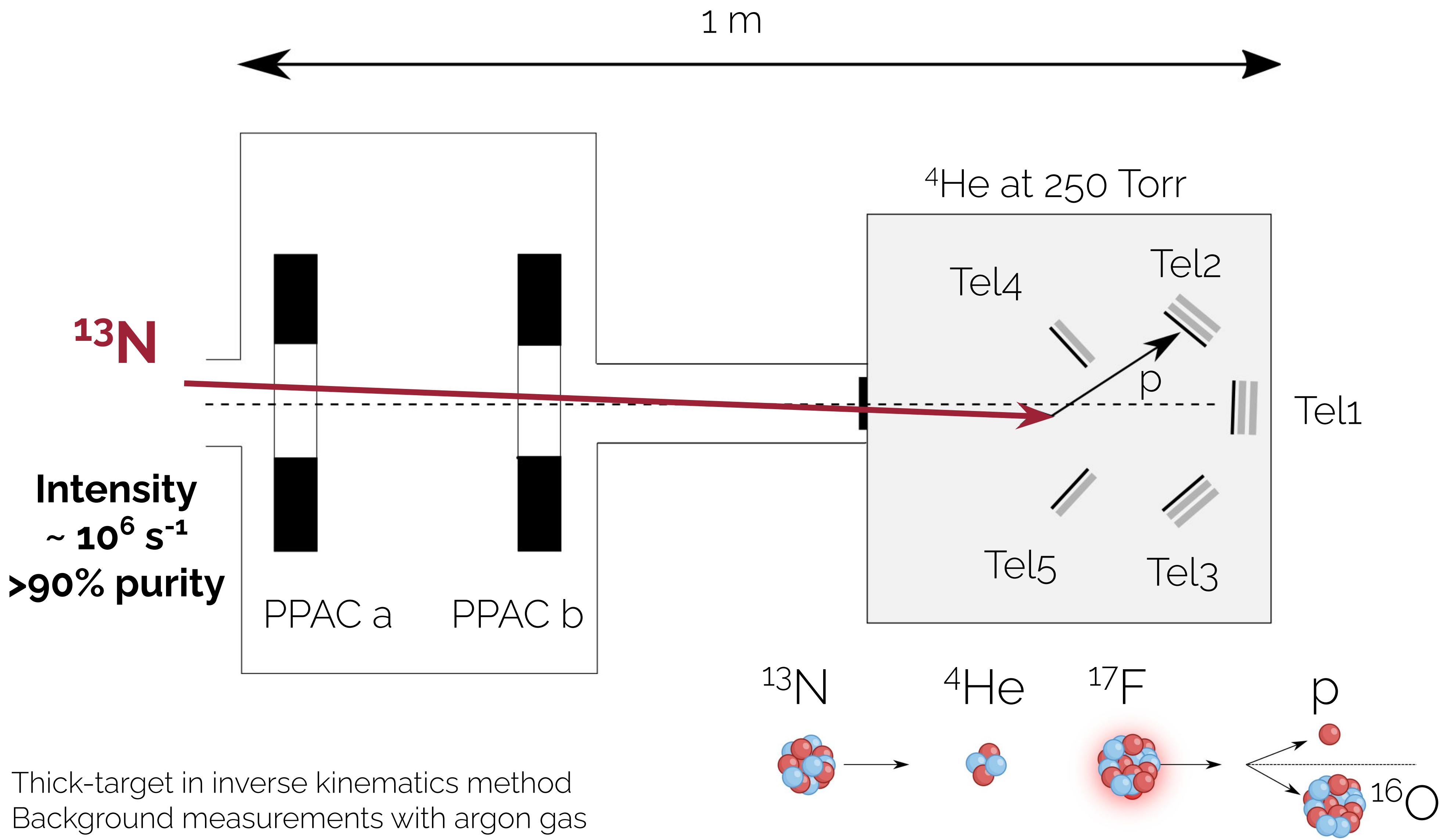
CNS RI-beam separator (CRIB)



RIBF Proposal NP-AVF69, PI: **Psaltis**

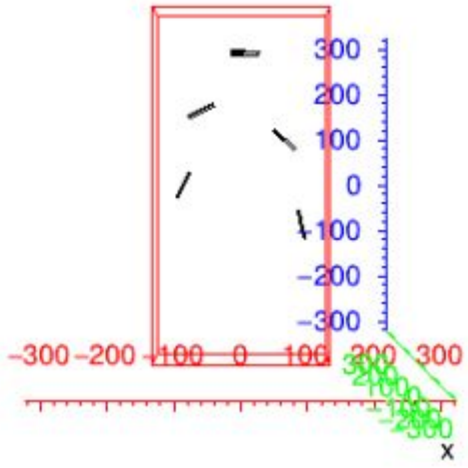


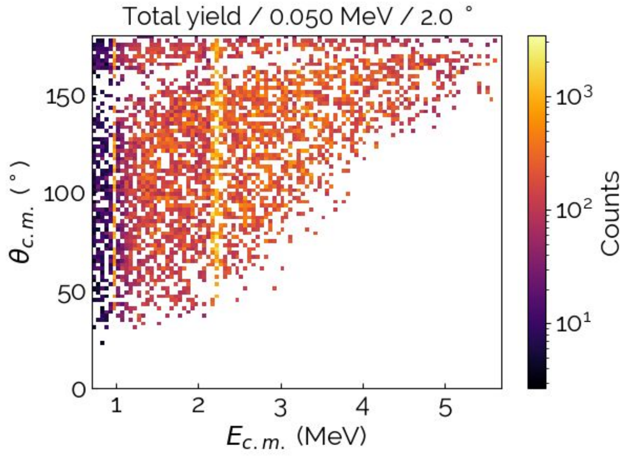
Preliminary
$^{13}N^{7+}$
$^{13}C^{6+}$
$^{12}C^{6+}$
$^{13}N^{6+}$
$^{13}C^{5+}$
Energy Deposited (MeV)
60
50
40
30
20
−960
−940
−920
−900
Cyclotron RF timing (ns)
100
75
50
25
0
Counts

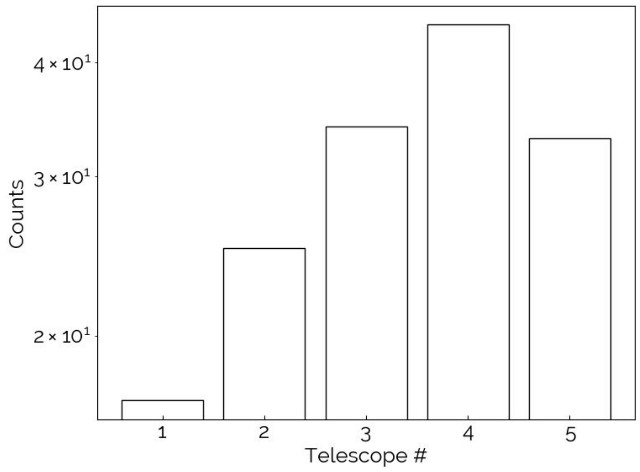


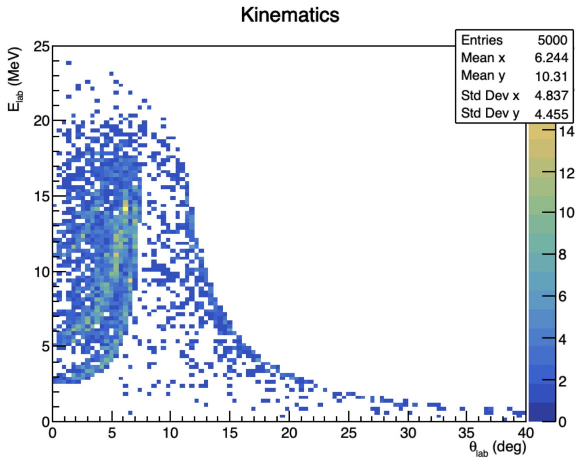
Thick-target in inverse kinematics method
Background measurements with argon gas

Simulations to determine the optimal detector positions



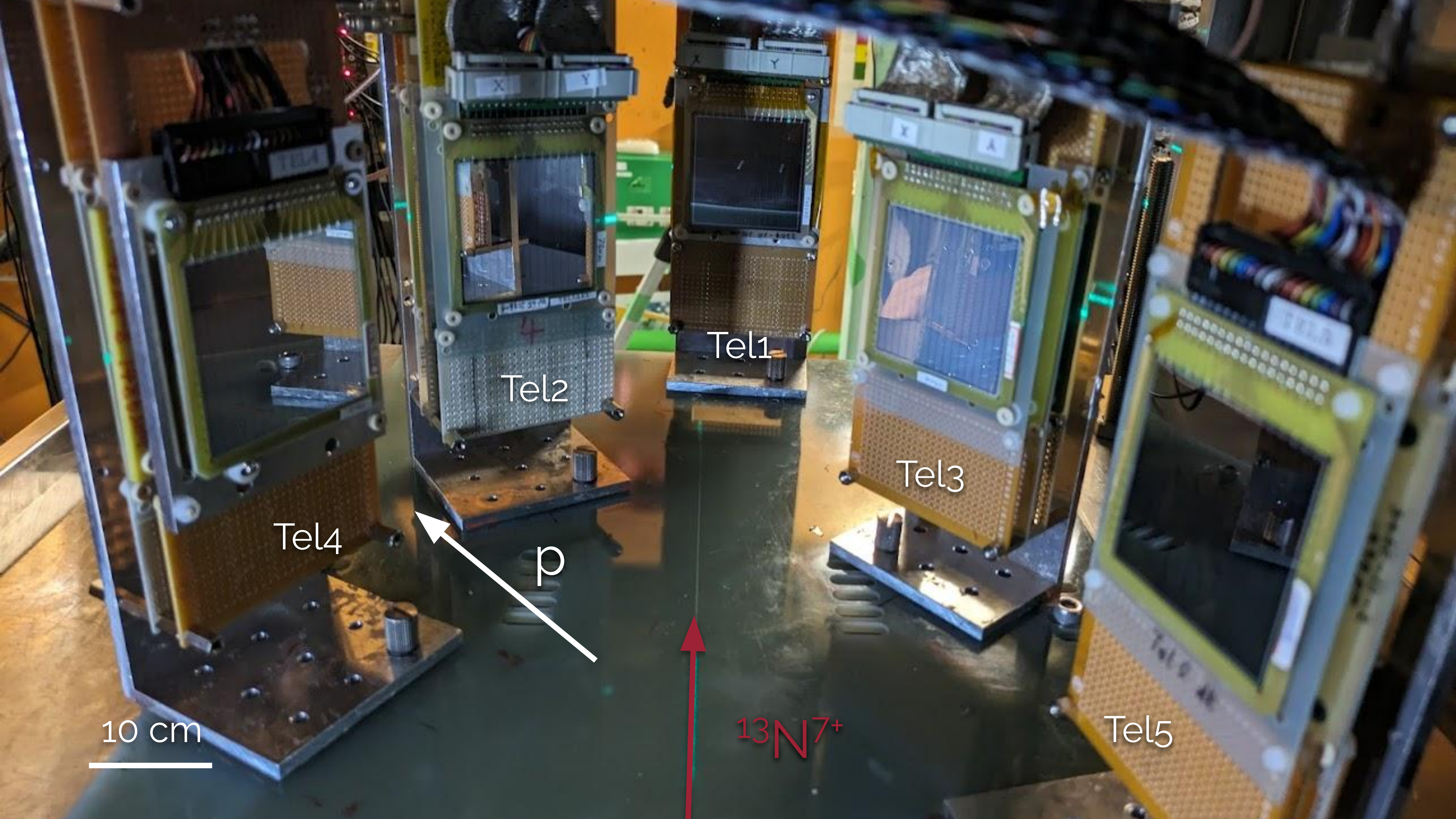




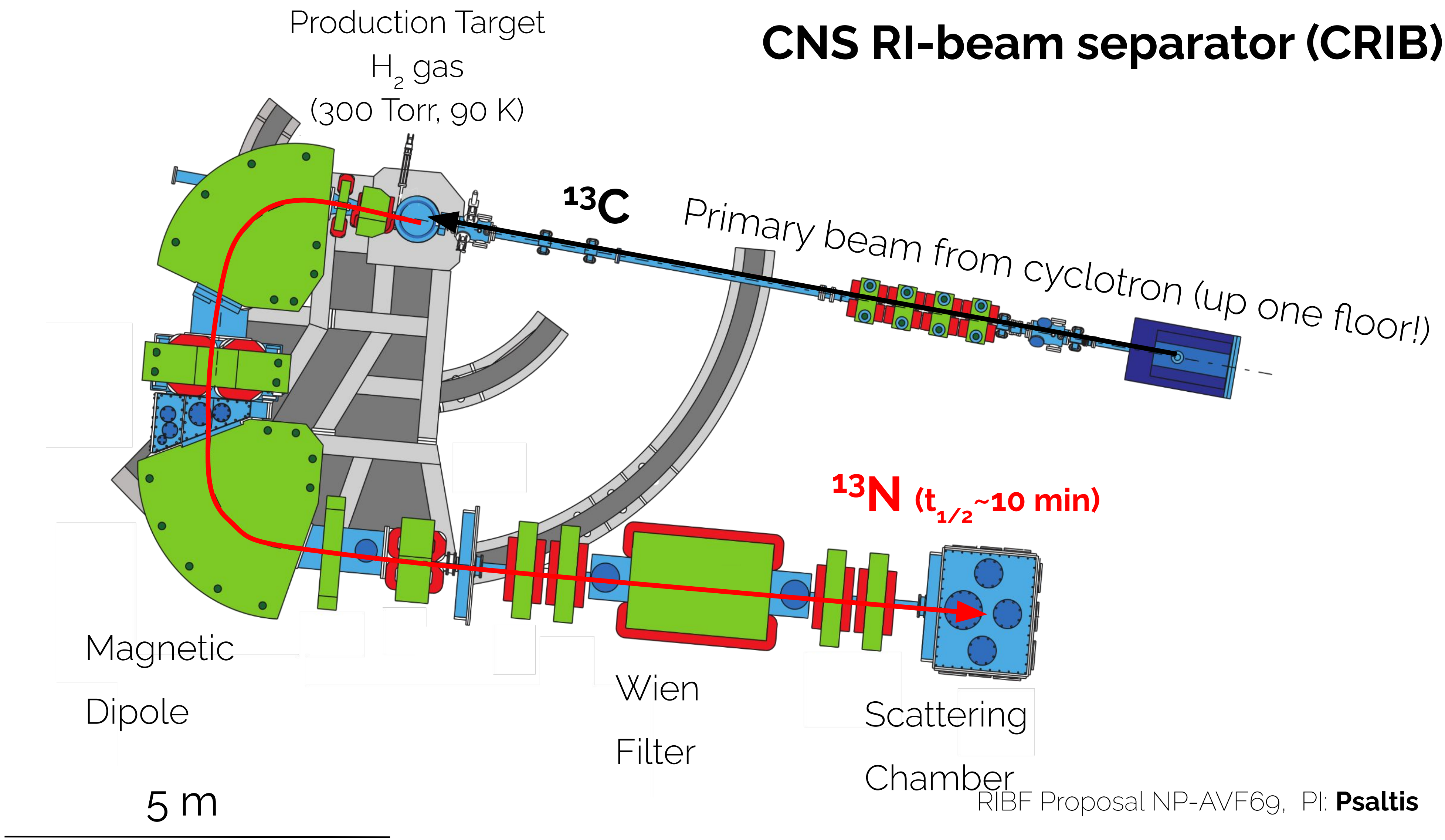


TGTIK simulator: Simulator for thick-gas-target in inverse-kinematics method written by S. Hayakawa

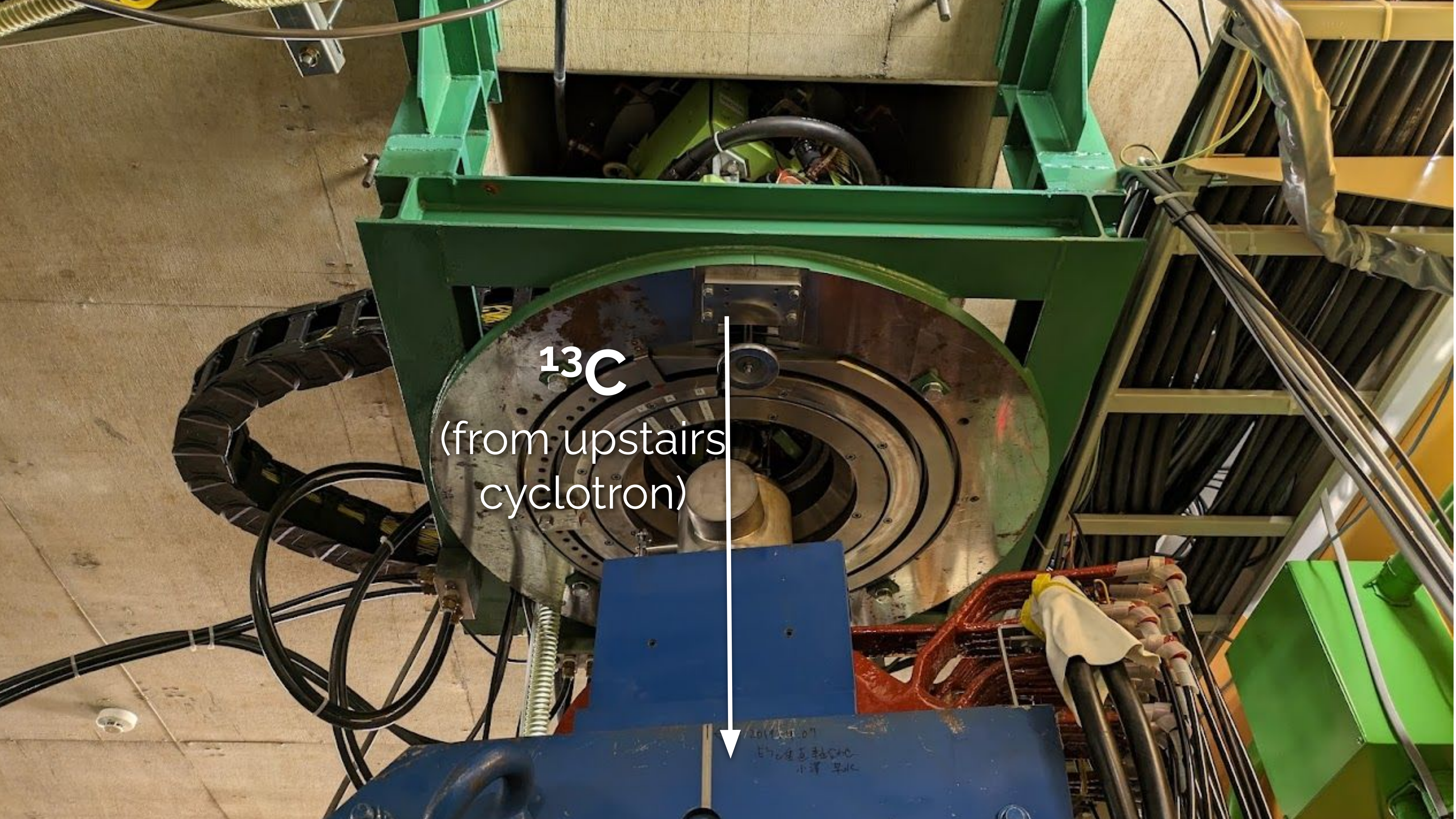
Luka Radulovic
(SMU undergraduate)

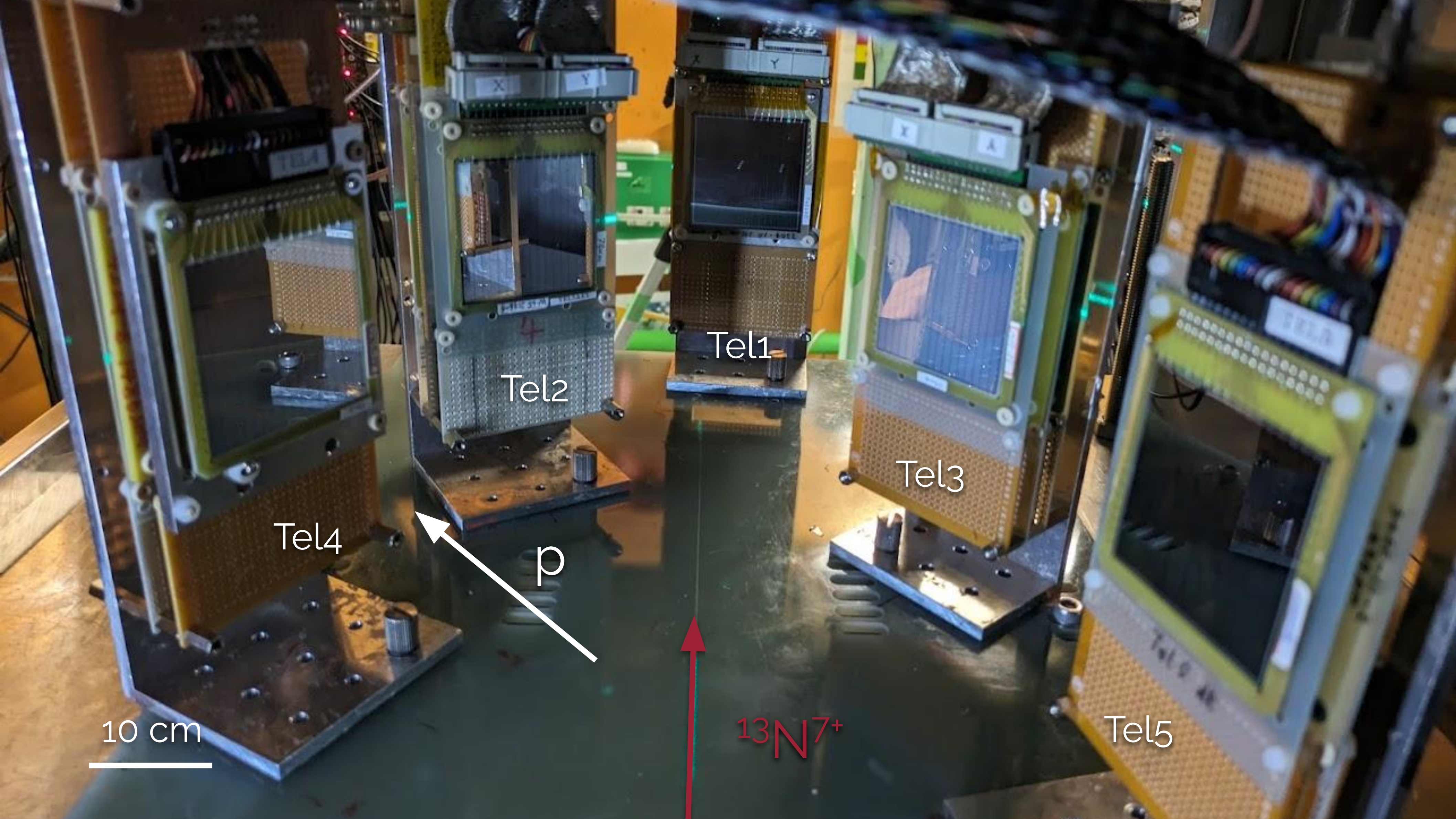

Tel1
Tel2
Tel3
Tel4
Tel5
p
13N7+
10 cm

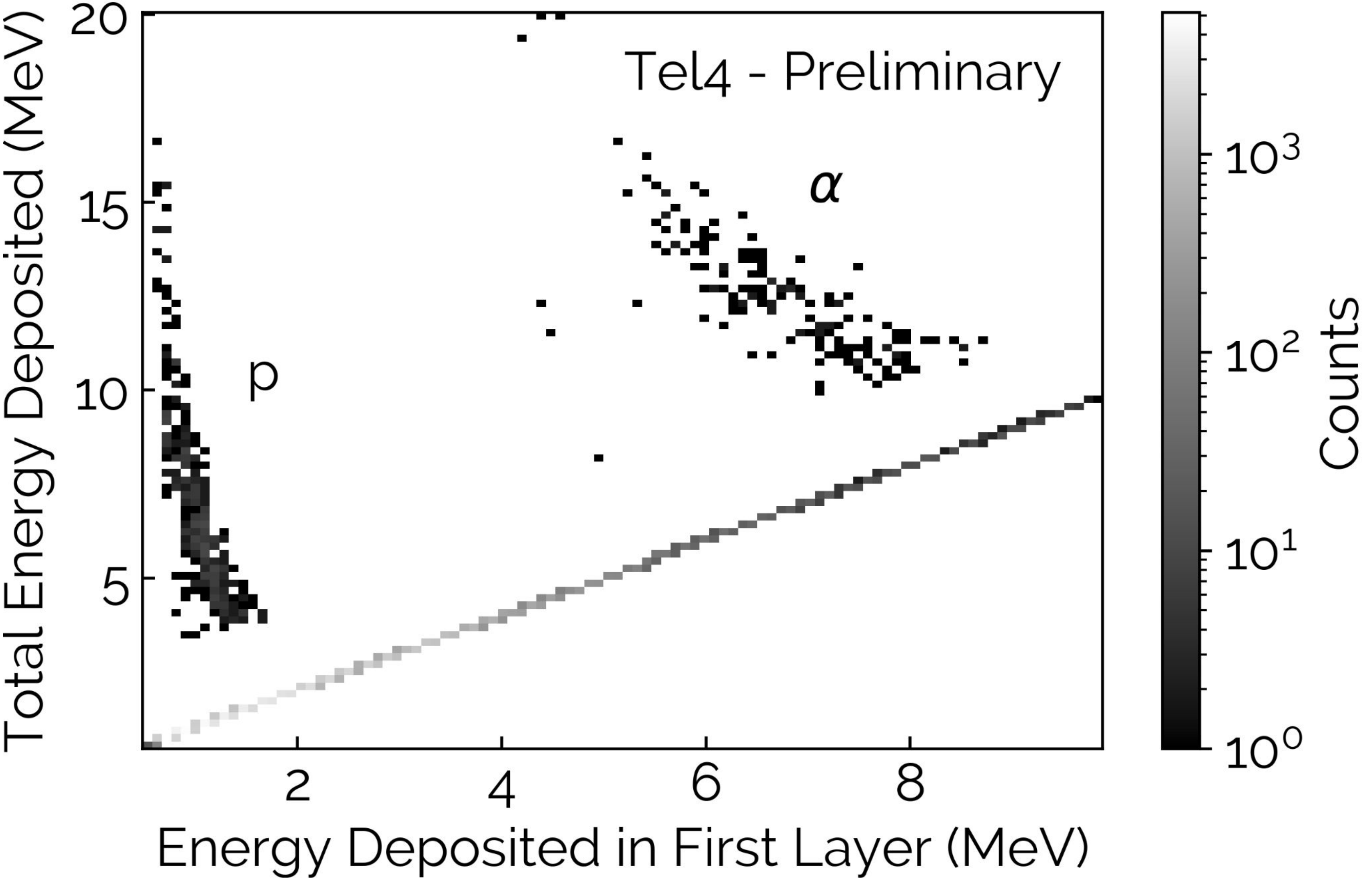
CNS RI-beam separator (CRIB)



RIBF Proposal NP-AVF69, PI: **Psaltis**

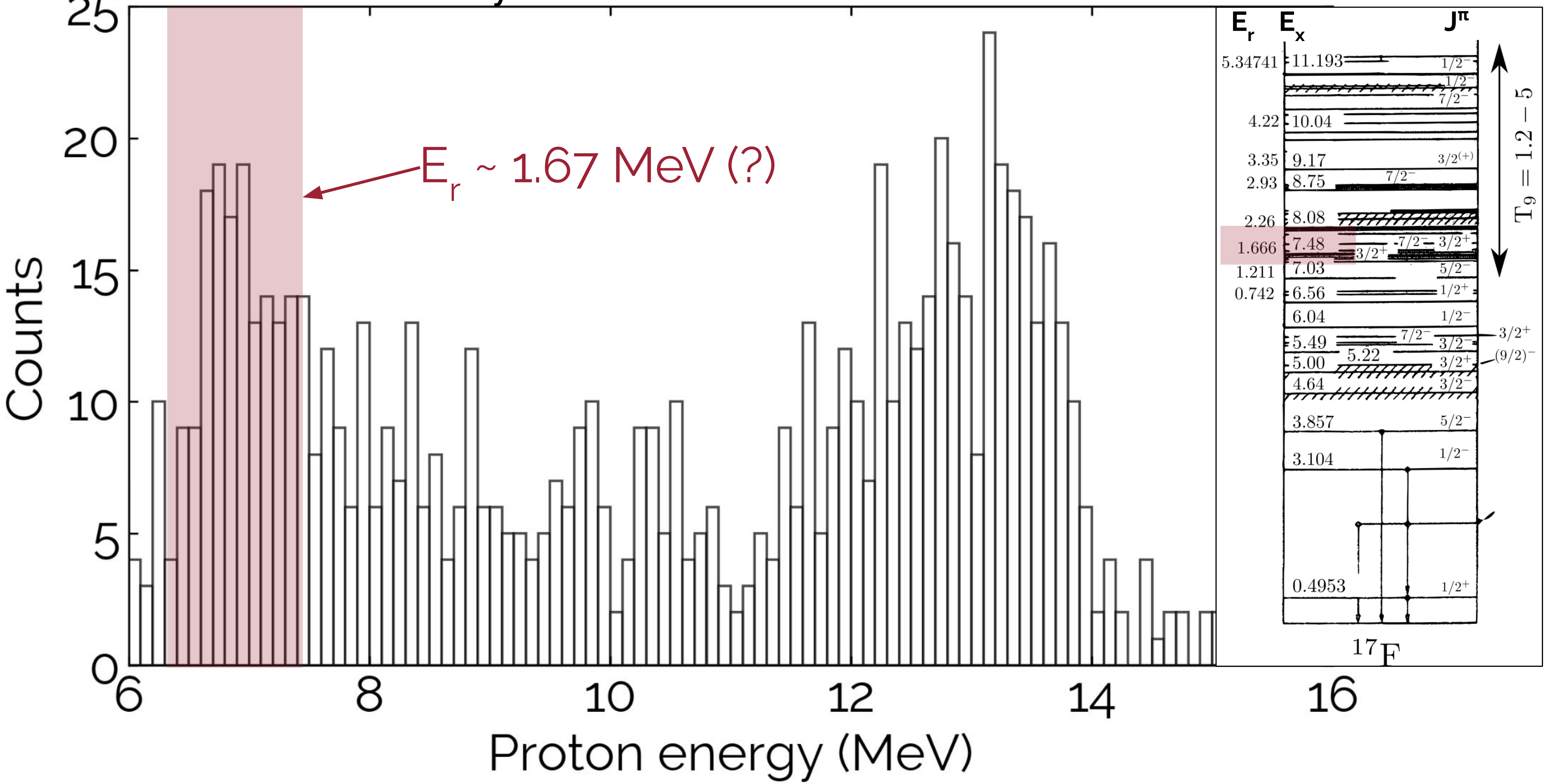

^{13}C
(from upstairs
cyclotron)


Tel1
Tel2
Tel3
Tel4
Tel5
p
$^{13}N^{7+}$
10 cm



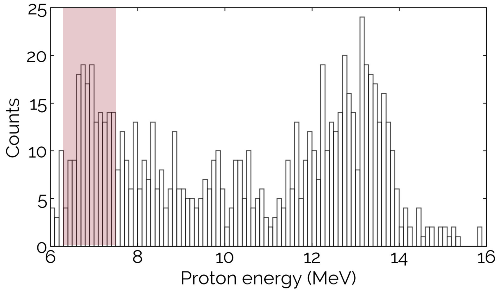
Tel4 - Preliminary
α
p
Total Energy Deposited (MeV)
Energy Deposited in First Layer (MeV)
Counts
20
15
10
5
2
4
6
8
10^3
10^2
10^1
10^0

Tel 1 Preliminary

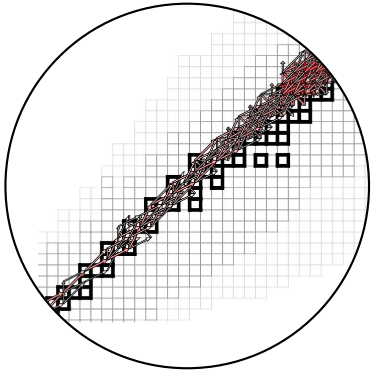



持ち出し
厳禁
CAEN
Nuclear

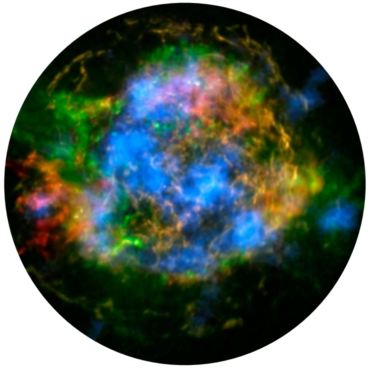
Future Directions



New direct measurement and reaction rate



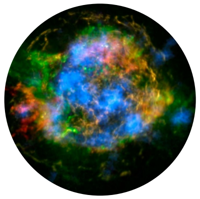
Updated simulation & nucleosynthesis models



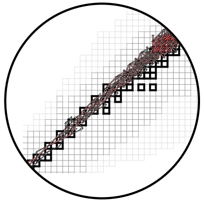
Better understanding of the production of ^{44}Ti and ^{56}Ni in ccSNe

Take home messages

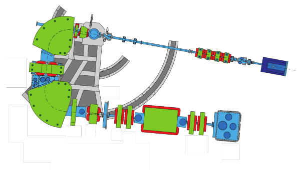
1. Radioactive isotopes provide direct constraints on explosive nucleosynthesis observables



2. The $^{13}N(\alpha,p)^{16}O$ reaction affects the $^{44}Ti/^{56}Ni$ ratio in CCSNe



3. Direct measurements are now within reach and are essential for reducing astrophysical model spread



Thank you for your attention!

ご清聴ありがとうございました。

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