



Initial analysis of charged particle reactions as a mix diagnostic for high-yield NIF implosions

JHEDS WIP

2026 October 1

Speaker

Oliver Gorton, postdoc | PLS, Nuclear Data and Theory

Principal Investigator

Jutta Escher, deputy group leader | PLS, NDT group

Team member

Aaina Thapa, staff scientist | PLS, NDT group

Team member

Andrew Ratkiewicz, staff scientist | PLS, NPAT group

Senior advisor

Charles Cerjan | Northwind

Project sponsor lead

Alastair Moore | NIF, HED

Project sponsor
advisor

David Schlossberg | NIF, HED

ICF RadChem analysis team (est. June 2026)



Jutta Escher
Principal Investigator,
RadChem data and theory
Theoretical nuclear physics
Nuclear Data and Theory group



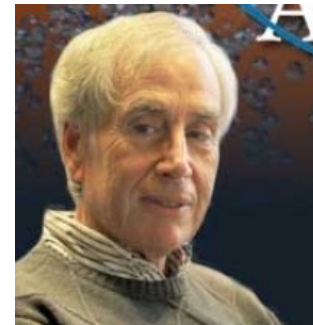
Aaina Thapa
RadChem data and theory
Theoretical nuclear physics
Nuclear Data and Theory group



Andrew Ratkiewicz
Gamma-ray data, simulations
Experimental nuclear physics
Nuclear Physics + Accelerator group



Oliver Gorton
Modeling and simulations,
data infrastructure
Theoretical nuclear physics
Nuclear Data and Theory group

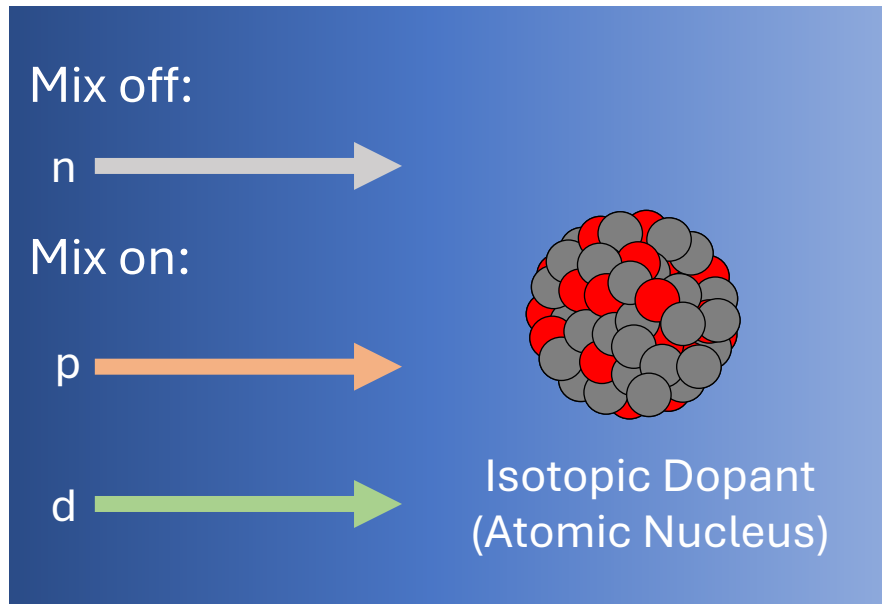


Charlie Cerjan
Senior Advisor,
Modeling and simulations
Theoretical physics
Northwind

Presentation Motivation and Summary

High yield ($> 10^{18}$ neutrons) will require NIF diagnostics to *adapt*, particularly *mix diagnostics*

The FY27 “Dark Mix” research campaign* will test a radiochemical diagnostic using ^{13}N



Mix influences nuclear reactions on dopants, creating a measurable RadChem signal

Many reactions contribute to a given signal, requiring comprehensive modeling

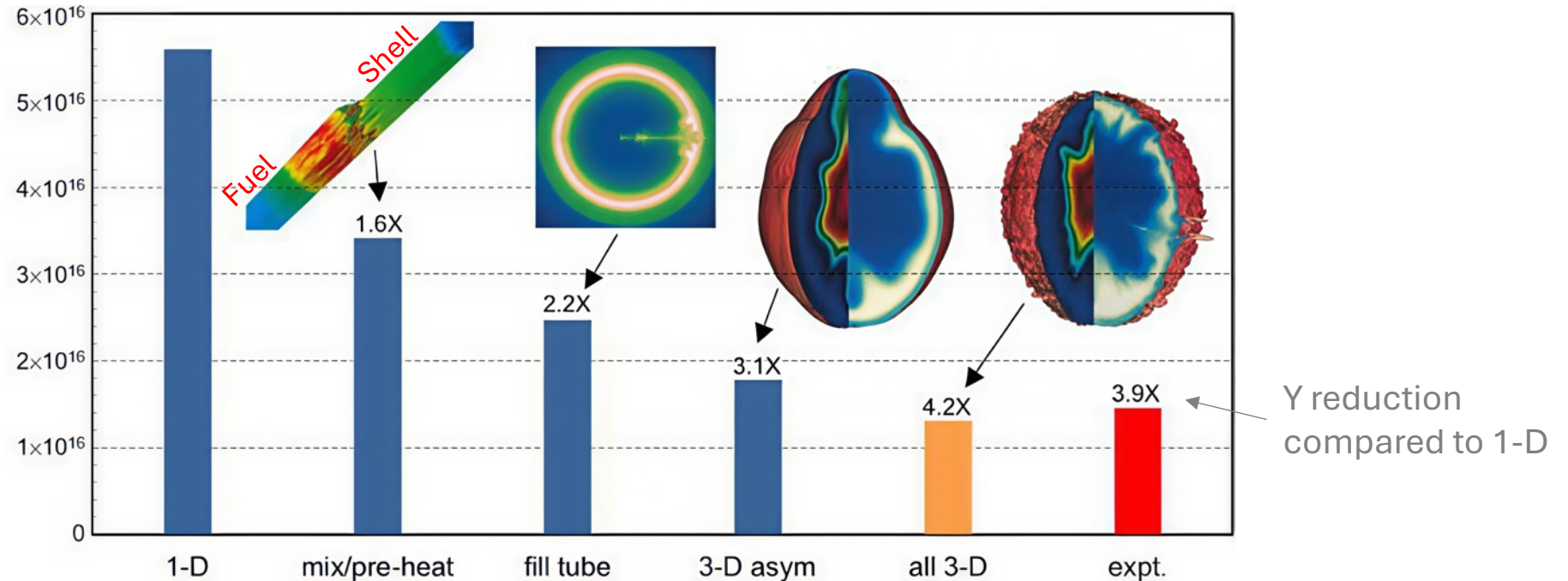
*Seth Davidovits, Gareth Hall, Justin Jeet, *et al.*
AKA “Dopant mix”, “N13 Calibration” campaign

Confidence in the quality and completeness of the ^{13}N nuclear reaction network must be assessed

Symmetry is king and mix is the enemy

Mix problem: When high-Z shell material **mixes** into the fuel, heat is lost to radiation
... and fuel may preheat, reducing compression

DT Neutron Yield



[D. Clark et al.,
Phys. Plasmas 26, 050601 \(2019\)](#)

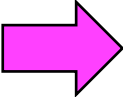


Yield degradation mechanism

Understanding and controlling *mix* has been key to achieving higher yields



How do we know if mix was the cause of a low yield?

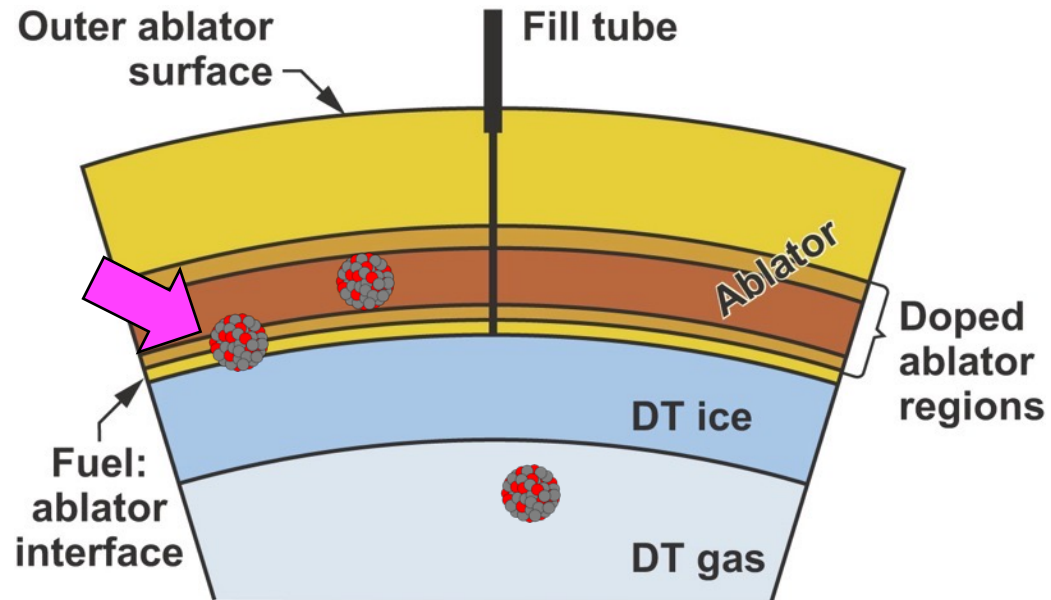


Diagnostic	Physics	Limitations
Down-scatter ratio (DSR) X-ray spectroscopy X-ray radiography Gamma reaction history (GRH) Radiochemistry (RadChem)	Change in areal density ρR Dopants fluoresce if enter hotspot Mix-width via radial optical depth Nuclear reactions produce gammas Nuclear reactions produce isotopic signature	Indirect X-ray background at high yield* X-ray background at high yield* Requires clean gamma signal Collection efficiency, reliability of nuclear data

*And also “dark mix”

Radiochemistry can be used as mix diagnostic

Question What particle flux did the dopant see?

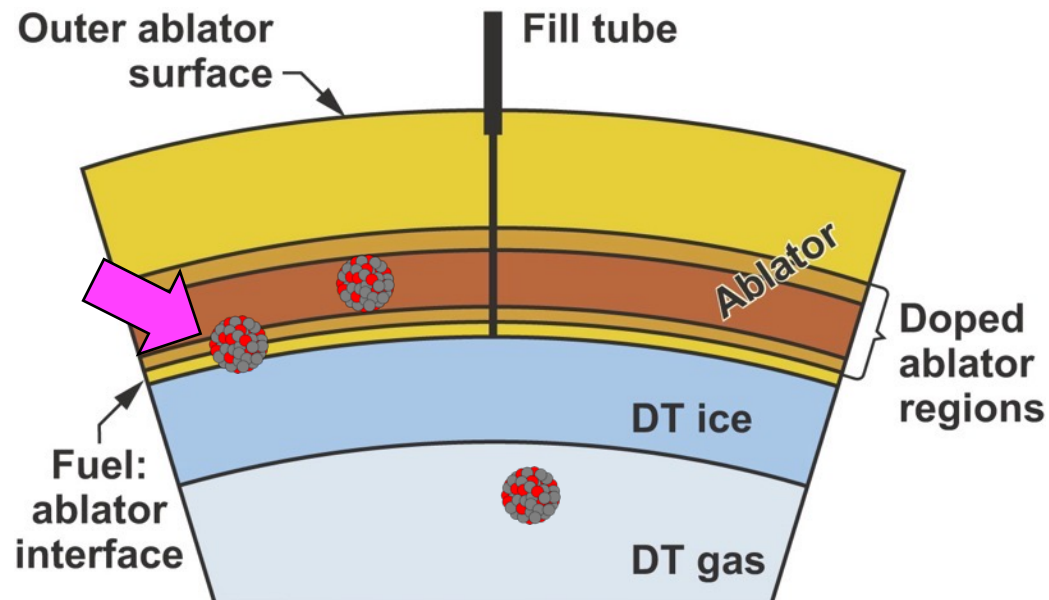


[B. Hammel et al., Phys. Plasmas 25, 080706 \(2018\).](#)

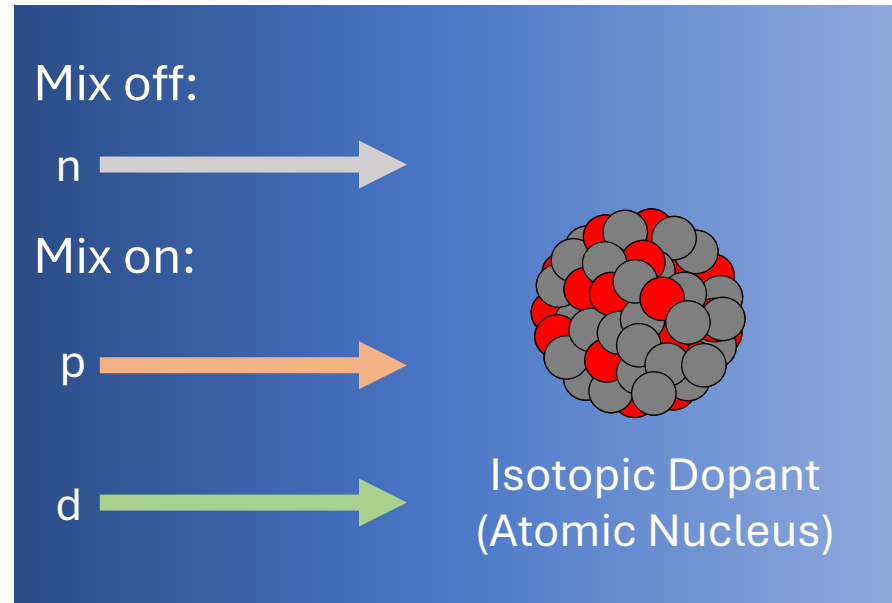
Radiochemistry can be used as mix diagnostic:

using charged particles

Task Interpret RadChem signal by modeling nuclear reactions in different mix scenarios

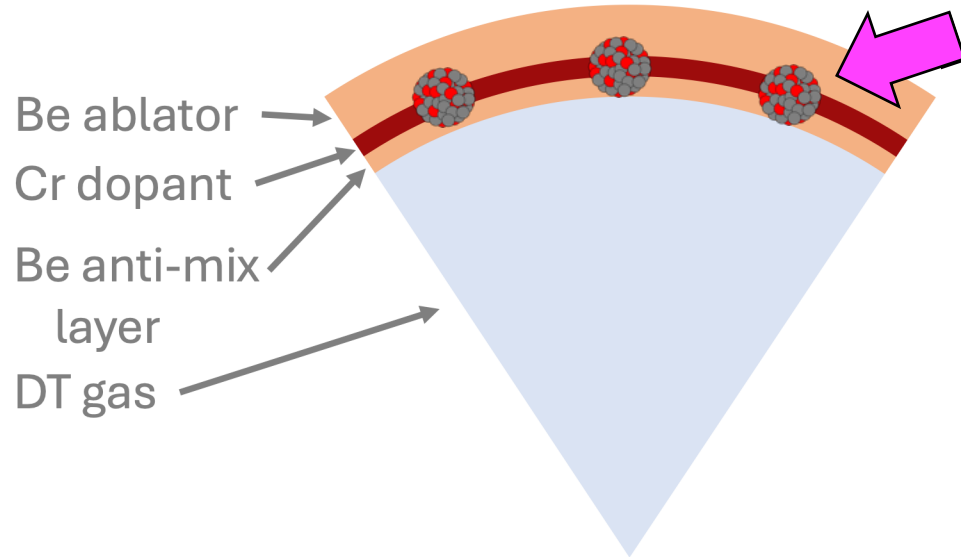


[B. Hammel et al., Phys. Plasmas 25, 080706 \(2018\).](#)



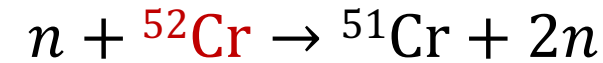
RadChem for mix was deployed on Pushered Single Shell (PSS) platform

S. MacLaren et al., Phys. Rev. Lett. 135, 085101 (2025)

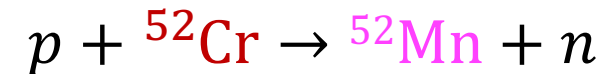
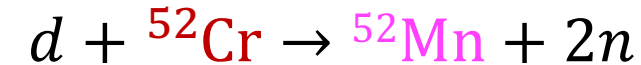


Chromium transformed into Manganese after it mixed into the burning fuel

Mix off:



Mix on:

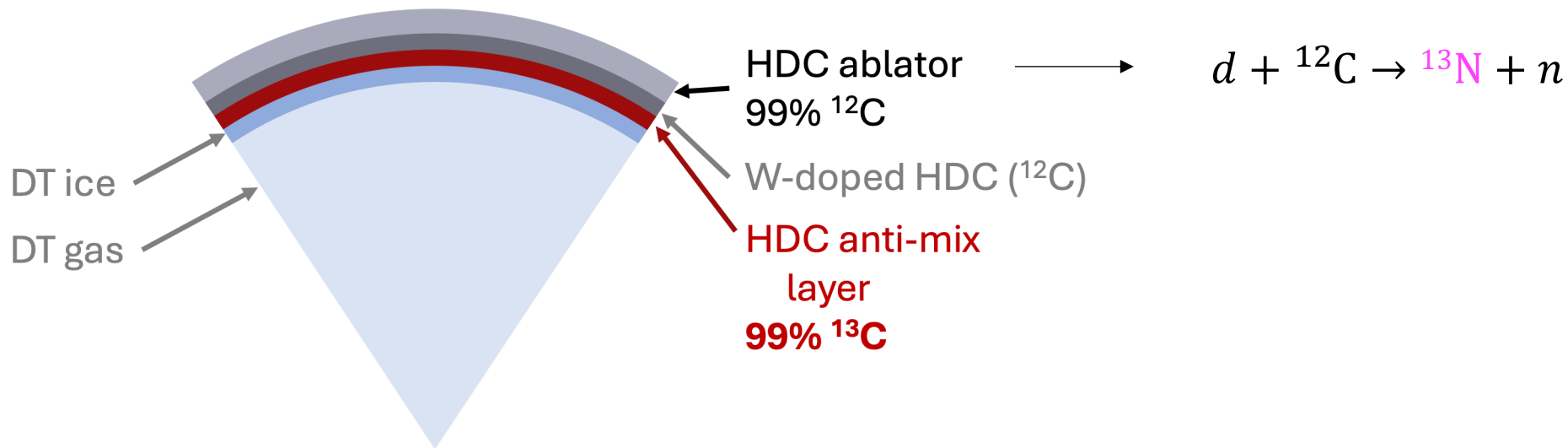


RadChem mix analysis requires ICF simulations and credible nuclear physics modeling

Dark Mix Campaign* uses ^{13}C RadChem to study mix

HDC capsules can be fabricated with either pure ^{12}C or pure ^{13}C

Charged particle reactions on ^{12}C shell should produce ^{13}N , *but 5-10x less using ^{13}C instead*

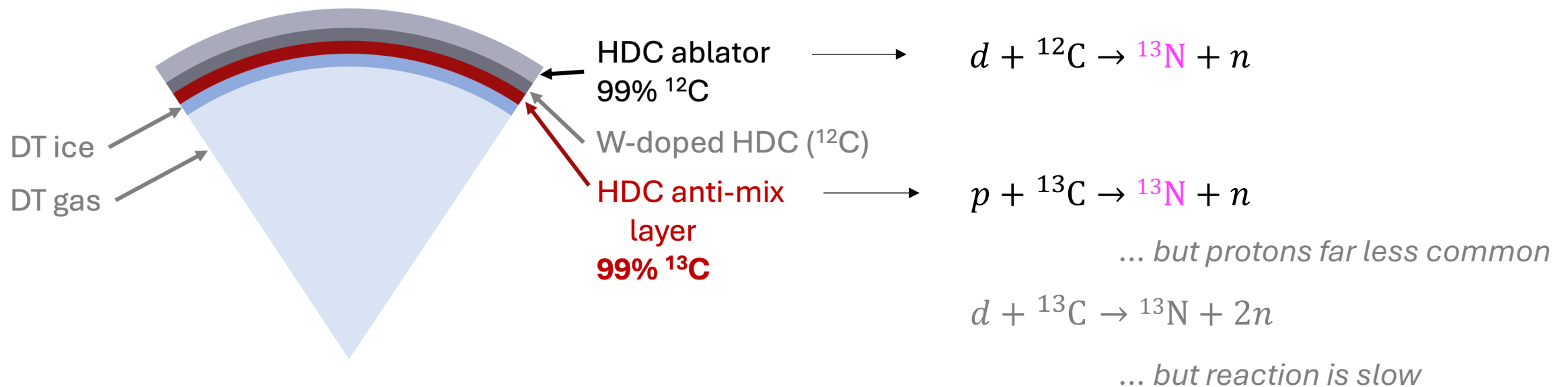


*Dopant Mix and N13 Calibration campaigns

Net ^{13}N production with a ^{13}C buffer layer could serve as a diagnostic for mix

HDC capsules can be fabricated with either pure ^{12}C or pure ^{13}C

Charged particle reactions on ^{12}C shell should produce ^{13}N , but 5-10x less using ^{13}C instead



Confidence in the quality and completeness of the ^{13}N nuclear reaction network must be assessed



Work in Progress

Area 1 Critical analysis and re-evaluation of RadChem data

Jutta Escher, Aaina Thapa

Area 2 Prospects for GRH diagnostic for mix

Andrew Ratkiewicz

Area 3 Rehabilitating RadChem modeling and simulation capabilities

Oliver Gorton, Charles Cerjan

Area 1 Critical analysis and preliminary re-evaluation of RadChem data



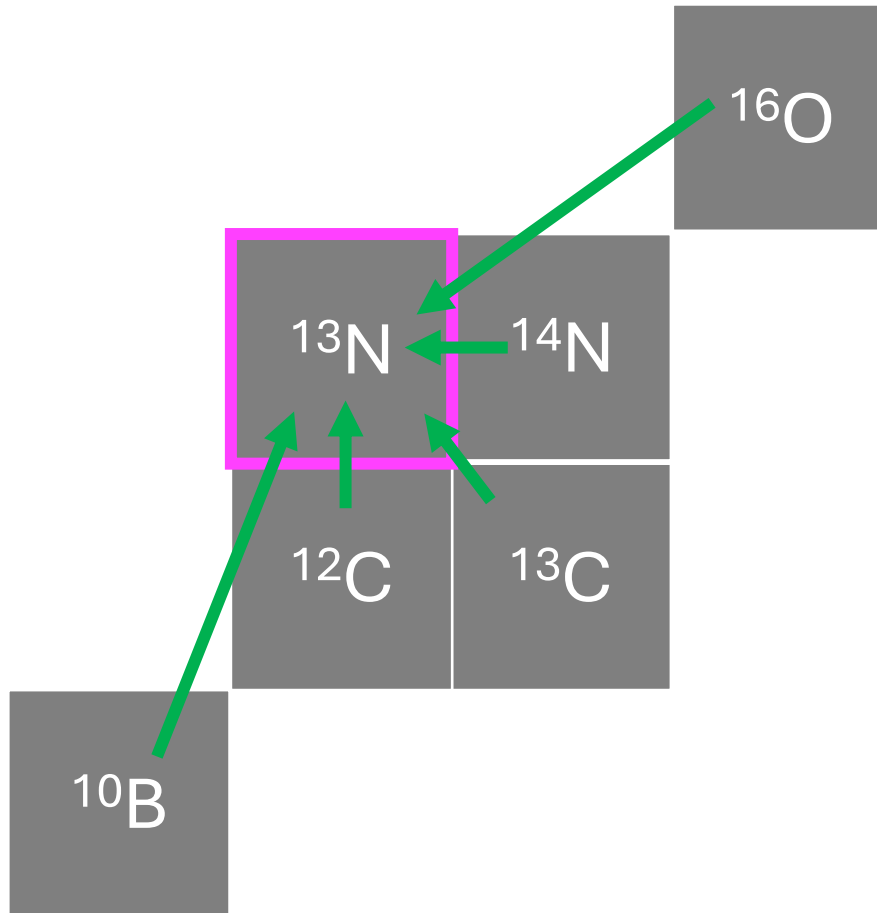
Jutta Escher



Aaina Thapa

“RadChem theory support from subject matter experts is essential for maintaining realistic nuclear reaction networks”

Net ^{13}N production depends on many reactions



Incident particle

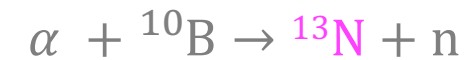
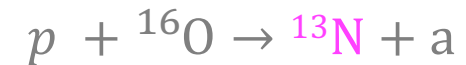
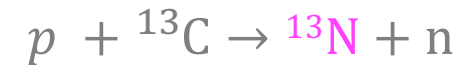
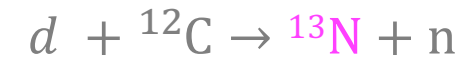
Neutron

Deuteron

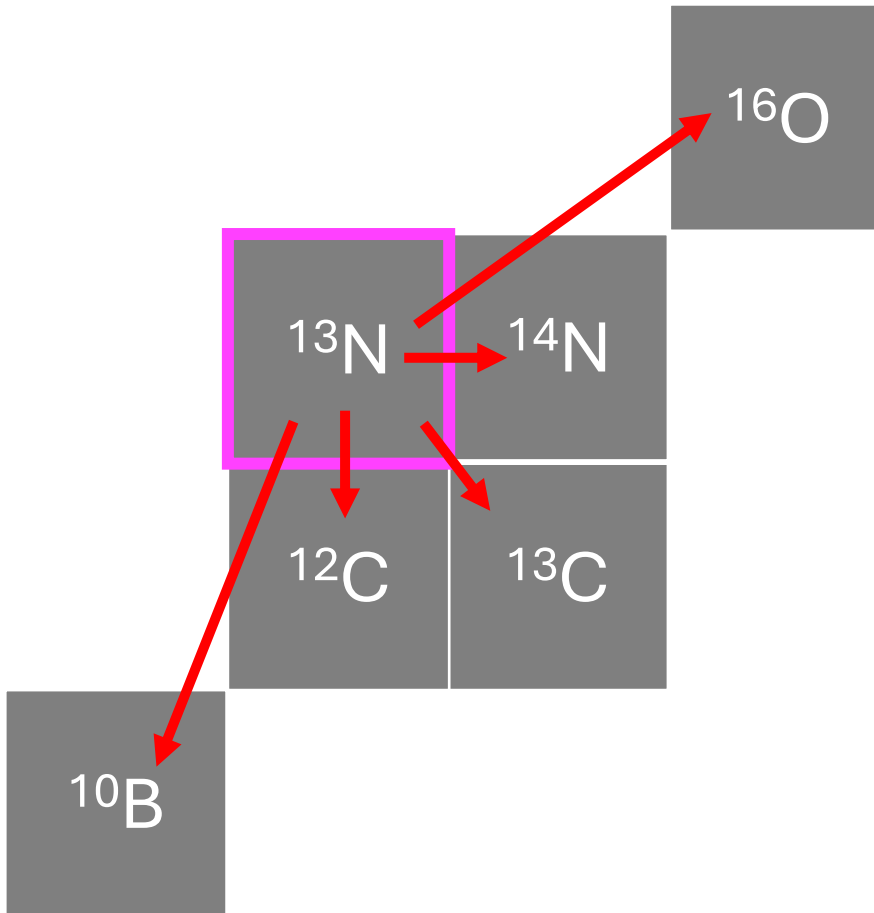
Proton

Alpha

Reactions



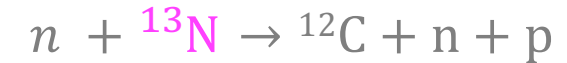
Net ^{13}N production depends on many reactions



Incident particle

Neutron

Reactions



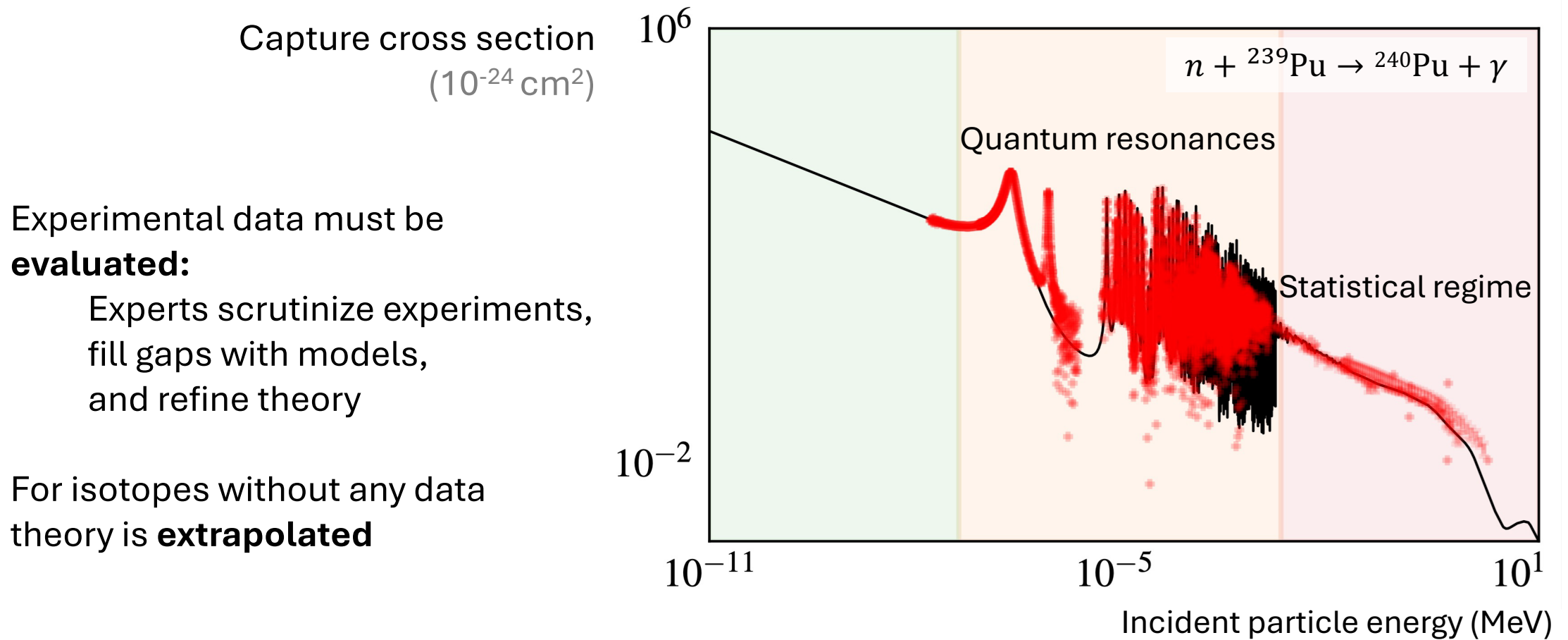
Deuteron



Alpha

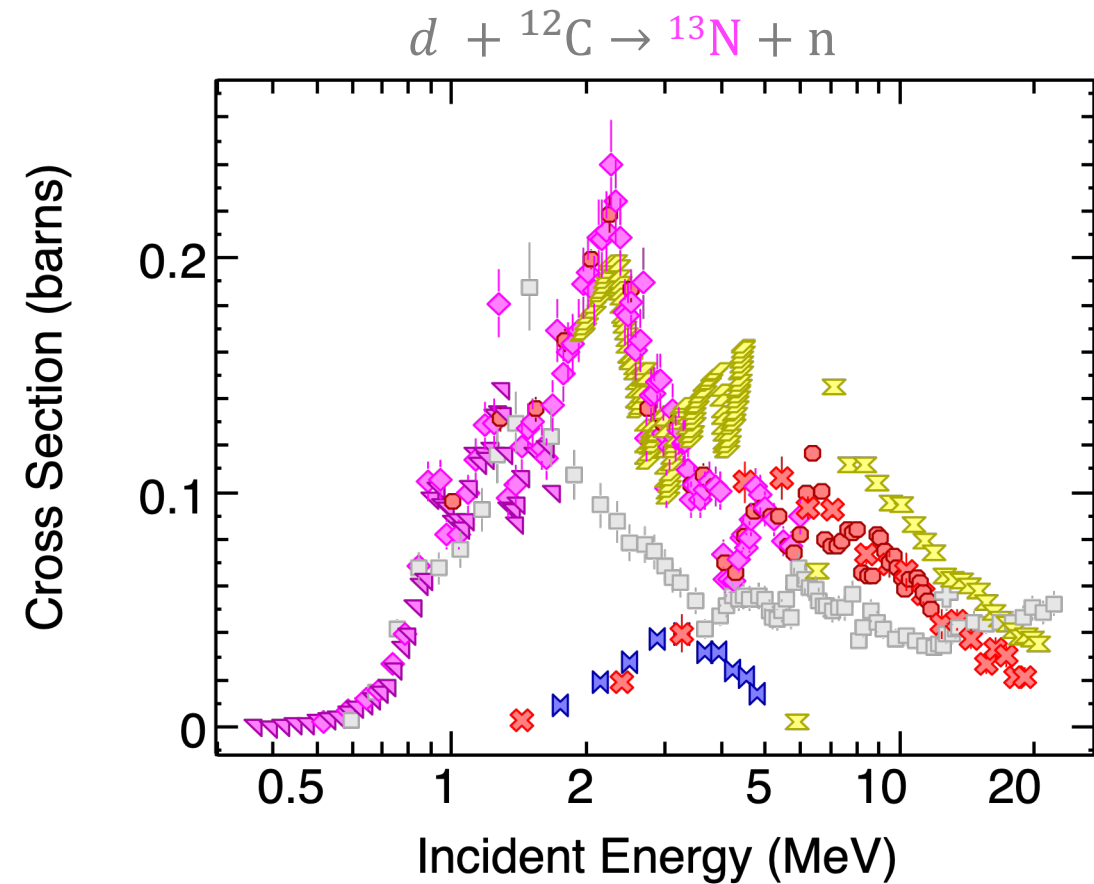
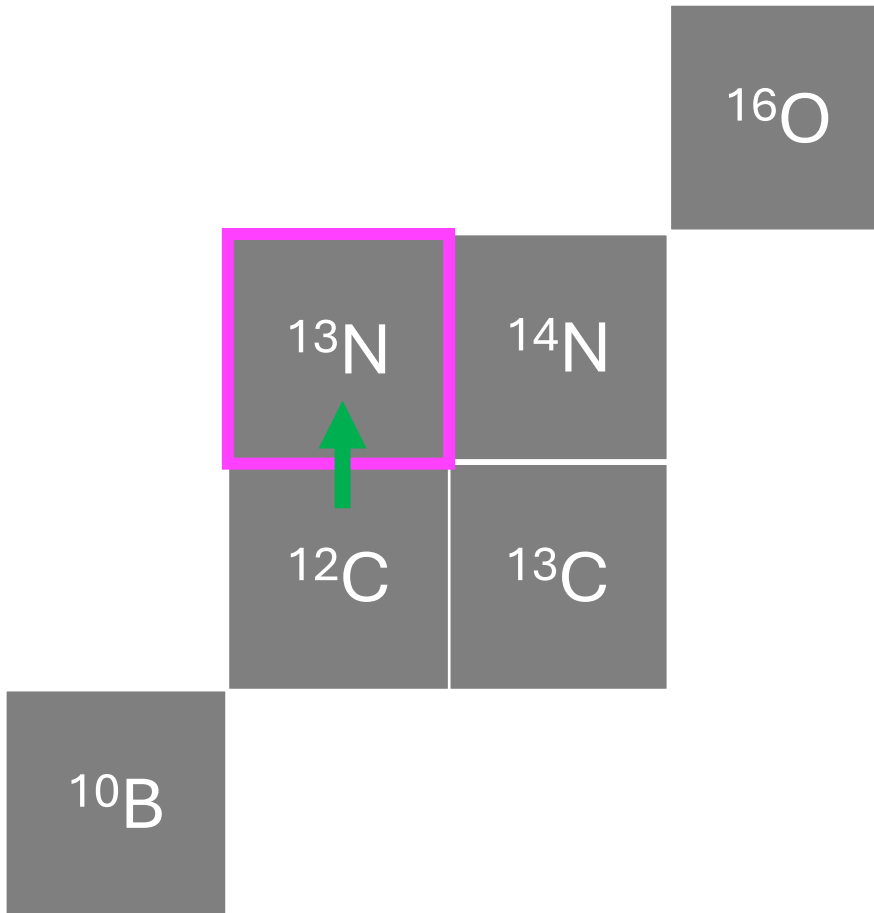


Nuclear reactions have *complex energy dependence*

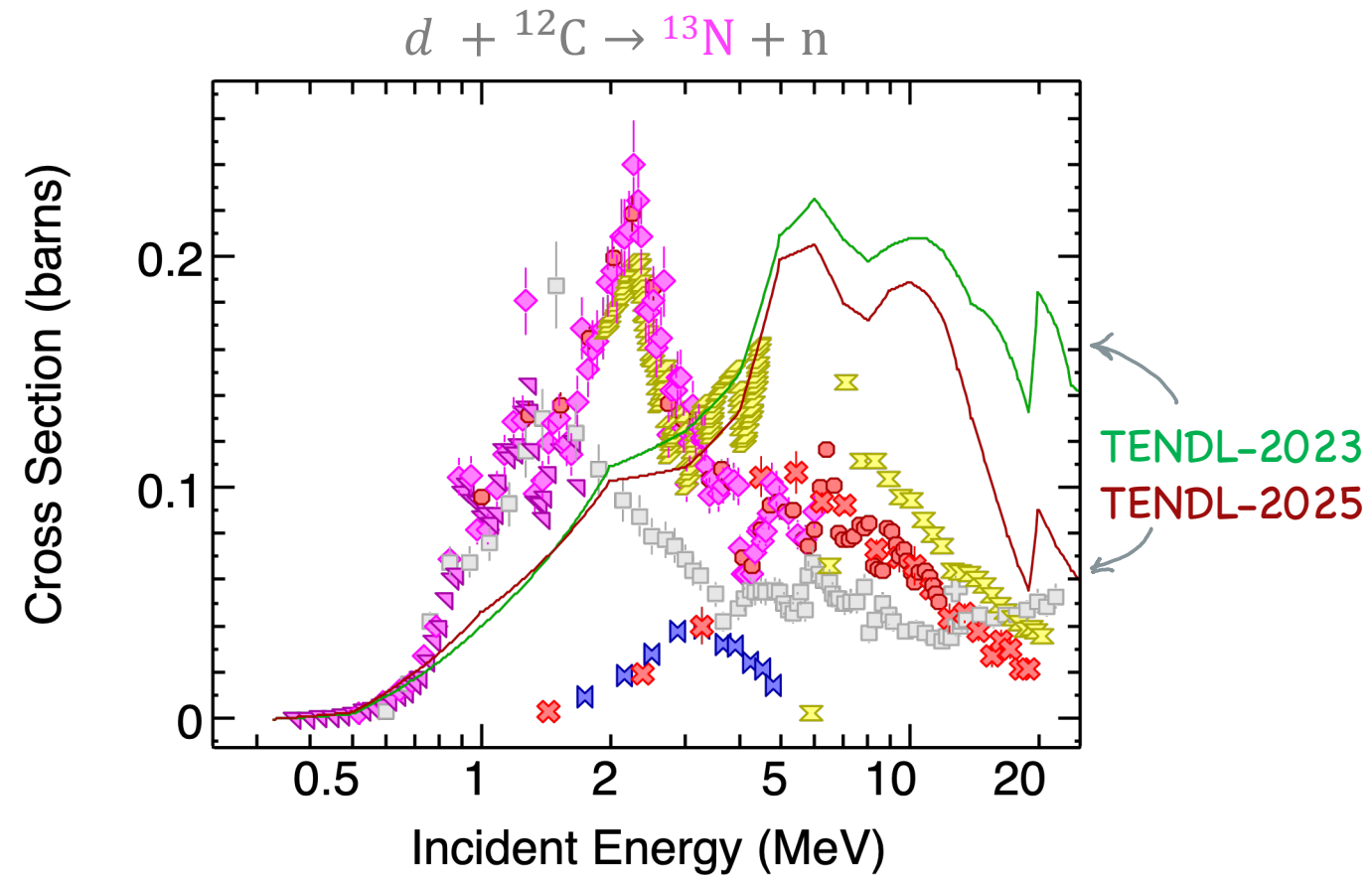
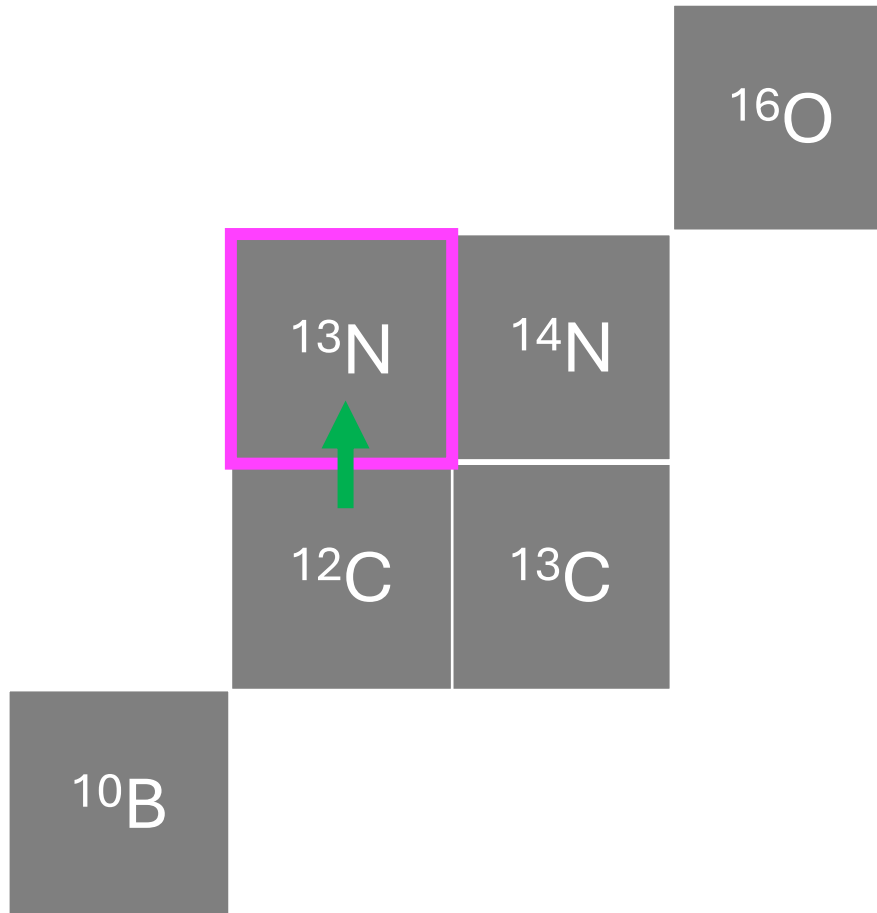


Nuclear data must be evaluated by experts to produce a continuous curve for simulations

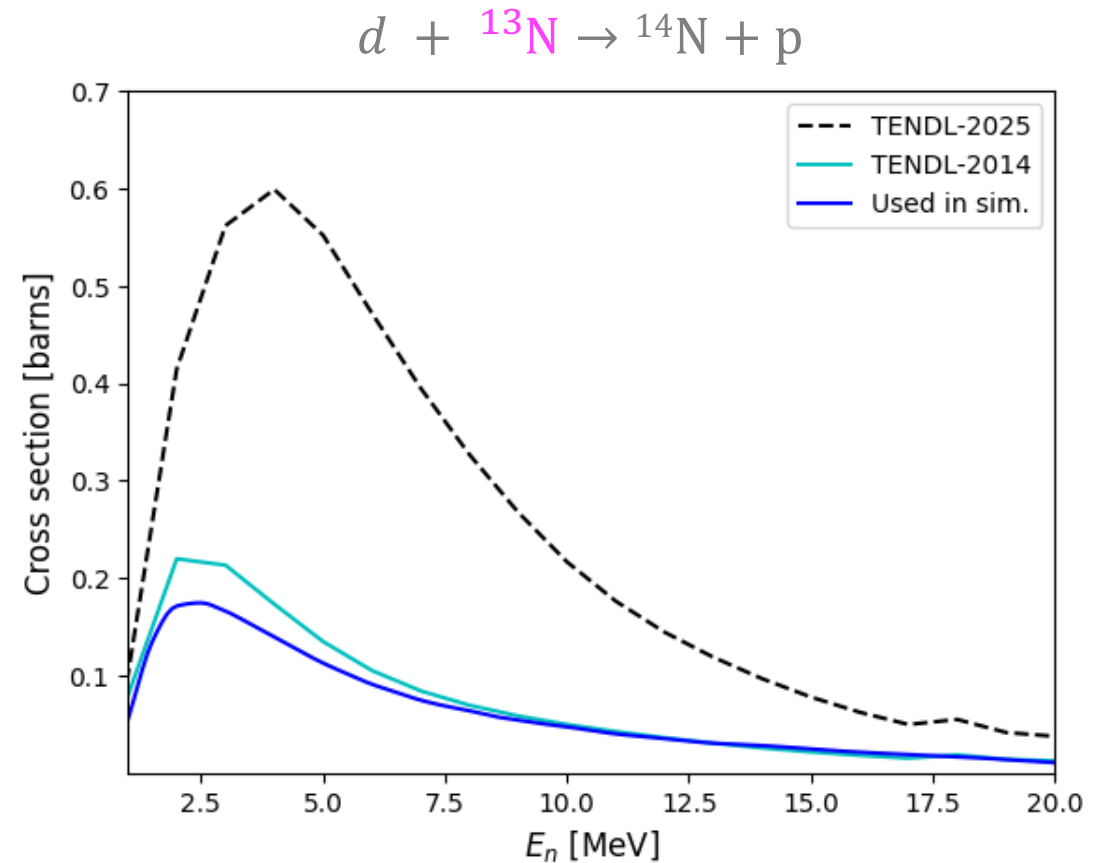
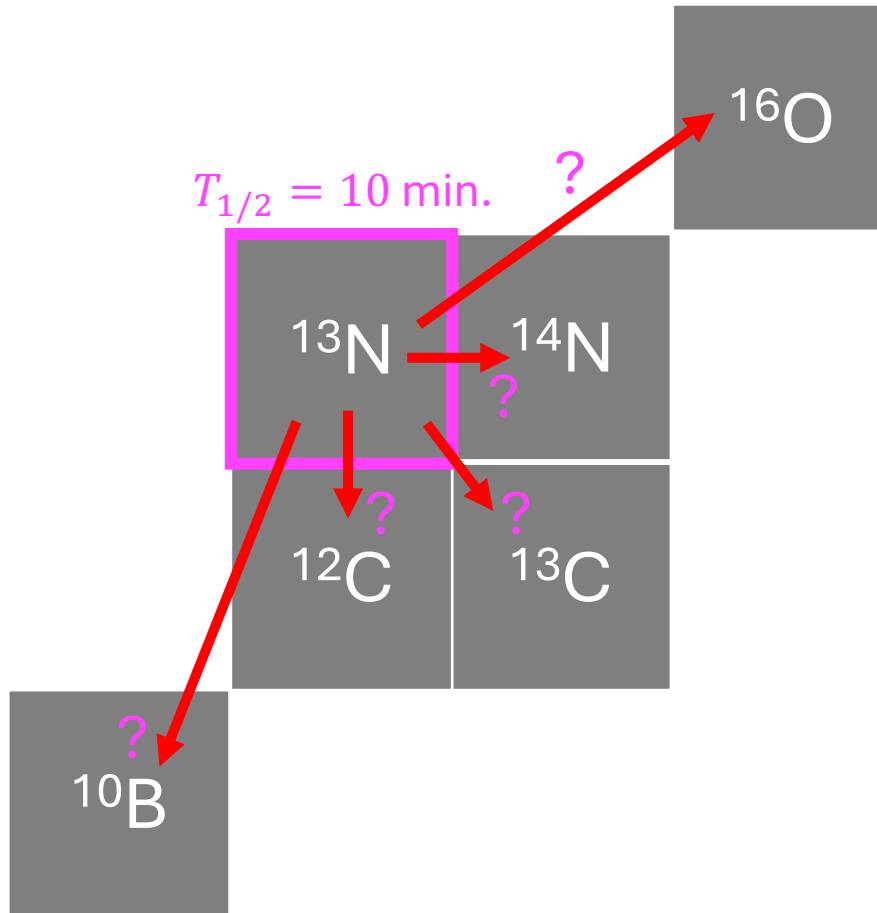
Experiments must be scrutinized by experts: Different sources do not always agree



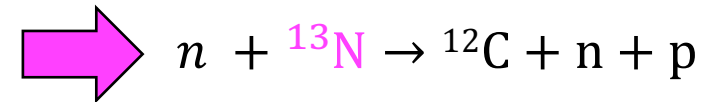
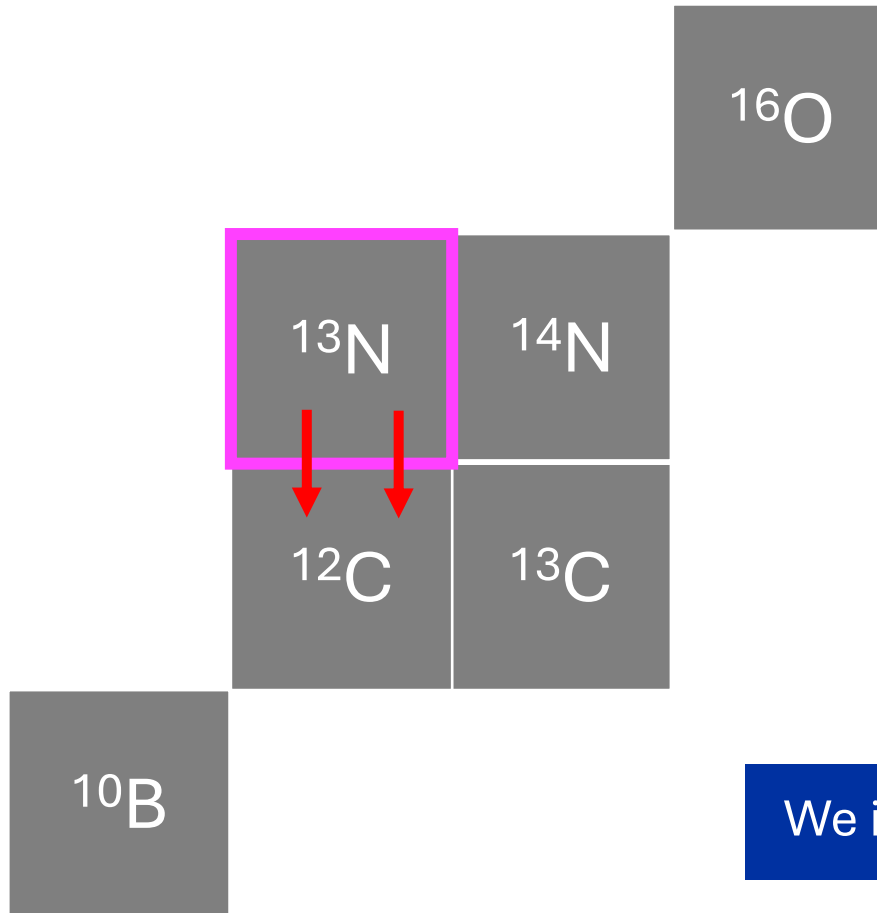
Published models can be out of date, or just wrong



Short-lived isotopes usually have no data!
Such is the case for ^{13}N



The network may be incomplete



We identified an additional reaction missing from the existing network

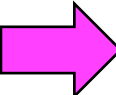


(Re)evaluating reaction data for ^{13}N production/destruction

- ✓ Identify relevant reactions – and – (✓) identify missing reactions
- ✓ Assess availability/quality of data, eliminate low-quality data
- ✓ Assess quality of available calculations, identify questionable models
- (✓) Apply appropriate models (if available) and adjust parameters
- ☐ Develop models where needed – or – (✓) interpolate (workaround)
- ☐ Determine credible uncertainty ranges

We will use new reaction evaluations to better quantify ^{13}N production and uncertainty for mix campaign

Area 2 Re-assessing GRH diagnostic for mix

Diagnostic	Physics	Limitations
Down-scatter ratio (DSR)	Change in areal density ρR	Indirect
<u>X-ray spectroscopy</u>	Dopants fluoresce if enter hotspot	X-ray background at high yield
<u>X-ray radiography</u>	Mix-width via radial optical depth	X-ray background at high yield
 <u>Gamma reaction history (GRH)</u>	Nuclear reactions produce gammas	Requires clean gamma signal
<u>Radiochemistry</u> (RadChem)	Nuclear reactions produce isotopic signature	Collection efficiency, reliability of nuclear data



Andrew Ratkiewicz

“Carbon-based GRH diagnostic for mix may be viable in the future, contrary to current assumptions”

Simulations in 2021 study* relied on data that are now obsolete

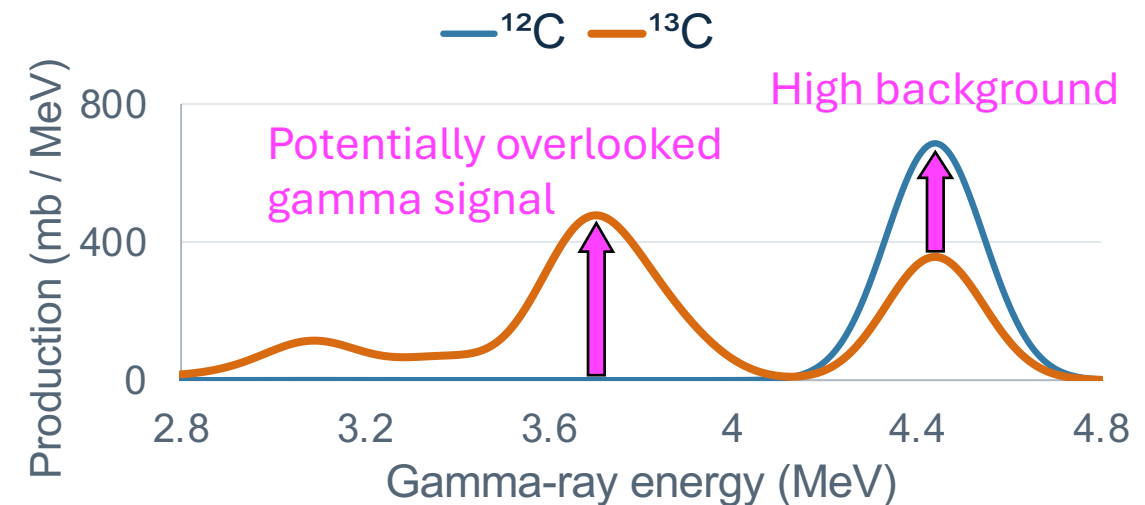
GRH records gamma-intensity in predefined energy band.

McEvoy 2021* showed high background for known 4.4 MeV line

New gamma-line data now available:

Simulations needed to test viability of new energy band(s)

Positive result would justify a new test measurement **onsite**



Carbon-based GRH diagnostic for mix may be viable in the future; new simulations needed

Area 3 Rehabilitating RadChem modeling and simulations

Simulating NIF shots and ^{13}N production considering different:

- models for mix
- nuclear reaction network inputs

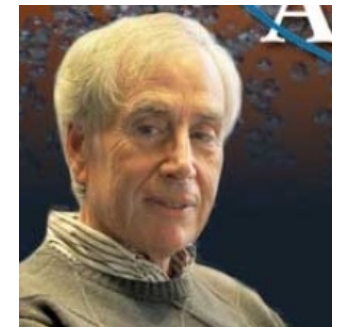
Establishing priorities for nuclear data which most impact the network

Revitalizing capabilities: code transitions + lack of RadChem users → atrophy

- nuclear data libraries and their processing codes:
Legacy ASCII files → GNDS + FUDGE
- multi-generational, multi-physics code ecosystem



Oliver Gorton



Charles Cerjan

Additional details in classified addendum

“We are working with code developers on multiple fronts to revitalize RadChem modeling capability to study mix at the NIF”



Initial analysis of charged particle reactions as a mix diagnostic for high-yield NIF implosions

Area 1 Critical analysis and re-evaluation of RadChem data:

We will use new reaction evaluations we develop to better quantify ^{13}N production and uncertainties for the Dark Mix campaign

Area 2 Prospects for GRH diagnostic for mix :

Carbon-based GRH diagnostic for mix may be viable in the future, contrary to current assumptions

Area 3 Rehabilitating RadChem modeling and simulation capabilities:

We are working with code developers on multiple fronts to revitalize RadChem modeling capability to study mix at the NIF



When we reach 100MJ, how will we know if mix was the cause of a lower-than-expected yield?

✖
✖
✖
TBD
✔

Diagnostic	Physics	Limitations
Down-scatter ratio (DSR)	Change in areal density ρR	Indirect
<u>X-ray spectroscopy</u>	Dopants fluoresce if enter hotspot	X-ray background at high yield*
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Rebuilding RadChem data and modeling for ¹³N now ensures this core competency is ready for EYC/HYF

ICF RadChem analysis team (est. June 2026)



Jutta Escher
Principal Investigator,
RadChem data and theory



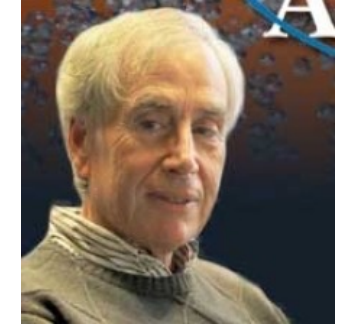
Aaina Thapa
RadChem data and theory



Andrew Ratkiewicz
Gamma-ray data,
simulations



Oliver Gorton
Modeling and simulations,
data infrastructure

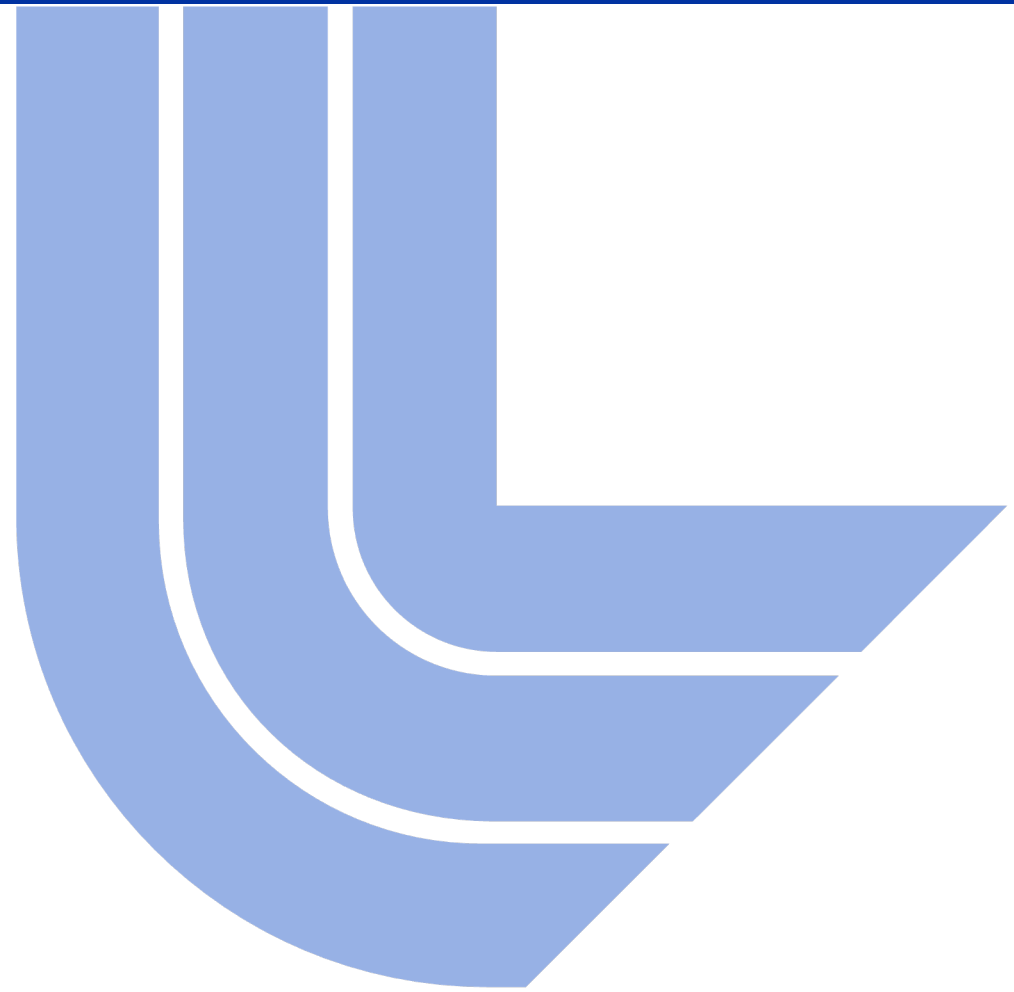


Charles Cerjan
Senior Advisor,
Modeling and simulations

Big thanks to:

- **Alastair Moore** and **Dave Schlossberg** for supporting this work and valuable feedback
- **Seth Davidovits** for sharing presentation materials
- **Rob Hoffman** for information on the earlier nuclear reaction data (2015)
- **Jack Bolster** (PD) for useful discussions

UNCLASSIFIED



Backup slides follow **(not for distribution)**