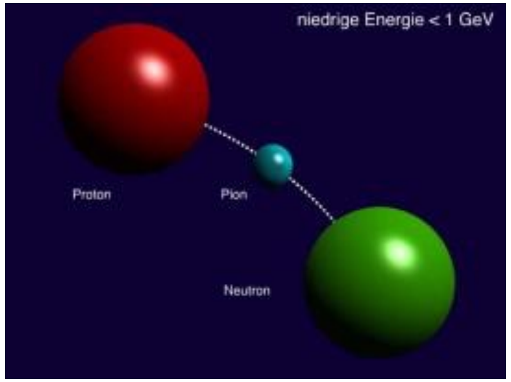
Two and Three-body Photodisintegration of the Triton at energies below 30 MeV

TUNL

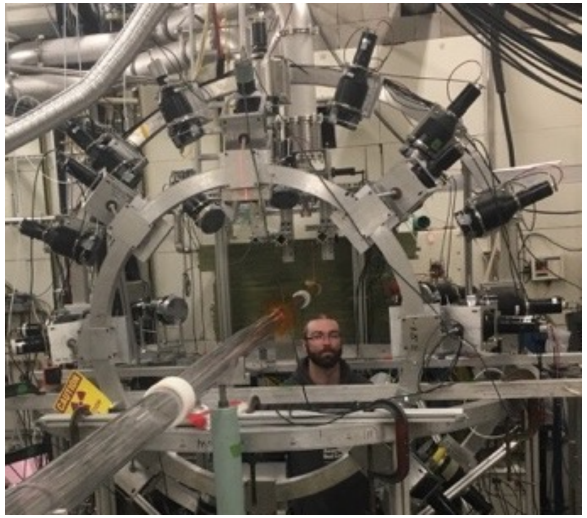


Collaborative research project

Duke University/TUNL
and
University of Rochester/Laboratory for Laser Energetics

Annual Progress Report

The Department of Energy, Office of Science
Nuclear Data Interagency Working Group
(NDIAWG)
Grant Number: DE-SC0022573



Project Period: July 1, 2022 – June 30, 2025

Duke University and TUNL
PI: Calvin R. Howell

Univ. of Rochester and LLE
Co-PI: Chad Forrest

By: Calvin R. Howell,
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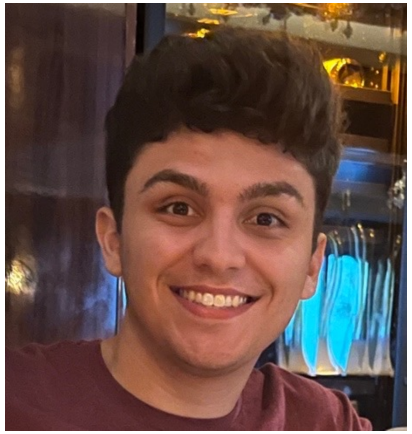

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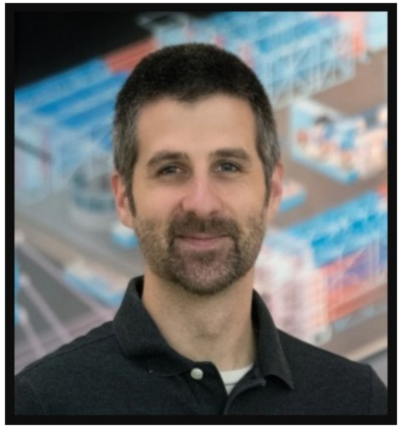

Matthew Sharpe
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Mark Wittman
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Project Objectives

Science Motivations:

- **Modernize the nuclear database** for photodisintegration of tritium: add differential cross sections for 2-body and 3-body photodisintegration of tritium.
- **Study** of low-energy neutron-neutron scattering
- **Provide opportunities for students and young scientists** to gain experience in experimental techniques used in measurements of photon-induced nuclear reactions on a tritium target.

Capabilities Developments:

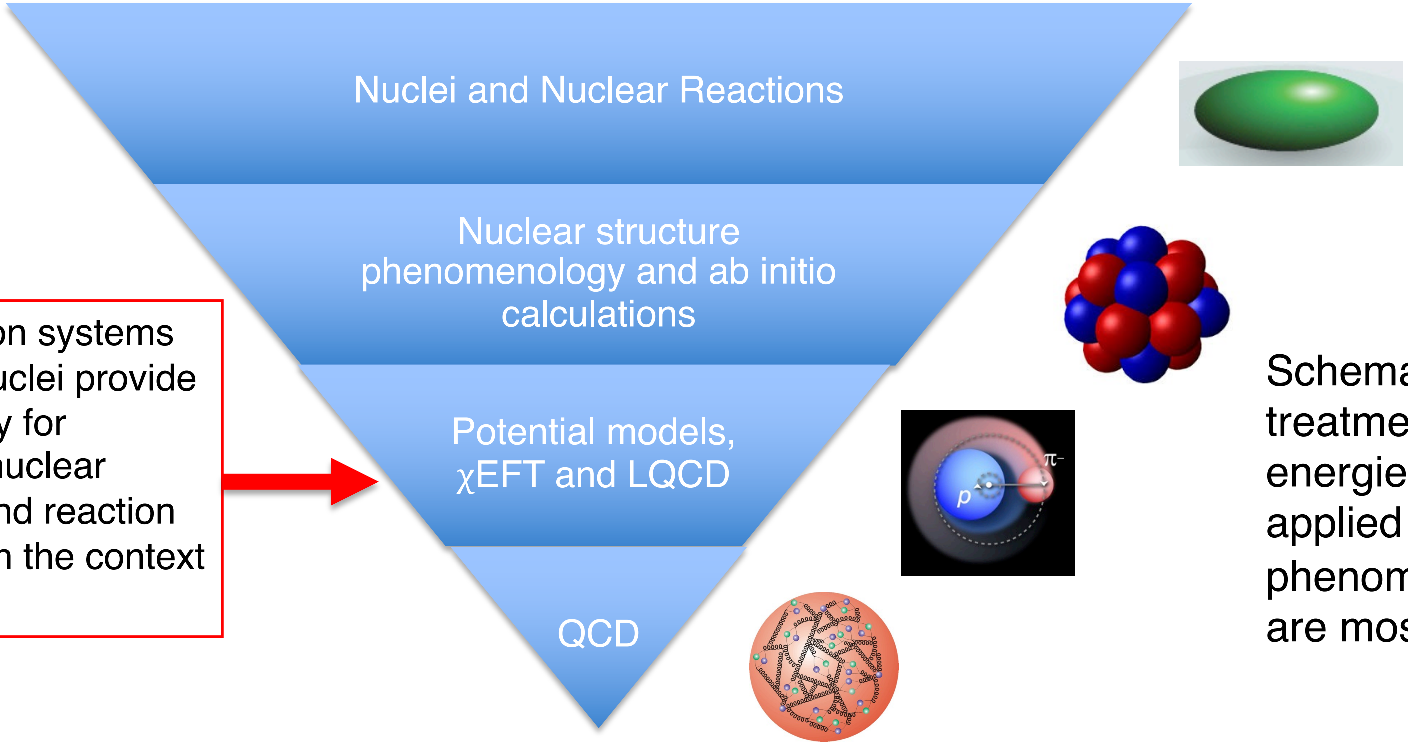
- **Upgrade the radiation safety infrastructure** and develop safety procedures at TUNL for safe handling of sealed tritium gas targets for use in measurements of photon-induced reactions.
- **Develop expertise at TUNL** for safe management of sealed tritium targets and use in nuclear-physics research in accordance with NRC regulations and safety standards at Duke University.
- **Develop experimental techniques** and setups for measuring cross sections of photodisintegration of tritium.

Science: Few-Nucleon Research

US 2023 Nuclear Science LRP: WHAT IS THE NATURE OF THE NUCLEAR FORCE?

“Ultimately, an accurate description of the nuclear force is needed for a precise and predictive theory of nuclei ... A challenge for the forthcoming decade is to make these lattice calculations accurate enough that they provide meaningful constraints and to connect them, via effective field theories, to microscopic calculations of nuclear structure and reactions, thus enabling predictions more firmly grounded in QCD.”

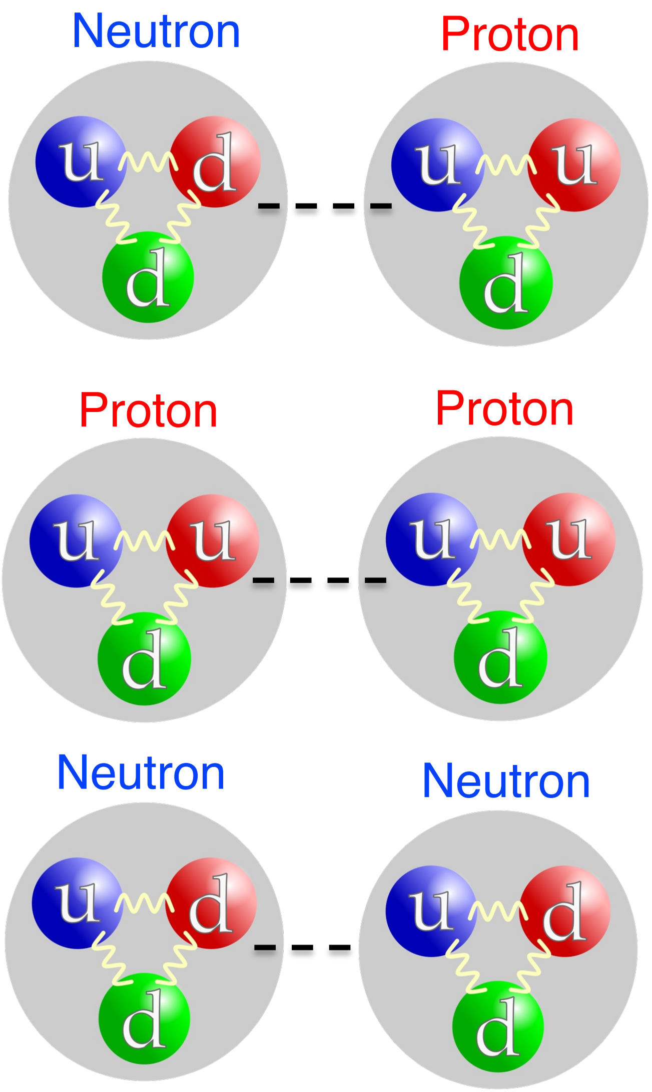
Hierarchy of theoretical treatments of nuclear systems

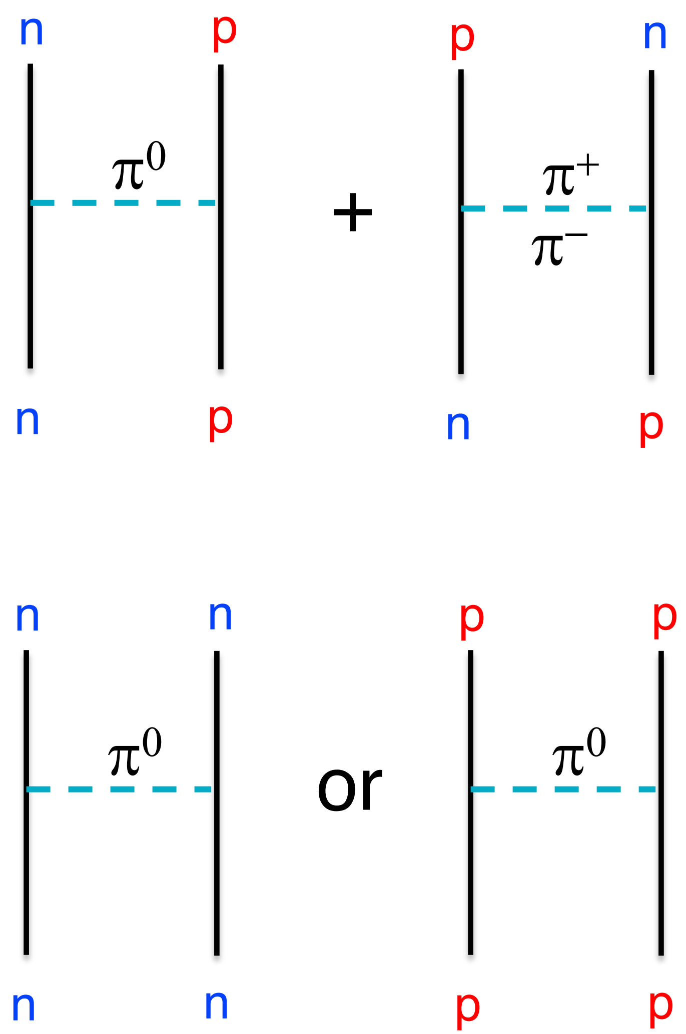


Few nucleon systems and light nuclei provide a laboratory for analyzing nuclear structure and reaction dynamics in the context of QCD.

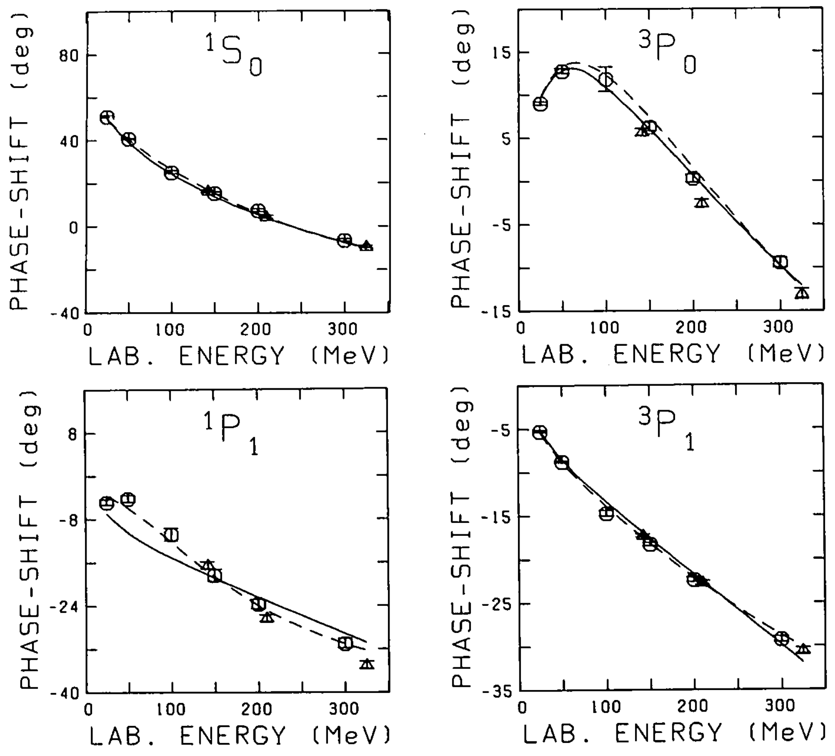
Schematic diagram for coherent theoretical treatment of nuclear systems starting from high energies where perturbative QCD can be applied going to low-energy nuclear phenomena where mean-field potential models are most efficient.

Science: Nucleon-Nucleon Interaction - charge dependence





R. Machleidt, K. Holinde and Ch. Elster, Phys. Rep. 149, 1 (1987).



$$\nabla V = V_{nn}^{N} - V_{pp}^{N}$$

Due to u-d mass difference
and
Difference in EM interactions

Science: World data on a_{nn}

Reactions used to determine a_{nn}

(1) $\pi^- + d \rightarrow n + n + \gamma$

(2) $n + d \rightarrow n + n + p$

Proposed Reactions to determine a_{nn}

(3) $\gamma + {}^3H \rightarrow n + n + p$

(4) $\mu^- + d \rightarrow n + n + \nu_\mu$

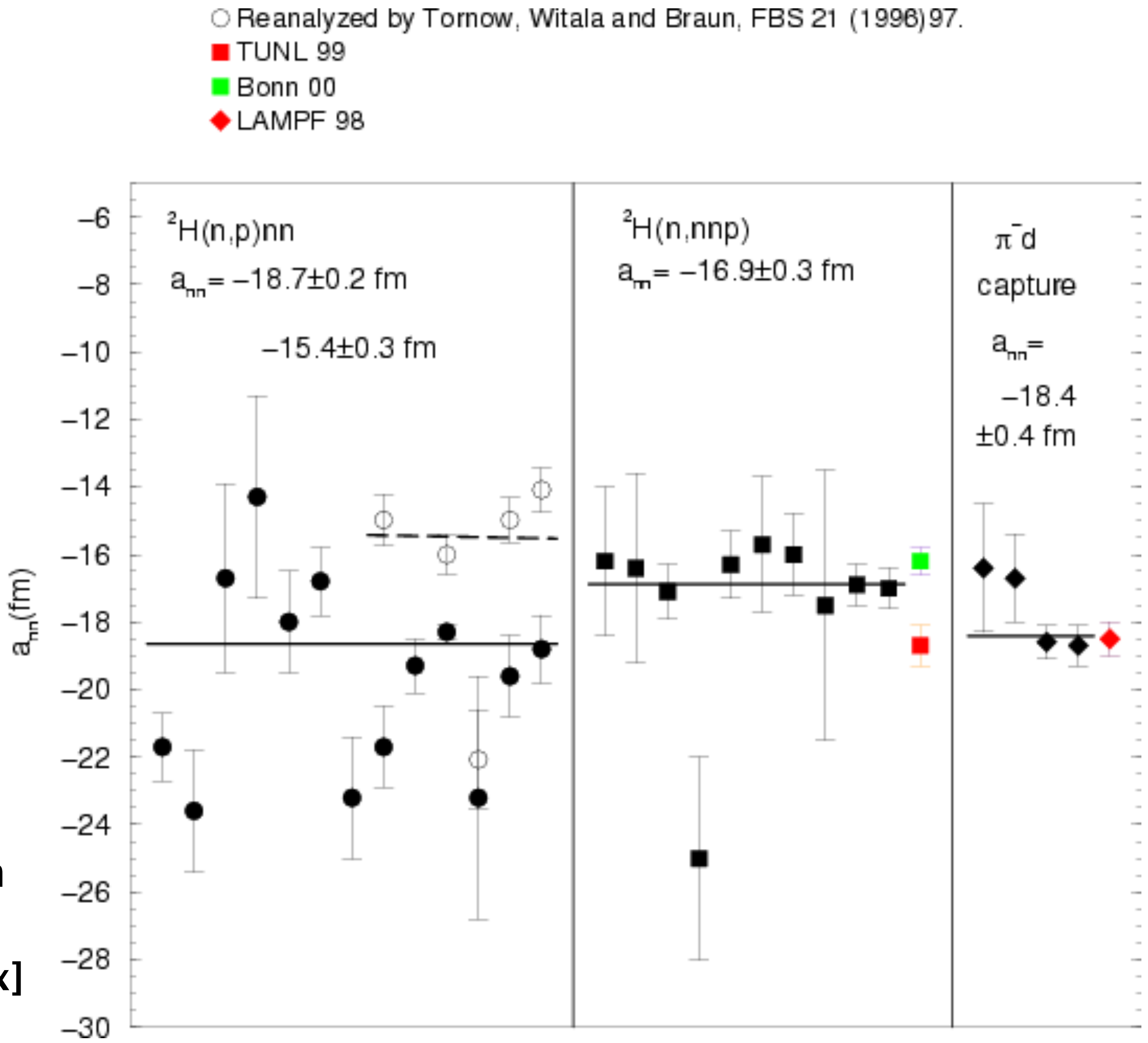
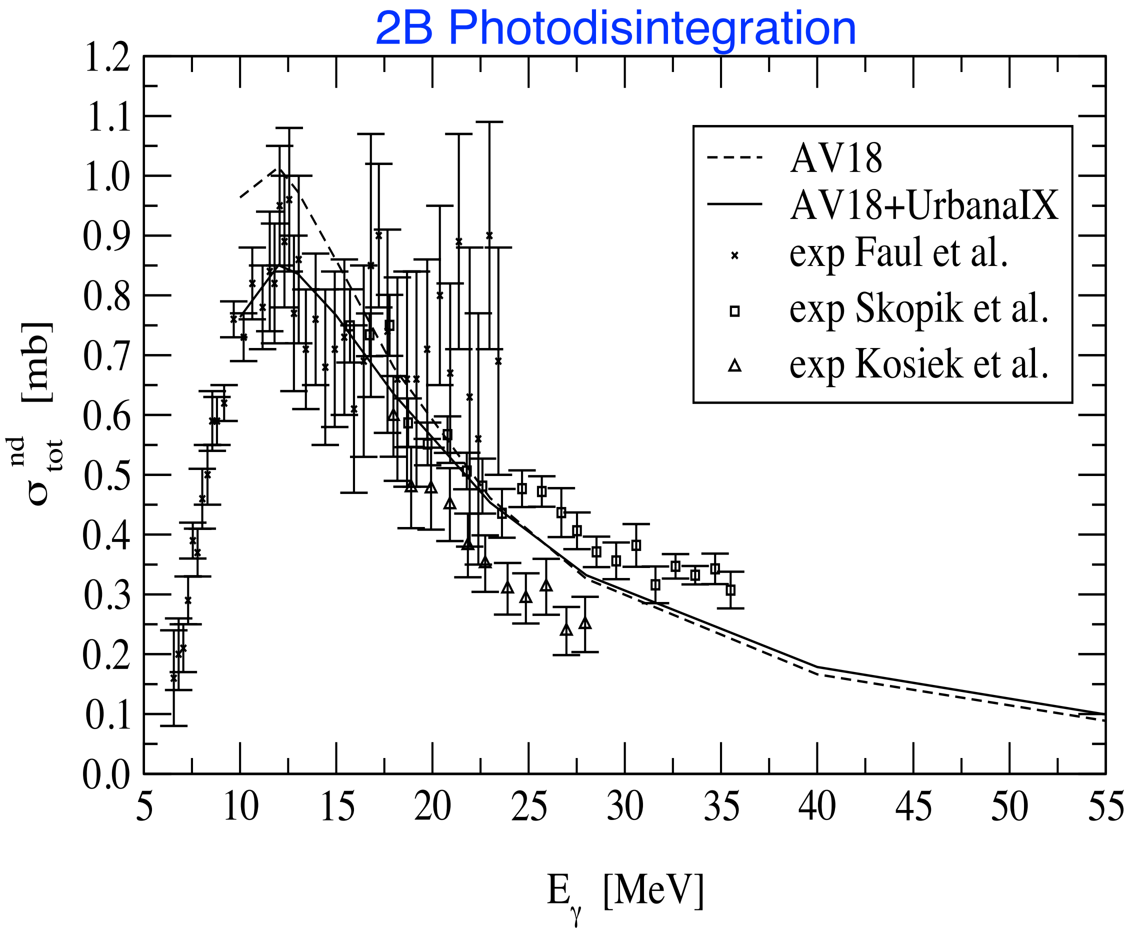
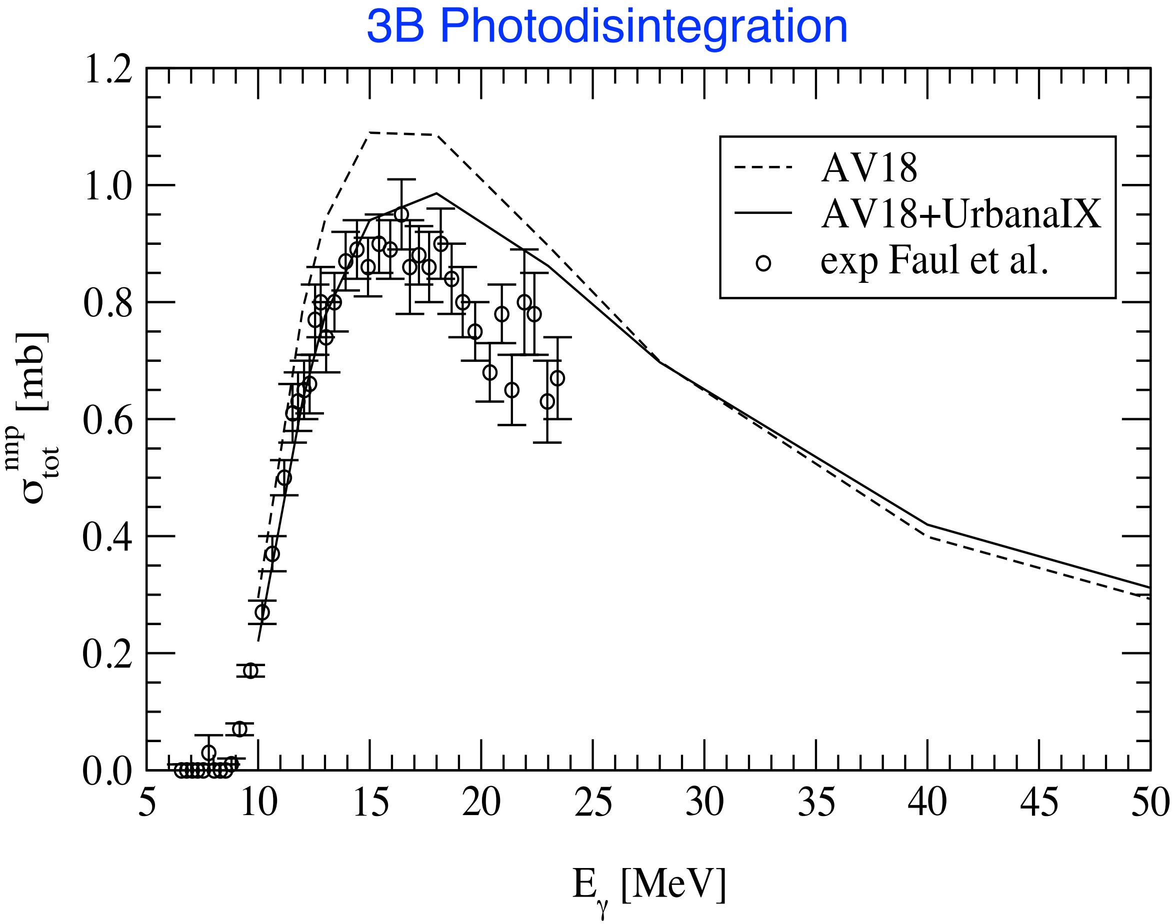


Figure made from table in C.R. Howell, arXiv:0805.1177 **[nucl-ex]**

Science: World data on ^{3}H photodisintegration





D.D. Faul *et al.*, Phys. Rev. C **24**, 849 (1981): LLNL; e+ annihilation beam; E_γ < 25 MeV; moderated BF_3 neutron detectors; 200 kCi gas target

D.M. Skopik *et al.*, Phys. Rev. C **24**, 1791 (1981): U. Saskatchewan; ^{3}H(γ, d) at E_γ = 15 – 36 MeV (bremsstrahlung); TiT (2 Ci) foil

R. Kosiek *et al.*, Phys. Lett. **21**, 199 (1966): U. Heidelberg; ^{3}H(γ,d) at E_γ = 17 – 31 MeV (bremsstrahlung); 191 Ci gas target

Science: ^{3}H Photodisintegration - Impact

$\gamma + {}^3H \rightarrow n + n + p$ (3-body photodisintegration)

$\gamma + {}^3H \rightarrow n + d$ (2-body photodisintegration)

- **First double differential cross-section measurements of 3-body photodisintegration of ^{3}H**
  - ❑ evaluate theory treatment of nucleon interactions and meson exchange currents in 3-nucleon system w/o complication of the Coulomb force
  - ❑ First determination of the $^1S_0$ neutron-proton scattering length with this reaction (probe long-range 3-nucleon interactions)
  - ❑ First determination of the $^1S_0$ neutron-neutron scattering length with this reaction
- **First angle differential cross-section measurements of 2-body photodisintegration of ^{3}H**

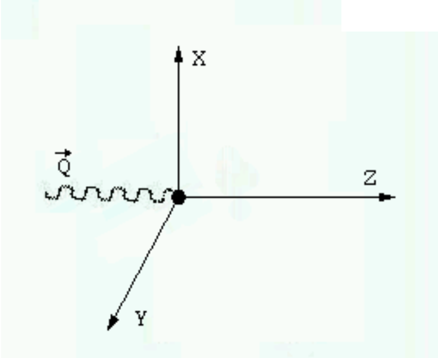
$$H \equiv H_0 + \sum_{i=1}^{3} V_i + V_4 .$$

$$\mathcal{L}_{int}(x) = j_\mu(x) A^\mu(x).$$

$$\vec{\nabla} \cdot \vec{j}_\mu^{\,1} + i[H_0, \rho(\vec{x})] = 0$$

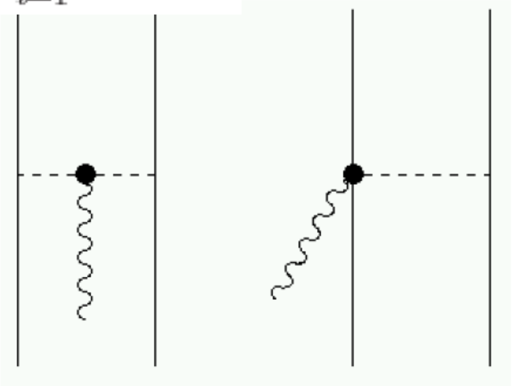
$$\vec{\nabla} \cdot \vec{j}_\mu^{\,2} + i[V, \rho(\vec{x})] = 0 .$$

$$j_\mu^2 = j_\mu^{2,\pi} + j_\mu^{2,\rho} .$$



1 body

+



2 body

+ [3-body MEC]

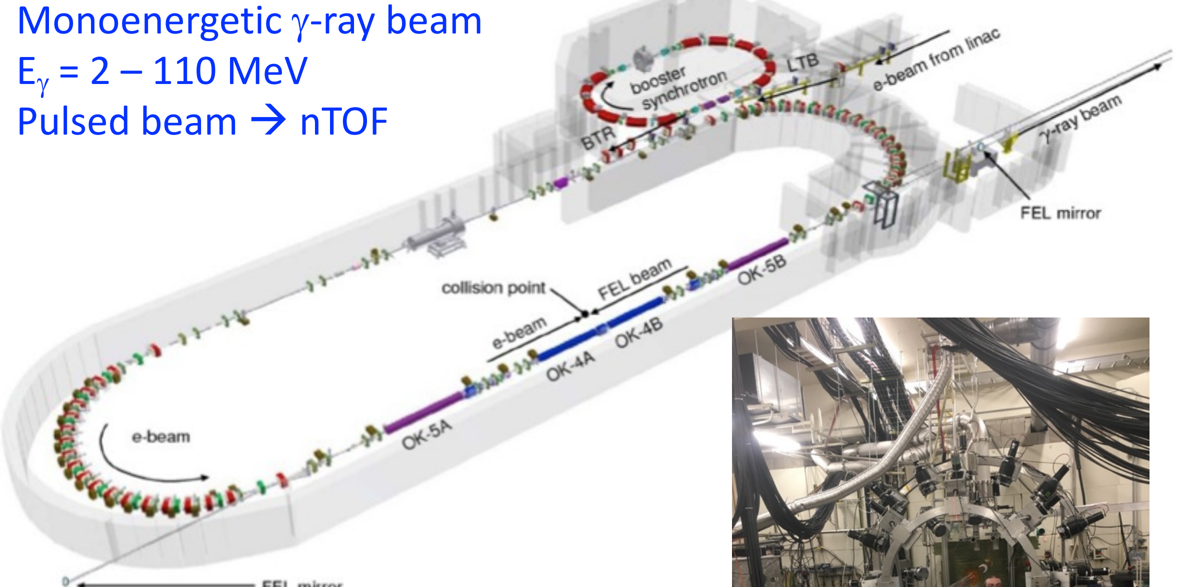
Project enabled by complimentary facility capabilities and technical expertise

TUNL

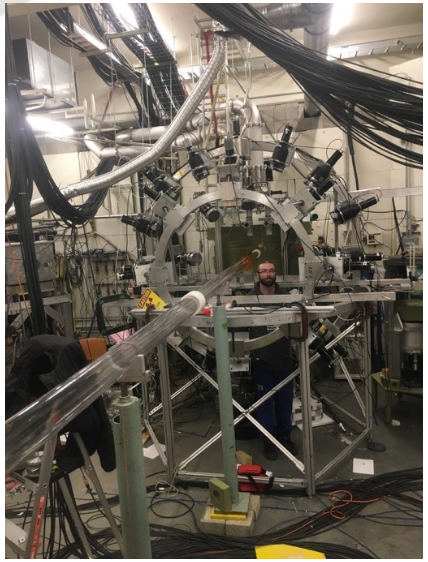
Triangle Universities Nuclear Laboratory (TUNL)

(1) High Intensity Gamma-ray Source (HIGS)

- Monoenergetic γ-ray beam
- E_γ = 2 – 110 MeV
- Pulsed beam → nTOF



(2) Neutron TOF Spectroscopy



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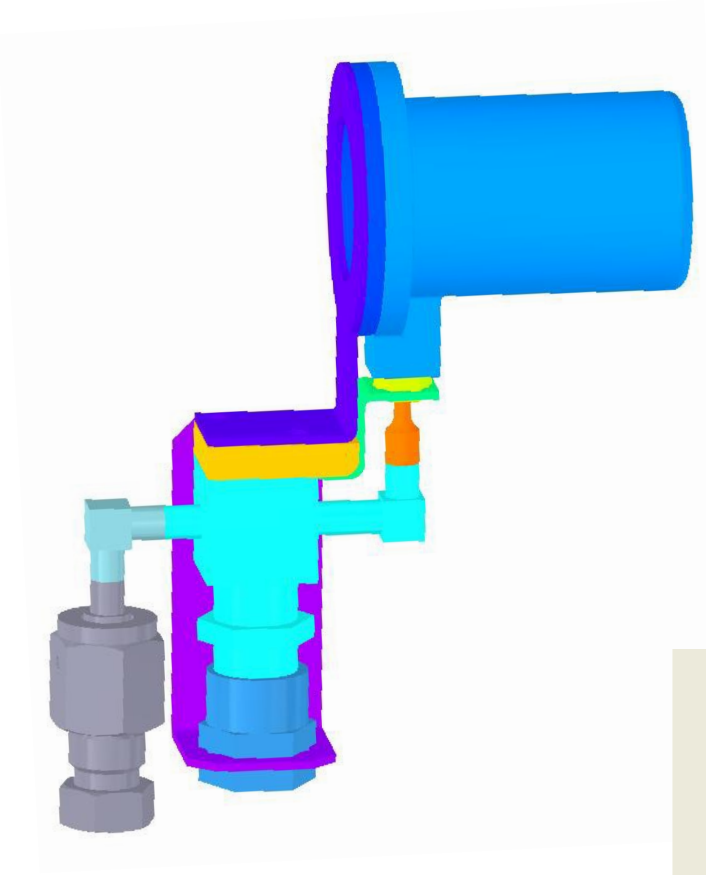
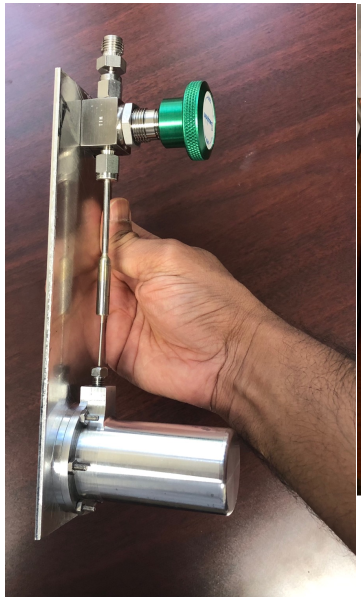
University of Rochester (UR)
Laboratory for Laser Energetics (LLE)

(1) Infrastructure for handling tritium gas inventory
(2) Expertise in fabricating and handling tritium targets for fusion and nuclear-physics research
(3) Expertise Neutron TOF Spectroscopy

- Measurements at HIGS
- Sealed gas target provided by UR/LLE
- Tritium safety systems and training at TUNL by UR/LLE experts

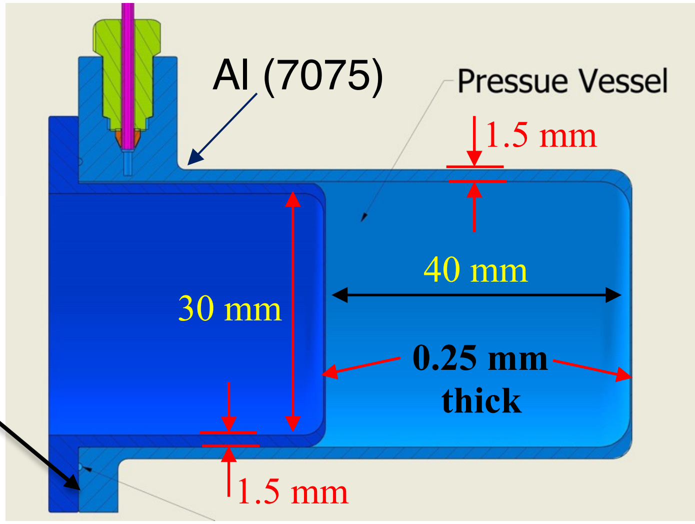
TDR: Tritium target cell design finalized, components fabricated and tested





Target cell active volume:
Diameter = 30 mm
Length = 40 mm
Wall thickness = 1.5 mm
Window thickness = 0.25 mm
Pressure = 13.6 atm
Activity = 990 Ci

Flange with gold o-ring



<u>Target cells are:</u>

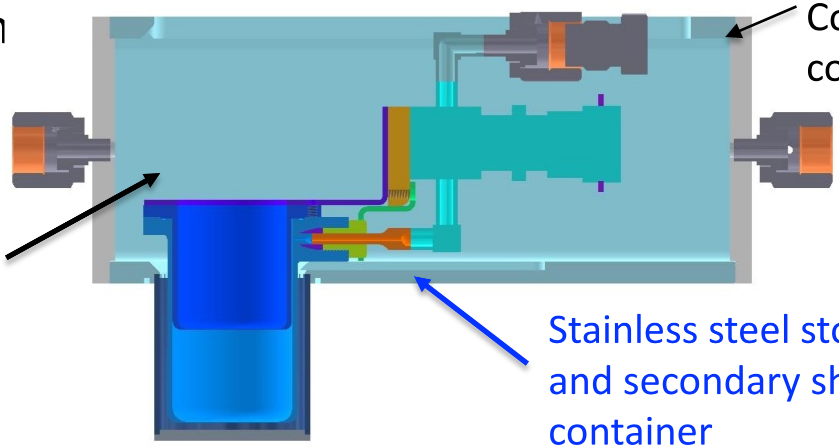
- Engineered at TUNL
- Fabricated and assembled at TUNL
- Pressure tested at TUNL (to 400 psi = 14.2 atm)
- Rupture tested up to 1000 psi (2 cells tested; no failures)
- Design review by independent engineer
- Meets ASME pressure vessel standards
- Filled at the LLE/UR

TDR: Target Management Strategy

Filled at UR/LLE → TUNL (sealed source)

- Final target cell assembly and evaluation
- ^{3}H gas diffusion measurement
- Fill target cell
- Ship target cell to TUNL (sealed source) in Type-A shipment container
- Oversight of installation of tritium radiation safety systems at TUNL
- Training Duke radiation safety personnel on operation of tritium safety systems
- Multiple layers of containment

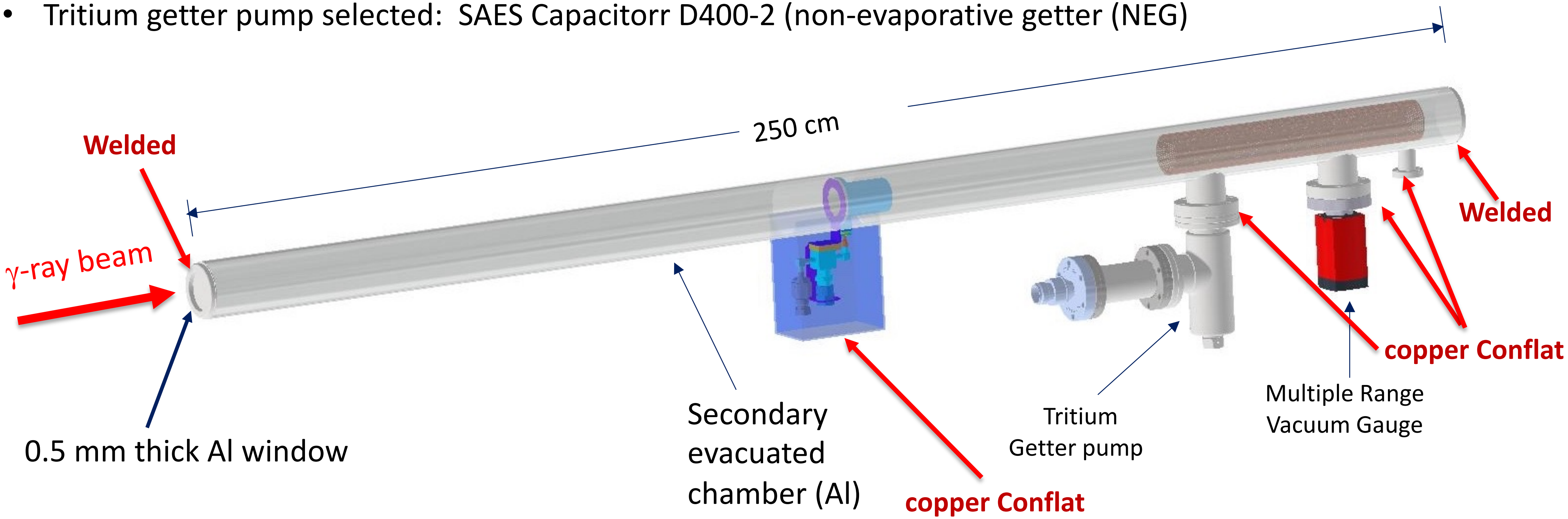
Type-A shipping container



TDR: Tritium Target Setup in Gamma Vault at HIGS

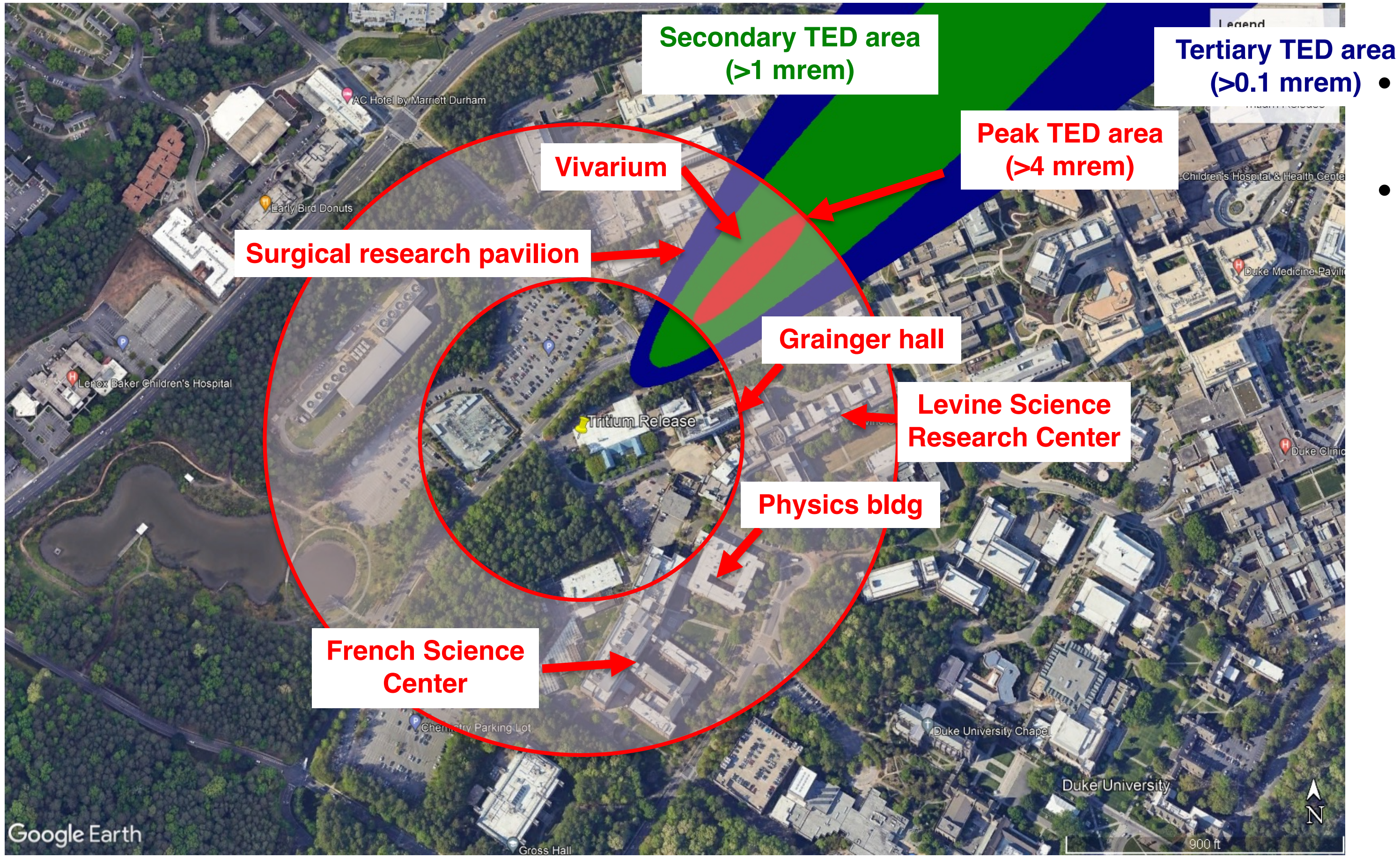
Secondary Containment Chamber

- Design Finalized
- Vacuum gauge selected: *PKR-360 (DN-40 CF-F)*
- Tritium getter pump selected: SAES Capacitorr D400-2 (non-evaporative getter (NEG)



Sum of all fears!!!

Worst case scenario: Release of substantial fraction of the target gas inside the lab at Duke University



- NRC general-public limit = 100 mrem/year = 0.40 μCi/m^3 (HTO)
- 100 Ci released in 24 hours, report to
  - Duke RSO
  - State NRC

Hot spot Input	
Stack height from ground	14.9 m
Exit velocity	3650 CFM
%HTO	100%
Wind speed @ 10-m	1.56 m/s
Atmospheric stability	Moderately stable
Terrain	City/Metropolitan

Coarse Project Timeline

Nov 2023
Finish pressure testing the prototype cells

March 2024
- Present the Technical Design Report to Duke RSO and receive feedback.
- ^3H diffusion measurements at UR/LLE – initial results ready

June 2024
Review of the TDR

July 2024
- Start purchase of equipment for the tritium safety infrastructure
- Submit experiment status update to the HIγS PAC

Aug. 2024
Duke RAM license increased to > 1000 Ci of ^3H

Feb 2025
Tritium radiation safety systems at TUNL: Finish installing and commissioning -- ready to receive the filled target cell

June 2025
First measurements

Thank you