Diamond Anvil Measurement of Muon-Catalyzed Fusion Kinetics

The MuFusE Collaboration

PSI BVR 56 Progress Report

February 11, 2025

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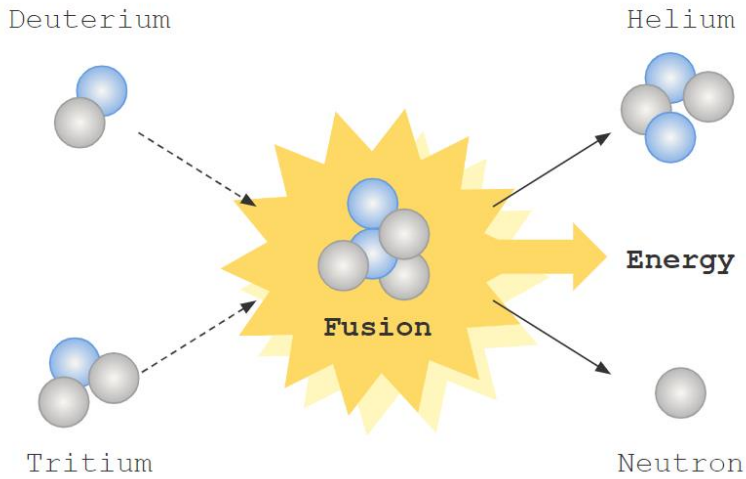
Introduction

Fusion is a safe, abundant source of clean energy

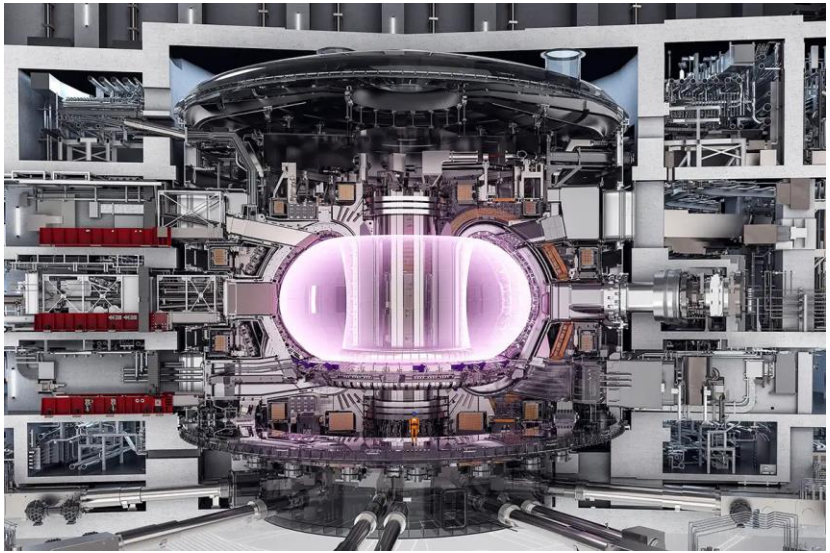
Fusion of the deuterium in a stream of tap water could power a city.

Introduction

Plasma fusion requires stable 100,000,000 °C plasma



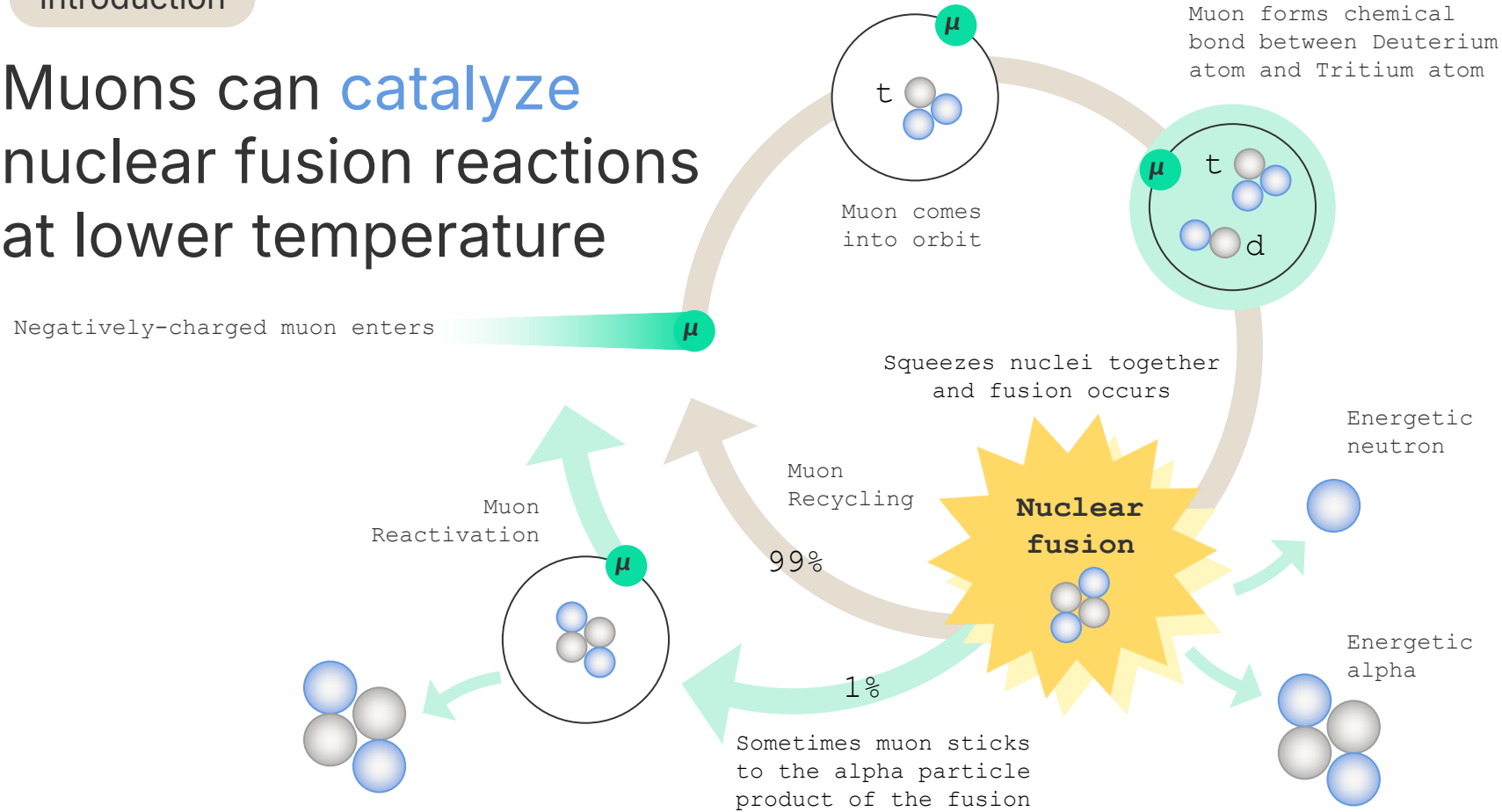
The deuterium-tritium fusion reaction has the highest cross section.



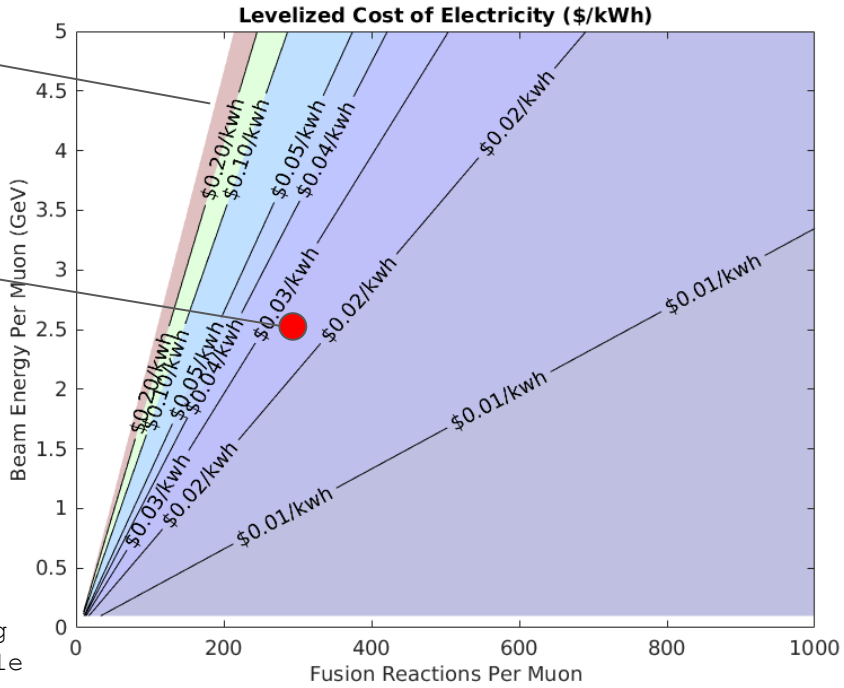
A cutaway view of the ITER tokamak, scheduled to burn DT in 2039.

Introduction

Muons can catalyze nuclear fusion reactions at lower temperature



Cost of electricity versus physics parameters



Engineering breakeven

Target operating point for a reactor

(Using a superconducting accelerator, Brayton cycle balance of plant, and revenue from heat sales.)

Cost of baseload power by source, $/kWh (1)

Coal	$0.089
Biomass	$0.077
Nuclear fission	$0.071
Gas:	$0.043

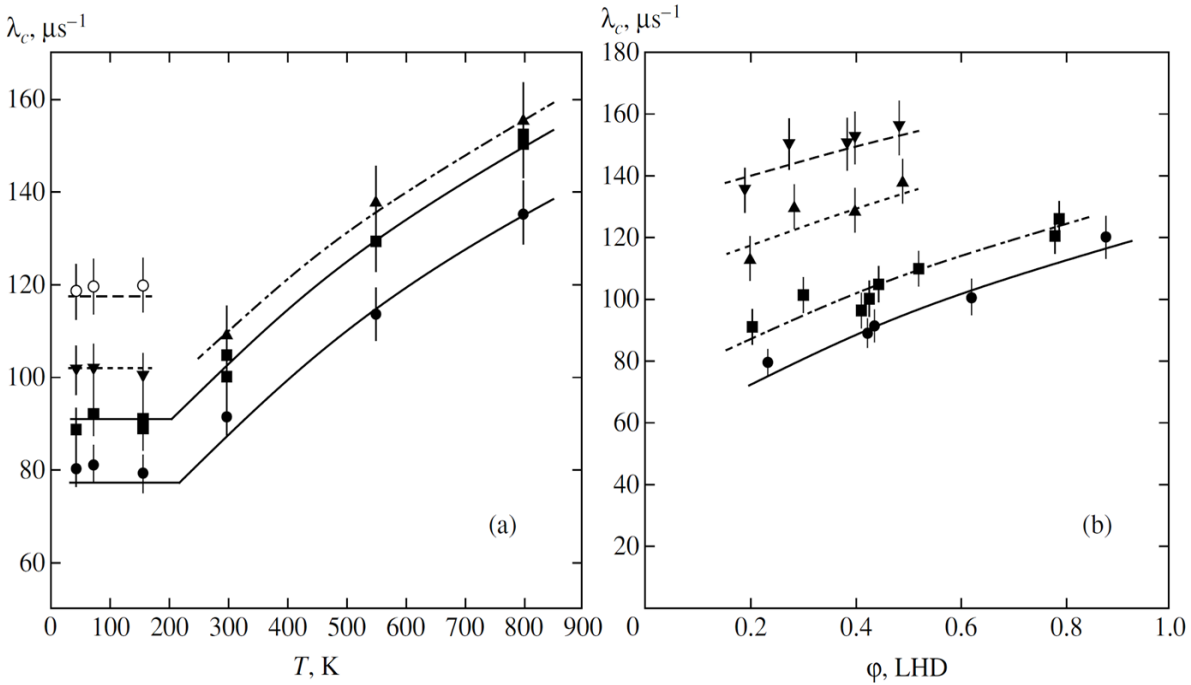
Target operating point:

Fusion (?):	$0.025

(1) Levelized Costs of New Generation Resources in the Annual Energy Outlook 2023, US Energy Information Administration, Document #AEO2023

Background

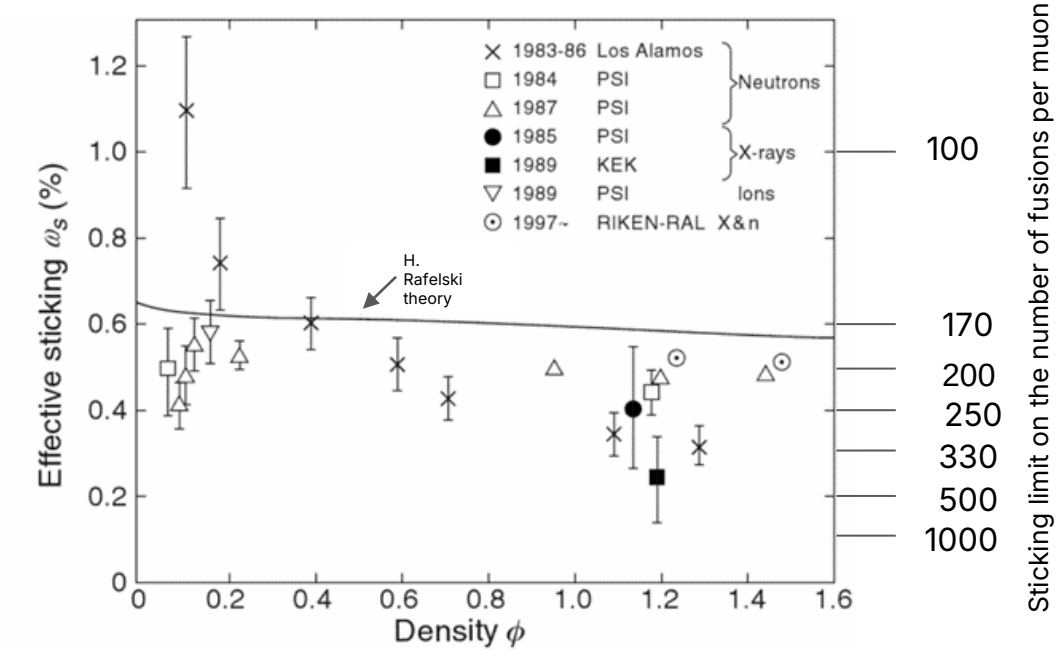
Fusion rate increases with temperature and density



Experimental Data from JINR measurements on DT
Ref: V.R. Bom et. al, JETP, 2005

Background

Sticking may decrease with density



Ref: K. Nagamine, 2008

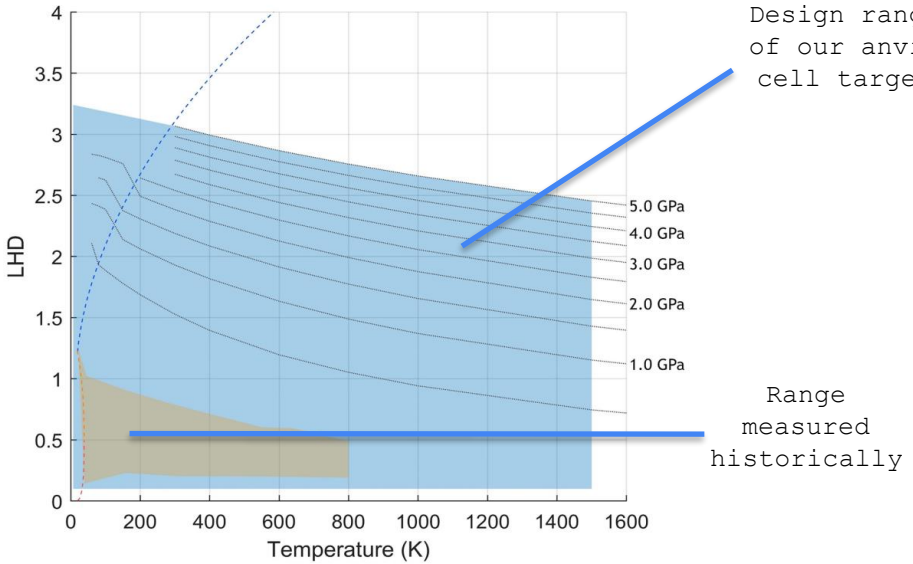
- Both experiment and theory predict that sticking decreases with density.
- Data from four experimental groups is shown.
- At high density, the measured sticking is uniformly lower (better) than predicted by theory
- Density is stated as a fraction of liquid hydrogen atomic number density.

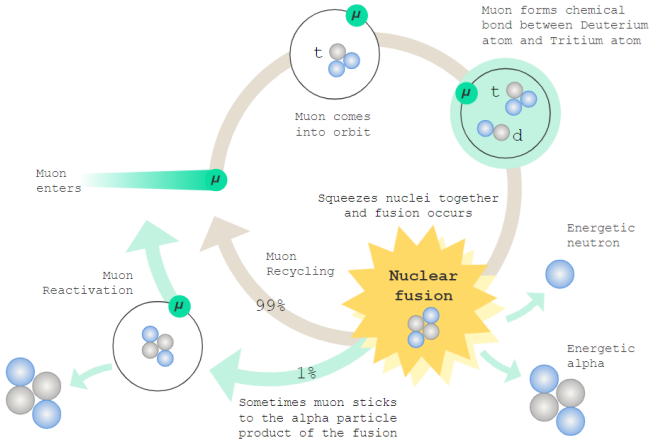
MuFusE — Muon-Catalyzed Fusion Experiment

Goals of our collaboration:

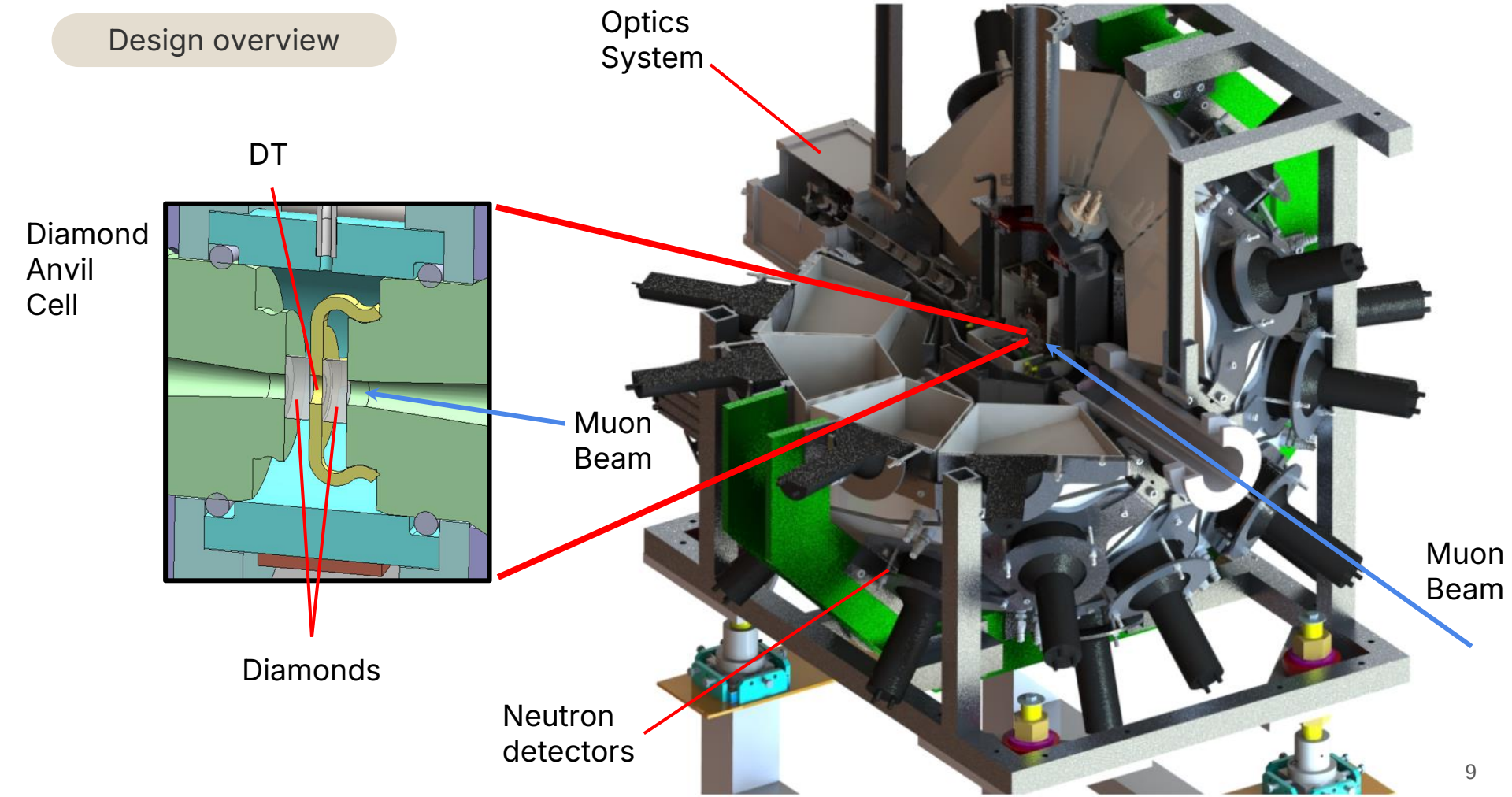
1. Measure DT cycling rate and sticking fraction at high density and temperature

2.Create open-source physics process models for GEANT4

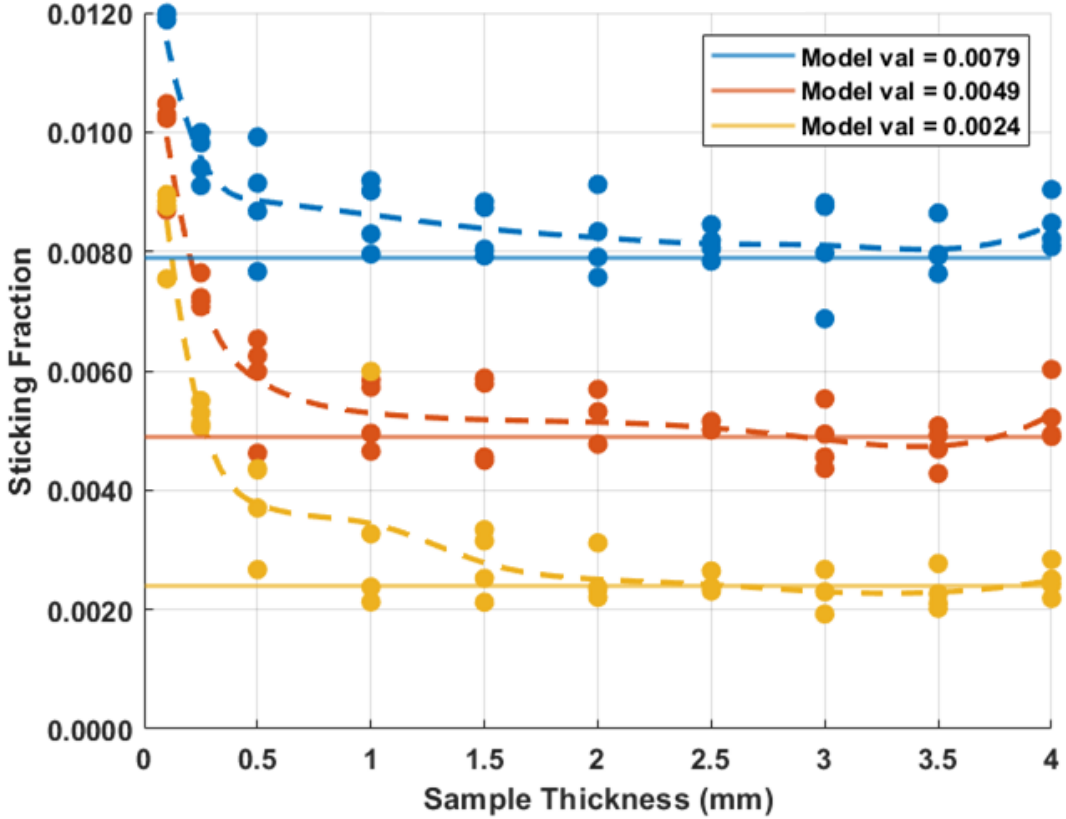


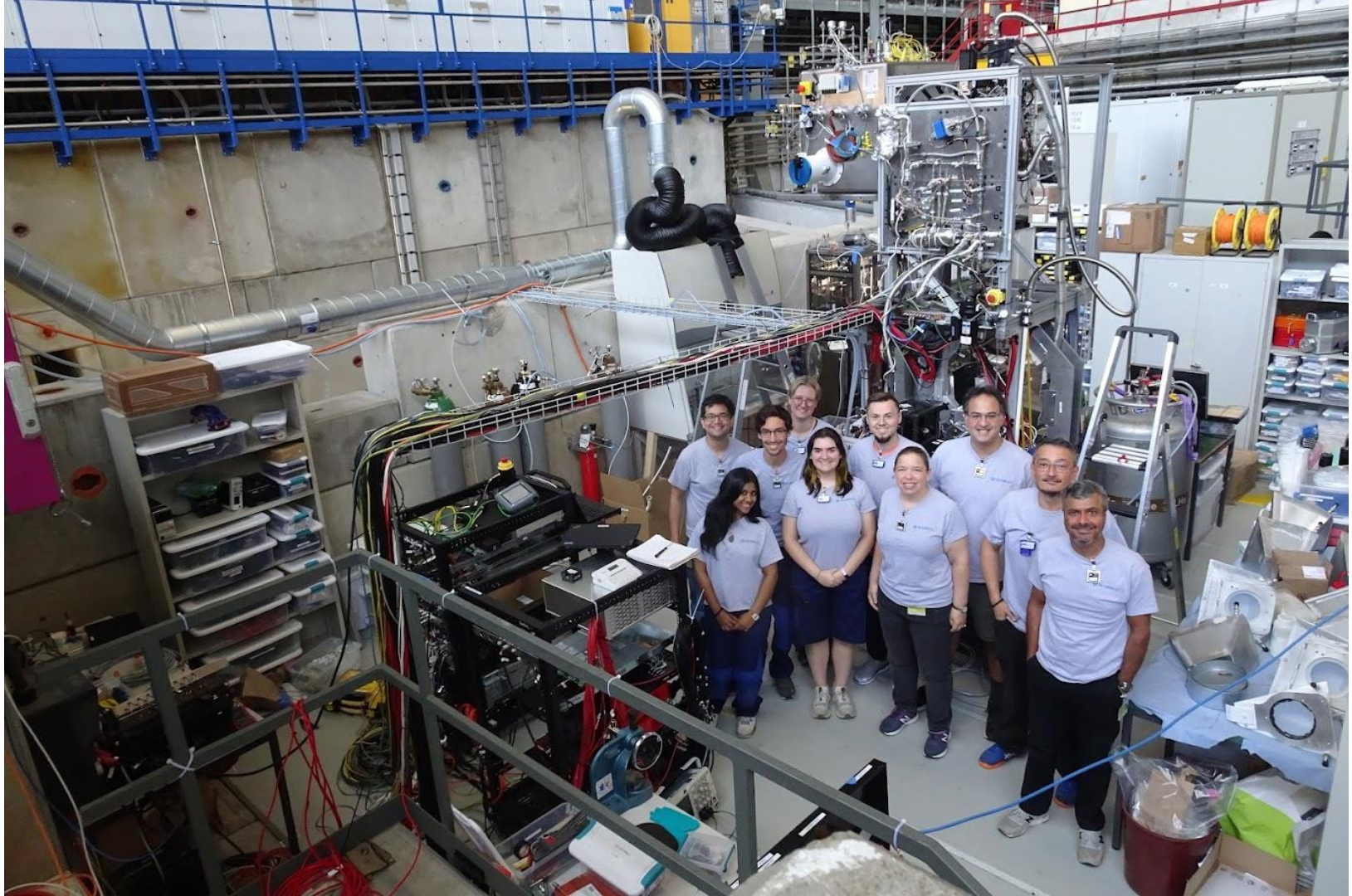


Design overview

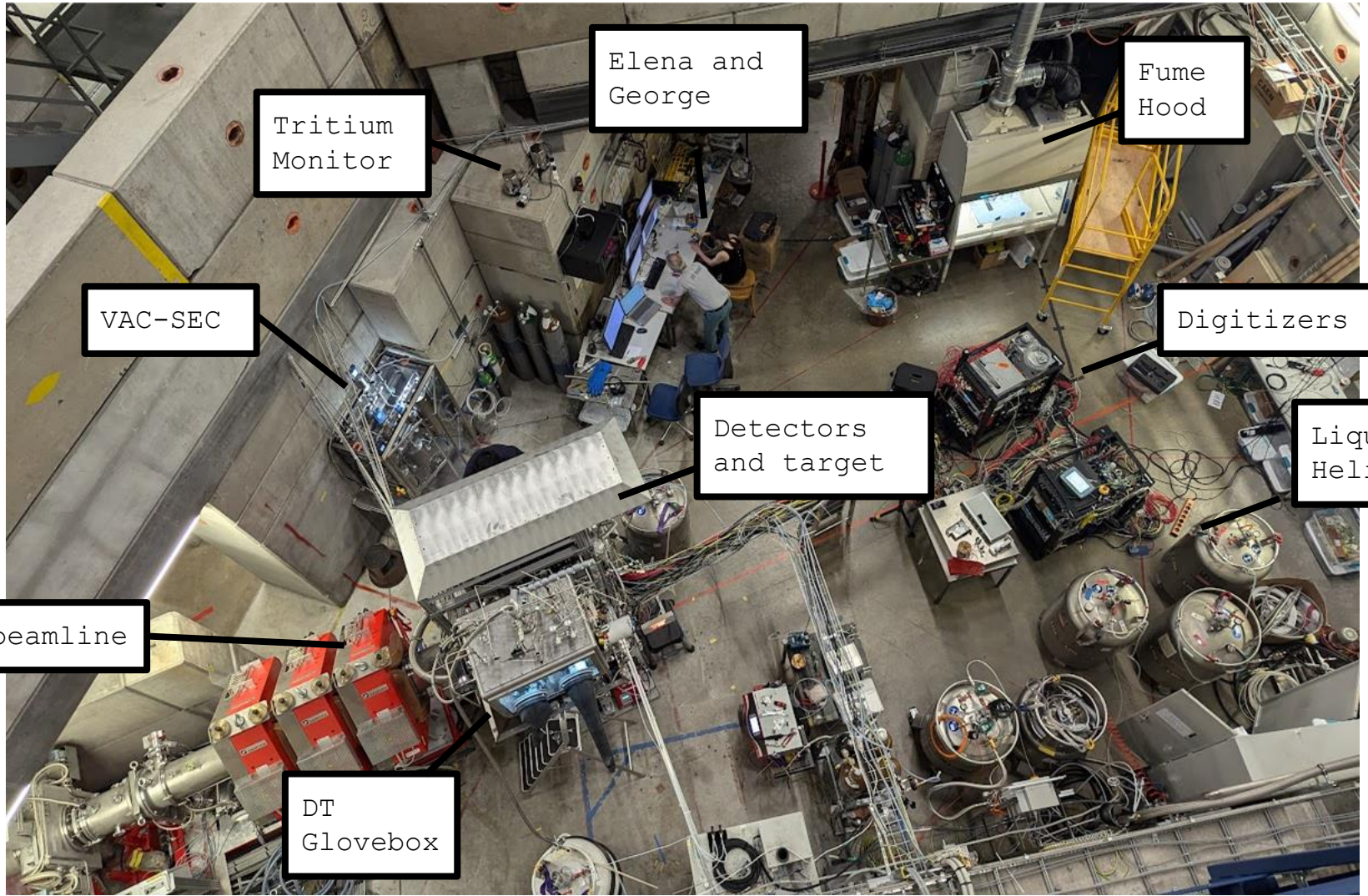


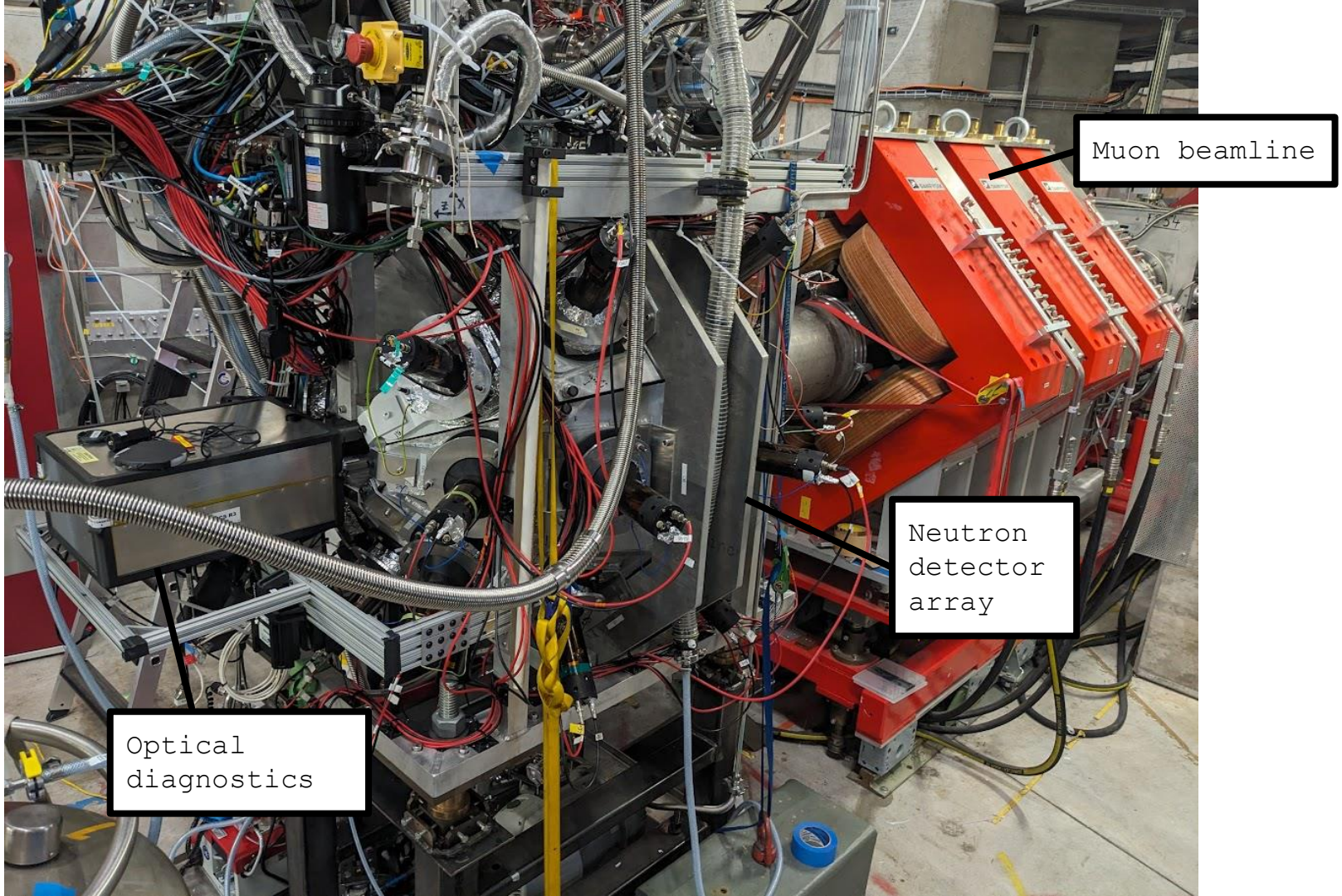
End-to-end simulation: sticking fraction vs cell size



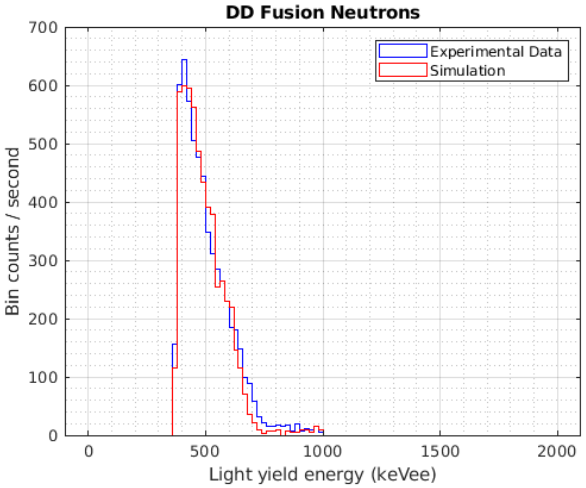


πE1.2 Beam Area

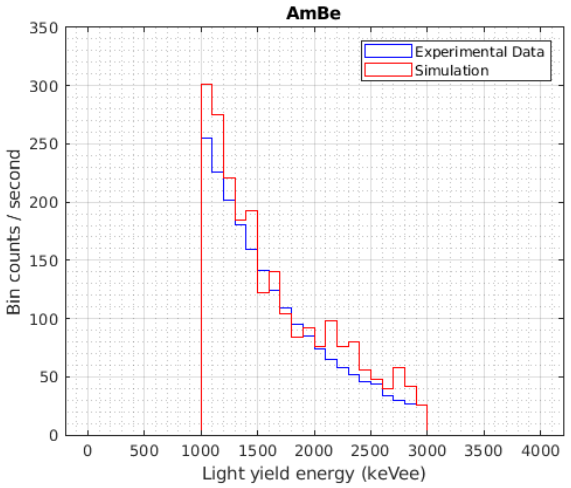



Muon beamline
Neutron detector array
Optical diagnostics

Measured spectra and rates align with simulation

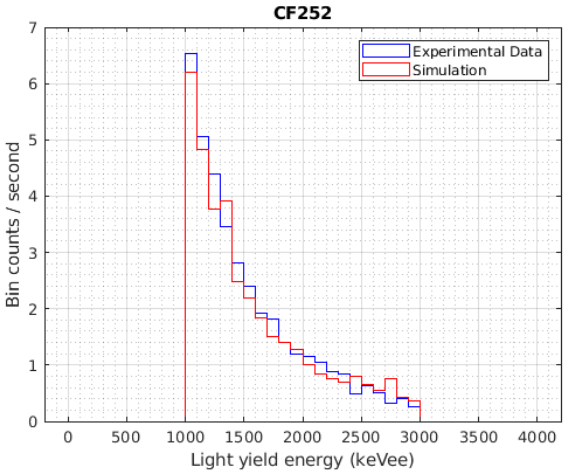


D-D Muon Catalyzed Fusion Neutrons



AmBe Neutron Source

+14%

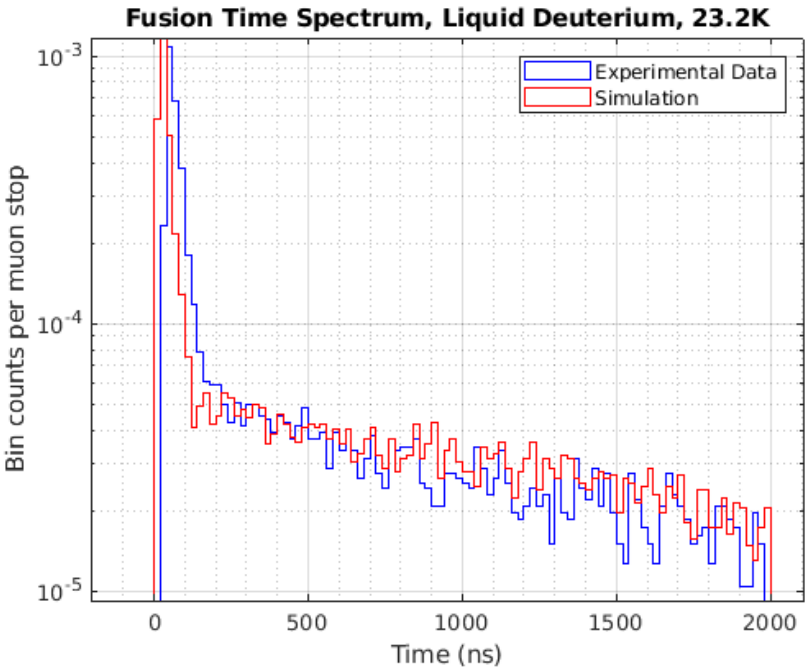


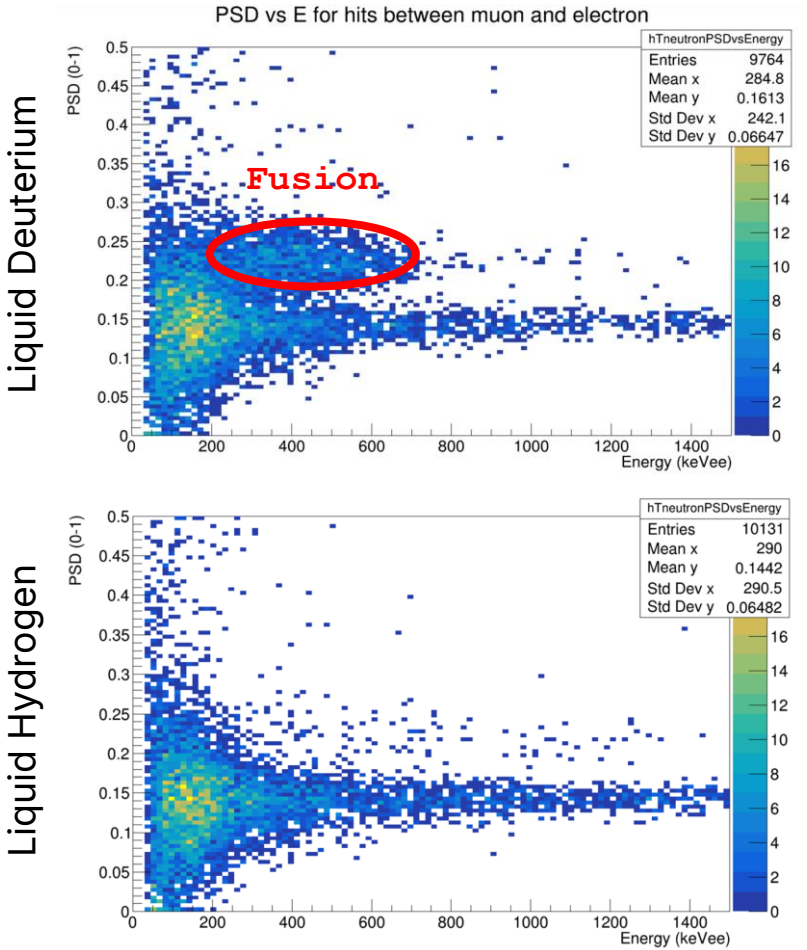
CF-252 Neutron Source

-9%

Results

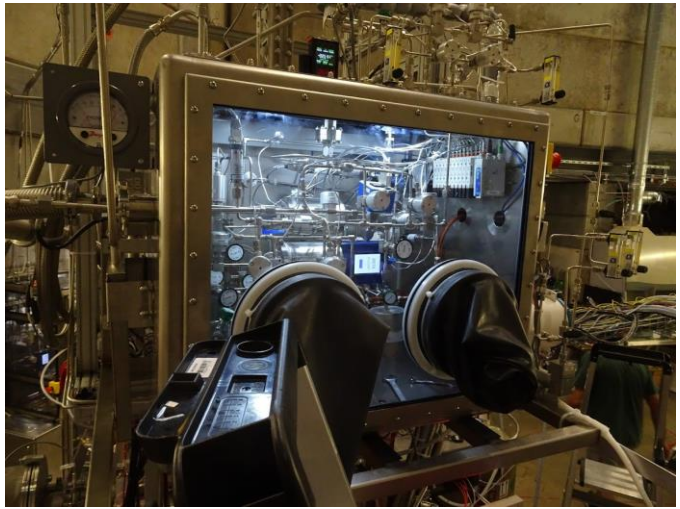
Neutron detection between the muon and electron

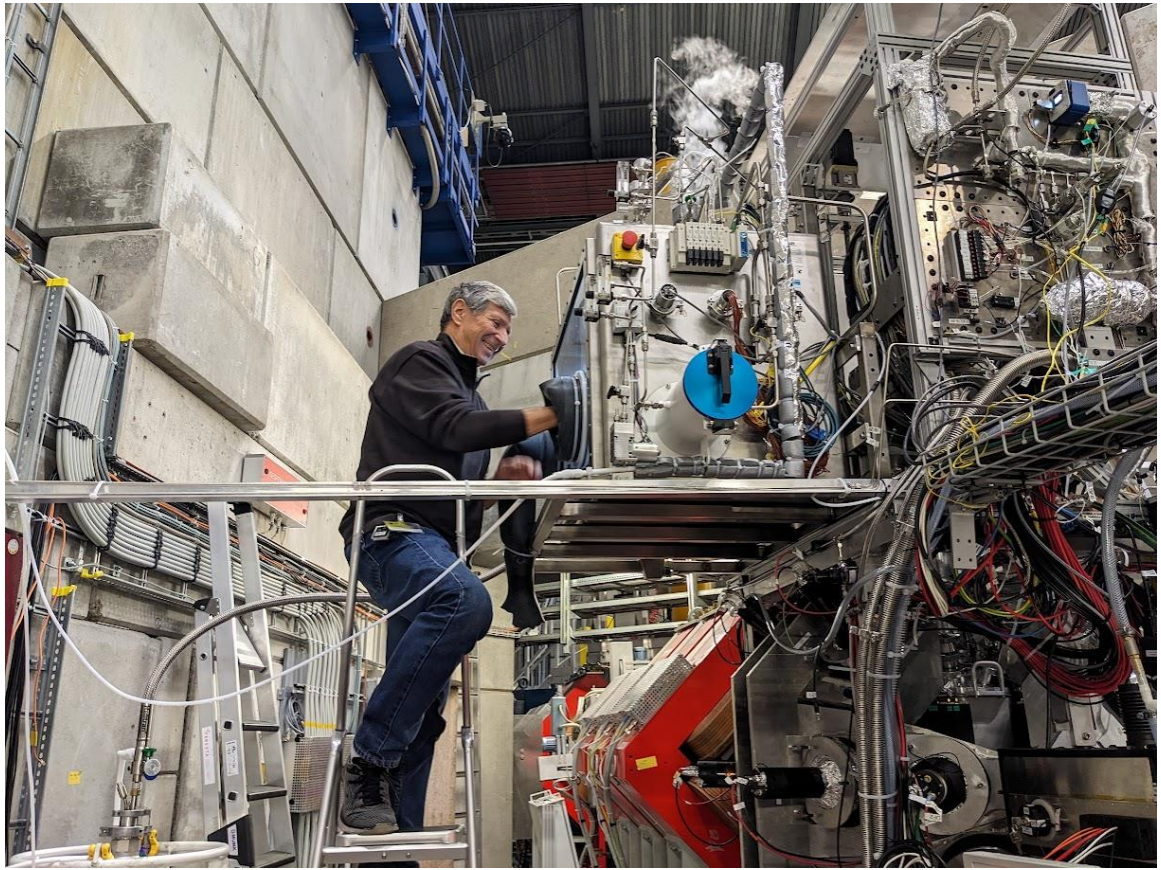




Materials and Methods

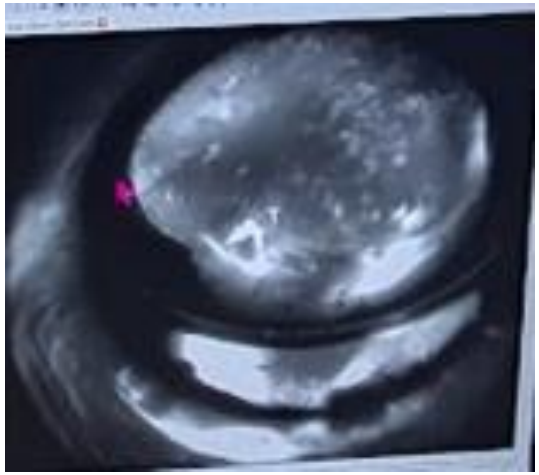
Loading the tritium into the U-beds

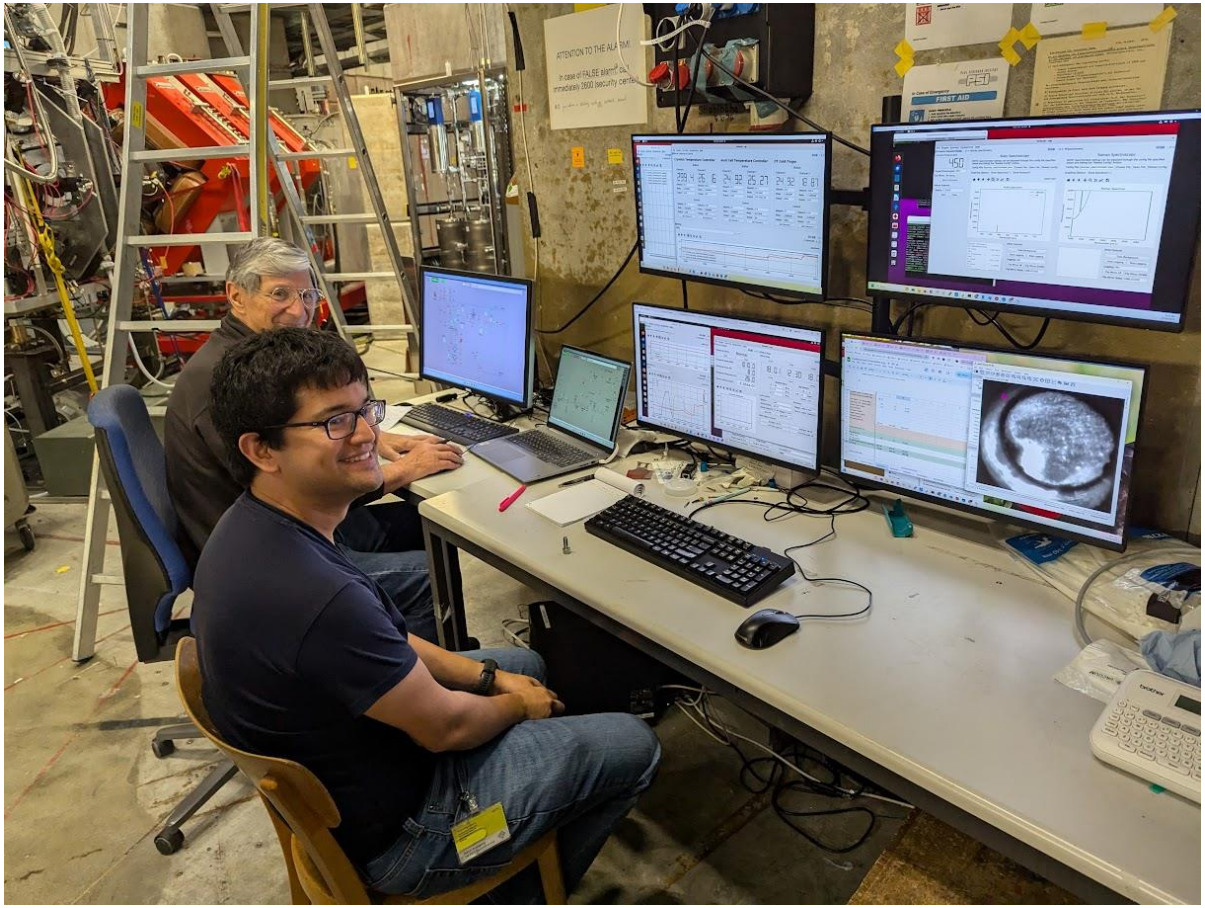




Materials and Methods

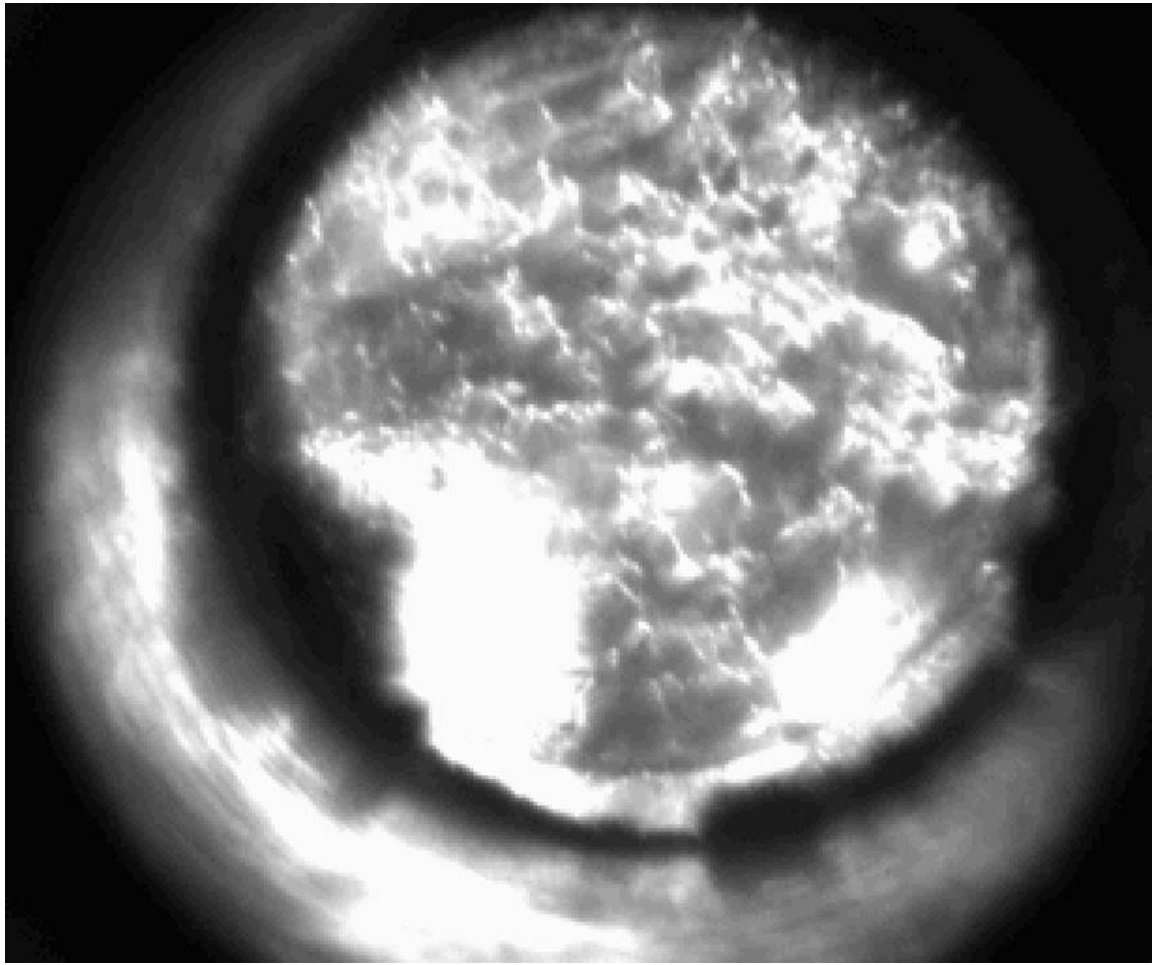
Loading the cell with liquid DT



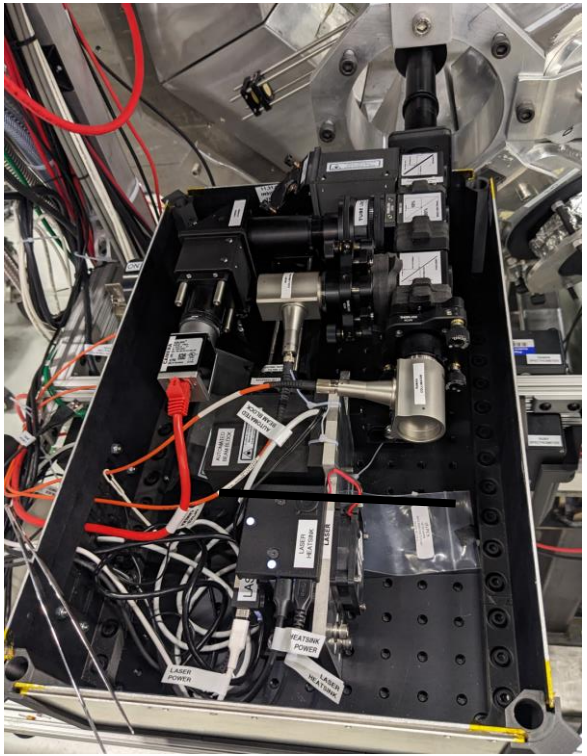


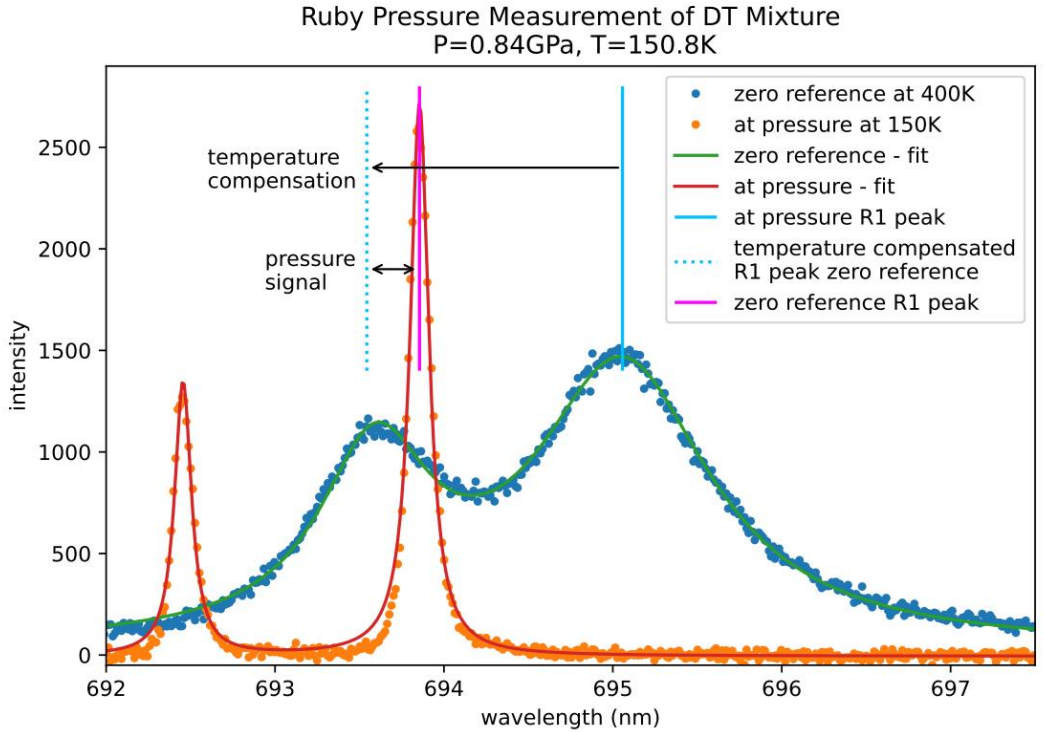
Materials and Methods

Compression of the liquid DT to a solid

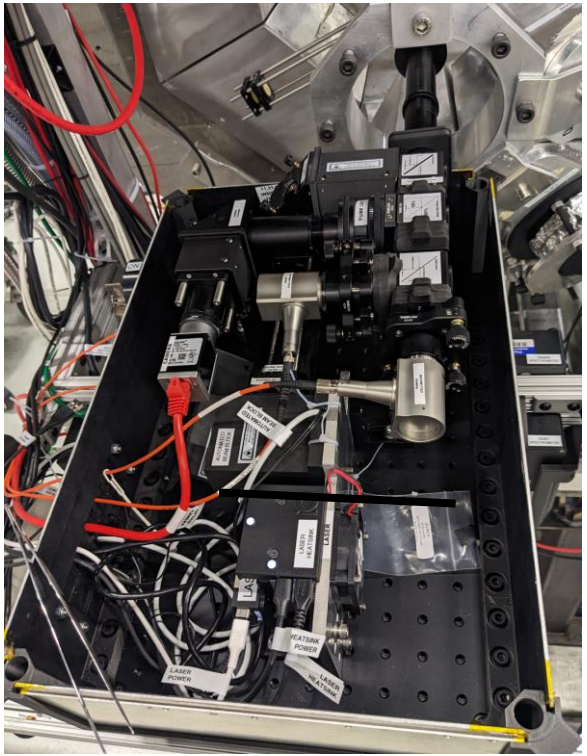


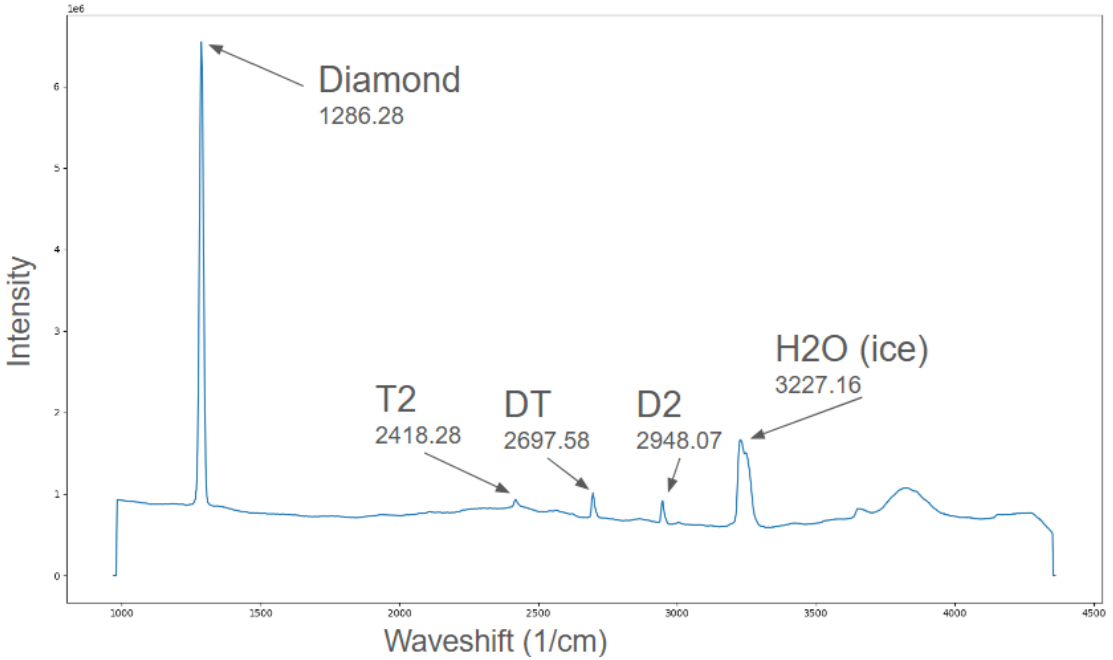
Optical pressure measurement via ruby fluorescence



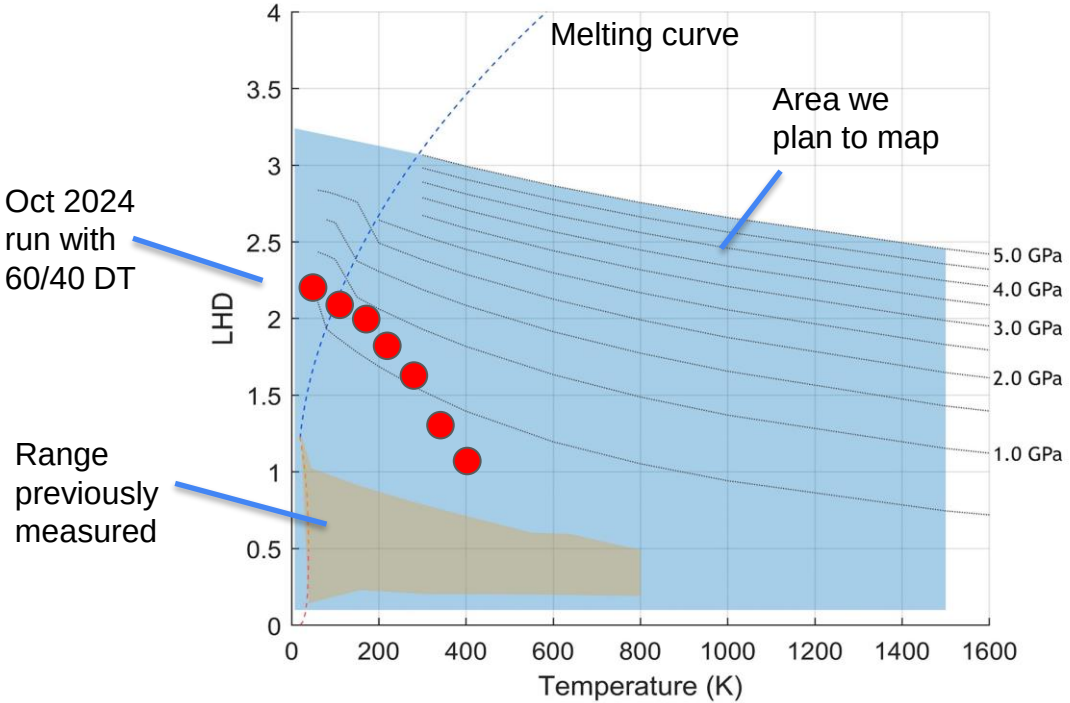


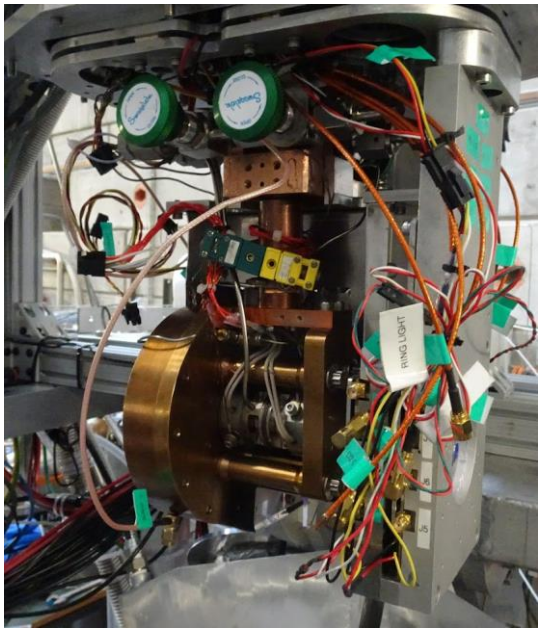
Real-time gas analysis via Raman spectroscopy





Pressure and temperature reached

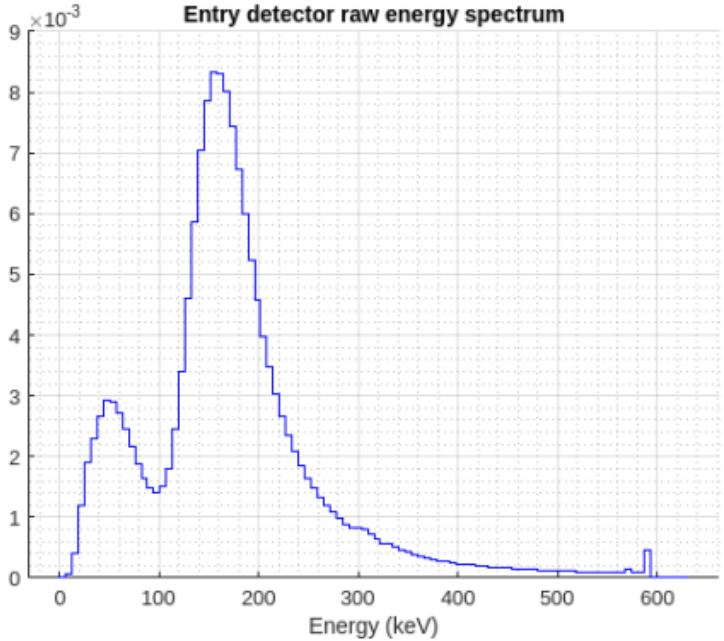


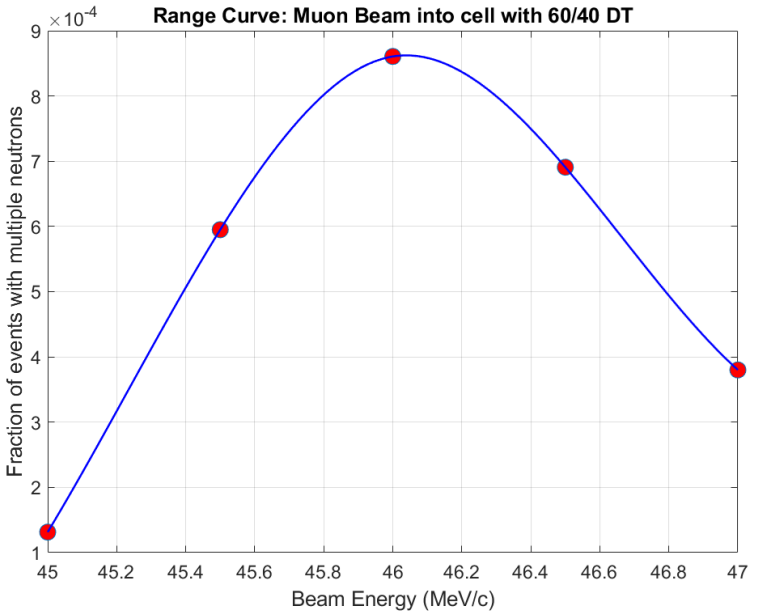


Diamond anvil cell

Results

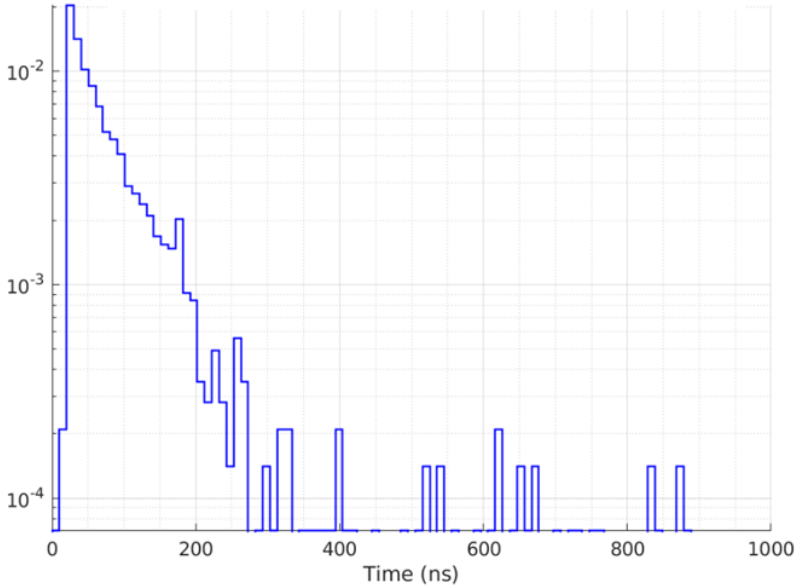
Hits classified as fusion neutrons peak at 46 MeV/c muon momentum, matching simulation



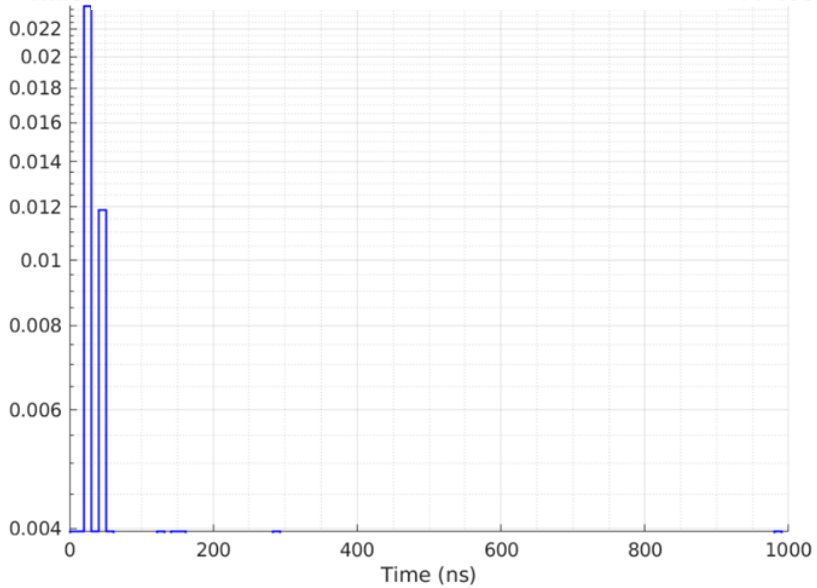


Results

Time spectrum of hits classified as fusion neutrons

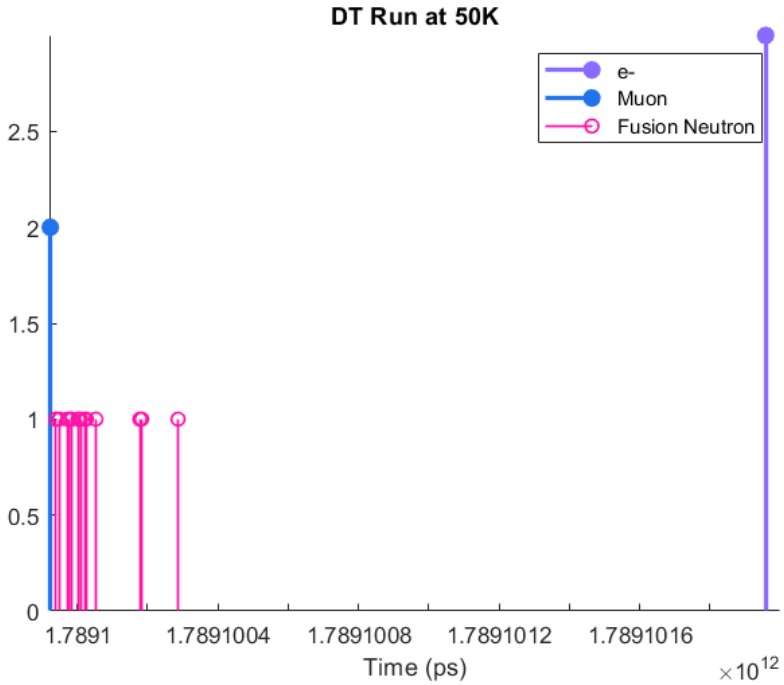


60/40 solid DT, 50K, at 2.2 LHD

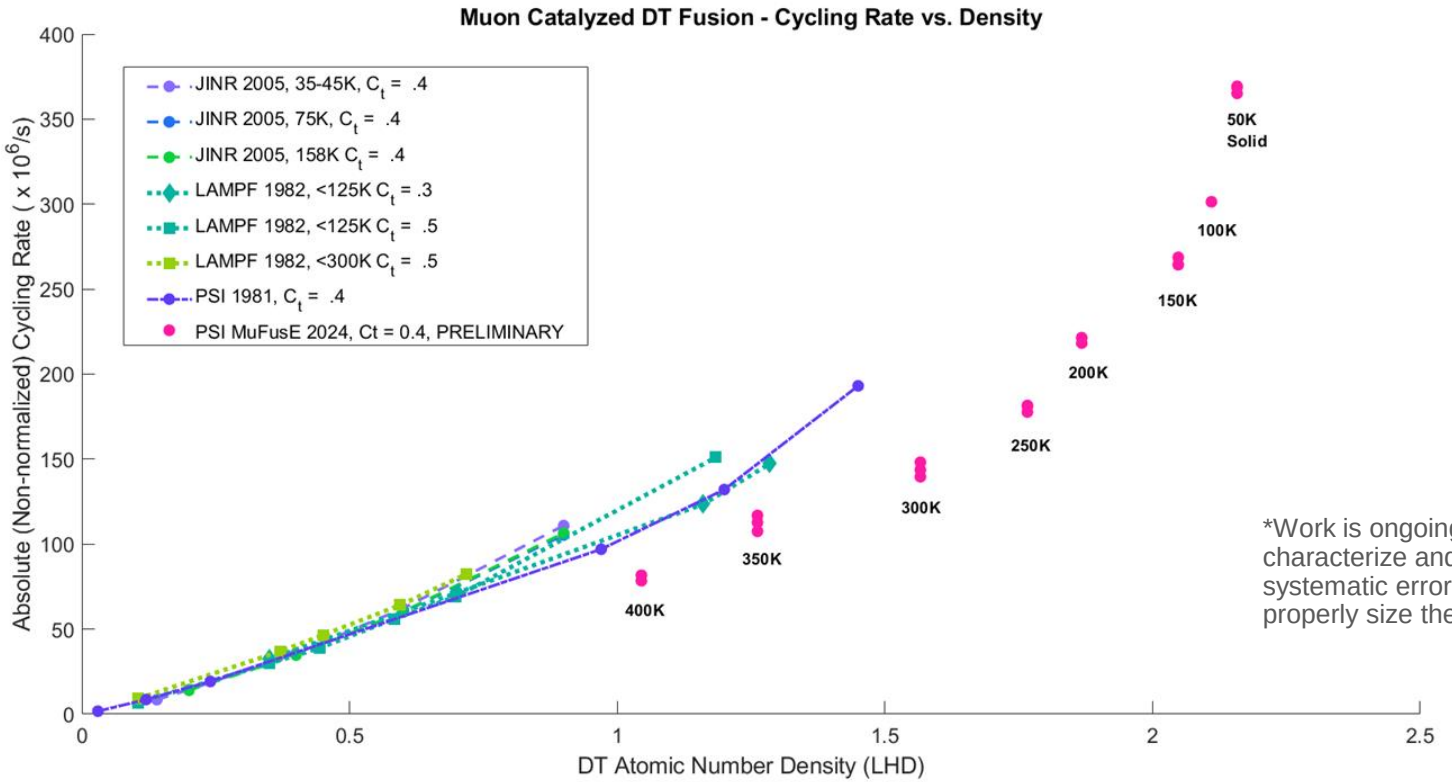


Empty target

Snapshot of a typical DT fusion event



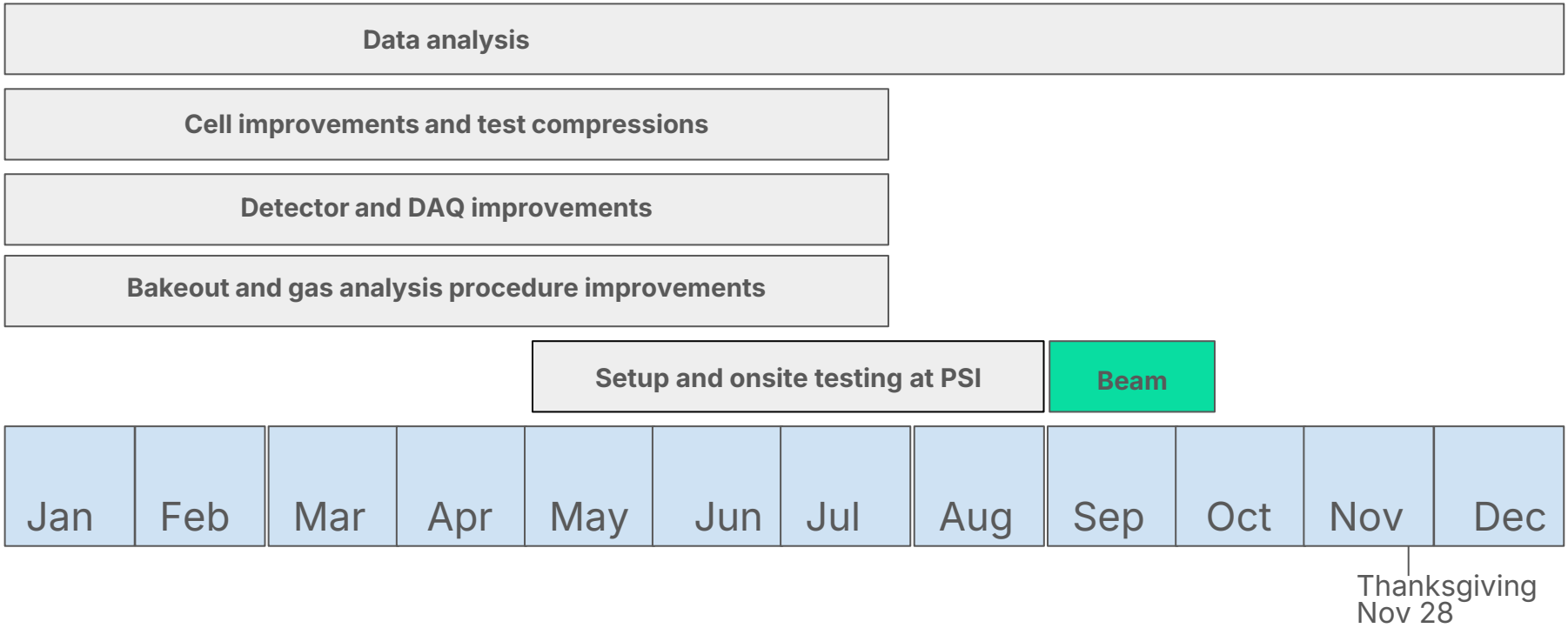
PRELIMINARY data on DT cycling rate to 2.2 LHD (2024)



*Work is ongoing to characterize and correct for systematic errors and to properly size the error bars.

Planning

2025 Timeline and Beam Request



Acknowledgements

A. Adamczak[o], J.A. Allen[a], A. Antognini[c,m], E. G. Badaracco[d,i], J. Betances[a,n], N.J. Brennan[a], R. Chaney[a], W. Cutler[f,j], J. Davies[e], C. Fagan[p], C. Forrest[e], A P. Gandhi[d], V. Glebov[e], A. Golossanov[c,f], D.M. Harrington[a], G. Harris[f], J.T. Hinchen[a], P.A. Holden[a], C. Izzo[d], C. Johnstone[d], J.D. Kalow[a], K. Kem[a], M. Khandaker[a], M. Kiburg[d], I. Kiniti[a,n], A.N. Knaian[a,c,d,f,2], L.E. Knaian[f], E. Koukina[f], K. Lau[a], J. Larson[k], K.R. Lynch[b,d,2], N.A. MacFadden[a,g], A. Mazzacane[d], P.A. McDaniel[a] , M. Mundt[a,j], S.O. Newburg[a,f], E. Niner, K. Payne[a], C.C. Petitjean[c] , R. Ridgeway[d] , A. Sampat[a], C.R. Shmayda[q], W.T. Shmayda[e,l], W. Stadolnik[a,j], I.D. Spool[a] , S. Tripathy[b,d], S. Varner[a], D. Zajac[a,j]