Beam Heat Load Effect on Polarization in the SpinQuest Experiment

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New Perspective
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NATIONAL CENTRE FOR PHYSICS ISLAMABAD

SPIN QUEST

Fermilab

UNIVERSITY of VIRGINIA

UVA - Spin PHYSICS GROUP

U.S. DEPARTMENT OF ENERGY | Office of Science

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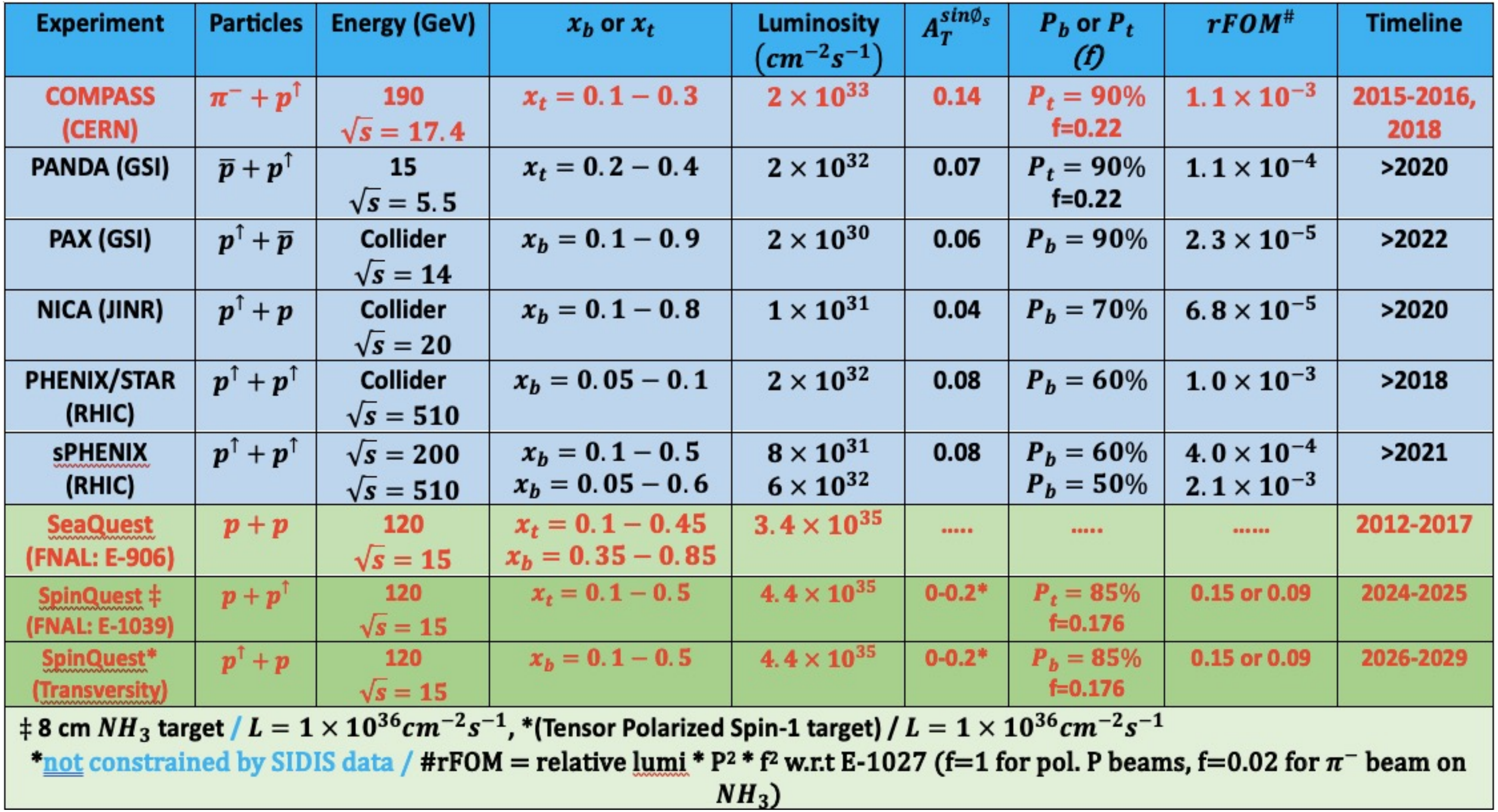
Outlines of the talk

- Fermilab (E1039) Experiment
- SpinQuest (E1039) experiment setup at Fermilab
- Target Material
- Preparation of Solid Ammonia
- Heat Load Effect on Polarization
- Beam Position Shift Effect on the LHe Bath
- Pumping on LHe Bath
- Next Plans
- Summary

FERMILAB (E1039) EXPERIMENT

(Un)Polarized Drell-Yan Experiments



Experiment	Particles	Energy (GeV)	x_b or x_t	Luminosity $(cm^{-2}s^{-1})$	$A_T^{sin\phi_s}$	P_b or P_t (f)	$rFOM^{\#}$	Timeline
COMPASS (CERN)	$\pi^- + p^\uparrow$	190 $\sqrt{s} = 17.4$	$x_t = 0.1 - 0.3$	2×10^{33}	0.14	$P_t = 90\%$ f=0.22	1.1×10^{-3}	2015-2016, 2018
PANDA (GSI)	$\bar{p} + p^\uparrow$	15 $\sqrt{s} = 5.5$	$x_t = 0.2 - 0.4$	2×10^{32}	0.07	$P_t = 90\%$ f=0.22	1.1×10^{-4}	>2020
PAX (GSI)	$p^\uparrow + \bar{p}$	Collider $\sqrt{s} = 14$	$x_b = 0.1 - 0.9$	2×10^{30}	0.06	$P_b = 90\%$	2.3×10^{-5}	>2022
NICA (JINR)	$p^\uparrow + p$	Collider $\sqrt{s} = 20$	$x_b = 0.1 - 0.8$	1×10^{31}	0.04	$P_b = 70\%$	6.8×10^{-5}	>2020
PHENIX/STAR (RHIC)	$p^\uparrow + p^\uparrow$	Collider $\sqrt{s} = 510$	$x_b = 0.05 - 0.1$	2×10^{32}	0.08	$P_b = 60\%$	1.0×10^{-3}	>2018
sPHENIX (RHIC)	$p^\uparrow + p^\uparrow$	$\sqrt{s} = 200$ $\sqrt{s} = 510$	$x_b = 0.1 - 0.5$ $x_b = 0.05 - 0.6$	8×10^{31} 6×10^{32}	0.08	$P_b = 60\%$ $P_b = 50\%$	4.0×10^{-4} 2.1×10^{-3}	>2021
SeaQuest (FNAL: E-906)	$p + p$	120 $\sqrt{s} = 15$	$x_t = 0.1 - 0.45$ $x_b = 0.35 - 0.85$	3.4×10^{35}	…..	…..	……	2012-2017
SpinQuest ‡ (FNAL: E-1039)	$p + p^\uparrow$	120 $\sqrt{s} = 15$	$x_t = 0.1 - 0.5$	4.4×10^{35}	0-0.2*	$P_t = 85\%$ f=0.176	0.15 or 0.09	2024-2025
SpinQuest* (Transversity)	$p^\uparrow + p$	120 $\sqrt{s} = 15$	$x_b = 0.1 - 0.5$	4.4×10^{35}	0-0.2*	$P_b = 85\%$ f=0.176	0.15 or 0.09	2026-2029

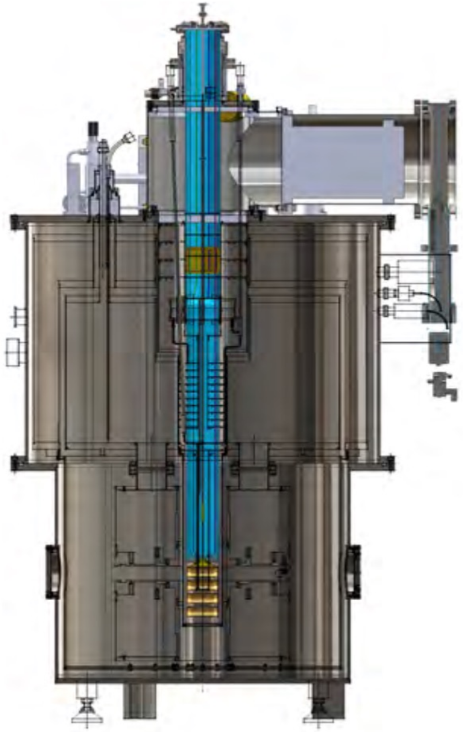
‡ 8 cm NH_3 target / $L = 1 \times 10^{36} cm^{-2}s^{-1}$, *(Tensor Polarized Spin-1 target) / $L = 1 \times 10^{36} cm^{-2}s^{-1}$

*not constrained by SIDIS data / #rFOM = relative lumi * P² * f² w.r.t E-1027 (f=1 for pol. P beams, f=0.02 for π^- beam on NH_3)

SpinQuest/E1039 Experiment Setup @ FNAL

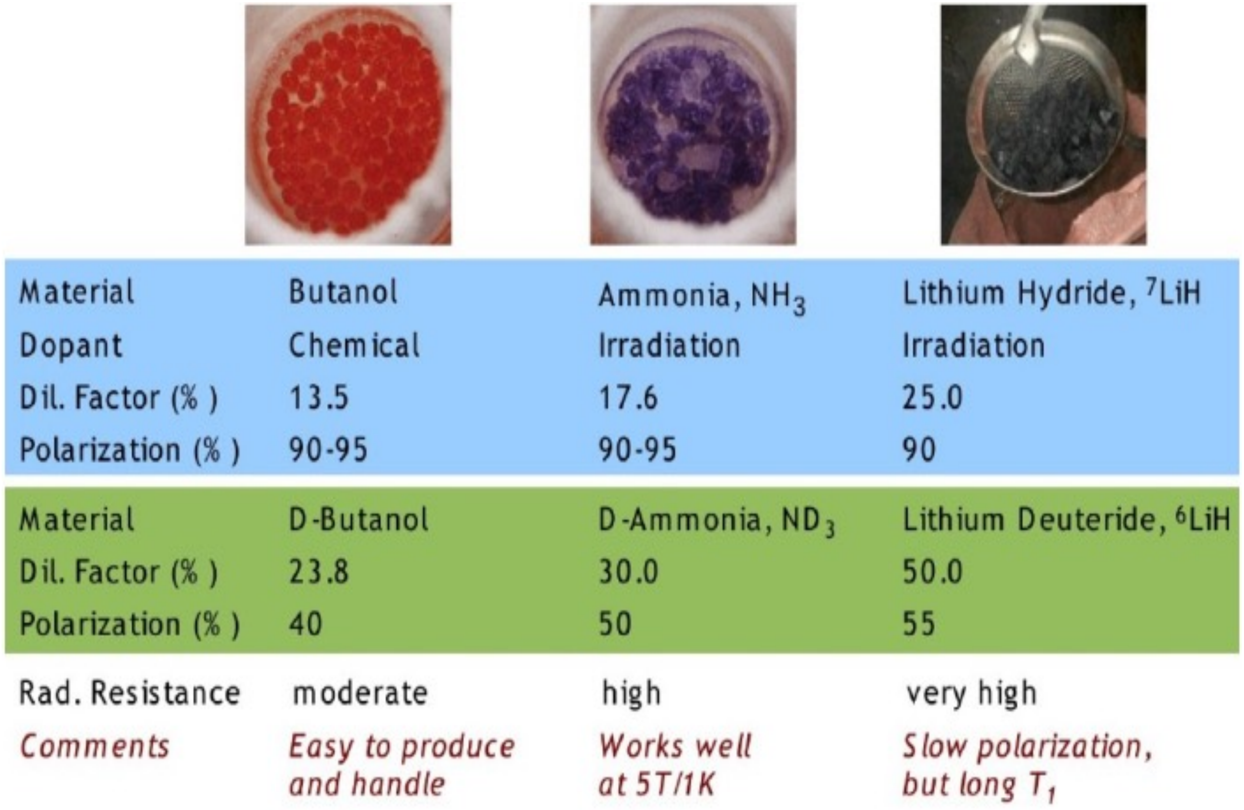
- **FNAL 120 GeV proton beam**
  - $\sqrt{s} = 15.5$ GeV
  - (5×10^{12}) protons/spill with 4.4 sec/min
  - 7.7×10^{17} protons on target/year

- **LANL/UVA Polarized Target**
  - Solid NH_3, ND_3
  - Superconducting magnet (5T) field, 1K evaporation fridge
  - 140 GHz microwave source (with DNP technique)
  - Helium Liquefier System (200L/day

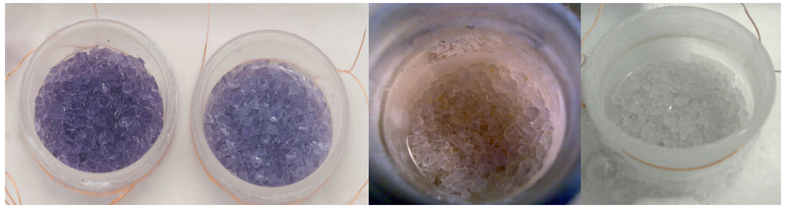


Target Material

- A successful target material candidates for the DNP can be characterized by:
    - Maximum achievable polarization
    - Dilution factor → total nuclear content
    - Resistance to radiation damage
- Paramagnetic centers can be doped into bulk target material (chemical or by radiation doping)
- The target consists of an 8cm long PTFE target cells containing ammonia beads immersed in LHe
- Target material NH_3/ND_3 are doped with paramagnetic free-radical by being irradiated at NIST
- The polarization decays over time due to the radiation damage and restored by annealing process (target is heated at 70-100K)



Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high	very high
Comments	*Easy to produce and handle*	*Works well at 5T/1K*	*Slow polarization, but long T_1*



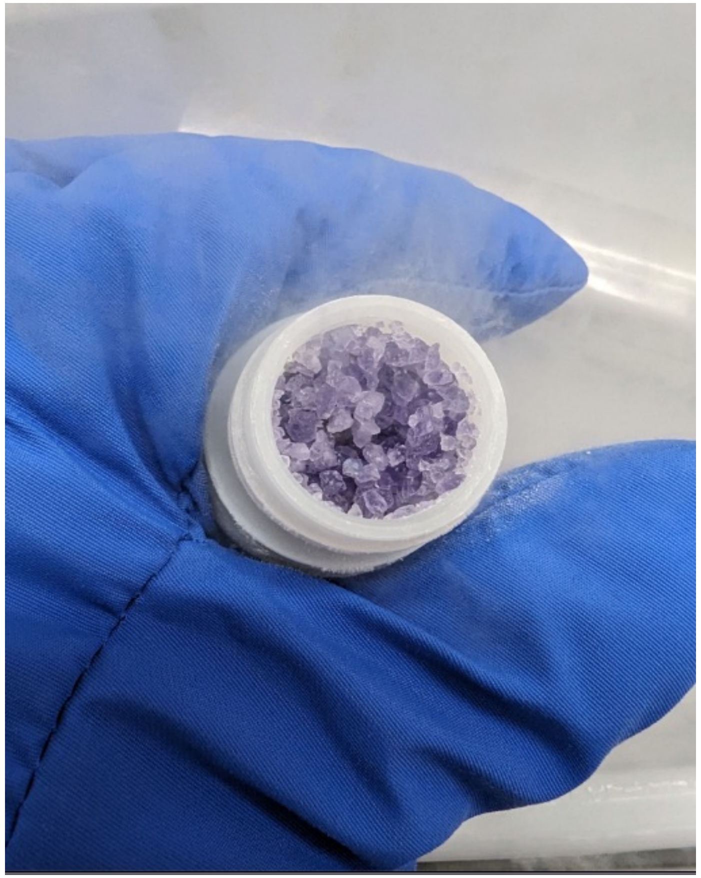
- Also, color centers should be formed that correlate to the accumulated dose during irradiation.

Target Material (NH_3/ND_3)

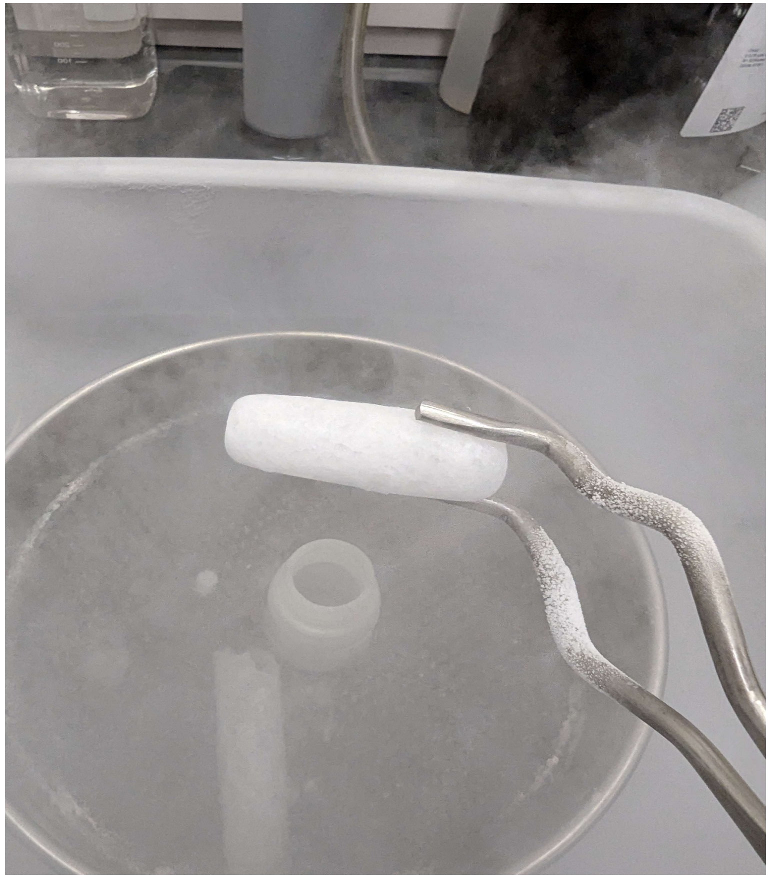
- The ***figure of merit*** **(FOM)** is crucial for target material:

$$FOM = P_T^2 . f^2 . \rho . \kappa$$

- The dilution factor and the target polarization have the largest impact on the FOM
- The filling factor $\boldsymbol{\kappa}$ is linked to the thermal conductivity and the shape of the target material



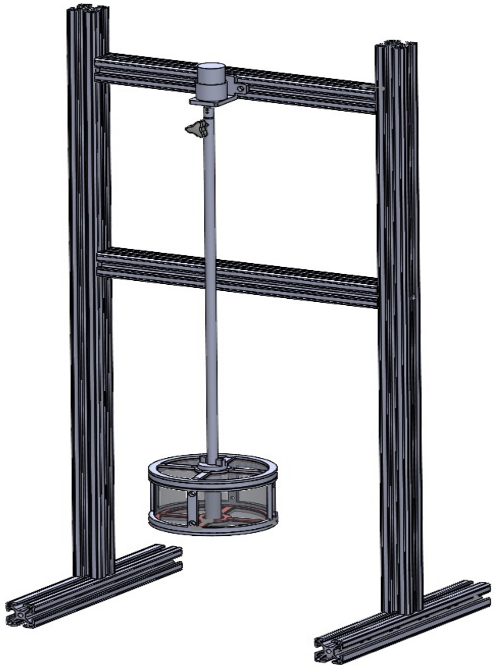
Irradiated NH3 Beads

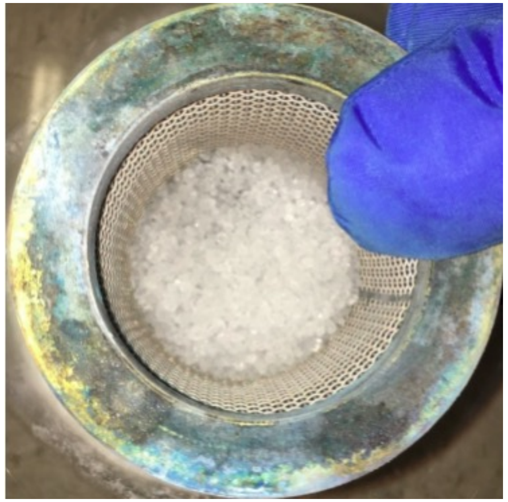


Un-irradiated NH3 Slab

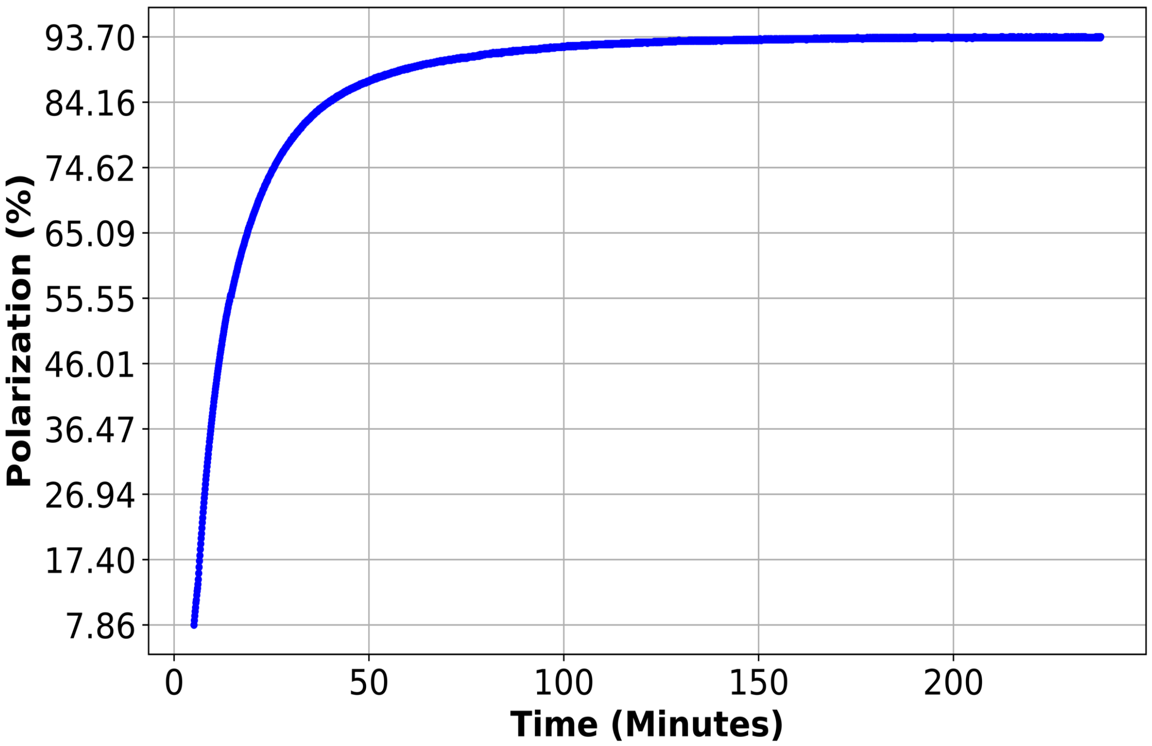
Preparation of Solid Ammonia

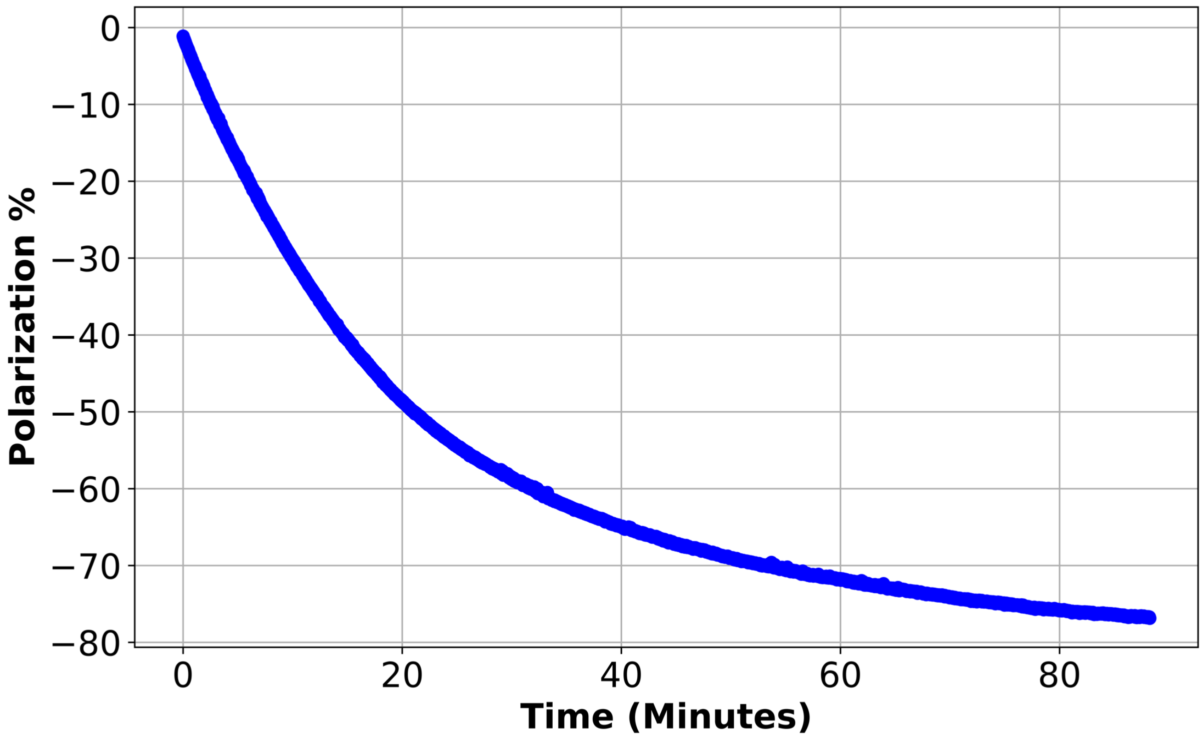
- The following cartoons depict the preparation of Solid Ammonia at UVA and irradiation at NIST.





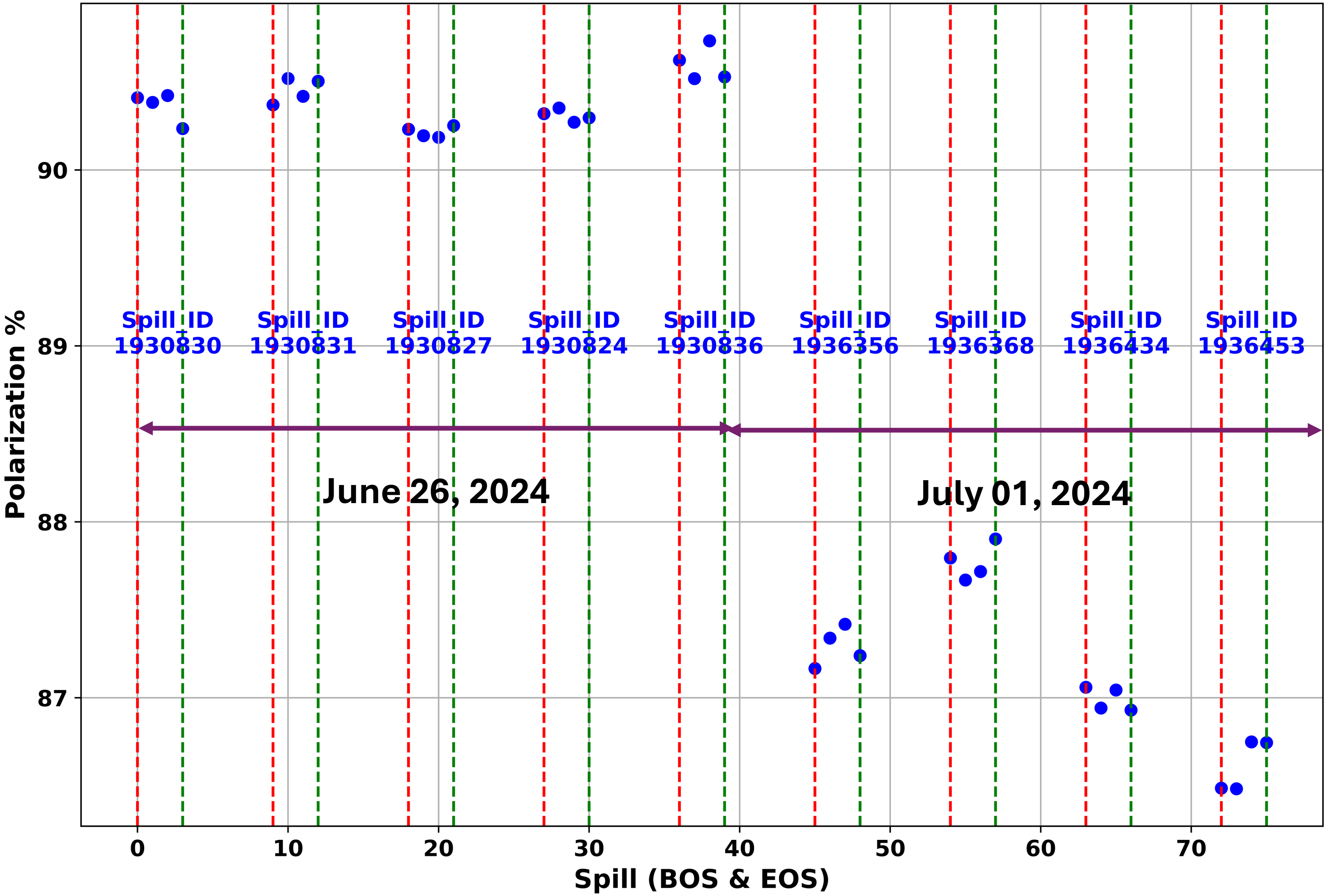
Polarization (Positive & Negative)



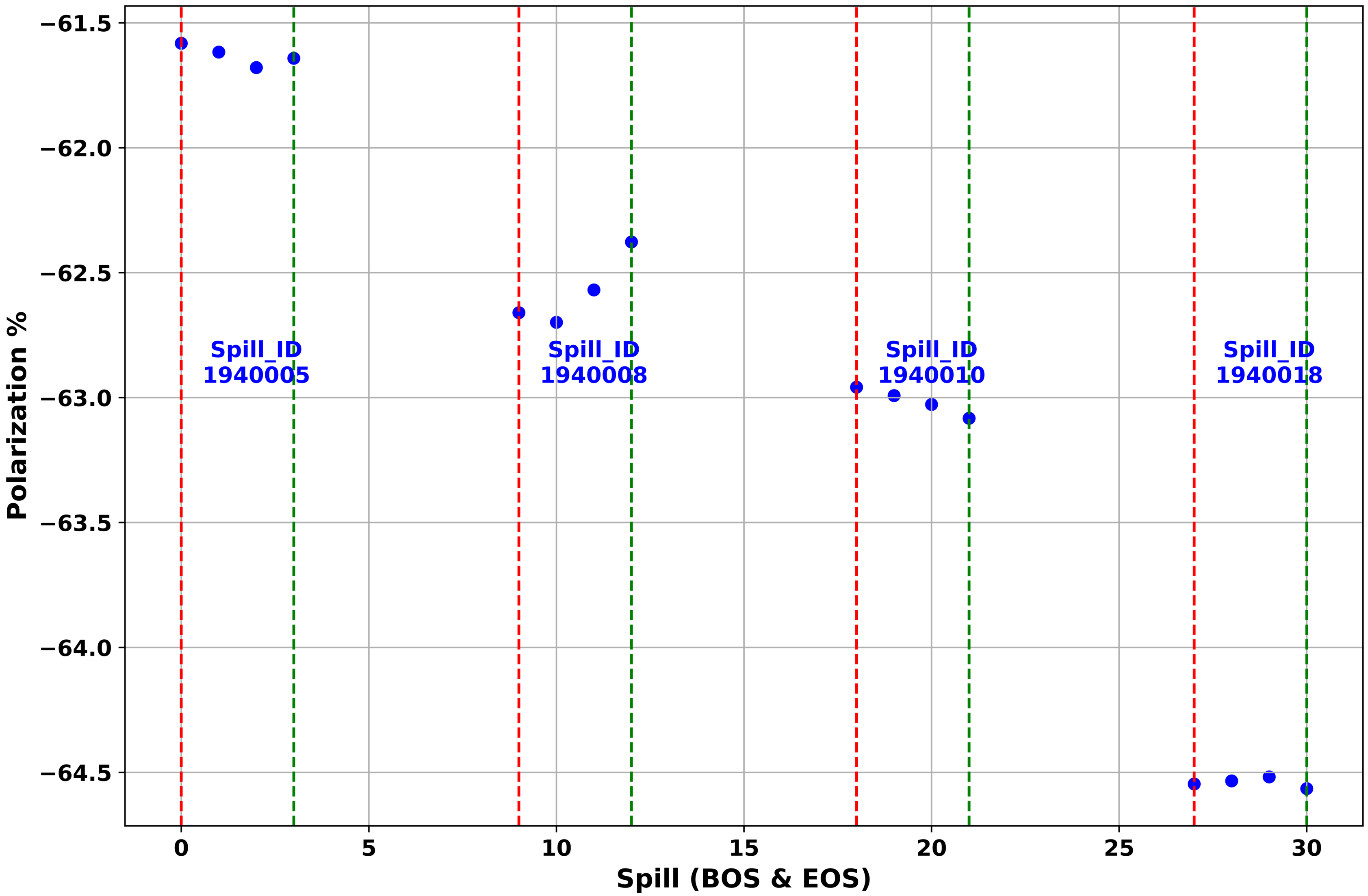


- Using the DNP (Dynamic Nuclear Polarization) technique, we obtained polarization for ammonia (NH_3) that was over 90% positive and 80% negative.
- A 140 GHz RF signal generator (EIO) (Extended interaction oscillator) is used for DNP. Please see the talk by **Vibodha Bandara (**Microwave System**)**
- A Liverpool-based NMR (Nuclear Magnetic Resonance) technique is used to measure the polarization.

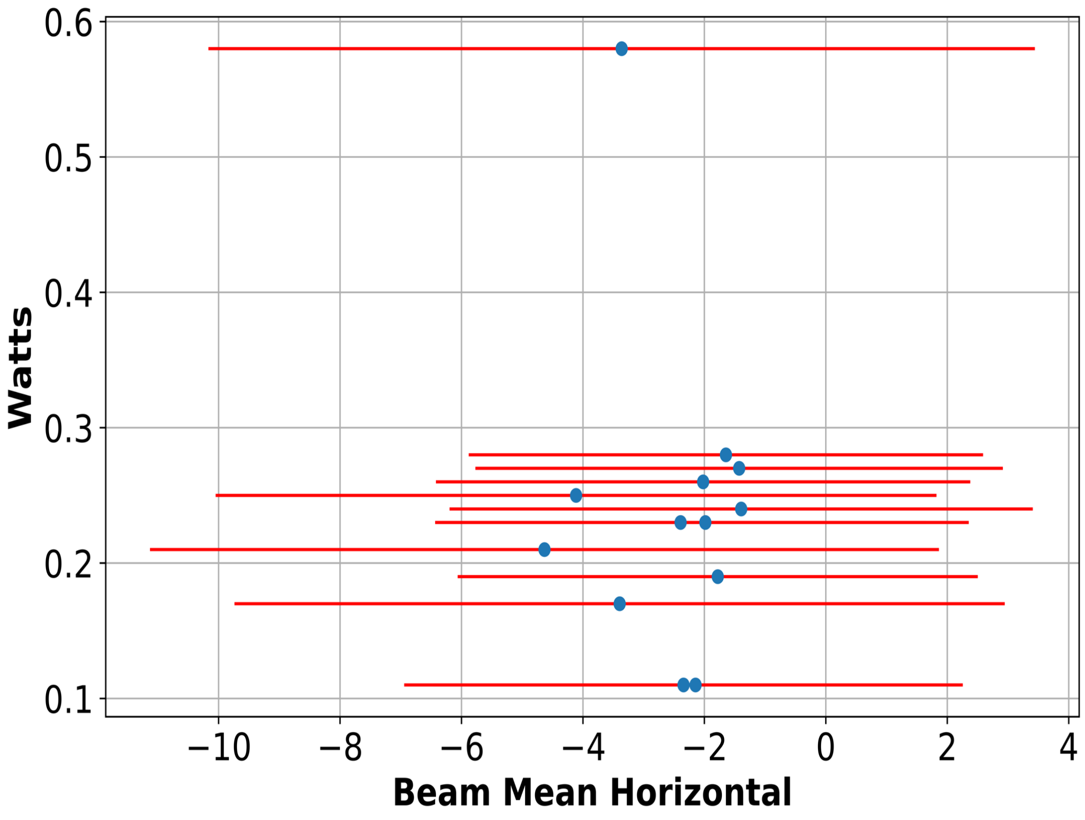
Heat Load Effect on the Positive Polarization

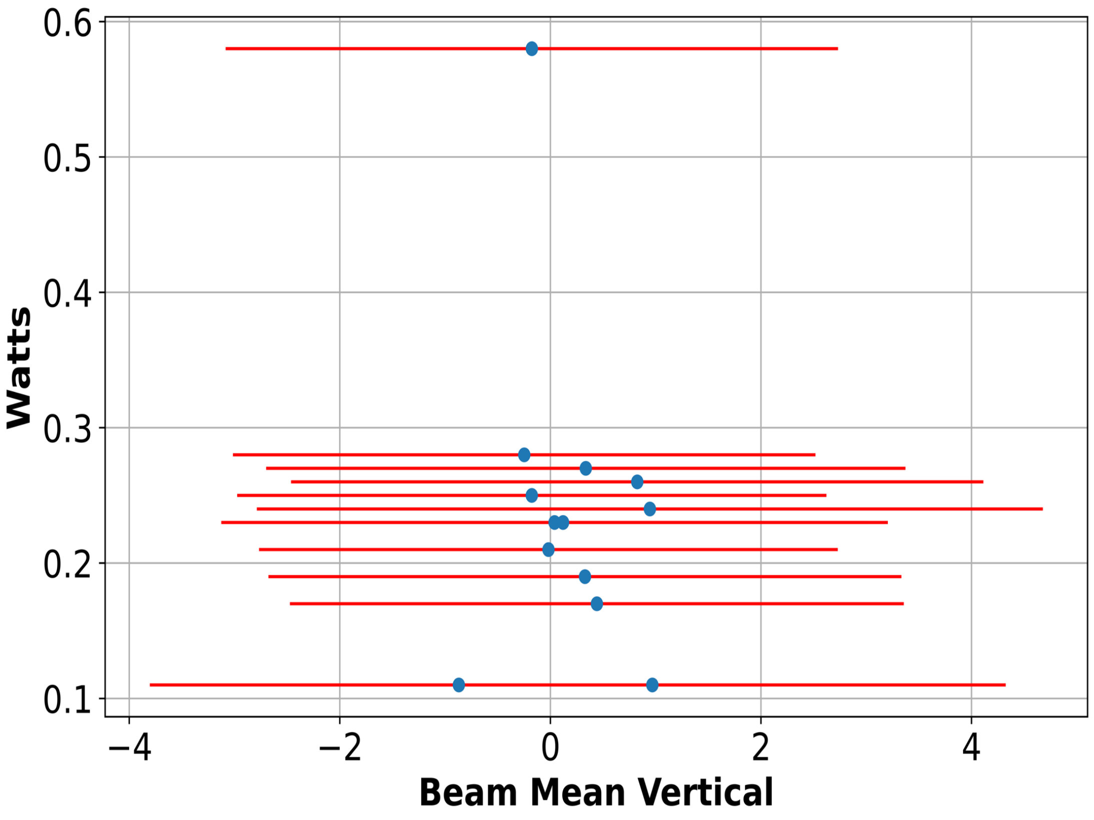


Heat Load Effect on the Negative Polarization on July 04, 2024



Beam Position Shift Effect on the LHe Bath





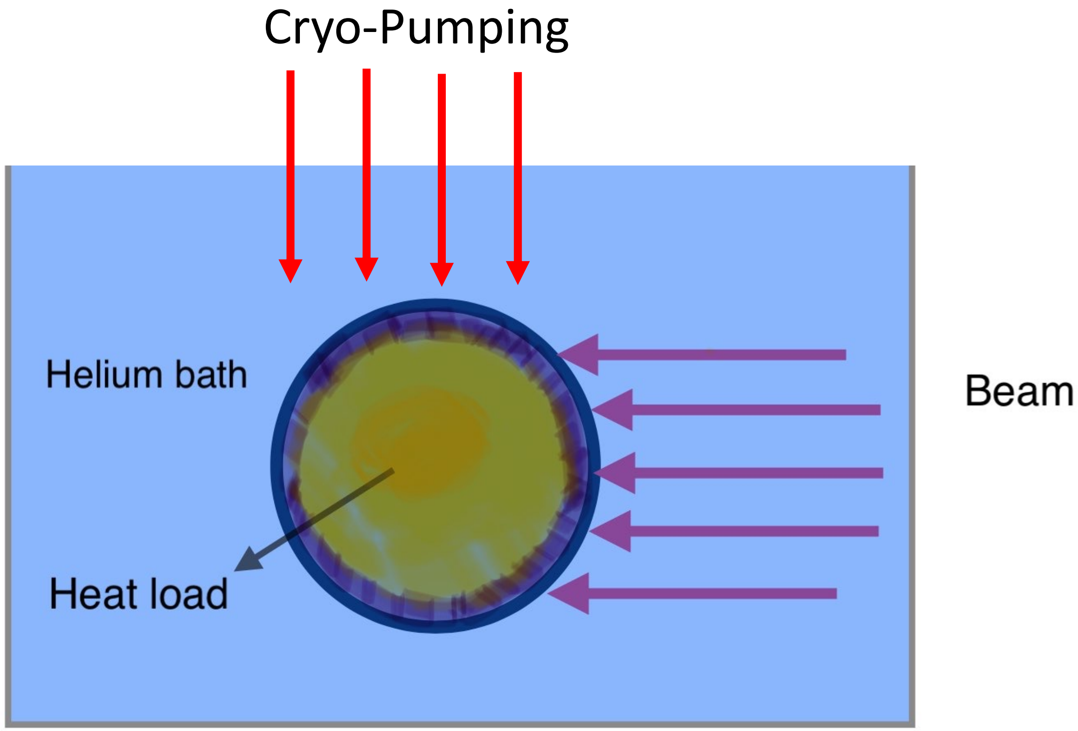
Horizontal Position: -1.88 mm

Vertical Position: 0 mm

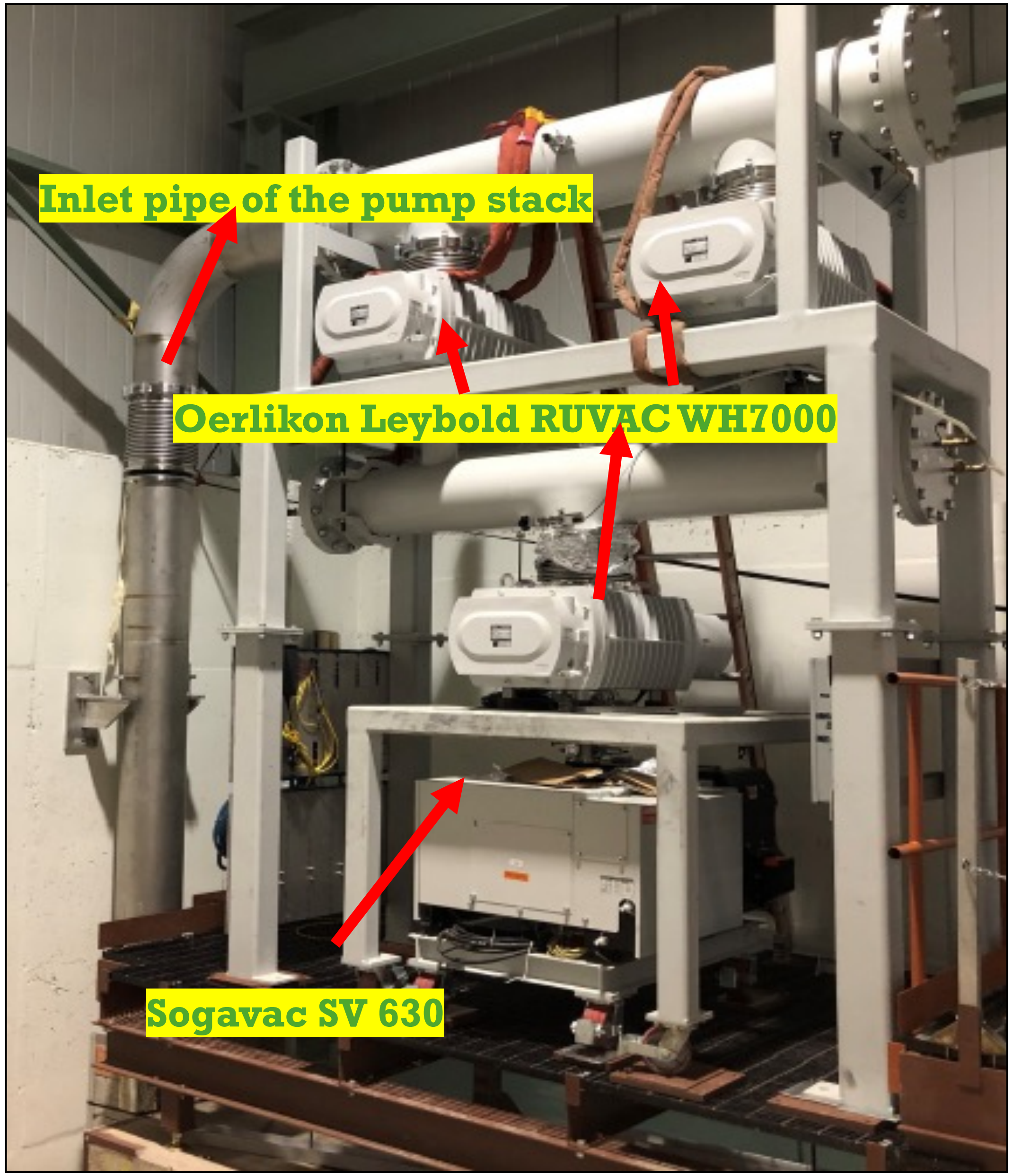
- This study indicates there is no strong correlation between position and heat load, but instead, there is greater dependence on intensity and another variable.
- The beam shifts from the set coordinates, dumps heat on the LHe bath, and evaporates the liquid.

Pumping on LHe Bath

- The root pump stacks, with a high pumping speed of 17,000 m3/hr, help maintain the LHe Bath temperature at around 1 K, but they cannot cool the inside of the material.
- Help us recover the polarization during the spill.

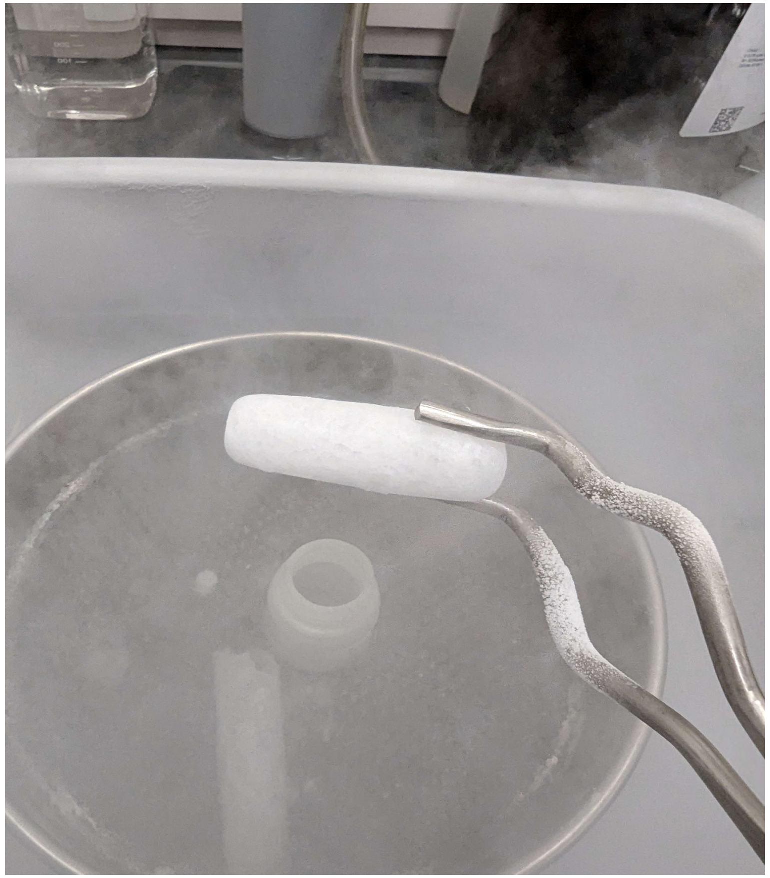


Target spherical bead



Next Plans

- We planned to interact with the beam on our target at 3 E12 proton/spill for the thermal depolarization.
- We will maximize the possible intensity without cryo-pumping.
- Above this intensity, we will cryo-pump our magnet liquid helium reservoir to avoid the possibility of magnet quenching due to high intensities.
- Increasing the target material packing fraction by enhancing the surface area to volume ratio could lower the thermal depolarization.
- We will optimize the target geometry by using NH3 slab and wafers.
- By enhancing the packing fraction it is possible to improve the FOM (Figure of Merit) with more polarized nucleons per target cell.



NH3 Slab

Summary

- There is no significant thermal depolarization during the beam spill (Intensity <=2.00E12 proton/spill).
- Thermal depolarization during the beam spill is recoverable due to the cryo-pumping on the liquid helium bath.
- The beam shifts from the set coordinates cause no increase in heat load to the target, yet high-intensity spills have yet to be studied well.
- Increasing the packing fraction by enhancing the surface area to volume ratio might enhance the Figure of Merit (FOM) for the polarizable observable measurement.