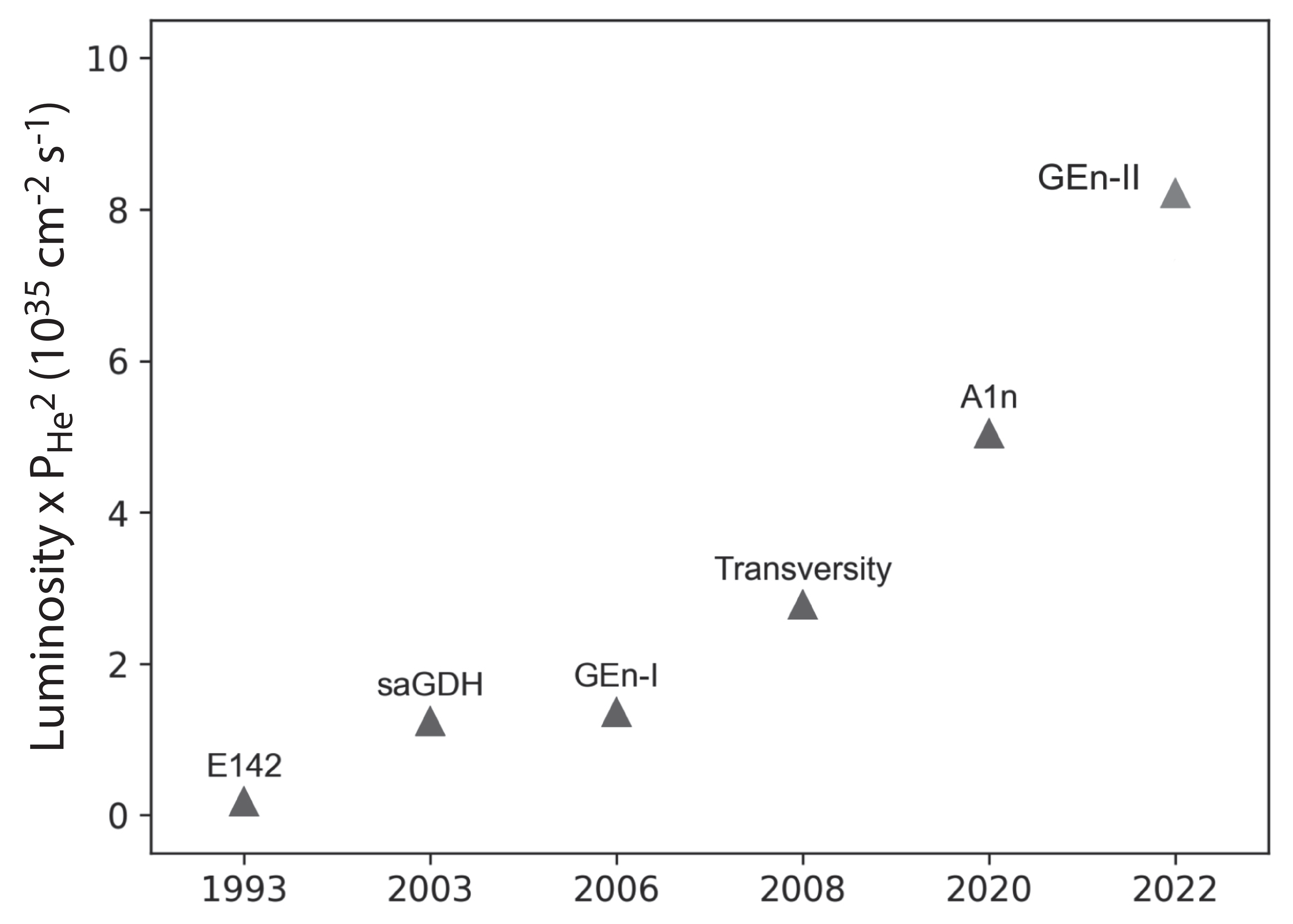
He-3 polarized targets now and into the future

- Lessons learned during GEn-II
- Quick look at the original target we used for Transversity in 2008/2009
- Design features to consider for the SBS SIDIS polarized 3He target.

Gordon D. Cates
SBS Collaboration Meeting
March 4, 2026

The performance of polarized ^{3}He targets based on spin-exchange optical pumping (SEOP) has increased dramatically over time

- The improvements have been driven by advances in both the underlying physics as well as laser technology.
- But the improvement were also hard won.
- New physics issues arose in successive generations of targets.



Target performance during GEN-II

Despite the challenges, with a luminosity more than twice that achieved during A1n, the target had record-breaking performance.

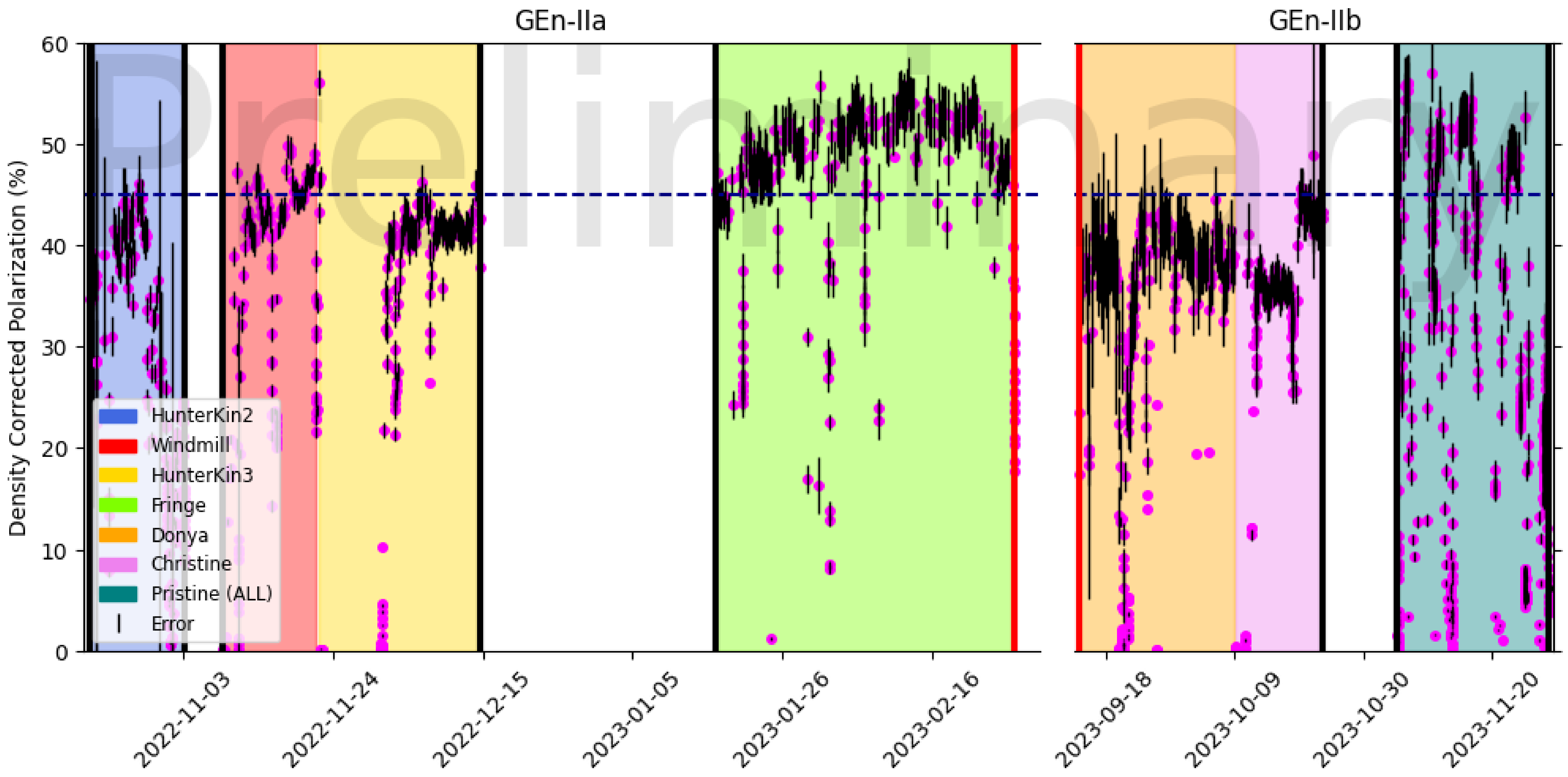
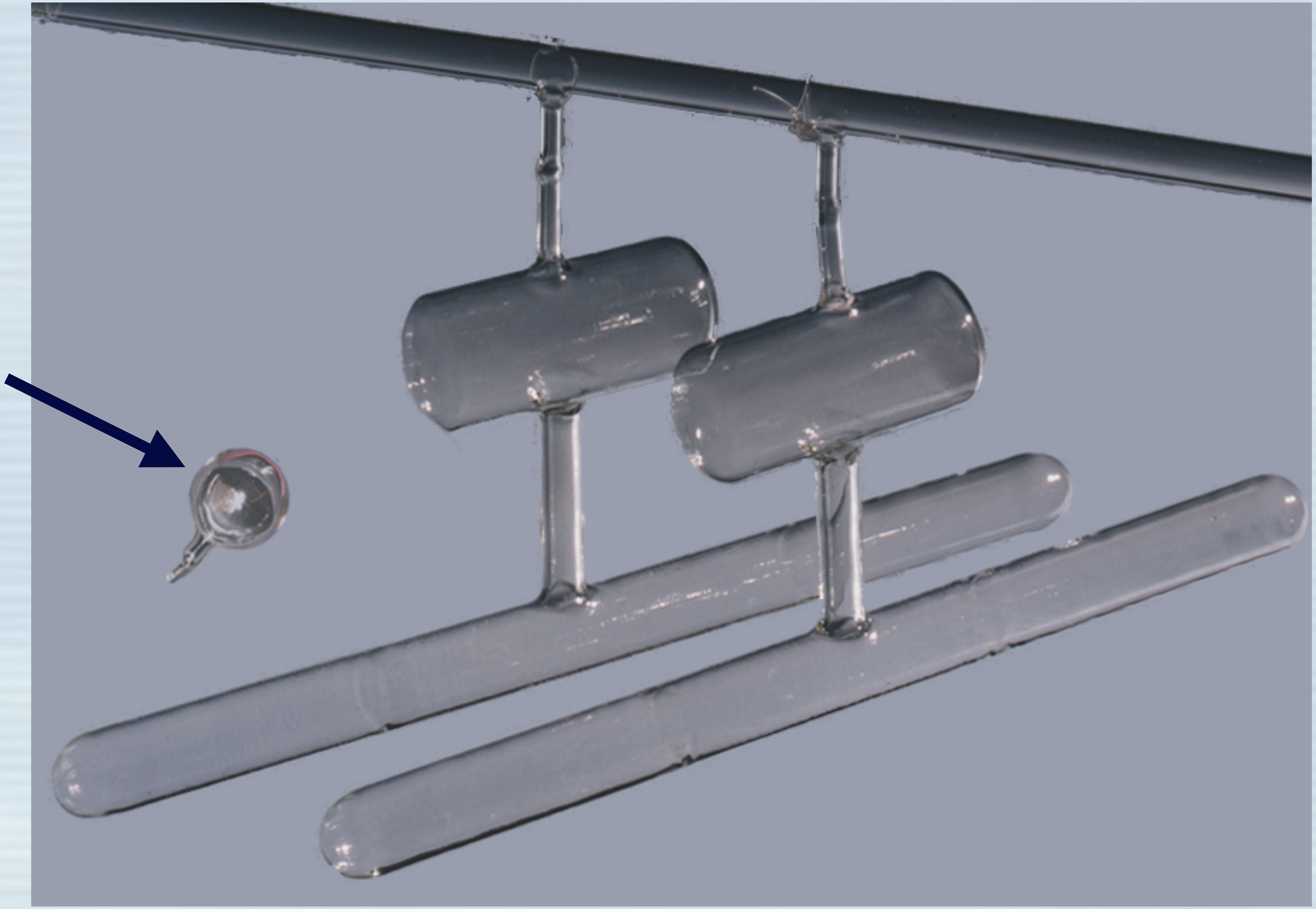


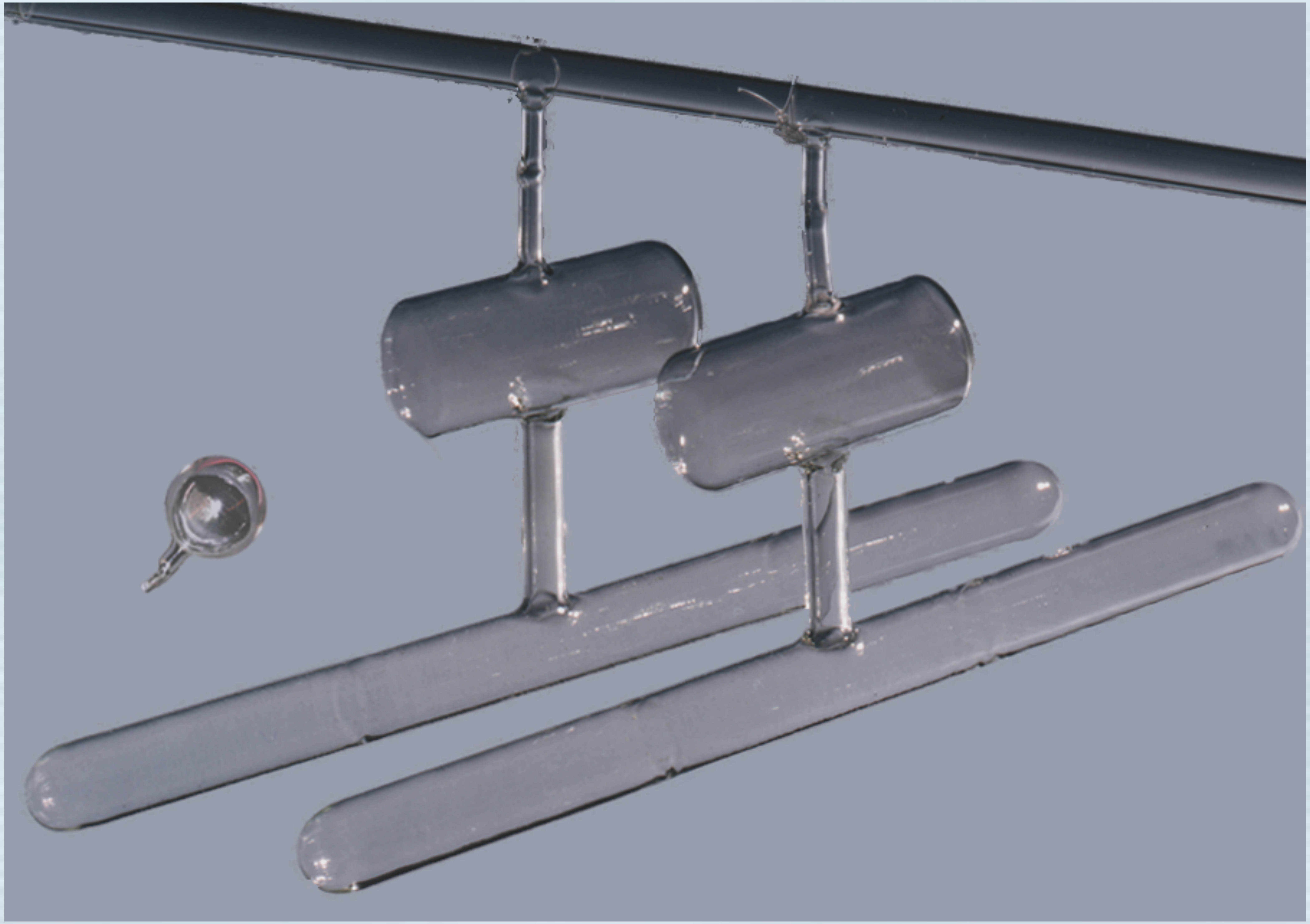
Figure 4. Shown above are the results of every NMR measurement on the polarized ^{3}He target during both the GEN-II and A_LL runs. The dashed line indicates a polarization level of 45%, which we treated as our nominal goal. Note that during the period prior to Nov. 11, 2022, we were collecting data at our lowest kinematic setting where we had very high event rates and could thus use the time to optimize the target. Note finally that during the period starting October 30, 2023 through the end of the run we had little to no beam and thus conducted numerous target-related tests when not taking data. Thus, the fluctuations in polarization during that time period were *not* during production running. The steady state polarization of that final target was well over 50%.

Early high-pressure polarized ^3He targets

- The first 10 atmosphere targets used to produce polarized muonic helium.
- Brought to light spin-relaxation due to dipolar interactions during ^3He-^3He collisions.



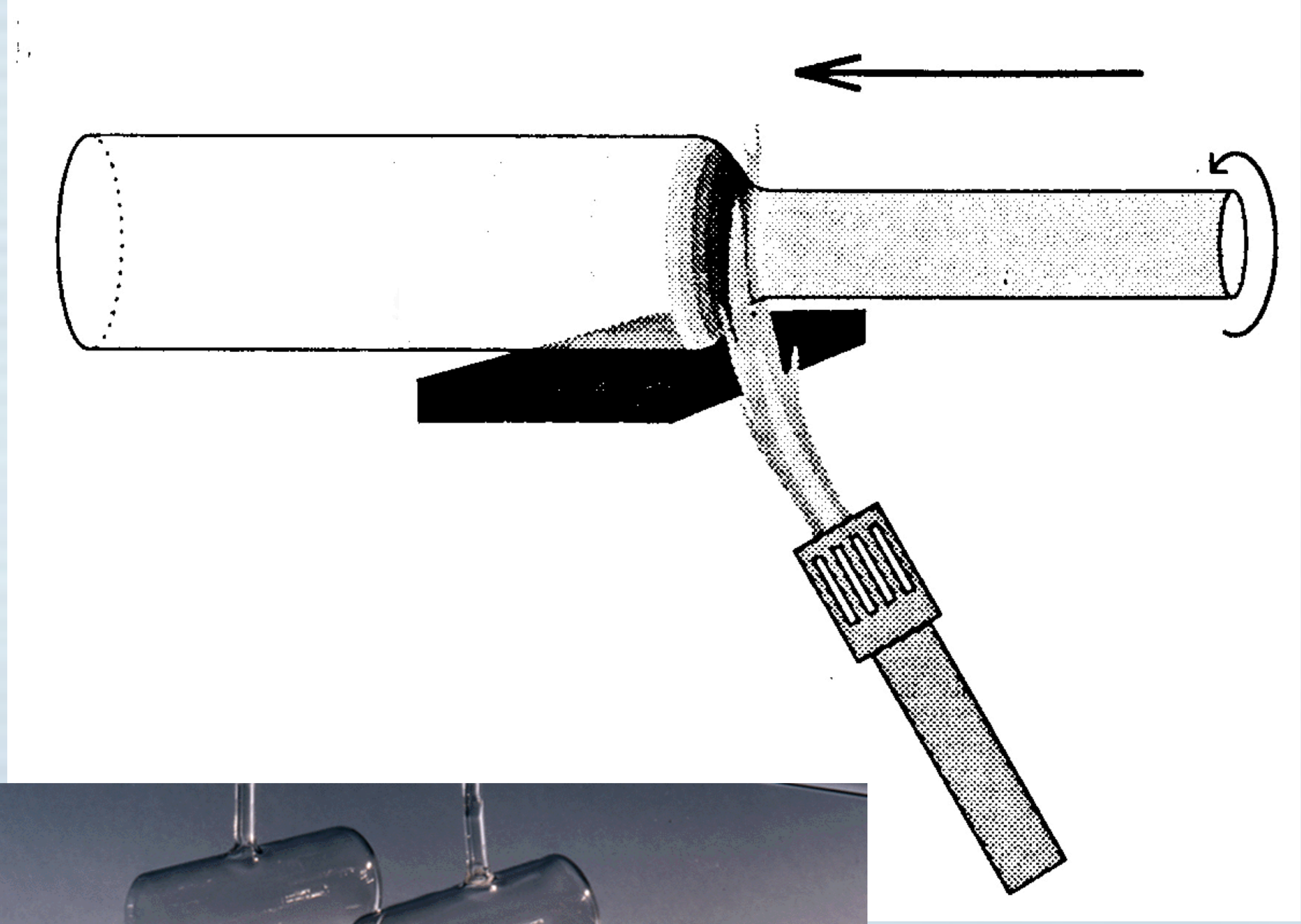
Early high-pressure polarized ^{3}He targets

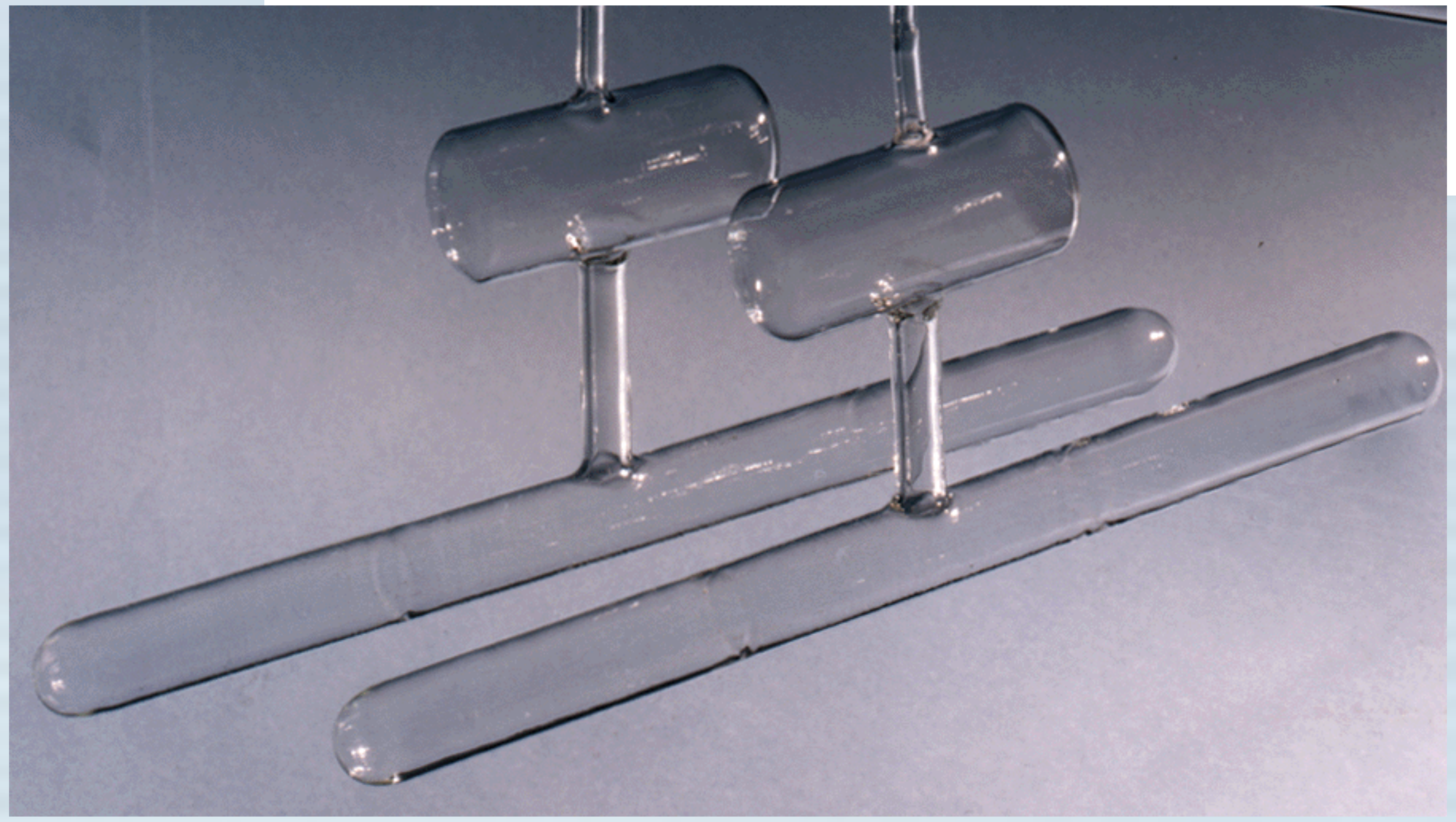


- The first large-volume 10 atmosphere targets produced for SLAC E-142
- Brought to light the role of micro-cracks in causing spin-relaxation

Minimizing the effects of micro-cracks

- The formation of micro-cracks in glass is a well-known phenomenon.
- They form spontaneously on the surface of glass within hours after the glass in molten.
- We found that a critical step in obtaining long-spin relaxation times in the SLAC target cells was “re-sizing the glass (illustrated at right).



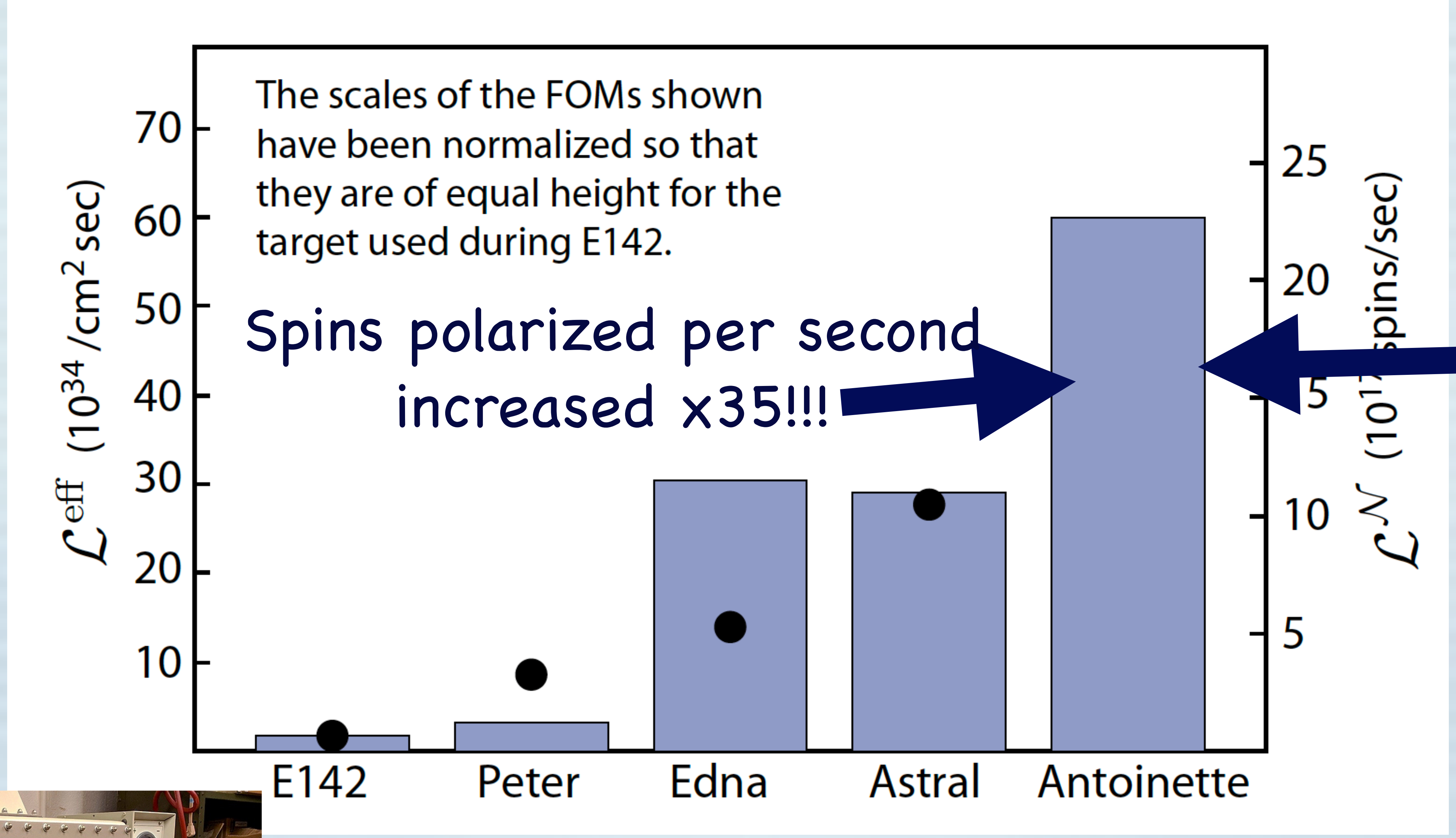


Alkali-hybrid spin-exchange optical pumping (AH-SEOP)

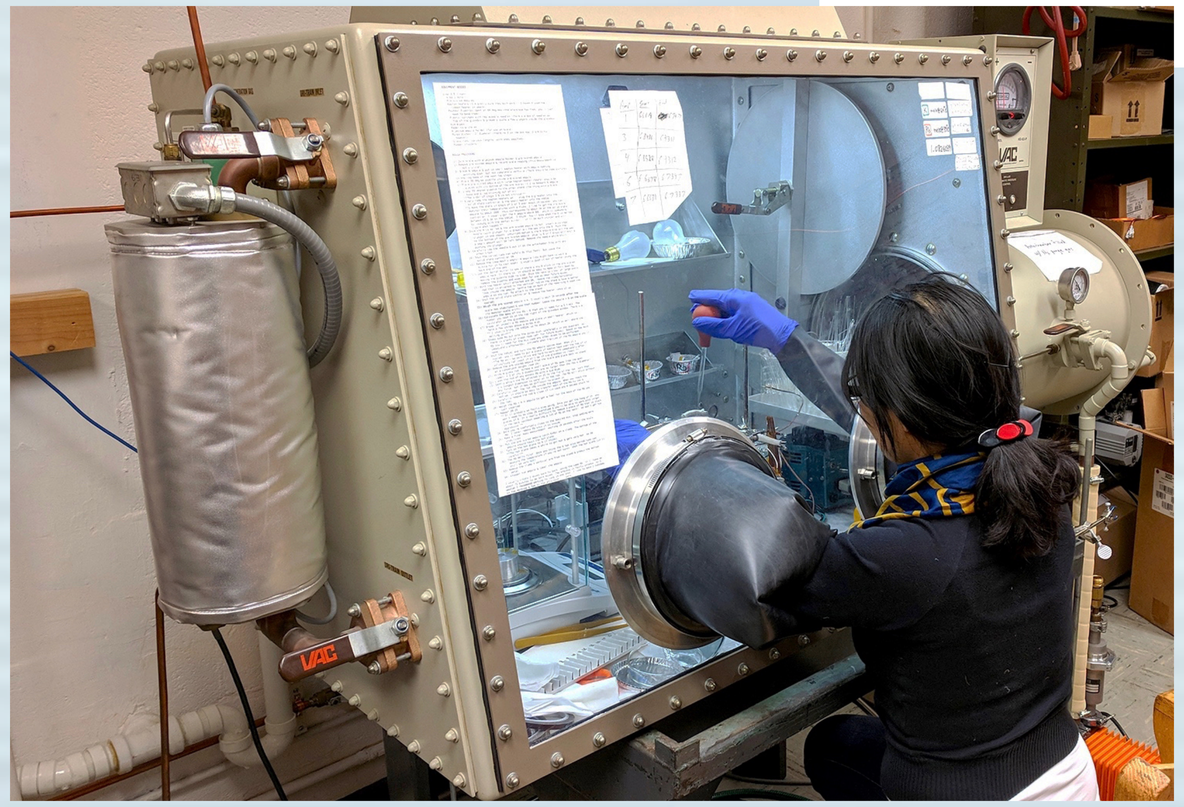
PHYSICAL REVIEW C **91**, 055205 (2015)

Development of high-performance alkali-hybrid polarized ^{3}He targets for electron scattering

Jaideep T. Singh,[1,2,3,*] P. A. M. Dolph,[1] W. A. Tobias,[1] T. D. Averett,[4] A. Kelleher,[4] K. E. Mooney,[1,†] V. V. Nelyubin,[1]
Yunxiao Wang,[1] Yuan Zheng,[1] and G. D. Cates[1]

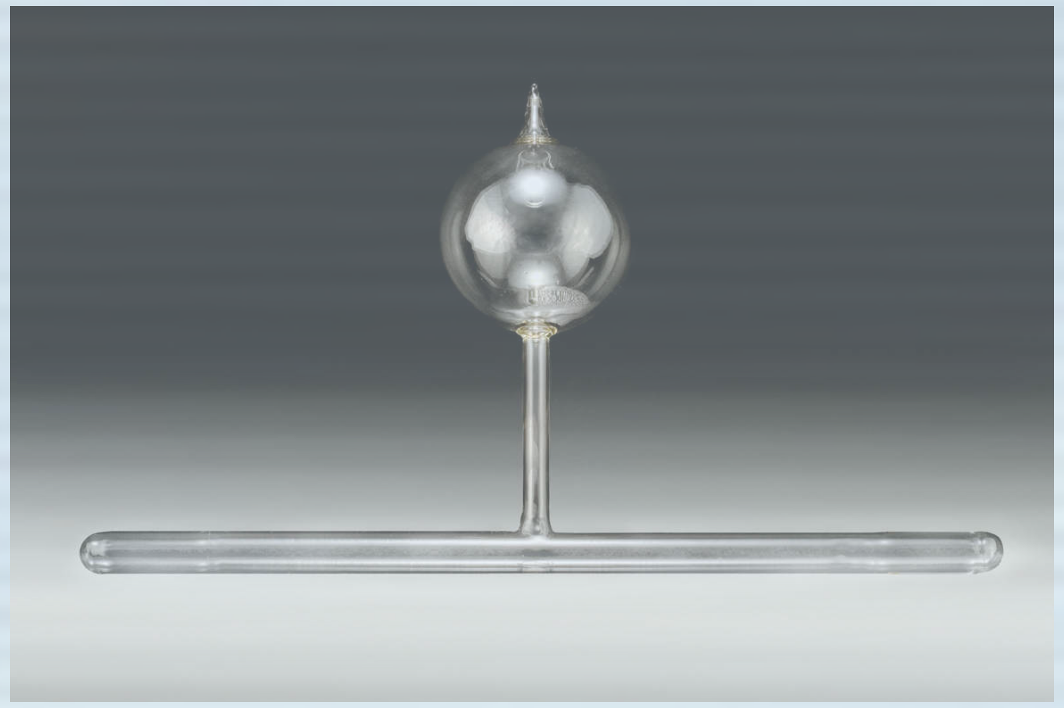


- The discovery that potassium is much more efficient at polarizing ^{3}He was a ***game changer***.
- Using mixtures of K and Rb in the target cells made it possible to polarize the ^{3}He MUCH more rapidly.
- This innovation made it possible to handle MUCH higher luminosity.



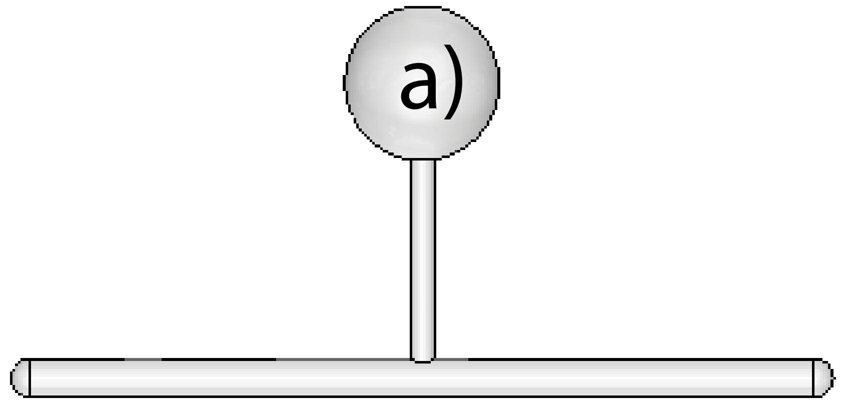
GEn-I →

Transversely →



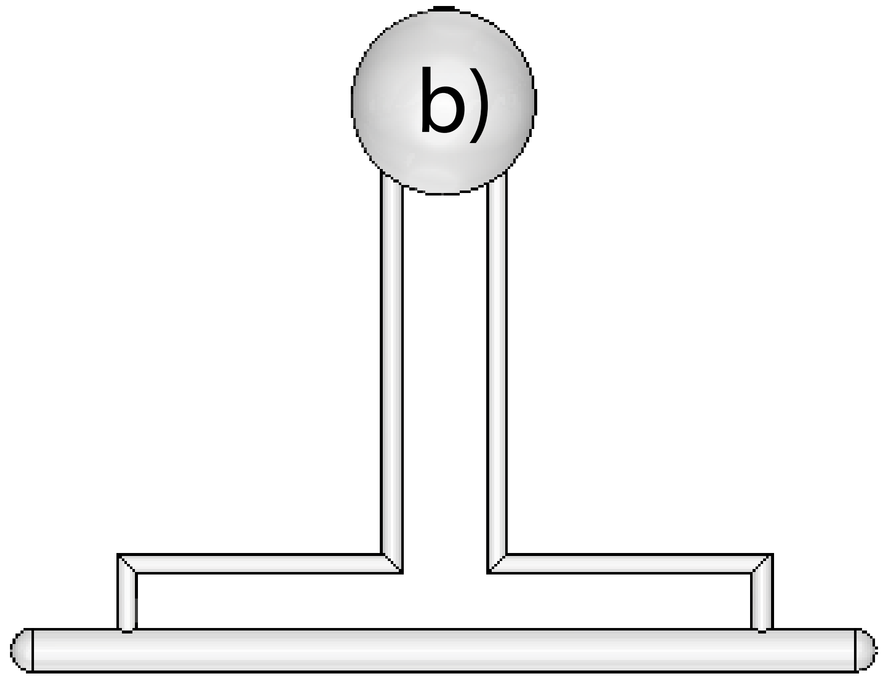
AHSEOP made it possible to dramatically scale up the size of target cells

Transversity/GEn-I



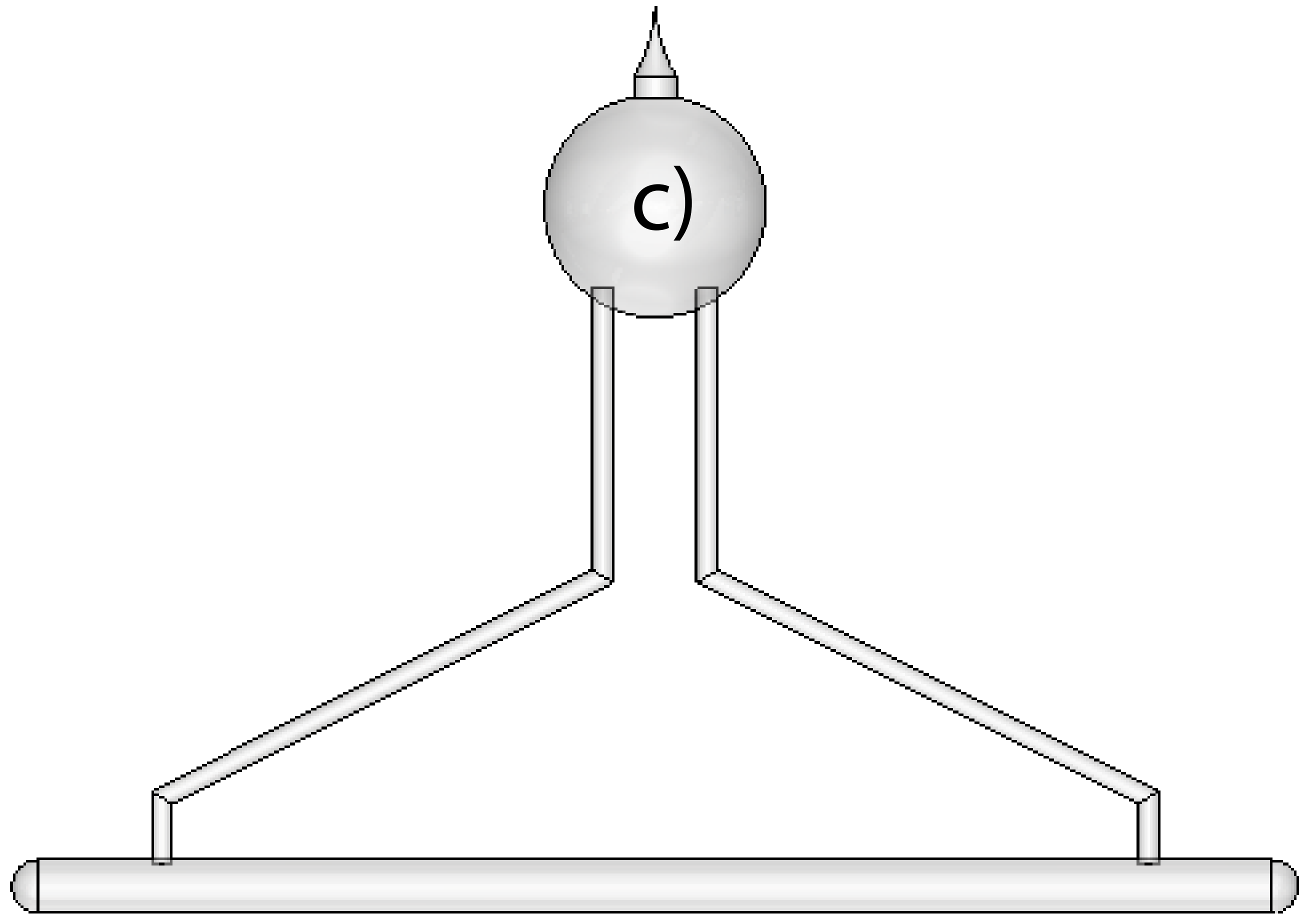
First generation to benefit from hybrid alkali mixtures (faster spin exchange) and narrow-band high-power diode laser arrays.

Hall C A1n



First generation to benefit from convection-based design.

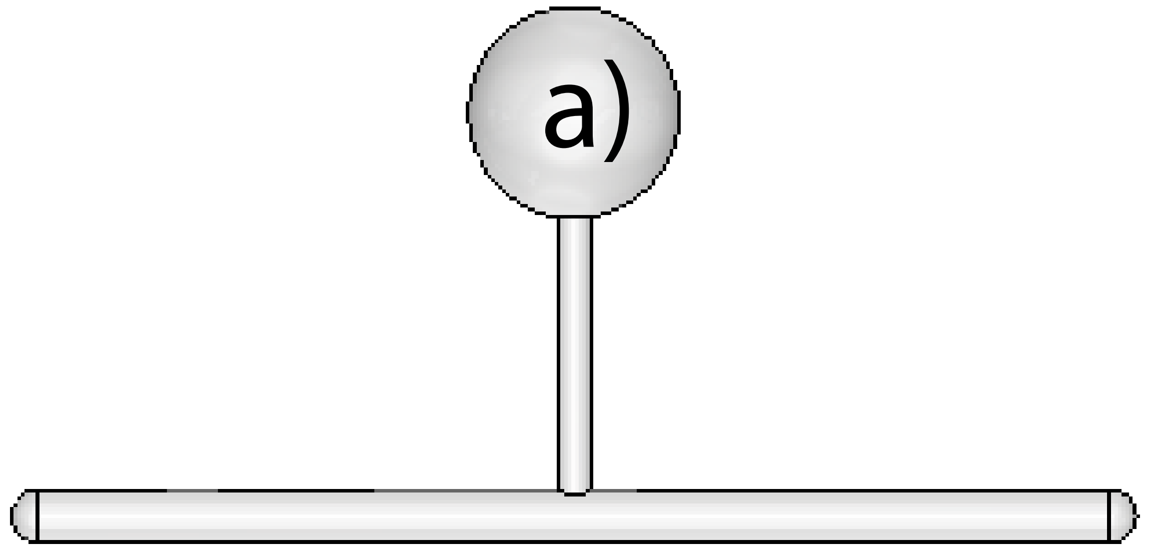
GEn-II



Designed with x1.5 increase in target thickness and ability to operate at x1.5 increase in beam current. Pumping from two directions.

The bad news - each improvement in figure-of-merit has proven quite challenging

Transversity/GEn-I

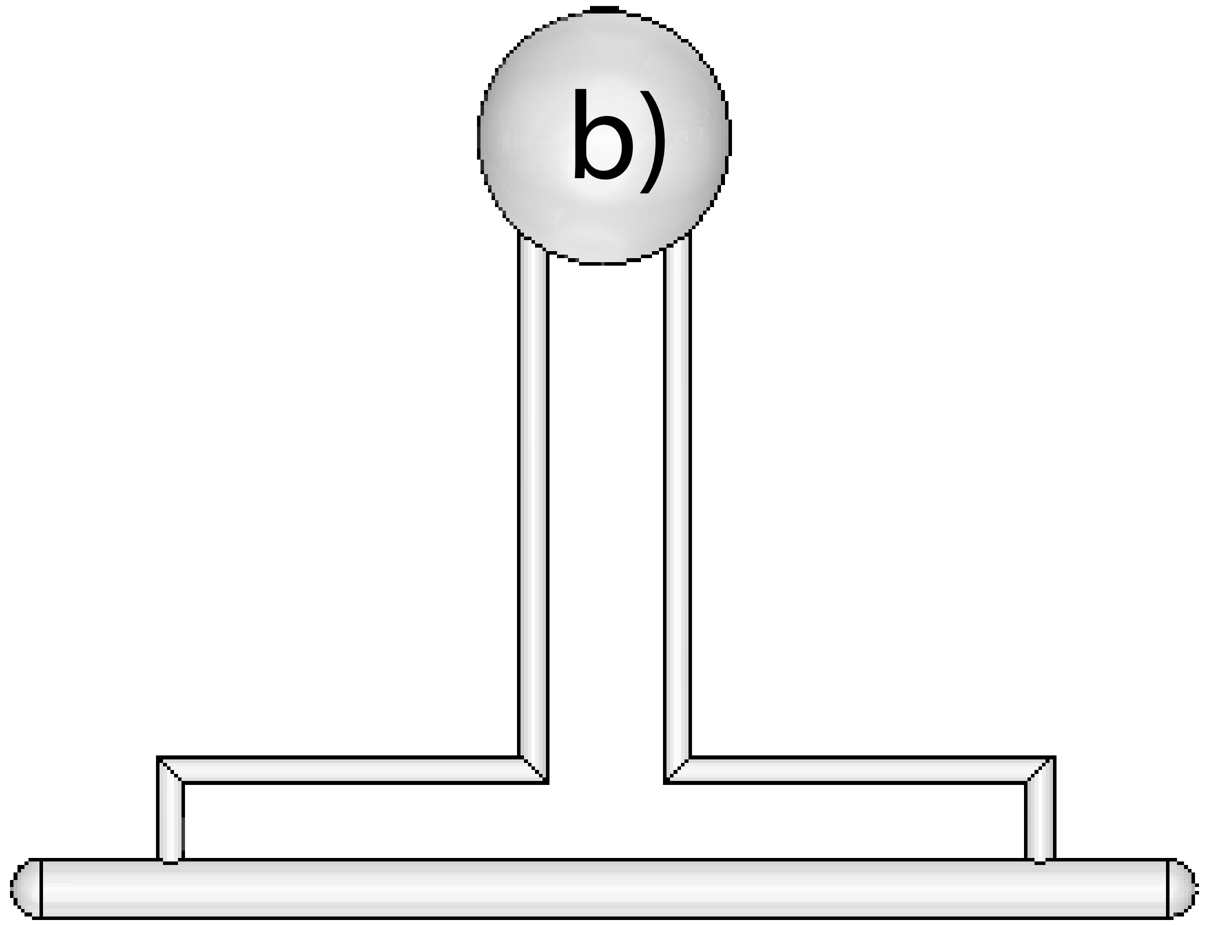


average = 29.1 hrs

median = 31.1 hrs

$P^2L = 2.8\times10^{35}/cm^2s$

Hall C A1n/d2n

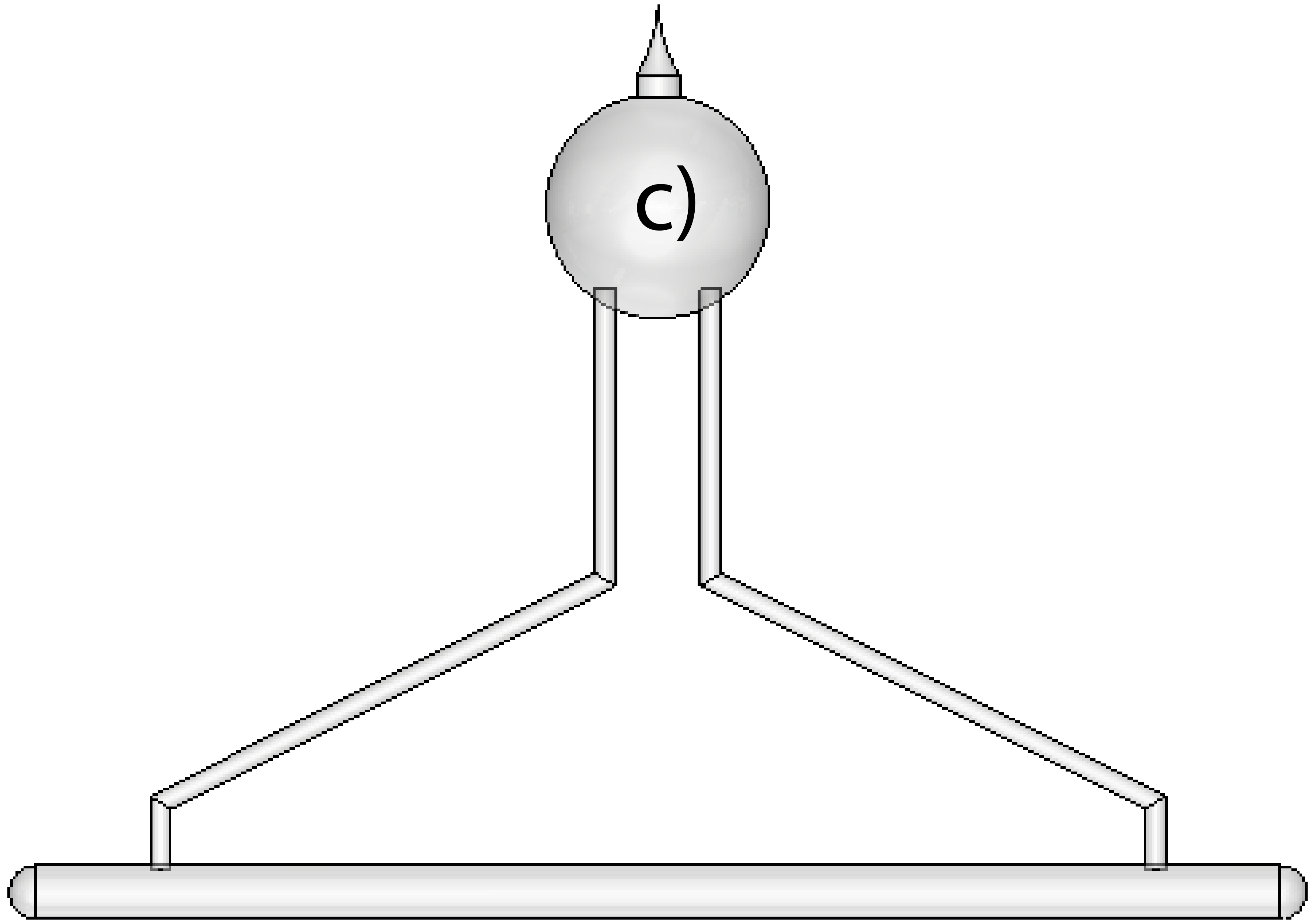


average = 19.6.5 hrs

median = 18.1 hrs

$P^2L = 5.0\times10^{35}/cm^2s$

GEn-II



average = 15.1 hrs

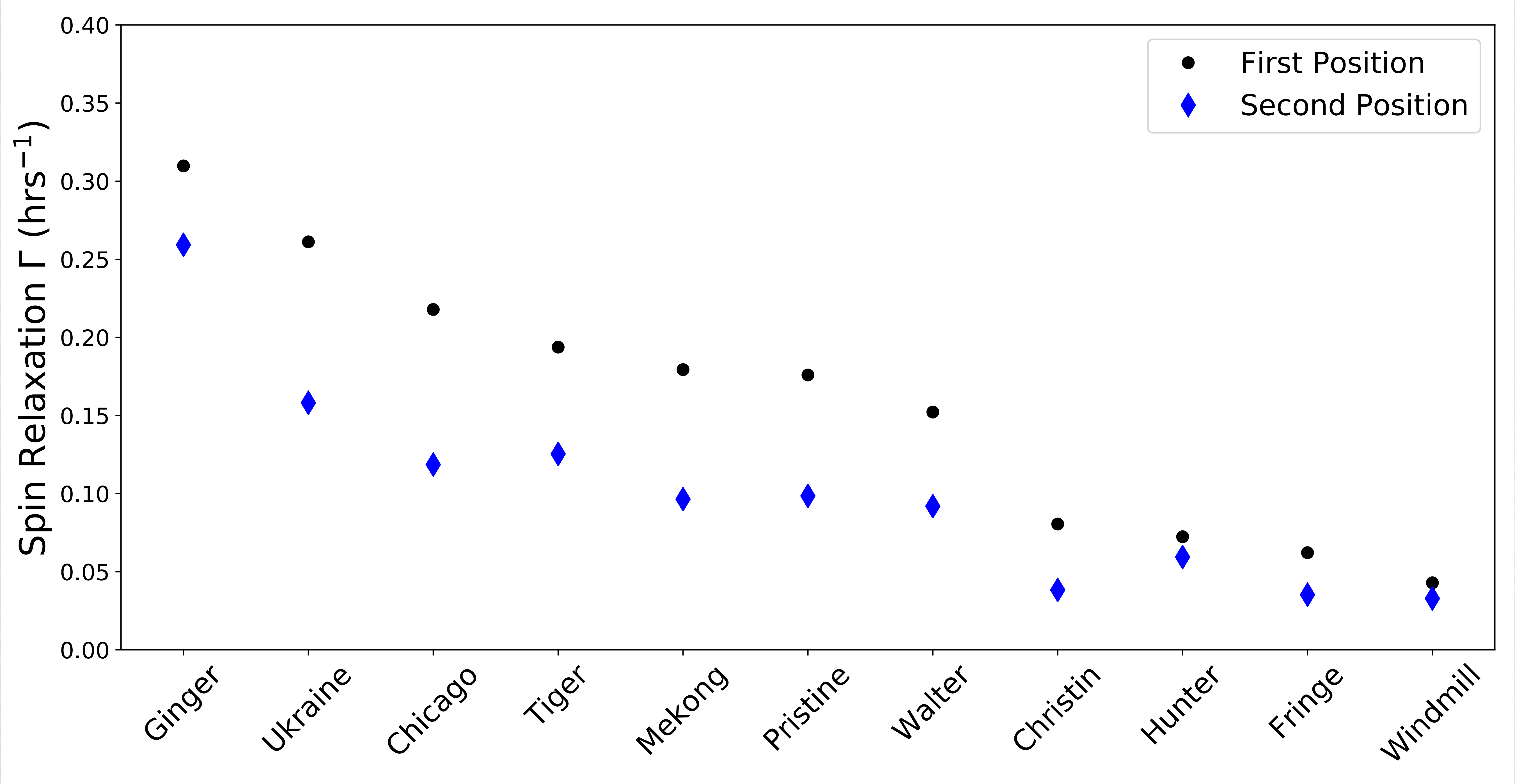
median = 12.8 hrs

$P^2L = 9.2\times10^{35}/cm^2s$

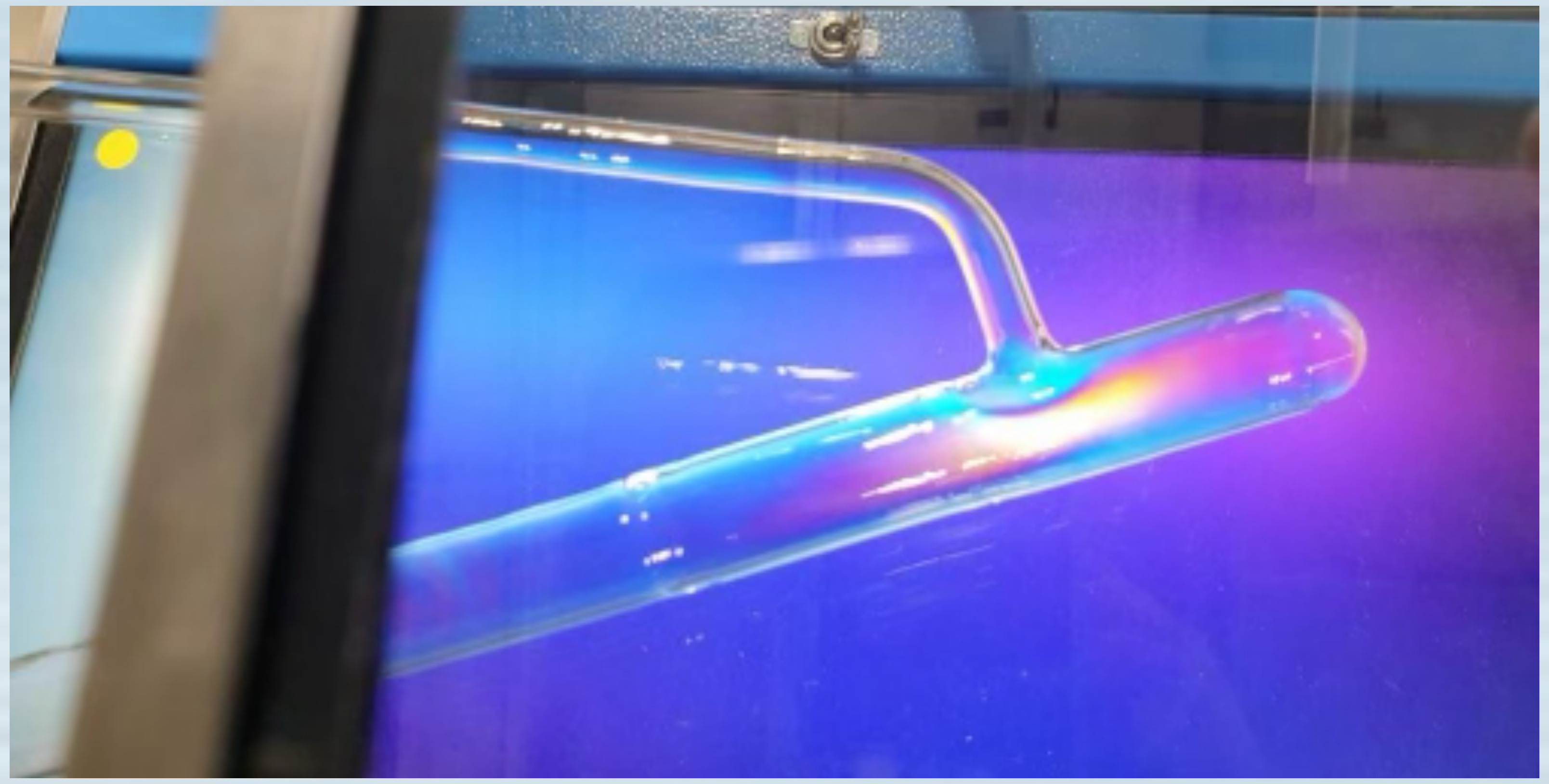
Spin relaxation clearly becomes more rapid with increasing size and complexity

Hysteresis and faster overall spin relaxation

- Pump up a freshly made target cell.
- Measure it's "lifetime".
- Flip the cell by 180 degrees (with respect to the magnetic field).
- Re-measure the lifetime, it is always longer.



Different microcracking patterns are observed at indentation sites depending on the glass composition and indentation cracks may form during both the loading and the unloading stages. Besides, we do



The are multiple phenomena (I won't cover them all) that point toward microcracks playing a central role.

What to do about reducing microcracks?

(other than simpler cells at lower pressure)

Corning® Gorilla®
Glass Ceramic 2

Chemical tempering by ion exchange (often with potassium)

Journal of Non-Crystalline Solids
Volume 669, 1 December 2025, 123815

Effect of strengthening methods on mechanical properties of Li_2O-Al_2O_3-SiO_2 glass

Penghui Yang [a], Yanhang Wang [a], Xianzi Li [a], Kun He [b]

Materials Science and Engineering B 149 (2008) 159–165

Review

Ion exchange for glass strengthening

René Gy

Journal of Non-Crystalline Solids 473 (2017) 170–178
Contents lists available at ScienceDirect
Journal of Non-Crystalline Solids
journal homepage: www.elsevier.com/locate/jnoncrysol
ELSEVIER

Chemical tempering of soda lime silicate glasses by ion exchange process for the improvement of surface and bulk mechanical strength

İpek Erdem[a], Duygu Guldiren[b], Suheyla Aydin[a,*]

Our next set of test cells will be made of Corning 2345 (Valor glass) – We'll see what happens! 🤞

Polarized ^{3}He target forSBS SIDIS

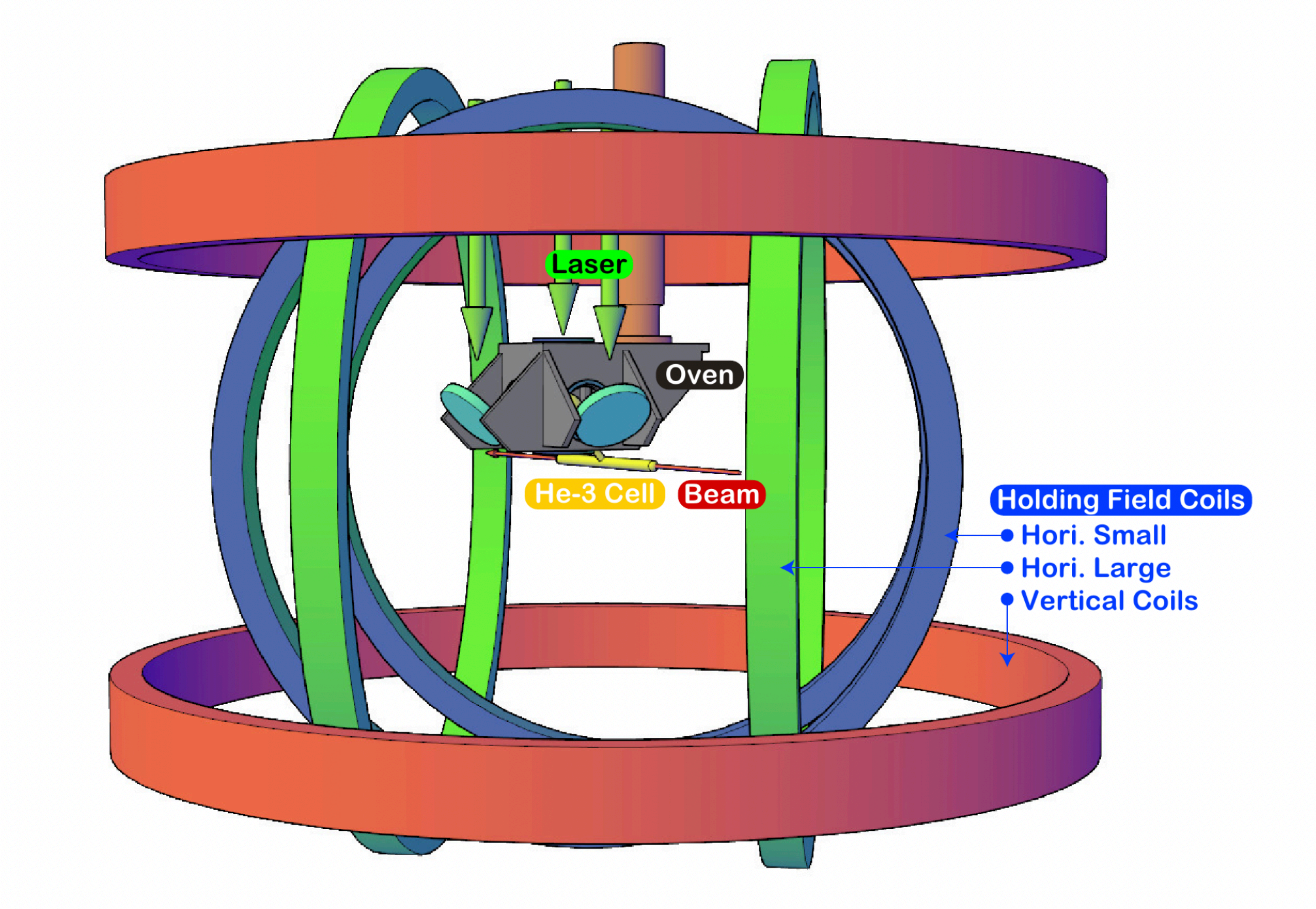
Proposal specs for SBS SIDIS:

- 40 μA
- 50 cm length
- 11.5 atmospheres
- 60% polarization … 🤔

Given our experience with GEn-II and prior experience with the Transversity experiment, we are confident that we can meet, or come close to meeting, the proposal specs

Polarized ^{3}He target for Transversity (E06-010)

Shown at right are some of the components that were used for the Transversity experiment (E06-010) that ran from November 2008 - February 2009.



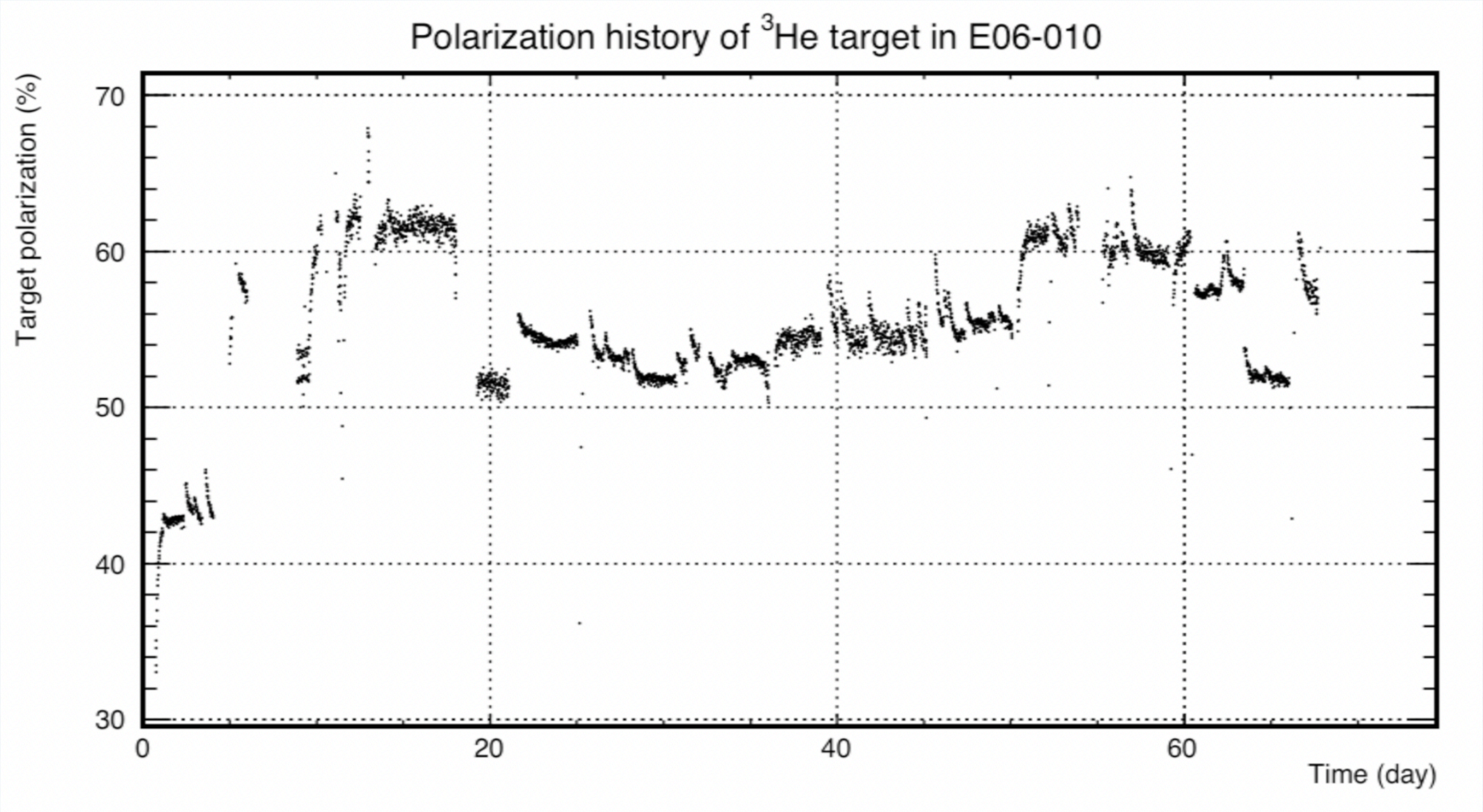
Requirements include:

- The ability to run with vertical polarization (notice direction of lasers above).
- The ability to reverse the direction of polarization quickly.

Performance of the polarized ^{3}He target during Transversity

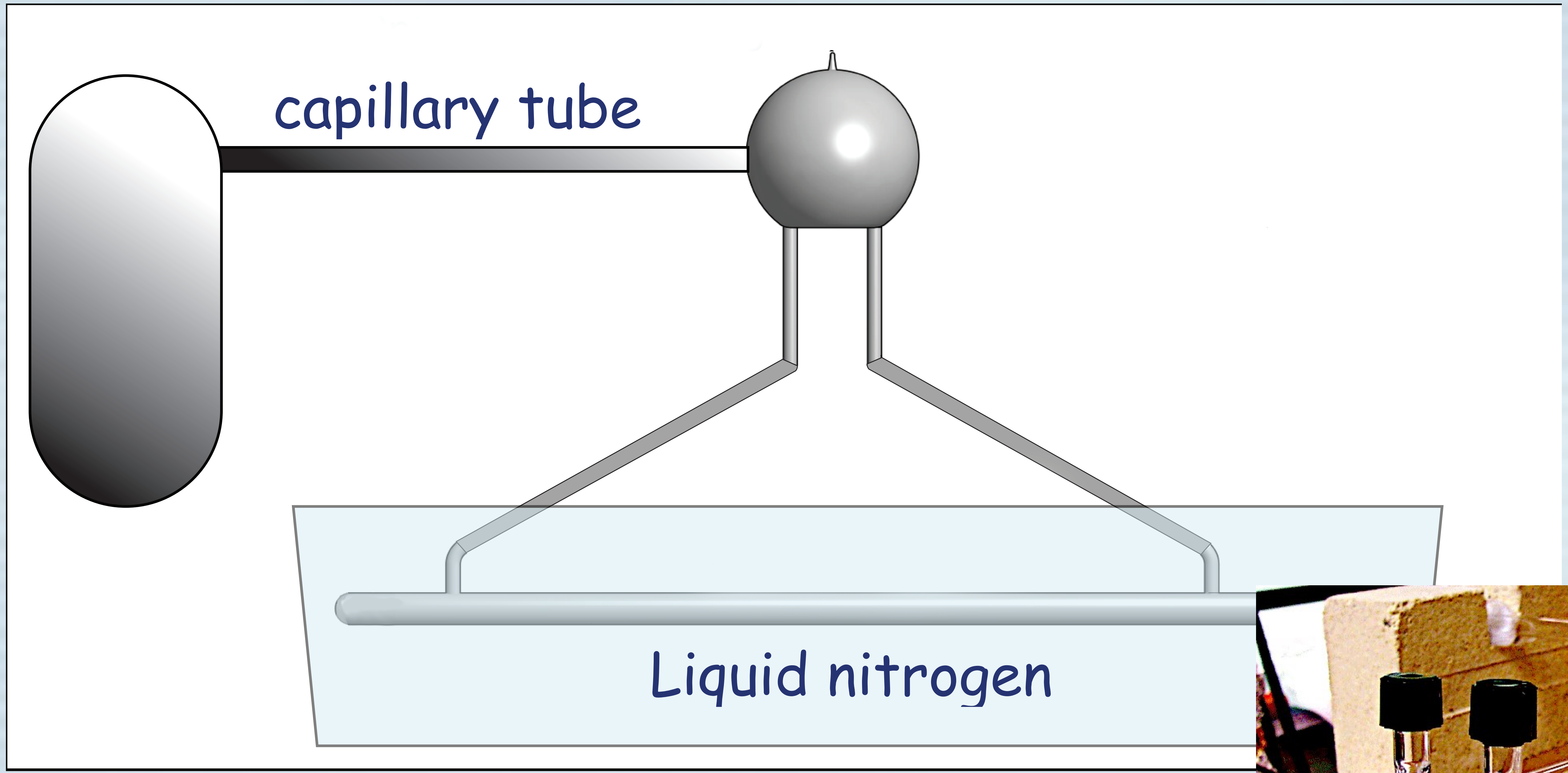
- Average polarization of gas in the beam of 55.4 +/- 2.8%
- Gas was distributed using diffusion resulting in significant polarization gradient of ~5% between the pumping and target chambers.
- Without beam, polarizations as high as 70% were observed.
- Current was typically 12 uA with a 40 cm long target chamber.
- Vertical polarization was reversed every 20 minutes using AFP with reasonably low losses.
- Gas was distributed using diffusion resulting in significant polarization gradient between the pumping and target chambers.

Performance of the polarized ^{3}He target during Transversity

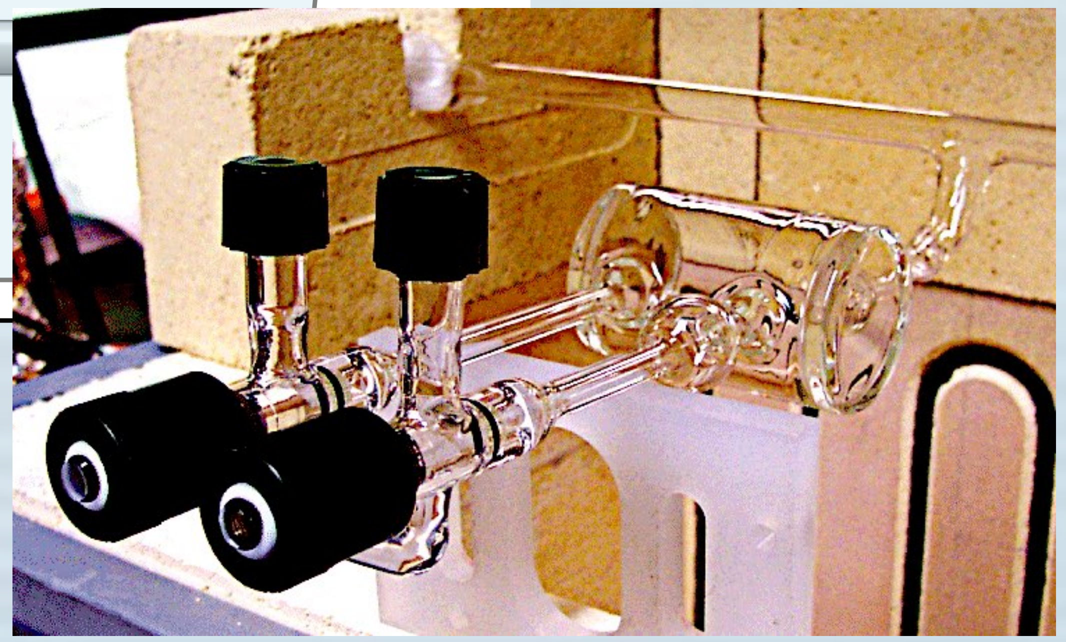


Target cells with connected to a ballast volume
(Bogdan's suggestion !)

- Connect the target cell to a ballast volume (also filled with ^3He)
- Cell pressure can be significantly lower than at present, while still providing a density of even 20-30 amagats (density corresponding to 1 atm STP).
- The capillary tube** insures that, the gas in the ballast volume will not cause additional spin relaxation, or for that matter, does not need to be polarized.



Identifying a material that has favorable spin-relaxation properties at 77K and that is also radiation and hard would make this idea quite practical.



Example shown above of capillary tubes being used in basically this fashion in commercial noble-gas polarizers.

** For the record, I have a patent on the use of capillary tubes for such purposes.

Thank you!