Polarized ^{3}He target update

- Comments on the evolving capabilities
- New developments for the 12 GeV era
- Milestone #1 - choice of target-cell design for SBS G_E^n

G. Cates - UVa
Hall A Collab. Mtg., December 9, 2014

Polarized ^{3}He target requirements:

past and future

Experiment	Current (μA)	Polarization	Luminosity
SLAC E142	3.3	33%	1.5×10^{35}
GDH	12.5	35%	1.0×10^{36}
GEn	8	47%	6.1×10^{35}
Transversity	12	55%	9.0×10^{35}
Hall A A1n	30	65%	3.3×10^{36}
SBS GEn	60	62%	6.6×10^{36}
Hall C A1n	60	60%	6.6×10^{36}

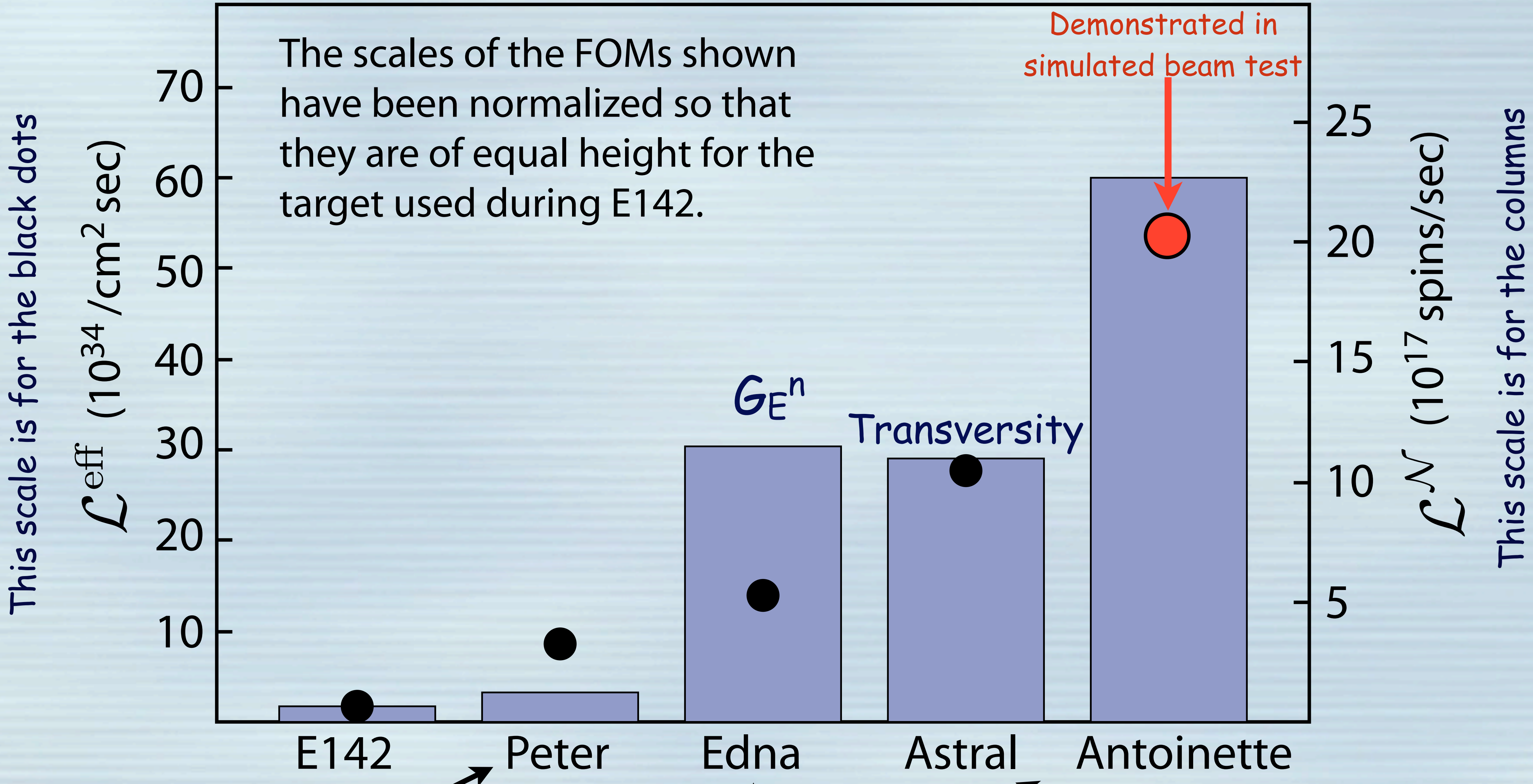
Past

Future

Important technology

- High-power diode-laser arrays (SLAC E154/JLab E-94-010 (GDH))
- Careful selection through full-power tests (E-99-117 (A1n))
- Alkali-hybrid spin-exchange optical pumping (GEn)
- Spectrally-narrowed high-power diode-laser arrays (Transversity)
- Convection-driven cells (demonstrated in bench tests)
- Metal end windows (in development)

The performance of polarized ^{3}He targets have increased by roughly a factor of 30 since SLAC E142



This scale is for the black dots

This scale is for the columns

The scales of the FOMs shown have been normalized so that they are of equal height for the target used during E142.

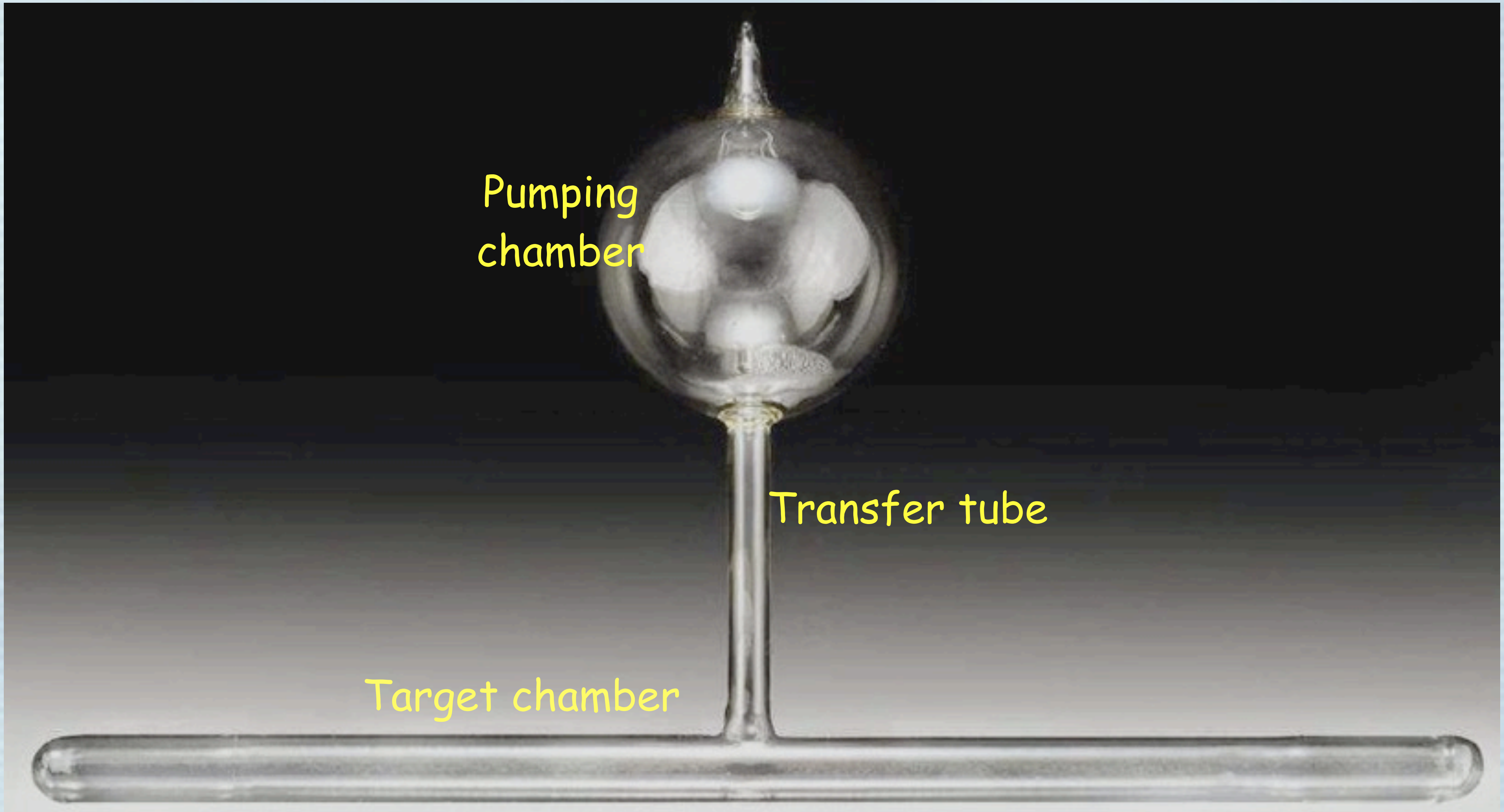
Demonstrated in simulated beam test

Commercial fiber-coupled high-power diode laser arrays: early JLab

Alkali-hybrid SEOP

Commercial spectrally narrowed high-power diode laser arrays

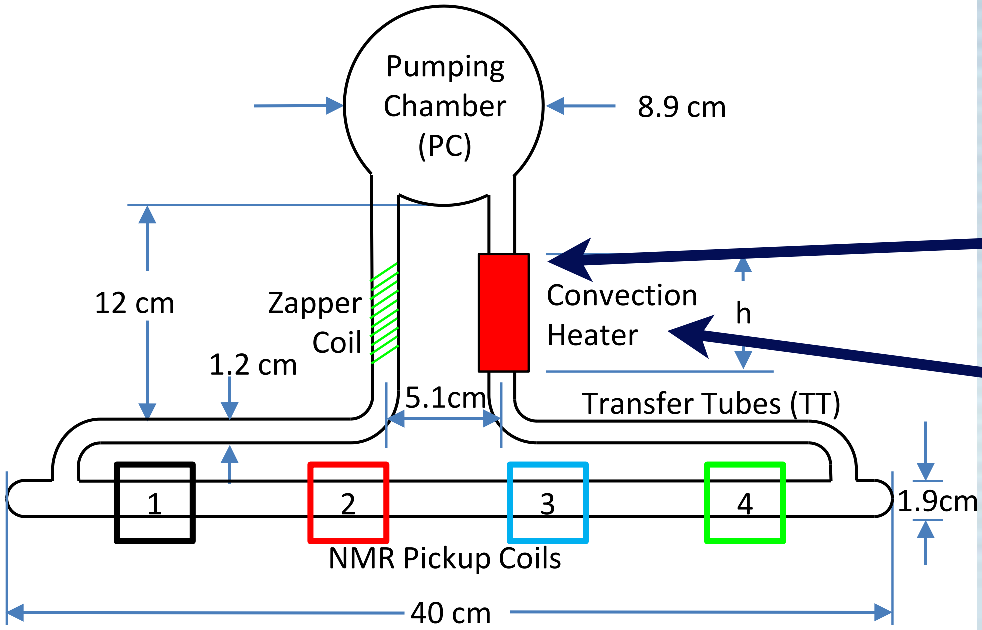
Most recent JLab targets



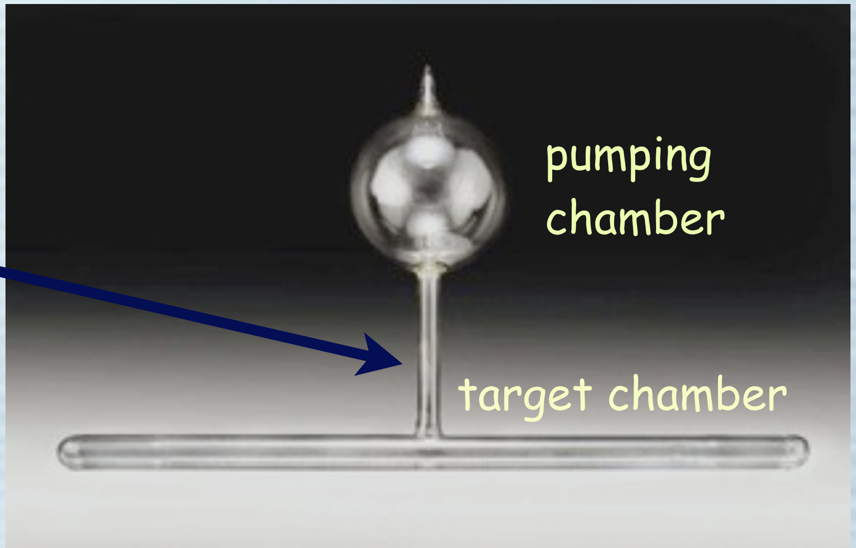
- Luminosity ~ 10^{36}cm^{-2}s^{-1}
- Total quantity of gas polarized: ~3 STP liters in larger cells
- Polarizations > 70%, >60% in 15μA beam, but only ~55% in the target chamber
- Ultimately, during Transversity, the single "transfer tube" became a performance limiting factor

New technologies important for the next jump in performance

Convection-based target cells



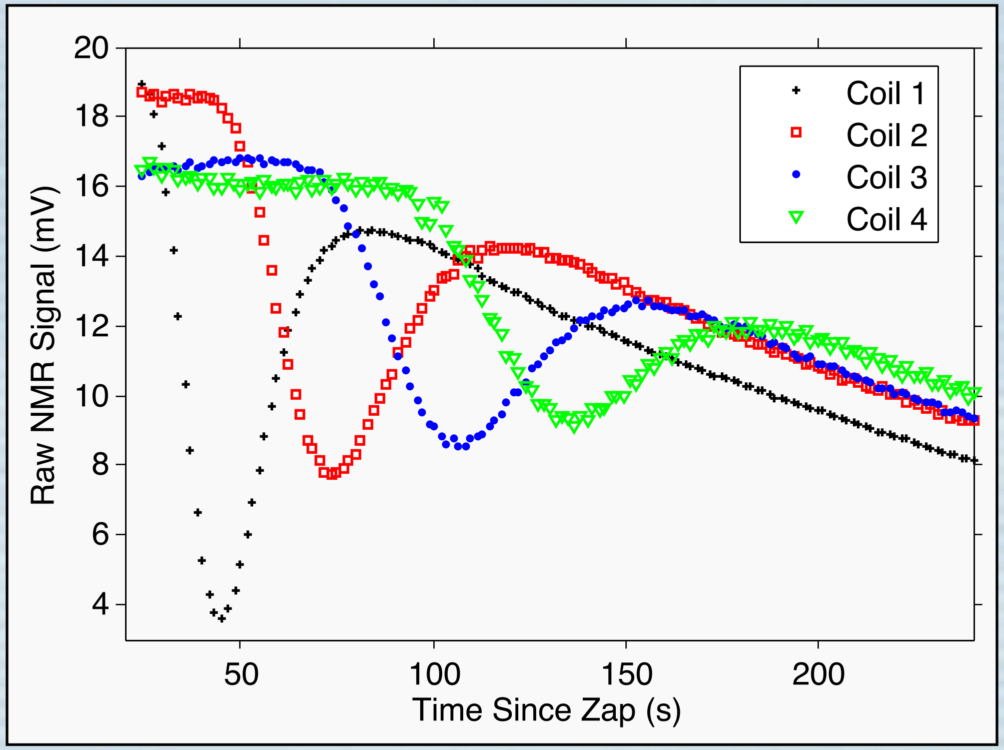
The convection-style cells have two transfer tubes instead of one.



A small heater on one transfer tube creates a buoyancy force that induces convection

<u>Measuring the gas speed</u>

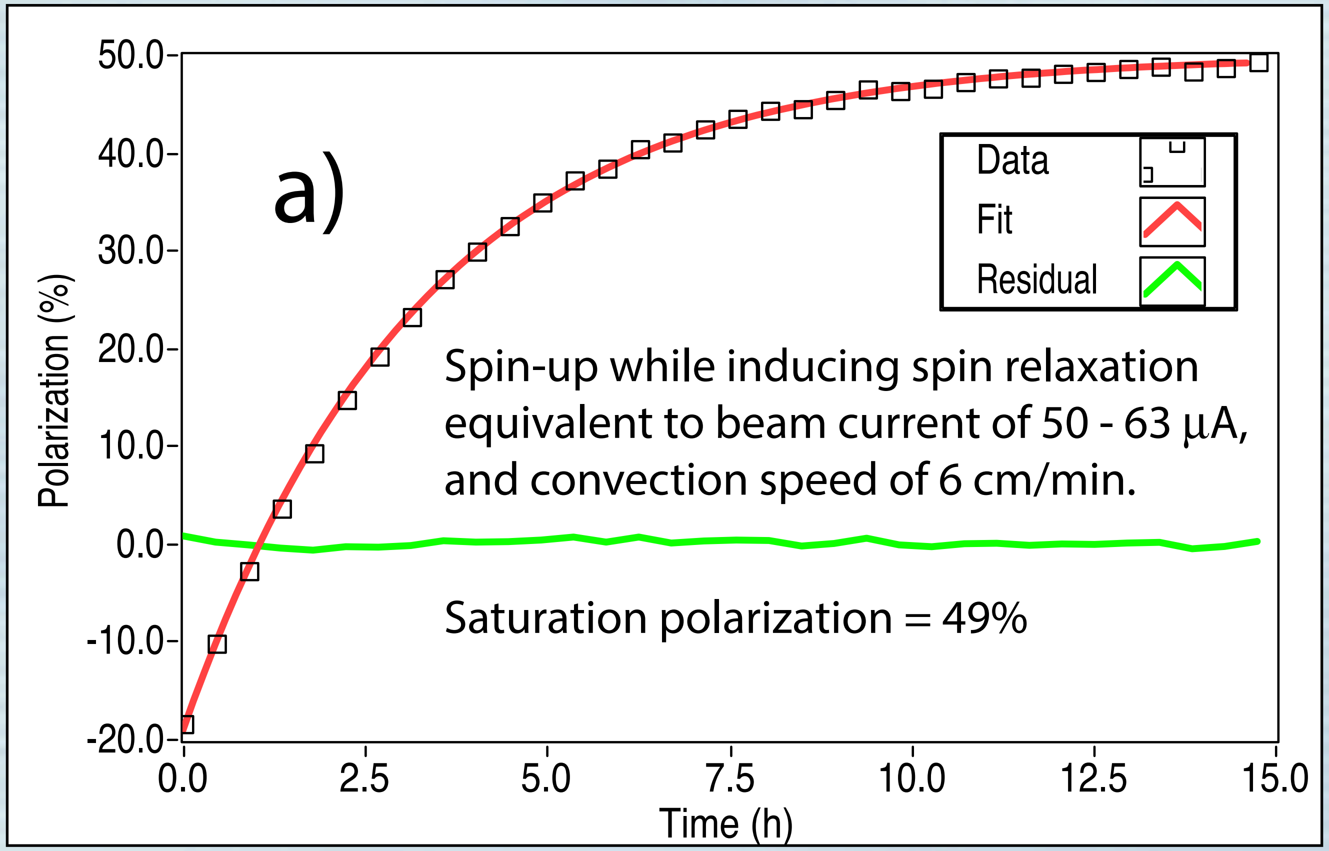
A "Zapper coil" is used to produce a depolarized slug of gas. Four NMR pickup coils register the passage of the slug of gas as a function of time.



Dolph, Singh, Averett, Kelleher, Mooney, Nelyubin, Tobias Wojtsekhowski and Cates, PRC vol 84, pg 065201 (2011)

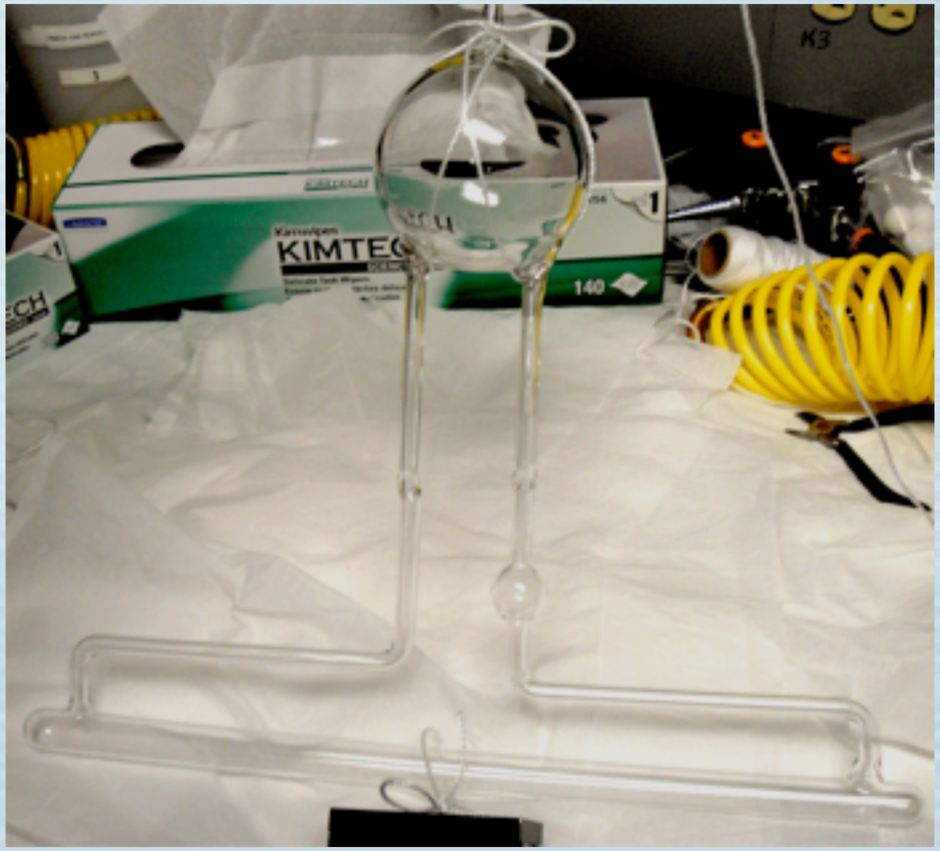
Simulated Beam Tests of Protovec-I targets

Tests from spring 2012



Spin-up while inducing spin relaxation equivalent to beam current of 50 - 63 µA, and convection speed of 6 cm/min.

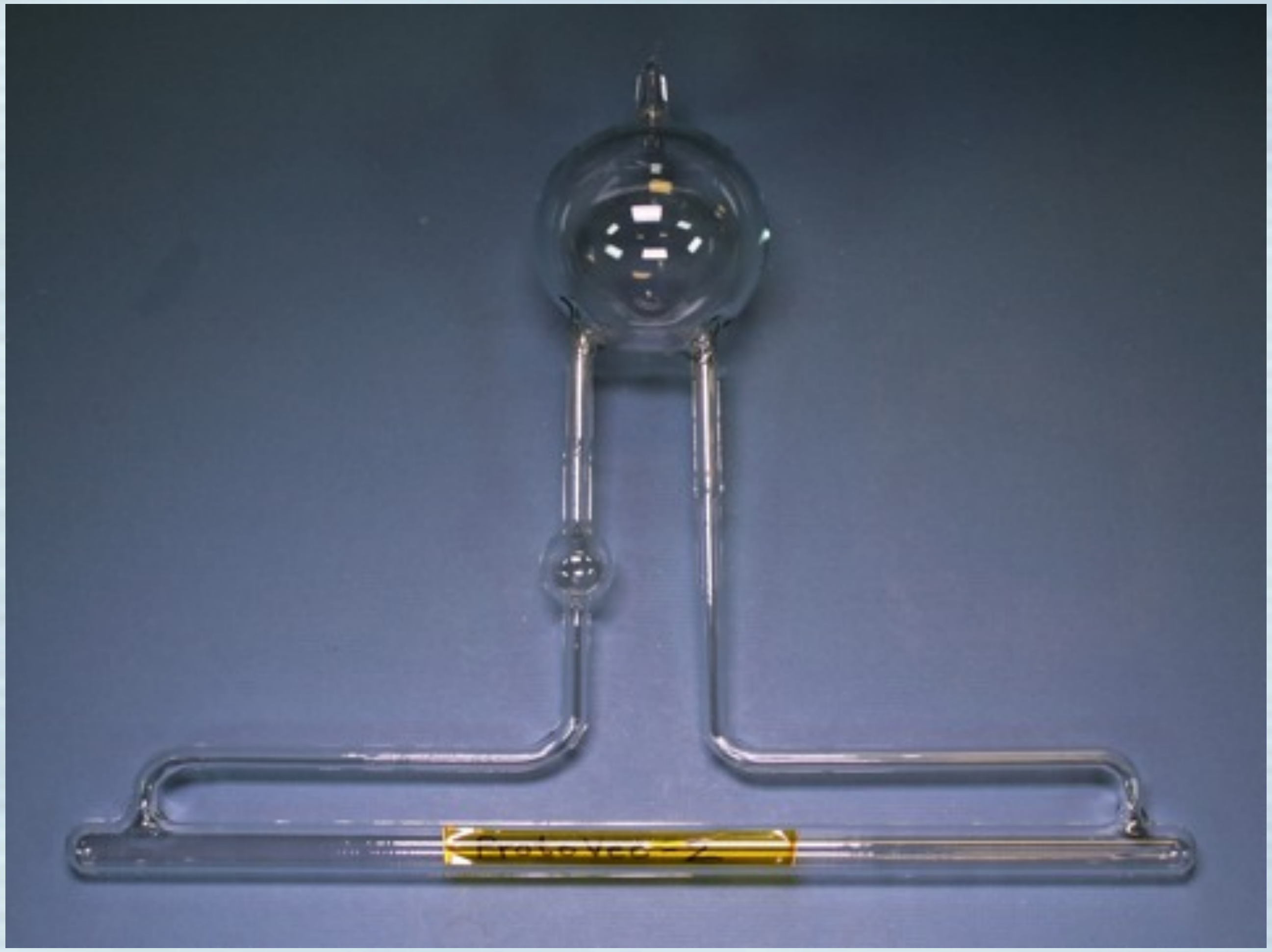
Saturation polarization = 49%

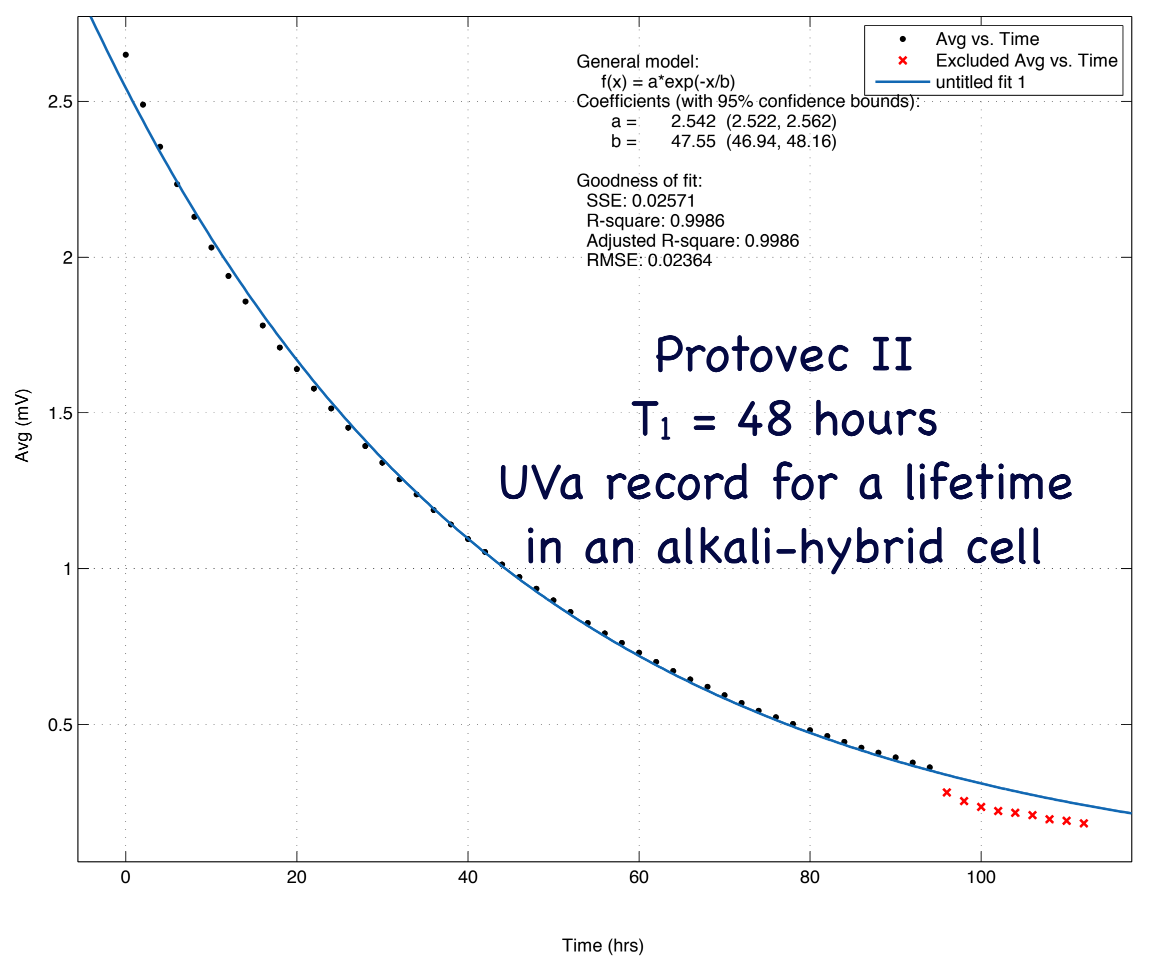


Simulated beam tests suggest that at least 49%, is achievable with 45 μA on a Protovec-style cell.

The above simulated beam test suggests that 60% is achievable with the chosen G_E^n cell design and 60 μA of beam

Tests of Protovec-II in 2014 show further progress





Protovec II

T_1 = 48 hours

UVa record for a lifetime in an alkali-hybrid cell

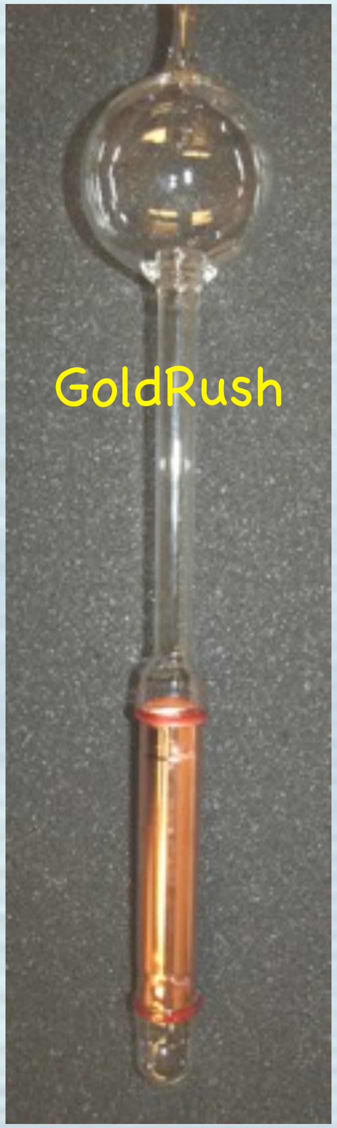
Progress on prototype testing since November 2013:

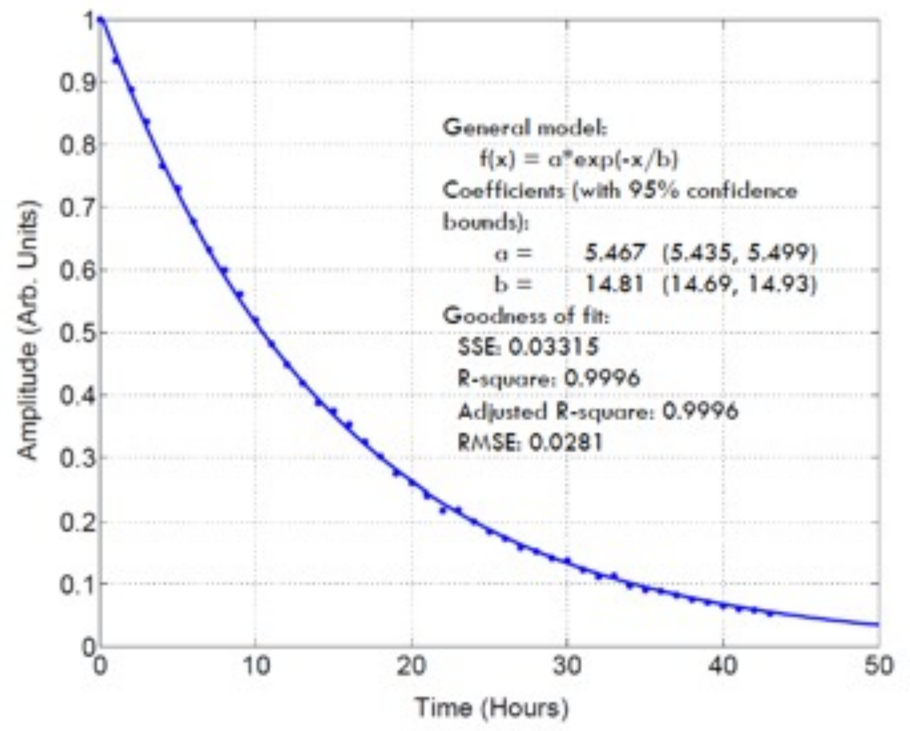
- Having previously studied Protovec-I, we have completed extensive testing on a second Prototype (Protovec-II). Fifty studies were completed over a four month period.
- Intrinsic cell lifetime of 48 hours measured, the longest of any JLab alkali-hybrid cell.
- Polarization of 64% was measured without convection, and 55% with convection speed at approximately 6cm/min.

For high beam currents, we would at least like metal end windows on the target chamber

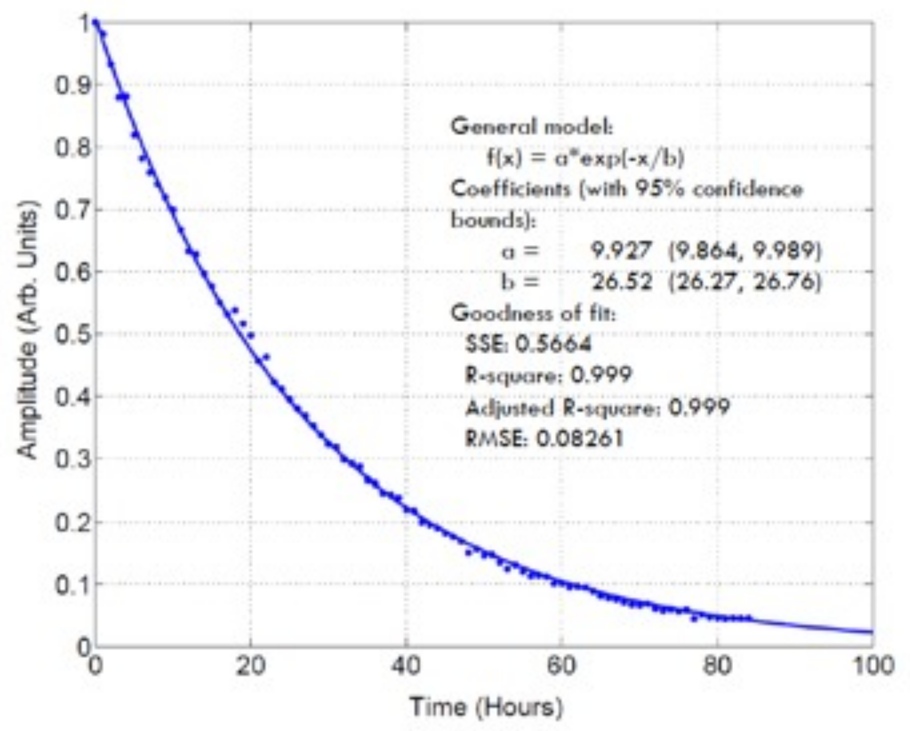
We have had a long campaign trying to incorporate metal into cells successfully!

In January 2014, we established acceptable spin-relaxation properties





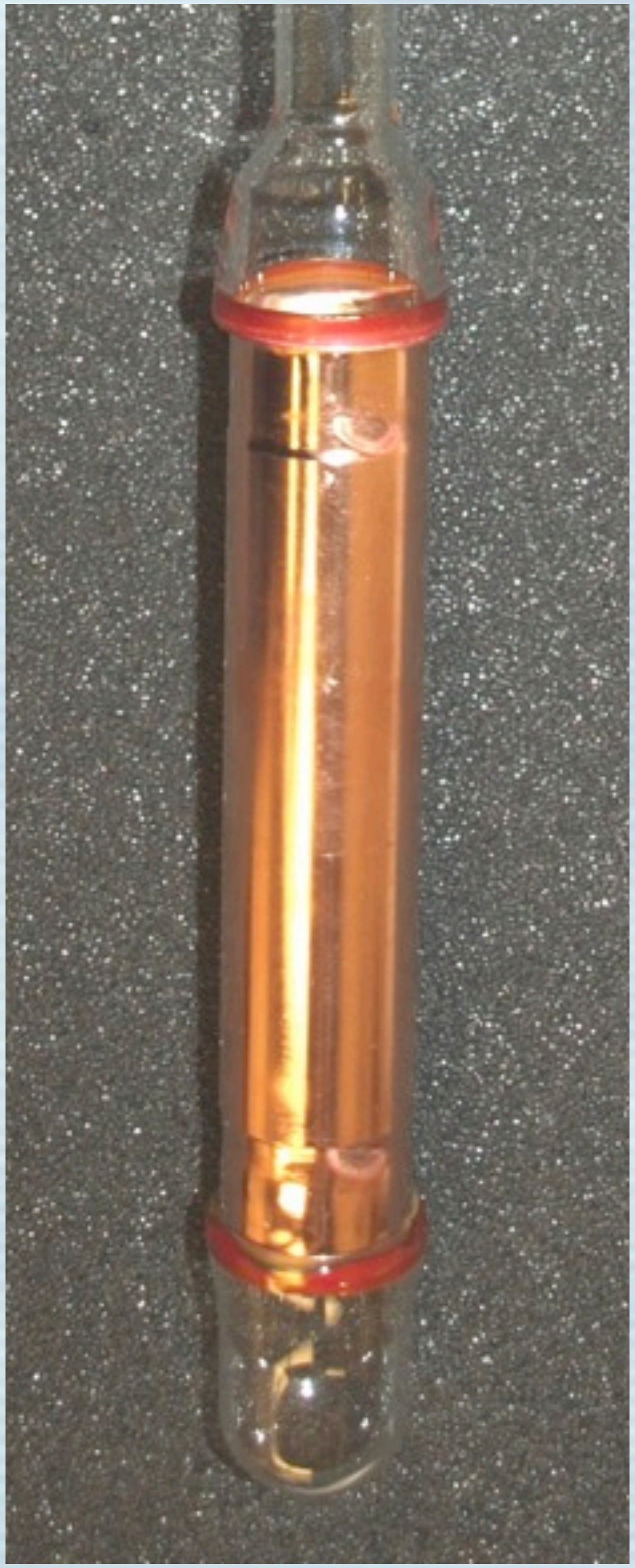
Gold Coated Cell $T_1 = 14.81\ hrs$



Control Cell $T_1 = 26.5\ hrs$

- Compared spin-relaxation of GoldRush with all-glass control cell.
- Relaxation difference implies the contribution from the metal of around 1/34 hours.
- Metal end caps on a Protovec-style cell would contribute less than 1/150 hours to cell's intrinsic spin-relaxation rate.
- For chosen G_E^n design, contribution would be even less.

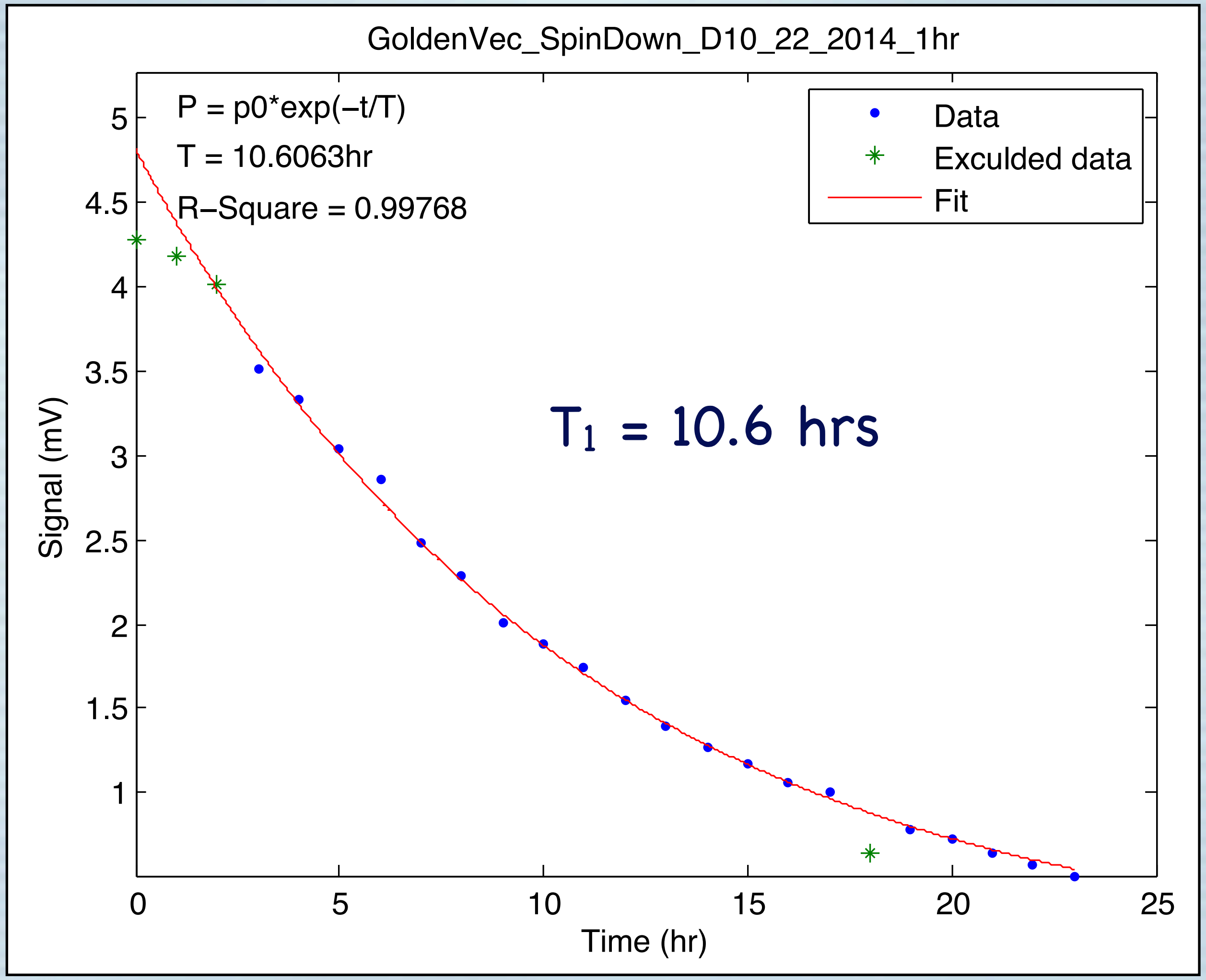
Technology (finally!) demonstrated for incorporating metal into our targets



Several years of development working closely with Larson Glass (glass-to-metal seals), Epner Technology Inc. (electroplating) and Mike Souza (Princeton glass blower).

- OFHC Glass-to-metal seal provides excellent vaccuum/pressure integrity.
- Metal is first mechanically polished.
- Next the metal is electropolished.
- Gold is next electroplated onto the interior surface.
- Finally, the piece is incorporated into a cell.

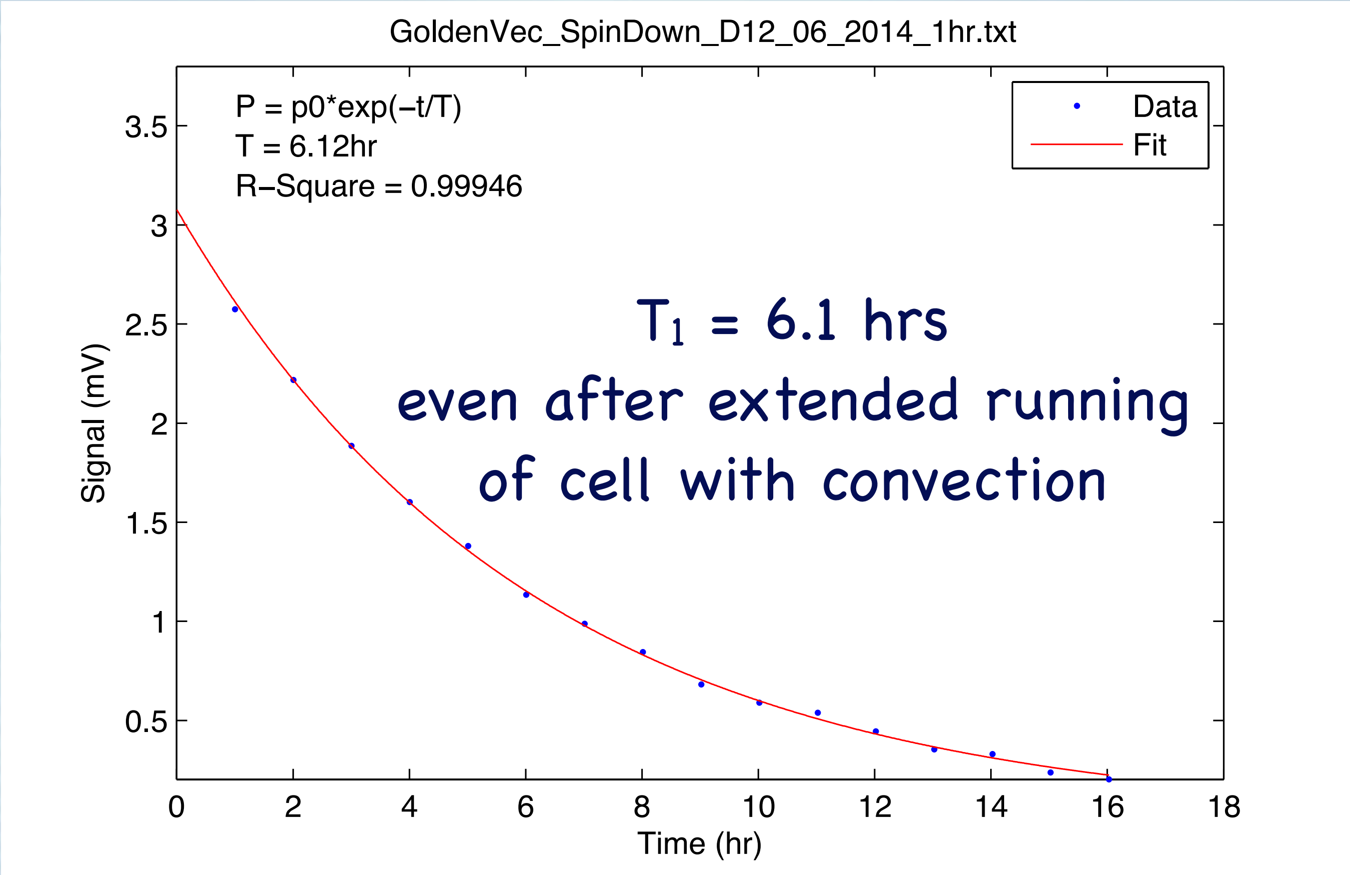
Tests of cell "GoldenVec" establish reproducibility



T_1 = 10.6 hrs

- Convection-style cell "GoldenVec" demonstrated fairly similar properties.
- While current performance appears quite adequate for GEn target cells, we believe it is likely that improved performance is possible.
- We hope for continued improvement through better control of the introduction of contaminant gases (not worth worrying about until basic technology is working).

Tests of cell “GoldenVec” AFTER convection

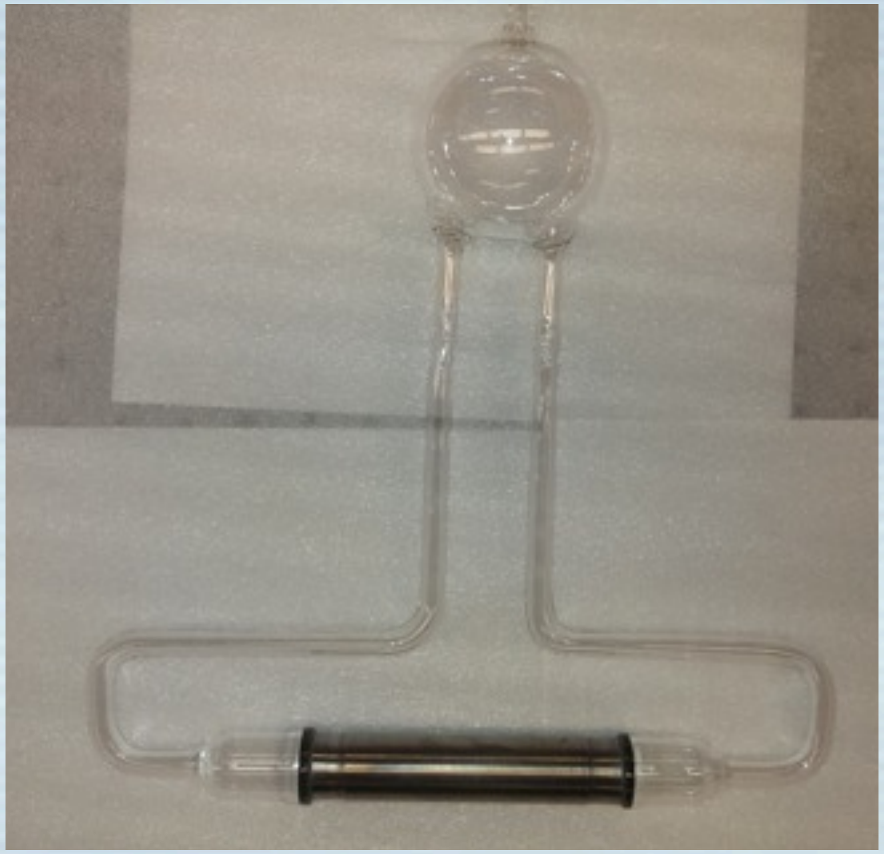


T_1 = 6.1 hrs
even after extended running
of cell with convection

- There appears to be some degradation of the cell during convection
- This performance, however, is already good enough.
- We believe we can do even better by further limiting contaminants (we’ll see!).

More tests coming!

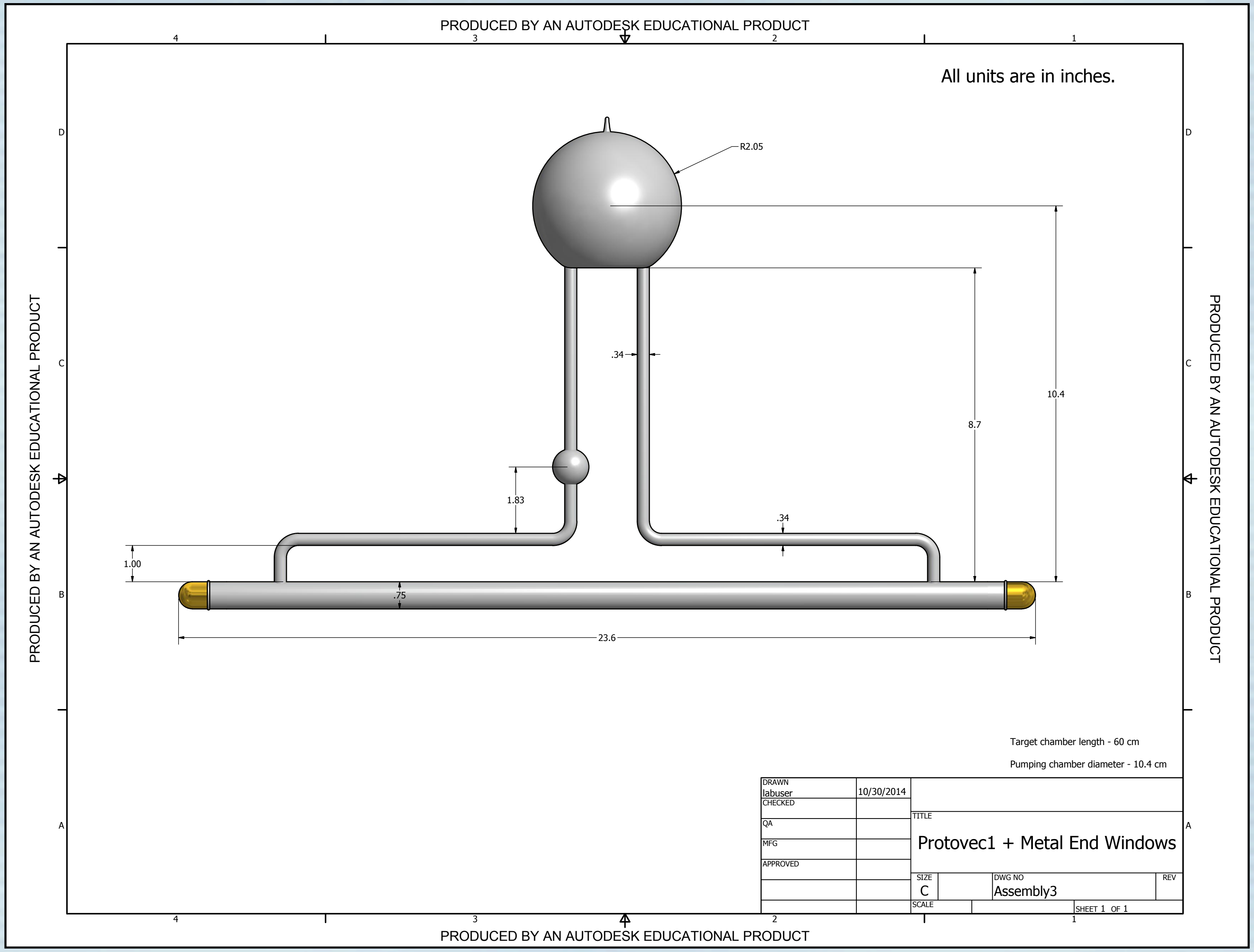
GoldenVec-II



TitanVec

- Want to improve on gold-coated OFHC copper
- Would prefer gold-coated titanium (this is at an earlier stage).

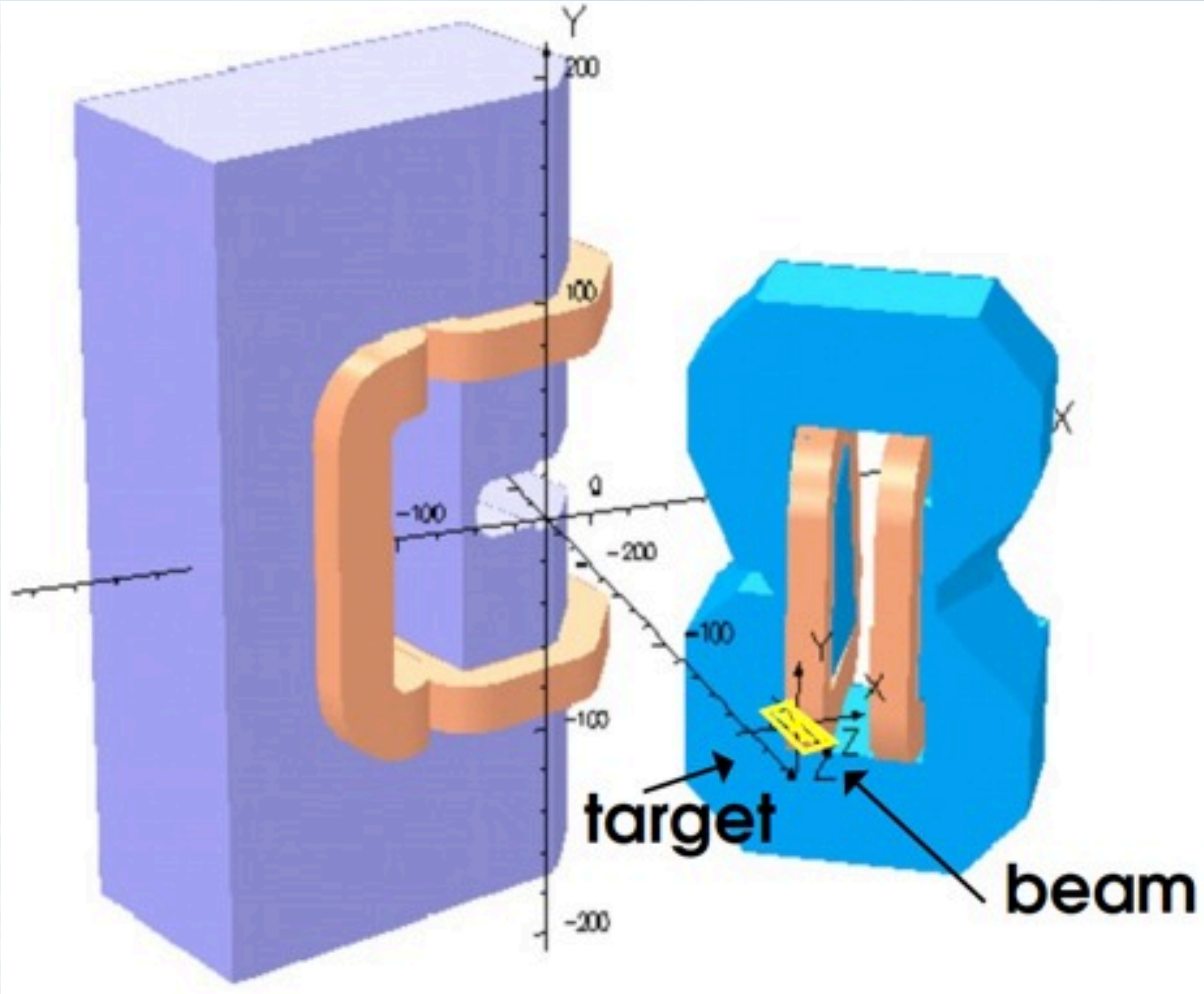
Polarized ^{3}He target milestone #1:
Selection of target cell design for G_E^n

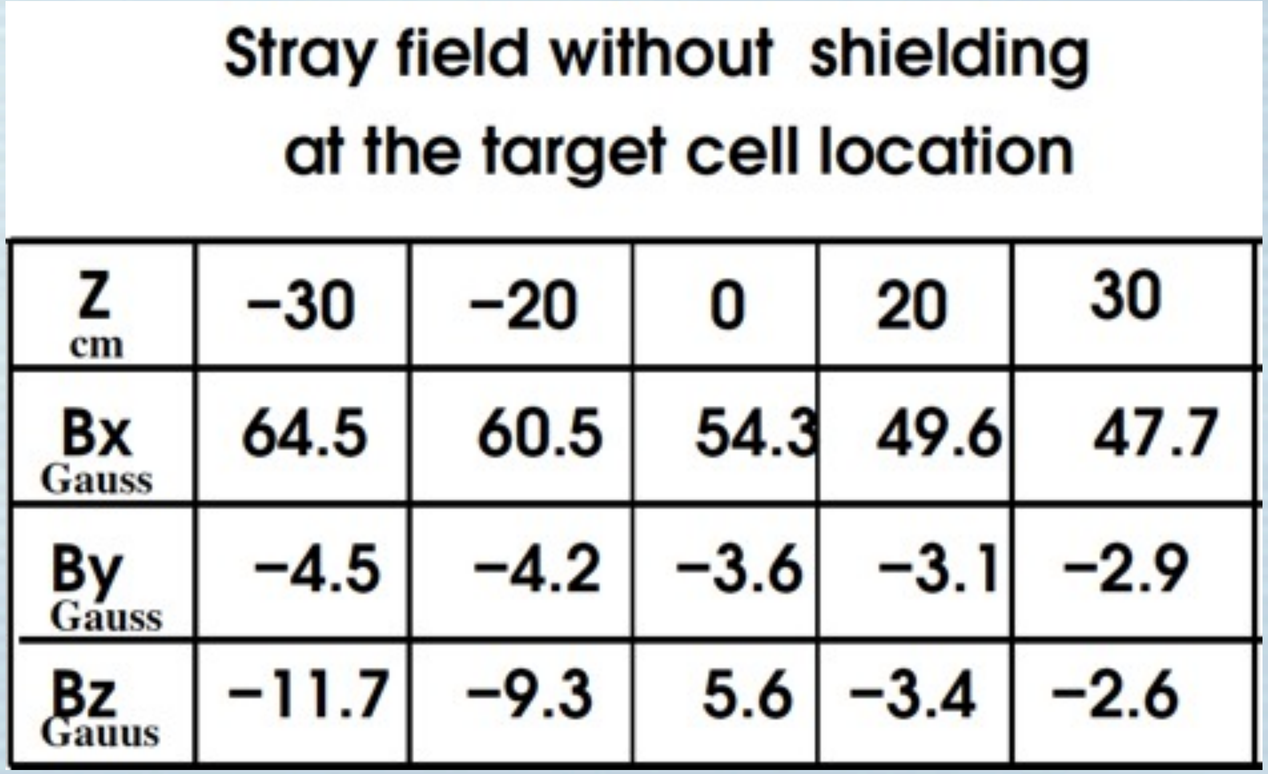


- Convection-based design, now well tested in Protovec-series cells.
- Contains 6 STP liters of ^{3}He in 750 cm^3 volume cell.
- OFHC copper metal end windows with gold electroplating on inner surface.
- 60 cm target-chamber length will deliver desired luminosity with 60 μA electron beam.

Additional progress on target-hardware design for Hall A since last review

Fringe fields during G_E^n

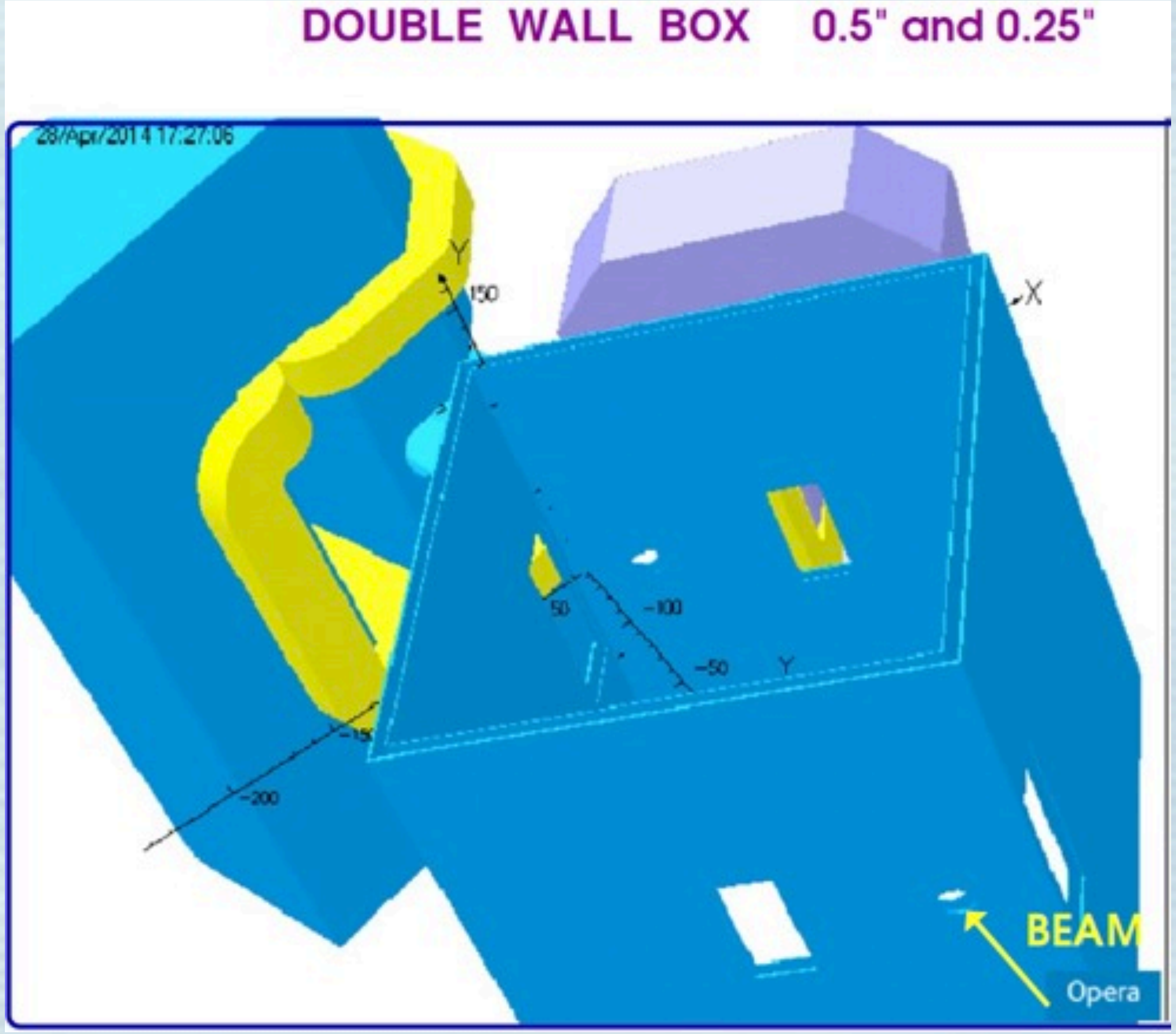



Stray field without shielding
at the target cell location

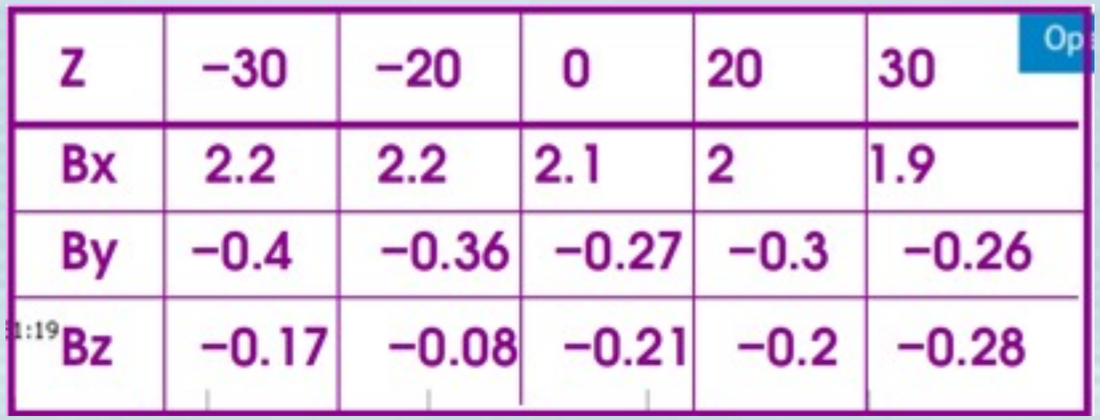
Z cm	−30	−20	0	20	30
Bx Gauss	64.5	60.5	54.3	49.6	47.7
By Gauss	−4.5	−4.2	−3.6	−3.1	−2.9
Bz Gauus	−11.7	−9.3	5.6	−3.4	−2.6

Tosca calculations indicate significant fringe fields in the vicinity of the polarized ^{3}He target when using the SBS geometry for the G_E^n measurement.

Advanced conceptual design for a magnetic-field solution



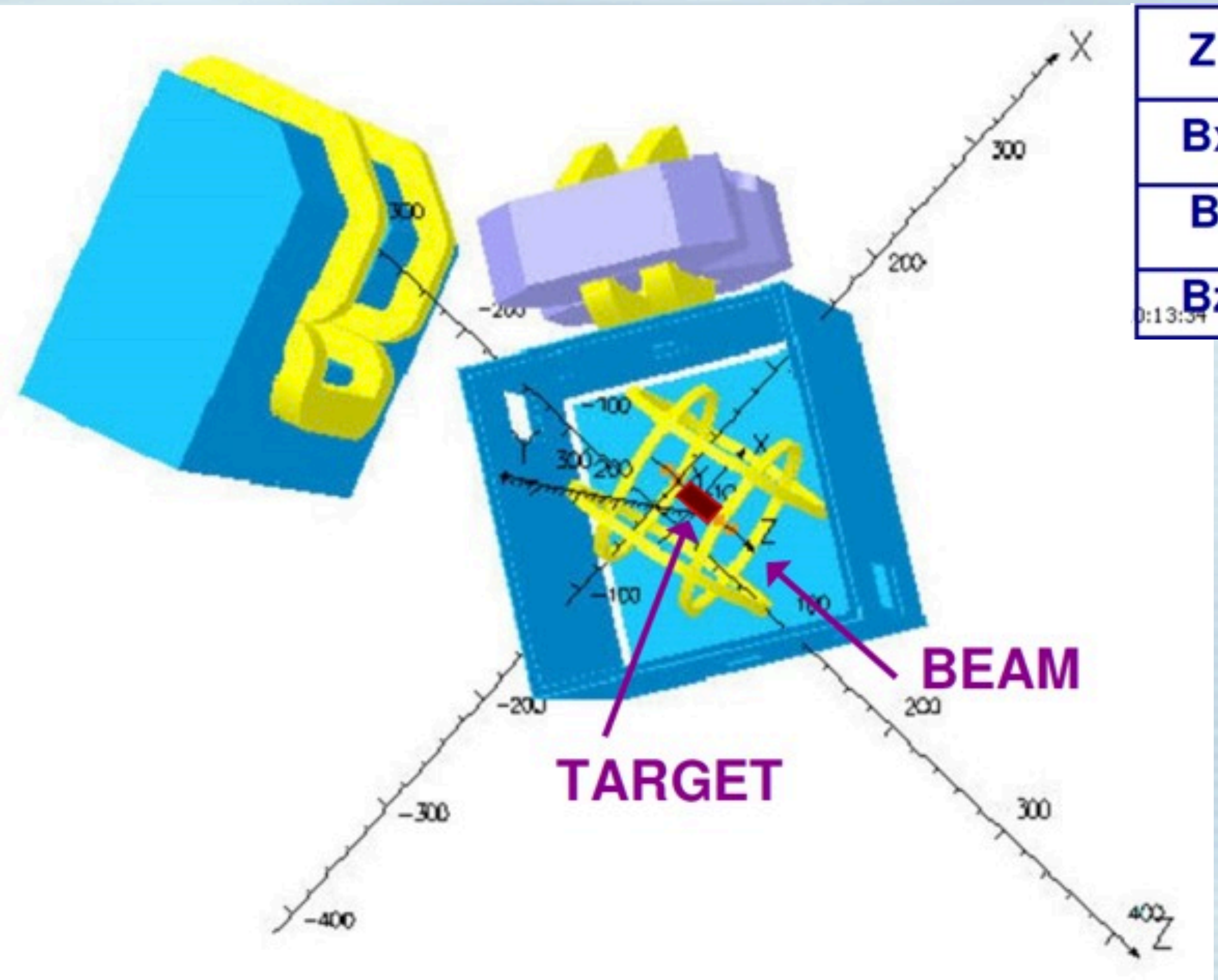
Developed by Vladimir Nelyubin, a double-walled box provides excellent shielding within limited space.



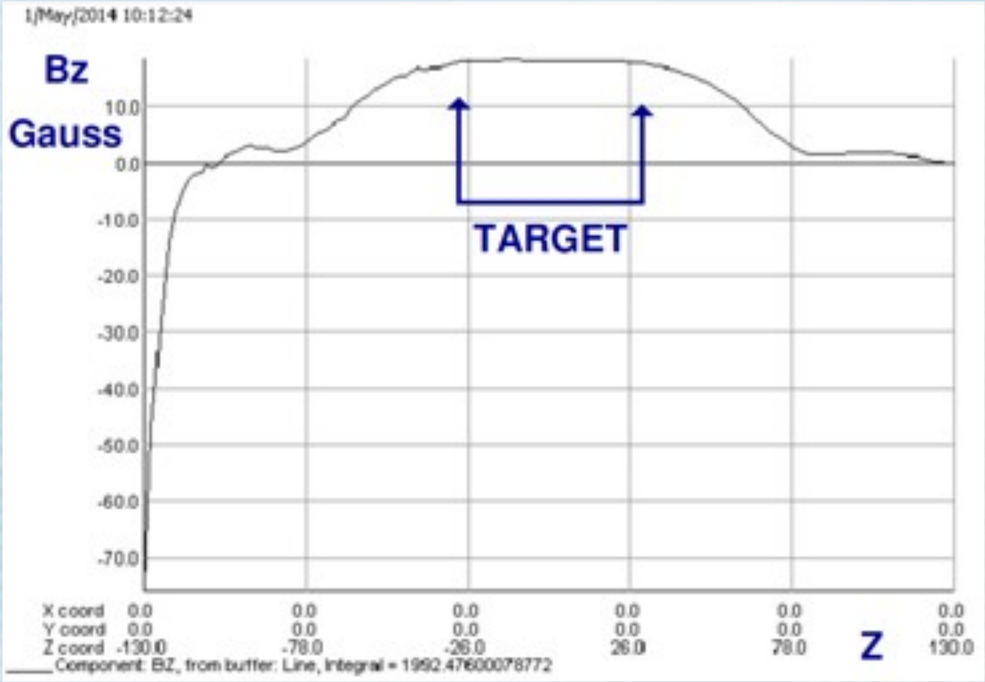
Z	−30	−20	0	20	30
Bx	2.2	2.2	2.1	2	1.9
By	−0.4	−0.36	−0.27	−0.3	−0.26
Bz	−0.17	−0.08	−0.21	−0.2	−0.28

- Uses both symmetry, and the concept that you want to keep your clamp away from the large fields so that it does not suck the flux lines in.
- Single-walled box doesn't quite cut it.

The double-walled box works with the Transversity coils

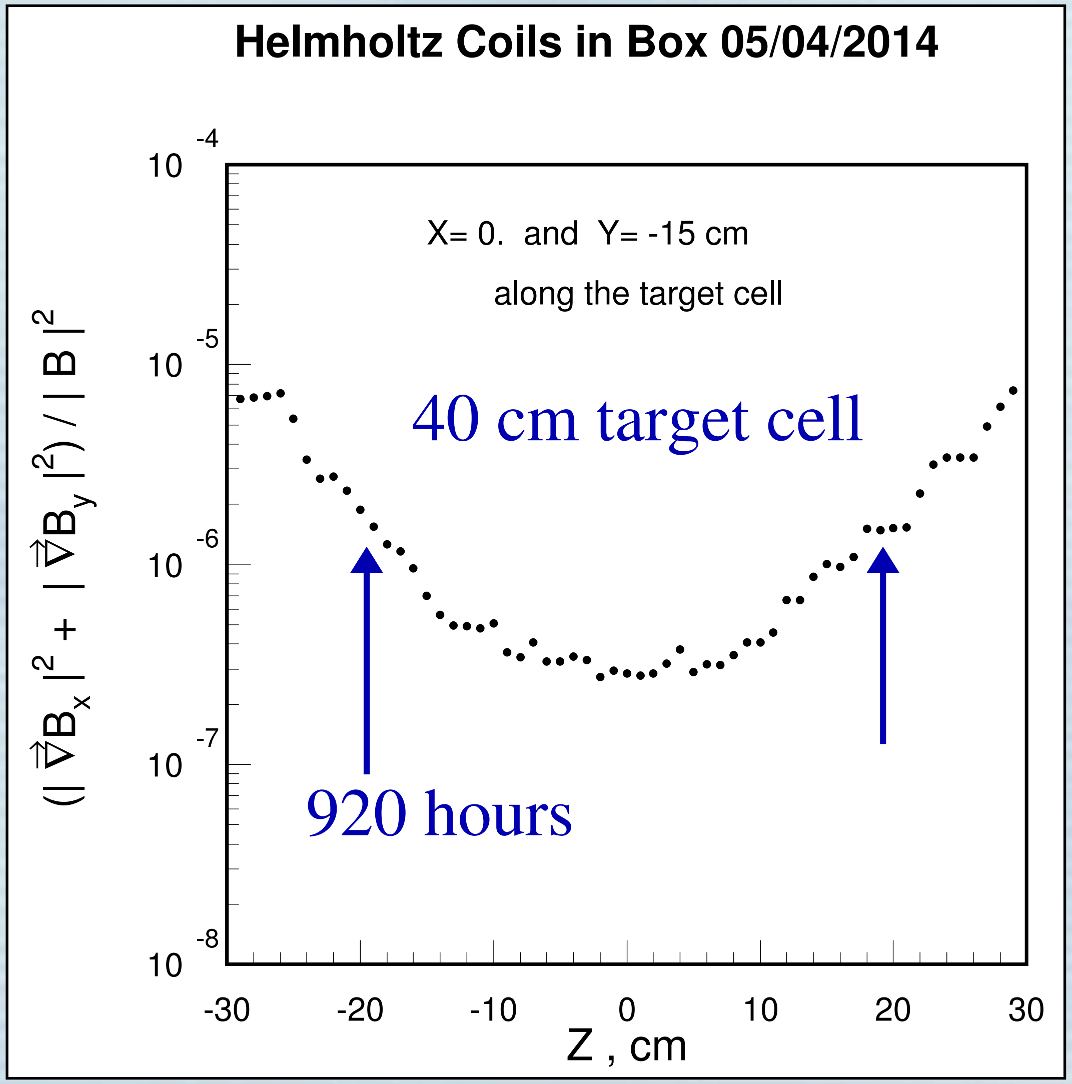


Z	–30	–20	0	20	30
Bx	–14.8	–14.4	–14.7	–14.8	–14.9
By	–0.4	–0.17	–0.37	–0.26	–0.28
Bz	17.7	18.0	17.9	17.8	17.5



The double-walled box also accommodates the Helmholtz coils (and most other hardware) used during the Hall A "Transversity" experiments.

The gradients look acceptable for the double-walled box + Transversity coils, for a single-pumping chamber 60 cm cell

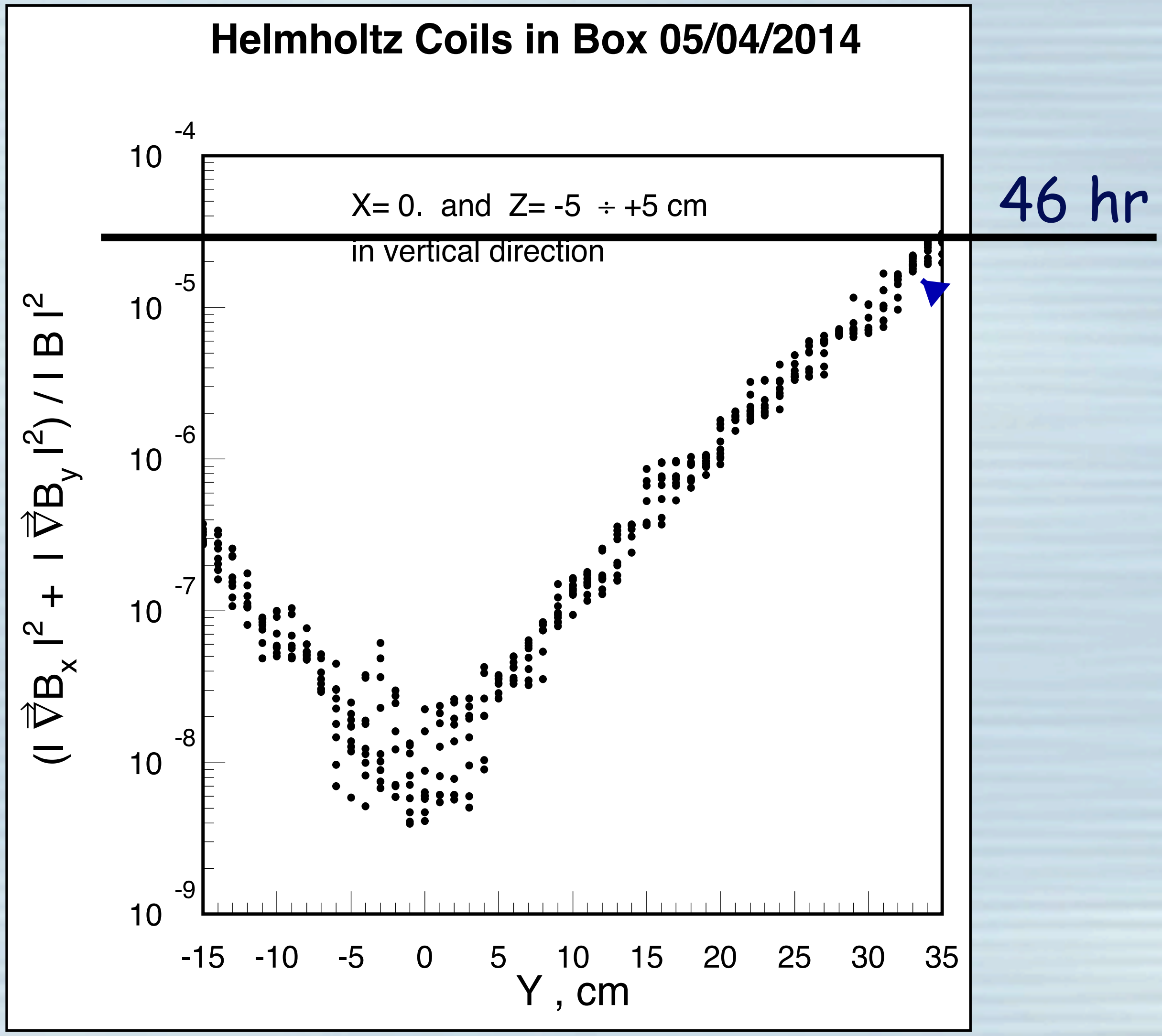

Helmholtz Coils in Box 05/04/2014

X= 0. and Y= -15 cm

along the target cell

40 cm target cell

920 hours


Helmholtz Coils in Box 05/04/2014

X= 0. and Z= -5 ÷ +5 cm

in vertical direction

46 hr

Magnetic field inhomogeneities with the geometry from the previous slide are acceptable for performance requirements of the G_E^n polarized target.

Activity in the JLab target lab testing new target technologies

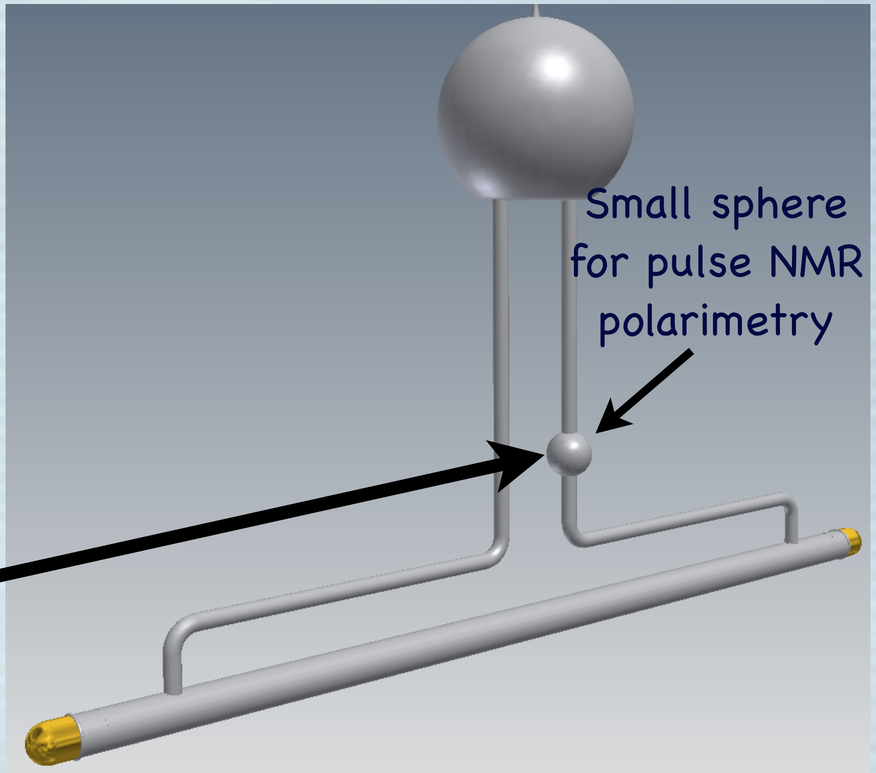
Highlights of activities in the JLab target lab

The integration of new target technologies into the JLab polarized ^{3}He target system is well underway

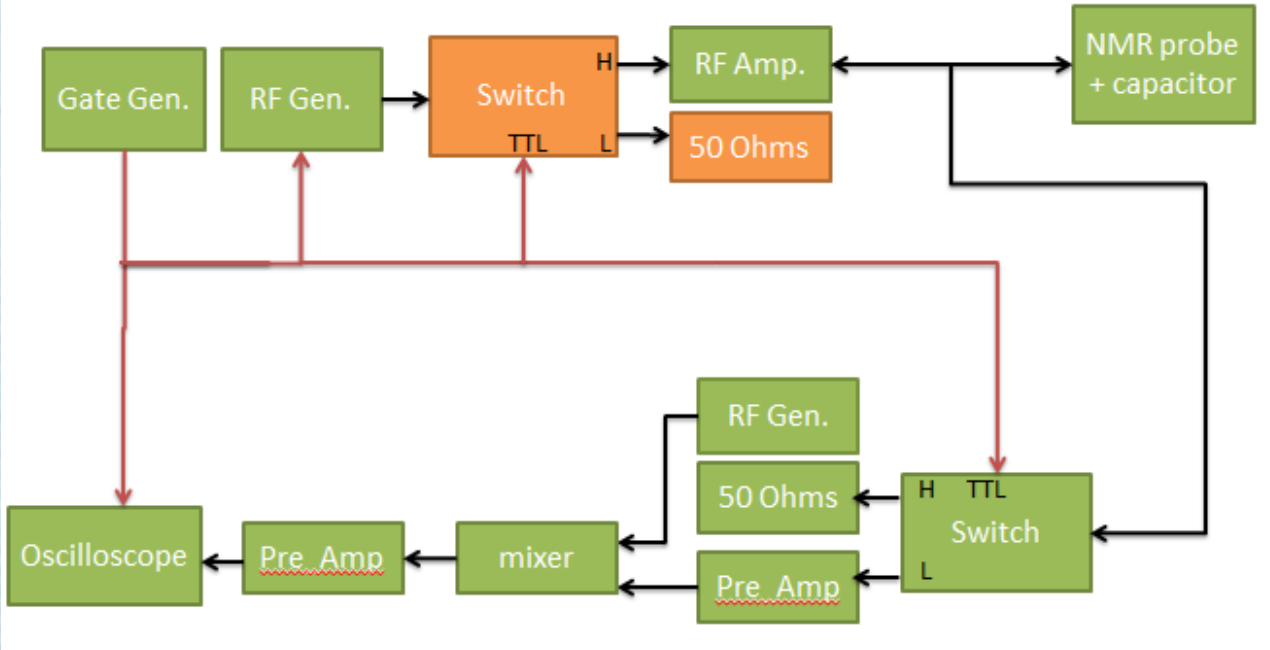
- New-style convection-based target cell (Protovec-I) has been installed in the JLab target system and is actively being tested.
    - Includes measurements of gas speed through the target chamber.
    - JLab target lab developed new simplified approach for driving convection.
- Pulse-NMR polarimetry system (necessary when we move to metal target-cell windows) is working, and polarimetry systematic studies are ongoing.
- Studies now complete of polarization losses in convection cells when using the NMR technique of Adiabatic Fast Passage (AFP).

Pulse NMR polarimetry at the JLab target lab

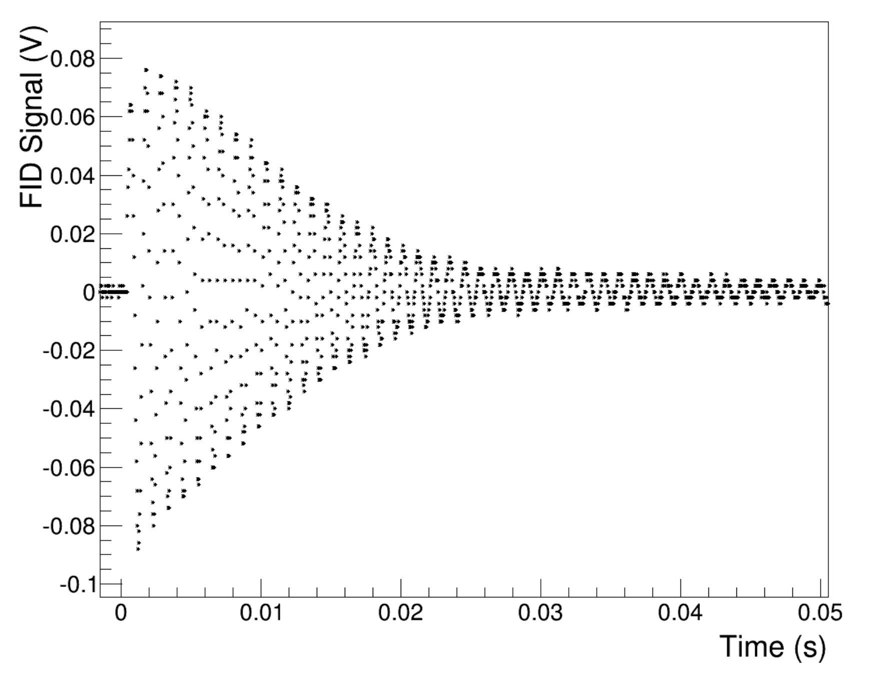
- Historically, we have used the NMR technique of AFP for online monitoring of polarization.
- During an AFP scan, ALL spins in the target are flipped twice.
- With metal end windows, huge losses occur wherever there is nearby metal.
- Solution: use pulse NMR, which can be performed on a small part of the target.



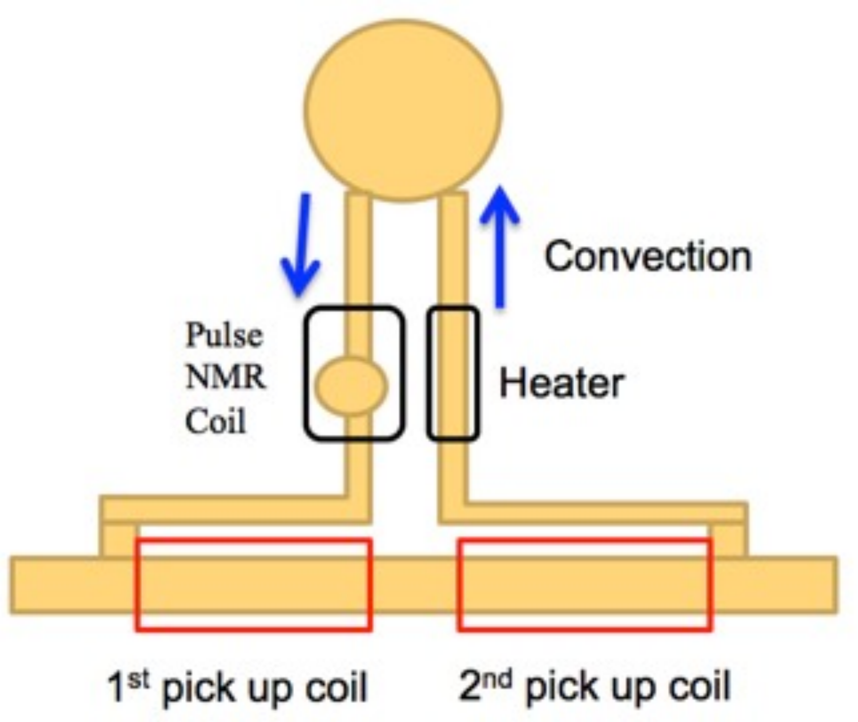
Small sphere for pulse NMR polarimetry



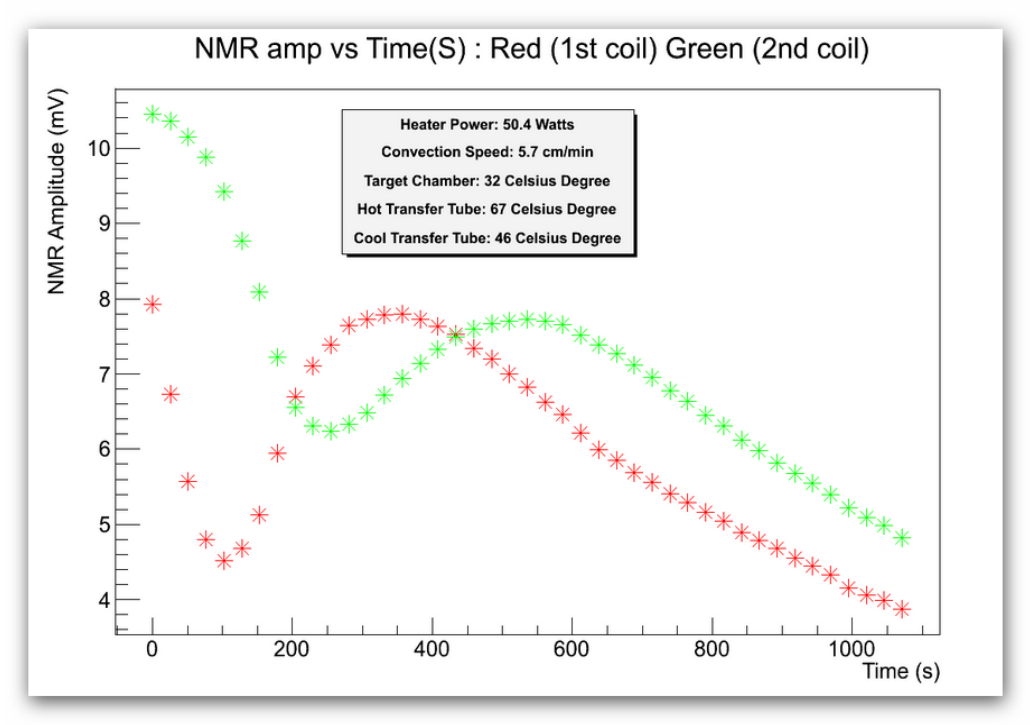
Gate Gen.
RF Gen.
Switch
H
TTL
L
RF Amp.
50 Ohms
NMR probe + capacitor
RF Gen.
50 Ohms
H
TTL
Switch
L
Oscilloscope
Pre Amp
mixer
Pre Amp

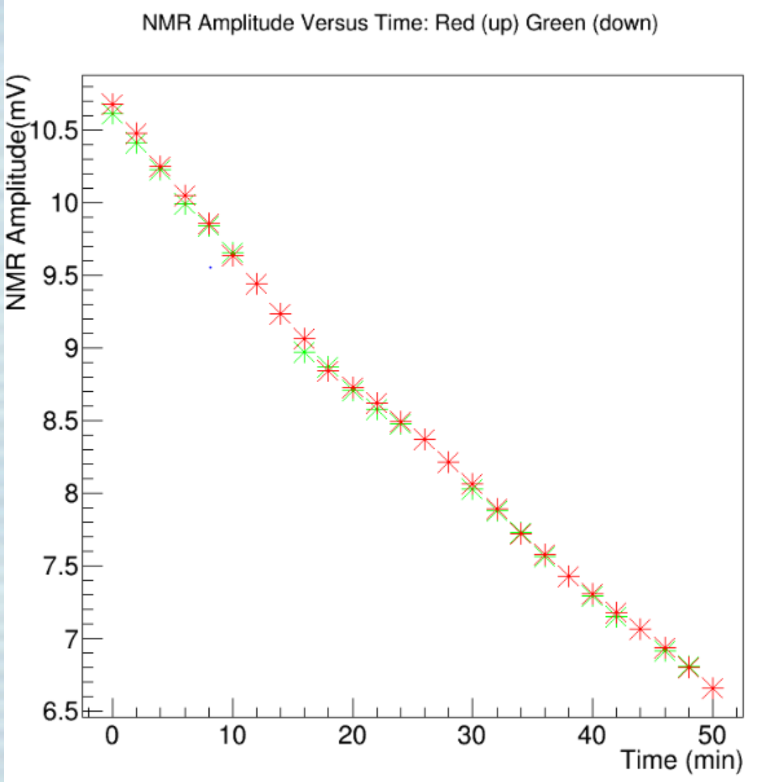


Examples of recent data from JLab target lab

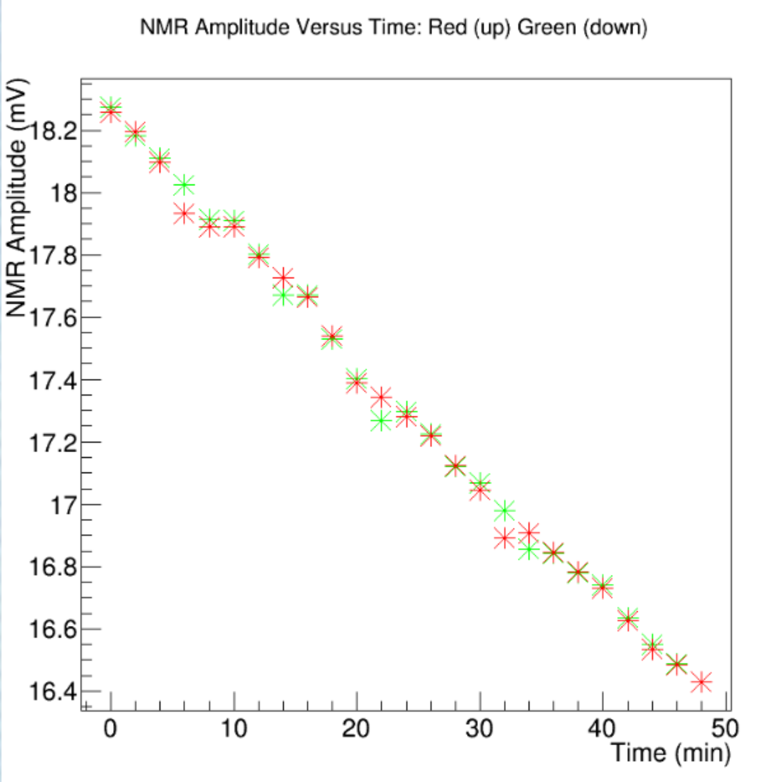


Measurement of NMR signal from 1st and 2nd pick-up coils provide measurement of gas speed by observing the passage of a depolarized "slug" of gas.





Successive rapid measurements of AFP signals provide measurements of AFP-related polarization losses with (at left) and without (at right) convection. In all cases, losses are less than 1% per sweep.

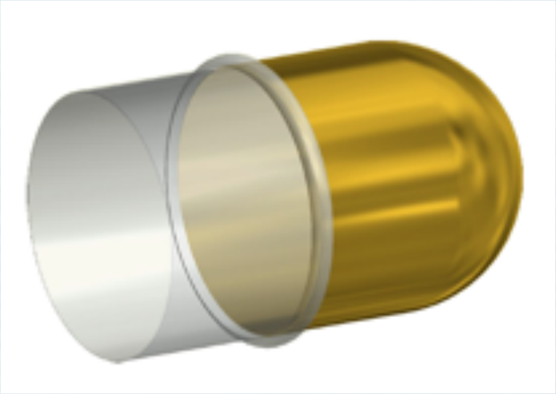


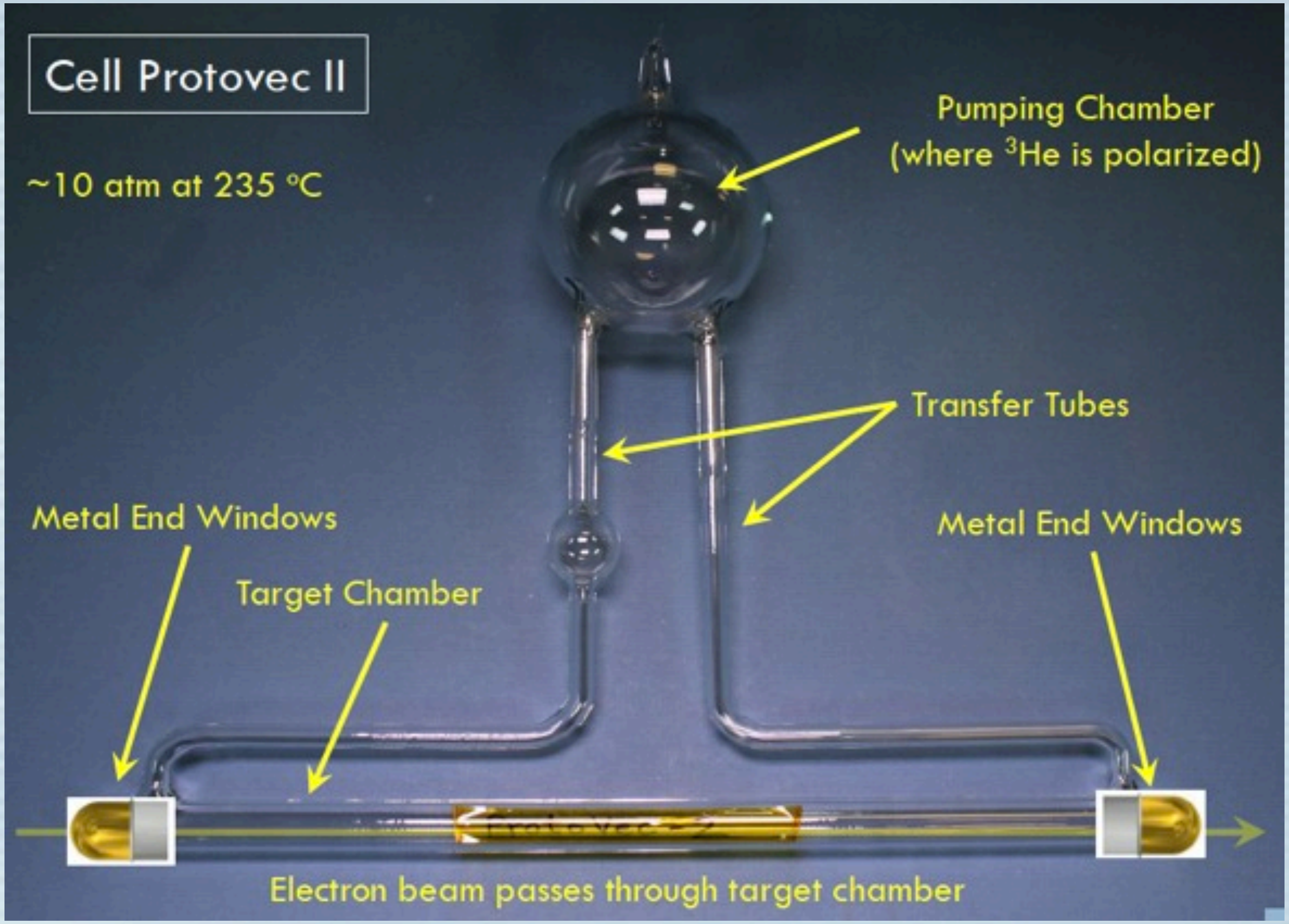
Summary

- We are ready to begin production on new target cells based on the Protovec-I and II. The size of the first production targets will depend on which polarized ^{3}He experiment is scheduled first.
- We are nearly ready to begin production on cells with metal end windows.
- Ready to begin design and engineering for target hardware on the Hall A pivot for the SBS G_E^n experiment.

Backup slides

Metal end windows



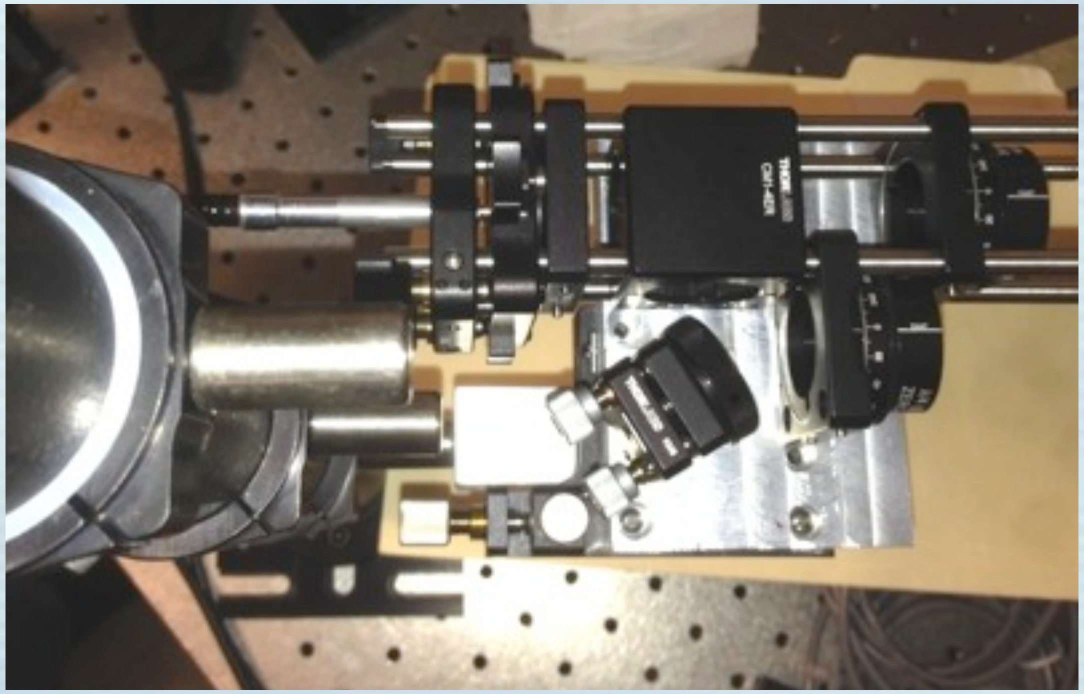


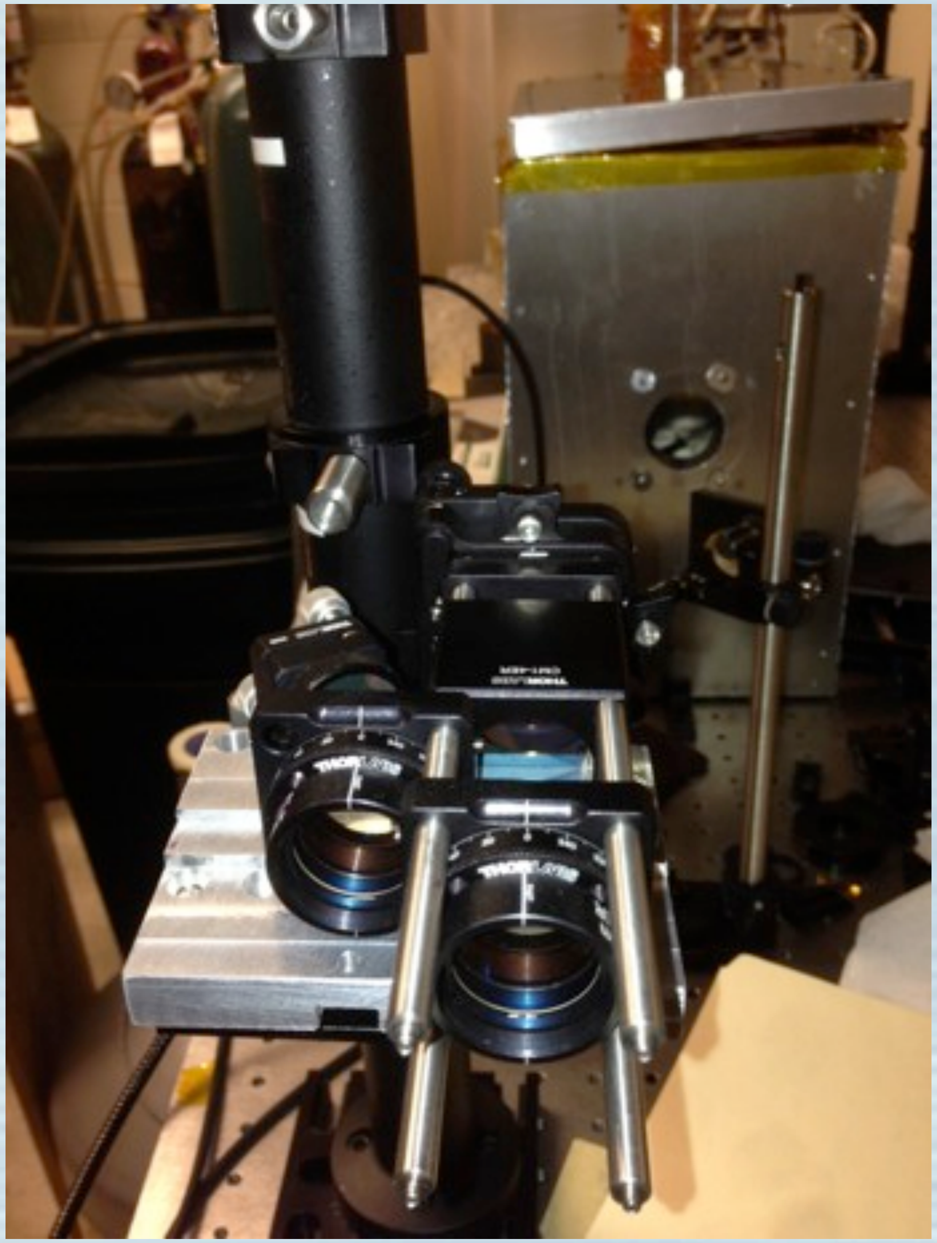
- Metal shape will be different, otherwise largely the same as in test cells.
- Gold-coated OFHC copper appears capable of achieving window thickness comparable to or smaller than glass windows.
- Gold-coated titanium may give us a factor of three or more.
- Am I being too conservative?

New 1-inch optics design specifically for G_E^n target

- Existing Hall A polarized ^{3}He optics system uses a “five-to-one” combiner, and 2-inch diameter optics (which are expensive).
- We have developed a modular one-inch optics system that can be duplicated for a scalable high-power system.
- This system is ideally suited to the new larger G_E^n target design, which will include:
    - a larger 4-inch diameter pumping chamber, and
    - laser illumination from two directions simultaneously, to limit laser intensity incident on the cell’s glass walls and to achieve more uniform alkali-vapor polarization.

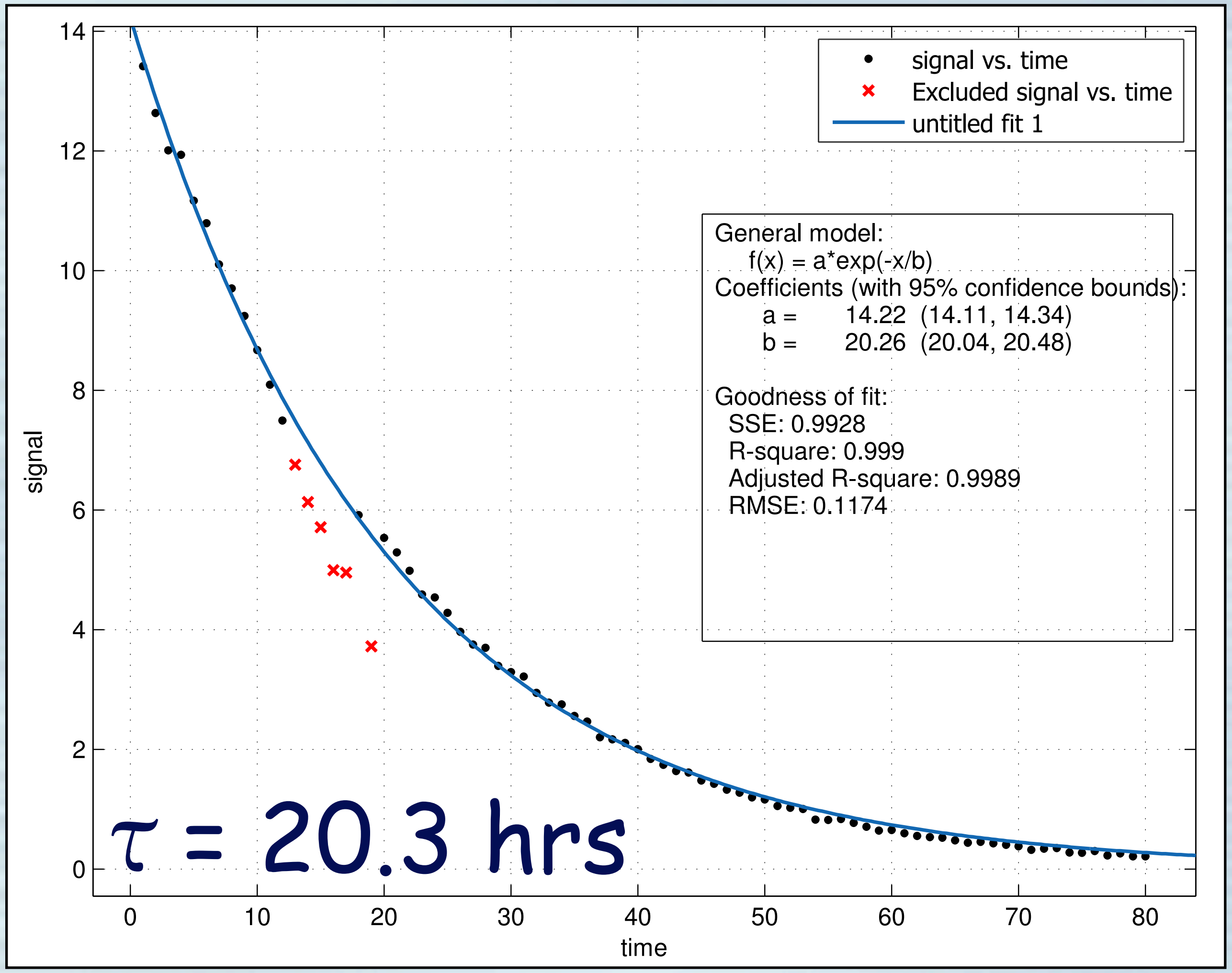
New 1-inch optics design for G_E^n target





- Modular design allows optics for multiple lasers to be stacked.
- With a single lens for each set of optics, it is trivial to acheive coverage for the larger four-inch diameter GEn target cell.
- Modular design also makes it easier to split available laser power between the two (front and back) simultaneous pumping directions.

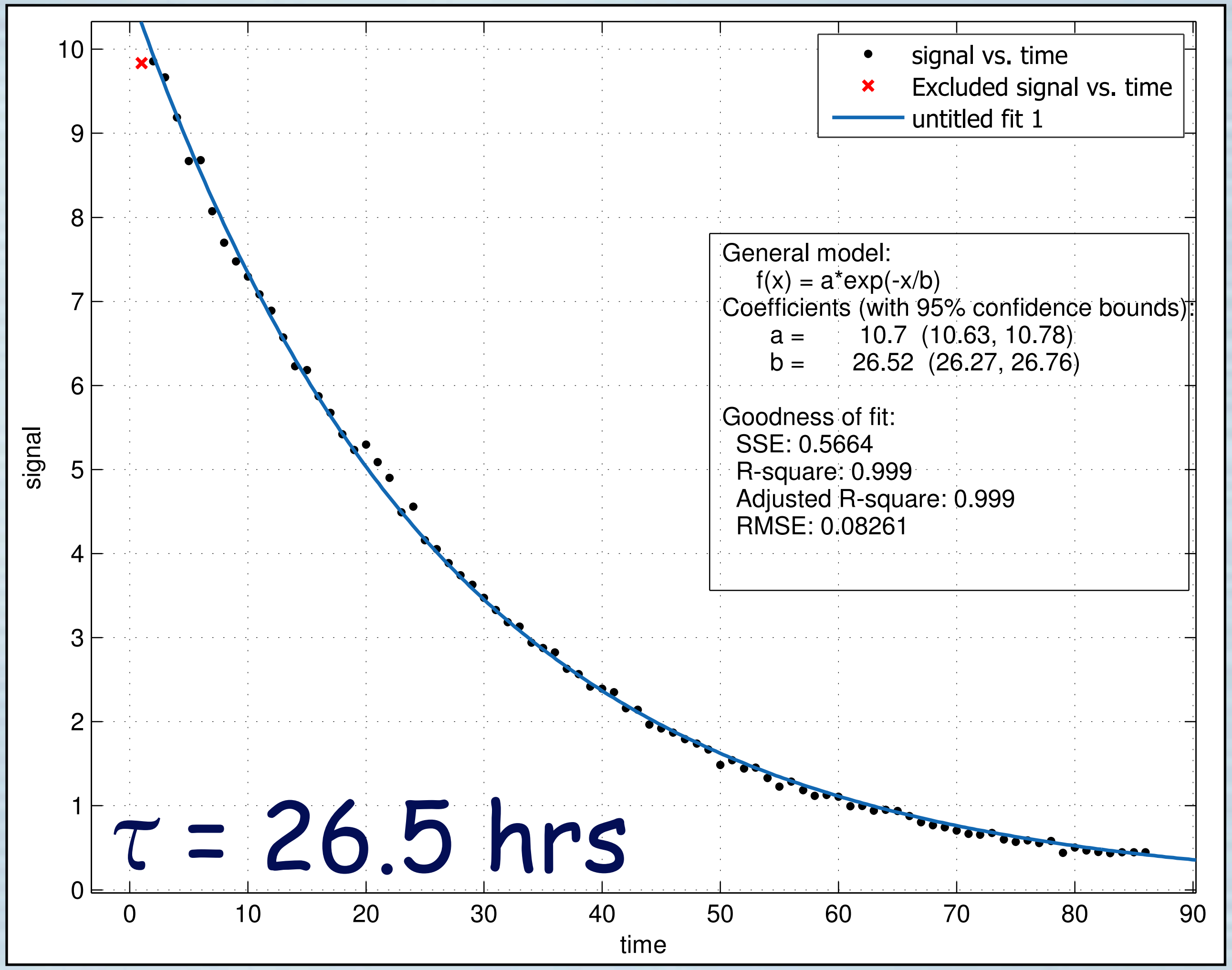
Control cell “Pyrah” for glass- and-metal-cell tests: centered and elevated positions



```
General model:
     f(x) = a*exp(-x/b)
Coefficients (with 95% confidence bounds):
       a =      14.22  (14.11, 14.34)
       b =      20.26  (20.04, 20.48)

Goodness of fit:
  SSE: 0.9928
  R-square: 0.999
  Adjusted R-square: 0.9989
  RMSE: 0.1174
```

τ = 20.3 hrs



```
General model:
     f(x) = a*exp(-x/b)
Coefficients (with 95% confidence bounds):
       a =       10.7  (10.63, 10.78)
       b =      26.52  (26.27, 26.76)

Goodness of fit:
  SSE: 0.5664
  R-square: 0.999
  Adjusted R-square: 0.999
  RMSE: 0.08261
```

τ = 26.5 hrs

Cell has pumping chamber centered in Helmholtz coils

Cell is elevated roughly 7cm relative to center of Helmholtz coils

We have noticable relaxation due to magnetic field inhomogeneities in these glass/metal test cells.