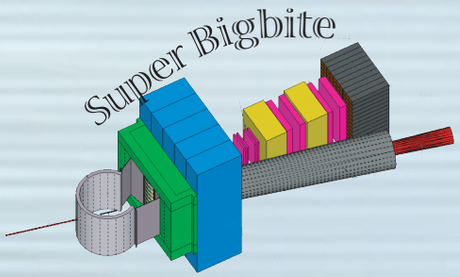
Polarized ^{3}He targets for SBS G_E^n and A_1^n

- Engineering and design on both targets
- Target-cell progress, both Stage I and Stage II
- Measurement of κ_0 and lessons learned

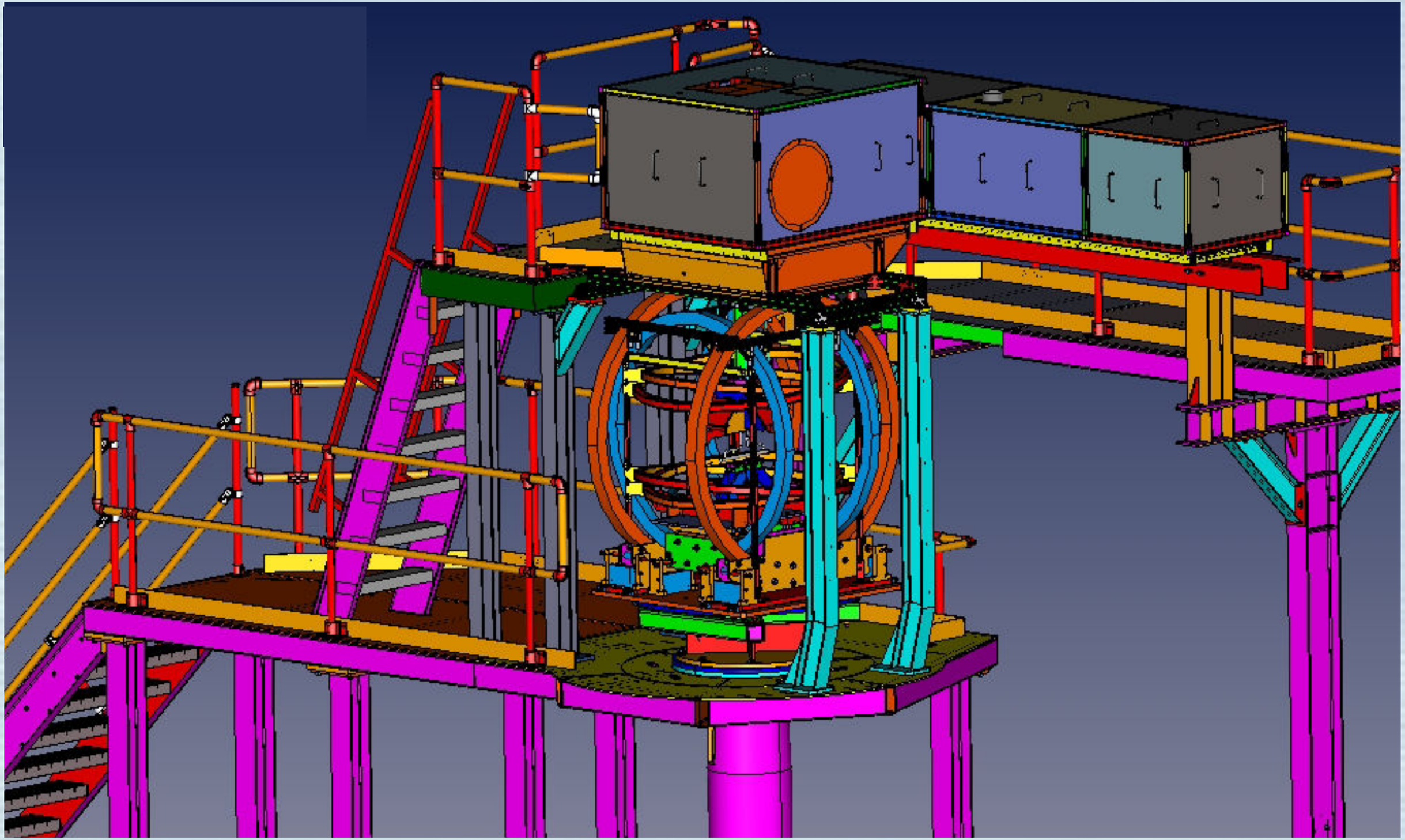
Watch for this symbol to identify stuff that is new since last November's SBS DOE review → New since Nov. review

G. Cates - UVa
July 14, 2017

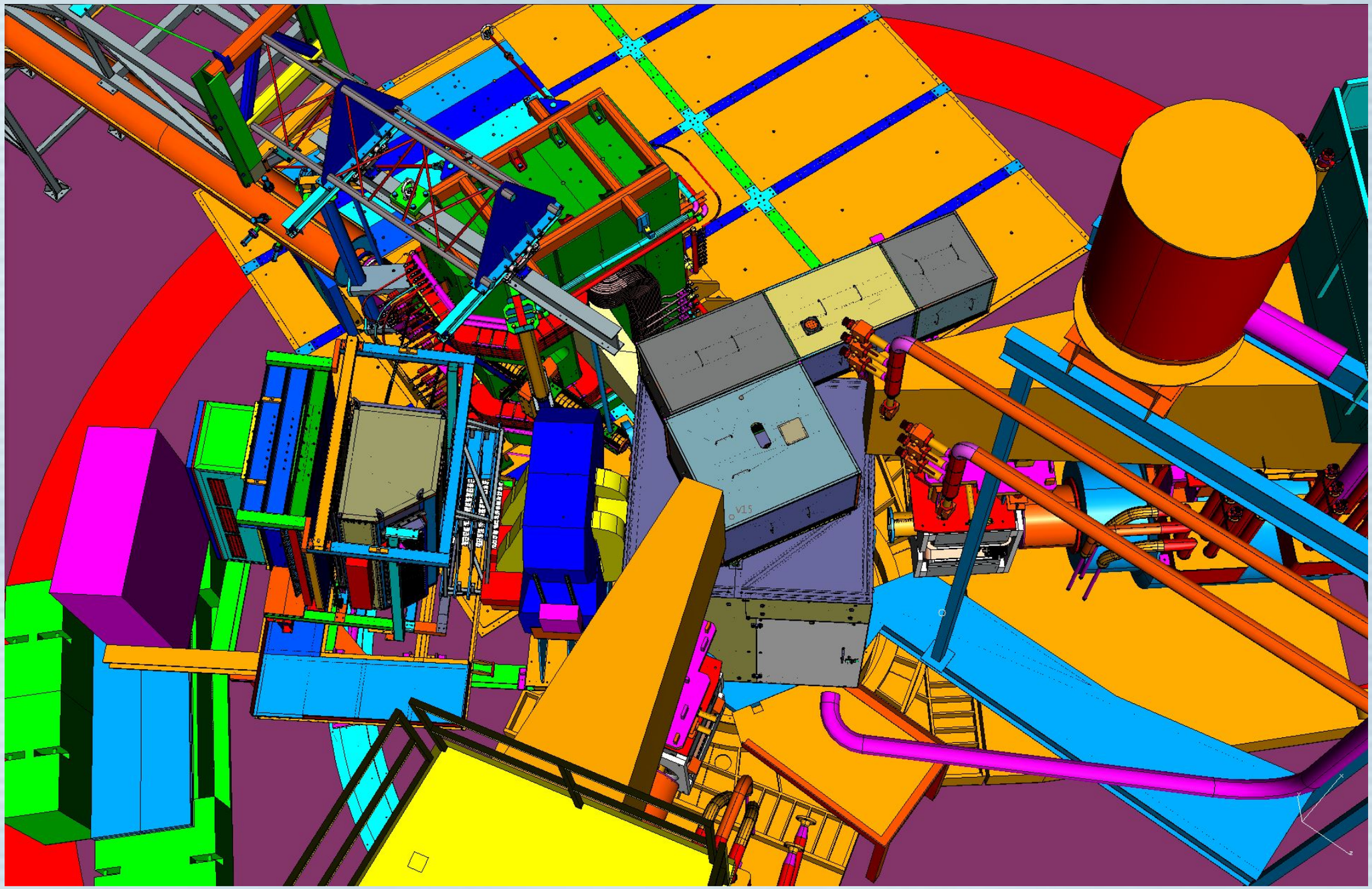


Engineering

Engineering on the Hall C A_1^n/d_2^n target



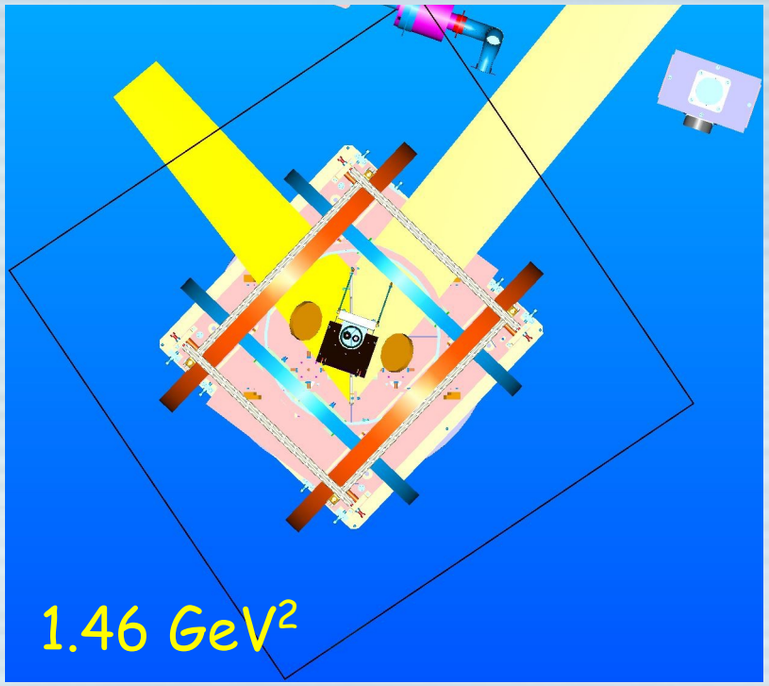
Engineering on the Hall A SBS G_E^n target

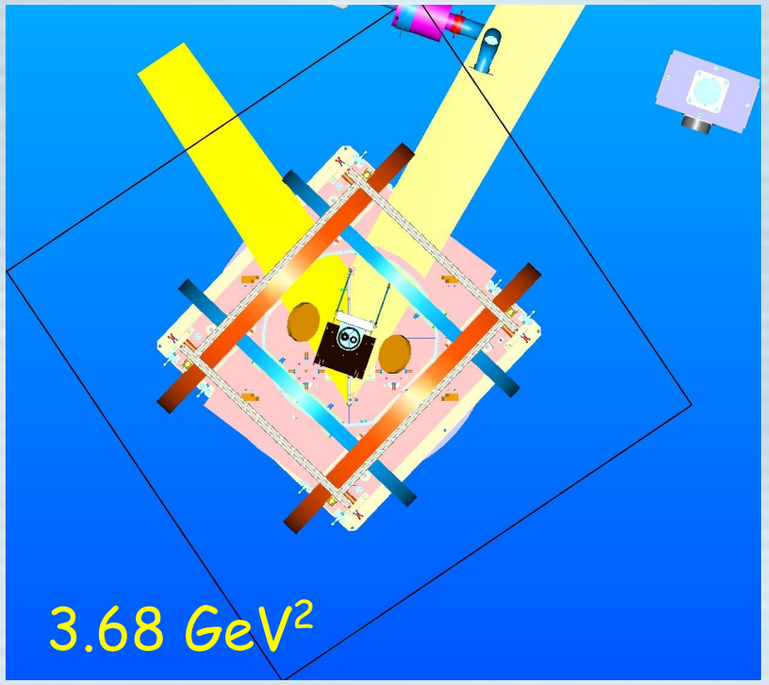


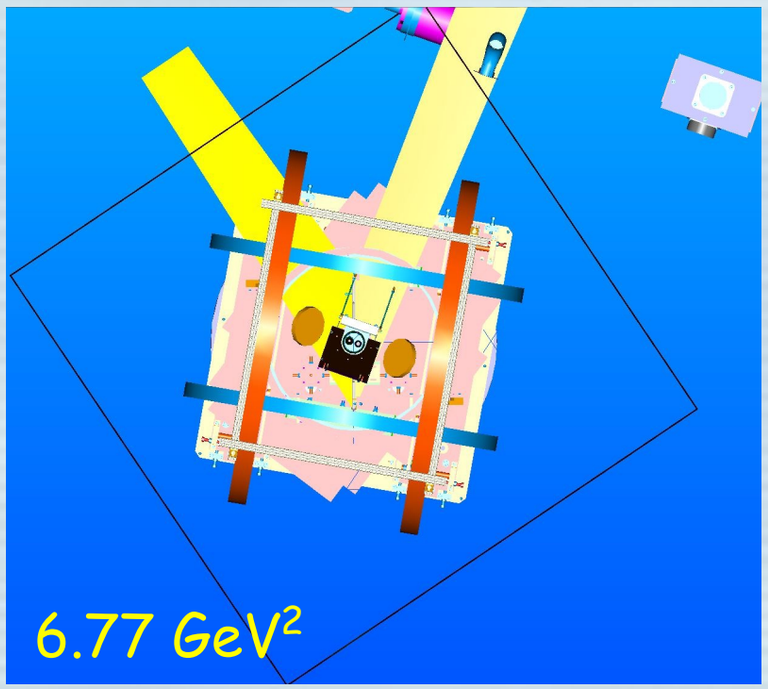
Overview of G_E^n target on the pivot.

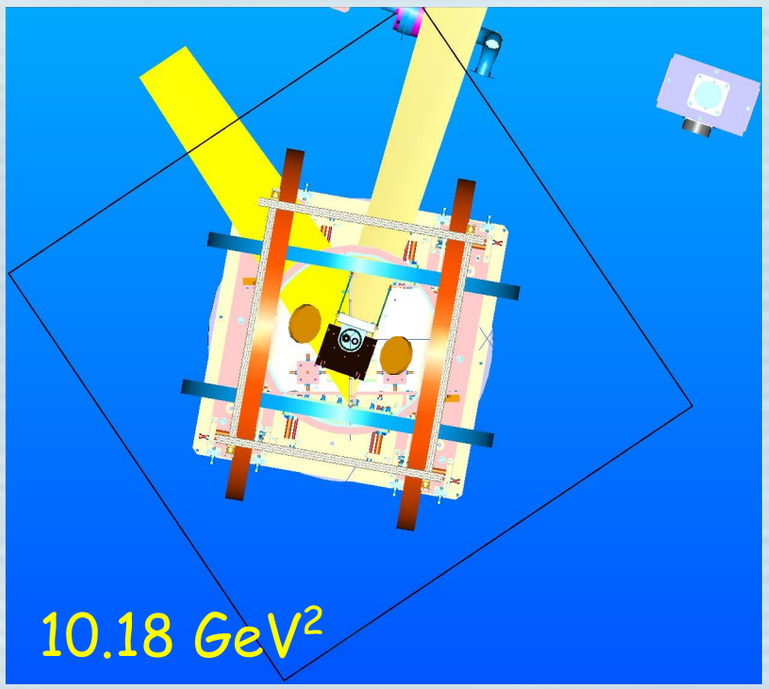
New since Nov. review

Kinematic settings for SBS G_E^n target



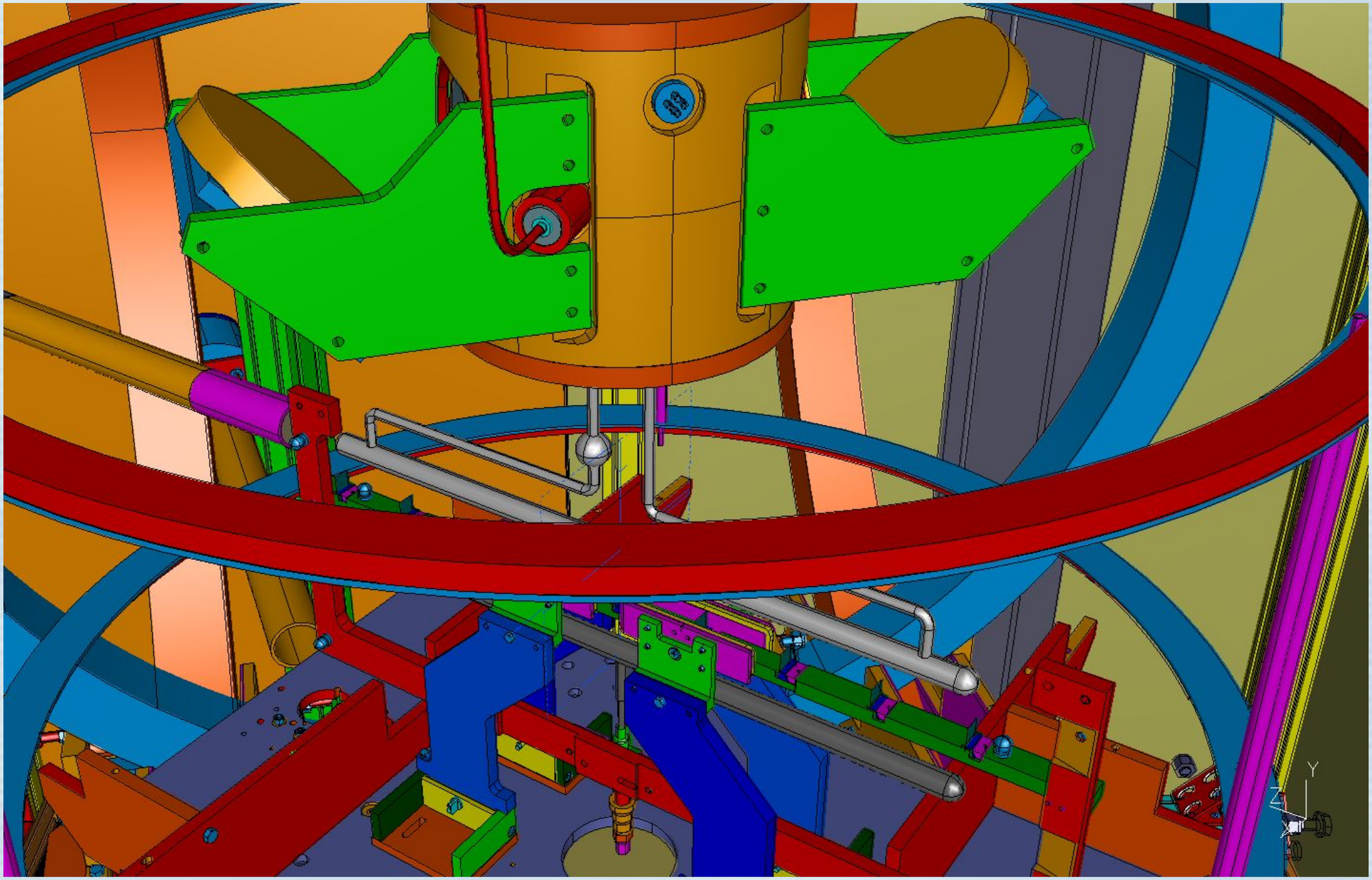






Design accommodates the acceptance for all kinematic points.

SBS GEn target emphasizing target-cell region



Note TWO mirrors to bring laser light in from two directions.

New since Nov. review

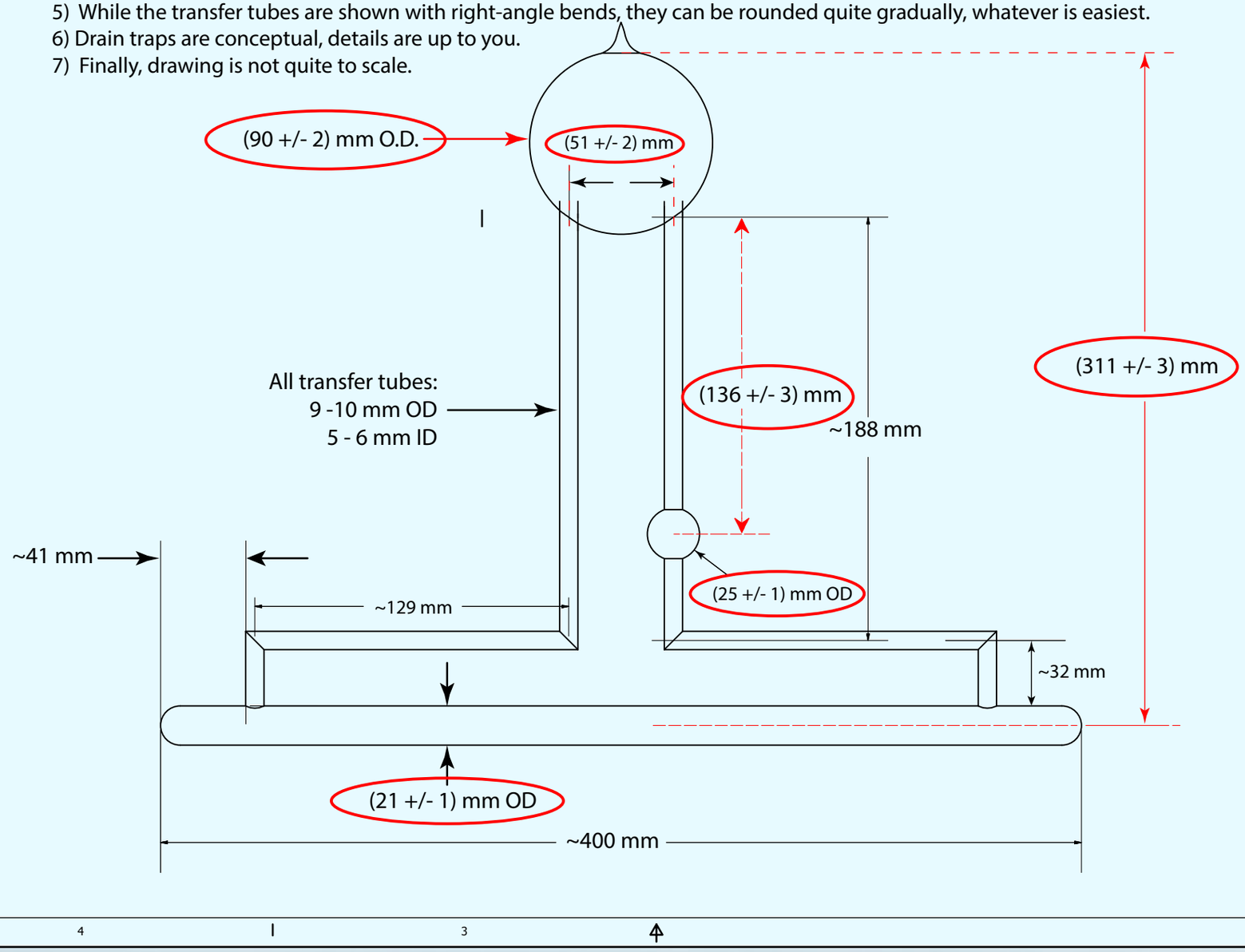
Cell development and production

- Stage I - 3 liter cells - A_1^n and d_2^n
- Stage II - 6 liter cells - G_E^n and SIDIS

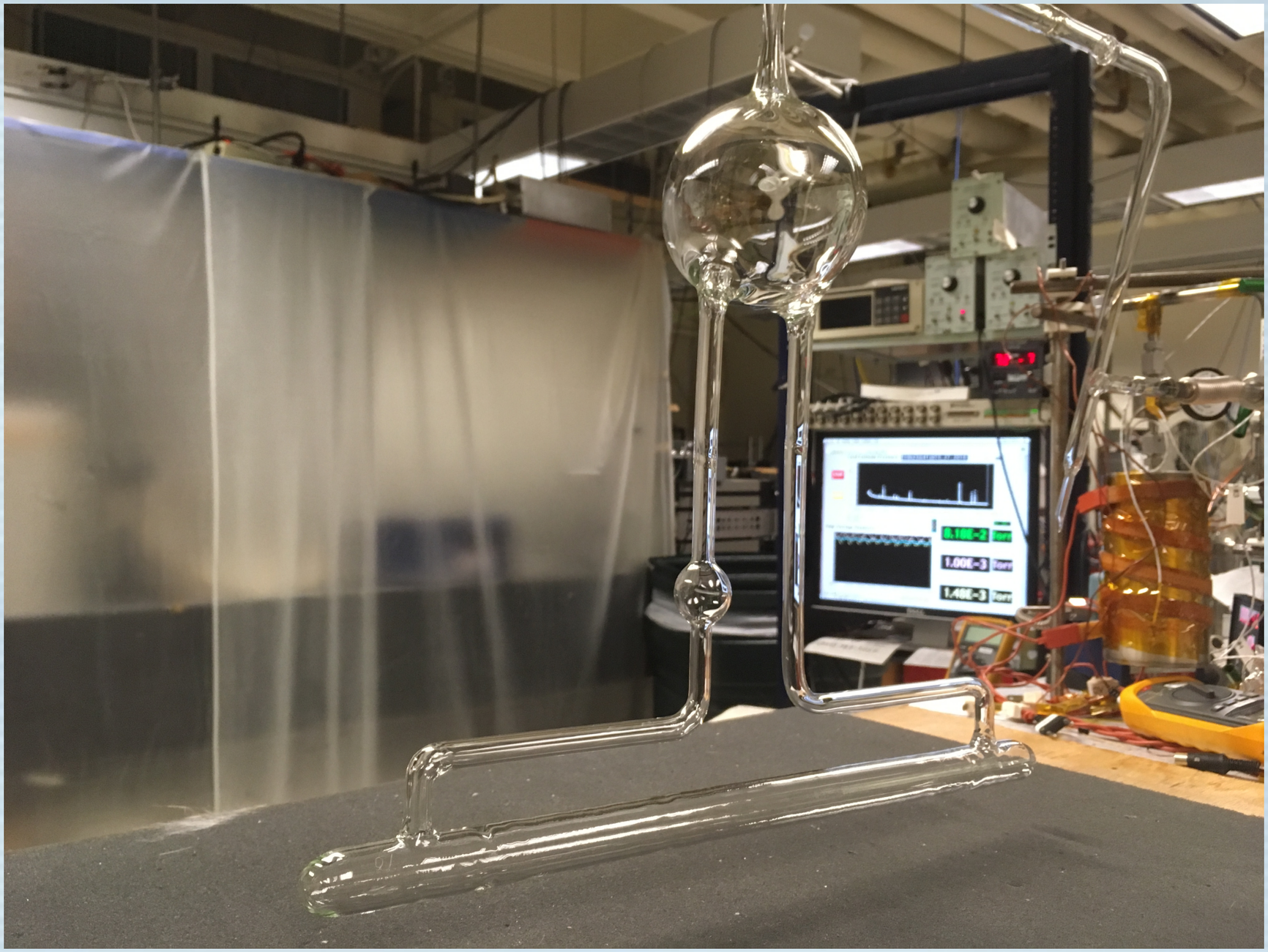
Stage I - 3 liter - Bastille Day design (2016)

Three liter convection-based target cell - Version Bastille Day, 2016
Drawn by Yunxiao Wang and Gordon Cates

Notes:
1) Target chamber should be as straight as possible (< 1mm) after attachment of thin windows.
2) Important dimensions indicated by red circles with tolerances as shown.
3) All other tolerances (shown with twiddle) are +/- 3mm.
4) While not shown, it is understood that the pumping chamber will be somewhat flattened at the bottom.
5) While the transfer tubes are shown with right-angle bends, they can be rounded quite gradually, whatever is easiest.
6) Drain traps are conceptual, details are up to you.
7) Finally, drawing is not quite to scale.

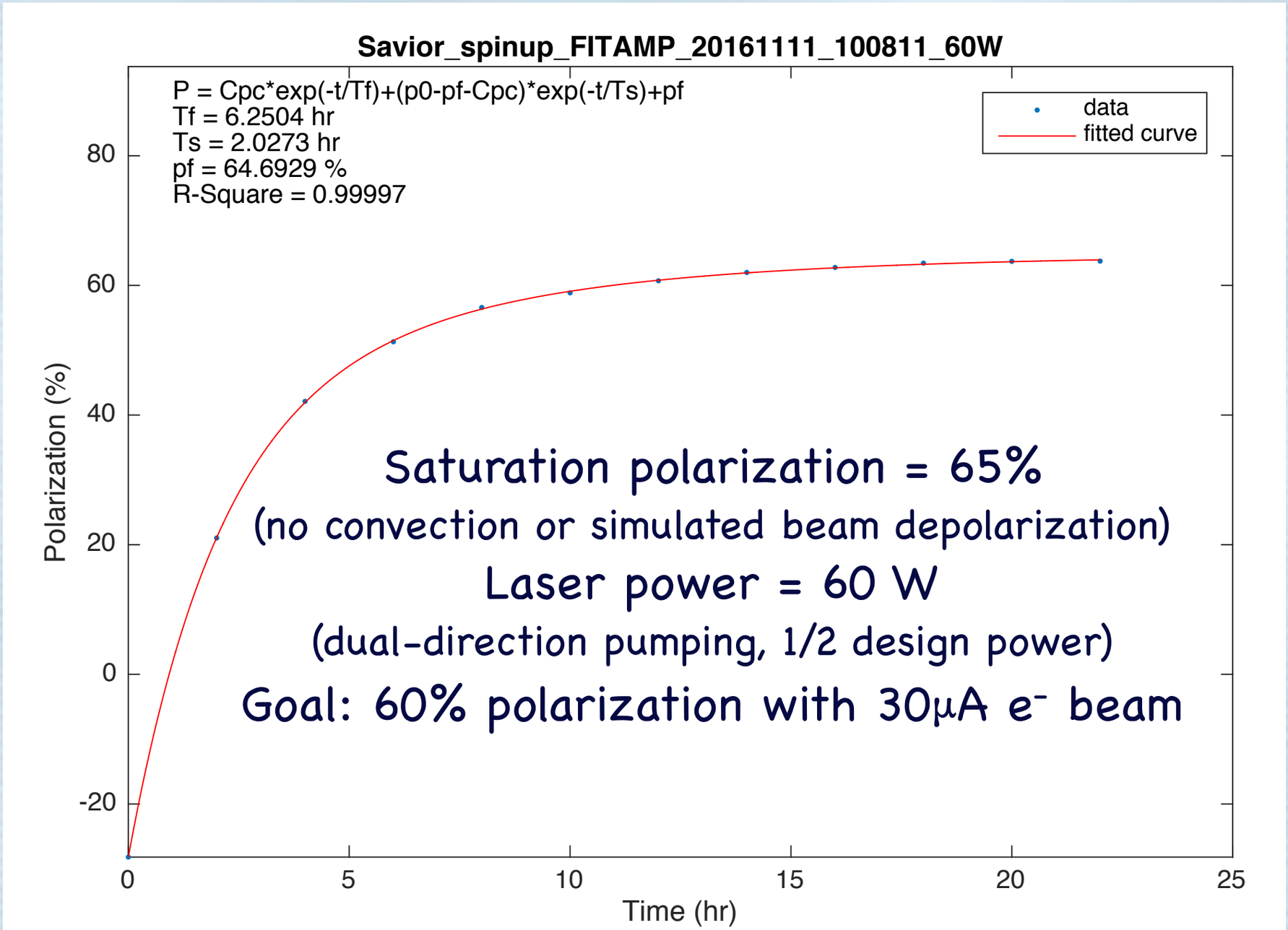


Stage I target production underway



Shown is the Stage-I (3-liter) target cell "Savior"on the UVa gas-handling system prior to being filled.

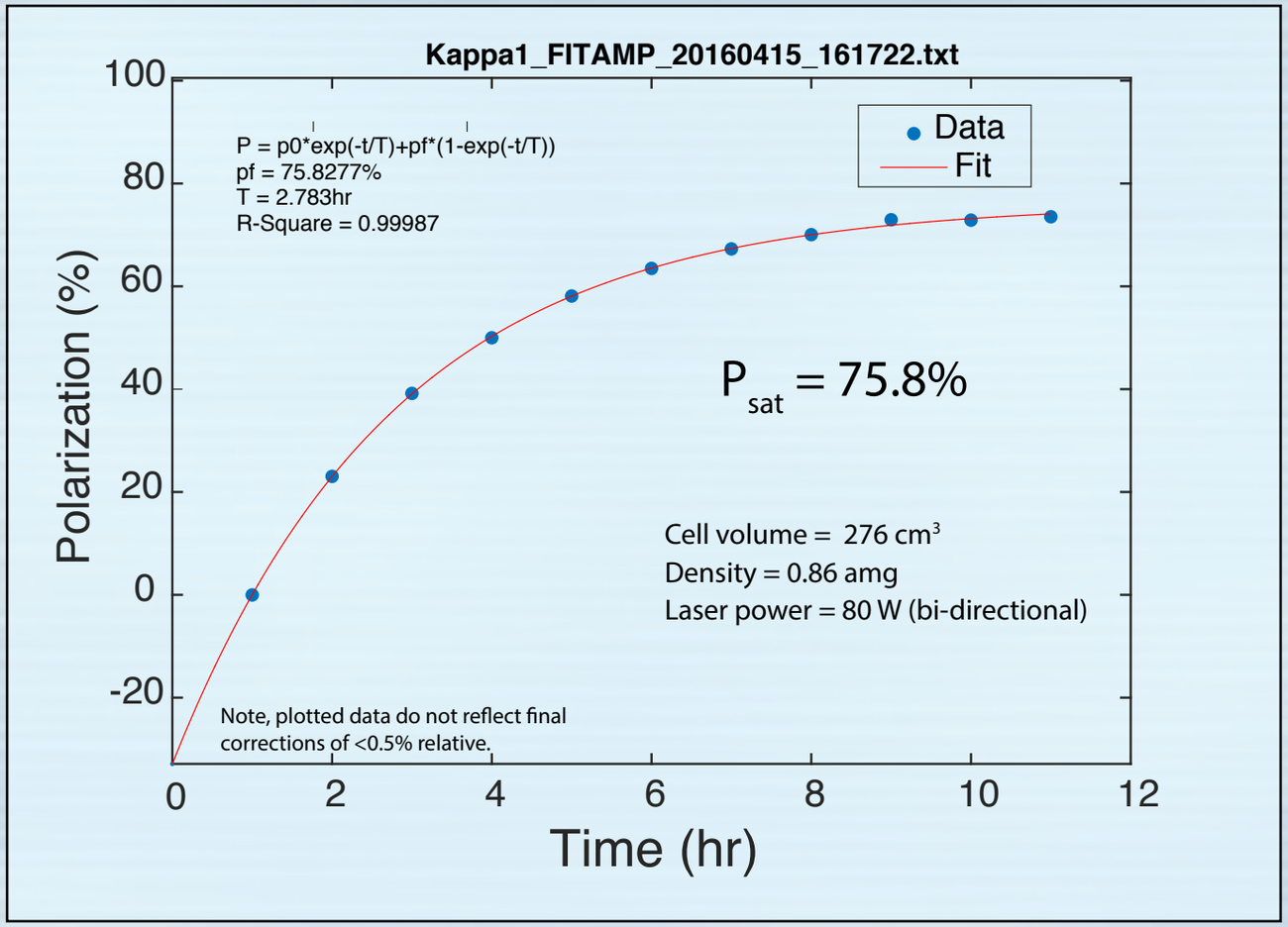
Stage-I polarization test of Savior

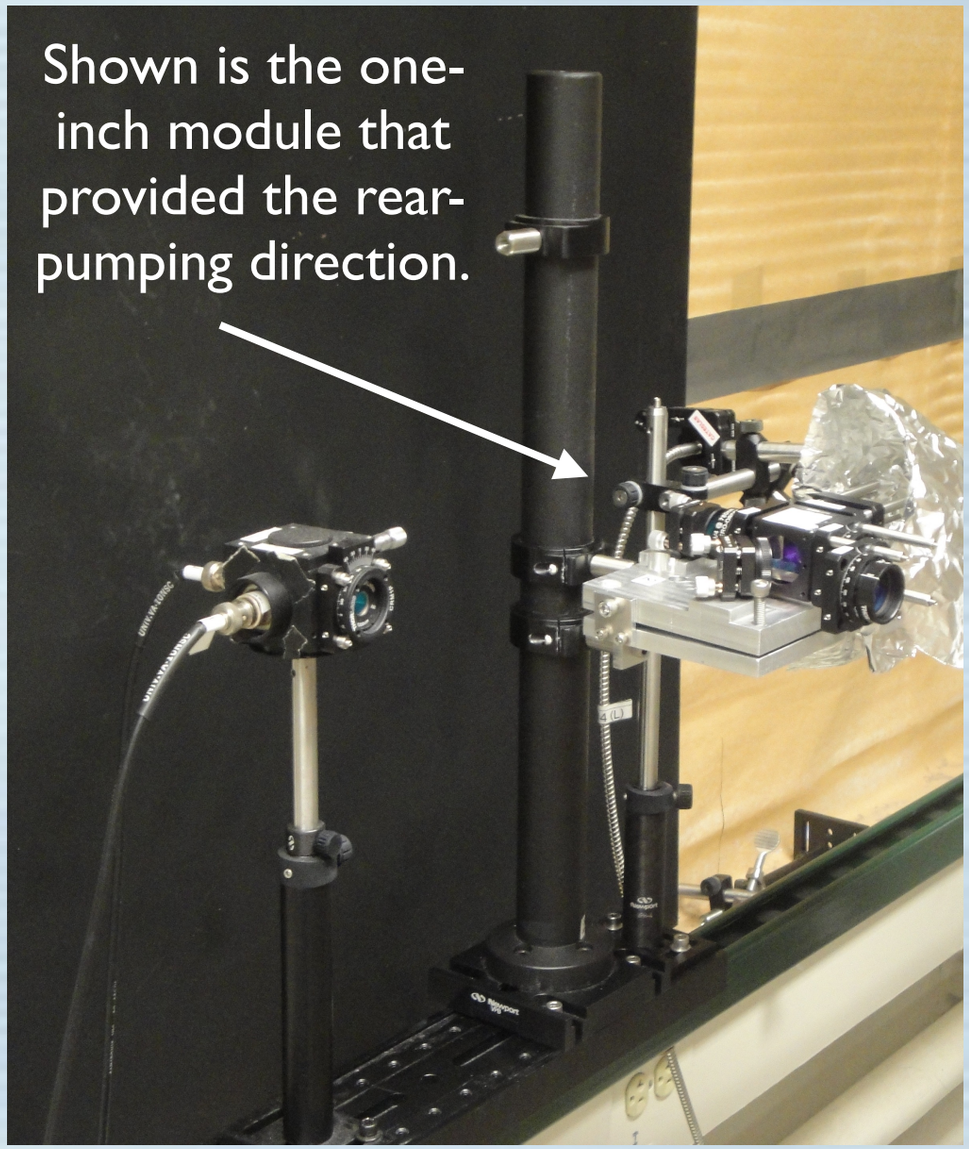


While not yet conclusive, test is very encouraging regarding the ultimate performance that is required.

New since Nov. review

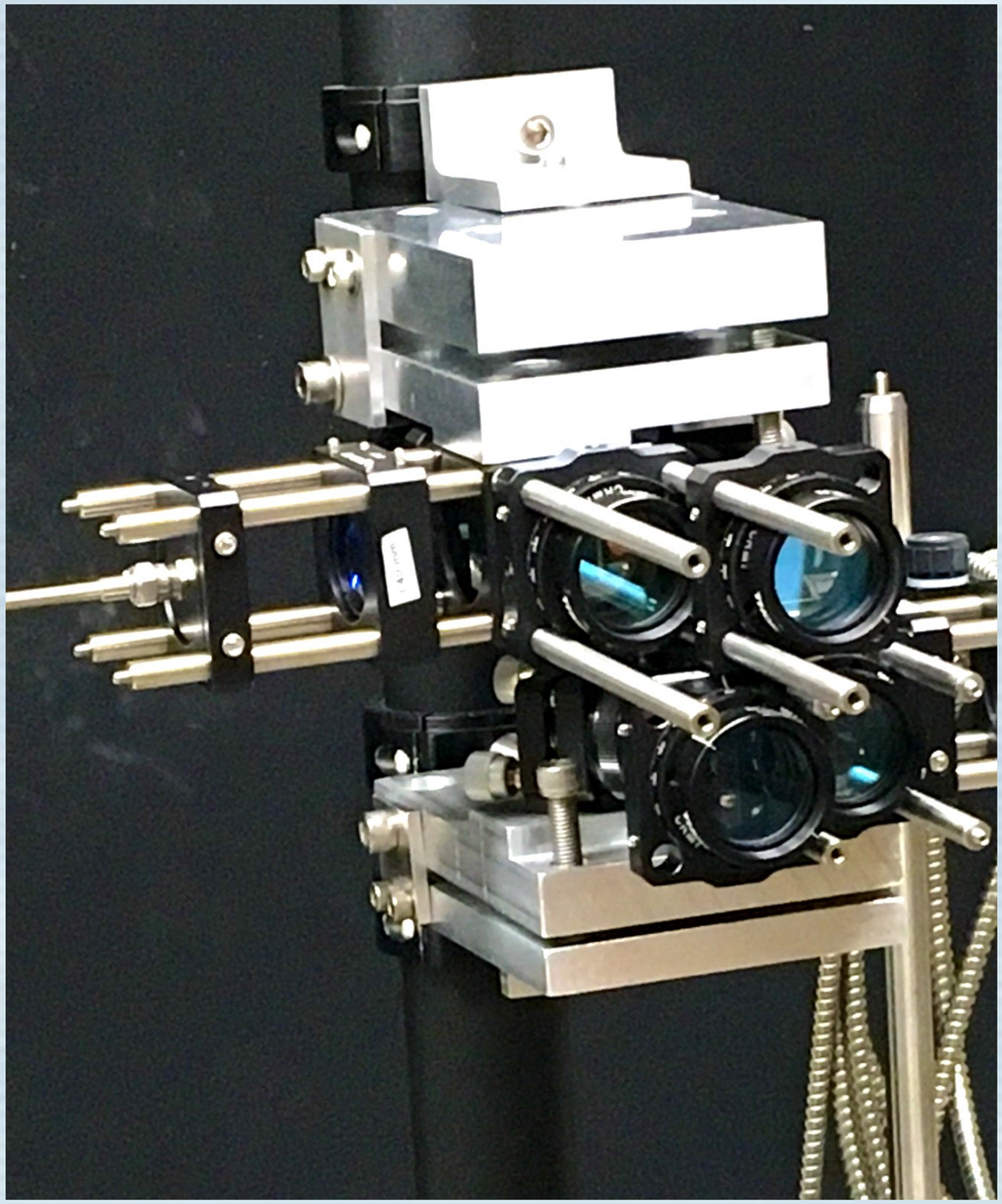
First test of dual-direction pumping





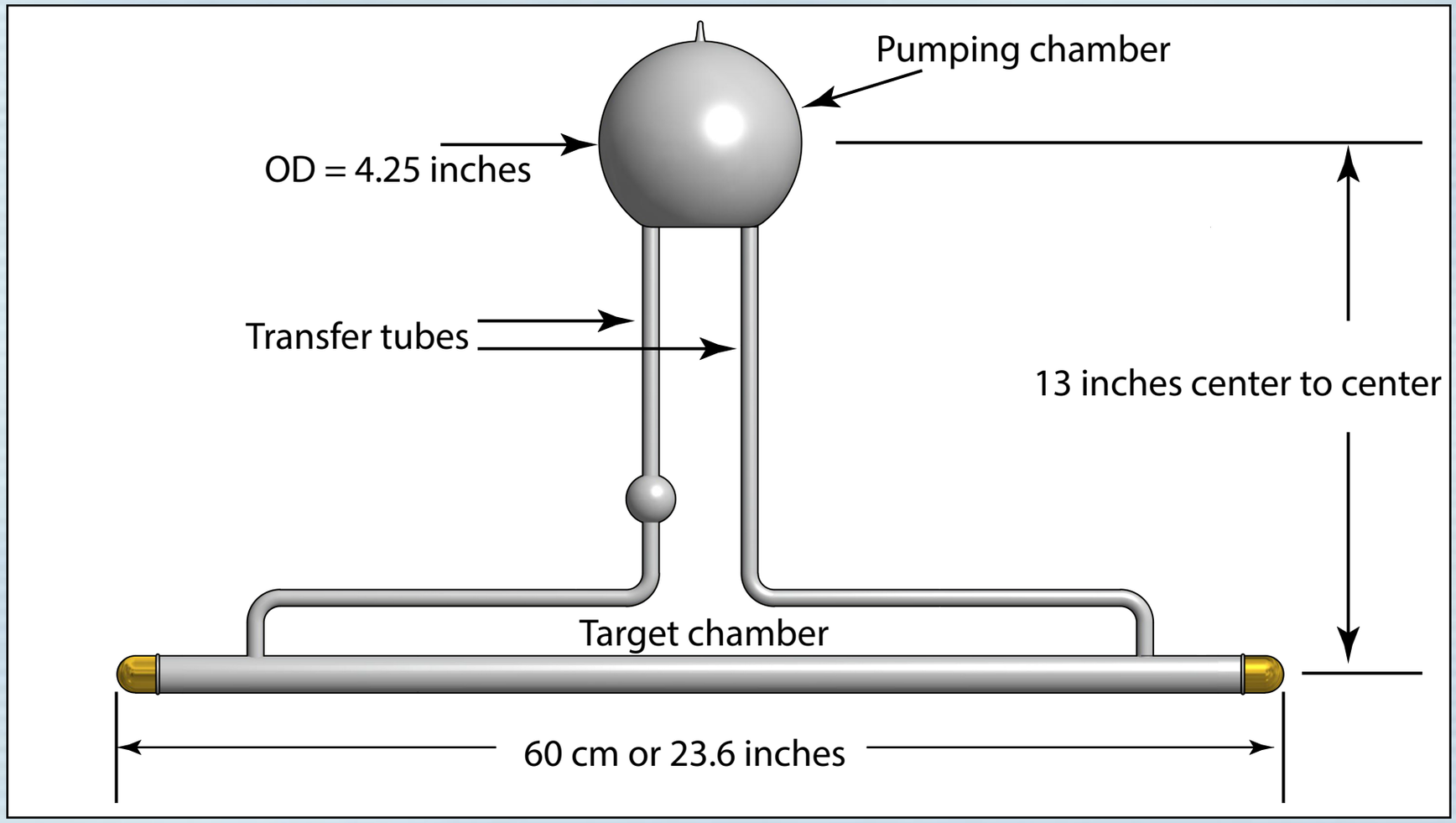
- Spherical cell, 3.25 inches outside diameter.
- Pressure just under one atmosphere.
- 40 Watts from three lasers combined with five-to-one combiner from the "front" pumping direction.
- 40 Watts from single one-inch module from the "back" pumping direction.

More recent setup with two sets of optics stacked vertically



New since Nov. review

G_E^n style (Stage II) target cell design



Shown is the G_E^n target-cell design as it appears in the Target Conceptual Design Report

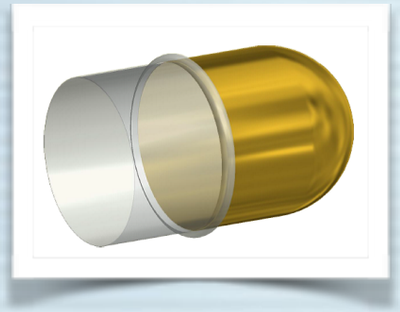
The long road to

Incorporating metal end windows

Many challenges!

- Transitioning from glass to metal with a sufficiently vacuum-tight seal that does not contaminate the gas.
  - ➡ Solved!
- Producing a metal surface, reproducibly, that does not cause excessive spin relaxation.
  - ➡ Solved!
- Identifying a material that has sufficient strength when thin enough to avoid excessive scattering that won't leak.
  - ➡ Solved, but only if the window is aluminum, which <u>cannot</u> be attached directly to the glass.
- If the window itself is a different piece of metal from the metal that attaches to the glass, finding a way to attach it that won't ruin bullets 1 — 3.
  - ➡ Solved (very recently) but not yet tested.

Properties of candidate window materials



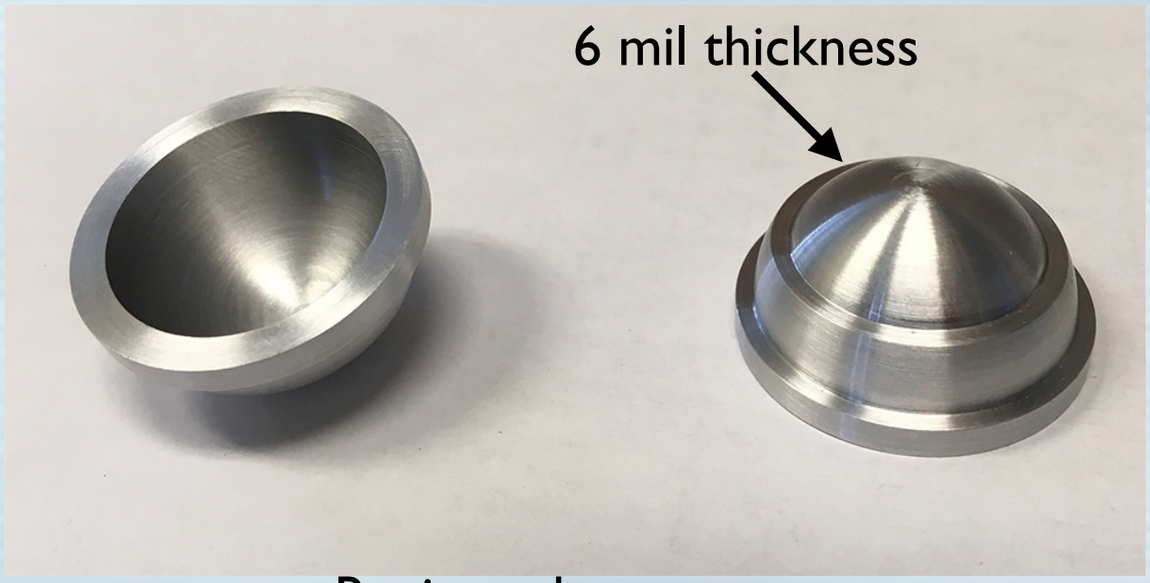
For several materials, the window thickness such that the "yield point" occurs at pressure 50% greater than the operating point. Existing GE-180 glass windows included for comparison.

Material	Density (g/cm^3)	Melting Point (^0C)	Yield Strength (MPa)	Min. Thickness Needed (um)	Min. Thickness Needed (mg/cm^2)	Radiation Length (mg/cm^2)	Number of radiation lengths
OFHC	8.9	1065	49	172.09	153.16	$1.247*10^4$	0.0123
Cartridge Brass	8.53	916	441	19.12	16.31	$9.439*10^3$	0.0017
Glidcop Al-60	8.81	1083	413	20.42	17.99	$9.693*10^3$	0.0019
GE 180	2.76	1015		139.7 (thickness used)	38.56 (thickness used)	$1.388*10^4$	0.0028
Al	2.7	~ 600	55	153	41.40	$1.591*10^4$	0.0026

If spin-relaxation properties are acceptable, aluminum is the preferred solution.

Completing fabrication on first test window

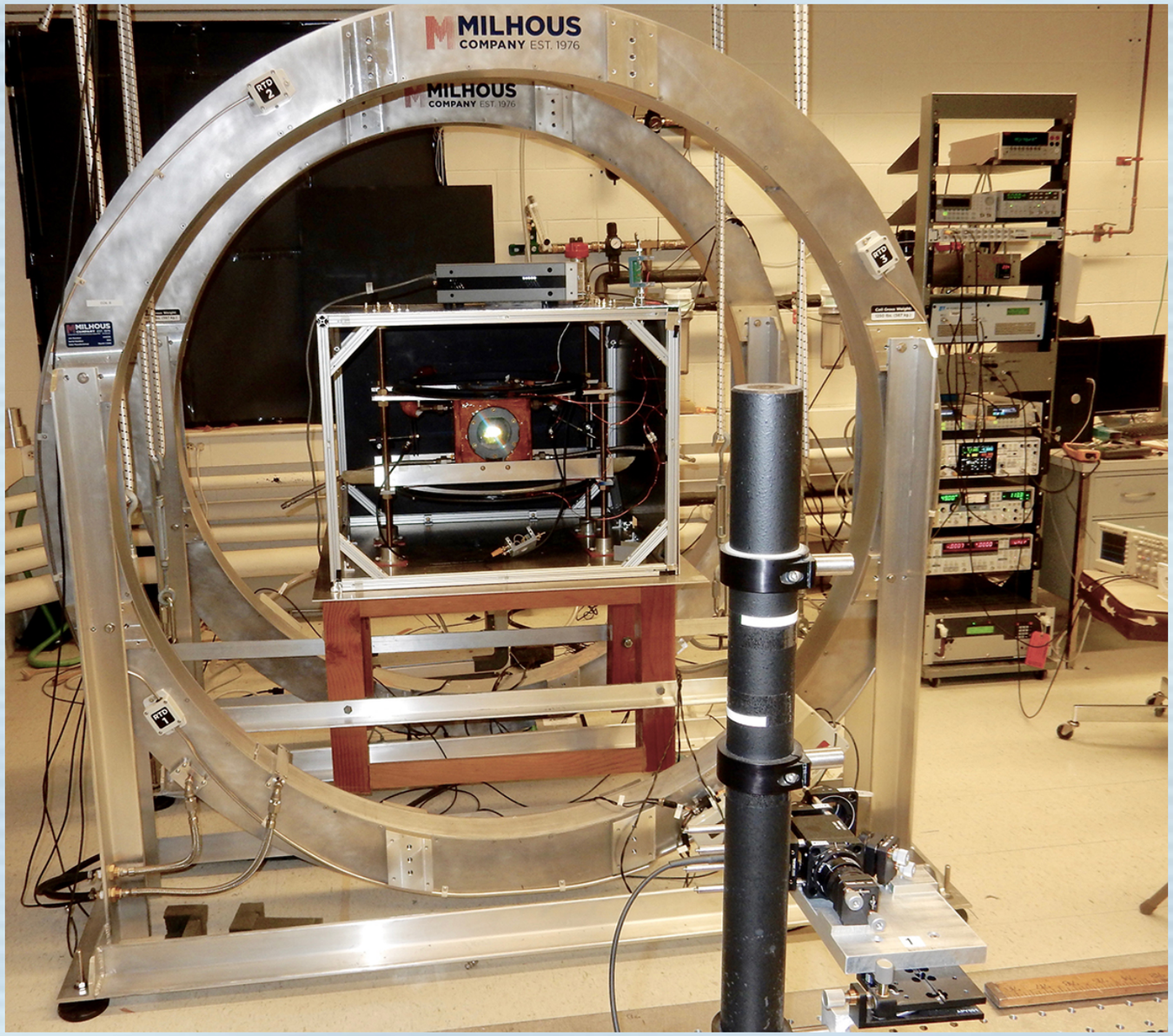
The pieces shown have not yet been electroplated with gold



- Aluminum end-cap, machined at UVa, has 6 mil thickness with a "clear" aperture diameter of 21 mm.
- The ^{3}He will only "see" gold surfaces.
- The end cap will be joined to the copper tube by electroplating more copper on the exterior of the point at which the two pieces meet.
- NO HEAT IS REQUIRED FOR THE JOINING PROCESS!!!
- The piece shown at left, once complete, will be incorporated into a test cell.

Progress on κ_0 measurement and lessons learned

Apparatus for K_0 measurement

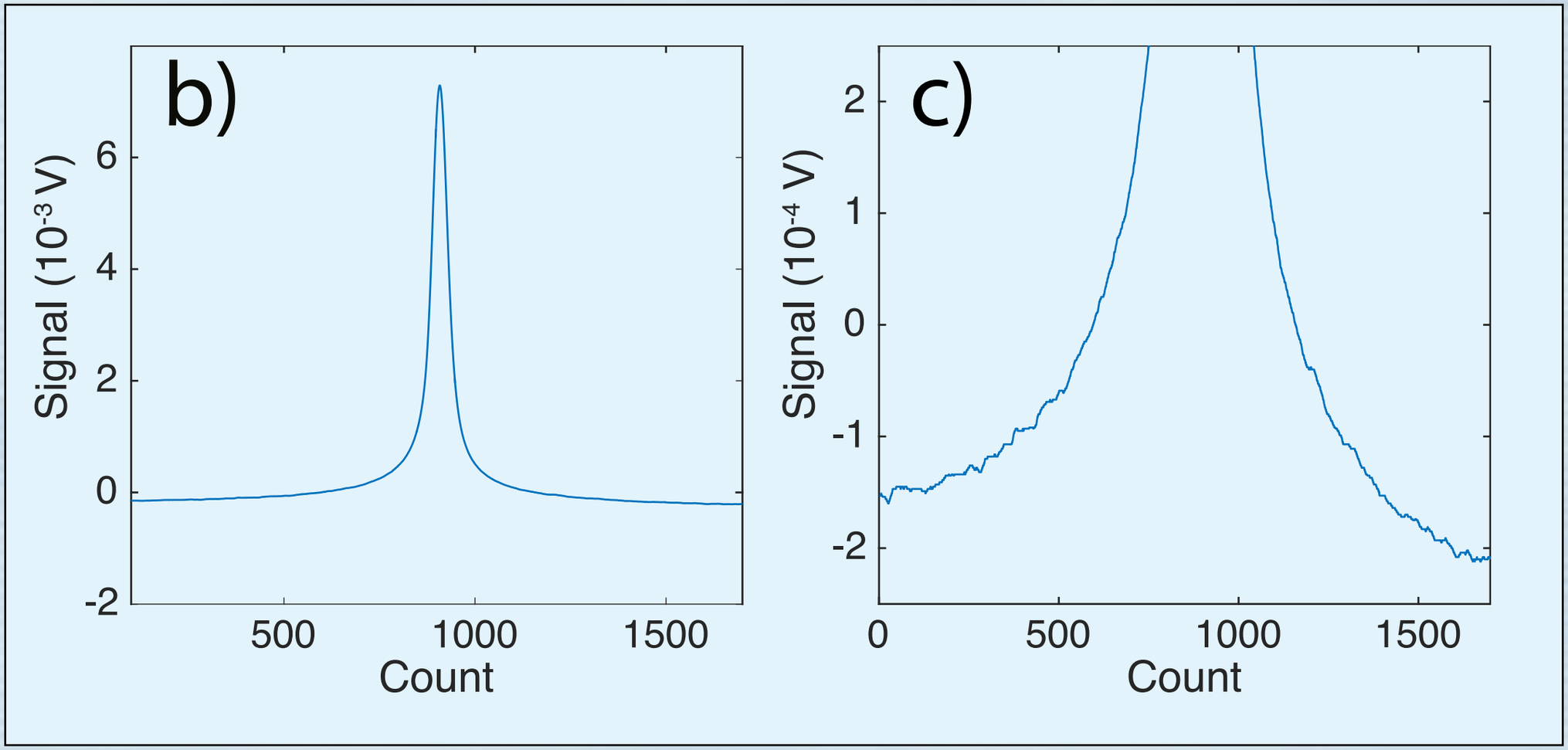


- Apparatus significantly more complete since November review
- Apparatus is suspended by bungee cords to suppress microphonic-induced noise.
- Aluminum shielding suppresses electromagnetic noise.
- Wonderful signal:noise ratio achieved.

New since Nov. review

S/N ratio approaching 1000 achieved

(and the system is not yet fully optimized)

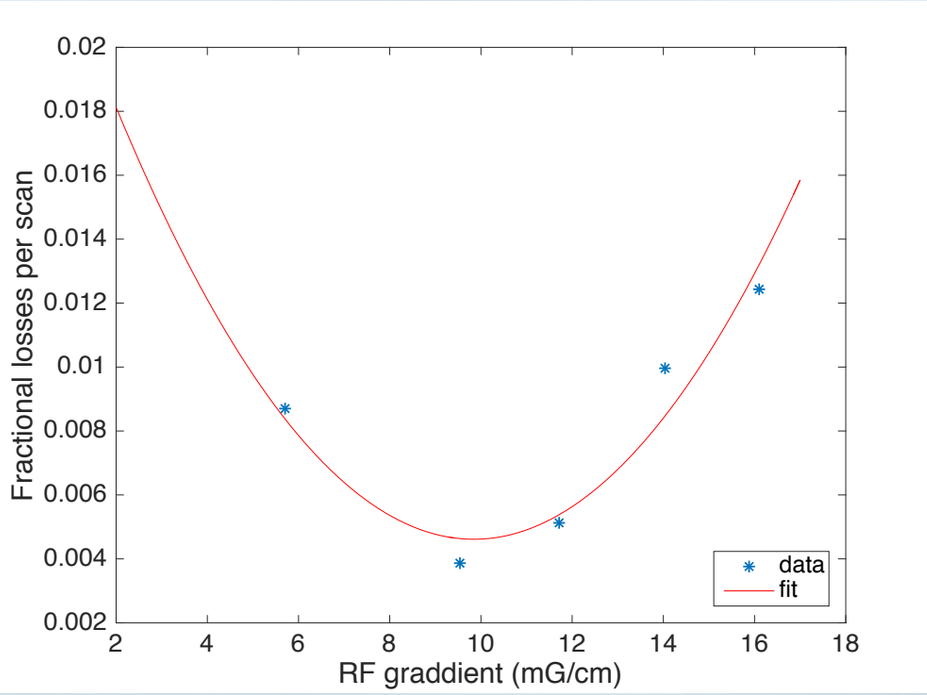


Design is working well for noise suppression.

New since Nov. review

Using the κ_0 apparatus to explore AFP issues relevant to GEn target

We have been exploring the issues that are important for limiting AFP losses



2013 Hall A Annual Report

$$\text{fractional relaxation} = \frac{1}{T_{1\rho}} \frac{\pi B_1}{2(\partial B_z/\partial t)}$$

PRA 38, 5092 (1988) and PRL 74, 4943 (1995)

$$\frac{1}{T'_{1\rho}} = D\left[\frac{|\nabla H_{0z}|^2}{H_{1l}^2} + \frac{|\nabla H_{1l}|^2}{H_{1l}^2}\right]$$

This term previously neglected

- Point sources of magnetic-field inhomogeneities.
- Overall inhomogeneities of the static magnetic field.
- Variations in the magnitude and direction of the RF field (B_1).

We have identified several important effects, and are still quantifying the important issues for the G_E^n target design.

New since Nov. review

Overall summary

- Engineering is on track, albeit there is much to do!
- We are formally in production of Stage-I targets (to be used in, for example, A_1^n).
- Early polarization tests look good, again, there is much to do, but we are on track.
- The κ_0 measurement is moving along, and has provided valuable lessons.
- There has been major progress in the metal end-window issue, although the proof will be in the upcoming tests.

Backup slides

Progress and plans on target-cell production

- Stage-I target-cell production has begun.
- Oven for pressure broadening studies has been built that will accommodate the larger target cells.
- Our old Coherent 899-29 laser, used to characterize the target cells, is ailing but is probably recoverable.
- New diode-based laser is in house and we are starting the process of incorporating it into our system.
- Fast converging on metal end-window tests.
- Stage-I cell production will greatly facilitate Stage-II cell production, although there will be new challenges.

Progress on target milestones and updates

As presented at November review

****

Target milestones **********

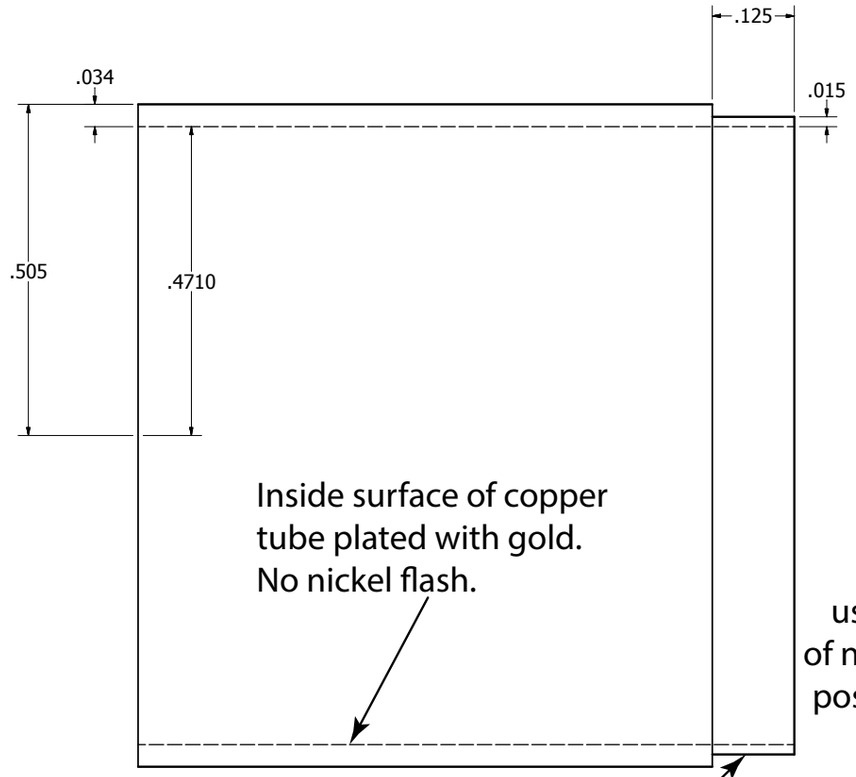
****

*** Selection of target cell design	Nov 2014	(Complete)
Conceptual design document complete	January 2016	(Complete)
Conceptual design review	March 2016	(Complete)
Start bench test of 3 liter glass conv. target	April 2016	(Complete)
Conceptual design frozen	June 2016	(Complete)
Test of glass/metal technology complete	June 2016	(Complete)
Begin engineering and design	July 2016	(Complete)
Bench test of 3 liter glass/metal target	January 2017 →	Nov. 2017
*** Simulated beam test (bench test) (full scale 6 liter cell)	September 2017 →	July 2018
Begin production of full-scale cells	November 2017 →	Aug. 2018
End of engineering	January 2018	
*** Design complete of target hardware and Instrumentation	June 2018	
*** Target is ready	January 2019	

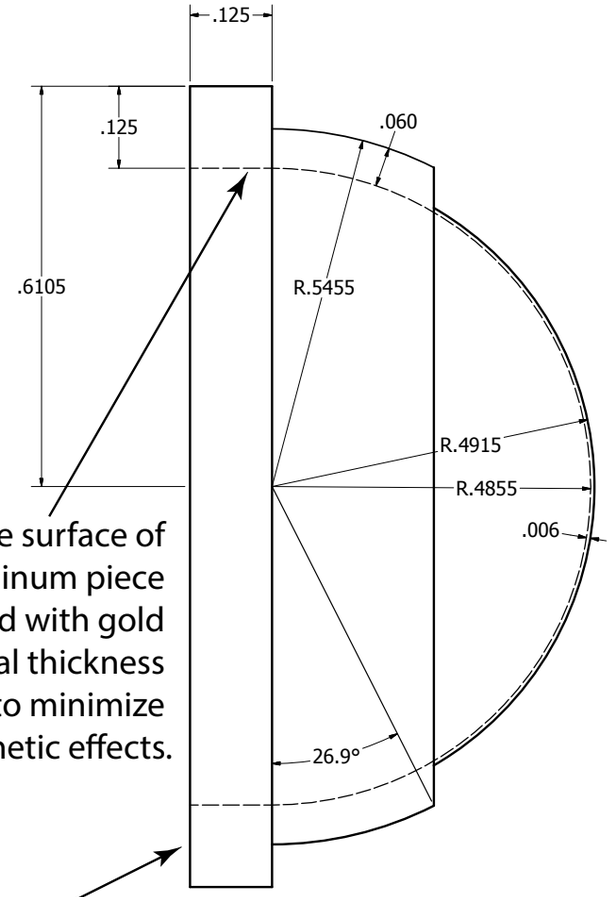
Cell production complete June 2019

Mtg. this afternoon to determine Probably March 2019?

Details on electroplating



Inside surface of copper tube plated with gold. No nickel flash.



Inside surface of aluminum piece plated with gold using minimal thickness of nickel flash to minimize possible magnetic effects.

Outside surface of copper tube in region that mates with aluminum piece plated with gold. No nickel flash.

Exterior of aluminum "flange" facing the copper tube plated with copper in preparation for joining

DRAWN		Drawing by Chris Jantzi and Gordon Cates July 12, 2017
CHECKED		
QA		TITLE: UVa glass-to-copper and aluminum endcap assembly
MFG		
APPROVED		SIZE C | DWG NO | REV
		SCALE 8 : 1 | SHEET 1 OF 1

Relaxation due to inhomogeneous magnetic fields during resonance conditions

This paper, the usual reference for AFP losses, neglects the effects of inhomogeneous RF fields.

PHYSICAL REVIEW A VOLUME 38, NUMBER 10 NOVEMBER 15, 1988

Spin relaxation in gases due to inhomogeneous static and oscillating magnetic fields

G. D. Cates, D. J. White, Ting-Ray Chien, S. R. Schaefer, and W. Happer
Department of Physics, Princeton University, Princeton, New Jersey 08544
(Received 27 June 1988)

We have extended a recent theory of spin relaxation in gases due to static magnetic field inhomogeneities to include the effects of oscillating magnetic fields. We use this theory to show how magnetic field inhomogeneities cause spin relaxation under magnetic resonance conditions. We have confirmed some of the main theoretical predictions by experimental observations. Spin relaxation in inhomogeneous magnetic fields can be used as a convenient new way to measure diffusion constants in gases.

Recent studies of the effects for earlier target work at JLab seemed to describe things nicely.

$$\frac{1}{T_{1\rho}} = \frac{|\vec{\nabla} B_z|^2}{B_1^2} D$$

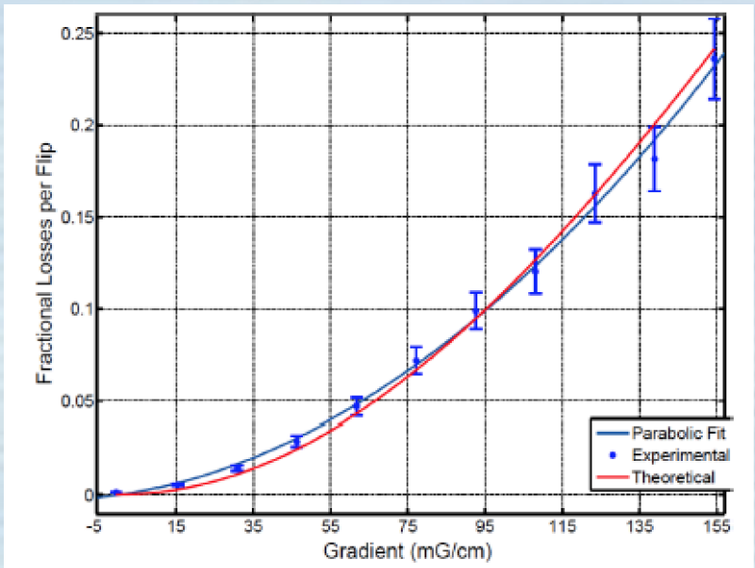


Figure 3.4: Fractional AFP loss (single flip) as a function of field gradient.

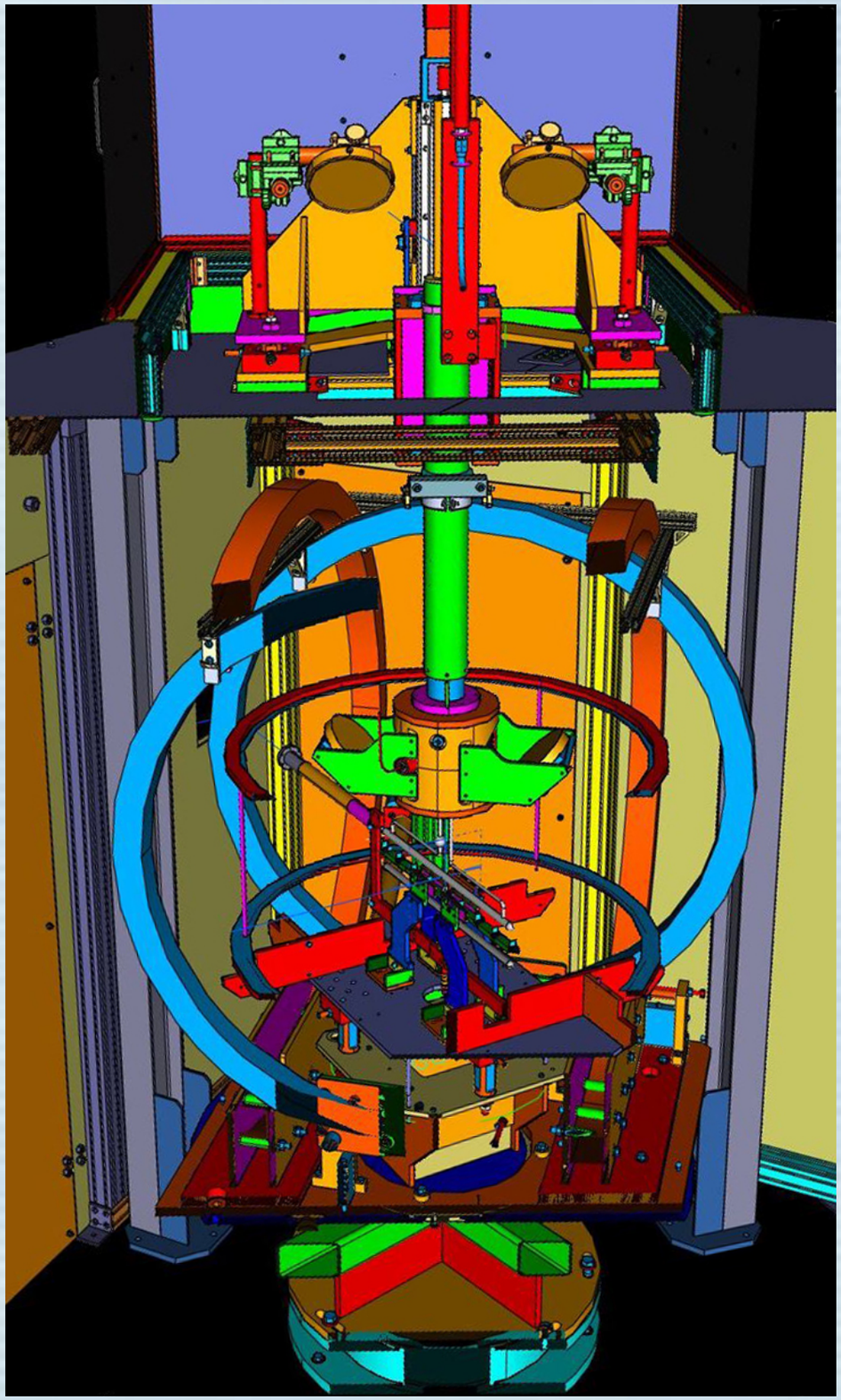
However, a later paper by Driehuys, Cates and Happer considered conditions where the RF inhomogeneities needed to be included:

PRL 74, 4943 (1995)

$$\frac{1}{T'_{1\rho}} = D\left[\frac{|\nabla H_{0z}|^2}{H_{1I}^2} + \frac{|\nabla H_{1I}|^2}{H_{1I}^2}\right]$$

New since Nov. review

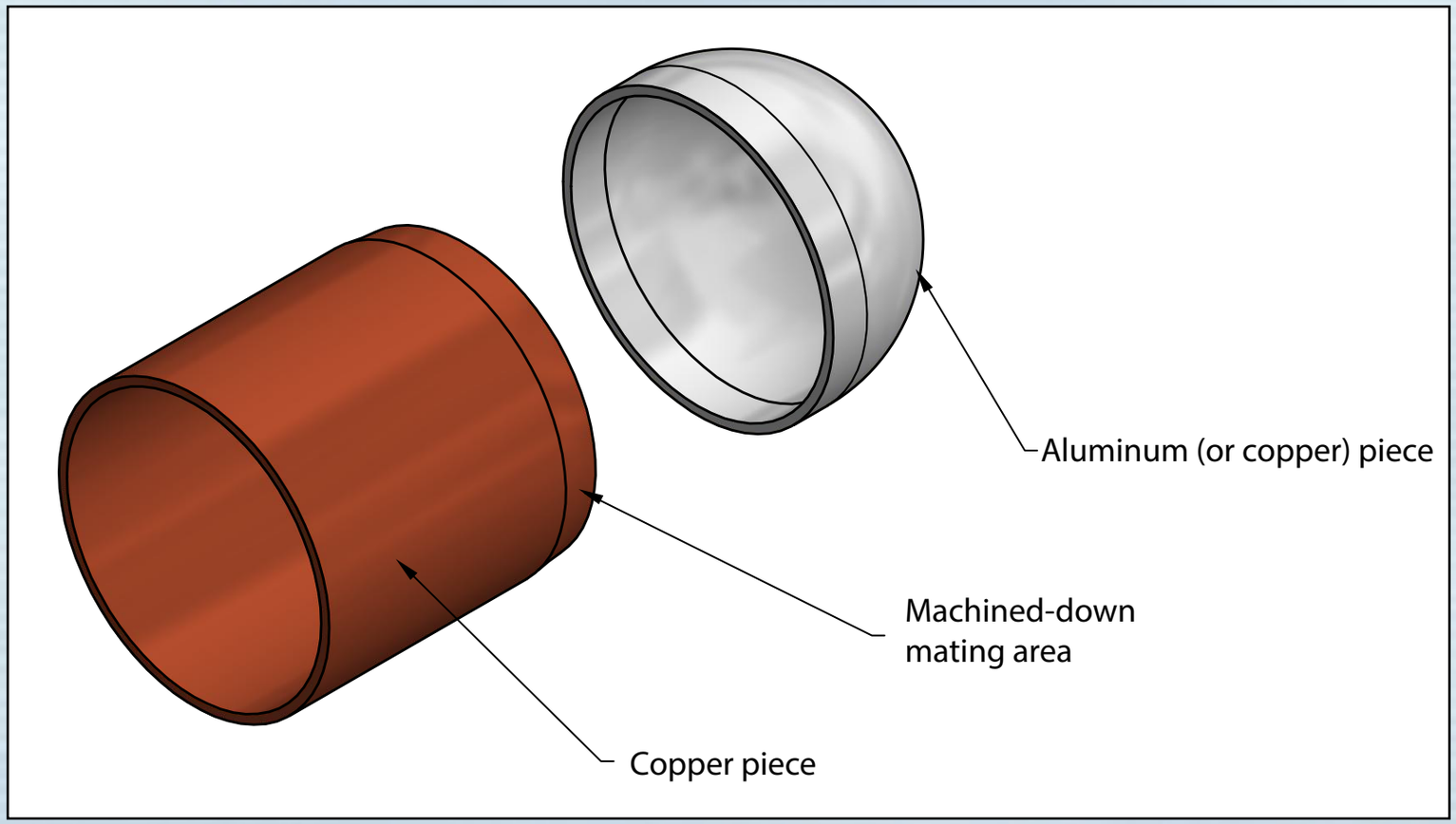
Current state of the engineering design



Closeup emphasizing target ladder.

New since Nov. review

Thin window development



- Aluminum is an attractive material for the end windows, but gold-coated aluminum has not yet been tested for its spin-relaxation properties.
- We are in conversation with Epner about the best way to attach and coat the aluminum "end cap".
- Hope to construct and study test cells with aluminum end caps within one or two months.
- A successful test could lead to a target cell with metal end windows within one to two months after successful test (3-4 months out).