Cryogenic Systems for the APS Upgrade

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ASD Seminar 30JAN2012

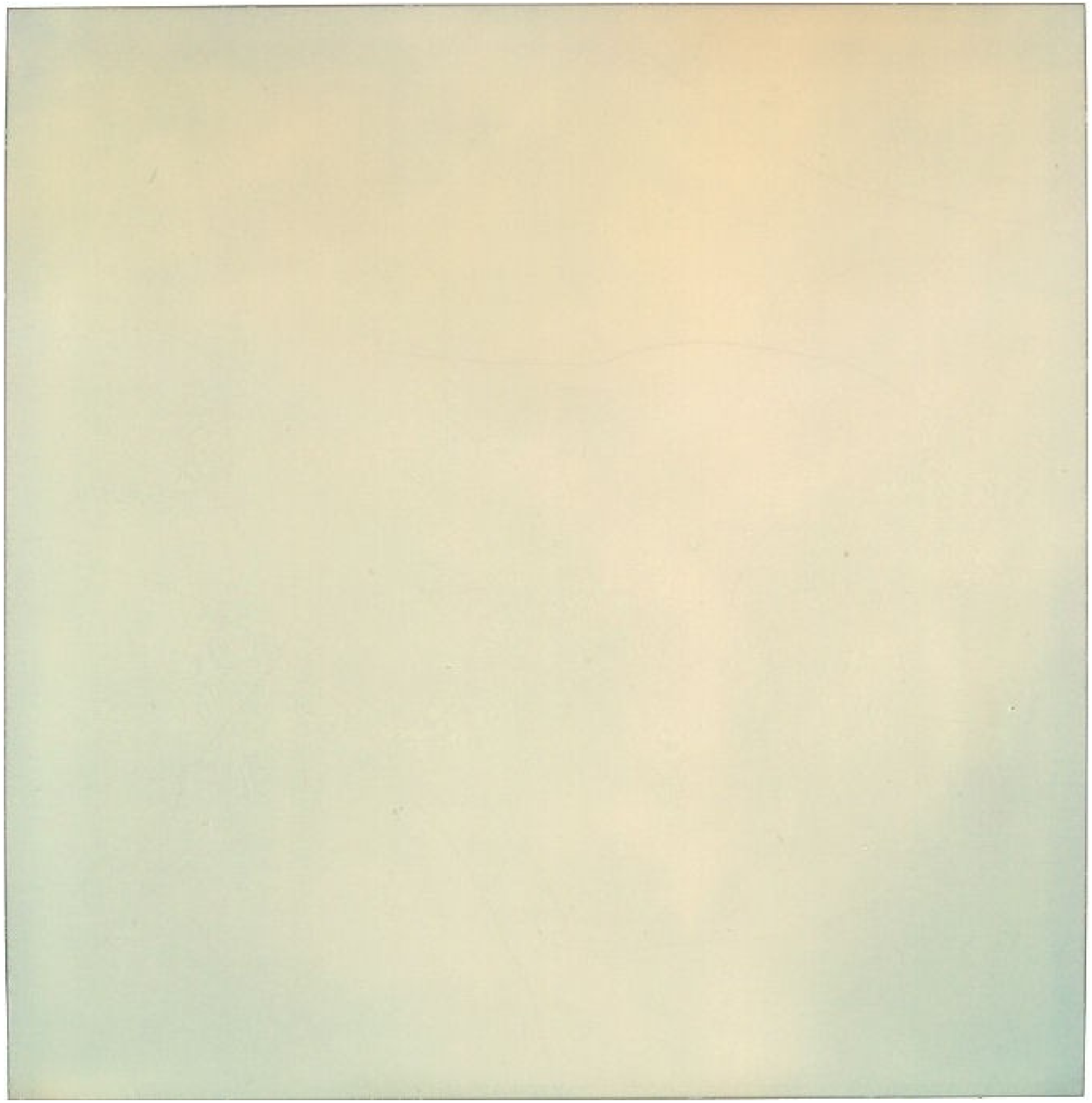
Outline

- Helium usage (1)
- Safety
- Loads/temperatures/locations
- Methods of refrigeration
  - SCU: cryocoolers
  - SPX: expansion engine refrigeration
- Support for SPX R&D
- Helium usage (2)
- Summary

Fermilab uses some helium – 1981 (1)

Fermilab uses some helium – 1981 (2)

Fermilab uses some helium – 1981 (3)



Fermilab uses some helium – 1981 (4)

Fermilab uses some helium – 1981 (5)

Cryogenic Systems Safety

- ES&H-4.10 Cryogenic Liquid Safety
- ES&H-13.1 Pressure Systems Safety
- Vacuum Systems Consensus Guideline for DOE Accelerator Laboratories
- 10 CFR 851 – Worker Safety and Health Program
  - 851.3(a): *Pressure systems* means all pressure vessels, and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum.
  - Appendix A, 4. Pressure Safety:
    - (a) establish policies & procedures to ensure systems follow sound engineering principles
    - (b) ensure pressure vessels & piping systems conform to the ASME Boiler & Pressure Vessel Code and the applicable ASME B31 piping standards
    - (c) when codes are not applicable, implement measures to provide equivalent protection
- PTSC (https://docs.anl.gov/lms/processes/safety/LABCOM-1.28)
- Training (Cryogenic Safety, ESH 145; Pressure Safety Orientation, ESH 119)
- Oxygen Deficiency Hazard (ODH) & engineered control measures
  - Environmental controls: ventilation (natural or forced), monitoring
  - Personnel controls: training, signage, barriers to entry, personal monitors, escape packs, etc. depending on hazard level

ODH

ODH Class	**Fatality Rate φ [hr-1]**
0	φ <1e-7
1	1e-7≤φ<1e-5
2	1e-5≤φ<1e-3
3	1e-3≤φ<1e-1
4	1e-1≤φ

$$\varphi = \sum_{i=1}^{n} P_i F_i$$

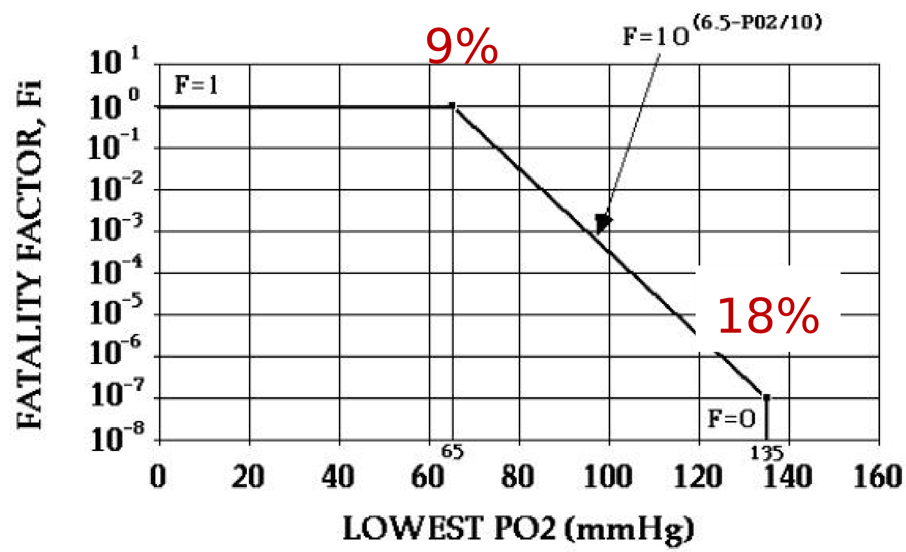
Effect Thresholds for Exposure to Reduced Oxygen

(Seated Individuals at Sea Level)

Volume % Oxygen	Effects
17	Night vision reduced. Increased breathing volume. Accelerated heartbeat.
16	Dizziness. Time required for novel tasks doubled.
15	Impaired attention. Impaired judgment. Impaired coordination. Intermittent breathing. Rapid fatigue. Loss of muscle control.
12	Very faulty judgment. Very poor muscular coordination. Loss of consciousness. Permanent brain damage.
10	Inability to move. Nausea. Vomiting.
6	Spasmodic breathing. Convulsive movements. Death in 5 - 8 minutes.

FNAL example failure rate Pi:
5A. Magnet (cryogenic)
"Up to January 1999, there have been 63,000 hours of Tevatron system powered conditions. There have been 11 magnet spill events mostly, if not all, due to single-phase rupture to vacuum from an electrical fault. Then magnet "powered, unmanned " failure rate is:

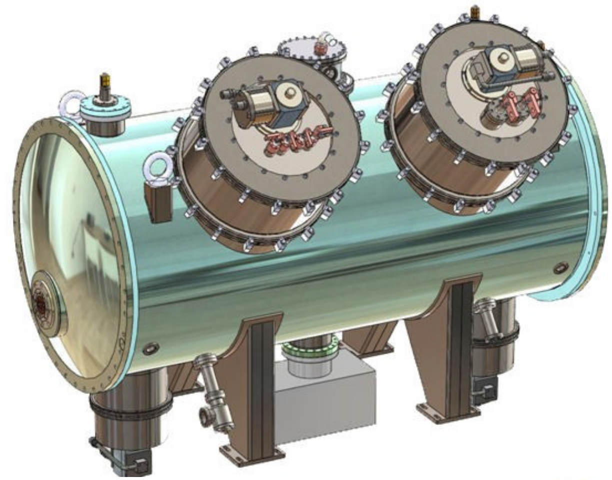
$$\text{failure rate} = \frac{11}{63000 \times 1000 \text{ magnets}} = 2 \times 10^{-7}\ /\text{hr}$$

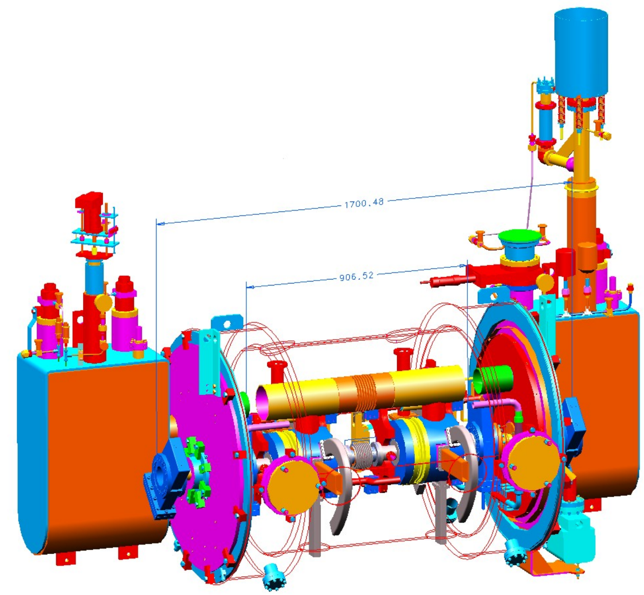


Heat loads/Operating temperatures

- SCU (design values per device)
- SPX (design values for full installation)

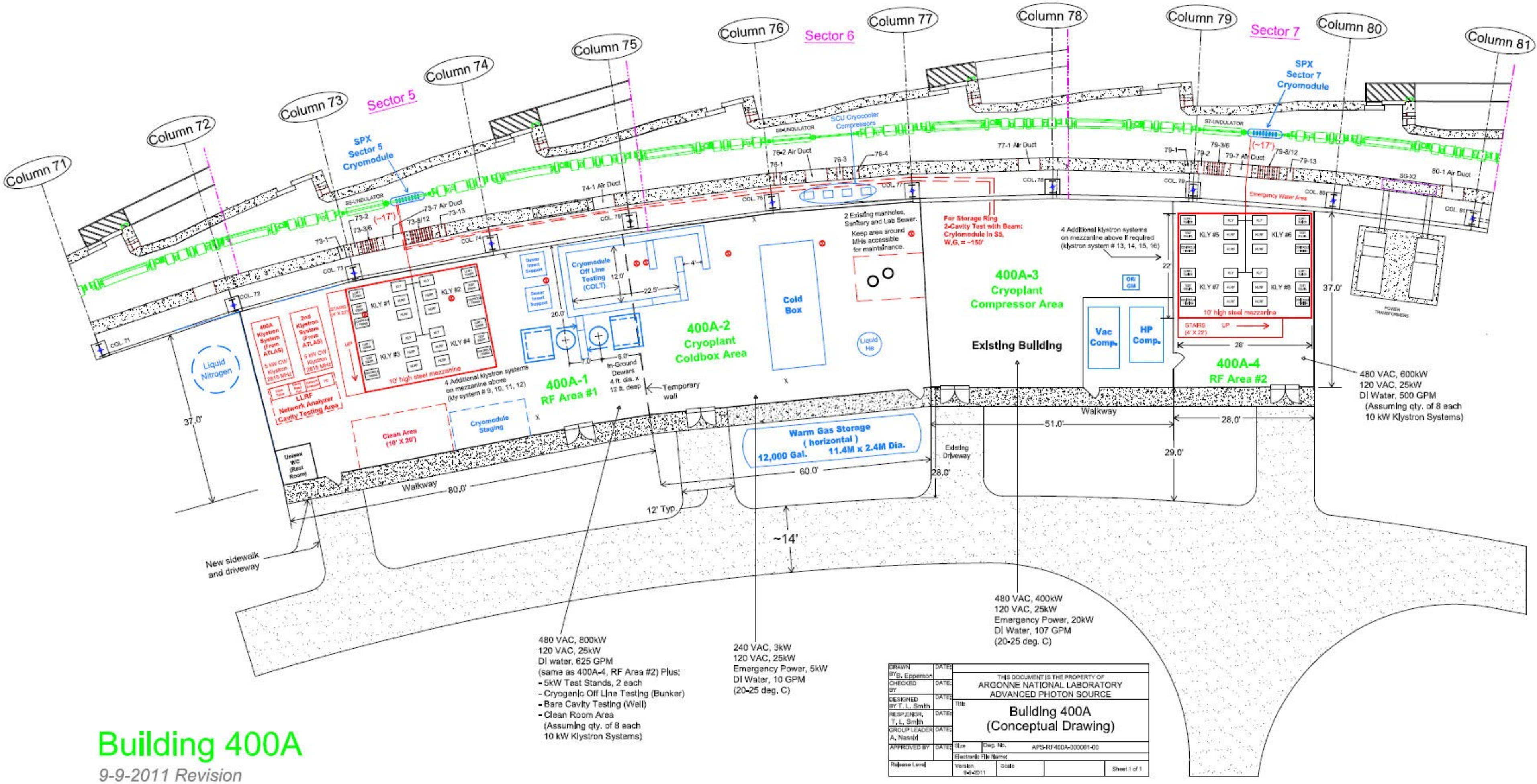
	Heat source	Temp [K]	Design load [W]	Installed capacity [W]
SCU	Magnet	4.3	0.7	3
	Rad shield/ beam tube	20	12	40
	Rad shield	60	86	224
SPX	Srf cavities	2.0	100	320
	Rad shield	5-8	300	500
	Rad shield	80	2000	4000 (LN2)





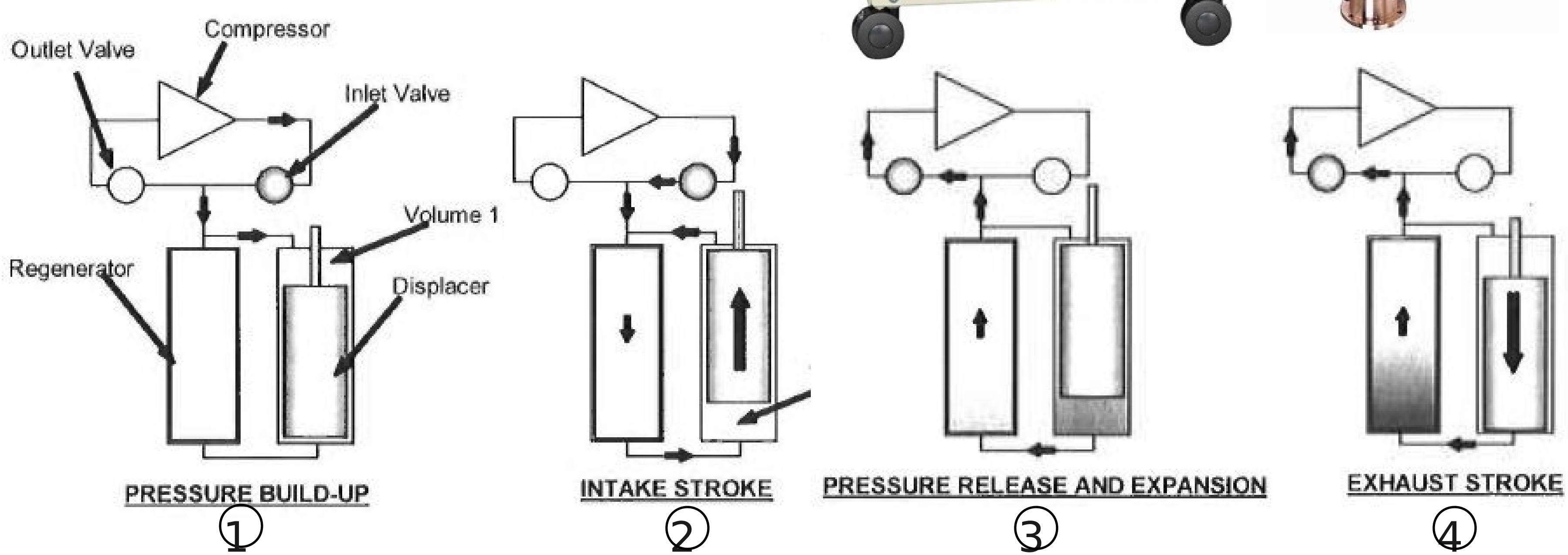
Cryogenic Systems Locations

- SPX0: sector 5 (production SPX in sectors 5 & 7)
- SCU0: sector 6



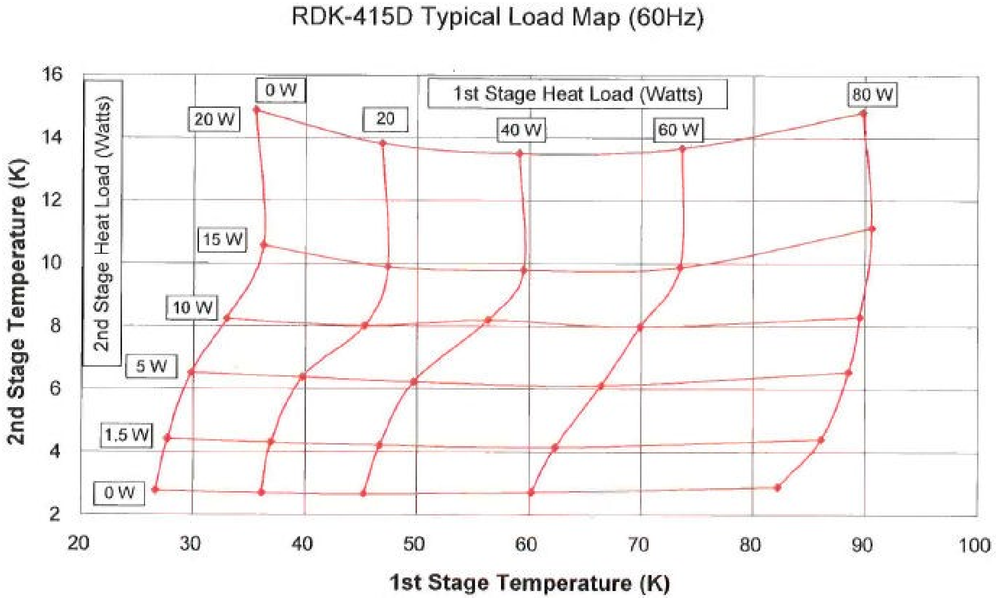
SCU: Gifford-McMahon (GM) cryocooler cycle

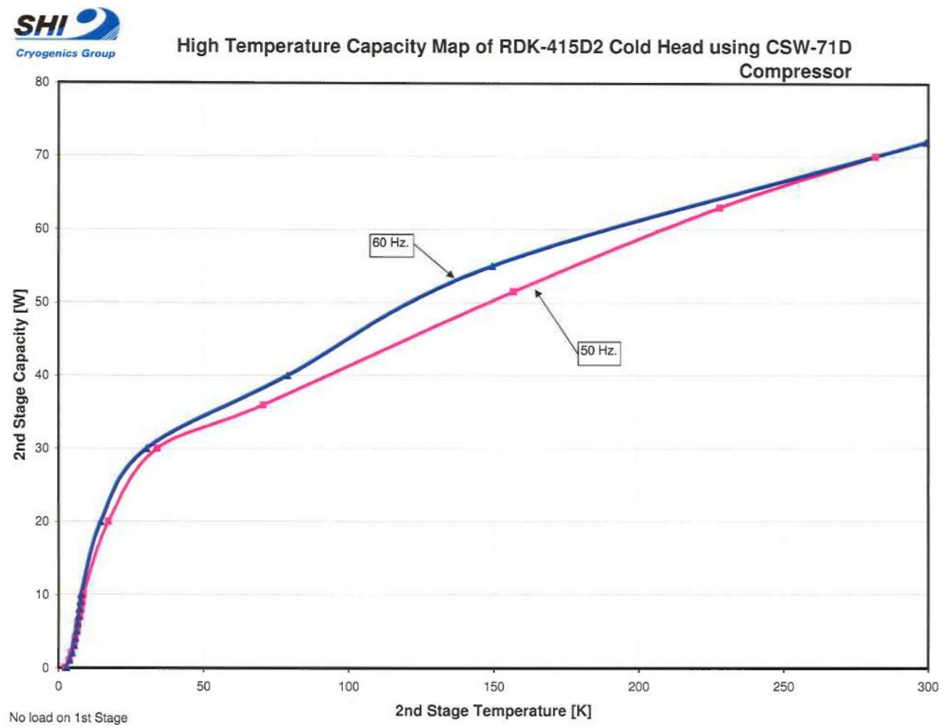
- Compact, simple, low capital cost
- Relatively inefficient (high operating cost)



Sumitomo RDK-415D Performance Maps

- Upper graph shows performance envelope under various operating conditions
- Lower graph shows available 2nd stage (lowest temperature) cooling power as a function of temperature during cooldown





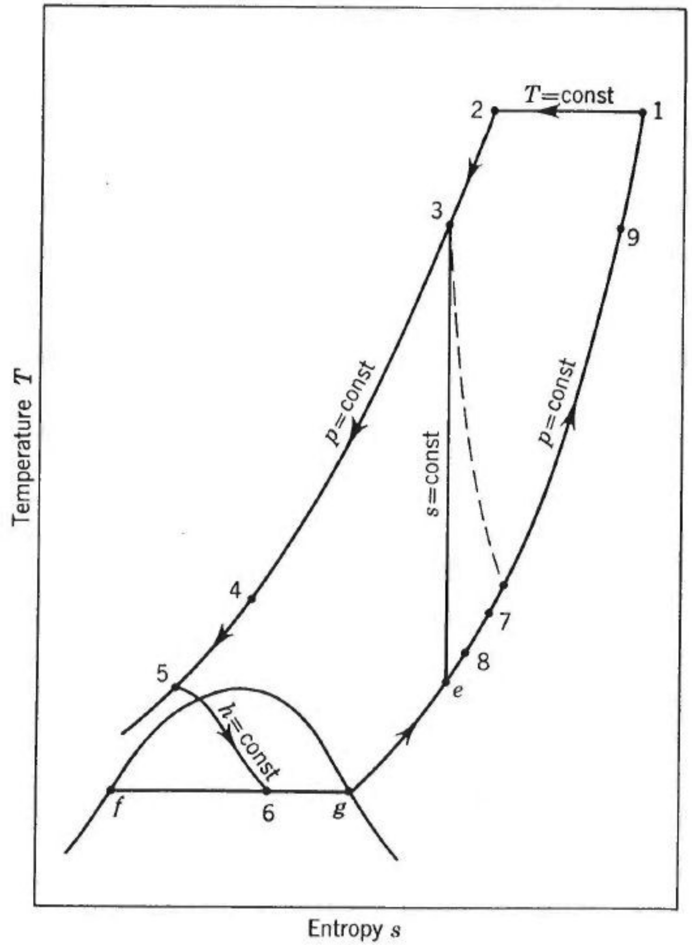
Bldg 314 – JAN2012

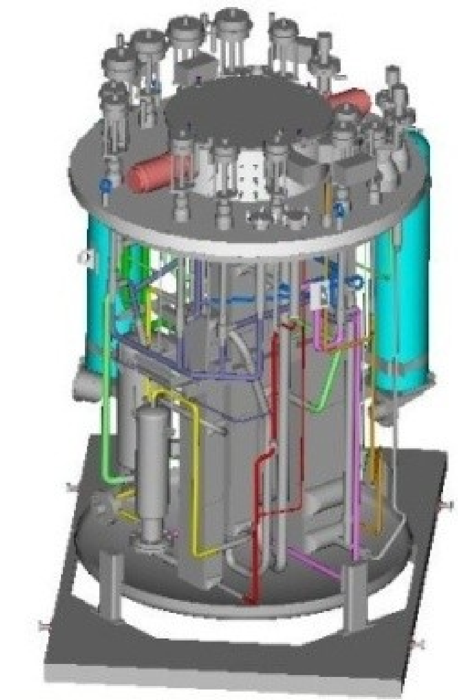
SPX Approach

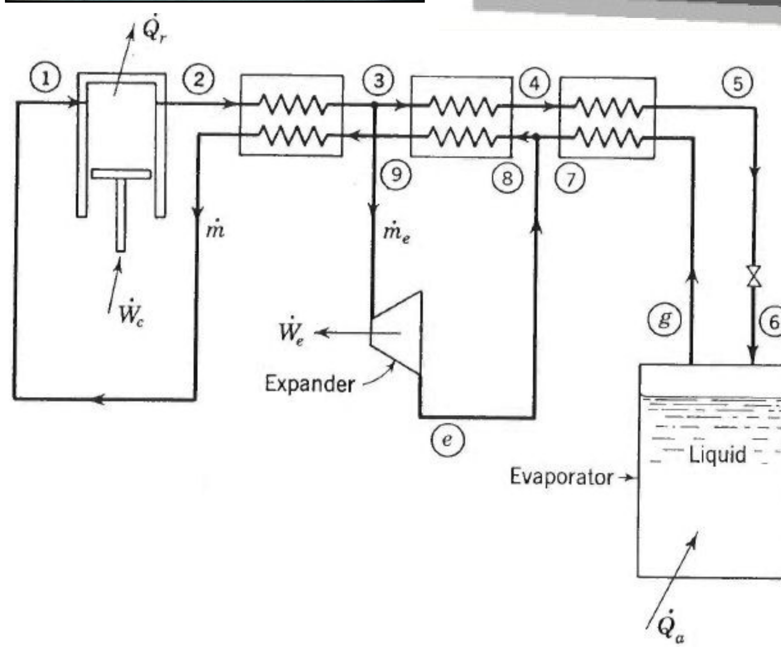
- Cryoplant purchased turn-key from industry
  - Build-to-performance based on peer-reviewed APS-U spec
  - Follow established procurement strategies (JLab, FNAL, FRIB, SNS)
  - Distribution system purchased and installed by industry
  - BOE drawn from recent plant procurements (FNAL) and SME input
- Cryomodules supplied by JLab
  - Designed in collaboration with ANL, to meet ANL ES&H requirements
  - Consistent with SR constraints
  - Cryomodule and distribution system heat loads set cryoplant performance spec
- Cryosystems for R&D phase
  - JLab contributions
  - ANL-designed components
- Reviews will follow SCU model

SPX: Expansion Engine Refrigeration

- Basic Claude cycle:







Existing SPX-sized cryoplants

- ELBE (Dresden-Rossendorf)
  - Electron Linac
  - Linde custom refrigerator operating since 1999
  - 220 W at 1.8 K

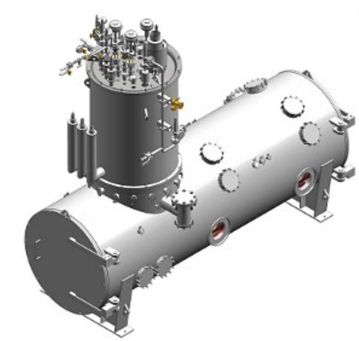
ELBE compressors, coldbox *ELBE compressors, coldbox*

- TRIUMF (Vancouver)
  - RIB Linac (ISAC-I, II)
  - Dual Linde *TCF50* refrigerators commissioned 2006 and 2008
  - Total 1200 W at 4.5 K

TRIUMF coldboxes & dewar *TRIUMF compressor*

- BESSYII (Berlin)
  - Light Source, ERL R&D
  - Linde *L700* liquefier: 710 L/hr
  - Linde *TCF50* refrigerator: 150 W at 4.5 K + 55 L/hr liquefaction
  - *HoBiCaT*: 80 W at 1.8 K via warm vacuum pump (+/-

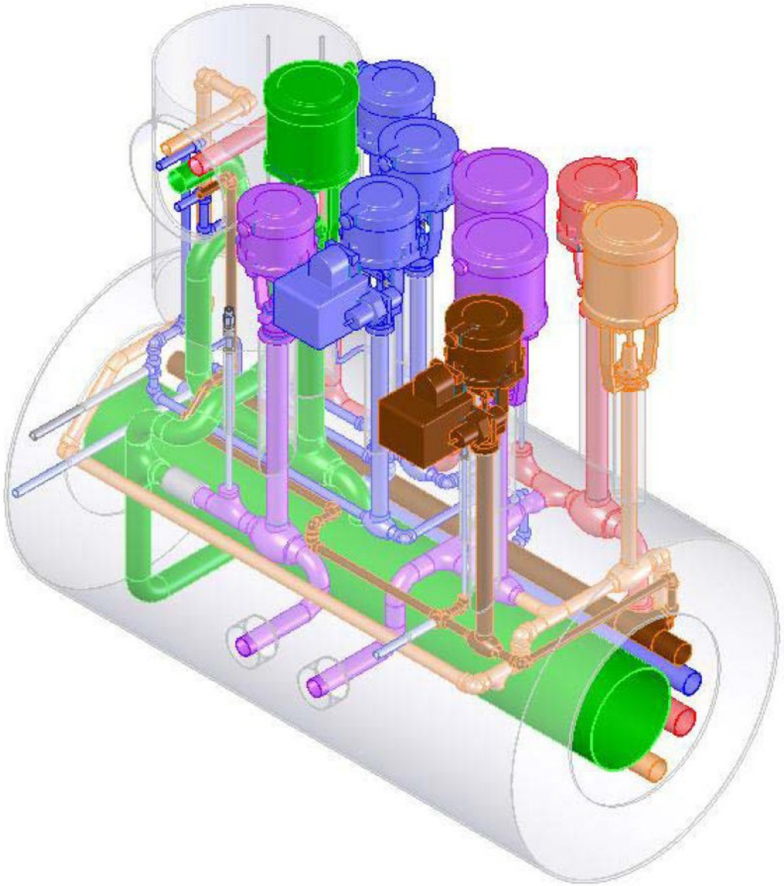
BESSY II coldboxes

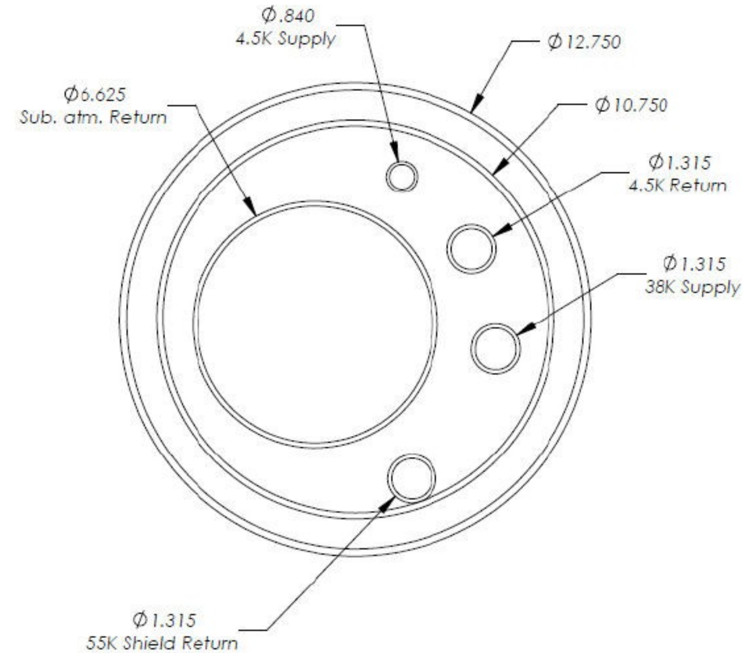


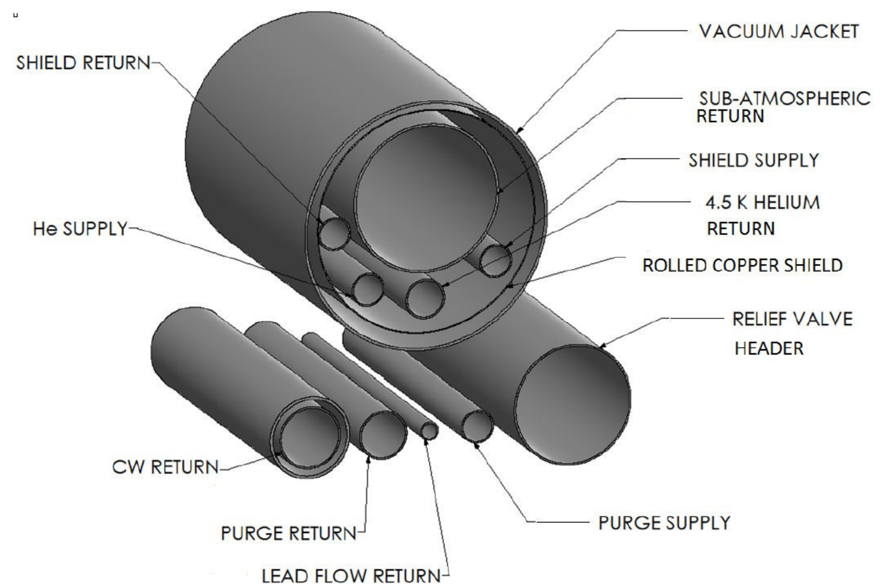
HoBiCaT test cryostat

Distribution system example: FRIB

- Transfer line – multiple line, shielded, vacuum jacketed
- Feedbox – connects transfer line to cryomodules
- s”

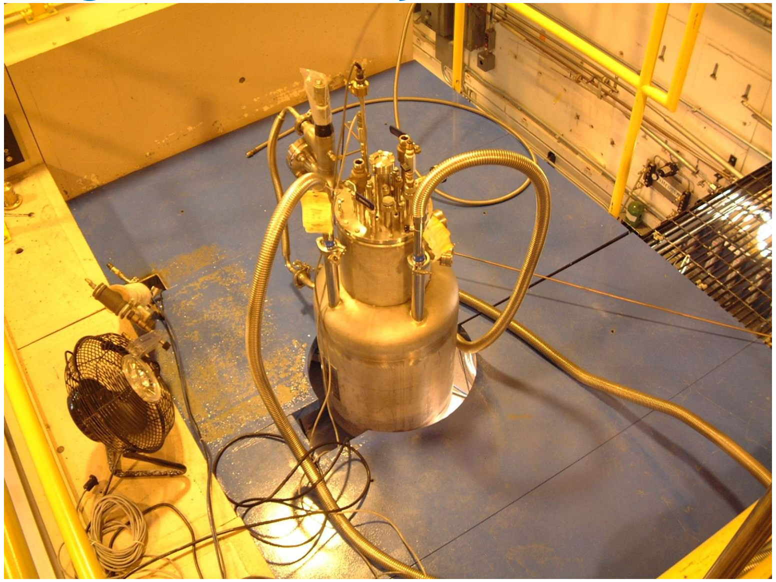


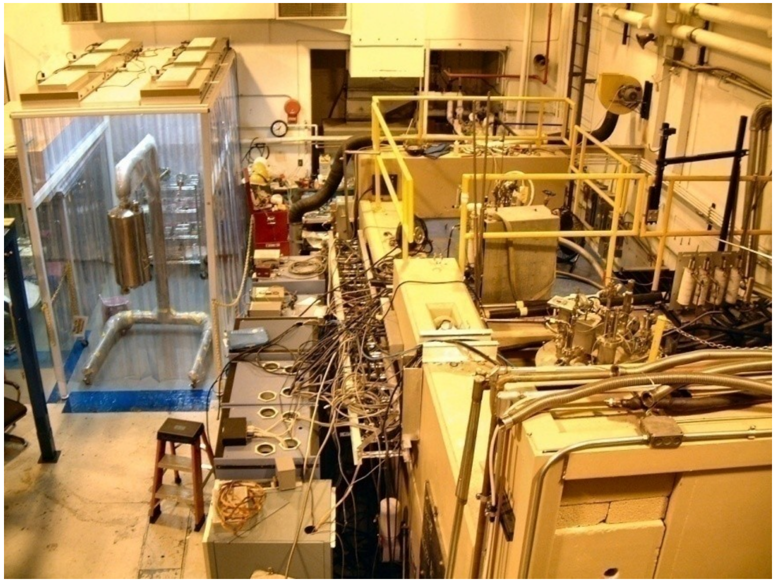


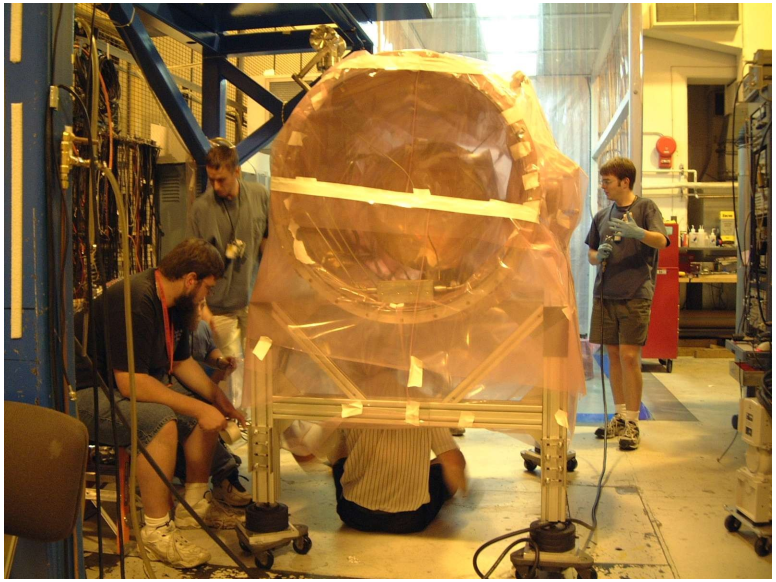


PHY resonator test area: existing srf facility at ANL

- Located in bldg 203
- Part of ATLAS heavy ion accelerator
- Low-beta srf cavity development
- Two shielded, interlocked test caves
- Cryogenic support (frig, dewars)
- <2.0K capability (>50W @2.0K thanks to APS improvements)
- Very crowded, esp. for HTB tests

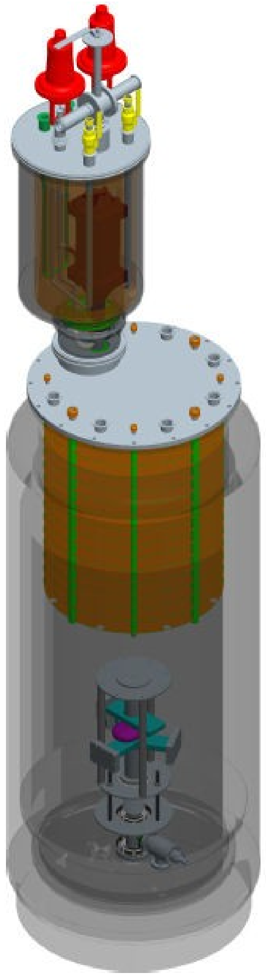




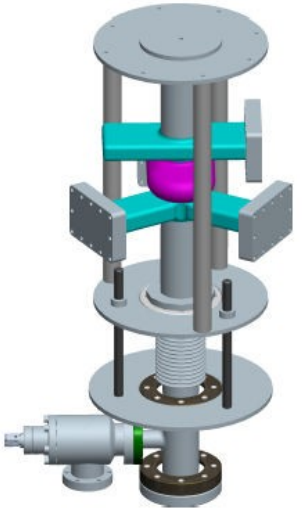


SPX srf cavity R&D at ANL

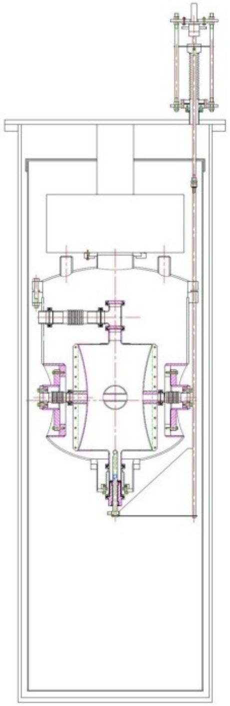
- New infrastructure provided by APSU:
  - 2.5g/s vacuum pump – needs to return to APS for SPX0 (or PHY buys us another)
  - Thermometry, liquid level, pressure instrumentation, LabView + PC
  - LLRF, HLRF and associated electronics
  - New JTHX feedcan + neck insert for 24” dewar
  - New transfer tubes as required
- R&D has 3 phases:
  1) Single “bare cavity” vertical tests in modified PHY 24” LHe vessel
  2) Single “dressed cavity” horizontal tests in modified PHY TC2 vessel
  3) Test of JLab Horizontal Test Bed (HTB) 2-cavity module (requires 2 complete rf stations)



24” dunk dewar



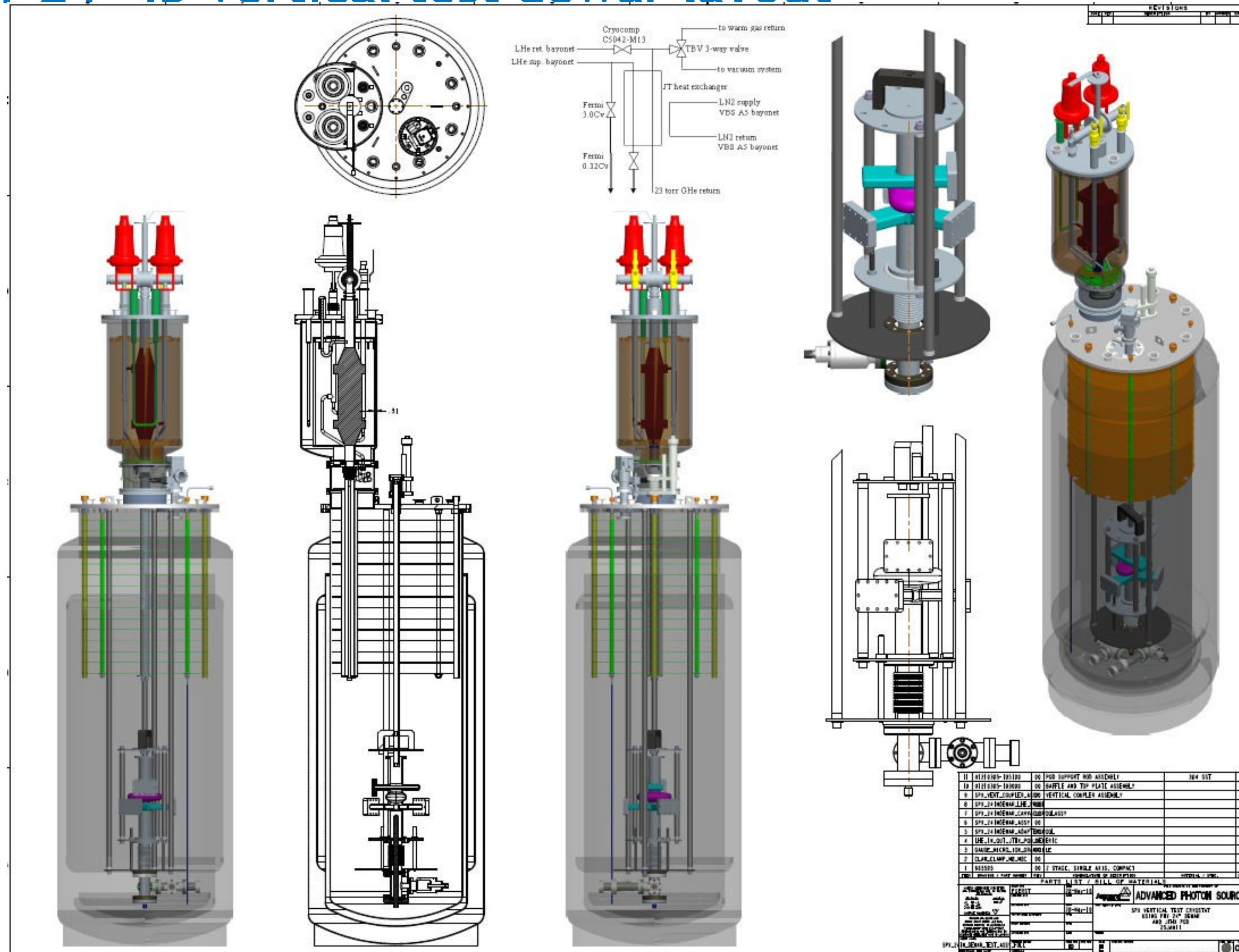
Bare cavity insert



TC2 with PHY SSR prototype

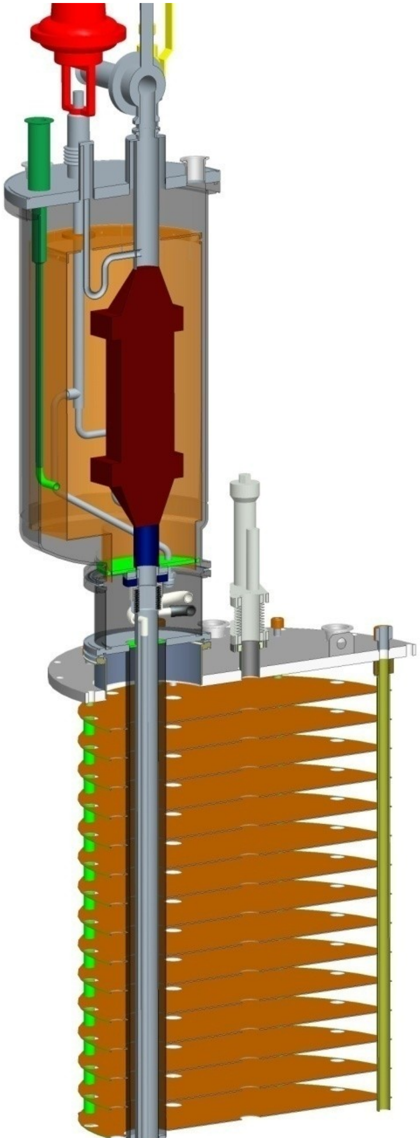
- **APSU covers cost of all make-up helium**

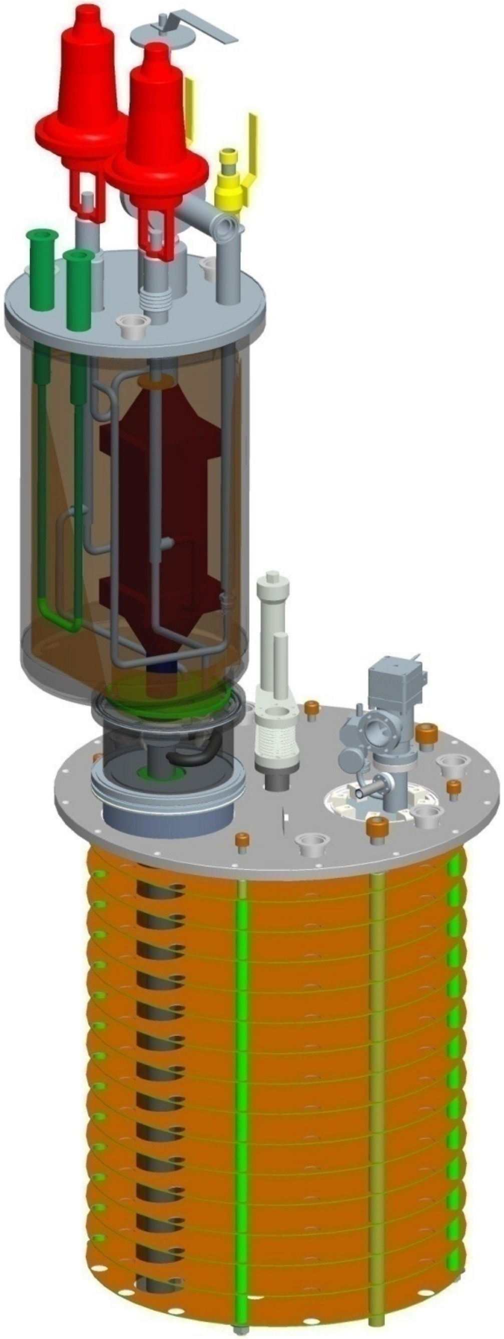
PHY 24” ID vertical test dewar layout



Test dewar: neck insert/JTHX feedbox

- Fabricated by Meyer Tool from ANL-supplied Pro/E model
- Designed to accommodate active cavity pumping
- JTHX sized for 2.5g/s at 1.8K:
  - HP stream: 4.5K inlet, ~2.2K outlet, <20kPa ΔP
  - LP stream: 1.8K inlet, <100Pa ΔP
  - 450mm x 150mm x 125mm (LxWxD)

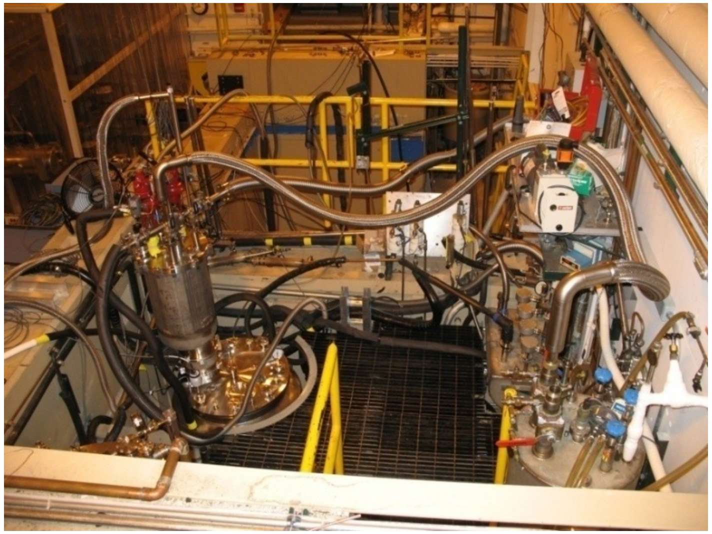




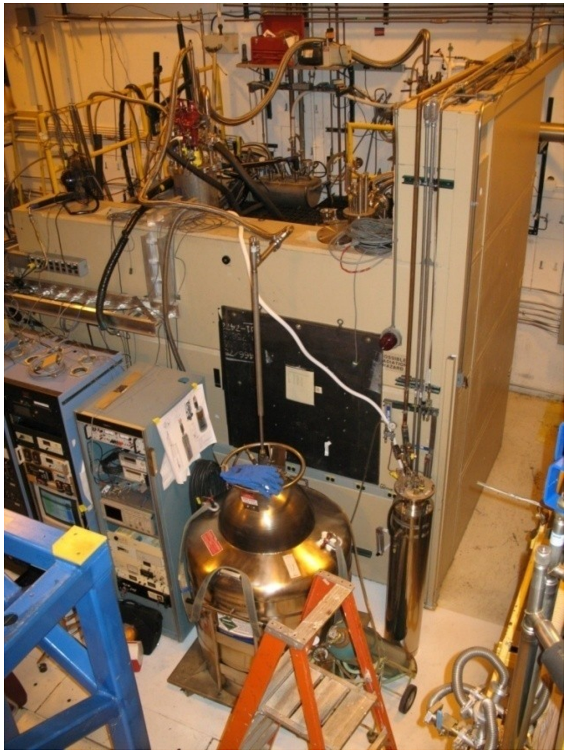
New vacuum system

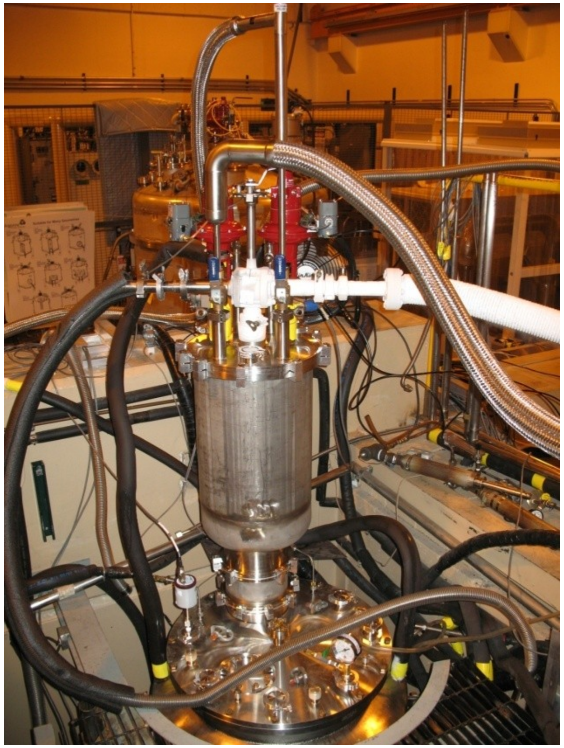
- Rated for 2.5 g/s at 20 torr
- Identical to units at Fermilab

Engineering Cooldowns



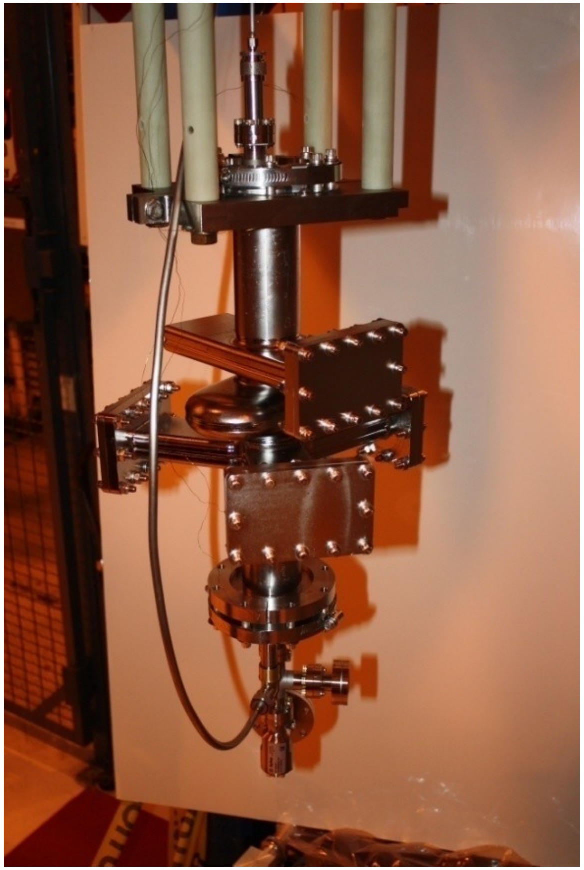
- Cryosystem works
- Vacuum pump measured performance:
  - 60 W at 2.0 K (~3 g/s at 24 torr)
  - 40 W at 1.9 K
  - 25 W at 1.8 K
  - 15 W at 1.7 K

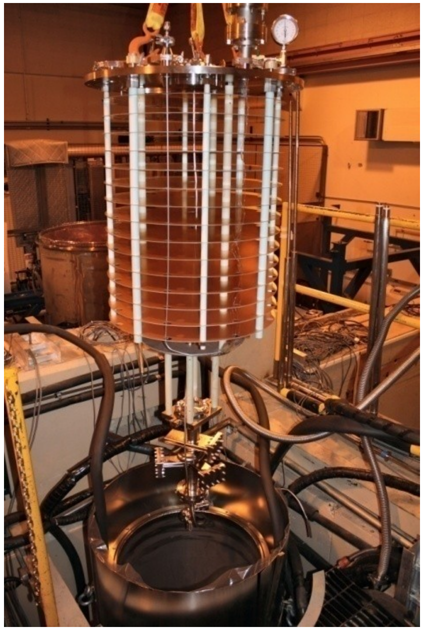




Neck Insert with Cavity

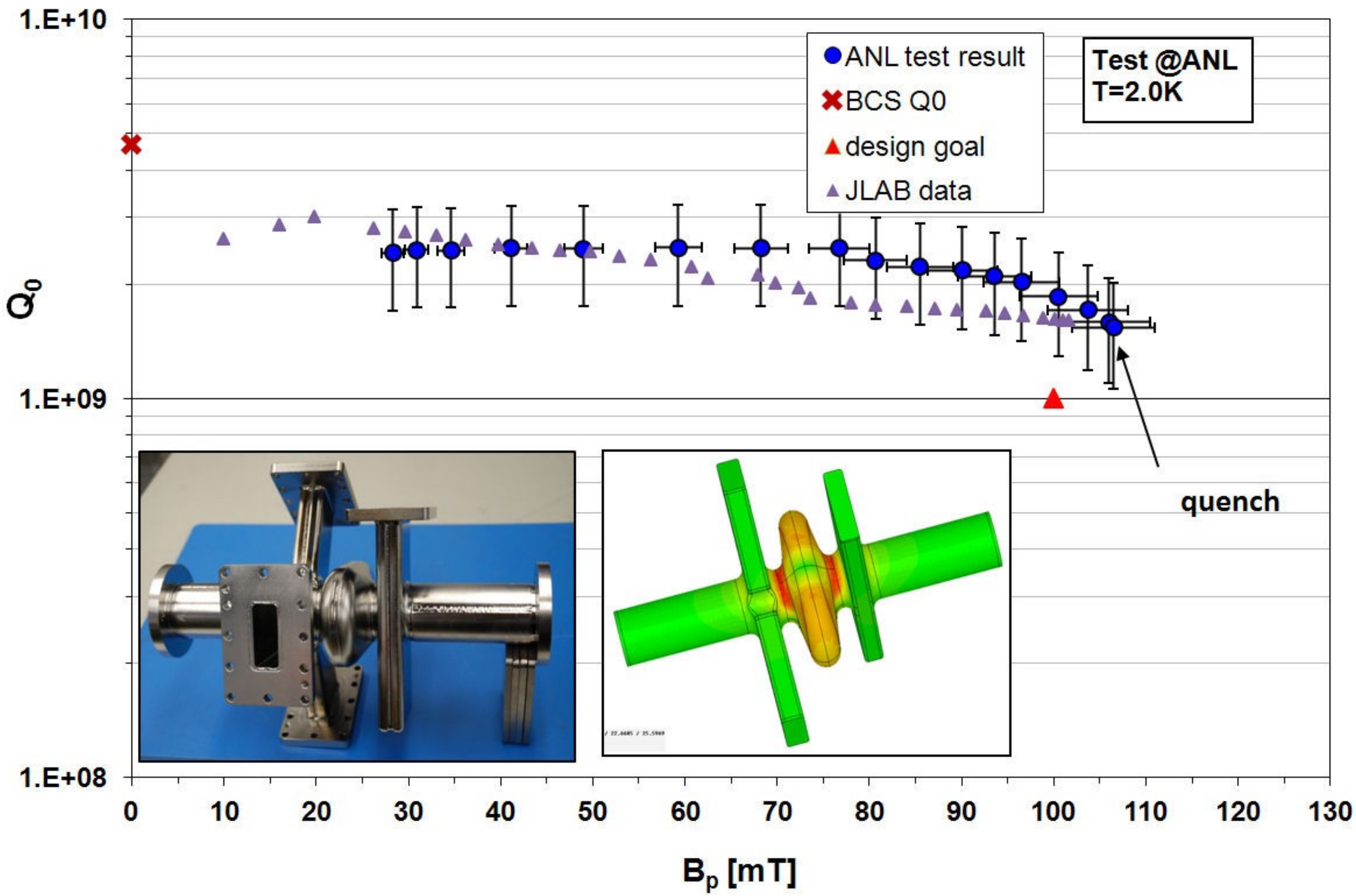
- Installation complete 30NOV11
- Ready for cooldown 02DEC11



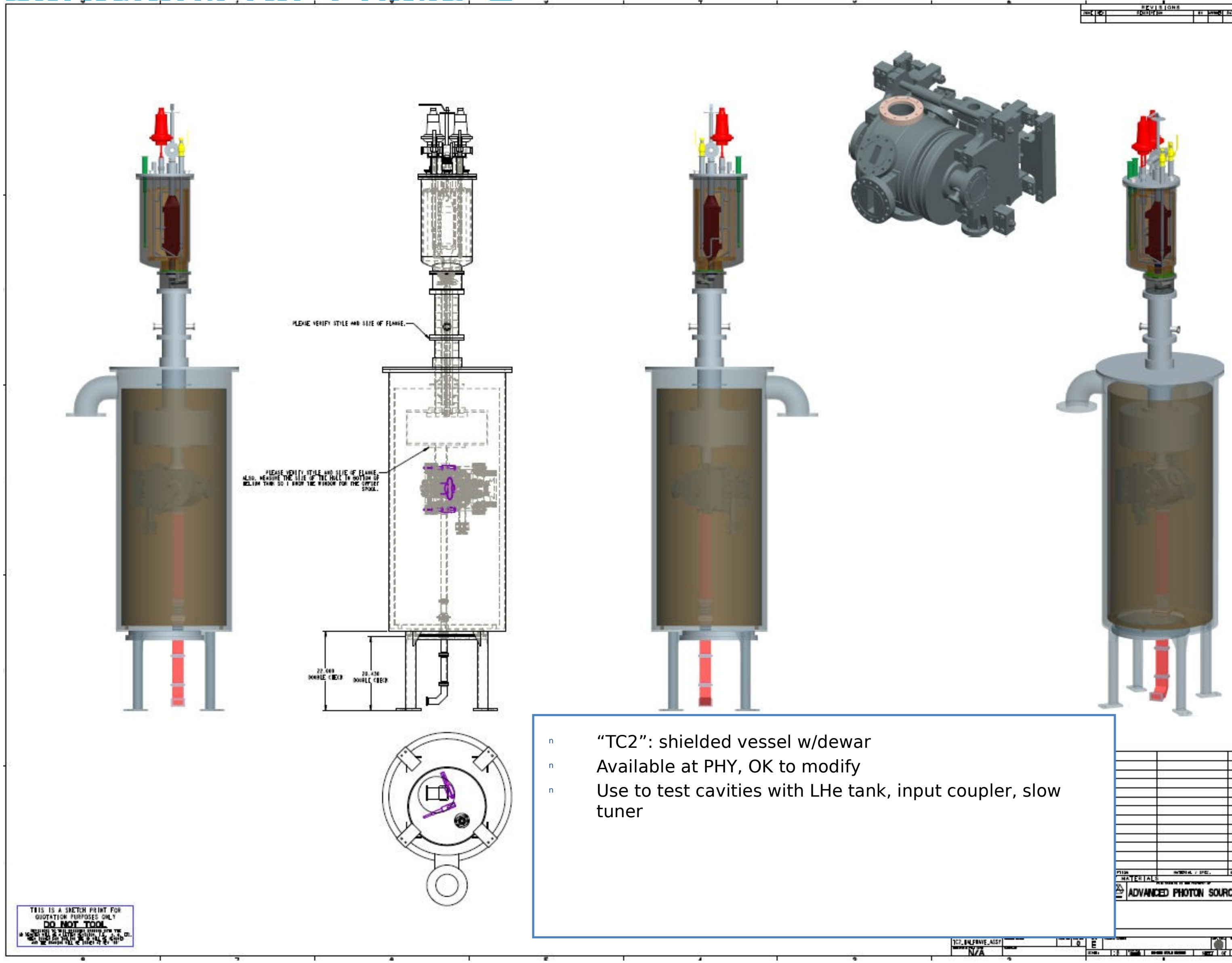


Cavity test results

Mark-I Cavity (CC-B1 for SPX Project) Vertical Test at ANL 12/20/2011



Preparations for Phase 2



- "TC2": shielded vessel w/dewar
- Available at PHY, OK to modify
- Use to test cavities with LHe tank, input coupler, slow tuner

Phase 3 example: FNAL "A0 North" cavity test area

- Vac system alongside supply dewars
- Vacuum instulated transfer line on the wall behind

- Transfer line enters cave, divides, connects to cryostat services

Helium usage

- FNAL Tevatron era: avg. 30,000 cubic feet/day = 1200 liquid liters/day
- FNAL A0 Photoinjector (1.8 K, 500L dewar fed): 500L/day for several years before finally installing a gas recovery system
- SPX0 will be dewar fed (like the A0PI…)
  - If the heat load is 40W,
  - Then the flow rate is about 2 g/s
  - Which equals 58 L/hr
  - So a 500L dewar lasts one 8 hr shift:
    - *How many shifts will it take to learn the lessons of SPX0?*
    - *How will these shifts be distributed, and what sort of "stand-by" can we implement when not testing?*

Major Challenges and Risks

- SCU:
  - Verify magnet cooling scheme
  - Verify heat load estimates
  - Verify cryostat assembly and alignment scheme

- SPX:
  - Accurate estimate for heat loads
  - Damper thermal load management
  - Cryomodule layout/subsystem packaging
  - Alignment
  - Microphonics

Summary

- Activities are aligned with laboratory standards & policies
- SME involvement end-to-end
- Consistent review process
- Close collaboration with partner laboratories
- Active communication with cryogenics community:
  - Laboratories
  - Universities
  - Industry