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Present and Future Cryogenics at Cornell

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Under "PRESENT" we'll discuss:

- cryo support only for CESR (3-6 GeV CM e^+e^- collider) and CLEO (the detector) operations and R&D.
- there's much more low-temp physics activity at CU

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A Brief History

•First 4.5K operation started ~1979 with 1T, 2m-diam. X 2m-long CLEO solenoid :

• indirectly cooled via 100m of 1/2" tubing in series flow path.

• LBL-inspired, not cryogenically stable– many quenches. •

• Built by AMI.

• retired to BNL in ~1987 after good service, 24hrs./day 7days/week, ~52 wks/yr. Many lessons learned!

•Initial Plant: (2) CTI 1430 fridges with LN2 assist, (2)93KW screw compressors. (CTI–>PSI–>Koch–>Chart–>Linde)

•"Ping-pong" OPERATION with 10-12 week cycle per fridge.

• Closed helium circuit, oil separation, no extra purification.

• 60,000 gallon (~2000 liters LHe) med. press. GHe storage.

A Brief History, continued..

1988 (CLEO II era). New 1.5T, 3m diameter. 25MJ solenoid ~ 12W + 15l/hr liquefaction load at 3300 A.

- Built by Oxford Instruments:

Thermosyphon cooled, cryo-stable, 700 l dewar, can run through power outages or fridge loss..

- Unchanged fridge plant, but added extensive UPS-maintained controls: compressor 480 V breaker contacts, fault relays, engine braking..

Still More, (1997-1999)

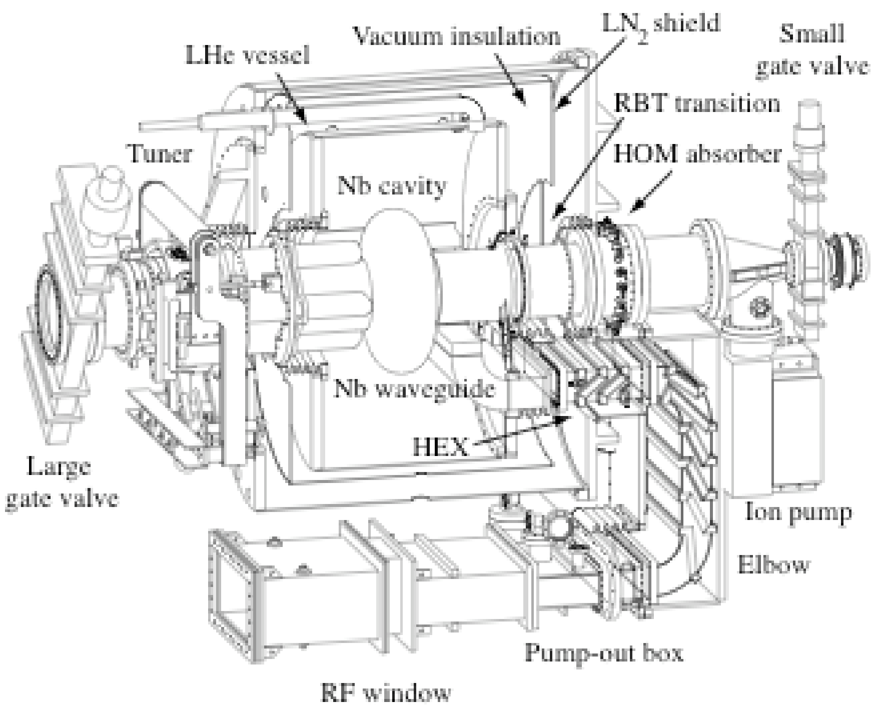


Figure 1. The CESR B-cell cryomodule.

SRF era, NEW plant:
installed four Nb cryomodules:
1-cell, 500 MHz, 6-10 MV/m,
up to 100 W each at 4.5K + 5 l/h
For HEX flow.

Refrigerate with 2 CCI Machines:
600W/150 l/h with LN2 reciprocating. 450-500 HP Sullair screw comp.
Buy one new, one *used* machine.

Transport 4.5K LHe as 2-phase from 2000 l storage dewar to loads ~80m away.

3 CCI Fridges

A compressor,with gas mgmnt.

Valve box, xfer lines, 1400's..

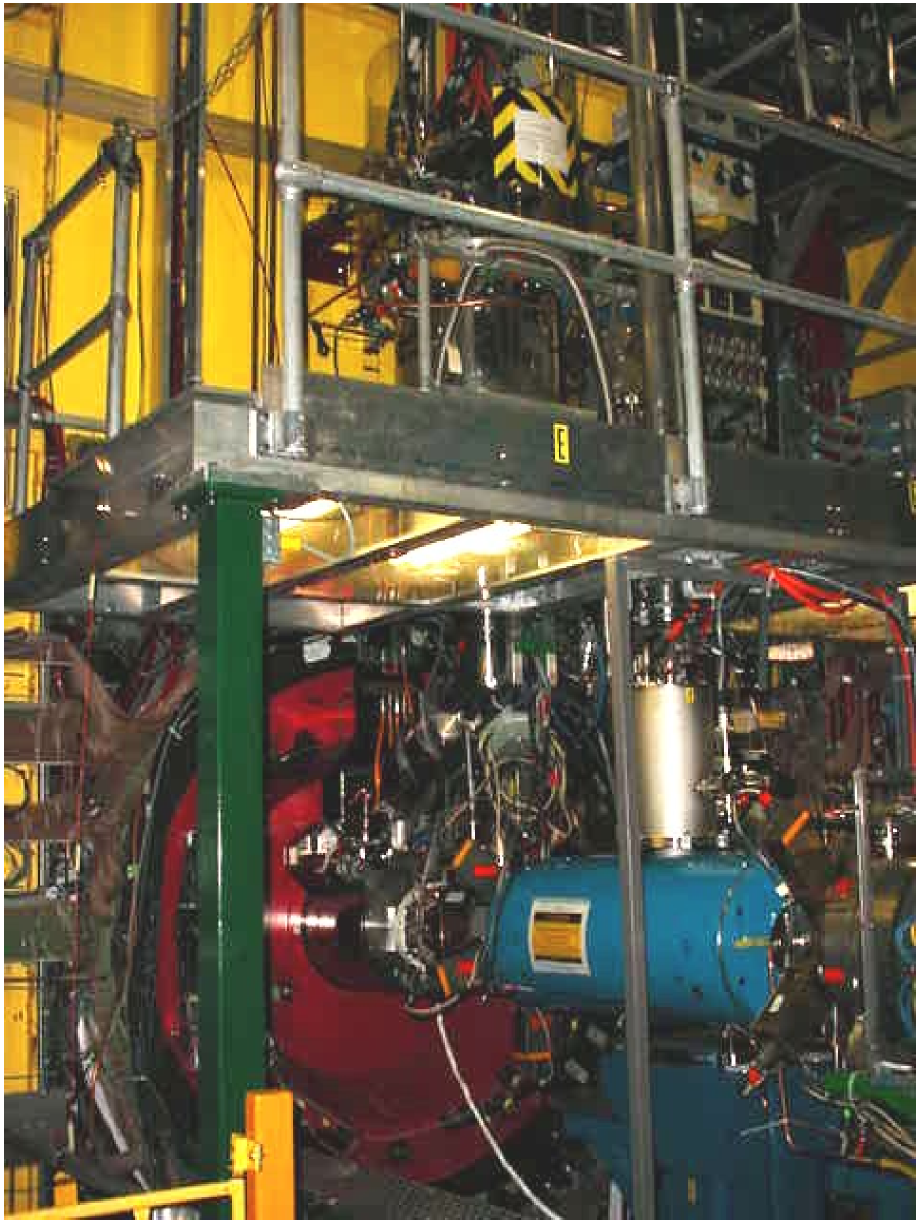
And then there followed…

Two SC final focus packages (1999-present):
Each with HF, VF, and skew quads + steering~ 200W equivalent with leads and xfer lines.

12 SC wigglers(superferric) in CESR tunnel to provide Damping for CESR-c , CLEO-c era. HTSC leads, ~3W heat load, up 100m further away from plant, but still use 2-phase flow LHe. Tee into SRF supply/return.

Two compensating “anti-solenoids” (2006) to improve CESR-c luminosity. Follow wiggler cryo design.

Third (used) CCI fridge: total capacity now ~ 2kW at 4.5K



CESR-c West IR

CLEO solenoid pole (red)
,SC quad cryostat (chrome)
“antisolenoid”(blue)

Three SC wiggler cryostats

and, by the way…

ILC Damping Ring Baseline Wiggler Recommendation:
Is based on the CESR-c wiggler design.

Cornell Plans:

- Optimize the CESR-c design for ILCDR use, adapt to
- Likely ILC cryoplant
- Prototype a realistic ILCDR wiggler

Present Plant Characteristics

• 2 kW at 4.5K, ~800W margin max. Typically, use two CCI fridges in parallel, common discharge press. for screw compressors. Siemens-Moore controls, with heater in 2000l dewar; 5% overcapacity.

• 6 PSIG supply pressure, ~3 PSIG return, simple 2-phase flow in 250 m-long transfer line. All cryostats, transfer lines have static vacuum.

• 96,000 gallon medium pressure storage. About 5000 l (equivalent).

• 0.6 MW + LN2 in typical mode.

• No cryo crew after 1630 or on weekends.

•1 year interval for major maintenance on CCI machines, 12 week cycle for 1400's.

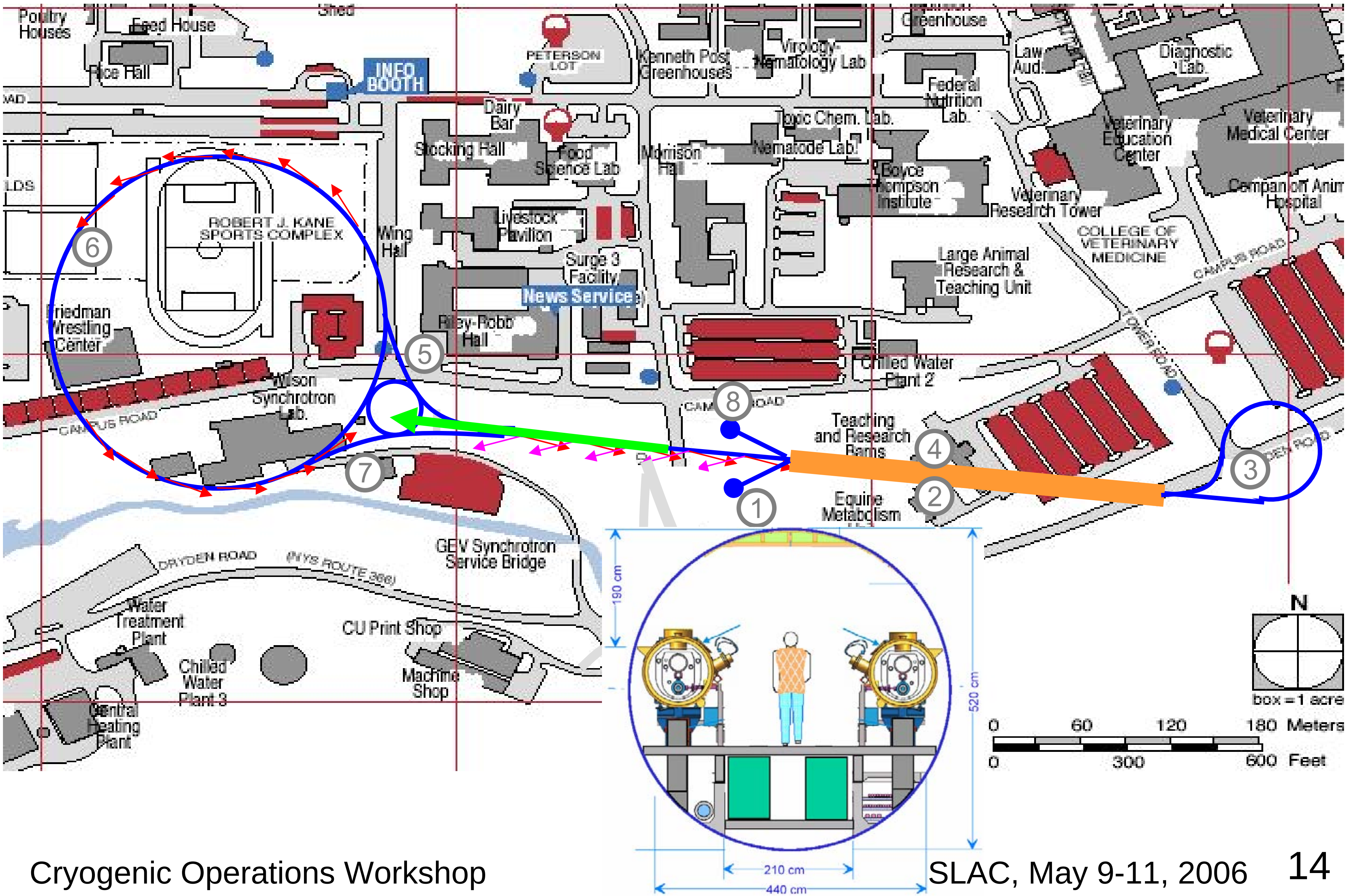
•Completely UNACCEPTABLE efficiency for future Cornell plans.

COP_{inv} =562 at 4.5K vs. 200 achievable.

Proposed Upgrade of CESR to ERL

- In 2008, the particle physics experimentation at CESR will shut down. Synchrotron radiation experimentation at CHESS will continue. It is desired to make a major upgrade of the accelerator to provide a light source with capabilities 10-100 times greater than current 3rd generation light sources.
- This project will involve a major extension of the existing accelerator and expansion of the infrastructure.
- One major feature of the new operation would be a cryogenics plant which will be roughly 20 times larger than the present system!

ERL Upgrade for CESR (5GeV)



Nature of the cryogenic loads

- 390 7-cell Nb 1.3GHz SRF cavities, similar to TESLA
- 100 mA, 5 GeV beam (cw operation)
- Operation at 16MV/m gradient in cavities, with average $Q=2\text{x}10^{10}$ while running at 1.8K.
- Higher order mode (HOM) power absorbed at 80K rather than room temperature.
- Expected operation 5000 hours per year for experimenters, additional 1000 hours per year for machine studies.
- Possible periods of operation at lower beam currents, resulting in greatly reduced HOM power.

Anticipated Refrigeration Requirements for the ERL at Cornell

Cooling Stream	Design Load (kW)	Load with 50% margin (kW)	Achievable COP (inv.) (W_{300}/W_T)	Wall Power Demand (MW)
1.8K He at 16 mbar	5	**7.5**	950 ~~590~~	7.1 ~~4.4~~
4.5K He at 3 bar	9	**13.5**	200	2.7
40-80K He At 10 bar	70	**105**	20	2.1

Comments on Preceding Table

- Design heat loads are challenging but probably achievable goals. We nonetheless need to allow a safety margin in the design of the cryogenic plant.
- Efficiency is highly important. With our projected cryogenics power demands drawing on the order of 10MW from the grid for 75% of the year, over the lifetime of the project the power bill is anticipated to be larger than the capital cost of the plant.
- The most optimistic literature estimates for the attainable efficiency of 1.8K operations are considerably more optimistic than what is currently achieved. Is there any chance for making improvements here?

Major question on approximate pricing

- A figure (originating from CERN) circulating in the recent literature suggests a refrigeration cost may be estimated as:

$$\text{Price }(\text{MCHF}_{1998}) = 2.2 \text{ x } (\text{kW@4.5K})^{0.6}$$

- We have heard rumors that this price is currently an underestimate. Is there a better estimation formula? Is the 0.6 power law a reasonable scaling? To determine the equivalent cost for 1.8K or 40K refrigeration, do we scale from 4.5K values by the ratio of COP at the two temperatures?

Several Questions for Discussion

1) Modularity. Our system demands are probably too large for a single cold box. How many subunits are likely to be optimal for construction? The load is likely to be constant (at maximum level) for the 1.8K cooling whenever the machine is in use. The 4.5K and 40-80K systems may have extended operation periods at as little as 25% of full load if operating in a low-beam-current configuration. Should the 1.8K system be operated as a completely separate system from the 4.5K/40-80K system?

Questions for Discussion (continued)

2) Efficiency. If we achieve design goals on heat loads, refrigerator will run at 2/3 of its design capacity. How will this affect the efficiency and stability of operation?

3) Nitrogen precooling? Total plant capacity is likely too large to truck in LN_2 for precooling (frequency and reliability of delivery, especially in winter). Is nitrogen liquefaction more efficient than helium refrigeration near 80K—would on-site nitrogen re-liquefaction make a sensible component of the plant?

Questions for Discussion (continued)

4) Cold vs. warm compression. For the 1.8K portion of the refrigeration, at least part of the compression will be in the form of cold compression. Some large refrigeration plants use exclusively cold compression for the sub-atmospheric gas, others use a mix of cold and warm compression. What are the impacts of using exclusively cold compression on the ease of control, the adaptability to moderate variation in average heat load (both in terms of efficiency and control), and the rather different operations of cooldown and warmup?

Questions for Discussion (continued)

5) Helium inventory for the system will be in the range of 10,000-15,000 liquid liters. Our initial thoughts are to use primarily a single 20,000 liter dewar for storage, with an additional medium pressure storage vessel for 4,000 liters additional capacity in gas form. This arrangement would presumably require an additional small re-liquefaction refrigerator for any periods of extended shutdown. Our main reasons for thinking of using dominantly cold storage is questions of smaller footprint on the somewhat crowded campus, but capital cost also looks probably advantageous. What are the reasons that warm medium-pressure storage seems more usual?

Questions for Discussion (continued)

6) There will be an extended distribution system to the actual refrigeration loads, which will be 15-20 meters below the plant level, and in some cases 150-200 meters distant from the plant. We anticipate a number of remote JT valves as part of the distribution system for the 1.8K coolant. What are the efficiency implications of such a configuration?
7) In specifying system loads, somewhat arbitrary choices were made for pressures of the 4.5K and 40K gas streams. What are the efficiency implications for circulating at different pressures (densities).

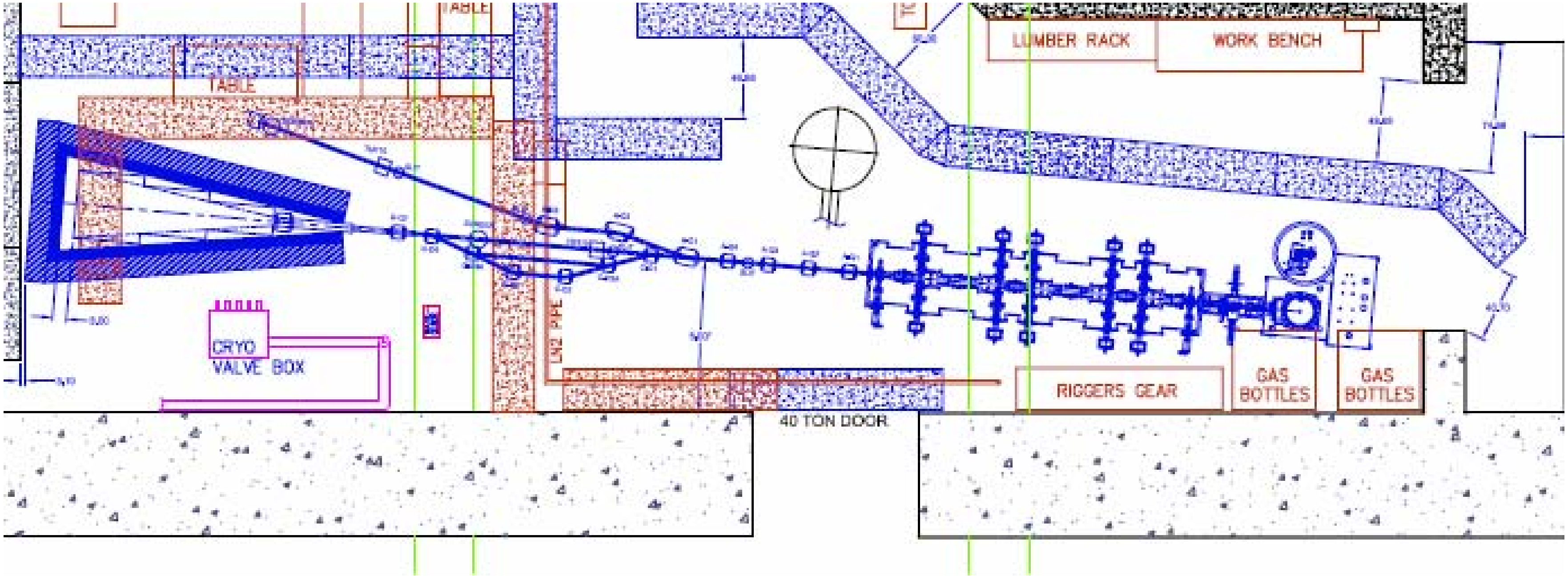
Questions for Discussion (continued)

8) What maintenance intervals are needed for a system of this size? How many months of continuous operation can be anticipated, and what is the minimum length of time that would be expected for a warmup/cooldown cycle?

Ongoing Smaller Project to Test ERL Injector (Phase 1a)

- There is already work in progress to test the proposed injector for the ERL.
- By comparison with the overall project, this is a rather small perturbation on the existing cryogenic setup.
- It does give us experience in working with cryomodules operating at 1.8K, and will test various aspects of cooling the large heat loads on the HOM loads and input couplers with gaseous helium stream (in particular, we have demands for very low vibration levels in the final ERL).

ERL injector overview



Max current	100 mA
Energy range	5 – 15 MeV
Installed RF power	0.5 MW + 75 kW HV PS
Emittance goal	0.1 – 1 mm-mrad
Typical bunch length	2-3 ps rms (shortest 0.2 ps)

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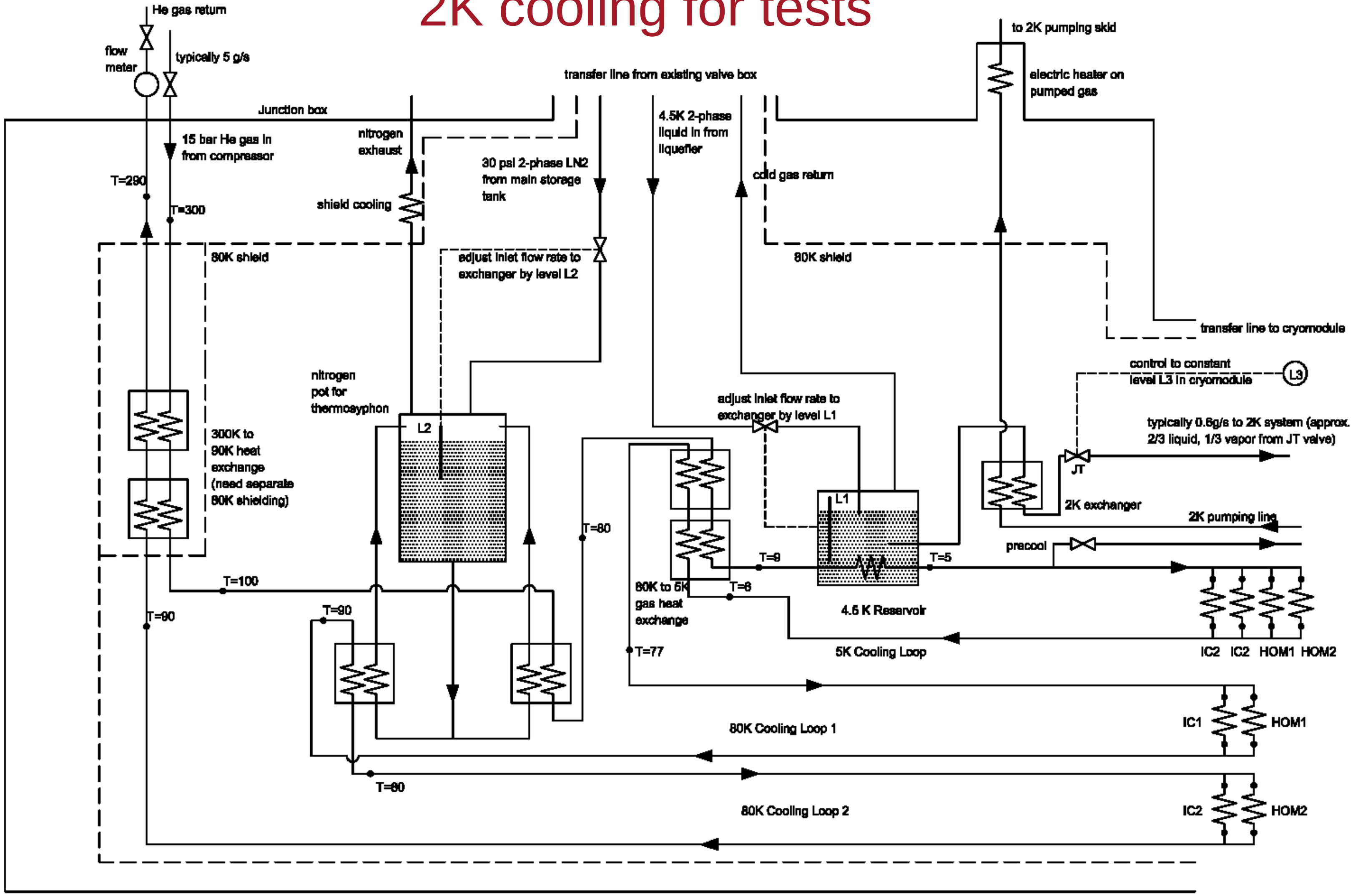
2K cooling for tests



Revised Cooling Scheme for the 2006 Horizontal Test. Provides He gas cooling for both 5K and 80K loads. Uses plate heat exchangers for gas/gas exchange and He/LN2 loads, finned tube HX for 4.5K. Uses thermosyphon control for LN2 flow. Orientation of exchangers is to remind us that bottom end should be cold end.
For 2008 testing, flow rates will be 5 times larger.

Revision of March 3, 2006—ens