Lecture 1 Introduction

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USPAS

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Class Goals

- Provide the basics of Cryogenic Engineering
  - At the end of the class students should:
    - Be familiar with principles and common practices of cryogenic engineering
    - Be able to perform basic analysis and design
    - Possess a solid foundation for further study in the field
    - Be able to understand the issues and concerns of experts in the field, particularly in an accelerator environment
- Use real world examples mainly from accelerator labs
  - Stress will be on large scale Helium systems
- Be interesting. None of us started in this profession to be bored – Cryogenics, we hope to show is an interesting application of engineering

Who We Are : Tom Peterson

- Currently, a Senior Engineer at SLAC National Accelerator Laboratory in Menlo Park, CA, USA
- 40 years of experience in cryogenics for accelerators
  - Helped to design, commission, and operate the Tevatron cryogenic system
  - Worked 1.5 years at DESY in Hamburg, Germany, on TESLA and TESLA test facility cryogenic system and cryomodule design
  - Collaborated with CERN on the US LHC final focus quadrupole magnet project, integration of the magnets into the LHC cryogenic system
  - Detector cryogenics for the D0 liquid argon calorimeter at Fermilab
  - Project engineer for various test stands, test cryostats, feed/distribution boxes, and SRF cryomodules for TTF at DESY, LHC at CERN, Fermilab's magnet test facility
  - Cryomodule Chief Engineer for LCLS-II at SLAC
- BA and MS from University of Wisconsin – Madison
- Interests: Cryogenic system design, SC magnet and SRF cavity thermal design, safety in cryogenics, international projects

Who We Are : John Weisend

- Currently, Deputy Head of Accelerator Projects at the European Spallation Source, Lund, Sweden & Adjunct Prof. Lund University
- Previous work at:
  - Michigan State University
  - National Science Foundation
  - Stanford Linear Accelerator Center (SLAC)
  - DESY Lab, Hamburg, Germany
  - Centre d'Etudes Nucleaires, Grenoble, France
  - SSC Laboratory
- PhD and MS from University of Wisconsin – Madison
- BSME from University of Miami
- Interests: Large scale cryogenics, writing, education, cryogenic safety, instrumentation, & organization of large international scientific projects

Evaluation

- Problem Sets 70%
- Design Project 30%

Resources

- Class slides
- Textbook Cryogenic Systems by R. Barron (2nd Edition)
- List of Suggested Additional Reading
- Ask lots of questions!
  - During class
  - During the week
  - After the class is finished

  - Instructors contact information

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John Weisend - john.weisend@esss.se

What is Cryogenics?

Cryogenics is the science & engineering of phenomena that occur

at temperatures below 120 K

Why 120 K?
The temperature below which "permanent gases" start to condense

Fluid	Normal Boiling Point (K)
Krypton	119.8
Methane	111.6
Oxygen	90.2
Argon	87.3
Nitrogen	77.4
Neon	27.1
Hydrogen	20.3
Helium	4.2

Cryogenics & Accelerators

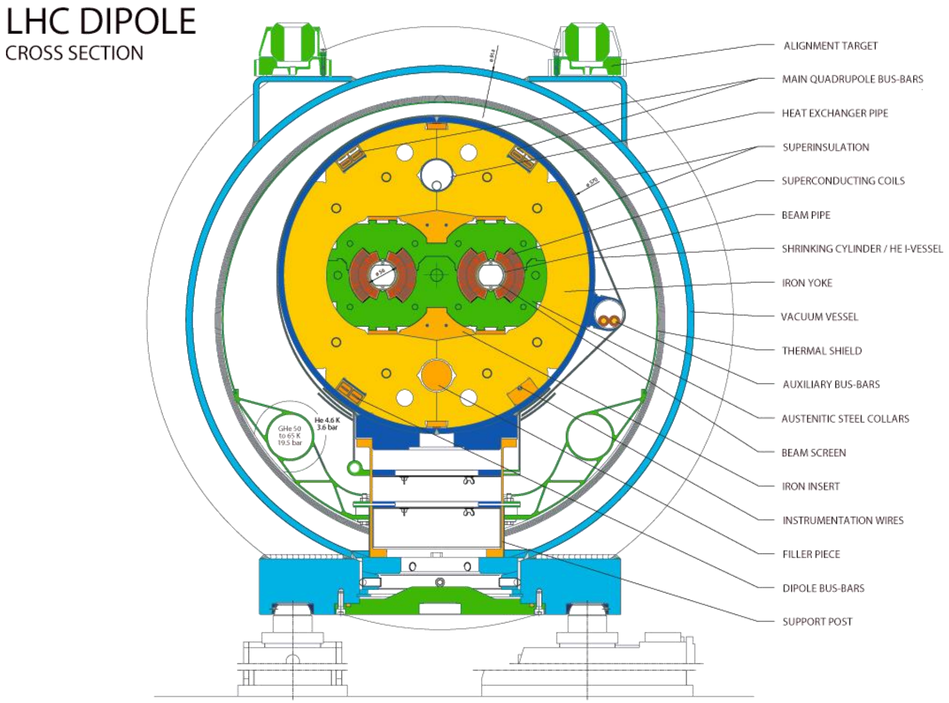
- Cryogenics plays a major role in modern particle accelerators
  - Enables superconductivity
    - Beam bending and focusing magnets (1.8 K – 4.5 K)
    - Magnets for particle identification in large detectors (4.2 – 4.5 K)
    - Superconducting RF cavities for particle acceleration (1.8 K – 4.2 K)
  - Allows dense pure liquids
    - LAr calorimeters (87 K)
    - LH_2 targets, moderators and absorbers (20 K)
  - Provides sub-Kelvin cooling for certain types of dark matter searches
- Since the Tevatron (1983) accelerator cryogenic systems have become larger, more reliable, more efficient, industrialized and much more widespread

Cryogenics & Accelerators

- Accelerator requirements have played a significant role in pushing cryogenic technology
  - Automated, efficient & reliable large scale Helium refrigeration plants
  - Development & industrialization of cold compressors
  - Studies on He II two-phase flow
  - Radiation resistant cryogenic temperature sensors
  - Production of reliable high field superconducting magnets
    - » MRI has also had a significant impact here
  - Production of high gradient SRF cavities

Superconductivity (enables high field magnets)

- Large Hadron Collider (CERN) 9 T magnets operating at 1.8 K (superfluid helium)

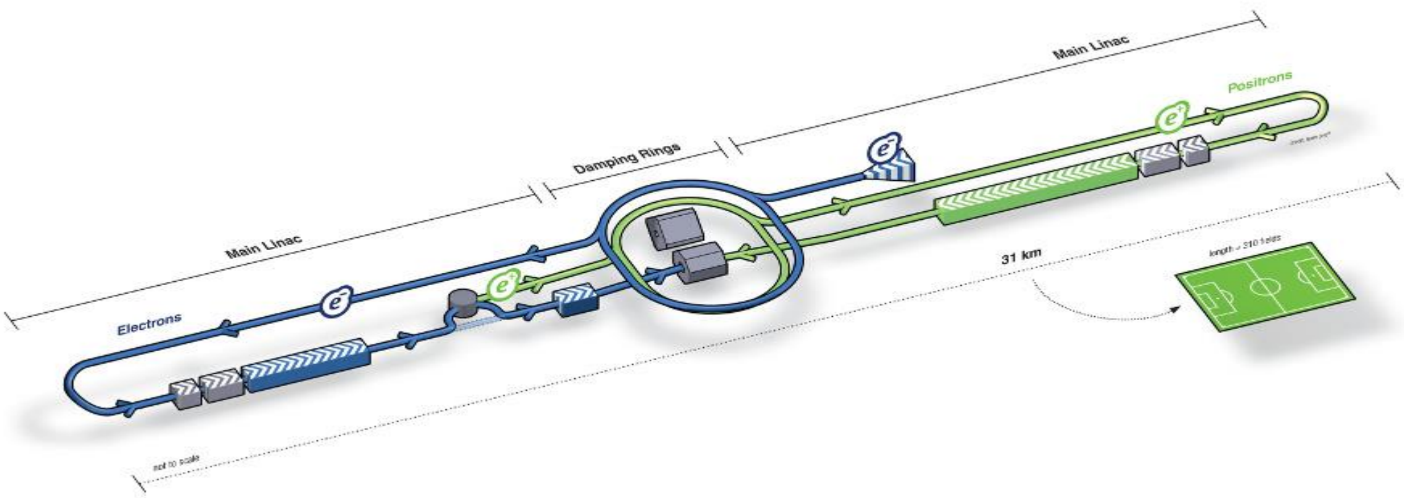


CERN AC/DI/MM — 06-2001

Superconducting RF is Very Popular

Name	Accelerator Type	Lab	T (K)	Refrigeration Capacity	Status
CEBAF	Electron Linac	JLab	2.1	4.2 kW @ 2.1 K	Operating
12 GeV Upgrade	Electron Linac	Jlab	2.1	4.2 kW @ 2.1 K	Operating
ESS ACCP	Proton Linac	ESS	2.0 40 -50 4.5	3 kW @ 2 K 11 kW @ 40 – 50 K 9 g/s liquefaction	Commissioning
SNS	H^- Linac	ORNL	2.1	2.4 kW @ 2.1 K	Operating
ERL	Electron Linac	Cornell	1.8	7.5 kW @ 1.8 K	Proposed
XFEL	Electron Linac	DESY	2.0 5 -8 40-80	2.5 kW @ 2 K 4 kW@ 5 -8 K 26 kW @ 40-80 K	Operating
LCLS II	Electron Linac	SLAC	2.1 K	4 kW @ 2 K 14 kW @ 35 -55 K 1.2 kW @ 5 – 8 K	Under construction (2 Plants req)
FRIB	Heavy Ion Linac	MSU	2.1 4.5 33/55	3.6 k W @ 2.1 K 4.5 kW @ 4.5 K 20 kW @ 35/55 K	Operating

International Linear Collider (most likely the upper limit of this approach)



- e-/e+ linear collider (250 GeV on 250 GeV)
- ~ 2000 Cryomodules,
- ~ 16,000 SCRF cavities
- 2 K operation
- 10 x 20 kW (4.5 K eq) cryoplants

Large He Systems Have Become Common

2007 LHC

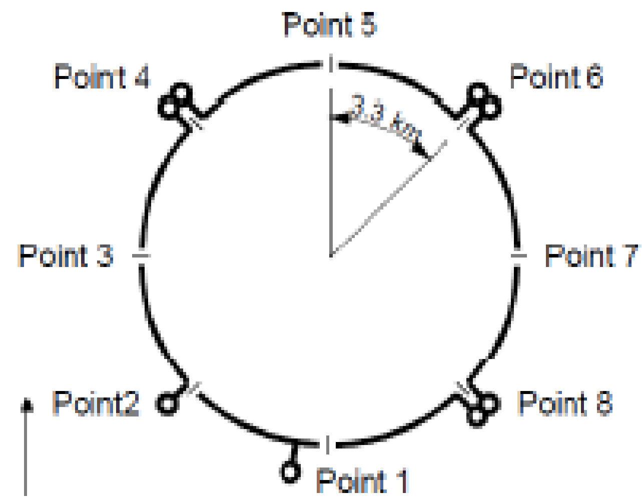
8 Plants each with 18 kW @ 4.5 K

Largest current use of He II

Each plant provides 2.4 kW @ 1.9 K

Total He inventory 120 metric tonnes

All plants were procured from industry



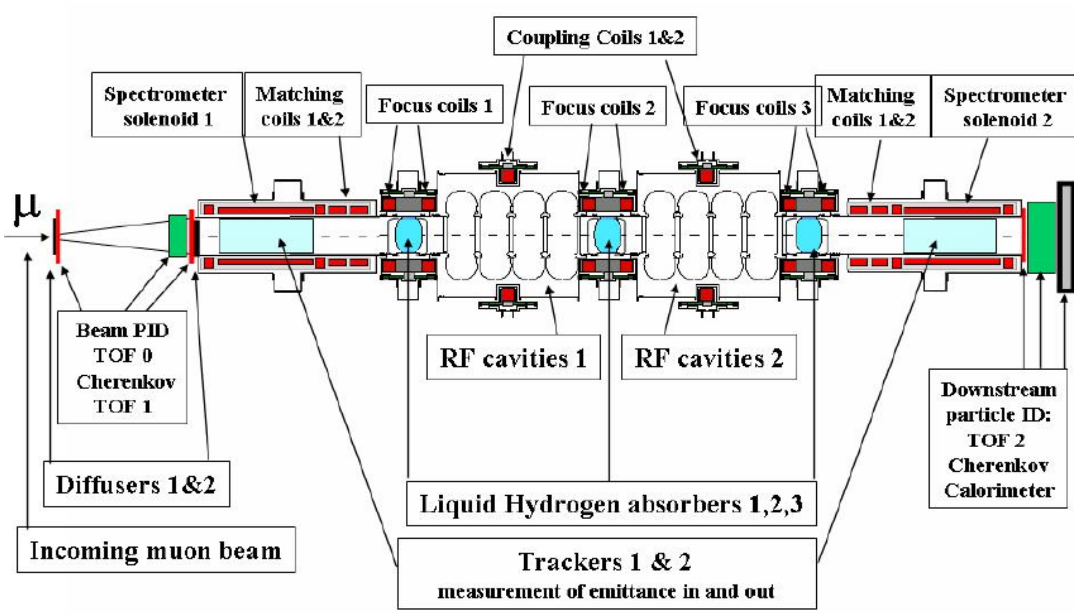
Use of Small Cryocoolers is Also Growing

- Small cryocoolers, particularly those based on pulse tube technology are becoming more reliable and commercially available. These may well play a role at various temperature levels in accelerator cryogenics
- Applications may include intermediate thermal shield cooling and the development of small cryogen free magnets or the use of cryocoolers to reliquefy LHe or LH_2
- The current maximum capacity of pulse tube coolers at 4.2. K is 1.5 W but devices with up to 5 W capacity are under development.
- Small cryocoolers may be particularly interesting in accelerators that only have a few cryogenic devices: e.g. light sources with superconducting undulators

CryoMech PT415
40 W @ 45 K
1.5 W @4.2 K

Small Cryocooler Application

- Muon Ionization Cooling Experiment
- A beam physics experiment in support of future muon colliders
  - Contains SCRF cavities, SC magnets and LH_2 absorbers
  - Extensive use of small cryocoolers to reliquefy both LHe and LH_2
  - Use of cryogen free magnets is also being investigated
  - Currently under design for operation at RAL



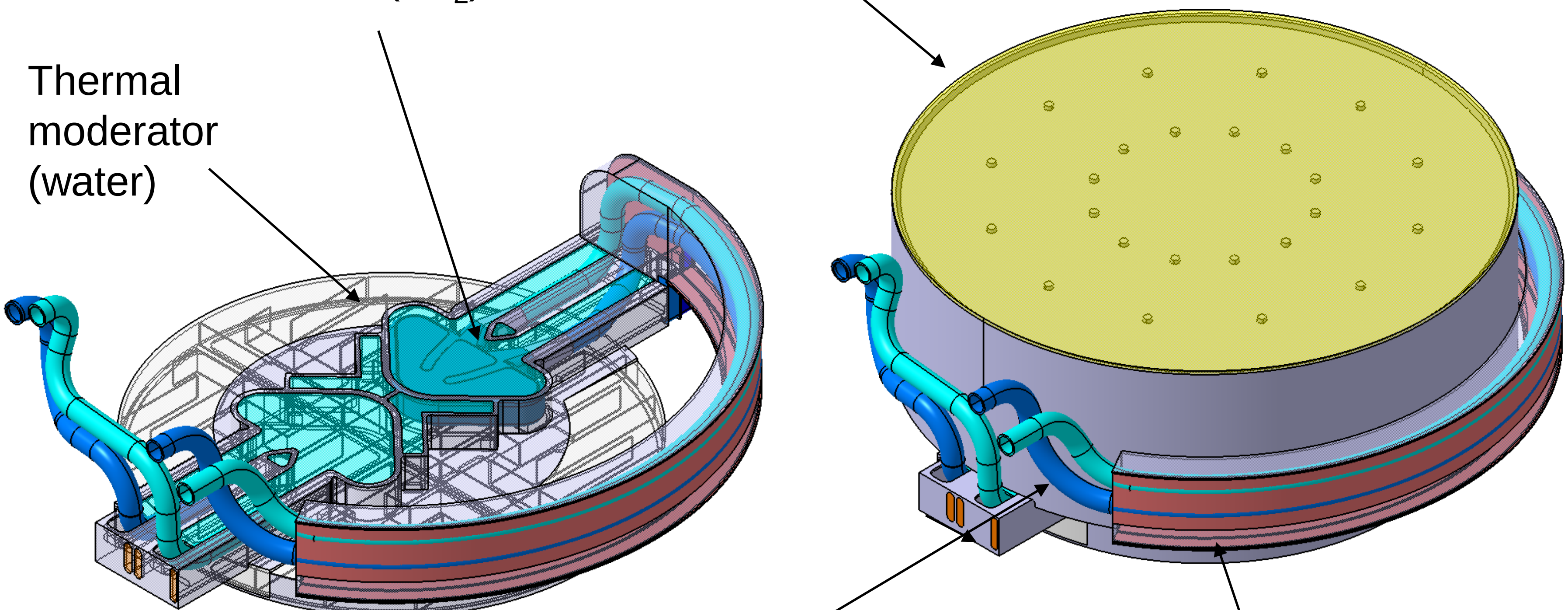
Cryogenics Provides Dense Fluids for Calorimeters, Moderators and Targets

ESS moderator & reflector unit design

Cold Butterfly moderator (LH_2)

Be-Reflector/ -vessel

Thermal moderator (water)

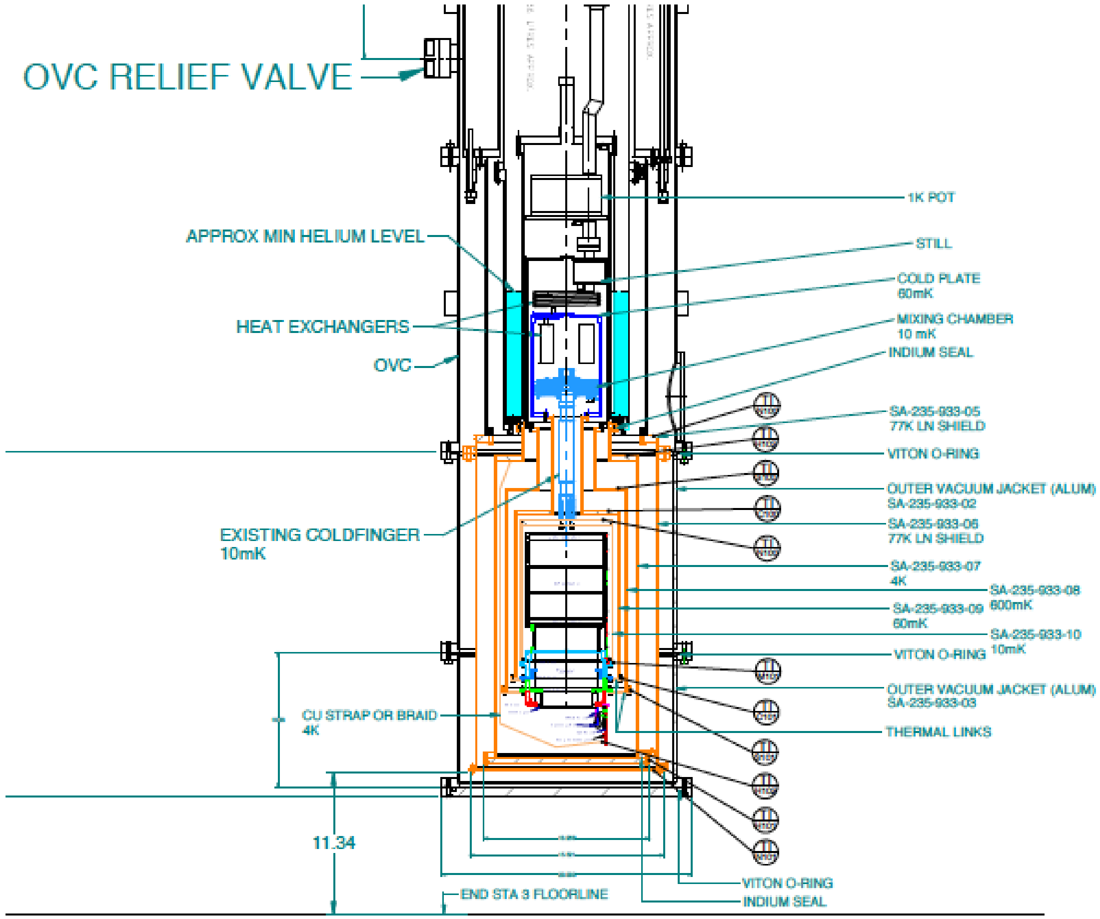


LH_2 pipework

20 K
30.3 kW of cooling required

Vacuum chamber (extruded profile include 2 cooling chambers for thermal moderator water

Cryogenics is Also Used in Non-Accelerator Based Fundamental Physics



CDMS detector test stand Dilution refrigerator ~ 20 mK operating temperature

Temperature level required for proper detector operation and low thermal background

Summary

- Cryogenics is an important enabling technology in accelerator and fundamental physics
- Cryogenic applications cover a wide range from the very small to the very large and from 120 K to μK
- Cryogenics also plays a major role in astronomy, solid state physics and medicine
- The study of cryogenics involves many disciplines including: thermodynamics, heat transfer, fluid mechanics, mechanical design, material science, instrumentation and quantum mechanics
- There's lots to learn

Let's Get Started