

# Lecture 1

## Introduction

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USPAS

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- 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

- 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

- Currently, Staff Engineer in Fermilab's Applied Physics and Superconducting Technology Division (APS-TD)
- Previous work:
  - Postdoc at National High Magnetic Field Laboratory, Tallahassee, Florida, US
  - Design engineer at General Electric, Bangalore, India
  - Visiting researcher at Queen Mary University of London, UK
- PhD in Mech. Eng. from Florida State University, US
- BS and MS in Mech Eng. From Indian Institute of Technology Bombay (IIT Bombay), India
- Interests:
  - Cryogenic system design, cryocoolers, instrumentation
  - Technical writing, education/teaching

- Problem Sets 70%
- Design Project 30%

- Class slides
- Textbook Cryogenic Systems by R. Barron (2<sup>nd</sup> 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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# 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



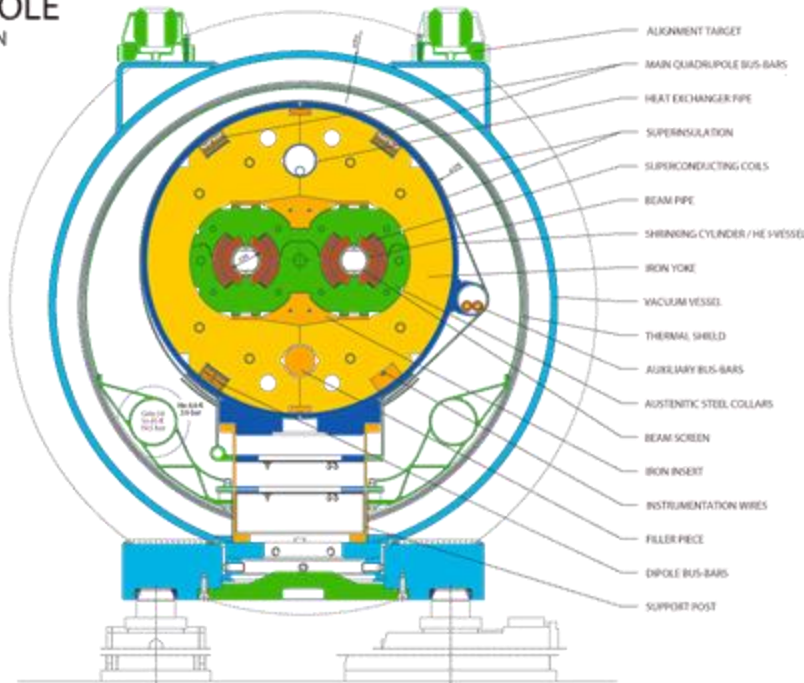
- Cryogenics plays a major role in modern particle accelerators
  - Enables superconductivity
    - Beam bending and focusing magnets (1.8 K – 4.5 K)
    - Magnets for particle identification in large detectors (4.2 – 4.5 K)
    - Superconducting RF cavities for particle acceleration (1.8 K – 4.2 K)
  - Allows dense pure liquids
    - LAr calorimeters (87 K)
    - LH<sub>2</sub> 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

- 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

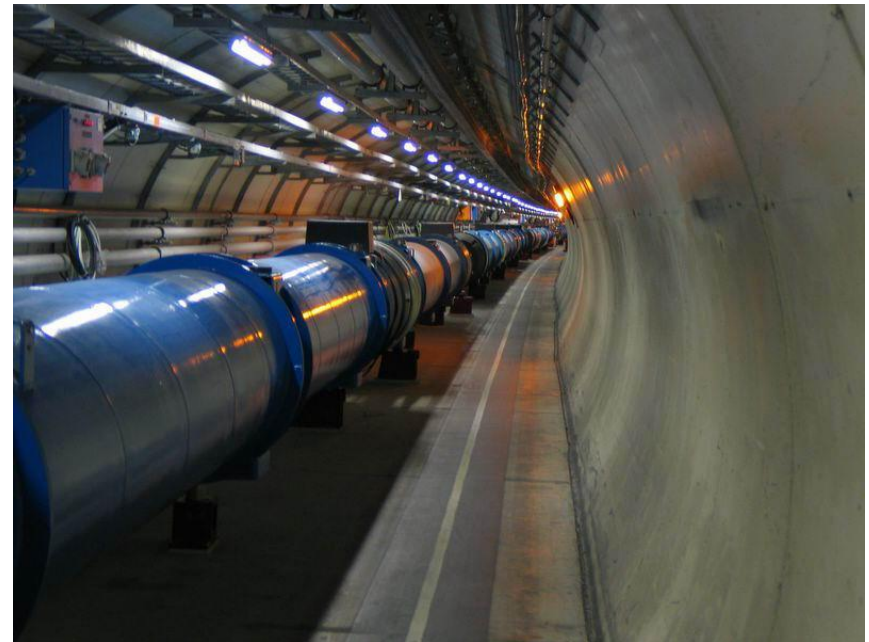
# Superconductivity (enables high field magnets)

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

LHC DIPOLE  
CROSS SECTION



CERN AC/DU/MM — 06-2001

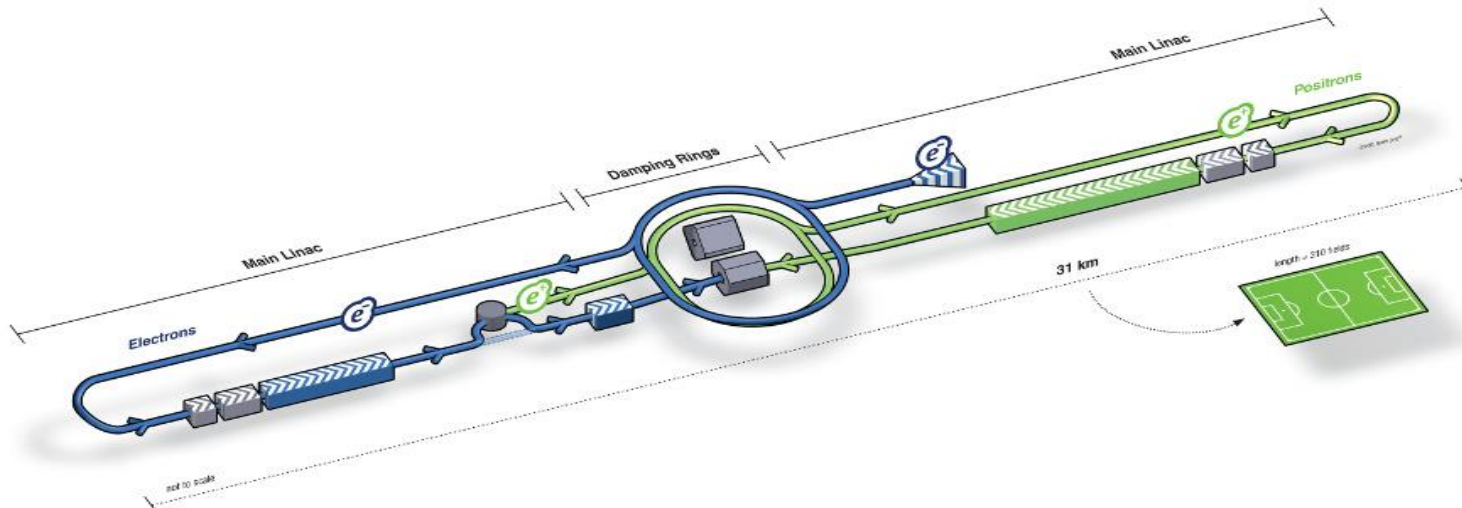


# Superconducting RF is Very Popular

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	Proton Linac	ESS	2.0	3 kW @ 2 K	Under Construction
SNS	H <sup>-</sup> Linac	ORNL	2.1	2.4 kW @ 2.1 K	Operating
E Linac	Electron Linac	TRIUMF	2.0	288 L/Hr	Operating
S-DALINAC	Electron Linac	TU Darmstadt	2.0	120 W @ 2.0 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
ATLAS	Heavy Ion Linac	ANL	4.7	1.2 kW @ 4.7	Operating
LCLS II	Accelerator	SLAC	2.0 K	8 kW @ 2 K 30.6 kW @ 35-55 K 2.6 kW @ 4.5-6 K	Under construction TESLA Tech
ISAC - II	Heavy Ion Linac	TRIUMF	4		Operating
FRIB	Heavy Ion Linac	MSU	2.1 4.5 33/55	3.6 kW @ 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



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# Large He Systems Have Become Common



2007 LHC

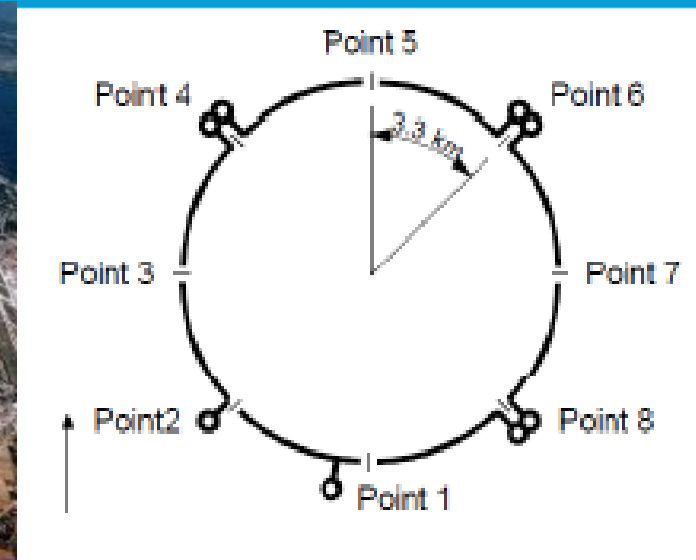
8 Plants each with  
18 kW @ 4.5 K

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





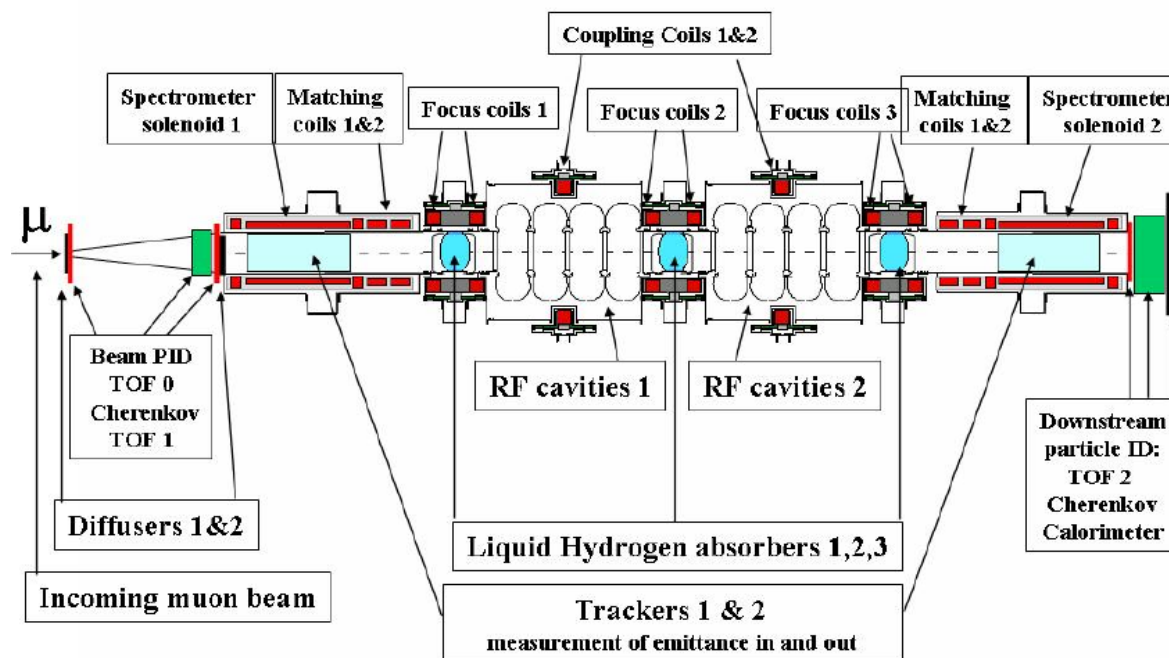
# Use of Small Cryocoolers is Also Growing

- 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 SRF Cavities and the use of cryocoolers to reliquefy LHe or LH<sub>2</sub>
- 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



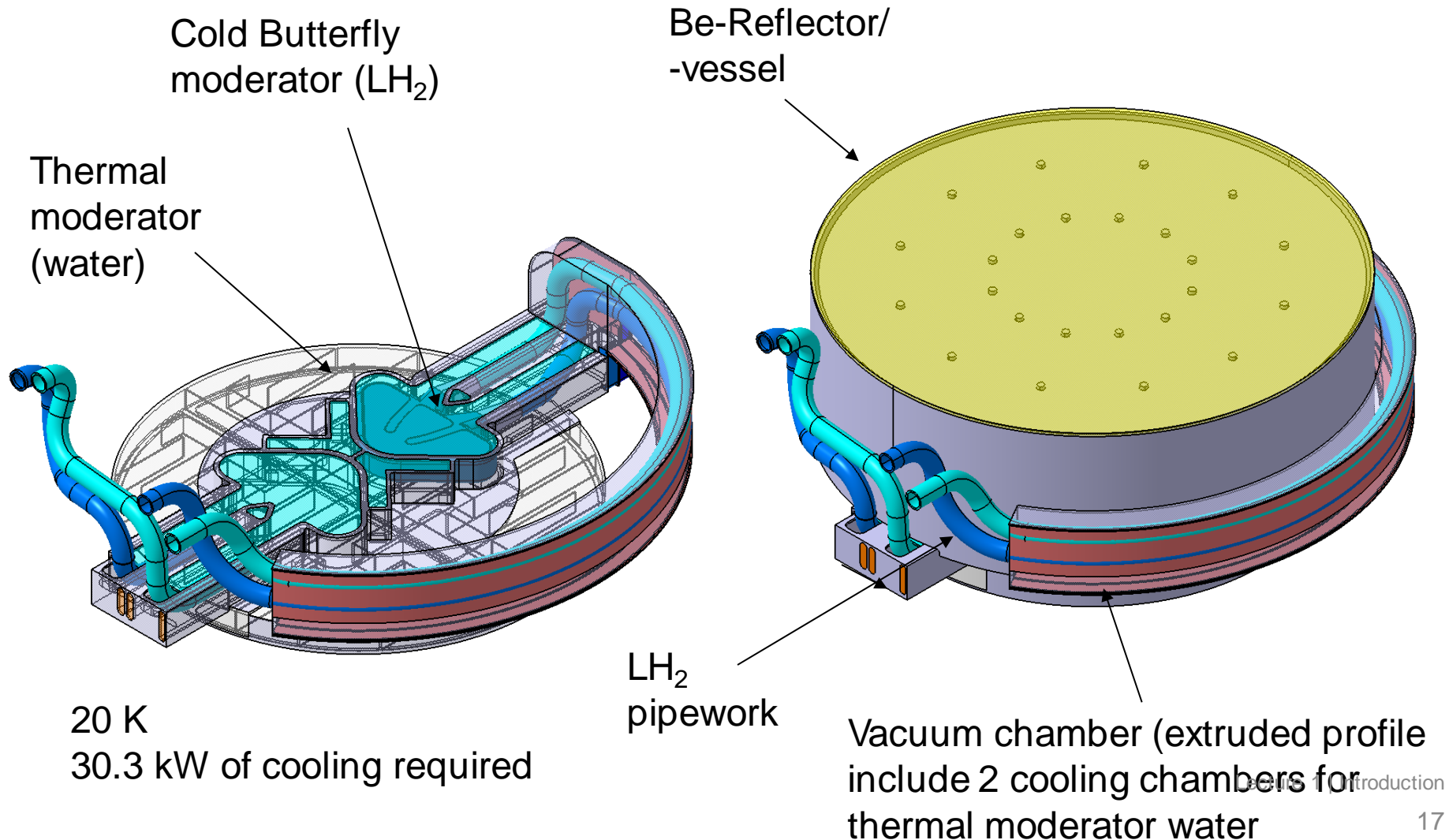
CryoMech PT415  
40 W @ 45 K  
1.5 W @ 4.2 K

- Muon Ionization Cooling Experiment
- A beam physics experiment in support of future muon colliders
  - Contains SCRF cavities, SC magnets and LH<sub>2</sub> absorbers
  - Extensive use of small cryocoolers to reliquefy both LHe and LH<sub>2</sub>
  - Use of cryogen free magnets is also being investigated
  - Currently under design for operation at RAL



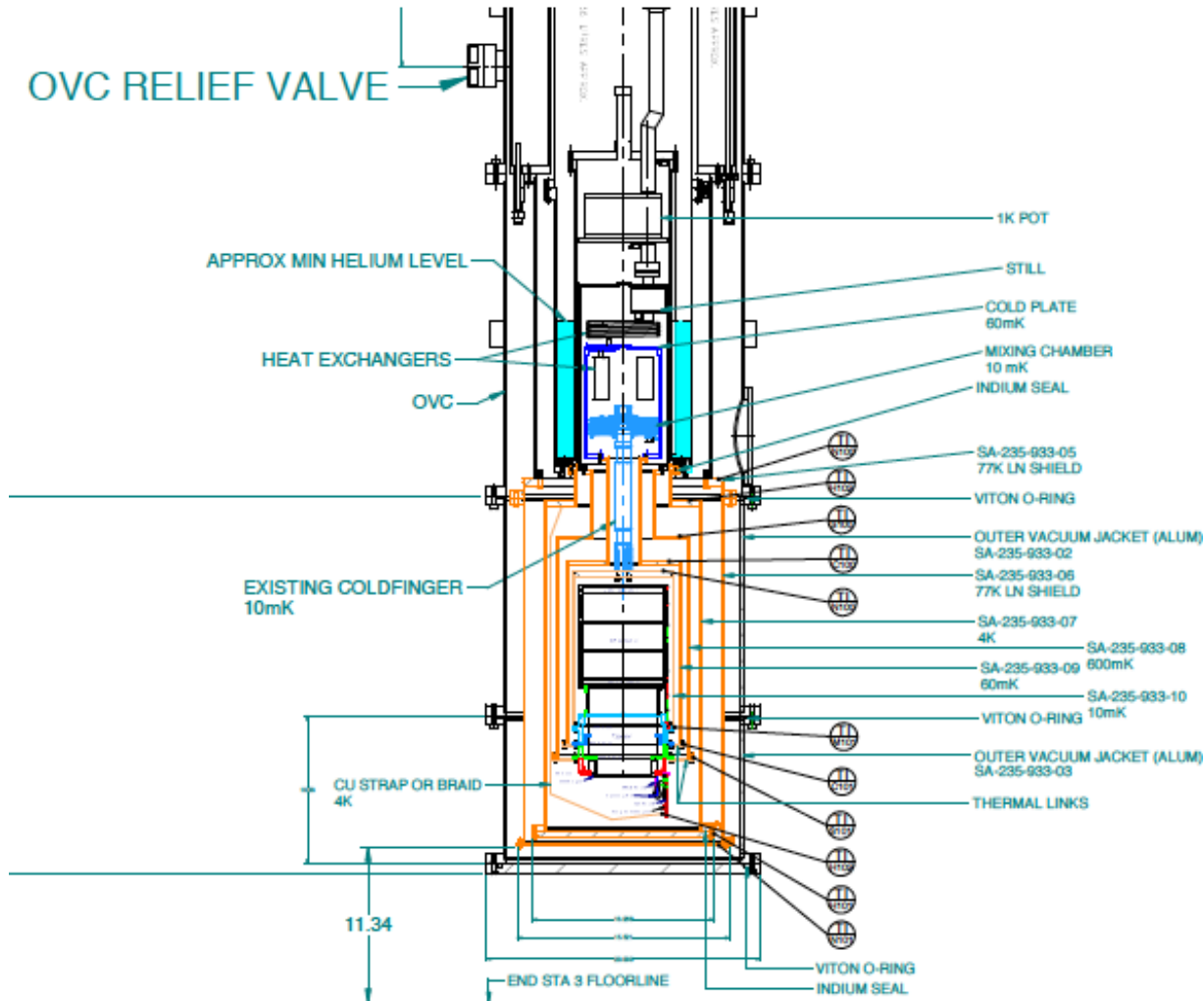


## ESS moderator & reflector unit design





# 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

- 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  $\mu\text{K}$
- 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