Università degli Studi di Padova

Sapienza Università di Roma

PhD Year One Recap:

Foundations Built and Next Steps Forward

Lorenzo Sclafani

National PhD Programme in Technologies for fundamental research in Physics and Astrophysics, Ex D.M. 117/2023

Mechanics curriculum

Hosting university: La Sapienza, University of Rome

Company: SpinItalia srl

Advisor: Prof. Antonio Carcaterra

Co-Advisor: Prof.ssa Silvia Milana

Research topic

The research focuses on using **mechatronic technologies to support fundamental physics experiments**. It involves advanced sensors, actuators, and controllers for monitoring complex mechanical systems, aiming to **measure disturbances in challenging conditions like cryogenic environments** with high sensitivity.

↓

Characterization of damping at cryogenic conditions to improve the monitoring of low-intensity disturbances in cryogenic environments

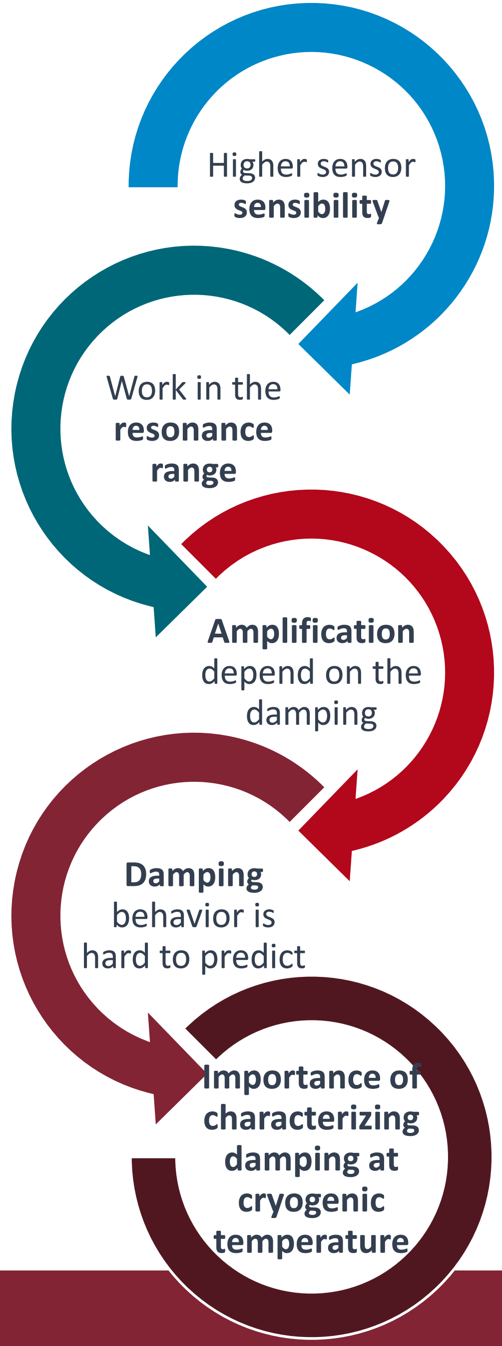
Vibration Monitoring in cryogenic environments

- Essential from both **theoretical and applicative** perspectives
- Crucial for identifying **mechanical interference phenomena** that can affect the operation of quantum computers and physics detectors

Problem:

- **Low-intensity disturbances** require higher sensor sensibility
- The resonant frequency and the amplification factor depend on the **fundamental characteristics** of the dynamic system:
    - Mass
    - Stiffness
    - Damping

Stiffness, Damping → Estimating their dependence on temperature is crucial



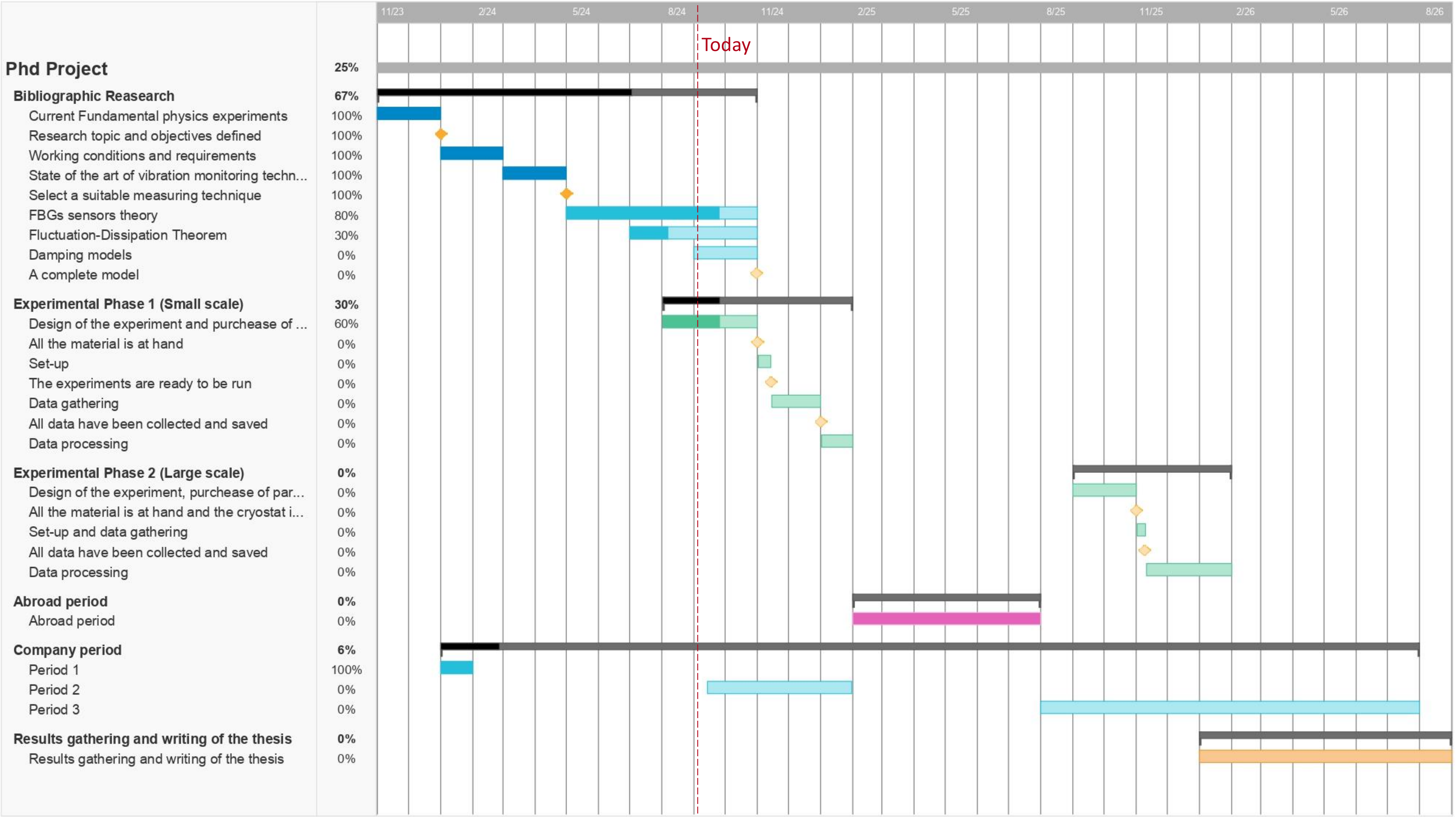
Objectives

Design a monitoring system that guarantees **real-time acquisition of dynamic variables** in the proximity of fundamental physics detectors.

Characterize damping and its relationship with fluctuating dynamic variables **down to cryogenic temperatures**

Characterize the **vibrations of multi-stage cryostats**

3 years planning – Gantt chart



Research activities so far

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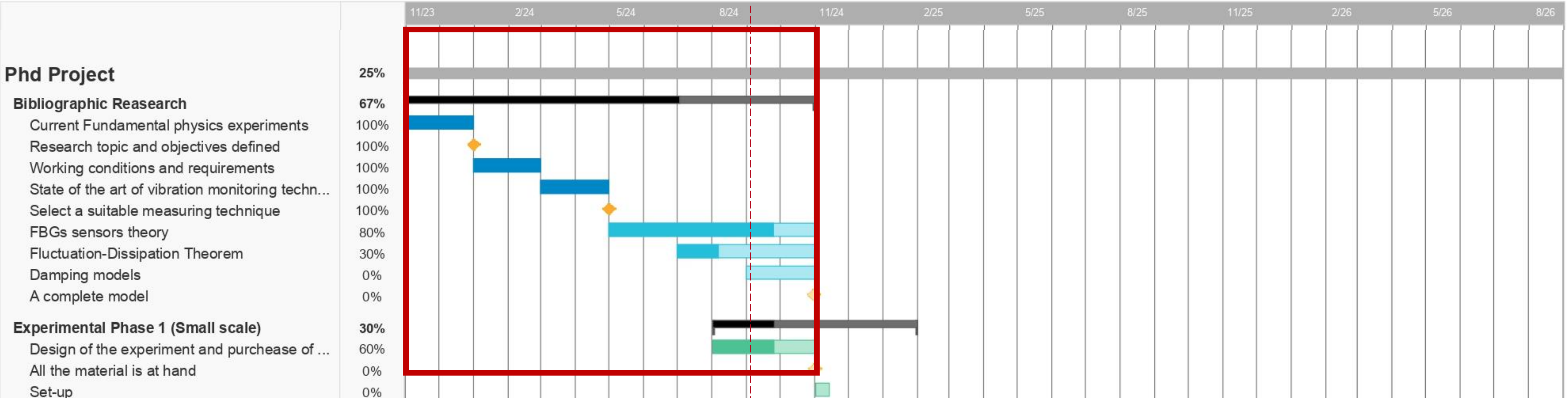

Research activities so far

- **Bibliographic Research:**
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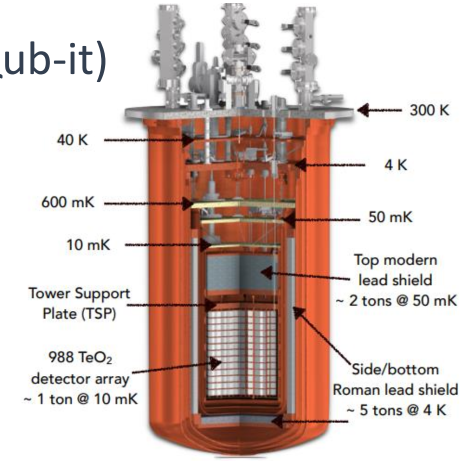
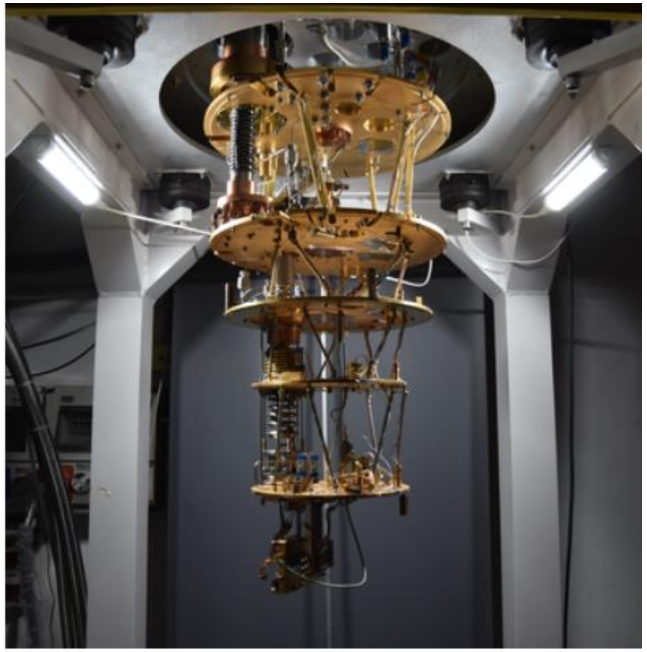
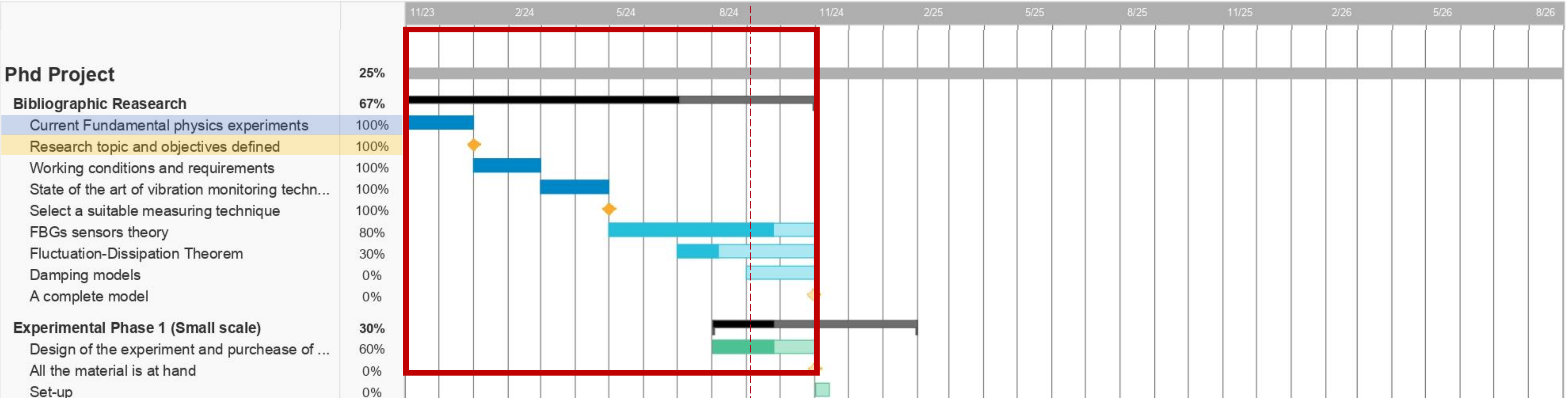


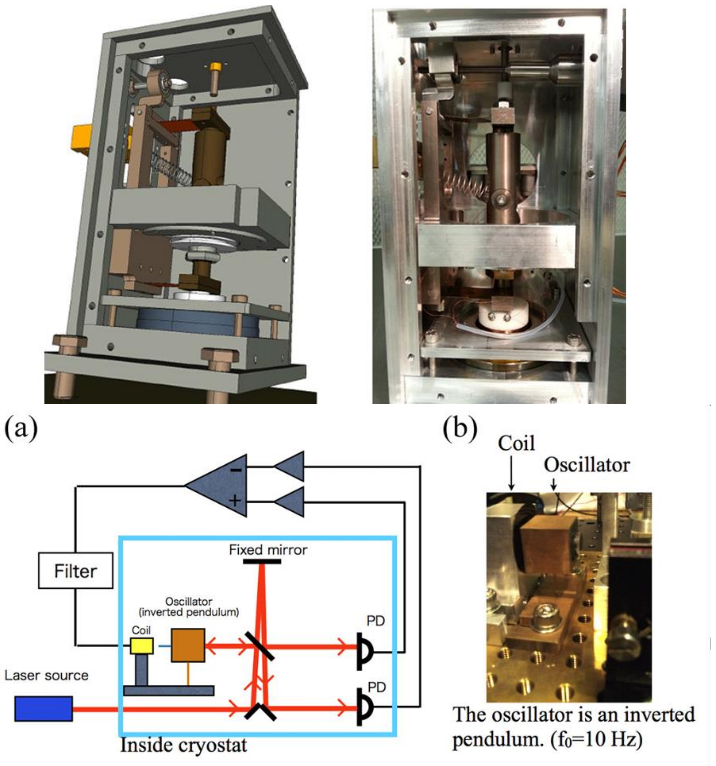


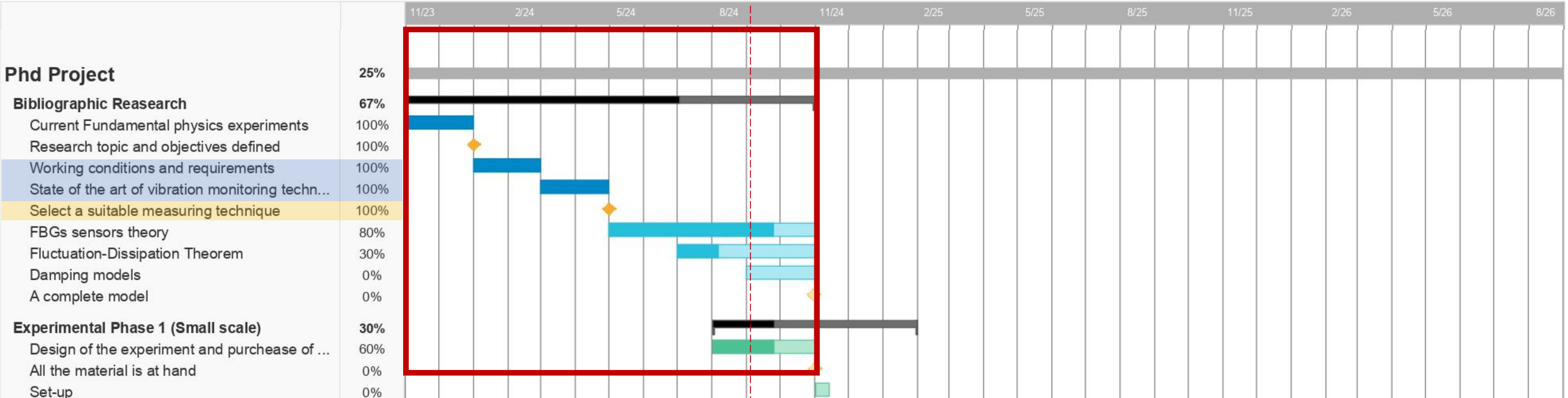


Research activities so far

- **Bibliographic Research:**
  - Modern physics experiments (e.g. CUORE and Qub-it)
  - Requirements and SOA of cryogenic sensing devices

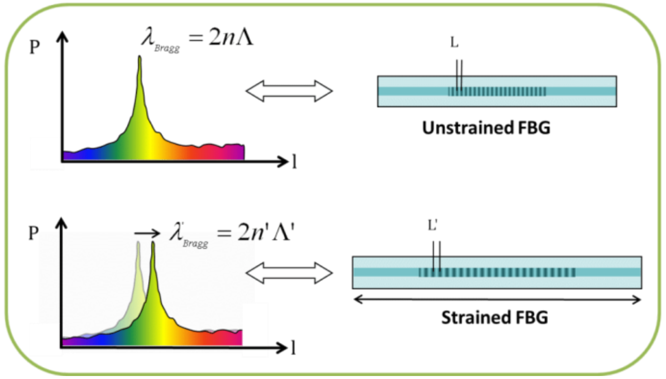
1. Non-intrusive
2. Operating temperature of ~10 mK
3. Radiopure materials, or protected with lead screens
4. No infrared laser
5. Avoid strong or varying magnetic fields

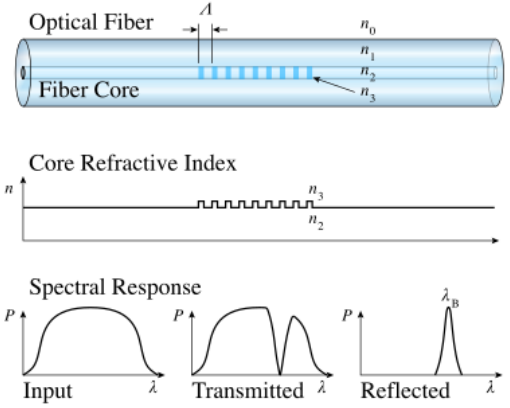


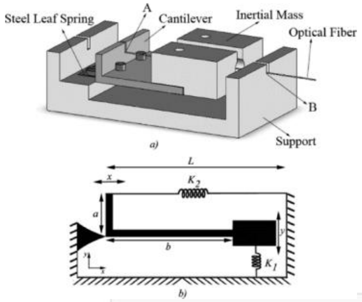


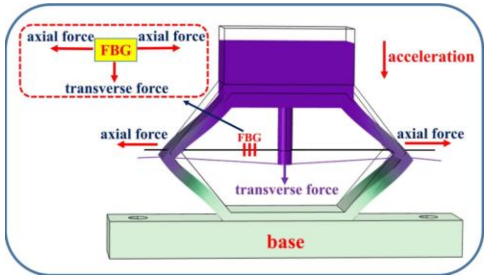
Research activities so far

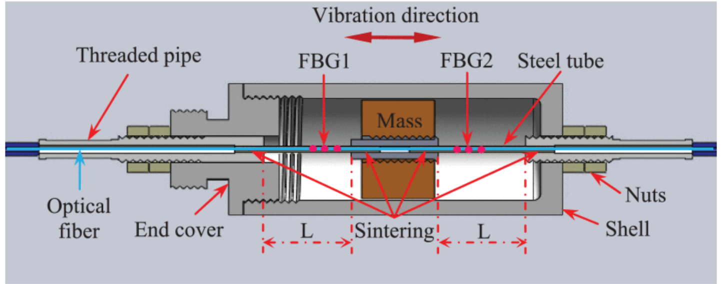
- **Bibliographic Research:**
  - Modern physics experiments (e.g. CUORE and Qub-it)
  - Requirements and SOA of cryogenic sensing devices
  - FBG sensors

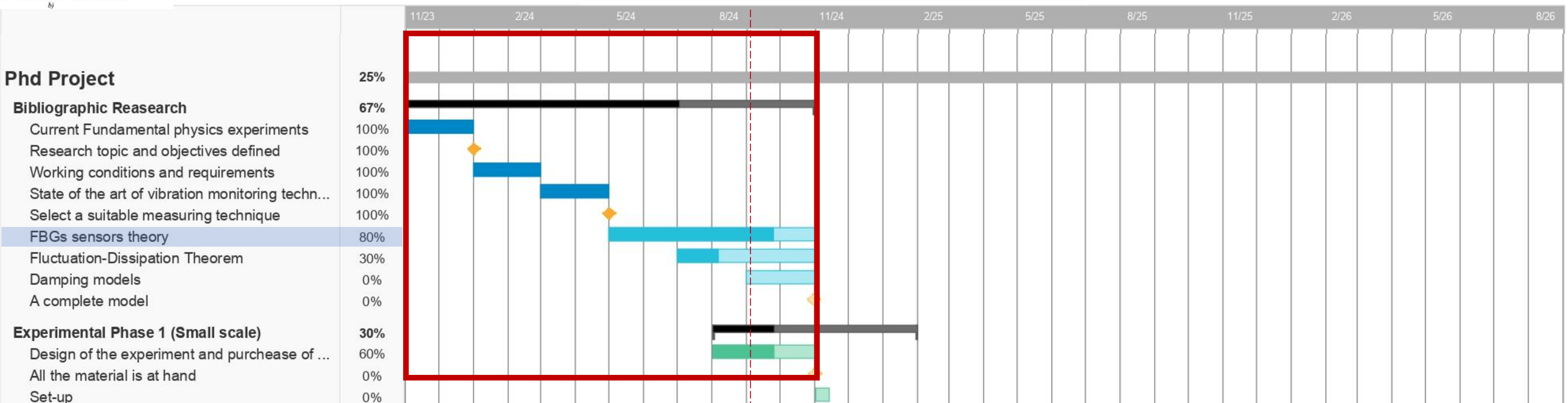








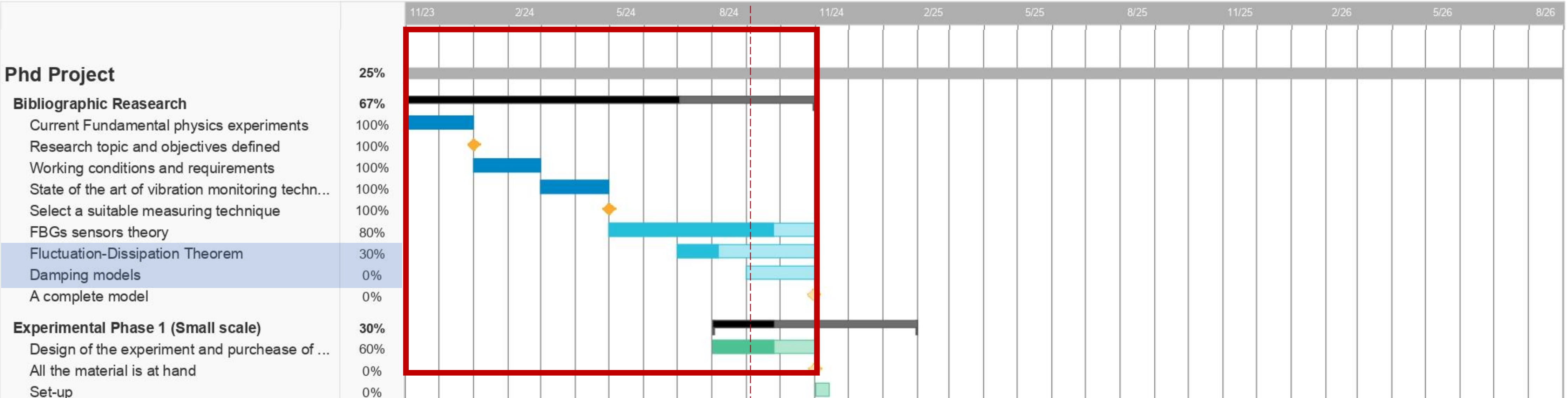




Research activities so far

- **Bibliographic Research:**
  - Modern physics experiments (e.g. CUORE and Qub-it)
  - Requirements and SOA of cryogenic sensing devices
  - FBG sensors
  - Fluctuation-dissipation theorem and Damping models

→ Direct relationship between the agitation of particles in a system and the effects of damping



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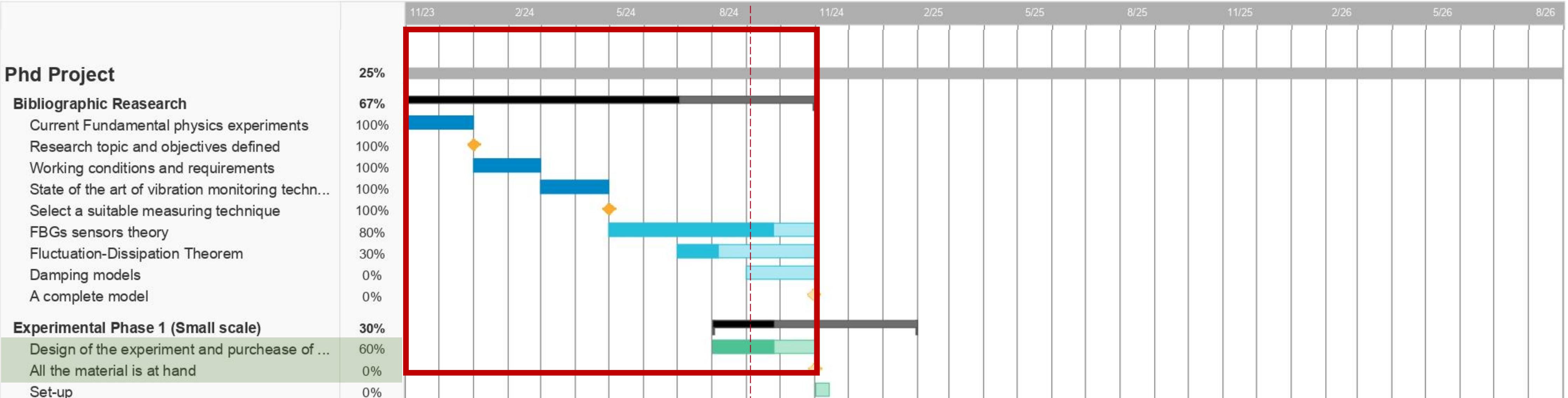
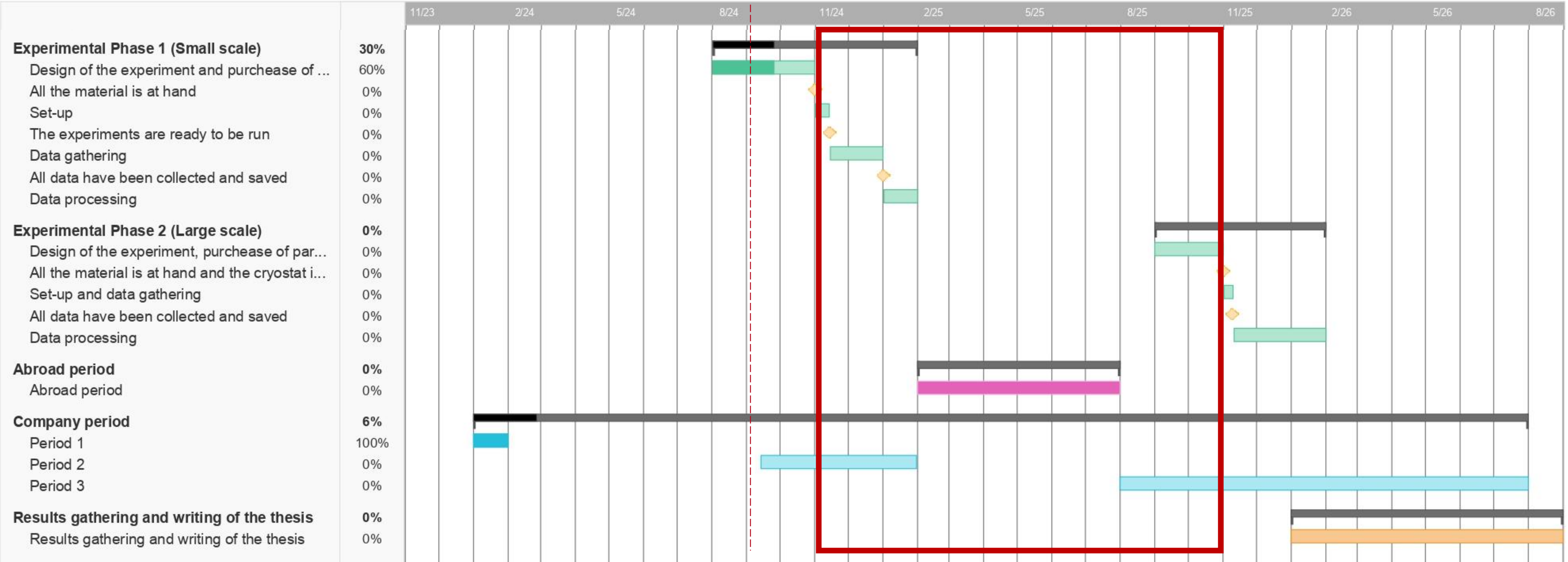
  - Fluctuation-dissipation theorem and Damping models
- **Experimental Phase 1:**
  - Department cryostat check
  - Purchase of materials



Next year activities

- Complete the bibliographic research and experimental phase 1 preparations
- Data acquisition and processing of small-scale experiment 1
- Period abroad
- Period in SpinItalia srl
- Prepare Experimental Phase 2



Experimental Phase 1

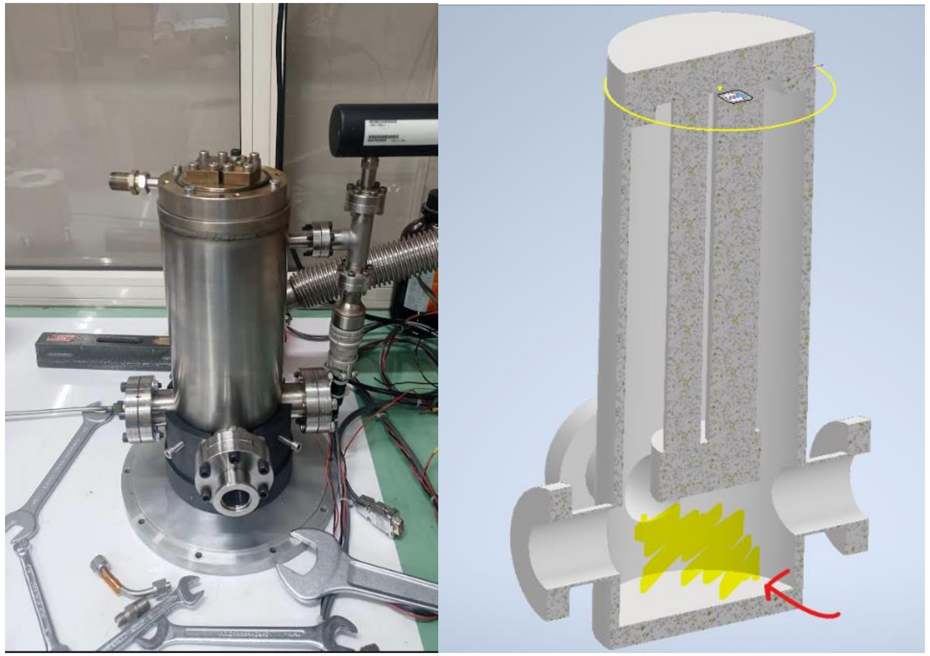
Objective: characterize the damping of a small cantilever (few cm) at low temperature and investigate the relationship between dissipation and fluctuations

Equipment:

- Single-stage pulse tube cryostat
- cm-scale cantilever
- Optical fiber with 3 FBG sensors
- SmartScan interrogator

Steps:

1. Vibrations at room temperature → Internal damping + Fluid damping
2. Vibrations at room temperature, in void → Internal damping
3. Vibrations at different temperatures (down to 70 K) → Influence of temperature
4. Different materials (e.g. metal, glass) → Different materials behavior



Educational activities

Completed courses:	**Coupled,electrical-thermal-structural Finite Element Analysis**	Finite Element analyses related to the structural, thermal and electrical fields. Coupled field analyses with plane and solid elements.
	Advanced electronic sensing devices	Advanced sensors and transducers for electronic applications: their working principle and their integration strategies with electronic systems.
	Deep Networks & Structured Learning	Integration of deep neural and kernel-based learning methods as modelling tools for complex structures.
	Fundamentals of system engineering and project management for large scientific projects	Multidisciplinary approach for the creation of complex systems, and the planning, organizing and implementing of projects at all scales.
Ongoing:	**Machine learning and numerical techniques for inverse problems and design of electrical and electronic systems**	The course provides the main numerical models and ML tools for the design and simulation of electrical and electronic systems.
Future courses:	**Statistical learning**	Hands-on perspective on some techniques for statistical learning in non-linear or unsupervised frameworks.
	School	Statistical mechanics or cryogenics

Other academic achievements of this year

Publications on the matter of **Signal Analysis**:

- **2 papers published** on the use of Cepstral Coefficients, combined with supervised ML techniques
- **1 paper submitted** on the use of Cepstral coefficients and unsupervised ML techniques

Participation in **other projects**:

- NeuroAiD: Bridging Minds and AI for Enhanced Autonomous Driving (progetto di ateneo medie dimensioni 2024)

Thank you!