KAGRA and LIGO

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Ando Group Midterm Seminar 2024/4/24

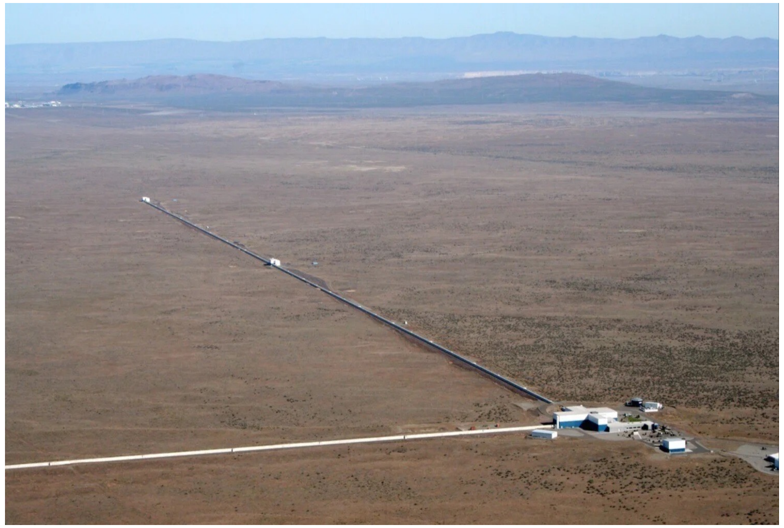
Abstract

- Introduction and comparison of KAGRA and LIGO
- Basics
- Suspension
- Optics and interferometric parameters
- Noise

Basics

➢LIGO Hanford

- One of two LIGO sites
- Located near the city of Richland, in south-eastern Washington St.
- On rocky Columbia Plateau
- Columbia River flowing nearby
- Hot and dry summer, cool and moist winter

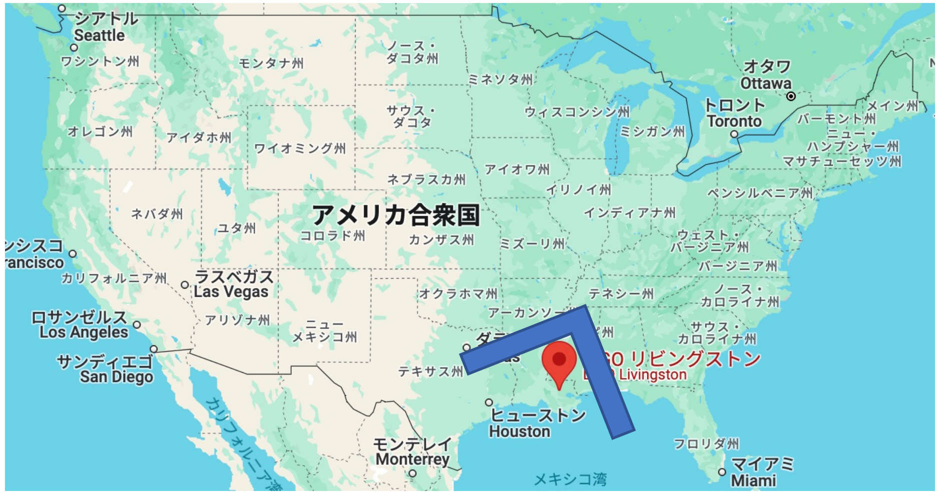


➢Remarks

- Strong wind sometimes affect the operation
- So many rolling tumble weed
- Ravens had caused noises with pecking frost-covered pipes connected to a nitrogen cryopump

Basics

- ➢LIGO Livingston
  - Located near the city of Baton Rouge in south-east Louisiana St.
  - Various wetlands and swamps
  - Mississippi River flowing nearby
  - Hot and humid summer with thunderstorm and hurricane
- ➢Remarks
  - Micro-seismic is often very high due to nearby sea
  - Train noise via scattering of light at cryo-baffle in O3
  - The antenna patter is very similar as LHO to achieve simultaneous observation



Basics

➢KAGRA

- KAmioka GRAvitational-wave observatory
- Inside Mt. Ikeno-yama at Kamioka-cho, Hida city, Gifu pref.
- Ikeno-yama Mt. contains also Kamiokande
- Relatively stable temperature and humidity

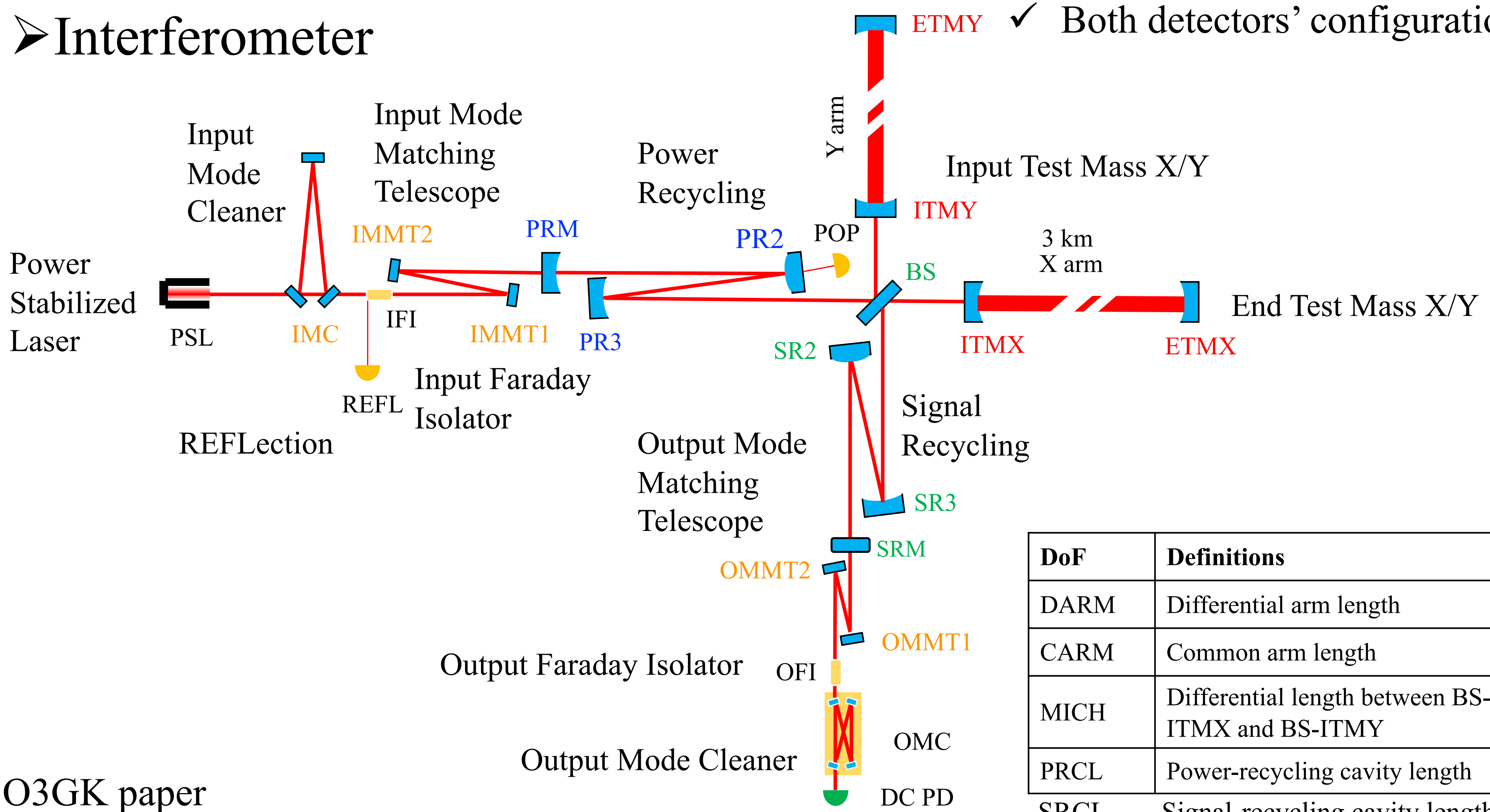
➢Remarks

- Cryogenic operation
- Low seismic noise
- Demonstration toward next-generation observatory
- Micro-seismic from Japan Sea, earthquakes

Basics

➢Interferometer

✓ Both detectors' configurations are the same



DoF	Definitions
DARM	Differential arm length
CARM	Common arm length
MICH	Differential length between BS-ITMX and BS-ITMY
PRCL	Power-recycling cavity length
SRCL	Signal-recycling cavity length

From O3GK paper

Suspension

➢KAGRA overview

High grade
Large vacuum tank

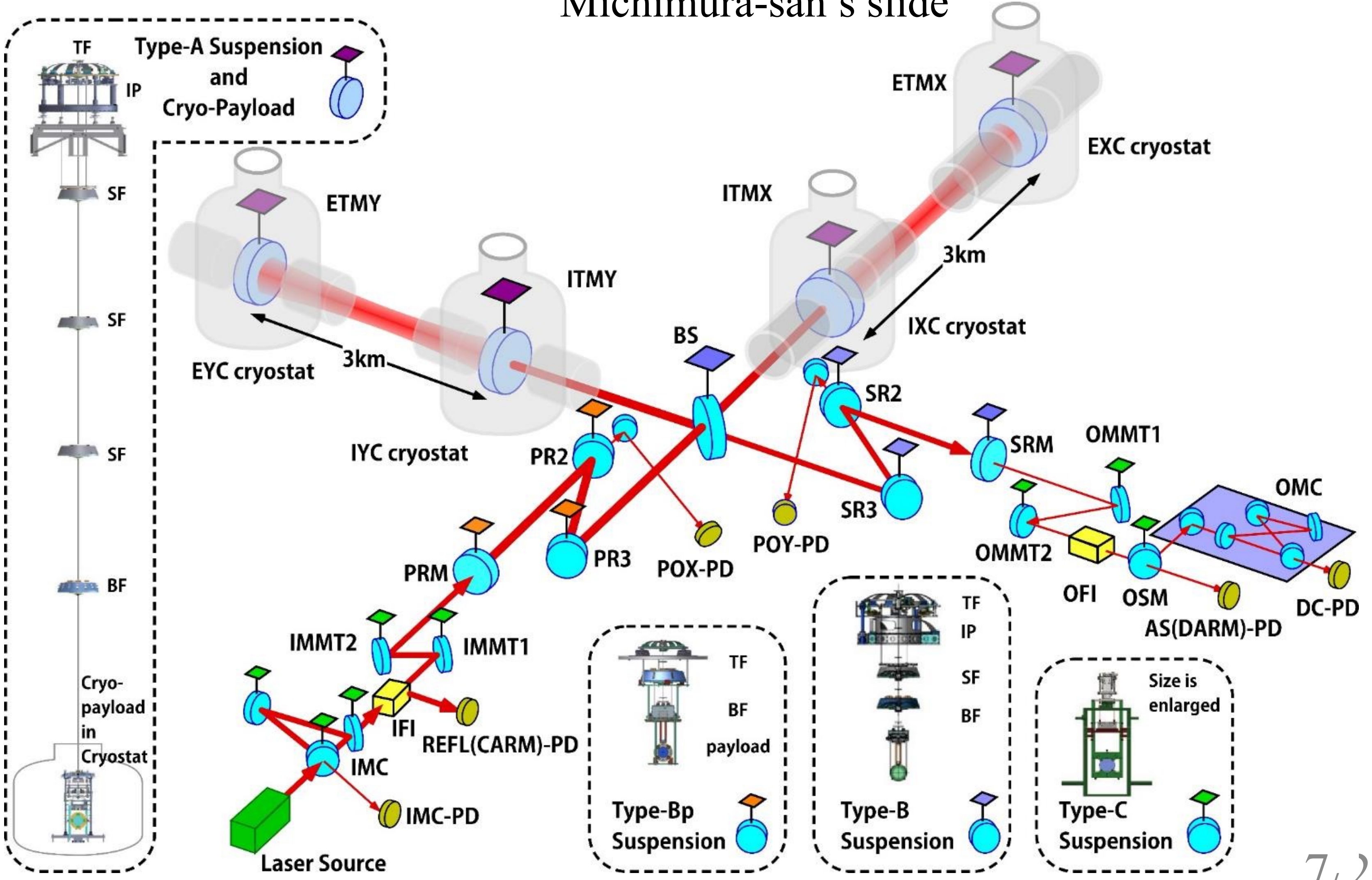
Type-A

Type-B

Type-Bp

Type-C

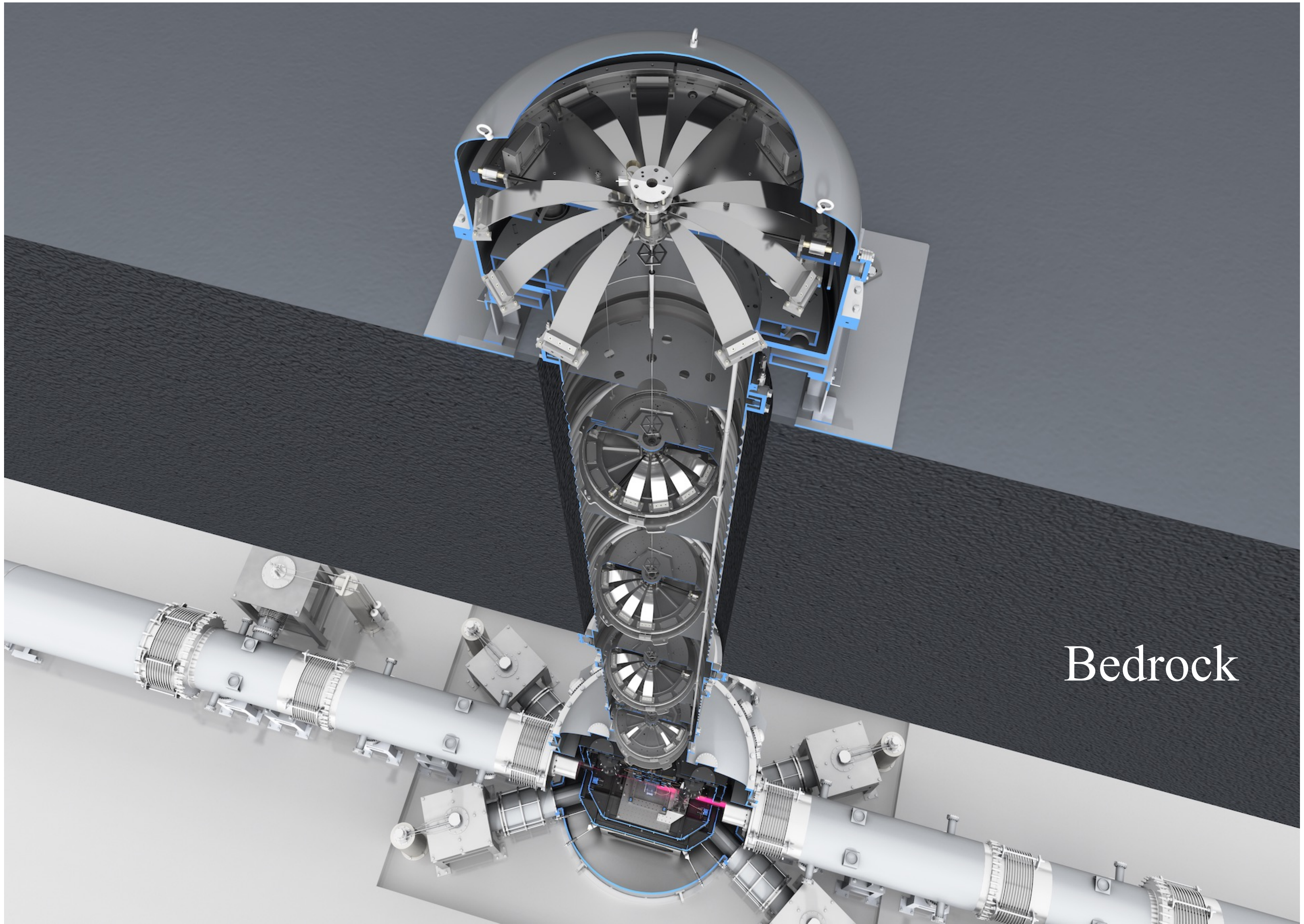
Michimura-san's slide



Suspension

➢Type-A

Multiple pendula
- ✓ Hor: 9 stages
- ✓ Ver: 5 stages



Credit: Rey.Hori

Top Filter

Standard Filter 1

SF 2

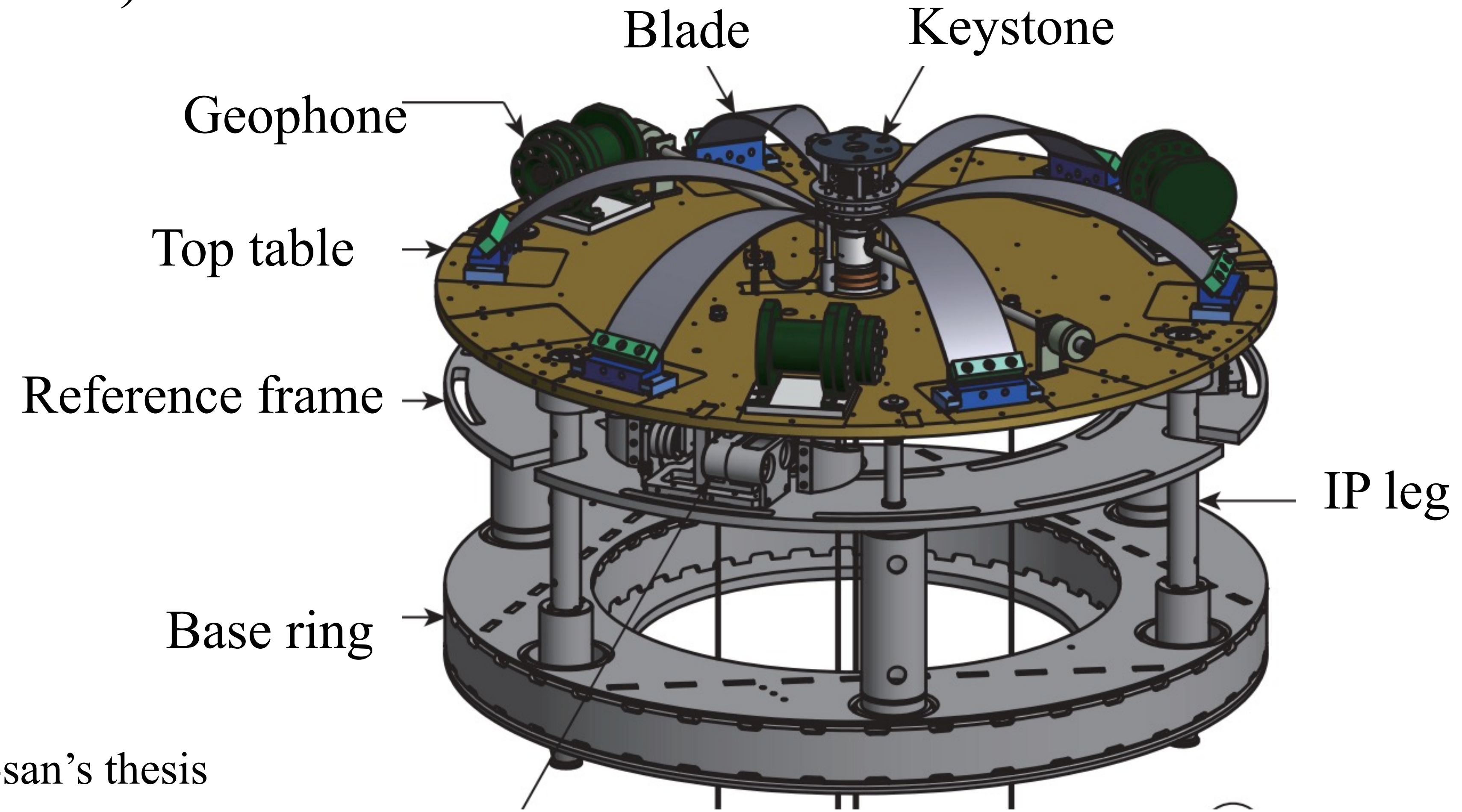
SF 3

Bottom Filter

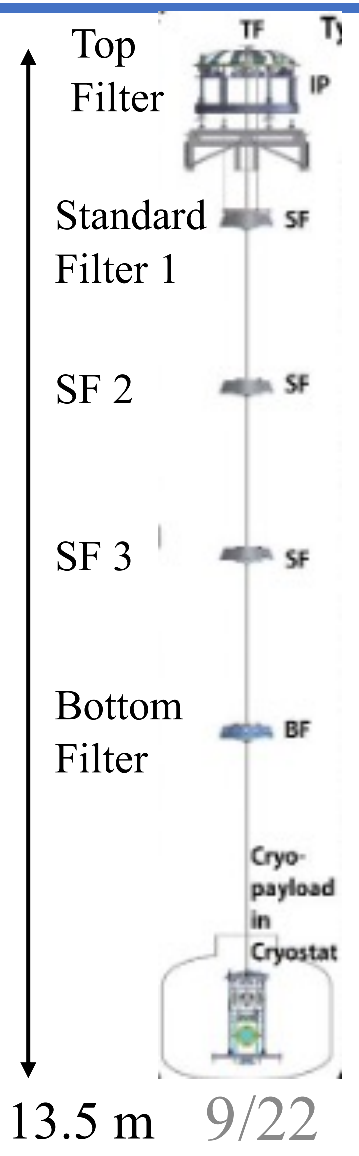
13.5 m

Suspension

- ➢Type-A: Inverted pendulum (IP) and Geometric Anti-Spring (GAS) filter

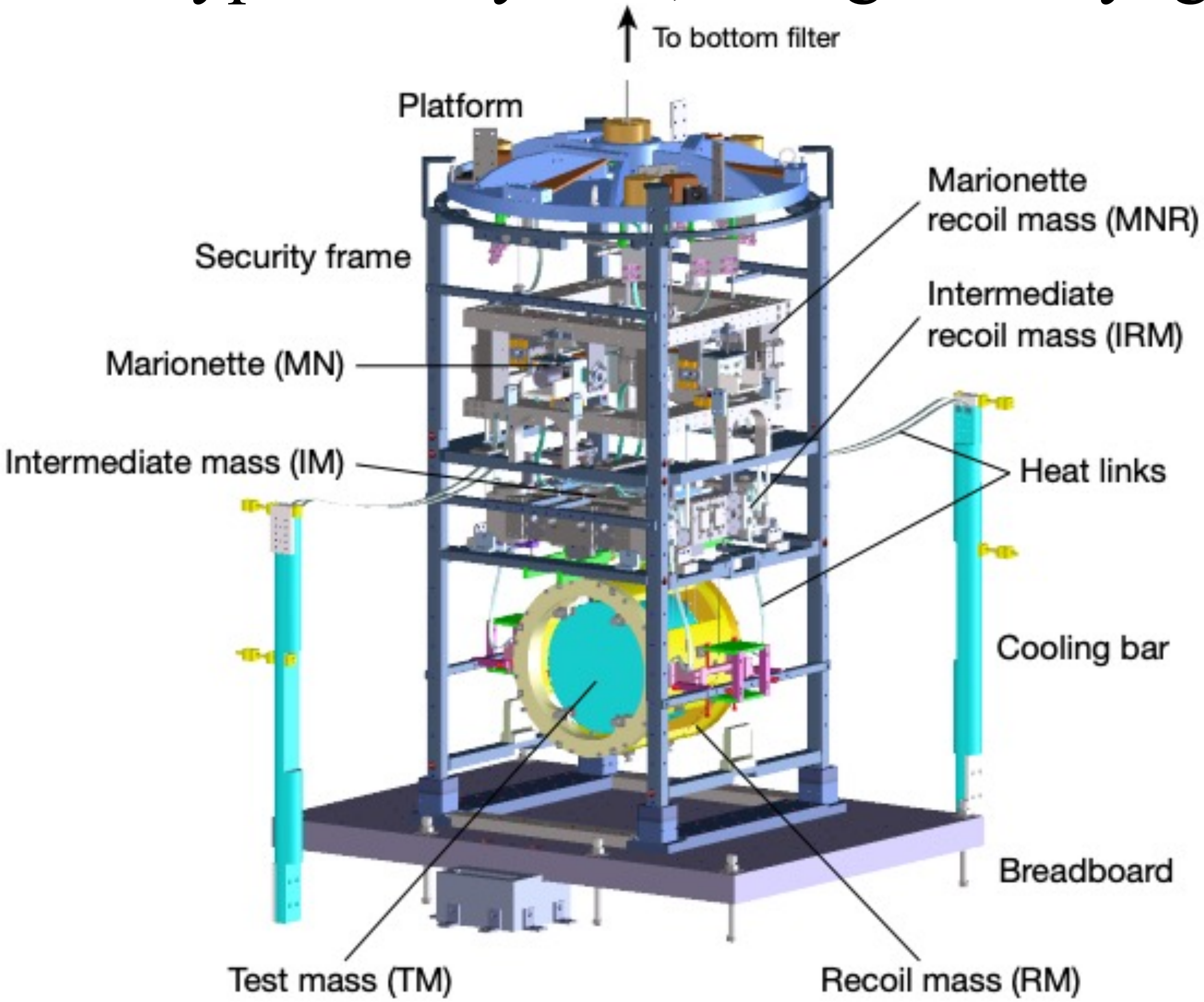


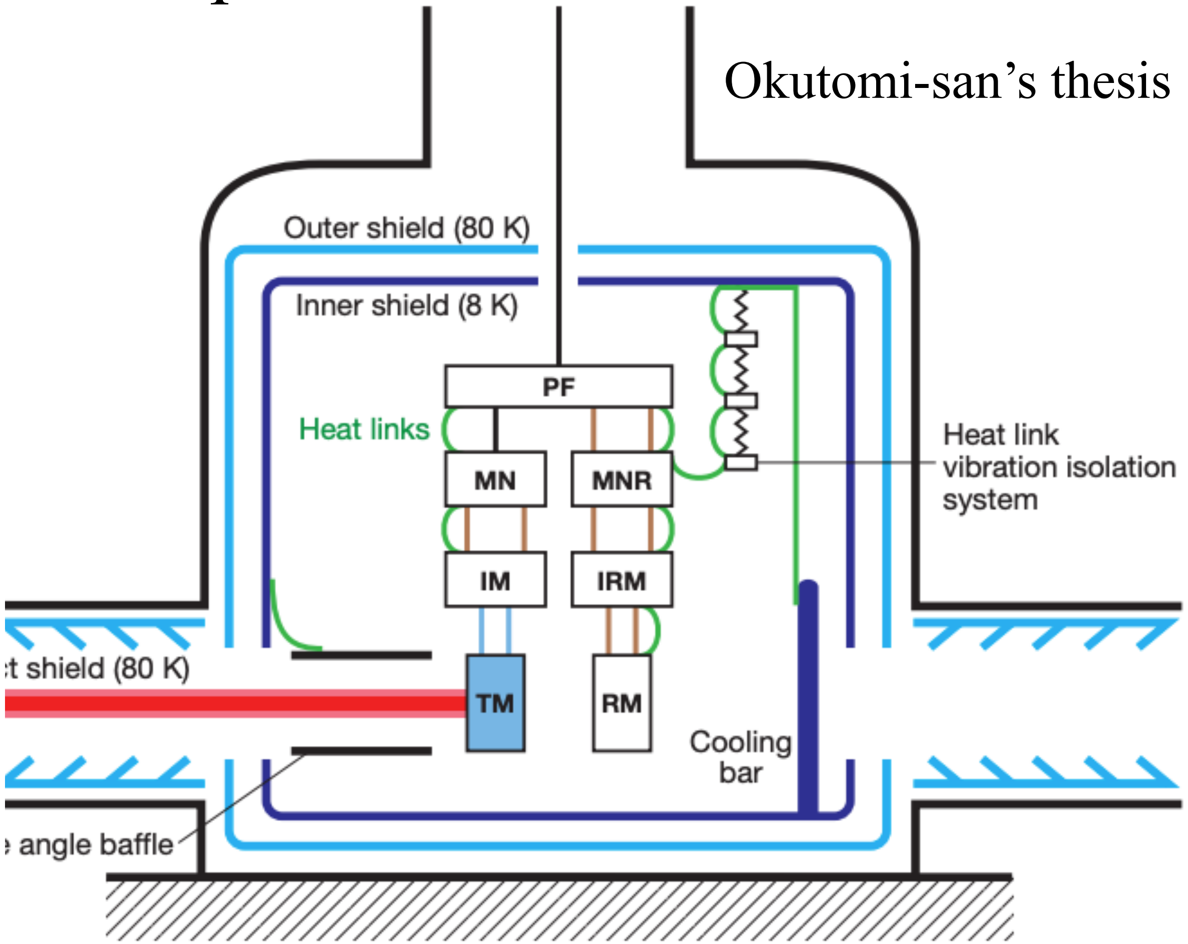
Okutomi-san's thesis



Suspension

- ➢Type-A: Cryostat, 4 stages in cryogenic temperature





Okutomi-san's thesis

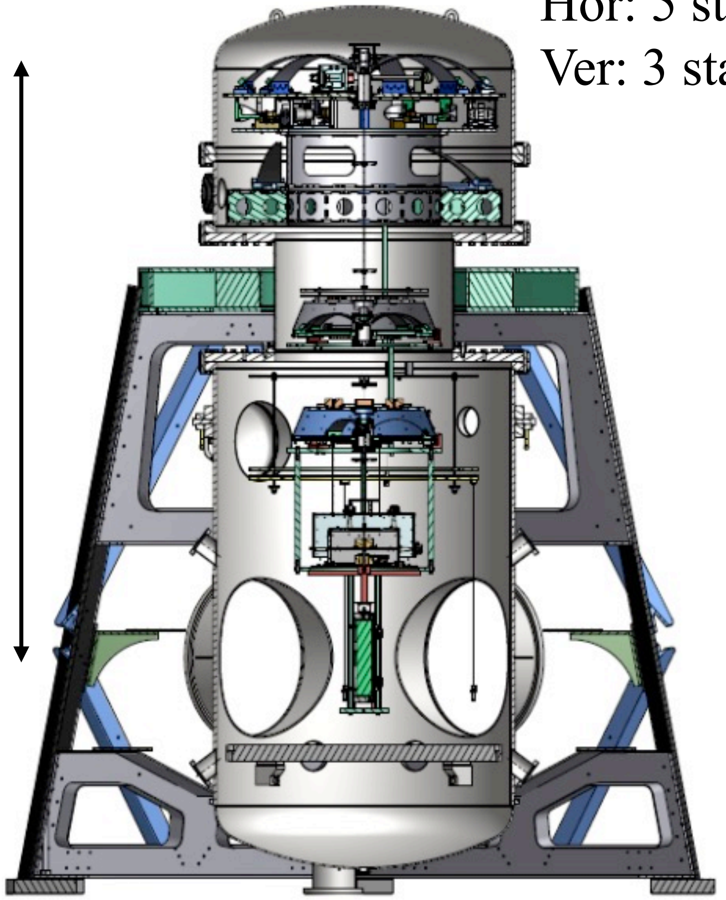
Suspension

- Other suspensions

IM and TM have the recoil masses

Hor: 5 stages (one IP)
Ver: 3 stages (GASs)

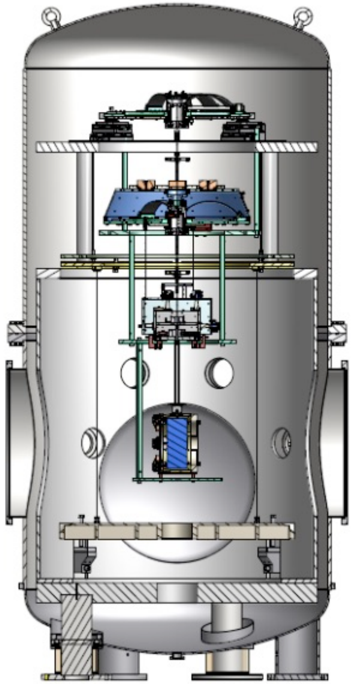
3.1 m



Type-B

Hor: 4 stages (no IPs)
Ver: 2 stages (GASs)

1.7 m

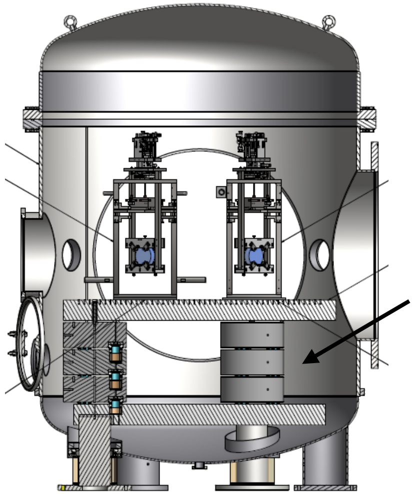


Type-Bp

Hor: 2 stages
Ver: partially 1 stage
(coil-spring)

0.4 m

Stuck:
3 stages

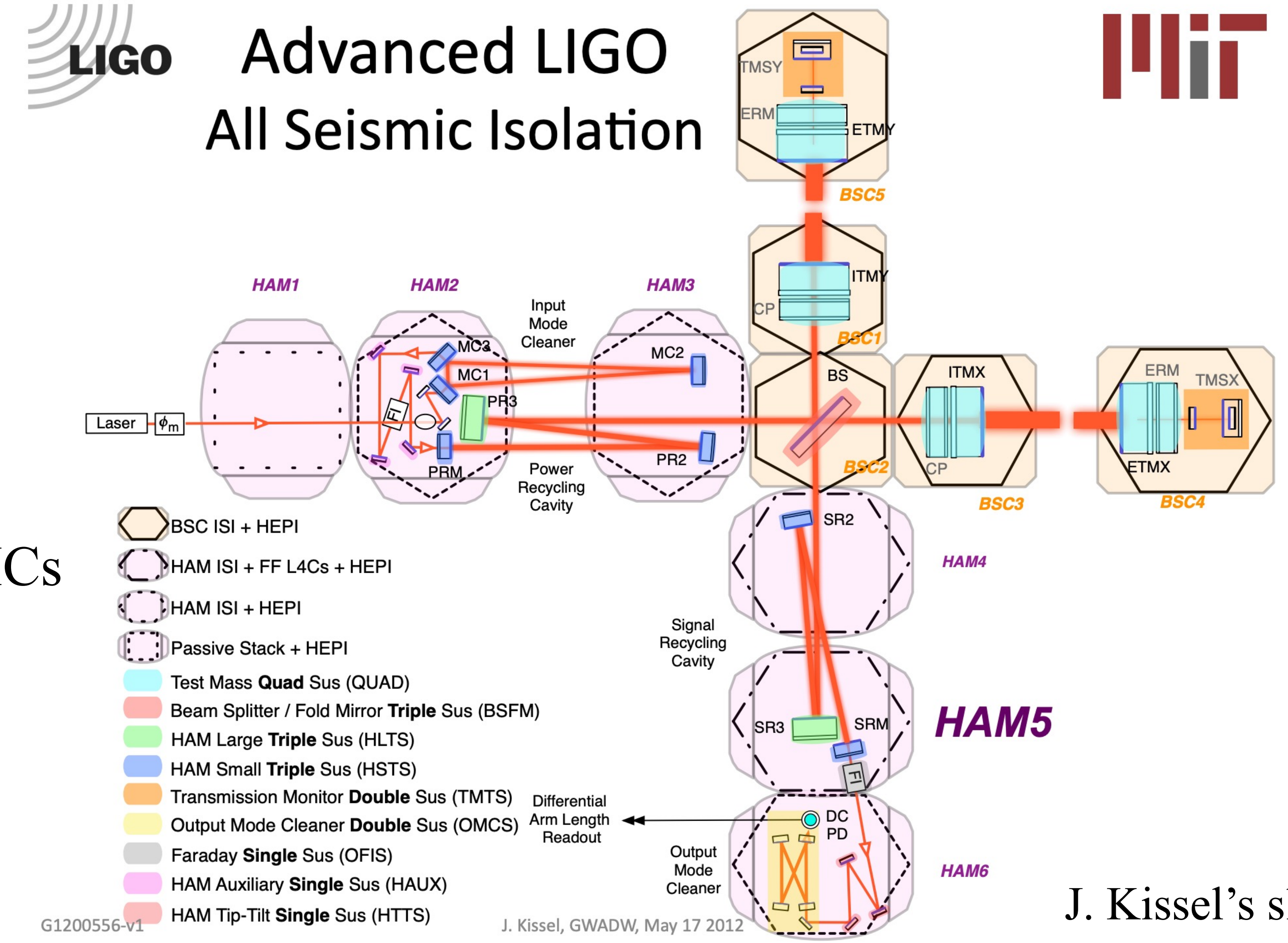


Type-C

Suspension

➤LIGO overview

- ✓ Vacuum chamber:
  BSC and HAM
- ✓ Suspension:
  - HEPI + ISI for the base
  - Quad for TMs
  - Triple for BS, PRs, SRs, MCs
  - Double or single for others

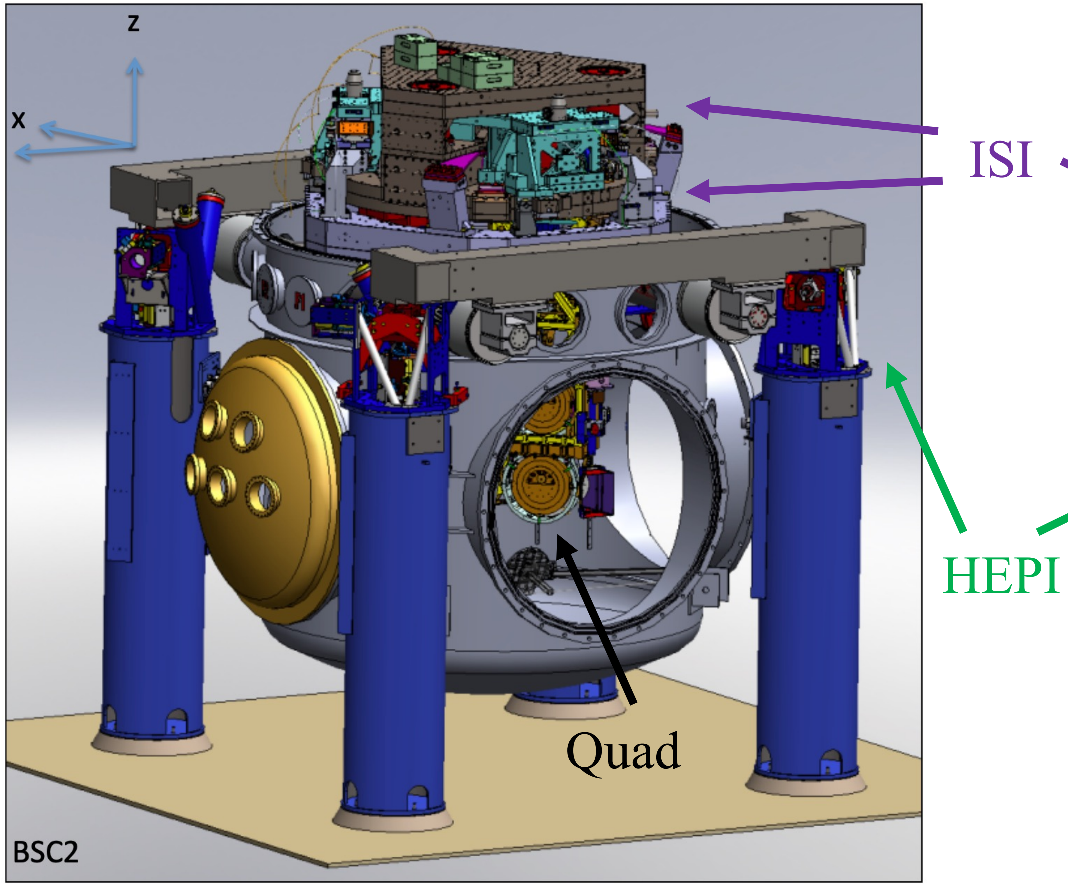


J. Kissel's slide

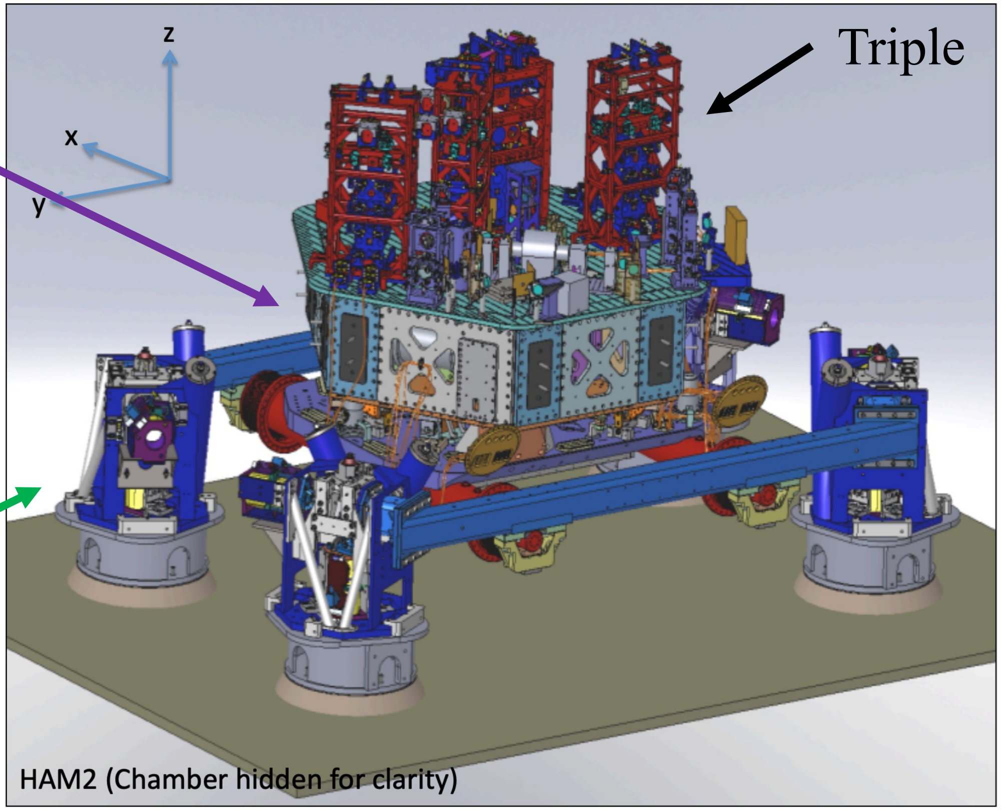
Suspension

➢HEPI (hydraulic external pre-isolator) and ISI (in-vacuum seismic isolator)

✓ Active isolation



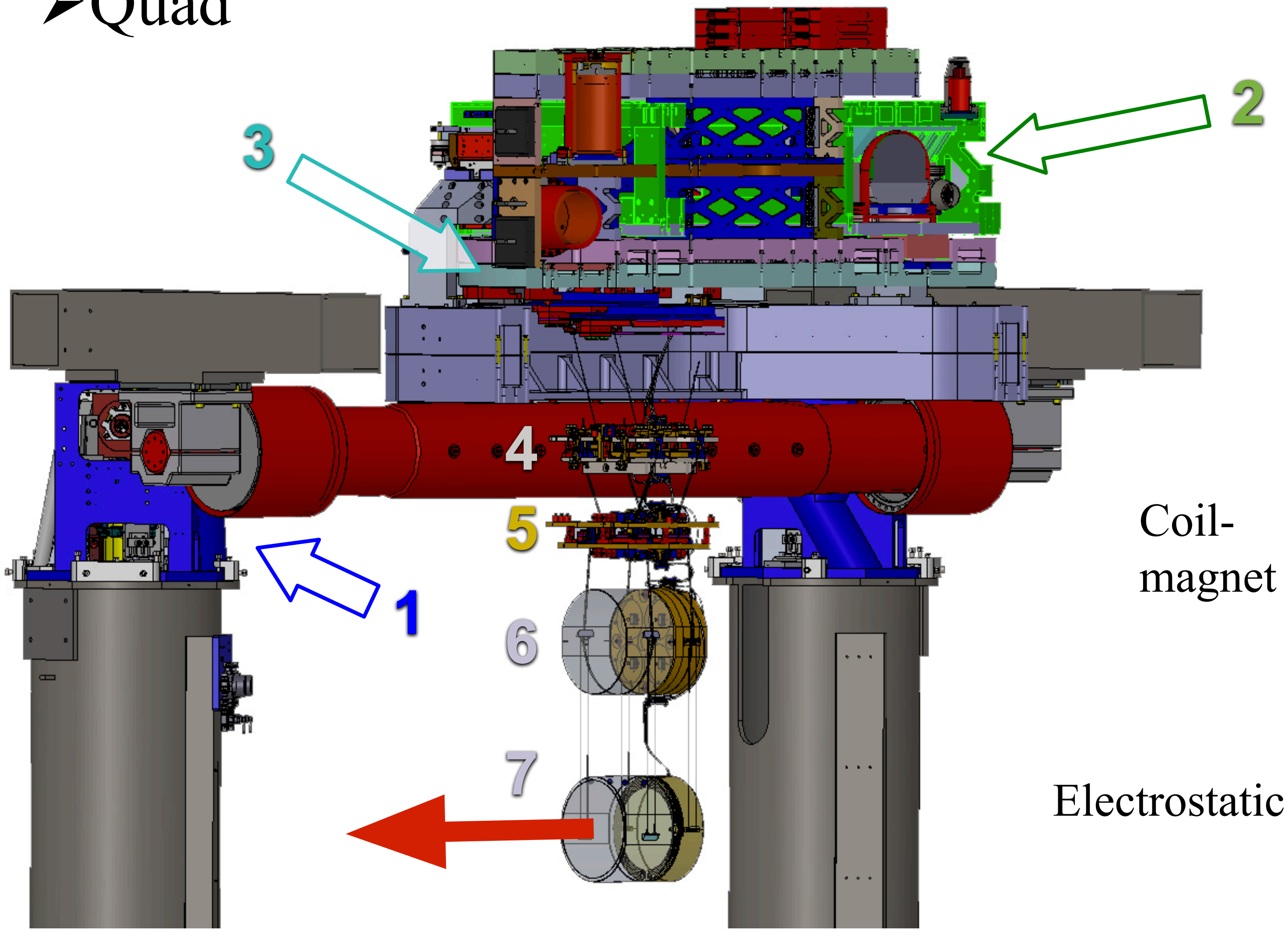
BSC HEPI (1 stage) and ISI (2 stages)

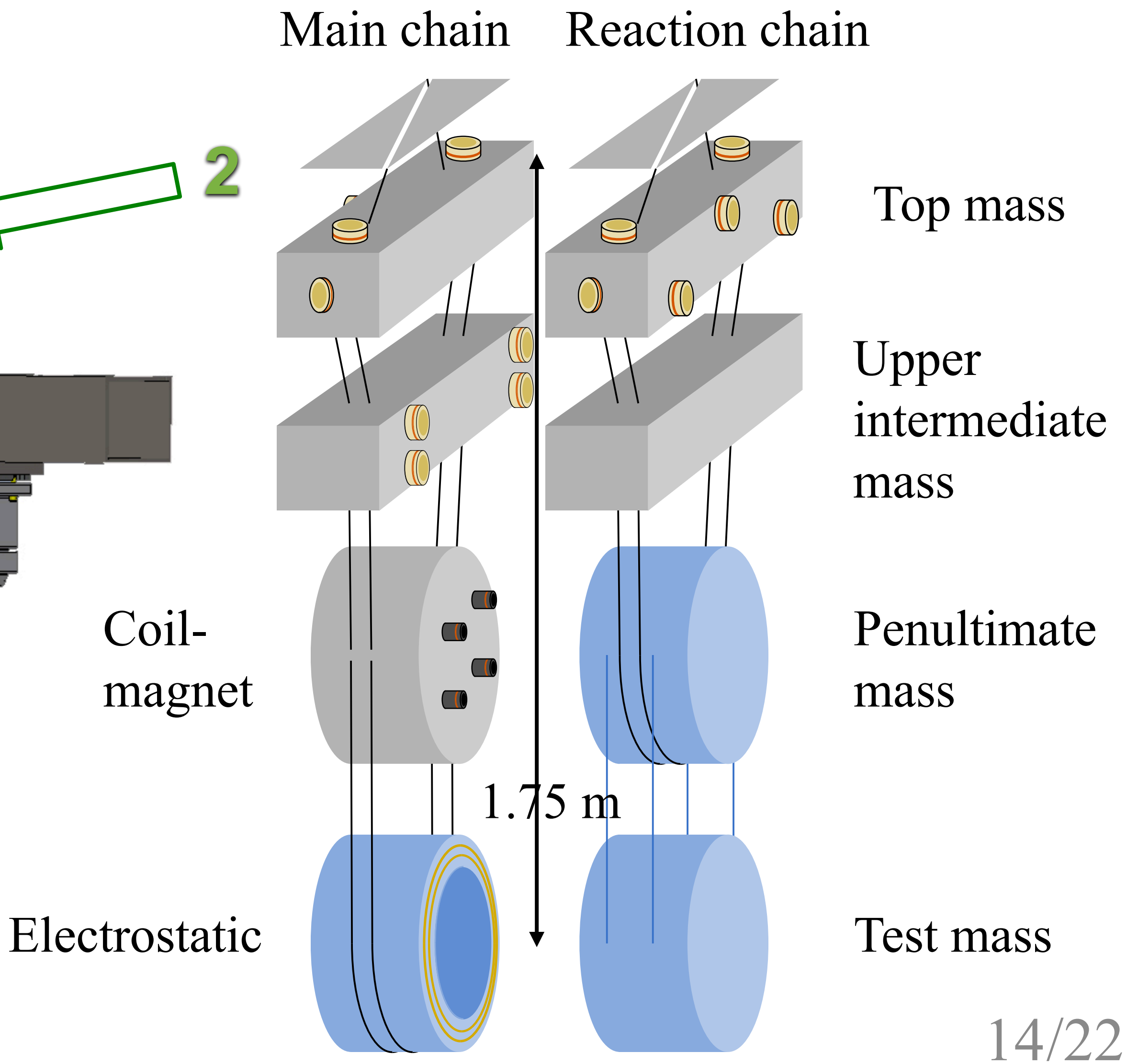


HAM HEPI (1 stage) and ISI (1 stages)

Suspension

➢Quad

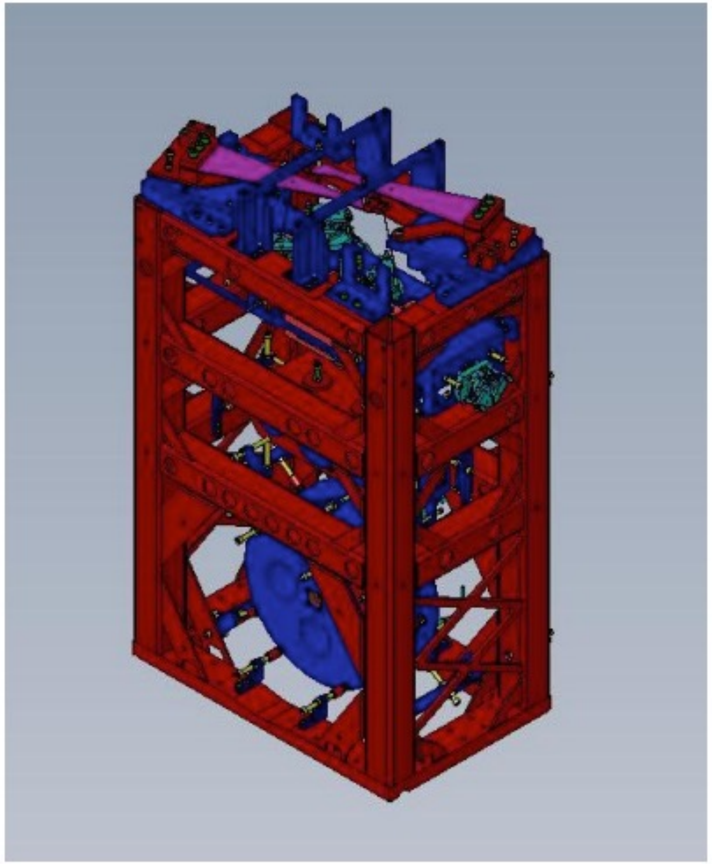




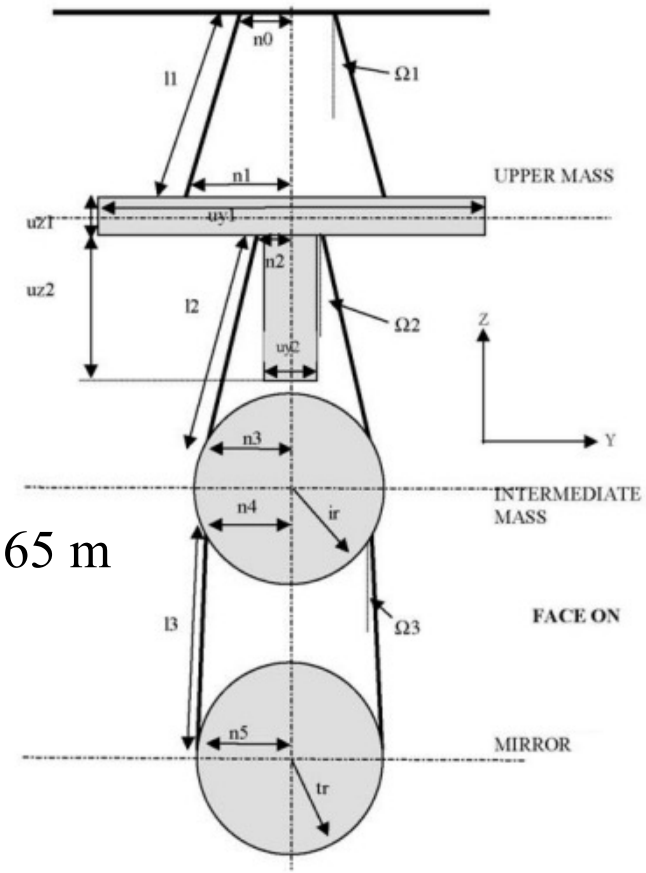
Suspension

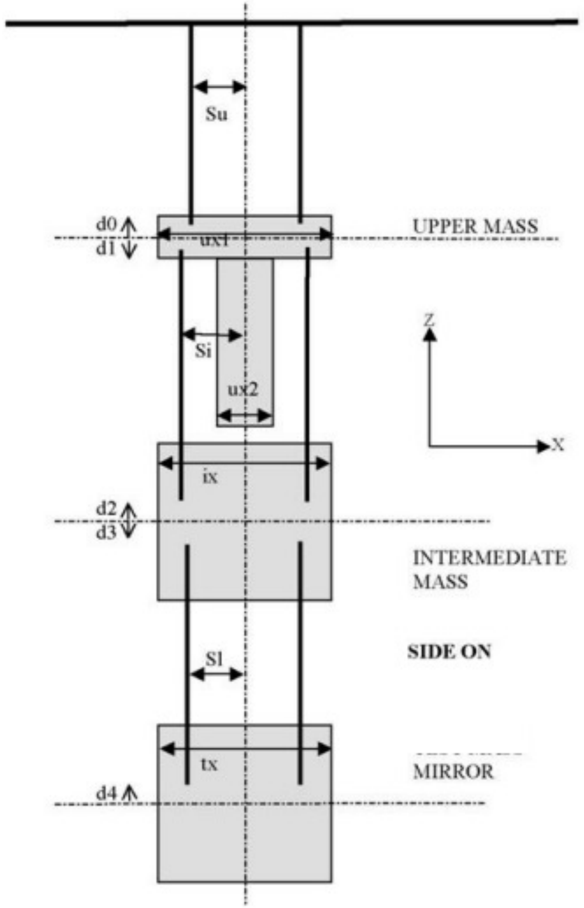
- Triple (HAM Large Triple Suspension: HLTS)

✓ No reaction chain



0.65 m





Optics

➢Overview

Core optics

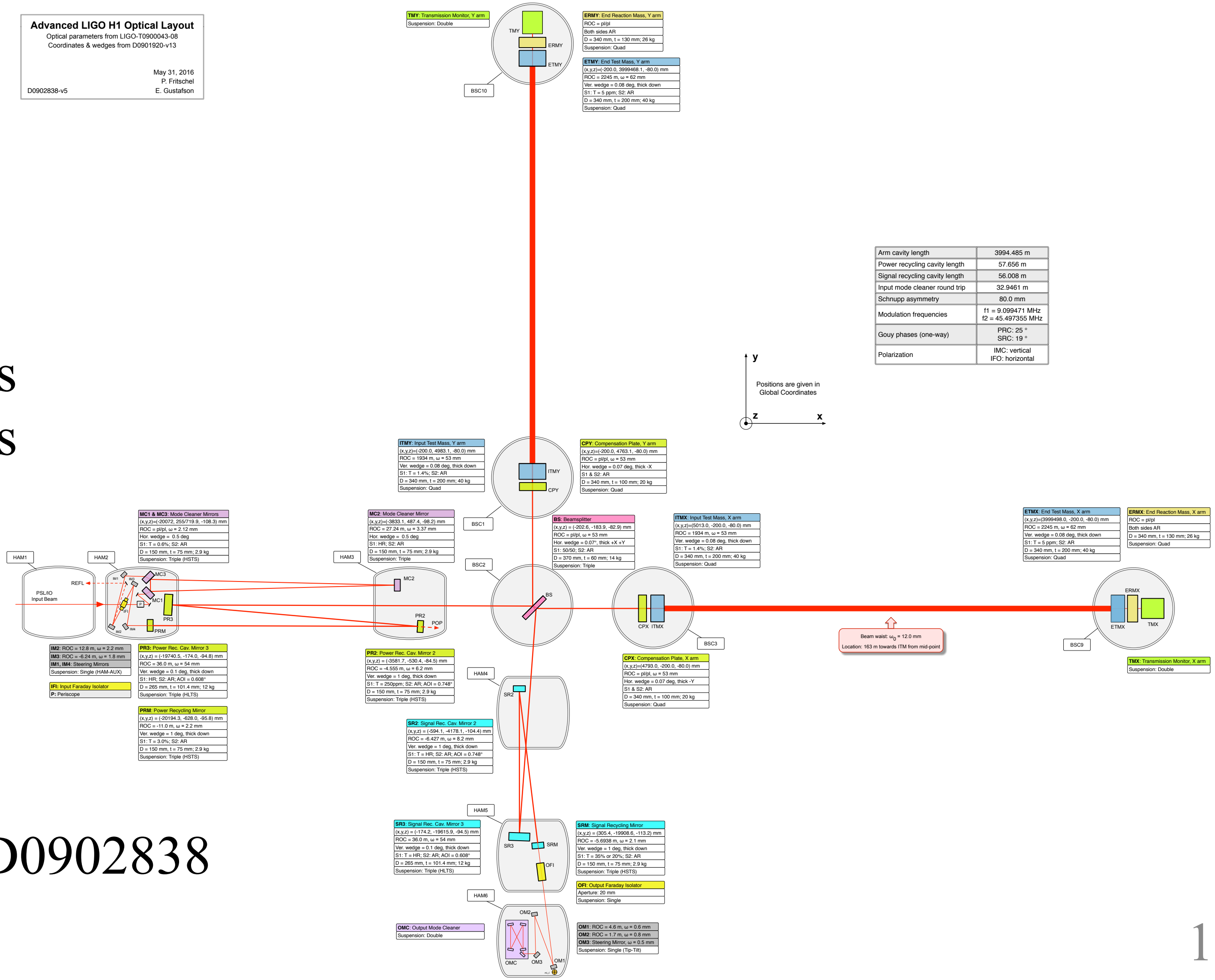
✓ Test mass

✓ Beam splitter

✓ Signal recycling mirrors

✓ Power recycling mirrors

✓ MCs

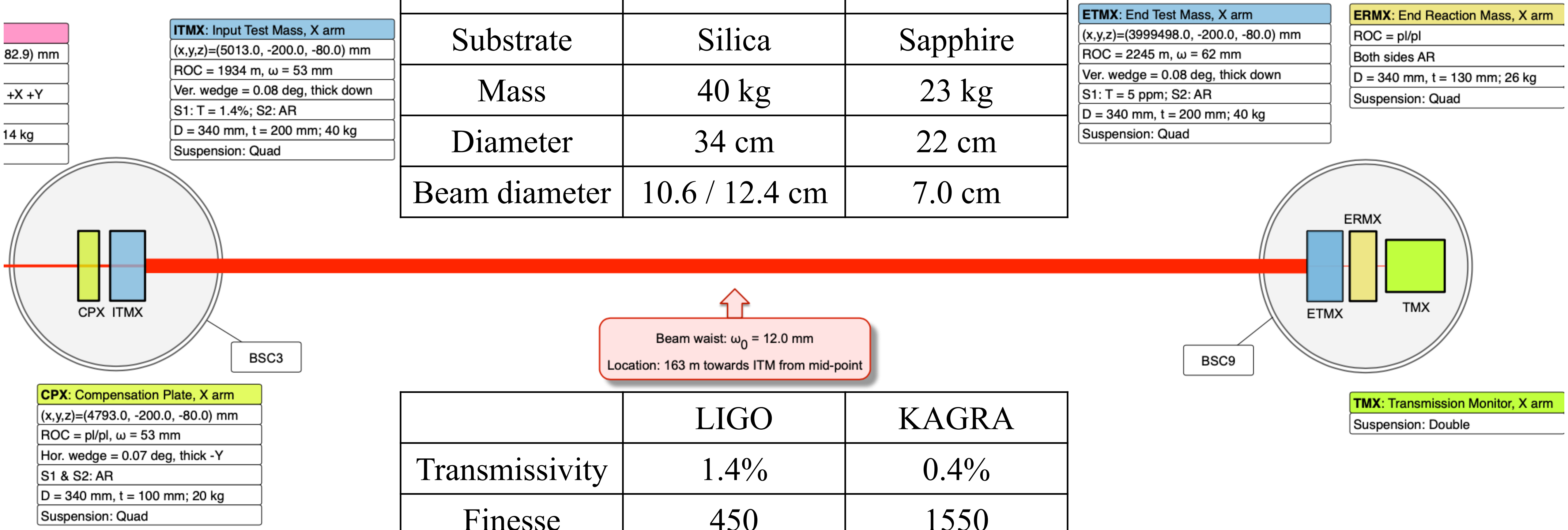


LIGO DCC, D0902838

Optics

➢ Test mass

	LIGO	KAGRA
Substrate	Silica	Sapphire
Mass	40 kg	23 kg
Diameter	34 cm	22 cm
Beam diameter	10.6 / 12.4 cm	7.0 cm



	LIGO	KAGRA
Transmissivity	1.4%	0.4%
Finesse	450	1550
Arm gain	290	1000

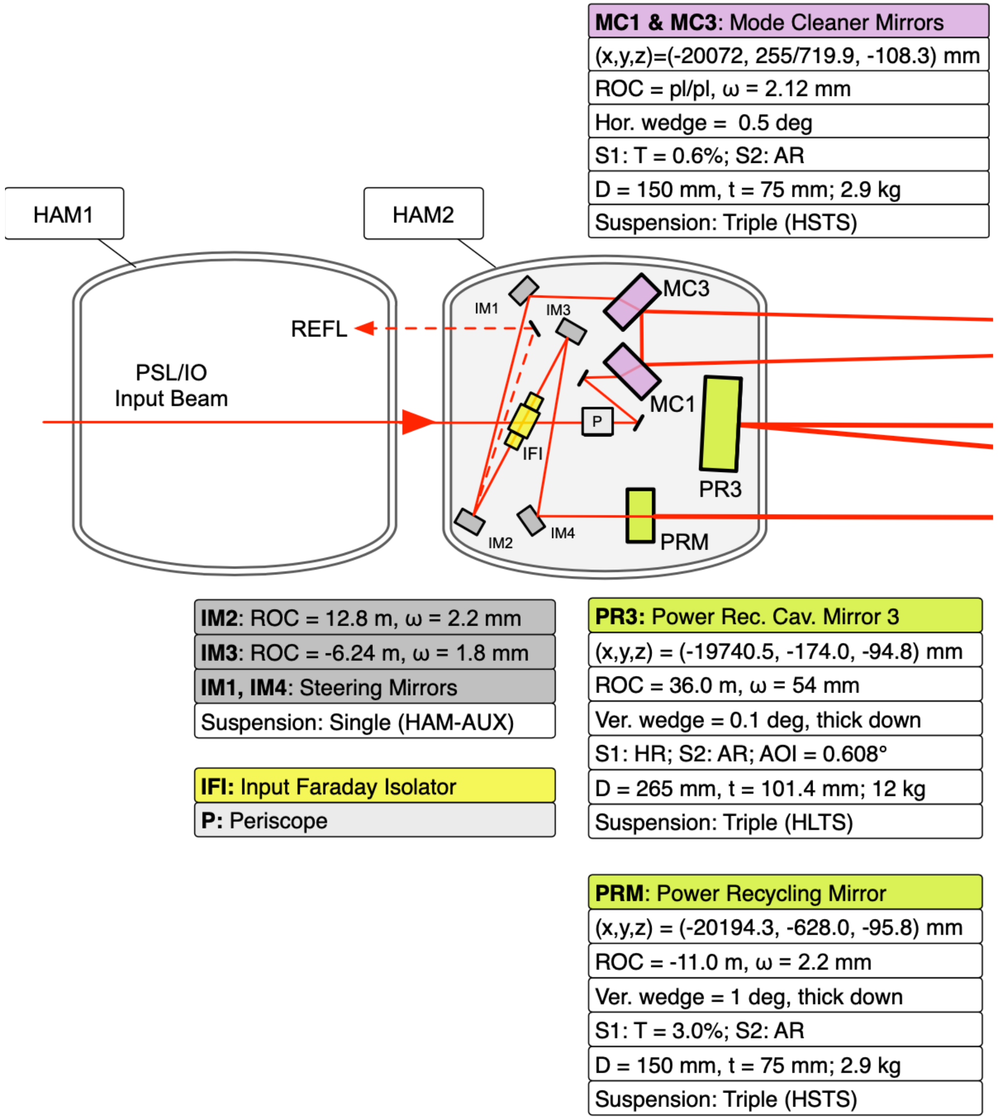
Optics

➢PRG and power

	LIGO	KAGRA
PRM trans.	3.0%	10%
PRG	45	10
Arm loss (design)	100 ppm	
Arm loss (design)	80 ppm	

✓ Total gain (P_{arm}/P_{in}) is roughly equal to the inverse of the arm round trip loss

	LIGO	KAGRA
Input power	60 W / 125 W	1.3 W / 68 W
Arm power	300 kW / 750 kW	10 kW / 340 kW



Noise

- Thermal noise comparison in displacement [m/√Hz]
  - ✓ Suspension thermal noise

$$x_{susp} \propto \sqrt{\frac{T}{mQ_{susp}}}$$

  - ✓ Coating thermal noise

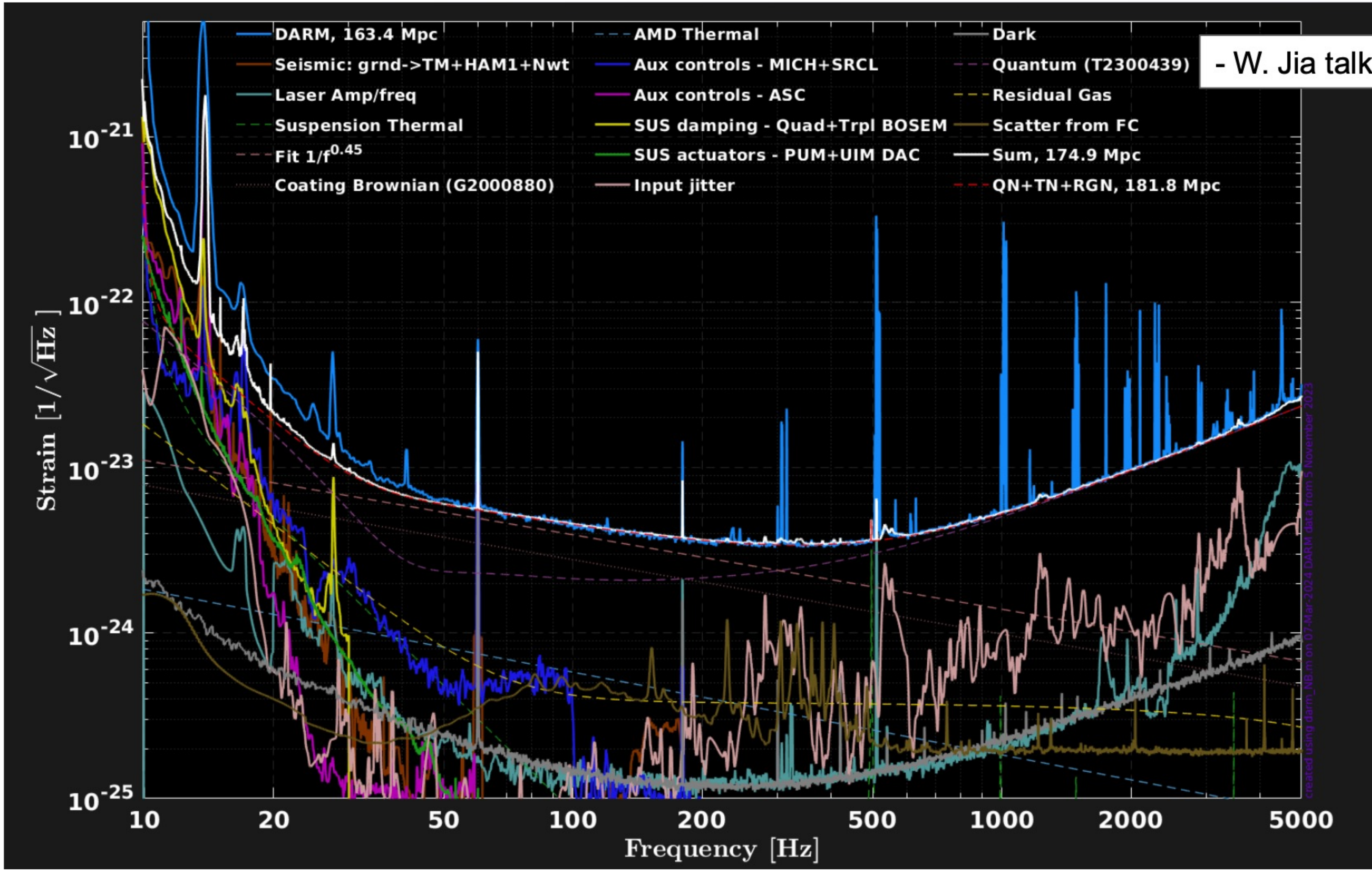
$$x_{coa} \propto \sqrt{\frac{T}{w^2 Q_{coa}}}$$

	LIGO	KAGRA
Temperature	300 K	20 K
Mass	40 kg	23 kg
Beam diameter	10.6 / 12.4 cm	7.0 cm
Q_{susp}	10^9	10^7
Q_{coa}	10^4	10^4

- ✓ Temperature: KAGRA's adv.
- ✓ Q_{susp}: LIGO's adv. (Thin wire)

Noise

- ✓ Livingston noise budget
- ✓ Surprising remarks:
  1. The shot noise ~ half of the coating thermal noise at 40 Hz
  2. Fundamental noises ~ 10 times larger than technical noises at 100 Hz
- ✓ Coating thermal noise is larger than expected



- W. Jia talk

G2400537

Noise

- ✓ KAGRA noise budget
- ✓ Dominant noise sources:

1. Suspension control noises
2. Acoustic noise
3. Shot noise
4. Frequency noise

Summary

- ➢Comparison of KAGRA and LIGO
  - Basics
  - Suspension
  - Optics and interferometric parameters
  - Noise

- ➢GW detectors are interesting! Please get familiar with detectors and chat with me!