The 3rd Korea-Japan Workshop on KAGRA
December 21 – 22, 2012
Sogang University, Seoul, KOREA

# Overview on Current Status of KAGRA

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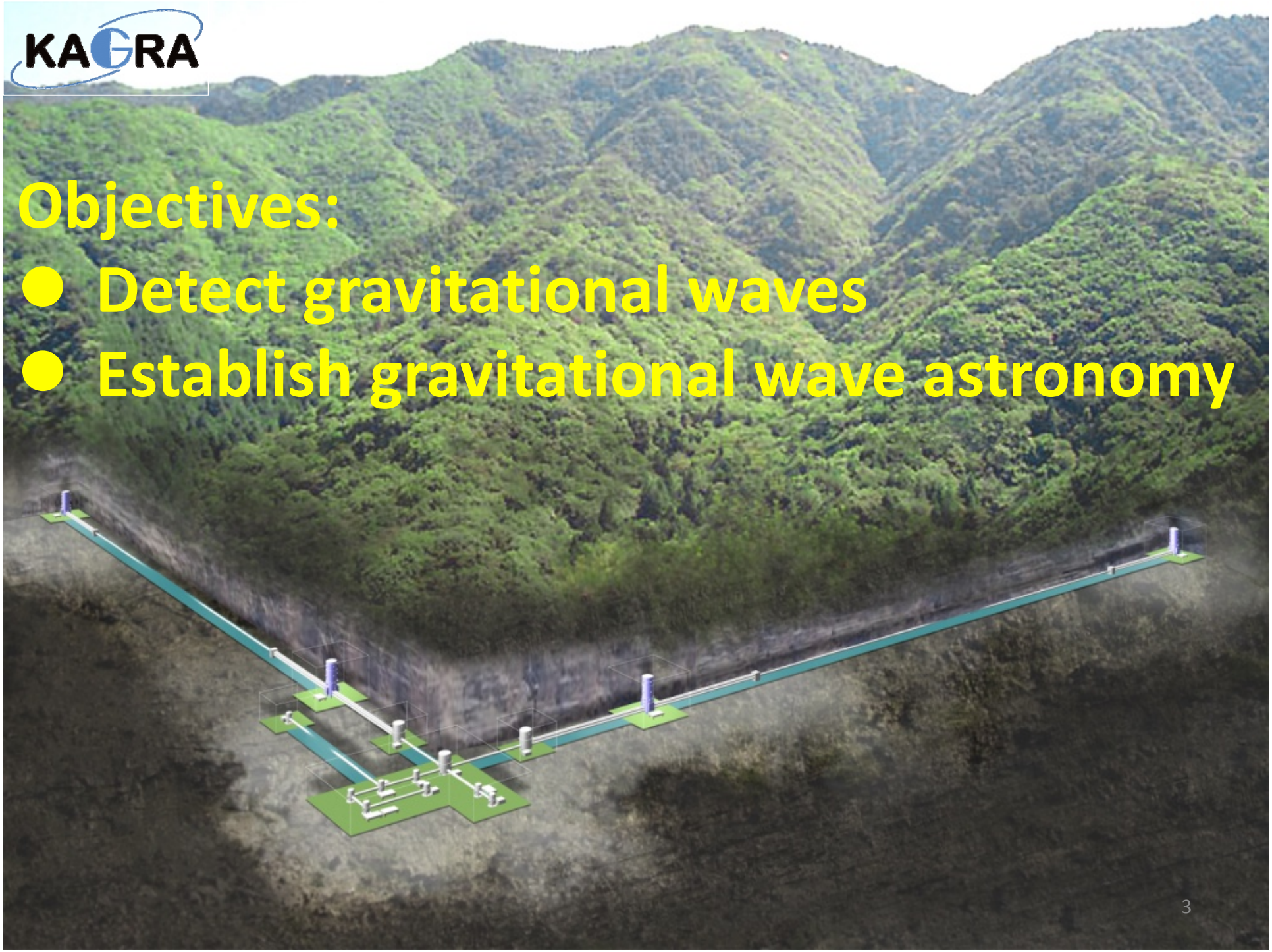
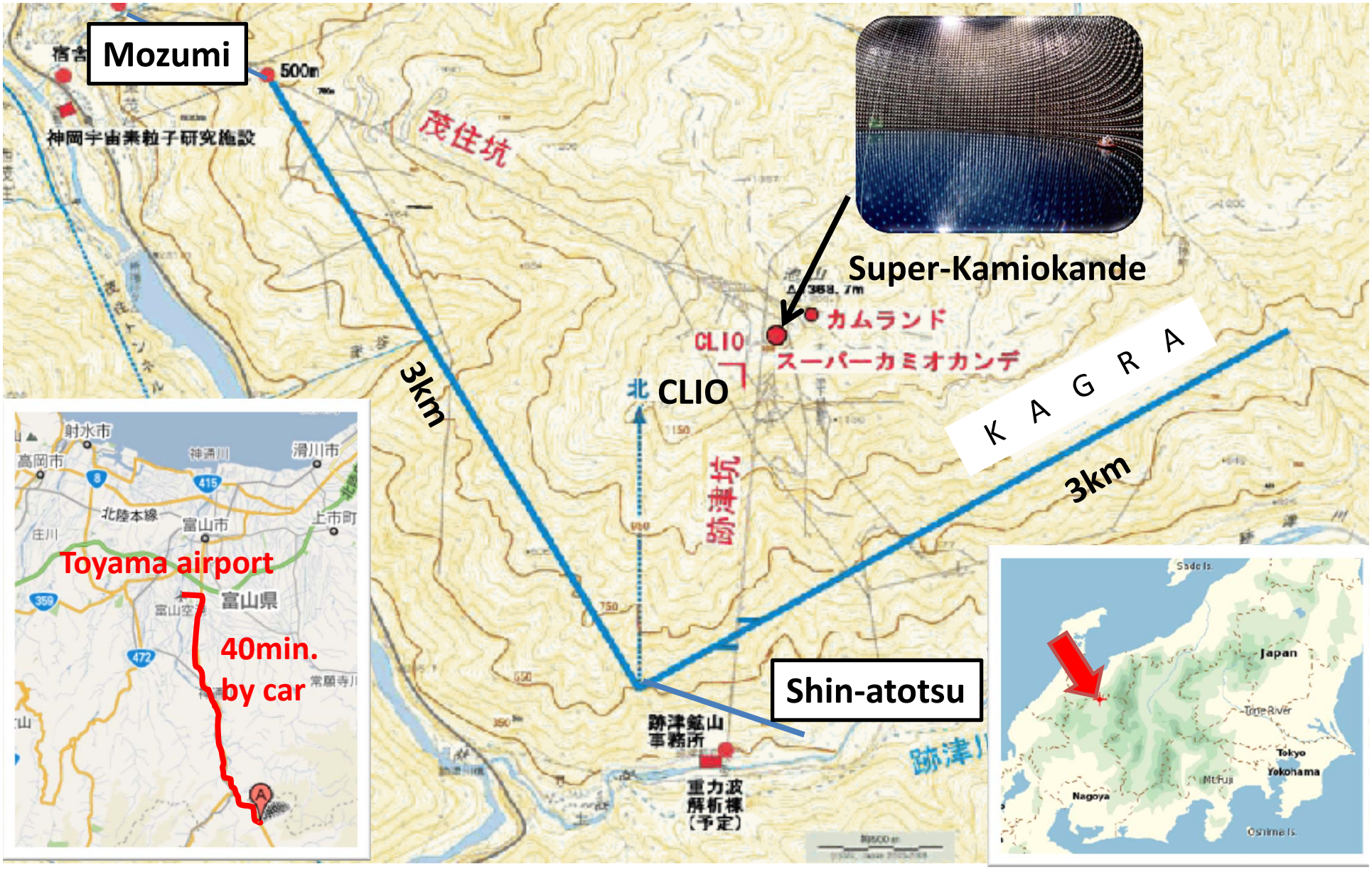
JGW-G1201462-v1


KAGRA
Outline:
Brief review of KAGRA
Current status of KAGRA


KAGRA
Objectives:
Detect gravitational waves
Establish gravitational wave astronomy

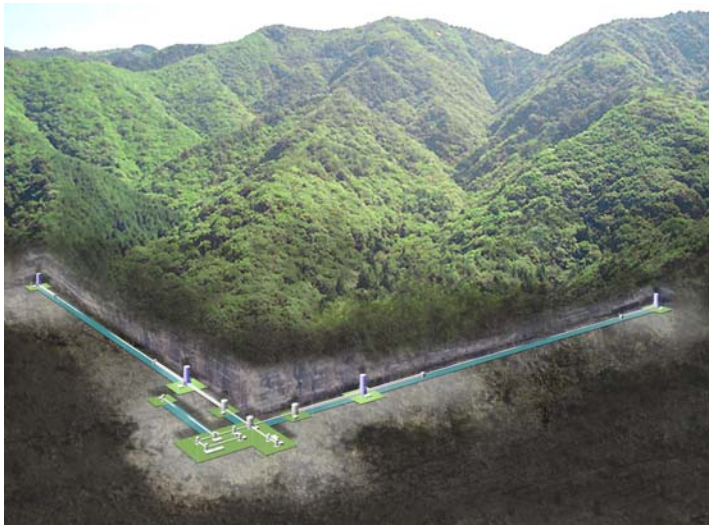
# Location (Kamioka)



# Key features of KAGRA

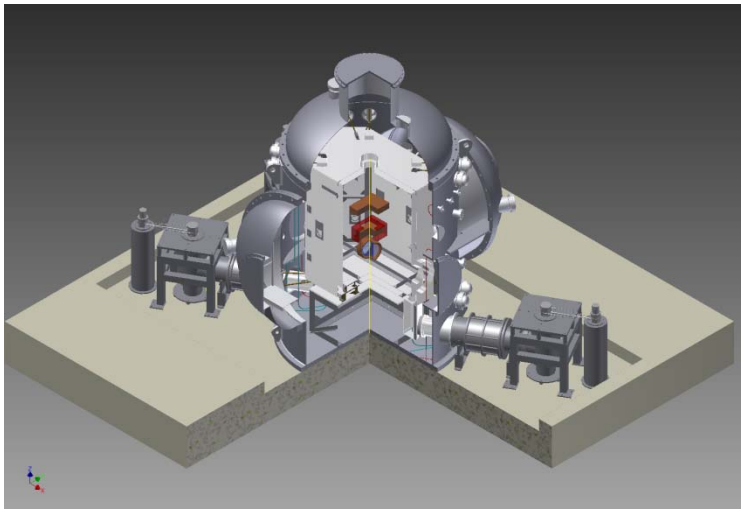
## Underground

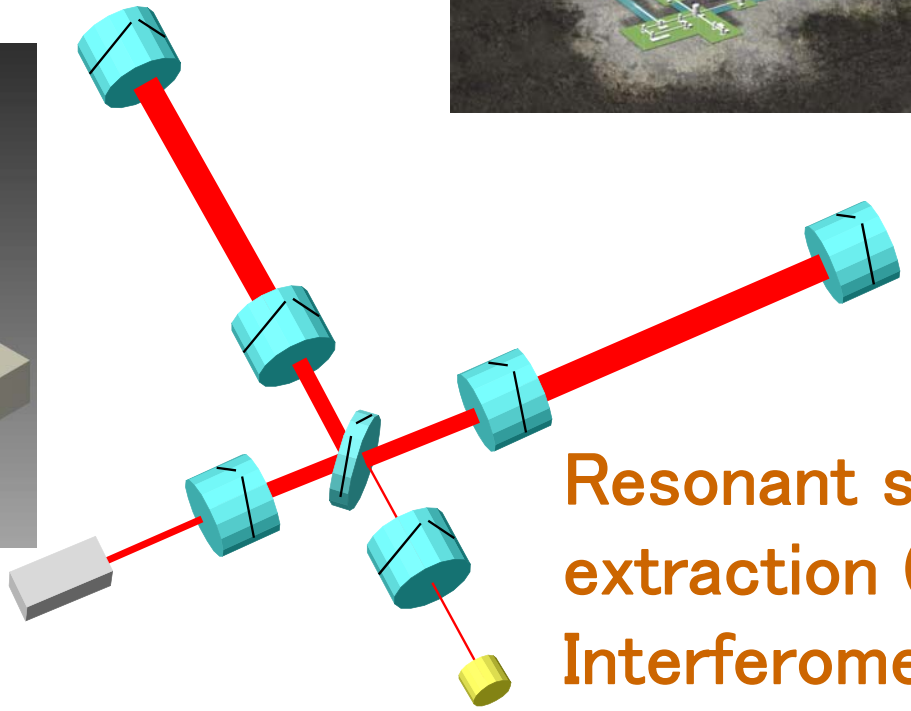
Reduce seismic noise



## Cryogenic Mirror

Reduce thermal noise

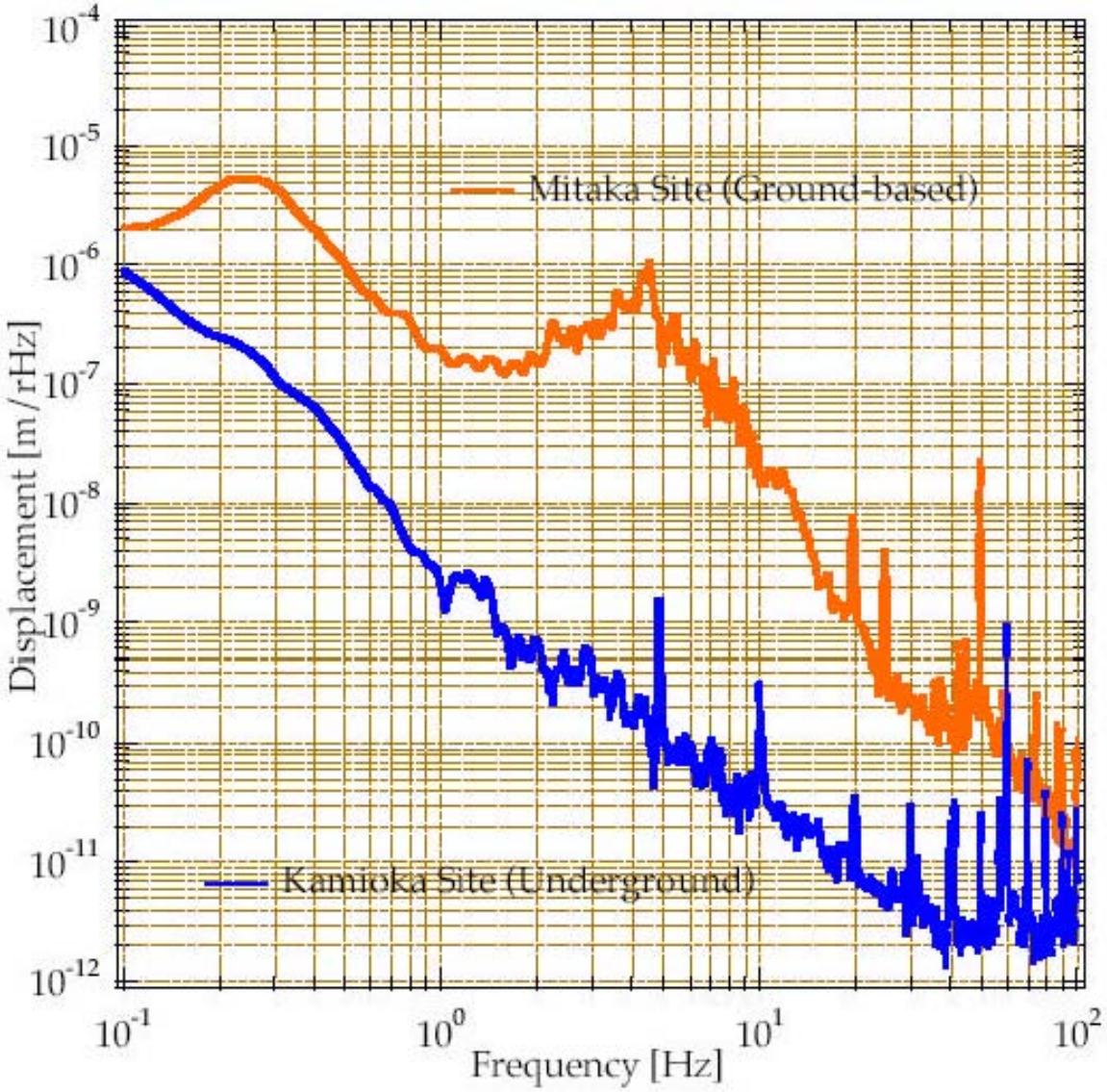




## Resonant sideband extraction (RSE) Interferometer

Optimize quantum noise

# Ground motion in Kamioka mine



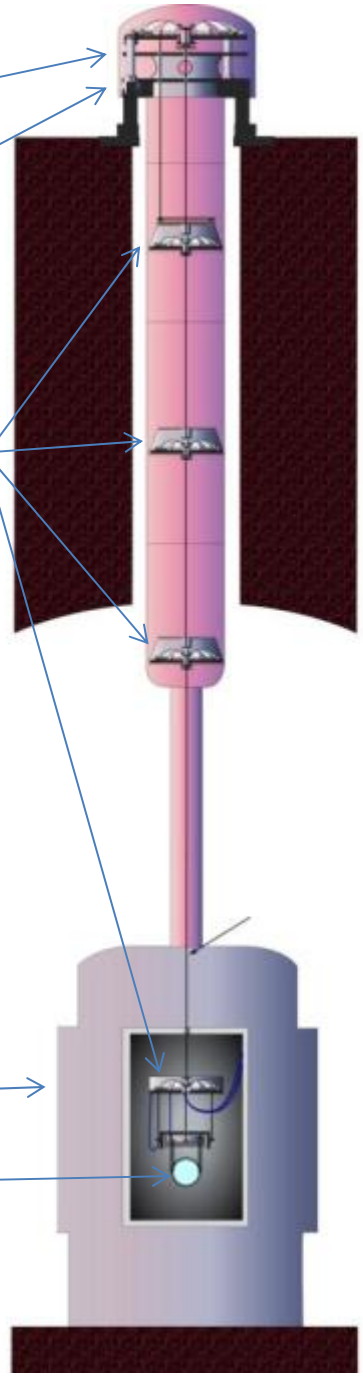
2nd floor

Chamber

Inverted pendulum

Geometrical antispring filter

# Vibration isolation system

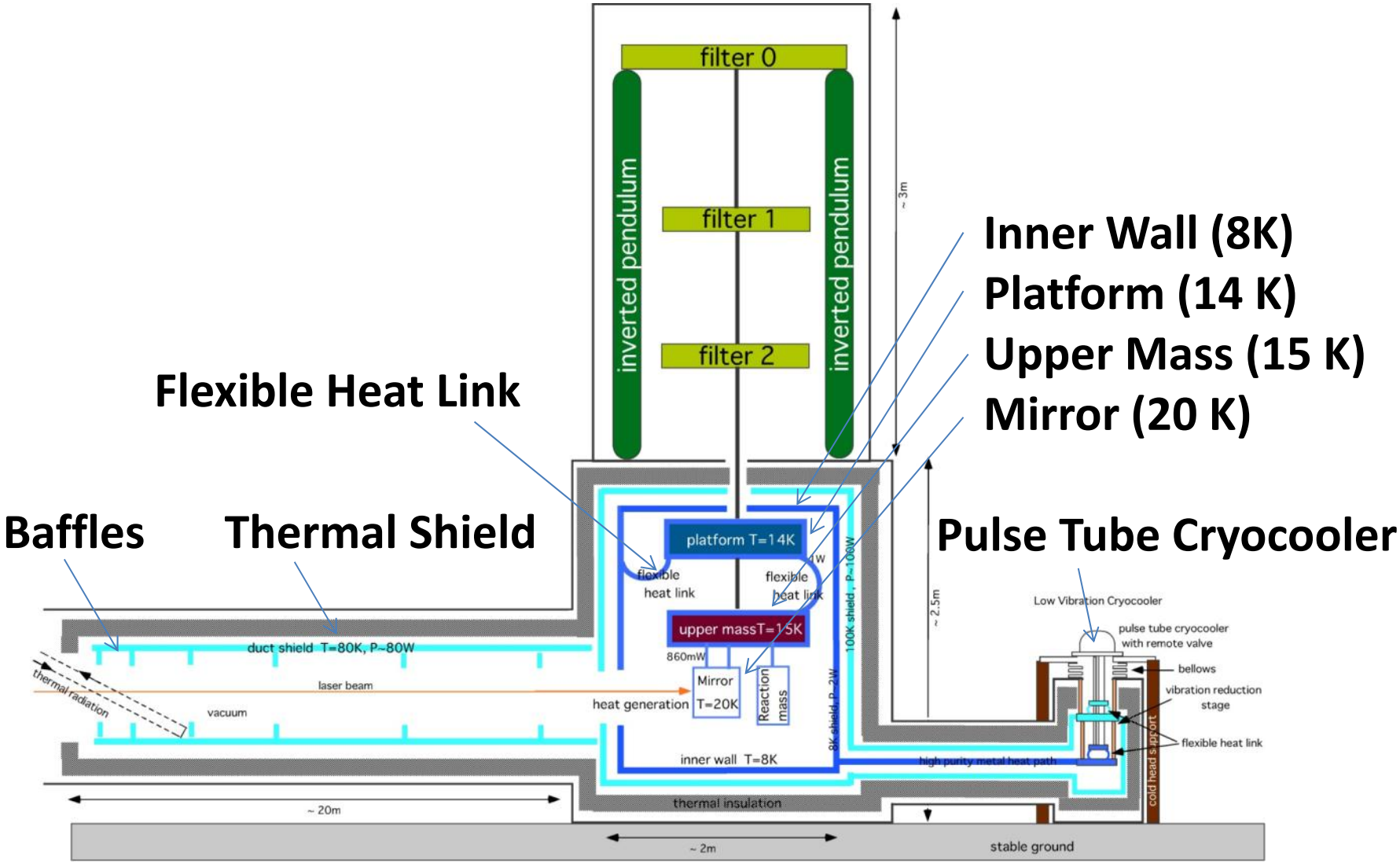


Chamber

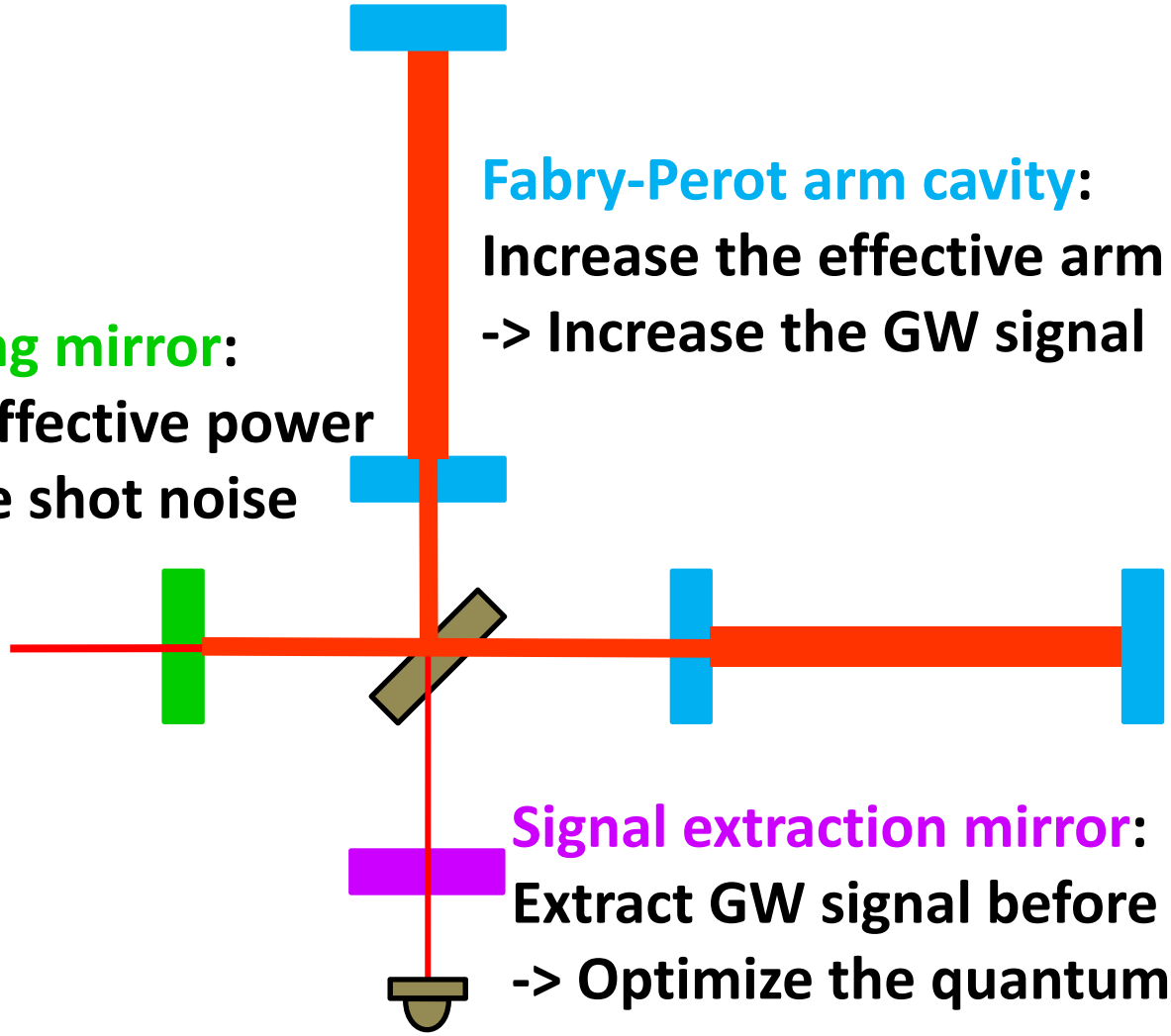
Mirror

1st floor

# Cryogenics System



# RSE interferometer

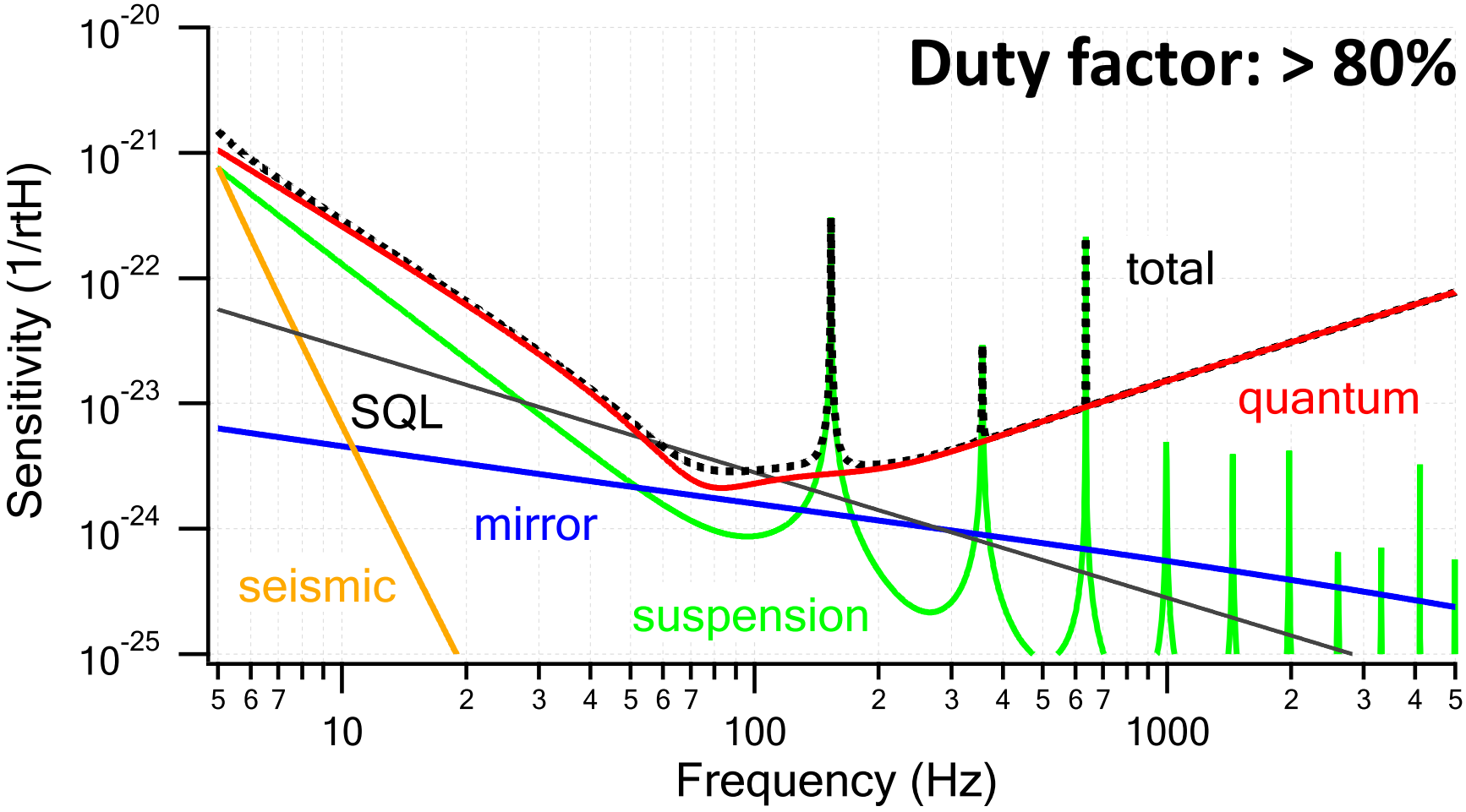


**Fabry-Perot arm cavity:**
**Increase the effective arm length**
**-> Increase the GW signal**

**Power recycling mirror:**
**Increase the effective power**
**-> Improve the shot noise**

**Signal extraction mirror:**
**Extract GW signal before cancellation**
**-> Optimize the quantum noise**

# Target sensitivity of KAGRA



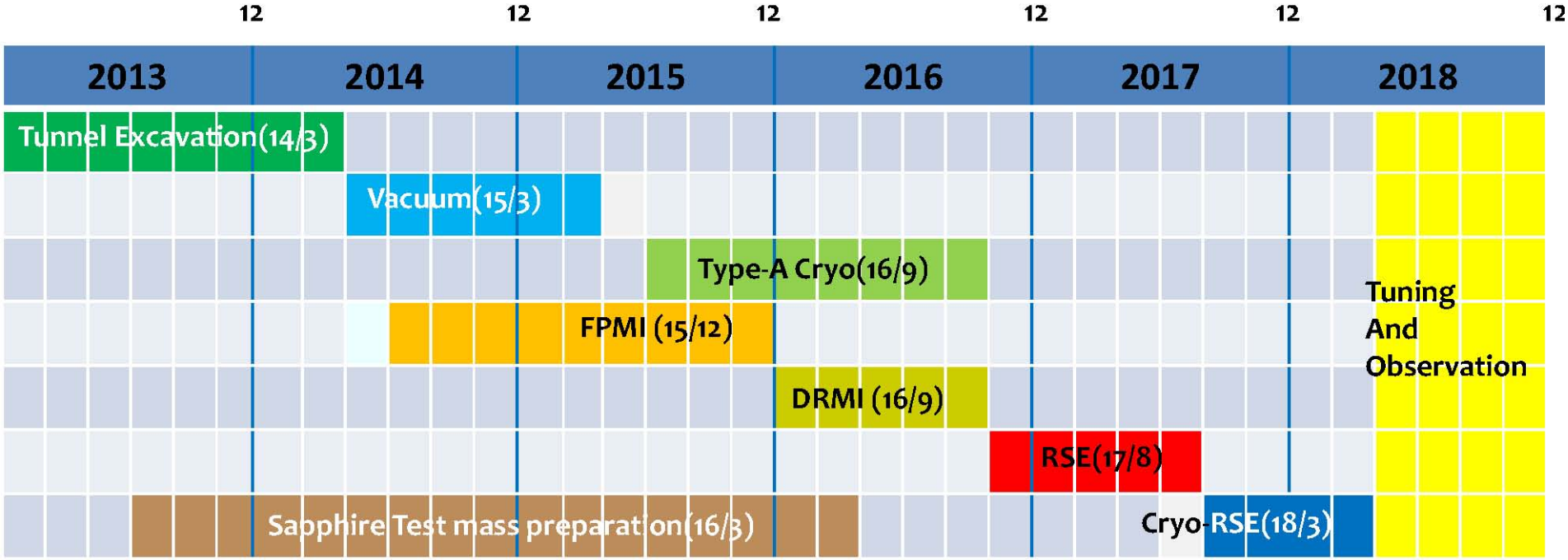
# Expected event rate for NS-NS coalescence

**Inspiral range: 167 Mpc**
**(the same definition as LIGO/Virgo)**

**Inspiral rate per galaxy** $118^{+174}_{-79}\,\mathrm{Myr}^{-1}$

**Expected event rate** $9.8^{+14}_{-6.6}\,\mathrm{yr}^{-1}$

# Schedule of KAGRA

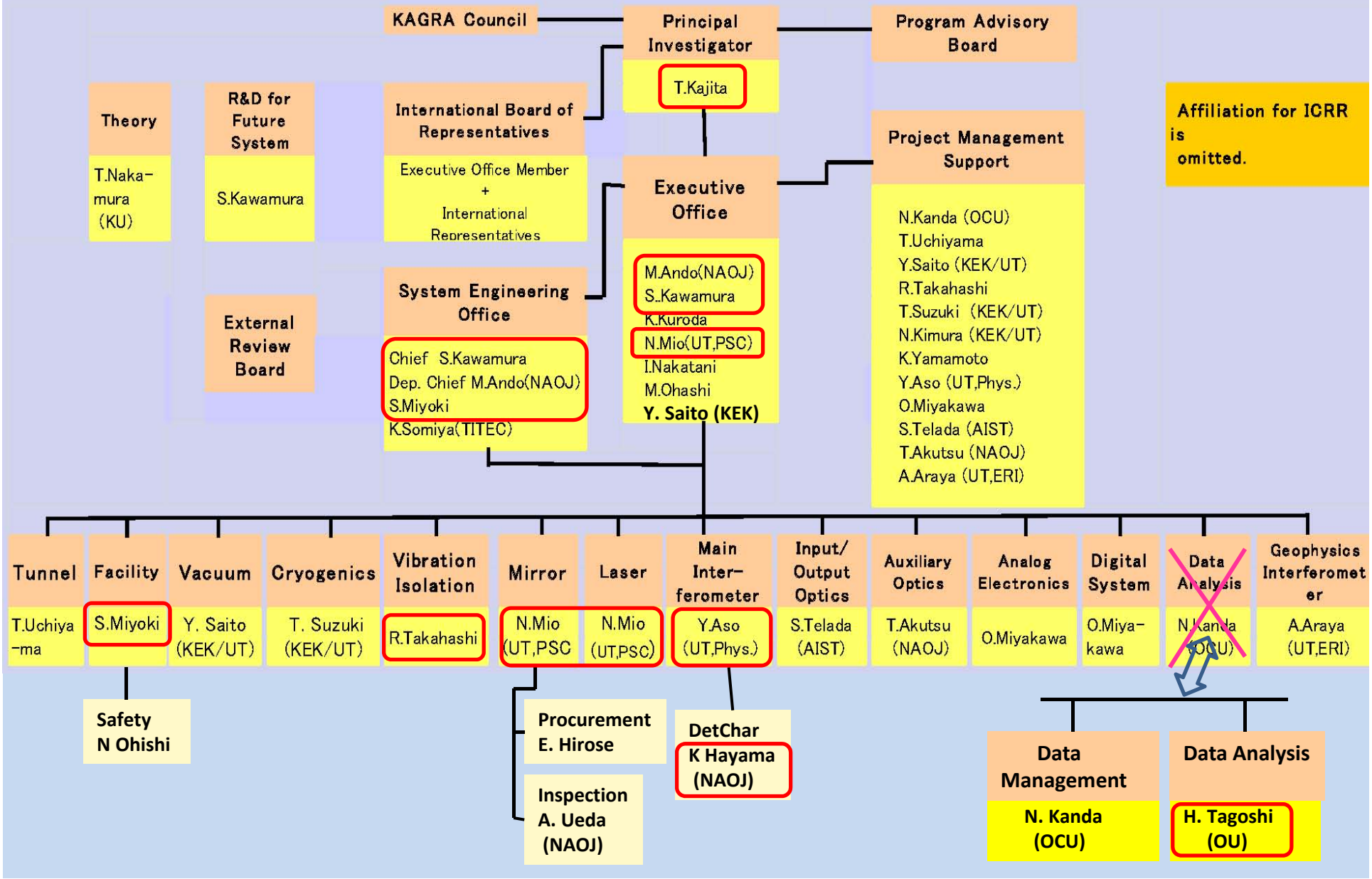



**i-KAGRA** → **b-KAGRA**

- Training for km-scale IFO.
- Sorting out the problems involved in KAGRA
- Short observation will be done

- Introduce Full Type-A SAS, Cryogenic and RSE Technique.
- Realize the targeted sensitivity and observation.

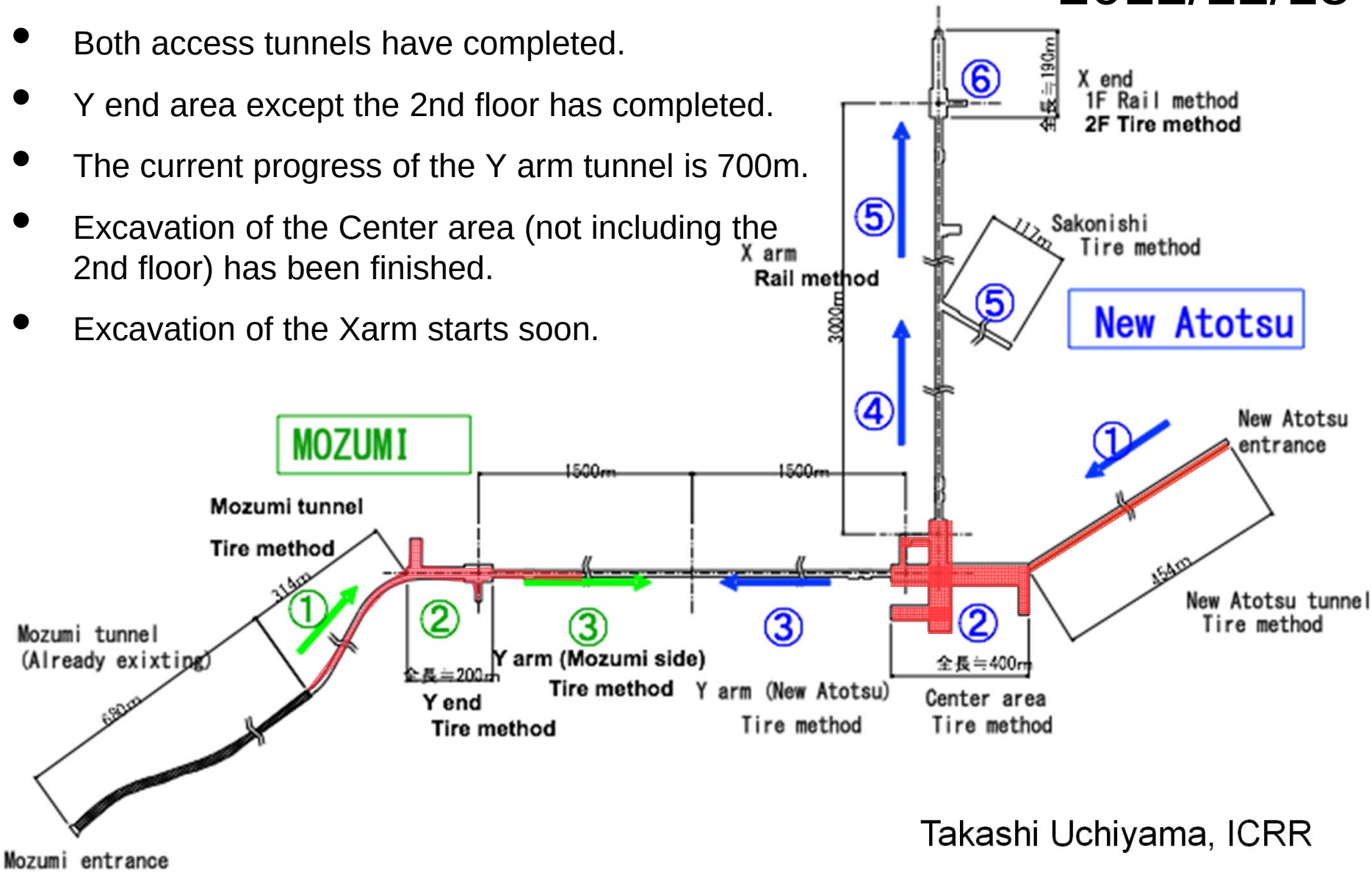
# Organization



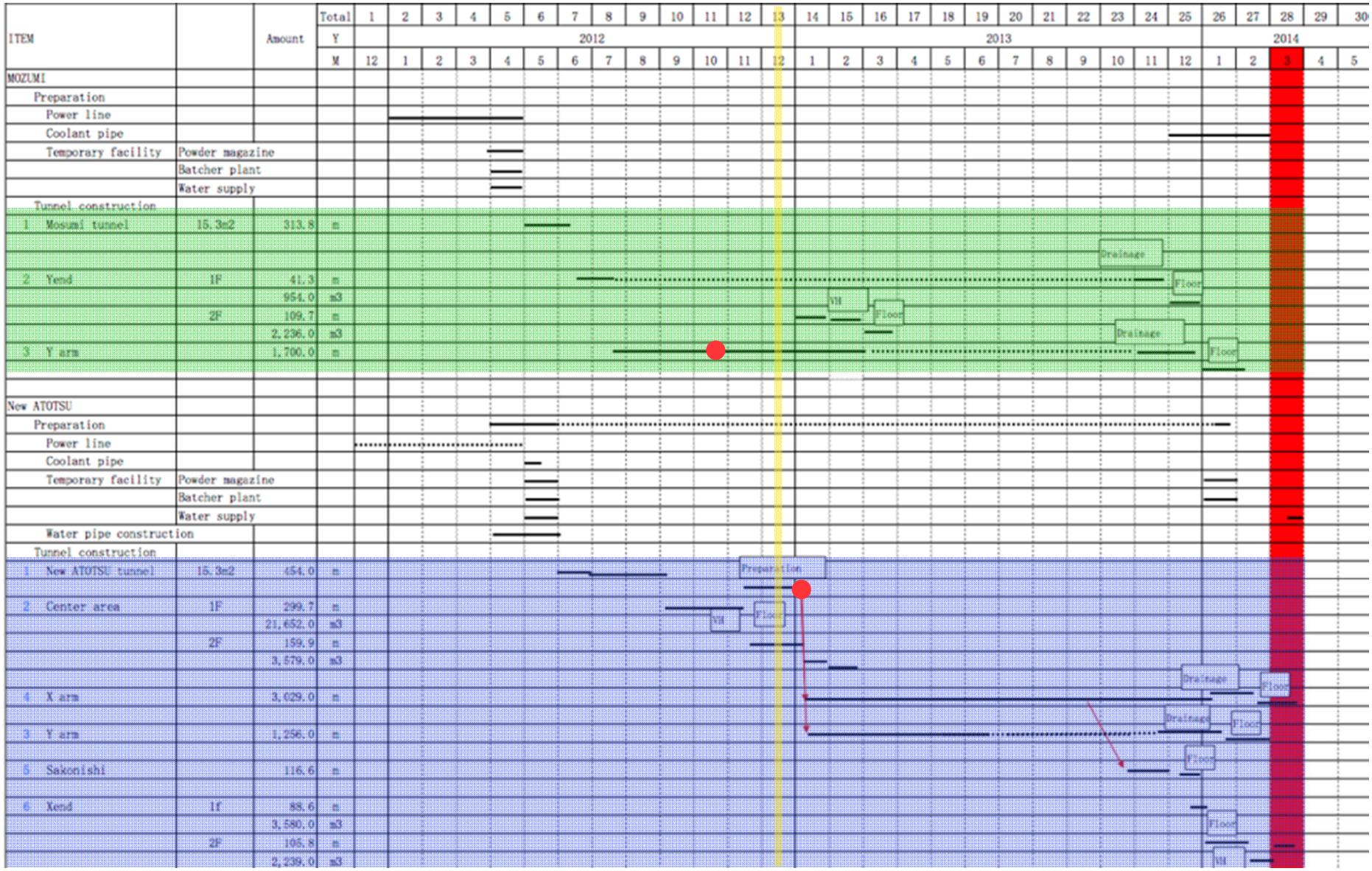
# Current status of the tunnel excavation.

2012/12/15

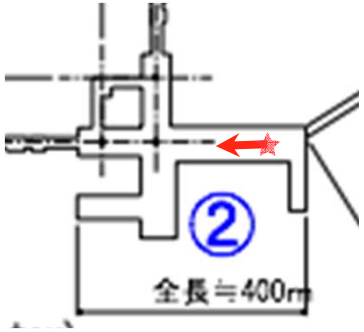
- Both access tunnels have completed.
- Y end area except the 2nd floor has completed.
- The current progress of the Y arm tunnel is 700m.
- Excavation of the Center area (not including the 2nd floor) has been finished.
- Excavation of the Xarm starts soon.




Takashi Uchiyama, ICRR


ITEM
Amount
Total
Y
M
2012
2013
2014
MOZUMI
Preparation
Power line
Coolant pipe
Temporary facility
Powder magazine
Batcher plant
Water supply
Tunnel construction
1 Mozumi tunnel
15.3m2
313.8
m
Drainage
Floor
2 Yend
1F
41.3
954.0
m3
2F
109.7
2,236.0
3 Y arm
1,700.0
New ATOTSU
Water pipe construction
1 New ATOTSU tunnel
454.0
Preparation
2 Center area
299.7
21,652.0
159.9
3,579.0
4 X arm
3,029.0
1,256.0
5 Sakonishi
116.6
6 Xend
88.6
3,580.0
105.8
2,239.0
Now here

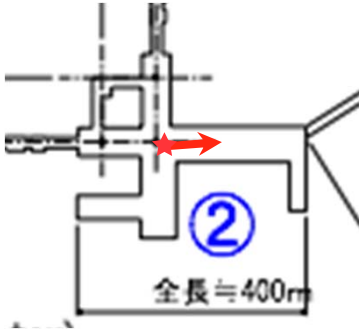

Center experiment room A




2012/12/02

Center experiment room A
(Reverse angle photo)

2012/12/13

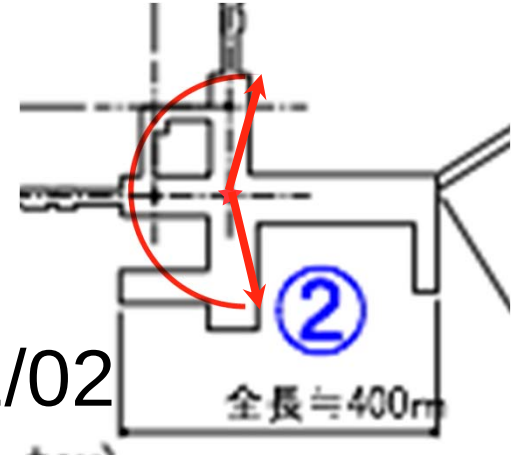


# Panorama photo from BS position.

Direction of Yarm

Direction of Xarm

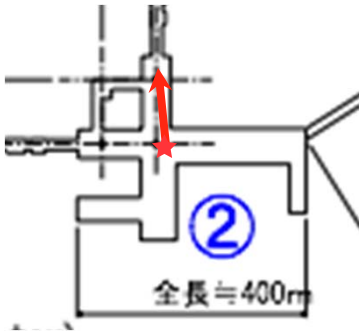
Direction of Laser booth
&
Mode Cleaner




2012/12/02

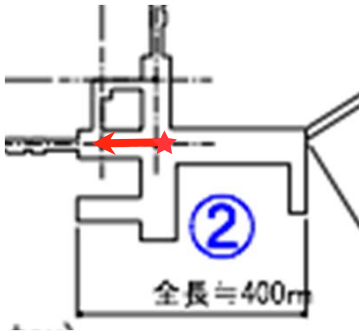
X-front cryostat room

2012/12/13

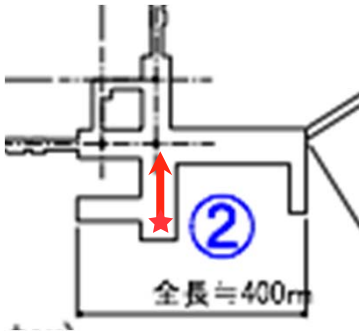



Y-front cryostat room

2012/12/13

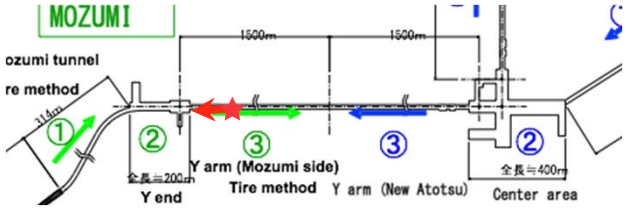


From Laser booth to BS




2012/12/13

Yarm tunnel
400m from Yend




2012/10/26

# KAGRA Vacuum System



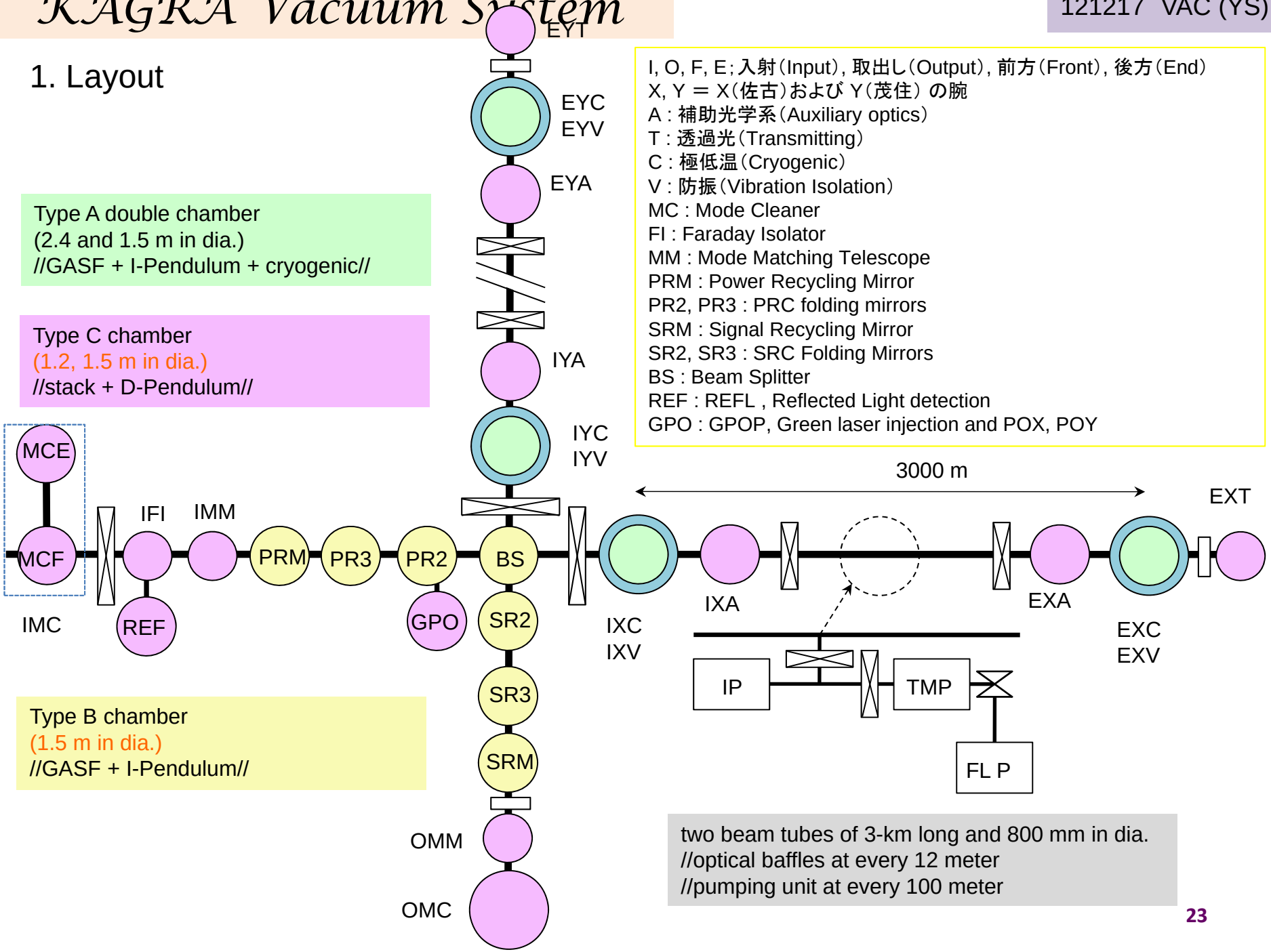
## 1. Layout

Type A double chamber
(2.4 and 1.5 m in dia.)
//GASF + I-Pendulum + cryogenic//

Type C chamber
(1.2, 1.5 m in dia.)
//stack + D-Pendulum//

Type B chamber
(1.5 m in dia.)
//GASF + I-Pendulum//

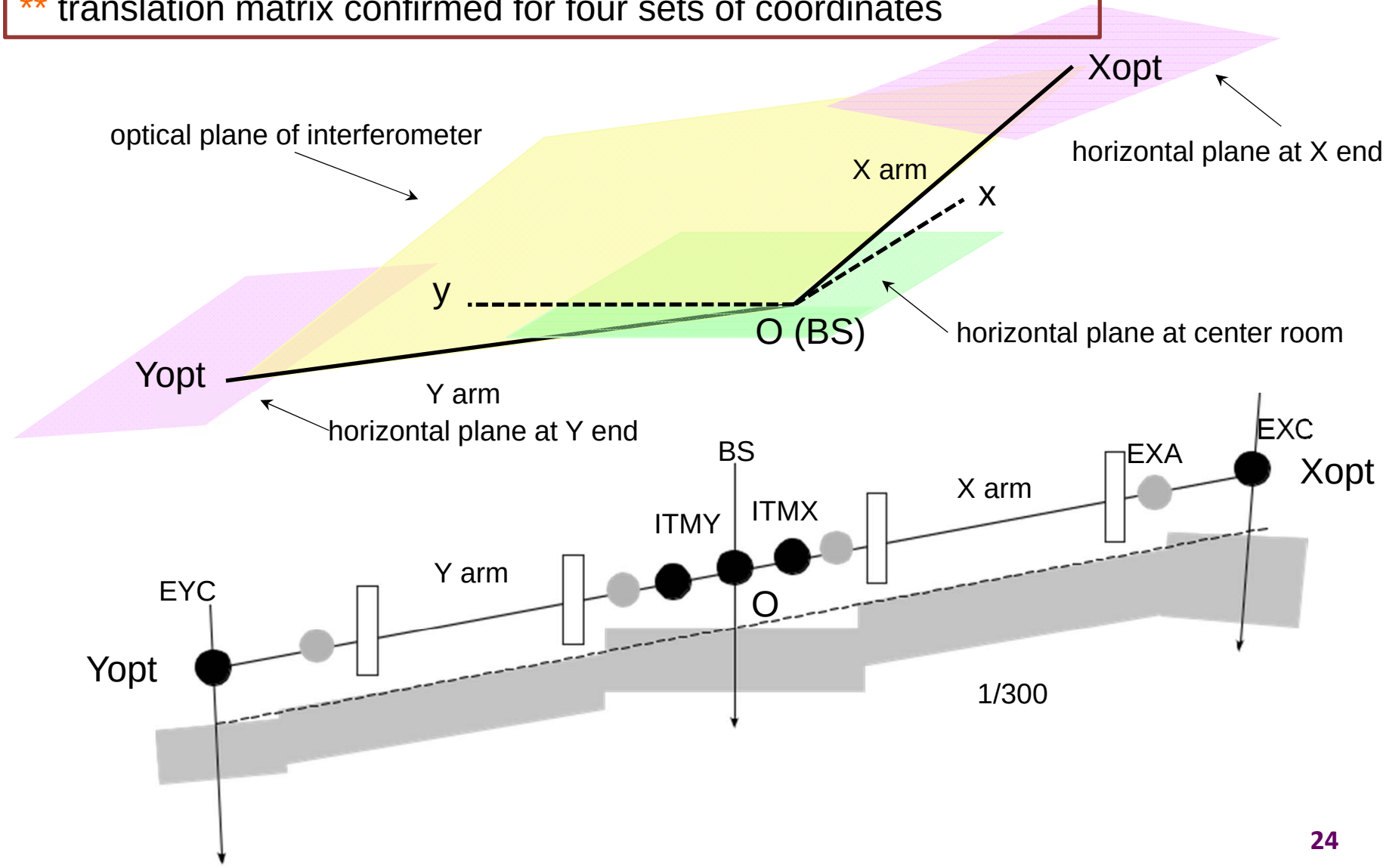
I, O, F, E; 入射(Input), 取出し(Output), 前方(Front), 後方(End)
X, Y = X(佐古)および Y(茂住) の腕
A : 補助光学系(Auxiliary optics)
T : 透過光(Transmitting)
C : 極低温(Cryogenic)
V : 防振(Vibration Isolation)
MC : Mode Cleaner
FI : Faraday Isolator
MM : Mode Matching Telescope
PRM : Power Recycling Mirror
PR2, PR3 : PRC folding mirrors
SRM : Signal Recycling Mirror
SR2, SR3 : SRC Folding Mirrors
BS : Beam Splitter
REF : REFL , Reflected Light detection
GPO : GPOP, Green laser injection and POX, POY




two beam tubes of 3-km long and 800 mm in dia.
//optical baffles at every 12 meter
//pumping unit at every 100 meter

## 1. Layout

** horizontal floors in each room prepared for installing chambers
** translation matrix confirmed for four sets of coordinates



## 2. Beam tube

*Beam tube (478 of 12-m long and 0.8 m in diameter)*; 426 tubes completed, so far.

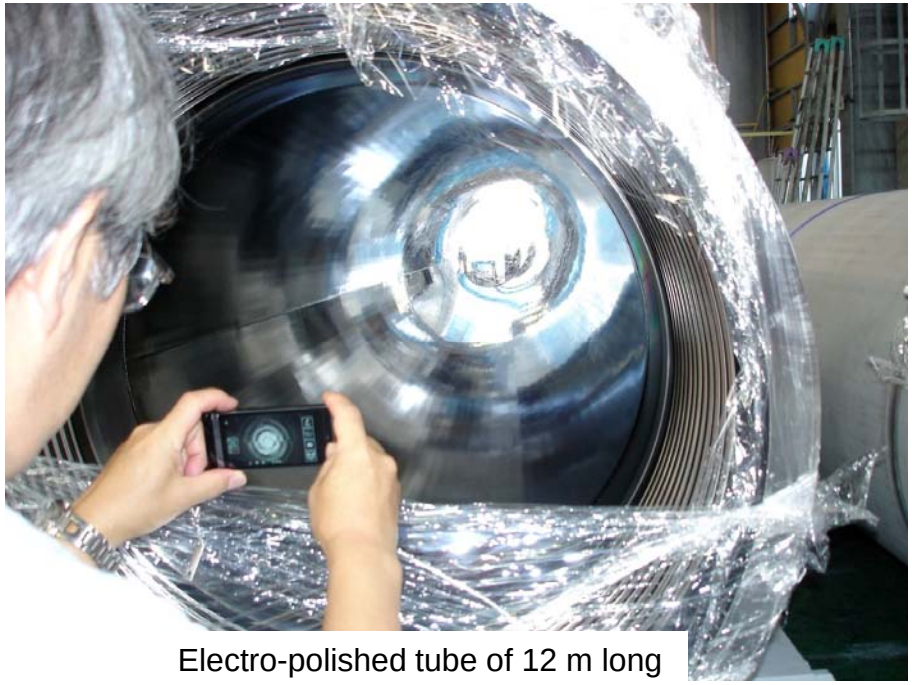
***"surface passivation by electro-polish followed by baking"***

outgassing rate; $10^{-8}$ Pa $m^3$ $m^{-2}$ $s^{-1}$, or lower
surface roughness; Rmax 3 μm, Ra 0.5 μm

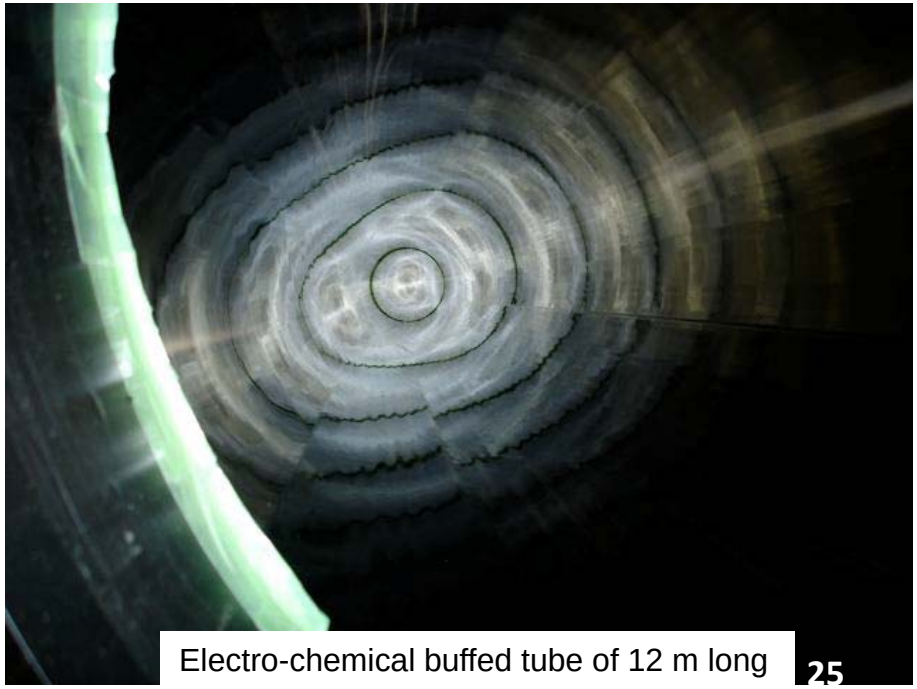
***"mirror finish by Electro-Chemical Buffing (tubes in the mid 800-m region)"***

surface roughness; Rmax 0.2 μm, Ra 0.03 μm

***"flange connection with metal O-ring (silver plated)"***; erosion proof by humidity test



Electro-polished tube of 12 m long



Electro-chemical buffed tube of 12 m long

## 3. Optical baffles in beam tubes

*Every 12-m, or longer, along the arm, 40-mm in height, 50-degree tilted*

** laser machining is tested for making serration edges

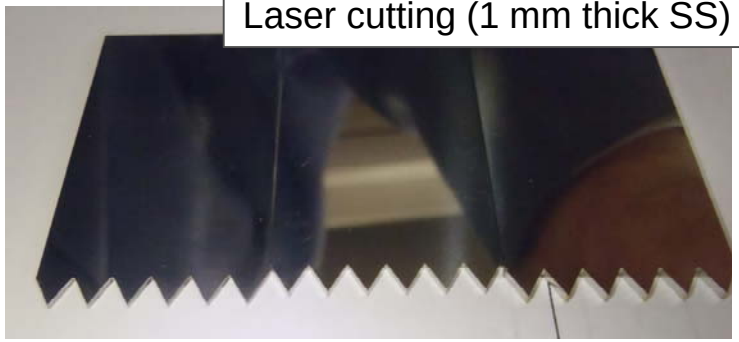
** "***DLC coating***" and "***NiP plating***" are examined to be chosen.

"***optical absorption coefficient***"

"***angular distribution of reflectivity***"

"***outgassing rate***"

Laser cutting (1 mm thick SS)



# KAGRA Vacuum System

## 4. Schedule for installing

*Finish X-arm at the end of 2014*

1) manufacturing 478 of tubes;
from Apr 2011 to Mar 2013

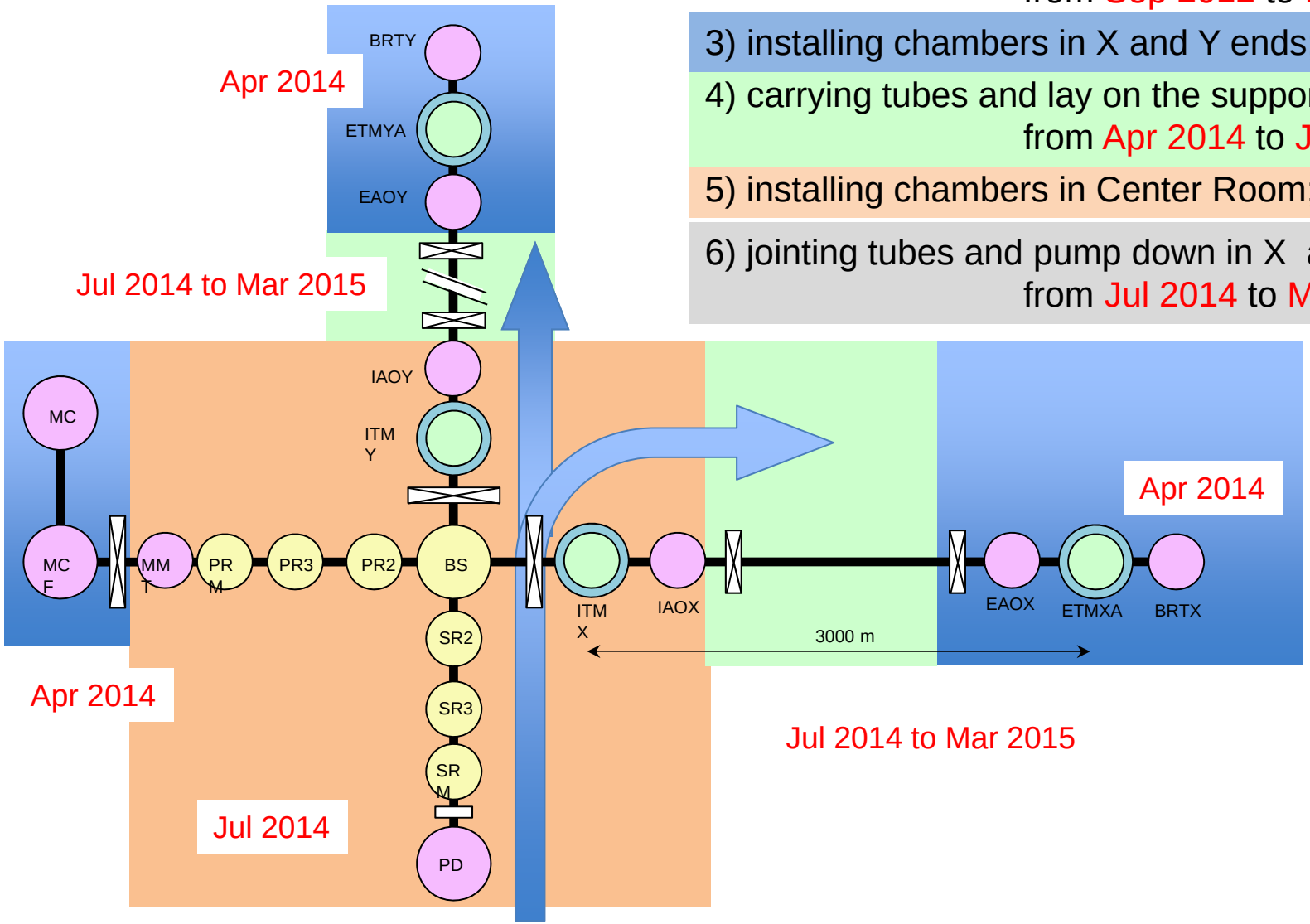
2) manufacturing chambers;
from Sep 2012 to Mar 2014

3) installing chambers in X and Y ends; Apr 2014

4) carrying tubes and lay on the supports;
from Apr 2014 to Jun 2014

5) installing chambers in Center Room; Jul 2014

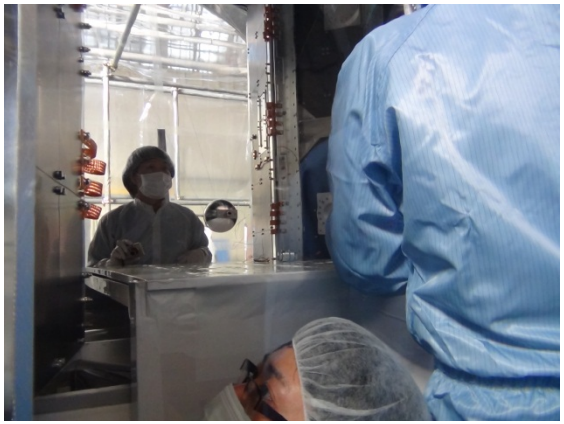
6) jointing tubes and pump down in X and Y arm
from Jul 2014 to Mar 2015



# Cryogenics : Cryostat assembling and performance test


Dressing partition of
No.1 Cryostat


Ceiling part of 8K shield

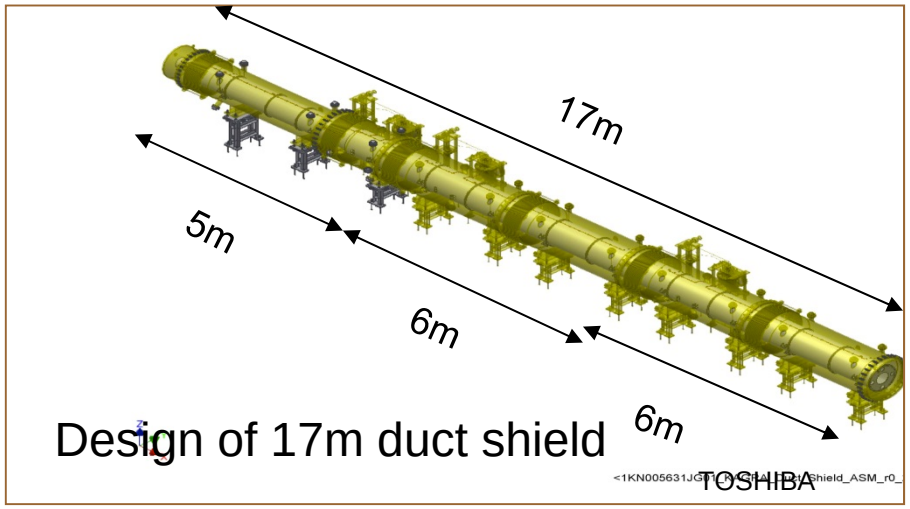


Al sphere for an initial cooling test of mirror suspension

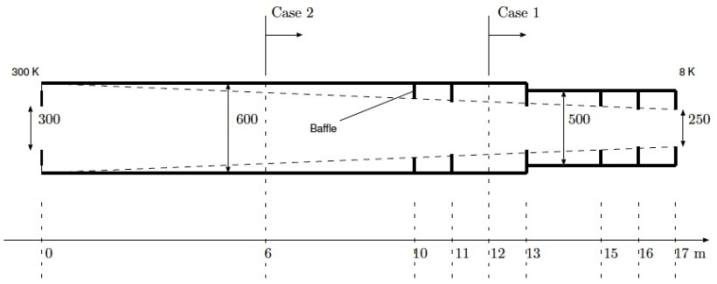
- Assembling of cryostats and preparation of performance tests are in progress in the TOSHIBA Keihin Factory.
- Basic test items
  - Cooling time, minimum attainable temperature under various heat loads.
- Specific test items
  - Cryostat No.1 : Cooling test of $\phi$105 Al sphere without DLC.
  - Cryostat No.2 : Cooling test of $\phi$105 Al sphere with DLC.
  - Cryostat No.3 : Vibration measurement of 8K shield using interferometer(ICRR) and accelerometer(Roma Univ.)
  - Cryostat No.4 : Cooling test of a scaled preliminary model of cryogenic payload.

# Cryogenics : Duct shield

# (17m vacuum duct + cryo-pipe)




Design of 17m duct shield




| Length [m] | P [W] | P/P$_0$ |
|---|---|---|
| 17 | 0.20 | $4.3 \times 10^{-3}$ |
| 11 | 0.32 | $6.8 \times 10^{-3}$ |
| 5.0 | 1.6 | $3.4 \times 10^{-2}$ |

Y.Sakakibara

- Duct shield has been designed with 17m vacuum duct and 17m cryo-pipe.
- One set of 17m duct shield is manufactured by TOSHIBA in 2012-2013.
- An investigation for shorter cryo-pipe is started by the requirement of cost reduction.

Investigation of shorter cryo-pipe

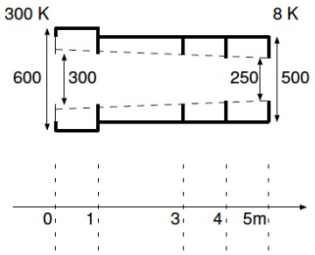



Figure 2: (A) ダクト長さ：5m、バッフル位置・枚数：元のデザインのまま

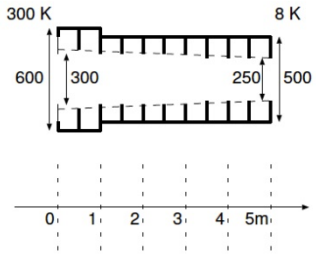


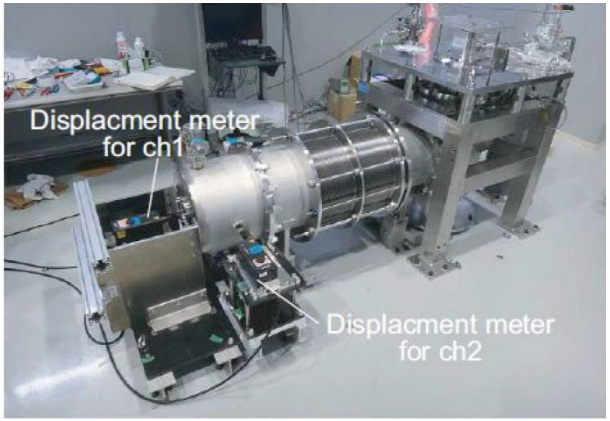

Figure 3: (B) ダクト長さ：5m、バッフル位置・枚数：0.5 m ごと

| | バッフル位置 [m] | $P/P_0$ | P[W] |
|---|---|---|---|
| (A) | 0,1,3,4,5 | 0.034 | 1.6 |
| (B) | 0,0.5,1,1.5,2,2.5,3,3.5,4,4.5,5 | 0.010 | 0.47 |

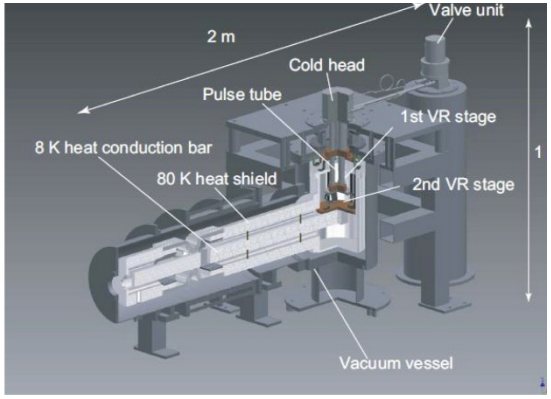
Table 1: ダクトシールド長さ 5 m の場合のバッフル位置と枚数

Y.Sakakibara

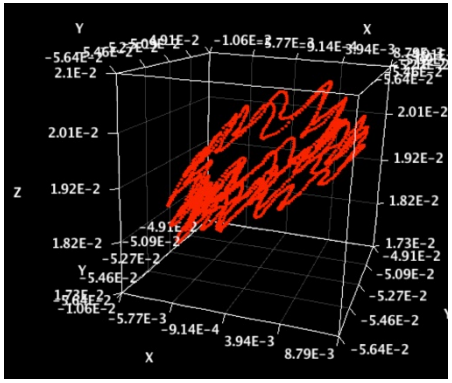
# Cryogenics: 4K cryocooler unit



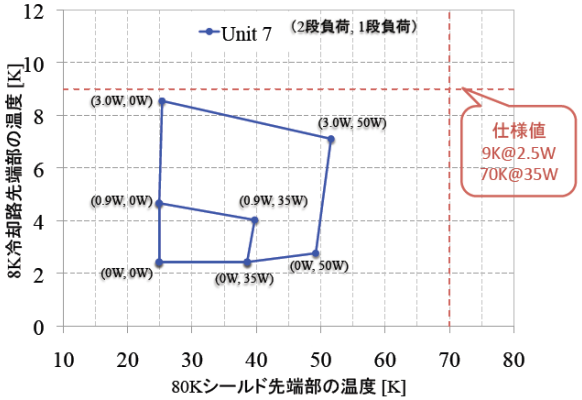

4K cryocooler unit and set of displacement meter.



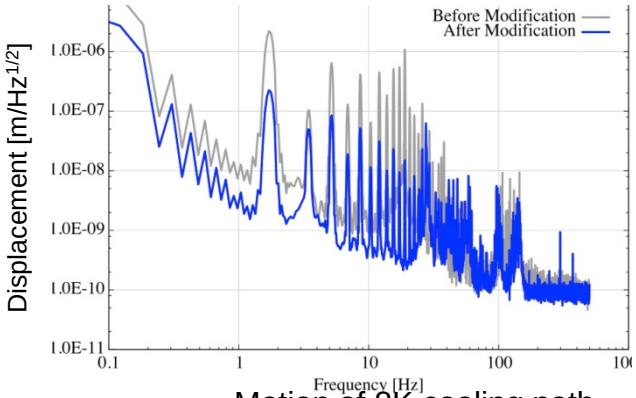

Inner structure of cryocooler unit.




3D plot of 8K cooling path. Voltage to displacement conversion factor is $10^{-5}$ m/V. Moving average of 0.2 sec was applied.




Load map of cryocooler. (C.Tokoku, 2012 Nov. CSJ )




Motion of 8K cooling path.

- 4K cryocooler units with vibration reduction mechanism are manufacturing.
  - 5 units in 2011FY and 9 units in 2012FY.
- Cooling power of the cryocooler satisfied the requirement.
- Vibration level was improved by a reinforcement of support structure.

# Cryopayload

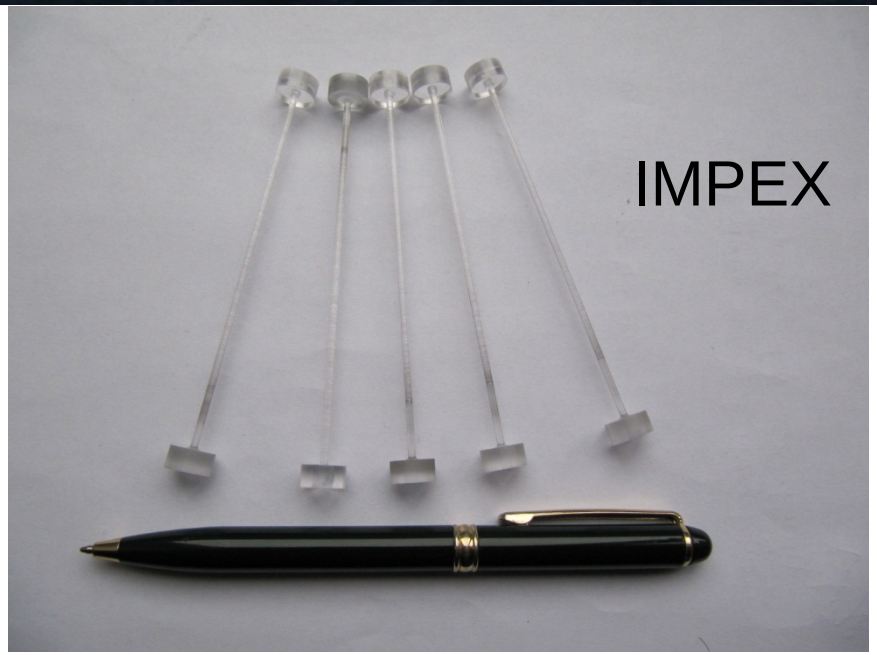
Sapphire fiber with nail head to suspend sapphire mirror

Moltech GmbH and IMPEX GmbH (Germany)

delivered !

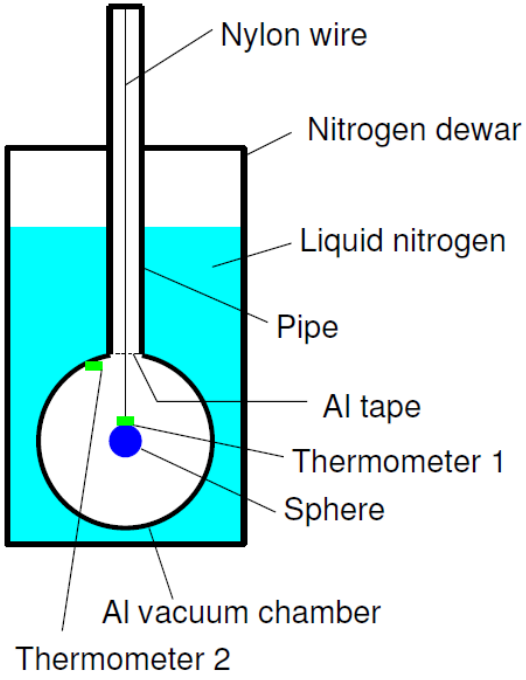
Quality check is in progress.

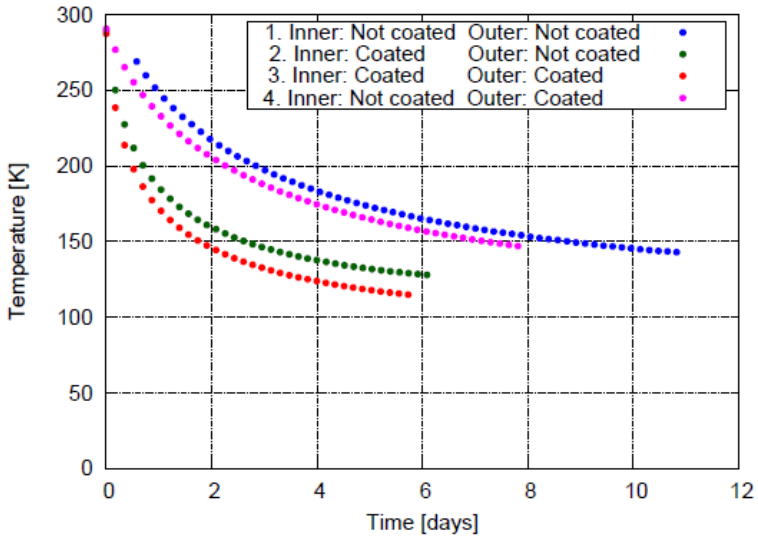
Moltech



# Cryopayload

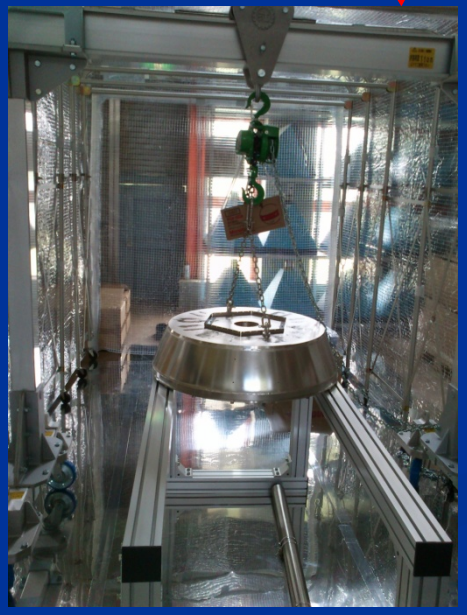
DLC coating (black coating) makes initial cooling time twice times shorter.
In ICRR, this DLC effect is observed in experiment.
Moreover, similar experiments will be conducted in cooling test of KAGRA cryostat in Toshiba.

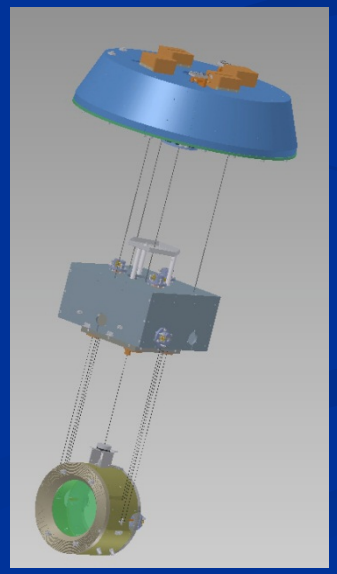


# Status of Vibration Isolation Subsystem

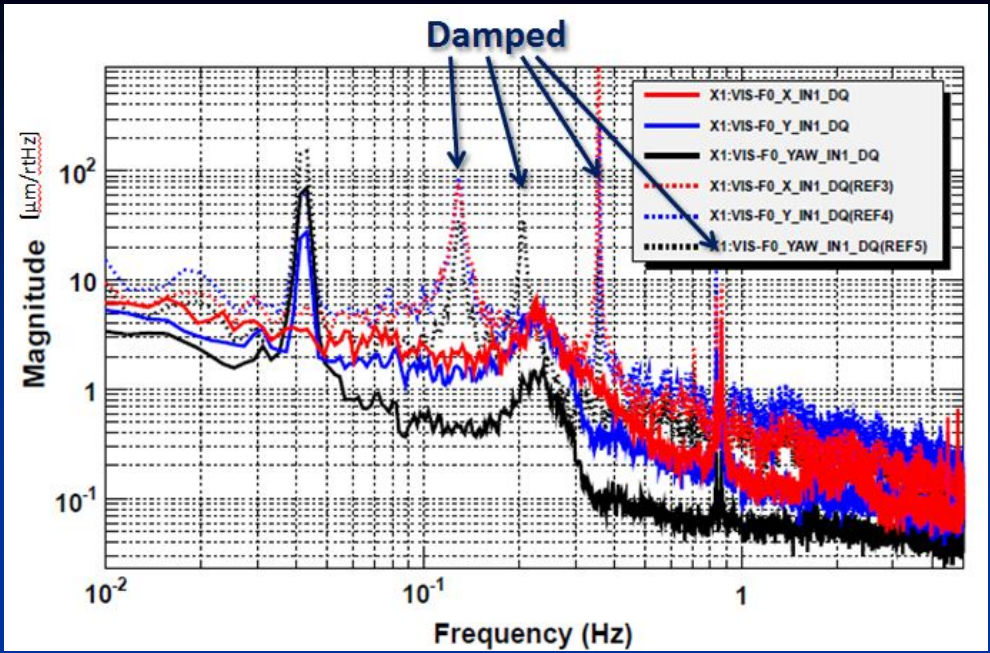
| | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|
| Standard GASF | Prototype test | | | | | | | in Nikhef /Kashiwa |
| | Procure | | | | | | | |
| | Assembling | | | | | | | in Akeno |
| Pre-isolator | Prototype test | | | | | | | in Kashiwa |
| | Procure | | | 6 SET | 5 SET | | | |
| | Assembling | | | 6 SET | | 5 SET | | in Akeno |
| Type-B payload | Prototype test | | | | | | | in Mitaka |
| | Procure | | | | | | | |
| | Assembling | | | | | | | in Kamioka |
| | Installation | | | | ETM ITM | | | |
| Type-A SAS | Prototype test | | | | | | | in Kamioka |
| | Installation | | | | | ETM ITM | | |
| Type-B SAS | Prototype test | | | | | | | in TAMA |
| | Installation | | | | PRM/BS | SRM | PRM/BS | |
| Type-C System | Assembling | | | | | | | in TAMA |
| | Installation | | | | | | | |



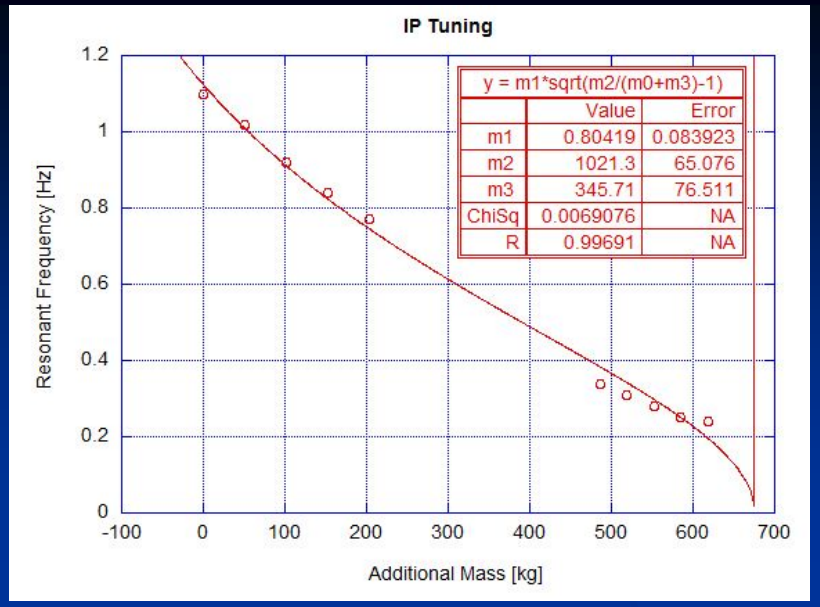


## Current status

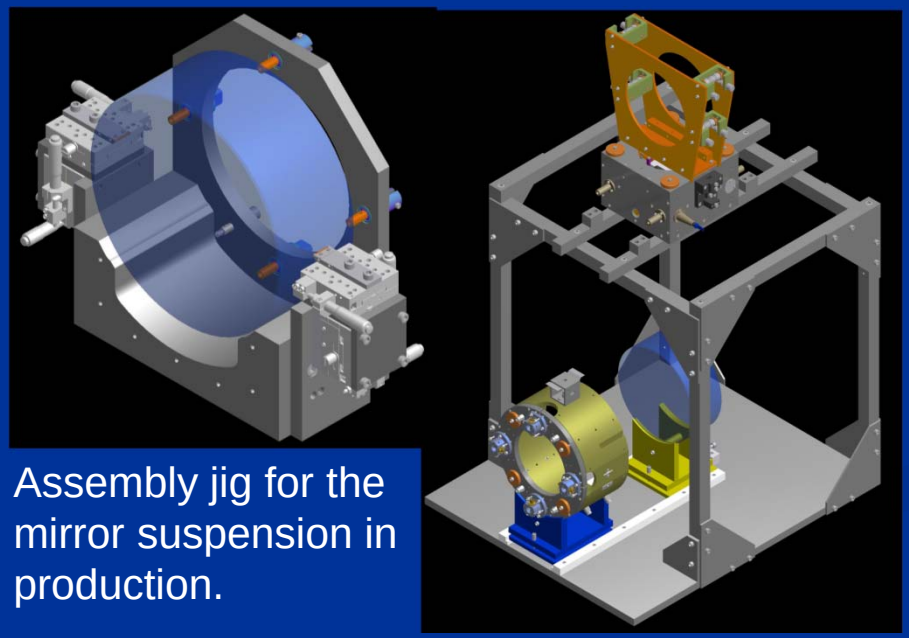
- The pre-isolaor prototype is working with digital control system in Kashiwa.
- Final assembly of the GAS filters is going in Akeno.
- The payload prototype is ready for assembly.
- 6 pre-isolators are in production at the facility.



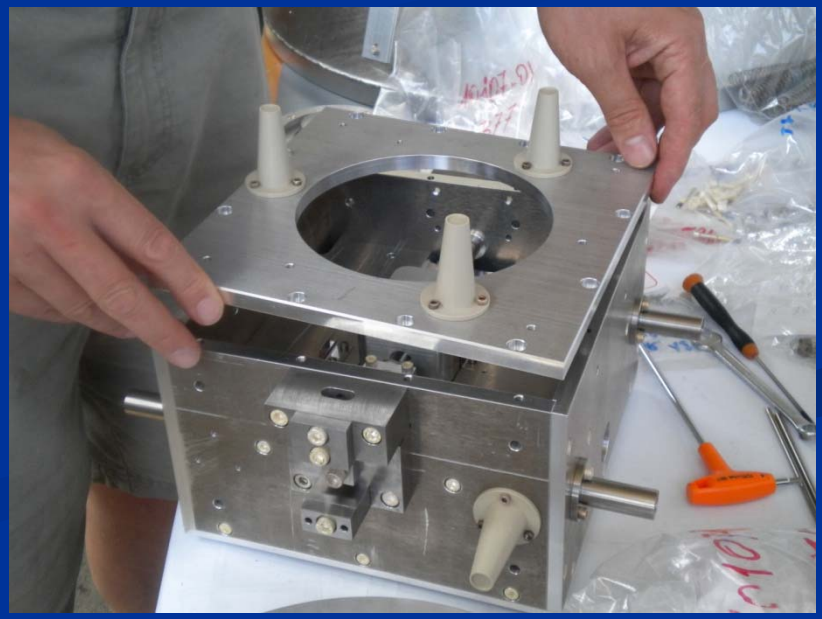

Control test of the inverted pendulum. Some resonances were damped effectively.




Tuning of the inverted pendulm. The present resonant frequency is 130mHz.



Assembly jig for the mirror suspension in production.



Assembling of the intermediate mass.

# Vibration isolation

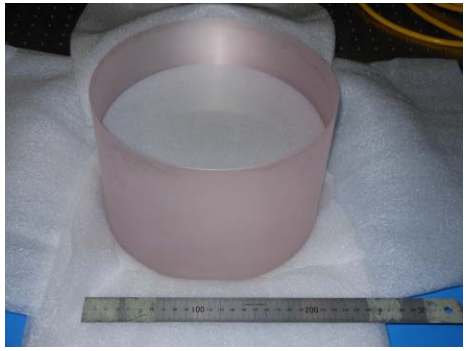
- **See Takahashi-kun's talk for more details.**

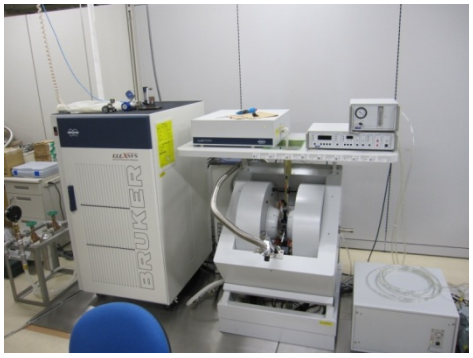
# Current status (Fabrication)

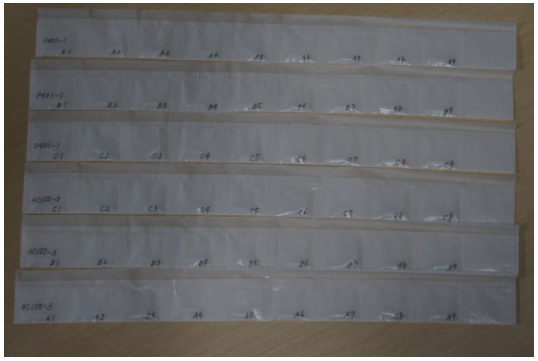
- Procedure for making a contract for polish and coating for BS has been started.
- Procedure for making a contract for polishing RMs and SRMs has been started.
- Preparation of ITMs for iKAGRA has been started; the use of iLIGO mirrors be comes possible by changing the wedge angle.
- Polished MC mirror substrates have been sent to LMA and inspected; the flat mirrors are OK but the curved mirror should be sent back to Japan to measure its ROC.

# Sapphire mirrors

- Large c-axis sapphire crystals have been obtained.
- Pathfinder polish of sapphire is being progressed; it seems good for the 10-cm diameter crystal.
- ESR measurement to investigate the cause of the optical absorption has been started at Prof. Ono's lab at Toyama Univ.





# Laser

- **See Mio-san's talk.**

# Main interferometer

- **See also Miyoki-kun and Aso-kun's talks.**

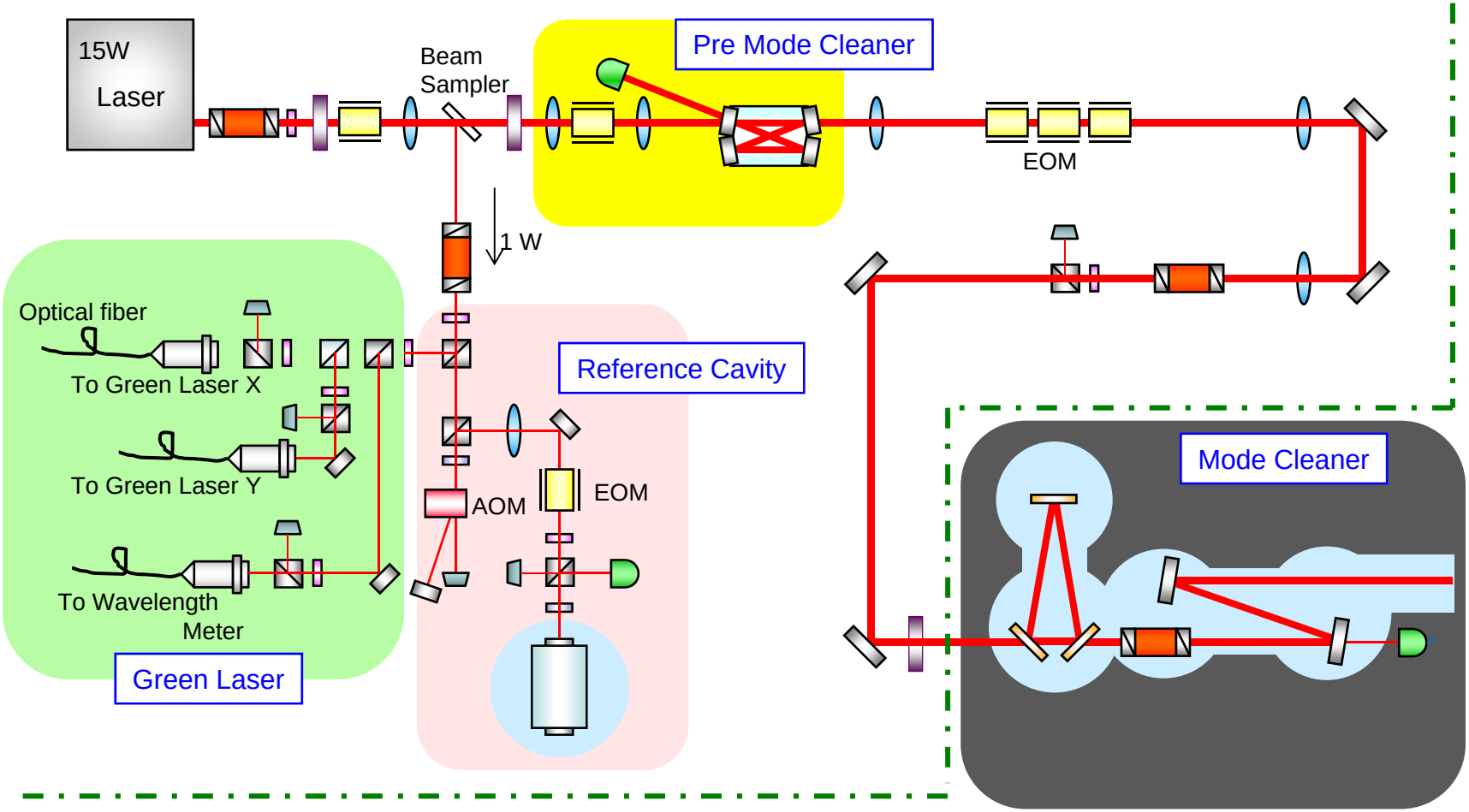
# Detector characterization

- **See Hayama-kun's talk.**

# Input/Output Optics subgroup

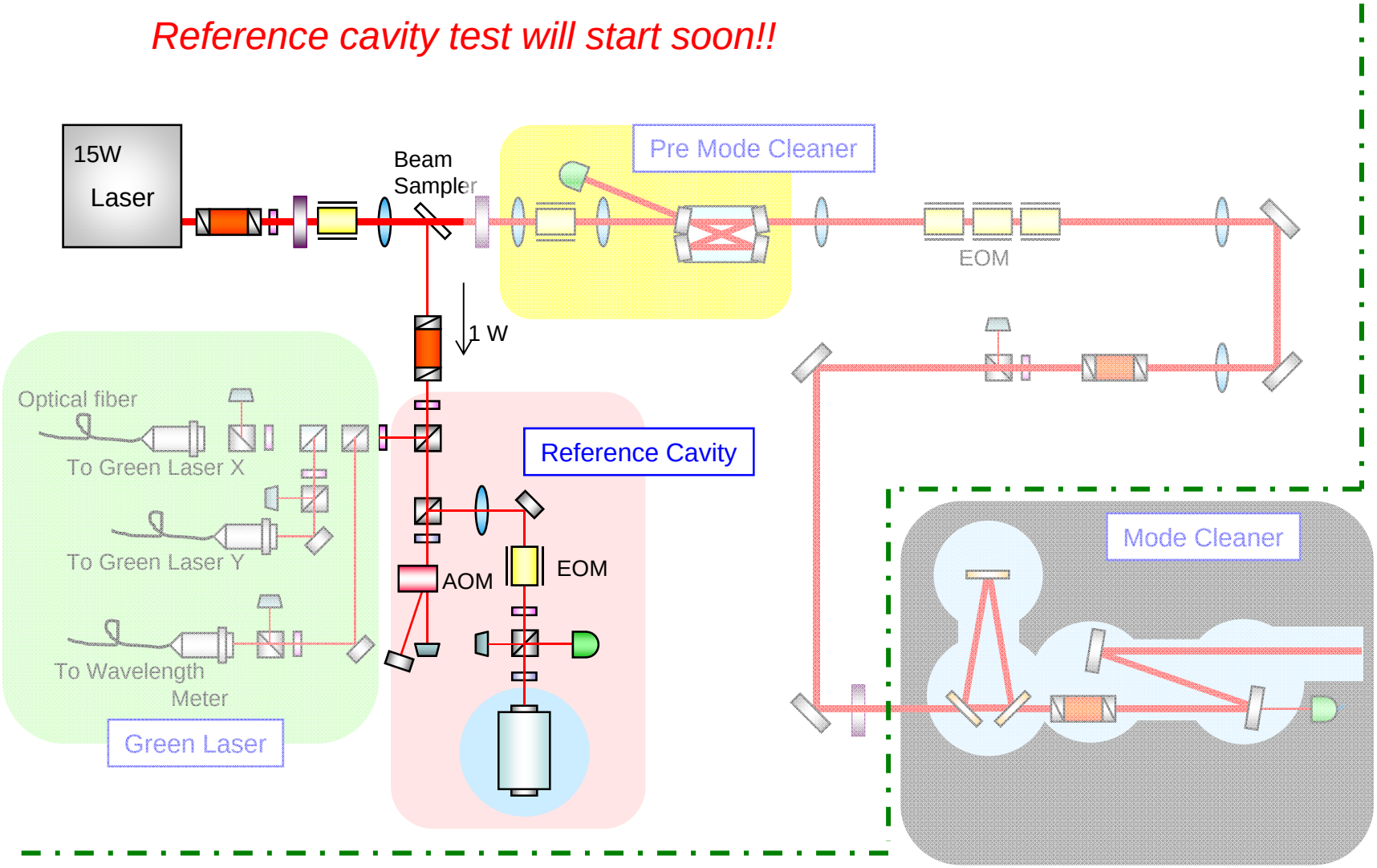
## Input Optics System for iKAGRA.

Those optics will be constructed and tested on the input optical table (except MC).



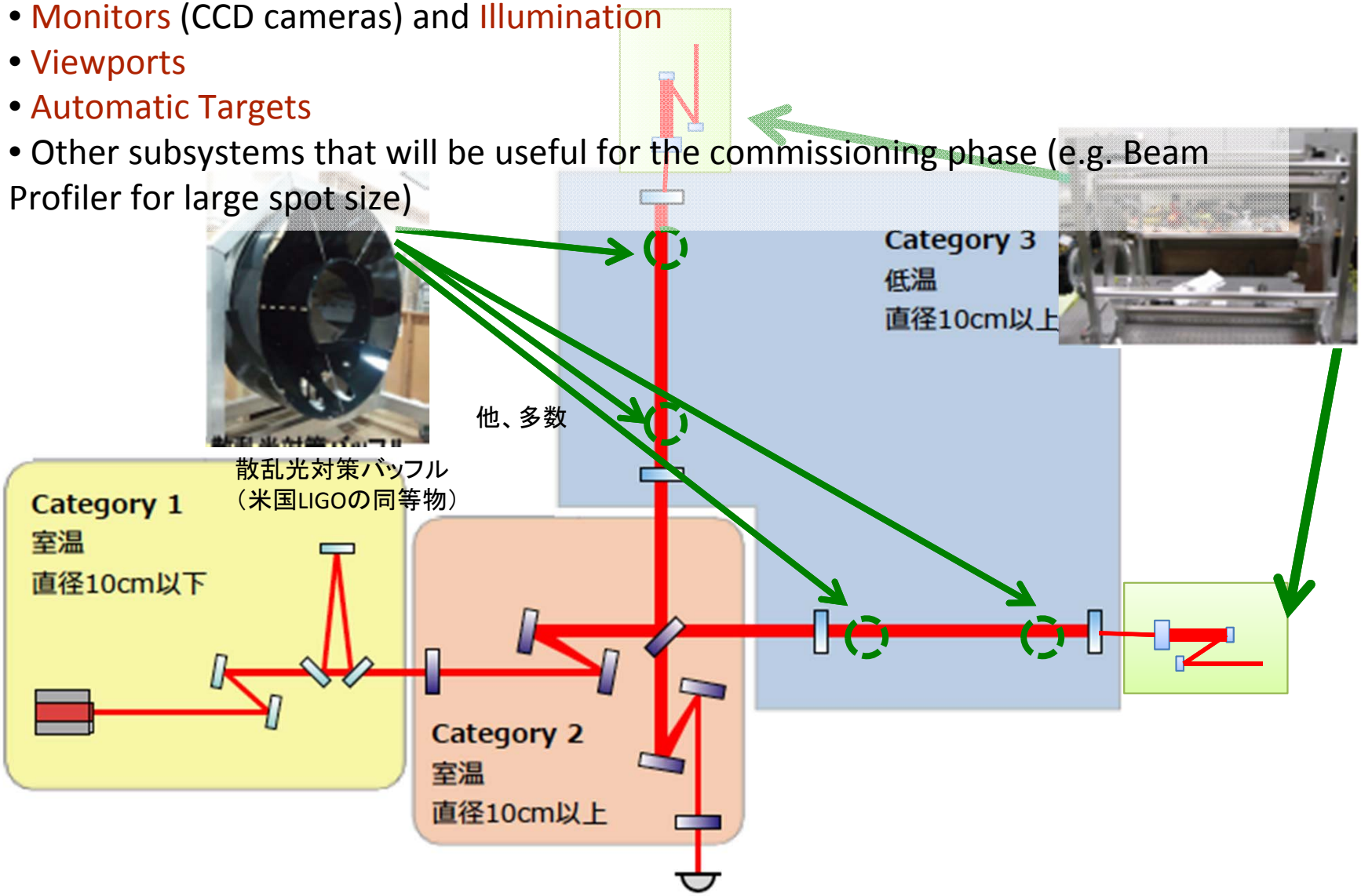
# Input/Output Optics subgroup

*Reference cavity test will start soon!!*

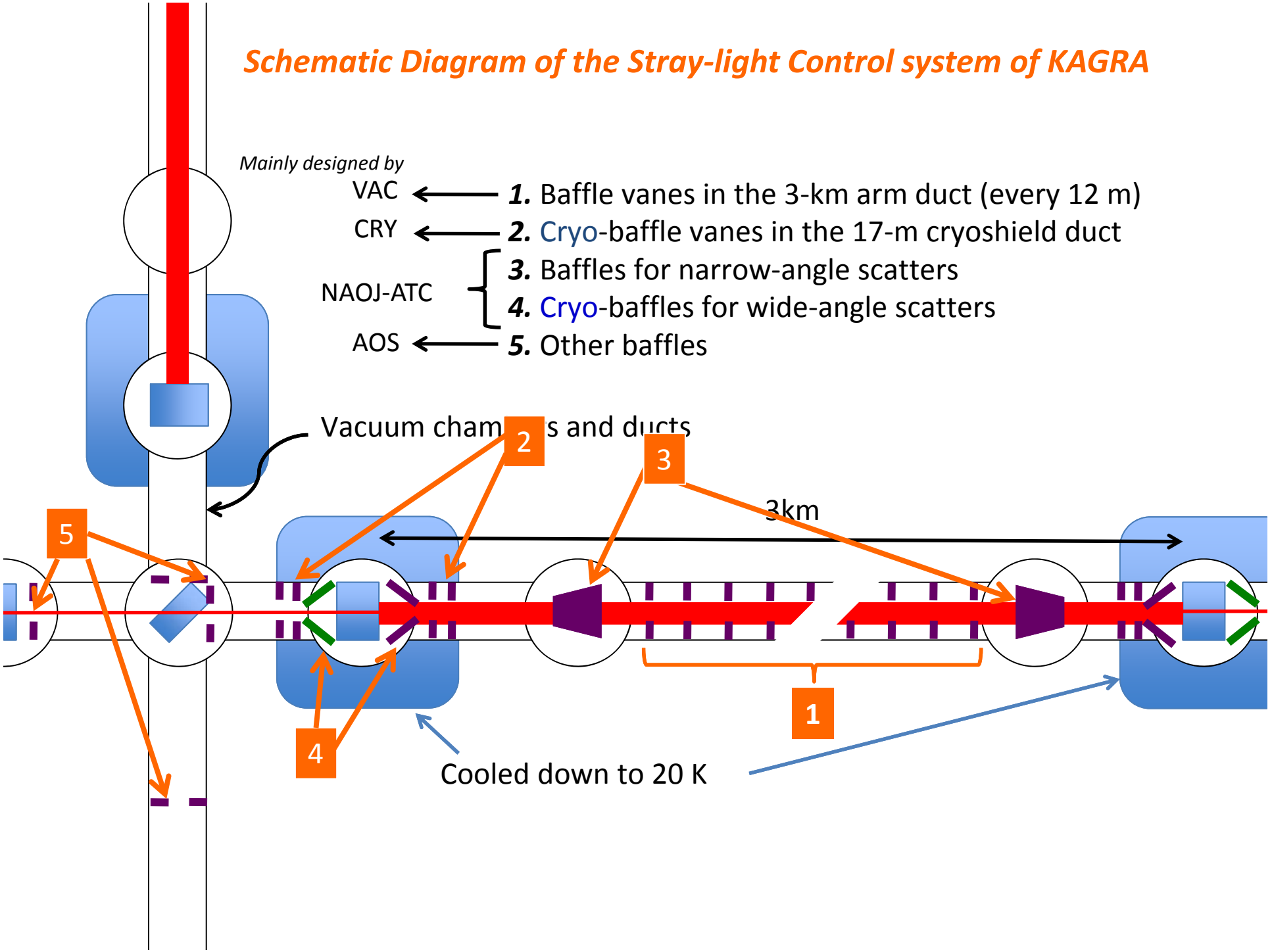


## *AOS tasks:*

- Stray Light Control (SLC)
- ETM Transmission Monitor Telescopes
- Optical Levers (OpLevs)
- Monitors (CCD cameras) and Illumination
- Viewports
- Automatic Targets
- Other subsystems that will be useful for the commissioning phase (e.g. Beam Profiler for large spot size)

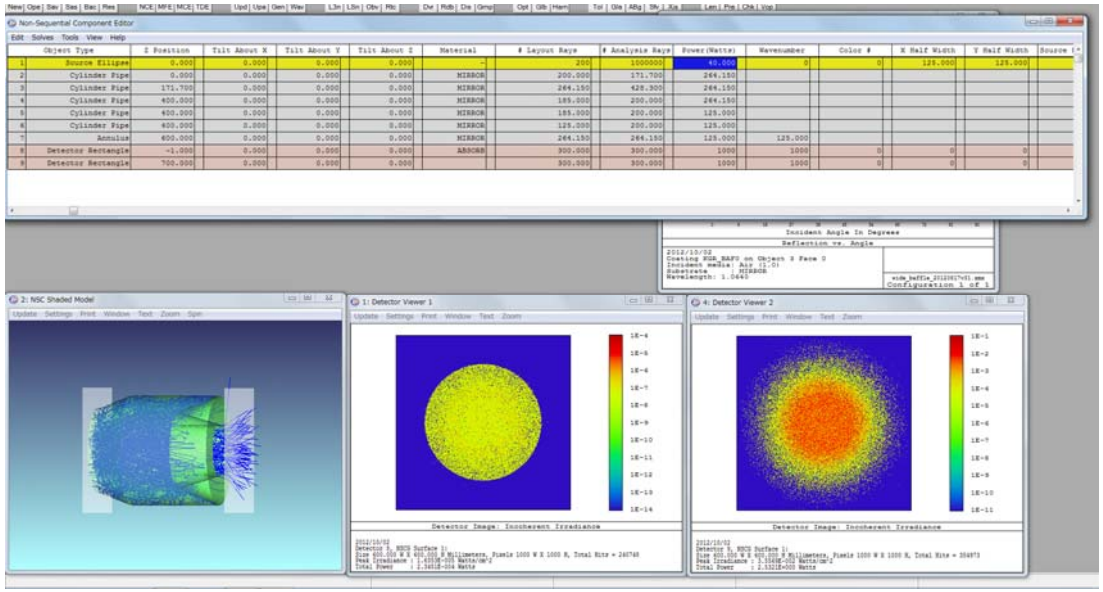


# *Schematic Diagram of the Stray-light Control system of KAGRA*



## *Stray-light Control*

• Baffle design (mechanical and optical) is ongoing.
• Black material for the baffles are under investigation; Diamond-like carbon (DLC), Ni-coat...



## *Optical Levers*

• Prototype tests are ongoing; combination of a fiber light-source and a position sensitive detector is now the first candidate.
• More discussion will be required for the design of OpLevs for bKAGRA main mirrors (in cryostats).

## *Viewports*

• Prototype tests of #2 are ongoing.
• Purchase list (planned) is as follows.

| Categories | Specification | Qty. |
|---|---|---|
| #1 Special | 1064nm AR | 2 |
| | 1064/532nm AR | 2 |
| #2 For OpLevs | ICF152 | 30 |
| | ICF70 | 10 |
| #3 General purpose | ICF203 | 100 |

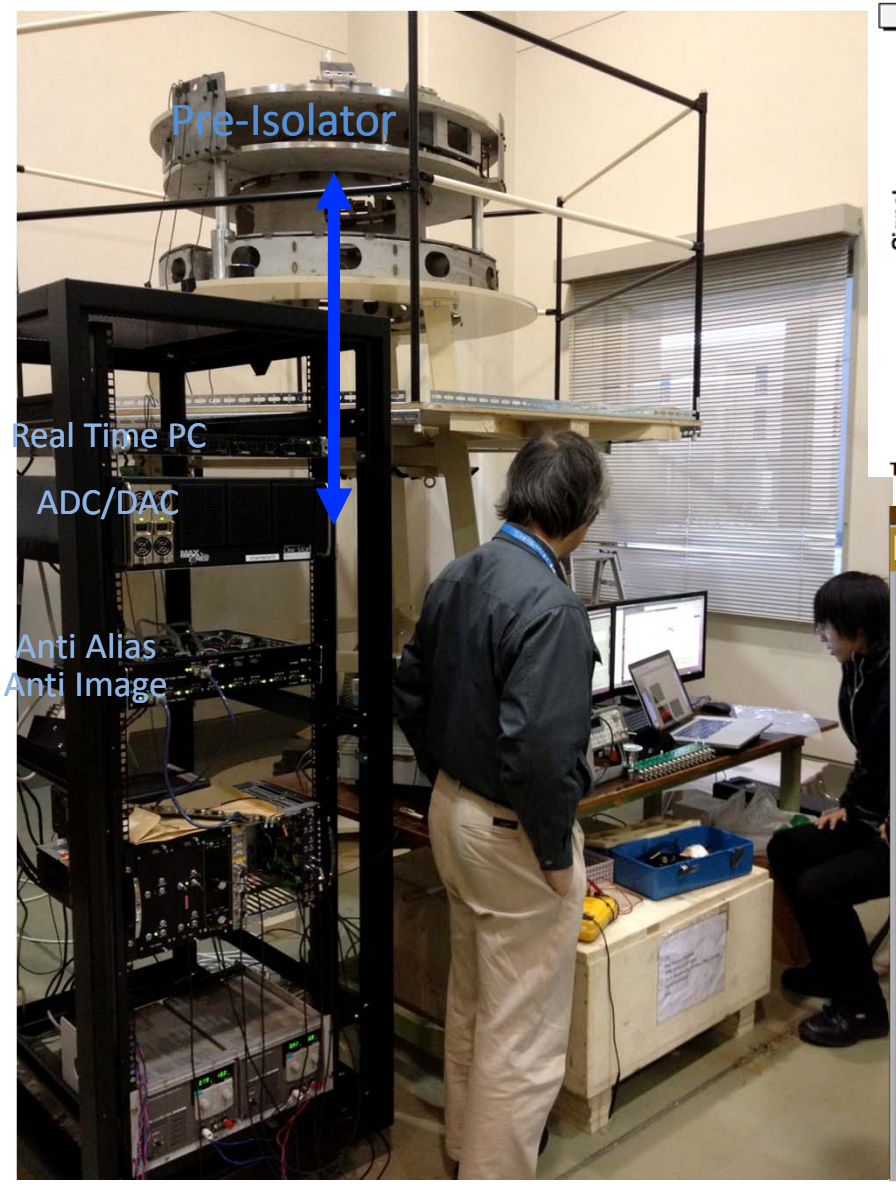
# Auxiliary optics

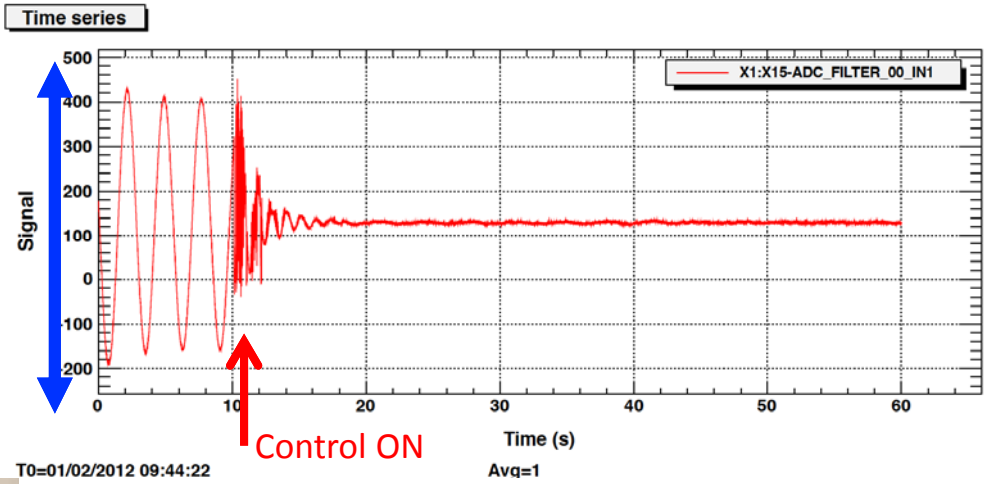
- **See Ando-kun's talk for more details.**

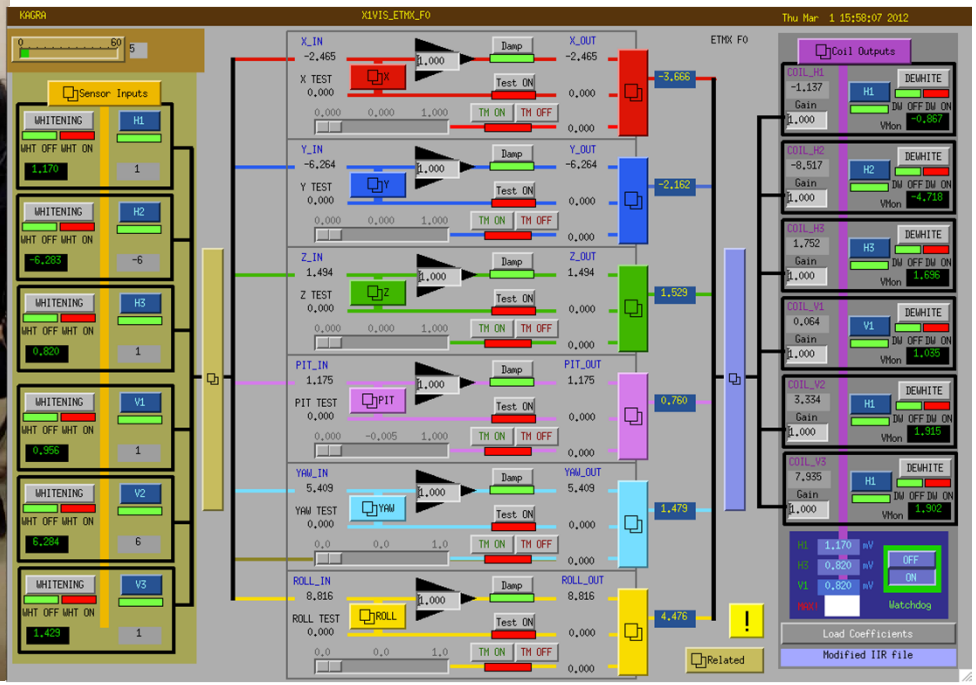
# Recent work for DGS

- Observation at CLIO with RT system for detector characterization. Lock acquisition, calibration and some software for data analysis. 13 hours data including 2 hours continuous lock.
- A new larger room at Kamioka Hokubu-kaikan for 7 racks RT system
- Making a signal list at ADC and DAC
  - Listed ~900ch/3200ch to estimate more accurate No. of ADC, DAC, IO chassis and RT-PC
- Making a location list for ADC, DAC, IO chassis and RT-PC on 19 inch racks
- Visiting LIGO to see km scale control system, estimating the total number of RT PCs, IO chassis, electronics etc.

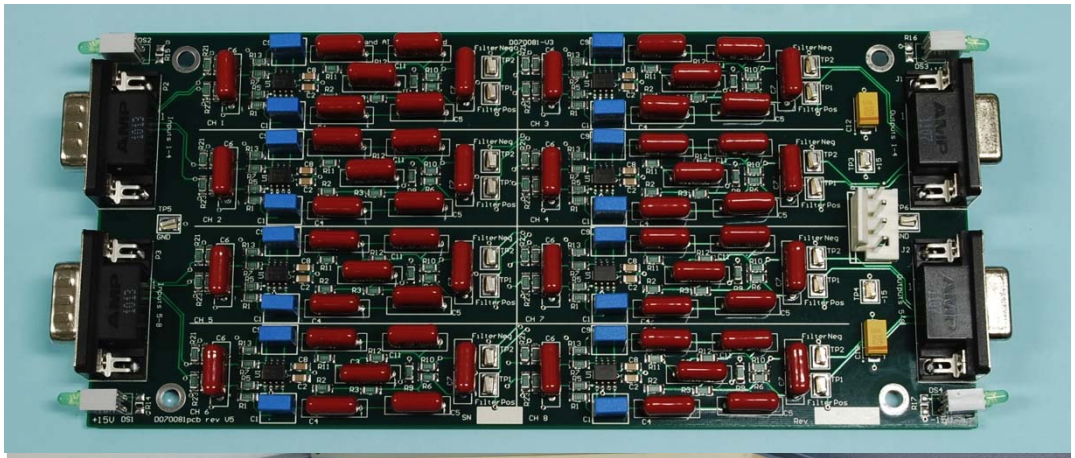
# Digital control system for Pre-Isolator



# Preparation for mass production of electronics for digital system





Example of electronics: AA filter

- 6 layers circuit board
- 8ch Differential input/output with buffer
- 3order 10kHz LPF, 65536Hz notch
- 0.2A/board
- 8 D-SUB 9pin connectors as signals input, total 32ch
- D-SUB 3pin connector as DC power supply input

Asking several companies for mass production of electronics

1. Design boards -> by each subsystem
2. Making boards, soldering electronic parts
3. Making chassis
4. Putting them into chassis
5. Inspection -> but probably limited test due to technological difficulty, limited budget

Lecture for subsystem: “How to make a circuit for KAGRA” in October

# Data management & Data analysis

- **See Tagoshi-kun's talk.**