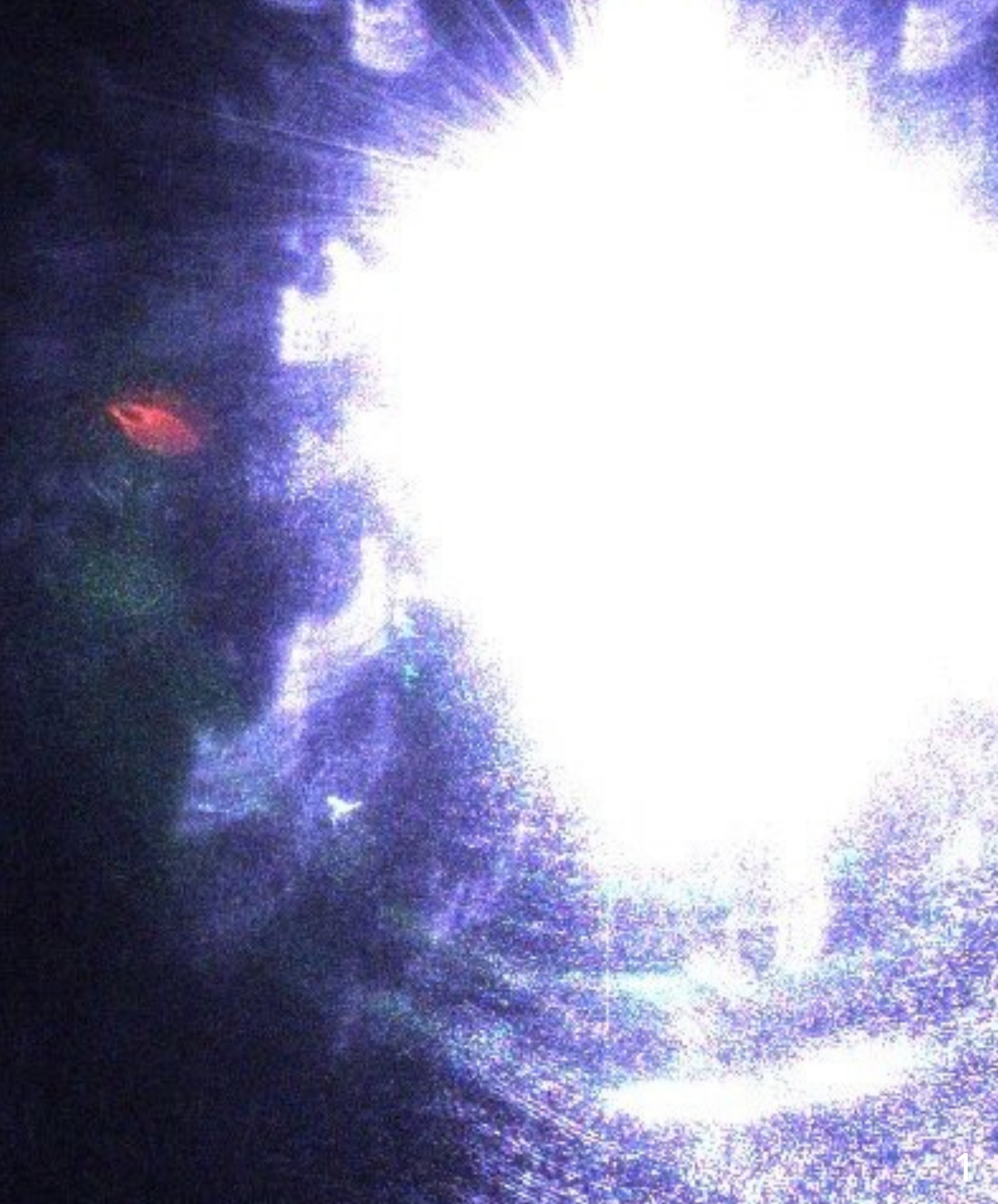
JGW-G2112924

Stray-light

not active

control in KAGRA



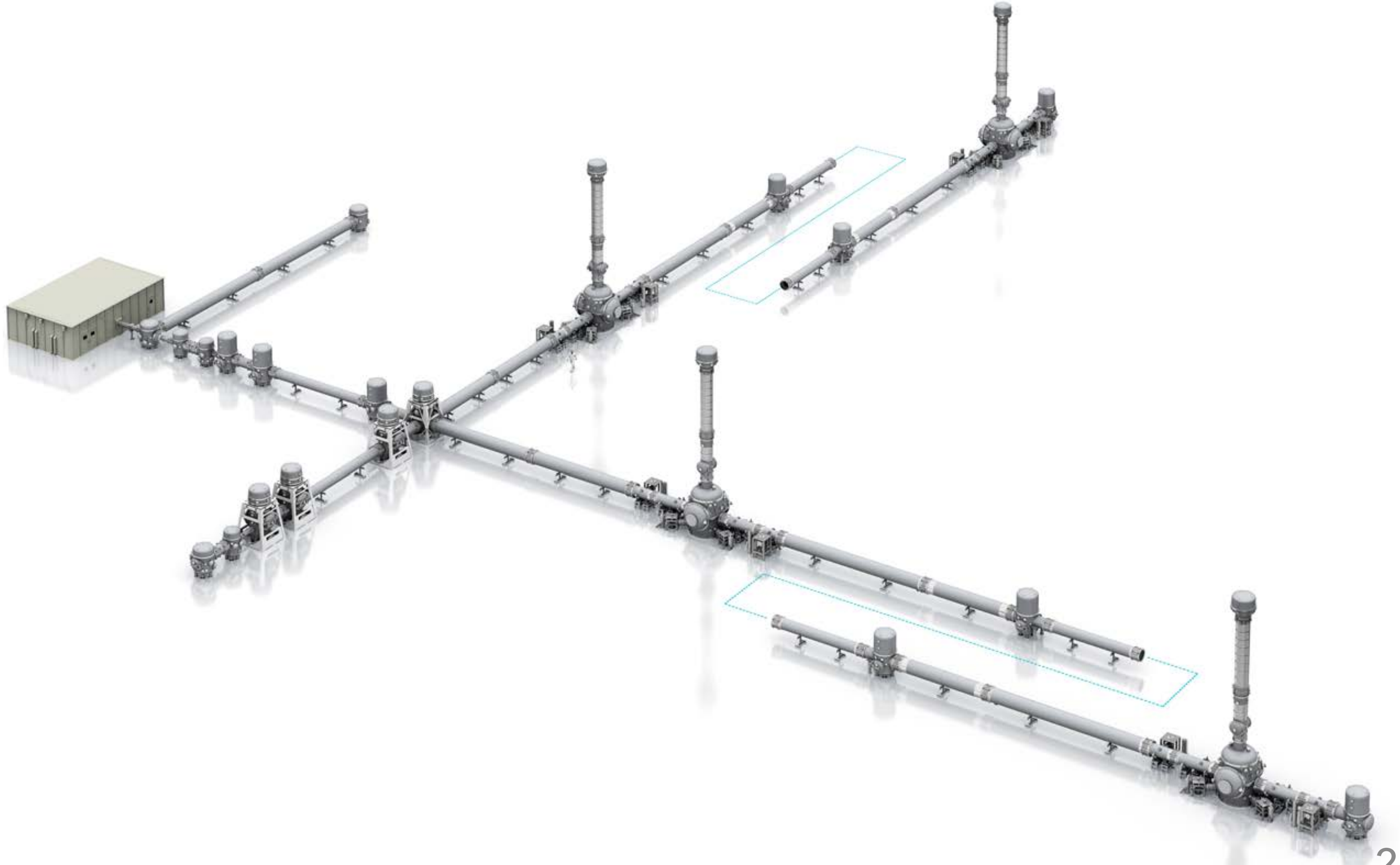
Tomo Akutsu (NAOJ)

for the KAGRA collaboration

GWADW 2021 online (17-22 May 2021)

Contents

- Until O3GK
- For O4
- Summary



(c) KAGRA Collaboration / Ray.Hori

Simulation/Noise Estimation for designing baffles

See details: https://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=8483

Fomulae related to the ray trace

Let's start with Flanagan+'s formula:

mb = main bear

$$\tilde{h}^2(f) = 4A_c\left(\frac{\lambda}{4\pi L}\right)^2 \frac{1}{\mathcal{P}_{\rm mb}} \int d\Omega_{\rm rec}\, \sigma_{\rm mb}(\mathbf{\Omega}) \frac{d\mathcal{P}}{dA\, d\Omega_{\rm rec}}(\mathbf{\Omega})\tilde{S}^2(f,\mathbf{\Omega})$$

Formula modified from Flanagan+ eq. (4.8)

This coeffiient is a constant of frequency; should be replaced with a modern(?) transfer function.

This integration is related to the ***ray trace***; in short, it corresponds to the net amount of $\left(\sqrt{\mathcal{P}_{\rm s}}\sin\phi_{\rm s}\right)^2$

Per one cavity

Strain $$h(f) = \frac{1}{L}\frac{G(f)}{\sqrt{\mathcal{P}_{\rm in}}}\left(\sqrt{\mathcal{P}_{\rm s}}\sin\phi_{\rm s}\right)$$

L: main arm length (3km for KAGRA)

*P*in: input power at the AR side of PRM (50W for KAGRA)

Yoichi did with Optickle (JGW-T1200913)

Note: the proportional coefficients in front of G are just chosen due to the definition of G.

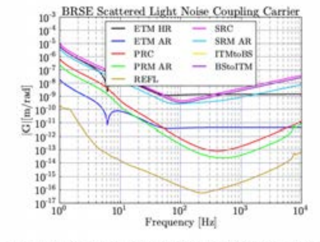


Figure 4.20: Coupling coefficients of scattered light for the carrier: BRSE

The behaviors in the lower freq range are due to radiation pressure by the stray light photons.

2018 July 13 JST

4

Relating to ray trace

A more useful form for the ray tracing is
or non dimensional

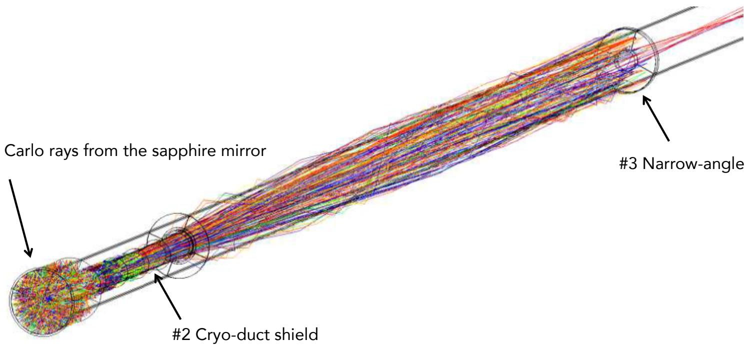
$$h(f) = \frac{1}{L}G(f)\sqrt{\frac{\mathcal{P}_0}{\mathcal{P}_{\rm in}}}\frac{\left(\sqrt{\mathcal{P}_{\rm s}}\sin\phi_{\rm s}\right)}{\sqrt{\mathcal{P}_0}}$$

P0 is the power illuminating the primary scatterer (for example, a cavity mirror) in the area to be considered; in the arm cavity of KAGRA, **P**0/**P**in = 5000 would be assumed. Now the term **P**s/**P**0 also becomes just a ratio without unit.

Note that ***phi_s*** is a function of frequency as well.

(Cont'd)

Run

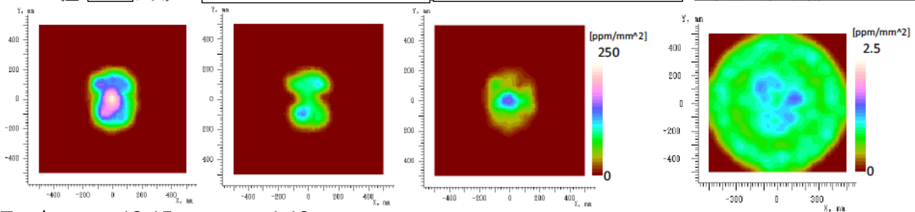


Modeling and simluation by Genesia corp.
Software: LightTools

Output 1: irradiance maps

As the rays cannot be intereferred, the map images would be fakes.

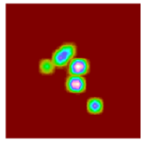
Receiver 1: irradiance map (reflected-back stray light)



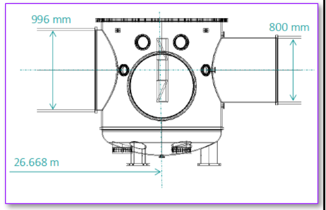
Total power 13.15 ppm | 6.68 ppm | 5.78 ppm | 0.69 ppm

Note: the input power to this model is assumed to total power of 1.

Receiver 2: irradiance map (transmitted stray light)



"Less than 0.001 ppm"



Output 2: tables of angular distribution

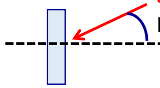
Note: the tables were not automatically produced… manually!! at that time (by Genesia corp).

Region of angle of incidence（θ1 < θ <θ2）

Preliminary

Number of the bounces of the rays

θ 1	0	0.3	0.3212	0.3456	0.3741	0.4076	0.4478	0.4967	0.5576	0.6356	0.7389	0.8824	1.0949	1.4423	2.1127	3.9474	30
θ 2	0.3	0.3212	0.3456	0.3741	0.4076	0.4478	0.4967	0.5576	0.6356	0.7389	0.8824	1.0949	1.4423	2.1127	3.9474	30	90
1回	0	0	0	0	0	0	0	1.50502E-07	5.31531E-08	0	3.5729E-08	3.65937E-08	4.45439E-08	7.64008E-08	4.91709E-07	1.03381E-06	0
2回	0	0	0	0	0	0	0	0	0	0	1.32442E-08	5.02045E-05	0.000142374	5.96981E-05	6.57337E-07	1.1196E-06	0
3回	0	0	0	6.16E-06	0	0	0	0	6.54E-09	0	6.74089E-05	0.000185972	7.01218E-05	3.88226E-05	1.99782E-07	2.46021E-07	0
4回	0	0	0	0	0	0	0	0	0	0	0	0	4.19296E-05	2.61E-09	6.12E-09	4.18782E-08	0
5回	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.66E-09	7.93322E-08	0
6回	0	0	0	0	0	0	0	0	0	0	4.39E-09	0	0	0	0	4.79575E-08	0
8回	0	0	0	0	0	0	0	0	0	0	0	1.06364E-07	5.54212E-06	0	0	1.43137E-06	0
9回	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.10094E-06	0
10回	0	0	0	0	0	0	0	0	0	0	2.49482E-06	0	0	0	0	3.26557E-07	0
11回	0	0	0	0	0	0	0	0	0	0	0	0	1.91722E-06	0	0	0	0
12回	0	0	0	0	0	0	0	0	0	0	0	1.0528E-06	0	0	0	0	0
13回	0	0	0	0	0	0	0	0	0	0	0	0	7.42294E-06	0	0	0	0
14回	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.75653E-08	0
16回	0	0	0	0	0	0	0	0	0	0	0	1.57658E-07	0	0	0	1.50E-08	0
39回	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.787E-08	0



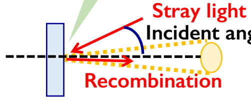
Post-processing

Taking summation of each cell in the table to get $\frac{\sqrt{\mathcal{P}_s}\sin\phi_s}{\sqrt{\mathcal{P}_0}}$ with the following treatments.

- Number of bounces → in short, the phase fluction term will become *n*-times (coherent) or sqrt(*n*)-times (incoherent).
- Incident angle → weighted by the recombination probability; it would change with respect to the incident angle to the mirror

Example: $$\left(\frac{1}{\mathcal{P}_0}\sum_{\theta}\lambda^2\frac{dP}{d\Omega_{\rm ms}}(\theta)\sum_{n=1}^{N}\delta\mathcal{E}_{\rm s}(\theta,n)(2kn\tilde{\xi}(f))^2\right)^{1/2}$$

Flanagan+ eq (3.3): **recombination cross section**
$$\sigma_{\rm mb}(\boldsymbol{\theta})=\lambda^2\frac{dP}{d\Omega_{\rm ms}}(\boldsymbol{\theta})$$



From the irradiance table

When the scondary scatterer's displacement is very small (for simplicity).

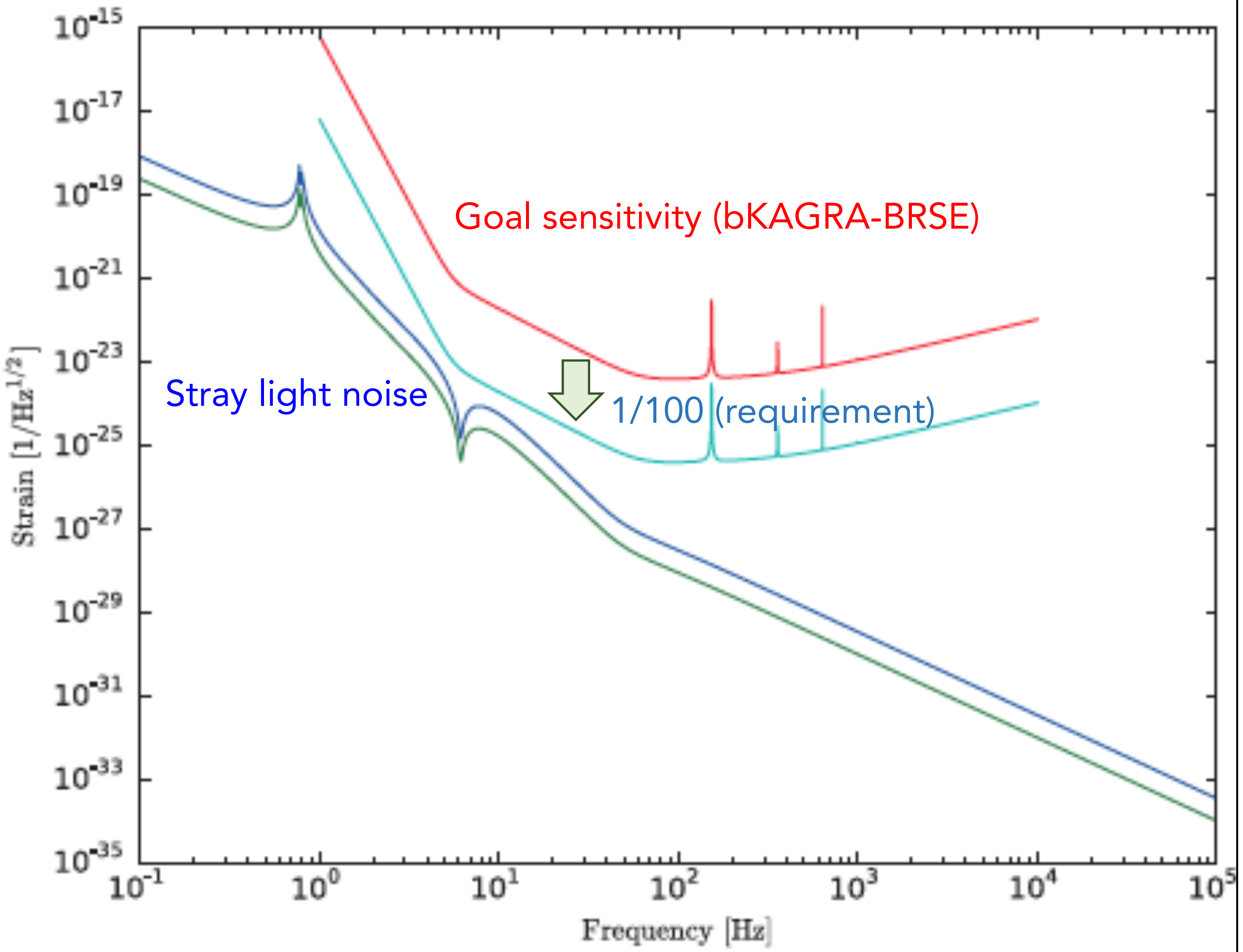
$$\frac{4\pi}{\lambda}\left(50.7\alpha_2\alpha_r\tilde{\xi}^2(f)\sum_{\theta}\sum_{n=1}^{N}\frac{Z(\theta,n)n^2}{\theta^{1.5}}\right)^{1/2}$$

where assuming $\frac{dP}{d\Omega_s}=\frac{\alpha_2}{\theta^2}$ $\frac{dP}{d\Omega_{\rm ms}}=\frac{\alpha_r}{\theta^{1.5}}$ ← Well, theoretical speaking ("reciprocity relation"), they should have the same form, but…

From the light souce: 0.0025 deg<θ<7.95 deg

(Cont'd)

Estimated noise contribution



What are included:
- #1, 2, 3 baffles
- Radiation pressures from stray light photons
- Multiple bounces of stray light

What are not included: actual seismic or acoustic noise level by air flow or cryo-cooler actuation or…

Replacing the phase fluctuation term with that of phase-wrapped one, the up-conversion effect can be estimated (not shown here).

Surface finishing

Common requirements:
- Vacuum compatibility: < 10^{-7} Pa
- As low reflectivity as possible at 1064 nm
- Industrial applicability for large areas up to φ 800 mm

For cryoduct shields (#2):
- Cryogenic compatibility: < 80 K
- As low reflectivity as possible for 300 K radiation (10 um)
- Applicability to aluminum

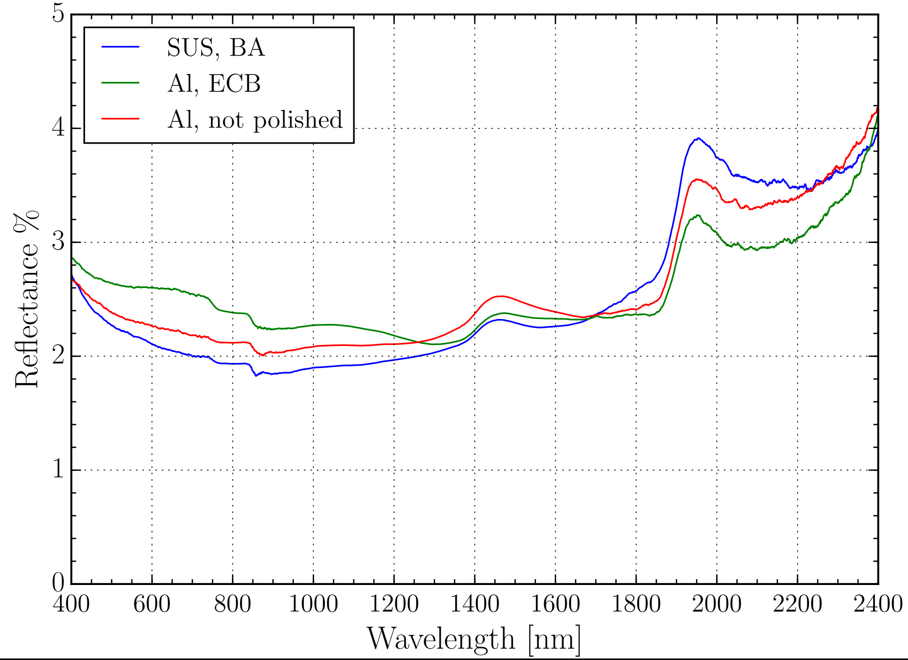
For wide-angle baffles (#4):
- More cryogenic compatibility: < 8 K

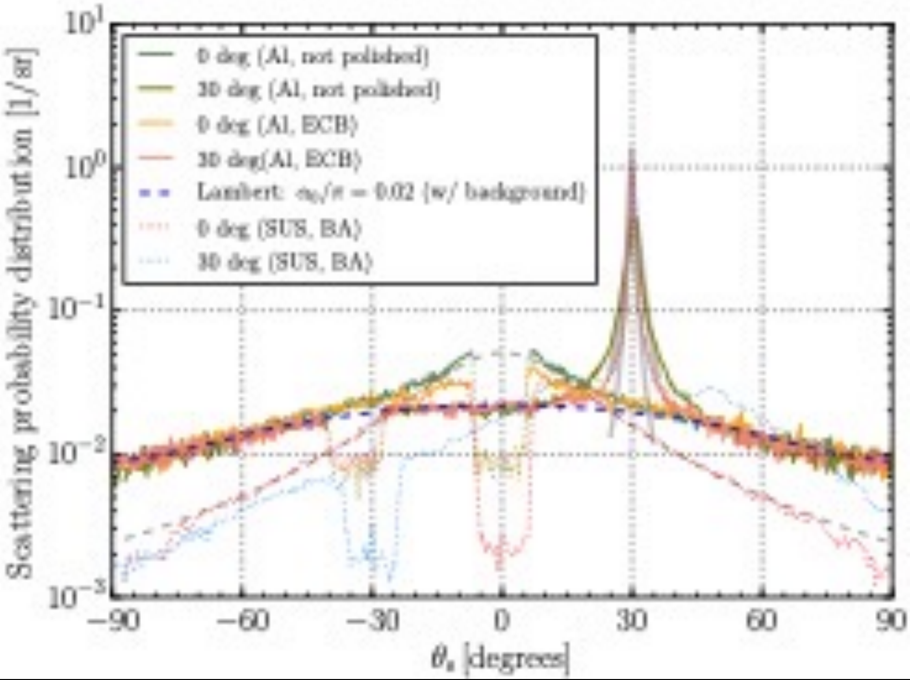
Getting stringent!

Unique to KAGRA

→ Black nickel plating for middle and large-size baffles

A sample in the N_2 liquid

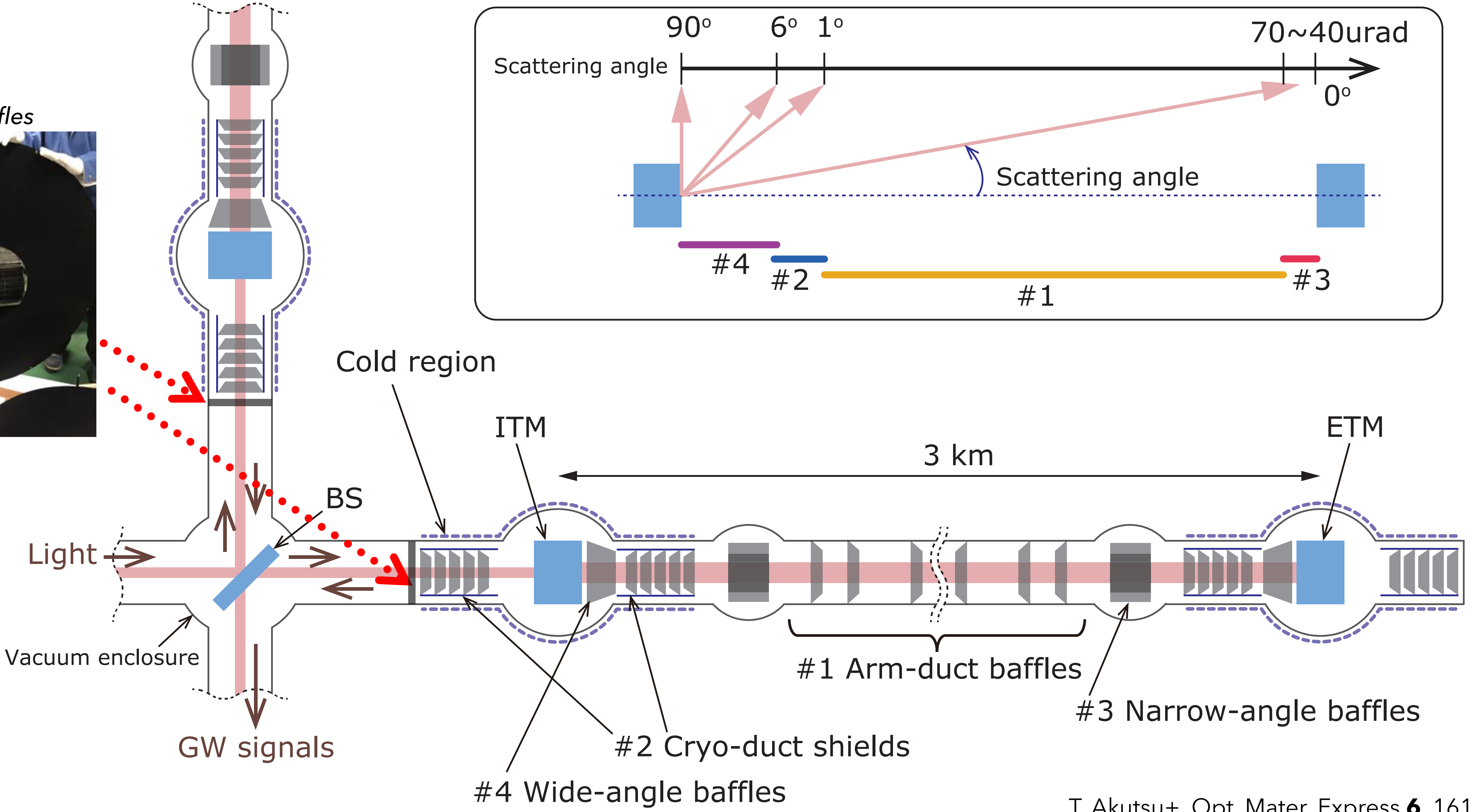




T. Akutsu+, Opt. Mater. Express **6**, 1613 (2016)

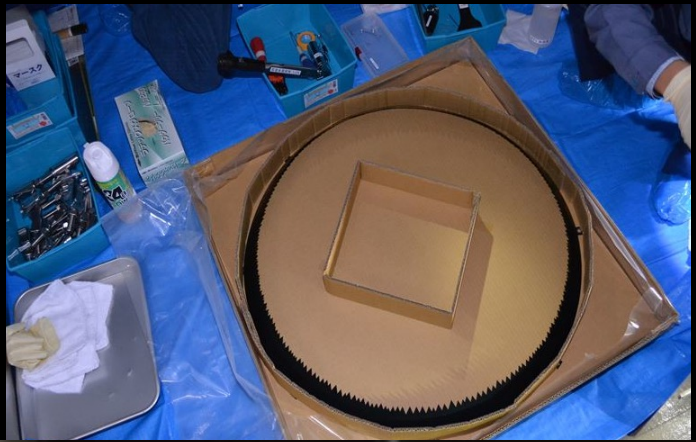
Baffles in KAGRA arms

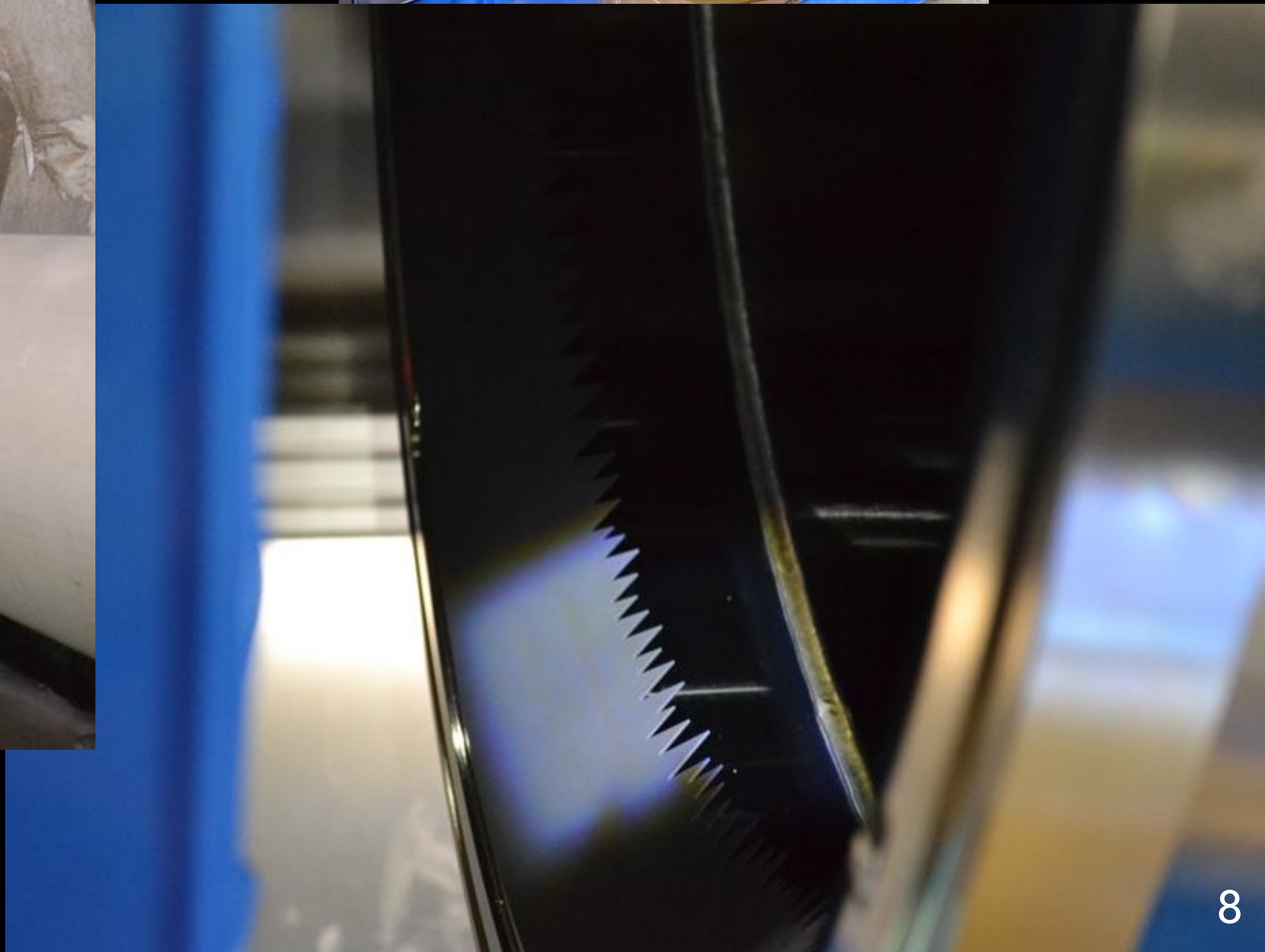
Septum baffles



T. Akutsu+, Opt. Mater. Express **6**, 1613 (2016)

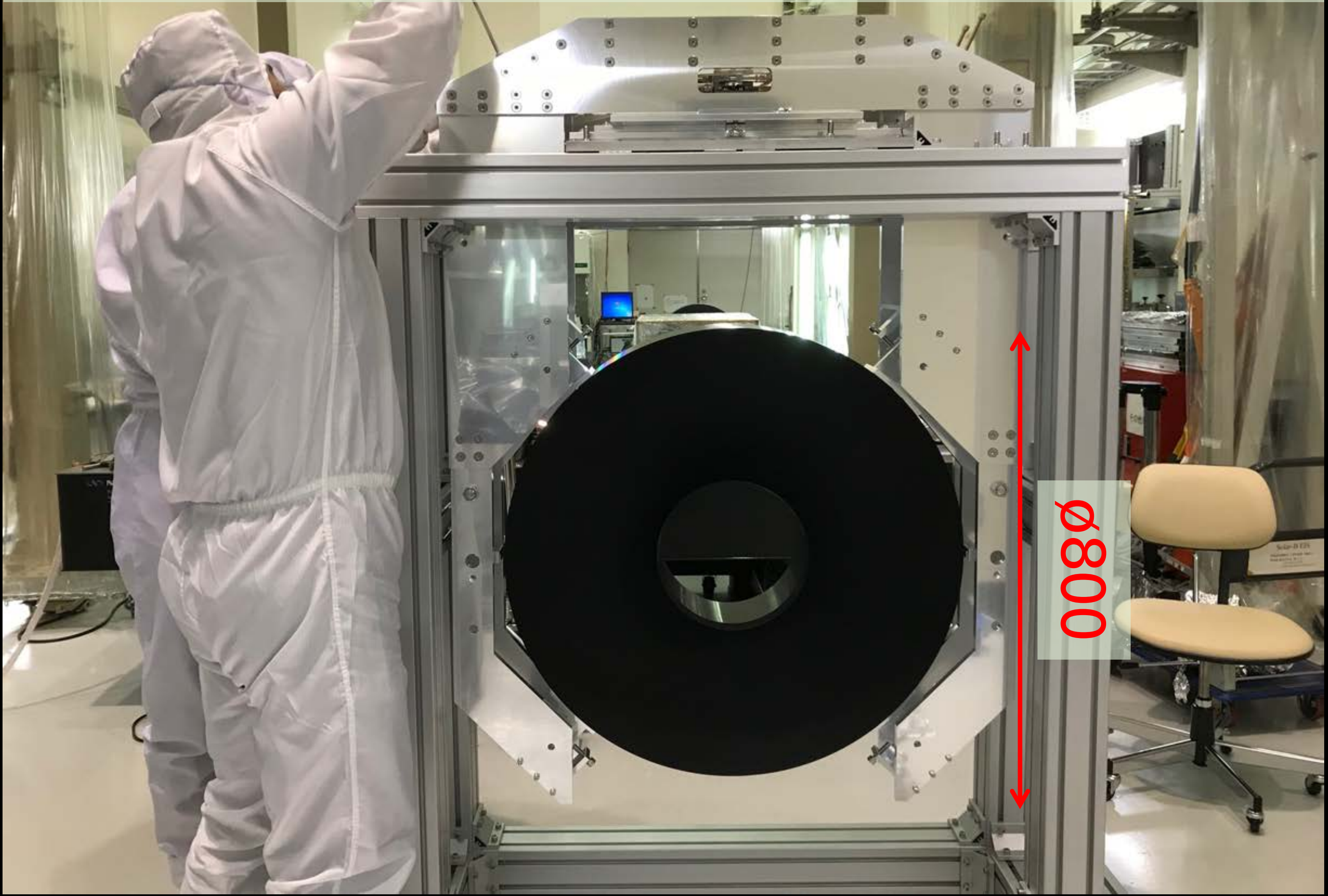
Arm-tube baffles



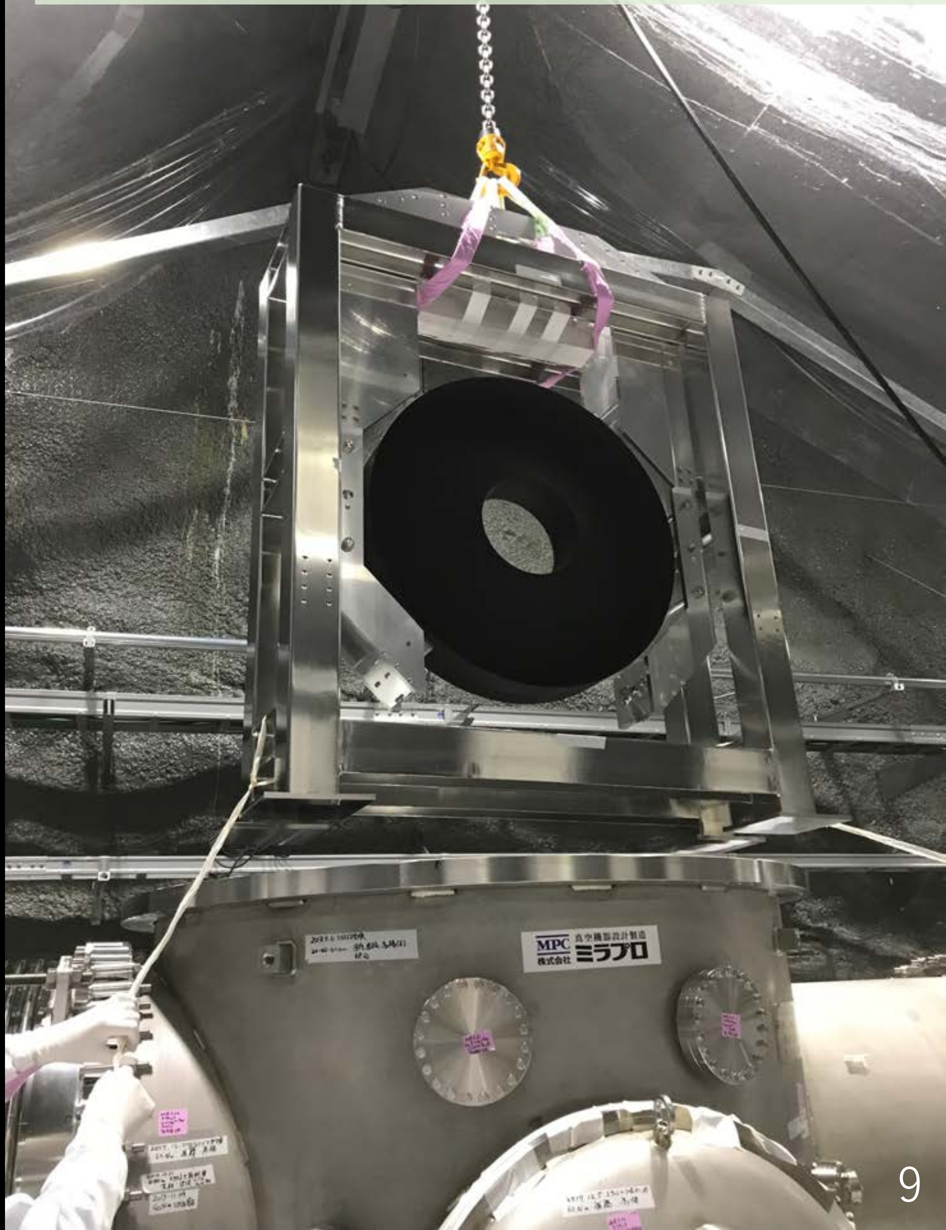


Narrow-angle baffles (NAB)

At the Advanced Technology Center (ATC) in NAOJ.
Assy of the NAB and its suspension.

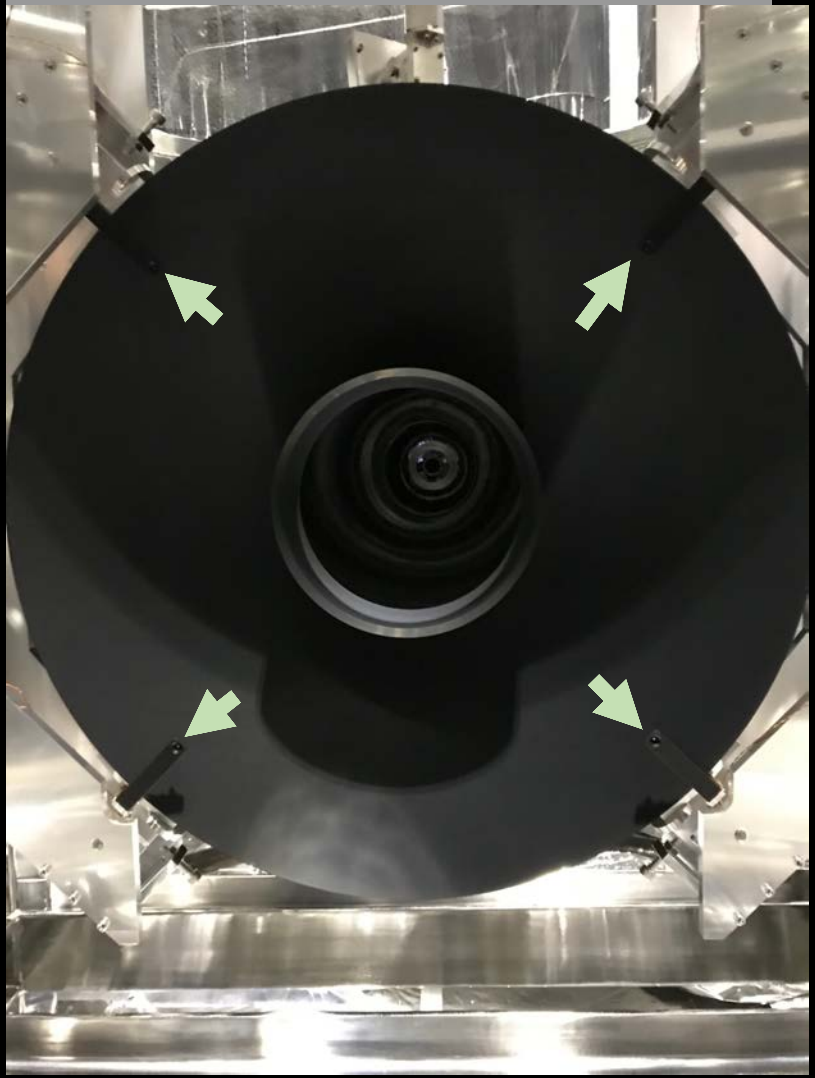


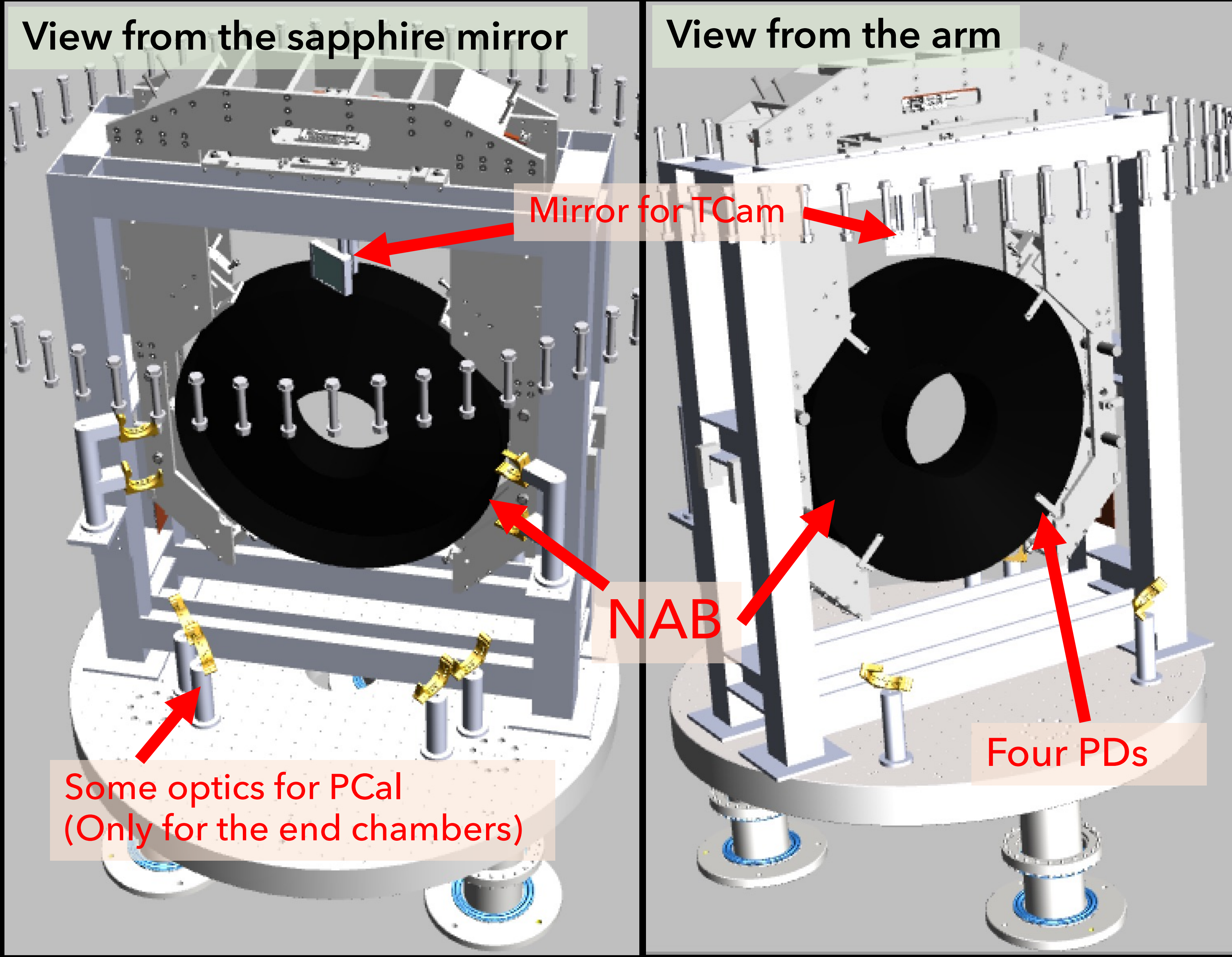
Installing the NAB into a chamber.

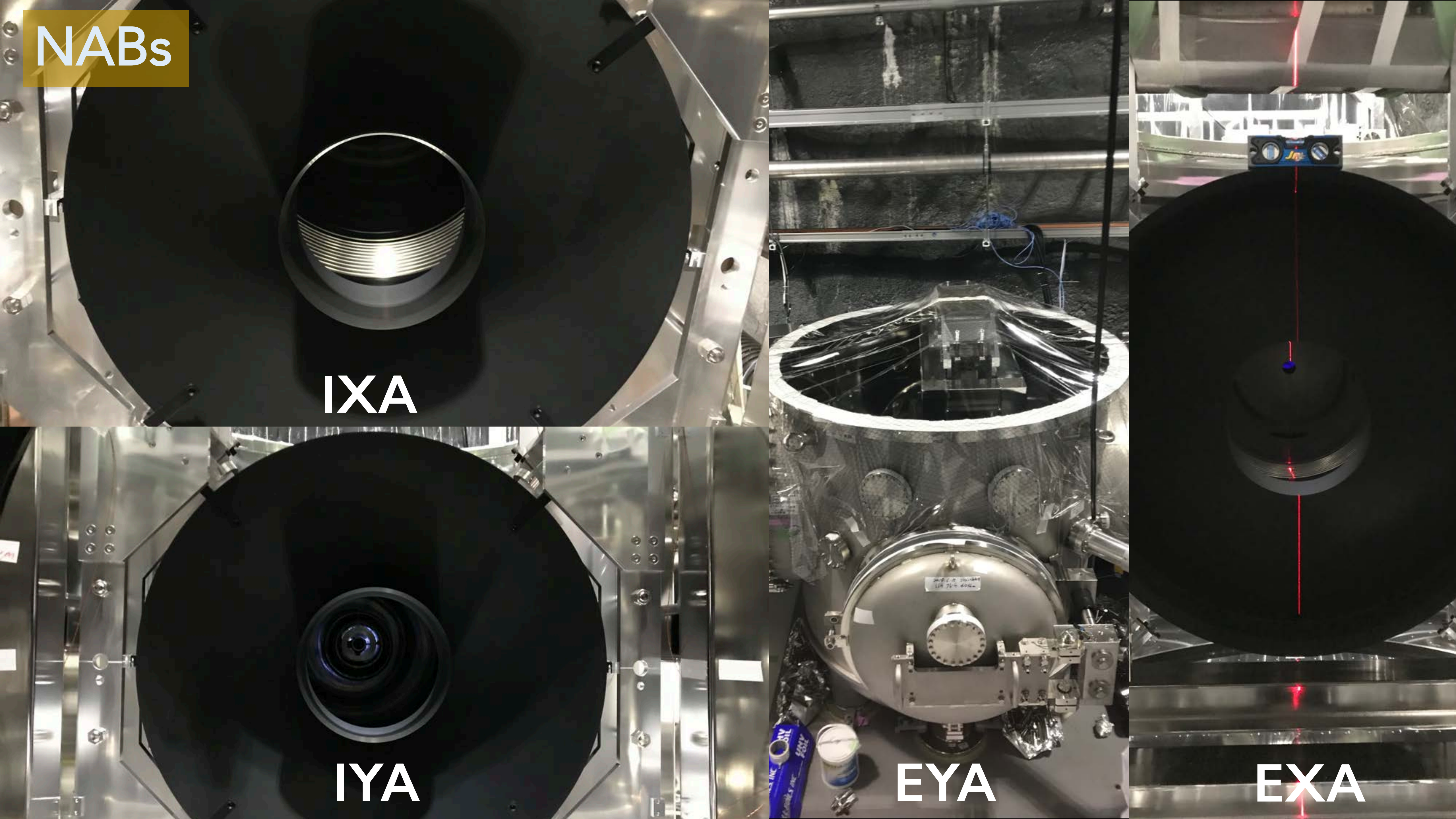


With four PDs

https://klog.icrr.u-tokyo.ac.jp/osl/?r=7197

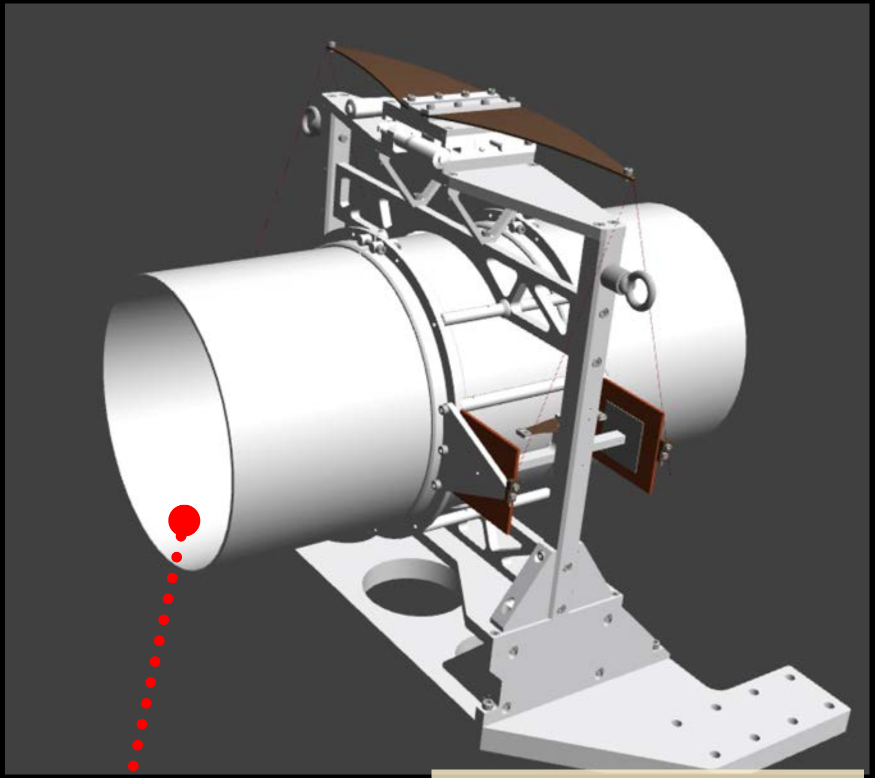





NABs
IXA
IYA
EYA
EXA

Wide-angle baffles (WABs)

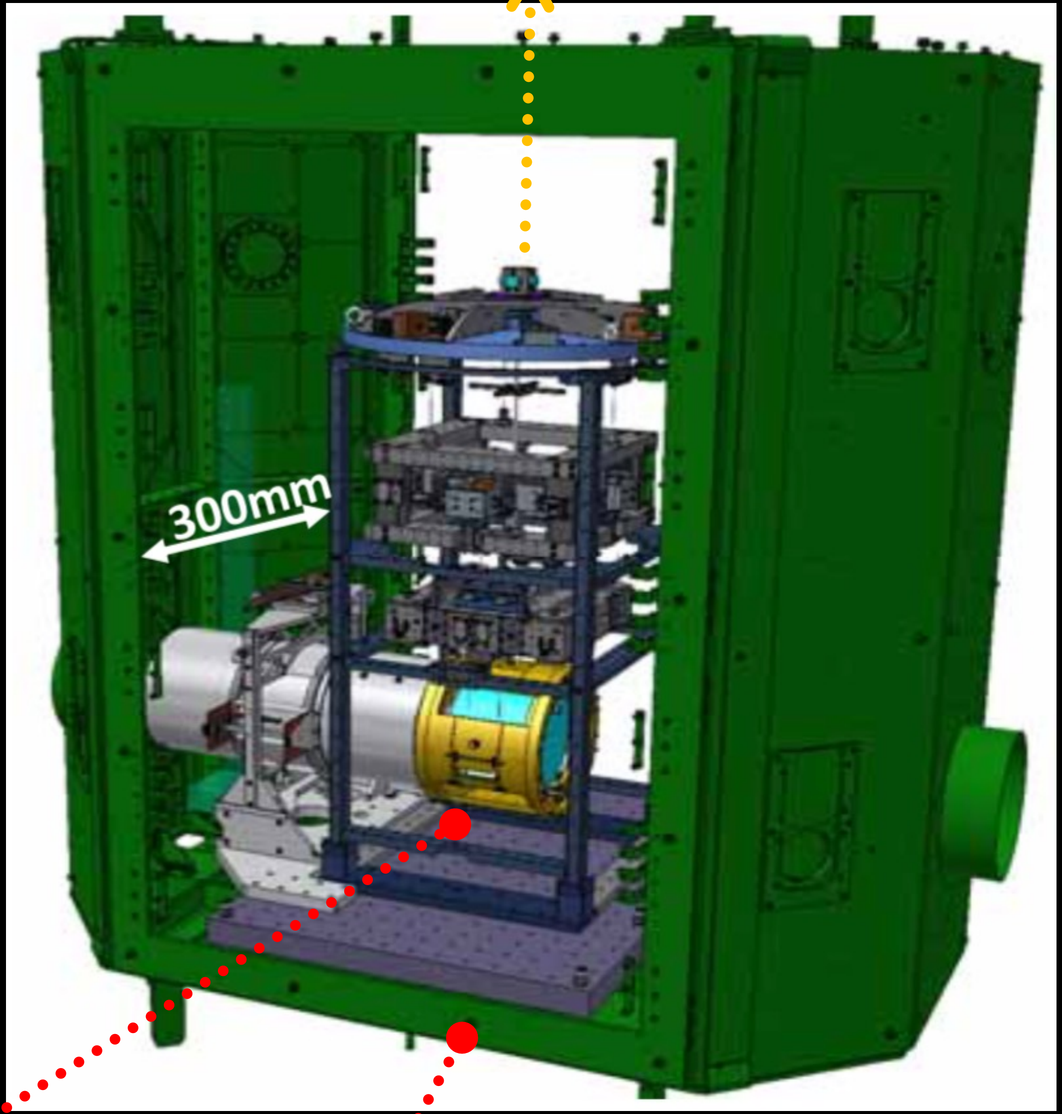
- To be cooled down ~ 15K without IR beams
- Over 4W input from the mirror → heat up to ~20K or so



Design: ATC/NAOJ

Inside: black coated

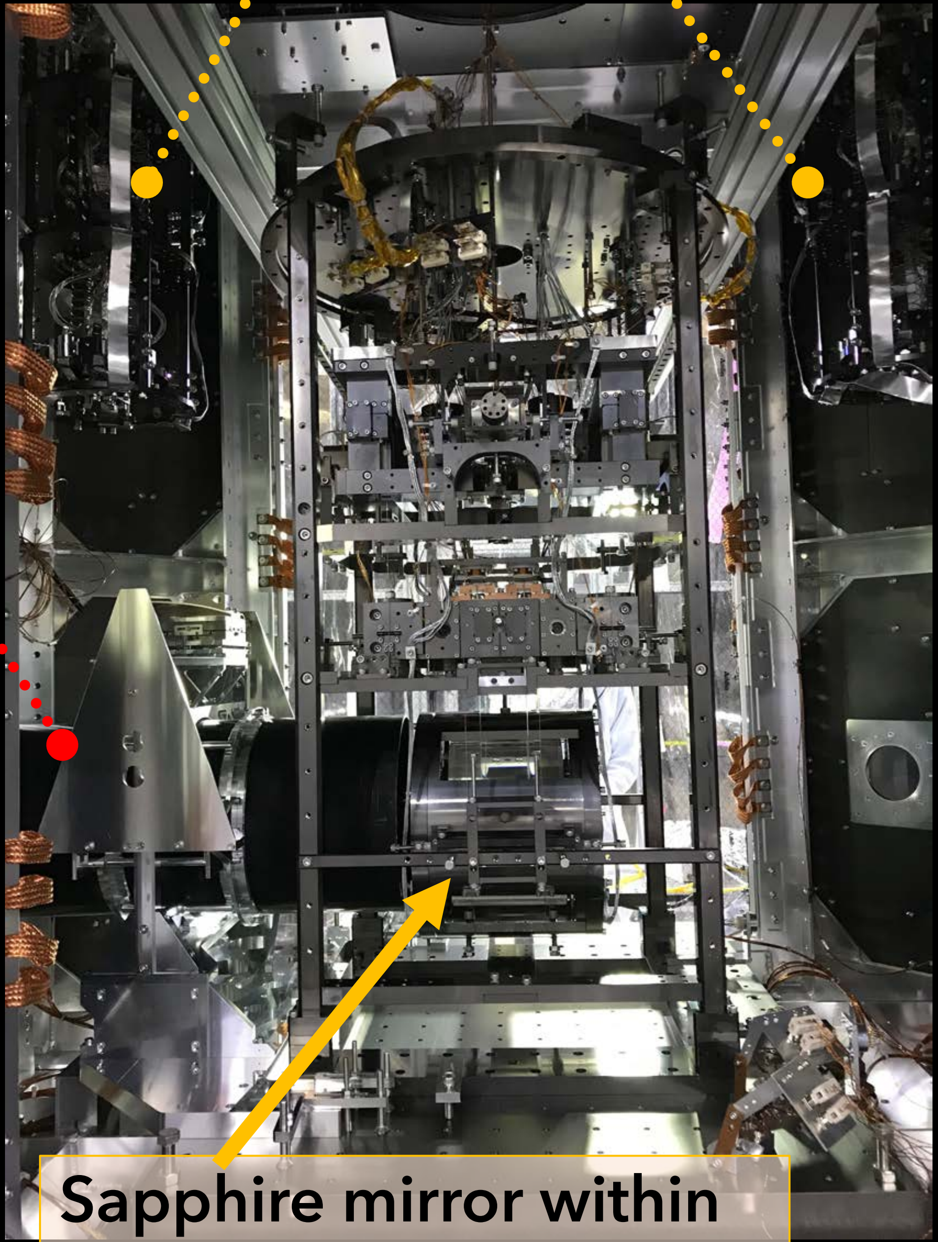
From14 m above



Sapphire mirror

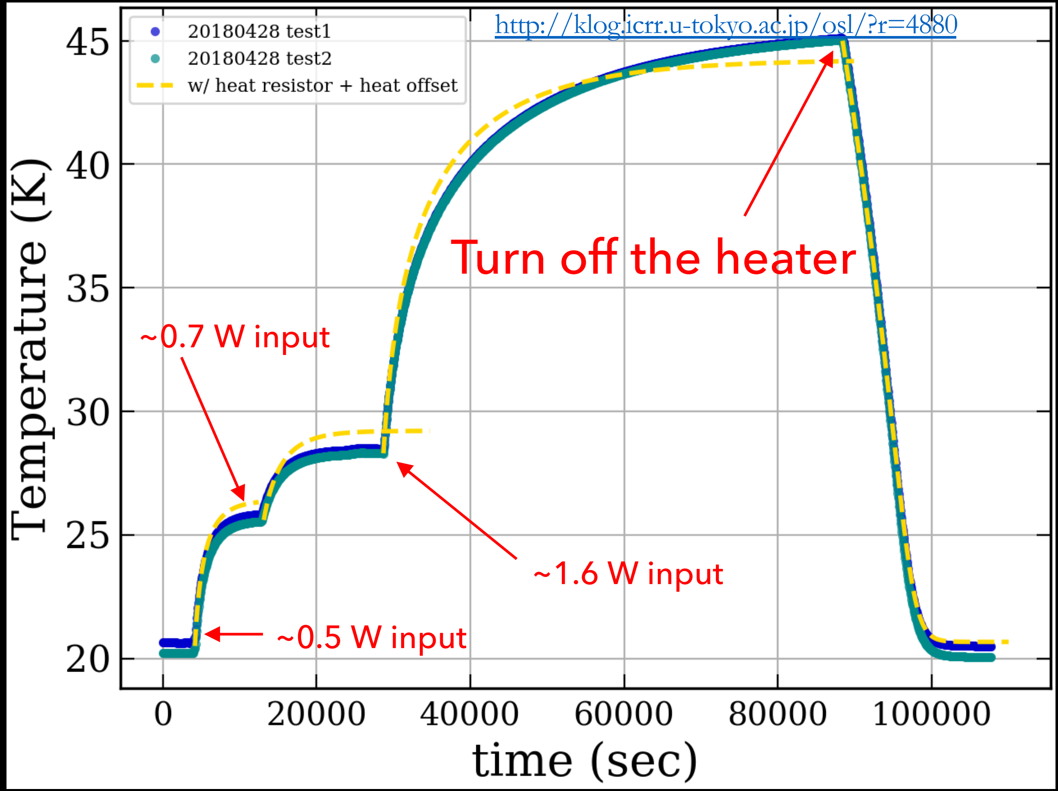
Cryostat 8K shield

Installed in the cryostat



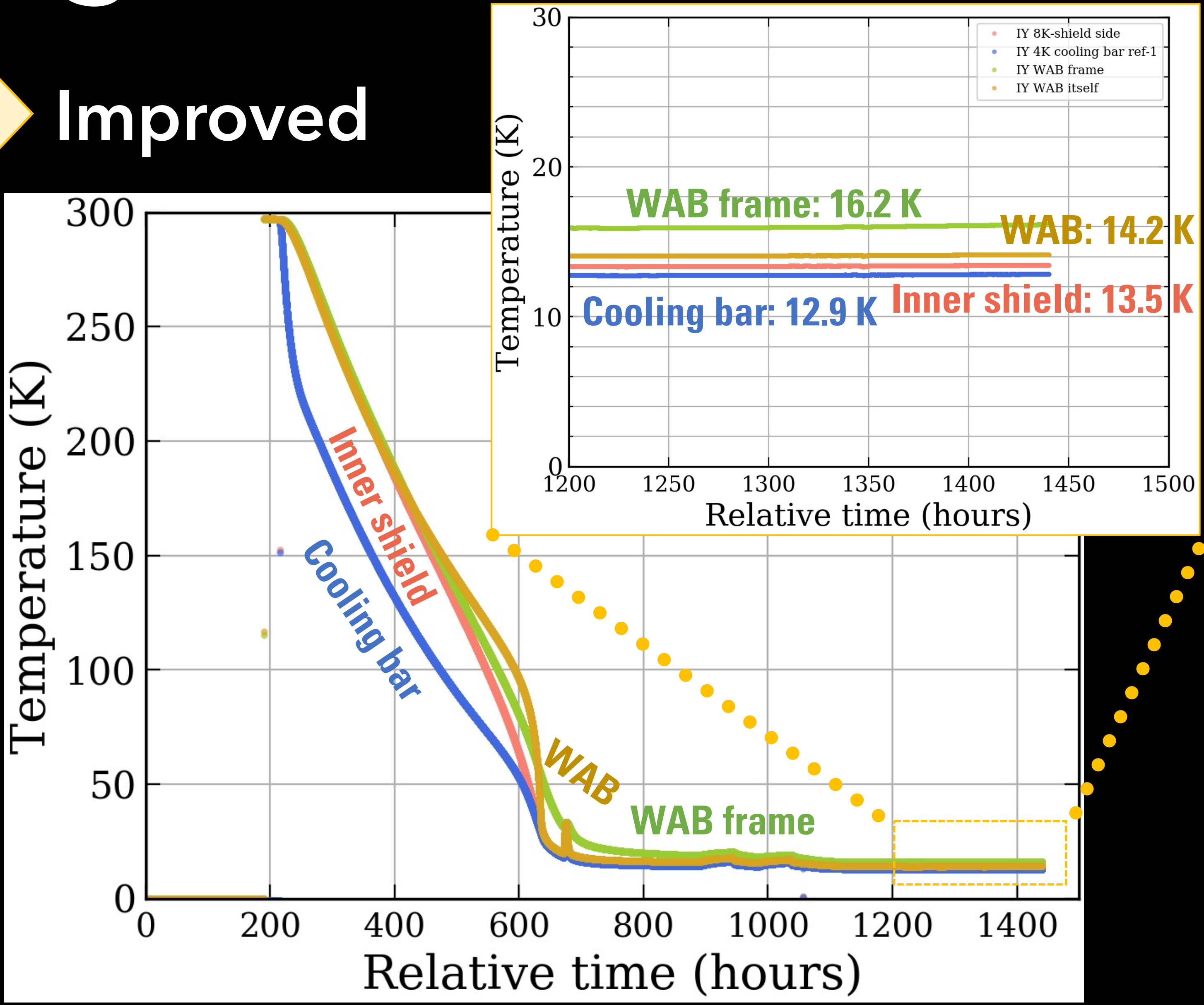
Response to heating

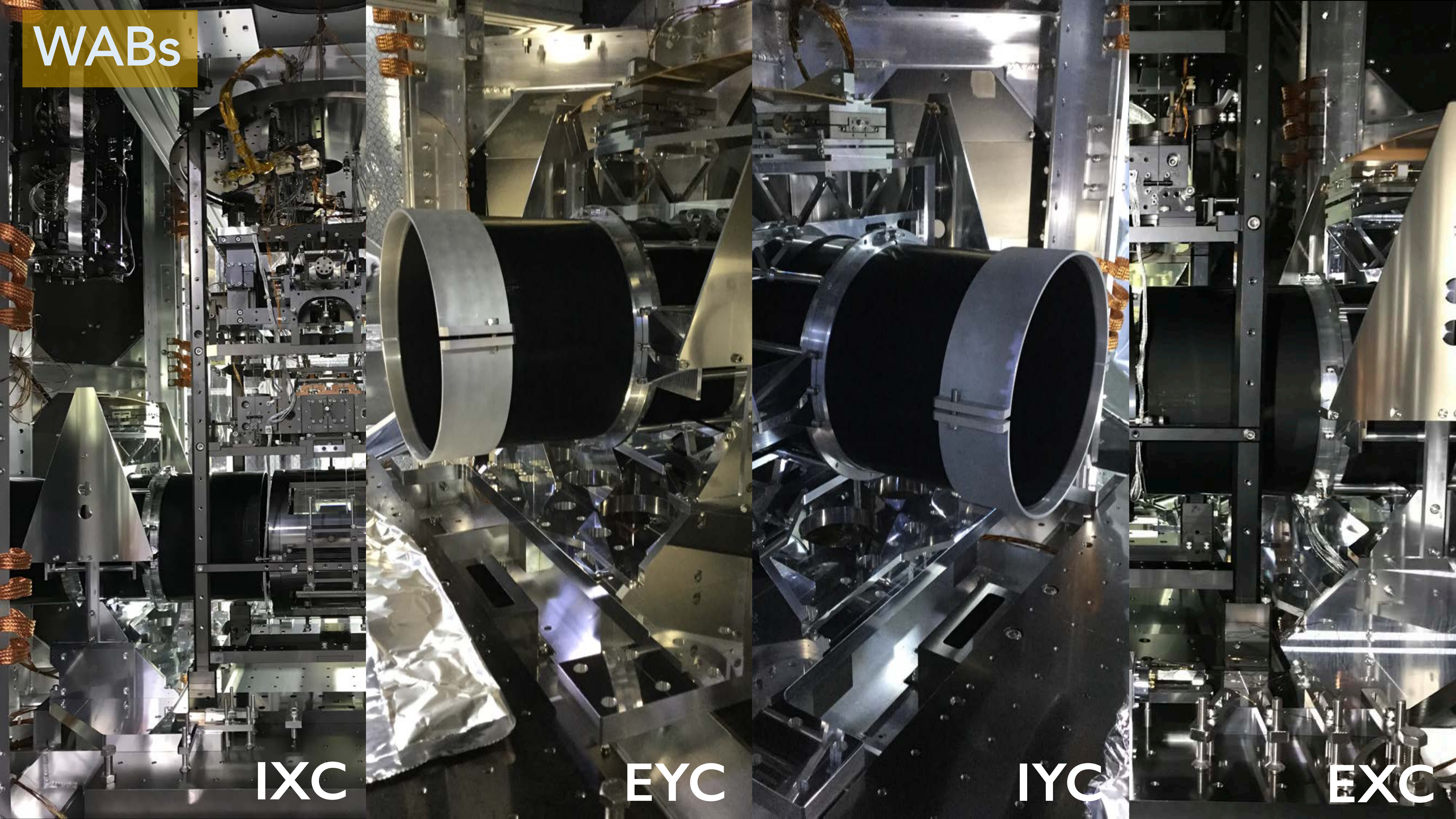
Test: cool down to only 20K



Fit: (assumption) 11.5K/W thermal res., 0.6W offset

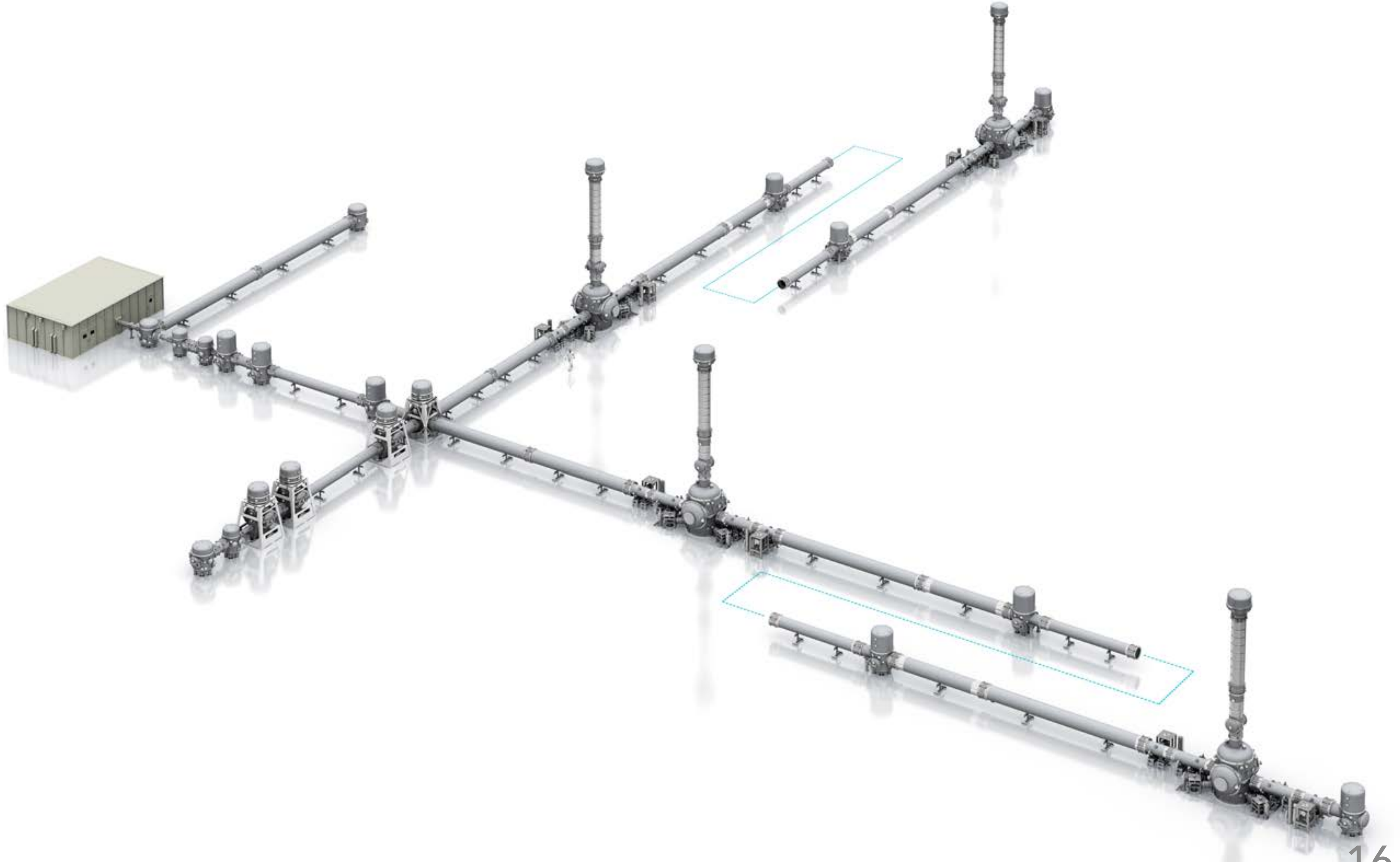
Improved




WABs
IXC
EYC
IYC
EXC

Contents

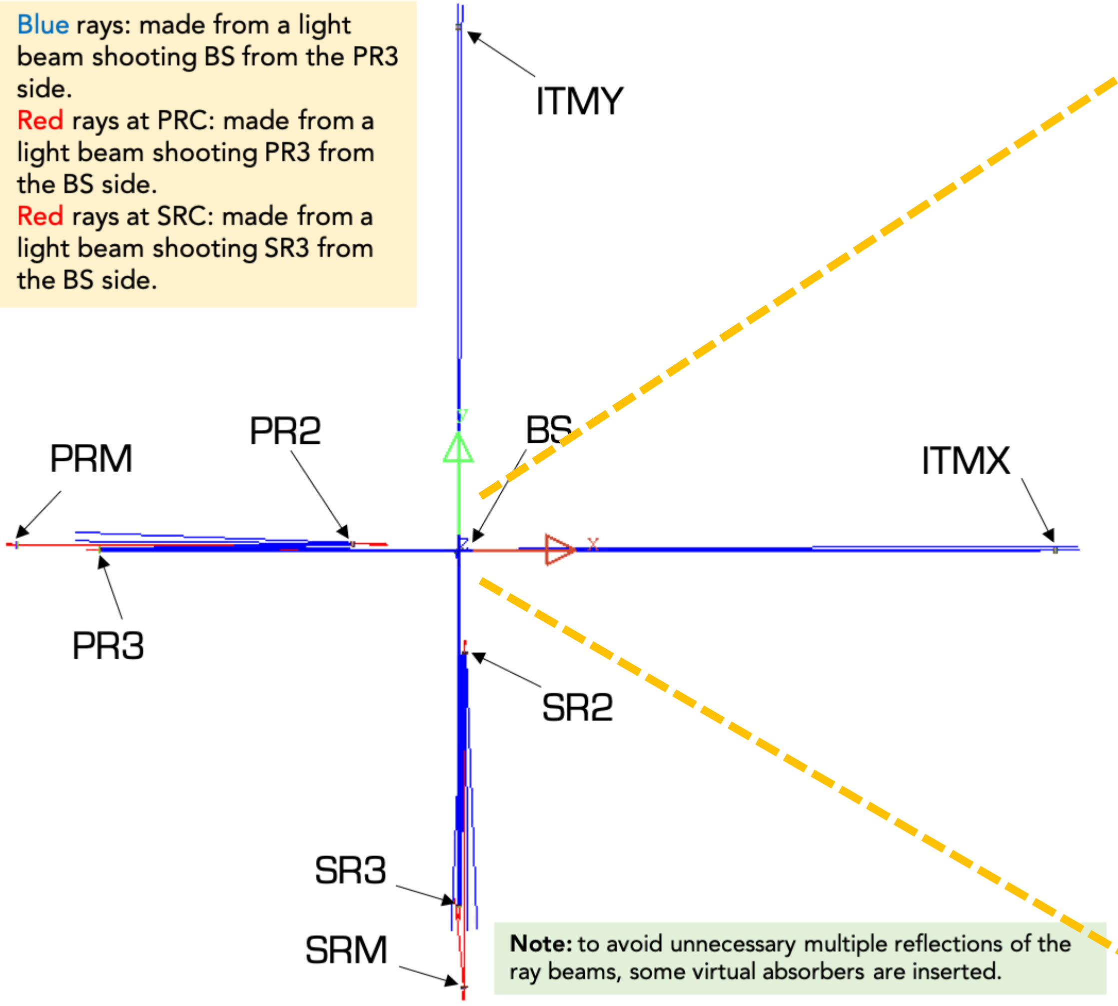
- Until O3GK
- For O4
- Summary



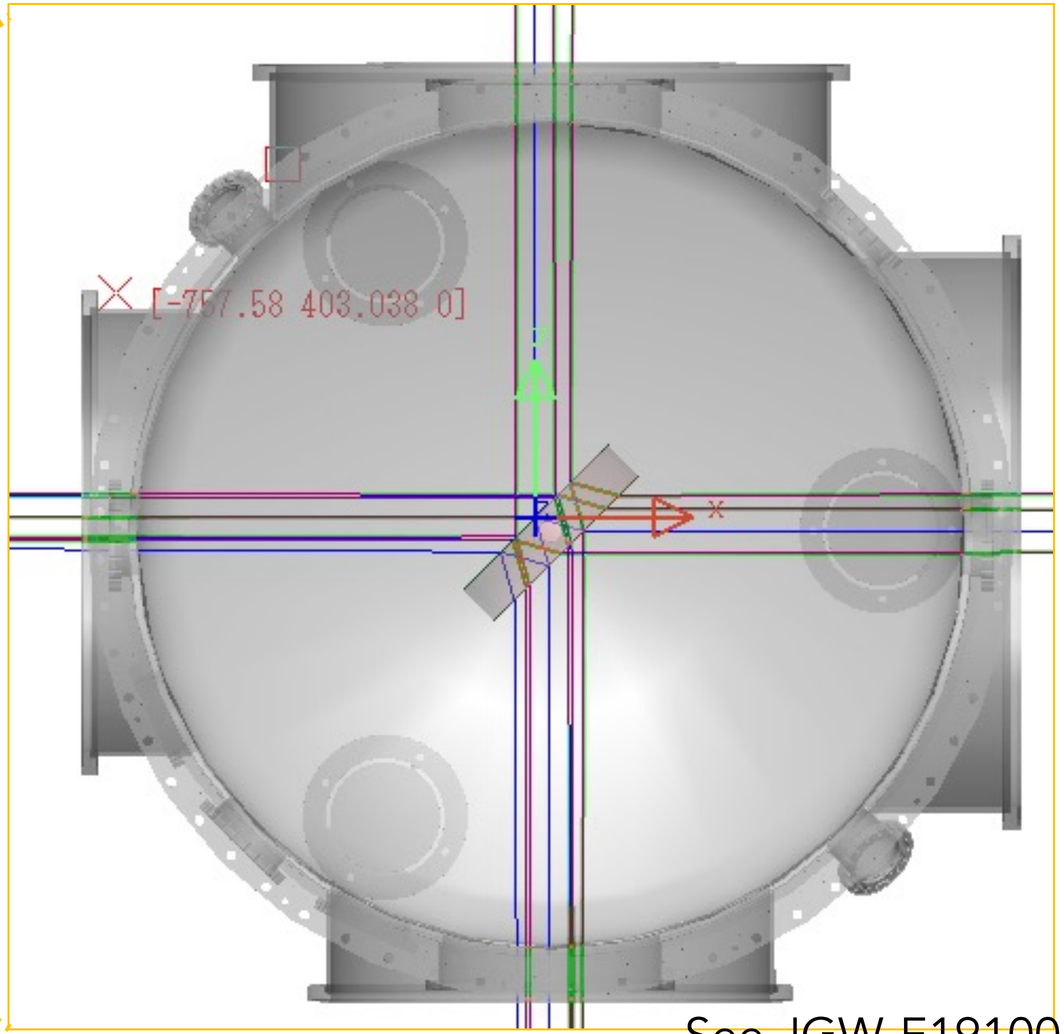
(c) KAGRA Collaboration / Ray.Hori

Ghost beams in the center area

- Blue rays: made from a light beam shooting BS from the PR3 side.
- Red rays at PRC: made from a light beam shooting PR3 from the BS side.
- Red rays at SRC: made from a light beam shooting SR3 from the BS side.



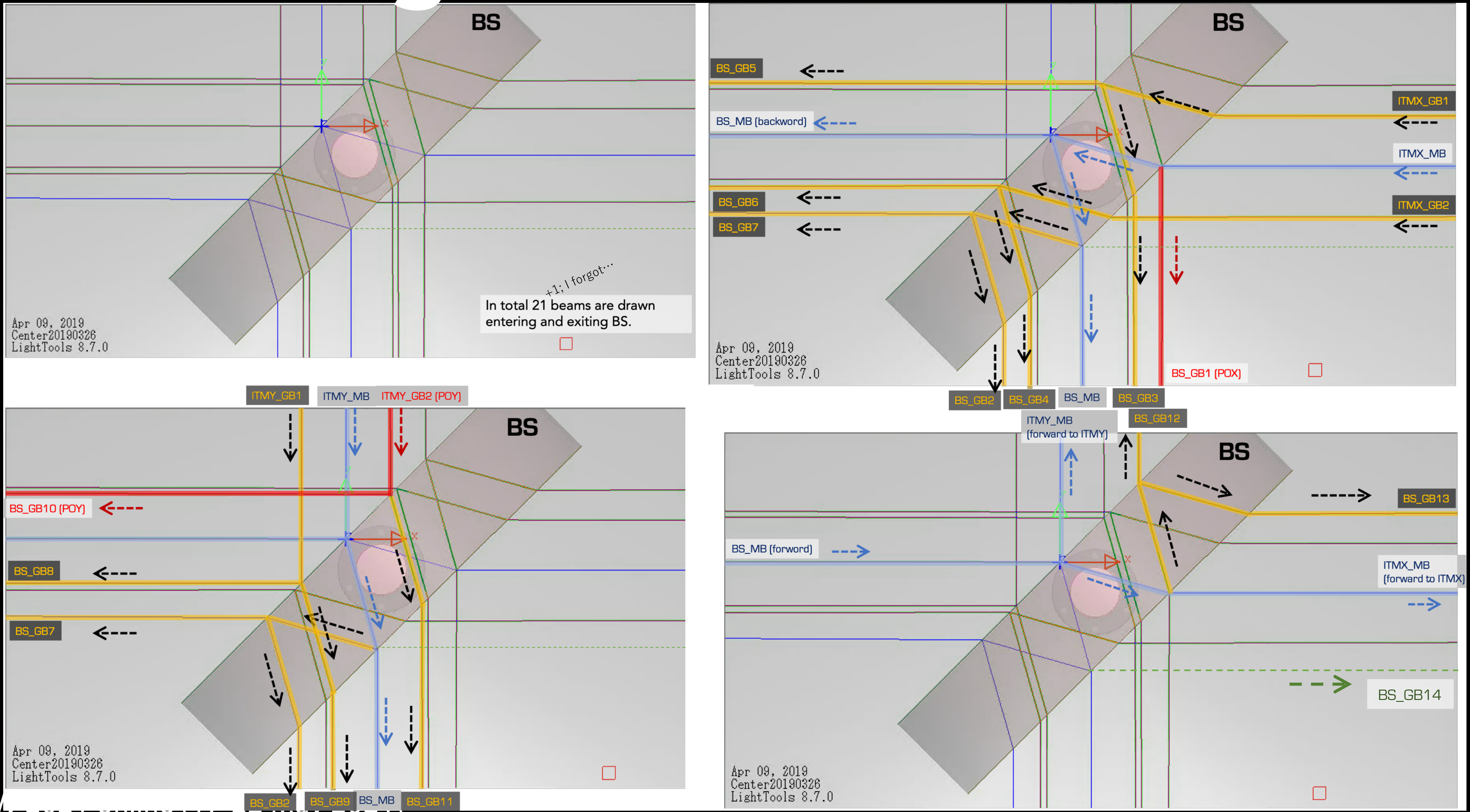
Note: to avoid unnecessary multiple reflections of the ray beams, some virtual absorbers are inserted.

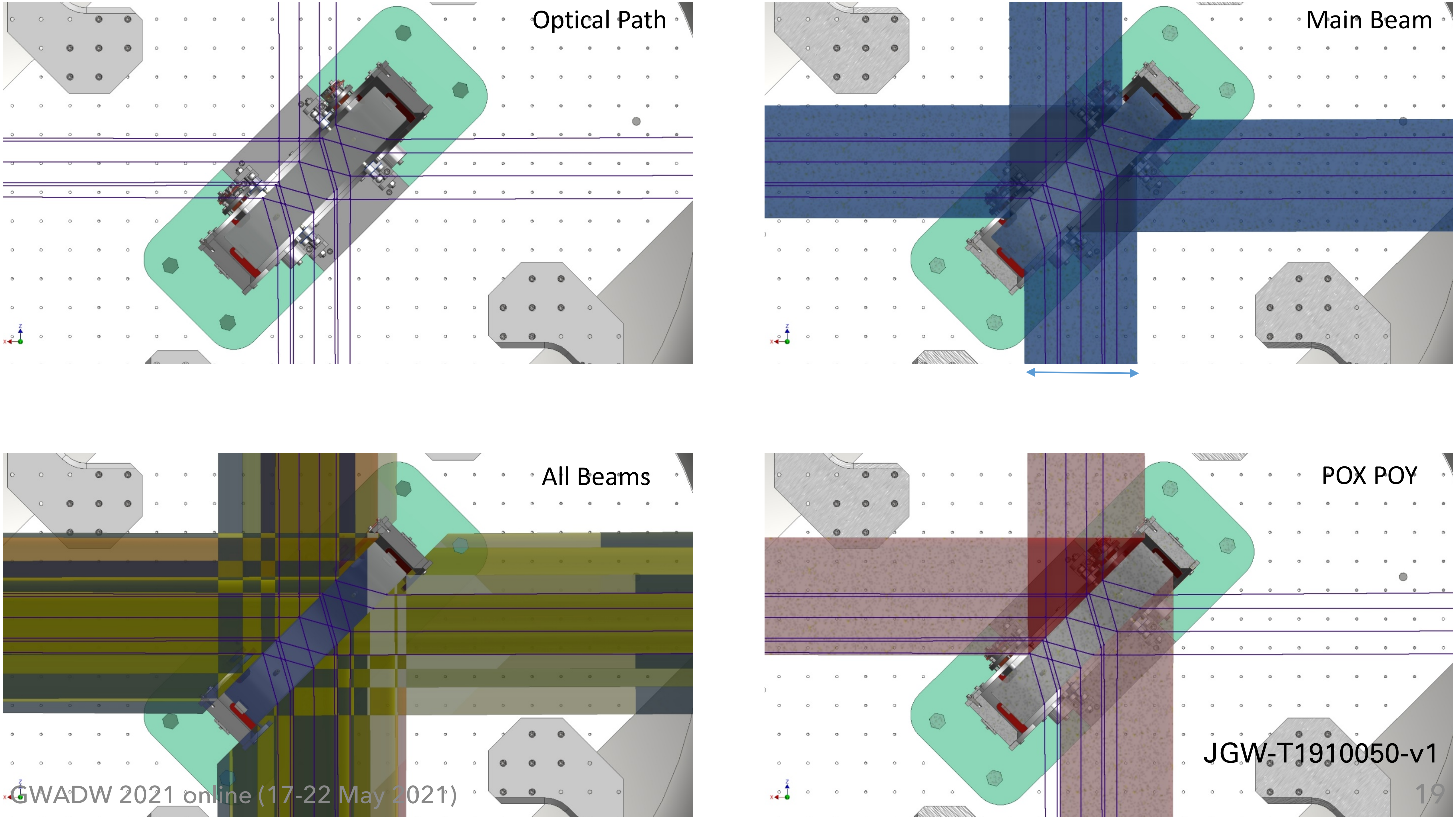


See JGW-E1910040

So much ghost beams…

See JGW-E1910040



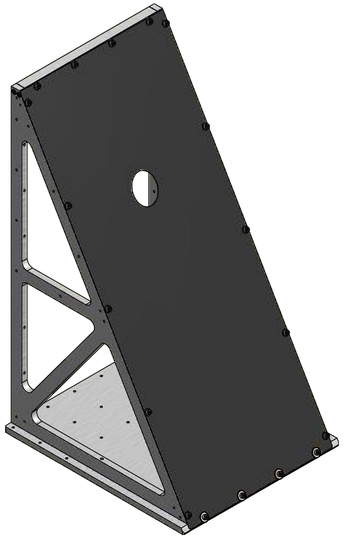


JGW-T1910050-v1

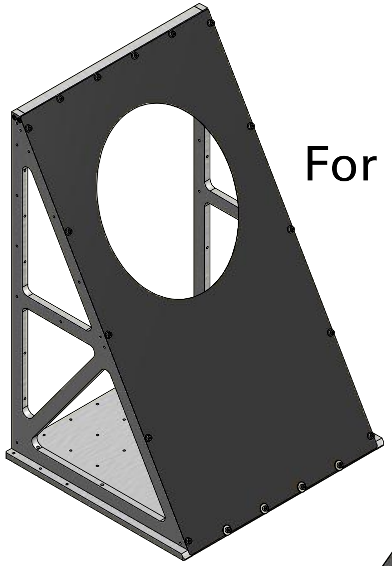
Mid-size baffles

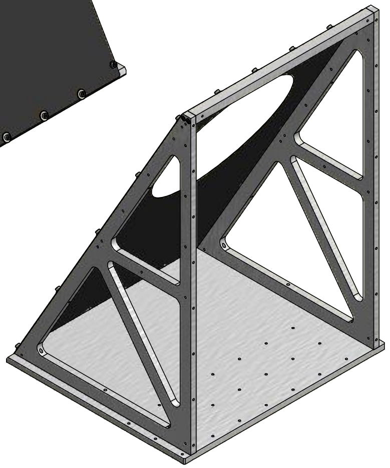
- To catch ghost beams in the center area (BS, PRC, SRC)
- Each a few x 10~100mW

Some examples:



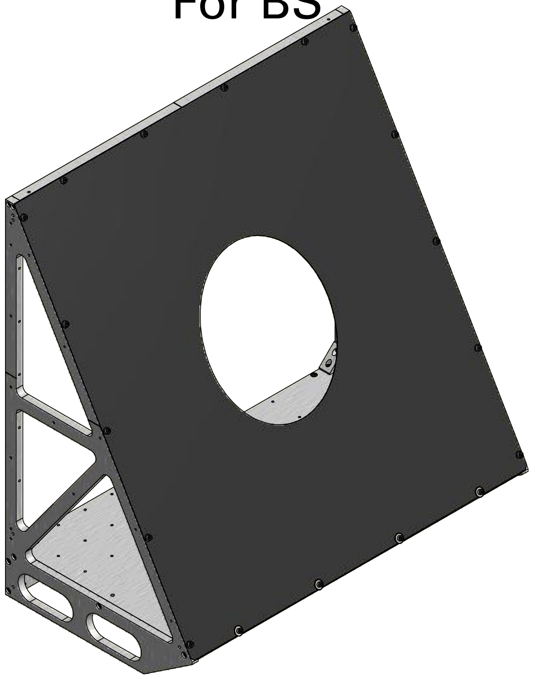
For SR2 HR side





For SR3 HR side

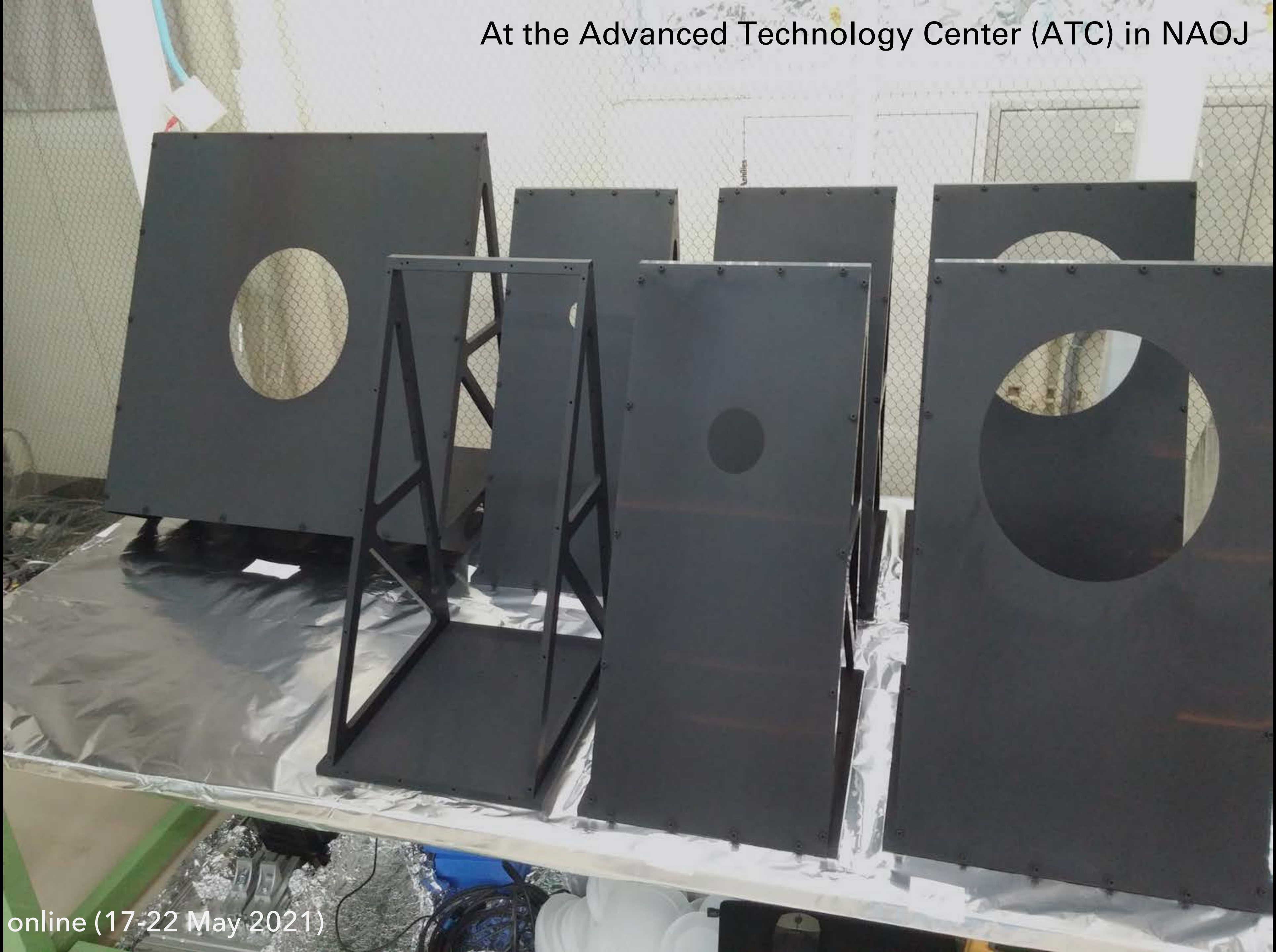
For BS



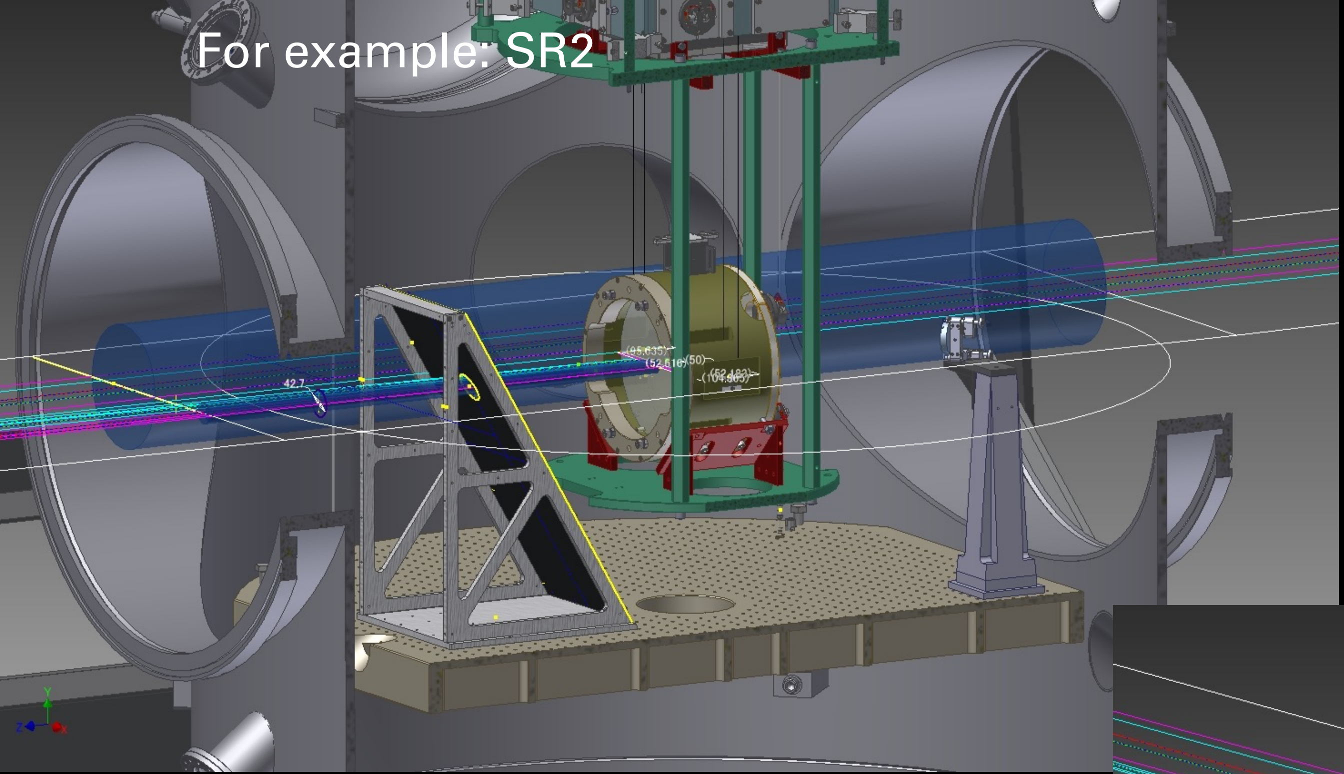
Drawn by N. Hirata

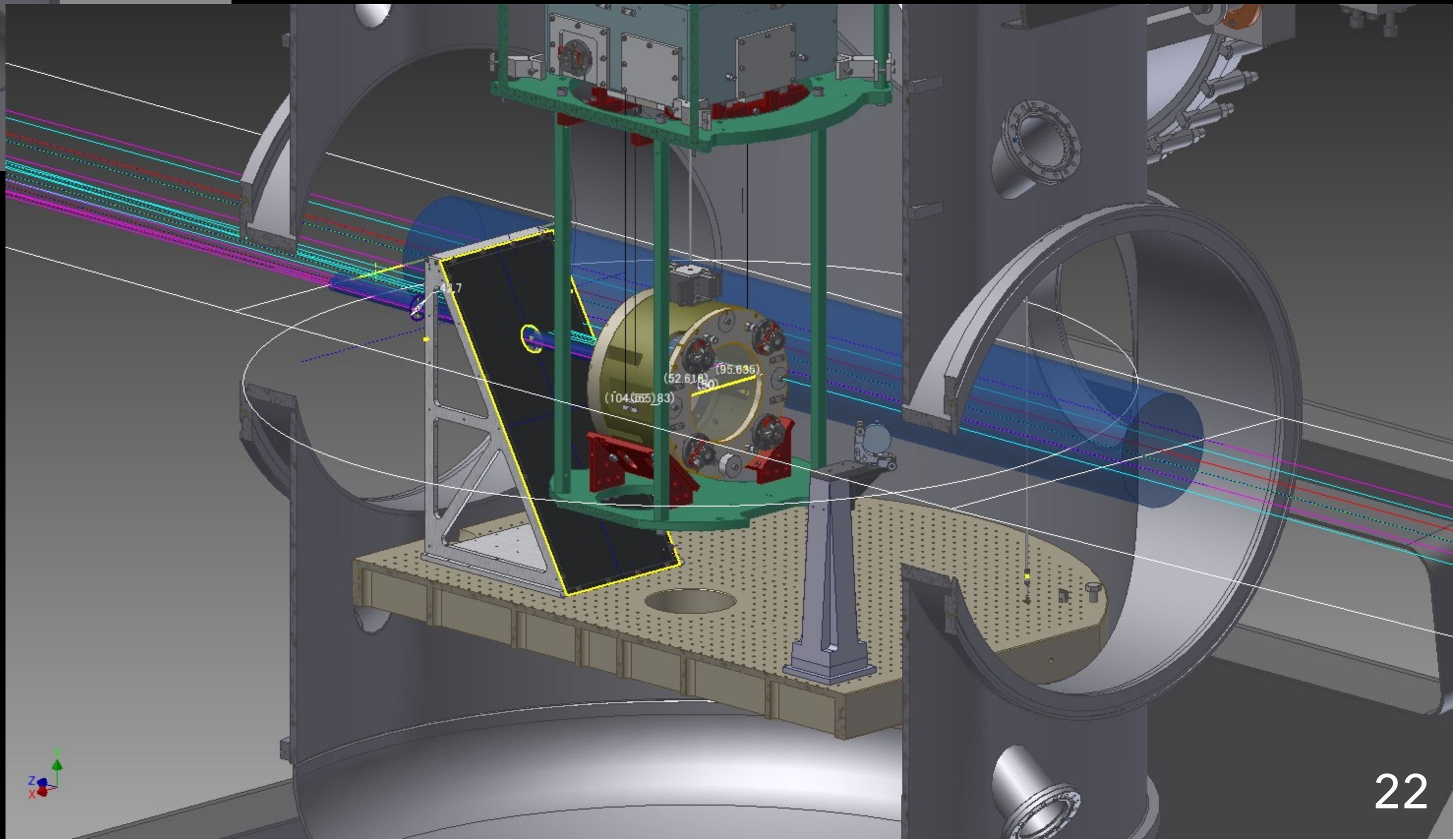
Note that all the sliver-ish parts will be also blackened later.

At the Advanced Technology Center (ATC) in NAOJ



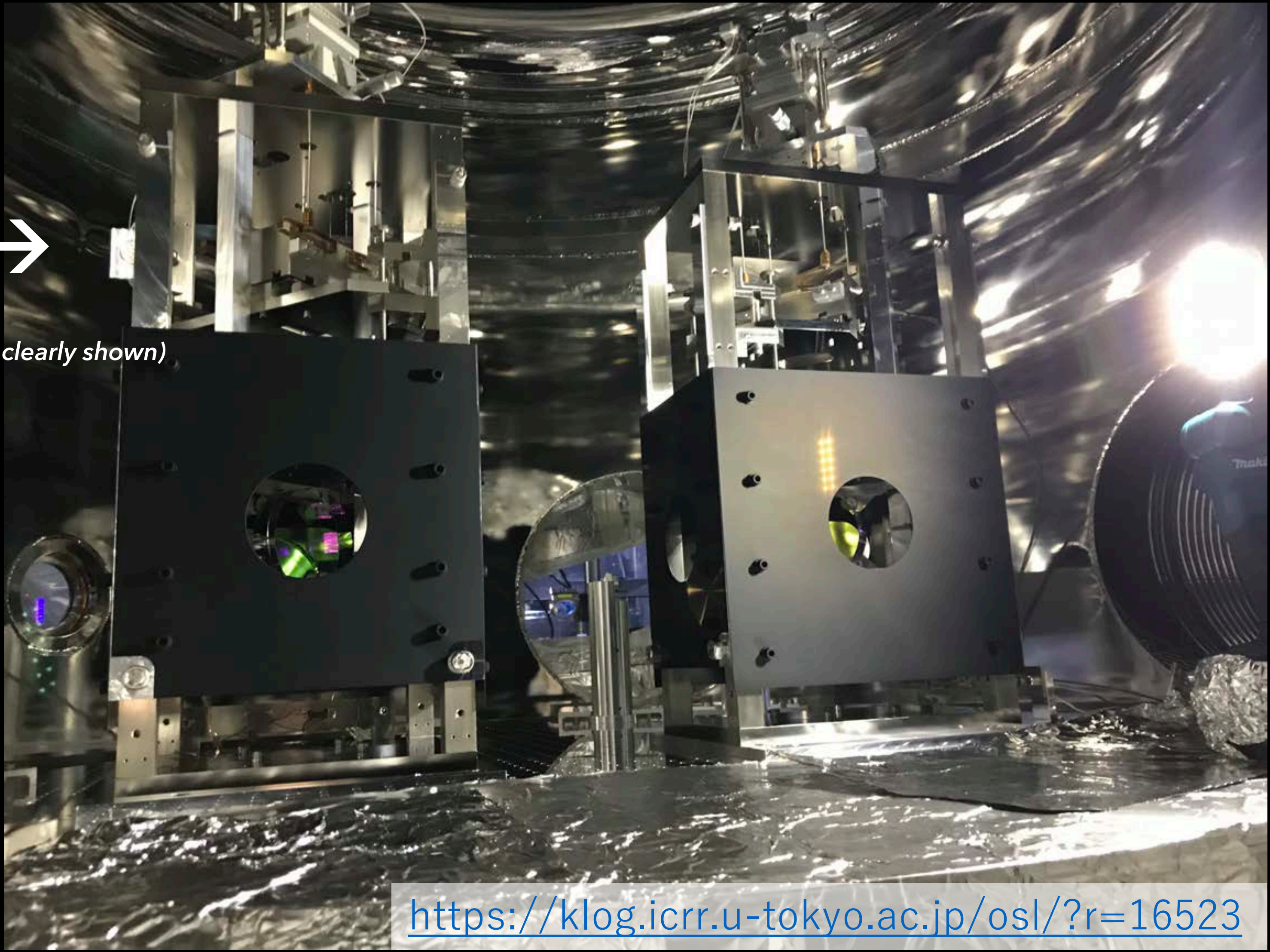
For example: SR2





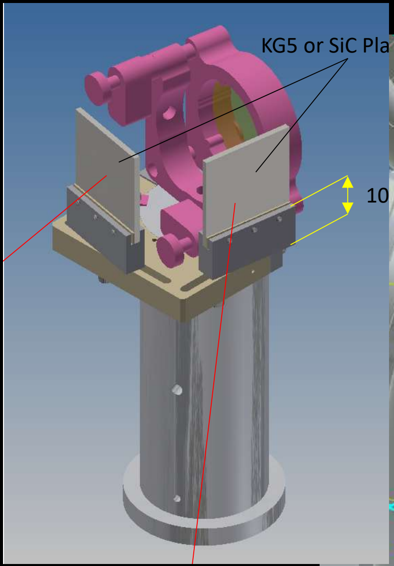
Input optics (IMC)
Input mode cleaner

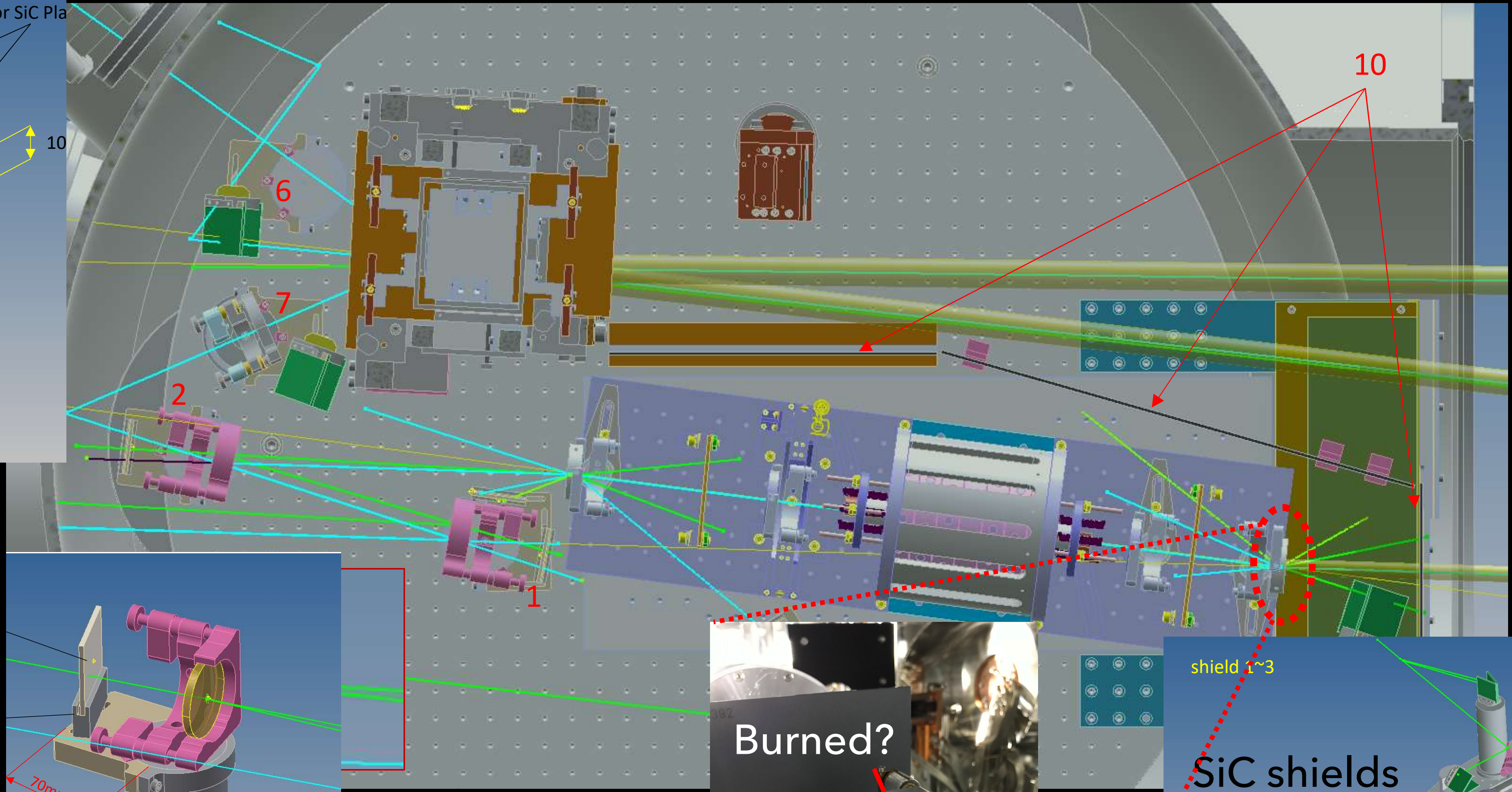
- Shields mainly for safety →
- The other beam dumps *(not clearly shown)*

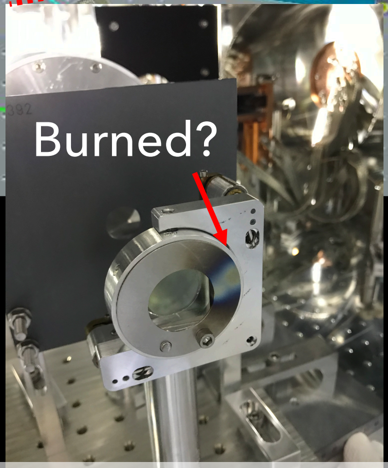


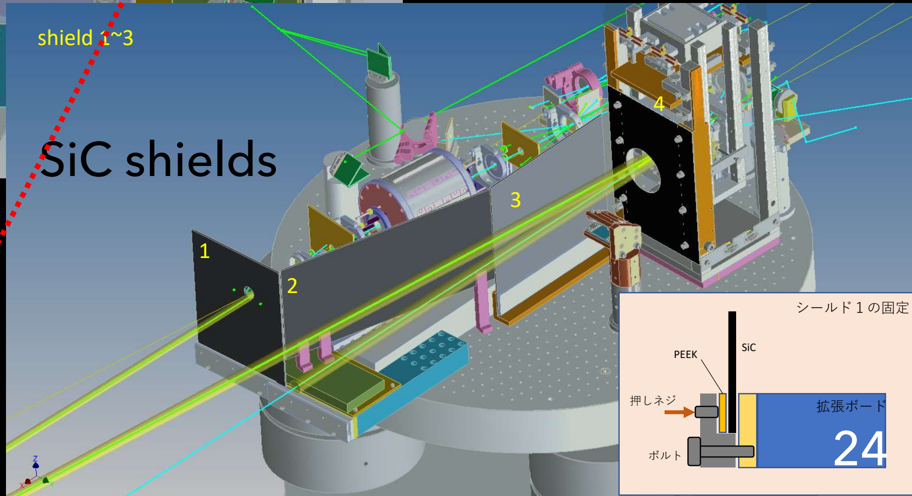
Input optics (IFI)

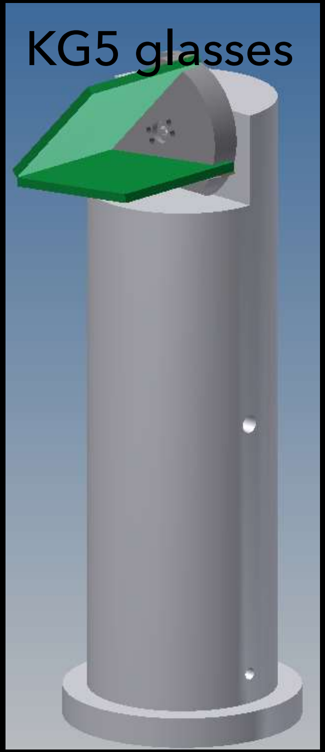
Input Faraday isolator











Beam dump for S-pol beam

https://klog.icrr.u-tokyo.ac.jp/osl/?r=15543

Summary

- KAGRA's large baffle design: a patch work of
  - partly by Monte-Carlo ray trace
  - partly by theoretical(?) calcs. [e.g. phase accumulation]
  - partly by considering diffraction…

  → Need further investigations
- Materials:
  - Ni black plating → Large and mid-size baffles/shields
  - KG5, SiC -> beam dumps
- Until O3: most of the baffles in the arms have been installed.
- By O4: cares for the central part will be done.