Calibration of Pcal laser power in O3GK

University of Toyama

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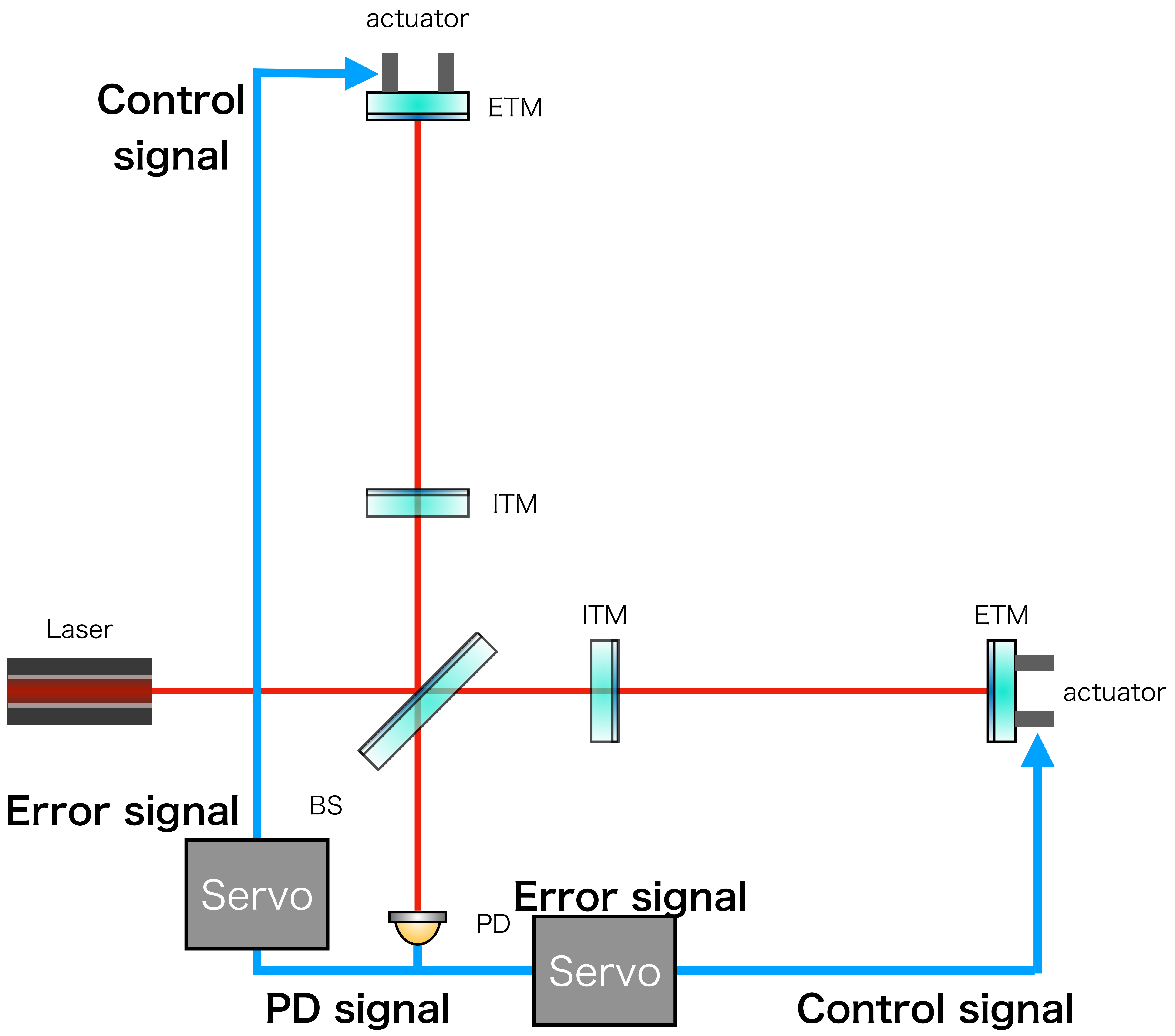
Outline

- Introduction
- Photon calibrator (Pcal)
- Calibration of Pcal laser power sensor
- Result calibration in O3GK
- Summary and Future plan

Introduction

- KAGRA is a Michelson interferometer-based gravitational wave telescope.
- The gravitational waves can be observed with a PD as the intensity of interference light.
- The PD signal is feedback to the actuator.
- Error signal → Gravitational wave signal



Introduction

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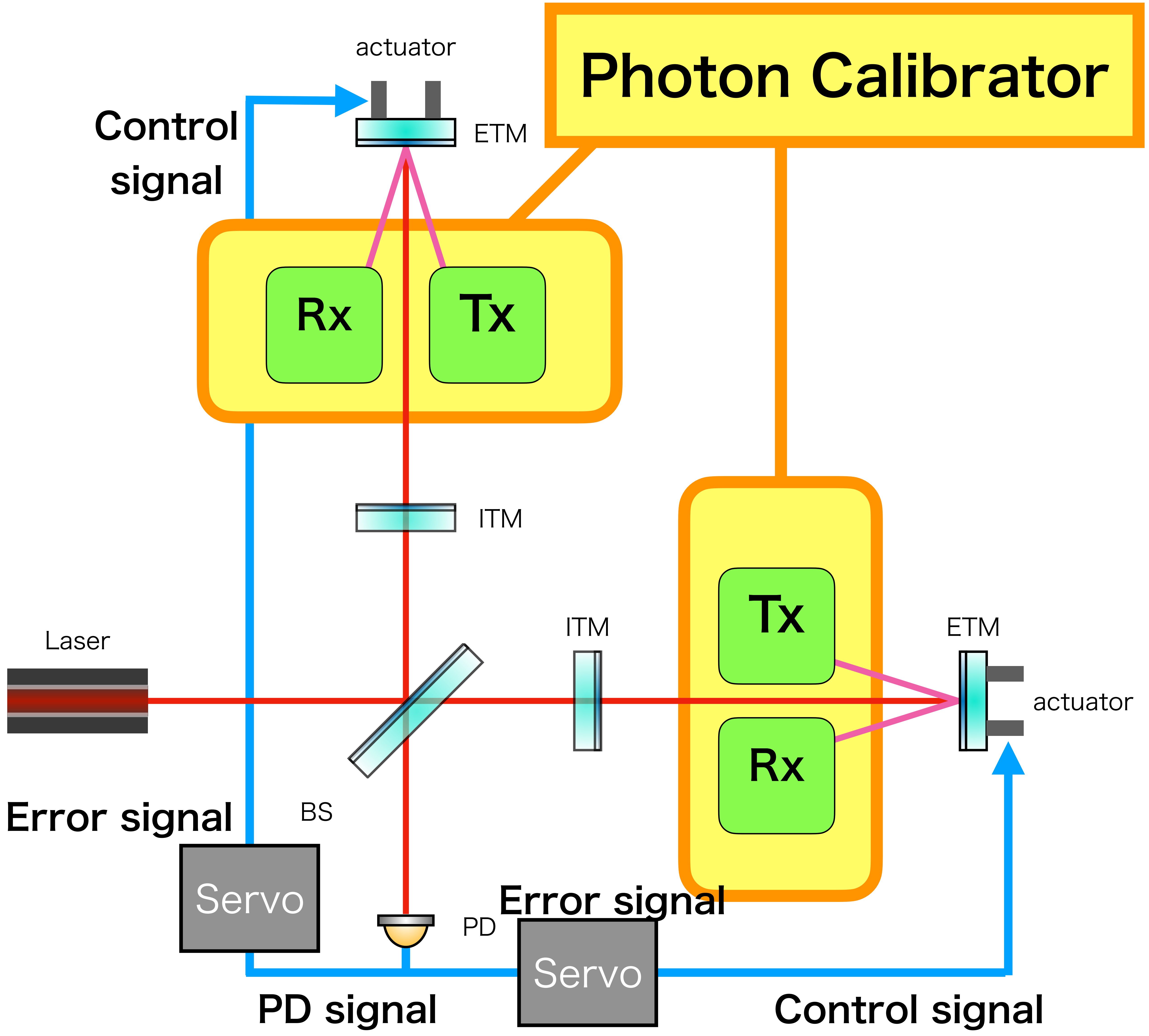


Photon calibrator

The calibration system that uses the radiation pressure of the additional laser.

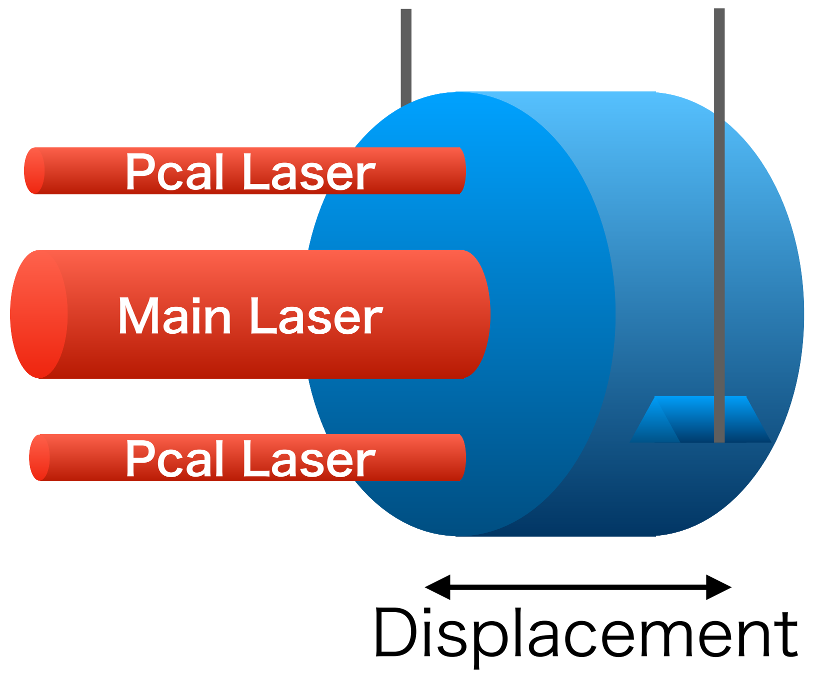
Photon calibrator (Pcal)

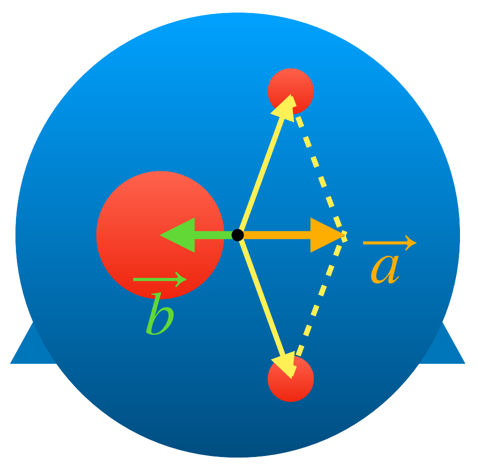
Transmitter module (Tx module)

- Emit two power stabilized lasers.
- Measure two laser powers.

Receiver module (Rx module)

- Measure the sum of the two laser powers.

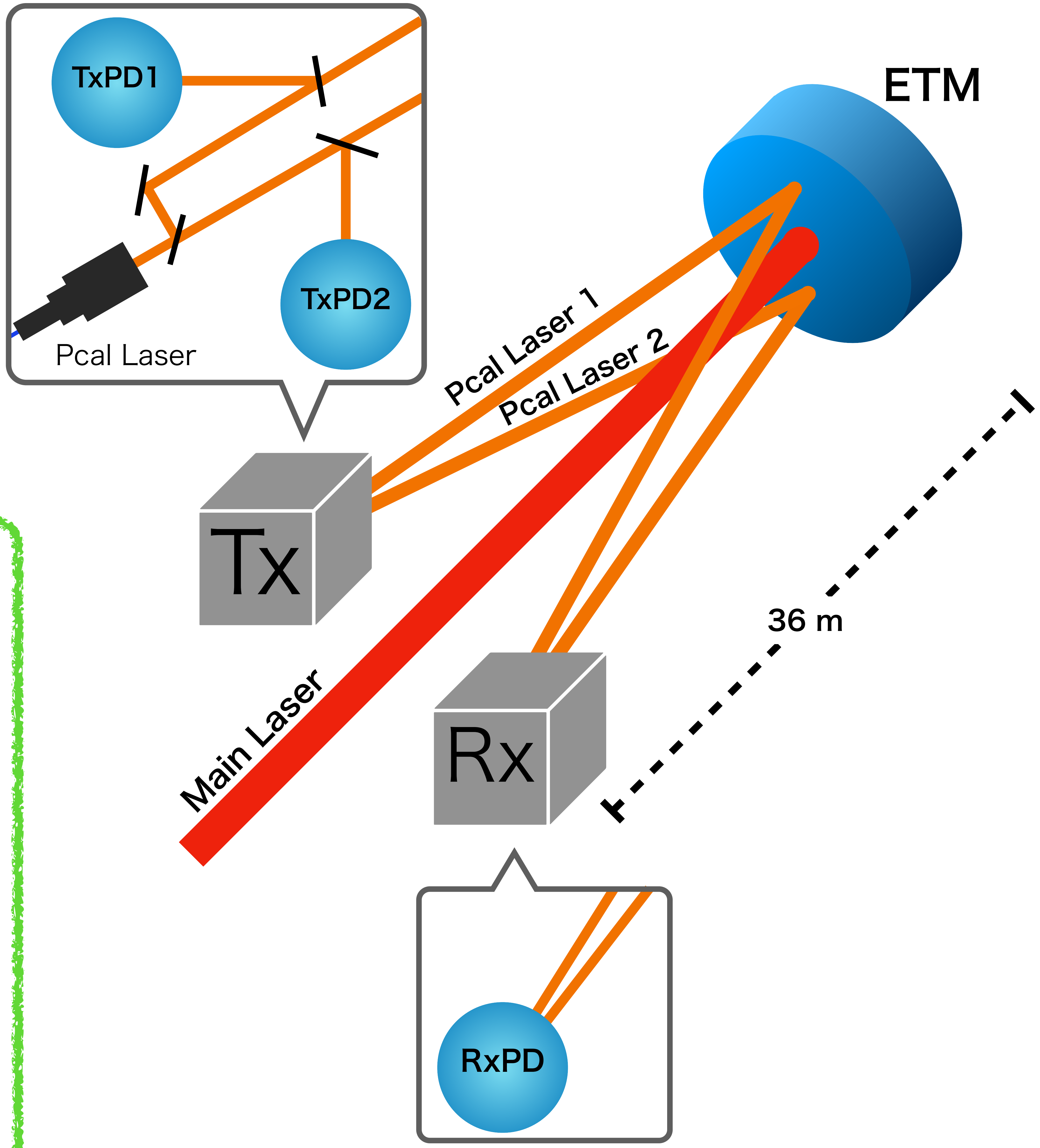




Displacement of the mirror given by the Pcal laser

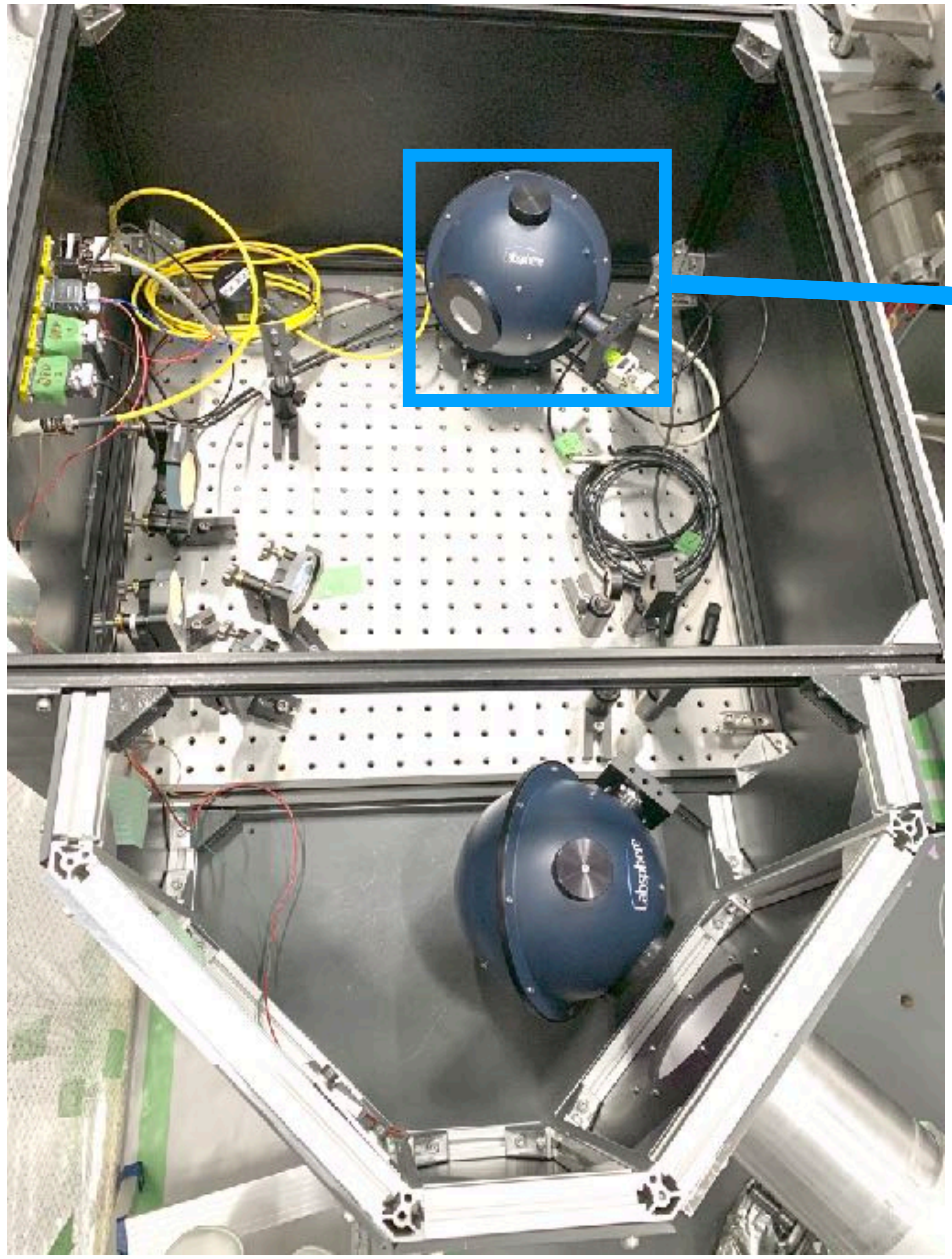
$$x(\omega) = \frac{2P\cos\theta}{cM\omega^2}\left(1 + \frac{M}{I}(\vec{a}\cdot\vec{b})\right)$$

- x Mirror displacement
- P Pcal laser power
- θ Incident angle of PCal laser
- c Speed of light
- M Mirror mass
- ω Angular frequency
- I Moment of inertia of mirror
- $\vec{a}$ PCal laser displacement vector
- $\vec{b}$ Main laser displacement vector

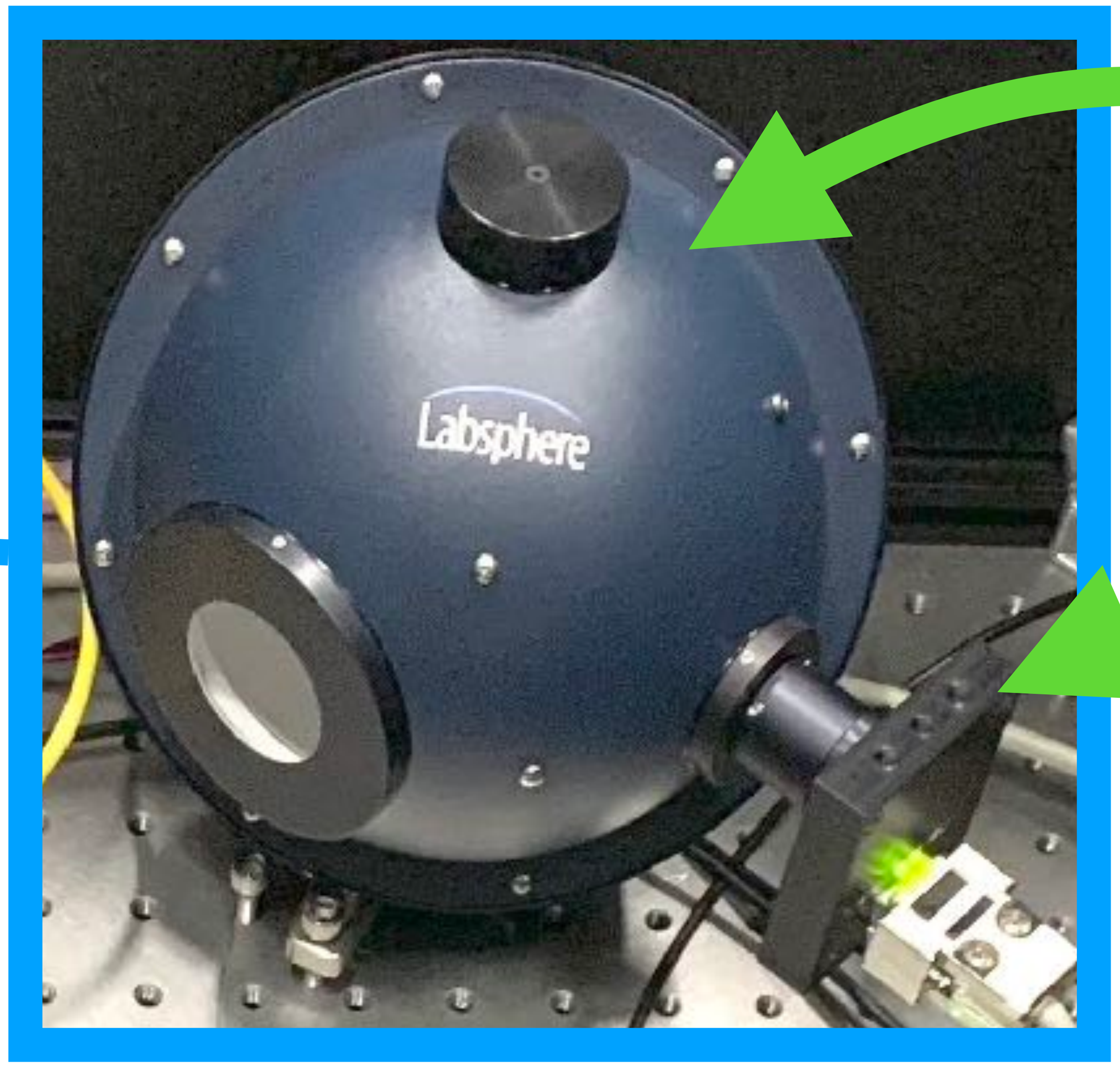


Pcal laser power sensor

TxPD and RxPD are an integrating sphere based power sensor.



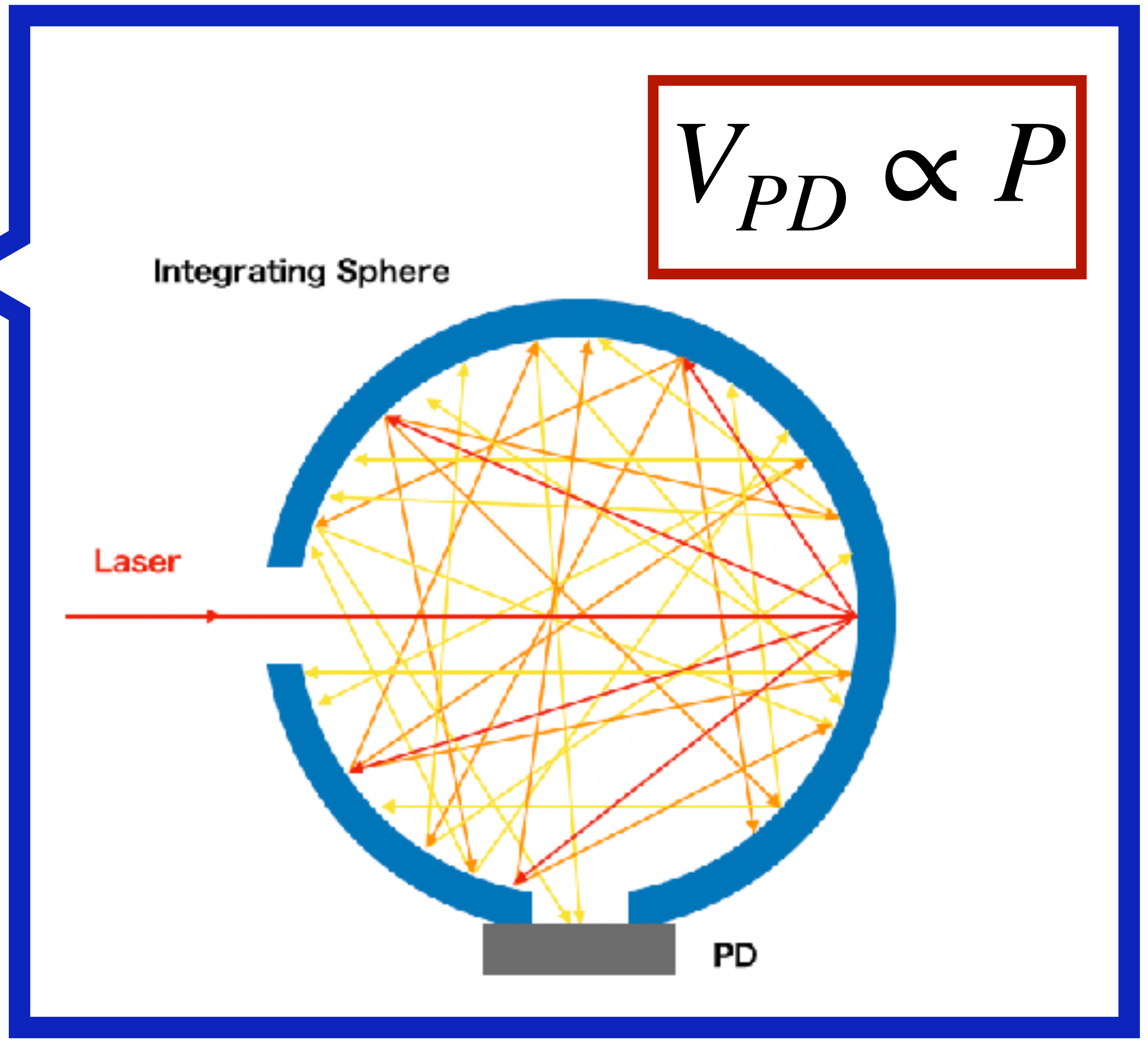
Rx module



RxPD

Integrating sphere

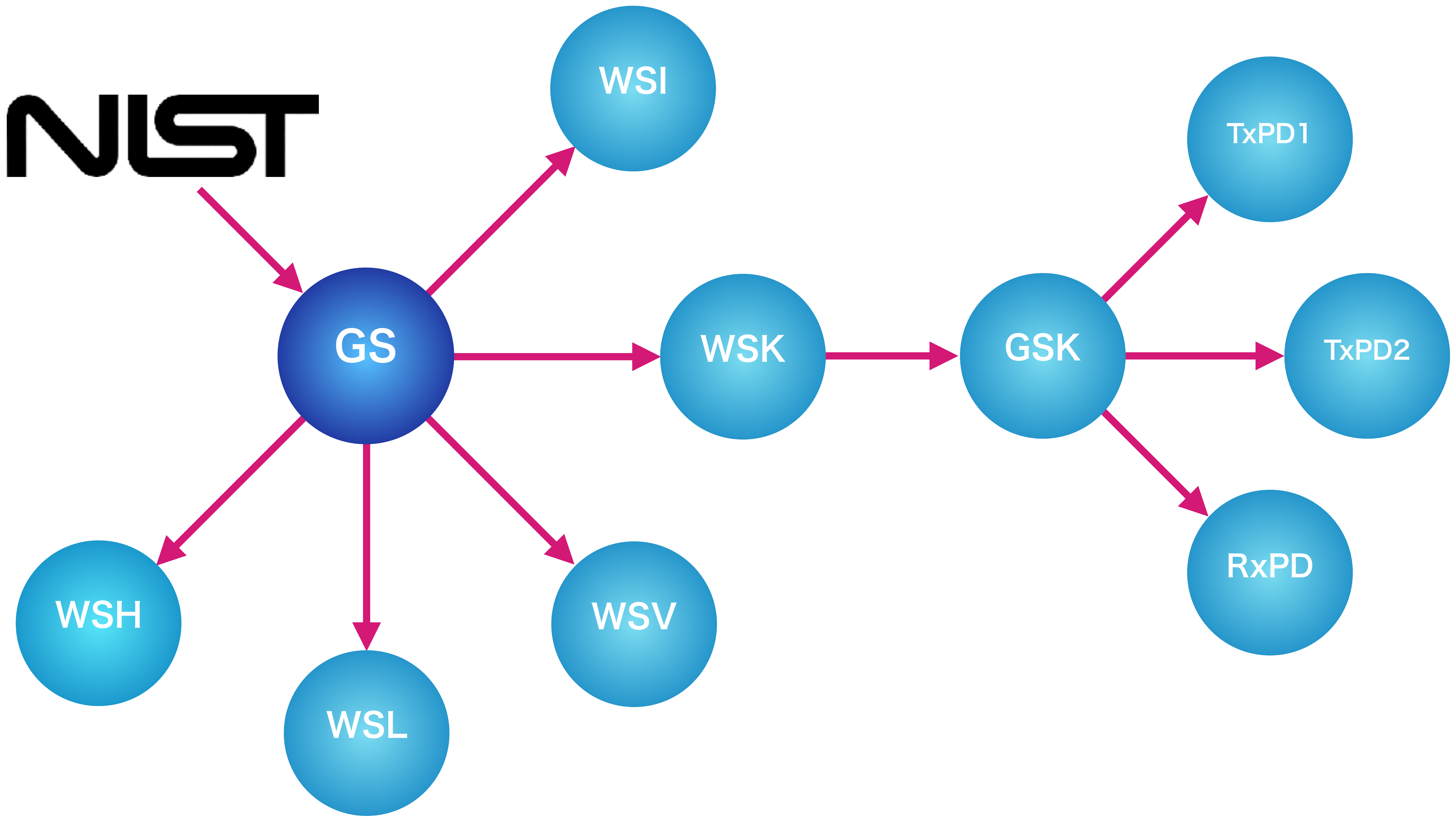
Photodetector



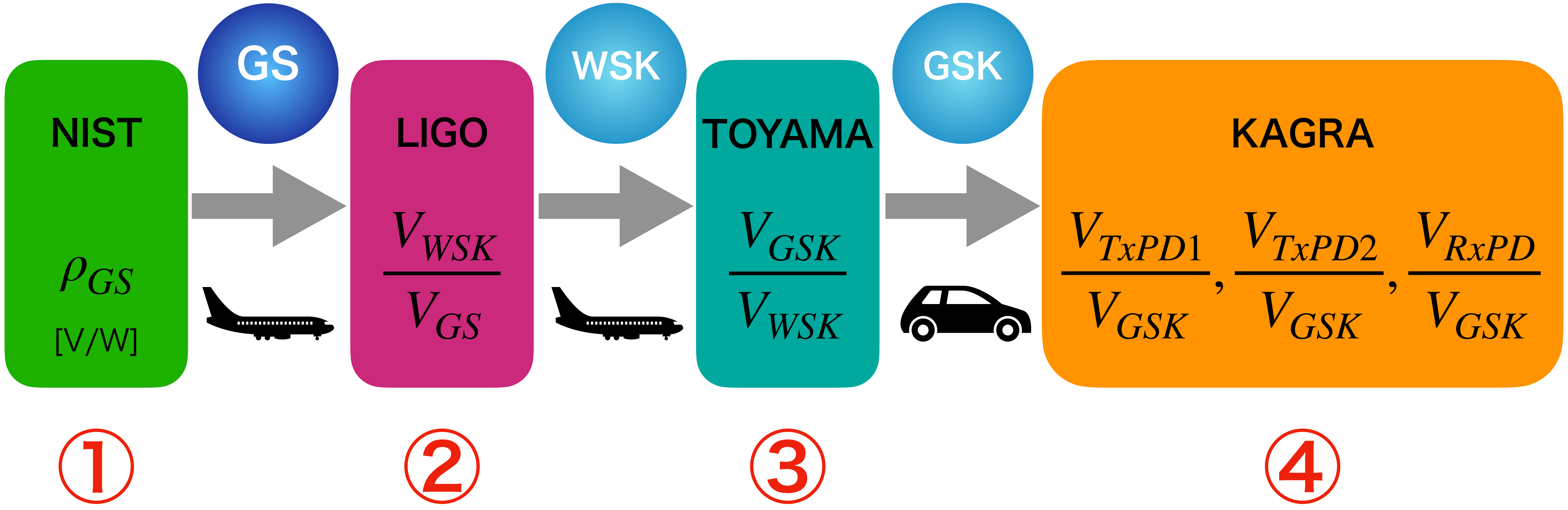
We need the Calibration factor $\rho_{PD} = \frac{V_{PD}}{P}$ [V/W] .

We measure ρ_{PD} by compare with the **NIST** calibrated integrating sphere.

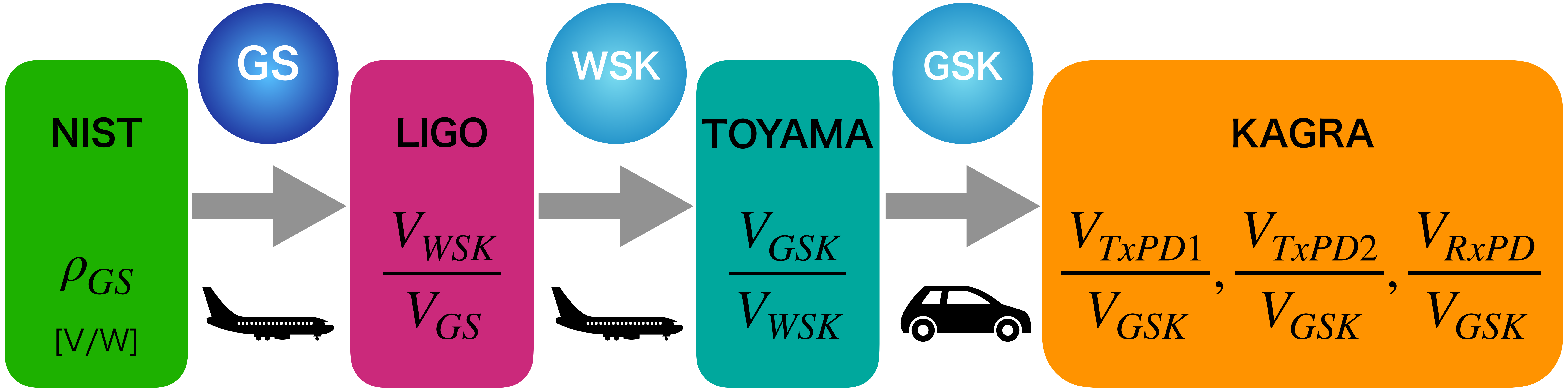
Calibration of Pcal laser power sensor



Calibration of KAGRA Pcal laser power sensor



Calibration of KAGRA Pcal laser power sensor



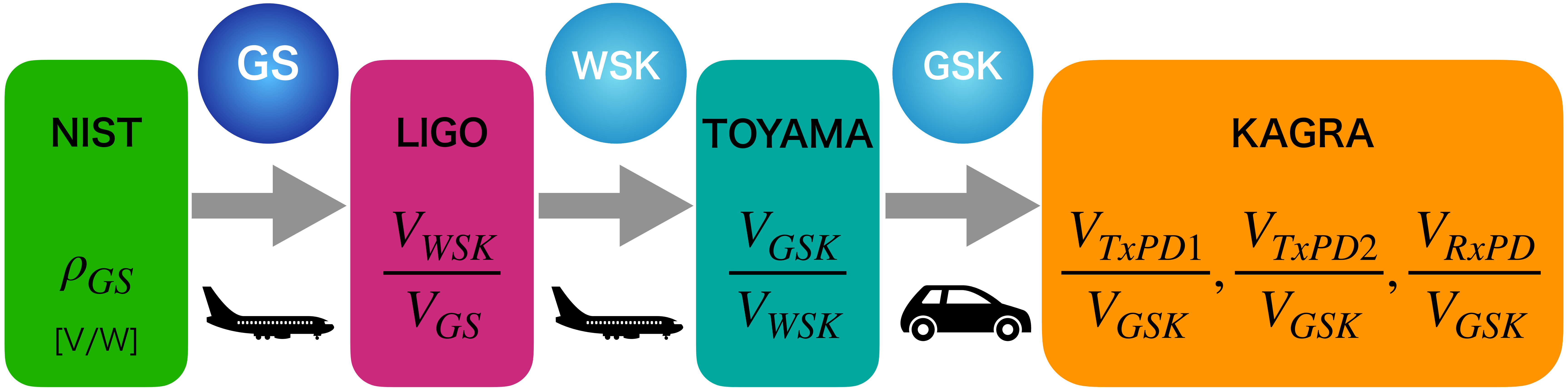
NIST

Calibration factor : $\rho_{GS} = \dfrac{V_{GS}}{P_{NIST}}$ [V/W]

V_{GS} ··· GS output voltage,

P_{NIST} ··· the laser power of NIST

Calibration of KAGRA Pcal laser power sensor



LIGO

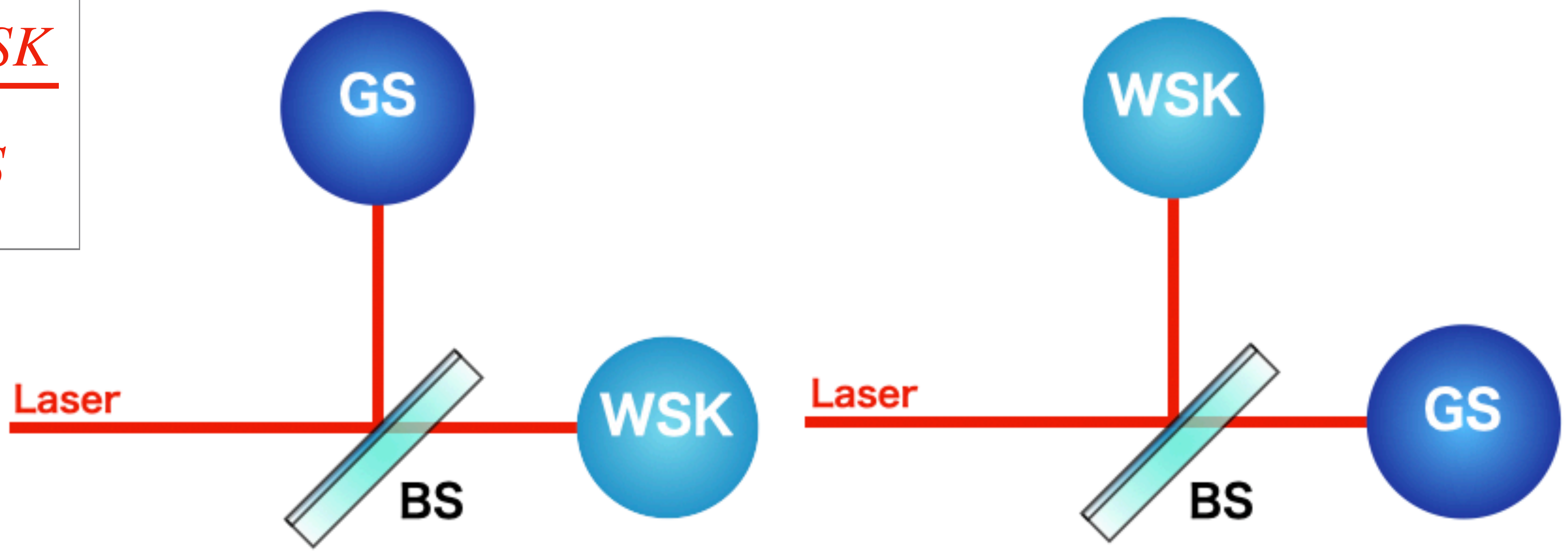
$$\frac{V_{WSK}}{V_{GS}} = \sqrt{\frac{V_{WSK_T} \times V_{WSK_R}}{V_{GS_R} \times V_{GS_T}}} = \sqrt{\frac{tP\rho_{WSK} \times rP\rho_{WSK}}{rP\rho_{GS} \times tP\rho_{GS}}}$$

V_{WSK} ⋯ WSK output voltage, V_{GS} ⋯ GS output voltage,

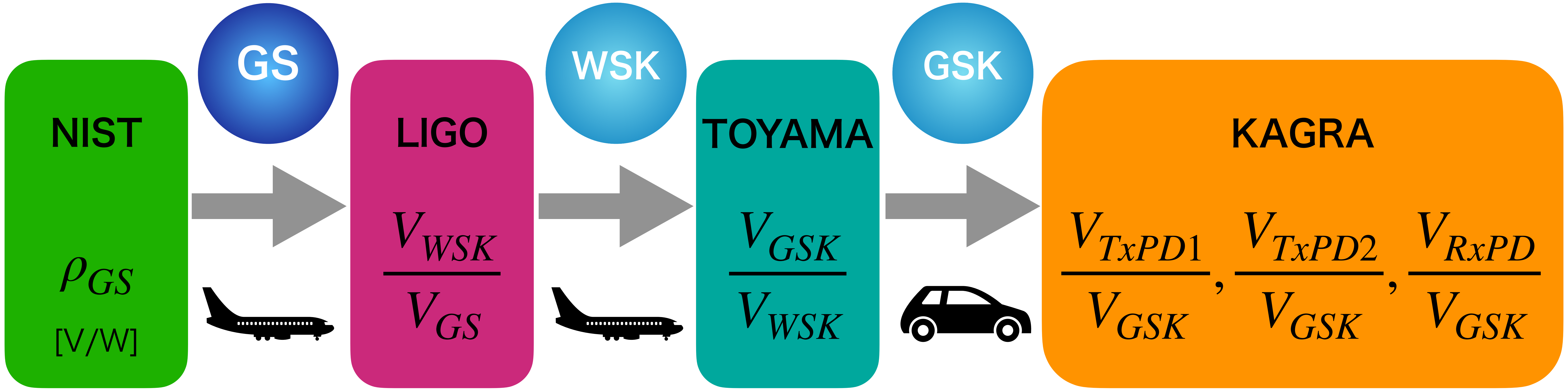
P ⋯ Laser power incident on BS

ρ ⋯ Responsivity of each integrating sphere

t ⋯ BS transmittance , r ⋯ BS reflectance

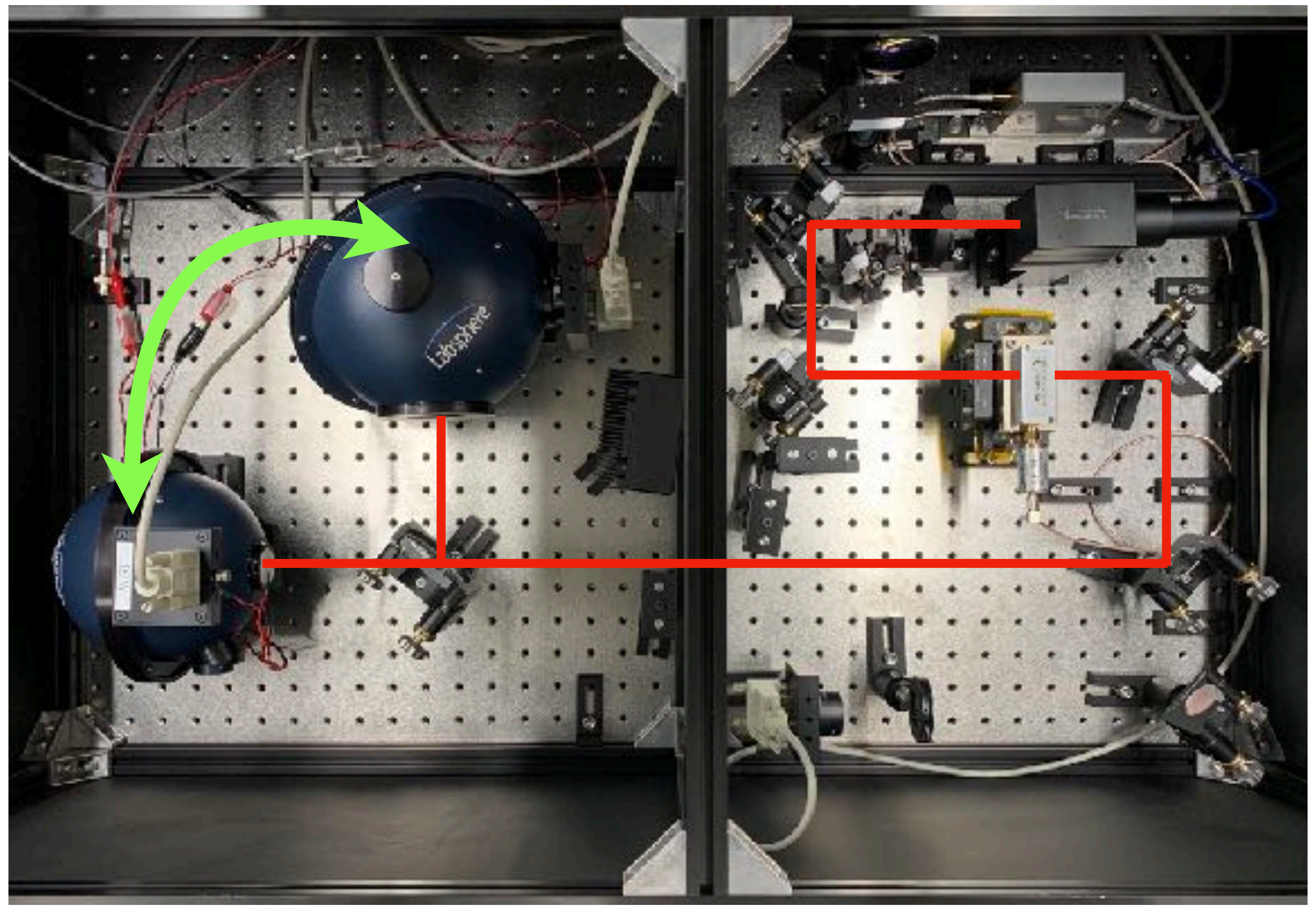


Calibration of KAGRA Pcal laser power sensor

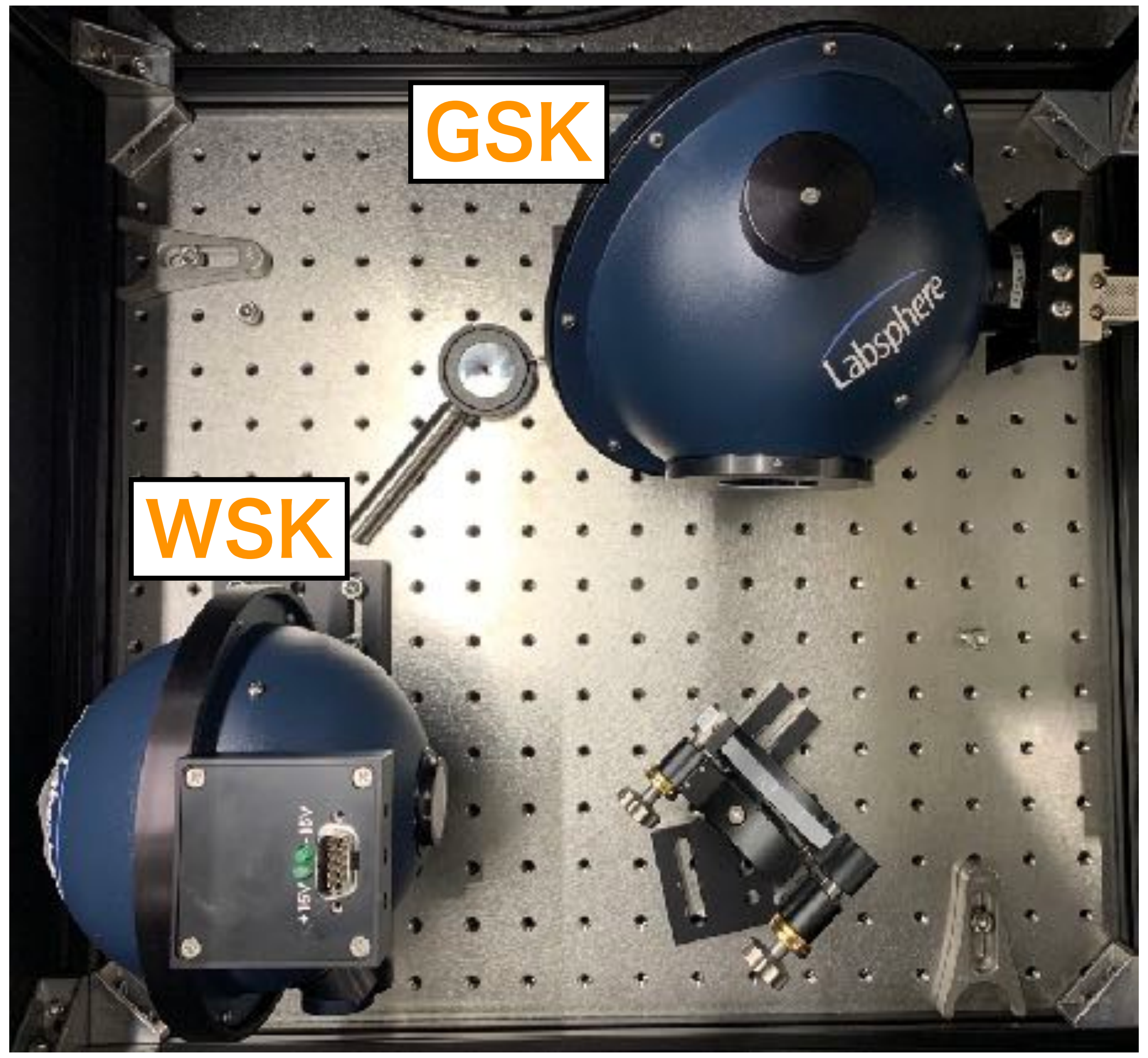


Toyama

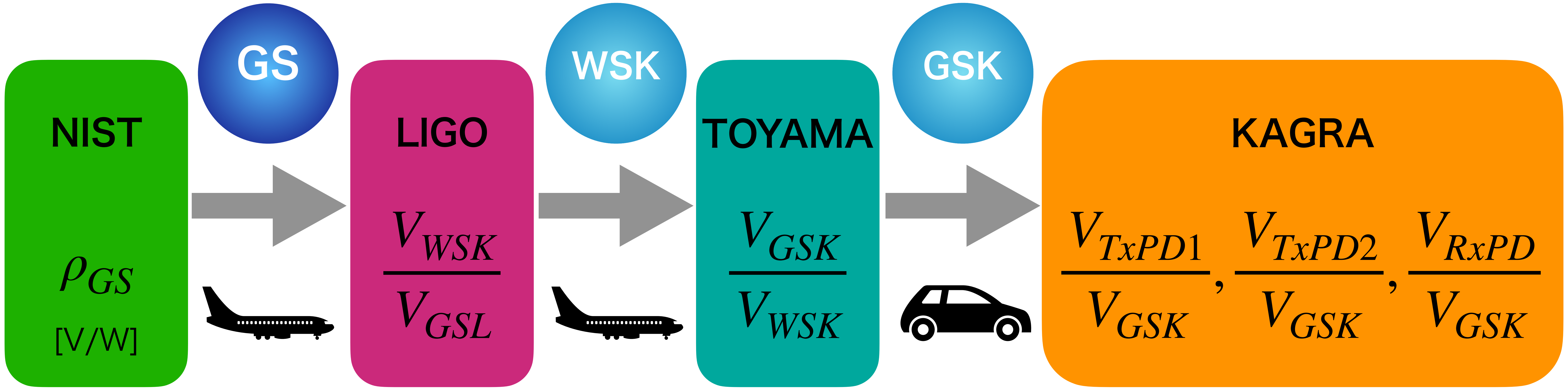
$$\frac{V_{GSK}}{V_{WSK}} = \sqrt{\frac{V_{GSK_T} \times V_{GSK_R}}{V_{WSK_R} \times V_{WSK_T}}}$$

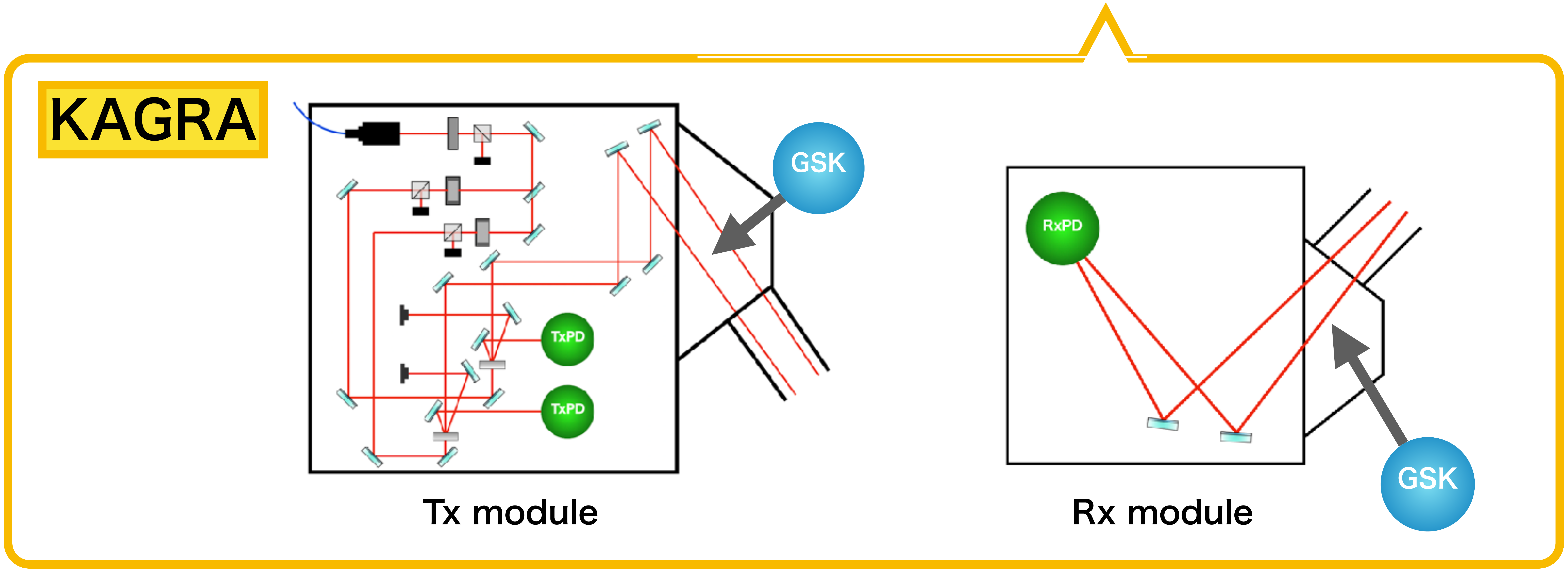


Optical system of University of Toyama

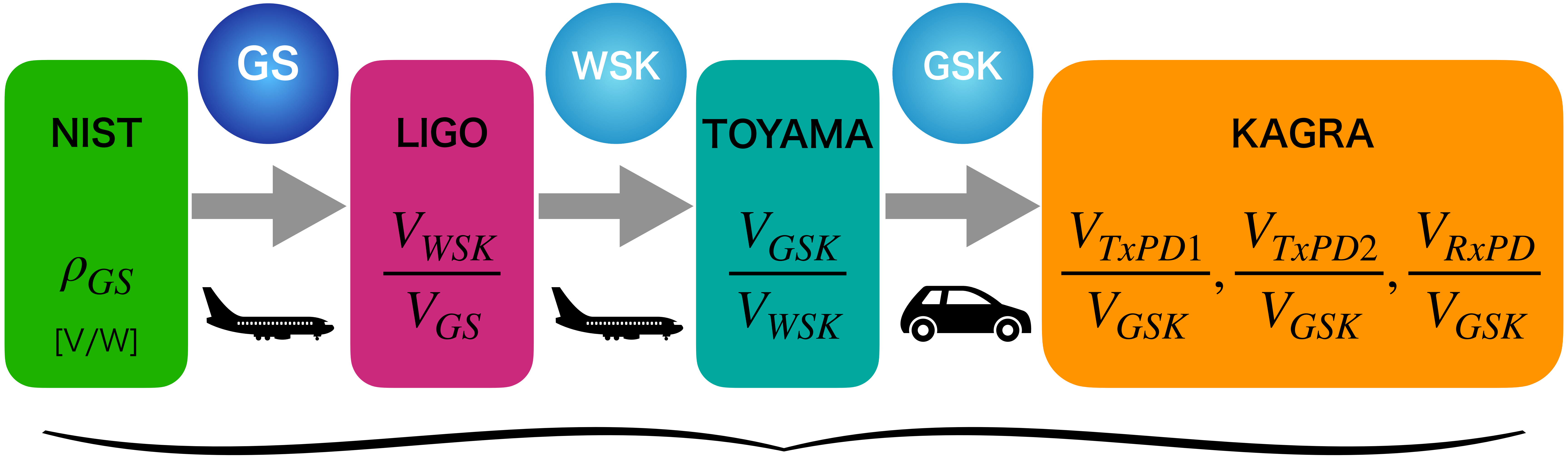


Calibration of KAGRA Pcal laser power sensor





Calibration of KAGRA Pcal laser power sensor



$$\rho_{GS} \times \frac{V_{WSK}}{V_{GS}} \times \frac{V_{GSK}}{V_{WSK}} \times \frac{V_{TxPD1}}{V_{GSK}} = \rho_{TxPD1} \text{ [V/W]}$$

$$\rho_{GS} \times \frac{V_{WSK}}{V_{GS}} \times \frac{V_{GSK}}{V_{WSK}} \times \frac{V_{TxPD2}}{V_{GSK}} = \rho_{TxPD2} \text{ [V/W]}$$

$$\rho_{GS} \times \frac{V_{WSK}}{V_{GS}} \times \frac{V_{GSK}}{V_{WSK}} \times \frac{V_{RxPD}}{V_{GSK}} = \rho_{RxPD} \text{ [V/W]}$$

Calibration factor of Pcal laser power sensor

Result calibration in O3GK

NIST

$$\rho_{GS} = 8.0985 \pm 0.026$$

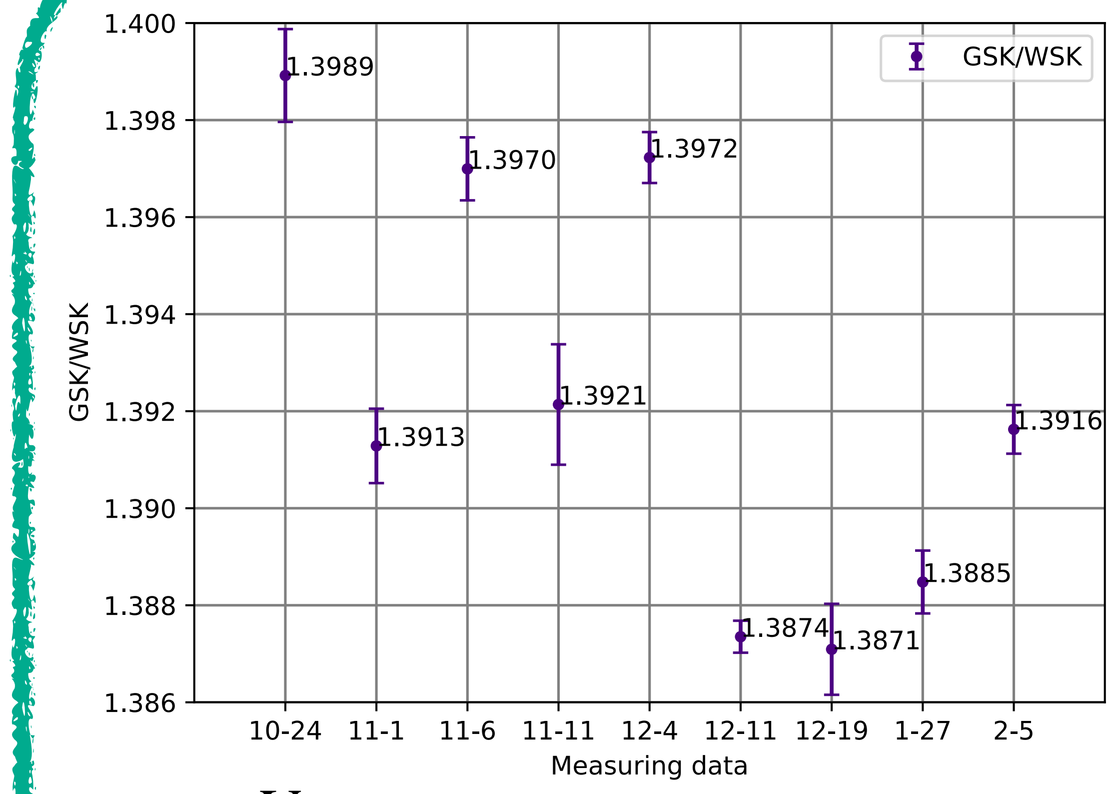
(0.32 %)

LIGO

$$\frac{V_{WSK}}{V_{GS}} = 0.05961 \pm 2.47 \times 10^{-5}$$

(0.041 %)

Toyama

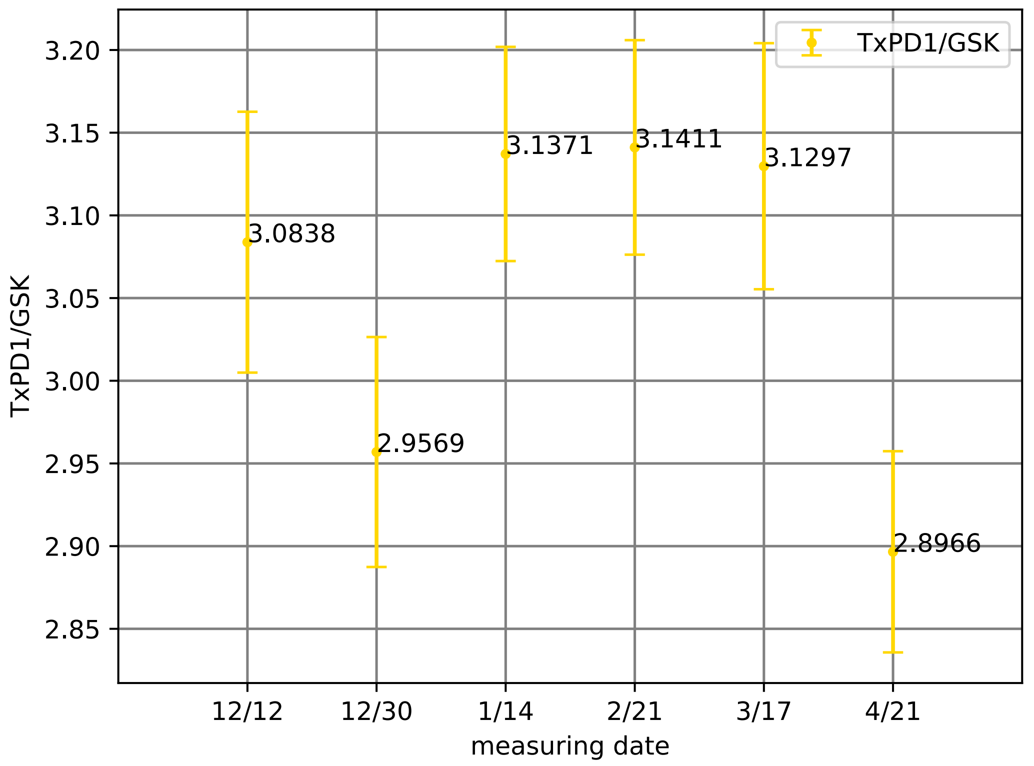


0.32 %

$$\frac{V_{GSK}}{V_{WSK}} = 1.39235 \pm 0.0044 \text{ (0.32 \%)}$$

KAGRA X_end

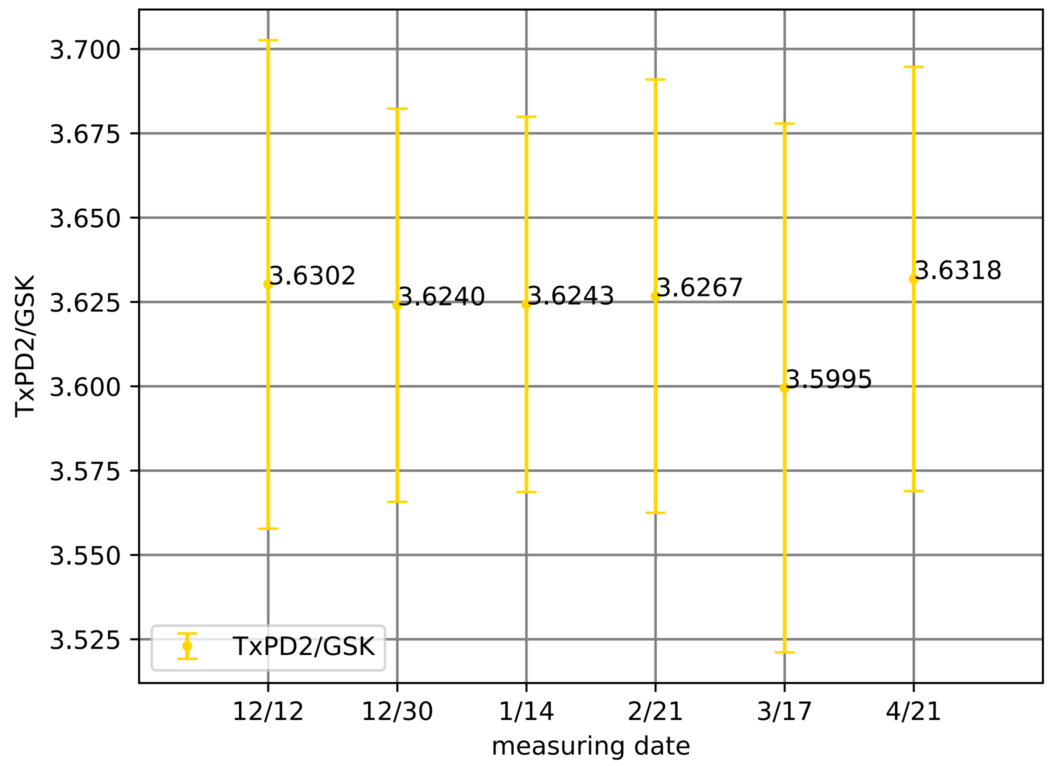
TxPD1



3.4 %

$$\frac{V_{TxPD1}}{V_{GSK}} = 3.05754 \pm 0.11 \text{ (3.4 \%)}$$

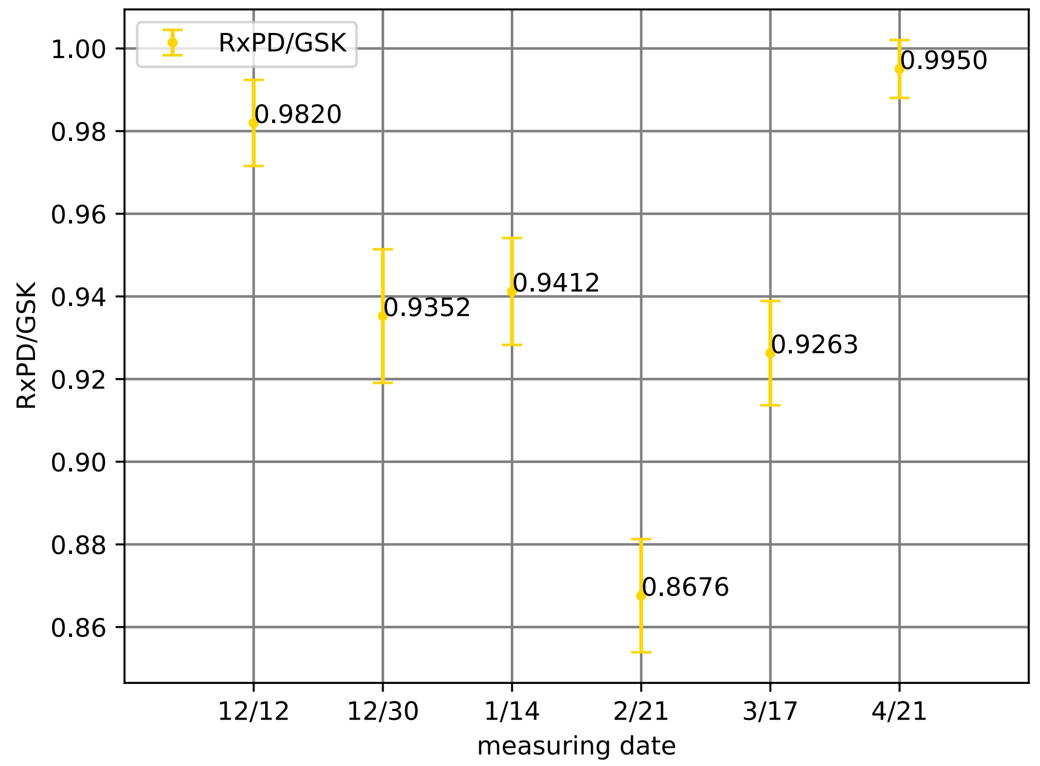
TxPD2



0.72 %

$$\frac{V_{TxPD2}}{V_{GSK}} = 3.62395 \pm 0.026 \text{ (0.72 \%)}$$

RxPD



4.8 %

$$\frac{V_{RxPD}}{V_{GSK}} = 0.94122 \pm 0.045 \text{ (4.8 \%)}$$

Result calibration in O3GK

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(0.041 %)

Toyama

$$\frac{V_{GSK}}{V_{WSK}} = 1.39235 \pm 0.0044$$

(0.32 %)

KAGRA X end

TxPD1

$$\frac{V_{TxPD1}}{V_{GSK}} = 3.05754 \pm 0.11$$

(3.4 %)

TxPD2

$$\frac{V_{TxPD2}}{V_{GSK}} = 3.62395 \pm 0.026$$

(0.72 %)

RxPD

$$\frac{V_{RxPD}}{V_{GSK}} = 0.94122 \pm 0.045$$

(4.8 %)

Calibration factor of Pcal laser power sensor

- TxPD1 : $\rho_{TxPD1} = 2.055 \pm 0.071 \ (3.5\%)$ [V/W]
- TxPD2 : $\rho_{TxPD2} = 2.436 \pm 0.021 \ (0.86\%)$ [V/W]
- RxPD : $\rho_{RxPD} = 0.6326 \pm 0.031 \ (4.9\%)$ [V/W]

Result calibration in O3GK

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$$\rho_{GS} = 8.0985 \pm 0.026$$

(0.32 %)

LIGO

$$\frac{V_{WSK}}{V_{GS}} = 0.05961 \pm 2.47 \times 10^{-5}$$

(0.041 %)

Toyama

$$\frac{V_{GSK}}{V_{WSK}} = 1.39235 \pm 0.0044$$

(0.32 %)

KAGRA X end

TxPD1

$$\frac{V_{TxPD1}}{V_{GSK}} = 3.05754 \pm 0.11$$

(3.4 %)

TxPD2

$$\frac{V_{TxPD2}}{V_{GSK}} = 3.62395 \pm 0.026$$

(0.72 %)

RxPD

$$\frac{V_{RxPD}}{V_{GSK}} = 0.94122 \pm 0.045$$

(4.8 %)

Calibration factor of Pcal laser power sensor

- TxPD1 : $\rho_{TxPD1} = 2.055 \pm 0.071$ (3.5%) [V/W]
- TxPD2 : $\rho_{TxPD2} = 2.436 \pm 0.021$ (0.86%) [V/W]
- RxPD : $\rho_{RxPD} = 0.6326 \pm 0.031$ (4.9%) [V/W]

Factor

- the scattered light in the Tx module
- the measurement method of RxPD

Summary and Future plan

Summary

- We calibrated the X end Pcal laser power sensor.
- The calibration error of all Pcal power sensors in O3GK was less than 5%.
- The KAGRA measurement error is not small.

Future plan

- Reduce the KAGRA measurement errors.

  Improvement points - the scattered light in the Tx module

  - the measurement method of RxPD
- The calibration error of all Pcal power sensors < 1 % Target value