KAGRA's situation

Mar. 2015: iKAGRA run (Simple Michelson Interferometer)

- There was no calibration group.
- Some site people worked on calibration and reconstruction.

May. 2018: bKAGRA phase-1 run (Cryogenic MI)

- Only online h(t) was provided.
- There were no photon calibrator (Pcal).

Now: Commissioning test

- We start to work on reconstructing the displacement of each DOF.
- Pcal installation is ongoing.

Dec. 2019: Join the O3 observation (DRFPMI)

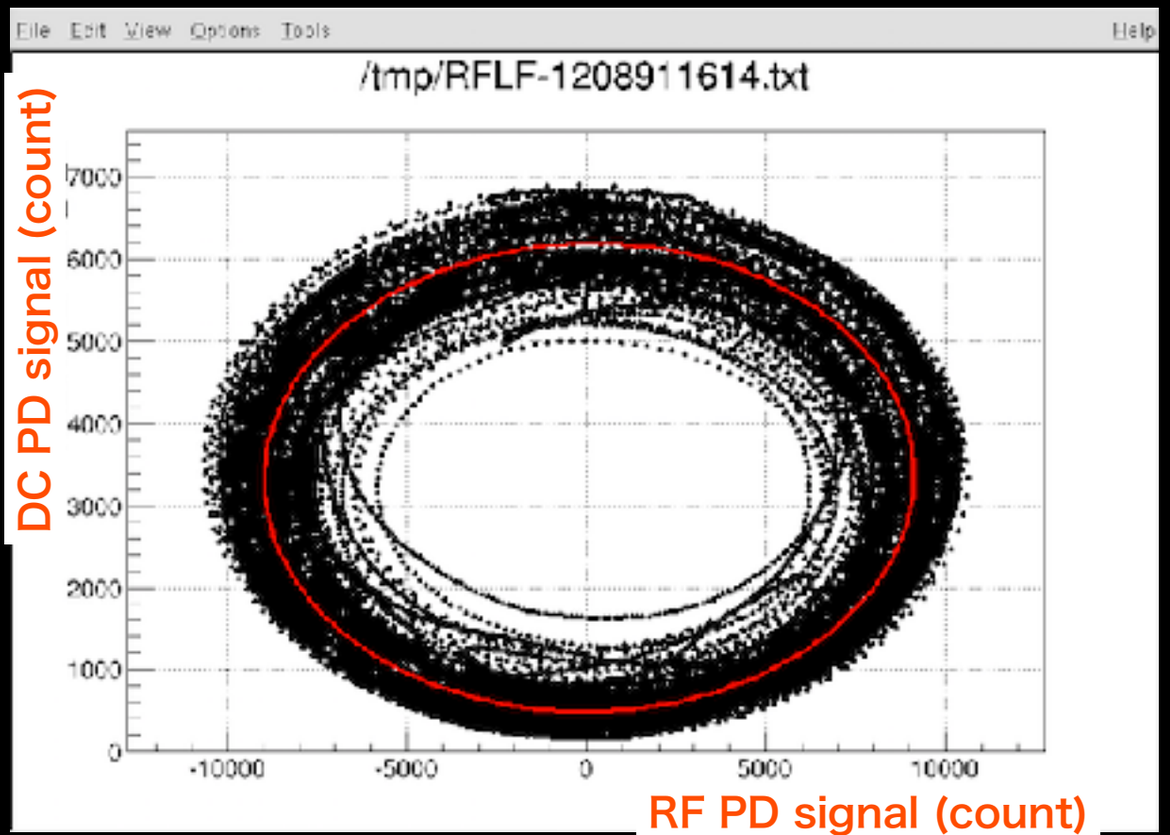
- Two Pcal will be ready.
- Online, low-latency, and offline h(t) will be provided.

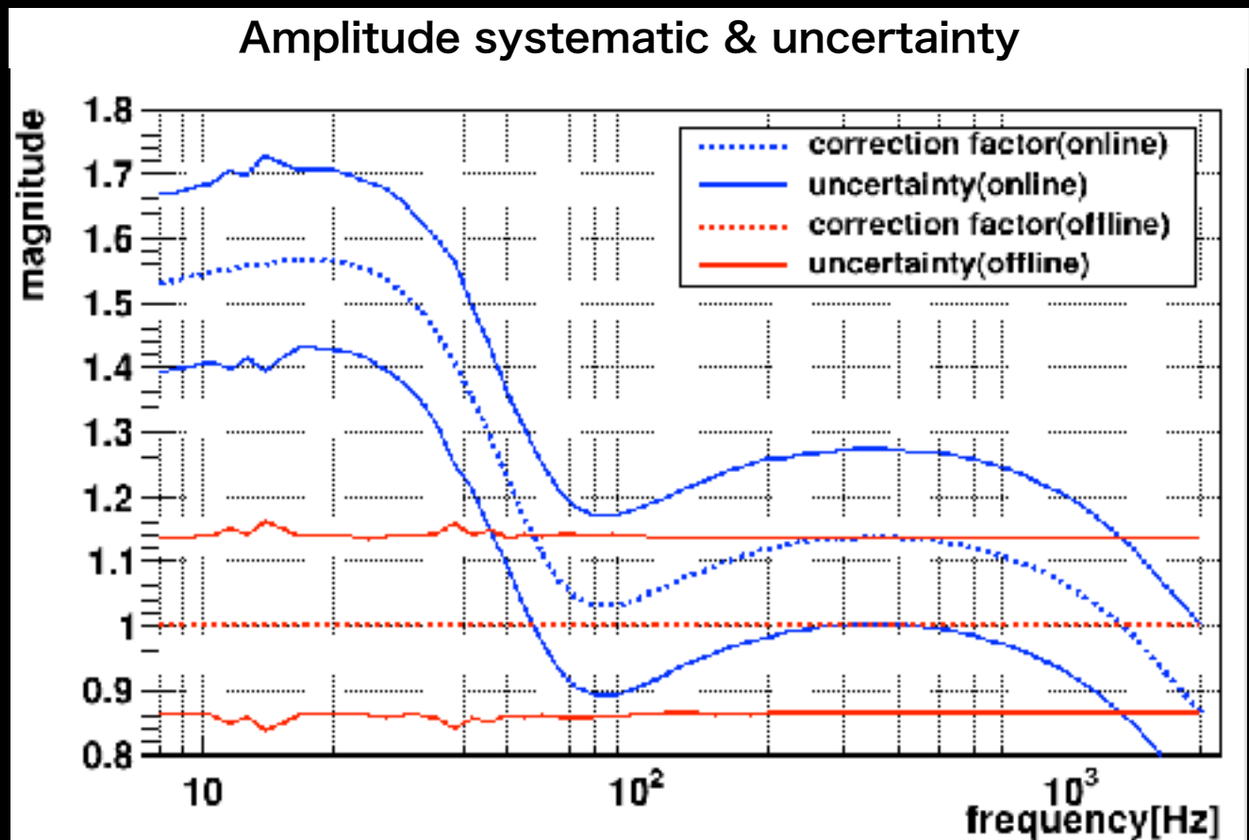
CAL activities during previous operation

- We measured the optical gain (C) response by Free-Swinging method.
  ～15% uncertainty in estimated optical gain.

- OLTF (G) was measured by the digital control system.

- Actuator efficiency (A) was estimated by G/C





Our mission on O3

Pcal instrument

- Calibration of the laser power with KAGRA's working standard.
- Monitoring beam positions of Pcal laser.

IFO instrument

- Measurement of the optical response with pcal.
- Independent measurement of the time dependent coefficients of the optical plant (C) and the actuation plant (A)

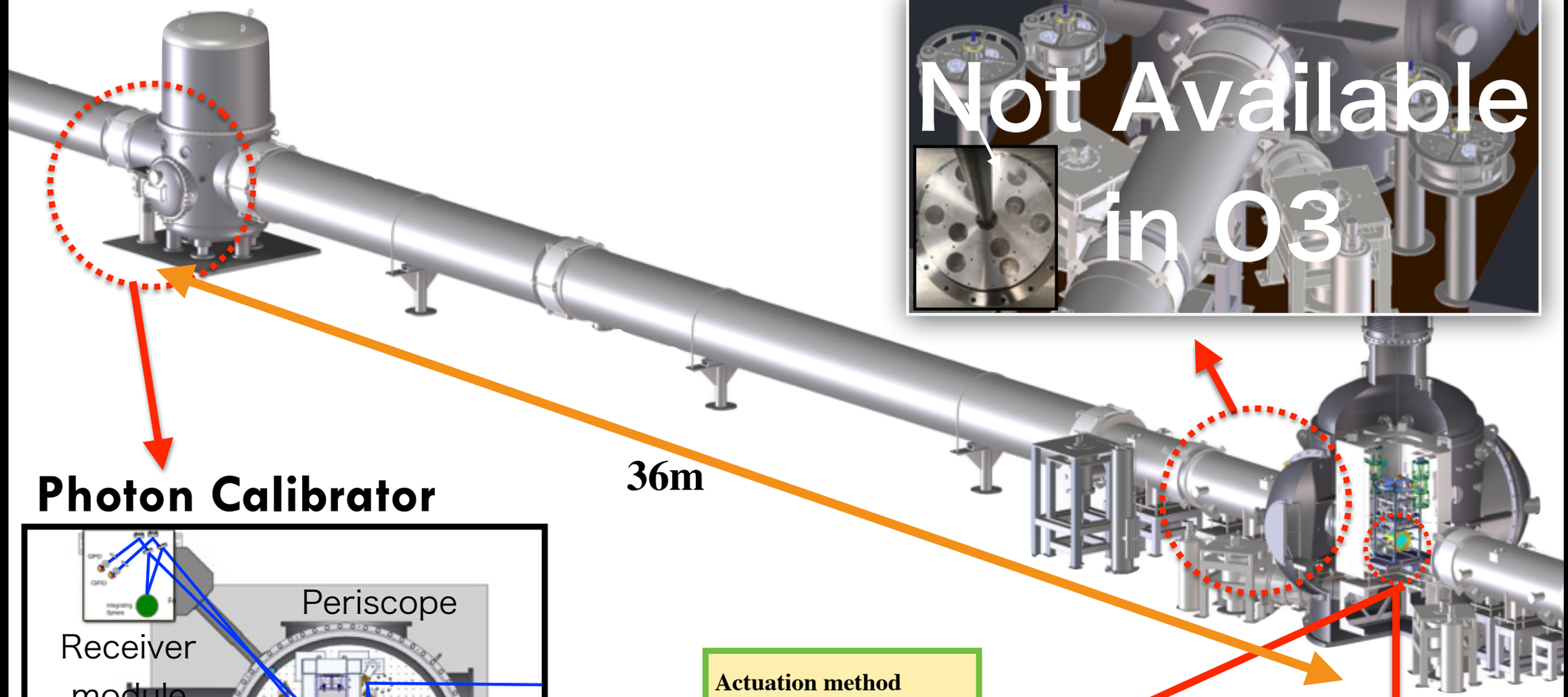
Software

- Providing low-latency and offline h(t)
    - Correcting time dependent coefficient.
    - Precise h(t) generation with FIR filters
- Providing information of the systematics and uncertainty of the reconstructed strain signal.

pcal installation

JGW-D1807705

KAGRACalibration instruments



pcal installation

Both X- and Y-Pcal had been installed
in last year.

We started to measure
- the accuracy of the beam position
- optical loss between Tx and Rx modules

JGW-D1807705

Optical efficiency

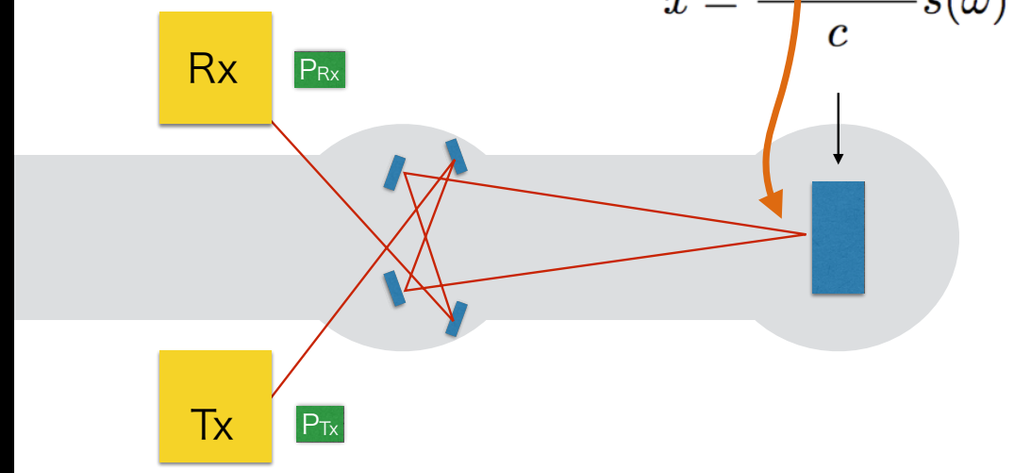
model

$P=(P_{Tx}+P_{Rx})/2$

$P=e_{Tx}P_{Tx}$

$P=e_{Rx}^{-1}P_{Rx}$

$$x = \frac{2P\cos\theta}{c}s(\omega)$$

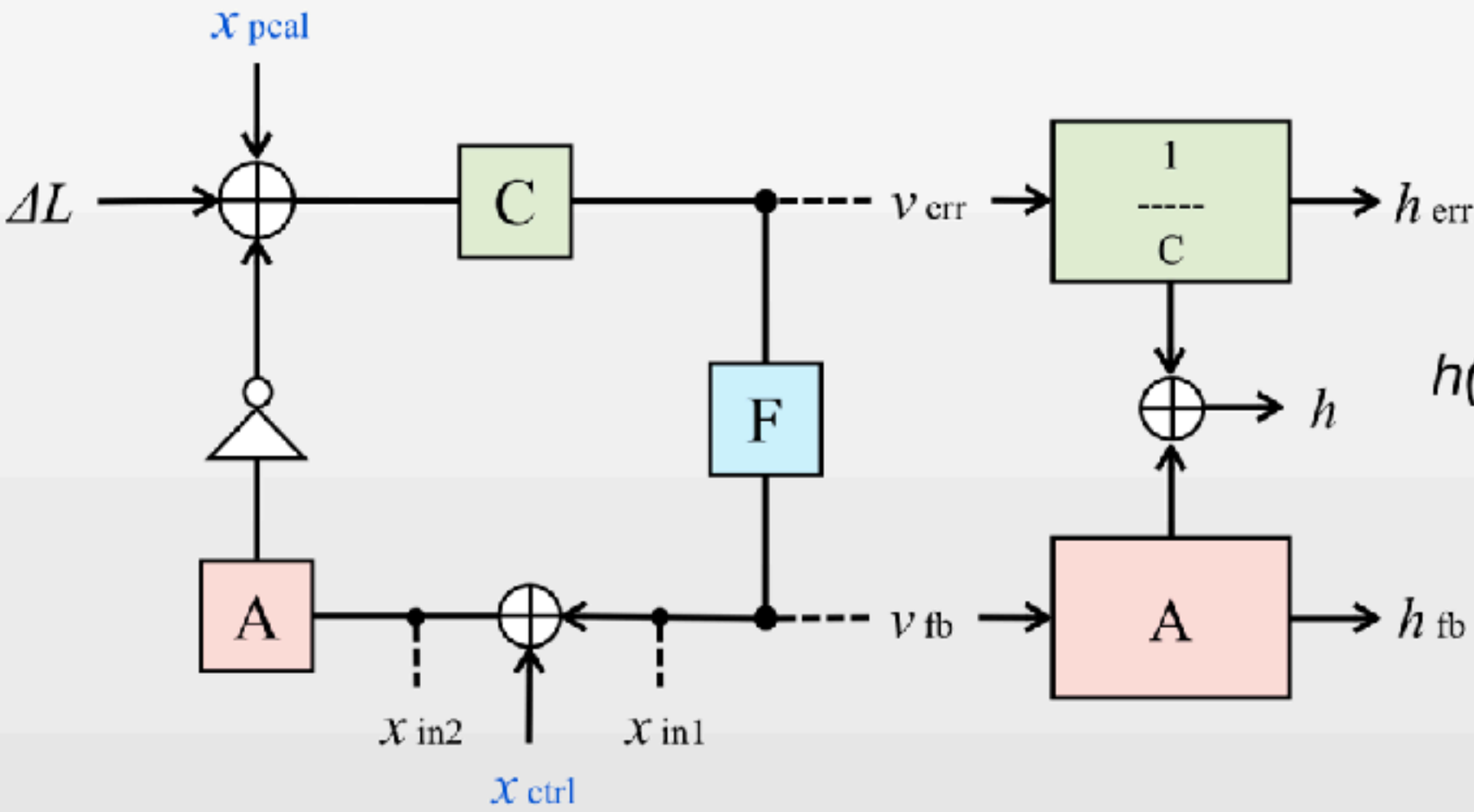


h(t) reconstruction scheme

JGW-G1707452

$$\frac{1+G}{C} = \frac{v_{\mathrm{err}}}{x_{\mathrm{pcal}}}$$

Pcal helps us for monitoring
fluctuations of A and C gain individually.



$$\frac{1+G}{AC} = \frac{v_{\mathrm{err}}}{x_{\mathrm{ctrl}}}$$

$$G = \frac{x_{\mathrm{in2}}}{x_{\mathrm{in1}}}$$

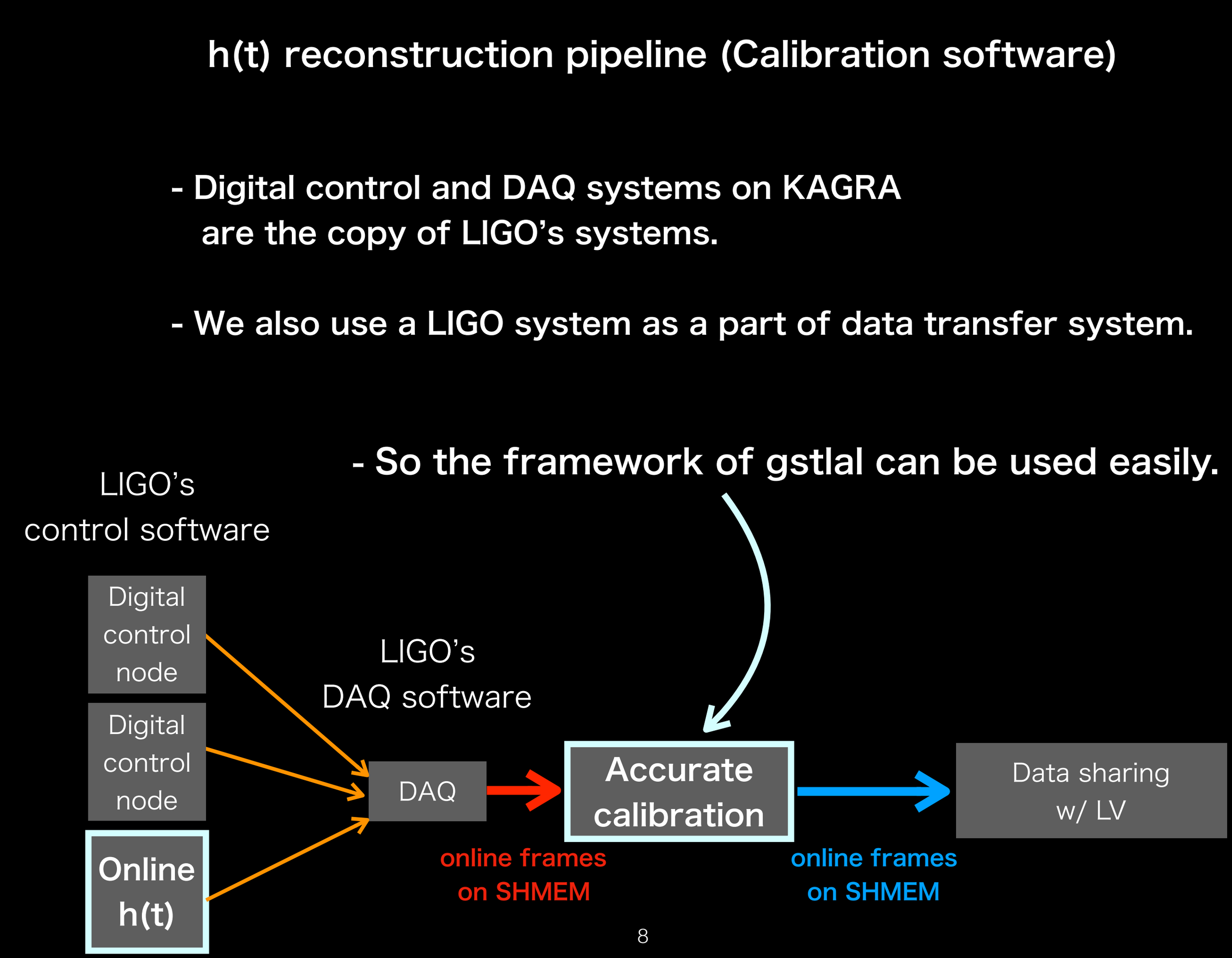
We can monitor the gain fluctuation of G.
Which is a cause of gain fluctuation, A or C ?

h(t) reconstruction pipeline (Calibration software)

- Digital control and DAQ systems on KAGRA
  are the copy of LIGO's systems.

- We also use a LIGO system as a part of data transfer system.

- So the framework of gstlal can be used easily.



Reconstruction pipeline

Online h(t) on digital control system

- Main user: commissioners
- Filter process: full IIR
- Delay: within 1s

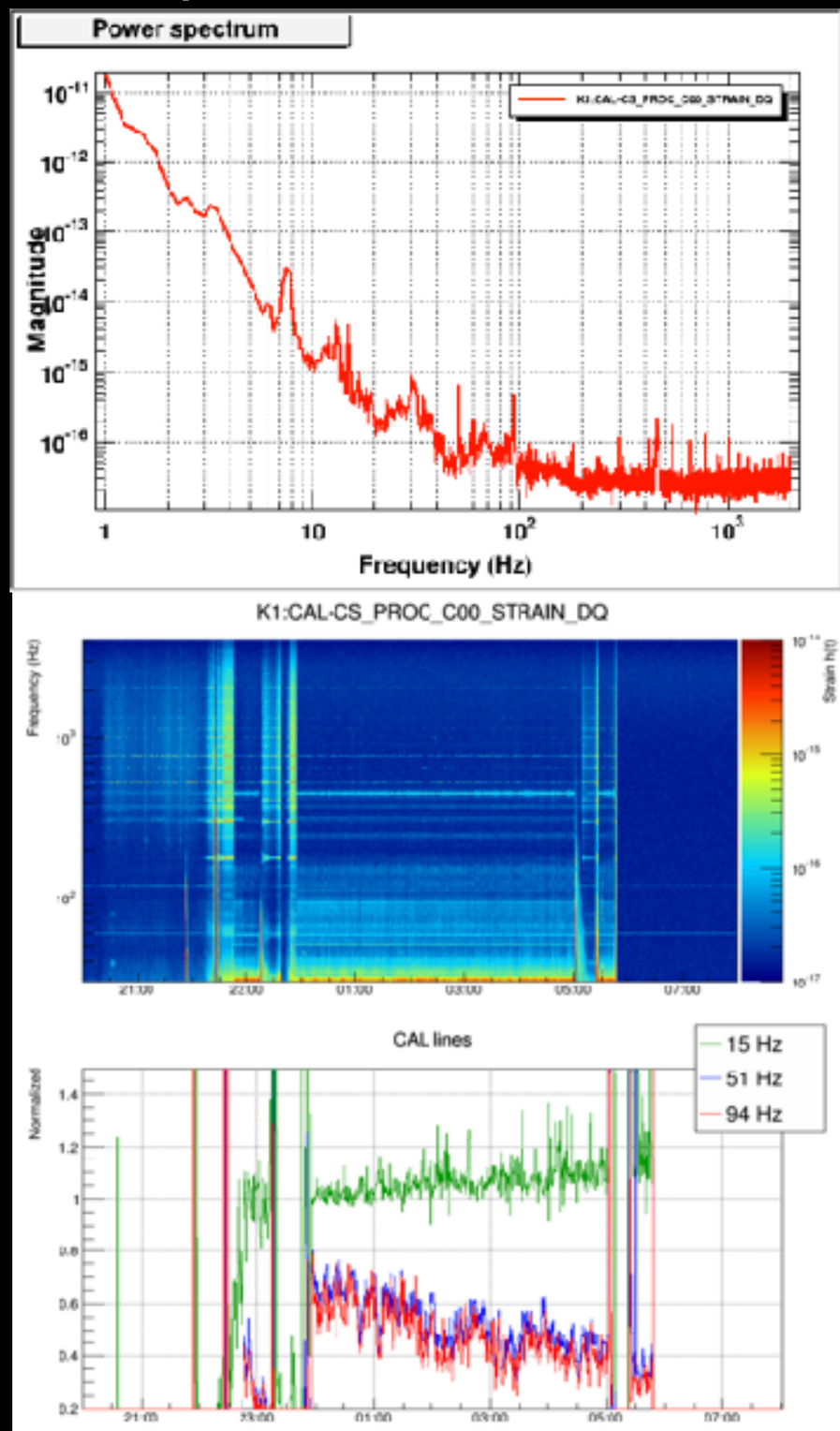
Low-latency h(t) on gstlal-calibraion

- Main user: data analysis
- Filter process: IIR + FIR
- Delay: ～4s

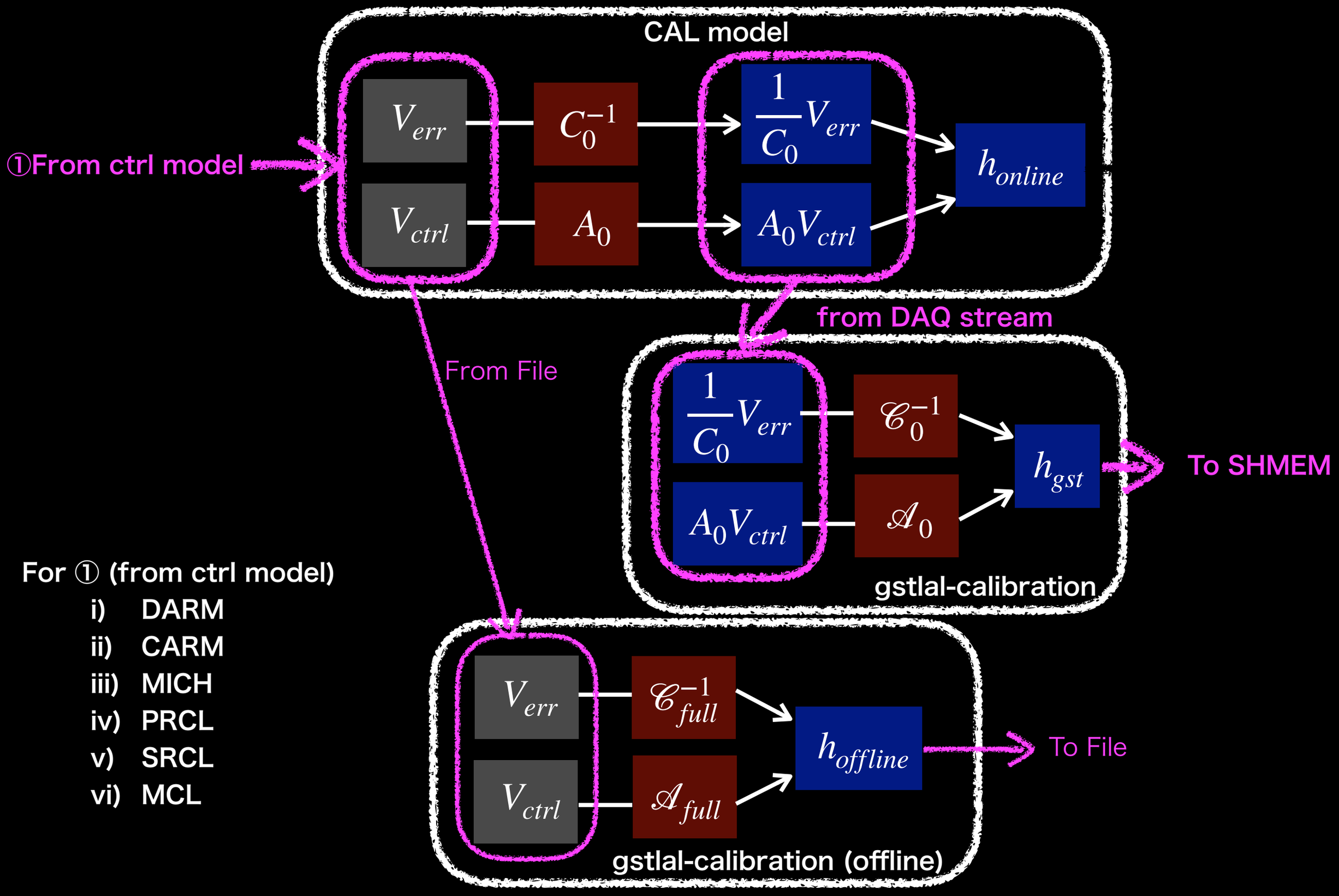
Offline h(t) on gstlal-calibraion

- Main user: data analysis
- Filter process: full FIR
- Delay: in discussion

phase-1 run monitors



Online h(t) by real-time model
+
Low-latency/Offline h(t) by gstlal-calibraion



For ① (from ctrl model)

i) DARM
ii) CARM
iii) MICH
iv) PRCL
v) SRCL
vi) MCL

KAGRA CAL Subway map

KAGRA Subway map ver.0

JGW-E1809550

Pcal

K1_CAL_X_EX1_OUT ← K1_CAL_X_EX1 → DTD IOP 16-64 AI(D) DAC V/ct DAC AI (A) DW OFS AOM

K1_CAL_X_EX2_OUT ← K1_CAL_X_EX2 → DTD IOP 16-64 AI(D) DAC V/ct DAC AI (A) DW OFS AOM

K1_CAL_Y_EX1_OUT ← K1_CAL_Y_EX1 → DTD IOP 16-64 AI(D) DAC V/ct DAC AI (A) DW OFS AOM

K1_CAL_Y_EX2_OUT ← K1_CAL_Y_EX2 → DTD IOP 16-64 AI(D) DAC V/ct DAC AI (A) DW OFS AOM

TPD1X A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) TPD1X V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_X_TXPD1

RPDX A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) RPD1X V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_X_RXPD

TPD2X A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) TPD2X V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_X_TXPD2

TPD1Y A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) TPD1Y V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_Y_TXPD1

RPDY A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) RPD1Y V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_Y_RXPD

TPD2Y A/W TIA V/A AA (A) AA Gain ADC ct/V 64-16 AA(D) iADC ct/V anti DW antiAI (A) TPD2Y V/W N/W Opt. Eff. Rot SUS L3-L3 → K1_CAL_Y_TXPD2

DARM

ATD ? ATA ? CC POLE SRC D-2N OPT GAIN

OMCA A/W HF OMC TIA-A V/A W-A (A) AA (A) AA Gain ADC ct/V 64-16 AA(D) anti iW_B (A)

OMCB A/W HF OMC TIA-B V/A W-B (A) AA (A) AA Gain ADC ct/V 64-16 AA(D) anti iW_B (A)

Sensing

Actuation

SUS L1-L3 Coil PD Gain DRVR AI gain AI (A) DAC DAC V/ct 16-64 AI(D) IOP DTD iDRVR DA1 → LF1

SUS L2-L3 Coil PD Gain DRVR AI gain AI (A) DAC DAC V/ct 16-64 AI(D) IOP DTD iDRVR DA2 → LF2

SUS L3-L3 Coil PD Gain DRVR AI gain AI (A) DAC DAC V/ct 16-64 AI(D) IOP DTD iDRVR DA3 → LF3

LF3 → DTD TD

Control filter

D

DTD

K1_CAL_SUS_INJ1_OUT ← 16-0.5 AI(D) ← K1_CAL_SUS_INJ1

K1_CAL_SUS_INJ2_OUT ← 16-0.5 AI(D) ← K1_CAL_SUS_INJ2

K1_CAL_SUS_INJ3_OUT ← 16-0.5 AI(D) ← K1_CAL_SUS_INJ3

K1_CAL_Soft_INJ → K1_CAL_Soft_INJ_OUT

Reconstruction

DTD

iOPT GAIN iCC POLE iSRC D-2N ROLL OFF iIIR WARP

Partial inverse sensting

K1_CAL_DARM_RESIDUAL_WHTEN

K1_CAL_DARM_EXTERMAL_WHITEN

K1_CAL_DARM_CTRL_SUM_WHITEN

1/K_C Sens sign ATA ? ATD ? HF OMC AA (A) AA Gain 64-16 AA(D)

1/2 TIA-A V/A W-A (A) anti W_A (A)

1/2 TIA-B V/A W-B (A) anti W_B (A)

Residual inverse sensting filter

iROLL OFF IIR WARP DTA

DTD

1/L → K1_CAL_GDS_Strain

Actuation

LF1 DA1 iDRVR DRVR DAC V/ct Gain Coil PD DC m/N ??Hz Pole L1-L3 NORM 16-4 AA(D) → K1_CAL_DARM_CTRL_L1-WHITEN

LF2 DA2 iDRVR DRVR DAC V/ct Gain Coil PD DC m/N ??Hz Pole L2-L3 NORM 16-4 AA(D) → K1_CAL_DARM_CTRL_L2-WHITEN

LF3 DA3 LIN iDRVR DRVR DAC V/ct Gain Coil PD DC m/N ??Hz Pole L3-L3 NORM 16-4 AA(D) → K1_CAL_DARM_CTRL_L3-WHITEN

4-2 AA(D) K_MN

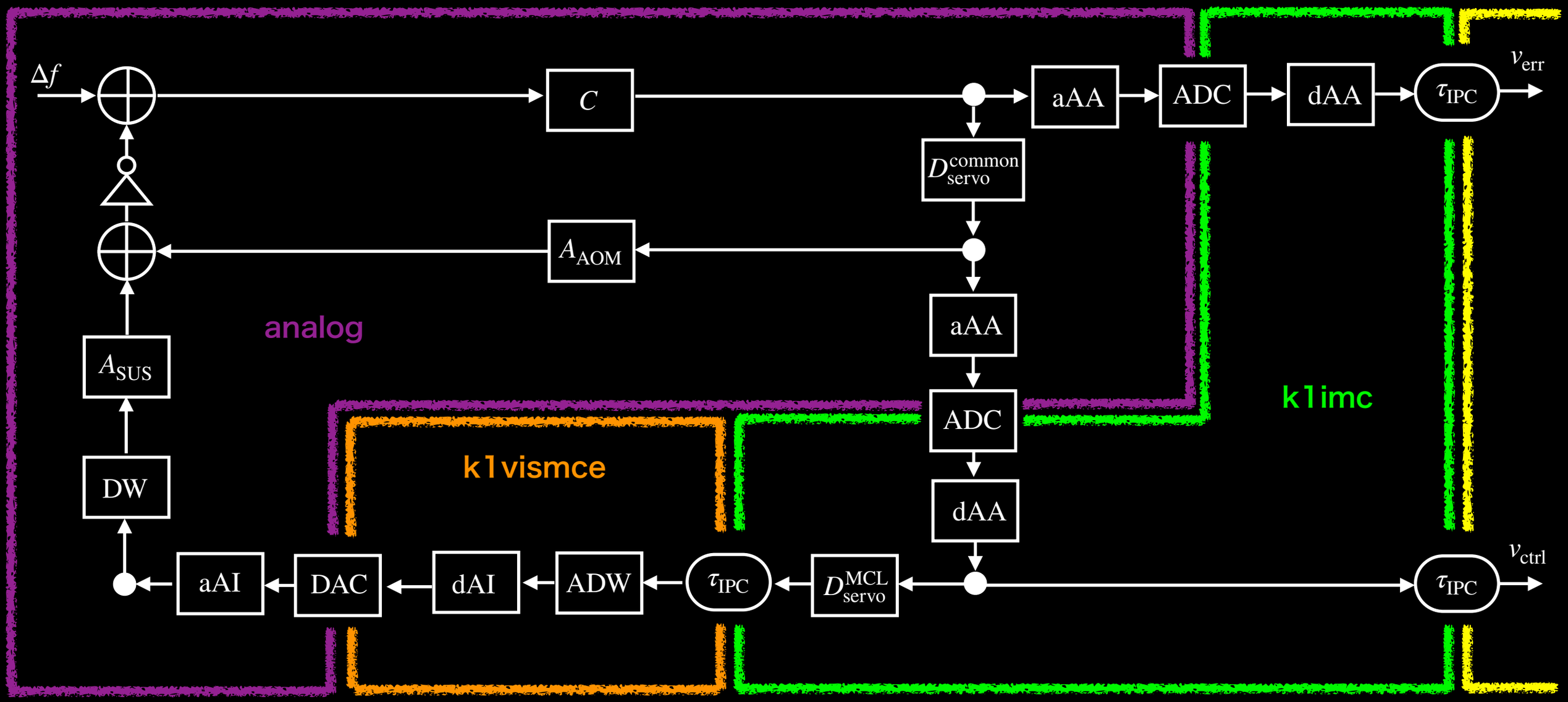
4-2 AA(D) K_IM

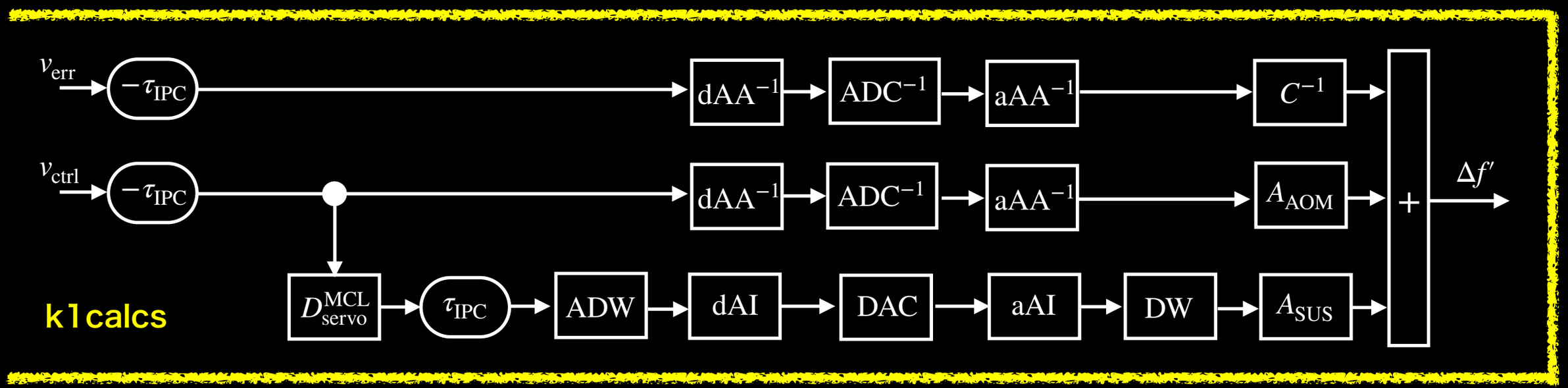
4-2 AA(D) K_TM

iDW 4 AI gain AI (A) 16-64 AI(D) DTD IOP DAC DTD TD? 16-4 AA(D) 2-16 AA(D) DTA

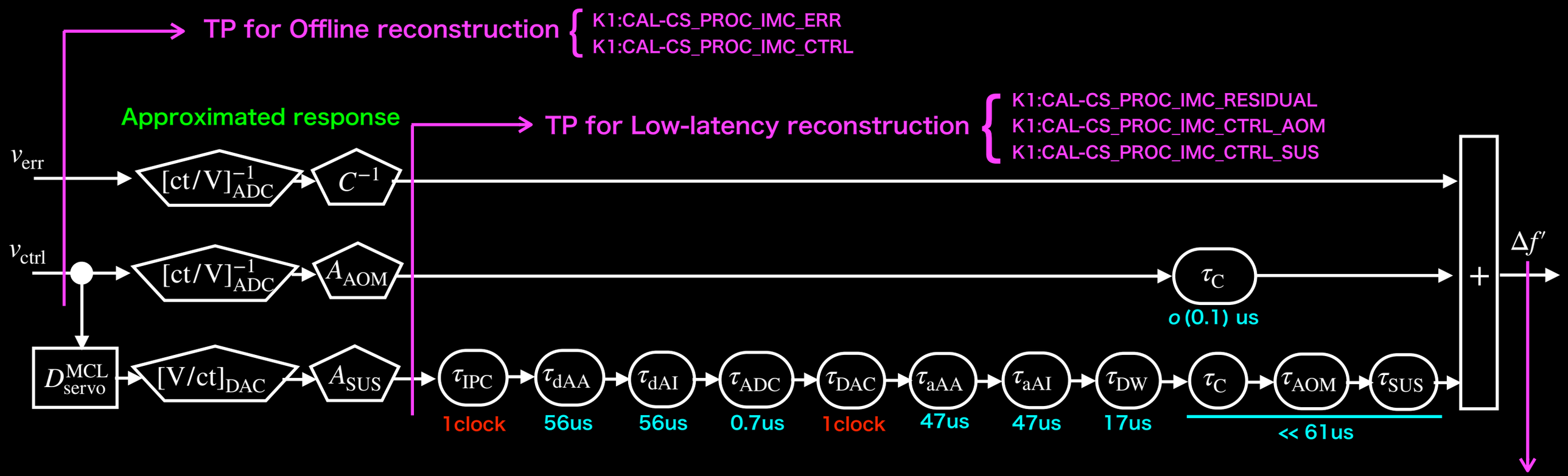
Residual inverse actuation filter

MCL reconstruction





MCL reconstruction



The time delay in the AOM path, τ_C, can be ignored.

The total delay in the SUS path can be approximated as 6 clocks in 16kHz sampling
because $\tau_C + \tau_{\mathrm{AOM}} + \tau_{\mathrm{SUS}} \ll 61\mathrm{us}$ (I hope).

The gstlal-calibration receives the signals before applying time delay.

$\Delta f'$ is 165us ($= \tau_{\mathrm{IPC}} + \tau_{\mathrm{dAA}} + \tau_{\mathrm{ADC}} + \tau_{\mathrm{aAA}} + \tau_C$) behind from true time.

Summary

Pcal installation is already finished.

Characterization of Pcal instrument is ongoing

- Stability of laser power
- Measurement of the optical loss
- Precision of the beam position

We are now developing the reconstruction pipeline of h(t)

- First pipeline test are planned during Commissioning test.
- Data transfer test had been already succeeded.