TypeBp SAS Study

- Frequency response investigation of typeBpp
- One modification idea for bKAGRA PR SAS

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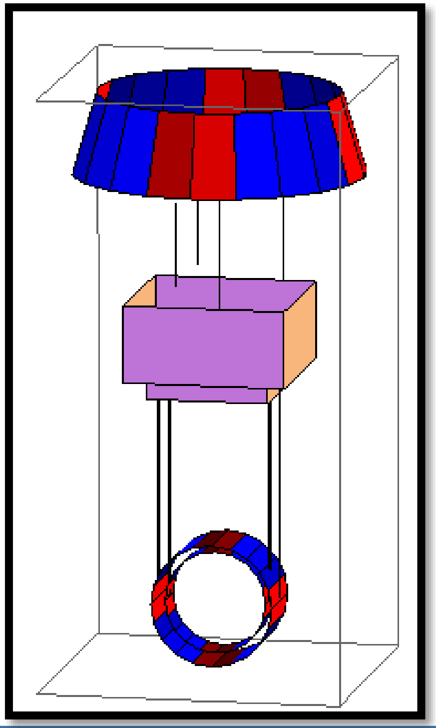
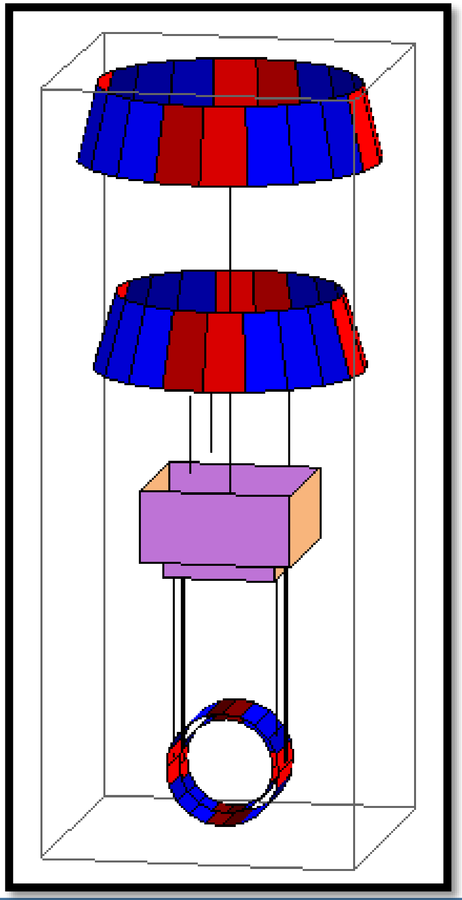
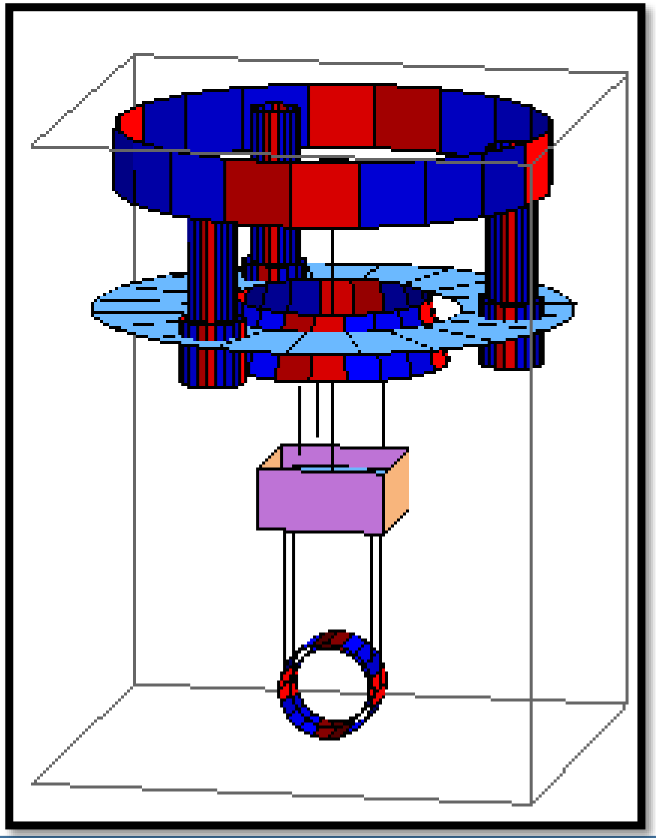
U. of Tokyo / NAOJ

Bpp



Bp

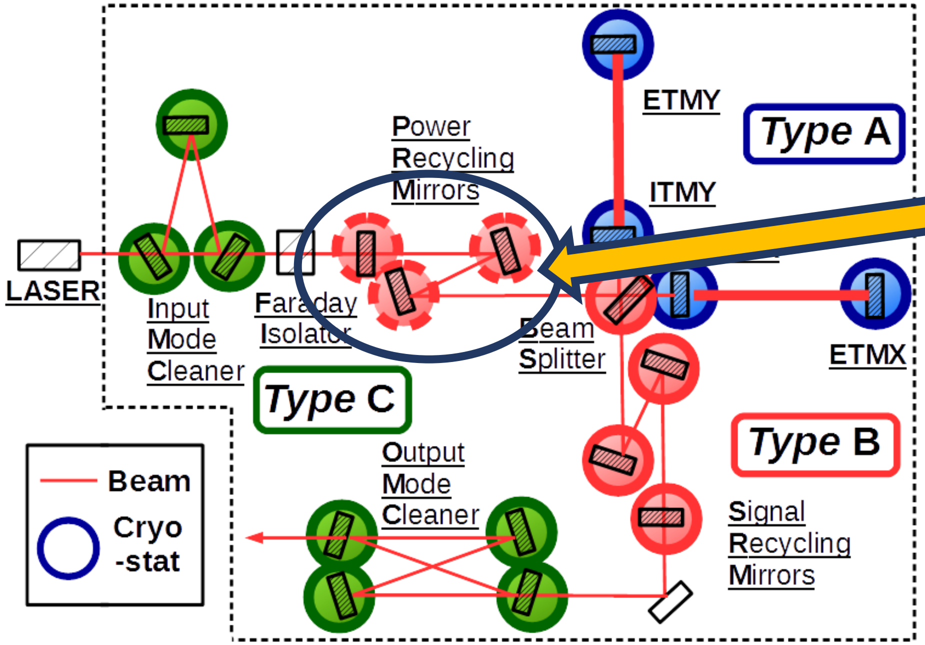


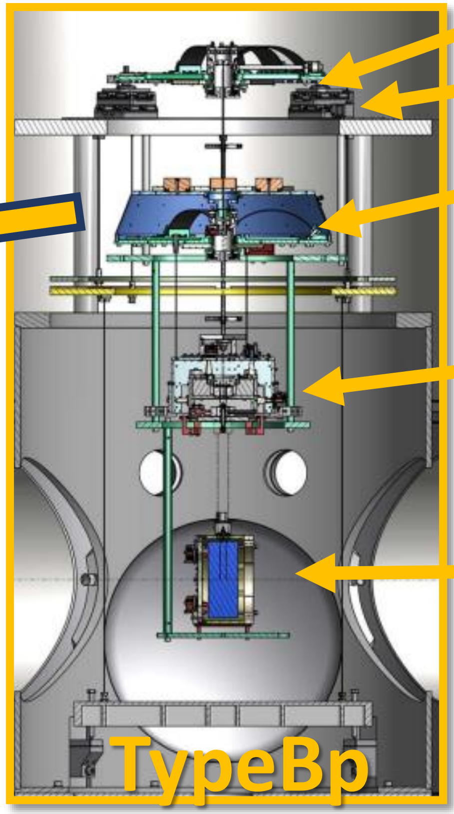


Contents

- Intro : PR SAS
  - TypeBp / TypeBpp
- Investigation of TypeBpp Frequency response
  - Transfer functions / Spectra
- One modification idea for bKAGRA
  - Requirement
  - TypeBp with IP

❖ Intro : PR SAS in bKAGRA (TypeBp)





Standard Filter (SF)

Traverser

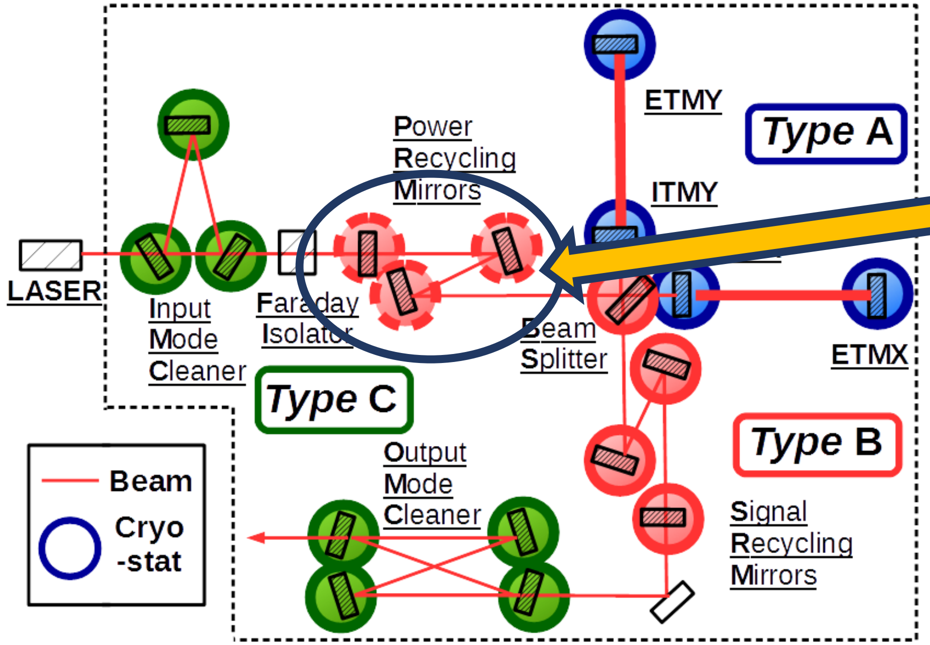
Bottom Filter (BF)

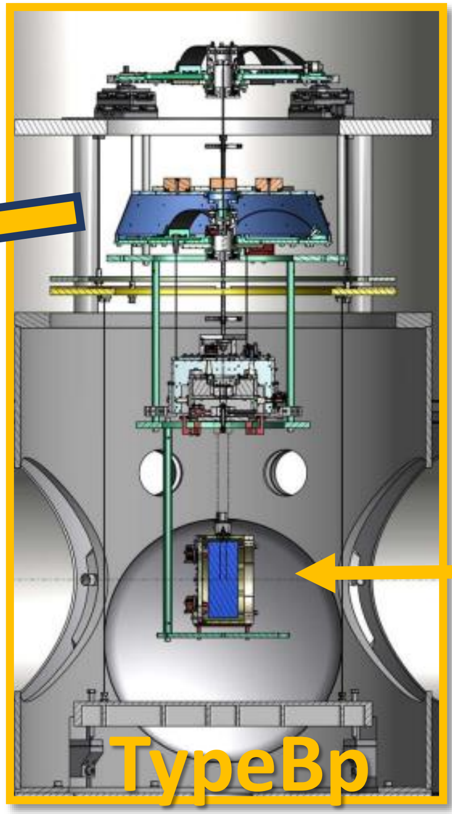
IR / IM

RM / TM

Current bKAGRA PR SAS = TypeBp

❖ Intro : PR SAS in bKAGRA (TypeBp)





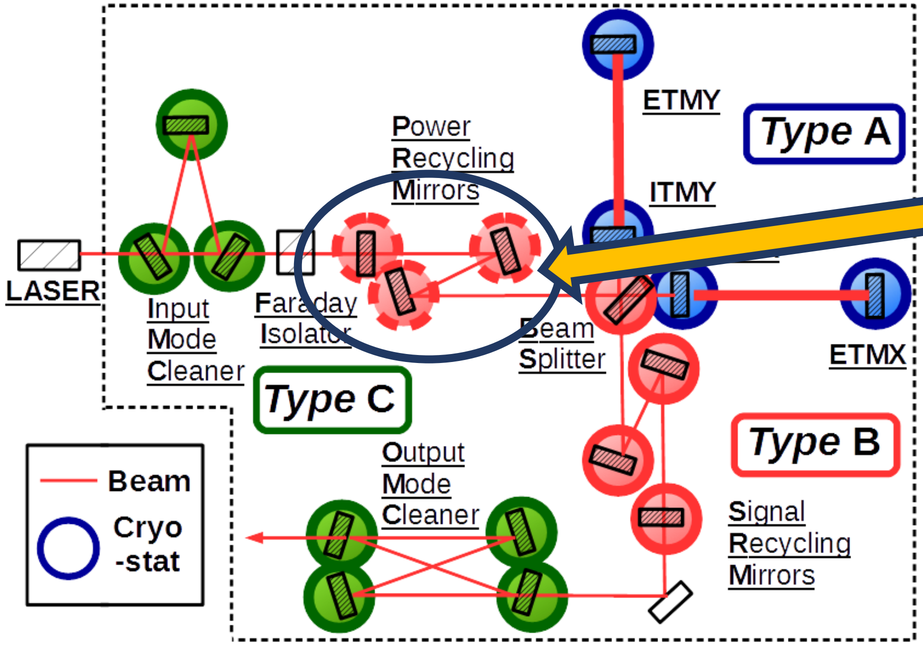
PR TMs are required :

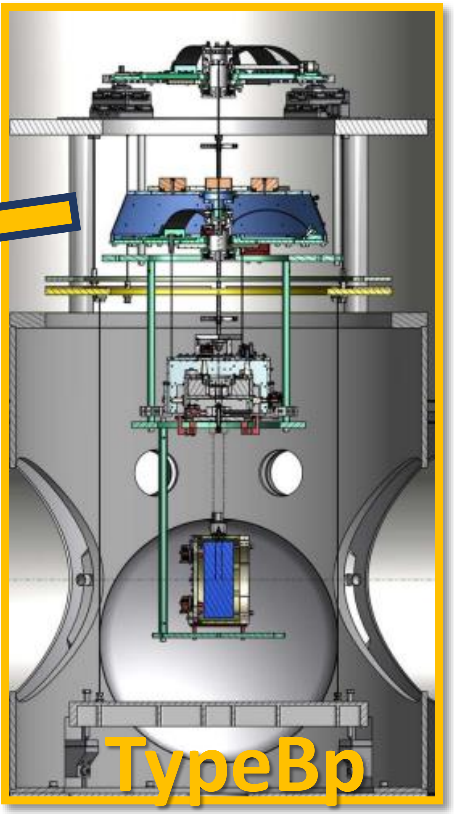
1) disp. < 10^{-15} m/rtHz at 10 Hz
2) RMS velocity < 0.5 um/s
3) RMS angular fluct. < 1 urad

RM / TM

Current bKAGRA PR SAS = TypeBp

❖ Intro : PR SAS in bKAGRA (TypeBp)





PR TMs are required :

1) disp. < 10^{-15} m/rtHz at 10 Hz
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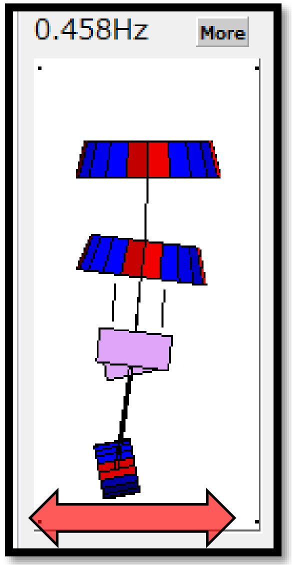
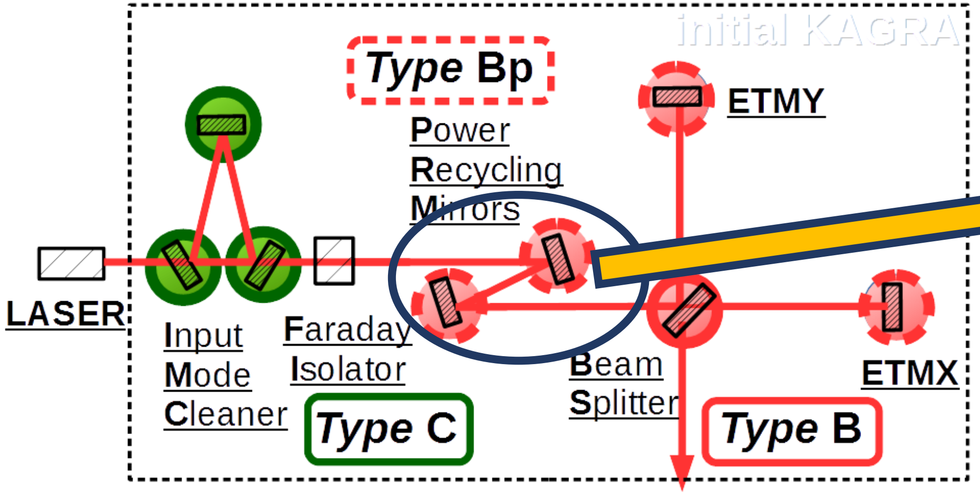


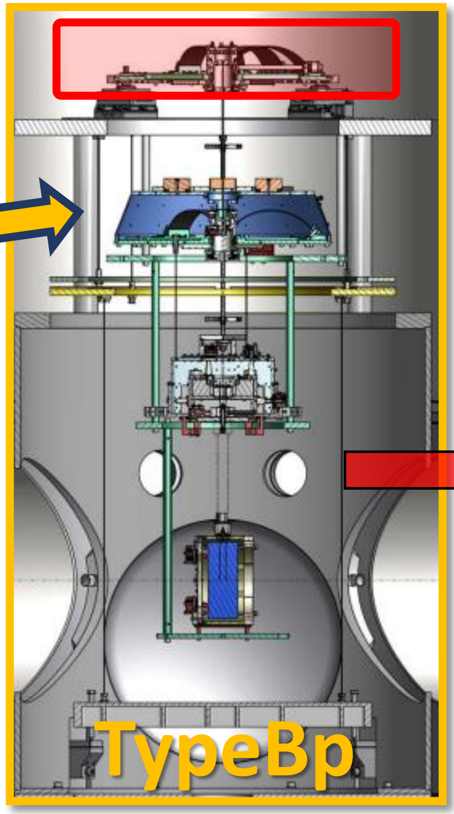
Problems :

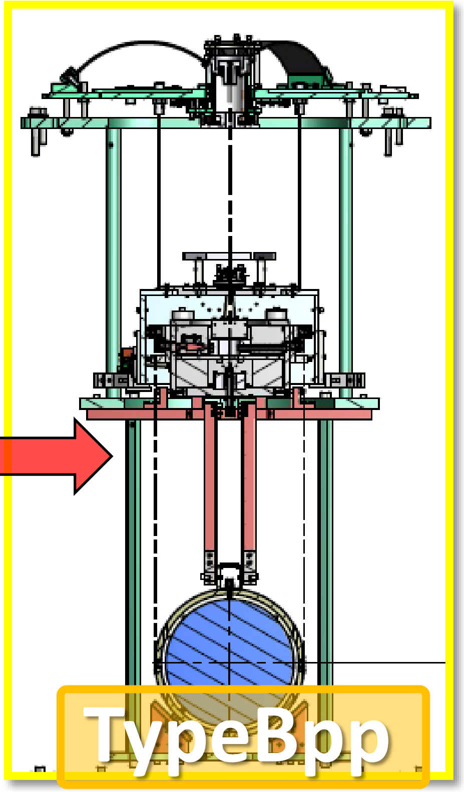
Whole suspension mode cannot be damped enough.

RMS velocity cannot reach lower than 0.7 um/s, because of seismic noise.

❖ Intro : PR SAS in iKAGRA (TypeBpp)







iKAGRA

If SF is removed,
though vibration isolation performance gets worse,
RMS velocity and RMS angular fluctuation get better.

(We have to modify this SAS design to meet the bKAGRA requirements.)

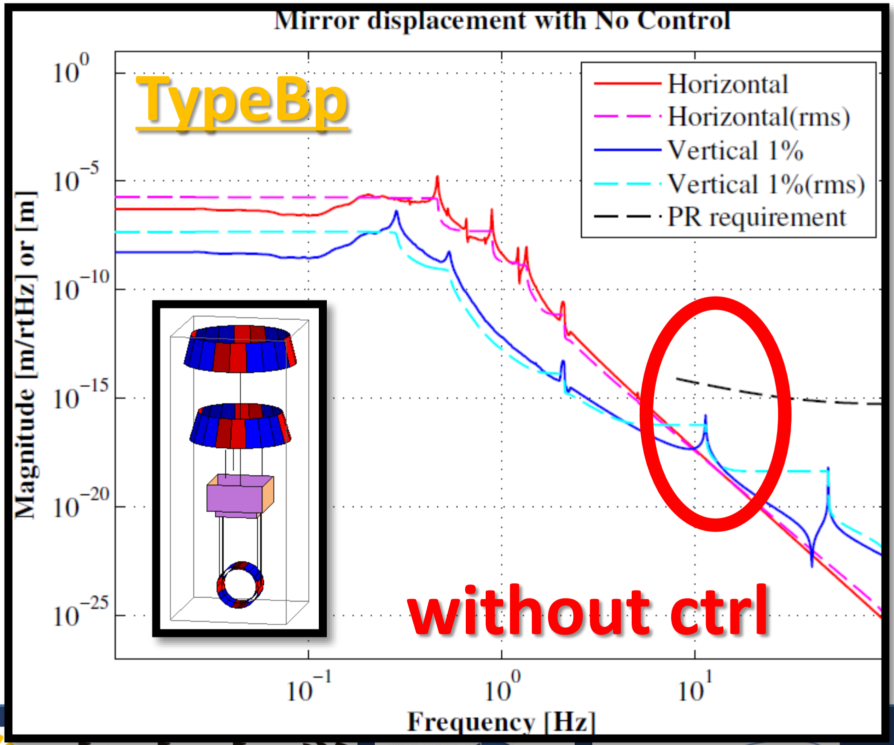
❖ Intro : PR SAS in iKAGRA (TypeBpp)

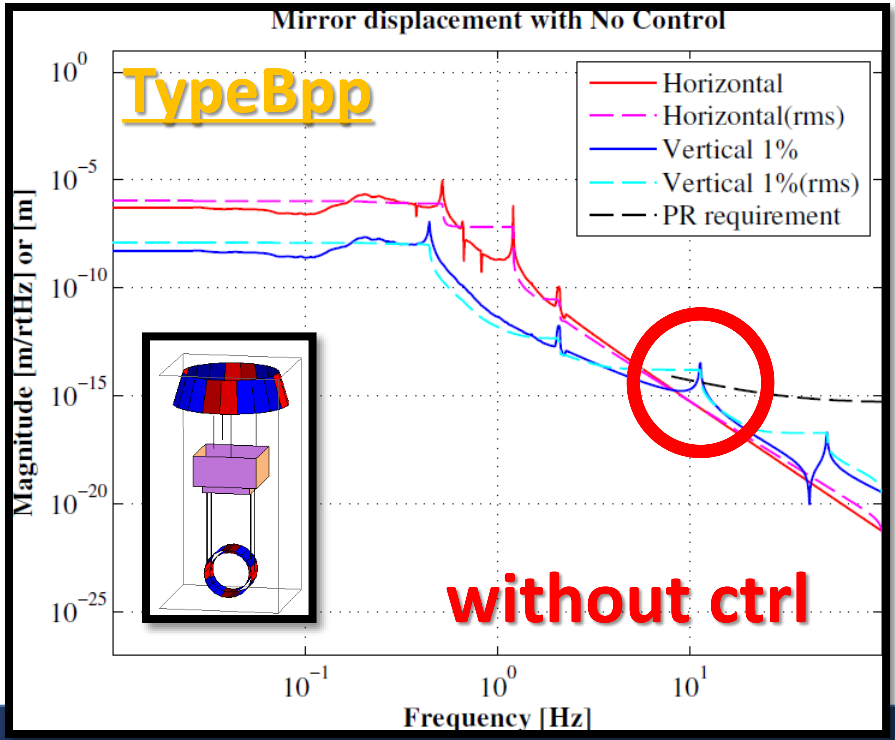
PR TMs are required :

1) disp. < 10^{-15} m/rtHz at 10 Hz
2) RMS velocity < 0.5 um/s
3) RMS angular fluct. < 1 urad

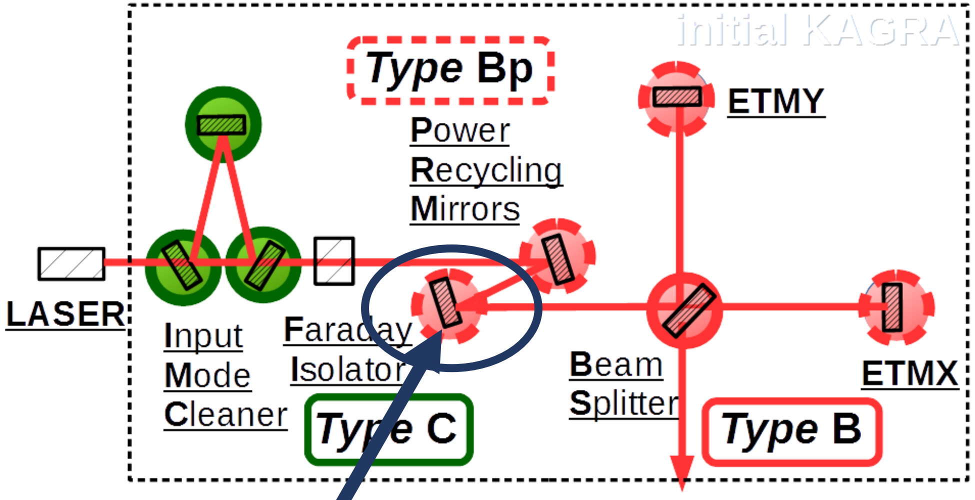
TypeBp	TypeBpp
meet	Not meet
~ 5 um/sec (with ctrl)	~ 1 um/sec (with ctrl)
~ 1.4 urad (with ctrl)	~ 0.4 urad (with ctrl)

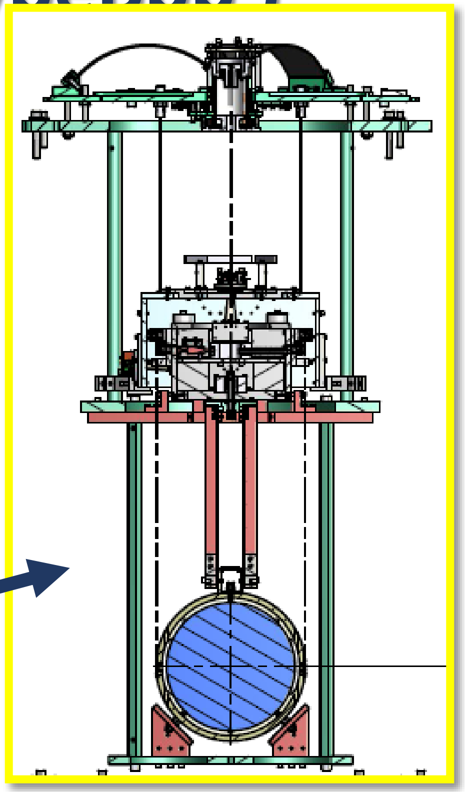
Also, RMS seismic velocity can be ~ 0.7 um/sec

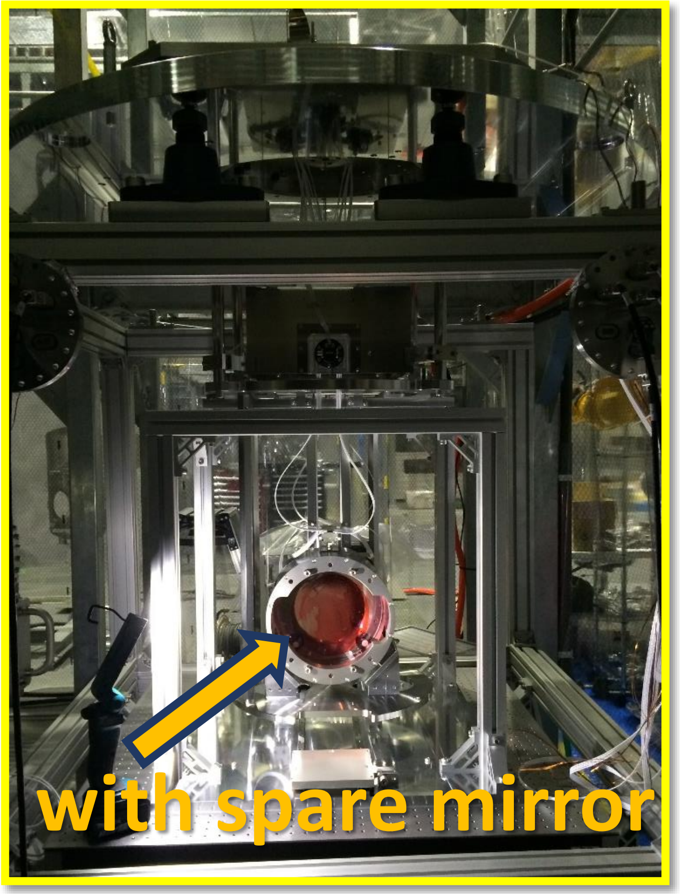




❖ Intro : PR SAS in iKAGRA (TypeBpp)





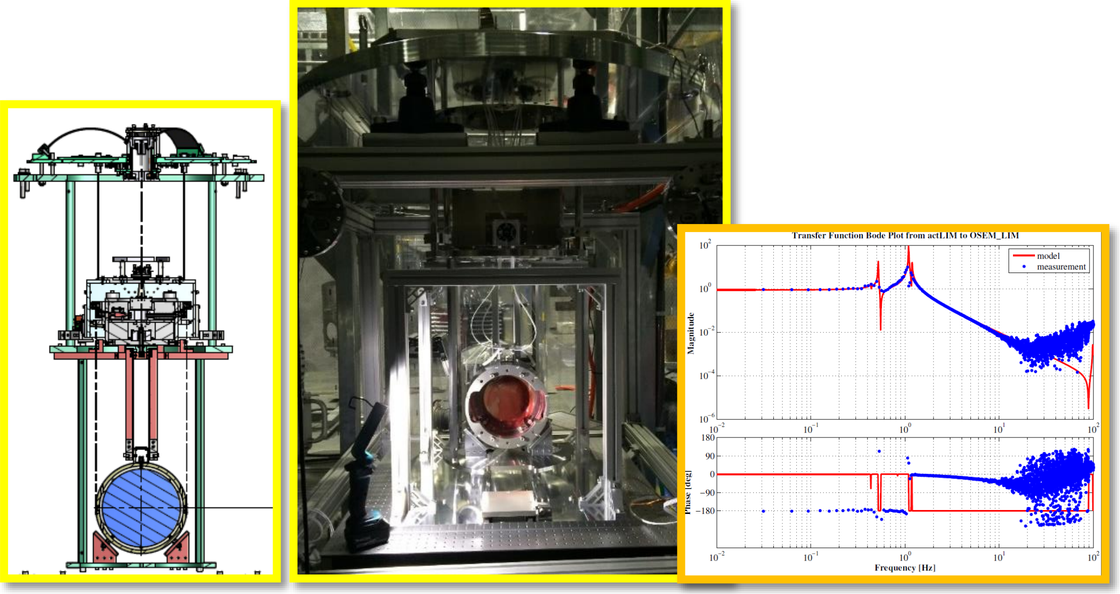


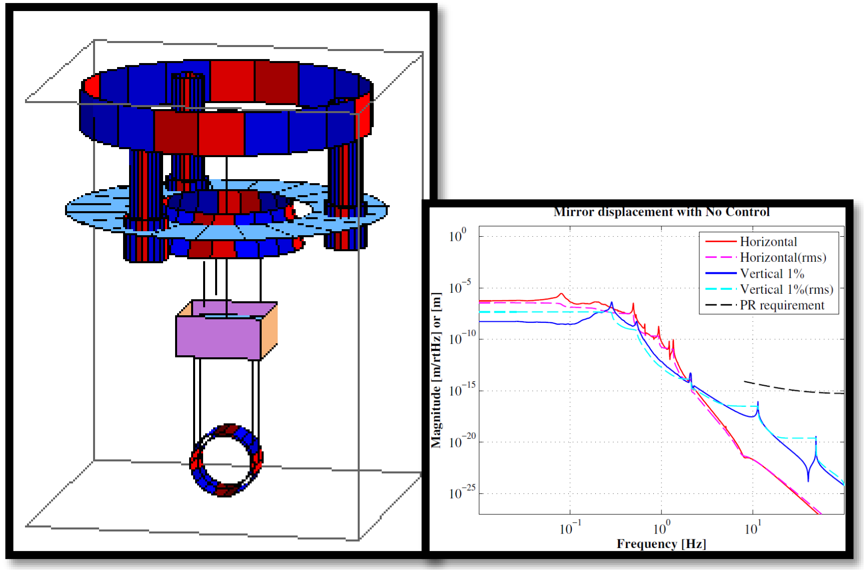
Now, we are constructing with real mirror.

iKAGRA PR SAS = TypeBpp

(= TypeBp without SF)

❖ Intro : PR SAS / Main topic of this talk





① Frequency response investigation of the TypeBpp SAS (, which we constructed in the tunnel)

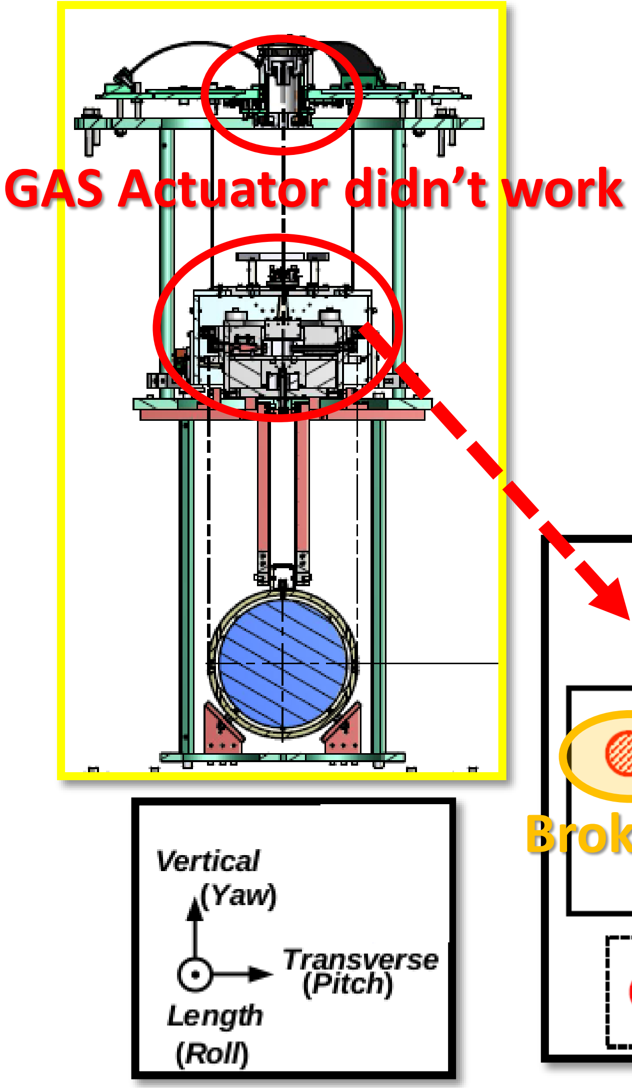
② One modification idea for bKAGRA PR SAS

How do we meet both (displacement and RMS) requirements?

Contents

- ❐ Intro : PR SAS
  - ❐ TypeBp / TypeBpp
- ❖ Investigation of TypeBpp Frequency response
  - ❖ Transfer functions / Spectra
- ❐ One modification proposal for bKAGRA
  - ❐ requirement
  - ❐ TypeBp with IP

❖ Investigation of TypeBpp Frequency response

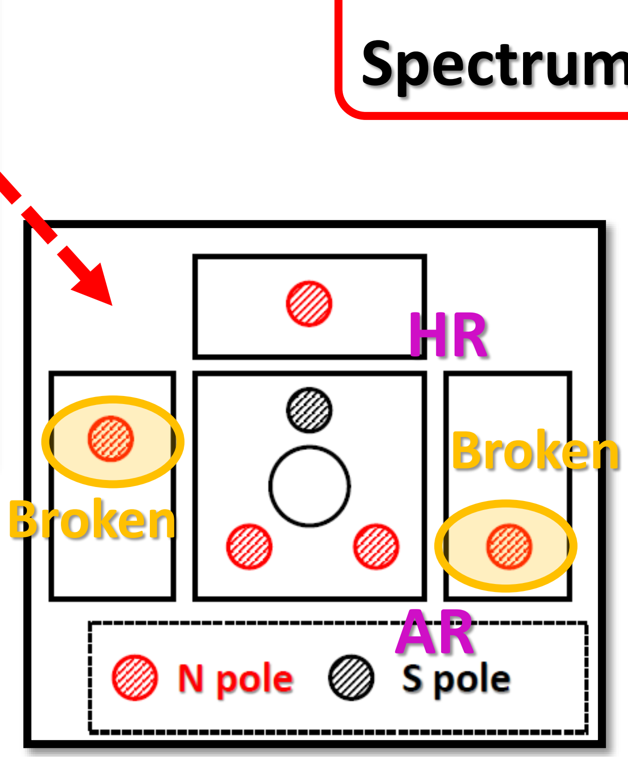


Measured DoF :

Transfer functions → IM (L, P, R), TM (L, P, Y)

Spectrums → BF (V), IM (L, P, R, V), TM (L, P, Y)

◯ Measured by Oplev and OSEMs
(The others → measured by OSEMs)



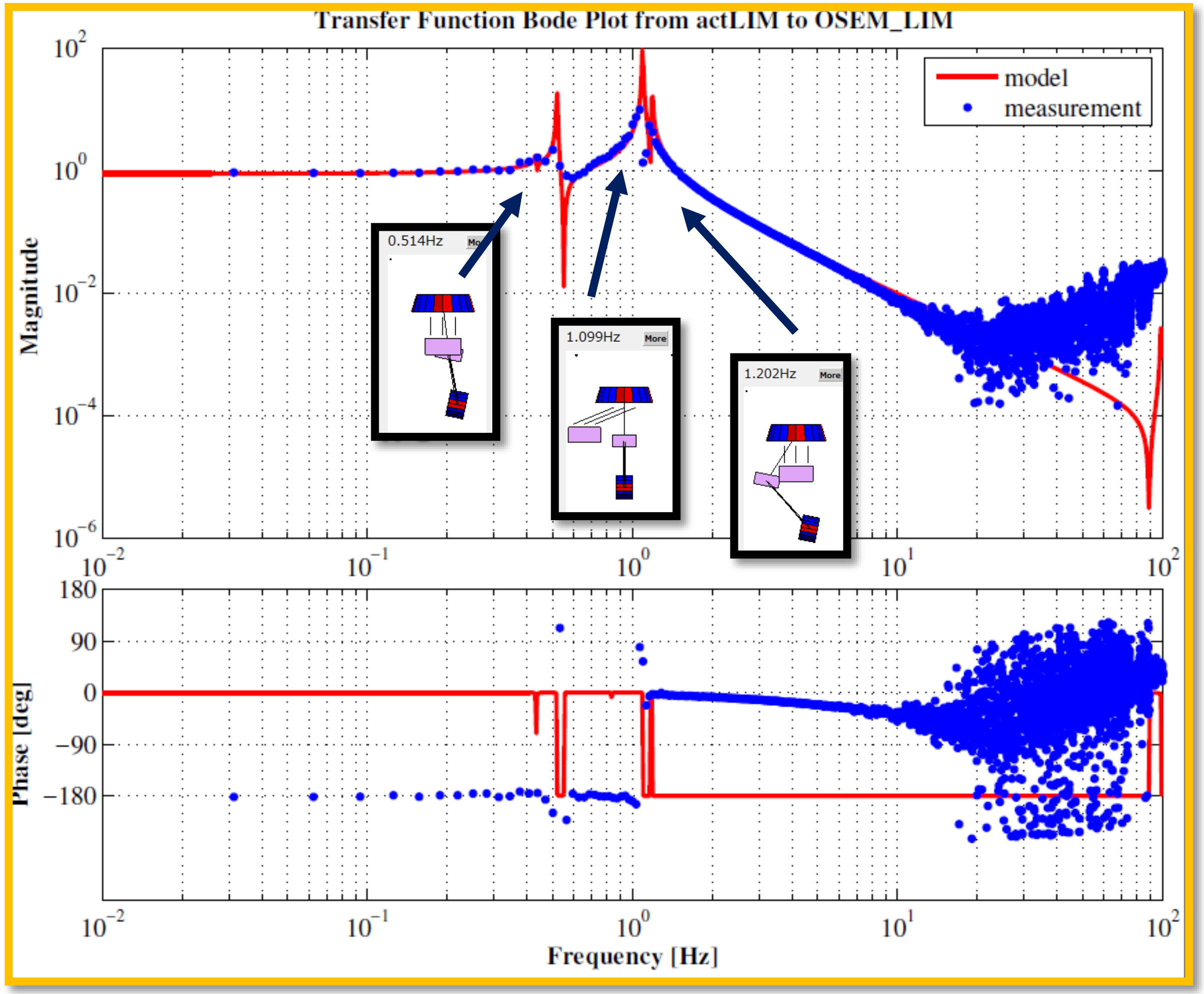
Not Measured DoF :

Transfer functions → BF(V), IM (T, V, Y)

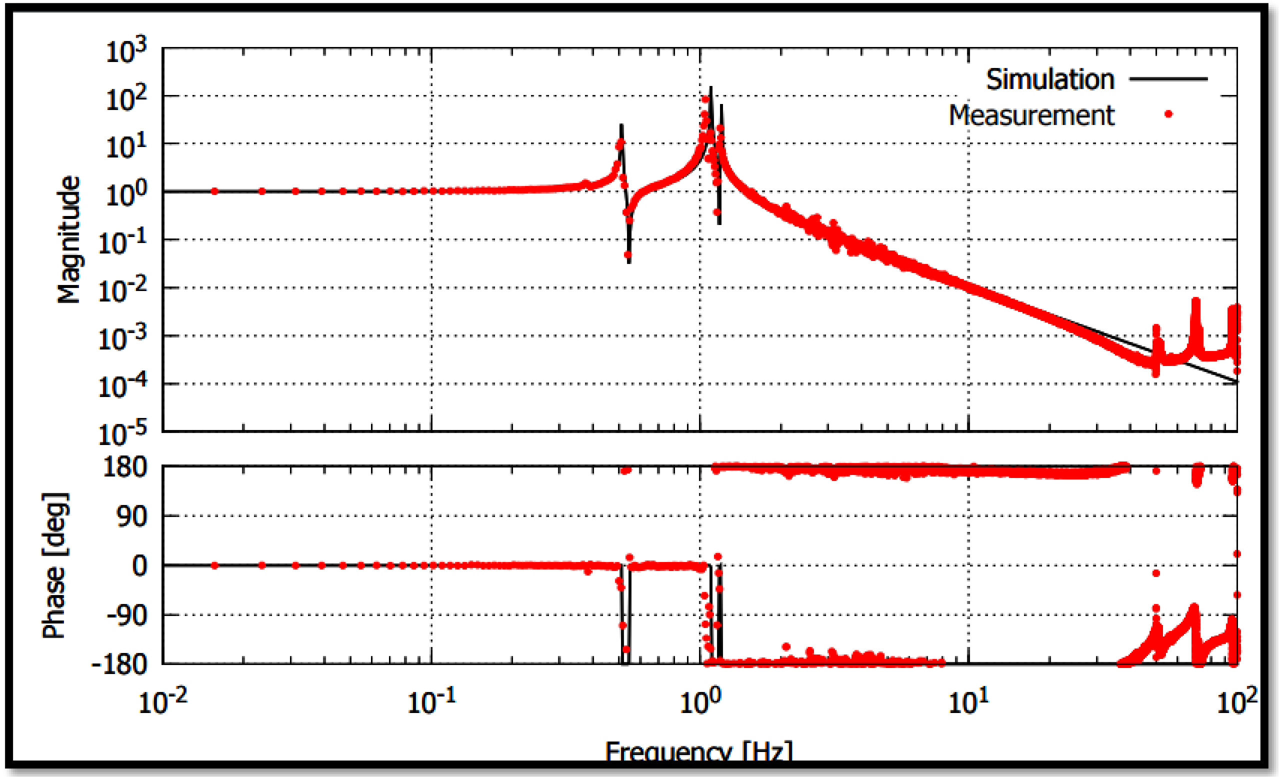
Spectrums → IM (T, Y)

Investigation of TypeBpp Frequency response

LIM (OSEM) TF

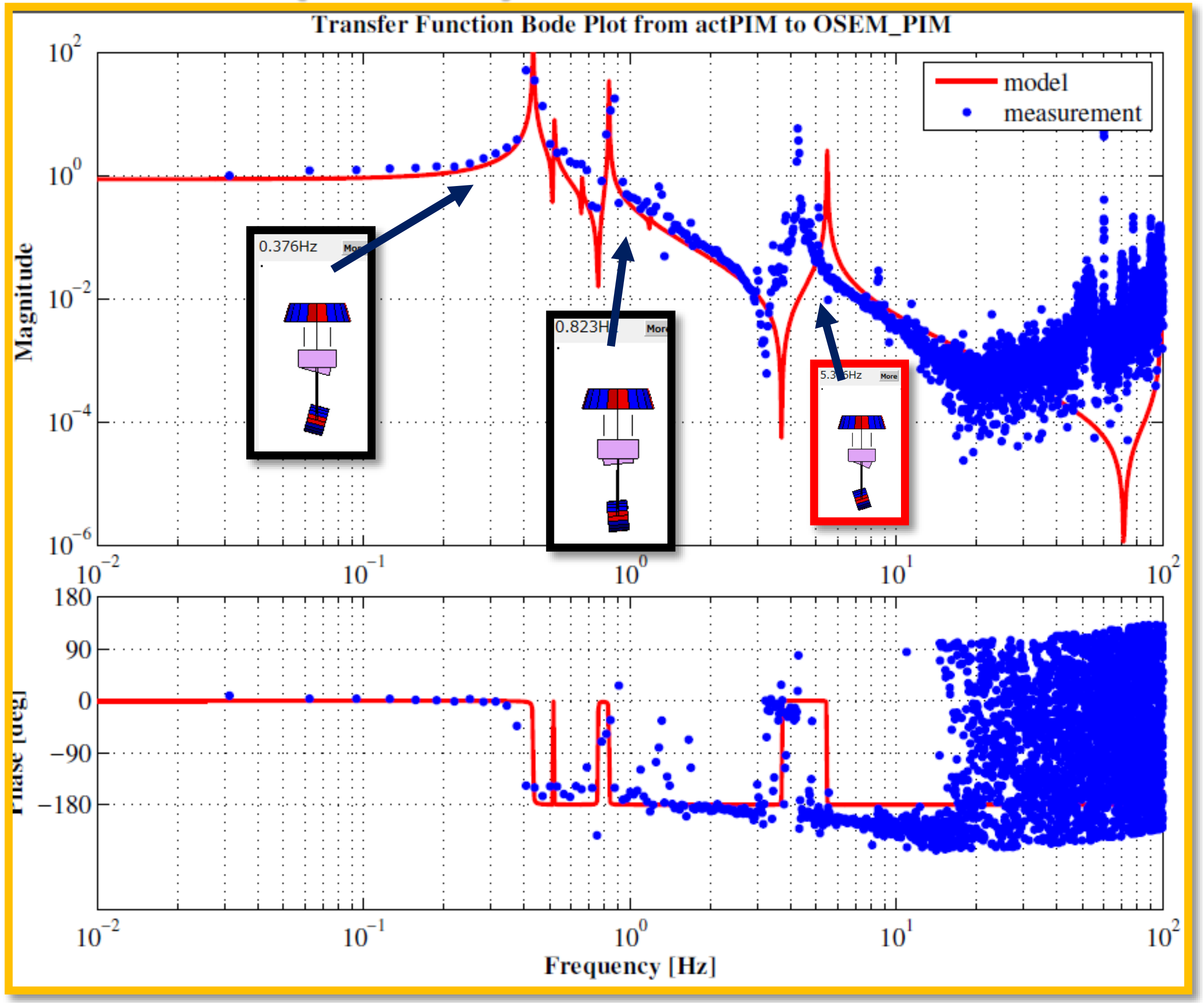


REF : LIM (OSEM) TF of 20 m SAS

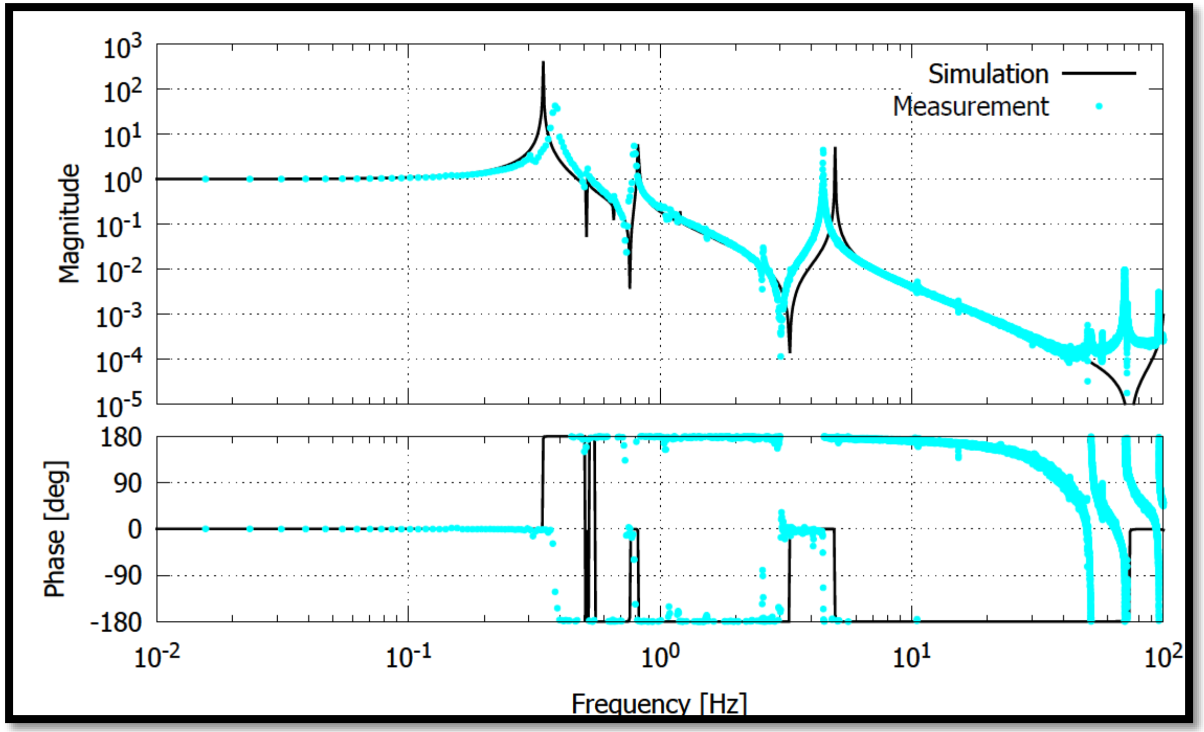


❖ Investigation of TypeBpp Frequency response

PIM (OSEM) TF

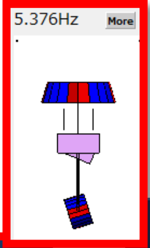


REF : PIM (OSEM) TF of 20 m SAS



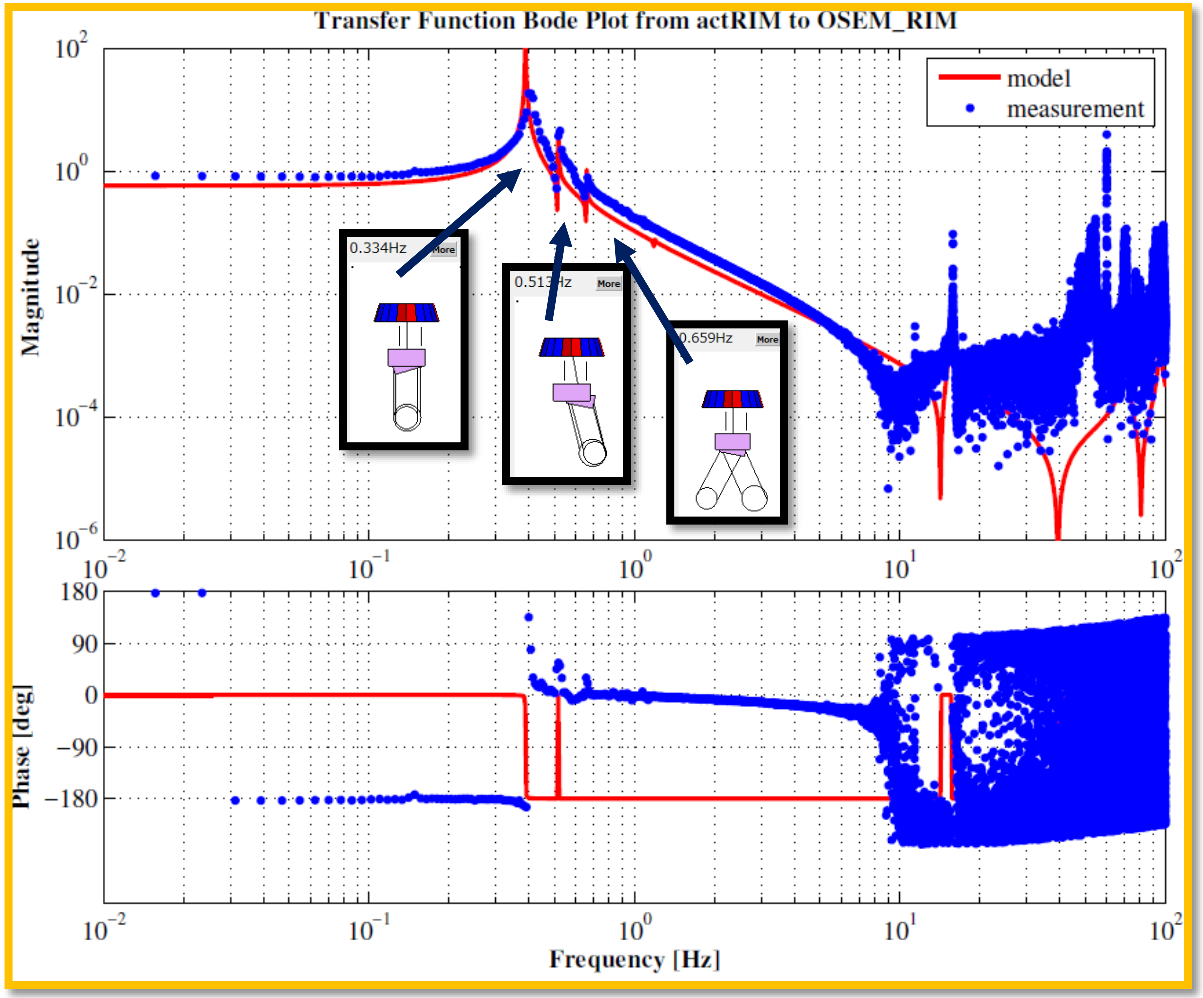
Resonance frequency is lower than its prediction by around 1 Hz.

→ **To be investigated.**

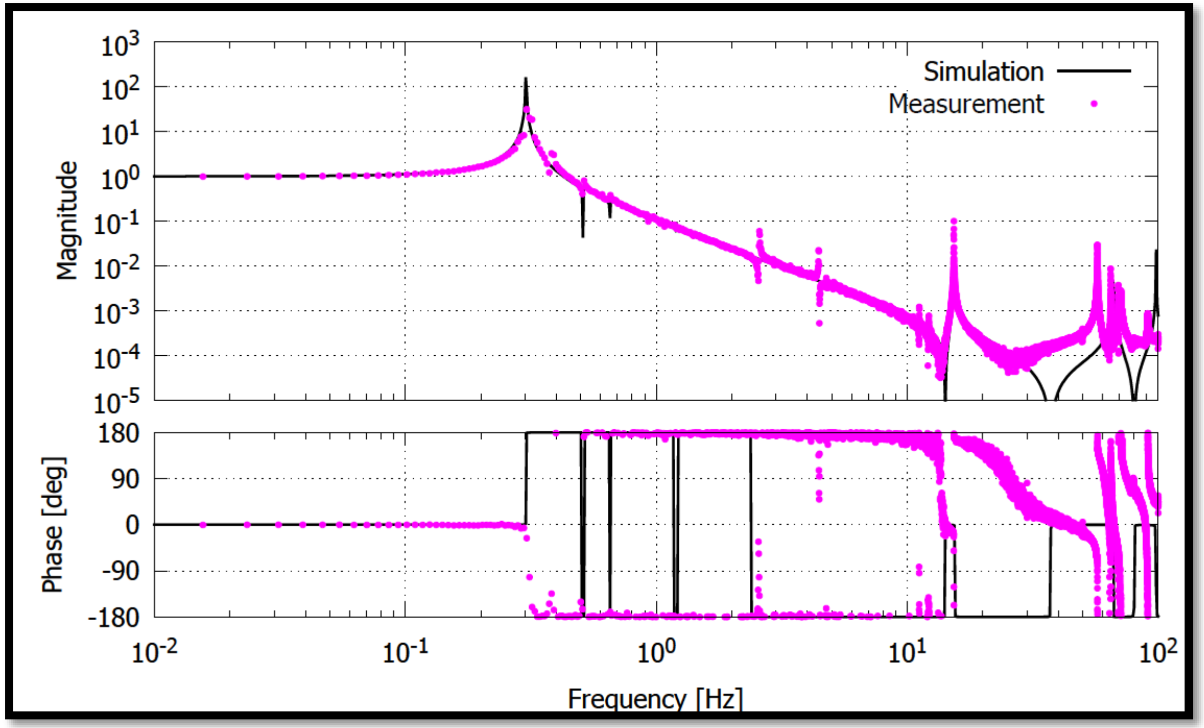


❖ Investigation of TypeBpp Frequency response

RIM (OSEM) TF

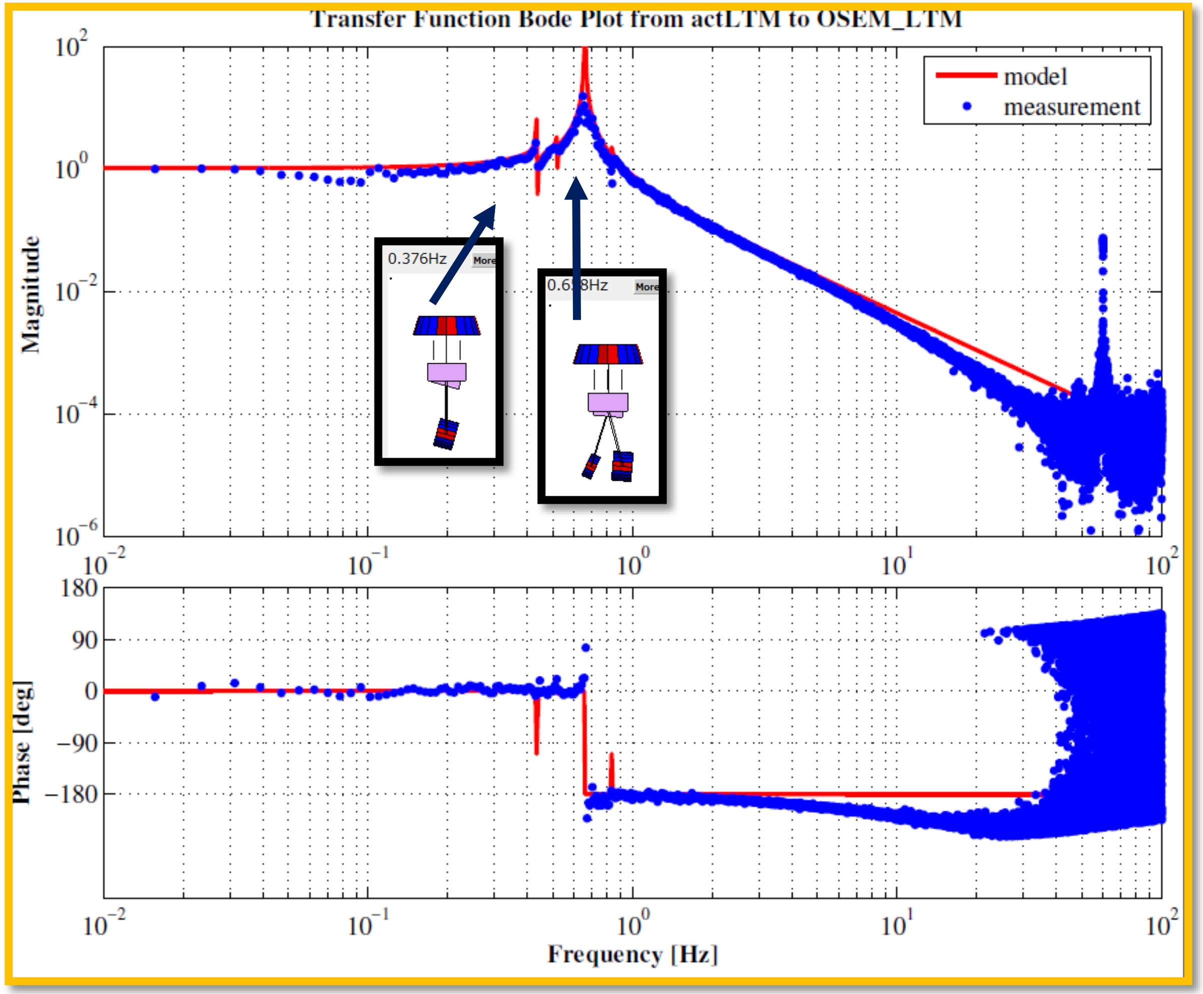


REF : RIM (OSEM) TF of 20 m SAS

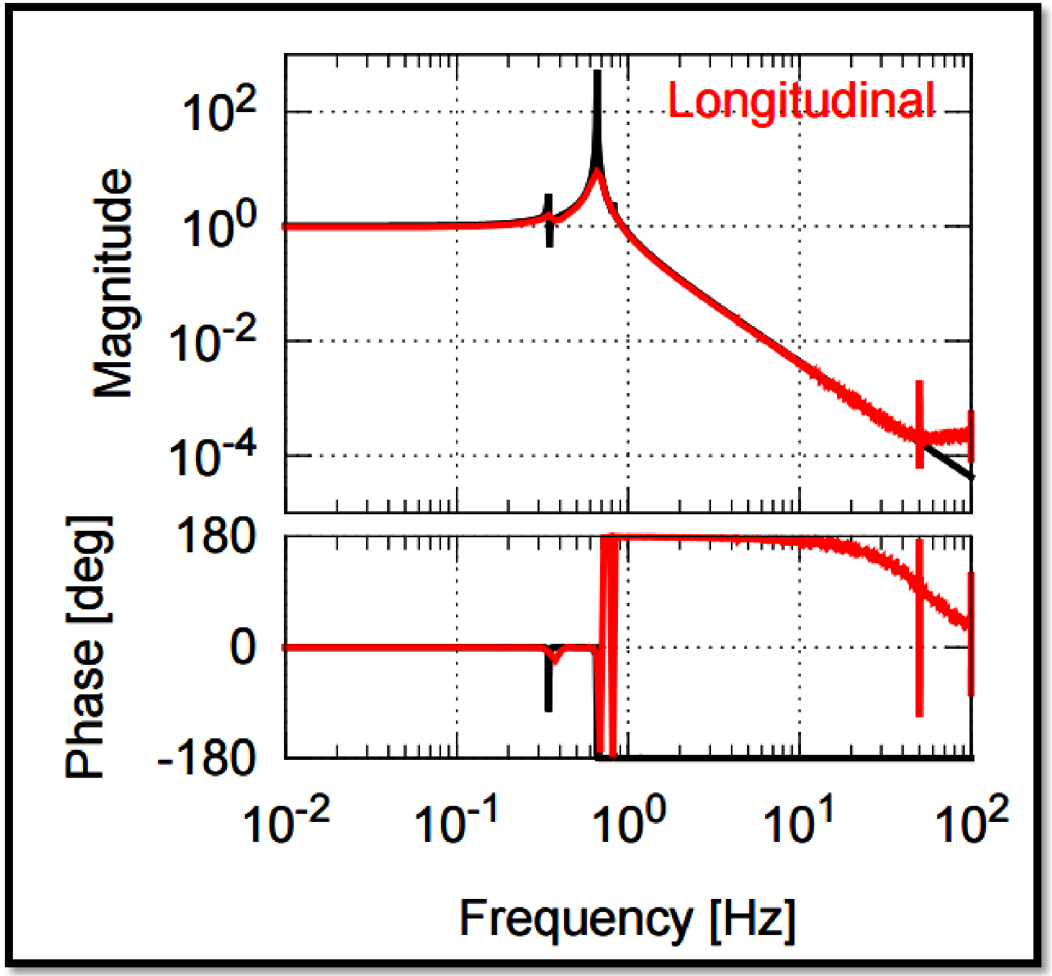


Investigation of TypeBpp Frequency response

LTM (OSEM) TF

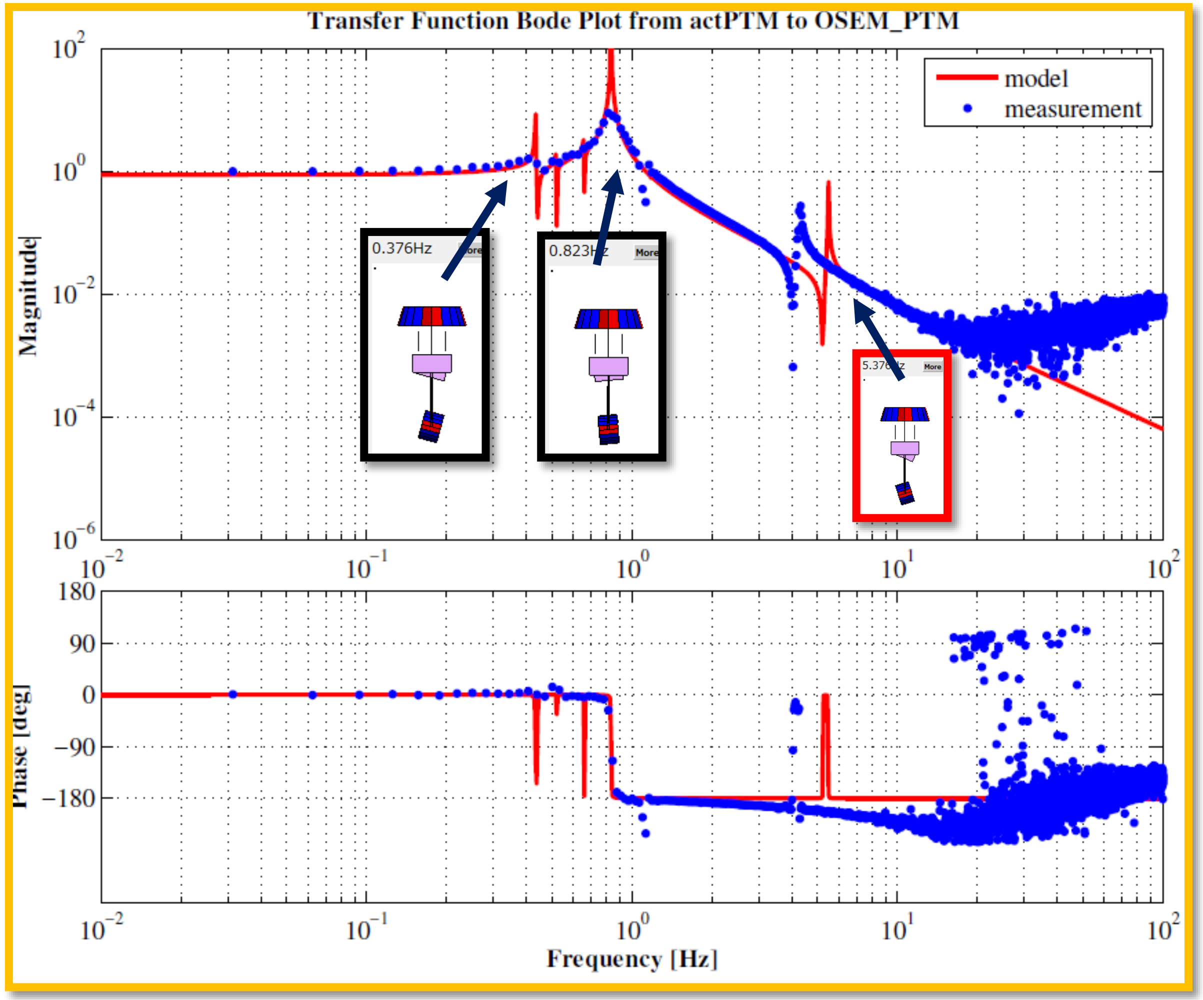


REF : LTM (OSEM) TF of 20 m SAS

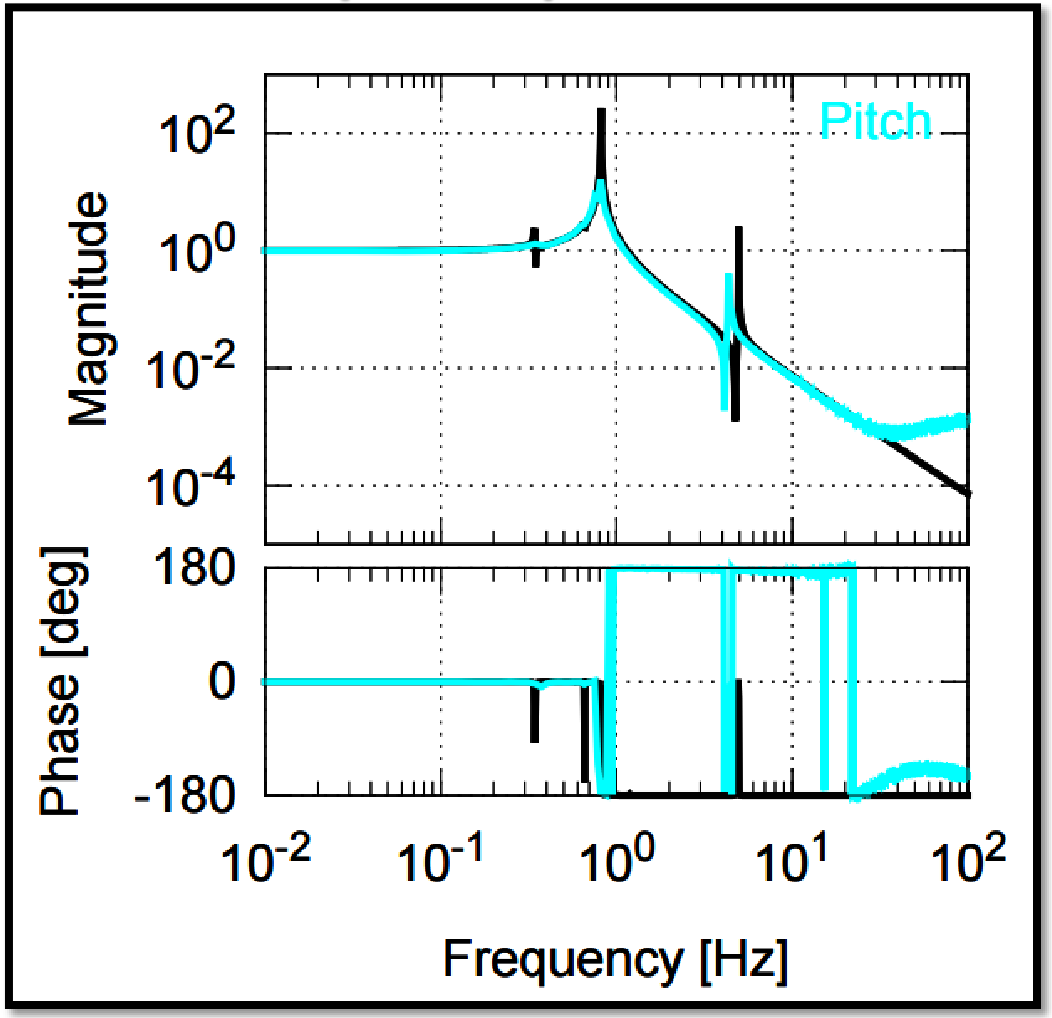


❖ Investigation of TypeBpp Frequency response

PTM (OSEM) TF

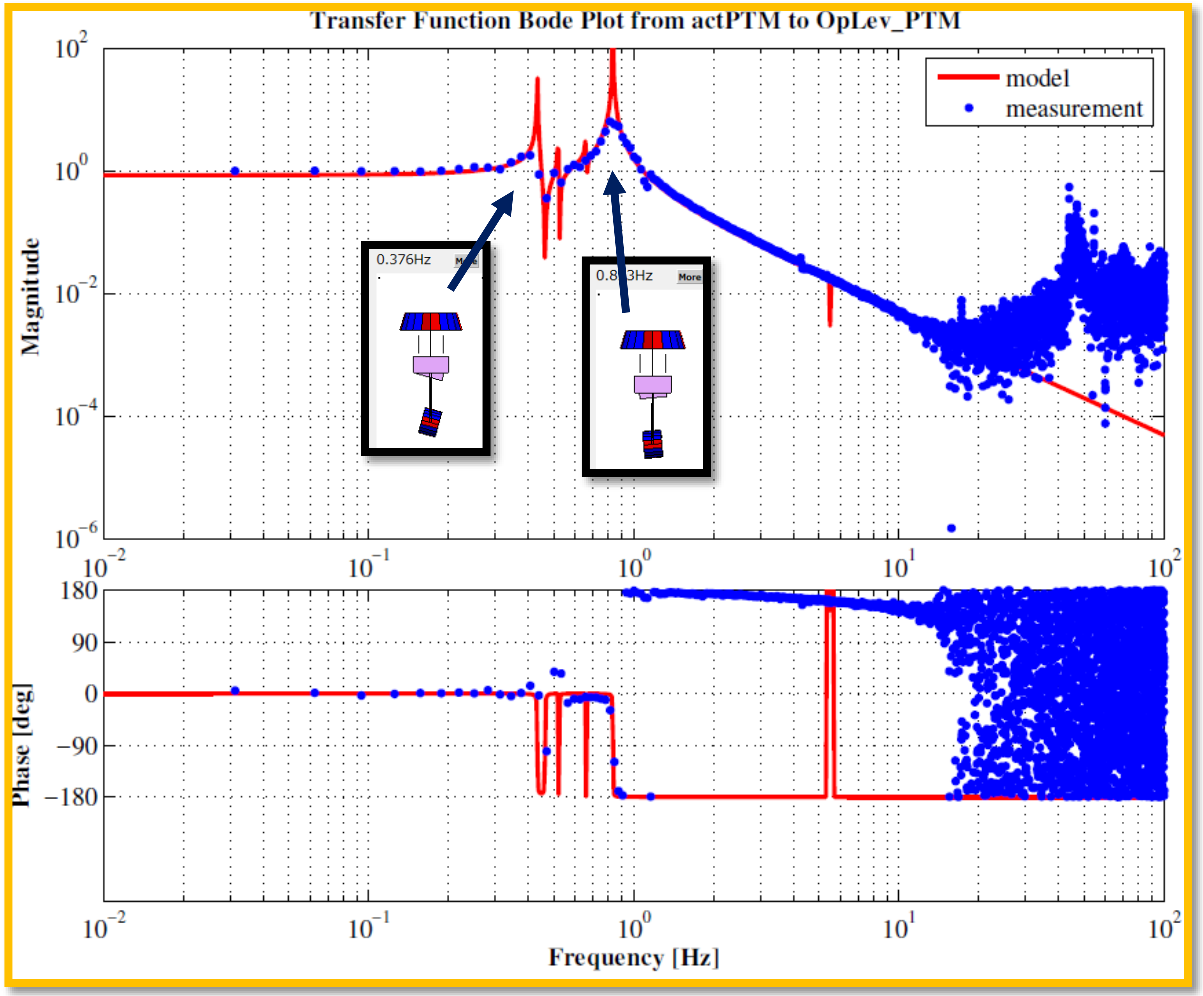


REF : PTM (OSEM) TF in 20 m SAS

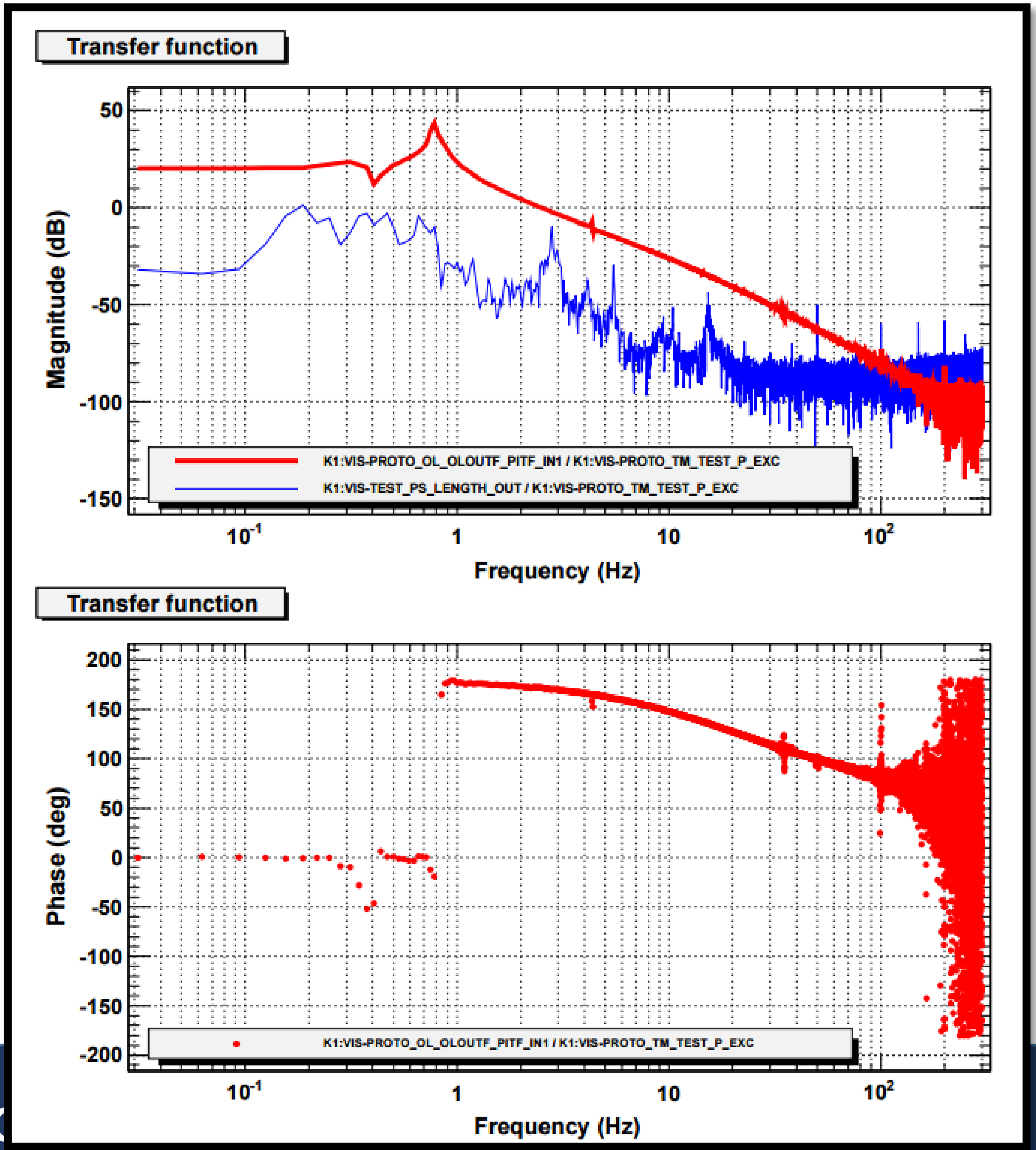


❖ Investigation of TypeBpp Frequency response

PTM (Oplev) TF

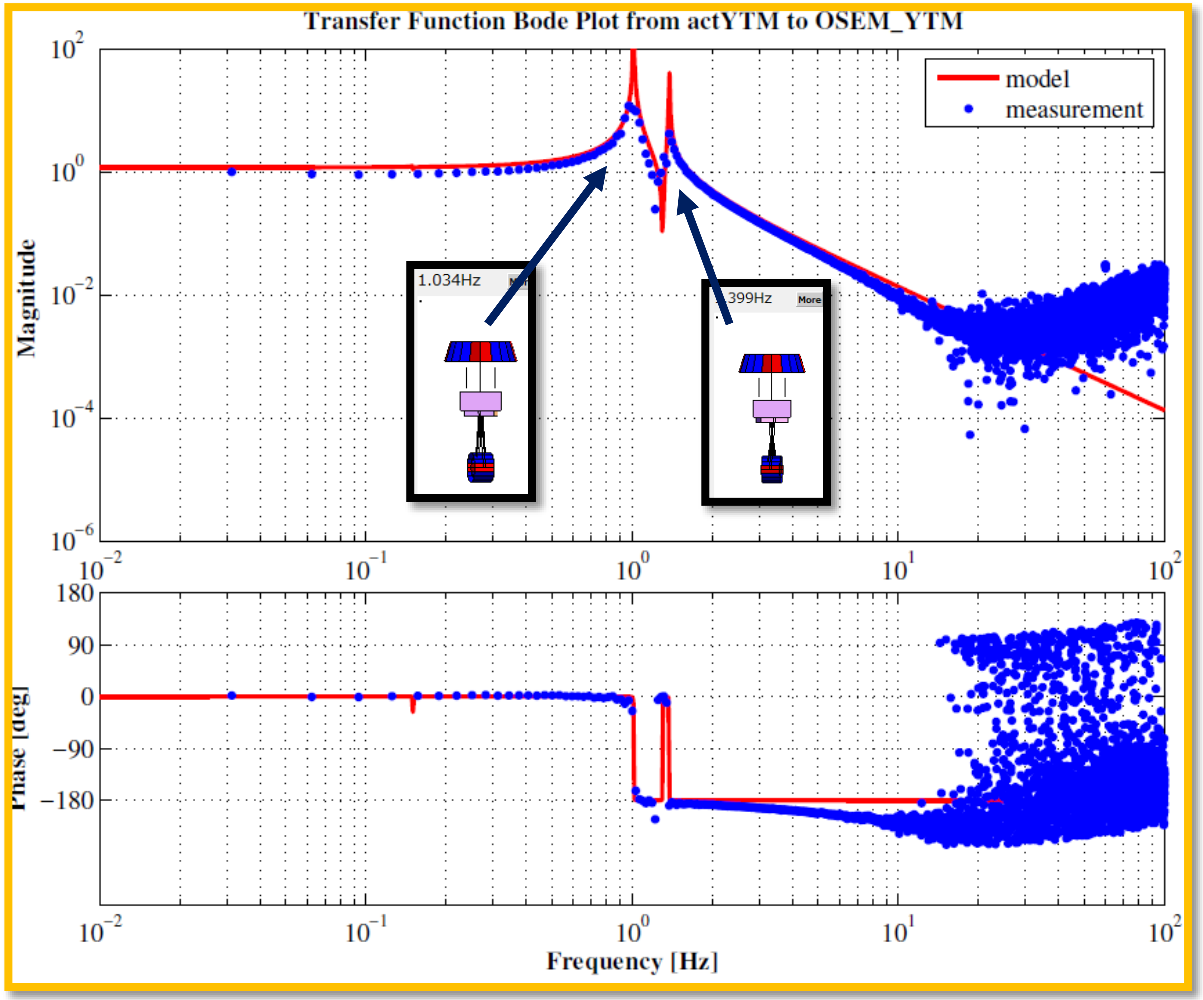


REF : PTM (Oplev) TF of Type B1

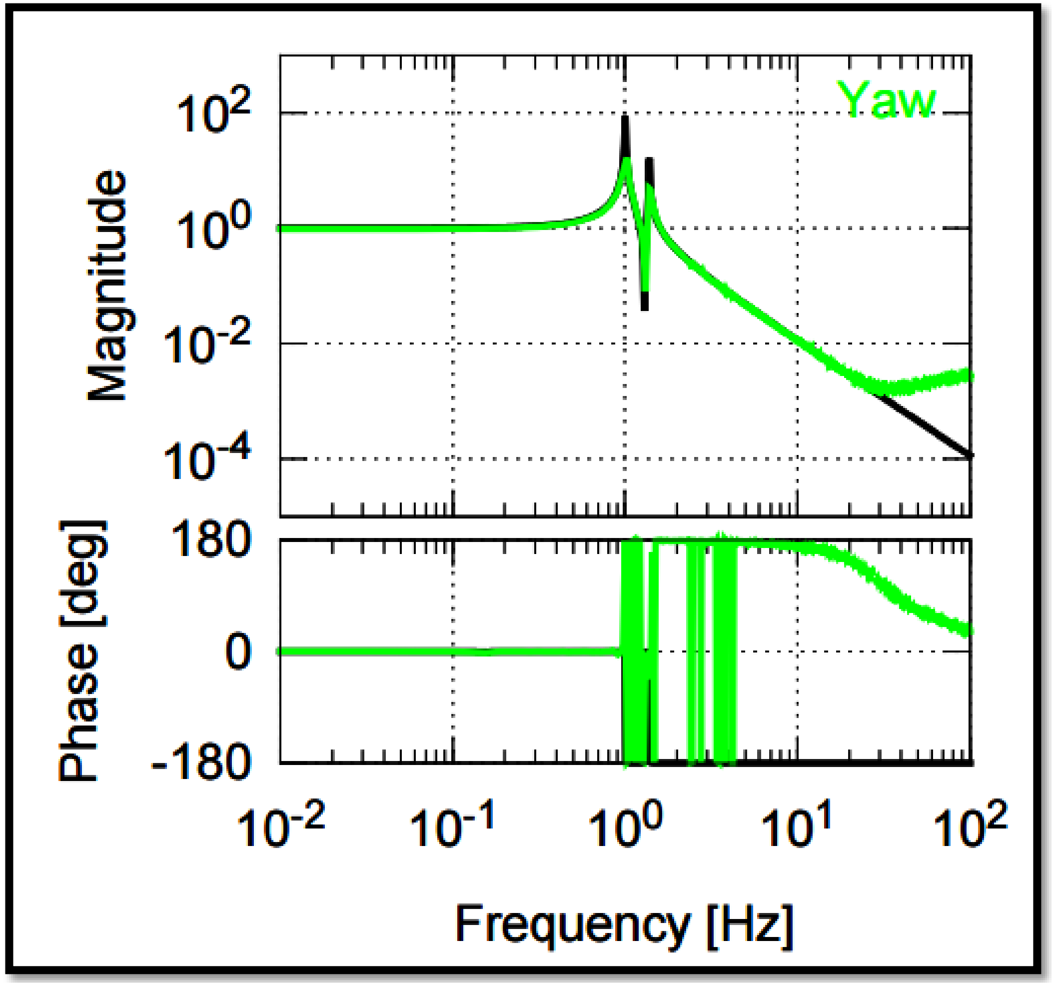


❖ Investigation of TypeBpp Frequency response

YTM (OSEM) TF

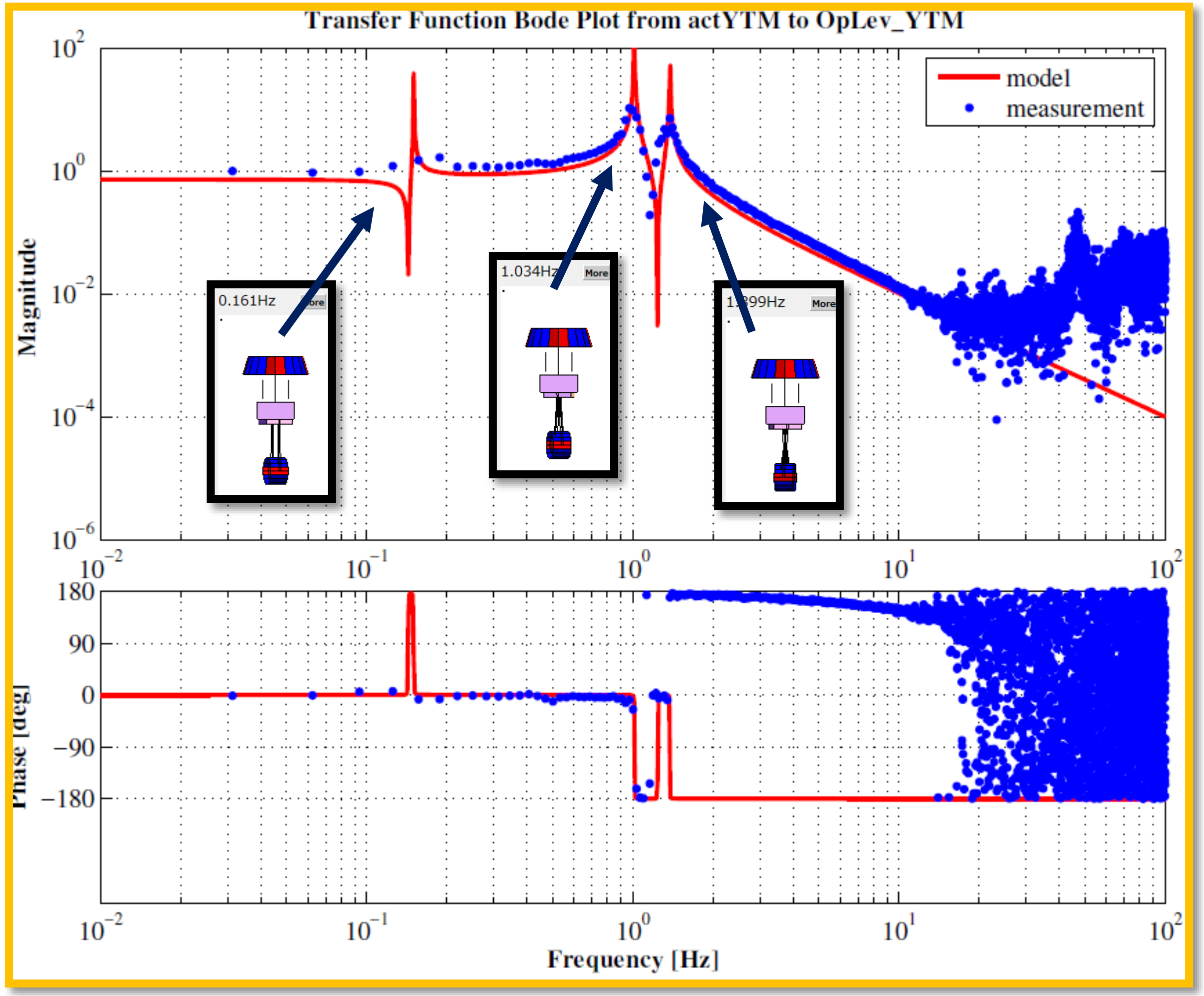


REF : LTM (OSEM) TF of 20 m SAS

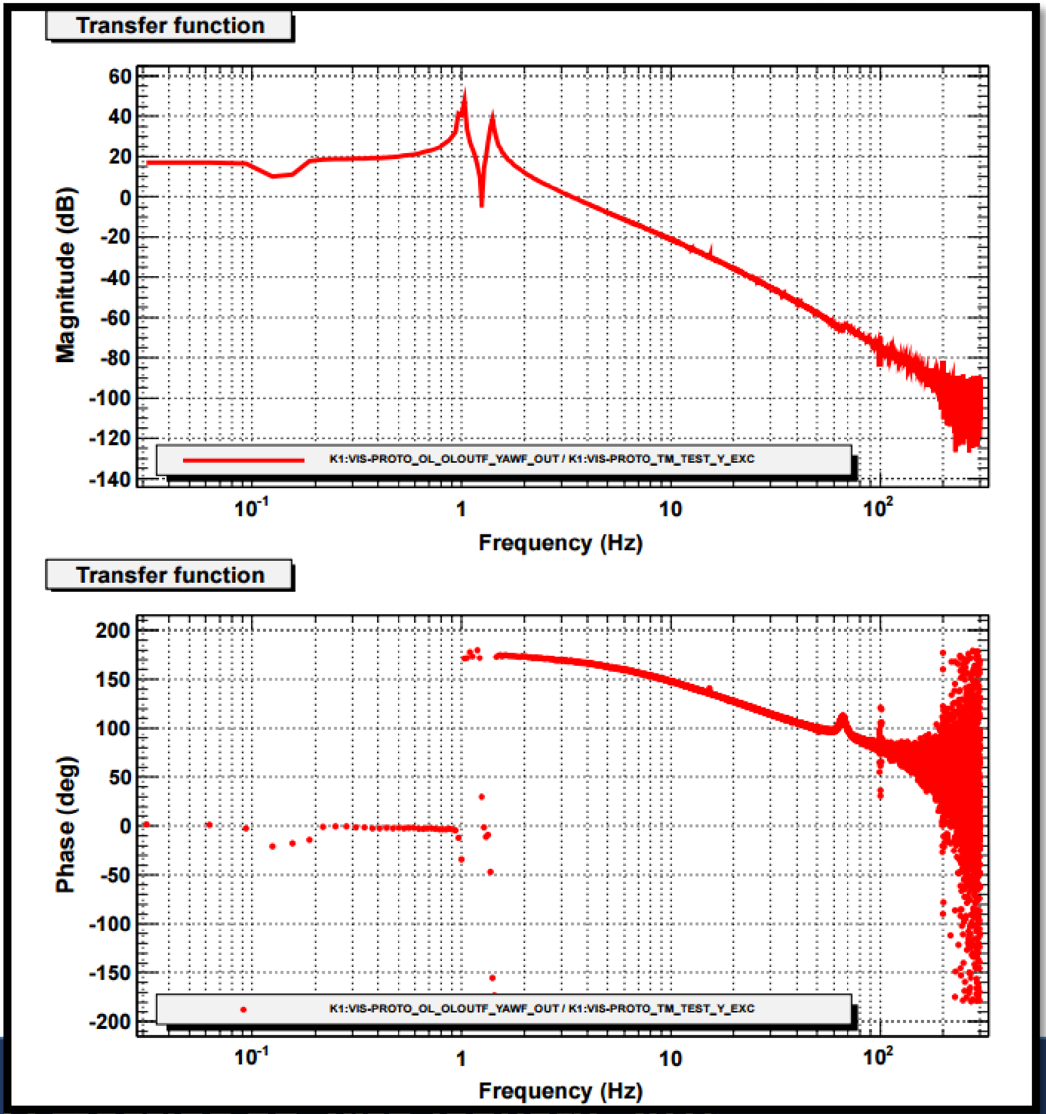


Investigation of TypeBpp Frequency response

YTM (Oplev) TF

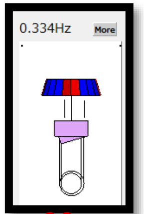


REF : YTM (Oplev) TF of Type B1



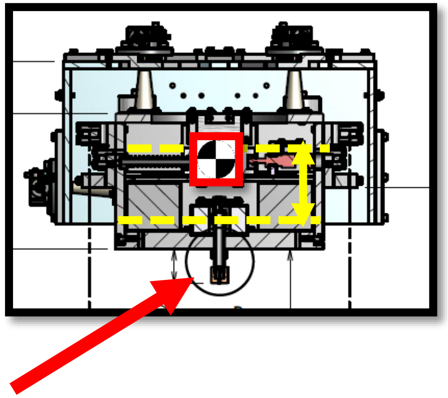
❖ Investigation of TypeBpp Frequency response

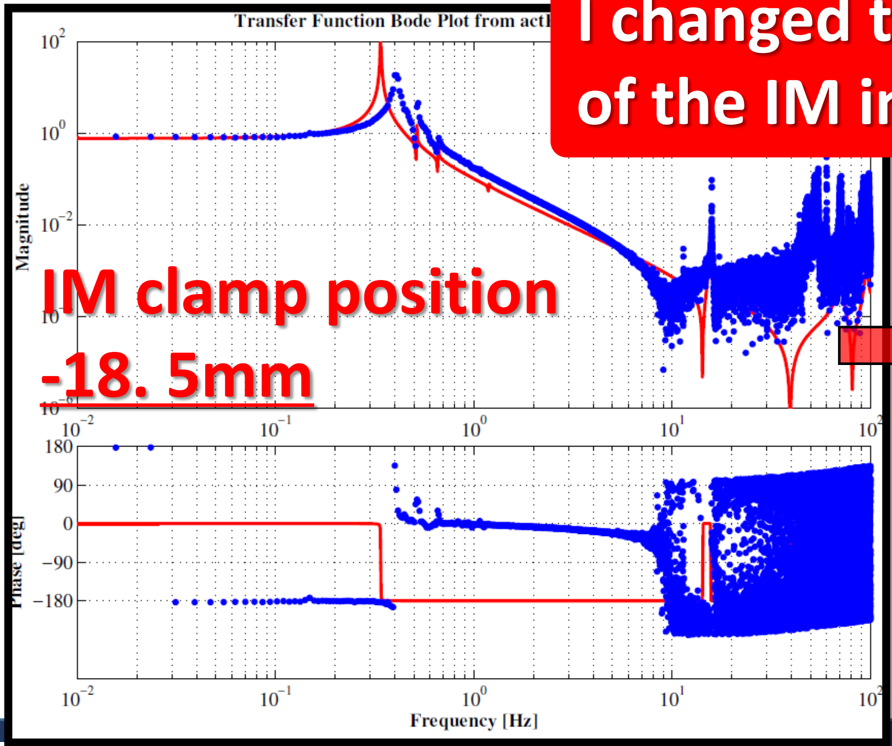
Note : Transfer function (measured in the chamber)

- Resonance frequency shift :
  - 

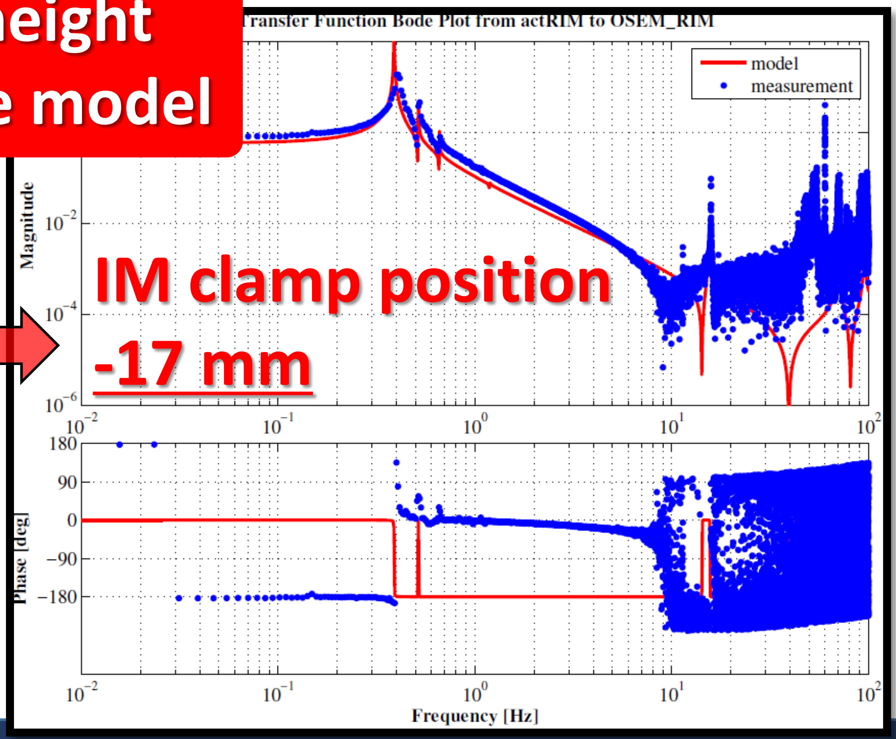
    → CoM position of the IM.

Roll IM



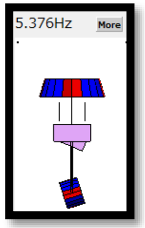


I changed the height of the IM in the model



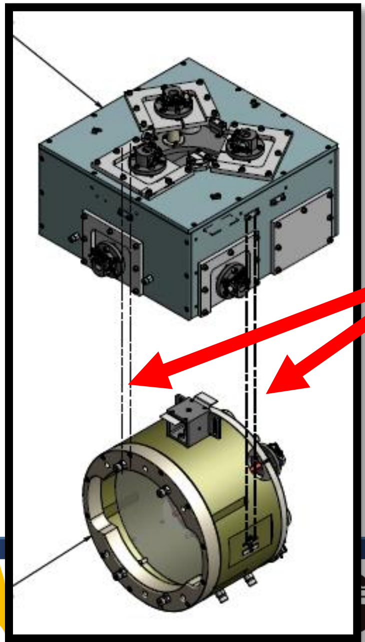
❖ Investigation of TypeBpp Frequency response

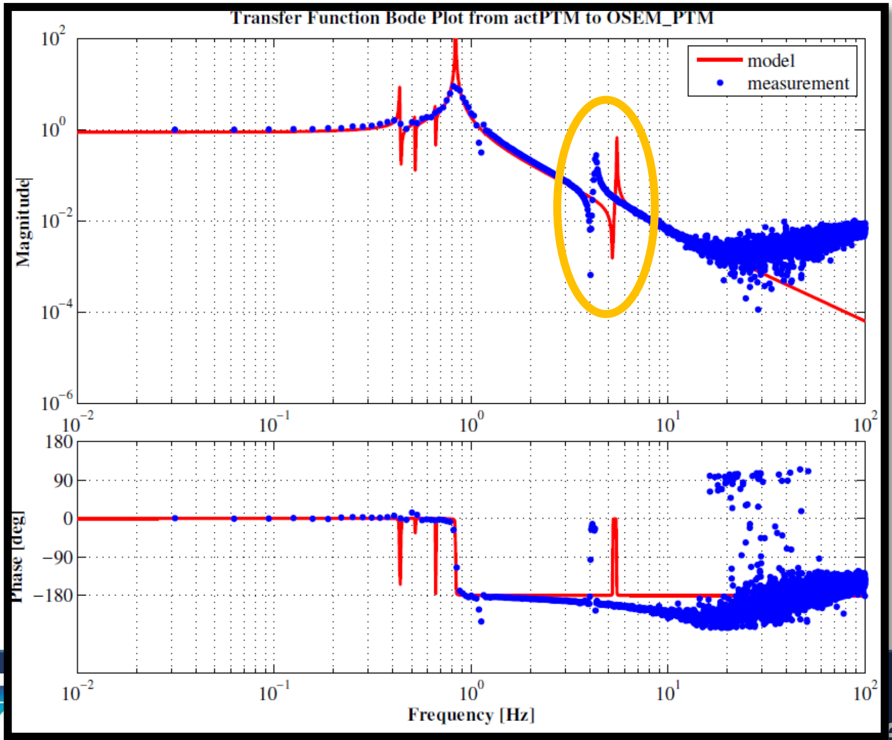
Note : Transfer function (measured in the chamber)

- **Resonance frequency shift :**
  - 

    → we changed the wire diameter to thicker one (600 -> 650 um) to increase the resonance frequency for robust control,

Pitch IM, RM

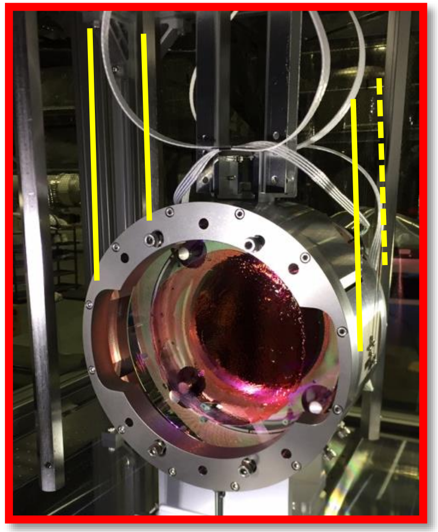


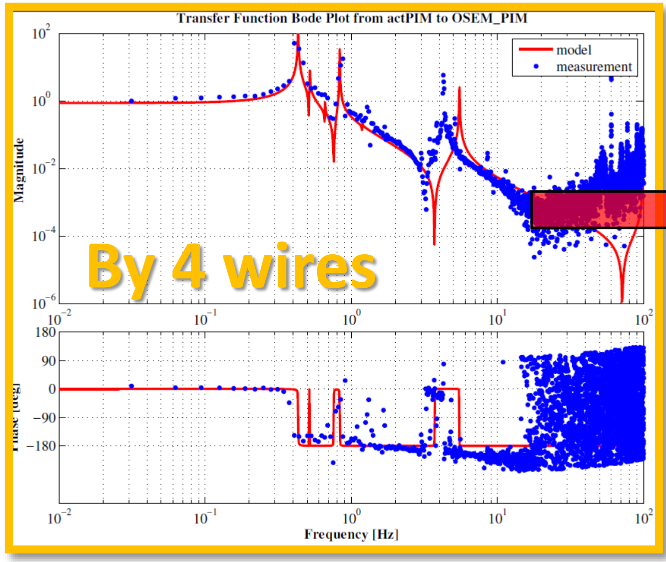


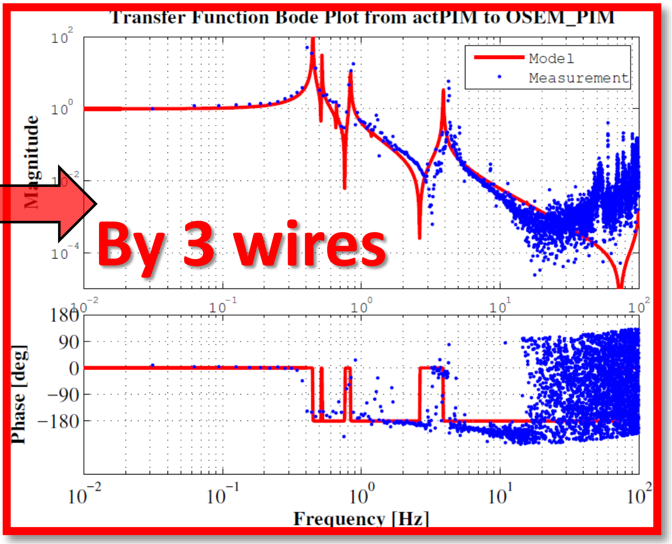
(after TypeB proto exp.)
However, the frequency is still low, for some reason.

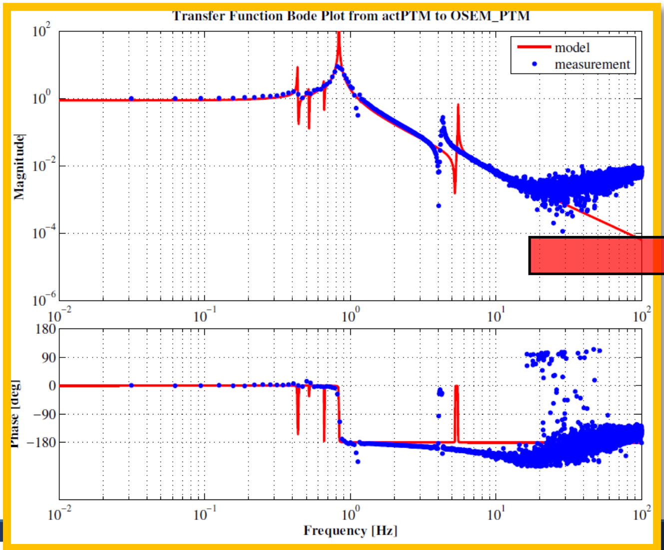
❖ Investigation of TypeBpp Frequency response

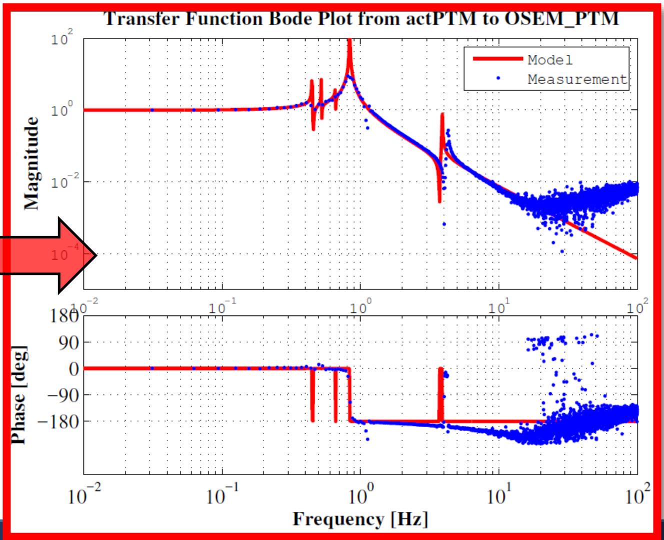
suspended
by 3 wires?

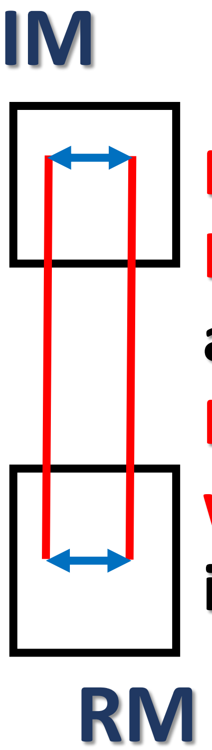








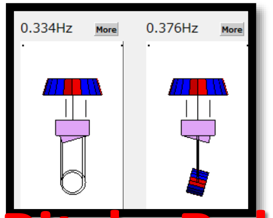




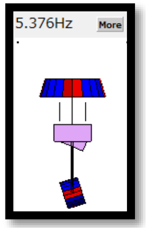
More thinner IM-RM wires, and More wider wire separation is better.

❖ Investigation of TypeBpp Frequency response

Note : Transfer function (measured in the chamber)

- Resonance frequency shift :
  - 

Pitch, Roll IM

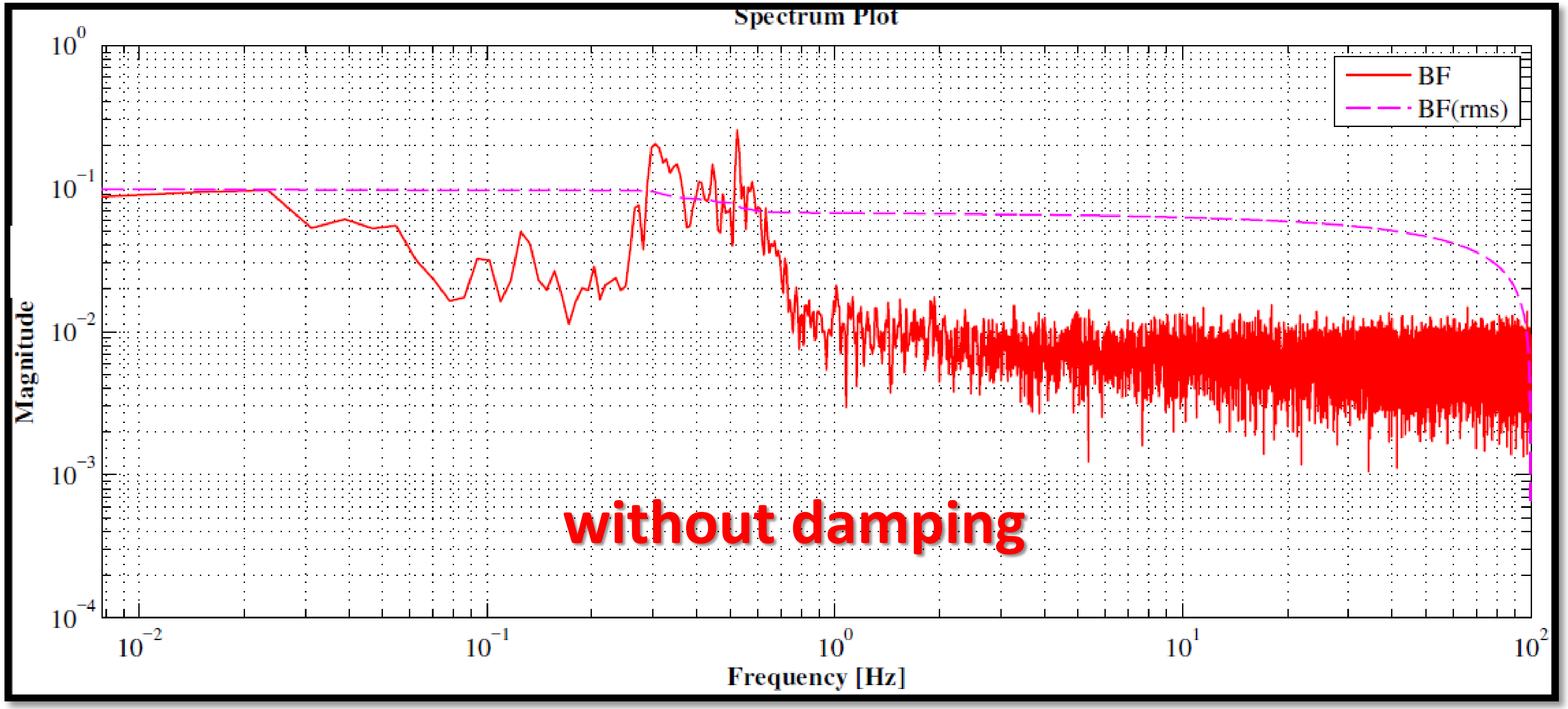
    → IM was suspended at higher position by 1.5 mm.
  - 

Pitch RM

    → Though wire diameter was increased, the resonance frequency is still lower than its prediction by 1 Hz. Not "4 wires", but "3 wires" ?
    The wire separation in our model seems to be wider than its actual system.
- Small mechanical Q factor? → to be investigated, resonance by resonance.

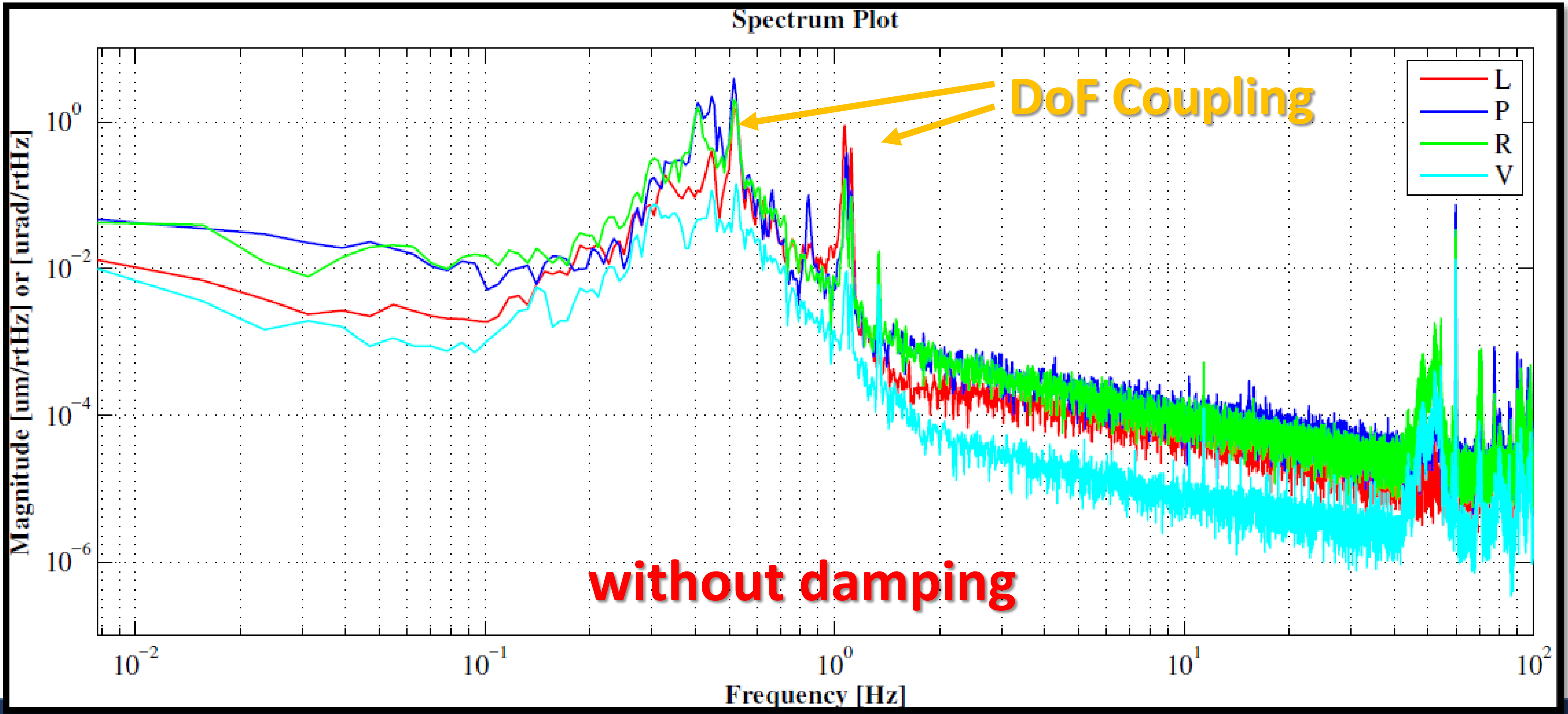
❖ Investigation of TypeBpp Frequency response

BF (LVDT) Spectra



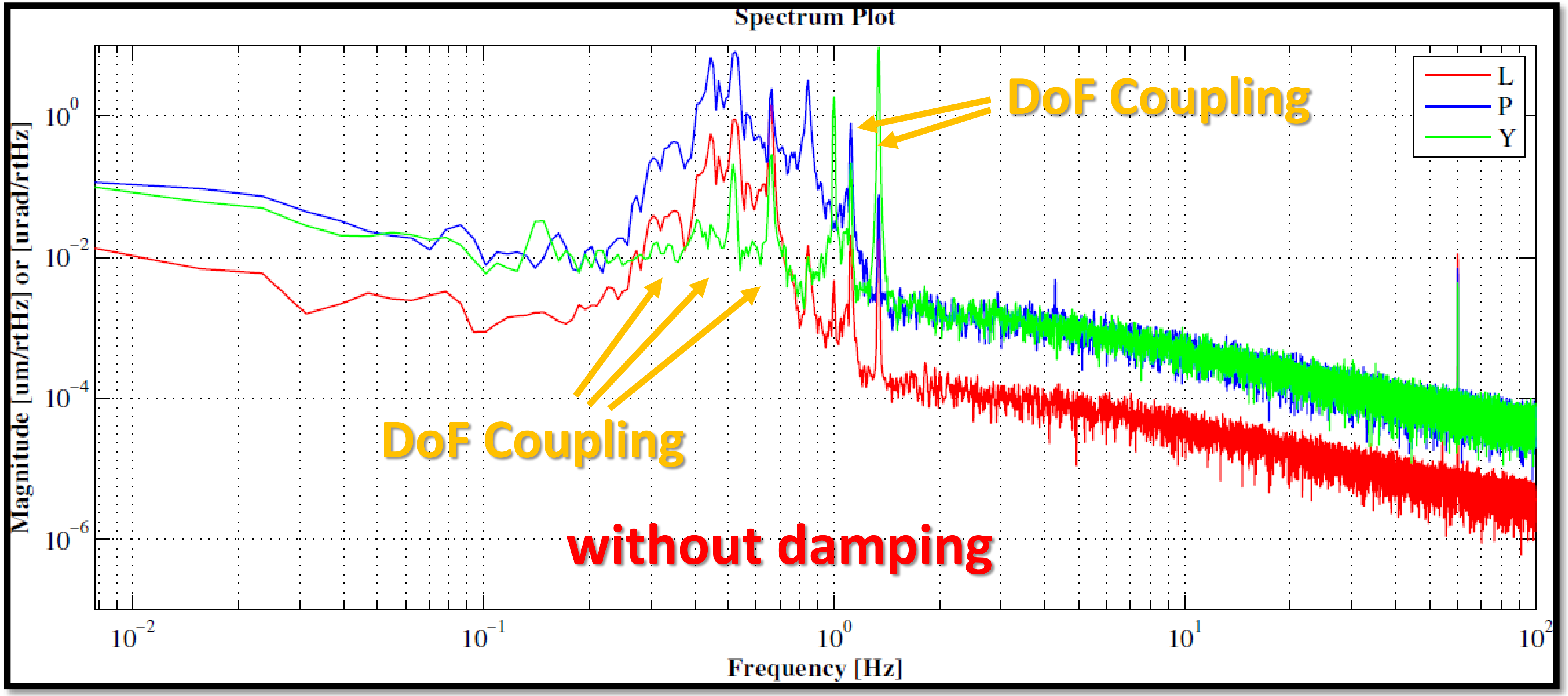
❖ Investigation of TypeBpp Frequency response

IM (OSEM) Spectra



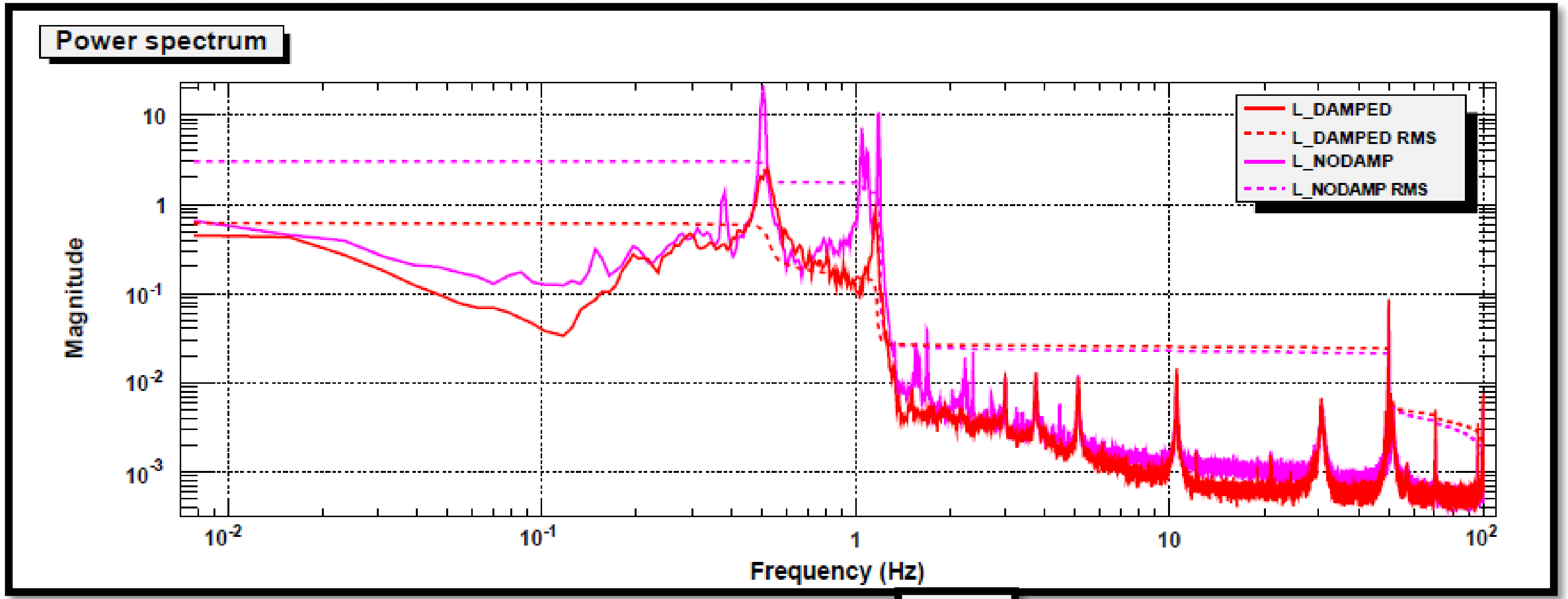
❖ Investigation of TypeBpp Frequency response

TM (OSEM) Spectra

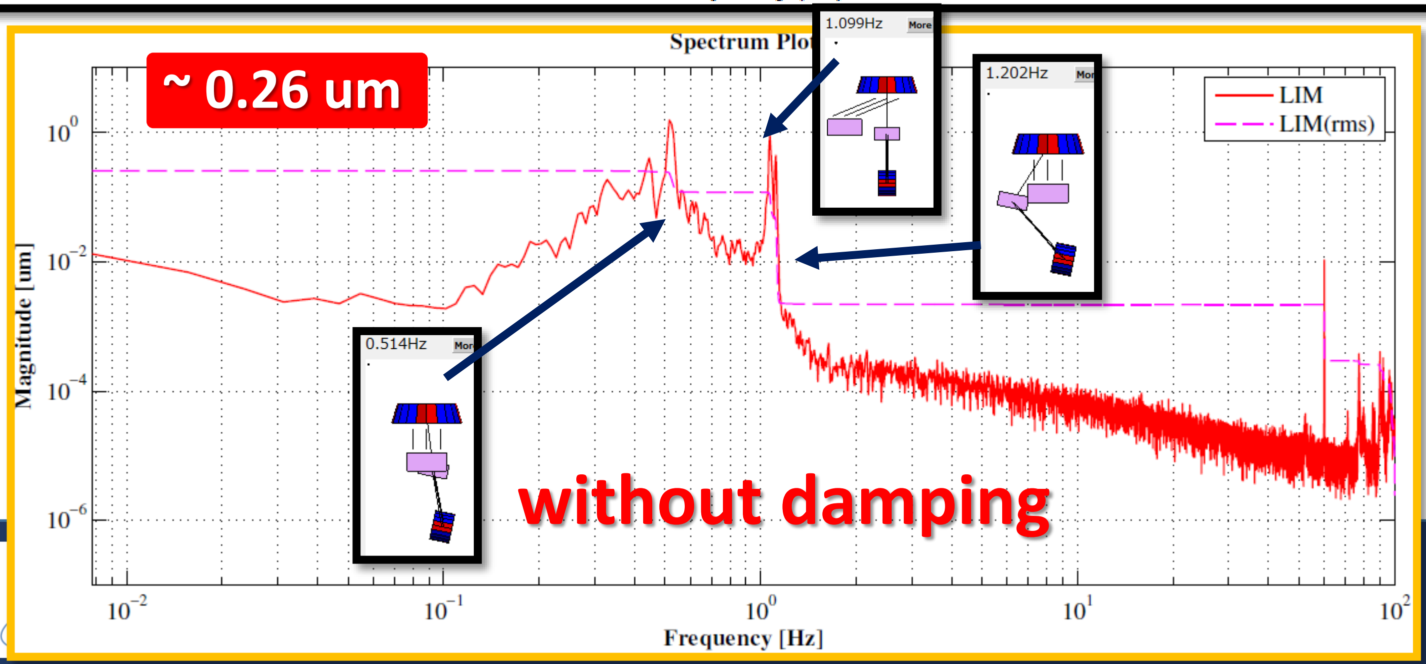


❖ Investigation of TypeBpp Frequency response

REF : LIM (OSEM) Spectra of 20 m SAS

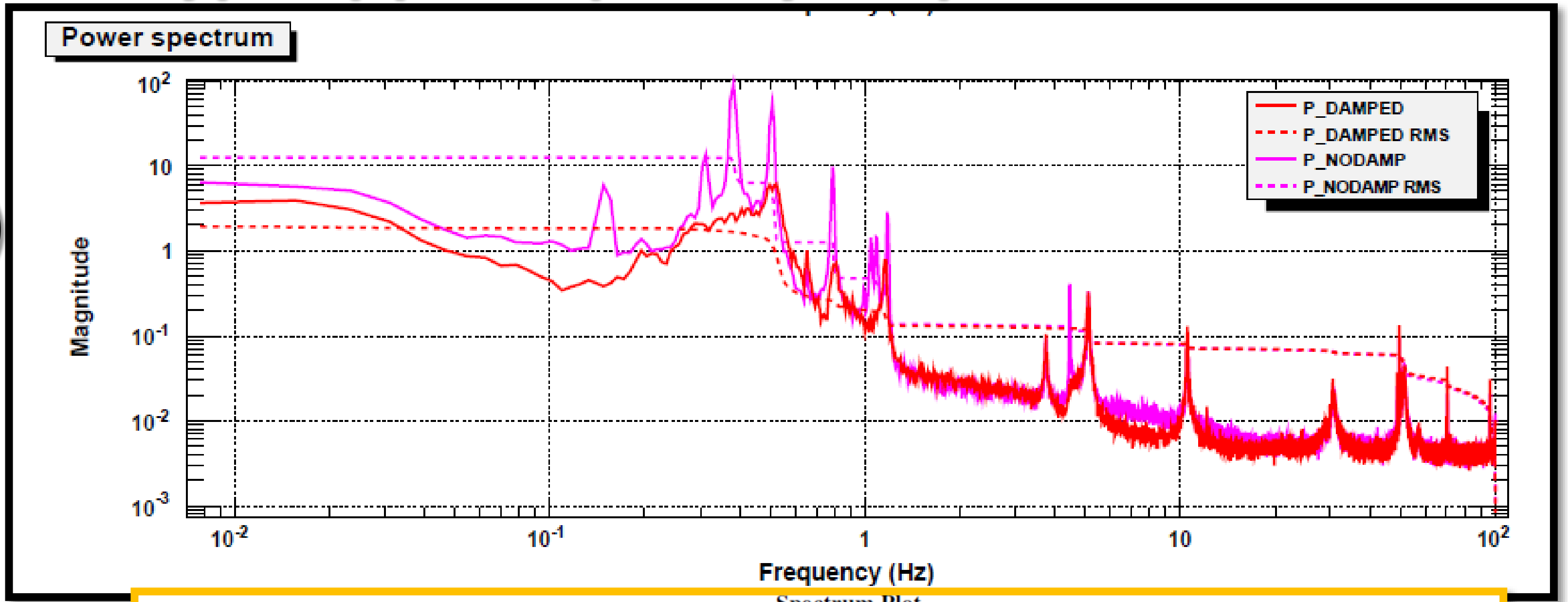


LIM (OSEM) Spectra of PR3 SAS

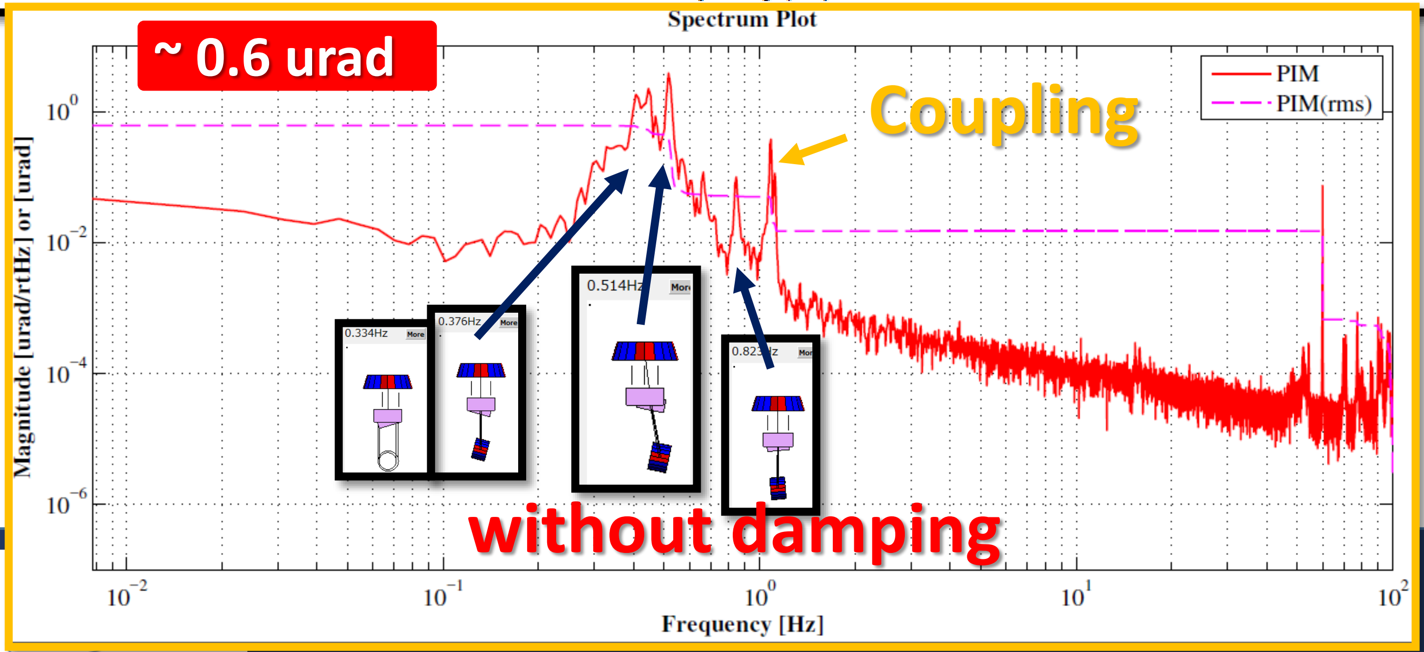


❖ Investigation of TypeBpp Frequency response

REF : PIM (OSEM) Spectra of 20 m SAS

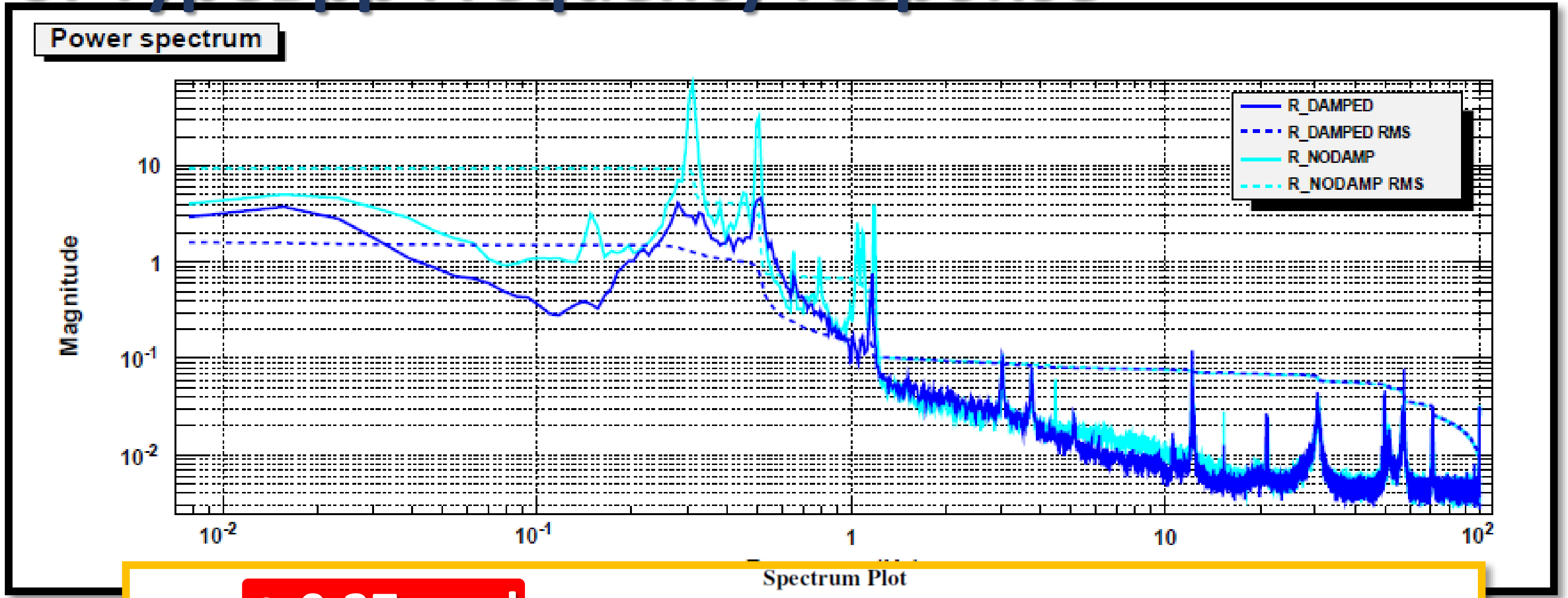


PIM (OSEM) Spectra of PR3 SAS

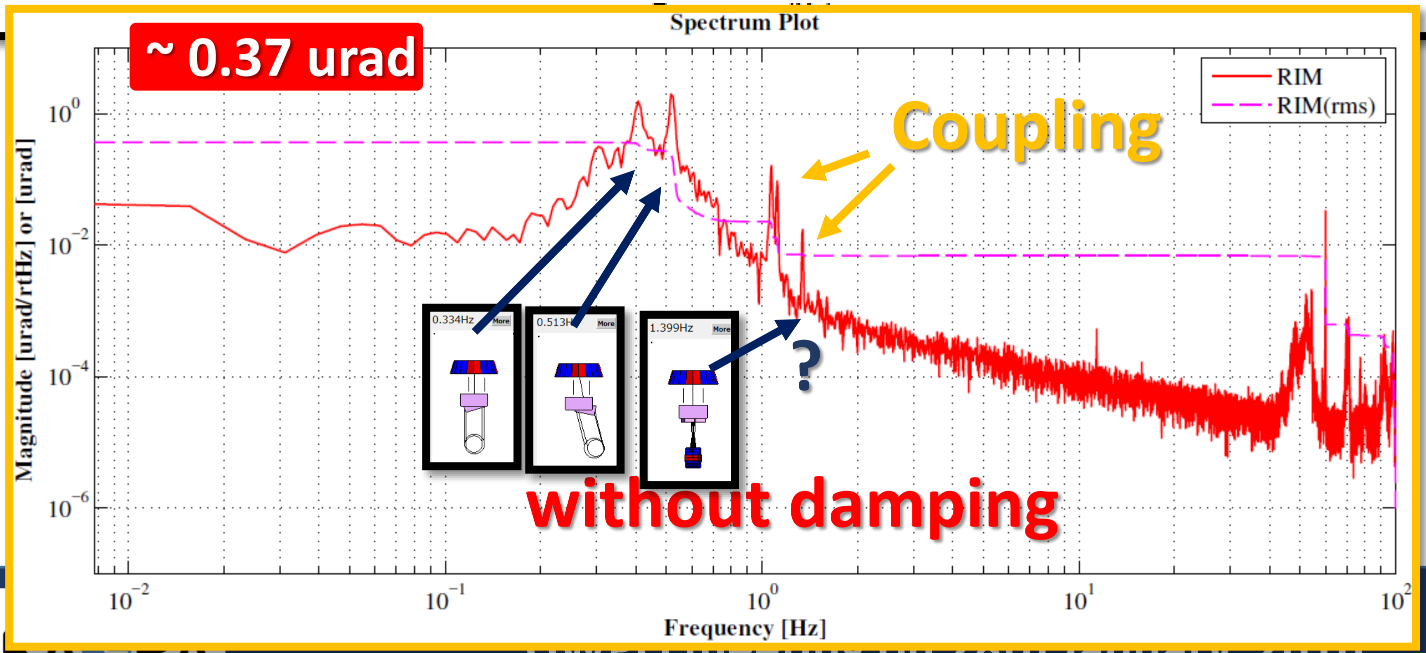


❖ Investigation of TypeBpp Frequency response

REF : RIM (OSEM) Spectra of 20 m SAS

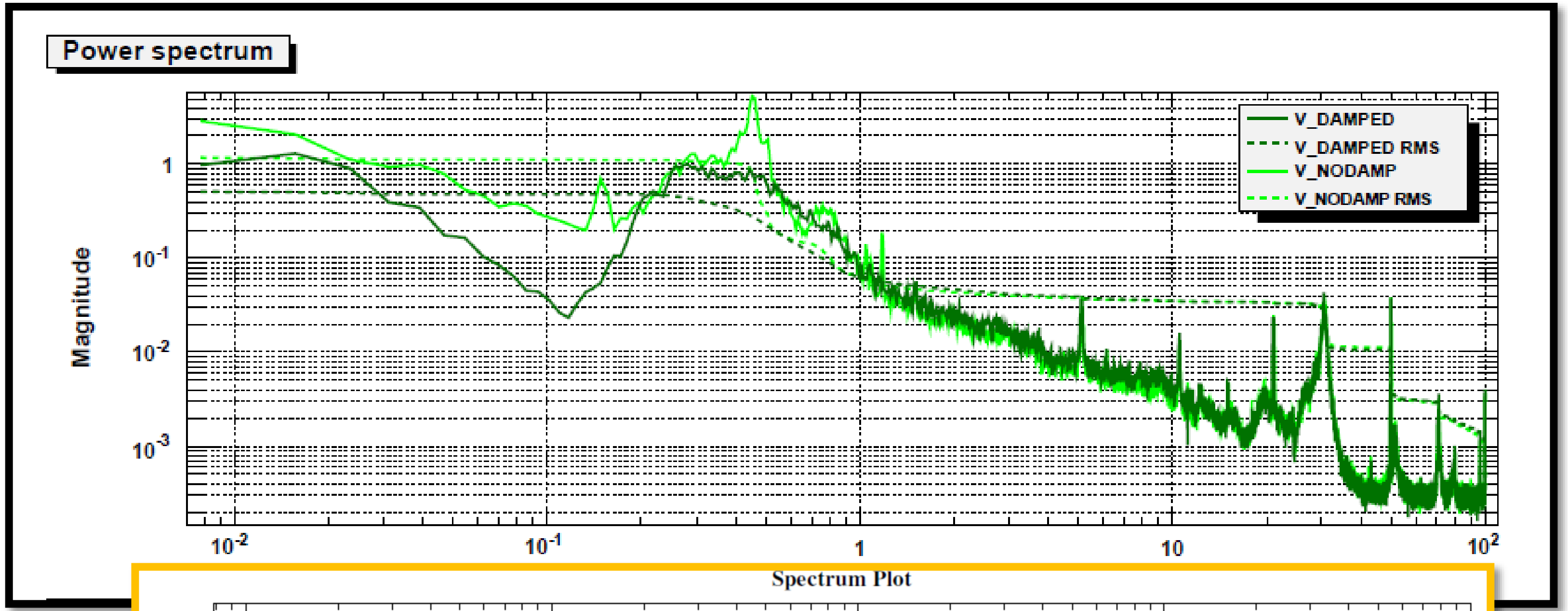


RIM (OSEM) Spectra of PR3 SAS

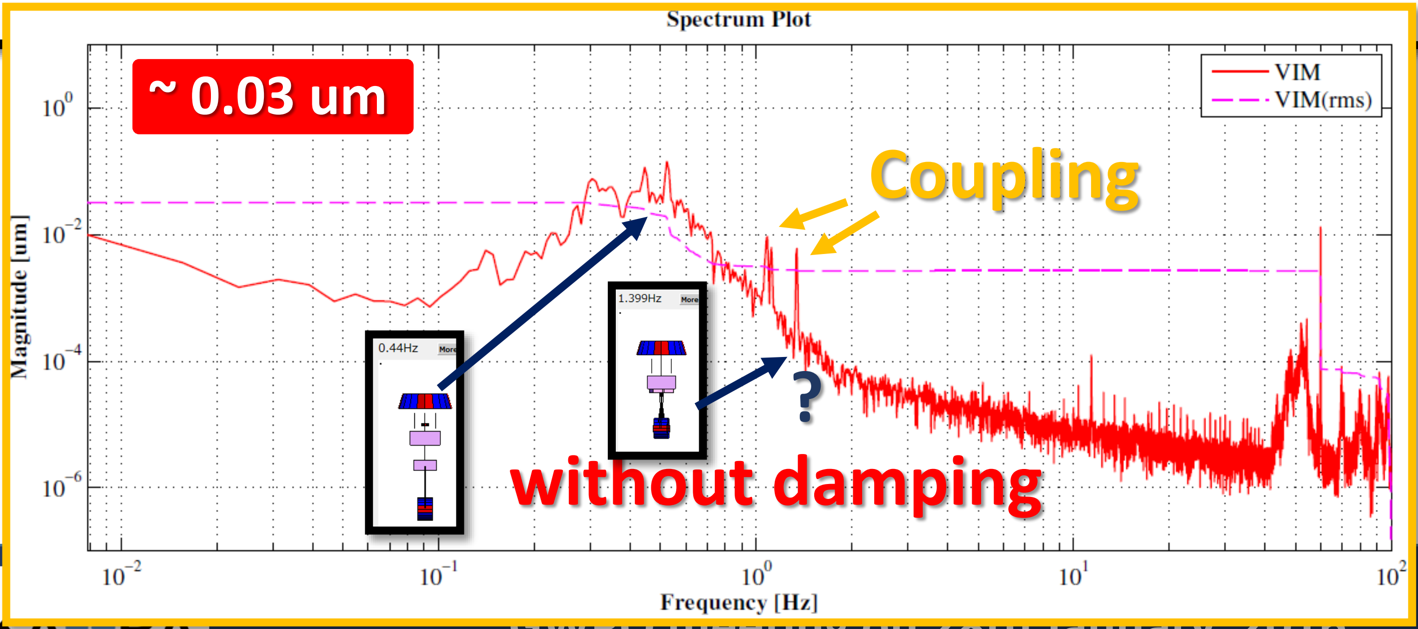


❖ Investigation of TypeBpp Frequency response

REF : VIM (OSEM) Spectra of 20 m SAS

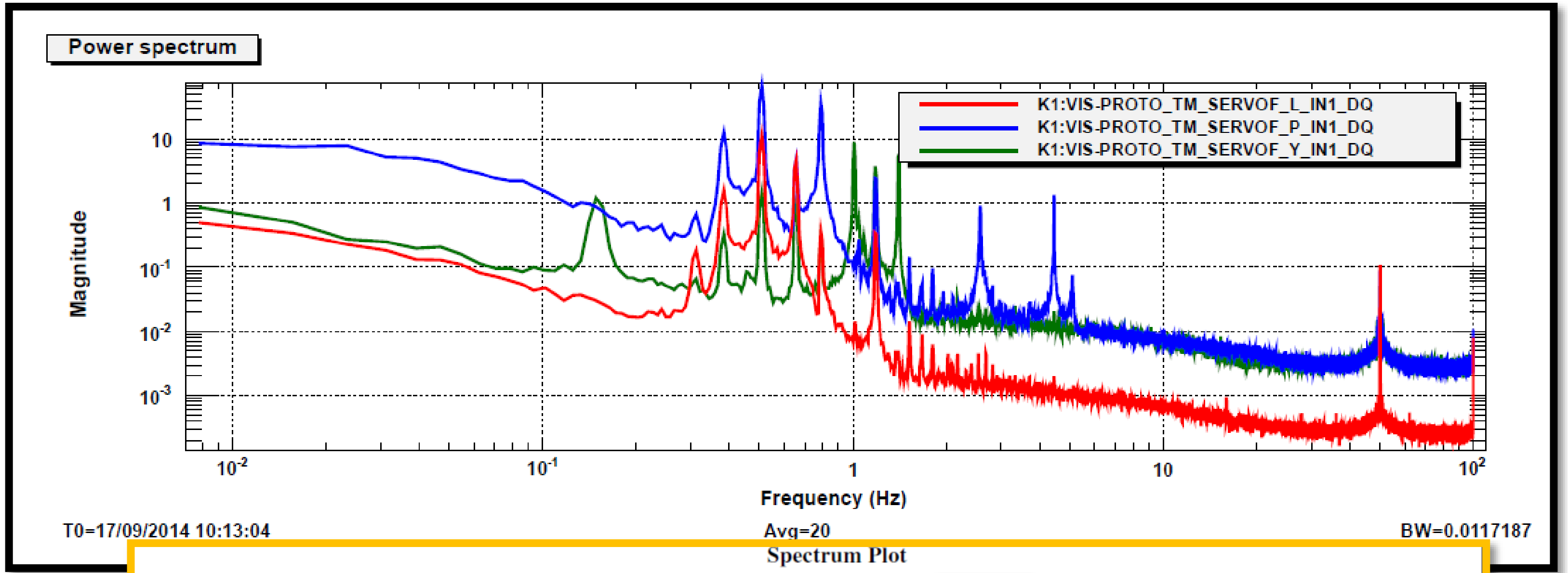


VIM (OSEM) Spectra of PR3 SAS

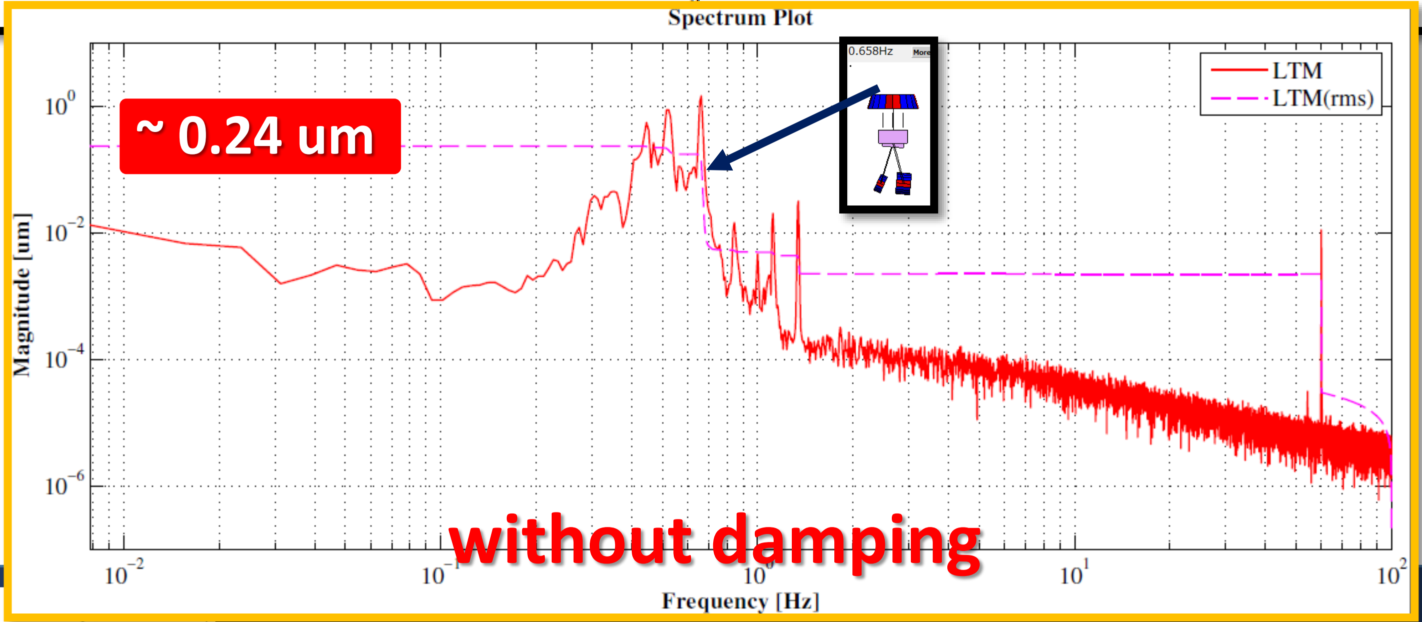


❖ Investigation of TypeBpp Frequency response

REF : TM (OSEM) Spectra of 20 m SAS

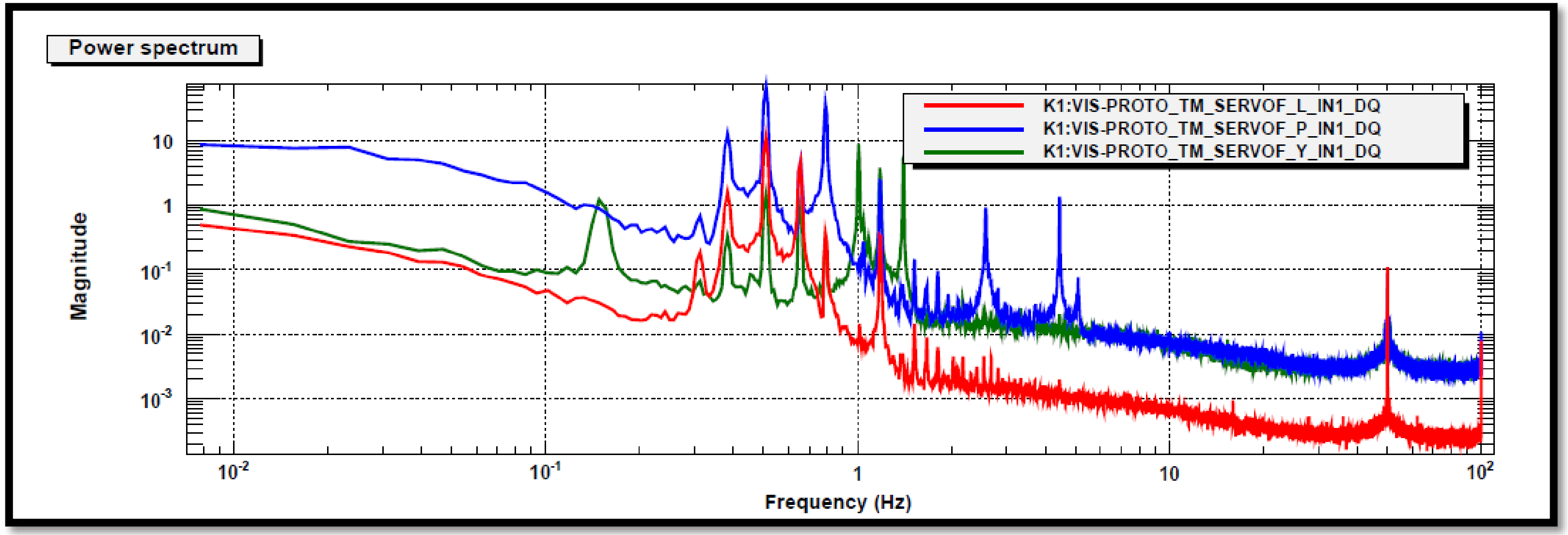


LTM (OSEM) Spectra of PR3 SAS

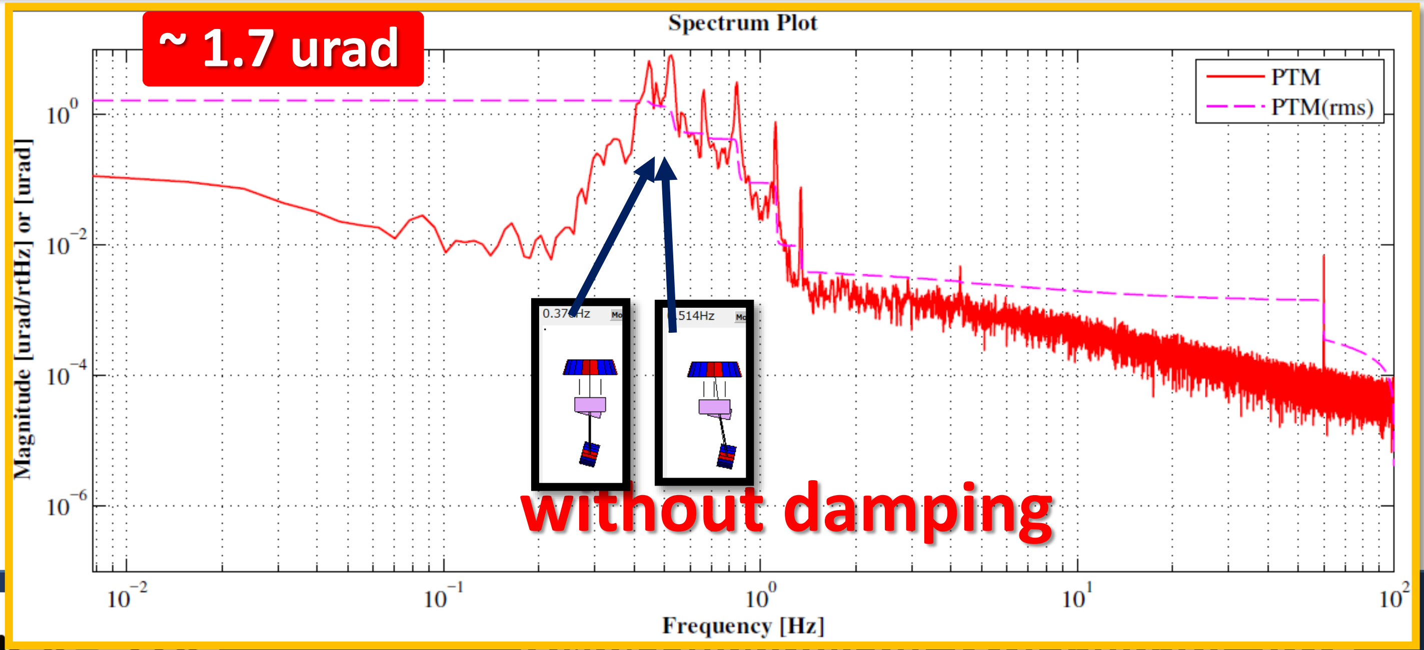


❖ Investigation of TypeBpp Frequency response

REF : TM (OSEM) Spectra of 20 m SAS

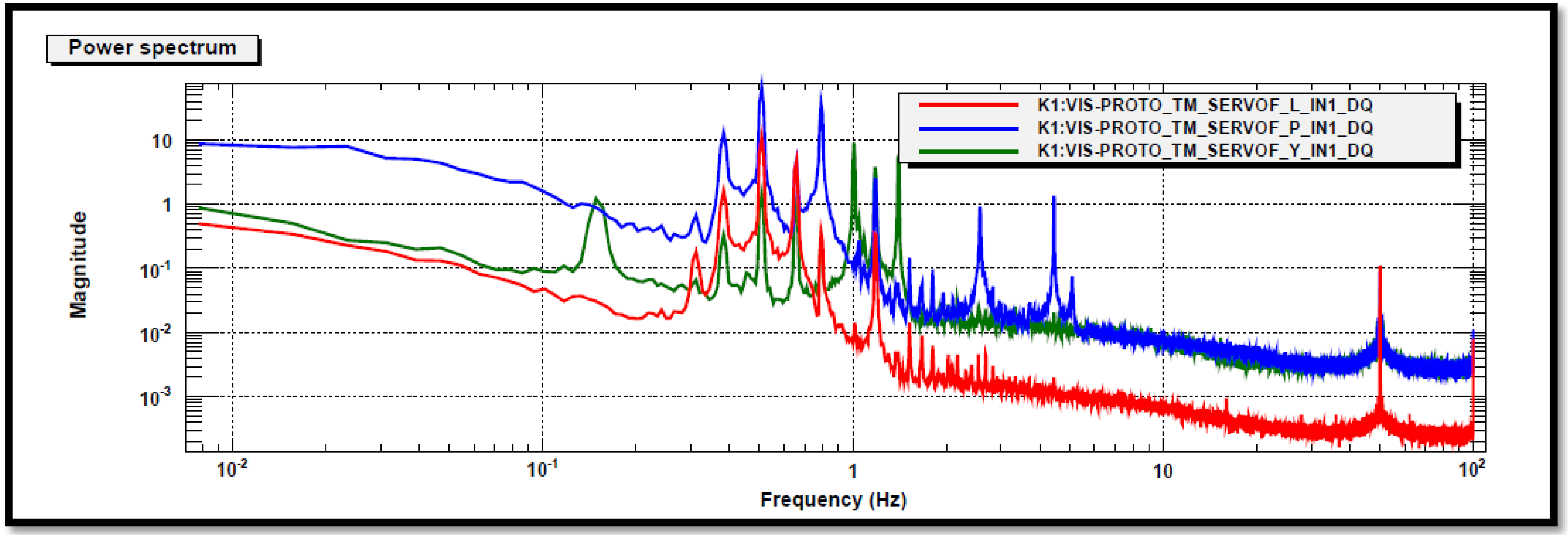


PTM (OSEM) Spectra of PR3 SAS

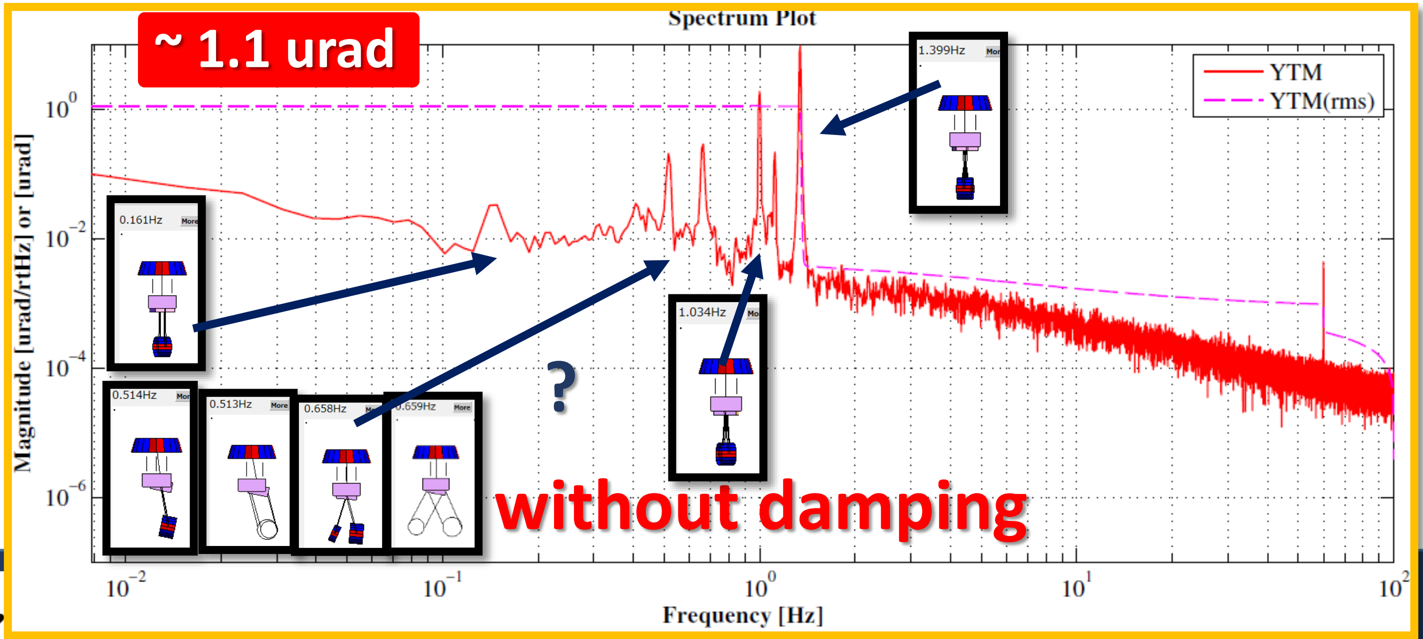


❖ Investigation of TypeBpp Frequency response

REF : TM (OSEM) Spectra of 20 m SAS

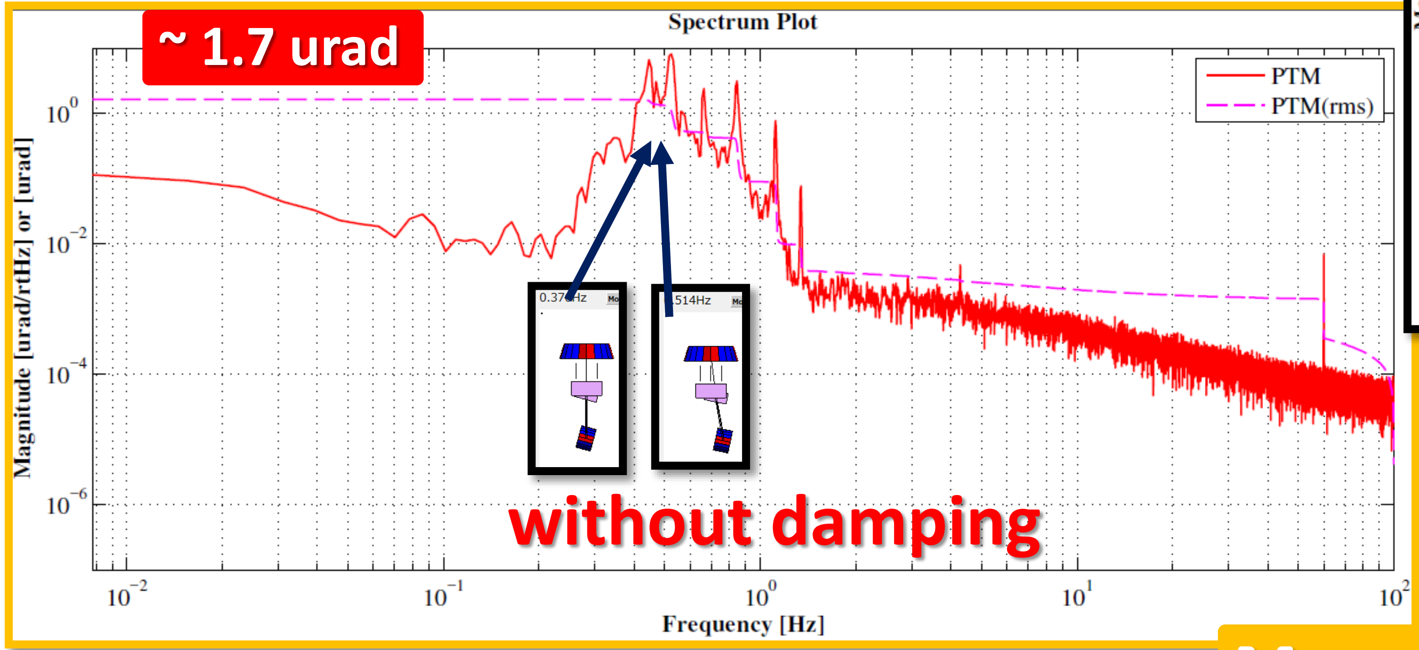


YTM (OSEM) Spectra of PR3 SAS

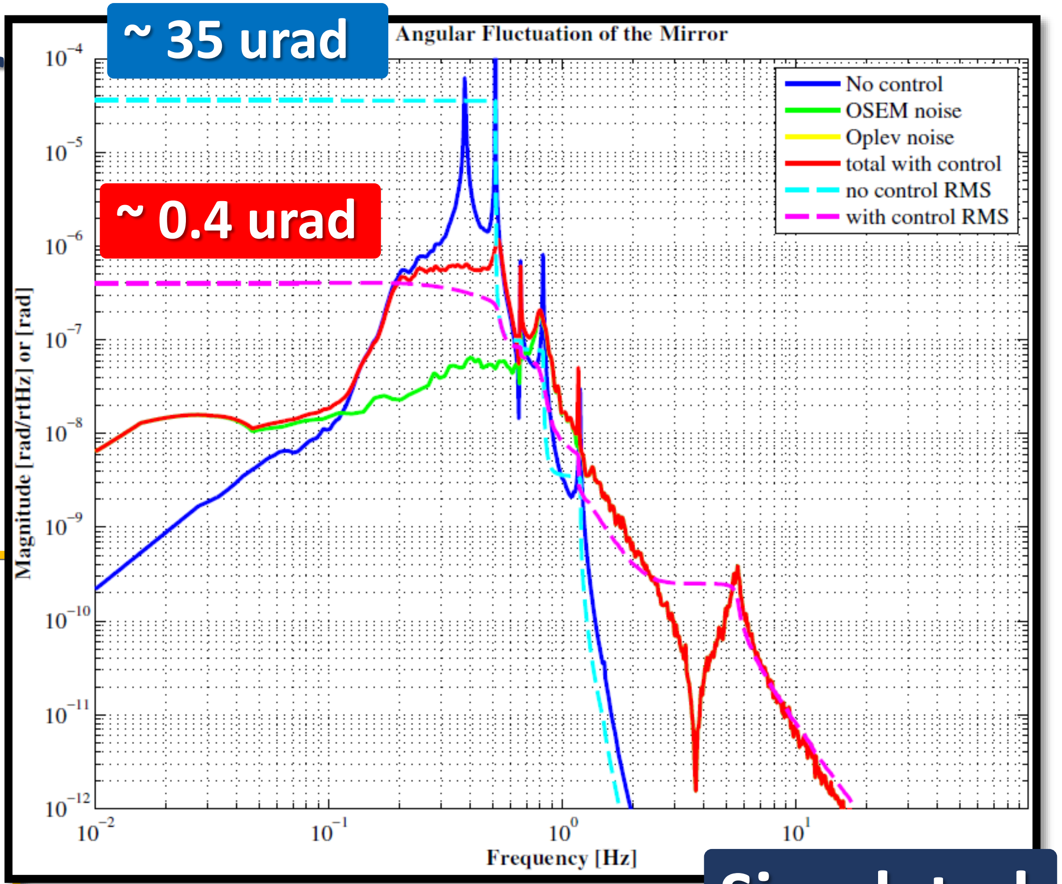


❖ Investigation of TypeBpp Frequency r

PTM (OSEM)
Spectra of PR3 SAS



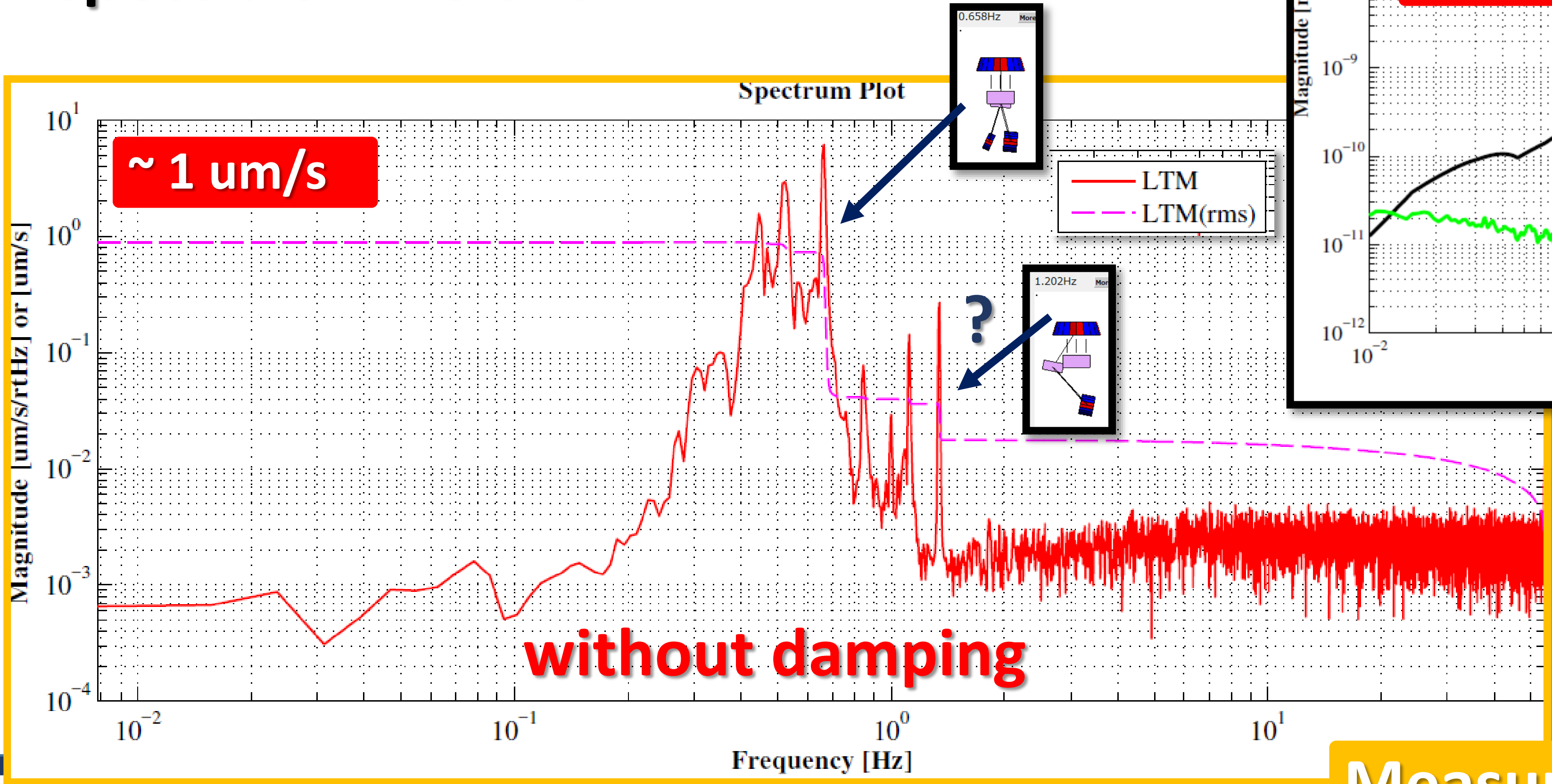
Measured



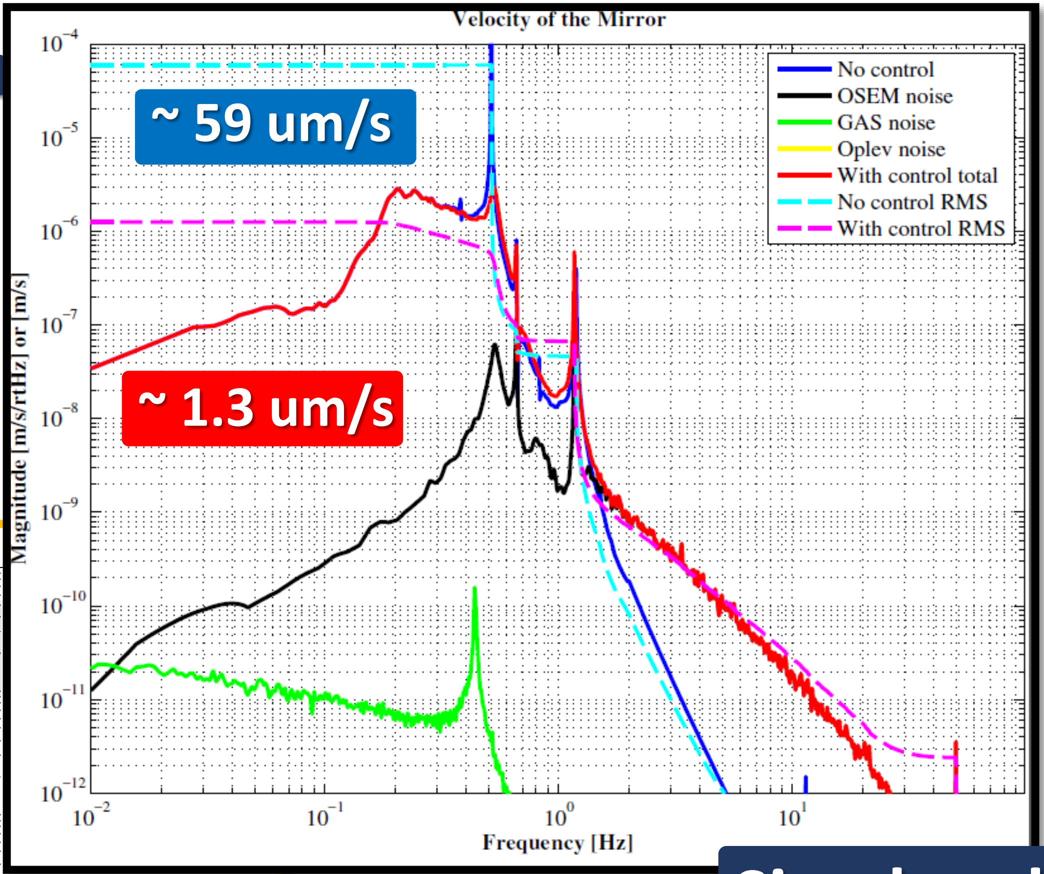
Simulated

❖ Investigation of TypeBpp Frequency r

LTM **velocity** (OSEM)
Spectra of PR3 SAS



Measured



Simulated

❖ Investigation of TypeBpp Frequency response

Note : Spectra (measured in the chamber)

- ❒ The difference in factor can be occurred due to rough calibration.
- ❒ Mode Identification → To be completed.
- ❒ Small Quality factors → To be investigated.
- ❒ DoF coupling → diagonalize actuator matrix
- ❒

Contents

- ❐ Intro : PR SAS
  - ❐ TypeBp / TypeBpp
- ❐ Investigation of TypeBpp SAS frequency response
  - ❐ Transfer functions / Spectra
- ❖ One modification idea for bKAGRA
  - ❖ Requirement
  - ❖ TypeBp with IP

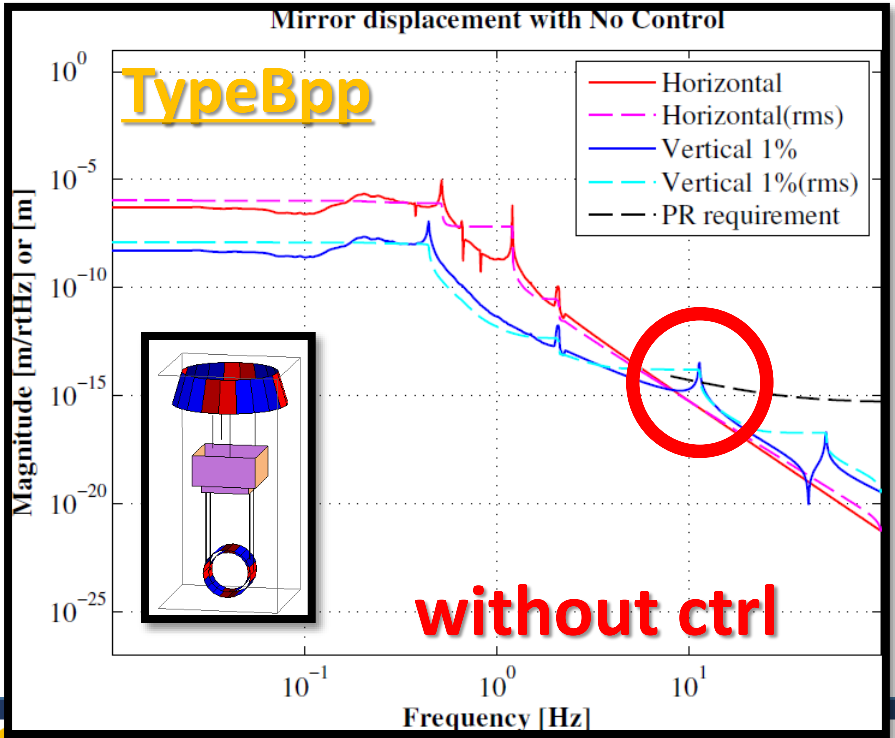
❖ One modification idea for bKAGRA / Requirement

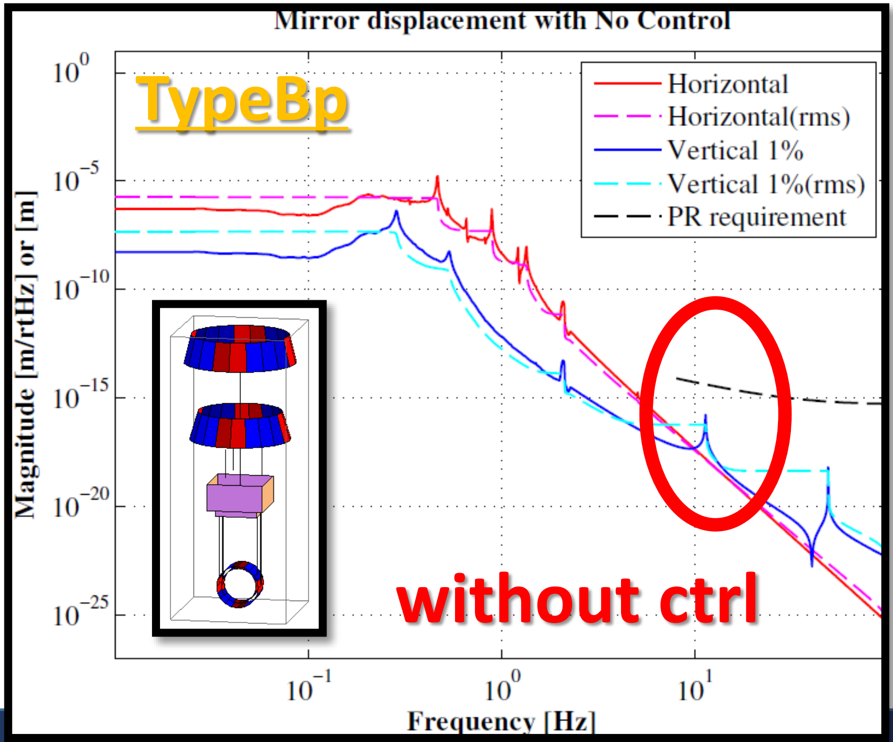
PR TMs are required :

1) disp. < 10^{-15} m/rtHz at 10 Hz
2) RMS velocity < 0.5 um/s
3) RMS angular fluct. < 1 urad

TypeBpp	TypeBp
Not meet	meet
~ 1 um/sec (with ctrl)	~ 5 um/sec (with ctrl)
~ 0.4 urad (with ctrl)	~ 1.4 urad (w ctrl)

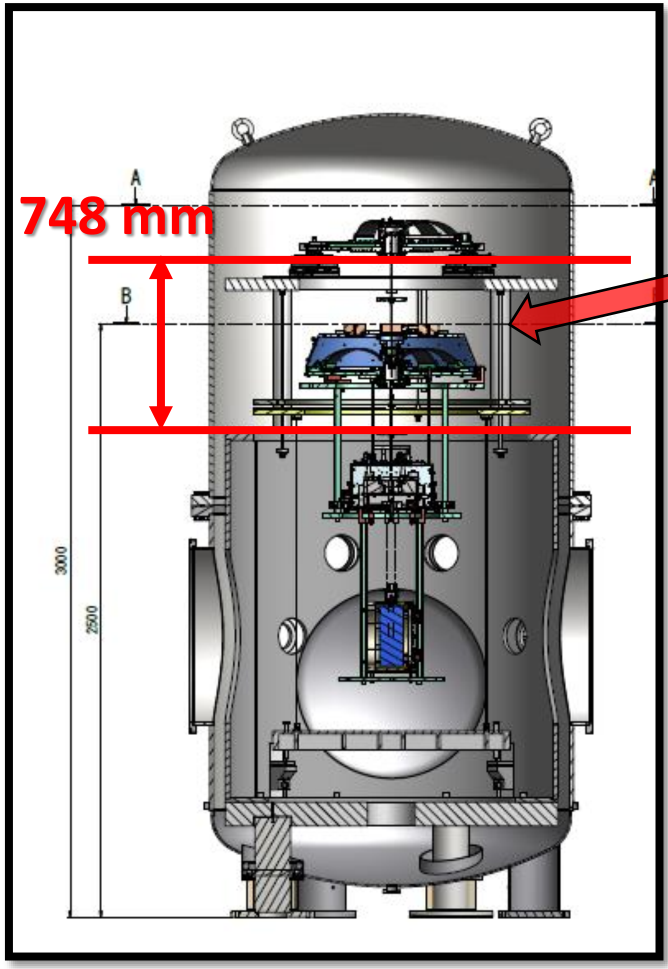
Also, RMS seismic velocity can be ~ 0.7 um/sec

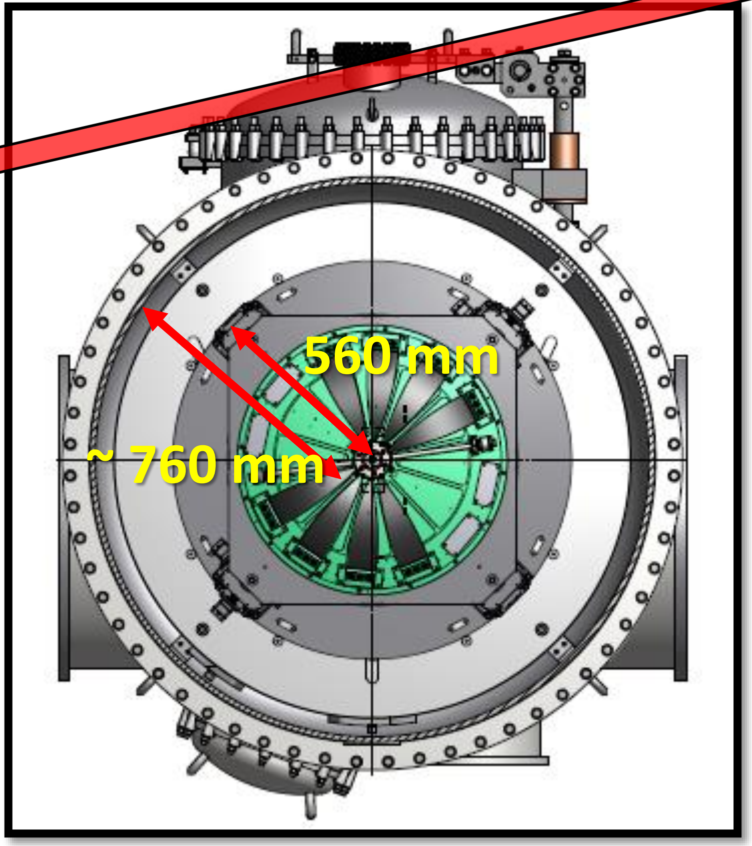


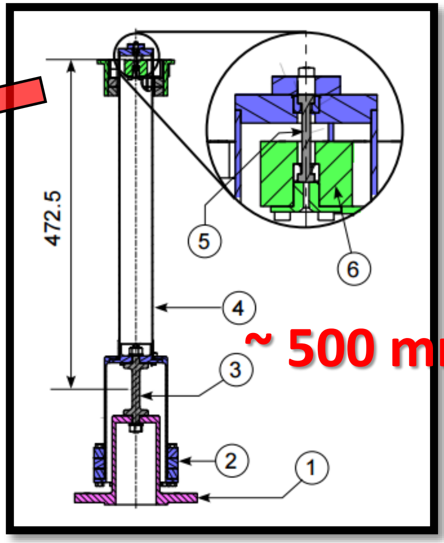


❖ One modification idea for bKAGRA / TypeBp with IP

To attenuate the micro seismic noise → Add Inverted Pendulum (IP)



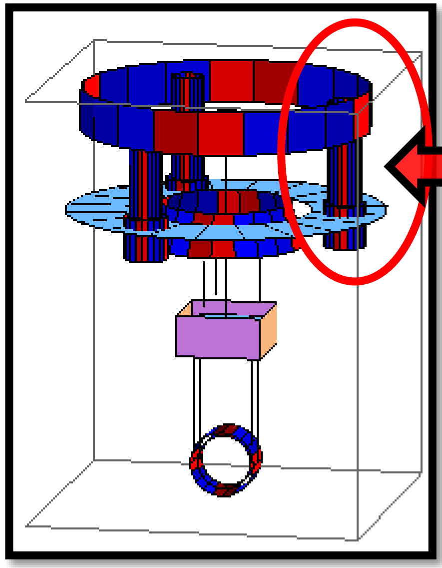


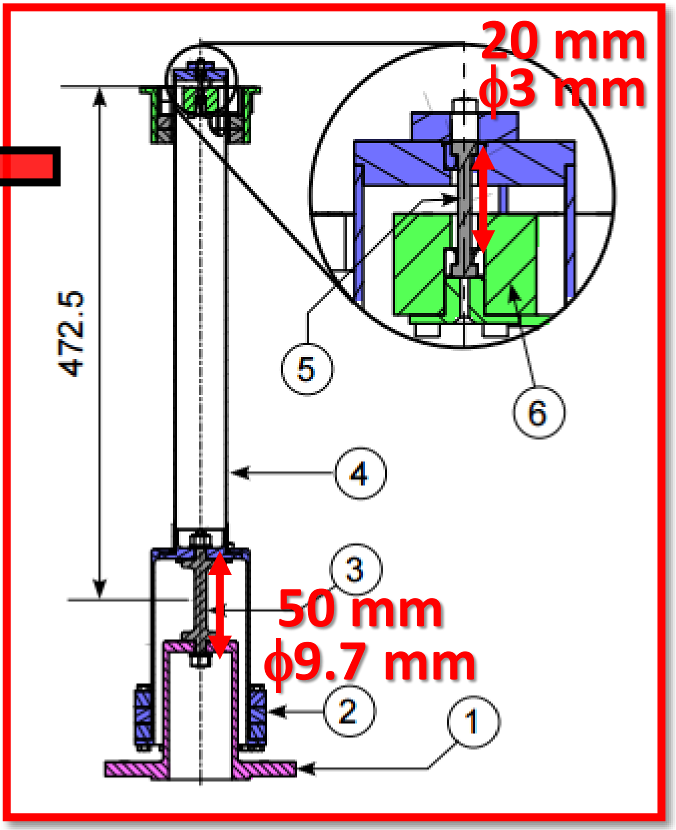


In principle,
the IP, such as used in TypeB1,
(its length is ~ 500 mm)
will be able to be implemented.

❖ One modification idea for bKAGRA / TypeBp with IP

To attenuate the micro seismic noise → Add Inverted Pendulum (IP)





typeB1 IP

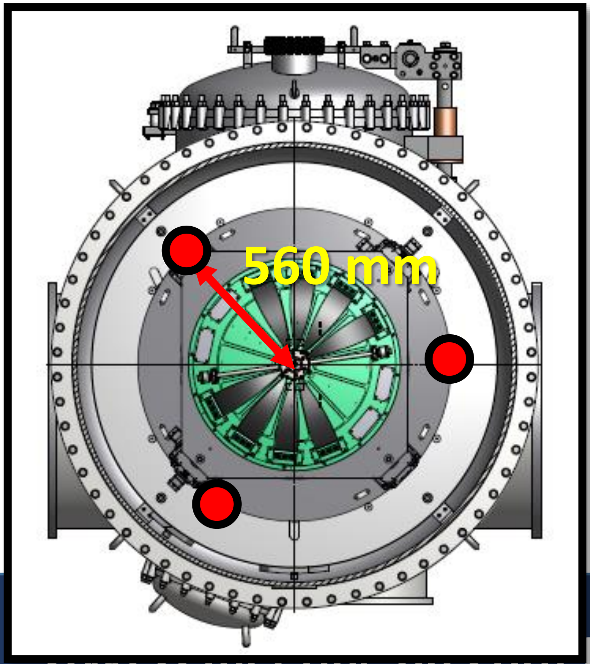
This time, I added “typeB1 IP” to typeBp.

Assuming :

1) add weight of 572 kg on the IP stage

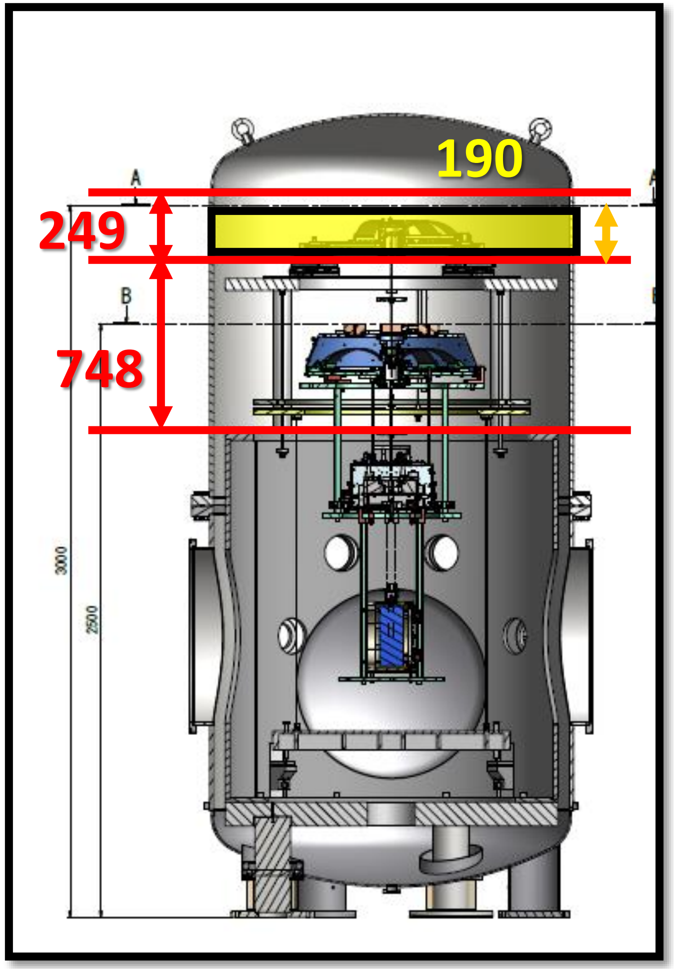
2) Set IP at position of 560 mm from the CoM

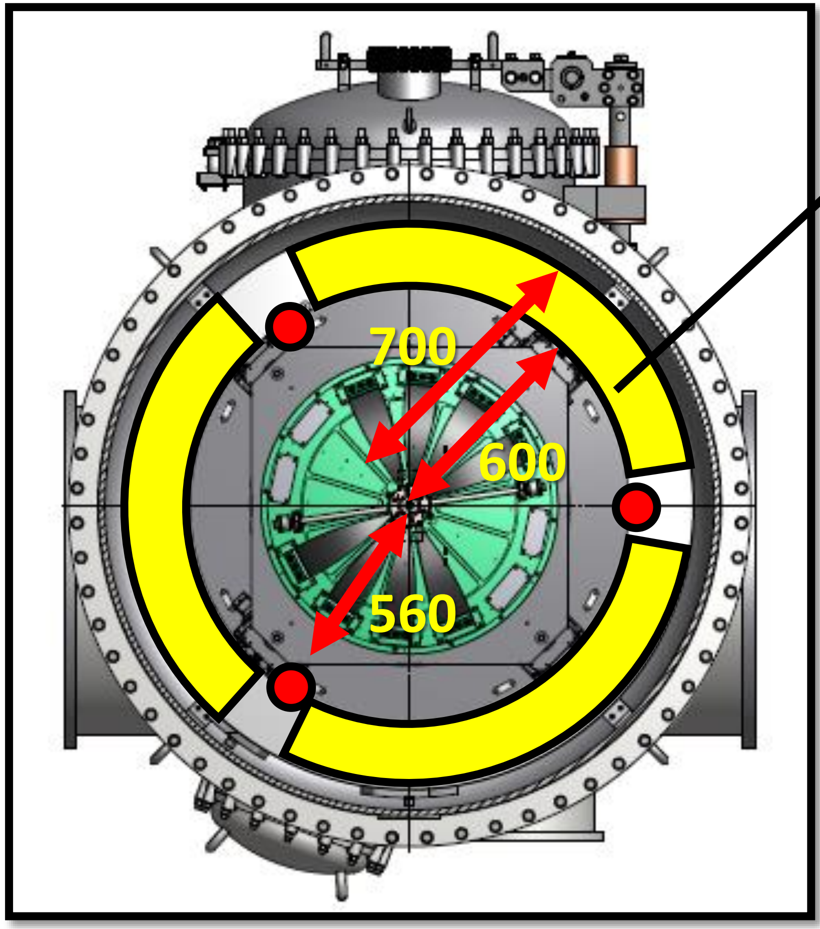
(In TypeB1 -> 610 mm)



❖ One modification idea for bKAGRA / TypeBp with IP

To attenuate the micro seismic noise → Add Inverted Pendulum (IP)

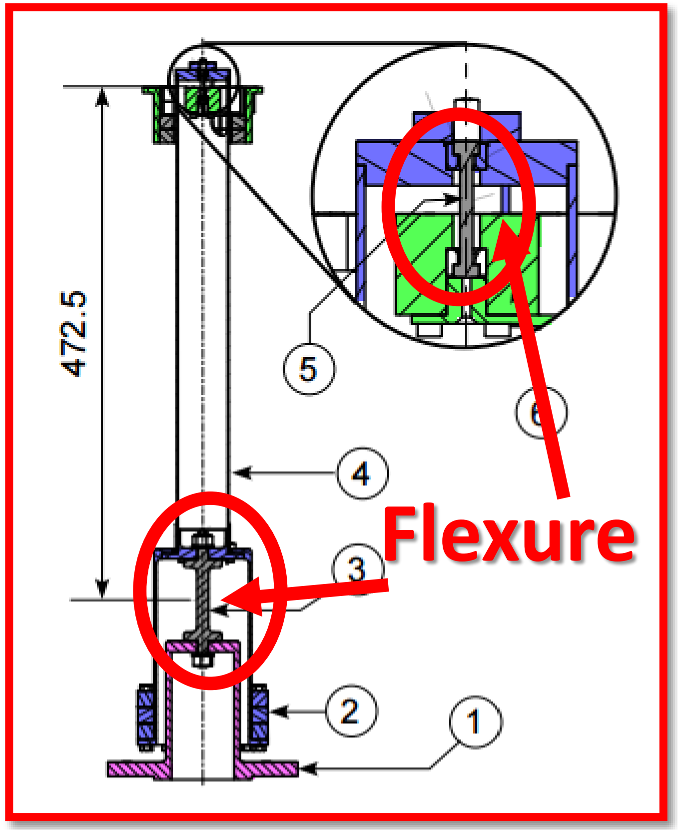




Compensation mass
If SUS is used.
(density ≡ 7.8 g/cm^3)

❖ One modification idea for bKAGRA / TypeBp with IP

IP modeling parameter :



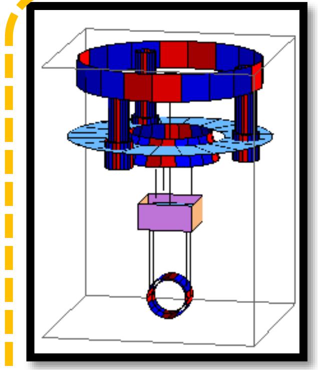
1) Load on IP
2) Horizontal distance of leg from CoM
3) Leg length
4) L,T resonance frequency (→ depends on bottom flexure)
5) Q factor of bottom flexure
6) Saturation level
7) Additional torsion stiffness (→ depends on top flexure)

Contributes to IP Yaw

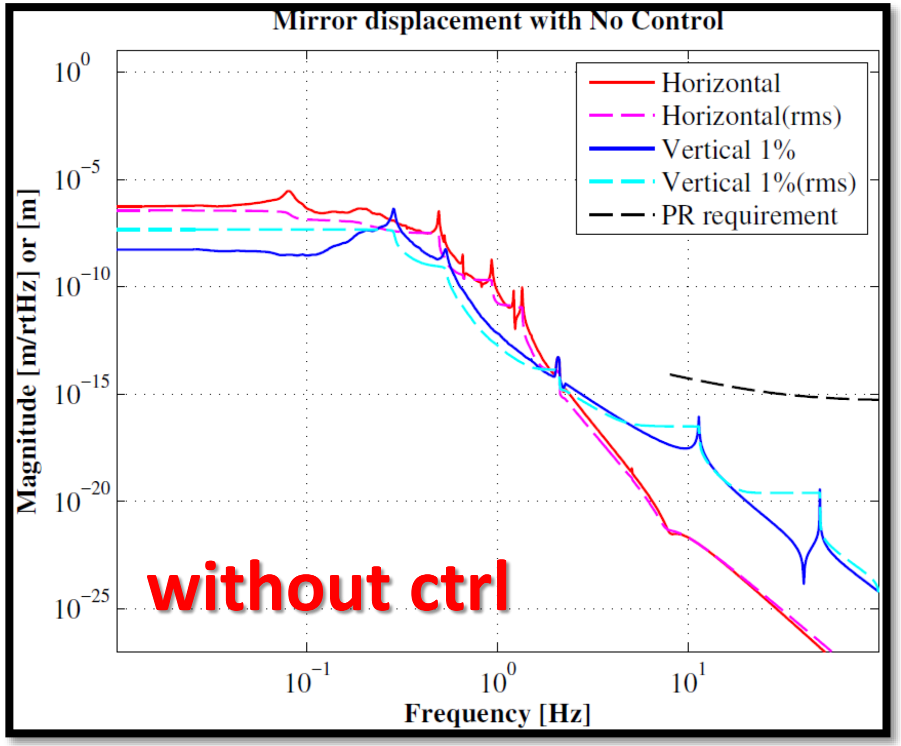
Needed preparation

❒ If the TypeB1 IP will be implemented,
Load have to be added more (~ 500 kg) to current TypeBp.
(❒ Or, we should shrink the bottom flexure diameter.)

❖ One modification idea for bKAGRA / TypeBp with IP

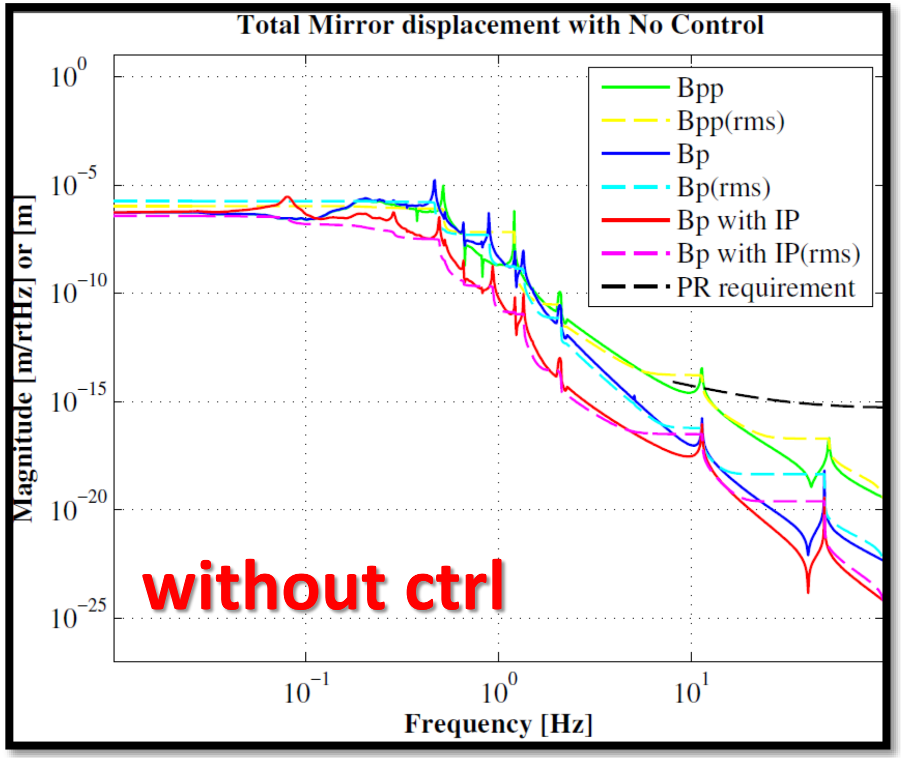


= IP + SF + BF + IR/IM + RM/TM

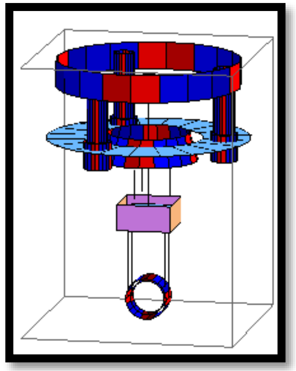


TM displacement of TypeBp with IP

Comparison

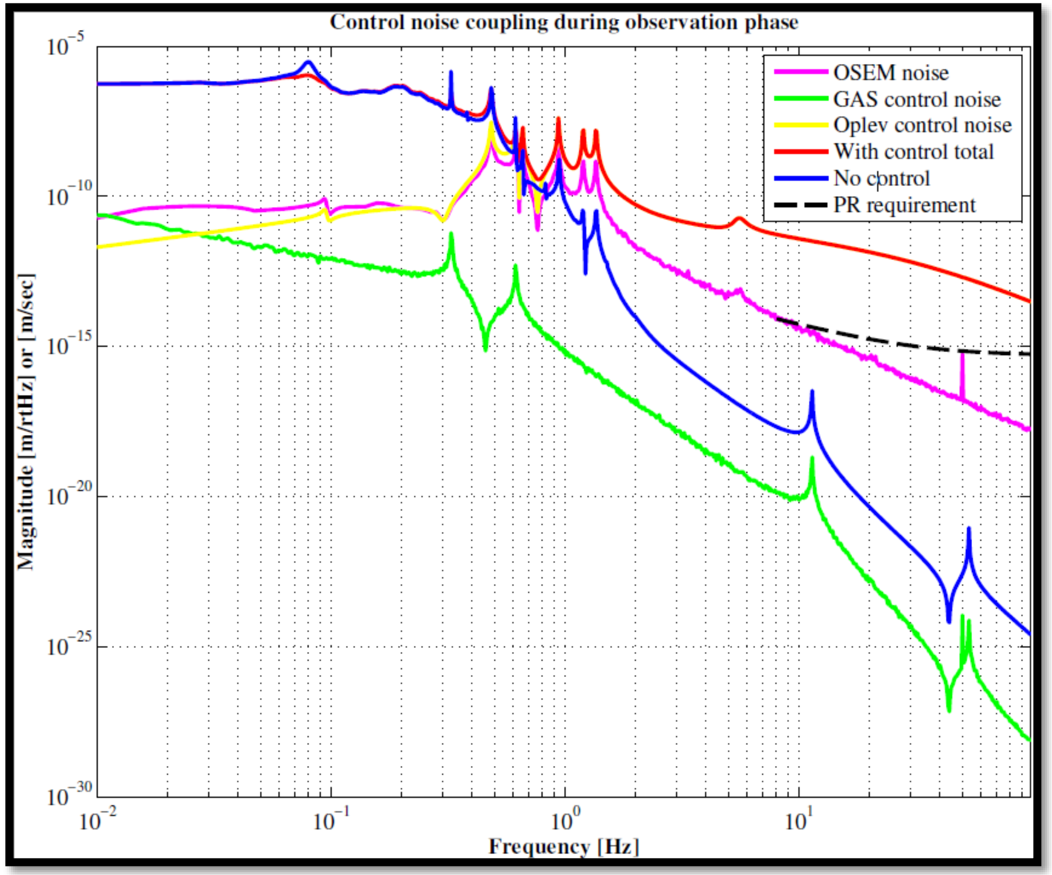


❖ One modification idea for bKAGRA / TypeBp with IP

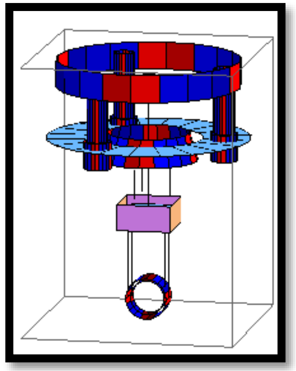


= IP + SF + BF + IR/IM + RM/TM

IP	SF / BF	IR/IM	RM/TM
Damping by LVDT	Dc Damp By LVDT	Damping by OSEMs & Oplev	Damping by OSEMs

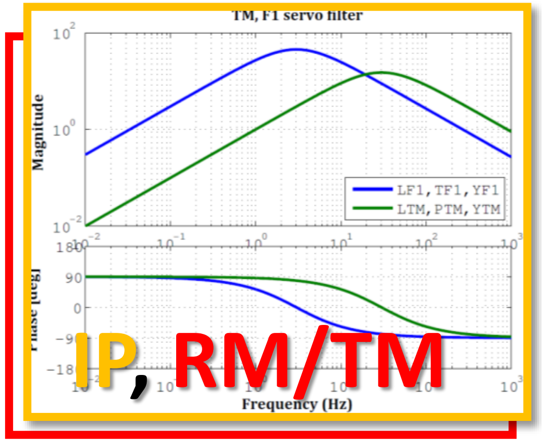


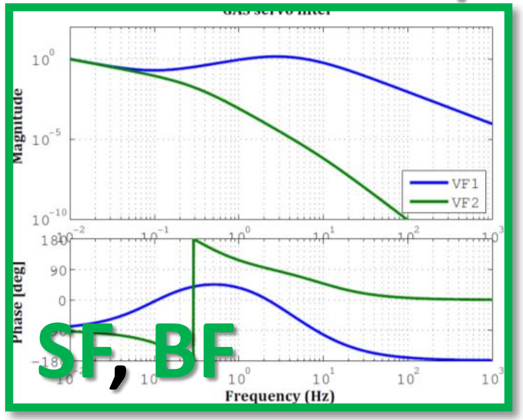
❖ One modification idea for bKAGRA / TypeBp with IP

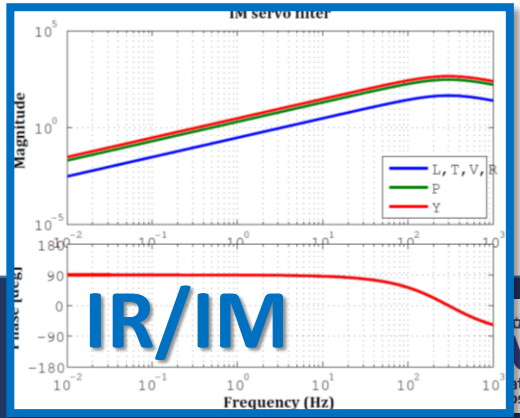


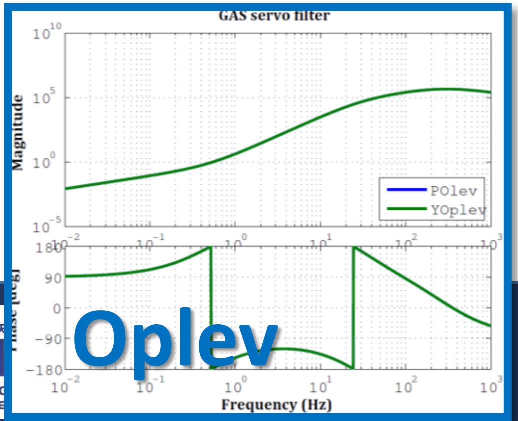
= IP + SF + BF + IR/IM + RM/TM

IP	SF	BF	IR/IM	RM/TM
Damping by LVDT	Dc Damp By LVDT		Damping by OSEMs & Oplev	Damping by OSEMs









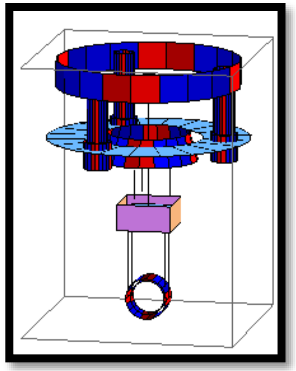
Lock aquisition phase :
LF1, TF1, YF1,
VF1, VF2,
RIM, PIM, YIM,
OplevPIM, OplevYIM

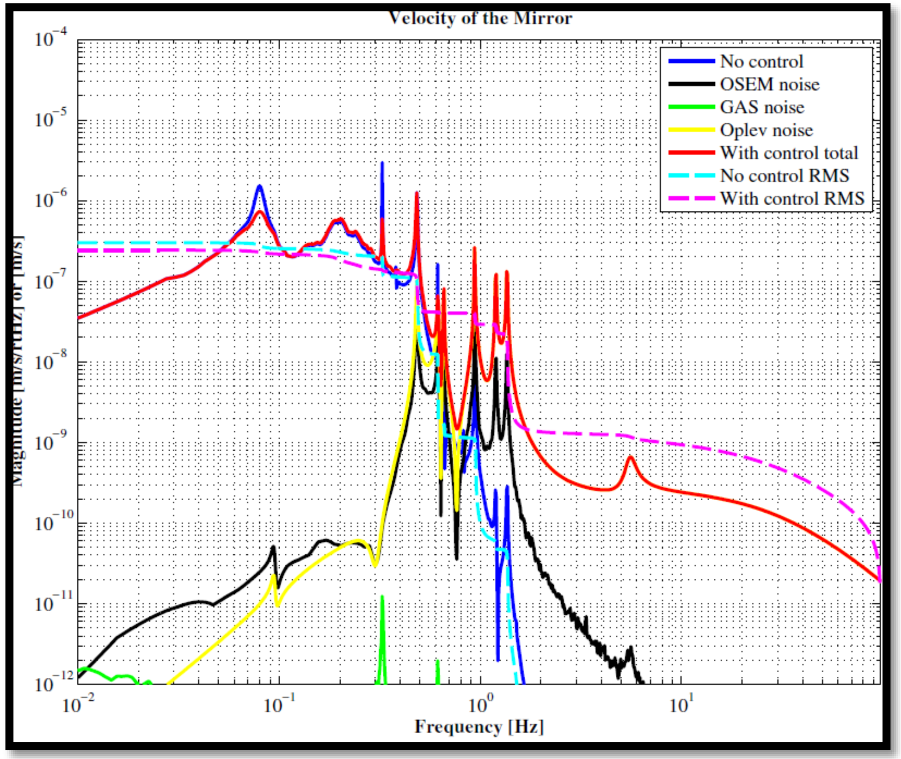
→ Controls ON

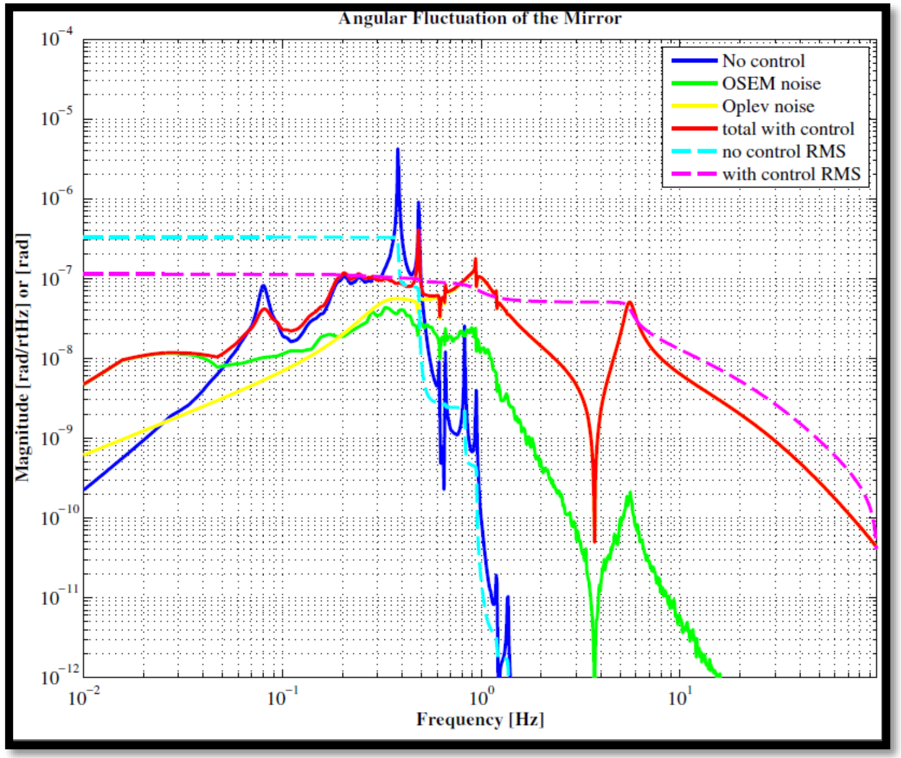
Damaping phase :
LF1, TF1, YF1,
VF1, VF2,
LIM, TIM, VIM,
RIM, PIM, YIM,
OplevPIM, OplevYIM
LTM, PTM, YTM

→ Controls ON

❖ One modification idea for bKAGRA / TypeBp with IP







RMS velocity : 0.24 um/sec

RMS pitch : 0.11 urad

Bp : 5.3 um/s
Bpp : 1.3 um/s

This SAS seems to meet all the three PR SAS requirements.

If geophones are added, the RMS can be reduce.

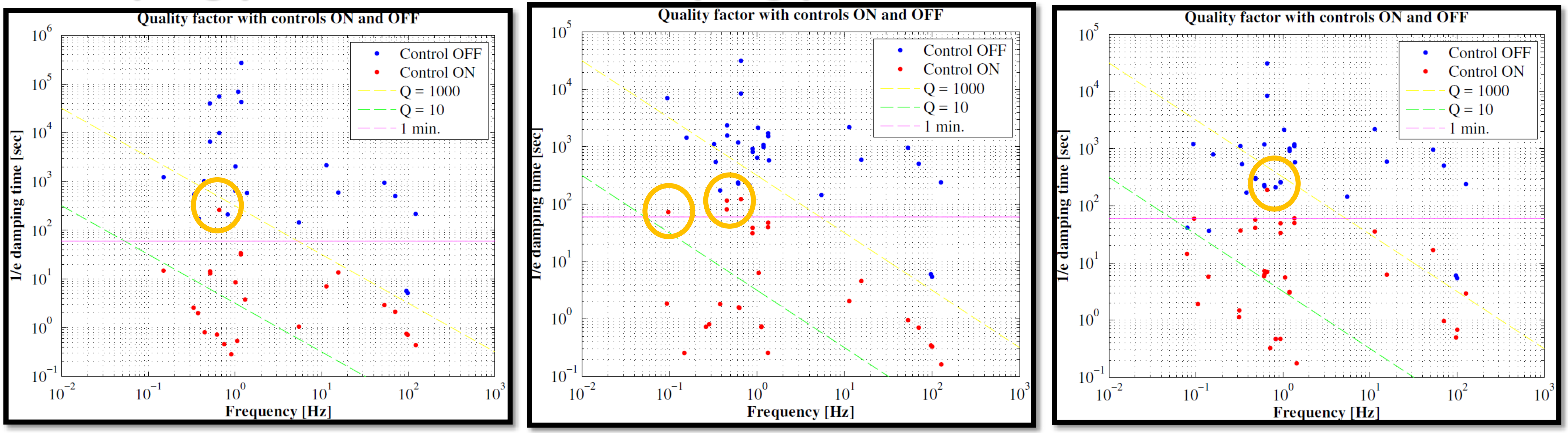
❖ One modification idea for bKAGRA

In addition,

Damping performance in damping phase

PR TMs are required :

1/e damping time < 1 min.



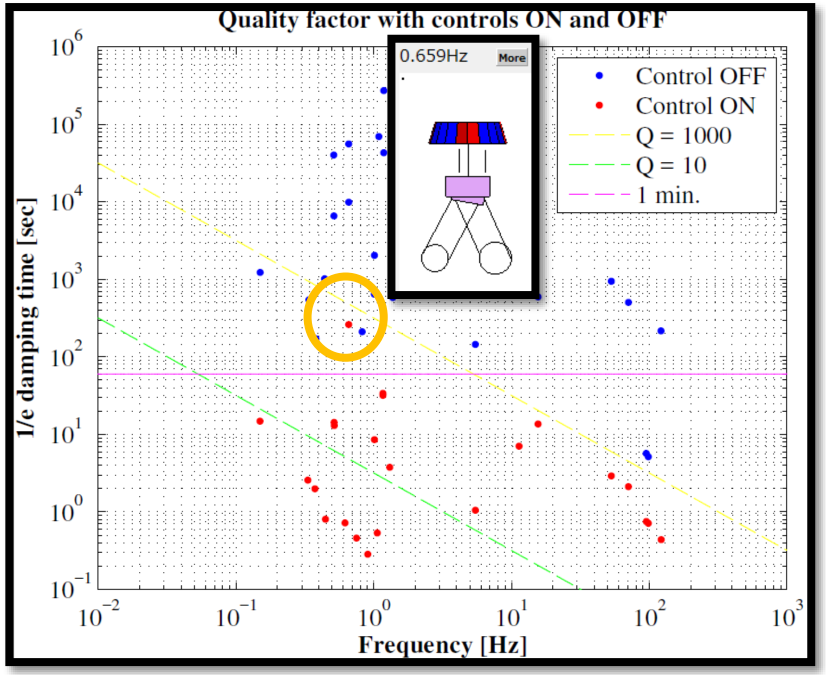
TypeBpp **TypeBp** **TypeBp with IP**

❖ One modification idea for bKAGRA

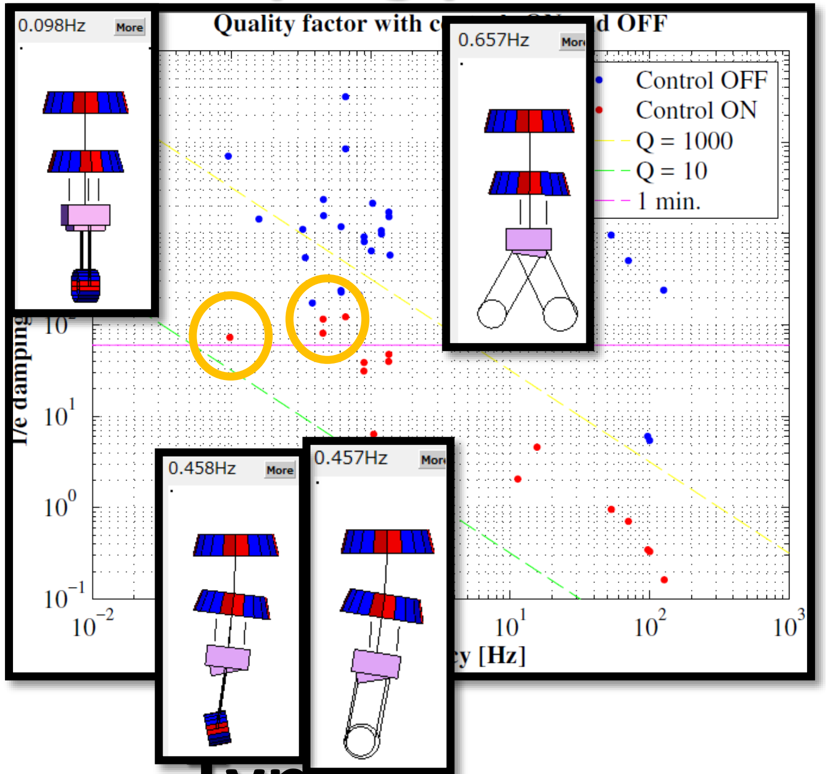
In addition,
Damping performance in damping phase

PR TMs are required :

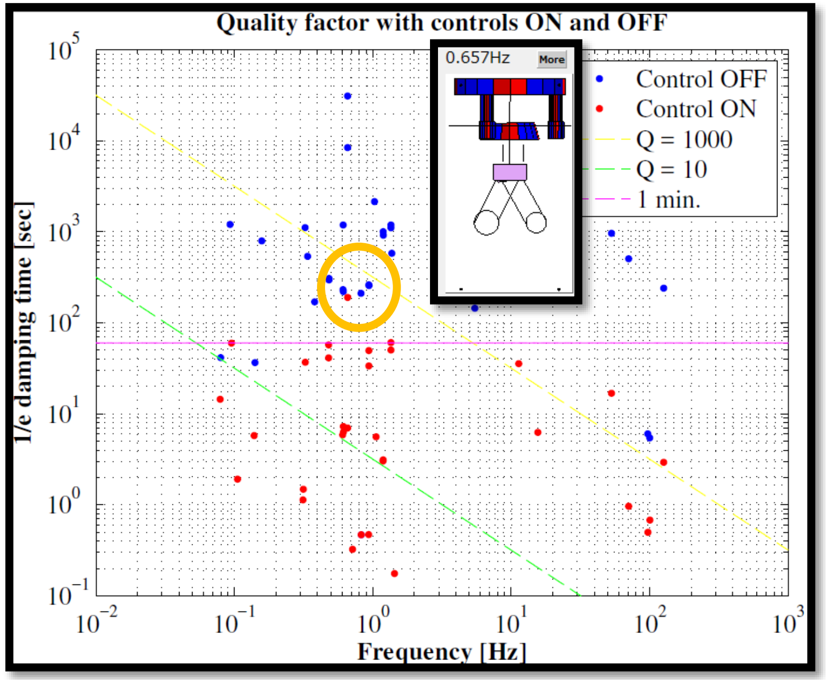
1/e damping time < 1 min.



TypeBpp



TypeBp



TypeBp with IP

❖ Summary

- ❐ TypeBpp SAS frequency responses are investigated.
  - → Mostly, the responses follow their predictions.
    (RM Pitch problem is still remains.)
  - → Quality factors should be investigated more in detail.

- ❐ We have to modify the current TypeBp SAS.
  - → If the current TypeBp SAS has IP,
    such as implemented to TypeB prototype at least,
    it can meet the PR SAS requirements.

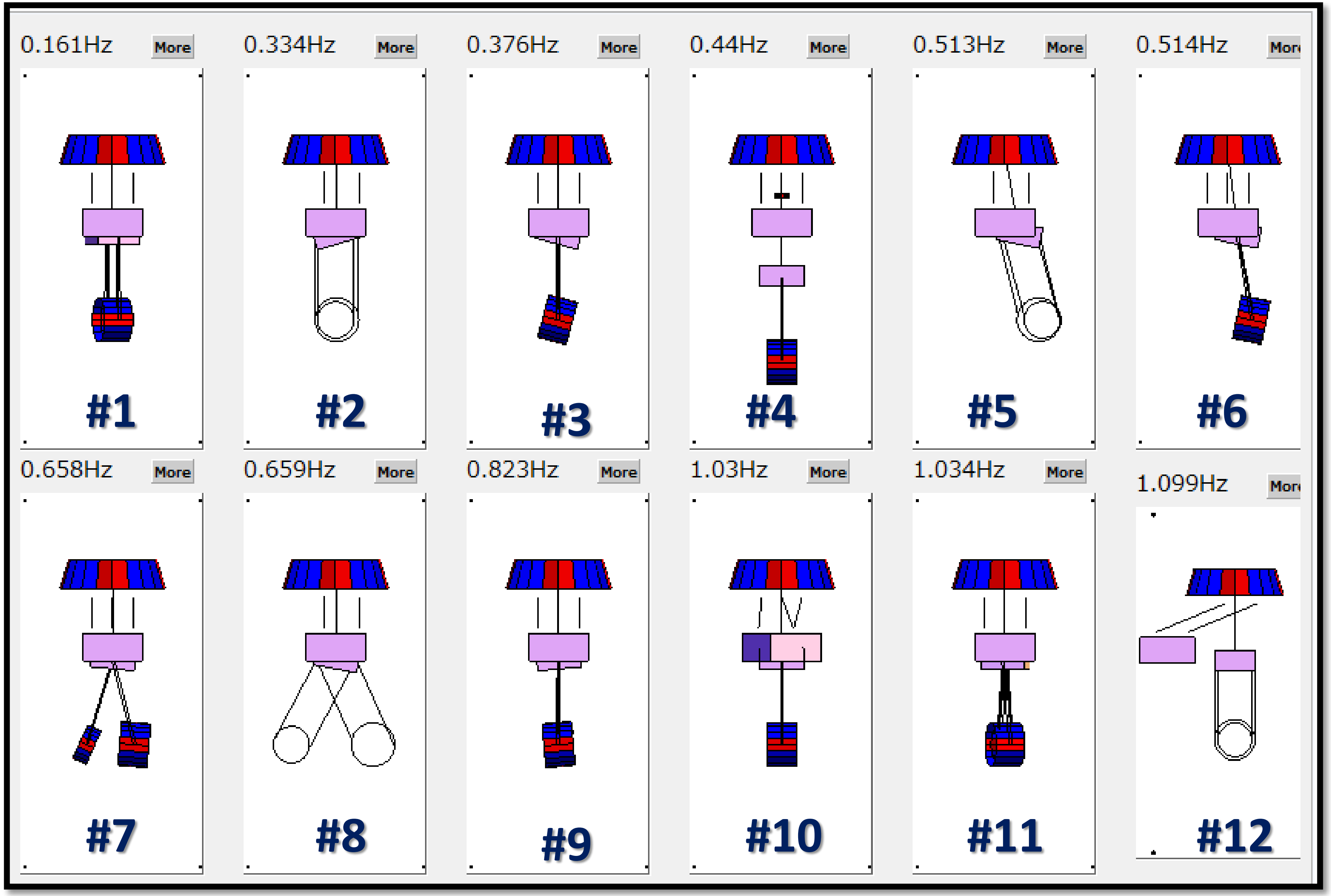
We should take IP back! (,if possible, I think.)

Thank you for your attention.

Back up

Eigen Mode Shape

TypeBpp



#1 : YPen
YIM, YRM, YTM

#2 : RPen
RIM, RRM, RTM

#3 : PTM
PIM, -PRM, -PTM

#4 : VPen
VIM, VRM, VTM

#5 : TPen
Pendulum

#6 : LPen
Pendulum

#7 : PTM
LTM, -PTM

#8 : TTM,-RM
TM, -TRM, etc

#9 : PTM
PTM

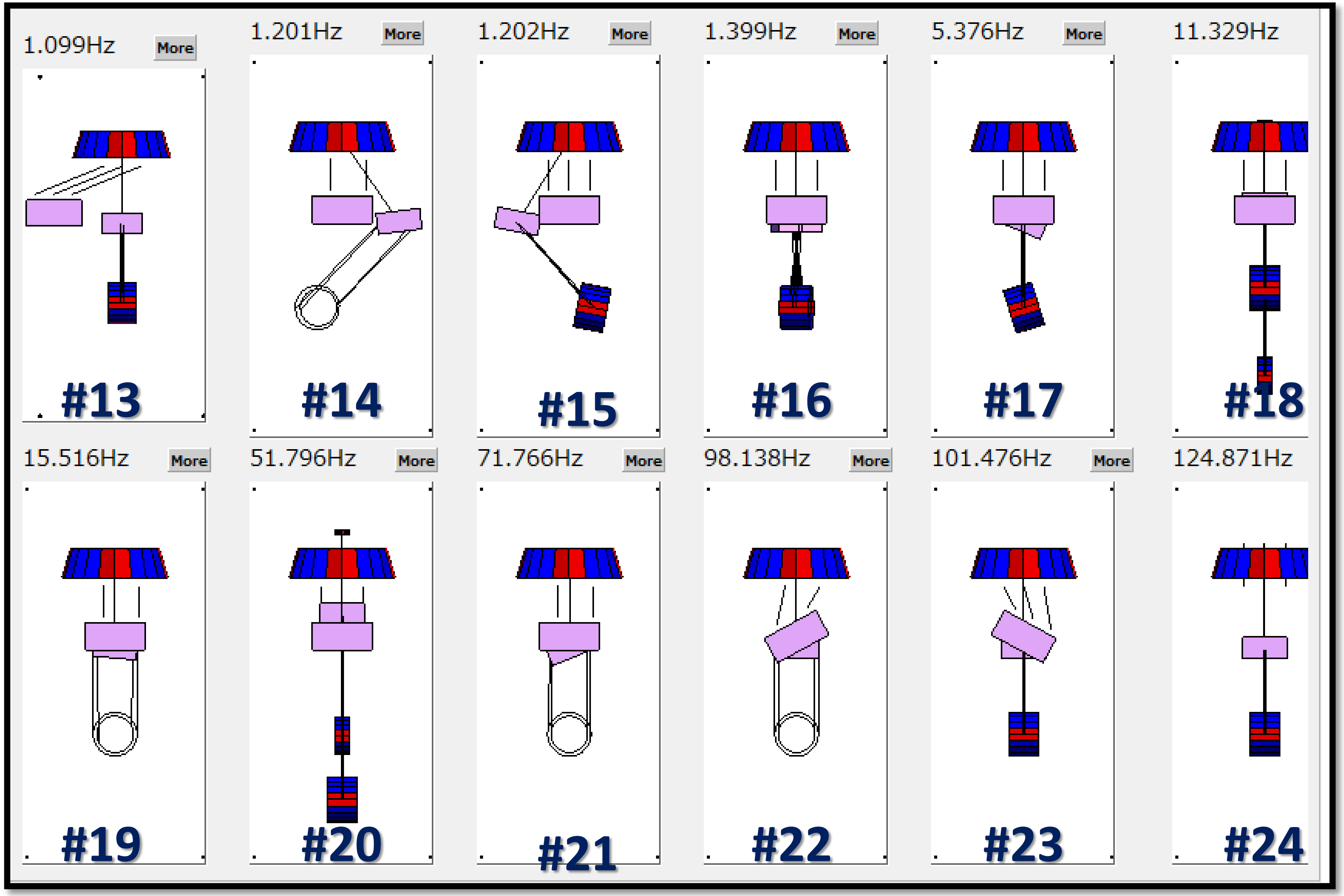
#10 : YIR
YIR

#11 : YTM
-YIM, YRM YTM

#12 : TRM
TRM

Eigen Mode Shape

TypeBpp



#13 : LRM
LRM

#14 :TIM
TIM, etc

#15 : LIM
LIM, etc

#16 : YTM
YIM, -YRM, -YTM

#17 : PIM
PIM, -PRM

#18 : VTM
-VIM, -VRM, VTM

#19 : RTM
RRM, -RTM

#20 :VIM
VIM, VRM

#21 : RIM
RIM, -RRM

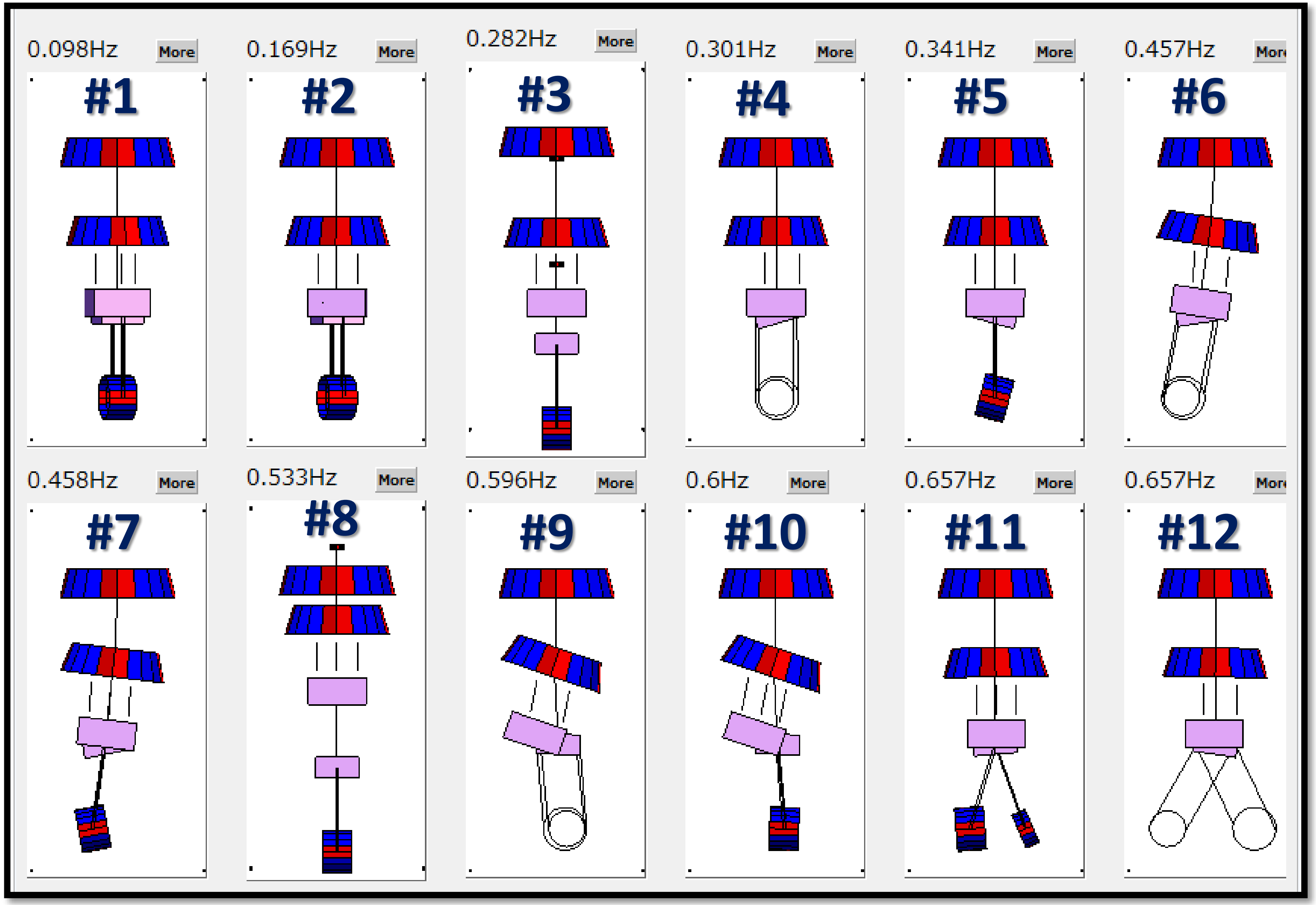
#22 : RIR
RIR

#23 : PIR
PIR

#24 : VIR
VIR

Eigen Mode Shape

TypeBp



#1 : YPen
YIM, YRM, YTM, YF2, YIR

#2 : YPay
YIM, YRM, YTM

#3 : VPay
VIM, VRM, VTM

#4 : RPay
RIM, RRM, RTM

#5 : PPay
PIM, PRM, PTM

#6 : TPen
Pendulum

#7 : LPen
Pendulum

#8 : VF2, VIR
VF2, VIR, VPay

#9 : RF2, RIR
RF2, RIR, TIP

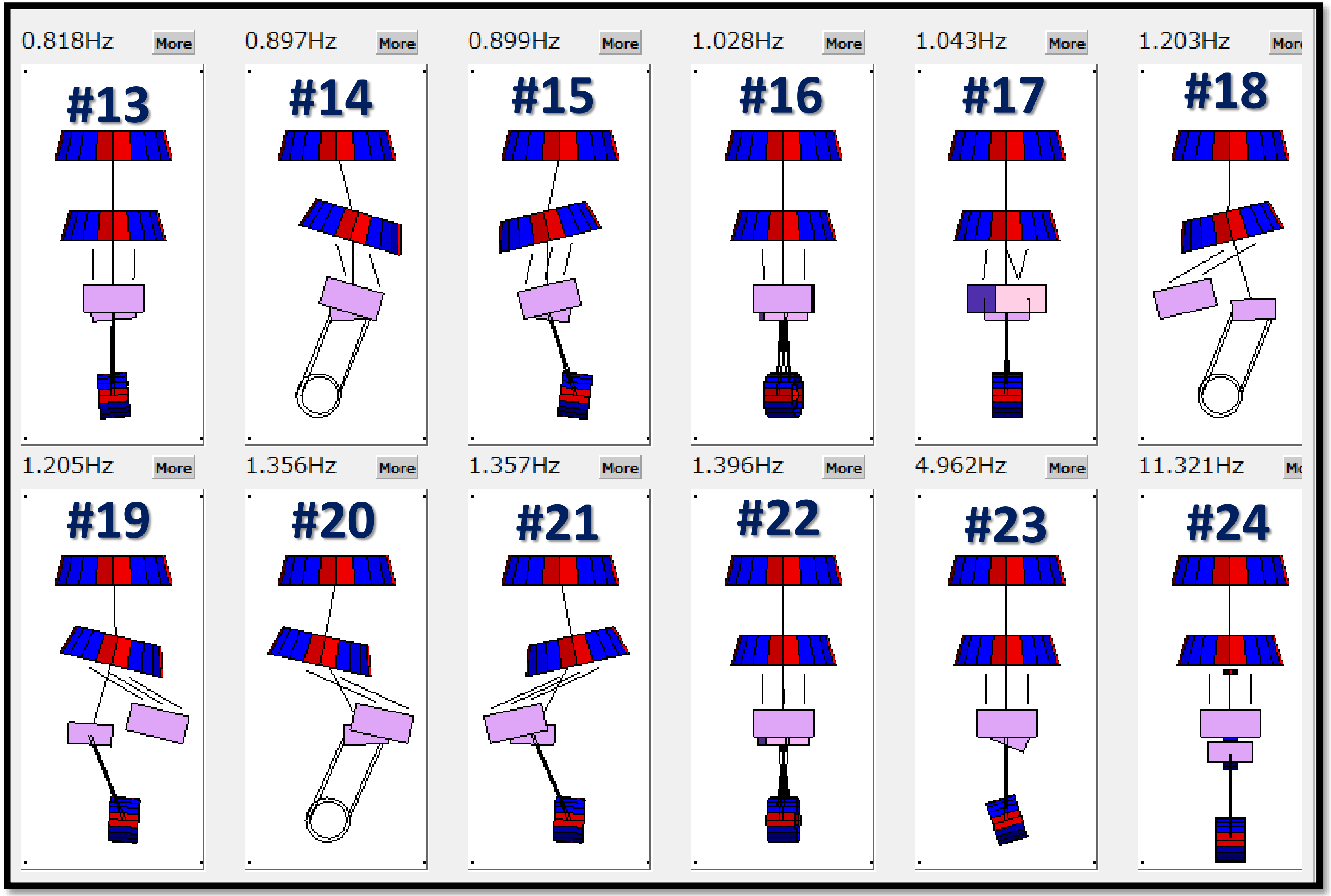
#10 : PF2, PIR
PF2, PIR, LIR

#11 : L deff
LRM, -LTM PTM

#12 : T deff
TRM, -TTM, RIM, RRM, RTM

Eigen Mode Shape

TypeBp



#13 : PTM
PTM

#14 :TPen
Pendulum

#15 : LPen
Pendulum

#16 : YTM
YIM, -YRM, YTM

#17 : YIR
YIR,

#18 : TPen
Pendulum

#19 : LPen
Pendulum

#20 : TPen
Pendulum

#21 : LPen
Pendulum

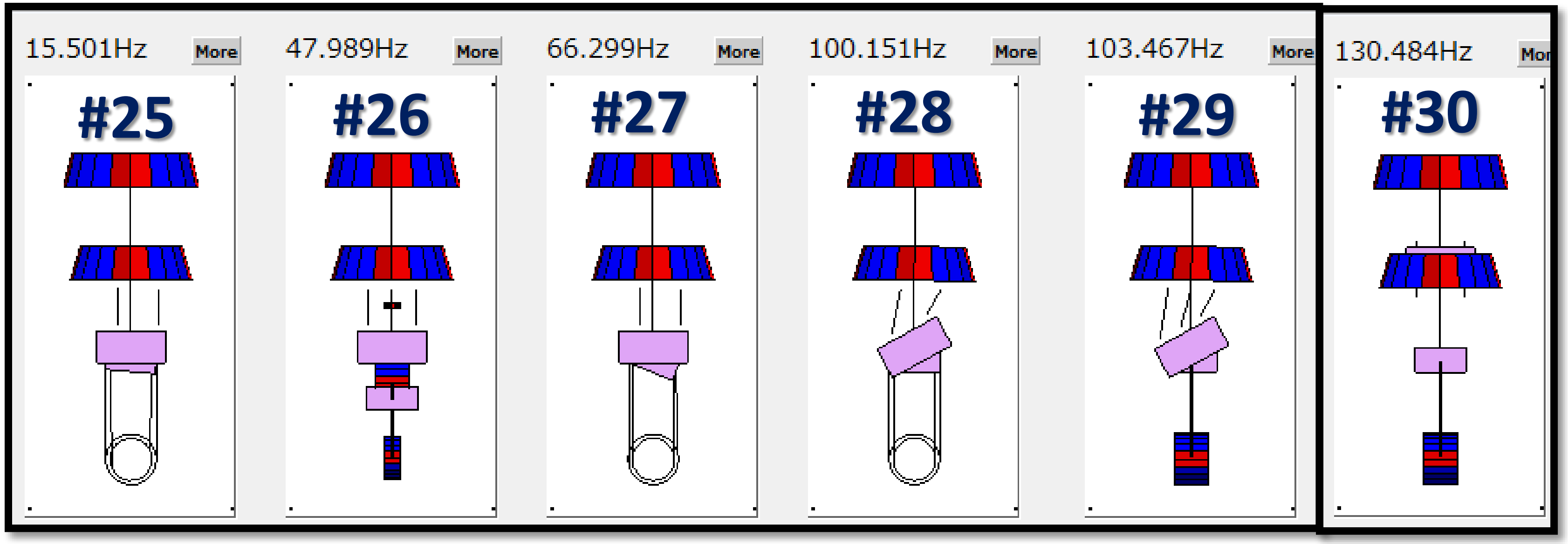
#22 : YTM
YIM, -IRM, -YTM

#23 : PIM
-PIM, PRM

#24 : VTM
-VIM, -VRM, VTM

Eigen Mode Shape

TypeBp



#25 : RTM

-RRM, RTM

#26 : VRM

-VIM, VRM

#27 : RIM

-RIM, RRM

#28 : YTM

YIM, -YRM, -YTM

#29 : PIM

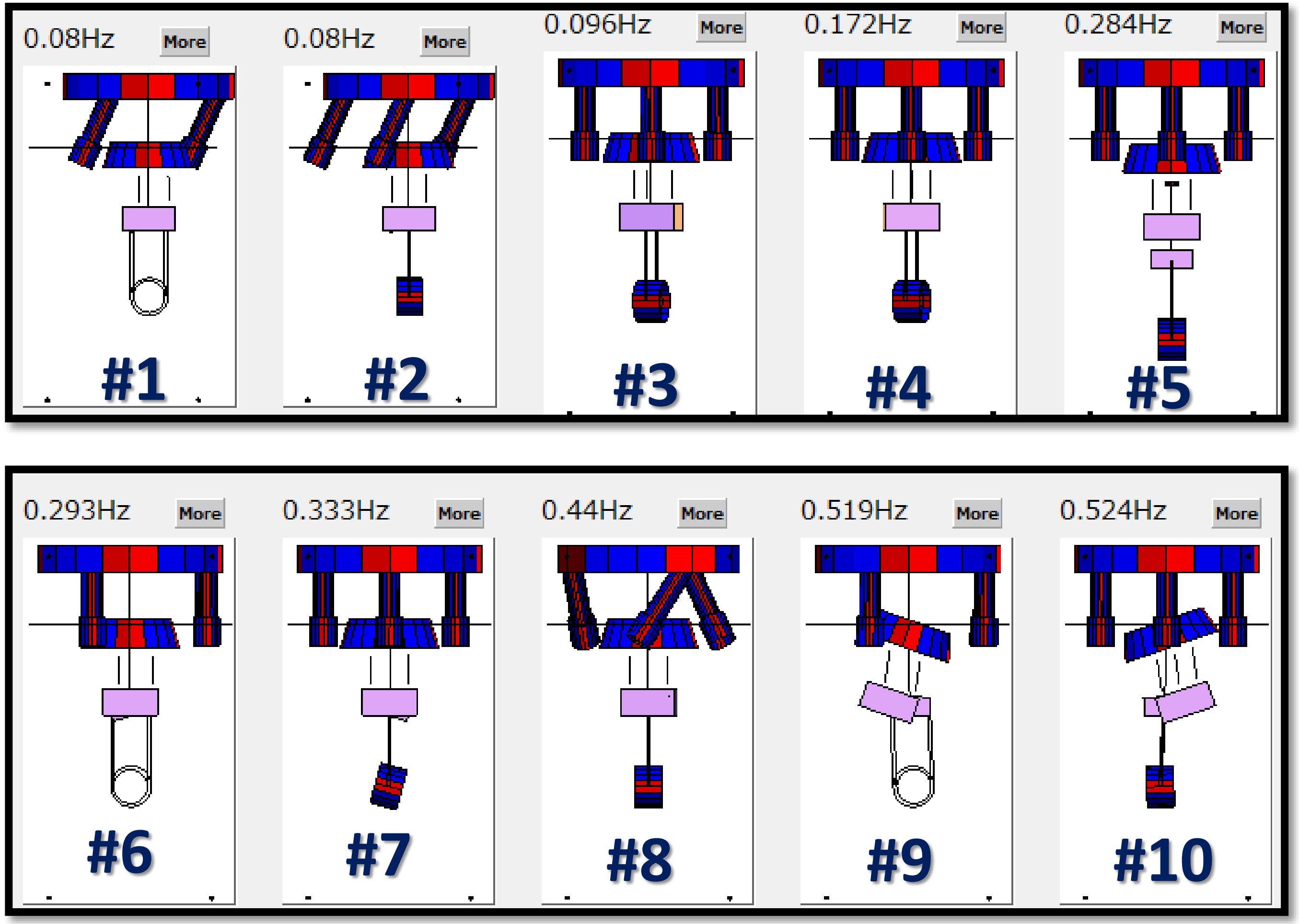
PIM, -PRM

#30 : VTM

-VIM, -VRM, VTM

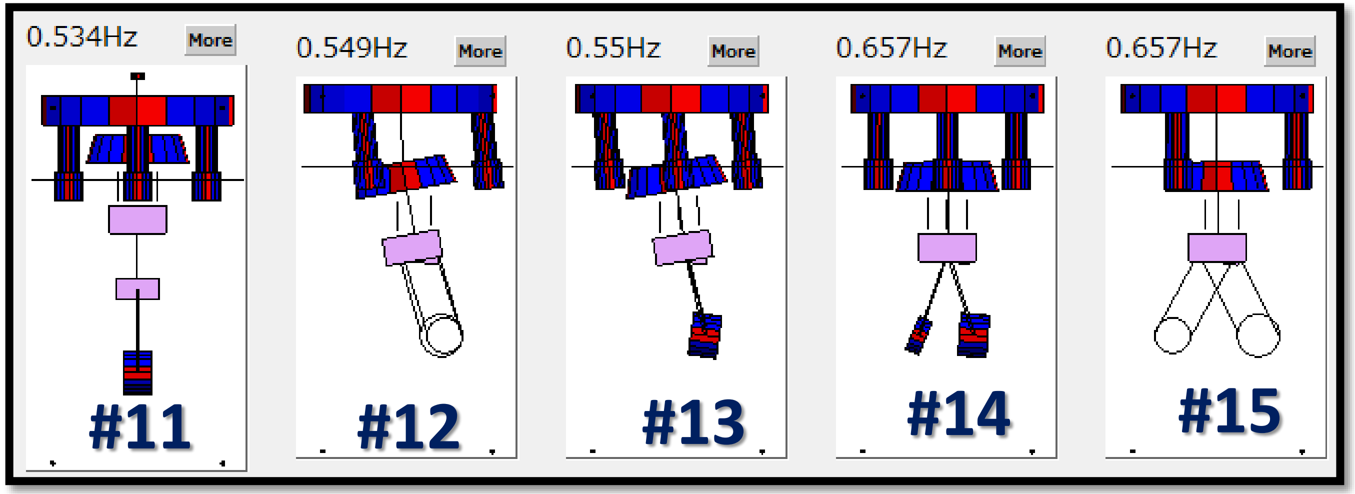
Eigen Mode Shape

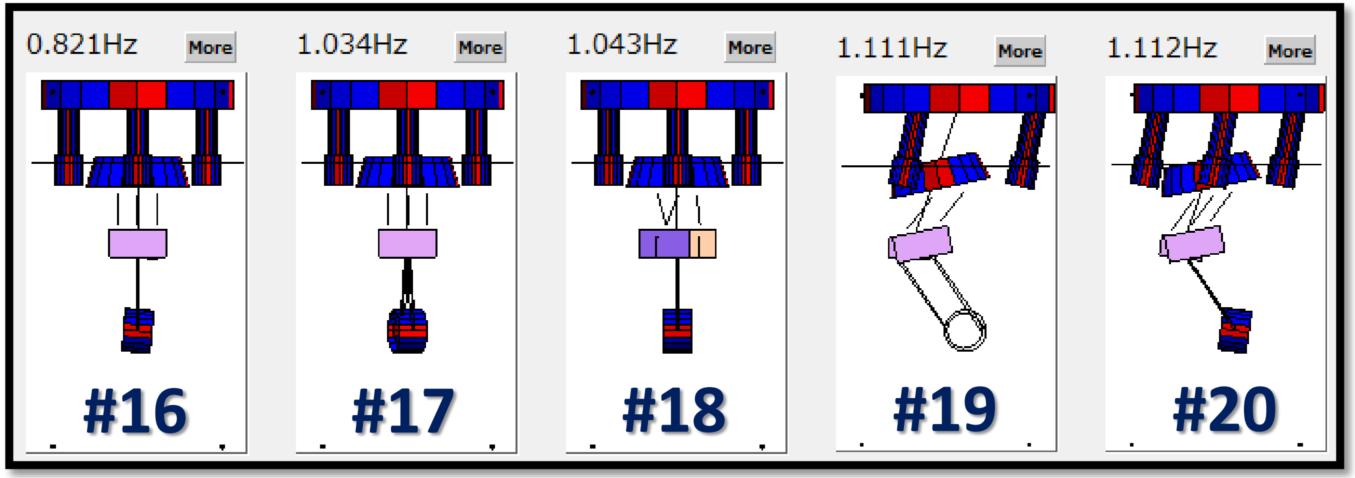
TypeBp with IP



Eigen Mode Shape

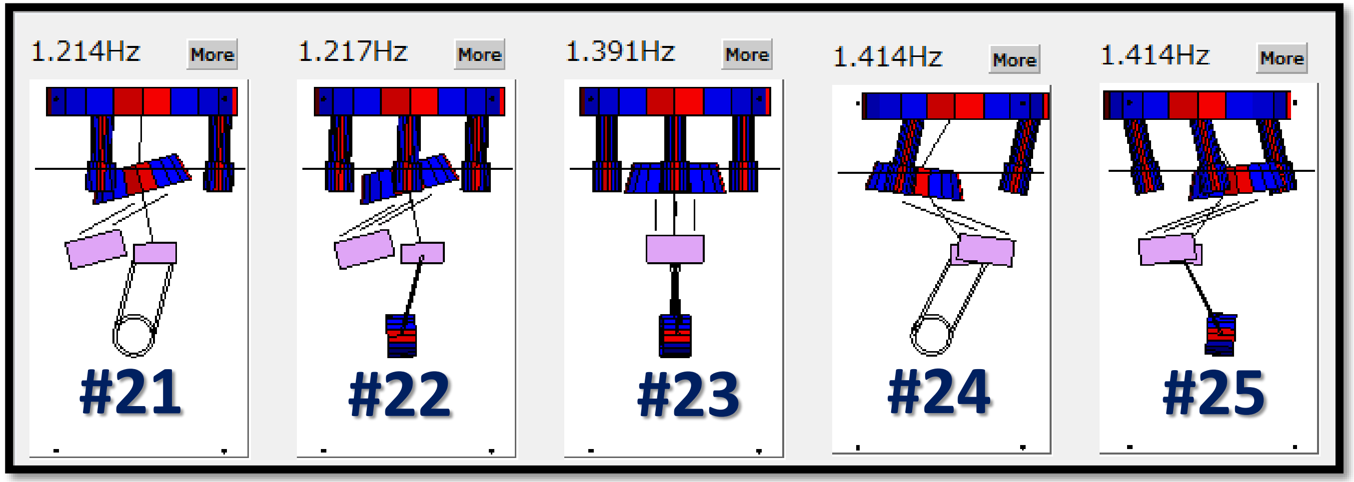
TypeBp with IP

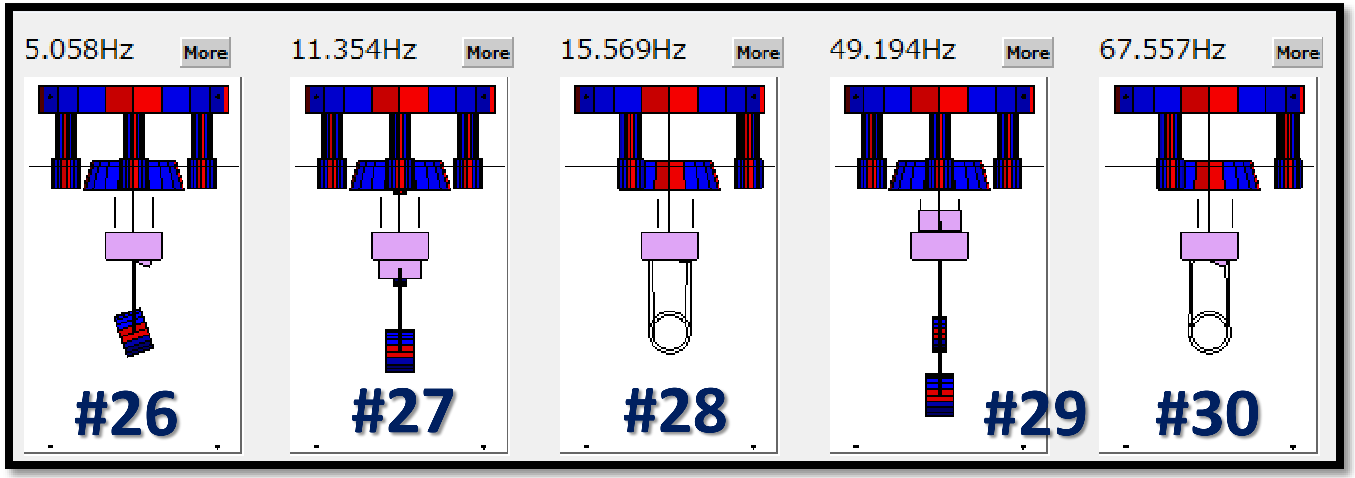




Eigen Mode Shape

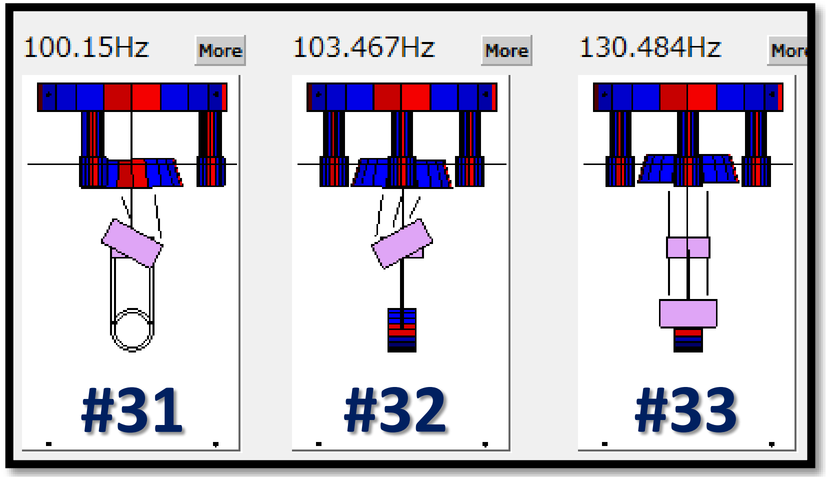
TypeBp with IP





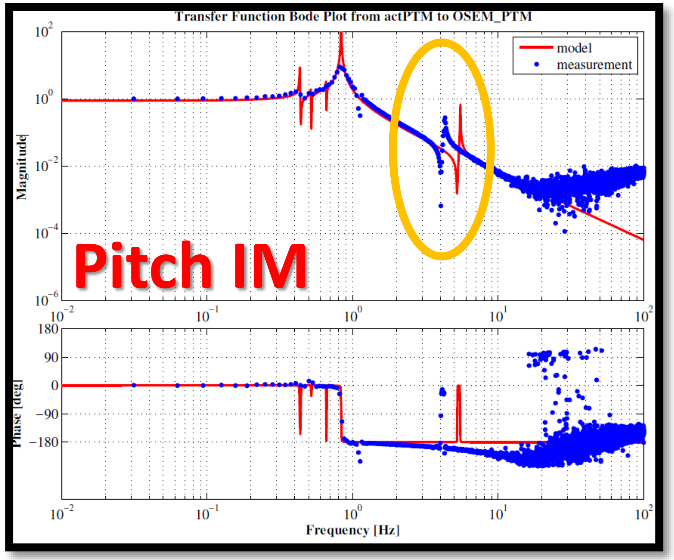
Eigen Mode Shape

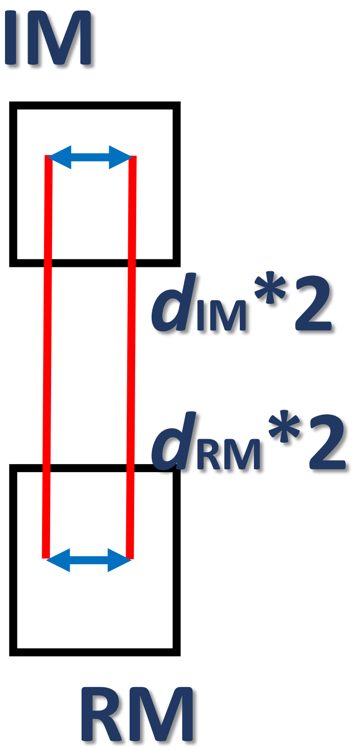
TypeBp with IP

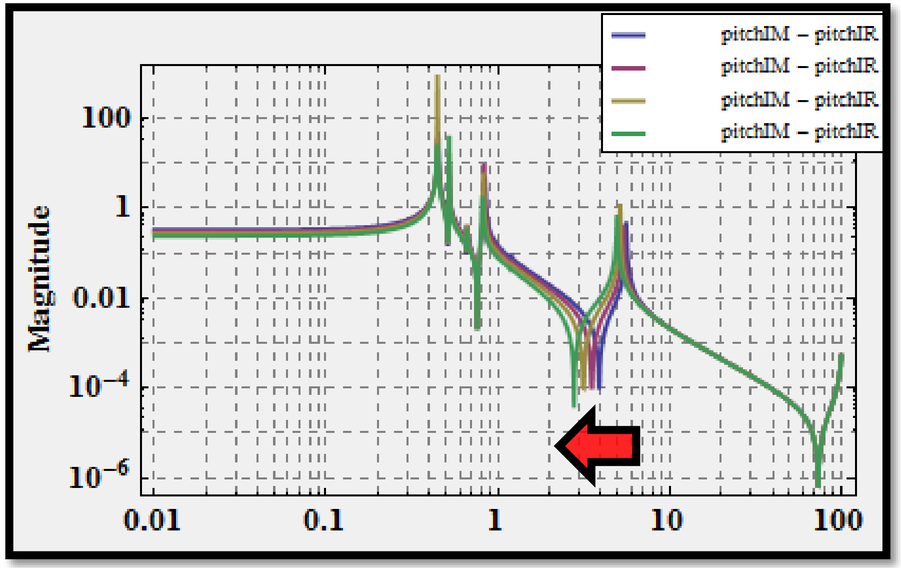


❖ Investigation of TypeBpp Frequency response

According to SUMCON,

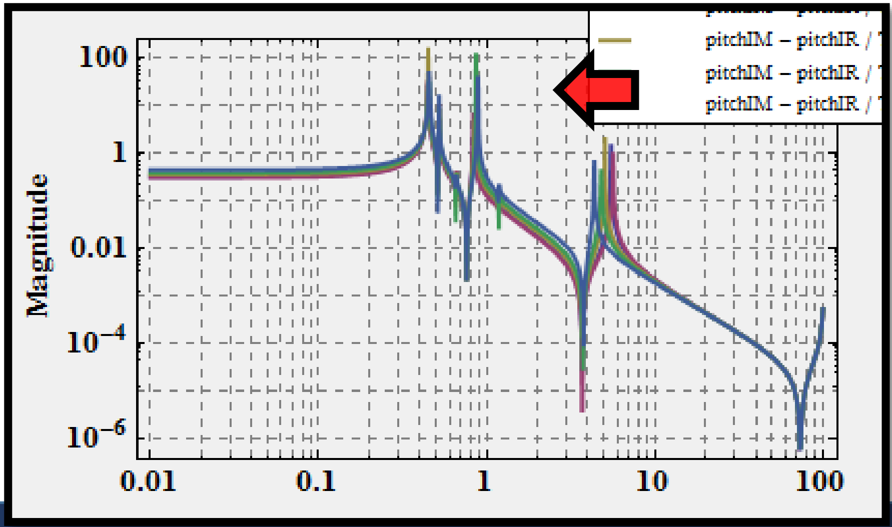






d_{IM} = 10 mm

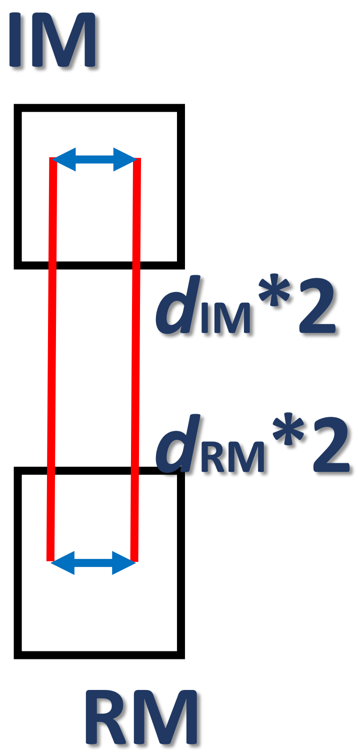
d_{RM} = 10.5 mm → 9.5 mm → 8.5 mm → 7.5 mm

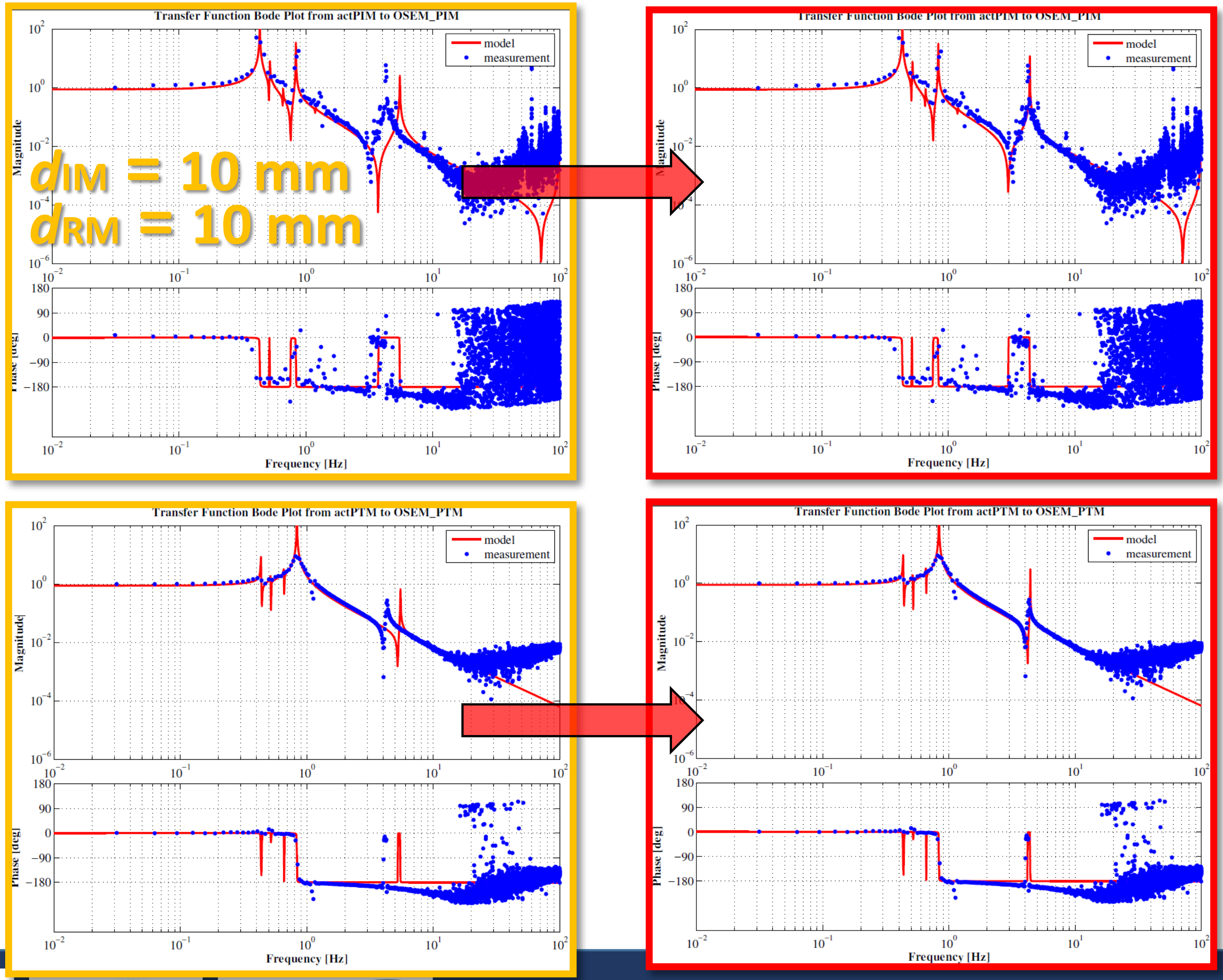


d_{IM} = 10.0 mm → 10.5 mm → 7.5 mm → 5.5 mm

d_{RM} = 10 mm

❖ Investigation of TypeBpp Frequency response





In Simulink

d_{IM} = 8 mm

d_{RM} = 10 mm

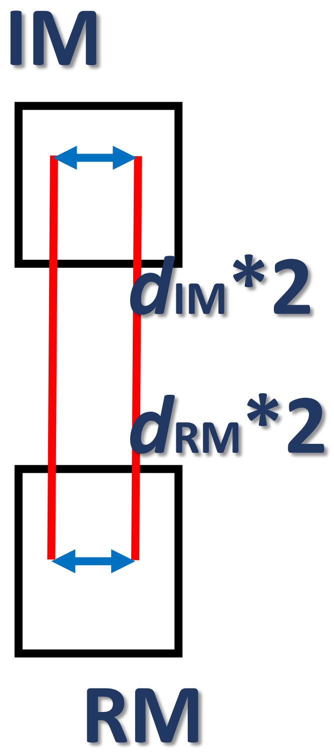
In SUMCON

d_{IM} = 7.3 mm

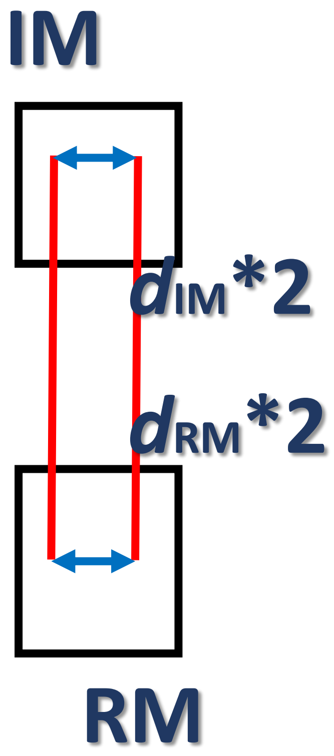
d_{RM} = 8.8 mm

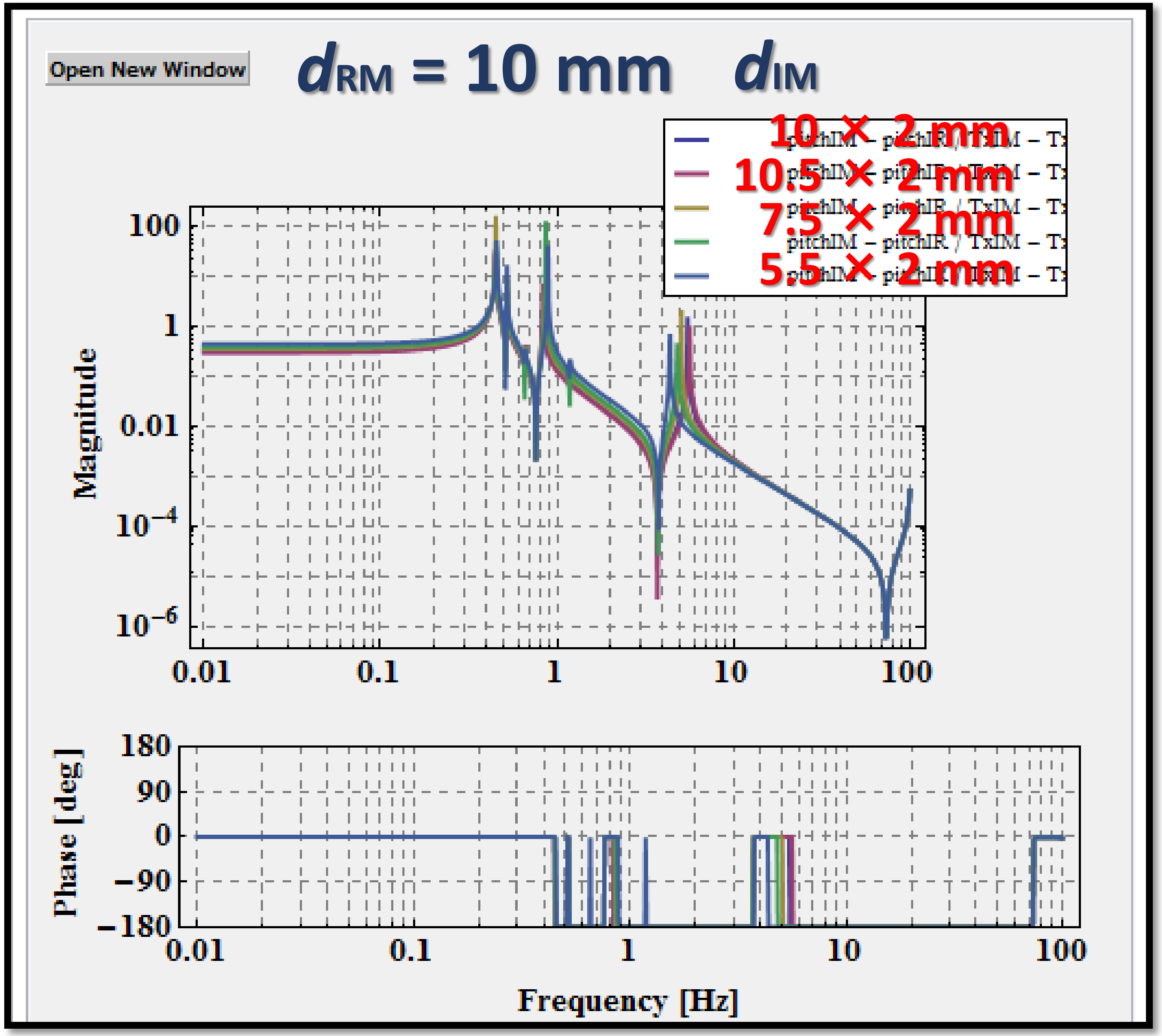
IM wire separation contributes to resonance frequency of Roll IM, Roll RM.

typeBpp_160108v2adj

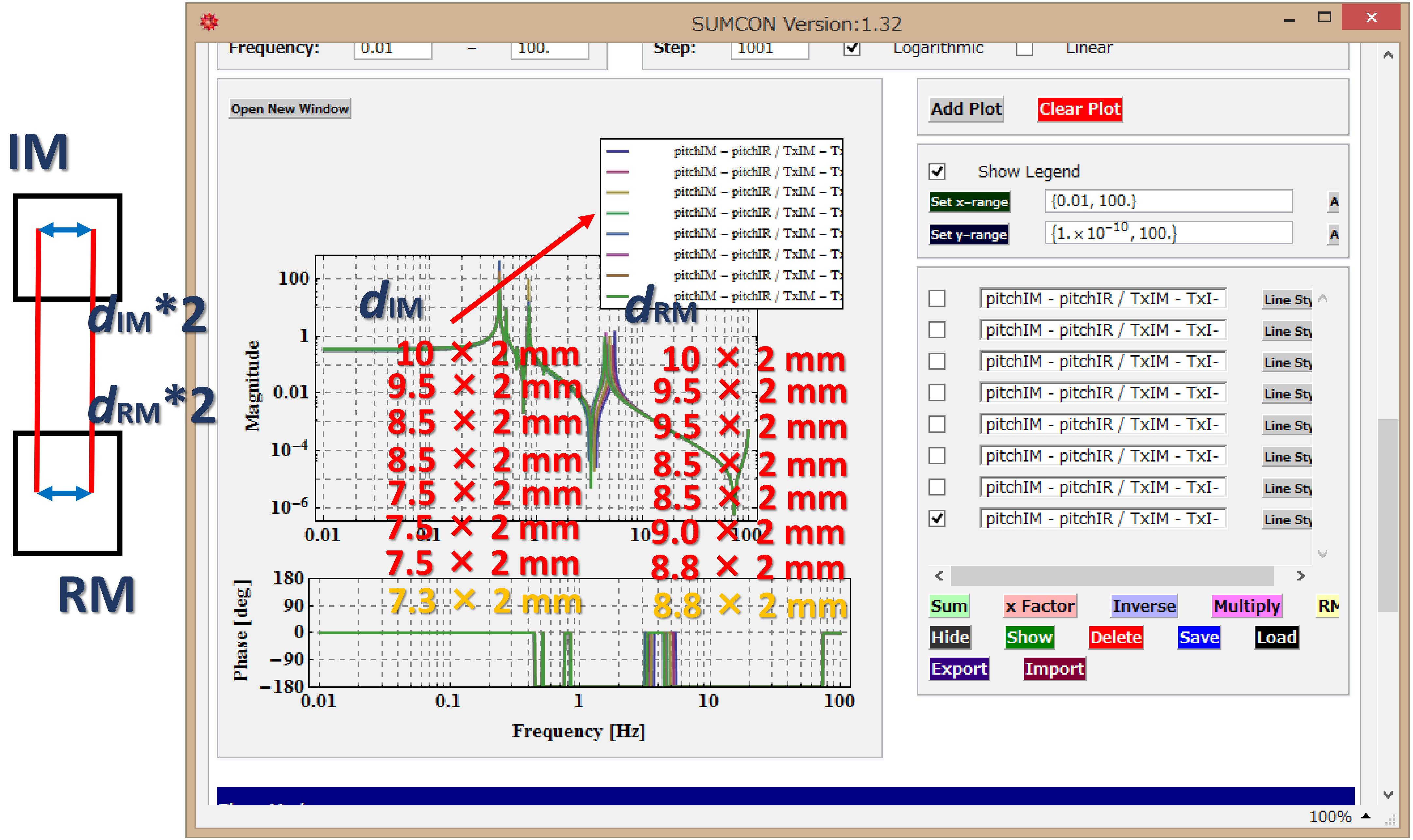


typeBpp_160108v2adj



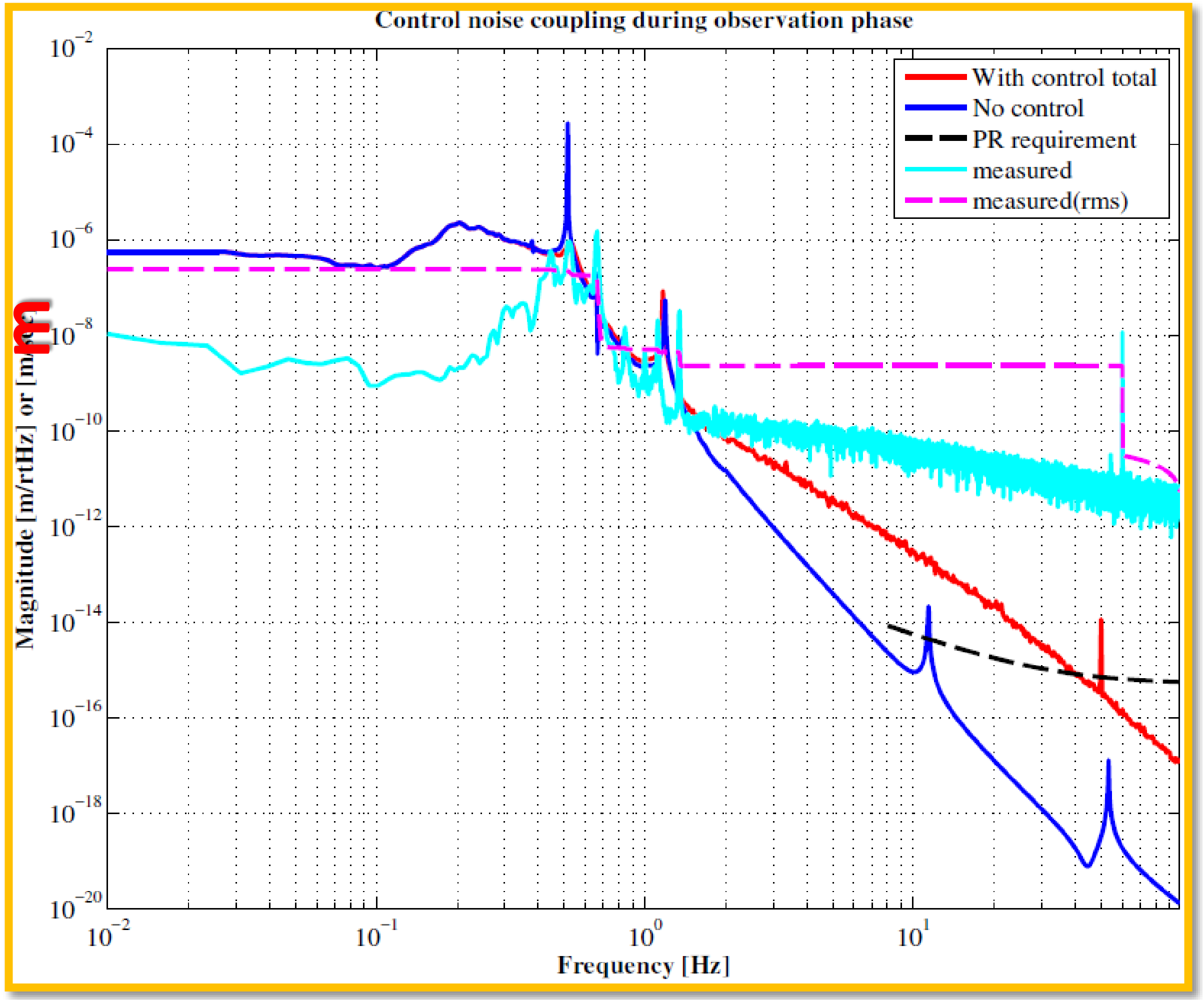


typeBpp_160108v2adj



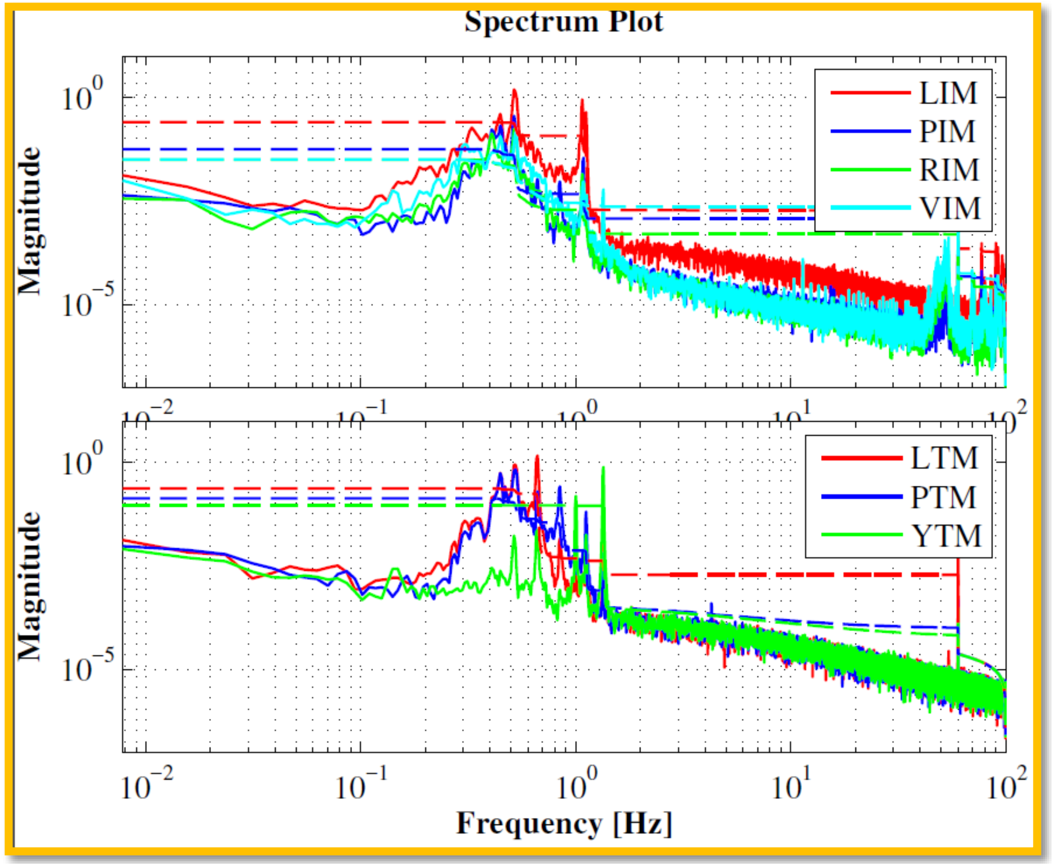
Measurement

LTM Spectrum in iKAGRA with no control



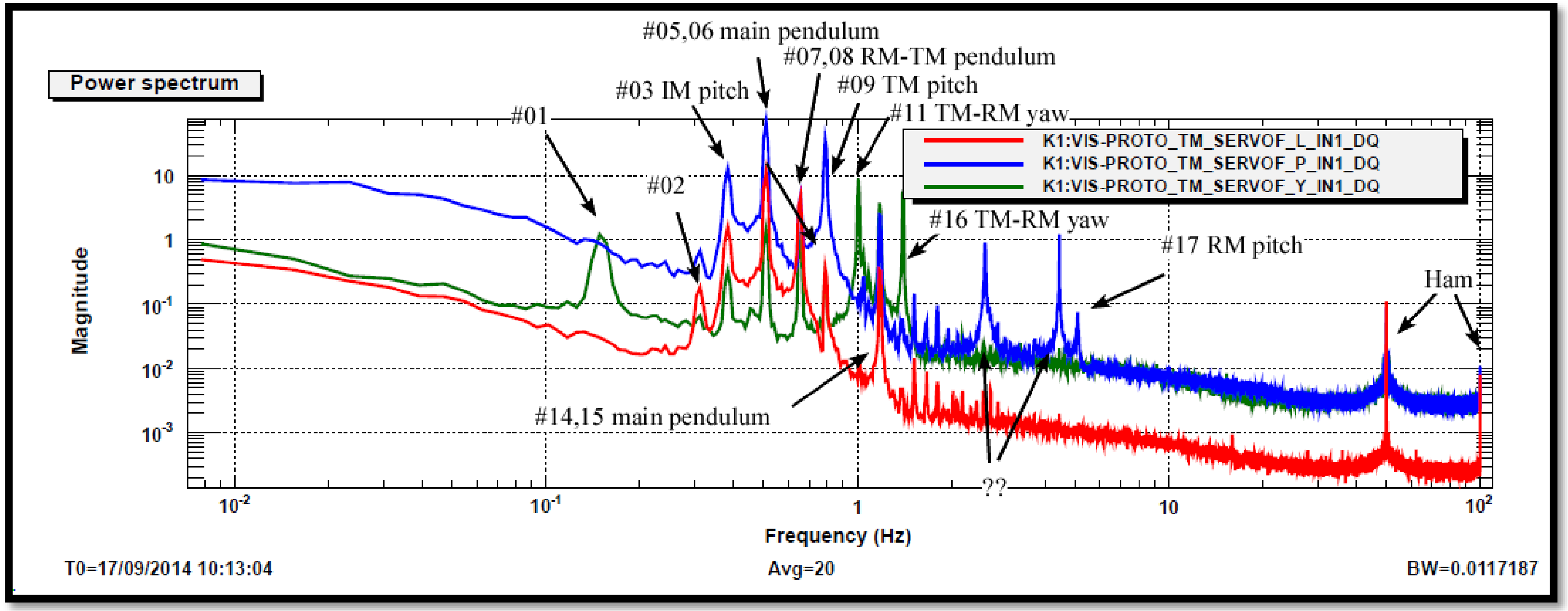
Measurement

IM, TM (OSEM) Spectrum in iKAGRA with no control

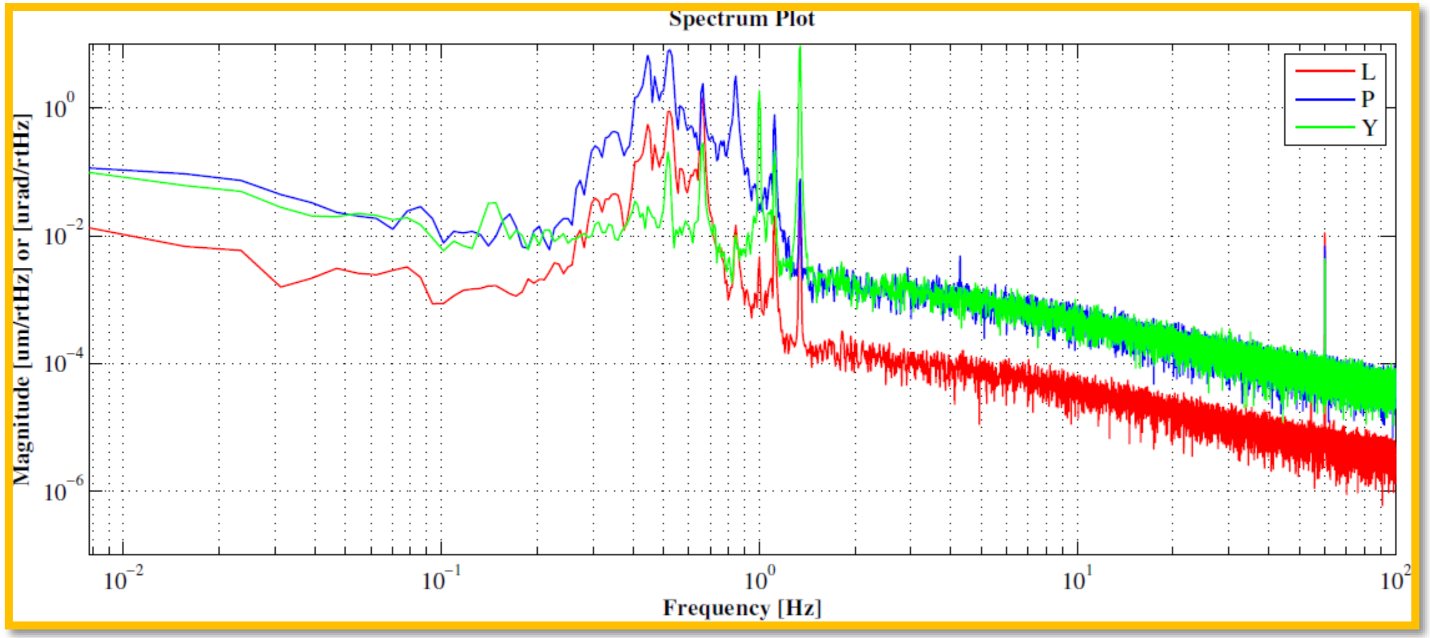


Measurement

REF : TM (OSEM) Spectrum in 20 m



TM (OSEM) Spectrum in iKAGRA



❖ From http://gwdoc.icrr.u-tokyo.ac.jp/DocDB/0039/T1503908/002/TypeBpDesign.pdf

2 Seismic noise level at the Kamioka site

The seismic displacement and velocity we used is shown in Fig.2 and **??**[2]. This is the one called high-noise model. The seismic displacement in Kamioka is below this level for 90 % of time.

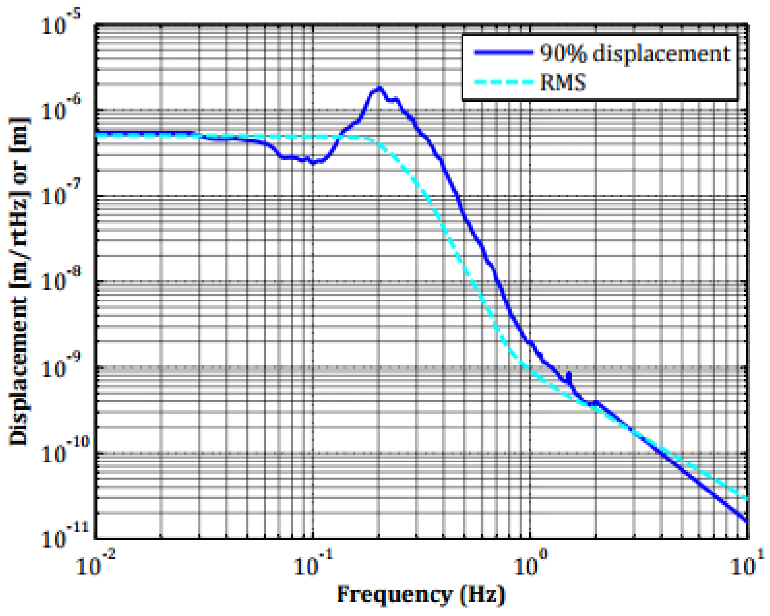


Figure 1: The high-level seismic displacement in Kamioka.

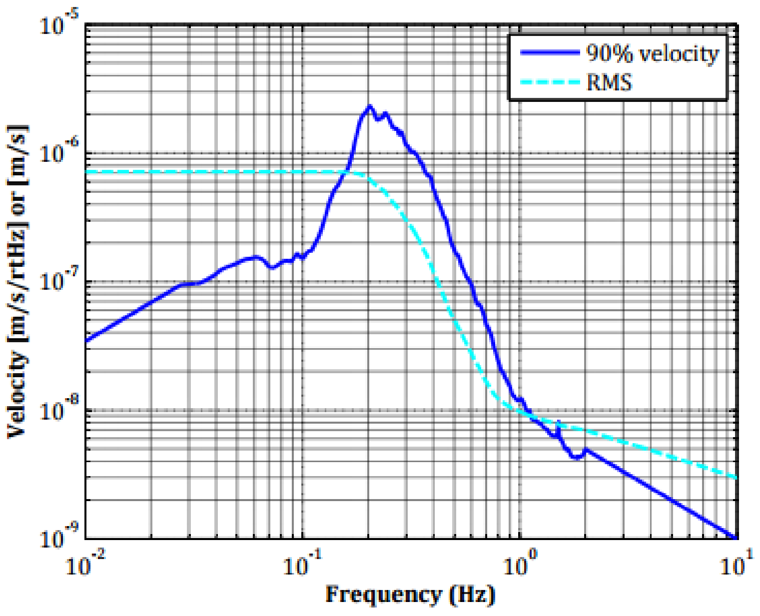
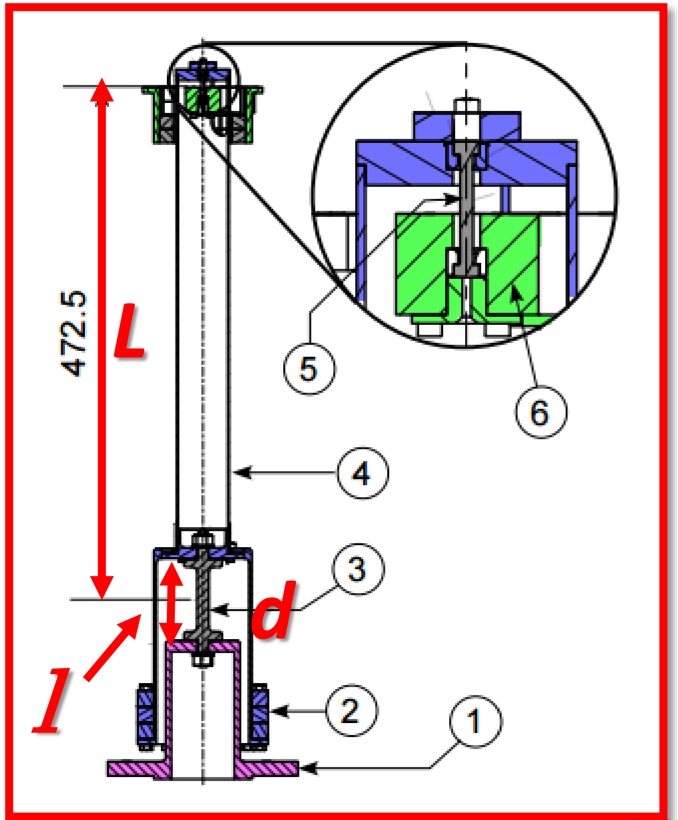


Figure 2: The high-level seismic velocity in Kamioka.

❖ One modification proposal for bKAGRA / TypeBp with IP

IP modeling parameter :

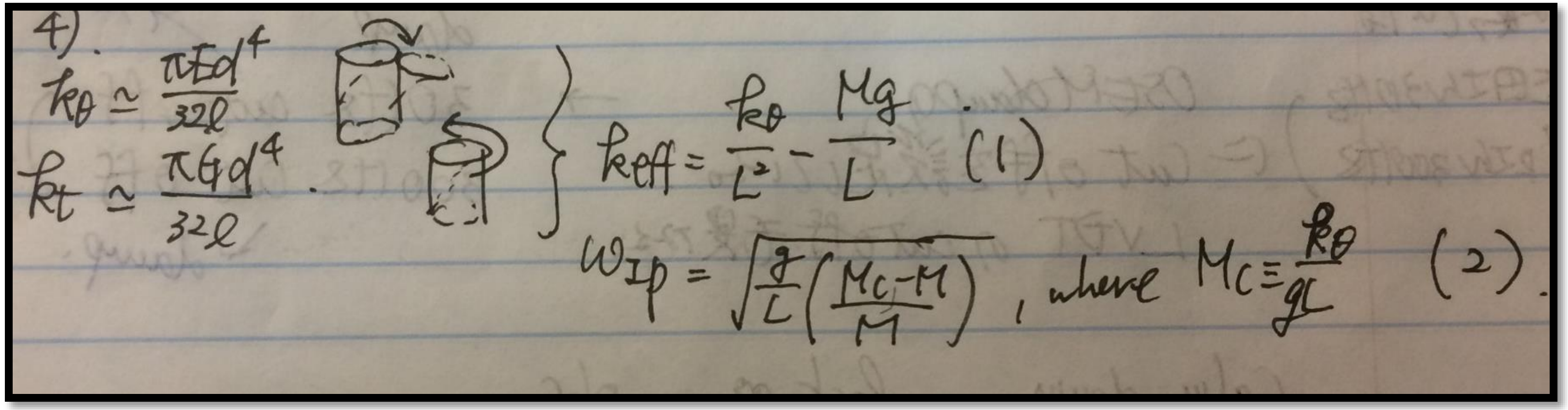


Load on IP M [kg]

Leg length L [m]

Resonant frequency ω_{IP} [rad/s]

Additional torsion stiffness k_t

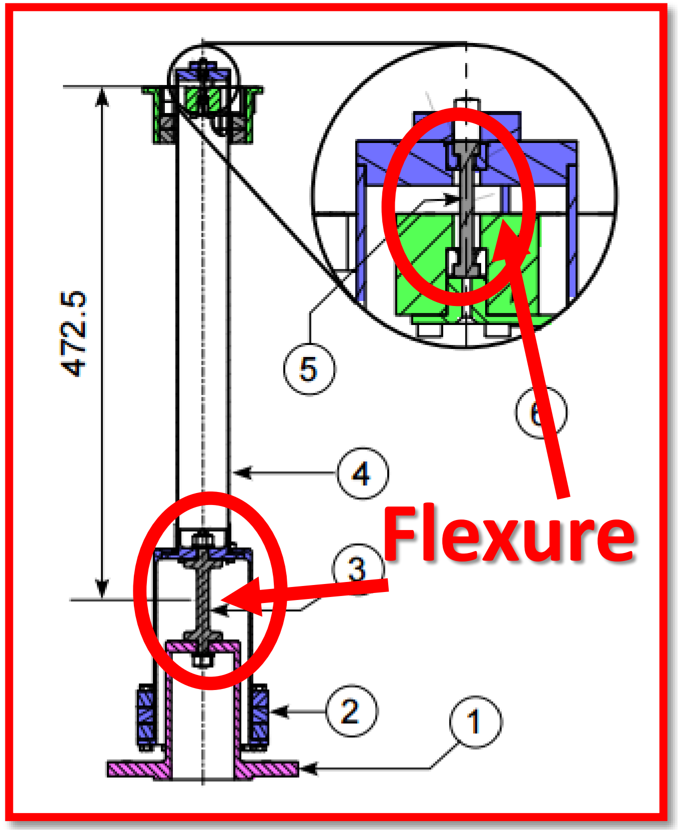


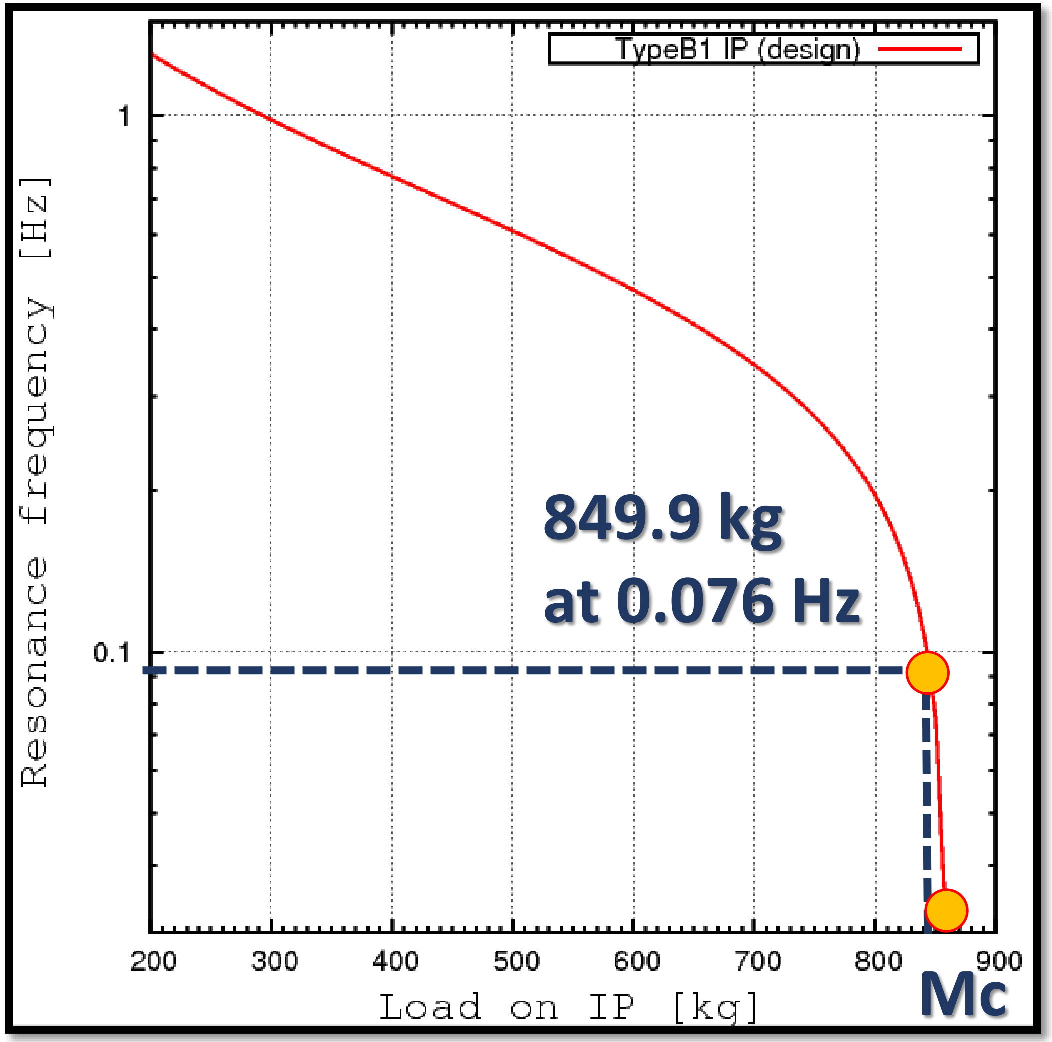
Y ➡ For top flexure : $k_t \rightarrow d_{top}$

L, T ➡ For bottom flexure : $M_c \rightarrow k_\theta \rightarrow d_{bottom}$

❖ One modification idea for bKAGRA / TypeBp with IP

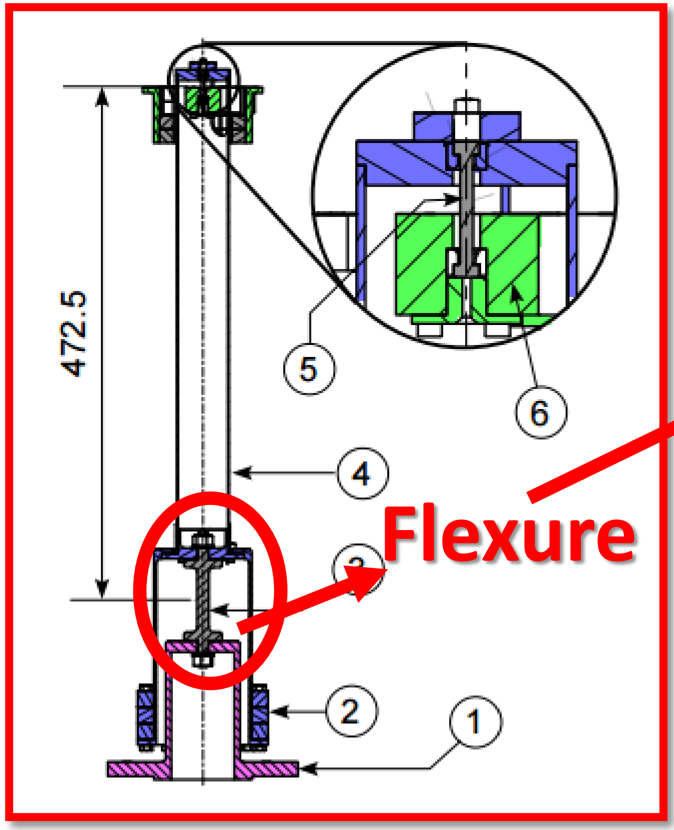
IP modeling parameter :

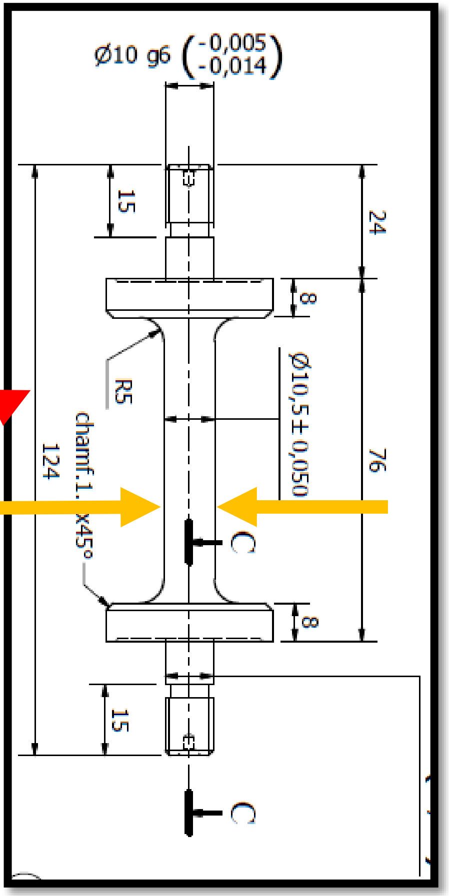




❖ One modification idea for bKAGRA / TypeBp with IP

IP modeling parameter :





TypeB proto	TypeB proto	TypeBp ?
10.5 mm →	9.7 mm →	7.8 mm
Mc ~1000 kg	Mc ~ 860 kg	Mc ~ 280 kg