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Finesse 3 simulation for GW detector

Using multi-modal simulation to design and prepare the O5 upgrade on Virgo

Finesse 3

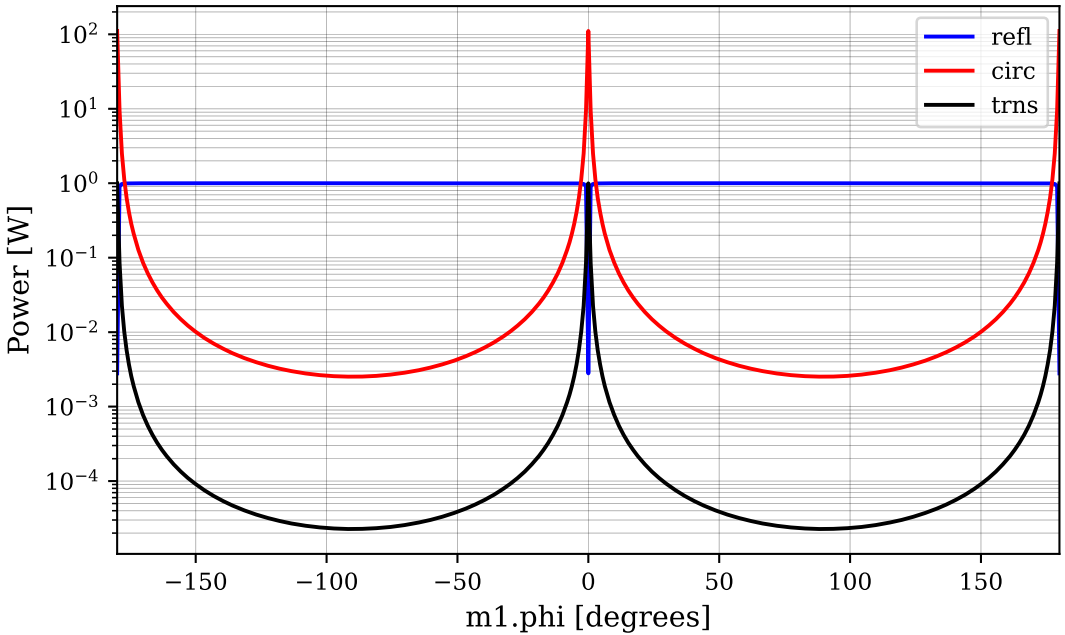
- Frequency-Domain interferometer simulation
- Modal model

Finesse 3

https://finesse.ifosim.org/

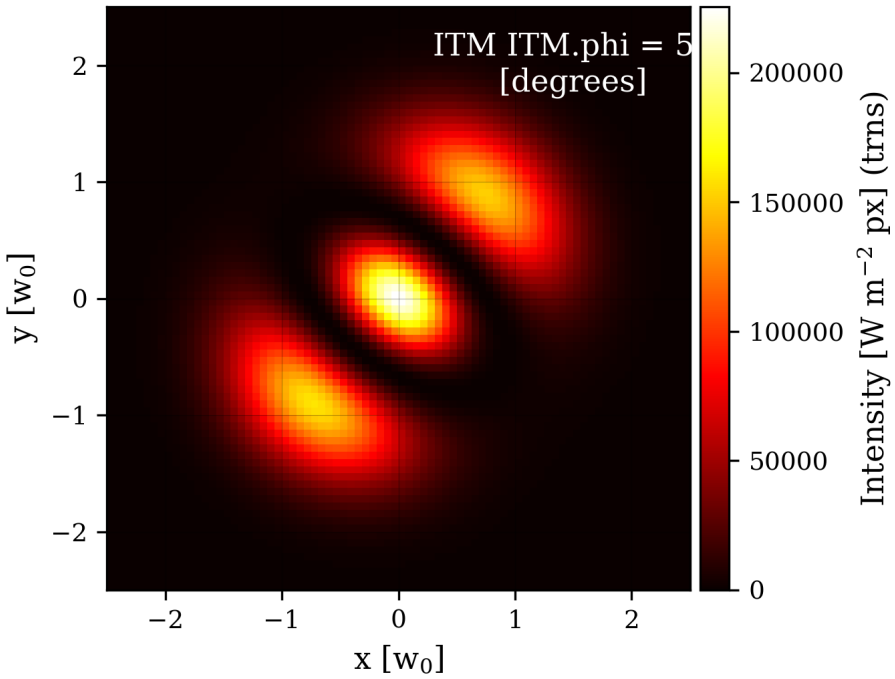
Nodal network

- Model: tree of components (mirror, beamsplitter, etc.)
- Solve ABCD matrices
- Compute HOM



Examples

- Gaussian beam tracing
- Scan with HOM
- Transfer Function
- Control loop



Backscattered light simulation

Some context & simulation with Finesse3

Benches layout

Benches :

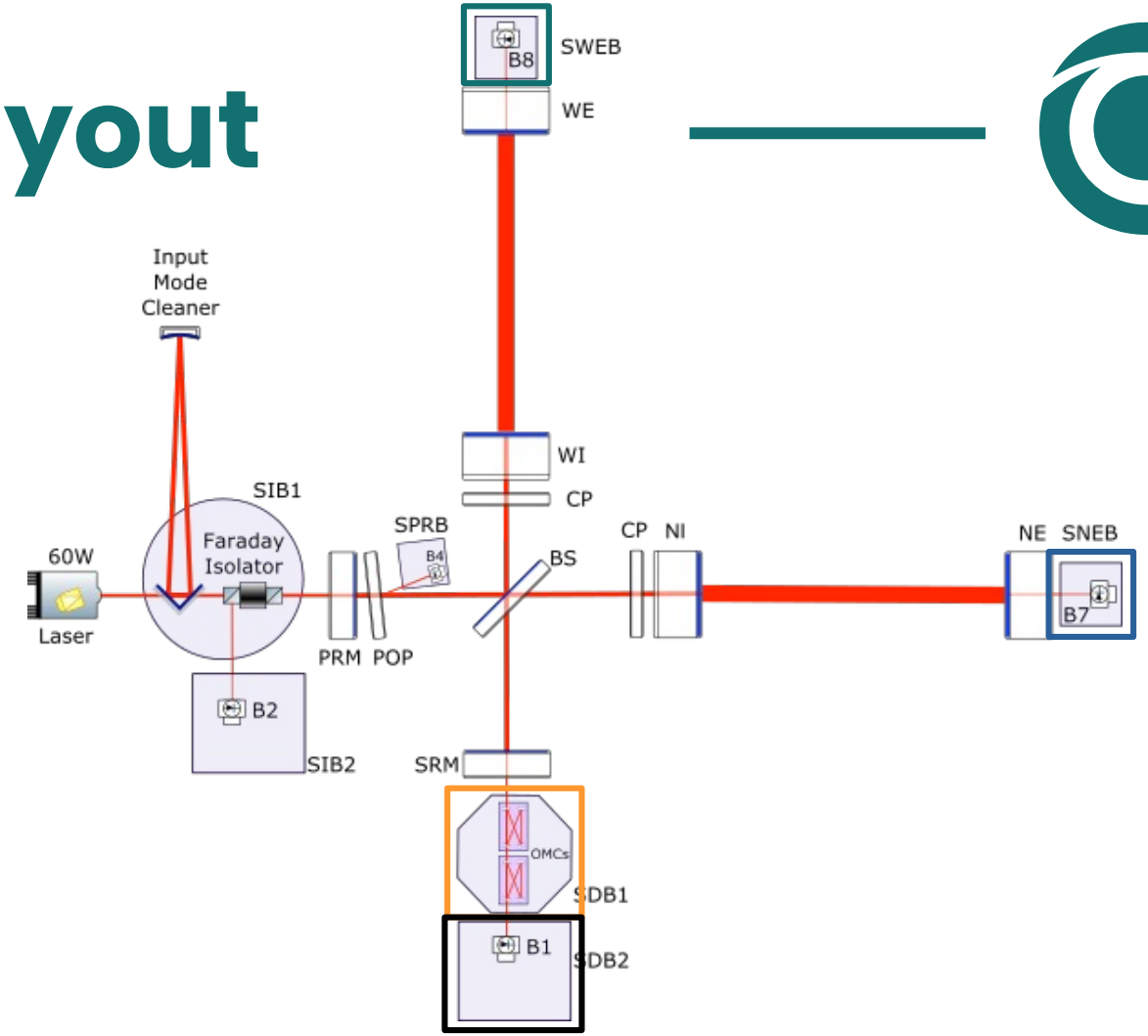
- SNEB
- SWEB

End-of-arms benches

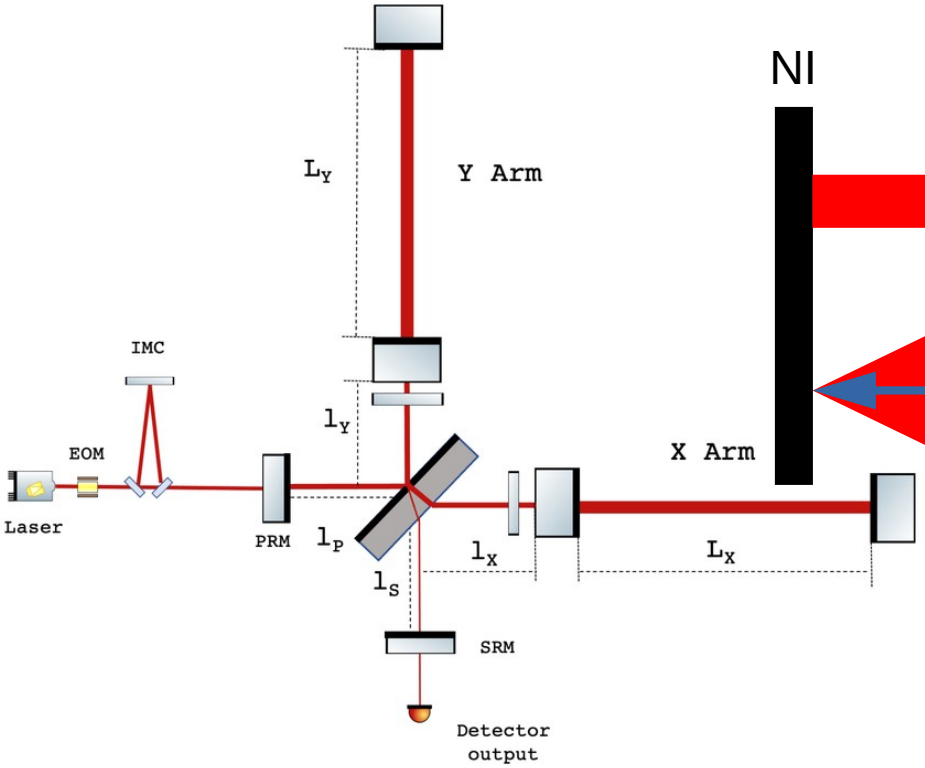
- SDB1
- SDB2

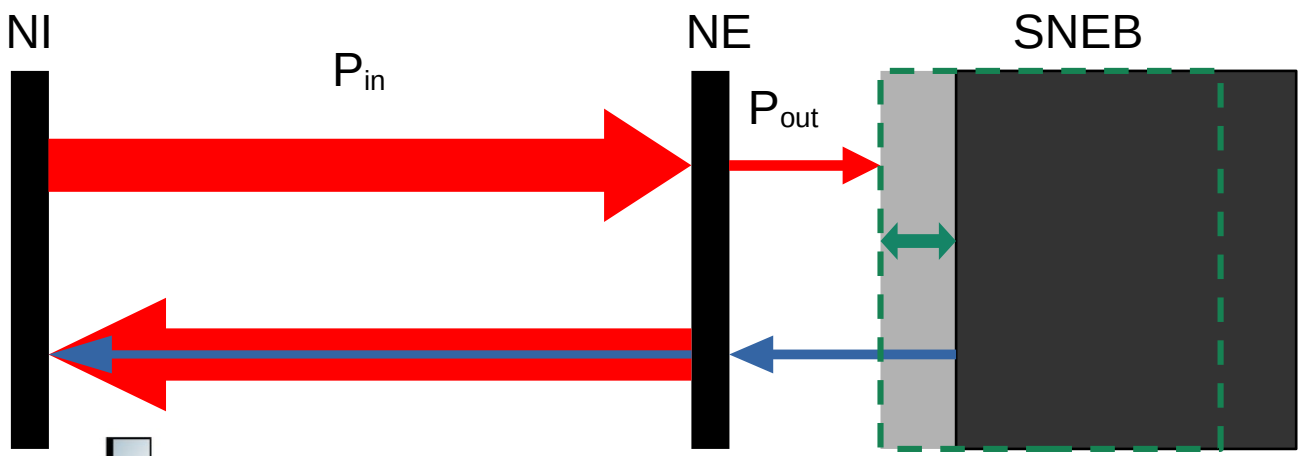
Detection benches

- In vacuum
- Suspended



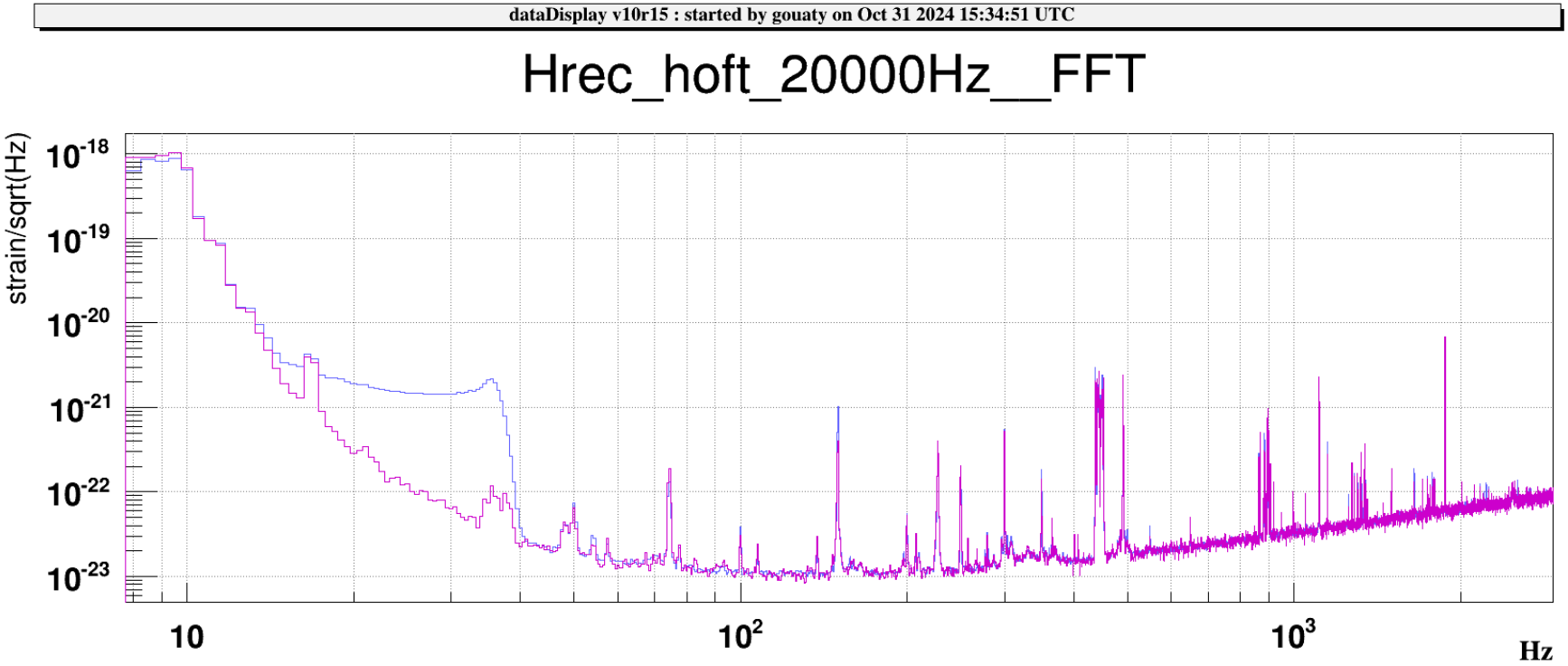
Backscattered noise





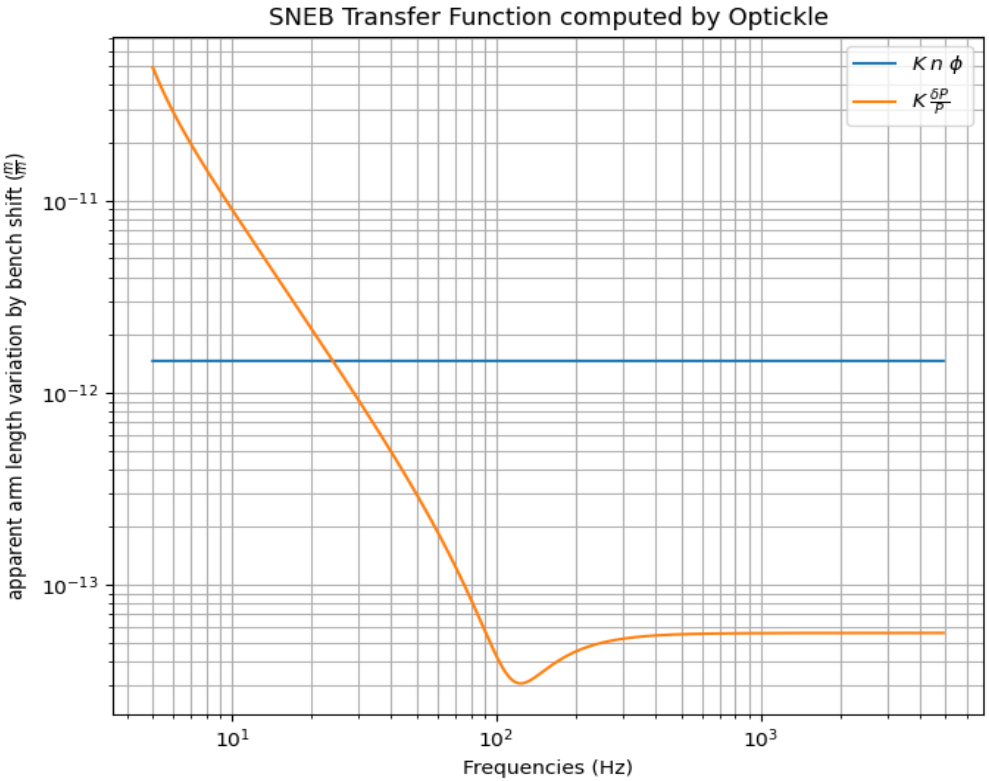
backscattered light

Impact of backscattered light on sensitivity



Sensitivity curve with (blue) and without (purple) SNEB vibration

Transfer function



Constructive/Destructive interference :
→ change amplitude of the beam
→ change radiation pressure

⇒ Named $K_{\frac{\delta P}{P}}$

Quadratic interference :
→ add phase noise
→ directly change measurement

⇒ Named K_{n_ϕ}

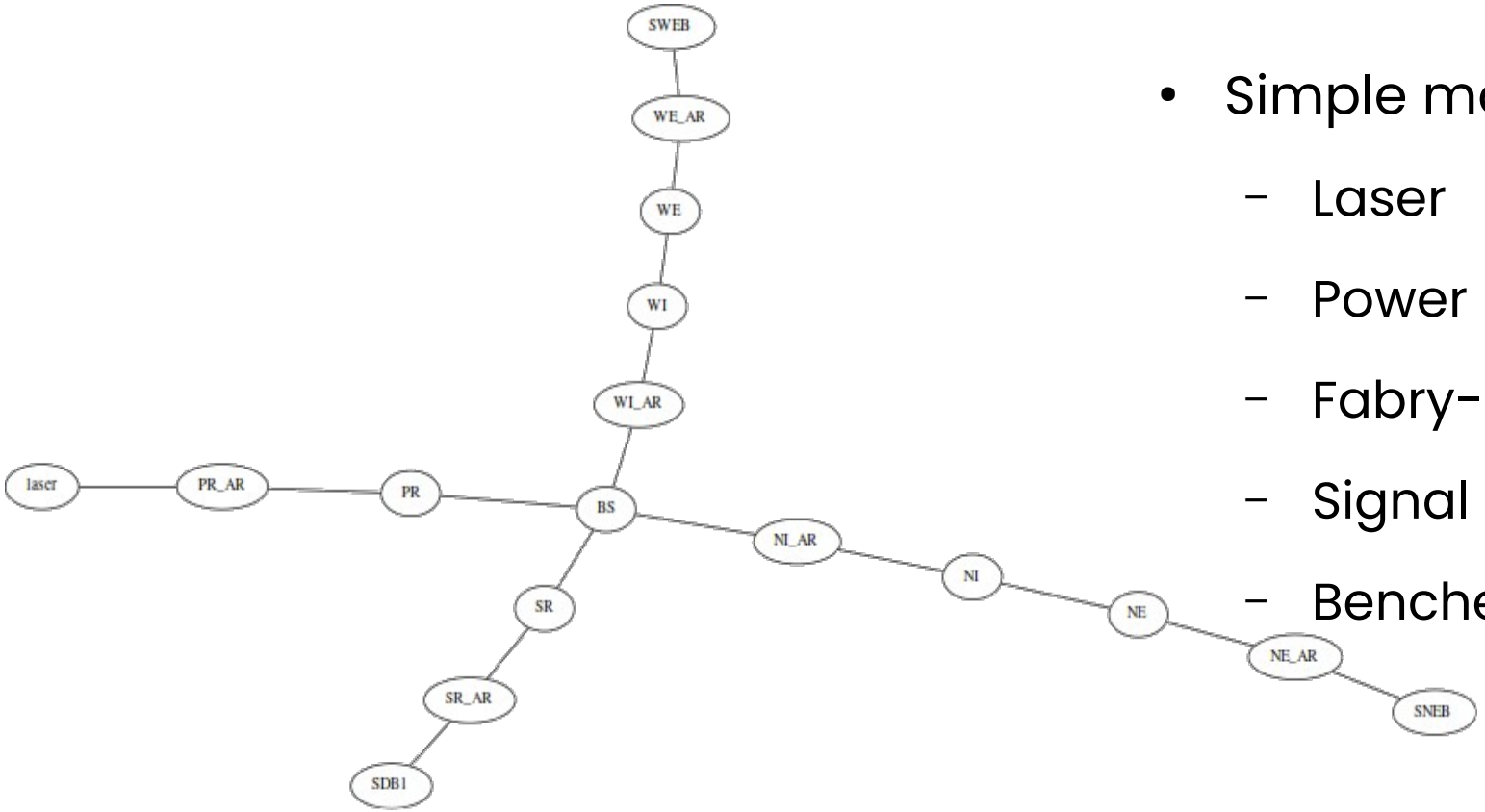
TF simulation

- Model already created by M. Was, using Optickle
- Cannot model mirror misalignement:
  - Adding losses on SR
  - Lowering transmission on SR

  } Physically incorrect
- Unmaintened for more than 5 years

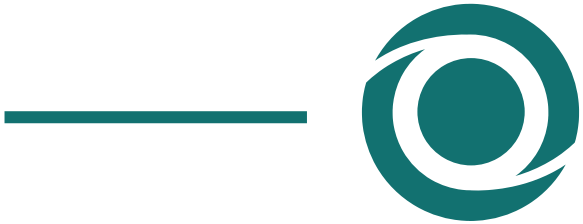
⇒ Needs for a new simulation

Current model



- Simple model with :
  - Laser
  - Power Recycling cavity
  - Fabry-Perot cavity
  - Signal Recycling cavity
  - Benches (mirrors here)

Example : How to model SNEB TF



- Define DOF `SNEB_z`
- Define `SNEB_suspension`
- Add `sgen` to `SNEB_z`
- Add PD at dark fringe
- Sweep `sgen` frequency into $[\text{min}_{\text{freq}}, \text{max}_{\text{freq}}]$

```
fsig(1)

dof     SNEB_z          SNEB.dofs.z     -1
pend    SNEB_suspension SNEB.mech       mass=42     fz=0.16     Qz=40

sgen    sig1            SNEB_z          1           0
pd1     power_detector  SDB1.p2.o       f=fsig.f

xaxis(fsig.f, log, 5, 1e4, 500)
```

…or use premade `FrequencyResponse` function…

Two effects

- Two transfer functions for SNEB

(δ: differential phase of NE - SNEB):

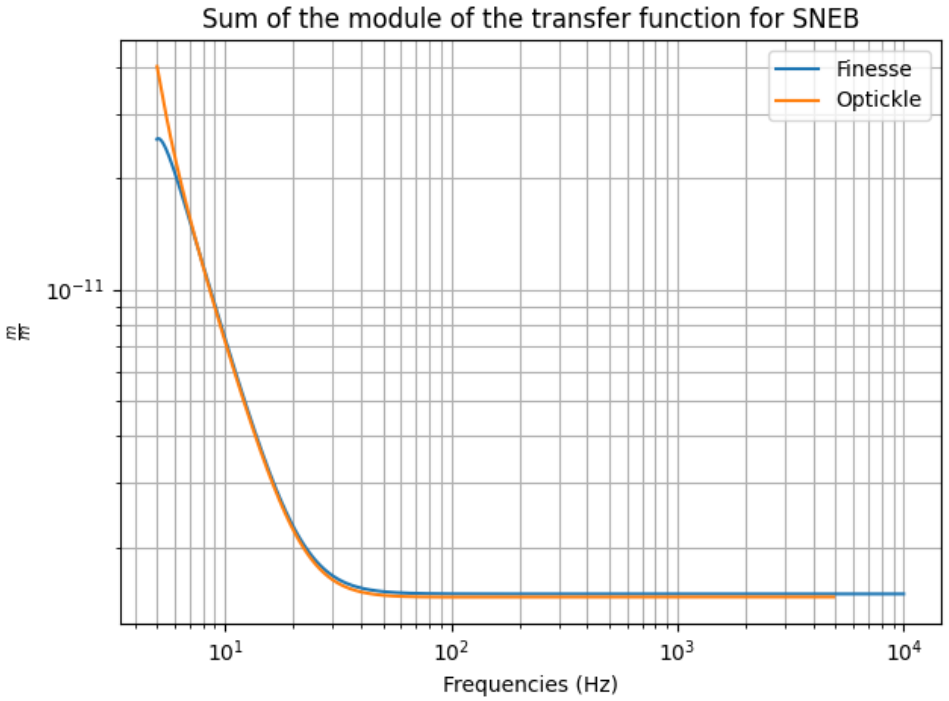
  - $\delta \equiv 0[\pi]$ $\left(K_{\frac{\delta P}{P}}\right)$
  - $\delta \equiv \pi/4[\pi]$ $\left(K_{n_\phi}\right)$

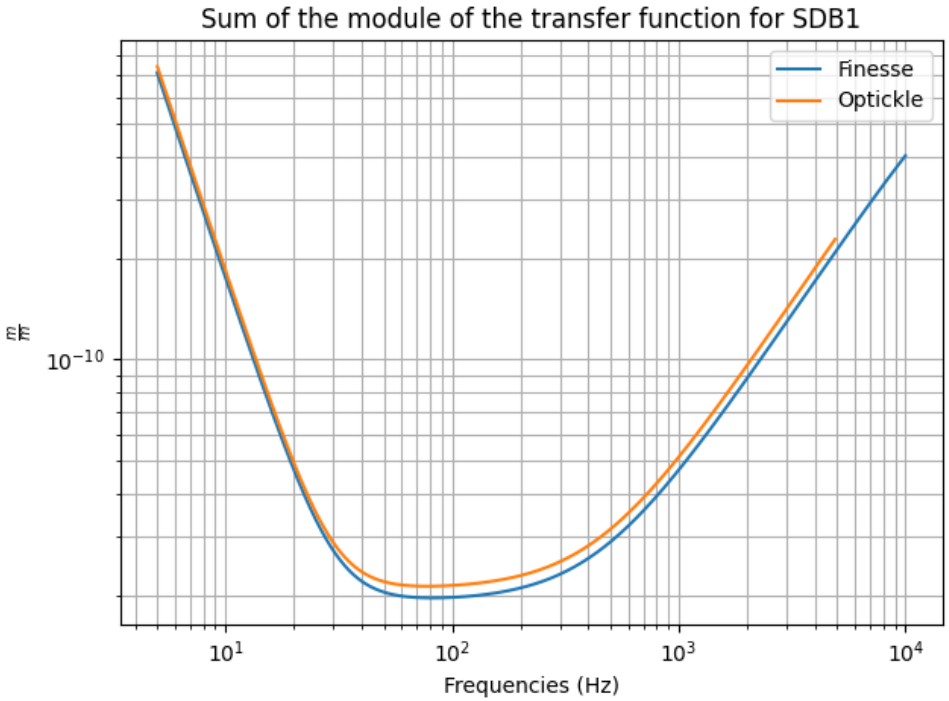
- The TF link bench movement *d* to differential arm length δl, hence:

$$TF_{\frac{d}{\delta l}} = \frac{TF_{\frac{d}{DF}}}{TF_{\frac{DF}{\delta l}} \cdot L} = \frac{TF_{\frac{d}{DF}}}{DARM \cdot L}$$

*L : arm length
*DF : dark fringe power

Comparison with Optickle

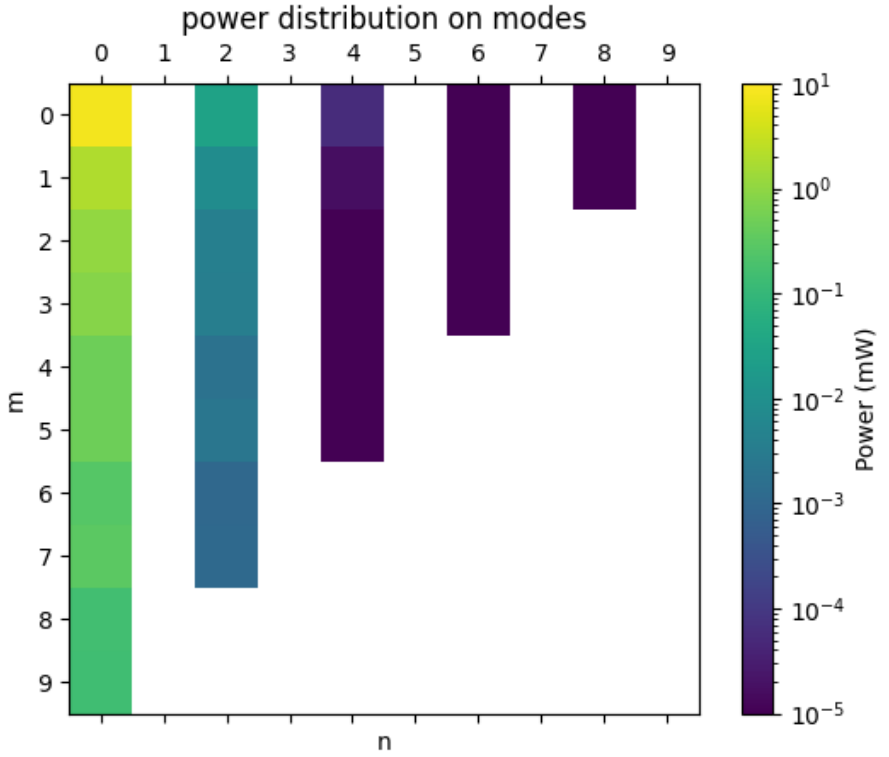




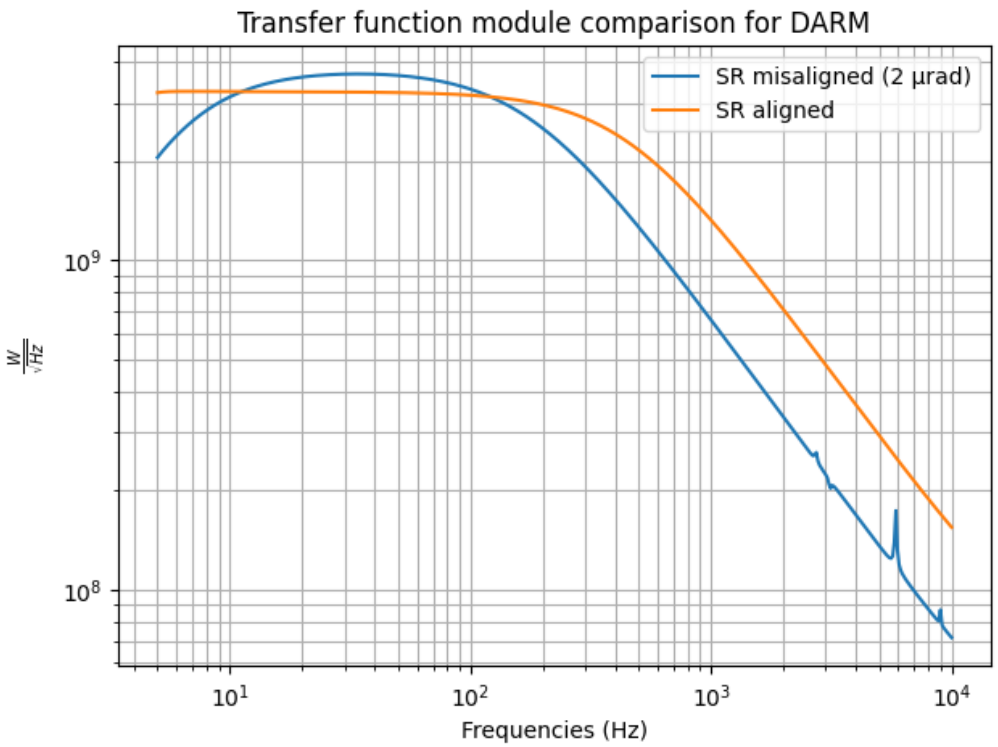
Same laser power, dark fringe offset, SR aligned, No HOM

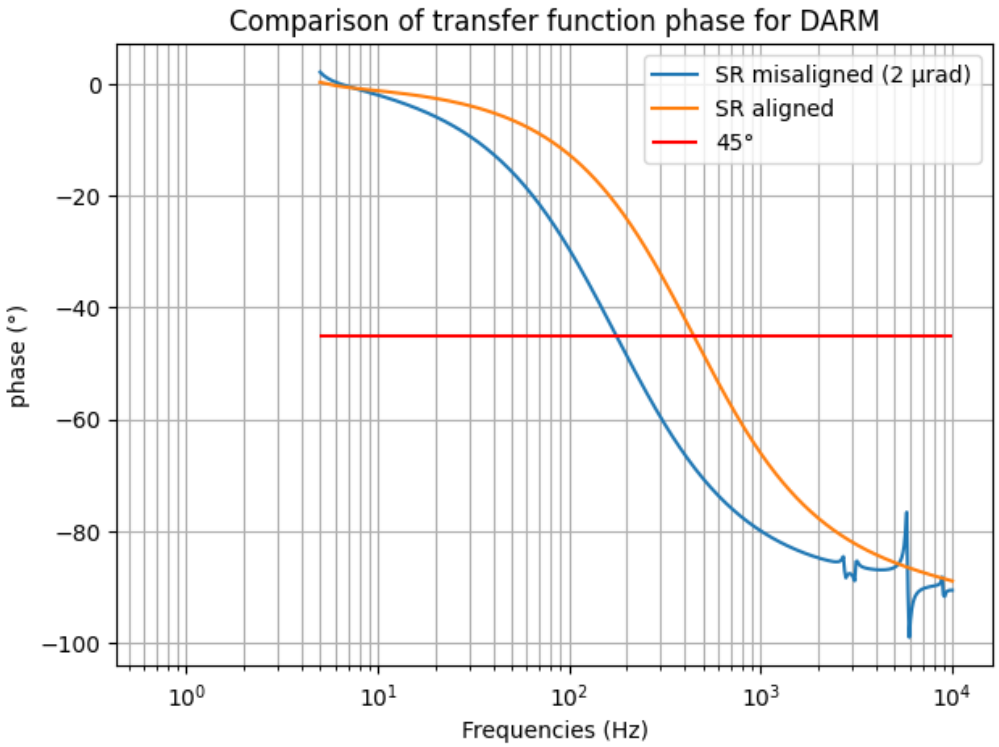
HOM & SR misalignment

- Adding HOM
- Rotating SR yaw
- Selecting TEM00 for the power detector

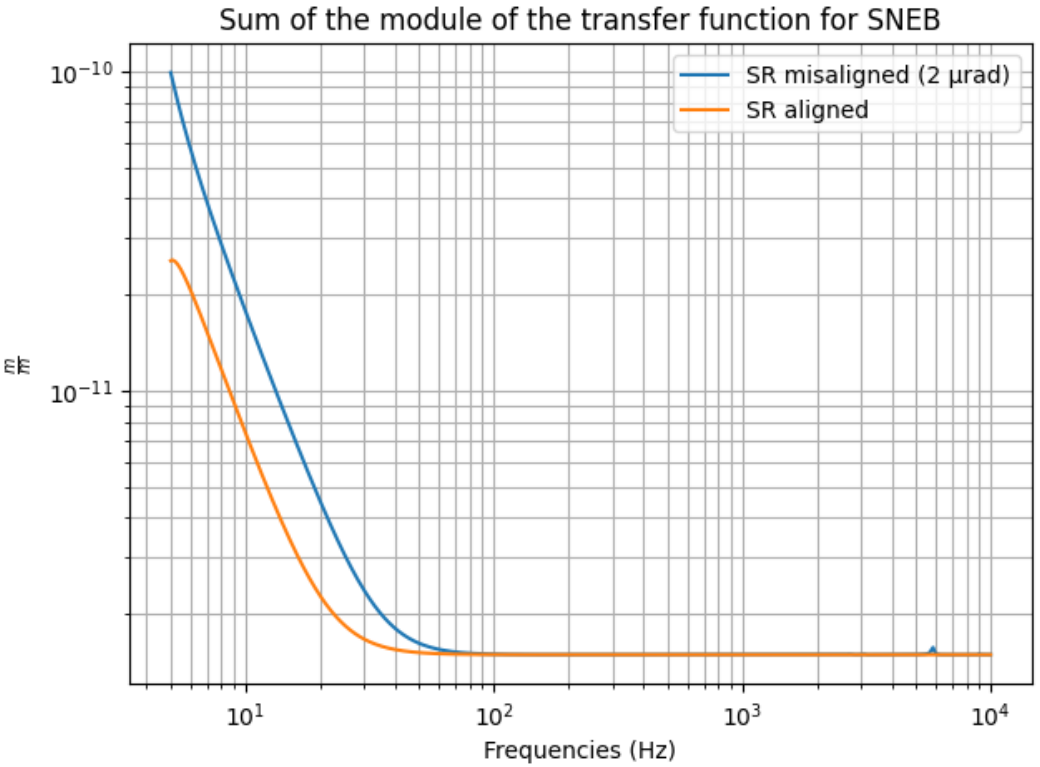


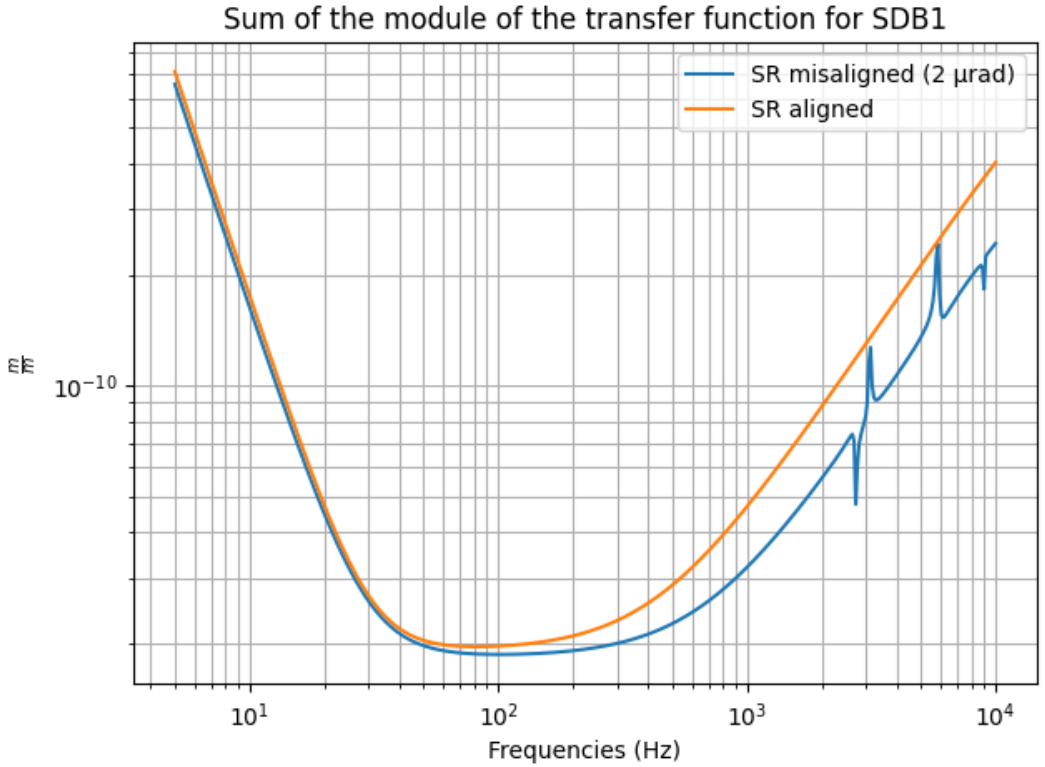
DARM evolution





Results with SR misaligned & HOM





Conclusion

- Successfully model current Virgo interferometer (with misalignment)
- Next step:
  - Model O5 design
  - Add more components
- Result: fraction of backscattered light for benches

Thanks for listening

Any questions ?