Studies on recycling cavities optical design

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Starting point

- We have preliminary designs for both HF and LF
- The designs are very different since the criticalities of both interferometers are very different

Common characteristics

- Telescope inside the recycling cavities: allows to accumulate enough Gouy phase -> better HOM rejection and alignment sensing
- Folded cavities: allow for longer recycling cavities, and so telescope requirements are less stringent for the same beam parameters / Gouy phase

Starting point

Critical points

- Length of the SRC: when the build-up time of the SRC is of the same order of the arm cavities we start to see a loss of sensitivity at high frequencies
  - Less important for LF because the sensitivity at kHz is not relevant anymore
  - For HF the safe range is 80-120 m
- Thermal lensing: in the HF detector, the power density is very high so we would like to avoid to have the waist on the BS (priority, no compensation) or the PR
  - A lower limit has been calculated at 26mm
  - Since the beam size is fixed at the ITMs, the waist shouls be between BS and PR/SR or outside the cavity

STARTING POINT

CRITICAL POINTS

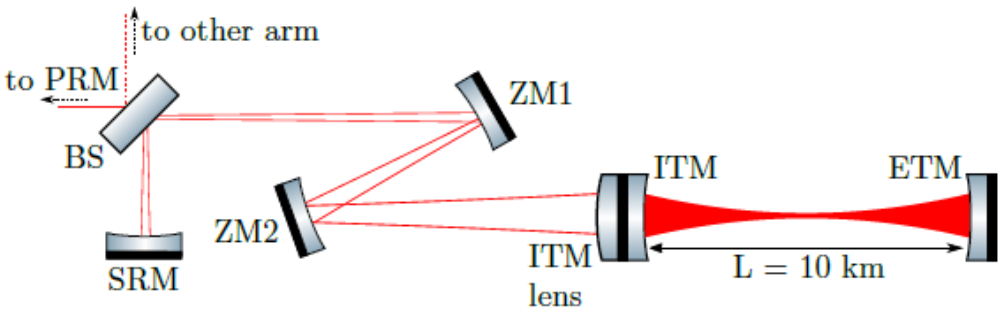
- Thermorefractive noise in the BS: it depends on the T and the mirror material
  - For SiO2 @ 290K it becomes limiting for the LF, the estimated lower limit around 2.2mm

- With this intial "constraints" it is easier to understand the present proposals

[1] Samuel Rowlinson, Artemiy Dmitriev, Aaron W. Jones, Teng Zhang, and Andreas Freise. Feasibility study of beam-expanding telescopes in the interferometer arms for the einstein telescope. Phys. Rev. D,103:023004, Jan 2021

LOW FREQUENCY CONFIGURATION

- For the LF detector we propose a telescope between the ITM and the BS since we don't have to worry about the beam size on the BS (except for the termorefractive noise!)[1]
- Total length 183m
- Total Gouy phase 52deg

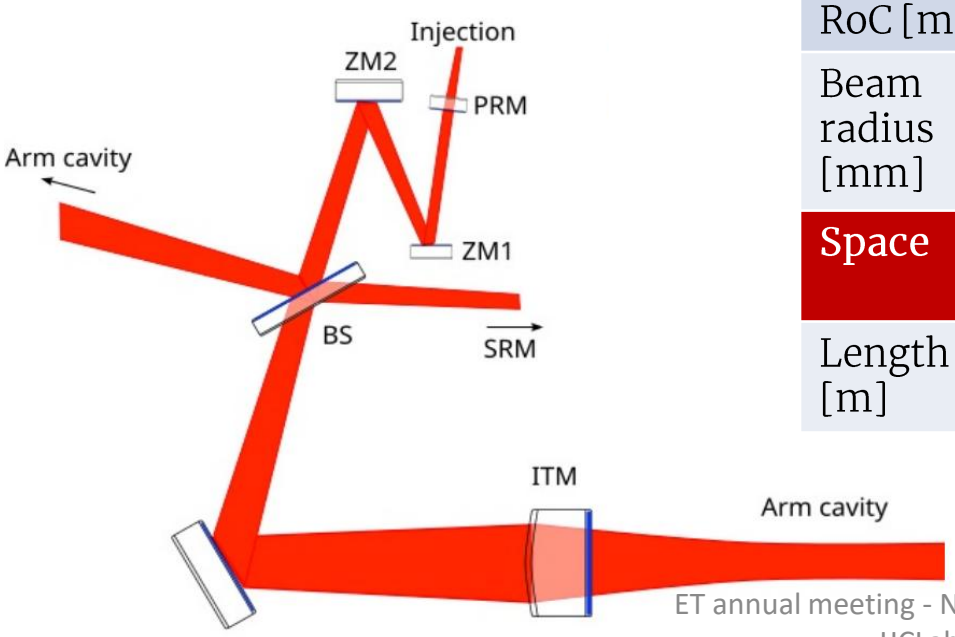


Optic	SRM	BS	ZM1	ZM2
RoC [m]	-9410	inf	-50	-82.5
Beam radius [mm]	6.1	6.2	8.9	30
Space	**SRM-BS**	**BS-ZM1**	**ZM1-ZM2**	**ZM2-ITM**
Length [m]	10	70	50	52.5
Gouy phase [deg]	7.5	39	5.3	0.6

[2] ET-0310A-22, J. Degallaix, S. Hild, InterferometerDivisionWPChairs

NEW! HIGH FREQUENCY CONFIGURATION

- For the HF detector we propose a telescope between the BS and the RM, with one flat element and one focusing element[2]
- Total length 100m
- Total Gouy phase 18deg

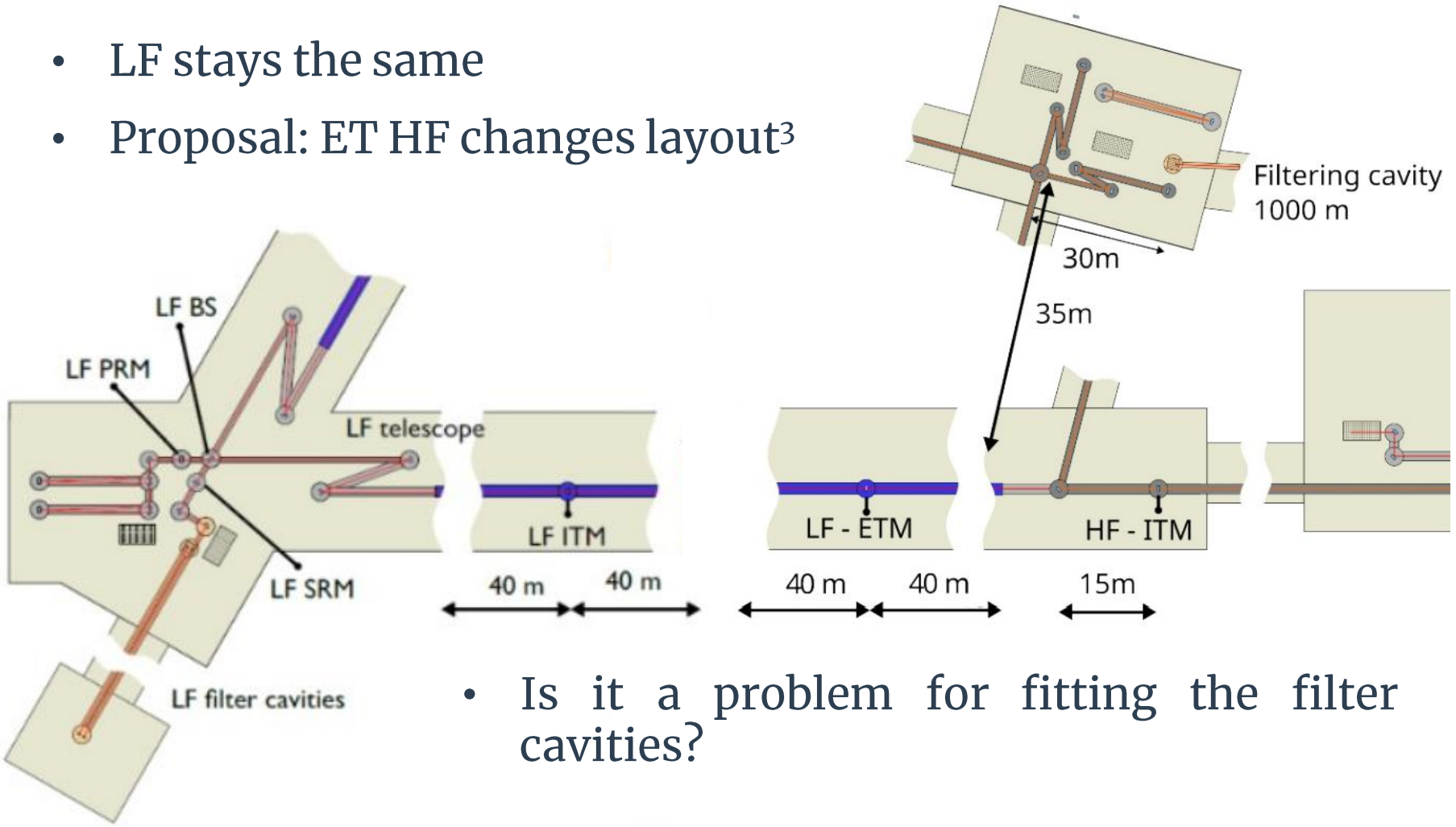


Optic	SRM	ZM1	ZM2	BS
RoC [m]	-41	inf	-4	inf
Beam radius [mm]	35	13	5	31
Space	**PRM-ZM1**	**ZM1-ZM2**	**ZM2-BS**	**BS-ITM**
Length [m]	25	10	15	50

[3] ET-0324A-23, J. Degallaix, S. Danilishin, InterferometerDivisionWPChairs

Infrastructure preview

- LF stays the same
- Proposal: ET HF changes layout[3]



- Is it a problem for fitting the filter cavities?

FUTURE WORK

- We have put together a series of studies that need to be completed / started in order to validate completely both proposals:[4]

For the HF this might mean to modify the telescope (ZM2 not flat!)

LF TELESCOPE + HF TELESCOPE

- A telescope off-axis will introduce aberrations, can we optimize the design (focal lenses vs AoI) to minimize these losses (targeting 0)?
- Which would be the impact of a residual movement (longitudinal or angular - also translation) on the telescope mirrors in terms of aberrations? Important for understanding the requirements for the suspensions
- Free form optics: How well do we realistically expect we could do with current polishing capabilities? How well centred would the beam need to be on such an optic?

Do we need Etalon?

FUTURE WORK

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Closed! Summarize it into a small document

BS CONSIDERATIONS

- How heavy can the BS be?
- HF: Angle of incidence, which is best if thermal lensing is present from a small spot? [4.1?]
- HF: What is an acceptable BS thermal lensing amount? [Wavefront sensing]
- HF: Can we do BS thermal actuation? [Wavefront sensing]
- Estimate the thermorefractive noise at the BS as a function of the BS, when it becomes limiting [6]
- A collimated beam is preferred through the BS, limit on divergence?

Future work

- We have put together a series of studies that need to be completed / started in order to validate completely both proposals:

Longitudinal sensing

- Which frequencies will be resonant in both recycling cavities as a function of the Schnupp asymmetry? Is there any combination of modulation frequencies and Schnupp that can be used as a starting point? [16]
- For a given length of the recycling cavities and for a given PR reflectivity, how much transmission towards the SRC and back-scattering towards the PRC there will be as a function of the Schnupp asymmetry?
- Do we want LIGO-like, slightly asymmetric recycling cavities, or Virgo-like symmetric recycling cavities?

Signal recycling in LF

- Detuned vs tuned SRC? As a starting point can we study both and establish residual movement requirements for reaching the target sensitivity?

Future work

- We have put together a series of studies that need to be completed / started in order to validate completely both proposals:

Angular sensing

• For a given Gouy phase of the SRC, and a Schnupp asymmetry, can we find modulation frequencies that could build a good SR alignment signal?

Robustness to HOMs

• What is the HOMs separation on the PRC and the SRC? How do they couple to the recycling cavities?
• How do this change as a function of the RT Gouy phase and the Finesse of the recycling cavities?
• How do the sidebands HOMs couple into the interferometer and how do they affect the longitudinal error signals? Do we need to worry about mode hopping?
• How the RT Gouy phase of the SRC affects the squeezing, does it get reduced?

FUTURE WORK

- We have put together a series of studies that need to be completed / started in order to validate completely both proposals:

SIGNAL EXTRACTION

- Where do we need to extract beams in order to produce error signals? Do the beam geometry/AOI allow to do this and where would we need optical benches?
- Balanced Homodyne Detection, where it is better to take the pick-off?

Can we identify a priority path that allows us to validate the present designs?