ET-LF Δ - Exploring filter cavities DOFs

M. Vardaro - A. Lartaux - G. Ciani - S. Steinlechner - V. Sequino - J.-P. Zendri

ET Task force meeting - 20-01-2025

EINSTEIN TELESCOPE

Maastricht University

Nikhef

Working group goal

In the Δ configuration, the LF filter cavities are a big driving force of the infrastructure cost.

At the end of 2024 a working group inside the SQZ working package was established with the following targets:

- Consider up to now only the ET-LF Δ baseline configuration
- Explore the possible DOF of the two 5km long filter cavities and determine alternative geometric configurations
- For each of them don’t perform a complete study but a list of possible issues, difficulties and concern
- Summarize them in a document as soon as possible (end of Jan 2025) and share with the collaboration
- As an extra, we briefly discuss also configurations that are different from the baseline. We are still deciding whether to keep or remove from this first document

Status of the document

The overleaf document status is quite advanced (>80% ready), conclusions are still missing.

Contents

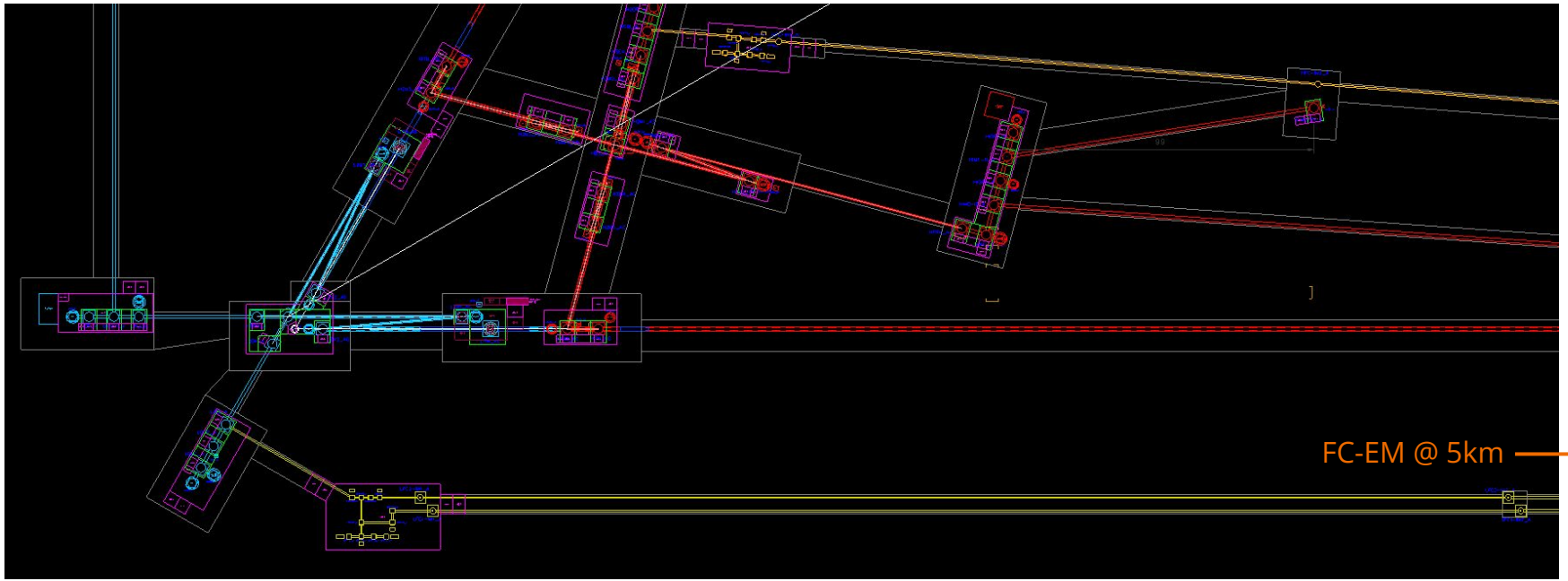
Baseline optical layout

- Two parallel filter cavities 5 km long
- Pipes 1m of diameter, 1 meter of distance to guarantee the access everywhere
- Filter cavities parallel to one interferometer arm
  - constraints defined so far required them to be in an external tunnel
- Proposed filter cavities composed by 3 mirrors each, to implement “variable finesse” (i.e., the bandwidth of the filter cavity can be tuned in-situ)

	IM-1	IM-2	EM-1
Mirror diameter	20 cm	20 cm	62 cm
Mirror mass	14 kg	14 kg	130 kg[1]
Mirrors RoC	3909 m	3909 m	4857 m
Beam diameters on the mirrors	5.7 cm	5.7 cm	19.2 cm
Vacuum pipes length	1145 m		3855 m
Vacuum pipes diameter	50 cm		1 m

Baseline optical layout

- Two parallel filter cavities 5 km long
- Pipes 1m of diameter, 1 meter of distance to guarantee the access everywhere
- Filter cavities parallel to one interferometer arm but in an external tunnel
- Proposed filter cavities composed by 3 mirrors each to implement variable finesse



Studied configurations

1. Reduce beam pipe diameter
2. Push FCs closer to each other

} reduce tunnel size

3. Both FCs on top of the main arms
4. FCs stacked on top of each other
5. FCs on both sides of a vertex

} go out of interferometer plane

Other options briefly considered (not in this presentation)

6. Use FCs of different lengths
7. Replacing 2 FCs by 1 three-mirror FC

Reduce beam pipe diameters

In the baseline configuration the beam diameter on FC EM is 19.2 cm (g factor of cavity =0.5). To avoid losses the mirror diameter was chosen ~ 3 times larger i.e. 62 cm. This led, as for the interferometer to 1m diameter tube for the filter cavity **- to be decided if reasonable**.

Attempts considered to reduce the diameter of the pipes: decrease cavity stability, remove intermediate mirror, reduce baffle diameter

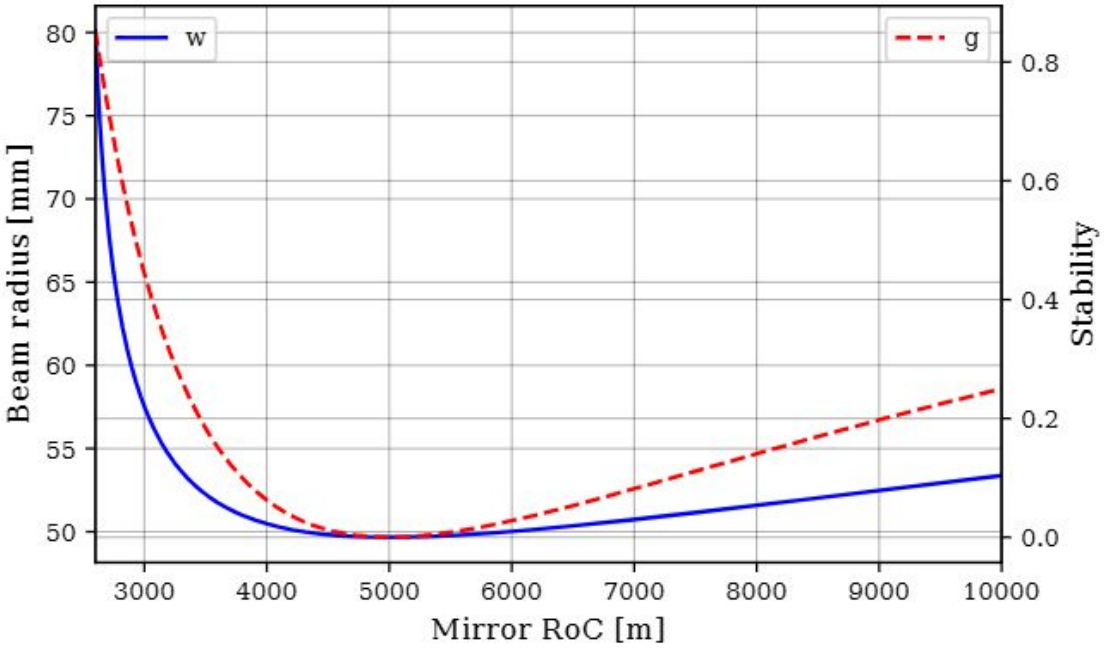
Going to less stable configurations results in quite a bit smaller mirrors and therefore tubes. **Risk?**

L_1	$g_1 g_2$	$g_2 g_3$	IM-1 and IM-2 mirrors RoC	EM-1 mirror RoC	Beam Ø on EM-1	EM-1 mirror Ø	EM-1 mirror mass	IM-2 to EM-1 pipe Ø
1145 m	0.5	0.5	3909 m	4857 m	19.2 cm	62 cm	200 kg	1 m
1145 m	0.5	0.9	3909 m	6132 m	19.2 cm	62 cm	200 kg	1 m
1145 m	0.9	0.5	2231 m	6427 m	13.9 cm	42 cm	78 kg	75 cm
1145 m	0.9	0.9	2231 m	13782 m	13.9 cm	42 cm	78 kg	75 cm
400 m	0.5	0.5	1366 m	5029 m	33.5 cm	100 cm	685 kg	1.5 m
400 m	0.9	0.5	7795 m	6301 m	20.4 cm	62 cm	200 kg	1 m

Reduce beam pipe diameters

Remove intermediate mirror

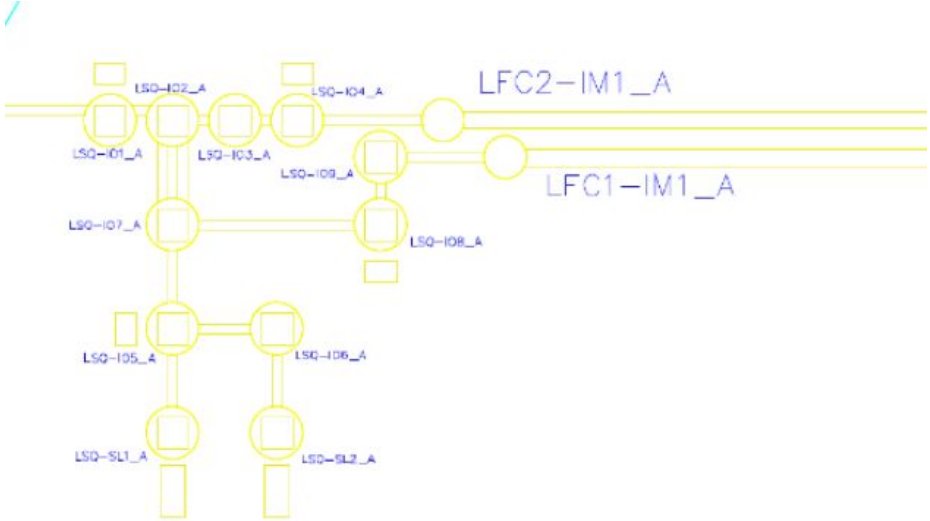
The finesse of the filter cavity can be controlled also with the Etalon effect on the input mirror (as in Virgo). ET Baseline configuration was chosen with three mirrors to be conservative. Further studies are needed to define the best configuration.



In this case, absolute minimum beam diameter of about 10.0 cm. This would be for a confocal configuration (L=RoC), which is not favourable because of high mode degeneracy.

Push FCs closer to each other

The distance between filter cavities should allow us to access to the optical benches inside the towers from two sides, preferable opposite. Taking this into account the distance between filter cavities can be reduced

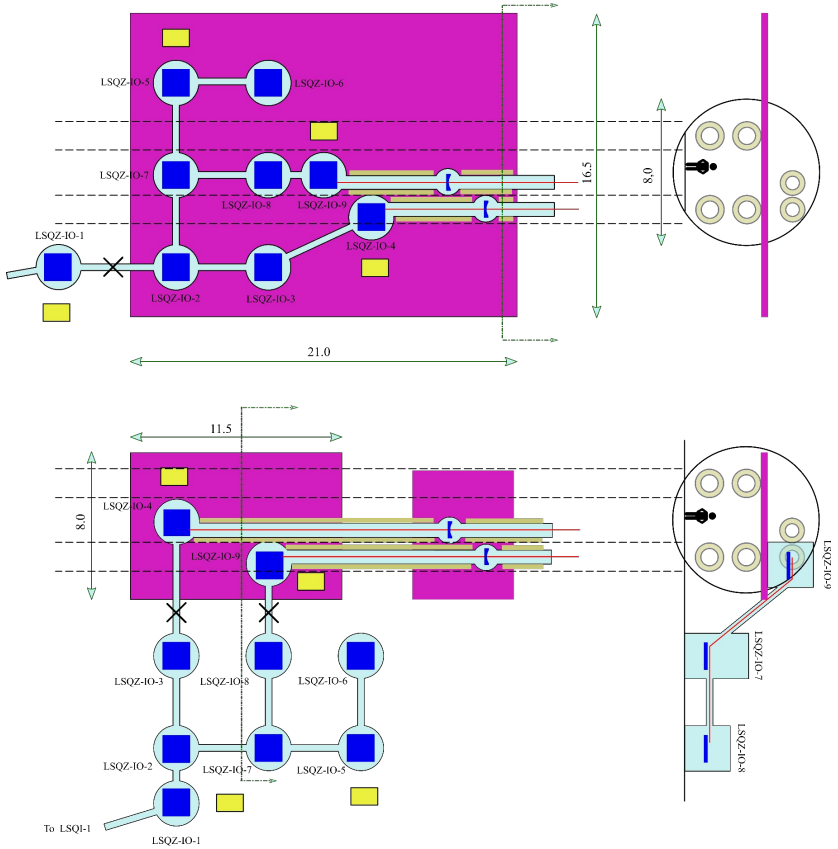


Second option: can merge the two filter cavities equivalent elements in the same tanks like (FC1-IM1 and FC2-IM1 ecc)

Concerns:

- Scattered light
- Space for the matching telescopes before the FCs

Both FCs on top of the main arms



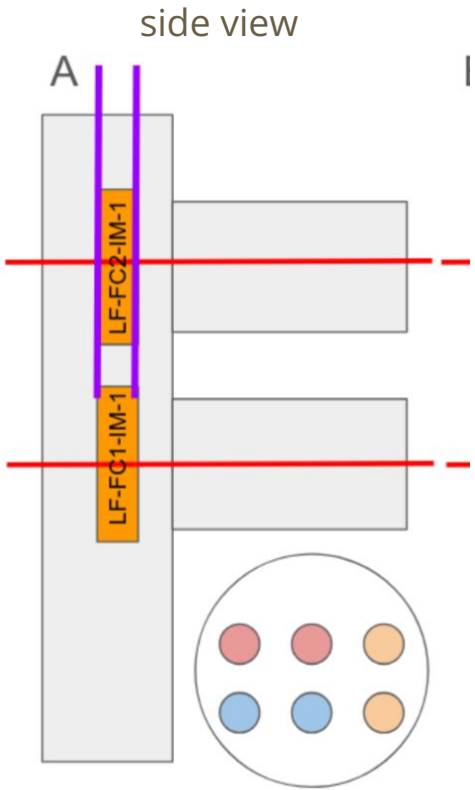
Increase the main arm tunnel from 6 to 8 m and put the filter cavities tunnels above them

Some of the SQZ benches should be put on a different height to not clash with the interferometer towers. **Periscopes are needed and 4.5m of total height should be covered**

Concerns:

- Polarization mixing
- Alignment (relative motion of the benches)
- Phase stability
- Increased losses (increased number of optics, clipping losses, astigmatism)
- Scattered light

FCs stacked on top of each other



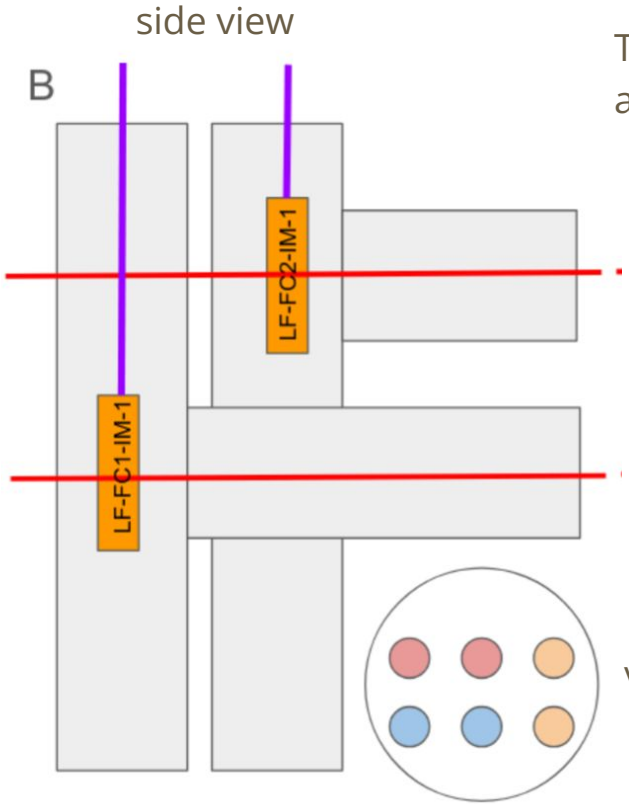
Two mirrors share the same payload

Concerns:

- Difficult to implement (coupling of DoF, comissioning tied together)
- Scattered light a big issue

Discarded

FCs stacked on top of each other

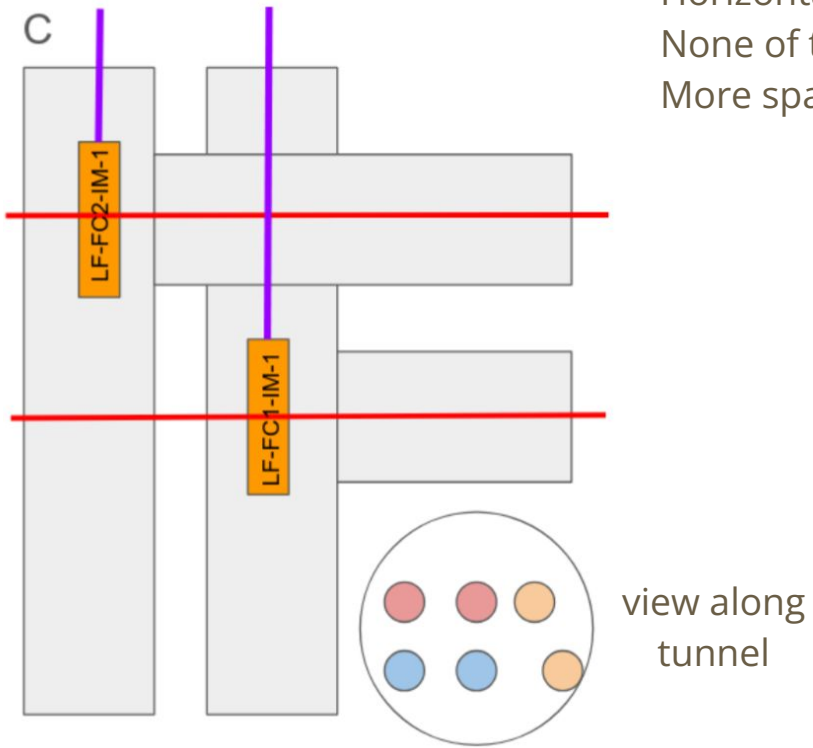


The tower are shifted, thus the payload of the second need to have an aperture to allow the beam to pass through

- FC2-IM1 clear aperture >15 cm
- FC2-IM2 clear aperture ~18cm
- FC2-EM1 clear aperture: dimension of mirror itself. Difficult to implement -> Possible solution: shorten FC2 in order to have FC2-EM1 before FC1-EM1. Some steering mirror for transmission benches needed

FCs stacked on top of each other

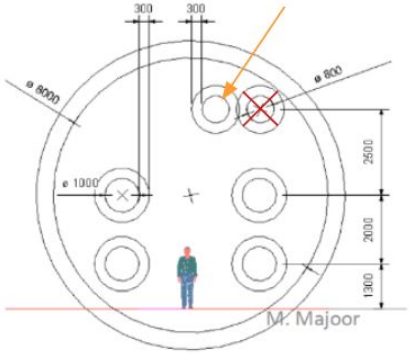
side view



Horizontal and vertical shift between FCs
None of the suspension is crossed
More space needed in the tunnel

view along tunnel

FCs on both sides of a vertex



- SQZ lab relocated near the detection and SR cavity.
- SQZ lab and FC in a plane ~ 6 m higher than ground (i.e. 4.5m above ITF plane)
- Only one periscope to go down toward detection bench
- To host all the filter cavity their length can be slightly changed. No difference in the final sensitivity
- Telescope to match SQZ to ITF has short space, thus wide optics are needed. **Solution:** focus the beam having FCIM acting also as a lens

Conclusions

- Alternative to the baseline configuration are qualitatively studied
- The document should be ready for the end of January
- On which channel should this document be shared?

Inputs for the working group are more than welcome

Thank you!