University of Glasgow | Faculty of Physical Sciences

Deconstruction of the ET optical layout

Stefan Hild
for the ET-WP3 working group

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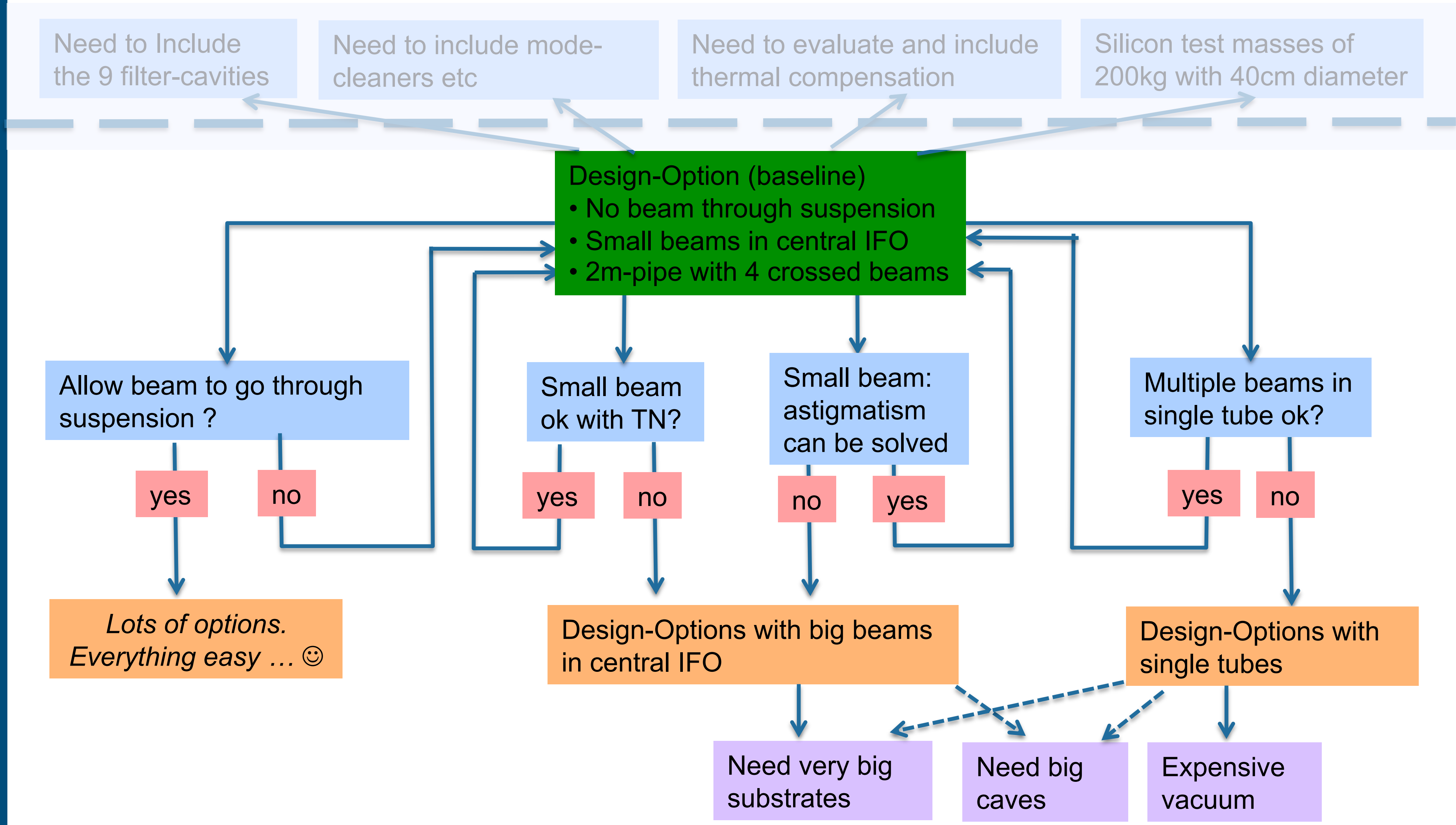
Context of this presentation

- **Presentation 'Construction of the ET optical layout' gives one possible candidate of a layout.**
  - Good enough for the infrastructure cost estimate
- **However, the story hides a lot of thoughts, arguments and details:**
  - Many points carry QUESTION MARKS
  - There are some ALTERNATIVES to be evaluated
- **In this talk I will present my favorite examples of interesting research tasks.**

Overview of this presentation



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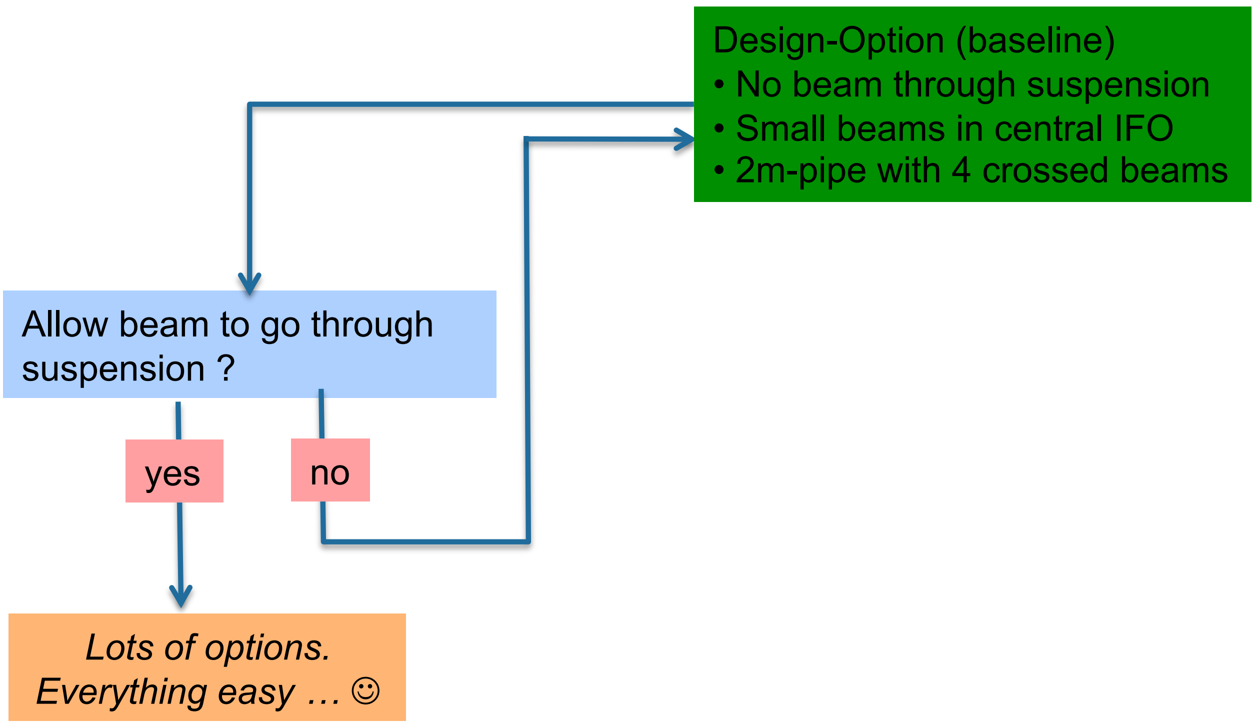
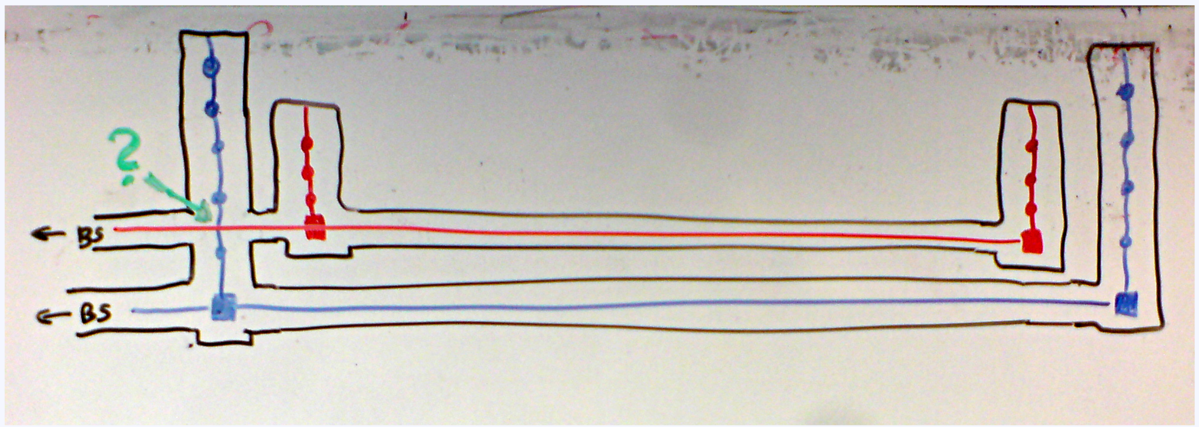


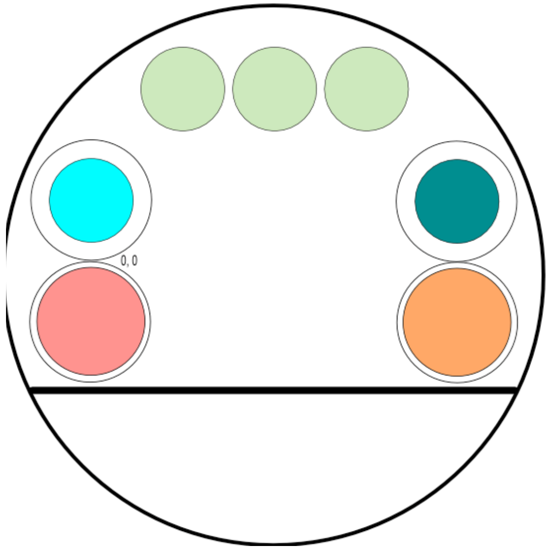
Can Laser Beams pass a suspension?

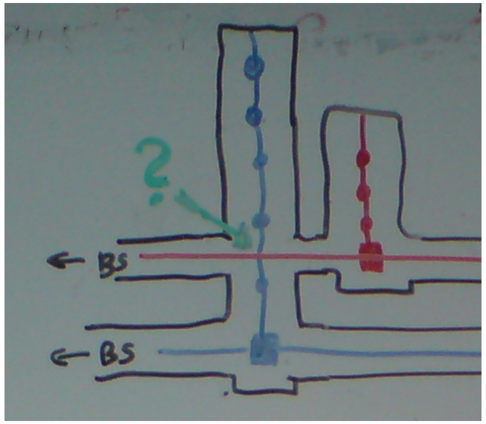
- **Can we pass one ifo beam through suspension of another ifo?**
- **In principle that does not sound impossible, perhaps rather an engineering task.**
- **If you do not want to cross the main arm cavities there is no way to avoid one input beam passing suspension of another ifo.**



Can Laser Beams pass a suspension?

- **However there are several constraints why we think it is not obvious that passing a beam through a suspension will work:**
  - The vertical distance between two beams is no free parameter, because we have to fit all the beams into the tunnel.
  - The length of the last suspension stage of at least the LF detector will be heavily constrained by thermal noise requirements as well as by heat extraction requirements.

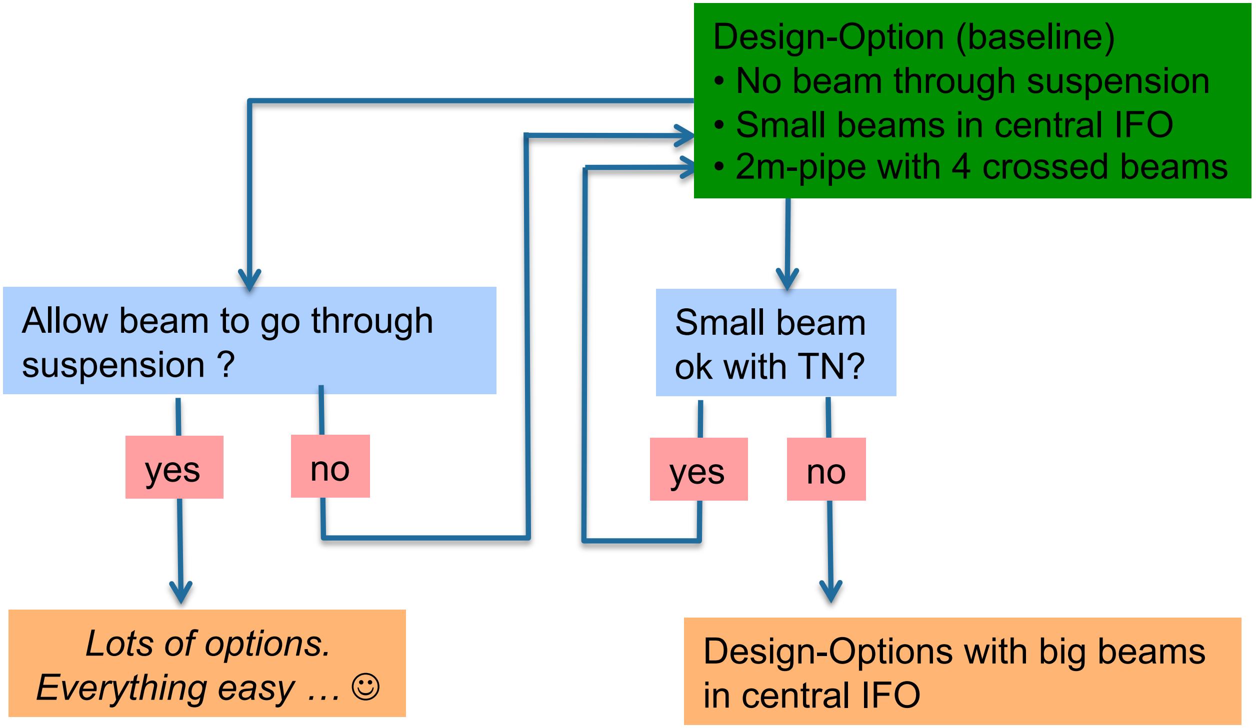




Research Task

- **Research task: Can we pass an interferometer beam through one input mirror suspension?**
- **Details of investigation:**
  - ➢ Is it easier to pass the LF beam through the HF input mirror suspension or vice versa?
  - ➢ Develop corresponding suspension design and show its compatibility with thermal noise, seismic isolation, heat extraction etc requirements.
- **Lots of room for suspension experts to get creative.**

Overview of this presentation

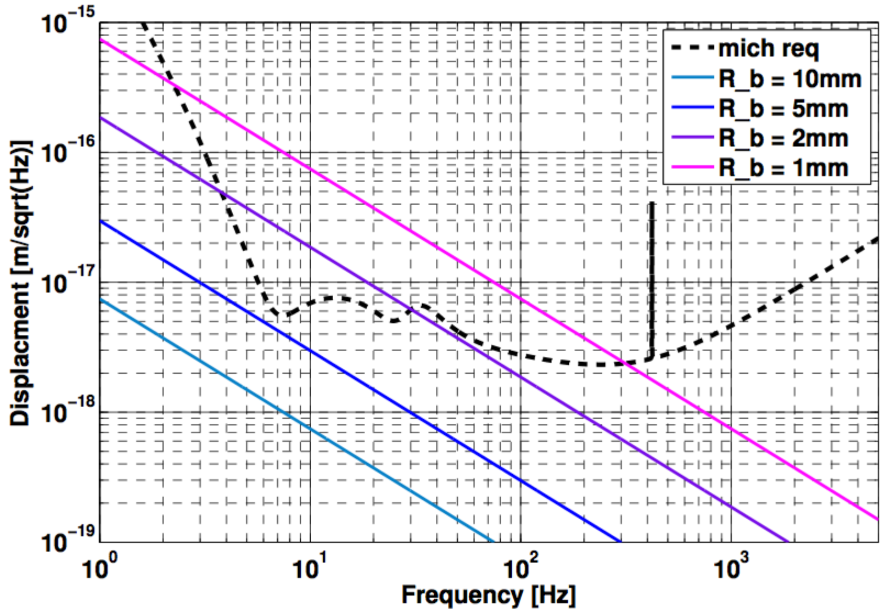


Small beams in central IFO vs Thermal Noise

- **Small beam design compatible with thermal noise requirements?**
- **Noise in central ifo suppressed by arm cavity finesse, i.e. about 800 for ET-C.**
- **Considered a roomtemperature fused silica BS of 10cm thickness.**
- **Dominant noise is substrate thermo-refractive.**
- **Need a minimum beam-size of about 1cm.**

$$S_R(\omega) = \frac{4\beta^2 l_c k_B T^2 \kappa}{(\rho C)^2} \frac{1}{\pi (R_b/\sqrt{2})^4 \omega^2}$$

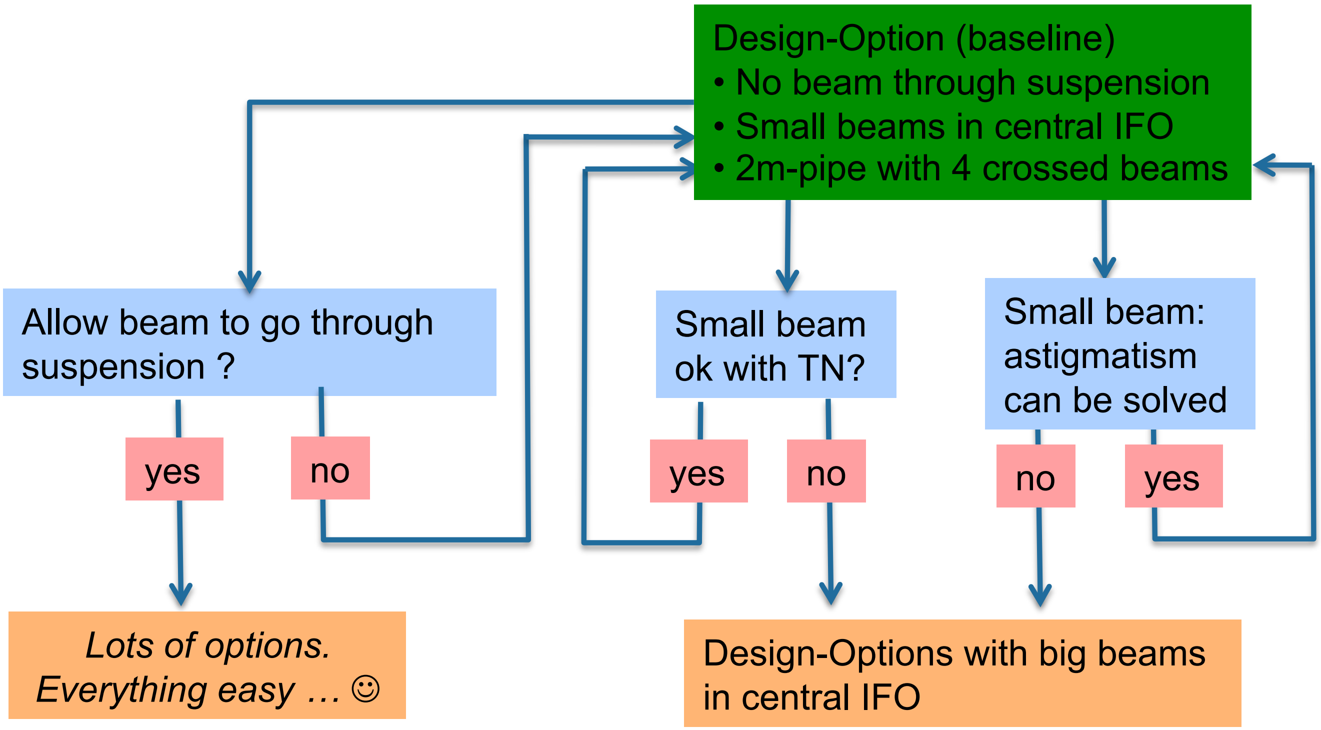
temperature dependence of refraction index	β	$-8 \cdot 10^{-6}\ \mathrm{K}^{-1}$
substrate density	ρ	$2200\ \frac{\mathrm{kg}}{\mathrm{m}^3}$
geometrical path length inside substrate	l_c	$0.121\ \mathrm{m}$
thermal conductivity	κ	$1.38\ \frac{\mathrm{W}}{\mathrm{m \cdot K}}$
temperature	T	$290\ \mathrm{K}$
specific heat	C	$746\ \frac{\mathrm{J}}{\mathrm{kg \cdot K}}$



Research Task

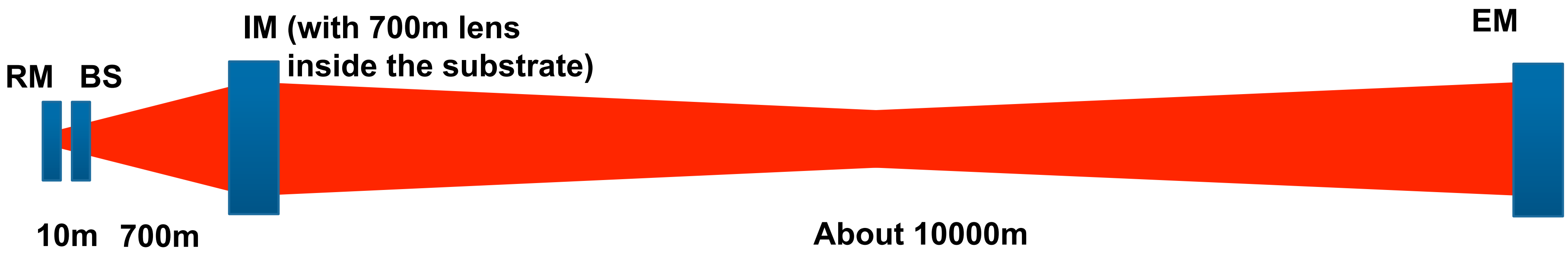
- **Research task: Thermal noise requirements for the central interferometer.**
- **Details of investigation:**
  - What are the minimal beam sizes for LF and HF detector that are compatible with the targeted sensitivity (ET-C).
  - Where is the cut between cold and warm optics? Only main test masses (IM+EM) cold and everything else warm?
  - What materials shall be used for the warm optics of the LF interferometer (1550nm)?

Overview of this presentation



Small beams in the central interferometer?

- For various reasons it would be nice to have small beams (few cm) rather than 60cm beams in the central interferometer.
- This could be achieved by focusing the beam down between IM and BS

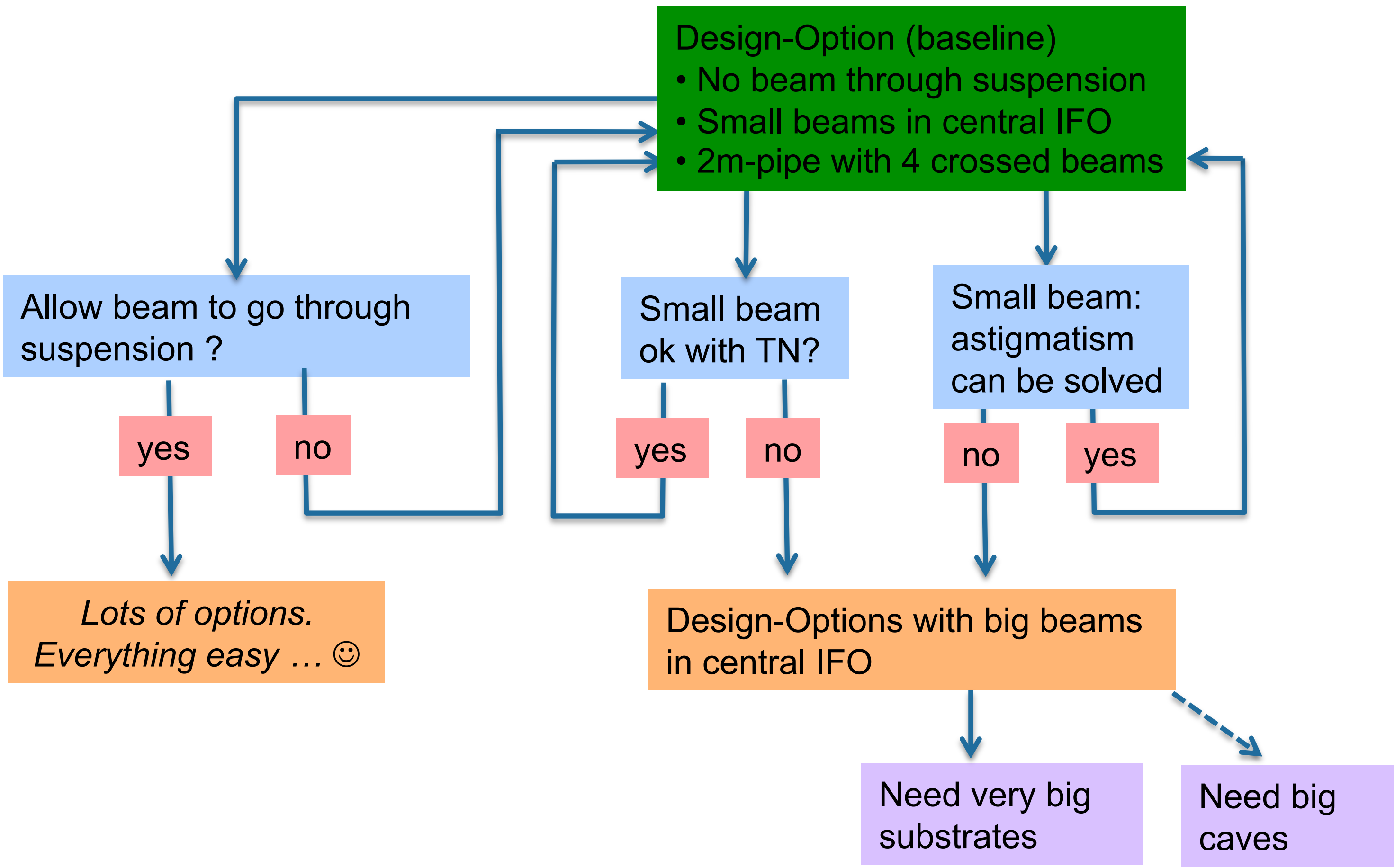


- In order to reduce problems from imperfect optics, the focusing should be rather gentle.
- For current dummy design we assume 700m to focus from 60cm down to 5cm.

Research Task

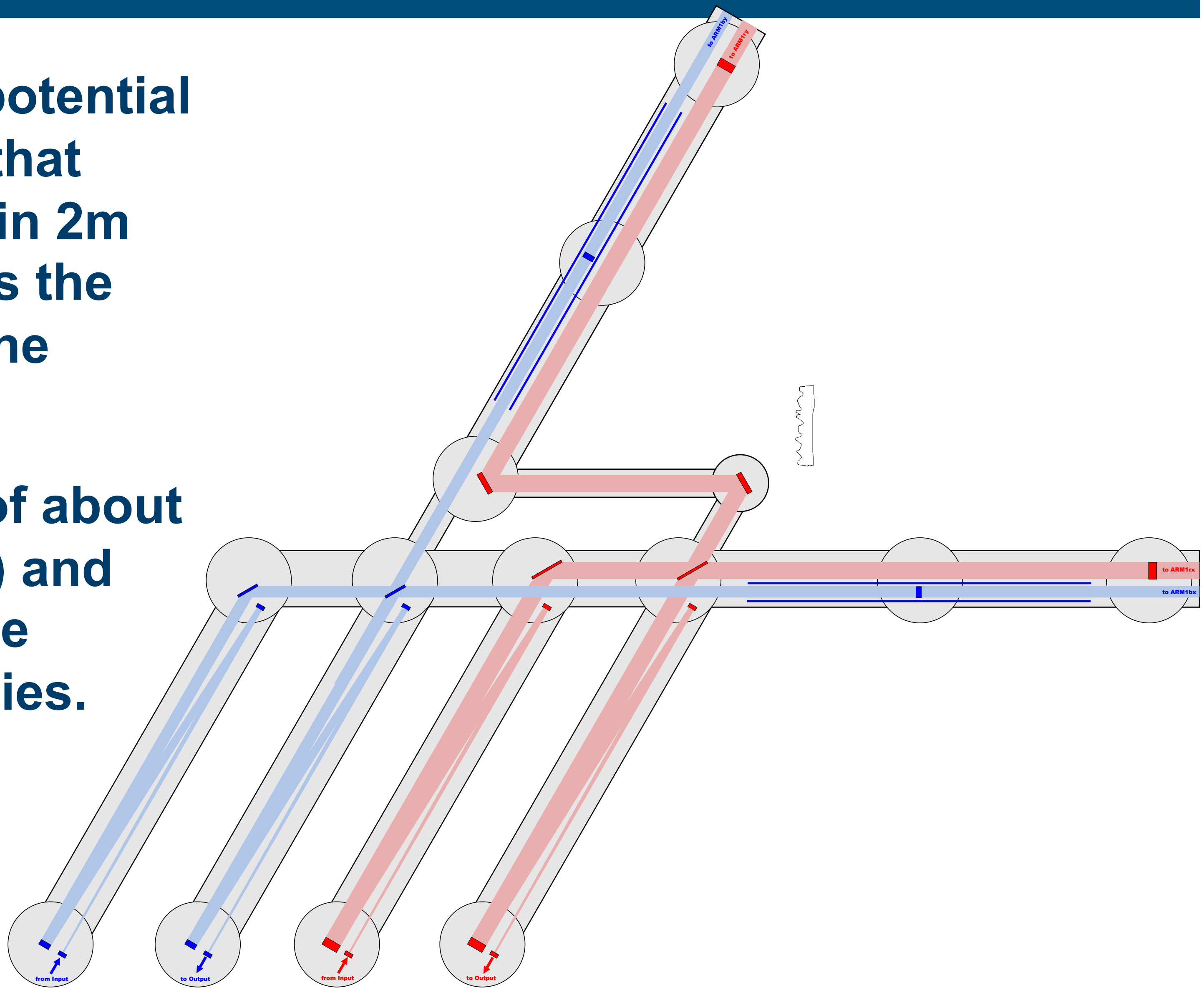
- **Research task: Thorough design of focussing elements, i.e. minimising astigmatism.**
- **Details of investigation:**
  - Position, type and strength of focusing elements (lenses, compensation plates etc).
  - Analysis of additional noise couplings
  - Investigations of losses originating from astigmatism
- **Comment: No immediate action needed, - will be solved by 2nd Generation.**

Overview of this presentation



4-beams per tube but with large beams in central

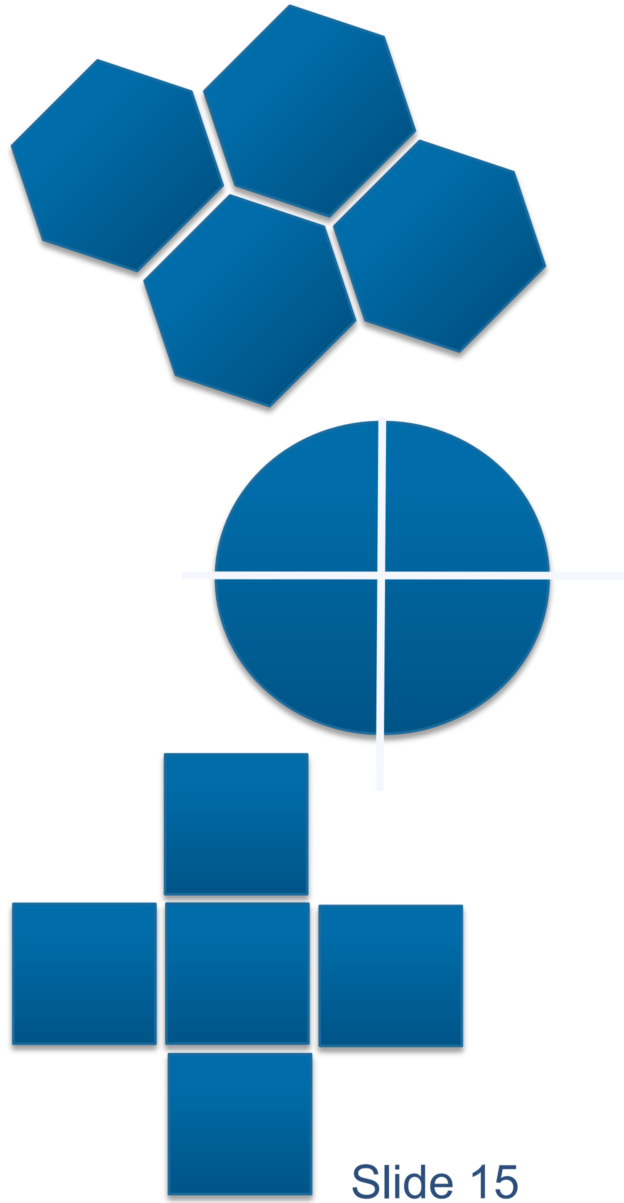
- **Example of a potential configuration that uses 4 beams in 2m tube, but keeps the beams big in the central area.**
- **Need big BS (of about 1.2m diameter) and non-degenerate recycling cavities.**



Research Task

- **Research task: Find out whether there is any chance to produce optics with 120cm diameter for the HF detector and 80cm diameter for the LF detector?**

- **Details of investigation:**
  - ➢ What can Heraeus deliver? Would the quality be sufficient?
  - ➢ Is there any chance to use a composite beam splitter made by silicate bonding?
  - ➢ Would the polishing and coating machines cope with these sizes?
  - ➢ Please note BS and folding mirrors have thermal noise requirements about 2 to 3 orders of magnitude less stringent than the main test masses



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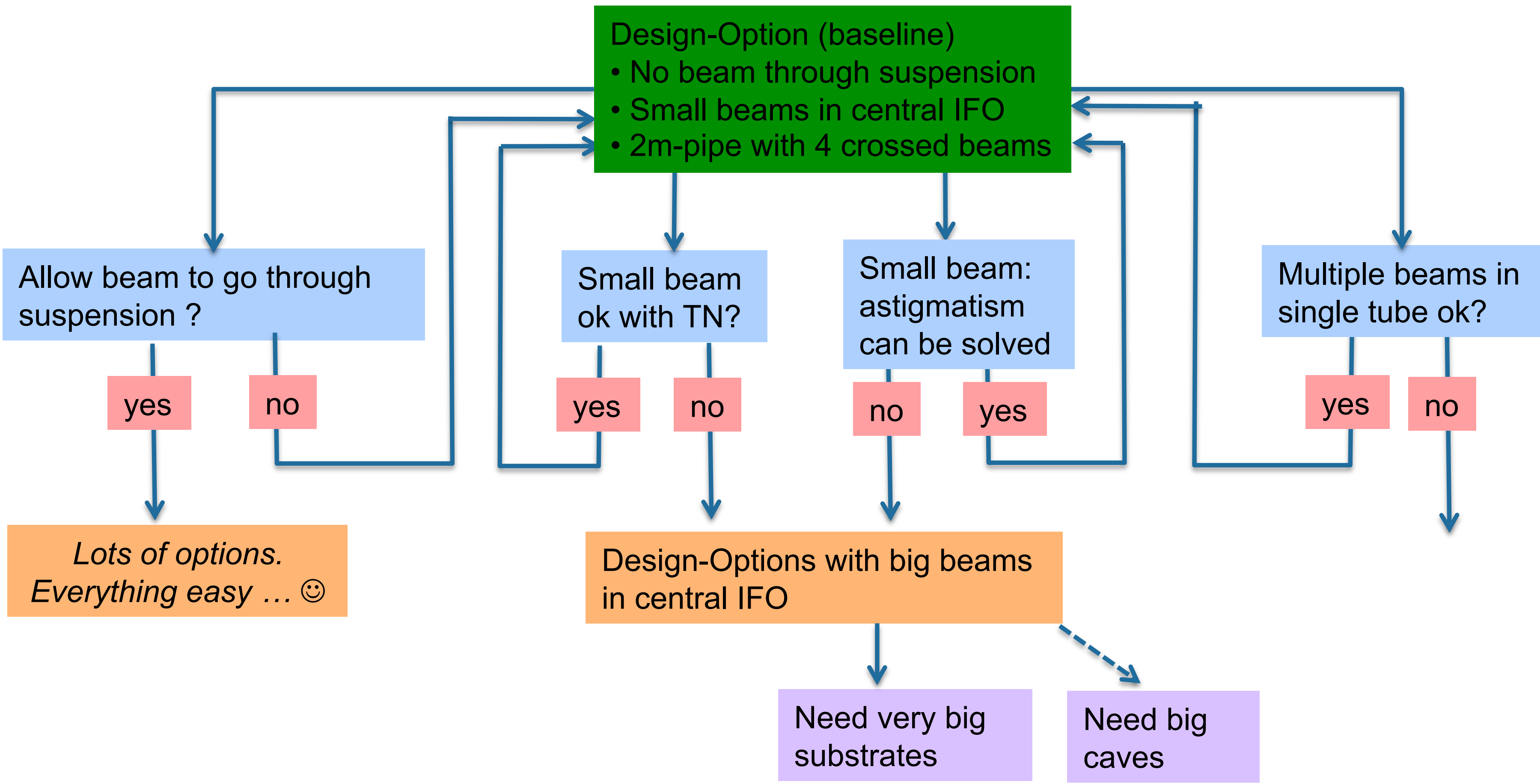
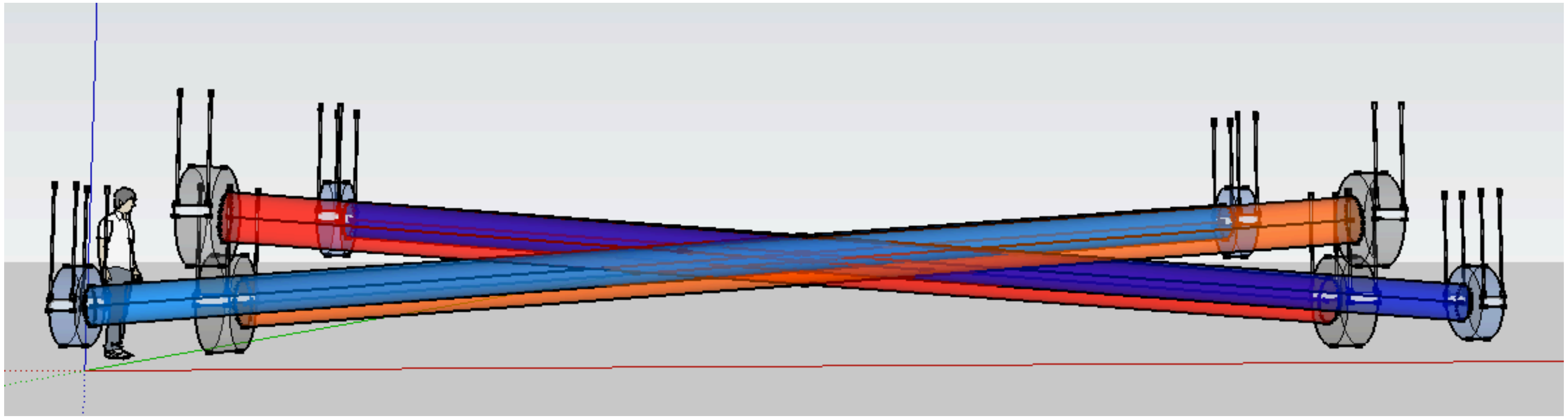


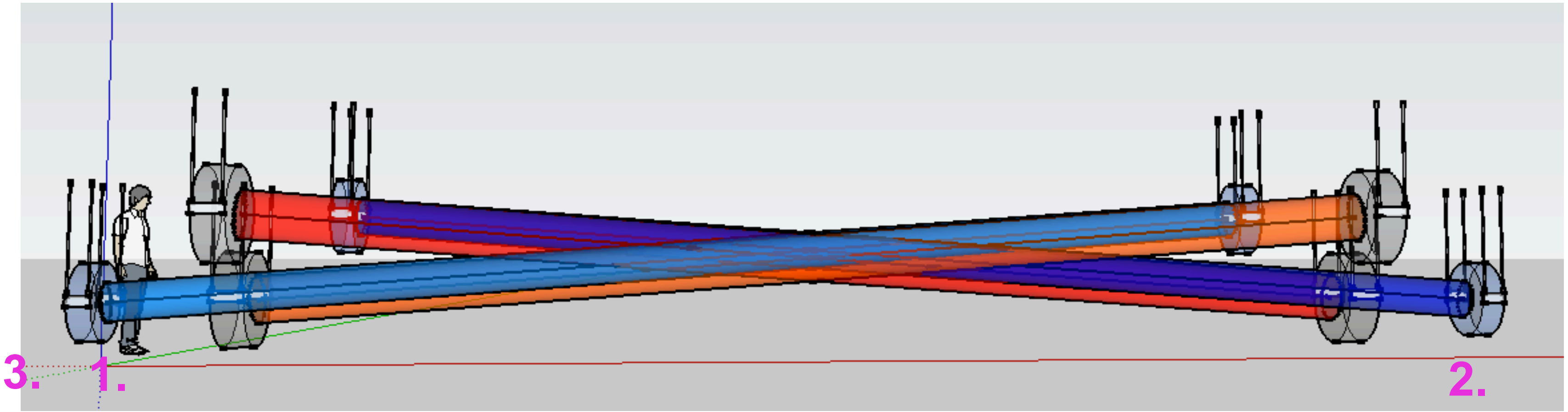
Scattered light problematic

- **For scattered light we would prefer to every interferometer in a single vacuum system. – disadvantages: expensive, perhaps even impossible.**



- **Crossed beam layout:**
  - 4 interferometers in a single tube.
  - Easy separation of the 4 instruments: a) different colour b) same colour ifos will be shifted by MHz or GHz.
  - Remaining PROBLEM: scattering into a different ifo and then back

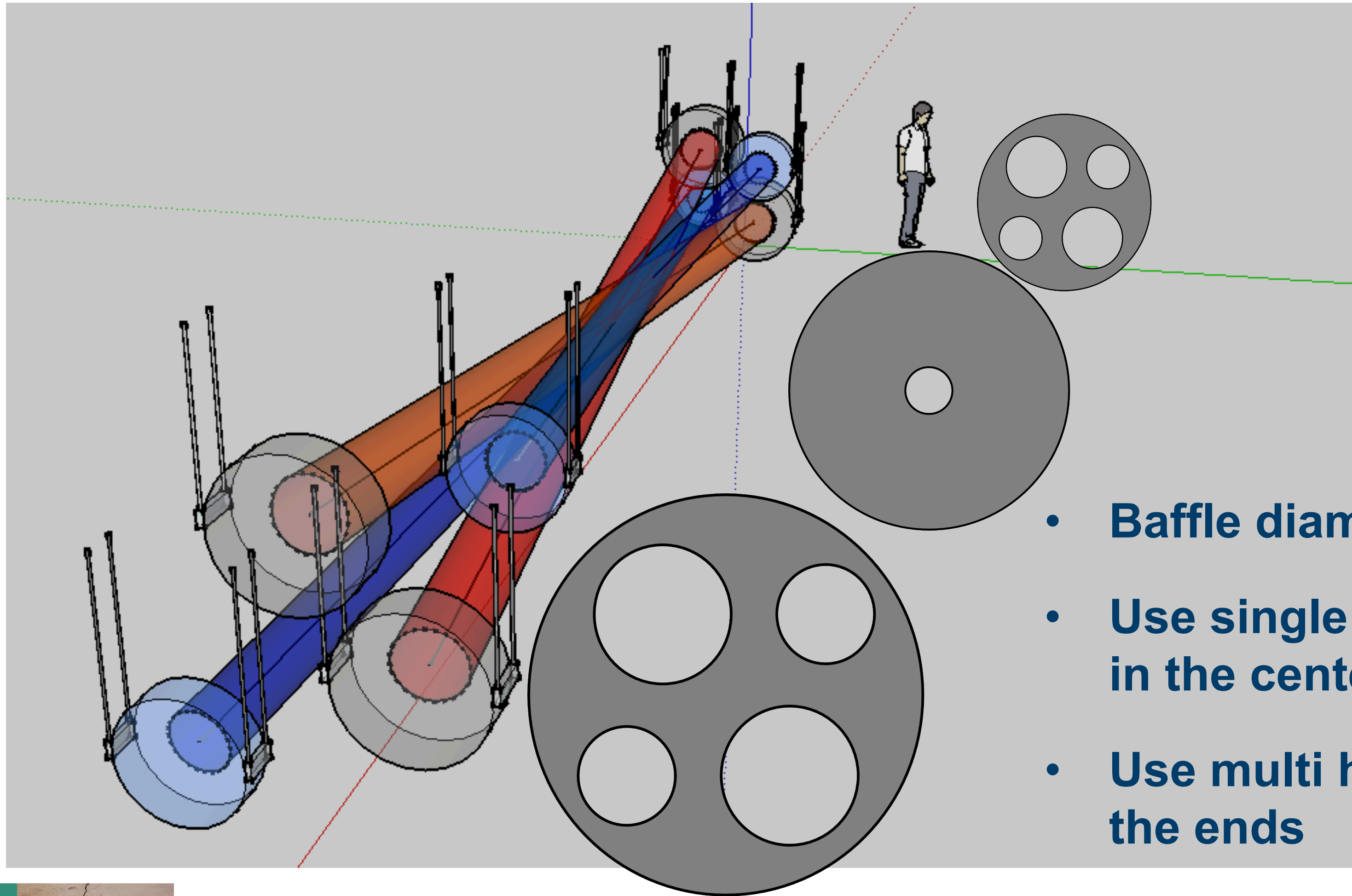
Scattered light problematic



- **Possible scattering mechanisms:**
- **No single or double process scattering possible. At least three scattering processes have to be involved to produce harmful scattering noise.**
- **3-point scattering:**
  - 1) scattering from left light blue mirror towards right dark blue mirror
  - 2) scattering from right dark blue mirror towards left light blue mirror
  - 3) scattering at left light blue mirror back into interferometer mode of light blue ifo.
- **4-point scattering: same as above, but additionally the light may also be stored for some time in the ifo mode of the dark blue arm cavity.**

Potential Baffle Design

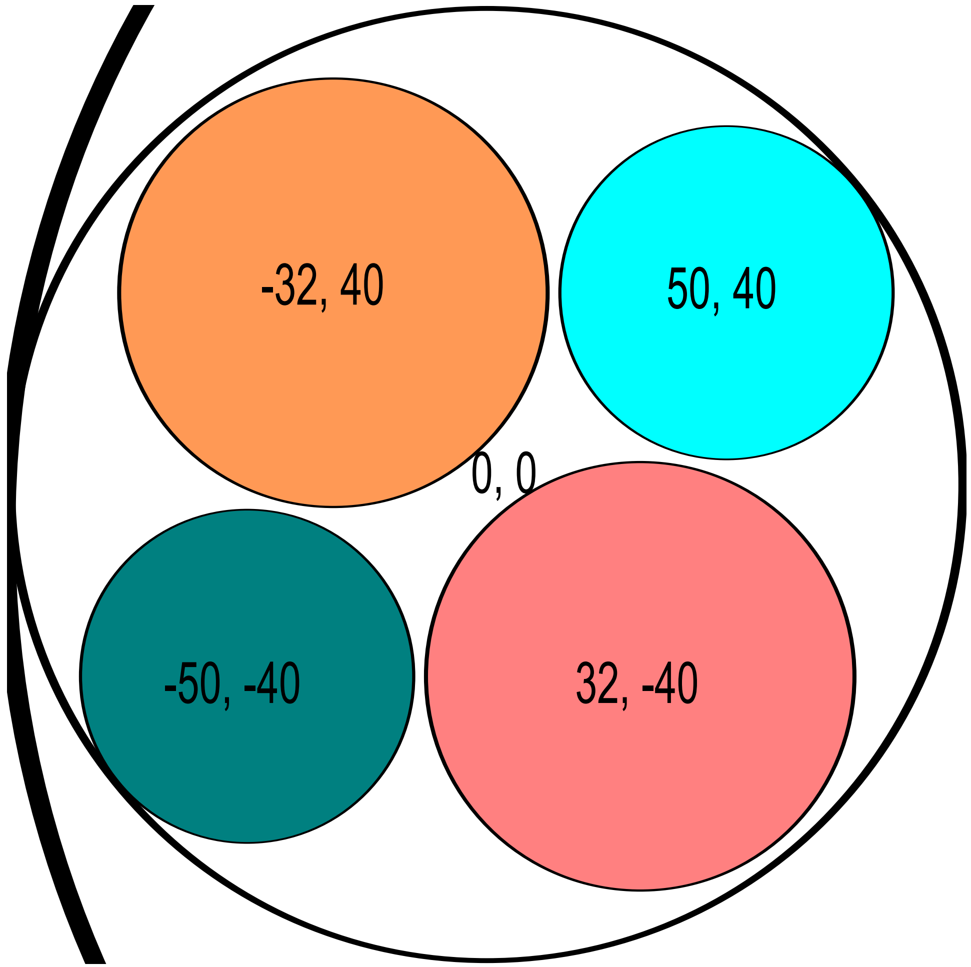
- **Perhaps it is possible to use baffles to prevent that any interferometer sees any of the test masses of another interferometer?**



- **Baffle diameter of 2m.**
- **Use single hole baffle in the center.**
- **Use multi hole baffle at the ends**

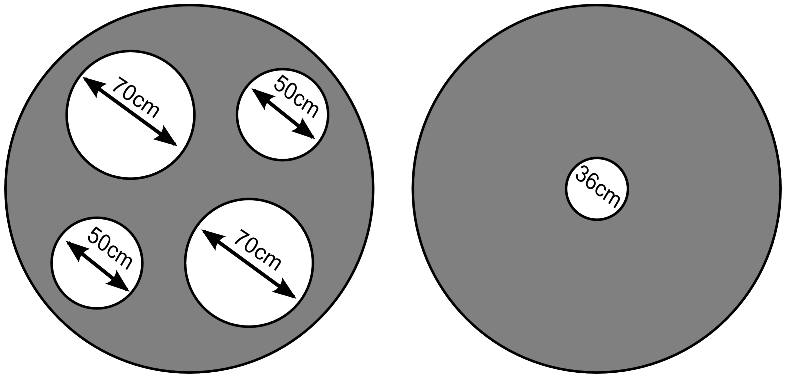
Potential Baffle Design

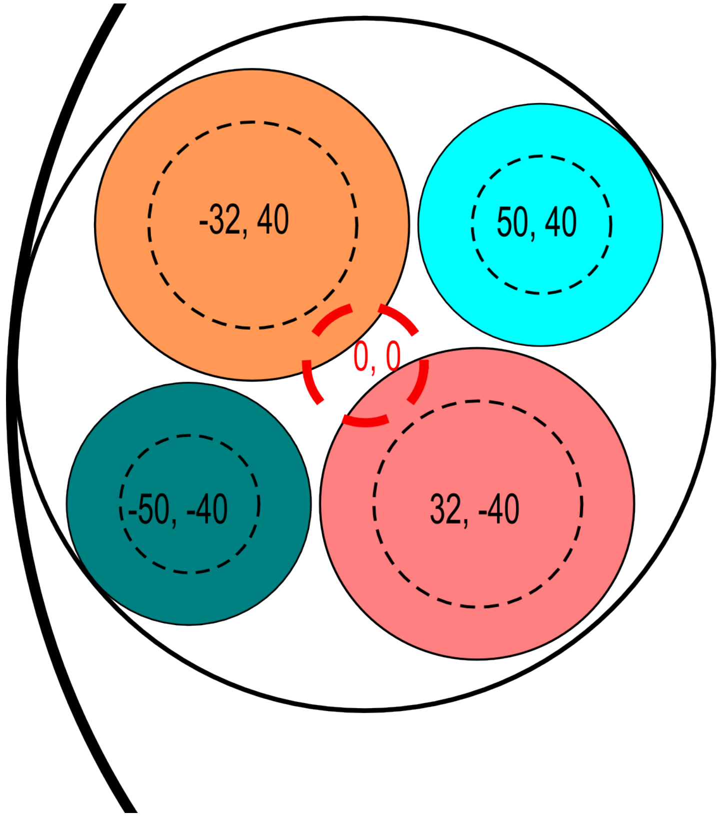
- **Consider geometry of a 2m diameter vacuum tube.**
- **Reddish circles represent HF detectors = 90cm diameter**
- **Bluish circles represent LF detectors = 70cm diameter**
- **Numbers give relative position (x, y) to center of tube**



Potential Baffle Design

- **At beam waist all four beams are centered around 0,0**
- **Beam diameter (5 sigma) at waist are 17cm for LF-ifos and 26cm for HF-ifos.**
- **Need to keep a free aperture of 26+10=36cm at the center of the tube.**



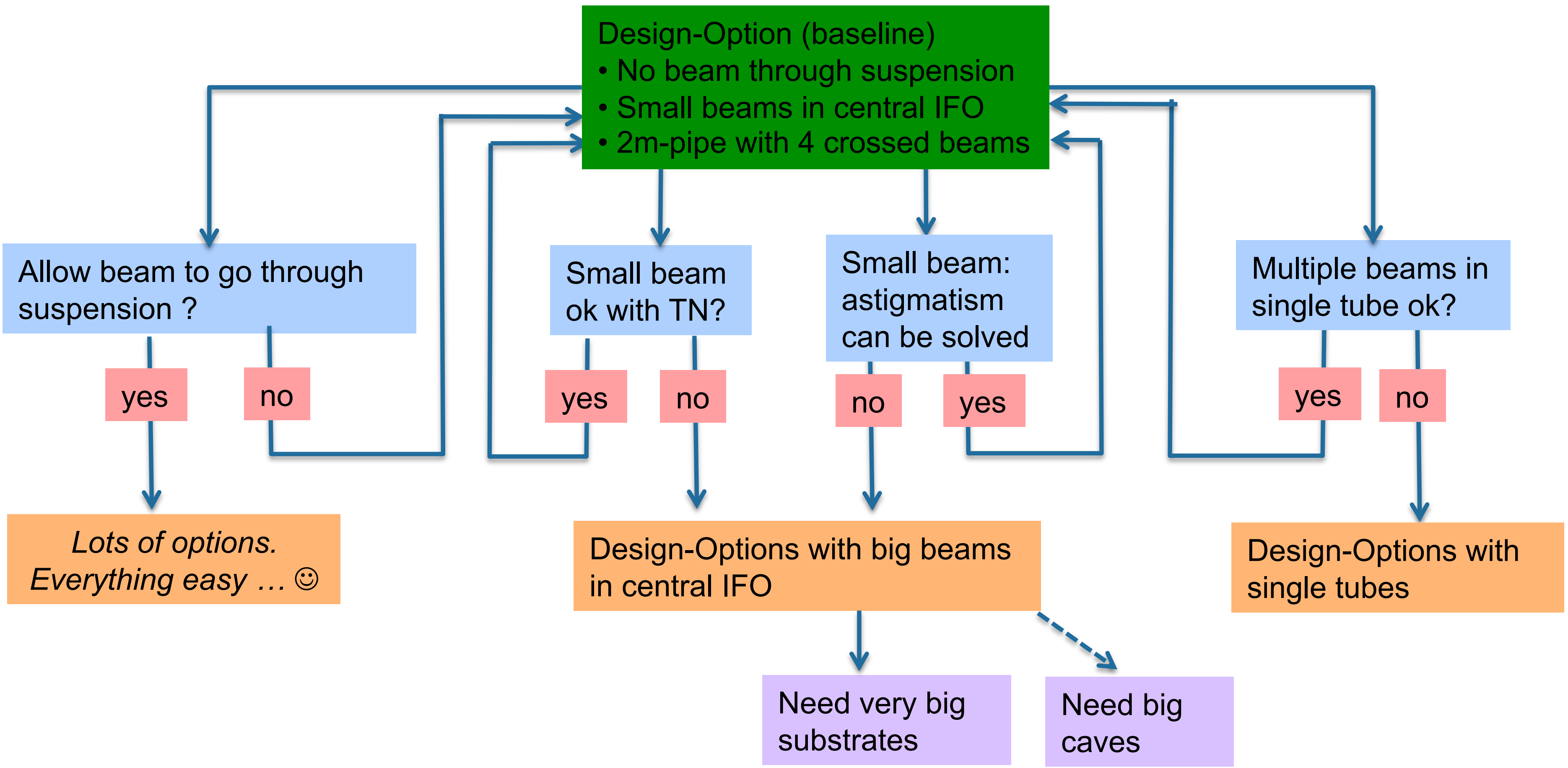


- **Using such baffles, no ifo 'sees' any testmass of another ifo (only geometrical optic), see red dashed circle.**

Research Task

- **Research task: Investigate scattering issues of 4-beam per tube configuration**
- **Details of investigation:**
  - Can we find a baffle designs that allows to run 4 interferometers in the same 2m diameter vacuum tube without introducing significant scattered light noise?
  - Considerations on the previous slides only include geometrical optics. Need also to take 'real-world' effects like diffraction etc into account.

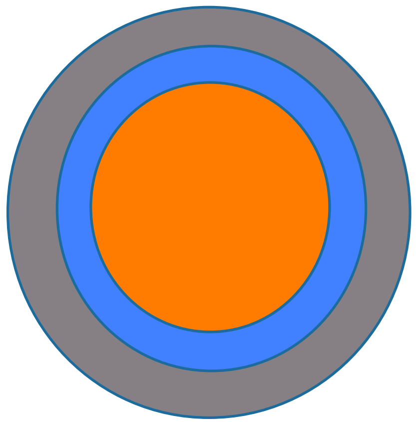
Overview of this presentation



Scattered light: Baffles for single beam

- **In order to determine the minimal space required for the beams we have to find:**
  - Minimal distance between beam and baffle?
  - Required thickness of baffle?

- **Until we have a proper analysis availabe we do as follows:**
  - Mirror diameter equals 5 beam radii (i.e. HF detector = 60cm, LF detector = 40cm).
  - 5cm distance between beam and baffle.
  - 10cm baffle on each side
  - Total for HF detector = 60+10+20 = 90cm
  - Total for LF detector = 40+10+20 = 70cm



Research Task

- **Research task: How much space is required for a single interferometer beam.**
- **Details of investigation:**
  - How much space is required between the laser beam and the baffles?
  - How much space is required for the baffles themselves

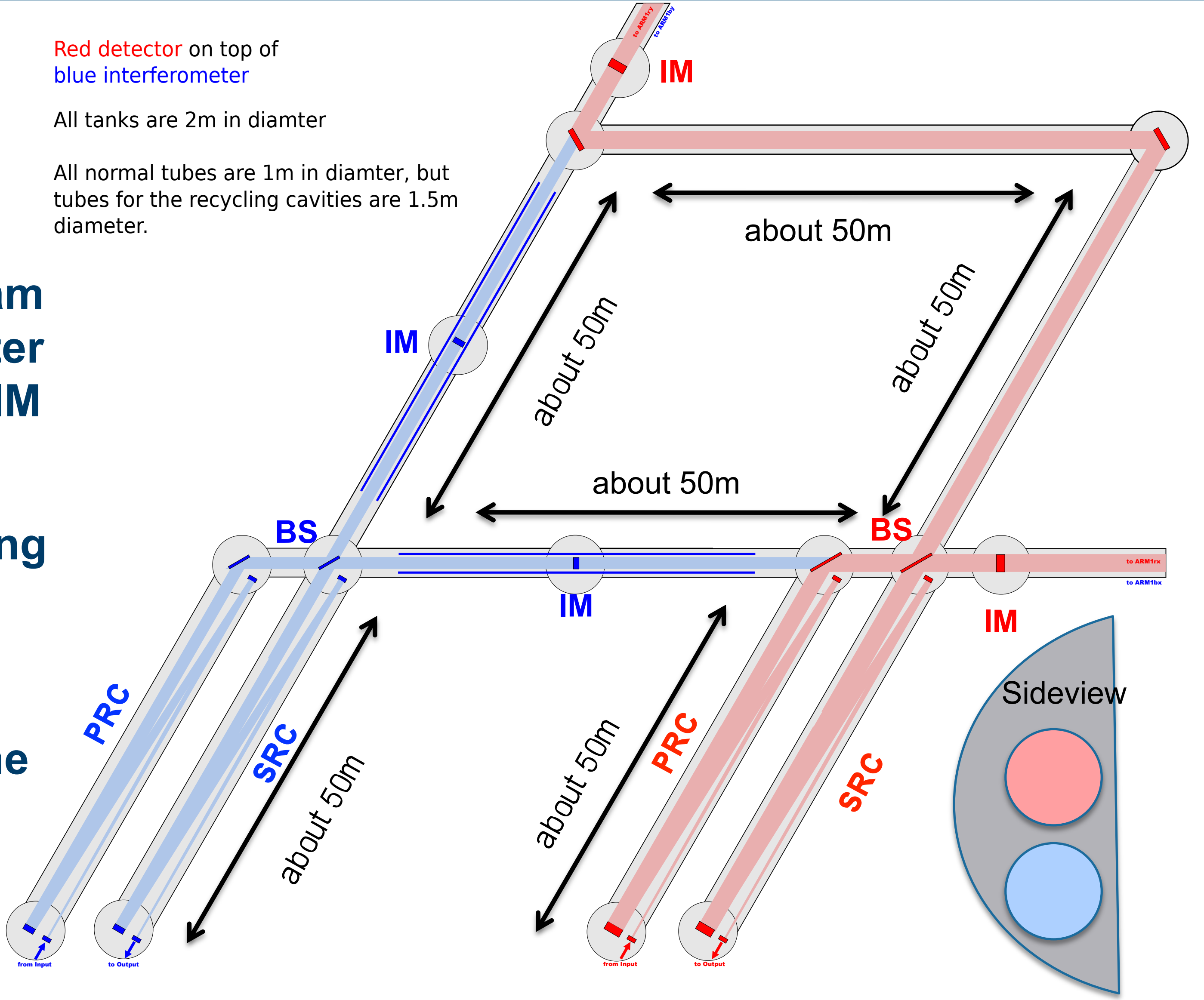
Single beam per tube configurations (1)

- **Assumption:**
  - ➢ Not possible to pass beam through suspension.
- **Have to extract beam of one interferometer before it would hit IM of other ifo.**
- **Want to avoid folding the LF ifo away, as that would mean high suspension requirements for the folding mirrors.**
- **4 non-degenerate recycling cavities.**

Red detector on top of blue interferometer

All tanks are 2m in diamter

All normal tubes are 1m in diamter, but tubes for the recycling cavities are 1.5m diameter.



Single beam per tube configurations (2)

- **Dimensions of trapezium / corner station are driven by the cryogenic shields around the LF IM.**
- **Huge beams on BS, folding mirrors and two thirds of the recycling mirrors**

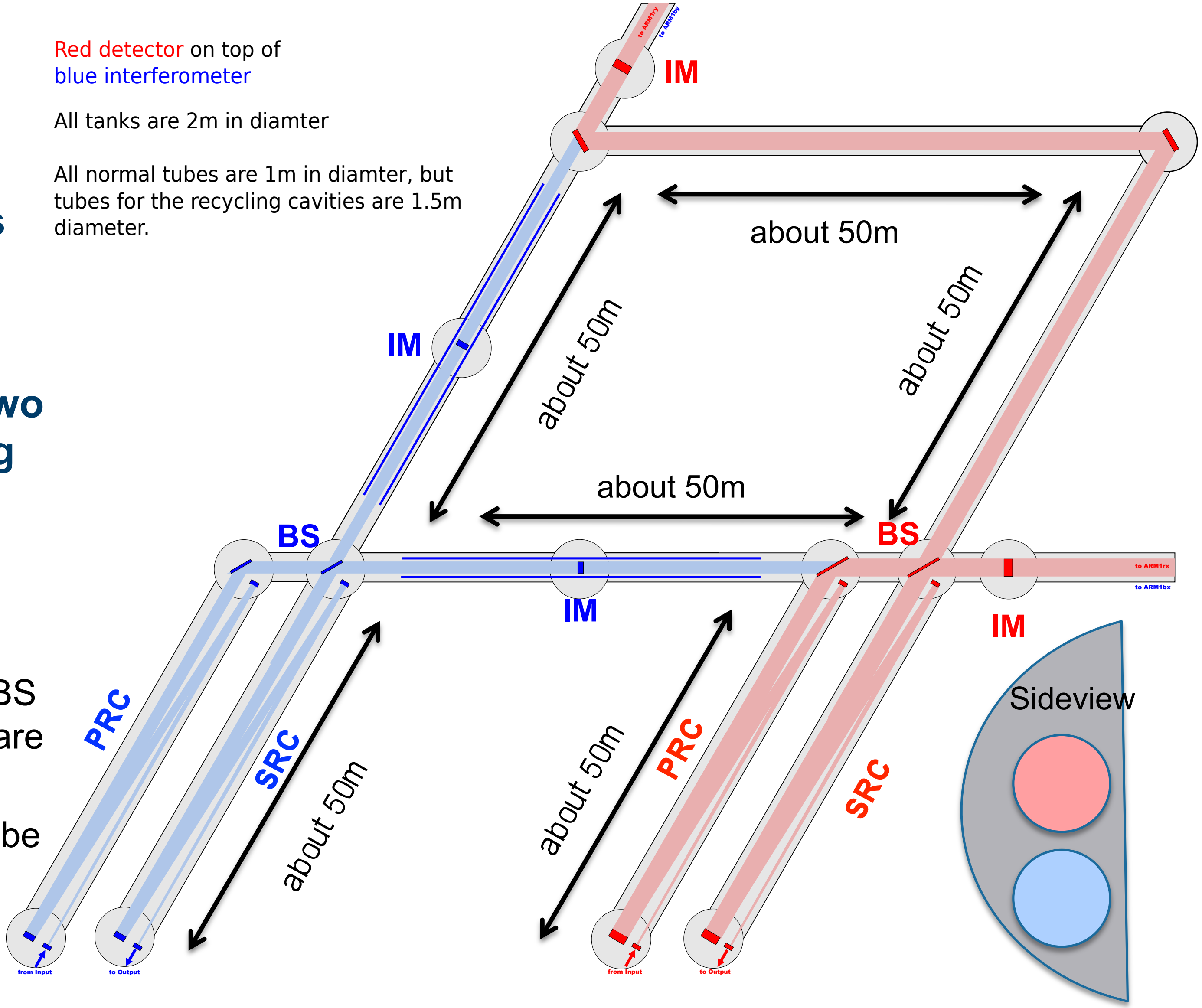
In Summary 2 major disadvantages:

- ➢ Currently required BS and folding mirror sizes are not available.
- ➢ Corner cave would be huge (min 50x100m).

Red detector on top of
blue interferometer

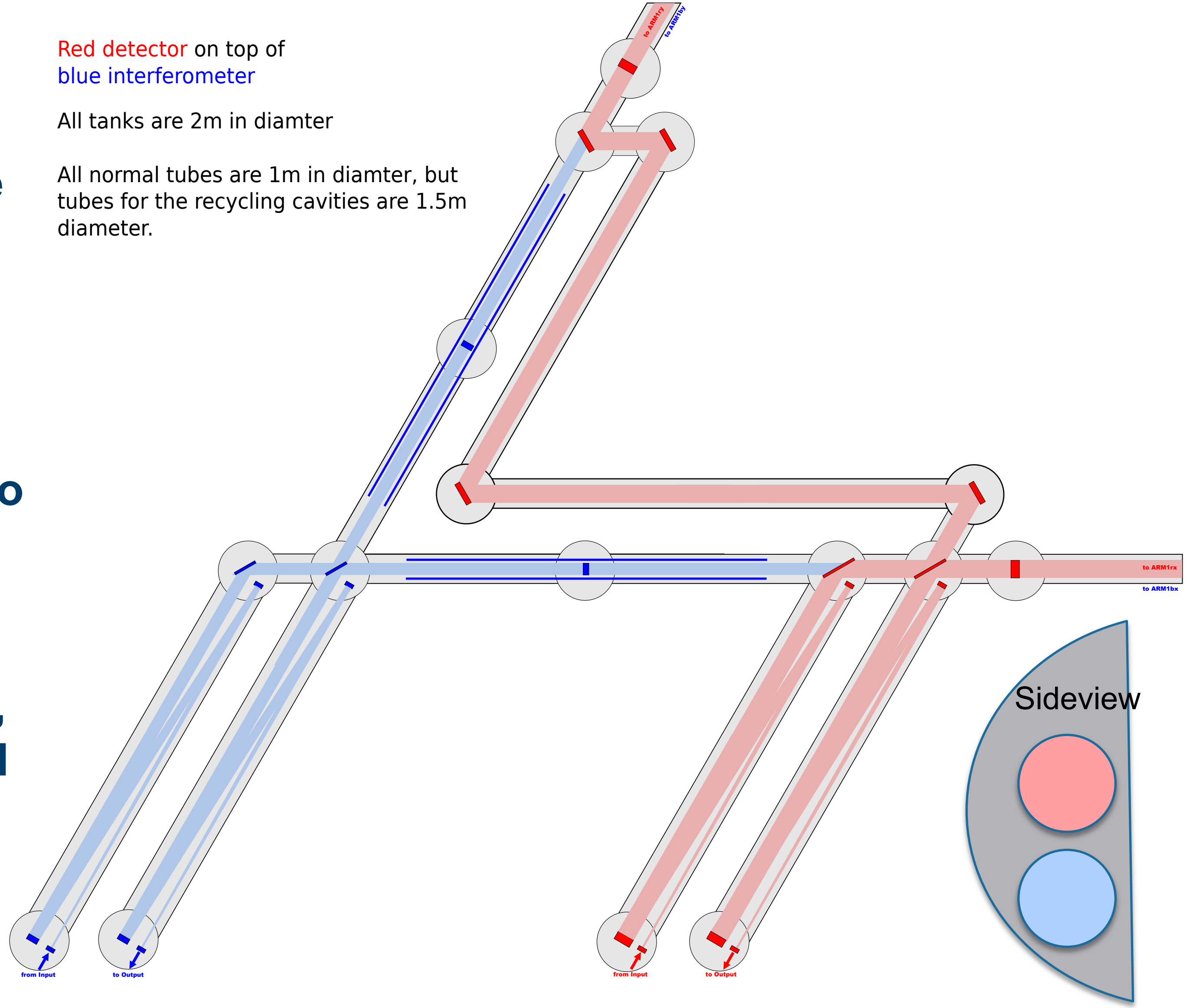
All tanks are 2m in diamter

All normal tubes are 1m in diamter, but tubes for the recycling cavities are 1.5m diameter.



Single beam per tube configurations (3)

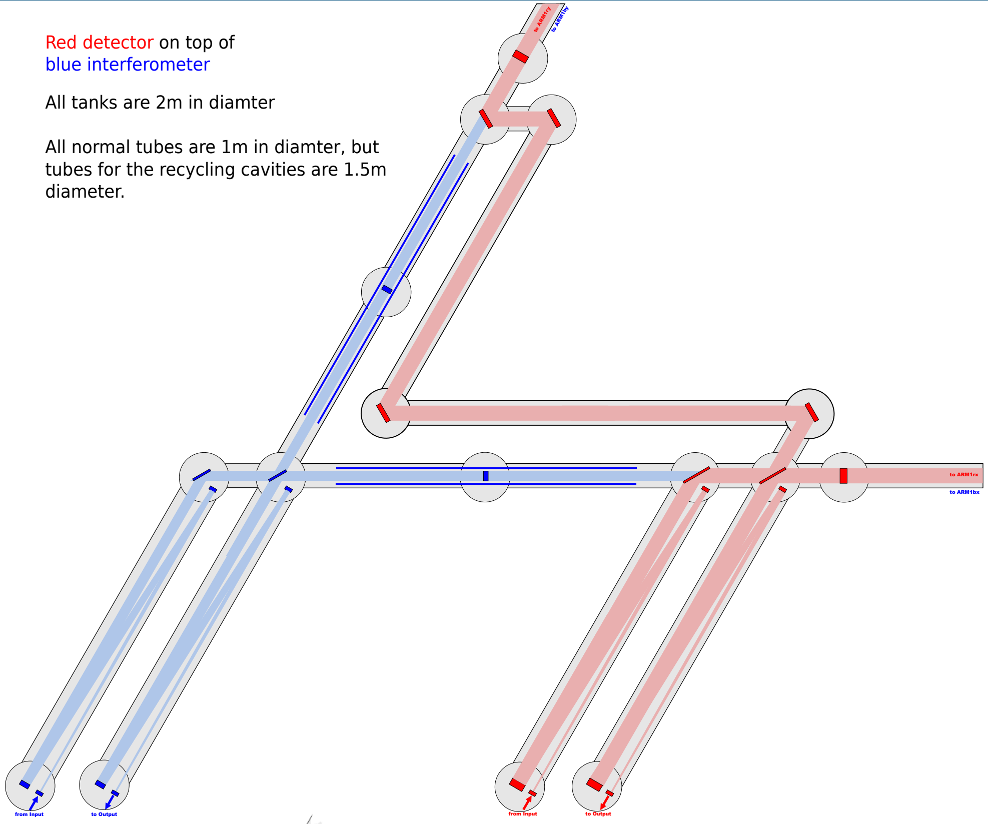
- **Introducing two more folding mirrors can reduce the space requirements for the corner stations to about 50x 50m.**
- **However there is no easy solution to avoid the having extremely large dimensions for BS, folding mirrors and 2 thirds of the recycling mirrors.**

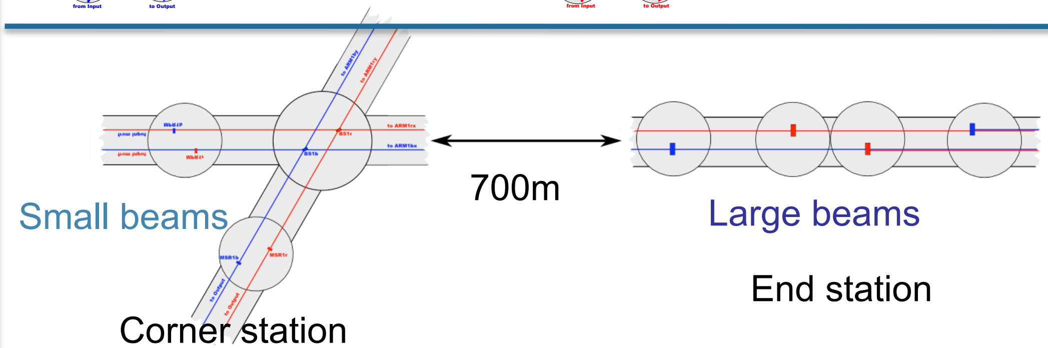


Small vs large beams in central IFO

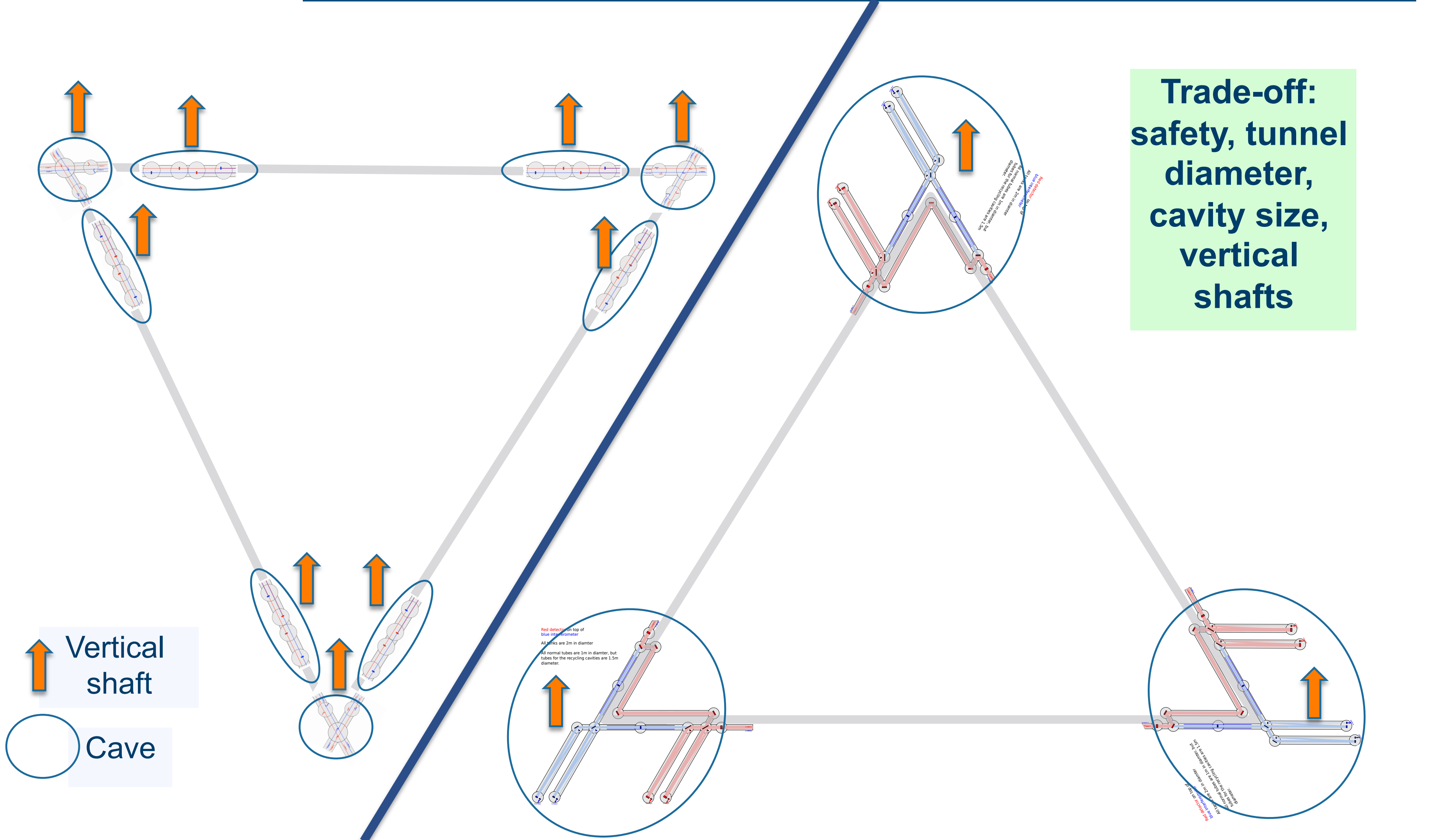
	Large	Small
Number of suspended main optics per ifo	12-16	7
Number of full scale optics (>40cm) per ifo	10	4
Min Size of corner-station [m^2]	Ca. 3500	Ca. 400
Min Size of end-station [m^2]	na	800
Number of vertical shafts	3	9

Values in the table are only for the main interferometers and only include the optics between power and signal recycling mirror.



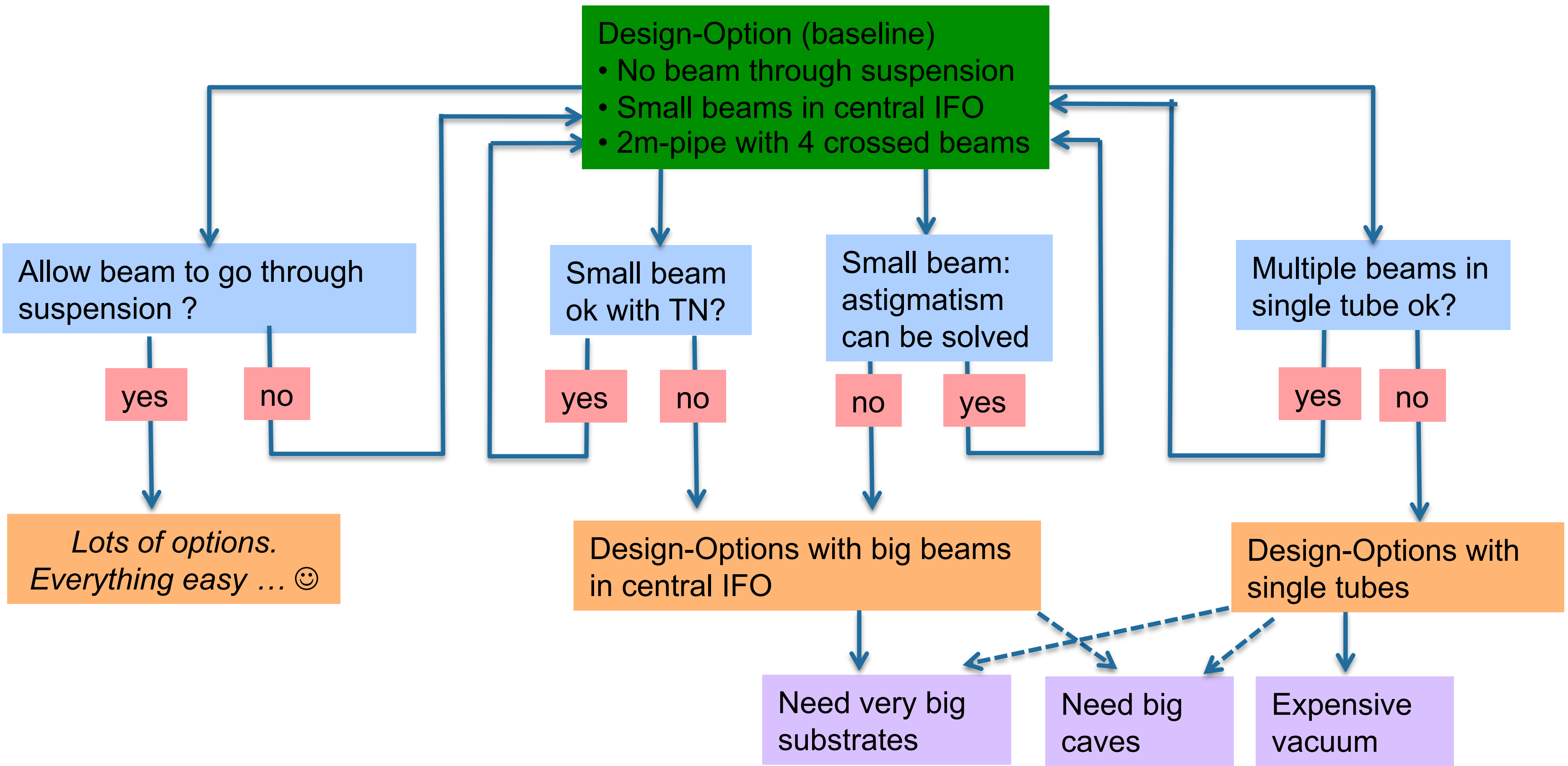


Small vs large beams in central IFO (2)



Trade-off: safety, tunnel diameter, cavity size, vertical shafts

Overview of this presentation



Many more Research Tasks in the Queue

- **Need to implement filter cavities for frequency dependent squeezing.**
- **Need to solve, minimise influence of losses in filter cavities.**
- **Need to extend design to include input and output optics (such as suspended mode cleaners etc).**
- **How heavy can we make Silicon input mirrors? 65cm thickness too much in terms of absorption or thermal noise?**
- **Need to look into thermal shielding to separate warm and cold optics within a single vacuum system.**
- **…**

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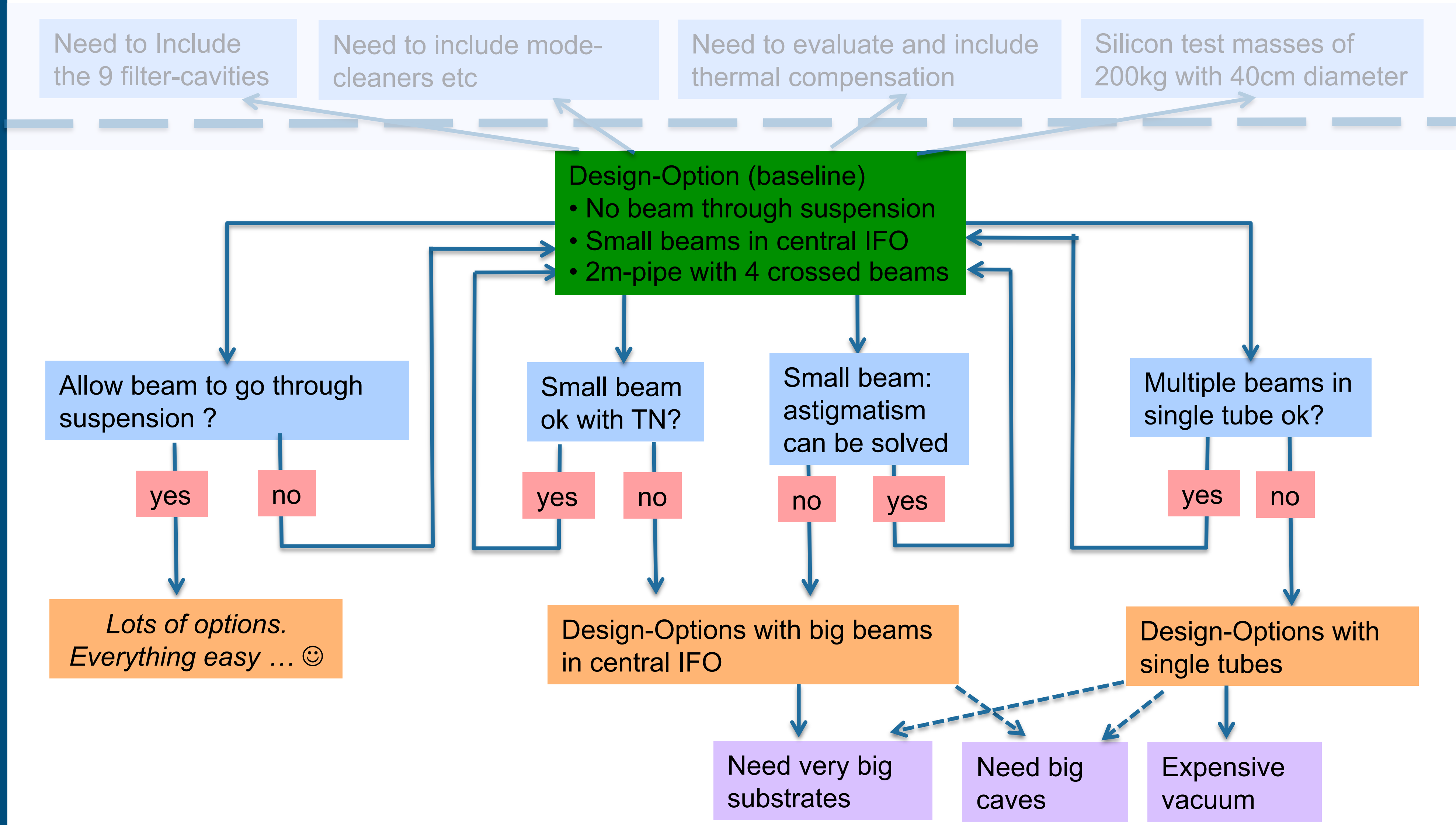
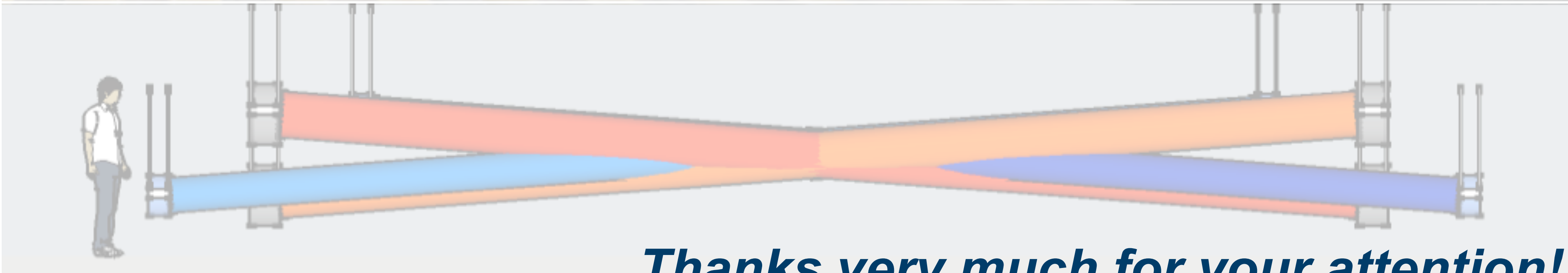
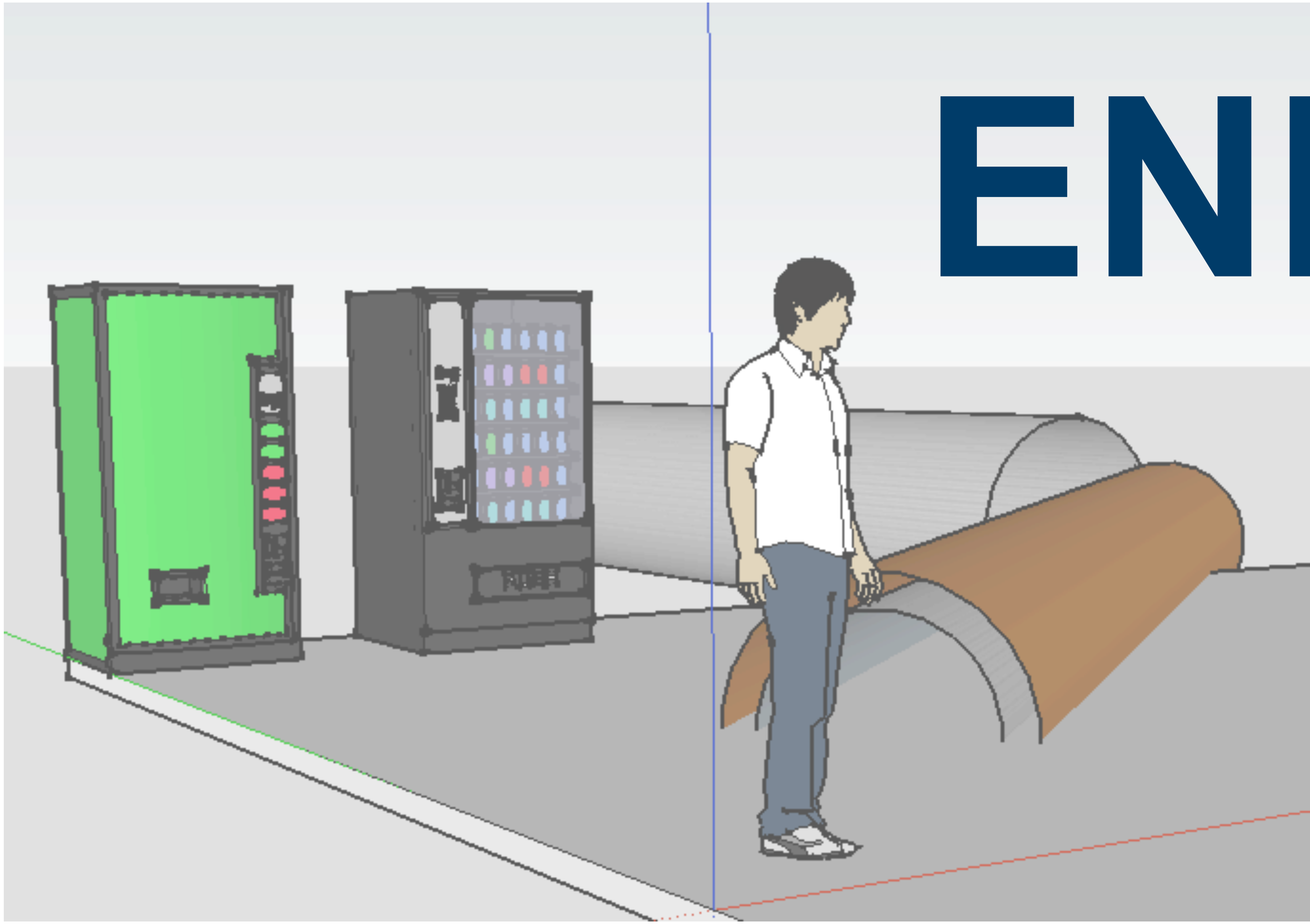


Summary

- **Triggered by a requested 'cost exercise' we needed to have a look at the ET optical layout from a different perspective.**
- **Encountered many new problems due to a) having several IFOs per arm, b) combination of warm and cold optics, c) presence of long cavities**
- **Simple dummy design is now in place:**
  - Please shoot it … that we see where it does not work.
  - There are many connected research tasks waiting for us. ☺



Thanks very much for your attention!



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