Advanced Virgo Design

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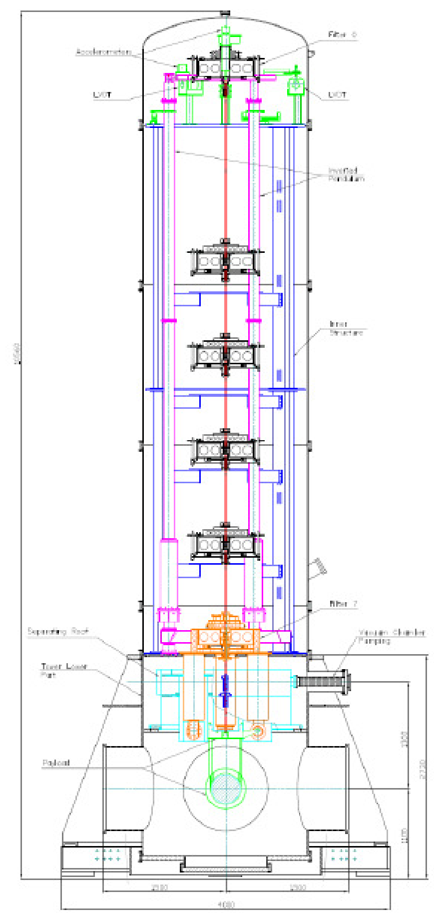
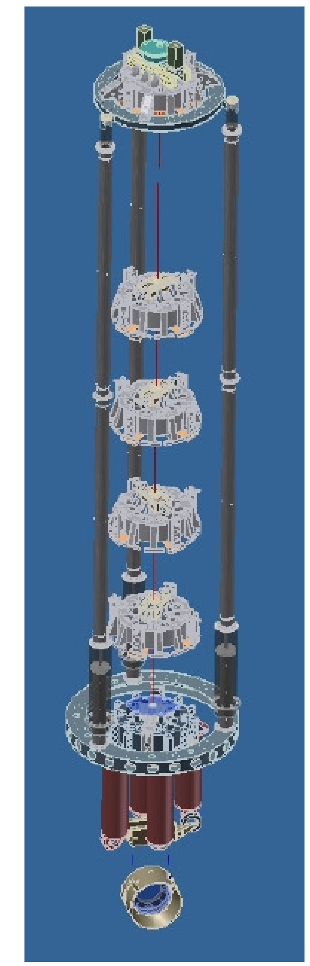
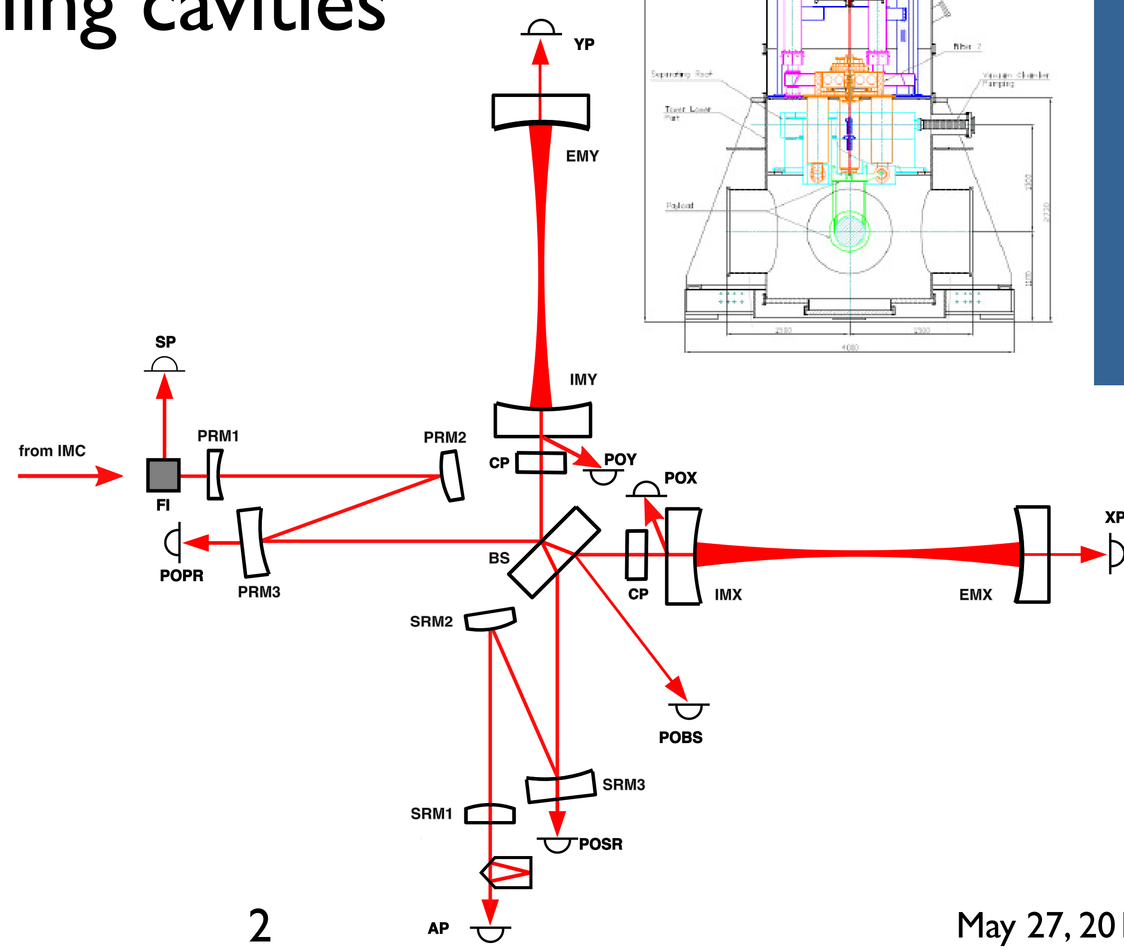
on behalf of the Virgo Collaboration

The Baseline Design

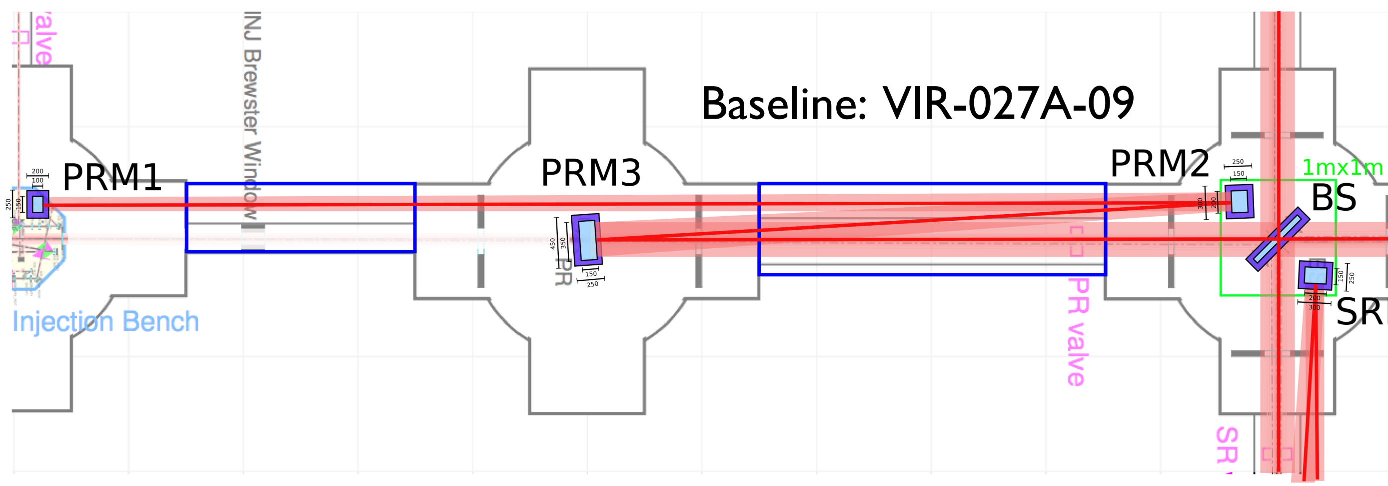
- Arm cavities with large spot size, concave-concave mirrors.
- Dual-recycled.
- Folded, stable recycling cavities (NDRC).
- DC readout.
- 2009





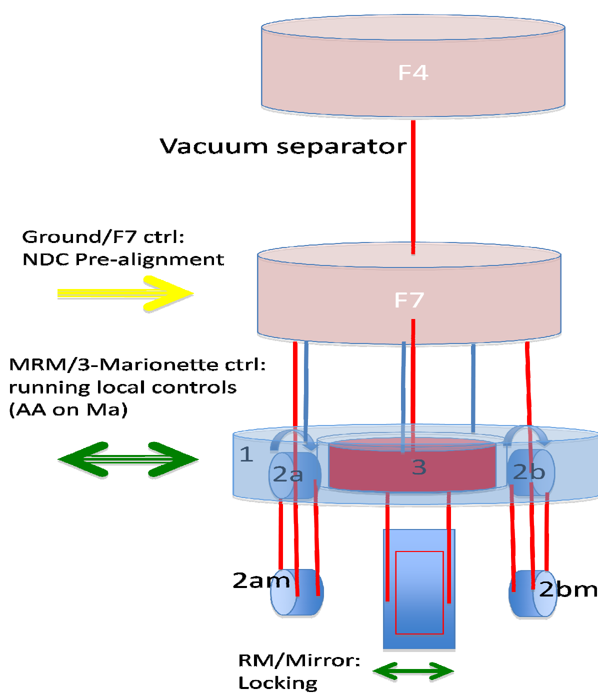


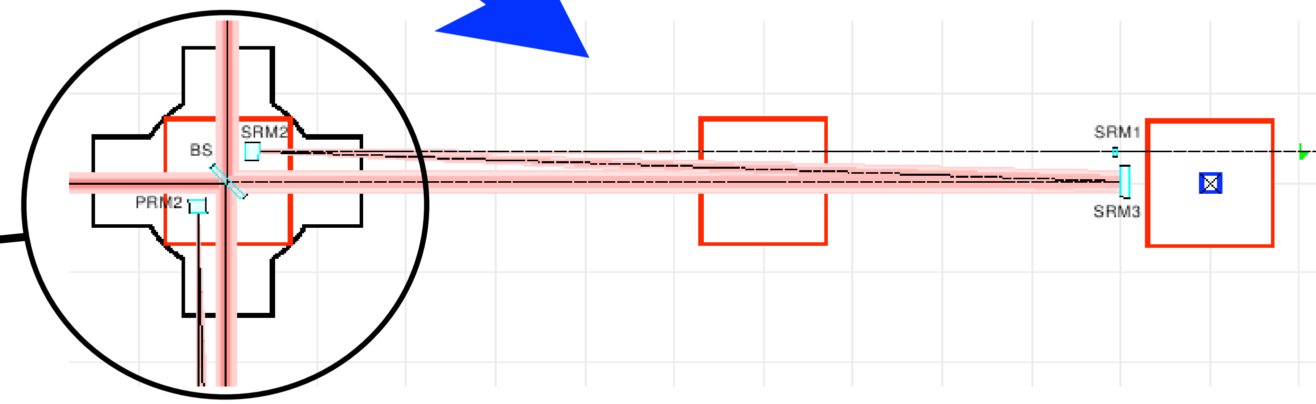
Evolution of details



RM3 - RM2 distance too small → too much astigmatism

Move RM3

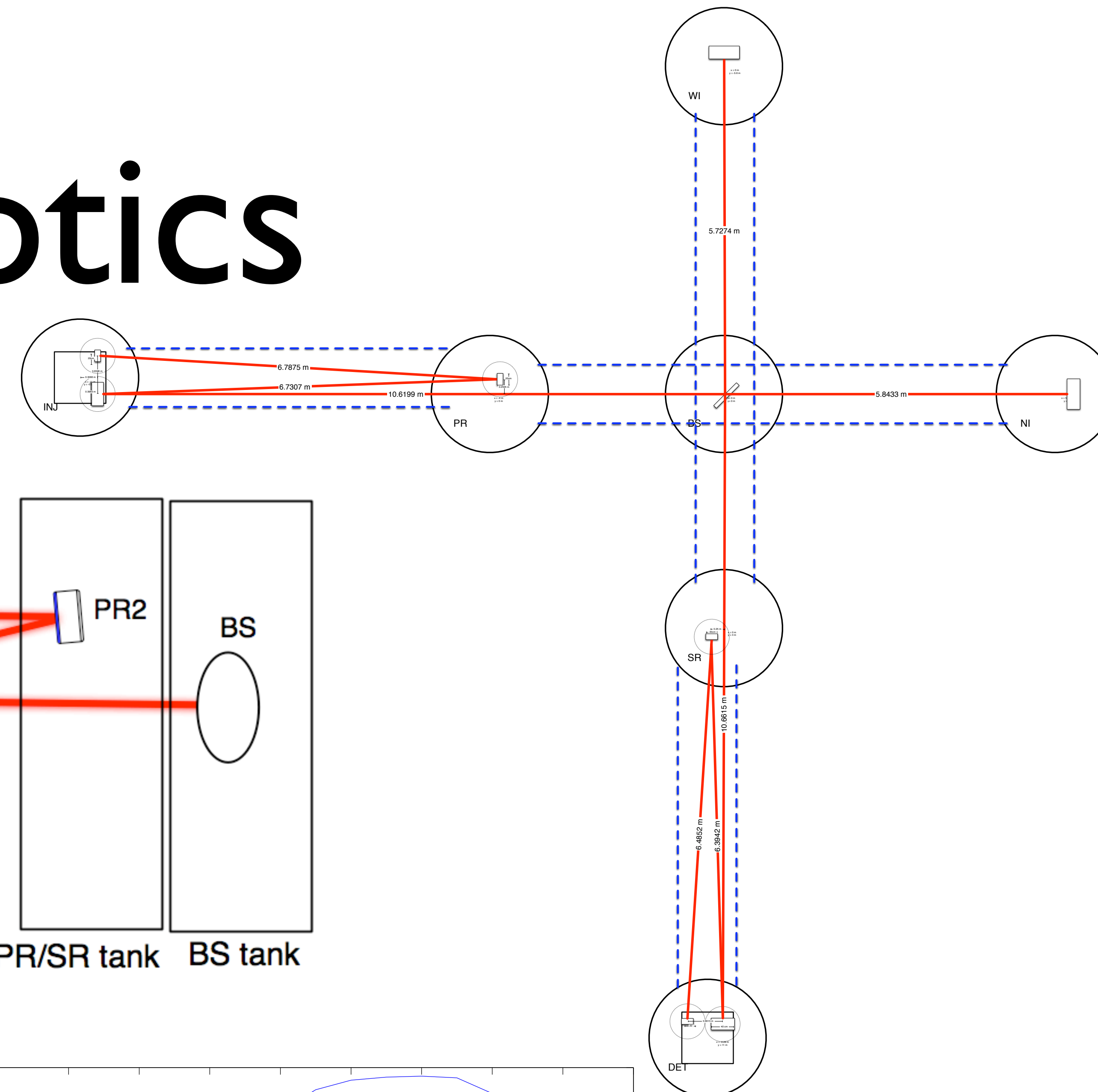


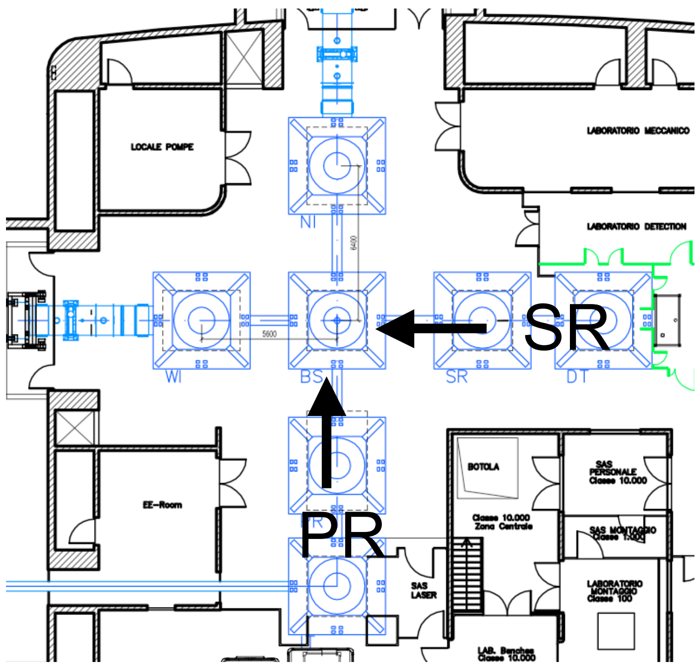


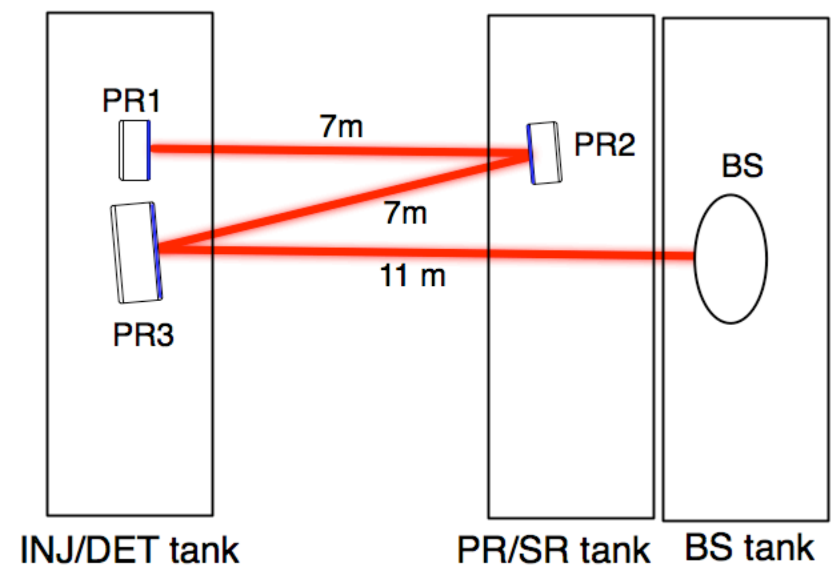
Beamsplitter multi-payload determined too risky.

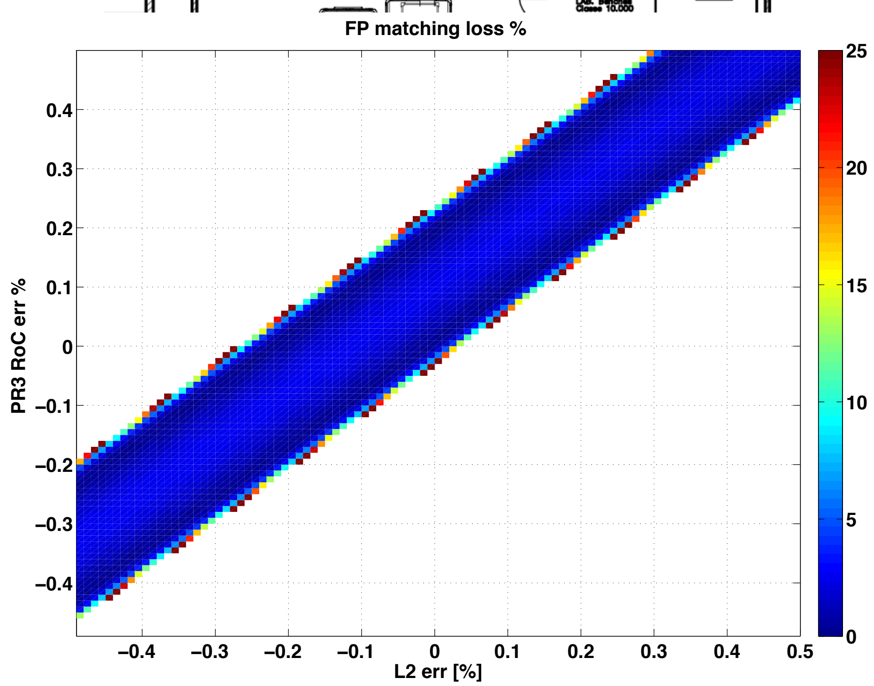
Move towers

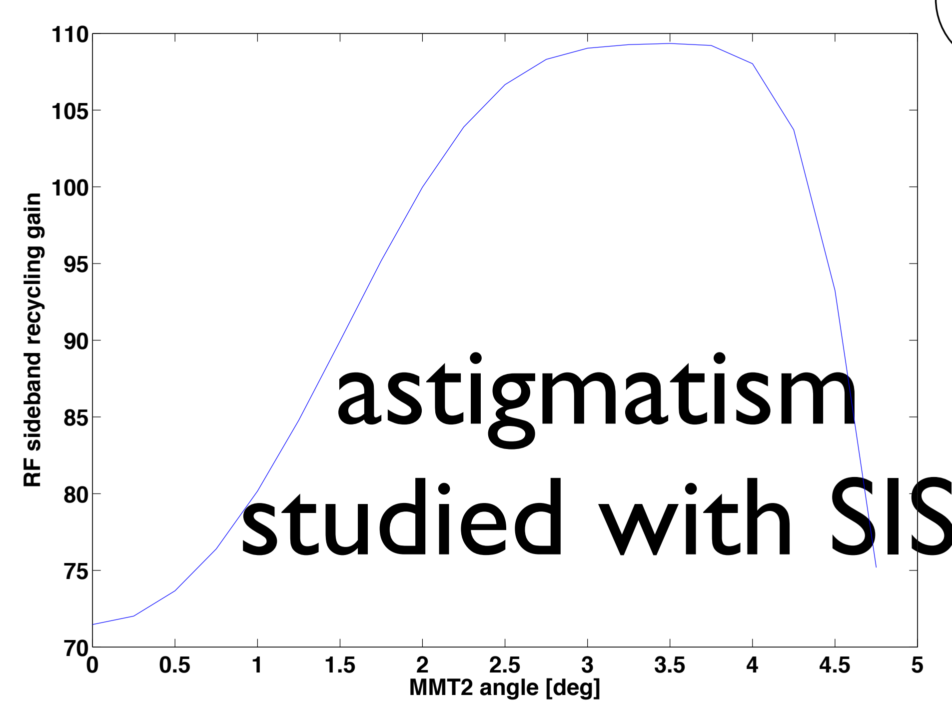
The optics







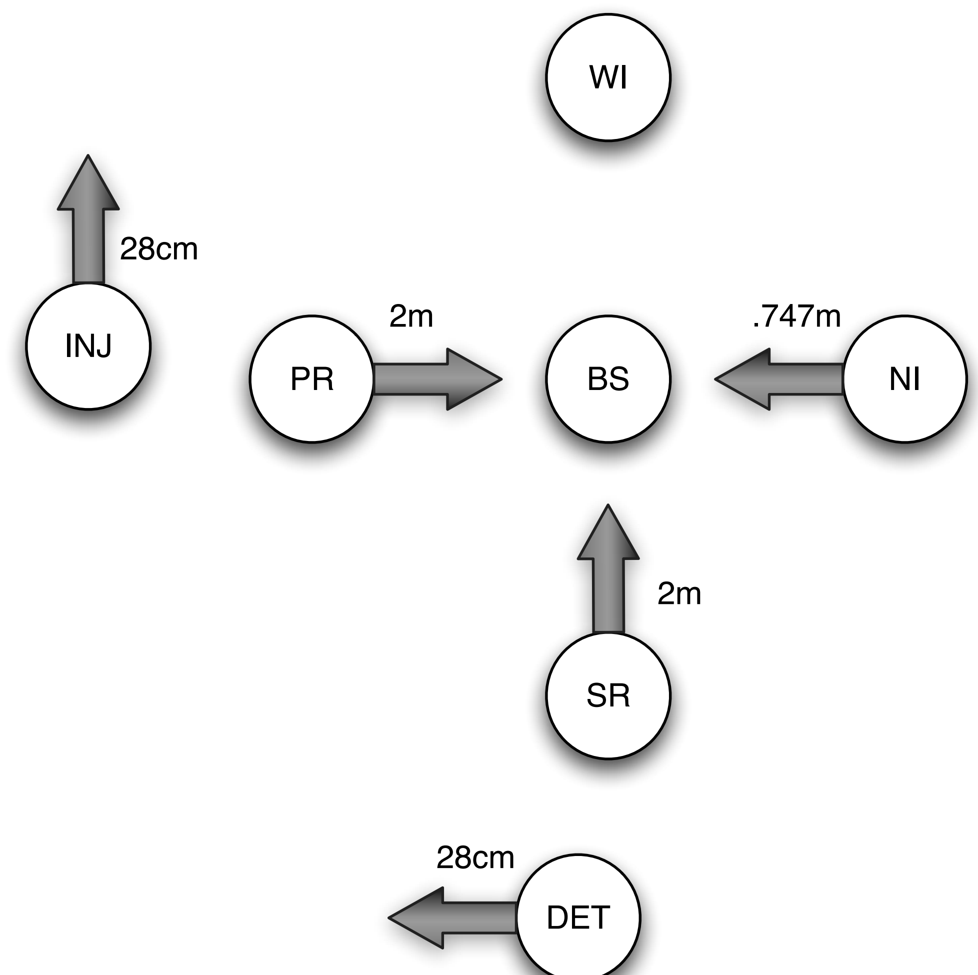




astigmatism
studied with SIS

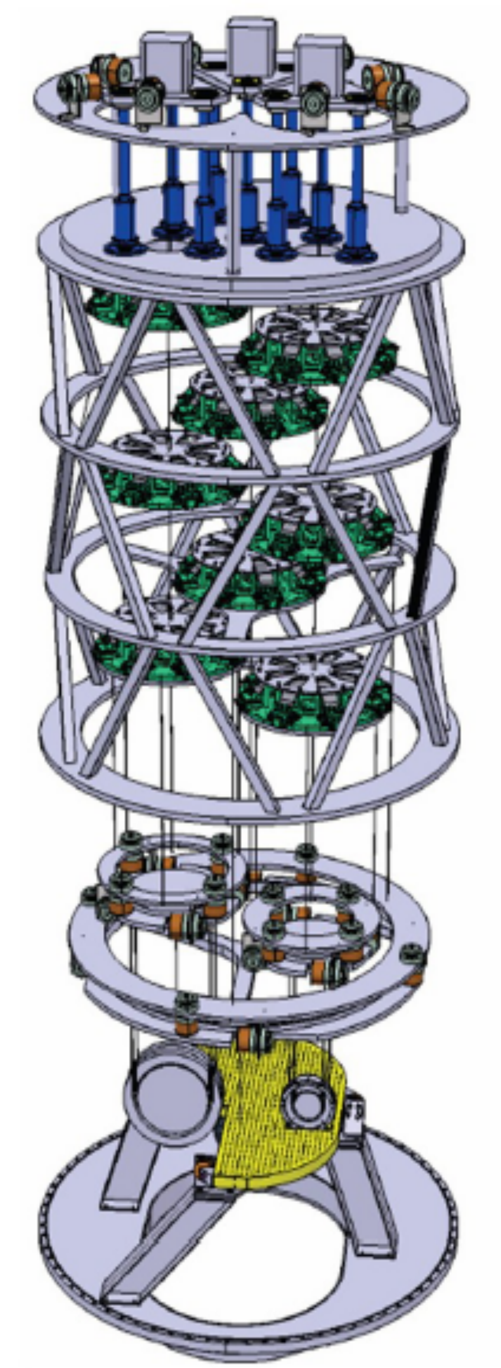
Moving the towers

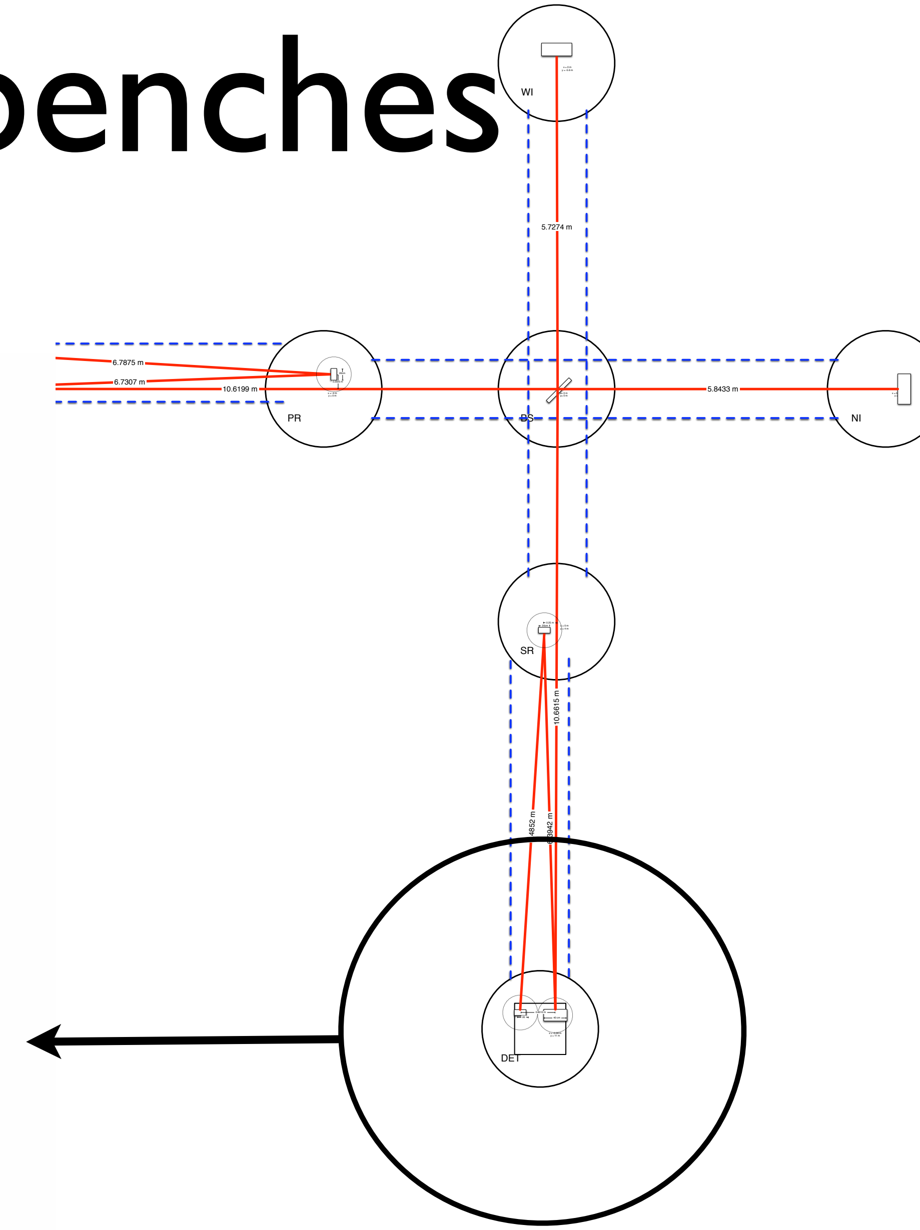
- The new solution eliminates the BS multi-payload but requires substantial displacement of 6 superattenuator towers (including MC end tower).
- This makes it impossible to use normal installation procedure (from below the tower).
- Two options for suspending multiple mirrors in one tower: MSAT and MPAY.



M-SAT for recycling mirrors and injection/detection benches

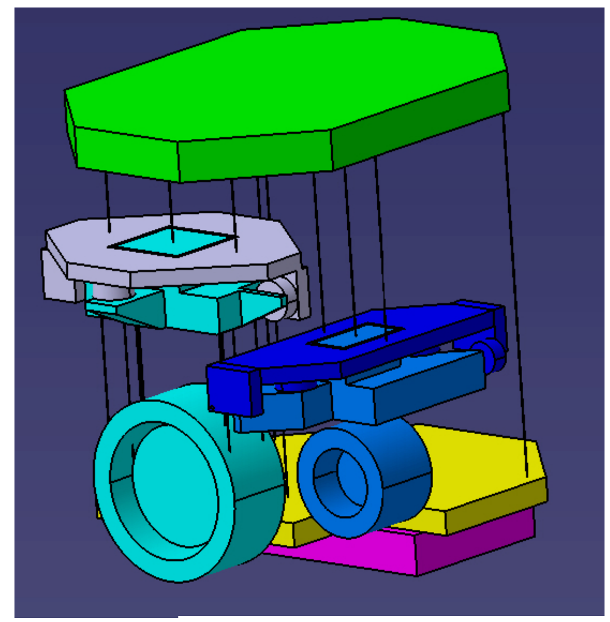
- Miniaturize the superattenuator, stiffen the frame, and squeeze three into a tower.
- Ultimately decided development process too long to meet schedule goals.

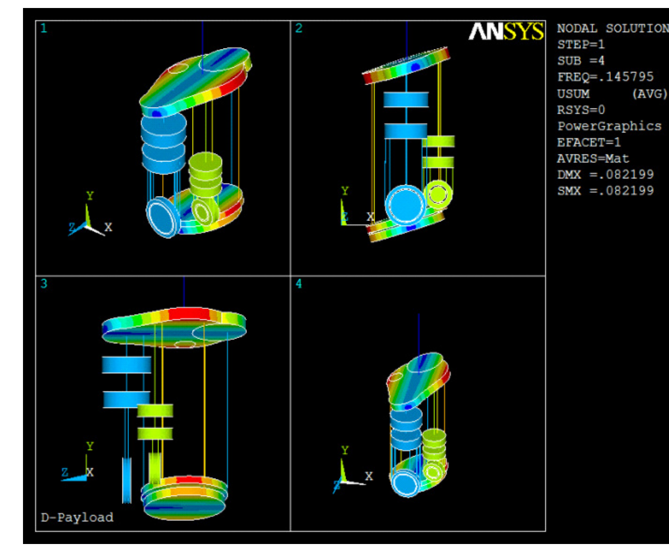




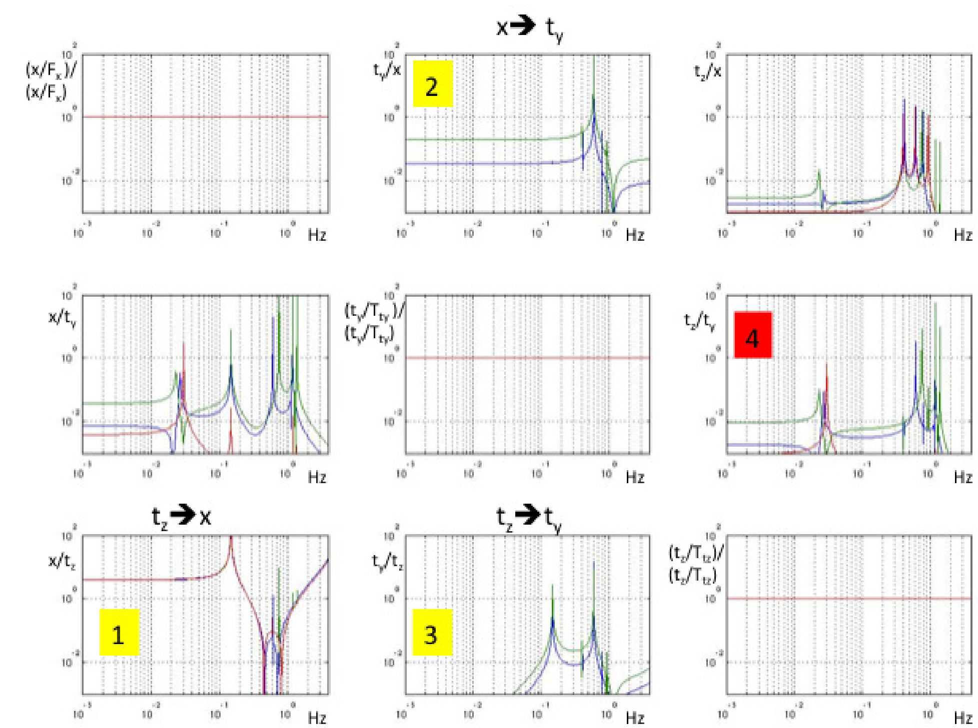
M-PAY for recycling mirrors and injection/detection benches

- Three separate objects (2 mirrors + 1 bench), each with reaction mass, suspended from a single superattenuator.





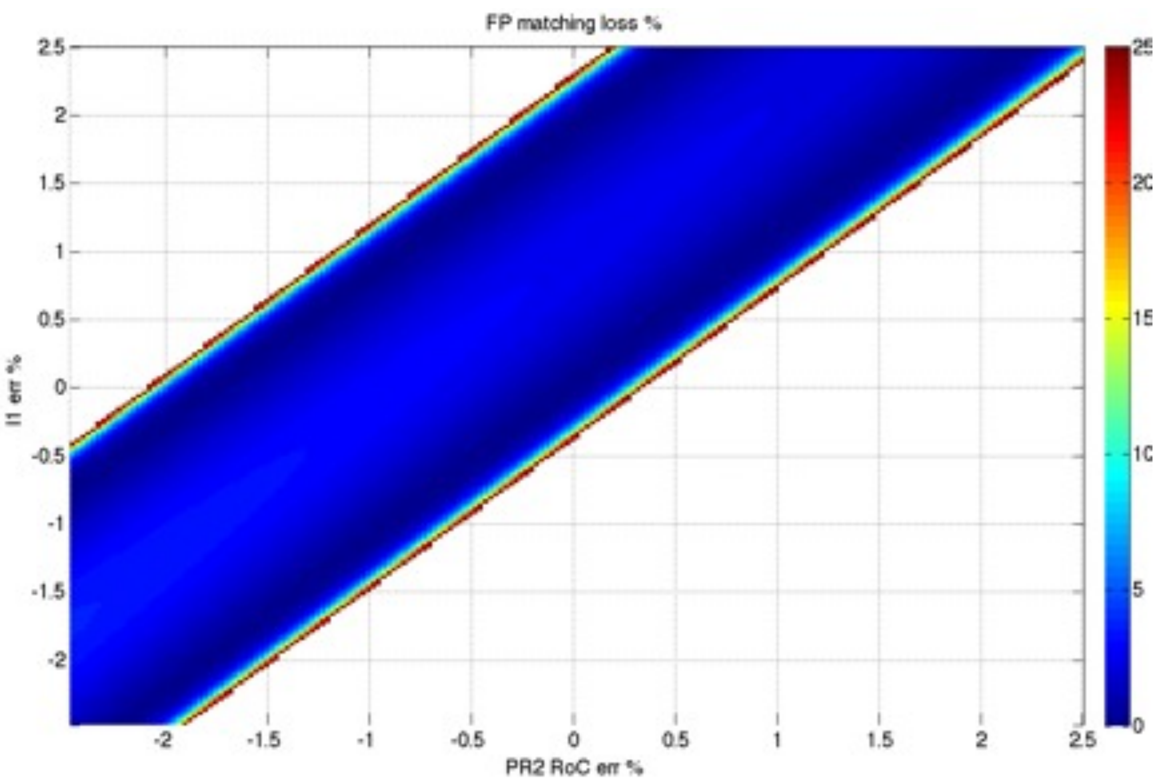
- After much simulation of mechanical cross-couplings, considered too risky by payload development team.

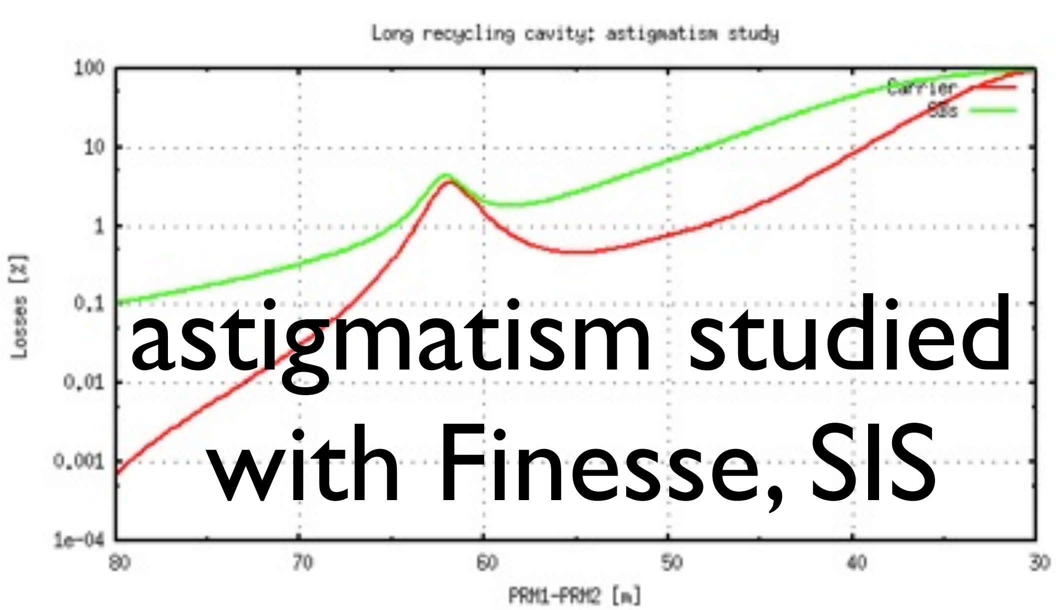


- Suspensions not on the superattenuator axis are the main problem.

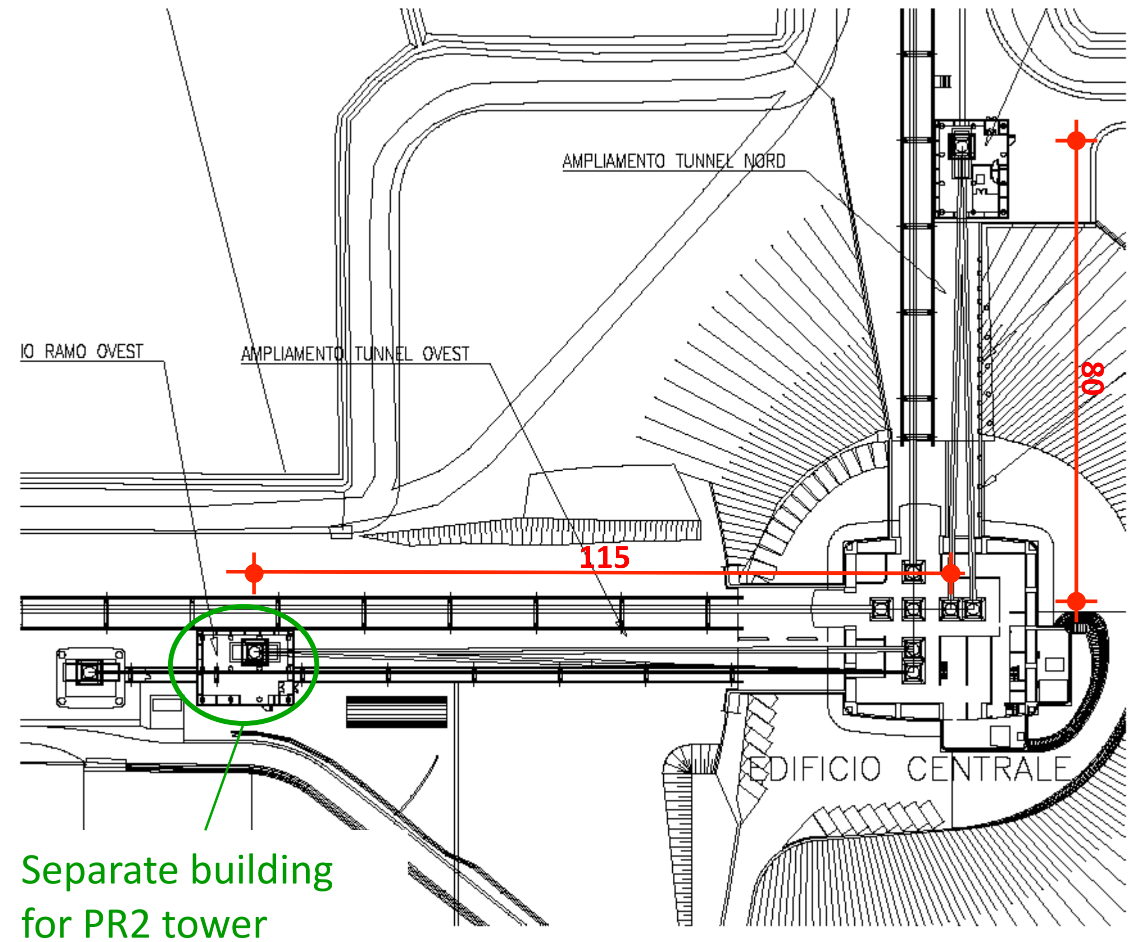
- Search begins for other solutions.

Long (~100m) Recycling Cavities





astigmatism studied with Finesse, SIS



Budget and Schedule Problematic

Issues

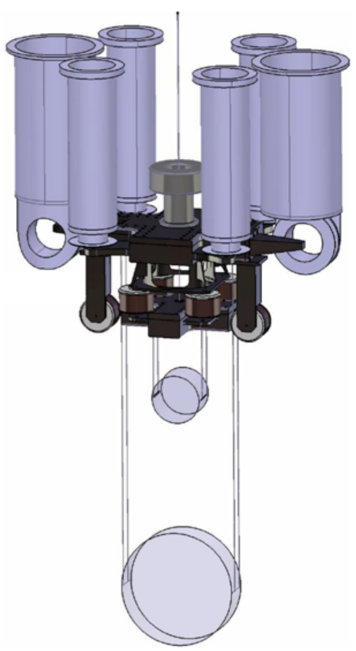
Decisions heavily influenced by simulation

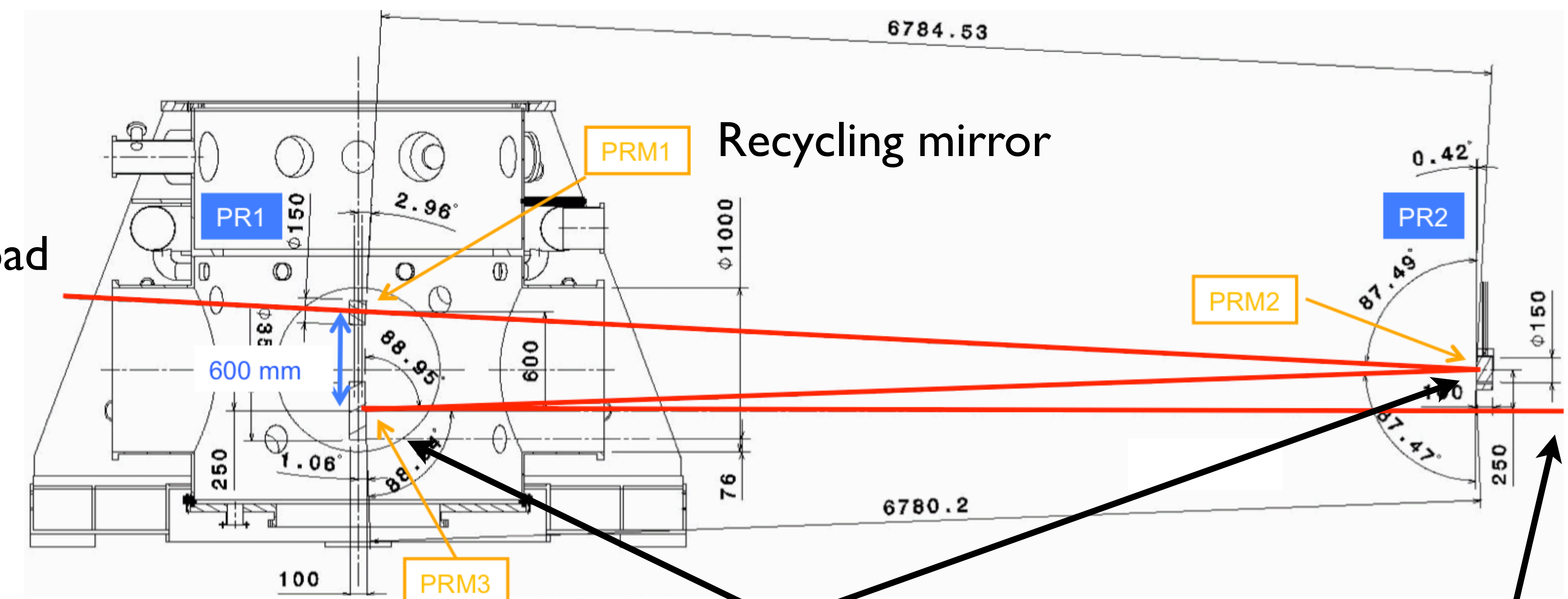
Baseline	Astigmatism
Baseline - 2	BS multipayload
MPAY	technical risk
MSAT	schedule/technical risk
Long cavities	schedule/budget risk

Vertically folded stable cavities (SVC)

All suspensions on superattenuator axis

double mirror payload



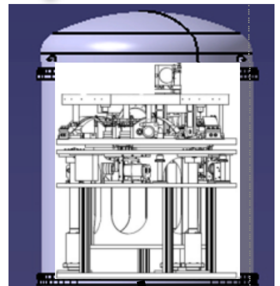


Focusing telescope using spherical mirrors reduce the beam by ~50x

Beam from ITF

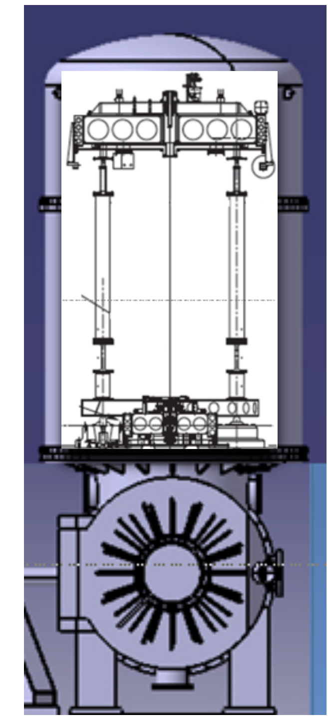
Proposed SVC central building layout

small chamber



new
vacuum
chambers

big chamber

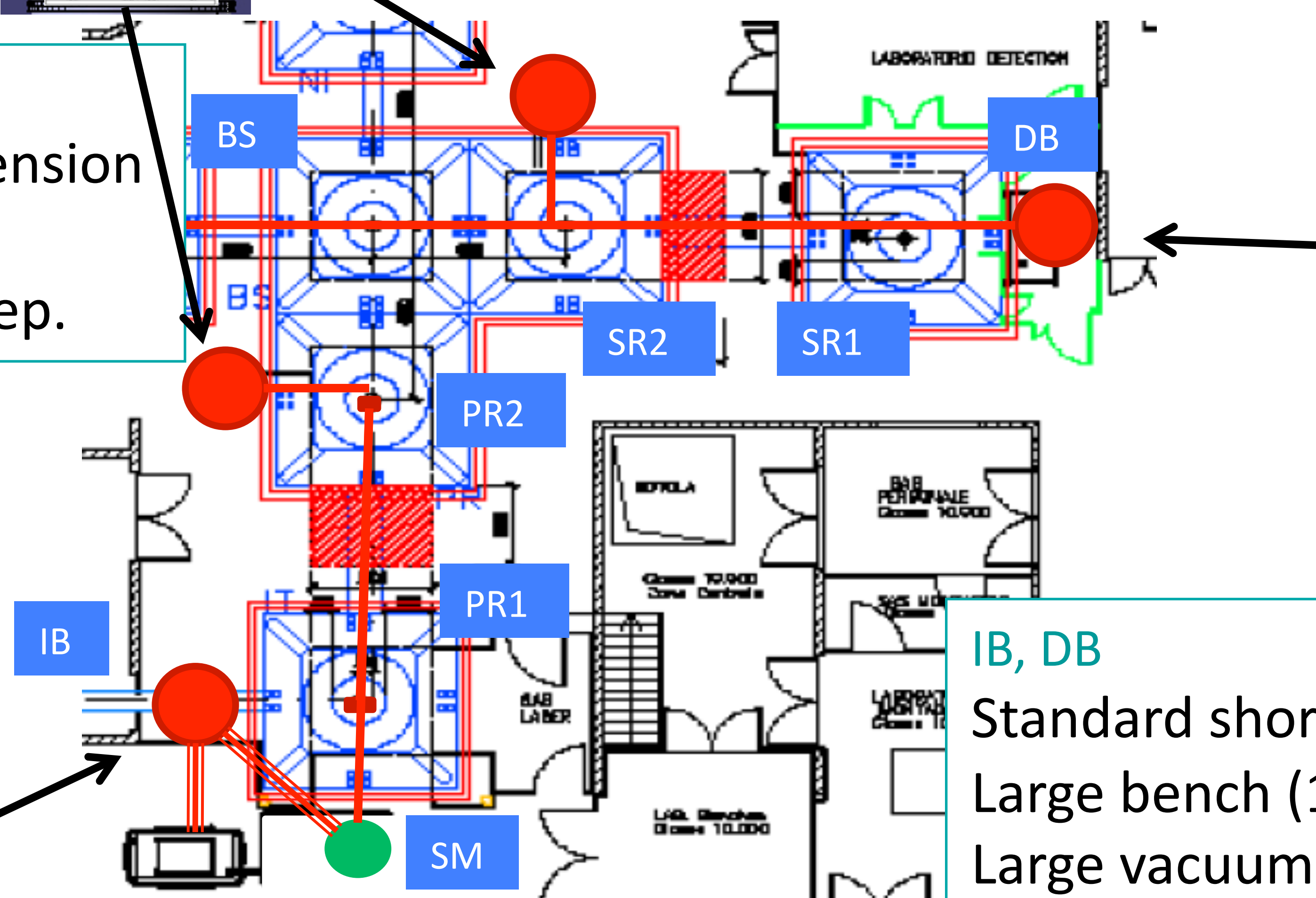


PR2, SR2 pickoffs

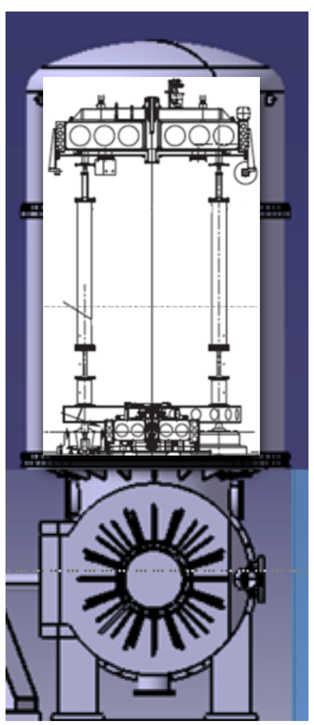
Compact SAS type suspension

Small vacuum chamber

Glass window vacuum sep.



big chamber

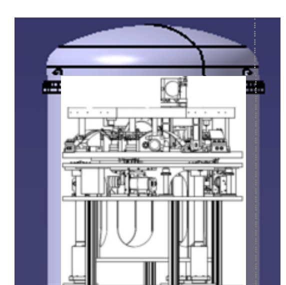


IB, DB

Standard short Virgo suspension

Large bench (1.3x1.3 m)

Large vacuum chamber



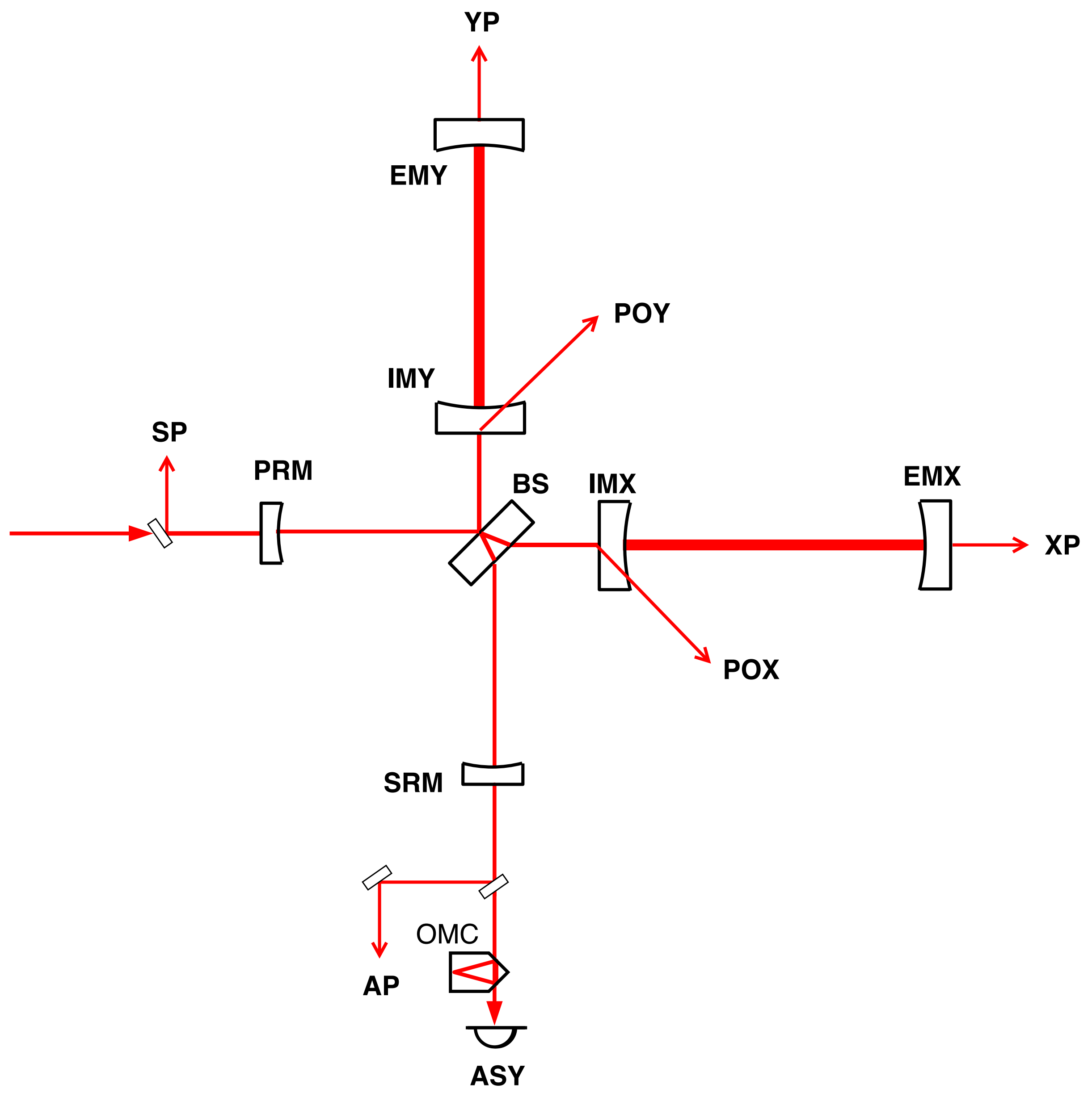
LL steering mirror

Compact SAS type suspension

Small vacuum chamber

MSRC

- The additional vacuum chambers in SVC incur additional budget/ schedule risks.
- At this stage, it was decided to re-evaluate the baseline choice of folded stable cavities by taking a closer look at a design with marginally stable recycling cavities (MSRC).
- Thought to be faster, cheaper, and rely only on proven Virgo technology.



Recycling Cavity Design

Stable or un-stable?

- ✓ Cavities are stable.
- ✓ More resistance to thermal effects.
- Suspensions more complicated.
- Additional vacuum chambers, new clean installation processes needed to fit in available space.
- Additional mirrors to sense and control.
- More expensive.

- Cavities close to instability.
- ✓ Fewer mirrors.
- ✓ More experience with this configuration.
- ✓ Fits in the current infrastructure.
- Pickoff and ghost beams problematic.
- Focusing telescopes critical.
- More sensitive to thermal effects.
- ✓ Less expensive.
- ✓ No mirrors with small RoC.

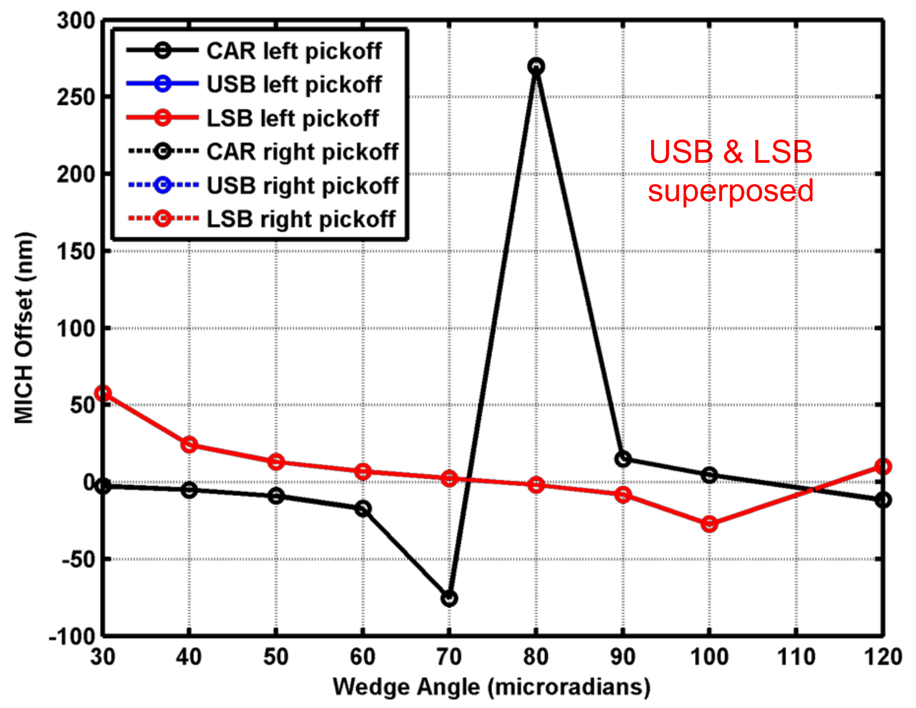
Simulation

- Since the perceived risks of MSRC are optical, a heavy program of simulation was undertaken to study in detail the configuration.
- The risks are perceived to be related almost entirely to the RF sidebands.
- Extraction of pick-off beams for sensing another concern.

Optical simulation tools			
Name	optical config.	language	comments
Modal codes			
Finesse	Advanced Virgo	C	HG based
LMA-code	Advanced Virgo	Octave	LG based
MIST	Advanced Virgo	Matlab	HG based
FFT codes			
DarkF	Virgo	Fortran90	
Siesta-FFT	simple cavity	C	
SIS	double cavity	C	
R. Day code	CITF	matlab	
OSCAR	Advanced Virgo	matlab	
Radiation pressure codes			
Optickle	Advanced Virgo	Matlab	only 2 modes

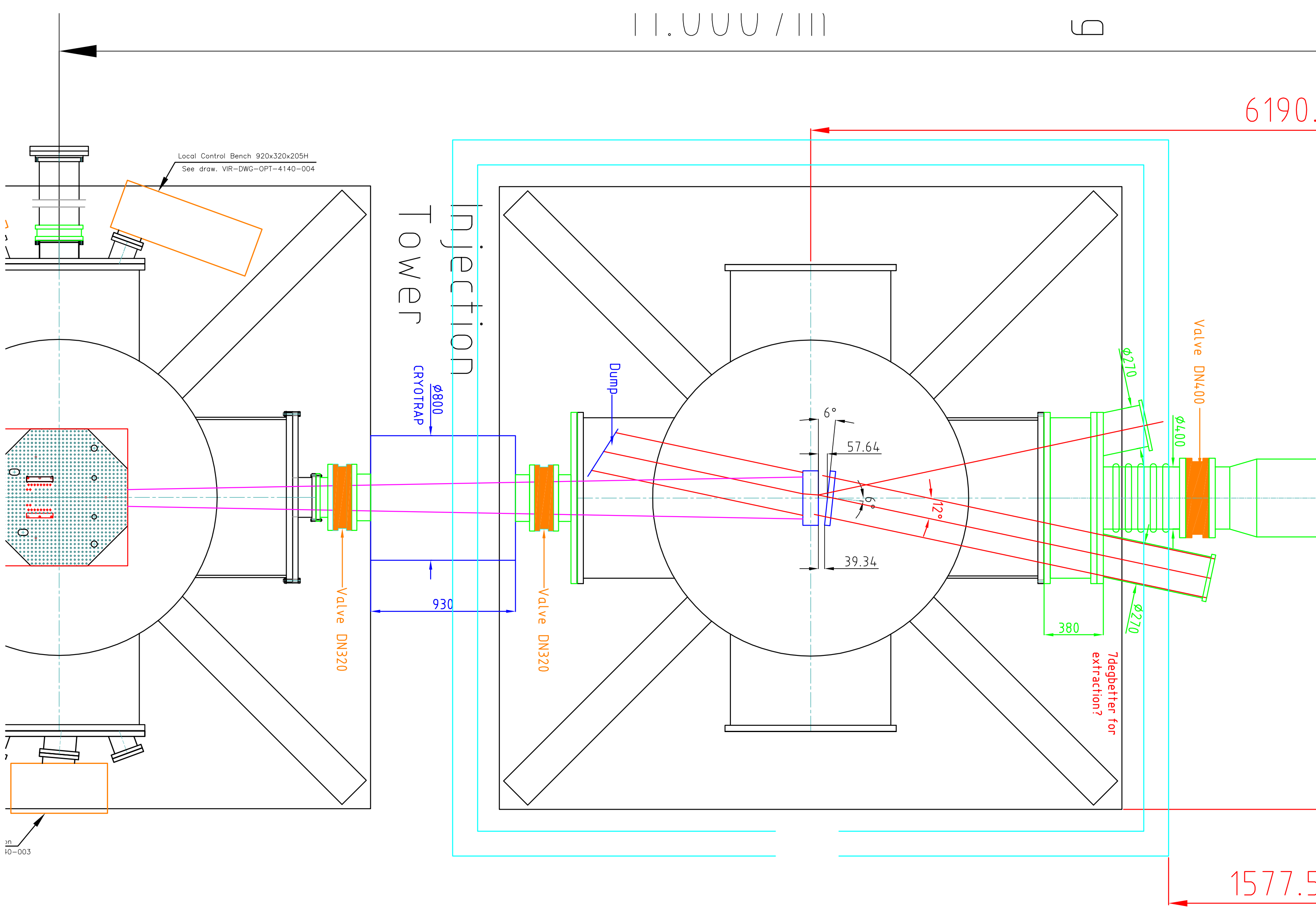
Pick-offs

- How to extract pick-off beams when the beams are large everywhere?
- Initial solution is small wedges in the input mirrors.
- Studied with matlab-based FFT code.
- Causes offsets in control signals. Idea discarded.



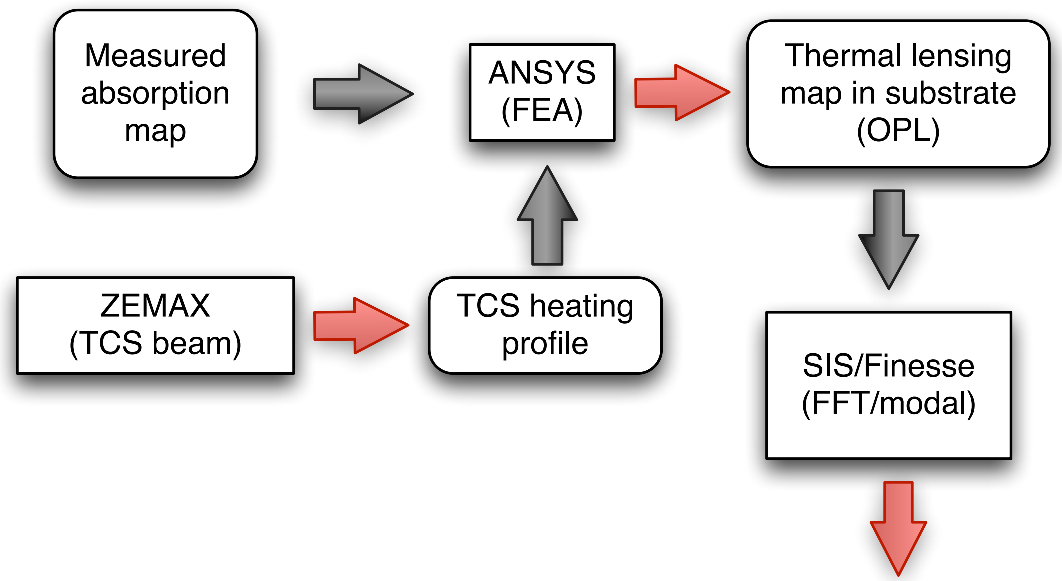
Pick-offs 2

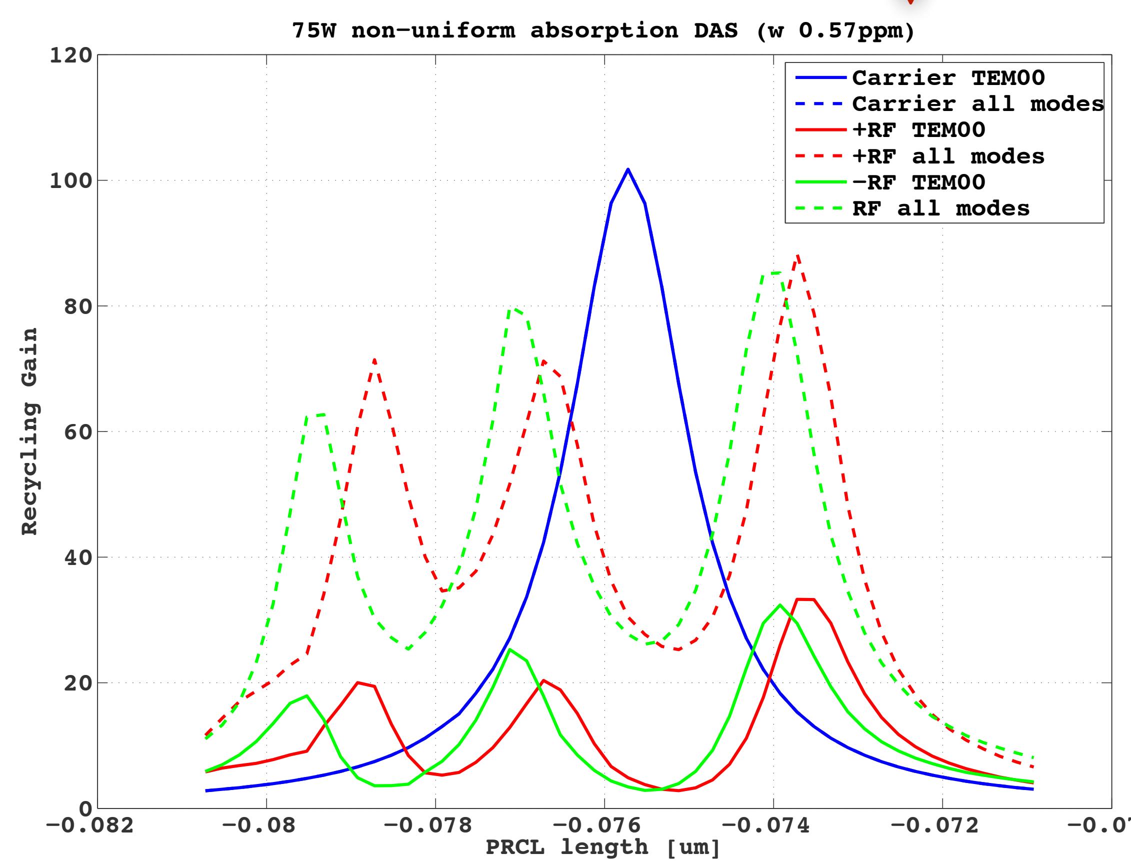
- A new plate suspended in front of the PRM is the current solution.
- Tilted by 6 degrees.
- Suspension similar to compensation plate.



Thermal Effects

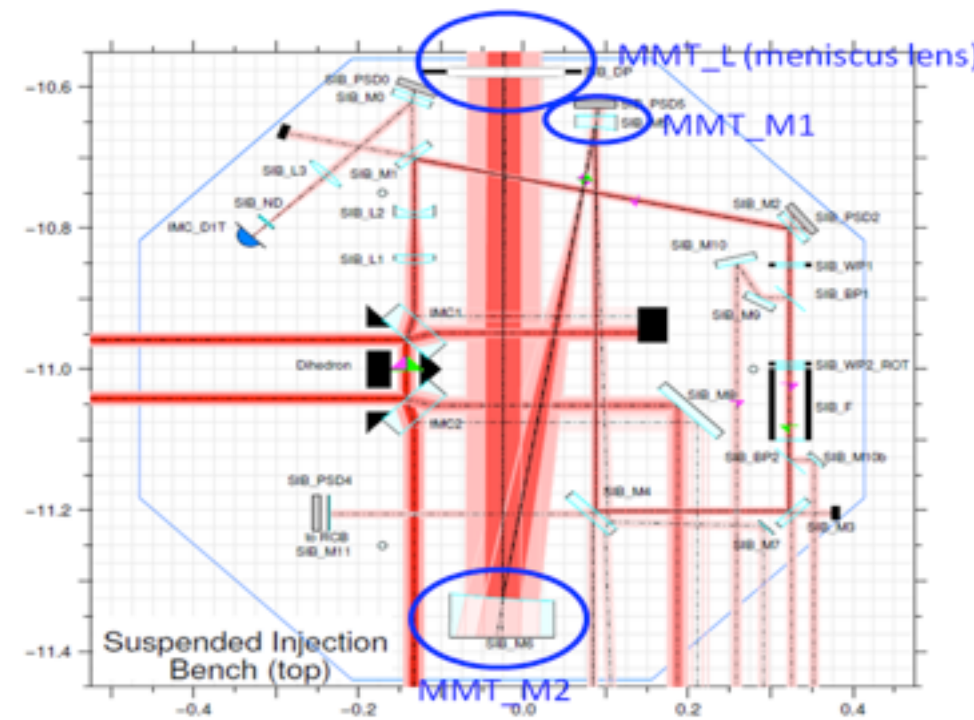
- Thermal effects studied with many different tools.
- Non-uniform coating absorption leads to significant sideband degradation.
- Non-axisymmetric TCS will be necessary.

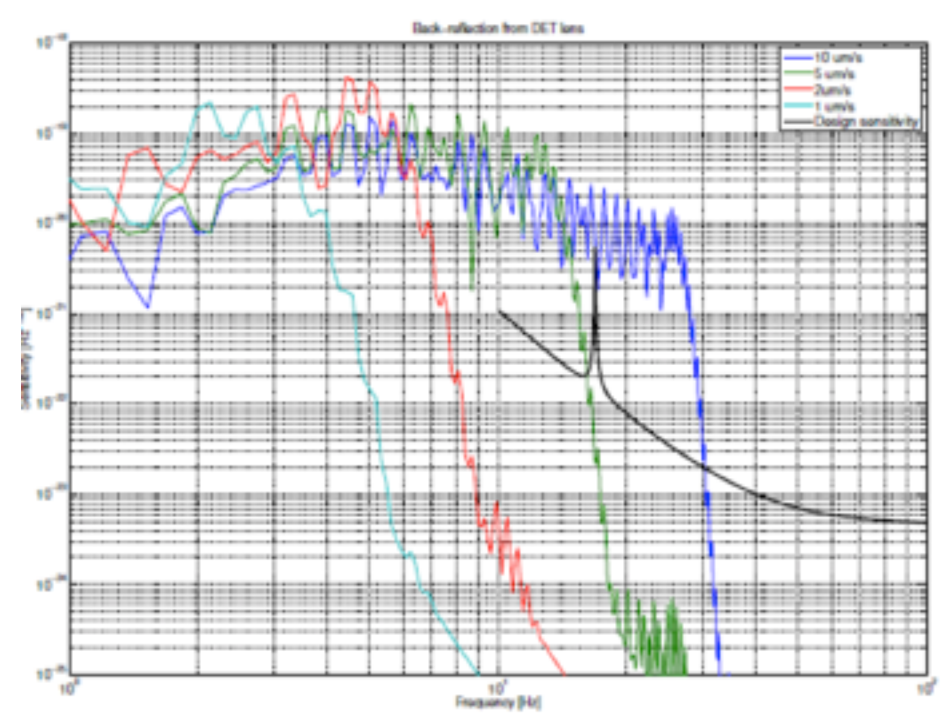




Telescopes

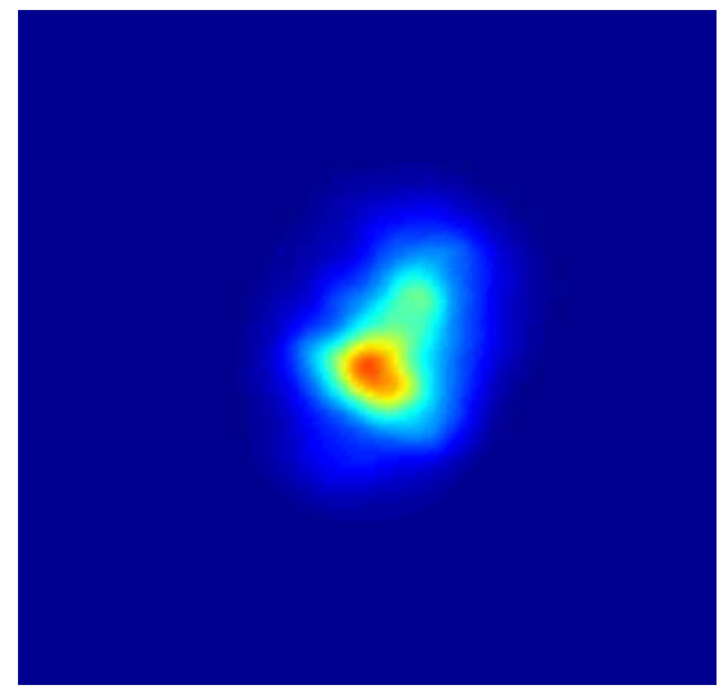
- With the large beams in the recycling cavity, the design of beam reducing telescopes is critical.
- Finesse/Optickle combination used to study upconversion of backscattered light from lens (10^{-11} with 50ppm AR surface) in catadioptric solution.





Mirror figure errors

- Impact of mirror figure errors studied with SIS.
- Even high-quality polishing (corrective coating) on the PRM leads to large sideband losses and aberrations in the recycling cavity.
- Losses depend on recycling gain. Need to lower recycling gain.

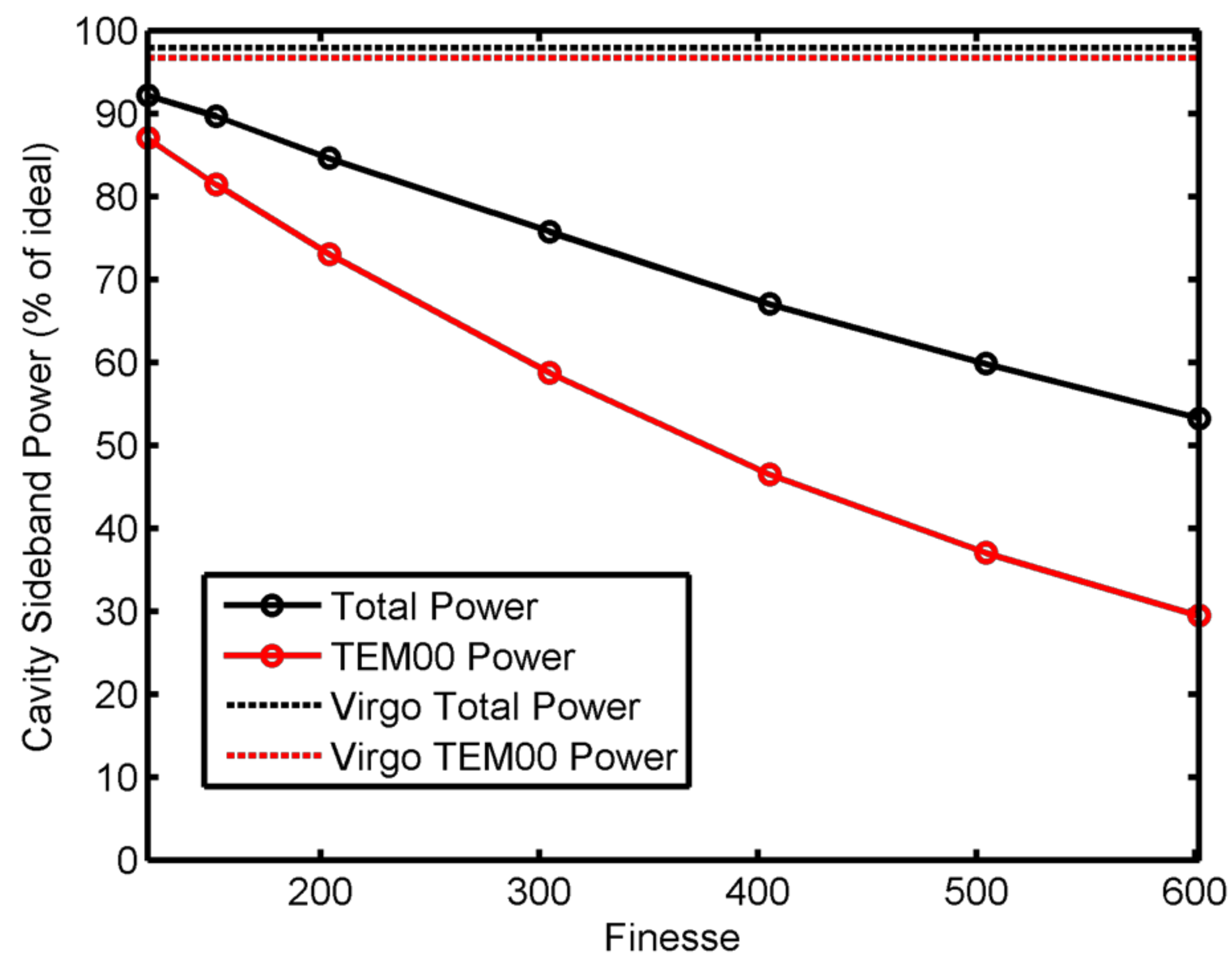


RFSB field in recycling cavity

Degeneracy mitigation

- Lowering the recycling gain can at least partially mitigate the effects of degeneracy in the recycling cavity.
- Recycling cavity becomes less sensitive to imperfections and aberrations.

FFT simulation of CITF

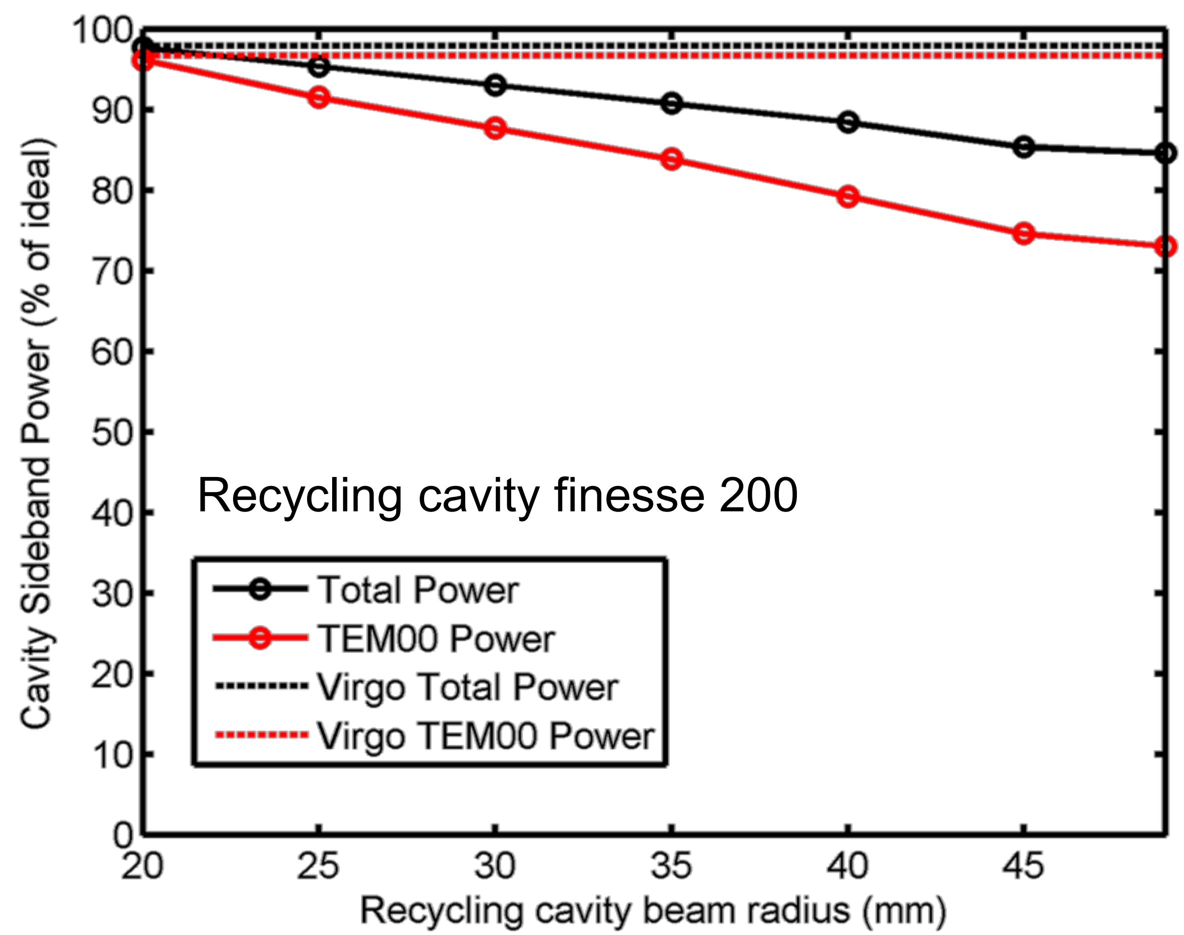


Losses due to mirror figure errors only. No thermal or index defects included.

Degeneracy mitigation 2

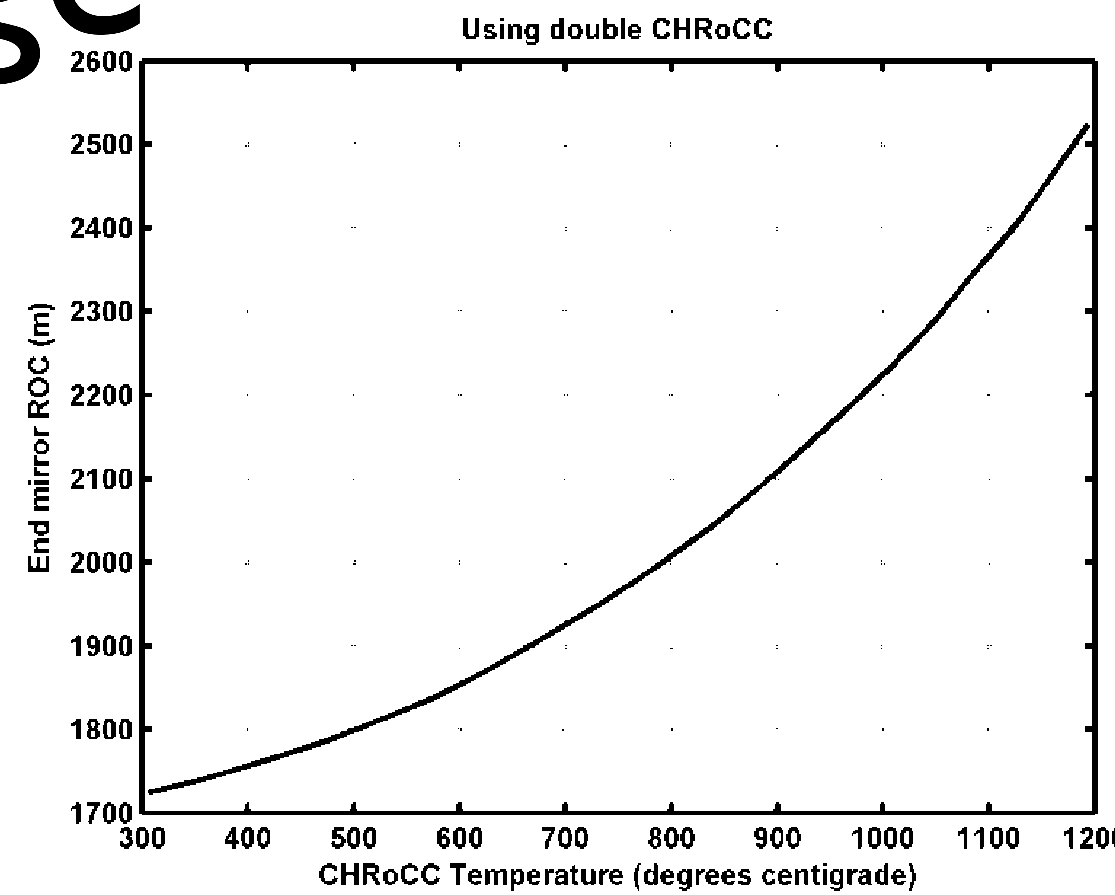
- The other additional factor is the recycling cavity Gouy phase.
- The beam size in the recycling cavity can be changed by changing the RoC of arm cavity end mirror (cf. R. Day's presentation on CHRoCC).

FFT simulation of CITF

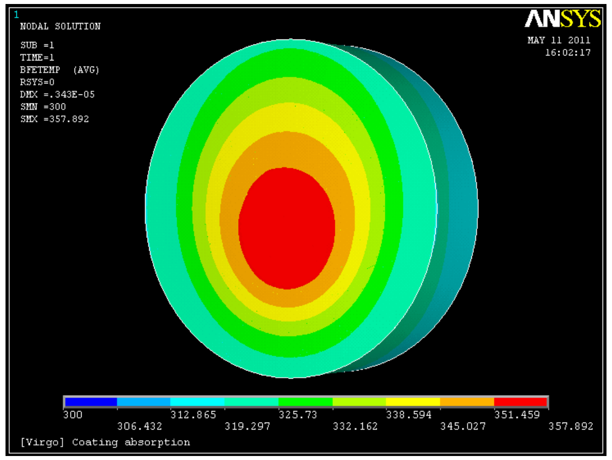


Losses due to mirror figure errors only. No thermal or index defects included.

RoC change dynamic range



- The system has enough dynamic range to bring the beam width in the recycling cavity down to that of Virgo.
- This allows a commissioning start with an ITF very similar to Virgo+.
- Beam size can be gradually increased as commissioning proceeds and we master the challenges.



Current Design

- After much deliberation and carefully weighing the risks, the collaboration has decided on the MSRC configuration.
- This is thought to allow earlier data taking with a smaller budget, in part by allowing a start to commissioning with a familiar configuration.

Summary

- The Advanced Virgo optical design has been a long process, guided my many people using many different simulation tools.
- The infrastructure constraints impel topologies similar to Virgo ➔ MSRC.
- New developments in mirror correction technologies give us some confidence in our ability to handle problems related to degeneracy.