Stable Recycling Cavities for Advanced LIGO

LIGO-G050423-00-Z

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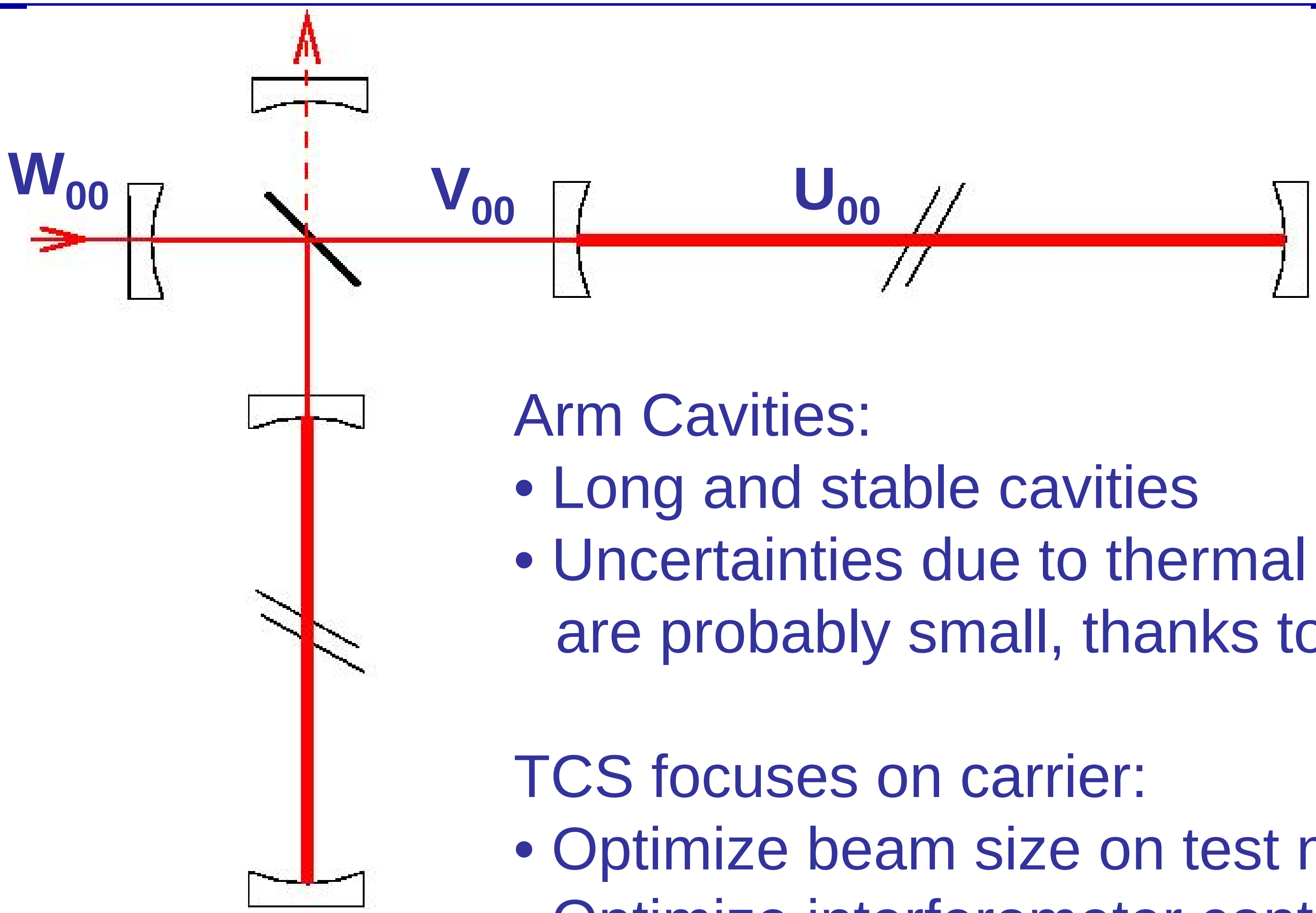
Advanced LIGO



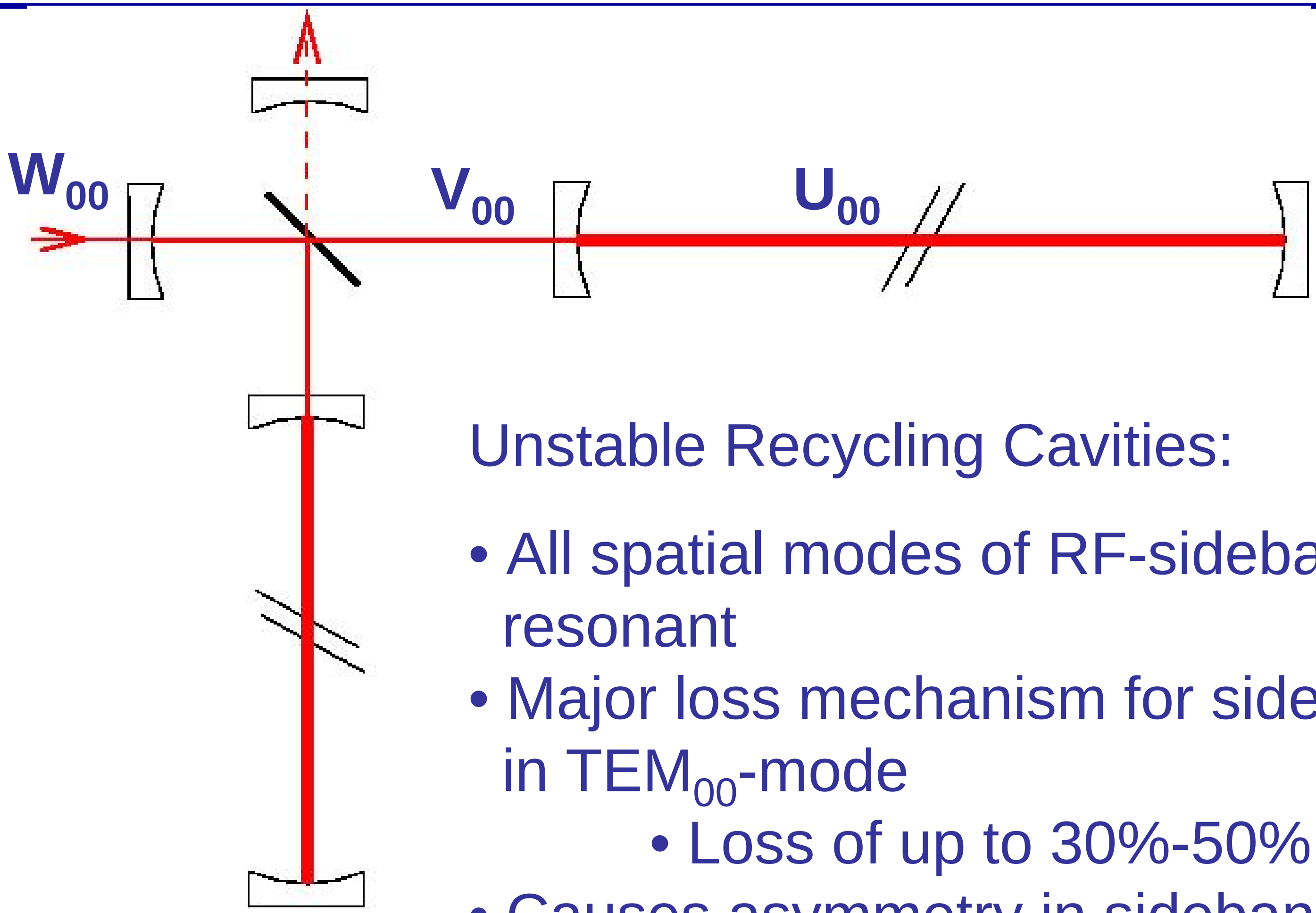
Arm Cavities:

- Long and stable cavities
- Uncertainties due to thermal lensing are probably small, thanks to TCS

TCS focuses on carrier:

- Optimize beam size on test masses
- Optimize interferometer contrast
- Optimize mode matching(?)

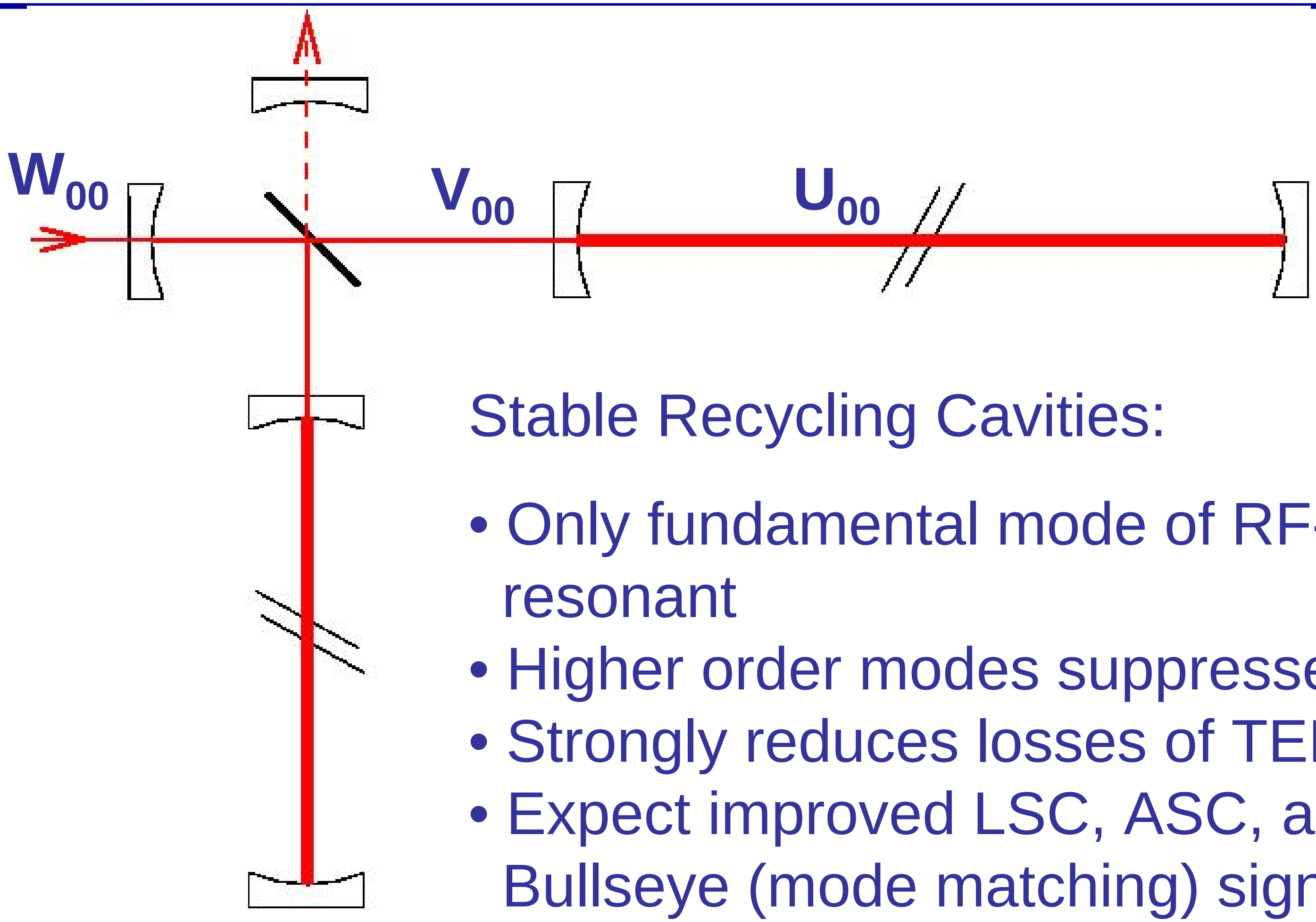
Advanced LIGO



Unstable Recycling Cavities:

- All spatial modes of RF-sidebands resonant
- Major loss mechanism for sidebands in TEM_{00}-mode
    - Loss of up to 30%-50%
- Causes asymmetry in sidebands in LIGO I
- Impact on LSC and ASC

Advanced LIGO



Stable Recycling Cavities:

- Only fundamental mode of RF-sidebands resonant
- Higher order modes suppressed
- Strongly reduces losses of TEM_{00}-mode
- Expect improved LSC, ASC, and even Bullseye (mode matching) signals
- Interferometer will be much easier to understand and debug

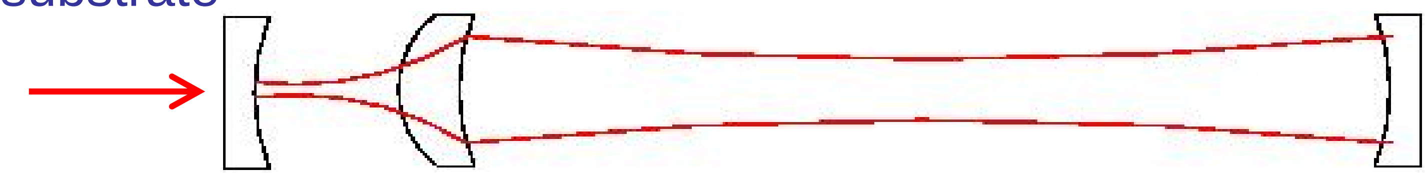
Stable Rec. Cavities

How?

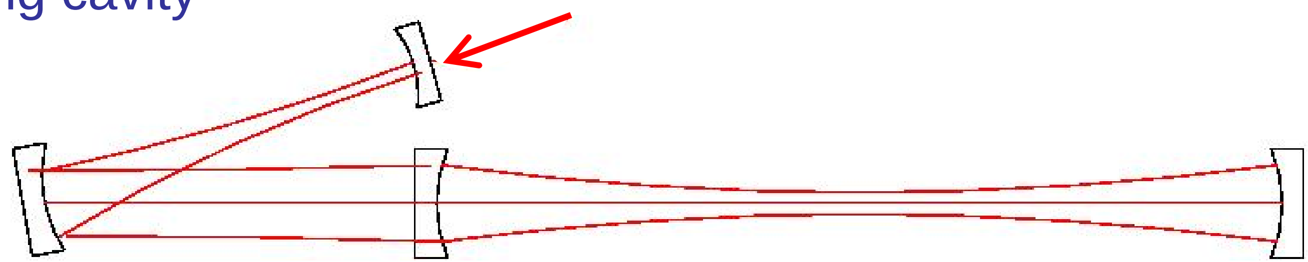
Need to have one mirror inside the Rayleigh range of the TEMs

Possible Solutions:

1. Lens in ITM substrate



2. Two mirror Recycling cavity



Problem:

Creates sub mm beam size on Recycling mirror (~ 10 GW/m^2)

Divergence angle:

α ~6cm/10m ~6mrad

Waist: $w_0=\lambda/\pi\alpha$ ~ 60μm

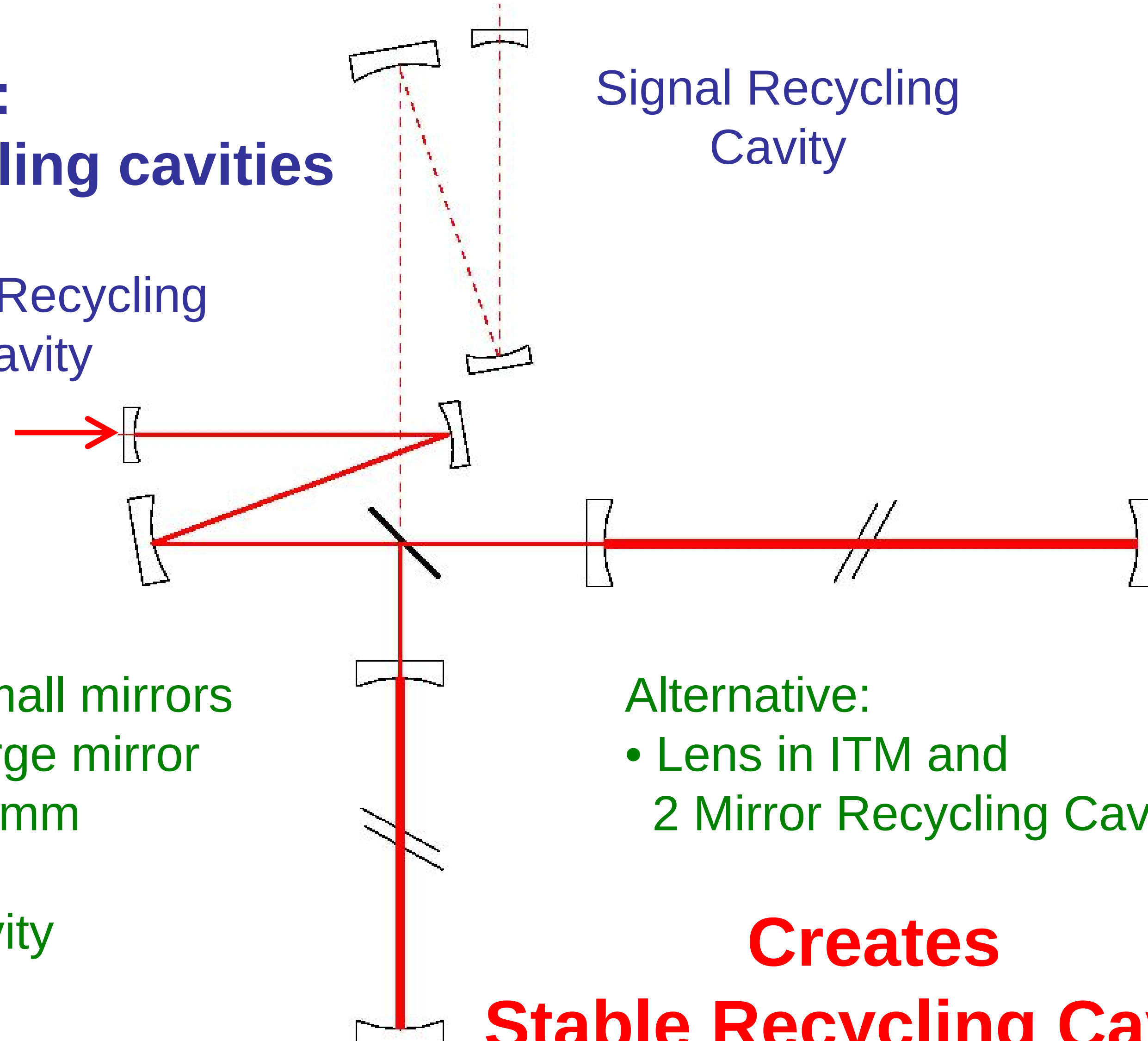
LIGO

Solution 3

Third option:
folded recycling cavities

Signal Recycling Cavity

Power Recycling Cavity



Design adds:

- 2 additional small mirrors
- Removes 1 large mirror
- Beam size > 2mm

Same for SR-Cavity

Alternative:

- Lens in ITM and 2 Mirror Recycling Cavity

Creates Stable Recycling Cavity

Design Drivers

- ✓ Spot Size
- Seismic Isolation
- Flexibility in mode matching
- Alignment
- Vacuum envelope
- …

Seismic Isolation

Requirements on single PR-mirror [1] :

- $3x10^{-16}$ m/rHz
  - Driven by frequency noise
    - For RF sensing
    - DC sensing should be factor 10 less critical (?)
  - Safety margin: 30
    - Additional factor 3 to get below noise from cavity mirrors

Target stability:

- $3x10^{-17}$ m/rHz
  - Same suspension than Mode cleaner mirrors (triple pendulum)

Necessary changes for New Recycling cavity:

- Move large PR substrate in triple pendulum to MMT3 location
- First small PR mirror in MC-triple pendulum on IO-table
- Second small PR mirror in MC-triple pendulum on PR-table
- Mode matching from MC into Recycling cavity might add two additional small mirrors (single pendulum suspension)

[1] Sources: Seimic Isolation Subsystem Design Requirements Document E990303-03-D
Advanced LIGO Systems Design T010075-00-D

Design Drivers

- ✓ Spot Size
- ✓ Seismic Isolation
- Flexibility in mode matching
- Alignment
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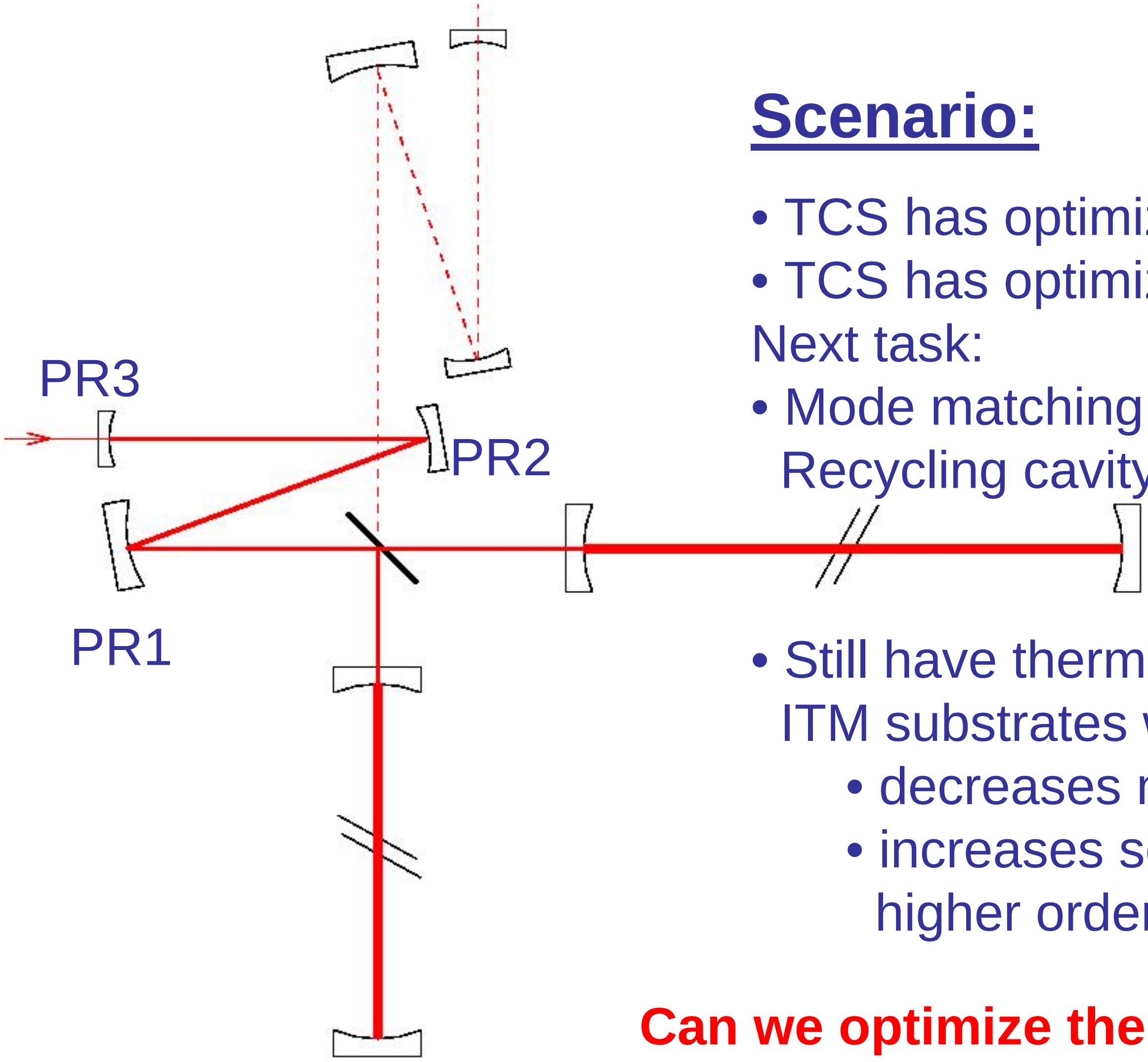
- …

Modematching



Scenario:

- TCS has optimized beam size in arms
- TCS has optimized contrast in MI

Next task:

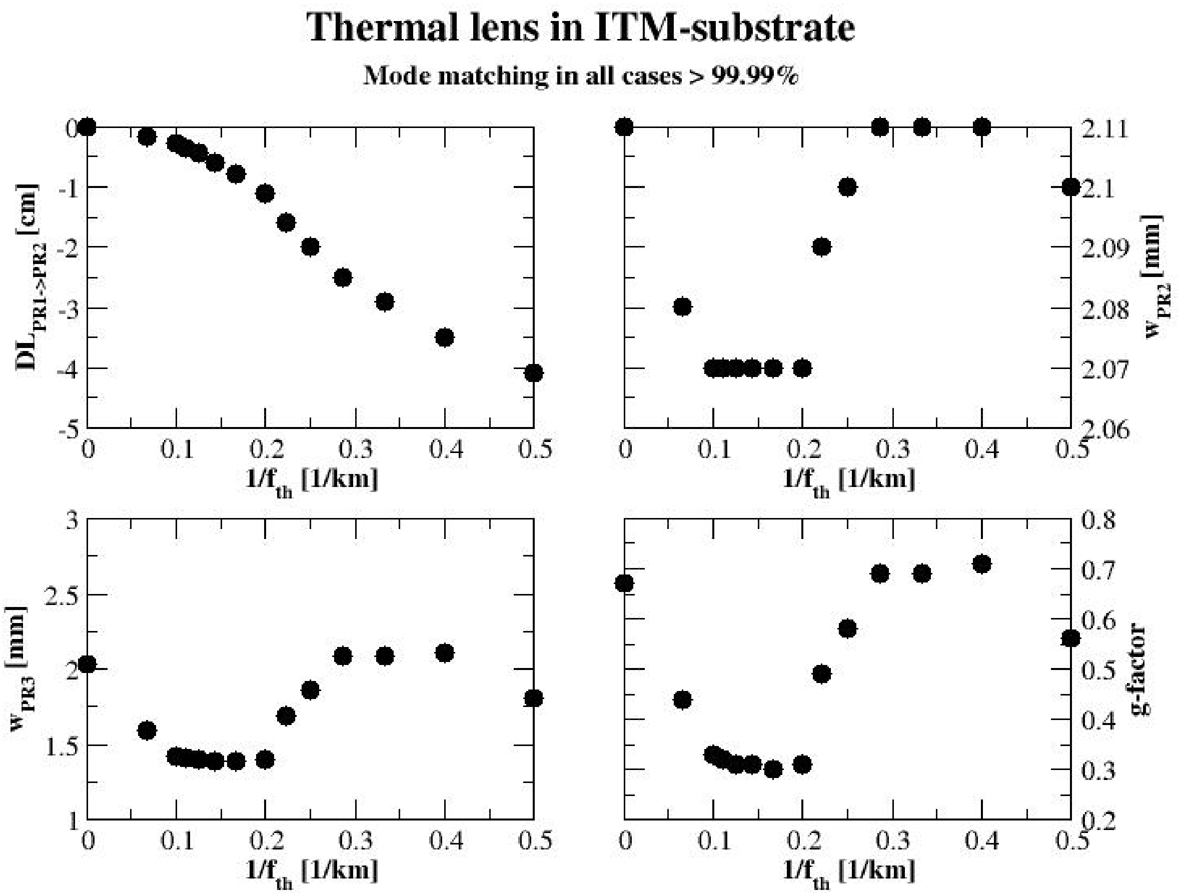
- Mode matching between Recycling cavity and arm cavities.

- Still have thermal lens in BS and/or ITM substrates which
  - decreases mode matching
  - increases scattering into higher order modes

Can we optimize the mode matching after we know the thermal lens ?

Modematching

Can we optimize the mode matching after measuring the thermal lens?



Yes!

Even without changing the length of the recycling cavity

How?

- Change distance between PR1 and PR2 until mode matching is optimized
- Compensate change in the length by moving also PR3

Alternative: Adaptive mode matching which changes ROC's (see Quetschke et al.)

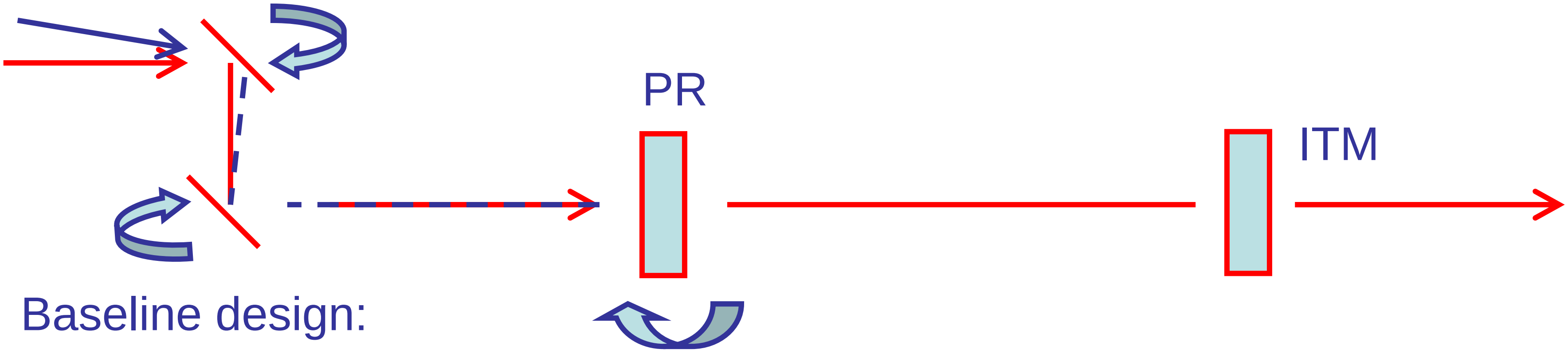
Design Drivers

- ✓ Spot Size
- ✓ Seismic Isolation
- ✓ Flexibility in mode matching
- Alignment
- Vacuum envelope
- …

Alignment Issues

Question:
Do we need to worry about additional alignment d.o.f as we have now more mirrors?

- Arm cavities are equal, no difference
- Any difference in Recycling Cavity?



Baseline design:

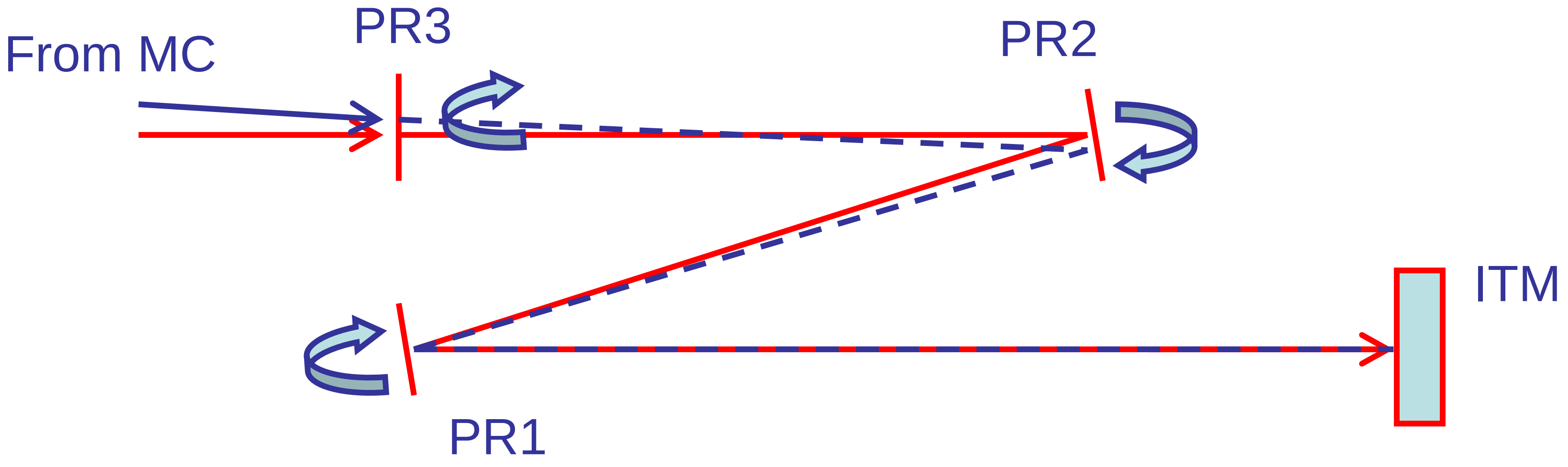
- Align orientation of PR
- Align propagation direction and position of Input beam

Total: 3 d.o.f. in horizontal and 3 d.o.f. in vertical direction

Alignment Issues

Alignment defined by arm cavity:

- Find position on PR1
- Propagation direction from PR1 to ITM1



Change in Input beam requires adjustment of 3 d.o.f. in each direction!
Other Option: Align input beam and only one of the PR mirrors.

Alignment Issues

Alignment sensing matrix: (Work in progress)

- Wrote program to calculate alignment sensing matrix for Advanced LIGO w. and w/o stable recycling cavities
- Signals: Carrier-9MHz, Carrier-180MHz, and SB-SB (at 171MHz) signal
  - Need to add 171MHz SB for series modulation

Intermediate (premature) results:

For Baseline Design:

- Difficult to distinguish between PR and ITM tilts (same Gouy phase)

For New Design:

- Same problem between PR1 and ITM tilts
- Easy to distinguish between PR2, PR3 tilts and ITM tilts

Preliminary conclusion:

Advantage for new design: Larger linear range in ASC-signals

Disadvantage: ?

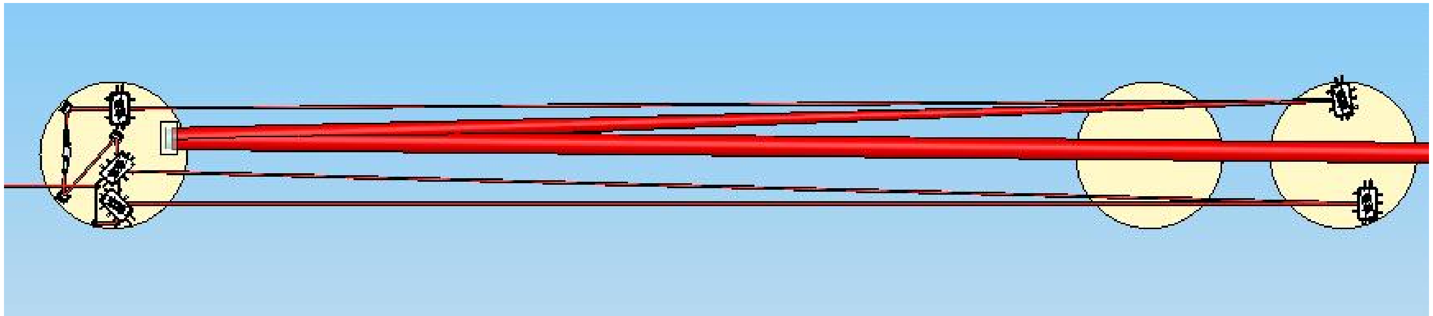
Design Drivers

- ✓ Spot Size
- ✓ Seismic Isolation
- ✓ Flexibility in mode matching
- ✓ Alignment
- Vacuum envelope
- …

Vacuum Envelope

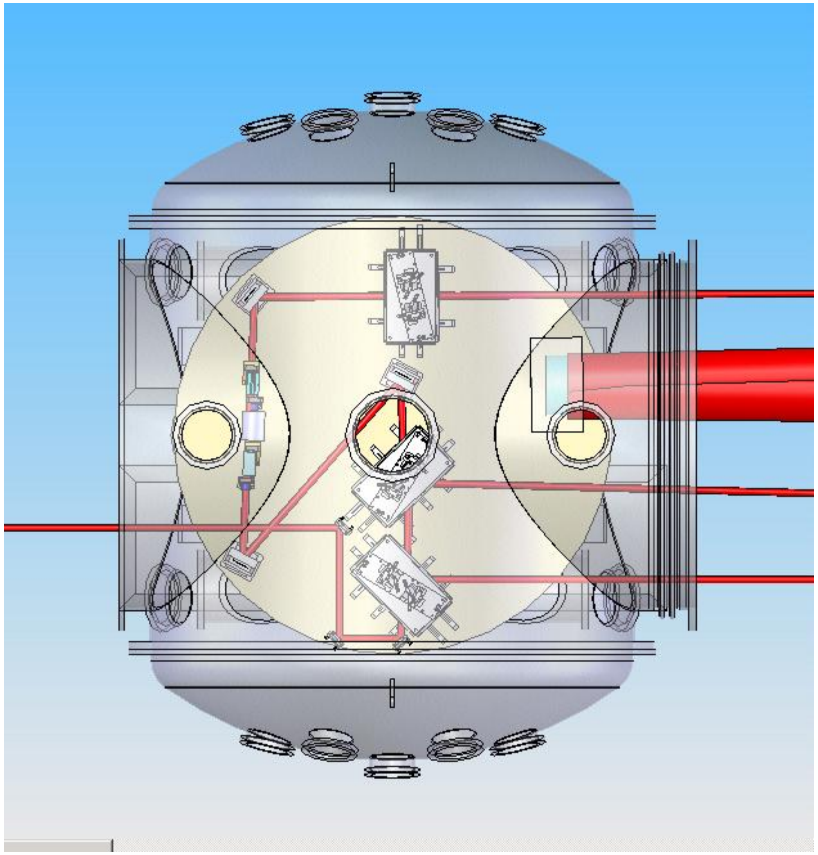
Top View:

HAM 1 HAM2 HAM3



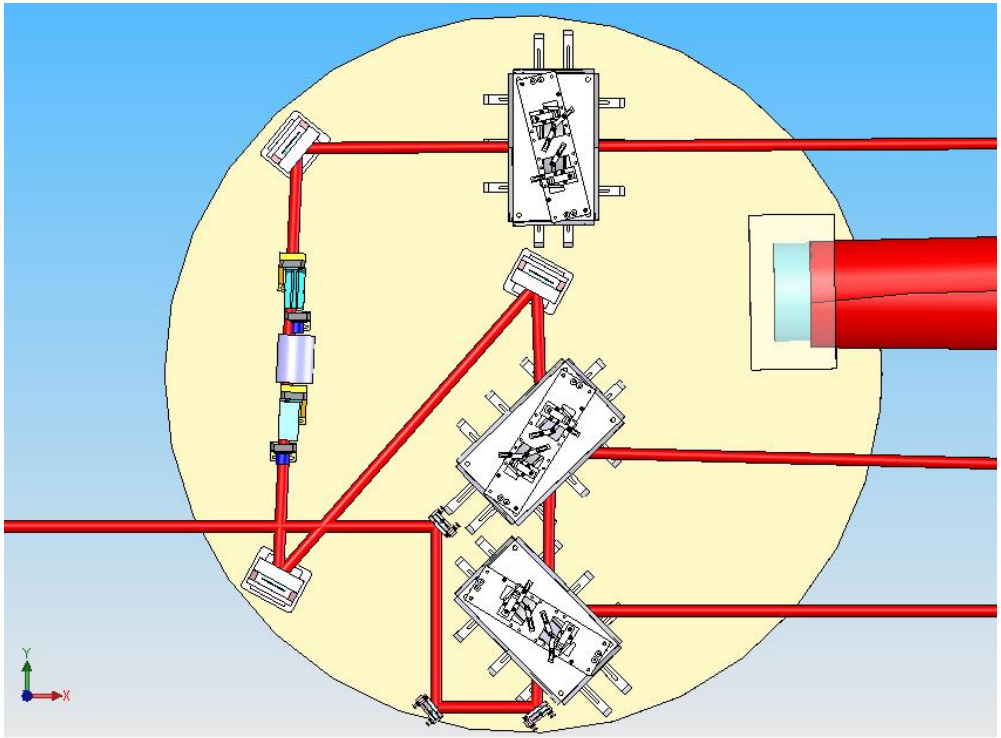
Vacuum Envelope

Top View:
HAM 1



Vacuum Envelope

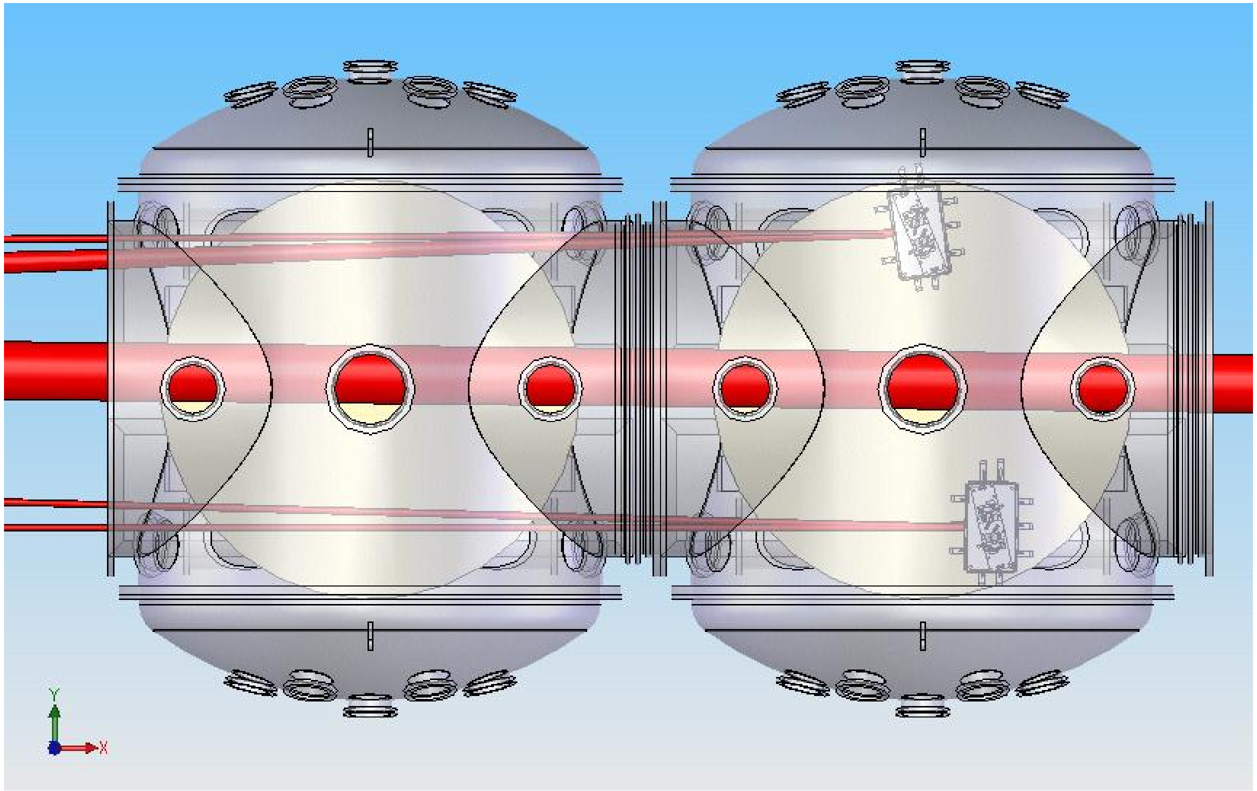
Top View:
HAM 1



Vacuum Envelope

Top View

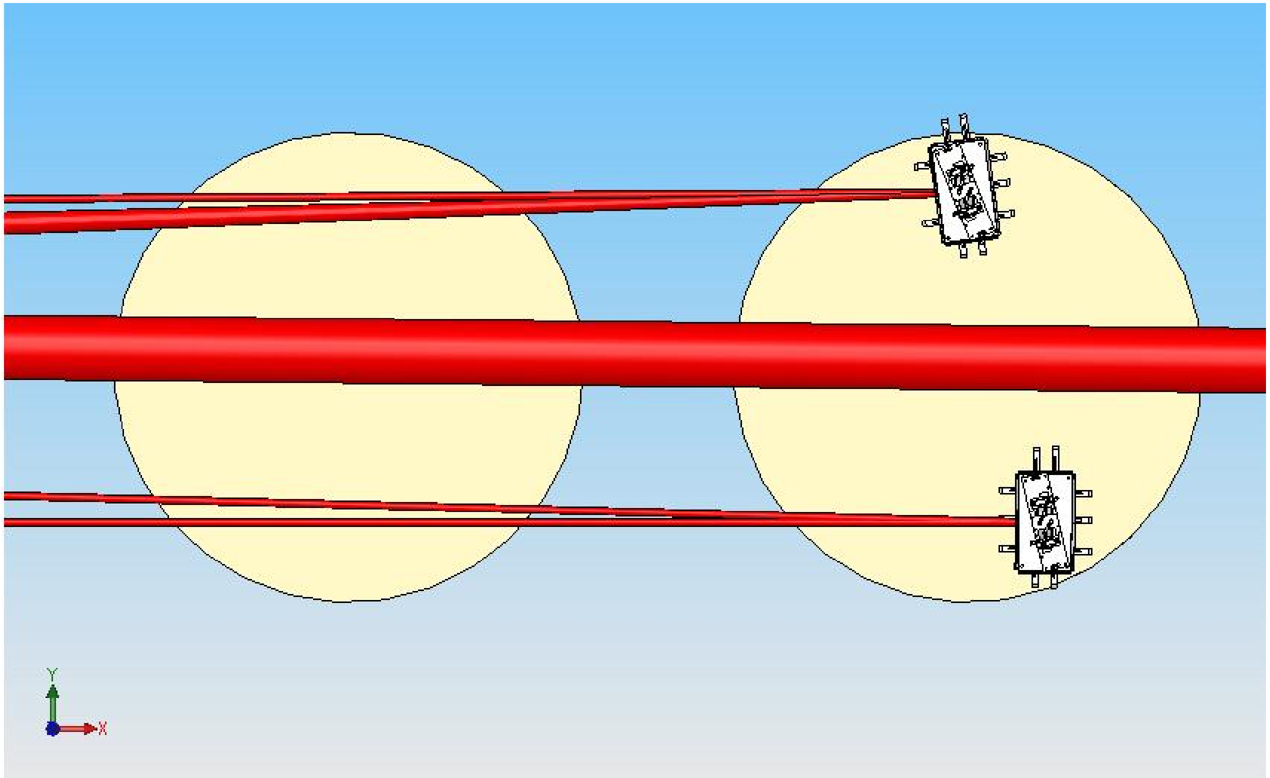
HAM 2 HAM 3



Vacuum Envelope

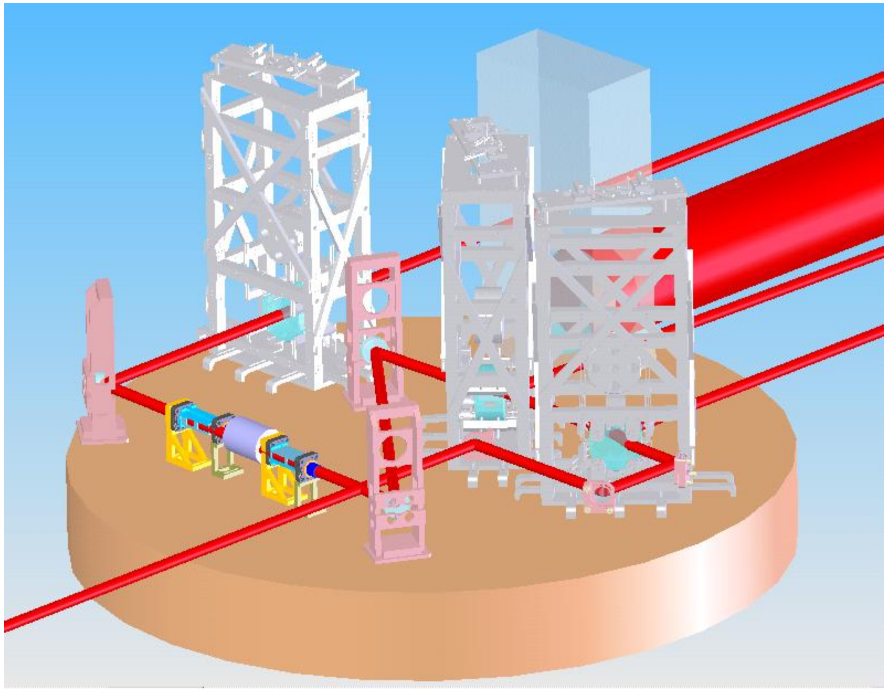
Top View

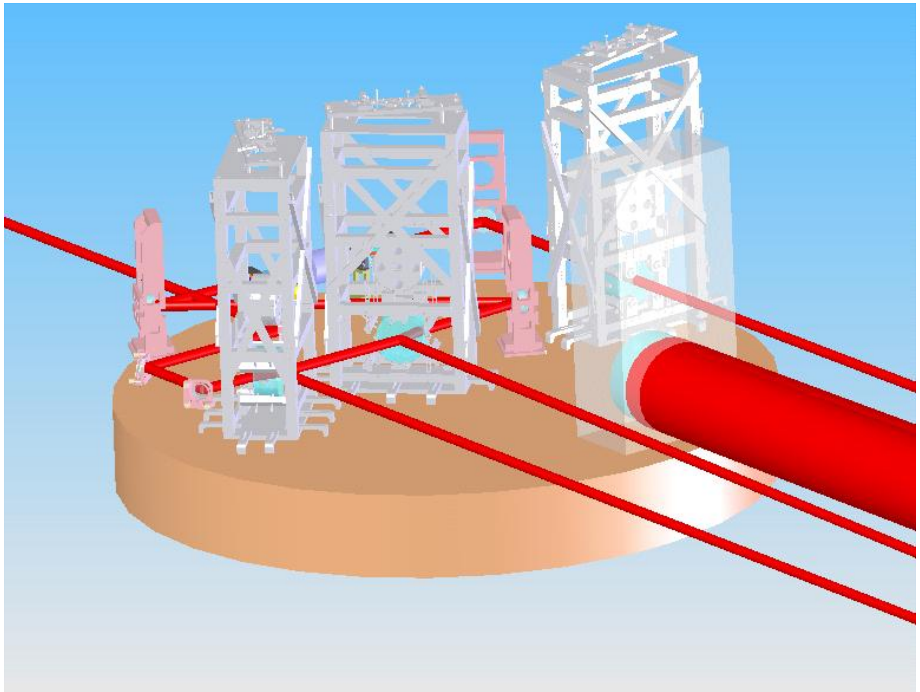
HAM 2 HAM 3



Vacuum Envelope

Side Views from HAM 1

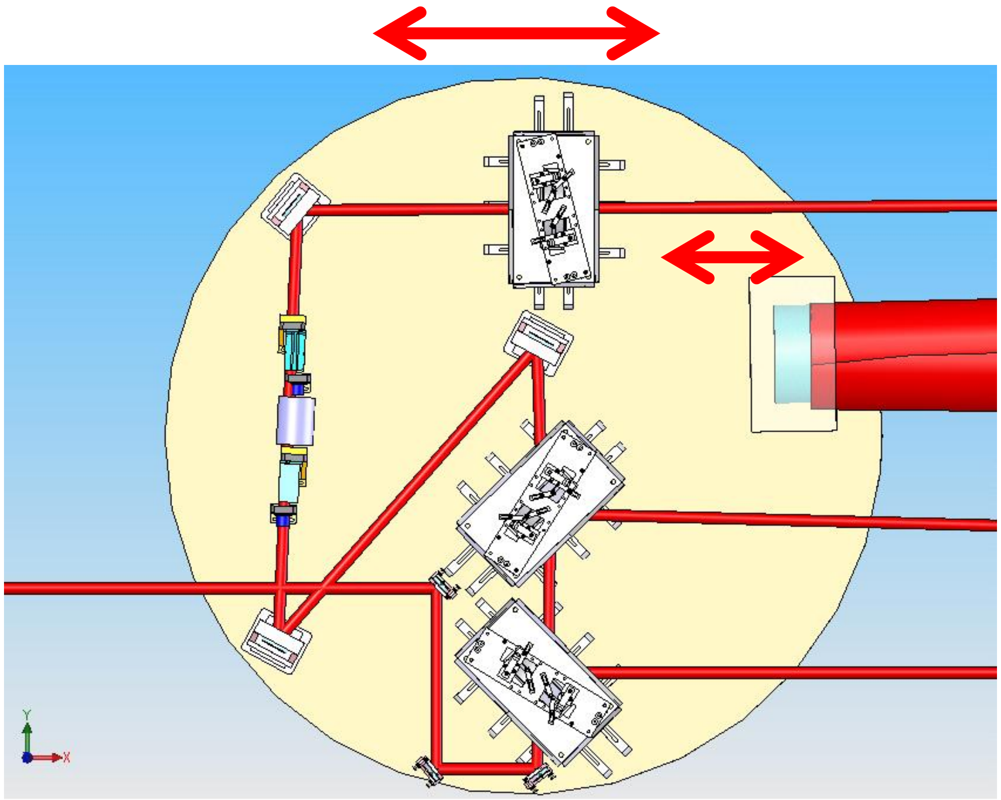




Vacuum Envelope

Top View:

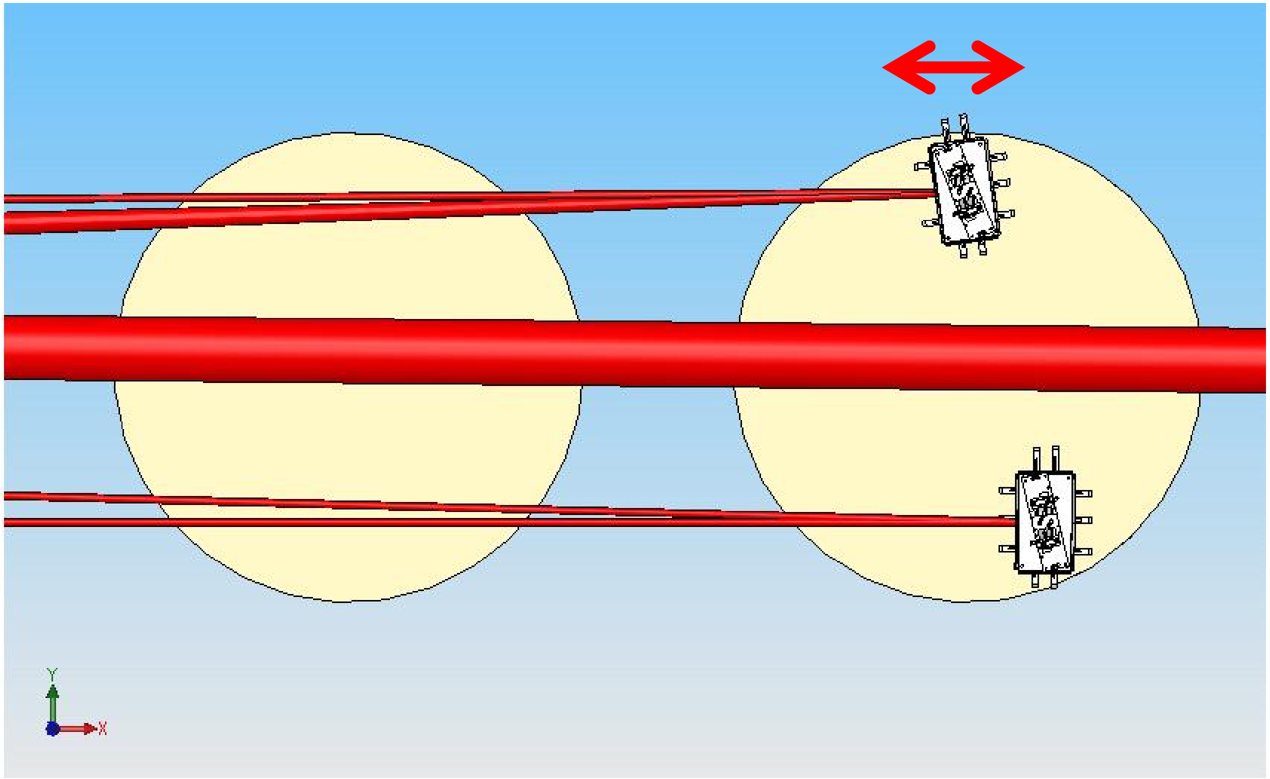
Plenty of space for mode matching adjustments



Vacuum Envelope

Top View

Plenty of space for mode matching adjustments



Design Drivers

- ✓ Spot Size
- ✓ Seismic Isolation
- ✓ Flexibility in mode matching
- ✓ Alignment
- ✓ Vacuum envelope
- …

Conclusions

Stable Recycling Cavity (SRC):

- Suppresses higher order modes of the RF-sidebands
- Increases Power in fundamental mode of sidebands
- Also advantages for the signal sidebands (see Yi Pan[1])
- Improves alignment sensing (larger linear range of ASC signals)
- Adds flexibility for mode matching
- Eases requirements on some technical noise sources

Baseline Recycling Cavity:

- Fewer Components (SRC has more small mirrors, one less large mirror)
- Fewer triple suspensions

Costs:

- Hardware costs probably higher for stable recycling cavity
    - Should fit in current vacuum envelope
- Expect shorter commissioning time for stable recycling cavity design
    - Higher order mode contamination often limits diagnostics

[1] Yi Pan/G.M. talk last LSC meeting: G050215-00-Z

Summary

Situation:

- Advantages seem to be obvious although difficult to quantify
- No major disadvantages (if any at all)

What else can we do?

- Thermal model (Melody, Finesse, …). On its way.
  - Very likely outcome:
    RF-sidebands are stable as higher order modes are suppressed
- Get ASC matrix. On its way.
  - Very likely outcome:
    No real difference between both designs except
    increase in linear range
- Bullseye matrix (nearly identical to ASC code)
  - Expected outcome: Similar to ASC results
- Requests?

[1] Yi Pan/G.M. talk last LSC meeting: G050215-00-Z