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Stable recycling cavities
LIGO-G080113-00-I

Guido Mueller, Muzammil Arain

with input from:
Hiro Yamamoto, Peter Fritschel, Mike Smith, Volker Quetschke, Eric Gustafson, Dennis Coyne, GariLynn Billingsley, Luke Williams, David Tanner, Dave Reitze, ...

Stable Recycling Cavities

After long discussions

and looking at this under

all possible and

impossible angles:

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Stable Recycling Cavities

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After long discussions

and looking at this under

all possible and

impossible angles:

We (Peter Fritschel, Hiro Yamamoto, Mike Smith, Eric Gustafson, Muzamil Arain, Volker Quetschke, Luke Williams, Rodica Martin, G.M.) had a final meeting early Feb in Gainesville for a final discussion and decided:

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Stable Recycling Cavities

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We want them!

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Table of Content

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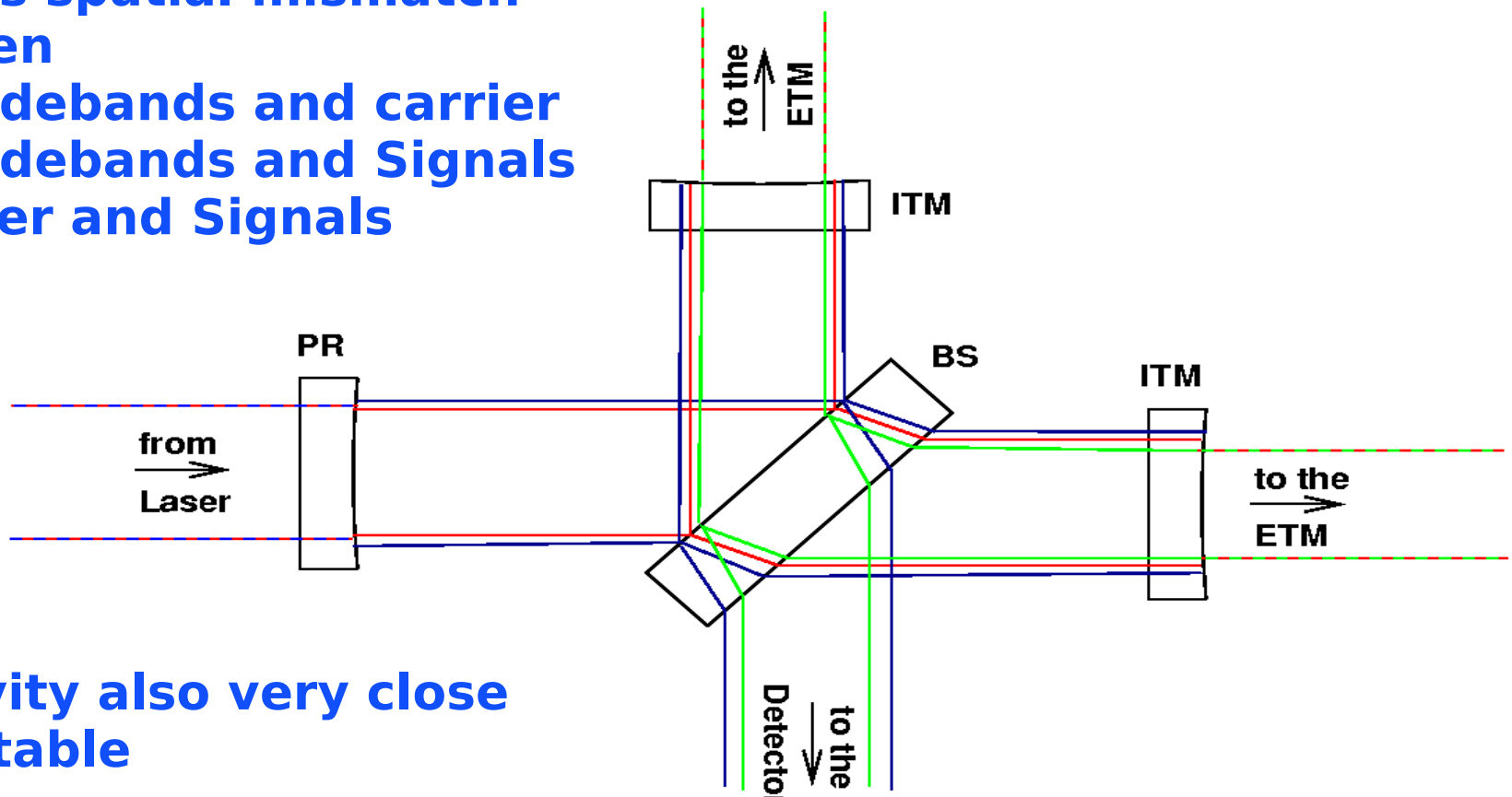
Current LIGO

Power recycling cavity accepts any spatial mode. Creates spatial mismatch between

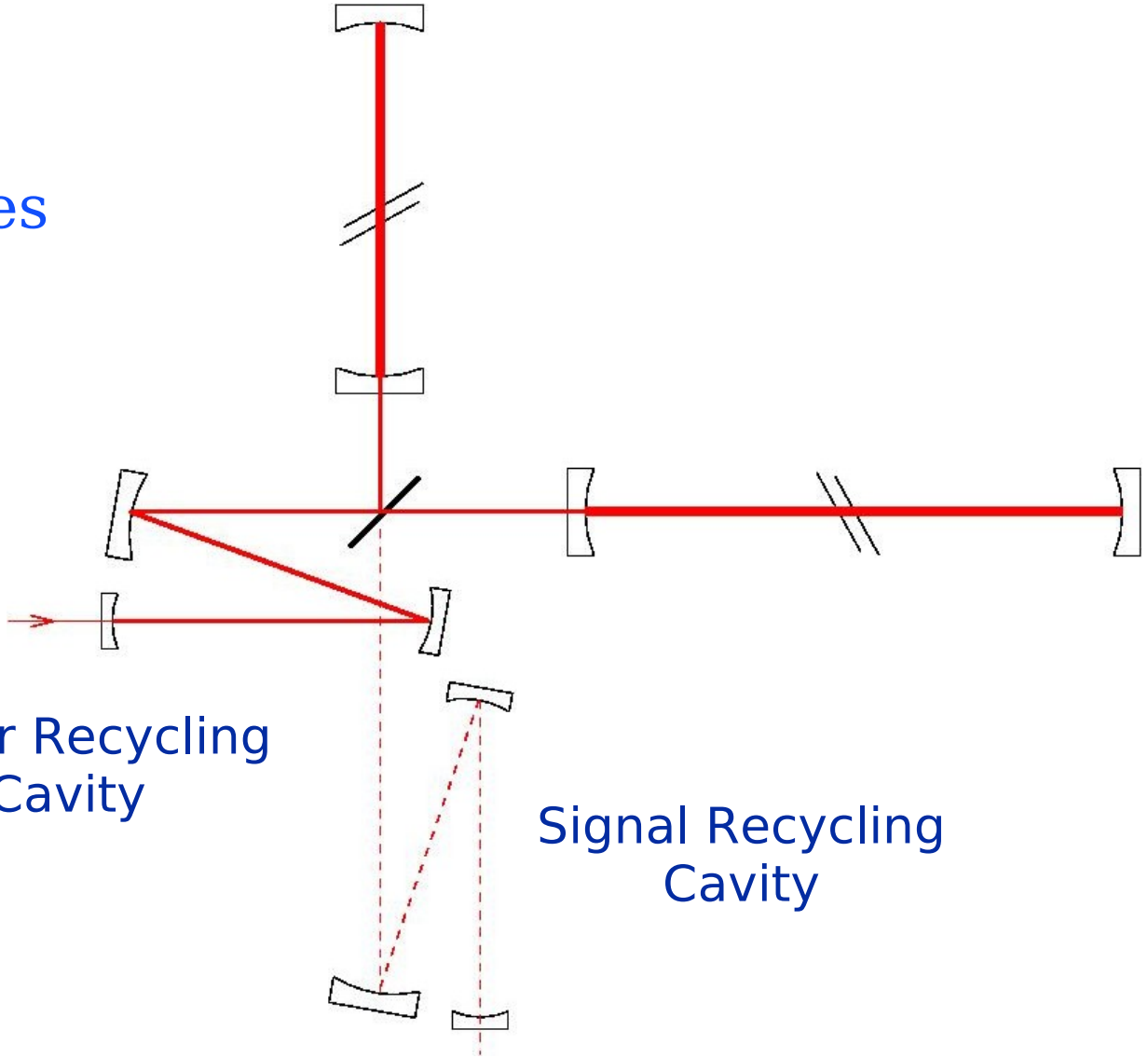
- **RF-sidebands and carrier**
- **RF-sidebands and Signals**
- **Carrier and Signals**



PR Cavity also very close to unstable

Stable Recycling Cavities

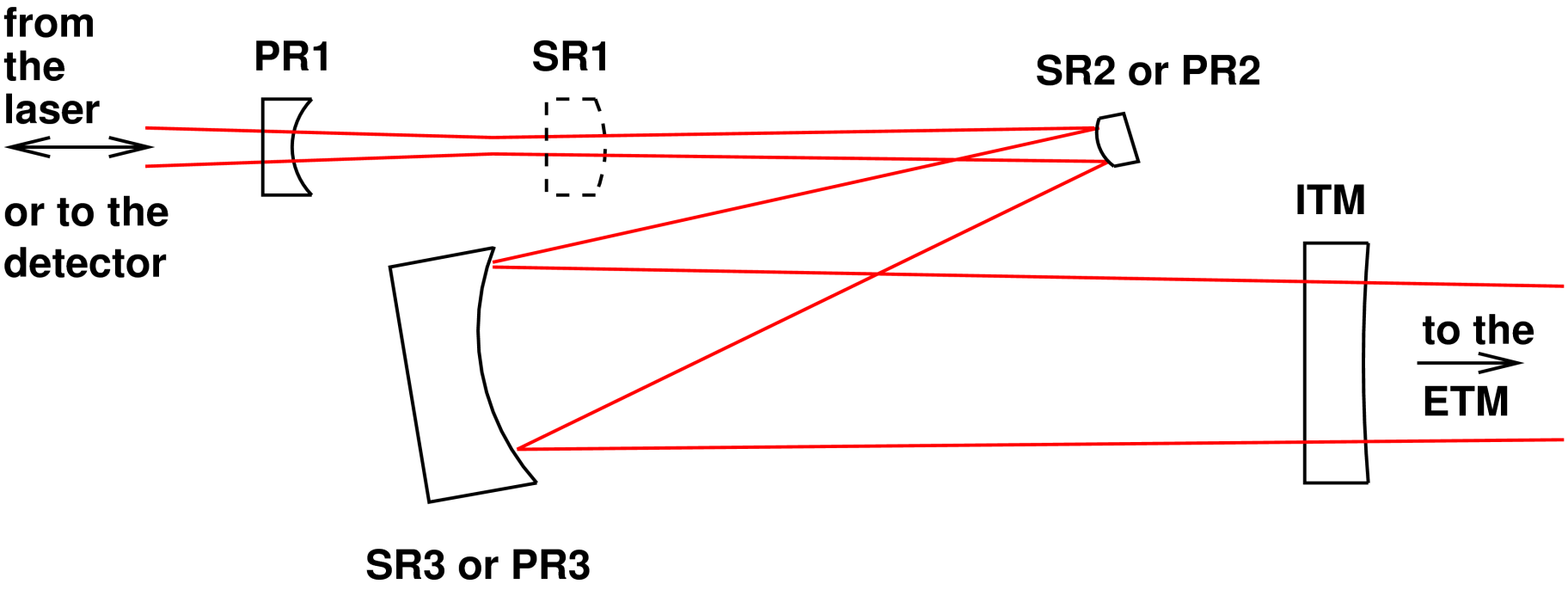
Creates
Stable Cavities



Power Recycling
Cavity

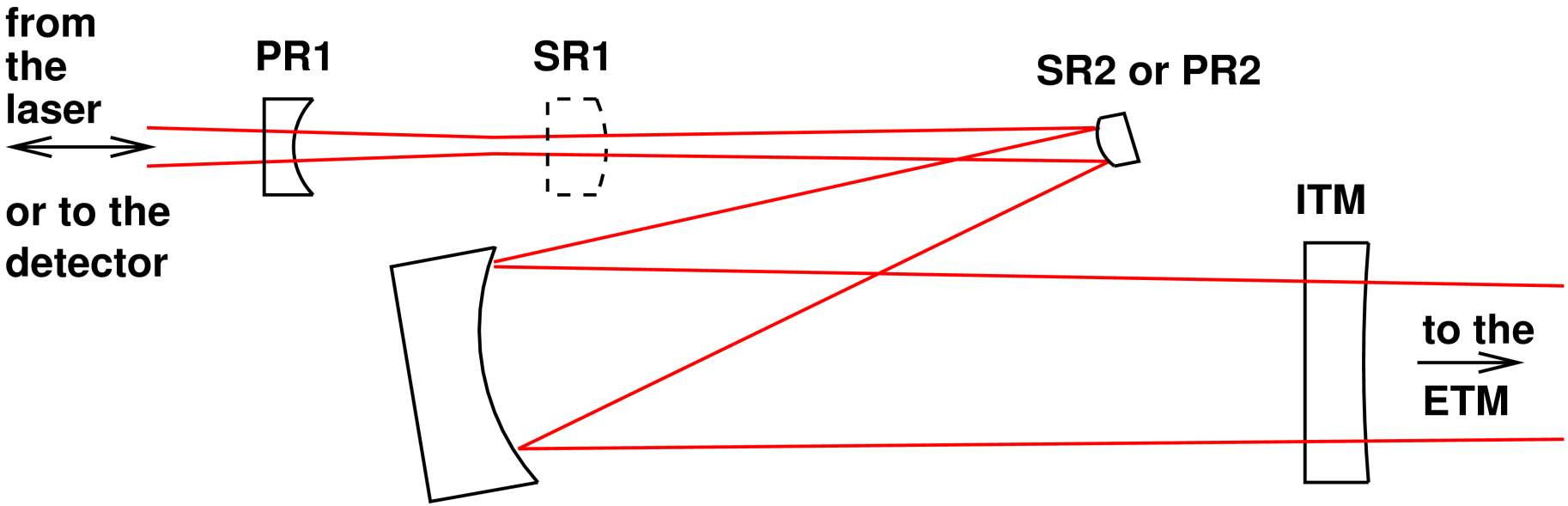
Signal Recycling
Cavity

Stable Recycling Cavities



A first design	PR1	PR2	PR3	SR1	SR2	SR3
Radius [m]	8.22	-2.35	34.75	-15.37	-3.26	34
Beamsize [mm]	1.75	3.45	56.52	2.22	5.03	56.5
	L12	L23	L3I	L12	L23	L3I
Distance [m]	15.76	16.52	25.39	15.42	15.68	24.93
Gouy Phase [rad]	2.05	0.03	0	0.49	0.02	0

Gouy Phases

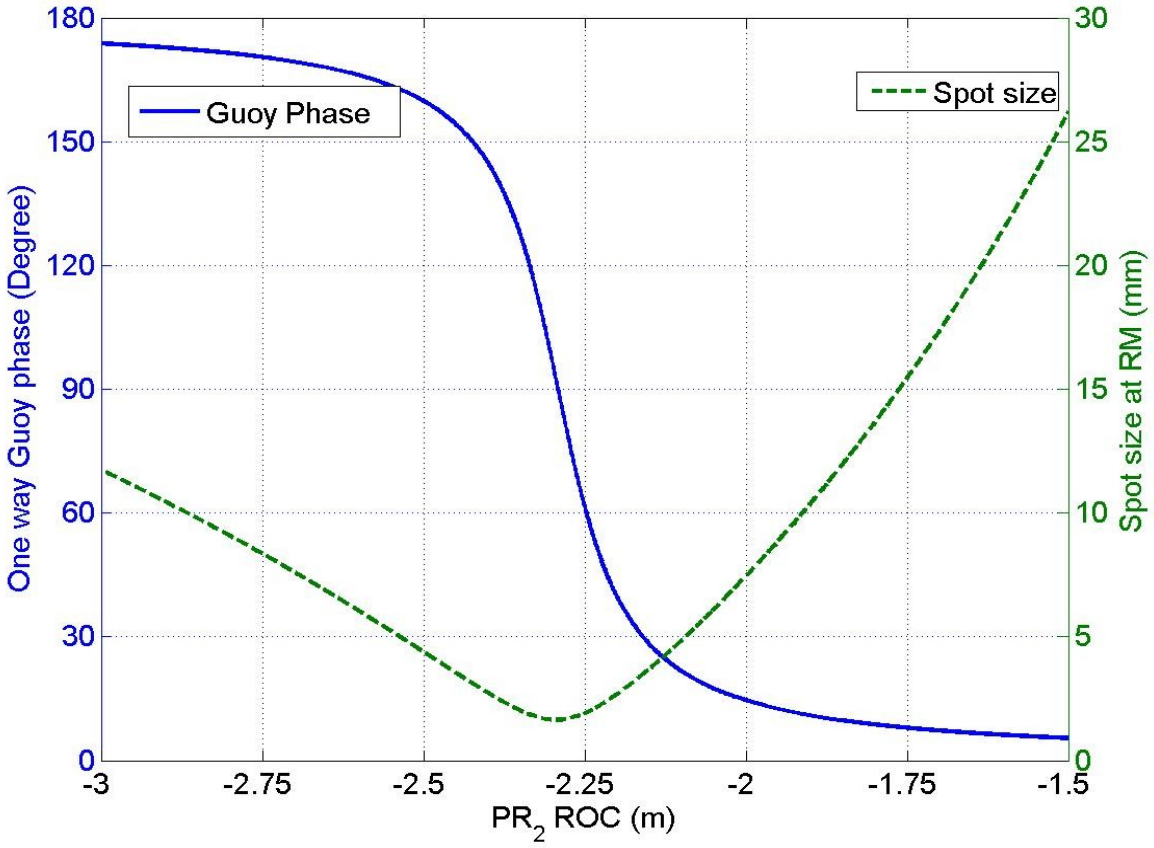


		PR			SR	
	L12	L23	L3I	L12	L23	L3I
Gouy Phase [rad]	2.05	0.03	0	0.49	0.02	0

➔ Gouy Phase accumulated between R_2 and R_1

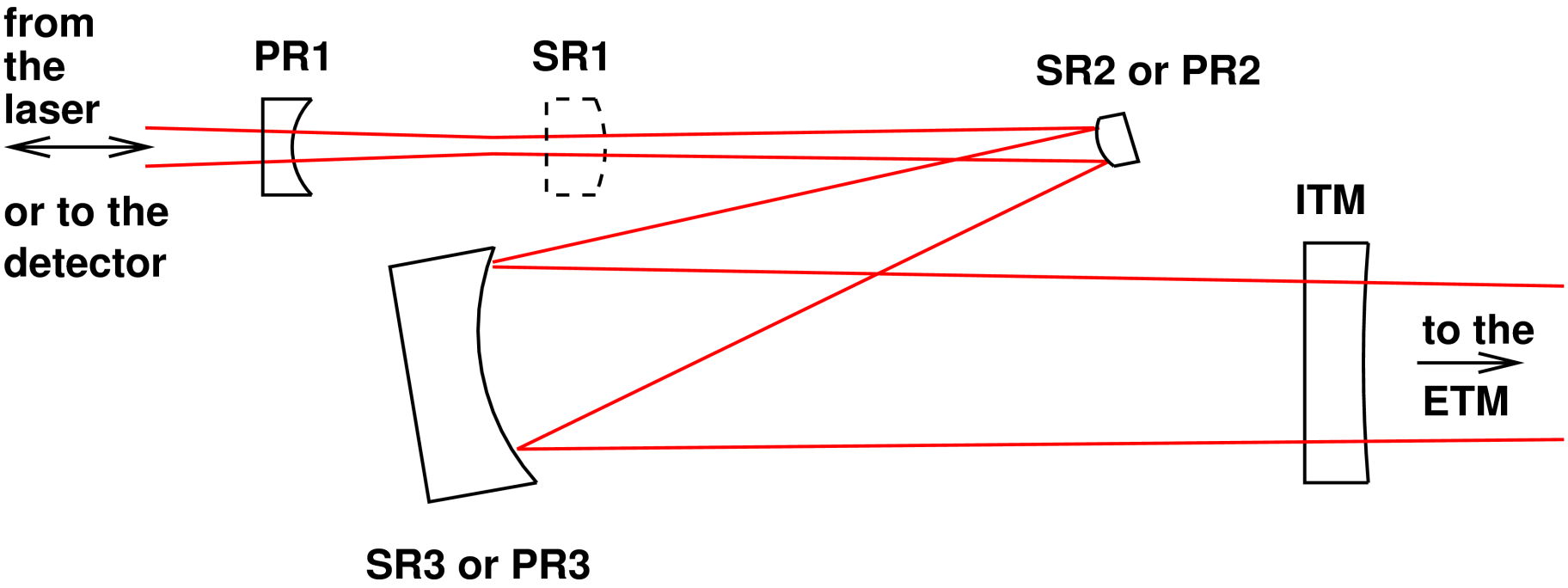
➔ Larger than 90° when waist is between R_2 and R_1

Gouy Phases



- Gouy phase and spot size on R_3 as a function of the ROC of R_2
- Allows to set transversal mode spacing

Stable Recycling Cavities



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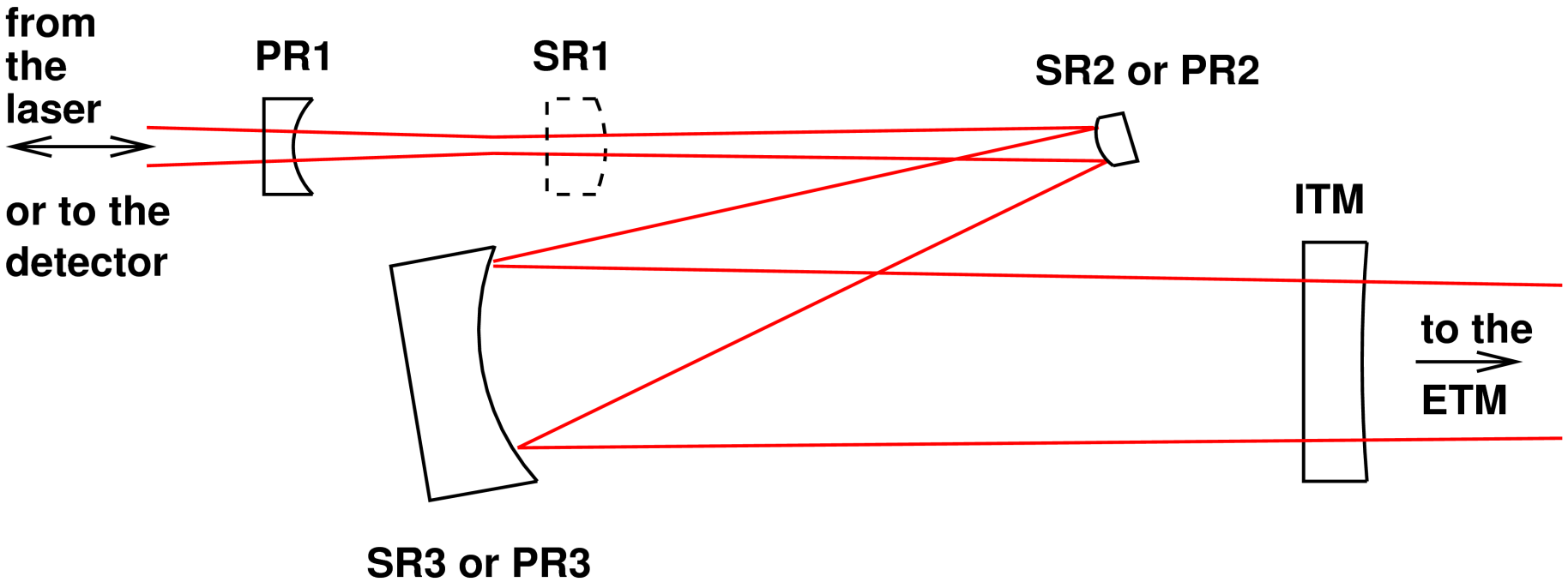
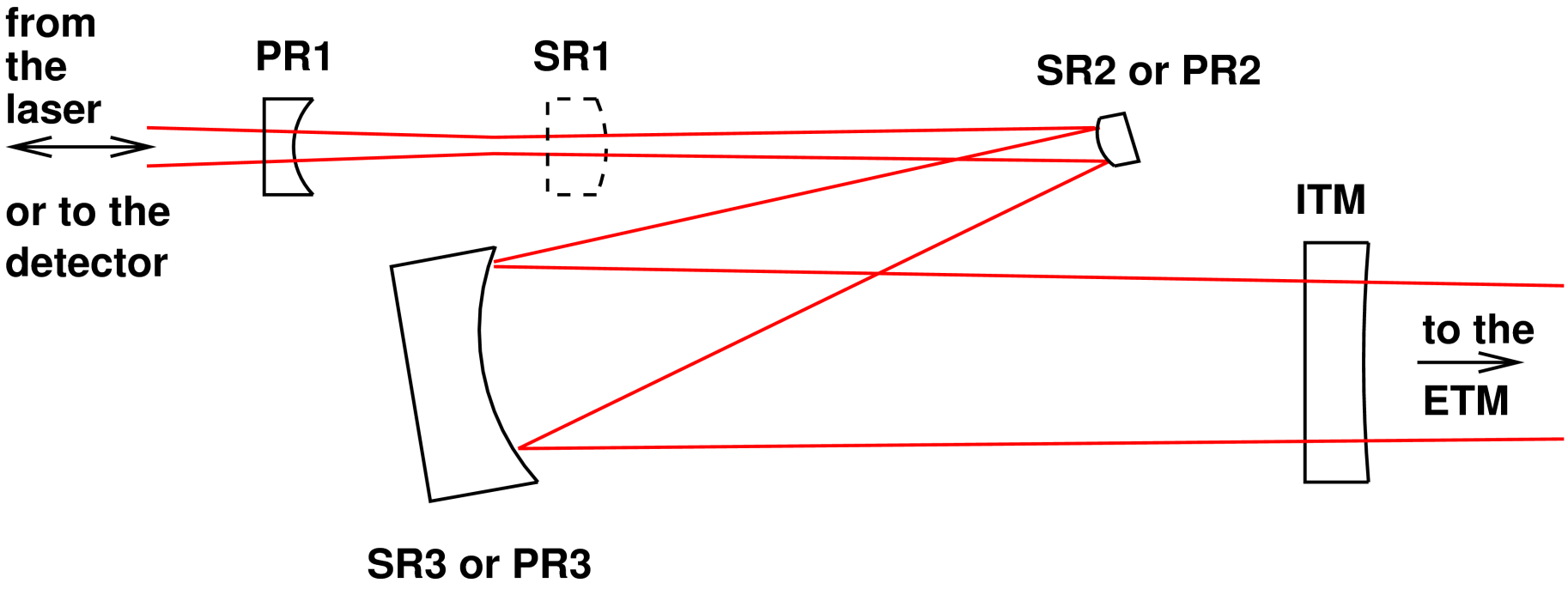
Mode Matching



Requirements:

- The wedge in the beam splitter will create an astigmatic beam ☞ Mode mismatch of ~1%
- Plan to stay well below that (Assumes that TCS works)

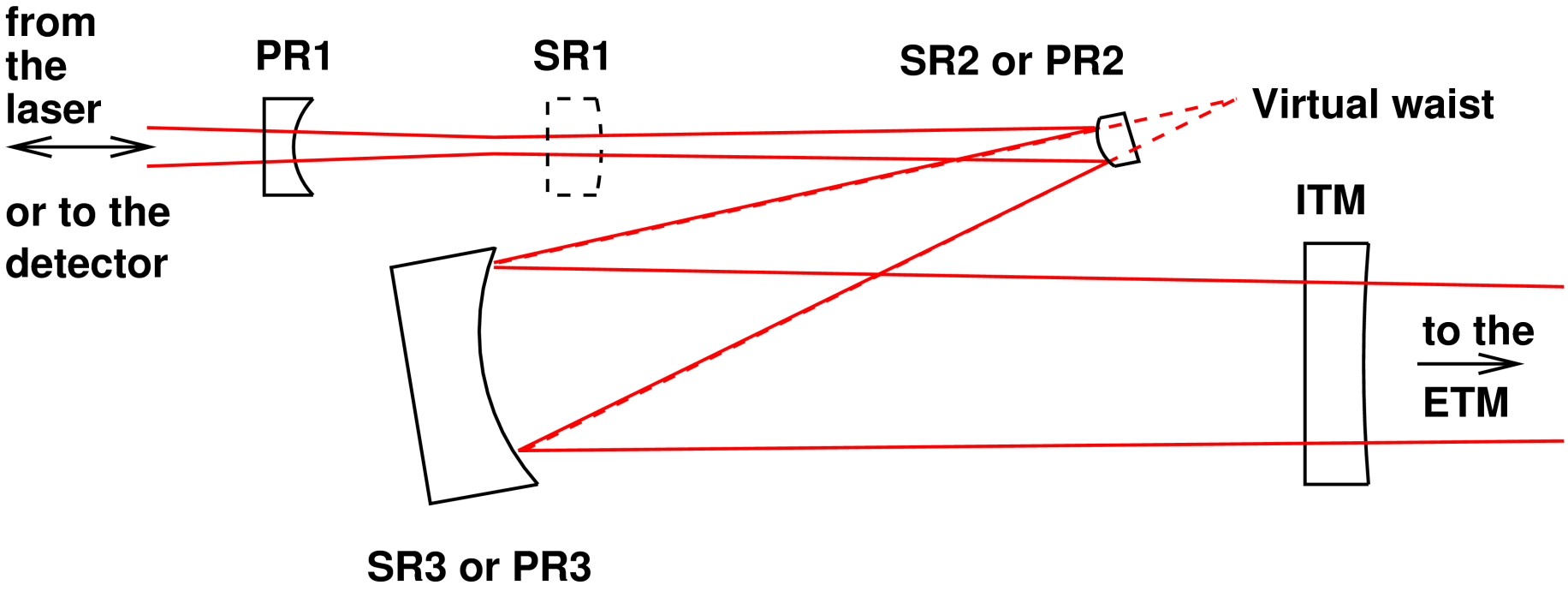
Mode Matching



Mode matching:

- Creating the right mode
  - ROCs and distances between R_1, R_2, and R_3
- Target mode: Average mode in the arm cavities
  - ROCs of ITMs and ETMs

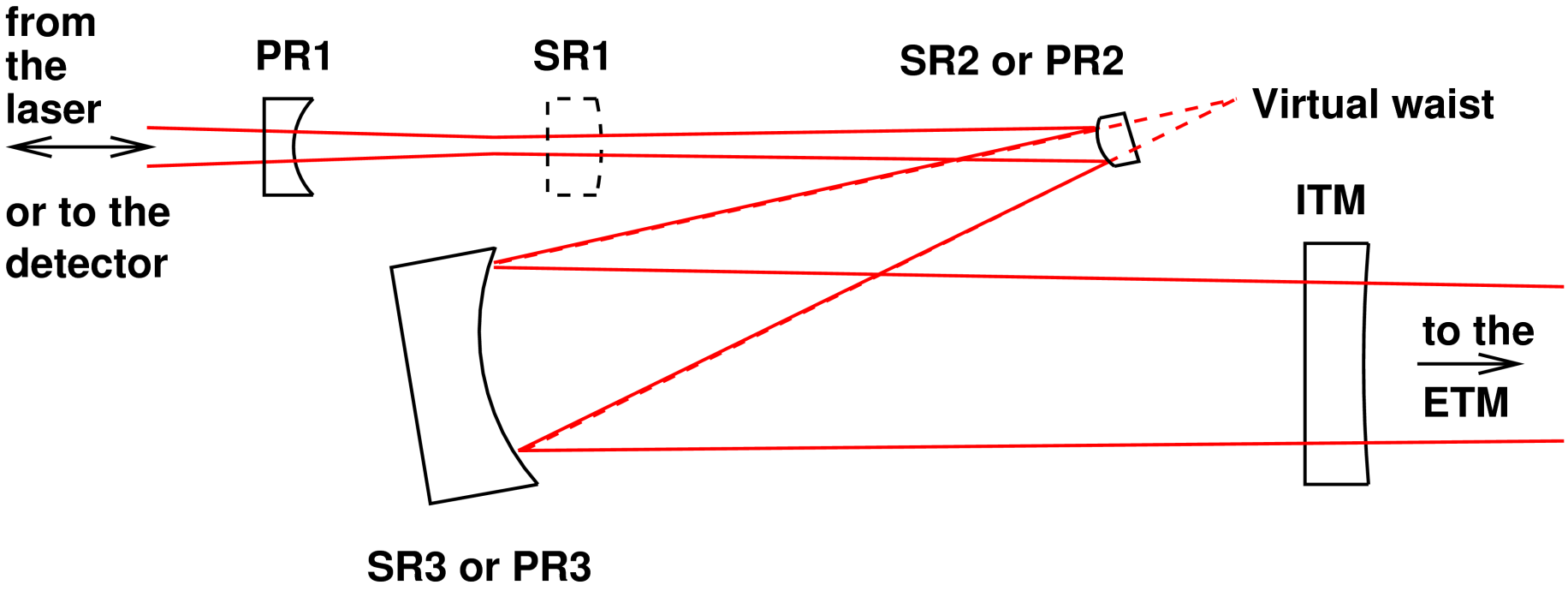
Mode Matching



Creating the right mode:

- Virtual focus behind R_2 (~ROC(R_3)/2 away from R_3)
- Imaged by R_3 to ~infinity (more accurately: to 1355m)

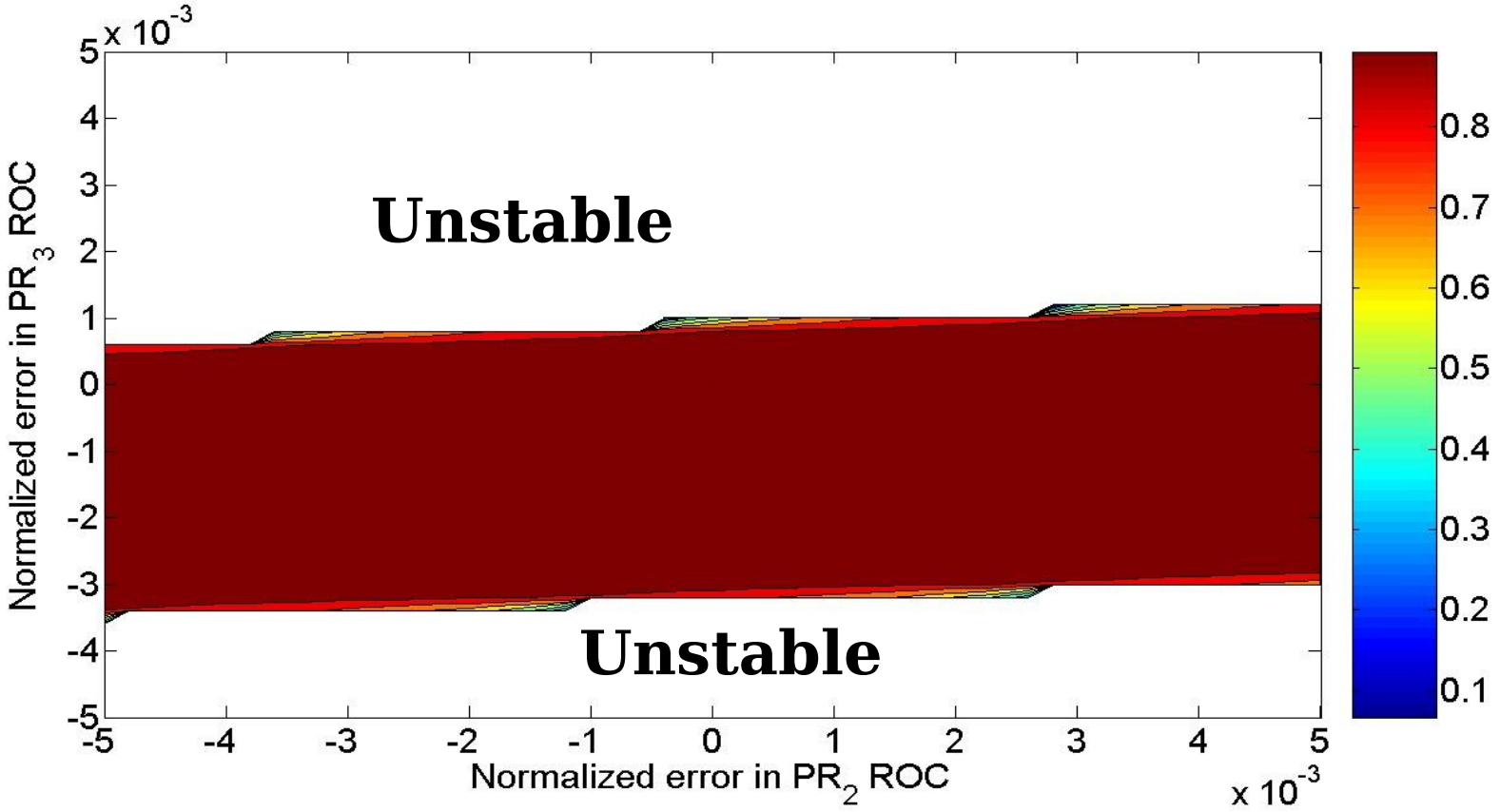
Mode Matching



Creating the right mode:

- Location of virtual focus changes with ROC(R_2)/2
- Optimum location changes with ROC(R_3)/2 = f_3
- Can be optimized by matching L_{23} to real ROCs
- Beam size mismatch is very minor effect

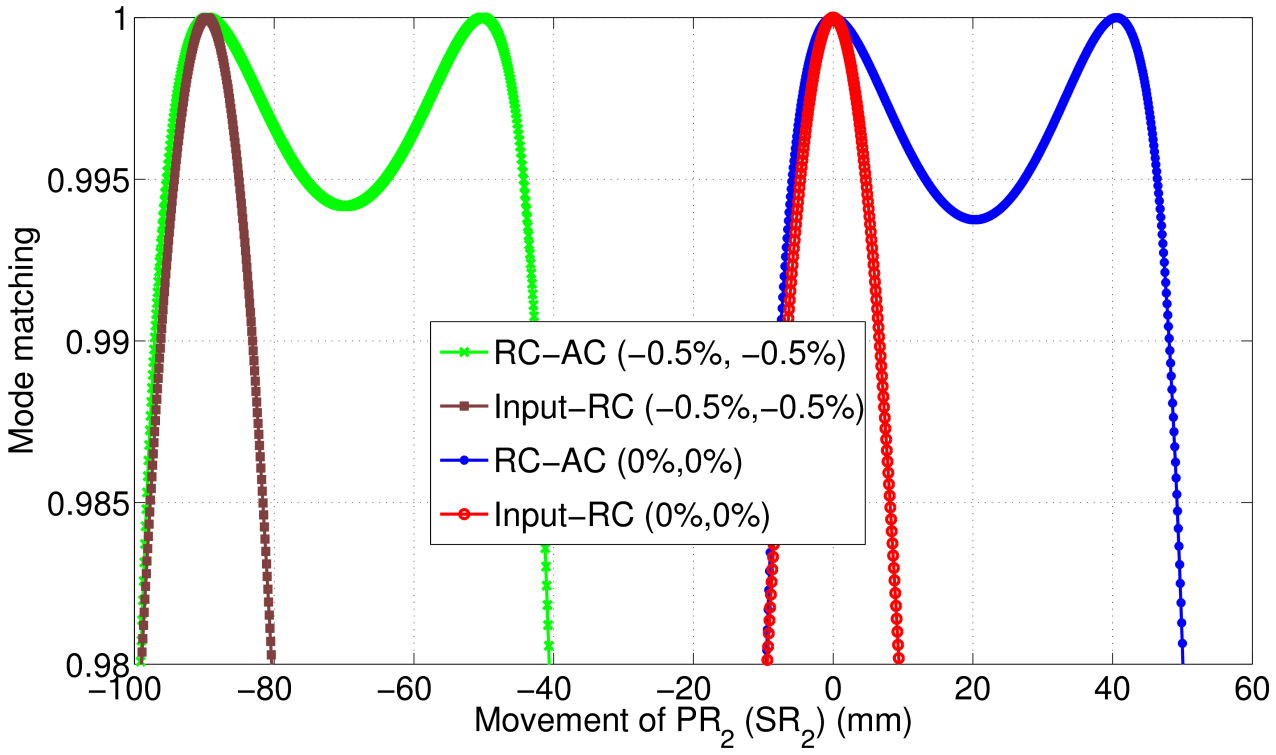
Mode Matching



Mode matching between Recycling Cavity and Arm Cavity:

- W/o adjusting the distance: Small range of stable operation
- With adjusting the distance: > 99.99...% betw. both cavities

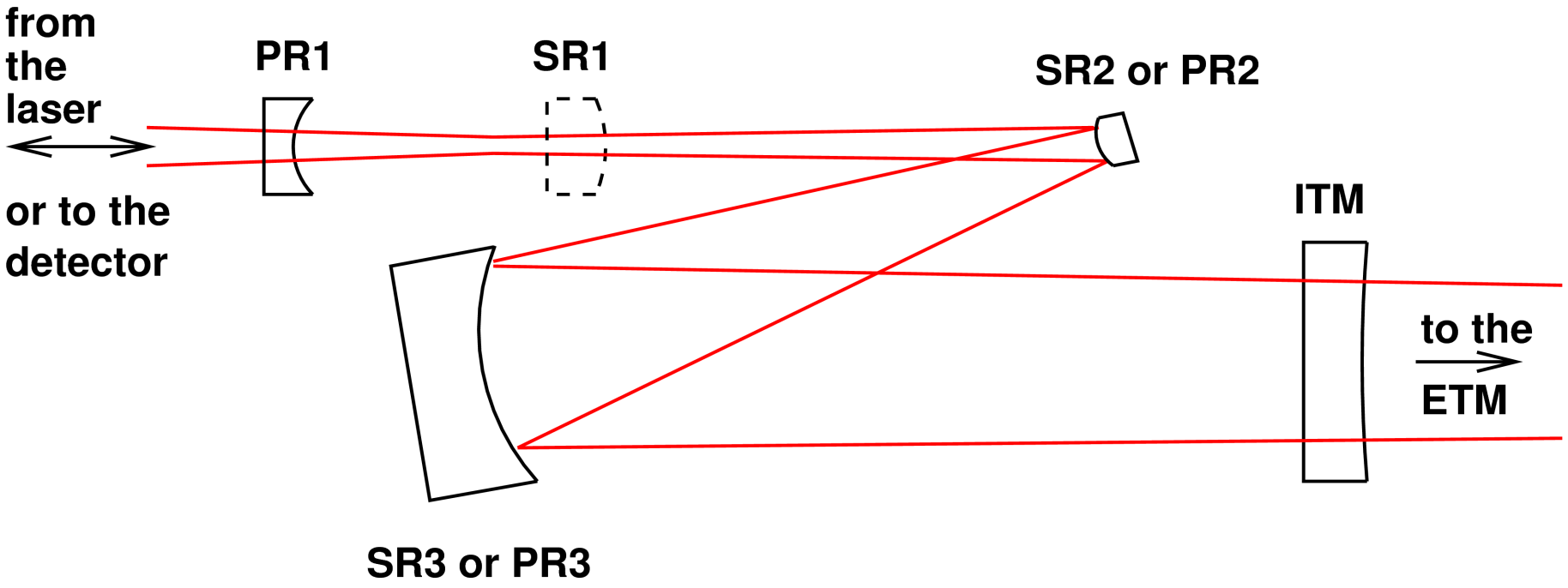
Mode Matching



Mode matching betw. Rec. Cavity, Arm Cavity, and Input Mode:

- With adjusting the distance: > 99.99...%
  - Two chances of getting Cavities matched
  - Need to be within ~5mm to be above 99.5%
  - Gouy Phase changes by 0.02rad/mm

Mode Matching



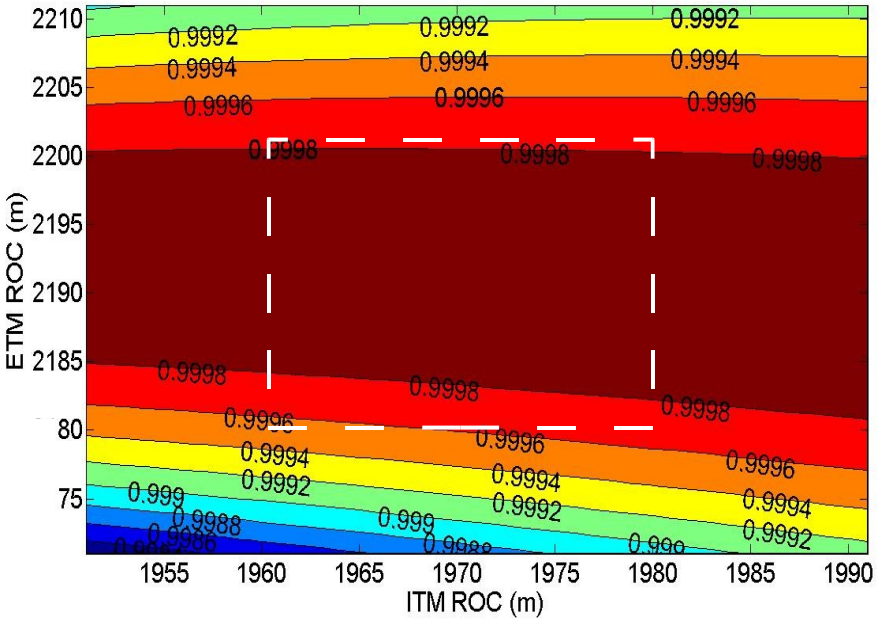
Target Mode: (ROCs of ITMs and ETMs)

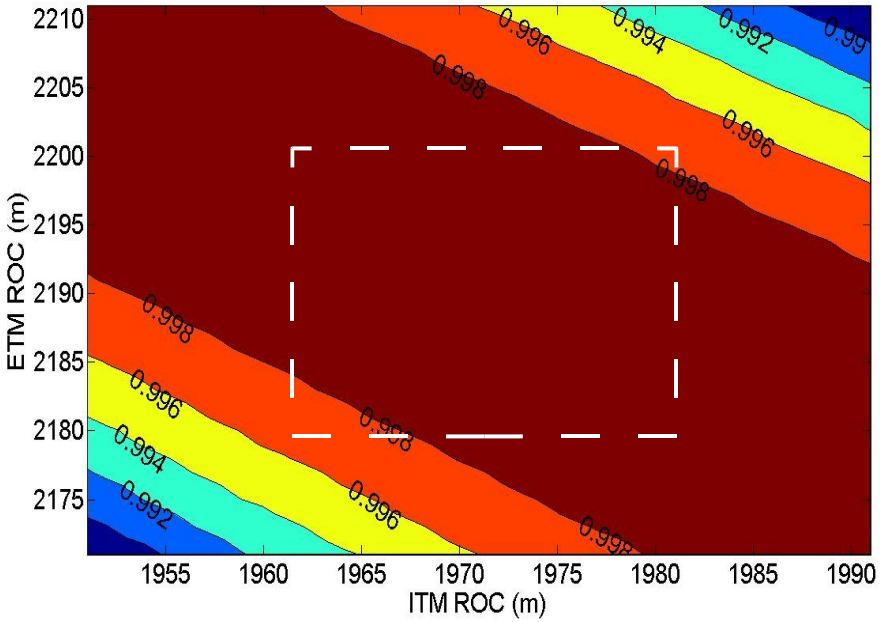
- Have to match to keep dark port dark (Visibility)
- Manufacturing tolerances: 2000m +/- 10m

Mode Matching

Between Recycl. and Arms

- Before Adjustments: >99.96%
- After Adjustments: ~100%
- This ignores Diffraction and errors in mirror surface





Loose <0.2% between MC and Recycl. Cavity (unless we also adjust that telescope)

Gouy Phases

Optimizing the Gouy phases …

Thinks to consider:
- Avoid having higher order modes resonant
  - Most important for low order modes
- Are there specific advantages for
  - ASC sensing?
  - Parametric Instabilities?

Thinks that make this hard:
- Tuning of SR Cavity
- Low Finesse of SR Cavity (large linewidth)

Gouy Phases

Current values:

- Γ_{PR}=2.08rad
- Γ_{SR}=0.51rad

Difference ~ $\pi/2$ **might** be useful for ASC/PI

➔ Michelson formed betw. Recycl. Cavities will be dark for 10-mode

➔ Separates X-arm from Y-arm in POX and POY

➔ Allows to track HOMs generated in arms better

➔ Odd modes are dark in the recycling MI

➔ Even modes are bright

➔ Generates some degeneracy for HOM resonances

➔ Decreases the chances of accidental resonances

Stable Recycling Cavities

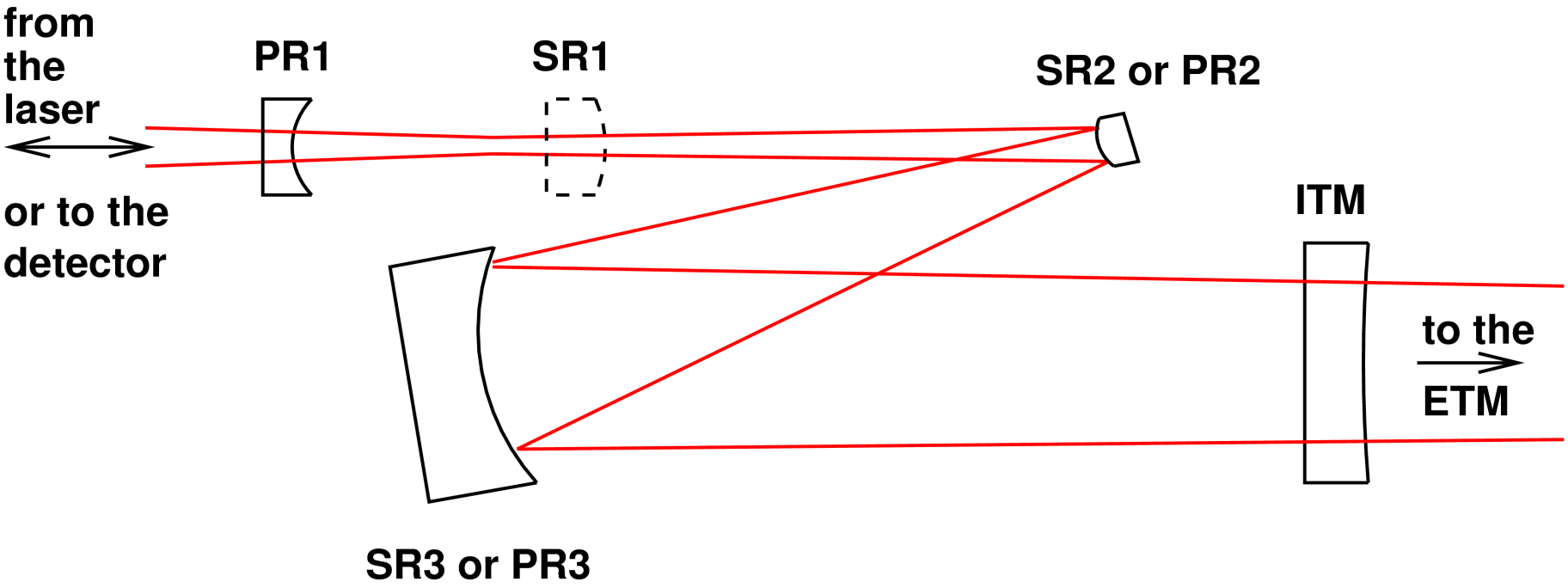
Summary:

- Stable Recycling Cavities will come
- Allow to maintain mode matching between all cavities to much better than 99%.

Challenge is to

- measure the ROCs of PR3 and PR2 before installing them
- or to optimize the mode matching during installation
- TCS has to take out thermal lens in substrate!

Stable Recycling Cavities



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Open Questions

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List of open questions after the February meeting:

- **How far can we decrease the beam splitter wedge?**
  - **Has been changed in sign and size from +0.9deg to now -0.4deg. Still ongoing.**
- **Substrate material for mirrors**
  - **Fused silica vs BK7 (already decided: all Fused Silica)**
- **Check modal calculation for wedge**
  - **Might try to compensate this a bit (Not yet started)**
- **Study different Gouy phases**
  - **avoid HOMs, improve WFS (ongoing)**
- **Study ways to measure critical ROCs (R2, R3) with cm accuracy**
- **...**