LIGO

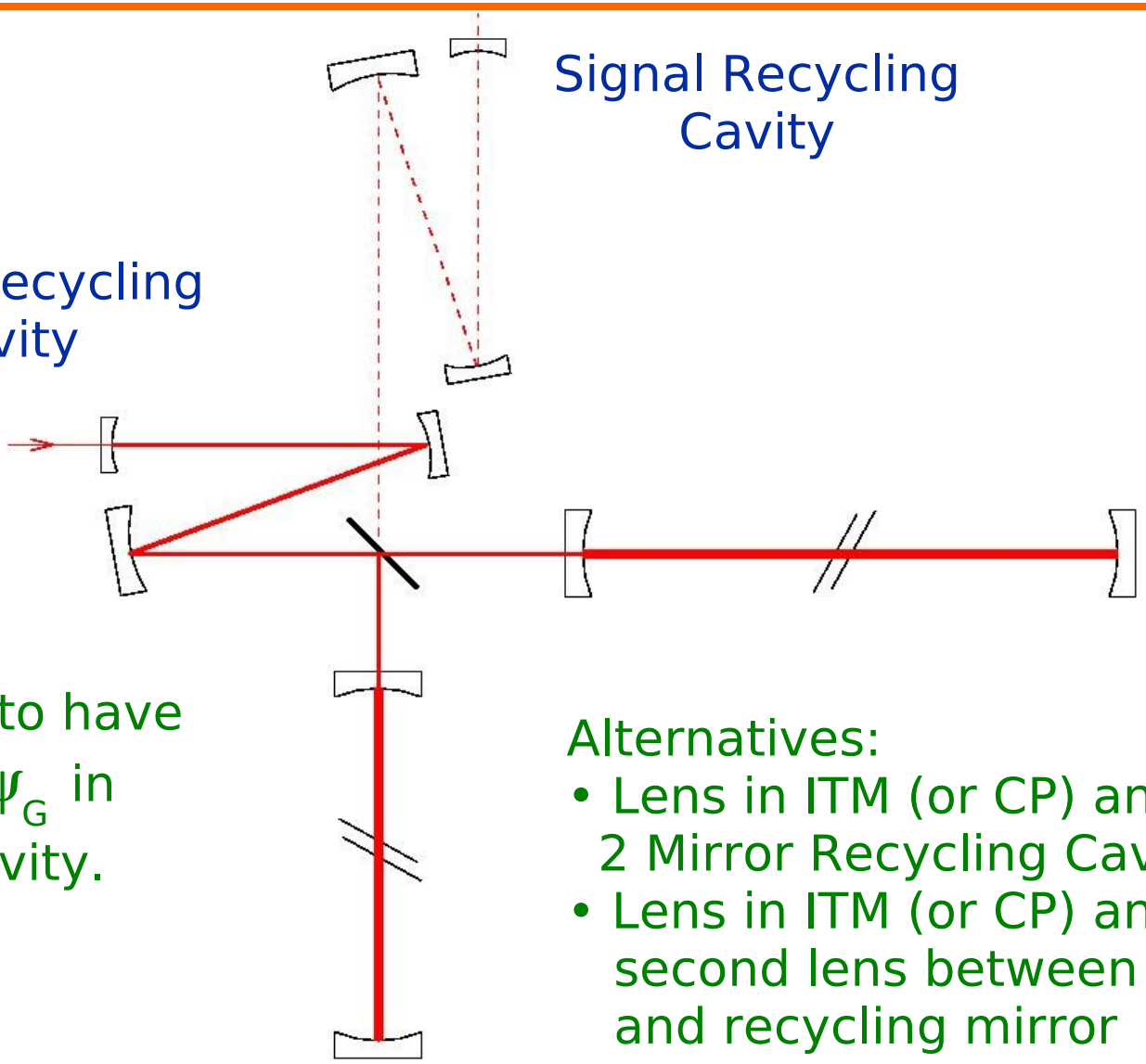
Parametric Instabilities and the geometry of the recycling cavities

LIGO-G070441-00-R

Guido Mueller

(Credit goes to Bill Kells, David Ottaway, Valera Frolov)

Stable Recycling Cavities

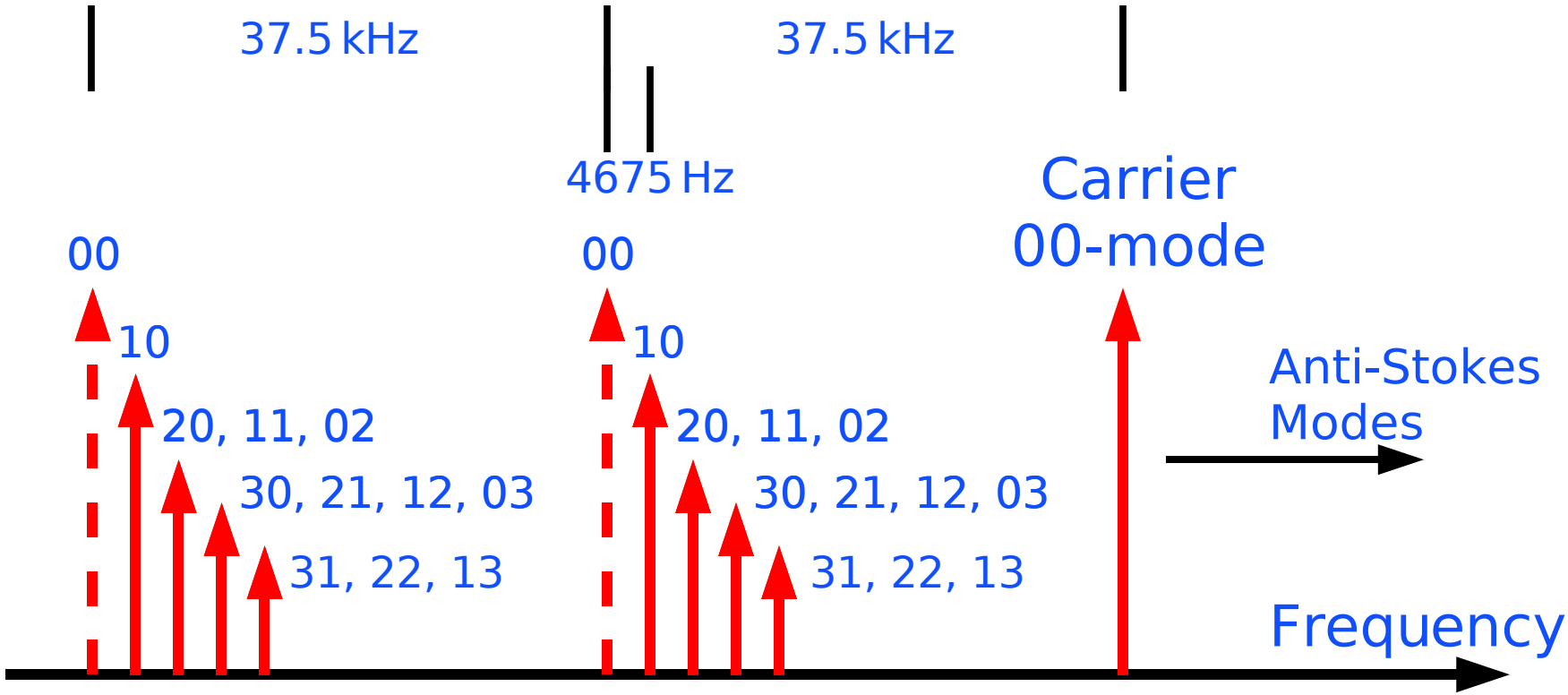


Can be designed to have any Gouy phase ψ_G in each recycling cavity.

Alternatives:
- Lens in ITM (or CP) and 2 Mirror Recycling Cavity
- Lens in ITM (or CP) and second lens between BS and recycling mirror

Stable Recycling Cavities

PI-Spectrum:



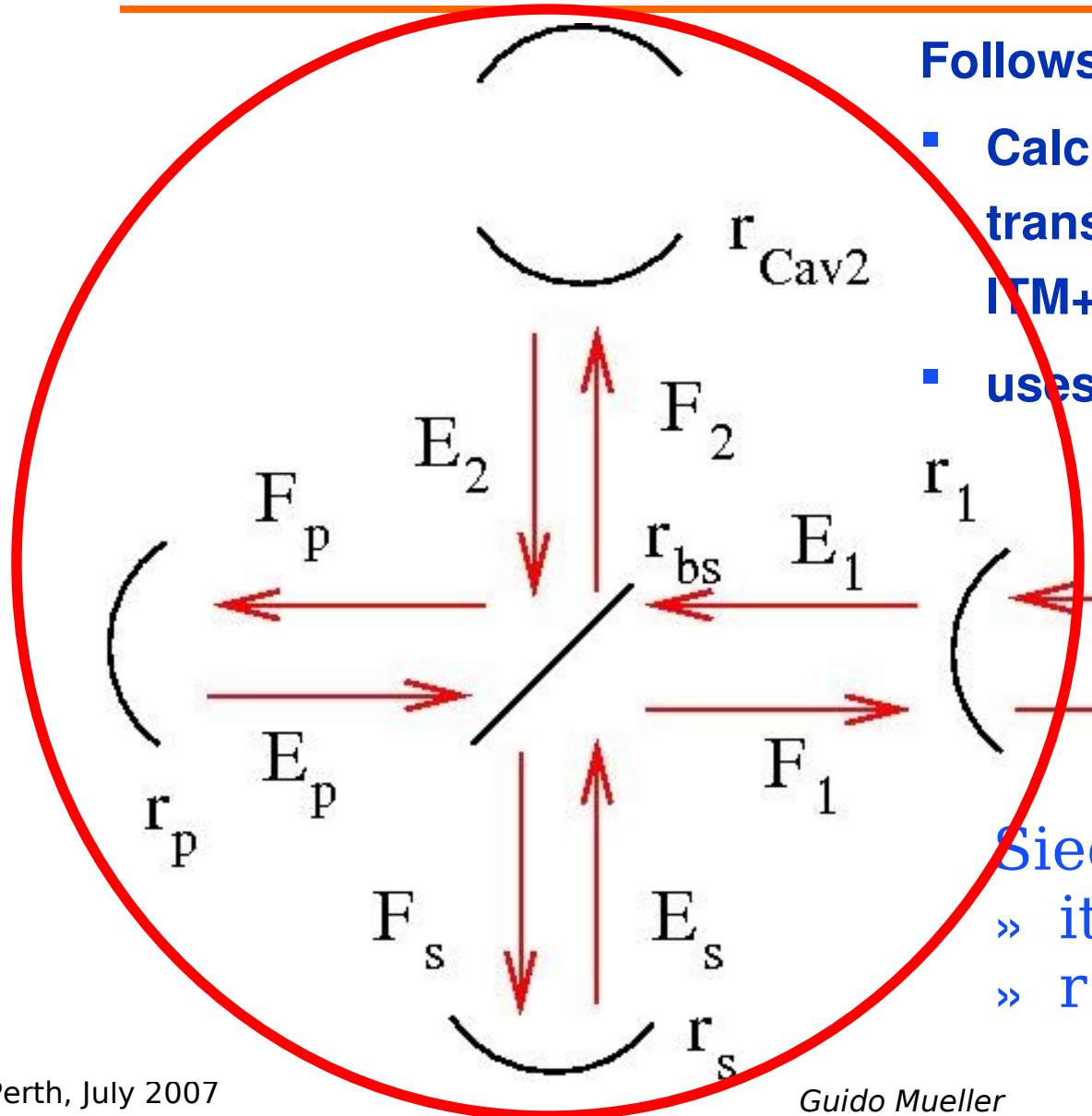
My understanding: PI limited to Hermite-Gauss modes up to n and m < 5
Higher order modes have Diffraction losses > ITM transmission

Simulation

Goal would be:

- **Compare optical gain of dual recycled interferometer with optical gain in single cavity**
  - **Will depend on round trip phase shift of higher order modes in recycling cavities (PI-mode recycling (bad) or extraction (good))**
  - **Try to find Gouy phases which reduce Q_{opt}**
- **Optimization is currently done**
  - **for Alignment sensing (try to get the 10-modes out of the arm cavities to the WFS)**
  - **and to suppress Bulls eye (HG 20, HG 02) modes in short Michelson IFO (reduce scatter losses in signal sideband (Yi Pan paper))**

Simulation



Follows David Ottaway's idea:

- **Calculate complex transmissivity of combined ITM+rest of IFO**
- **uses Valera's ASC code**

Siegman convention:

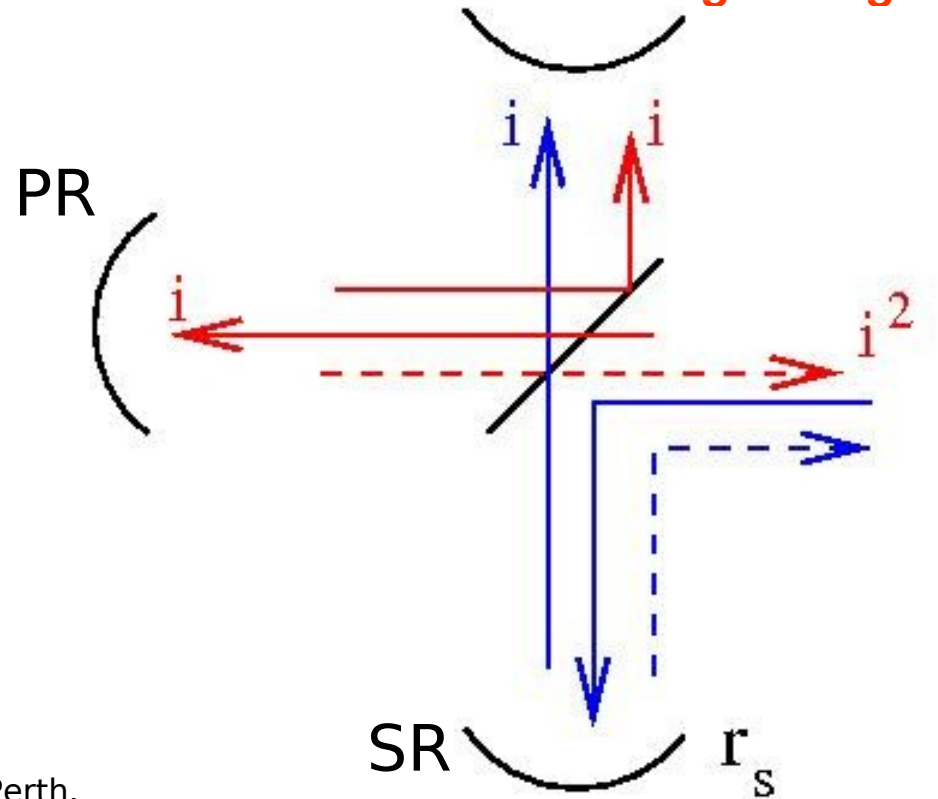
- it for transmission
- r for reflection

Simulation

- Strongly undercoupled cavity
- (R_{ITM}=0.995, R_{rest}<0.94)
- Roundtrip phase shift:
  - π: Power recycling -> PI mode will build up
  - 2π: Signal extraction -> PI mode will be damped
- Roundtrip phase depends on Gouy phases and positions of all other mirrors

Simulation

- **Start discussion with following configuration:**
  - » **symmetric BS: $t_{BS} = r_{BS}$, no Gouy phases on recycling arms**
  - » **PR mirror is power recycling the carrier**
  - » **SR mirror is extracting the signal mode (RSE configuration)**



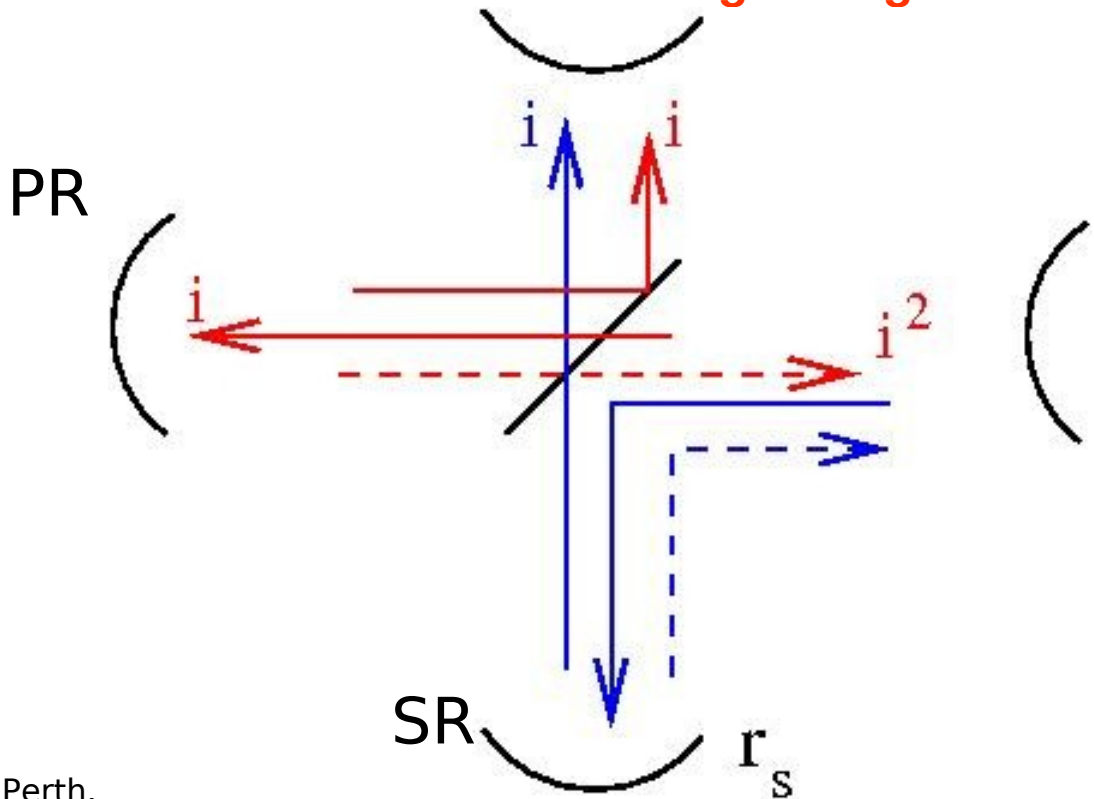
Power recycling:
The i^2 ensures destructive interference with cavity leakage at ITM

☞ Power recycl.

✝ Bad for PI modes.

Simulation

- **Start discussion with following configuration:**
  - » **symmetric BS: $t_{BS} = r_{BS}$, no Gouy phases on recycling arms**
  - » **PR mirror is power recycling the carrier**
  - » **SR mirror is extracting the signal mode (RSE configuration)**



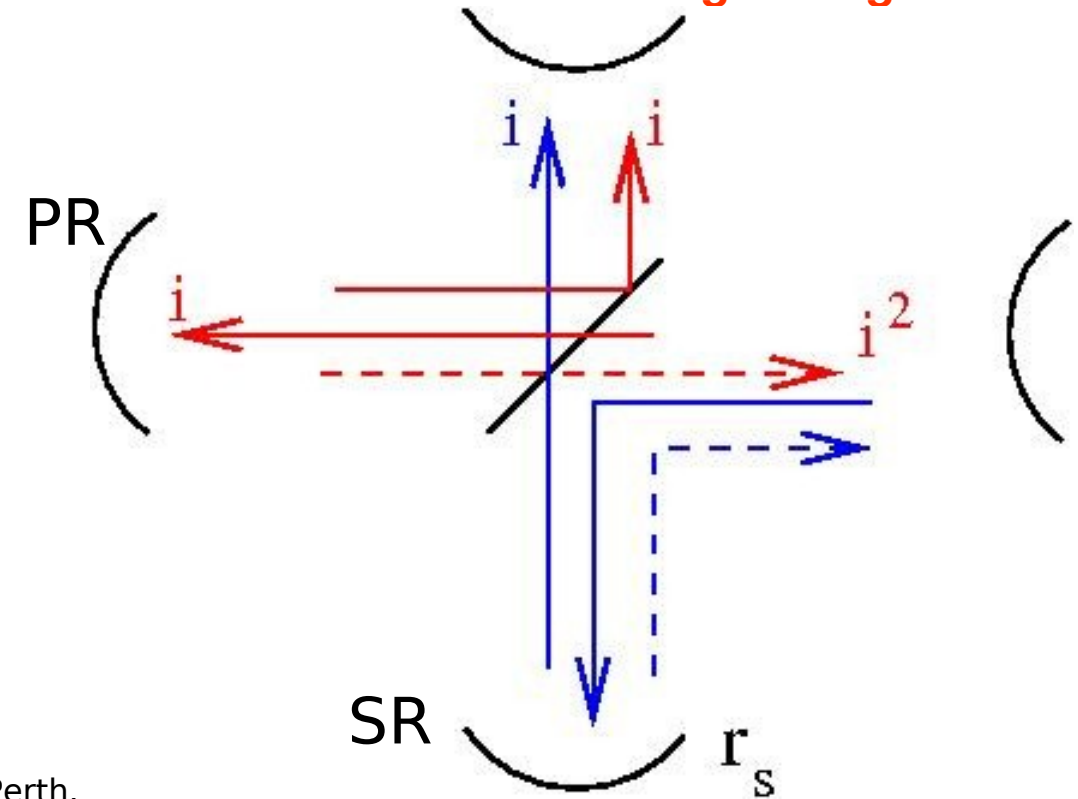
Signal recycling:
the real SR field ensures construct. interference with cavity leakage at ITM

☞ RSE

✌✌ Very good for us

Simulation

- **Start discussion with following configuration:**
  - » **symmetric BS: $t_{BS} = r_{BS}$, no Gouy phases on recycling arms**
  - » **PR mirror is power recycling the carrier**
  - » **SR mirror is extracting the signal mode (RSE configuration)**



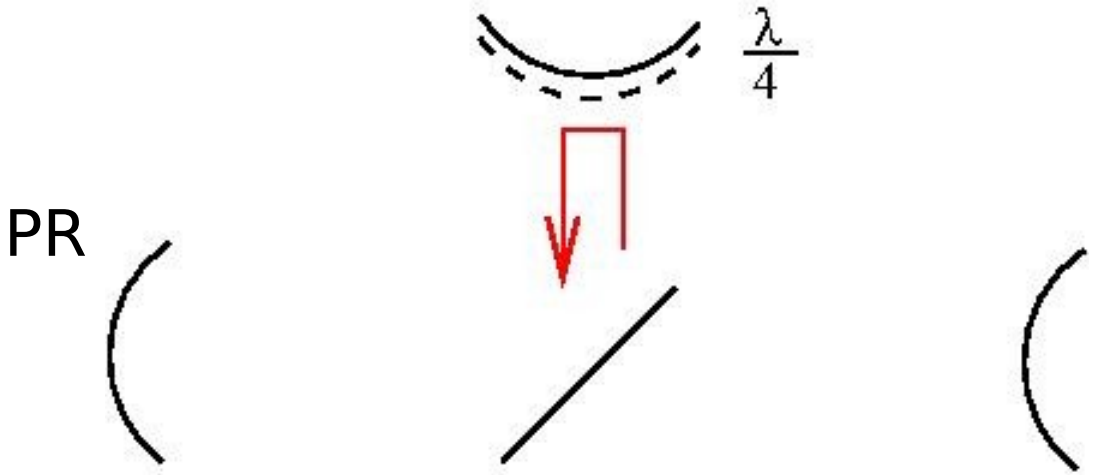
Recycling arm Michelson IFO would be bright!

☞ PI-mode travels 100% to 2nd Cavity

OK????

Simulation

2nd Cavity moved by λ/4 compared to
1st cavity to have MI dark (compensates the $(it)^2$ in BS)



- 2nd Cavity off-resonant
  - ☞ Phase shift: π
- 2nd Cavity on-resonance
  - ☞ Phase shift: 2π

Simulation

1st Case:

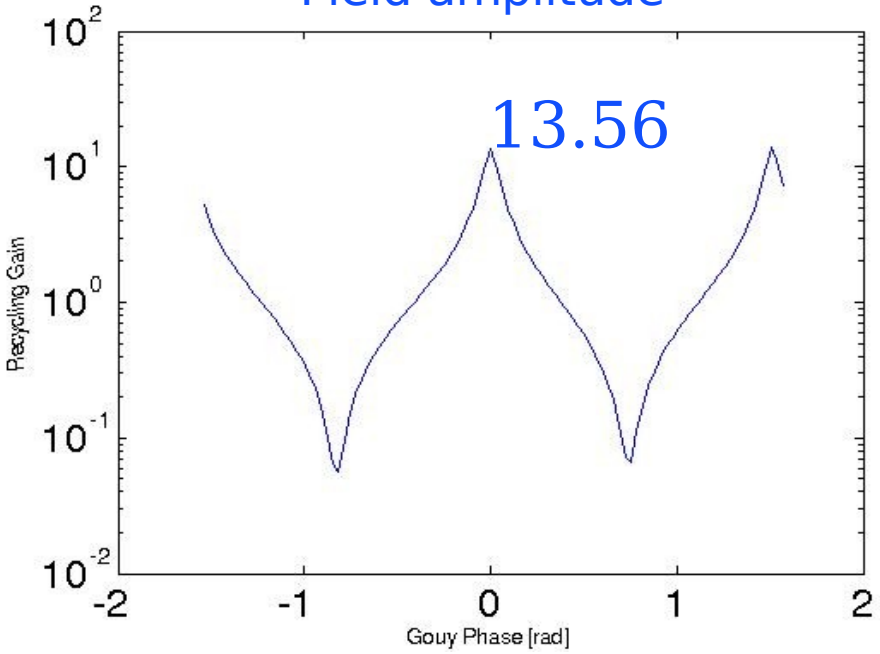
- 2nd Cavity resonant with PI mode (unlikely):

  Light reflects back into short recycling cavity MI
  Picks up another 90deg phase shift

- ☞ **Round trip phase shift is 180deg ☞ signal recycling (very bad)**
- » **Add now identical Gouy phases to recycling cavities**
  - recycling cavity MI stays bright
  - move from signal recycling to signal extraction

relative recycling gain:

Field amplitude



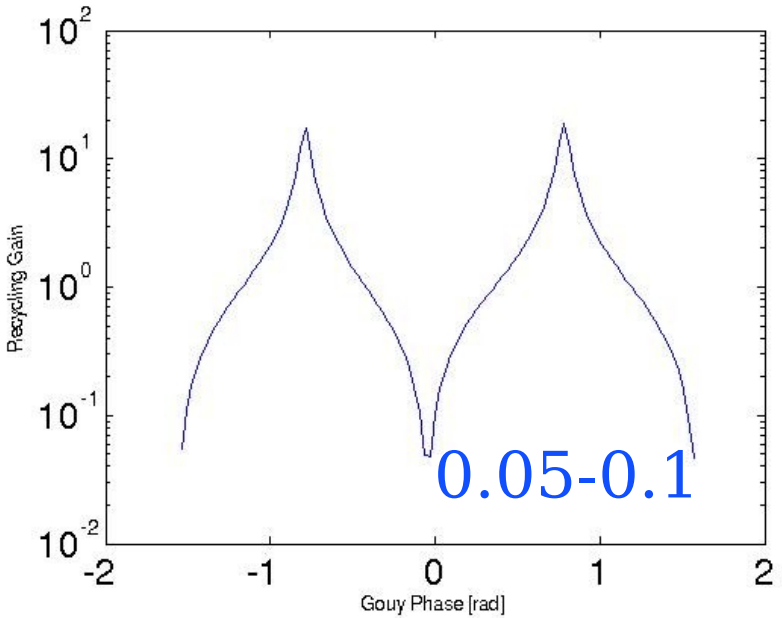
Simulation

2nd Case:

- 2nd Cavity non-resonant with PI mode (likely):
  - Picks up 180deg phase shift at 2nd Cavity
  - Light reflects back into short recycling cavity MI
  - Picks up another 90deg phase shift

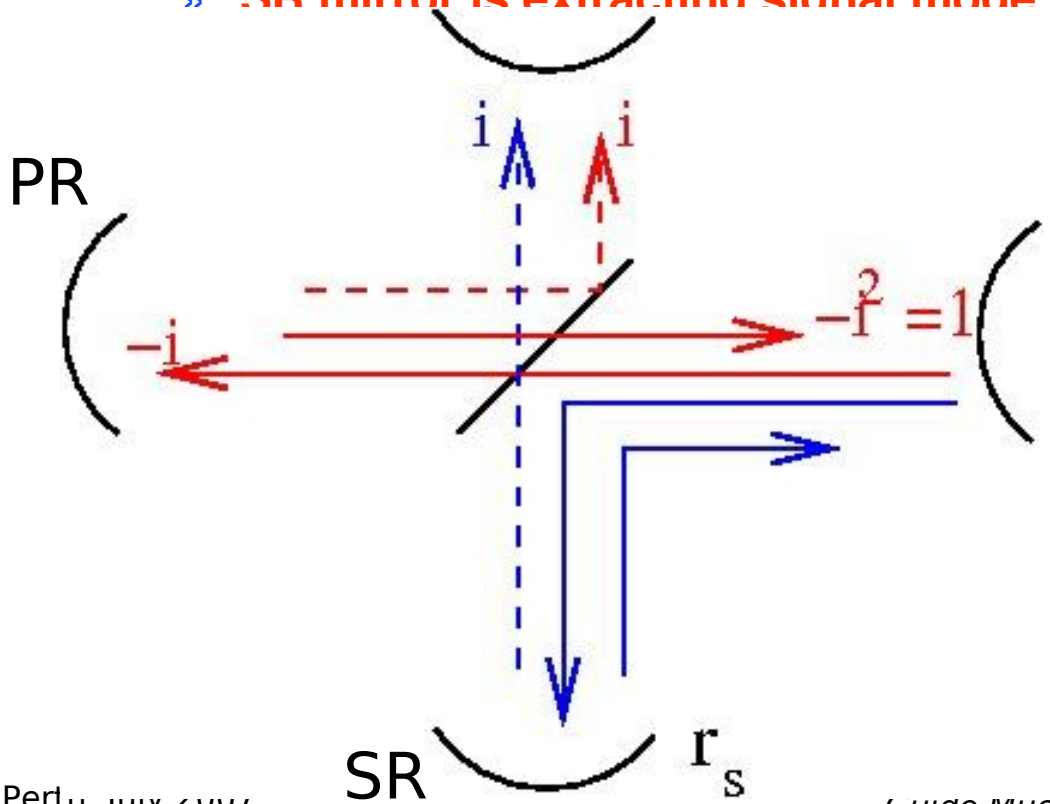
- ☞ **Round trip phase shift is 360deg ☞ signal extraction (very good)**
- » **Add now identical Gouy phases to recycling cavities**
  - recycling cavity MI stays bright
  - move from signal extraction to signal recycling

relative recycling gain:
Field amplitude



Simulation

- **Currently I optimized for alignment sensing (detect the 10-mode) keeping the signal losses in mind (20-mode):**
  - **PR recycling cavity would have $\psi_G \sim \pi/2$ (to extract the 10-mode)**
  - **SR mirror is extracting signal mode (RSE configuration)**



Recycling arm Michelson IFO is dark for odd modes!

☞ 2nd Cavity doesn't matter anymore

Note:
Nothing has changed for even modes!

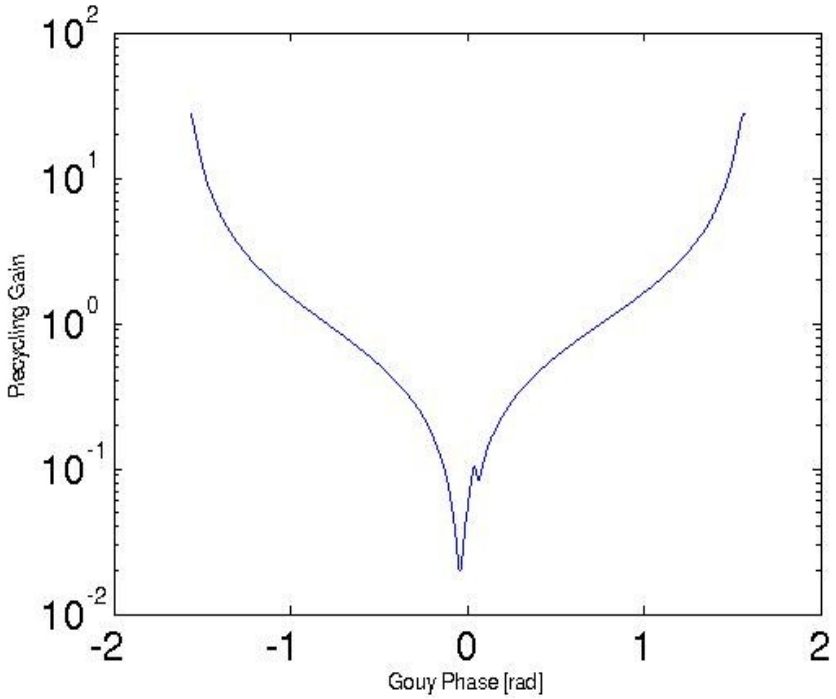
Simulation

Only new case:

- ☞ **Round trip phase shift is 360deg ☞ signal extraction (very good)**
- » **Add now identical Gouy phases to recycling cavities**
  - recycling cavity MI stays dark
  - move from signal extraction to signal recycling

(Structure in center caused by SR-detuning)

relative recycling gain:
Field amplitude



Simulation

- One possible design has the following configuration:
  - Power recyling cavity will have $\psi_G \sim \pi/2+0.1$
  - Signal recyling cavity will have $\psi_G \sim 0.1$
- **Odd Modes:**
  - **relative recycling gain < 1 for n+m < 8**
- **Even Modes (2nd Cavity off-resonant):**
  - **relative recycling gain < 1 for n+m < 4**
- **Even Modes (2nd Cavity on-resonance, unlikely):**
  - **relative recycling gain > 1 for n+m < 4**

Simulation

- One possible design has the following configuration:
  - Power recyling cavity will have $\psi_G \sim \pi/2+0.1$
  - Signal recyling cavity will have $\psi_G \sim 0.1$
- One problem:
  - Optimum design for 20-mode suppression is $\psi_G \sim \pi/4$ rad (Yi Pan's paper)

Ongoing discussion …