SIESTA simulations of a power-recycled interferometer

LABORATOIRE MATÉRIAUX AVANCÉS

Outline

SIESTA simulation of a power-recycled ITF:

- how the algorithm works
- validation / results
- another algorithm: ITF dynamics
- final considerations

Outline:

- **how the algorithm works**
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SIESTA command ***OPitf***:

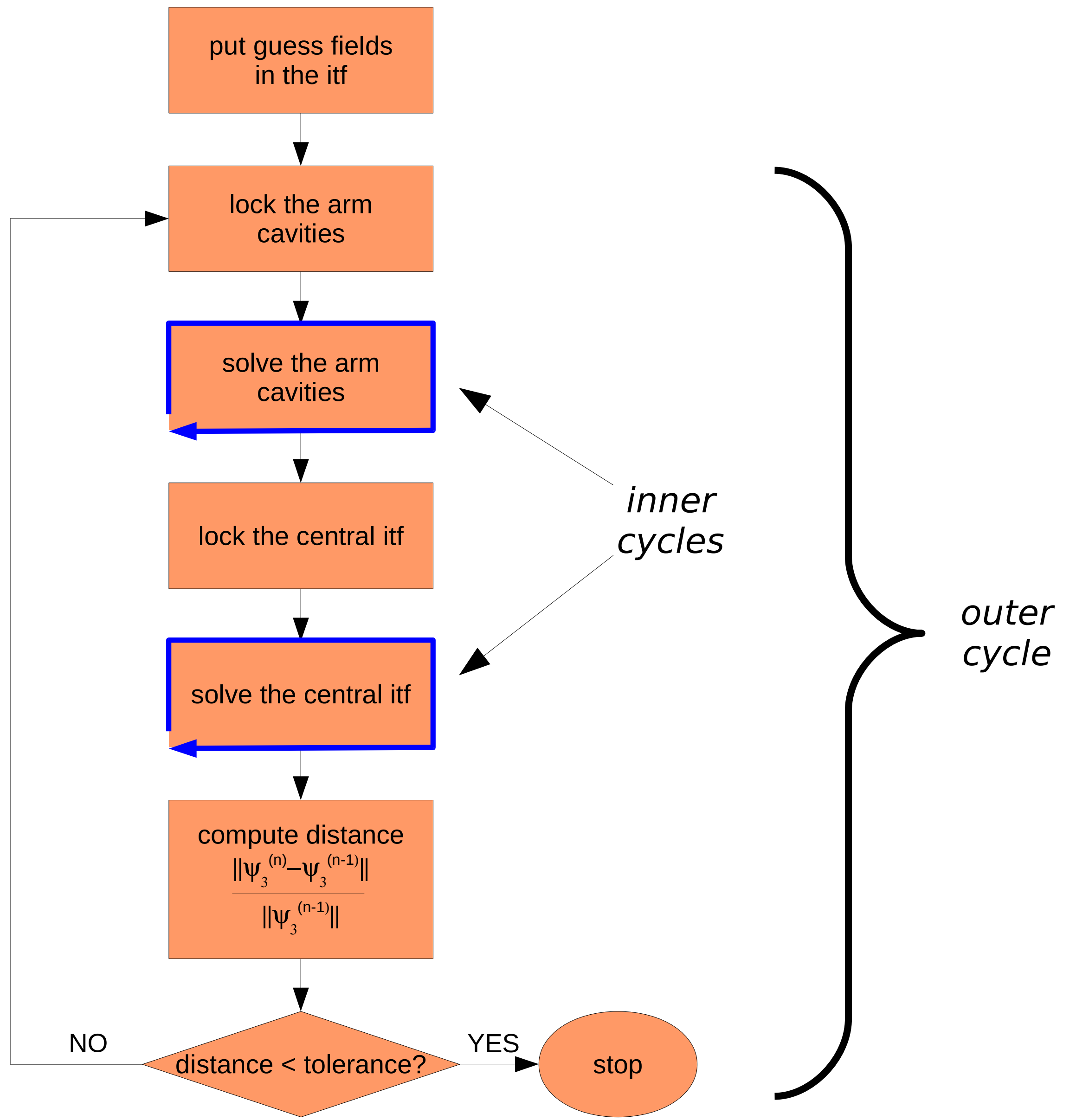
- FFT simulation of a power-recycled interferometer
- computation of stationary fields inside the ITF
- solution searched by successive iterations

Power-recycled ITF

The same mechanisms used for a simple FP cavity are extended to a power-recycled ITF.

Basically, the ITF is treated as a set of three communicating cavities:
- North arm cavity
- West arm cavity
- central Michelson

Power-recycled ITF



1. Guess fields

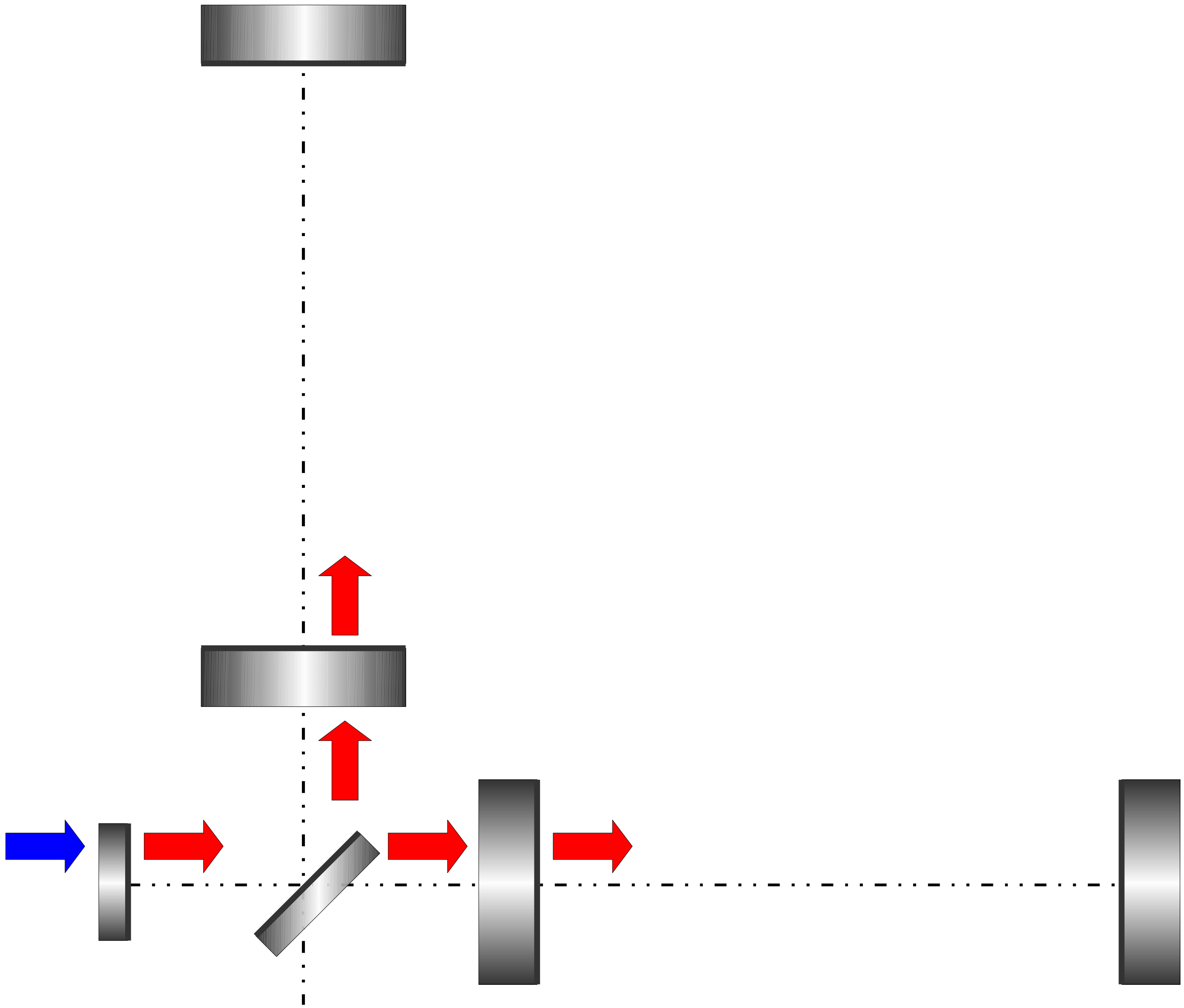
put guess fields in the itf

lock the arm cavities

solve the arm cavities

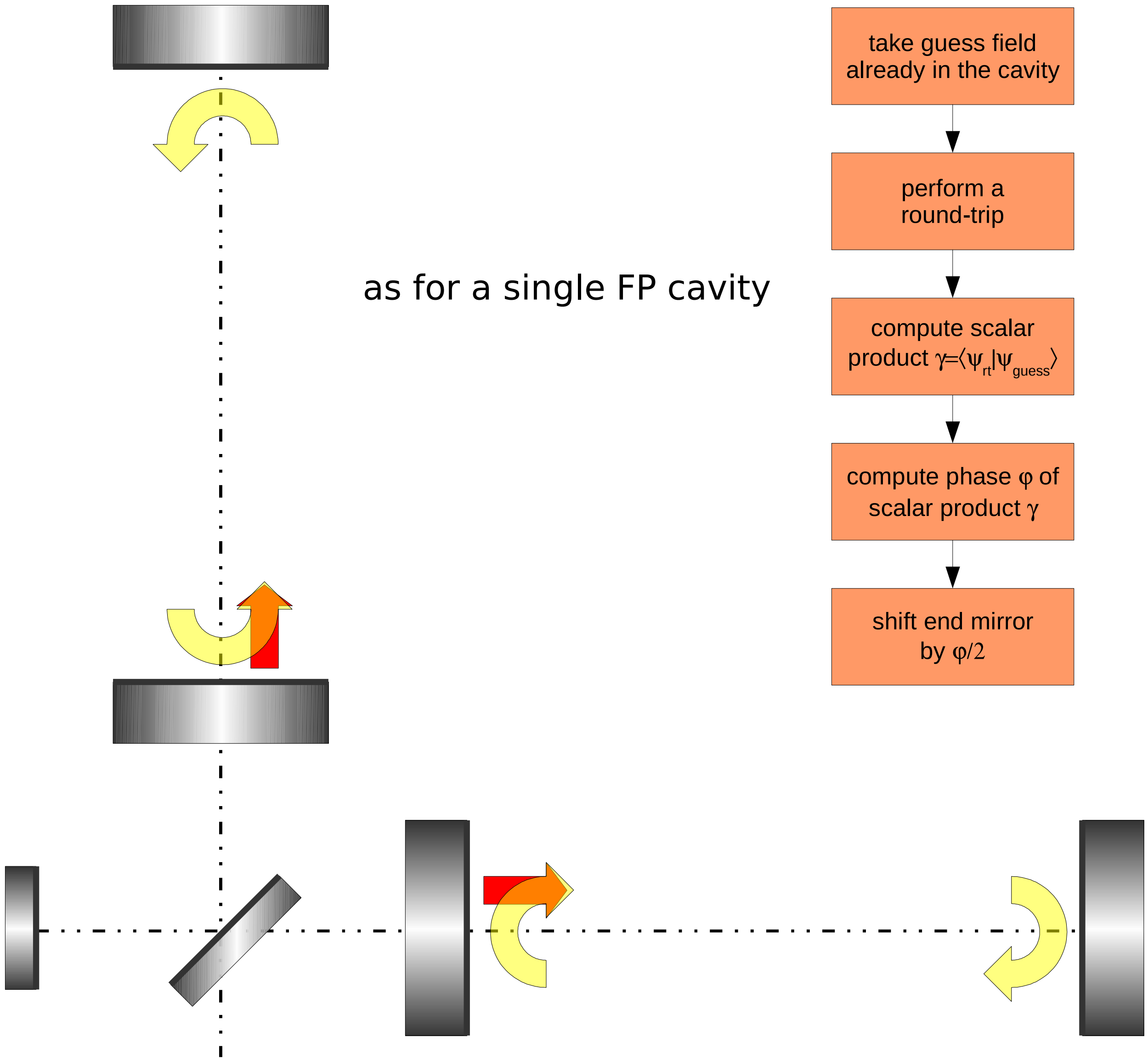
lock the central itf

solve the central itf



2. Lock arm cavities

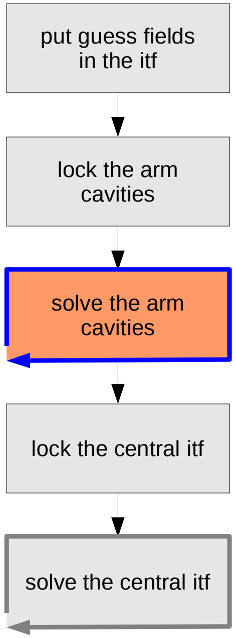
- put guess fields in the itf
- ↓ lock the arm cavities
- ↓ solve the arm cavities
- ↓ lock the central itf
- ↓ solve the central itf

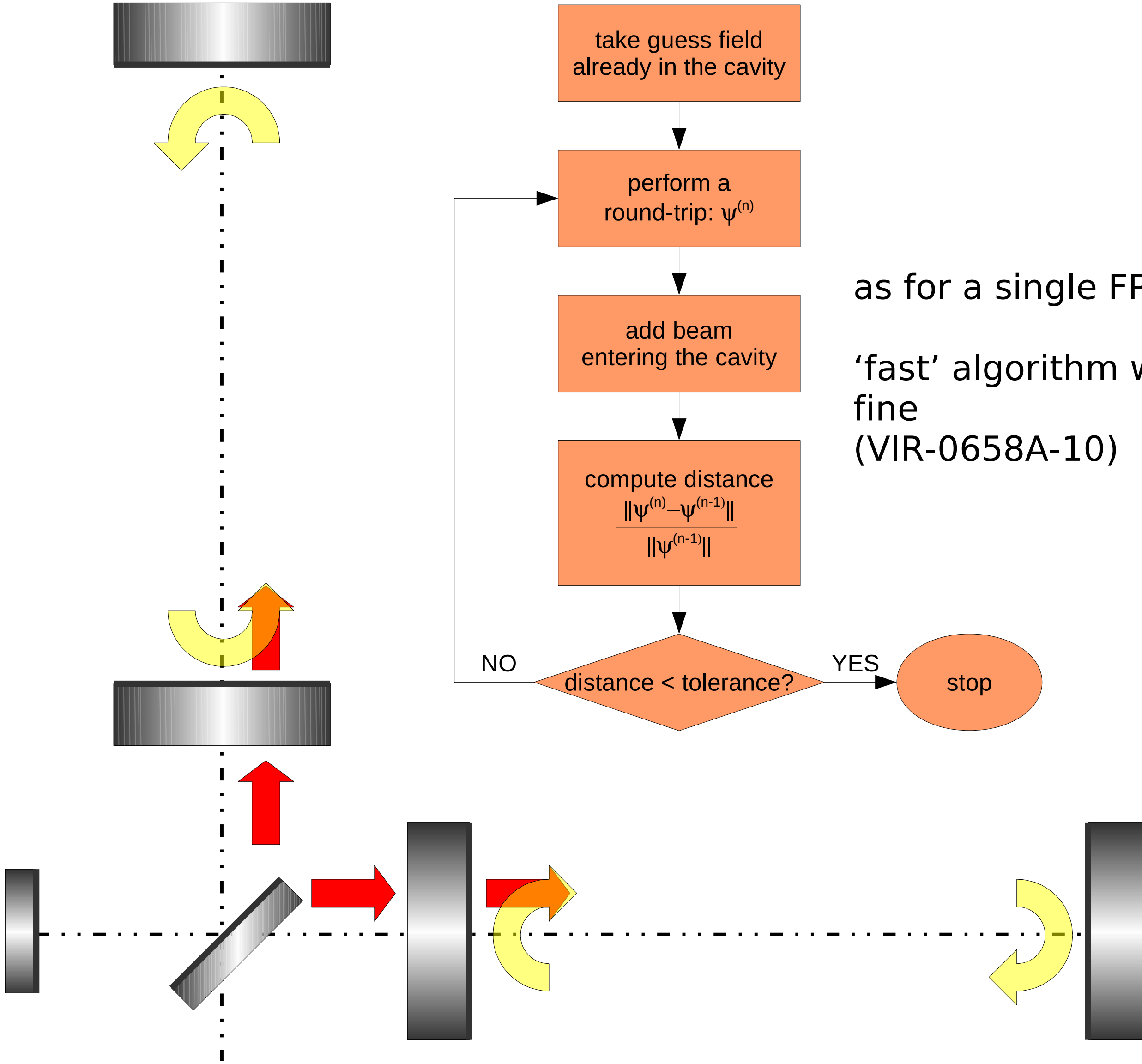


as for a single FP cavity

1. take guess field already in the cavity
2. perform a round-trip
3. compute scalar product $\gamma = \langle \psi_{rt} | \psi_{guess} \rangle$
4. compute phase φ of scalar product γ
5. shift end mirror by $\varphi/2$

3. Solve arm cavities





as for a single FP cavity

‘fast’ algorithm works fine (VIR-0658A-10)

4a. Lock power recycling

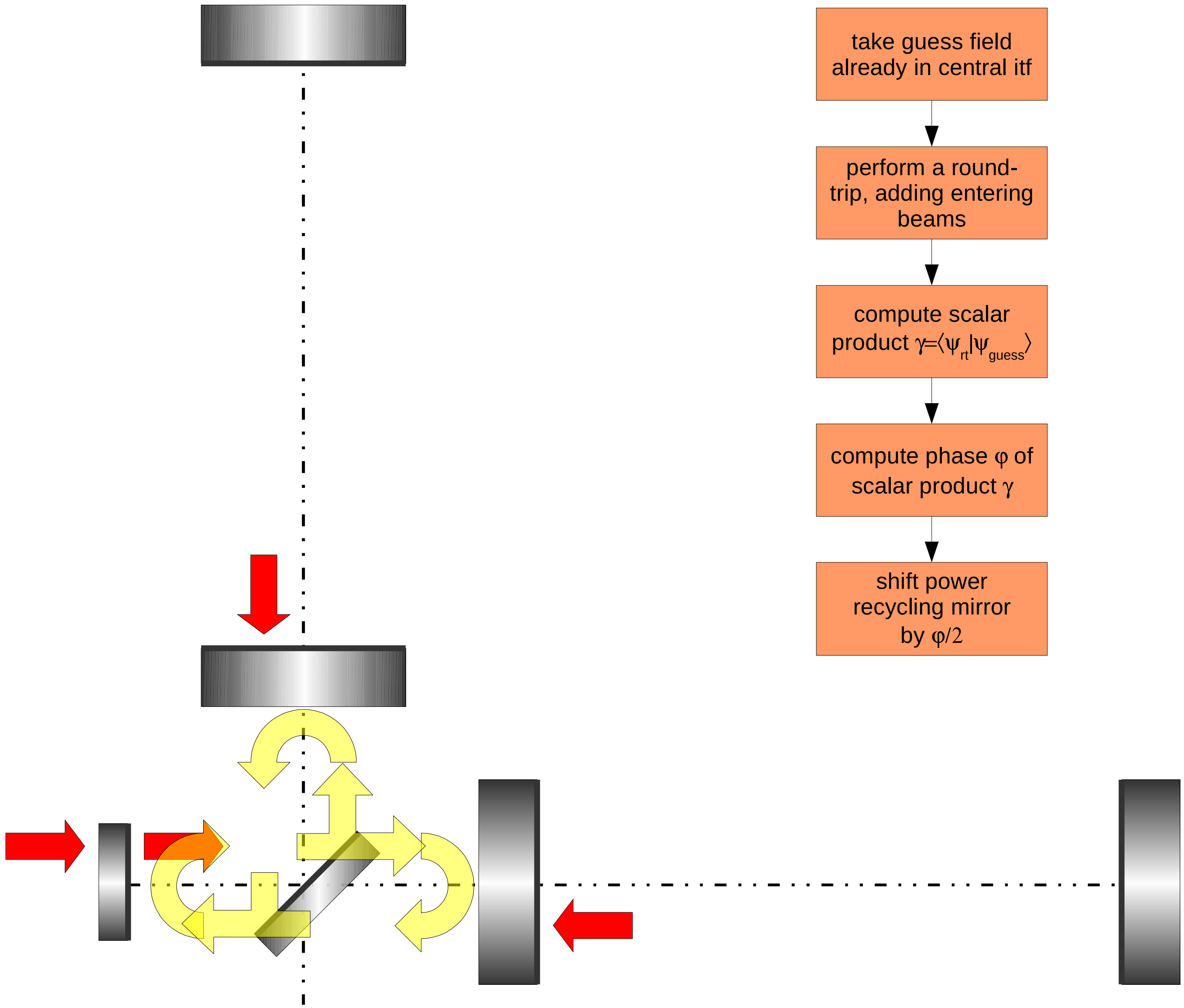
put guess fields in the itf

lock the arm cavities

solve the arm cavities

lock the central itf

solve the central itf



take guess field already in central itf

perform a round-trip, adding entering beams

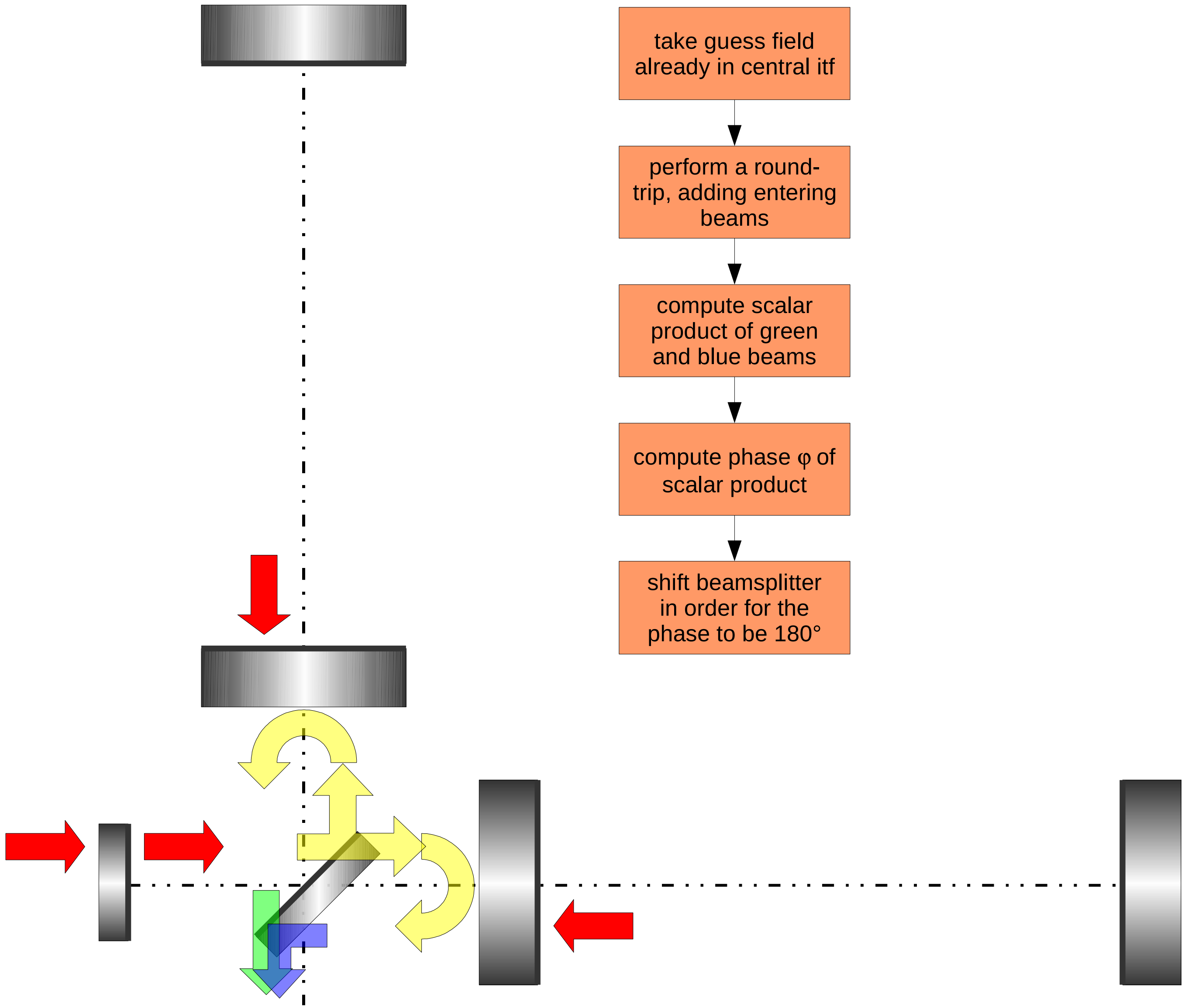
compute scalar product $\gamma = \langle \psi_{rt} | \psi_{guess} \rangle$

compute phase φ of scalar product γ

shift power recycling mirror by $\varphi/2$

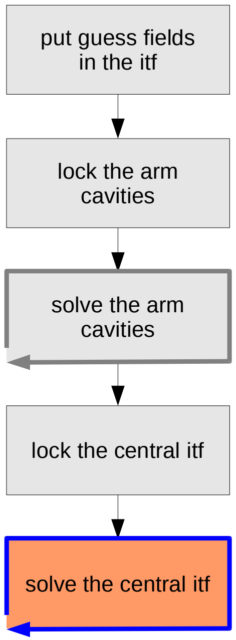
4b. Lock dark fringe

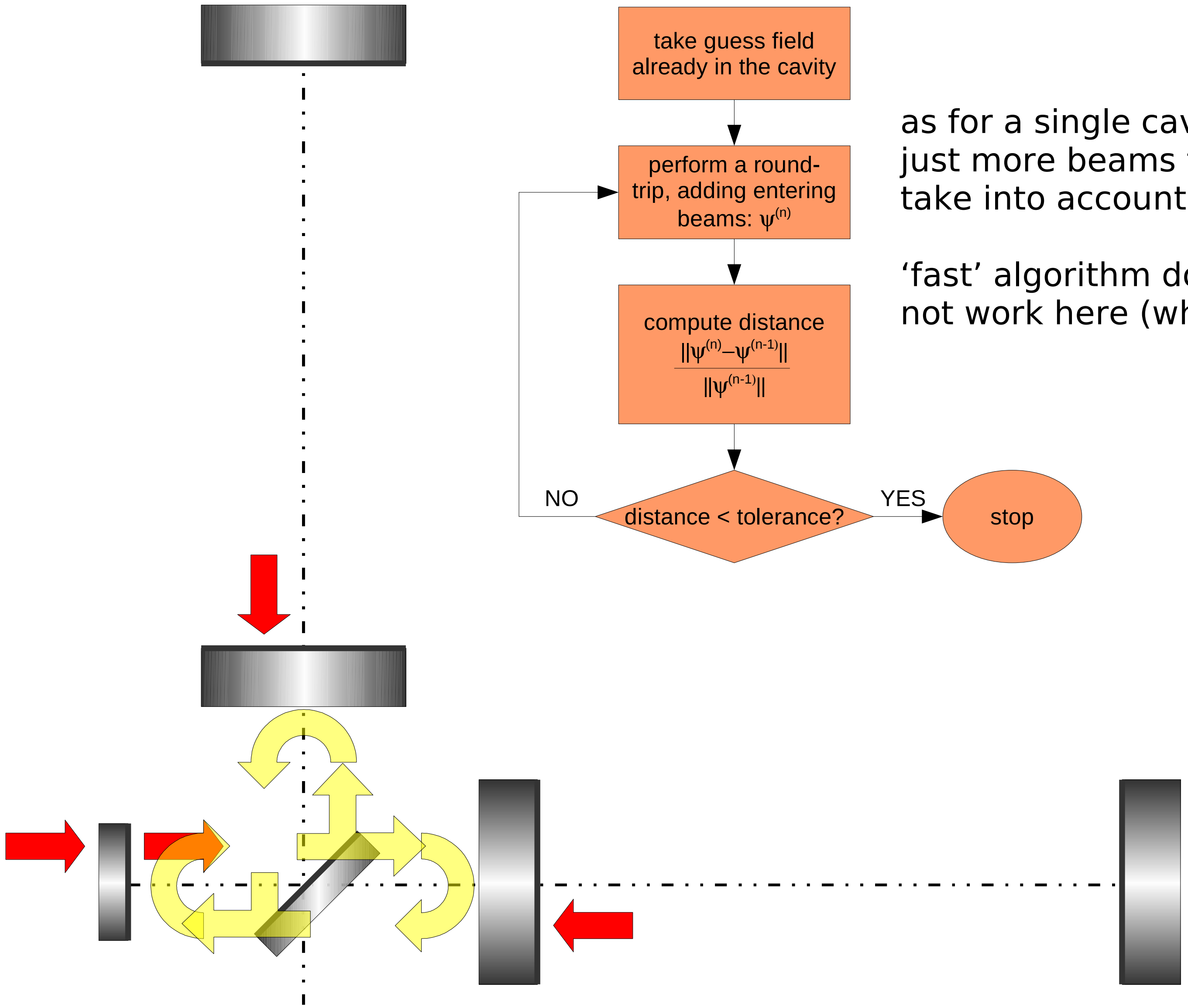
put guess fields in the itf
↓
lock the arm cavities
↓
solve the arm cavities
↓
lock the central itf
↓
solve the central itf



take guess field already in central itf
↓
perform a round-trip, adding entering beams
↓
compute scalar product of green and blue beams
↓
compute phase φ of scalar product
↓
shift beamsplitter in order for the phase to be 180°

5. Solve central Michelson

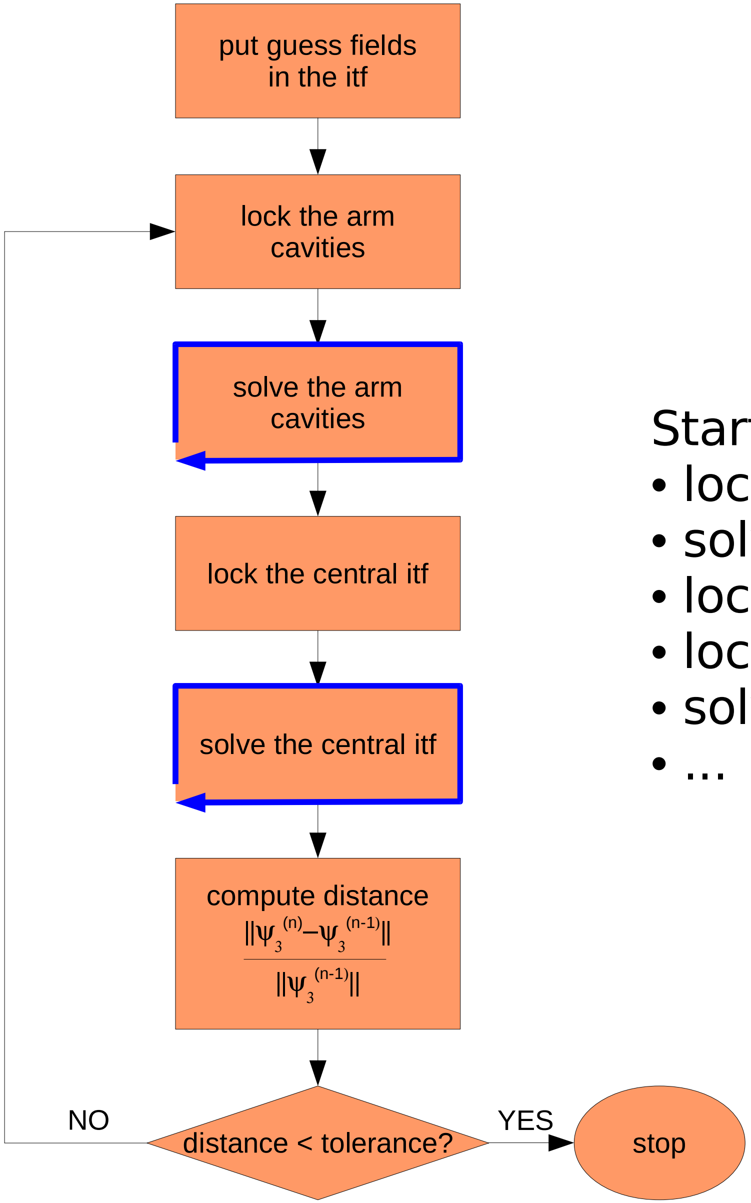




as for a single cavity, just more beams to take into account

'fast' algorithm does not work here (why?)

Again and again



Start again!

- lock arm cavities
- solve arm cavities
- lock PR
- lock DF
- solve central itf
- ...

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Let's have a look at some results...

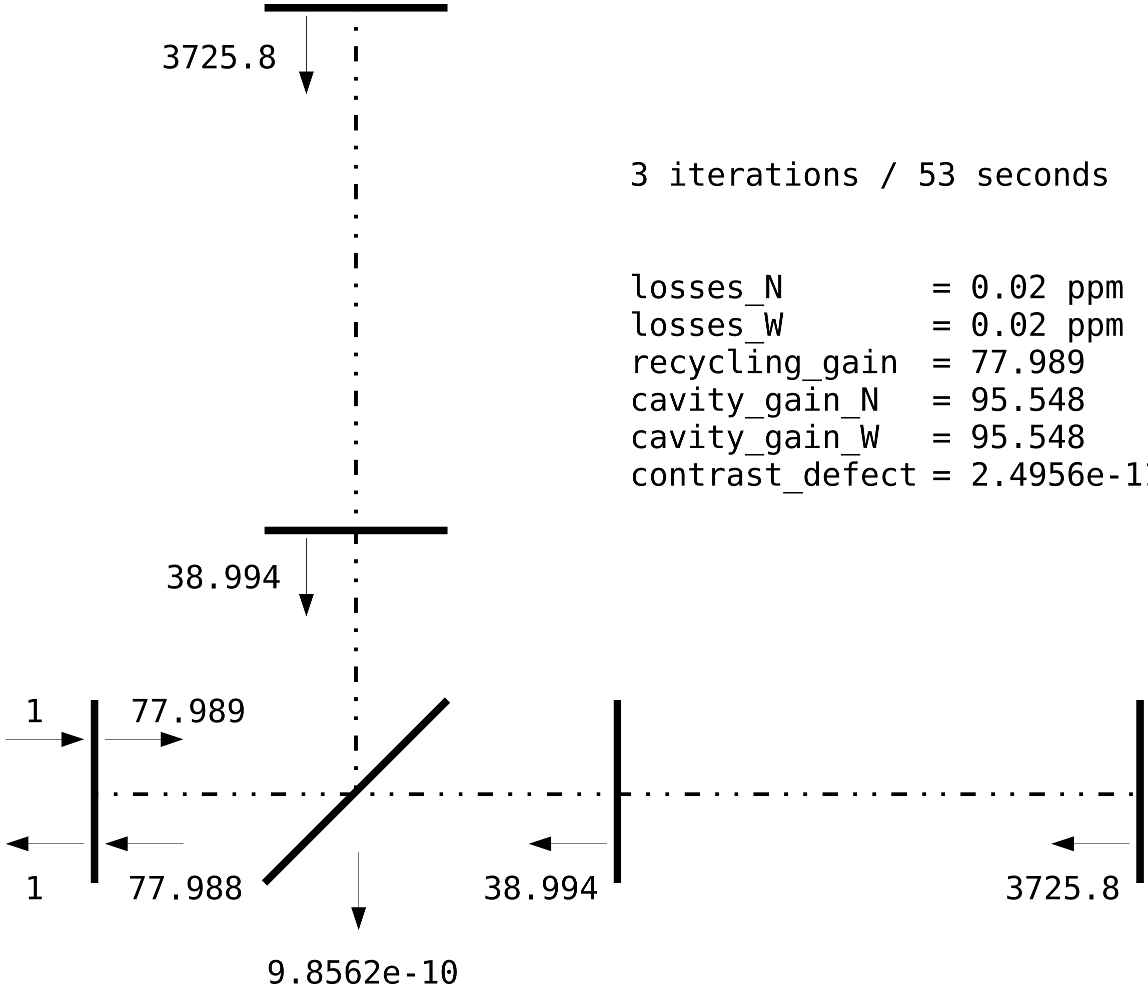
unless otherwise stated : grid 717mm, 256 points

cavity adjustment @ every cycle

pixel size = 2.8mm
= 8 × MiniFiz pixel size

Virgo+

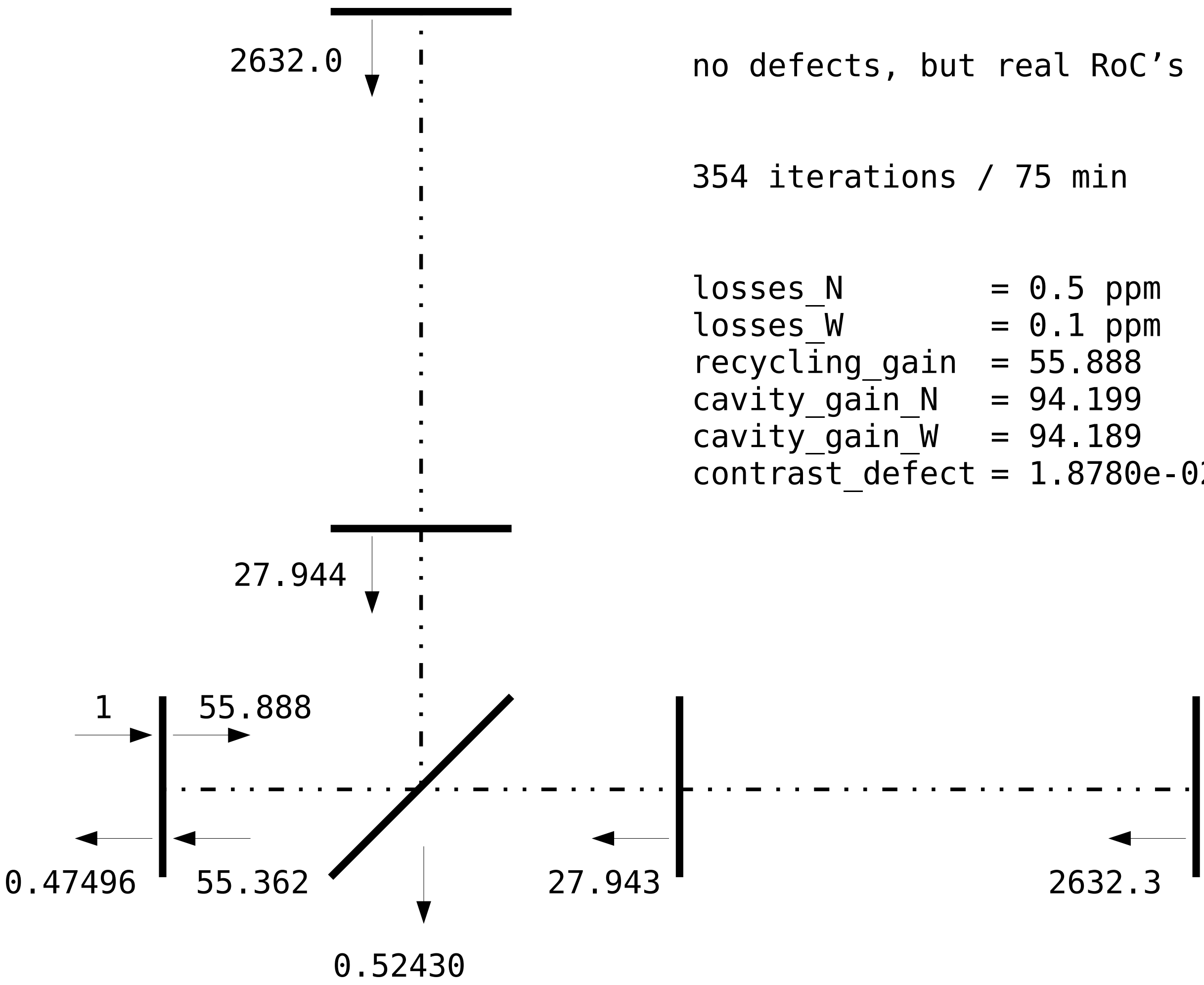
Virgo+ – no defects




```
3 iterations / 53 seconds

losses_N        = 0.02 ppm
losses_W        = 0.02 ppm
recycling_gain  = 77.989
cavity_gain_N   = 95.548
cavity_gain_W   = 95.548
contrast_defect = 2.4956e-11
```

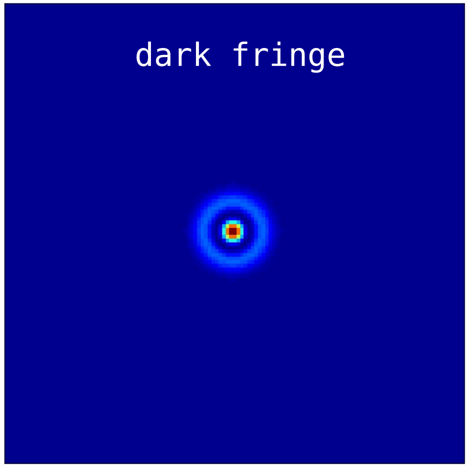
Virgo+ – real RoC's




```
no defects, but real RoC's & no CHRoCC

354 iterations / 75 min

losses_N        = 0.5 ppm
losses_W        = 0.1 ppm
recycling_gain  = 55.888
cavity_gain_N   = 94.199
cavity_gain_W   = 94.189
contrast_defect = 1.8780e-02
```

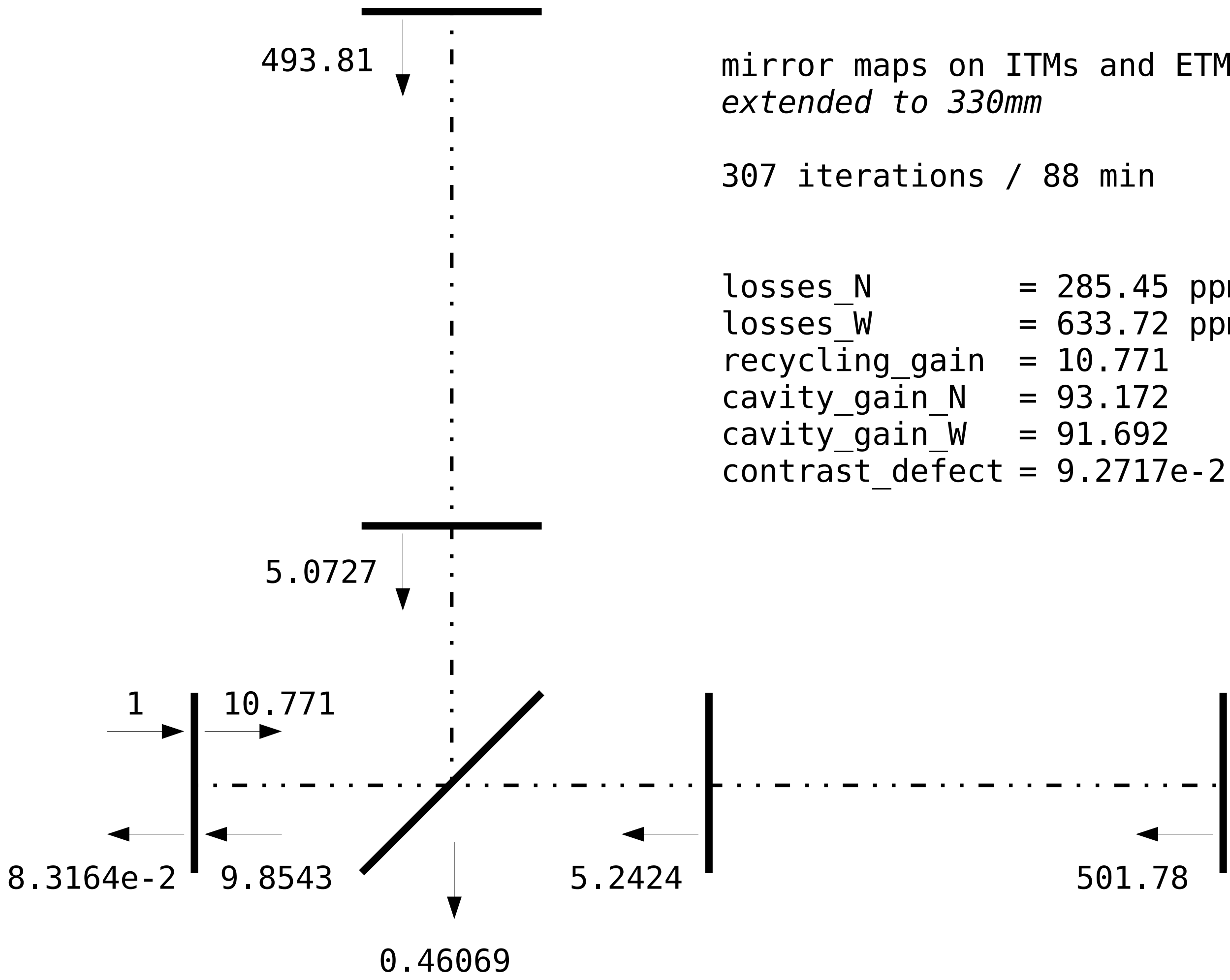


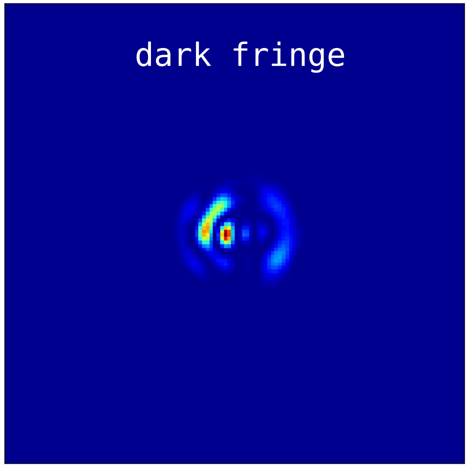
Virgo+ – real maps

mirror maps on ITMs and ETMs,
extended to 330mm

307 iterations / 88 min

```
losses_N         = 285.45 ppm
losses_W         = 633.72 ppm
recycling_gain   = 10.771
cavity_gain_N    = 93.172
cavity_gain_W    = 91.692
contrast_defect  = 9.2717e-2
```



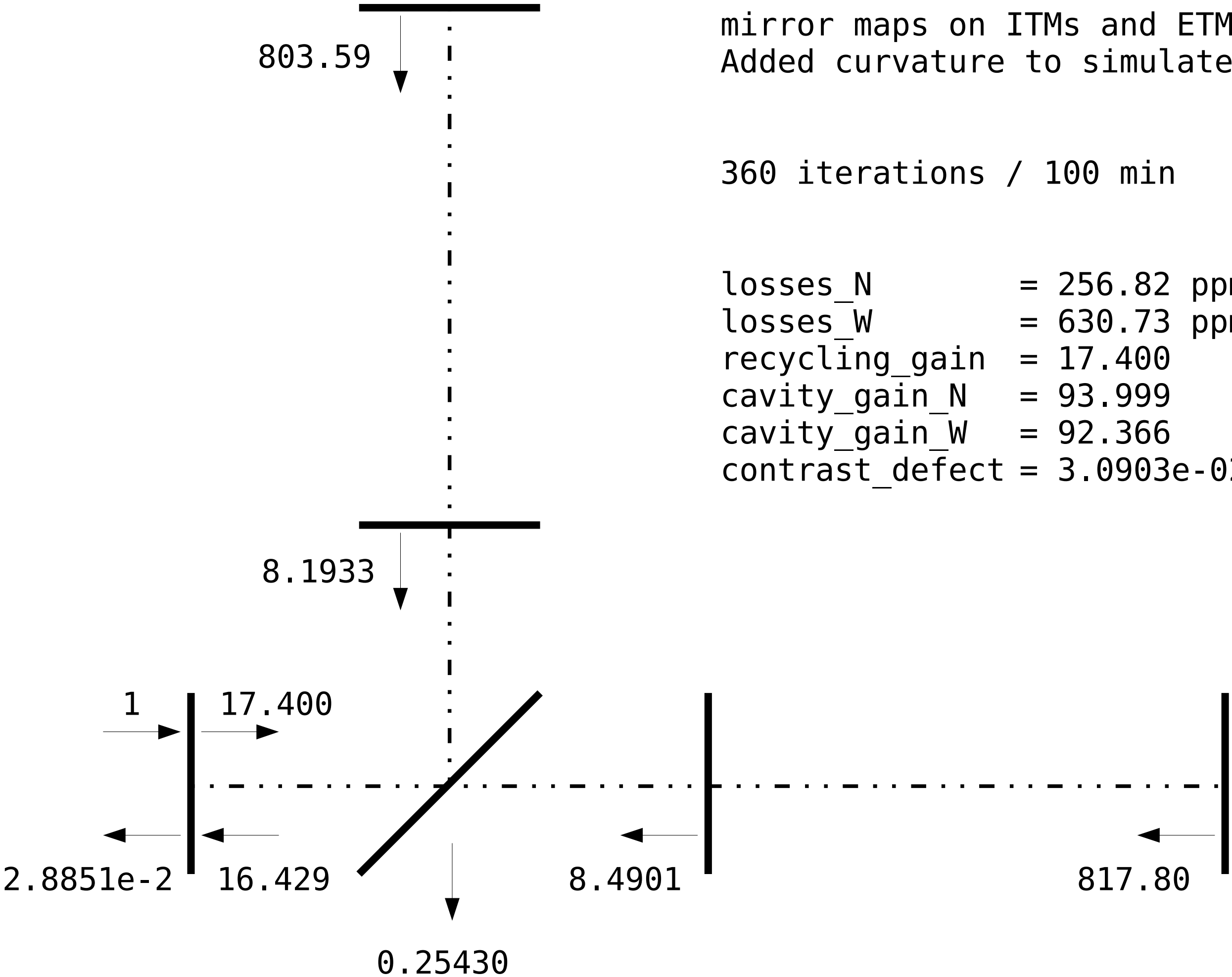


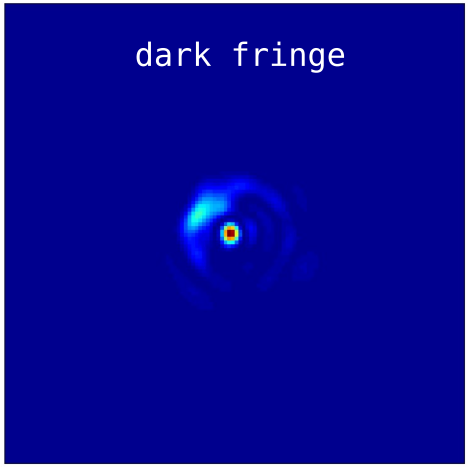
Virgo+ – real maps & CHRoCC 3600m

mirror maps on ITMs and ETMs, extended to 330mm
Added curvature to simulate CHRoCC -> 3600m

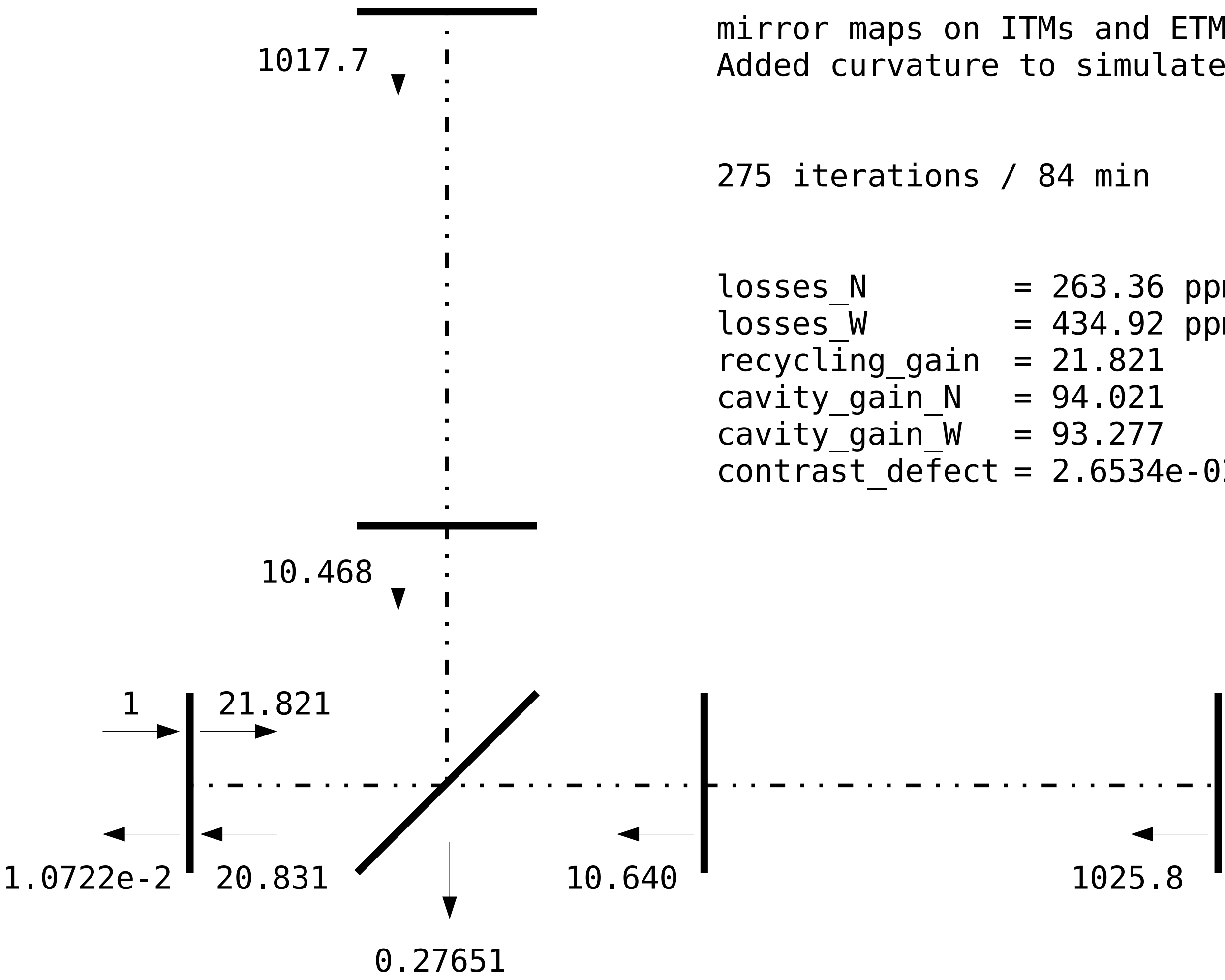
360 iterations / 100 min

```
losses_N        = 256.82 ppm
losses_W        = 630.73 ppm
recycling_gain  = 17.400
cavity_gain_N   = 93.999
cavity_gain_W   = 92.366
contrast_defect = 3.0903e-02
```





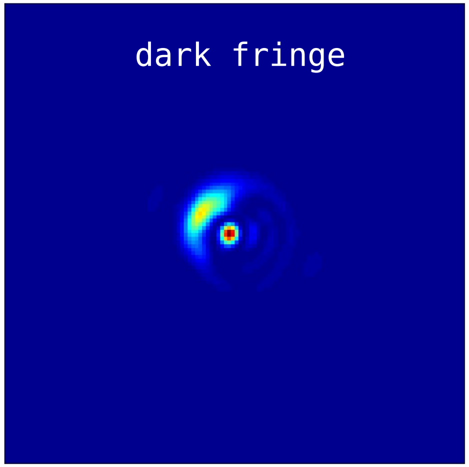
Virgo+ – real maps & CHRoCC 3650m



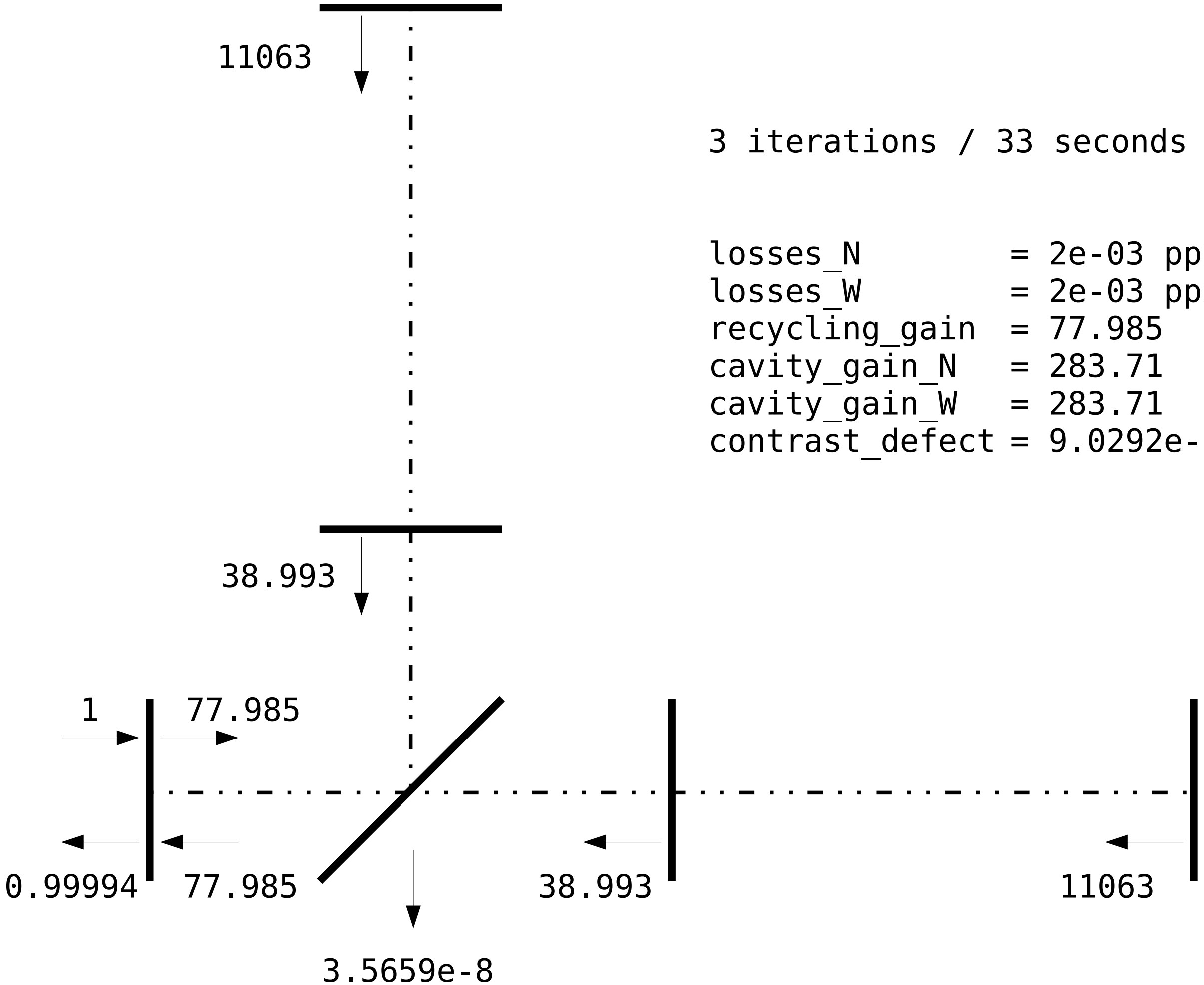
mirror maps on ITMs and ETMs, extended to 330mm
Added curvature to simulate CHRoCC -> 3650m

275 iterations / 84 min

```
losses_N        = 263.36 ppm
losses_W        = 434.92 ppm
recycling_gain  = 21.821
cavity_gain_N   = 94.021
cavity_gain_W   = 93.277
contrast_defect = 2.6534e-02
```



Advanced Virgo

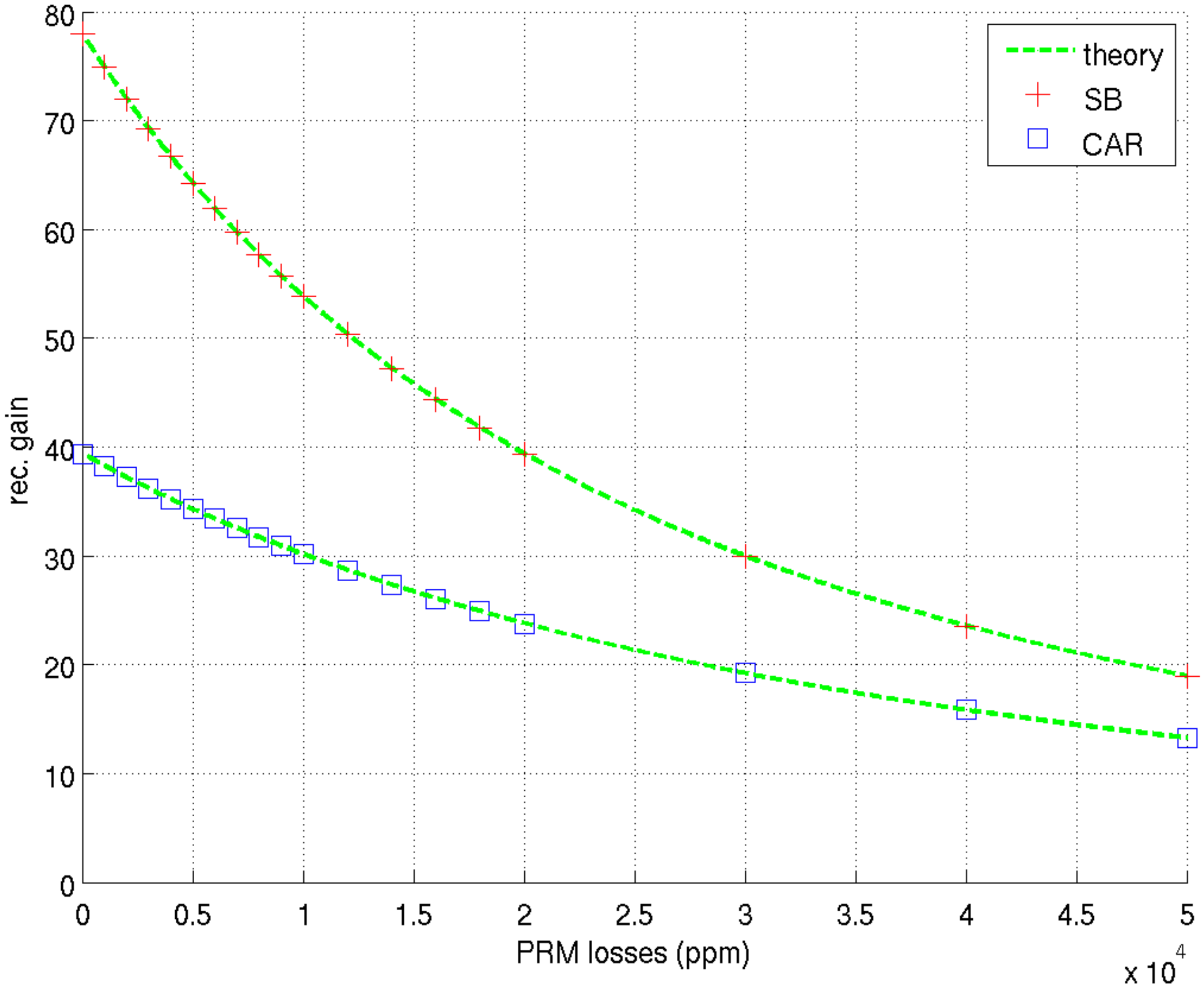



```
3 iterations / 33 seconds

losses_N       = 2e-03 ppm
losses_W       = 2e-03 ppm
recycling_gain = 77.985
cavity_gain_N  = 283.71
cavity_gain_W  = 283.71
contrast_defect = 9.0292e-10
```

What about the sidebands?

Simulation of AdV with increasing losses in the central ITF (affected to the PRM)




```
on the average:
CAR: 4 iterations
SB:  6 iterations
CPU time: 4.5 min
```

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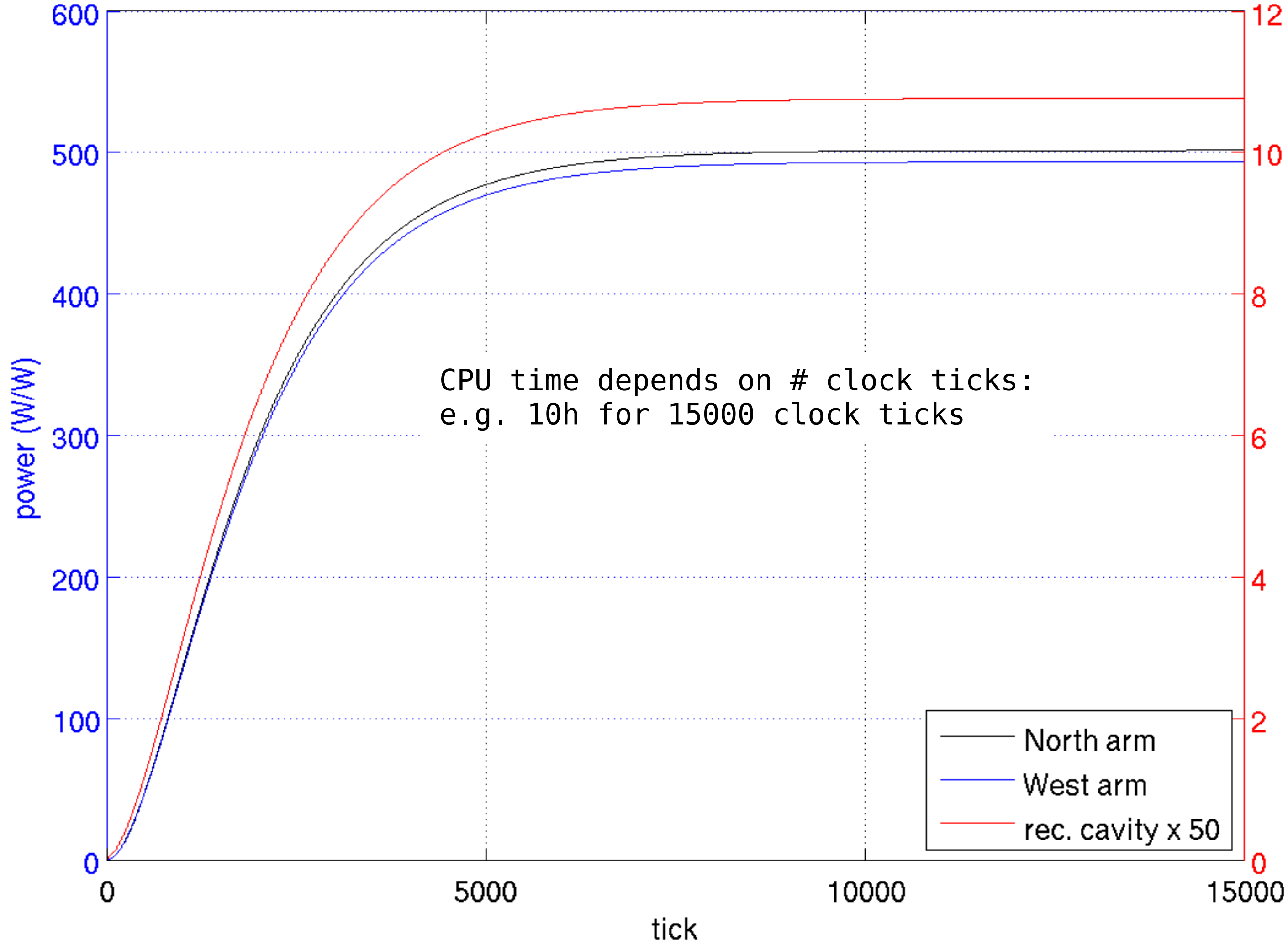
OPglobal card:

• FFT simulation of a power-recycled interferometer
• computation of the temporal evolution of the fields inside the ITF (‘dynamics’)
• already presented in VIR-0563A-10, so I will not go into details
• *slow but reliable method to validate other results!*

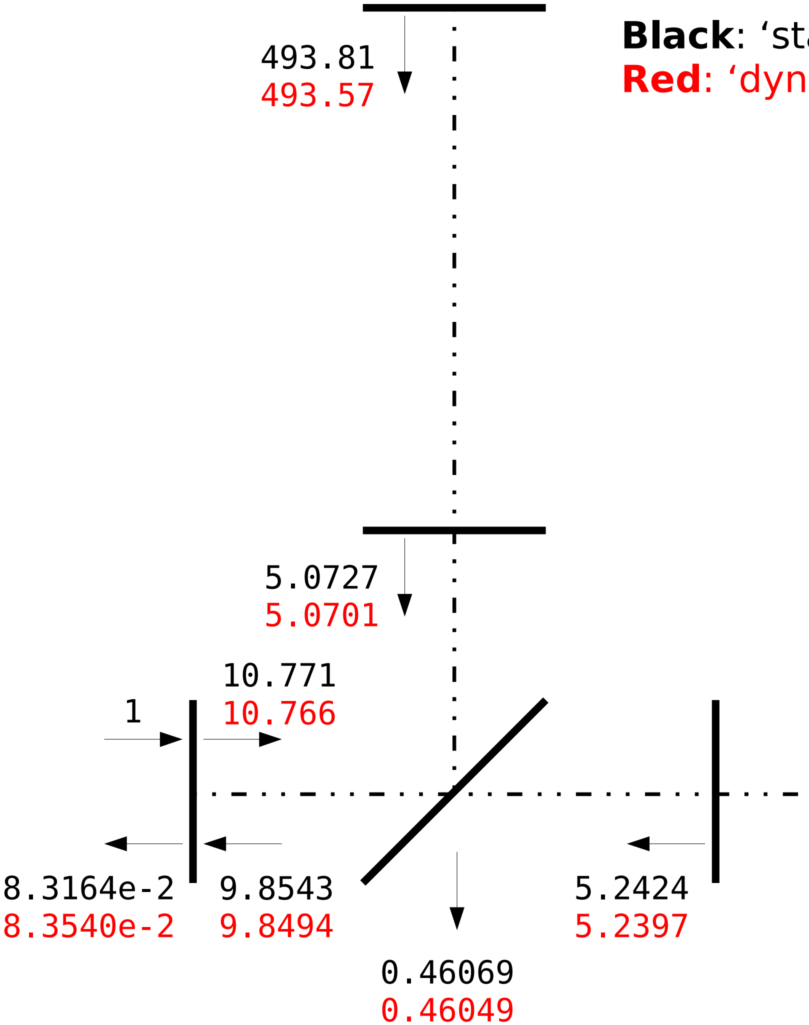
Virgo+ with real mirror maps (extended to 330 mm)

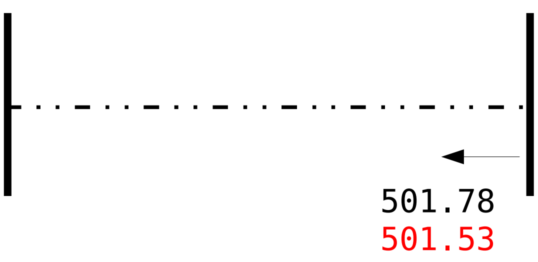


Comparison: ‘stationary’ vs ‘dynamic’

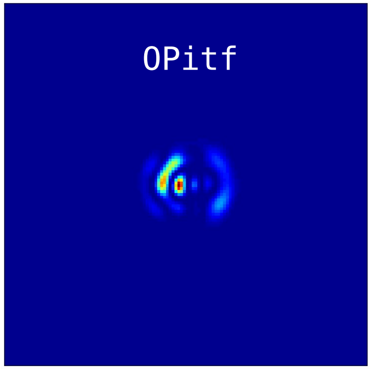
Virgo+ with real mirror maps (extended to 330 mm)

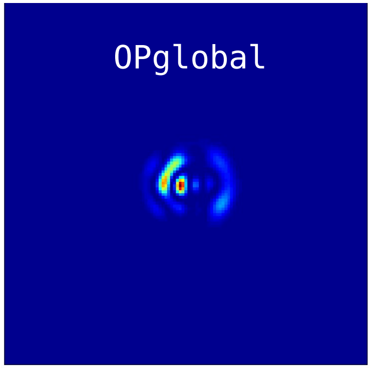
Black: ‘stationary’ solution (*OPitf*)
Red: ‘dynamic’ solution (*OPglobal* at the end of the simulation)





dark fringe:





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Several things to do

Incomplete TODO list:

➔ implement signal recycling

➔ ‘fast’ algorithm for the central Michelson (should work in principle but it does not... hunt the bug!)

➔ allow the use of transmission maps

➔ implement FFTW instead of the current FFT implementation

➔ implement multithreading (for instance: carrier and sidebands on different threads)

➔ whatever users want...

But most of all...

Some personal considerations:

SIESTA-FFT is a half-sleeping project (no pun intended):
1 developer (me) + 1 user (Romain).
I am leaving the collaboration in two weeks;
Romain will finish his PhD ~ october 2012

It is big and heavy and slow to evolve, but I think still useful because:
• it tries to be as versatile as possible
• it integrates with the Virgo software environment (e.g. input/output in *frame* format)
• it can be easily run in `batch' mode via shell scripts
• the source code is open to everybody in the collaboration

However:
It <u>really</u> needs a boost:
• in the dreamworld, 1 developer 100% on SIESTA
• even more important: a user community (if nobody uses it, there is no reason to develop)

That’s all folks

Thank you.

Nice SIESTA to everybody.

SPARES

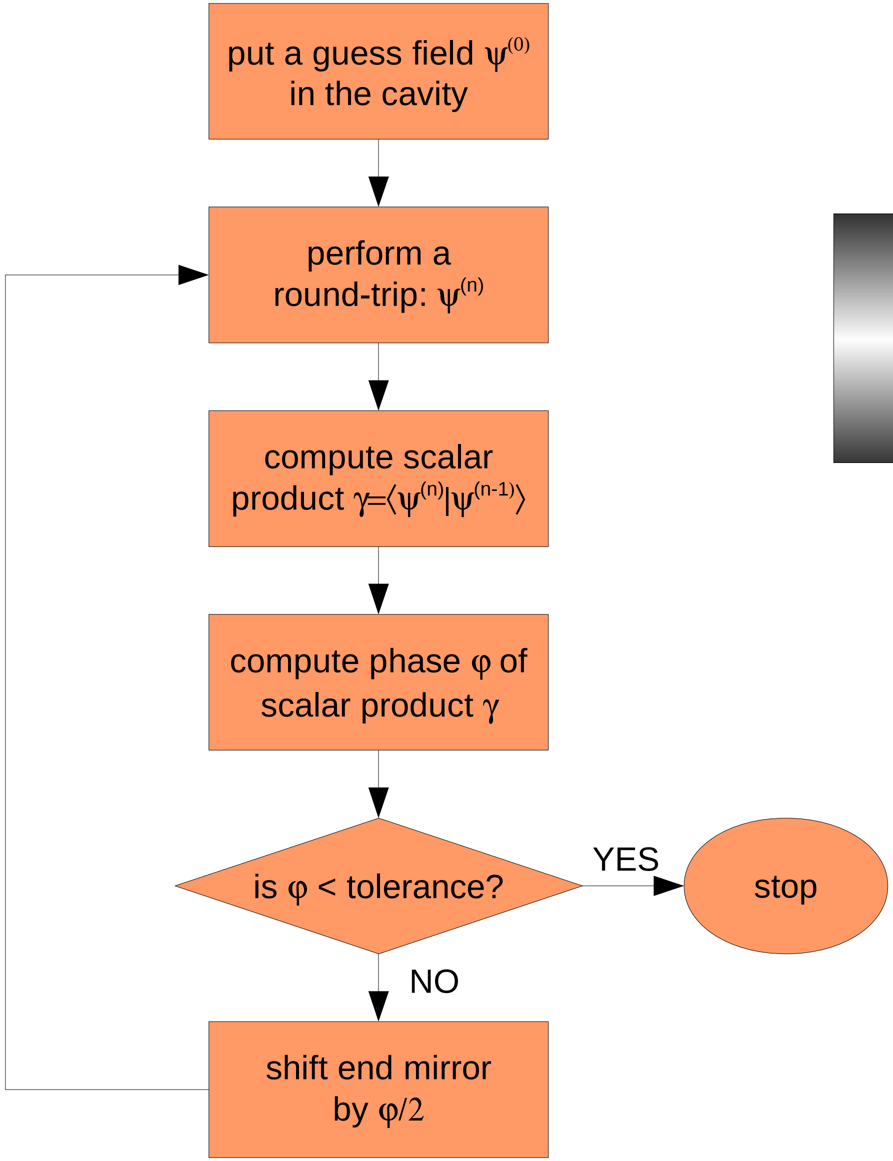
FP cavity

Before addressing the algorithms for the power-recycled ITF, I will explain/remind how SIESTA works for a simple FP cavity.
The very same mechanisms are applied to the ITF.

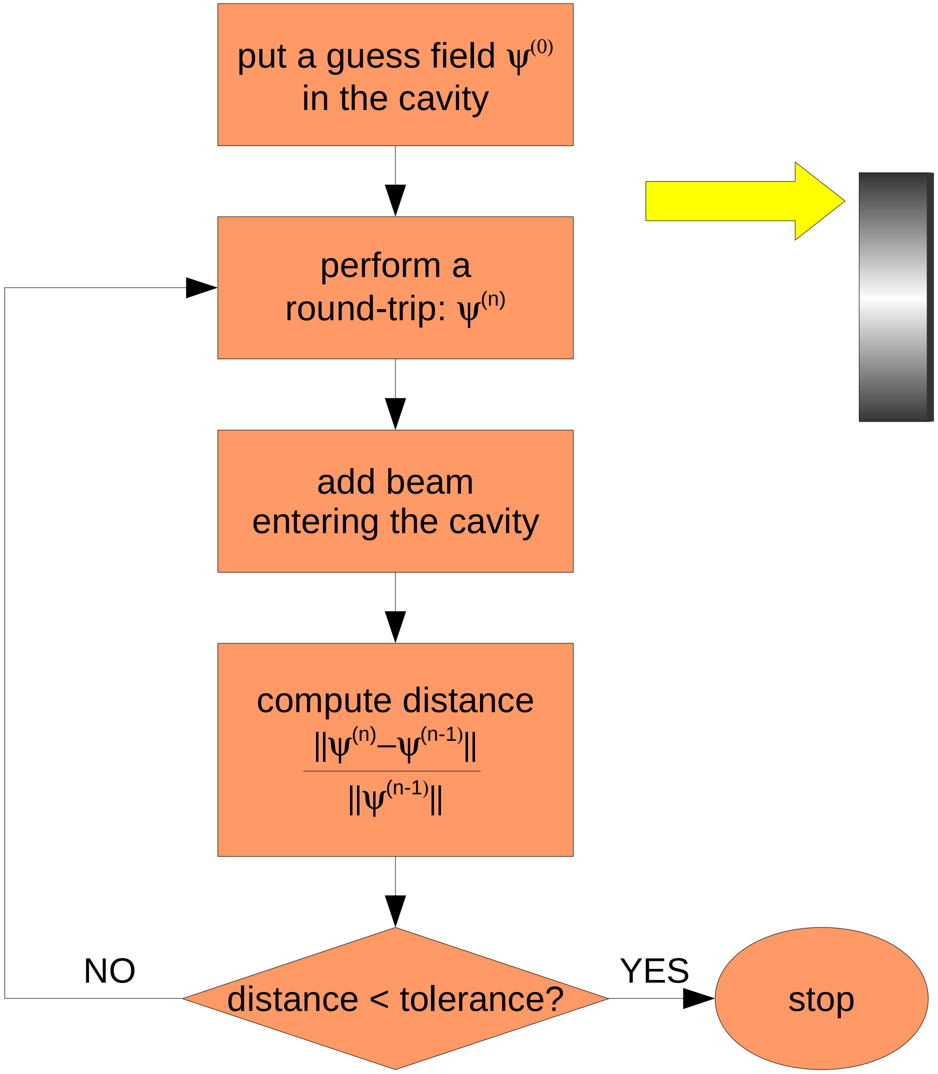
So, here is what SIESTA does for a FP cavity:

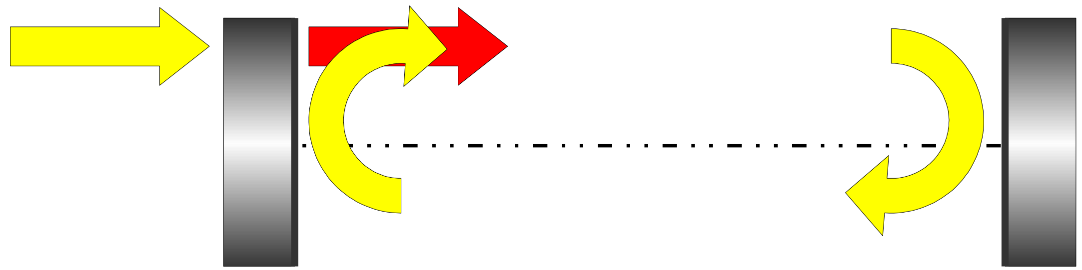
1) adjust the cavity to resonance
• compute the stationary field

adjust a FP cavity



solve a FP cavity





About the use of mirror maps

WARNING #1

Measured maps are about 900×900 pixels wide. Reducing map resolution is delicate, since it can significantly influence gain and losses.

After some tests, my conclusion is that the best practice is to reduce map resolution by averaging an integer number of neighbor pixels (e.g. averaging over 2×2 pixels, 4×4, etc.).

This is what one gets for Virgo+ West cavity:

grid (mm)	grid points	gain	losses (ppm)
717	**2048**	**90.25**	**1004**
717	1024	90.24	1008
717	512	90.21	1015
717	256	90.04	1054
717	128	89.89	1093

→ no resampling of the maps (first row)

(why losses so high?
see next slide)

About the use of mirror maps

WARNING #2

Why losses are so high?

→ The maps have a diameter of 312 mm.

If we extend artificially the West map to 330 mm:

grid (mm)	grid points	diameter (mm)	gain	losses (ppm)
717	256	312	90.04	1004
717	256	330	92.09	583

Power-recycled ITF

SECOND POSSIBILITY:
cavities adjusted only at the beginning