TIFOSI: A Quantum Scattering Simulation

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Why TIFOSI?

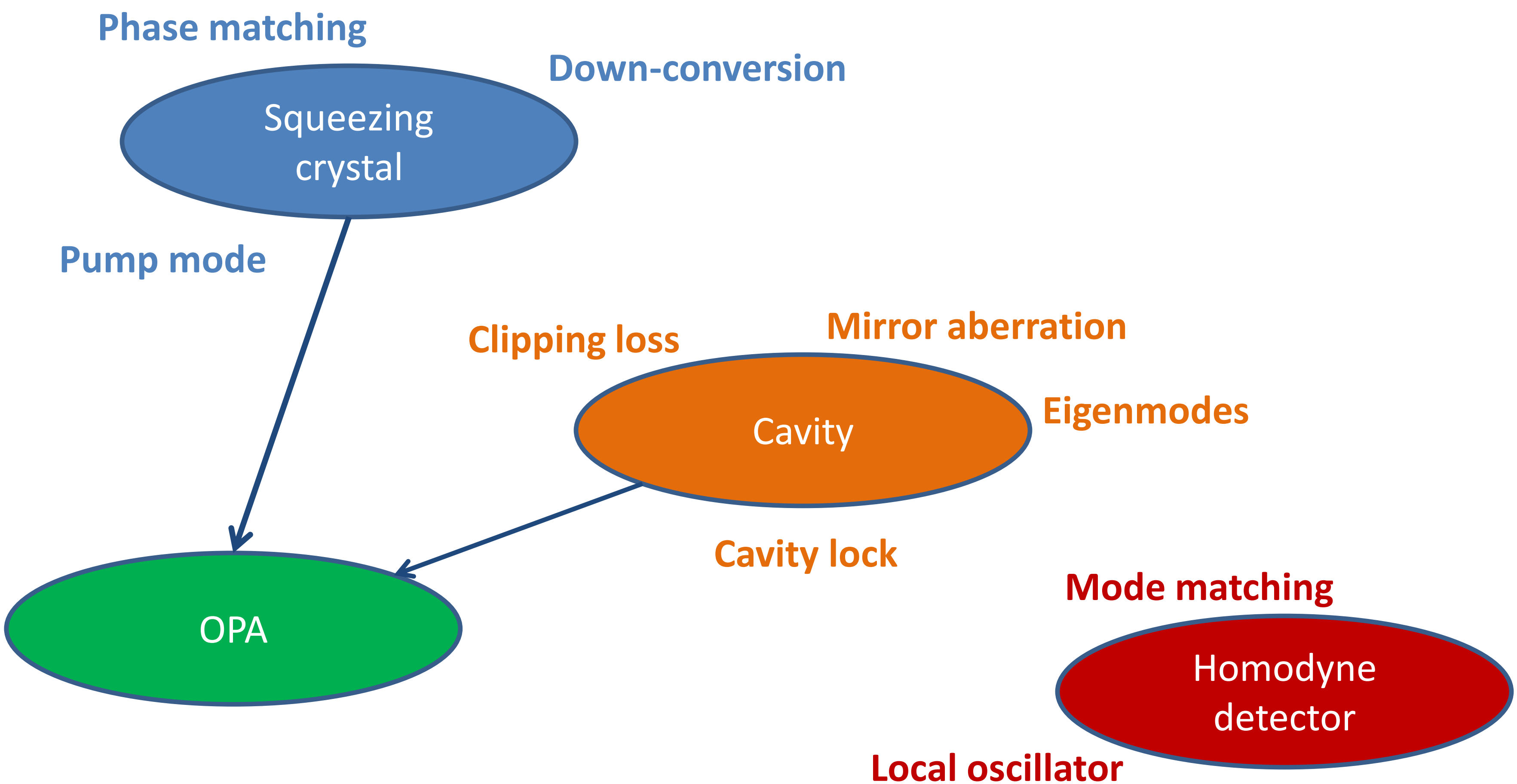
1. We should be able to model realistic OPAs. Down-conversion is not yet described in LG/HG bases.

2. We want to understand what happens to quantum fields when they interact with cavities subject to scattering and clipping.

3. One day we want to do really good with squeezing and QND (and therefore care about details).

4. You want an alternative approach to compare with LG/HG quantum simulations (Finesse, MIST).

TIFOSI Building Blocks



Classical Versus Quantum FFT

Oscar, SIS, Fog

Fields =
N-dim vectors

Calculate propagated fields

Calculate fields interacting with cavities as stationary solution

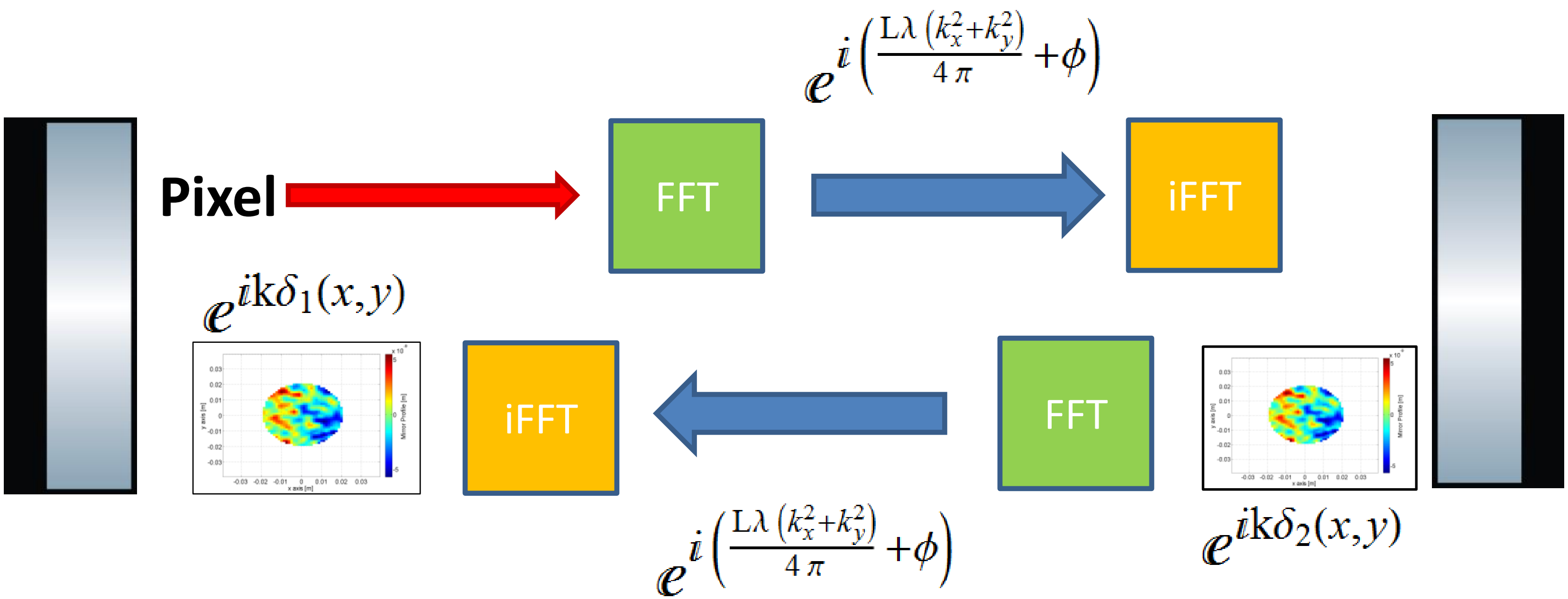
TIFOSI

Fields =
NxN-dim matrices

Calculate propagated fields starting with vacuum field

Directly calculate cavity resonance
1/(1-Roundtrip)

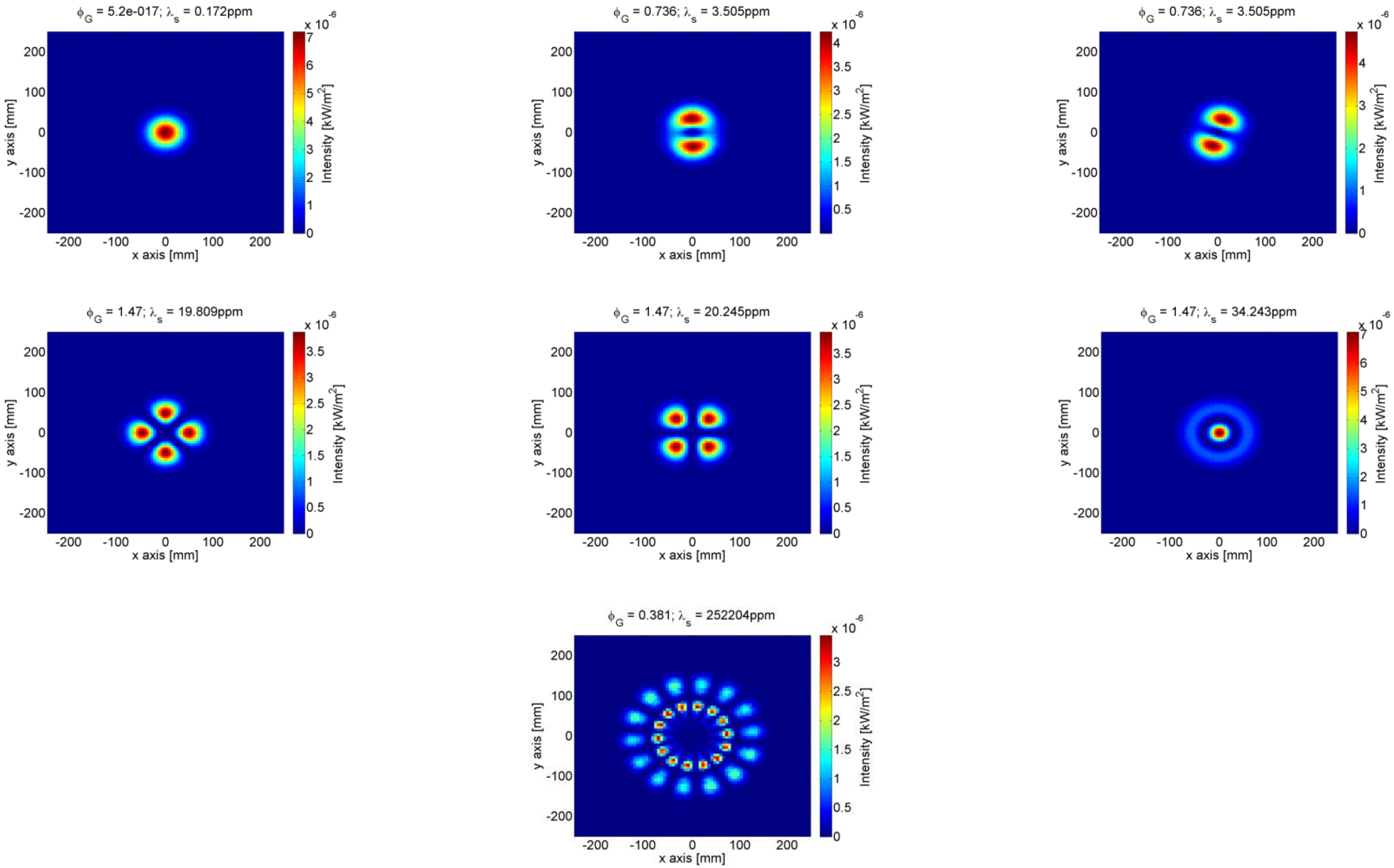
Building a Round-Trip Matrix



Jerome Degallaix said:
Repeat this procedure
for entire pixel basis.

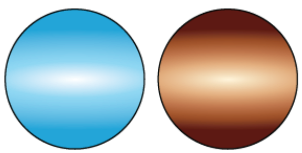
This is the fastest and (therefore)
numerically most accurate procedure.

Cavity Eigenmodes



Quantum Noise and Cavities

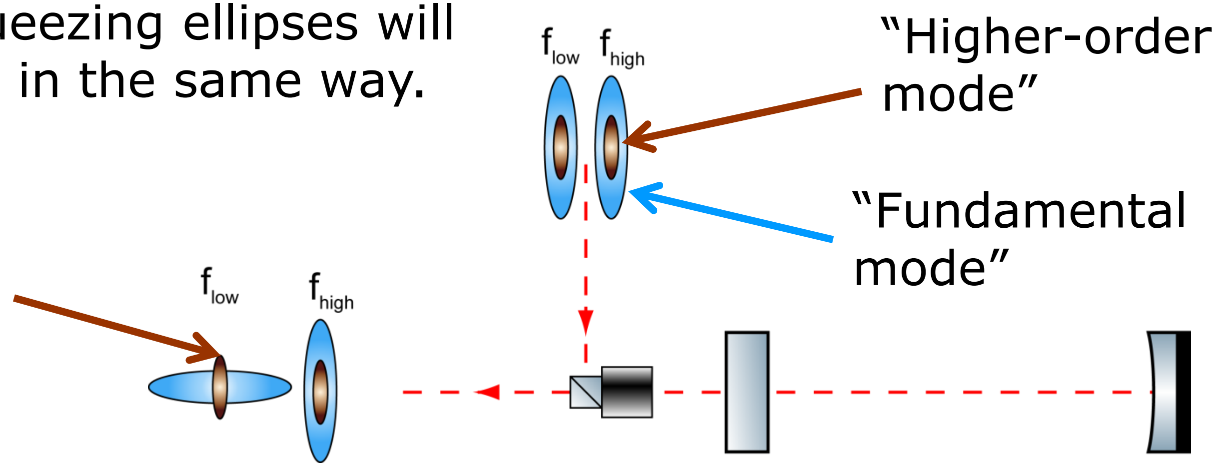
R_{ij} eigenvectors:



Cavity couples spatial modes since its eigenmodes are different from “external” basis.

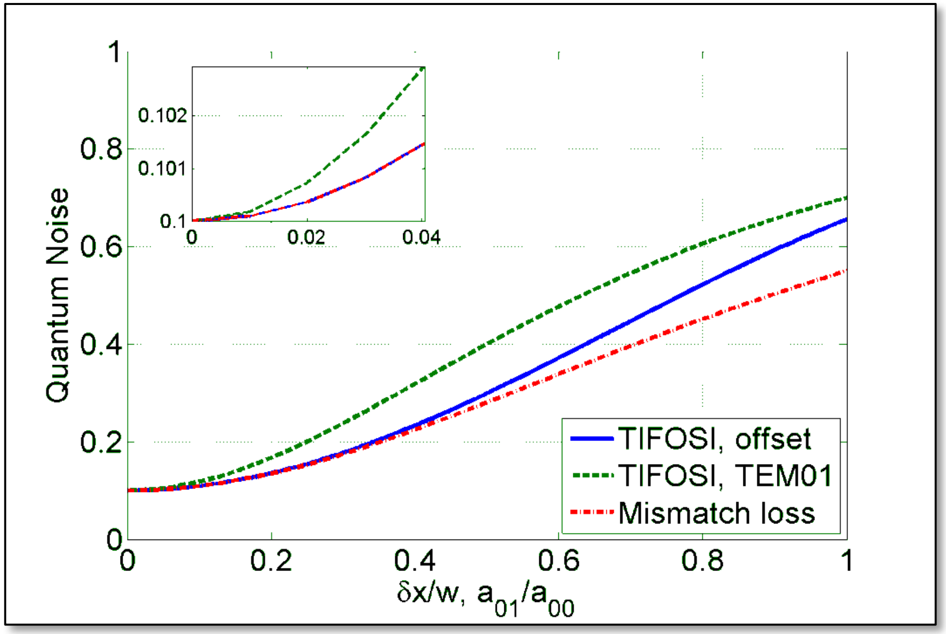
Not all squeezing ellipses will be rotated in the same way.

Excess noise



The Ideal OPA

Variations of local oscillator



Ideal means:

(1)The OPA has no clipping or absorption loss.

(2)The eigenmodes are LG/HG, or as close to this as possible (LG/HG cannot be represented by Fourier simulations)

(3)Pump is a plane wave.

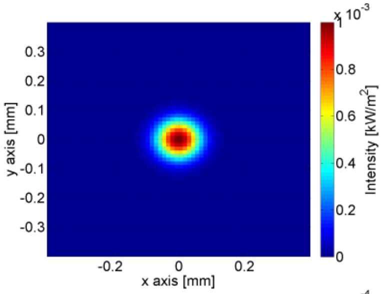
RED: QN according to mode-mismatch loss produced by TEM01 content
GREEN: QN according to TIFOSI produced by TEM01 content
BLUE: QN according to TIFOSI produced by LO offset

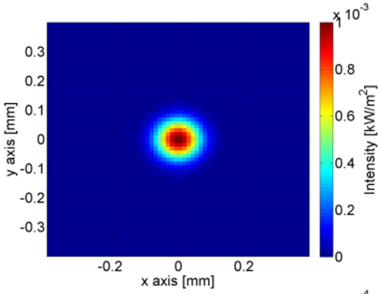
LG/HG to DFT

If you have the guts to guess OPA eigenmodes: HG

DFT

TEM 0 0





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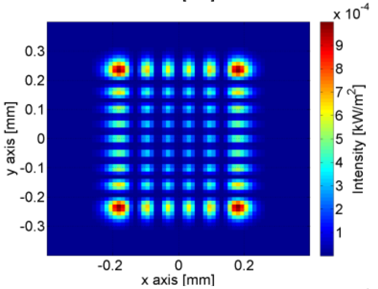
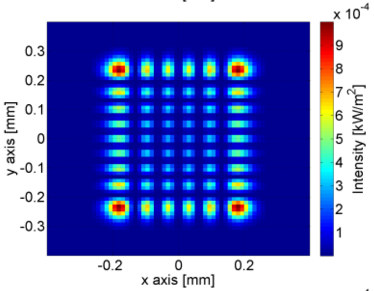
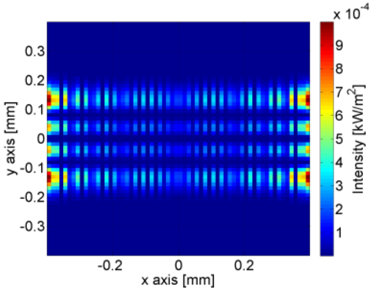


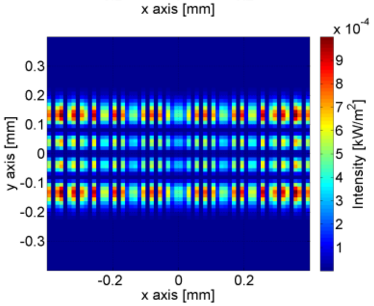
Gram-Schmidt orthogonalization
(QR decomposition)



TEM 3 28



This transform must be unitary, otherwise you have artificial loss.



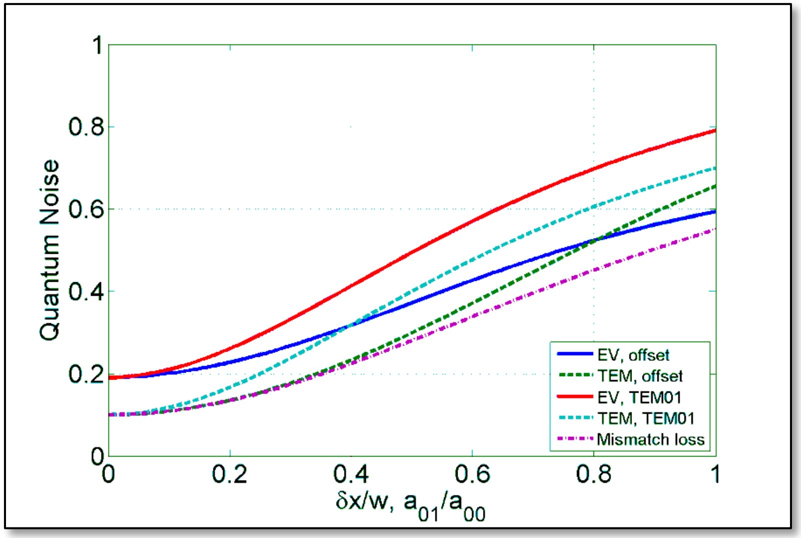
A Realistic OPA

(1) Calculate OPA eigenmodes.

(2) Expand pump beam into plane waves.

(3) Calculate OPA output for each plane wave of the pump for each eigenmode.

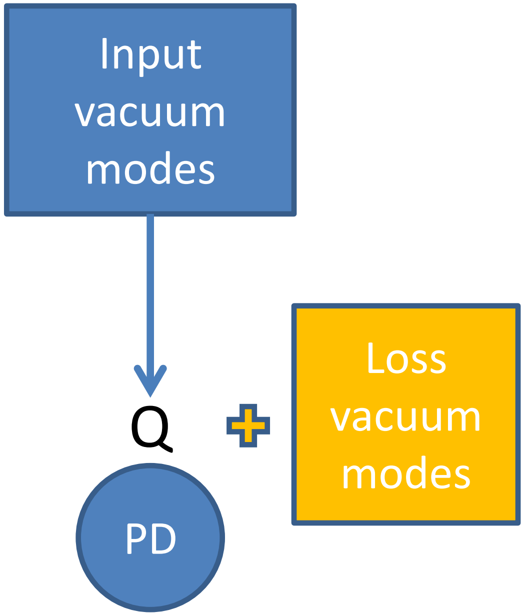
(4) Sum contributions from all plane waves of the pump.



Items (1) and (3) implemented, assuming plane-wave pump (EV curves)

Optical Loss

Current implementation in TIFOSI:
Vector (1-Loss) = diagonal of (Q Q*), where Q is the quantum field at the photodiode.



The problem is that this loss vector does not tell you anything about the nature of the injected loss field (whether it is squeezed or not).

Therefore, what about loss that occurs inside an OPA?

Aliasing Problem in FFT Codes

Simple understanding of aliasing based on rays:

(1) DFT can only simulate cyclic systems.

(2) Rays can hit a copy of a mirror next door, which is indistinguishable from the "real" mirror.

Anti-aliasing methods used:

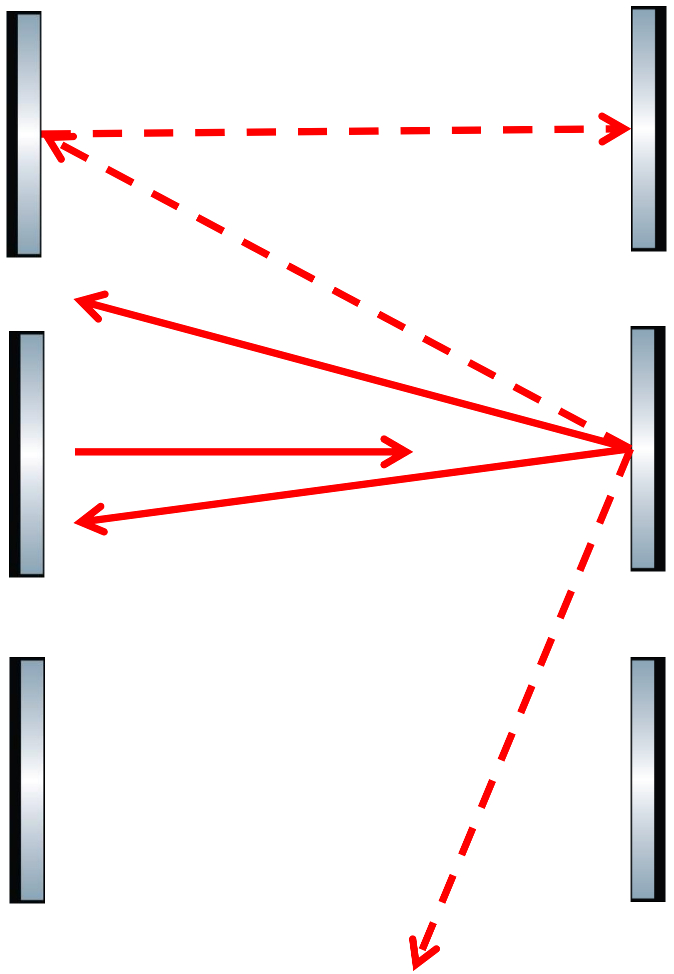
(1) Set "rays" to zero that propagate at too large angle: JOSA A 31, 652 (2014)

(2) Use FFT-DI (direct integration) propagation of fields: Applied Optics 45, 1102 (2006).

Limitations:

(1) Setting ray (i.e. plane-wave) amplitudes to zero can lead to systematic errors.

(2) FFT-DI does not seem to work for short cavities.



Future Work

(1) Study alternative anti-aliasing methods (has been done by other people to some extent, but not very carefully).

(2) Ask experimentalists what I can do for them.

(3) Suggest to experimentalists what would be nice to measure (e.g. dedicated study of mode mismatch including beam jitter to quantum noise,).