e2e
LIGO Time domain simulation

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- e2e Basics
  - physics
  - software structure
- e2e News
  - dual recycled Michelson
  - dynamics threading
  - dynamic modules
  - variable timing
- Applications
  - lock acquisition studies
  - MC dynamics with local correlations

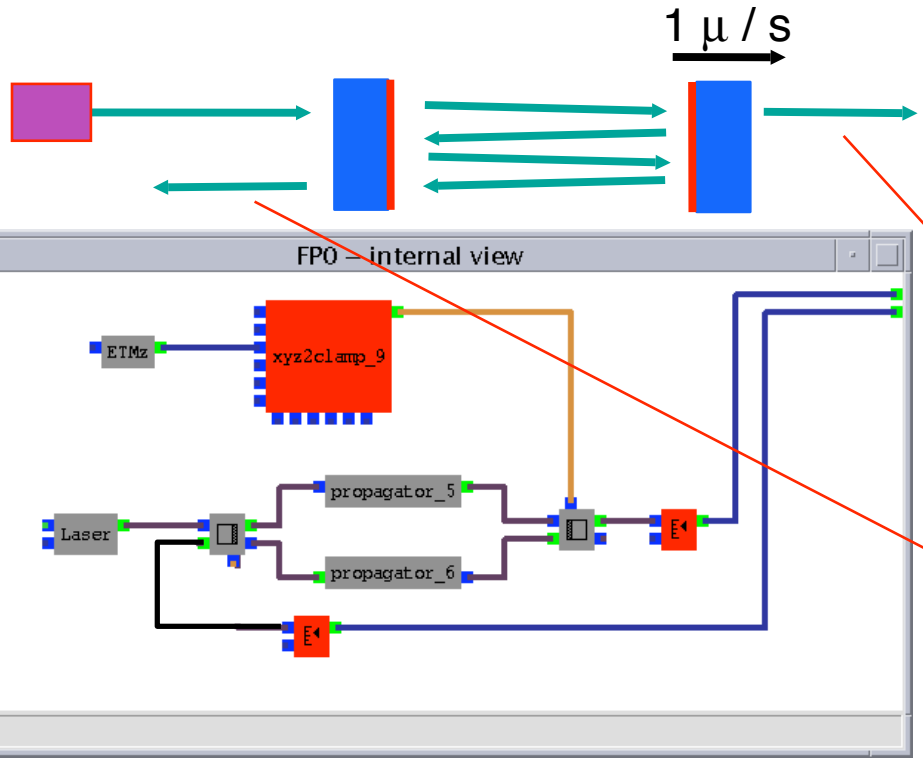
e2e basics
software ingredients

- Time domain simulation of opto-mechanical systems with control systems around
- matlab-like generic programming environment tailored for GW interferometer study
  - » object oriented system developed in house at Caltech using C++
- Graphical User Interface for ease of development and maintenance
- statespace, digital filter
  - » mechanical system simulation of other subgroups' models
  - » control systems
  - » quad precision option for steep spectrum
- c/c++ code integrator
  - » Ease of inclusion of control system code

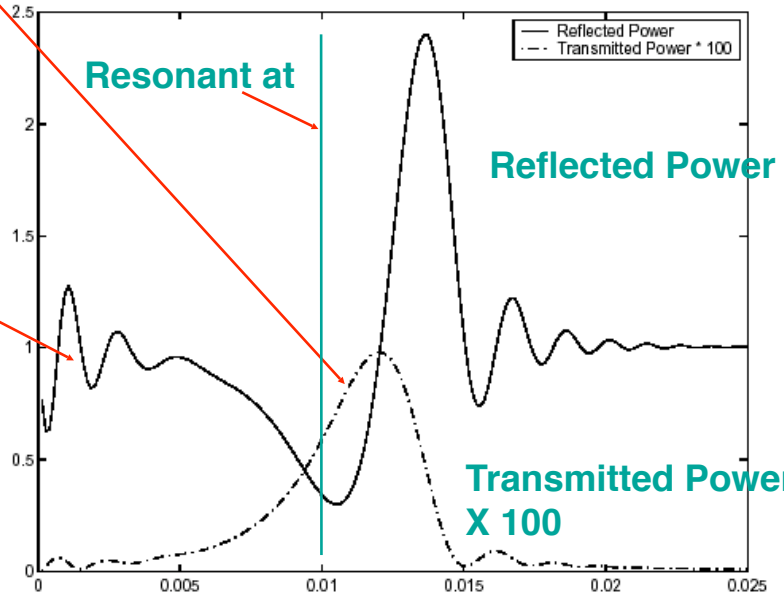
e2e basic physics ingredients

- Modal Model for spatial profile of beams and optics
  - Shot noise and radiation pressure noise by photon counting
- Primitive optics, compound optics
  - mirror, propagator, telescope, etc
  - fast simulation of compound system
    - dual recycled Michelson
- Triple (input optics, PRM, SRM, BS) and Quadruple (ITM, ETM, double chain) pendulums
  - Mark Barton of SUS group provides State Space model
- HAM and BSC seismic isolation system
  - parameterization of design performance
  - State Space model from SEI groups
- ADC/DAC for contrl systems

e2e basic simple example : FP dynamics



ETMz = $-10^{-8} + 10^{-6}$ t



Power = 1 W, T_{ITM}=0.03, T_{ETM}=100ppm,
L_{cavity} = 4000m

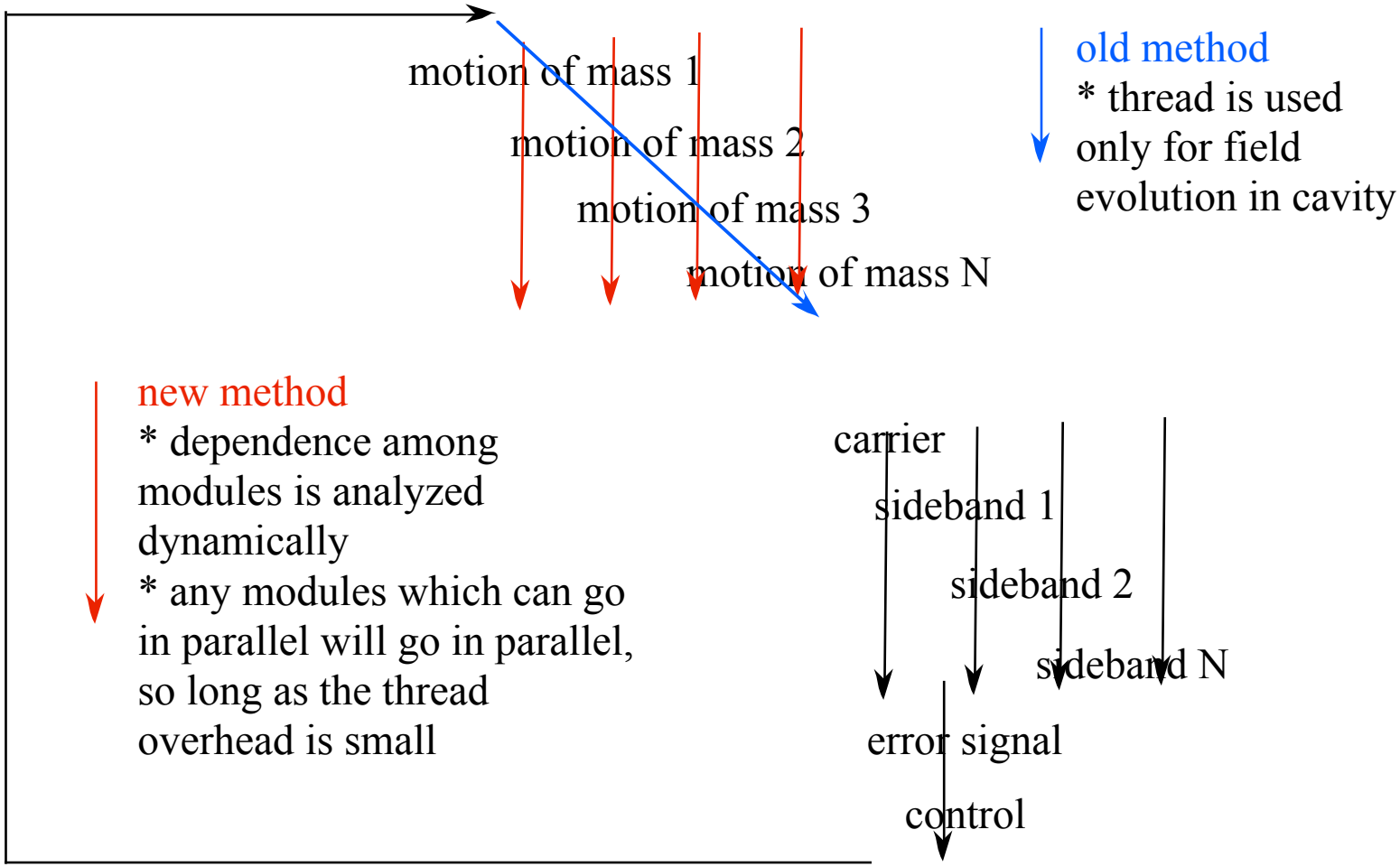
e2e news
Dual recycled Michelson cavity

- ~100 times faster simulation by sacrificing frequency response at 10 MHz down to 100kHz
- planewave or TEM00 only approximation
  - to be expanded to use modal model
- use linear approximation
  - all physics quantities, field and positions, change in linear between on time step
  - needed for frequency noise study
- C++ class independent from e2e framework
- Injection ports for scattered light study

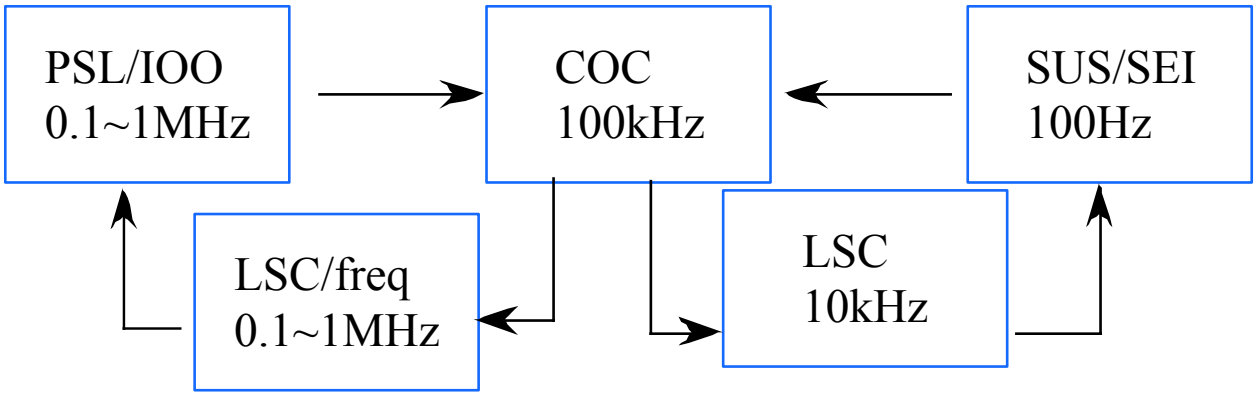
e2e news
Dynamic Threading - 1

- Parallelizing the GW simulation is difficult
  - all are sequential
- Module level parallelization
  - Single and dual recycled Michelson cavity modules
  - Evolution of each sideband fields are calculated using different threads
- Dynamic parallelization
  - Analyze speed of each component and dependence
  - Group related modules to one simulation chain
    - each seismic isolation system and pendulum
  - Run independent chain using separate threads
  - Merge simulation chains when needed
    - cavity, error signal

e2e news
Dynamic Threading - 2



e2e news
Multiple Simulation time steps



- Entire system is running using one time step which corresponds to analog world
- Each data stream has timing information, like 16kHz betwee ADC & DAC
- Each module can skip or react at each time step
- When timing changes, low pass filter is used to suppress aliasing

e2e news
FUNC_X & UserDefinedPrimitive

- Module with C++ class as settings
  - » useful for writing control system setups.
  - » best suited for control system implementation
- When the simulation starts running, the code in the module is placed in temporary C++/header files, compiled and dynamically linked.
- FUNC_X
  - » double and vector< double > with fixed number of input and output ports.
- UserDefinedPrimitives
  - » arbitrary types and number of data for inputs and outputs.
  - » almost all modules can be replaced by this module

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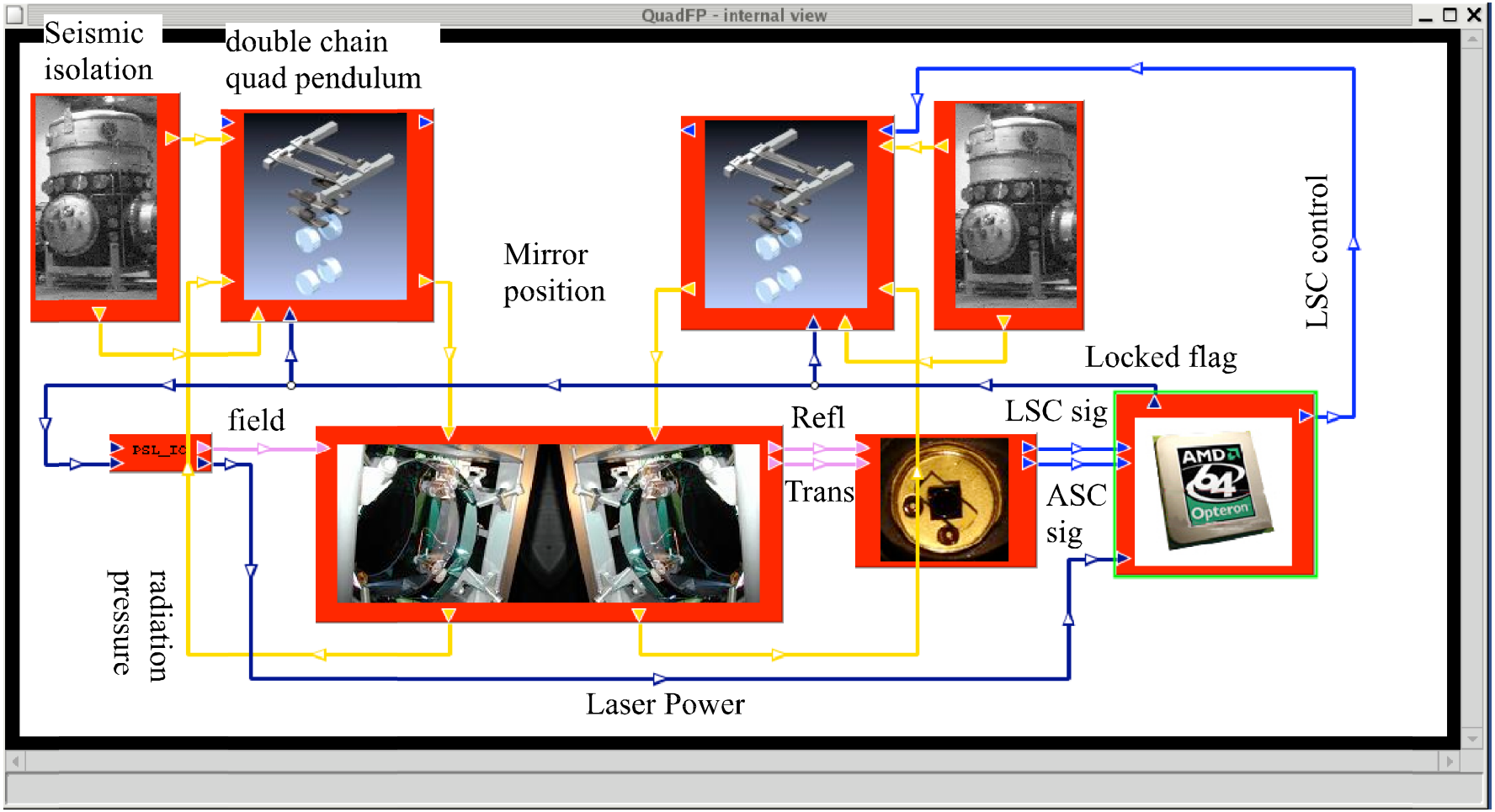
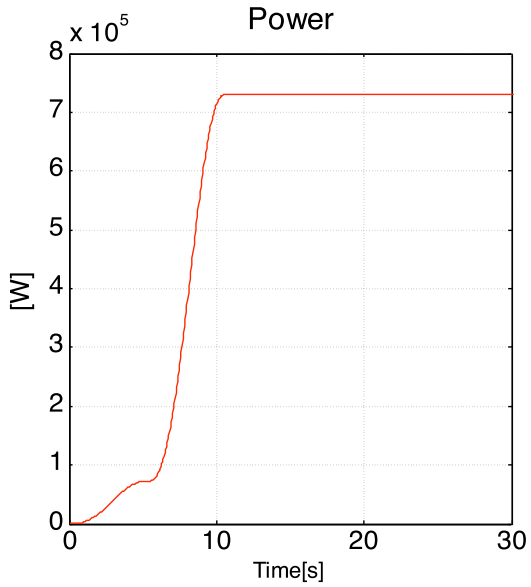
Applications

- Osamu Miyakawa
  - AdvLIGO arm lock
  - FP cavity with modal model
  - Double chain quad Pendulum
  - LSC, ASC with WFS,optLever
- Lisa Barsotti, Matt Evans
  - AdvLIGO Full configuration lock
  - Dual recycled Michelson module + arm with scalar field
  - simple pendulum
  - LSC
- Sany Yoshida
  - Mode cleaner on advLIGO SEI with triple suspension
  - Two HAMs 15m apart, two suspensions on the same table

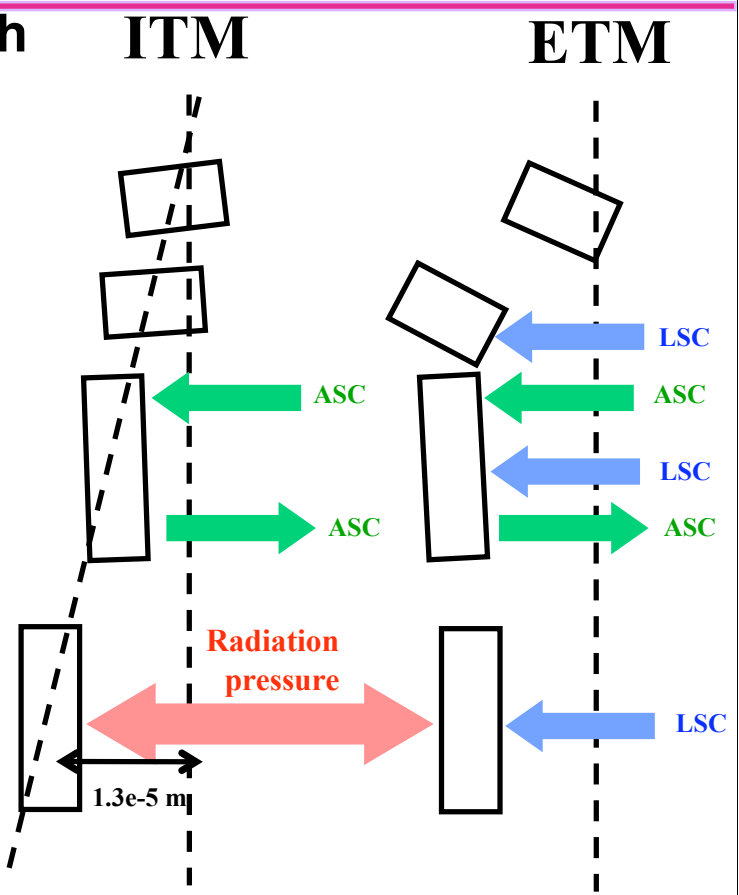
e2e example
advLIGO arm cavity

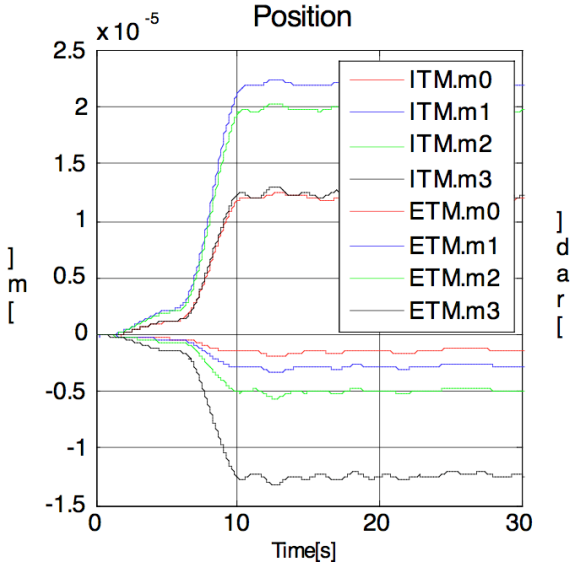


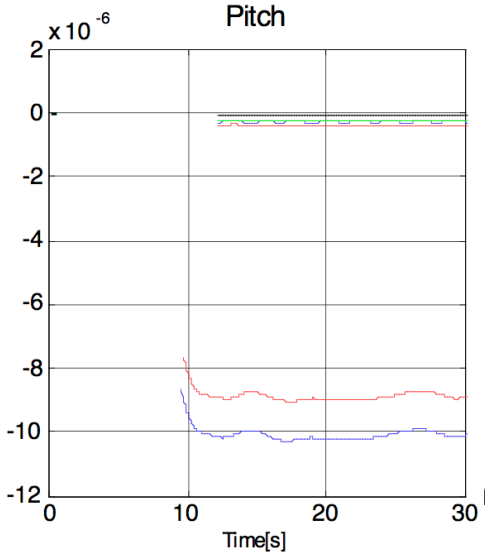
Test mass alignment control through M2 with radiation pressure



- Control M3 through M2
- f^3 filter
- Boost at 2Hz
- 10Hz control band width







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Future issues

- Modal model version of dual recycled Michelson cavity
- Speed
- Better implementation of quantum noise
  - » injecting vacuum from dark port
- 96bit real
  - » quad pendulum spectrum, f^{-8}, not correct above 15Hz (comparing double precision statespace vs quad precision)
  - » Cavity signal = ITM position - ETM position
- More precise field profile tracing
  - » FFT in time domain?