Chicane BPM Design and Expectations

Perpendicularly mounted strip-line for dispersive areas

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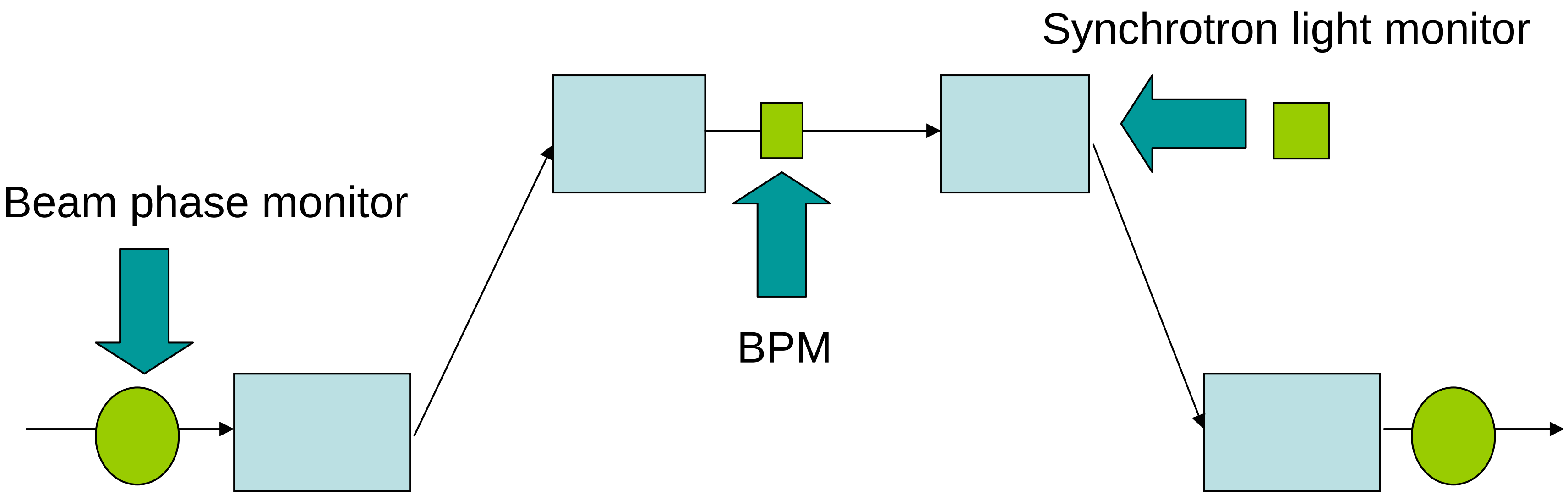
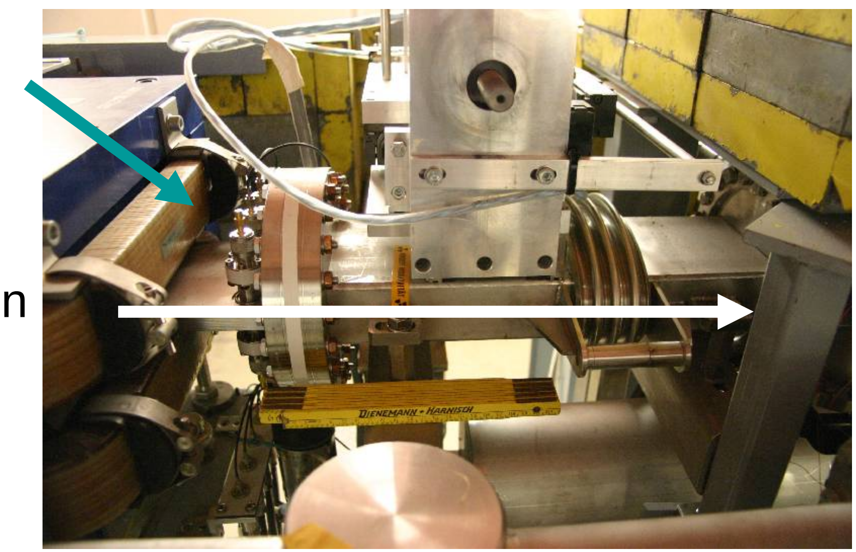
Introduction

- Range and resolution requirements
- Design choice and alternatives
- Simulation expectations
- Front-end prototype measurements
- Stretched-wire prototype measurements
- Expectations for bunch-to-bunch energy measurement

BC2 BPM Placement



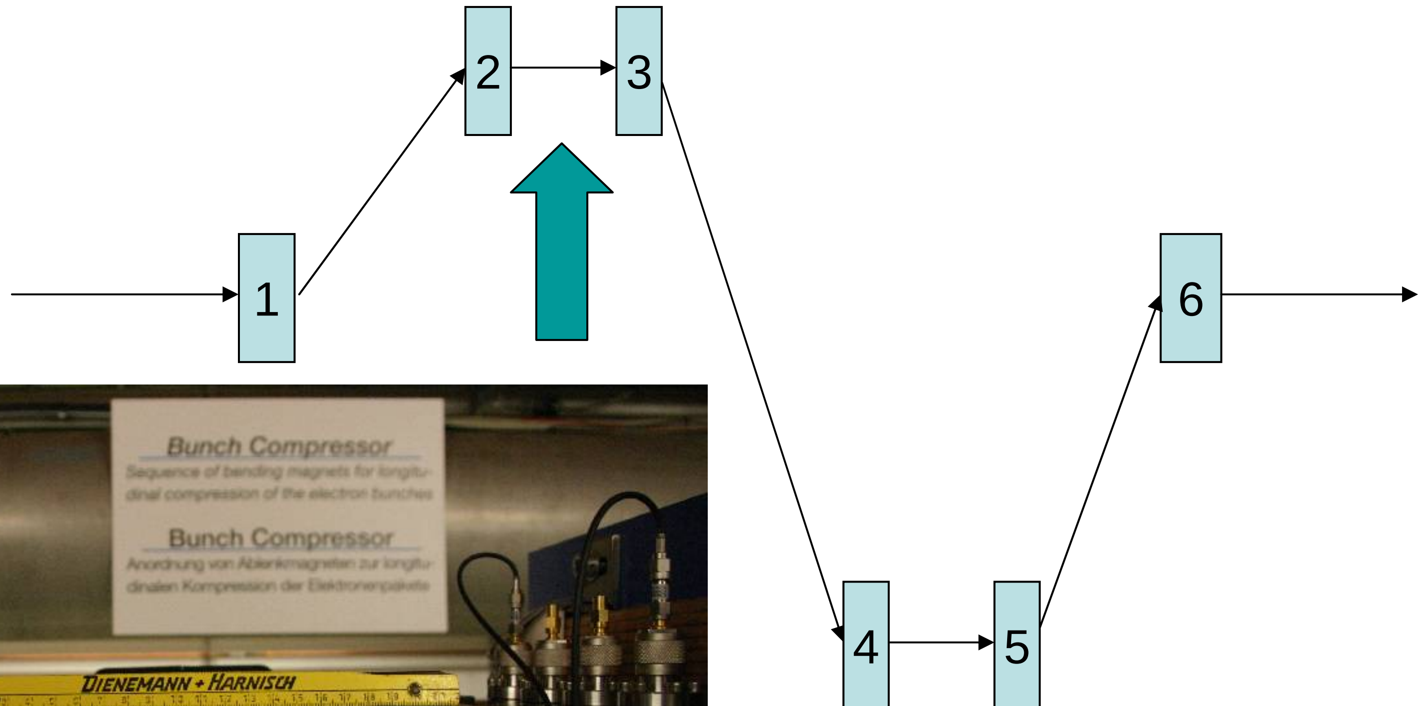
Requires replacement of central vacuum chamber in coordination with location of screen and collimator

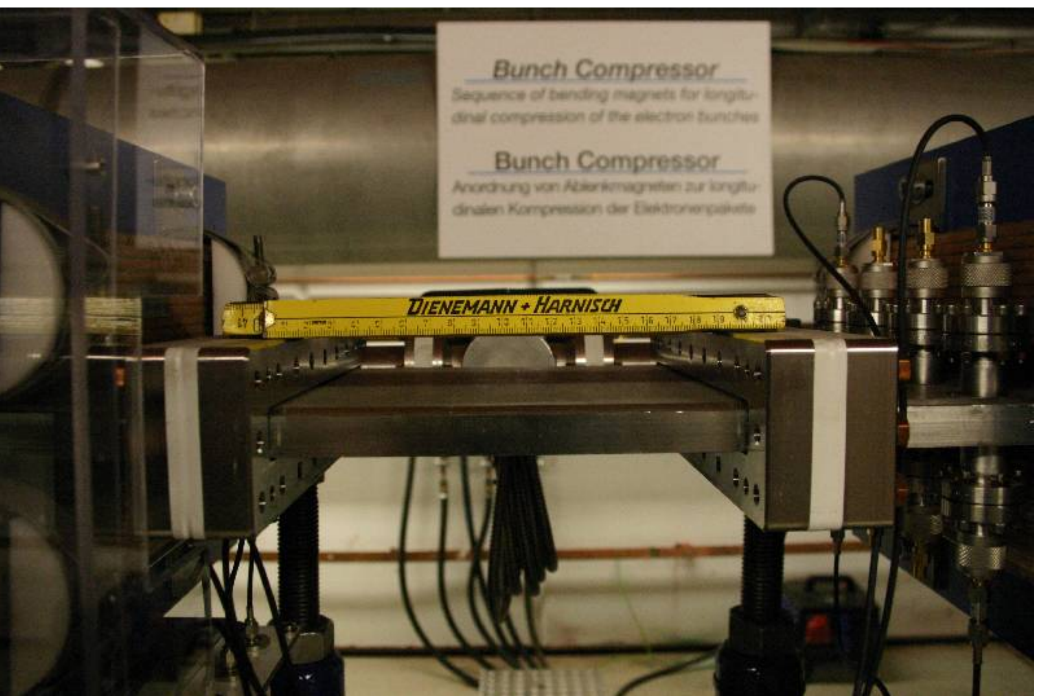


Installation is scheduled for October 2006.

BC3 BPM Placement

In between 2nd & 3rd dipole of BC3 there is a section of empty vacuum chamber





Large Horizontal Aperture

- Accommodates large range of operating R_{16}
  - 74 mm range for FLASH BC2
  - 150 mm range for FLASH BC3
  - 100 mm range for XFEL BC1
- Large beam energy-spread becomes position-spread
  - ~ 10 mm (6 sigma) in FLASH BC2 chicane (0.5% rms)
  - ~ 6 mm (6 sigma) in FLASH BC3 chicane (0.5% rms)
  - ~ 60 mm (6 sigma) XFEL BC1 chicane (1.8% rms)

FLASH (BC2 16-20°)
R_{56} = 140-228 mm
R_{16} = 284-358 mm
E = 120-140 MeV

XFEL (BC1)
R_{56} = 100 mm
R_{16} = 500-600 mm
E = 500 MeV

FLASH (BC3 2-5°)
R_{56} = 14-84 mm
R_{16} = 100-250 mm
E = 380-450 MeV

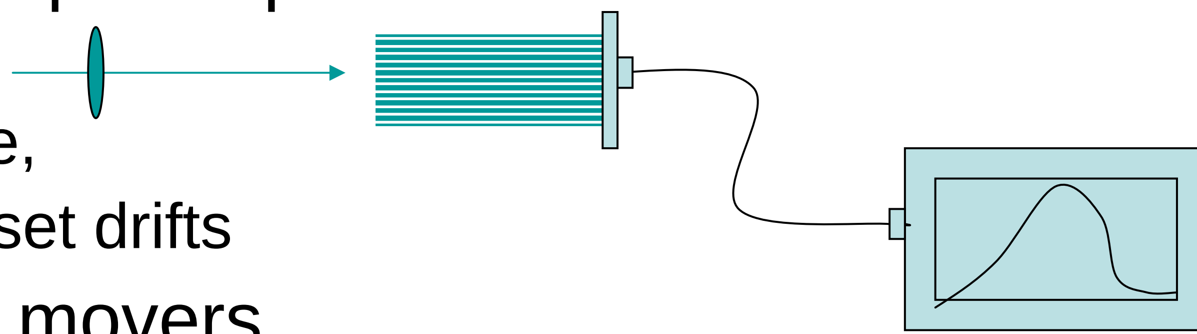
XFEL (BC2)
R_{56} = 40 mm
R_{16} = 200-300 mm
E = 2,000 MeV

High Resolution (<10 um)

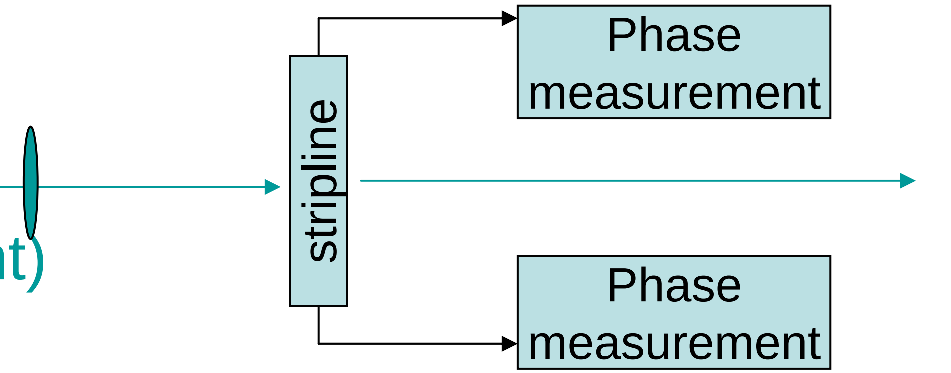
- Need energy feedback in BC2 to keep beam arrival-time constant to 30 fs (~10um @v=c) for pump-probe experiments
- BC2 energy jitter (10^{-4}) times R_{16} (345 mm) becomes transverse position jitter (34.5 um) in chicane
- After the chicane this becomes 10^{-4} * R_{56} = 18 um or 60 fs (rms) arrival-time jitter
- That means the energy jitter must be made better than $5*10^{-5}$
- A monitor for a feedback system must be at least a factor of 3 better than this for a single-bunch measurement
- This means that the desired resolution for a BPM is 5 um The same argument goes for BC3, but it is less critical because the R_{56} is a factor of 4 smaller

Possible Candidates

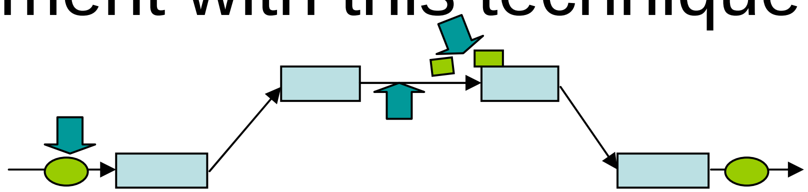
- Array of small striplines parallel to beam direction
  - Wire interference,
    Calibration, Offset drifts



- Normal BPM on movers
  - Bellows, space constraints
- Perpendicularly-mounted stripline
  - RF measurement
    can't get resolution
  - Optical method can
    (5 um is 17 fs for a single time-of-flight measurement)



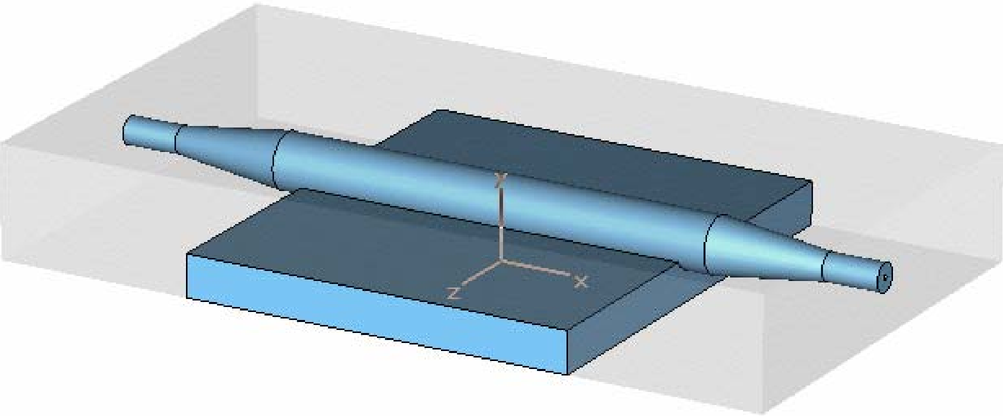
- Beam arrival-time has been measured with phase-monitor with 30 femtosecond accuracy using optical method (F. Loehl)
- Improved electronics (diode and filter noise) could give factor of 10 improvement
- Placing EOM in tunnel (no 30 meter cable) gives a factor of ~2 improvement
- Using monitor with larger bandwidth transmission gives factor of ~2 improvement
- 2 measurements give a sqrt(2) improvement
- R_{16} has a factor of 5 advantage over R_{56} for an energy measurement with this technique in the XFEL BC1



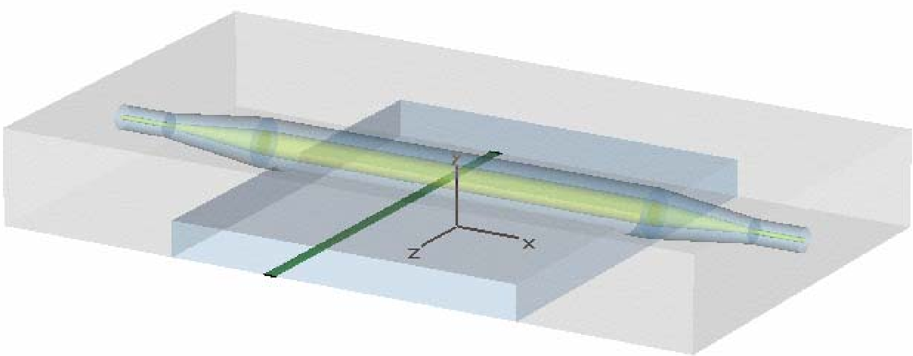
=> Systematic errors will be the largest limitation of resolution

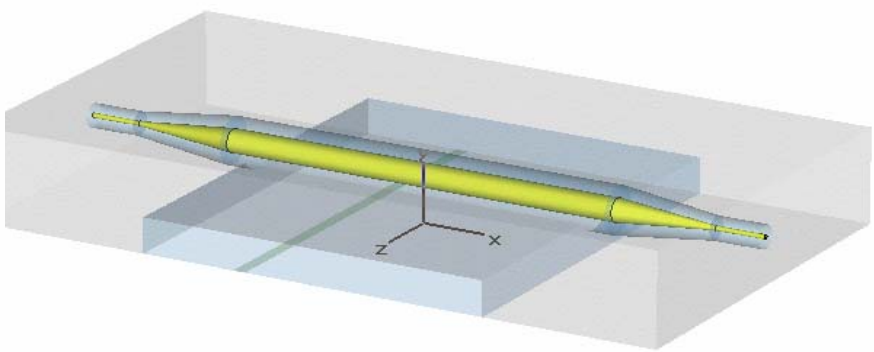
(10 fs phase measurement => 6 um position resolution)

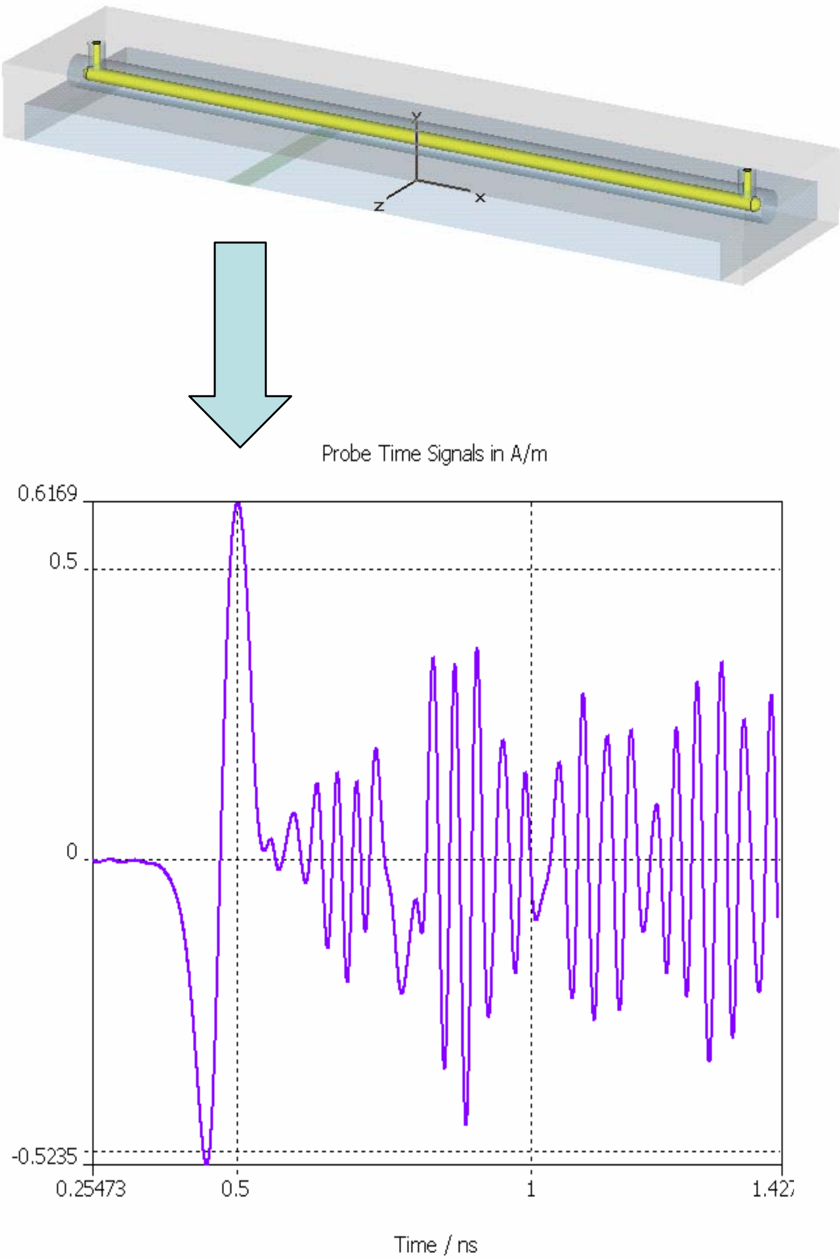
MW Studio Simulation



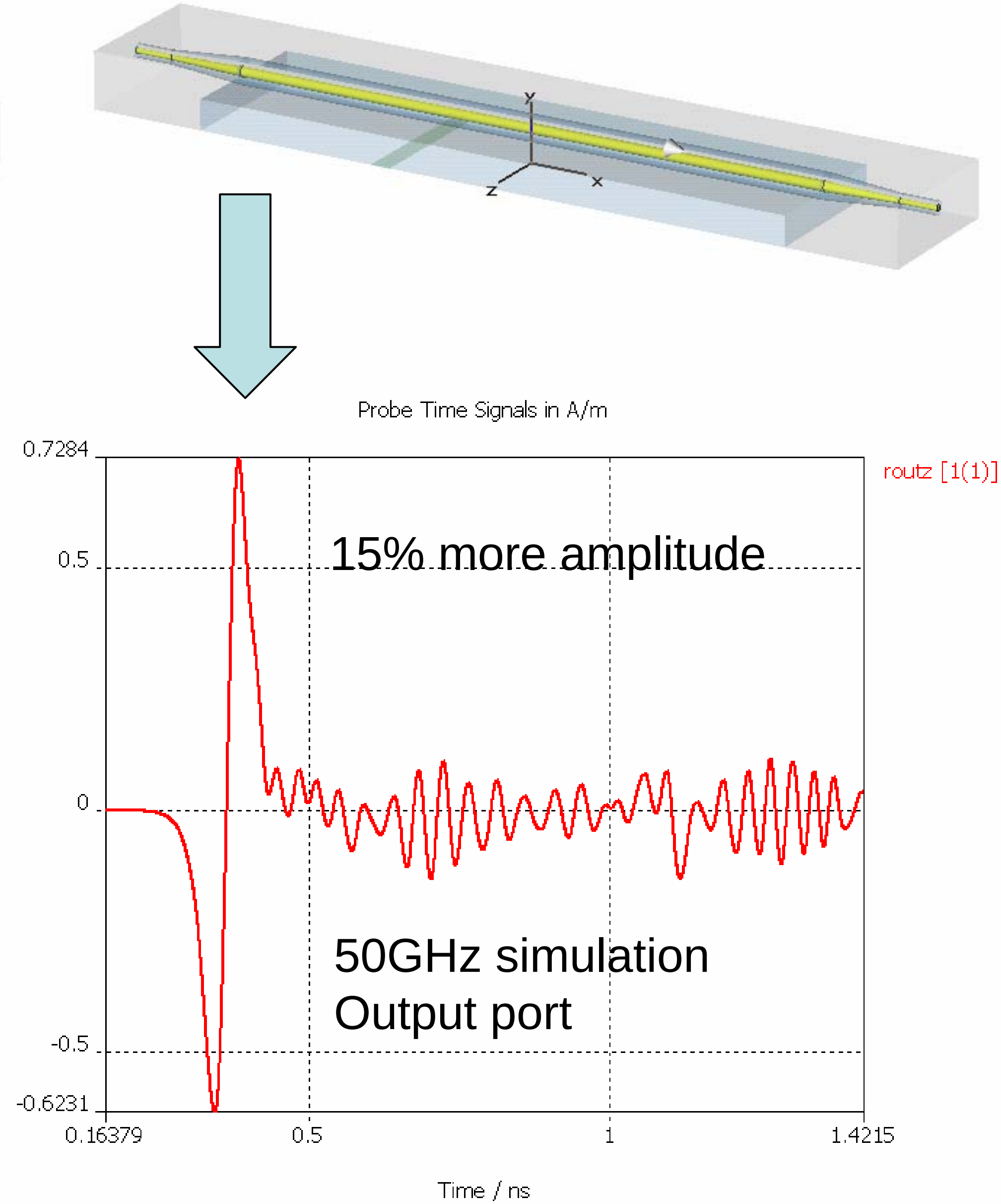
Coaxial cable impedance matching model
Tapered to SMA connector to maximize bandwidth of output





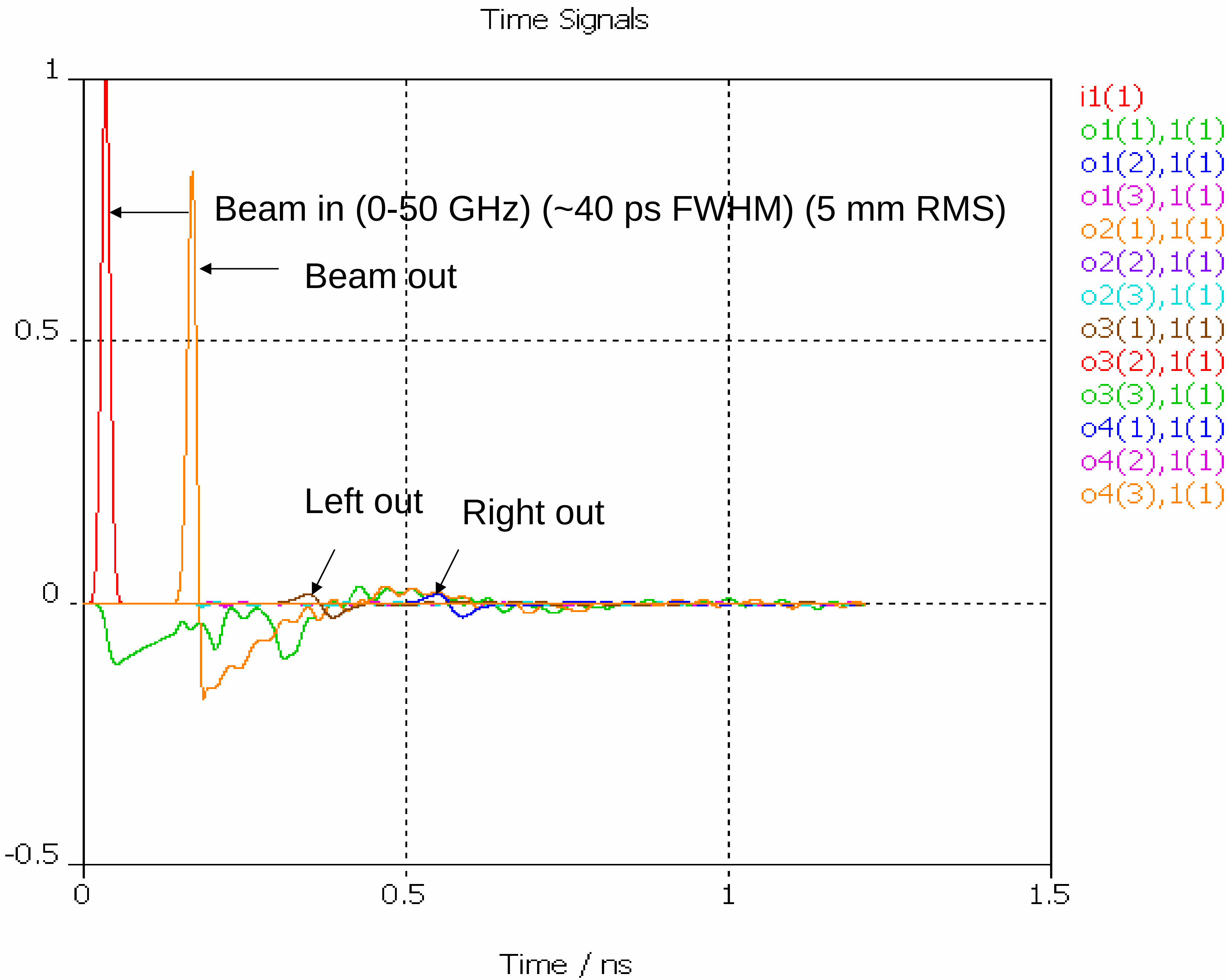


y
z
x
Probe Time Signals in A/m
0.6169
0.5
0
-0.5235
0.25473
0.5
1
1.42
Time / ns

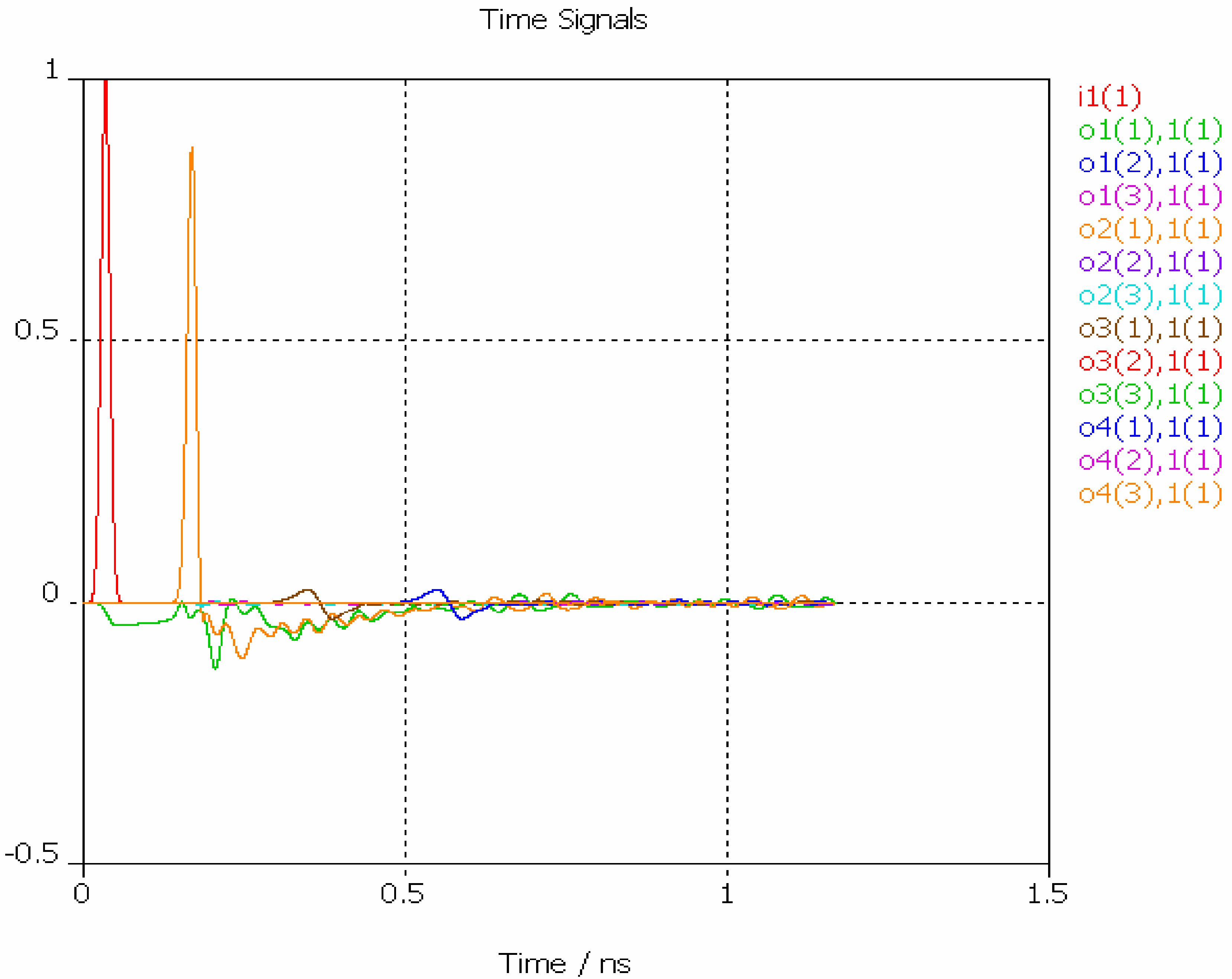


y
z
x
Probe Time Signals in A/m
0.7284
0.5
0
-0.5
-0.6231
0.16379
0.5
1
1.4215
Time / ns
routz [1(1)]
15% more amplitude
50GHz simulation
Output port

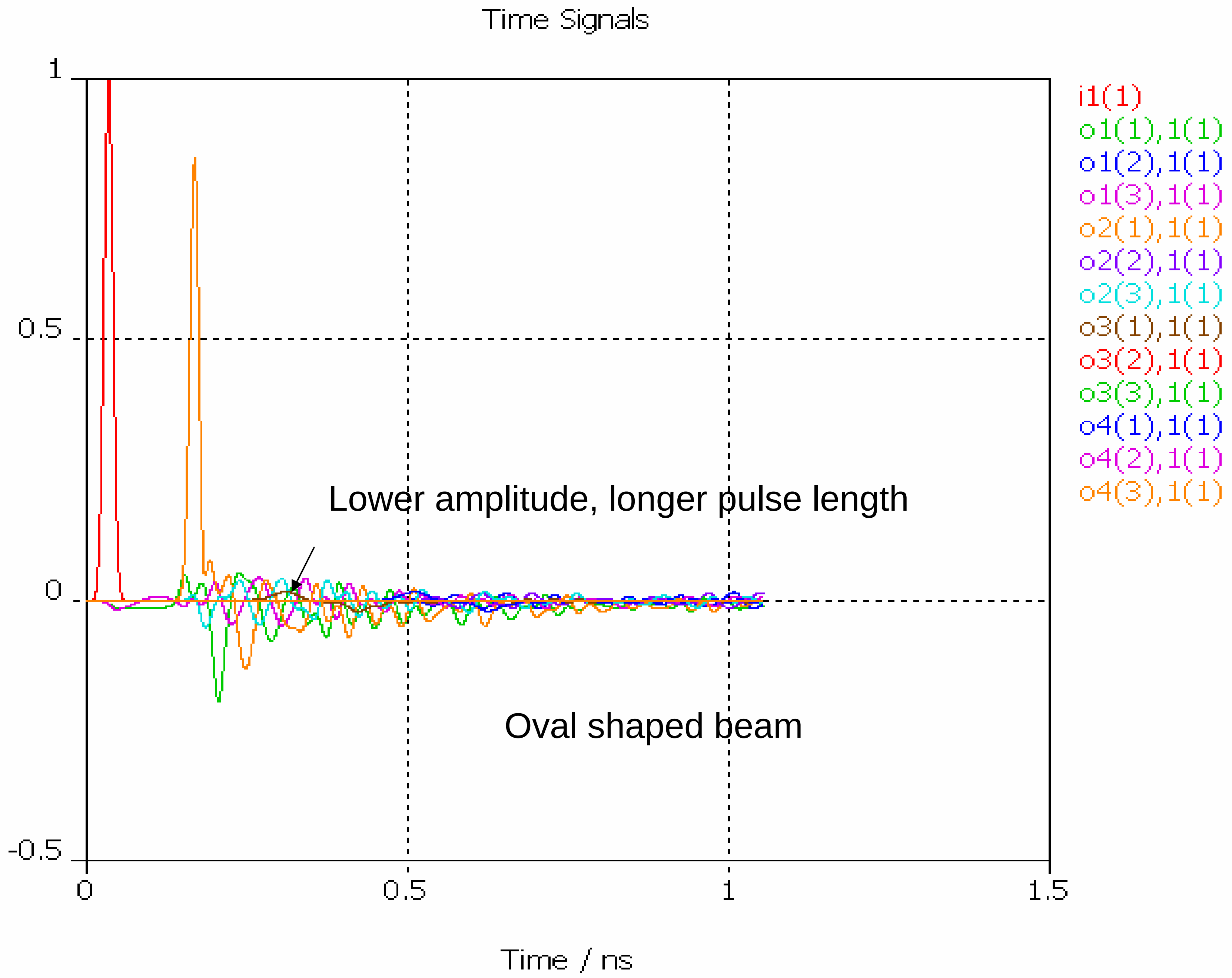
freq = 0-50 GHz, pos = -3 cm, beam width=0.2 mm



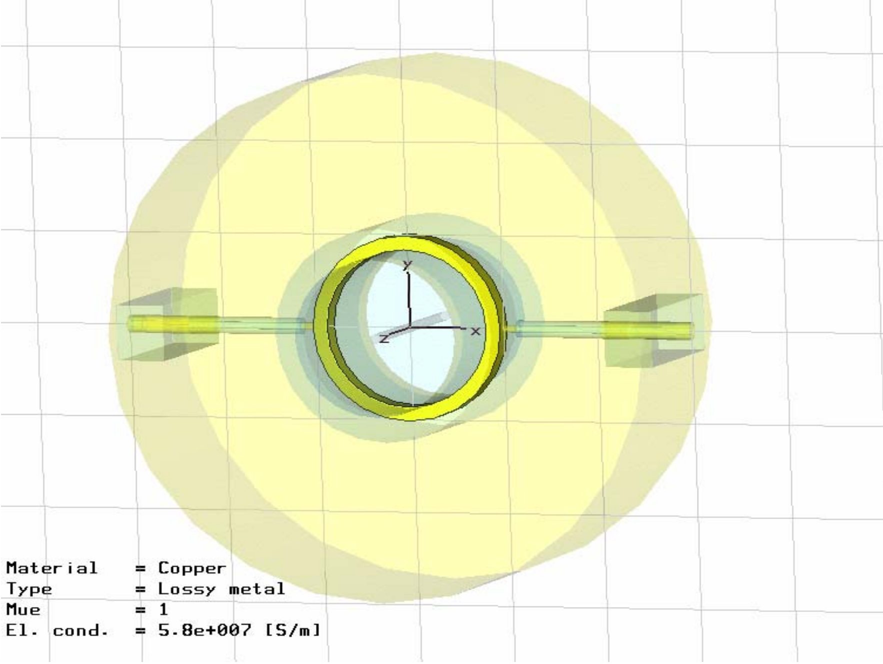
freq = 0-50 GHz, pos = -3 cm, beam width = 5 mm



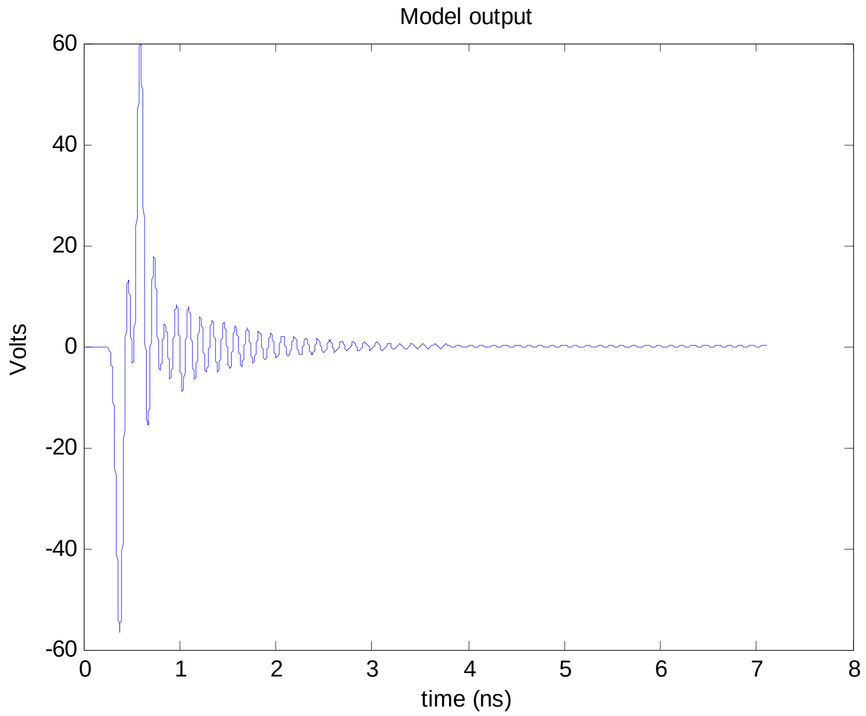
Freq = 0-50 GHz, pos = -3 cm, beam width = 30 mm

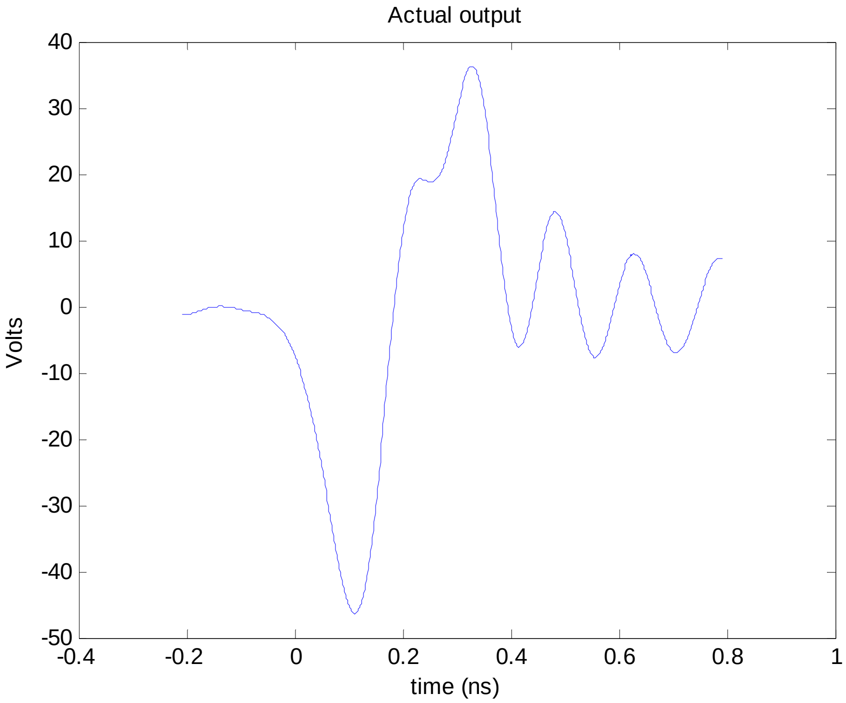


Beam Phase Monitor Simulation

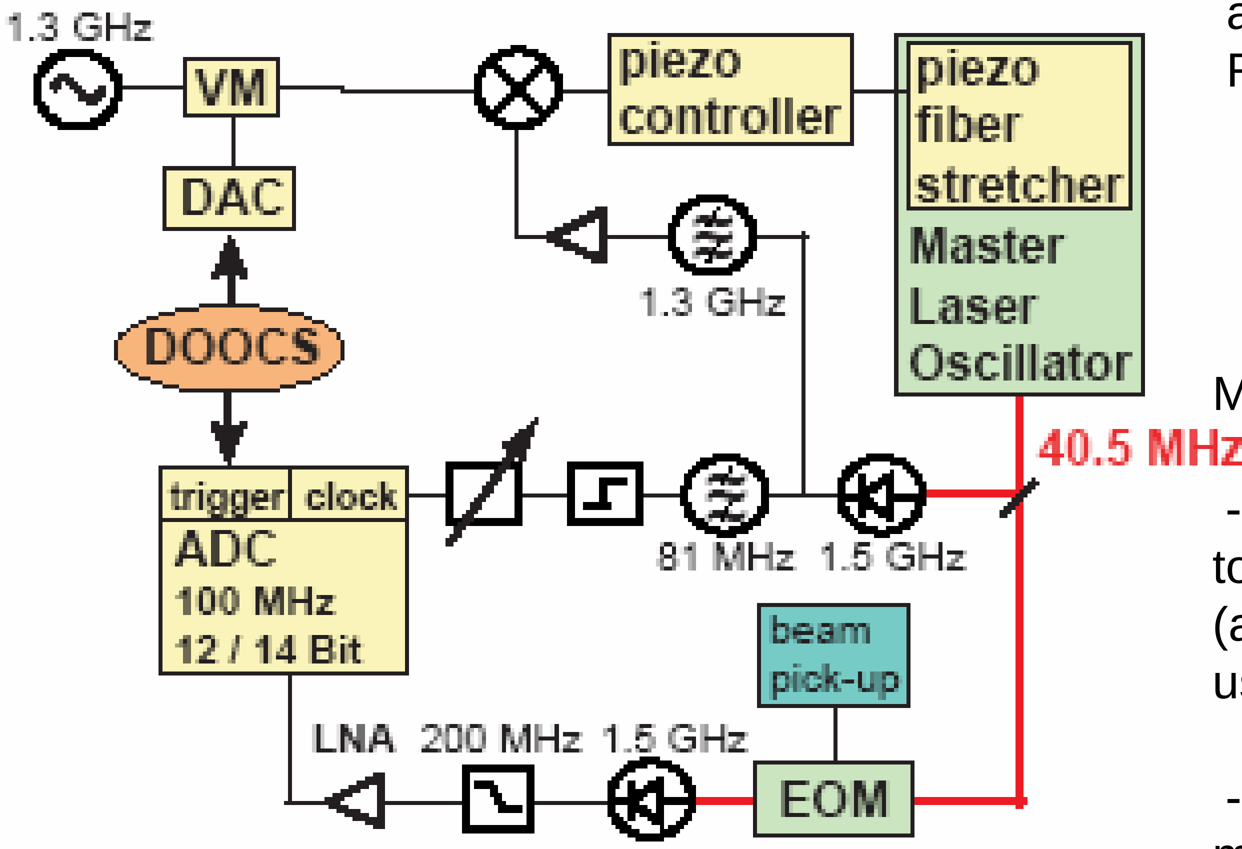


8 GHz scope
8 GHz (FWHM) simulation





Test bench



Use electro-optical modulators and a timing laser to sample RF pulses

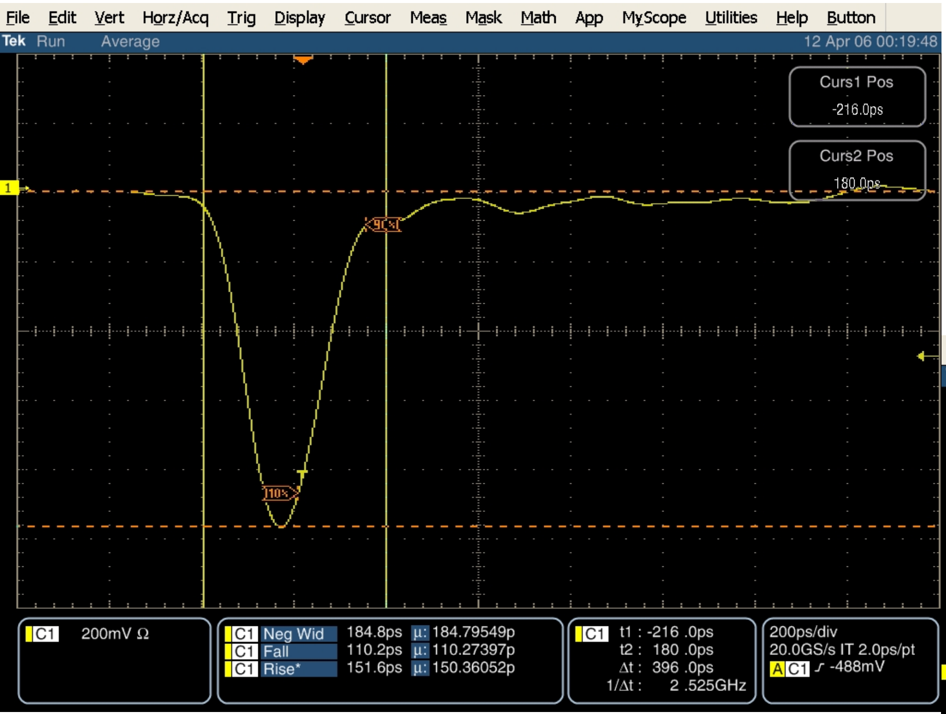
Measurement is limited by:

- the electro-optical modulator's tolerance for high voltage (attenuator or limiter must be used)

- slope of RF (BC BPM slope is more than twice as steep as beam phase monitor slope)

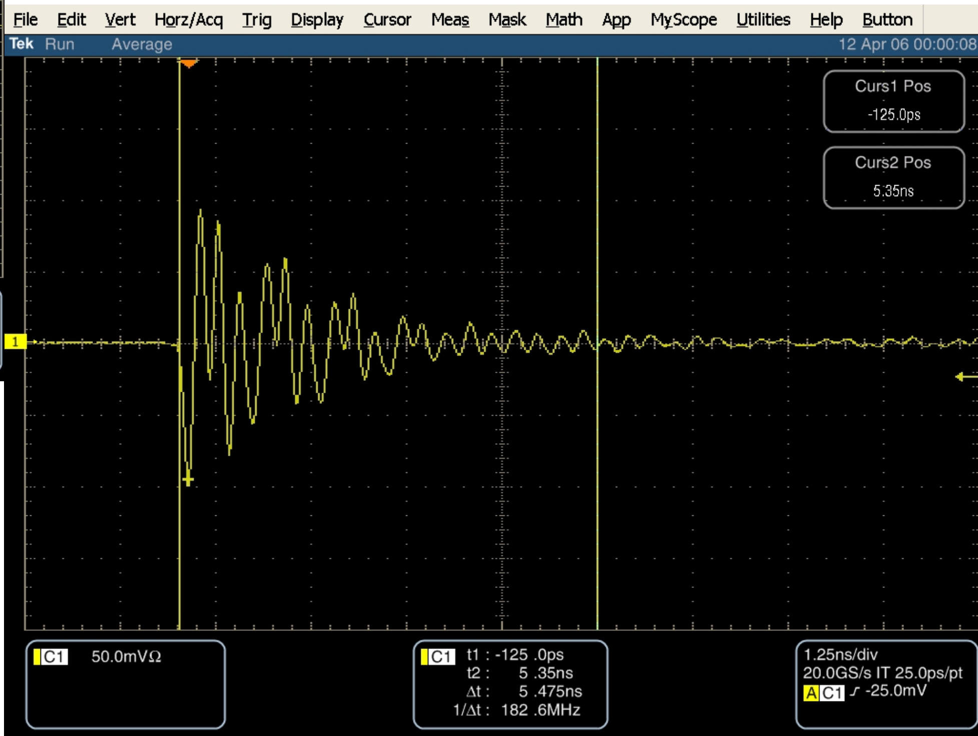
Setup developed by Florian Loehl

Stretched-wire tests w/ 7GHz scope and short-pulse generator

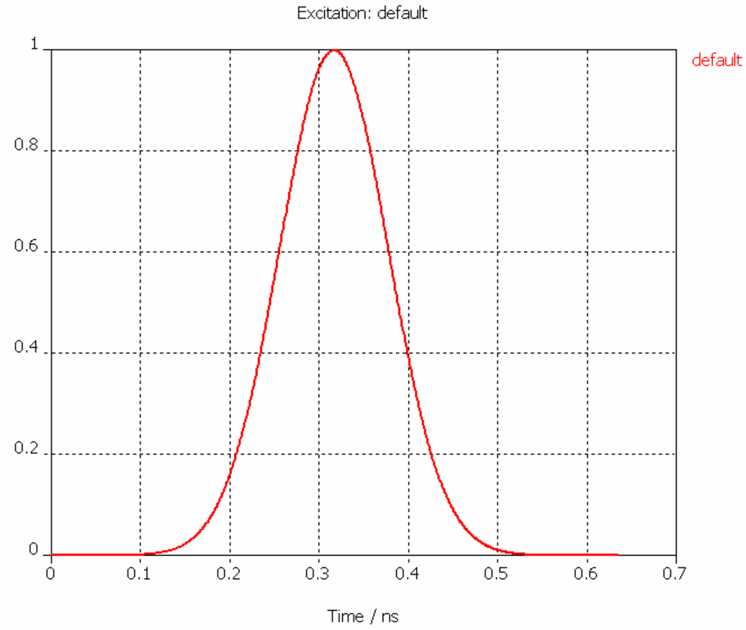


<- Input 9.8 Volts peak, 5.6GHz bandwidth
Of course, some of this signal will be reflected at the entrance to the chamber and at the end of the chamber

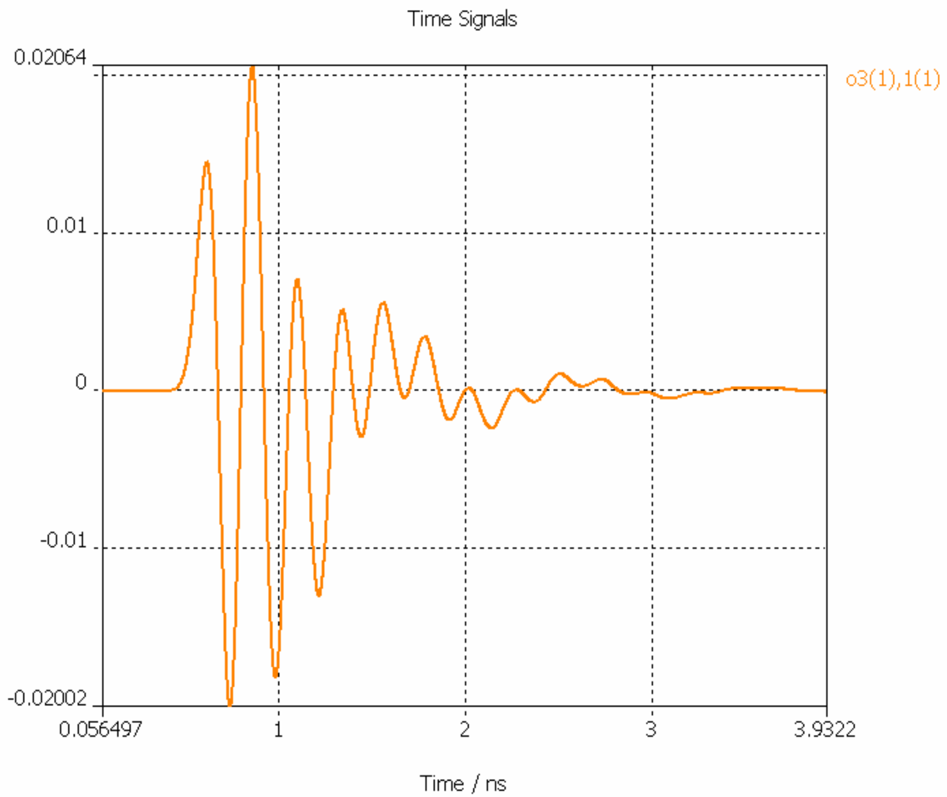
Output ->
5ns ringing
190 mV pp
amplitude is 2% of input



Stretched-wire simulation



<- Input 5.6 GHz bandwidth, arbitrary units
10% of this is reflected at chamber entrance

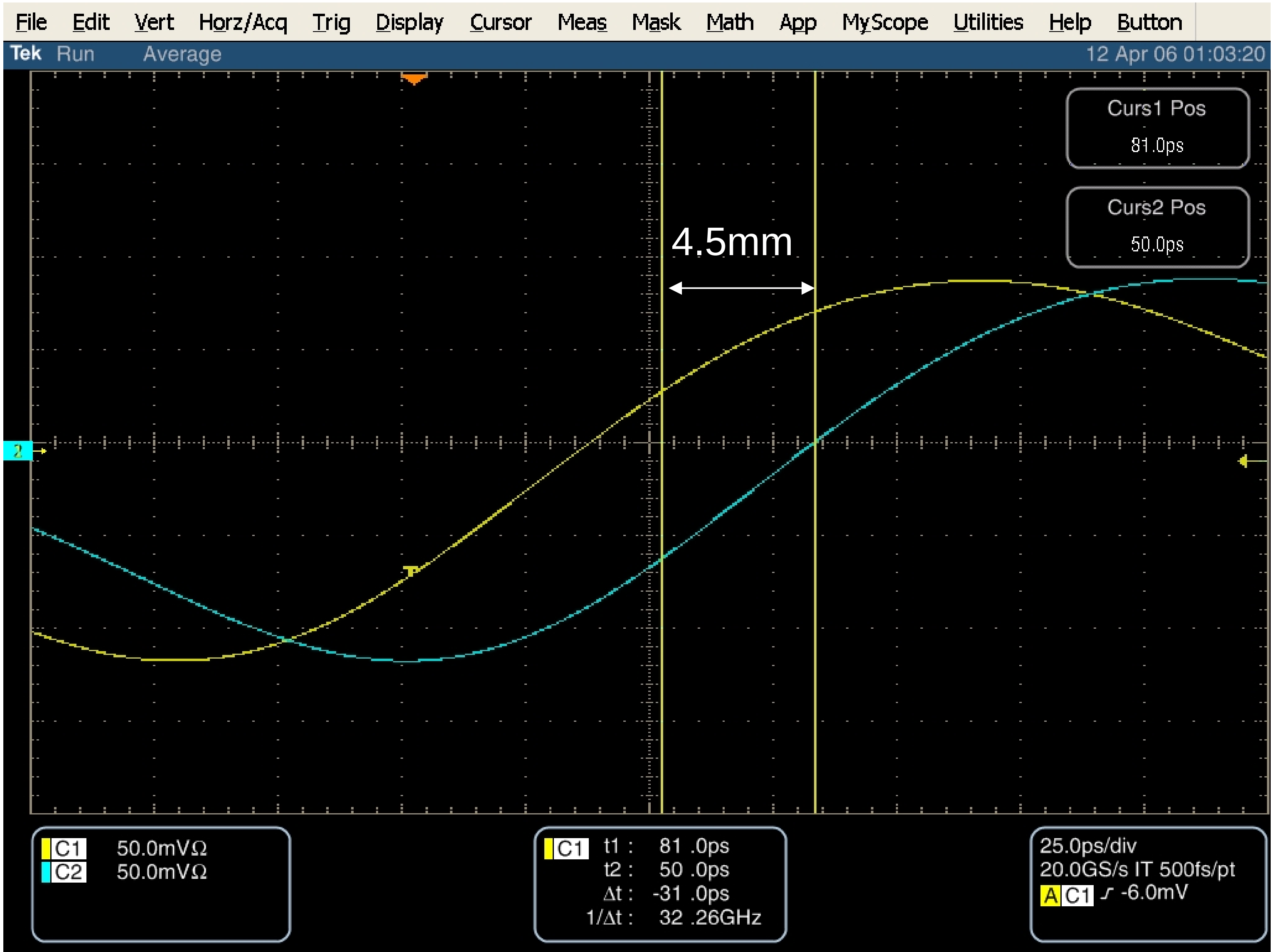


Output ->
5 ns ringing
amplitude is 3.5% of input

Conclusion: reality is 3/5 as good as simulation

Phase changes vs. wire movement

- Stretched-wire moved in steps of 0.5 mm (one full rotation of micrometer) produced 3.5 ps phase shift and 3.6 is exactly what we wanted to see



Concerns

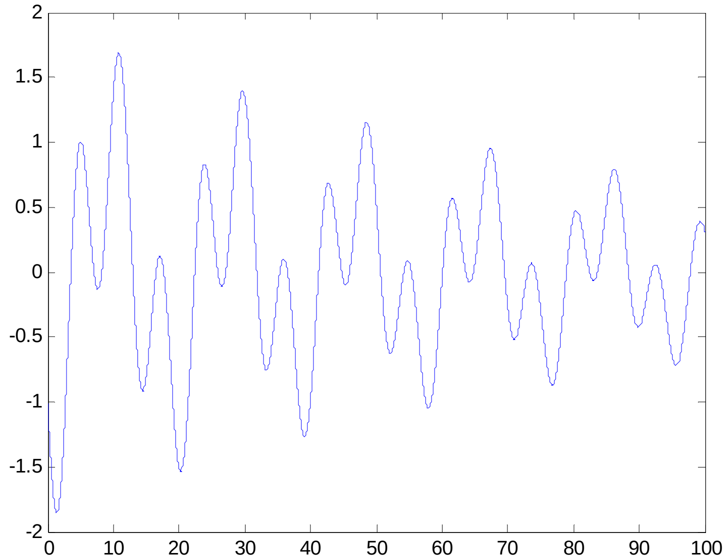
- If one side's phase measurement is at the zero-crossing and the other is not, the position measurement will change when certain beam parameters change
- Nevertheless, optical delay-lines and piezo line-stretchers can be used in a macro-pulse-to-macro-pulse feedback to keep the system measuring at exactly the zero-crossing

- Charge dependence of slope (scales linearly)
  - Charge stability is 2 to 3 % RMS
- Transverse width dependence
  - Simulation shows 1.9 ps change of zero crossing for 1 cm change in width
  - Slope change is more significant
- Longitudinal shape dependence
  - Much smaller than transverse dependence

What this means for a chicane energy measurement

- Arrival-time measured with phase-monitor can distinguish gun timing jitter induced energy jitter from the beam energy measured with the chicane BPM
- Bunch-length monitor used in conjunction with BPM can distinguish energy modulations caused by LLRF phase changes from amplitude changes
- Upstream and downstream BPMs will be needed to correct for the incoming orbit error contribution to the BPM energy measurement
- Two phase-monitors (before and after the chicane) can provide a good energy measurement as well, but the BPM can offer a factor of >5 advantage, based on simulation
- BPM offers the potential for an energy spread measurement (sum) when used in conjunction with the phase-monitor

Thank you for your attention!



plot(x,-(sin(x)-sin(x/3-pi/2)).*exp(-x/100))

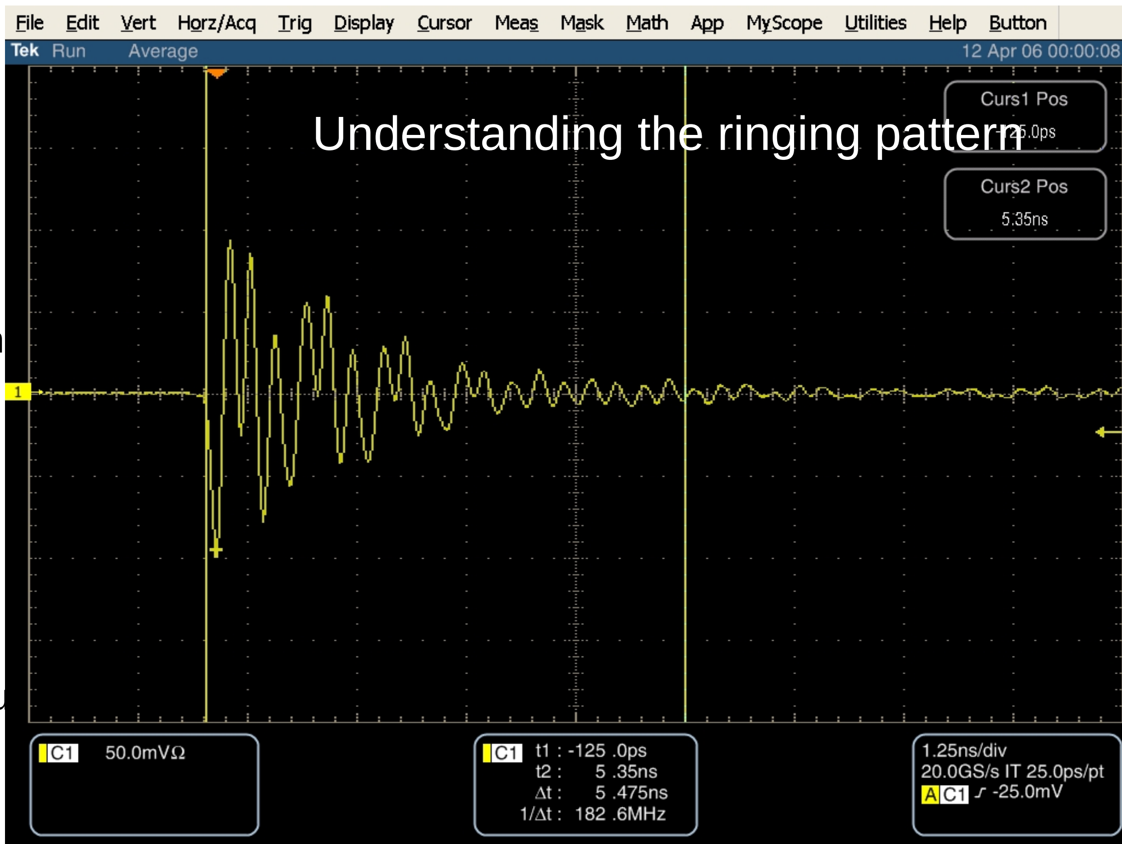
The similarity between the above function and the scope trace suggests that the 3rd harmonic or sub-harmonic of the transient might be reflected at one of the boundaries with a phase shift between -pi and –pi/2

Since a phase shift of pi is like a shorted-transmission line and a phase-shift of zero is like an open-transmission line, the phase-sh seen on the scope trace could imply that the impedance of the stretched wire termination is too small

The 4 cm long stretched wire's 1st harmonic is 7.5 GHz (3*2.5 GHz input pulse)
The 2ond would have a zero crossing at the antenna location
If this is the case then moving the wire will not change the pattern

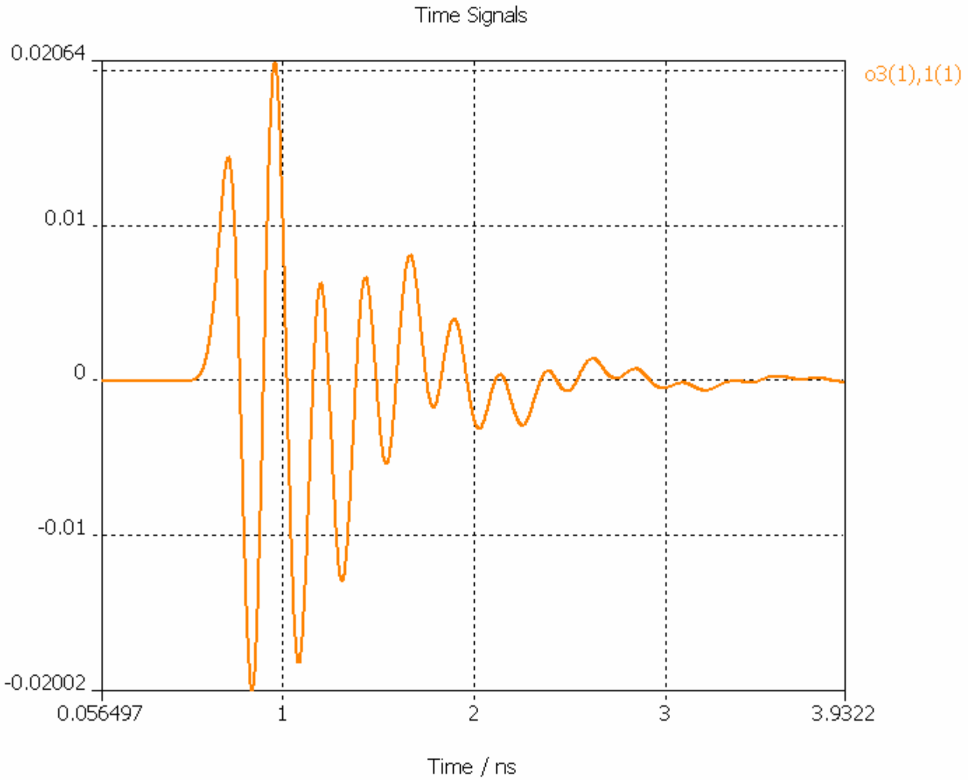
An alternative is that a cavity mode in the 16cm stripline direction, due to the end-plates, creates the reflection with a 1st harmonic of 0.93 GHz
If this is the case then moving the wire will change the pattern
(in simulation, it does, but it is hard to see in the prototype)
Unfortunately, the rectangular shape of the inpu port for the wire also affects the signal, so distinguishing all of the effects is not completely straightforward

Understanding the ringing pattern

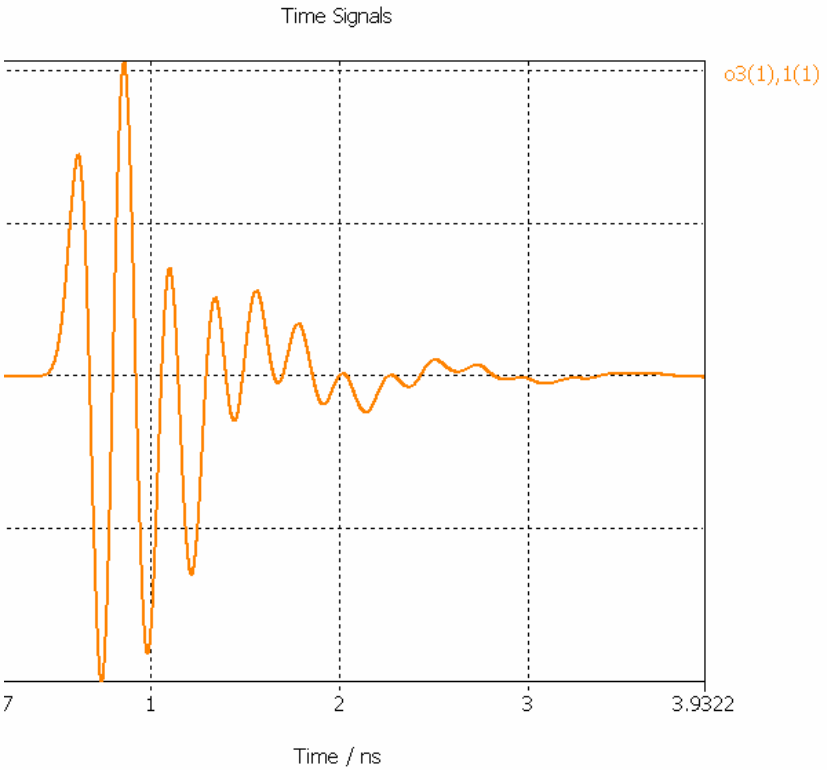


Moving wire away from center of cavity makes influence of artificial cavity mode caused by endplates slightly weaker

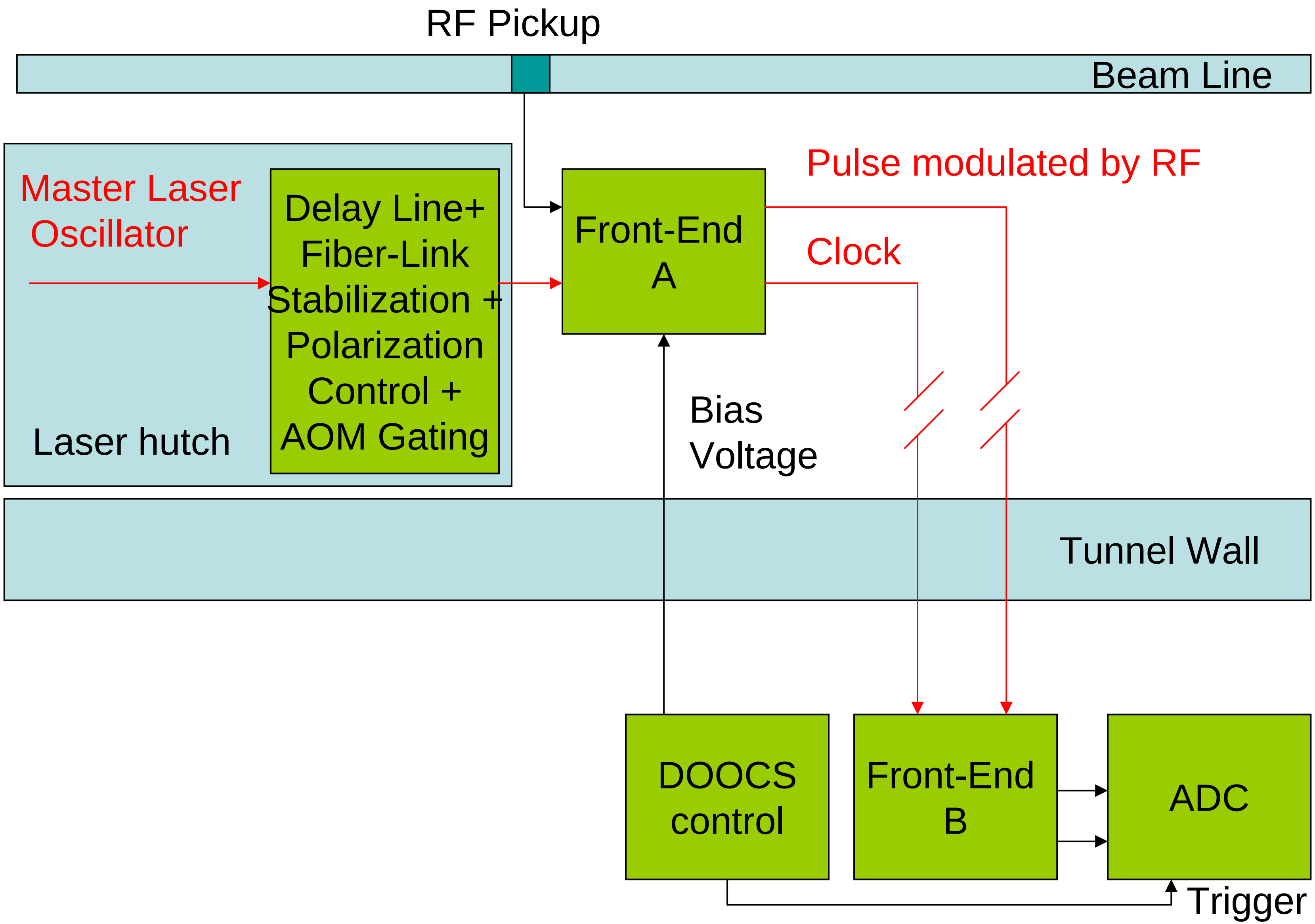
center



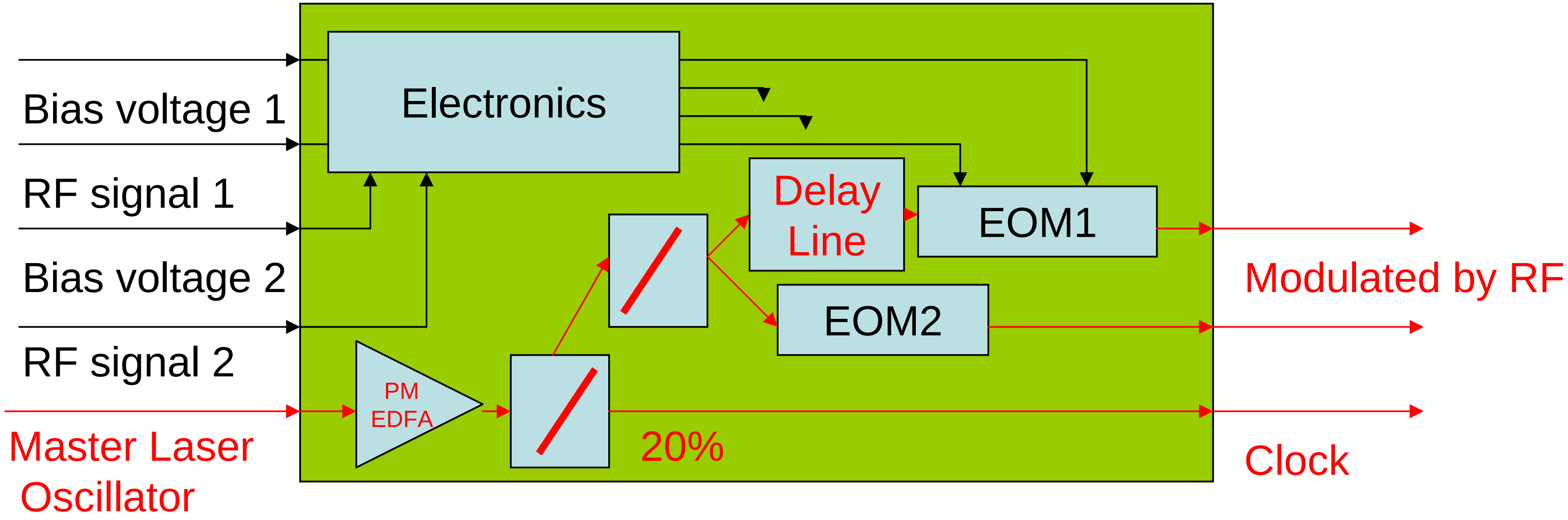
3 cm



Simplified Layout



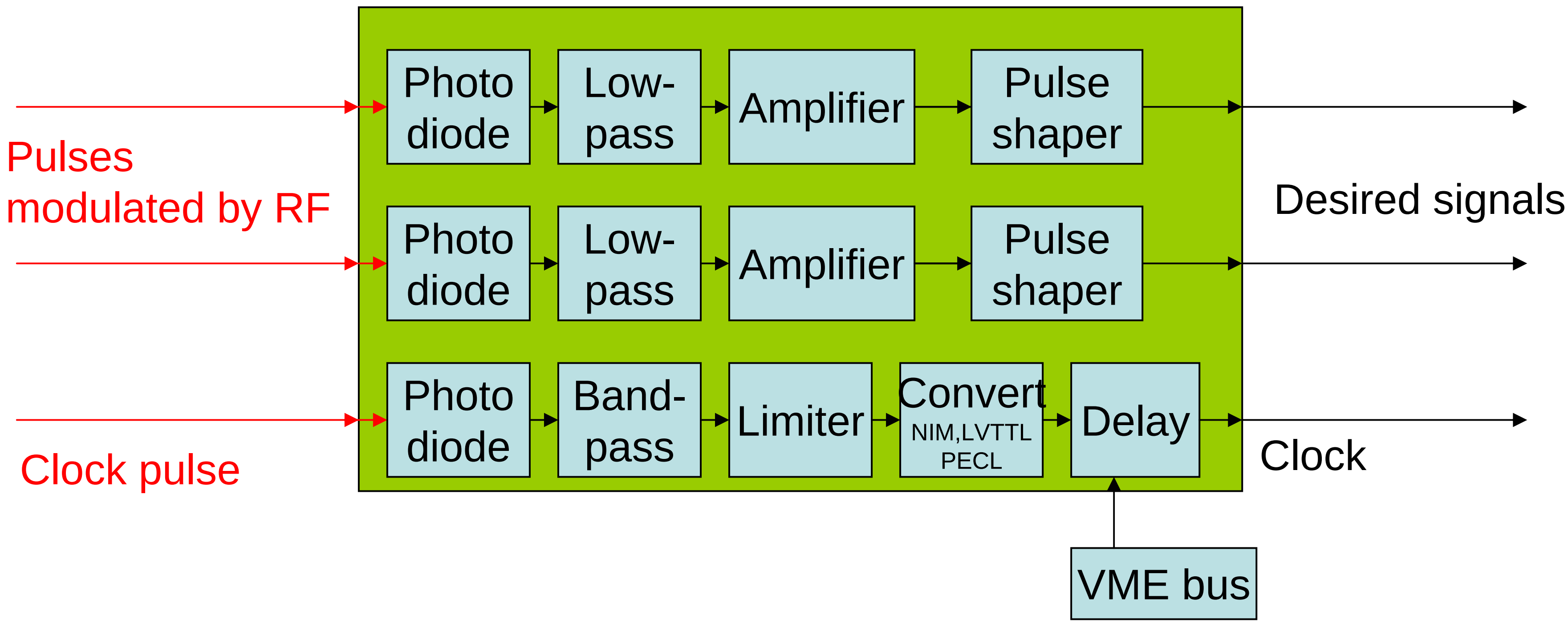
Front-End A



-Temperature controlled
-Radiation shielded
-EMI shielded

Modular electronics space could provide room for limiters, attenuators, or other RF conditioning as well as conditioning for the bias voltage

Front-End B



Should be a 3HI VME card in same crate as ADC
Each front-end has its own Clock, and must, therefore, have its own ADC

Clock operates at 108 MHz, so a separate module could provide a gating function, for slower photo-diode/slower ADC option

-Temperature controlled
-EMI shielded