TeraHertz Pulse Modelling

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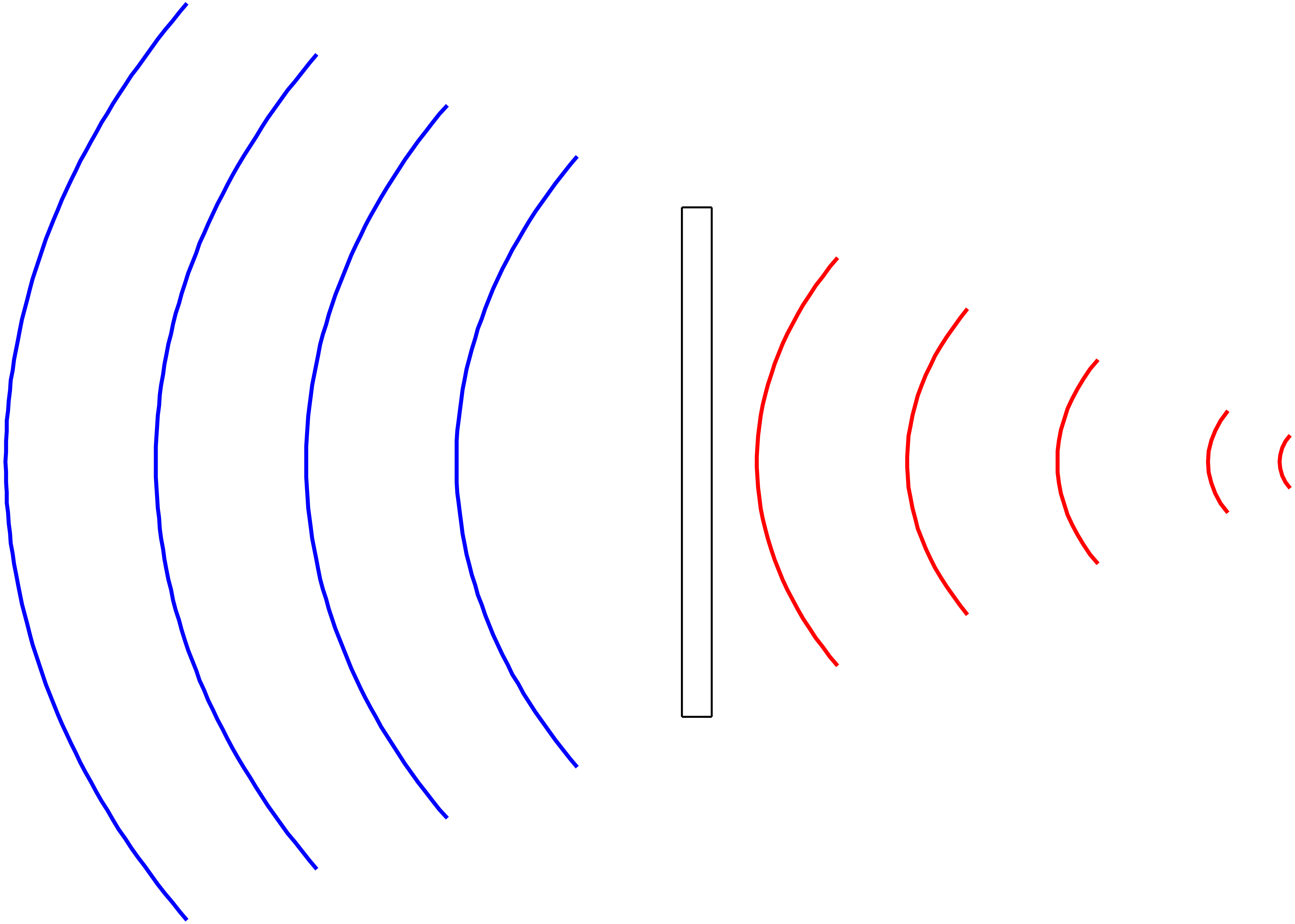
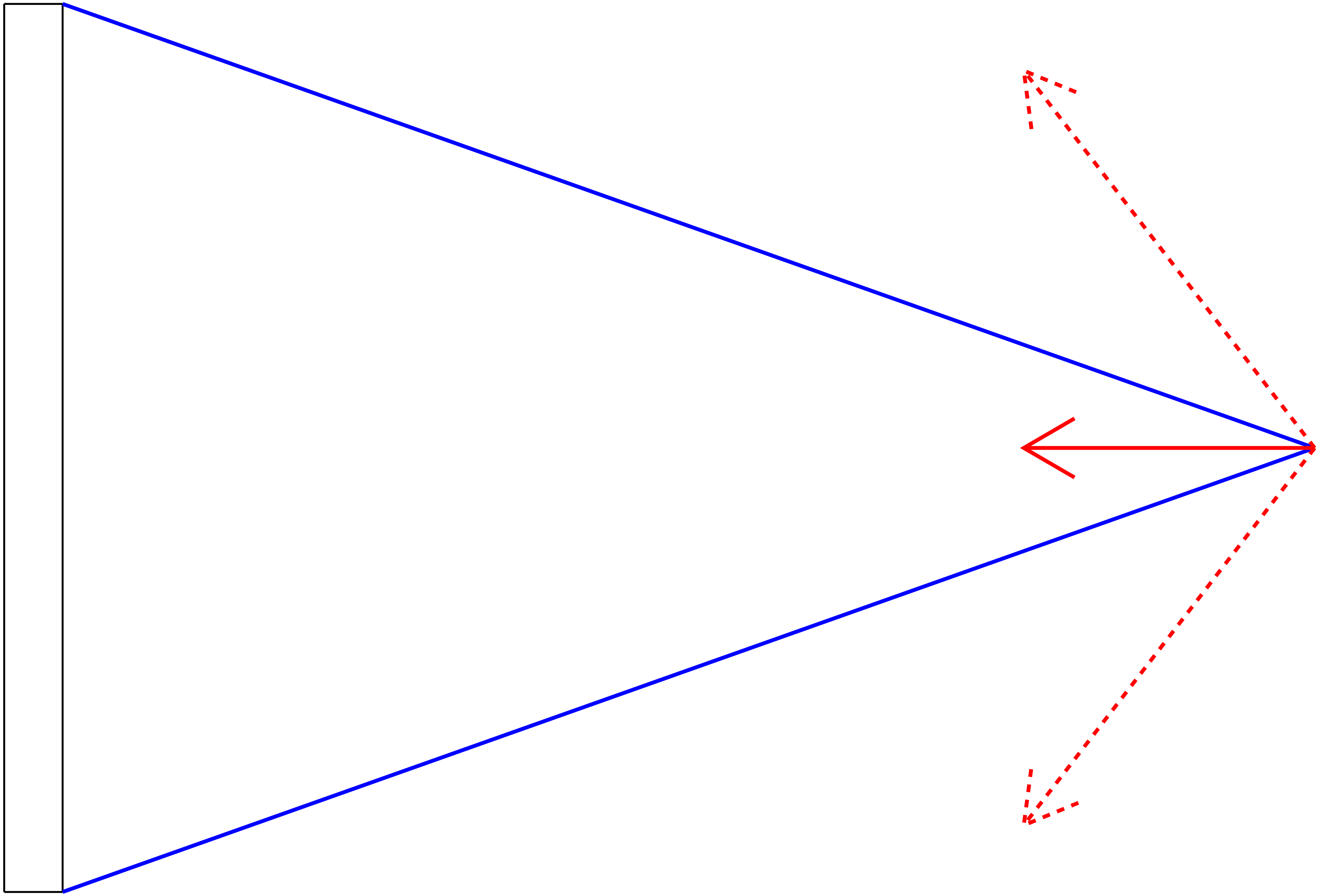
Project Outline

- Aim – to produce evidence of a interaction of an EM wave with a electron beam in free space;
- By – using a longitudinally polarised terahertz beam to produce energy modulation in ALICE electron beam;
- How - terahertz radiation generated by converting the mid-IR multi- 10 ***terawatt*** laser into ***terahertz*** radiation using a semiconductor wafer-based antenna;
- Observe - the result of the radiation-electron bunch interaction in a high-dispersion region of ALICE.

Focusing of the THz Pulse



Generation of a Longitudinal Electric Field



Synchrotron Radiation Calculation

Accelerated charges radiate energy.
The observed electric field of the emitted radiation is:

$$\vec{E}(t) = \frac{n_e e}{4\pi\epsilon_0 c}\left(\frac{c(\vec{n}-\vec{\beta})}{\gamma^2|\vec{R}|^2(1-\vec{\beta}\cdot\vec{n})^3} + \frac{\vec{n}\times[(\vec{n}-\vec{\beta})\times\dot{\vec{\beta}}]}{|\vec{R}|(1-\vec{\beta}\cdot\vec{n})^3}\right)_{RET}$$

To calculate $\vec{E}(t)$ we need to know n_e, v_d and $\dot{v_d}$.

Modelling the Surge Current

At the last talk the current was modelled using an expression (after Benicewicz et.al. J. Opt. Soc. Am. B, 11,12 (1994))

$$\vec{J}_s(t) = \frac{\sigma_s(t)\vec{E}_b}{\frac{\sigma(s)(t)\eta_0}{1+n} + 1} = n_e q \vec{v}_d(t)$$

n is the refractive index of the wafer, η_0 is the impedance of free space and σ_s is the surface conductivity:

$$\sigma_s = \frac{e(1-R)}{\hbar\omega} \int_{-\infty}^{t} dt' \, m \, I_{opt}(t')$$

where,

$\vec{E}_b$ is the bias voltage

R is the wafer reflectivity

m is the carrier mobility (assumed to be constant, with a lifetime $>>$ laser pulse)

Modelling the Surge Current

A more ‘physical’ description is given by the Drude model:

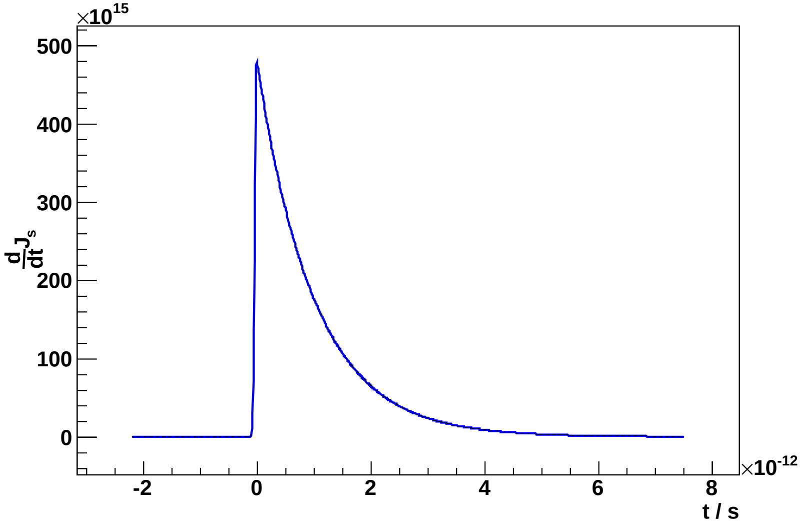
$$\vec{J}_s(t, t_0) = \frac{n_e q^2 \tau}{m} \vec{E}_b = n_e q \vec{v}_d(t, t_0)$$

$$\vec{v}_d(t, t_0) = \frac{q \tau \vec{E}_b}{m^*} \left(1 - \exp(-\frac{t - t_0}{\tau} \right)$$

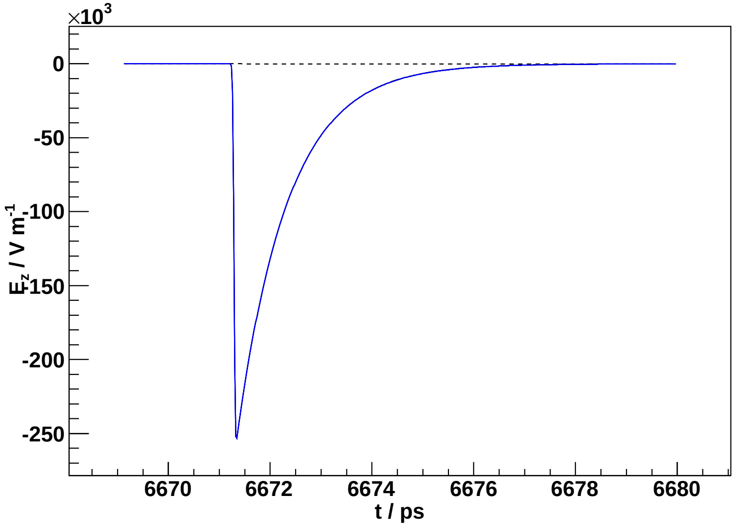
$\vec{v}_d(t, t_0)$ is the drift velocity, at time t, of charge carriers created at time t_0
τ, is the scattering constant (assumed to be $10^{-12}\, s^{-1}$)
m^* is the effective mass of the carriers.
$n_e q$ is the charge density, which is proportional to the laser intensity.
Finally,

$$J_s(t) = \int_{-\infty}^{t} J_s(t, t_0)\, dt_o$$

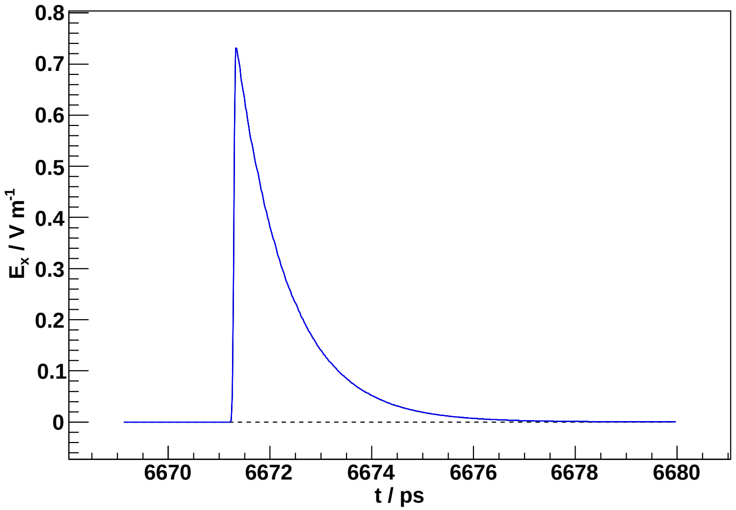
The Surge Current and the on-axis pulse



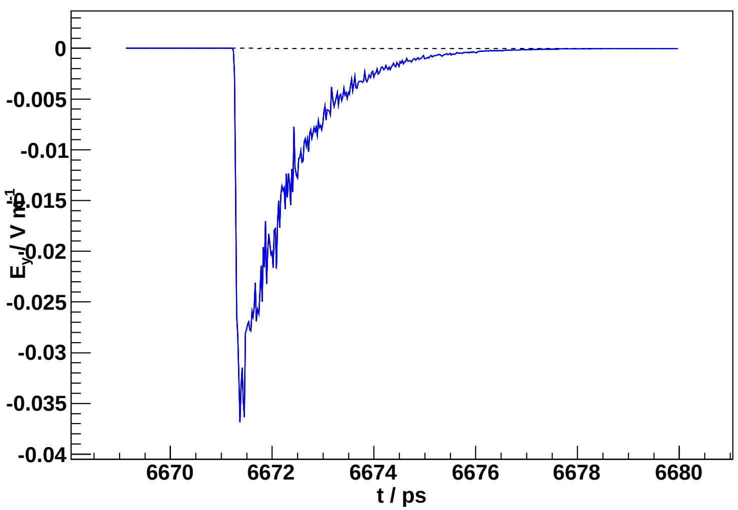
$$\frac{dJs}{dt}$$



$$E_z$$



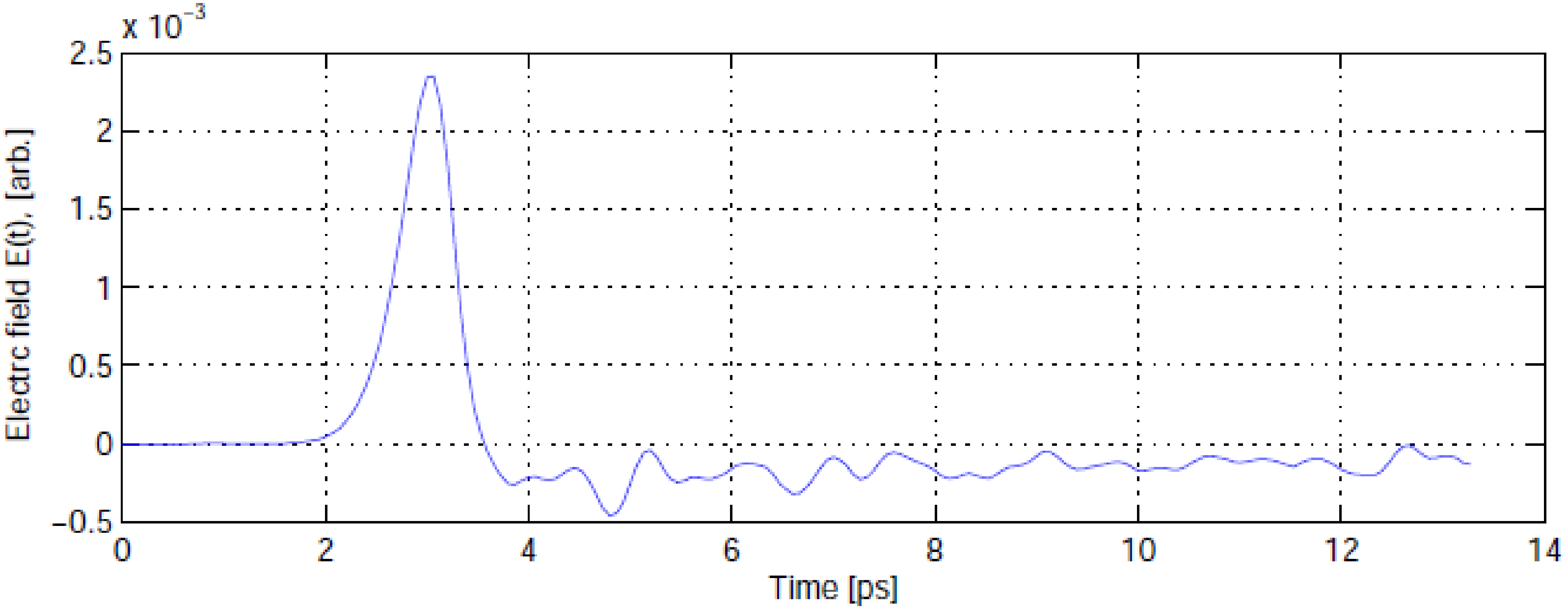
$$E_x$$



$$E_y$$

Comparison with Experimental Results

Example pulse from a SQUARE wafer:

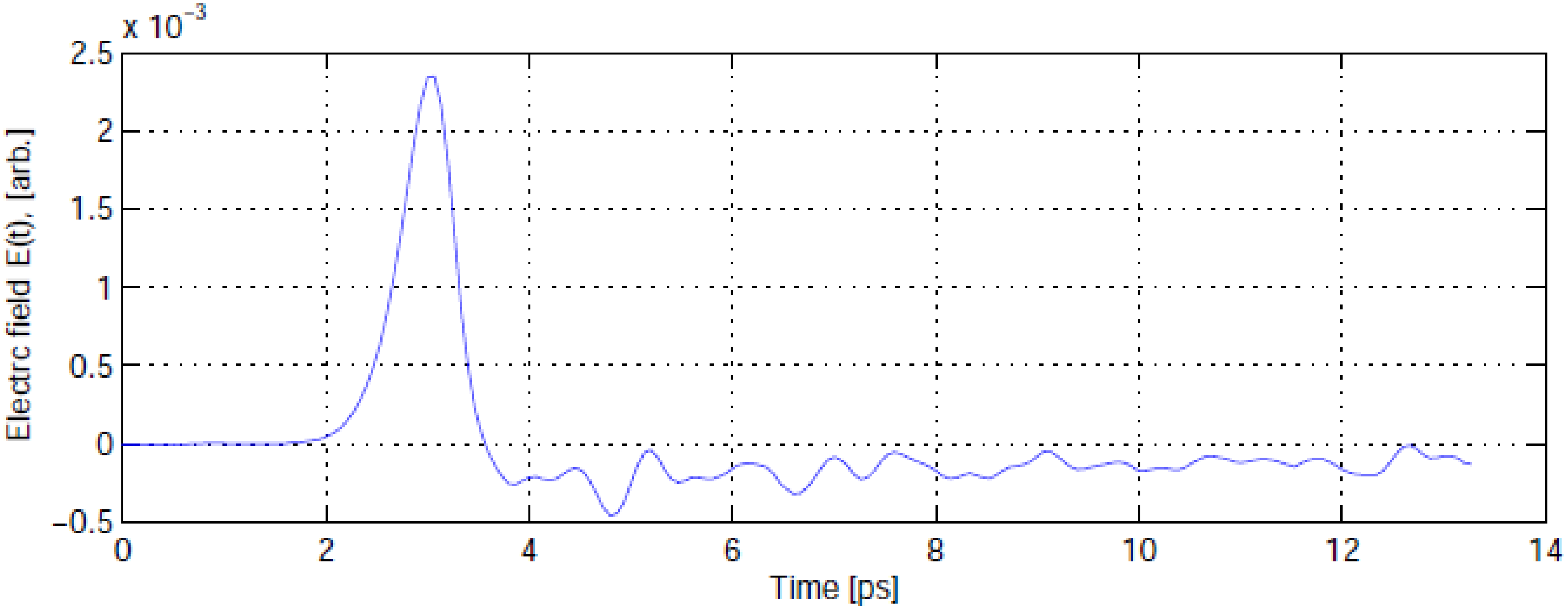


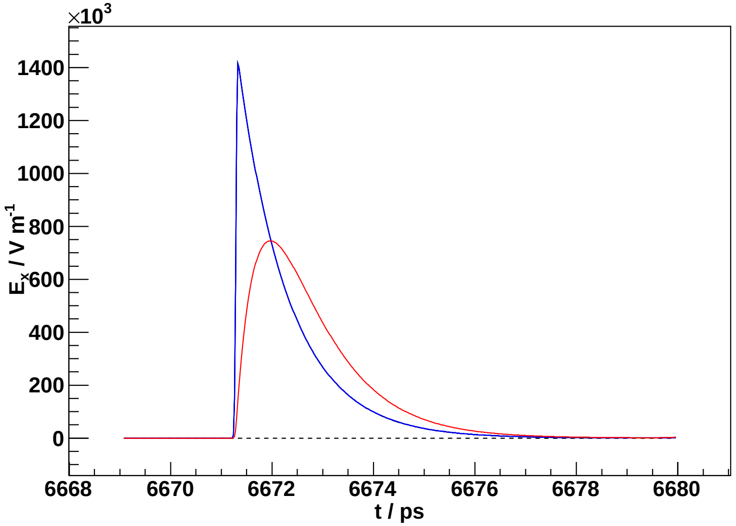
Model Parameters Square Wafer

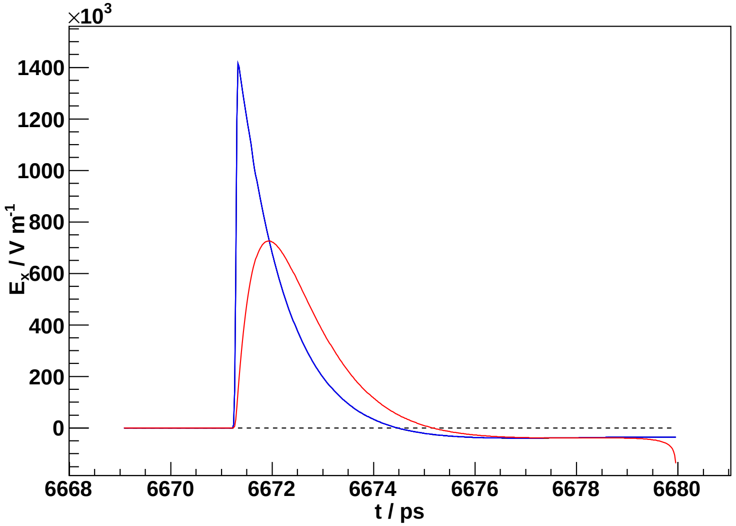
- Wafer dimension = 7.5cm
- Bias Voltage = 5,000 V
- Laser Characteristics:
    - Gaussian Profile, FWHM=40 fs
    - Top-Hat transverse profile
    - Energy / Pulse: 1 mJ
- Scattering Rate = 1.10^{12}
- electron effective mass = 0.063 m_e
- Reflectivity = 0.5

Square Wafer

Ex,Ez observed at (0.0,0.0,2.0)
(near field:dash, far field: solid, total field: blue, convolved field: red)





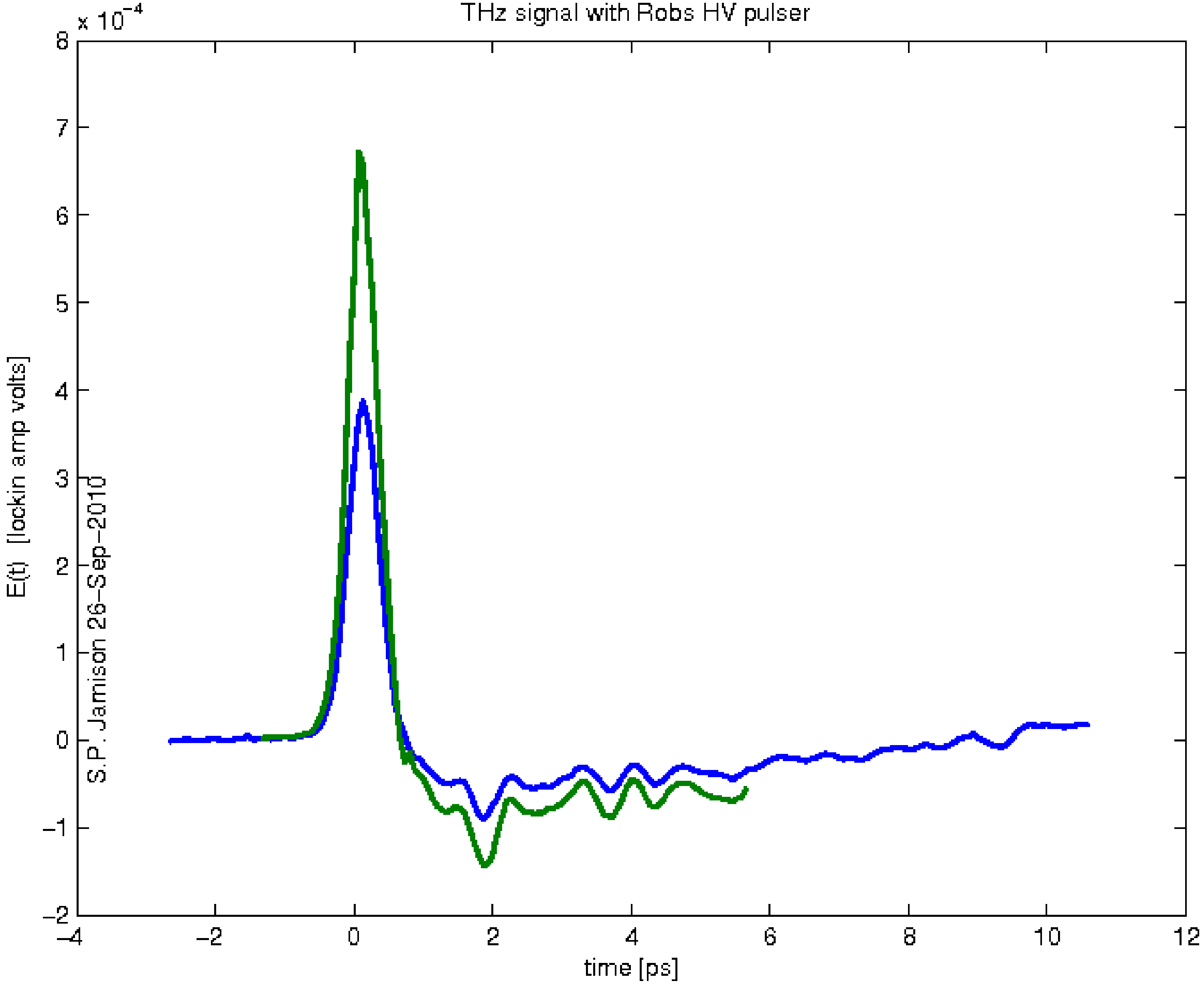


Model Parameters Round Wafer

- Wafer dimension = 7.5cm
  - Outer electrode: 2.5 mm radius
  - Inner electrode: 10 mm radius
- Bias Voltage = 30,000 V
- Laser Characteristics:
  - Gaussian Profile, FWHM=40 fs
  - Top-Hat transverse profile
  - Energy / Pulse: 1 mJ
- Scattering Rate = 1.10^{12}
- electron effective mass = 0.083 m_e
- Reflectivity = 0.5
- Laser Focus = 2 m

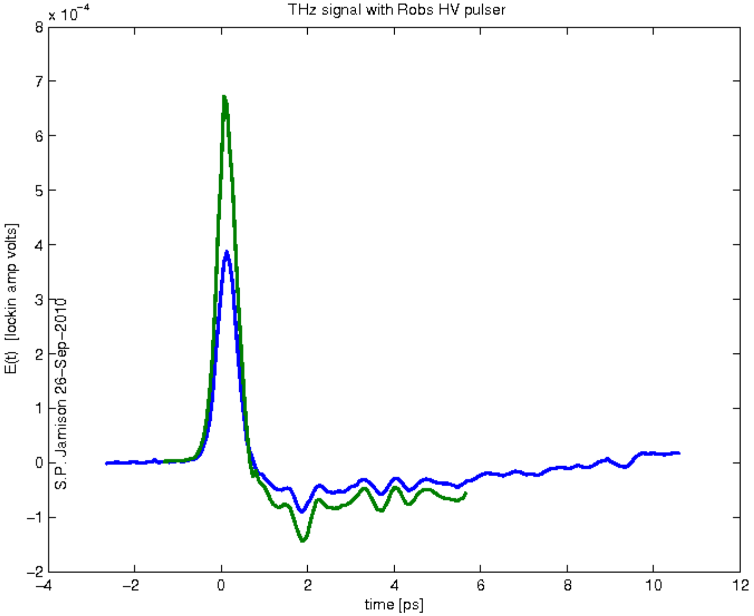
Round Wafer Experimental Result

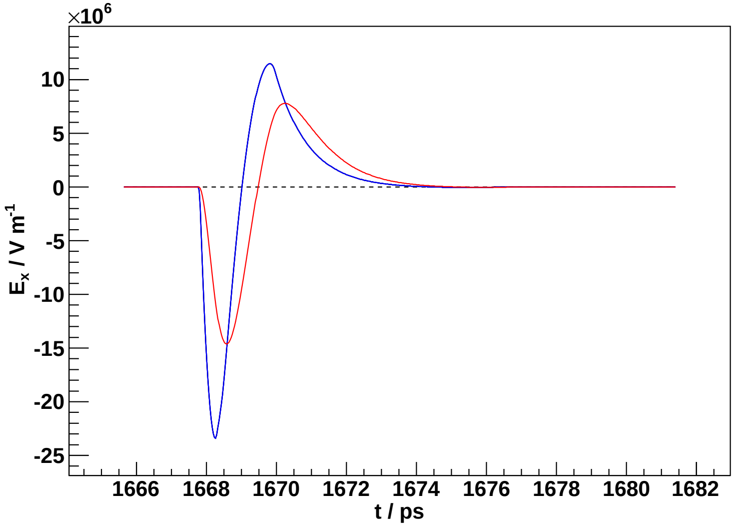
The Longitudinual Electric Field (note: arbitrary units)



Round Wafer off-axis Longitudinal Field

Experimental vs Simulation

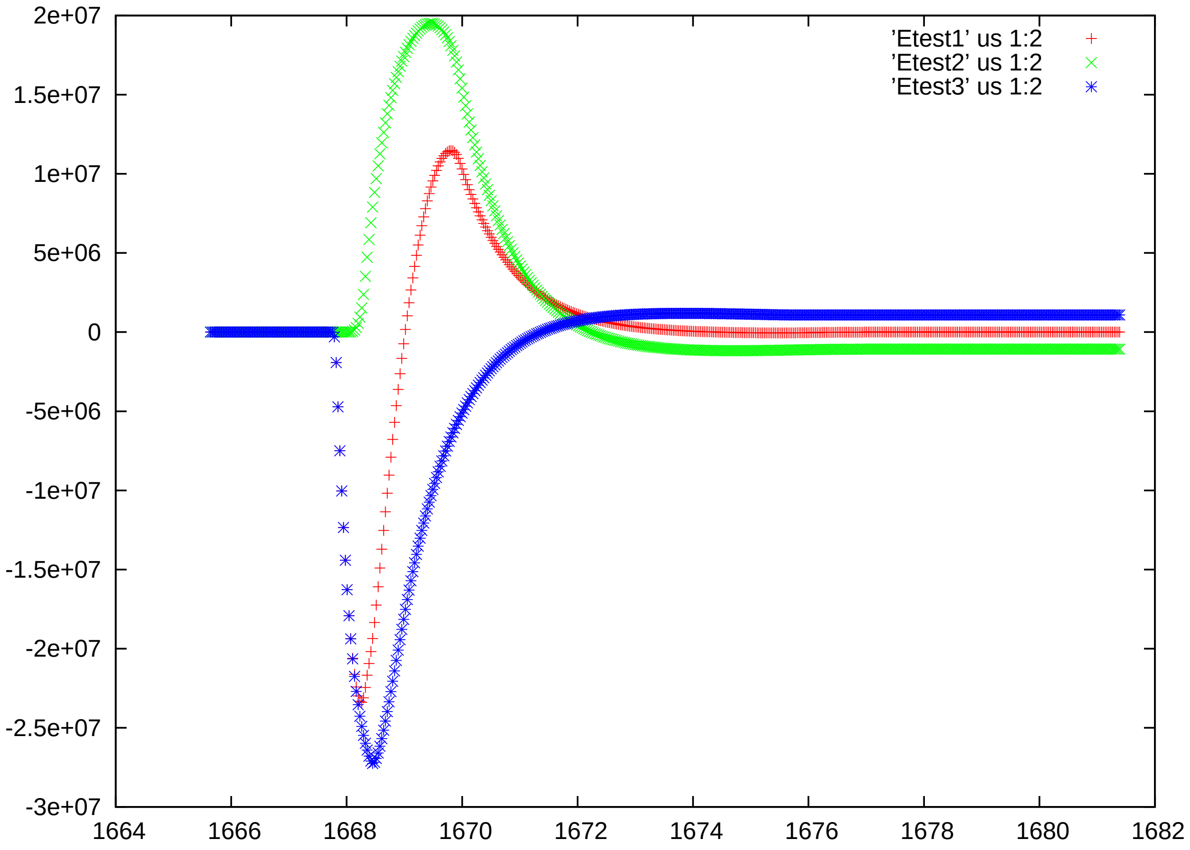




Round Wafer Simulation

Off-axis Longitudinal Field

Double pulse is due to symmetry breaking from different section of the wafer



Red points - Total pulse

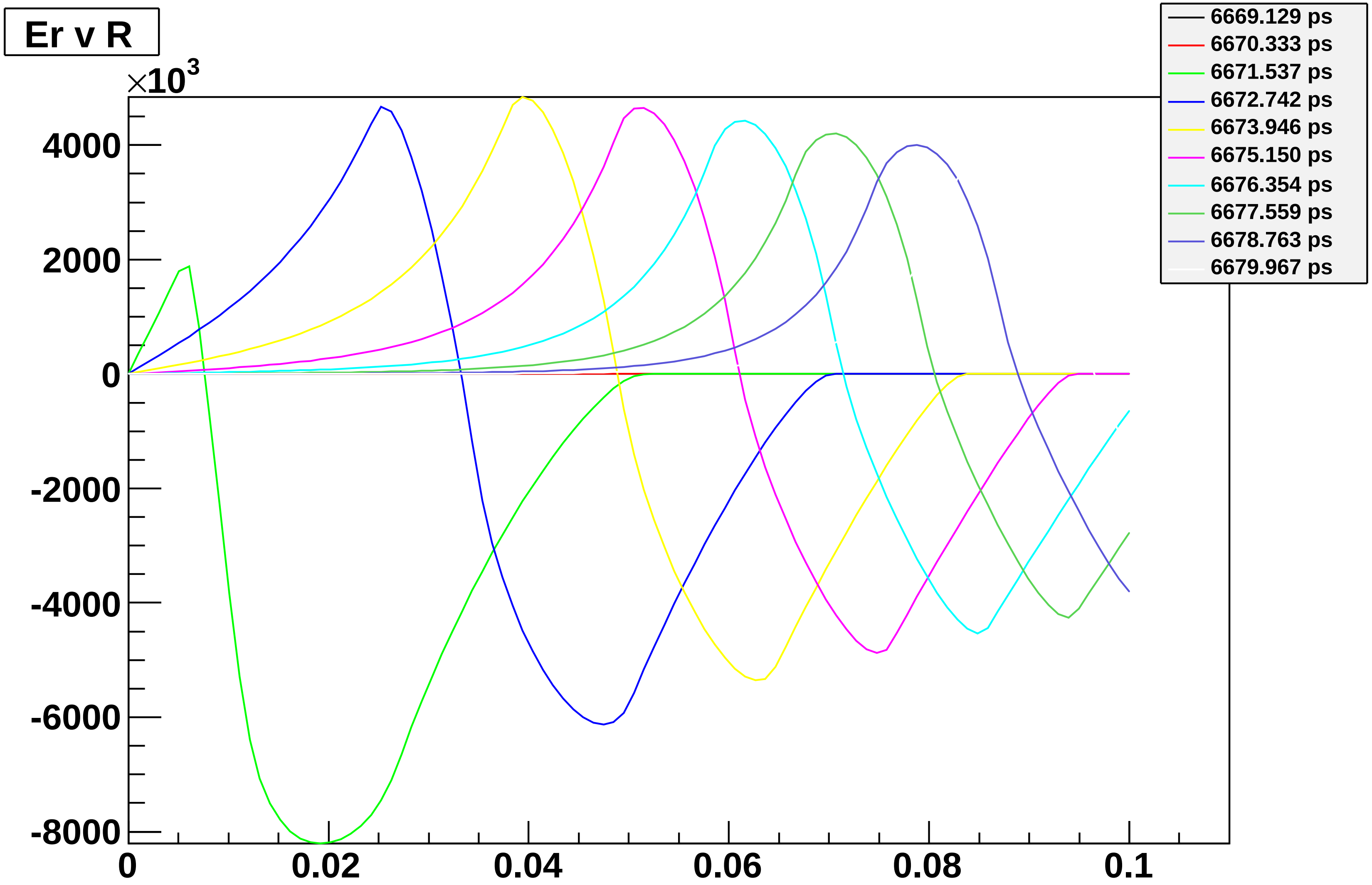
Blue points - pulse from half the wafer

Green points - pulse from the other half of the wafer

nb - No overshoot!

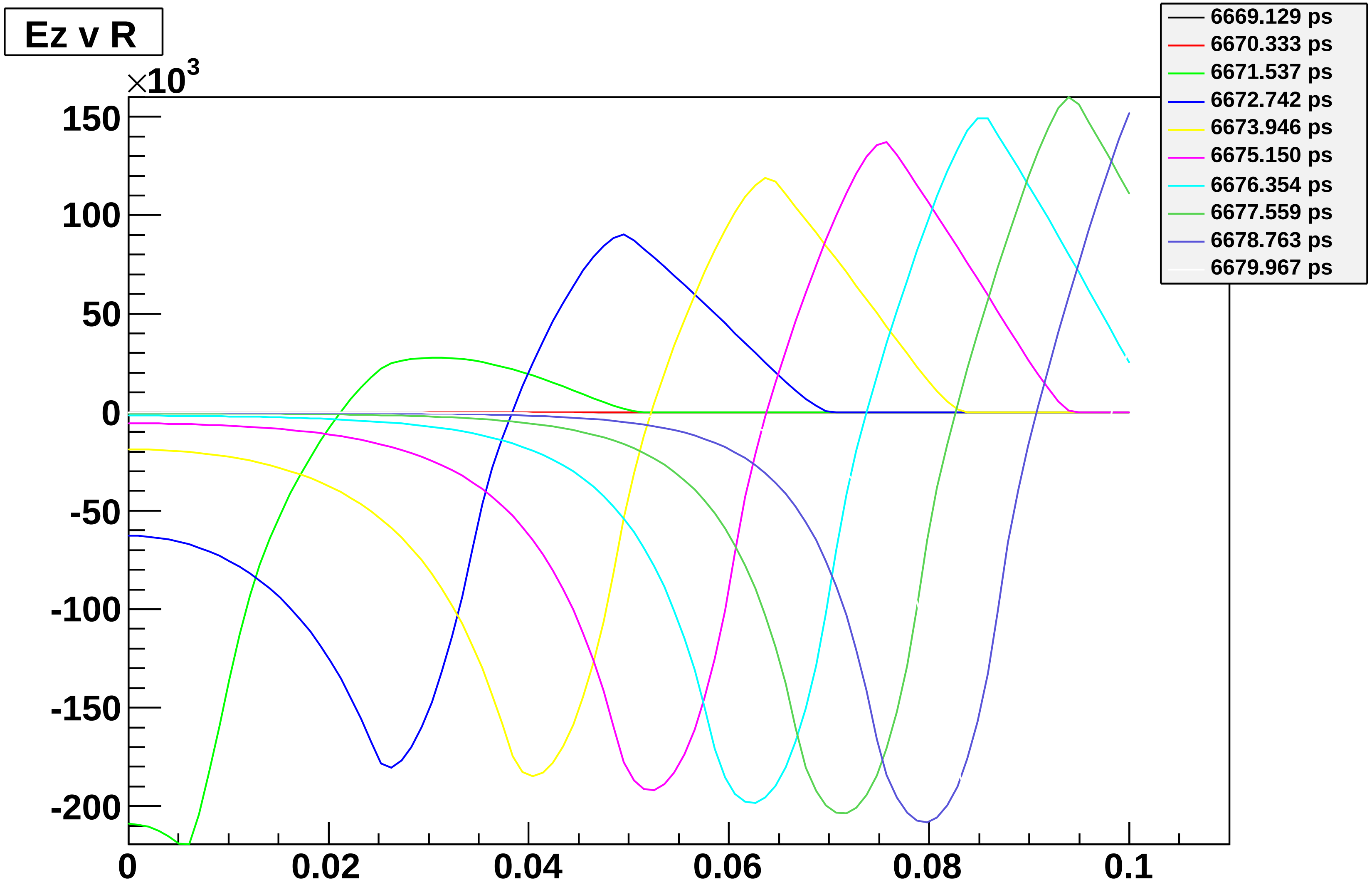
Round Wafer

Simulated off-axis radial fields at 2.0 m



Round Wafer

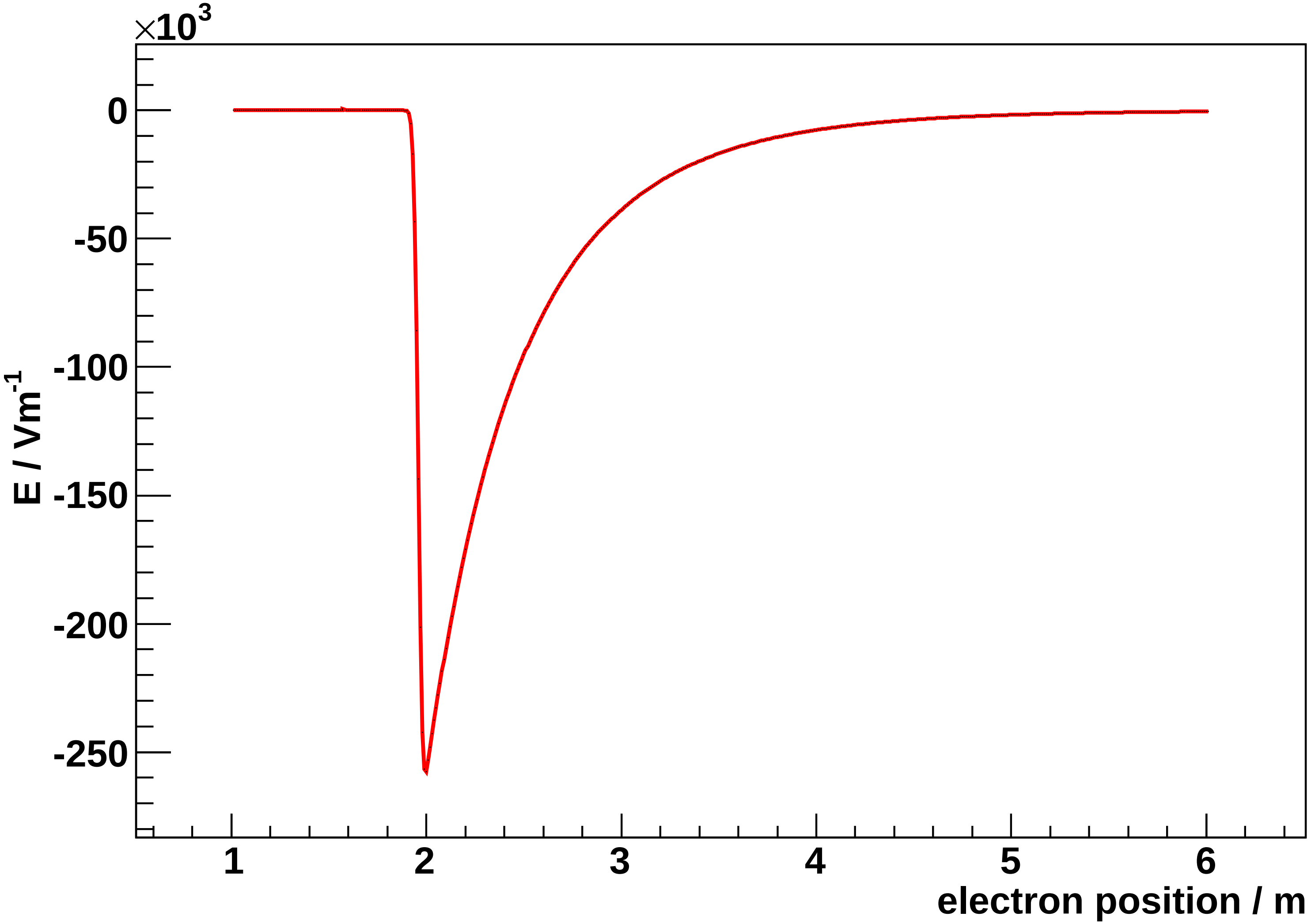
Simulated off-axis radial fields at 2.0 m



Particle Tracking

E_z seen by an 'on-axis' refeference particle (20.8 MeV) coincident with the pulse at 2 m

Integrated field: -150 keV



Concludions

- Code has been optimised and CUDA (GPU) enabled
- Electric field calculation time $\sim$ 300 points per second
  - previously $\sim$ 10 seconds per point
- Benchmarking with experimental results is underway
  - Need to understand the overshoot pulse - could be important in tracking
- Energy could be modulated by several hundred keV - detectable
- Bunch Tracking is under way