Electro-Optic Sampling of Transient $\vec{E}$ Fields

Michael J. Fitch

University of Rochester

FNAL Beams Division Graduate Fellow

- **Electric fields from passage of 10nC bunch: few MV/m**
  vs. "Wakefield"
- **Terahertz bandwidth → Electro-Optic detection.**
- **We have measured the time-domain waveform with picosecond resolution.**
- Goal: Wakefield characterization of structures
- Goal: Bunch length measurement
- Non-intercepting, minimally invasive, all optical

Electro-Optic Estimates: $LiTaO_3$

- For an electron bunch of charge $Q = 10$ nC, the radial field is estimated:

$$\int_S \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$$

$$|E_r| = \frac{q}{2\pi\epsilon_0 a l} = 3 \text{ MV/m}.$$

  Taking the bunch length l =1–3 mm (3–10 ps) and observation radius $a = 2$ cm.

- There is a phase shift between the two polarization components which is linear with the Electric field in the crystal $\rightarrow$ Depends on geometry!

$$\Gamma_r(T) = 2\pi(l/\lambda)\frac{1}{2}n_o^3 r_{22} E_r(T)\, dy. \qquad \text{(for radial fields)}$$

$$\Gamma_{z,\phi}(T) = 2\pi(l/\lambda)\frac{1}{2}(n_e^3 r_{33} - n_o^3 r_{31})\, E_{z,o}(T) dy.$$

- The coefficients are quite different:

$$\frac{1}{2}(n_e^3 r_{33} - n_o^3 r_{31}) = 115 \times 10^{-12}\text{m/V}$$

$$\frac{1}{2}n_o^3 r_{22} = 4 \times 10^{-12}\text{m/V} \quad \text{(radial)}$$

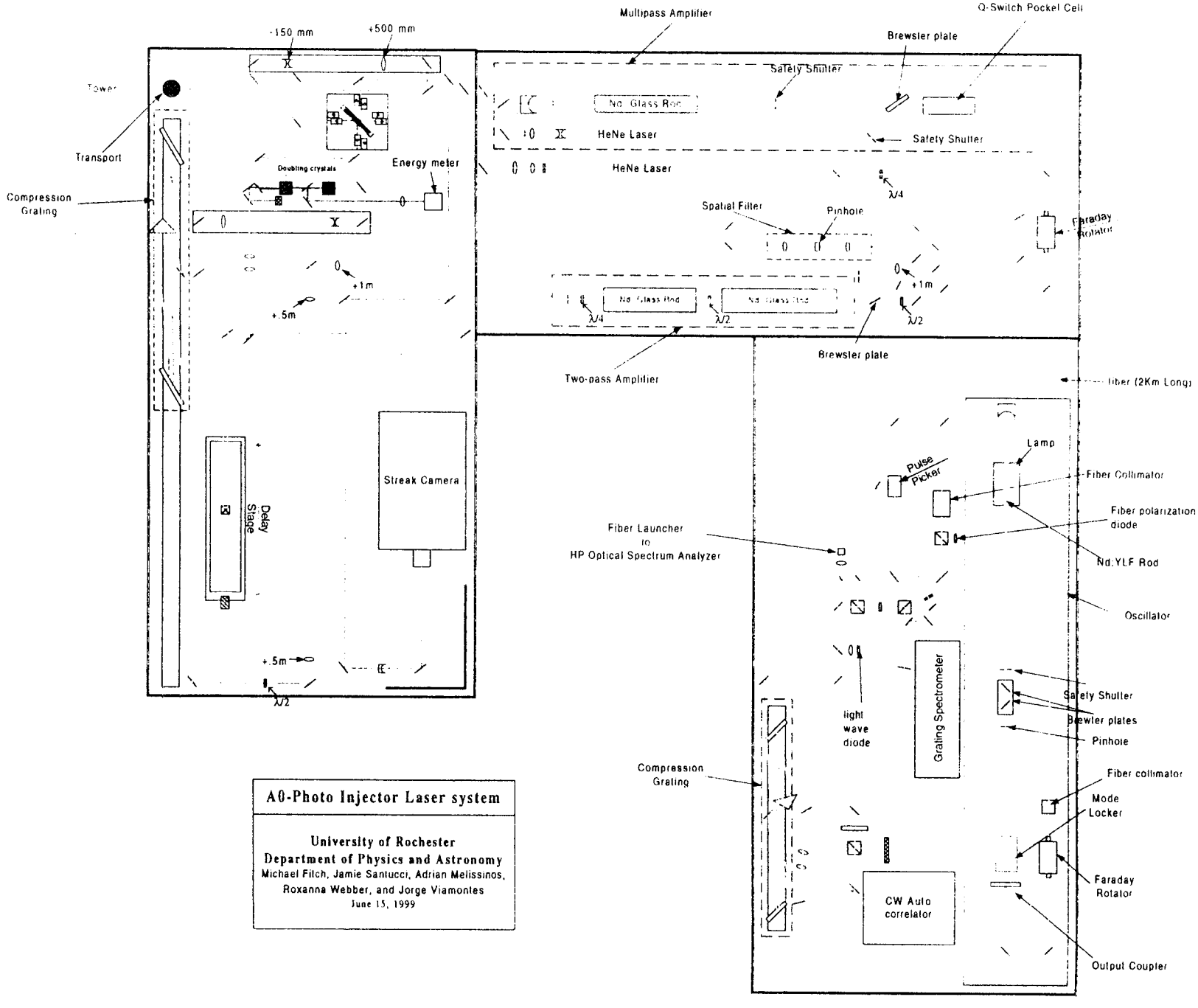
- The bunchlength information in the radial field is swamped by the other field components. Next: different crystal KD*P.

- Using a waveplate to adjust the static retardation. the laser intensities I_a and I_b passing on either side of a polarizing beam splitter are

$$I_{a,b} = \frac{I_0}{2}(1 \pm \sin\Gamma)$$

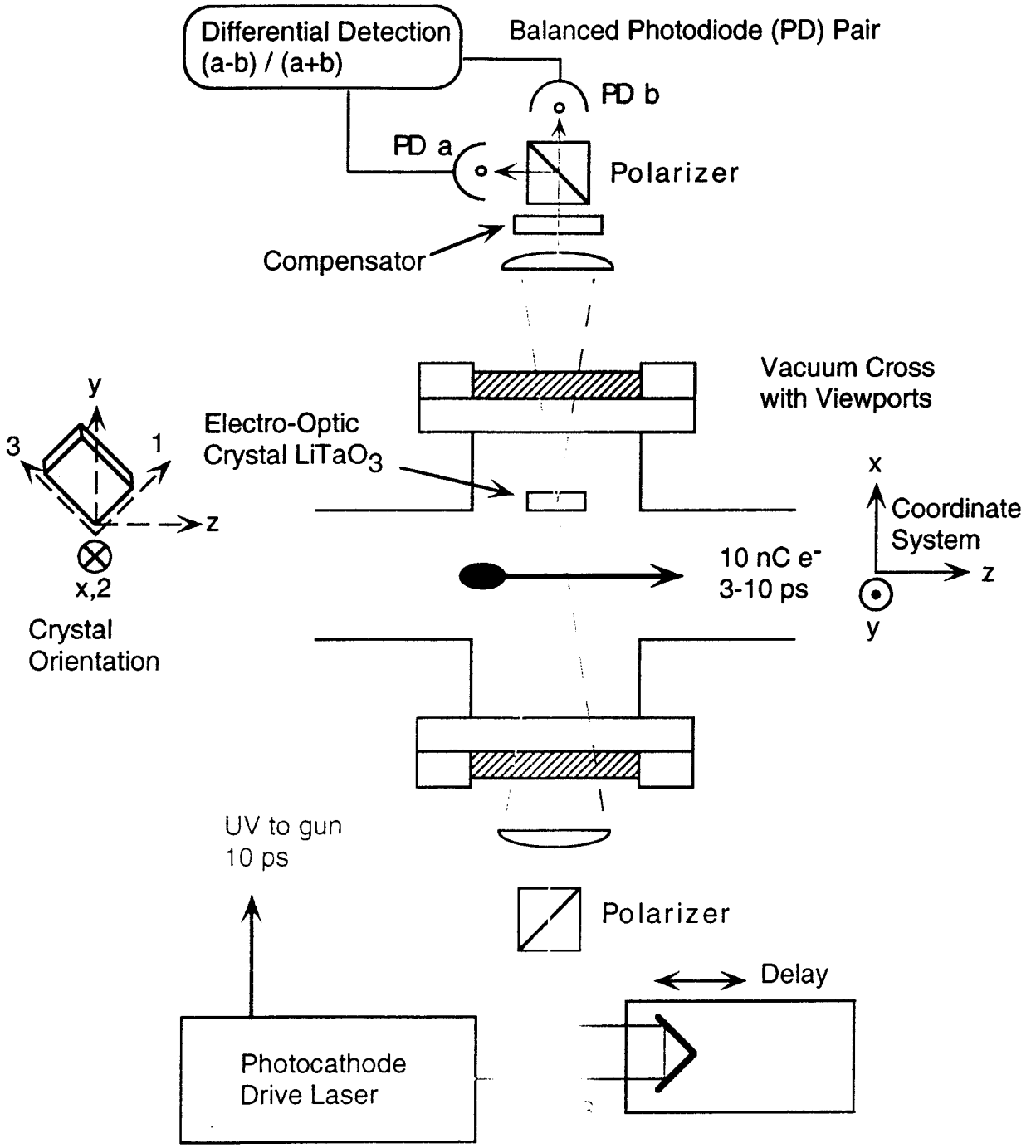
- Measure pairs of I_a and I_b at each delay step T gives

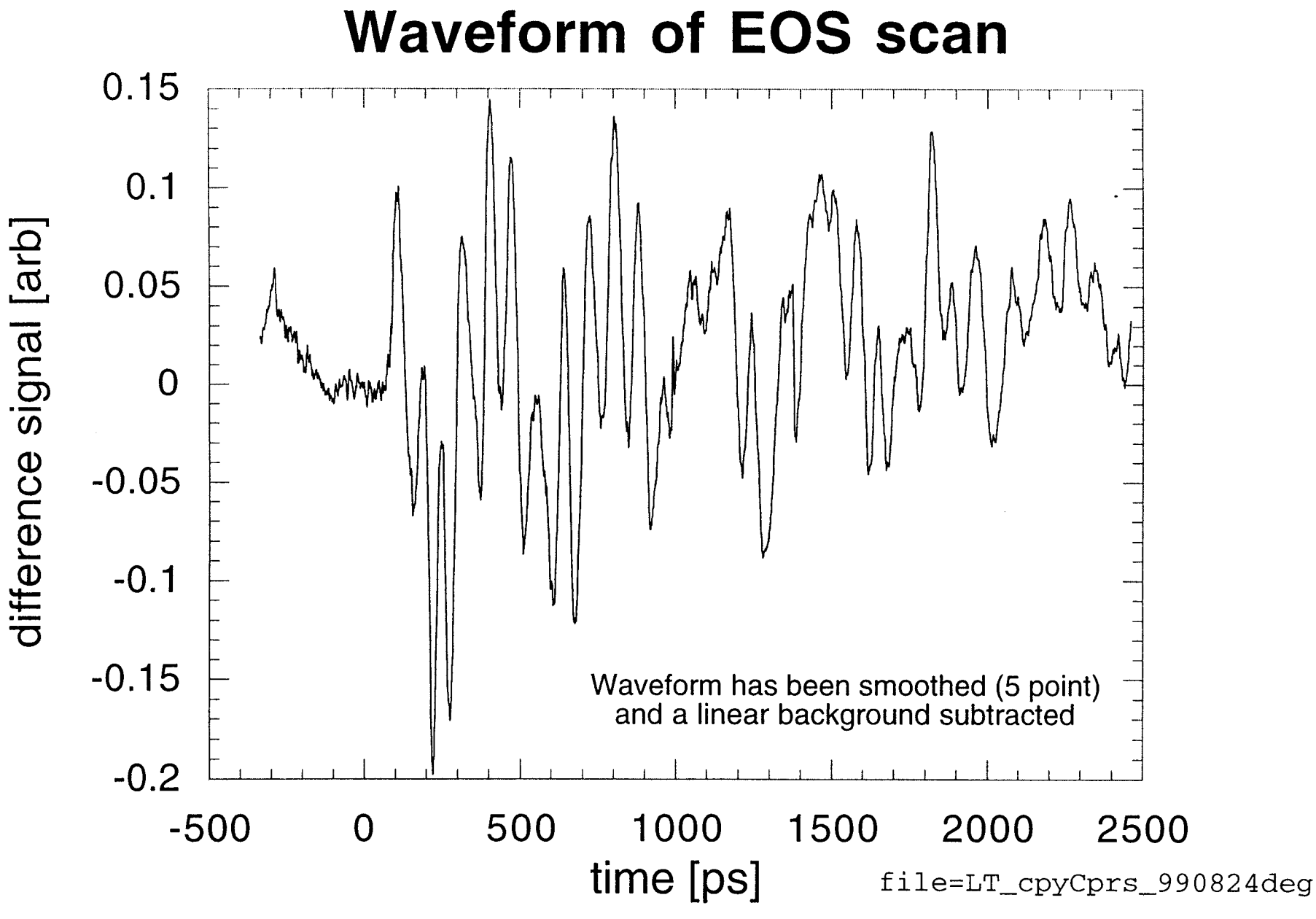
$$\sin\Gamma(T) = \frac{I_a - I_b}{I_a + I_b}$$

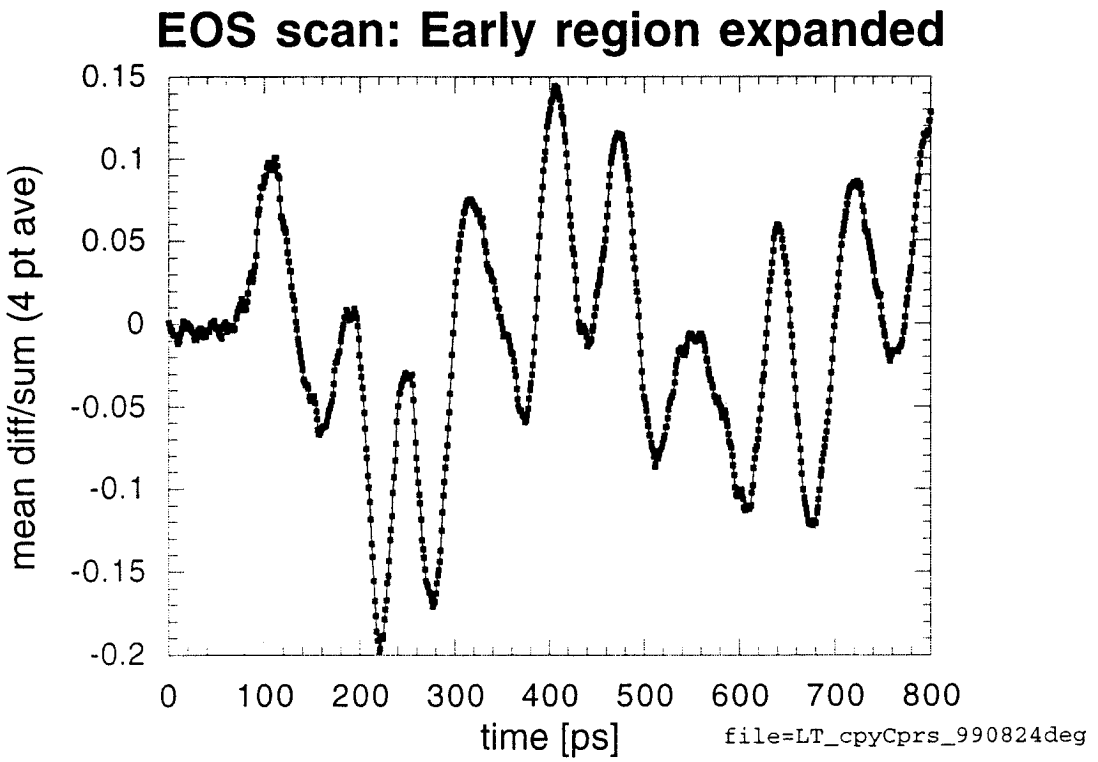


A0-Photo Injector Laser system

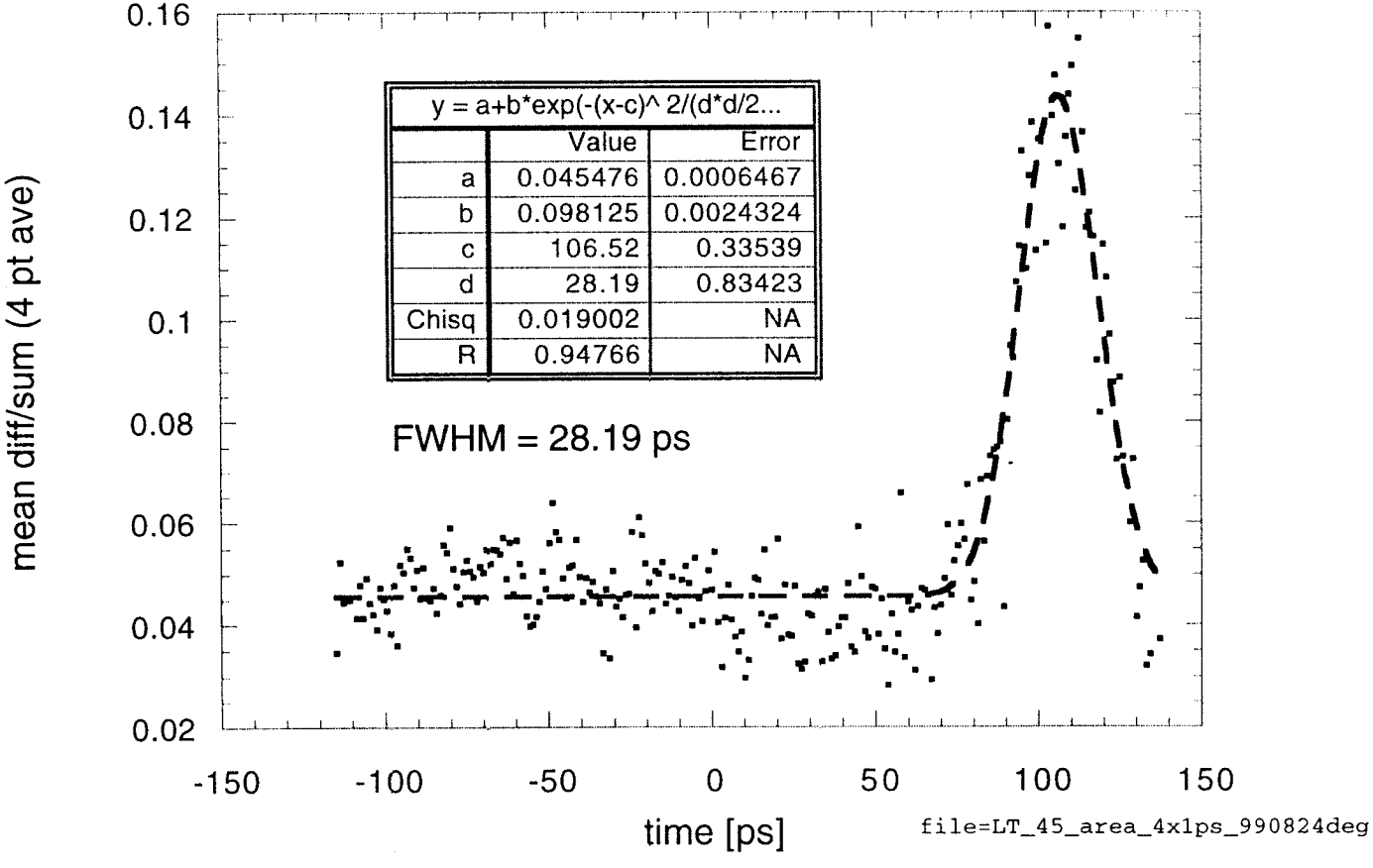
University of Rochester
Department of Physics and Astronomy
Michael Filch, Jamie Santucci, Adrian Melissinos,
Roxanna Webber, and Jorge Viamontes
June 15, 1999

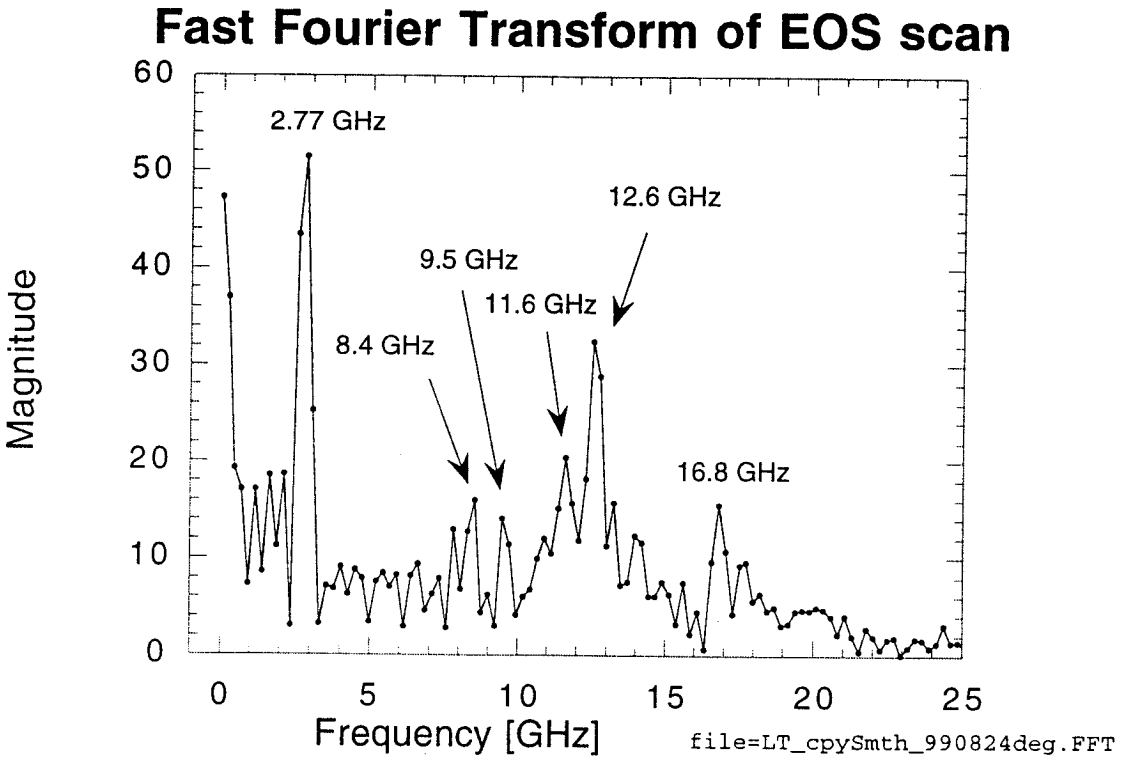

Differential Detection
(a-b) / (a+b)
Balanced Photodiode (PD) Pair
PD b
PD a
Polarizer
Compensator
Vacuum Cross
with Viewports
y
3
1
z
x,2
Crystal
Orientation
Electro-Optic
Crystal LiTaO3
x
Coordinate
System
z
y
10 nC e-
3-10 ps
UV to gun
10 ps
Polarizer
Delay
Photocathode
Drive Laser

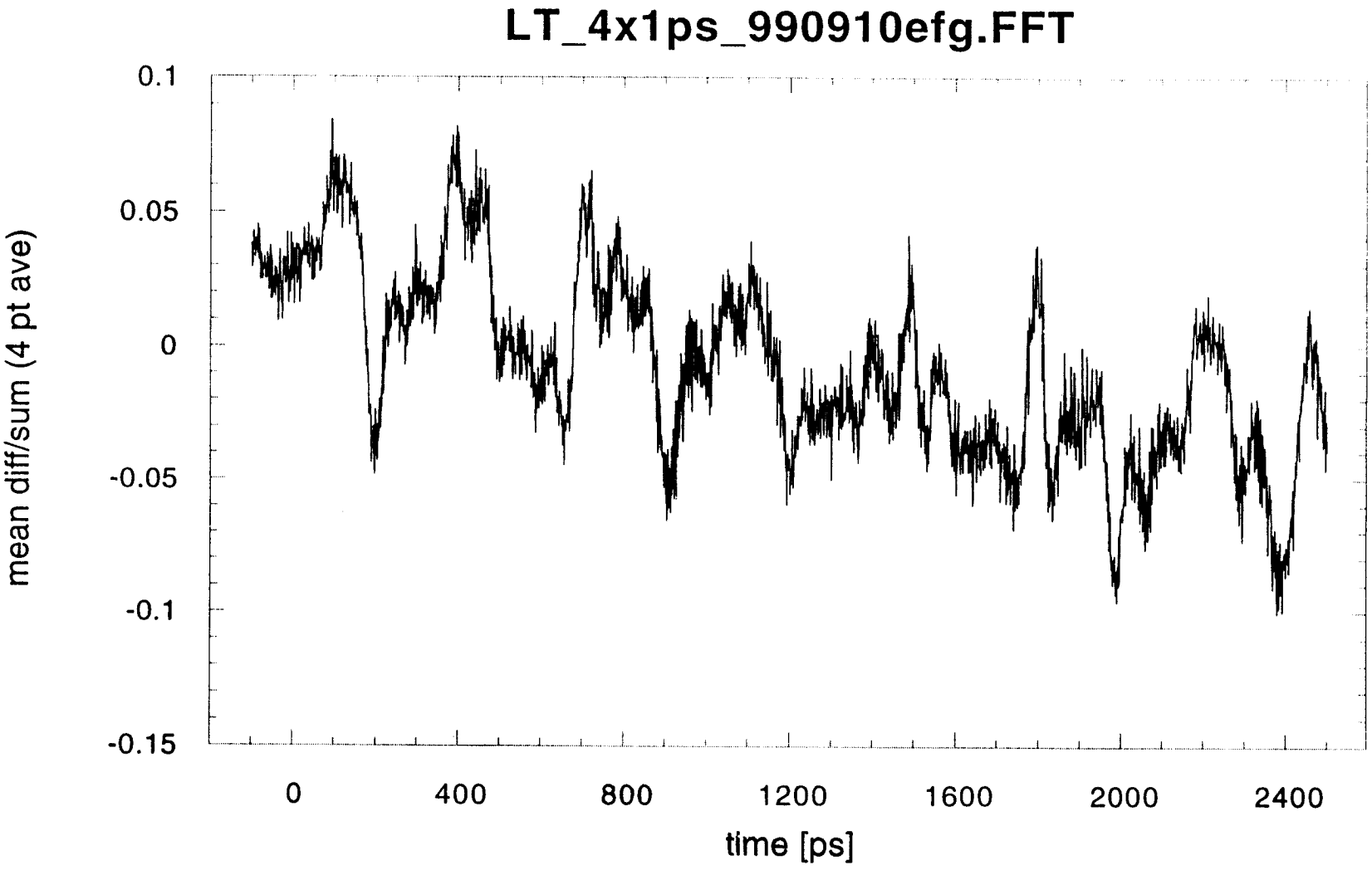

Waveform of EOS scan
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
difference signal [arb]
-500
0
500
1000
1500
2000
2500
time [ps]
Waveform has been smoothed (5 point)
and a linear background subtracted
file=LT_cpyCprs_990824deg

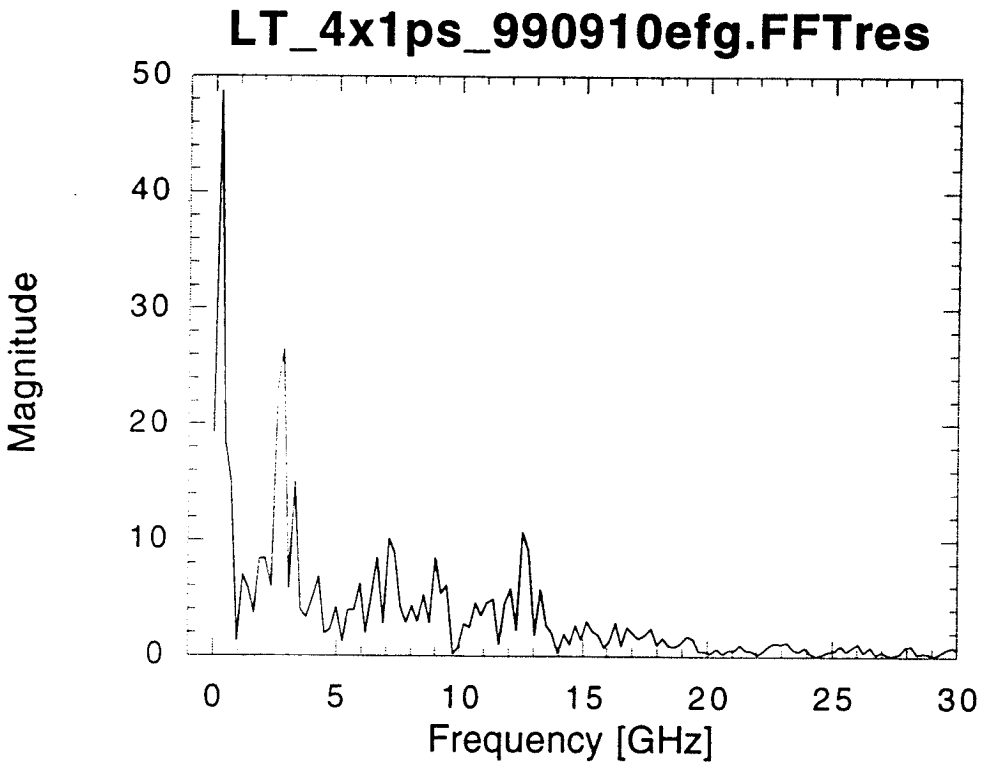

EOS scan: Early region expanded
mean diff/sum (4 pt ave)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
100
200
300
400
500
600
700
800
time [ps]
file=LT_cpyCprs_990824deg

Gaussian fit to first peak in EOS scan




Fast Fourier Transform of EOS scan
Magnitude
60
50
40
30
20
10
0
2.77 GHz
12.6 GHz
9.5 GHz
11.6 GHz
8.4 GHz
16.8 GHz
0
5
10
15
20
25
Frequency [GHz]
file=LT_cpySmth_990824deg.FFT


LT_4x1ps_990910efg.FFT
0.1
0.05
0
-0.05
-0.1
-0.15
mean diff/sum (4 pt ave)
0
400
800
1200
1600
2000
2400
time [ps]


LT_4x1ps_990910efg.FFTres
Magnitude
50
40
30
20
10
0
0
5
10
15
20
25
30
Frequency [GHz]