Time Domain Pulse Shaping through a learning algorithm in a feedback loop

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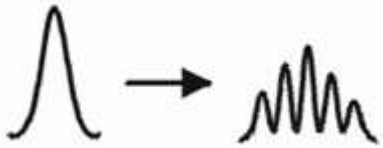
our future through science

Introduction

- Project Relevance
  - Coherent Control of Atoms and Molecules
    - Complex time profiles
- Project Aims
  - Time pulse shaper
    - Accurate amplitude and phase control
  - Automated dispersion compensation
    - SHG maximization experiment
    - Genetic algorithm in a feedback loop

Introduction to time domain pulse shaping

- Time domain pulse shaping



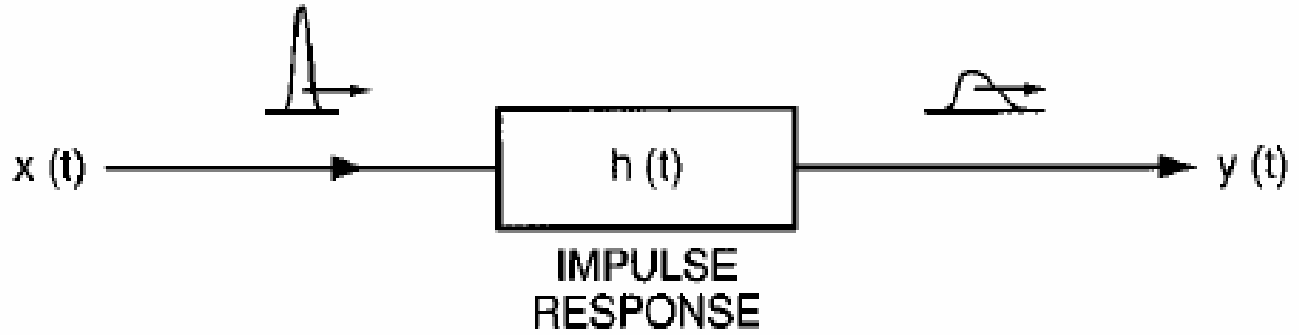
- Linear filtering – Time domain

$$e_{\text{out}}(t) = e_{\text{in}}(t) * h(t) = \int dt' e_{\text{in}}(t') h(t - t')$$

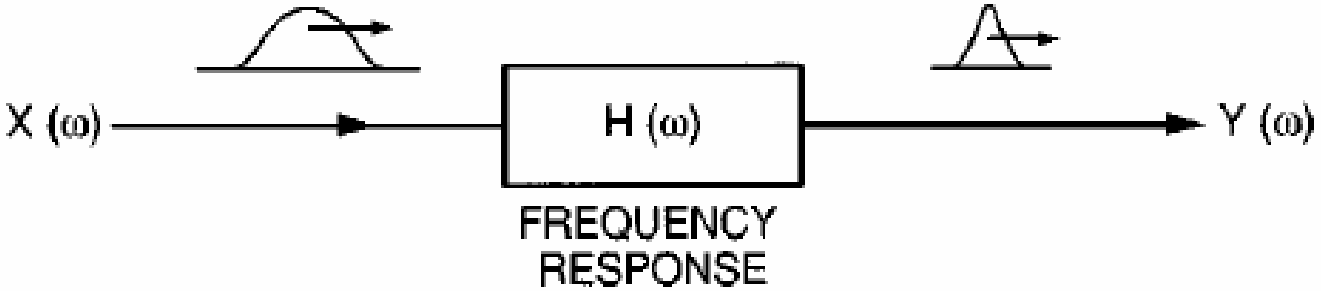
- Frequency Domain $E_{\text{out}}(\omega) = E_{\text{in}}(\omega) H(\omega).$

$$H(\omega) = \int dt\, h(t) e^{-i\omega t} \qquad h(t) = \frac{1}{2\pi} \int d\omega\, H(\omega) e^{i\omega t}.$$

(a) TIME DOMAIN



(b) FREQUENCY DOMAIN



- Time domain pulse shaping achieved with :

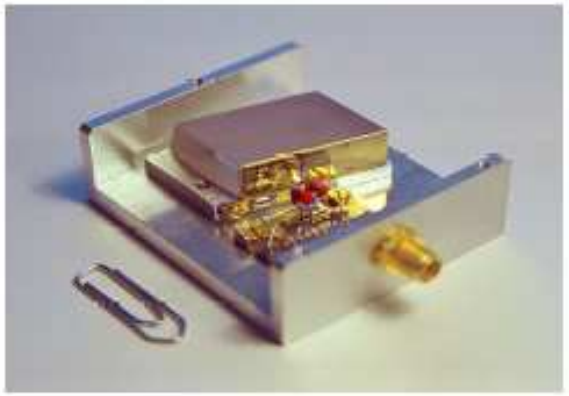
- Amplitude modulation
- Phase modulation

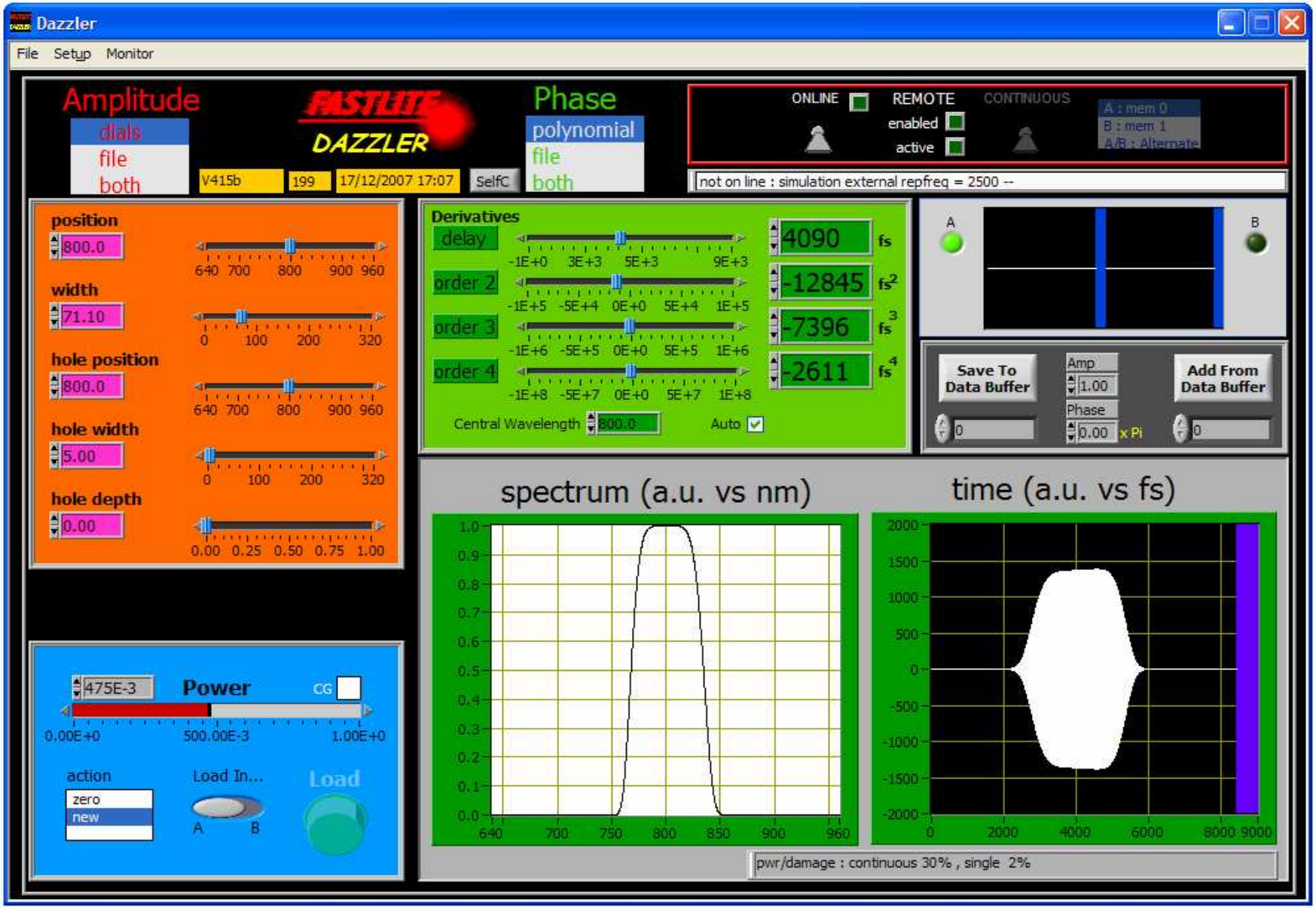
  - For a USP propagating in a nonlinear optical crystal the wave vector k can be described as an expansion about the central frequency

$$k(\omega) = k(\omega_0) + \left(\frac{\partial k(\omega)}{\partial \omega}\right)_{\omega_0} \delta\omega + \frac{1}{2}\left(\frac{\partial^2 k(\omega)}{\partial \omega^2}\right)_{\omega_0} \delta\omega^2 + \\ + \frac{1}{6}\left(\frac{\partial^3 k(\omega)}{\partial \omega^3}\right)_{\omega_0} \delta\omega^3 + \ldots \\ = k(\omega_0) + \frac{1}{\beta_1}\delta\omega + \frac{1}{2\beta_2}\delta\omega^2 + \frac{1}{6\beta_3}\delta\omega^3 + \ldots$$

Dazzler

- AOM as a spatial light modulator





Experimental proposal

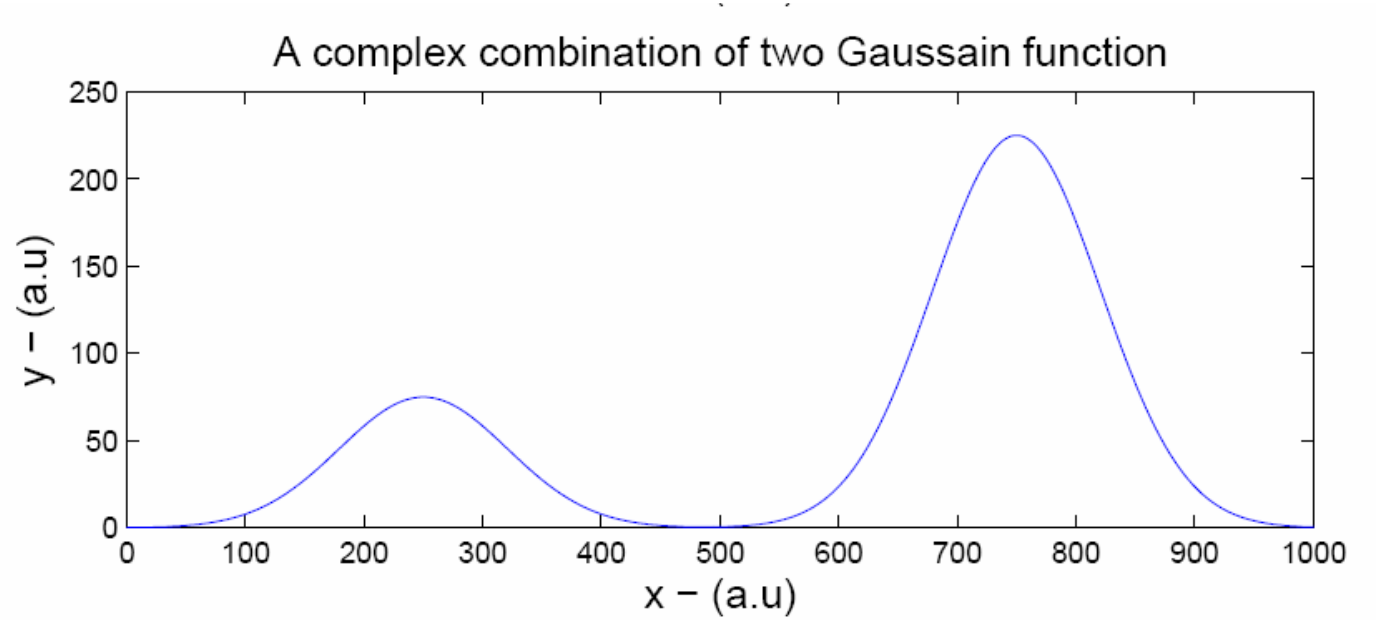
- Dispersion Compensation
  - Remove CHIRP from a pulse
    - Shortest possible pulse duration
    - Vary the amount of GVD imposed on the input pulse
  - Automate the process
    - Genetic algorithm in a feedback loop
    - AC traces become cumbersome
    - SHG signal maximization implies shortest pulse duration!
    - Genetic algorithm searches the 2nd order dispersion parameter space for the configuration which produces the maximum SHG signal.

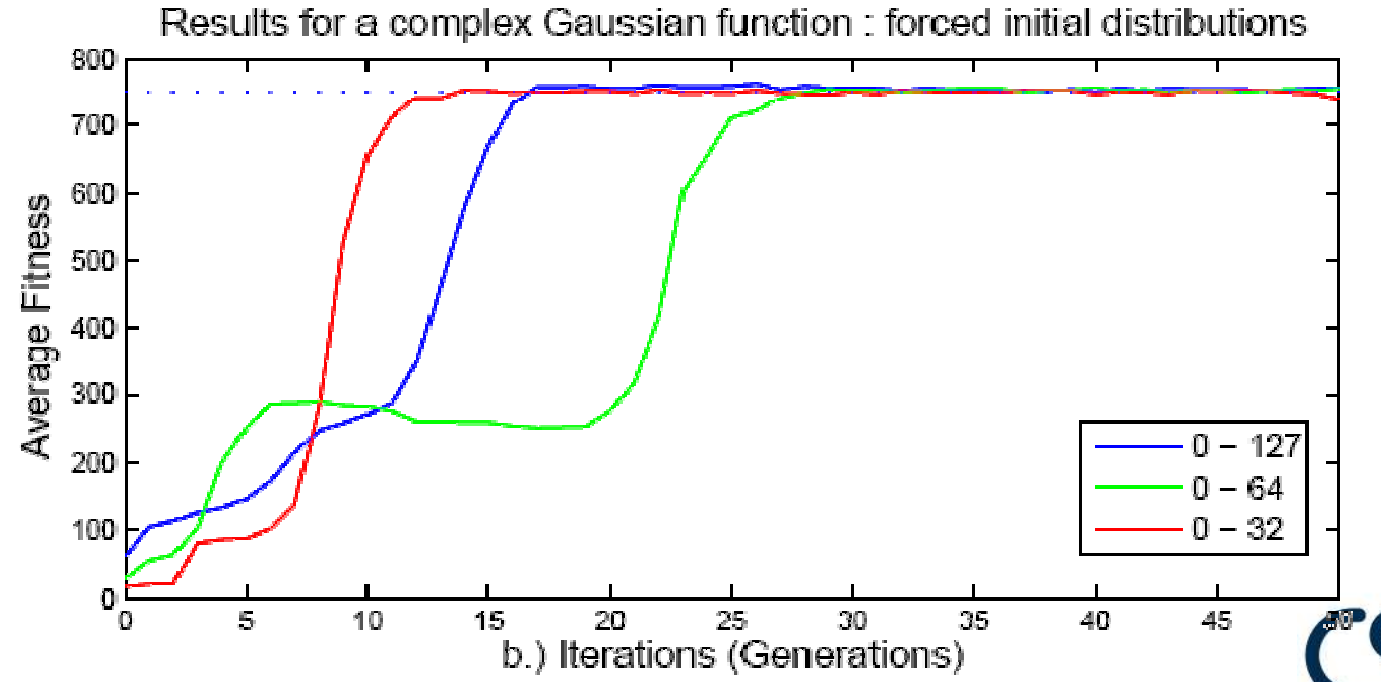
Genetic Algorithms

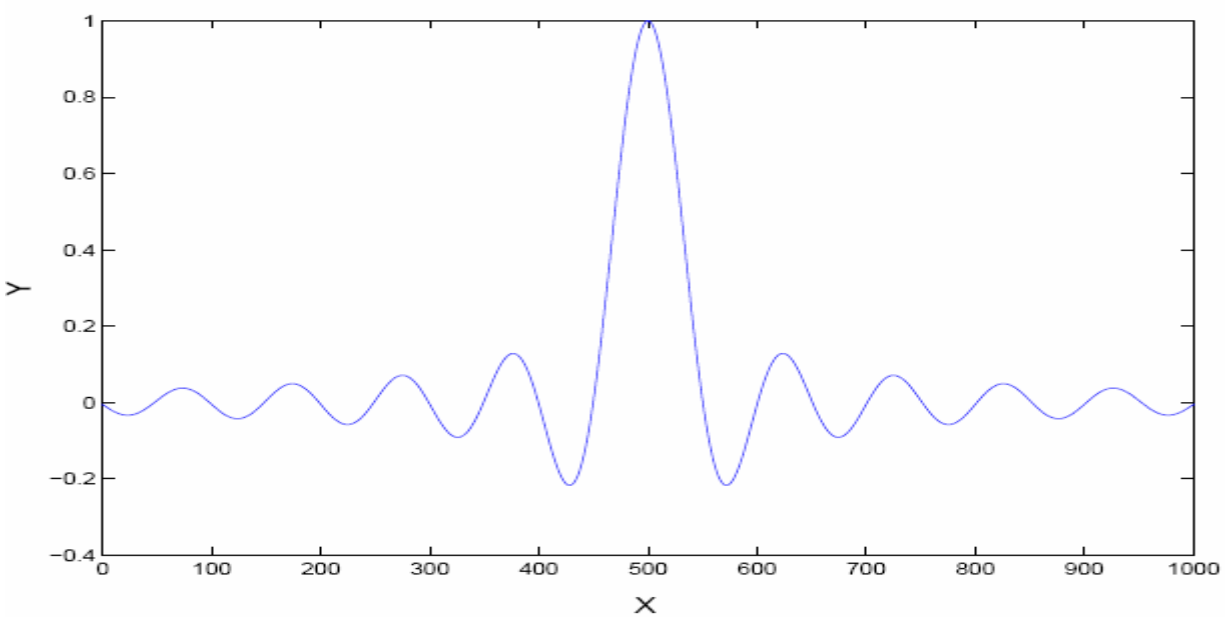
- Search algorithms:
- Calculus based, Enumerative and random methods.
- Calculus based:
  - Gradient based
  - Direct or indirect searching
  - Solving sets of (usually) Non-linear equations
- Enumerative methods:
  - Test objective functions at each point in the search space
- Random based methods:
  - Directed randomness as a search method
  - Highly exploitative search

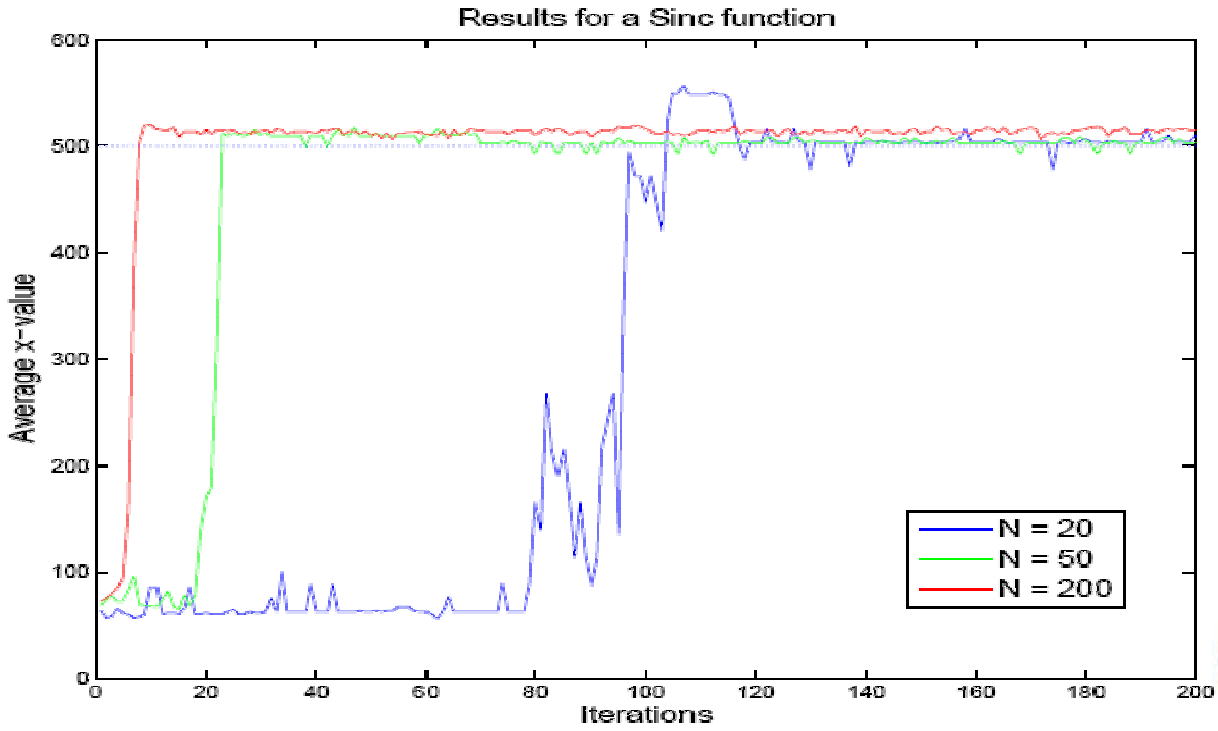
Genetic Algorithms

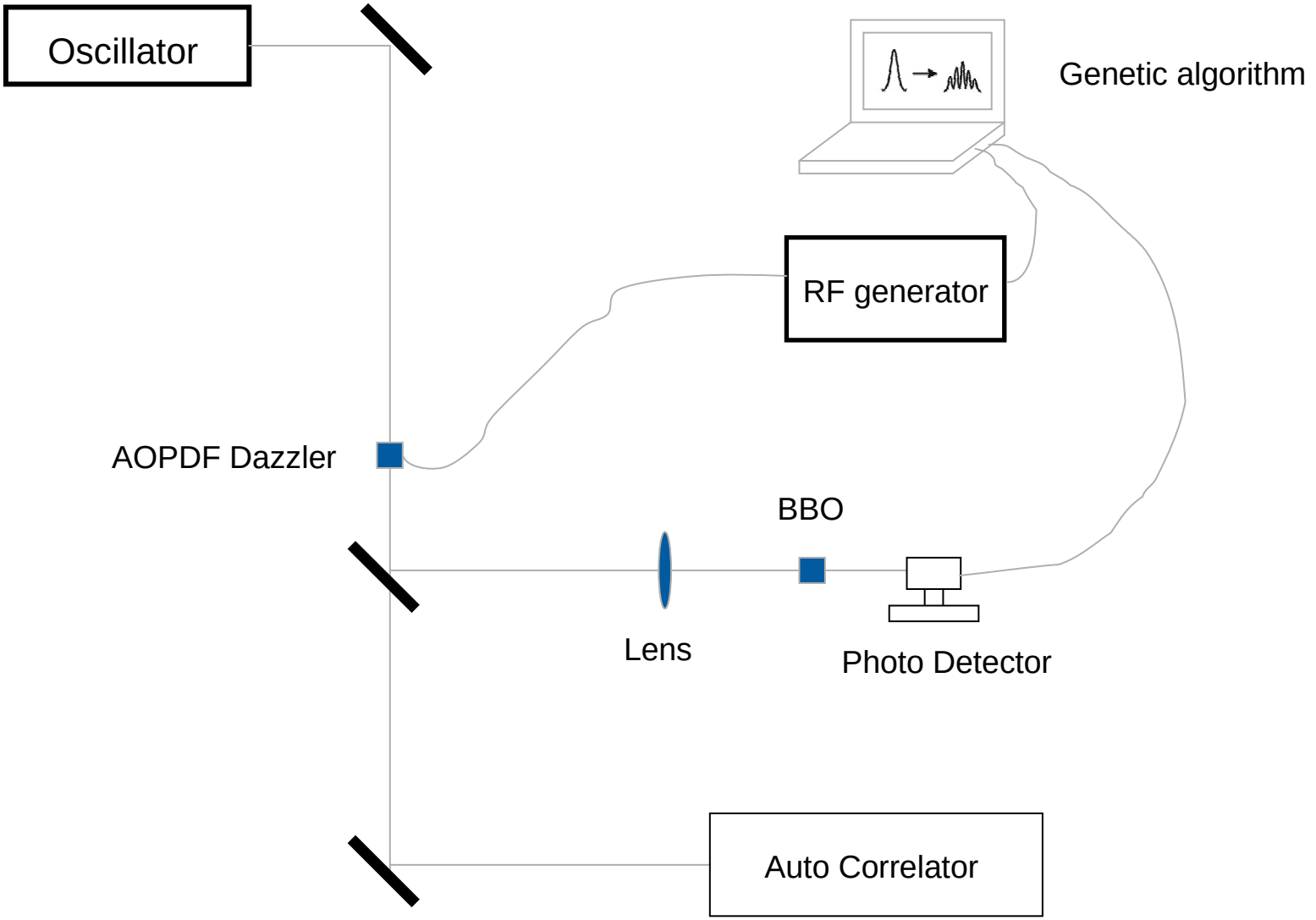
- Main differences:
  - Parameter set is encoded and not worked on.
  - A population of initial points are chosen, not a single one.
  - Objective/fitness functions – not derivatives
  - Probabilistic transition rules – not deterministic.
- Based on natural systems
  - The evolution of species and survival of the fittest
- Evolution: 3 main operators
    - Reproduction, crossover and mutation



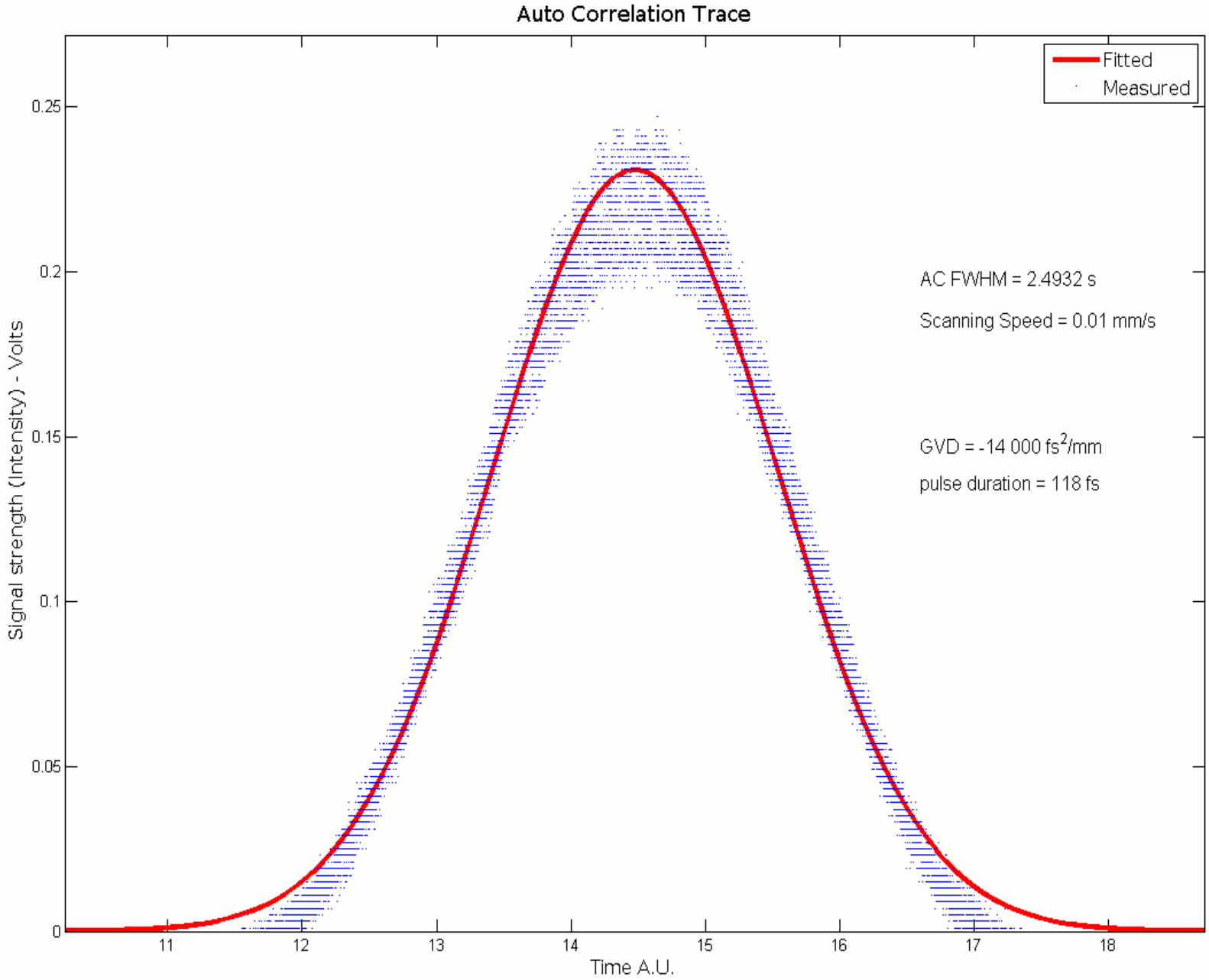


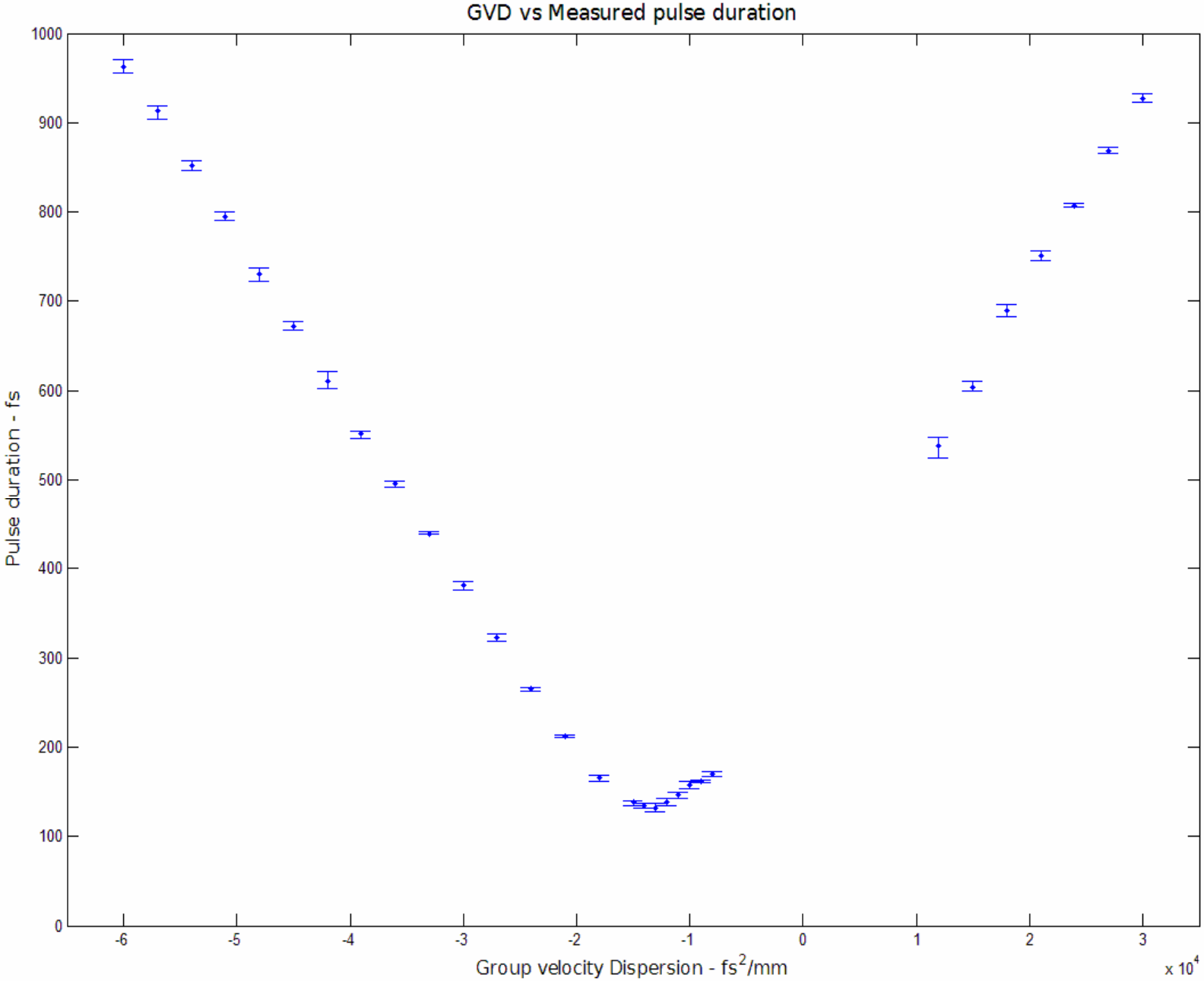






GVD (fs^2/mm)	SHG signal (mV)	PD (fs)	Power
-30 000	1085	296	85
-15 000	3550	121	85
+15 000	620	422	85
+30 000	420	625	85


Auto Correlation Trace
Fitted
Measured
AC FWHM = 2.4932 s
Scanning Speed = 0.01 mm/s
GVD = -14 000 fs^2/mm
pulse duration = 118 fs
Signal strength (Intensity) - Volts
Time A.U.
0
0.05
0.1
0.15
0.2
0.25
11
12
13
14
15
16
17
18


GVD vs Measured pulse duration
Pulse duration - fs
Group velocity Dispersion - fs^2/mm
x 10^4
1000
900
800
700
600
500
400
300
200
100
0
-6
-5
-4
-3
-2
-1
0
1
2
3

Current Work

- Completing the feedback loop (LABVIEW)
- Genetic algorithm adaptation – (DLL in C++)
- DAQ

Thank you

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CSIR

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