Shaping Laser Pulses

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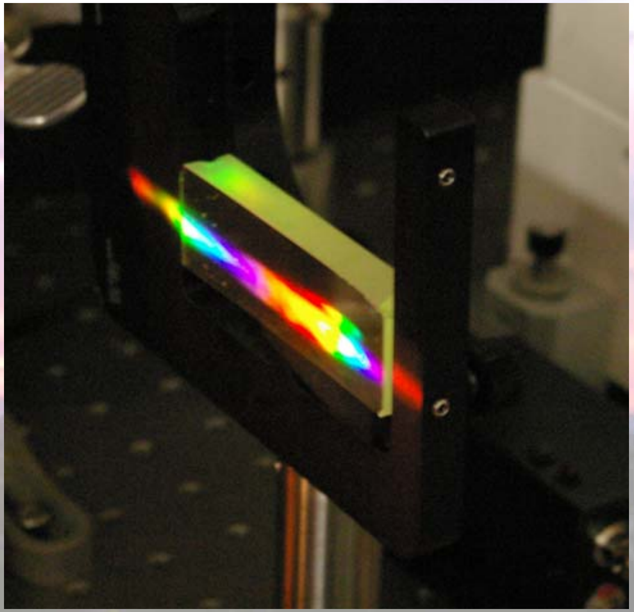
Outline

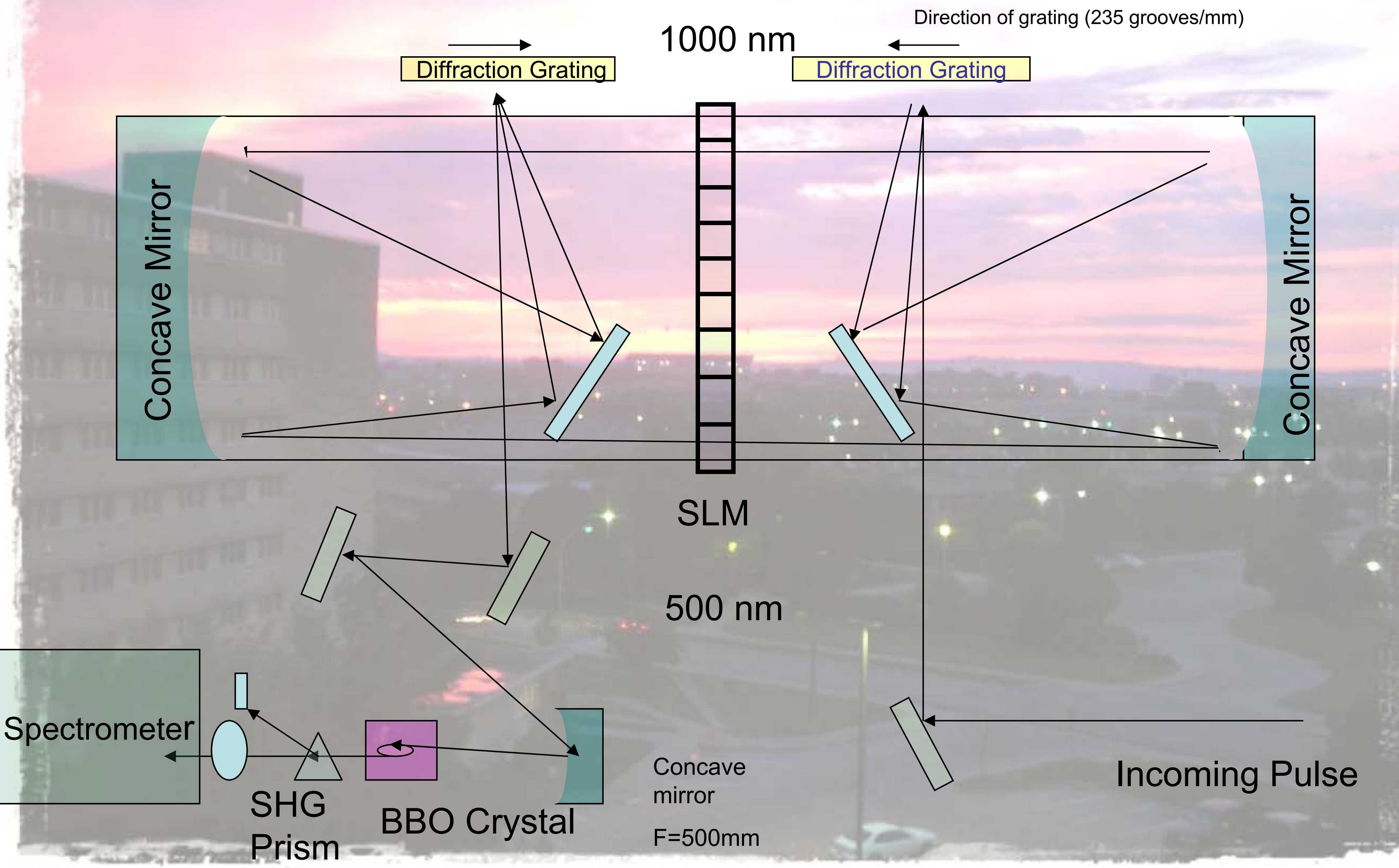
- Motivation
- Experimental Set-Up
- Theory behind the set-up
- Results
- Acknowledgements



Motivation

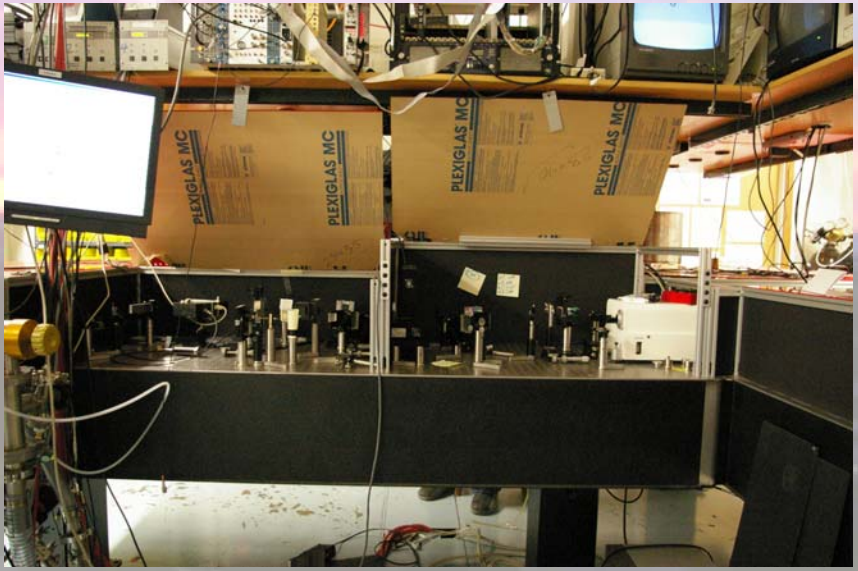
- Attosecond pulses could be used to study time-dependence of atomic dynamics.
- Greater control of pulse duration gives a better control of the power produced from each pulse as well.

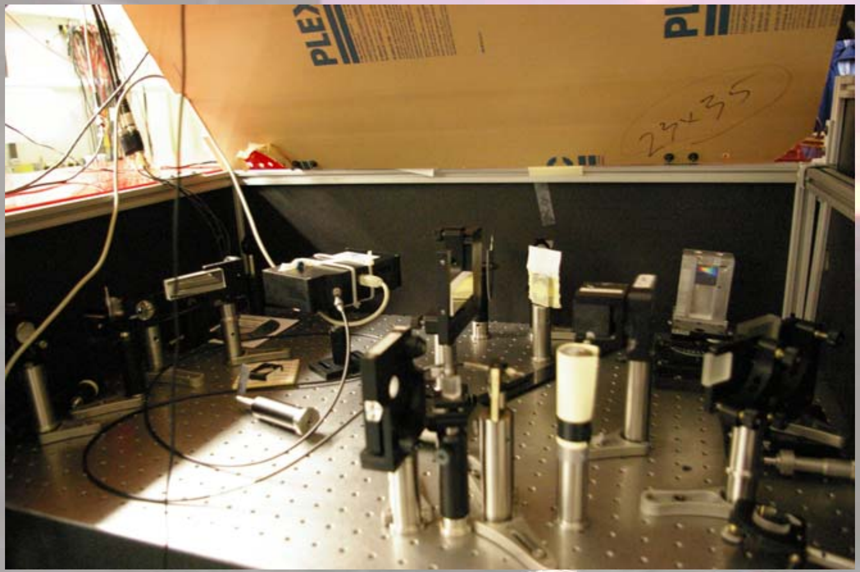
The Set-Up

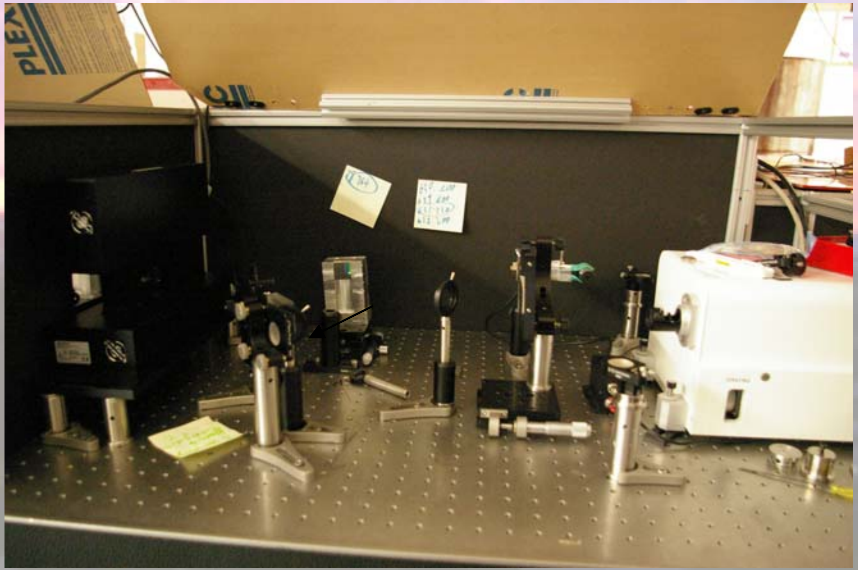


Direction of grating (235 grooves/mm)
1000 nm
Diffraction Grating
Diffraction Grating
Concave Mirror
Concave Mirror
SLM
500 nm
Spectrometer
SHG
Prism
BBO Crystal
Concave
mirror
F=500mm
Incoming Pulse

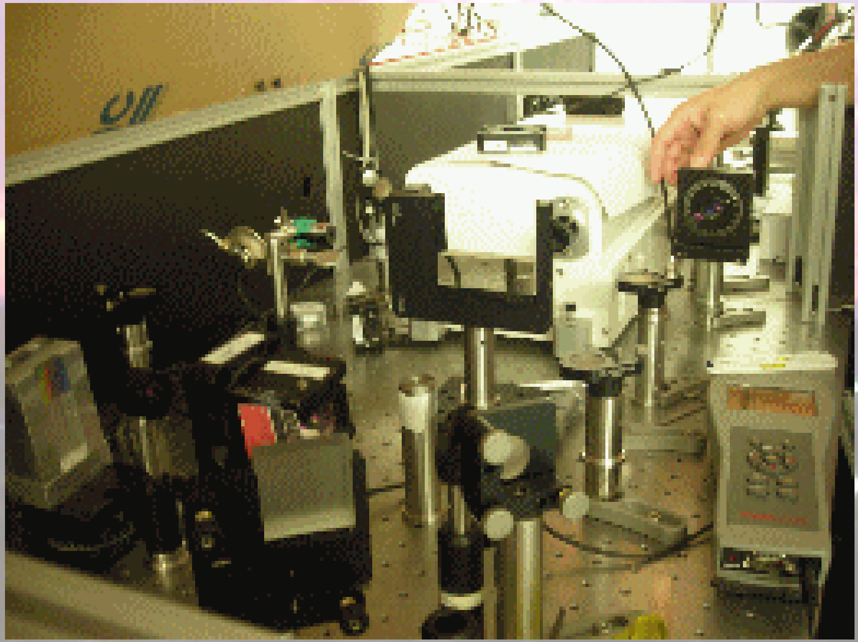
What it really looks like



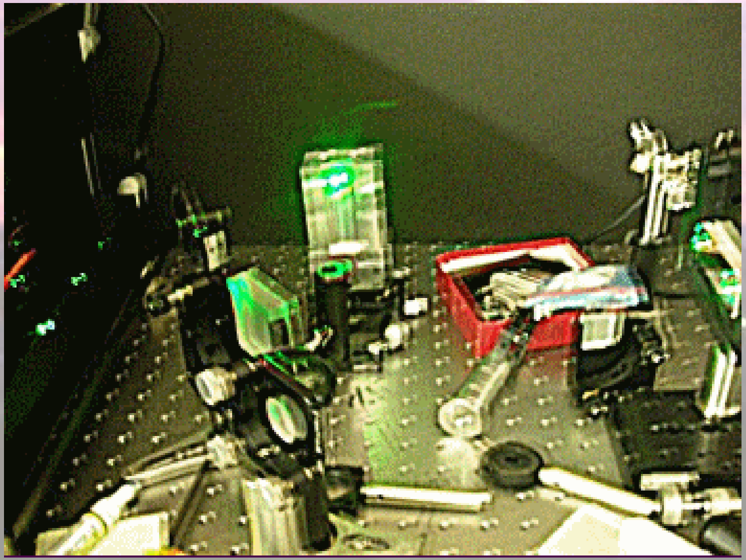

PLEX


PLEX

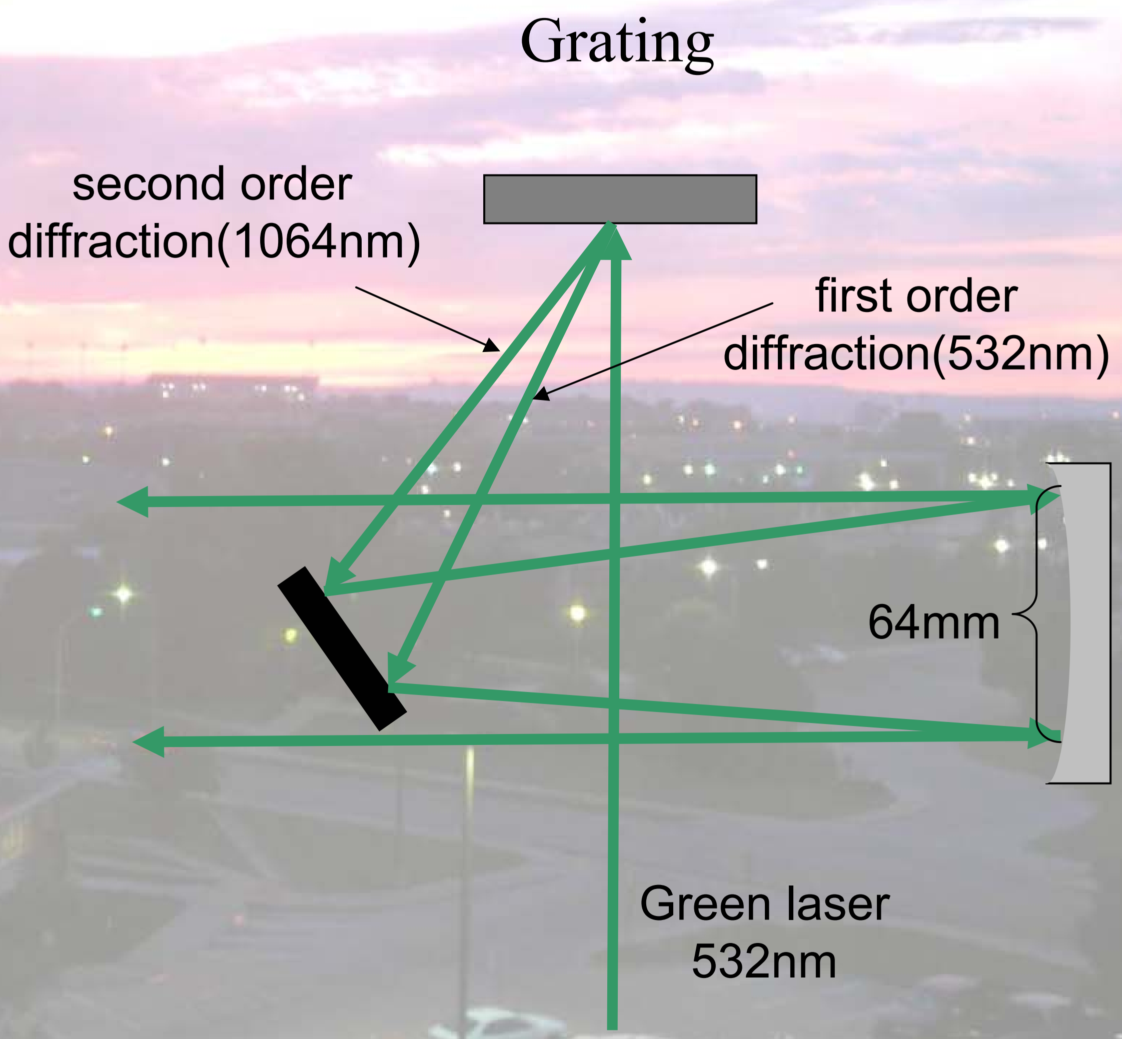
Getting Ready



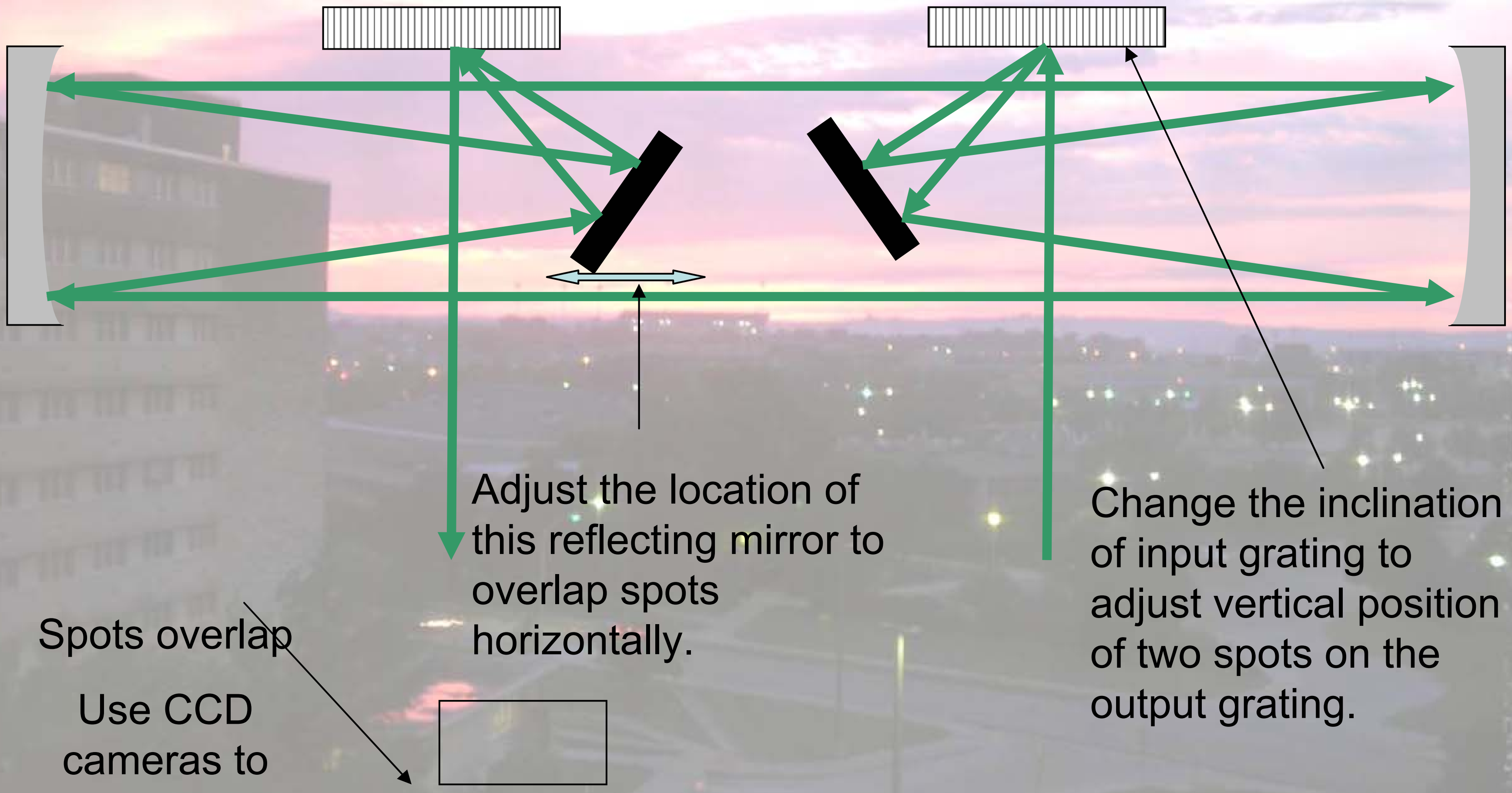
More set up



Alignment


Grating
second order
diffraction(1064nm)
first order
diffraction(532nm)
64mm
Green laser
532nm

Make 1 order and 2 order spots overlap on the output grating



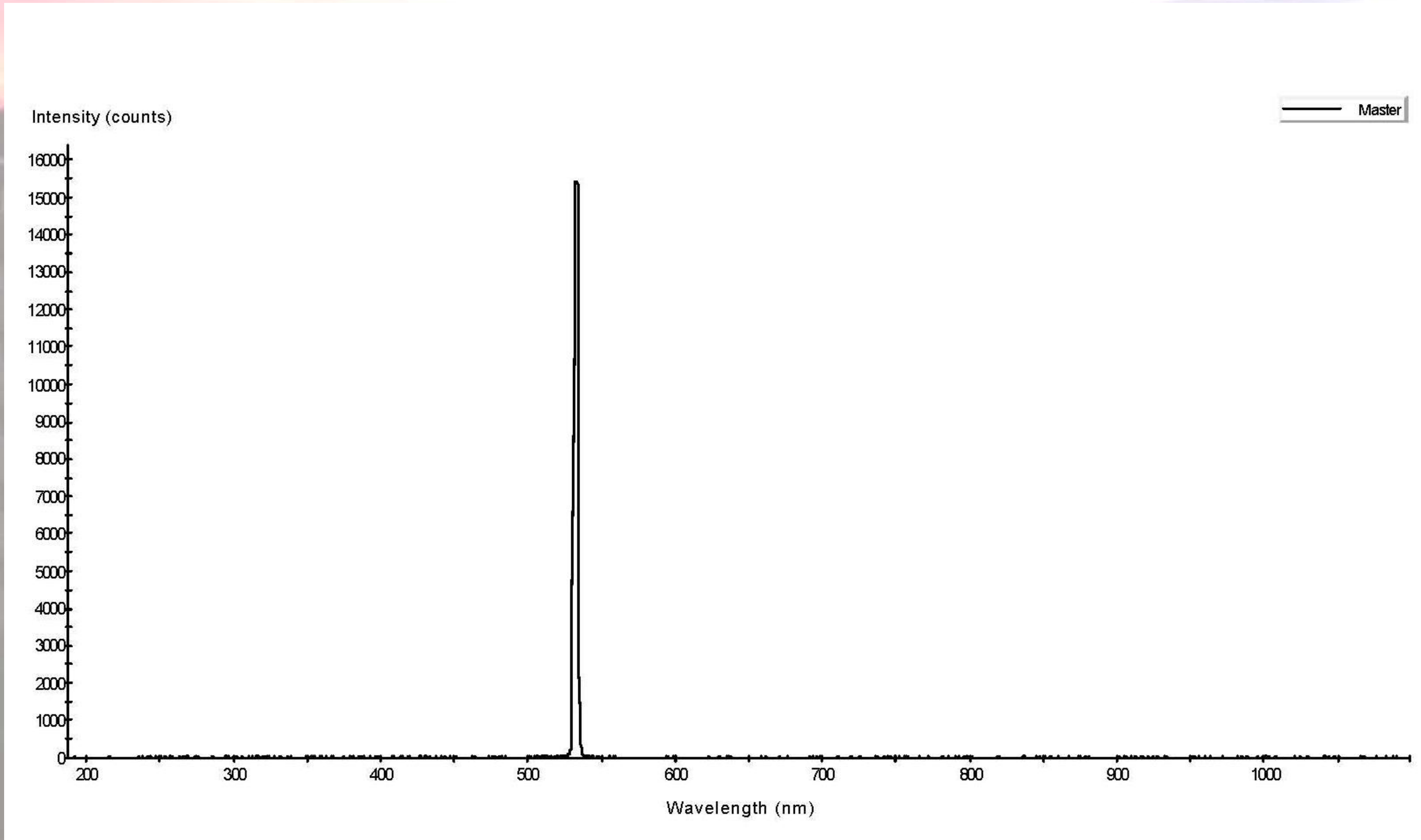
Adjust the location of this reflecting mirror to overlap spots horizontally.

Change the inclination of input grating to adjust vertical position of two spots on the output grating.

Spots overlap

Use CCD cameras to detect the overlap

Trials-green laser and spectrometer



For SHG

- Two photons γ enter the BBO. Each γ has a frequency Δ. One photon leaves the BBO with frequency (2Δ).
- The contribution of each initial photon γ_1, γ_2 is as follows

$$\Delta_1 = \Delta + \Omega \;\; ; \;\; \Delta_2 = \Delta - \Omega \;\; ; \; 2\Delta = \Delta_1 + \Delta_2$$

Where Ω is just a way of expressing the energy difference between the contributions of each photon

The spectrum of a beam is given by

$$\boxed{S^{(2)}(\Delta) \equiv \left| \mathrm{F} \;\; \{E(t)\} \right|^2}$$

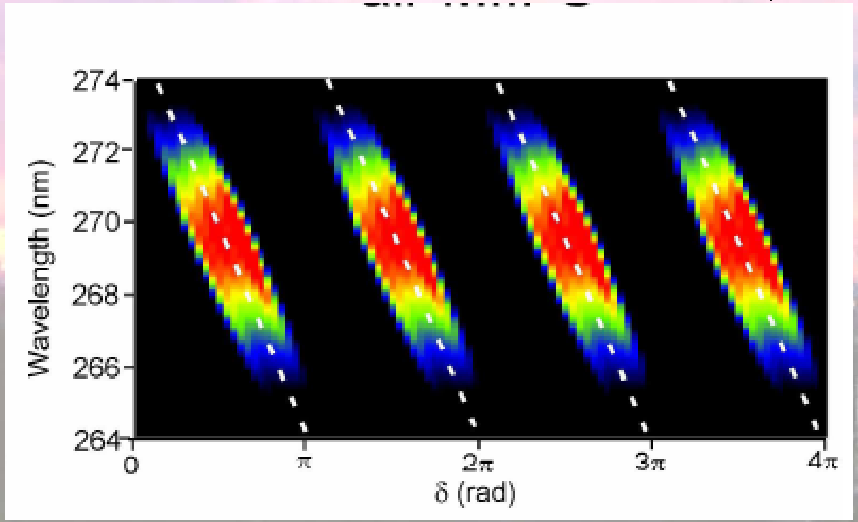
……

MIIPS (Multiphoton Intrapulse Interference Phase Scan)

Let frequency=Δ ; difference=Ω ; parameters=γ,α ; phase= φ ;

phase correction = f

$$S^{(2)}(2\Delta) \propto= \left| \int \left| E(\Delta+\Omega) \right| \left| E(\Delta-\Omega) \right| \times \exp\{ i[\varphi(\Delta+\Omega)+\varphi(\Delta-\Omega)] \} d\Omega \right|^2$$



Take a Taylor approximation

And

You get

$$= 2\varphi(\Delta) + \varphi''\Omega^2$$

Let frequency=Δ ; difference=Ω ; parameters=γ,α ; phase= φ ;

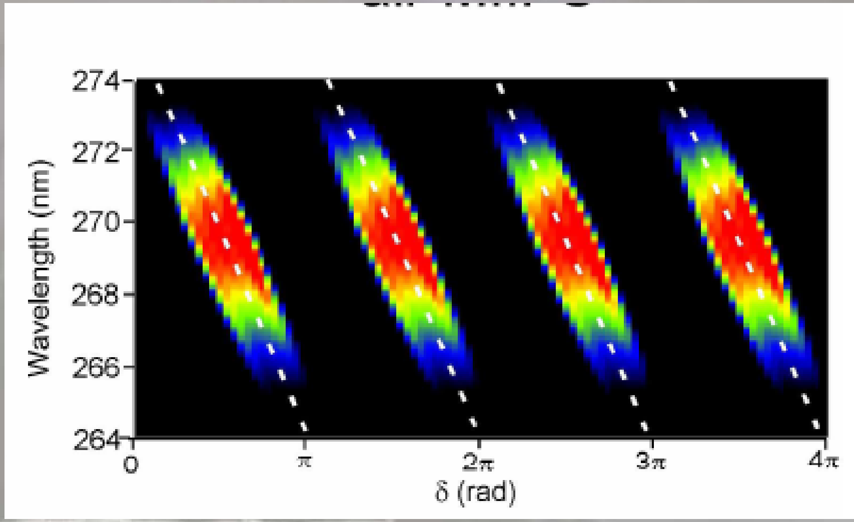
phase correction = f

A maximum SHG signal corresponds to flat phase. If we can modulate some phase Δ make $f'' + \varphi'' = 0$ set α , γ , and scan δ

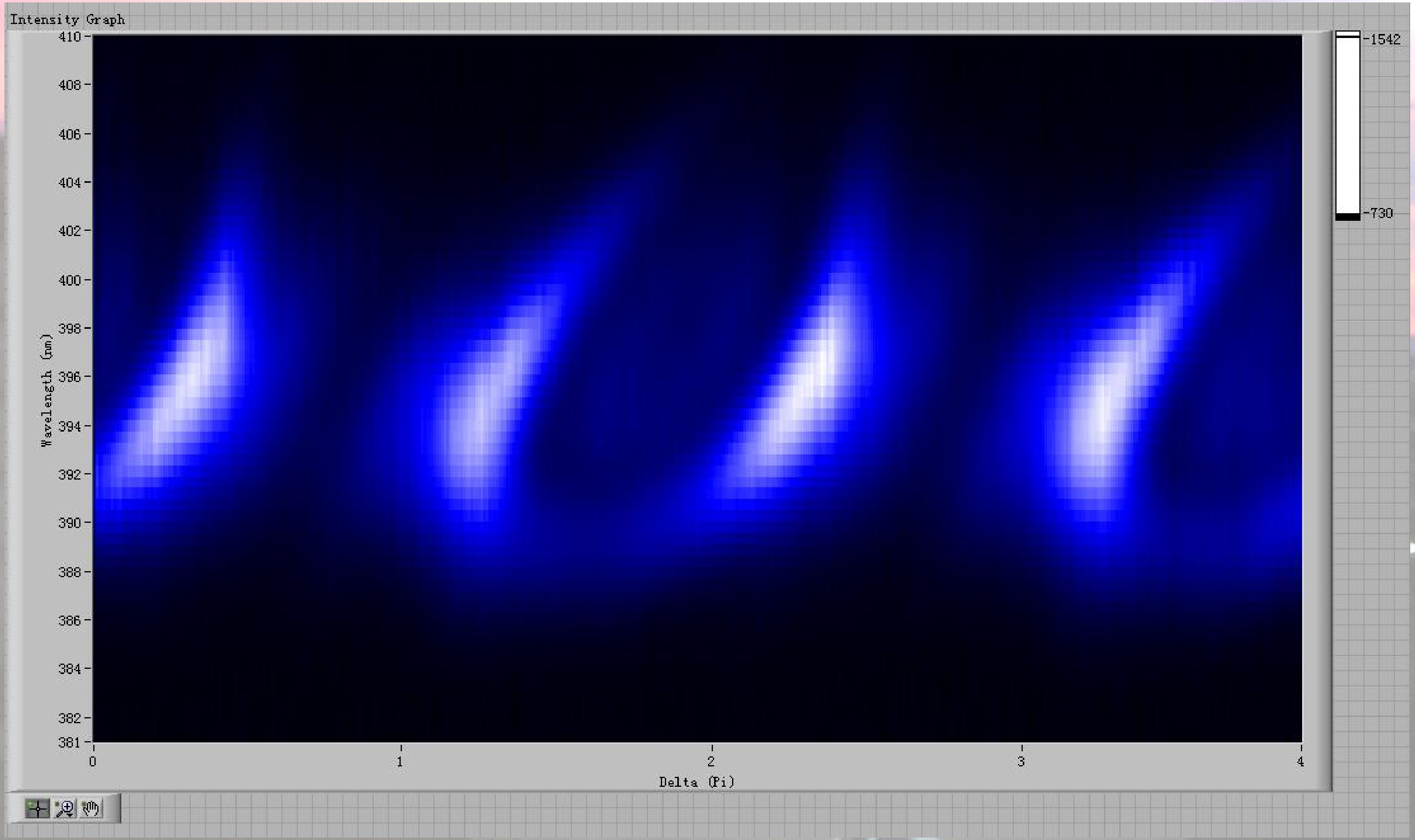
$$f(\Delta) = \alpha \cos(\gamma\Delta - \delta)$$

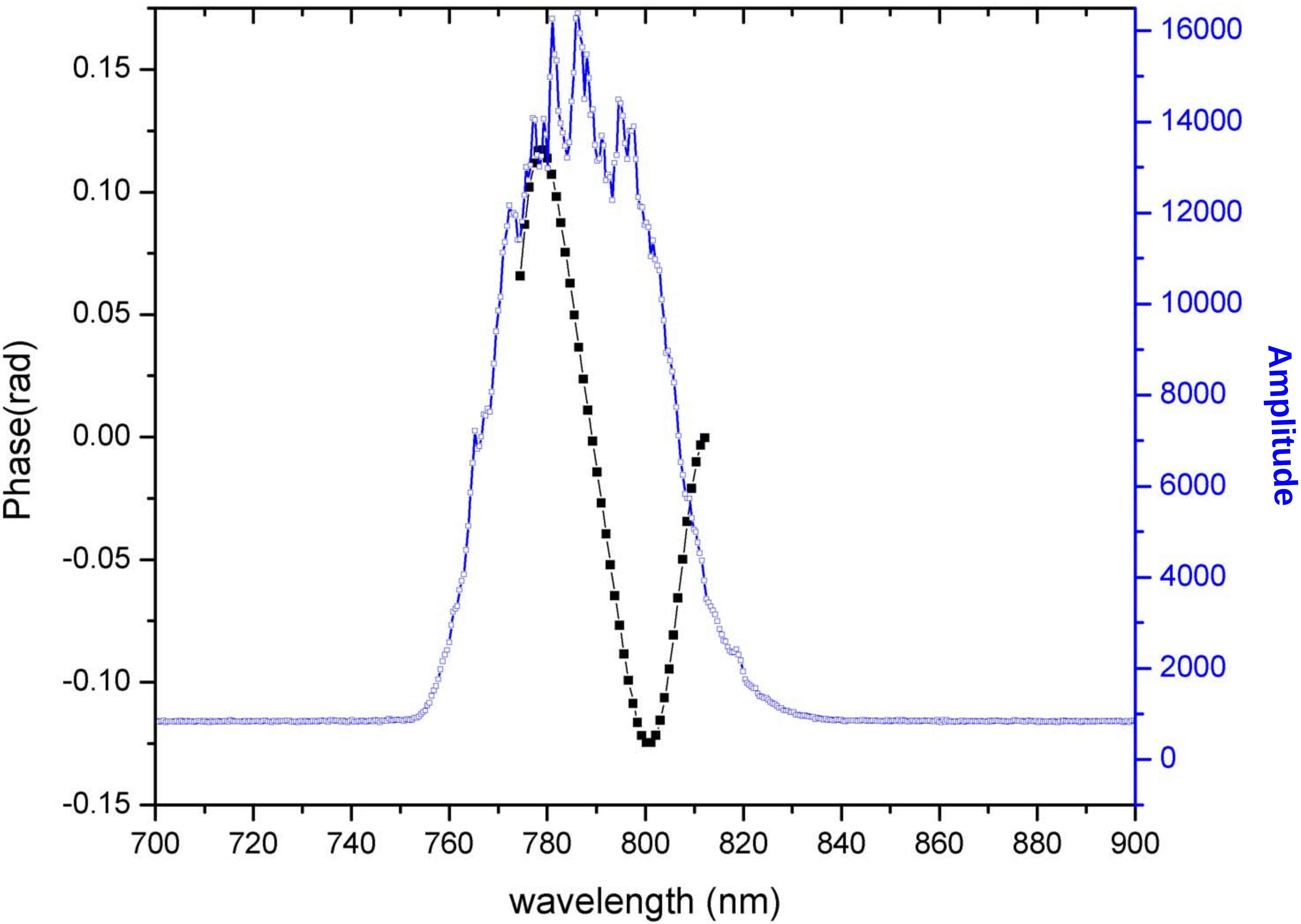
$$f''(\Delta) = -\alpha\gamma^2 \cos(\gamma\Delta - \delta)$$

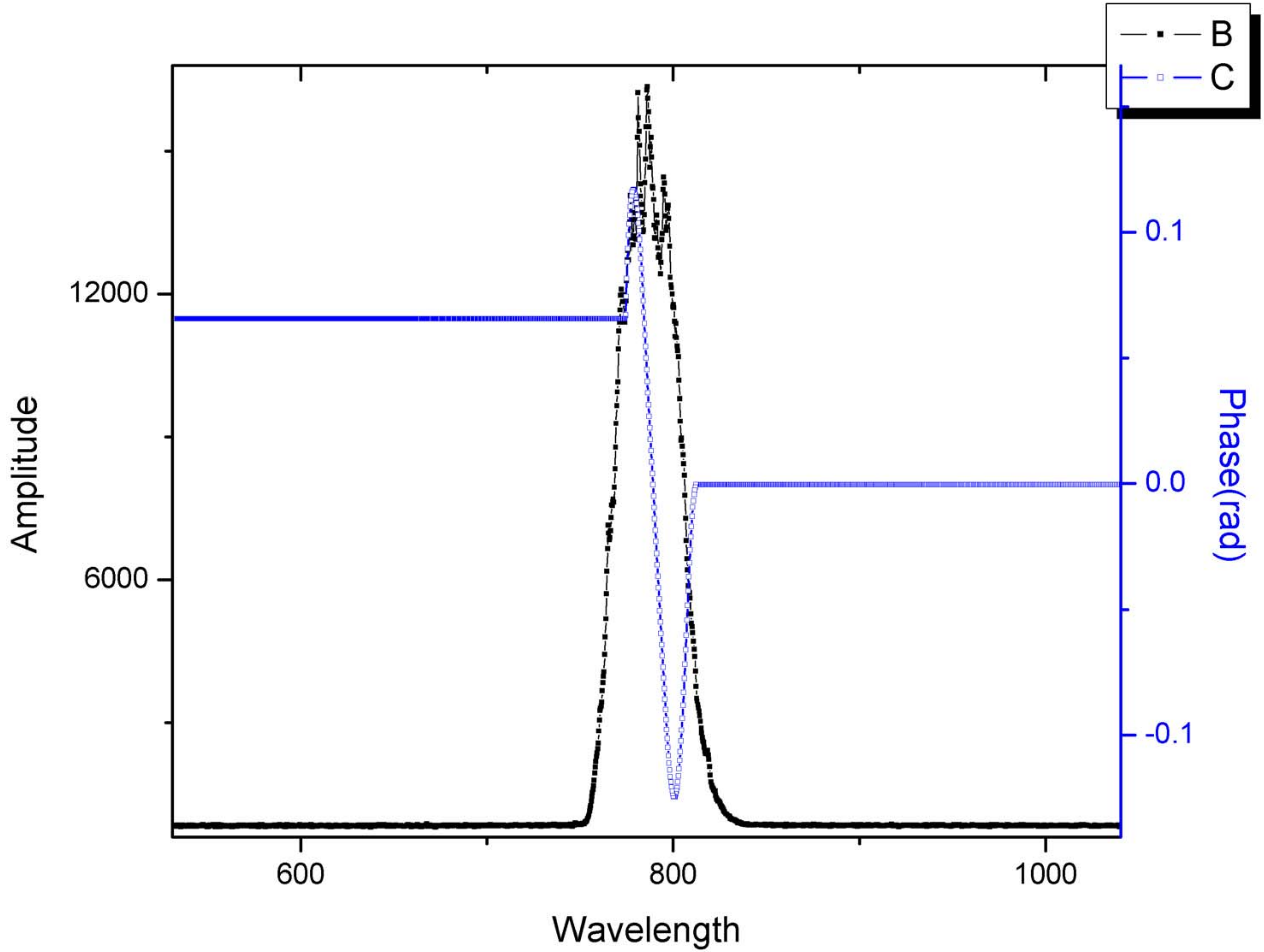
$$\left.\begin{aligned} \varphi''(\Delta) &= -f''(\Delta) \\ \varphi'(\Delta_0) &= 0 \\ \varphi(\Delta_0) &= 0 \end{aligned}\right\} \varphi(\Delta)$$



Data obtained using the 10% beam



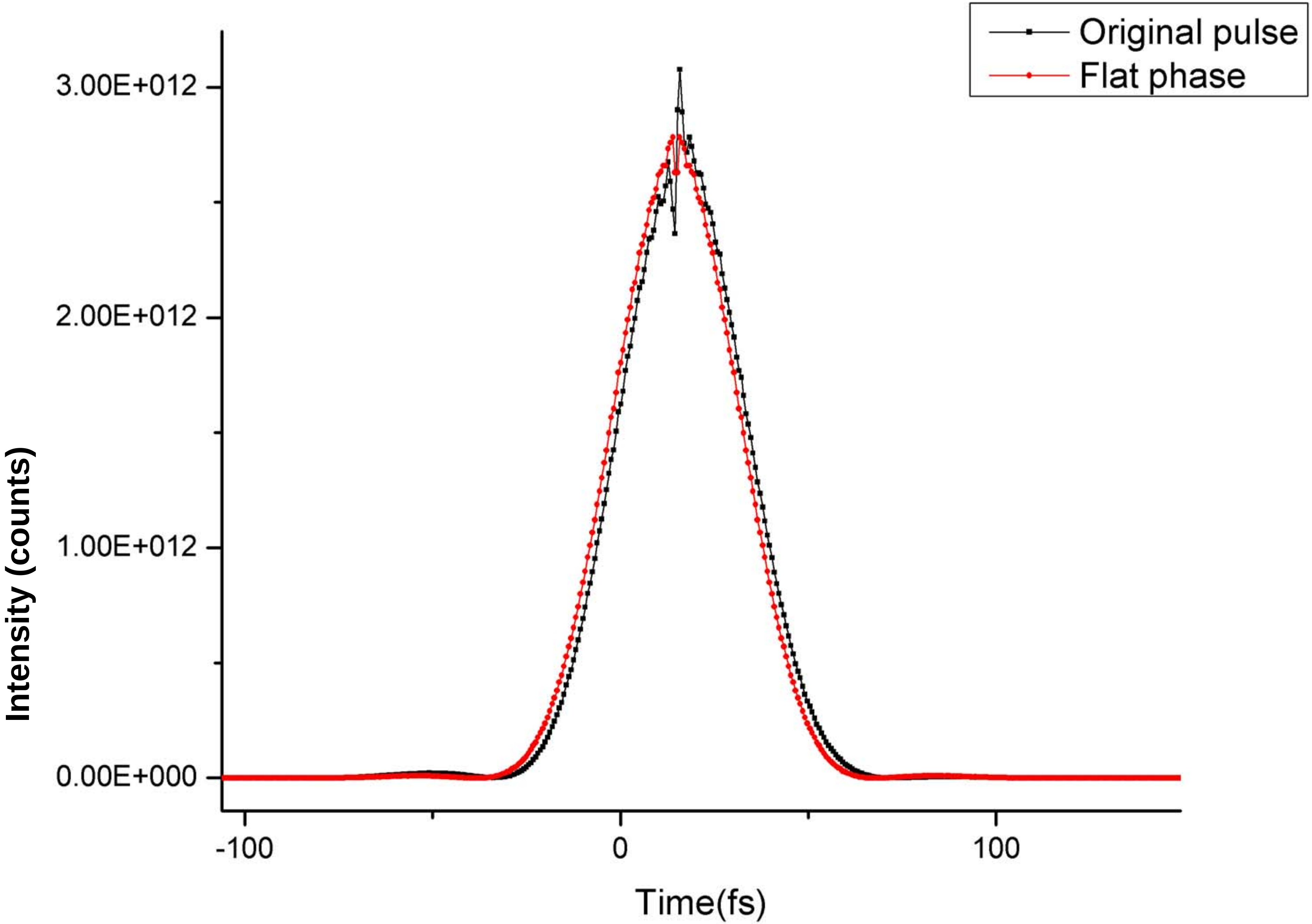

Phase(rad)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
Amplitude
16000
14000
12000
10000
8000
6000
4000
2000
0
700
720
740
760
780
800
820
840
860
880
900
wavelength (nm)


B
C
12000
6000
Amplitude
0.1
0.0
-0.1
Phase(rad)
600
800
1000
Wavelength

Fourier Transform

- By performing an inverse Fourier transform we can change the information from a graph showing frequency ω to a graph showing time t.

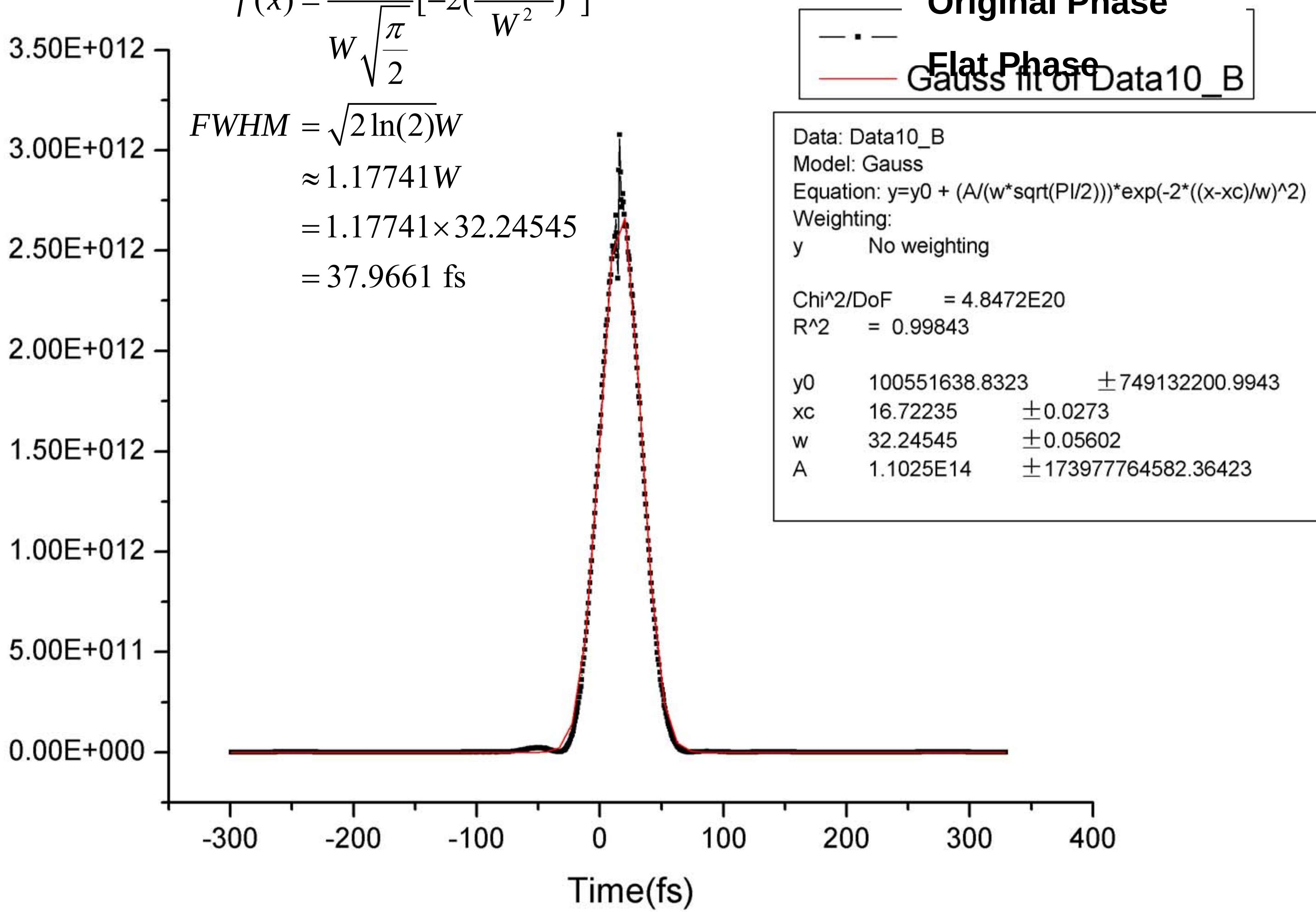
$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)\exp(i\omega t)\,d\omega$$



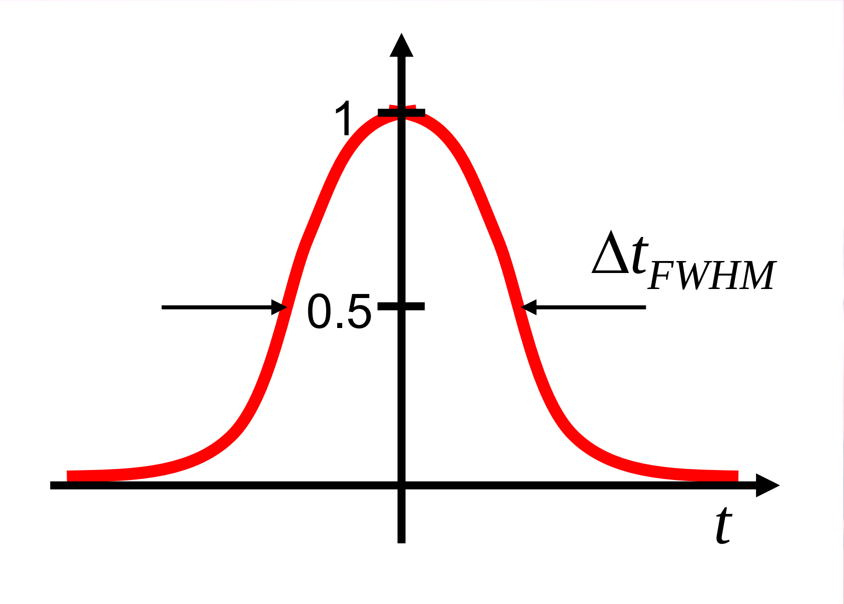
Original pulse
Flat phase
3.00E+012
2.00E+012
1.00E+012
0.00E+000
Intensity (counts)
-100
0
100
Time(fs)

$$f(x)=\frac{1}{W\sqrt{\frac{\pi}{2}}}[-2(\frac{x-x_0}{W^2})^2]$$

$$FWHM=\sqrt{2\ln(2)}W$$
$$\approx 1.17741W$$
$$=1.17741\times 32.24545$$
$$=37.9661\ \text{fs}$$



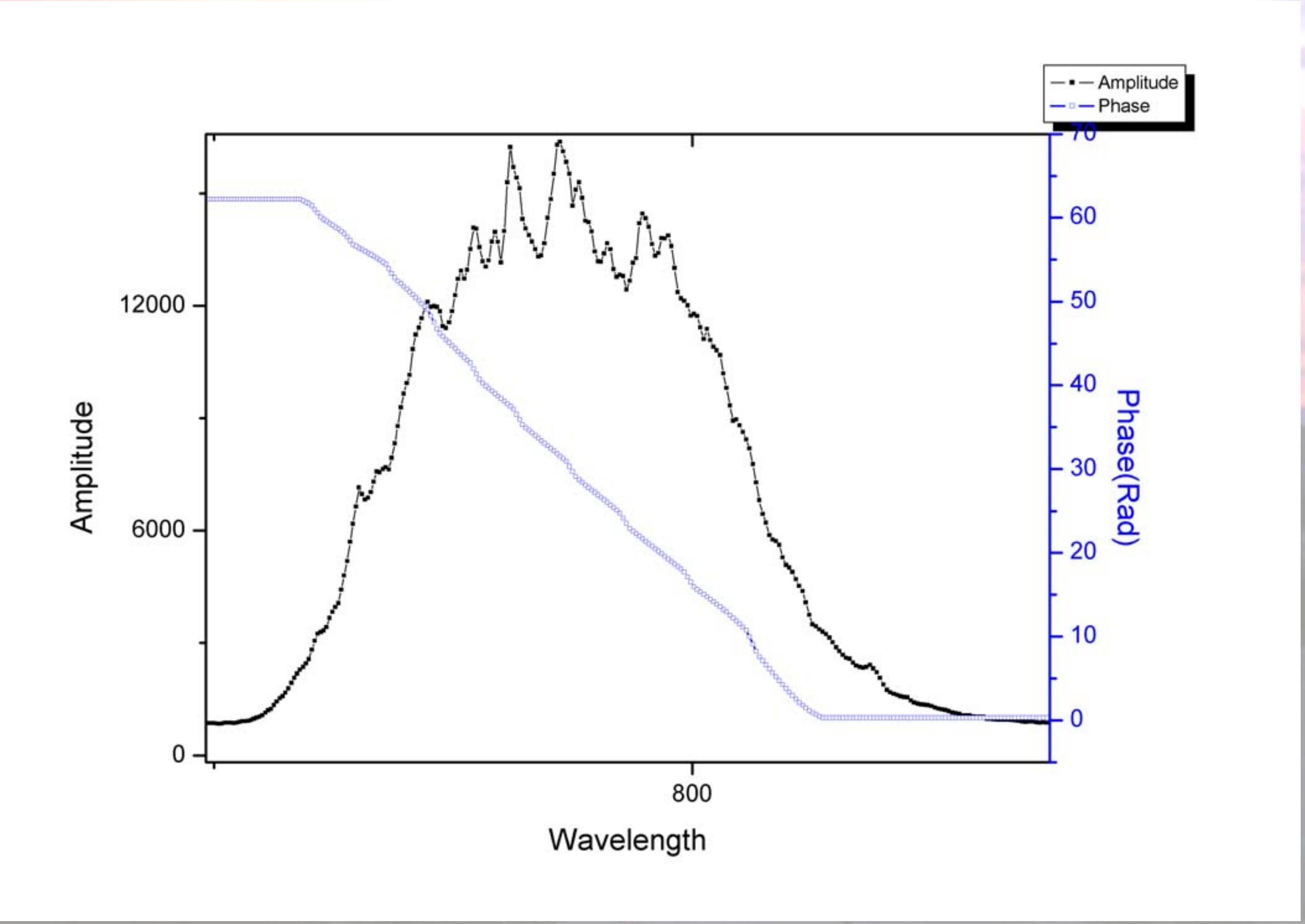
The Full-Width-Half-Maximum

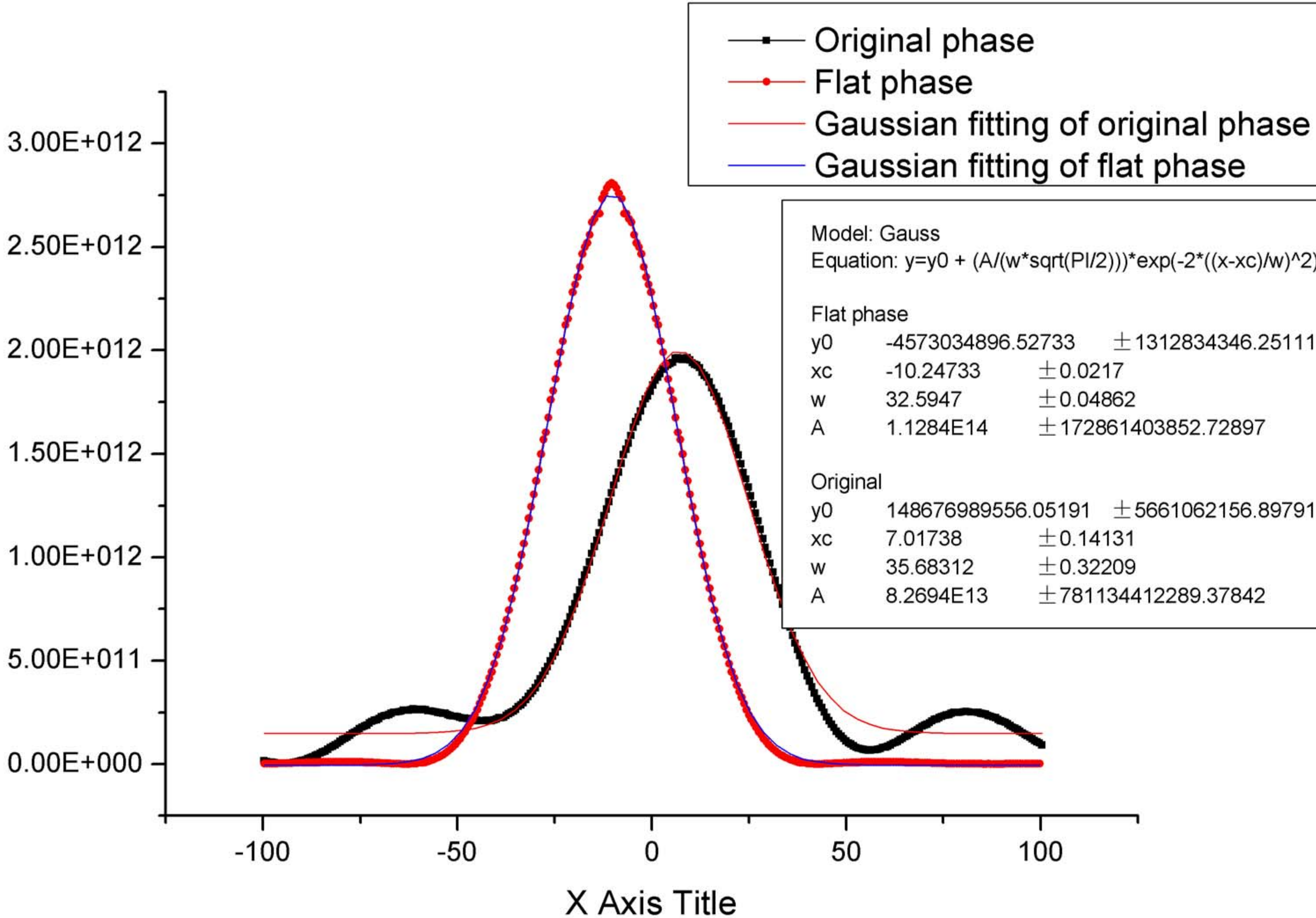


Full-width-half-maximum is the distance between the half-maximum points.

Also: we can define these widths in terms of $f(t)$ or of its intensity, $|f(t)|^2$. Define *spectral* widths ($\Delta\omega$) similarly in the frequency domain ($t \rightarrow \omega$).

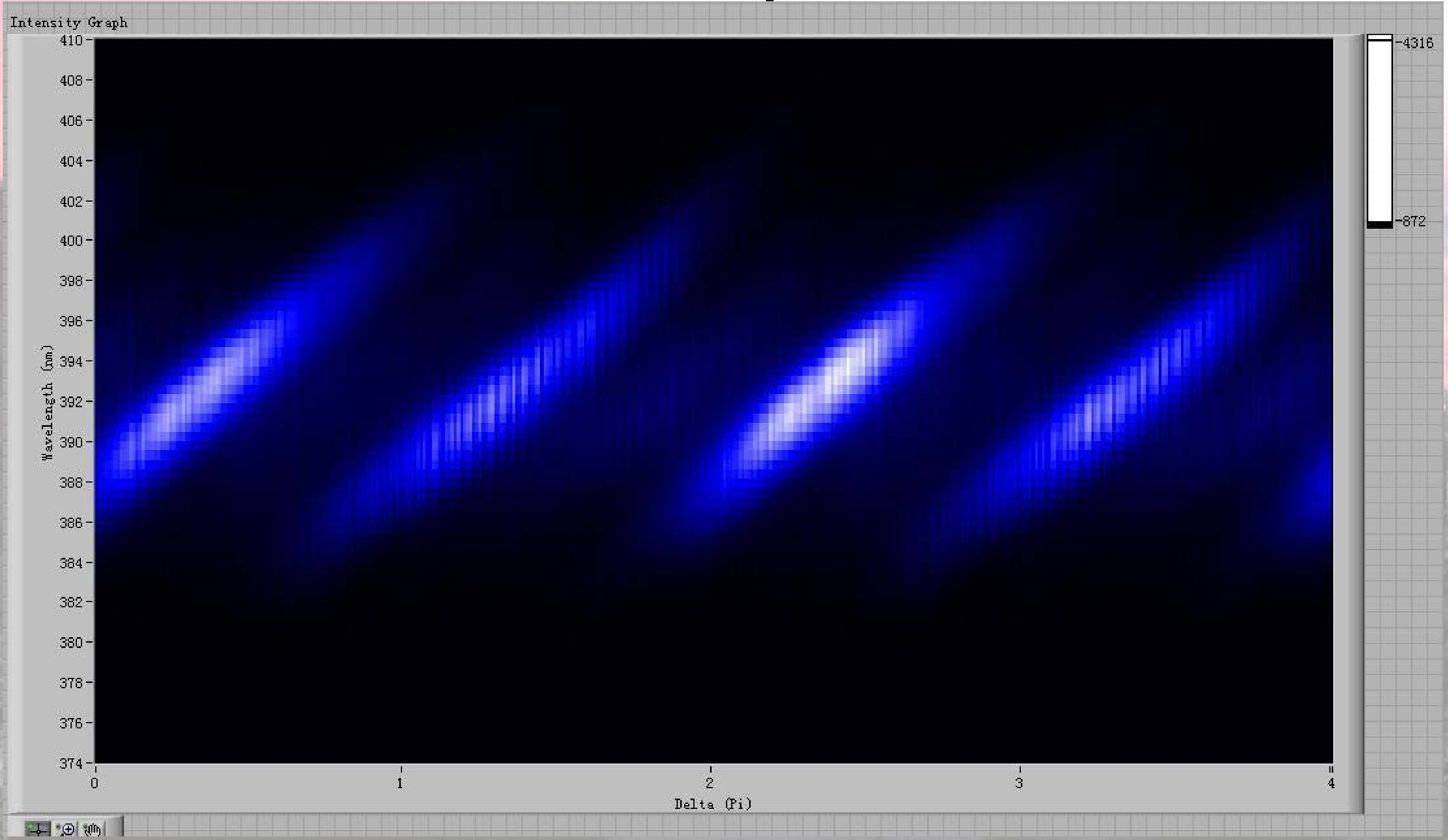
With some small phase corrections The last week's work



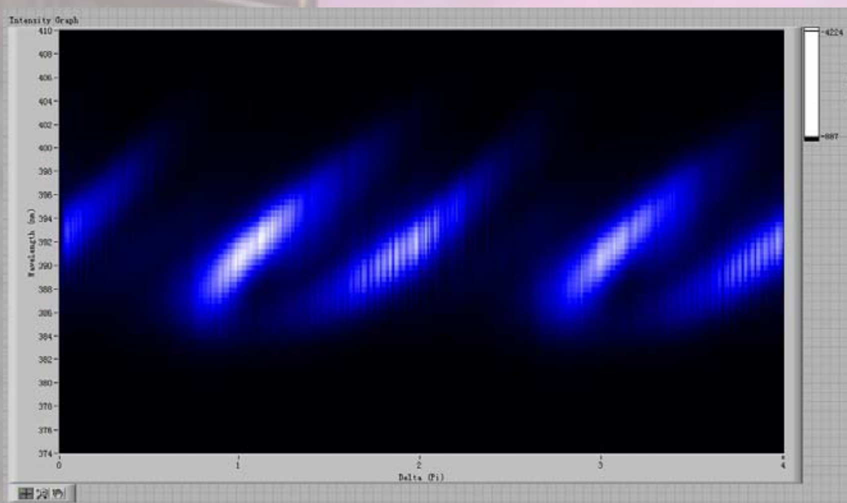


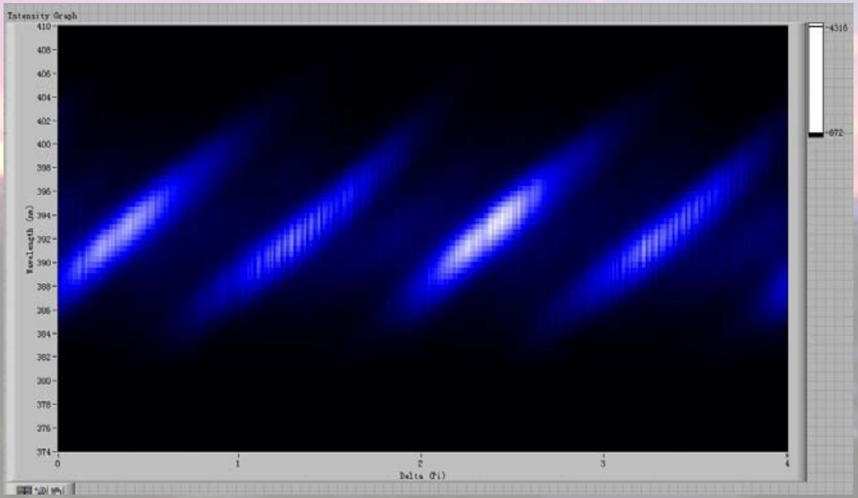
Original phase
Flat phase
Gaussian fitting of original phase
Gaussian fitting of flat phase
Model: Gauss
Equation: y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)
Flat phase
y0 -4573034896.52733 ±1312834346.25111
xc -10.24733 ±0.0217
w 32.5947 ±0.04862
A 1.1284E14 ±172861403852.72897
Original
y0 148676989556.05191 ±5661062156.89791
xc 7.01738 ±0.14131
w 35.68312 ±0.32209
A 8.2694E13 ±781134412289.37842
3.00E+012
2.50E+012
2.00E+012
1.50E+012
1.00E+012
5.00E+011
0.00E+000
-100
-50
0
50
100
X Axis Title

MIIPS after 9 phase correction attempts



Comparison


Intensity Graph
410
408
406
404
402
400
398
396
394
392
390
388
386
384
382
380
378
376
374
Wavelength (nm)
0
1
2
3
4
Delta (Pi)
4224


Intensity Graph
410
408
406
404
402
400
398
396
394
392
390
388
386
384
382
380
378
376
374
Wavelength (nm)
0
1
2
3
4
Delta (Pi)
4316

Acknowledgements and Citations

- Professor Zenghu Chang
- He Wang, Yi Wu
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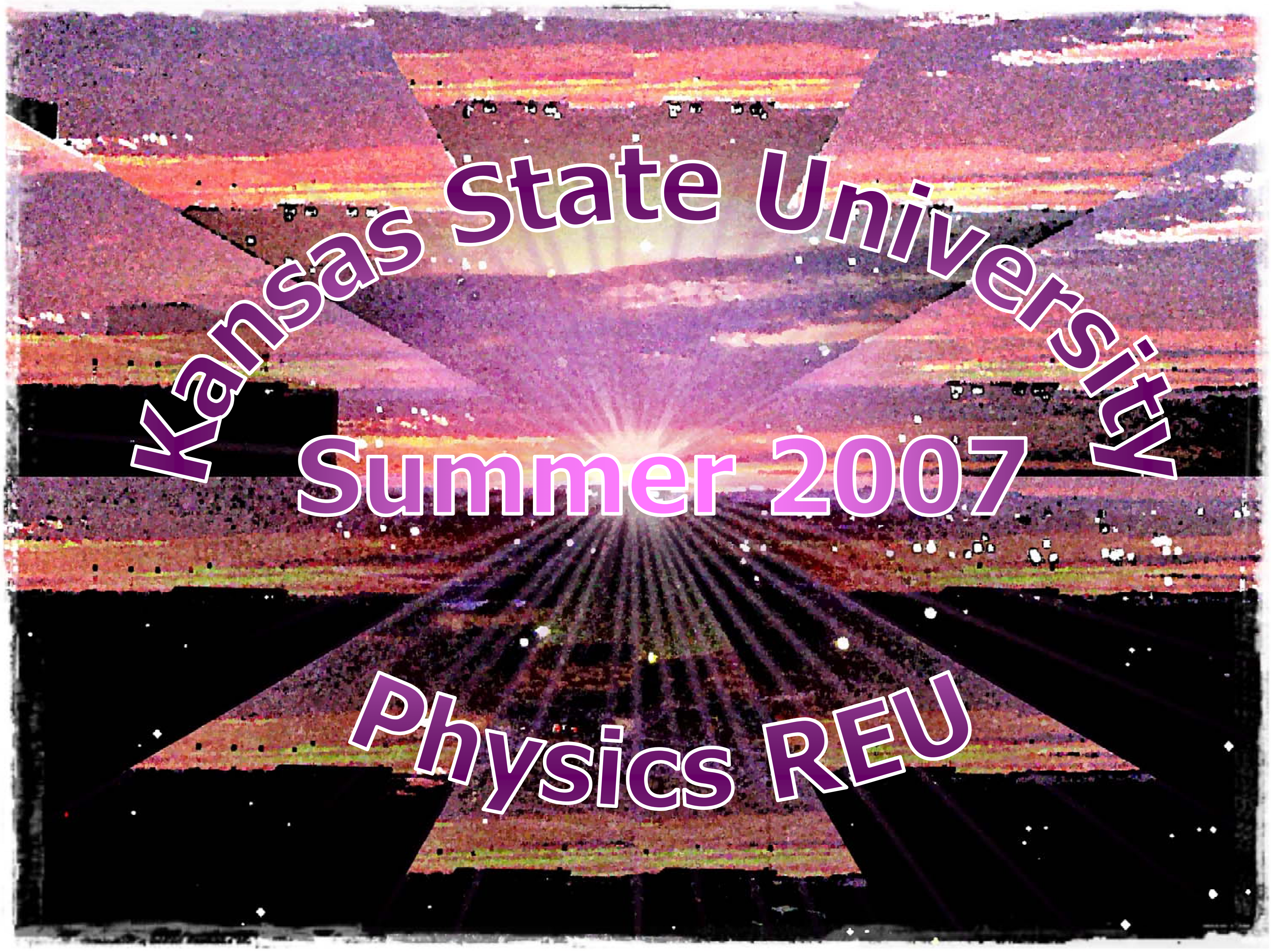
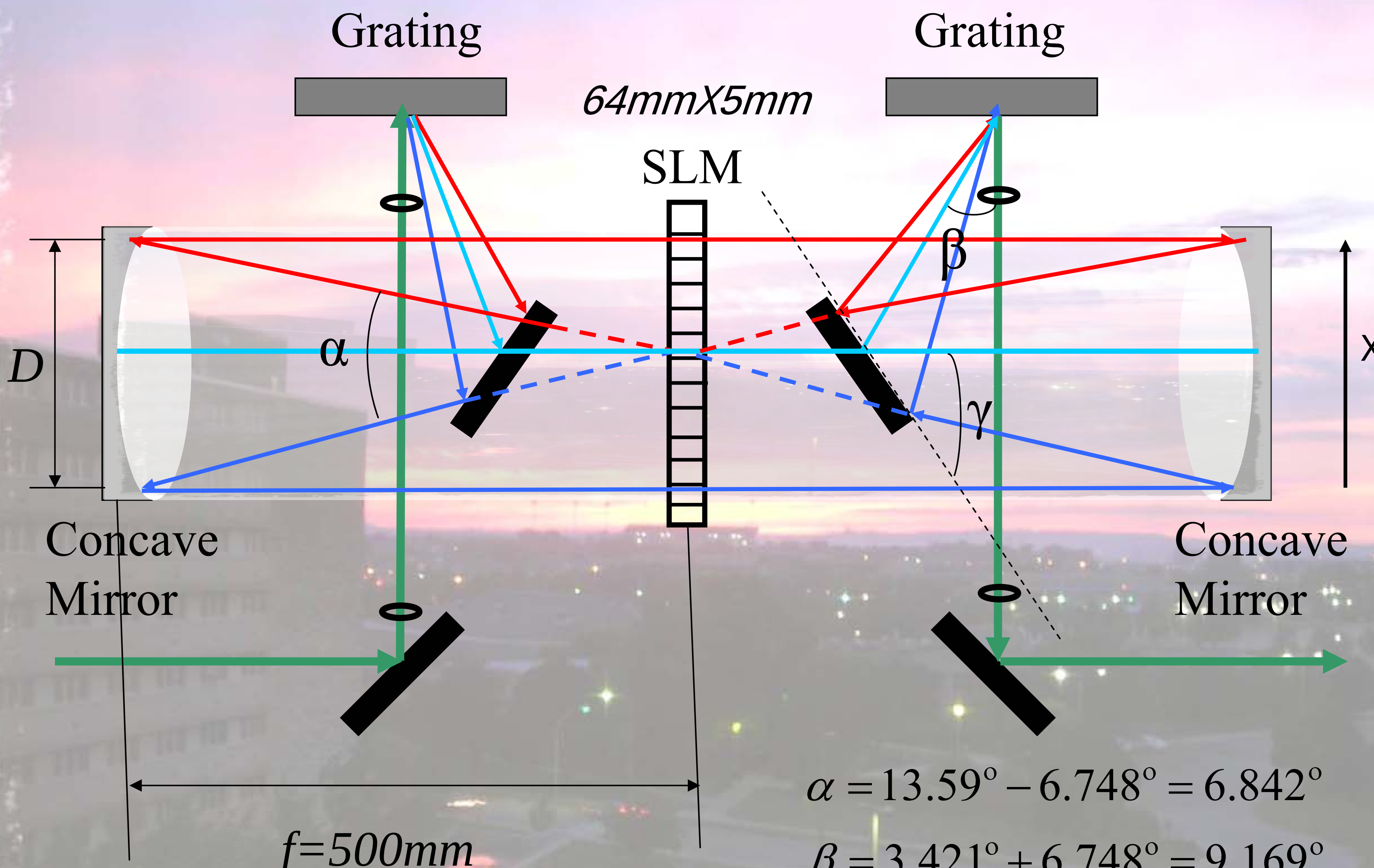
- Dr. Kristan Corwin
- Kansas State University

- Trebino, Rick. "FROG:Lecture Files." Georgia Institute of Technology School of Physics. Georgia Tech Phys Dept. 29 Jul 2007 <http://www.physics.gatech.edu/gcuo/lectures/>.
- Lozovoy, Vadim. "Multiphoton Intrapulse Interference." Optics Letters 29.7(2004): 775-777.


Kansas State University
Summer 2007
Physics REU



$$\alpha = 13.59^{\circ} - 6.748^{\circ} = 6.842^{\circ}$$

$$\beta = 3.421^{\circ} + 6.748^{\circ} = 9.169^{\circ}$$

$$\sin[\arctan(x / f) + \beta] = \lambda / a$$

$$\gamma = (90^{\circ} + \beta) / 2 \approx 49.45^{\circ}$$

BBO (β- Barium Borate) Crystal

Why is the BBO crystal used??

- Used to separate the beam into it's fundamental and second harmonic frequencies

For SHG

- Two photons γ enter the BBO. Each γ has a frequency Δ. One photon leaves the BBO with frequency (2Δ).
- The contribution of each initial photon γ_1, γ_2 is as follows

$$\Delta_1 = \Delta + \Omega \;;\; \Delta_2 = \Delta - \Omega \;;\; 2\Delta = \Delta_1 + \Delta_2$$

Where Ω is just a way of expressing the difference between the contributions of each photon

The spectrum of a beam is given by

$$\boxed{S^{(2)}(\Delta) \equiv \left| \mathcal{F}\{E(t)\} \right|^2}$$

The spectrum of the beam is given by S^2 of 2 Δ is

$$S^{(2)}(2\Delta) \propto = \left| \int \left| E(\Delta+\Omega) \right| \left| E(\Delta-\Omega) \right| \times \exp\{ i[\varphi(\Delta+\Omega) + \varphi(\Delta-\Omega)] \} d\Omega \right|^2$$

We used MIIPS (Multiphoton Intrapulse Interference Phase Scan) to get a picture of the phase of each wavelength contained in the pulse

Let frequency=Δ difference=Ω parameters=γ,α phase= φ phase correction =f

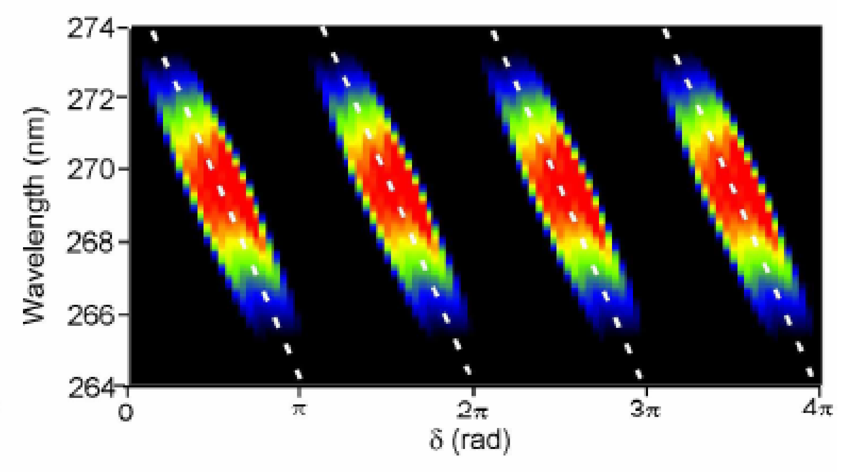
$$S^{(2)}(2\Delta) \propto= \left| \int |E(\Delta+\Omega)||E(\Delta-\Omega)| \times \exp\{i[\varphi(\Delta+\Omega)+\varphi(\Delta-\Omega)]\} d\Omega \right|^2$$

$$\varphi(\Delta+\Omega)+\varphi(\Delta-\Omega)$$

$$=\varphi(\Delta)+\varphi'\Omega+\frac{\varphi''}{2}\Omega^2+\frac{\varphi'''}{6}\Omega^3$$

$$+\varphi(\Delta)-\varphi'\Omega+\frac{\varphi''}{2}\Omega^2-\frac{\varphi'''}{6}\Omega^3$$

$$=2\varphi(\Delta)+\varphi''\Omega^2$$



Maximum SHG signal correspond to flat phase. If we can modulate some phase Δ make $f''+\varphi''=0$ set α , γ , and scan δ

$$f(\Delta)=\alpha\cos(\gamma\Delta-\delta)$$

$$f''(\Delta)=-\alpha\gamma^2\cos(\gamma\Delta-\delta)$$

$$\left.\begin{aligned} \varphi''(\Delta) &= -f''(\Delta) \\ \varphi'(\Delta_0) &= 0 \\ \varphi(\Delta_0) &= 0 \end{aligned}\right\} \quad \varphi(\Delta)$$

Project Goals

During the summer of 2007, I spent approximately ten weeks studying and researching at Kansas State University Physics Department. My project during this time was to work with two graduate students to shape laser pulses. Specifically, we designed and set up a system that (hopefully) allows us to adjust the phase of each separate frequency of a laser light pulse. Using a device called an SLM, Spatial Light Modifier, we were able to apply different voltages to each pixel on a liquid crystal screen. Each pixel corresponds to a different frequency of light. When we apply the different voltages, we change the phase of each frequency, our goal is to make the phase of each frequency the same. Then applying a Fourier Transform we were able to see how this phase shift changed the time-dependence of the pulse. Our goal is to be able to control the pulse as we choose, thus making it possible to control the duration of each pulse. We are hoping to attain attosecond pulses through this method.

As a part of this research, I was also given the opportunity to learn many different styles of programming, including, C, C++ ,and LabView. To many, these programs might seem basic, but I had not yet encountered them in my normal studies, so this presented a new and interesting challenge for me. LabView especially proved to be quite the ordeal and I spent a good deal of time learning this program and attempting to write a program that would be useful to our experiment with it.