Progress of the Optical Replica Synthesizer Experiment

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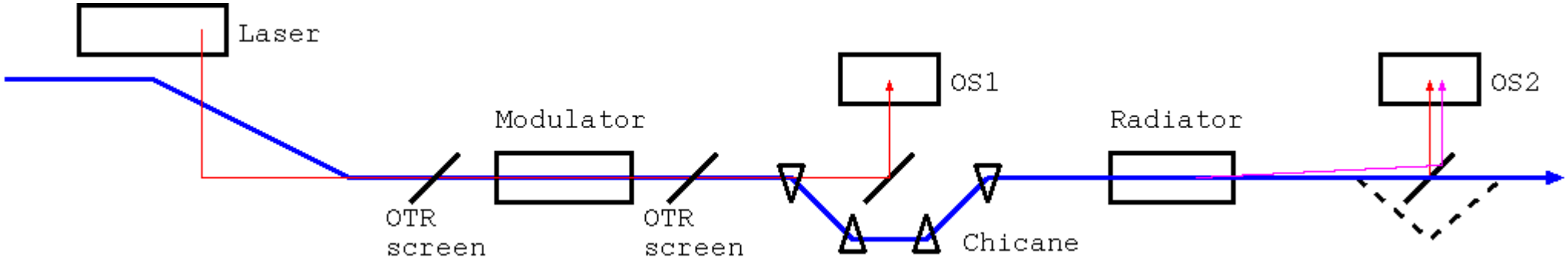
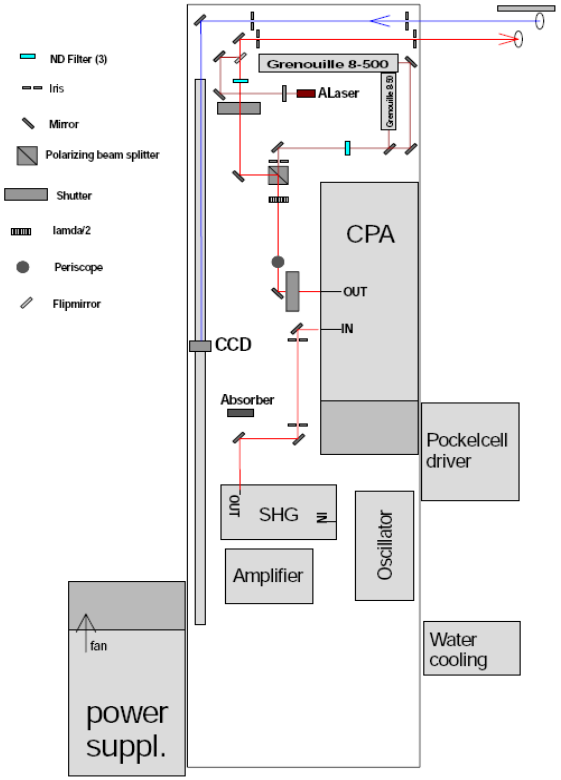
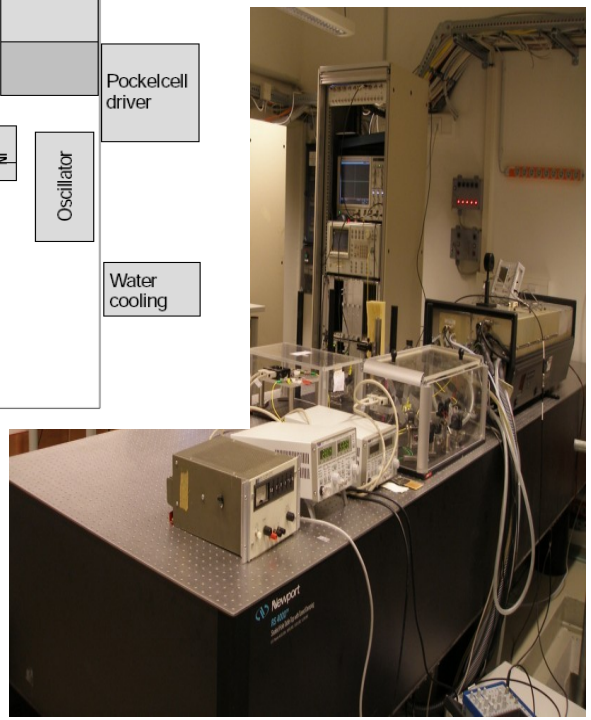
The Idea

- Problem: measure ultra-short bunches in the 10s of fs range: EOS, TEO, LOLA, ORS
  - too fast for electronics (10 Gsamples/s --> 100 ps)
  - but laser folks know (autocorrelation, FROG)
- Solution: make an optical copy of the electron bunch and analyze that with laser methods.



The Seed Laser





- Er-fiber ring-oscillator (~1550 nm) phase locked to RF (micro-timing)
- Booster amplifier
- 2nd harmonic generation to 772 nm
- CPA 2001 regenerative amplifier on loan from Stockholm
- Pockels cell fire to let the light pulse out (macro-timing)
- 0.7 mJ/pulse, 200 fs
- Safety shutters (ND and other)
- Diagnostics: Frog, virtual waist

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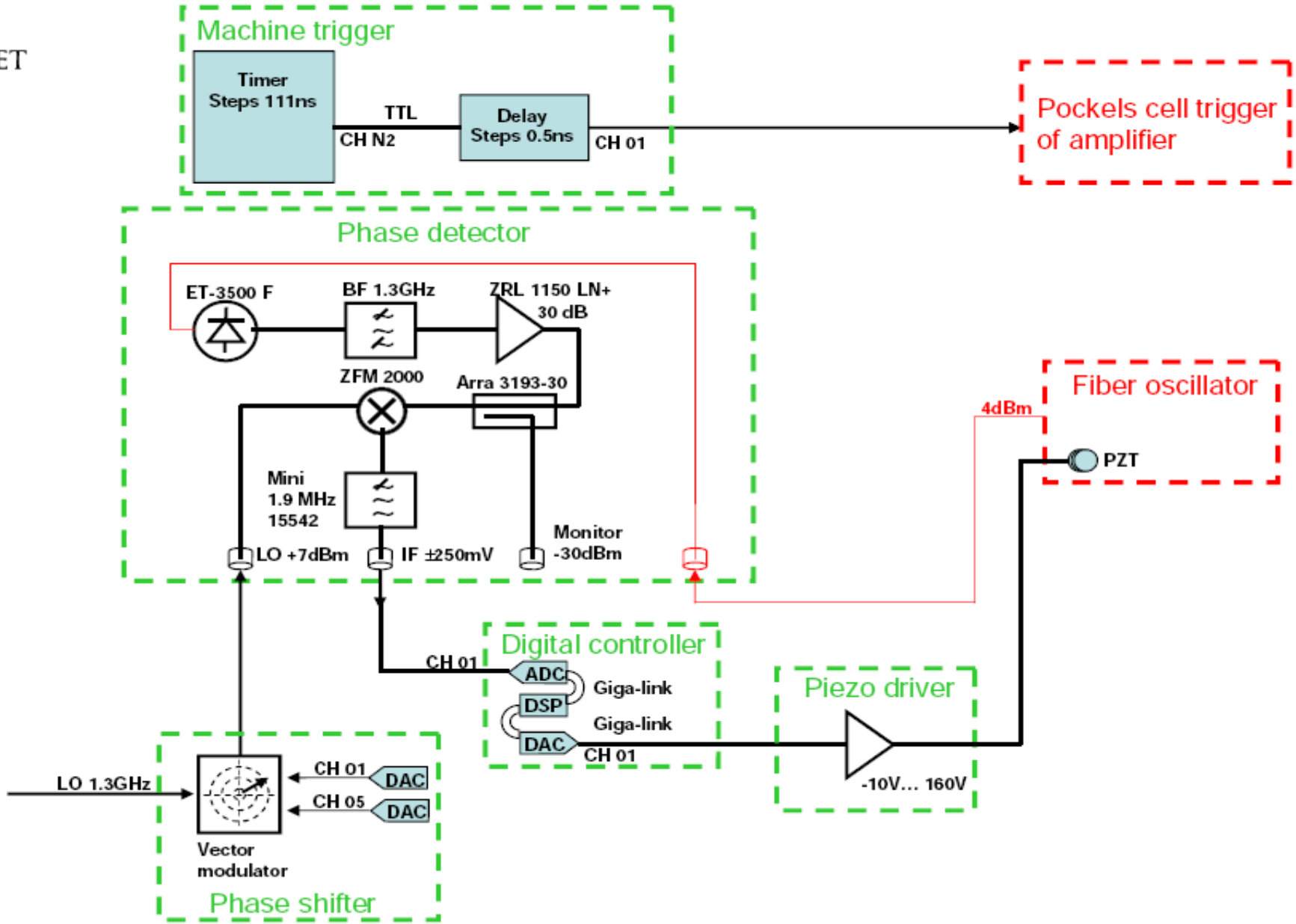
Scheme of the ORS synchronization & trigger system



Laser Transfer Line and OS0

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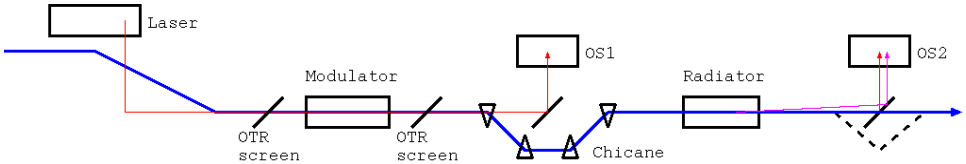
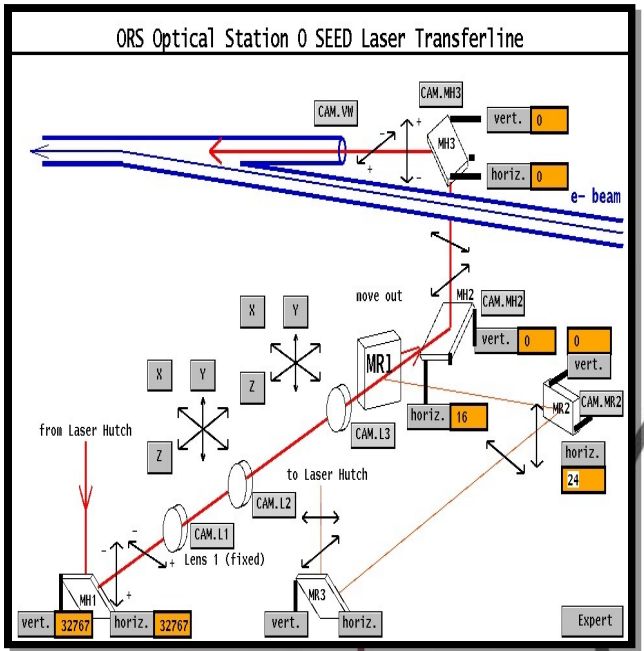
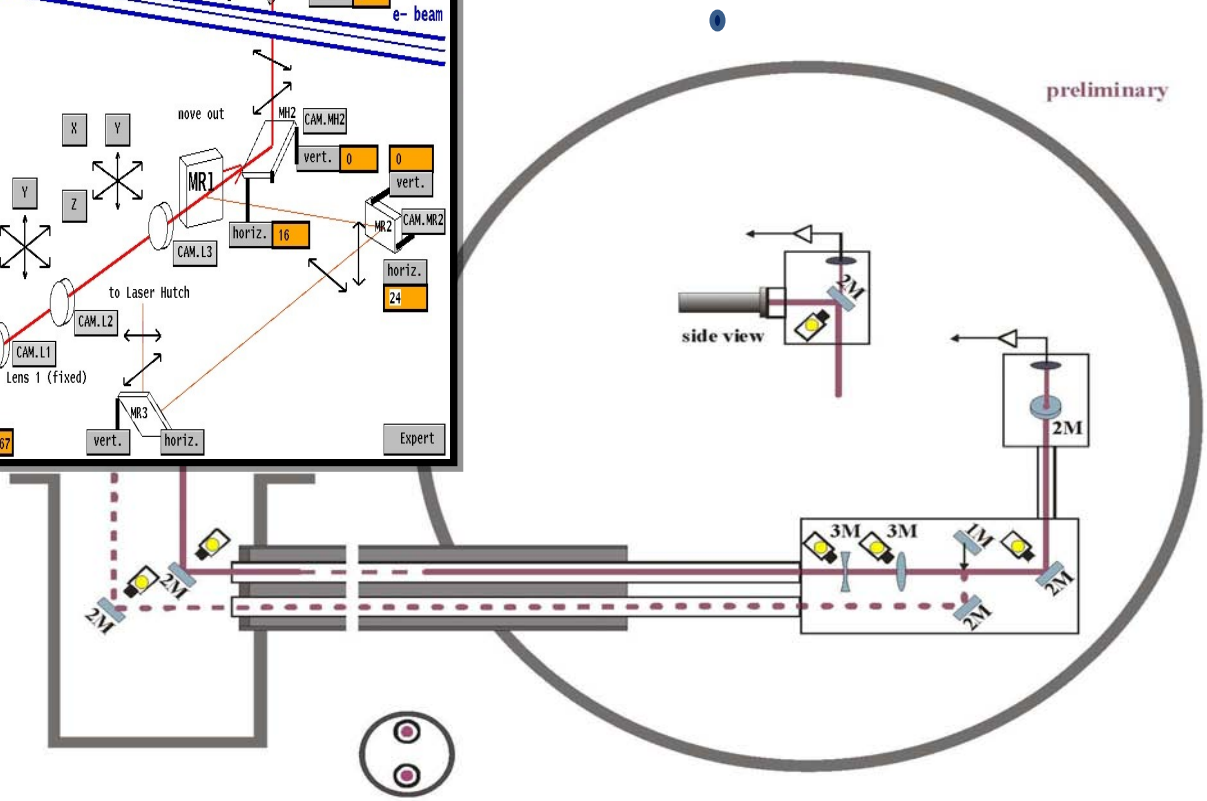
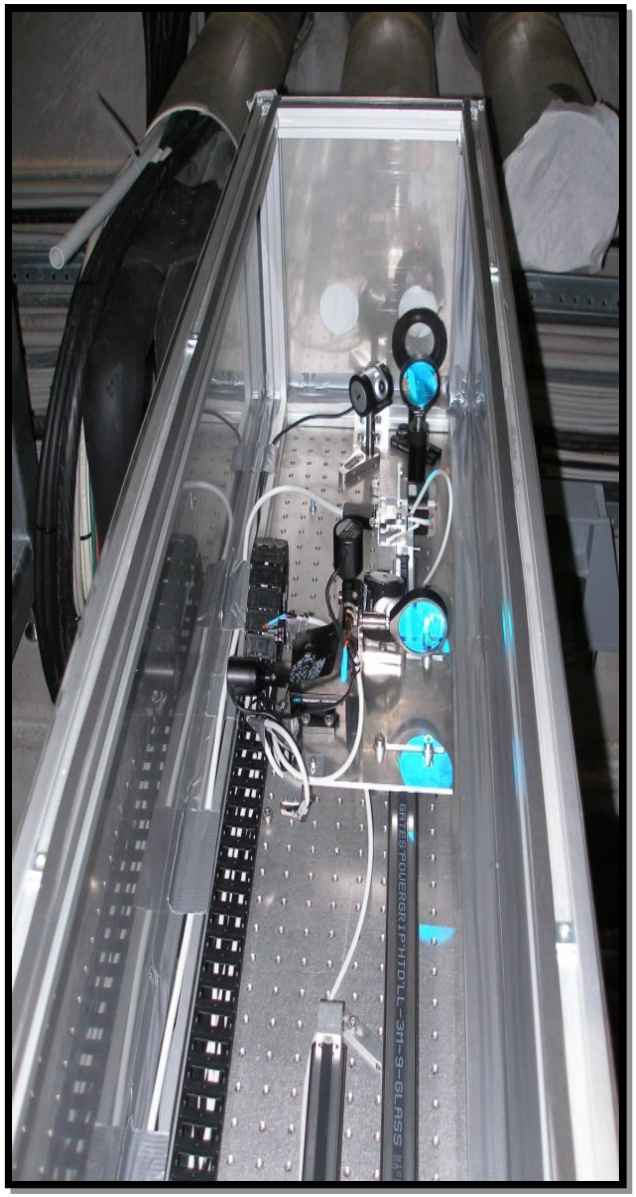
Optical Replica

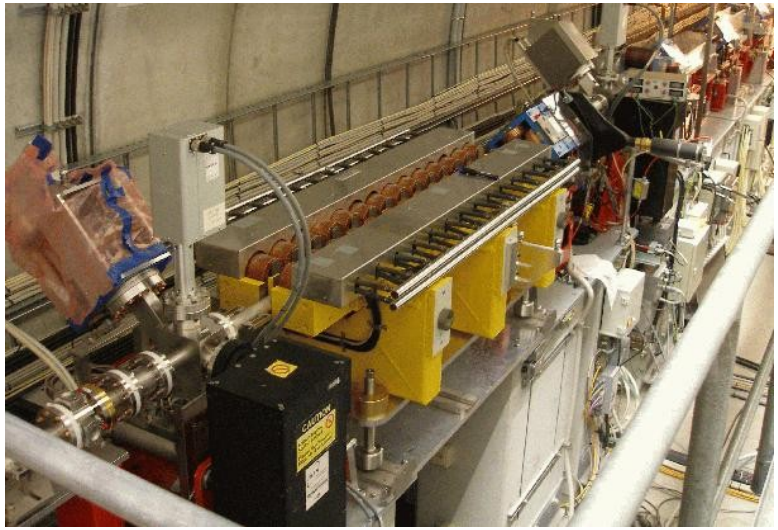




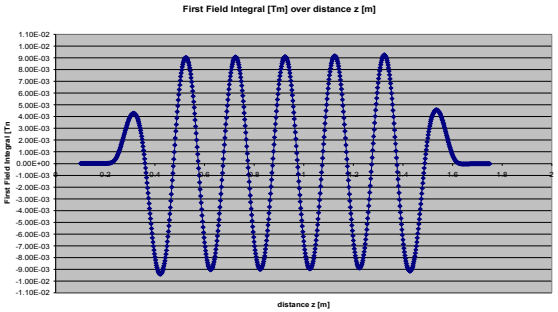


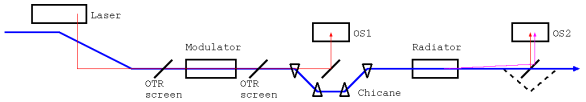


The Undulators



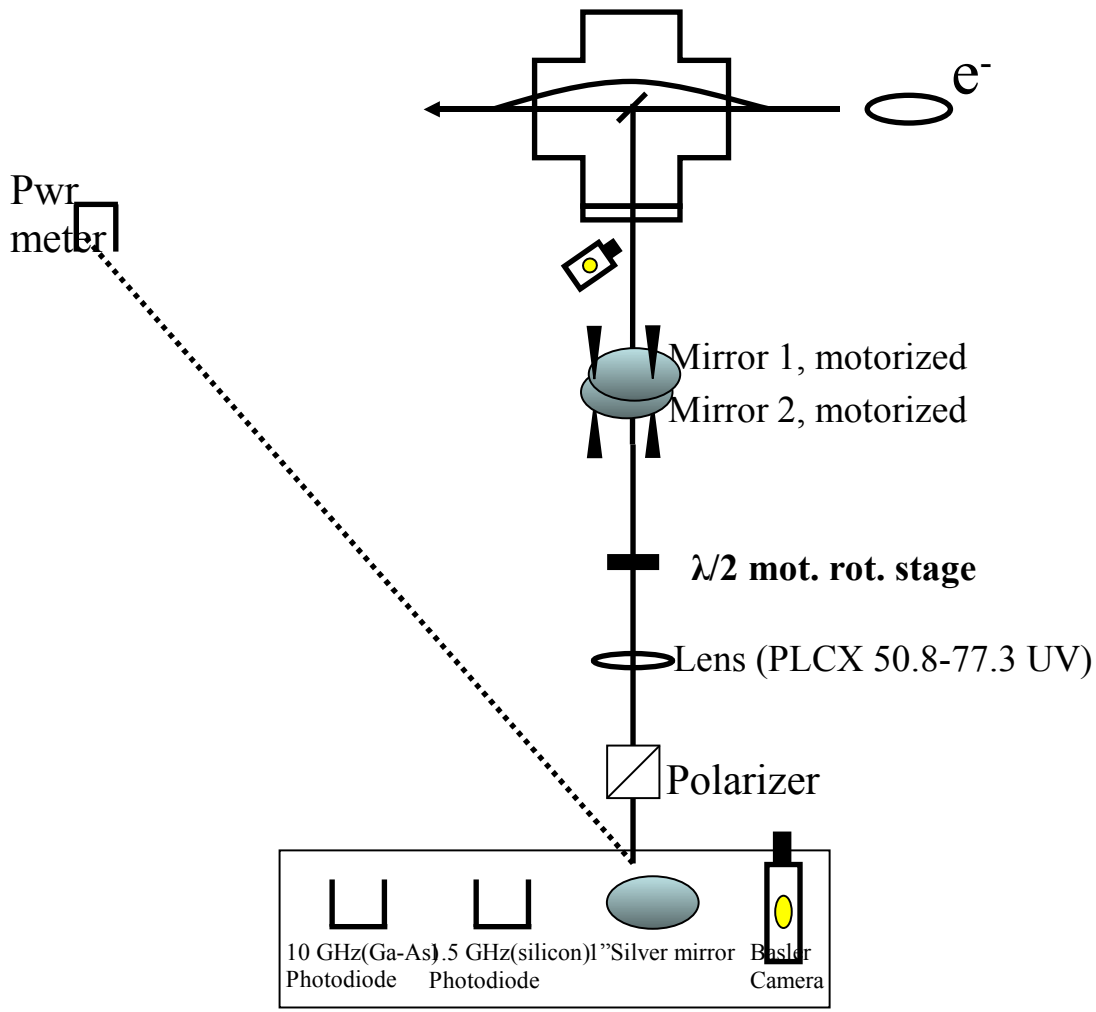
- Electromagnets
- Designed and built by Scanditronix, Vislanda
- Period 20 cm
- 5+2 periods
- 4 power supplies per magnet
- Modulator=(V)eronica
- Radiator=(H)ilda

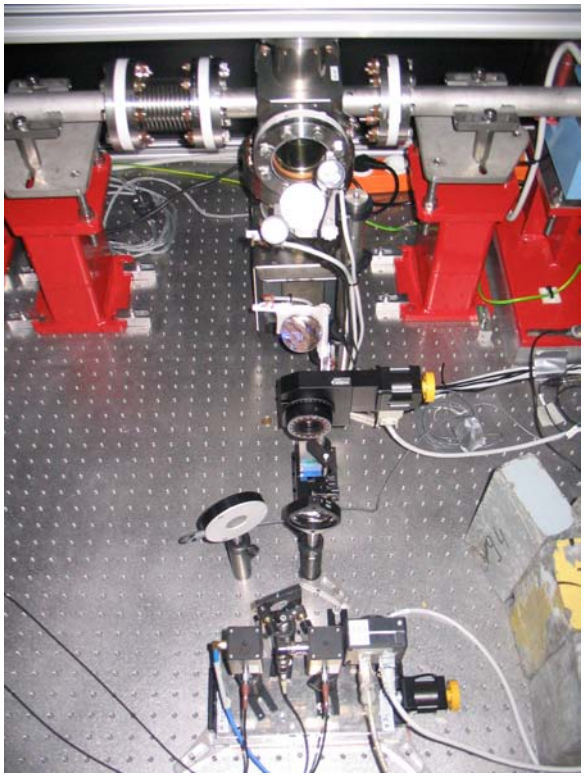


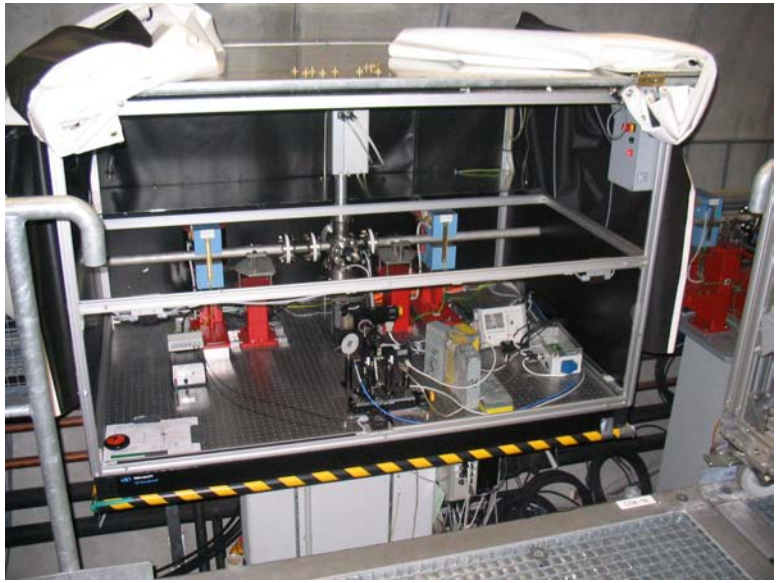


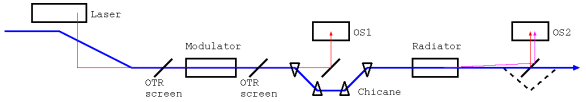
Optical Station 1

Essential for timing: Laser + Synchrotron radiation









Optical Station 2

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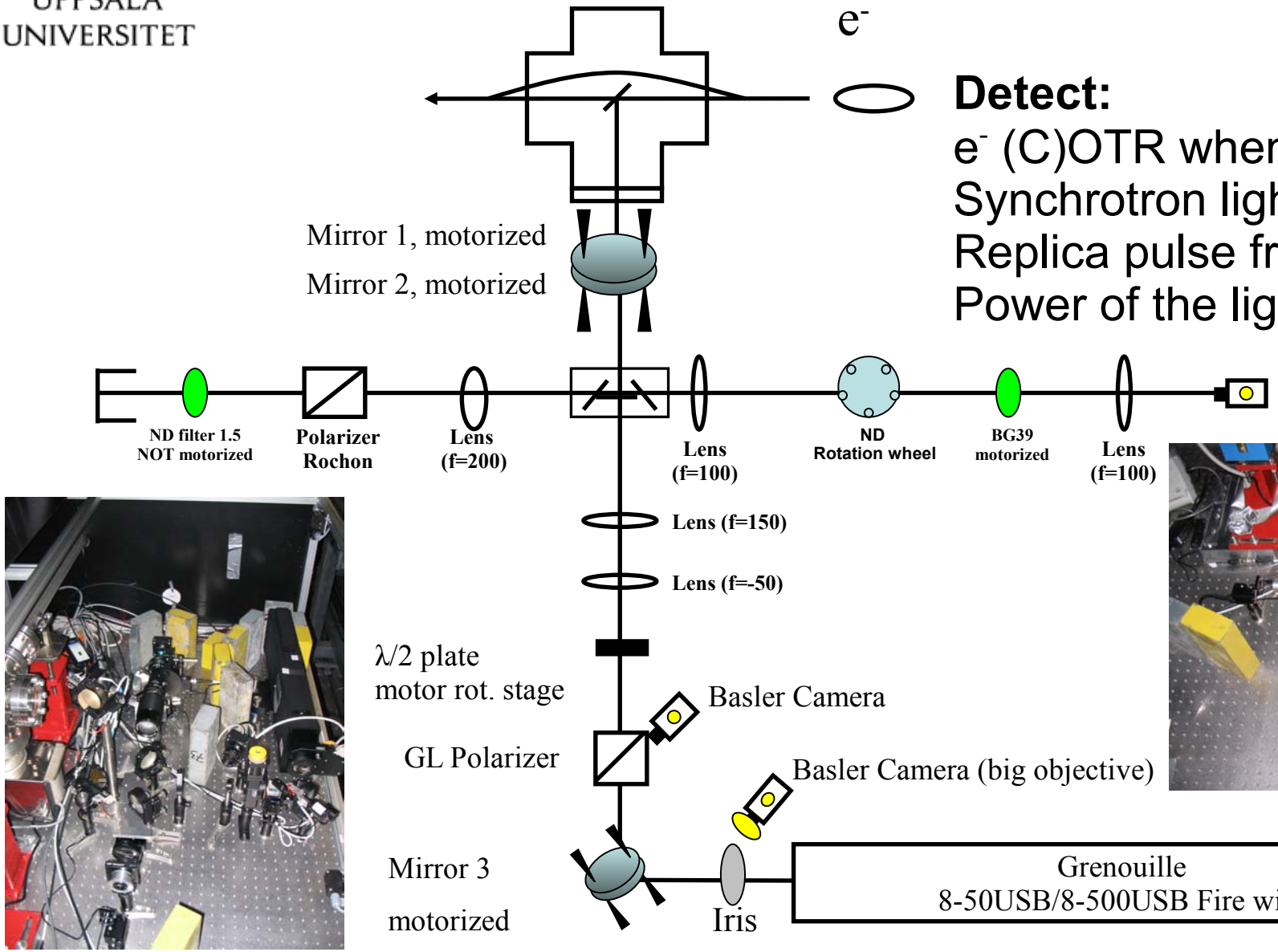
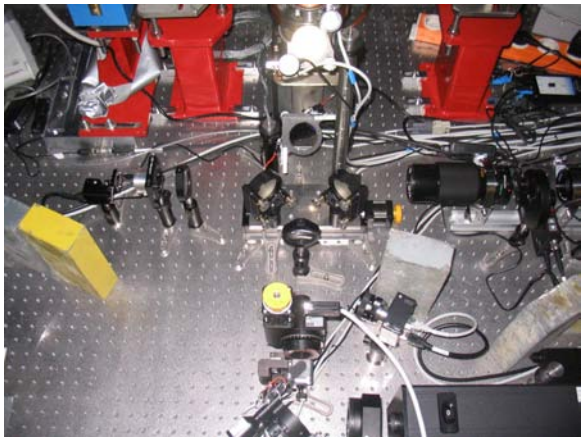
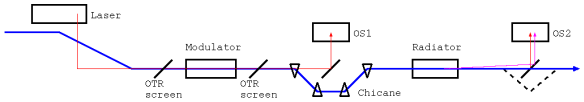
Optical Replica

Detect:

e^- (C)OTR when hitting the screen
Synchrotron light from HILDA
Replica pulse from HILDA
Power of the light



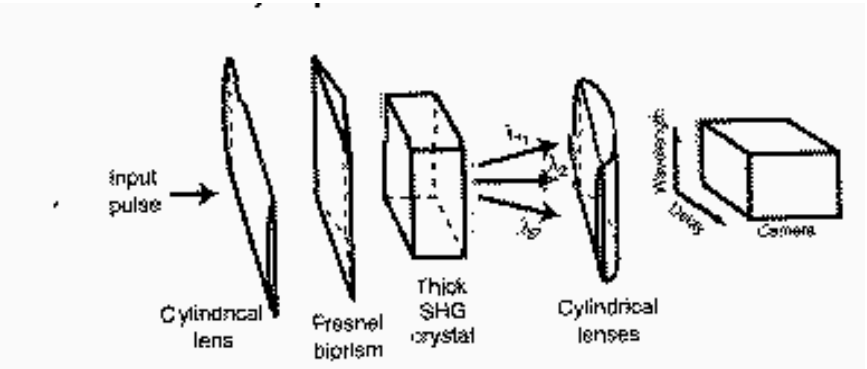


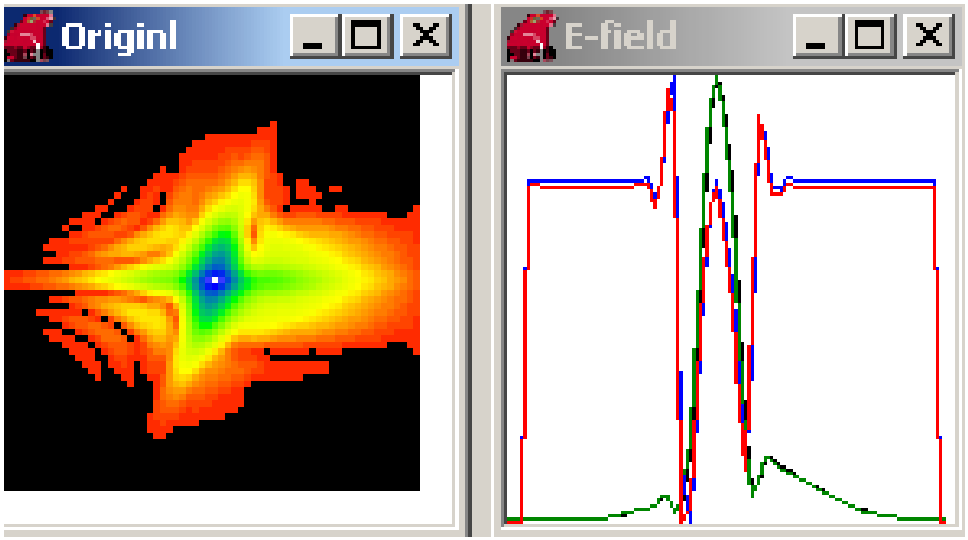


GRENOUILLE

- *Cyclidrical lens* makes horizontal strip
- *Fresnel biprism* creates crossing wavefronts in thick *SHG crystal* → auto-correlator
- Effective thickness of SHG crystal varies with viewing angle → Spectrally resolved
- Second double cylidrical lens images onto camera
- Horizontally → time
- Vertically → spectrum
- Possible to reconstruct electric field profile in software from R. Trebino's book on FROG.

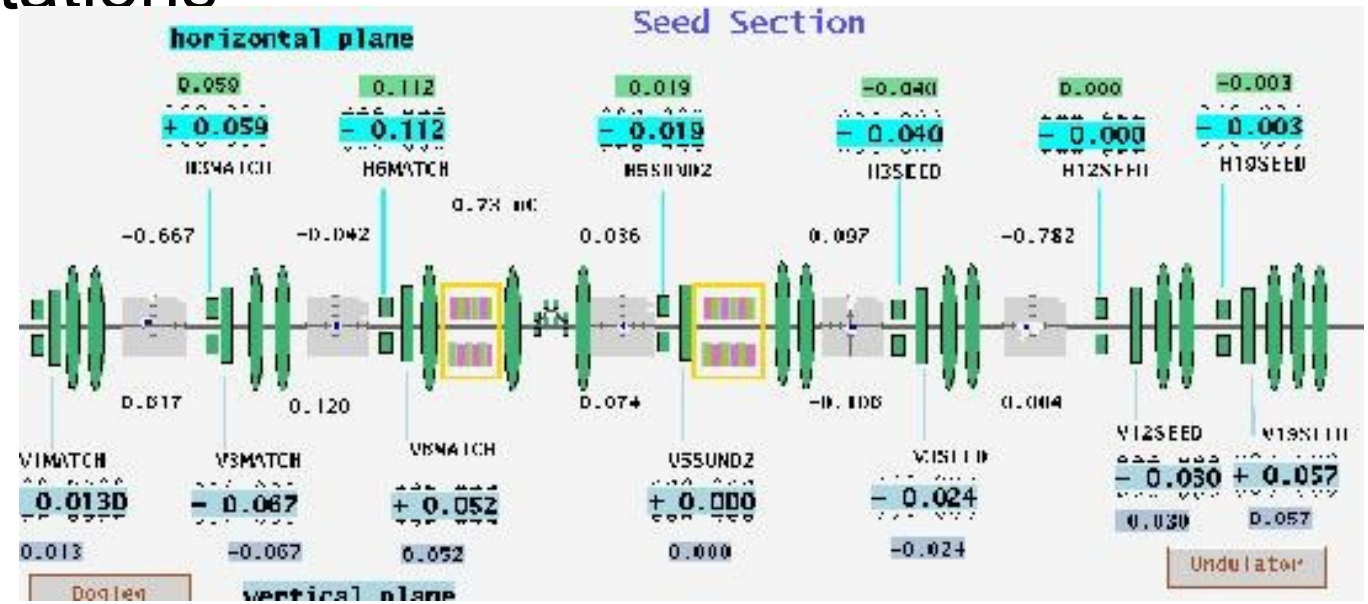
- Picture from Trebino's book



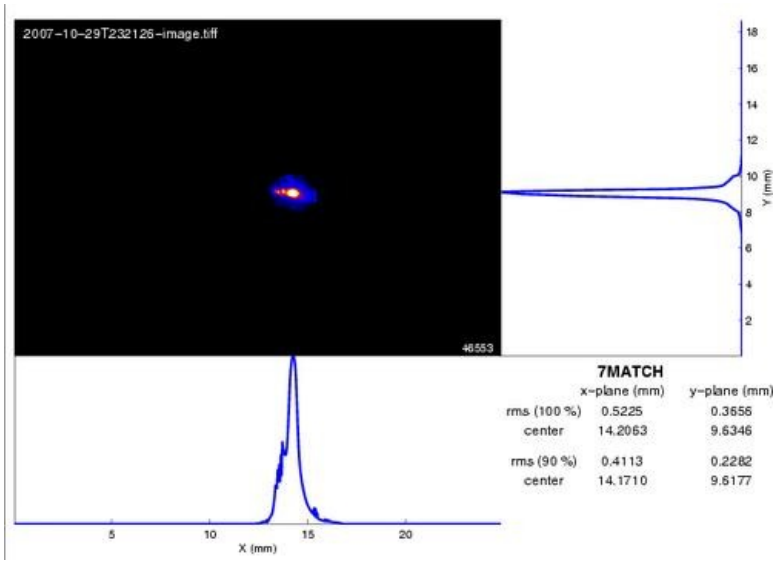


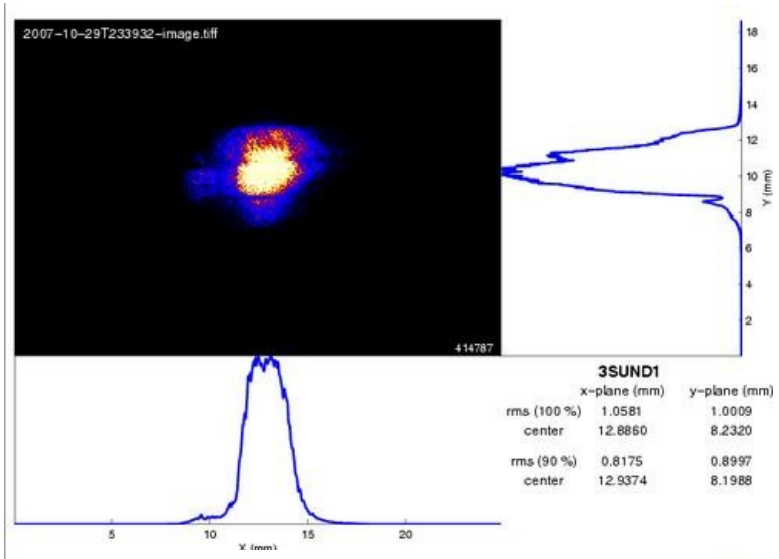
Experiments: A day in BKR...

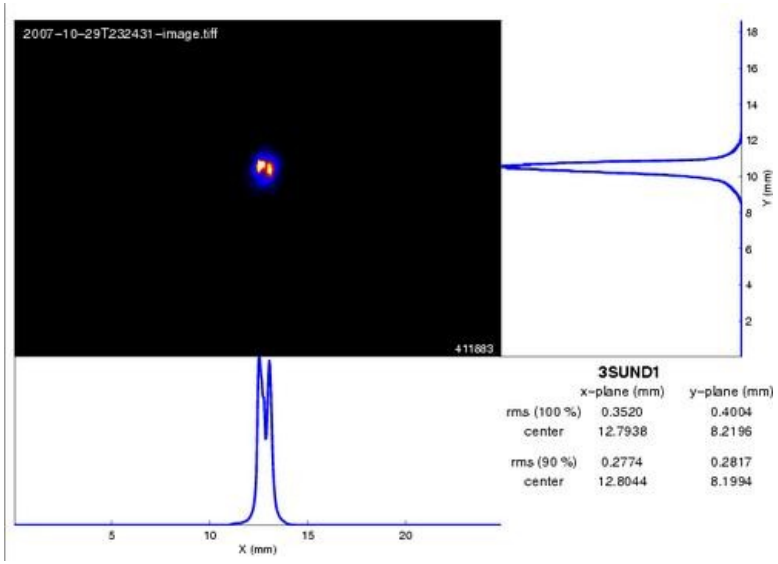
- Start out with e- (preferably compressed nowadays) to beam dump or tuneup dump
- Flatten orbit in 'our section' with undulators off
  - BPMs < 0.1 mm and small steering magnet excitations

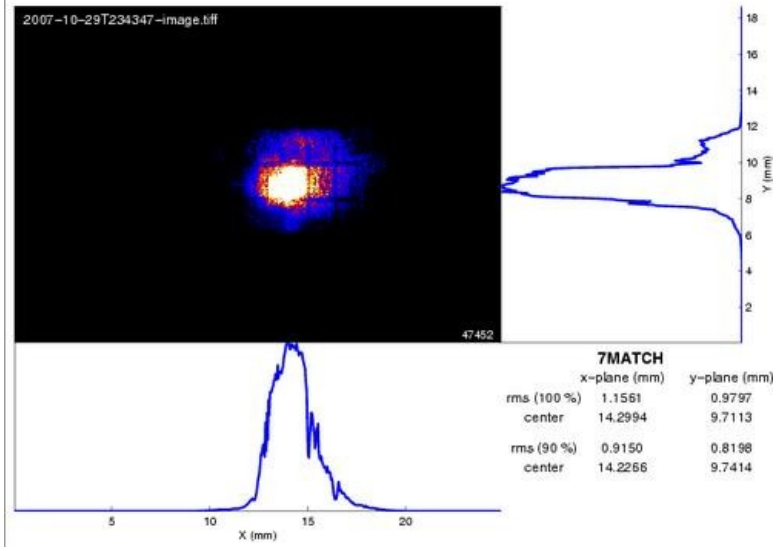


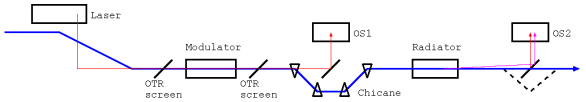
Transverse Overlap







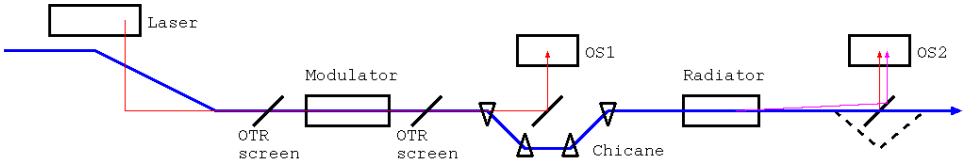




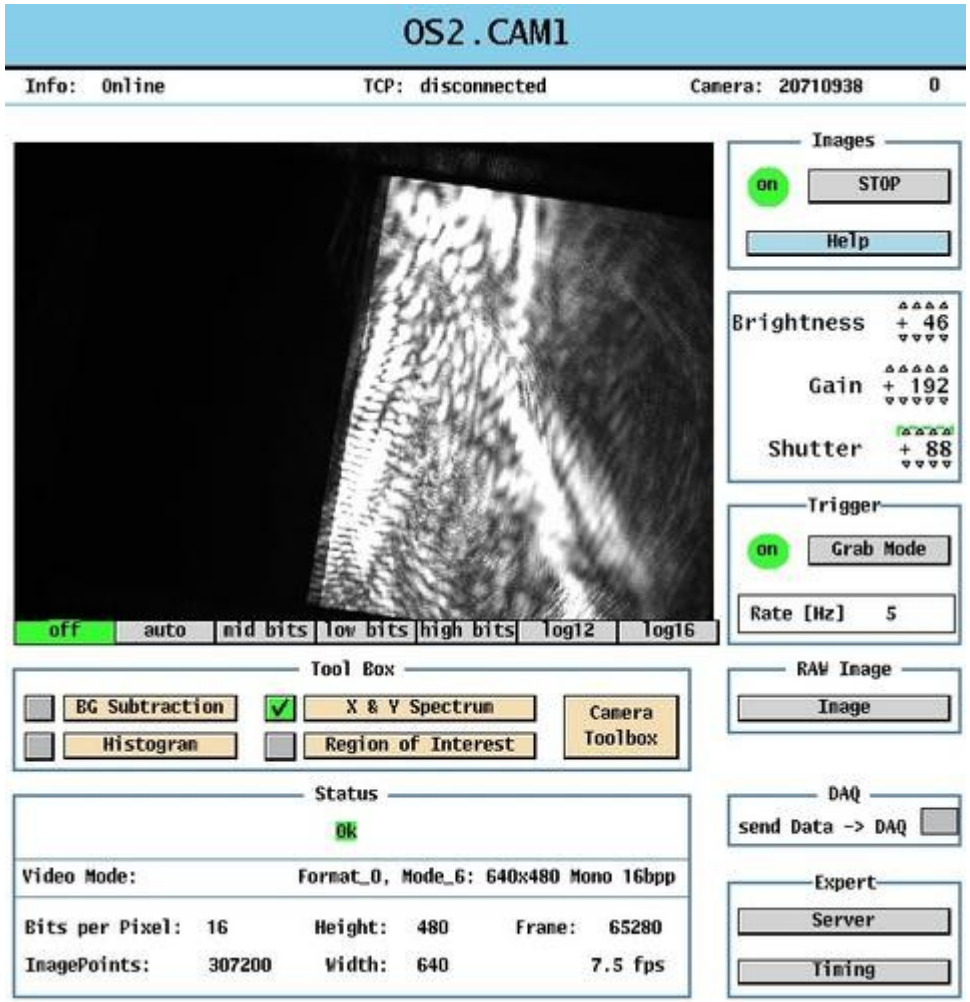
Rough temporal Overlap

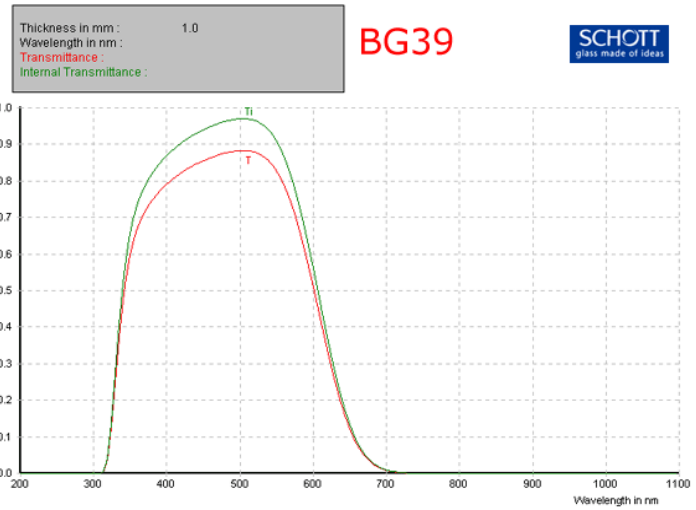
- Turn on Veronica+Chicane
- Remote 1 GHz scope
- Photo diode on OS1

- Detect signal from
  - attenuated seed laser
  - spontaneous synchrotron radiation from VERONICA
- on photo diode
- good to ≈ 100s ps
- move relative timing with the phase shifter

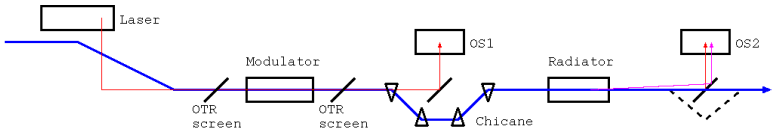


Problem with Seed laser leakage

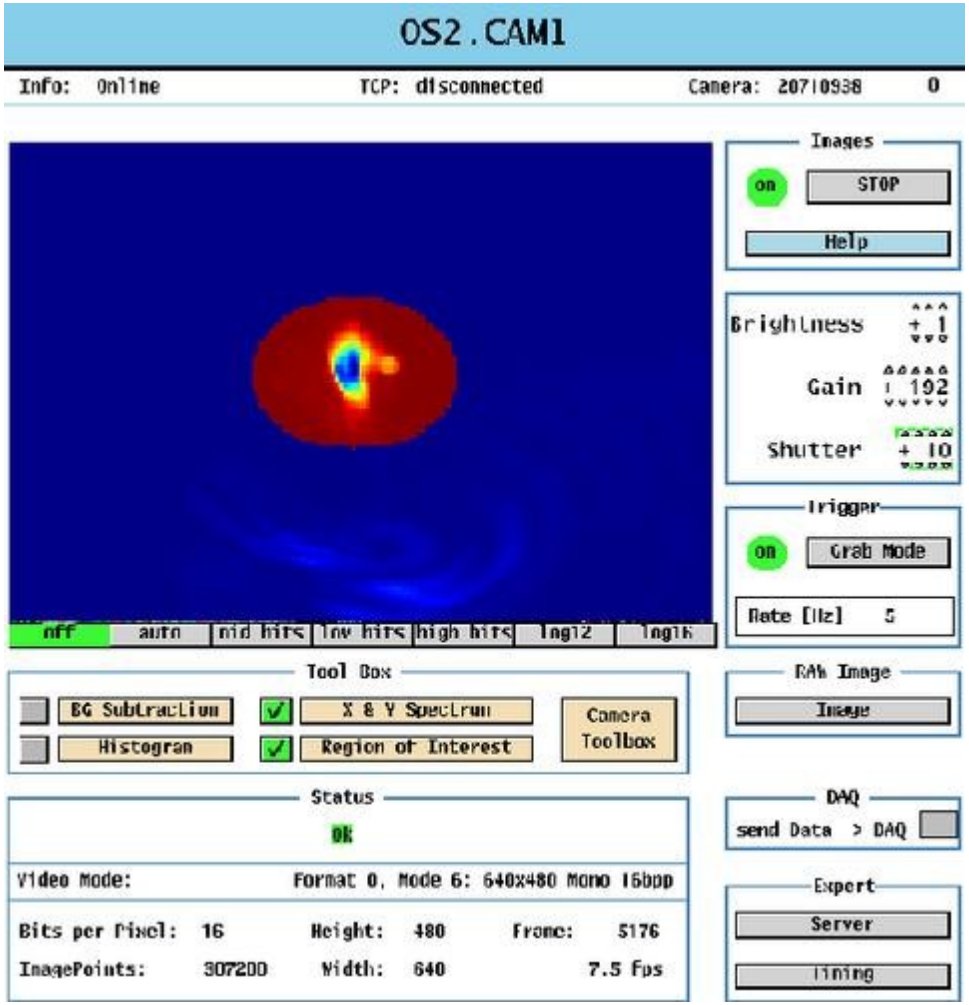




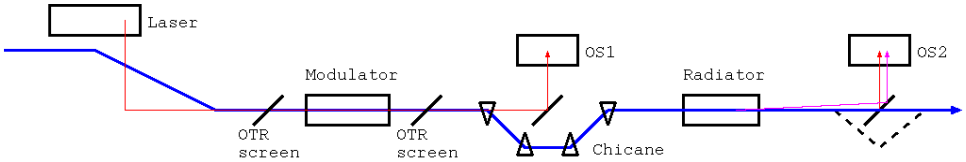
- Bunching also causes radiation at higher harmonics
- Insert BG39 filter before camera



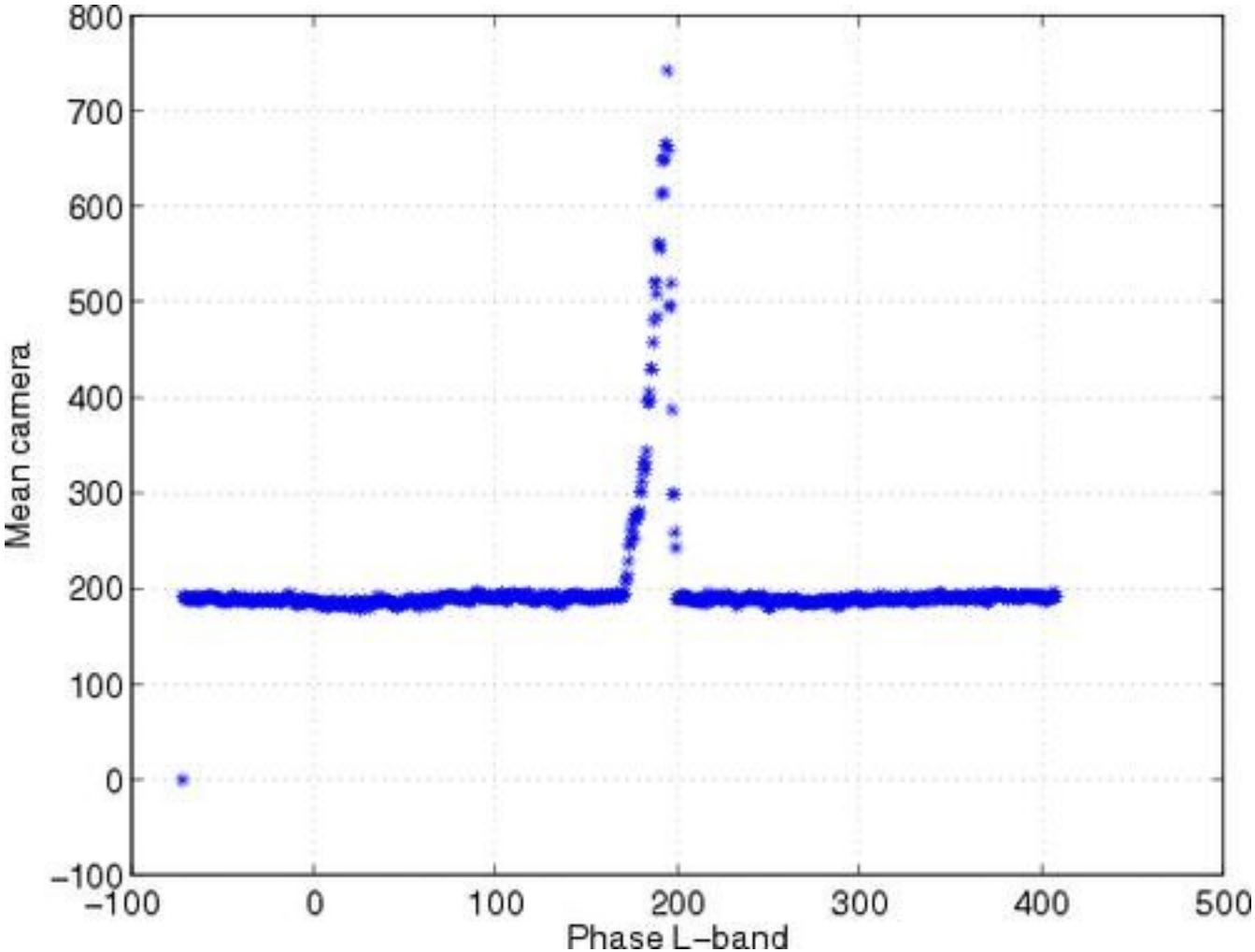
With Seed laser filtered



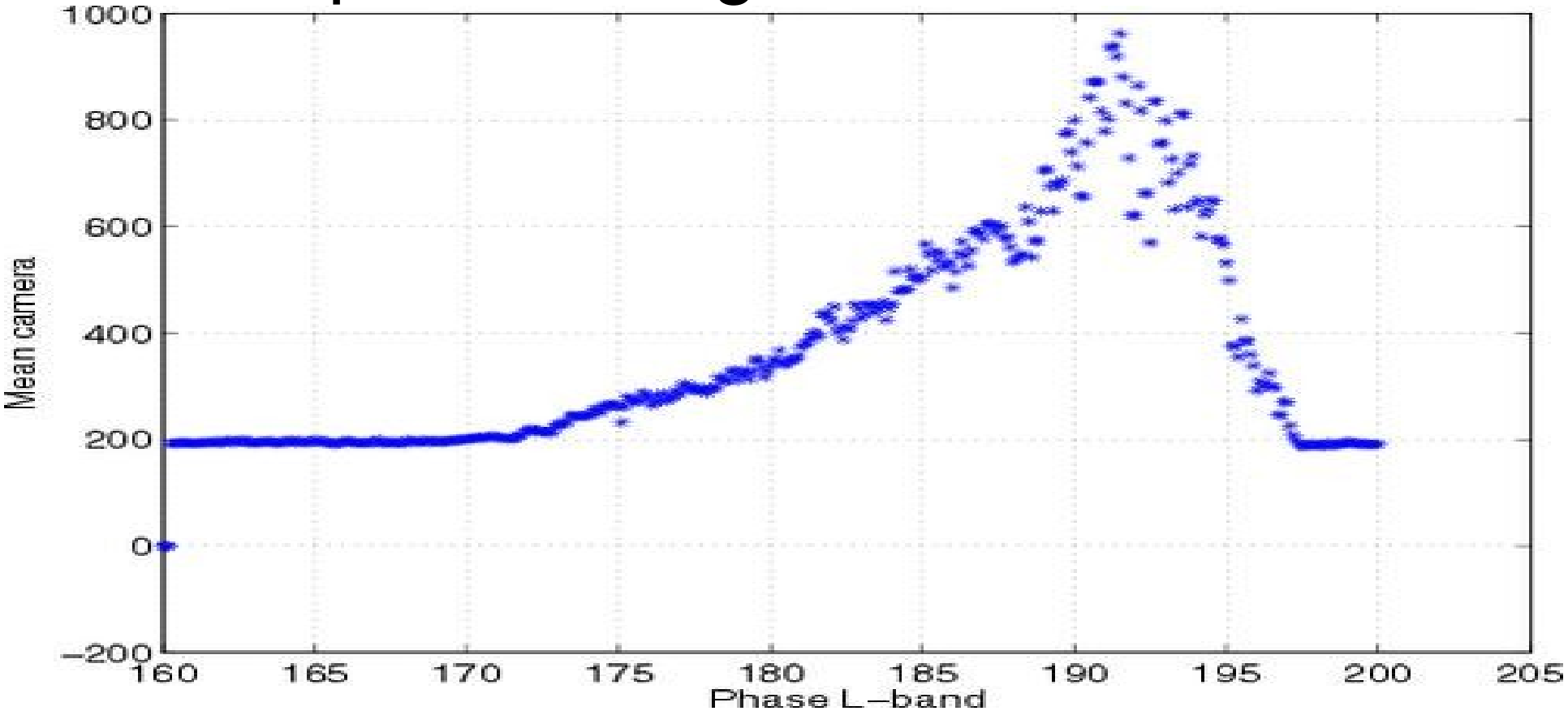
- OTR at 2nd harmonic
- Radiator OFF
- Need signal that identifies overlap
- Use average pixel value in *Region of interest*

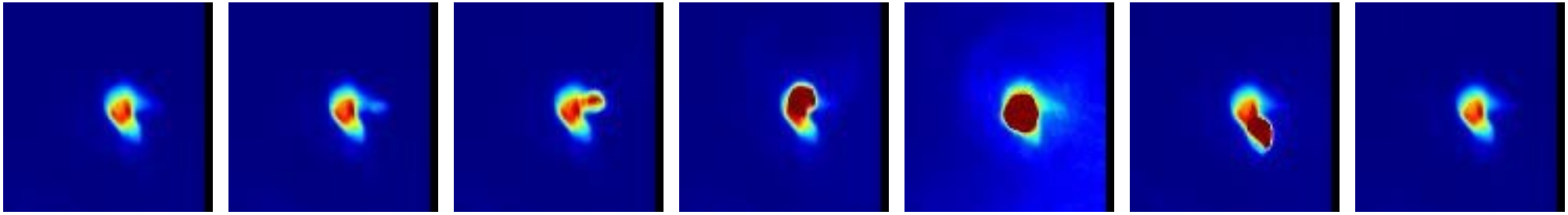


After some scanning...

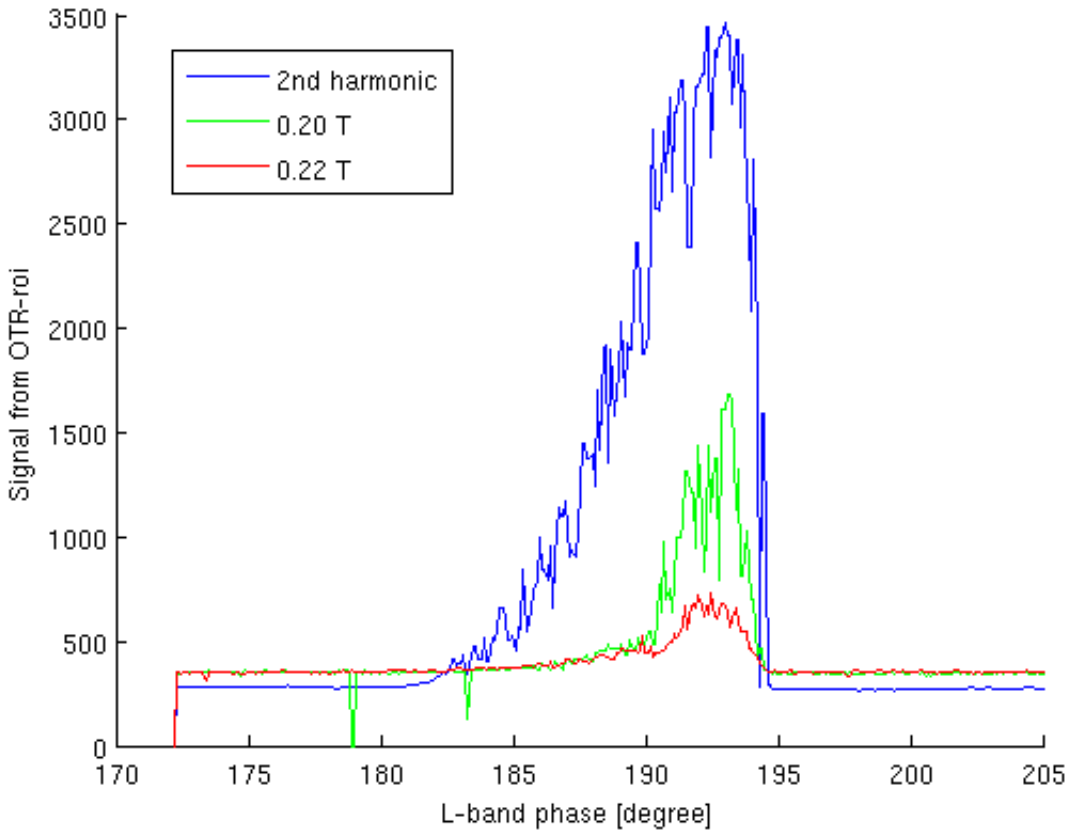


CTR on screen 1SEED while passing a 200 fs laser pulse through an electron bunch

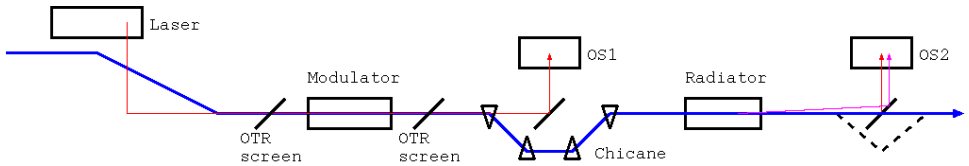




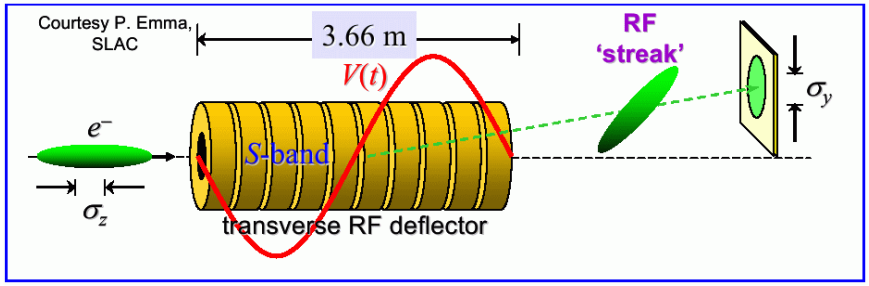
Tune Radiator to 2nd harmonic

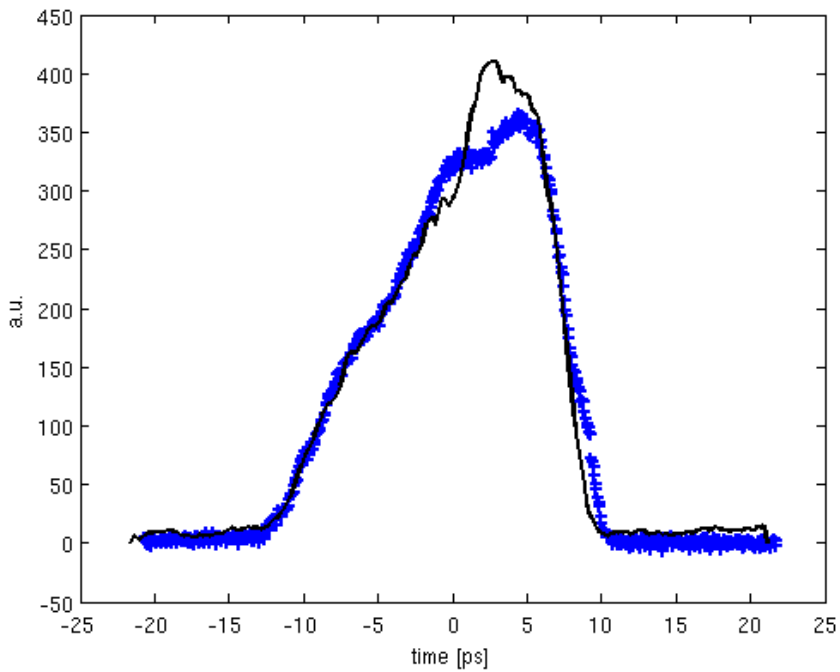


- Harmonic Generation
- Tune away from resonance and signal goes down
- Also scanned chicane and found optimum but that varies daily.



Comparison with LOLA

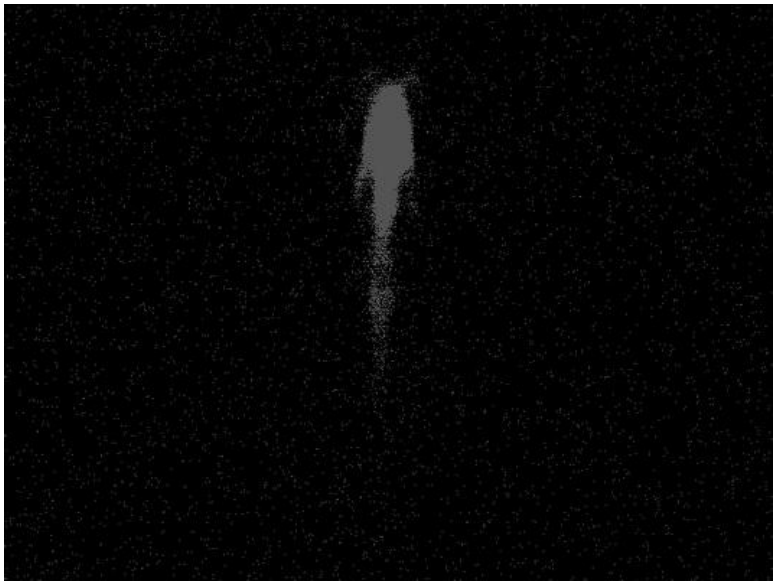


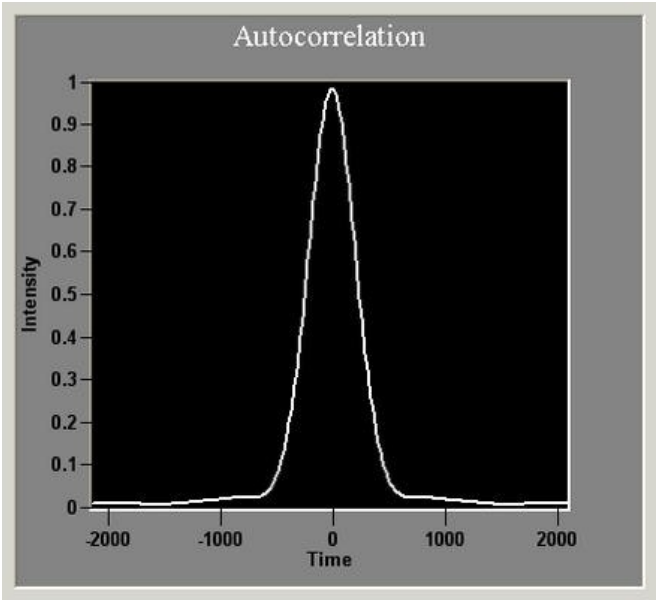


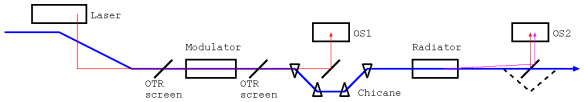
- Simultaneous (almost, 30 min) measurement of bunch profile with transversely deflecting cavity LOLA (blue) and ORS (black).
- Initially the time calibration of LOLA was off by 20 %, now fixed.
- OD2 Neutral density filter before the Basler camera to prevent saturation
- smoothing and sqrt(ORS)
- Very good agreement of the recorded bunch length
- Some saturation of LOLA?

Testing the GRENOUILLE on OS2

- Send seed laser (400 fs) all the way to OS2
- and pass it to the GRENOUILLE
  - observe on spatial camera and on temporal camera
  - and observe autocorrelation and FROG trace

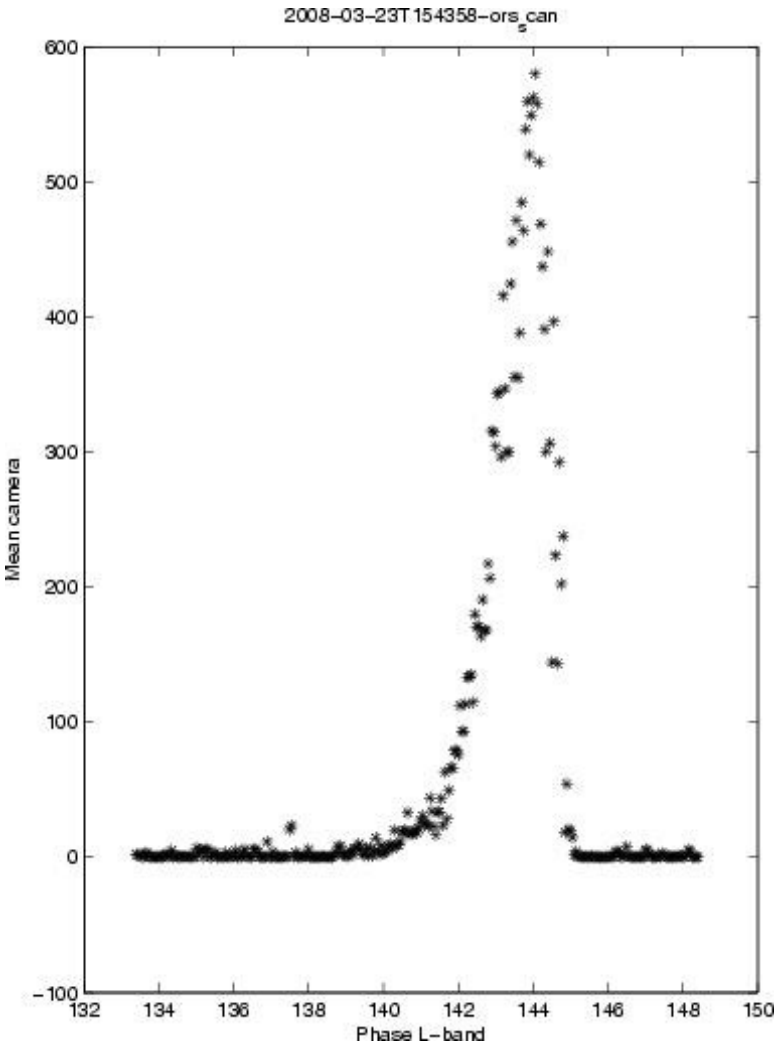


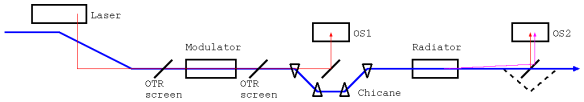




Trying to really make replicas

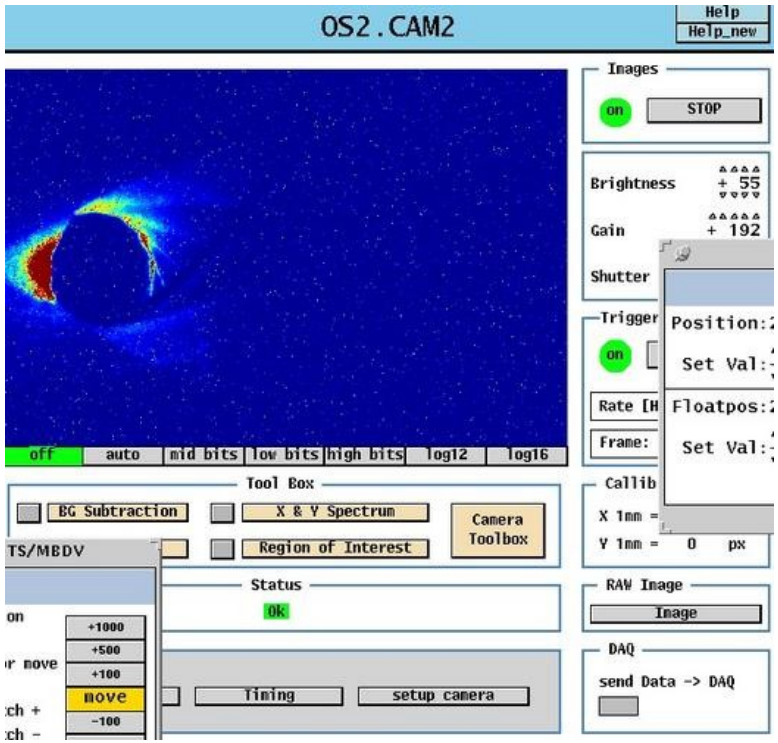
- Short compressed electron bunch (off-crest)
- Short laser, FWHM=400 fs
- Transverse an longitudinal overlap (works, even when both electrons and laser are short!)
- Put laser on top of electrons

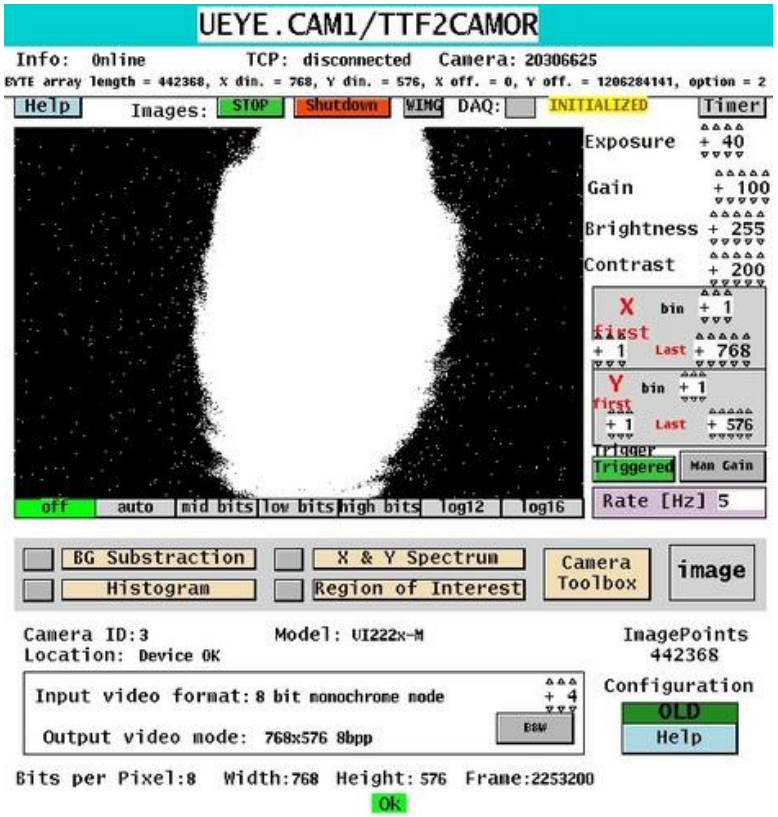




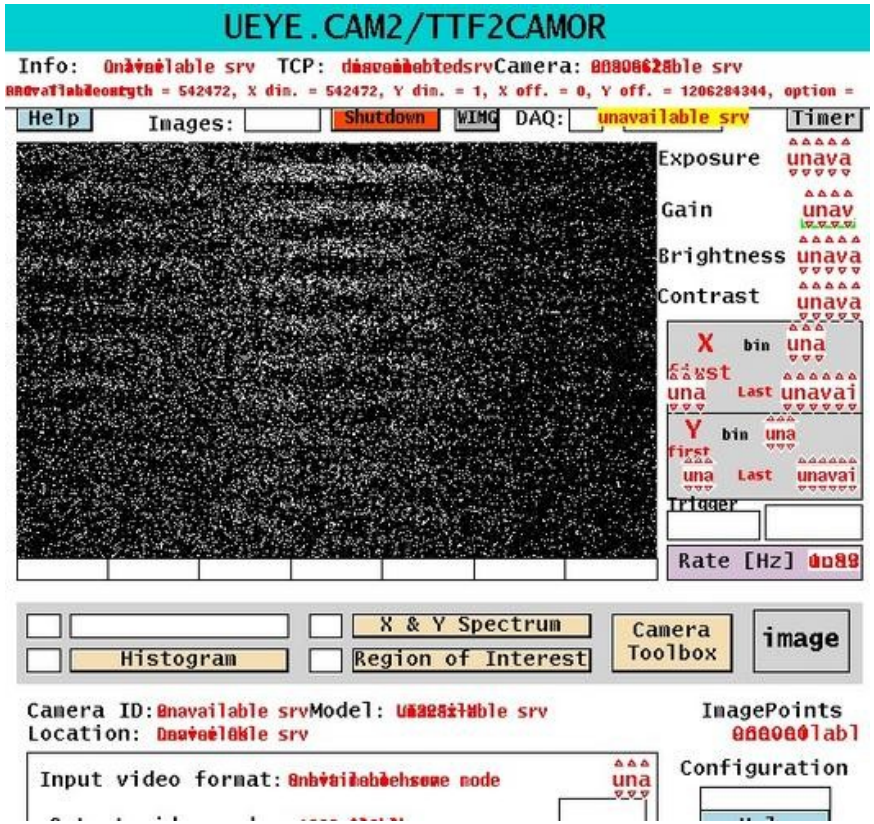
Still trying...

- OS2: HILDA radiation on iris before the GRENOUILLE
- and on the spatial (alignment) camera inside the GRENOUILLE





...and on the FROG camera



- too little signal
- and a glitch in the power grid killed the rest of shift
- that's what we had after the easter shifts, we were close...

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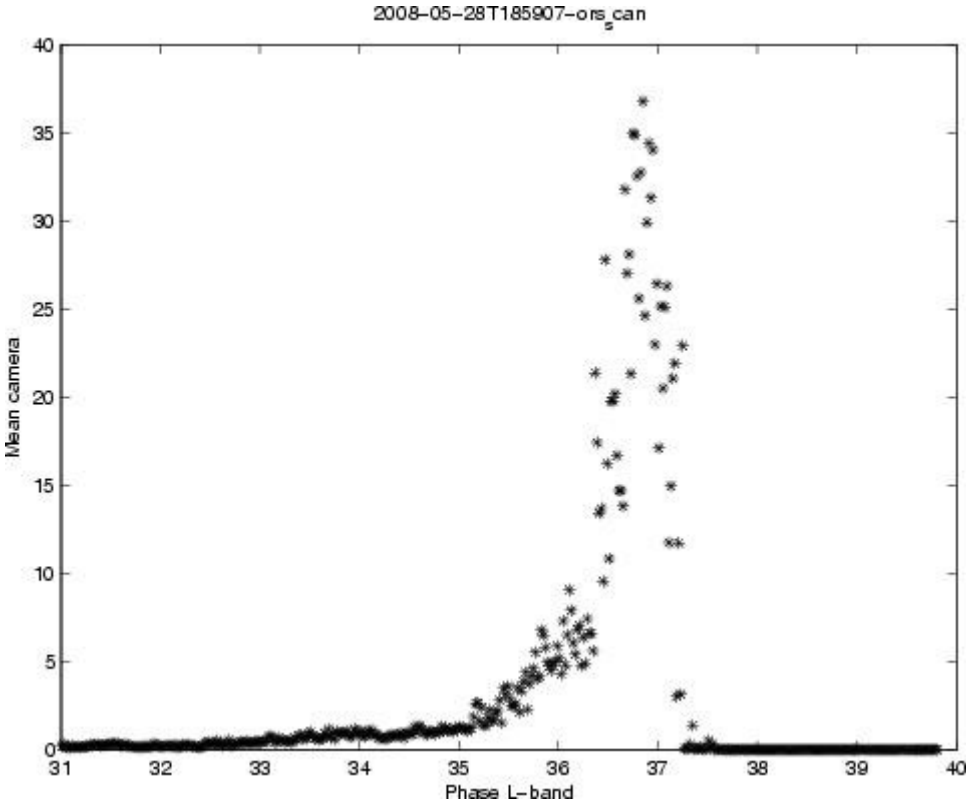
...and this is how it went last week

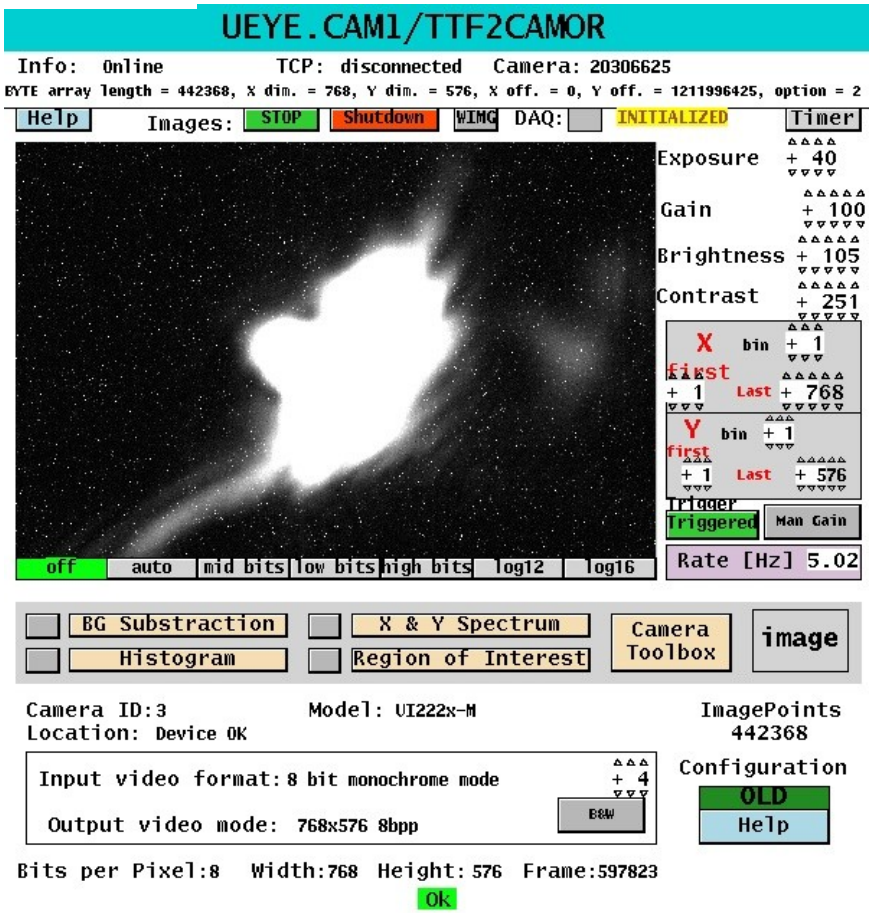
- It started the way it ended: with a power glitch on the friday before the week with our shifts
  - this knocked out a lot of stuff on the optical stations
  - dead power supply
- but we got it fixed up to and during the half-shift on monday (26.5) and the access on tuesday
- so we could start for real on the 12 hrs shift on wednesday.

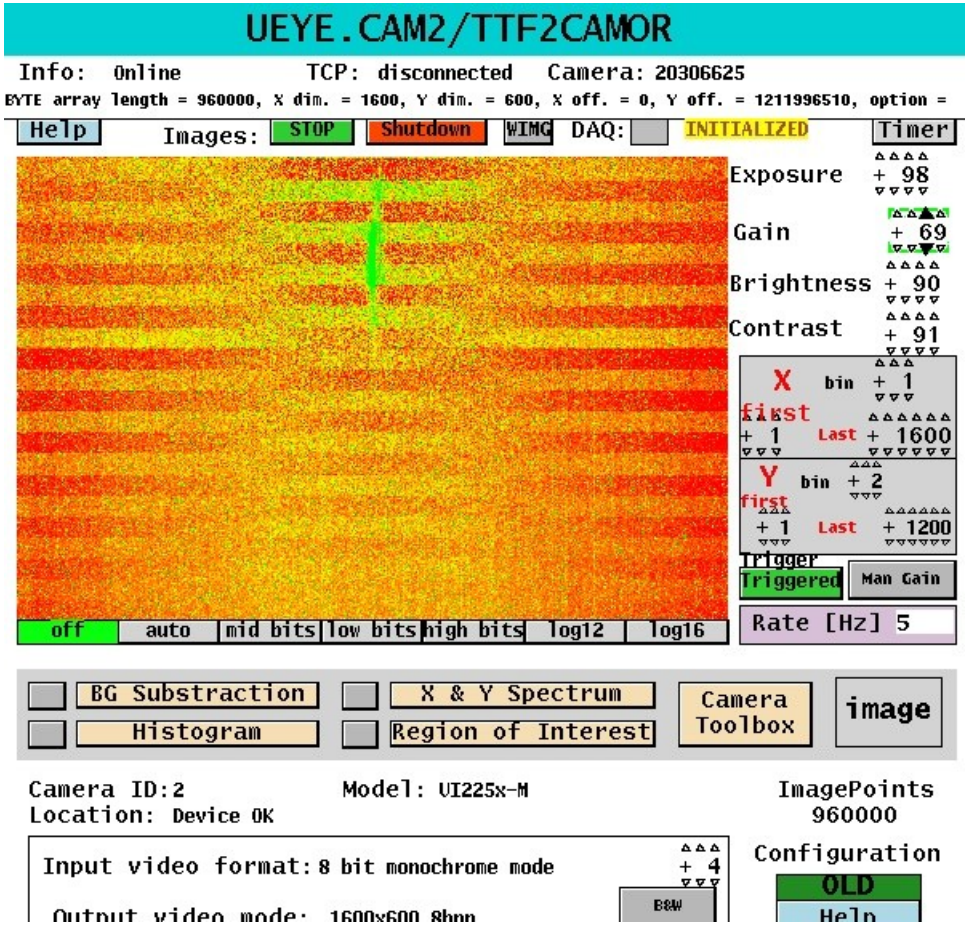
Setup on Wednesday and ...

- Standard setup with
  - flat orbit and transverse overlap
  - longitudinal overlap (after restarting a DAC of the vector modulator in the timing system)
- Compressed bunches
- HILDA on and a lot of tuning (thanks Dirk)



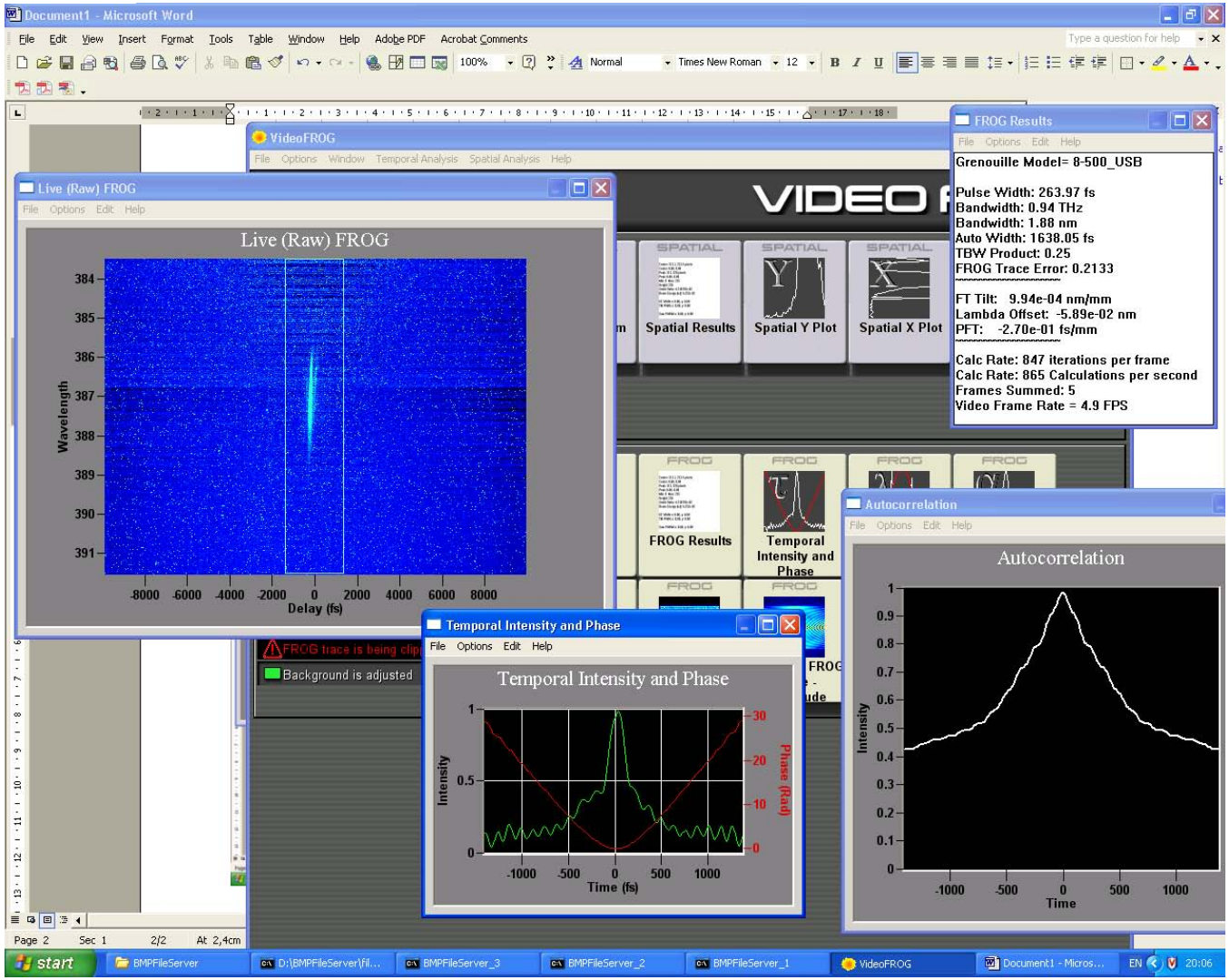
The first FROG trace



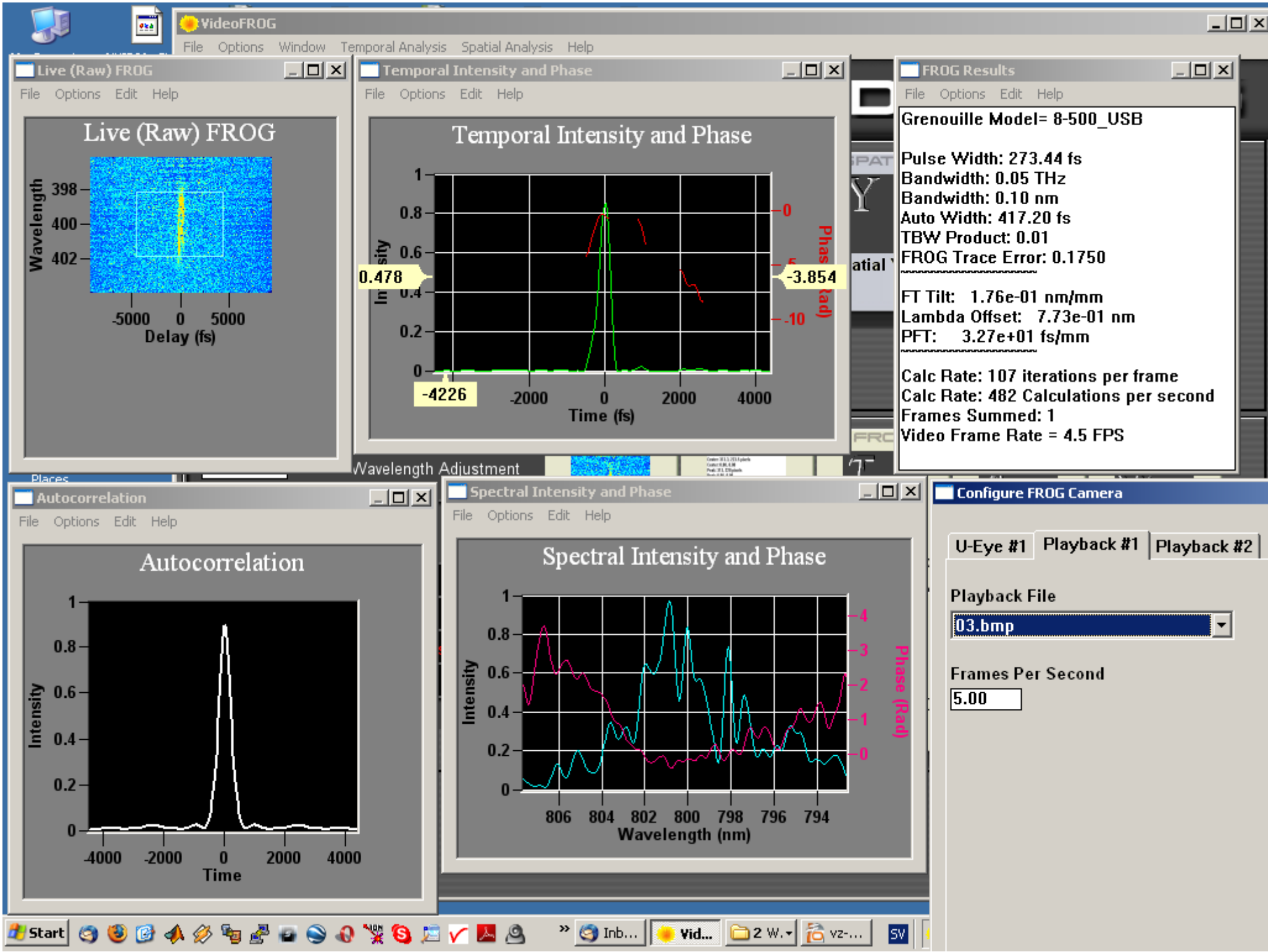


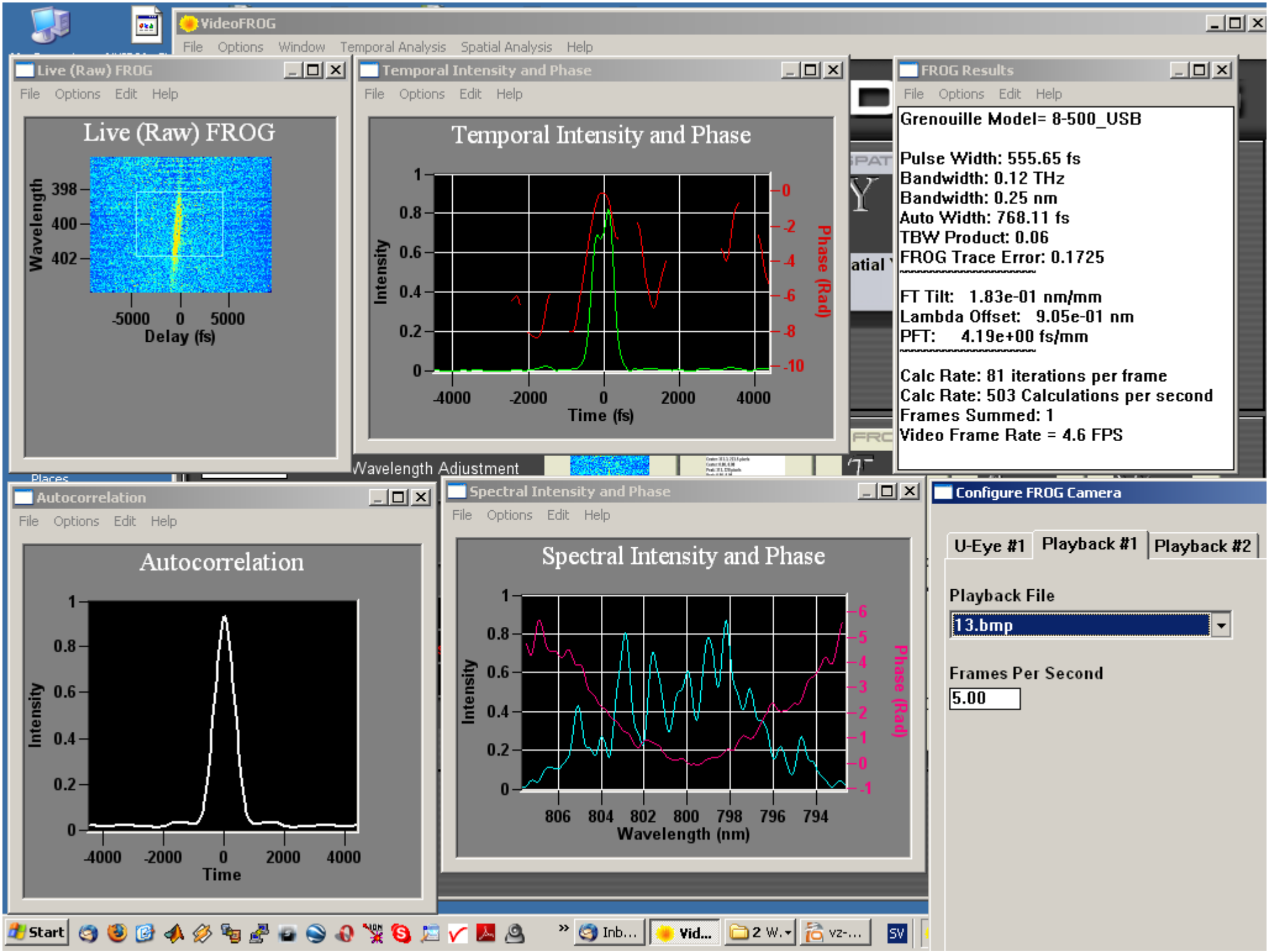
Spend a lot of time improving the signal intensity

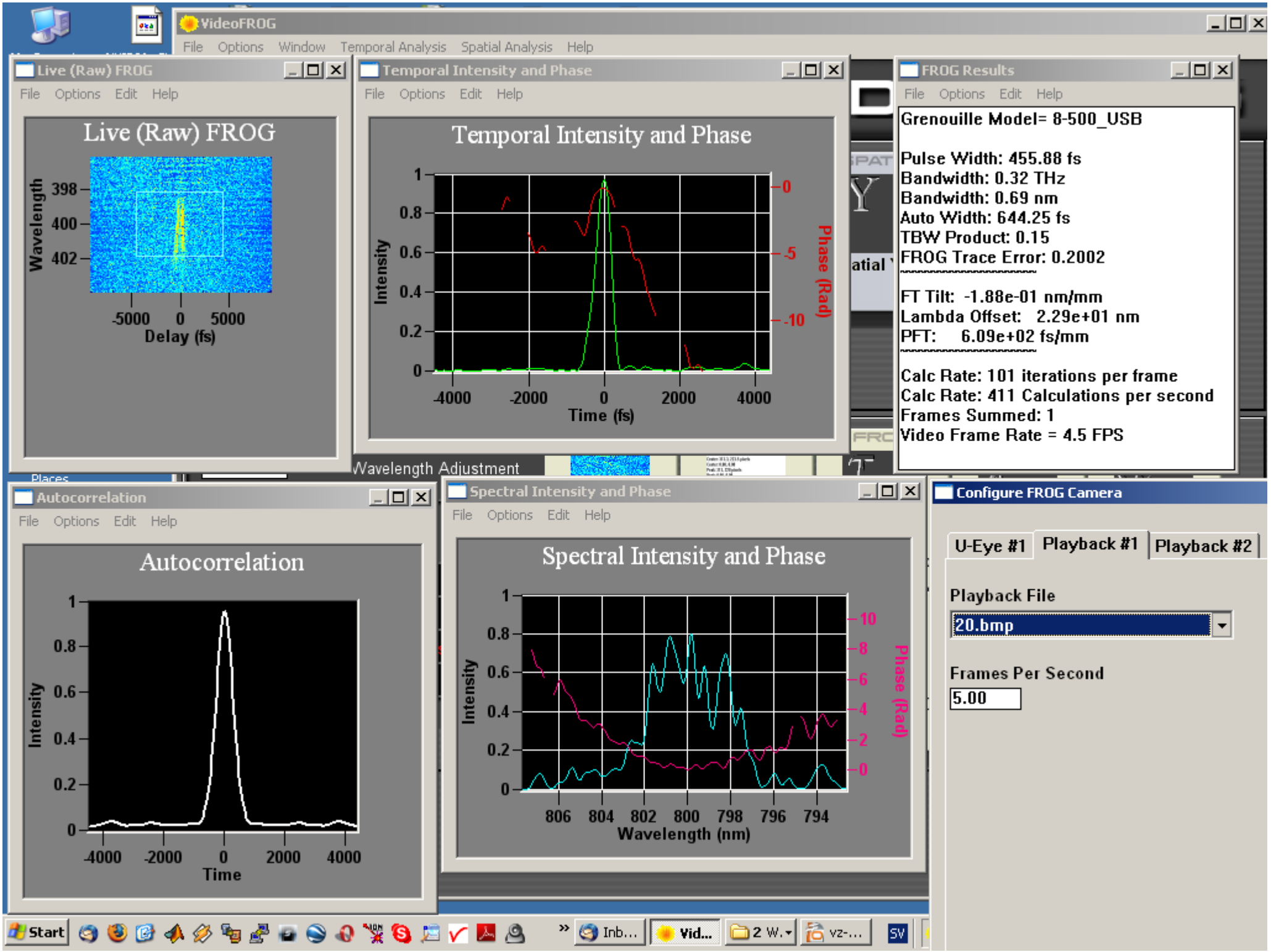
Online VideoFROG software



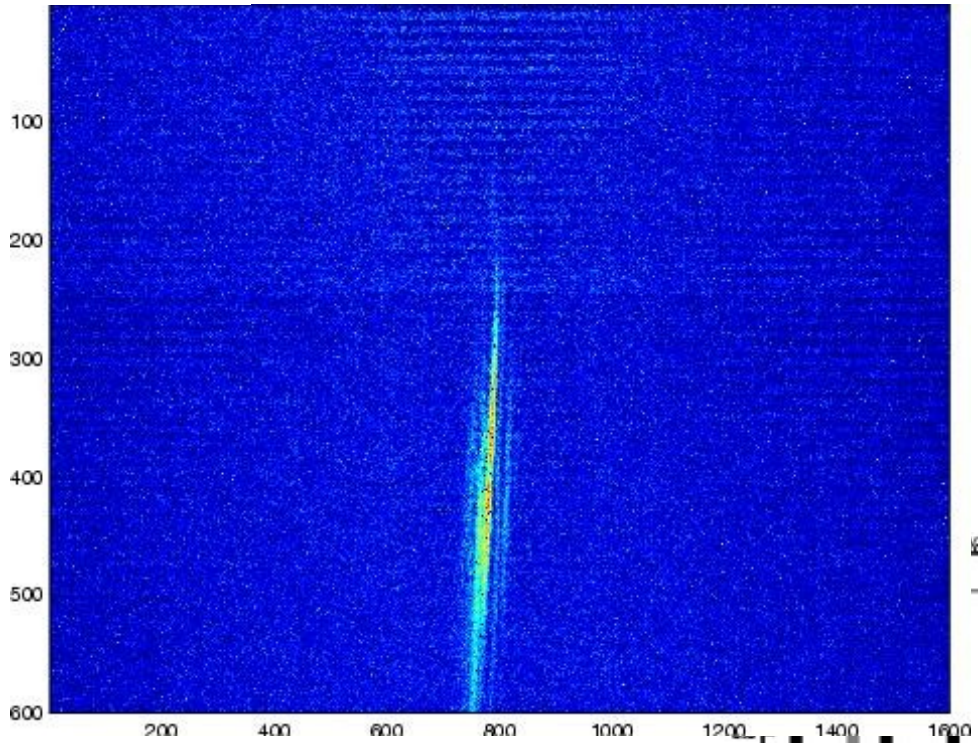
Averaging
TBP too small
Intensity


VideoFROG
File Options Window Temporal Analysis Spatial Analysis Help
Live (Raw) FROG
File Options Edit Help
Live (Raw) FROG
Wavelength
398
400
402
-5000 0 5000
Delay (fs)
Temporal Intensity and Phase
File Options Edit Help
Temporal Intensity and Phase
Intensity
Phase (Rad)
0.478
-3.854
-4226
-2000 0 2000 4000
Time (fs)
FROG Results
File Options Edit Help
Grenouille Model= 8-500_USB
Pulse Width: 273.44 fs
Bandwidth: 0.05 THz
Bandwidth: 0.10 nm
Auto Width: 417.20 fs
TBW Product: 0.01
FROG Trace Error: 0.1750
FT Tilt: 1.76e-01 nm/mm
Lambda Offset: 7.73e-01 nm
PFT: 3.27e+01 fs/mm
Calc Rate: 107 iterations per frame
Calc Rate: 482 Calculations per second
Frames Summed: 1
Video Frame Rate = 4.5 FPS
Wavelength Adjustment
Autocorrelation
File Options Edit Help
Autocorrelation
Intensity
-4000 -2000 0 2000 4000
Time
Spectral Intensity and Phase
File Options Edit Help
Spectral Intensity and Phase
Intensity
Phase (Rad)
806 804 802 800 798 796 794
Wavelength (nm)
Configure FROG Camera
U-Eye #1
Playback #1
Playback #2
Playback File
03.bmp
Frames Per Second
5.00
Start

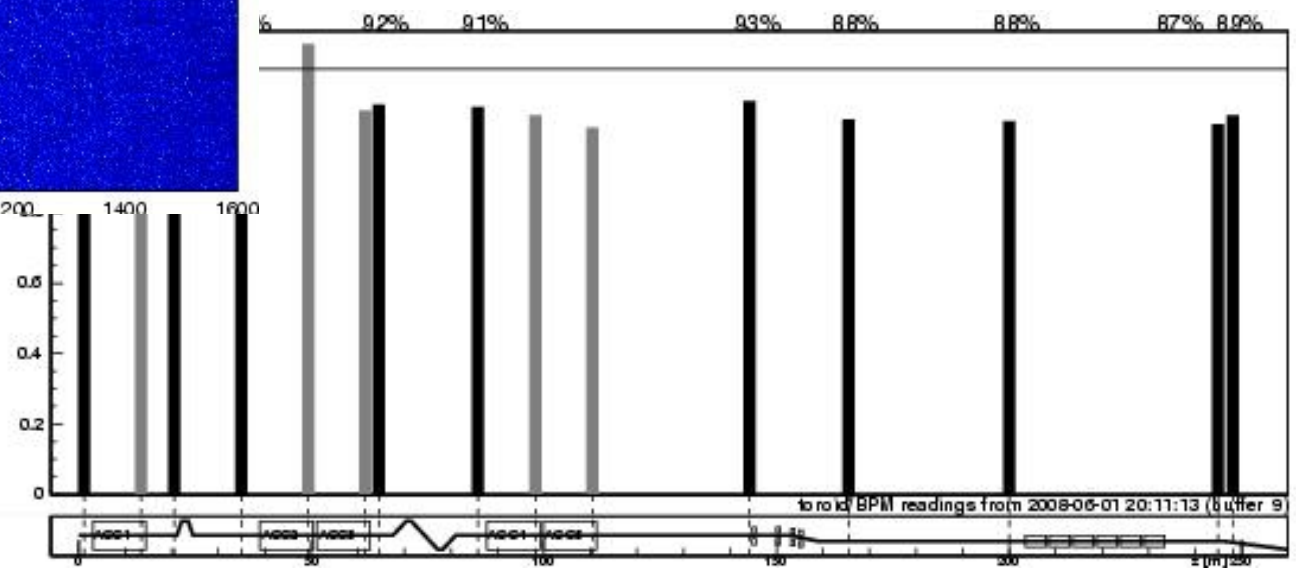

VideoFROG
File Options Window Temporal Analysis Spatial Analysis Help
Live (Raw) FROG
File Options Edit Help
Live (Raw) FROG
Wavelength
398
400
402
-5000 0 5000
Delay (fs)
Temporal Intensity and Phase
File Options Edit Help
Temporal Intensity and Phase
Intensity
Phase (Rad)
Time (fs)
FROG Results
File Options Edit Help
Grenouille Model= 8-500_USB
Pulse Width: 555.65 fs
Bandwidth: 0.12 THz
Bandwidth: 0.25 nm
Auto Width: 768.11 fs
TBW Product: 0.06
FROG Trace Error: 0.1725
FT Tilt: 1.83e-01 nm/mm
Lambda Offset: 9.05e-01 nm
PFT: 4.19e+00 fs/mm
Calc Rate: 81 iterations per frame
Calc Rate: 503 Calculations per second
Frames Summed: 1
Video Frame Rate = 4.6 FPS
Wavelength Adjustment
Autocorrelation
File Options Edit Help
Autocorrelation
Intensity
Time
Spectral Intensity and Phase
File Options Edit Help
Spectral Intensity and Phase
Intensity
Phase (Rad)
806 804 802 800 798 796 794
Wavelength (nm)
Configure FROG Camera
U-Eye #1
Playback #1
Playback #2
Playback File
13.bmp
Frames Per Second
5.00
Start


VideoFROG
File Options Window Temporal Analysis Spatial Analysis Help
Live (Raw) FROG
File Options Edit Help
Live (Raw) FROG
Wavelength
398
400
402
-5000 0 5000
Delay (fs)
Temporal Intensity and Phase
File Options Edit Help
Temporal Intensity and Phase
Intensity
Phase (Rad)
Time (fs)
FROG Results
File Options Edit Help
Grenouille Model= 8-500_USB
Pulse Width: 455.88 fs
Bandwidth: 0.32 THz
Bandwidth: 0.69 nm
Auto Width: 644.25 fs
TBW Product: 0.15
FROG Trace Error: 0.2002
FT Tilt: -1.88e-01 nm/mm
Lambda Offset: 2.29e+01 nm
PFT: 6.09e+02 fs/mm
Calc Rate: 101 iterations per frame
Calc Rate: 411 Calculations per second
Frames Summed: 1
Video Frame Rate = 4.5 FPS
Wavelength Adjustment
Autocorrelation
File Options Edit Help
Autocorrelation
Intensity
Time
Spectral Intensity and Phase
File Options Edit Help
Spectral Intensity and Phase
Intensity
Phase (Rad)
Wavelength (nm)
Configure FROG Camera
U-Eye #1
Playback #1
Playback #2
Playback File
20.bmp
Frames Per Second
5.00
Start

FROG plus Undulator



- Good transmission through SASE undulators with bumps around OS1 and OS2 and observing FROGs simultan-eously.



But very restricted range of SASE tuning knobs available

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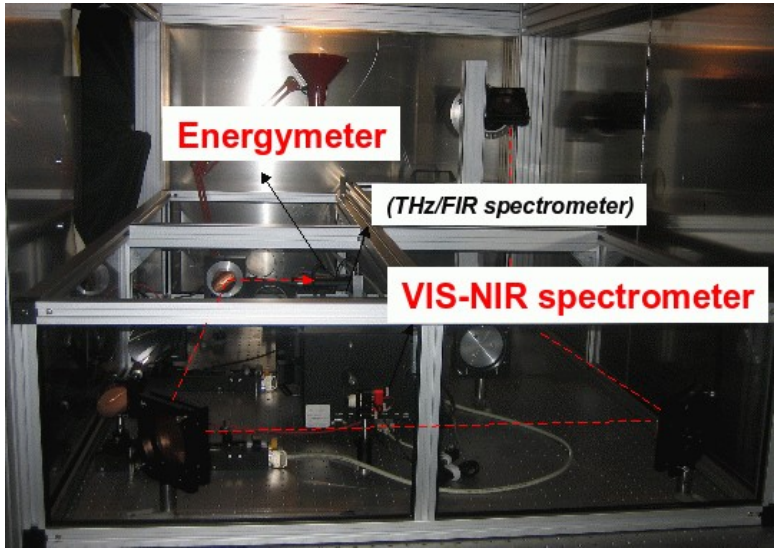
Current Limitations

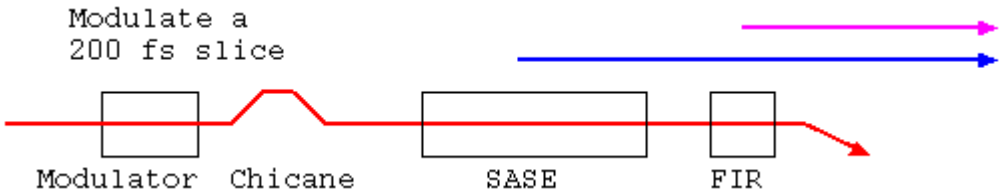
Optical Replica

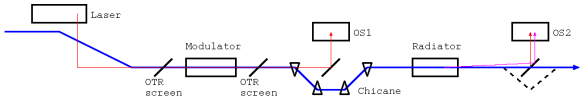
- Could find FROG traces during three shifts
  - but with short laser pulse
  - and they were weak
- Need more intensity to permit lengthening the laser pulse to cover larger fraction of the bunch.
- Current GRENOUILLE is for 5 ps and operationally convenient but the pulse is too short
  - replace by 500 fs GRENOUILLE (has only one camera)
- Alignment sensitivity on OS2

Future Plans

- Improve optics on OS2
- Replace GRENOUILLE (is available)
- ORFIR: use ORS to μbunch slice of beam and FIR undulator to radiate 200 fs pulses
  - synchronized 780 nm pulse
  - for pump-probe experiments
  - Simple test once ORS is set up







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Conclusions

Optical Replica

- We found FROG traces repeatedly 700+900 MeV
  - but with short laser and too weak
  - Have ideas to improve situation
- Comparing with LOLA works well (and found bug)
- New experiment
  - Use ORS in combination with FIR undulator
- Is it crazy to suggest using the HHG laser (much more powerful) to use for sFLASH ORS?
  - HHG would get timing setup for fundamental