Recent Results from the Optical Replica Synthesizer Experiment at FLASH

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for the ORS collaboration:

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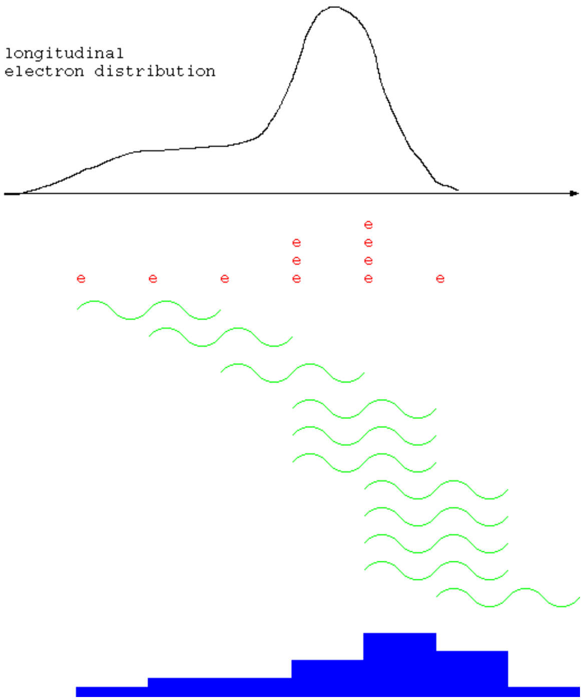
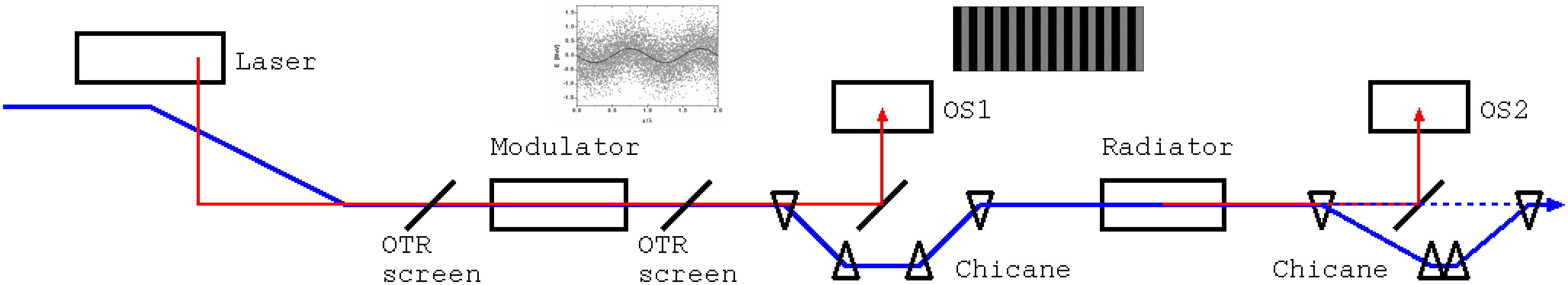
The Idea behind the ORS

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





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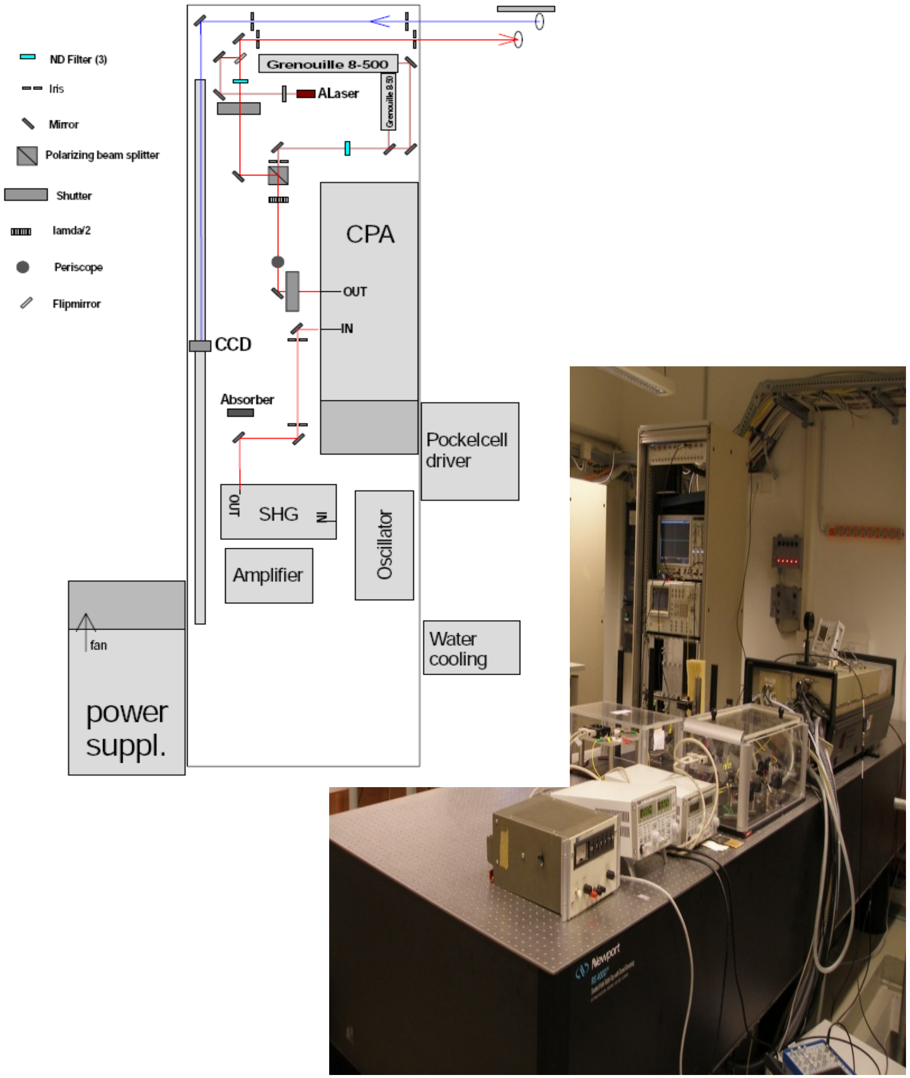
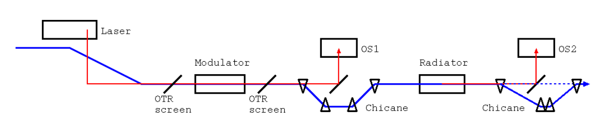
The Seed Laser

Optical Replica



- 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, 150 fs to 2 ps
- Safety shutters (ND and other)
- Diagnostics: Frog, virtual waist



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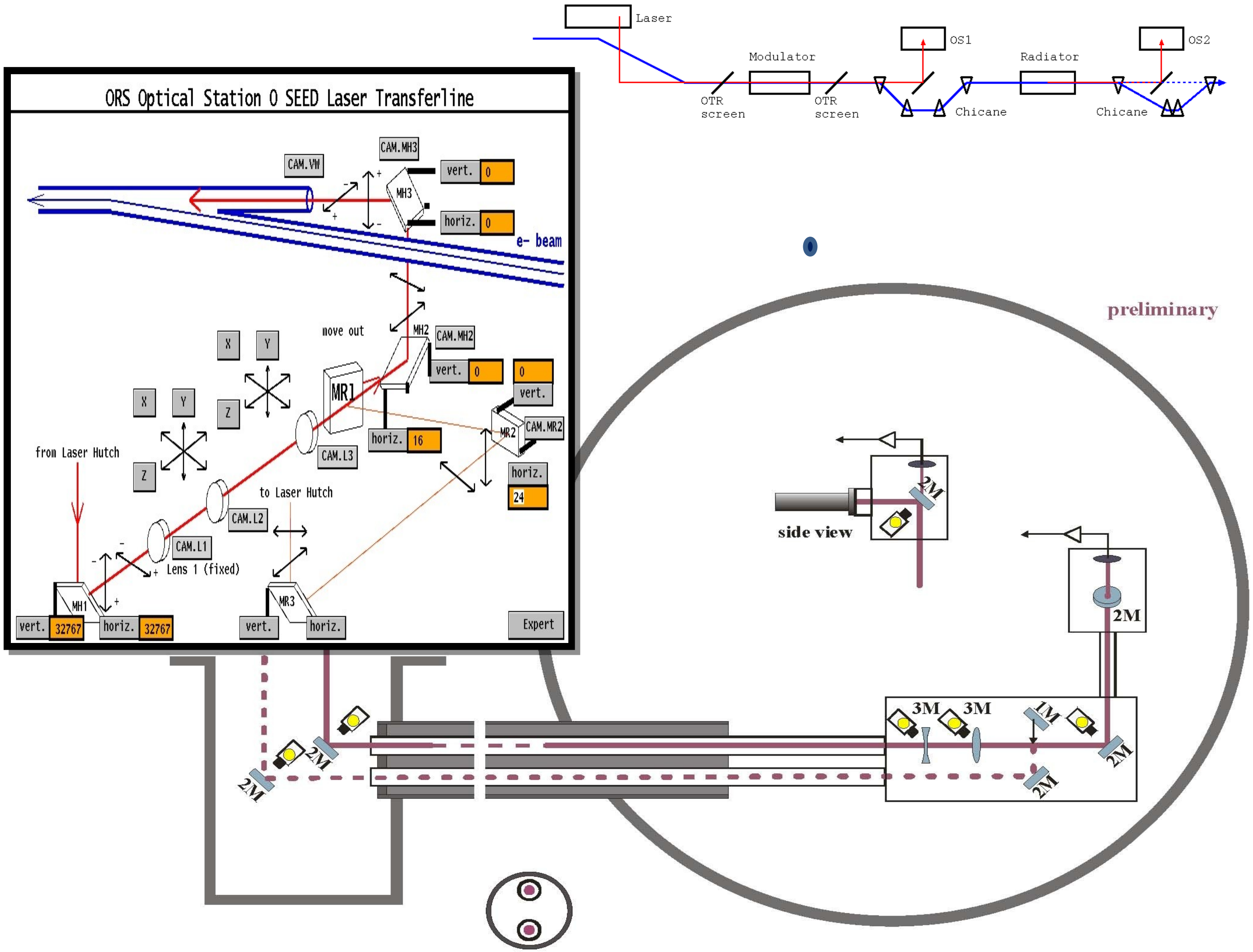
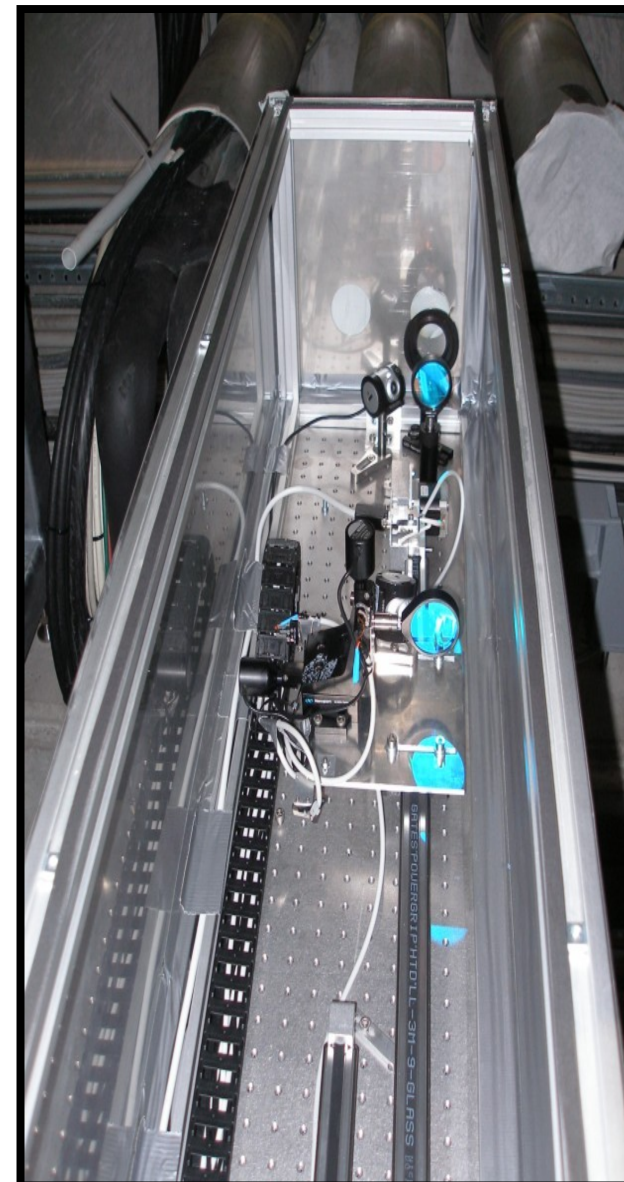
Laser Transfer Line and OS0





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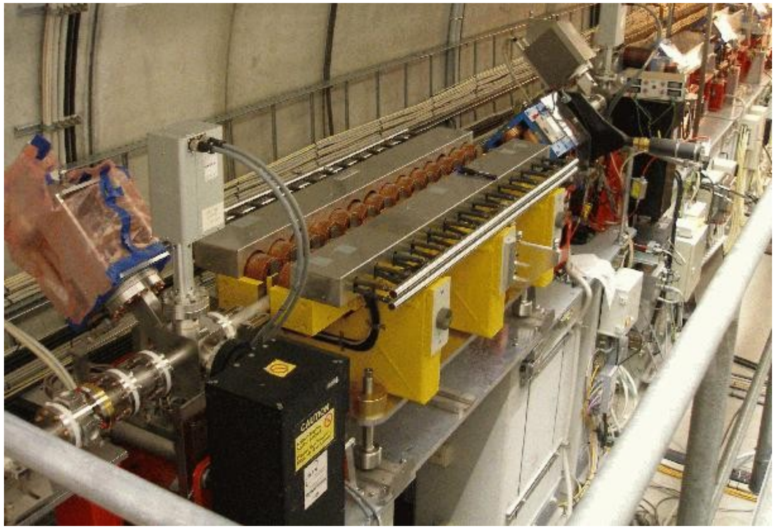
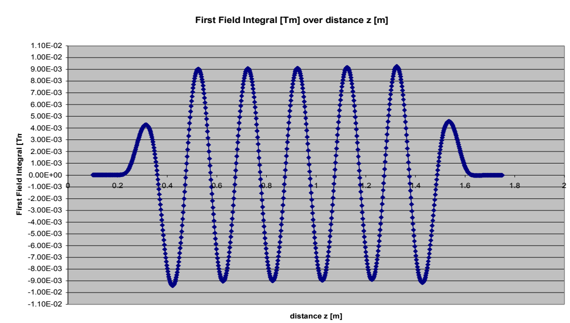
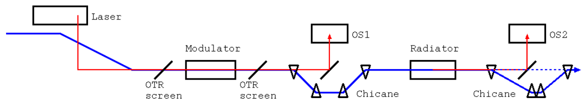
Optical Replica

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





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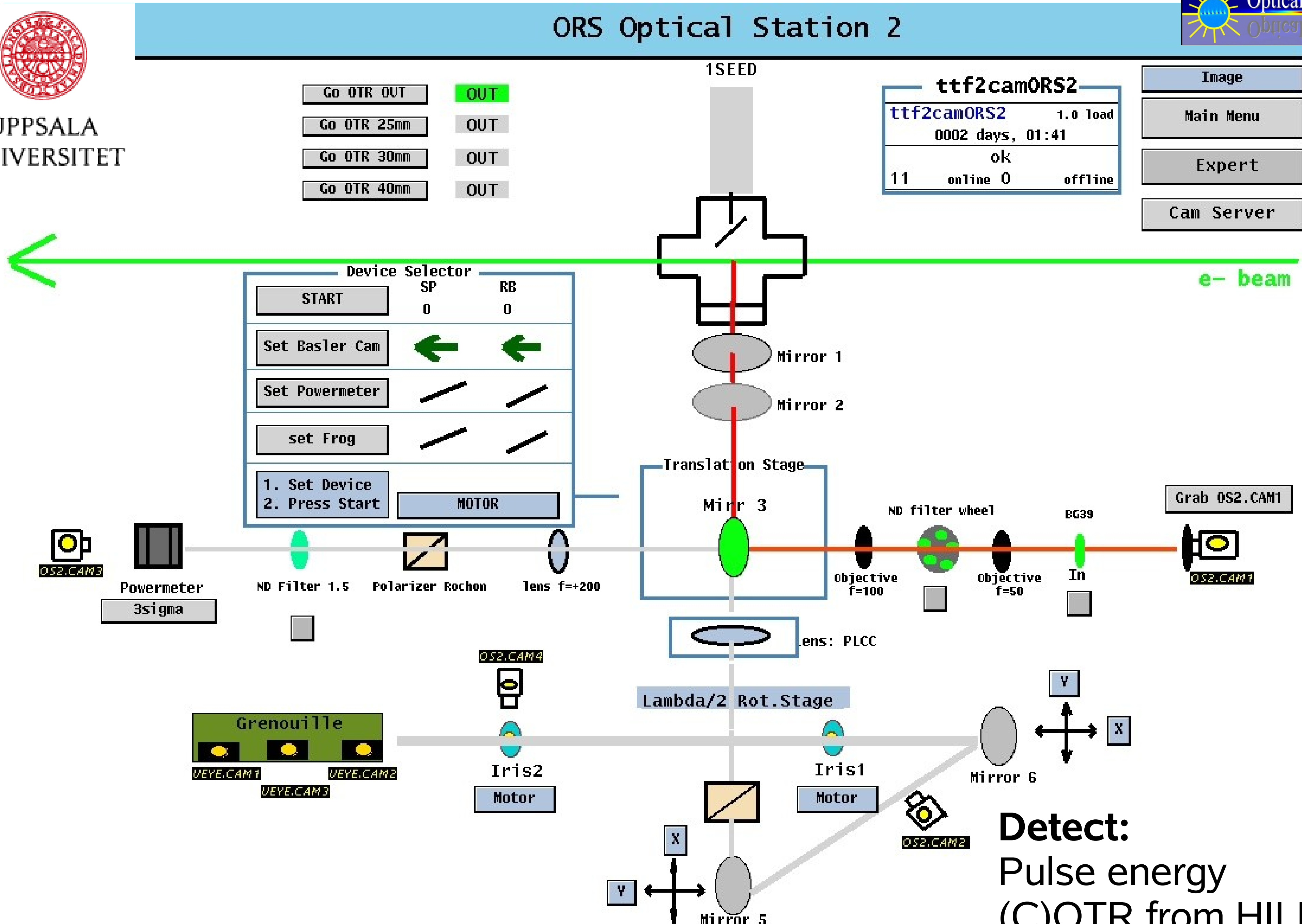
Optical Replica



Detect:

Pulse energy

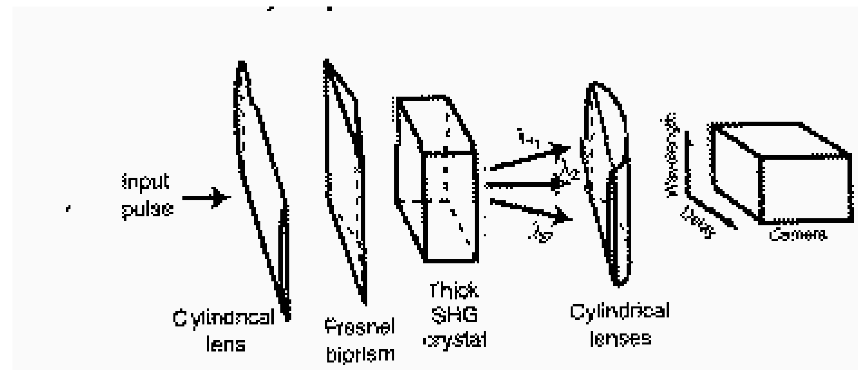
(C)OTR from HILDA

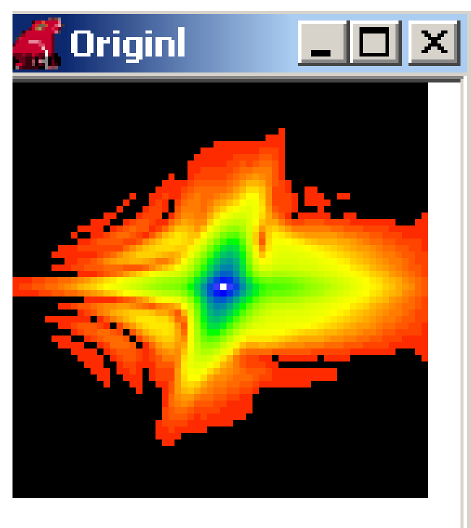
FROG

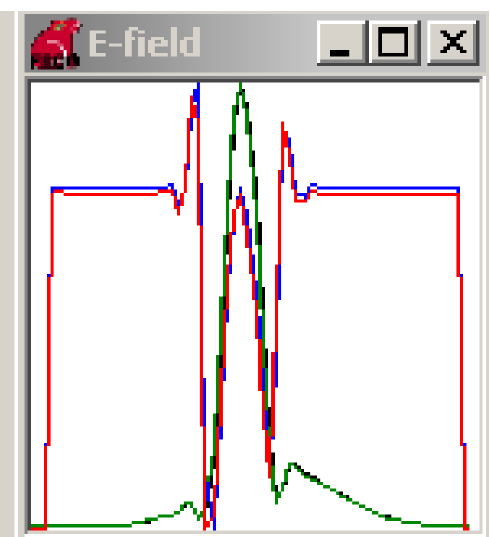
GRENOUILLE

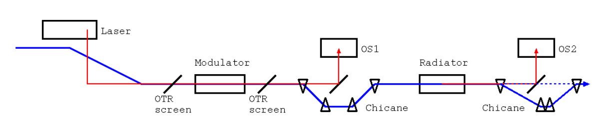
- *Cyclidrical lens* makes horizontal strip
- *Fresnel biprism* creates crossing wavefronts in thick *SHG crystal* → auto-correlator
- Effective thickness of SHG crystal varies with viewing angle → Spectrally resolved
- Second double cylidrical lens images onto camera
- Horizontally → time
- Vertically → spectrum
- GRENOUILLE USB 8-50 controlled by VideoFROG software

- Picture from Trebino's book









Experiment Preparation: Transverse Overlap

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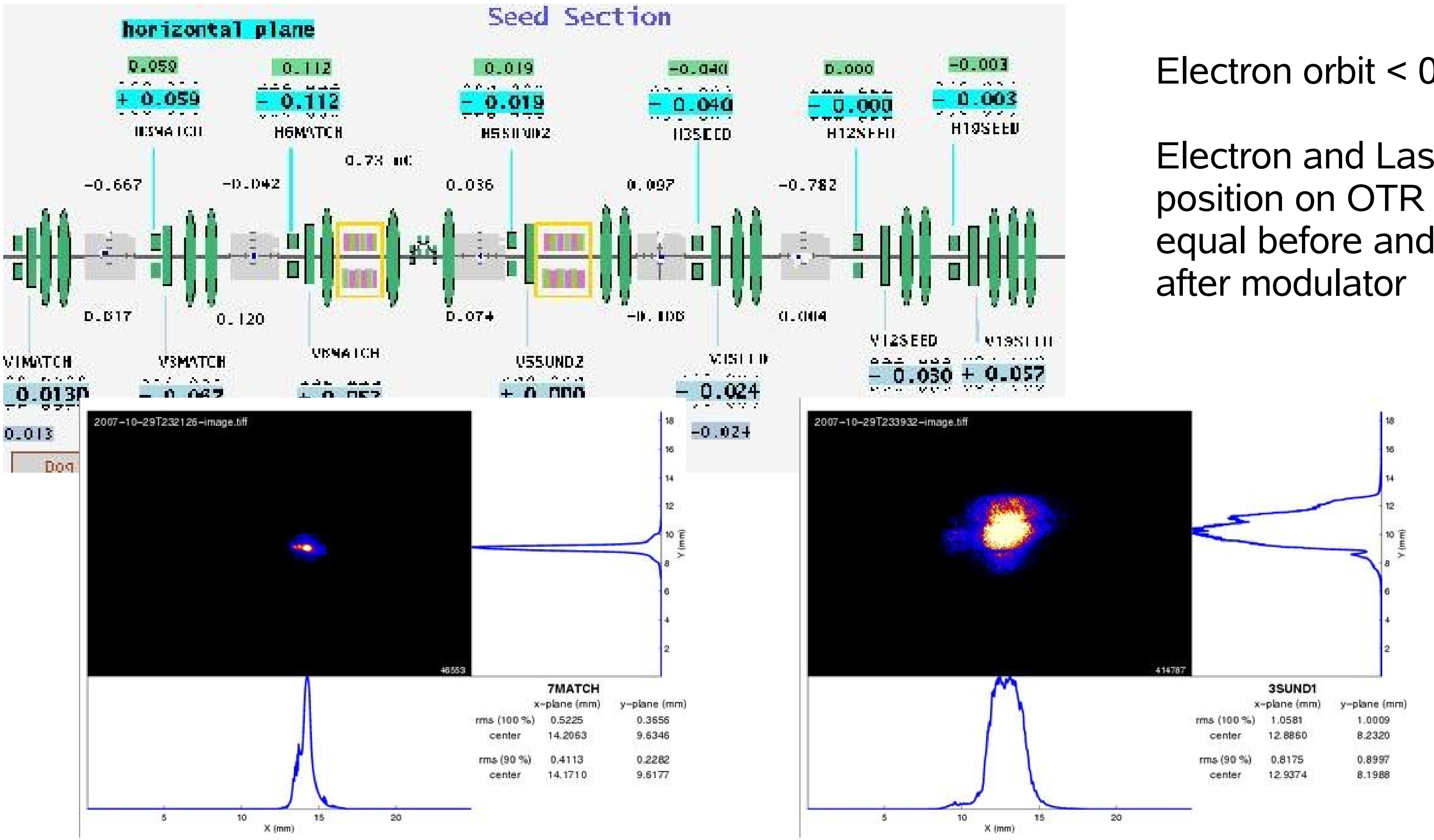
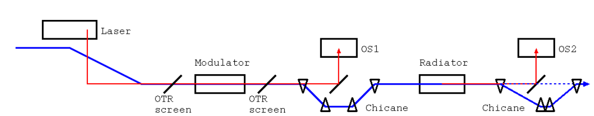
Optical Replica



Electron orbit < 0.1 mm

Electron and Laser-position on OTR equal before and after modulator



Temporal Overlap of sub-ps Electron bunch und Laser pulse

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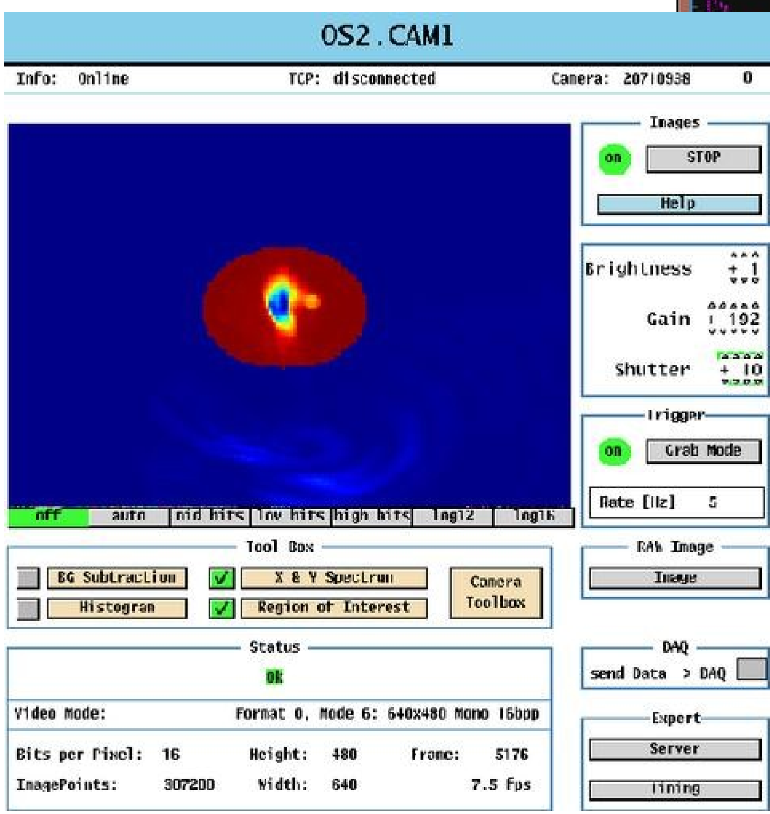
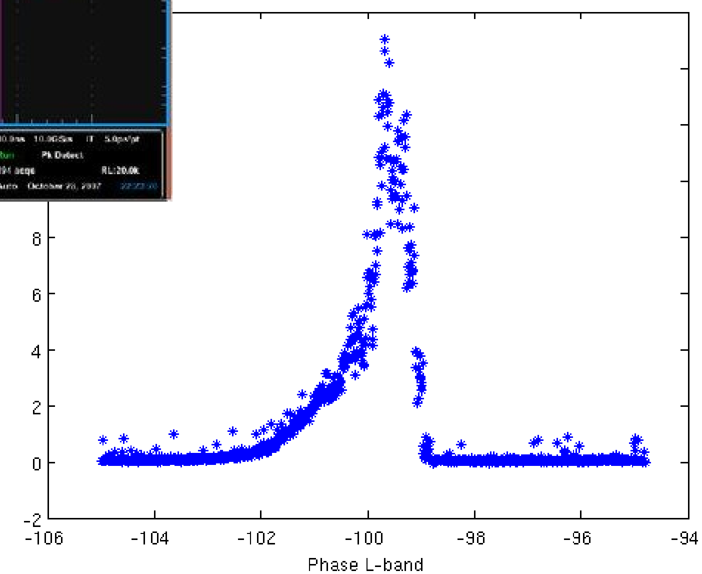
Optical Replica

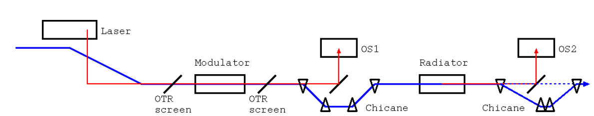
Rough adjustment on photo diode on OS1 per synchrotron radiation and laser ~ 100 ps

Fine-tuning on OS2 by observing cohrrent OTR of modulated electrons
* 2nd harmonic (BG39)
* Intensity in R.O.I



Adjust laser-timing in ~100 fs steps



OTR on OS2-camera while 200 fs laserpulse passes through electron bunch

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **11**, 070702 (2008)

Observation of two-dimensional longitudinal-transverse correlations in an electron beam by laser-electron interactions

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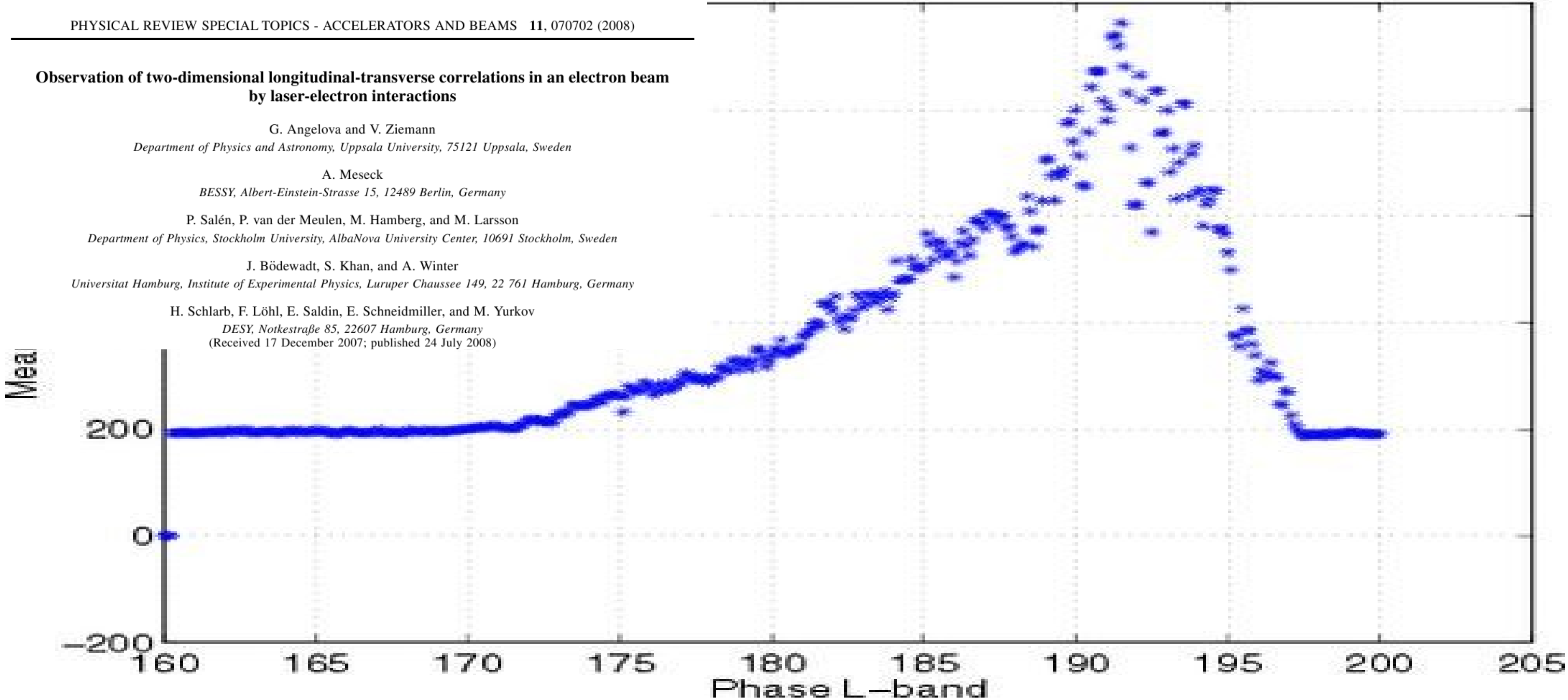

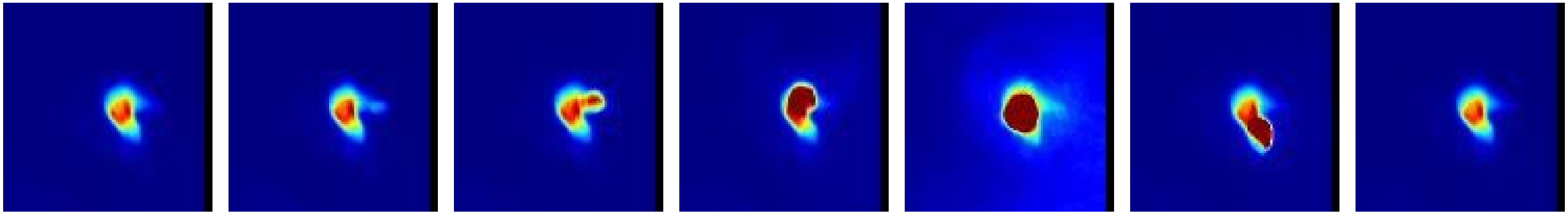

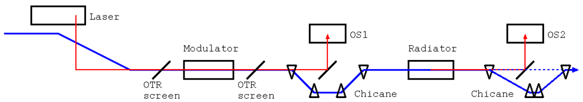

...finally: Single-shot FROGs (preliminary, analysis in progress)

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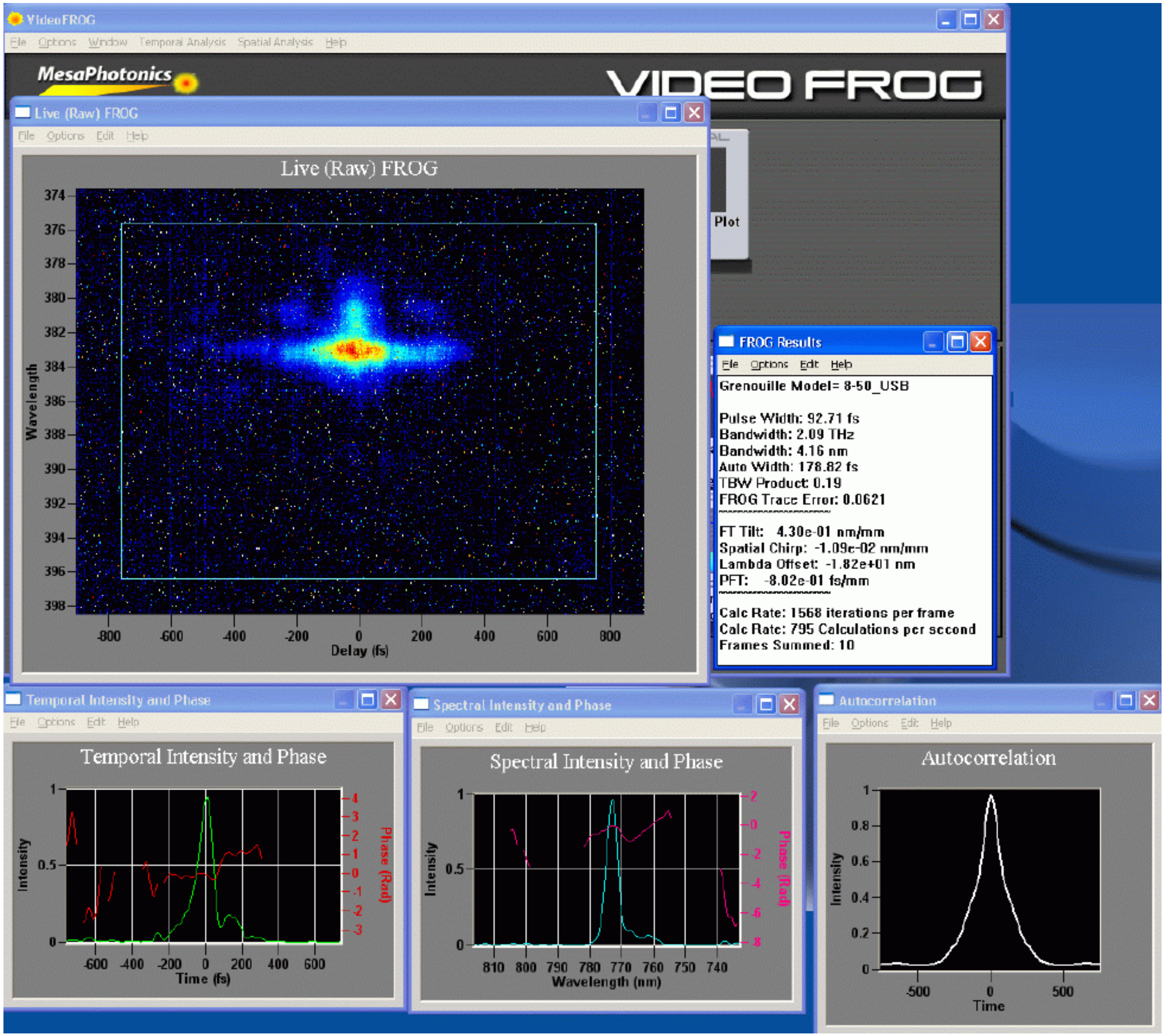
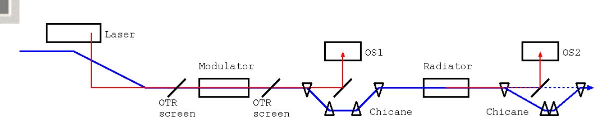
Optical Replica



- From radiator (HILDA)
- Significant tuning with OS2 Setup
- long/short Grenouille
- First shortE/shortL because of intensity
- Here shortE/longL during SASE conditions at 700 MeV (13 nm)
- Unfortunately no simultaneous LOLA measurement
- Parasitic operation



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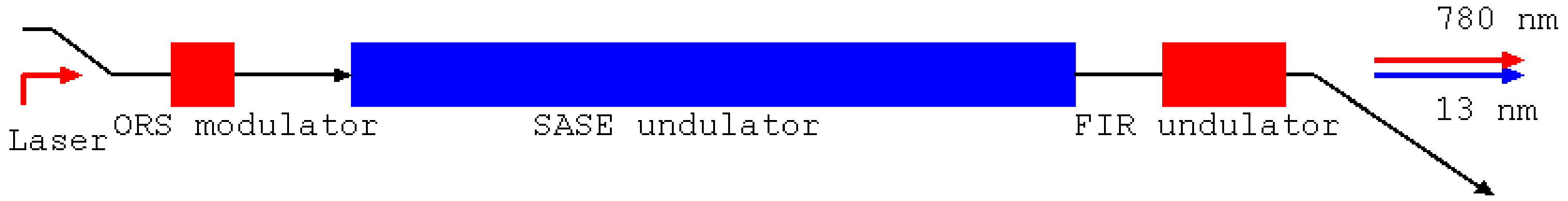
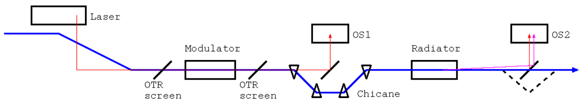
Spin-off: ORFIR



- ORS modulator (Laser + Veronica + Chicane) generates density modulation at 780 nm
- SASE-undulator generates VUV pulse (13 nm)
- FIR-undulator emits 780 nm pulse from the same electron bunch (synchronized)
- Tested successfully in January and March in collaboration with M. Gensch's group



Conclusions

- Installed and commissioned the optical replica synthesizer in FLASH since fall 2007
- We managed to hit the electron bunch with laser
  - can be used to measure longitudinal-transverse correlations in long (few ps) bunches
- Eventually recorded online FROG traces from the short-pulse GRENOUILLE
  - unfortunately no simultaneous LOLA measurements
- Need time for parameter scans to learn system
- Electron-laser interaction spin-off: ORFIR
- ORS is scheduled to be moved to sFLASH

Backup slides

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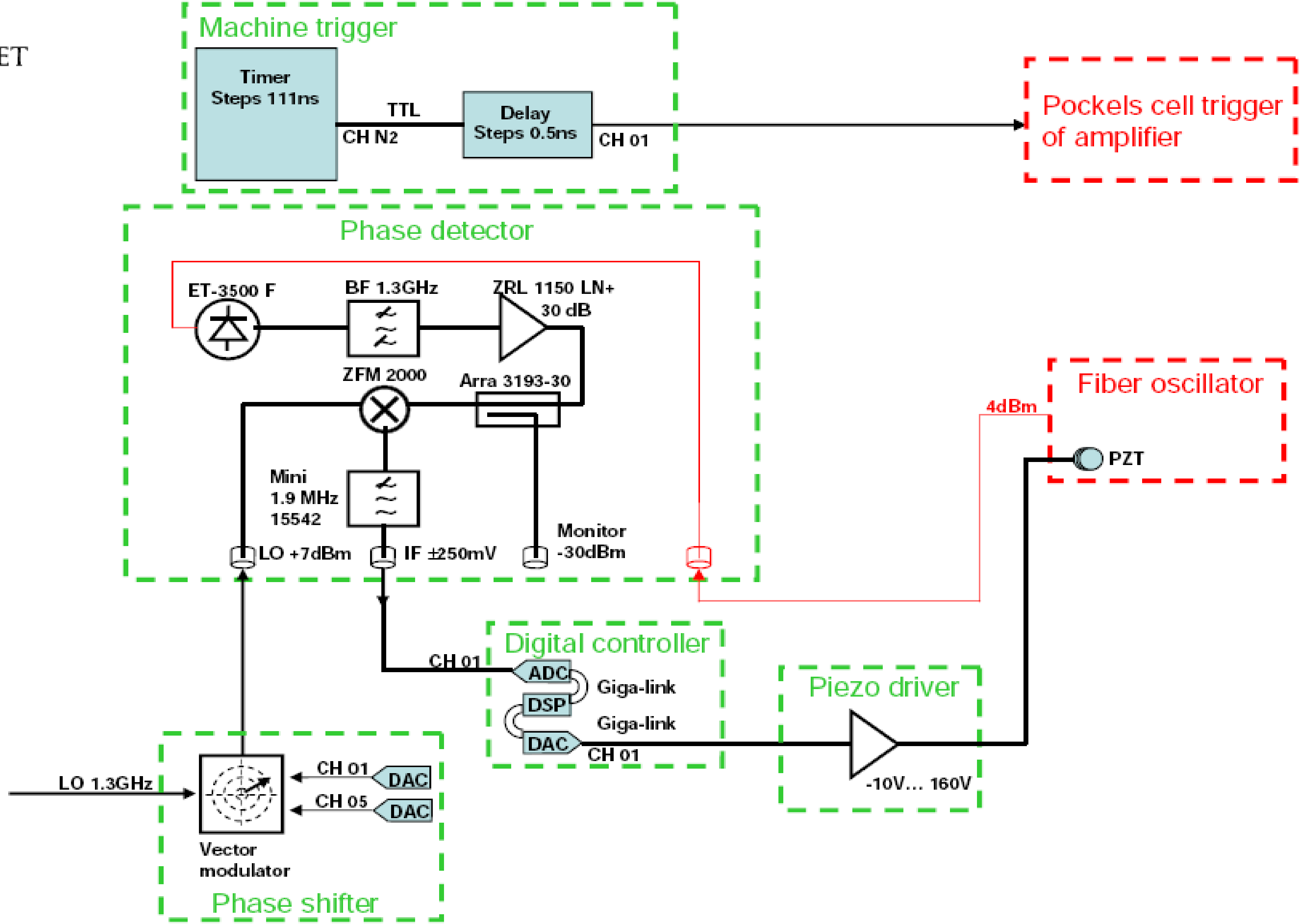
Scheme of the ORS synchronization & trigger system



Optical Station 1

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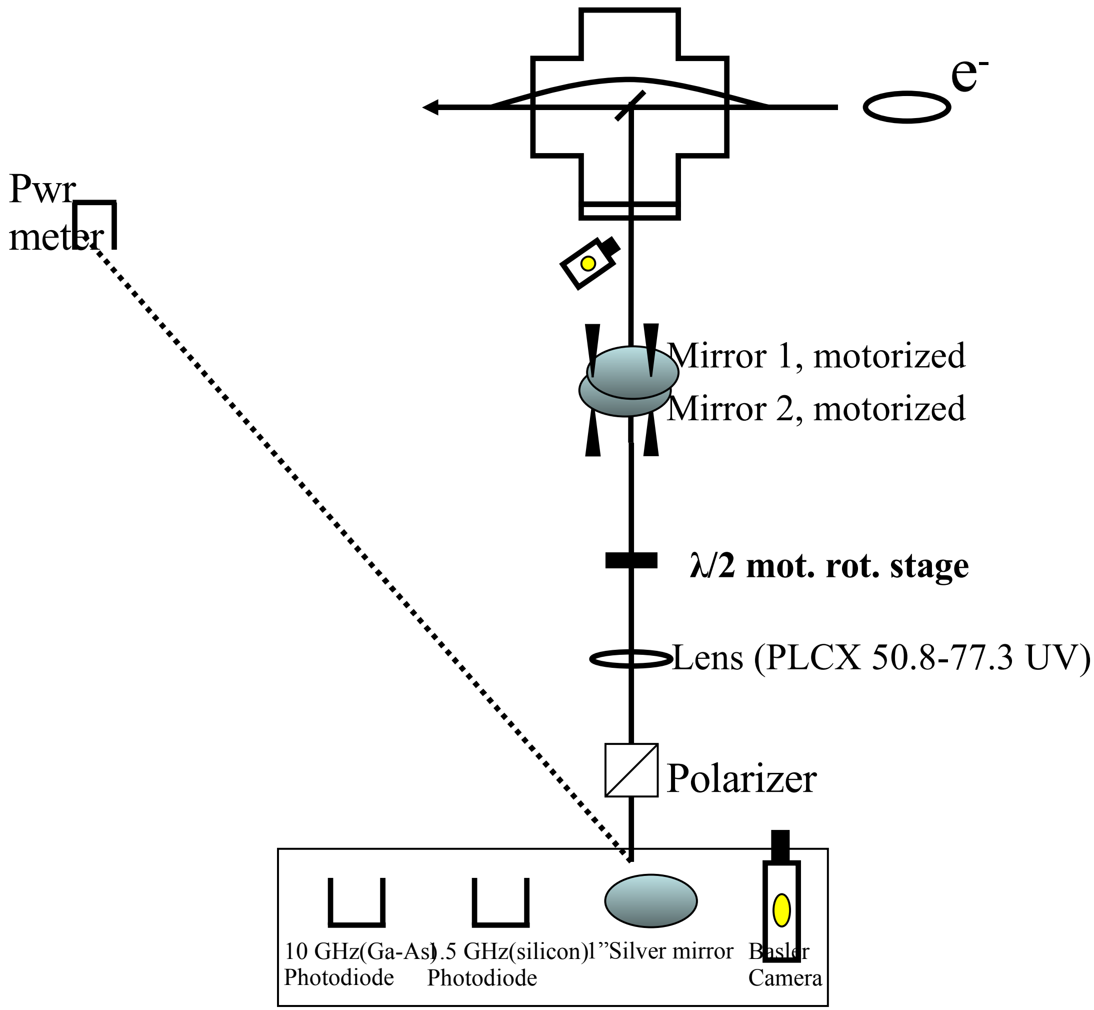
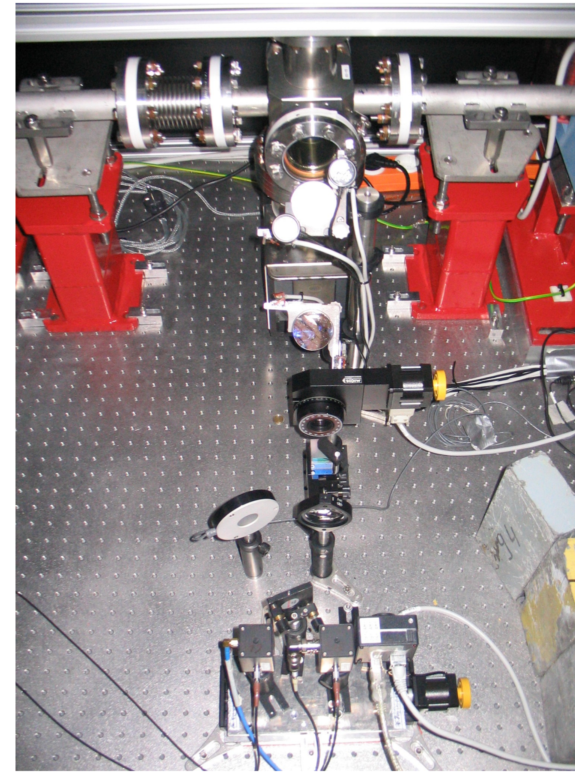
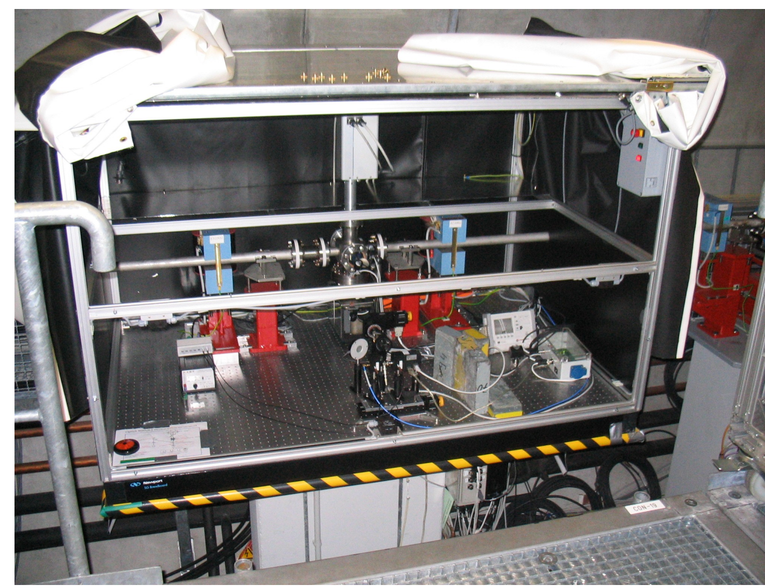
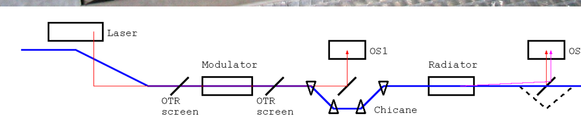
Essential for timing: Laser + Synchrotron radiation









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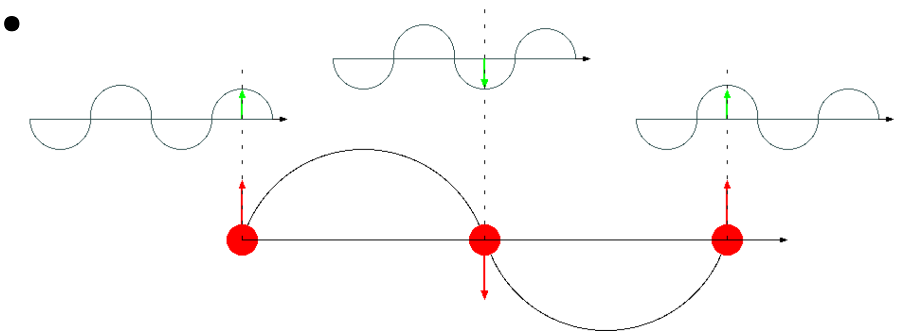
Seed Laser and Modulator

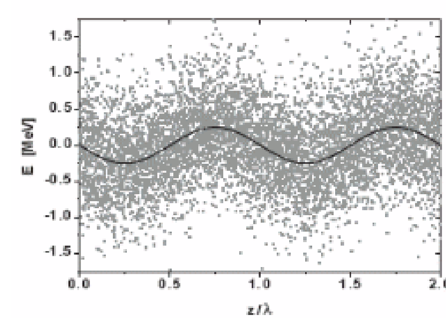
- Seed laser must overlap electron bunch and provide sufficient strength to modulate the energy
- probably Ti:Sapphire
- Length: a few ps, say 10 ps
- Synchronization to bunch RF and electron gun
- Power: 100 MW, 1 mJ/pulse, 5 Hz
- modulation amplitude: dp/p ~ 10^{-3}
- Need dog-leg to shine laser onto electron trajectory
- Undulator with about 5 periods

- Coupling between laser and electrons

$$\Delta U = e\int(\vec{E}.d\vec{s}) = e\int E_x v_x dt$$

- 

- Some gain, some loose, depending on initial phase



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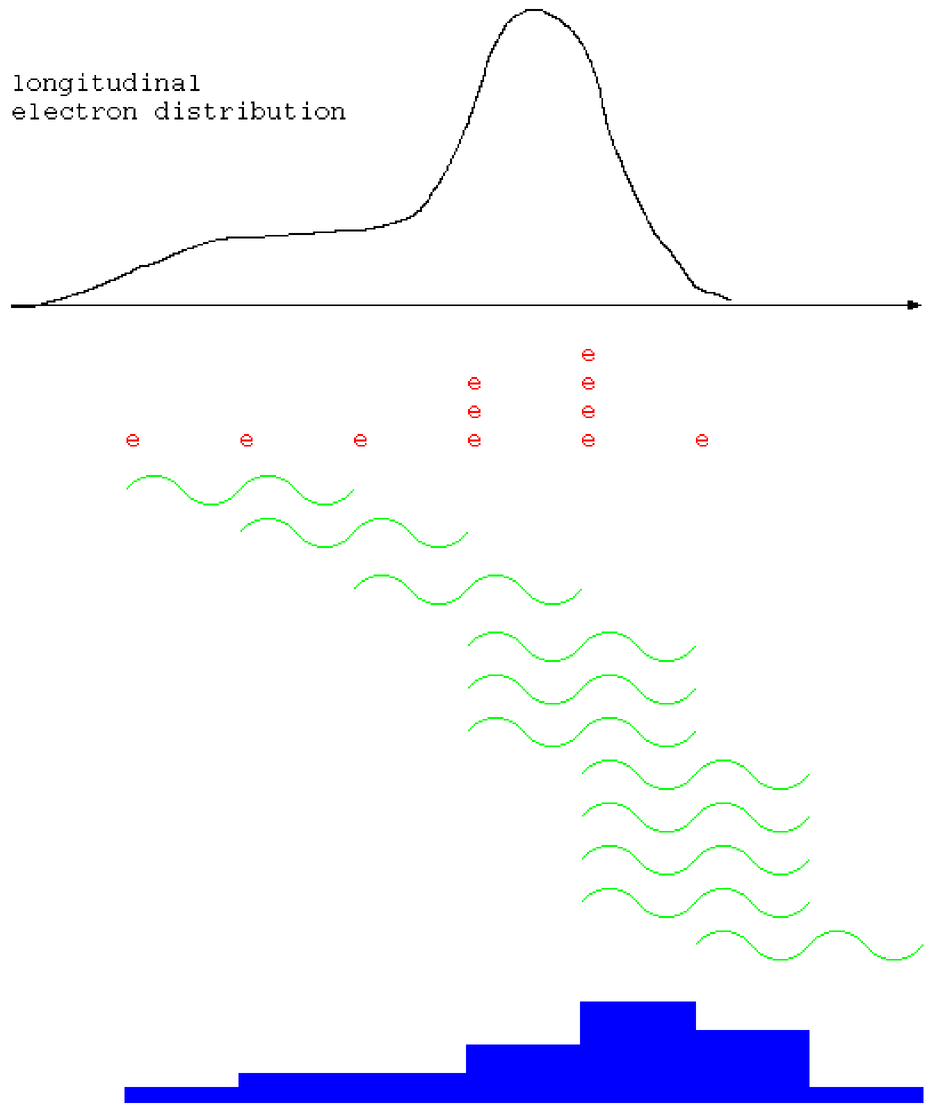
Radiator Undulator



- Electrons have longitudinal density modulation and can radiate coherently.
- Each electron slice oscillates in undulator (like an antenna) and all contributions are added in phase.
- Number of periods *N* determines the length of the light pulse that an electron emits → short undulator
- Need to propagate replica pulse to diagnostic section

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Resolution

- 8-50: 17 fs
- 5 Periods
  - 4 µm/13 fs
- Wavefront tilt
- Dispersion in optics on OS2
- Bent(?) mirrors
- Plasma-oscillations(?)

- Grenouille: Datenblatt von Swamp Optics

GRENOUILLE model:	8-9USB	8-20USB	8-50USB	8-300USB	8-500USB
Wavelength range:	700 – 1100 nm				700 – 900 nm
Pulse-length range @ 800 nm:	~10 – ~100 fs	~20 – ~200 fs	~50 – ~500 fs	~0.3 – ~2 ps	~0.5 – ~5 ps
Pulse-length range @ 1050 nm:	~8 – ~80 fs	~15 – ~80 fs	~30 – ~100 fs	~0.1 – ~1 ps	na
Temporal resolution @ 800 nm:	3.7 fs	12 fs	17 fs	50 fs	90 fs
Temporal resolution @1050 nm:	2 fs	9 fs	13 fs	41 fs	na
Delay increment[1]:	0.95 fs/pixel	0.85 fs/pixel	1.145 fs/pixel	11.5 fs/pixel	11.5 fs/pixel
Temporal range[3]:	336 fs	480 fs	1.9 ps	19 ps	19 ps
Spectral resolution @ 800 nm:	5 nm	4 nm	2 nm	0.23 nm	0.05 nm
Spectral resolution @1050 nm:	6.5 nm	15 nm	7 nm	0.8 nm	na
Spectral range @ 800 nm[3]:	300 nm	160 nm	50 nm	8 nm	10 nm
Spectral range @1050 nm[3]:	400 nm	400 nm	125 nm	20 nm	na
Pulse complexity:	Time-bandwidth product < ~10				
Intensity accuracy:	2%				
Phase accuracy:	0.01 rad (intensity-weighted phase error)				
Single-shot possible?	Call us.[2]	Yes; both free-running mode & triggered single-shot are now standard.			
Sensitivity (single-shot):	Call us.[2]	1 µJ			
Sensitivity (at 10^3 pps):	500 µW (500 nJ)	100 µW (100 nJ)			
Sensitivity (at 10^8 pps):	50 mW (500 pJ)	10 mW (100 pJ)			
Spatial profile accuracy:	< 0.2 % (Camera has true 8 bits and 480 x 640 pixels)				
Spatial chirp accuracy (dx/dλ):	1 µm/nm				
Pulse-front tilt accuracy (dt/dx):	0.05 fs/mm				
Required input polarization:	Any (just rotate GRENOUILLE!)				
Required input-beam diameter:	2 – 4 mm (collimated)				
Input-beam lateral-displacement tolerance:	> 1 mm				
Number of alignment knobs:	Zero				
Time to set up:	~ 10 minutes				
Dimensions (L x W x H) w/camera:	33 cm x 7.5 cm x 16.5 cm	33 cm x 7.5 cm x 16.5 cm	33 cm x 4.5 cm x 11.5 cm	45 cm x 7.5 cm x 16.5 cm	61 cm x 7.5 cm x 16.5 cm
Weight:	3 kg	3 kg	1.2 kg	3 kg	6 kg

1. At full camera resolution.
2. The Model 8-9 can be modified to allow single-shot measurement, but at a reduction in sensitivity.
3. Temporal and spectral "ranges" are the full-scale ranges, not the pulse FWHM (which is typically a factor of 2 to 3 smaller).

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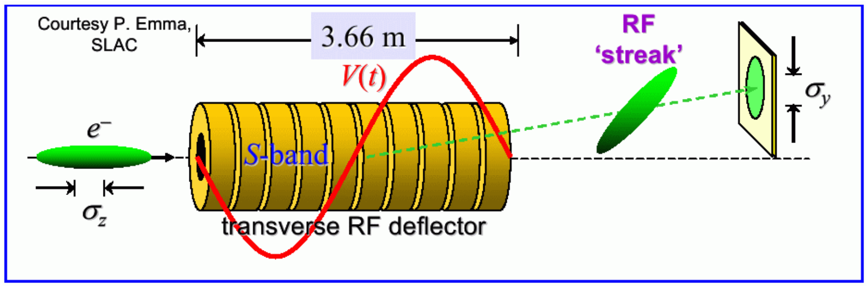
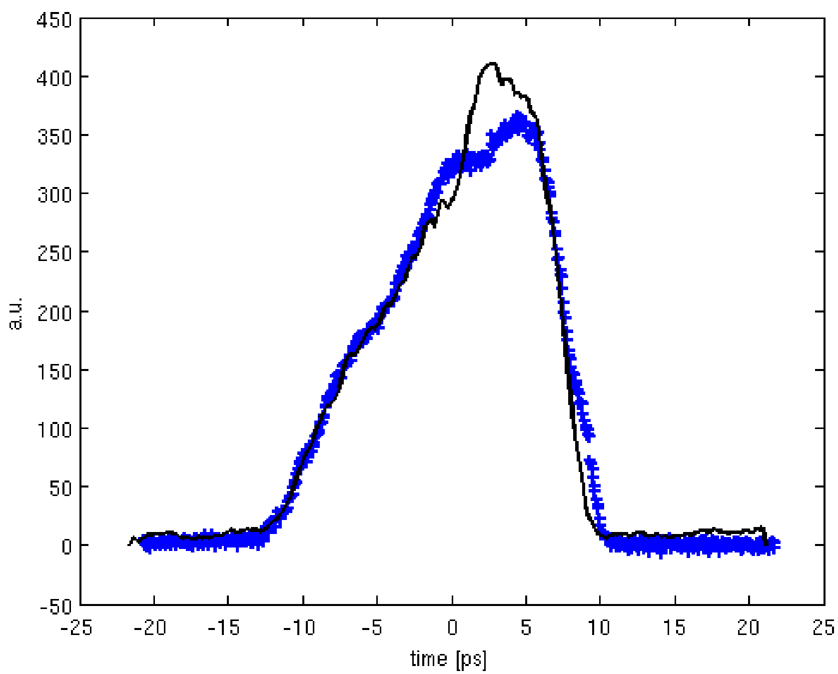
Comparison with LOLA (long several ps bunches)





- 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