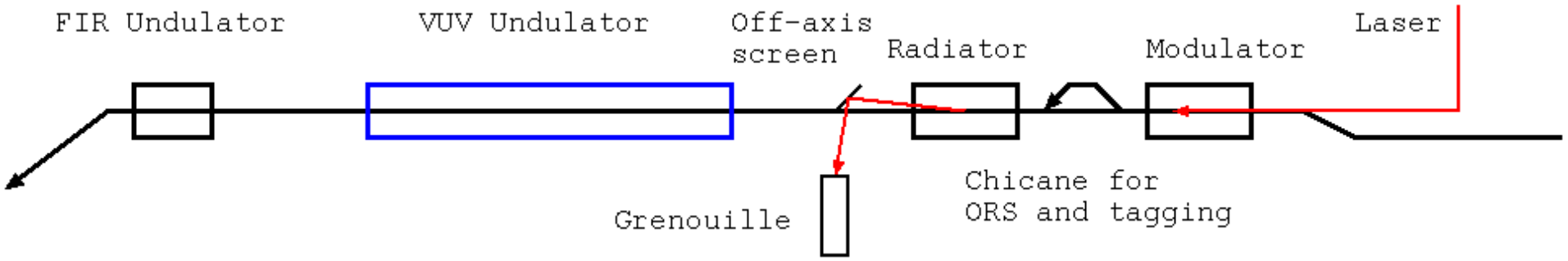
Status of the Optical Replica Synthesizer at DESY

V. Ziemann, Uppsala University
P. van der Meulen, M. Larsson, Stockholm University
H. Schlarb, M. Yurkov, E. Schneidmiller, E. Saldin, DESY

What and How?



- Measure the longitudinal bunch profile of the femto-second long electron bunches (Saldin, Schneidmiller, Yurkov: NIM A 539 (2005) 499.)
- Energy modulation via (v.E) coupling
- Longitudinal density modulation in chicane
- Cause coherent emission of light pulse in radiator that mimics the longitudinal shape of the electron bunch (optical replica).

What else can we do with it?

- Second coherent pulse from FIR undulator or radiator for time-stamping (Bunch in modulator and use the FIR to generate coherent pulse synchronized with the beam that can be mixed with the pump-probe laser).
- Coherent transition radiation from modulated electron beam (Poor man's replica).
- Use as first stage of HGHG FEL.
- X-FEL Laser heater is very similar to modulator plus laser.

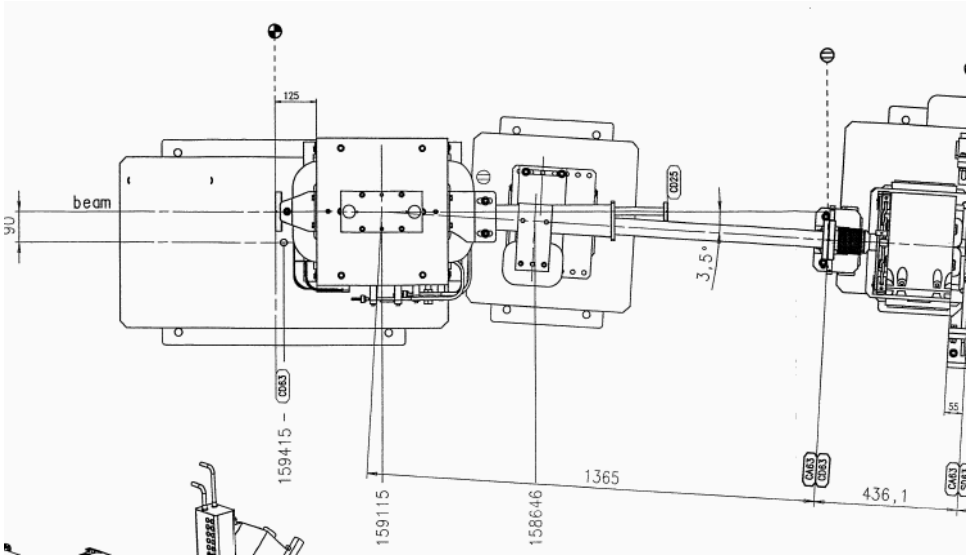
Seed Laser

- Peter van der Meulen (SU) and Axel Winter (DESY).
- Synchronized Er-fiber oscillator with frequency doubler from DESY.
- CPA2001 Ti:Sapph amplifier from Stockholm University.
- Internals (stretcher and compressor gratings) of CPA are unknown and grating misalignments may results in chirped and tilted pulses.
- Parameters:
  - Length = 2 ps (FWHM)
  - Energy/pulse=0.25 mJ, Peak field = 1.8 10^8 V/m
  - Width = 0.75 mm (FWHM)
- Post Doc for the laser starts in May.

Laser Hut

- Presently lasers (electro-optical) are housed in a container next to the tunnel.
- On hole to the tunnel exists.
- A new hole into the tunnel close to the chicane will be dug.
- A large laser villa (150 m^2) for the existing lasers and the optical replica seed laser is planned.

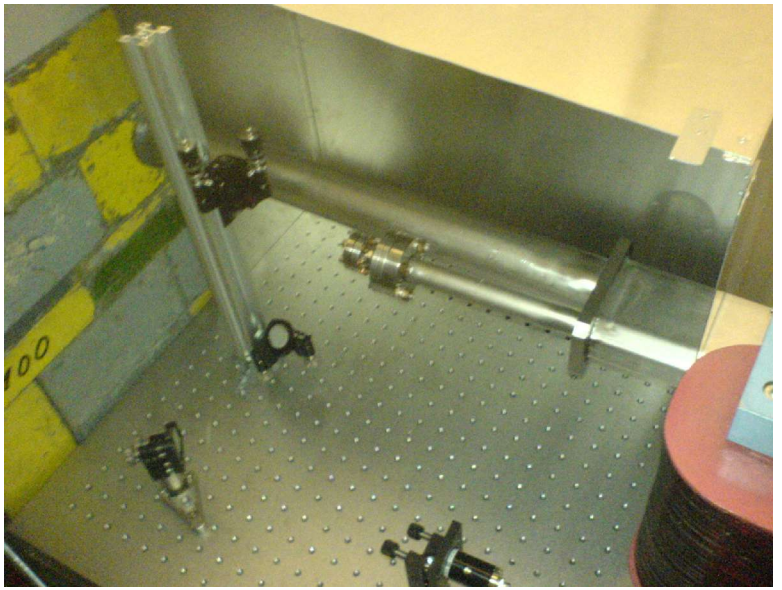
Seed Laser Vacuum Interface and Characterization and Alignment



Laser feed just upstream D7ECOL at 159.1 m

Need bigger window than the present 16 mm

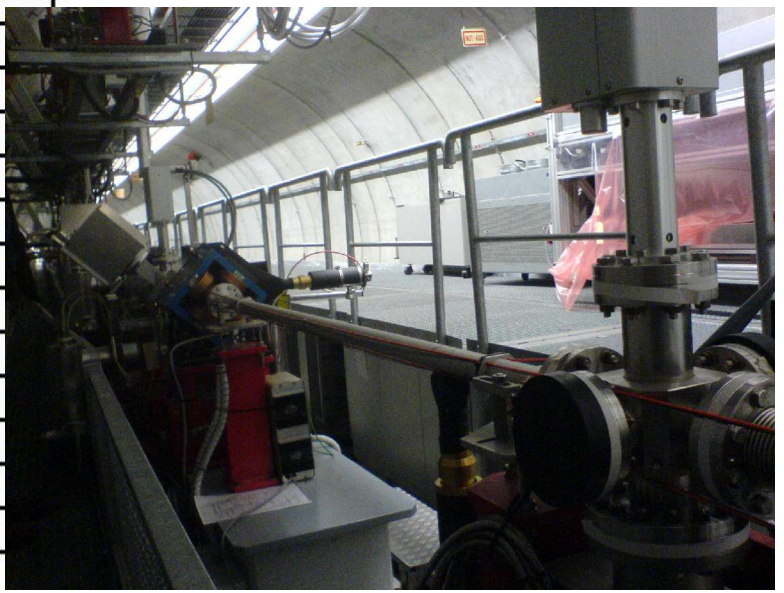
- Need to characterize seed laser with nearby GRENOUILLE
- Alignment of the laser requires more thought, possibly with remotely controlled mirrors and diodes.
- Matching of the waists with remotely controlled lenses.
- Monitoring during operation.



Undulators

Parameter	Value
Type	Electromagnetic
Number of undulator	1-2 (vert + horiz)
Gap	40 mm
Period length	200 mm
Pole length/width	50/100 mm
Number of full periods	5
Number of poles	14
Nominal field	0.31 T
Nominal K-Value	5.7
Maximal field	0.42 T
Maximum K-Value	7.7
Iron yoke length	1400 mm
Overall length incl. coils	< 1500 mm
Ampere-turns per coil	to be decided
Number of turns	to be decided
Maximal current	< 400 A, better < 100 A
Number of basic / end coils	10 main, 4 end coils
Vacuum chamber diameter	35 mm
First field integral	5×10^{-5} Tm
Second field integral	2×10^{-4} Tm^2

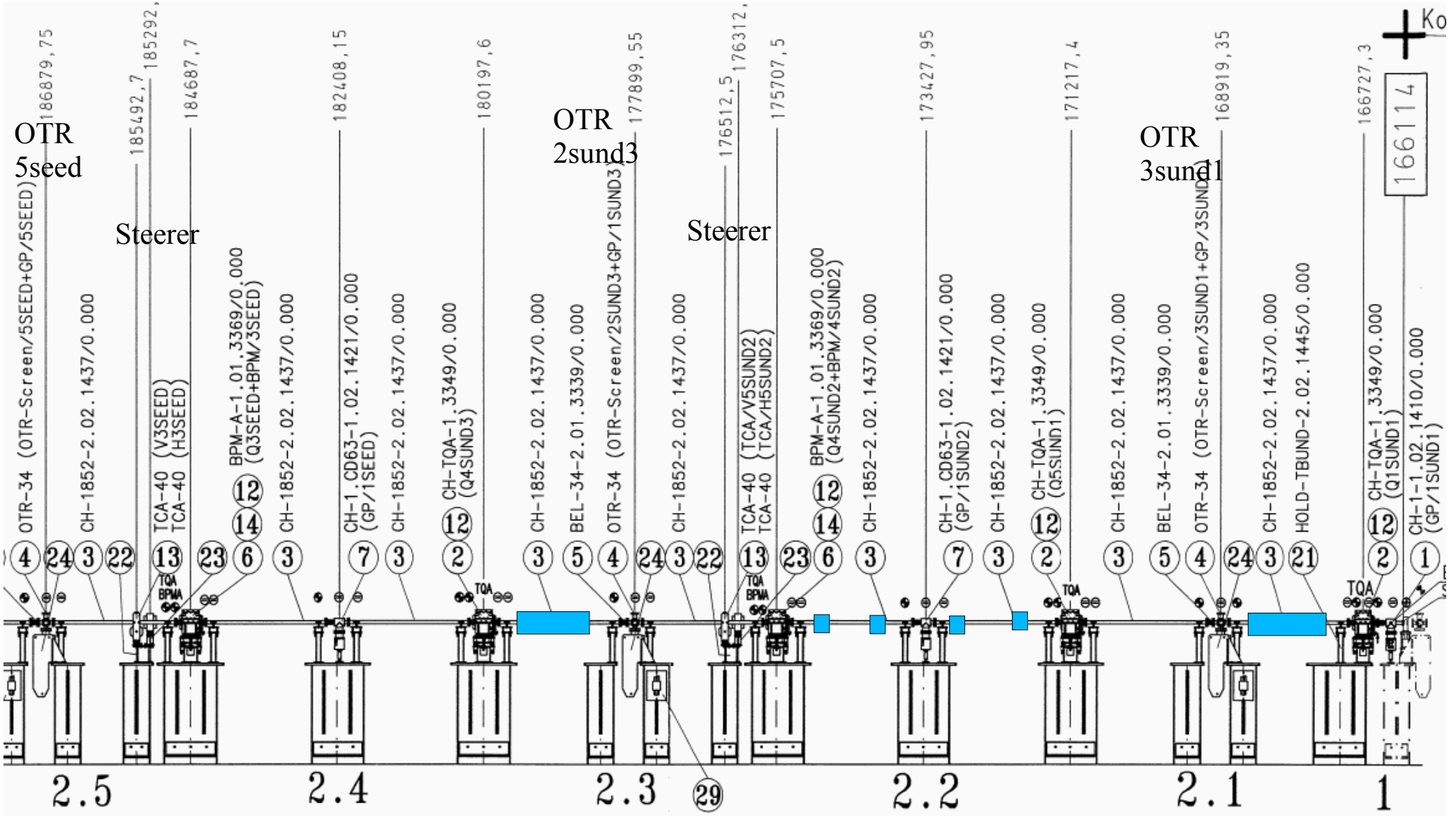
- Two electro-magnetic undulators are ordered from Scanditronix
- Delivery in spring 2007
- Space for one undulator



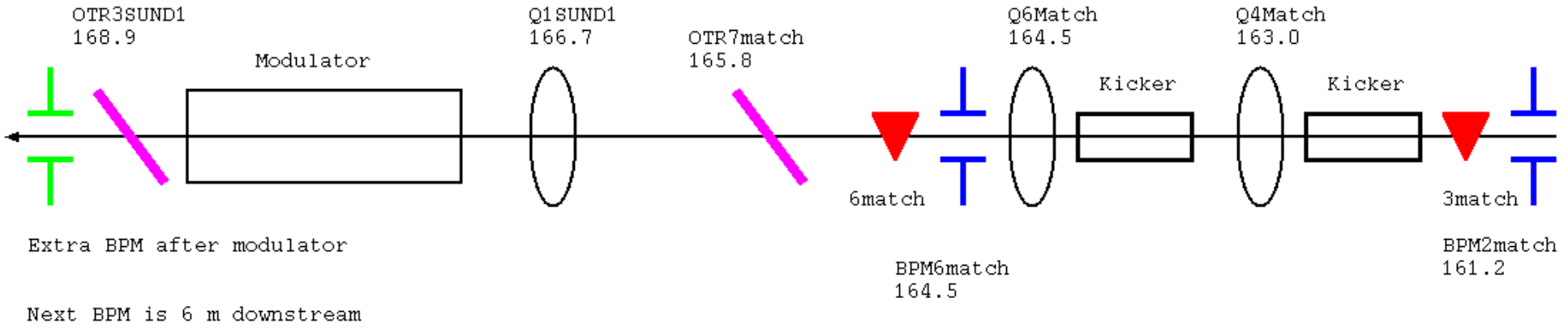
Separating the (strong, mJ) seed laser from the (weak, tens of μJ) replica pulse

- Orthogonal polarization from crossed undulators.
- Modulator vertically polarized. (Separation of the spontaneous radiation from dog-leg dipole with horizontal polarization)
- Radiator horizontally polarized.
- Absorb the seed laser in the chicane.
- Higher harmonics problematic: The TiSa 800 nm has 2^{nd} harmonic 400 nm, which cannot be phase-matched in the BBO.

Magnet Positions, etc



Alignment of electron beam in Modulator



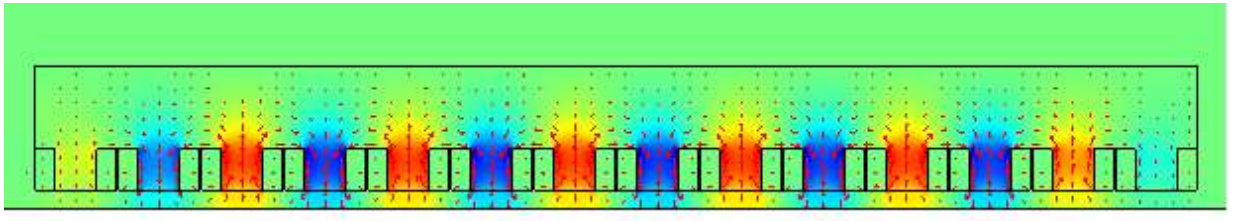
- Two steering magnets (3match + 6 match) available, R_{12}s are approx 2 and 5 m, seems OK.
- OTR screens (7match and 3sund1) near the modulator for overlap determination.
- One extra BPM downstream of modulator for alignment is part of orbit feedback system done by DESY and PSI.

Chicane

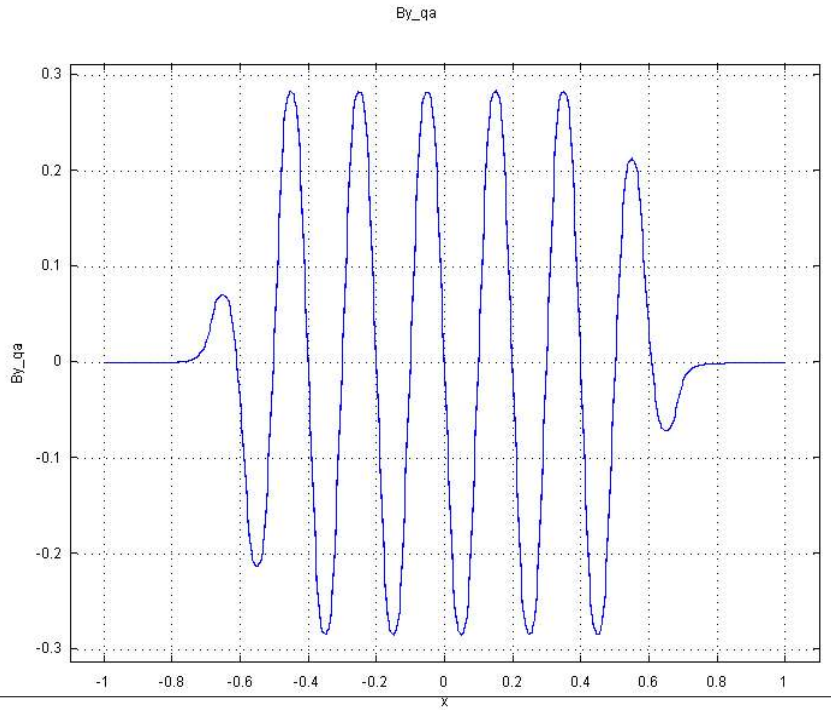
- Transform energy- into density-modulation.
- Use for ORS but also for timing/tagging in conjunction with FIR undulator.
- 1.5 m between dipoles
- 10 mrad (33 10^{-3} Tm @ 1 GeV)
- $R_{56} \approx 2 \times 1.5 \times \theta^2 = 300$ micron

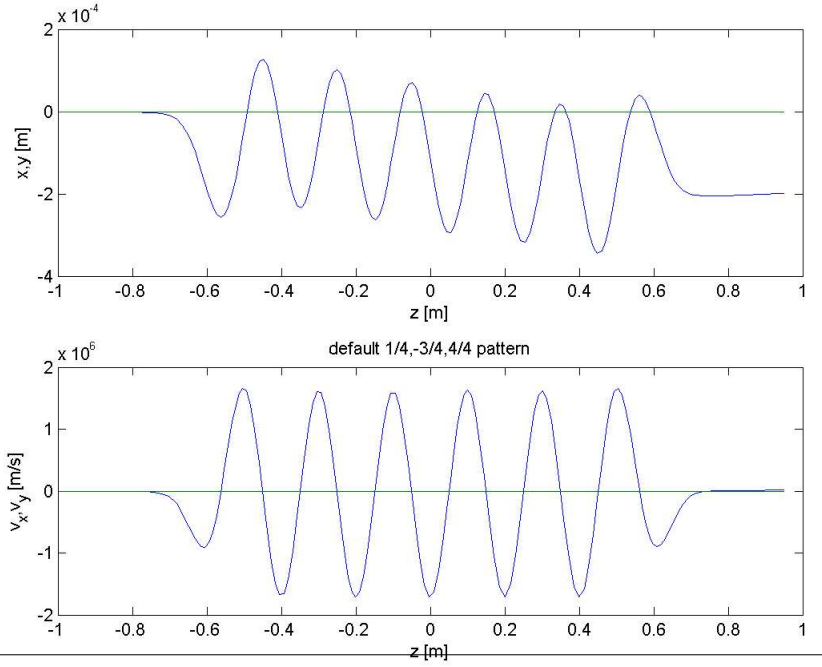
- maximum displacement ≈ 15 mm @ 300 micron
- maximum displacement ≈ 7.5 mm @ 75 micron
- Place mirror to extract seed laser in chicane.

Radiator Field, Integrals and Orbit

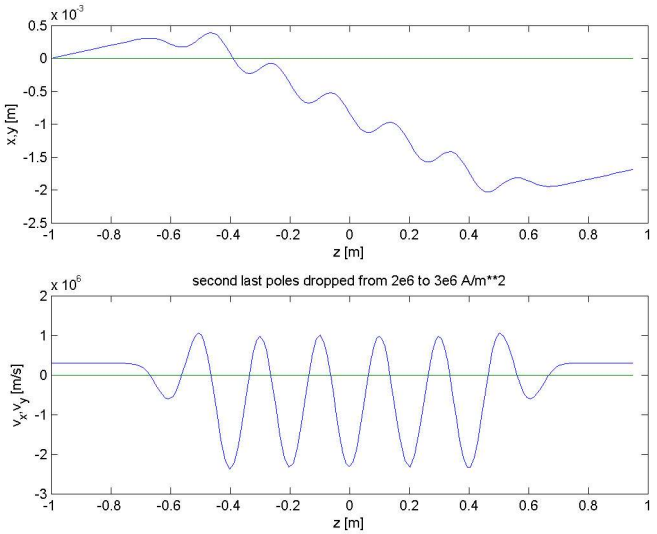


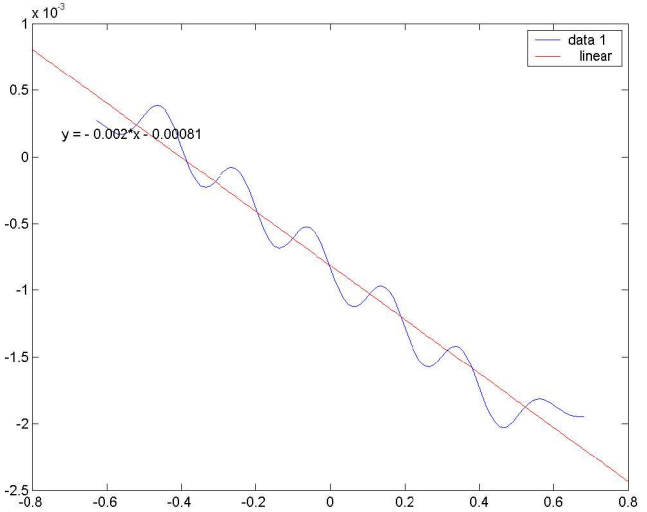
- 2-D model with FEMLAB
- Integrate Lorentz force equation with MATLAB yields field integrals and orbit (± 150 microns)





Aim for off-center screen near OTR5seed





- Change excitation of second to last pole from 3 10^6 to 2 10^6 A/m^2.
- 2 mrad angle of the orbit in the radiator easily achievable.
- Yields about 14 mm offset at screen OTR5seed (186.9 m).
- Need at least two steerers to provide about 1 mrad incoming angle (H5sund2 and last dipole of chicane)
- Clean up orbit with second to last coil in radiator and H3seed.
- *Problems* due to tilted wave fronts → will need other solution with hole in mirror or chicane around off-axis screen

Conclusion

- Generate an optical replica of the longitudinal bunch profile and diagnose with laser methods.
- Key locations in VUV-FEL identified.
- Moderate changes in the beam line.
- Stringent time window. Must be installed during early summer 2007.
- Undulators are ordered.
- PostDoc wanted for beam dynamics simulation and implementation at DESY.

SU-KTH-UU Free-Electron Laser Center

- About 2 year ago SU-KTH-UU consortium to further FEL activities was founded with two participants from each university.
- Three rektors signed LOI with DESY in Dec 2004.
- Report to Rektors in Summer 2005 requesting 3 yr x 3 x 1.5 MSeK/yr
- SU-KTH-UU FEL-center officially founded in March 2006 with Mats Larsson as director.
- Two workshops (accelerator and experiments)
- Identified three attractive accelerator projects
  - Specialty quadrupoles in the undulator section
  - Surface physics and resistive wall wakes
  - Optical Replica Synthesizer

Component List

- Seed Laser, hutch, optical table, optical transport
- Two undulators and power supplies
- Chicane and power supplies
- Laser Diagnostic, Grenouille
- Extra beam diagnostics
- Person-power
- Good-will
- Help

Position of interest, approximately

- Vacuum window 158.2
- Modulator start 167.0
- Chicane 171.5, 172.9, 174.8, 175.3
- Radiator start 178.2
- Existing OTR screens
  - 7match 165.8 (overlap)
  - 3sund1 168.9 (overlap)
  - 2sund3 177.9 (CTR)
  - 5seed 186.9 (extract)
  - 14seed 195.8
- Existing BPM
  - 2match 161.2
  - 6match 164.7 (modulator)
  - Q4sund2 175.7
  - Q3seed 184.7
  - Q12seed 193.7
  - Q20seed 201.7
- Existing steering magnets
  - 3match 161.5 (modulator)
  - 6match 165.0 (into modulator)
  - 5sund2 176.3 (into radiator)
  - 3seed 185.3 (out radiator)
  - 12seed 194.3
  - 19seed 200.6

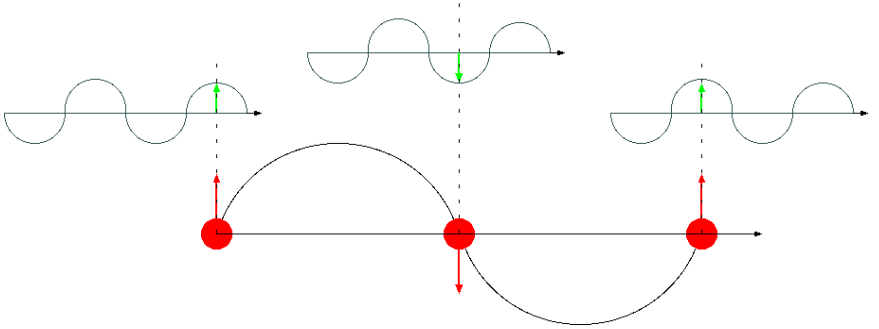
Seed Laser and Modulator

- Seed laser must overlap electron bunch and provide sufficient strength to modulate the energy
- probably Ti:Sapphire
- Length: 2 ps, Width: 0.75 mm
- Synchronization to bunch RF and electron gun
- Power: 100 MW, 1 mJ/pulse
- modulation amplitude: dp/p ~ 10^{-3}
- Need dog-leg to shine laser onto electron trajectory
- Undulator with about 5 periods

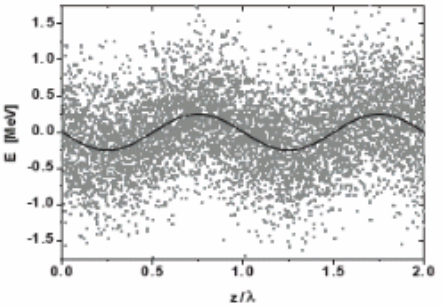
- Coupling between laser and electrons

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

- Transverse *E* and *v* (undulator!)

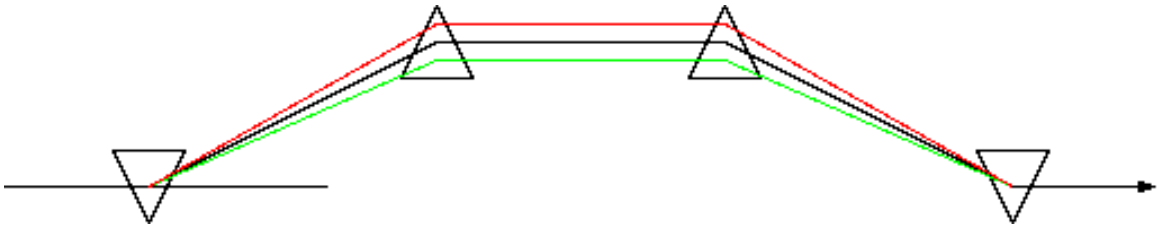


- Some gain, some loose, depending on initial phase

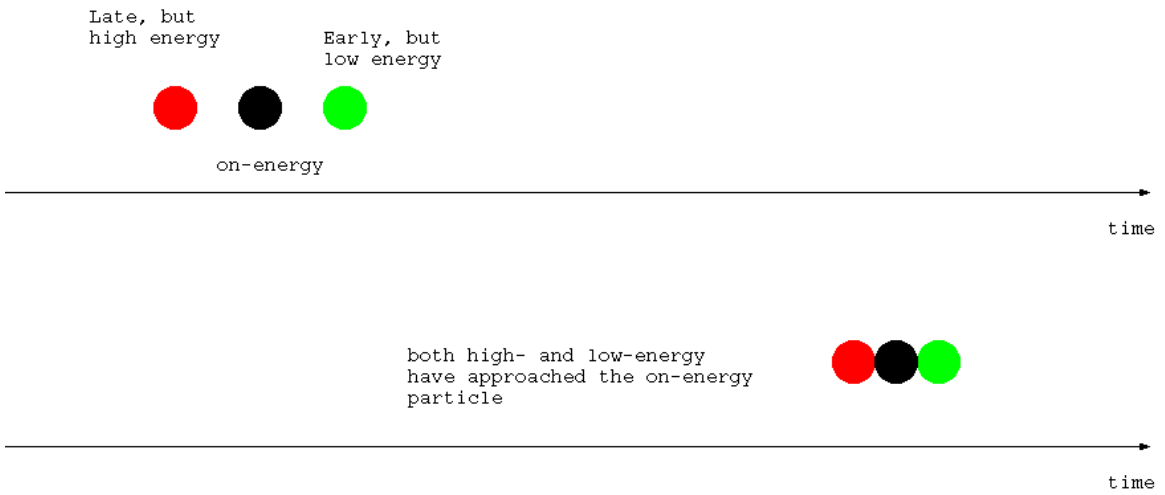


Chicane

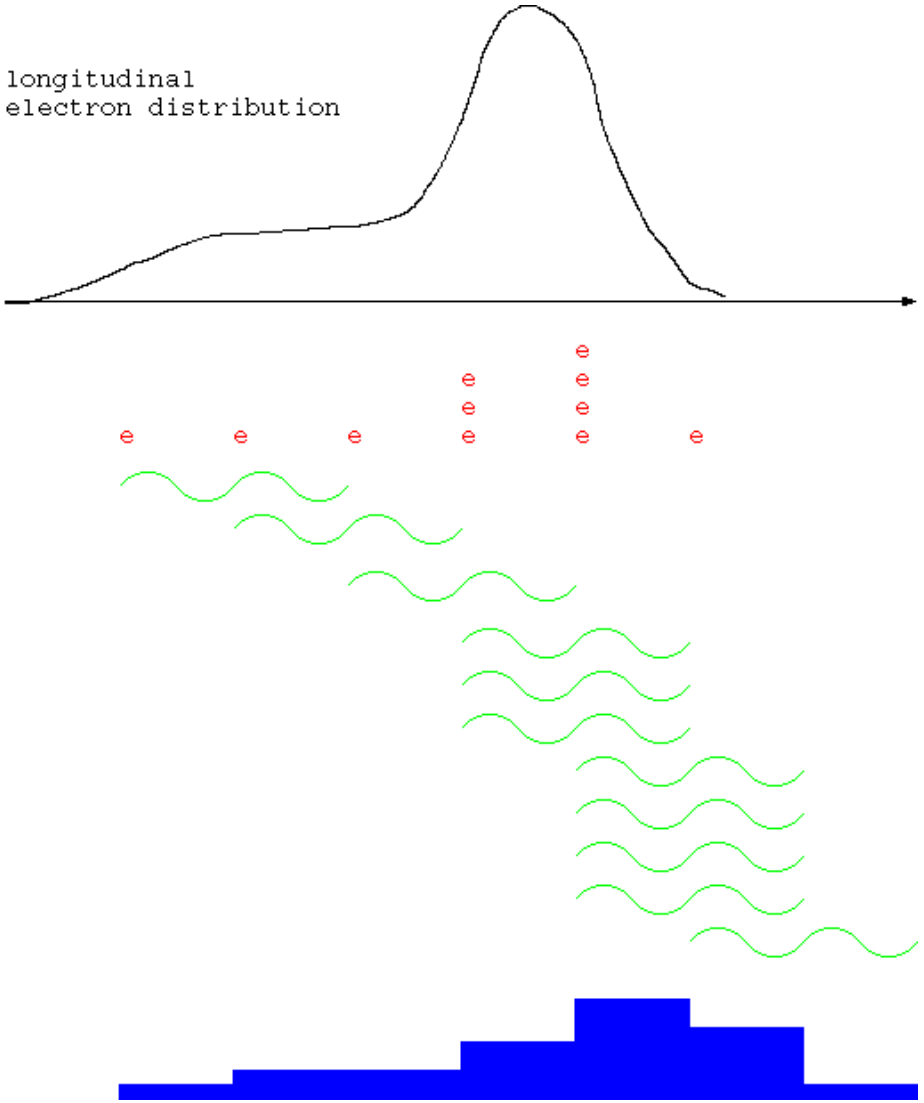
- The four dipole chicane turns a momentum modulation into a longitudinal density modulation.



- High energy particles take short-cut and arrive earlier.



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 with Grenouille.

Diagnosis of Replica Pulse in 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