A Screen Monitor for the Swiss FEL

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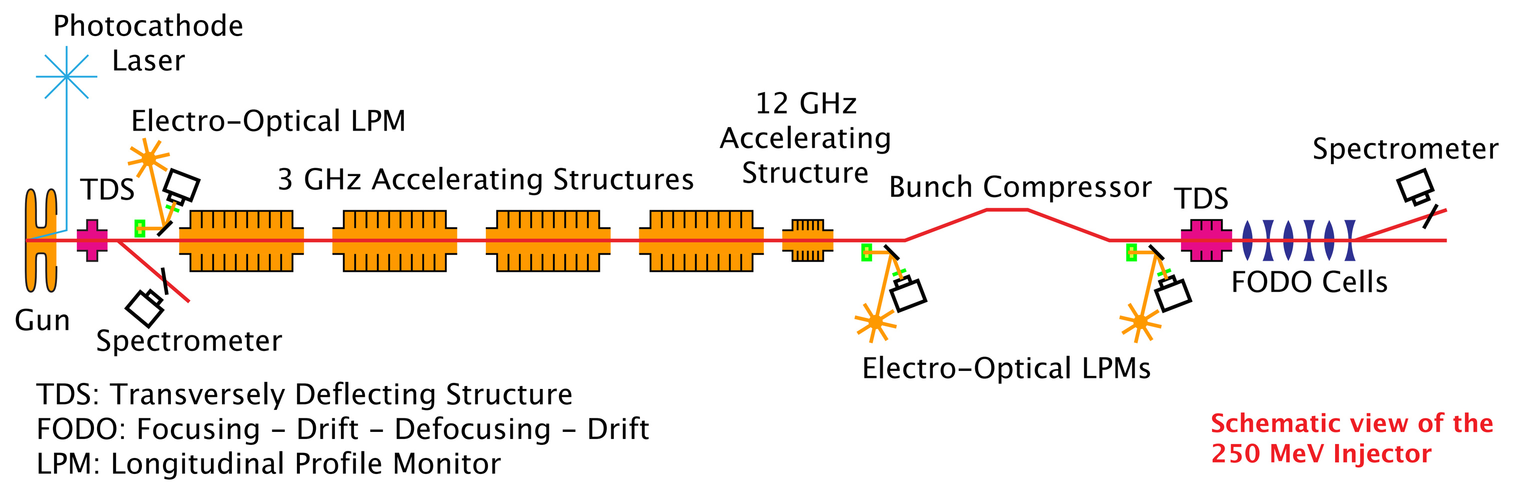
The Swiss FEL

Paul Scherrer Institut is planning a free electron laser for X-Ray wavelengths, the Swiss FEL. The baseline design foresees to generate electron bunches with a charge between 10 and 200 pC and a normalized emittance below 0.4 µm in an RF photocathode gun. These bunches will be accelerated in a normal-conducting linear accelerator (linac) to a particle energy of up to 6 GeV and sent through one of two undulators with 15 and 40 mm period, respectively, where they radiate coherently at wavelengths between 0.1 and 7 nm.
The repetition rate of this device will be 100 Hz initially, with an option to upgrade to 400 Hz. The baseline design foresees one electron bunch per RF pulse, but future extensions could allow for up to three electron bunches.
To test the feasibility of the concepts behind the generation of such high-brightness beams, their longitudinal compression and the preservation of the emittance, a 250 MeV Injector is currently being assembled. Commissioning will start early 2010, and by the end of the year PSI will submit a proposal to build the Swiss FEL to the Swiss Government.
The 250 MeV Injector will have three diagnostic sections: one directly after the RF photocathode gun, at a particle energy of 7 MeV, one before and one after the bunch compressor, at an energy of 250 MeV. The repetition rate of this accelerator will be 10 Hz.

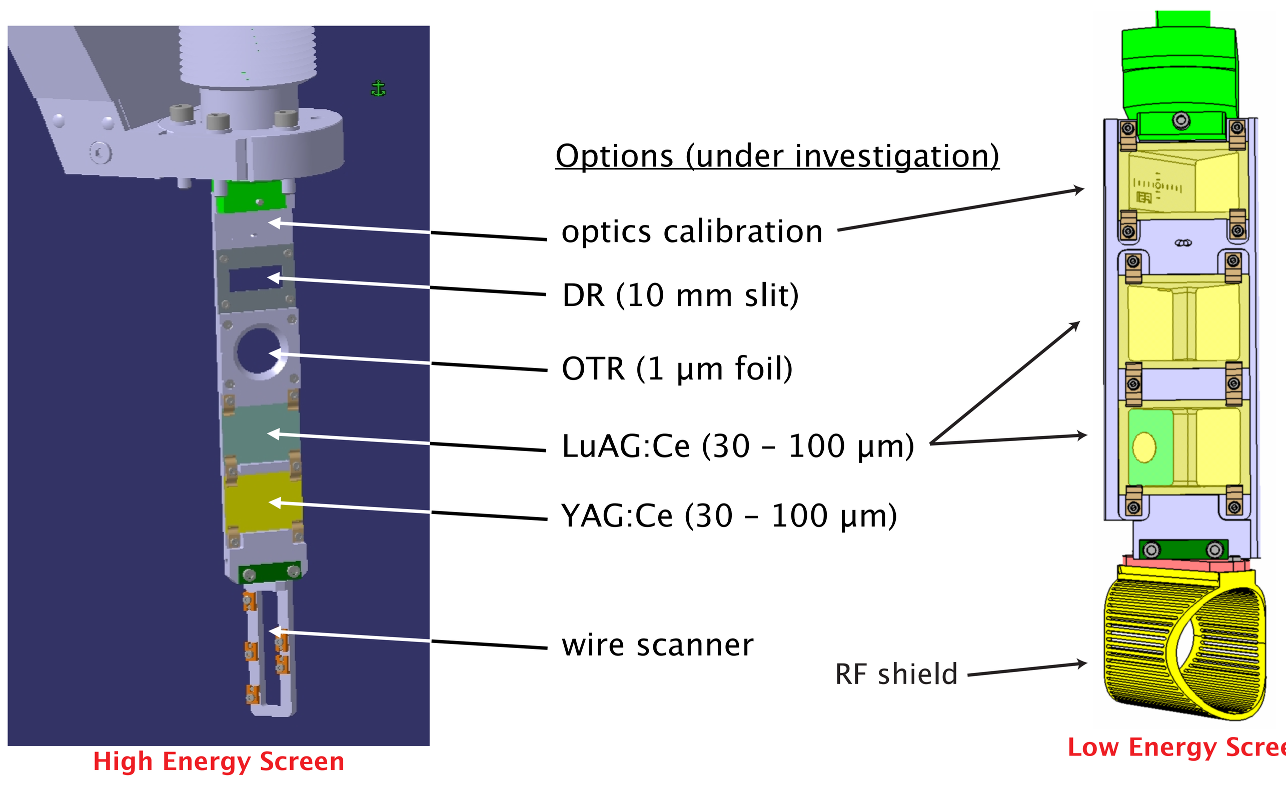


Schematic view of the 250 MeV Injector

Ideally, one would like to know the entire phase space distribution of the bunches, i.e. the phase space coordinates of each electron in the bunch. However, no method exists to measure the entire distribution directly. Instead, the distribution is projected onto sub-spaces such as the (x,y) plane which will be measured by screen monitors or the time axis which will be measured by coherent radiation and by electro-optical methods. Phase space transformations are applied to the electron beam prior to the measurements to infer the distributions in the other dimensions.
If these transformations are linear, they can then be described by a matrix formalism. By scanning these transformations and measuring projections at each step, a Radon transformation of the phase space distribution is acquired. Inverse Radon transformations are used to reconstruct the phase space. Maximum entropy methods are particularly useful because there are often relatively few projections, which are furthermore not uniformly distributed.

Quantity	Method	Gun	BBC	ABC	Notes
Projected emittance	OTR screens, phase advance scan, quadrupole scan	✓	✓	✓	Alternatively, phosphor screens may be used
	OTR screens, FODO lattice			✓	
Horizontal slice emittance	Transverse deflector, OTR screens, quad scan or FODO lattice	✓		✓	Bunch compressor is horizontal
Bunch length	Electro-optical	✓		✓	non-destructive, single-pulse
	Transverse deflector	✓		✓	
Bunch arrival time	Bunch arrival monitor		✓	✓	
Transverse position	BPMs	✓	✓	✓	non-destructive, single-pulse
Energy spread	Spectrometer dipole	✓		✓	
Slice energy spread	Transverse deflector, spectrometer dipole	✓		✓	
Charge	ICMs	✓	✓	✓	non-destructive, single-pulse
	OTR screens	✓	✓	✓	It will have to be seen whether this measurement is affected by COTR
	Phosphor screens	✓	✓	✓	Saturation of the phosphor may affect this measurement

Screens



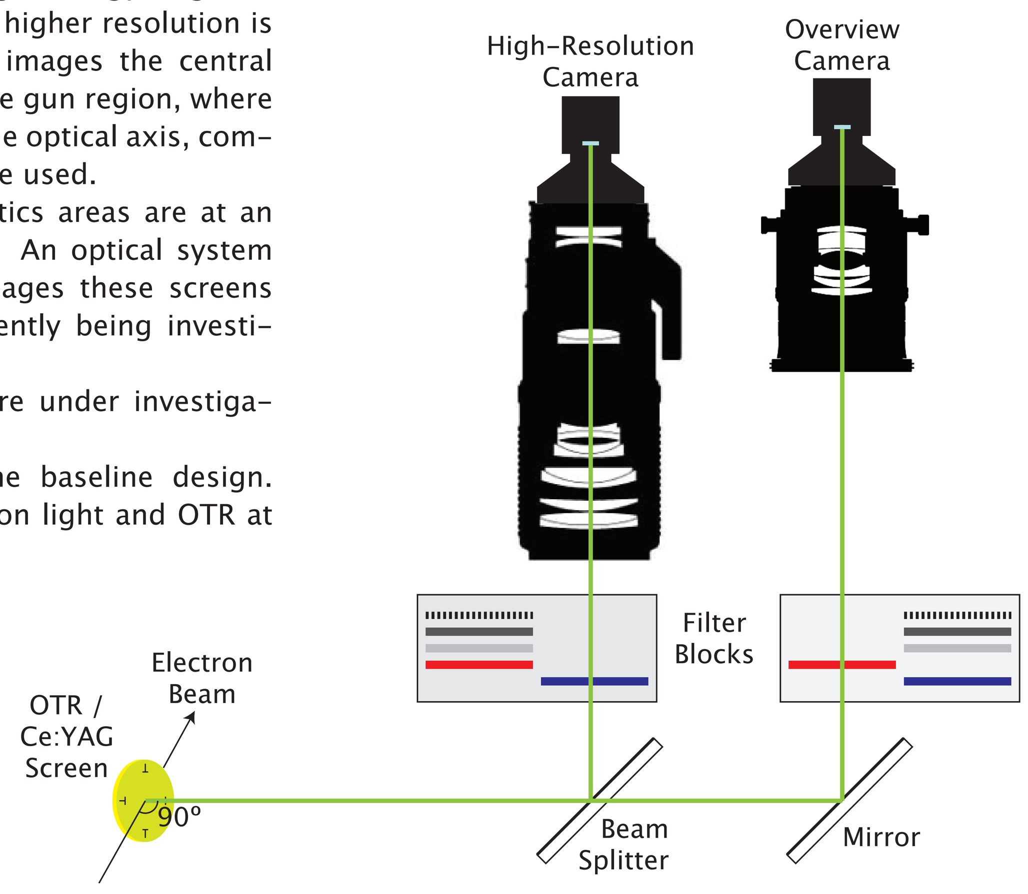
High Energy Screen

Low Energy Screen

A total of 32 screen monitors will be built for this project. Besides measuring projected and slice emittance, they serve as prototypes for monitors for the Swiss FEL.
Screens convert the electron distribution into visible light. At particle energies around 7 MeV in the gun region, scintillating crystals are used to image the beam. For higher energies, the scintillators will be complemented by optical transition radiation (OTR) foils.
The screens are mounted to a ladder and positioned in the beam with a vacuum feedthrough by a stepper motor actuator. The position is monitored by an absolute encoder mounted to the feedthrough. A scale engraved in the ladder serves as a focusing target and as pixel size calibration.
In the gun region, the scintillators are mounted at right angle to the beam; a mirror reflects the light out of the vacuum chamber. For the diagnostic sections around the bunch compressor, the screens are mounted at an angle of 45° to the beam; OTR is emitted at a right angle through the vacuum window. The cameras will be able to image either screen, depending on the position of the screen ladder.

Cameras

The wide parameter range in beam sizes and the wide dynamic range in the expected intensity requires different methods for imaging and detection of the light. At each screen monitor location, two cameras can be installed, with a removable beam splitter for selection: An overview system that images the entire screen with reasonable resolution (projected pixel size 23 µm) will be used during commissioning and to find the beam if it is off center. This can be achieved with commercially available perspective control lenses, which at the same time allow for correction of the inclined object plane in the high-energy diagnostic sections. For screens where a higher resolution is required, a second camera that images the central part of the screen is set up. In the gun region, where the screens are at right angle to the optical axis, commercial micro-photo lenses will be used.
Screens in the 250 MeV diagnostics areas are at an angle of 45° to the optical axis. An optical system that corrects for this tilt and images these screens with a 1:1 imaging ratio is currently being investigated (see below).
Three types of photodetectors are under investigation:
Room temperature CCDs are the baseline design. They are able to detect scintillation light and OTR at high bunch charges.
Room temperature CMOS detectors offer exposure times down to 50 ns and may be used to distinguish individual electron bunches emitted during a single RF pulse, as well as to map dark current from the cathode.
Cooled CCD detectors have a superior signal-to-noise ratio and offer therefore the possibility to use OTR at low bunch charges, or to measure bunches dispersed by the RF deflector.



Controls

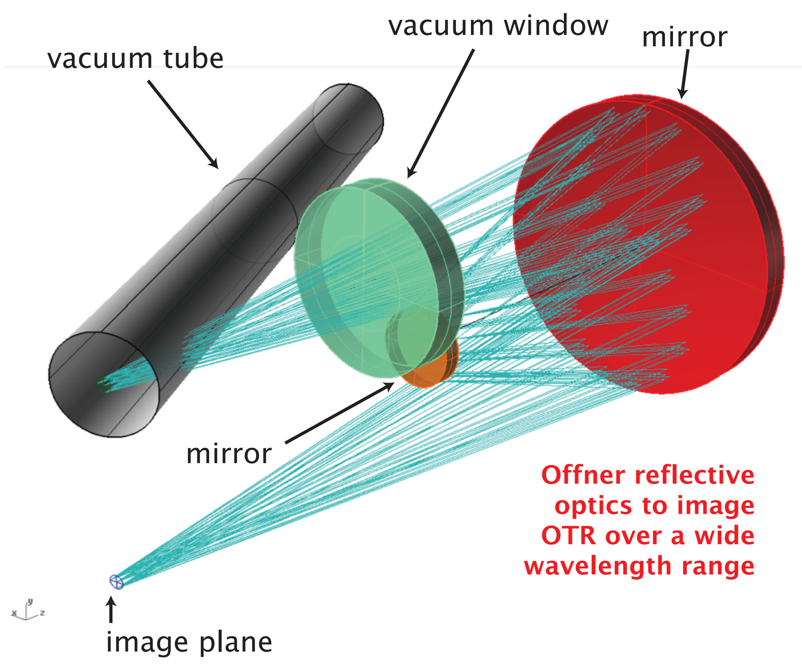
The screen monitors are controlled and read out by the Epics control system. Camera readout is not done by a realtime operating system, but a special hardware trigger allows to synchronize the data stream with all other devices in the linac. This way, a pulse-to-pulse correlation can be established. Images can be displayed at a rate of 1…2 Hz, and simple analysis procedures can be performed in real time. For further analysis, the data can be written to HDF5 files, compatible to the Nexus format.

Data Analysis

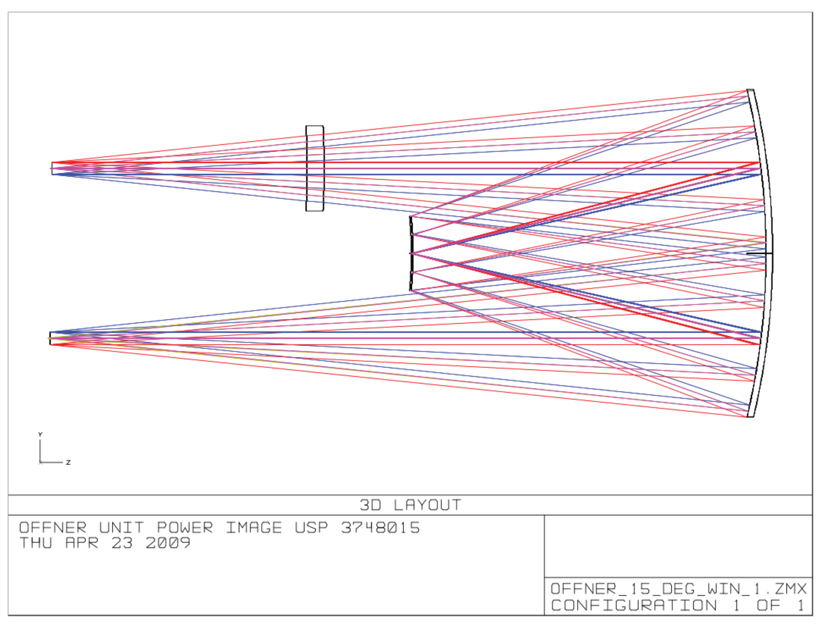
Phase space transformations in the (x,x') and (y,y') planes are controlled by quadrupole magnets. By scanning multiple quadrupole magnets, or in FODO cells, the phase space is rotated while the beam size is kept constant. Thus, a Radon transformation of the phase space is acquired. An inverse Radon transform, based on the maximum entropy algorithm, is used to reconstruct the phase space.
Two transverse deflecting RF structures will be installed in the 250 MeV Injector, one in the gun region and one behind the bunch compressor. These allow to streak the beam vertically, i.e. a (y,y',t) phase space transformation. With this additional transformation, the longitudinal bunch structure as well as the slice emittance can be measured.

Future Developments

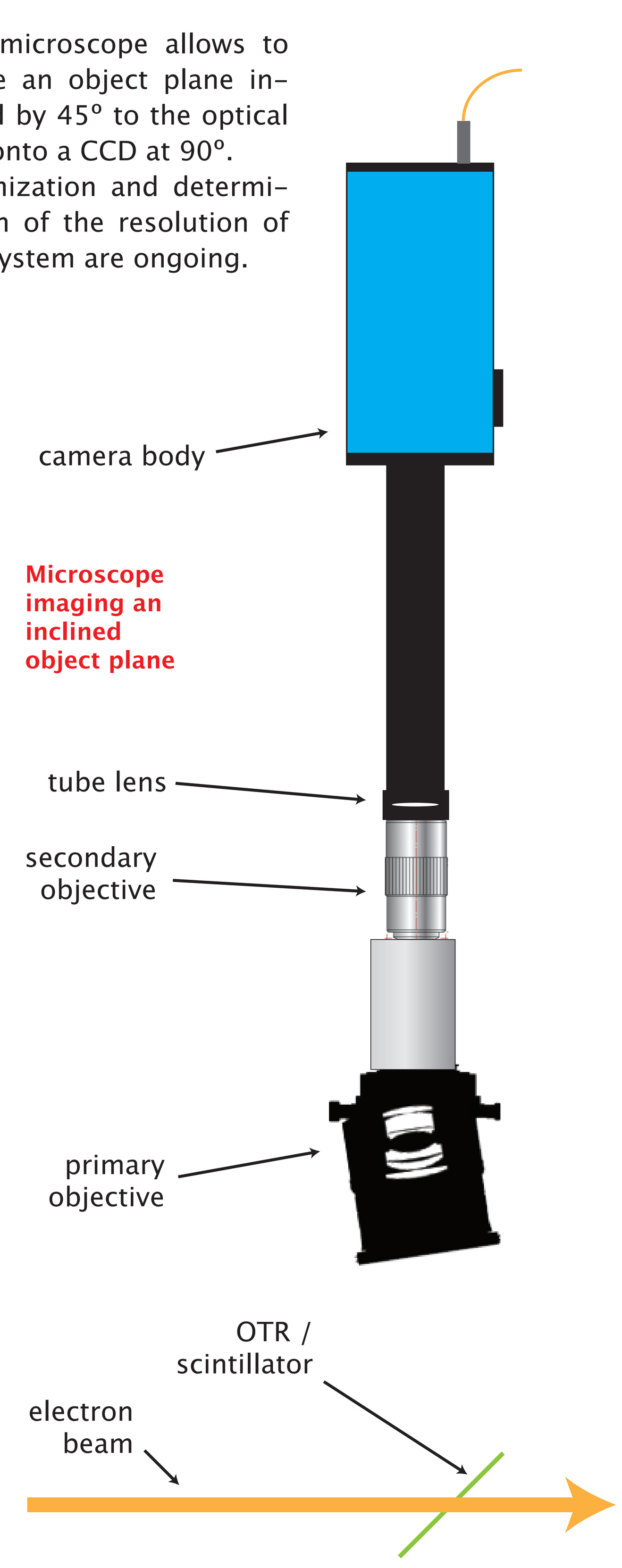
Coherent optical transition radiation is being expected for high bunch compression ratios. This effect depends strongly on the wavelength of the radiation, and it is unclear where the cutoff wavelength will be for the monitors in the 250 MeV Injector and the Swiss FEL. To pursue research in this topic, we are considering the construction of a system based on reflective optics. This would allow imaging the OTR source at a wide range of wavelengths.



Offner reflective optics to image OTR over a wide wavelength range



This microscope allows to image an object plane inclined by 45° to the optical axis onto a CCD at 90°. Optimization and determination of the resolution of this system are ongoing.



Microscope imaging an inclined object plane