Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

Gian Luca Orlandi

6th Microbunching Workshop, Trieste 6-8 October 2014

“Overview of Transverse Profile Monitors in SwissFEL”

Overview

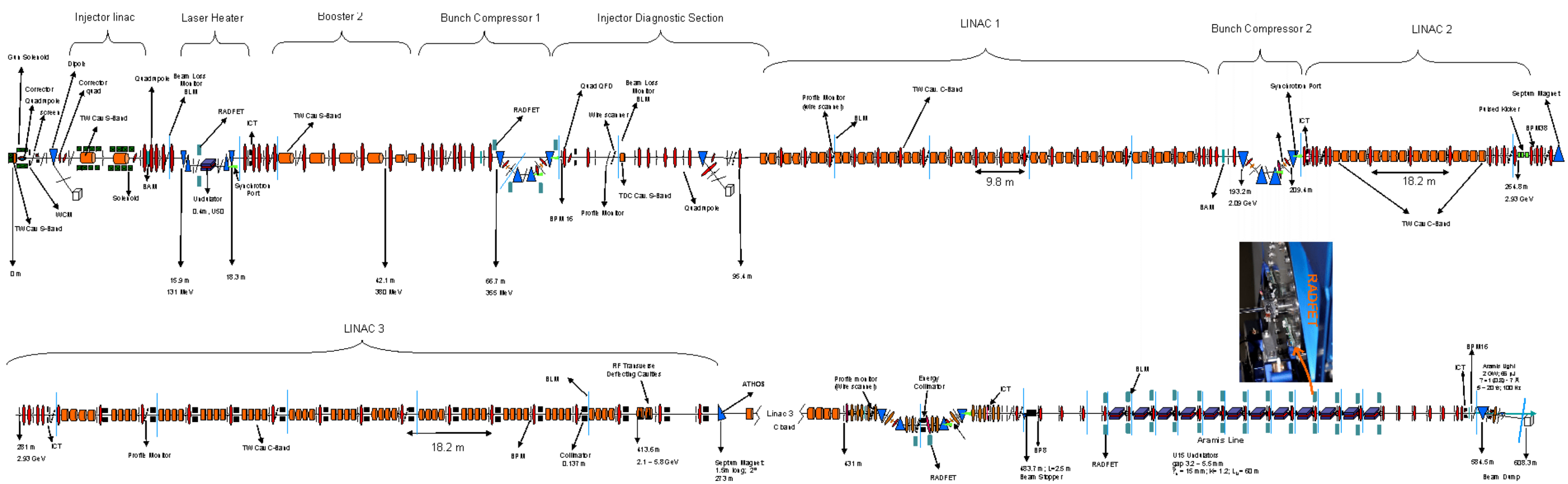
- The SwissFEL Project
- Design Criteria and Prototype Results of the SwissFEL Transverse Profile Monitors:
  - **Wire-Scanner**
  - **View-Screen**
  - **SR Monitor**
- Conclusions

SwissFEL electron linac driver:

- S-band RF Booster (330MeV) + C-band RF Linac (5.8GeV)
- 2-bunches with a 28ns time-structure @100Hz from a RF gun
- 200/10pC with normalized emittance 0.4/0.2mm.mrad
- Bunch compression (3/1ps→20/3fs rms) with a 2-stages magnetic chicane
- 2-Xband structure to linearize the longitudinal phase space
- Laser heater in the Booster section

SwissFEL light facility: 2 X-rays beam lines (7-0.7nm and 0.7-01 nm) @100Hz

Aramis phase-1: first experiments at SwissFEL are expected for 2017



SwissFEL Transverse Profile Monitor, Design Criteria:

- Bypass possible effects of the COTR drawback in view-screens
- Imaging of the beam transverse profile in the visible with standard cameras
- Routine monitoring of the beam profile during FEL operations with a minimum impact on the laser beam quality
- Discriminate the 28ns time structure of the two-bunches beam @100Hz

SwissFEL Transverse Profile Monitor, Technical Design:

- Two complementary solutions for monitoring the beam transverse profile along the entire machine:
  - View-screen (Ce:YAG) with “off-axis” optics (to overcome COTR) and standard cameras
  - Wire-Scanner
- SR monitors to image the beam profile in the magnetic chicanes with non-standard cameras

SwissFEL View-Screens, Technical Design:

- fluorescent crystal (Ce:YAG) and
- "off-axis" optics to bypass possible COTR effects
- Imaging feature:
  - different magnification to account for change in beam size along the machine
  - observation at the Snell's angle of refraction to achieve resolution that is not affected by crystal thickness
  - Scheimpflug principle to image the entire screen without depth-of-field issue

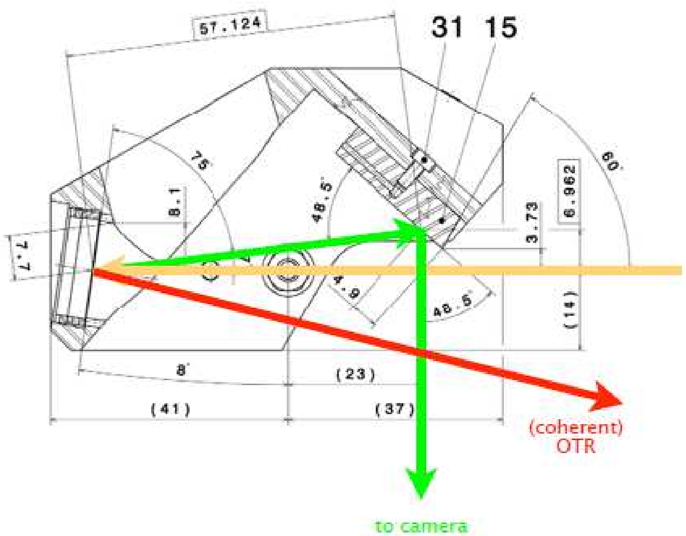
SwissFEL View-Screens, Experimental Test:

- bypass COTR effects
- High sensitivity: slice emittance measured @1.3 pC
- High resolution: 8μm over a field of view of 6x16mm

More information, R.Ischebeck IBIC2014

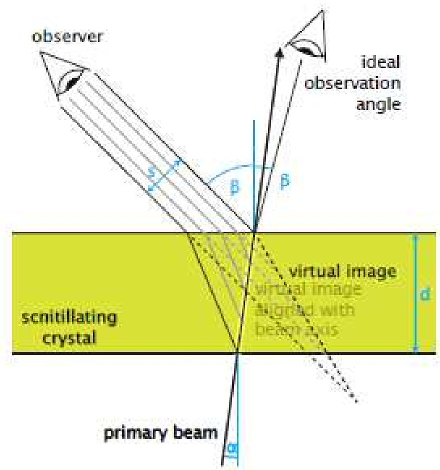
Solution: Use Scintillator, Direct COTR Away from Camera

> Transverse profile imager developed at PSI directs COTR away from the camera:



> At the same time, it achieves a good spatial resolution:

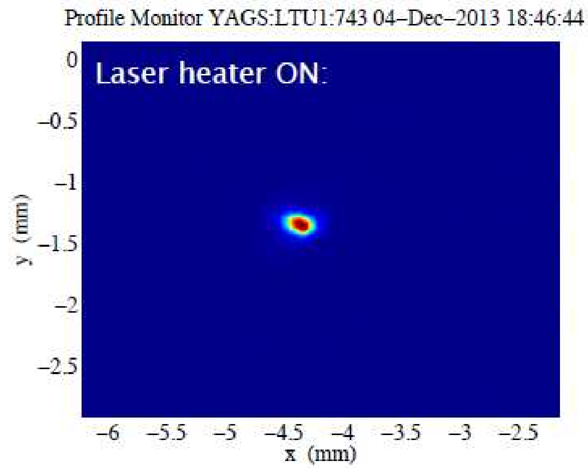
The YAG / LuAG scintillators are observed at such an angle that Snell's law of refraction is observed. As a consequence, we can image beams that are smaller than the thickness of the scintillator. (Patent pending)

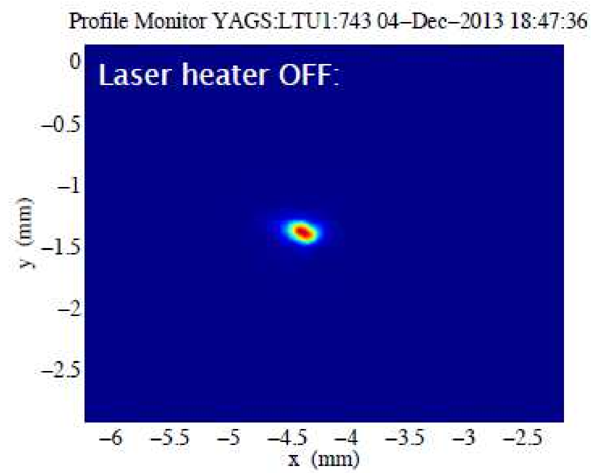


R. Ischebeck
SwissFEL Meeting
PSI 24.04.2014

Measurements — December 2013

> First Measurements at LCLS show no sign of coherent OTR on the camera:





Rasmus Ischebeck, A Transverse Profile Imager for SwissFEL 7

R. Ischebeck
SwissFEL Meeting
PSI 24.04.2014

SwissFEL Wire-scanner (WSC), Conceptual Design:

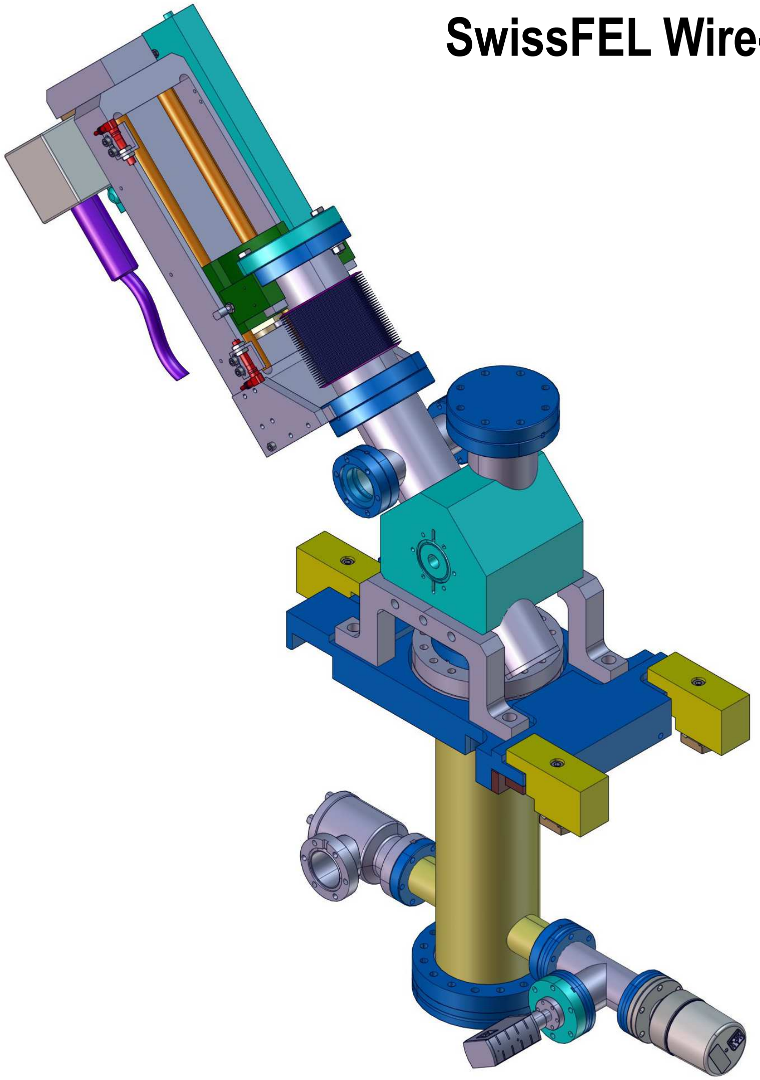
- **monitor beam transverse profile 5-500 μm (rms) (X,Y and X-Y coupling);**
- **scan bunch in charge range 10-200 pC and energy range 0.330-5.8 GeV;**
- **resolve the 28ns time structure of two-bunches @ 100Hz;**

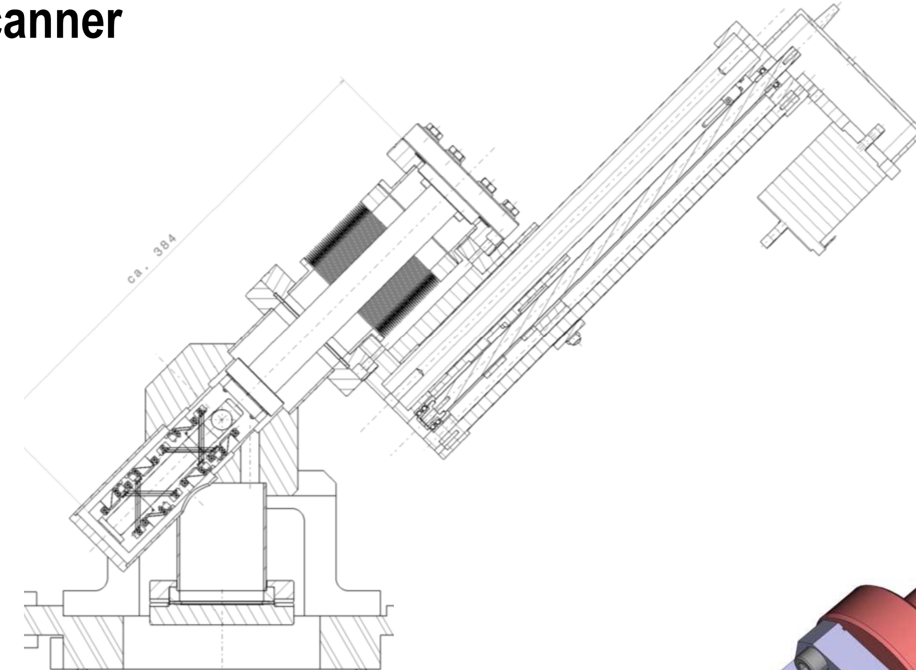
SwissFEL WSC, Technical Design:

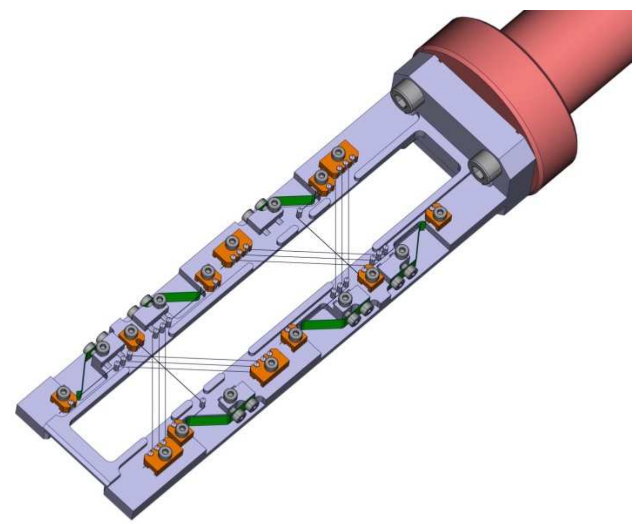
- **single UHV linear stage to scan beam profile in the X,Y and X-Y directions;**
- **Tungsten wire with different diameters 5-13 μm (resolution 1.5-3.5 μm, rms);**
- **wire-fork equipped with spare/different-resolution wires;**
- **wire-losses detection with scintillator fiber downstream the wire;**
- **Beam-Synchronized-Acquisition (BS-ACQ) of read-out of both encoder and loss-monitor;**
- **wire-fork designed for routine scanning of the beam during FEL operations (no beam interception with the wire-fork);**
- **wire-fork equipped with different pin-slots (different distance of wire-vertex from vacuum-chamber axis: 8, 5.5, 3 mm).**

More information, G.L. Orlandi FEL014

SwissFEL Wire-Scanner



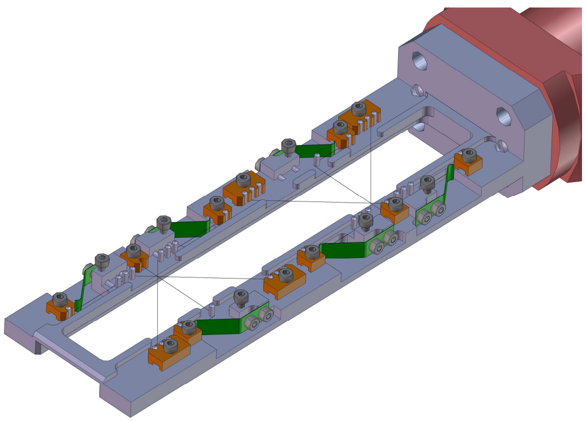


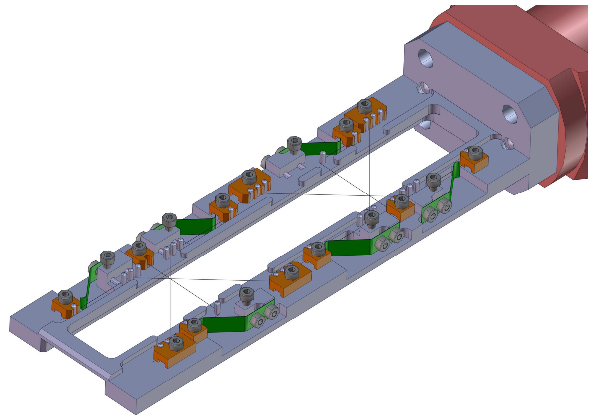


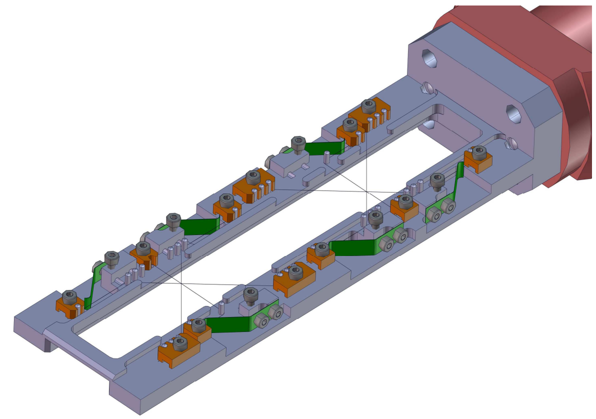
Wire configuration DN16

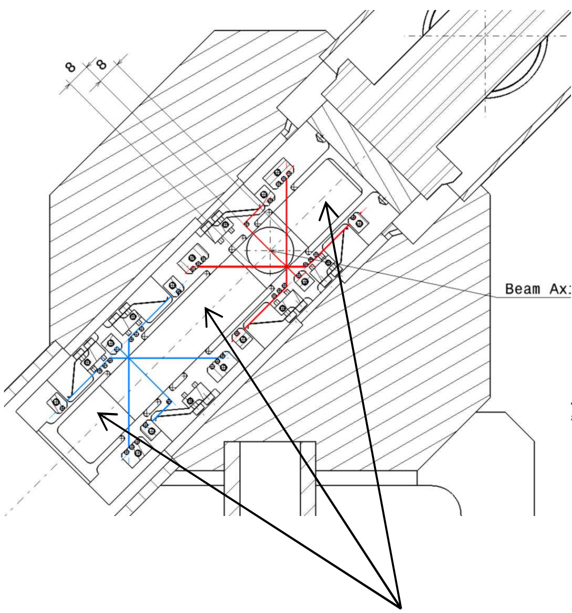
Wire configuration DN11

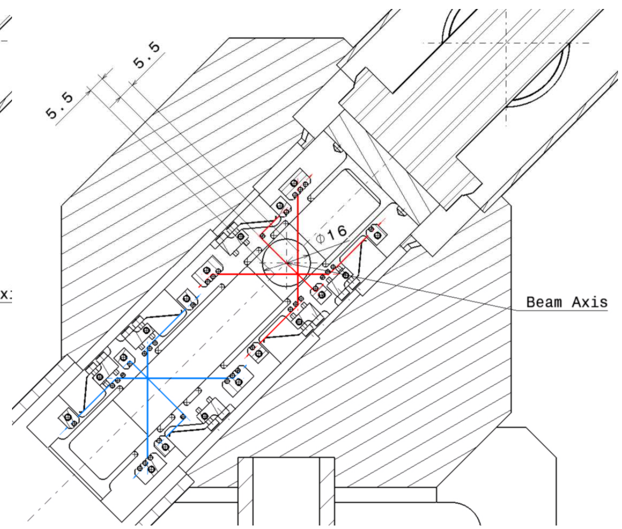
Wire configuration DN6

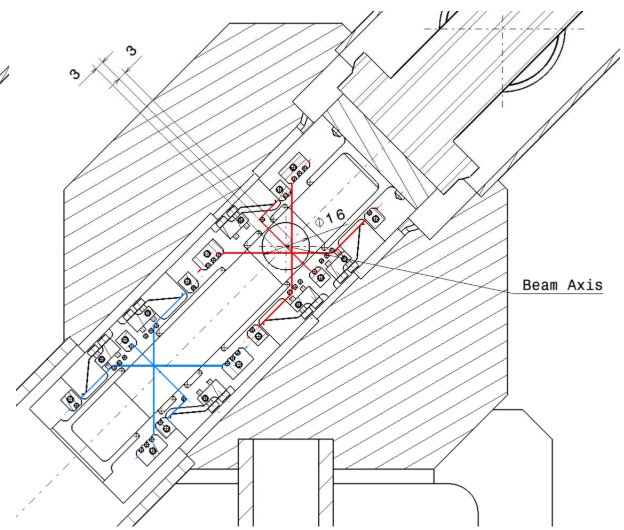












3 possible rest positions of the wire-fork

WSC: Wire-Vibration Measurements (Summer 2012)

SITF-WSC lab set-up:

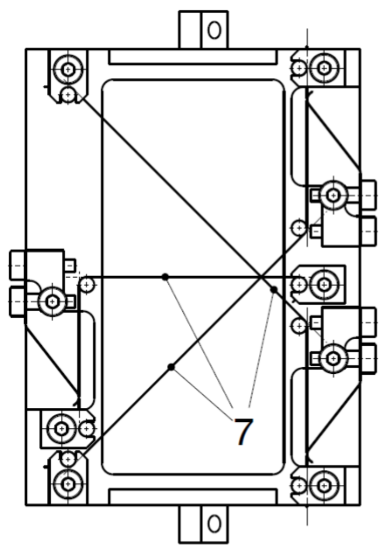
- SITF wire-fork
- VAB vacuum feed-through
- 3-phase motor
- Absolute optical encoder
- SITF motor-controller

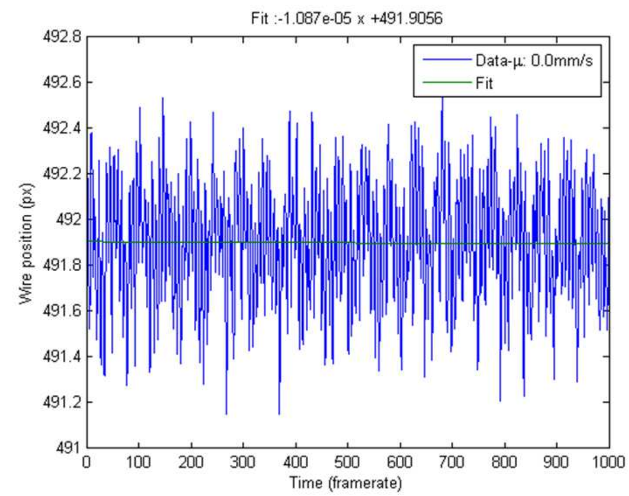
Measurement set-up:

- Microscope 10X
- Resolution 1px=1 μm
- Camera exposure: 3μs
- Camera frame rate: 1kHz
- Tungsten Wire diameter: 25μm
- Wire velocity: 0.1-10.0mm/s

Measured Vibration:

- 0.62 μm (rms)
  (wire speed v=2mm/s)
- Appreciable vibration for wire-velocity >1.0 mm/s

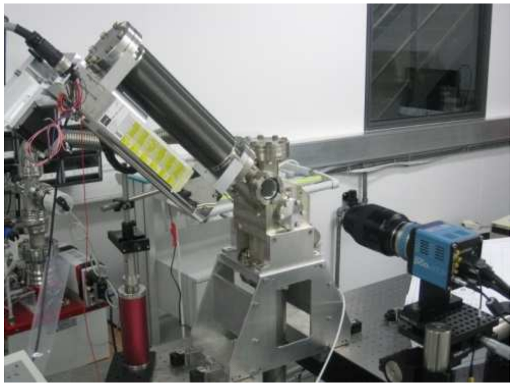




WSC: Wire-Vibration Measurements (April-May 2014)

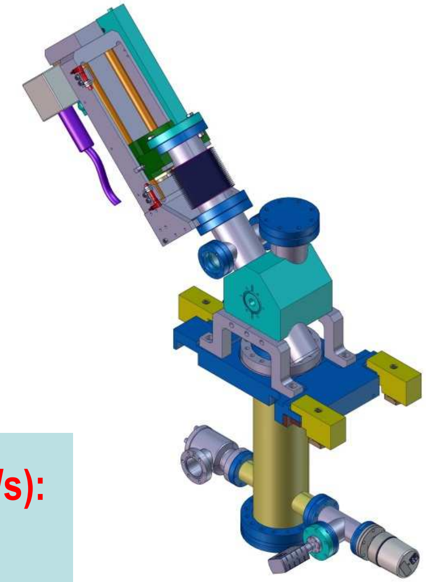
SwissFEL-WSC lab set-up:

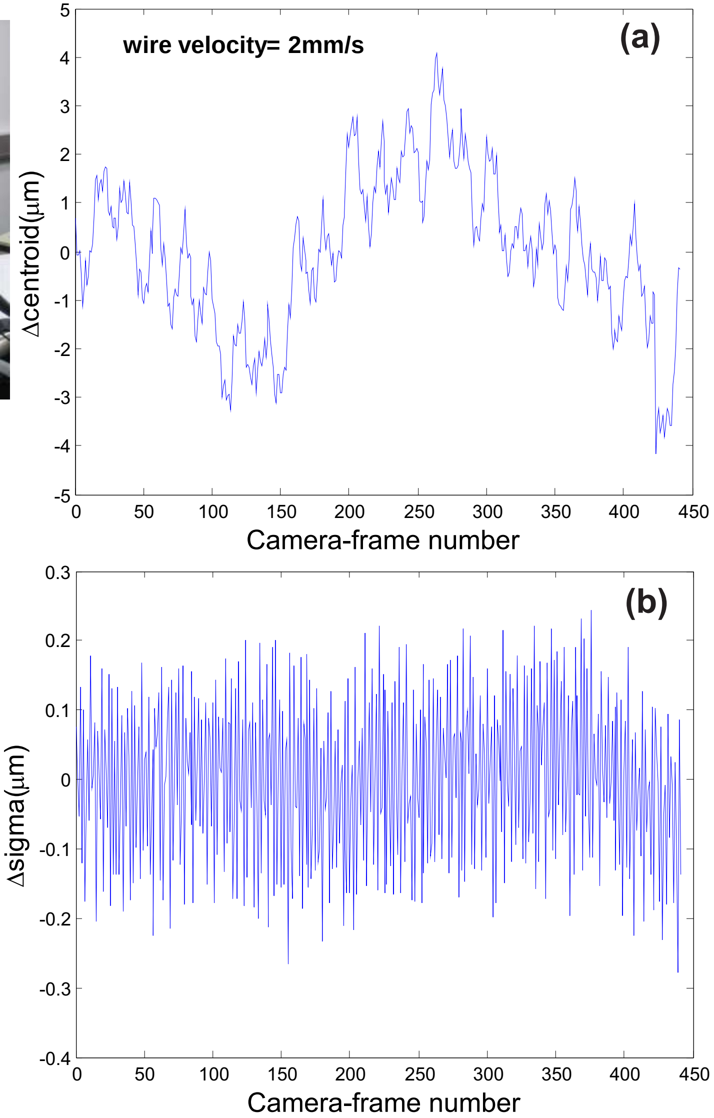
- VAB vacuum-chamber
- UHV-Design vacuum feed-through
- 2-phase Oriental-Motor stepping motor
- NumerikJena incremental optical encoder
- DELTA-TAU motor controller
- Wire-scanner fork with Tungsten wire (diameter 5,13 and 15 μm)
- Wire velocity range: 0.2-> 2mm/s
- Wire horizontal excursion: 1->8mm



Measurement set-up:

- PCO Edge sCMOS camera, 500 fps (2ms exposure time), Resolution(HxV):2560X2160 px px=6.5x6.5um^2
- Camera lens Nikon 200mm
- Distance camera-wire: about 53 cm
- Projected pixel size: 9.75um
- Effective camera ROI: 2560X394





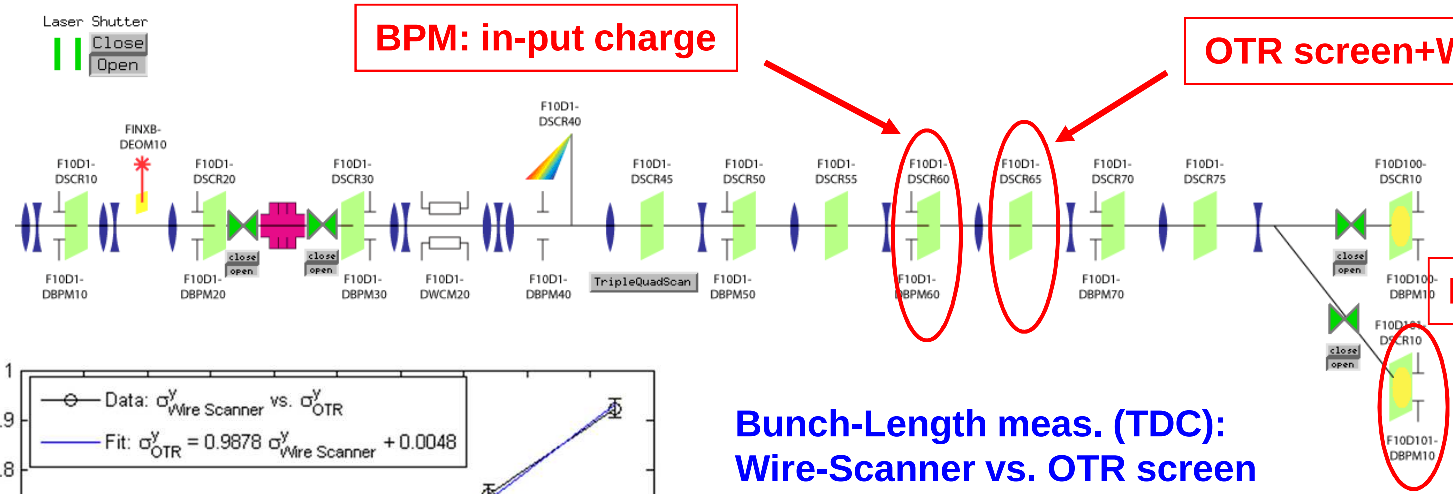
WIRE-VIBRATION (wire-velocity 0.2-2 mm/s):

- ➢ **max centroid variation 1.3 μm (a)**
- ➢ **max sigma variation 0.1 μm (b)**

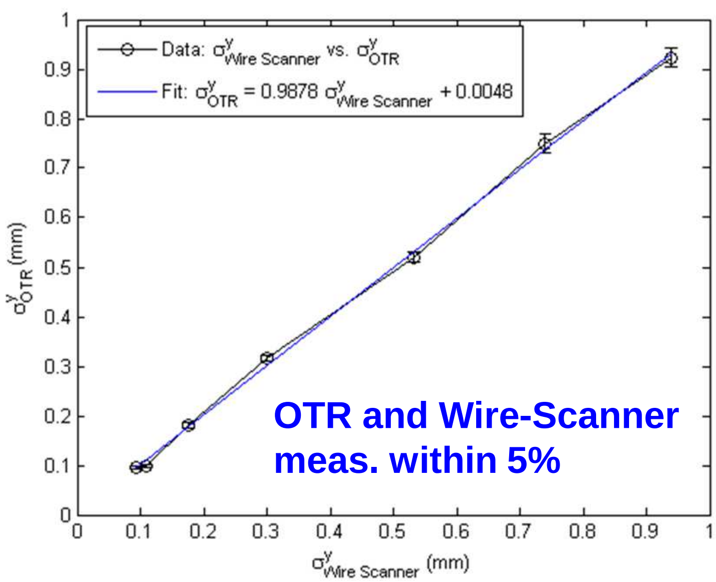
WSC: beam-tests at SITF (Summer 2012)

BPM: in-put charge

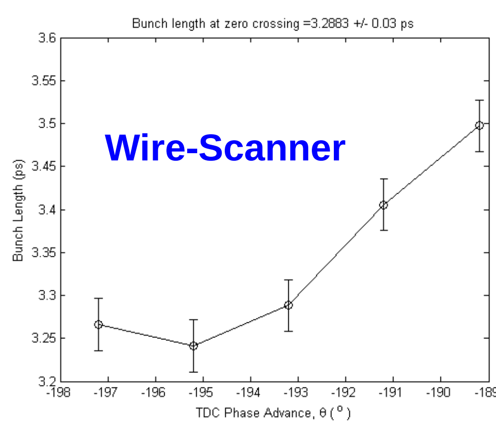
OTR screen+Wire-Scanner

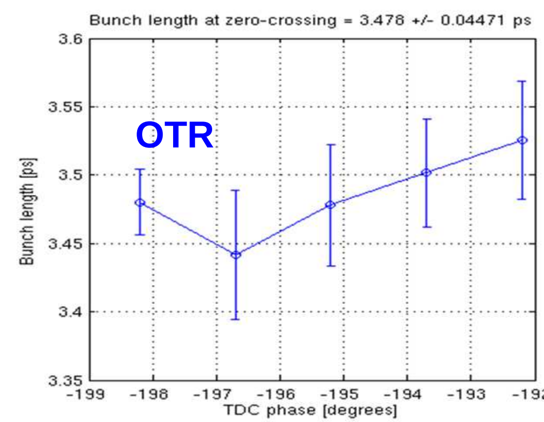


BPM: out-put charge

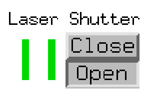


Bunch-Length meas. (TDC): Wire-Scanner vs. OTR screen

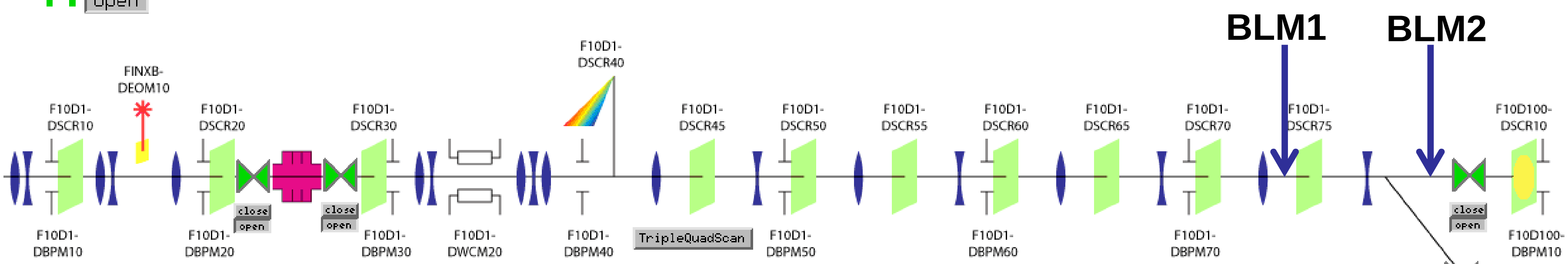




- Beam Synchronous Acquisition of wire-encoder and BPM-charge read-outs
- Comparison Wire-Scanner and OTR measurements



WSC: beam-test at SITF (October 2013)



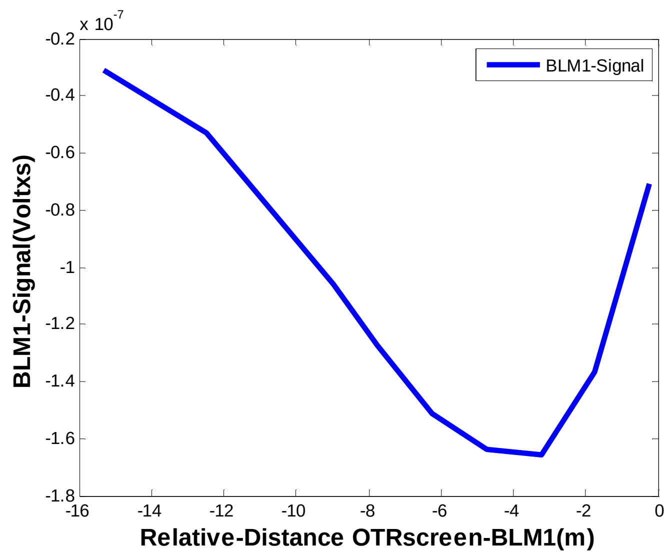
BLM set-up at SITF:

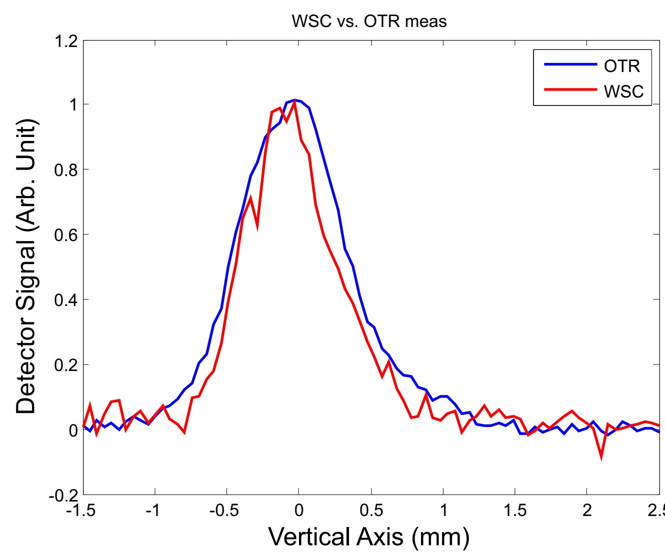
- 2 BLM installed before and behind the HE spectrometer dipole, respectively.
- scintillator fiber (PMMA, Poly-Methyl-Methyl-Acrylate, Saint Gobain BCF-20, emission in the green) winding up the beam pipe;
- PMT (Hamamatsu H10720-110) directly connected to the scope

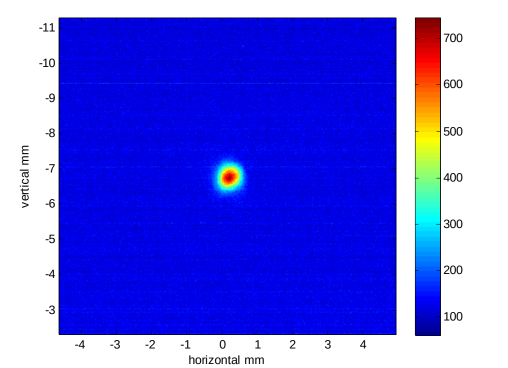
Wire scanner vs. OTR benchmark

sigma_Y(OTR)=(0.308+/-0.008)mm

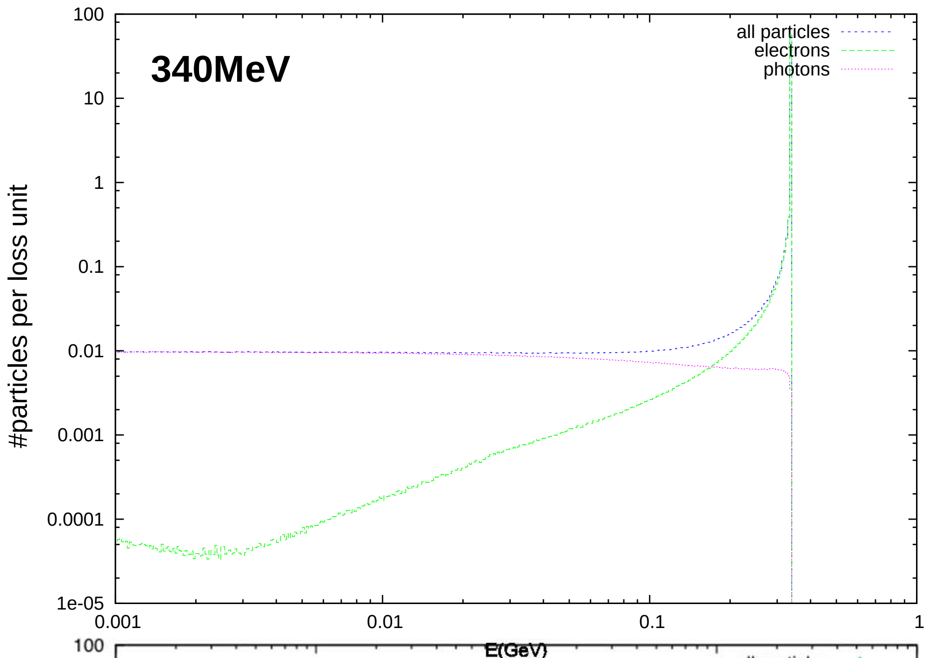
sigma_Y(WSC)=(0.304+/-0.014)mm

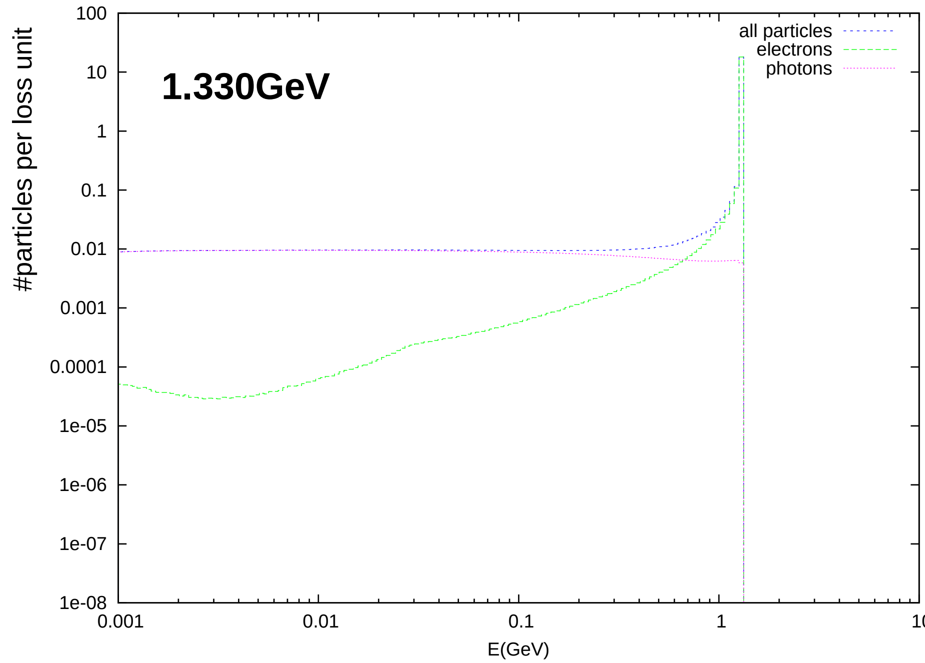


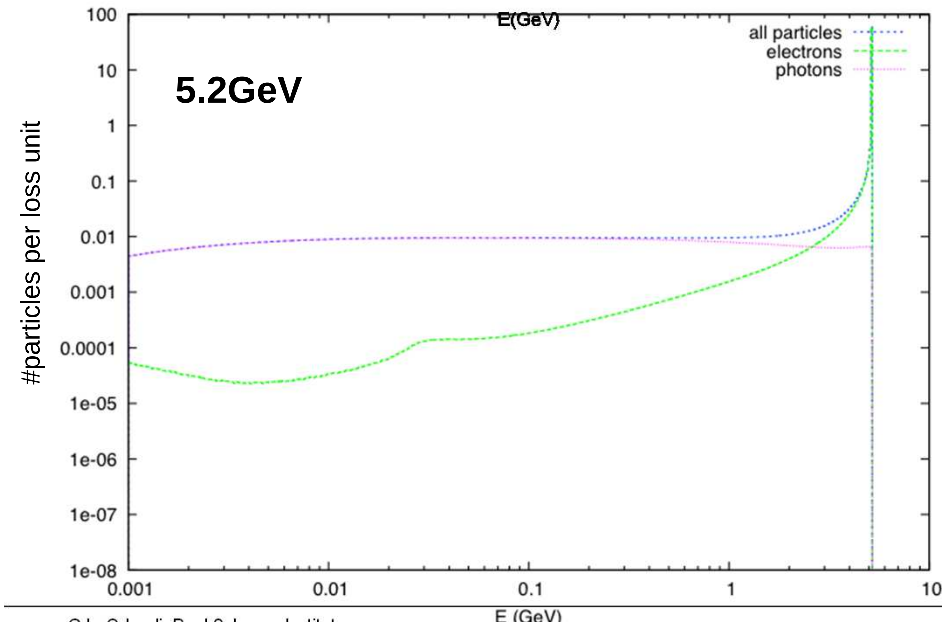




FLUKA simulations: determine optimum distance wire-scanner beam–loss-monitor

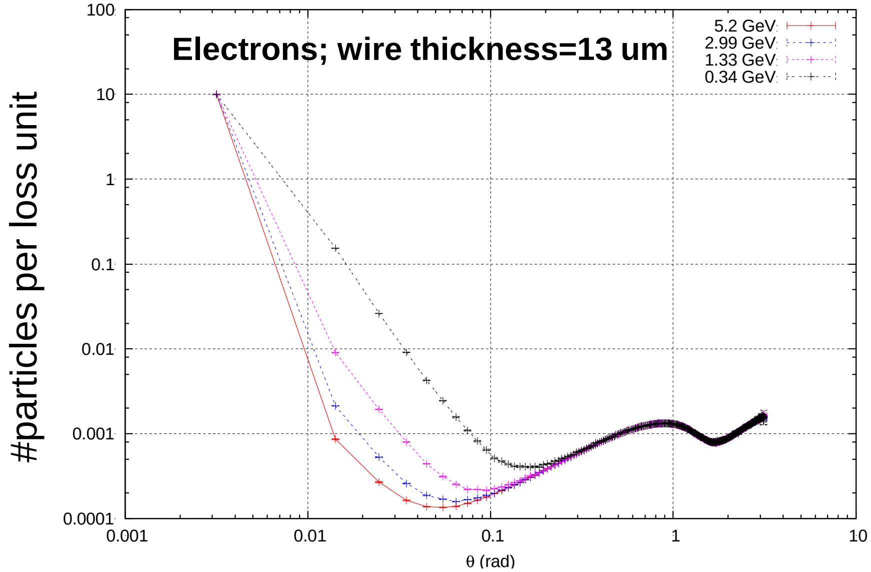


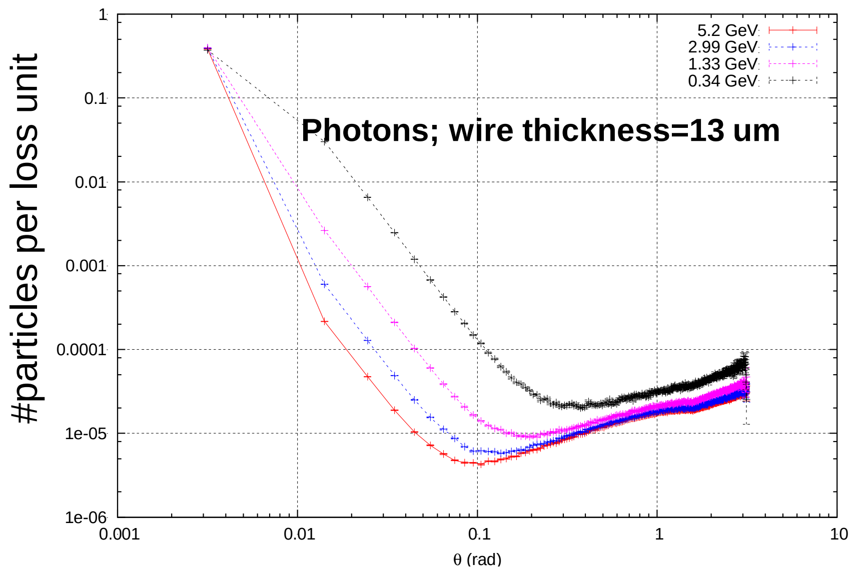




- **Energy distribution of the "wire-signal" in the polar angle interval 0-$\pi/6$**
- **Photons and electrons mainly contribute to the "wire-signal"**

S. Trovati, PSI Internal Note, FEL-TS96-001-0.





FLUKA simulations: determine optimum distance wire-scanner beam–loss-monitor

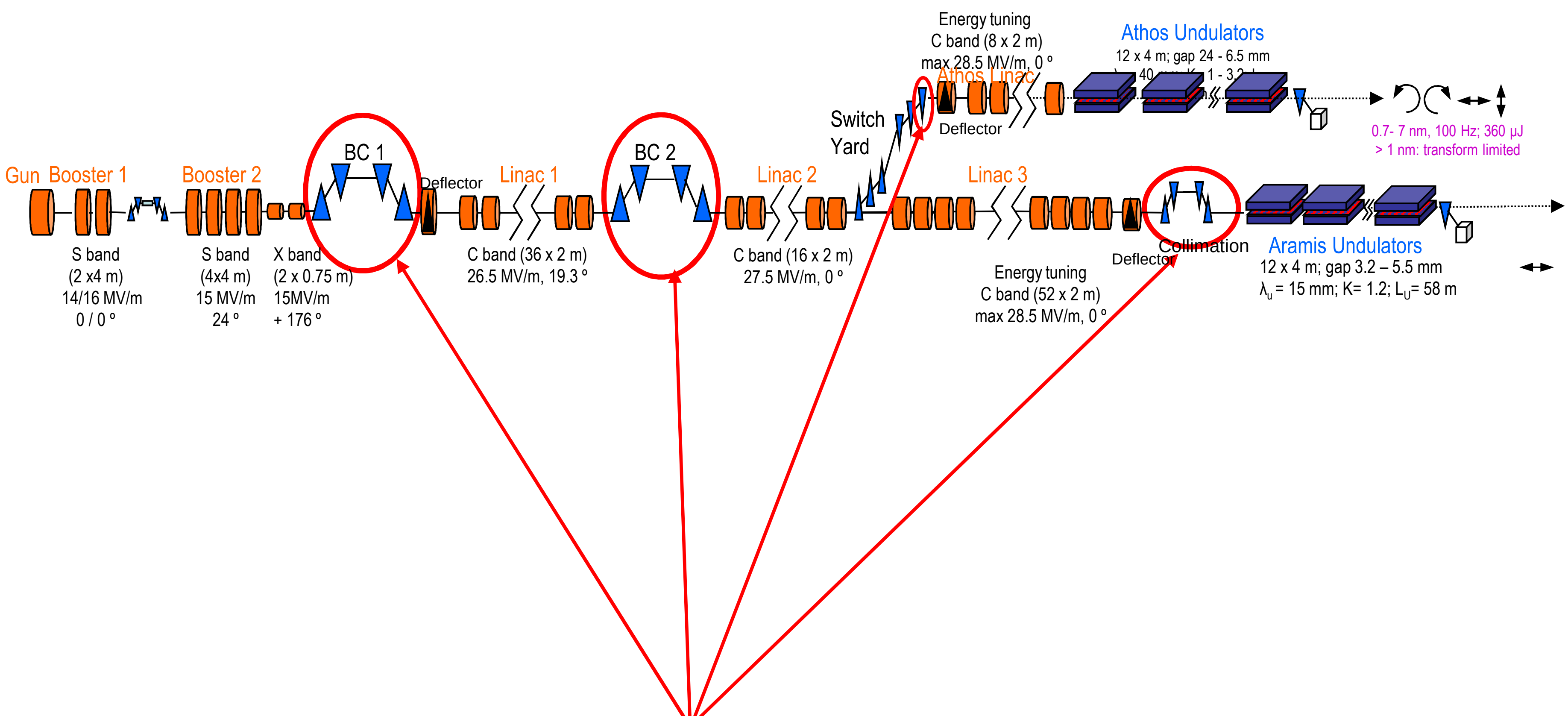
Angular distribution of the "wire-signal":

- **the electron contribution is much larger than the photon contribution**
- **more than 95% of the "wire-signal" is emitted within a polar angle < 0.1 rad**
- **<-> for a CF16 vacuum pipe, more than 95% of the wire-signal intercepts the vacuum chamber at a distance from the wire between 80mm and 4000mm**

FLUKA simulations and beam-tests:

- **optimum distance wire-loss monitor 1-4 m**

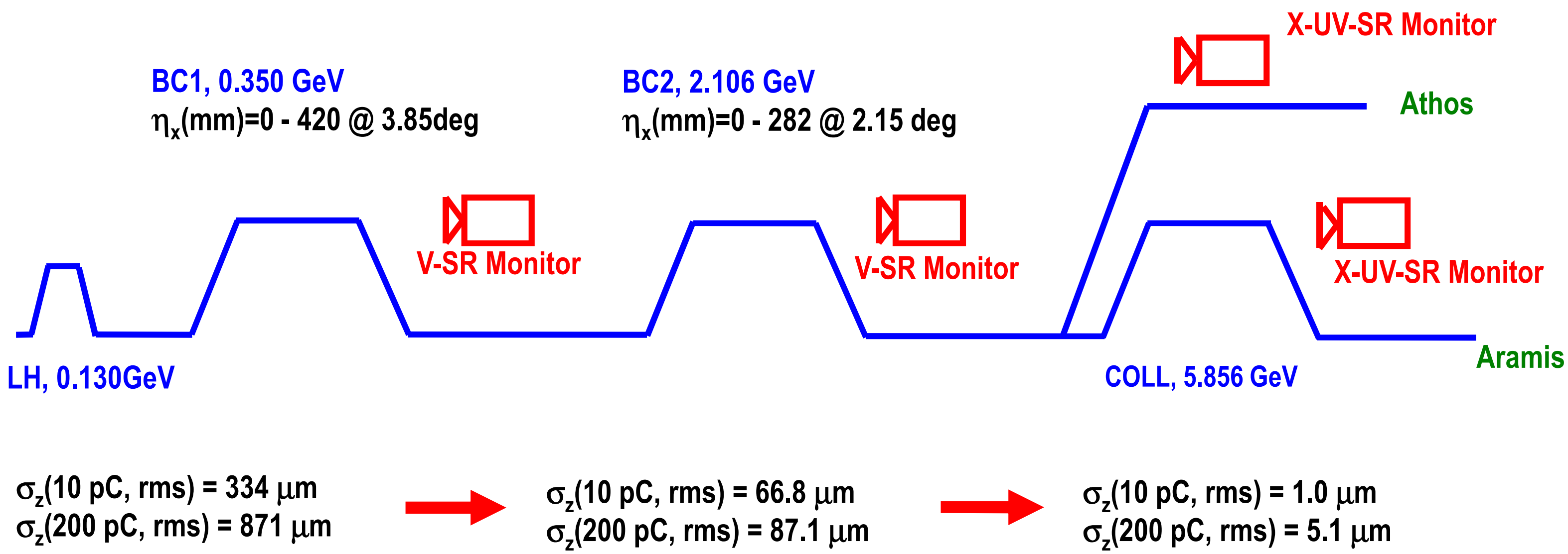
SwissFEL, SR monitors



SR-Monitors under design by Diagnostics Section of PSI

More information, G.L. Orlandi IBIC2012, IBIC2013

SwissFEL SR Monitors



SR-Monitors BC1 & BC2 (Technical Design completed):

- SR detection in the visible
- Measure the relative energy spread of the beam (resolution ~10^-4)

SR-Monitors COLLIMATOR and Athos Beam Line (Conceptual Design under development):

- SR X-ray or UV detection
- Monitor the beam transverse profile (COLL and ATHOS)

SwissFEL Bunch-Compressor SR Monitor, Conceptual Design:

- **Monitor the beam transverse profile over the entire range of the bunch-compressor bending angle to determine the beam energy and relative energy spread**
- **Charge sensitivity range 10-200pC**
- **Monitor interface with feed-back system (real-time 100Hz) under routine FEL operations to account for variations of beam energy/relative-energy-spread**
- **Aramis-phase-1: operation mode @100Hz**
- **Athos-phase: resolve the 28ns time structure of the two-bunches beam @100HZ.**
  Two-cameras system under development (beam splitter, internal optics and fast switchable MCP intensifier).

More information, G.L. Orlandi IBIC2012, IBIC2013

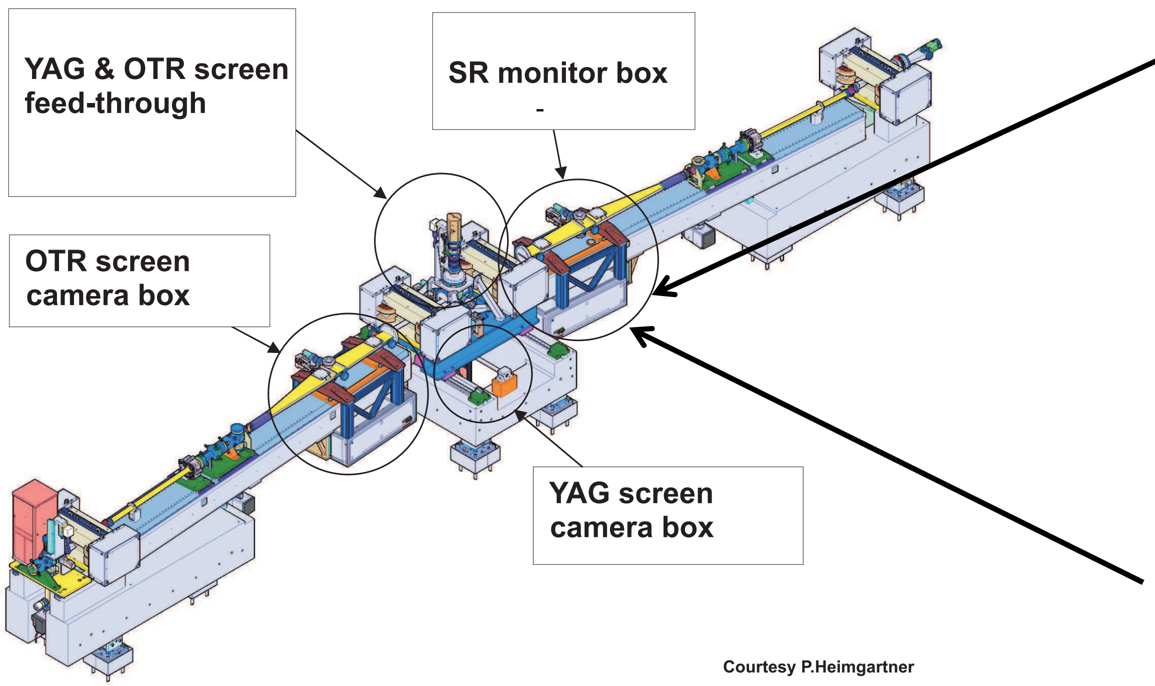
SwissFEL BC-SR Monitor Specifications

	BC1	BC2
Nominal bending angle θ	3.85 deg	2.15 deg
Mechanical bending angle range	-0.1 $\leftrightarrow$ 4.6 deg	-0.1 $\leftrightarrow$ 3.8 deg
Operational bending angle	2.85 $\leftrightarrow$ 4.6 deg	1.15 $\leftrightarrow$ 3.15 deg
Horizontal Dispersion	419.6 mm	281.56 mm
Nominal Beam Energy	350 MeV	2100 MeV
Range for transverse movement	-10 $\leftrightarrow$ 500 mm	-10 $\leftrightarrow$ 495 mm
Beam Size (rms) at the 3rd dipole	6.0 mm	1.2 mm
Field-of-View (mirror length=68 mm)	68 mm	68 mm
Projected pixel size	48 μm	43 μm
Relative Energy Spread Resolution	1.1*10^-4	1.5*10^-4
Lens focal length	300 mm	300 mm
Lens diameter	107 mm	107 mm
Camera (PCO.EDGE) pixel size	6.5x6.5 μm^2	6.5x6.5 μm^2
Camera Resolution	hor x ver = 2560x2160	hor x ver = 2560x2160
Camera Frame Rate	100 Hz	100 Hz
Separation mirror-edge and central trajectory	40 mm	61.5 mm

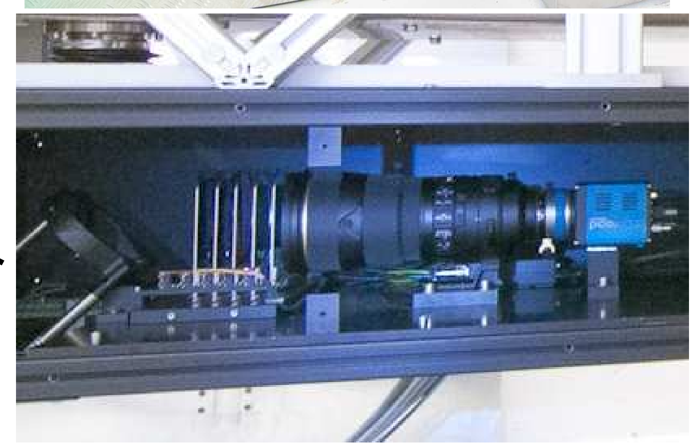
BC Prototype: SwissFEL 250 MeV Injector Test Facility (SITF)

Transverse Profile Monitor at the SITF BC(bending angle acceptance 3-5deg):

- **SR-monitor: CMOS camera+300mm lens, projected pixel size 0.040 mm, ΔE/E=1.2x10-4 (@hx=404 mm)**
- **YAG-Monitor: CCD camera+45mm lens, projected pixel size 0.115 mm, ΔE/E=3.5x10-4 (@hx=404 mm)**

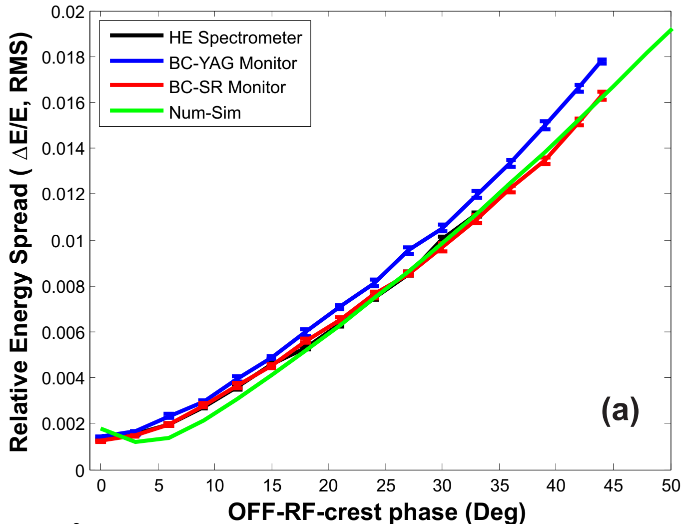


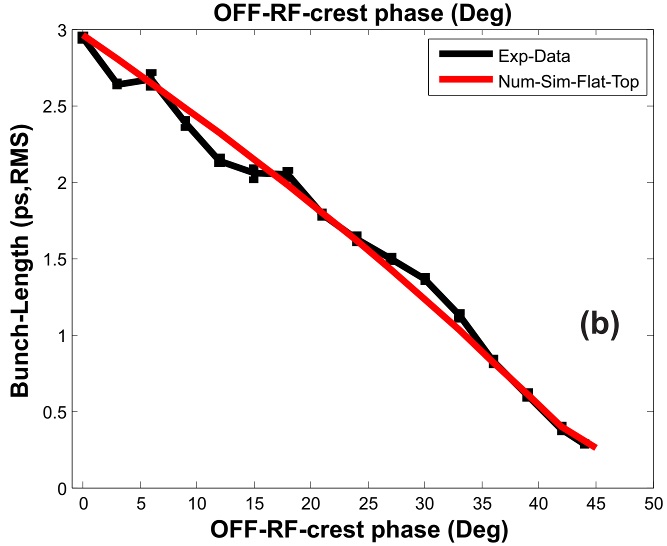
Courtesy P.Heimgartner

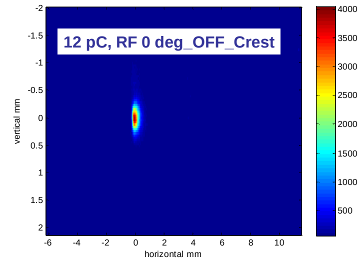


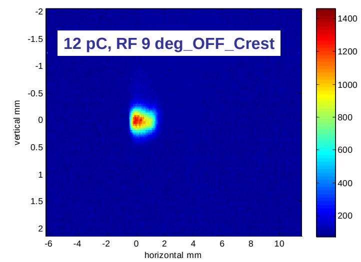
Bunch-Compression Studies at 250MeV SITF

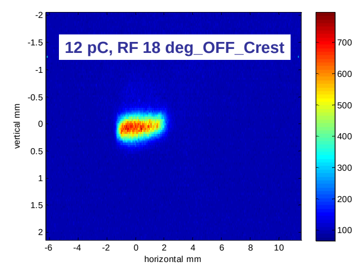
200MeV, 180 pC

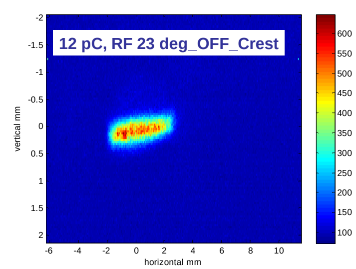




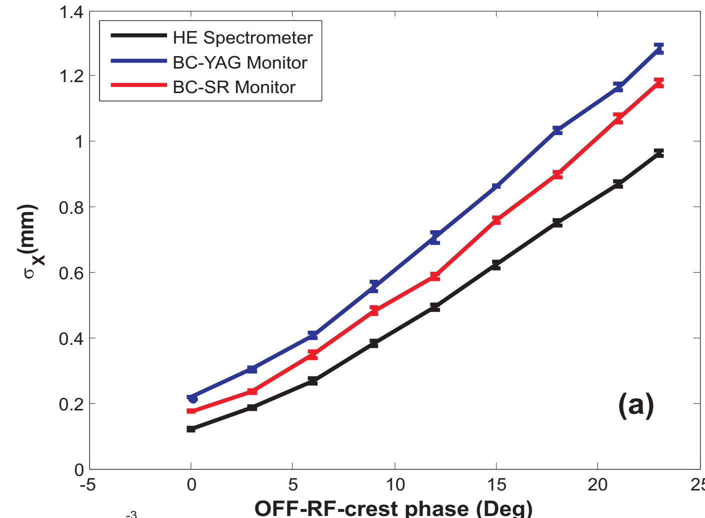


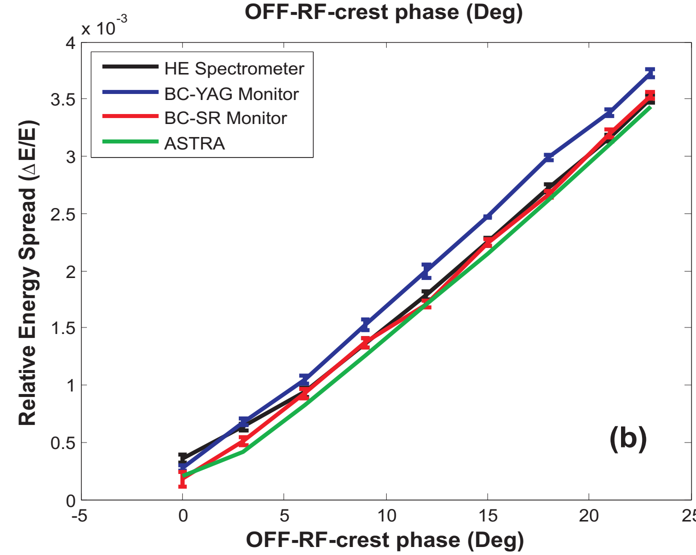






230MeV, 12 pC





Conclusions

SwissFEL Transverse Profile Monitor:

- **View-Screen:**
    - **COTR-free Design**
    - **High Sensitivity (slice emittance @1.3 pC)**
    - **Resolution 8 μm**
- **Wire-Scanner:**
    - **Wire-Vibration less than expected resolution 1.5 μm rms**
    - **Beam Test at 250MeV SITF and benchmark w.r.t. OTR screens**
    - **100Hz Beam-Synchronous-Acquisition (BSQ of encoder and loss-monitor) under development (10Hz BSQ already tested at the 250MeV SITF)**
- **SR Monitor:**
    - **Real time analysis of camera images @100Hz (data in EPICS channels for feed-back)**
    - **Two-cameras system to resolve the 28ns two-bunches time structure under development**

Thanks to

M. Baldinger
H. Brands
P. Heimgartner
M. Heiniger
R. Ischebeck
C. Ozkan
V. Schlott
L. Schulz
S. Trovati
P. Valitutti

…and thank you for your attention...