Electron Beam Diagnostics

In collaboration with: CEA-Saclay, SLAC, INFN, PSI

Abstract

In the large parameter space and tight tolerances of a machine like XFEL well designed electron beam diagnostics are crucial to achieve stable and reliable operation of the entire facility.

Electron Beam Diagnostics has to provide the tools to

- Characterize each Single Bunch in a Macro-Pulse with High Precision
- Provide Tools to correct the Beam Properties for optimum Performance along the Train
- Measure Losses and Transmission for the entire Machine
- Provide Access to Slice Parameters
- Deliver Beam Based Timing Information
- Allow for fast Fault Analysis

General Idea

TTF2 has already similar Beam Properties like XFEL except of the Energy. Almost all Diagnostic Tools developed for TTF2 are suited for the XFEL. Therefore, the strategy is:

- Push the further development of TTF2 components, e.g.
  - BPMs
  - Charge Monitors
  - Screens, Wire Scanners
- Use TTF2 as the Test Bed for developing new Techniques, like
  - Electro-Optical Sampling
  - Transverse Mode Cavity
  - Compression Monitor
  - Feedback Systems

The Collaboration with SLAC allows the Development of Instrumentation at high Beam Energies up to 20 GeV (SPPS/LCLS).

Standard Diagnostics

Topics of standard diagnostics:

- Charge
  - Toroid (0.1 –3 nC, $\Delta Q/Q \approx 10^{-3}$)
  - Faraday cup
  - Sum of BPM signal (Cold)
- **Orbit**
  - Stripline BPM (10 µm @ 35 mm BP*)
  - Pickup (5 µm @ 10 mm BP)
  - High res. cavity BPM (< 1 µm@ few mm BP)
  - Reentrant cavity BPM in the modules (10-20 µm)

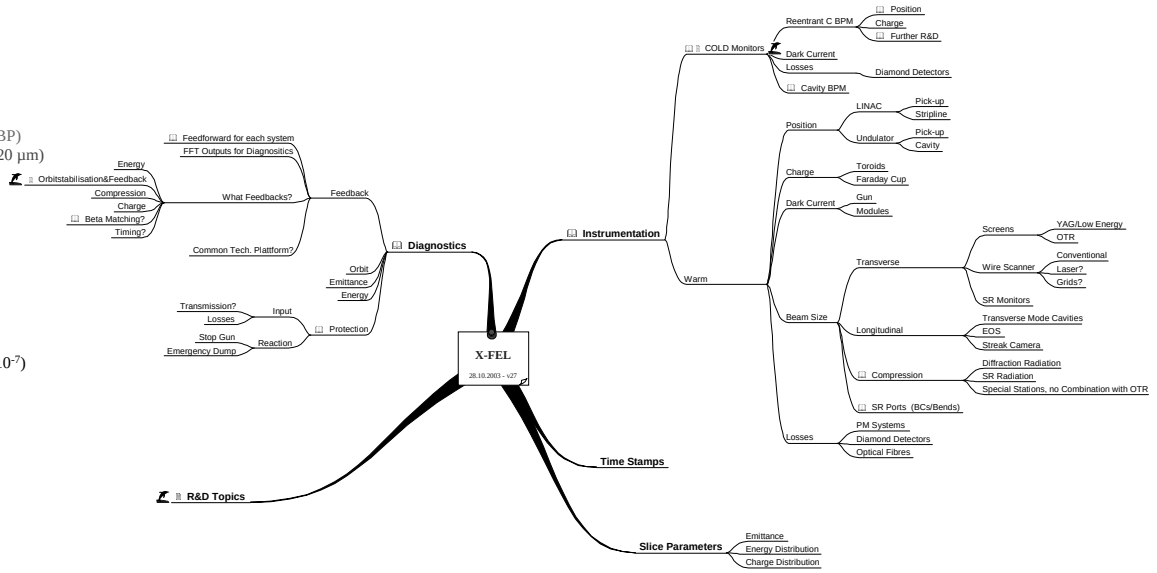
(*BP stands for Beam Pipe)

- **Energy**
  - BPM in spectrometer ($\approx 10^{-4}$, rel.)
  - Pick-up array in BC´s ($\approx 10^{-4}$, rel.)
  - Spontaneous Spectrum (< 10^{-4}, abs.)
- **Transverse beam size**
  - OTR screens (≈20 µm Resolution)
  - Wire scanner (< 5 µm Resolution)
  - Laser wire (sub µm)
- **Losses**
  - Photo multiplier (bunch to bunch, $\Delta Q/Q \approx 10^{-7}$)
  - Optical fiber (pulse to pulse)
  - other, e.g. Diamond Detektors

Further Topics:

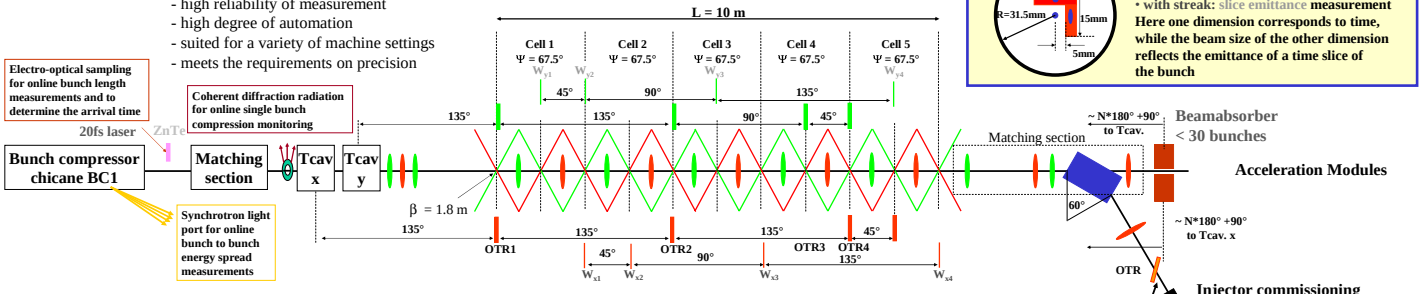
- Compression
  - Pyro-detectors (sensitivity 0.1°)
- Time stamps
  - Electro Optical Sampling (EOS)

Status:
- **Available**
- **Available; Improvements possible/required**
- **Development ongoing**



Possible Layout of a Diagnostic Section

Requirements:
- projected emittance and energy spread measurements during nominal operation conditions
- single bunch profiling during nominal operation conditions
- access to slice emittance and slice energy spread
- single shot bunch length measurement
- non-disruptive online monitoring
- high reliability of measurement
- high degree of automation
- suited for a variety of machine settings
- meets the requirements on precision



Off-axis screen design

Transverse deflecting cavities allow to kick a single bunch onto the screens:
- **no streak: beam profile measurement with OTR foils are 22.5 shifted to wire scanners ⇒ 8 beam profiles allow a precise phase space reconstruction via tomographic methods**
- **with streak: slice emittance measurement**

Here one dimension corresponds to time, while the beam size of the other dimension reflects the emittance of a time slice of the bunch

R&D:
- **The demanding tolerances on the RF acceleration phase stability (~0.1°) requires i.e. an online compression monitoring, also suited as a detector for a fast feedback. Tests are ongoing.**
- **Electro-optic sampling provides the possibility to resolve time scales in the 10 fs regime. Different techniques and limits on the resolution have to be evaluated.**
- **Transverse deflector with filling time <200ns**

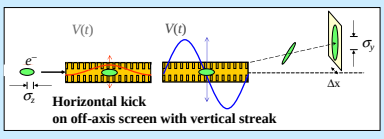
Transverse deflecting cavities (x&y):

TM110 mode, 2π/3 per cell
f = 3 GHz*
G = 10 MV/m
l = 0.60 m
t_{rf} = 0.1 ...3 µs
β_{cav} ~ 6 m

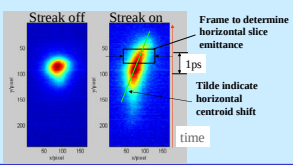
Streak on screens:
β_{OTR}~ 1.8 m
Δy/Δt ~1.9 mm/ps

Bunch length resolution:
σ_t ~ 50 fs

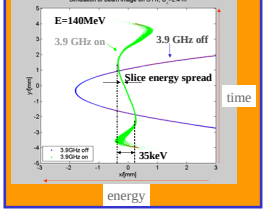
* to be defined.



Two images of the beam taken from the length measurement at **SPPS (SLAC):** ~ 60µm could be resolved at 28.5 GeV



Measurement of the correlated and the residual (slice) energy spread of the bunch: D = -2.4m, β_{OTR} = 0.3 m Resolution ~ 2.2 keV, (on-crest accel.)



Presently two such diagnostic stations are planed. The second one is located behind the high energy compressor. The design will be similar.

References:

[1] D. Nölle, "The Diagnostic System of TTF2", EPAC02
[2] P.Emma, J. Frisch, P. Krejcik "A Transverse RF Deflecting Structure for Bunch Length and Phase Space Diagnostics", LCLS-TN-00-12
[3] "LCLS Conceptual Design Report", SLAC-R-593
[4] M. Hüning, H.Schlarb "Measurement of the Beam Energy Spread in the TTF Photo-injector", PAC03
[5] Emma et. al. "Measurement of Transverse Emittance Growth due to Coherent Synchrotron Radiation", PAC03
[6] J.Schmerge "Lonitudinal and slice emittance measurements at the SLAC Gun Test Facitility", talk S2E workshop 03, Zeuthen
[7]H.Schlarb "Bunch length measurements at SPPS", talk S2E workshop 03, Zeuthen

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