The Diagnostic System of TTF II

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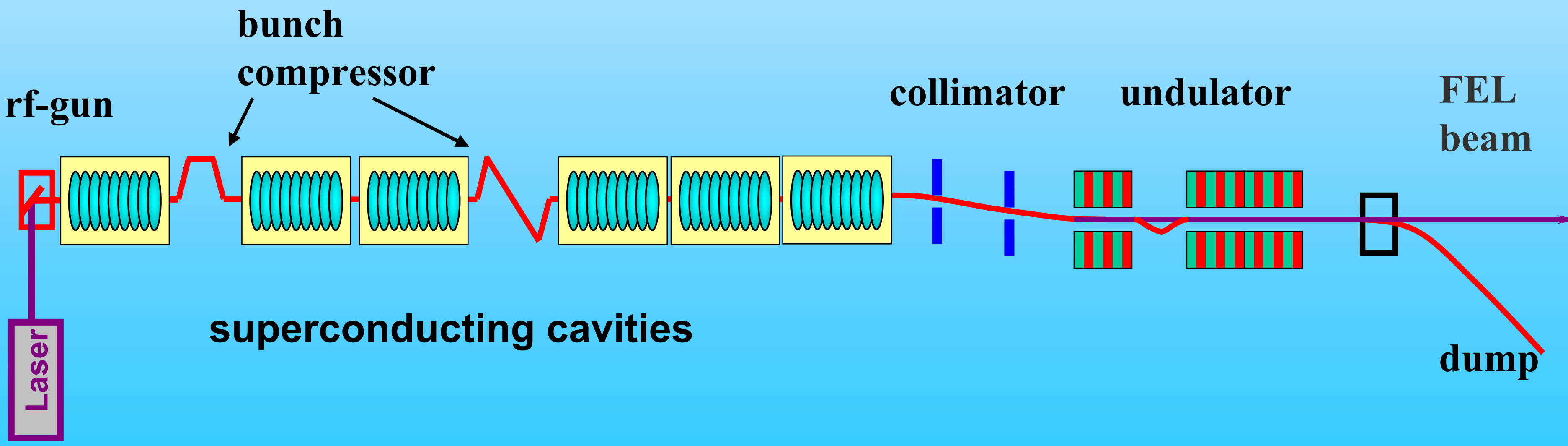
TTF II at DESY:

- Superconducting 1 GeV LINAC
- Charge between 0.1 and 4 nC
- Normalized Emittance ≈ 2 π mm mrad
- Bunchlengths as short as ≈ 50 μm
- Up to 7200 Bunches with 110 ns Spacing
- 10 Hz Operation
- VUV - Soft X-Ray FEL User Facility (down to ≈ 6 nm)



Challenges of the Diagnostics

- LINACs are Open Loop Systems
  - Beam Parameters change during the Pass through the Machine; They have to be measured at different Locations from Gun to Dump.
  - Diagnostics have to have Single Bunch Resolution over the whole Bunch Train.
  - Pulse to Pulse AND Bunch to Bunch Fluctuations have to be detected.
- High Duty Cycle Single Pass Machines can destroy themselves
  - Radiation Damage, Heat Load
  - Need a very sensitive fast acting Protection System.
  - Threshold and Reaction Time is determined by the most sensitive Component ($\approx$ 3 μs).
- Challenge of Ultra short compressed Electron Bunches
  - How to measure bunch lengths in the 100 fs Regime?
- SASE Characteristics (Intensity, Pulse Length)
  - Strong Dependencies between Laser and Machine Operation
  - Operator needs FEL Parameters and their Statistics.

LINAC - Storage Rings

LINAC

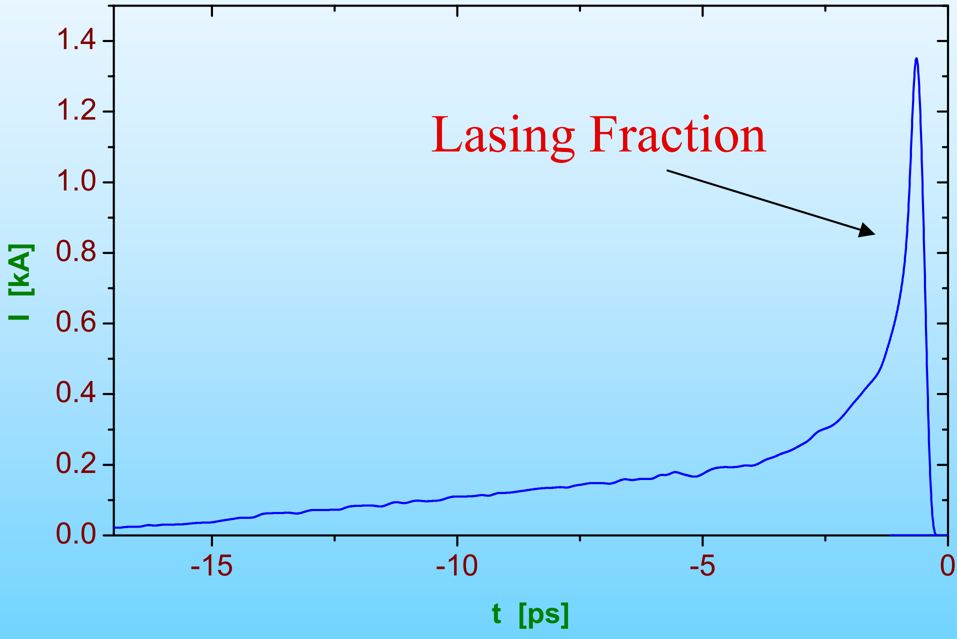
- Pulsed System with high Fluctuations
- Triggered Electronics have to take Pulses with the rep. Rate of the Bunches.

  (9 MHz for TTF II)

Storage Rings

- Closed loop Equilibrium System
- Watch beam Parameters under stable Conditions.
- Systems can be much slower and can average over long Times.
- Precise Measurements in the Frequency Domain.

... further Complication



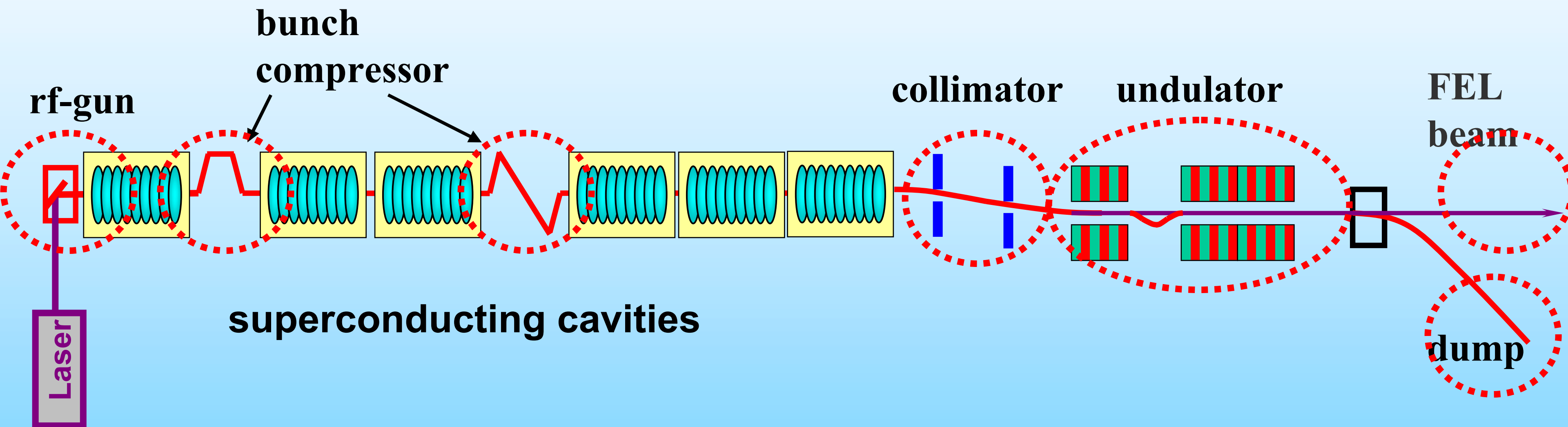
Longitudinal Charge Distribution
at TTF I

What do Monitors see:

- Mean value of charge per bunch
- Mean value of position per bunch
- Projected emittance
- ...

What is contributing to the FEL process?

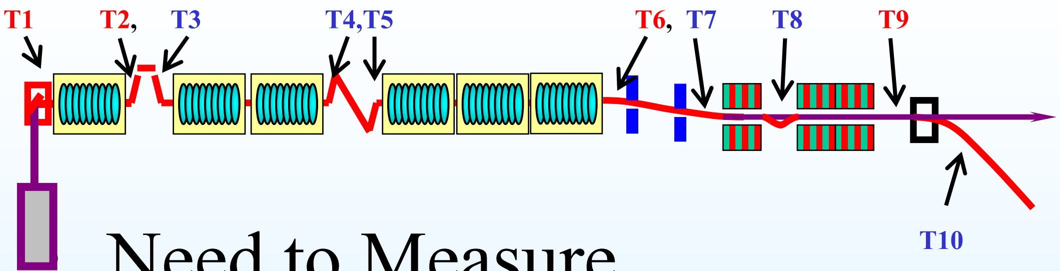
Areas of Special Interest for Diagnostics



Remark: TTF has everything, a big Machine also has, but everything concentrates in a limited Area !

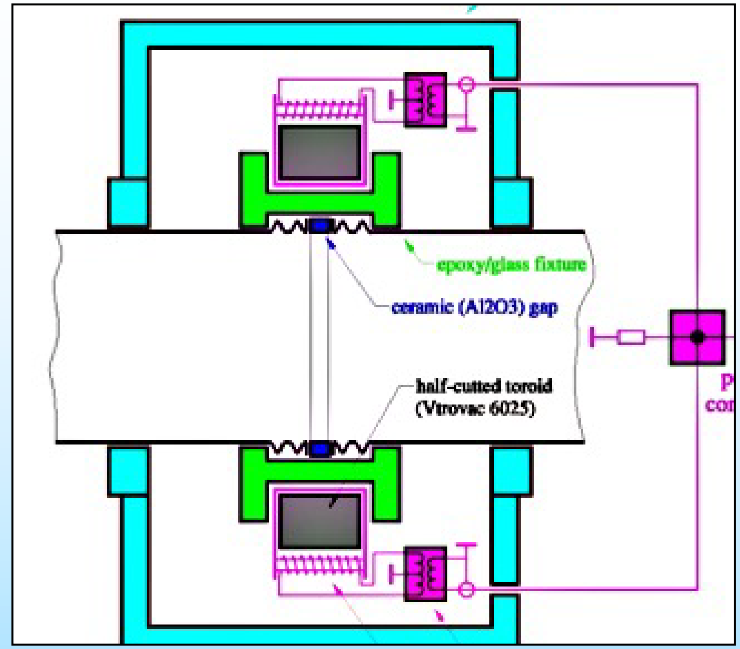
„Butter and Bread Diagnostics“

- Charge



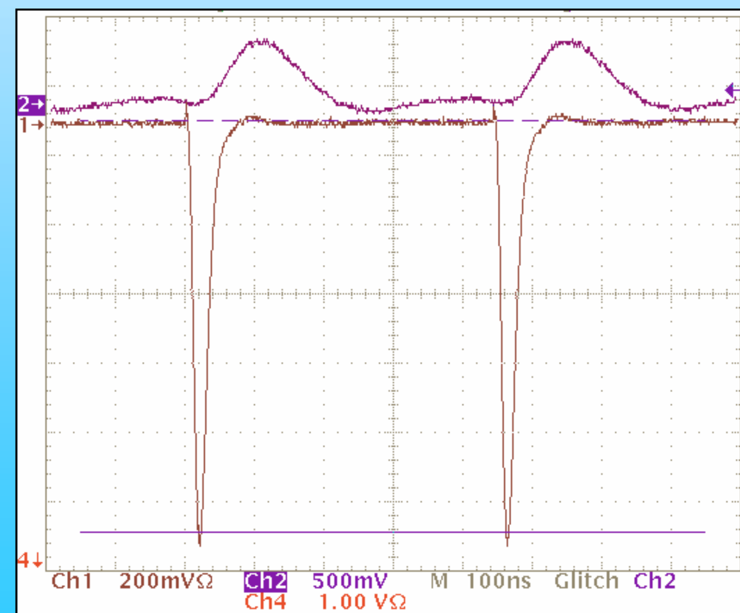
Need to Measure

- Charge
- Charge Distribution of the Bunches in the Beam Pulse
- Transmission



Fast Toroid System

- Single Bunch Resolution
- Time Constant < 110 ns
- Bunch Rep. Rate = 9.9 MHz
- Range 0.1 to 5 nC
- Accuracy ≈ 10^{-3}

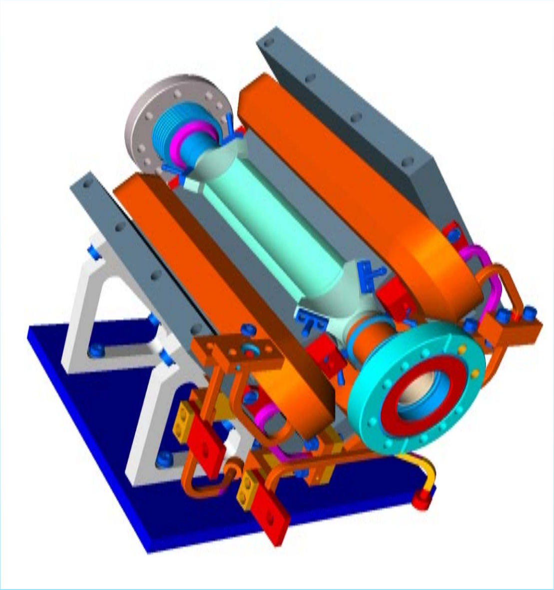


„Butter and Bread Diagnostics“

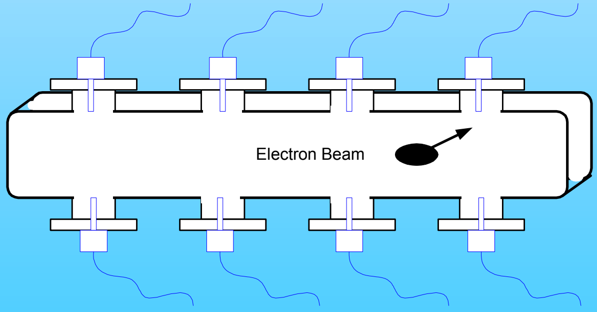
- Charge
- Beam Position

Warm Parts of TTF II:

Striplines, Pickups



- Use a modular electronics system for all BPMs based on AM/PM Signal Processing
  - Single Shot, Single Bunch Readout
  - Variation of the Beam Position over the Macro Pulse
  - External Trigger
- Striplines installed inside the Quads, and aligned to the magnetic Axis (Res. < 30 μm, 34 mm Pipe)
- Button Arrays (8 Pickups per Monitor) for Bunch Compressors (large variation of Beam Position)
- Pickups in the Diagnostic Blocks between Undulator Sections and 2 inside each Undulator (Res. ≈10 μm)



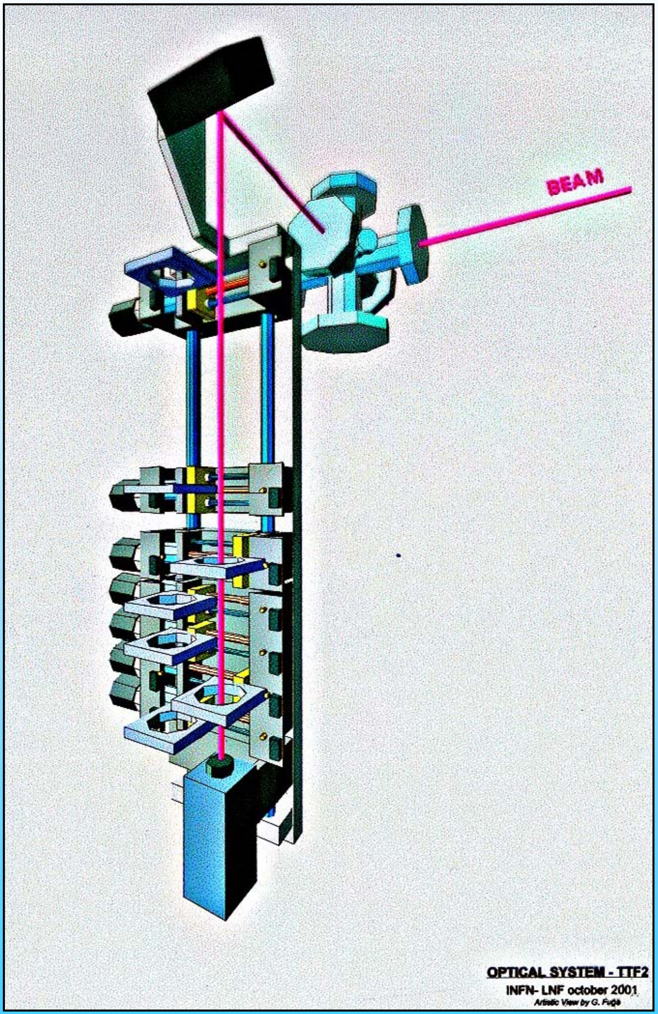
In the cold Modules:

- Cavity BPMs
- Prototype of a Cold Reentrant Cavity (by CEA)

„Butter and Bread Diagnostics“

- Charge
- Beam Position
- Transverse Electron Distribution

Screen & Wire Scanner



OTR Station for TTF II

- Screens* (OTR, Diff. Radiation, Ceramics)
  - Beam Size (typical O(100µm)), Measure Emittance, Energy Distribution
  - Resolution ≈ 20 µm
  - Interceptive
  - Damage Threshold: 3 – 10 bunches only
- Extraction of Coherent FIR Radiation
  - Measurement of Compression
  - Measurement of Bunchlength
- Wire Scanners
  - Modified CERN Scanners with a „V Fork“ and 45° Assembly with Respect to the Beam
  - New developed Type using an unidirectional Drive Unit (used in the Undulator)

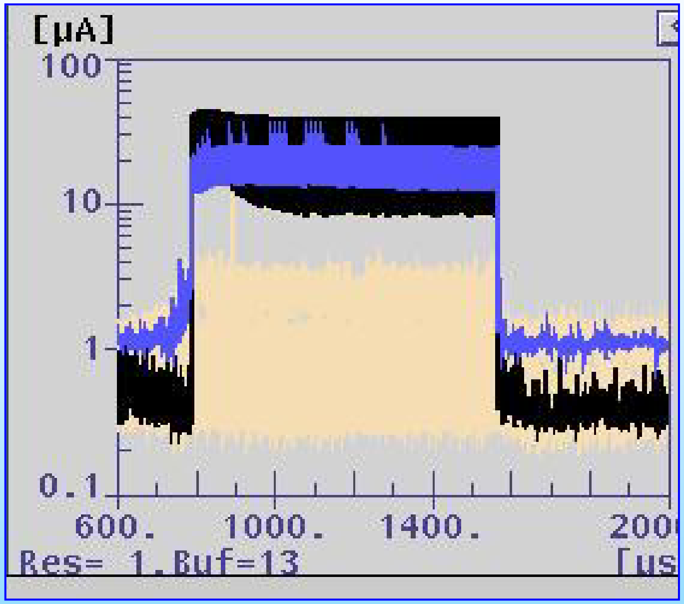
*In collaboration with INFN, Frascati, Italy

„Butter and Bread Diagnostics“

- Charge
- Beam Position
- Transverse Electron Distribution
- Dark Current

Dark Current

- Fills every RF-bucket
- Produces losses along the machine
- Contributes to Cryo-Load



Dark Current at TTF I:

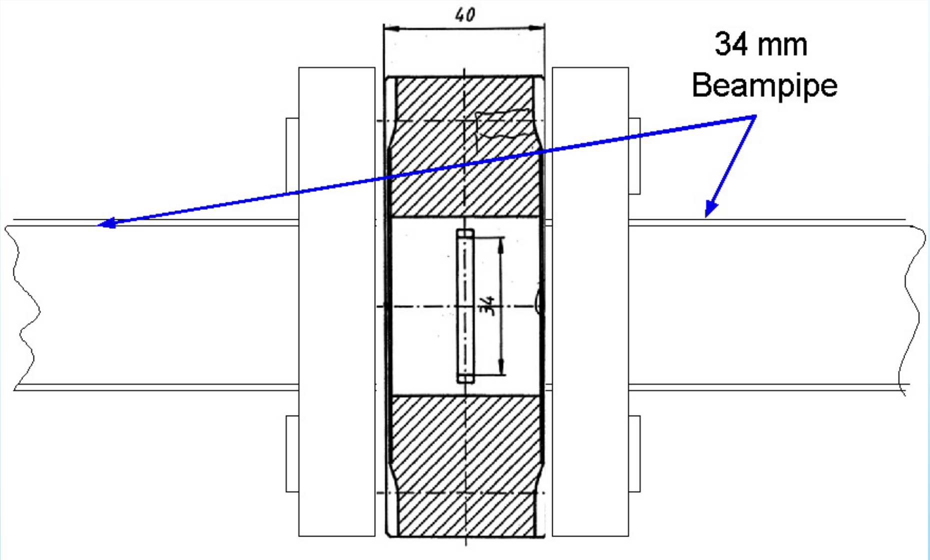
Sum Signal of Reentrant Cavity BPM sampled between Laser Buckets

- is emitted by the Gun
  - Increases with the age of the cathode
  - Cathode has to be changed
    - if DC gets to big compared to normal current, or
    - if DC produces to much losses
  - Measured by Sum Signal of a Reentrant Cavity BPM (O(500 nA))
- and by the Modules
  - At very high Gradients
  - Needed for Module Development
  - Sensitive Cavity Monitor (10 nA, installed outside the vacuum)

„Butter and Bread Diagnostics“

- Charge
- Beam Position
- Transverse Electron Distribution
- Dark Current
- Phase

Phase



- Isolated impedance-matched Ring Electrode installed in a „thick Flange“
- Broadband, Position independent Signal
- One installed after the Gun, each magnetic Chicane (BCs and Collimator)

- Due to magnetic Bunch Compression Energy Fluctuations turn into Phase Fluctuations
- Beam Signal mixed with the (1.3 GHz) Master provides a Signal proportional to the Beam Phase
- Time Of Flight Measurement: Resolution < 0.5° or 1 ps (tested with TTF I Stripline as a Pickup)

„Butter and Bread Diagnostics“

- Charge
- Beam Position
- Transverse Electron Distribution
- Dark Current
- Phase

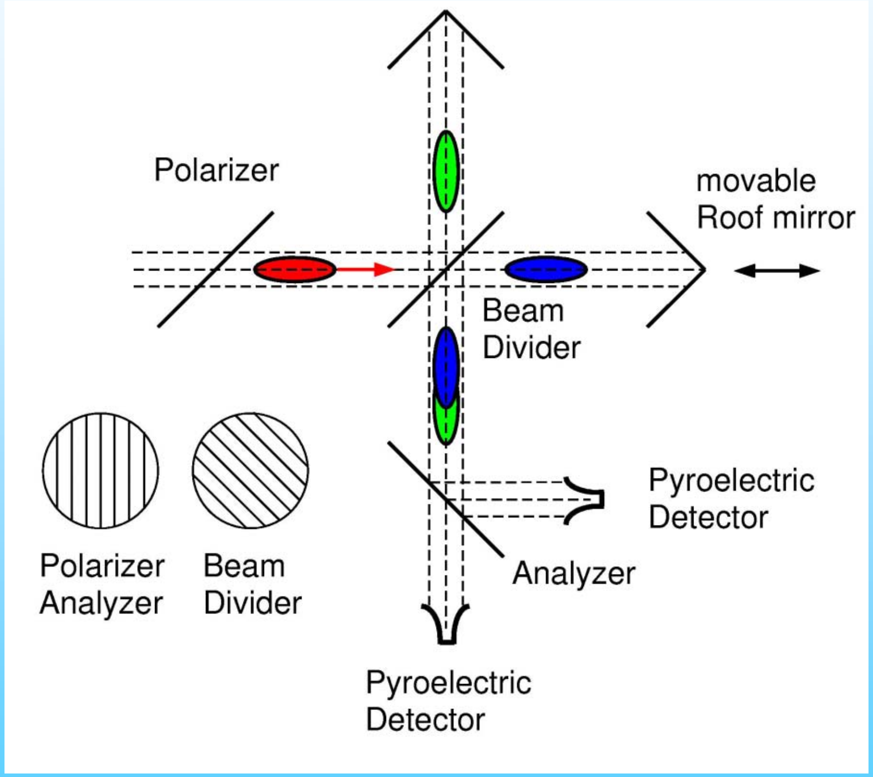
… this is not sufficient for a SASE Machine!

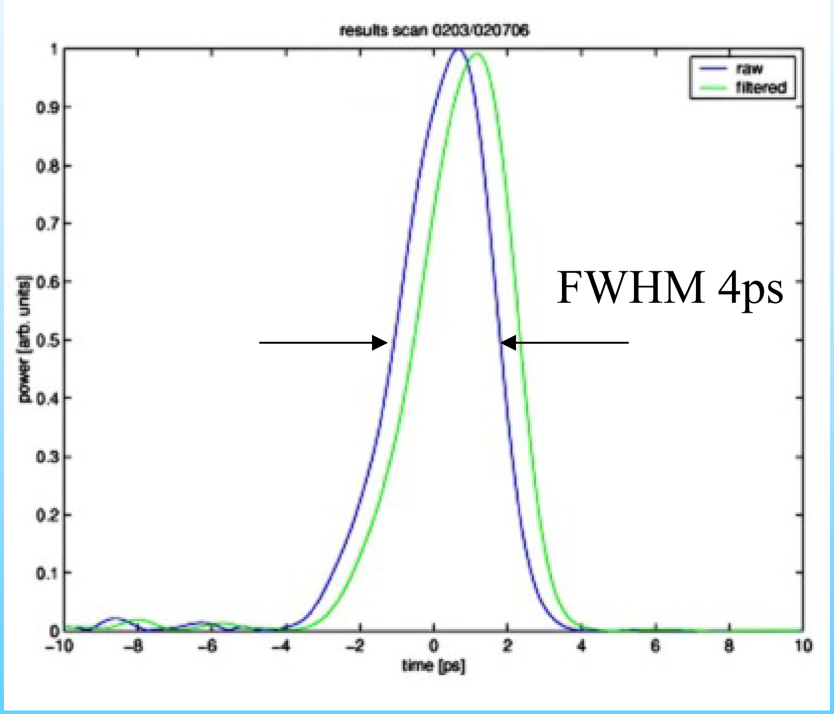
Bunchlength and Compression

Scale: Resolve Structures of 100 fs and less

- Qualitative: Optimization of the Compression
  - Phase Tuning to maximize the coherent FIR Emission from the Beam.
  - Emission $\approx n^2$ for $\sigma_s \leq \lambda$
  - Use of simple Pyro-Detectors in the FIR
- Quantitative: Measurement of Bunch Length
  - Use coherent FIR Radiation and Autocorrelation Methods.
  - Transverse Mode Cavity (integrated Streak Camera)
  - Electro-Optical-Sampling

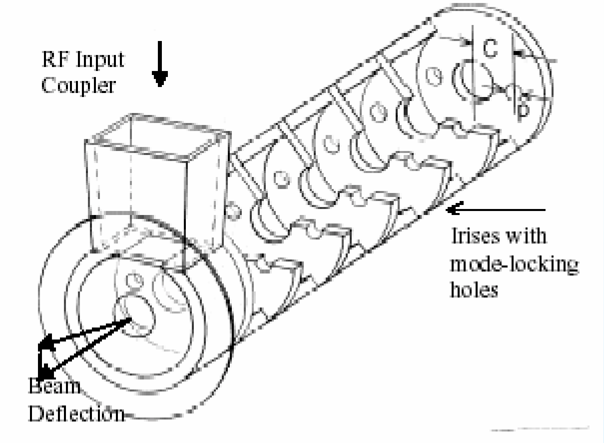
Interferometric Bunch Length Measurements





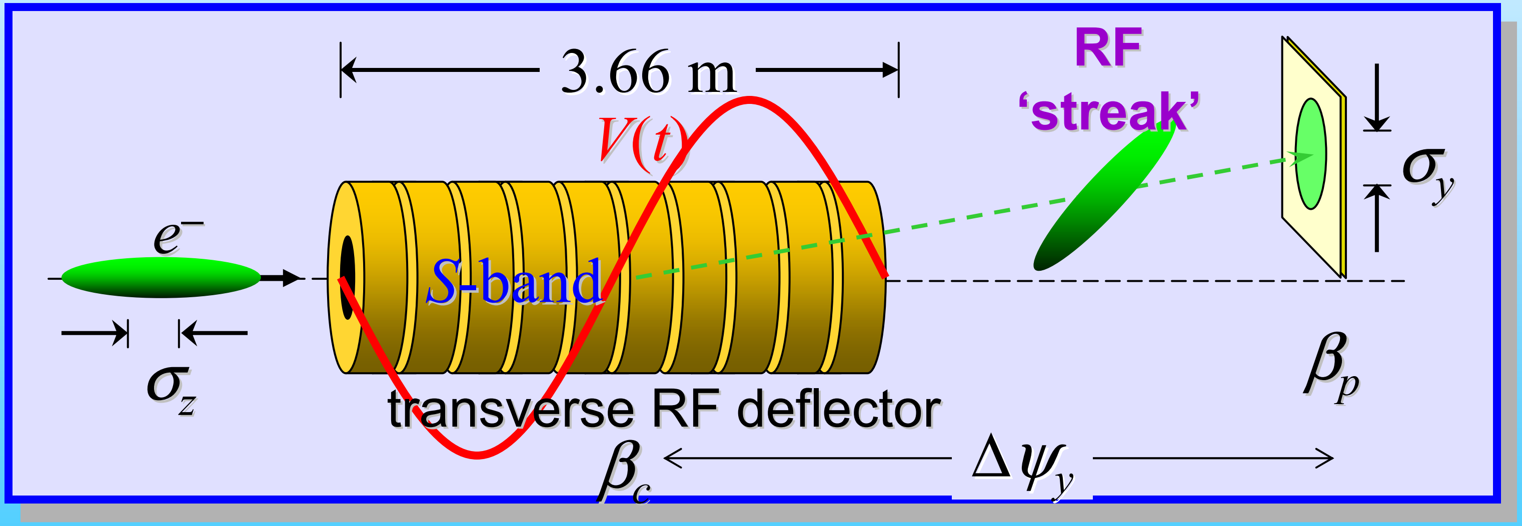
Using Coherent Transition and Diffraction Radiation

In Collaboration with University of Aachen, Germany



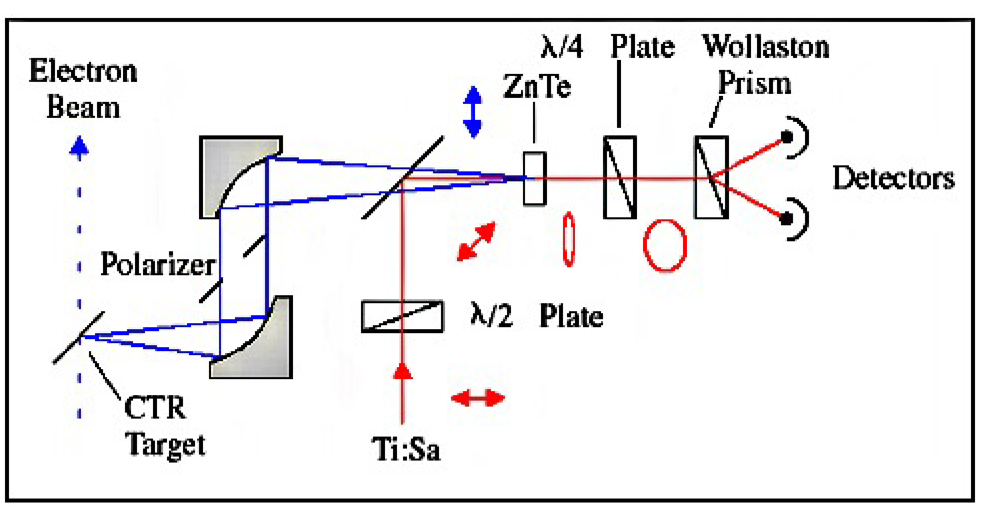
Transverse Mode Cavity: „Intra Beam-Streak Kamera“

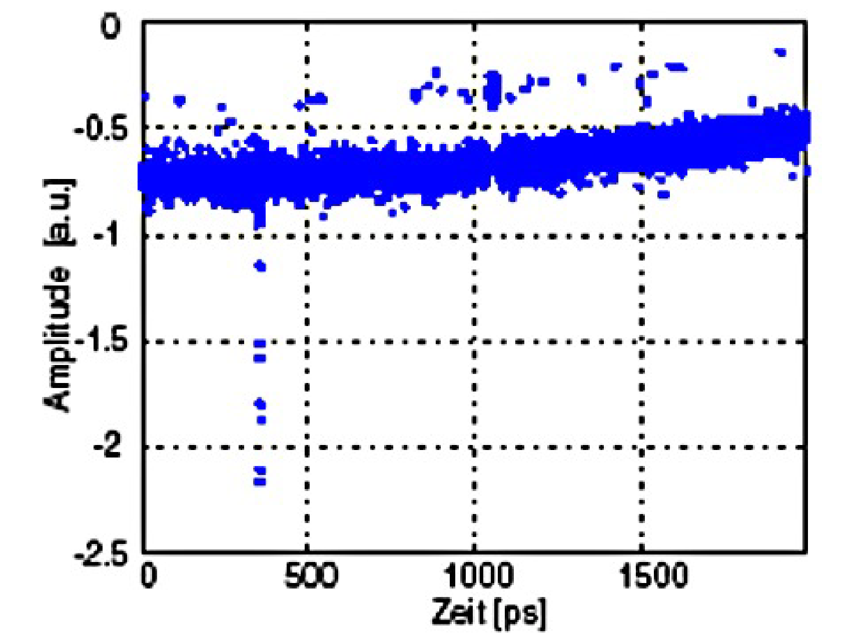
Poster on Transverse Mode Cavities: Today THPRI097
By P. Emma, R. Akre, L. Bentson, P. Krejcik



In collaboration with SLAC, USA

Electro-Optical-Sampling





- Coherent Terrahertz (Transition or Diffraction) Radiation is combined with an ultra short Ti:Sa Laser (15 fs) in a ZnTe Crystal.
- The Polarization of the Ti:Sa Laser is changed depending on the Amplitude of the „Beam Fields".
- The Bunch Length can be scanned by varying the Delay of the Ti:Sa Laser
- Resolution limits: Laser Pulse Length and Timing Jitter of Laser and LINAC
- Single shot Measurement using a Chirped Laser are under Investigation

In collaboration with TU Darmstadt and TU Aachen, Germany

Protection Systems

- SASE LINAC:
  - „Biggest Welding Machine“
  - „Biggest X-Ray Tube“

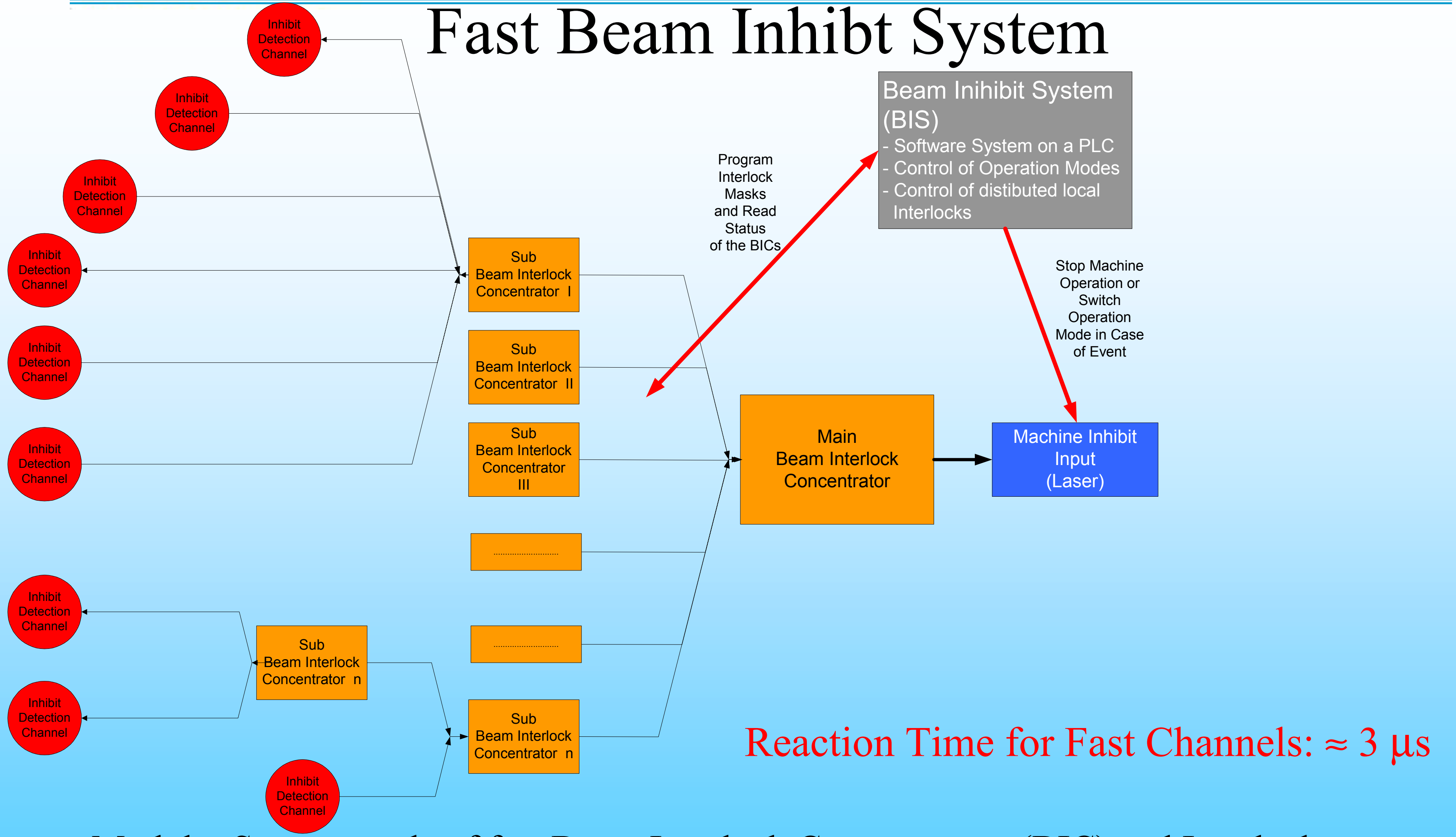
  Therefore:
  - Need of fast Interlocks to avoid Mechanical Damage.
  - Need of continuous Monitoring to minimize Radiation Damage.
- Transmission and Loss based Systems
  - Thresholds given by most sensitive Component (Undulator)
  - Reaction Time by „Worst Case Events“
  - Fast and Slow Systems

Slow Loss Monitoring Systems

- TLDs
  - TLD crystals located at sensitive regions (undulator section)
  - Document the Irradiation Profile over long Times
  - Data on a weekly Basis
- Optical Fibers used as Dosimeters*
  - Small Opt Fiber Coils installed close to the Undulator Gap
  - Transmission Decrease of the Fiber due to Radiation Damage
  - Allows
    - Avoid Operation Modes with medium high losses
    - Correlation of Dose Measurement with operation Modes
  - Reaction Time ≈ 1h

*In collaboration with Fraunhofer INT, Euskirchen, Germany

Fast Beam Inhibt System



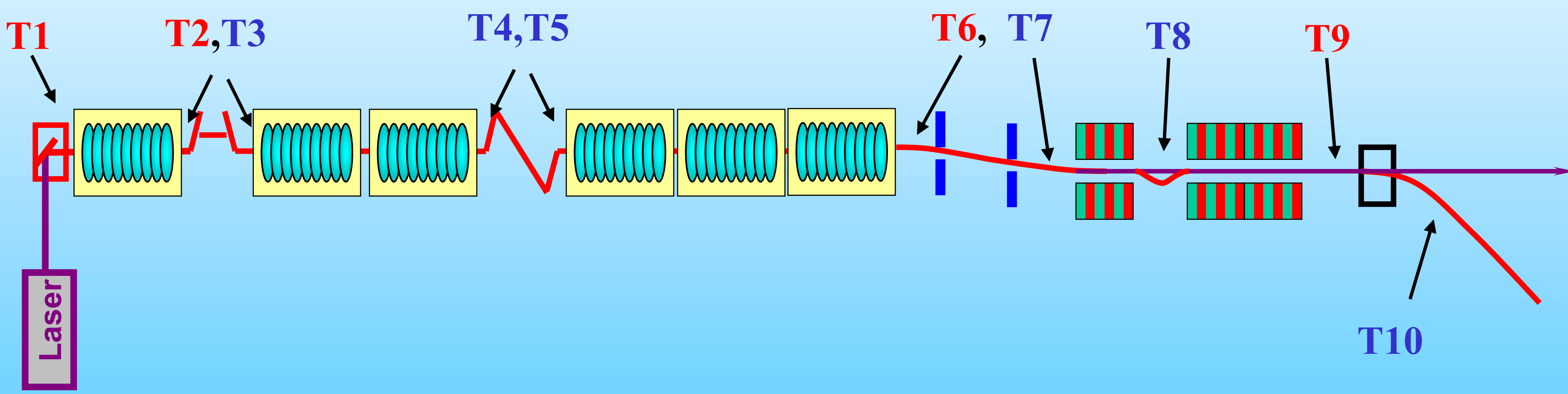
- Modular System made of fast Beam Interlock Concentrators (BIC) and Interlock Inputs with well specified interfaces.
- BIC Modules can be cascaded, Input Mask and Event Status controlled by BIS
- Interlock Inputs: Different Systems using Same Communication Protocol: Protection Systems, RF, Fast Acting Valves, ...

Transmission Based Protection System for TTF II

Pairs of Current Monitors + fast acting Interlock Electronics

Two Measurement:

- Fast, detecting high losses O(10%) ⇒ Cut this Beam Pulse
- Slow, averaging over the bunch train (O(10^{-3})) ⇒ Inhibit next Long Pulse



Inhibit Pairs for TTF II:

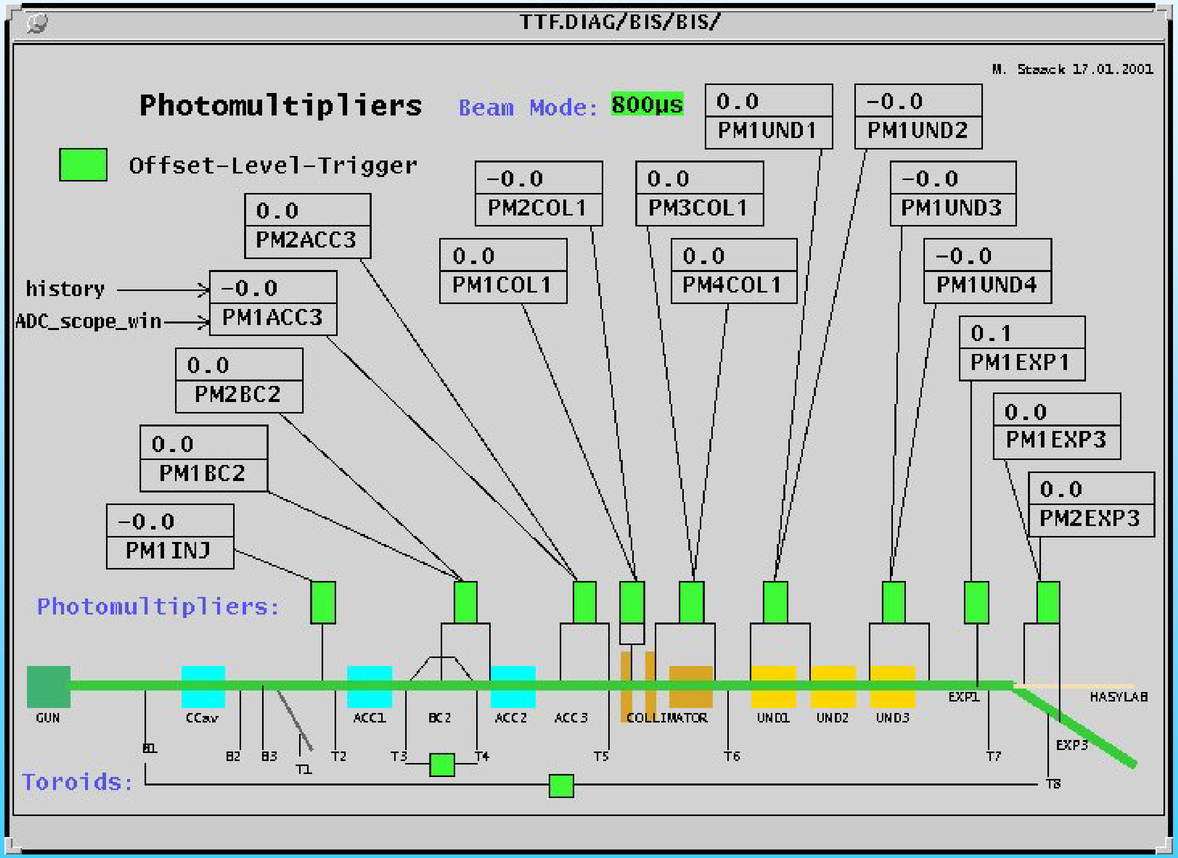
- $T_1 - T_9$: Whole Machine (FEL Mode)
- $T_1 - T_{11}$: Whole Machine (Bypass Mode)
- $T_2 - T_6$: 2nd System for both Modes

- Used for Beam Inhibit
- Charge Measurement only

In collaboration with CEA, Saclay, France

Loss Monitor Systems

- ≈ 50 Fast Loss Monitors (Photomultipliers) at critical Machine Parts
- Used as fast input Channels for the Fast Beam Inhibit system



PM Operation Panel of TTF I

Poster Today!: THPRI119 by H. Schlarb et al.

SASE Diagnostics

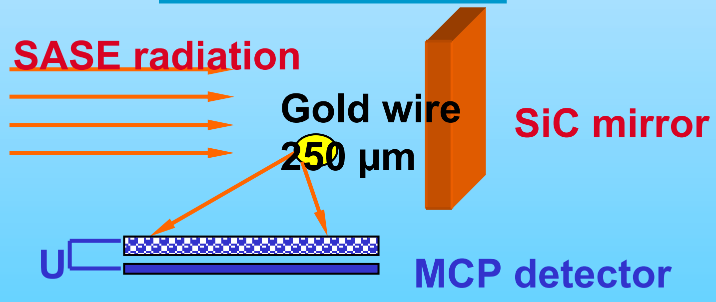
- Tolerances on Machine Settings are very tight!

⇒ Light Production has to be controlled from the Operators Console.

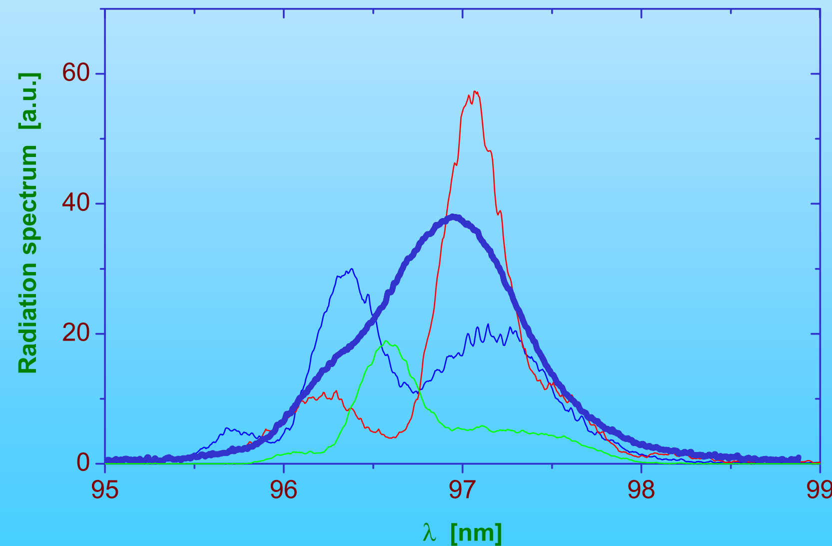
- Operator needs to keep optimum Performance:
  - SASE Signal + Statistics
  - Radiation Spectrum (Pulse Length)

    (few modes only ⇒ high peak power, Operation Experience of TTF I)

MCP detector



MCP has been calibrated for different voltage settings dynamic range: 10^7



Thin lines: Single Shot Spectrum

Bold: Average over many Shots

Conclusion

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I am sure time is over

………..