Coherent Diffraction Radiation (CDR) for short bunch length diagnostics

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CERN

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Bunch length for various accelerators

ILC	500fs
CLIC	130fs
XFEL	80fs
LCLS	75fs

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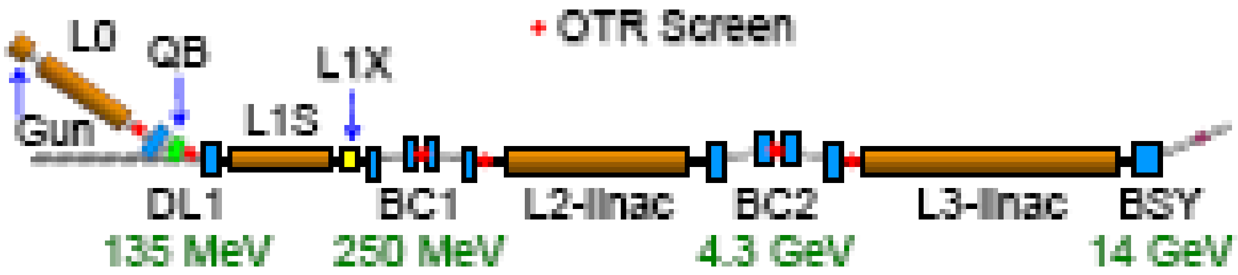
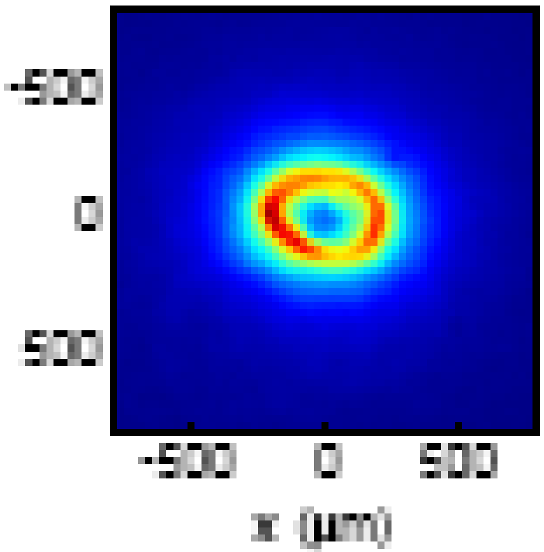
Coherent Optical Transition Radiation Observation at LCLS





H. Loos, et al., SLAC-pub-13395

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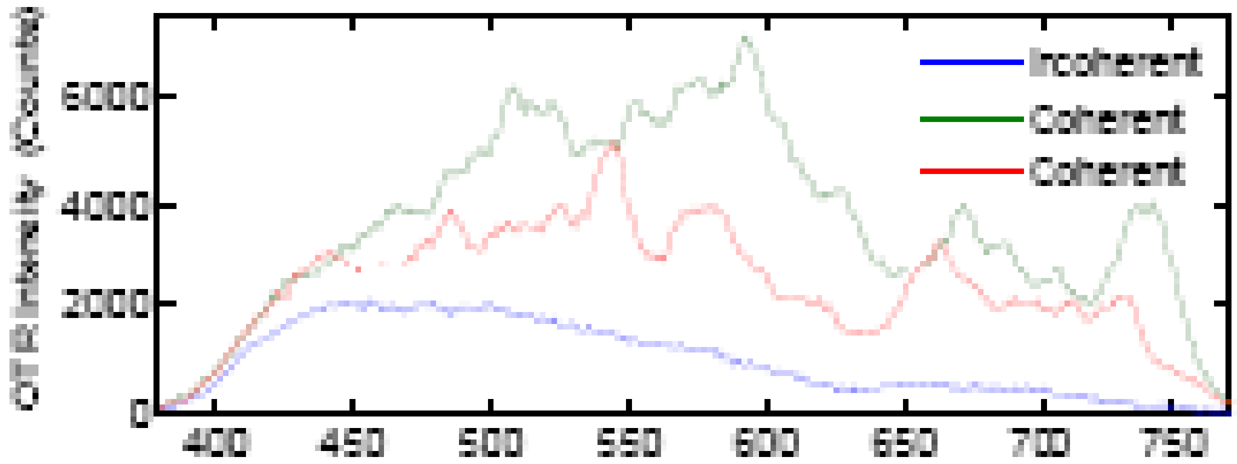
COTR spectra



- The form of the coherent spectrum fluctuates from shot to short
- Existence of spikes in the spectrum suggests that there are a few microbunches in the longitudinal particle distribution
- The coherent part of the OTR intensity could be much higher than the incoherent one

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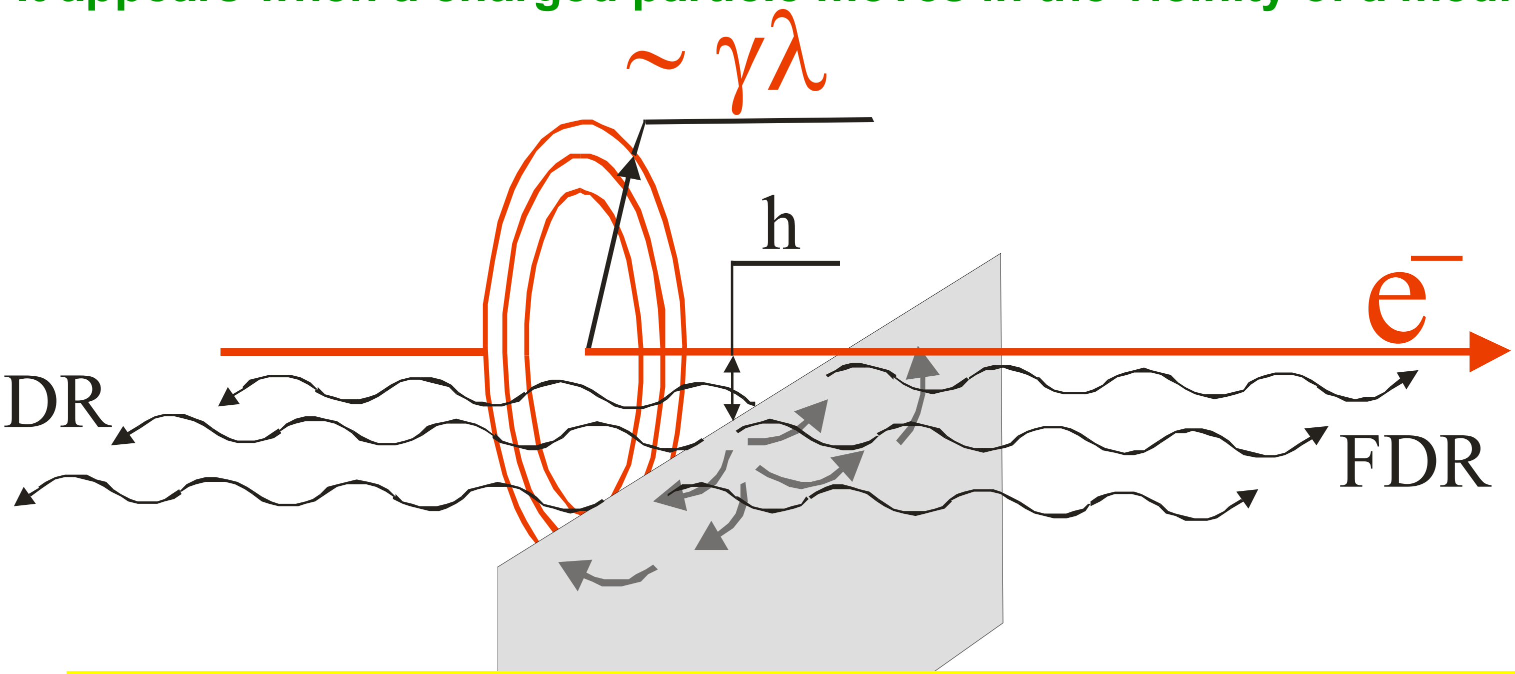
Advantages

It appears when a charged particle moves in the vicinity of a medium



For our setup at CTF3, $h \approx 15$ mm $\ll \gamma\lambda = 1175$mm

for $\gamma = 235$ and $\lambda = 5$mm.

Impact parameter, h, – the shortest distance between the target and the particle trajectory

$$h \leq \gamma\lambda$$

λ - observation wavelength

$\gamma = E/mc^2$ – Lorentz - factor

Advantages

- Non-invasive method
- Instantaneous emission
- Single shot measurement option
- Large emission angles ($0 \sim 180^0$)
- Single electron spectrum is predictable
- Relatively inexpensive and easy in use
- No theoretical resolution limit
- Gives information about the longitudinal profile

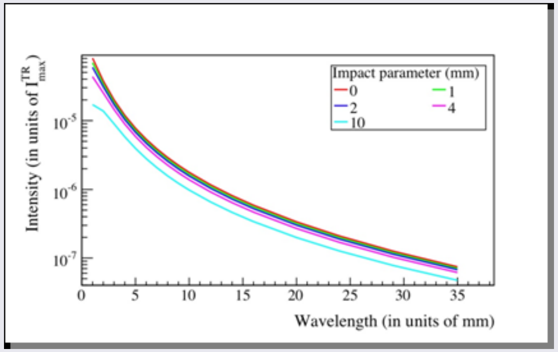
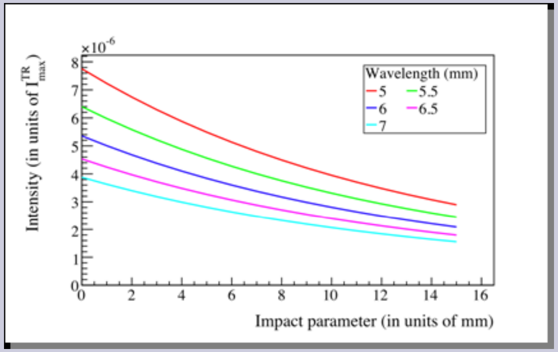
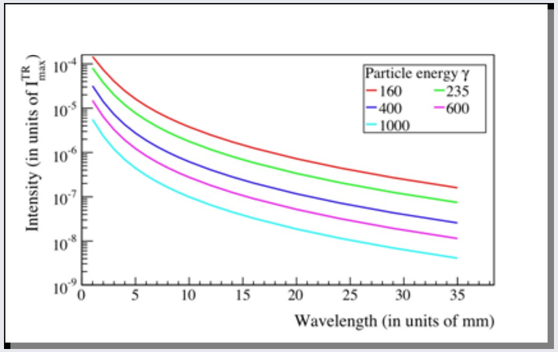
- Coherent radiation:

$$S(\boldsymbol{\omega}) = [N_e + N_e (N_e - 1) F(\boldsymbol{\omega})] \, S_e(\boldsymbol{\omega})$$

Incoherent part — Coherent part

- $S(\boldsymbol{\omega})$ is the signal, known from the experiment
  - this can be obtained by using an interferometer
- $S_e(\boldsymbol{\omega})$ is the single electron radiation, which should be predictable form theory
- N_e is the number of electrons, known from the experiment
- $F(\boldsymbol{\omega})$ is the longitudinal bunch form factor, which is the measurement purpose.
  - the bunch form factor is just the Fourier transform of the spatial charge distribution in space
  - the longitudinal bunch profile can therefore be reconstructed using Kramers-Kronig relation

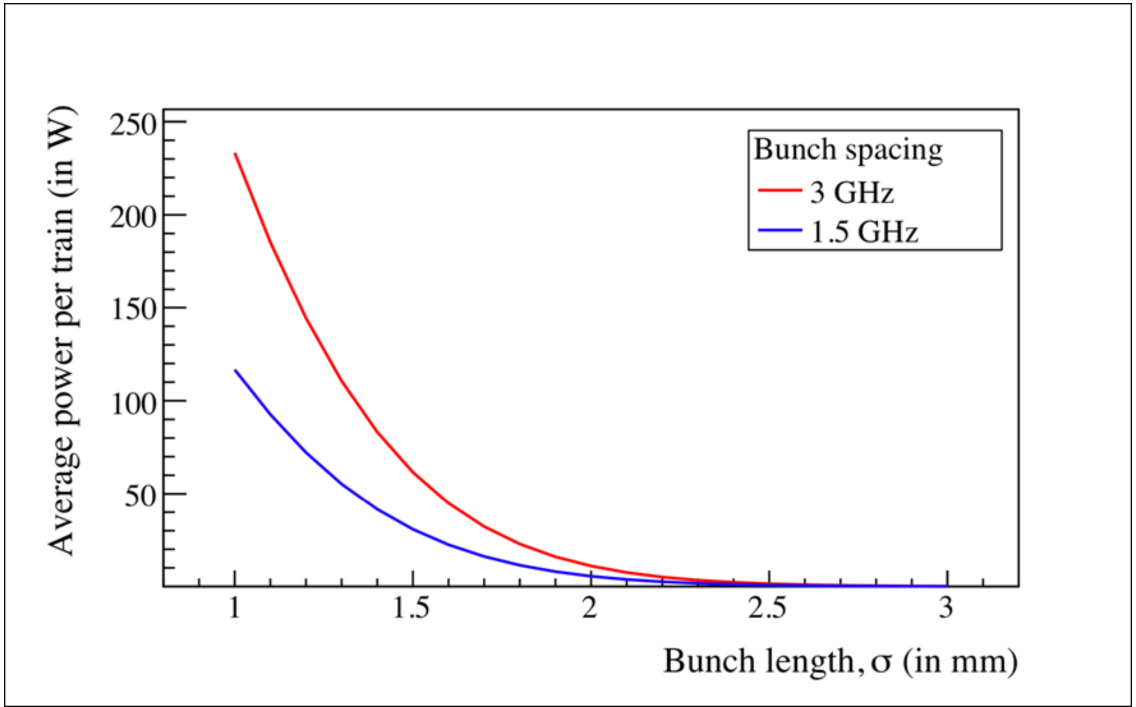
Simulation studies

• Diffraction radiation spectra with [redacted] • needed in the de-convolution of the spectral information (see previous slide) • $S(\omega) = N_e^2\, F(\omega)\, S_e(\omega)$	
• Intensity dependence on impact parameter (γ=235): • at a considerable distance from the beam the signal level is still high • non-invasive measurements	
• Diffraction radiation spectra for different beam energies • zero-impact parameter • for higher energies the intensity increases	

Power generated by CDR

Average power emitted per train by DR for DXP19 and impact parameter (h=10 mm):

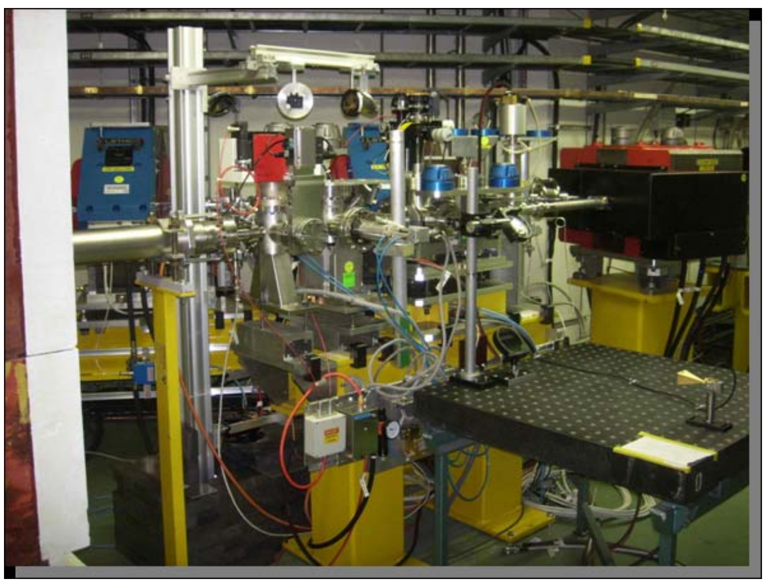
- For a 2mm Gaussian beam the energy emitted into the detector is 3.6x10^-9 J/bunch
- The average power per train is 5.5W and 11.0W for 1.5GHz and 3GHZ operation
- For 2.5 x 10^10 electrons per bunch the energy contribution per electron is 0.9eV

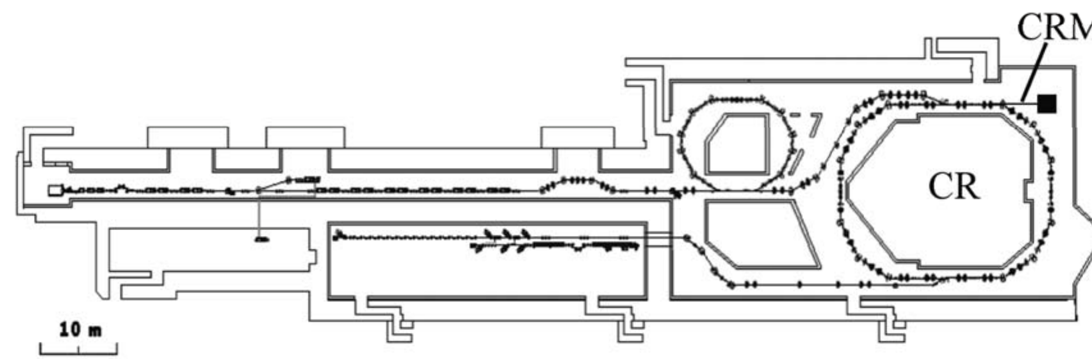


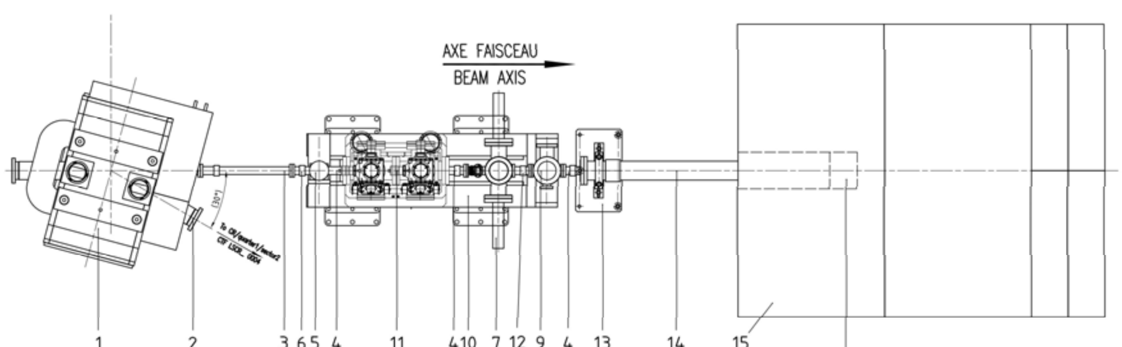
CDR setup @ CTF3

CDR setup:

- Installed the vacuum hardware in the CRM line at CTF3
- The technical drawing of the CRM line (bottom right) shows the CDR setup (11) just in front of the OTR screen (7)







CDR Setup in 2008

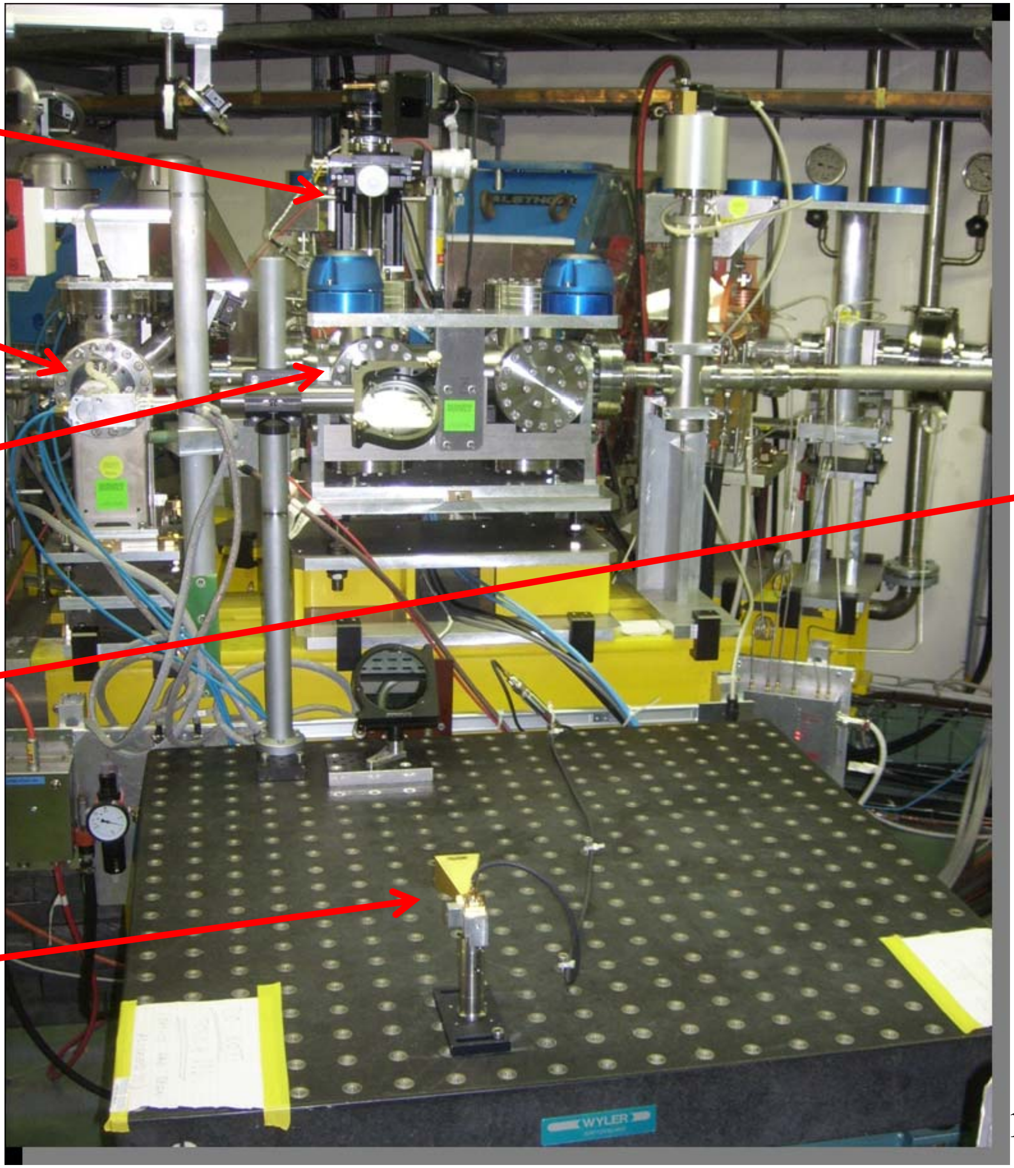
Vacuum manipulator for target rotation and translation

OTR screen for target reference position

CDR target within six-way cross

BPM (not shown in picture) for beam position and charge readings

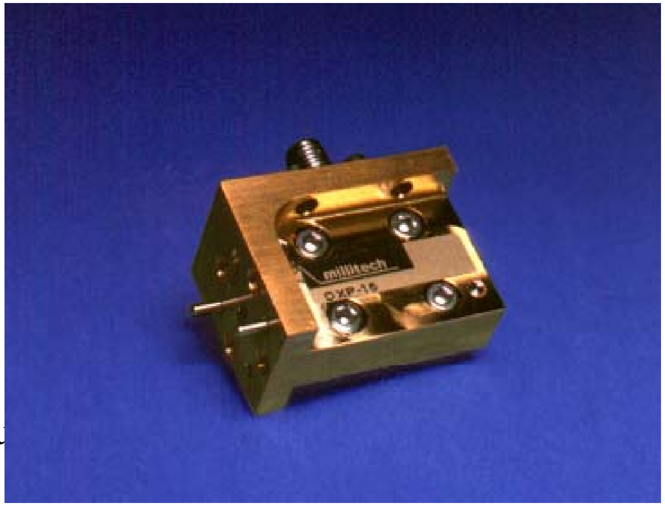
Schottky barrier diode detector connected to DAQ

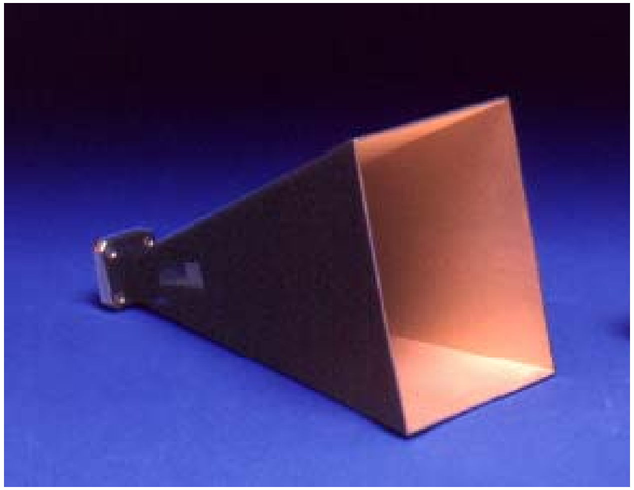


SBD detector

As a detector we used an Ultra-fast Schottky Barrier Diode with the following parameters

Frequency range	90 – 140 GHz
Wavelength range	2.14 – 3.33 mm
Sensitivity range (freq. dep.)	1530 - 400 – mV/mW
Horn Antenna Gain (freq. dep.)	22.42 – 23.69
Time response (FWHM)	~250ps

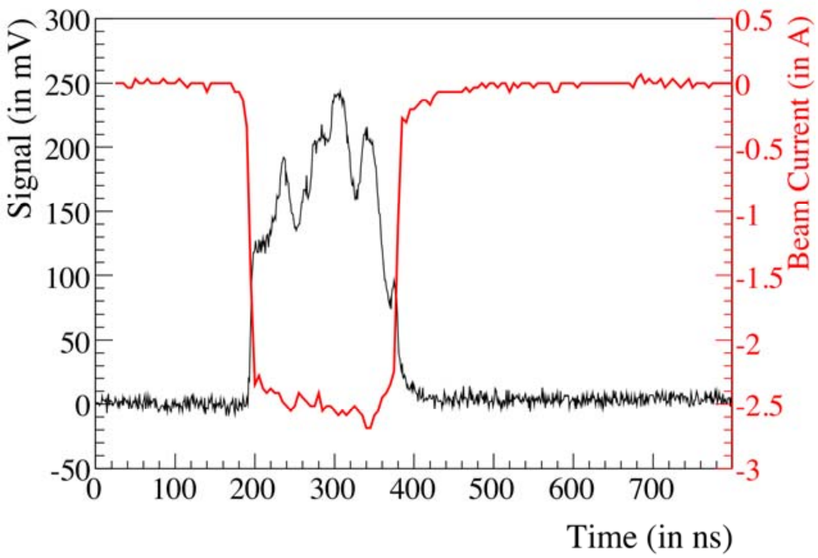




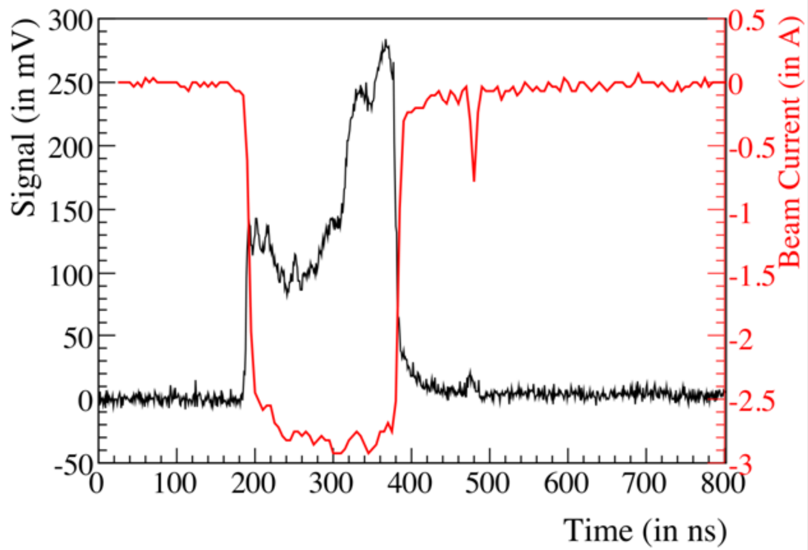
Signals observed at CTF3 in 2008:

- Signal of CDR and CSR including the BPM current reading
- Variation of the SBD signal for CSR and CDR suggests a bunch length variation along the train

→ CDR signal:



→ CSR signal:

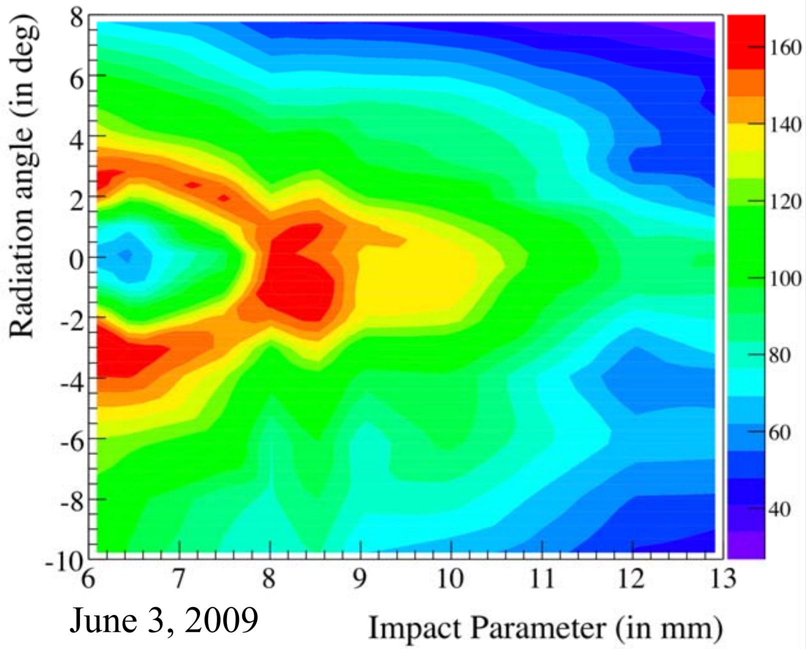


Observation of CDR signal

CDR and CSR signal dependences (horizontal polarization):

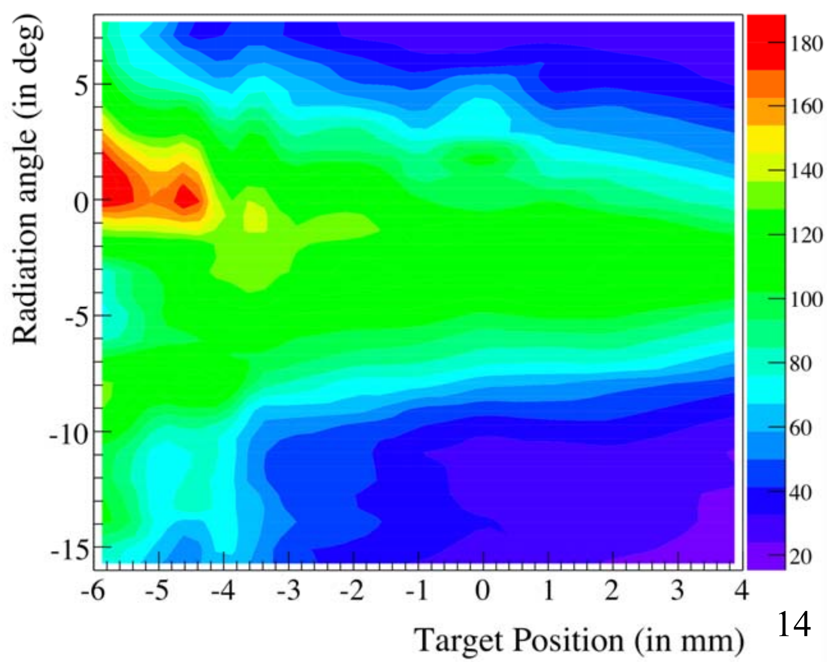
- Checked the signal level depending on the target position and orientation
- Good agreement with expectation but some distortion (CDR, CSR) and offset (CSR)
  - Distortion can be explained by background caused upstream (wake-fields, CSR, etc.)
  - Offset can be explained by the offset beam in the bending magnet

Diffraction radiation:



June 3, 2009

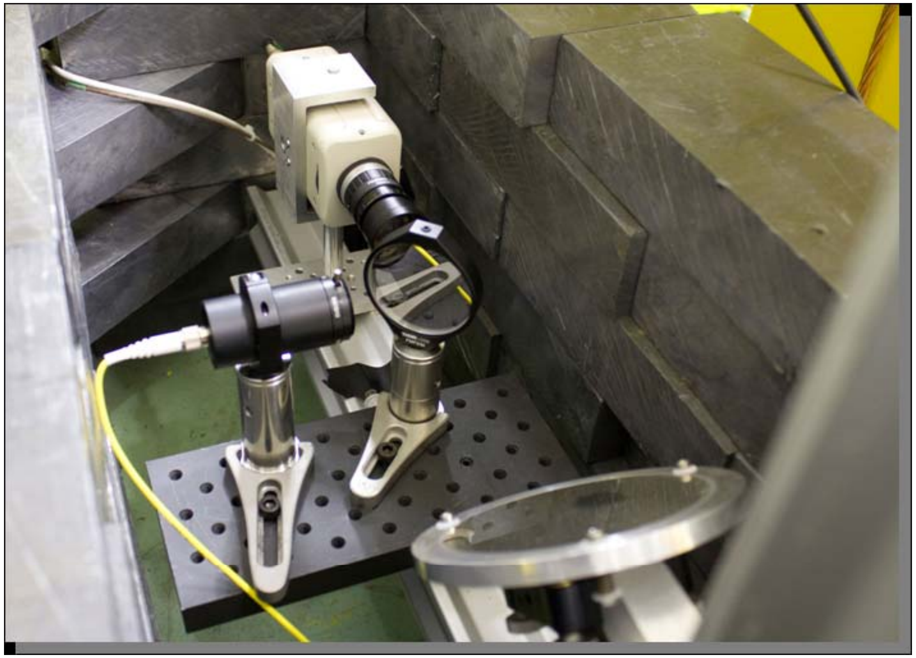
Synchrotron radiation:

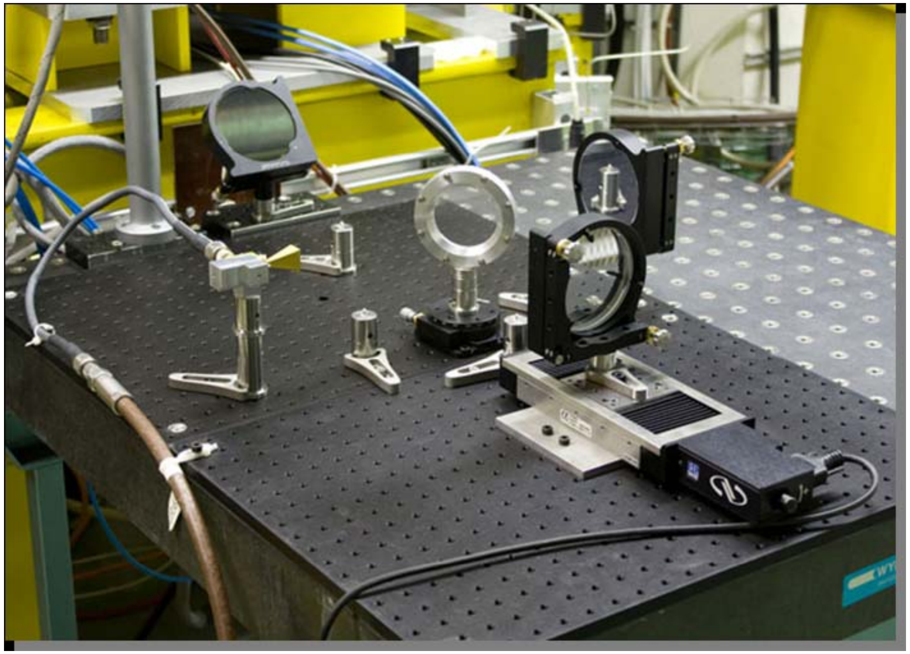


Current system

2009 Upgrades:

- Installed the interferometer (right hand picture)
- Photo diode (incl. beam splitter) in the OTR optical line installed (left hand picture) for fast charge measurements
  - OTR light is linearly proportional to the bunch charge





Summary

Status of experiment at CERN:

- Installed the update of the system in the CRM line
  - Interferometer
  - Photodiode in OTR optical line
- Currently experiencing some problems
  - Did not have sufficient beam time to find interference with CDR (dedicated beam time)
  - Cabling between the photo diode and the DAQ
- Still debugging the system and understanding the new setup

Plans:

- Continue debugging and understanding the system
- Interferometric measurements
- Reconstruction of the longitudinal bunch shape using Kramers-Kronig method (on going)
- Calculate interferometer splitter efficiencies (on going)

Future upgrade

Insert a second target to cut the background off