Coherent Diffraction Radiation

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- Introduction
- Basic theory and characteristics of CDR
  - Phenomenon
  - Coherent Radiation
  - Simulations
  - Spectra calculations
  - Characteristics
  - Power estimation
- Experimental hardware
  - CDR Location
  - Vacuum assembly
  - Optical system
- Outlook
- Appendix

Why CDR ???

- Advantages of CDR:
  - non-invasive measurements
  - instantaneous
  - very high photon yield
  - large emission angles
  - possibility to measure the longitudinal bunch profile
- Importance for CLIC:
  - Longitudinal beam profile monitoring is important to prevent luminosity losses due to the hour-glass/pinch effect if the beam is too long/short
  - For an optimal performance of the CLIC drive beam the longitudinal beam profile must be controlled after it has been:
    - stretched for injection into the combiner ring
    - extracted and compressed

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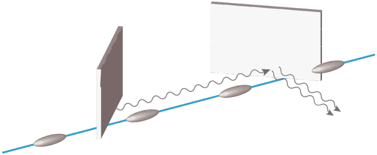
CDR Phenomenon

- Diffraction radiation (DR) appears when a charged particle moves in the vicinity of a medium
- Impact parameter, h, is the shortest distance between the target and the particle trajectory
- The criterium for DR to be emitted is

$$h \leq \gamma\lambda \tag{1}$$

where $\gamma = \frac{E}{m_e c^2}$ is the Lorentz factor and λ is the observation wavelength



- In our setup in CTF3 $h \approx 15\ mm \ll \gamma\lambda = 1175\ mm$ for $\gamma = 235$ and $\lambda = 5\ mm$

Coherent Radiation

- Coherent radiation

$$S(\omega) = N_e^2 F(\omega) S_e(\omega) \qquad (2)$$

- $S(\omega)$, the signal, known from the experiment
- N_e, the number of electrons, know from the experiment
- $F(\omega)$, the longitudinal bunch form factor, the measurement purpose
- $S_e(\omega)$, the single electron radiation, should be predictable from theory

Basic CDR theory

- The two polarization components of diffraction radiation are given by:

$$E^{l}_{x,y} = \frac{1}{4\pi^2} \iint \frac{iek}{\pi\gamma} \begin{pmatrix} \cos\psi_s \\ \sin\psi_s \end{pmatrix} K_1\left(\frac{k}{\gamma}\rho_s\right) \times$$

$$\times \frac{e^{ika}}{a} \exp\left[\frac{ik}{2a}\left(x_s^2 + y_s^2\right) - \frac{ik}{a}\left(x_s\xi + y_s\eta\right) + \right.$$

$$\left. + \frac{ik}{2a}\left(\xi^2 + \eta^2\right)\right] dy_s dx_s \qquad (3)$$

More theory

Basic CDR theory

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- Pseudo-photon field

More theory

Basic CDR theory

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$$E^l_{x,y} = \frac{1}{4\pi^2}\iint \frac{iek}{\pi\gamma}\begin{pmatrix}\cos\psi_s\\ \sin\psi_s\end{pmatrix} K_1\left(\frac{k}{\gamma}\rho_s\right)\times \frac{e^{ika}}{a}\exp\left[\frac{ik}{2a}\left(x_s^2+y_s^2\right) - \frac{ik}{a}\left(x_s\xi+y_s\eta\right) + \frac{ik}{2a}\left(\xi^2+\eta^2\right)\right] dy_s\,dx_s$$

- Pseudo-photon field
- Phase difference

More theory

Basic CDR theory

- The two polarization components of diffraction radiation are given by:

$$E^{l}_{x,y} = \frac{1}{4\pi^2}\iint \frac{iek}{\pi\gamma}\begin{pmatrix}\cos\psi_s\\ \sin\psi_s\end{pmatrix} K_1\left(\frac{k}{\gamma}\rho_s\right)\times$$

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$$\left.+\frac{ik}{2a}\left(\xi^2+\eta^2\right)\right]dy_s dx_s$$

- Pseudo-photon field
- Phase difference
- ρ_s and ψ_s are the radius and azimuthal angle of the particle field in polar coordinates
- Therefore $x_s = \rho_s cos\psi_s$ and $y_s = \rho_s sin\psi_s$
- $\rho_s = \sqrt{x_s^2 + y_s^2}$

▸ More theory

CDR Spectra calculations

- The spatial distributions are calculated using:

$$\frac{d^2W^{DR}}{d\omega d\Omega} = 4\pi^2 k^2 a^2 \left[\left| E_x^{DR} \right|^2 + \left| E_y^{DR} \right|^2 \right] \tag{4}$$

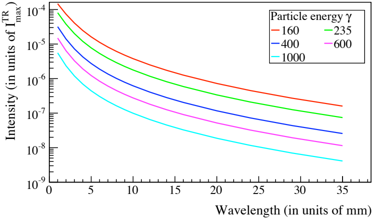
- The spectra are then found by integrating Eq. 4 over the angular detector aperture. Changing this to Cartesian coordinates the spectra are then given by:

$$\frac{dW^{DR}}{d\omega} = \int_{-\frac{\Delta\xi}{2}}^{\frac{\Delta\xi}{2}} \int_{-\frac{\Delta\eta}{2}}^{\frac{\Delta\eta}{2}} 4\pi^2 k^2 \left[\left| E_x^{DR} \right|^2 + \left| E_y^{DR} \right|^2 \right] d\xi \; d\eta \tag{5}$$

where $\Delta\xi$ and $\Delta\eta$ are the detector apertures.

CDR Spectrum

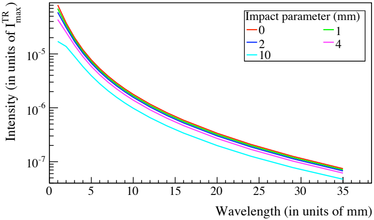
- This plot shows the DR spectrum for different beam energies for the DXP19 Schottky Barrier Diode (SBD) detector (wavelength range 5 - 7.5mm) for a zero impact parameter:



- Simulations take the conditions of the CDR setup at CTF3 into account:
  - Finite target size, x_s and y_s (40 × 40mm)
  - Finite distance from target to the detector, a (≈ 1.5m)
  - DXP19 Detector aperture, $\Delta\xi$ and $\Delta\eta$ (46 × 35mm)
  - $I^{TR}_{max} = \dfrac{\alpha\gamma^2}{4\pi^2}$

CDR Spectrum

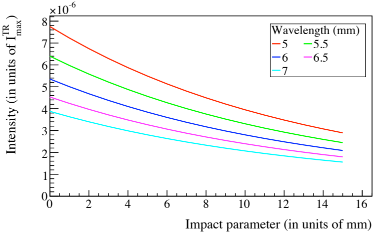
- This plot shows the DR spectrum for different impact parameters for the DXP19 detector at a beam energy of $\gamma = 235$:



- The intensity for wavelength smaller than 1mm and for non-zero impact parameters will drop to zero but due to CPU time the simulations in this area were not performed. An indication for this can be seen for $h = 10\ mm$

CDR Intensity Variation with Impact Parameter

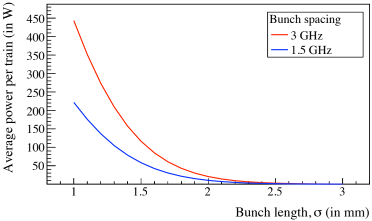
- This plot shows the DR intensity variation with impact parameter for different wavelengths for the DXP19 detector at a beam energy of $\gamma = 235$:



- The CDR intensity for increasing impact parameters only shows a slight decrease
- Allows for measurements $10 - 15\ mm$ away from the beam

Power generated by CDR at CTF3

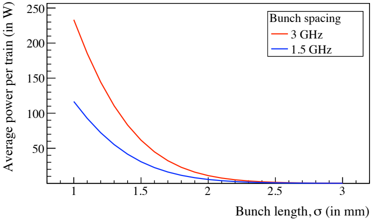
- This plot shows the average power emitted per train by DR for DXP19 detector for a zero impact parameter ($h = 0$):



- Assuming longitudinal Gaussian beam shape
- Bunch separation of 0.33 ns and 0.66 ns, respectively
- For a 2 mm Gaussian beam the energy emitted into the detector is $6.8 \times 10^{-9}\ J$
- The average power per train is 10.3 W and 22.7 W for 1.5 GHz and 3 GHz operation, respectively.
- For 2.5×10^{10} electrons per bunch the energy contribution per electron is 1.7 eV

Power generated by CDR at CTF3

- This plot shows the average power emitted per train by DR for DXP19 detector for a non-zero impact parameter ($h = 10\ mm$):



- For a 2 mm Gaussian beam the energy emitted into the detector is $3.6 \times 10^{-9}\ J$
- The average power per train is 5.5 W and 11.0 W for 1.5 GHz and 3 GHz operation, respectively.
- For 2.5×10^{10} electrons per bunch the energy contribution per electron is 0.9 eV

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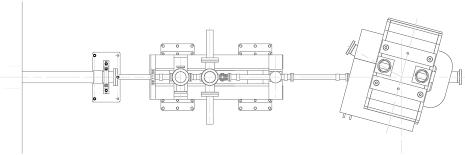
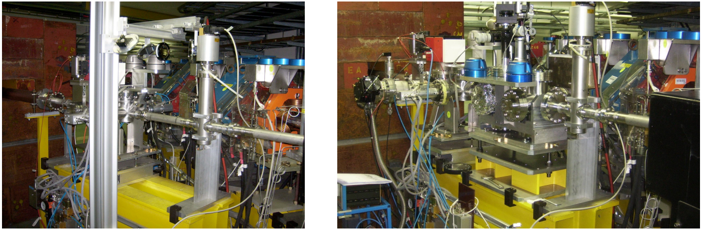
Location of CDR setup

- CDR setup in the CRM line after the vacuum pump and in front of the OTR screen



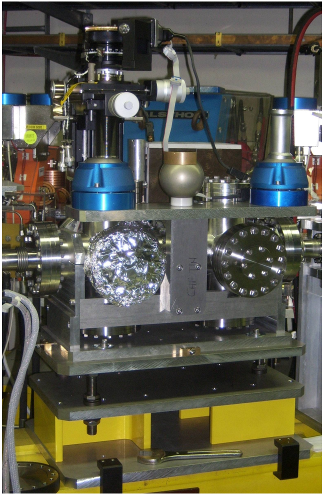
- CRM line (before & after installation of CDR):



▸ CTF3 Layout

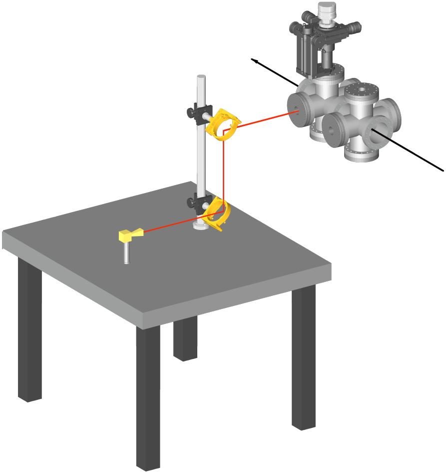
Vacuum assembly

- Vacuum assembly of the CDR setup in the CRM line:



Optical system

- This drawing shows the optical system which will be used during the first stage of the experiment (explained later):



- The diffraction radiation emission and the **beam axis** is shown.

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Outlook and Future Plans

- Different phases of CDR:
  1. October 2008 - December 2008:
     - Observation of CSR signal
     - Check hardware performance
     - Check signal level
     - Debugging the DAQ
     - Study CSR characteristics
     - Observation of CDR signal as function of target position and orientation angle
     - Single target
  2. March/April 2009:
     - Setting up an interferometer for spectral measurements
  3. May - December 2009:
     - Interferometric measurements of CDR and CSR spectra
     - Detailed data analysis and reconstruction of the longitudinal electron beam profile
  4. Later:
     - Inserting second target
     - Considering putting interferometer in vacuum
     - Single shot spectral measurements using grating type spectrometer

More theory

- Polarization components:

$$E^{l}_{x,y} = \frac{1}{4\pi^2} \iint E^{i}_{x,y}\left(x_s, y_s\right) \frac{e^{i\varphi}}{|\vec{r}|} dy_s \, dx_s \tag{6}$$

with $E^{i}_{x,y}$ the pseudo-photon field and $\dfrac{e^{i\varphi}}{|\vec{r}|}$ the phase difference.

- Pseudo-photon field:

$$E^{i}_{x,y}(x_s, y_s) = \frac{iek}{\pi\gamma} \begin{pmatrix} \cos\psi_s \\ \sin\psi_s \end{pmatrix} K_1\left(\frac{k}{\gamma}\rho_s\right) \tag{7}$$

- Phase difference:

$$\frac{e^{i\varphi}}{|\vec{r}|} = \frac{e^{ik|\vec{r}|}}{|\vec{r}|} = \frac{exp\left(ik\sqrt{a^2 + \left(x_s - \xi\right)^2 + \left(y_s - \eta\right)^2}\right)}{\sqrt{a^2 + \left(x_s - \xi\right)^2 + \left(y_s - \eta\right)^2}} \tag{8}$$

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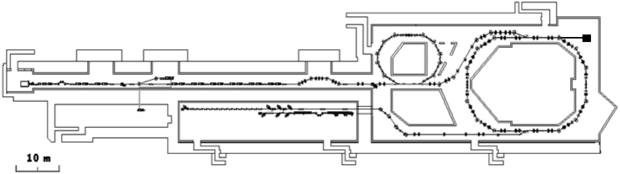
CTF3 layout

- CTF3 layout:



- CRM line at the top right of the combiner ring

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