PROPERTIES OF CHERENKOV DIFFRACTION RADIATION AS PREDICTED BY THE POLARISATION CURRENTS APPROACH FOR BEAM INSTRUMENTATION

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Cherenkov Diffraction Radiation (ChDR)

ChDR appears when a charged particle moves in the vicinity of a dielectric medium with velocity higher than the phase velocity of light inside the medium. Detecting ChDR in accelerators is being explored in the development of non-invasive beam diagnostics ChDR appears at the same distinctive angle as Cherenkov radiation:

$$\cos(\theta_{\mathrm{Ch}}) = \frac{1}{\beta n},$$

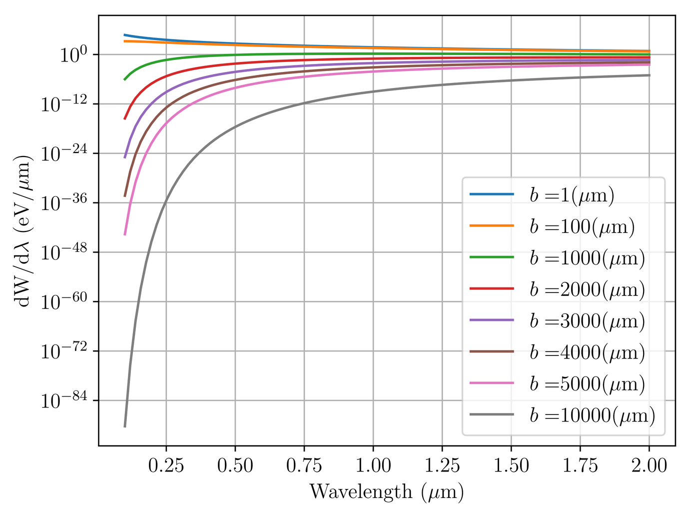
Single Particle Simulations

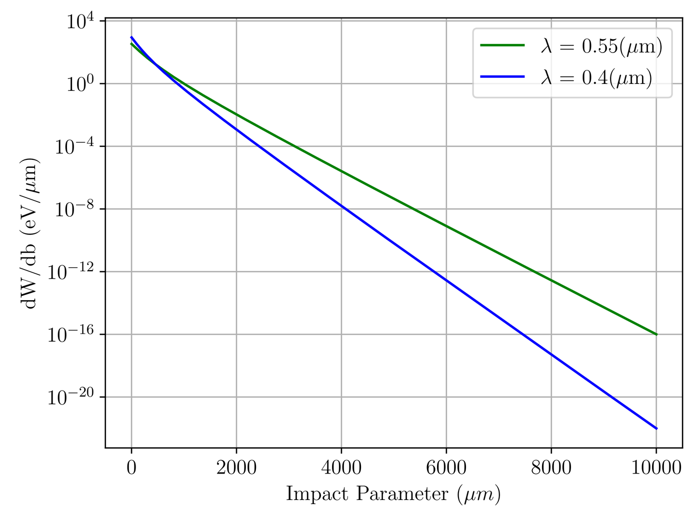
An intensity value can be obtained by integrating over the angular distributions produced with the PCA model. By producing a series of angular distributions then integrating each one, parameter dependencies of the emitted ChDR can be calculated.

The single particle spectrum follows the Cherenkov spectral dependence at low impact parameters. The peak of the distribution appears at:

$$b \simeq \frac{\gamma\lambda}{2\pi},$$

Observing the impact parameter dependence at fixed wavelengths shows that the shorter wavelength dominate here, as the impact parameter gets larger the longer wavelengths dominate.



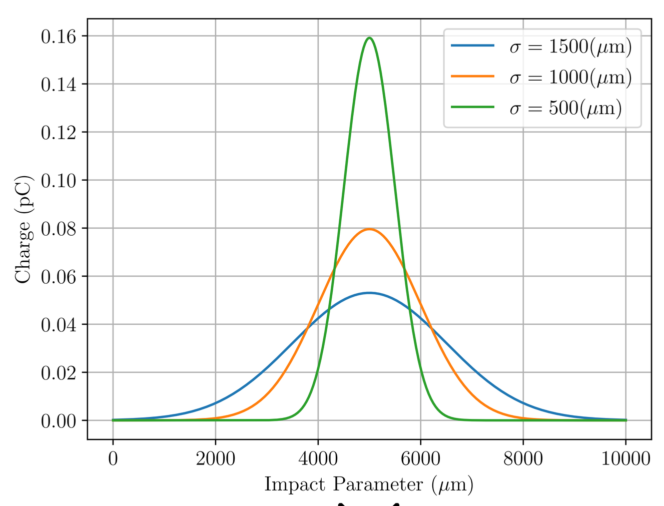


Beam Distribution Simulations

To confirm the PCA model it is beneficial to work in a regime where the ChDR spectral response does not follow that of Cherenkov radiation.

Performing an element wise multiplication between a transverse beam distribution and impact parameter dependency the intensity contribution at each impact parameter is produced.

For the horizontal beam sizes of 1000 and 1500µm the signal is dominated by the edge of the beam profile located at low impact parameters. This is of concern as particles at low impact parameters produce a spectrum that appears as the Cherenkov spectrum



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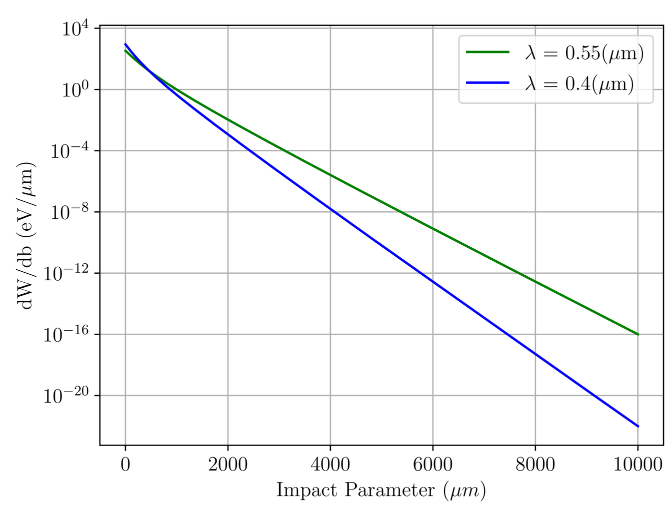

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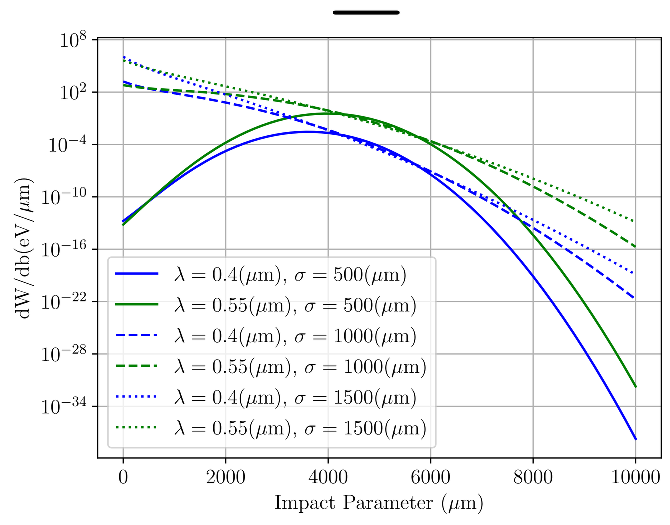
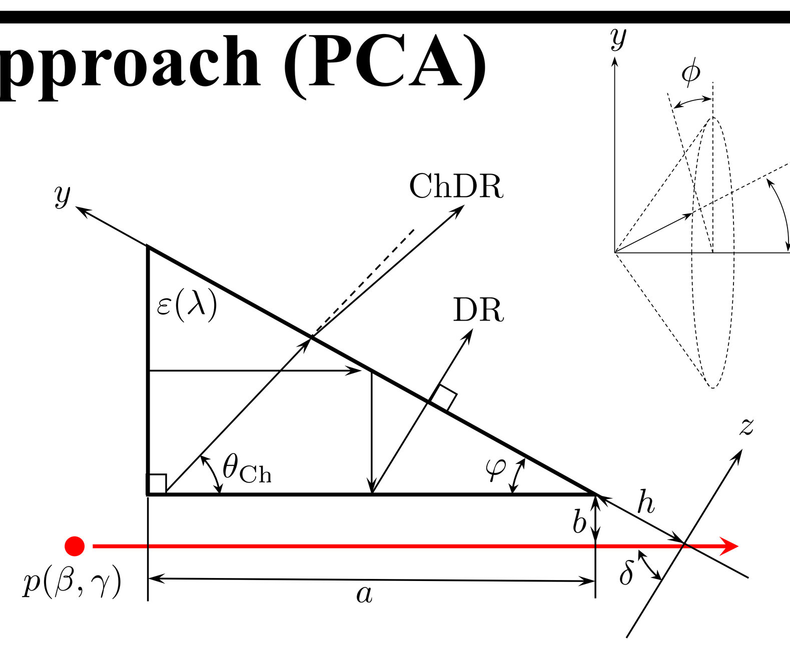


Polarisation Currents Approach (PCA)

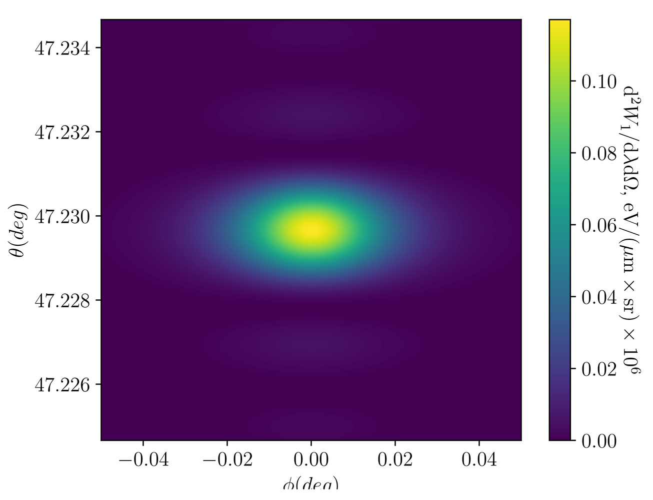
The PCA model can be applied to different radiator geometries where the geometry selected will effect the ChDR emission. Extensive work has been done previously to obtain the ChDR angular distribution emitted from a prismatic radiator when a charge particle moves parallel to one side.



$$U = \sqrt{\varepsilon(\lambda) - \sin^2(\theta-\delta)},$$
$$P = \cos(\delta) - \beta U + i\gamma^{-1} K \sin(\delta),$$
$$\Sigma = \sin(\delta) + \beta\sin(\theta-\delta)\cos(\phi) - i\gamma^{-1} K\cos(\delta),$$
$$K = \sqrt{1 + (\gamma\beta\sin(\theta-\delta)\sin(\phi))^2},$$

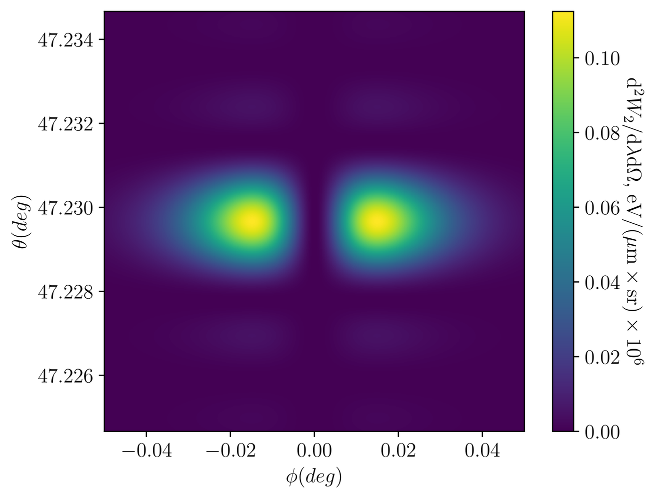
$$\frac{\mathrm{d}^2W_1}{\mathrm{d}\lambda\mathrm{d}\Omega} = \frac{\alpha\hbar c\beta^2\cos^2(\theta-\delta)}{2\pi^2\lambda^2K^2|P|^2}\left|\frac{\varepsilon(\lambda)-1}{\varepsilon(\lambda)}\right|^2 \times \Bigg|1 - \exp\left[-ia\frac{2\pi}{\beta\lambda}(P+\Sigma\cdot\cot(\varphi))\sin(\varphi)\right]$$
$$-\frac{P\exp\left[i\frac{2\pi}{\beta\lambda}\Sigma\cdot a\cdot\cos(\varphi)\right]}{P+\Sigma\cdot\cot(\varphi)} + \frac{P^2+\Sigma^2\cdot\cot^2(\varphi)}{P^2-\Sigma^2\cdot\cot^2(\varphi)}\exp\left[-ia\frac{2\pi}{\beta\lambda}P\cdot\sin(\varphi)\right]$$
$$-\frac{\Sigma\cdot\cot(\varphi)\exp\left[-i\frac{2\pi}{\beta\lambda}\Sigma\cdot a\cdot\cos(\varphi)\right]}{P-\Sigma\cdot\cot(\varphi)}\Bigg|^2 \times$$
$$\frac{\exp\left[-\frac{4\pi}{\gamma\beta\lambda}(h+a\cdot\cos(\varphi))K\cos(\delta)\right]}{1-\beta^2\cos^2(\theta-\delta)+\beta^2\sin^2(\delta)(1-\sin^2(\theta-\delta)\sin^2(\phi))+2\beta\sin(\delta)\sin(\theta-\delta)\cos(\phi)}$$
$$\times\left|\frac{\varepsilon(\lambda)}{\varepsilon(\lambda)\cos(\theta-\delta)+U}\right|^2|\cos(\delta)(\gamma^{-1}\sin(\theta-\delta) - iKU\cos(\phi)) +$$
$$\sin(\delta)(iK\sin(\theta-\delta)+\gamma^{-1}U\cos(\phi)) - \gamma\beta U\sin(\theta-\delta)\sin^2(\phi)|^2,$$

$\Longrightarrow$



$$\frac{\mathrm{d}^2W_2}{\mathrm{d}\lambda\mathrm{d}\Omega} = \frac{\alpha\hbar c\beta^2\cos^2(\theta-\delta)}{2\pi^2\lambda^2K^2|P|^2}\left|\frac{\varepsilon(\lambda)-1}{\varepsilon(\lambda)}\right|^2\gamma^2\sin^2(\phi)\left|\frac{\sqrt{\varepsilon(\lambda)}}{\cos(\theta-\delta)+U}\right|^2(\sin^2(\theta-\delta)+|U|^2)$$
$$\times\Bigg|1-\exp\left[-ia\frac{2\pi}{\beta\lambda}(P+\Sigma\cdot\cot(\varphi))\sin(\varphi)\right] - \frac{P\exp\left[i\frac{2\pi}{\beta\lambda}\Sigma\cdot a\cdot\cos(\varphi)\right]}{P+\Sigma\cdot\cot(\varphi)} +$$
$$\frac{P^2+\Sigma^2\cdot\cot^2(\varphi)}{P^2-\Sigma^2\cdot\cot^2(\varphi)}\exp\left[-ia\frac{2\pi}{\beta\lambda}P\cdot\sin(\varphi)\right] - \frac{\Sigma\cdot\cot(\varphi)\exp\left[-i\frac{2\pi}{\beta\lambda}\Sigma\cdot a\cdot\cos(\varphi)\right]}{P-\Sigma\cdot\cot(\varphi)}\Bigg|^2\times$$
$$\frac{\exp\left[-\frac{4\pi}{\gamma\beta\lambda}(h+a\cdot\cos(\varphi))K\cos(\delta)\right]}{1-\beta^2\cos^2(\theta-\delta)+\beta^2\sin^2(\delta)(1-\sin^2(\theta-\delta)\sin^2(\phi))+2\beta\sin(\delta)\sin(\theta-\delta)\cos(\phi)}$$
$$\times[1-\beta^2\cos^2(\theta-\delta)+2\beta\gamma^{-2}\sin(\theta-\delta)\cos(\phi)-\gamma^{-2}\sin^2(\delta)(K^2-\gamma^{-2})],$$

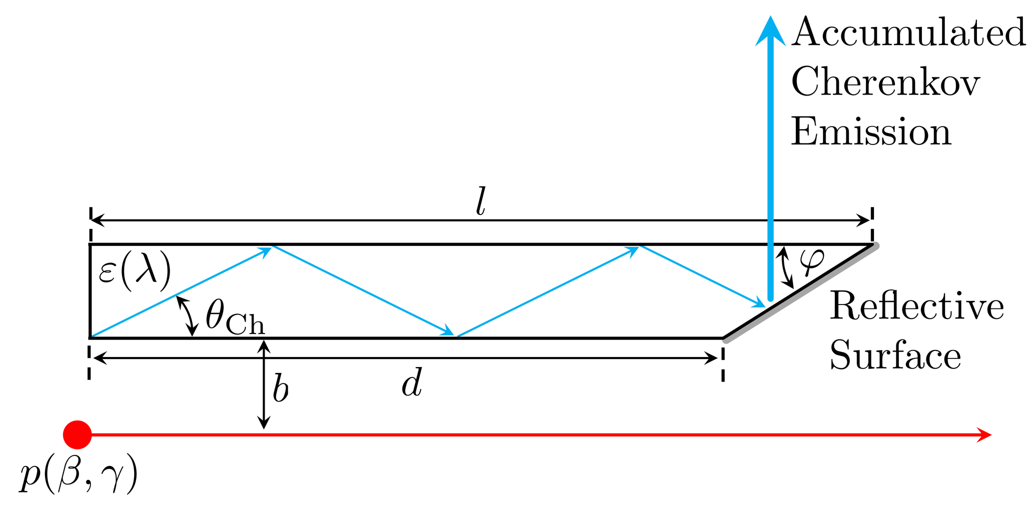
$\Longrightarrow$



Diamond Light Source Booster-to-Storage Ring Test-Stand

Diamond Light Source is a 3rd generation synchrotron light source in the U.K. The Diamond accelerator chain consists of three accelerators; a linac, a booster synchrotron, and a storage ring. On the Booster to Storage-ring (BTS) transfer line is a beam test-stand available for testing accelerator components and novel diagnostic instrumentation.

Standard BTS Parameter	Value
Beam Energy	3 GeV
Horizontal Beam Size σ_x	1.27 – 1.42 mm
Vertical Beam Size σ_y	0.57 – 0.6 mm
Extraction Rate	5 Hz
Max Bunch Charge (SBE)	0.2 nC
Bunch Length	≃ 2.5 mm



The BTS ChDR experiment is fitted with a CVD Diamond accumulator target with a length, of 15mm and a vertex angle, of 12.5°. It is assumed that the angular distributions simulated from a prismatic radiator will have similar angular distributions to those measured from the accumulator radiator as long as the radiator parameters are the same

Conclusion

This paper presents simulations of ChDR emission for the BTS test-stand at Diamond Light Source using the PCA model. It has been found that ChDR emission at longer wavelengths is most sensitive to the core of the beam, whereas shorter wavelengths are dominated by the particles in the beam tails. For BPM applications, an infrared system is most suitable whereas a beam halo monitor could be developed using the ChDR emission in he visible range.

Future steps for this research will compare the angular distributions measured from the optical system on the BTS test-stand with those simulated. Differences are expected between the simulations and measurements due to the different radiator geometries used in each. More in-depth and useful experiments would compare the spectral emission and impact parameter dependences.

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