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Status for 2019, CERN NA63

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NA63

Abstract

In the NA63 experiment of April 2018 data was taken for 20, 40 and 80 GeV electrons and positrons aligned to the $\langle 100 \rangle$ axis of a diamond crystal of thickness 1.5 mm, as well as for 40 and 80 GeV electrons on a 1.0 mm thick diamond aligned to the $\langle 100 \rangle$ axis. Off-line analysis has shown that the direction of the crystallographic axis cannot be found with certainty for the 2018 data for 20 GeV, and thus this data set has been discarded. However, the comparison between data and theoretical simulations performed for several angular settings for the 40 and 80 GeV data show remarkable agreement with calculations including the Landau Lifshitz force with a few quantum corrections. A draft of a paper for submission will be finished within the coming month.
For the 2017 data, the analysis is finished, shows good results, and a draft of a paper for submission will be finished within the coming month.

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1 Test of the radiation emission in strong fields using single crystals

With a setup very similar to the one used in 2016 and 2017, and two thicknesses of axially aligned diamond crystals, we have performed measurements that agree very well with strong field theory.

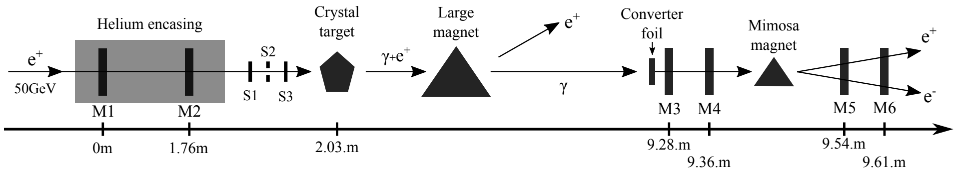

Figure 1: A schematic of the 2018 experimental setup.

A schematic of the setup used – which is almost identical to the one used in 2016 and 2017 – can be seen in figure 1. We use MIMOSA detectors, with a position resolution of about 5 μm, the first two of which – both kept in helium to reduce multiple scattering – are used to determine the entry angle to the crystalline target. The detectors have a sensitive area of 1×2 cm^2. Following emission of photon(s) in the crystalline target, the primary particle – in this case a positron or an electron – is deflected in a single MBPL magnet supplied by CERN. The photon(s) are then incident on a thin Ta converter foil, the thickness Δt of which corresponds to approximately 5% of a radiation length, $\Delta t/X_0 \simeq 5\%$, i.e. the probability that two photons convert is kept low. The pair generated from the conversion is then tracked in two additional MIMOSA detectors, and subsequently separated in a 'Mimosa magnet', a magnetic dipole produced from permanent magnets that generates a field of approximately 0.12 T over a length of 0.15 m. The 'Mimosa magnet' is kindly supplied by DANFYSIK, and represents an essential component of the setup, given that it neither requires cooling nor current supplies, which means that it is an extremely compact device allowing a very short distance to the up- and down-stream MIMOSA detectors. These MIMOSA detectors are then used to determine the momenta of the produced electron and positron, allowing the energy of the originally emitted photon to be determined. Finally, a lead glass detector (90×90 mm^2 and 700 mm long, corresponding to 25 X_0) at the end enables a cross-check of the energy/momentum of the pairs, and is used for alignment of the crystallographic planes to the beam.

2 Examples of results from the June 2017 run.

Figures 2 and 3 show very convincing agreement between accurate calculations of the theoretically expected spectra for the particular crystallographic orientation used in the 2017 experiment, and a final analysis of the experimental spectra. We clearly see a large discrepency between curves where radiation reaction has been excluded, and remarkable agreement between spectra including the Landau Lifshitz equation. A paper will be submitted within the coming few months.

3 Examples of results from the April 2018 run.

We have investigated diamond crystals of thicknesses 1.0 and 1.5 mm, both aligned to the $\langle 100 \rangle$ axis using 40 GeV and 80 GeV electrons.

Figures 4 and 5 show very convincing agreement between accurate calculations of the theoretically expected spectra for the particular crystallographic orientation used in the experiment, and a final analysis of the experimental spectra. As we are in a regime where the strong-field parameter χ is larger than in the 2017 case, quantum effects has shown to have a larger effect on the spectra and the trajectory. We see that the Landau Lifshitz equation overestimates the dampening force in the trajectory which results in less radiation than emitted in the experiment. By introducing the dampening factor $G(\chi)$ on the Landau Lifshitz force, which is the ratio of the radiation emitted in the classical case and the quantum case in the Local Constant Field Approximation (LCFA), we again see remarkable agreement between theory and experiment. This shows that even when quantum effects become non-negligible, the Landau Lifshitz equation, together with a few quantum corrections, reproduces the experimental radiation spectra. A paper will be submitted within the coming few months.

4 Concluding remarks

We have in 2017 and 2018 measured the radiation spectra within different strong-field regimes, and shown the inadequacy of the Lorentz force in describing the motion of charges moving in very strong electric fields. Our results strongly points at the LL equation as a satisfactory answer to the century-old problem of radiation reaction in classical electrodynamics when $\chi \ll 1$. We have also shown that when including a few simple quantum corrections to the motion and the radiation spectra, one is able to describe the radiation spectra for larger values of chi.

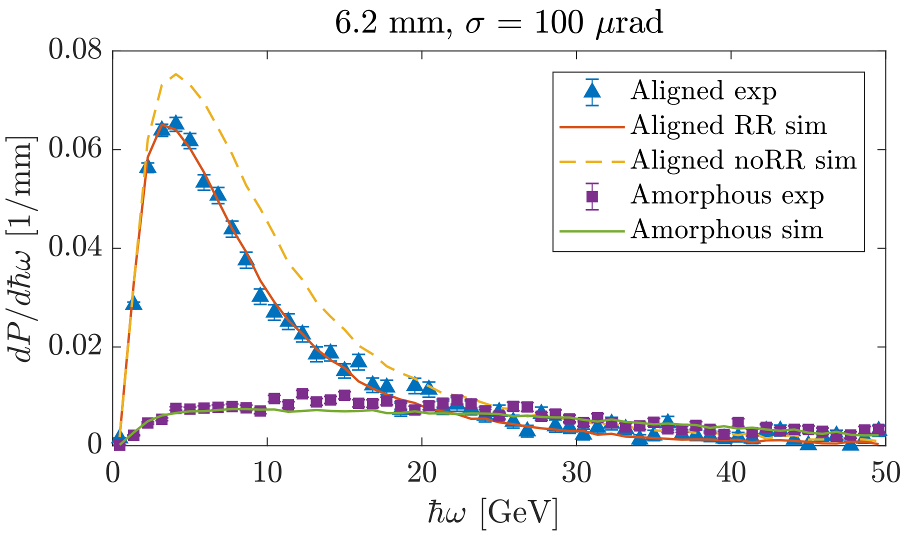

Figure 2: Radiation power spectra obtained for 50 GeV positrons passing a 6.2 mm thick silicon crystal aligned to the (110) plane, and the corresponding amorphous/random spectra. These spectra has no angular cuts and all particles in the beam are included. The dashed yellow lines show the theoretically expected values excluding the radiation reaction, the full-drawn red lines the theoretically expected values with full inclusion of the radiation reaction and the filled blue triangles show the experimental data for the oriented crystals with statistical error bars. The full-drawn green line is the theoretical amorphous expected values and the purple squares are the amorphous experimental data. The experimental preference for including the effect of radiation reaction is clearly visible.

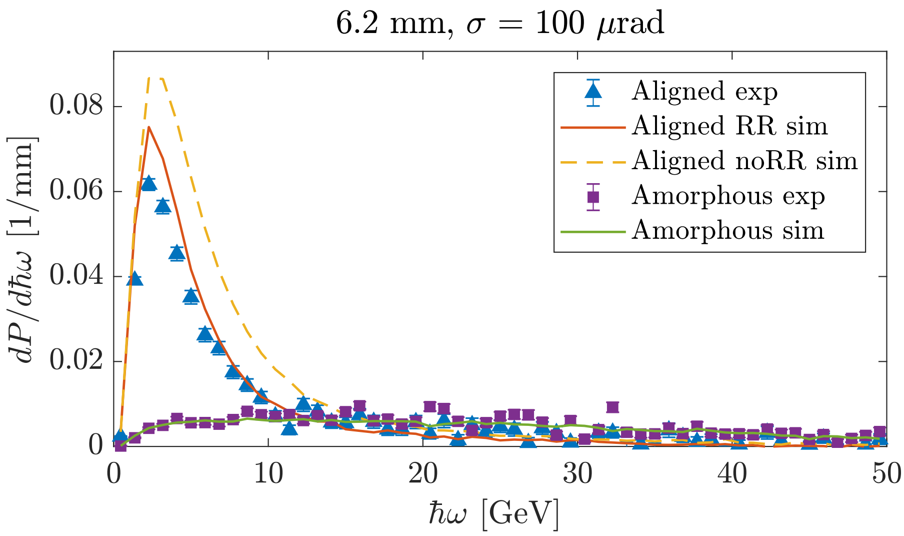

Figure 3: Radiation power spectra obtained for 50 GeV positrons passing a 6.2 mm thick silicon crystal aligned to the (110) plane, and the corresponding amorphous/random spectra. These spectra has angular cuts, meaning that only particles with entry angle between $\pm$ 30 μrad with respect to the crystal planes are included. The two top most figures are experimental data and calculations obtained for a beam with a divergence of $\sigma_\perp = 100\ \mu$rad in the direction transverse to the plane, while the three bottom figures are obtained for a beam with a divergence of $\sigma_\perp = 85\ \mu$rad. The dashed yellow lines show the theoretically expected values excluding the radiation reaction, the full-drawn red lines the theoretically expected values with full inclusion of the radiation reaction and the filled blue triangles show the experimental data for the oriented crystals with statistical error bars. The full-drawn green line is the theoretical amorphous expected values and the purple squares are the amorphous experimental data. The experimental preference for including the effect of radiation reaction is clearly visible.

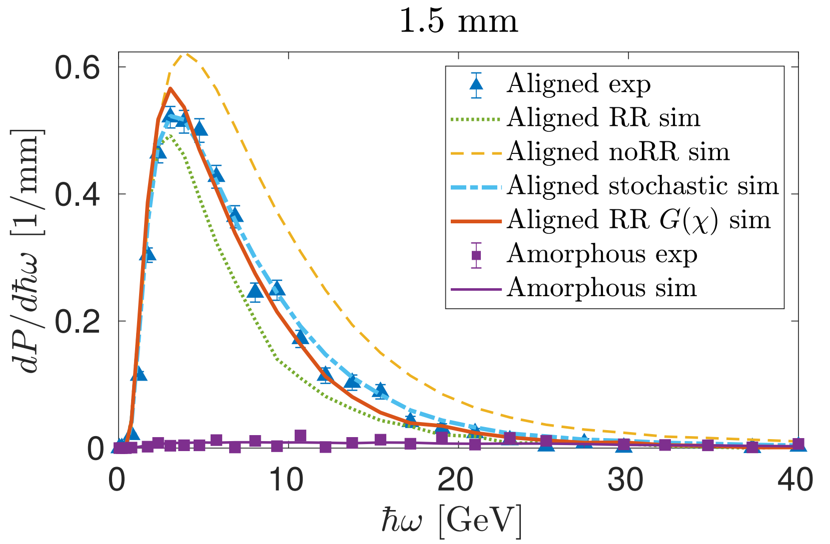

Figure 4: Experimental data and calculations for a diamond crystal of thickness 1.5 mm, aligned to the ⟨100⟩ axis for an electron energy of 40 GeV. An angular cut within $\theta_{inc} < \psi_1$, where ψ_1 is the Lindhard critical angle for axial channeling, has been applied. The triangles and square points are the experimental data in the aligned and amorphous case respectively. The dashed yellow line is the simulation without Radiation Reaction. The dashed green line is the simulation including radiation reaction where we in the red line have included the dampening factor $G(\chi)$ on the Landau Lifshitz force. The blue line is the quantum stochastic simulation and the purple line is the amorphous simulation.

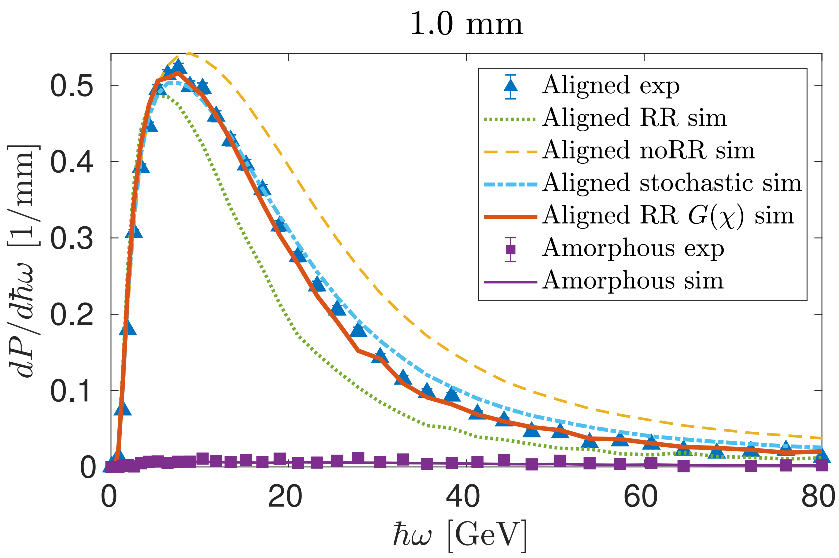

Figure 5: Experimental data and calculations for a diamond crystal of thickness 1 mm, aligned to the ⟨100⟩ axis for an electron energy of 80 GeV. An angular cut of the 'doughnut region' $2\psi_1 < \theta_{inc} < 4\psi_1$, where ψ_1 is the Lindhard critical angle for axial channeling, has been applied. The triangles and square points are the experimental data in the aligned and amorphous case respectively. The dashed yellow line is the simulation without Radiation Reaction. The dashed green line is the simulation including radiation reaction where we in the red line have included the dampening factor $G(\chi)$ on the Landau Lifshitz force. The blue line is the quantum stochastic simulation and the purple line is the amorphous simulation.

5 Status of publications

Publications related to the activities of NA63:

1. T. Virkus, U.I. Uggerhøj, H. Knudsen, S. Ballestrero, A. Mangiarotti, P. Sona, T.J. Ketel, A. Dizdar, S. Kartal and C. Pagliarone (CERN NA63): *Direct measurement of the Chudakov effect*, Phys. Rev. Lett. **100**, 164802 (2008)

2. A. Mangiarotti, S. Ballestrero, P. Sona and U.I. Uggerhøj: *Implementation of the LPM effect in the discrete-bremsstrahlung simulation of GEANT 3 and GEANT 4*, Nucl. Instr. Meth. B **266**, 5013 (2008)
3. H.D. Thomsen, K. Kirsebom, H. Knudsen, E. Uggerhøj, U.I. Uggerhøj, P. Sona, A. Mangiarotti, T.J. Ketel, A. Dizdar, M. Dalton, S. Ballestrero and S. Connell (CERN NA63): *On the macroscopic formation length for GeV photons*, Phys. Lett. B **672**, 323 (2009)
4. J. Esberg and U.I. Uggerhøj: *Does experiment show that beamstrahlung theory - strong field QED - can be trusted?*, Journal of Physics Conference Series, **198**, 012007 (2009)
5. J. Esberg, K. Kirsebom, H. Knudsen, H.D. Thomsen, E. Uggerhøj, U.I. Uggerhøj, P. Sona, A. Mangiarotti, T.J. Ketel, A. Dizdar, M. Dalton, S. Ballestrero, S. Connell (CERN NA63): *Experimental investigation of strong field trident production*, Phys. Rev. D **82**, 072002 (2010)
6. K.K. Andersen, J. Esberg, K.R. Hansen, H. Knudsen, M. Lund, H.D. Thomsen, U.I. Uggerhøj, S.P. Møller, P. Sona, A. Mangiarotti, T.J. Ketel, A. Dizdar and S. Ballestrero (CERN NA63): *Restricted energy loss of ultrarelativistic particles in thin targets - a search for deviations from constancy*, Nucl. Instr. Meth. B **268**, 1412 (2010)
7. H.D. Thomsen, J. Esberg, K.K. Andersen, M. Lund, H. Knudsen, U.I. Uggerhøj, P. Sona, A. Mangiarotti, T.J. Ketel, A. Dizdar, S. Ballestrero and S.H. Connell (CERN NA63): *Distorted Coulomb field of the scattered electron*, Phys. Rev. D, **81**, 052003 (2010)
8. H.D. Thomsen and U.I. Uggerhøj: *Measurements and theories of the King-Perkins-Chudakov effect*, Nucl. Instr. Meth. B **269**, 1919 (2011)
9. A. Mangiarotti, P. Sona, S. Ballestrero and U.I. Uggerhøj: *A general semi-analytic method to simulate discrete bremsstrahlung at very low radiated photon energies by the Monte Carlo method*, Nucl. Instr. Meth. B **269**, 1977 (2011)
10. A. Mangiarotti, P. Sona, S. Ballestrero, K.K. Andersen and U. I. Uggerhøj: *Comparison of analytical and Monte Carlo calculations of multi-photon effects in bremsstrahlung emission by high-energy electrons*, Nucl. Instr. Meth. B **289** 5-17 (2012)
11. K.K. Andersen, S.L. Andersen, J. Esberg, H. Knudsen, R. Mikkelsen, U.I. Uggerhøj, P. Sona, A. Mangiarotti, T.J. Ketel and S. Ballestrero (CERN NA63): *Direct measurement of the formation length of photons*, Phys. Rev. Lett. **108**, 071802 (2012); see also accompanying Physics Synopsis and Science Daily.
12. K.K. Andersen, J. Esberg, H. Knudsen, H.D. Thomsen, U.I. Uggerhøj, P. Sona, A. Mangiarotti, T.J. Ketel, A. Dizdar and S. Ballestrero (CERN NA63): *Experimental investigations of synchrotron radiation at the onset of the quantum regime*, Phys. Rev. D **86**, 072001 (2012)
13. K.K. Andersen, J. Esberg, H.D. Thomsen, U.I. Uggerhøj and S. Brock: *Radiation emission as a virtually exact realization of Heisenbergs microscope*, Nucl. Instr. Meth. B **315**, 278 (2013)
14. U.I. Uggerhøj: *Crystals, critical fields, collision points and a QED analogue of Hawking radiation*, in W. Greiner (ed.): Exciting Interdisciplinary Physics, Springer Verlag (2013)
15. K.K. Andersen, S.L. Andersen, J. Esberg, H. Knudsen, R. Mikkelsen, U.I. Uggerhøj, T.N. Wistisen, A. Mangiarotti, P. Sona and T.J. Ketel (CERN NA63): *Experimental investigation of the Landau-Pomeranchuk-Migdal effect in low-Z targets*, Phys. Rev. D **88**, 072007 (2013)
16. T.N. Wistisen and U.I. Uggerhøj: *Vacuum birefringence by Compton backscattering through a strong field*, Phys. Rev. D **88**, 053009 (2013)
17. K.K. Andersen, S.L. Andersen, J. Esberg, H. Knudsen, R. Mikkelsen, U.I. Uggerhøj, T.N. Wistisen, A. Mangiarotti, P. Sona and T.J. Ketel (CERN NA63): *Measurements of the spectral location of the structured target resonance for ultrarelativistic electrons*, Phys. Lett. B **732**, 309-314 (2014)
18. J. Esberg, U.I. Uggerhøj, B. Dalena and D. Schulte: *Strong field processes in beam-beam interactions at the Compact Linear Collider*, Phys. Rev. Spec. Top. Acc. Beams **17**, 051003 (2014)
19. T.N. Wistisen, K.K. Andersen, S. Yilmaz, R. Mikkelsen, J.L. Hansen, U.I. Uggerhøj, W. Lauth and H. Backe: *Experimental realization of a new type of crystalline undulator*, Phys. Rev. Lett. **112**, 254801 (2014)
20. R.E. Mikkelsen, A.H. Sørensen and U.I. Uggerhøj: *Bremsstrahlung from relativistic heavy ions in a fixed target experiment at the LHC*, Advances in High Energy Physics **2015**, 625473 (2015)
21. R.E. Mikkelsen, A.H. Sørensen and U.I. Uggerhøj: *Elastic photonuclear cross sections for bremsstrahlung from relativistic heavy ions*, Nucl. Instr. Meth. B **372**, 58-66 (2016)
22. A. Di Piazza, T.N. Wistisen and U.I. Uggerhøj: *Investigation of classical radiation reaction with aligned crystals*, Phys. Lett. B **765**, 1-5 (2016)
23. T.N. Wistisen, A. Di Piazza, H.V. Knudsen and U.I. Uggerhøj: *Experimental Evidence for Quantum Radiation Reaction in Aligned Crystals*, Nature Communications **82**, art. 795 (2018)