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The O(alpha^2) Initial State QED Corrections to e+ e- Annihilation into a Neutral Vector Boson Revisited

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At $e^+ e^-$ colliders the QED–initial state radiation forms a large part of the radiative corrections. Their precise and fast evaluation is an essential asset for the experiments at LEP, the ILC and the FCC-ee, operating at
high luminosity. A long standing problem in the analytic understanding of the $\mathcal{O}(\alpha^2)$ initial state radiation is the observed discrepancy between the calculation of Berends et al. (1988) in the limit $m_e^2 \ll s$ and
the result of the effective calculation using massive operator matrix elements by Blümlein et al. (2011) aiming directly for this limit. In order to resolve this important issue we recalculated this process by integrating directly
over the phase space without any approximation. For parts of the corrections we find exact solutions of the cross section in
terms of iterated
integrals over square root valued letters representing incomplete elliptic integrals and iterations over them. The expansion in the limit $m_e^2 \ll s$ reveals errors in the constant $O(\alpha^2)$ term of the former calculation and yields agreement with the calculation based on massive operator matrix elements, which has impact on the
experimental analysis programs. This finding also explicitly proofs the
factorization of massive initial state particles in the high energy limit at $\mathcal{O}(\alpha^2)$ for this process.

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