Parametric Mössbauer Radiation: General Diffraction Geometry and Coherent Amplification

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Ultranarrow nuclear resonances in Mössbauer isotopes are essential for precision spectroscopy and X-ray quantum optics; however, their extreme narrowness makes efficient excitation difficult with conventional X-ray sources. Parametric X-ray radiation (PXR)—generated by relativistic electrons traversing a crystal—offers a high-quality, low-divergence alternative. By incorporating Mössbauer nuclei into the crystal lattice, spectrally narrow Parametric Mössbauer Radiation (PMR) can be produced. In this talk, we present a comprehensive dynamical diffraction theory for PMR across arbitrary emission directions, encompassing both conventional and extreme grazing-specular geometries. We demonstrate that the grazing-specular configuration significantly enhances PMR intensity through global optimization of the diffraction geometry. This enhancement is enabled by the specular diffraction of the electron's virtual-photon fields at the crystal surface, allowing radiation to form primarily outside the crystal and thus circumventing internal absorption. Finally, we extend this framework to superradiant PMR (SPMR) driven by microbunched XFEL electron beams. We show how the superradiant amplification and geometric optimization yields intense, coherent, and spectrally narrow Mössbauer X-ray sources for the next generation of quantum optical applications.