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Ultrabright Laser-based MeV-class Light Source

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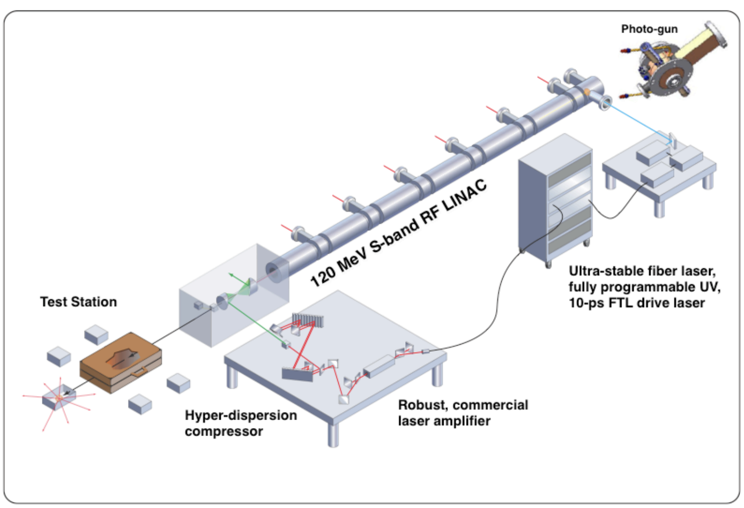
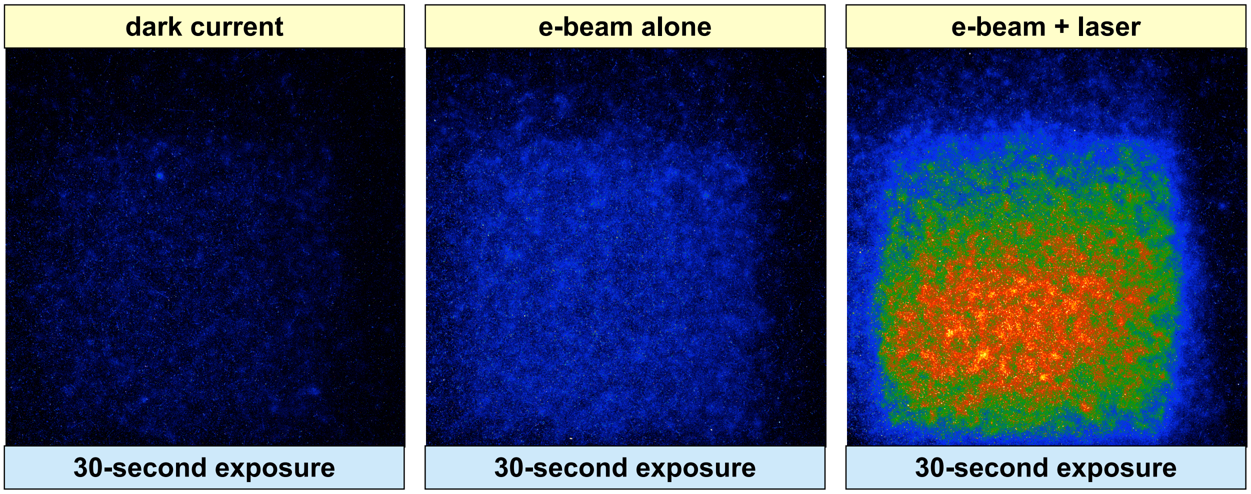
Abstract: *We report first light from a novel, new source of 10-ps 0.776-MeV gamma-ray pulses known as T-REX (Thomson-Radiated Extreme X-rays). The MeV-class radiation produced by T-REX is unique in the world with respect to its brightness, spectral purity, tunability, pulse duration and laser-like beam character. With T-REX, one can use photons to efficiently probe and excite the isotope-dependent resonant structure of atomic nucleus. This ability will be enabling to an entirely new class of isotope-specific, high resolution imaging and detection capabilities.*

Laser based Thomson or Compton scattering based gamma-ray light sources are the path to ultrahigh brightness tunable light sources above 100-keV. For head-on collisions, the peak brightness of Compton scattering light sources, scaling inversely with the electron pulse duration, linearly as the number of electrons and laser photons, and as the square of the e-beam emittance, is ideal for ultrahigh brightness gamma ray generation [1]. In contrast to previous efforts, which have either been low energy [2, 3] or recirculating [4], this effort simultaneously optimizes the electron beam energy spectrum and emittance as well as the laser bandwidth and focusing to generate ultrabright (>10^{17} photons/sec/mm^2/mrad^2/0.1%BW), monochromatic (<1%), and highly directional (mrad) gamma rays near 1-MeV.

We have demonstrated 10^6 gamma-ray photons per pulse at 0.776-MeV using a specially designed laser system in concert with a 120-MeV electron beam. The laser system uses a common all-fiber femtosecond front-end to drive a dual-arm and dual-wavelength 10-Hz amplifier chain. First, a photo-gun drive laser, producing 250-fs ~mJ pulses at 1053-nm which are up-shifted and pulse stacked to produce a 10-ps temporal top-hat pulse at the fourth harmonic. This pulse illuminates a novel high-gradient (120-MeV/m) photogun utilizing a sputtered magnesium photocathode. With a QE in excess of 10^{-4}, over a nanoCoulomb of charge is produced with only 10-uJ of illumination with our 263-nm spatially and temporally flat-top pulse. After a five-section linear accelerator, 120-MeV nC electron bunches are produced, importantly preserving the 2.5 mm-mrad emittance measured at injection.



The second arm of the laser system produces an interaction drive laser pulse which produces 10-ps 1-J pulses at 1064-nm through chirped pulse amplification in flashlamp-pumped Nd:YAG. High-dispersion chirped fiber bragg gratings are used at both wavelengths to produce 2-ns and 6-ns, respectively, stretched pulses. As the spectral bandwidth of the 10-ps interaction pulses is 10x or more narrower than previous chirped-pulse amplified laser systems based on, for example, Ti:Sapphire or Nd:glass, we employ a novel hyper-dispersion pulse compressor to provide the ~4x10^9 fs^2 (7100 ps/nm) dispersion required to recompress the 1-J amplified pulses, which are subsequent frequency tripled to provide 100-mJ, 10-ps, 355-nm interaction laser pulses at a common 35-um FWHM focus with the 120-MeV electron beam.



The electron and laser beams were used in a full 180-degree backscattering geometry. Spatial and temporal overlap were achieved using a precision metal cube inserted at the focal region, thereby deflecting both UV light and optical transition radiation from the e-beam onto a high-speed streak camera. Scattered gamma rays exited the interaction region, following a bend magnet to deflect and dump the electron beam, and were detected using a CsI scintillator fiber-coupled to a multi-channel plate (MCP) and CCD camera. Importantly, the MCP was electronically gated to reject brehmstralung photons from dark current in the linac. The figure above shows the acquired images in three cases: linac dark current alone, 120-MeV e-beam, and e-beam with UV interaction laser. The square profile is from a lead aperture placed before the camera. Given the laser photon energy, electron beam energy, and the Compton scattering relation, 0.776-MeV scattered photons are produced.

As mentioned above, ~10^6 photons per shot were seen. Given the measured ~5-mrad divergence angle, 10-ps pulse duration, and 35-um laser spot size, we estimate the peak brightness of this source to exceed 1×10^{17} photons/sec/mm^2/mrad^2/0.1%bandwidth, limited primarily by the estimated few keV energy spread of the scattered gammas. This brightness is well in excess of that produced by bend magnets at 3rd generation synchrotrons such as the Advanced Photon Source (US) and SpRING8 (Japan), which produce 10^8 and 10^{11} photons/sec/mm^2/mrad^2/0.1% BW respectively.

In conclusion, we report first-light on a new MeV-class light source with ultrahigh peak brightness significantly in excess of current 3rd generation facilities. This ~10-ps, monochromatic, tunable source will enable an entirely new class of isotope-specific, high resolution imaging and detection capabilities. Envisioned national security applications include detection of hidden nuclear materials and weapons, analysis and optimization of nuclear power fuel assemblies, non-invasive quantitative assay and classification of the contents of nuclear waste containers, non-destructive imaging of aging weapons components and dynamic isotope-specific imaging of important high energy density weapons science experiments. Development of these applications will also lead to new medical and industrial applications of isotope-specific imaging.

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