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The Dawn of Nuclear Photonics with Laser-based Gamma-rays

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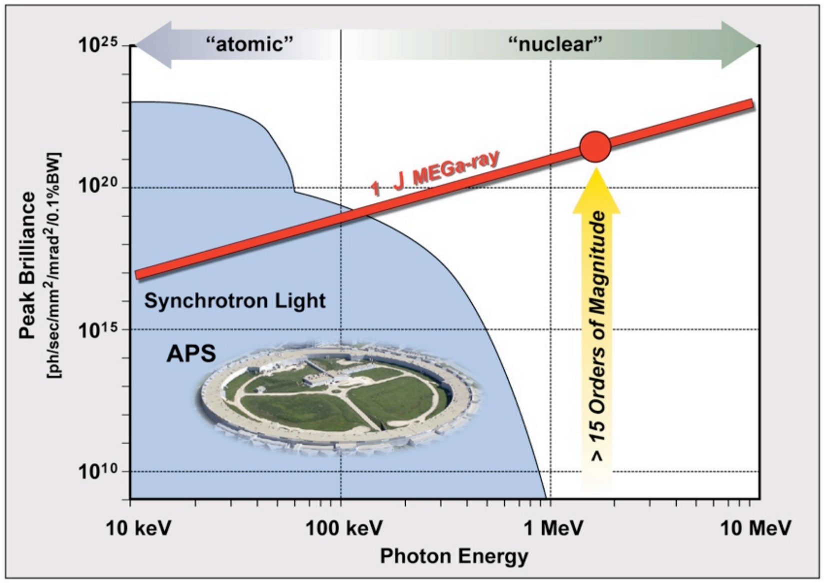
A renaissance in nuclear physics is occurring around the world because of a new kind of incredibly bright, gamma-ray light source that can be created with short pulse lasers and energetic electron beams. These highly Mono-Energetic Gamma-ray (MEGa-ray) sources produce narrow, laser-like beams of incoherent, tunable gamma-rays and are enabling access and manipulation of the nucleus of the atom with photons or so called "Nuclear Photonics". Just as in the early days of the laser when photon manipulation of the valence electron structure of the atom became possible and enabling to new applications and science, nuclear photonics with laser-based gamma-ray sources promises both to open up wide areas of practical isotope-related, materials applications and to enable new discovery-class nuclear science.

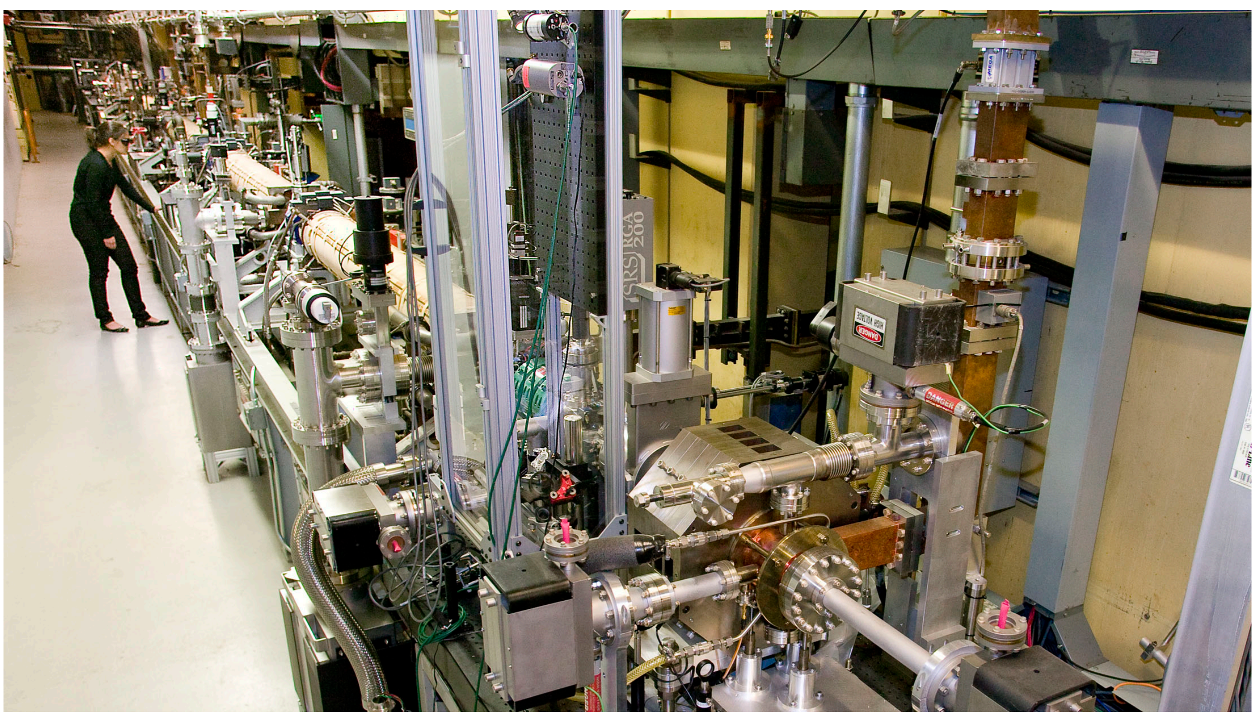
In the United States, the development of high brightness and high flux MEGa-ray sources is being actively pursued at the Lawrence Livermore National Laboratory in Livermore (LLNL), California near San Francisco. The LLNL work aims to create by 2013 a machine that will advance the state of the art with respect to source the peak brightness by 6 orders of magnitude. This machine will create beams of 1 to 2.3 MeV photons with color purity matching that of common lasers. In Europe a similar but higher photon energy gamma source has been included as part of the core capability that will be established at the Extreme Light Infrastructure Nuclear Physics (ELI-NP) facility in Magurele, Romania outside of Bucharest. This machine is expected to have an end point gamma energy in the range of 13 MeV. The machine will be co-located with two world-class, 10 Petawatt laser systems thus allowing combined intense-laser and gamma-ray interaction experiments. Such capability will be unique in the world. In this talk, Dr. Chris Barty from LLNL will review the state of the art with respect to MEGa-ray source design, construction and experiments and will describe both the ongoing projects around the world as well some of the exciting applications that these machines will enable.

The optimized interaction of short-duration, pulsed lasers with relativistic electron beams (inverse laser-Compton scattering) is the key to unrivaled MeV-scale photon source monochromaticity, pulse brightness and flux. In the MeV spectral range, such Mono-Energetic Gamma-ray (MEGa-ray) sources can have many orders of magnitude higher peak brilliance than even the world's largest synchrotrons (see Figure 1). They can efficiently perturb and excite the isotope-specific resonant structure of the nucleus in a manner similar to resonant laser excitation of the valence electron structure of the atom.

Figure 1. Peak brilliance of a MEGa-ray source created from interaction of a nC electron beam and a 1 J interaction laser vs. the APS synchrotron. Above 2 MeV, MEGa-ray peak brilliance exceeds that of synchrotrons by more than 15 orders of magnitude.



This nuclear resonance structure depends upon the number of neutrons and protons in the nucleus and is thus a unique signature of the isotope as opposed to the element. Because MEGa-ray photons are in the MeV spectral range they are also highly penetrating and capable of seeing through dense objects. At LLNL a proof of principle machine was constructed and used to detect with photons the presence of Li concealed behind aluminum and lead [1-2]. (see Figure 2).



source at LLNL. T-REX was LLNL's first MEGa-ray machine. At 500keV T-REX was the world's highest peak brilliance source by nearly 5 orders of magnitude.

Next generation MEGa-ray machines will have beam fluxes that are 3 to 5 orders of magnitude higher than previous proof of principle demonstrations. Such capability will be transformational to an astonishingly wide variety of unresolved nuclear problems and issues. Examples include: rapid (milliseconds) detection of concealed nuclear material, high precision (<100 parts per million) non-destructive assay of spent nuclear fuel assemblies, isotope-specific, high-resolution (~10 micron) imaging of complex objects in 3D, simultaneous measurement of the magnitude and direction of moving isotopic material in dynamic, multi-component material systems and novel forms of medical radiography and radiotherapy. Recently the ELI-NP project has identified a wide range of potential science applications of next generation machines as well including generation of brilliant and intense positron beams and fundamental studies of nuclear structure and photo-fission (http://www.eli-np.ro/documents/ELI-NP-WhiteBook.pdf). The era of nuclear photonics is clearly upon us.

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[1] **Isotope-specific Detection of Low Density Materials with Laser-based Mono-energetic Gamma-rays,** *F. Albert, et al.,* Optics Letters, 35, 3 354 (2010)

[2] **Design and Operation of a tunable MeV-level Compton-scattering-based (gamma-ray) source,** *D. J. Gibson, et al.,* PRSTAB, vol. 13, no. 7, July 27, 2010, pp. 070703