A 4π GAMMA-RAY TRACKING ARRAY

The detection of gamma-ray emission from excited states in nuclei plays a vital and ubiquitous role in nuclear science experiments and with each step forward in gamma-ray detector technology there has been a significant advance in our understanding of nuclei. At the time of the last Long Range Plan, it was realized that large gains in resolving power (see accompanying figure) would be possible by applying the new concept of gamma-ray energy tracking to a 4π detector shell consisting of electrically segmented germanium crystals. This major advance in technology promises to revolutionize gamma-ray detector design and will enable a new class of high-resolution gamma-ray experiments in nuclear structure, nuclear astrophysics, and weak interactions at existing facilities and at RIA. Highly segmented tracking detectors also have a broad application within other fields, e.g. medical, environmental, security, space exploration, and, as with earlier gamma-ray detection advances, timely pursuit of their development will benefit a large community spanning many areas of science and applications.

In the proposed gamma-ray tracking detector the energy and position of each gamma-ray interaction point is obtained by using germanium crystals which have a high degree of electrical segmentation. Since most gamma-rays interact more than once within the crystal the energy-angle relationship of the Compton scattering formula is used to “track” the path of a given gamma-ray, and the full gamma-ray energy is obtained by summing only the interactions belonging to that gamma-ray. Suppression shields are not required and the complete 4π solid angle is available to the germanium. In this way very high photon detection efficiencies can be achieved (~60% for a single 1 MeV gamma-ray and 10% at 15 MeV). Tracking also provides the position of the first interaction to within1-2mm, allowing high-resolution gamma-ray studies of nuclei produced in fragmentation reactions at high recoil velocity where Doppler broadening is significant. Other key design benefits of a highly segmented germanium array include the ability to handle high counting rates, high multiplicities, and to pick out low multiplicity events hidden in a high background environment.

In the last five years substantial R&D has been carried out and the technology needed to realize a 4π gamma-ray tracking array has been identified and developed leading to a demonstration of the “proof of principle” in all the key areas. (A) Highly segmented germanium detectors have been successfully manufactured (a 36 segmented detector has been used for testing purposes for several years). (B) Pulse shape digitization and digital signal processing methods have been developed to determine the position, energy, and time of gamma-ray interactions (position resolutions of <2mm have been achieved). (C) Tracking algorithms have been developed, which are capable of identifying the interaction points of a particular gamma ray.

A detector design for a 4π array, called GRETA (Gamma-Ray Energy Tracking Array), was featured in the previous Long Range Plan. It contains about 100 coaxial germanium crystals, each segmented into 36 portions and arranged in a highly efficient 4π geometry. It is calculated that GRETA will have a resolving power of 100-1000 times that of Gammasphere (the present state-of-the-art detector array) while being of similar overall cost. In addition, this versatile modular design, as with Gammasphere, will allow a coupling to auxiliary detector devices, enhancing the physics capabilities. A detector technology based on segmented planar (strip) germanium detectors is also being pursued. Arranged into a box-like configuration, the GARBO (GAmma-Ray Box) design is an important complementary detector system rather than an alternative to the high efficiency 4π coaxial detector array described above. In addition, a system of eighteen 32-fold segmented germanium detectors with limited angular coverage has just been completed for experiments using fast exotic beams, and is a significant step towards a full 4π germanium tracking array.

Gammasphere, the first national gamma-ray facility in the US, has had a profound impact on nuclear structure research, and continues to act as a focal point for the US and worldwide community. Today, there is an opportunity to create a new generation of gamma-ray spectrometers based on gamma-ray tracking and to expand upon the success of Gammasphere. The physics justification for such a 4π tracking array is extremely compelling, spanning a wide range of fundamental questions in nuclear structure, nuclear astrophysics, and weak interactions.

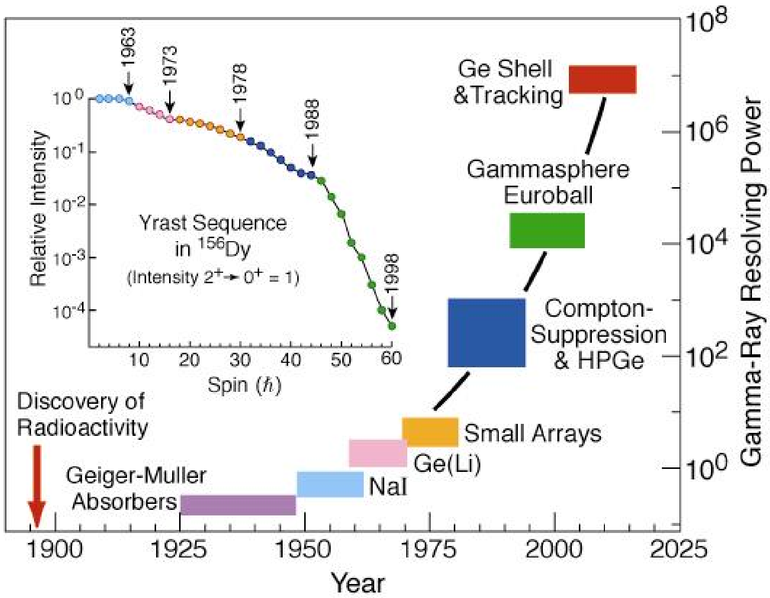

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Figure Caption:
Evolution of gamma-ray detection technology with time. The large gain provided by the 4π tracking array GRETA is clearly shown. The calculated gamma-ray resolving power is a measure of our ability to observe the faint emissions from rare and exotic nuclear states. This is illustrated in the top left-hand insert, which indicates the strong inverse relationship between resolving power and the experimental observational limit for excited states in a typical rare-earth nucleus.