Letter of Intent (Category C): Development of Detectors for the Imaging of Single Particles and Biomolecules at the Linac Coherent Light Source (LCLS)

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Introduction:

New Science at the LCLS, such as the imaging of single particles and bio-molecules, nano scale dynamics or femto-second crystallography will require detector planes with unique capabilities. The high detector granularity (50µm), extremely high dynamic range (>10^6), the very high beam repetition rate (120 Hz) and the intensity at the LCLS are severe constraints to the design of the detector array.

The very short beam pulses totally preclude using photon-counting techniques. Current integration at the level of the pixel (integrated charge measurement) is the only feasible approach to measuring the number of incident photons. Commercially available Charge Coupled Devices (CCDs) cannot provide the dynamic range. It is unlikely that using devices with smaller pixels will provide the required dynamic range. Increasing the number of pixels will slow the frame rate. Techniques such as CCDs hybridized with an Application Specific Integrated Circuit (ASIC) for columnar readout may constitute one approach. An alternative is to use hybrid sensors whereas a sensor array is bump bonded to an ASIC consisting of a processing chain per pixel, a digitization function common to all pixels and a readout and data transmission feature.

Proposal:

It is our intent to submit a proposal to:

1. Evaluate the different options for the detector plane.
2. Select the option that will best guarantee satisfying the requirements while minimizing construction and long term operation costs.
3. Perform a top down design of the system.
4. Fabricate and characterize a "16^{th} size" system (~64,000 pixels) that once certified could be used as a building block for full size detectors. This limited detector could be tested on the SPPS.

The period of performance would extend over two years.

Approach:

The photon "count" per pixel decreases from the center to the periphery of the detector plane. While the dynamic range must be in excess of 10^6 over the area it must be noted that the accuracy on the charge in each pixel probably can be limited to 1 part in 4000.

The sensor converting the photons to electric charge cannot sustain full charge deposition by 8KeV photons close to the center of the detector. If the energy of 10^6 8KeV photons was deposited in a single pixel in 1pico-second the peak current could reach 400A on that pixel. The photon flux and/or the energy deposited must be limited! This can be achieved in three ways by:

1. Inserting a profiled absorber upstream of the detector. The absorber is shaped to attenuate the photon beam as a function of the distance to the detector center. The absorber could be micro-machined or built from the layering of epoxy loaded with high Z material (Pb, W, Bi, Ta…). Such a layering can be done using specialized plotters.
2. Using thin sensors and a photon stopping interposing layer between the sensor array(s) and the ASICs. The interposer layer protects the ASIC from over-exposure to radiation. An option is to use thin diamond detectors at the center of the detector and thicker silicon detectors at the periphery. The lower Z and higher pair creation energy of diamond provide additional energy scaling capability.
3. Using a combination of the above and relaxing the requirements on each of them.

The implementation will use a modular approach whereas individual assemblies will be fabricated and tested then tiled to form the entire detector. It is expected that gaps between tiles will be less than a pixel. The approach should yield low production and maintenance costs.

Digitization of individual pixel data could be performed within a few milliseconds (<4ms) by distributing a common ramp to each pixel processor and comparing the ramp with the analog value of the charge under the pixel (Wilkinson). This will leave several milliseconds before the next beam pulse to transfer the digitized data to the computer and storage. Calibration tables and possibly linearity curves will be required for each pixel

Budget:

A total budget of $1,200K over two years is required for this development. It includes:

1. System design: evaluation of options and implementation of the selected architecture: $250K
2. ASIC design: $450K
3. Sensors and ASICs procurement: $200K
4. Packaging: hybridization technologies, etc…: $100K
5. Miscellaneous engineering and technical support: $100K
6. Miscellaneous procurements: $100K

Personnel:

The P.I. will be in responsible for the overall system design and verification of performance. An ASIC design engineer (to be named) will be responsible for the detail design, simulation, layout and characterization of the ASIC.

References:

M. Wright, J. Millaud and D. Nygren A Pixel Unit-Cell Targeting 16ns Resolution and radiation Hardness in a Column Read-out Particle Vertex Detector. Third International Conference on Advanced Technology and Particle Physics Como Italy June 22-26 1992. LBNL report: LBL-32912

Millaud and D. Nygren Lawrence Berkeley National Laboratory. The column architecture - a novel architecture for event driven 2D imagers. Proceedings of the 1995 IEEE Nucl. Science Symposium (San Francisco).