High-speed event-based electron counting for *in situ* TEM

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Apollo's unique design for electron counting

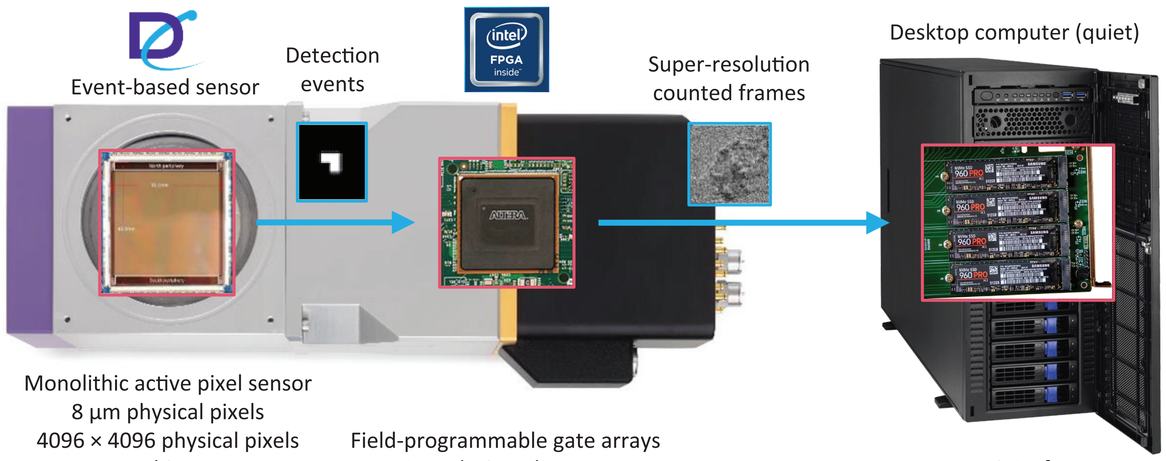


Figure 1: Apollo is based on a novel (US Patent #10,616,521) ultra-fast, event-based, direct detection device (DDD®). The sensor detects incident electrons and outputs the location and shape of each detection "blob" registered on the sensor. Sensor noise is minimized through on-chip correlated double sampling (CDS), on-chip thresholding, and noise-free digital output. The super-resolution centroid of each detected event (which may span multiple pixels) is calculated in FPGA. Detected events are accumulated in 8192 × 8192 dose-fractionated movie frames, which are output to the computer.

Achieving the highest resolution wherever it's installed

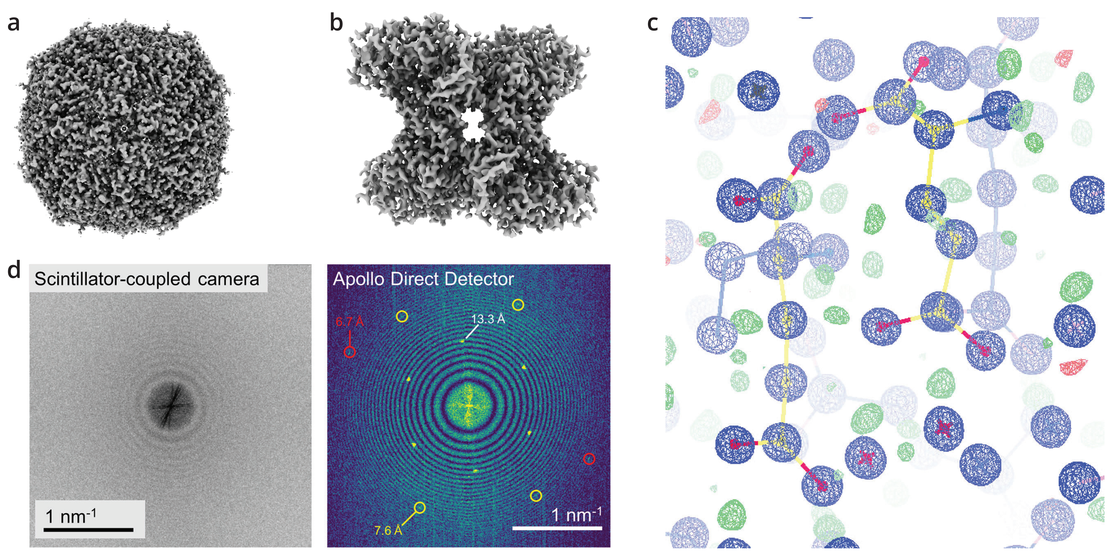


Figure 2: (a) Cryo-EM of apoferritin at 1.68 Å from a Titan Krios Gen1 (Scott Stagg, Florida State University, USA). Data deposited as EMPIAR-11254. **(b)** Cryo-EM of apoferritin at 1.46 Å from a JEOL CRYOARM 300 (JEOL Ltd., Japan). Data deposited as EMPIAR-11101. **(c)** Continuous rotation microED maps of monohydrate sodium glutamate (MSG) at 0.5 Å resolution (Takanori Nakane, Osaka University, Japan), which is the highest known microED resolution. Data was acquired on a JEOL CRYOARM 300 using SerialEM. **(d)** Fourier transforms of HRTEM images of a triazine-based 2D polymer from a scintillator-coupled camera at 50 $e^-/Å^2$ (left) and Apollo at 5 $e^-/Å^2$ (right), using a CEOS CEFID energy filter. (Mücke, et al., 2023).

Minimizing coincidence loss to maximize data quality

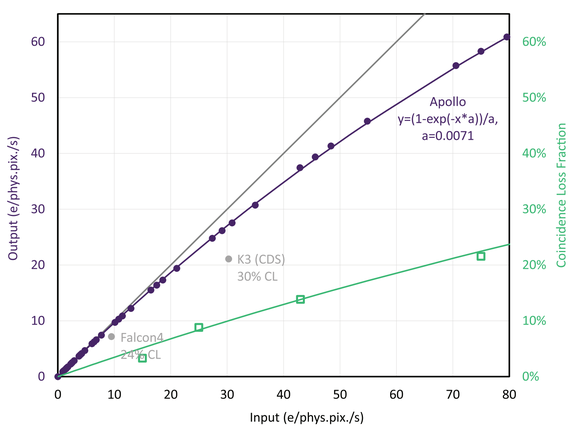


Figure 3: Coincidence loss for Apollo. The dashed line represents the theoretical maximum (absence of coincidence loss). Solid purple circles show the measured output based on the mean intensity of each image compared to the expected input flux. The purple line shows the fit of these data points to the model used in Nakane, et al., 2020. The green line shows the calculated coincidence loss (CL) from the purple line. Outlined green squares show the magnitude of NPS suppression for a few exposure rates. Two solid gray circles show the maximum published exposure response of the Gatan K3 and Thermo Fisher Scientific Falcon4 cameras, as shown in Fig. S1 of Sun, et al., 2023 and Fig. 1e of Nakane, et al., 2020, respectively.

Pre-announcing "ApolloXS" for *in situ* TEM

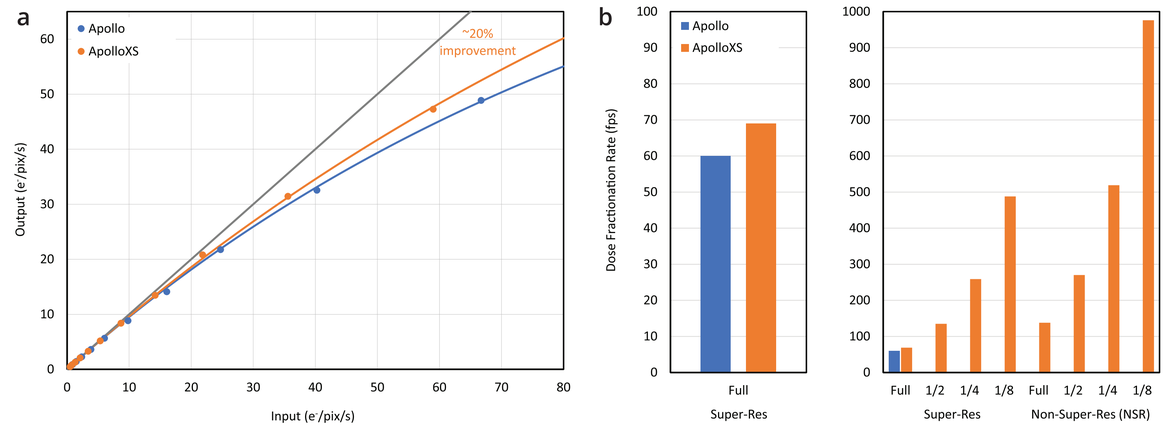


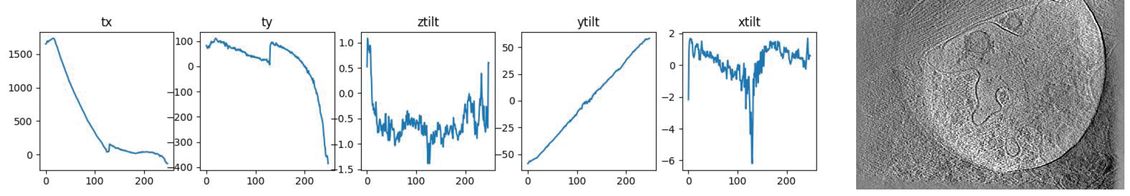
Figure 4: The new "ApolloXS" version of the camera includes faster sequencer timing for running the sensor, a new strategy in FPGA for identifying the boundaries of single detection events (which are connected groups of pixels output from the sensor), and new readout modes (which also require updated hardware). **(a)** Coincidence loss curves at 200 kV for Apollo and the new ApolloXS models, showing ~20% less coincidence loss in the new model. **(b)** New firmware increases the dose fractionation time resolution from ~60 fps to ~69 fps (15% increase). The combination of new firmware and updated hardware also introduces new readout modes. Non-super-resolution (NSR) output increases the dose fractionation rate by ~2×, without changing the coincidence loss rate. Sub-array readout (all columns but only the middle fraction of rows) improves *both* the dose fractionation rate the coincidence loss rate.

Readout Area	Max FPS	Time Res.*	Max Exp. Rate
4096 × 4096	138 fps	384 µs	85 e^-/pixel/s
4096 × 2048	270 fps	192 µs	170 e^-/pixel/s
4096 × 1024	519 fps	96 µs	340 e^-/pixel/s
4096 × 512	976 fps	48 µs	680 e^-/pixel/s

* Using CES mode. The file format is not yet determined.

Figure 5: In addition to frame readout from the camera (see the "Max FPS" column), ApolloXS also includes "centroided event streaming" (CES) mode, in which counted events are streamed directly to the computer at the full time resolution of the sensor (shown in the "Time Res." column). For each readout area, the maximum recommended exposure rate (representing 25% coincidence loss) is also shown.

Figure 6: Bidirectional low-dose continuous-rotation tomography acquired in ~60 seconds on ApolloXS (Phillip Baldwin, Baylor College of Medicine, USA).



Or, use CeleritasXS to enable 5D STEM

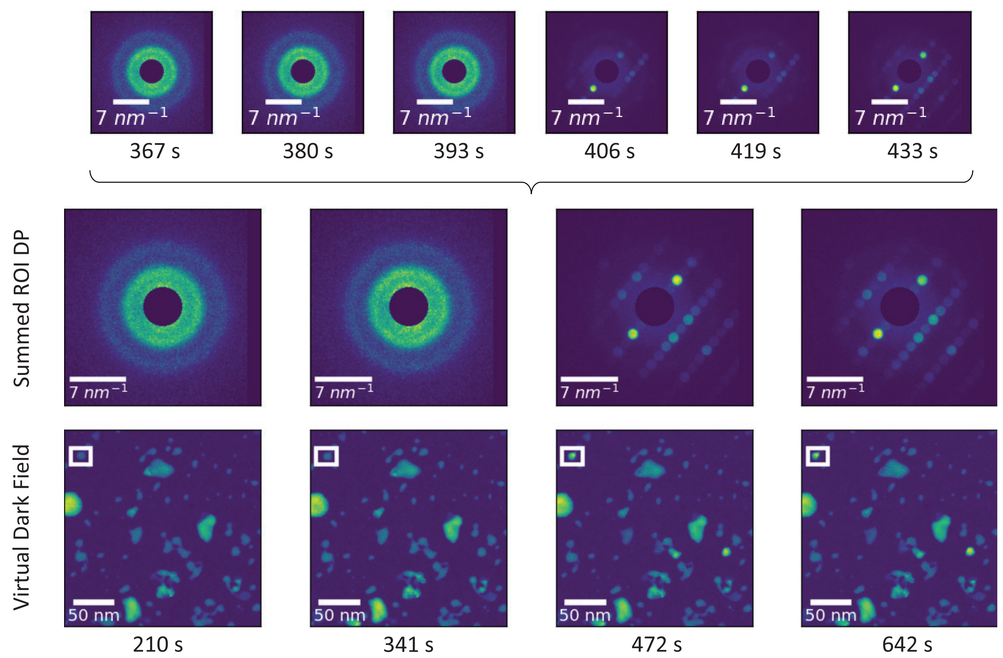


Figure 7: 5D STEM of PdCuSi nano structures (some glassy and some crystallized), acquired on a CeleritasXS camera with 256 × 256 readout pixels at 20,000 fps. Each 4D STEM acquisition had 512 × 512 STEM pixels, requiring 13 seconds each. The specimen was held at 410˚ C for ~15 minutes using a DENS Solutions heating holder, while continuously acquiring 4D STEM data to watch the crystallization behavior. The bottom row of larger images shows a virtual dark field reconstruction from the 4D STEM data at four time points. The top row of larger images and the smaller images along the top show the average diffraction pattern recorded on the camera within the specimen region of interest (ROI) shown by the white box in the virtual dark field images (Paul Voyles, University of Wisconsin, Madison, USA).