ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

EPICS IOC DEVELOPMENT FOR HIGH-SPEED AND HIGH-RESOLUTION IMAGING WITH THE AXIS CAMERA

K. Kim†, B. Hill, E. Williams, K. Kunnus, K. Kim, P. C. O'Grady
SLAC National Accelerator Laboratory, Menlo Park, CA, USA

Abstract

At SLAC National Accelerator Laboratory, we recently integrated a high-performance AXIS-SXRF-60 camera into the EPICS control system for advanced imaging applications. The AXIS camera features a 6144 × 6144 pixel sensor with 16-bit depth per pixel, generating approximately 75 MB per image. With a maximum frame rate of 26 frames per second, the system must handle a sustained data throughput of nearly 1.9 GB/s. This paper presents the development and deployment of EPICS IOC designed to interface with the AXIS camera, focusing on software optimization strategies to manage the substantial data volume efficiently. Leveraging the areaDetector framework, the ADGenICam and ADEuresys modules, we expedited the integration process while ensuring compatibility with the Euresys frame grabber hardware. Key topics include multi-threaded data pipelines, network optimization, and techniques to maintain stable, real-time image acquisition. The work demonstrates how high-speed imaging systems can be effectively supported within an EPICS environment, providing a template for similar large-scale instrumentation efforts.

INTRODUCTION

High-performance cameras are increasingly critical in modern accelerator facilities for both machine protection and scientific productivity. High-brightness, short-pulse beams demand single-shot, low-latency diagnostics to characterize beam size, shape, position, and pointing on every pulse. These measurements underpin fast feedback loops for orbit stabilization, emittance tuning, and jitter reduction, enabling reliable delivery of tightly specified beam parameters to users. In addition, advanced experiments—from soft X-ray imaging and spectroscopy to pump–probe studies—benefit from large field-of-view, high-dynamic-range sensors capable of capturing weak features alongside bright structures in a single exposure. The combination of high resolution, high frame rate, and low read noise offered by modern sCMOS/CMOS sensors makes them well-suited to these tasks [1, 2].

Across the community, facilities have adopted high-speed area cameras for beam profile monitors, optical transition radiation screens, scintillator-based diagnostics, and X-ray imaging. EPICS areaDetector is widely used to integrate such devices with control system infrastructure, data acquisition, and data reduction pipelines [3-6]. CoaXPress frame grabbers, GenICam-compliant camera interfaces, and robust EPICS plugins have enabled reliable deployments for high-data-rate applications at multiple labs [3, 6-9].

At SLAC, the AXIS-SXRF-60 camera was chosen for this project, which provides the largest sensor currently available at our lab, a 36 Mpix, 6144 × 6144 sCMOS sensor with 16-bit depth [10, 11]. Its combination of very large field-of-view, soft X-ray optimization, and CoaXPress connectivity addresses our requirements for (1) full-aperture imaging in a vacuum environment, (2) high sustained bandwidth for continuous acquisition, and (3) compatibility with existing SLAC timing, controls, and data systems [10-12]. The camera's integration with a Euresys CoaXPress frame grabber and its GenICam compliance made it a strong fit for rapid integration with EPICS via areaDetector, ADGenICam, and ADEuresys [3, 7, 8].

SYSTEM ARCHITECTURE

Hardware

Figure 1 shows the wiring diagram of the complete system (modified from [10]). The main elements are:

- A: Duplex optical cable from the camera head
- B1: Optical converter
- B2: Four coaxial cables (CoaXPress links)
- B3: Euresys CoaXPress frame grabber (Coaxlink Quad CXP-12) installed in the host PC
- C: Host PC, which runs EPICS IOC and areaDetector on RHEL7
- D: DB15 to BNC cable to receive trigger signals
- E: 12 VDC universal power supply
- F: Water cooler for camera thermal management
- G: F-mount adaptor for test and development

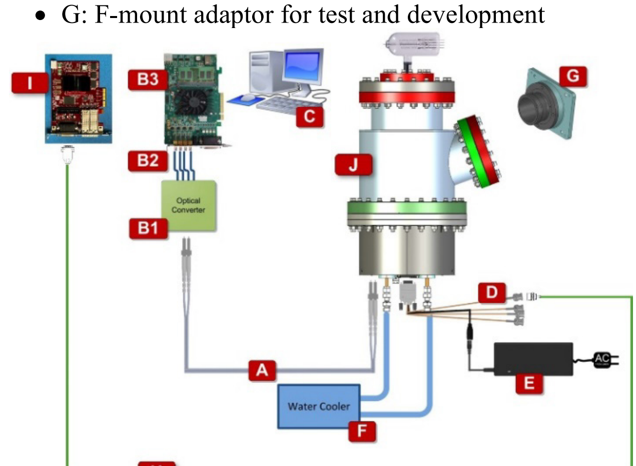

Figure 1: Wiring diagram of the system.

† ktkim@slac.staford.edu

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

- H: DB26-M to BNC cable to send trigger signals to the camera
- I: SLAC timing pattern receiver (TPR) trigger card installed in the host PC
- J: AXIS-SXRF-60 camera integrated with the vacuum chamber

Signal and Data Flow Overview

Triggering: The SLAC TPR trigger (I) provides deterministic triggers synchronized to the accelerator timing system.

Data path: Raw image data are transmitted from the camera over the duplex optical link (A) to the optical converter (B1), then over four CoaXPress cables (B2) to the Euresys Coaxlink Quad CXP-12 frame grabber (B3). The frame grabber performs DMA transfers to the host PC (C).

IOC and plugins: The EPICS IOC uses areaDetector with ADGenICam and ADEuresys to configure the camera, acquire images, and distribute them as NDArrays to plugins for display and saving. EPICS PVs expose camera

Figure 2 shows the AXIS-SXRF-60 camera [10], with and without the F-mount adaptor. The F-mount adaptor is particularly useful for EPICS IOC development, as it allows testing without requiring a beam. The camera is shown disassembled from the vacuum assembly illustrated in Fig. 1.

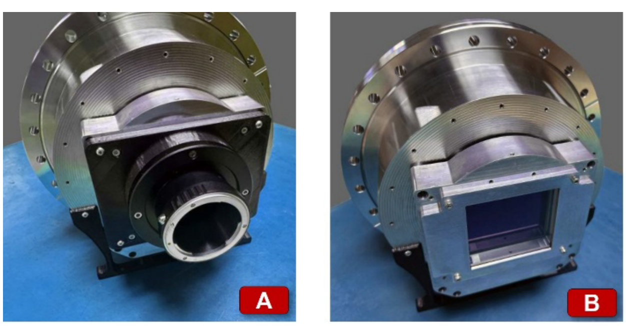

Figure 2: AXIS-SXRF-60 camera, (A) with and (B) without the F-mount adaptor.

Software

Figure 3 shows the general areaDetector architecture [3]. We followed this architecture for our development since both the camera and frame grabber vendors provide GenICam APIs and device drivers. This allowed us to use the ADGenICam and ADEuresys drivers from the EPICS community, which significantly reduced development time and effort, while also making it easier to receive support from the community.

In addition, we used the following areaDetector modules: ADCore, ADGenICam, ADEuresys, ADSimDetector, ADStream, ADSupport, and ffmpegServer. Other modules, including SLAC-specific ones, include: EPICS base, asyn, ATCACommon, autosave, busy, calc, caPutLog, diagTimer, event2, history, iocAdmin, MCoreUtils, sscan, timeStampFifo, timingApi, tprTrigger, and yamlLoader.

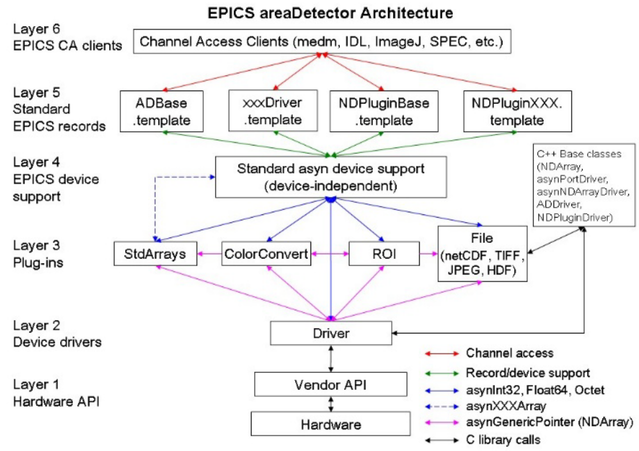

Figure 3: areaDetector architecture.

IMPLEMENTATION

Host PC Specifications and Configuration

Table 1: Host PC Specifications

OS	RHEL7
CPU	AMD EPYC 7282 16-core processor
RAM	64 GB
Storage	Diskless image

Table 1 summarizes the specifications of the host PC. At SLAC, diskless images are employed to facilitate centralized management, consistent environments across clients, simplified deployment of new systems, and efficient maintenance of a large number of servers.

AXIS-SXRF-60 Camera

The AXIS camera employs a 6144 × 6144 pixel sensor with 16-bit depth, producing approximately 75 MB per image. Operating at its maximum full-frame rate of 26 fps requires a sustained data throughput of nearly 1.9 GB/s [10, 11]. The camera uses a rolling shutter CMOS sensor (GSENSE6060BSI) that reads each row in 14.4 µs, taking 88.5 ms to read all 6144 rows, which corresponds to a maximum frame rate of 11.3 fps.

In high-speed mode, the sensor reads even and odd rows simultaneously at 12-bit depth, effectively more than doubling the frame rate to 26 fps. The camera interfaces via CoaXPress 4 × 6.25 Gbps, providing a maximum transfer rate of 25 Gbps, which is sufficient for full-frame operation.

To achieve 100 Hz image acquisition, we reduced the region of interest (ROI) to 6144 × 796 pixels with a Y-axis offset of 2674. This allows a maximum capture rate of 174 fps in high-speed mode. The resulting image size is approximately 9.3 MB, yielding a data throughput of about 0.91 GB/s (7.3 Gb/s) at 100 Hz, which can be continuously handled by a 10 Gb Ethernet connection.

Coaxlink Quad CXP-12 Frame Grabber

The Euresys Coaxlink Quad CXP-12 frame grabber is one of the two officially supported CoaXPress frame

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

grabbers for this camera [10]. It supports link speeds of 1.25 Gbps (CXP-1), 2.5 Gbps (CXP-2), 3.125 Gbps (CXP-3), 5 Gbps (CXP-5), 6.25 Gbps (CXP-6), 10 Gbps (CXP-10), and 12.5 Gbps (CXP-12). With four connections, the maximum aggregated data transfer rate from the camera reaches 50 Gbps in CXP-12 mode [12].

SLAC DAQ Card and Data Storage

Data are recorded using the SLAC DAQ card, which is connected to a 10 Gb Ethernet network to write directly to the SLAC Shared Science Data Facility (S3DF). The DAQ produces eXtensible Tagged Container (xtc) files, which efficiently capture raw data along with timing and metadata directly from the hardware. These XTC files are then converted to HDF5 format, providing a standardized, portable structure that facilitates analysis, visualization, and integration with scientific tools, while enabling fast access to subsets of large datasets.

PERFORMANCE OPTIMIZATION

Test Environment for High-Throughput Imaging

We captured full-frame images (6144 × 6144 pixels) at the camera's maximum speed of 26 fps, corresponding to a data throughput of nearly 1.9 GB/s, to evaluate performance under demanding conditions. Although the region of interest (ROI) will be reduced to 6144 × 796 pixels in actual operation to accommodate network bandwidth limitations and achieve higher frame rates, full-frame testing provides insight into system behavior under extreme conditions.

Polling Behavior and Selective PV Reading

Polling (ReadStatus.SCAN) was initially configured to allow users to monitor sensor and device temperatures for interlocks, as the camera employs a Peltier module to cool the sensor down to –25 °C. The hot side of the Thermoelectric Cooler (TEC) must be continuously cooled by circulating water; any water supply failure could cause the camera to overheat in vacuum and potentially damage the electronics or sensor.

However, polling can block other tasks and reduce the image capture rate. In ADCore, the ADBase.template provides a ReadStatus record that reads all GenICam features. During the poll cycle, the asyn port is locked, which blocks the read thread and slows acquisition. Since ReadStatus.SCAN reads all GenICam features and many of which are unnecessary for our purposes, we set the polling mode to Passive during image acquisition. Instead, we implemented a readFloat64 function in the ADGenICam class (Listing 1), allowing users to selectively read only the PVs of interest.

Listing 1: readFloat64 Function

```
asynStatus ADGenICam::readFloat64(asynUser
*pasynUser, epicsFloat64 *value)
{
    asynStatus status = asynSuccess;
    int function = pasynUser->reason;
    static const char *functionName =
"readFloat64";

    GenICamFeature *pFeature = mGCFeature-
Set.getByIndex(function);
    if (pFeature) {
        pFeature->read(value, true);
    }

    asynPrint(pasynUserSelf,
ASYN_TRACEIO_DRIVER,
        "%s::%s function=%d, value=%f, sta-
tus=%d\n",
        driverName, functionName, function,
*value, status);

    callParamCallbacks();
    return status;
}
```

CPU Affinity Configuration

We configured CPU affinity using MCoreUtils rules (Listing 2) to optimize performance. Specifically, CPU threads 4–7 were assigned to scanning tasks, while threads 8–28 were dedicated to areaDetector plugins. This allocation ensures that acquisition and processing tasks run efficiently without interfering with each other.

Listing 2: CPU Affinity Configuration

```
mcoreThreadRuleAdd CAM_cpu * * 2 CAM.*
mcoreThreadRuleAdd scan_cpu * * 4-7 scan.*
mcoreThreadRuleAdd plug_cpu * 70 "8-
28" .*Plug.*
```

Muti-threading Optimization for Plugin

We optimized the areaDetector plugins, as they consume significant resources, and used only two plugins: NDPluginStdArrays for raw data streaming and NDPluginROI for monitoring. Both plugins support multithreading.

NDPluginStdArrays handles large volumes of raw streaming data, with a throughput of nearly 1.9 GB/s, so we allocated 5 threads for this plugin. NDPluginROI handles a reduced image size (768 × 768), and since monitoring is not performance-critical, we ran it with a single thread.

When NDPluginStdArrays was set to a single thread, CPU usage reached up to 69%. After increasing to 5 threads, CPU usage dropped to 13% per thread. Using one NDPluginROI plugin resulted in 53% CPU usage, which was acceptable for monitoring purposes.

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

OPERATIONAL EXPERIENCE

We observed that the IOC would crash if the ROI, offset, or pixel binning were modified without first stopping image acquisition with the AXIS-SXRF-60 camera. To address this, we updated the ADGenICam.cpp code so that image acquisition now stops automatically whenever the user changes the ROI, offset, or pixel binning, as shown in Listing 3.

Since not all GenICam cameras exhibit this crash behavior when acquisition is modified without stopping, we did not submit this update to the EPICS community.

Listing 3: Snippet of Updated ADGenICam.cpp

```
else if ((function == ADSizeX)       ||
         (function == ADSizeY)       ||
         (function == ADMinX)        ||
         (function == ADMinY)        ||
         (function == ADBinX)        ||
         (function == ADBinY)) {

# Begin updated code to prevent IOC crashes
when ROI, offset, or binning is changed
            if (acquiring) {
                status = stopCapture();
                asynPrint(pasynUserSelf,
ASYN_TRACEIO_DRIVER, "%s%s: called stopCap-
ture() for ROI change\n", driverName, func-
tionName);
            }
# End updated code to prevent IOC crashes
when ROI, offset, or binning is changed

    status = setImageParams();
}
```

LESSONS LEARNED: DRIVER MANAGEMENT

We observed that the Euresys frame grabber driver did not automatically load after a power cycle in RHEL7, unlike Rocky9. To address this issue, the driver must be manually reloaded after each reboot. To automate this process, we created a systemd service file at /etc/systemd/system, as shown in Listing 4.

This service ensures the driver is properly loaded after boot, improving system reliability and minimizing manual intervention.

OPERATIONAL INTERFACE

The main user interface (UI) screen shown in Fig. 4 serves as the central control panel for operating the AXIS-SXRF-60 camera. SLAC uses a similar main interface across the facility, ensuring that operators can work consistently and without confusion. The UI provides quick access to essential camera functions, including exposure settings, trigger controls, acquisition modes, and a link to the live image preview for detector operation. Its intuitive layout enables users to monitor system performance and perform basic tasks efficiently, without navigating through multiple menus.

Listing 4: Euresys-drivers.Service

```
[Unit]
Description=Load Euresys Coaxlink drivers
with delay
After=network.target

[Service]
Type=oneshot
ExecStart=/bin/bash -c "sleep 10 &&
/sbin/modprobe -r coaxlink && sleep 5 &&
sbin/modprobe coaxlink"
RemainAfterExit=yes

[Install]
WantedBy=multi-user.target
```

The detailed configuration screen in Fig. 5 allows for advanced parameter adjustments, including sensor-specific settings such as gain mode, offset, frame rate, region of interest (ROI), and sensor cooling. This level of control is essential for optimizing camera performance in various experimental conditions and ensuring accurate and precise data acquisition.

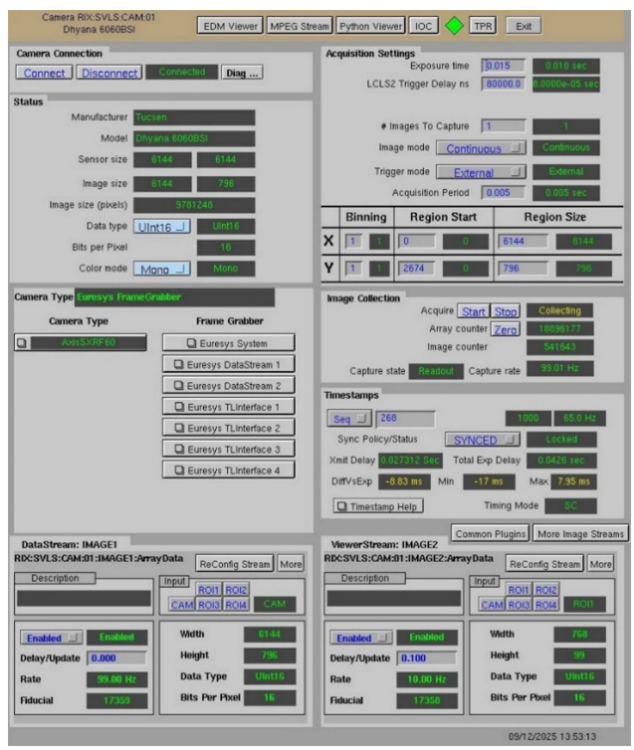

Figure 4: Main UI screen of the AXIS camera.

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

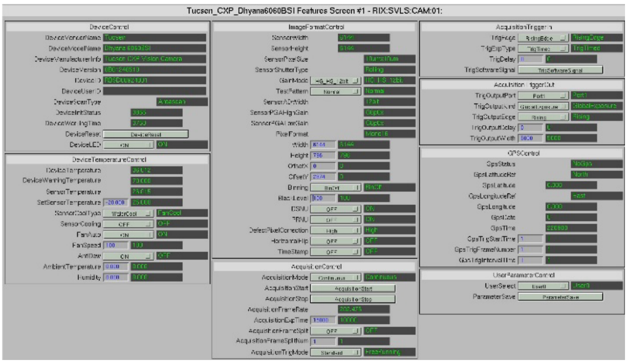

Figure 5: Detailed configuration screen of the AXIS-SXRF-60 camera.

CONCLUSION

We developed and deployed an EPICS IOC for the AXIS-SXRF-60 detector, integrating a very large-area, soft X-ray sCMOS camera with SLAC's controls and timing infrastructure. Using areaDetector with ADGenICam and ADEuresys, we achieved robust operation at high data rates, including real-time monitoring and saving of 6144 × 796 images at 100 Hz, as shown in Fig. 6 and Fig. 7. The approach and lessons learned provide a practical template for integrating similar high-speed, high-resolution imaging systems in accelerator environments.

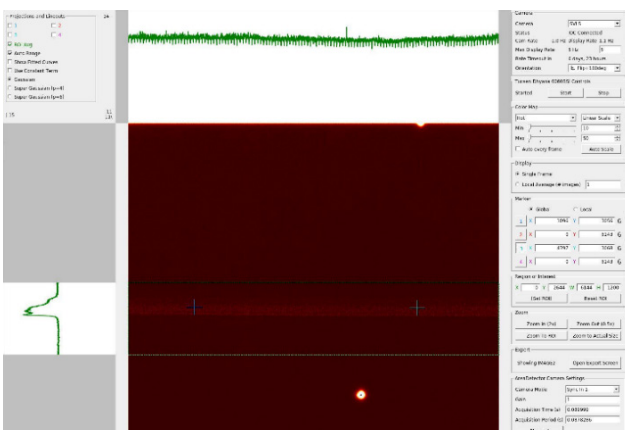

Figure 6: Spectrum image of the beam acquired with the AXIS-SXRF-60 detector.

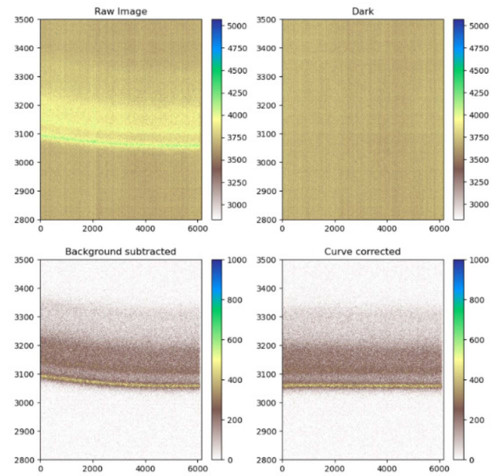

Figure 7: Processed image reconstructed from raw data acquired with the AXIS-SXRF-60 detector.

REFERENCES

[1] K. Desjardins *et al.*, "Backside-illuminated scientific CMOS detector for soft X-ray resonant scattering and ptychography", *J. Synchrotron Radiat.*, vol. 27, no. 6, pp. 1577-1589, Oct. 2020. doi:10.1107/s160057752001262x

[2] C. Léveillé *et al.*, "Single-shot experiments at the soft X-FEL FERMI using a back-side-illuminated scientific CMOS detector", *J. Synchrotron Radiat.*, vol. 29, no. 2, pp. 594–594, Feb. 2022. doi:10.1107/s1600577522001370

[3] M. L. Rivers, "areaDetector: EPICS Software for 2-D Detectors", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017, pp. 1245-1251. doi:10.18429/JACoW-ICALEPCS2017-THDPL03

[4] J. Wlodek and K. J. Gofron, "ADUVC - an EPICS Areadetector Driver for USB Video Class Devices", in *Proc. ICALEPCS'19*, New York, NY, USA, Oct. 2019, pp. 1499. doi:10.18429/JACoW-ICALEPCS2019-WEPHA174

[5] K. J. Gofron *et al.*, "Deployment of ADTimePix3 areaDetector Driver at Neutron and X-ray Facilities.", in *Proc. ICALEPCS'23*, Cape Town, South Africa, Oct. 2023, pp. 90-94. doi:10.18429/JACoW-ICALEPCS2023-MO2AO05

[6] Q. Zhang *et al.*, "Detector integration at HEPS: a systematic, efficient and high-performance approach", Nov. 2024, arXiv:2411.01260 [physics.ins-det]. doi:10.48550/arXiv.2411.01260

[7] areaDetector ADGenICam driver documentation, https://areadetector.github.io/areaDetector/ADGenICam/ADGenICam.html

[8] areaDetector ADEuresys driver documentation, https://areadetector.github.io/areaDetector/ADEuresys/ADEuresys.html

[9] EMVA, GenICam Standard., https://www.emva.org/standards-technologies/genicam

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-THPD067

[10] *AXIS-SXRF-60-SLAC: 36 Mpix sCMOS Soft X-ray Camera User Manual*, Document No. UM-SXRF-60 Rev2, AXIS Photonique Inc., Quebec, Canada, 2024.

[11] AXIS-SXRF-60 detector, https://www.axis-photon.com/streak-camera/axis-sxrf-60-very-large-area-soft-x-ray-scmos-camera-on-a-flange

[12] Coaxlink Quad CXP-12 CoaXpress frame grabber, https://www.euresys.com/en/products/frame-grabber/coaxlink-quad-cxp-12