The FERMI@Elettra CCD acquisition system

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Abstract

FERMI@Elettra is a new 4th generation light source based on a linac-driven Free Electron Laser (FEL) which is currently being built in Trieste, Italy. The CCD image acquisition system is a fundamental diagnostic tool for the commissioning of the new accelerator. It is used for the characterization and tuning of the laser, electron and photon beams. The Tango based software architecture, the soft real-time performance and the embedded image processing algorithms are described.

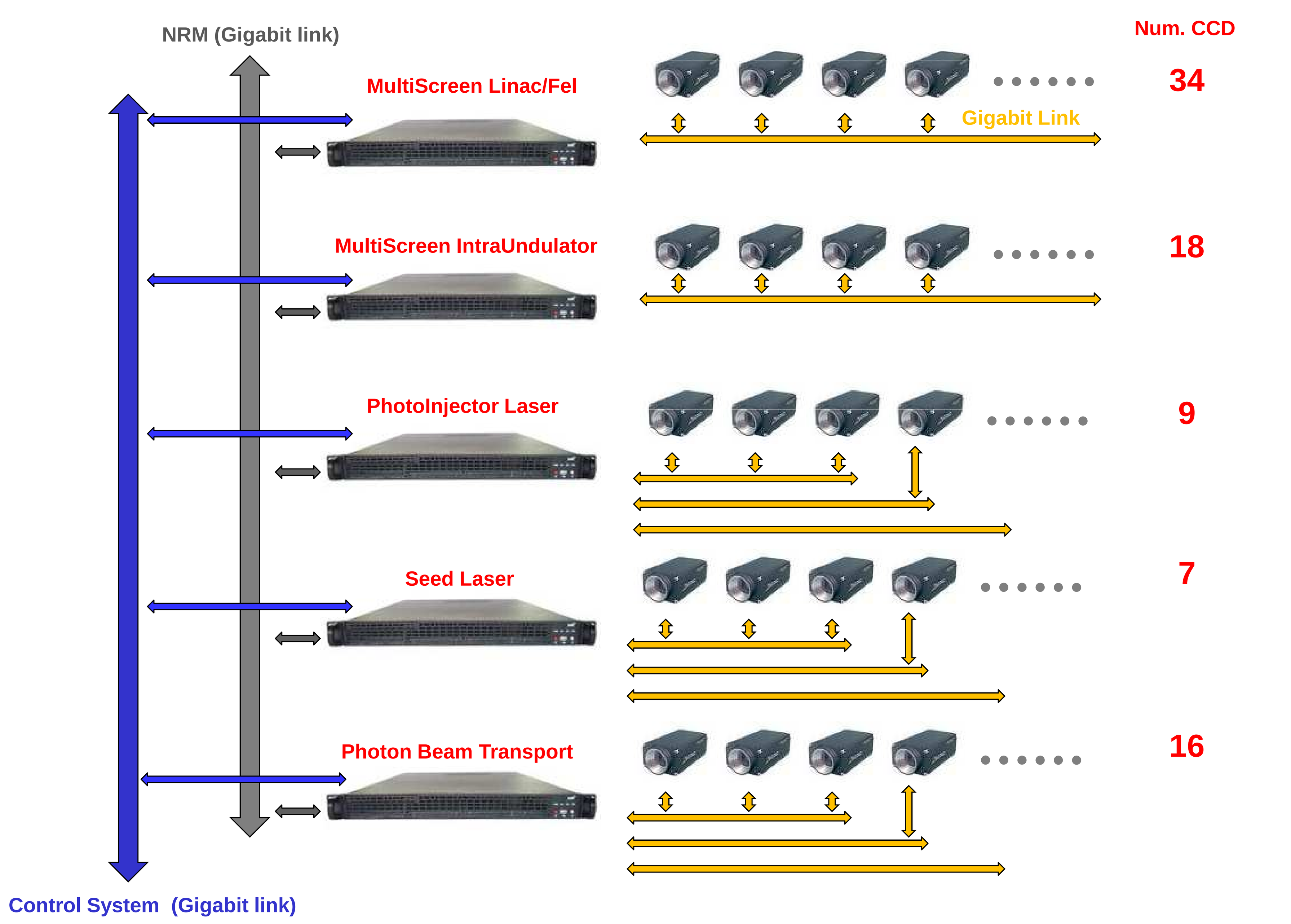
The FERMI@Elettra CCD Acquisition System

A total of 84 gigabit CCD cameras are installed:

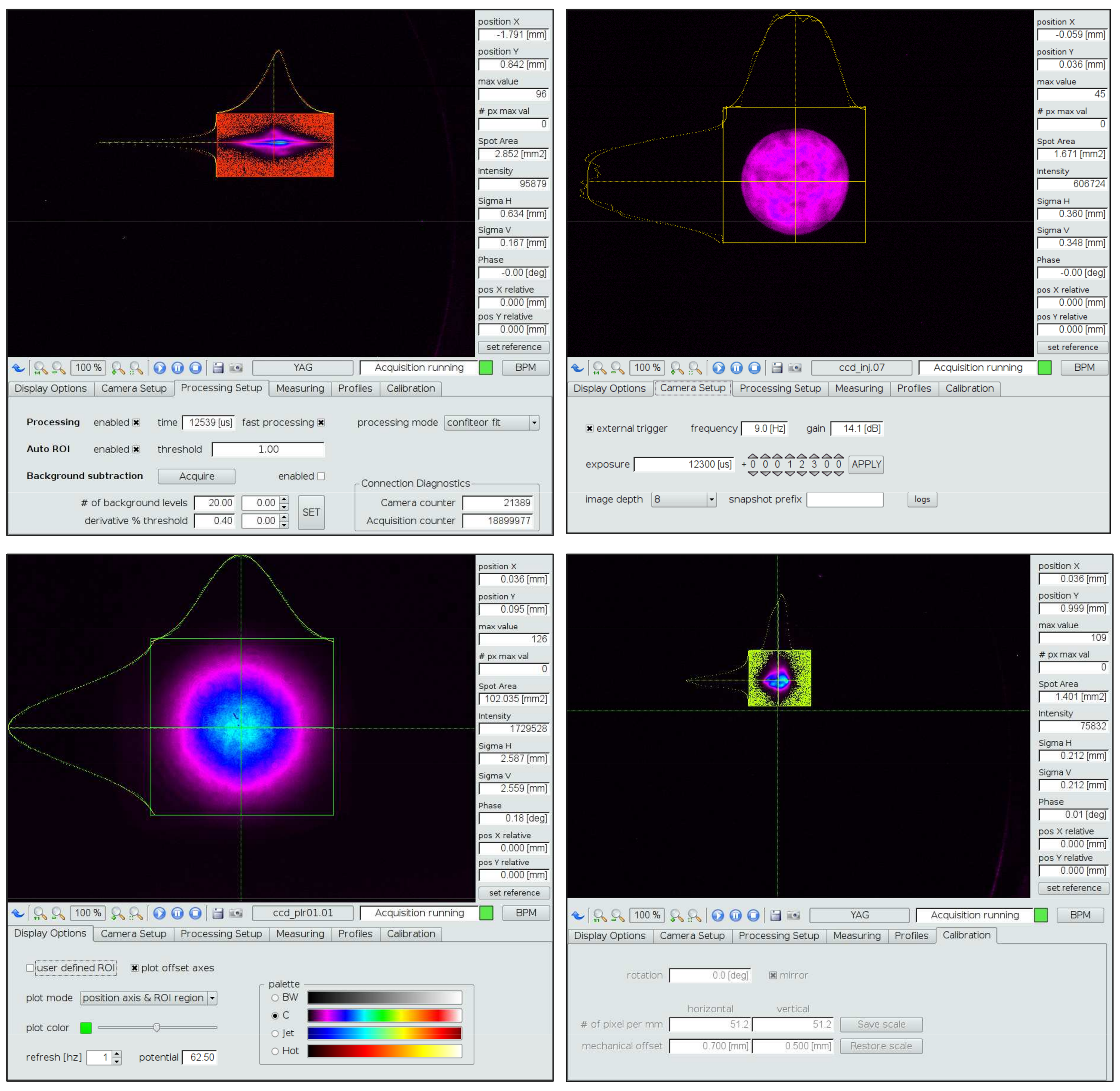
- 16 are dedicated to the diagnostics of the photo-injector and seed lasers; their purpose is the measurement of the laser beam trajectory along the optical path and the characterization of the laser beam profile;
- 52 are integrated in the fluorescent screen system, which allows the analysis of the electron and photon beams along the linac and the FEL undulators;
- 16 are installed in the photon beam transport system and will be used for the measurement of the parameters of the photon beam provided to the experimental stations.

Five server computers will take care of the acquisition of all the CCD cameras.

Each of them consists of a one-unit 19-inch rack mount server configured with two Xeon QuadCore 3.0GHz processors, 4Gb of DDR3 RAM and up to six Gigabit Ethernet links. One of them is connected to the control system network, three are dedicated to the acquisition of the CCDs and one is used for the real-time communication through the Network Reflective Memory (NRM)



Client applications (GUI)



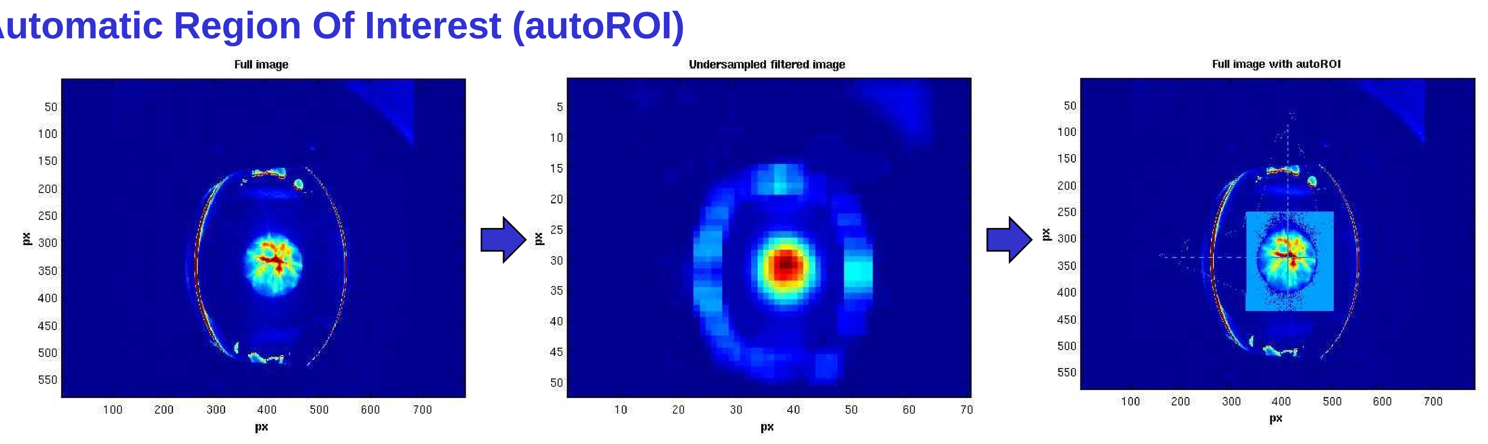
A GUI developed using Q-**Tango** supervises the operation of the CCD camera. The graphical panel allows to deal with the CCD Tango device server API (attributes and commands) and visualizes the beam image at a selectable refresh rate and with the preferred false colour palette. It is possible to magnify the image, save a snapshot (TIFF) and store the image raw data (CSV). Moreover, the panel features a smart interface for the CCD calibration process and for measuring distances in the beam image (pixel and mm).

Image Processing

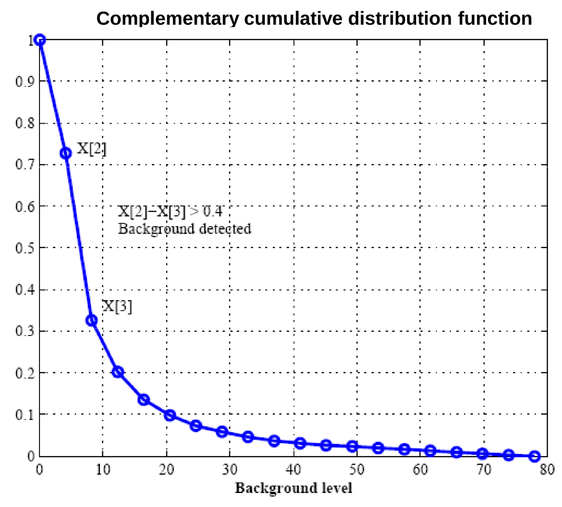
The image processing is divided in three steps:

- **Beam detection inside the image (automatic Region Of Interest)**
- **Beam profile moments estimation (raw calculation + non linear fitting)**
- **Data storage**

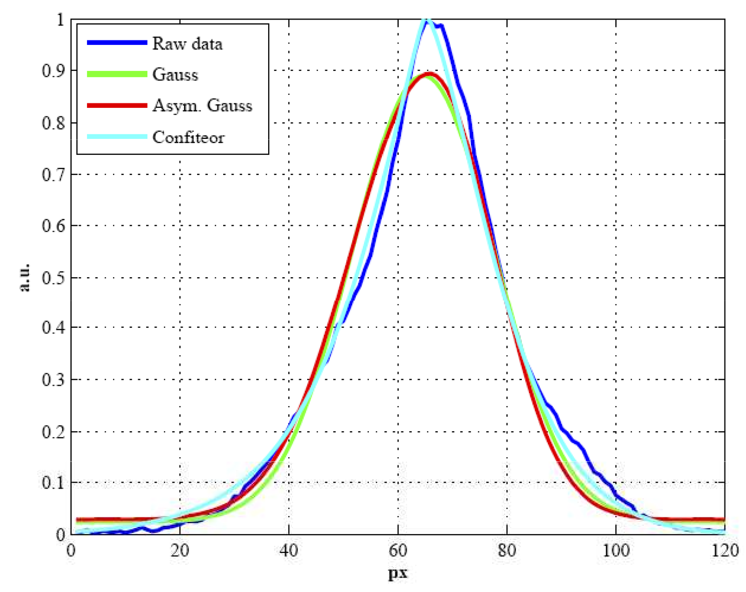
Automatic Region Of Interest (autoROI)



In order to perform the **ROI** detection efficiently, the full scale image is under-sampled. The resulting samples size should be at least twice the minimum size of the beam spot in both planes in order to have at least a few points of the beam in the under-sampled image. If necessary, the image is smoothed by a low pass filter to mitigate the presence of artifacts. A thorough design of the low pass filter parameters can dramatically enhance the magnitude of the beam profile with respect to the noise due to reflections on the vacuum pipe surface. The background level is estimated through the analysis of the complementary cumulative distribution function of P(*X*<=*x*), which represents the probability that a pixel value *X* is lower then *x*.



Beam profile moments estimation



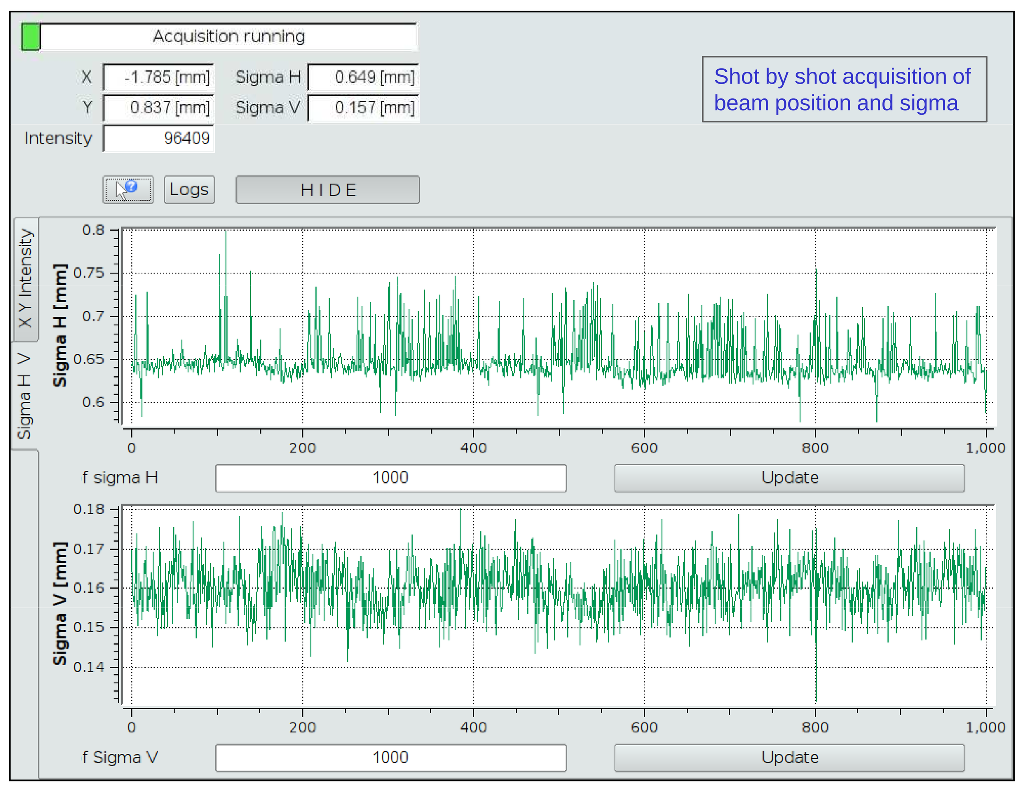
Calculation mode	Process. time	σ_x
Raw	2.4 ms	0.309 mm
Gaussian	4.8 ms	0.255 mm
Asymmetric Gaussian	5.2 ms	0.254 mm
Confiteor	9.6 ms	0.326 mm

In order to estimate the moments of the beam profile, besides the **"raw" algorithm** (average and rms), three possible fitting functions can be used: **gaussian**, **asymmetric gaussian** and **a seven-parameter function** called "Confiteor", of which the gaussian fitting function is a particular case. With the exception of the raw algorithm, the calculation of the fitting function parameters is based on the **GNU Scientific Library** (GSL) non-linear least-squares algorithm..

A software library for the calculation of the jacobian matrix of derivatives needed in the iterative GSL algorithm has been developed. The fitting iterations stop when the predefined fitting error or a time limit is reached. The first and second moments are then analytically calculated.

Data Storage

The proprietary binary libraries provided by the CCD cameras vendor can only be used in the Linux user space domain , therefore it is not possible to acquire and store the CCD data in real-time. Despite this limitation, a thorough tuning of the priorities in the Tango device server and the overruling in the assignment of interrupts and processes to the eight CPU cores, allows anyway the acquisition of the beam image shot-by-shot in a reliable way. .



The beam parameters calculated by the image processing are stored into circular buffers, which support both storing and retrieving operations in kernel and user space. The buffered data can be extracted specifying either the time limits or the bunch numbers. A number of filter methods (**mean**, **median**, **kalman**, etc.) can be used to extract already de-noised data.

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