Overview of DMCS Projects and MicroTCA.4 Developments

DSc Dariusz Makowski, Associate Professor
Lodz University of Technology

CADAQ
CONTROL AND DATA ACQUISITION LABORATORY

DMCS

Plasma Diagnostics

Diagnostic Systems provide data for:

- **Plasma Diagnostics, physics study (non-real-time)**
  - Physical studies, observation, measurements
  - Archiving measurements, raw data – **could be challenging (transferring and archiving ~TBs of data)**
    - Stored data: raw data, pre-processed, calibrated, measurements, meta-data (labels, tags)
    - Important for ML and AI
- **Machine and Plasma Control (real-time, soft real-time)**
  - Diagnostic systems supply information for Plasma Control System
  - Primary and supplementary systems
  - **Latency from 10 - 100 ms**
- **Machine Protection (hard real-time)**
  - Trigger interlocks to protect machine against damage
  - **Latency from 100 - 1000 ms**

Dariusz Makowski (dmakow@dmcs.pl)

ITER Plasma Diagnostics

- **Imaging Diagnostics**
  - **Divertor IR Thermography (IRTh)**
    - Camera Link and 10GigE Vision
  - **Boundary Imaging System (BIS)**
    - CoaXPress
  - **Upper Wide Angle Viewing System (UWAVS)**
    - 10GigE Vision
  - **H-Alpha and Visible Spectroscopy Diagnostic**
    - Camera Link High Speed
- **Spectroscopic Diagnostics**
  - **Hard X-Ray Monitor (HXRM)**
  - Radial Gamma Ray Spectrometer (RGRS)
  - High Resolution Neutron Spectrometer (HRNS)
- **And a few more systems, but no time today…**

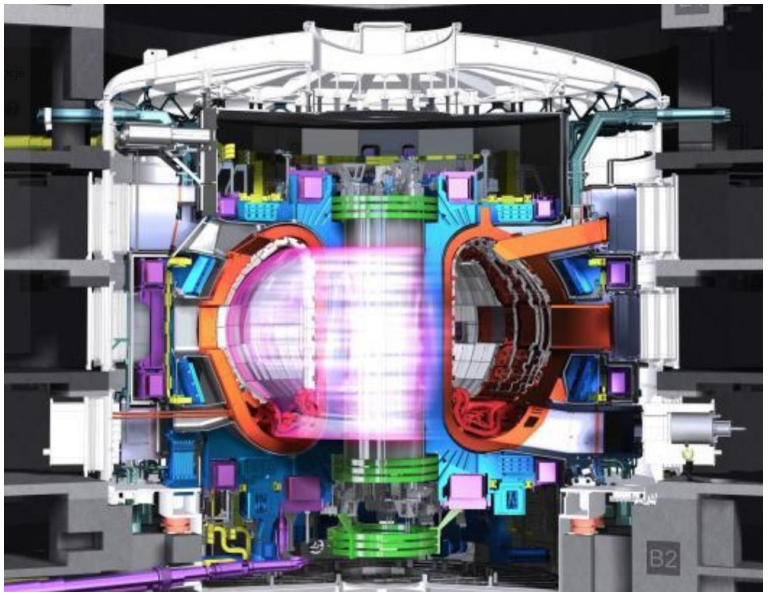
Dariusz Makowski (dmakow@dmcs.pl)

Fusion Projects - Plasma Diagnostics

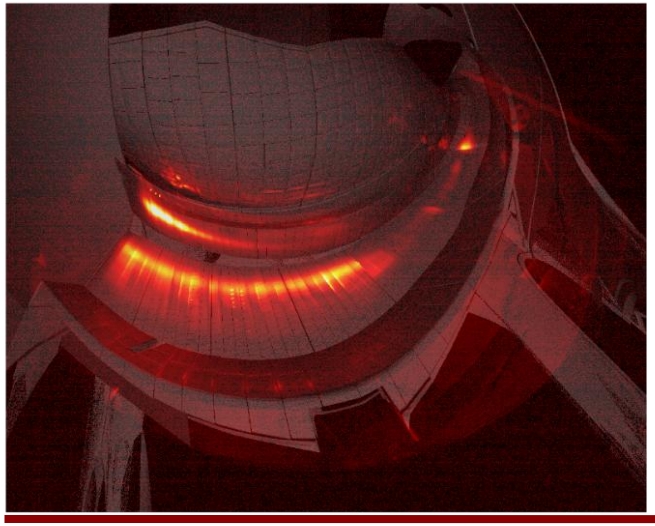
Imaging diagnostics:

- **W7-X:**
  17 VIS and 13 IR cameras (OP2.1-OP2.5)
- **ITER:**
  more than 200 VIS and IR cameras

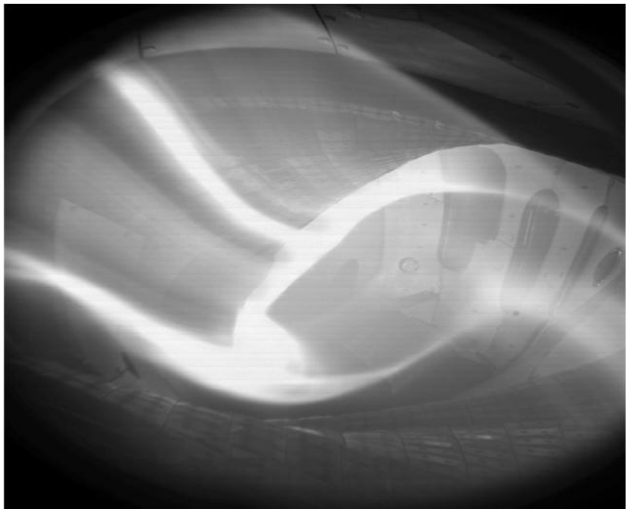
ITER Tokamak



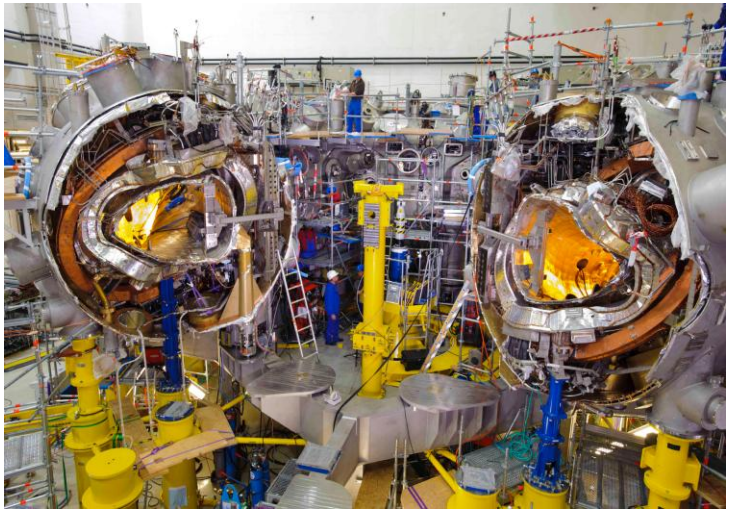
IR Diagnostics



VIS Diagnostics



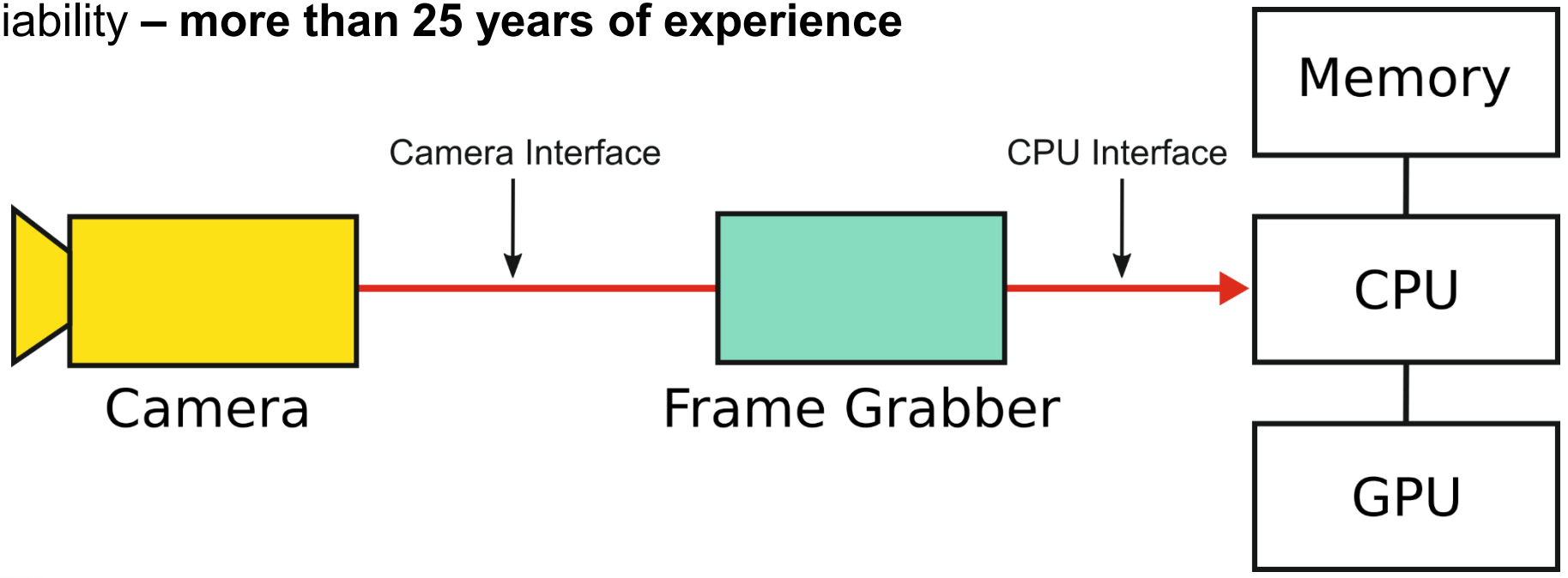
Wendelstein 7-X Stellarator



Dariusz Makowski (dmakow@dmcs.pl)

Imaging Diagnostics – Image Acquisition and Processing (1)

- A single camera provides **one or more streams** of images
- **Frame grabber** configures camera, start and stop DAQ
- **All operations must work in real-time (hard real-time system)**
- **Developed reliable, scalable and standardized solution (hardware/software)** suitable for **AI and ML real-time** applications
- Methodology to build complex and scalable imaging systems with improved reliability **– more than 25 years of experience**



Dariusz Makowski (dmakow@dmcs.pl)

Image Acquisition and Processing with MicroTCA.4 (2)



6-128 Gbps

Frame Grabber

32-128 Gbps

MTCA.4 12-slot Chassis

PCIe gen. 4
4-5x 64 Gbps (320 Gbps)

High Performance CPUs with GPUs

Timing module

Artificial Intelligence
DNN, CNN

Dariusz Makowski (dmakow@dmcs.pl)

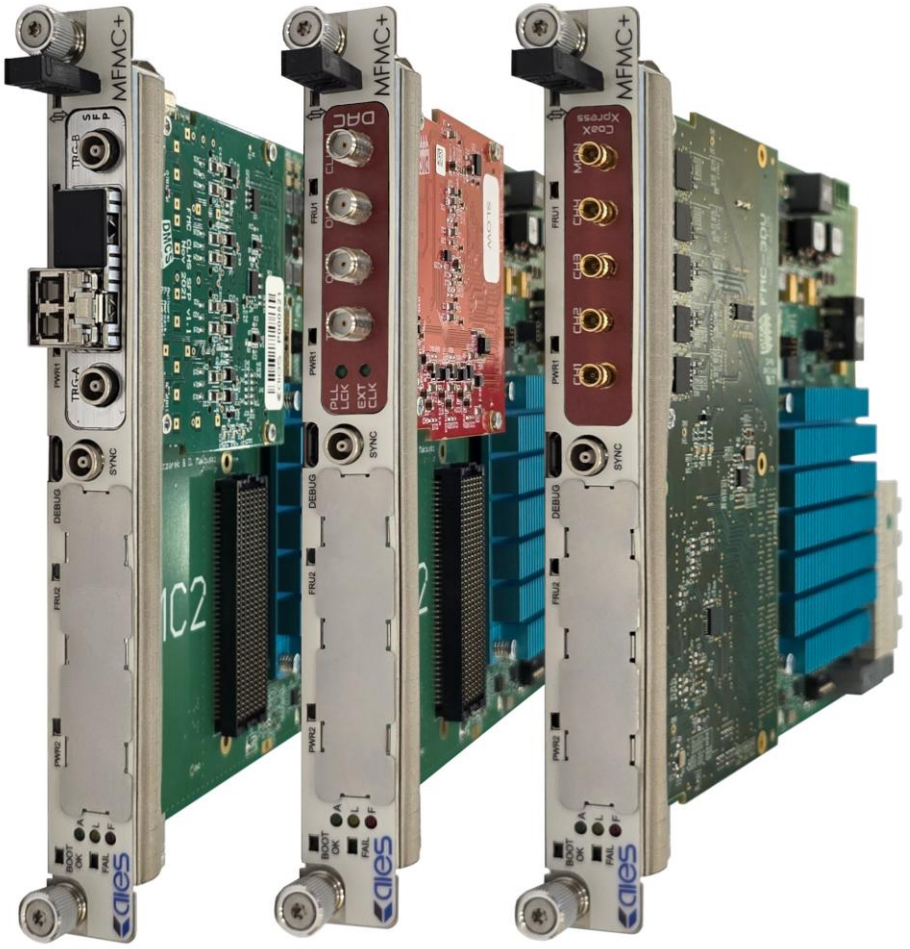
Universal Frame Grabber Module for MicroTCA.4

Frame grabber is composed of:

- **FMC carrier** (FPGA, DDR, PCIe, trigger, etc.)
- **FMC modules** supporting various camera interfaces (8 standards)

In addition, we need (**software**):

- **FPGA firmware**
  - **IP core** for selected camera interface
  - **Xilinx (IP Cores, Vivado)**
- **Linux driver**
  - Dedicated camera library
- **Image processing framework**
- **Additional tools**
  - Visualisation application



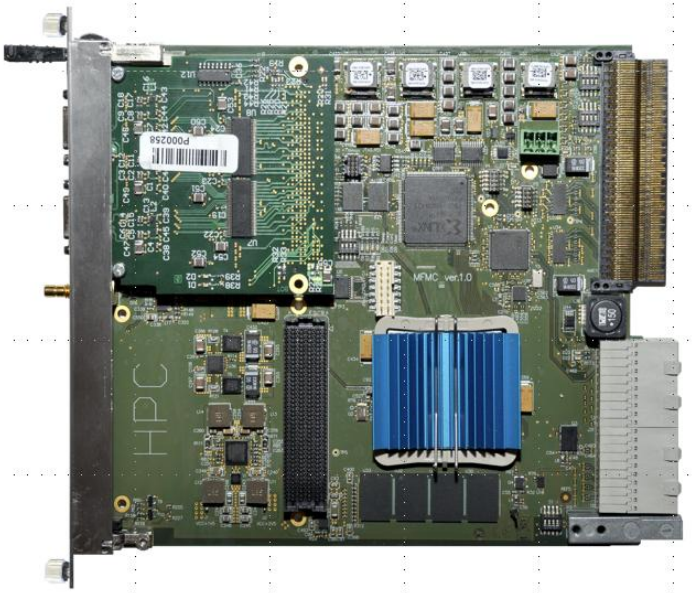
Carrier module + Mezzanine module

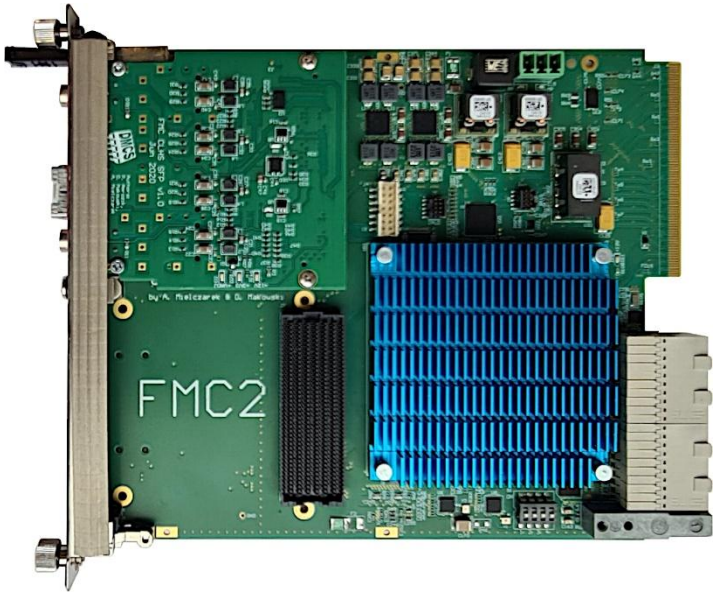
Dariusz Makowski (dmakow@dmcs.pl)

FMC Carrier Modules

Frame grabber is composed of:

- FMC carrier
  - Artix 7 FPGA (<6.5 Gb/s)
  - **Kintex US+ (>6.5 Gbps, 32 Gb/s per lane)**
- Mezzanine modules (FMCs) supporting various camera interfaces (8 standards)
  - **Galvanically isolated IO module**





Software support:

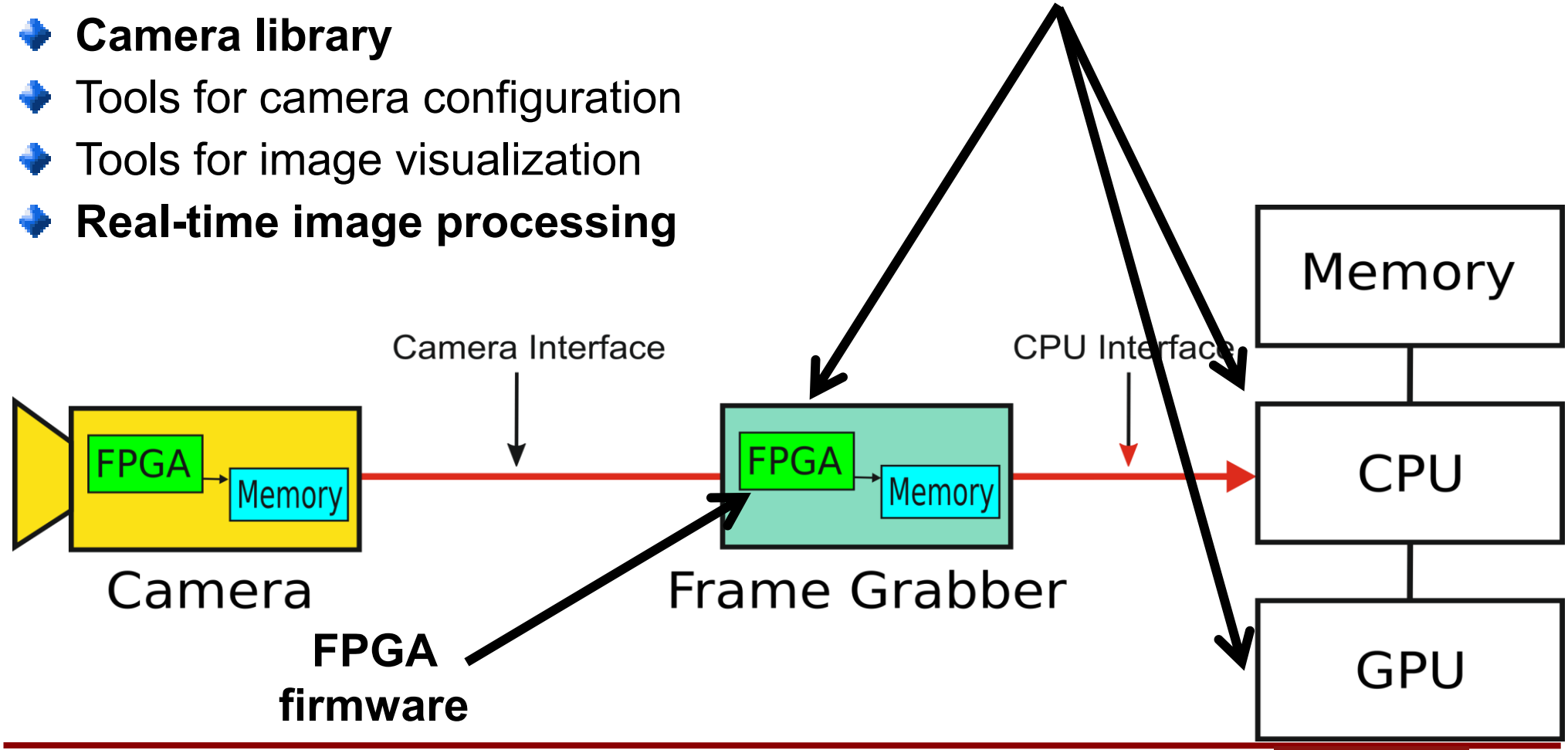
- **IP cores** for selected **camera interfaces**
- Common Linux driver
- **Dedicated camera library (GenICam)**
- Real-time processing software
- **Algorithms (FPGA, CPU, GPU)**

Dariusz Makowski (dmakow@dmcs.pl)

Universal Frame Grabber Module - Software

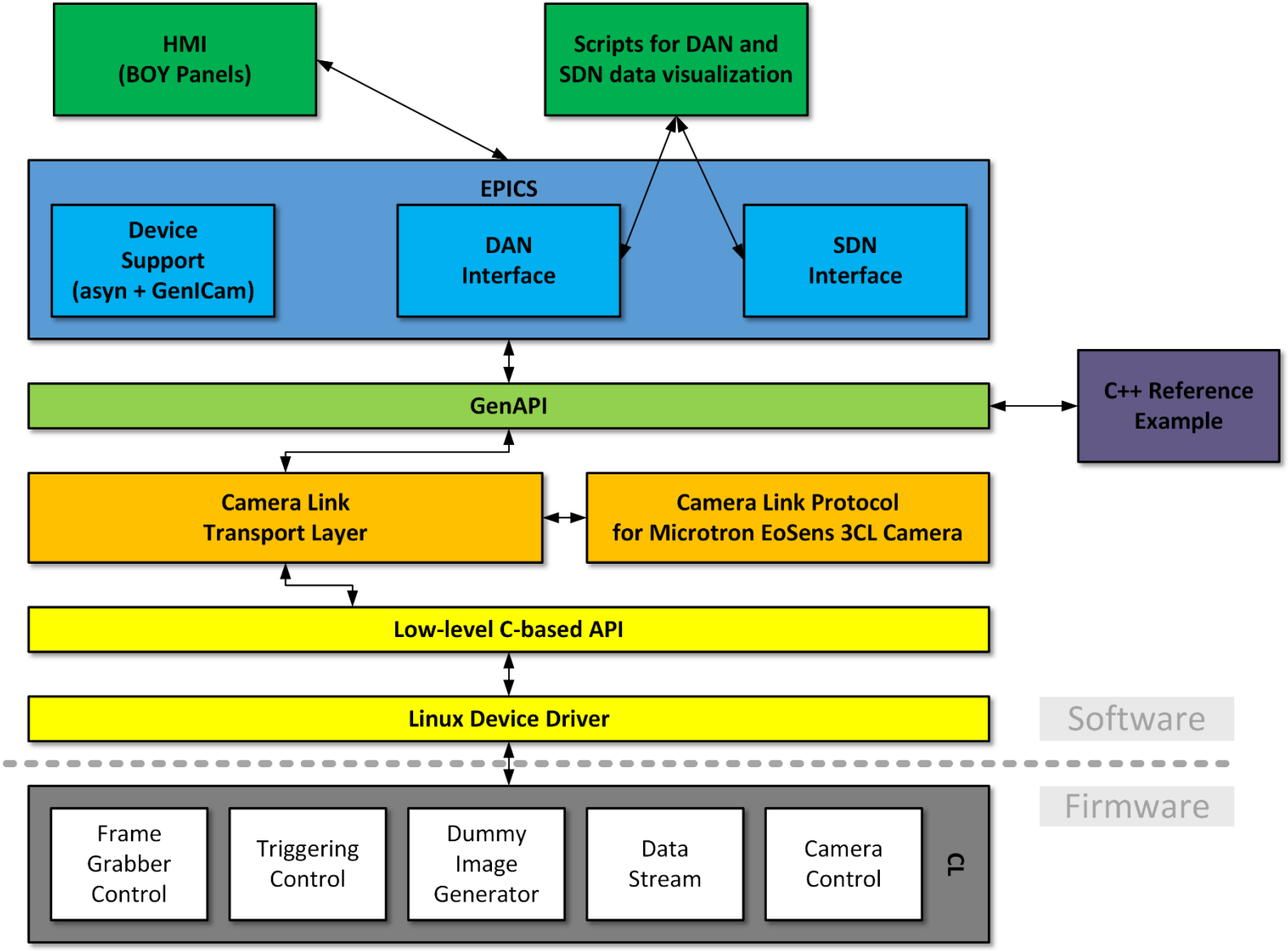
- **FPGA firmware**
- Linux driver
- **Frame grabber library**
- **Camera library**
- Tools for camera configuration
- Tools for image visualization
- **Real-time image processing**

Hardware we have now
Software is actually the main part of work
Working on an **universal IA and IP framework**



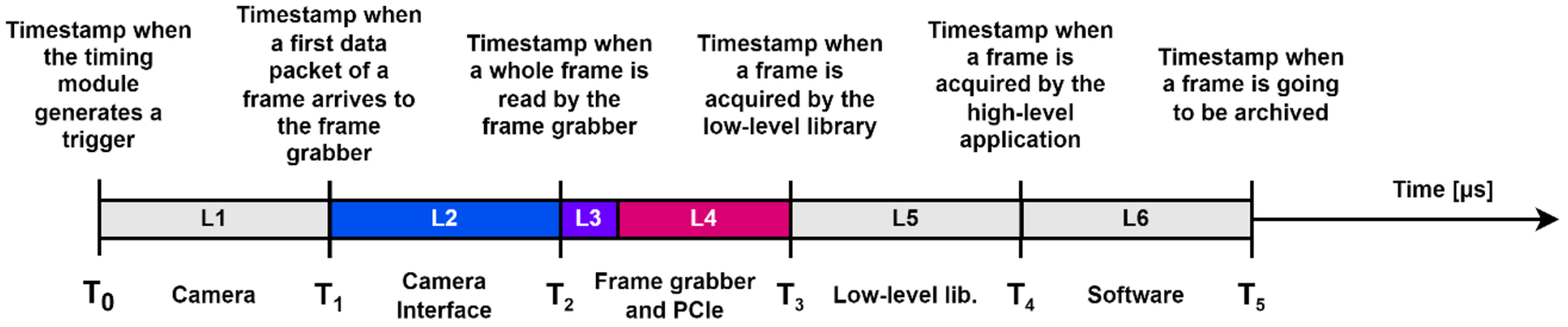
Dariusz Makowski (dmakow@dmcs.pl)

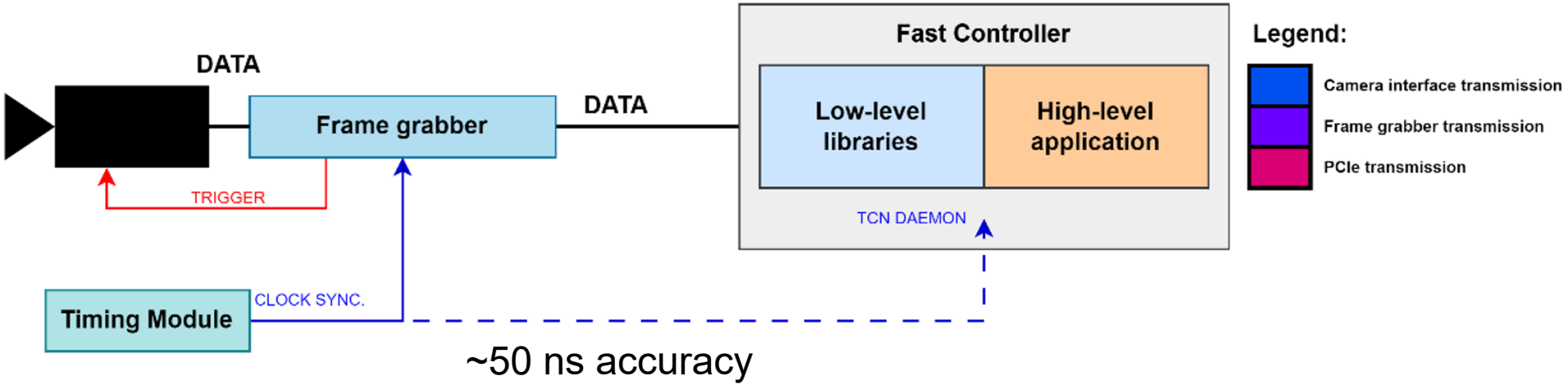
Image Acquisition Software Framework Based on GenICam



Dariusz Makowski (dmakow@dmcs.pl)

Imaging Diagnostics – Latency Measurements





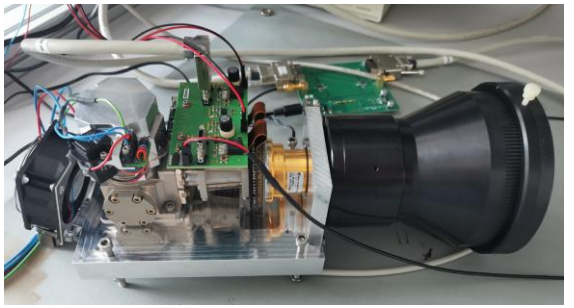
~50 ns accuracy

Dariusz Makowski (dmakow@dmcs.pl)

Frame Grabbers and Supported Interfaces

Low Performance

- **Camera Link** (basic, medium, full, single, dual)
- 1 GigE Vision
- **CoaXPress 1.1** (CXP-1…CXP-6)
- Fire Wire (S800, S1600, S3200)
- Serial Digital Interface (3G-SDI, 6G-SDI)
- HDMI (both input and output)
- Digital low-latency IO module (various variants)



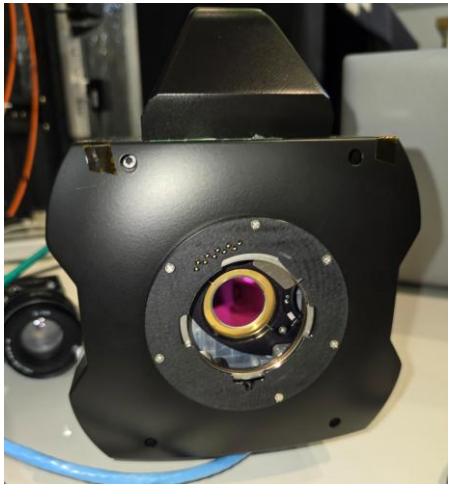
High Performance

- **Camera Link High Speed**
- **10/25 GigE Vision**
- **CoaXPress 2.0 (CXP-10, CXP-12)**
- Serial Digital Interface (12G-SDI, 24G-SDI)
- Digital low-latency IO module (various variants)

Dariusz Makowski (dmakow@dmcs.pl)

55.G6 - Divertor IR Thermography

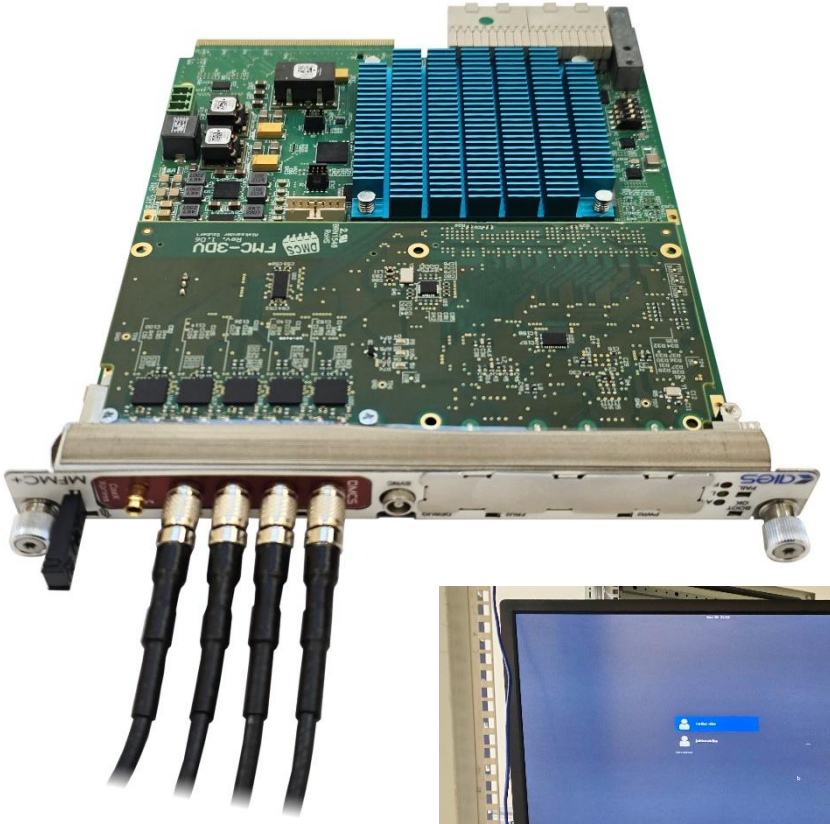
- **Surface temperatures** and **power loads** on divertor and baffles
- Temperature: **200°C - 3600°C**
- Time resolution: **from 35 µs** to 2 ms
- Wavelength range: 1.5 µm - 4.5 µm
- **FLIR camera with 10 GigE interface**
- **Alignment camera with Camera Link**
- Resolution: 640 × 512 px



Dariusz Makowski (dmakow@dmcs.pl)

55.GE - Boundary Imaging System

- **Detects ELMs (20 µs) and LH D-Alpha step**
- **Camera**
  - Mind Vision MV-PXL164BM
  - Resolution: 16384 x 4 @ 56 kHz
  - **Tested with CXP6-4**
- **Frame Grabber**
  - High-performance carrier
  - Supports CoaXPress 2.0
  - CXP12-4 - up to 4 lanes (4x 12.5 Gbps, total 50 Gbps)
  - PCIe 8-lanes, gen. 3
  - External trigger output
  - **GenICam interface**



Dariusz Makowski (dmakow@dmcs.pl)

55.GA - Upper Wide Angle Viewing System

Frame Grabber

- High-performance carrier, 10 GigE
- PCIe 8-lanes, gen. 3
- External trigger output
- GenICam interface
- **Frame grabber latency: 130.01 us**, std: dev. 39.31 us for 4096x3068 resol.

Baumer VQXT-120M.HS

Emergent HR-12000M

Camera

VIS:

- Emergent: 4096x3068
  Baumer: 4096x3068

IR: not yet selected

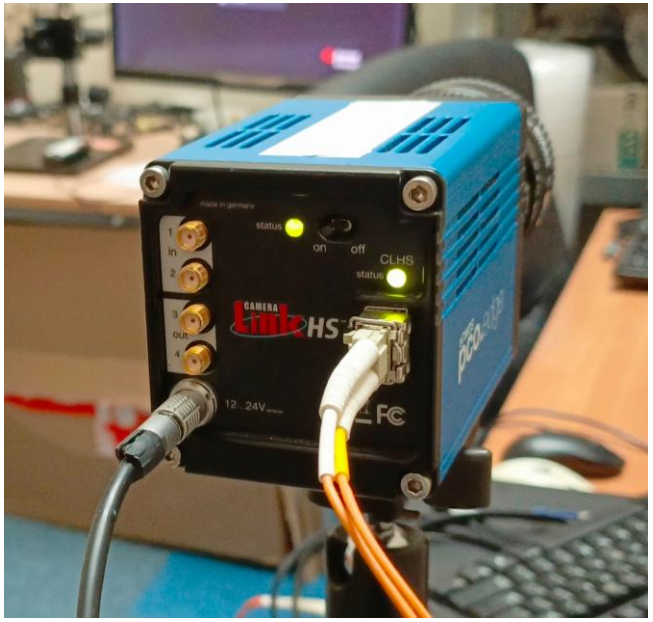
Dariusz Makowski (dmakow@dmcs.pl)

Upper Wide Angle Viewing System (2)

Dariusz Makowski (dmakow@dmcs.pl)

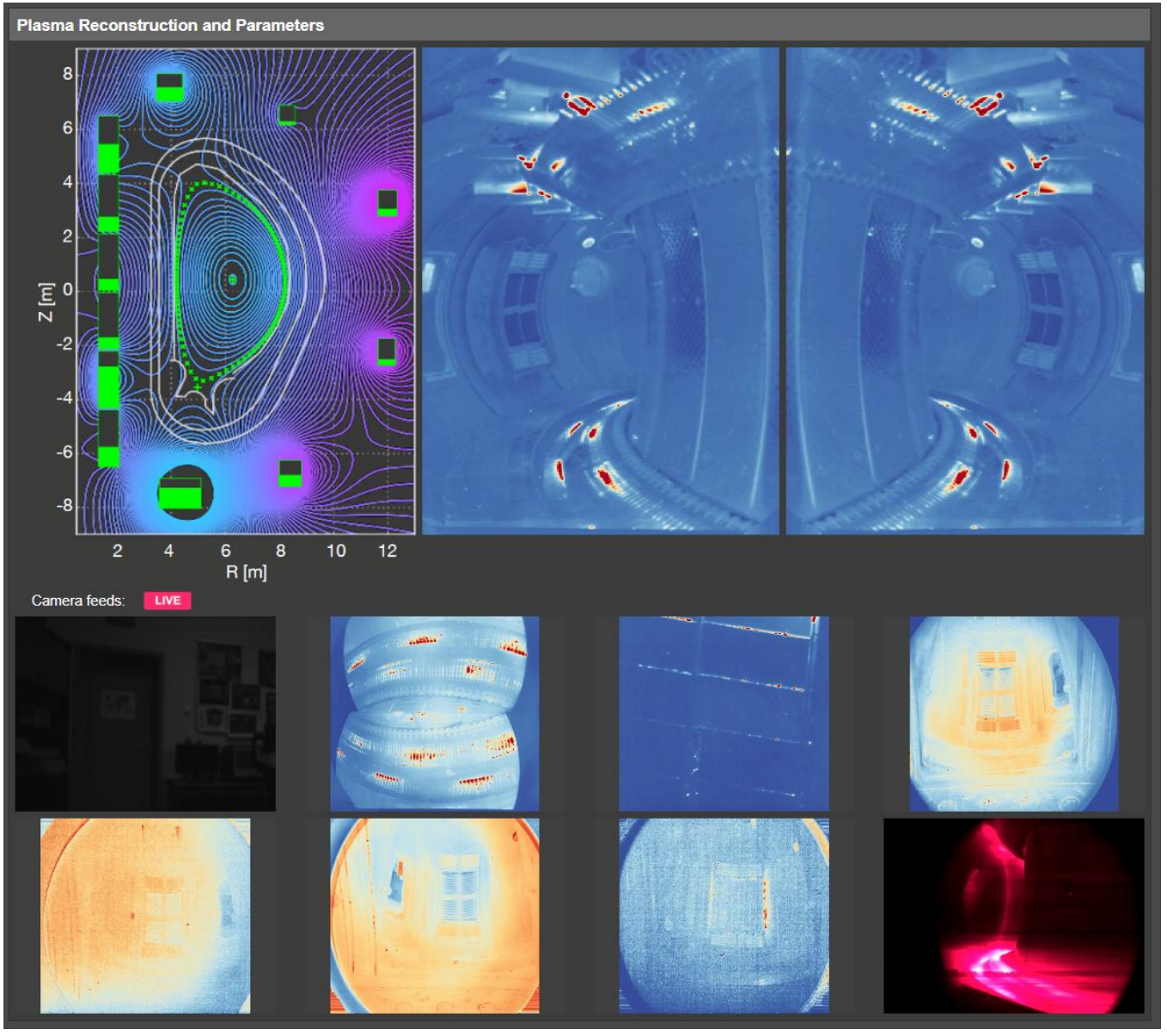
55.E2 - H-Alpha and Visible Spectroscopy Diagnostic

- **Camera**
  - PCO Edge 5.5
  - Resolution: 2560x2160 @ 100 fps
  - **Exposed to neutrons and gamma radiation**
- **Frame Grabber**
  - Supports Camera Link HS
  - High performance frame grabber
  - External trigger output
  - **GenICam interface**



Dariusz Makowski (dmakow@dmcs.pl)

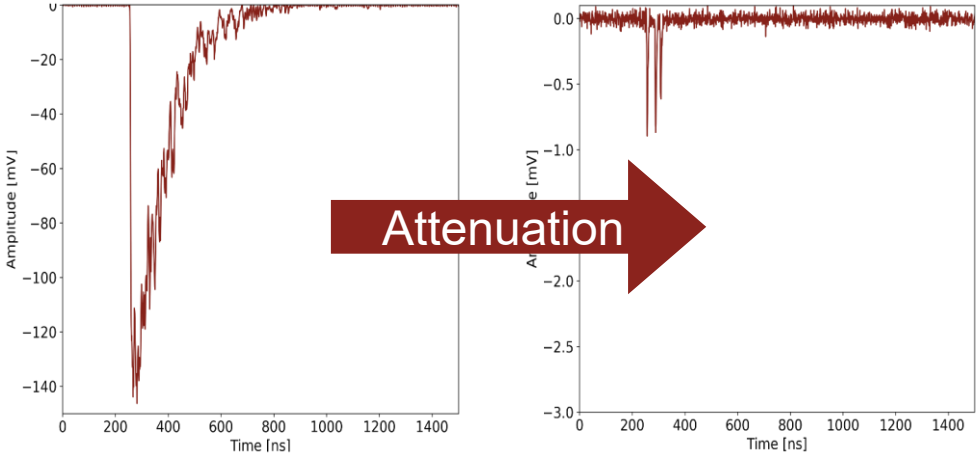
Framework for Images Visualisation on Large Scale Display



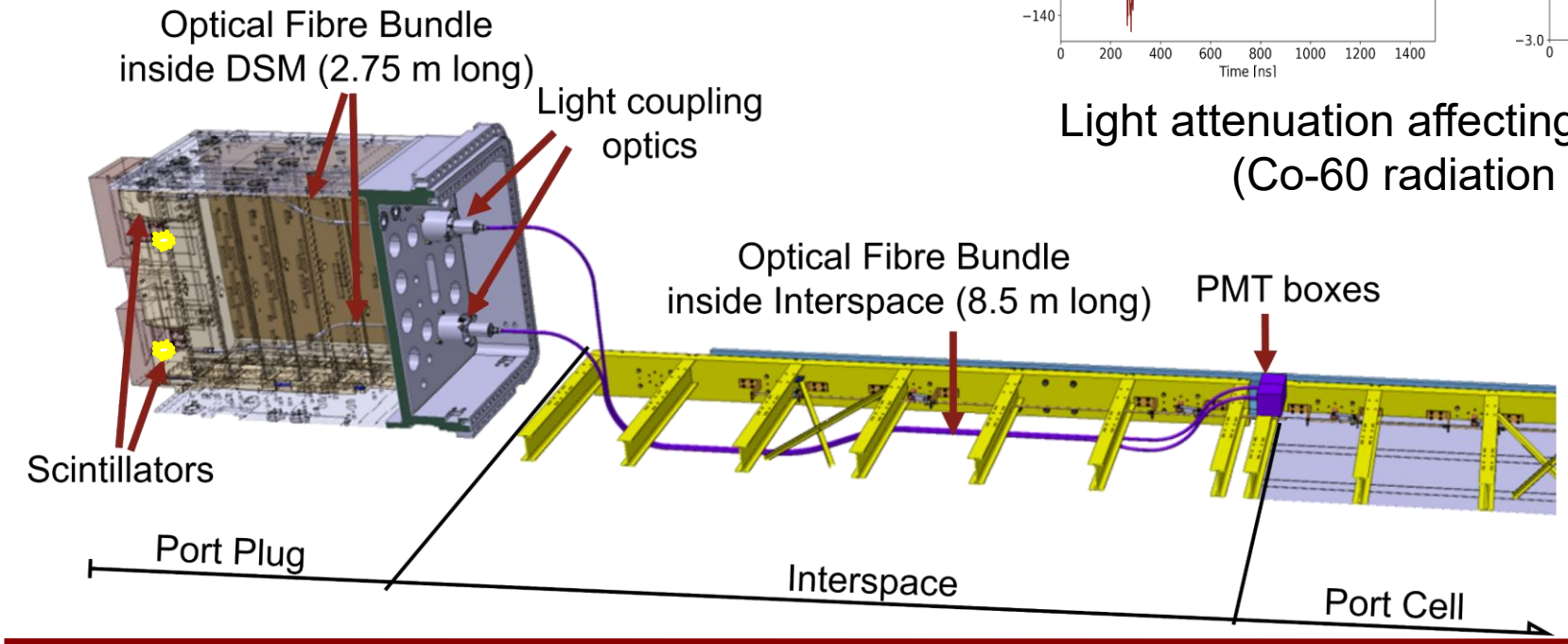
Dariusz Makowski (dmakow@dmcs.pl)

Hard X-Ray Monitor

- Run-away Electrons measurements
  - Measures X-ray radiation (5 - 20 MeV)
  - PMT with scintillator
  - Connected using ~11 m long fibre bundle
  - Uses 1 GS/s ADQ14 digitiser



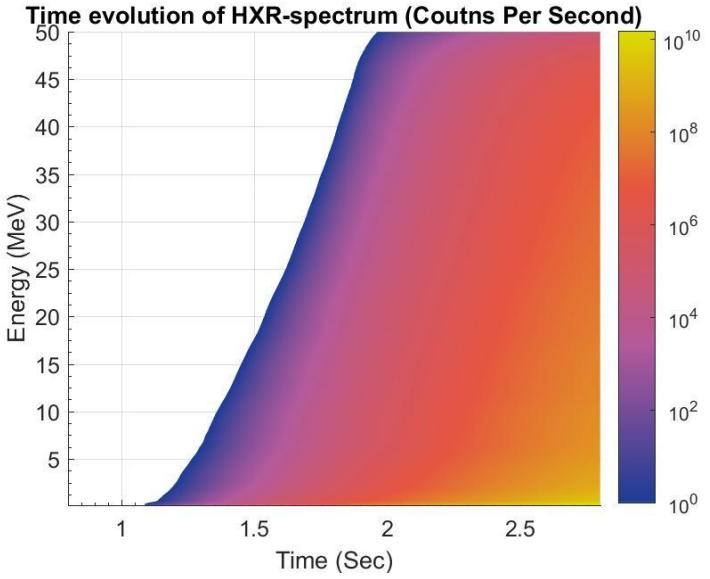
Light attenuation affecting the PMT signal (Co-60 radiation source)



Dariusz Makowski (dmakow@dmcs.pl)

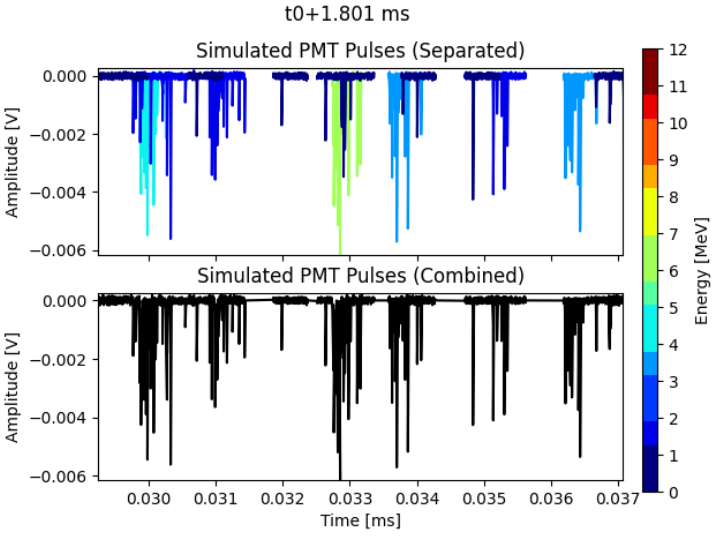
Hard X-Ray Monitor

- Run-away Electrons measurements
  - PMT pulses have a different shape
  - Current algorithms for PMT pulses discrimination do not work
  - **ITER data not available – results need to simulated**



Input ITER First Plasma Scenario

PMT simulations

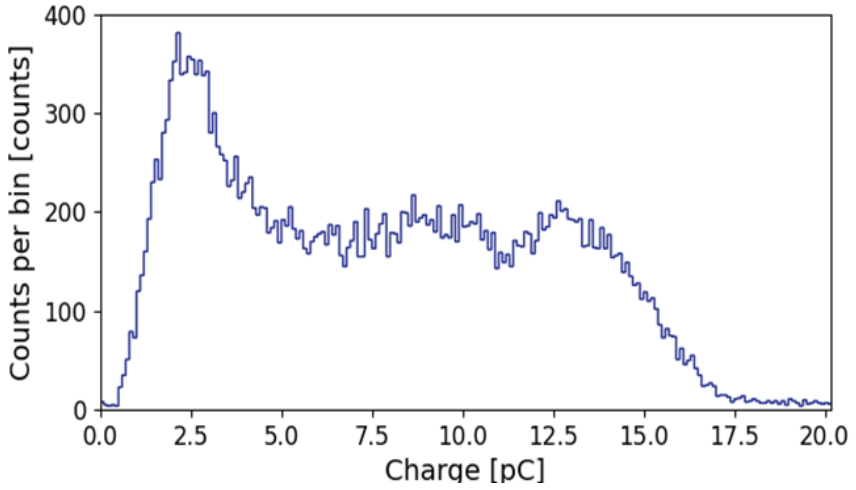


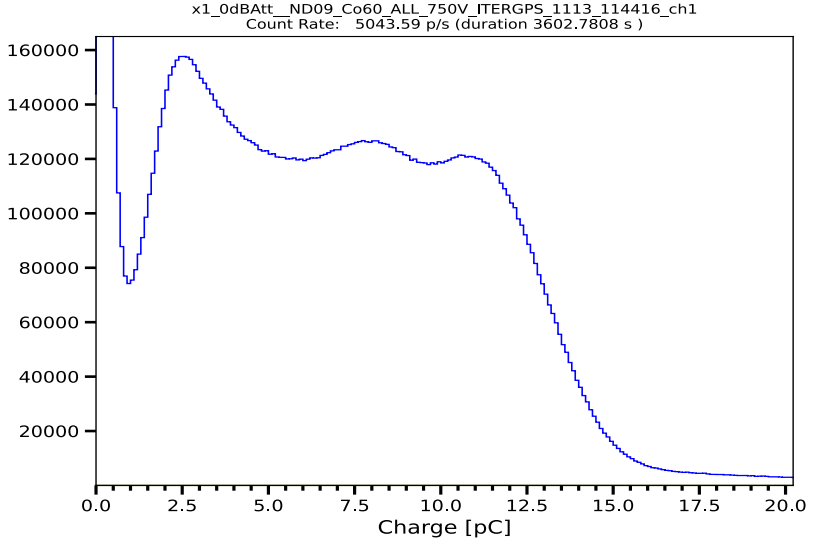
PMT measurements

Dariusz Makowski (dmakow@dmcs.pl)

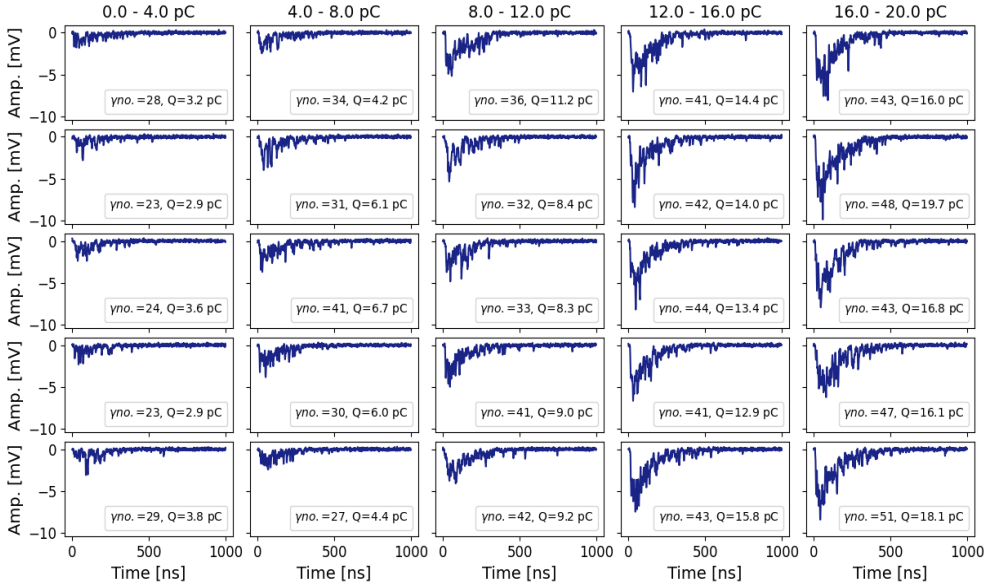
Simulation results for 2.26% Optical Transmission Efiiciency

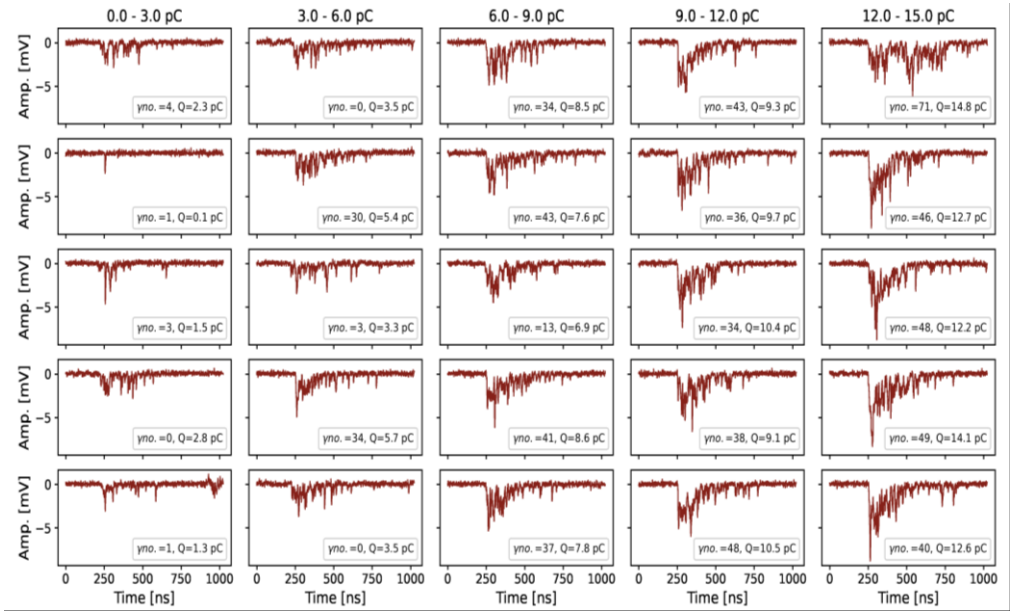
Simulations





Experiments





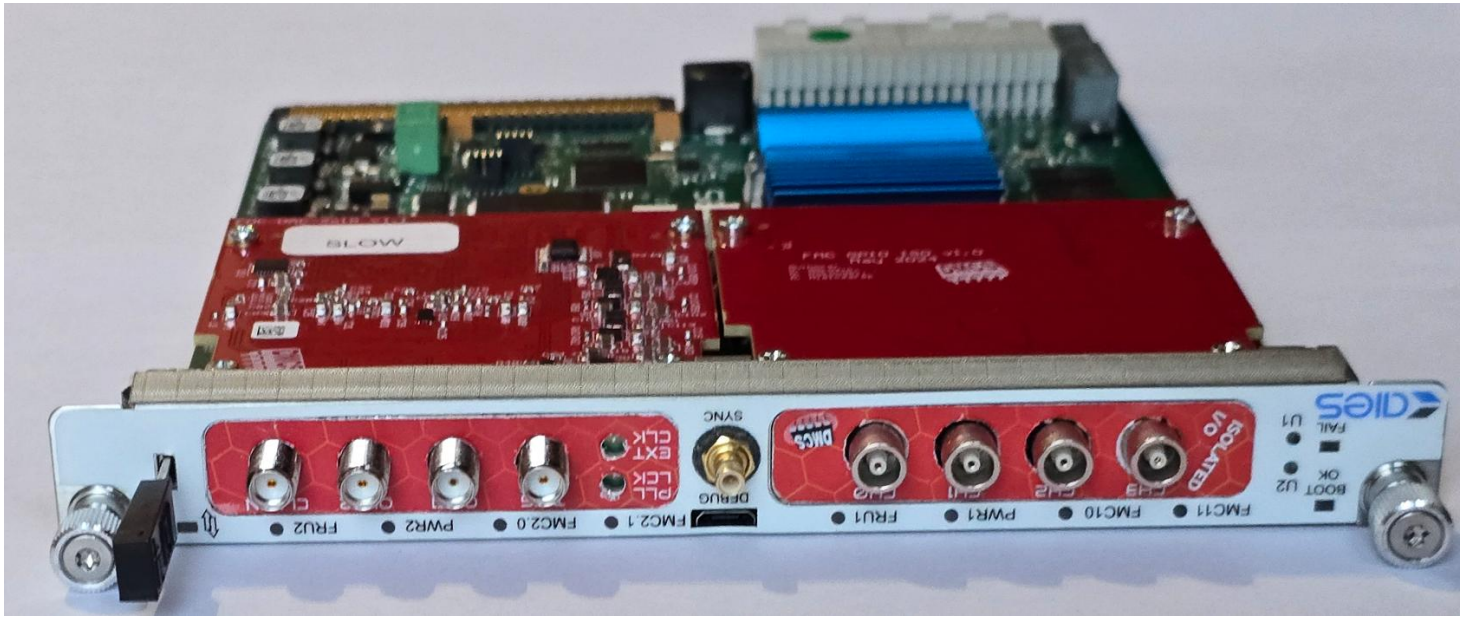
Dariusz Makowski (***dmakow@dmcs.pl***)

CADAQ CONTROL AND DATA ACQUISITION LABORATORY

DMCS

Arbitrary Waveform Generator dedicated for MTCA.4

- Provides emulated signal for HXRM system for algorithms development, testing and performance evaluation
- **Two variants: 500 MS/s and 1 GS/s, 2 or 4 channels, 16-bit**
- Output voltage: ±5 V (Z=50 R)
- Uses low- or high-performance carrier (16 GB of DDR)
- Fully synchronised with digitiser and ITER timing (PTP1588)
- Provides samples from DDR memory or CPU



Dariusz Makowski (dmakow@dmcs.pl)

Summary

- Processing of images from VIS or IR cameras for fusion requires a **flexible and scalable hardware platform**
- Developed and evaluated **low latency solutions** for Mega Pixel cameras
- **FPGA and GPU** could be used for executing AI-based algorithms
- Developed **frame grabbers supporting various camera interfaces**
- Developed universal **software framework based on GenICam**
- Developed a dedicated solution based on **NVIDIA GPUDirect RDMA** solution that significantly reduces the total image processing latency and releases the CPU
- Working on real-time AI algorithms and design methodology

Looking for imaging solution – contact with us ☺

Dariusz Makowski (dmakow@dmcs.pl)

Thank you for your attention

Dariusz Makowski (dmakow@dmcs.pl)