EDICAM: A multi-timescale real-time processing CMOS camera for fusion applications

The EDICAM concept

Application in fusion research

- Wendelstein 7-X (Germany)
- JT-60SA (Japan)

Future plans

- Camera development
- With ITER in mind

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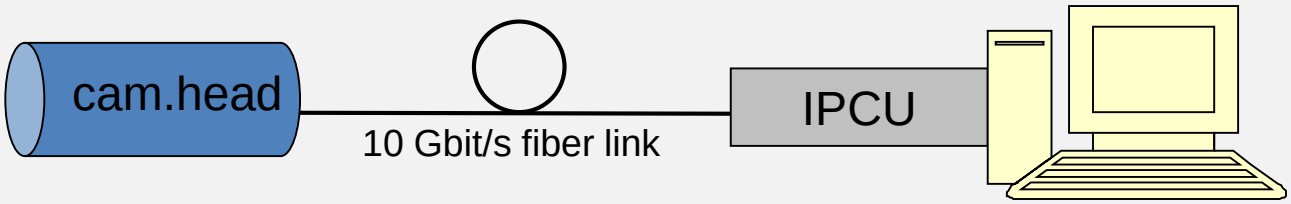
The EDICAM concept

Event Detection Intelligent CAMera – Developed by Wigner RCP

- 12 bit CMOS sensor
- modular: camera head + intelligent control unit (IPCU)



Camera head

→ small: Ø 6 cm × 20 cm

→ minimal electronics

→ works in magnetic field (3 T)

→ produce image frames (individually requested)

→ transfer frames to IPCU

IPCU (Image Processing and Control Unit)

→ commercial FPGA board

→ uses PCIe (8x)

→ frame request generation

→ real-time image processing (event detection)

→ automatic actions (←events)

PC

→ user GUI

→ data storage

→ high level data processing

→ …

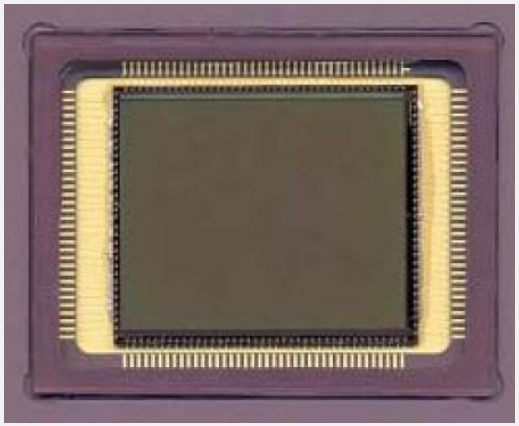
The EDICAM concept

Main features

Lupa-1300 CMOS sensor (2006, Cypress Semiconductor)

- resolution: 1280x1024 (1.3 Mpixel), 12-bit monochrome
- max. frame rate: 400 fps (full frame); 50,000 fps (64x56)
- extremely flexible ROI (region-of-interest) definition

  → size and position can be chosen in (32,1) pixel steps
- **non-destructive readout** → exposure and readout cycles can be decoupled



The EDICAM concept

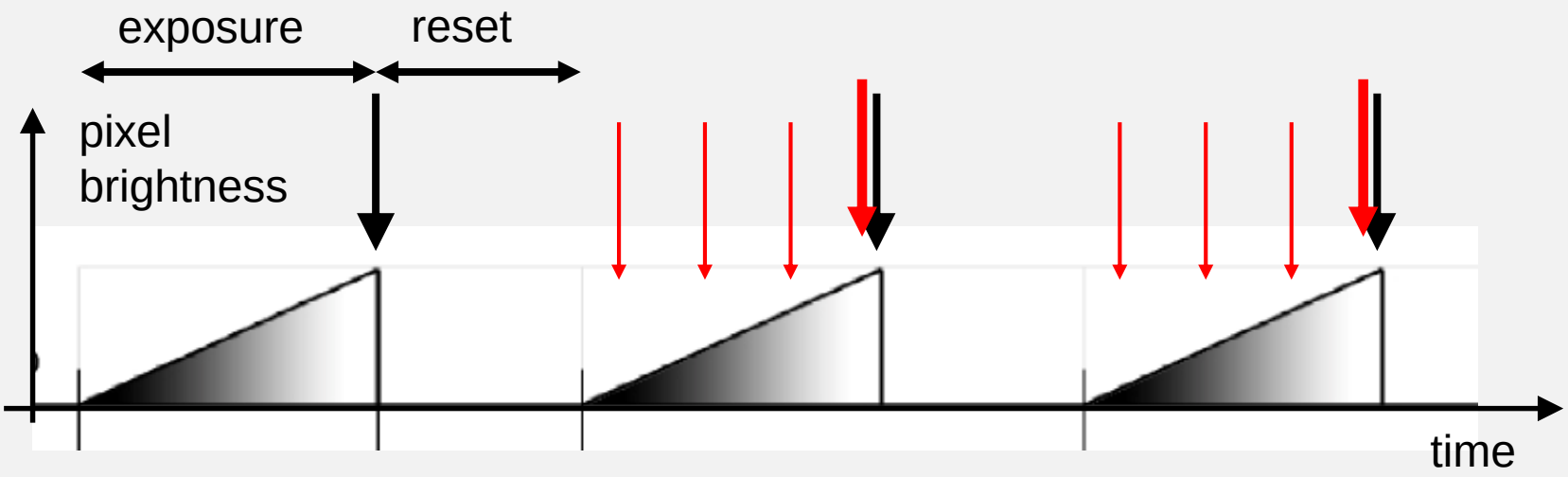
Non-destructive readout (NDR)

- „extend” the standard camera operation concept

- read frames without destroying image content

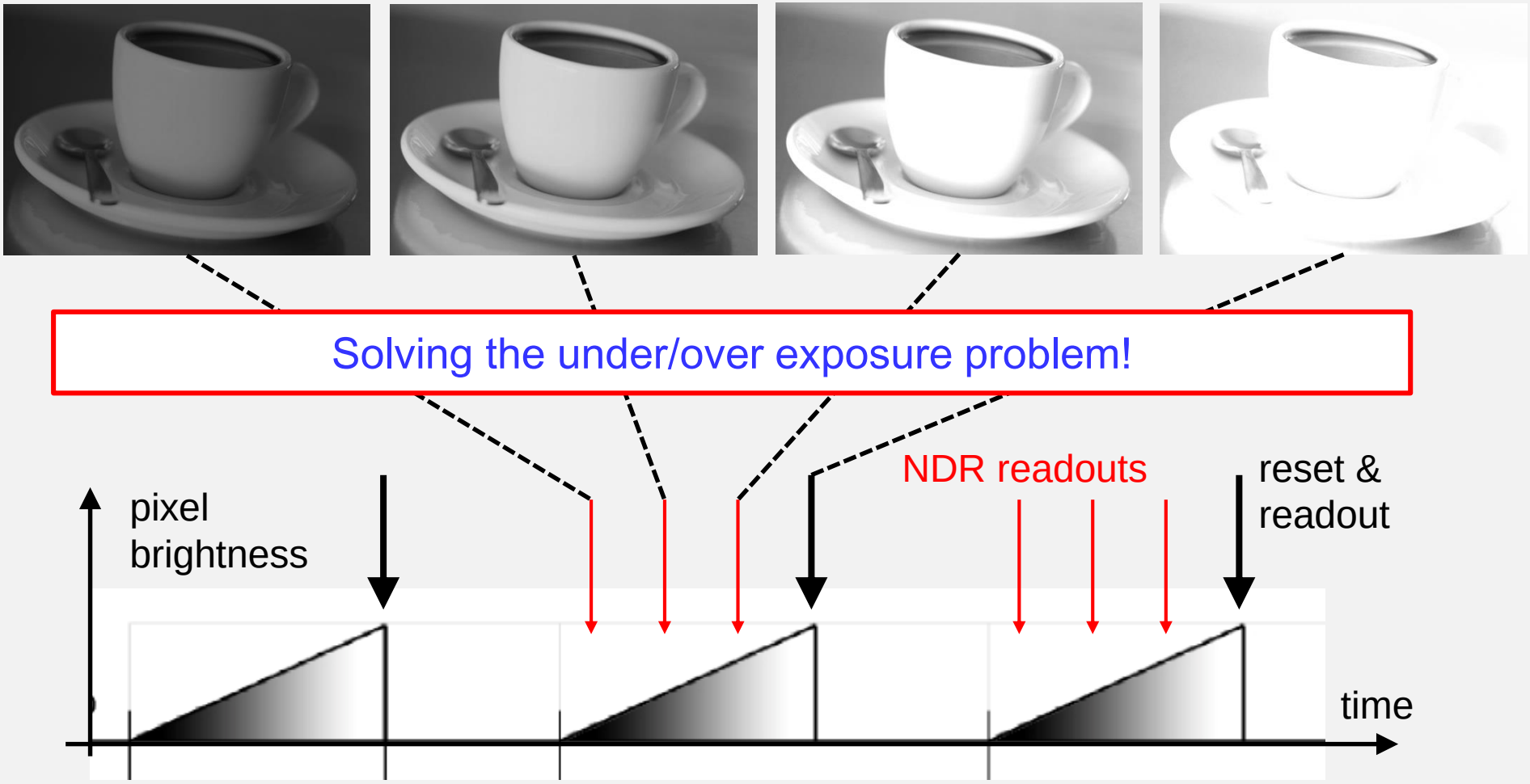
  → needs special hardware: extra Ts for each pixel (this sensor is 7T design)

  → usually also reduces fill factor…



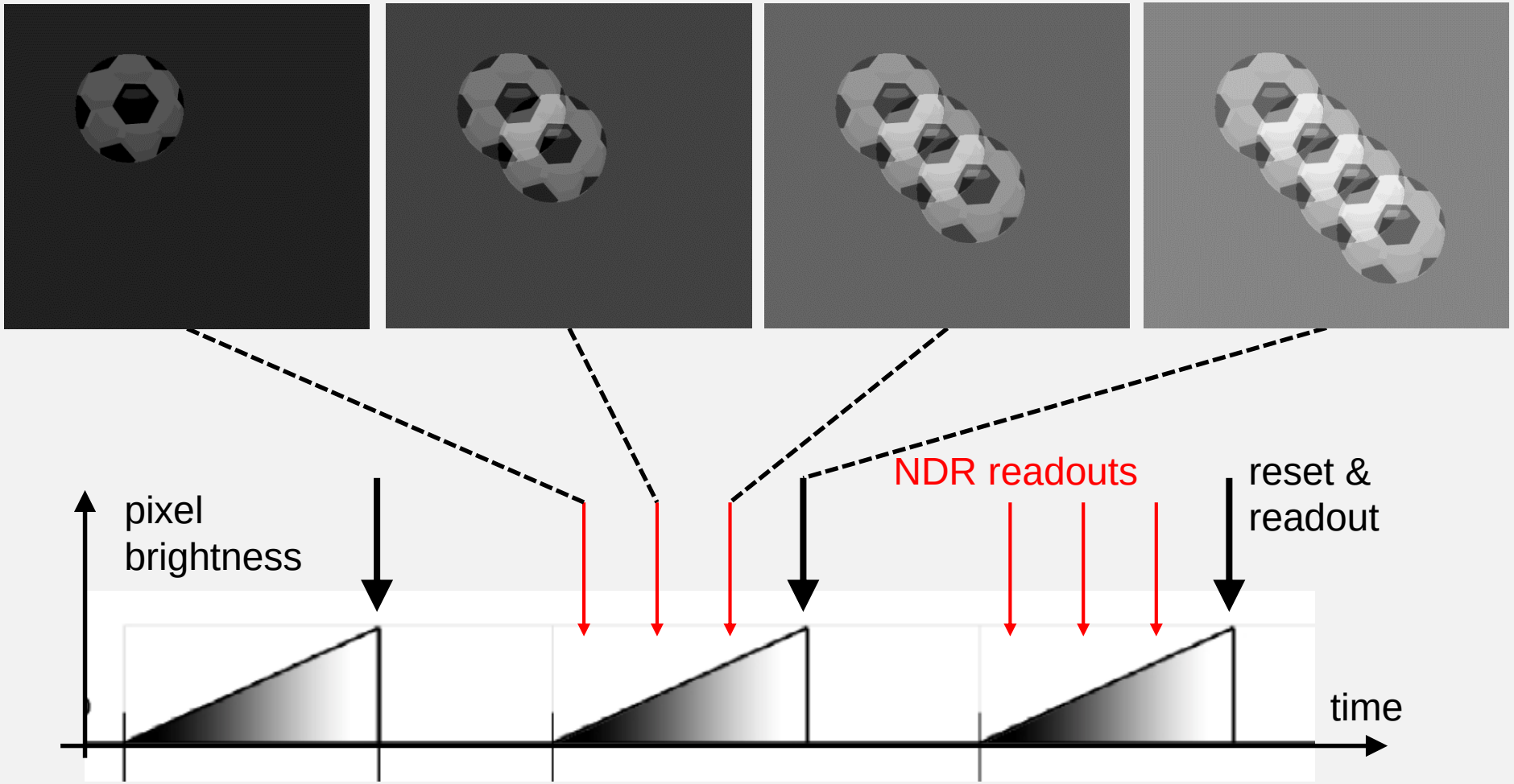
The EDICAM concept

Stationary objects:



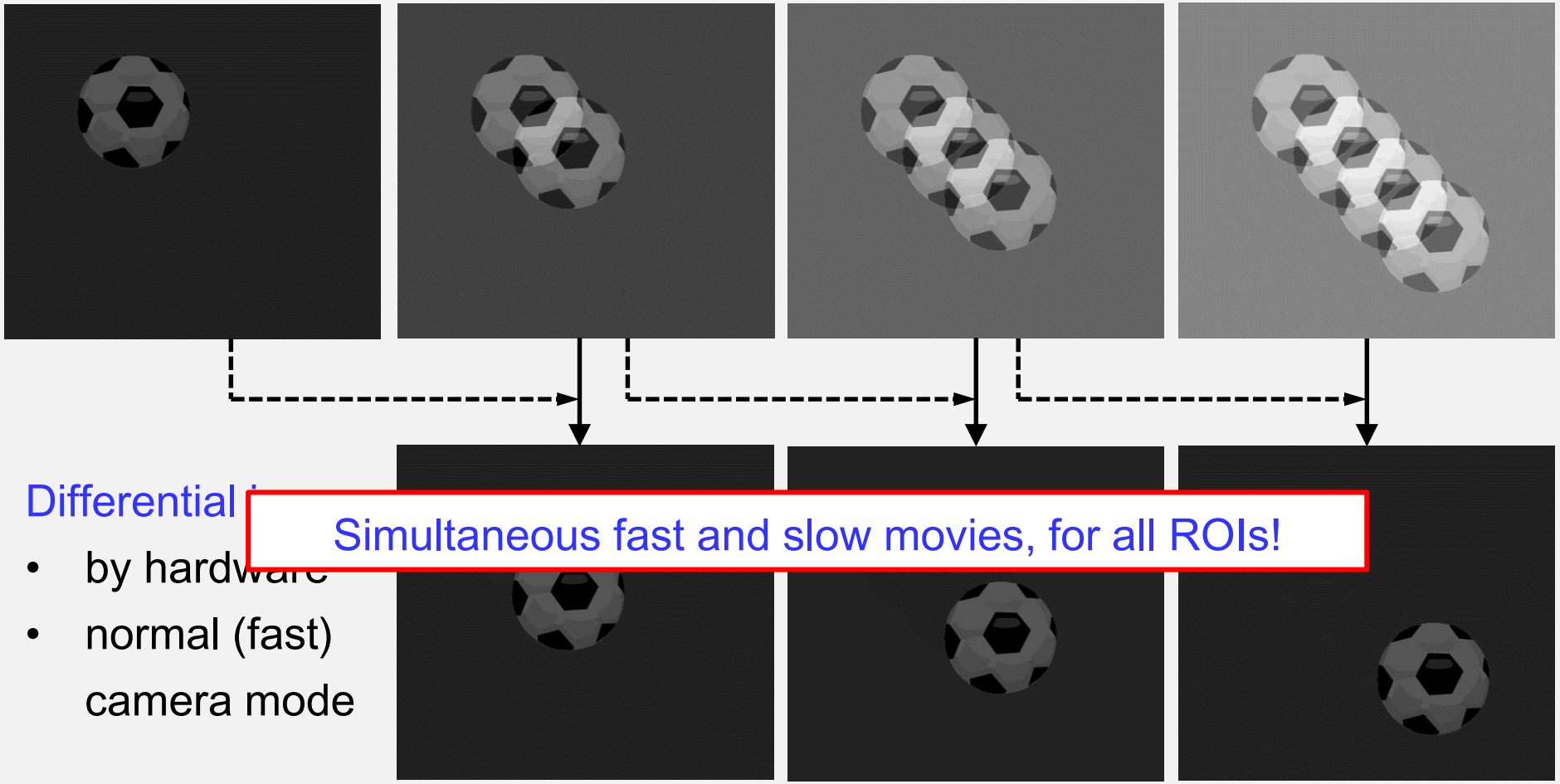
The EDICAM concept

Moving objects:



The EDICAM concept

Moving objects:



Differential i

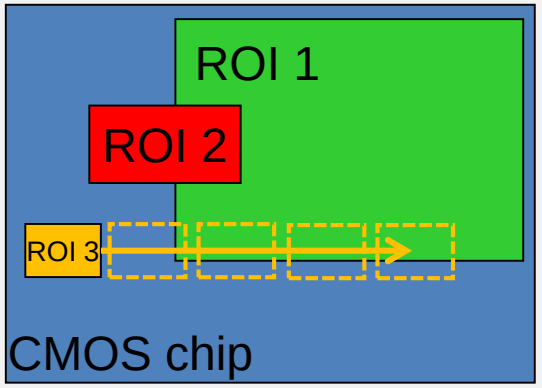
- by hardware
- normal (fast) camera mode

Simultaneous fast and slow movies, for all ROIs!

The EDICAM concept

Main features

EDICAM system (IPCU)

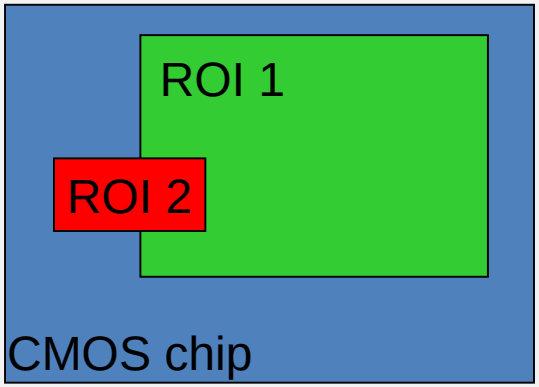


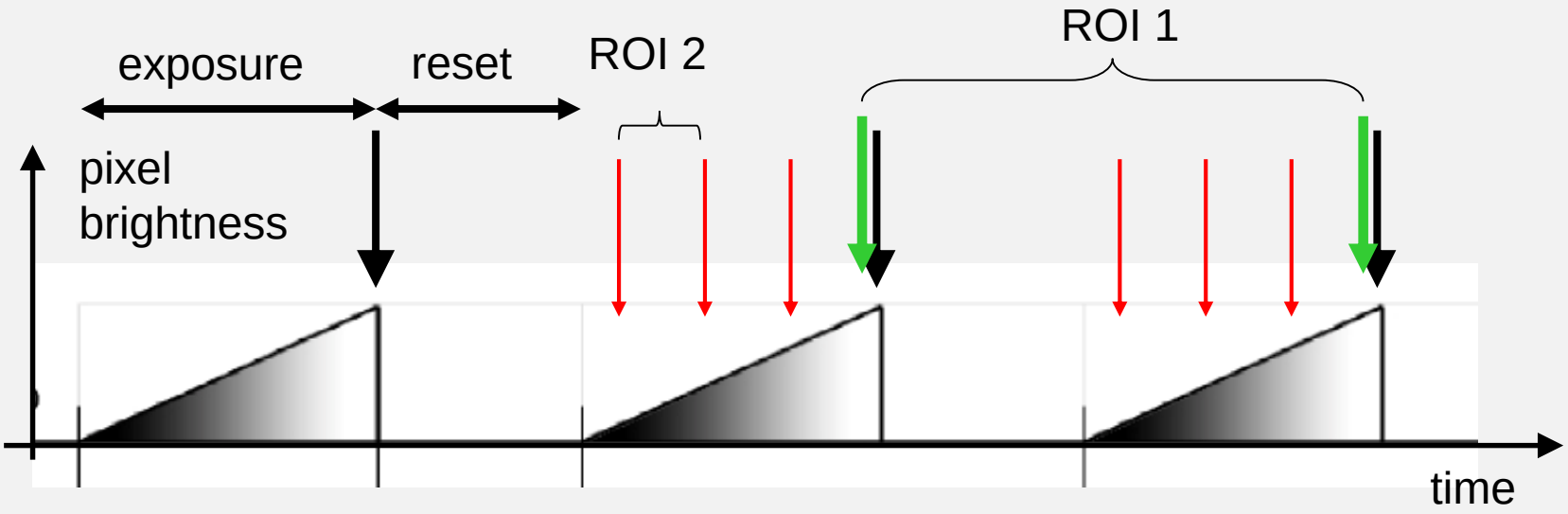
- multiple region-of-interest (ROI) handling
  → up to 6 ROIs can run simultaneously
- moving ROI: can follow e.g. pellets in space at a pre-defined speed
- automatic detection of pre-defined events (real-time image processing in FPGA)
  → brightness threshold (in a sub-area), time, external trigger
- event-driven actions
  → ROI start/stop, data saving on/off, external trigger
- … S. Zoletnik et al, Fus.Eng.Des. **88** 1405 (2013)

The EDICAM concept

Non-destructive readout (NDR)

- „extend” the standard camera operation concept
- ROIs can overlap, image content unchanged
  - → e.g. ROI 1: 640x480 @ 1.000 fps
  - → e.g. ROI 2: 256x100 @ 10.000 fps

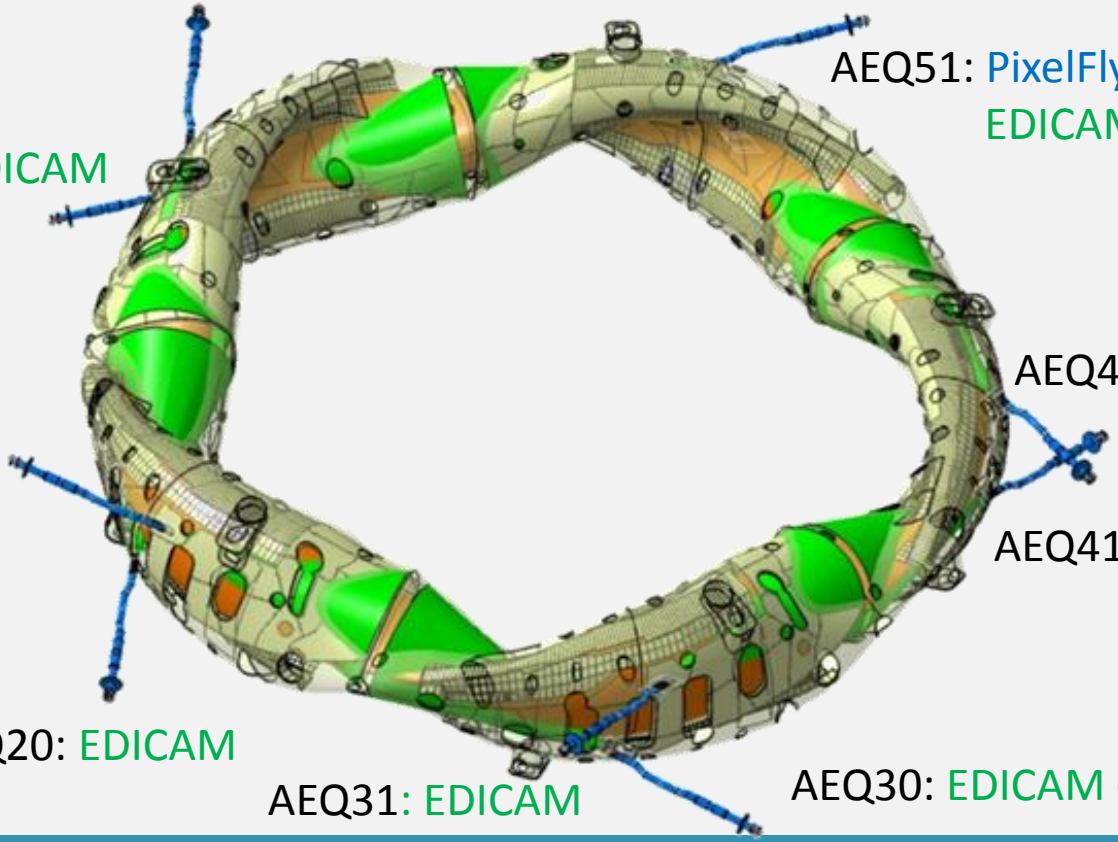




Application in fusion research: W7-X

10-channel overview video diagnostic system

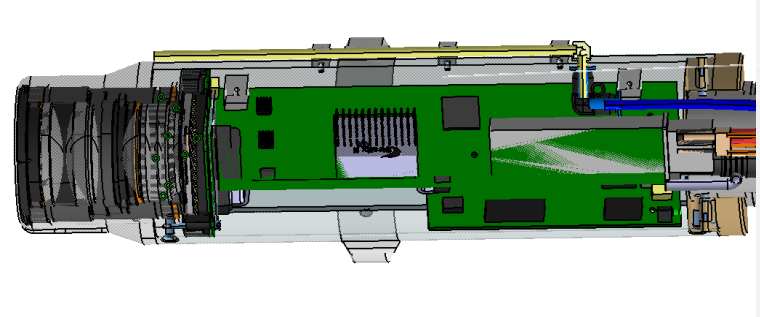
- tangential views (30°)
- 10 ports ↔ 9 EDICAMs, 4 fast cameras, 2 CCD cameras



Application in fusion research: W7-X

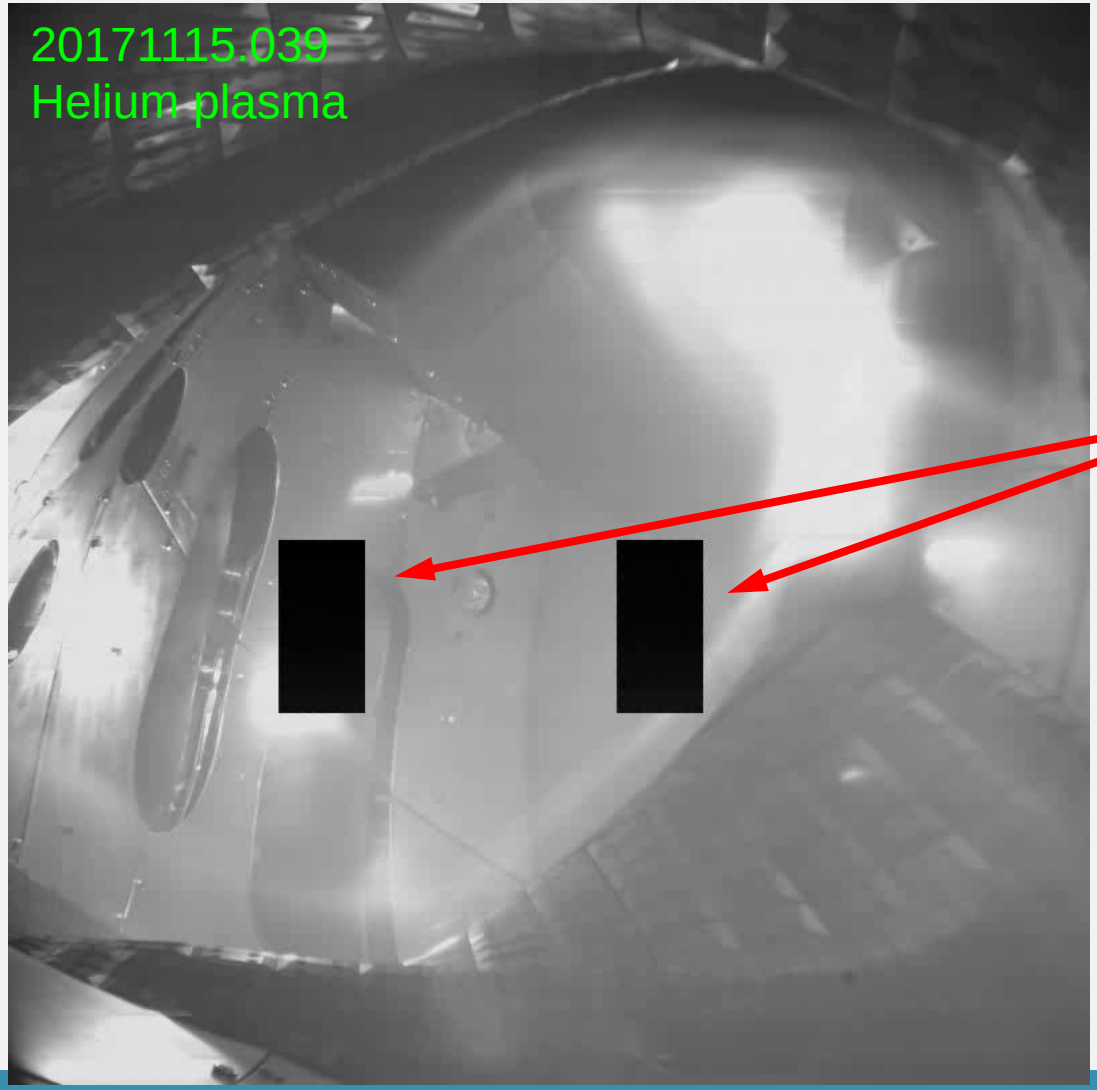
Diagnostic head layouts and installation

- Ø 60 mm camera capsule → EDICAM electronics + special optics + docking head



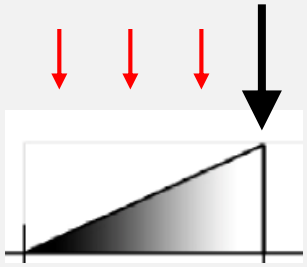
Application in fusion research: W7-X

Non-destructive readout utilization



ROI #1: full frame
100 Hz
Here: still image
time ~ pellet injection

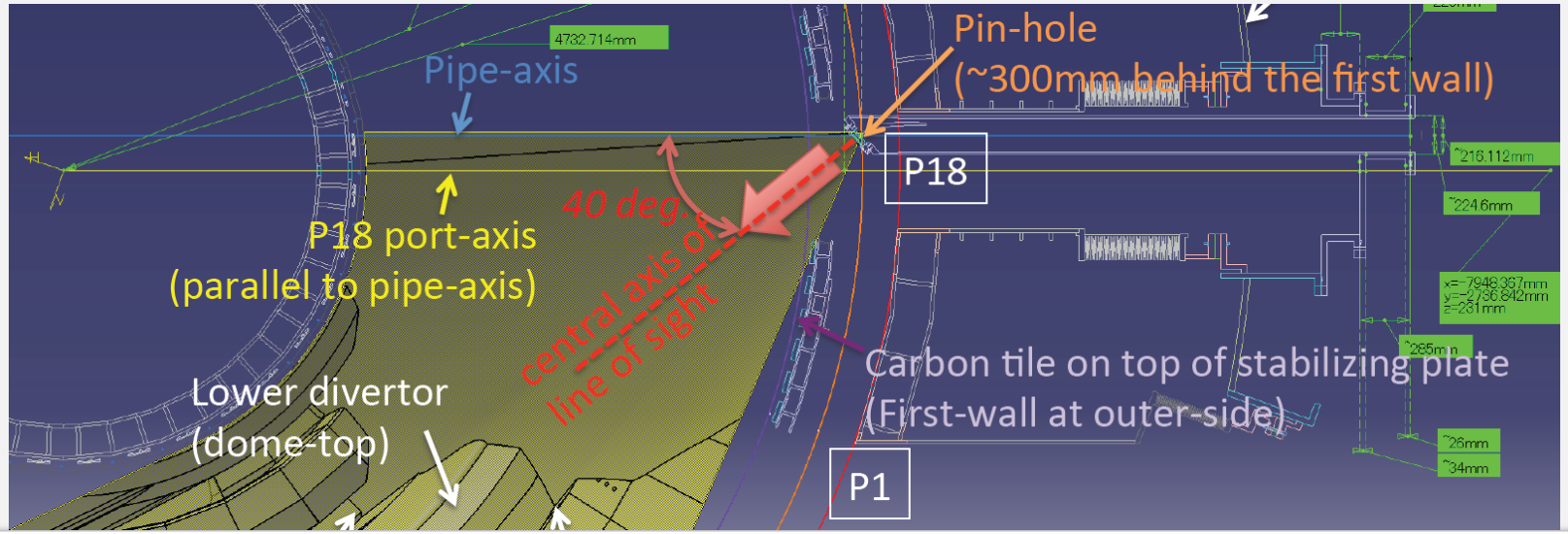
ROI #2 and #3:
Small area (160x100)
10 kHz
Pellet penetration is temporally resolved!

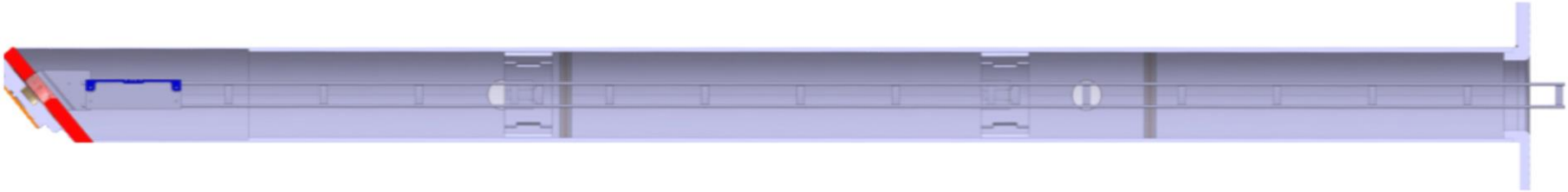


Application in fusion research: JT-60SA

Single channel wide-angle fast video diagnostics

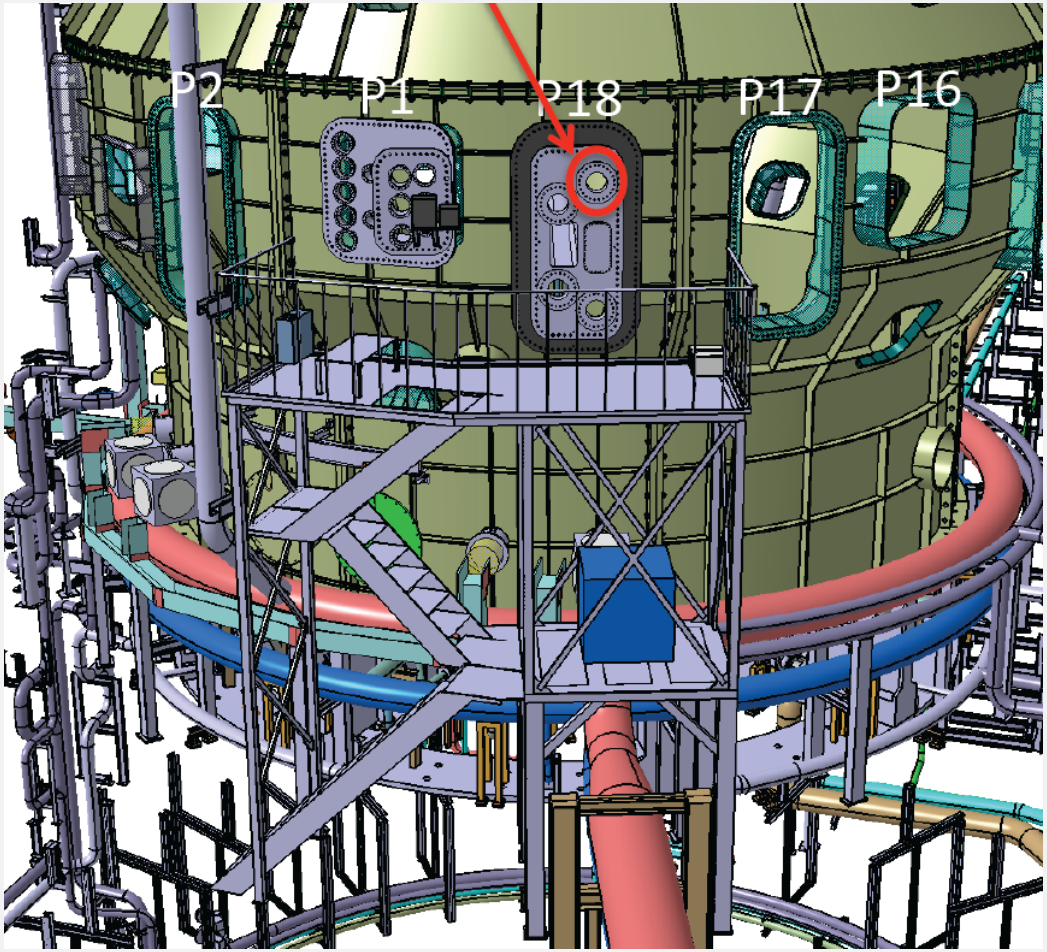
- wide-angle view (80°)
- radial port with relatively large inner diameter (18 cm)



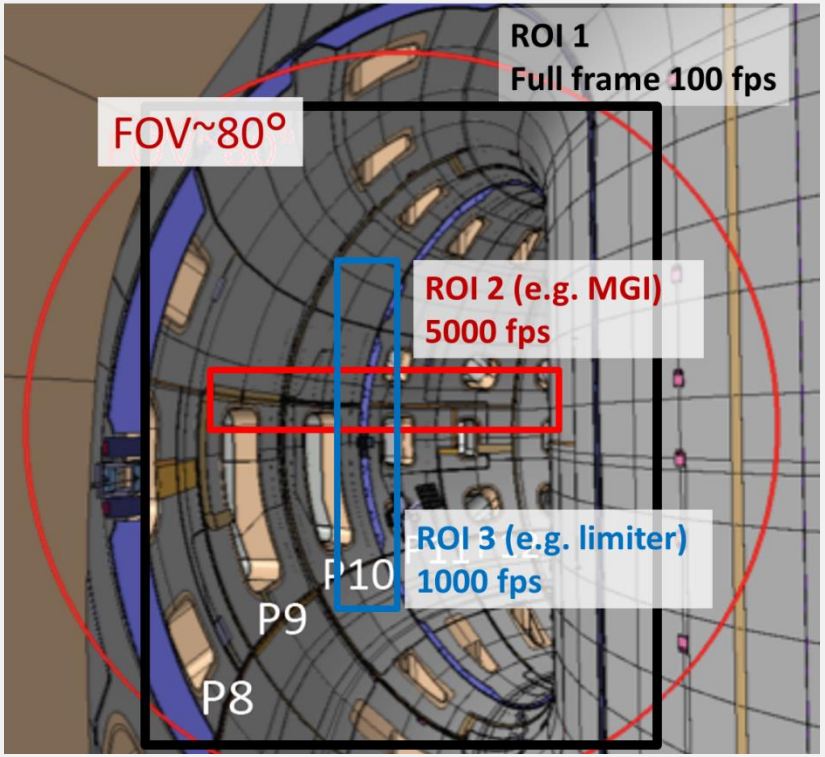


Application in fusion research: JT-60SA

Location of the diagnostic



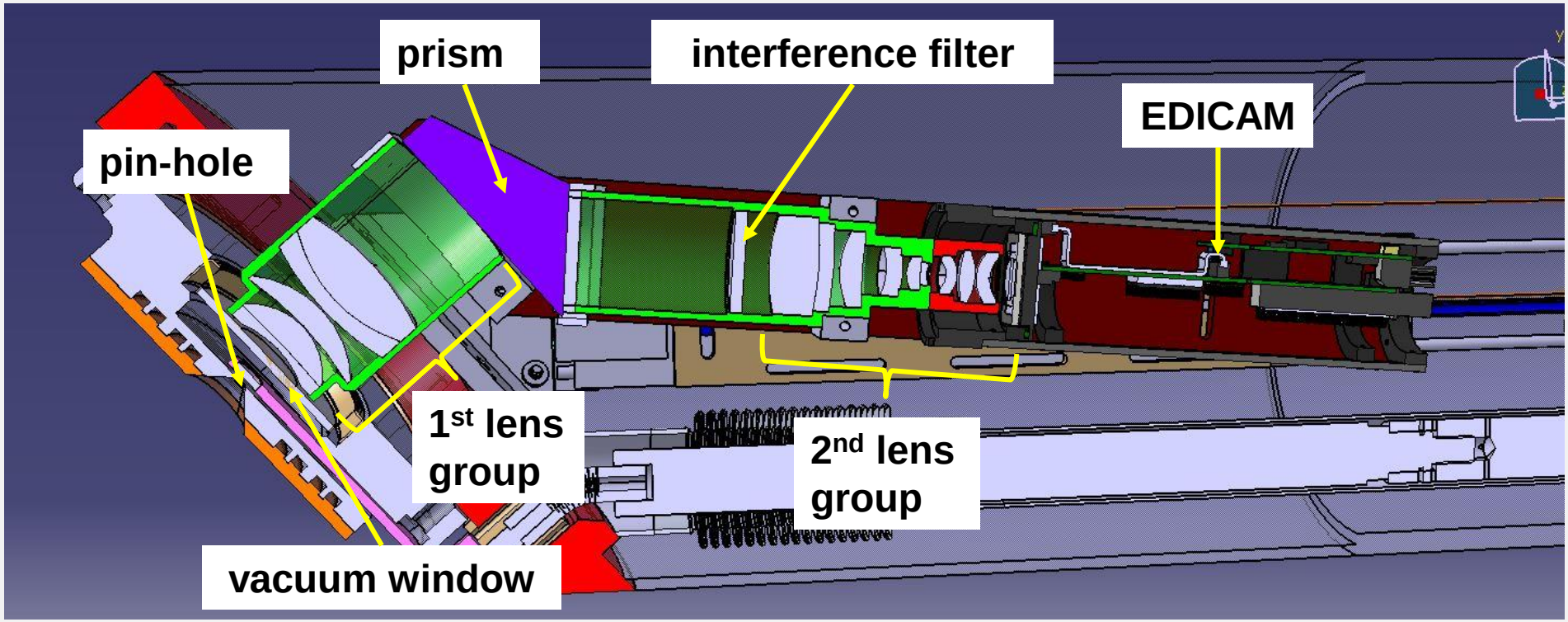
CAD view of the camera with a possible ROI set-up



Application in fusion research: JT-60SA

- more complex optics design

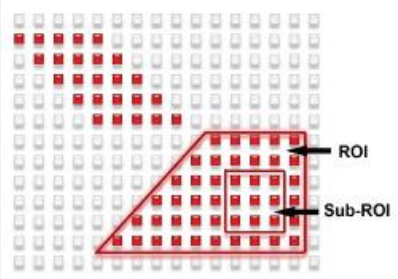
  → camera must be slightly tilted w.r.t. port axis



MAYBE optics could be simpler with a curved sensor…

Future plans – Camera development

Event Detection Intelligent CAMera – Developed by Wigner RCP



Developments of the present version

- ROI definition: arbitrary shape
- real-time image processing
  - → low level (FPGA): centre of gravity, ROI positioning
  - → high level (PC): complex calculations (e.g. shape), MARTe?

New FPGA board (IPCU)

- 40 Gbit/s transfer rate
- 10x logic units → needed to implement additional functionality
- necessary for future use – present board is discontinued

Future plans – With ITER in mind

The EDICAM concept already fullfills the ITER way of thinking

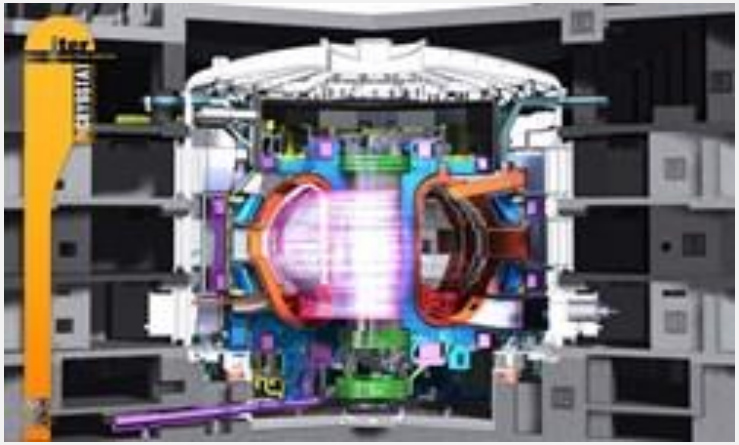
- International Thermonuclear Experimental Reactor (2025…)

  → the last step before fusion electricity production

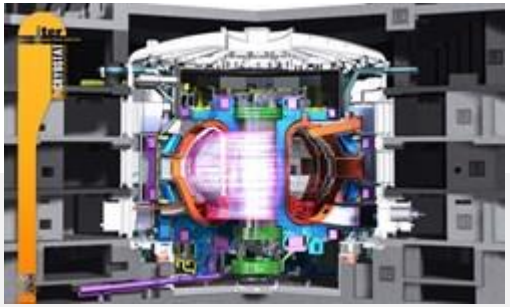
- camera = custom head electronics + commercial DAQ card
- need for standardized DAQ?

  → e.g. NI devices?

  → What about programming? Need for a common framework?



Future plans – With ITER in mind



New sensor (LUPA-1300 is 12 years old…)

- Present-day sensors have **no NDR**!

  → change present camera philosopy

  → custom sensor development (~1 Mio EUR)

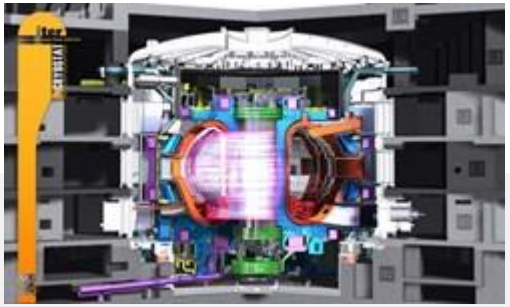
- ITER port cell radiation level: 1e7 n/cm^2/s (behind bioshield)

  → present experiments: 1e9 n/cm^2/s or 1e13 – 1e14 n/cm^2/year

Development timeline

- need the new system in ca. 5 years
- sensor design + development: 2-3 years
- „IPCU” development and diagnostic design: 2 years

Future plans – With ITER in mind



New sensor – our needs

- 1 Mpix @ 5 kHz or 4 Mpix @ 1 kHz (full frame rate)
- pixel size min. 10x10 μm
- flexible x-y windowing (ROI), e.g. 32x32 pixel step size
- fast windowed readout up to 100 kHz or beyond
- QE*ff >50% in the visible range
- global shutter
- on-chip 12-bit ADCs
- full well capacity: >20 ke^-
- temporal noise: <5 e^-
- non-destructive readout

- **curved sensor?**
- **radiation hardened design?**

We are looking forward to cooperate!

Thank you!