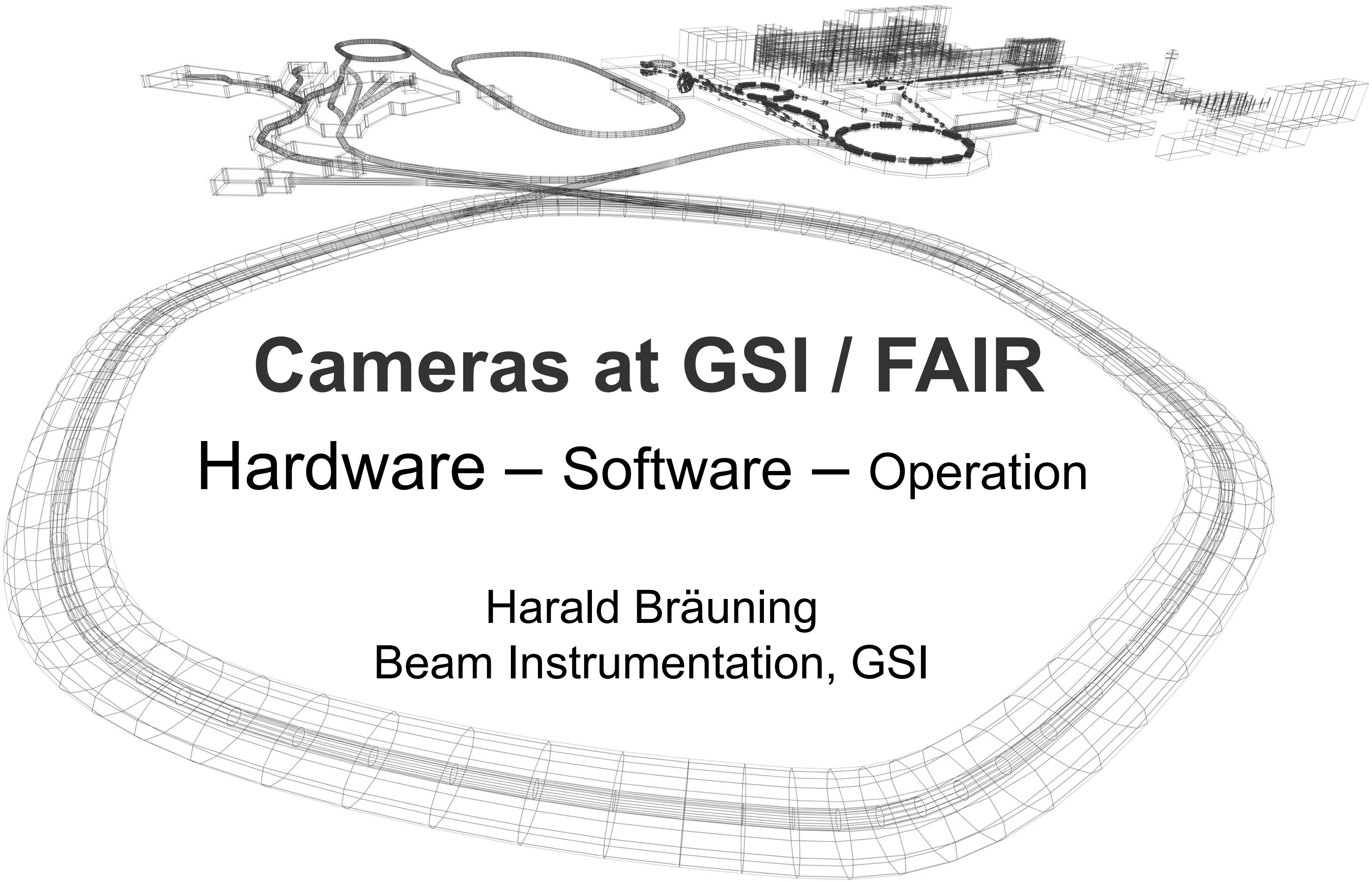


Cameras at GSI / FAIR

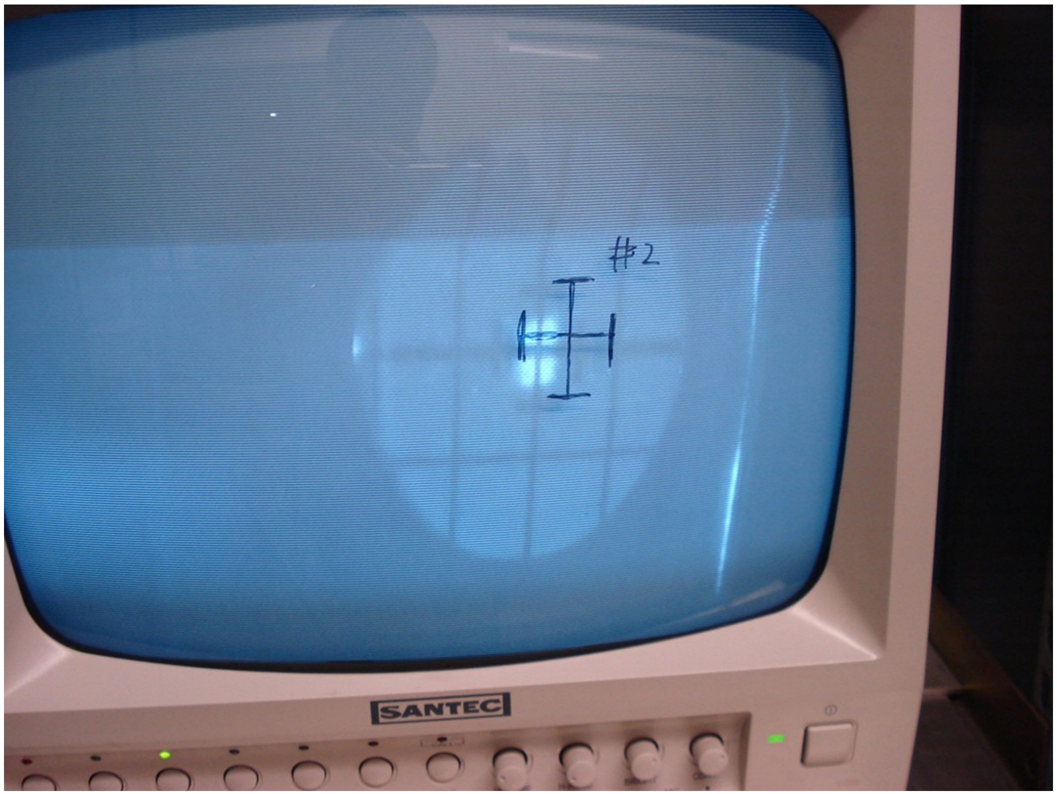
Hardware – Software – Operation

Harald Bräuning
Beam Instrumentation, GSI

Stone Age Beam Diagnostics

Scintillating Screen Readout at GSI prior to 2013

Image Readout

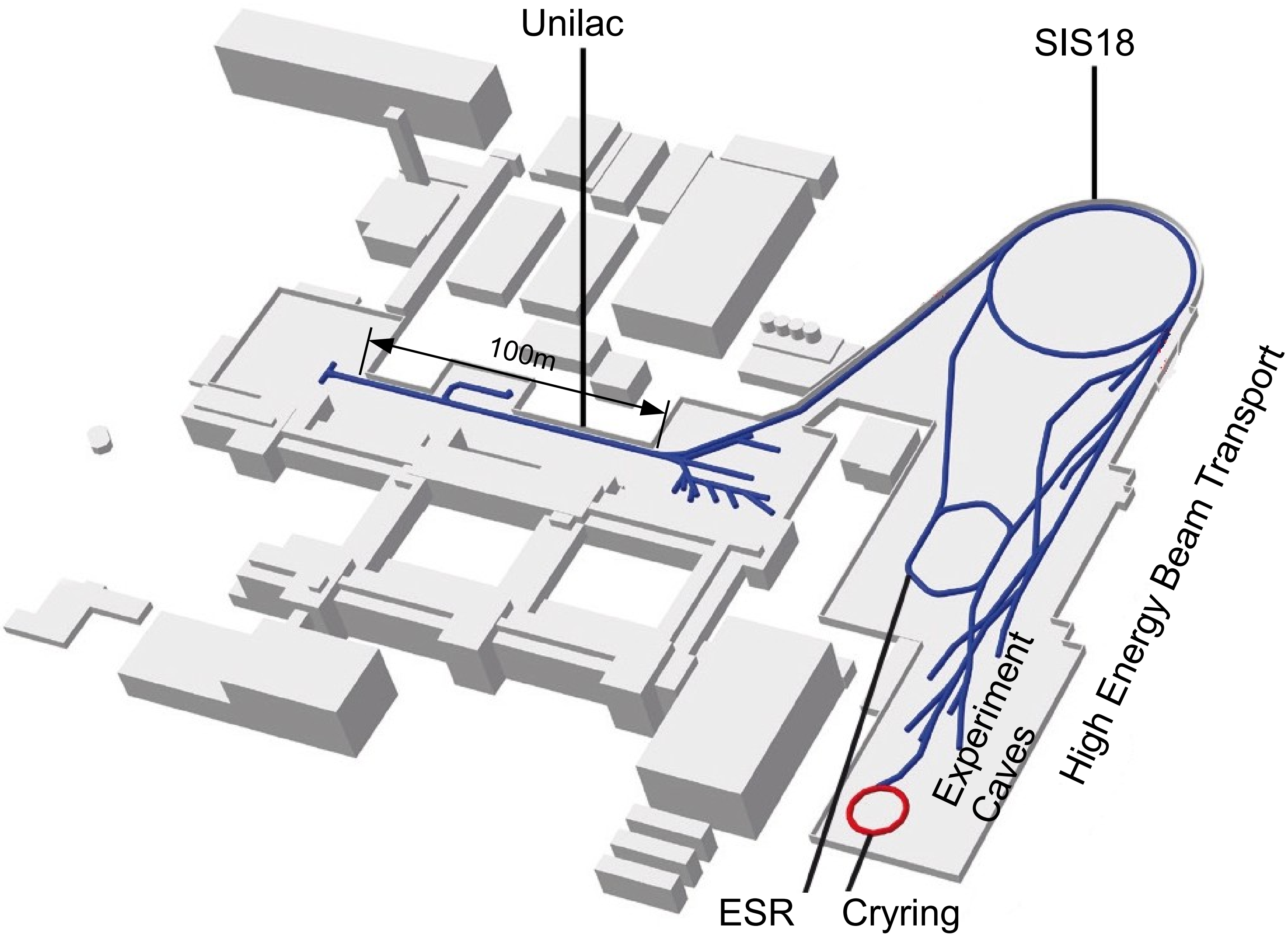


Transport Protocol
from Experiment Cave
to Main Control Room

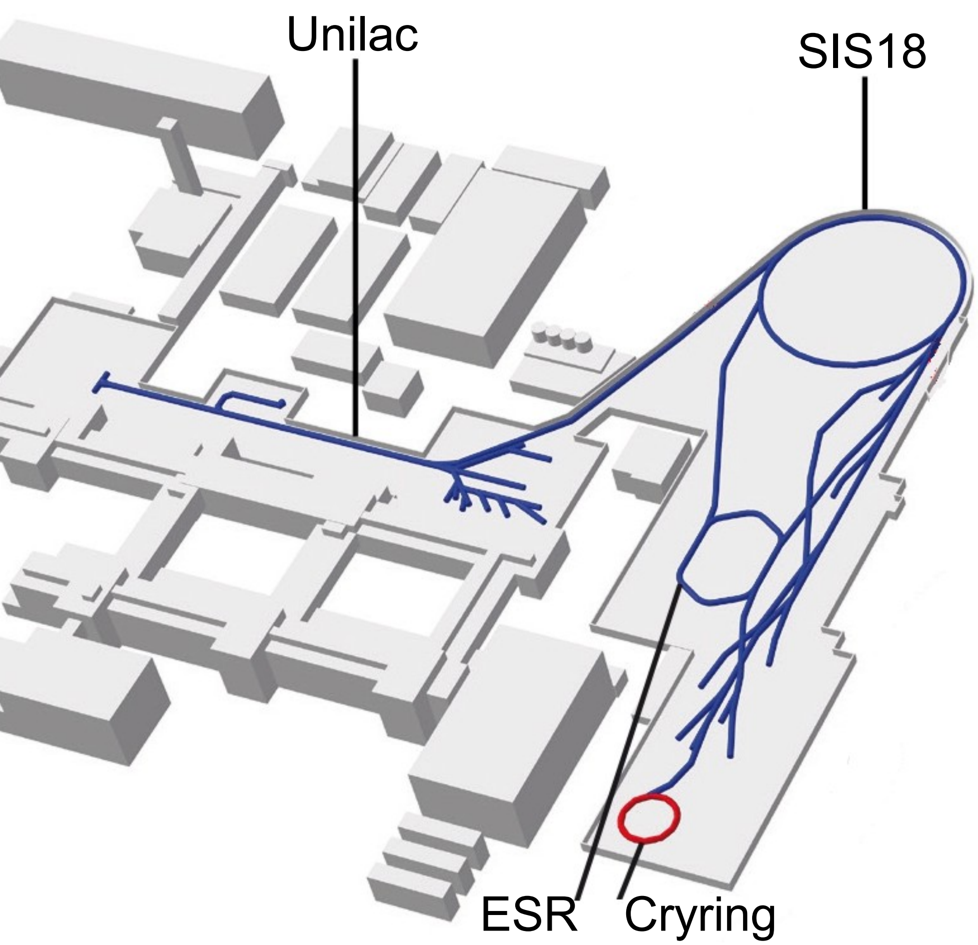
Lots of room for improvement . . .

GSI – Overview

GSI accelerates all ions from protons up to uranium



GSI – Overview



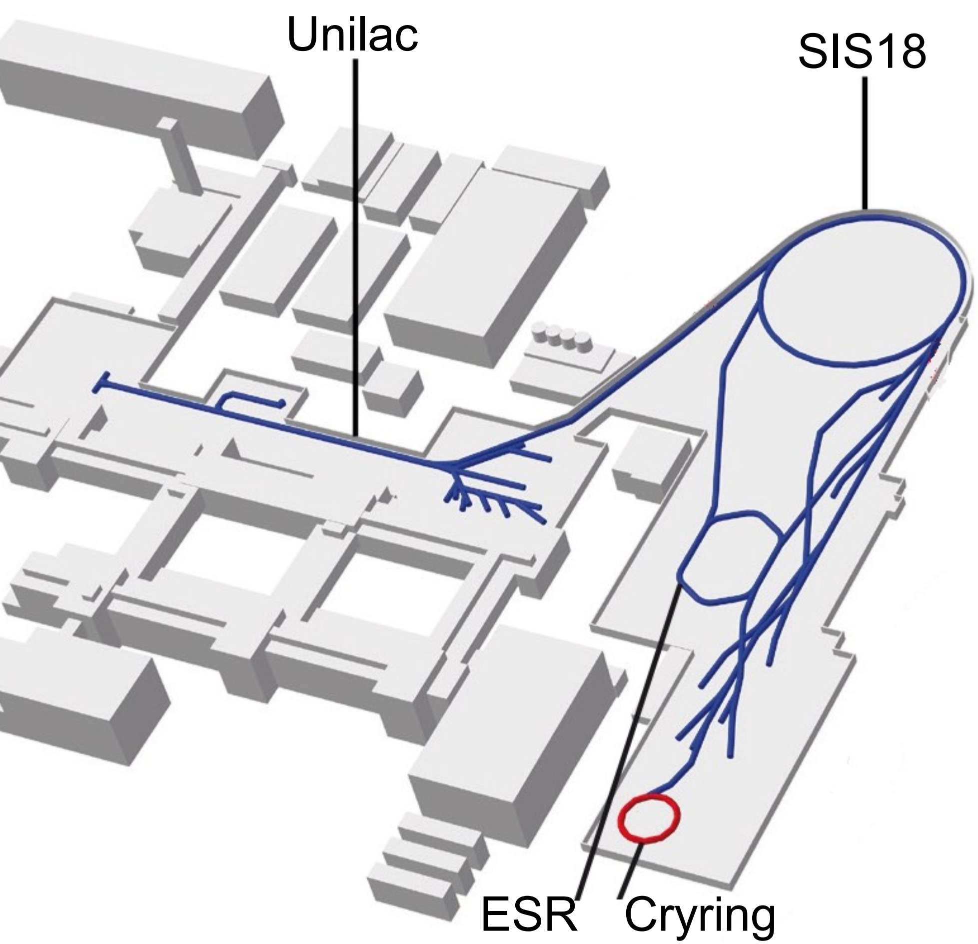
Unilac

- energies up to 11.4 MeV/u
- up to 10^{12} particles per ms pulse
- up to 50 Hz repetition rate
- beam size: mm – cm

SIS18

- energies up to 4 GeV/u
- electron cooler
- up to 10^{11} particles
- fast extraction (1µs)
- slow extraction up to 10 s
- beam size (incl. HEBT): mm – cm

GSI – Overview



ESR

- primarily storage ring
- stochastic and electron cooling
- deceleration to 4 MeV/u
- fast extraction to Cryring (few μs)
- slow extraction up to 60s and more

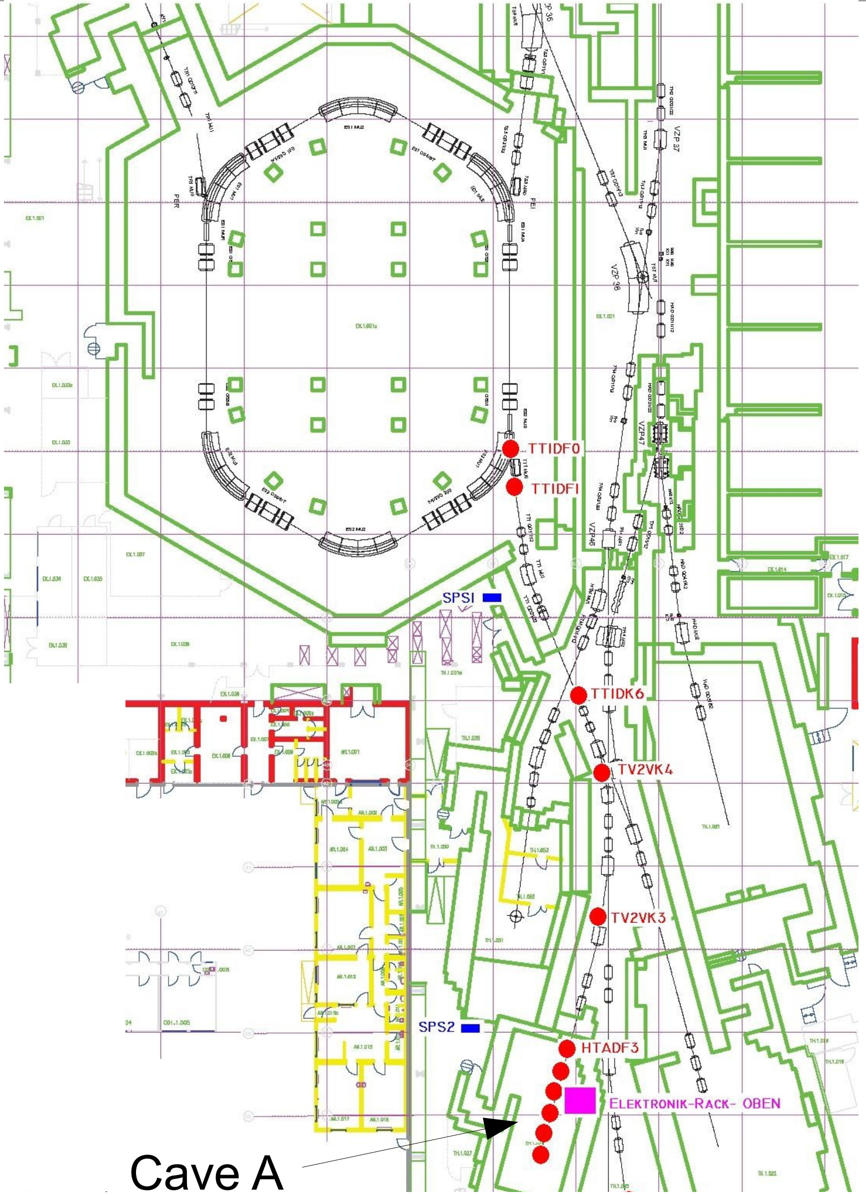
Cryring

- recent addition (from Stockholm)
- test bench for FAIR control system
- primarily storage ring
- energy range 0.3 – 14 MeV/u
- electron cooling
- 2 injectors
  - Linac for light ions at 0.3 MeV/u
  - cooled heavy ions from ESR at 4MeV/u

Up..., Up..., Upgrade

2013: Upgrade Cave A

- driven by atomic physics experiments
- improve beam diagnostics on beamline from ESR to Cave A
  - low energy ions
  - low intensity
- required for optimizing beam transport and emittance / collimation
- 6 new scintillating screens on path from ESR to Cave A
- 5 experiment screens in Cave A (only temporarily installed)
- digital readout



Up..., Up..., Upgrade

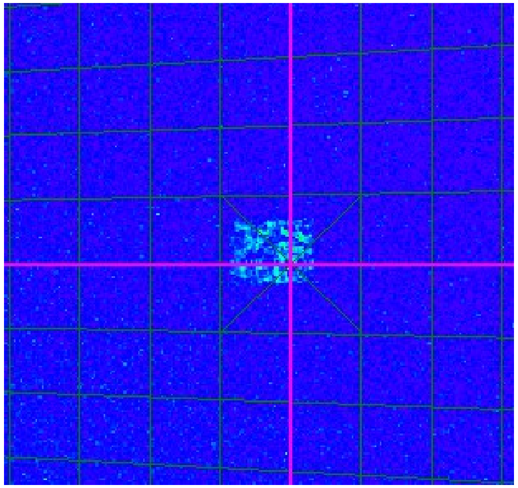
2013: Upgrade Cave A

Requirements from experiments:

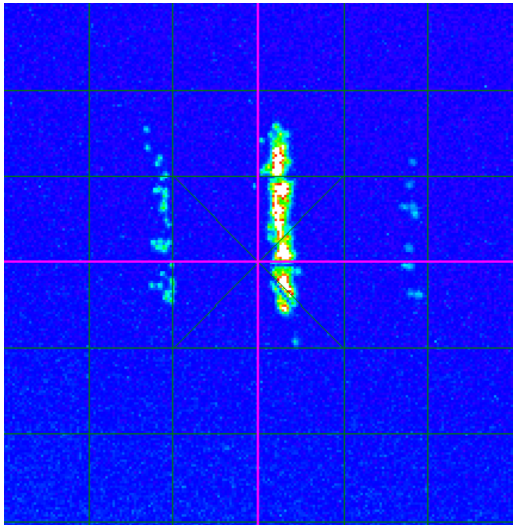
- slow and fast extraction from ESR
- ions up to uranium
- down to about 10^4 particles per second
- energies 4 MeV/u up more than 200 MeV/u

- simultaneous view in experimental hut and main control room
- storage of images for later analysis
- measurement of beam position and approximate FWHM in SI units
- free run and triggered image acquisition

Cave A: 190MeV/u U^{89+}
collimated beam on 1st experiment screen



charge state distribution on screen after analysing magnet



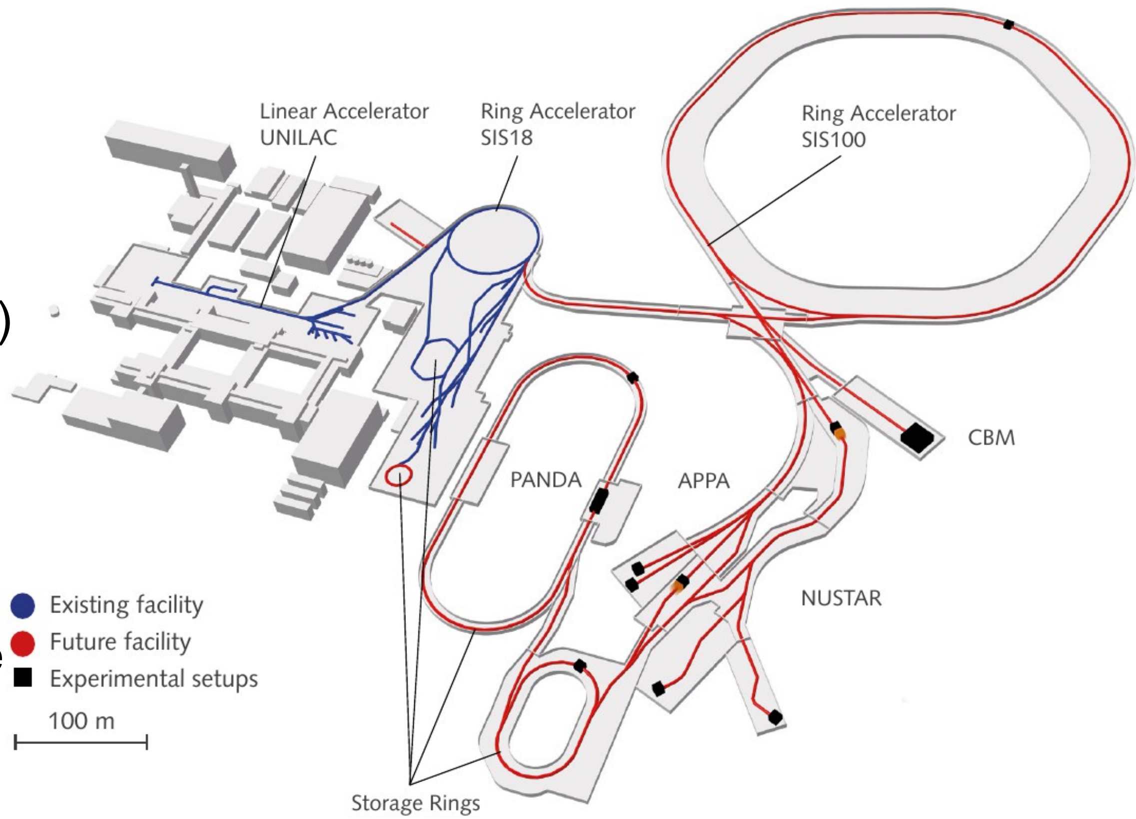
Upgrade – Contraints by FAIR

2013: Upgrade Cave A

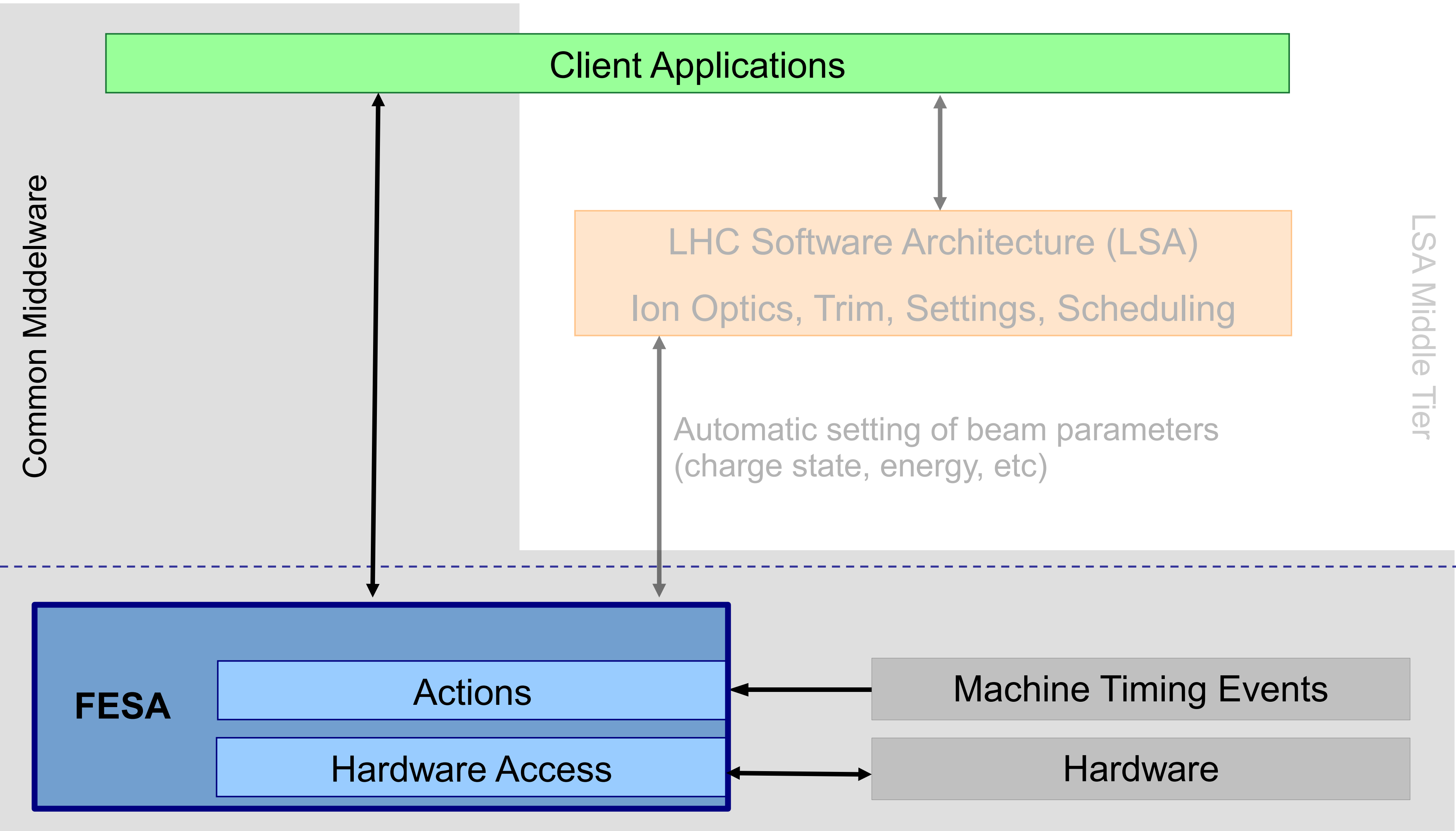
Prototype for scintillating screen readout in the FAIR accelerator complex!

Constraints imposed by the FAIR Control System:

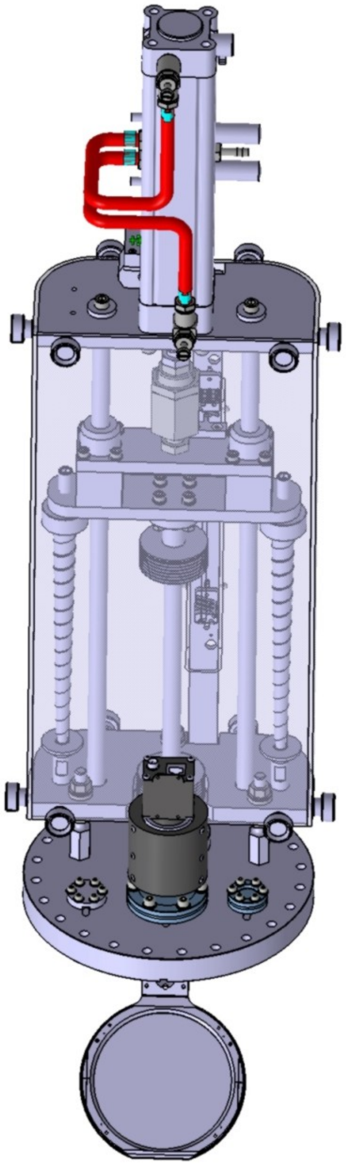
- Client – Server architecture
- Server (Frontend Controller)
  - Linux operating system
  - based on Cern's FrontEnd Software Architecture (FESA)
    - C++
- Client (GUI, ...)
  - based on Java / JavaFX
  - number of clients is indefinite



General Architecture

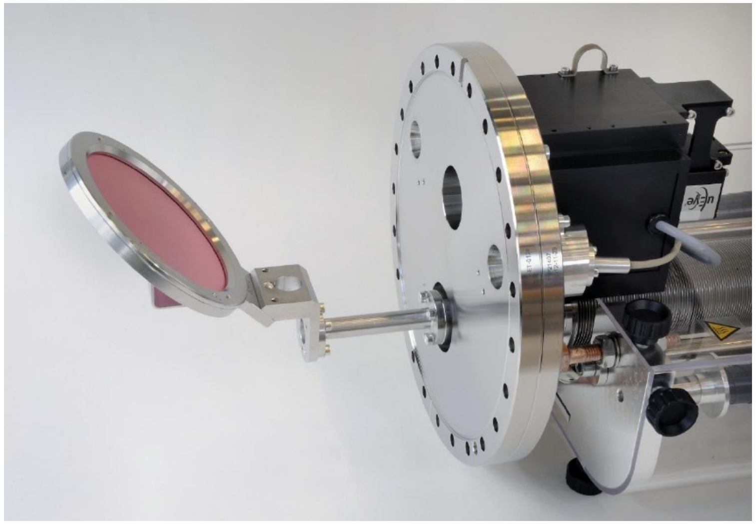


Standard Assembly



Linear Feedthrough

- mostly driven by pressurized air
- some driven by stepper motors



Camera

Remote Controlled Lens

LED for target illumination

Scintillating screen in standardized holder

Camera

iDS UI-5240SE-M (monochrome)

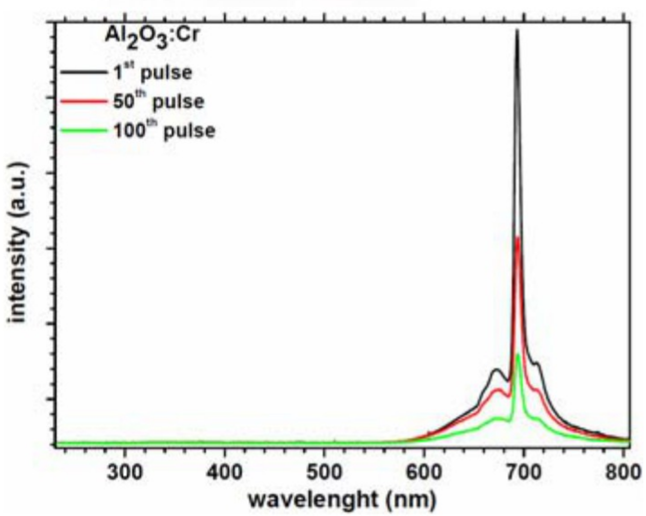
	specification	remarks
interface	GigE	
sensor	CMOS (e2v)	**selection criteria**
pixel	1280 x 1024	prog. AOI
pixel pitch	5.3µm	
shutter	global	
max. framerate	50fps	≤ 10fps
exposure time	9µs – 2s	1ms – 1s
binning	h + v (2x)	
analog gain boost	2x	
ADC	10bit	8bit readout
I/O	trigger input	trigger by event
	strobe output	monitor

http://ids-imaging.com

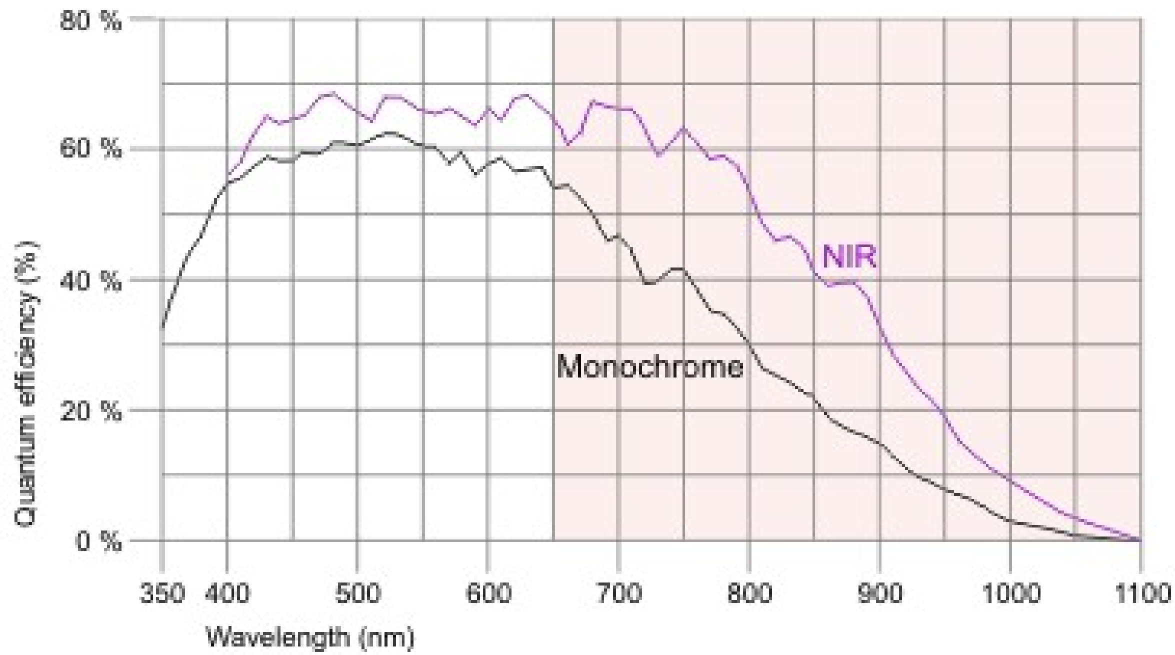
e2v Image Sensors:

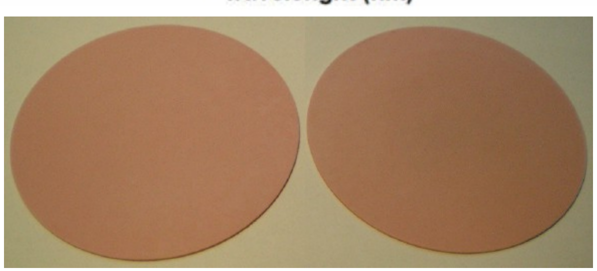
- high sensitivity
- good radiation tolerance
  - used in a space environment

Camera



iDS UI-5240SE-M (monochrome)

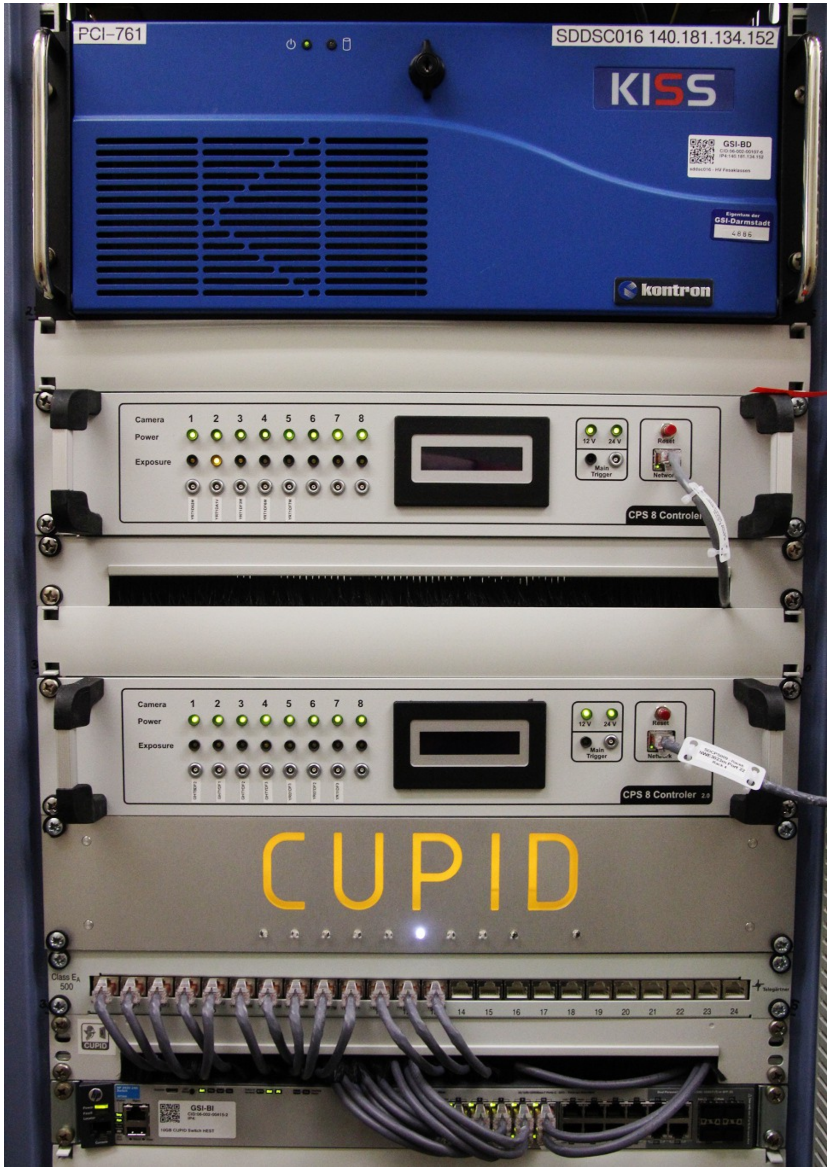




Standard scintillating screen for **FAIR**:

chromium doped aluminum oxide Al_2O_3:Cr (0.04%mass)

Camera Readout Hardware



Industrial PC

- data acquisition for cameras
  - via 10 Gbit ethernet switch (local network)
    - camera configuration
    - camera readout
  - via standard LAN (accelerator network)
    - control of CPS8 controllers
  - Fair Timing Receiver Node
    - hardware trigger (LVTTL)
      - based on machine event
      - distributed via CPS8 controller
      - currently: all cameras = one trigger
      - future: one camera = one trigger

10 Gbit Ethernet Switch

Camera Readout Hardware

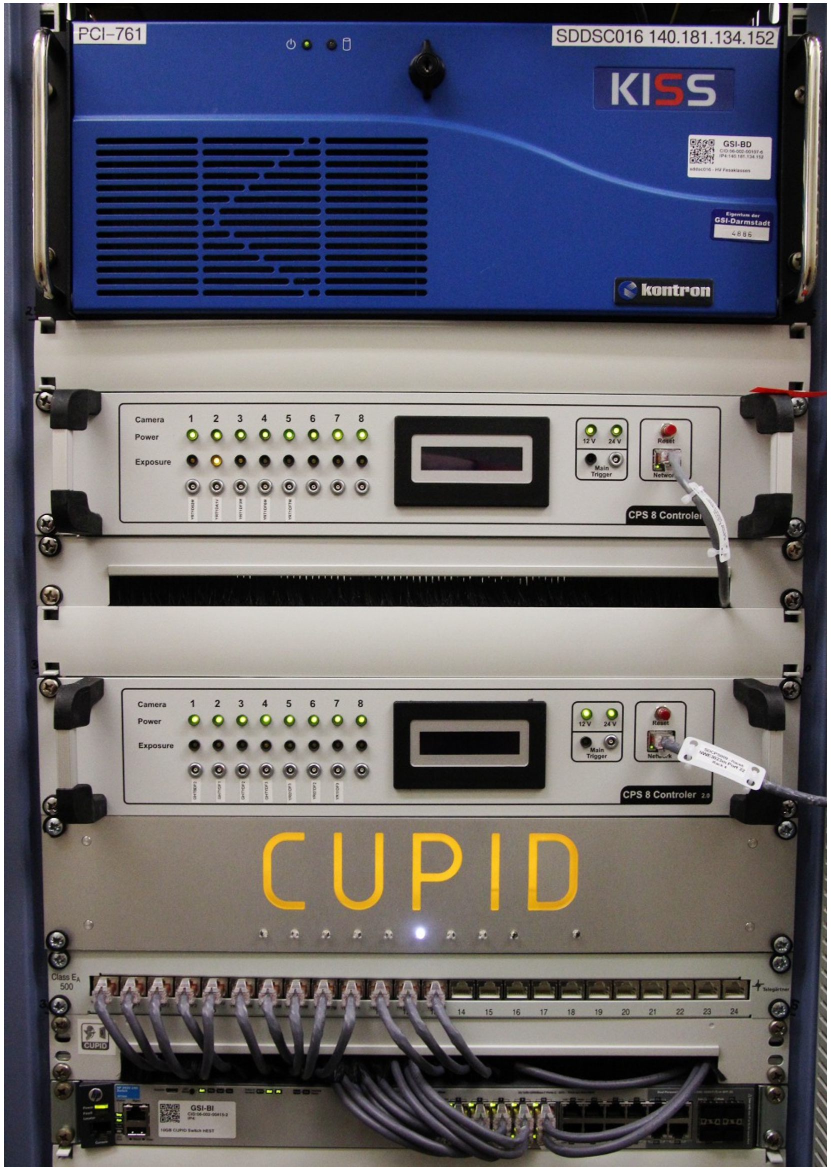
New Systems: µTCA based

- compact modular system
  - 8 Port Gbit ethernet switch
    - data acquisition from cameras
    - multiple switches in principle possible
  - Fair Timing Receiver Node
- disadvantages:
  - complicated configuration of µTCA backplane ethernet lines
    - at first suboptimal configuration:
      - system worked
      - 30s discovery time of cameras after camera power cycle
        (typical with optimal configuration: 2 – 3s)

Fair Timing Receiver Node

8 Port Gbit Ethernet Switch

Camera Control Hardware



CPS8 Controller

- build in-house
- Atmel Microcontroller (Arduino) based
- simple ethernet based access
- camera power control
- camera power status
- camera trigger
  - software trigger
  - hardware trigger distribution
    - currently: all cameras = one trigger
    - future: one camera = one trigger
  - further options like burst mode could be implemented
- front panel indicators
  - camera power
  - camera exposure (camera strobe output)

Remote Controlled Lens

Remote Controlled Lenses

- mainly to adjust image intensity via iris
- occasionally focus in case of different screen positions
  - i.e. Cryring: different correct beam position on injection screen depending on source path

Pentax -ER Series

- iris control by DC voltage (1.5 – 5.5V)
- iris closes when power is cut off
- manual focus
  (usually sufficient)

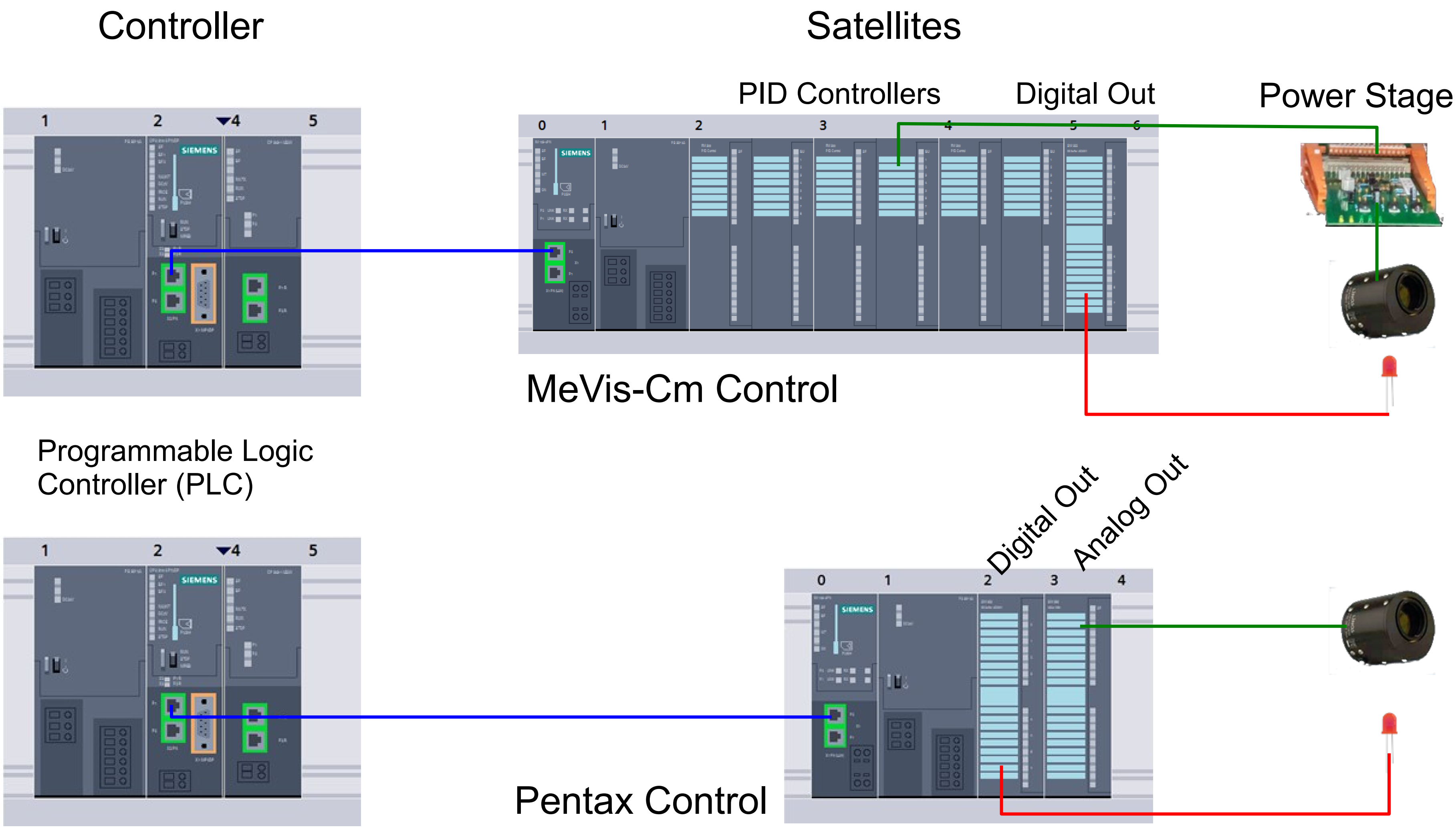
DISCONTINUED
(but we have 60 pcs in reserve)

Linos MeVis-Cm

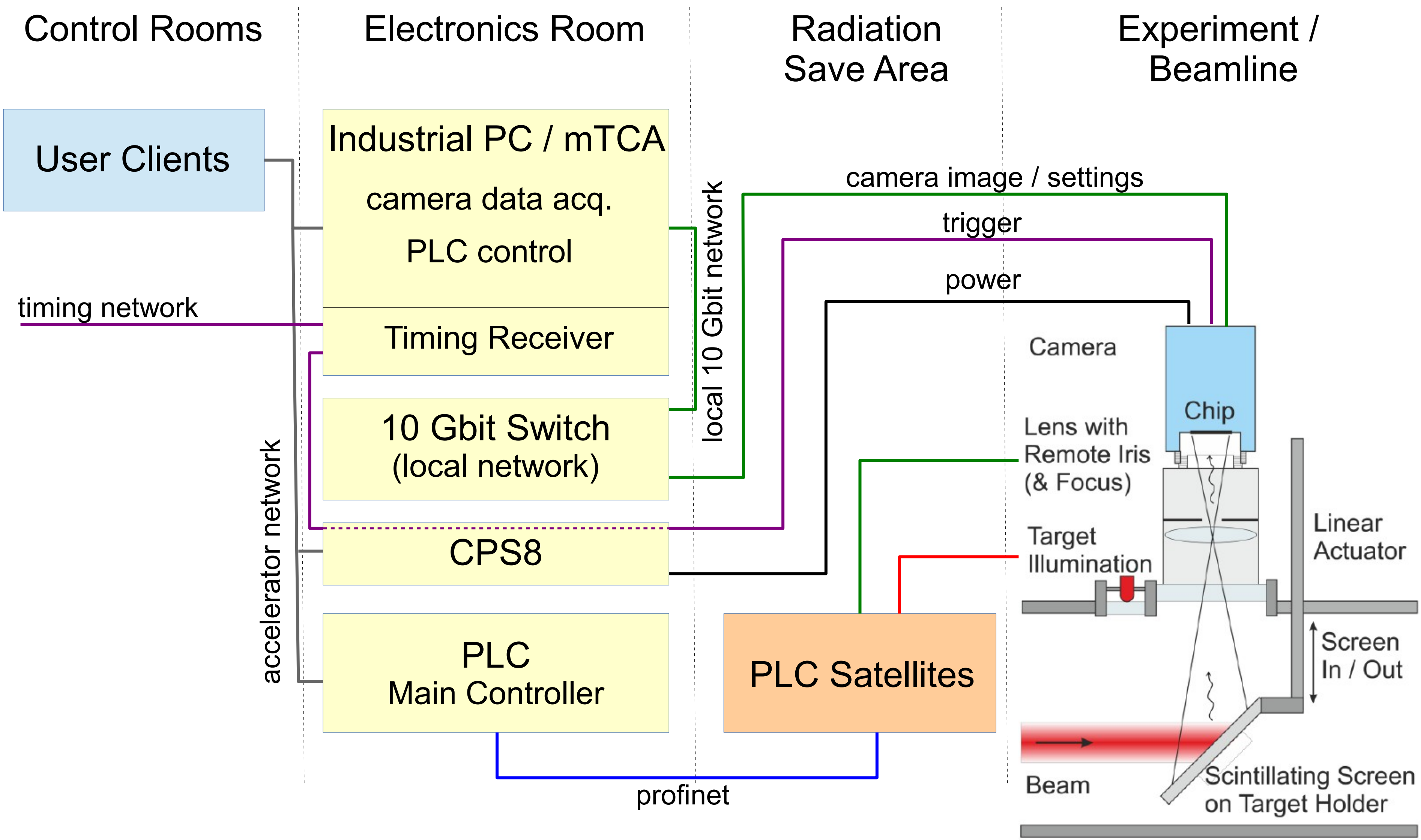
- intended as replacement
- motorized iris
- motorized focus
- encoders for precise and reproducible adjustment

DISCONTINUED

Remote Controlled Lenses



Complete System Overview



Frame Grabber

Analog Cameras

- legacy cameras already installed
- Thermo Fischer RadHard camera (MegaRAD3)

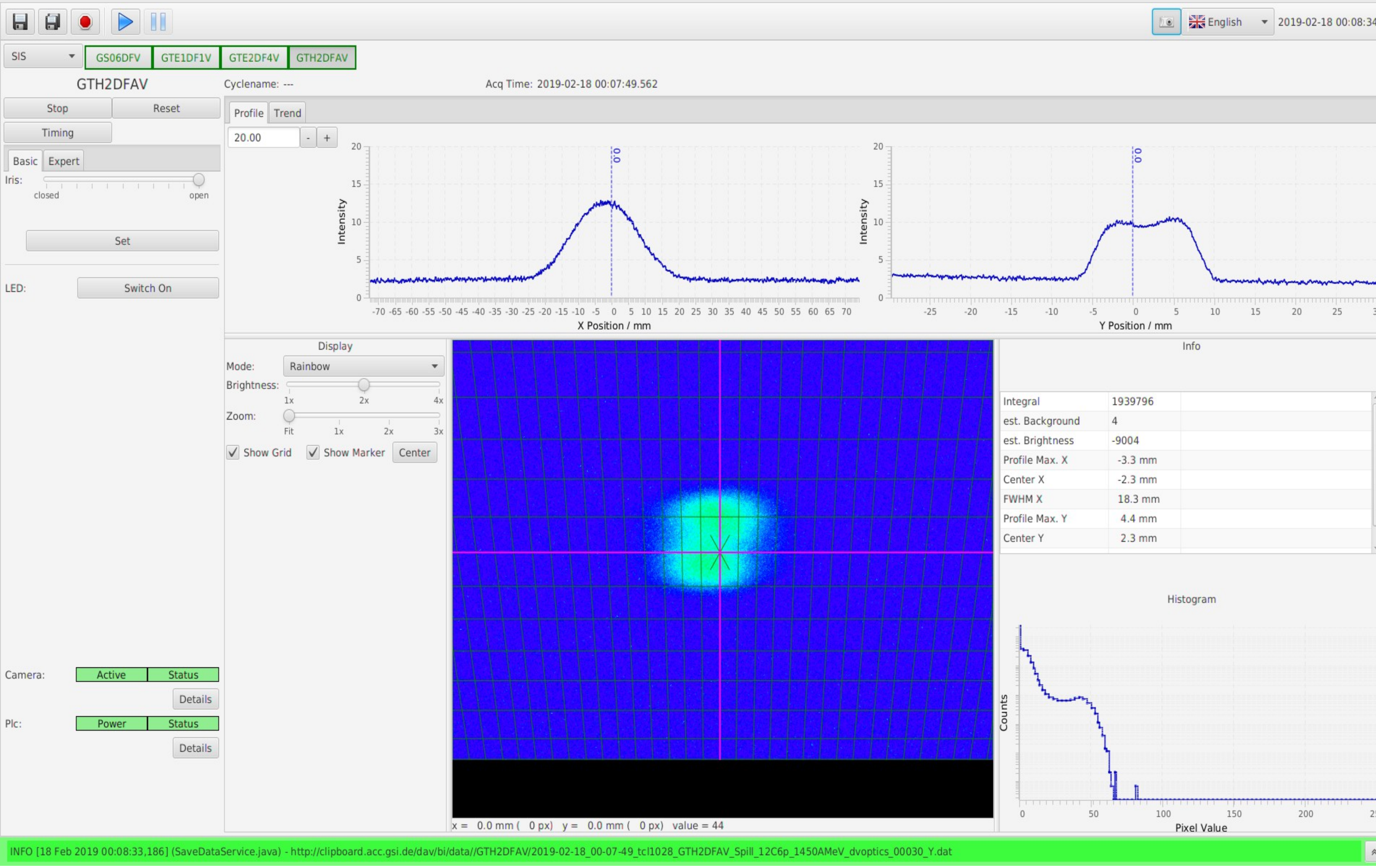
Pleora iPort Analog-Pro External Frame Grabber

- Gbit ethernet based
- GigE Vision and GenICam compatible

Analog cameras run continuously

- rate reduction in software to 10Hz
- trigger by software
  - all frames are discarded but next frame after trigger

Client – User Application



Server – Data Acquisition

Data Acquisition on the Frontend: Server for Multiple clients

Image Acquisition and Processing

- image acquisition
- software crop
- rotation (90°, 180°, 270°)
- mirror
- simple image scaling
- projections
- simple analysis neglecting further perspective distortion
  - histogram
  - position of brigthest pixel
  - center-of-brightness
  - FWHM

Camera / Software Settings (if supported)

- acquisition mode (free running / triggered)
- exposure time
- binning
- gain boost
- contrast
- brigthness
- rotation / mirror
- area-of-interest (fixed during runtime)

Perspective Distortion

Perspective Distortion

scintillating screen is typically mounted under 45° with respect to the optical axis

- short distance leads to visible perspective distortion
- position (x,y) in SI units can be calculated for each pixel by

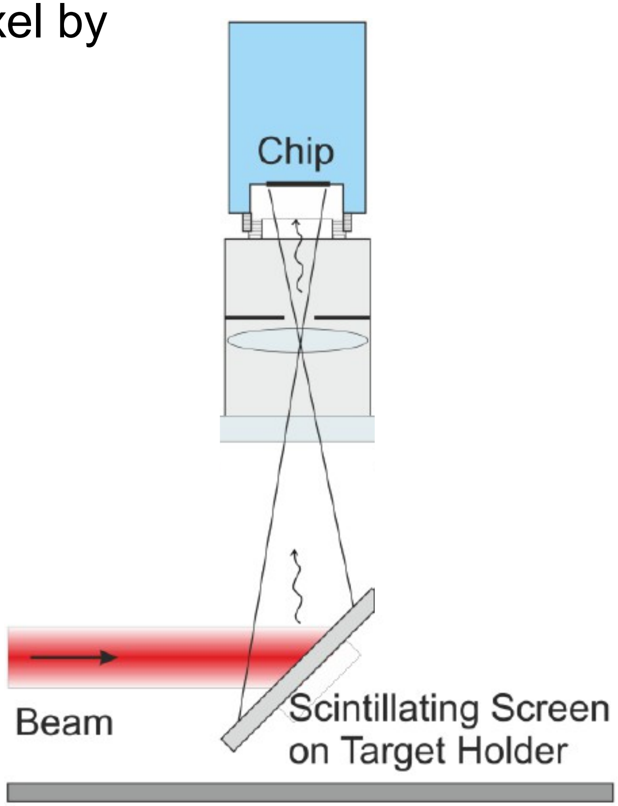
$$x'_p = x_p - x_{p0}$$

$$y'_p = y_p - y_{p0}$$

$$x = (s_x + \Delta s_{xx} x'_p + \Delta s_{xy} y'_p) x'_p$$

$$y = (s_y + \Delta s_{yx} x'_p + \Delta s_{yy} y'_p) y'_p$$

- we do not rectify the image!



x_p, y_p = pixel position; x_{p0}, y_{p0} = pixel position of screen center

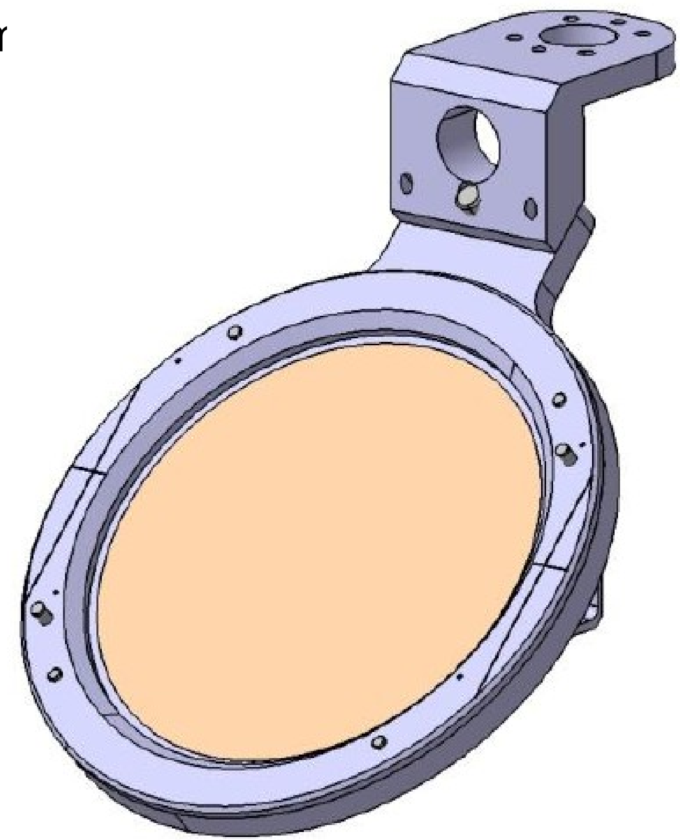
s,Δs = scale factors

Perspective Distortion

Perspective Distortion

scintillating screen is typically mounted under 45° with respect to the optical axis

- standard target holder contains alignment marks
- all scale factors are determined from the alignment m
- vertically mounted assemblies
  - $\Delta s_{xx} = 0$ and $\Delta s_{yx} = 0$
- horizontally mounted assemblies
  - $\Delta s_{xy} = 0$ and $\Delta s_{yy} = 0$



$$x'_p = x_p - x_{p0}$$

$$y'_p = y_p - y_{p0}$$

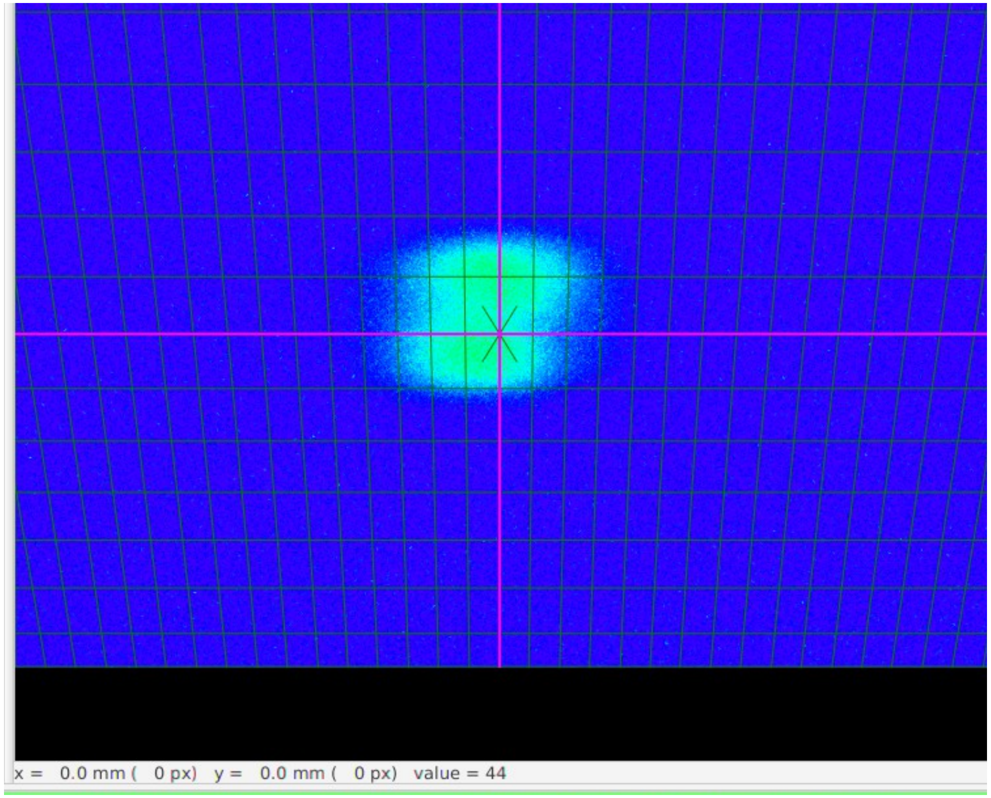
$$x = (s_x + \Delta s_{xx} x'_p + \Delta s_{xy} y'_p) x'_p$$

$$y = (s_y + \Delta s_{yx} x'_p + \Delta s_{yy} y'_p) y'_p$$

Perspective Distortion

perspective distortion is solely handled by the client

- overlay a grid showing the perspective distortion
- display pixel coordinates in SI units taking perspective into account



$$x'_p = x_p - x_{p0}$$

$$y'_p = y_p - y_{p0}$$

$$x = \left(s_x + \Delta s_{xx} x'_p + \Delta s_{xy} y'_p\right) x'_p$$

$$y = \left(s_y + \Delta s_{yx} x'_p + \Delta s_{yy} y'_p\right) y'_p$$

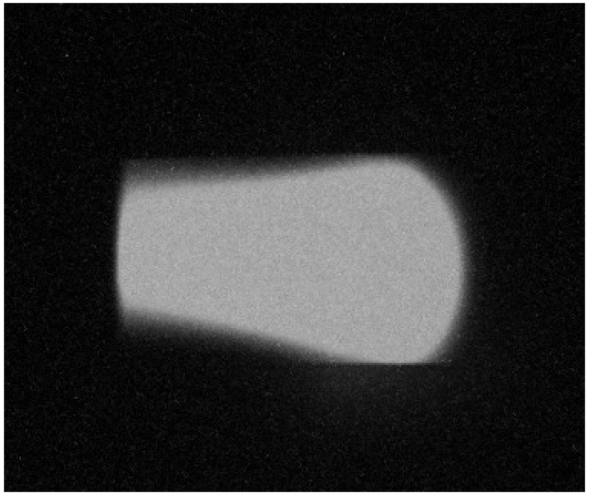
Experiences

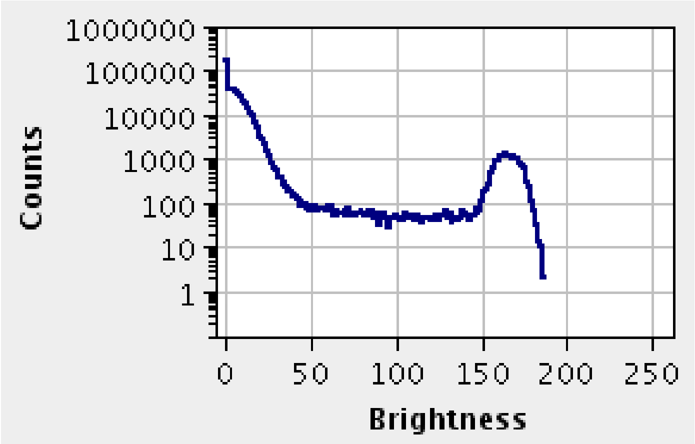
iDS Ueye

- operational: 34 cameras
- stable operation
- no degradation due to radiation visible so far
- well supported under Linux
- firmware update in situ possible

Problem (more a really not understood / further investigated observation)

- saturation with max pixel value <8bit (255) for short pulses (few μs length)





Experiences

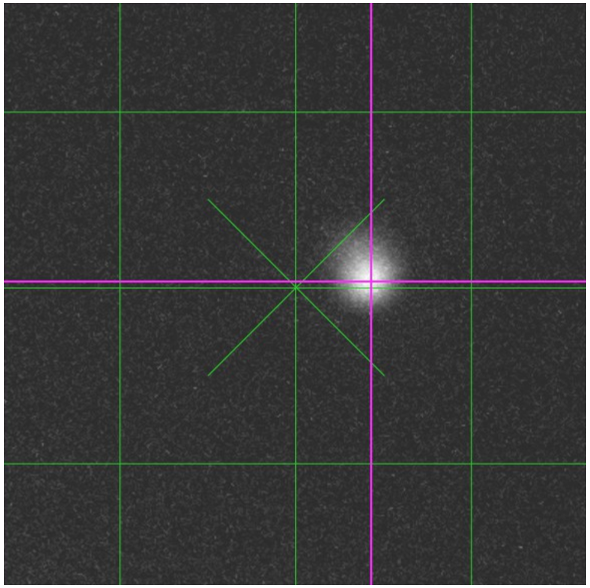
Pleora iPort Analog-Pro

- operational: 3 cameras
- well supported under Linux
- some stability problems
    - frame grabber stops sending images
    - maybe due to too many dropped packets?
    - bad µTCA configuration?
    - frame grabber internal counter, which stops data receiver on too man packet resends?

END

Special thanks to...

- André Petit – PLC programming
- Rolf Lonsing – PLC and electronics
- Christian Schmidt – CPS8 controller box
- Christoph Dorn and group – mechanics
- Beata Walaseck-Höhne - Coordination



view into the Cryring ion source

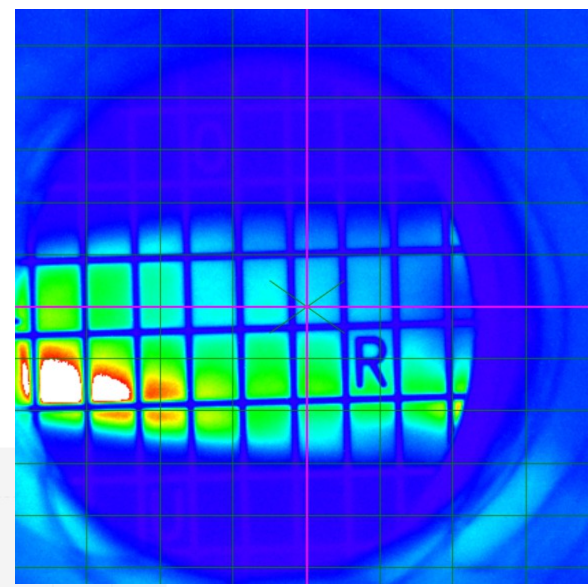
Thank You for Your Attention...

Full Width Half Maximum

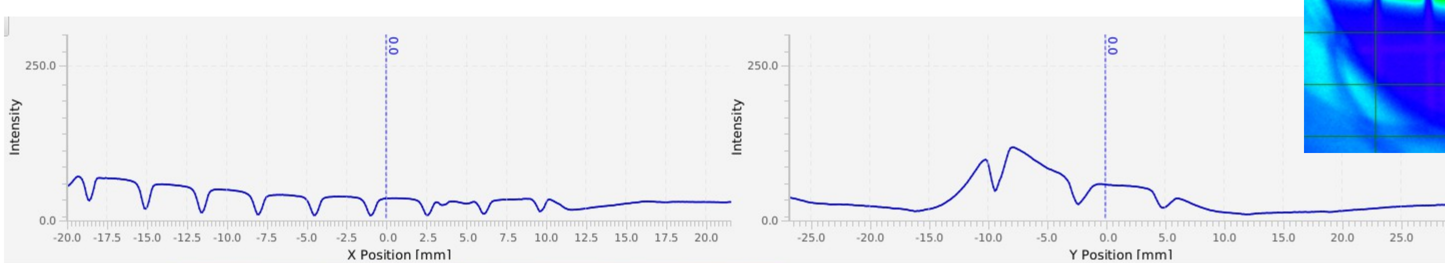
Full Width Half Maximum is calculated on the profiles

1. Simple Algorithm

- find position and value of brigthest pixel
- find value of dimmest, non-zero pixel
- go to both sides of brigthest pixel until value drops below half of distance between maximum value and mininimum value



Fails on older scintillating screens with etched-on grid!



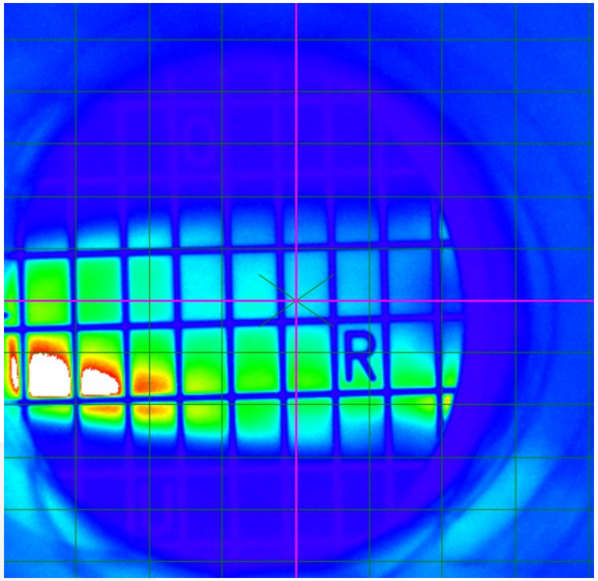
Full Width Half Maximum

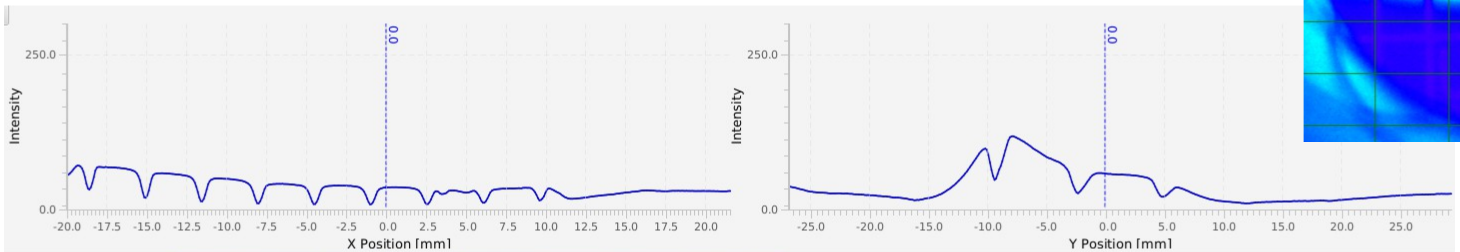
Full Width Half Maximum is calculated on the profiles

2. Standard Deviation

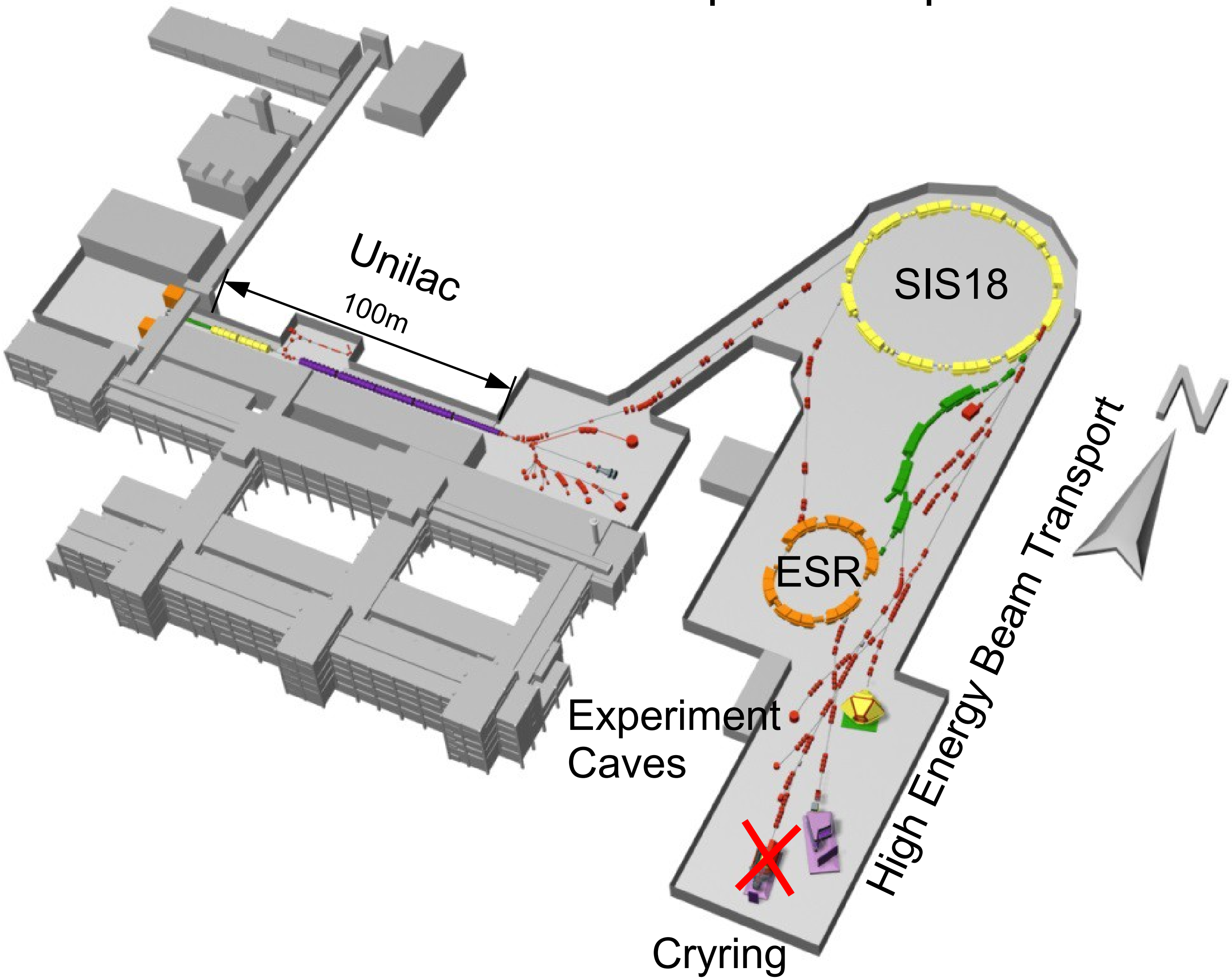
- find position and value of brigthest pixel
- find value of dimmest, non-zero pixel
- calculate standard deviation of profile's center-of-brightness
  - use only data points with

$$v > v_{min} + (v_{max} - v_{min})/4$$



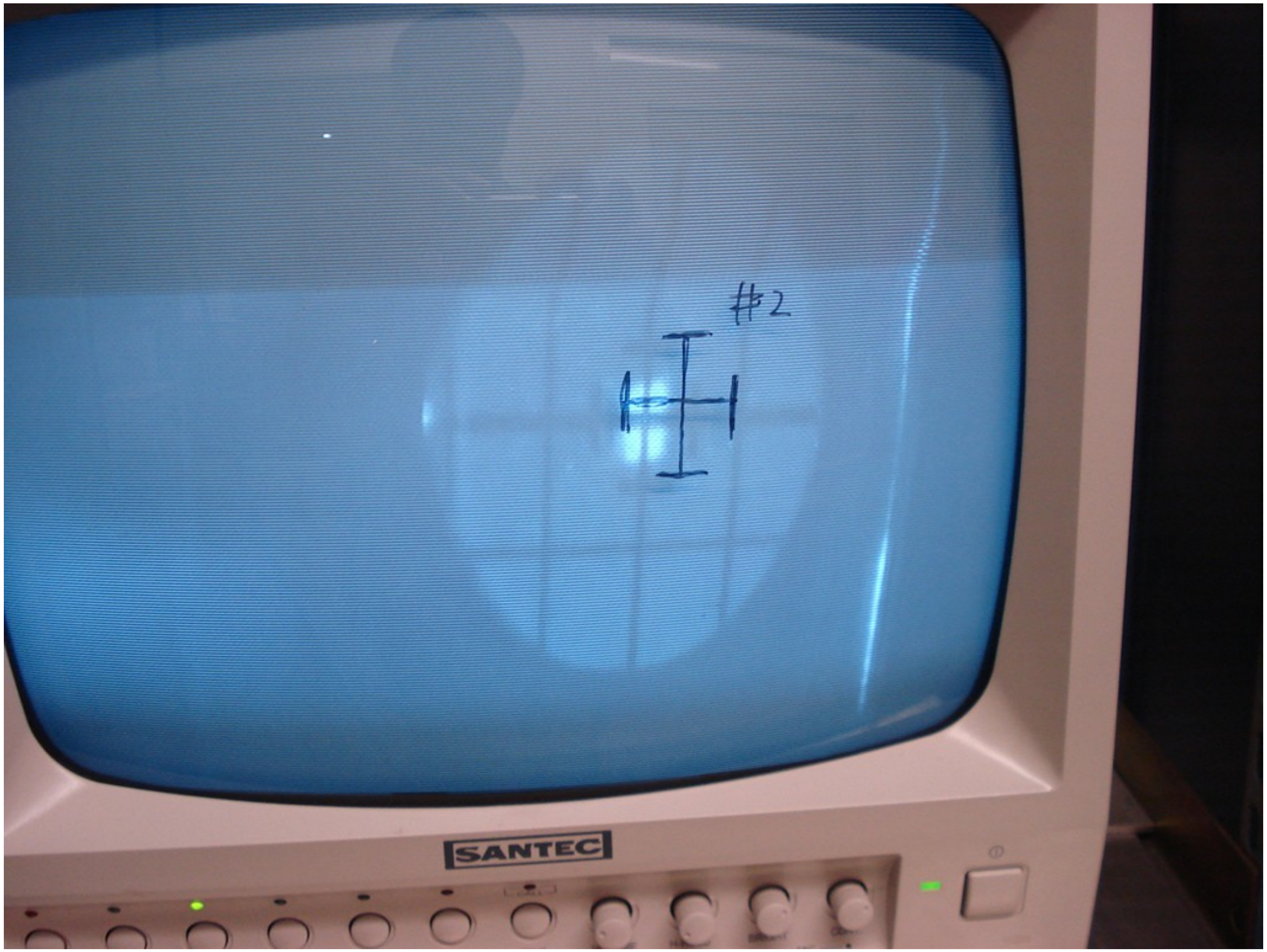


GSI accelerates all ions from protons up to Uranium



Stone Age Beam Diagnostics

Scintillating Screen Readout at GSI prior to 2013



Lots of room for improvement . . .