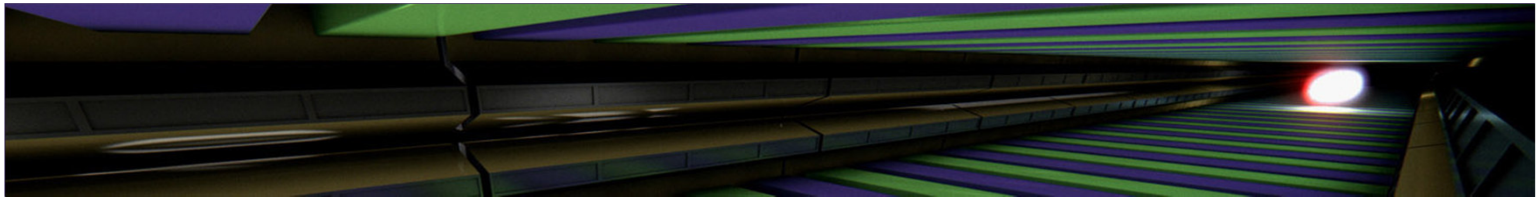


Imaging Stations for Invasive Photon Diagnostics at the European XFEL

XFEL User Meeting

Photon Diagnostics Satellite

Cigdem Ozkan

26th Jan 2012

Scope & Aim

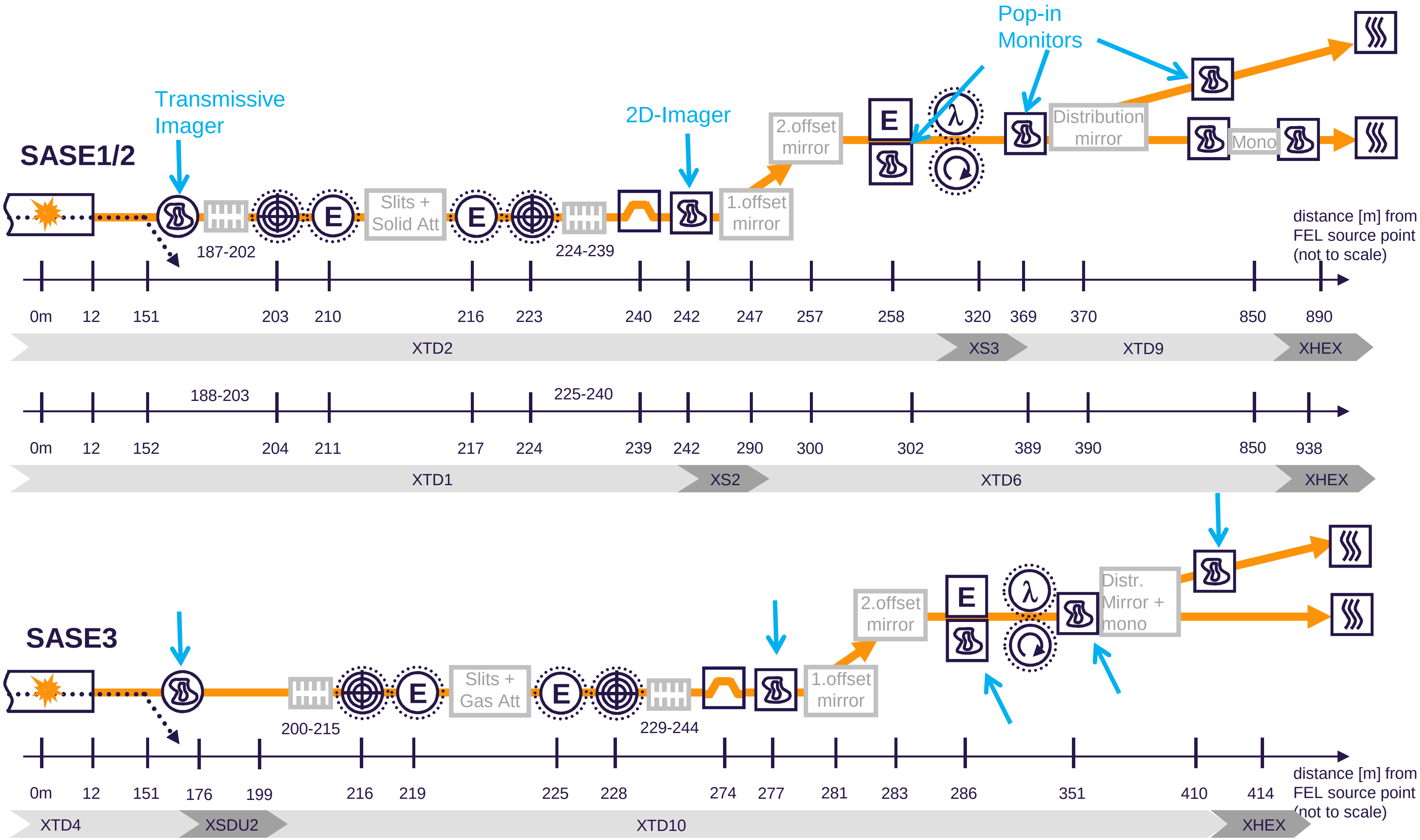
- Imaging stations for photon beam diagnostics located between electron beam separation and experimental hall, for the three Undulator beamlines: SASE1, SASE 2 & SASE3

- Reliably measure the beam profiles → establish, diagnose & optimize lasing

Types of Imaging Stations

- Imaging of two types of radiation:
  - Spontaneous Radiation (SR)
    - ➔ Undulator gap adjustment and phase tuning with the Undulator Commissioning Spectrometer (K-monochromator)
    - ➔ Trajectory alignment
  - SASE Radiation
    - ➔ Beamline Commissioning and maintenance → align optical elements, re-adjustment of optical elements
- Three types of Imaging Stations:
  - Transmissive Imager
  - 2D-Imager
  - Pop-in Monitors
- Based on optical imaging of an X-ray scintillation material
- Aim of high spatial resolution
- Simultaneous use of at least 2 Imaging Stations
- **Total number of stations: 19**

Locations



N. Kohlstrunk, X-ray Beam Layout, EDMS Nr.: 2278111,
Release: 29 Aug 2011

Transmissive Imager

- First ever device downstream of Undulators to “see” beam
- Aid in measuring beam pointing
- Not transmissive in SASE3 energy range

- Requirements:
  - Scintillator has to be radiation hard and thin enough to transmit a fraction of the beam
  - Camera and optics need to be shielded to avoid radiation damage
  - Must operate at the bunch repetition rate of 10Hz
  - Statistics required from the images acquired: center-of-mass, intensity, width for a Region-Of-Interest
  - Possibility of image/data storage

European XFEL

2D-Imager

- Capturing 2D beam profile:
  - Check the functionality of any upstream beamline components
  - Aid in commissioning of the Undulators
  - Visualization of the initial lasing after first time of establishing SASE

- Requirements:
  - SR vs FEL visualization
    - ➔ Two Field-of-Views
    - ➔ Two types of scintillators (different materials & thicknesses)
    - ➔ Two cameras
      - low-light level capability for SR
      - high dynamic range for FEL
  - Function at the bunch repetition rate of 10Hz
  - Algorithms to extract parameters for Undulator commissioning
  - Possibility of image/data storage

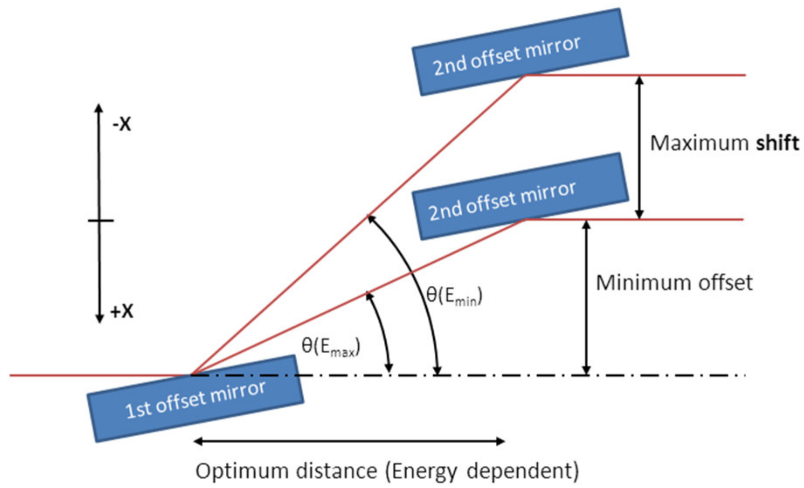
Pop-in Monitors

- Alignment and re-adjustments of optical elements:
  - Offset mirrors
  - Distribution mirrors
  - Hard X-ray monochromators (SASE1/2)
  - Soft X-ray monochromator (SASE3)

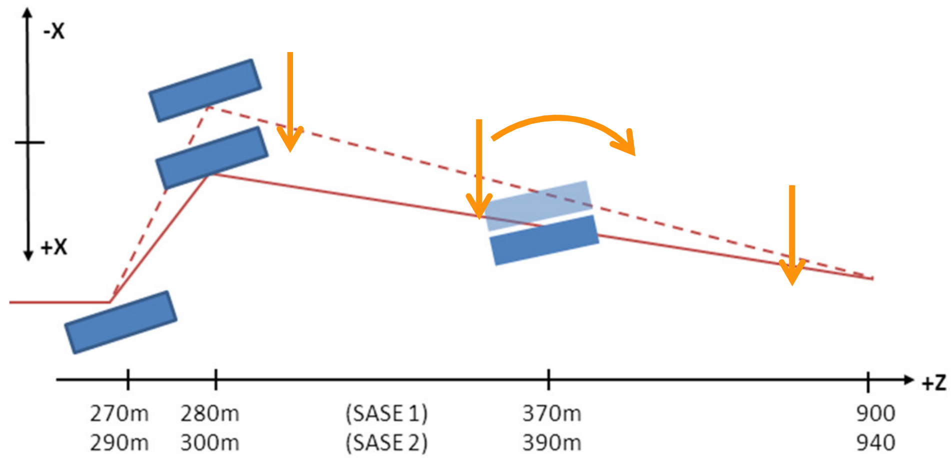
- Requirements:
  - Flexibility in motion where beam displacements are expected
  - High resolution spatial imaging required
  - Function at the bunch repetition rate of 10Hz
  - Statistics required from the images acquired: center-of-mass, intensity, width for a Region-Of-Interest
  - Possibility of image/data storage

Pop-in Monitors (mirrors)

- Offset mirrors
  - Horizontal deflection range:
    - ➔ 25-57mm SASE1/2
    - ➔ 35-125mm SASE3



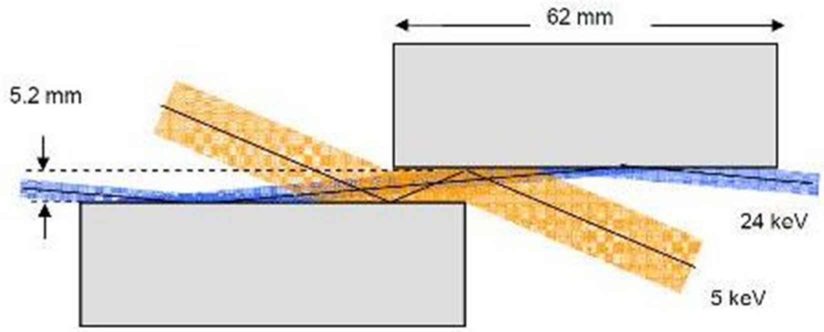
- Distribution mirrors
  - Horizontal deflection range:
    - ➔ max ~46mm SASE1/2
    - ➔ max ~100mm SASE3



A. Trapp, *Transverse and angular motion, tolerances, resolution calculations,* August 2011

Pop-in Monitors (monochromators)

- Before and after Hard X-ray monochromators
  - Artificial channel-cut crystal
  - Vertical deflection: 9.7-19.3mm
  - Motion to additionally account for vertical deflection is required for downstream pop-in



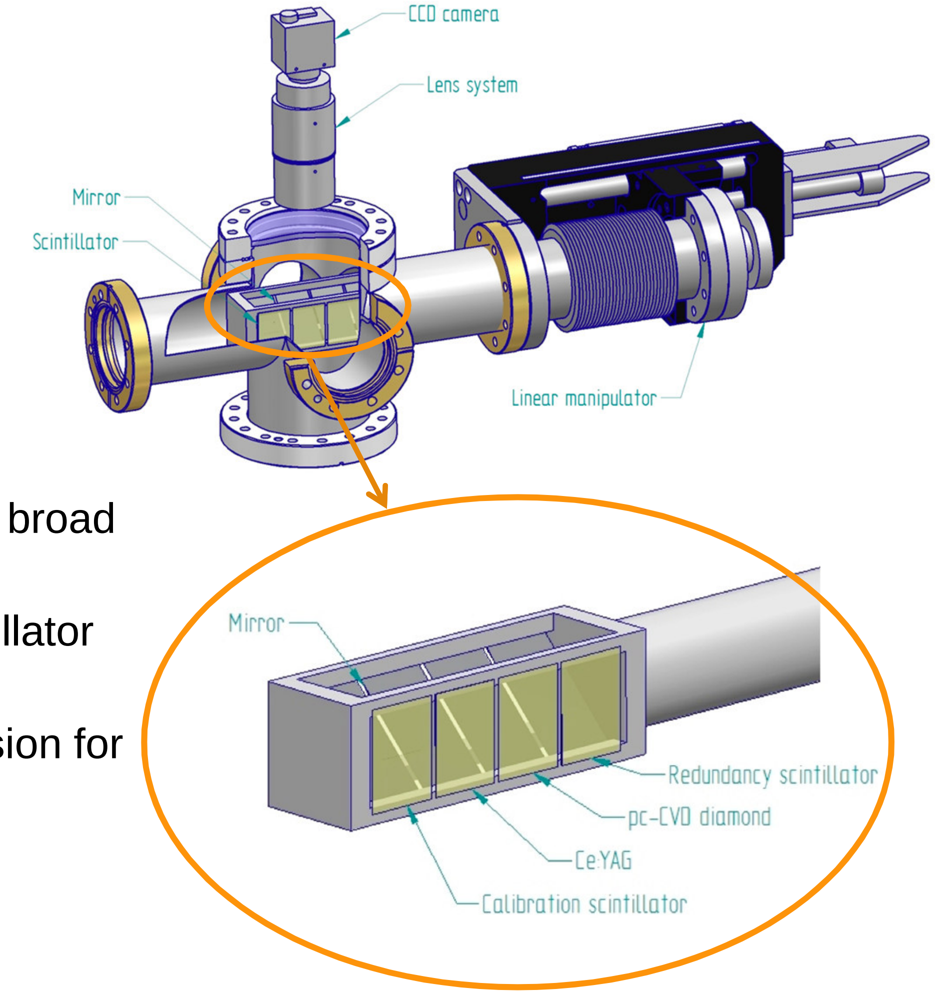
H. Sinn et. al., Conceptual Design Report X-ray Optics and Beam Transport, http://edmsdirect.desy.de/edmsdirect/file.jsp?edmsid=2081421

- Soft X-ray monochromator
  - Imager located downstream → chose spectral mode
  - Horizontal and vertical deflections: TBD

Final design has to accommodate beam deflection

Main Components

- Chamber
  - On linear adjustment stages
- Scintillator screens
  - Calibration screen
  - On-axis screen
  - Redundancy screen
- Mirrors
  - Quality: optical grade
  - Reflectivity: > 95% @ 45º incidence, in broad spectrum
  - Viewing aperture matches size of scintillator screen
  - Thickness: suitable for >50% transmission for X-ray energies >5keV
- Cameras
- Optics



Scintillator Screens

- Choice depends on:
  - Light Yield
  - Emission wavelength
  - Effect of material on achievable spatial resolution
  - Survival: Number of pulses

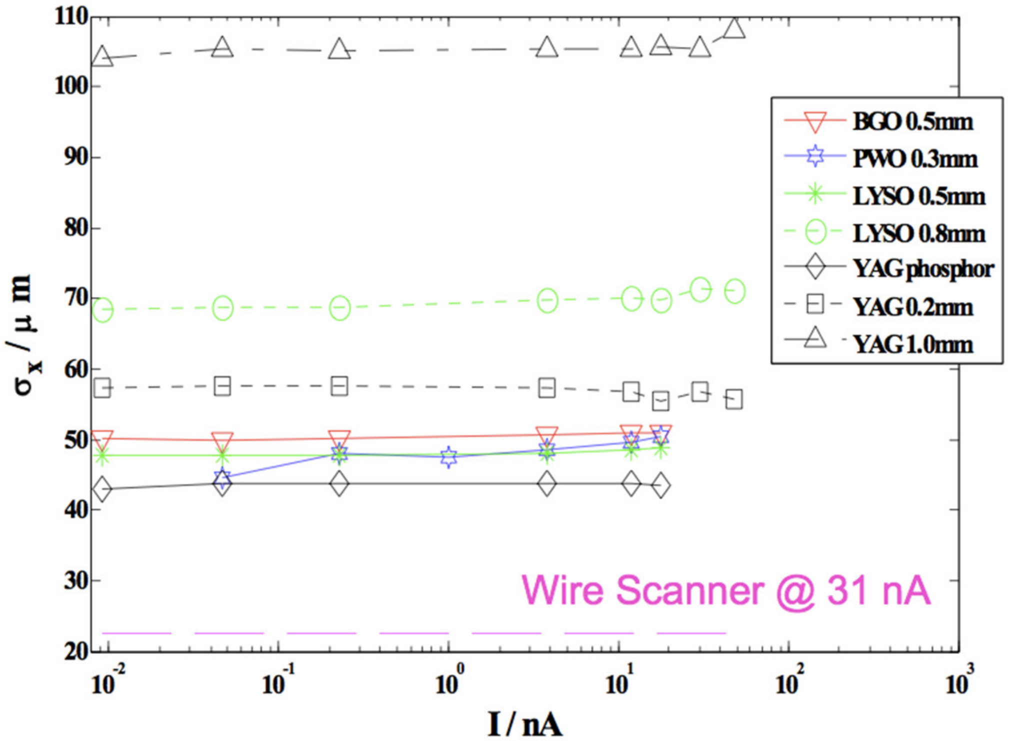
Scintillator Candidates	Density (g/cm^3)	Emission Wavelength	Decay time (ns)	Index of Refraction	Light Yield	Intended Imager
YAG:Ce	4.55	550nm	70	1.82	35 ph/keV	2D Imager (SR,FEL), Transmissive, Pop-in
LuAG:Ce	6.73	535nm	70	1.84	28 ph/keV	2D Imager (SR)
LYSO	7.30	375nm	41	1.81	32 ph/keV	2D Imager (SR)
BGO	7.13	480nm	300	2.15	8-10 ph/keV	2D Imager (SR)
Boron doped pc-CVD Diamond	3.515	550-700nm	-	2.41	-	Transmissive (FEL), Pop-in

Does not match QE of most cameras **Low yield for SR is not good!**

Scintillator Screens - Resolution

- Scintillator parameters affecting resolution:
  - Material
  - Thickness
  - Observation geometry (variation of scintillator-beam angle and camera-beam angle)
- Experiments with electron beam comparison of spatial resolution obtained from images of illuminating
  - BGO, YAG, LYSO, PWO
  - Resolution of YAG > LYSO

Investigation: same for X-ray interaction with scintillators



*G. Kube et. al., Resolution studies of inorganic scintillation screens for high energetic and high brilliant electron beams, presentation Workshop of Scintillating Screen Applications

Scintillator Screens - Damage

- Melt thresholds:

	Material Properties			Absorbed Dose (eV/atom) @ 1nC bunch charge, 200m from source point 1mJ pulse energy			
	Heat Capacity (J/g/K)	Thermal Conduct. (W/cm/K)	W_{melt} (eV/atom)	7.75keV	12.4keV	20.7keV	3.1keV
Diamond	0.502	15	1	1.7E-04	4.3E-05	1.9E-05	1.4E-3
YAG	0.59	0.13	0.57	1.4E-01	3.7E-02	7.8E-02	0.8
LYSO	0.31	0.036	0.6	9.8E-01	1.2	4.8E-01	5
LuAG	0.411	0.096	0.59	4.2E-01	5.E-01	1.9E-01	2.1
BGO	0.040	0.02	0.34	6.6E-01	3.E-01	3.4E-01	3.7

- Number of shots survival:

Number of pulses	3.1keV	7.75keV	12.4keV	20.7keV	0.28keV
Diamond	88	Whole train	Whole train	Whole train	85
YAG	5	31	181	70	4
LYSO	2	7	6	15	3
LuAG	3	10	8	22	4
BGO	0	0	1	1	0

Diamond is the optimal candidate for FEL imaging

Single-shot mode for FEL imaging

Optics

- Resolution Requirements:
  - To resolve position jitter of 0.1σ → Settle on resolution of 0.05σ → best case resolution: 6-7μm
  - Expected beam drift in a day *:
    - 7-10μm at Undulator, 30-40μm at first mirrors, 40-50μm at distribution, ~100μm at experimental hall
  - Additional requirements: reproducibility of scintillator positioning

- Large format lens design with an extended depth-of-field & short Working Distance (WD)
  - Two FOVs
    - SR imaging: 30x30mm^2
    - FEL imaging: 20x20mm^2
  - Corresponding Sensor sizes
    - 2500x2200 pixels for SR
    - 1600x1200 pixels for FEL
  - Zoom optics for Pop-in Monitors
  - WD = 86-160mm
- Detailed info in CDR (under review)

* H. Sinn et. al., Conceptual Design Report X-ray Optics and Beam Transport, http://edmsdirect.desy.de/edmsdirect/file.jsp?edmsid=2081421

Cameras

- Requirements:
  - Have to deliver images at machine repetition rate (10Hz)
  - High sensitivity
  - Large dynamic range
  - Low noise
  - External trigger
- h/w and s/w compatibility with DAQ&Control system
- Built-in cooling system preferable for performance stability
- Commercial products based on visible light CCD or CMOS sensors

Device Controls

Given one or more imaging stations, in collaboration with WP76:

- Synchronization of cameras with train arrivals (XFEL.EU timing system)
- Controlling the cameras (h/w & s/w)
- Control of motors and other mechanical pieces via Beckhoff Controls:
  - Motors – movement of screen holder
  - Limit switches – screen stage safety
  - Environmental sensors – camera cooling
  - Camera power – cycle power
- Processing and storing of camera images
- Visualization of image and control data

Control/DAQ concept

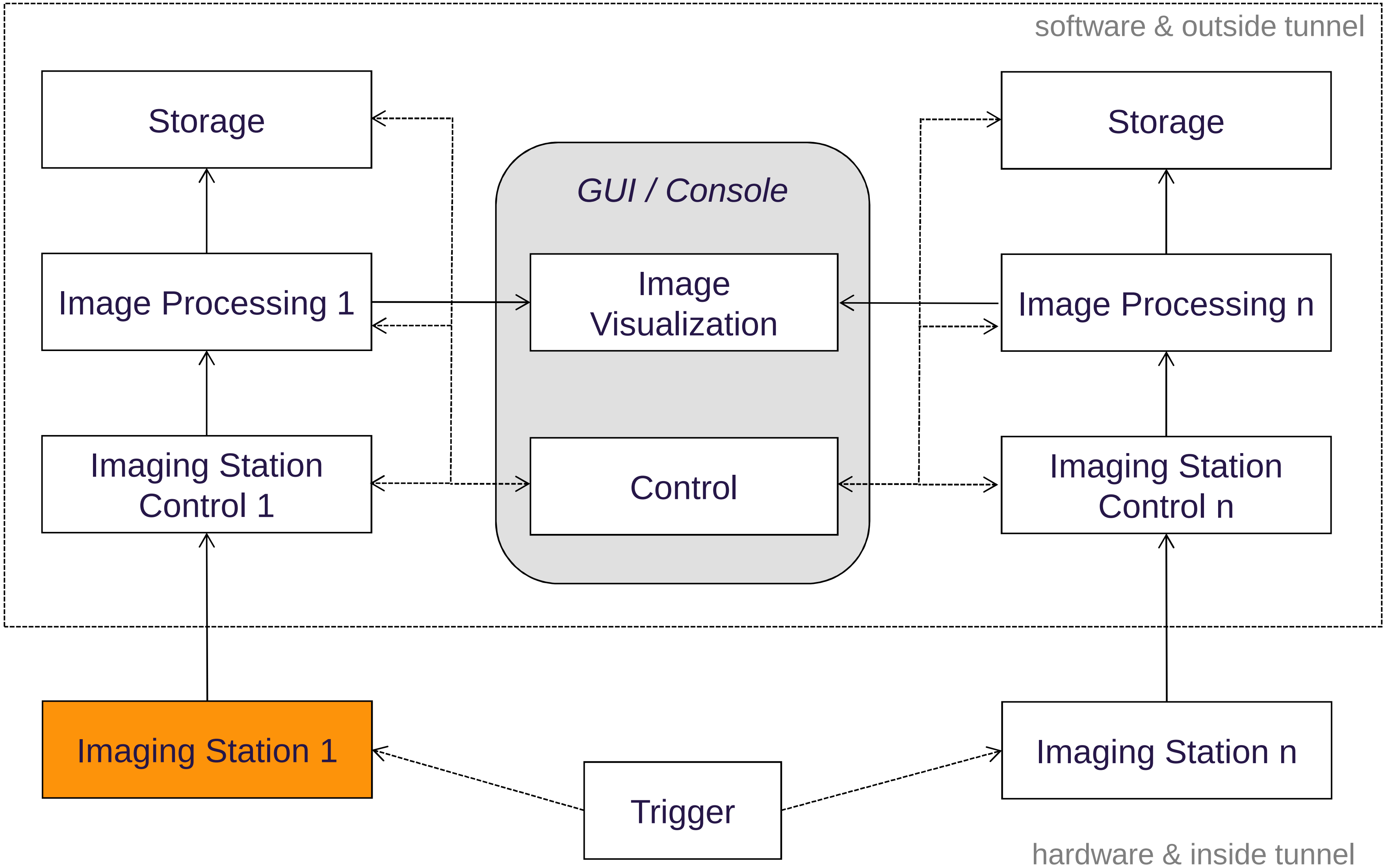
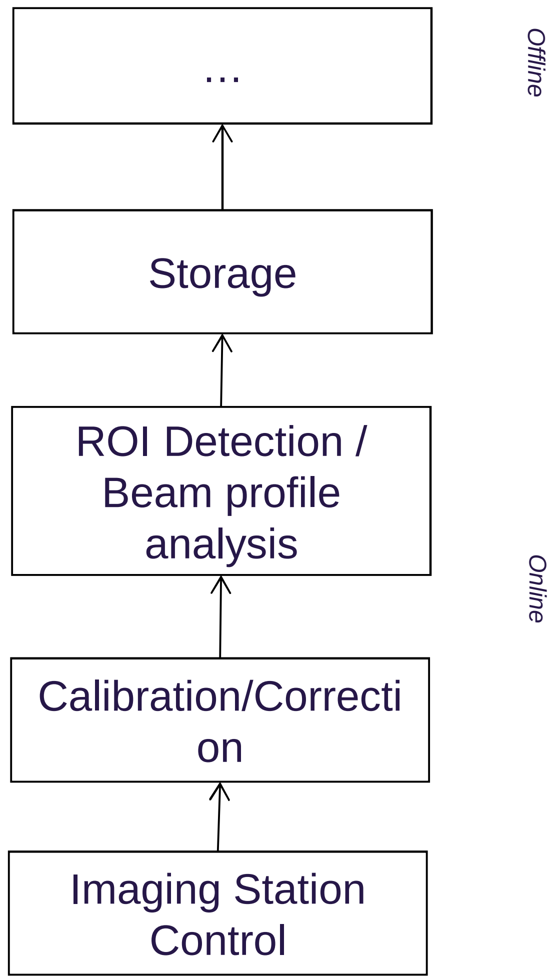


Image processing and storing

- Processing algorithms will be implemented in a modular way
- Simple image analysis/manipulation tasks can be done online (must match the 10Hz frame rate)
- Time-consuming tasks → Offline beyond the initial storage point in the pipeline
- Images may be visualized at a lower frame rate (and/or lower resolution)



Conclusions

- Building prototype this year
- Scintillator choice
  - YAG:Ce and/or LuAG for SR
  - YAG:Ce and B-doped pc-CVD Diamond for FEL
- Commercial cameras have been tested and integrated into software for image capture, external trigger functionality.

- Further investigation into:
  - Scintillator screen damage threshold in XFEL.EU energy range due to
    - → high-energy SR background
    - → FEL beam
  - Suitable mirrors (flatness, damage concerns) OR
  - Changing observation geometry (related mechanical design limitations)

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Thank you for your attention!!!