eli beamlines

MTCA.4 at ELI-Beamlines – status and plans

Petr Pivonka, Control Systems Dept @ ELI-Beamlines

Fyzikální ústav
Akademie věd ČR, v. v. i.

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Agenda

- Basic facts on ELI Beamlines
- Image acquistion & image processing at ELI
- MTCA applications at ELI: adaptive optics
- MTCA applications at ELI: beam alignment
- Further plans & Conclusions

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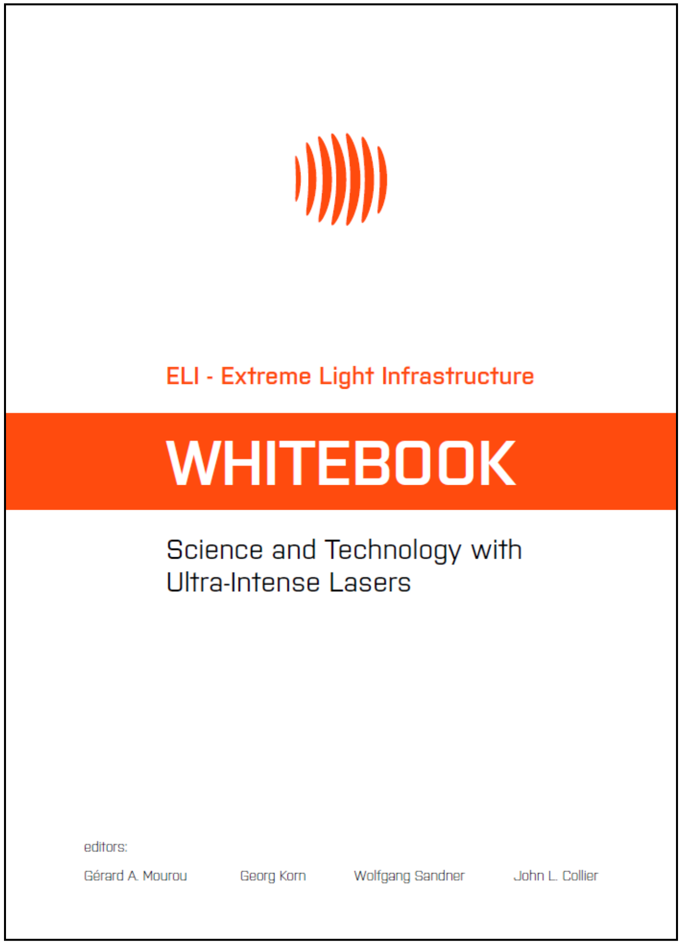
Project origins

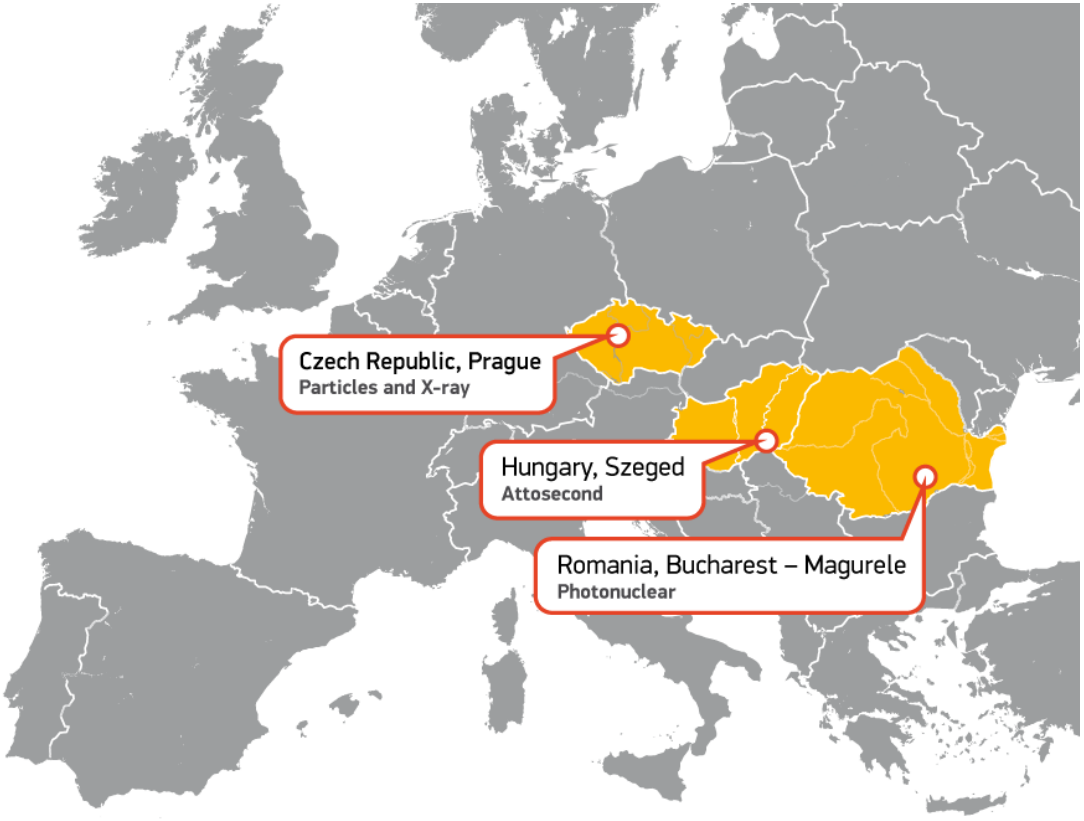

ELI - Extreme Light Infrastructure

WHITEBOOK

Science and Technology with
Ultra-Intense Lasers

editors:

Gérard A. Mourou Georg Korn Wolfgang Sandner John L. Collier



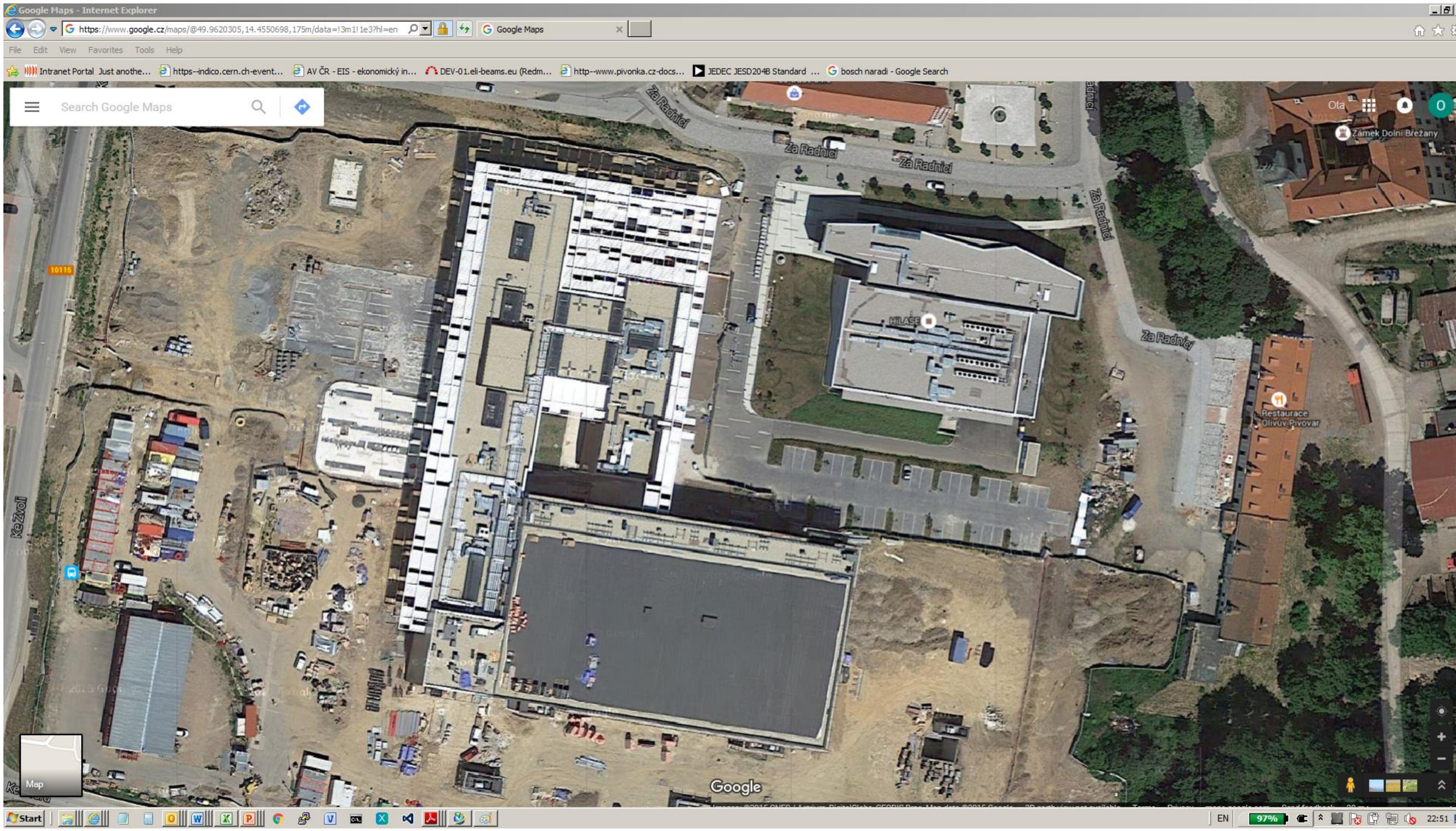
Source: ELI Attosecond, Hungary

ELI in the Czech republic

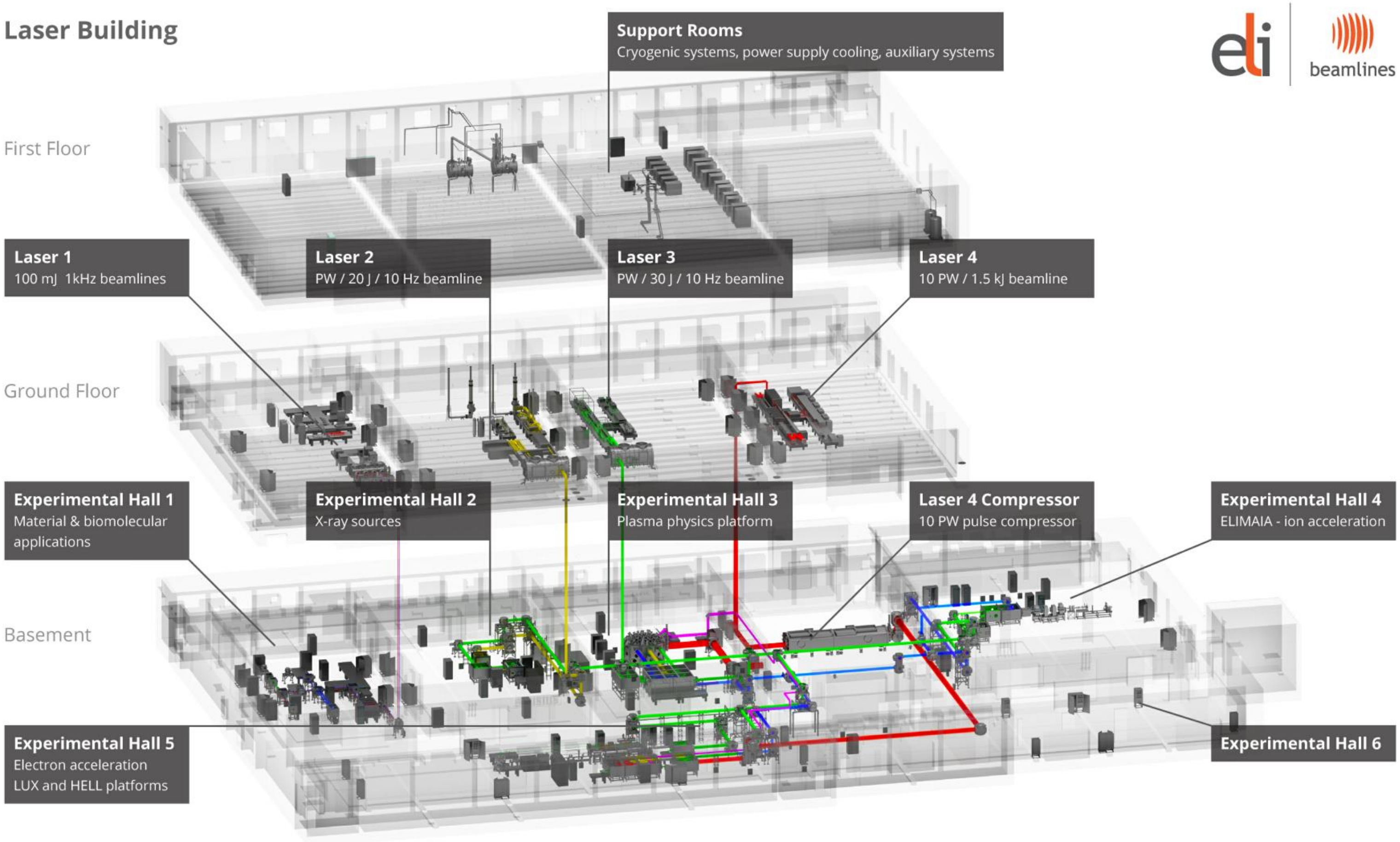
Location: Dolní Břežany
(SSW off Prague)

Cost: EUR 278M

Construction site



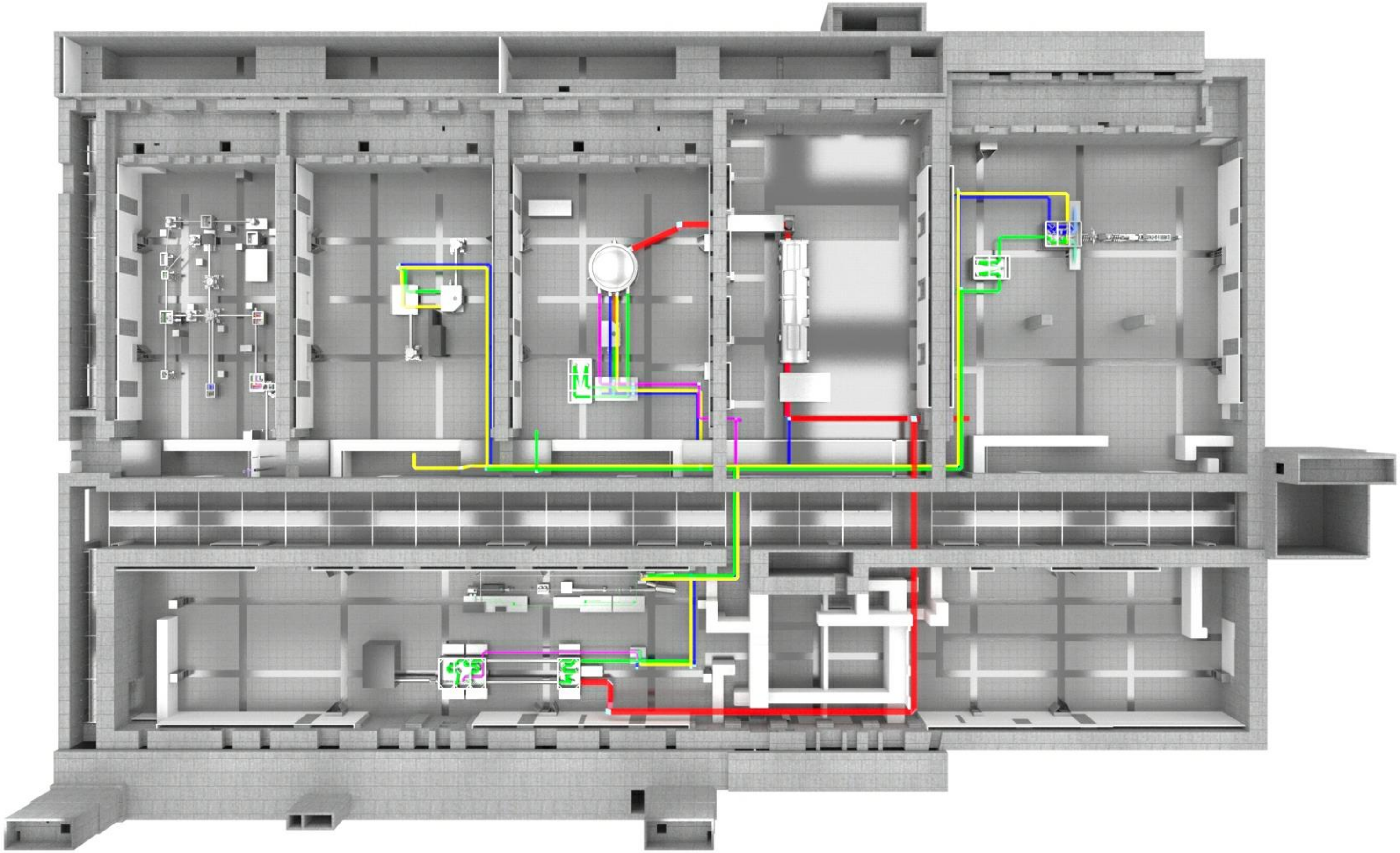
Facility structure



Beamlines

Beamline		Wavelength	Repetiton rate	Peak power	Pulse energy	Pulse duration	Beam profile	Beam shape	Beam dimensions		Delivery
L1		830-870 nm	1 kHz	1 TW	50-200 mJ	30-15 fs	GAUSSIAN	CIRCULAR	DIA 20 mm		IN-HOUSE DEV
L2		850 nm	10 Hz	100 TW	2J	15 fs	FLAT-TOP	SQUARED	80x80 mm		
L3		750-850 nm	10 Hz	1PW	20-50 J	50-20 fs	FLAT-TOP	SQUARED	20x20 cm		LLNL
L4		800-1200 nm	1/min	10 PW	1.2-1.8 kJ	150-120 fs	FLAT-TOP	SQUARED	40x40 cm		EKSPLA/NE

Beam transport



Beam transport & diagnostics

Beam transport system:

- delivers laser beams to experimental halls (L1-E1, L234-E23456)
- consists of: switchyards, delay lines, alignment, diagnostics
- key parameters: pointing stability 10 µrad, path length up to 100 m

Beam diagnostics:

- power domain (average/peak power, pulse energy)
- spatial domain (wavefront shape)
- temporal domain (pulse duration, spectrum)

Data intensive, RT response

Beam alignment:

- RT image processing
- pattern recognition

Need for high performance platform:
MTCA.4 and FPGA

eli beamlines

Image sensors at ELI

Camera connectivity protocols:

- CoaXPress — A JIIA standard
- GigE Vision
- USB3 Vision
- Camera Link

GigE Vision, USB3 Vision and Camera Link: An AIA standard

COTS industrial-grade still cameras:

- most principal image sensor at ELI
- multiple distinctive applications
- need for unified control approach

Source: Allied Vision, Baumer, Teledyne Dalsa

Camera software abstraction:

GEN<i>CAM GenICam

An EMVA standard

Unified programming interface for cameras, consisting of:

- *GenApi* - camera configuration
- *SFNC* - naming conventions
- *GenTL* - enumeration & grabbing

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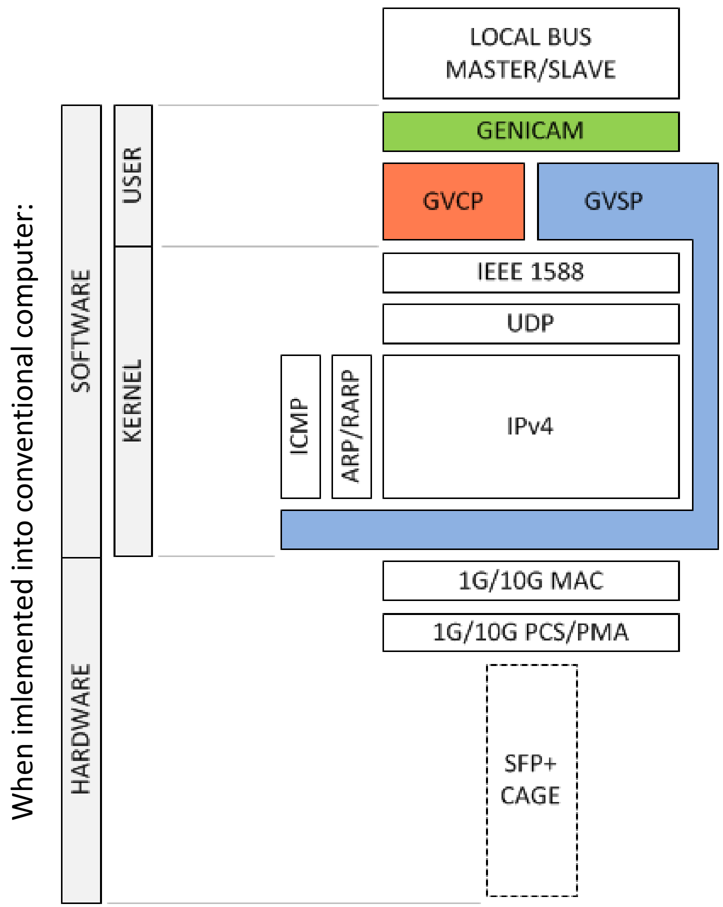
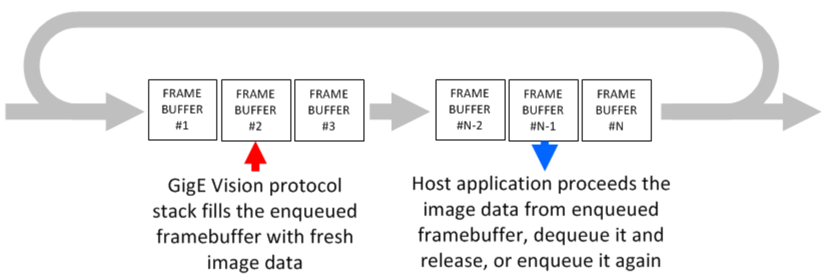
GigE Vision protocol stack in FPGA

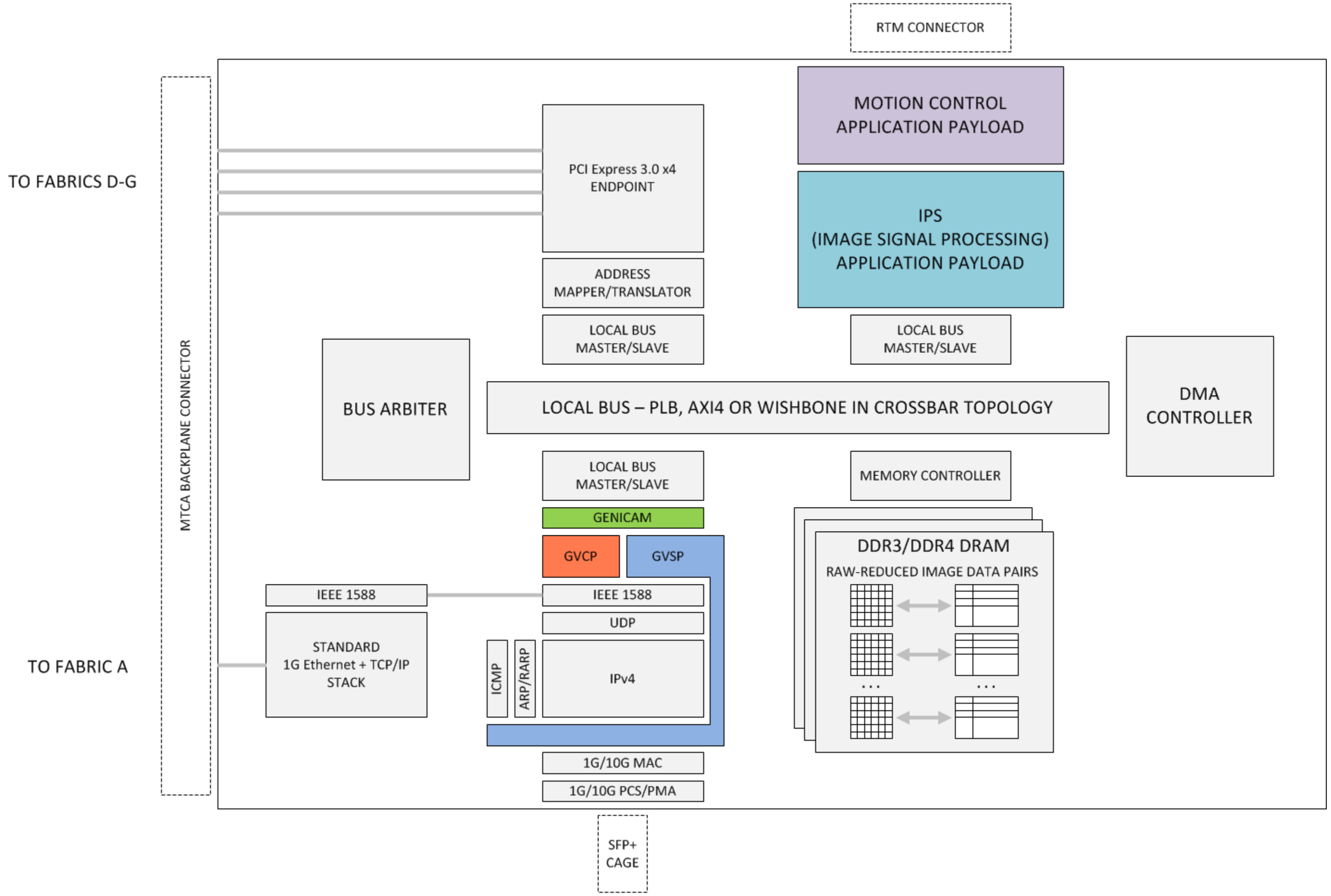


GenICam – its GenTL (transport layer)
GVCP – GigE Vision Control Protocol
GVSP – GigE Vision Stream Protocol

GigE Vision provides the stream of still images, not the video-stream !



Common FPGA application framework



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Tools & implementation

HLS, C/C++, OpenCL, Mathlab/Simulink

Implementation scheme:

- COTS (or customized COTS):
  - FPGA AMCs w/ FMC
  - FMC w/ conventional interfaces: RJ-45/SFP/SFP+/QSFP ...
- In-house dev:
  - RTMs & FMCs for specific motion control/drives
  - FMCs w/ specific interfaces

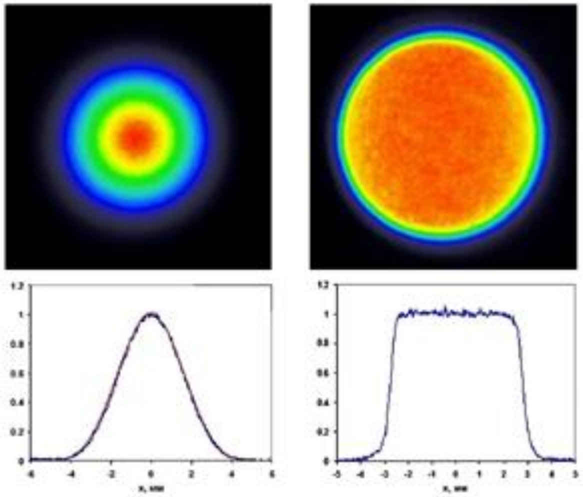
Core functional blocks implemented into FPGA AMCs featuring:

- Kintex-7 or Virtex-7 grade FPGA
- good routing of GTx and LVDS to all AMC interfaces (Fabrics, FMC, RTM)
- DDR3/DDR4 DRAM about 8-16 MB
- dual-port SRAM is "nice-to-have" >>> MESSAGE TO MANUFACTURERS-)

#1 - **Adaptive optics**

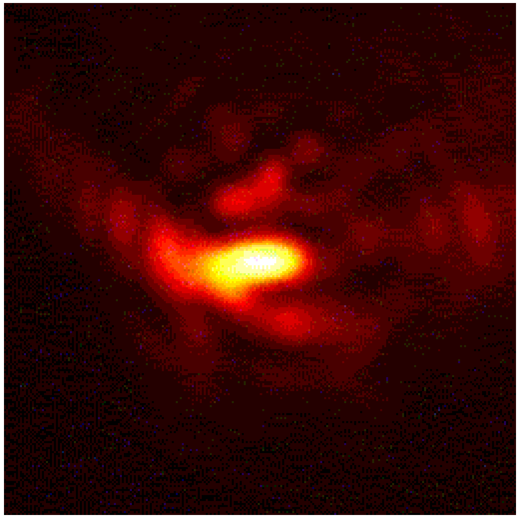
Applications: adaptive optics

Expectations ...



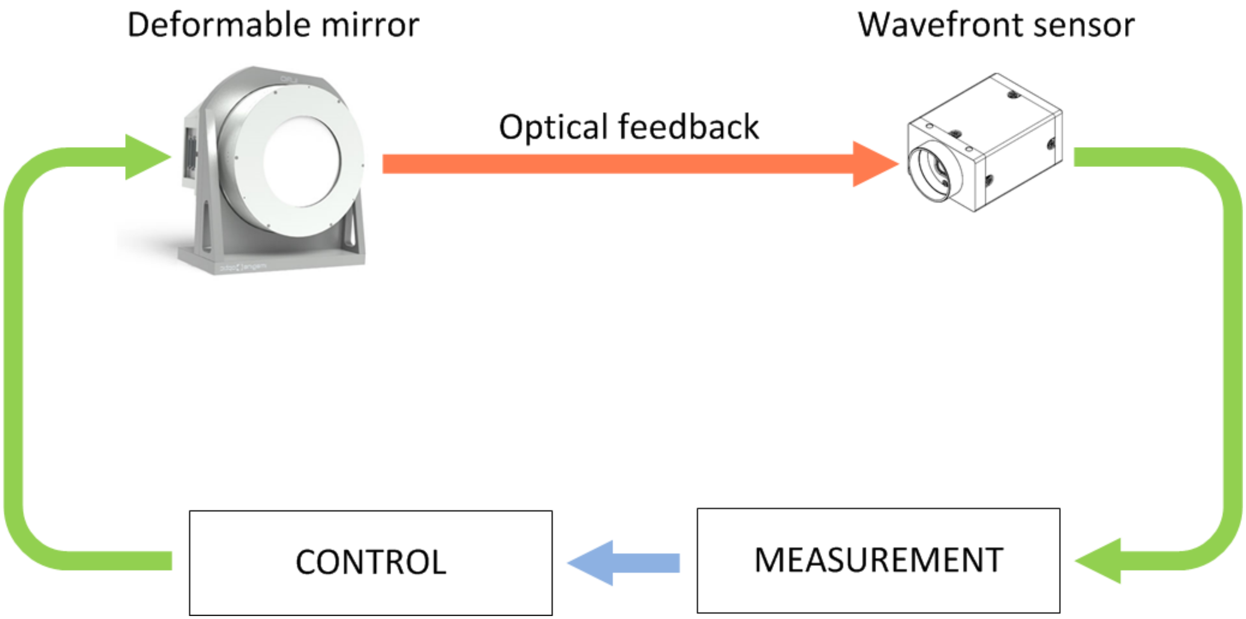
Source: SHIOM, Shanghai, China

... and reality

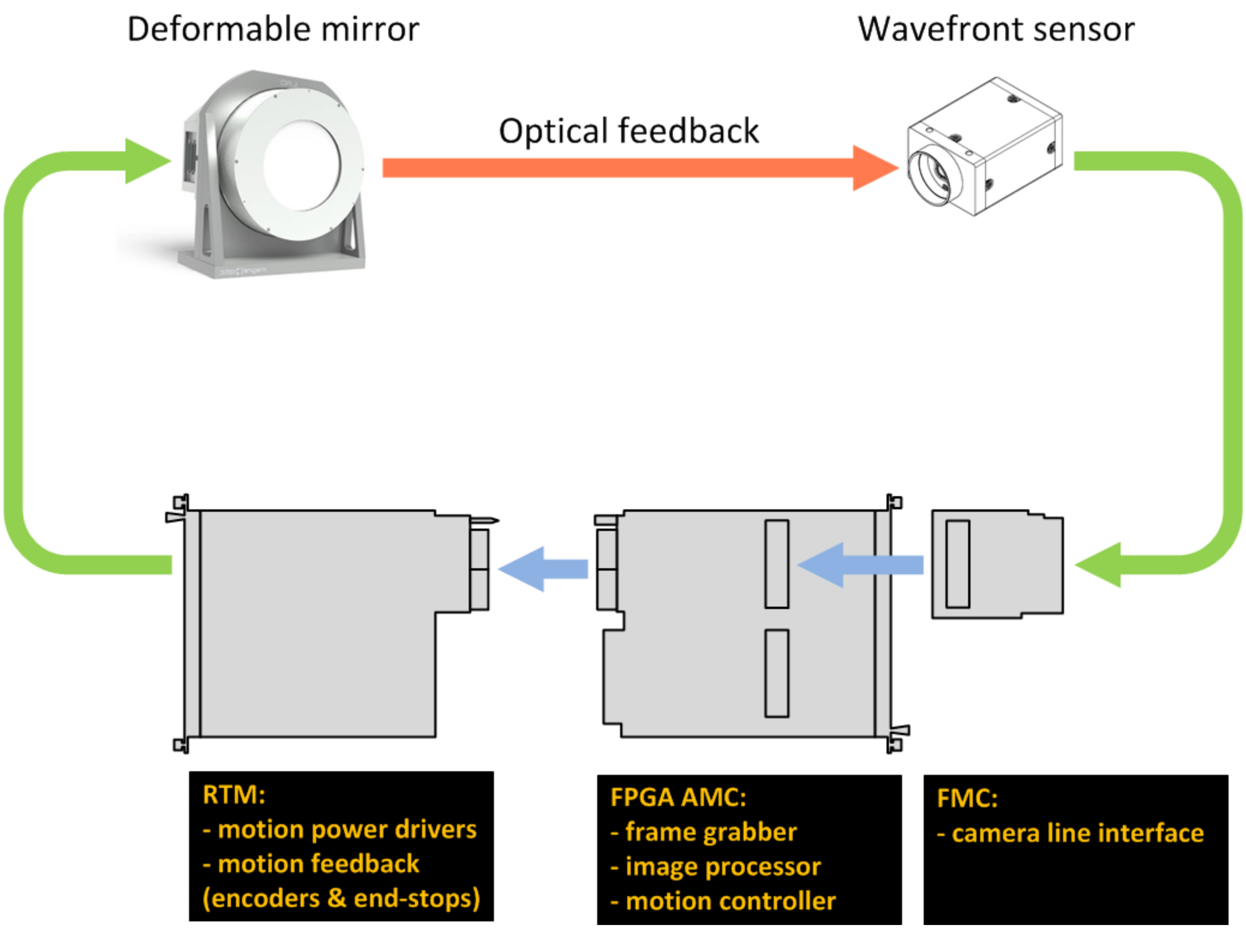


Source: OOO Aktyivnaya Optika NaitN, Shatura, Russia

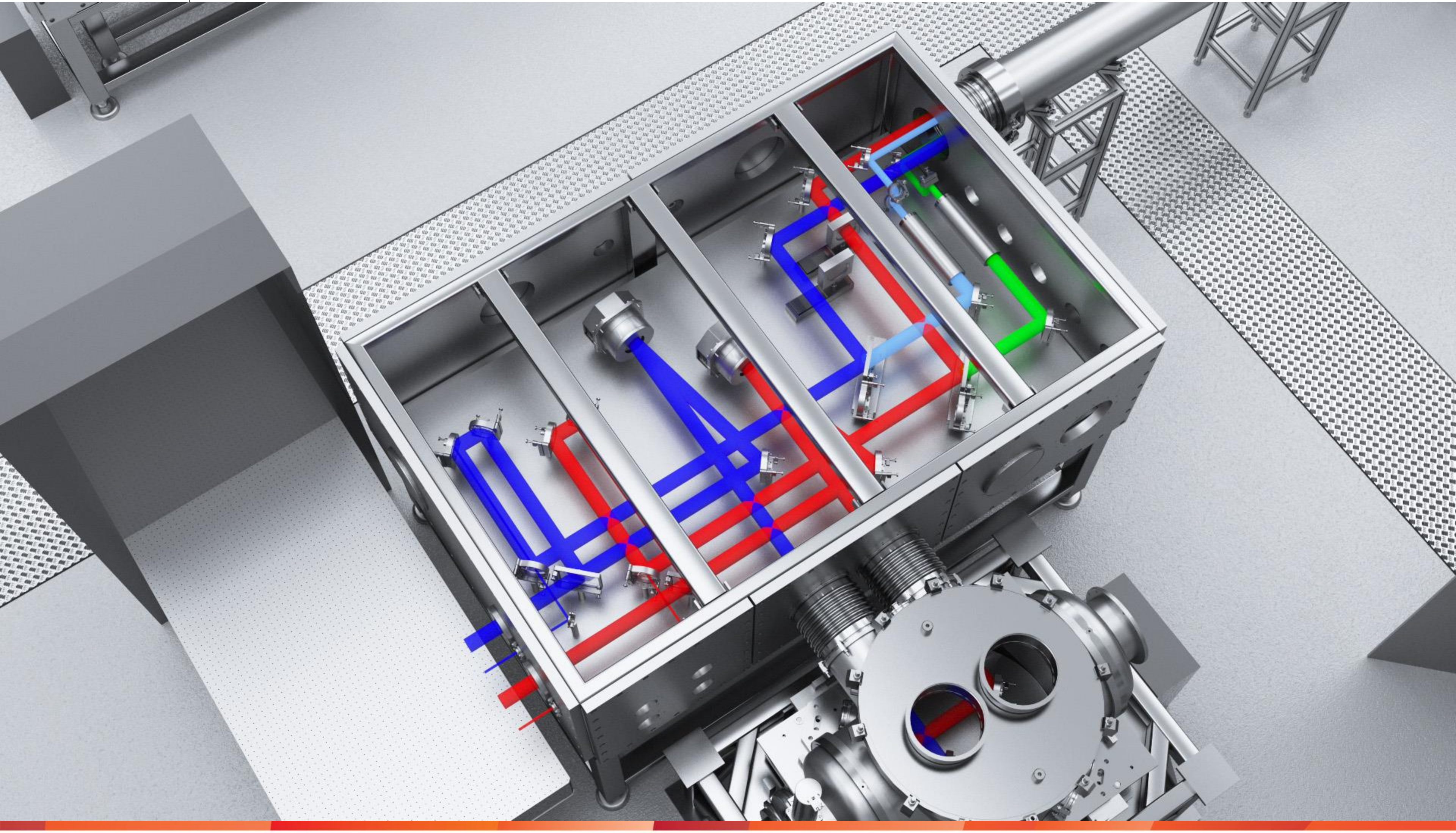
Applications: adaptive optics



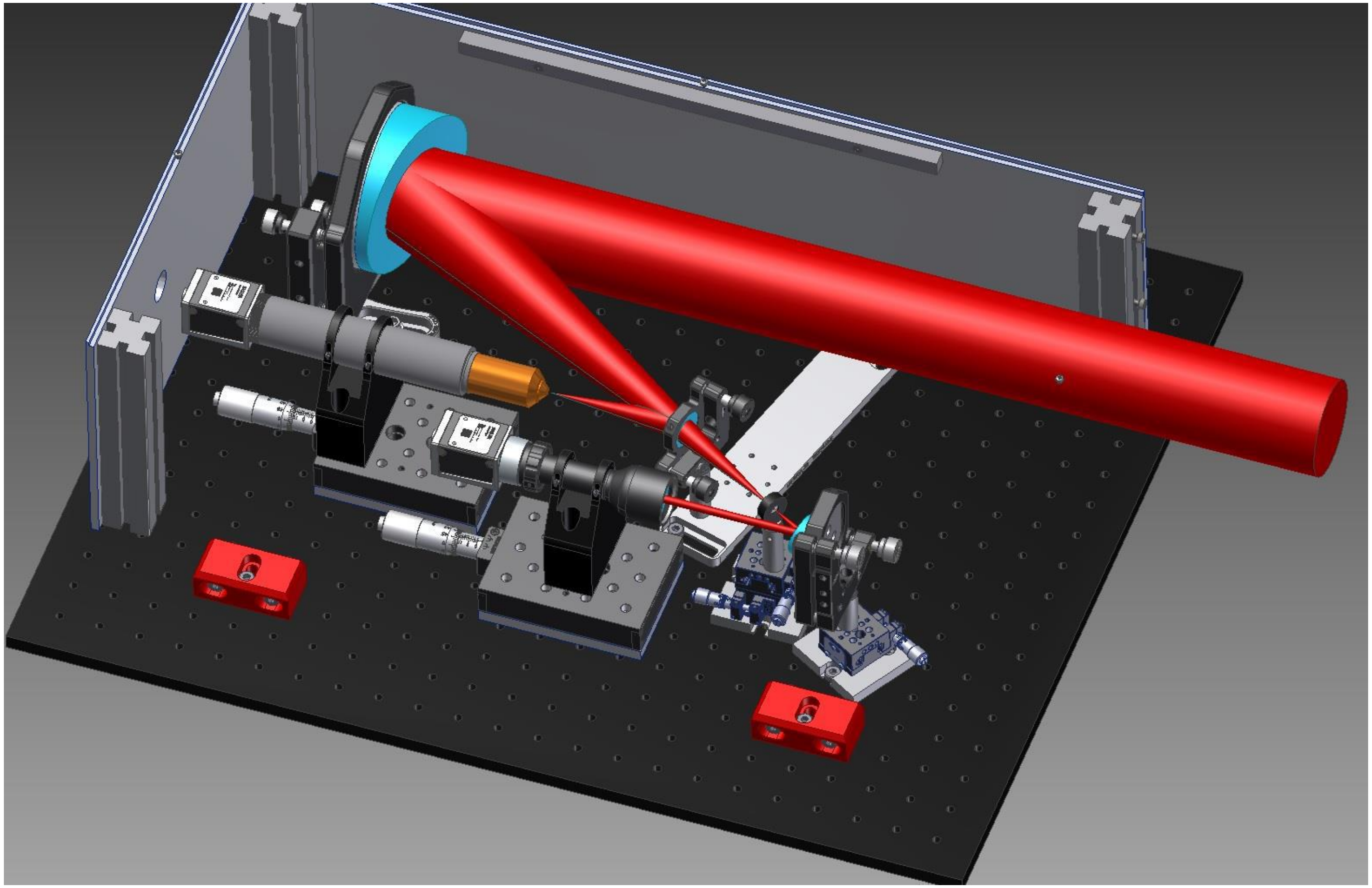
Applications: adaptive optics



Applications: adaptive optics



Applications: adaptive optics



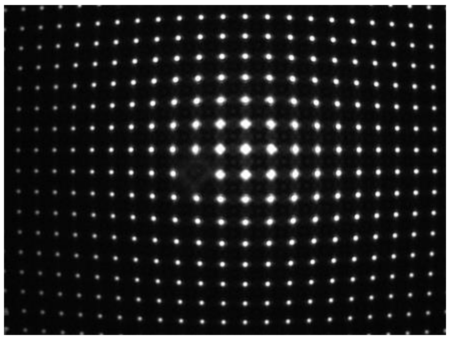
Source: ELI Beamlines

Applications: adaptive optics

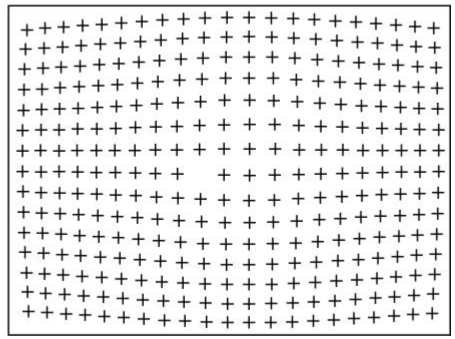
Wavefront sensor (Shack-Hartmann) image processing

Arbitrary wave

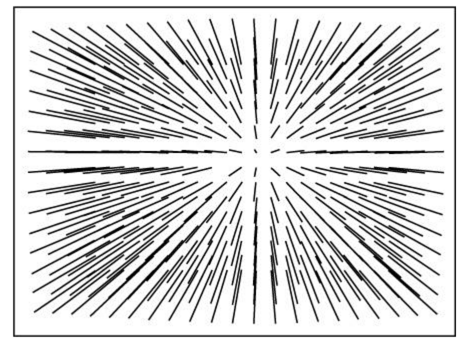
Raw image



Spot detection



Displacement array



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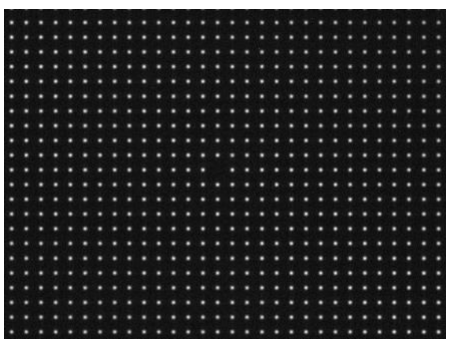
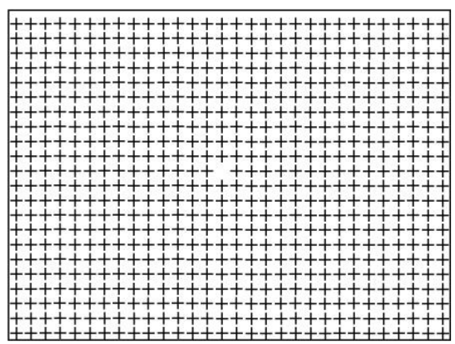
Reference wave





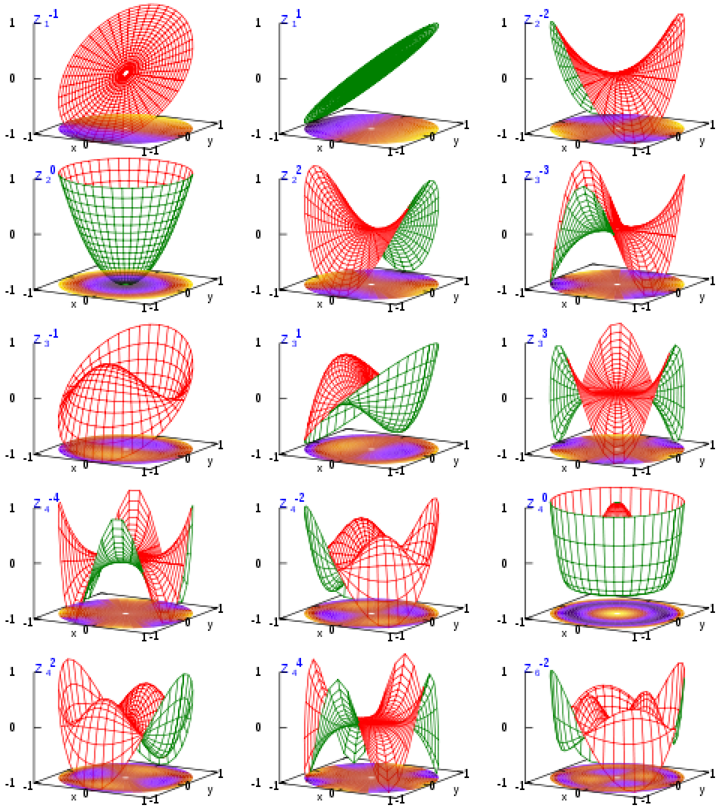
Source: ELI Beamlines (all pictures)

Applications: adaptive optics

Zernike polynomials:

$$Z_n^{-m}(\rho,\varphi) = R_n^m(\rho)\,\sin(m\,\varphi),$$
$$Z_n^{m}(\rho,\varphi) = R_n^m(\rho)\,\cos(m\,\varphi)$$

$$R_n^m(\rho) = \sum_{k=0}^{\frac{n-m}{2}} \frac{(-1)^k\,(n-k)!}{k!\,\left(\frac{n+m}{2}-k\right)!\,\left(\frac{n-m}{2}-k\right)!}\,\rho^{n-2\,k}$$



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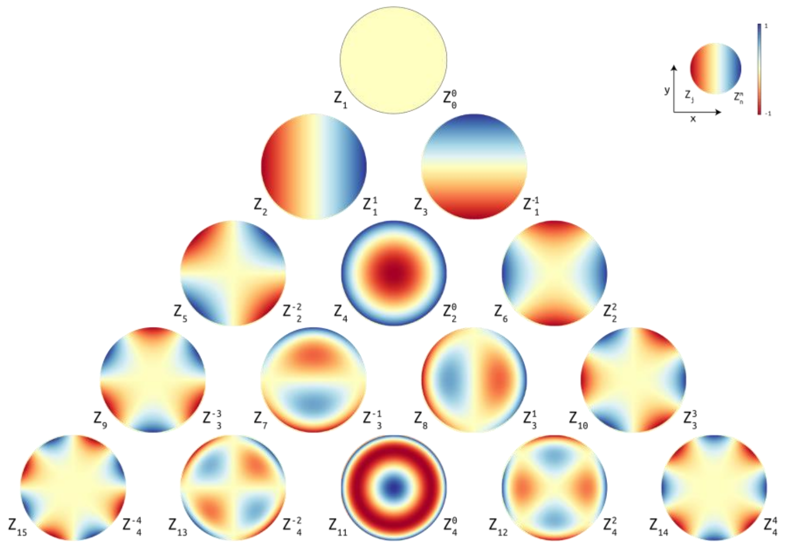
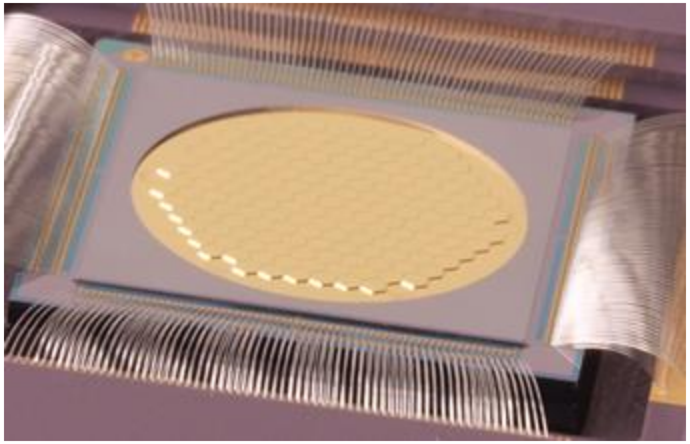


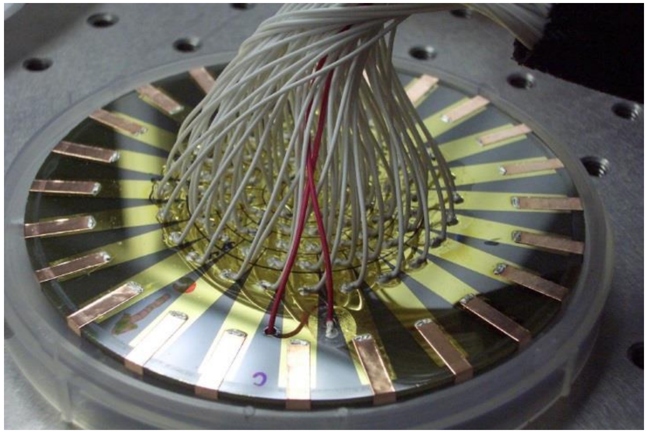
Source: Wikipedia (all pictures)

Applications: adaptive optics



Source: *Iris AO, Berkeley, USA*

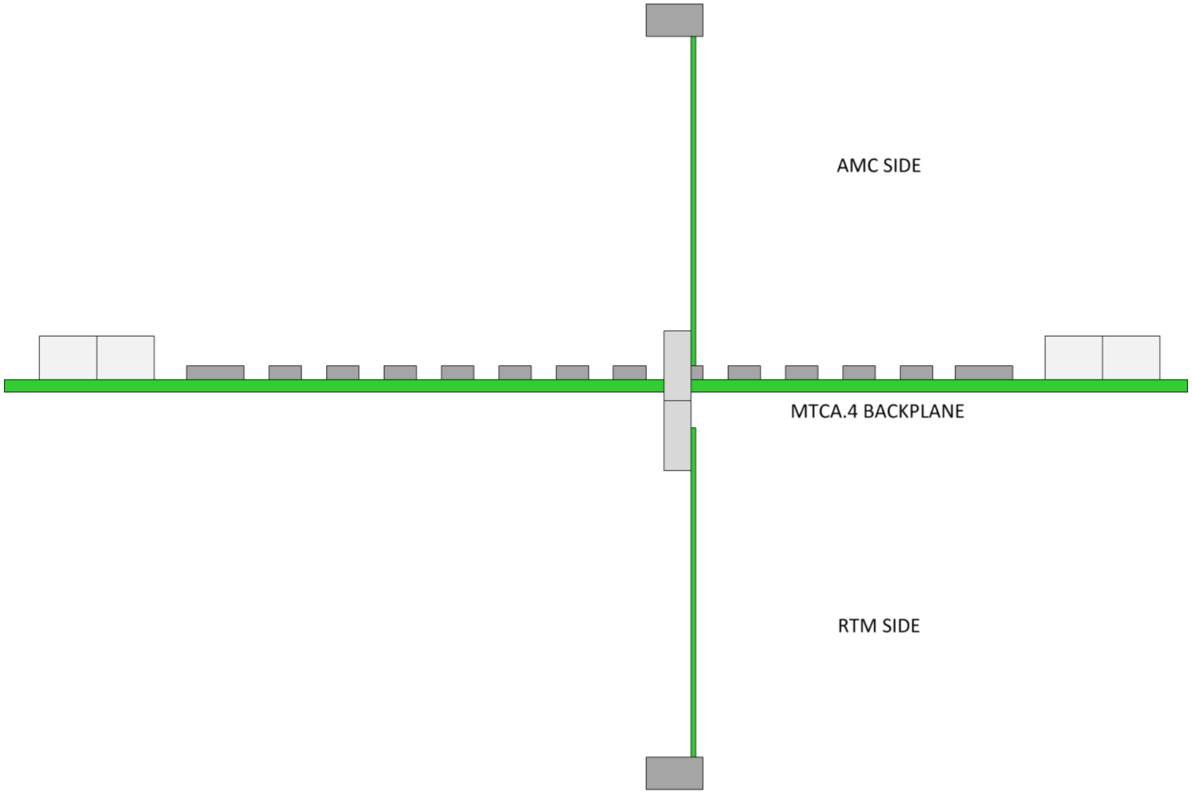
Deformable mirror, MEMS



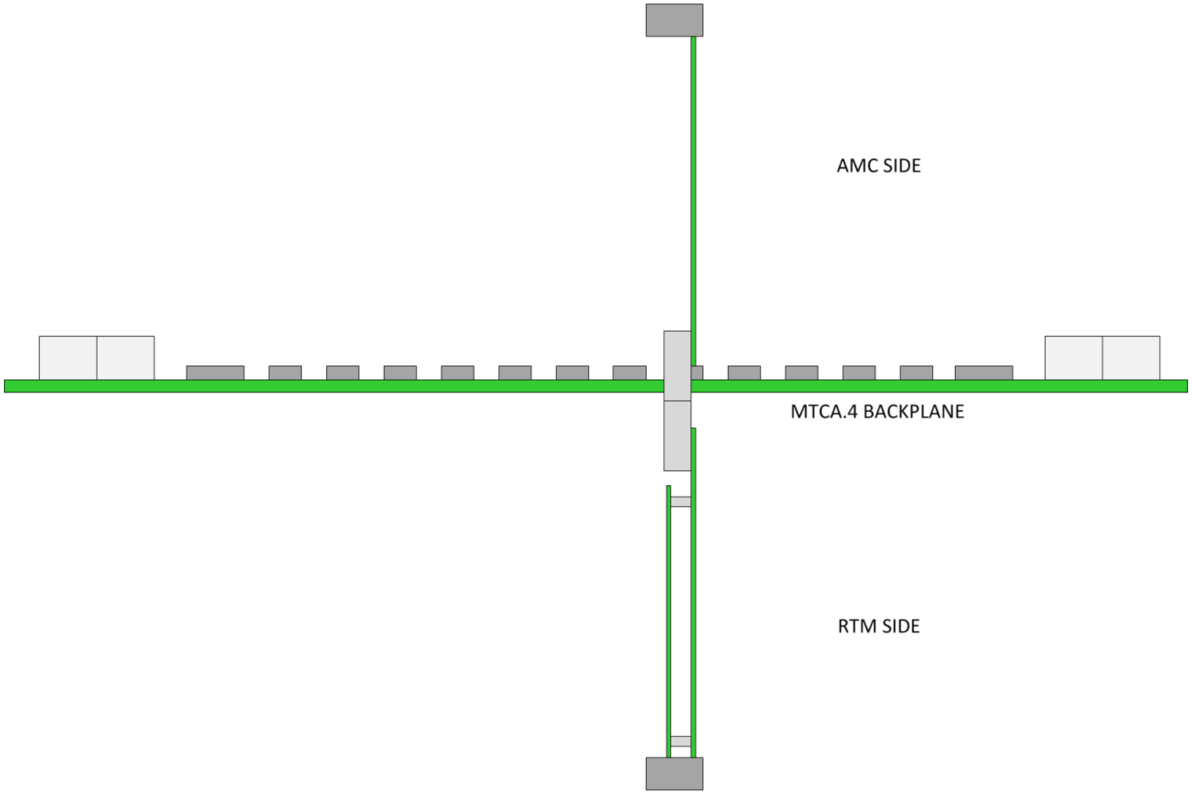
Source: *MPI, Heidelberg, Germany*

Deformable mirror (rear view), bimorph

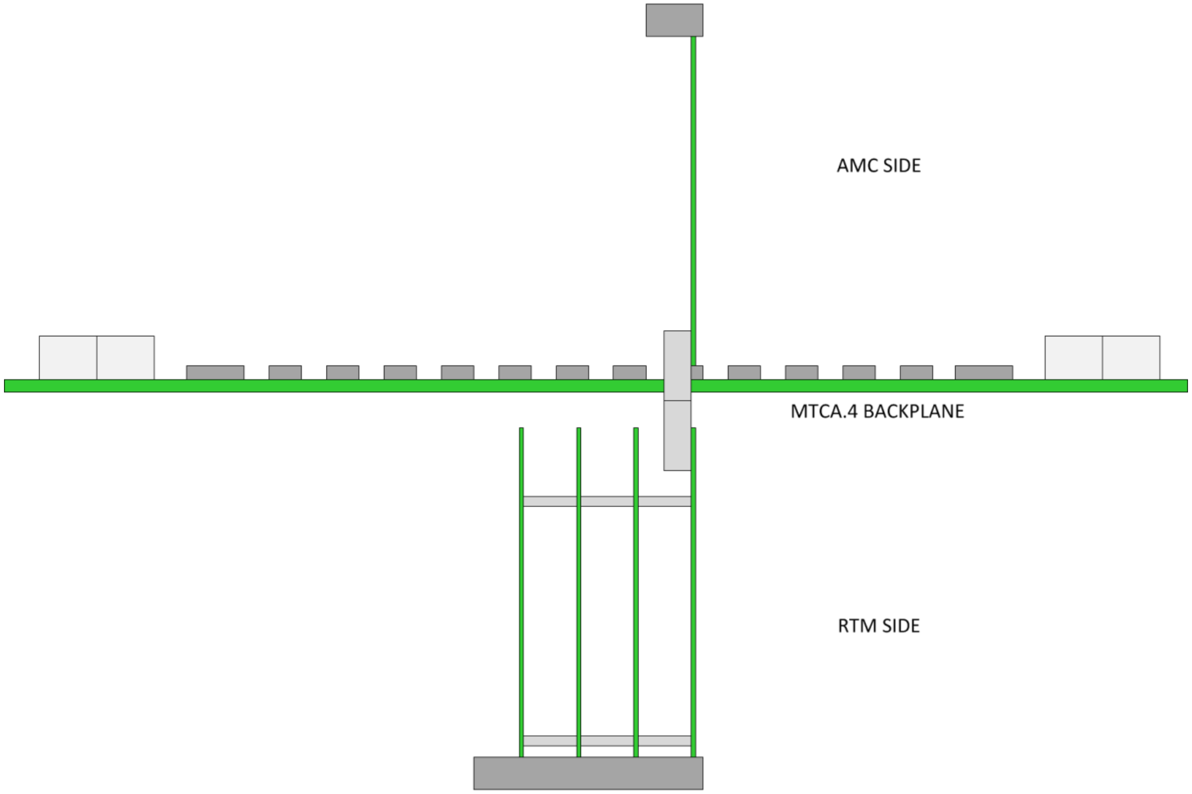
Applications: adaptive optics



Applications: adaptive optics

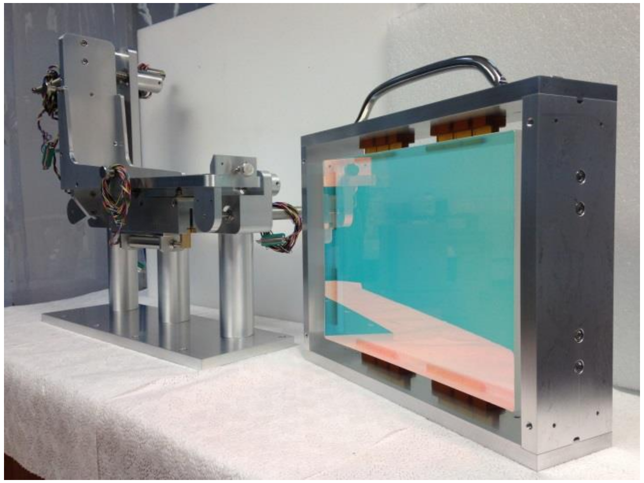


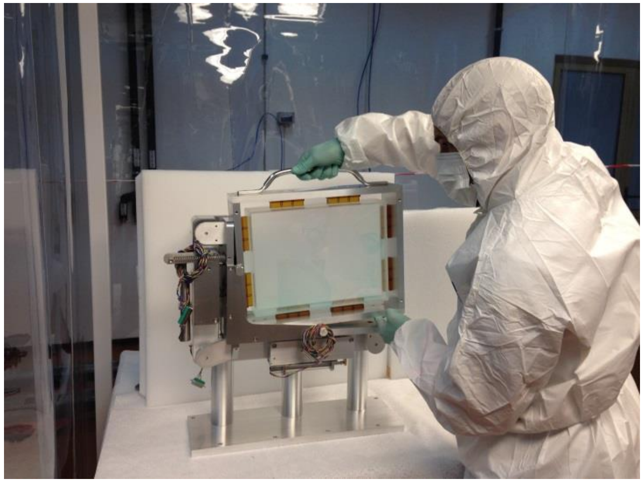
Applications: adaptive optics



#2 - **Beam alignment**

Applications: beam alignment





Variety of mirror sizes:
from tiny to massive

Implies variety of drives:
piezo to DC motors

Source: ARDOP, Newport

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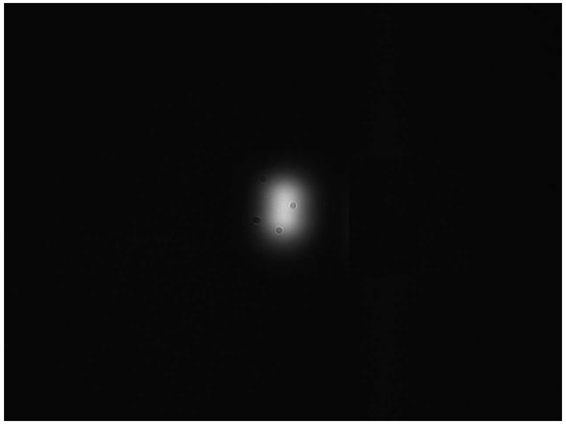
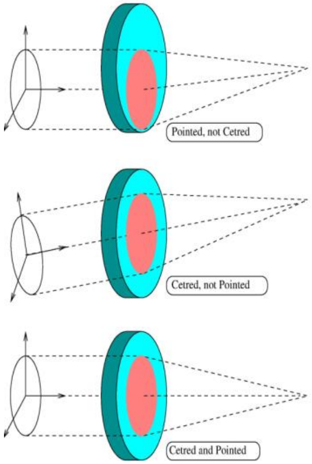
Applications: beam alignment

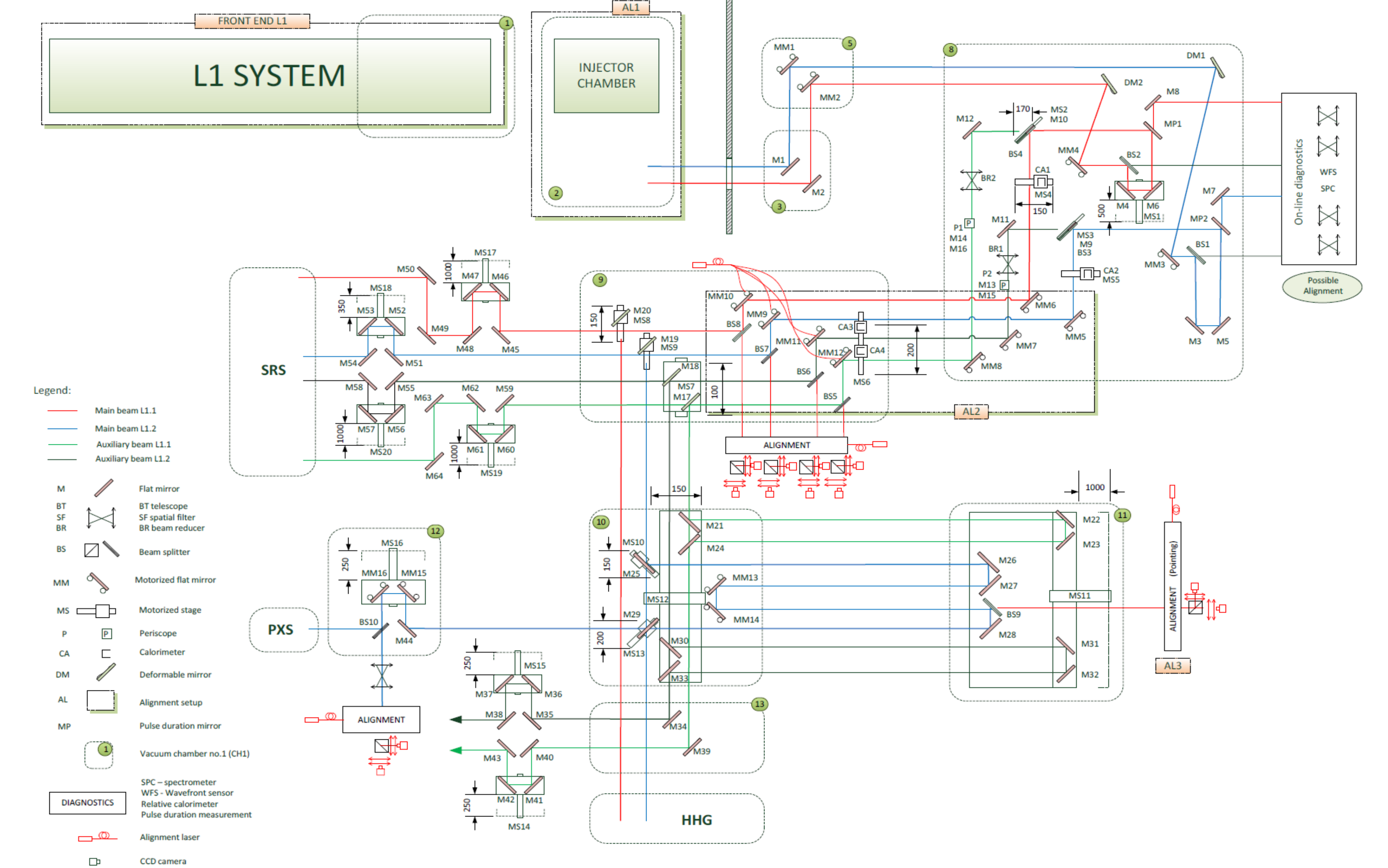




Alignment process:

- splitted into two parts: centering & pointing
- beamline aligned section-by-section

L1 to E1



  Latest version is available in electronic repository V4

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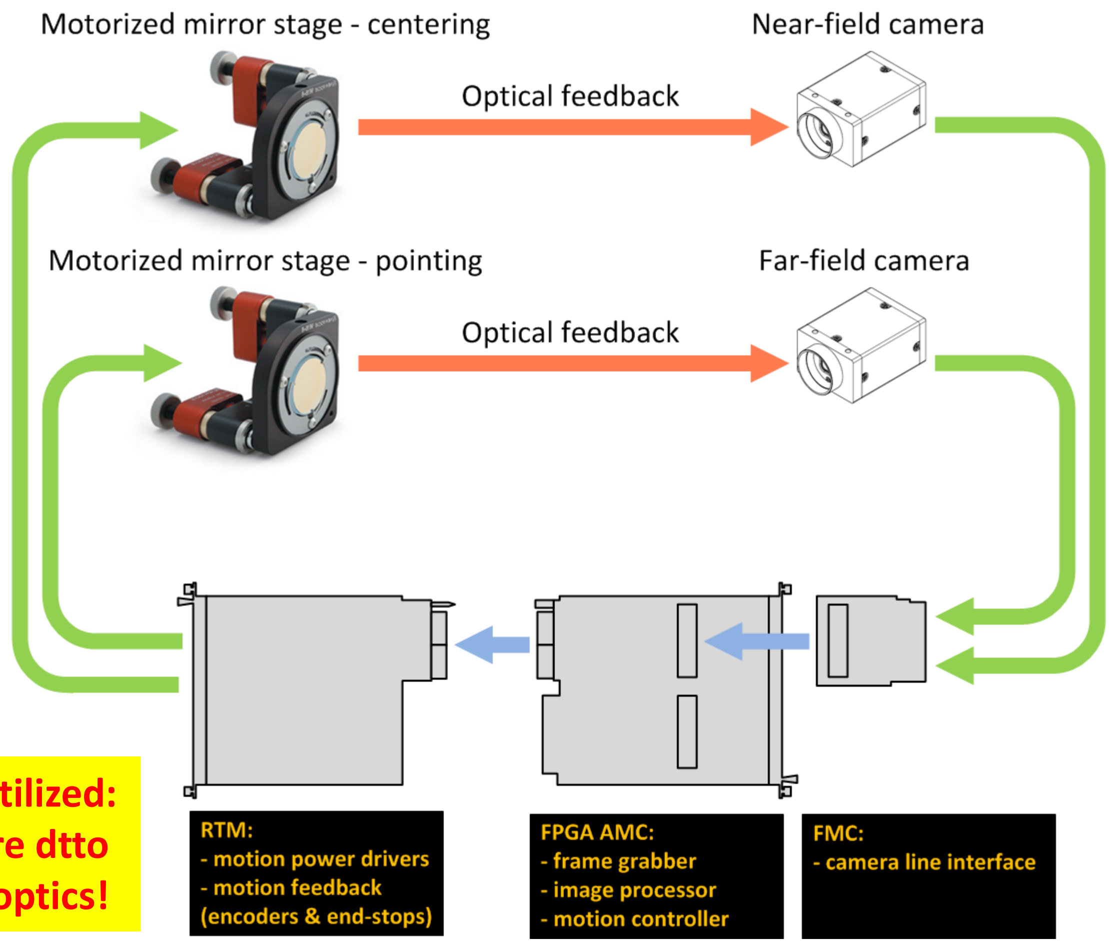
Applications: beam alignment



Most of effort re-utilized: front-end blocks are dtto with the adaptive optics!

Other plans
&
Conclusions

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Other plans & Conclusions

1. To build a versatile, modular, scalable and OPEN eco-system for image acquisition and image processing, based exclusively on FPGA (and MTCA)

2. More focus on fast, low latency and ZERO COPY inter machine transmissions of image data (i.e. Infiniband/RDMA or Converged Etherned/RoCE) >>> MESSAGE TO MANUFACTURERS-)

3. Soon more focus on temporal domain diagnostics & control, as synchronization of multiple beamlines become a reality (cross-corellator)

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Thank you

General Deployment Timeline