Warning!
Laser control systems

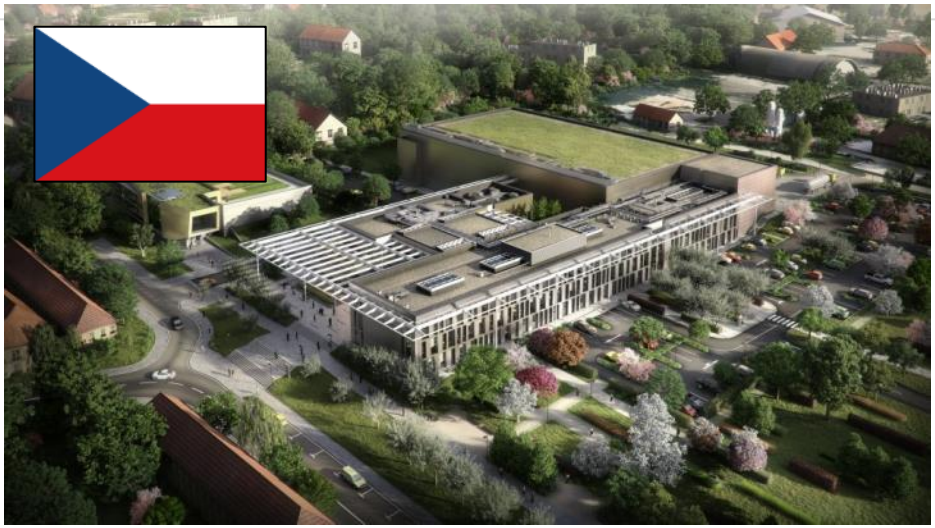
Control system architecture for the L1 laser at ELI Beamlines

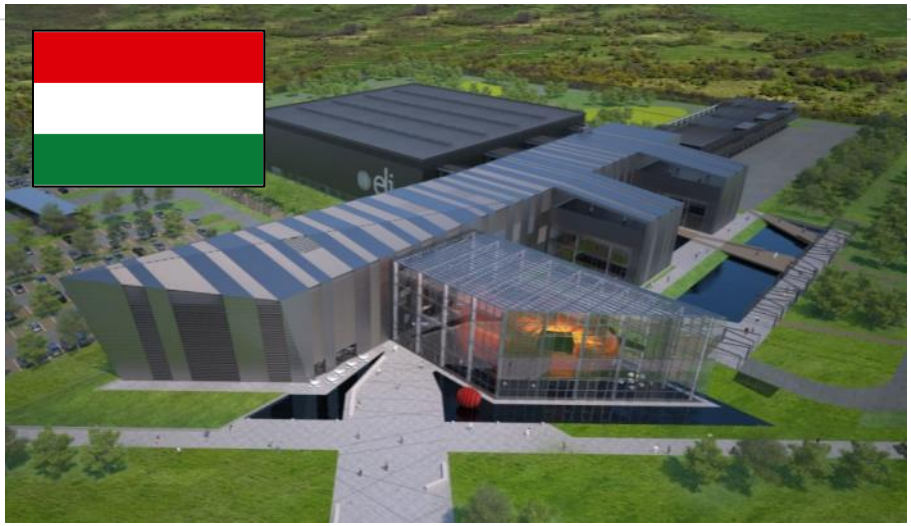
Jack Naylon, Tomáš Mazanec, Alan Greer**, Chris Mayer**, Martin Horáček, Bedřich Himmel, Marc-André Drouin, Karel Kasl, Jakub Horáček, Pavel Škoda, Pavel Bakule and Bedřich Rus

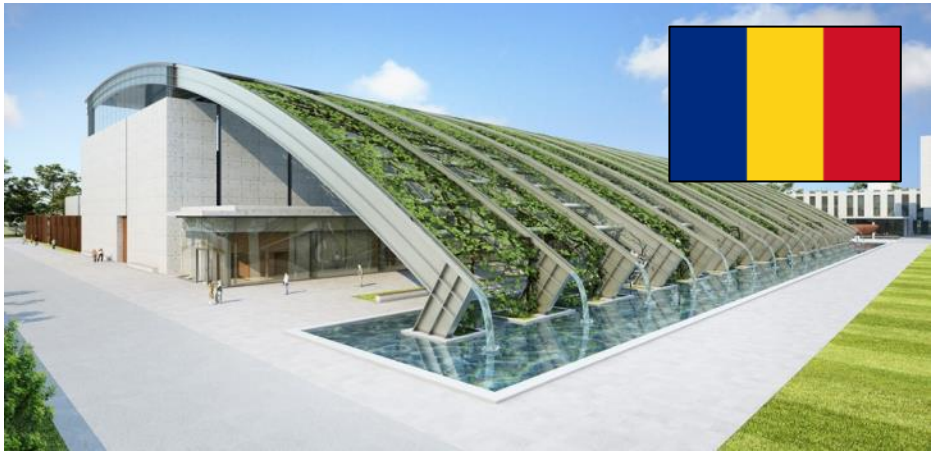
Institute of Physics AVČR, v.v.i., Prague, Czech Republic
** Observatory Sciences Ltd., Cambridge, UK

projekt podporovaný:
EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI
OP Výzkum a vývoj pro inovace

Extreme Light Infrastructure







Network of user facilities focusing on nuclear physics, attosecond science, and secondary source generation

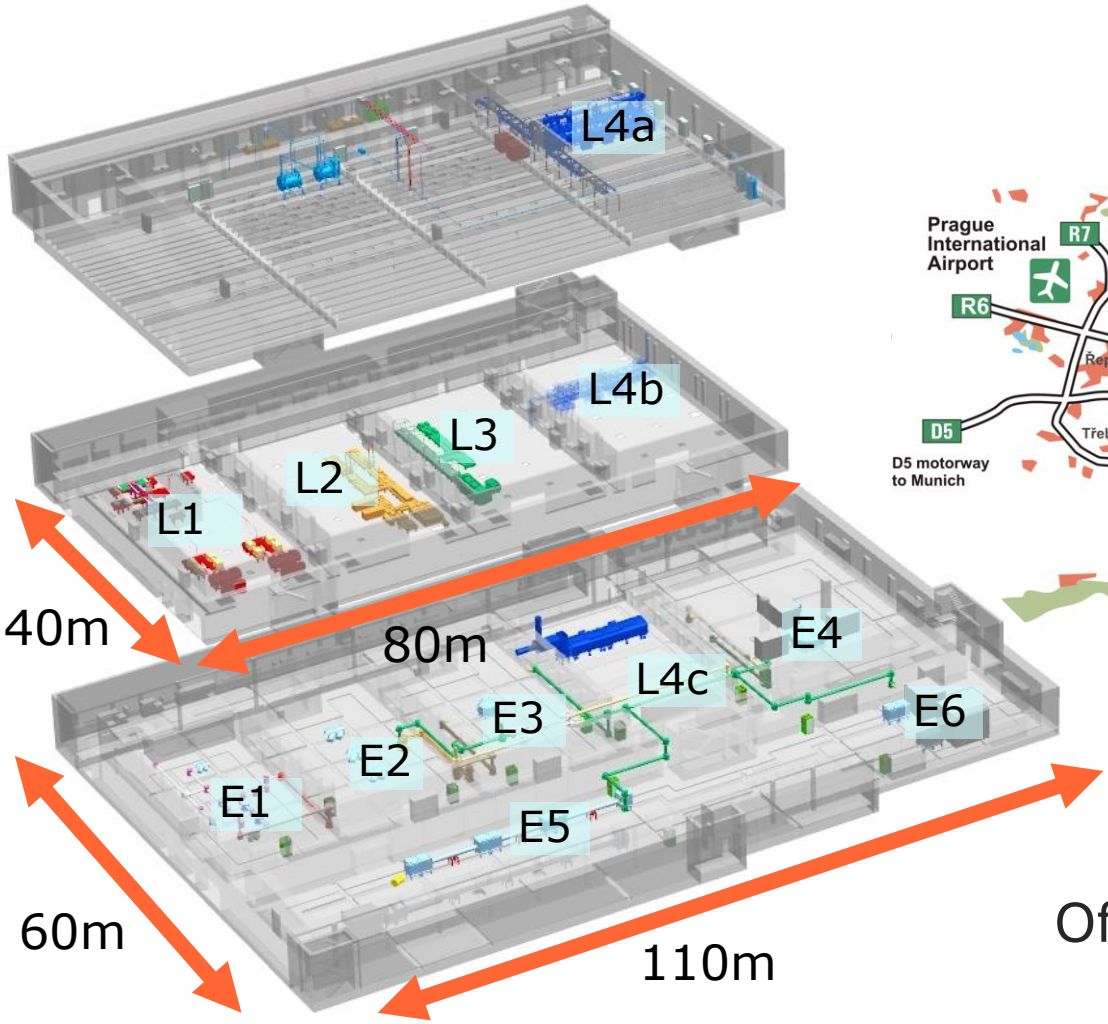
Managed independently and developed autonomously within host institutes until post-2018

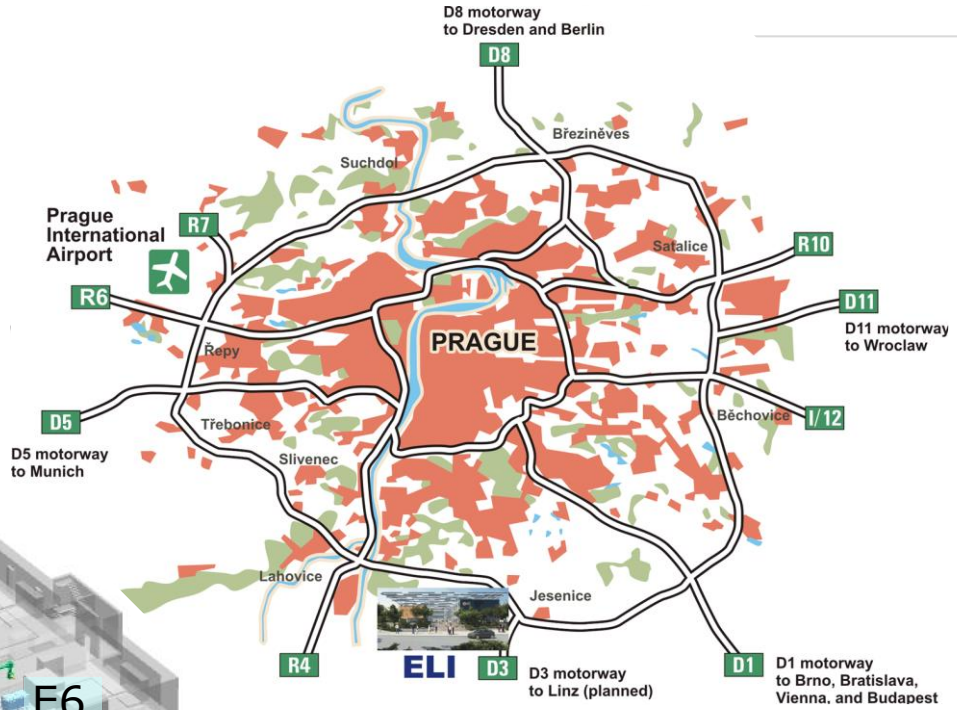
Building status

Spot the difference!

ELI-BL Grand Opening was on Monday October 19…

ELI Beamlines Facility in Prague





4 laser beamlines

6 experimental halls

Offices, labs and workshops for □300 staff

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

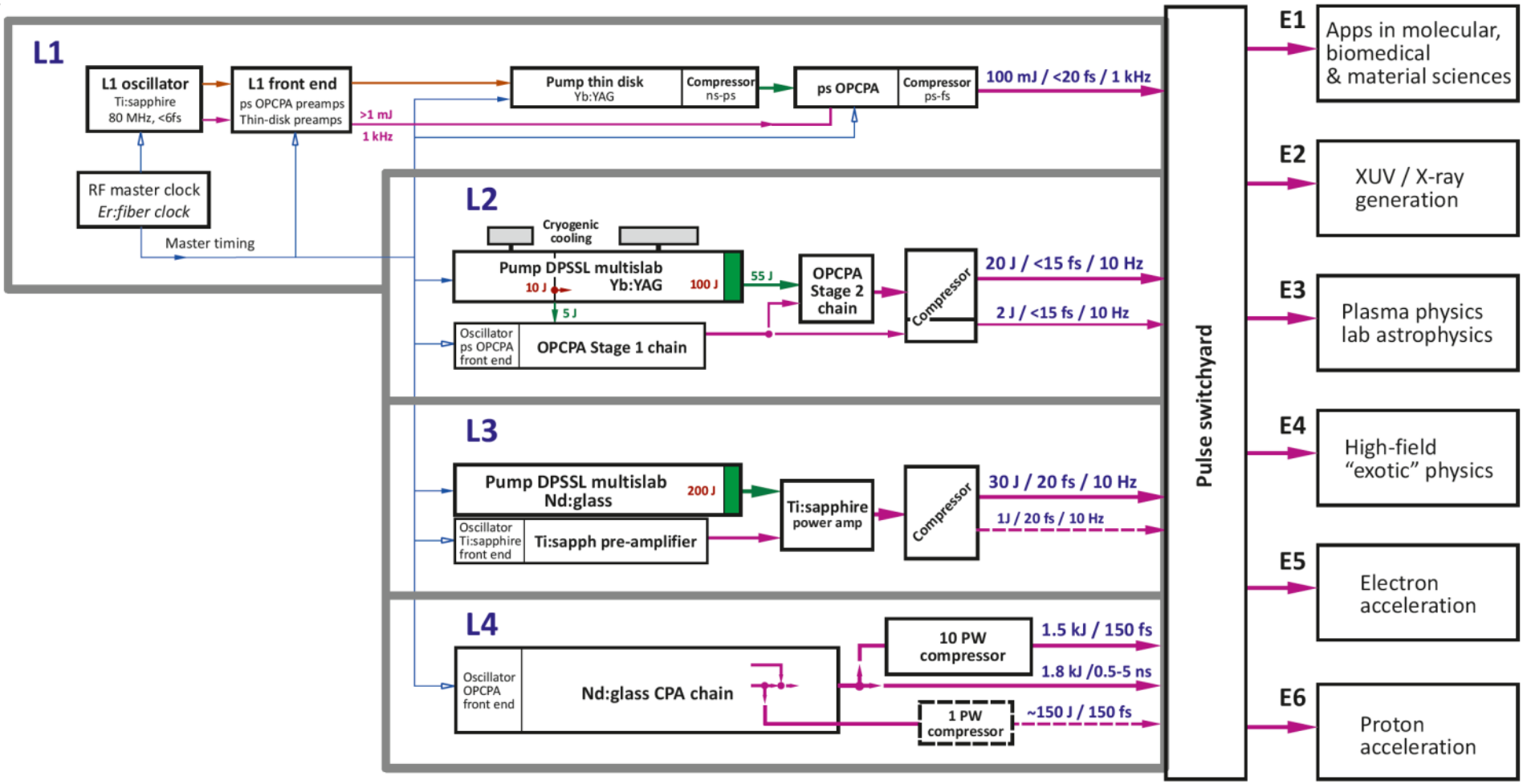
projekt podporovaný:

EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI

2007-13
OP Výzkum a vývoj pro inovace

Photos September 2015

The lasers at ELI-BL



Laser summary

Beamline	L1	L2	L3	L4
Peak power	> 5 TW	PW	≥ PW	10 PW
Energy in pulse	100 mJ	≥ 15 J	≥ 30 J	≥ 1.5 kJ
Pulse duration	< 20 fs	≤ 15 fs	≤ 30 fs	≤ 150 fs
Rep rate	1 kHz	10 Hz	10 Hz	1/60 Hz
Supplier	Commercial pump lasers (Trumpf Scientific & …)	STFC RAL major supplier and technology developer	LLNL major contractor	National Energetics & EKSPLA major contractor
IoP activities on control systems	**Complete control system and integration**	**Complete control system and integration**	**Integration** and joint software development	**Integration** and collaboration on HW & SW

Challenges for ELI-BL' laser control systems

Most laser control is not *technically* challenging…

Mostly sub-kHz diagnostics, slow feedback, modest AI/AO Ch. counts, □50 cameras, □150 *simple* motion axes, □1k control points per laser

…however there are still many challenges

ELI-BL's rep-rate lasers require real-time control systems and machine intelligence – very new compared to <1/hour shot rates

Resources for control systems underestimated

Difficult to attract skilled, experienced staff – limited salaries, competition from IT sector, no 'fame'

Greenfield project & cutting-edge laser tech – no experience base was available & laser requirements often changing

Strict tendering rules and laws make purchasing a nightmare

Challenges for ELI-BL' laser control systems

Some general challenges…

Industrial laser manufacturers generally in-house basic electronics – no market for 'industrial quality' laser electronics at OK prices

Some HW is very specific with only 1 or 2 suitable vendors – e.g., autocorrelators, wavefront sensors, deformable mirrors, dispersion correction – no incentive to customise SW/drivers/interface

Laser diagnostic & equipment vendors generally do not appreciate control system integration

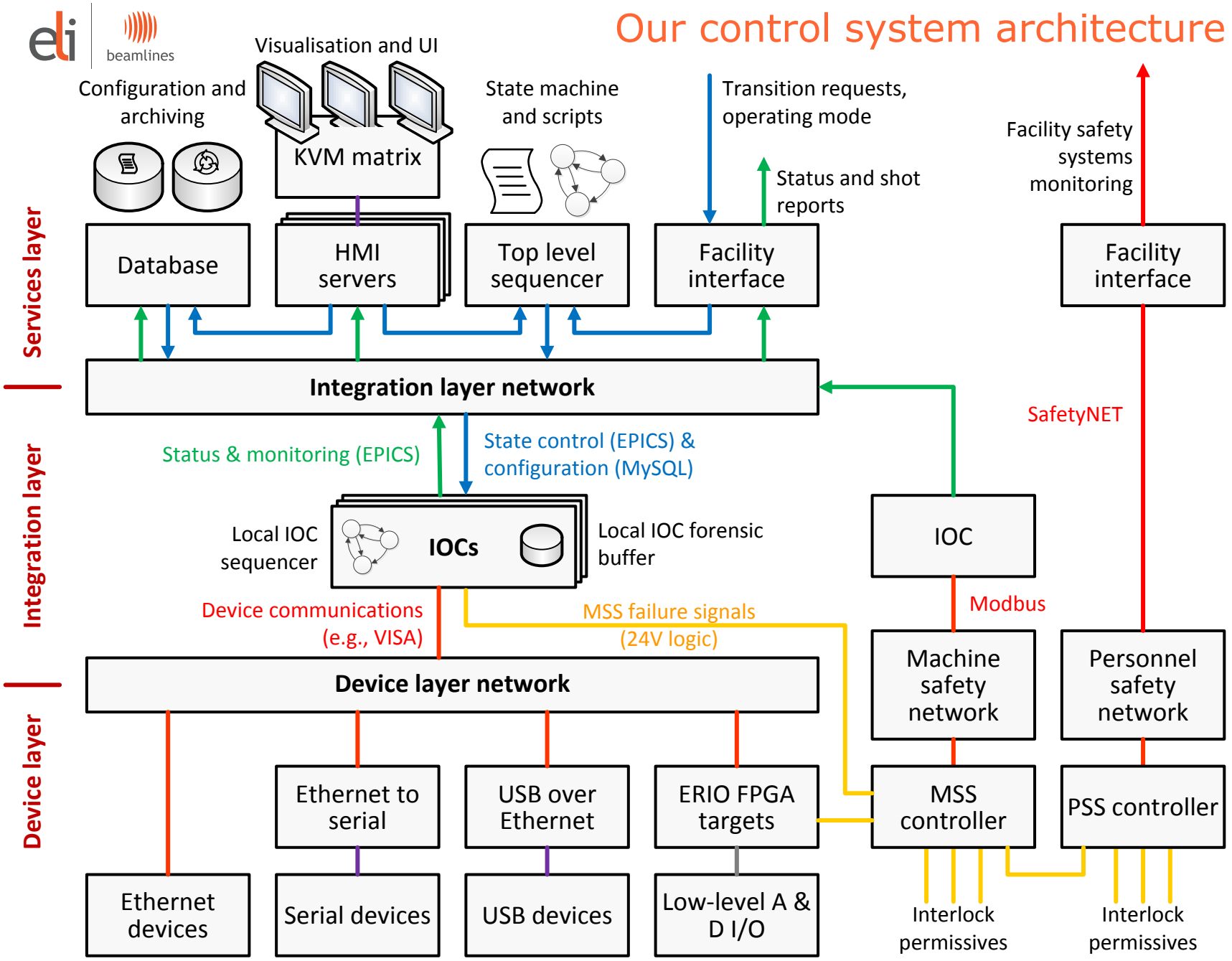
- Predominance of 'quick and easy' USB-Windows solutions only suitable for laboratory research environment
- Poor integration options and/or terrible drivers – LabVIEW is usually the only alternative to custom applications for Windows

From challenges to architecture

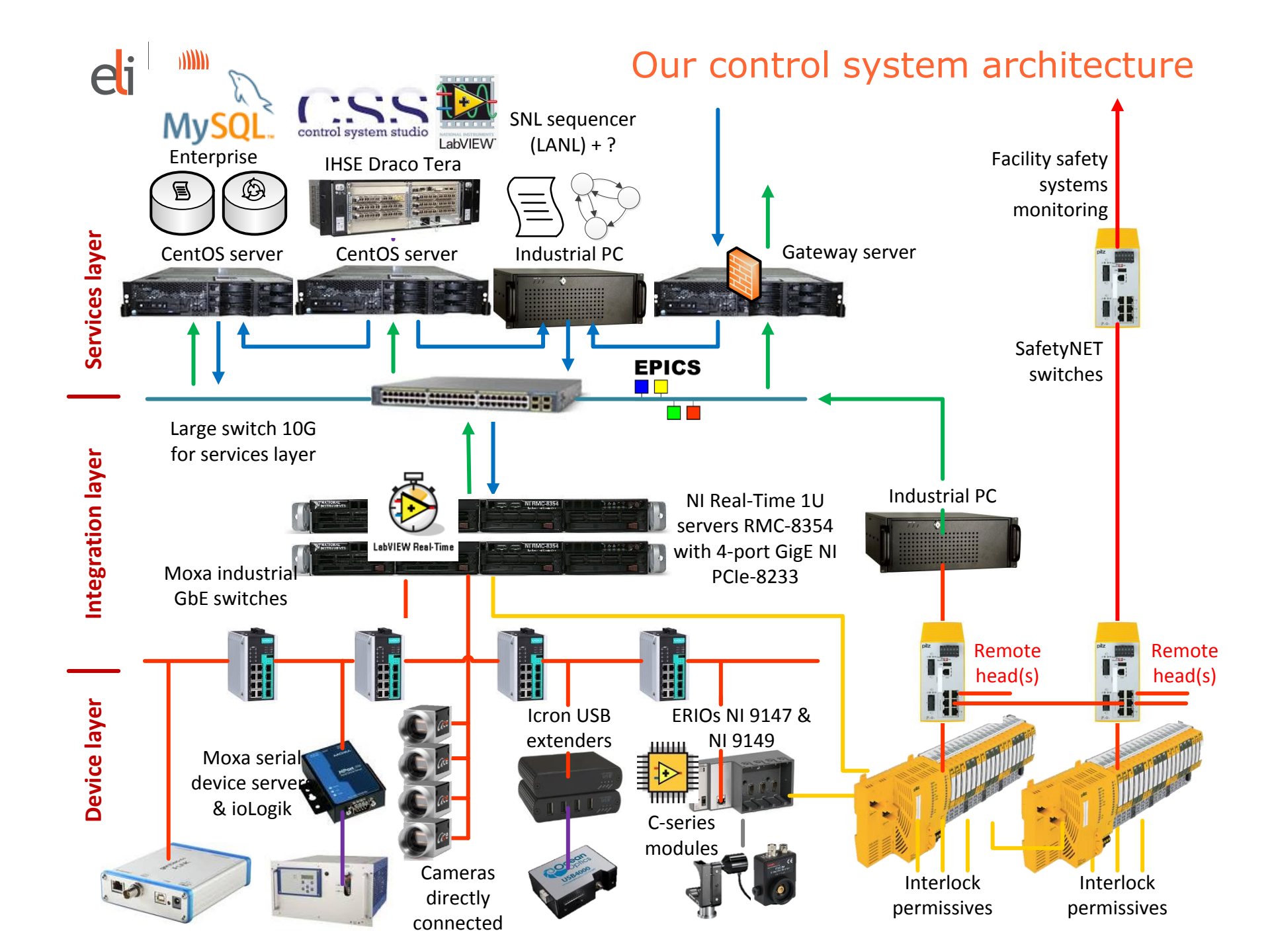
A good architecture aims for scalable, adaptable, maintainable and reliable integration but must consider project constraints:

Project	Architecture
Technically modest	Avoid uTCA, PXI
Medium scale	Distributed reusable HW/SW modules
Real-time intelligence	Real-time OS & FPGA
Low manpower	Simple software, easy hardware
Limited budget	Low cost HW platform
No prior experience	Avoid C++ & Java development
Changing requirements	Fast, flexible development platform
Strict tendering rules	Single vendor, volume order (NI!)
DIY electronics required	Leverage modular IO for electronics
Vendor driver support	LabVIEW essential; integration focus

Our control system architecture



Our control system architecture



LabVIEW-EPICS control systems

Many solutions exist with various advantages and disadvantages*

Shared memory on VxWorks (LANL+Cosylab)
Hypervisor shared memory - Hyppie (LNLS)
ActiveX CA (ORNL-SNS)
CaLab Win DLL (HZB-BESSYII)
DCOM Win API via EPICS driver (STFC-ISIS)

Incompatible platform

DIM Interface (GSI+CERN)
LV-native EPICS implementation (ORNL-SNS)

Compatible platform

DSC Module via Shared Variables (NI)
LV-native CA (Observatory Sciences)

Compatible and COTS

*surveyed 2014 - not an exhaustive list! Credit goes to: various presentations at EPICS collaborations and NIWeek by Alexander Zhukov, ORNL; GSI wiki summary [wiki.gsi.de/cgi-bin/view/Epics/]; Tech Talk [http://www.aps.anl.gov/epics/tech-talk/]

Early testing with the NI EPICS module

Basically works, but…

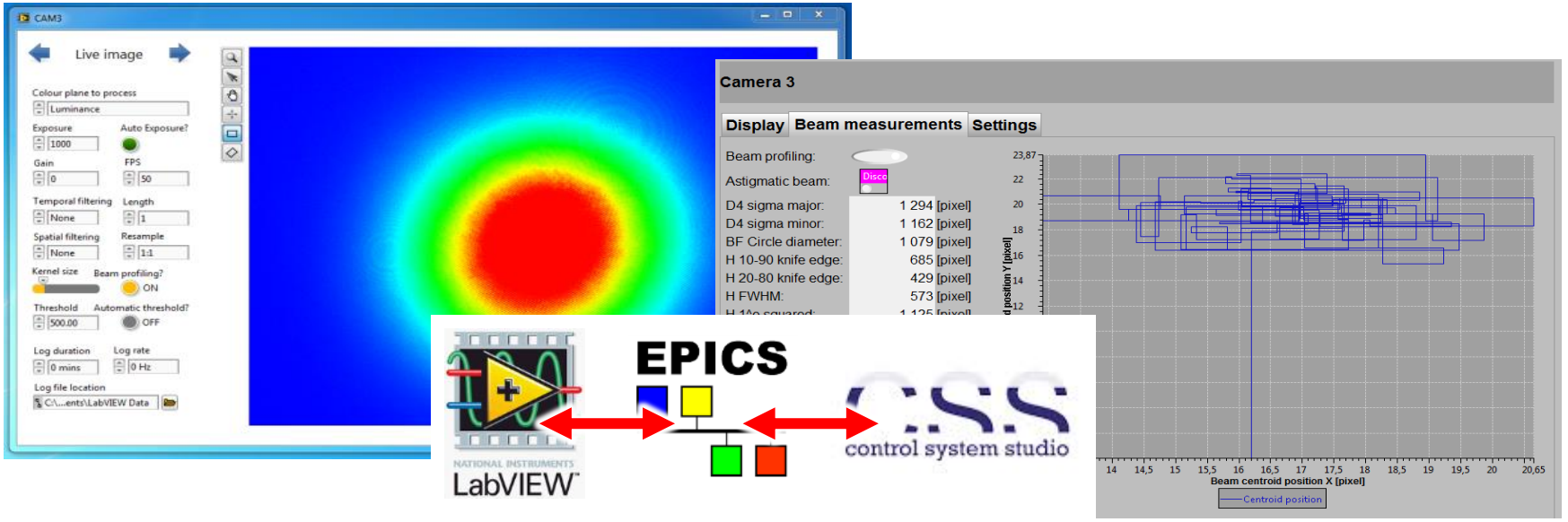
Project has been put on ice (NI's unofficial warning in 2013)

Network SVs must be used (slow, unstable, poor scalability)

Not a full implementation (PVs on server-side have only few fields)

Missing fields confuse clients (e.g., Control System Studio)

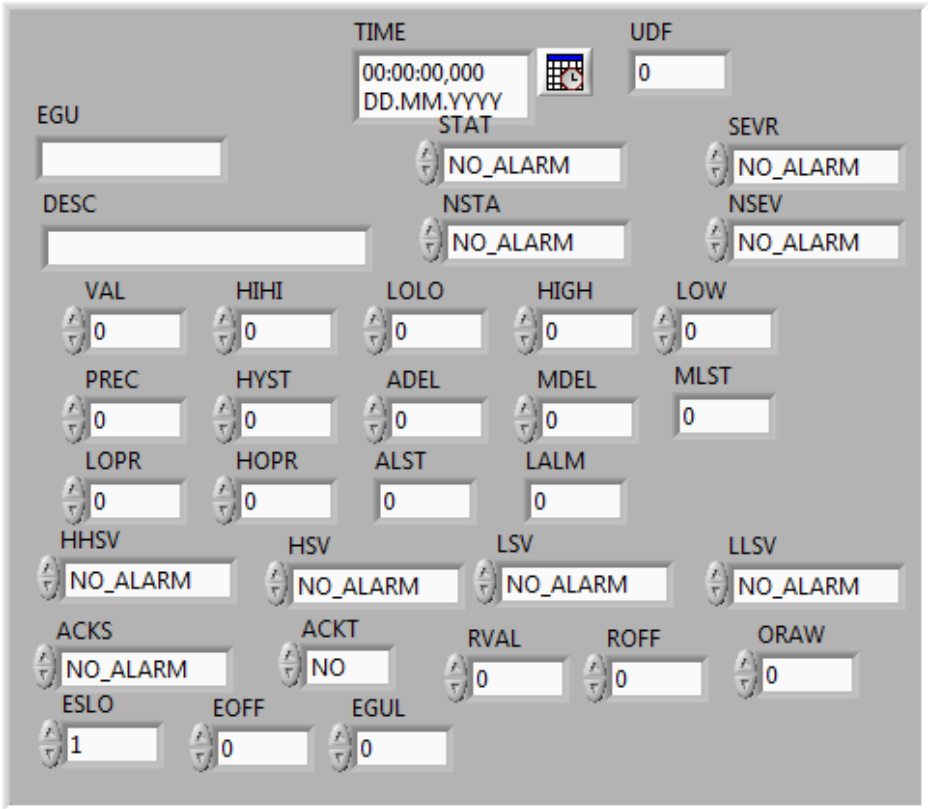
Type-casting bugs (string and integer)



Demonstration LabVIEW camera server on RMC-8354 using NI EPICS module to link to a Control System Studio secondary display (developed 2012-2013)

LabIOC from Observatory Sciences

AI Record



Existing codebase was upgraded for ELI-BL by OSL – almost final release

CA Server has full support for basic record types: ai/ao, bi/bo, longin/longout, mbbi/mbbo, stringin/stringout, waveform)

Polymorphic for standard LabVIEW types: I8, I16, I32, SGL, DBL, STR, Boolean, arrays of these – typecasting as appropriate

LabIOC from Observatory Sciences

Access methods: caGet, caPut, dbPut, dbGet, caMonitor

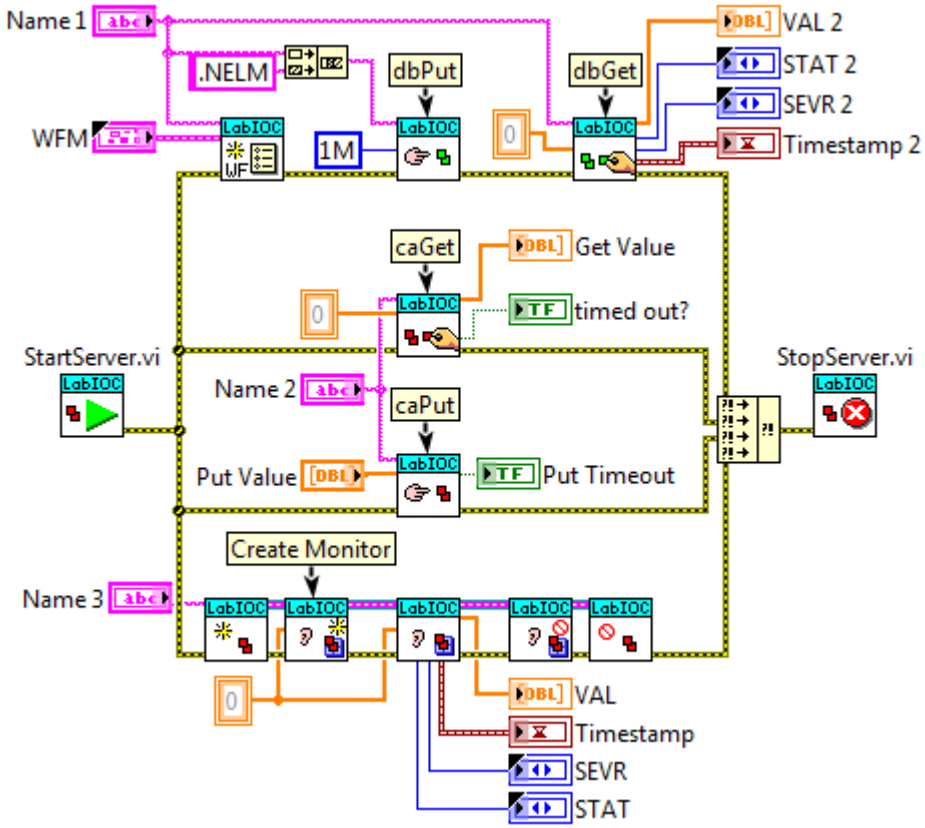
Easy to use, simple LabVIEW code

Should be 'virtualisable'

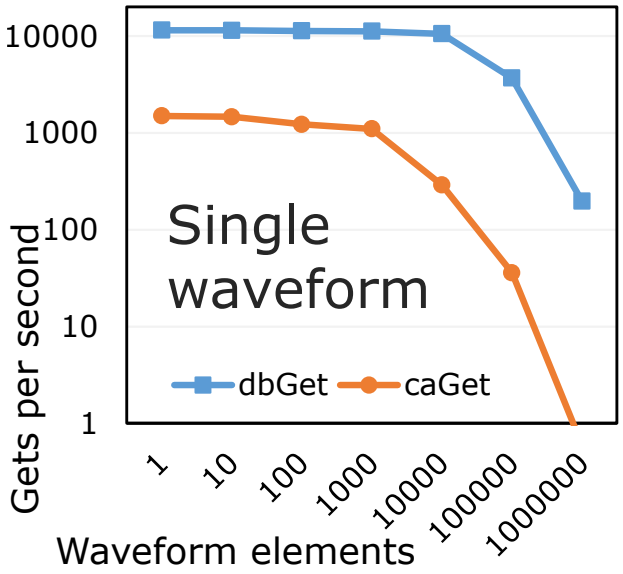
Add 'SocketSetReuseAddr=TRUE' to LabVIEW INI file to share UDP port with multiple instances

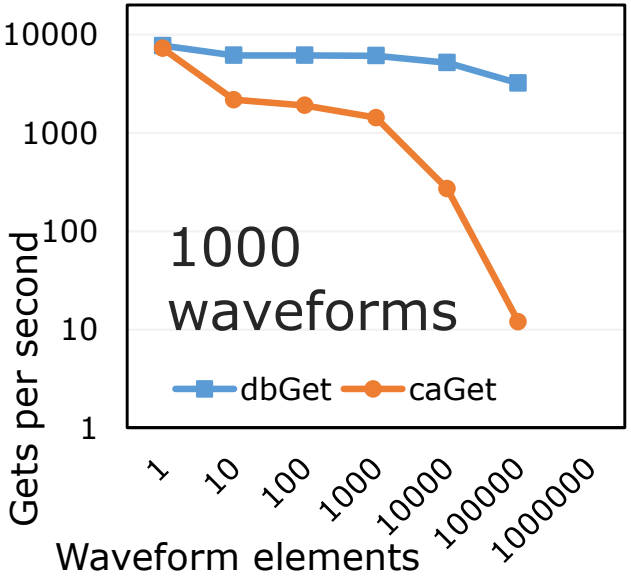
All source code was provided by OSL

ELI-BL will not customise – will continue to work with OSL if any additional features required

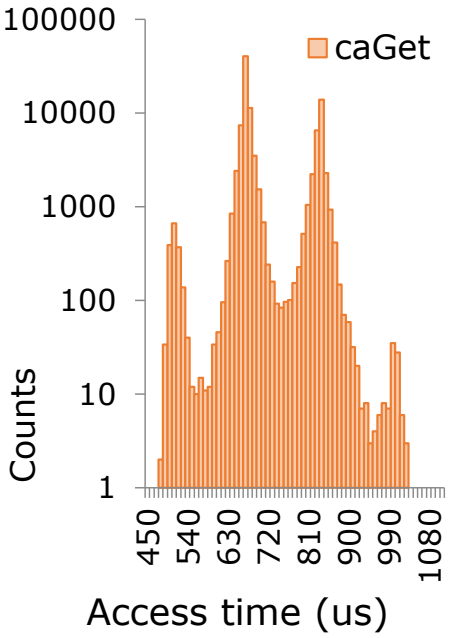


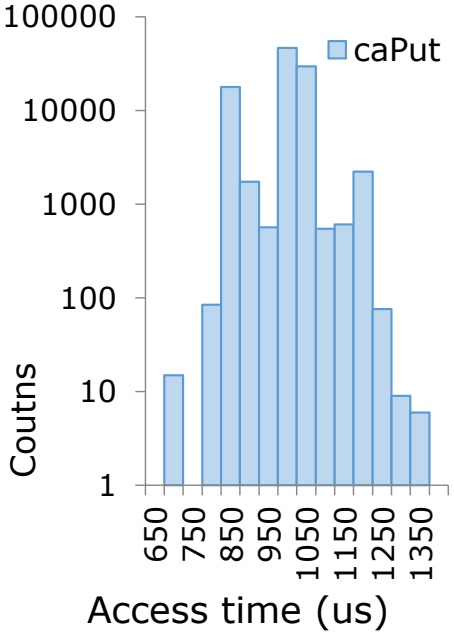
LabIOC testing results





Scalar PV repeated access

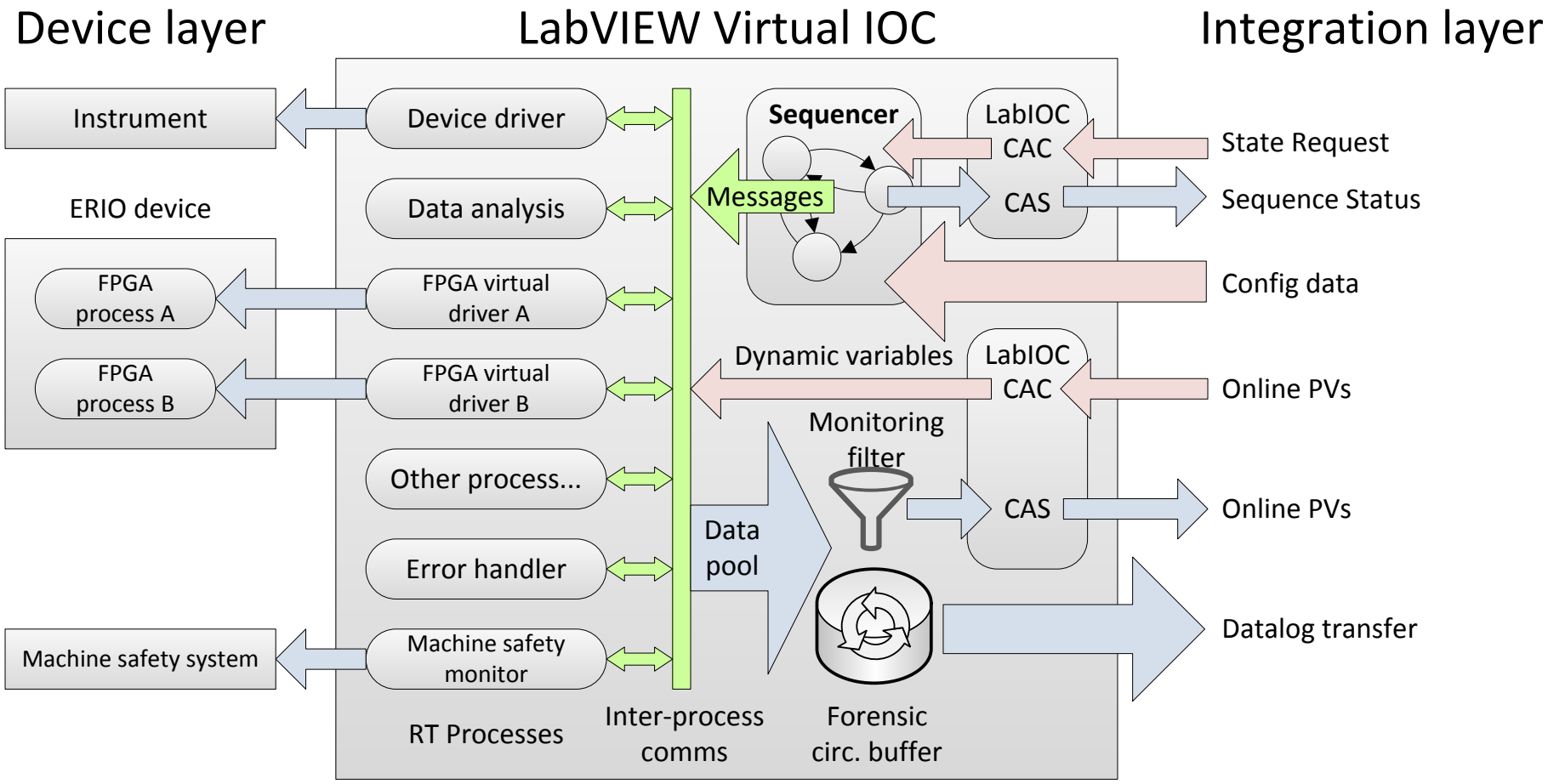




Testing ongoing at ELI and National Energetics (L4 laser)

Performance is good but library is quite large – streamlining would be needed for low-end cRIOs…

Our LabVIEW IOC framework

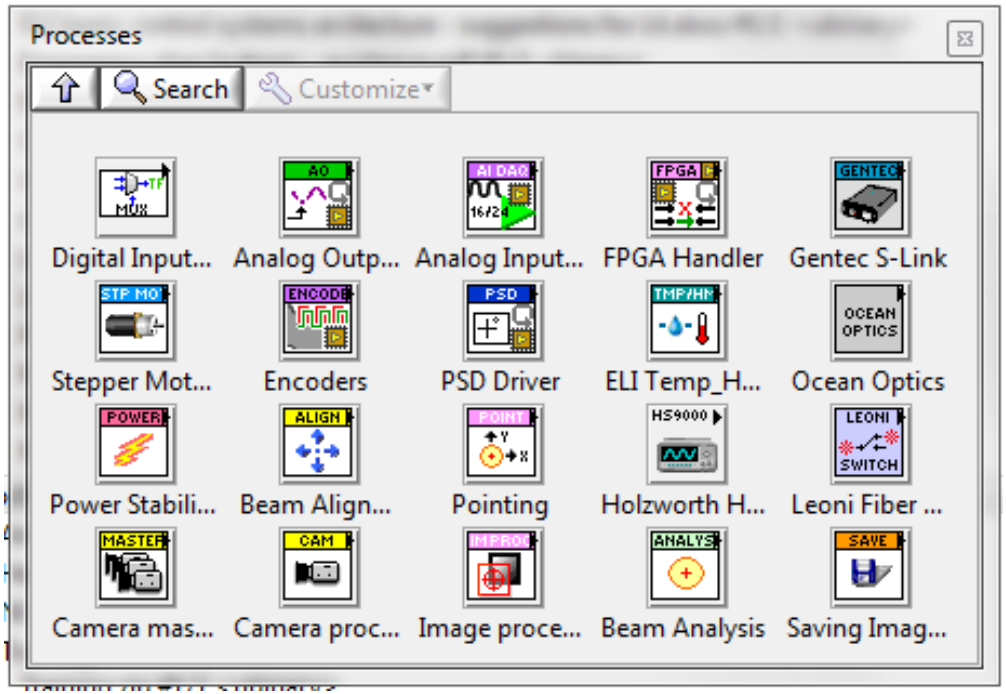


Process model based on QSM (simpler than Actor Framework)

Messages must go through local Sequencer (message broker)

Data in hierarchical current value table (DVR variant attribute)

LabVIEW IOC progress

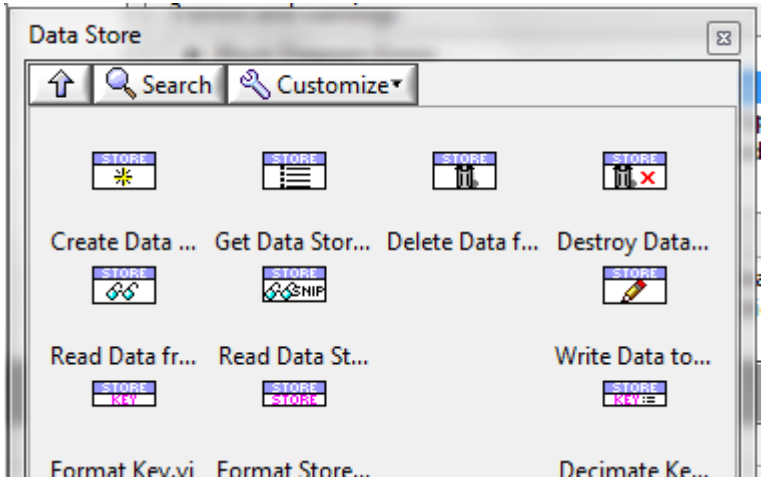


Around 20 processes completed, 10 more in development

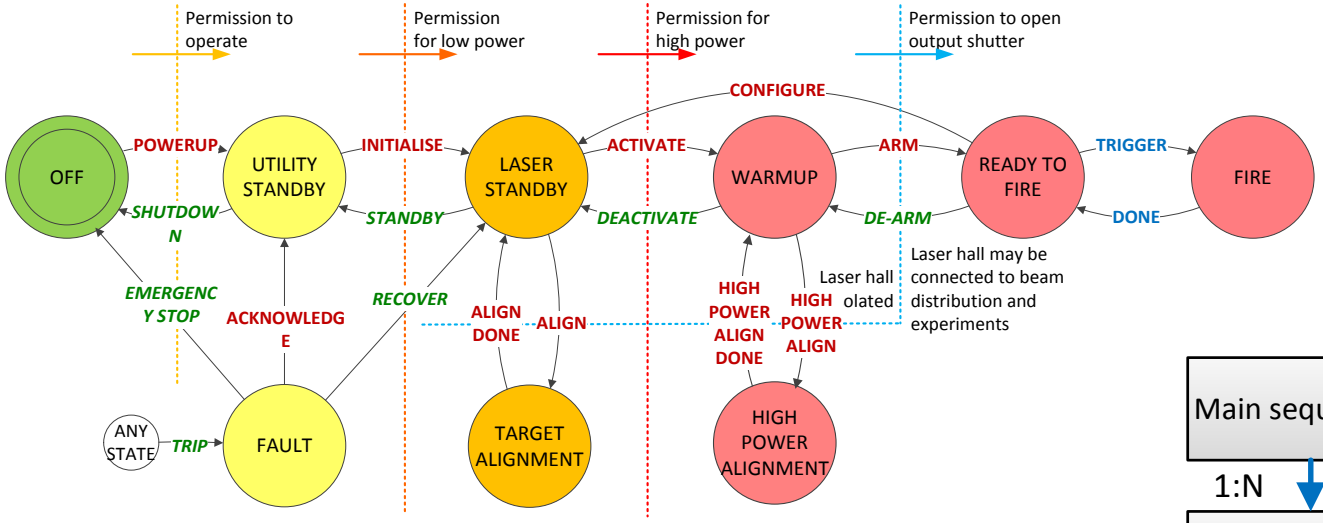
So far one Virtual IOC is deployed

ELI-BL LabVIEW library >7000 VIs

4 full-time developers

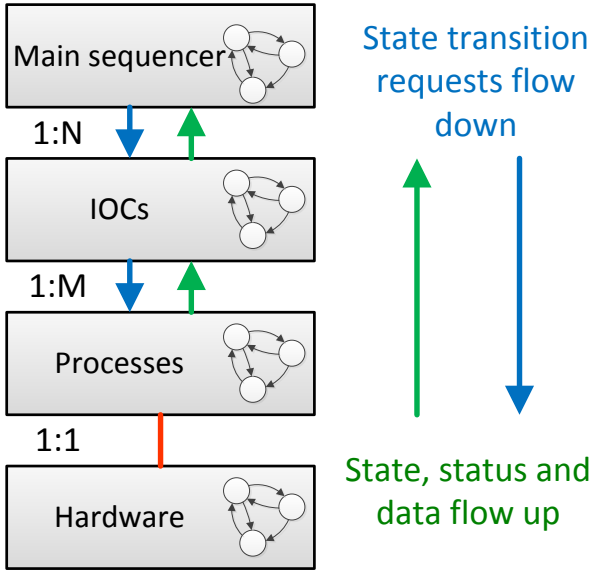


Hierarchical state machine model for system design



Generic state machine for each laser beamline

Interface requirement



Hierarchical state machine model has been extremely useful for integration

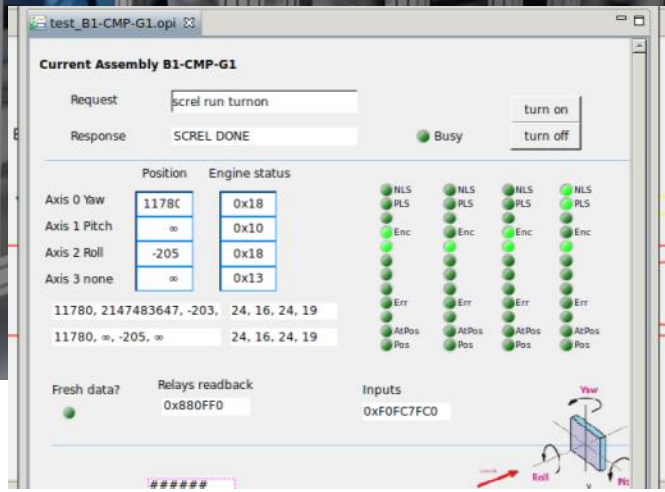
Good communication tool for contractors and stakeholders

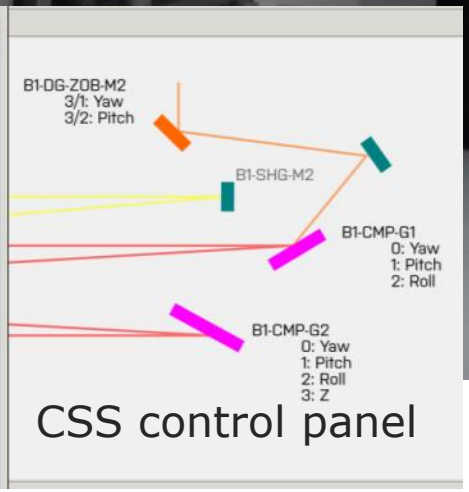
Works well in the software architecture too – rigid but highly testable and deterministic

Integration challenges and successes 1

L1: Three separate picosecond grating compressors in one 4m chamber. 68 motorized axes. Tendered with EPICS interface using NI module. Now working on LabIOC upgrade…

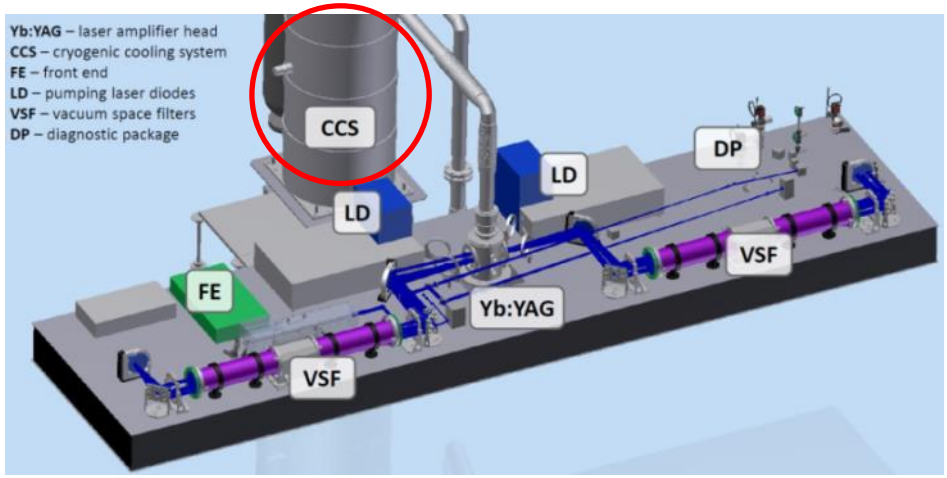
Assembly in March 2015





CSS control panel

Integration challenges and successes 2

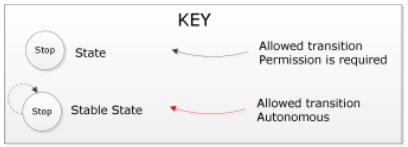


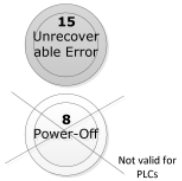
L2: Bryton cryogenic cooling system (150K He)

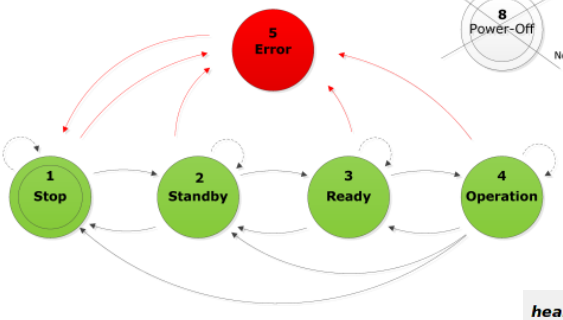
Specified state machine in contract (very positive)

Machine and personnel safety integration to SIL-2

Integrated via EPICS IOC and Modbus

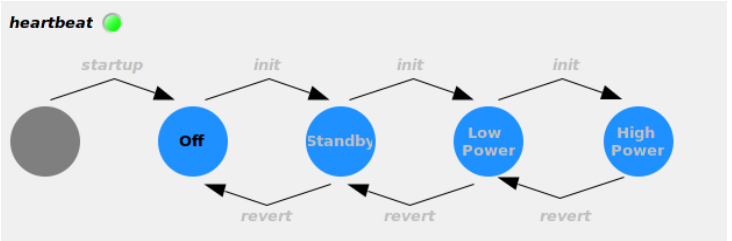




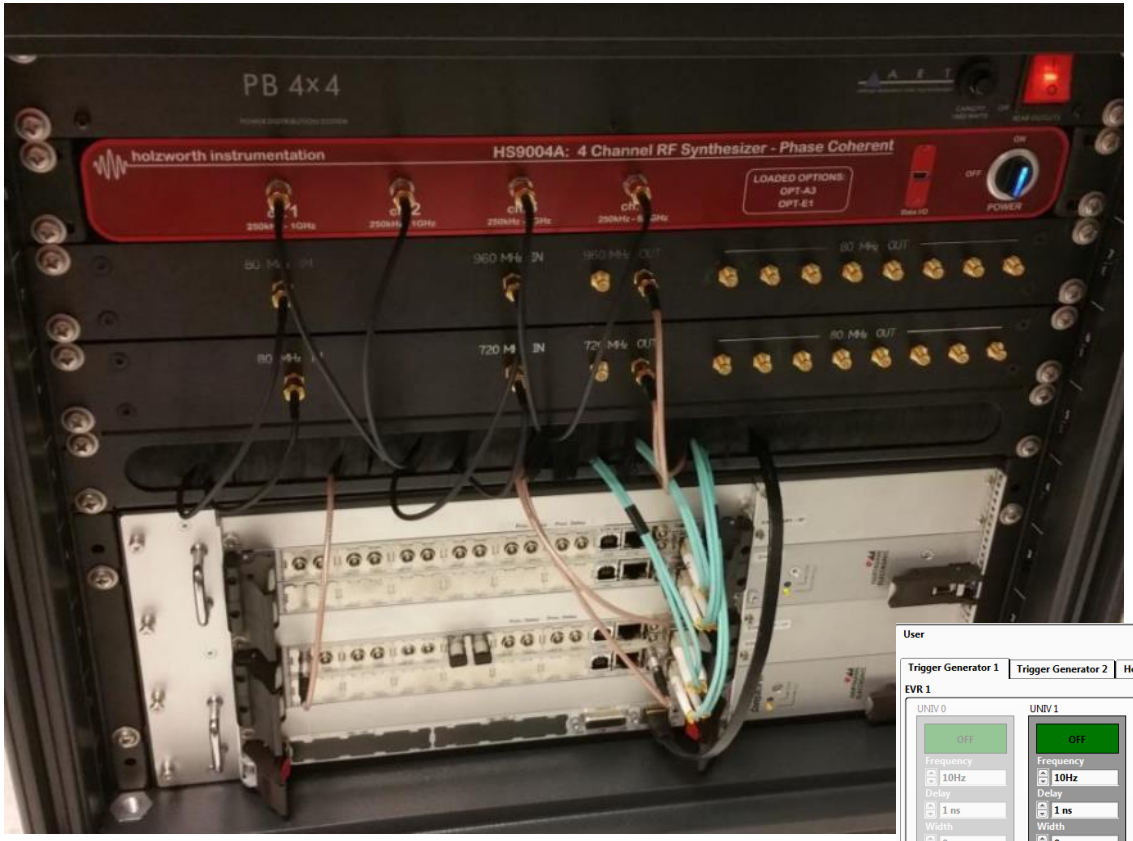


System state specification

Trial CSS control panel for state machine



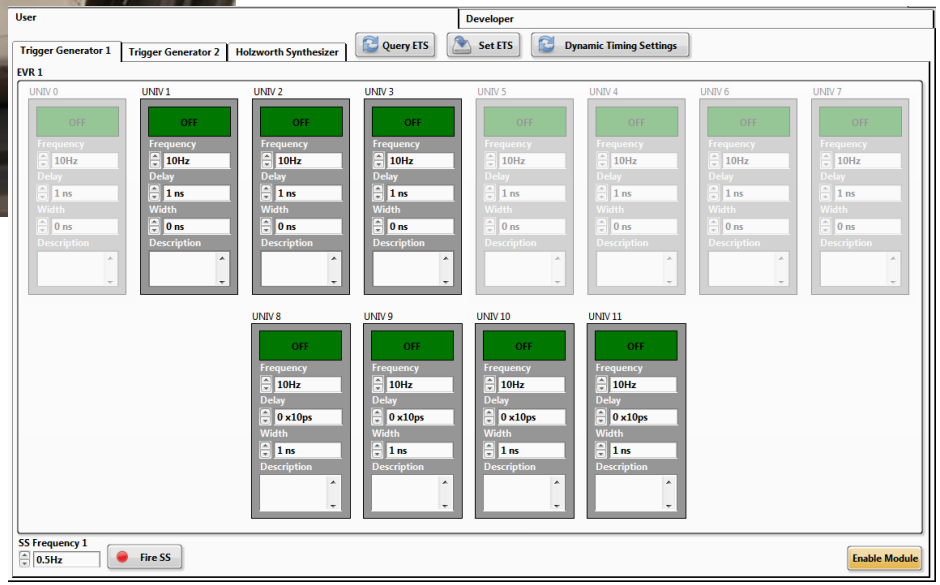
Integration challenges and successes 3



L4: Timing and sync delivered by IoP to ensure successful integration later

All lasers have same system

First test of LabIOC package



Integrates EPICS MRF with LabVIEW Holzworth controller

Provides low-jitter triggers, RF references and PTP sync

Fyzikální ústav AV ČR, v. v. i.
Na Slovance 2
182 21 Praha 8
info@eli-beams.eu
www.eli-beams.eu

Contact:

Dr Jack Naylon
jack.naylon@eli-beams.eu
www.eli-beams.eu

Institute of Physics
Na Slovance 2
182 21 Praha 8
Prague
Czech Republic

Thanks to:

Funding bodies: ERDF and ESF under operational programs ECOP and RDIOP

Observatory Sciences (Booth 8!): www.observatorysciences.co.uk

Gary Johnson and the HAPLS team at LLNL
Article: str.llnl.gov/january-2014/haefner

Chris Malato and the L4 team at National Energetics/EKSPLA: nationalenergetics.com

Tomáš Mazanec and the rest of the LCS team!

projekt podporovaný:
EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI
OP Výzkum a vývoj pro inovace

LabVIEW-EPICS in our architecture

Requirements:

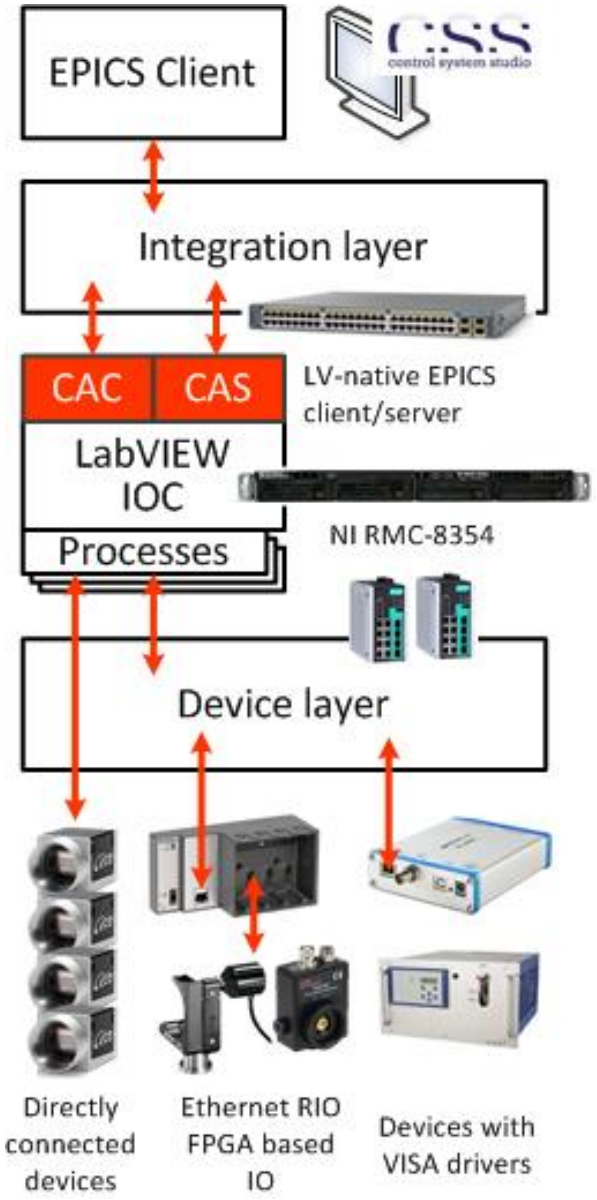
Commercially-supported product – not another project for us!

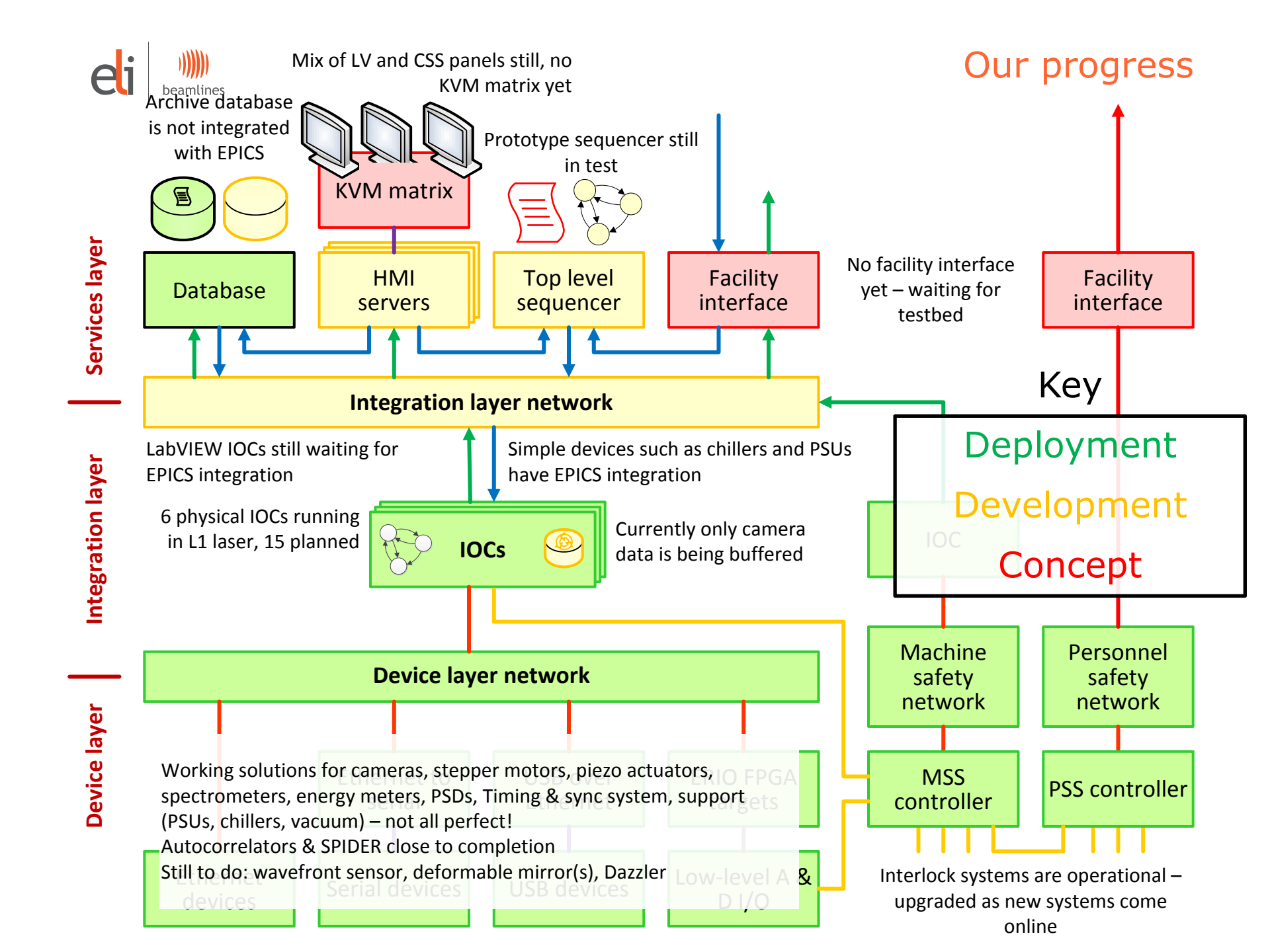
LV-native – Pharlap now and future-proof for NI Linux-RT

Minimum specialist knowledge required (EPICS, Linux, C++…)

Simple LabVIEW interface – no LVOOP (idiot-proof!)

Both NI's EPICS client/server module and the solutions offered by Observatory Sciences seemed to meet these RQs




Our progress
beamlines
Mix of LV and CSS panels still, no KVM matrix yet
Archive database is not integrated with EPICS
KVM matrix
Prototype sequencer still in test
Services layer
Database
HMI servers
Top level sequencer
Facility interface
No facility interface yet – waiting for testbed
Facility interface
Integration layer network
Key
Deployment
Development
Concept
Integration layer
LabVIEW IOCs still waiting for EPICS integration
Simple devices such as chillers and PSUs have EPICS integration
6 physical IOCs running in L1 laser, 15 planned
IOCs
Currently only camera data is being buffered
IOC
Device layer network
Machine safety network
Personnel safety network
Device layer
Working solutions for cameras, stepper motors, piezo actuators, spectrometers, energy meters, PSDs, Timing & sync system, support (PSUs, chillers, vacuum) – not all perfect!
Autocorrelators & SPIDER close to completion
Still to do: wavefront sensor, deformable mirror(s), Dazzler
MSS controller
PSS controller
Interlock systems are operational – upgraded as new systems come online