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
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

ELI Beamlines Facility in Prague

40m, 80m, 60m, 110m
The lasers at ELI-BL

**L1**
- L1 oscillator: Ti:sapphire, 80 MHz, <8 fs
- L1 front end: ps OPCPA preamps, Thin-disk preamps
- RF master clock: Er:fiber clock

**L2**
- Pump DPSSL multislab: Yb:YAG, 100 mJ, <20 fs, 1 kHz
- Compressor: ns-ps
- ps OPCPA
- OPCPA Stage 1 chain
- OPCPA Stage 2 chain
- 20 J, <15 fs, 10 Hz
- 2 J, <15 fs, 10 Hz

**L3**
- Pump DPSSL multislab: Nd:glass, 200 J
- Oscillator: Ti:sapphire, OPCPA front end
- Ti:sapphire power amp
- 30 J, 20 fs, 10 Hz
- 11 J, 20 fs, 10 Hz

**L4**
- Oscillator: Nd:glass CPA chain
- 10 PW compressor
- 1.5 kJ, 150 fs
- 1.8 kJ, 0.5-5 ns
- 1 PW compressor
- ~150 J, 150 fs

**E1** Apps in molecular, biomedical, & material sciences
**E2** XUV / X-ray generation
**E3** Plasma physics lab astrophysics
**E4** High-field "exotic" physics
**E5** Electron acceleration
**E6** Proton acceleration

*Fyzikální ústav Akademie věd ČR, v. v. i.*
## Laser summary

<table>
<thead>
<tr>
<th>Beamline</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power</td>
<td>&gt; 5 TW</td>
<td>PW</td>
<td>≥ PW</td>
<td>10 PW</td>
</tr>
<tr>
<td>Energy in pulse</td>
<td>100 mJ</td>
<td>≥ 15 J</td>
<td>≥ 30 J</td>
<td>≥ 1.5 kJ</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>&lt; 20 fs</td>
<td>≤ 15 fs</td>
<td>≤ 30 fs</td>
<td>≤ 150 fs</td>
</tr>
<tr>
<td>Rep rate</td>
<td>1 kHz</td>
<td>10 Hz</td>
<td>10 Hz</td>
<td>1/60 Hz</td>
</tr>
<tr>
<td>Supplier</td>
<td>Commercial pump lasers (Trumpf Scientific &amp; ...</td>
<td>STFC RAL major supplier and technology developer</td>
<td>LLNL major contractor</td>
<td>National Energetics &amp; EKSPLA major contractor</td>
</tr>
<tr>
<td>IoP activities on control systems</td>
<td>Complete control system and integration</td>
<td>Complete control system and integration</td>
<td>Integration and joint software development</td>
<td>Integration and collaboration on HW &amp; SW</td>
</tr>
</tbody>
</table>
Most laser control is not *technically* challenging...

Mostly sub-kHz diagnostics, slow feedback, modest AI/OO 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
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
A good architecture aims for **scalable**, **adaptable**, **maintainable** and **reliable** integration but must consider project constraints:

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

From challenges to architecture
Our control system architecture

Integration layer network

Integration layer

Device layer network

Device layer

- Database
- Database HMI
- Top level sequencer
- Facility interface

Integration layer network

- IOC
- MSS controller
- PSS controller

Device layer network

- Ethernet to serial
- USB over Ethernet
- ERIO FPGA targets
- Ethernet devices
- Serial devices
- USB devices
- Low-level A & D I/O

Configuration and archiving

State machine and scripts

Transition requests, operating mode

Status and shot reports

SafetyNET

Facility safety systems monitoring

Machine

Personnel safety

Interlock permissives

Interlock permissives

Status & monitoring (EPICS)

State control (EPICS) & configuration (MySQL)

Device communications (e.g., VISA)

MSS failure signals (24V logic)
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)

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

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

*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/]
 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)
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
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
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...

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...
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)
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 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
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

Trial CSS control panel for state machine

System state specification
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
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/EKS PLA: nationalenergetics.com

Tomáš Mazanec and the rest of the LCS team!
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

Database

HMI

servers

Integration layer network

IOCs

Top level sequencer

Facility interface

Prototype sequencer still in test

Mix of LV and CSS panels still, no KVM matrix yet

No facility interface yet – waiting for testbed

Facility interface

Service layer

Integration layer

Device layer

Archive database is not integrated with EPICS

KVM matrix

LabVIEW IOCs still waiting for EPICS integration

6 physical IOCs running in L1 laser, 15 planned

Simple devices such as chillers and PSUs have EPICS integration

Currently only camera data is being buffered

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

Interlock systems are operational – upgraded as new systems come online

Machine safety network

Personnel safety network

MSS controller

PSS controller

Key