Development and delivery of key subsystems of L2 Stage 1 high repetition rate OPCPA beamline

1. Background

The ELI Beamlines project requires a PW-class, high repetition rate, high power contrast laser system for use in a wide-ranging, internationally based scientific research programme. The provisional specification is an output pulse energy of >15 J, pulse duration ≤15 fs and repetition rate of at least 10 Hz, with a contrast of at least $1{:}10^{11}$ @ 20 ps before the main pulse.

The architecture of the L2 system is to be based on an OPCPA amplifier chain, to provide the short pulse capability, pumped by a frequency doubled, diode pumped, solid state laser (DPSSL) operating at 10 Hz.

A two stage procurement strategy has been devised that mitigates the substantial technical risks at the lowest possible cost. These include the performance of low dispersion compression gratings, $>10^{10}$ pulse contrast and the maintenance of >200nm amplification bandwidth in the >1 J regime at high repetition rate (≥10 Hz).

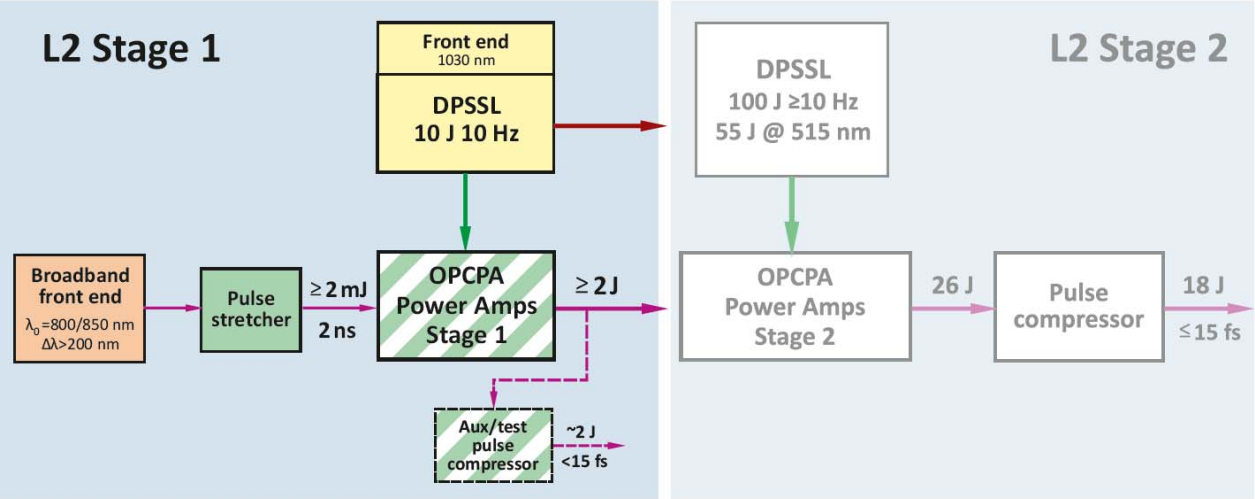
Stage 1, which is the subject of the current procurement, involves the modeling and design of the complete L2 system and the construction of the first part of the L2 chain to validate the modeling and design and to mitigate the most serious technical risks. **Stage 2**, which will be a subject of a future procurement, will take the information developed in Stage 1 and will deliver the additional OPCPA amplification to boost the energy to >20 J, using total available pump energy (frequency upconverted output of the 100 J high-rep rate laser) of 60 J and pulse compression systems necessary to realize the full L2 OPCPA beamline specification.

2. Objective of the L2 Stage 1 contract

Stage 1 delivery has for the goal demonstrating the concept of high-repetition rate OPCPA power beamline using recently developed 10 J 10 Hz Yb:YAG pump laser and two OPCPA amplifiers. A specific goal is demonstrating generation of optical spectrum with bandwidth of 200 nm or larger, centered at nominally 850 or 800 nm depending on the choice of the amplifier crystals (LBO or YCOB). Stage 1 shall provide quantitative benchmark against design values such as amplified spectrum, temporal contrast (superfluorescence), pulse energy stability, beam profile, etc. It will serve as testbed for dispersion management in the OPCPA chain and for ultra-broadband pulse stretcher and pulse compressor using low-dispersion gratings (e.g. 900 l/mm). Another important activity within Stage 1 will be development of operation of the chain at 20 Hz or higher repetition rate.

A supplier for Stage 1 is sought that has world leading experience in both OPCPA and DPSSL systems and, furthermore, an extensive track record in the provision of state-of-the-art laser facilities to the scientific user community. Furthermore, the Supplier must have and make available specific equipment necessary to conduct the programme of the technical risk reduction to the Stage 1 development. This includes notably a 10 J laser running at 10 Hz, equipped with frequency doubling providing in excess of 5 J per pulse.

Works on all deliverables of this project will require extensive cooperation with the ELI-Beamlines laser team, including frequent meetings in the ELI-Beamlines project offices in Prague.



Block scheme of the L2 Stage 1 and schematic scheme of L2 Stage 2. Scope of the Stage 1 delivery, i.e. subsystems of the L2 Stage 1 required to be provided by the Supplier are indicated in green (existing Yb:YAG cryogenic diode-pumped solid state 10 J / 10 Hz laser is indicated in yellow, the broadband front end implemented by ELI-Beamlines team is in orange). Details are specified below.

3. Major performance requirements

The performance requirements stated for Stage 1 in the table below represent a set of values that are to be met simultaneously. The values are based on results of the existing full L2 beamline modeling and design work that has been undertaken at FZU by the ELI-Beamlines laser team. Requirements for Stage 2 represent tentative values based on the full PW L2 beamline modeling by ELI-Beamlines; these values are to be re-iterated upon experience gained in Stage 1.

Stage 1 must employ as pump engine the 10 J 10 Hz laser using the Yb:YAG cryogenically cooled multislab power amplifier, which is currently being implemented by ELI-Beamlines in FZÚ premises, or a system with equivalent performance. The laser provides ≥2 ns pulses at the fundamental wavelength 1030 nm, in square beam with 22x22 mm size with near top-hat intensity spatial profile. Development of this laser by the Supplier does not form part of this Procurement.

The broadband part must employ front end with characteristics comparable to those of the front end developed by ELI-Beamlines. This front end delivers broadband pulses with energy of 3.3 mJ, with FWHM length 1.5 ps Gaussian temporal profile, in circular beam with Gaussian spatial intensity distribution. The central wavelength is adjustable between 800 and 850 nm, with FWHM spectral bandwidth of the pulses of approximately 200 nm. Development of this broadband front end by the Supplier does not form part of this Procurement, however reasonably minor modification of the Supplier's existing front end, necessary for exploiting it for the L2 Stage 1 development, may be included in scope of this Procurement. Testing performance of the OPCPA L2 Stage 1 chain against the designed parameters at central wavelengths near 900 nm will be accepted, however appropriate modelling of performance wavelength scaling between 800 and 900 nm has to be supplemented.

Parameter	Stage 1	Stage 2 [1]
Completion date	12/2015 [2]	*09/2017* [3]
Energy	≥ 2 J	*≥ 20 J*
Pulse duration (adjustable) [4]	≤ 15 fs to 50 fs	*≤20 fs (or <15 fs* [5]) to 50 fs
Central wavelength	850 nm [6]	

Peak power	≥100 TW	*≥1 PW*
Repetition rate	10-20 Hz	*≥20Hz, scalable to 50 Hz*
Shot-to-shot pulse energy stability (RMS) [7]	better than +/- 1%, desired 0.5% or better	
Power contrast [8]	better than $1:10^{11}$ @ 20 ps	
Beam size (after compression) [9]	<80 mm	*180 mm*
Beam intensity spatial profile modulation (peak-to-peak) [10]	Smaller than +/-10%	
Beam pointing RMS stability [11]	<10 µrad, desired value <3 µrad	
Single shot capability	Yes	
Output beam quality: encircled energy in diffraction limited spot [12]	better than 80%	
Operation	autonomous	autonomous synchronized to facility L1 clock
Precision of synchronization relative to the facility L1 clock [12] (RMS stability)	N.A.	<20 ps to RF clock ≤5 fs to optical clock

[1] Stage 2 is contingent on successful completion of Phase 1

[2] at Stage 1 Supplier's facility or in the SOFIA laboratory, prior moving into the ELI-Beamlines facility (laser hall L2)

[3] Targeted date at the ELI-Beamlines facility

[4] Bandwidth limited, i.e. unchirped, pulse; the pulse duration has to be adjustable over the specified interval

[5] Depending on the choice / availability (technology development needed) of large PW compressor gratings for broadband and repetition rate pulses: expected pulse duration of approximately 20 fs if large gratings identical to L3 (1480 l/mm) are used, <15 fs if low-dispersion, 900 to 1000 l/mm, gratings, are used

[6] Depending on the crystals for the power amplifiers: 850 nm for LBO (baseline design), 800 nm for YCOB

[7] Depending on pulse-to-pulse stability of the Yb:YAG pump laser

[8] Given by superfluorescence, value better than $1:10^{10}$ expected from numerical simulations; the front end producing the seed signal shall have energetics allowing implementation of extra pulse cleaning (e.g. XPW)

[9] FWHM value - actual size will depend on the compression gratings used; the value for Stage 2 is estimated

[10] Top-hat beam profile; nominal profile approximated by a Gaussian of 8^{th} order or higher

[11] Actual value will depend on the pump laser beam pointing stability. High beam pointing stability is necessary for experiments using long focal lengths (off axis parabola)

[12] It is expected that significantly better value will be obtained, depending on quality of the seed and of the pump beam

[13] The RF electronic facility clock is 480 MHz square pulse signal; the optical clock is a fiber-laser generated pulse train with 240 MHz repetition rate, at about 1.5 µm wavelength

The OPCPA Stage 2 power beamline should be designed to allow possibility to exploit the idler beam for experiments.

4. L2 Stage 1 contract scope

The L2 Stage 1 contract includes:

- Conceptual design of Stage 1, numerical modeling and optimization of the complete L2 OPCPA PW beamline, cost estimate of the L2 Stage 2. The conceptual design shall exploit the existing L2 modeling and design work undertaken by the ELI-Beamlines laser team; this report will be provided to the Supplier after signing the contract.
- Development of the Stage 1 OPCPA beamline delivering ~2 J in $\leq$15 fs pulses, pumped by the frequency converted output of the 10 J 10 Hz Yb:YAG laser
- Commissioning of the prototype OPCPA beamline incorporating existing equipment from ELI-Beamlines and Supplier, a new pulse stretcher and a new pulse compressor
- A report on the performance of the system, validation of the system modeling and development of the Stage 2 design. Information from Stage 1 should substantially mitigate the risk of Stage 2, increasing confidence in the delivery and reducing the cost of full L2 PW beamline
- Delivery of the pulse stretcher, of the optimized frequency crystal doubler for the 10 J 10 Hz laser, of the specific optical components of the OPCPA chain, and of the optical components of the Stage 1 compressor to ELI-Beamlines

5. L2 Stage 1 Contractual Deliverables

Assumed start of the contract: February 2014

D1: Deliverable D1 comprises the conceptual design of the complete PW OPCPA-based L2 beamline, supported by numerical modeling and performance data obtained from existing state-of-the-art OPCPA systems. This deliverable will benefit from access to the existing L2 beamline modeling and design work that has been undertaken at FZU by the ELI-Beamlines laser team. A preliminary cost estimate of key components will also be developed for the full L2 PW OPCPA based beamline to assist FZU in finalizing the specifications of the L2 beamline.

Result of the D1 Deliverable will be a report on the conceptual design of the L2 OPCPA beamline including comparison with the L2 beamline design works previously made by the ELI-Beamlines, and including the full L2 cost estimate.

Date: 30 June 2014

D2: Deliverable D2 comprises the ordering of the pulse stretcher and compressor optics, and operating and optimizing of a 200-nm-bandwidth front end which will be used by the Supplier for testing performance of the L2 Stage 1 OPCPA system in the subsequent Deliverables.

Result of the D2 Deliverable will be a report on ordered components of the stretcher and compressor optics, and a report on parameters of the front end up and running to be used for testing performance of the L2 Stage 1 OPCPA chain.

Date: 30 September 2014

D3: Deliverable D3 comprises construction and commissioning of the Stage 1 OPCPA power amplifiers. The system will be pumped by a 10 J single beam, frequency doubled, 10 Hz DPSSL laser of identical type as the 10 J 10 Hz system operated by ELI-Beamlines. The pump laser shall be equipped by performance optimized frequency doubler (SHG crystal assembly) that will be delivered to ELI-Beamlines within Deliverable 5 of this contract. The tests of the OPCPA amplifiers will be performed using both LBO and YCOB crystals and system performance will be included within the D3 report.

In parallel to this activity Supplier will advise ELI-Beamlines on the development of a 20 Hz DPSSL architecture, including the current 10 J 10 Hz laser operated by ELI-Beamlines, to facilitate future upgrades of the L2 system to 20 Hz and beyond.

The result of the D3 Deliverable will be a report on performance of commissioned repetition rate OPCPA power chain. The report shall include description of optimized frequency doubler for the repetition rate 10 J laser and its performance. The report shall further detail on upgrade of the OPCPA system to achieve its operation at 20 Hz and beyond.

Date: June 2015

D4: Deliverable D4 comprises the construction and commissioning of the pulse stretcher, and construction and commissioning of a pulse compression system designed to operate with the output of the Stage 1 OPCPA power amplifiers developed in D3 and scalable to PW powers. The system will be optimized, with a target performance of 2 J / $\leq$15 fs. Suitable short-pulse diagnostics will be provided by ELI-Beamlines to the Supplier.

Result of the D4 Deliverable will be report on commissioned pulse stretcher and pulse compressor for the L2 Stage 1 system. The report will detail performance of optimized L2 Stage 1 OPCPA chain, with comparison of achieved performance with respect to the Major Performance Requirements.

Date: September 2015

D5: Deliverable D5 comprises a final assessment of the L2 Stage 1 system and comparison of performance with the modeling performed at D1. The model will be updated and improved as necessary and used to re-validate and develop the overall conceptual design of the L2 OPCPA beamline.

Deliverable 5 further comprises delivery of components of the OPCPA system to FZU, including the optimized second harmonic generator, the pulse stretcher, compressor gratings, and OPCPA Stage 1 amplifiers.

Result of the D5 Deliverable will be delivered to FZU premises the optimized second harmonic generator developed in D3, OPCPA Stage 1 amplifiers developed in D3, and the pulse stretcher and compressor gratings developed in D4. Result of the D5 Deliverable will further be a report comparing in detail the achieved performance of the OPCPA Stage 1 chain against modeling undertaken in D1.

Date: December 2015

6. Intellectual property

The Supplier is asked to make available to ELI-Beamlines existing proprietary information and know-how for the purposes of this L2 Stage 1 contract. The right to commercial exploitation of intellectual property that arises during the course of the Supplier's activities in the contract can reside with the Supplier. In such case, a royalty free license shall be made available to FZU for the purpose of construction of the full L2 PW beamline (Stage 2).