**XCELS – CREMLIN**

The project CREMLIN – Connecting Russian and European Measures for Large-scale Research Infrastructures – was a Coordination and Support Action supported by the Horizon 2020 framework programme of the European Union. The project was launched in October 2015 and aimed at fostering scientific cooperation between the Russian Federation and the European Union in the development and scientific exploitation of large-scale research infrastructures. 19 European research centers, including 6 Russian institutions, established a consortium the principal goal of which was the development of coordination and support measures for each research infrastructure and common best practice and policies on internationalisation and opening. The project was intended for 3 years during which each consortium member organized working meetings and/or focus workshops with participation of other CREMLIN members, where problems of mutual interest were discussed and plans for further collaborative efforts were formulated.

The successful implementation of the project gave an impetus to start up a new project – **CREMLINplus** – aimed at scientific and technical collaboration (*Cremlinplus.eu*). The two principal objectives of CREMLINplus are the technical preparation of the megascience projects for European and international utilization and the elaboration of measures for preparing a set of Russian research infrastructures for international access and utilisation by developing and implementing suitable framework conditions for opening and accessing these Russian facilities.

35 partners, 10 from Russia and 25 from the EU and associated countries take part in the project. The project tasks will be implemented by 10 work packages (WP). Each work package includes several partners from the European Union and the Russian Federation. The Institute of Applied Physics of the Russian Academy of Sciences is the leading partner of work package 6 (WP6). The other WP6 partners are Commissariat à l'Énérgie Atomique et aux Énérgies Alternatives, France (CEA), Association Internationale Extreme-Light-Infrastructure Delivery Consortium, Czech Republic (ELI-DC AISBL), and Laserlab-Europe AISBL, Belgium (LLE-AISBL). WP6 is dedicated to joint technology development around XCELS – Exawatt Center for Extreme Light Studies.

One of the major motivations of XCELS is reaching the non-linear QED regime, using an approach based on the combination of 12 multi-PW laser beams. Such a huge laser will provide peak intensities that will be around 1026 W/cm 2, 3 orders of magnitude below the Schwinger limit, but still 2 orders of magnitude above the intensity of any other laser project under construction. Finding realistic approaches to reaching XCELS’ intensity and further is essential for such a project.

WP6 aims at developing the necessary technologies to provide the key technological foundations for the XCELS project:

For nonlinear optical devices:

- Conceptual design of a relativistic plasma mirror well-suited for XCELS;

- Design and development of a prototype of nonlinear compressor of ultraintense laser pulses.

For ultrashort beams:

- Develop technologies for ultrashort laser pulse contrast enhancement based on non-linear optical devices;

- Design a single-shot spatio-temporal diagnostic device for ultrashort / ultraintense laser pulses well-suited for XCELS.

- Training and scientific exchange on beam delivery, laser pulse contrast issues, metrology and best practices.

*Description of the work*

**Task 6.1**: **Pulse compression and contrast enhancement in nonlinear optical devices** (**IAP, CEA-LIDYL)**

In the last decade, physicists have put forward the idea that relativistic plasma mirrors might be used as light condensers, making it possible to reach the Schwinger limit with much less laser energy than expected. Preliminary calculations and numerical simulations performed by CEA-LIDYL demonstrate that temporal compression and tighter spatial focusing

could make it possible to reach the Schwinger limit with a single 10 PW laser beam, provided an adequate target design is used.

In the framework of CREMLINplus, *CEA-LIDYL will investigate this new scheme in detail, by combining analytical calculations based on simple* models, with the most advanced 3D Particle-In-Cell simulations to date. This theoretical work would be used as a crucial input to guide preliminary experiments, which are essential to design future experiments at XCELS.

First demonstration experiments with such optically-controlled curved plasma mirrors would then be performed on 100 TW class (e.g. UHI100 @CEA Saclay) or even PW-class lasers (e.g. APOLLON, CORELS, BELLA). One of the important goals of these preliminary experiments would be to find ways to diagnose the increase in peak intensity induced at the focus of the plasma mirror. Ultimate power of ultrahigh intensity lasers is limited by the damage threshold of diffraction gratings of the pulse compressor. Typically, after pulse compressor the laser beam cannot be passed through solid-state optics due to the optical self-focusing effect. Plasma mirrors represent an exception due to the plasma nature. Nevertheless, *IAP proposed different ways to use solid-state based nonlinear optics in order to compress powerful laser pulses after the compressor:*

Compression after Compressor Approach (CafCA). The basic idea is to use self-phase modulation and chirped mirrors. The following aspects will be studied in detail: influence of residual spectral phase on self-phase modulation, two-stage CafCA, small-scale self-focusing suppression, second harmonic generation followed by CafCA, self-compression after

compressor. Similar ideas (nonlinear interferometer), have been also recently proposed for contrast enhancement.

**Task 6.2:** **Advanced metrology of ultrashort laser beams** **(CEA-LIDYL, IAP)**

Advanced optical metrology is essential for the ultimate optimization of high-power ultrashort laser beams. Thanks to the research carried out in the last 20 years, accurate metrology tools now exist to separately measure the spatial and temporal properties of ultrashort lasers. However, a characteristic feature of these beams is that they can exhibit spatiotemporal

couplings, i.e. a spatial dependence of their temporal properties, or vice versa. If uncontrolled, these couplings can easily decrease the peak intensity at focus of high-power femtosecond lasers by more than one order of magnitude. CEA-LIDYL is a pioneer in the development of new techniques for the spatio-temporal metrology of high-power

femtosecond lasers. They recently achieved a complete spatio-temporal characterization of the BELLA PW laser in Berkeley, at full power, and with two independent measurement techniques.

In the framework of CREMLINplus, *CEA-LIDYL will improve these techniques, make sure that they will be suitable for the characterization of the complex beam combinations envisioned for XCELS, and investigate single-shot versions suited to low-repetition rate lasers.* Having such techniques available at the early stage of XCELS would be a crucialasset to guarantee the optimal performances of this laser. *IAP will also develop new nonlinear devices for E-field reconstruction.*

**Task 6.3**: **Training and scientific exchange (LLE AISBL, ELI-DC AISBL, IAP)**

Paramount to the success of CREMLINplus is trained personnel with specialized knowledge in state-of-the-art technology and scientific methodologies related to high power laser matter interaction, nonlinear pulse forming techniques and diagnostics methodologies. These issues are of equal interest for existing infrastructures such as ELI and European XFEL and the members of the pan-European international association Laserlab-Europe AISBL (LLEAISBL). Here, LLE-AISBL unites most relevant outstanding scientific and technical skills, and much premier knowhow, among its partners. Thus, we aim to leverage synergies in knowledge sharing and training between LLE-AISBL and the other WP6 partners as an effective means to boost global effectiveness.

*LLE-AISBL will provide a platform for dedicated knowledge sharing and training on the topics of intense laser pulse propagation, pulse contrast enhancement, and pulse metrology. This will be realized through a series of three events in* which these relevant topics will be discussed among the partners in conjunction with experts from Laserlab-Europe andexternal internationally renowned instructors. The regularity of these training events will provide a sustainable laserscience forum in which knowledge and state-of-the-art results are shared and best practices are developed.

*Results*

*WP 6 Progress report for the first year (February 2020 - January 2021)*

The workshop “The status of the XCELS project” planned to be organized in Russia by the IAP in the first year of the project had to be delayed due to the travel restrictions associated with the COVID-19 pandemic. It was held as a videoconference on June 10. The information about it is available on the

Website:

*[https://www.cremlinplus.eu/news/events/2021/workshop\_the\_status\_of\_the\_xcels\_project/](https://www.cremlinplus.eu/news/events/2021/workshop_the_status_of_the_xcels_project/" \t "_blank)*

The value of 11 fs record for a 1.5 PW pulse was obtained at the PEARL laser of the Institute of Applied Physics. This became possible thanks to the use of the unique method of additional compression of laser pulses CafCA (Compression after Compressor Approach). The optical pulse becomes several times shorter than the original one, and its peak power increases by the same number of times, since the pulse energy practically does not change during the conversion.