Report on XCELS
by the
International Advisory Committee

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Since their inception, particle accelerators have been workhorses for high energy physics which in turn has motivated the advance of high energy accelerator technology. However, in recent years the scientific community has garnered a compelling scientific case that invites the exploration of fundamental problems in physics using ultra high peak power lasers that can be focused to ultra-high peak intensities and fields. The proposed XCELS high power laser facility would provide the highest laser peak power and intensity achievable and become the foremost facility in the world. This distinction is given by the unique ambitious parameters:

- the highest electric fields
- the highest electron energy (>100 GeV)
- the highest radiated photon energy (>100 GeV) and
- the shortest pulse durations (~ zeptosecond).

Implementing a laser-based fundamental research infrastructure in Russia, particularly at Nizhny Novgorod, is highly appropriate considering the pioneering work performed in the early 60's by scientists from this famous Russian Physics School immediately following the invention of the laser. This includes the highly original work of luminary scientists such as A. Nikishov, V. Ritus, N. Narozhny, V. Popov, V. Demur in strong field vacuum physics; A. Gaponov-Grekhov, V. Talanov, A. Litvak, V. Gildenburg in plasma physics and, more recently, E. Kazhanov and A. Sergeev in short pulse laser amplification. Furthermore, future leading research should arise from the large scale Russian Megajoule system being constructed in Sarov, which is close to the Institute for Applied Physics, RAS in Nizhny Novgorod.

We recently completed a two-day technical and scientific review of the XCELS science case, design concept and other more general issues. The proposed system could potentially achieve a record peak power of 200 PW, which could provide intensities in excess of 10^{25} W/cm^2. This would exceed current obtainable intensities by three orders of magnitude through the use of a new laser amplification system and beam phasing approach. The XCELS international scientific committee is convinced that this facility has the potential to provide laser beams with unique parameters to the scientific community, thus enabling significant advances in fundamentally new regimes of physics. The committee therefore strongly recommends that the project advance from the conceptual phase to the preparatory-prototyping phase.

Furthermore, moving to the prototyping phase now is timely. One of the declared objectives of this new infrastructure is to serve the international community. As the project is very challenging, it is of paramount importance that the international community be involved as soon as possible to advance the proposed science case as well as in all aspects of the design of XCELS to ensure that the laser specifications are robustly achieved (i.e. energy, peak power, focused intensity, stability, beam quality and repetition rate), and that suitable beamline configurations, experimental halls and diagnostics are planned.

The funding level planned for this infrastructure is sufficiently high to enable the development of the very best technology to ensure a very high quality science programme, which is one of the main objectives of the facility. In order to obtain record breaking performance, several key technologies will need to be aggressively advanced with critical involvement and support of the international community. These include thin crystal growth, diffraction gratings, mirror coating, frequency conversion, interferometric alignment, beam diagnostics and control techniques. Particularly strong interaction is recommended with the European laser community, engaging in the Pan-European Extreme Light Infrastructure ELI which, at its present stage, is constructing laser facilities at power levels between today's state-of-art and the XCELS project.

We estimate that the preparatory/prototyping phase should take two to three years and could constitute 5-10 % of the construction cost. This number needs to be confirmed.

Technology Transfer is an expected outcome and an important part of the mission. A philosophy that brings a strong desire to deliver excellence with the highest possible specifications is propitious to scientific and technological breakthroughs that can lead to important societal applications, job creation and diverse spin-off ventures. Studies of large scale fundamental research infrastructures such as CERN and the ESRF have indicated that the long-term socio-economic return on the investment can be as high as 3€ for every 1€ invested. It is therefore important that an aggressive technology transfer programme is established.

Knowledge Transfer must also be an important mission for XCELS. This fundamental research infrastructure will be driven by top scientists and engineers in all disciplines, which would benefit knowledge transfer. The activities will involve not only high energy fundamental physics, which is a core activity, but also cross-disciplinary fields such as laser physics, optics, biophysics, material science, electrical engineering, mechanical engineering, complex system engineering and information technology. This could also be extended to project management and business to generate a vibrant entrepreneurial culture. The committee recommends that an “Institute” be created to facilitate the knowledge transfer to the community.

Science will be greatly advanced by this laser facility. Because of the field coherence, monochromaticity and magnitude, the laser is a gateway to novel spectroscopic methods of investigation which could significantly deepen our understanding of atomic, nuclear and nucleonic structure. Probing the subsequent strata of the nucleus, the nucleon or vacuum is currently impossible because of insufficient field strength. To date, neither the laser photon energy nor its electric field strength are high enough to conceive decisive experiments beyond the atomic level. It is the objective of the XCELS center to perform research well beyond the eV energy level and to reach the GeV-TeV range where the nucleus and its constituent parts can be probed.

The main scientific and technological topics that will be addressed by XCELS include:

- exawatt laser technology
- TeV physics
- physics beyond 100GeV in the non-collider paradigm

- TeV astrophysics
- nonlinear effects in vacuum
- attosecond/zeptosecond ultrafast science
- dark energy and dark matter
- radiation near the Schwinger field
- precision particle/radiation metrology
- Lorentz invariance.

The laser technology development programme will emphasize the following topics:

- highest intensity/electric field (~10^{25} W/cm^2, through judicious 12 beam distribution and interferometric synchronization)
- highest laser intensity contrast >10^{24} through frequency doubling
- wave-front quality – better than l/10 r.m.s. of each beam
- beam phasing – better than l/10 r.m.s. of each beam
- repetition rate of one shot every 20 minutes.

These specifications are indicative of the level of excellence to which XCELS aspires. They may not all be realistic. They will be confirmed during the preparatory-prototyping phase.

Conclusion

Based on the description of the conceptual design, the scientific committee is convinced of the quality and timeliness of the XCELS project. XCELS is ambitious and designed to introduce a new paradigm in High Energy Physics where high-energy particles are replaced by an ultrahigh laser field. XCELS could be the premiere laser-based High Energy Physics platform in the world occupying a prominent scientific position. The committee is of the opinion that the XCELS conceptual design phase has been completed and recommends advancement to the prototyping phase. The appropriate funding should be allocated. During this phase, which would last two to three years, we recommend that the current team works in concert with the international community as early as possible. This, includes, in particular the ELI Consortium.

During this phase the design will be finalized. It should include specification of the laser, the beamline configuration and experimental halls. An early integration with the international community will facilitate and encourage other countries to join and help to fund the project.

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Chair of the International Advisory Committee