LETTER OF INTENT FOR STUDIES OF ULTRAFAST PROCESSES IN CONDENSED MATTER

SUMMARY

This LOI is centred around the tasks within the European Marie-Curie Research Training Network "FLASH". The unifying scientific aim of **FLASH** is to exploit recently developed ultrafast pulsed X-ray technology, together with complementary methodologies so as to open new windows on fundamental processes in photo-chemistry and photo-physics. Connections with the ERATO project in Japan through a French partner and other collaborations are manifested through the participation of Japanese scientists in this LOI.

Within this collaboration involving about 40 scientists, we intend to investigate the temporal evolution of matter following excitation by short laser pulses. Using time-resolved x-ray diffraction we will follow atomic motions in real time.

The LOI involves utilizing LCLS as a part of a wider theme where x-ray and visible pump/probe methodologies, as well as theoretical development and molecular dynamics simulations are employed. We will address key scientific issues as the role of optical phonons in phase-transitions, describing non-equilibrium states of matter, identifying intermediate complexes in chemical reactions, using shock-waves to probe and control matter, triggering by light coherent macroscopic switching and domain-reversal in materials (ferroelectric or other ones). .

Driving phase-transitions with compression waves
Optical phonon-softening during phase-transitions
Phase-transitions in semi-metals and metals
Multi-photon damage of material
Molecular switching and photo-induced phase transitions
Ferro-electric phase-transitions
Charge-transfer reaction dynamics
Coherent phenomena in the disordered phase

EXPERIMENTS

Direct visualisation of atomic movements on the sub-ps time scale through time resolved X-ray scattering will break new ground in material physics and chemistry. Several non-equilibrium problems of both scientific and technological interest will be studied with X-ray probes, visible probes and theoretical calculations [1-15].

Driving phase-transitions with compression waves

The vast majority of methods used to diagnose shock waves in solids measure macroscopic parameters, and give no information on the lattice level. On the other hand, X-ray diffraction affords the possibility to directly measure the lattice spacing, and potentially the phase, of materials, as they are shocked to pressures up to a few Mbars, where shock melting typically takes place. The fundamental physics of such shock waves remains elusive – that is to say, the exact mechanisms by which the material behind a strong shock rapidly attains hydrostatic conditions is poorly understood. **We anticipate a**

breakthrough where in situ x-ray diffraction can shed considerable light on these issues, as it allows the measurement of elastic strain. We will use X-ray diffraction to directly measure the lattice spacing, and potentially the phase, of materials, as they are shocked to pressures up to a few Mbars, where shock melting typically takes place. It has not previously been possible to follow shock-driven phase-transitions with high temporal resolution in real time. Ultrafast melting has been shown to occur in semiconductors, but using a multi-peak analysis (rather than a single Bragg peak), the motion of atoms could be followed in real time showing possible new phases just prior to melting. The work being done in the project goes well beyond the present state of the art knowledge of phase transitions. The mechanisms studied are responsible for the refractive index modification of dielectric materials processed with ultrashort pulses. The study of single crystalline dielectric materials will help in understanding the modification mechanisms (i.e. chemical modification, densification by pressure, defect formation) present. The broad applicability of refractive index modification spans information storage and direct waveguide manufacturing. In order to better understand the deformation mechanisms that take place in crystalline solids subject to shock compression **(Wark)** have been using molecular dynamics techniques to model motion at the atomic level. Calculations can involve up to 10^8 atoms with the equations of motion for each atom solved for periods of up to a few picoseconds. **Wark** has developed X-ray diffraction post-processors to these simulations which give sophisticated predictions for the expected diffraction patterns expected when femtosecond duration X-rays are scattered from the shocked samples. The insights gained are giving considerable insight into new methods of diagnosing deformation mechanisms and rates on both a temporal and length scale hitherto inaccessible, and will, we believe, result in a deeper understanding of how materials respond under ultra high strain rates.

OPTICAL PHONON-SOFTENING DURING PHASE-TRANSITIONS

Upon femtosecond laser excitation strong changes of the effective potential energy surfaces, which determine the equilibrium structure of a solid, can be induced. This may lead to atomic rearrangement even on a sub-picosecond time-scale. A very exciting example is the sub-picosecond solid-liquid phase transition induced by femtosecond laser-irradiation in covalently bonded semiconductors. This process is often called non-thermal melting since the transition takes place on a time scale much shorter than the time required to transfer the energy from the excited electrons to the thermal motion of the lattice, which is of the order of several picoseconds. Using a novel multi-peak diffraction analysis, time resolved on the femtosecond time scale, **we plan to study the onset of non-thermal melting and track the coherent and incoherent atomic displacements (acoustical and optical phonons) near the melting threshold to understand the contribution, if any, of these atomic vibrations to the whole dynamics**.

The unprecedented flux at LCLC will allow for studies of photo-induced phase transitions in solid-matter by diffuse scattering. This x-ray scattering technique provides many more details about microscopic changes during the transition than the integrated intensity in the Bragg spot. This technique could be applied to photo-excitation of single crystals (e.g. melting type transitions or solid-solid transitions) and to phase formations.

Sondhauss and Wark have extended the Takagi-Taupin theory in order to model optical phonons. By splitting up the susceptibility into the contributions from each atom in a unit-cell modifications to the structure factor, as well as lattice parameter, are taken into account. The result is a compact, surprisingly simple equation with a strong formal similarity to classical Takagi-Taupin equation, with the latter included as a special case.

MOLECULAR SWITCHING AND PHOTO-INDUCED PHASE TRANSITIONS

The ultra-fast macroscopic switching of materials in solid state opens new avenues for the manipulation of matter with light and it will present, in fact, a high potential for new keys in industrial innovation. Indeed, information storage in materials is based up to now on switching kinetics governed by slow thermal activated nucleation-growth processes above the ns time-scale. Switching in a macroscopic or nano-structured material triggered by coherent motions (molecular, domain wall, …) would signify a technological breakthrough. Especially, in relation with the investigated molecular materials, there is a large demand in optical information processing (ultra-fast writing and/or erasing) and optical devices for telecommunication applications (large spectral photo-induced changes). In addition, the (dis)appearance of magnetic species controlled by light (as in spin transition systems) supplies a new channel for information storage. This is coming up in molecular materials by virtue of photo-induced co-operative and coherent change in molecular identity, such as its charge state and/or spin state. Thus in some unconventional photo-active materials, the structural relaxation of the localised or delocalized excited states following the absorption of photons are not independent, as in conventional excitonic or photo-chemical processes, or for the conventional excitation of coherent collective phonons, but entails a photo-induced phase transition towards a new lattice structure and electronic order, as discovered during pioneering works performed in Japan. This gives the possibility of an ultra-fast tuning of optical, magnetic, dielectric and other macroscopic physical properties of materials by light pulse stimuli. This also opens the way for light to induce symmetry breaking from a stable high temperature phase and so to establish a new self-organised long-range order. In addition light pulse driven coherent reversal of domain orientations (ferroelectric or other ones) appears possible with the control of the interplay between the number of excited molecules and the amplitude of the related soft mode. Indications of such processes have already been observed [16].

The exceptional possibilities of ultra-fast X-ray techniques promise direct access to see an assembly of a huge number of molecules in a crystal moving in a regimented way and getting self-organized. This provides an outstanding opportunity for the direct observation of the dynamics of photo-induced co-operative phenomena as recently shown in pioneering works [17]. These takes place intrinsically at different scales (spatial and temporal) : sub-ps precursor phenomena, such as formation of (1D, 2D or 3D) dynamical nano-domains (diffuse scattering) and the excitation of coherent phonons and non-linear excitations, 3D ordering and macroscopic transformation triggering phase separation at ps time scale. In addition, the collection of complete diffraction data, needing short wavelength and large detector, will give access to the precise structural determination of the photo-induced states (average structure) at different stages, from the precursor phenomena to the establishment of the new metastable macroscopic state (in general phase coexistence). It will take advantage of the experience and methodological progress acquired around synchrotron and present fs sources. In the same way, a close coupling with optical pump-probe progresses is needed.

FERRO-ELECTRIC PHASE-TRANSITIONS

We will investigate solids exhibiting displacive structural phase transitions (soft mode dynamics). Focus will be given to materials commonly used in optics technology (e.g. KDP), as quantum paraelectric systems.

CHARGE-TRANSFER REACTION DYNAMICS

A set of fundamental light-triggered reactions in the solid state apply the so-called topochemical principle. Depending on the chromophore packing, photoactivity is selectively given or not, i.e. reactions with transition state geometries which are not

allowed by the crystal packing are strongly disfavoured. These crystal-packing properties of reactants have far-reaching consequences e.g. for optical applications of such materials, e.g., photo-driven nanometer-scale actuators or holographic and three-dimensional memories, as the reversible morphological changes of blue-white photochromic diarylene crystals show. Unfortunately, no detailed time-resolved studies have been carried out in order to understand their kinetics and structural mechanisms. We will focus our attention on how reactants form a transient phase following the absorption of a photon and the structural characterisation, by sub-picosecond to picosecond x-ray diffraction studies, of the fast intermediates within the reaction cavity. Structural results from **MPIBPC** and **ESRF** suggest that it is possible to follow such photo-induced solid-state dimerisation reactions. **The planned experiments will shed light on how the topochemical principle and how the photo-chemical dynamics of medium-sized systems can be strongly affected by their immediate environment. This understanding will prove instrumental as crystals with novel optical properties are to be tailored.**

COHERENT PHENOMENA IN THE DISORDERED PHASE

Complementary to the proposals suggested above we wish to study the light-driven dissociation and elimination reactions of halide and aromatic compounds in the solution and amorphous phase (*ie*. films and liquids). These experiments would benefit from the gain in flux when compared with the SPPS facilitating the visualisation of coherent motions in disordered systems at low concentrations. In particular, for dissociation and elimination reactions, the so-called transition state dynamics are structurally uncharacterised. The unique temporal and spatial resolution foreseen at the LCLS will enable us to characterise atomic movements on the time-scale of bond breaking and formation, as well as coherent motions. The scientific impact of these experiments is underpinned by the fact that it is these motions which control the outcome of the photochemical reaction. As an extension we would like to use the experimental setup to control and select the photochemical products in solution.

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Participant	**Main Scientific Roles**
Lund University	Facilities for ultrafast visible pump/X-ray probe experiments X-ray diffraction studies of ultrafast processes in laser-excited solids (optical and acoustic phonons, phase transitions). DFT calculations
Max-Planck institute….. Göttingen	Photo-activated chemistry, Femtosecond spectroscopy Time-Resolved X-ray Diffraction
University of Oxford	Time-Resolved X-ray Diffraction Theory, Shock Wave Physics, and Coherent Phonon Studies
Uppsala University	Photo-activated chemistry, Femtosecond spectroscopy Liquid-phase dynamics
LOA, CNRS Paris	Facility for ultra-fast visible pump/X-ray probe experiments. X-ray diffraction investigations of solid-state physics and chemistry
ESRF Grenoble	Facility for visible pump/X-ray probe experiments. Investigations of chemical reactions in liquids
UR1 Rennes	Co-operative molecular switching in solid state Photo-induced electronic and structural phase transitions
Chalmers Göteborg	Diffuse scattering
CSIC Madrid	Light induced phase-transitions in solids Thin-film sample manufacturing
IEP-UDE Essen	Facilities for optical pump-probe experiments and optical pump/X-ray probe experiments. X-ray diffraction studies of ultrafast processes in laser-excited solids (optical and acoustic phonons, phase transitions).
DESY Hamburg	Co-operative molecular switching Photo-induced phase transitions
Universität Jena	X-ray spectrometer and optics design
CNR Pisa	Laser synchronisation and diagnostics
KEK Tsukuba	Co-operative molecular switching Photo-induced phase transitions

Researchers

Jörgen Larsson Jorgen.Larsson@fysik.lth.se started in the research field of time-resolved X-ray diffraction in 1996. Since then, this has been his main field of work. He has performed experiments at SPPS and at synchrotron radiation facilities worldwide and used the laser-produced plasma source at Lund Laser Centre in order to study solid-state physics using diffraction techniques. Larsson is co-ordinator of Research Training Networks "XPOSE" and "FLASH".

Peter Sondhauss Peter.Sondhauss@fysik.lth.se More than 8 years experience in fast X-ray science both theoretically and experimentally covering fields such as X-ray spectroscopy, X-ray optics and ultrafast X-ray diffraction Contribution to the development of the dynamical theory of X-ray diffraction by extending it to 'optical phonon'-type distortions This extension has made the theory applicable to a wider range of lattice dynamical phenomena, like e.g. optical phonons, phonon-polaritons or structural phase transitions.

Tue Hansen Tue.Hansen@Maxlab.lu.se During the time as guest researcher at the Atomic Physcis Div, LTH, work was carried out mostly at beamline D611 at Maxlab. This has included work with a femtosecond Ti:Sapphire laser used in optical pump/X-ray probe experiments and development of an averaging X-ray streak-camera with low jitter. Work has also been carried out at SPPS.

Simone Techert Simone.Techert@mpi-bpc.mpg.de performed her post-doc at the time-resolved beamline ID09B of the ESRF from 1997 – 2000 where the first picosecond time-resolved x-ray diffraction experiment were undertaken. Now, she is Emmy Noether fellow of the German Scientific Council as a group leader at the MPIbpC.

Professor Justin Wark, justin.wark@trinity.oxford.ac.uk has worked in the field of time-resolved X-ray diffraction for over a decade, publishing numerous papers in this field, including 3 Physical Review Letters.

Jon Sheppard jonathan.sheppard@sjc.ox.ac.uk has worked experimentally at SPPS and with modelling of experiments.

Jan Davidsson jand@fki.uu.se He spent one year as a post-doc in the group of Prof. R. N. Zare, at the department of chemistry, Stanford University, USA (89-90). His current research topics are 1) Photoinduced reaction dynamics in solution visualised through diffuse X-ray scattering 2) Ultrafast reaction dynamics of small polyatomic molecules in molecular beams 3) Combining electrospray mass spectrometry and femtosecond laser spectroscopy.

Antoine ROUSSE antoine.rousse@ensta.fr is a senior researcher at the L.O.A. European facility. He's involved on the study of ultrashort and intense laser-matter interactions. He leads a project at the L.O.A. of ultrabright and short X-ray pulse generation and applications. He's developing a scheme of femtosecond time-resolved x-ray diffraction and applies it to the study of ultrafast phenomena in solid state physics. He's the co-ordinator of an RTD project FAMTO (ultraFast Atomic Movie Tools) within the FP5 in the field of ultrafast x-ray science.

Davide Boschetto boschett@enstay.ensta.fr Has a background in a large area of solid-state physics: crystallography, X-ray analysis by diffraction and reflection, physics of superconductor, spin dynamics and charge transfer dynamics, laser driven phase transition and femtosecond X-ray diffraction techniques.

Michael Wulff wulff@esrf.fr is the scientist charge of beamline ID09B, i.e. responsible for operation, instrumentation and research on the beamline. His is current working on the time resolved structure of ligand binding heme proteins (collaboration with Philip

Anfinrud, NIH, Washington DC). He is also working on the structure of reacting molecules in solution in collaboration with Anton Plech (Konstanz), Savo Bratos (Paris) and Simone Techert (Goettingen). He is finally working on the promotion of the free electron laser in Europe.

Maciej Lorenc (Lorenc@esrf.fr) has a postdoc position on ID09B. His is an expect in femtosecond lasers. He is currently working on the structure of HgI_2 and $C_2H_4I_2$ in the solvent CH_3OH.

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Hervé CAILLEAU herve.cailleau@univ-rennes1.fr is professor of physics at the University of Rennes 1(France), whre he was previously Director of the joint research CNTS-University Unit in condensed matter and materials. He has a long general experience on co-operative phenomena and structural phase transitions in molecular solids. Now, he is working on co-operative molecular switching in solid state and photo-induced electronic-structural phase transition, in particular by time-resolved X-ray diffraction. He leads the european part of different official collaborations with Japan (NEDO, ERATO, exchange programs,..).

Marylise BURON marylise.buron@univ-rennes1.fr is Maître de Conférences in Physics At the University of Rennes 1. She has a great competence in structural and dynamical investigations of electronic-structural phase transitions in molecular solids combining X-ray and neutron scattering with magnetic resonance technics. transitions in molecular solids.

Eric COLLET eric.collet@univ-rennes1.fr occupies since three years a Maître de Conférences position in physics at the University of Rennes 1 in France. He has a background in solid-state physics. He is developing X-ray diffraction studies for probing photo-induced phase transitions, both on slow and fast time scales, in molecular solids where cooperative phenomena play a key role. He is also promoting ultra-fast time-resolved X-ray diffraction with the project on SOLEIL synchrotron in France and collaborations with M. Wulff (ESRF) and A-R ring (KEK, Japan).

Laurent GUÉRIN laurent.guerin@univ-rennes1.fr has just begun a PhD work October 2002 on photo-induced phase transitions in organic solids. He is presently in Japan (S.Koshihara group) for one year to perform pum-probe optical experiments on new charge-ordering molecular systems.

Dr. Richard Neutze, neutze@molbiotech.chalmers.se born 1969, completed his PhD research in theoretical optics in 1995. He has postdoctoral experience in both electron interferometry and biophysics. Since 1997 his major activities have been protein crystallography and ultrafast methods for studying light-sensitive systems. His group moved to Chalmers in the autumn of 2000, and the new laboratory is now fully commissioned. Dr. Neutze has extensive experience with synchrotron radiation.

Ms. Annmarie Wöhri Worhi@molbiotech.chalmers.se is a PhD student within the group. She will contribute to the crystallisation of light-sensitive membrane proteins.

Javier SOLIS J.Solis@io.cfmac.csic.es was born in Spain in 1964. His PhD in Physics/Material Science (Madrid, 1990) was carried out at the Instituto de Óptica (CSIC) and was related to the study of the structural transformation dynamics induced by laser irradiation in materials for optical recording. As post-doc (Imperial College, UK) he pioneered the demonstration of ultrashort laser pulse driven recording materials. His research interest includes the study of ultrafast phase transitions for optical recording, and

the non-linear optical interactions in nano-structured materials and glasses for their application to functional wave-guiding

Jan Siegel X, j.siegel@io.cfmac.csic.es has worked on time-resolved phase transformation studies on semiconductor materials. As post-doc (Imperial College, UK) he worked on advanced imaging techniques including fluorescence lifetime imaging, optical sectioning, and photorefractive holography. He is currently working on direct writing of waveguides in dielectric materials with femtosecond laser pulses.

Carmen N. Afonso cnafonso@io.cfmac.csic.es was born in Spain 1952. She obtained her PhD also in Madrid in 1979 and since 1986 is the leader of the Laser Processing Group at the Instituto de Optica (CSIC). Her current interest of research includes fundamental processes in laser-matter interaction including laser ablation and plasma expansion, and the development of optical waveguides for amplifying, frequency conversion and switching devices.

Klaus Sokolowski-Tinten (PhD) kst@iep.physik.uni-essen.de has a position as a senior scientist in the *High Intensity Lasers and Ultrafast Spectroscopy* group of the IEP-UDE. He is leading the research activities of the group concerning the generation and application of ultrashort hard X-ray pulses. He has also large experience in ultrafast optical spectroscopy and in the study of laser-driven phase transitions.

Dietrich von der Linde (Prof.) phy600@uni-essen.de is the head of the *High Intensity Lasers and Ultrafast Spectroscopy* group of the IEP-UDE. He is a leading scientist in ultrafast science and was among the first who established this research field in Germany.

Michael Horn-von-Hoegen (Prof.) horn-von-hoegen@uni-essen.de leads the *Surface Science and Epitaxy* group of the IEP-UDA. Within the project he will be responsible for the hetero-epitaxial growth of single-crystalline thin films to be used in the time-resolved diffraction experiments.

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Shin-ya KOSHIHARA skoshi@cms.titech.ac.jp is the Professor of Dept. Materials Sci.,Tokyo Institute of Technology and Leader of ERATO Koshihara nonequilibrium dynamics project. He started his carrier about 18 years ago as a research associate of Professor Y.Tokura lab. (Dept. Physics, Tokyo University) and began the research on photo-induced phase transition at that occasion. He has been working also on the development of experimental technologies, especially ultrafast spectroscopic study for solid and SOR related ones. He became associate Professor of Tokyo Inst. Tech. in 1993 and leaded the 5 years project (KAST project) for photo-induced phase transition funded by local government between 1998-2003. His work on photo-magnetism in KAST project largely contributed for starting the field of the Spintronics. He became full Professor in 2000. He is playing main role in Japanese part for 3 collaboration program with France (NEDO, ERATO, Dr. Course Student Exchange).

Shin-ichi ADACHI shinichi.adachi@kek.jp is the associate Professor of KEK and sub leader of ERATO project in KEK part. He is the specialist of time-resolved X-ray structural analysis of solid state and biological system. He has deep experience in this field from the early stage of ESRF ID-09. He has already nealy finished the construction of 100ps X-ray port in KEK-AR ring.

Jiro ITATANI is the sub leader of ERATO project in USA branch and stay in ALS for laser slicing collaboration with Dr.Cavalleri and Dr.Schoenline in LBL. He is the specialist of high intensity ultra-short laser and its application in molecular imaging.

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Eckhart Förster foerster@ioq.uni-jena.de His main research interests are high resolution x-ray spectroscopy and study of ultrashort and intense laser-matter interactions. In particular, he has developed sophisticated x-ray devices for x-ray diagnostics and applications of laser-produced plasmas, such as ultrashort x-ray diffraction devices.

Ingo Uschmann uschmann@ioq.uni-jena.de He is an expert in designing X-ray optical devices for diagnostics and applications of laser-produced plasmas. In particular, he is able to fabricate and characterize two-dimensionally bent crystals. Furthermore he designs sophisticated X-ray diagnostics, performs experiments and evaluates the experimental datas by using plasma physics and X-ray diffraction codes.

Roland Sauerbrey worked as a Professsor of Physics from 1985 to 1994 at RICE University Houston, Texas. Since 1994 he has been director of the Institute for Optics and Quantum Electronics. His main research areas are study of laser-matter interaction, development of high-power laser facilities, and wide use of short pulse lasers in physics.

BEAMLINE

We wish to make use of a femtosecond laser synchronized to the X-FEL with as high an accuracy as possible. If that accuracy is below 50 fs a signal measuring the delay with that accuracy is useful.

We envision the beamline as a low-vacuum beamline with a high level of flexibility. A relatively large $1m^3$ vacuum chamber with ports for diagnostics. Fast pumping times to reach 10^{-6} torr and access through a door. Sample goniometer, laser mirror and mounts, detectors, should be possible to mount in vacuum chamber. Some experiments may be best suitable to be conducted in air. Health hazards due to ozon formation and other issues related to the beam interacting with air, may require that a helium atmosphere is considered.

- Vacuum chamber with pumps ($50 000)
- In-vacuum 4-6 axis goniometer ($500 000)
- Sample rastering ($50 000)
- CCD-cameras and Image plates as detectors. ($1 000 000)
- Fast photodiodes for timing monitoring+ >5 GHz analog bandwidth oscilloscope. ($50 000)
- Ce:Yag crystals or other scheme to measure spatial overlap
- X-ray and laser pulse energy monitor on shot-to-shot basis. ($ 10 000)
- Equivalent plane setup for measuring spatial mode of visible laser. ($10 000)

- Monochromators with 10^{-2} and 10^{-4} bandwidth. ($ 1 000 000)
- Variable focusing of X-ray beam 100 nm / 10 micron / 1 mm ($ 200 000)
- Laser beam transport ($100 000)
- Laser safety equipment (personal and laboratory) ($ 100 000)
- Samples and diagnostics for each experiment ($200 000)
- OPG $200 000
- Femtosecond laser
- A laser with 30 fs pulse length and ≥ 5 mJ pulse synchronized to the LCLS at 120 Hz. ($500 000)
- Pulse-shaping capabilities for laser ($100 000)
- Solution phase flow cell environment compatable with vacuum chamber. ($ 50 000)
- Acoustic tweezers for sample manipulation ($ 20 000)
- Travel costs from Europe and Japan will also need to be covered as well as salaries for post-docs working on the project ($400 000 per year)
- Set-up for visible pump-probe experiments to be carried out simultaneously as additional diagnostic and as preparation for X-ray experiments. ($100 000)

Financial support:

EU

Development of equipment could be supported by the European Union through STREP programmes. Development of the samples and diagnostics for individual experiments are expected to be supported by national funding agencies. Samples and diagnostics tested out at 3rd generation sources available within the collaboration.

National

So far concrete plans for co-financing has started in Germany and Sweden.

Germany:

DESY has asked for specific money for contributions to SPPS & LCLS for the years 2005-2006. There are also plans to establish an R&D effort for detectors suitable for usage at the XFELs. Both proposals are currently evaluated by our funding institutions.

Sweden:

An application for travel costs and experimental equipment for research LCLS is under preparation. This is a joint application involving Jorgen Larsson, Janos Hajdu and Richard Neutze.

Contact:

We consider this LOI to be in category A.

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