## Working group 6 - Ions and Leptons: Advanced Concepts

### Abstract Index

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**Name of submitter**  Sergey Antipov  
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**Abstract title**  Paramagnetic Materials for PASE and Tunable RF Absorption  
**Author/affiliation list**  Paul Schoessow, Alexei Kanareykin, Chunguang Jing, (Euclid Techlabs LLC)  
Oleg Poluektov, Wei Gai (Argonne National Laboratory)  

**Abstract (approx. 50 words maximum)**  We report on the use of paramagnetic active media for the PASER and for dielectric loaded accelerating structures with tunable absorption for high order modes. The dielectric is doped with a material exhibiting high paramagnetic resonance, e.g. ruby with Cr3+. The absorption frequency can be tuned by a magnetic field.

**Summary (approx. 350 words maximum, including references)**  We have studied various spin triplet systems in a search for high performance active microwave media and identified PCBM as one of the most promising active materials. We studied various solvents and concentration effects. The use of a solid solution of PCBM in polystyrene was found to increase the temperature range of the paramagnetic activity: room temperature activity was observed. We are in the process of developing improved techniques for making solid active media.  
Currently levels of activity are comparable to the dielectric losses in the host media. Direct RF measurements demonstrated a quality factor increase of a resonator loaded with optically pumped PCBM.  
These new paramagnetic materials may find applications for low noise microwave amplification and tunable RF coupling or absorption.

We performed an initial analysis and simulations of a dielectric loaded accelerating (DLA) structure with built in tunable absorption for high order modes (HOM). The principle for HOM absorption is based on electron paramagnetic resonance of the dielectric material. The dielectric tube of the DLA has to be doped with a material exhibiting high paramagnetic resonance. We consider several possible materials, for example ruby (Al2O3) doped (~1%) with Cr3+. The absorption resonance frequency can be tuned by an external DC magnetic field to match the frequency of the transverse mode.
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<th>Name of submitter</th>
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<td>Institution</td>
<td>Lawrence Berkeley National Laboratory</td>
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<td><a href="mailto:MinChen@lbl.gov">MinChen@lbl.gov</a></td>
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<tr>
<td>Abstract title</td>
<td>Effects of Target Fabrication, Radiation Reaction on the Stable Proton Acceleration in the Radiation Pressure Dominated Regime</td>
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<td>Author/affiliation list</td>
<td>M. Chen (LBNL), A. Pukhov, T. P. Yu, N. Kumar (Heinrich Heine Universitaet, Duesseldorf), and Z. M. Sheng (Shanghai Jiao Tong University)</td>
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**Abstract (approx. 50 words maximum)**

Ion acceleration in the laser radiation pressure dominated regime is studied analytically and by multi-dimensional particle-in-cell (PIC) simulations. Shaped and surface rippled targets are used to match the laser profile and stabilize the acceleration structure. Radiation reaction effects are also investigated, which suppresses electron heating and benefits the acceleration.

**Summary (approx. 350 words maximum, including references)**

Using multidimensional particle-in-cell simulations we study ion acceleration from a foil irradiated by a circularly polarized laser pulse at $10^{22}$ W cm$^{-2}$ intensity. When the foil is shaped initially in the transverse direction to match the laser intensity profile, three different regions (acceleration, transparency, and deformation region) are observed. In the acceleration region, the foil can be uniformly accelerated for a longer time compared to a usual flat target. Undesirable plasma heating is effectively suppressed. The final energy spectrum of the accelerated ion beam in the acceleration region is improved dramatically. Transverse and longitudinal electron heating effects on the beam plasma stability during ion acceleration process is also studied. For efficient ion acceleration, the longitudinal electron temperature should be kept as low as possible. However, for the transverse temperature we find proper transverse temperature can suppress the transverse instability and keep the acceleration structure uniform and stable. Using surface rippled target can increase the transverse temperature, which improves both the final peak energy and the spectrum quality. The radiation reaction effects on ion acceleration in laser foil interaction are also investigated. We find that the radiation effects are important in the area where some electrons move backward due to a static charge separation field at a laser intensity of $10^{22}$ W cm$^{-2}$. Radiation reaction tends to impede these backward motions. In the optical transparency region ion acceleration is enhanced when the radiation effects are considered.
### Name of submitter
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### Abstract title
Prospects for and progress towards laser-driven Particle Therapy accelerators

### Author/affiliation list
T.E. Cowan, U. Schramm, M. Bussmann, S.D. Kraft, R. Sauerbrey (FZD); M. Baumann, W. Enghardt, J. Pawelke (Oncoray, TU Dresden, Germany)

### Abstract (approx. 50 words maximum)
Recent successes in laser-ion acceleration have motivated research towards laser-driven compact accelerators for medical therapy. Realizing this goal will require significant advances in laser-acceleration physics, beam manipulation and delivery, real-time dosimetry, treatment planning, and translational research into a clinical setting.

### Summary (approx. 350 words maximum, including references)

Laser-ion acceleration is being explored by researchers world-wide as a potential technology for future, compact medical accelerators for tumor therapy. In Germany, the Research Center Dresden (FZD) and the university clinic for Radiation Oncology (OncoRay) have established a comprehensive long-term research program to develop new therapy modalities based on high-intensity, high rep-rate lasers.

Realizing laser-ion acceleration for medical therapy will require adapting both the laser-ion acceleration to the medical requirements, as well as the treatment methodology to the foreseeable laser constraints. In particular, proton energies up to 200 MeV are required, with dose delivery of ~10 Gy throughout a tumor mass in a few minutes, and with high precision. The well-established Target Normal Sheath Acceleration (TNSA) provides an initial point design, requiring a diode-pumped solid-state petawatt laser, having about 200 J in 150 fs pulses at 10 Hz, which is proposed as a prototype laser driver.

Research to extend TNSA beyond the long-standing limit of 58 MeV has led to consideration of a variety of novel target designs, which are explored experimentally with existing Nd:glass lasers, as well as high rep-rate 100 TW, 30 fs Ti:sapphire laser systems. Recently protons have been accelerated at the LANL Trident laser to 67.5 MeV using novel cone targets.

Pulsed magnet ion-beam optical elements are being developed, to collect, energy select and transport the proton beams. New beam scanning techniques are being considered, which can accommodate the projected 10 Hz laser repetition rate, while enabling full 3D coverage of a tumor volume with high reproducibility, which will be modelled with new treatment planning tools. In addition, these require a new degree of real-time determination of the deposited dose, and feedback to the beam delivery system to affect both spectrum and coverage on subsequent pulses. The limitations of in-beam PET have been determined, motivating on in-beam single photon emission computed tomography (SPECT), for realtime imaging of the therapeutic beam. Finally, long-term translational research towards eventual clinical evaluation has begun, with laser-proton irradiation of tumor cells in-vitro.
Abstract (approx. 50 words maximum)
The empirical barrier of 60 MeV for laser-accelerated protons was recently broken by ultra-high contrast irradiation of novel cone-targets at the LANL Trident laser. The responsible mechanism is identified by PIC simulations, and opens a new path for robust target design to increase the energy of Target Normal Sheath Acceleration protons and ions.

Summary (approx. 350 words maximum, including references)
Maximizing the energy of laser-accelerated proton beams is important for many applications including their potential use in Particle Therapy. The therapeutic window for cancer treatment starts at ~65 MeV for eye cancers, and extends to ~250 MeV for deep-seated tumors. The highest published laser-accelerated proton energy to-date is 58 MeV, obtained 10 years ago using the LLNL Nova-Petawatt laser, with over 400 J of laser pulse energy incident on flat solid target foils [1]. Recent experiments at the LANL Trident laser have established a new world record of 67.5 MeV, using 80 J very high contrast pulses, in grazing incidence upon novel cone-shaped Cu targets [2].

The measured enhancement in proton energy is understood from collisional Particle in Cell simulations, which show that the hot electron temperature, responsible for the Target Normal Sheath Acceleration at the cone-top, is significantly increased when the laser grazes the cone wall. This is due to the extraction of electrons from the cone wall by the laser electric field, and their boost in the forward direction by the vxB term of the Lorentz force. This is in contrast to previous predictions of optical collection and wall-guiding of electrons in angled cones [3]. This new mechanism should enable new and more robust target designs for reaching high laser-accelerated proton energies.

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**Abstract title**  
HIGH INTENSITY LASER ION ACCELERATION USING LOW DENSITY TARGETS  

**Author/affiliation list**  
E. d'Humières, J. L. Feugeas, P. Nicolaï and V. Tikhonchuk - CEntre Lasers Intenses et Applications, Université de Bordeaux - CNRS - CEA.  

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**Abstract (approx. 50 words maximum)**  
Using Particle-In-Cell simulations, we studied in detail the shock-like regime of underdense laser ion acceleration. This regime depends strongly on the spatial and temporal shape of the laser pulse and on the target density gradient. It can lead to very efficient ion acceleration.  

**Summary (approx. 350 words maximum, including references)**  
An intense research is being conducted on sources of laser-accelerated ions and their applications. Proton beams accelerated from planar targets have exceptional properties, such as high brightness, high spectral cut-off, high directionality and laminarity, and short duration. Another promising way to accelerate ions to high energies with a laser is to use low density targets. Compared to solid targets where laser absorption is limited to the target surface, the laser pulse inside low density plasmas heats electrons on a large volume leading to higher laser absorption. This acceleration regime is also advantageous for applications as less debris are produced. It is more adapted for utilization with high repetition rate lasers. The laser contrast, which can be problematic with thin solid targets, is less detrimental.  
The main acceleration processes in this low density regime are still being debated. Using 1D, 2D and 3D Particle-In-Cell simulations, we studied in detail the interaction of a high intensity laser pulse with underdense targets. The proton acceleration processes depend strongly on the characteristics of the density gradient. In smooth density gradients the most energetic protons can be accelerated by a shock-like mechanism. This mechanism depends strongly on the spatial and temporal shape of the laser pulse and can lead to very efficient proton acceleration.  
We discuss the limits of the shock-like regime in terms of proton beam characteristics (maximum proton energy, divergence, intensity) and the possibility to accelerate heavier ions.  
A model describing this acceleration process has been developed and used to prepare new experiments of laser proton acceleration with gaseous targets.
Beam optimization of laser-accelerated protons is a crucial point for the development of applications in various areas. High-energy protons in the TNSA regime can be enhanced, in maximum energy or regarding the laser-to-protons conversion efficiency, using reduced mass solid targets or by enhancing the laser intensity by reducing the focal spot size.

We will present recent experimental results and simulations on these topics. We will show that high-energy protons in the TNSA regime could be enhanced, in maximum energy or regarding the laser-to-protons conversion efficiency, using reduced mass solid targets [3] or by enhancing the laser intensity. The latter is achieved by reducing the focal spot size. For this, we developed for the first time very compact (<1 cm³) extremely low f-number (0.4) plasma-based, confocal ellipsoid focusing systems. Direct measurement of the laser focal spot using low-energy laser indicates 1/5 reduction of spot size compared to standard focusing (using a f/3 optics). Around tenfold enhancement of laser intensity by reduction of the spot size for high power shots is clearly evidenced by remarkable enhancement of proton energy. These experiments were performed at the LULI 100TW laser facility.

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<td>Abstract title</td>
<td>Narrow energy spread protons and ions from high-intensity, high-contrast laser solid target interactions</td>
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<tr>
<td>Author/affiliation list</td>
<td>F. Dollar, T. Matsuoka, C. McGuffey, L. Willingale, S. S. Bulanov, V. Chvykov, G. Kalinchenko, V. Yanovsky, A. Maksimchuk, and K. Krushelnick, University of Michigan; G. Petrov, J. Davis, Naval Research Laboratories</td>
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**Abstract (approx. 50 words maximum)**

Using the HERCULES laser facility, quasi-monoenergetic protons with energies up to 10 MeV and quasi-monoenergetic light ions with energies over 2 MeV per nucleon were observed experimentally. Plasma mirrors and adaptive optics used to generate a high intensity, high contrast laser pulse. 2D PIC modelling corroborates results.

**Summary (approx. 350 words maximum, including references)**

Recent simulations show that an idealized, high intensity, short pulse laser can generate quasi-monoenergetic proton beams with energies over 100 MeV in an interaction with a thin film[1]. However, most short pulse laser facilities with sufficient intensity lack the nanosecond and picosecond constrast necessary to realize such a regime. Experiments were performed to investigate proton and ion acceleration from a high contrast, short pulse laser by employing dual plasma mirrors along with a deformable mirror at the HERCULES laser facility at the Center for Ultrafast Optical Sciences, University of Michigan. Plasma mirrors were characterized, allowing a 50% throughput with a contrast increase of 10^5. The focal quality was also characterized, showing a 1.1 micron full width at half maximum (FWHM) focal diameter. Experiments were done using temporally cleaned 30 TW, 32fs pulses to achieve an intensity of up to 10^21 W/cm^2 on Si3N4 and Mylar targets with thicknesses ranging 50nm to 13 um. Proton beams with energy spreads below 75% were observed from all thicknesses, peaking with energies up to 10.3 MeV and an energy spread of 25% FWHM. Similar narrow energy spreads were observed for oxygen, nitrogen, and carbon at the silicon nitride thickness of 50nm with energies up to 2 MeV per nucleon with an energy spread of 23%, whereas the energy spread is greatly increased at higher thicknesses. Maximum energies were confirmed with CR39 track detectors, while a Thomson ion spectrometer was used to gauge the monoenergetic nature of the beam. 2D PIC simulations were also performed at parameters representative of the experimental conditions.

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**Abstract title**  
Advanced Laser Particle Accelerator Development at LANL:  
From Fast Ignition to Radiation Oncology

**Author/affiliation list**  
K. A. Flippo, J. A. Cobble, D. C. Gautier, D. S. Montgomery, D. T. Offermann,  
(LANL, P-24), T. J. Kwan, M. J. Schmitt (LANL, XCP-6); S. A. Gaillard, T. Kluge,  
M. Bussmann, T. E. Cowan (ForschungsZentrum Dresden-Rossendorf,  
GERMANY); B. Gall, S. Kovaleski (University of Missouri, Columbia); T.  
Lockard, Y. Sentoku (University of Nevada, Reno); S. Malekos, G. Korgan  
(Nanolabz, Reno, NV); D. Welch (Voss Scientific, Albuquerque, NM)

**Abstract (approx. 50 words maximum)**

Laser-plasma accelerated ion and electron beam sources are an emerging field with vast prospects, and promise many superior applications in a variety of fields such as hadron cancer therapy, compact radioisotope generation, table-top nuclear physics, laboratory astrophysics, nuclear forensics, waste transmutation, SNM detection, and inertial fusion energy. LANL is engaged in several projects seeking to develop compact high current and high energy ion and electron sources. We are especially interested in two specific applications: ion fast ignition/capsule perturbation as part of the National Ignition Campaign (NIC) and radiation oncology in conjunction with our partners at the ForschungsZentrum Dresden-Rossendorf. Laser-to-beam conversion efficiencies of over 10% are needed for practical applications, and we have already shown inherent efficiencies of >5% from flat foils, on Trident using only a 5th of the intensity and energy of the Nova Petawatt. With clever target designs, like structured curved cone targets, fabricated by Nanolabz, we have also been able to achieve major ion energy gains, leading to the highest energy laser-accelerated proton beams in the world. The significant ion yields of these beams will pave the way toward both of our intended applications. In addition to cone targets and hemispherical diamond focusing targets, we are developing new near-critical density targets for ion and electron acceleration to tailor the ion energy and lead to staging of acceleration for further increases in energy, efficiency and improved beam characteristics. These new target designs and laser regimes promise to help usher in the next generation of particle accelerators realizing the potential of laser-accelerated particle beams.

**Summary (approx. 350 words maximum, including references)**

Laser-plasma accelerated ion and electron beam sources are an emerging field with vast prospects, and promise many superior applications in a variety of fields such as hadron cancer therapy, compact radioisotope generation, table-top nuclear physics, laboratory astrophysics, nuclear forensics, waste transmutation, SNM detection, and inertial fusion energy. LANL is engaged in several projects seeking to develop compact high current and high energy ion and electron sources. We are especially interested in two specific applications: ion fast ignition/capsule perturbation as part of the National Ignition Campaign (NIC) and radiation oncology in conjunction with our partners at the ForschungsZentrum Dresden-Rossendorf. Laser-to-beam conversion efficiencies of over 10% are needed for practical applications, and we have already shown inherent efficiencies of >5% from flat foils, on Trident using only a 5th of the intensity and energy of the Nova Petawatt. With clever target designs, like structured curved cone targets, fabricated by Nanolabz, we have also been able to achieve major ion energy gains, leading to the highest energy laser-accelerated proton beams in the world. The significant ion yields of these beams will pave the way toward both of our intended applications. In addition to cone targets and hemispherical diamond focusing targets, we are developing new near-critical density targets for ion and electron acceleration to tailor the ion energy and lead to staging of acceleration for further increases in energy, efficiency and improved beam characteristics. These new target designs and laser regimes promise to help usher in the next generation of particle accelerators realizing the potential of laser-accelerated particle beams.
Proton Acceleration in CO2 Laser-Plasma Interactions in a Gas Target

D. Haberberger, S. Tochitsky, A. Pak, K. Marsh, C. Joshi

Abstract (approx. 50 words maximum)
The CO2 MOPA laser system at the Neptune Laboratory at UCLA has been upgraded producing picosecond pulses with peak powers up to 15TW. These pulses are applied to ion acceleration in a critical density H2 gas jet. The status of the experiment will be reported.

Summary (approx. 350 words maximum, including references)
Over the last several years, the Target Normal Sheath Acceleration (TNSA) mechanism in solid density plasmas produced by a laser pulse has achieved proton energies up to 10’s of MeV and quasi-monoenergetic beams at lower energies. Although solid-target experiments have demonstrated high-charge and low-emittance proton beams, little work has been done with gaseous targets which in principle can be operated at a very high repetition frequency. At the Neptune Laboratory, there is an ongoing experiment on CO2 laser driven proton acceleration using an H2 gas jet as a target. The main goal is to study the coupling of the laser pulse into a plasma with a well defined density in the range of 0.5 to 5 times critical density and characterize the corresponding spectra of accelerated protons. Towards this end, the Neptune CO2 MOPA laser system was upgraded to produce 3ps pulses with powers up to 15TW. Various nozzles have been characterized with H2 in our density of interest using plasma interferometry to obtain an optimal plama density profile. Results on a conical nozzle with a 1mm opening show a quasi-gaussian profile with ~500um ramps up to 5 x 1e19cm^-3 densities. The current status of the proton source experiment will be presented as well as simulation results from particle-in-cell code modeling the interaction.
<table>
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<tr>
<th><strong>Name of submitter</strong></th>
<th>Carol Johnstone</th>
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<td><strong>Institution</strong></td>
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<tr>
<td><strong>Abstract title</strong></td>
<td>Isochronous (CW) Non-scaling FFAGs</td>
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<tr>
<td><strong>Author/affiliation list</strong></td>
<td>C. Johnstone, M. Berz, S. Koscielniak, K. Makino, P. Snopok</td>
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</table>

**Abstract (approx. 50 words maximum)**

Recently, isochronous orbits have been developed for non-scaling FFAGs enabling the simplicity of fixed RF. The FFAG can remain isochronous beyond cyclotrons, well into the relativistic regime. The machine proposed here has the high current and duty cycle of the cyclotron and the strong focusing, smaller losses, and energy variability of the synchrotron.

**Summary (approx. 350 words maximum, including references)**

The drive for higher beam power, high duty cycle, and reliable beams at reasonable cost has focused world interest on fixed field accelerators, notably Fixed-field Alternating Gradient accelerators (FFAGs). High-intensity GeV proton drivers encounter duty cycle and space-charge limits in the synchrotron and machine size concerns in the weaker-focusing cyclotrons. A 10-20 MW proton driver is challenging, if even technically feasible, with conventional accelerators - with the possible exception of a SRF linac, which has a large associated cost and footprint. Recently, the concept of isochronous orbits has been explored and developed for non-scaling FFAGs using powerful new methodologies in FFAG accelerator design. The property of isochronous orbits enables the simplicity of fixed RF and, by tailoring a nonlinear radial field profile, the FFAG can remain isochronous beyond the energy reach of cyclotrons, well into the relativistic regime. With isochronous orbits, the machine proposed here has the high average current advantage and duty cycle of the cyclotron in combination with the strong focusing, smaller losses, and energy variability that are more typical of the synchrotron. With the cyclotron as the current industrial and medical standard, a competing CW FFAG, would have broad impact on facilities using medical accelerators, proton drivers for neutron production, accelerator-driven nuclear reactors, waste transmutation, and the production of radiopharmaceuticals and open up a range of as-yet unexplored industrial applications. Further, a high-intensity proton driver is a critical technology for the Neutrino Factory and Muon Collider. This presentation reports on these new advances in FFAG accelerator technology.
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**Abstract title**  
Train of relativistically intense radiation few-cycle pulses: Novel optical source based on non-resonant amplitude self-modulation and electromagnetic cascading in plasmas

**Author/affiliation list**  
S. Kalmykov, B. A. Shadwick (Univ. Nebraska, Lincoln), G. Shvets, M. C. Downer (Univ. Texas, Austin)

### Abstract (approx. 50 words maximum)

Nonlinear refraction due to the plasma wave excitation and group velocity dispersion transform the beat wave of initially bi-color pulse into the hair-comb of relativistically intense (>10^{19} W/cm^2) few-cycle pulses. Well focusable pulse train is a novel light source interesting for ultrafast science applications.

### Summary (approx. 350 words maximum, including references)

Nonlinear refraction due to the plasma wave excitation transforms the beat wave of initially bi-color pulse into the train (hair-comb) of relativistically intense (>10^{19} W/cm^2) few-cycle pulses. When the difference frequency of two initial pulses is less than the electron Langmuir frequency, the non-resonantly driven 3D electron density perturbation acts as a periodic focusing channel that drastically reduces the self-focusing threshold. A feedback loop between the plasma wave excitation and laser focusing results in the amplitude self-modulation instability, which is sensitive to the plasma parameters and thus can be controlled in order to preserve the laser beam quality. After the stabilization of self-modulation, electromagnetic cascading and local index gradients inside the plasma wave buckets increase the laser bandwidth. Subsequent self-consistent compression of individual beat notes due to the effect of group velocity dispersion produces a periodic sequence of few-cycle length radiation spikes guided by the plasma wave buckets. This unique light beam cannot be obtained through conventional chirped-pulse amplification. The radiation pulse train is well focusable to high intensity (possibly in higher-density plasma). This, combined with the large total beam energy, makes it interesting for particle accelerator and fast ignition applications. The recent surge of interest in using radiation pulse trains to all-optical manipulation of laser-solid interactions makes this novel light source especially valuable. Proposed laboratory experiments with available bi-color light sources will be discussed. References: S. Kalmykov and G. Shvets, Phys. Plasmas 13, 056707 (2006); AIP Proc. 877, 395 (2006)
Name of submitter | Anatoly Maksimchuk
---|---
Institution | University of Michigan
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Abstract title | Studies of laser-driven ion acceleration at the University of Michigan
Author/affiliation list | A. Maksimchuk, S. S. Bulanov, F. Dollar, V. Chvykov, G. Kalinchenko, T. Matsuoka, C. McGuffey, S. Reed, A. Thomas, L. Willingale, V. Yanovsky, K. Krushelnick (University of Michigan) A. Brantov, V. Yu. Bychenkov (Lebedev
Abstract (approx. 50 words maximum) | An overview of the theoretical work and the experimental efforts in laser-driven ion acceleration at the Hercules (300 TW, 30 fs) and T-cubed (15 TW, 400 fs) laser facilities at the Center for Ultrafast Optical Science of the University of Michigan will be presented.
Summary (approx. 350 words maximum, including references) | Ultra-high intensity (10^21 W/cm^2) and ultra-high contrast (10^(-10)) short laser pulses interacting with ultra-thin membranes with thicknesses approaching the relativistic plasma skin depth are capable to expel electrons from the target focal volume by the laser’s ponderomotive force allowing for direct laser ion acceleration combined with a Coulomb explosion [1,2]. That may results in the generation of proton approaching 100 MeVs with a quasi-monoenergetic energy spectrum. We also consider another mechanism of ion acceleration in the interaction of high-intensity laser with a near critical density plasma. In this case, the propagation of intense laser pulses through plasma results in the generation of strong, moving magnetic fields in the channel and the formation of a thin ion filament [3]. At the plasma exit magnetic fields displace electrons and generate a quasi-static electric field capable of accelerating protons to 100 MeV and collimating them [4]. The results of the experiments on the Hercules laser facility on generation of protons (~10 MeV) and carbon ions (~25 MeV) with narrow energy spread, as well as on two stage proton acceleration from hydrogen containing targets [5] and the development of a relativistic plasma shutter [6] will be reported. In the experiments on the T-cubed facility we have studied front versus rear side light-ion acceleration from laser-solid interaction by coating the front or rear surface of the target with deuterated plastic. We found that deuterons originating from the front surface can gain as much energy as those from the rear surface and spectra from either side can be non-Maxwellian [7]. 2D PIC simulations model the acceleration and show that any presence of a proton rich contamination layer over the surface is detrimental to the deuteron acceleration from the rear surface, whereas it is likely to be less influential on the front side acceleration mechanism.
### Abstract title
Enhanced ion peak energy by controlling the preplasma of thin foil irradiated by intense and high contrast laser pulse

### Author/affiliation list
V. Malka (1), A. Flacco (1), F. Sylla (1), M. Veltcheva (1), S. Kahaly (1), M. Carrié (1), R. Nuter (2), E. Lefebvre (2)  
(1) LOA, (2) CEA DAM DIF

### Abstract (approx. 50 words maximum)
The development of temporal cleaning techniques allows ion acceleration from very thin foils irradiated by intense lasers. We show that the ion energy can be increased by around 20% by controlling properly the pre-plasma while keeping the same amount of laser energy.

### Summary (approx. 350 words maximum, including references)
The increase of laser contrast allows the interaction of intense laser pulse with a clean surface, free of any plasma, before the short laser pulse arrives on the target. As a consequence the absorption of the laser energy is strongly reduced. To overcome this problem we have done a set of experiments in order to define the optimal preplasma scale length. The scale length and the shock breakout time have been measured using a few tens of mJ laser respectively by interferometry and by reflectivity techniques. These measurements have been also compared successfully with hydrodynamic simulations. The optimum conditions defined by these experiments have been set for a real experiment were a 500 mJ, 30 fs laser pulse has been used to accelerate protons. An increase of 20% of the ion peak energy has been observed by keeping the same laser energy.
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<tr>
<th>Name of submitter</th>
<th>Vasiliy Morozov</th>
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<tr>
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<tr>
<td>Abstract title</td>
<td>TWIN-HELIIX CHANNEL FOR PARAMETRIC-RESONANCE IONIZATION COOLING</td>
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<tr>
<td>Author/affiliation list</td>
<td>V.S. Morozov, Old Dominion University, Norfolk, VA, USA. A. Afanasev, Hampton University &amp; Muons, Inc., A.S. Bogacz and Y.S. Derbenev, Jefferson National Accelerator Facility, Newport News, VA, USA</td>
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**Abstract (approx. 50 words maximum)**

A linear optics solution compatible with Parametric-resonance Ionization Cooling (PIC) is presented which consists of a superposition of two counter-rotating equal-period equal-strength helical dipole harmonics and a straight normal quadrupole. This system can be adjusted to meet all of the PIC linear optics requirements while retaining large acceptance.

**Summary (approx. 350 words maximum, including references)**

Parametric-resonance Ionization Cooling (PIC) is envisioned as the final 6D cooling stage of a high-luminosity muon collider. Implementing PIC imposes stringent constraints on the cooling channel’s magnetic optics design. This paper presents a linear optics solution compatible with PIC. Our solution consists of a superposition of two counter-rotating equal-period equal-strength helical dipole harmonics and a straight normal quadrupole. We demonstrate that such a system can be adjusted to meet all of the PIC linear optics requirements while retaining large acceptance.

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<tr>
<th><strong>Name of submitter</strong></th>
<th>Wayne D. Kimura (talk will be given by Patric Muggli)</th>
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<tr>
<td><strong>Abstract title</strong></td>
<td>A Proposed High-Energy, Compact, Optical Electron Accelerator Based on Particle Acceleration by Stimulated Emission of</td>
</tr>
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</table>
| **Author/affiliation list** | Wayne D. Kimura/STI Optronics, Inc.  
Patric Muggli/University of Southern California  
Levi Schächter/Technion, Israel Institute of Technology |

**Abstract (approx. 50 words maximum)**
A novel scheme for a new type of high-energy electron accelerator is presented, which does not require a high-power laser or electron beam driver. It provides for its own microbunching and is its own injector. It does not require phase-matching nor is it affected by phase slippage.

**Summary (approx. 350 words maximum, including references)**
We present the design essentials of a proposed optical electron accelerator based on particle acceleration by stimulated emission of radiation (PASER). It relies on a moderate-pressure (e.g., 50-Torr) gas discharge as the active medium and a Malmberg-Penning trap as the buncher and injector. The trap is basically a cylindrical vessel containing a cylindrical anode in the middle, cylindrical cathodes at both ends, and a solenoid magnetic field around the entire vessel. Electrons are injected into the trap using a hot-cathode source. While the electrons are circulating inside the trap filled with the active medium, a two-beam instability develops between the two species. This instability causes the electrons to group together with a bunch spacing equal to the emission wavelength. Hence, microbunches are inherently formed at the resonant wavelength. Once formed, these microbunches begin to extract energy from the active medium via the PASER effect. External excitation of the active medium ensures the electrons continue to gain energy until their energy exceeds the trapping potential and the electrons escape the trap. Electrons exiting the trap can be sent into a PASER acceleration cell where the microbunches gain energy by circulating within the active medium inside the cell. Various configurations are possible for the cell, for example a betatron or racetrack geometry. This acceleration process is greatly simplified because there is no phase-matching required and there is no problem with phase-slippage as the electrons gain energy. This enables generating high-energy electron beams in a compact geometry.
Inverse Compton Scattering (ICS) is a promising approach towards generation of energetic pseudo-monochromatic gamma pulses for applications for research and security applications. RadiaBeam, in collaboration with BNL and UCLA, is developing a number of enabling technologies to improve the average power and compactness of gamma-ICS sources.

Stand-off detection of Special Nuclear Materials at distances >100 meters requires directional beams of >6 MeV gamma rays. Similar beams can be also utilized in a number of research applications, such as positron generation. The most promising source to deliver such a beam is an ICS system driven by a high energy accelerator. RadiaBeam Technologies in has an extensive R&D program to improve the average power and compactness of such a source. An overview of the enabling technologies under development is presented to achieve the practical implementation of a field deployable gamma-ICS source for mobile platform applications.

Improving the average power of gamma-ICS is critical to the system’s effectiveness. Specific technologies under investigation include laser recirculation and high average power photoinjectors. Recirculating the ICS interaction laser has been proposed using an innovative technique termed Recirculating Injection by Nonlinear Gating (RING). A high average power (1 kHz rep rate), high gradient S-band photo-injector using novel fabrication techniques is also under development for a number of demanding applications, including gamma-ICS.

For deployable systems, compactness is essential. RadiaBeam is currently developing both high gradient S-band (50 MeV/m) and X-band (>80 MeV/m) structures. In addition, we are investigating Inverse Free Electron Lasers (IFELs), which can use the same laser as the ICS interaction, and provides high-gradient (up to 500 MeV/m), highly-stability acceleration.

The authors would like to thank funding agencies, DOE, DTRA, and DHS, and our collaborations at BNL, LLNL, Perdue University, SLAC, UCLA, and MIT Lincoln Labs.
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### Abstract title
High Gradient Inverse Free Electron Laser Acceleration

### Author/affiliation list
Pietro Musumeci (UCLA)

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<th>Abstract (approx. 50 words maximum)</th>
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<td>A renovated interest in IFELs comes from the continuous progress in laser and undulator magnet technology. The possibility of using helical undulators and TW-class laser systems allows gradient in excess of 400 MV/m. A summary of current experimental efforts and an outlook on the future of this high gradient acceleration scheme will be offered.</td>
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| Inverse Free Electron Laser acceleration experiments have demonstrated both high quality, low energy spread accelerated beams [1] and high accelerating gradient [2]. Even though the applicability of this acceleration scheme for high energy physics is dwarfed by the gradients achievable in plasma-based schemes and has critical issues due to the synchrotron radiation losses, the IFEL is still a very viable and valid alternative for mid-class accelerator in the few-GeV range. Applications of electron accelerators in such energy range includes gamma ray production by inverse compton scattering, or even soft-x-ray production by FEL interaction. 

In the 500 MeV -2 GeV energy range, the IFEL scales ideally well due to the availability of high power laser source and the size of typical permanent magnet based undulators. The acceleration can all be performed in one stage, eliminating the need of staging and/or refocusing the high power laser beam. The scaling laws for optimizing such accelerator will be analyzed. An important improvement in the gradient with respect to previous experiments will derive from the use of helical undulators and circularly polarized laser pulses. Future developments include the possibility of recirculating the laser power for increasing the wall-plug efficiency and the average power of the generated beams. A small summary of the experimental efforts aimed at improving the IFEL accelerator to a reliable and mature advanced accelerator scheme will be also discussed. |

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<th>David Neely</th>
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<tr>
<td>Abstract title</td>
<td>Laser Ion accelerator developments</td>
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</table>
| Author/affiliation list | David Neely,  
STFC, Rutherford Appleton Laboratory, Didcot OX11 0QX, UK  
SUPA, Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK |

**Abstract (approx. 50 words maximum)**

The acceleration of ion beams, by the radiation pressure associated with the driving laser pulse is being investigated by many groups worldwide. This new acceleration mechanism is predicted to have very favourable scaling with intensity and its potential as a future ion beam source will be explored.

**Summary (approx. 350 words maximum, including references)**

Advances in the contrast which intense multi TW and PW class laser pulses can be generated have enabled ion acceleration from foil targets of only a few nm in thickness to be studied. This has opened up a new regime of acceleration where the “light pressure” can become a significant factor in the ion acceleration process. Results from a number of experiments examining the spectral ion beam changes as the polarization is modified and the resulting insights into the interaction physics will be presented and the potential of this technique for future studies examined.

Much effort has also been directed by the research community into examining the beam qualities of laser based ion accelerators. Applications have been primarily limited to scientific studies such as plasma probing so far, but first results of biological interactions are currently underway and plan to build ion sources for secondary users are being pursued. A review of the challenges and new techniques being developed to transform ion accelerators into a “useful” ion beam source will be given.
Using a double pulse, the spectral content of a laser driven ion beam can be significantly enhanced and modified. The effect of the ratio and timing between the double pulses is reported. Also, the effect which changing the intensity distribution in the focal plane and hence electron temperature has on the accelerated ion beam is examined.

As the physical processes controlling the transfer of energy between the driving laser, the intermediate electrons and the ions becomes more fully understood, new methods for controlling the accelerated ion beam become accessible. Here, two optically based techniques will be examined which have the ability to enhance the production efficiency and modify the spectral content of the beam.

In an experiment conducted using the Vulcan Nd:glass laser, pulses of 0.7 ps were directed onto thin Al foils. The spectral content of the ion beam produced from the Al targets was monitored as the laser focal spot size on target was increased from 5 microns to 300 microns. As the spot size is increased the intensity reduces and it is possible to use thinner targets. Generally, the flux of ions increases as the foil thickness decreases until a critical minimum thickness is reached for a given irradiance. This result gives a clear demonstration of the effect of refluxing on the ion beam spectrum and maximum energy. Results showing the scaling and efficiency of this technique will be reviewed.

In a second experiment, a dual pulse drive was used to modify the spectral content of the ion beam. Results showing the sensitivity of this technique to the relative ratio and timing between the two drive pulses will be presented.
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<th>Robert B Palmer</th>
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<tr>
<td>Abstract title</td>
<td>Towards an end-to-end design of cooling for a muon collider</td>
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<tr>
<td>Author/affiliation list</td>
<td>Robert B Palmer, Rick Fernow, Juan gallardo, Diktys Stratakis ; Brookhaven National Lab</td>
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Abstract (approx. 50 words maximum)
A muon collider requires a complex sequence of beam manipulations: phase rotation into multiple bunches, initial cooling of both charges, charge separation, 6 dimensional cooling, bunch merging, more 6 dimensional cooling, and final transverse cooling in high magnetic field solenoids. Progress towards the designs, and end to end simulation, will be discussed.

Summary (approx. 350 words maximum, including references)
Muons for a collider, generated from pion decay, have a very large initial phase space. For use in a collider they must be cooled (emittance reduction), in all six dimensional, by a factor of more than a million. This requires a complex sequence of beam manipulations: 1) With drifts and rf, the muons are phase rotated into multiple bunches of both signs. 2) Initial cooling of both charges is needed to enable 3) charge separation, followed by 4) six dimensional cooling until the bunch emittances are small enough to allow 5) bunch merging. This is followed by 6) more six dimensional cooling of the merged bunches, as far as is practical. The transverse emittance is now still an order of magnitude too large, but the longitudinal emittance is two orders of magnitude less than needed. So the final stage is 7) cooling in high magnetic field solenoids, that reduces only the transverse emittance to it required value, while allowing the longitudinal emittance to rise. Each stage of these manipulations has been simulated at some level, and now we are working towards a simulation of all parts together. Progress on this will be reported, and a brief mention made of the technical challenges.
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<th>Name of submitter</th>
<th>Kevin Paul</th>
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<tr>
<td>Abstract title</td>
<td>Recent developments in simulations of an inverse cyclotron for intense muon beams</td>
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<td>Author/affiliation list</td>
<td>K. Paul/Tech-X Corporation, E. Cormier-Michel/Tech-X Corporation, D. J. Summers/University of Mississippi, T. L. Hart/University of Mississippi</td>
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**Abstract (approx. 50 words maximum)**

Preliminary designs for a muon inverse cyclotron for cooling intense muon beams have been developed in recent months. We present an overview of the inverse cyclotron concept and simulations of the muon inverse cyclotron with the particle-in-cell code VORPAL.

**Summary (approx. 350 words maximum, including references)**

A number of recent developments have lead to simulations of an inverse cyclotron for cooling intense muon beams for neutrino factories and muon colliders [1,2]. Such a device could potentially act as a novel beam cooling mechanism for muons, and it would be significantly smaller and cheaper than other cooling channel designs. Realistic designs are still being explored, but the first simulations of particle tracking in the inverse cyclotron, with accumulation in the cyclotron core, have been done with electrostatic simulations in the particle-in-cell code VORPAL. We present an overview of the muon inverse cyclotron concept and recent simulation results.
Progress in Picosecond 10 µm Laser Pulse Amplification for Ion Acceleration

Mikhail N. Polyanskiy, Igor V. Pogorelsky, Vitaly Yakimenko
Brookhaven National Laboratory, Bldg. 820M, Upton, NY 11973, USA

Abstract (approx. 50 words maximum)

Using isotopically enriched carbon dioxide in a CO2 laser amplifier we eliminated the splitting of a picosecond pulse during amplification that usually results from modulations in the periodical spectrum caused by the rotational line structure. The resulted pulse with improved time structure and increased peak power is used for laser ion acceleration studies.

Summary (approx. 350 words maximum, including references)

A relatively long 10 µm wavelength makes a CO2 laser an important complementary tool for experimental physics, including strong-field physics applications such as ion acceleration. One of the current challenges in the development of pulsed CO2 lasers is expanding their peak power to multi-TW range. The fundamental difficulty in amplifying a picosecond pulse in a CO2 laser arises from the discrete rotational structure of the gain spectrum of a molecular-gas active medium. Upon amplification, the initially smooth (Gaussian) pulse spectrum acquires a pronounced periodical structure. In the time domain this corresponds to splitting of the pulse into a train of equidistant sub-pulses. The peak power of the resulting pulse train is several times smaller than one could expect if the same energy is reached in a single pulse.

Although elevated pressure (10 atm) allowed us to reduce splitting to some extent via collisional spectral broadening, the complete splitting suppression has been achieved only when isotopically-enriched carbon dioxide was used. Substituting 50% of natural 16O oxygen with its 18O isotope in carbon dioxide provided us, after statistical equilibration via inter-molecular isotope exchange, with a mixture of three isotopes:

\[ [\text{C16O2}]:[\text{C16O18O}]:[\text{C18O2}] = 1:2:1. \]

Superposition of their spectra resulted in the bandwidth homogenization to allow single 5 ps pulse amplification up to the 5 J energy.

Elimination of the pulse splitting resulted in 2-3 times increase in the peak pulse power and suppression of parasitic sub-pulses that should greatly benefit the ATF laser experimental program. The first experiment to take advantage of the improved laser intensity was ion acceleration from a thin metal foil where the maximum proton energy has been increased by 50%. This agrees with the scaling of the proton energy as the square root of the laser intensity expected for the TNSA mechanism. The experiment provides also verification of the theoretically predicted quadratic increase of the proton energy with the laser wavelength.
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<tr>
<th>Name of submitter</th>
<th>Tom Roberts</th>
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<td>Institution</td>
<td>Muons, Inc.</td>
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<td><a href="mailto:tjrob@muonsinc.com">tjrob@muonsinc.com</a></td>
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<tr>
<td>Abstract title</td>
<td>Particle Refrigerator</td>
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<tr>
<td>Author/affiliation list</td>
<td>Tom Roberts, Muons, Inc.</td>
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**Abstract (approx. 50 words maximum)**

The particle refrigerator is a promising new device to greatly reduce the emittance of charged particle beams. By using frictional cooling at very low energies, large cooling factors can be achieved in a small device. The refrigerator solves the vexing problem of frictional cooling: efficiently matching a beam into its inherently tiny energy/momentum acceptance.

**Summary (approx. 350 words maximum, including references)**

The particle refrigerator uses a series of thin (sub-micron) foils and a d.c. voltage between them to create a frictional cooling channel. Frictional cooling happens at very low energies, with $\beta\gamma \sim 0.01$, in a regime where the energy loss in matter is an increasing function of energy. This permits the device to be tuned to a stable equilibrium kinetic energy where the energy lost in each foil is replaced by the d.c. potential between it and the next foil. Fluctuations of energy loss in one foil are compensated by the energy dependence of the energy loss in the next foil. For muons, a 25 nanometer carbon foil corresponds to about 3 keV of loss, so 1,000 foils require a total d.c. potential of about 3 MegaVolts. Remember that in ionization cooling the transverse emittance of the beam is reduced by a factor of $1/e$ each time the beam loses and regains its kinetic energy; in the frictional regime this happens every 3 or 4 foils, so a device a few meters long will bring the beam to the equilibrium emittance of the channel. As the energy is very low ($\sim 8$ keV, $\beta\gamma \sim 0.01$), the normalized transverse emittance is very small.

The primary difficulty in using frictional cooling is that its acceptance is very tiny: incoming muons must be between 3 and 10 keV kinetic energy. The particle refrigerator's novel feature is that it uses the electrostatic potential to bring the incoming beam to a stop and turn it around. In doing so, the particles naturally are within the acceptance of the frictional channel. With a 5 MegaVolt total potential and a modest degrader, it can match an incoming beam with particles having kinetic energies that range from 3 to 8 MeV into the frictional channel with 40-60% efficiency (compared to <0.1% obtainable using degraders alone).

The particle refrigerator is particularly well suited for trapping antiprotons in an atomic trap. In the simplest design, 20 MeV antiprotons pass through a modest degrader and a Penning trap into a refrigerator located on the other side of the trap; the refrigerator turns them around and they re-enter the Penning trap with a kinetic energy of about 15 keV, well within the trap's acceptance. Simulations show the trapping efficiency for this is several orders of magnitude better than the traditional method using degraders alone.
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<th><strong>Name of submitter</strong></th>
<th>Levi Schächter</th>
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<tr>
<td><strong>Abstract title</strong></td>
<td>PASER: options and perspectives</td>
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<td><strong>Author/affiliation</strong></td>
<td>Levi Schächter</td>
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**Abstract (approx. 50 words maximum)**

We briefly review the PASER concept and early experiments as well as undergoing programs. Indications are that the recently proposed Penning-trap configuration that contains active-medium, has the potential of acting as a compact optical buncher/injector. Future perspectives relying on Penning trap with either gaseous or solid-state active medium will be elaborated.

**Summary (approx. 350 words maximum, including references)**

We briefly review the PASER concept and early experiments as well as undergoing programs. Due to relatively weak single particle interaction, for collective effects to become dominant long interaction regions are required – similar to SASE. In order to overcome this stringent constraint the Active Penning Trap concept was suggested. In the absence of the active medium this trap confines the electrons in an equivalent mode to the way a cavity confines radiation. As an active medium is incorporated in the trap, its effect is similar to that of inserting it in a cavity – it obviously amplifies the energy of the stored energy. In case of the trap, electrons get bunched and due to the efficient interaction they gain energy from the medium therefore, they may escape the trap. This paradigm has the potential of being a very compact optical injector. A promising configuration has been recently proposed (pending approval) and it will be briefly discussed. Its advantage is twofold: the photon energy is almost two orders of magnitude higher than the one employed in the past and the medium is gaseous. A solid-state (Nd:YAG) active Penning trap configuration is in its early testing stages. Preliminary results whereby during one-pass (no trapping) up to 30% of increase of dc current was measured is indicative that there is enough energy-transfer in one pass to facilitate a reasonable energy transfer over many round trips. The difficulty associated with the necessity of having the electrons in close proximity to the medium's surface for many round trips, is yet to be confronted. With this regard, the former configuration has the significant advantage of not having to confront this obstacle.
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<th><strong>Name of submitter</strong></th>
<th>Paul Schoessow</th>
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<tr>
<td><strong>Abstract title</strong></td>
<td>Numerical Modeling of PASER Experiments</td>
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<tr>
<td><strong>Author/affiliation list</strong></td>
<td>P. Schoessow, S. Antipov, A. Kanareykin (Euclid Techlabs) and L. Schächter (Technion)</td>
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</table>

**Abstract (approx. 50 words maximum)**

The PASER is one of the first advanced accelerator modeling applications that requires a more sophisticated treatment of dielectric and paramagnetic media properties than simply assuming a constant permittivity or permeability. We present a report on our development of numerical techniques to model beam interactions with active media.

**Summary (approx. 350 words maximum, including references)**

We have been investigating numerical techniques to study various PASER configurations. Devices of particular interest are the recently proposed active Penning trap based electron source and PASERs based on active paramagnetic media. We will focus on modeling of active media in the continuum approximation (effective permittivity and permeability) under FDTD/PIC algorithms. Results to be reported include treatment of multiple Lorentz resonances using the auxiliary differential equation approach. Also being developed are techniques to handle simulations of media with Kerr, Brillouin and Raman nonlinearities. The work described also has applications for modeling of other electromagnetic problems involving realistic dielectric and magnetic media.
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<th>Name of submitter</th>
<th>Ulrich Schramm</th>
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<tr>
<td>Institution</td>
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<tr>
<td>Abstract title</td>
<td>Energy scaling of ultrashort pulse laser accelerated proton beams and first radiobiological applications</td>
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**Abstract (approx. 50 words maximum)**

Ultrashort pulse laser proton acceleration is demonstrated to yield energies hitherto only accessible with high energy lasers. This energy range allows for first well controlled applications as well as for systematic investigations of novel acceleration regimes.

**Summary (approx. 350 words maximum, including references)**

A systematic investigation of ultra-short pulse laser acceleration of protons is presented yielding unprecedented maximum proton energies of 17 MeV [1]. The study has been performed with the Dresden table-top Ti:Sapphire laser Draco operating at a power level of 100 TW. For few micron thin foil targets a linear scaling of the maximum proton energy with laser power is observed and attributed to the short acceleration time close to the target rear surface.

The radiation dose on film for energies above 10 MeV amounts to few Gy and thus provides excellent starting conditions for the irradiation of in vitro tumour cells aiming for dose dependent biological damage. A first experiment demonstrates the availability of all components indispensable for systematic radiobiological studies: A laser-plasma accelerator providing stable proton spectra with maximum energy exceeding 15 MeV over hundreds of pulses and applicable doses of a few Gy within few minutes, a beam transport and filtering system, an in-air irradiation site, a dedicated dosimetry system providing both online dose monitoring and a precise absolute dose information applied to the cell sample, and the full infrastructure for analysing radiation induced damage in cells.

<table>
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<tr>
<th><strong>Abstract (approx. 50 words maximum)</strong></th>
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<td>We discuss a four-beam approach for achieving the ten-TeV energy range when parameters are optimized in such a way that for the un-compensated collisions the disruption effect is small, while the beamstrahlung energy spread can be very large. This allows avoiding beam beam instability and allows to sharpen the luminosity spectrum near the top energy.</td>
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<th><strong>Summary (approx. 350 words maximum, including references)</strong></th>
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<td>Extension of e+e- linear collider parameters into the ten-TeV energy range is usually complicated due large beamstrahlung energy spread generated during collisions of the beams. We suggest evaluating a four-beam approach for achieving the ten-TeV energy range, when the harmful beam-beam effects would be compensated by collisions of two pairs of electron and positron bunches. In contrast to four-beam collision schemes considered in the past [1,2], we suggest to optimize parameters in such a way that for the un-compensated collisions the disruption parameter $D_y$ will be small, while the beamstrahlung energy spread $dE$ will allowed to be very large. In this case, four-beam collision would not exhibit the beam-beam instability, allowing for an accurate compensation of the field and therefore suppression of the beamstrahlung energy spread. Moreover, for simplification of the beamline design and for simplification of decoupling the e-e- and e+e+ luminosity signals, we also consider the case when the two pairs of colliding beams have different energy, such as 1 TeV and 5 TeV per beam. This paper describes the overall concept, presents an example parameter set, discusses the scaling of the parameters, and outlines further studies needed for development of the concept. The work was supported by DOE under Contract DEAC02-76SF00515. The author is grateful to T.Raubenheimer and M.Peskin for stimulating and very useful discussions.</td>
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</table>
Abstract title
First experiments on laser acceleration of protons in overdense gas jet plasma

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(1) Imperial College, London, 2 BNL, USA 3 University of MD, USA 4 Stony Brook University, USA 5 Ludwig-Maximilians-Universitat Germany 6 Max-Planck-Institut fur Quantenoptik, Germany

Abstract (approx. 50 words maximum)
First experiments on laser acceleration of protons in overdense gas jet plasma, enabled by the ultrafast TW CO2 laser at BNL, produced direct demonstration of radiation pressure acceleration and first visual observation of structures related to relativistic laser plasma solitons.

Summary (approx. 350 words maximum, including references)
In a typical laser-ion acceleration experiment so far, a linearly polarized laser beam accelerates electrons in plasma on a surface of a thin metal film and pushes them through the target. Emerging from the cold rear surface, electrons create a strong charge separation field, which ionizes target atoms and pulls out ions. Ion beams produced through this Transverse Normal Sheath Acceleration (TNSA) [1] are well-collimated and bright but have energy spread too broad for many important applications. A promising alternative proposed recently, Radiation Pressure Acceleration (RPA), relies on circularly polarized laser radiation, which pushes "cold" electrons inside a target, thus creating a charge separation field that accelerates ions. Ultra-thin targets could be accelerated as a whole to GeV/ion energies [2]. The first experiments on RPA [3] reveal significant problems with solid targets. A CO2 laser provides unique opportunities for experimental investigation of RPA, because its wavelength of 10 mum allows for using gas jets as targets. Subsequently, it becomes much easier to observe plasma processes in the interaction region and work close to the optimal slightly-overcritical densities. We report the first to our knowledge experimental investigation of proton acceleration by a laser in an overdense gas jet, in particular first direct experimental observations of quasi-monoenergetic spectra of ion accelerated by radiation pressure created by a relativistically intense circularly polarized laser radiation. CO2 laser radiation with the wavelength $\lambda \approx 10 \mu m$, focused to the intensities of up to $10^{16}$ W cm$^{-2}$ into a hydrogen gas jet with densities of 3-5x10$^{19}$ cm$^{-3}$ generates proton beams with energy in a narrow range around 2 MeV, in a reasonable agreement with Radiation Pressure Acceleration theory.

### Abstract (approx. 50 words maximum)

A new approach to injecting plasma electrons into various plasma-based accelerators (LWFA, electron-driven PWFA, proton-driven PWFA) will be discussed. Our approach assumes that the accelerator operates in the full blow-out regime and that the properties of the blow-out ("bubble") region is slowly varied along the propagation length, e.g. via density tapering.

### Summary (approx. 350 words maximum, including references)

Injection into a plasma-based accelerator is one of the most serious challenges facing all plasma-based concepts, including LWFA, lepton-driven PWFA, or a recently proposed proton-driven PWFA. External injection is often challenging because of the short wavelength of the plasma schemes. Self-injection from the ambient plasma is also difficult, especially in the regimes corresponding to ultra-relativistic phase velocities of the plasma wake typical of beam-driven schemes and laser-driven schemes with tenuous plasma. In those regimes, ambient plasma's flow is quasi-static, and additional physics needs to be introduced to induce particle injection into the wake through breaking the quasi-static nature of the flow. We will demonstrate that the slow evolution of the wake presents such new physics, especially in the full-blowout (or "bubble") regime. Such slow evolution can be achieved through density gradient, laser diffraction, channel engineering, or driver beam manipulation. Examples of laser-driven and electron-driven accelerators will be presented, where ambient plasma electrons are injected into the first period of the bubble. We will also discuss the possibility of using protons or positrons for injection into the second period of the wake. Perspectives for using the LSC or Fermilab beams will be discussed.
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<tr>
<th>Name of submitter</th>
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<tr>
<td>Abstract title</td>
<td>Recent advances on theory and modelling of ion acceleration in overdense targets</td>
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<tr>
<td>Author/affiliation list</td>
<td>L. O. Silva, F. Fiúza, R. A. Fonseca, F. Peano (IST), W. B. Mori (UCLA)</td>
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**Abstract (approx. 50 words maximum)**

Recent advances on modelling of ion acceleration in overdense targets are reviewed, using either PIC or hybrid/PIC simulations and examining a wide range of scenarios (from ultra thin solid targets to thick targets, from solid targets to gas targets), and examining finite/isolated target and multidimensional effects.

**Summary (approx. 350 words maximum, including references)**

Ion acceleration using intense lasers in plasmas in an important topic of research with many potential applications. Significant experimental progress has been achieved in recent years, but modelling of ion acceleration in solid targets remains a challenge due to the wide range of scales involved and the importance of multidimensional effects. A review of recent progresses with PIC simulations and in support to recent experiments will be presented. A discussion of the key theoretical and computational challenges will be presented, and some of the recent developments in hybrid/PIC simulations that open the way to one-to-one modelling of ion acceleration scenarios in thick targets beyond the PIC time scale, will also be presented. The acceleration mechanisms of ions in overdense targets will be discussed in different scenarios (e.g. ranging from acceleration in ultra-thin targets to thick targets, with different geometries - from planar to spherical targets). The possibility to accelerate ions or muons directly with the laser field for the production of very high quality beams, in a colliding chirped laser configuration, will also be discussed.
Abstract title: Demonstration of a magnetic insulated cooling lattice for a neutrino factory

Author/affiliation list: Diktys Stratakis (University of California, Los Angeles), Robert B. Palmer (Brookhaven Lab), Juan C. Gallardo (Brookhaven Lab), D. V. Neuffer (Fermi Lab)

Abstract (approx. 50 words maximum):
Reduction of the cavity’s accelerating gradient when exposed to external magnetic fields is a longstanding problem which limits the performance of muon accelerators. We present a conceptual design of a cooling lattice with magnetically insulated cavities. We show that such lattice can be a satisfactory alternative option for the front-end of a Neutrino Factory.

Summary (approx. 350 words maximum, including references):
In this paper, we demonstrated that by designing a magnetically insulated cavity such that its walls are parallel to chosen magnetic-field contour lines, we can suppress damage from field emission. We then detailed its application to cooling channels for a muon accelerator, and presented a conceptual representation of a muon-transport lattice with magnetically insulated cavities. We demonstrated ionization cooling with such a lattice, and compared its performance against a conventional lattice with pillbox cavities. Our findings indicated that a lattice with magnetically insulated cavities is a satisfactory alternative option for the front-end of a Neutrino Factory or a Muon Collider.
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<th>Sergei Tochitsky</th>
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<tr>
<td>Abstract title</td>
<td>Multiterawatt Picosecond CO2 Laser Pulses for Particle Acceleration</td>
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<tr>
<td>Author/affiliation list</td>
<td>S. Ya. Tochitsky, D.J. Haberberger, C. Gong, C. Joshi/Neptune Laboratory, Department of Electrical Engineering, UCLA, Los Angeles, CA 90095</td>
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</table>

**Abstract (approx. 50 words maximum)**
We report on the production of picosecond pulses with unprecedented 10-15 TW peak power in the Neptune CO2 laser system. We explore advantages of multiterawatt 10 micron sources for particle acceleration and present first experimental results on proton acceleration in laser-plasmas.

**Summary (approx. 350 words maximum, including references)**
High-gradient advanced laser-driven electron and ion acceleration schemes are based on energy transfer from the ultrarelativistic laser field to electrons and ions. This process is characterized by ponderomotive potential which has quadratic dependence upon the laser wavelength. That is why, at a given intensity, a 10 micron laser reaches 100 times higher ponderomotive potential than a 1 micron solid-state laser. The UCLA Neptune Laboratory for advanced accelerator studies hosts a TW-class master oscillator-power amplifier CO2 laser system [1] and a high-brightness photoinjector producing a 14 MeV electron beam synchronized with the 10 micron pulse. Terawatt (100ps, 100J) pulses have been successfully applied for high-gradient acceleration of externally injected electrons in the plasma beatwave accelerator and the Inverse Free Electron Laser. Recently the laser was upgraded for generation of 3 ps pulses and a record 15TW peak power was achieved. Final amplification in a 2.5atm large-aperture CO2 module was realized at 1e11W/cm2 intensity, when strong power- or ac Stark-broadening provides sufficient bandwidth for amplification of the 3 ps pulse. Up to 100 J of the output energy is generated typically in a short pulse train with a 18.5 ps periodicity corresponding to the CO2 molecule line spacing. 2D PIC simulations of LDIA in a gas target at critical plasma density show that multiple multiterawatt pulses have an accumulated effect on ion acceleration and result in higher maximum energy of protons. Currently we use these pulses for ion acceleration in a gas jet target. Experimental results on production of collimated forward MeV protons will be discussed. Along with the ultra-high power, picosecond pulse amplification is a very efficient method to extract energy from the manifold of rotational levels of the CO2 molecule. Saturation energy reached in experiment 125 mJ/cm2. Simulations show that further amplification of a 3 ps pulse will cause Rabi flopping in the CO2 gain medium and result in pulse shortening producing 100 TW (100J, 1 ps) pulse. It will open wide range of experiments on nonlinear plasma physics and particle acceleration in an unexplored parameter space.

**Abstract title**  
The Prometheus project: a hybrid acceleration scheme for proton therapy  

**Author/affiliation list**  
Authors: G. Turchetti, A. Bacci, C. Benedetti, P. Londrillo, D. Quatraro, G. Servizi, A. Sgattoni, S. Sinigardi  
Affiliation: Dipartimento di Fisica Università di Bologna, INFN Sezione di Bologna and Milano.  

**Abstract (approx. 50 words maximum)**  
The hybrid acceleration scheme we propose for proton therapy is based on a TiSa laser to produce proton beams with $E > 30$ MeV via TNSA, a transport line with collimators, a chicane and a solenoid, a few high field RF to reach the 60 MeV threshold of medical relevance. Upgrades in energy and intensity will follow.  

**Summary (approx. 350 words maximum, including references)**  
We present a conceptual study of a hybrid acceleration scheme where optically accelerated protons are injected into a high field RF to reach the energy required for therapy. The TNSA acceleration of protons in the range 100-250 MeV requires a multi PW laser. For this reason we develop the feasibility study of a facility to be installed in the Montecuccolino Laboratory of the University of Bologna, aimed at accelerating the protons with a hybrid scheme consisting of three stages: a TiSa laser with power $P \leq 300$ TW to accelerate proton beams above 30 MeV, a transport line for collimation and focusing, a high field (10 MV/m) RF for post-acceleration. The first milestone, to be achieved within four years, is the acceleration of $N \geq 3 \times 10^6$ protons per shot at an energy $E \geq 60$ MeV to start radiobiological and preclinical research activity. Energy and intensity will be progressively increased by improving, the targets design, the number of post-acceleration RF units and the laser power. The optimal set up will be explored until the final goal of a fully optical acceleration is reached. In the meanwhile prototypes for medical use will be developed. For the design study, to be completed within the 2011 fall, intensive simulations are planned jointly with experiments at PMRC, to validate our simulations. The main simulation tool is the electromagnetic code AlaDyn developed by the Bologna, based on high order space-time schemes; the fully 3D cylindrical version is now completed. For the transport, collimation, focusing and RF acceleration integration in the time domain is used with and without space charge. Preliminary results are reported.
Abstract (approx. 50 words maximum)

Development scheme and roadmap of laser plasma ion accelerators were discussed among the members of ICFA and ICIUL (Int. Com. Ultra Intense Lasers). The results are reported. Further, design study, proposal and preliminary experimental results for all optical Compton scattering X-ray source for nuclear material detection is introduced.

Summary (approx. 350 words maximum, including references)

Starting from the cases of the current clinical facilities as a source of reference to compare with, final performance of lasers and accelerators and even cost target were discussed. We assume maximum flexibility to enable treatment of small as well as large in-depth tumor volumes requiring the maximum energy of 250 MeV for protons and 400 MeV/u for carbon. We adopt their reference numbers for the required total number of protons/carbon ions per fraction (5 min) as well as peak numbers (per second). Other parameters (like energy spread and total number of voxels) are adjusted to the particularities of laser acceleration, which include a much higher production energy spread than in the synchrotron case and a laser pulse rate currently suggested by technology. As far as cost, it is assumed that a single laser driver unit is foreseen for one treatment room. It is suggested that the target for 10-20 years of development could be a cost of the laser driver unit not exceeding ¼ of the conventional synchrotron facility cost, which is 40 M€. Further, design study, proposal and preliminary experimental results for all optical Compton scattering X-ray source for nuclear material detection at University of Tokyo is introduced. By using the Ti:Sapphire laser at about 7 TW and our original jas-jet and magnetic plasma channel, we succeeded in generating more than 100 MeV electrons with a reasonable emittance. Compton scattering with beam-spread Ti:Sapp laser pulse can yield quasi-monochromatic X-rays around 110 keV near the K-edges of U, Np, Pu. Subtraction imaging across the K-edge realizes clear recognition and distinguishment of those compounds in liquid.
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<th><strong>Name of submitter</strong></th>
<th>Louise Willingale</th>
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<td><strong>Email address</strong></td>
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<tr>
<td><strong>Abstract title</strong></td>
<td>Ion acceleration from underdense to near-critical density plasmas using the Omega EP laser</td>
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<tr>
<td><strong>Author/affiliation list</strong></td>
<td>L Willingale, P M Nilson, S Craxton, J Cobble, A Maksimchuk, C Stoeckl, T C Sangster, W Nazarov, R Scott, P A Norreys and K Krushelnick</td>
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**Abstract (approx. 50 words maximum)**

Experiments using the Omega EP laser (1000J, 10ps) investigate ion acceleration from underdense to near-critical density plasma. Diagnostics include radiochromic film stacks to measure proton spectra and divergence, a Thomson parabola spectrometer to measure proton and ion spectra and proton radiography is implemented to image the interactions.

**Summary (approx. 350 words maximum, including references)**

The Omega EP laser system can currently deliver 1000J, 10ps laser pulses focused to intensities of around $2 \times 10^{19}$ Wcm$^{-2}$. The proton and ion acceleration is investigated using either low-density foam targets to create a near-critical density plasma, or an underdense plasma using a CH plasma plume target. The foam target density is varied to give plasma densities from 0.9nc to 30nc, where nc is the non-relativistic critical density, whilst the proton spectra and beam divergence are monitored on radiochromic film stacks. The longitudinal and transverse proton and ion spectra are monitored using a Thomson parabola spectrometer from the CH plasma plume interaction. Electromagnetic field structures within the interaction channel are imaged using proton radiography and observe the laser pulse traveling though the plasma. Particle-in-cell simulations of the interactions provide insight into the physics of the interactions.
<table>
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<th>Abstract title</th>
<th>Helical Channel Design and Technology for Capture and Cooling of Muon Beams</th>
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<tr>
<td>Author/affiliation list</td>
<td>Katsuya Yonehara/FNAL, Yaroslav Derbenev/JLab, Rolland Johnson/Muonsinc</td>
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**Abstract (approx. 50 words maximum)**

Novel magnetic helical channel designs for capture and cooling of bright muon beams are being developed using numerical simulations based on new inventions such as helical high-temperature superconducting solenoid magnets and hydrogen-pressurized RF cavities. We are close to the factor of a million 6D phase space reduction needed for muon colliders.

**Summary (approx. 350 words maximum, including references)**

The Muon Accelerator Program (MAP) has been established to promote Muon Collider R&D [1], such as the Helical Cooling Channel (HCC) approach to 6D muon cooling, which is under active investigation under SBIR-STTR grants to Muons, Inc. [2] and its national laboratory and university partners. The initial cooling would be done in an HCC that has solenoid, helical dipole, and helical quadrupole magnetic fields superimposed on high-pressure hydrogen-gas-filled RF cavities. G4beamline [3] simulations of this HCC have indicated almost six orders of magnitude cooling in a 300-m-long channel, with only 40% beam loss (including decays) [4], in agreement with theoretical predictions [5]. The implementation of such a channel with embedded RF cavities is challenging, but progress is being made [6]. HCC component development now underway includes:

* a helical solenoid (HS) solution to the HCC field requirements [7];
* YBCO magnets for the final (and most demanding) helical solenoid section [8];
* phase- and frequency-locked magnetrons [9]; and
* pressurized RF cavities [10], soon to be tested in beam at Fermilab in 2010 [11].

HS solutions for muon capture and matching to the first HCC cooling section as well as matching from the final HCC to the extreme final muon cooling channel are also described.

[3] T.J. Roberts et al., EPAC08, WEPP120
[6] K. Yonehara et al., IPAC10, MOPD076
[7] V. Kashikhin et al., EPAC08, WEPD015
[8] M. Lopes et al., PAC09, MO6PFP060
[9] M. Neubauer et al., PAC09, TU5PFP019
[10] K. Yonehara et al., IPAC10, WEPE069
We report on experimental demonstration of fast protons (>6 MeV) generated by the interaction of modest laser intensities (~10^17 W/cm^2) with micro-structured H2O (snow) targets. The ability to generate fast proton from small and relatively inexpensive systems is of great importance to many applications such as medical radiation treatments and others. The presented scheme of using snow nano-wires can relieve the demand for very high laser intensities, thus reducing the size and the cost of laser system.

Usually ultra high intensity laser beams produce protons above the MeV energy level when the intensity is at least 10^18 – 10^19 W/cm^2 and the beam irradiates targets such as thin-foils or gas jets. In this study, we examined the ability to achieve the same proton energy range with use of relatively modest laser intensity (~10^17 W/cm^2) and a micro-structured H2O target.

Recently we have demonstrated a very efficient coupling of laser energy to frozen H2O deposited on a Sapphire substrate [1] and the generation of 0.1 MeV multi-charged Oxygen ions measured using X-ray emission spectra [2,3]. For the present experiments, we used a frozen H2O deposited on Sapphire, which were shaped as a nanometer sized elongated wires with characteristic diameter in the range of 0.01-0.1μm and length of several μm. The almost full absorption of laser radiation (>95%) and large total surface of the sponge-like H2O target provided effective proton acceleration of both proton energy and proton yield.

We recorded protons with energies of at least 6 MeV. These were measured using CR39 stacks with various filters of different stopping powers. The protons were accelerated backward mainly along the target normal direction. We are planning to extend our study to