Overview of Discussions Held in Working Group 1: HEDP Science, Experiments Diagnostics

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1. Moveable chambers versus moveable beams?

Considering the large forest of diagnostics and wires that sprout from a chamber it seems unlikely that moving the chambers in and out of the ion beam line makes much sense. It seemed more likely that either a beam switchyard is built which redirects the beam along a number of beamlines just prior to drift compression, or the accelerator and drift is built upon a large, railroad- like turntable, which could direct the beamlines physically to one of a number of chambers. A third option was mentioned which places the chambers on colinear or nearly colinear paths, with the velocity tilt determining where the maximum compression is reached. Since the maximum beam intensity varies with velocity tilt, this option would mean the closer chambers could achieve the highest particle intensities, and so flexibility is limited in this option.

2. Are solenoids consistent with diagnostics?

If the target is placed in the middle of a solenoid, diagnostic access becomes problematic. It is better if the beam is focused onto a target which is a few cm (5 to 20 cm seem possible) past the edge of the solenoid. (Here we were considering solenoids with bores of ~ 6 cm radius, fields of ~ 10 T). There are some diagnostics which are sensitive to magnetic fields (CCD's and fast X-Ray streak cameras) so those situations would require shielding the diagnostic. More often the constraint will be having line of site access to the target, which would be highly constrained if the target were deep within the solenoid. Many lines of site to probe the target are preferred.

3. What is the spatial and temporal resolution of diagnostics?

Typically, short pulse lasers, can diagnose samples in the 50 micron regime, and some experiments have been proposed to resolve down to 10 microns using laser based backlighting probes. Typical time scales of ~50 ps should be easiliy achievable with lasers. Synchronicity may be the bigges t issue, i.e. how does one trigger the accelerator pulse and the probe laser pulse with 50 ps resolution? How does one control the jitter in the accelerator firing mechanism to achieve such resolution?

4. How important are multiple chambers?

One approach is to have a single chamber wit h a comprehensive set of diagnostics, so diagnostics are not duplicated. For each experiment perhaps only a small subset of the diagnostics could be used. However, Dick Lee thought it is obvious that you will start with one chamber, but almost certainly that chamber could be completely devoted to facility experiments. Ultimately more chamber s are required to satisfy users and develop user interest. Thus we must do the research, to incorporat e switching to allow for more than one chamber. It is clear the chamber radius itself need only be about 20 or 30 cm, but that the the diagnostics and particular the shielding between chambers will lead to footprints which are ~2-3 m in radius. The shielding is needed because the short pulse lasers used for diagnostics will produce MeV electrons (which can result in X-ray emission, which must be shielded with ~ a few feet of concrete or somewhat less than a few feet of lead), whereas the HEDP ion accelerators may produce ~1MeV/amu, which does not require such thick shielding. The shielding would be required around each chamber, if experimenters are allowed to be present in one chamber area, while experiments are occurring in another, deemed to be a very import attribute. Thus the shielding itself may be the driver that determines how closely the chambers can be spaced, which in turn helps set the bending angle needed for the beams.

5. How flexible in energy, ion mass, and ion current, should facility be?

It should be flexible enough so that as much of the rho-T plane in WDM regime can be explored as possible. Further, for measuring dE/dX a range in ion energy, and ion mass is desirable. Simulations and analytical calculations should continue to be carried out which explores possible operating regimes.

6. What should the rep rate be?

There will be a large fraction of time for setting up the diagnostics for the experiment. The rep rate will be largely for setting up and aligning the diagnostics, and for scanning some diagnostics, for example, taking spectra on device that measure a small range of wavelengths, and the wavelengths must be scanned. It is likely that accelerators operating at the 1 Hz level, would be useful for both setting up the experiments and scanning type experiments.

7. What equation of state questions will be studied?

Simple equations of state, such as the QEOS of Lee and More will be adequate to get into the ball park to design experiments. But the experiments should be flexible enough so that parameters can be varied . Many of the questions will be material science motivated, and colleagues at LLNL and LBNL should be consulted as to how measurement s in the .1 to 10 eV range may be of interest. Many of the detail ed measurements of quantities such as energy levels and energy bands, and transport parameters will require very sophisticated EOS models, and this comparison of the data with detailed theories will be the scientific bounty .

8. What is the time scale for equilibrium to occur?

This is not well known, but it is thought that it may take a few ps for local thermodynamic equilibrium (LTE) to be established. This is an area where the longer length scales of ion-driven HEDP may be a big advantage over lasers. For ion driven HEDP on the 1 ns timescale , states will be more likely to have achieved LTE.

9. Ion stopping; is range shortening significant?.

The energy loss rate of an ion, dE/dX, is proportional to the charge of the projectile squared, over the velocity squared times a logarithmic term given by ln(m_e v^2/ Ip) for bound electrons or and ln(m_e v^2/[h_bar omega_p]) for unbound electrons. (The velocity dependence of 1/v^2 is in the high energy limit; at low energy the dE/dX is proportional to v. The peak occurs roughly where the electron velocity in the target medium equals the ion projectile velocity). Here, m is the electron mass, v is the ion velocity, Ip is the ionization potential, omega_p is the electron plasma frequency. Since for aluminum, at room temperature the number of free electrons, is already ~ a few, increasing the target temperature to a few eV, will not significantly change the range, so cold dE/dX is not a bad estimate for rough scoping of experiments. For detailed experimental comparisons of data with theory the details will matter, and stopping power will be temperature dependent.

10 Targets

Tamping of targets . It was found by D. Callahan that initial scoping of target tamping did not show dramatic improvement of solid density experiments. That is, targets a few microns thick which are bombarded with ~ 10^13 20 MeV Ne ions per square mm in a ns, would reach temperatures of order a few eV, if the target did not dissassemble befor e a ns is reached. The question Debbie explored was whether tamping (by sandwiching layers of tamping material (such as gold) about the material to be studied) could help change this conclusion. Debbie found that since the range was limited, only a small fraction of the target could be of the material under investigation. Further, wave s were generated at the boundaries of the materials. Further, the equation of state of the tamping material complicates the hydro motion, so Debbie did not believe this was a significant improvement although factors of ~ two might be achieved. Others felt there was more to be tried including using plastics as tamping material, which would have a tendency to apply pressure to the central slice. Further as experiments progressed the uncertainties in the tamping material would be reduced, and comparing motion as a function of material composition might be a sensitive experimental tool. Again it was advised that talking to material scientists to find out the interest of their community, would help design target experiments for particular measurement s (such as finding maximum strain rates of the heated materials, and for looking at dislocation dynamics as a function of strain).

11. What diagnostic tools will be available?

The GSI collaboration HEDGEHOB letter of intent document outlines a number of diagnostics which they are considering for use on the GSI HEDP experiments.
The current plans for the GSI upgrade include two target chambers: one for materials (such as metals) initially at room temperature, and one for cryostatic targets (such as solid hydrogen). The plans call for ~12 M Euros per beamline for experiments.

The diagnostics include: VISAR (a laser interferometry technique) ; a fast multi-channel pyrometer; proton radiography; a laser for making X-rays for backlighting the target and imaging it; spectroscopic methods (measuring K-alpha shifts, Stark broadening of lines, level depressions, and other line shfts), contact pressure measurements, electrical conductivfity measurements, and a Thomson X-ray scattering diagnostic.

<u>12. Can Thompson scattering experiments be used to study density and temperature of matter in the WDM regime?</u>

There are two experimental methods where Thompson scattering is used as part of the experiment. One of them, is to use an accelerator and a laser to upscatter the laser photons to X-ray energy, and use the scattered photons to illuminate a target sample. The accelerator can be a traditional accelerator (as in experments with a rf accelerator at LLNL) or a laser based accelerator.

The second method uses Thompson scattering as the diagnostic within the target sample. Here laser generated X-ray line radiation is scattered in the heated material, and the Thompson scattered line width and intensity give temperature and density information.

<u>13. What scientific areas will benefit by the study of Warm Dense Matter?</u>

The oft-cited areas of Warm Dense Matter studies, are equation of state of closely coupled matter, including transport properties (electrical and heat) conductivities , dielectric constant, and wave properties (sound speed and shock speeds). The most direct application appears in the interior of giant planets and low mass stars. But material scientists may also have an interest in understanding yield strengths of material s at these temperatures and densities. Other possibilities offered by R. More include: Magnetic transient phenomena, ionic and electronegative plasmas, refractory metals (such as Tungsten), switching transistors, lasers, and possibly electromechanical devices. Stopping power of ions in this regime is also of interest from a fundamental physics point of view.X-ray diffraction experiments, gives the density structure S(k) and the ion structure factor. MHD behavior may also be studied in this regime. Ion beam heating has the potential of yielding high resolution data, due to the ability to volumetrically heat samples.

<u>14. What happens if the pulse duration is too long, even if the intensity is satisfactory? (Can one perform meaningful experiments during heating of the material?)</u>

Difficult question to answer a-priori. Simulations are needed for definitive answers.

<u>15.What simulations and analysis should be done?</u>

There are three types of targets:

a). Solids (tamped and untamped) H, Al, and Cl
b). Foams (Aluminum at manufacturable densities)
c). Gas (e.g. Neon at 10^{20}/cm3)

There are a number of ions that should be explored (both low Z and high Z, e.g. H, He, Ne, Ar).Particles per pulse: 10^{10} - 10^{13}, Pulse durations of 100 ps (a very demanding possibility for the accelerator); 1 ns (achievable) and 10 ns (perhaps achievable near term).

Ion energies should explore both Bragg peak heating, and energies well beyond Bragg peak (as in the GSI regime). Particles such as Hydrogen could, in principal reach the higher energy regime where dE/dX is nearly constant, (but will be utilizing the energy gained in the pulse to a far lesser extent than experiments at the Bragg peak.)

So to order of magnitude there are 9 targets by 4 ion species by 4 ion intensities, by 3 ion times by 2 ion energies or ~ 1000 simulations or analyses to carry out.

<u>16. What new capabilities needed in the experimental path towards a user facility?</u>

In answering this question a list of new experiment s as well as existing facilities which could play a role was generated The list included:

X-Ray diagnostic development (Source development; ~ 6 keV broad band source/spectrometer; Proton source to evaluate HIB/HED experiments; Cluster/gas jets- diagnostic development; 1020 H inverse bremstrahluing heating (extendable to Ne, Ar, Kr);

Wire array development (to study initial dynamics of wire arrays, and also for a stand-in for foam experiments);

X-ray heating on the ns timescale (Bunch of ps bursts over ns timescale, heating matter to a few eV. Nevada Terrawatt Facility (NTF) (Zebra + laser). Will develop techniques at this facility);

NTF magnetized laser target (volumetric heating by electrons, Z pinch induced B-field);

Ionization Front Accelerator (IFA) concerning possibly building an IFA at LBNL's L'Oasis facility.

Sandia/Naval Research Laboratory Experiments; rf experiments ; other pulsed power experiments

<u>17.What plans are needed for the near term (by ~Jan 1, 2005)?</u>

a) A plan for what facility is to be defined. Need the flexibility to achieve the ion mass, energy , and intensity as determined by the analysis and simulations indicated above.

b) A plan to develop the experimental techniques (diagnostics) necessary to perform the experiments.

c) A plan to improve and develop a local computer and theory capability, so that simulations can be carried out in a rapid and unclassified environment.