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Input to NAS Plasma 2010 panel

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To: Jim Callen, Steve Cowley, Dave Hammer, Max Tabak, and Lia Merminga
From: Art Molvik, LLNL and LBNL
Subject: Input to NAS Plasma 2010 panel

Dear Colleagues,

A number of areas of plasma physics have had outstanding success over the last decade. Below I comment on progress in understanding and manipulating particle beams, a variety of non-neutral plasmas. Some of the key manipulations were made possible by immersing a particle beam in neutral plasma in order to greatly reduce space-charge forces on the beam.

1. What were the most notable scientific highlights and advances in plasma science over the past decade?

Longitudinal and Transverse Beam Compression: The Neutralized Transport Experiment (NTX) at LBNL demonstrated transverse beam density enhancement by a factor of 400 when an otherwise space-charge dominated ion beam was neutralized by a plasma source[1]. This experiment was followed by the Neutralized Drift Compression Experiment (NDCX), in which an ion beam was longitudinally compressed by a factor of 50[2]. This was accomplished by applying a linear head-to-tail velocity tilt to the beam, and then allowing the beam to drift through a meter-long neutralizing plasma. In both the transverse and longitudinal experiments, extensive 3-D simulations, using LSP, were carried out, and the agreement with experiments was excellent[3]. .A three-dimensional kinetic model for longitudinal compression was developed, and it was shown that the Vlasov equation possesses a class of exact solutions for the problem [4].

[1] P. K. Roy et al., "Results on intense beam focusing and neutralization from the neutralized beam experiment," *Phys Plasmas, Vol. 11, 2890 (2004).*
[2] P. K. Roy *et al.*, "Drift Compression of an Intense Neutralized Ion Beam," *Phys. Rev. Lett.* **95**, 234801 (2005).
[3] D. R. Welch *et al.*, "Simulations of Neutralized Final Focus", *Nucl. Instrum. Meth. Phys. Res*. **A544**, 236 (2005).
[4] R. C. Davidson and H. Qin, "Kinetic Description of Neutralized Drift Compression and Transverse Focusing of Intense Ion Charge Bunches", Phys. Rev. ST Accel. Beams **8**, 064201 (2005).

[The item below is a notable advance but is perhaps more significant as a harbinger of results to be realized in the next decade.]

> 3-D codes accurately predict behavior of non-neutral particle beams and when polluted by electrons. Good agreement between experiment and simulation can be achieved for sections all the way from an ion source to the target, and integrated source to target simulations are within sight.

2. What plasma science problems do you consider most likely to yield

exciting and important results in the next decade? Why?

Ion and positron beams, which are non-neutral plasmas, can become polluted by electrons. This is the electron-cloud effect that limits major high-energy physics accelerators. Major advances can be expected both in simulations exploiting algorithms with enhanced efficiency [5.6] and in experiments by developing more quantitative diagnostics, forerunners of which are beginning to appear [7], that are capable of discovering new phenomena and more thoroughly testing and validating simulations. Understanding the rich plasma phenomena already observed is of inherent interest; plus by understanding and learning how to mitigate electron clouds, success in the accelerators that enable **Quark-to-Cosmos** [8] will come faster.

[5] J.-L. Vay, P. Colella, J. W. Kwan, P. McCorquodale, D. B. Serafini, A. Friedman, D. P. Grote, G. Westenskow, J.-C. Adam, A. Heron, I. Haber, "Application of adaptive mesh refinement to particle-in-cell simulations of plasmas and beams" *Phys. Plasmas* **11**, 2928-2934 (2004)
[6] R. H. Cohen, et al., "Simulating Electron Clouds in Heavy Ion Beams," *Phys. Plasmas* **12**, 056708 (2005).
[7] R. Macek, et al., "Electron cloud diagnostics in use at the Los Alamos PSR," Paper ROAB003 in Proc. Of Particle Accelerator Conf. 2003, available at JACOW website: accelconf.web.cern.ch/accelconf/
[8] Committee on the Physics of the Universe, National Research Council, "Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century," (2003).

3. Do you think the current strategy to support the investigation of these problems is correct? Are there alternative methodologies that should be considered? If so, what are they?

Funding of universities, and more recently of National Labs, to do basic plasma science is a successful program that could be expanded. Currently it is a low priority, modestly funded activity with little chance of growth (or even survival) within OFES. In addition, ITER funding pressures are weighing heavily on all non-ITER related elements of the OFES. The benefits of this program are broader than the OFES, so also the amount and sources of funding should be broader.