Advanced Computational Tools for the Energy Frontier

ComPASS SciDAC-3

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U.S. DEPARTMENT OF ENERGY | Office of Science

CONTEXT

***Large accelerators** of particles are among the **most complex & expensive** tools for **scientific discovery**.*

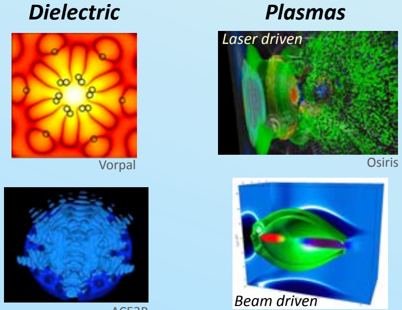
Courtesy S. Myers (IPAC 2012)

- Next accelerator at the energy frontier will rely on new technology or new paradigm (e.g. muon accelerators).
- Computer simulations will play:
  - an increasinlgy important role in designing, commissioning and operating these very complex machines,
  - a key role in discovering new technologies.

New technologies (plasmas, dielectric)** offer great promise for **smaller & cheaper accelerators:

- accelerators based on standard technology are limited by the metallic electrical breakdown limit of ~50-100 MV/m,
- dielectric laser accelerations: a laser propagating through a dielectric lattice can generate electric fields ~ GV/m,
- plasma based acceleration: a driver beam (laser/particles) propagating through a plasma creates a wake with accelerating gradients exceeding 50 GV/m.

Dielectric | ***Plasmas***



Vorpal, Osiris, ACE3P, QuickPIC

METHODS & TOOLS

***ComPASS SciDAC-3** will **push further** the **state-of-the-art** in **modeling of accelerators**, using (developing if unavailable):*

- the most advanced algorithms & performance optimization on the latest most powerful supercomputers,
- cutting-edge non-linear parameter optimization and uncertainty quantification (UQ) methods.

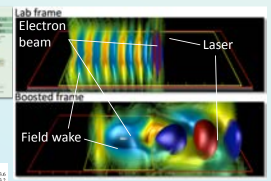
*A **comprehensive set** of **accelerator codes** is being developed (**ACE3P, Osiris, QuickPIC, Synergia, Vorpal, Warp)** that include **state-of-the-art electrostatic (ES) & electromagnetic (EM) field solvers:***

- ES: multigrid (Synergia, Warp, FastMATH), AMR multigrid (Warp, FastMATH)
- EM: finite element (ACE3P-FastMATH), extended stencil finite-difference (Osiris, Vorpal, Warp), AMR finite-difference (Warp, FastMATH),
- Quasi-static: spectral (QuickPIC).

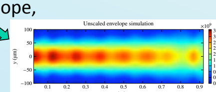
Scaling: Osiris ~30% of peak speed on the entire 220,000 cores on Jaguar.

Original methods developed under SciDAC-2 will be perfected

- boosted frame
  - uses special relativity to speed-up calculation by orders of magnitude,
  - up-to 1 million speedup demonstrated on single 1 TeV stage,
- phase-tracking envelope,
- laser launcher,
- reach quasi-static theoretical speedup.



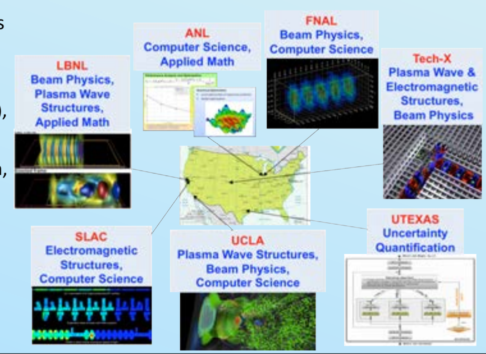
Warp simulation of LPA in lab (top) and boosted (bottom) frames.



Vorpal simulation of meter scale LPA stage w/ laser envelope solver.

Code development coordinated with SciDAC institutes:

- **FastMATH:** field solvers (SuperLU, Chombo),
- **QUEST:** uncertainty quantification (QUESO),
- **SUPER:** performance analysis & optimization, non-linear parameter optimization.



APPLICATIONS

***New tools** will provide **unprecedented capabilities** that will be used for:*

- understanding and optimizing existing accelerators,
- developing new acceleration technologies,

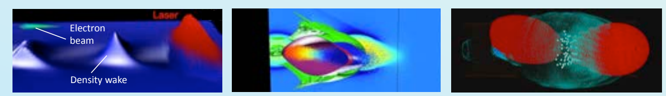
(relevant to HEP stewardship of accelerator technology).

ComPASS SciDAC-3 collaborators** are at the **forefront** in the **modeling** of **plasma-based** and **dieletric laser accelerators.

- accomplishments of the HPC plasma-based acceleration have led to many publications, including some in journals such as Science, Nature, and Physical Review Letters.

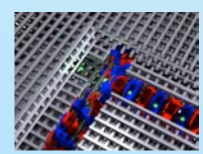
With SciDAC-3 tools, the ComPASS collaboration will:

- **Plasma-based acceleration:**
  - support HEP investment in BELLA and FACET experiments,
  - develop techniques to improve beam quality,
  - evaluate options for controlled electron beam injection,
  - improve staging toward future lepton collider concept.

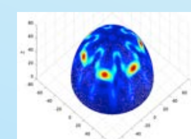


10 GeV BELLA stage (Warp). | FACET stage (QuickPIC). | Colliding pulse injection (Vorpal).

- **Dielectric laser acceleration:**
  - design efficient power couplers between optical fiber and accelerator structure,
  - explore wakefield effects and associated break-ups,
  - design structures accelerating high-quality beams from low to high energy,
  - explore various topologies (a) 3D silicon woodpile photonic crystal waveguide, (b) 2D glass photonic band-gap (PBG) hollow-core optical fiber.



Coupling element in a woodpile silicon structure (Vorpal).



Far field radiation pattern from a hollow-core PBG structure (ACE3P).

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