ComPASS SciDAC-3

Advanced Computational Tools for the Energy Frontier

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CONTEXT

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

CERN Large Hadron Collider (Switzerland)

**~27 km circumference**
~$10B to build

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:
  o an increasinly important role in designing, commissioning and operating these very complex machines,
 o 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.
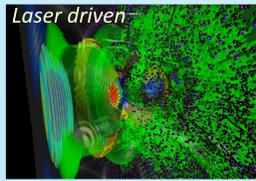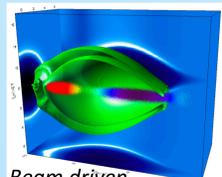
Dielectric

Vorpal

ACE3P

Plasmas

Laser driven

Osiris

Beam driven
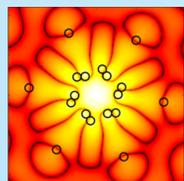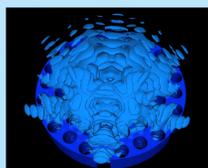
QuickPIC

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), ES-AMR multigrid (Warp, FASTMath)
– EM-finite element (ACE3P-FASTMath),
– EM-extended stencil finite-difference (Osiris, Vorpal, Warp),
– EM-AMR finite-difference (Warp, FASTMath),
– Darwin-finite-difference (QuickPIC).

Original methods developed under SciDAC-2 will be perfected

– boosted frame
  o uses special relativity to speed-up calculation by orders of magnitude,
  o up-to 1 million speedup demonstrated on single 1 TeV stage,
– envelope,
– laser launcher.

Lab frame
Electron beam
Laser

Boosted frame
Field wake
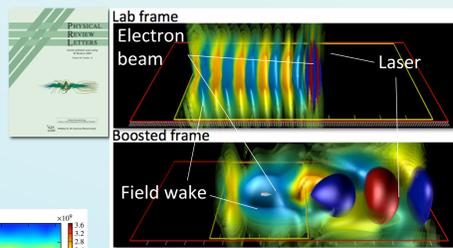
Warp simulation of LPA in lab (top) and boosted (bottom) frames.

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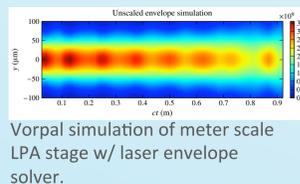
Vorpal simulation of meter scale LPA stage w/ laser envelope solver.

Capability development with SciDAC institutes:

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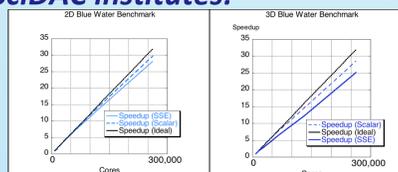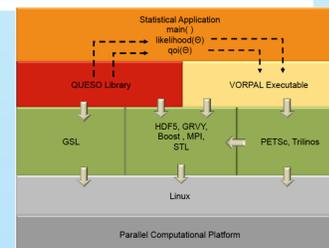

2D Blue Water Benchmark

3D Blue Water Benchmark

Figure Scaling 1: Strong scaling studies on the Blue Waters platform in 2D and 3D using 256 billion particles. OSIRIS has shown to be >93% efficient in 2D and >87% efficient in 3D

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).

The ComPASS SciDAC-3 collaboration has extended experience 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 is:

– **Plasma-based acceleration:**
  o supporting HEP investment in BELLA and FACET experiments,
  o developing techniques to improve beam quality,
  o evaluating options for controlled electron beam injection,
 o improve staging toward future lepton collider concept.

Electron beam
Laser
Density wake
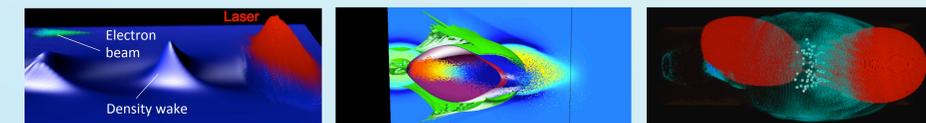
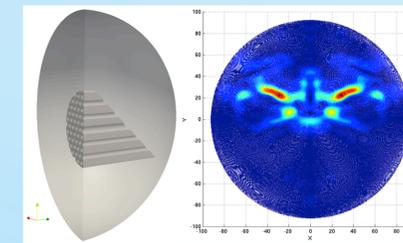10 GeV BELLA stage (Warp).

FACET stage (QuickPIC).

Colliding pulse injection (Vorpal).

– **Dielectric laser acceleration:**
  o designing efficient power couplers between optical fiber and accelerator structure,
  o exploring wakefield effects and associated break-ups,
  o designing structures accelerating high quality beams from low to high energy,
  o exploring various topologies (a) 3D silicon woodpile photonic crystal waveguide, (b) 2D glass photonic bandgap hollow-core optical fiber.
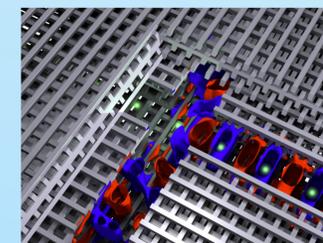
VORPAL simulation of a DLA woodpile sructure

ACE3P simulation of an improved power coupling scheme for PBG fiber

Argonne National Laboratory

Berkeley Lab

Fermilab

SLAC National Accelerator Laboratory

TECH-X

UCLA

THE UNIVERSITY OF TEXAS AT AUSTIN