ComPASS
SciDAC-3

Advanced Computational Tools for High Energy Accelerators

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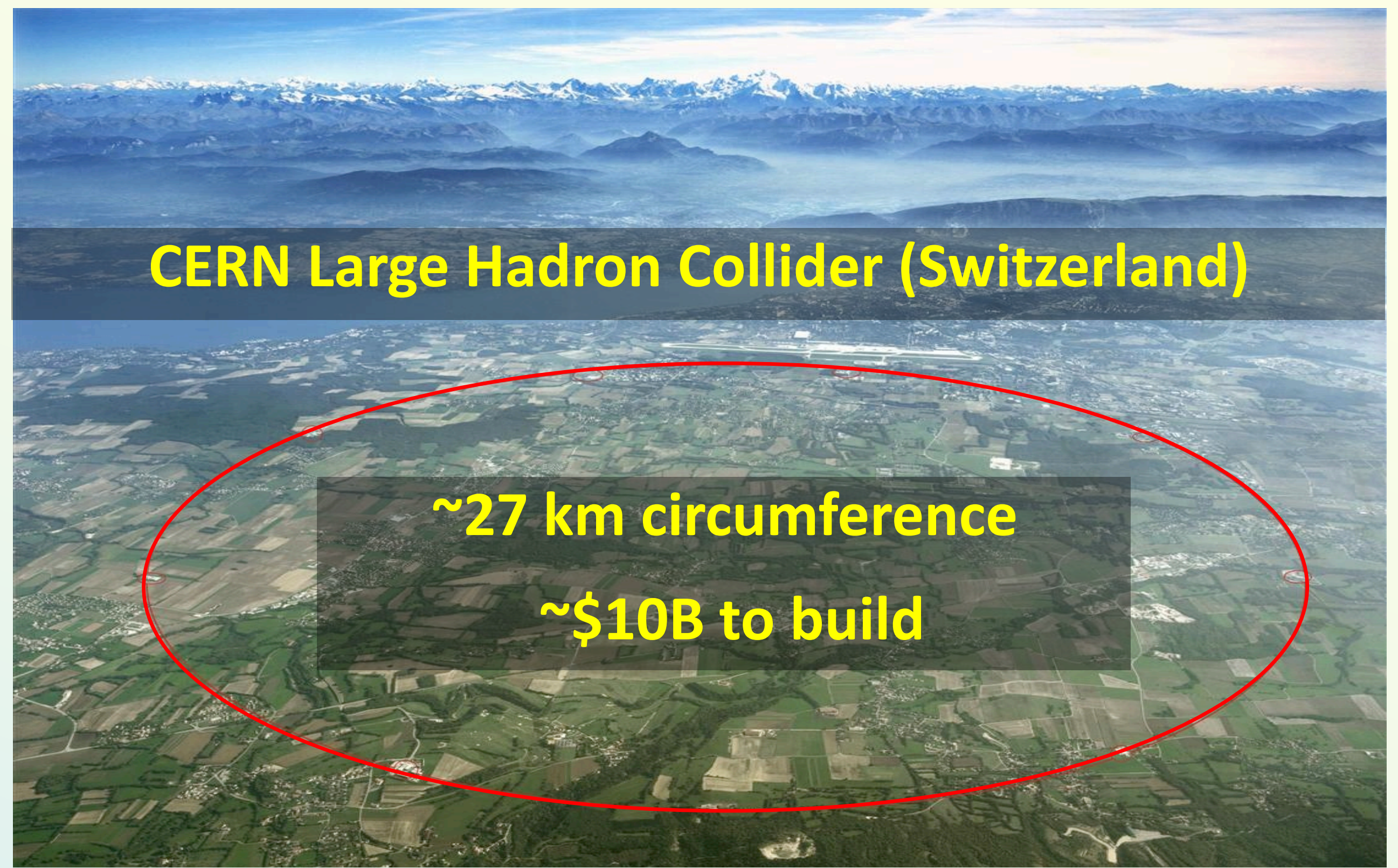
CONTEXT

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



Courtesy S. Myers (IPAC 2012)

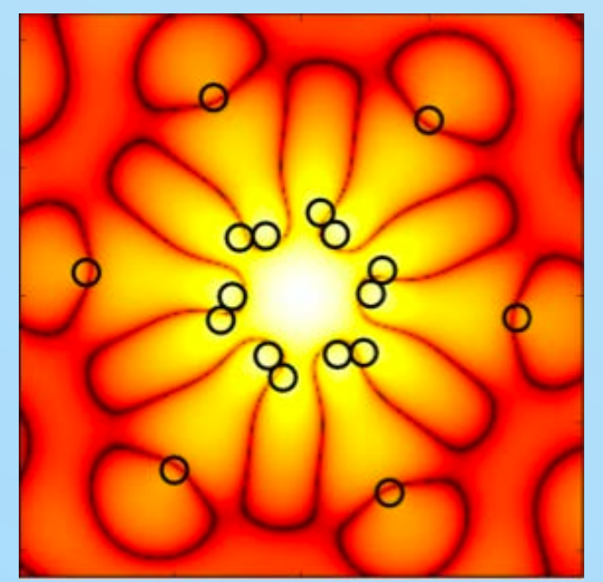
- Next accelerator at high energy will rely on new technology or new paradigm for high gradient acceleration.
- Computer simulations will play:
  - an increasinlgy important role in designing, commissioning and operating these very complex machines,
  - a key role in discovering new technologies.

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

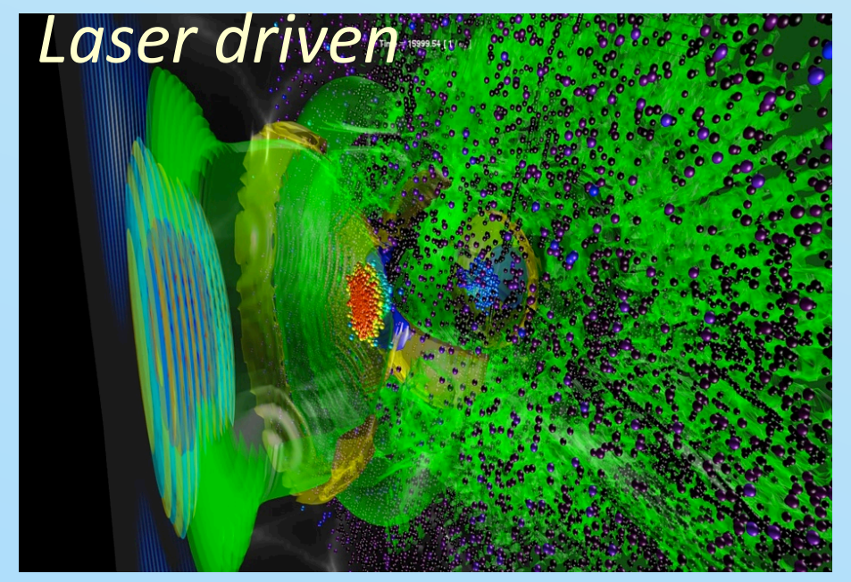
- accelerators based on standard technology are limited by the metallic electrical breakdown limit of ~50-100 MV/m,
- dielectric laser accelerations: a laser propagating through a dielectric lattice can generate electric fields ~ GV/m,
- plasma based acceleration: a driver beam (laser/particles) propagating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

Dielectric

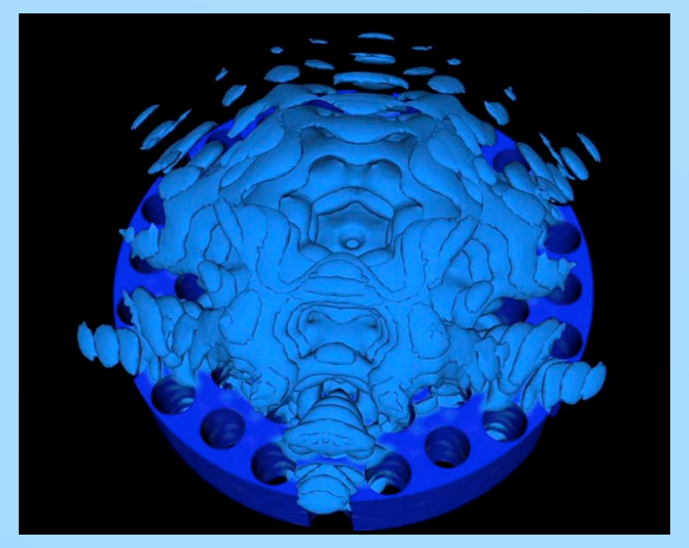
Plasmas



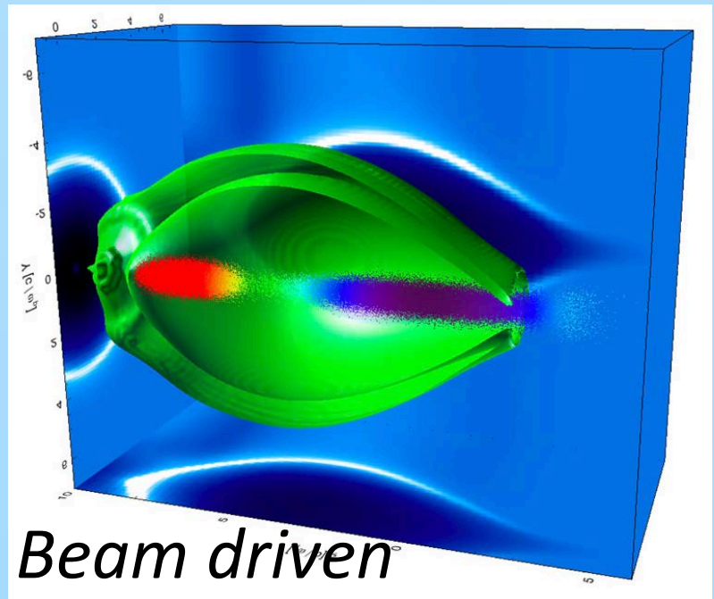
Vorpal



Osiris



ACE3P



QuickPIC

METHODS & TOOLS

***ComPASS SciDAC-3** is **pushing 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); with AMR (Warp, FASTMath)
- EM-finite element (ACE3P-FASTMath),
- EM-extended stencil finite-difference (Osiris, Vorpal, Warp),
- EM-AMR finite-difference (Warp, FASTMath),
- EM pseudo-spectral solvers (UPIC-EMMA, Warp)
- EM arbitrary order finite-difference & pseudo-spectral (Warp)
- EM embedded boundary (Vorpal)
- Quasi-static, FFT field solver (QuickPIC).

Original methods partially funded under SciDAC-2 & 3

- boosted frame [1,2]
  - uses special relativity to speed-up calculation by orders of magnitude,
- novel parallel decomposition paradigm for EM spectral [2]
  - uses finite speed of light to replace global FFTs by local FFTs
- Pipelining parallelization routine
  - uses causality to launch multiple 2D slices in quasi-static approximation

J.-L. Vay recipient of:

[1] *2013 USPAS Prize for Achievement in Accelerator Science and Technology*

[2] *2014 NERSC Achievement Award in Innovative Use of HPC*

Capability development with SciDAC Institutes:

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

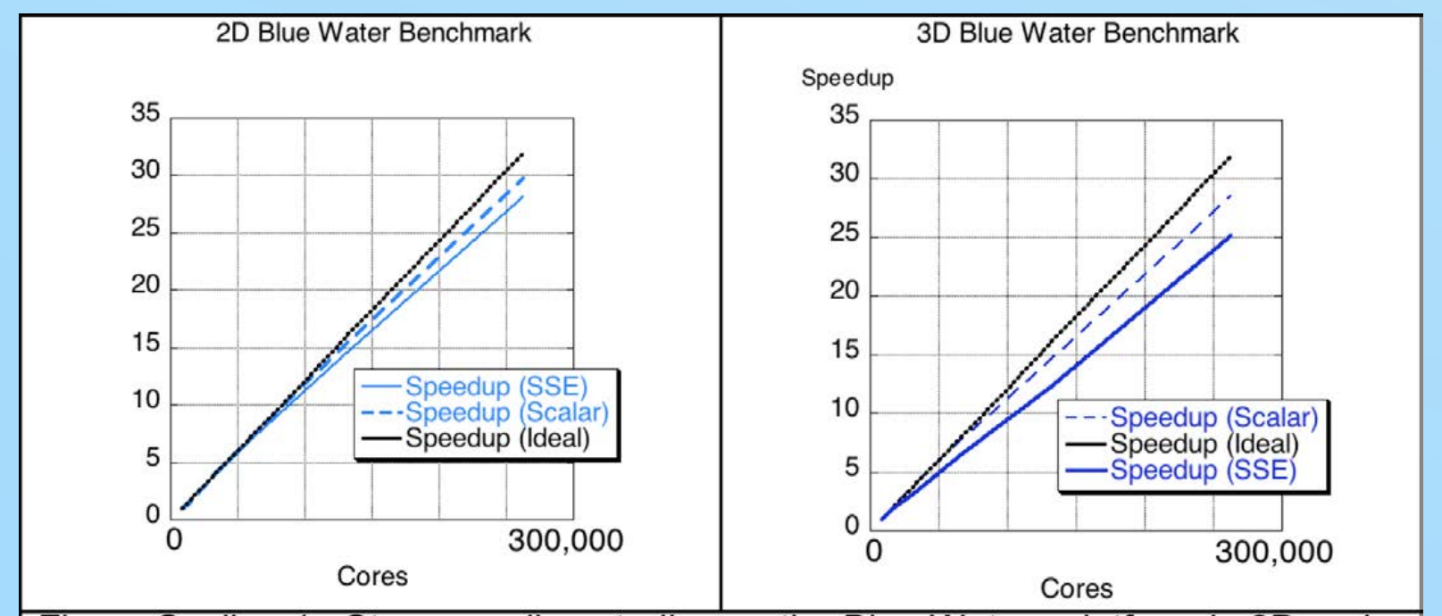
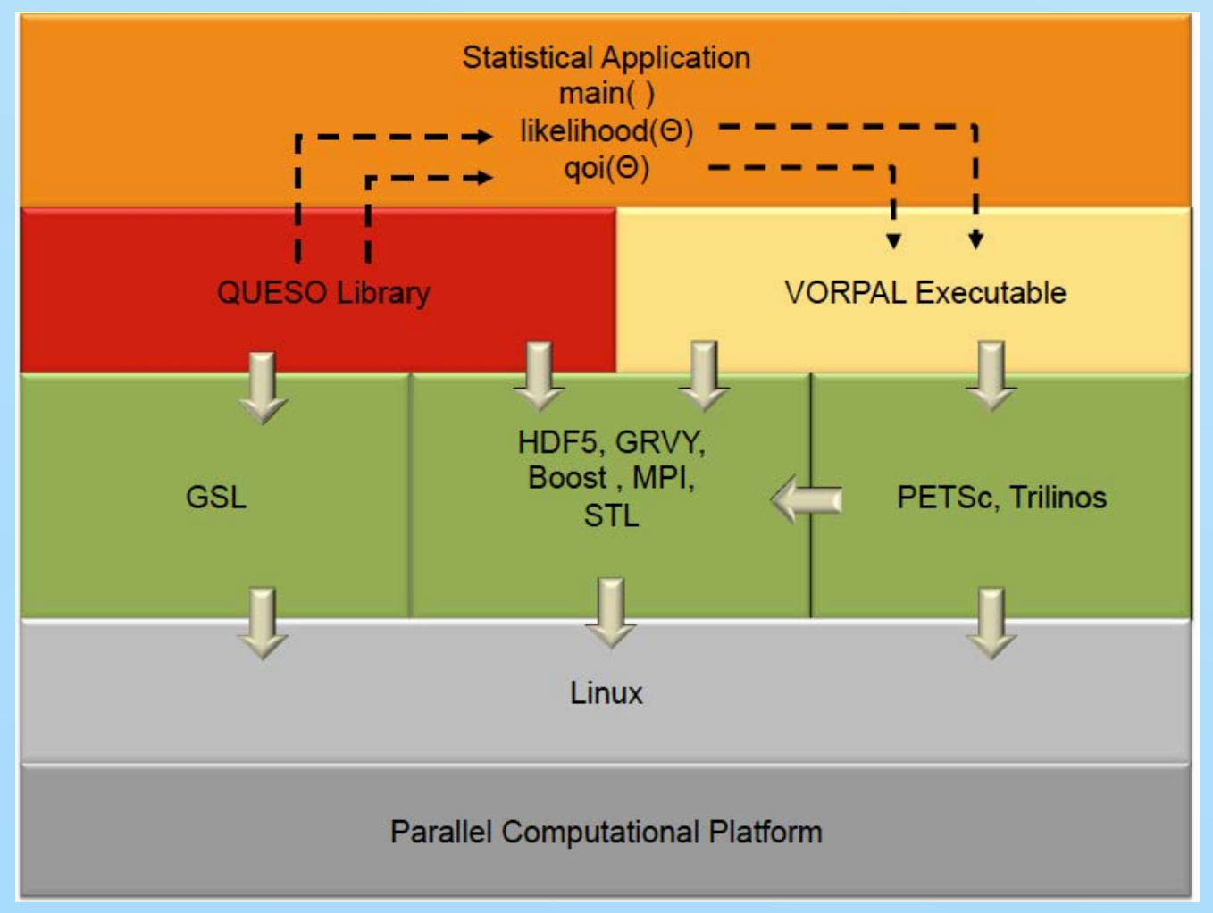


Figure Scaling.1: Strong scaling studies on the Blue Waters platform in 2D and 3D using 256 billion particles. OSIRIS has shown to be >93% efficient in 2D and >87% efficient in 3D



APPLICATIONS

New tools** are providing **unprecedented capabilities** that are used for**:

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

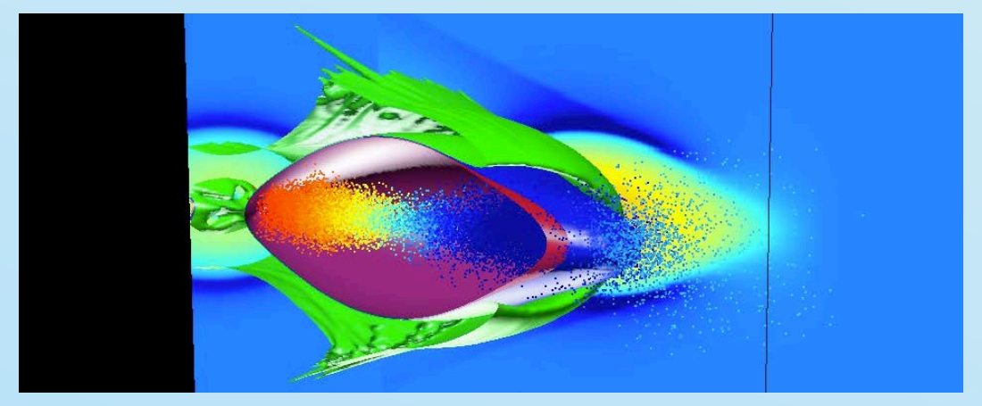
(relevant to HEP stewardship of accelerator technology).

*The **ComPASS SciDAC-3 collaboration** has **extended experience** in the modeling of **plasma-based** and **dieletric laser accelerators.***

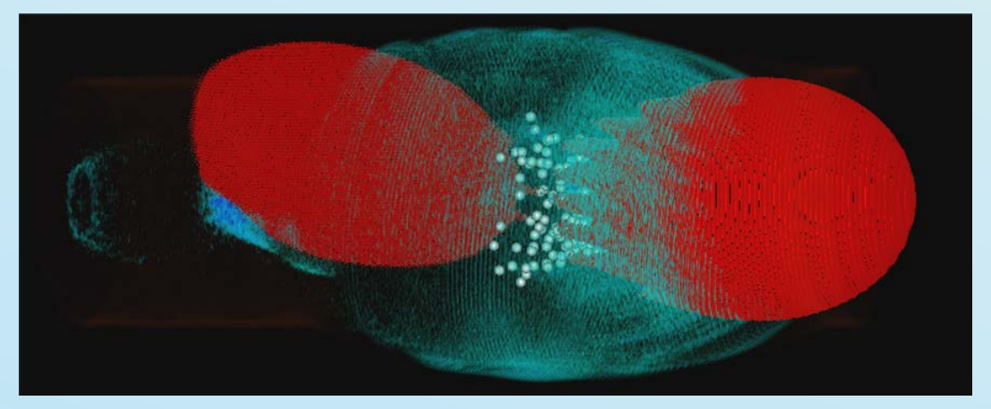
- accomplishments of the HPC plasma-based acceleration have led to many publications, including some in journals such as Science, Nature, and Physical Review Letters.

With SciDAC-3 tools, the ComPASS collaboration is:

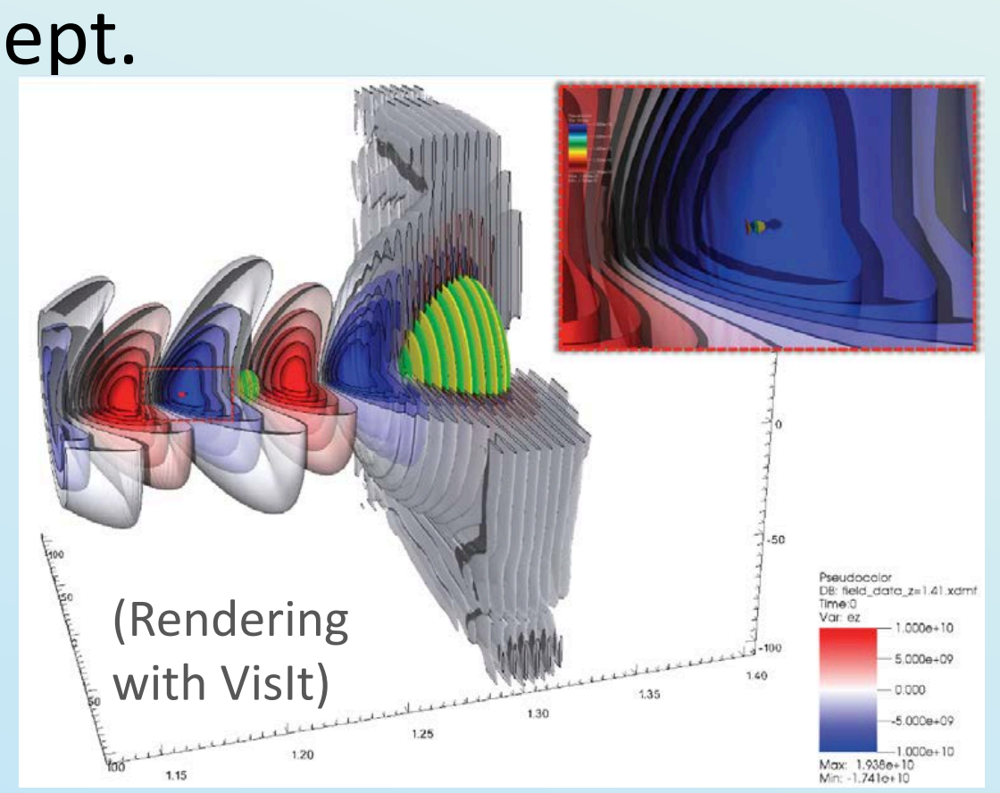
- **Plasma-based acceleration:**
  - supporting HEP investment in BELLA and FACET experiments,
  - developing techniques to improve beam quality,
  - evaluating options for controlled electron beam injection,
  - improve staging toward future lepton collider concept.



FACET stage (QuickPIC).

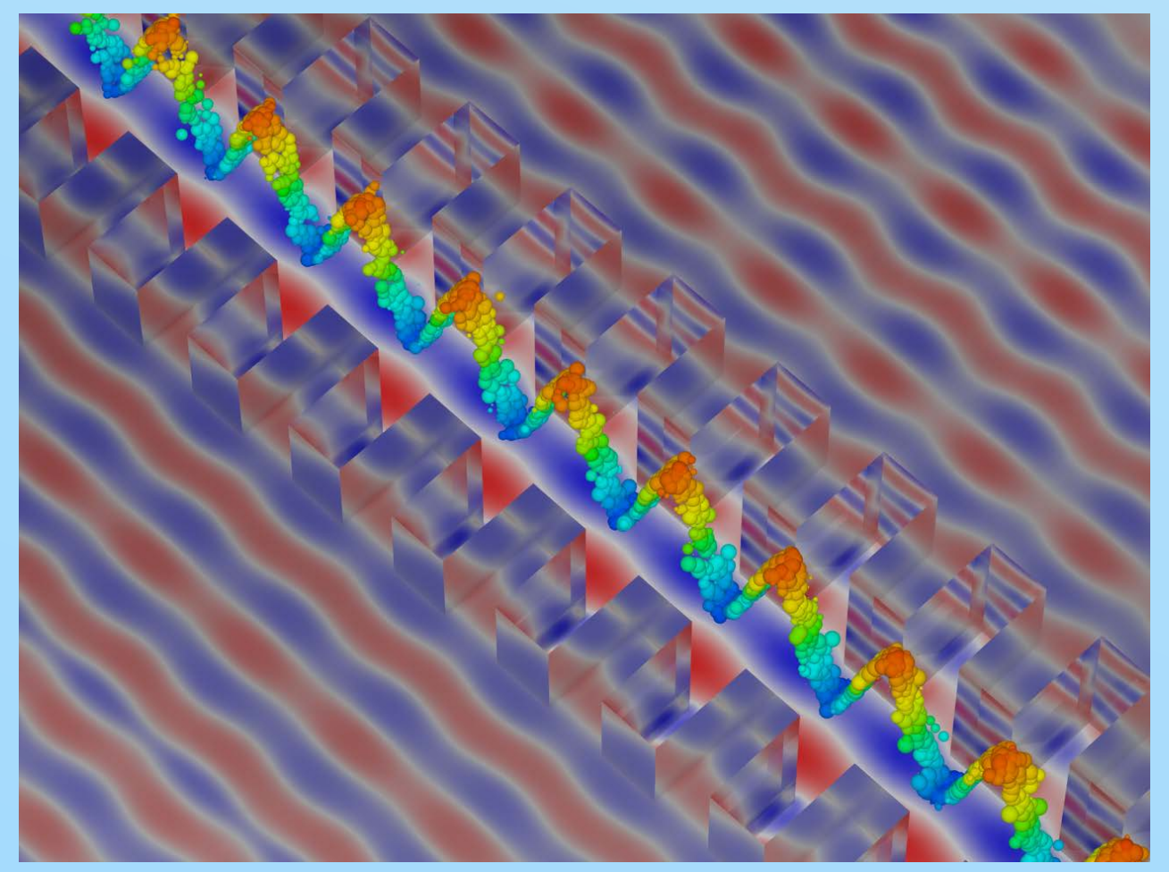


Colliding pulse injection (Vorpal).

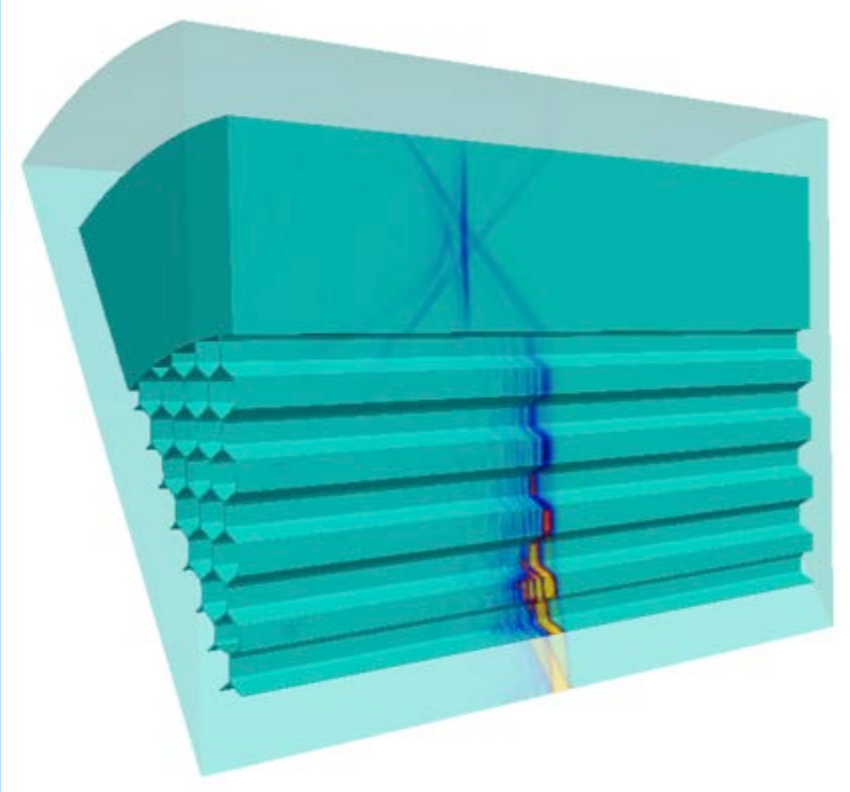


Novel 2-color injection (Warp).

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



VORPAL simulation of particles accelerated in a dielectric grating structure



ACE3P simulation of wakefield in a PBG fiber

Argonne NATIONAL LABORATORY

BERKELEY LAB

Fermilab

SLAC NATIONAL ACCELERATOR LABORATORY

TECH-X

UCLA

THE UNIVERSITY OF TEXAS AT AUSTIN