ComPASS SciDAC-3

Advanced Computational Tools for High Energy Accelerators

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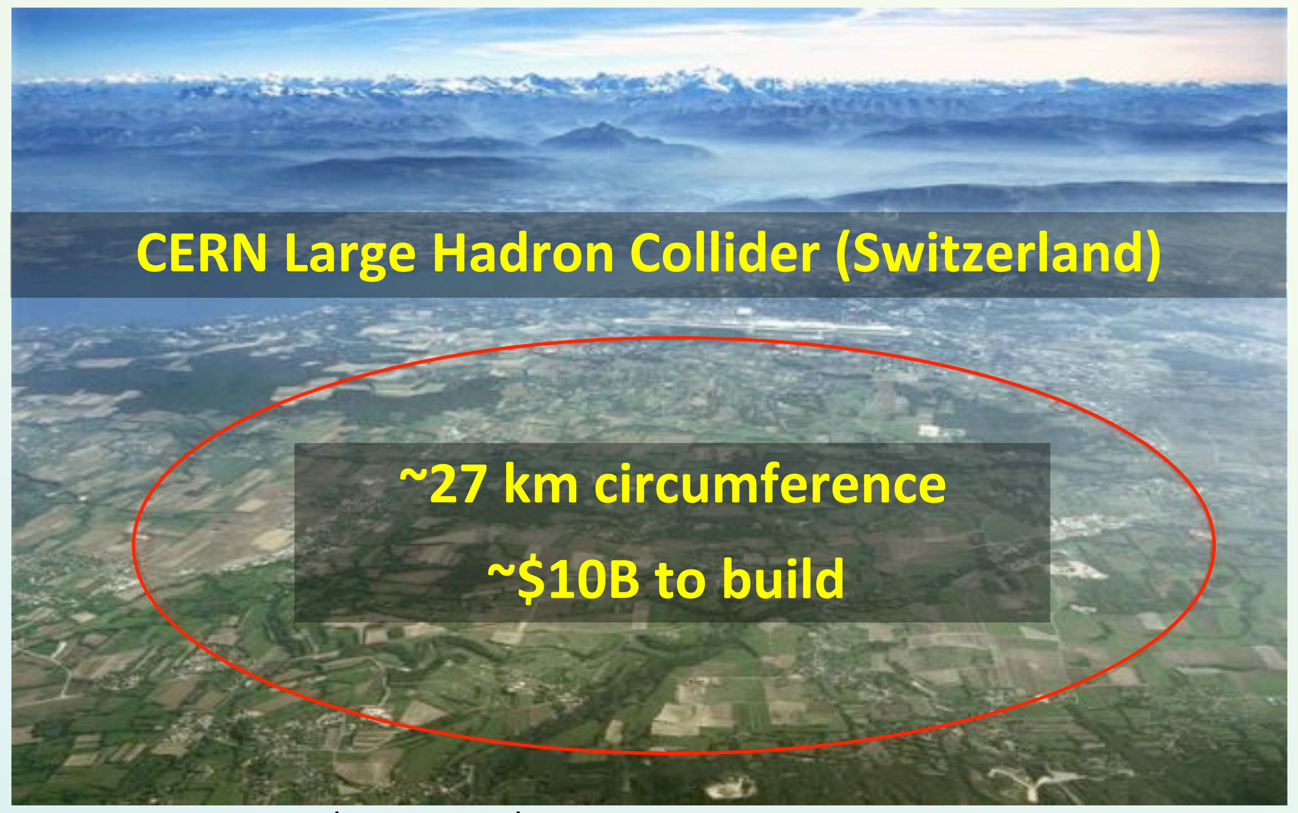
CONTEXT

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



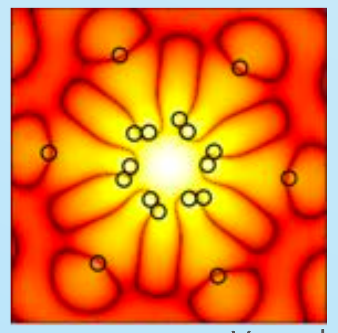
Courtesy S. Myers (IPAC 2012)

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

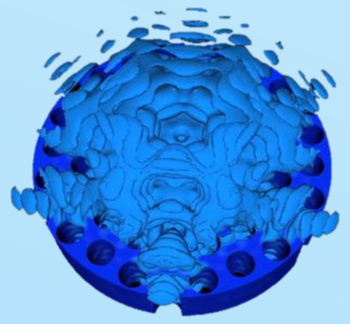
New technologies (plasmas, dielectric)** offer great promise for **smaller & cheaper accelerators:

- 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

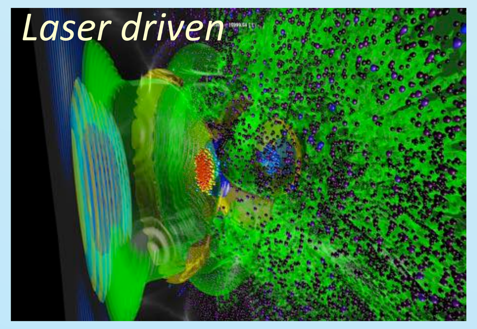


Vorpal

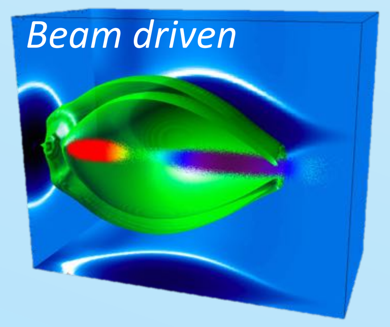


ACE3P

Plasmas



Osiris



QuickPIC

METHODS & TOOLS

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

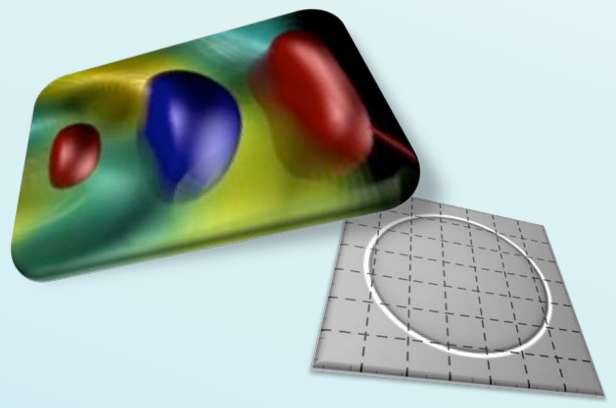
- the most advanced algorithms & performance optimization on the latest most powerful supercomputers,
- cutting-edge non-linear parameter optimization and uncertainty quantification (UQ) methods.

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

Original methods partially funded under SciDAC-2 & 3:

- Boosted frame[1,2]
  - o uses special relativity to speed-up calculation by orders of magnitude,
- EM spectral w/ domain decomposition[2]
  - o uses finite speed of light to replace global FFTs by local FFTs
- Pipelining parallelization routine
  - o uses causality to launch multiple 2D slices in quasi-static approximation
- Improved envelope solvers



Capability development with SciDAC Institutes:

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

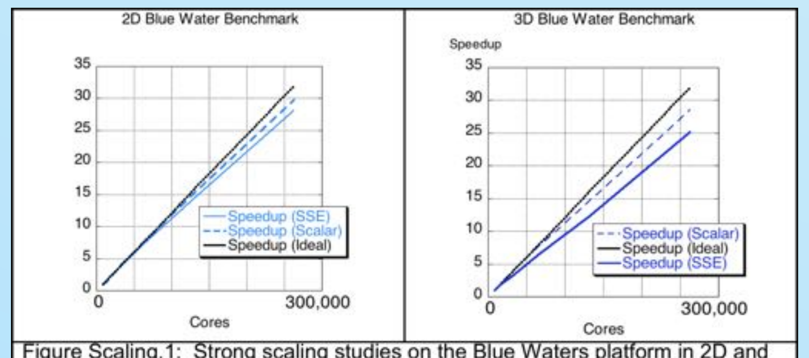
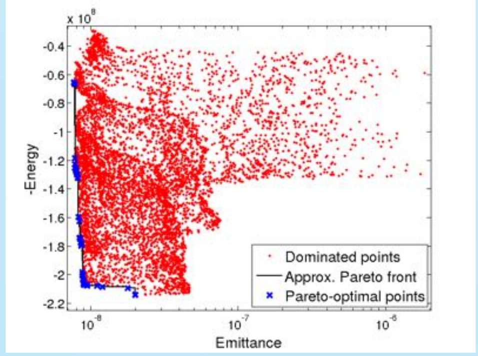


Figure Scaling.1: Strong scaling studies on the Blue Waters platform in 2D and 3D using 256 billion particles. OSIRIS has shown to be >93% efficient in 2D and >87% efficient in 3D



SUPER/Warp optimization of electron beam energy and emittance in a laser-plasma accelerator chanin.

[1]*2013 USPAS Prize for Achievement in Accelerator Science and Technology*
[2]*2014 NERSC Achievement Award in Innovative Use of HPC*

APPLICATIONS

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

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

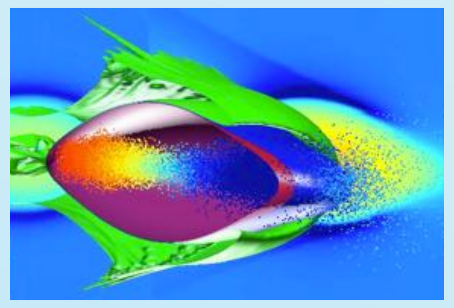
(relevant to HEP stewardship of accelerator technology).

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

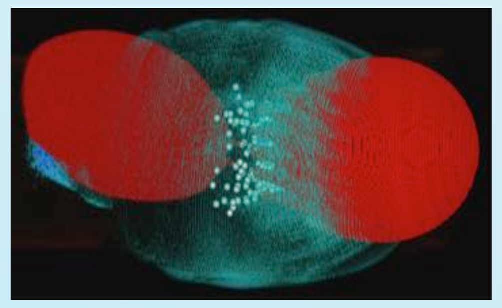
- accomplishments of the HPC plasma-based acceleration have led to many publications, including some in journals such as Science, Nature, and Physical Review Letters.

With SciDAC-3 tools, the ComPASS collaboration is pushing the frontier in advanced accelerator concepts:

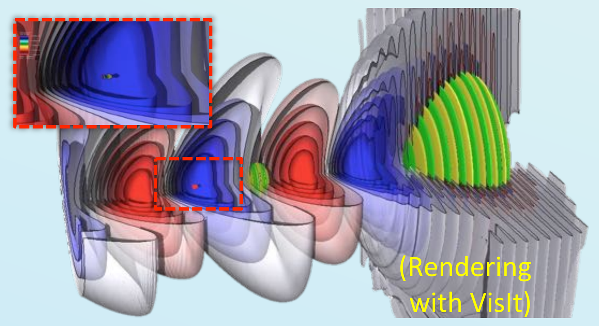
- **plasma-based acceleration:**
  - i. supporting HEP investment in BELLA and FACET experiments,
  - ii. developing techniques to improve beam quality,
  - iii. evaluating options for controlled electron beam injection,
  - iv. improving staging options toward future lepton collider concept,



FACET stage (QuickPIC).

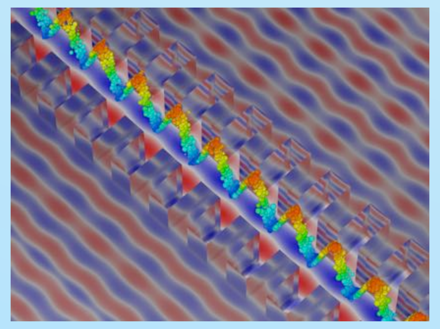


Colliding pulse injection (Vorpal).

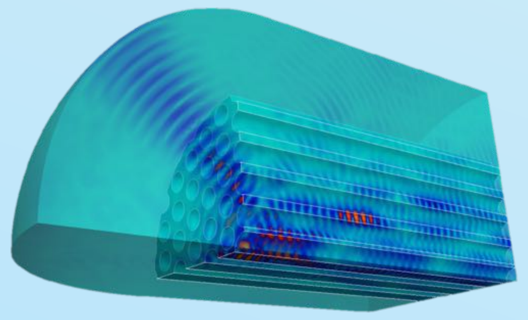


Novel 2-color injection (Warp).

- **dielectric laser acceleration:**
  - i. designing efficient power couplers between optical fiber & accelerator structure,
  - ii. exploring wakefield effects and associated break-ups,
  - iii. designing structures accelerating high quality beams from low to high energy,
  - iv. 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 used to investigate coupling mechanism for optimum power transfer from laser to accelerating mode in PBG fiber

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