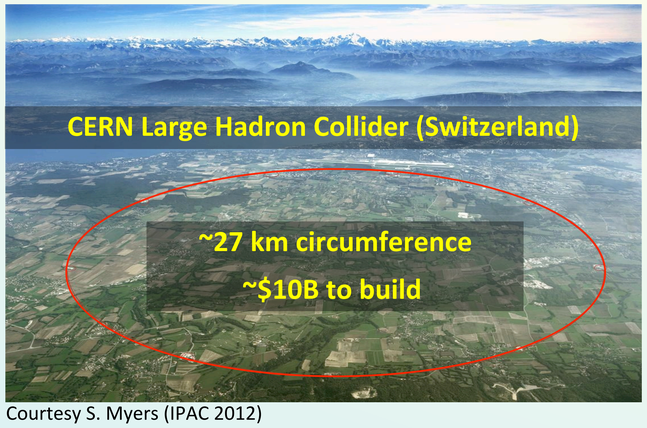
ComPASS SciDAC-3

Advanced Computational Tools for the Energy Frontier

PI: P. Spentzouris[1] – Co-PIs: J. Cary[2], W. Mori[3], C. Ng[4], E. Ng[5], B. Norris[6], E. Prudencio[7], J.-L. Vay[5]
[1]Fermilab, [2]Tech-X, [3]UCLA, [4]SLAC, [5]LBNL, [6]ANL, [7]UT Austin

CONTEXT

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



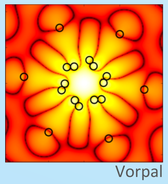
Courtesy S. Myers (IPAC 2012)

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

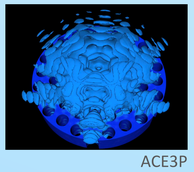
New technologies (plasmas, dielectric)** offer great promise for **smaller & cheaper accelerators:

- 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

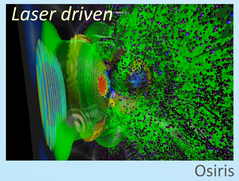


Vorpal

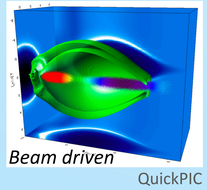


ACE3P

Plasmas



Osiris



QuickPIC

METHODS & TOOLS

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

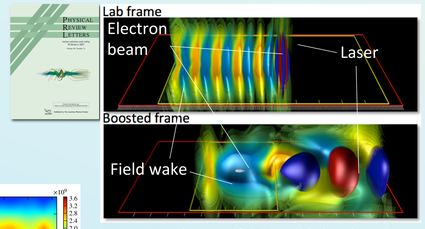
- the most advanced algorithms & performance optimization on the latest most powerful supercomputers,
- cutting-edge non-linear parameter optimization and uncertainty quantification (UQ) methods.

*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:***

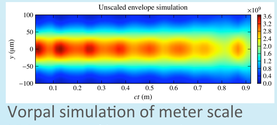
- ES-multigrid (Synergia, Warp, FASTMath), ES-AMR multigrid (Warp, FASTMath)
- EM-finite element (ACE3P-FASTMath),
- EM-extended stencil finite-difference (Osiris, Vorpal, Warp),
- EM-AMR finite-difference (Warp, FASTMath),
- Darwin-finite-difference (QuickPIC).

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.



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



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.

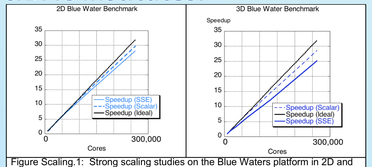
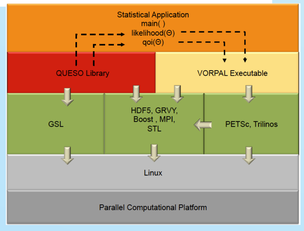


Figure Scaling.1: Strong scaling studies on the Blue Waters platform in 2D and 3D using 256 billion particles. OSIRIS has shown to be >93% efficient in 2D and >87% efficient in 3D



APPLICATIONS

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

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

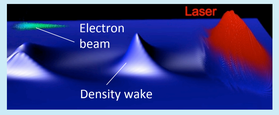
(relevant to HEP stewardship of accelerator technology).

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

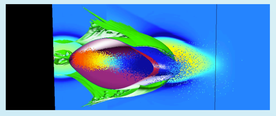
- accomplishments of the HPC plasma-based acceleration have led to many publications, including some in journals such as Science, Nature, and Physical Review Letters.

With SciDAC-3 tools, the ComPASS collaboration is:

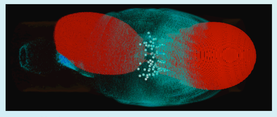
- **Plasma-based acceleration:**
  - o supporting HEP investment in BELLA and FACET experiments,
  - o developing techniques to improve beam quality,
  - o evaluating options for controlled electron beam injection,
  - o improve staging toward future lepton collider concept.



10 GeV BELLA stage (Warp).

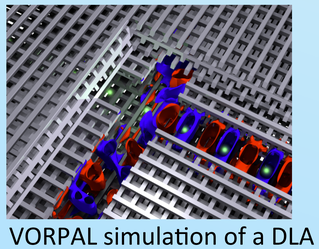


FACET stage (QuickPIC).

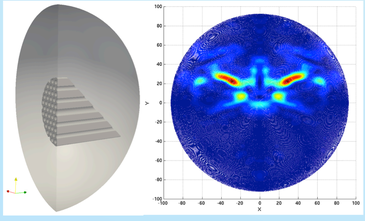


Colliding pulse injection (Vorpal).

- **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

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