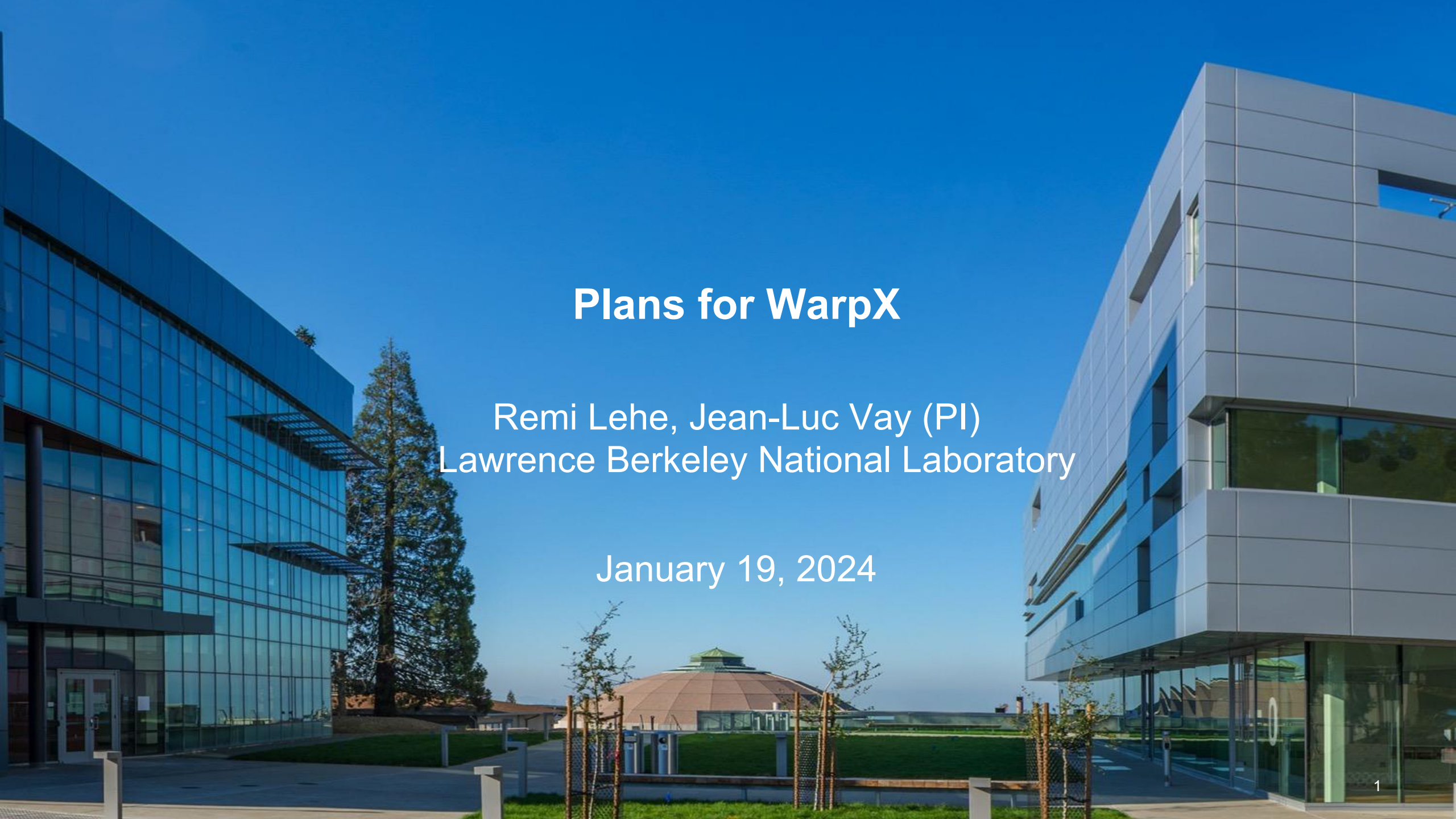


Plans for WarpX

Remi Lehe, Jean-Luc Vay (PI)
Lawrence Berkeley National Laboratory

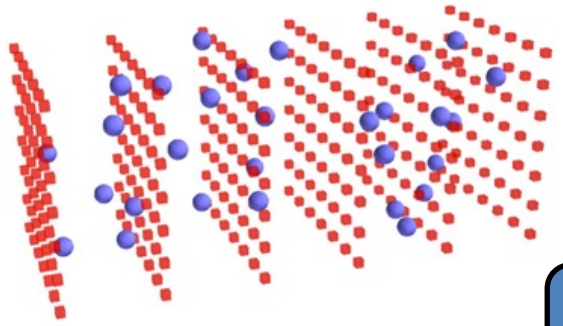
January 19, 2024

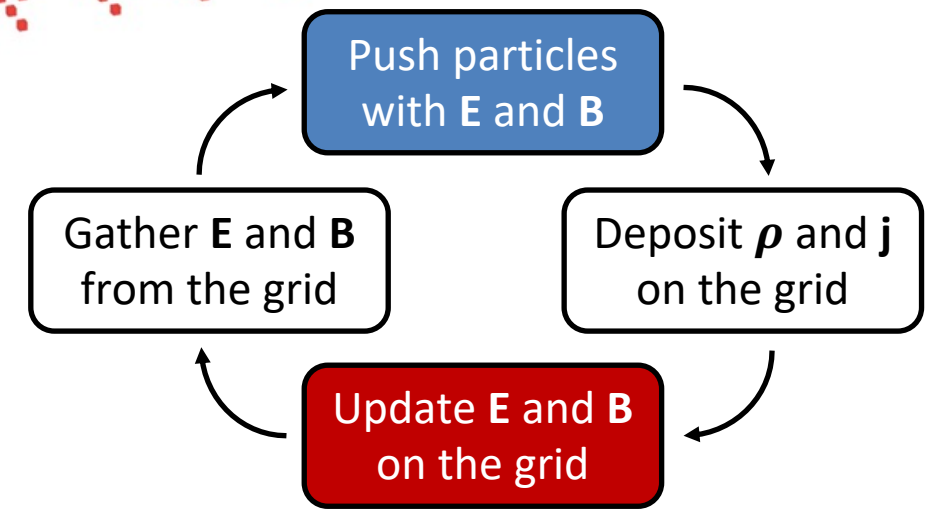
Outline

- WarpX: introduction
- Simulations of beam crossing at the interaction point
- Simulations of beam delivery system (BDS)

WarpX: a high-performance Particle-In-Cell code

- **Particle-In-Cell code:** captures self-consistent evolution of charged particles in electromagnetic fields
- Developed within the **Exascale Computing Program**
- Open-source: *github.com/ECP-WarpX/WarpX*
- Currently used for the study of **plasma-based accelerators, RF accelerators, fusion devices, laser-plasma interactions…**





EXASCALE COMPUTING PROJECT

Funding landscape for WarpX

2016 – 2023 : Exascale computing project

Focused on simulating multi-stage laser-plasma accelerators

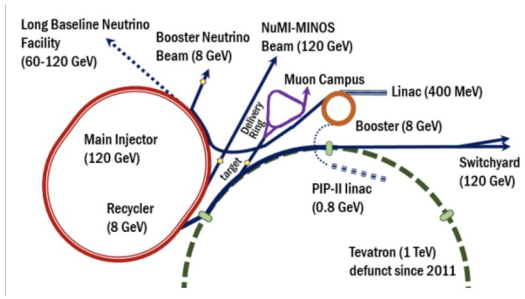
EXASCALE COMPUTING PROJECT

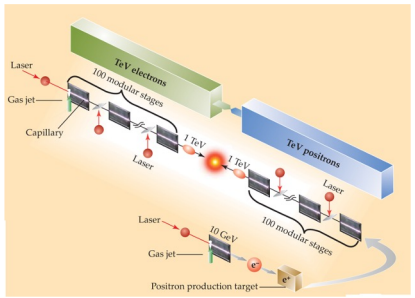
2022 – 2027 : SciDAC projects

SciDAC
Scientific Discovery through Advanced Computing

HEP SciDAC “CAMPA”

Simulations for accelerator research
(both RF and plasma-based accelerators)



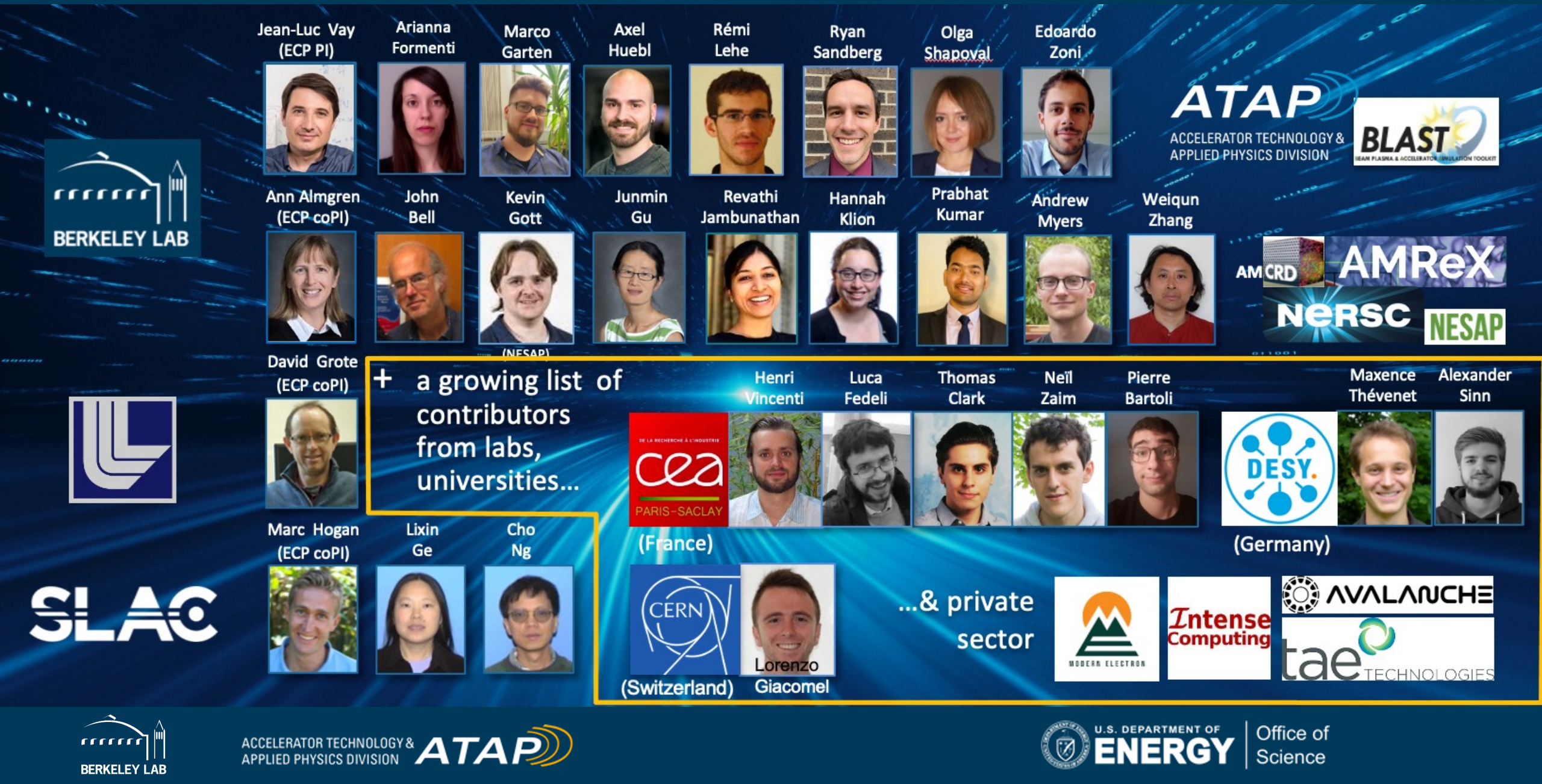


FES SciDAC “KISMET”

Simulations for laser-driven Inertial Fusion

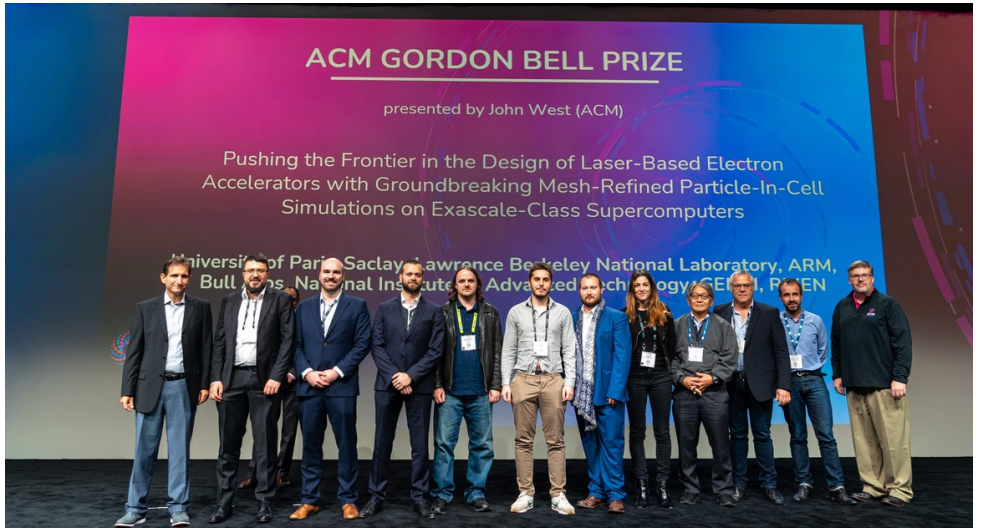
Current funding source for
WarpX collider-relevant simulations

WarpX: conceived & developed by a multi-disciplinary, multi-institution team



WarpX leverages modern high-performance computing resources

- **Portable across computing architectures**
  The same WarpX source code can be compiled for CPU, NVIDIA GPUs, AMD GPUs, …
- **Massively parallel**
  Can use thousands of CPU/GPU nodes
- **Dynamic load-balancing capability**
  Dynamically redistributes particles & grid cells across compute nodes to avoid bottlenecks.
- **Mesh refinement capability**
  Can use finer grid around regions with sharp gradients

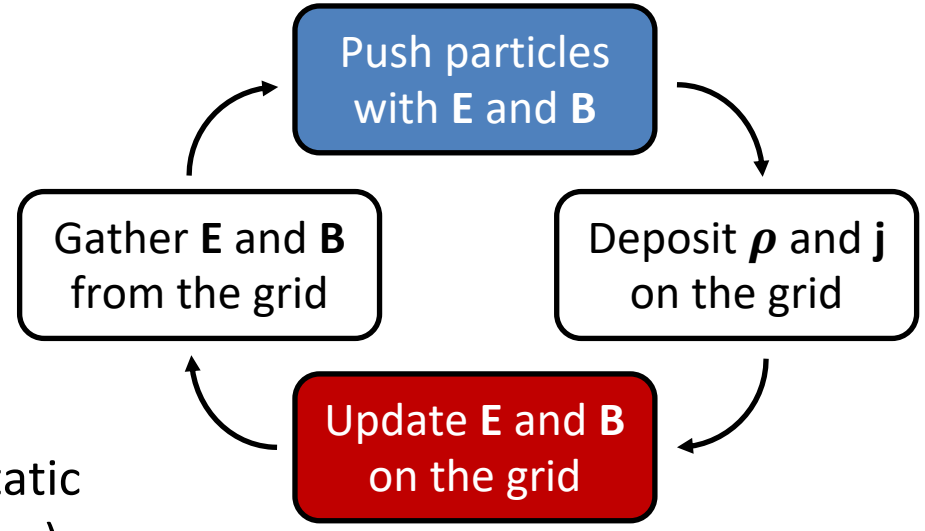


WarpX was recognized by the 2022 ACM Gordon Bell Prize.

WarpX is a highly flexible simulation code

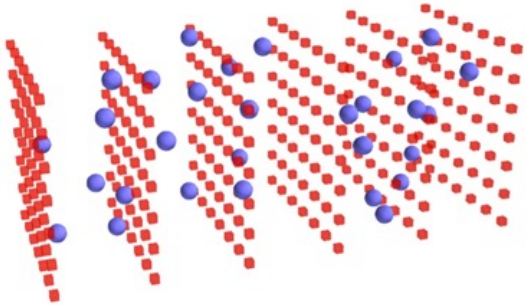
Several field solvers available:

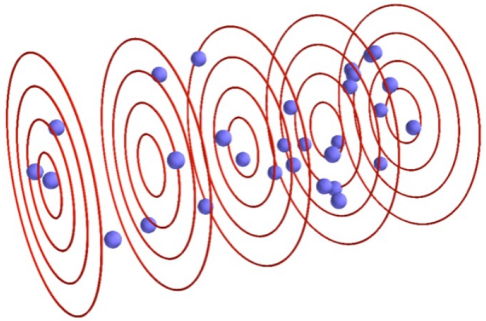
- Fully electromagnetic (captures e.g. radiation, laser)
- Electrostatic and/or magnetostatic (incl. electrostatic in beam frame)
- …



Several geometries available:

- 1D/2D/3D Cartesian
- Cylindrical (with azimuthal decomposition)





WarpX includes several multi-physics modules

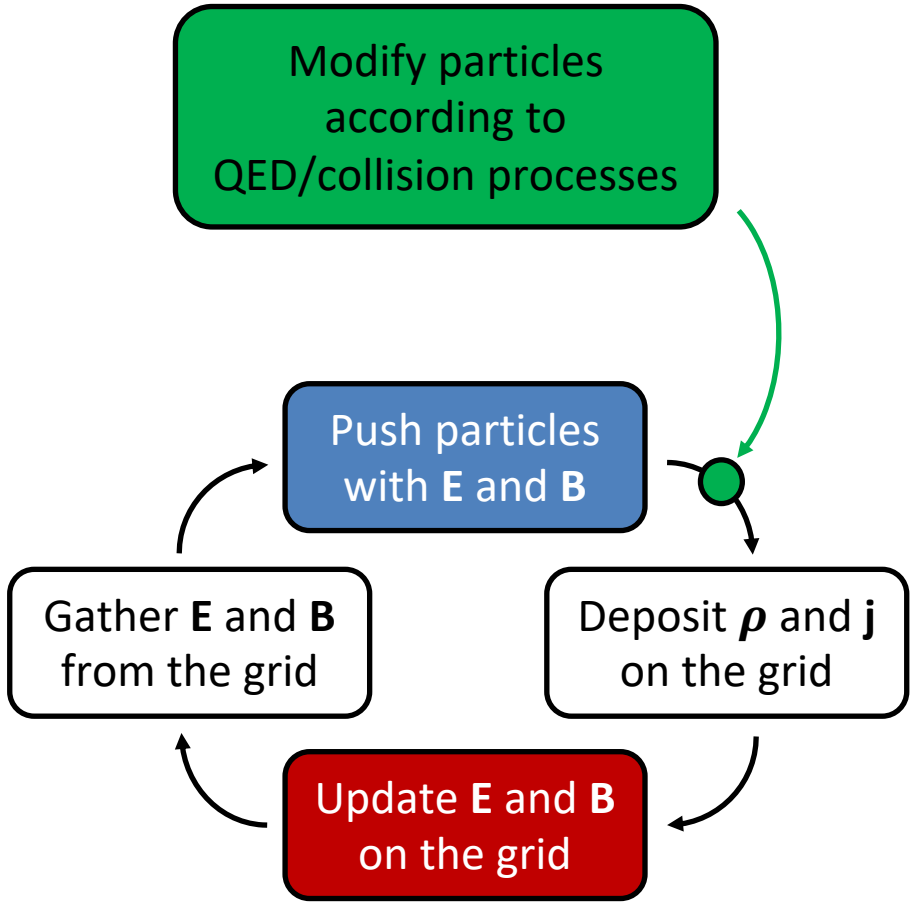
Capture **additional physics** that is not captured by solving the field equations on the grid.

- **Quantum electrodynamic (QED) processes:**

  - Quantum synchrotron
  - Breit-Wheeler pair production

- **Collision processes**
  includes Coulomb collisions between charged particles

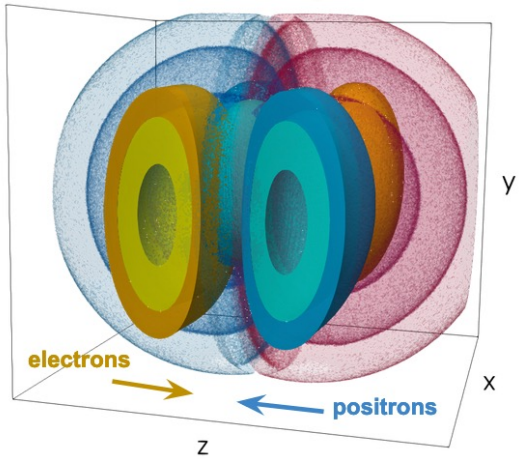
  (used e.g. to study the growth of emittance due to collisions in plasma-based accelerators: Zhao et al., Phys. Plasmas, 2020)



Outline

- WarpX: introduction
- **Simulations of beam crossing at the interaction point**
- Simulations of beam delivery system (BDS)

WarpX can simulate beam crossing at the interaction point



As beams cross at the interaction point,
several physical processes can alter the luminosity.

WarpX aims:

- Capture the same physics as Guinea-Pig (disruption, beamstrahlung, pair creation), but with faster simulations
- Capture pair plasma effects, which may not be captured in Guinea-Pig

Benchmarks between WarpX and Guinea-Pig are being performed:

- See presentation by Arianna Formenti
- Plans to publish results in PRAB, to establish WarpX as a simulation tool for beam crossing

Work is under way to include more QED processes

- **Quantum synchroton**
  (discrete emission of photons by accelerated particles)
- **Coherent pair production, a.k.a. nonlinear Breit-Wheeler**
  (photon decays into an electron-positron pair, in the space–charge field of the beams)

Implemented in WarpX

- **Incoherent pair production, a.k.a. linear Breit-Wheeler**
  (two photons annihilate and produce an electron-positron pair)

Implementation is almost complete

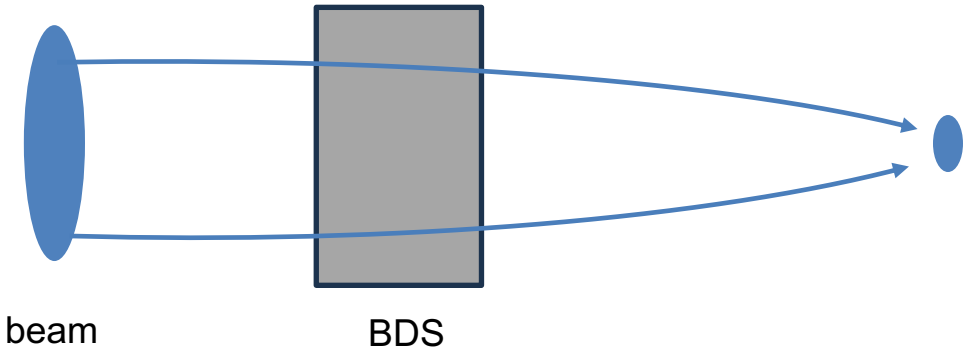
- **Bethe-Heitler pair production**
  (photon decays into an electron-positron pair, when passing close to an individual charged particle)
- **Landay-Lifschitz**
  (a charged particle emits an electron-positron pair, when passing close to an individual charged particle)

Implementation planned over the next few months

Outline

- WarpX: introduction
- Simulations of beam crossing at the interaction point
- **Simulations of beam delivery system (BDS)**

WarpX could capture the physics of the BDS



Several effects as the beam is focused:

- **Coherent synchrotron radiation:**
  Could be simulated with WarpX's electromagnetic solver
- **Emission of discrete hard photons**
  (leads to the Oide effect)
  Can be captured with WarpX's quantum synchrotron module

- What are interesting open questions / interesting parameters to explore?
- Would it be useful to simulate plasma lenses for final focus?
- Are there standard codes / results against which to benchmark