x

Needs, considerations and solutions for a consortium of accelerator modeling

J.-L. Vay

Lawrence Berkeley National Laboratory

BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science

HB2014

East Lansing, MI

10-14 November 2014

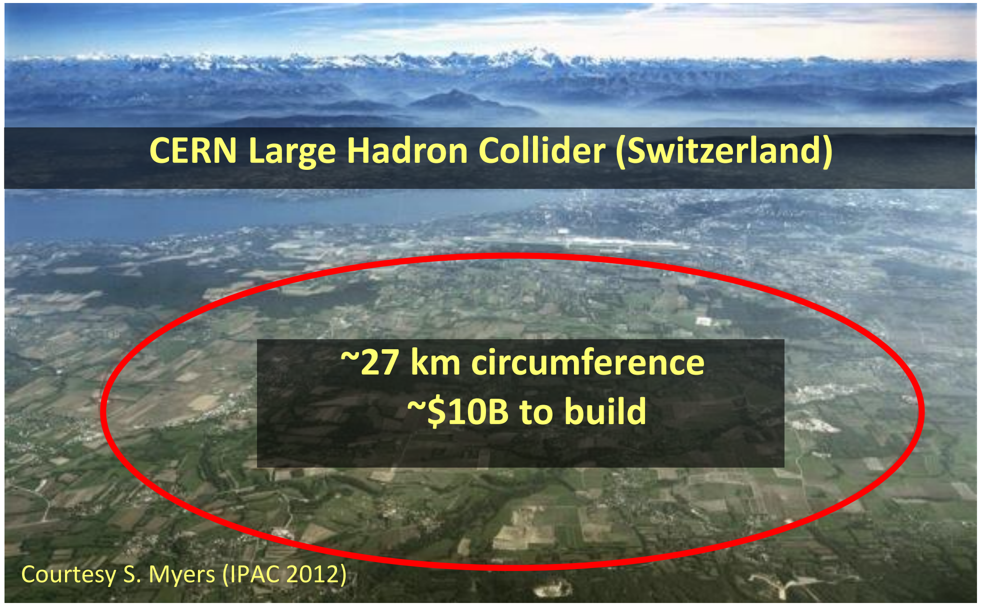
54th ICFA Advanced Beam Dynamics Workshop on High-Intensity, High Brightness and High Power Hadron Beams

Accelerators are essential tools of science and tech.

There are > 30,000 particle accelerators in operation around the world,

serving:

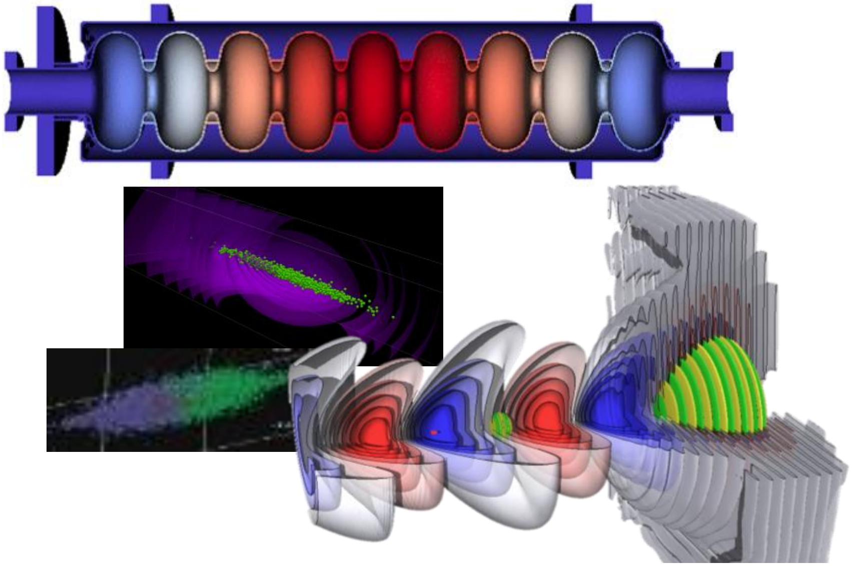
- discovery science,
- medicine,
- industry,
- energy,
- the environment,
- national security.



Size and cost are a limiting factor for many applications

➔ active research worldwide to conceive smaller & cheaper accelerators.

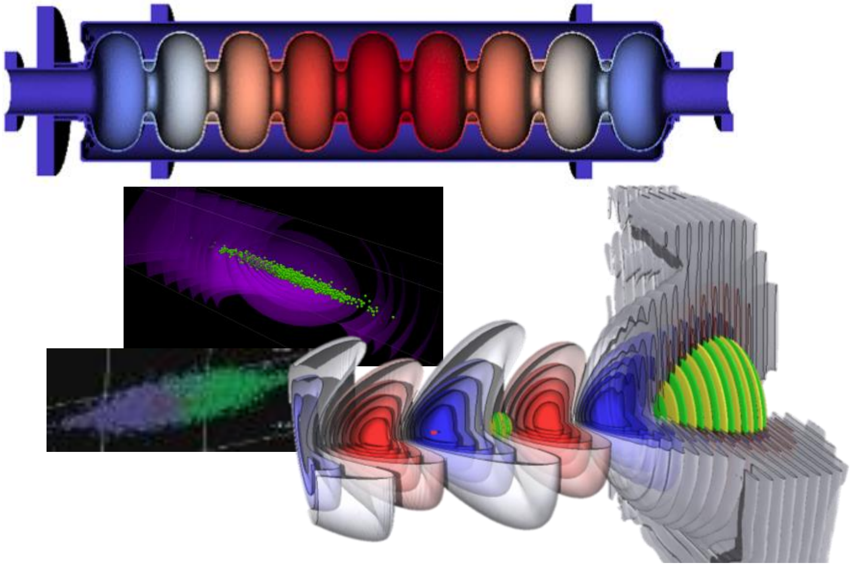
Computer modeling is key to progress



Essential for increasing performance, bringing size and cost down:

- **optimizing** existing accelerators,
- **cost effective** design,
- **game changing** technologies.

Computer modeling is key to progress



Essential for increasing performance, bringing size and cost down:

- **optimizing** existing accelerators,
- **cost effective** design,
- **game changing** technologies.

- **Trend requires team work**

  increasingly complex accelerators call for

  increasingly sophisticated simulation software

- Current situation is **inefficient**
  - numerous codes within projects with little coordination or reuse
  - **no dedicated funding** for development, support & training

  ➔ especially problematic for codes with growing popularity

Example of duplication in beam dynamics codes

Codes section from Accelerator Handbook (A. Chao, 2013)

Beam Dynamics Codes:

(Below, PIC refers to codes with particle-in-cell space-charge capability.)

Code	URL or Contact	Description/Comments
ASTRA	tesla.desy.de/~meykopff	3D parallel, general charged particle beams incl. space charge
AT	sourceforge.net/projects/atcollab/	Accelerator Toolbox
BETACOOL	betacool.jinr.ru	Long term beam dynamics: ECOOL, IBS, internal target
Bmad, Tao	www.lns.cornell.edu/~dcs/bmad/	General purpose toolbox library + driver program
COSY INFINITY	www.cosyinfinity.org	Arbitrary-order beam optics code
CSRTrack	www.desy.de/xfel-beam/csrtrack	3D parallel PIC; includes CSR; mainly for e^- dynamics
Elegant/SDDS suite	aps.anl.gov/elegant.html	parallel; track, optimize; errors; wakes; CSR
ESME	www-ap.fnal.gov/ESME	Longitudinal tracking in rings
HOMDYN	Massimo.Ferrario@LNF.INFN.IT	Envelope equations, analytic space charge and wake fields
IMPACT code suite	amac.lbl.gov	3D parallel multi-charge PIC for linacs and rings
LAACG code suite	laacg.lanl.gov	Includes PARMILA, PARMELA, PARMTEQ, TRACE2D/3D
LiTrack	www.slac.stanford.edu/~emma/	Longitudinal linac dynamics; wakes; GUI-based; error studies
LOCO	safranek@slac.stanford.edu	Analysis of optics of storage rings; runs under matlab
LUCRETIA	www.slac.stanford.edu/accel/ilc/codes	Matlab-based toolbox for simulation of single-pass e^- systems
MaryLie	www.physics.umd.edu/dsat	Lie algebraic code for maps, orbits, moments, fitting, analysis
MaryLie/IMPACT	amac.lbl.gov	3D parallel PIC; MaryLie optics + IMPACT space charge
MAD-X	mad.web.cern.ch/mad	General purpose beam optics
MERLIN	www.desy.de/~merlin	C++ class library for charged particle accelerator simulation
OPAL	amas.web.psi.ch	3D parallel PIC; cyclotrons, FFAGs, linacs; particle-matter int.
ORBIT	jzh@ornl.gov	Collective beam dynamics in rings and transport lines
PATH	Alessandra.Lombardi@cern.ch	3D PIC; linacs and transfer lines; matching and error studies
SAD	acc-physics.kek.jp/SAD/sad.html	Design, simulation, online modeling & control
SIMBAD	agsrhichome.bnl.gov/People/luccio	3D parallel PIC; mainly for hadron synchrotrons, storage rings
SIXTRACK	frs.home.cern.ch/frs/	Single particle optics; long term tracking in LHC
STRUCT	www-ap.fnal.gov/users/drozhdin	Long term tracking w/ emphasis on collimators
Synergia	https://compacc.fnal.gov/projects	3d parallel PIC: space charge, nonlinear tracking and wakes
TESLA	lyyang@bnl.gov	Parallel; tracking; analysis; optimization
TRACK	www.phy.anl.gov/atlas/TRACK	3D parallel PIC, mainly for ion or electron linacs
LIBTRACY	libtracy.sourceforge.net/	Library for beam dynamics simulation
TREDI	www.tredi.enea.it	3D parallel PIC; point-to-point Lienard-Wiechert
UAL	code.google.com/p/ual/	Unified Accelerator Libraries
WARP	DPGrote@lbl.gov	3D parallel ES and EM PIC with accelerator models
ZGOUBI	sourceforge.net/projects/zgoubi/	Magnetic optics; spin; sync radiation; in-flight decay

Example of duplication in beam dynamics codes

Codes section from Accelerator Handbook (A. Chao, 2013)

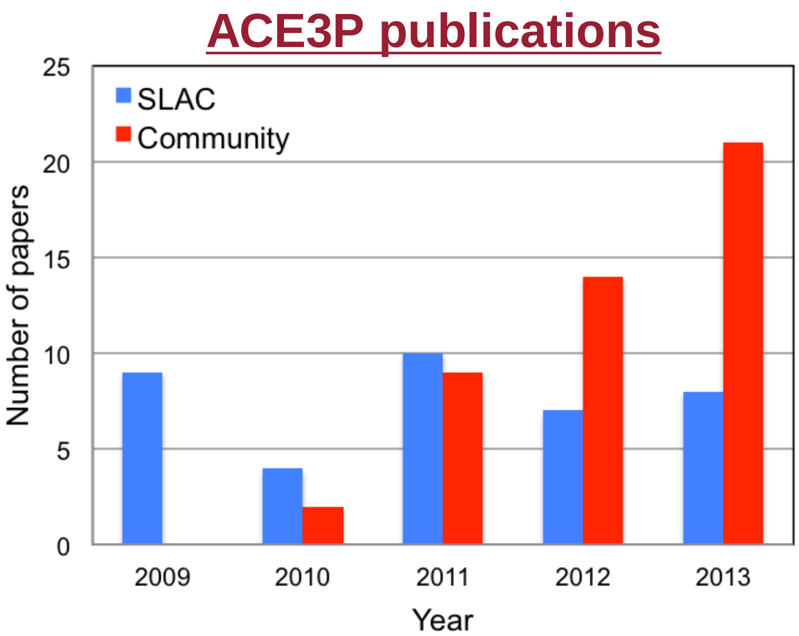
Beam Dynamics Codes:

(Below, PIC refers to codes with particle-in-cell space-charge capability.)

Code	URL or Contact	Description/Comments
ASTRA	tesla.desy.de/~meykopff	3D parallel, general charged particle beams incl. space charge
AT	sourceforge.net/projects/atcollab/	Accelerator Toolbox
BETACOOL	betacool.jinr.ru	Long term beam dynamics: ECOOL, IBS, internal target
Bmad, Tao	www.lns.cornell.edu/~dcs/bmad/	General purpose toolbox library + driver program
COSY INFINITY	www.cosyinfinity.org	Arbitrary-order beam optics code
CSRTrack	www.desy.de/xfel-beam/csrtrack	3D parallel PIC; includes CSR; mainly for e^- dynamics
Elegant/SDDS suite	aps.anl.gov/elegant.html	parallel; track, optimize; errors; wakes; CSR
ESME	www-ap.fnal.gov/ESME	Longitudinal tracking in rings
HOMDYN	Massimo.Ferrario@LNF.INFN.IT	Envelope equations, analytic space charge and wake fields
IMPACT code suite	amac.lbl.gov	3D parallel multi-charge PIC for linacs and rings
LAACG code suite	laacg.lanl.gov	Includes PARMILA, PARMELA, PARMTEQ, TRACE2D/3D
LiTrack	www.slac.stanford.edu/~emma/	Longitudinal linac dynamics; wakes; GUI-based; error studies
LOCO	safranek@slac.stanford.edu	Analysis of optics of storage rings; runs under matlab
LUCRETIA	www.slac.stanford.edu/accel/ilc/codes	Matlab-based toolbox for simulation of single-pass e^- systems
MaryLie	www.physics.umd.edu/dsat	Lie algebraic code for maps, orbits, moments, fitting, analysis
MaryLie/IMPACT	amac.lbl.gov	3D parallel PIC; MaryLie optics + IMPACT space charge
MAD-X	mad.web.cern.ch/mad	General purpose beam optics
MERLIN	www.desy.de/~merlin	C++ class library for charged particle accelerator simulation
OPAL	amas.web.psi.ch	3D parallel PIC; cyclotrons, FFAGs, linacs; particle-matter int.
ORBIT	jzh@ornl.gov	Collective beam dynamics in rings and transport lines
PATH	Alessandra.Lombardi@cern.ch	3D PIC; linacs and transfer lines; matching and error studies
SAD	acc-physics.kek.jp/SAD/sad.html	Design, simulation, online modeling & control
SIMBAD	agsrhichome.bnl.gov/People/luccio	3D parallel PIC; mainly for hadron synchrotrons, storage rings
SIXTRACK	frs.home.cern.ch/frs/	Single particle optics; long term tracking in LHC
STRUCT	www-ap.fnal.gov/users/drozhdin	Long term tracking w/ emphasis on collimators
Synergia	https://compacc.fnal.gov/projects	3d parallel PIC; space charge, nonlinear tracking and wakes
TESLA	lyyang@bnl.gov	Parallel; tracking; analysis; optimization
TRACK	www.phy.anl.gov/atlas/TRACK	3D parallel PIC; mainly for ion or electron linacs
LIBTRACY	libtracy.sourceforge.net/	Library for beam dynamics simulation
TREDI	www.tredi.enea.it	3D parallel PIC; point-to-point Lienard-Wiechert
UAL	code.google.com/p/ual/	Unified Accelerator Libraries
WARP	DPGrote@lbl.gov	3D parallel ES and EM PIC with accelerator models
ZGOUBI	sourceforge.net/projects/zgoubi/	Magnetic optics; spin; sync radiation; in-flight decay

SLAC ACE3P supports large user community

- **User community**
  – **>50 active users** in labs, universities & industry worldwide
  – growing # of papers from community of users ➔



- **User support necessitates sustained effort**
  – Code **workshops** at SLAC (CW09, CW10, CW11 & CW14) and conf. (NAPAC-13)
  – **Dedicated website** (w/ online tutorials and doc.)
    https://confluence.slac.stanford.edu/display/AdvComp/Materials+for+cw11
  – Phone calls and email exchanges (~20/month)
  – Personal visits to SLAC

Berkeley Lab Accelerator Simulation Toolkit has a worldwide user base

BERKELEY LAB

BLAST

- B – BeamBeam3D
- I – Impact
- P – Posinst
- W – Warp

United States

1. ANL (B,I,P)
2. BNL (B,I,P,W)
3. Cornell (I,P)
4. FNAL (B,I,P,W)
5. ISU (I)
6. Jlab (B,I,P)
7. LANL (I,P)
8. LBNL (B,I,P,W)
9. LLNL (W)
10. MSU (I,W)
11. NIU (I,W)
12. ODU (I)
13. ORNL (I,P)
14. SLAC (I,P,W)
15. Stanford (I)
16. Tech-X (P)
17. Texas A&M (I)
18. U. Chicago (I)
19. UM (W)
20. UMD (W)
21. UW (I)
22. UCLA (I)
23. WSU (W)
24. Yale U (B,I)

Europe/Asia

1. ASLS (I)
2. CERN (P,W)
3. CIAE (I)
4. DESY (I,W)
5. Diamond (I)
6. ESS (I)
7. Fermi/Elettra (I)
8. Frankfurt (I)
9. GSI (I,W)
10. Hiroshima U. (W)
11. Hong Kong U. (W)
12. IBS (I)
13. IHEP (I,P)
14. IMPCAS (I)
15. IRE (I)
16. KAERI (I)
17. KEK (I)
18. Mumbai Univ. (I)
19. PAL (I)
20. Peking Univ. (I)
21. PSI (I)
22. RRCAT (I)
23. RAL (I)
24. SINAP (I)
25. Technion (W)
26. USTC (I)

Over past year, code developers responded to >500 emails received from >40 research institutes/universities & list is growing.

Mostly on overhead with little dedicated funding for support.

Key roles & needs recognized in P5 report

- **Accelerator modeling contributes to two enabling technologies**:
  - ***Accelerator Research***:
    - "The future of **particle physics depends critically** on **transformational accelerator R&D** to enable new capabilities and to advance existing technologies at lower cost. "
  - ***Computing***:
    - "The use of **high-performance computing**, combined with **new algorithms**, is advancing full 3-D simulations at realistic beam intensities of nearly **all types of accelerators**."
    - "This will enable **"virtual prototyping"** of accel. components on a larger scale than is currently possible."

- **Recommendation 29:**

"**Strengthen** the **global cooperation** … to address **computing** and **scientific software** needs, and provide **efficient training** in **next-generation hardware** ...
Investigate models for the **development** and **maintenance** of major software within and across research areas…"

P5 report reinforces conclusions from from Snowmass & HEP computing topical panel (2013)

- **"increased coordination** of modeling efforts"
- **"dedicated support** of code **modernization**, **maintenance** & **dissemination**"
- "increase emphasis on use & development of **common tools**"
- "better **user support**"
- "more **training** in HEP computational physics"
- "**HEP distributed center** for computational excellence (single point-of-contact, cross-cutting activities)"

Consensus that there are issues:

lack of cohesion, support, training….

Question: how do we solve it?

Need of solution for non-disruptive integration

Significant investments of HEP into existing pool of codes:

- essential to **minimize disruptions** to developers and users,
- while **enabling interoperability** and **expandability**.

Challenges:

Need of solution for non-disruptive integration

Significant investments of HEP into existing pool of codes:

- essential to **minimize disruptions** to developers and users,
- while **enabling interoperability** and **expandability**.

Challenges:

Technical

- programming languages
- data formats, parallelism
- code architectures
- open vs proprietary sources
- keep creativity

Human

- changing habits is hard
- different visions
- (re)build trust
- corporatism/rivalry
- recognition
- distance

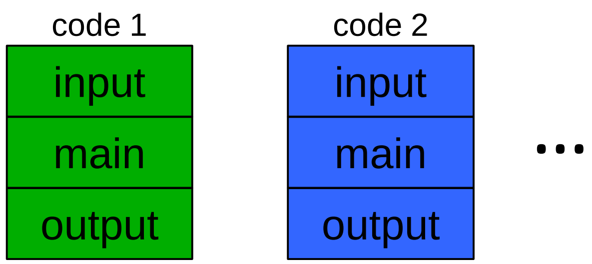
Mitigation of difficulties through adiabatic transition

Mitigation of difficulties through adiabatic transition

Existing set of separate codes → **ecosystem** of **interconnected codes**

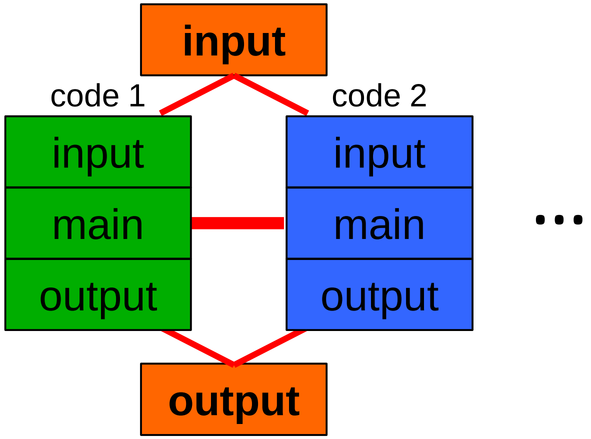
Mitigation of difficulties through adiabatic transition

Existing set of separate codes → **ecosystem** of **interconnected codes**



Mitigation of difficulties through adiabatic transition

Existing set of separate codes → **ecosystem** of **interconnected codes**

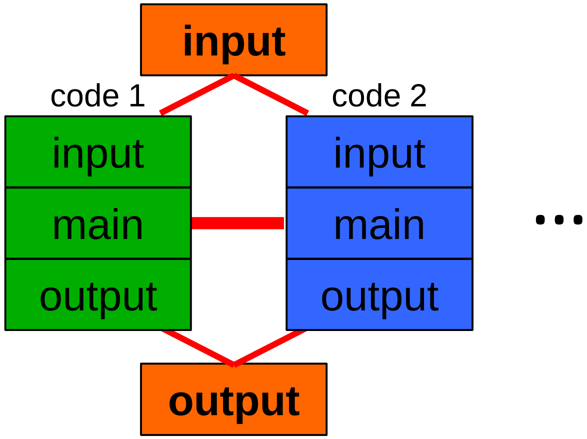


Bridge codes to enable:

- **unified** input/output interface
- **sharing** of functionalities
- **collaborative** development of common units
- “natural” **down selection** of modules
- devel. & users playing **Lego** with “code genes”

Mitigation of difficulties through adiabatic transition

Existing set of separate codes → **ecosystem** of **interconnected codes**



Bridge codes to enable:

- **unified** input/output interface
- **sharing** of functionalities
- **collaborative** development of common units
- “natural” **down selection** of modules
- devel. & users playing **Lego** with “code genes”

Common modules in libraries of compiled C, C++ or FORTRAN

Unified I/O and framework in Python:

- Python scripting language has unique attributes:
  - rapid development and prototyping of scientific applications
    on par with e.g. Maple, Matlab (which it is often supplanting)
  - is expandable and couples to FORTRAN, C and C++

New initiative:

Consortium for
Advanced
Modeling of
Particle
Accelerators

CAMPA

BERKELEY LAB
BLAST
(Warp, IMPACT, BeamBeam3D, Posinst)

Fermilab
SYNERGIA
(space-charge, wakes, e-cloud, beam-beam...)

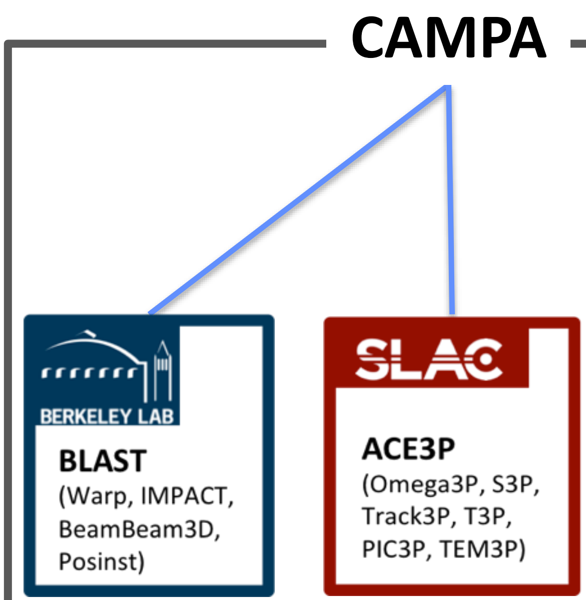
SLAC
ACE3P
(Omega3P, S3P, Track3P, T3P, PIC3P, TEM3P)

Points of contact:

LBNL: J.-L. Vay, J. Qiang
SLAC: C.-K. Ng, Z. Li
FNAL: J. Amundson, E.G. Stern

CAMPA started as LBNL-SLAC collaboration

x



DOE-HEP

Initial investment by DOE-HEP:

- $250k in FY14 for LBNL-SLAC

CAMPA now

x

CAMPA

DOE-HEP

BERKELEY LAB

BLAST
(Warp, IMPACT, BeamBeam3D, Posinst)

SLAC

ACE3P
(Omega3P, S3P, Track3P, T3P, PIC3P, TEM3P)

Fermilab

SYNERGIA
(space-charge, wakes, e-cloud, beam-beam...)

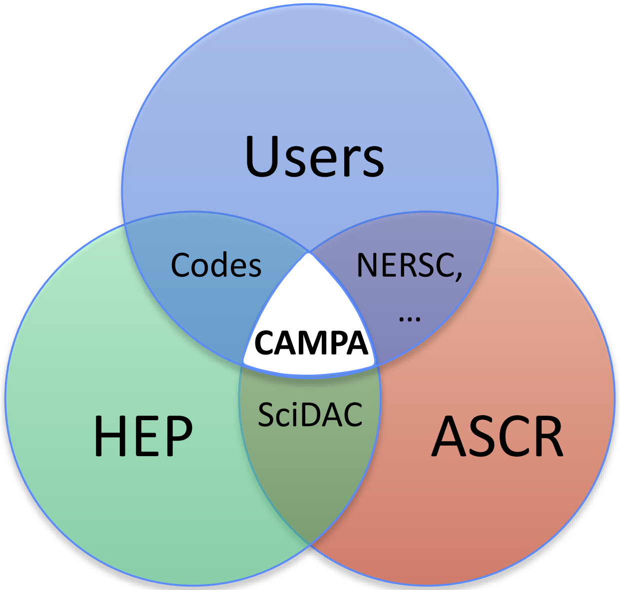
Initial investment by DOE-HEP:

- $500k in FY15 for LBNL-SLAC-FNAL

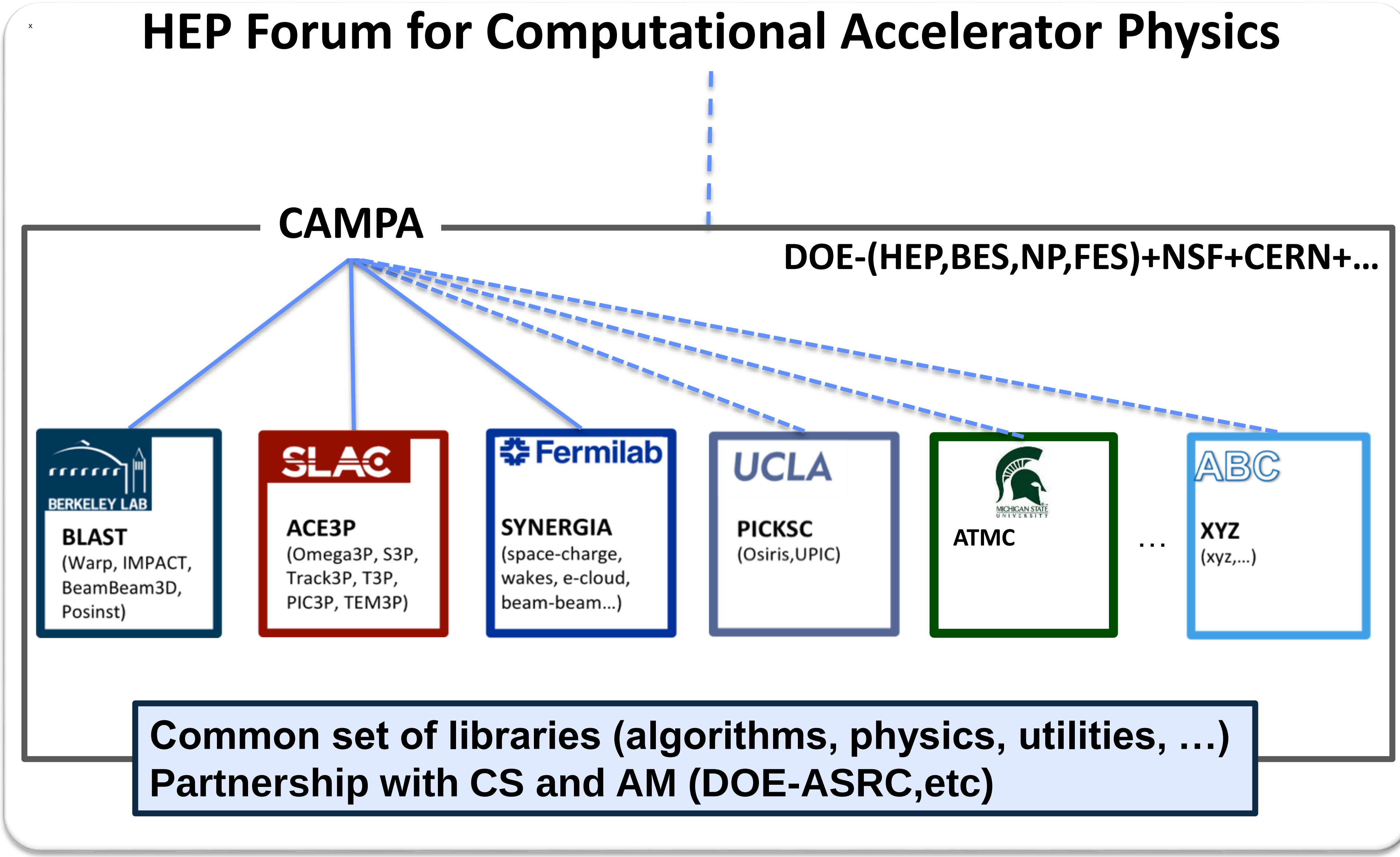
CAMPA's mission to address mid/long term needs

Mission:

- **develop**, **maintain**, **distribute** & **support** an **integrated** suite of state-of-the-art accelerator computer codes
    - **BLAST**, **ACE3P**, **SYNERGIA**
- promote **collaboration** & **re-use** of codes & data through **common** interfaces, data standards, visualization and analysis capabilities;
- use codes to **advance accelerator science** through **advanced computation**
- **train** new generation in accelerator modeling on the latest hardware
- at the **nexus** of physics, computing and users



Possible evolution of CAMPA



Value added to science, agencies, users & developers

- **Accelerator S. & T.**
  - offers path toward **game changer modeling tools**
    - virtual prototyping/experiments
    - online modeling for realtime feedback
  - ➔ **speed up design** and **innovation**

Value added to science, agencies, users & developers

- **Accelerator S. & T.**
  - offers path toward **game changer modeling tools**
    - virtual prototyping/experiments
    - online modeling for realtime feedback
  - ➔ **speed up design** and **innovation**

- **DOE**
  - **accelerate discovery**
    ➔ higher return on investment
  - **single point of contact** for modeling tool funding

Value added to science, agencies, users & developers

Accelerator S. & T.

- offers path toward **game changer modeling tools**
  - virtual prototyping/experiments
  - online modeling for realtime feedback

➔ **speed up design** and **innovation**

DOE

- **accelerate discovery**

  ➔ higher return on investment
- **single point of contact** for modeling tool funding

Code users

- **integrated**, **comprehensive** & **more capable** (multiphysics/multiscale) software
- **single point of contact** for simulation tool solutions

Value added to science, agencies, users & developers

Accelerator S. & T.

- offers path toward **game changer modeling tools**
  - virtual prototyping/experiments
  - online modeling for realtime feedback

➔ **speed up design** and **innovation**

DOE

- **accelerate discovery**
  ➔ higher return on investment
- **single point of contact** for modeling tool funding

Code users

- **integrated**, **comprehensive** & **more capable** (multiphysics/multiscale) software
- **single point of contact** for simulation tool solutions

Code developers

- **dedicated funding** for user support, algorithmic, code implementation & maintenance
- **recognition** for acc. software development,
- a **carrier path**

New environment creates opportunities

New environment creates opportunities

Novel architectures + **integrated simulation tools** can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**

New environment creates opportunities

Requires team work!!

Novel architectures **+ integrated simulation tools** can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

→ mitigating **budget constraints**

New environment creates opportunities

Status quo is risky

Requires team work!!

Novel architectures + integrated simulation tools can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**

New environment creates opportunities

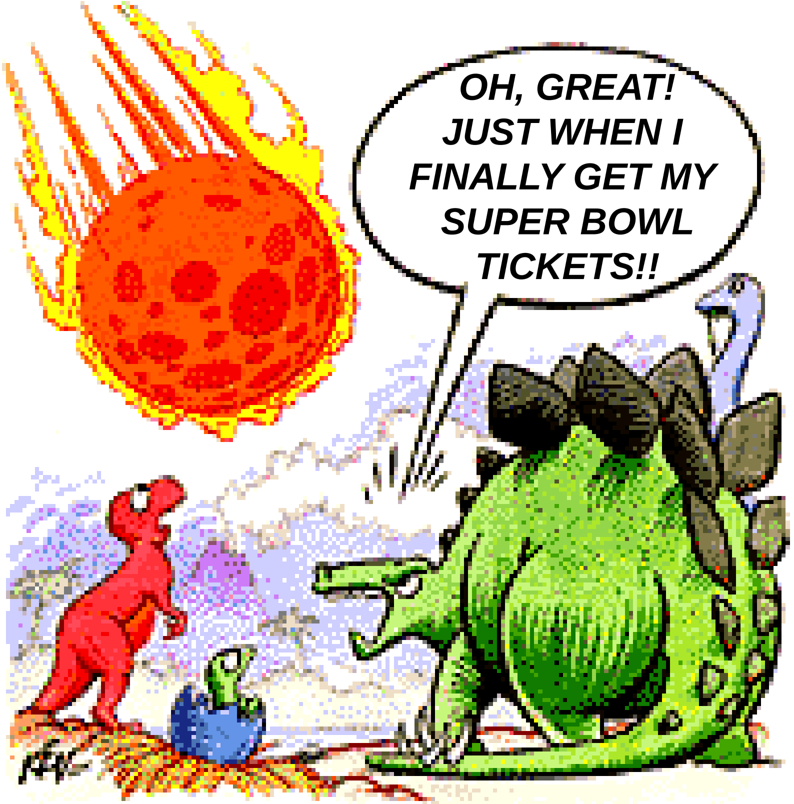
***Status quo** is risky*

Requires team work!!

Novel architectures + integrated simulation tools can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**



New environment creates opportunities

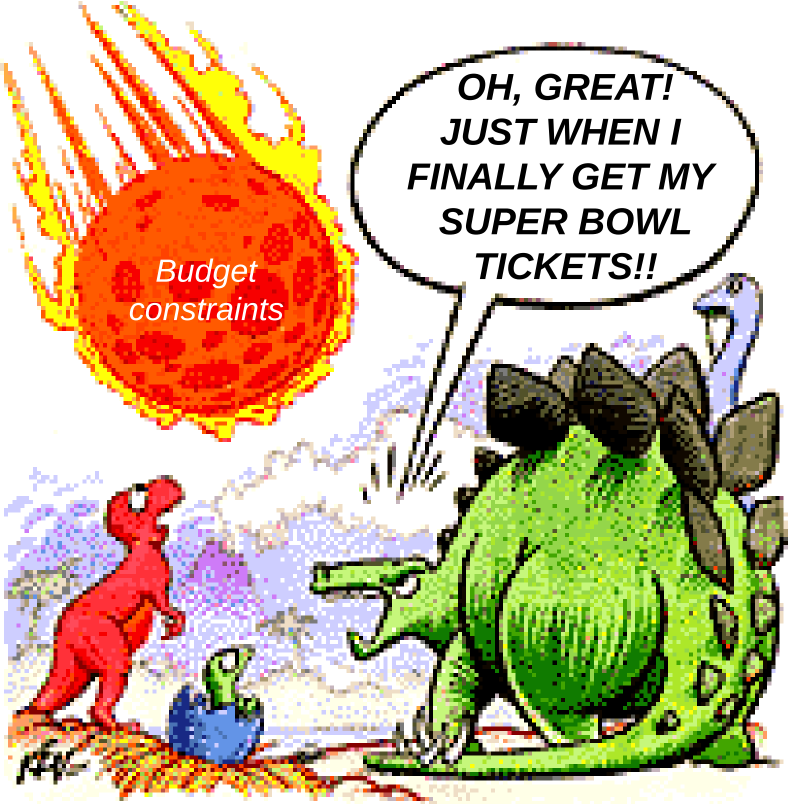
Status quo is risky

Requires team work!!

Novel architectures + integrated simulation tools can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**



New environment creates opportunities

Status quo is risky

Requires team work!!

Novel architectures + integrated simulation tools can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**

New environment creates opportunities

Novel architectures + **integrated simulation tools** can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

Requires team work!!

➔ mitigating **budget constraints**

***Status quo** is risky*

New environment creates opportunities

Requires team work!!

Status quo *is risky*

Novel architectures **+ integrated simulation tools** can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**

New environment creates opportunities

Status quo is risky

Requires team work!!

Novel architectures + integrated simulation tools can enable:

- virtual prototyping/experiments
- online tools for realtime feedback

➔ mitigating **budget constraints**

Community modeling effort will enable to adapt & thrive!!!

Thank you for your attention