Boosted frame PIC simulations of LWFA: Towards the energy frontier

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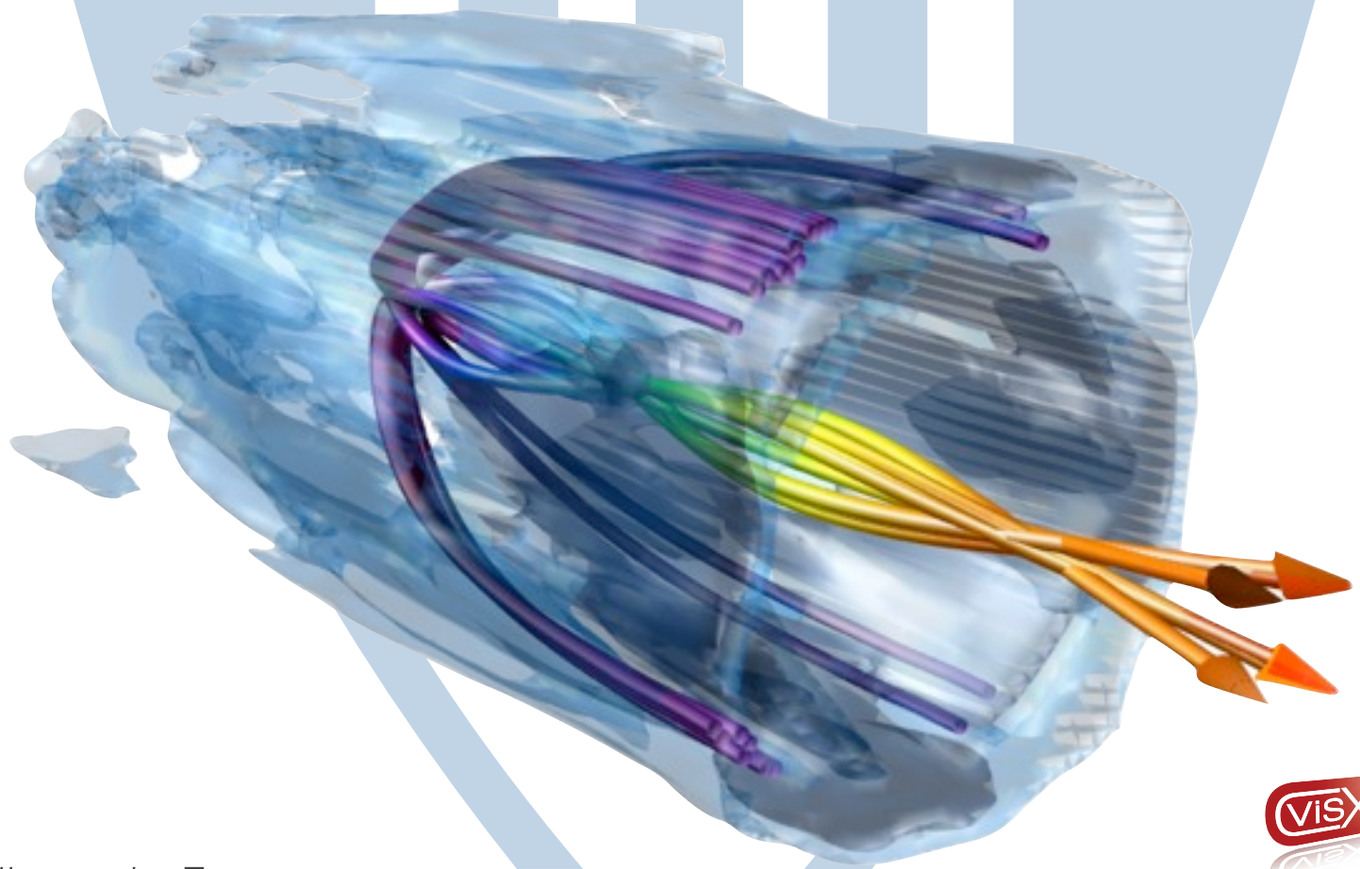

Motivation: Parameter range for a 300J laser

	Self-guiding		External-guiding	
Laser	Self Injection I*	Self Injection II**	Self Injection**	External Injection**
a0	43	5.8	3.5	2
Spot [μm]	9	50	70	101
Duration [fs]	30	110	155	224
Plasma				
Density [cm^{-3}]	1.5×10^{19}	2.7×10^{17}	8.2×10^{16}	2.2×10^{16}
Length [cm]	0.25	22	100	500
e- Bunch				
Energy [GeV]	**4**	**13**	**25**	**53**
Charge [nC]	14	2	1.8	1.5

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** W. Lu *et al.* PR-STAB (2007)

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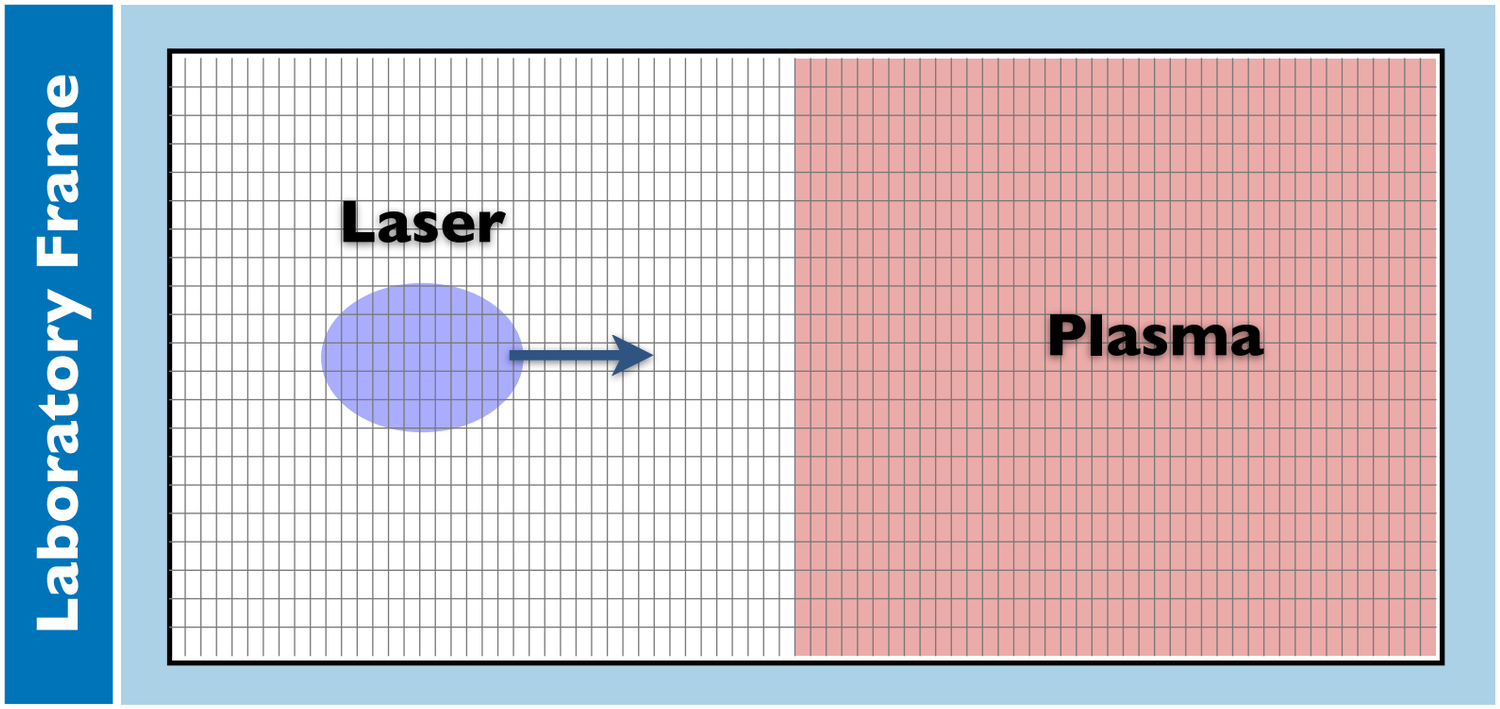
Boosted Frames in LWFA simulations

Grid resolution in Laboratory and Boosted frame



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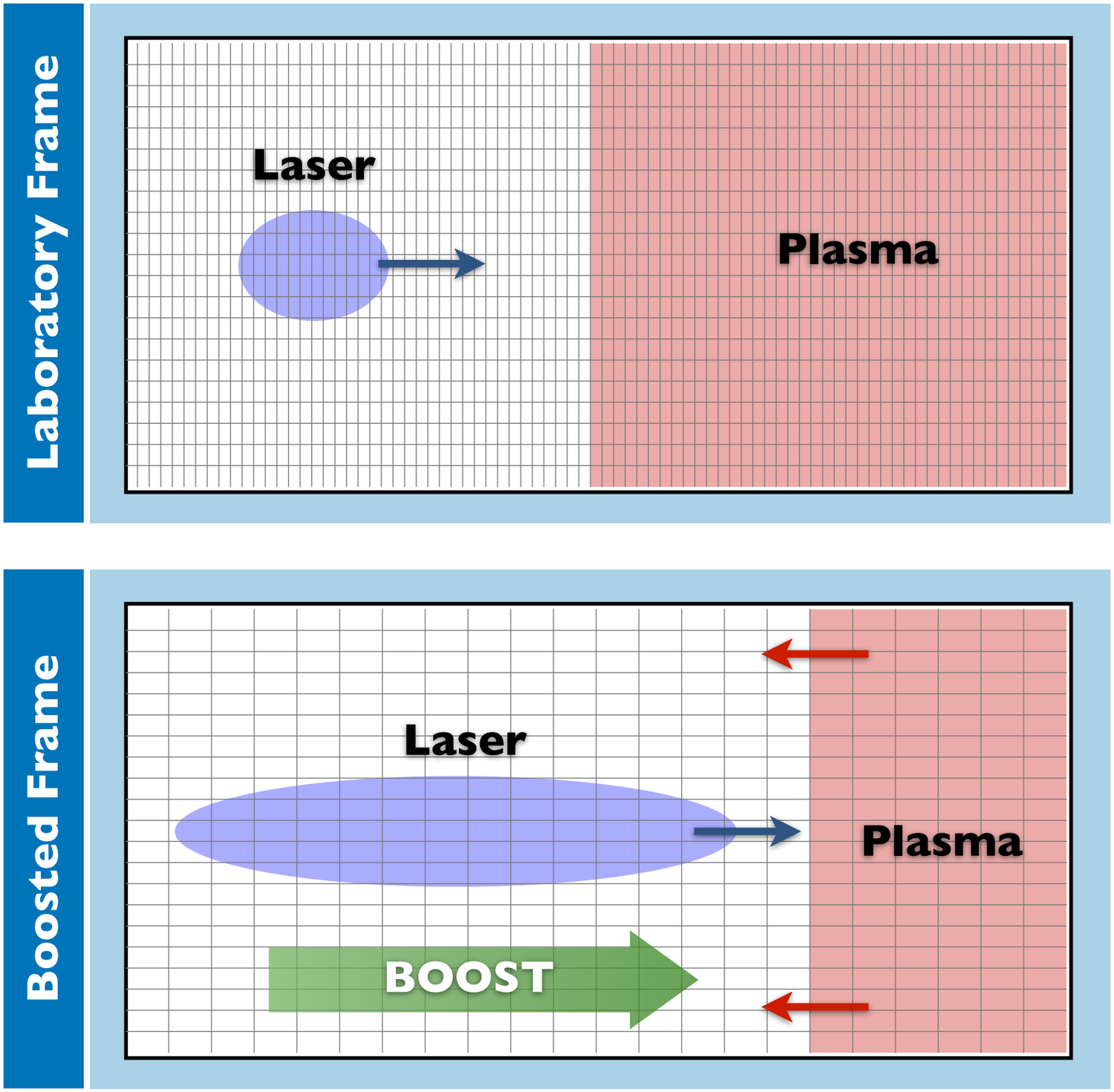

Boosted Frames in LWFA simulations

UCLA

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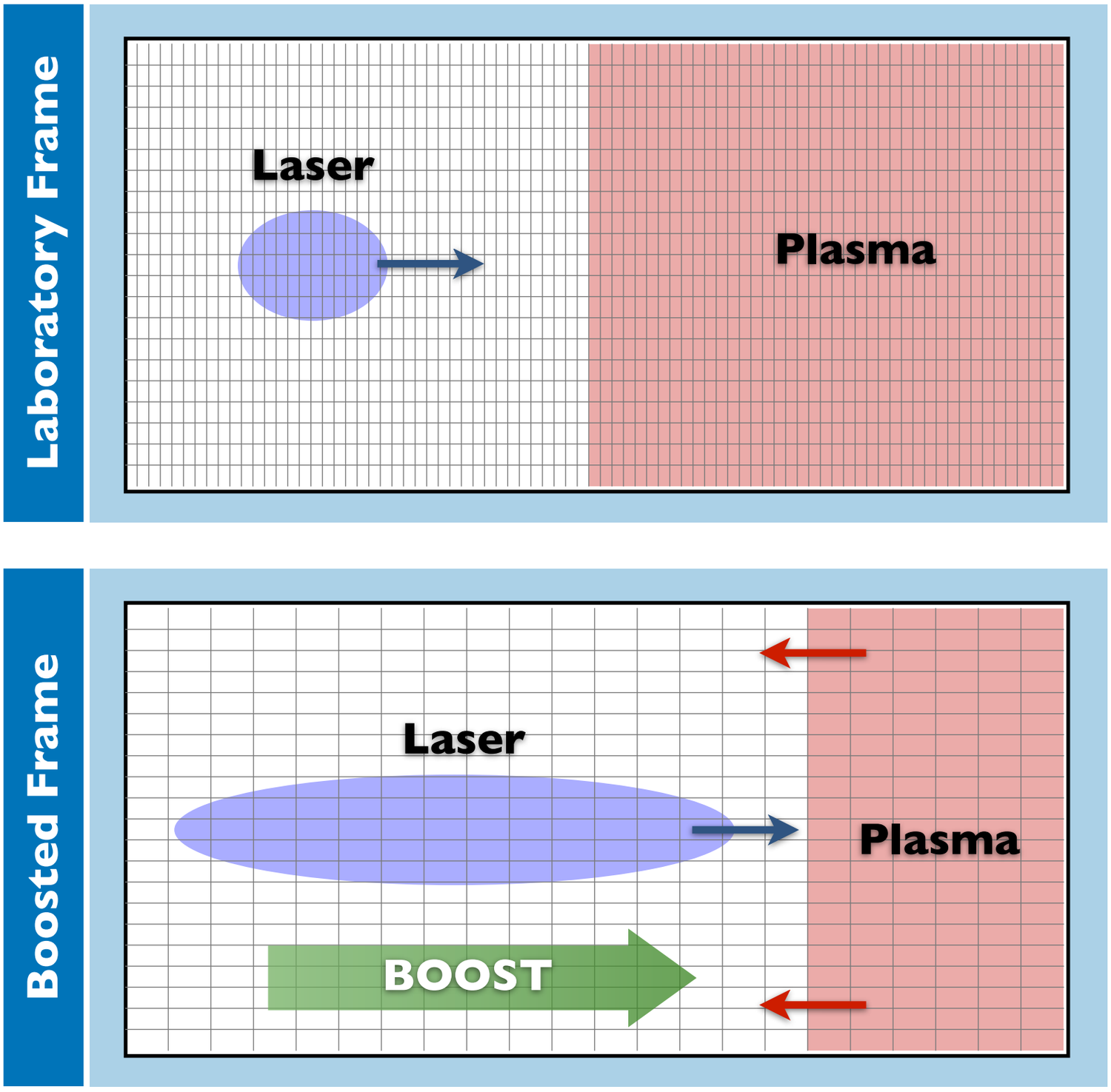


Resolution gains

Particles

Resolution $\beta)$

Plasma contraction γ

Moving window in Lab Frame

Time steps

Time step $\gamma(1+\beta)$

Total time $\gamma(1+\beta)$

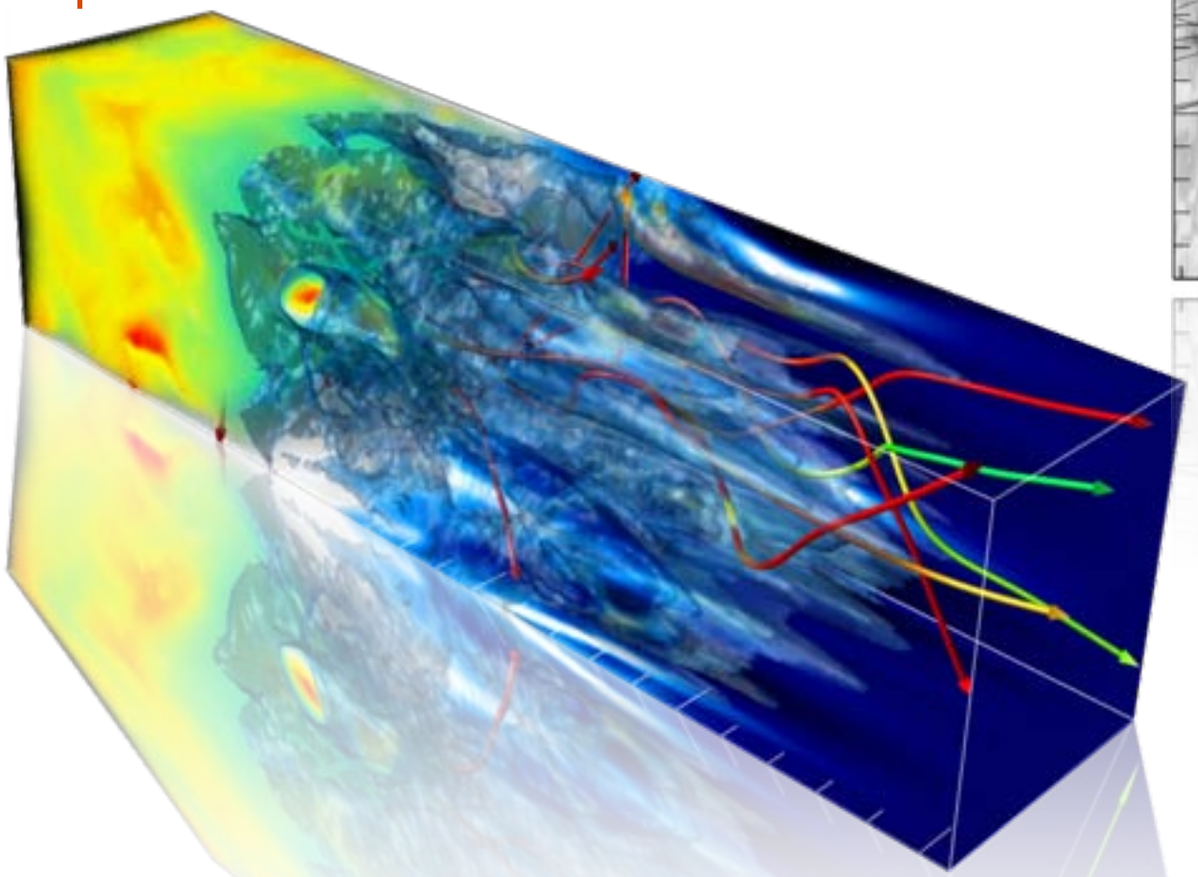
Total $\gamma^2(1+\beta)^2$

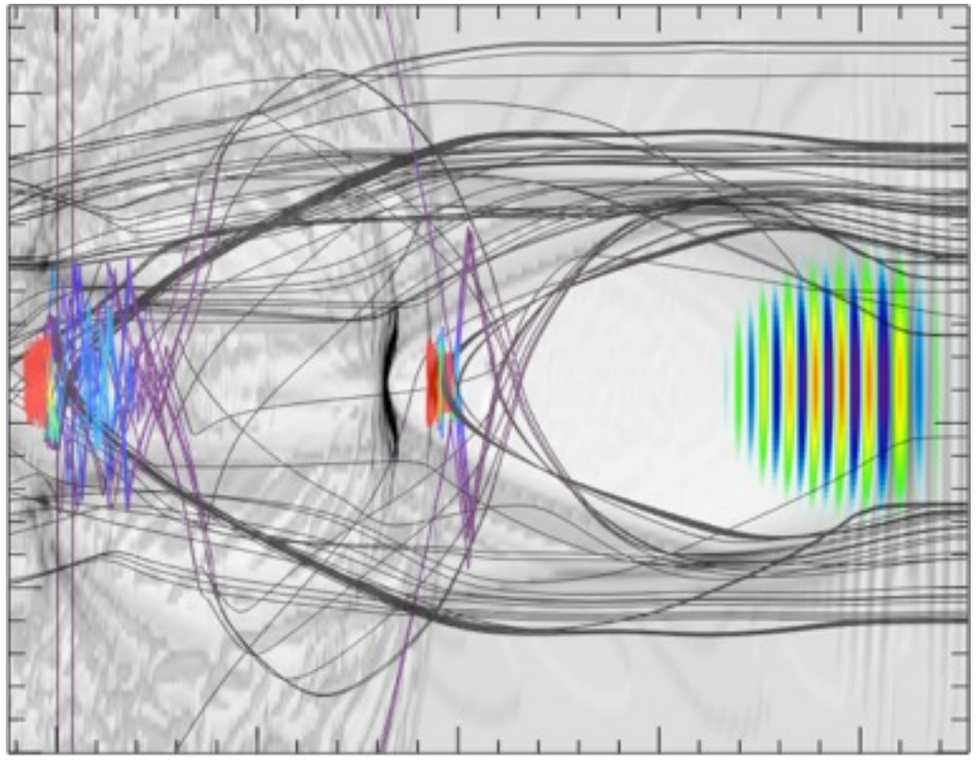
OSIRIS 2.0

osiris
v2.0

osiris framework

- Massivelly Parallel, Fully Relativistic Particle-in-Cell (PIC) Code
- Visualization and Data Analysis Infrastructure
- Developed by the osiris.consortium
  ⇒ UCLA + IST





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Frank Tsung: tsung@physics.ucla.edu

http://cfp.ist.utl.pt/golp/epp/
http://exodus.physics.ucla.edu/

New Features in v2.0

- Bessel Beams
- Binary Collision Module
- Tunnel (ADK) and Impact Ionization
- Dynamic Load Balancing
- PML absorbing BC
- Optimized higher order splines
- Parallel I/O (HDF5)
- Boosted frame in 1/2/3D

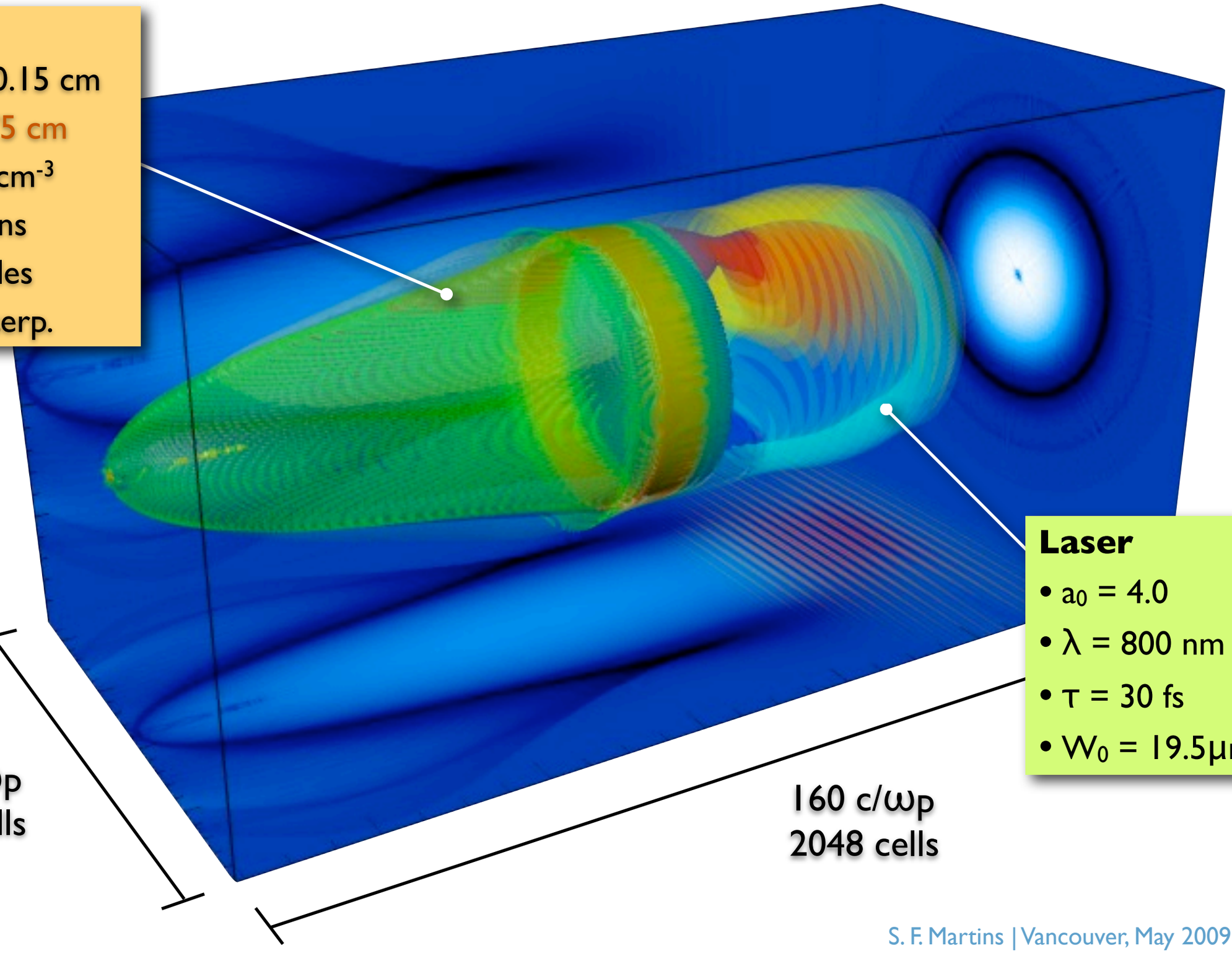
Benchmark with OSIRIS Lab

UCLA

Boosted frame simulation apparatus (γ = 5)

Plasma

- Boost length: 0.15 cm
- Lab length: 0.75 cm
- n_e = 1.5x10^{18} cm^{-3}
- Electrons + ions
- 2.2x10^9 particles
- Quad. part. interp.



32 c/ωp
256 cells

32 c/ωp
256 cells

160 c/ωp
2048 cells

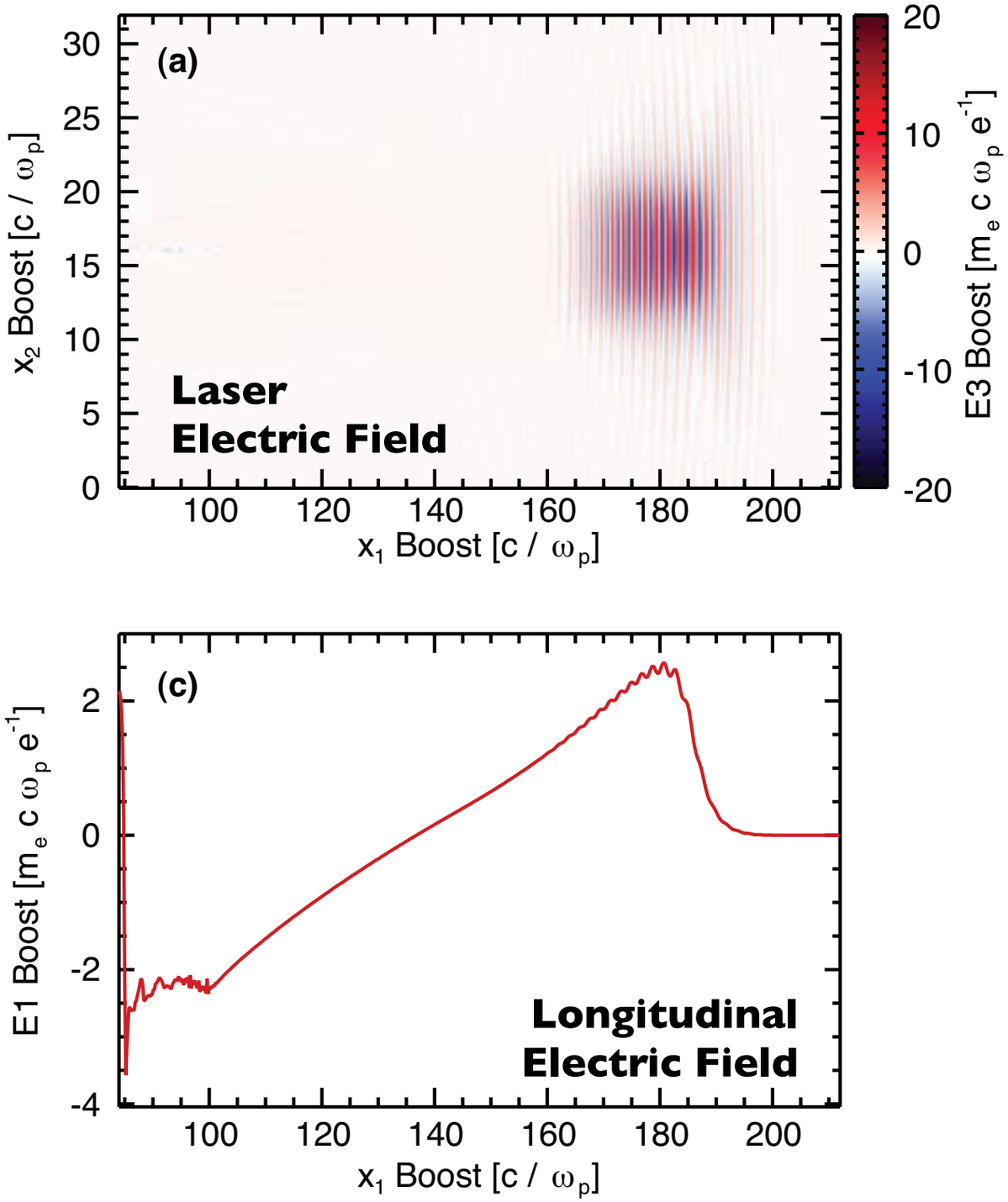
Laser

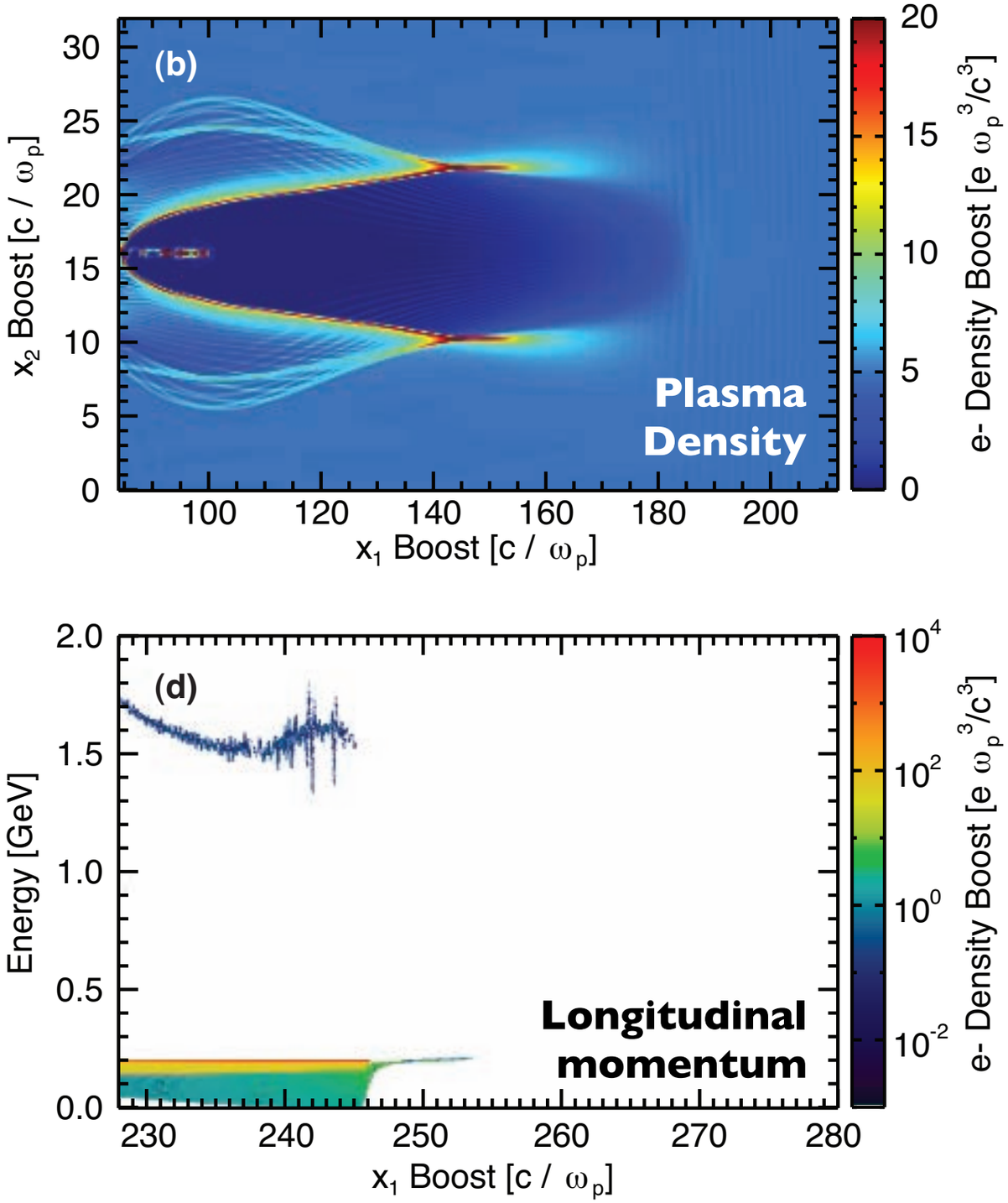
- a_0 = 4.0
- λ = 800 nm
- τ = 30 fs
- W_0 = 19.5μm

Benchmark with OSIRIS Lab

UCLA

Main quantities in Boosted frame

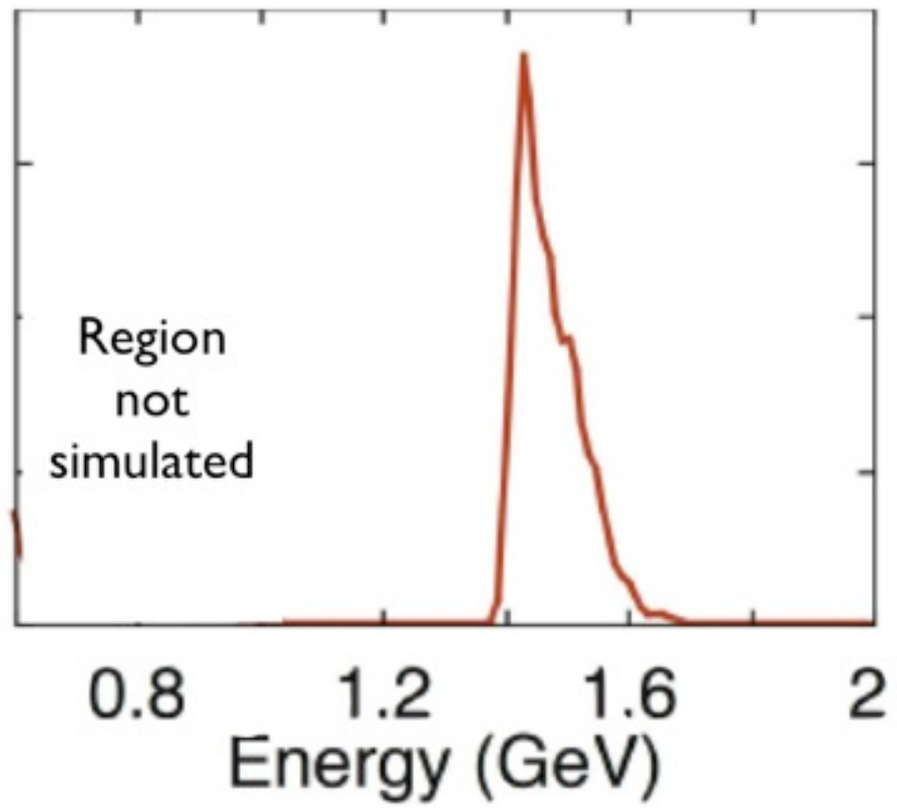




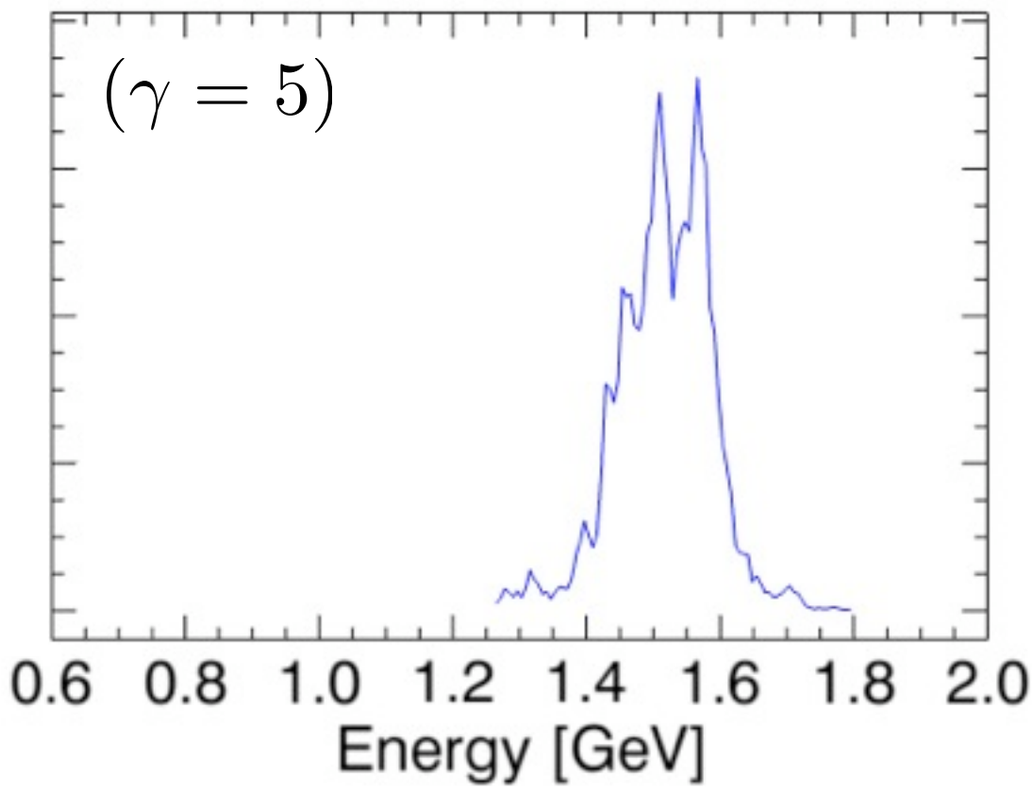
Benchmark with OSIRIS Lab

Energy spectrum comparison

Laboratory Frame



Boosted Frame



	Theory	Laboratory	Boosted
Bunch Energy (GeV)	**1.6**	1.5	**1.5**
Injected Charge (nC)	**0.6** (max)	0.3	**0.6-1.0**

Benchmark with OSIRIS Lab

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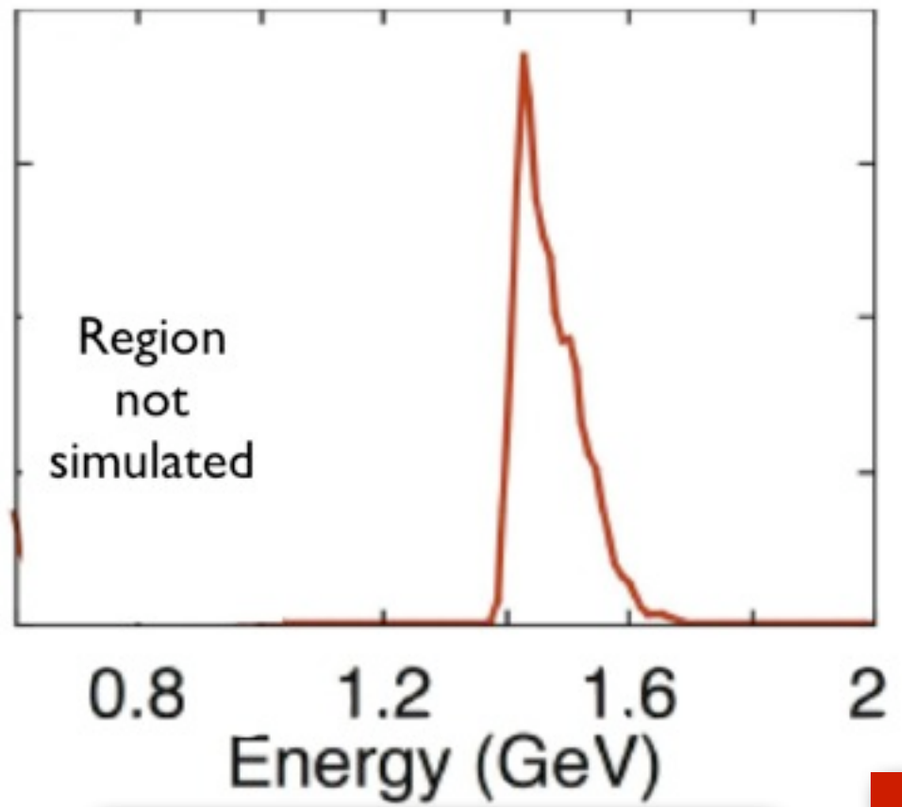
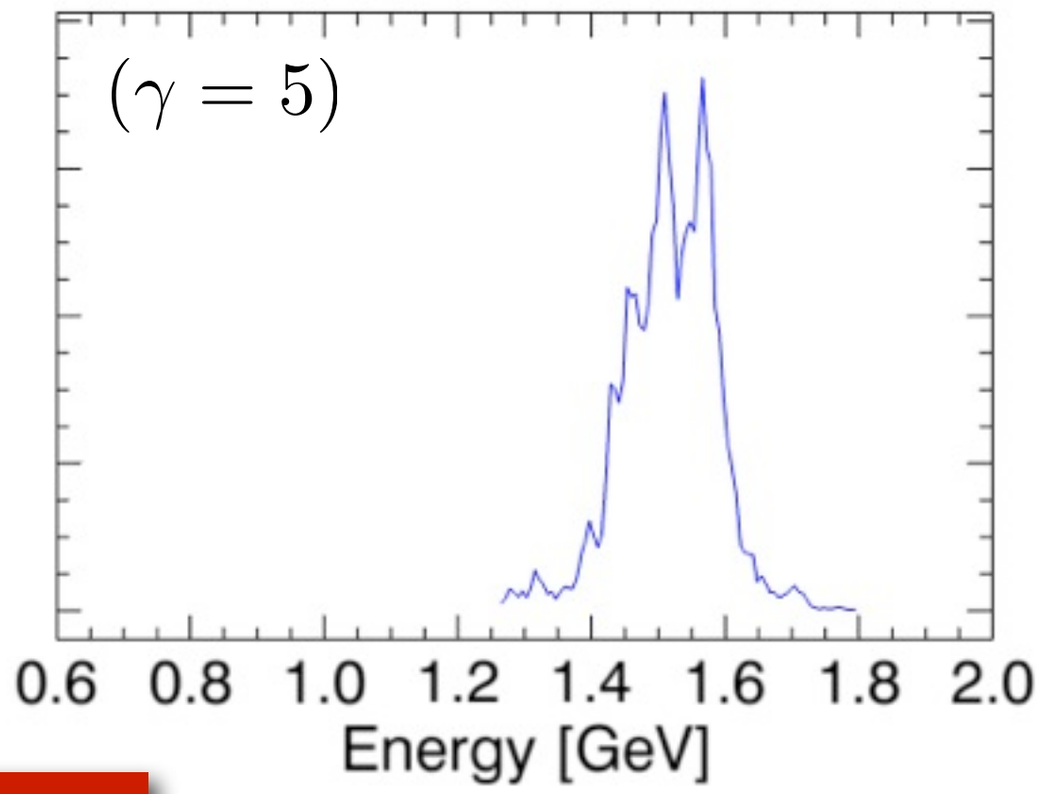


~21 days in 100 CPUs
(50,000 CPU.h)

Boosted Frame



~1 day in 100 CPUs
(2,400 CPU.h)

20x faster in boosted frame

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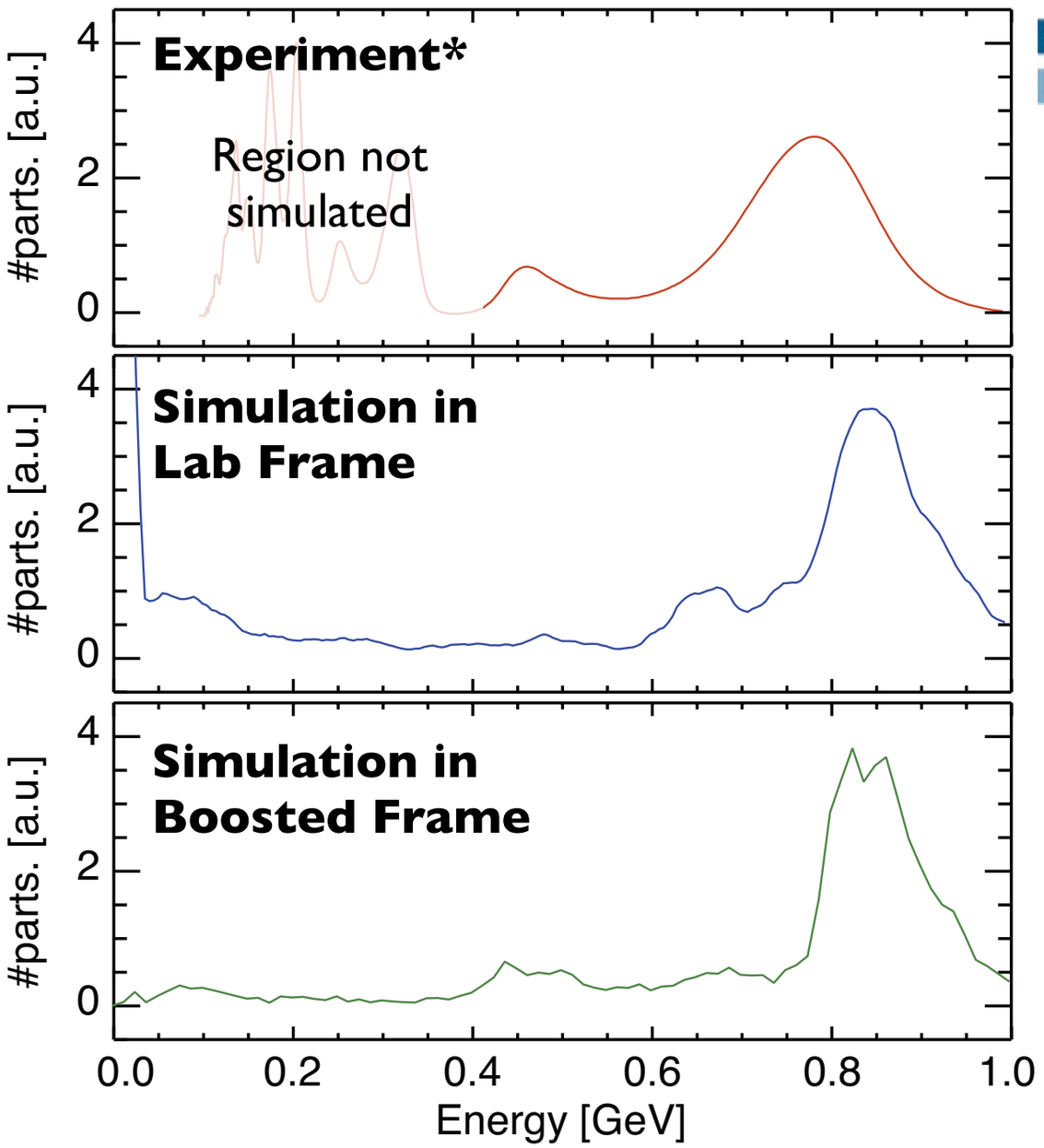
Benchmark with experiment

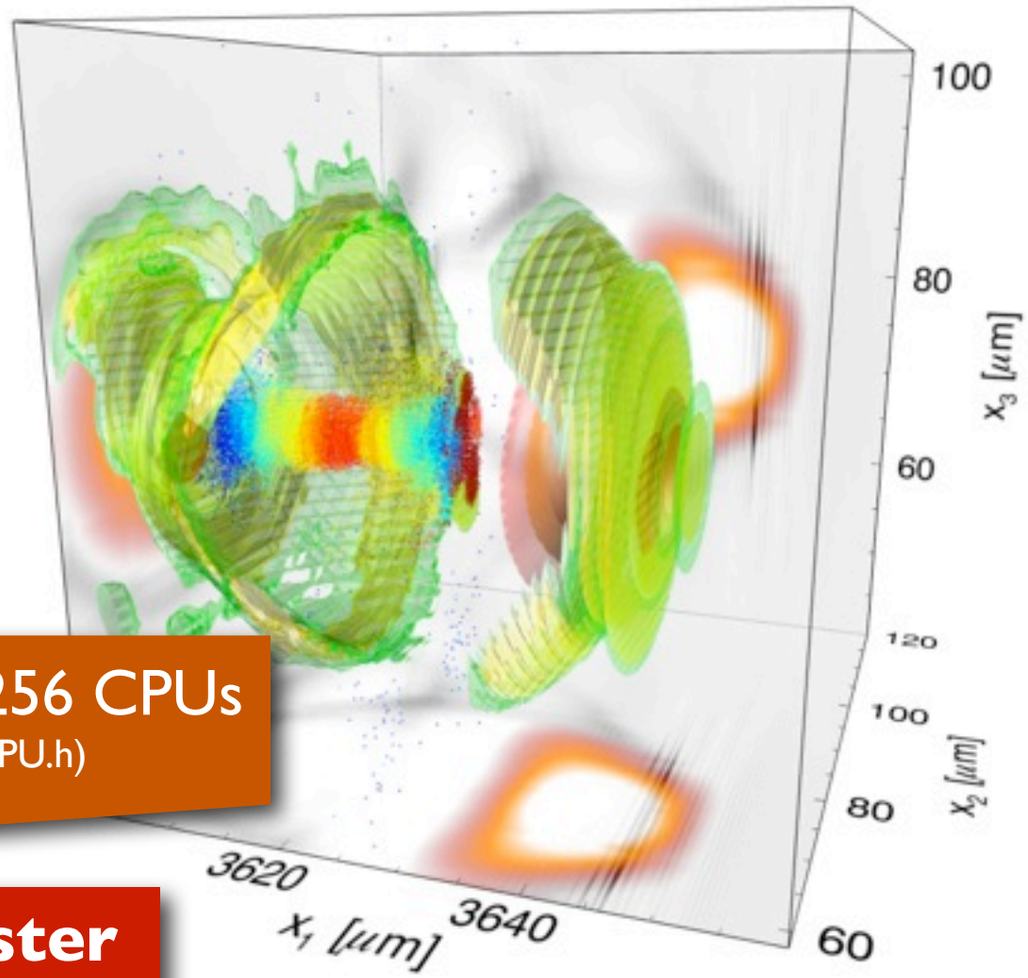
Imperial College London

UCLA

Energy spectrum comparison



Imperial College London



~20 days in 256 CPUs
(122,900 CPU.h)

20x faster in boosted frame

~1 day in 256 CPUs
(6,100 CPU.h)

Stefan Kneip *et al.

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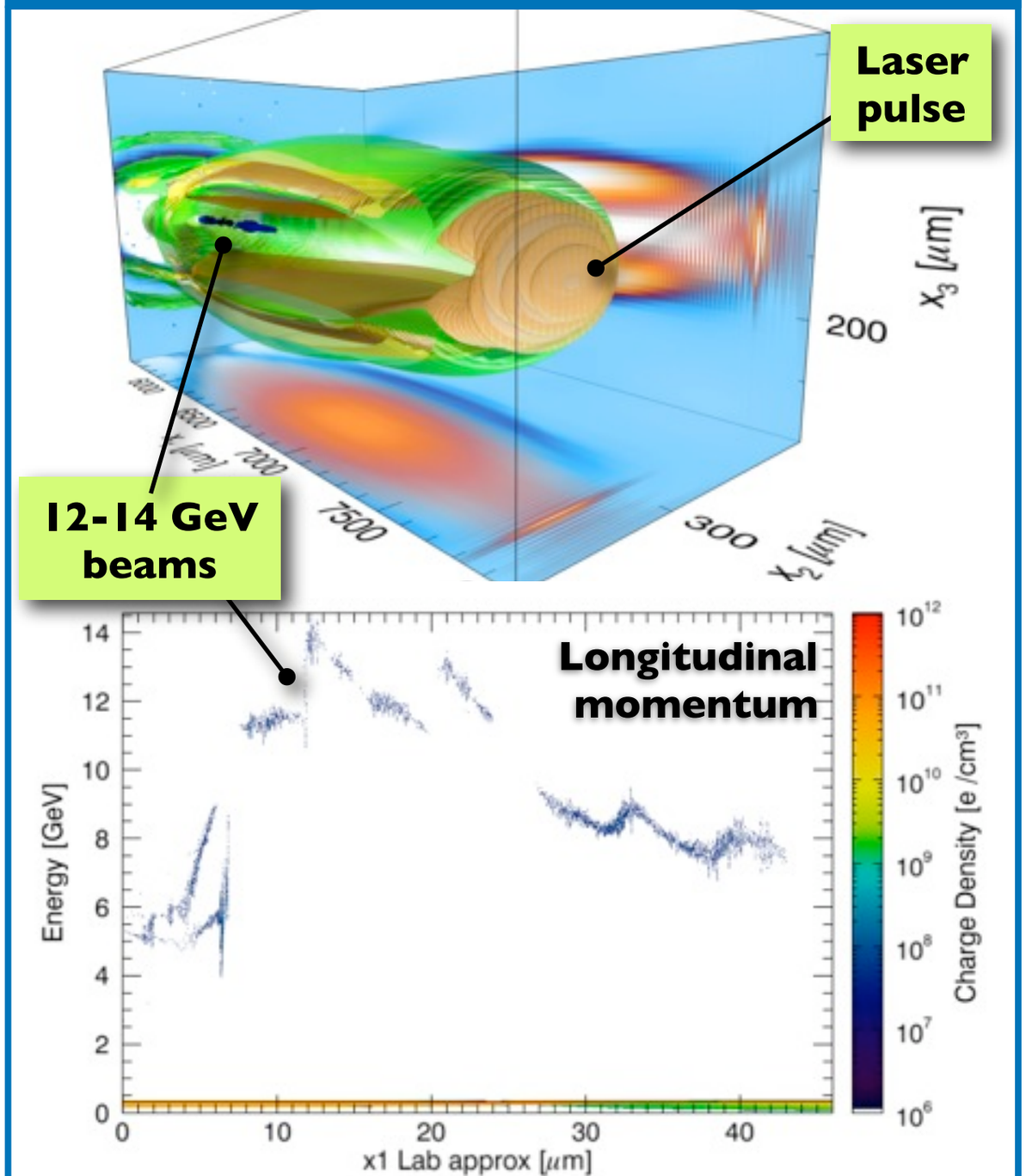
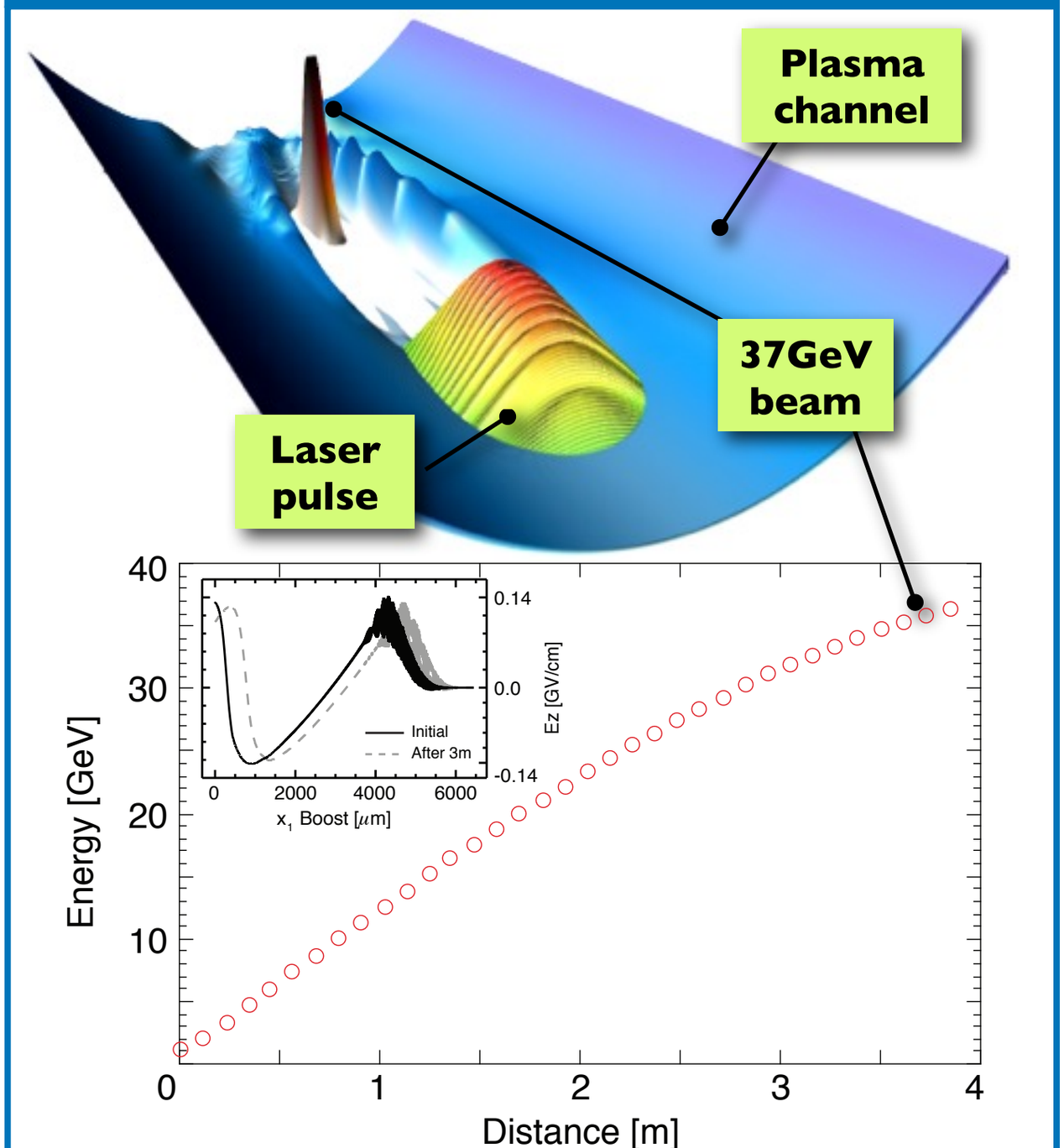
Full 3D ultra-fast boosted frame simulations for next generation lasers using OSIRIS

UCLA

Self-injection: >10 GeV



External-injection: 37GeV & counting...



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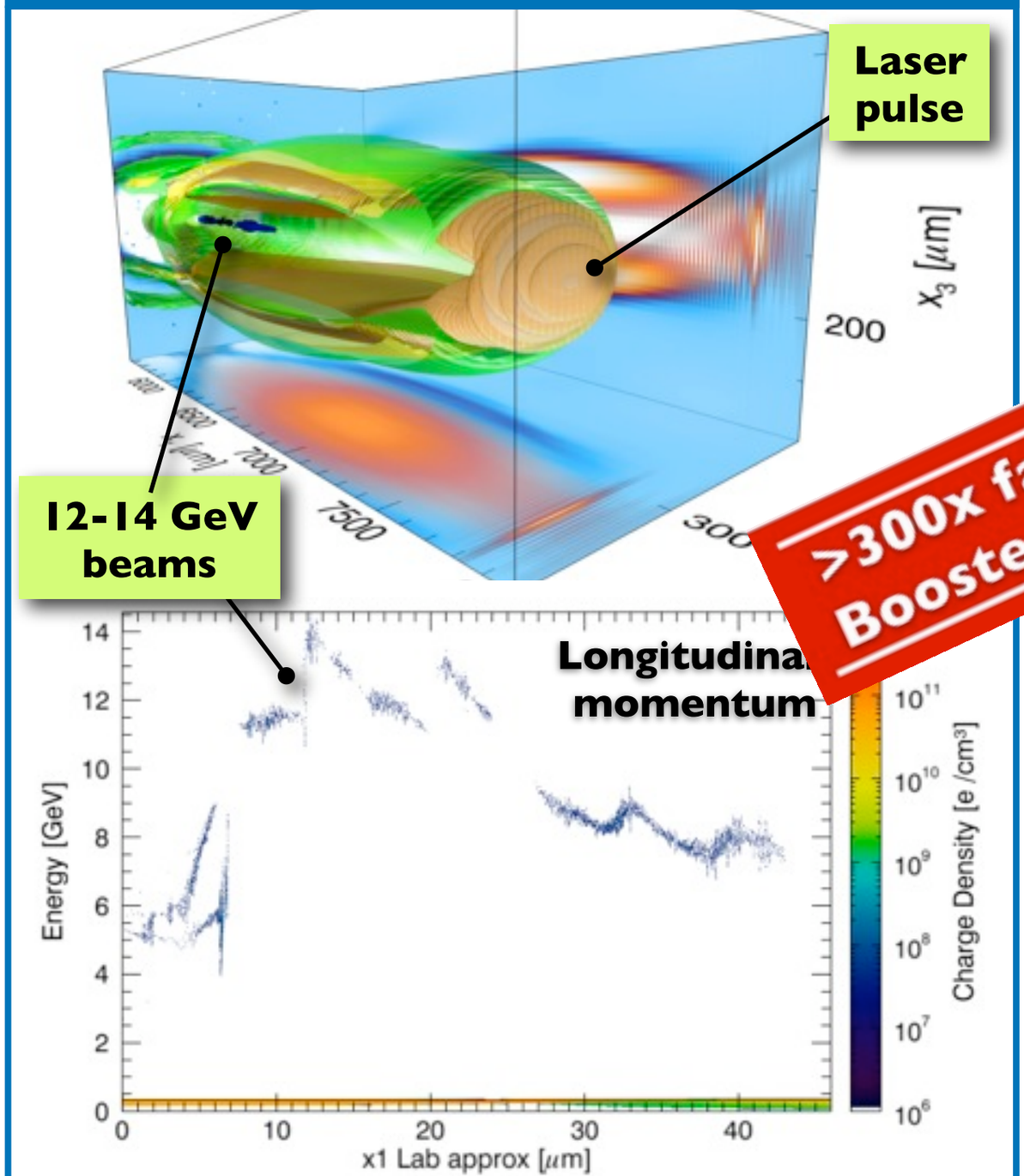

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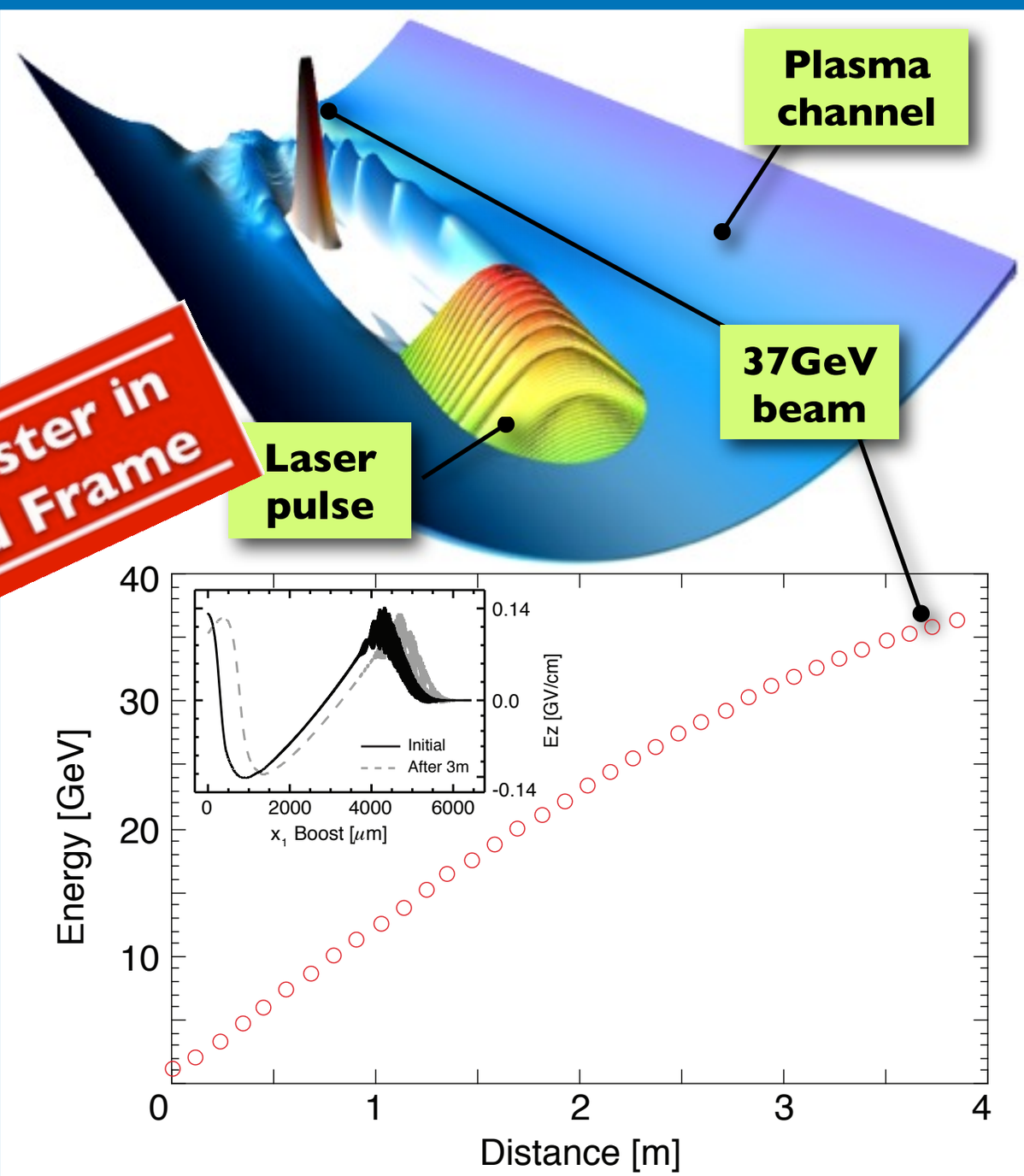

Conclusions

- **Boosted frames can provide the means for full-PIC simulations of long-scale LWFA**
  - Laser frequency decrease: grid resolution decrease
  - Compression of rest structures: smaller simulation time
- **Good quantitative agreement for several LWFA configurations**
  - Plasma channel
  - 2GeV with External injection
  - 1.5GeV & 0.8GeV with Self-injection
  - >10GeV with Self-injection
- **OSIRIS Simulations of next generation of laser systems already suggest the parameter range for >10GeV acceleration**

Next steps

- Test higher boost velocities to achieve higher computational gains
- Further explore scheme to model next generation of LWFA experiments