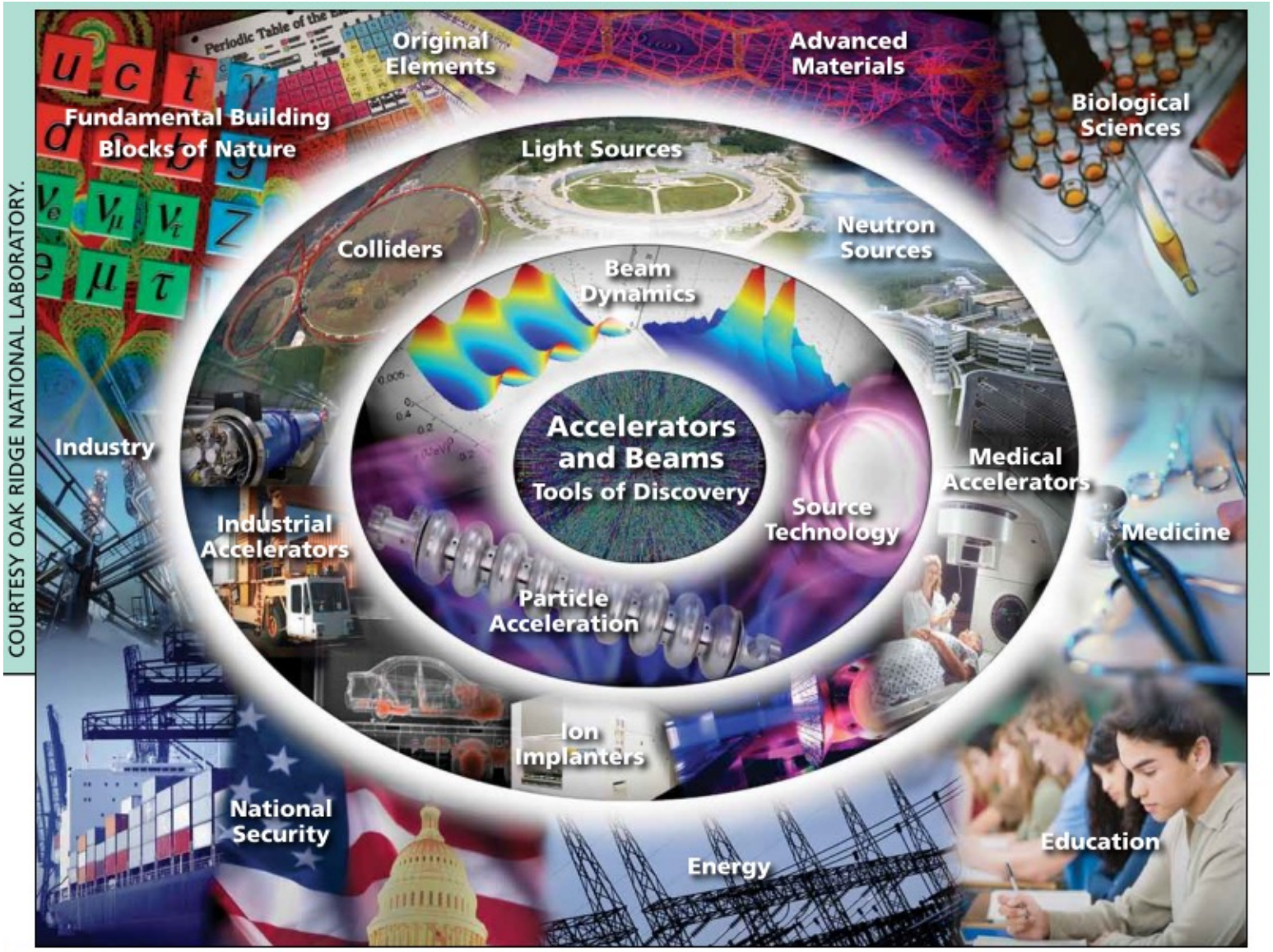
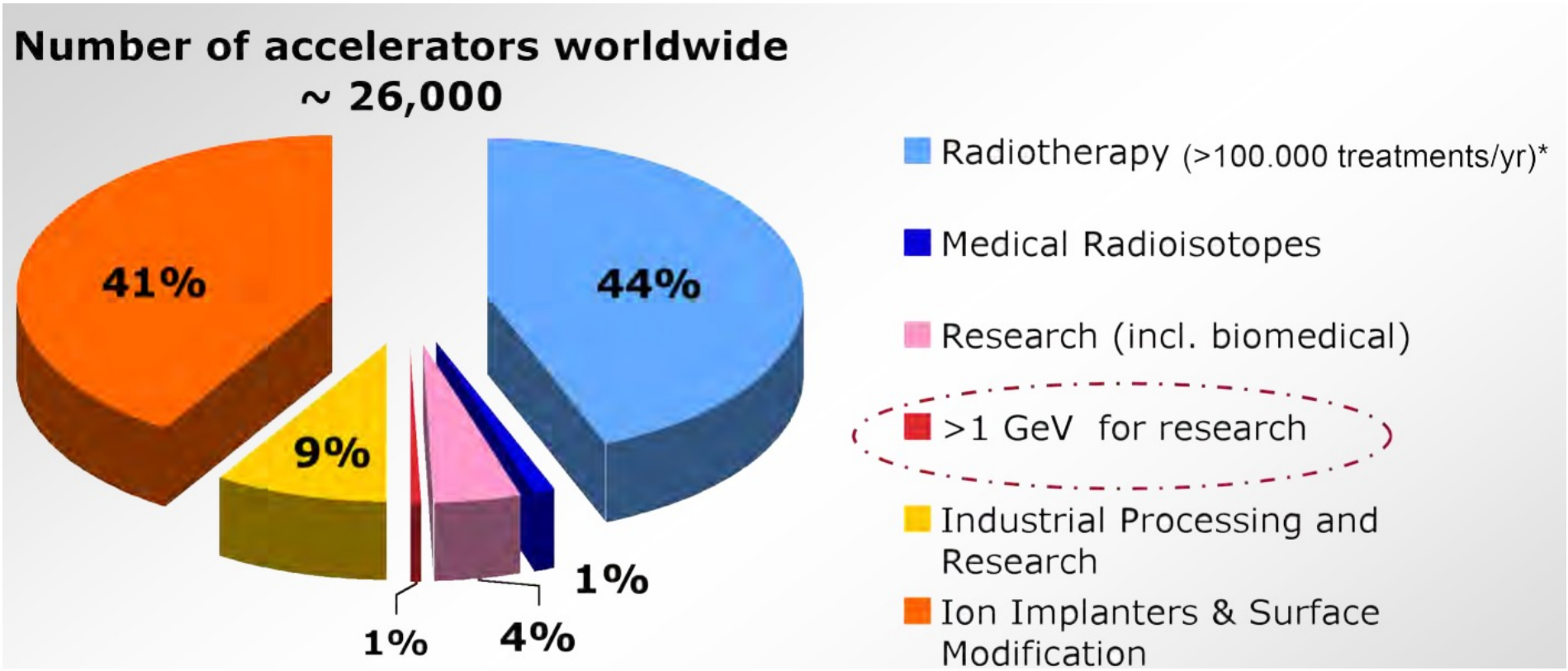
# Accelerator Physics at SLAC

Ago Marinelli
*Assistant Professor of Photon Science and*
*Particle Physics and Astrophysics*
marinelli@Stanford.edu

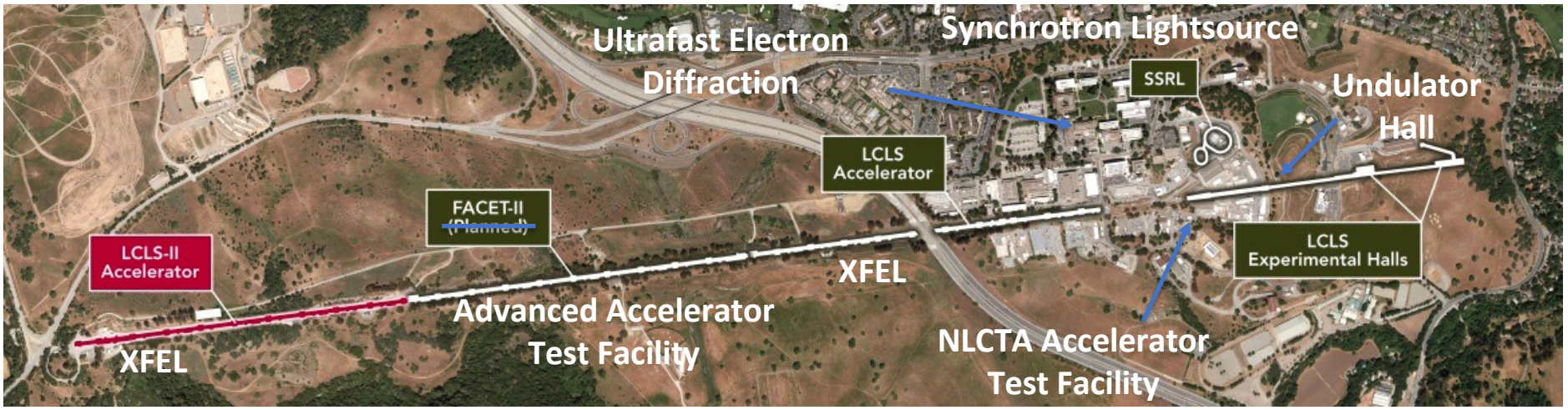
On behalf of SLAC Accelerator and Technology Innovation Directorates

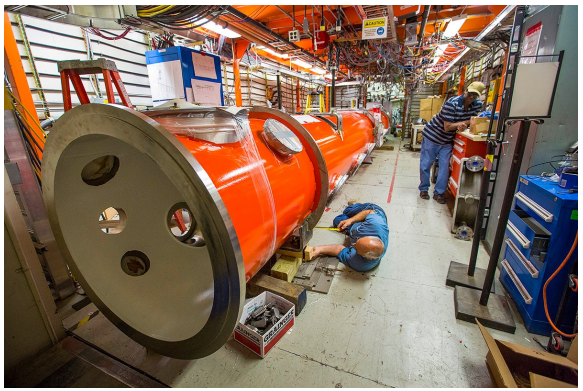




Periodic Table of the
Original Elements
Advanced Materials
Biological Sciences
Fundamental Building Blocks of Nature
Light Sources
Neutron Sources
Colliders
Beam Dynamics
Accelerators and Beams
Tools of Discovery
Source Technology
Particle Acceleration
Industry
Industrial Accelerators
Medical Accelerators
Medicine
Ion Implanters
National Security
Energy
Education
COURTESY OAK RIDGE NATIONAL LABORATORY.


Number of accelerators worldwide
~ 26,000
41%
44%
9%
1%
1%
4%
Radiotherapy (>100.000 treatments/yr)*
Medical Radioisotopes
Research (incl. biomedical)
>1 GeV for research
Industrial Processing and Research
Ion Implanters & Surface Modification

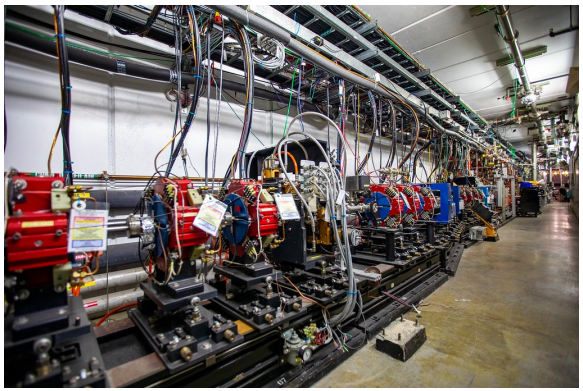
# Accelerators at SLAC



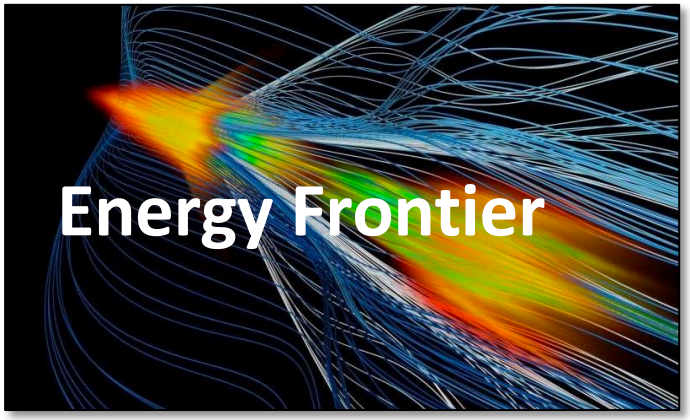
LCLS-II Cryomodule

LCLS-II Undulator Hall

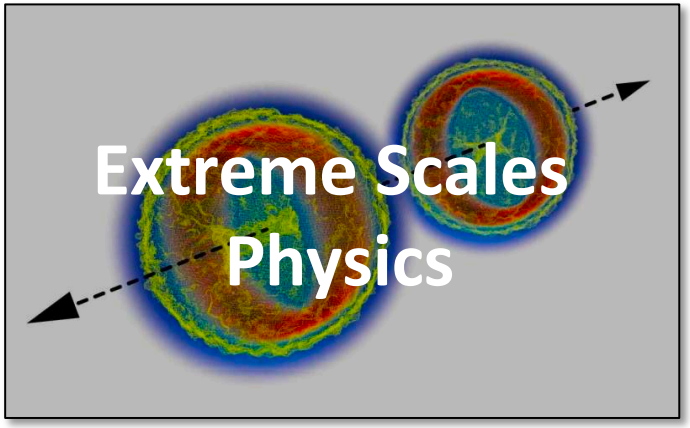


NLCTA

# Accelerator Research at SLAC

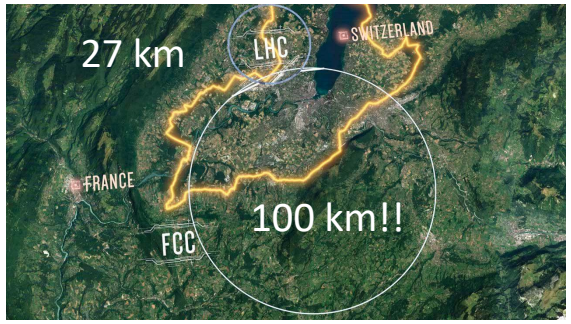







# Energy Frontier

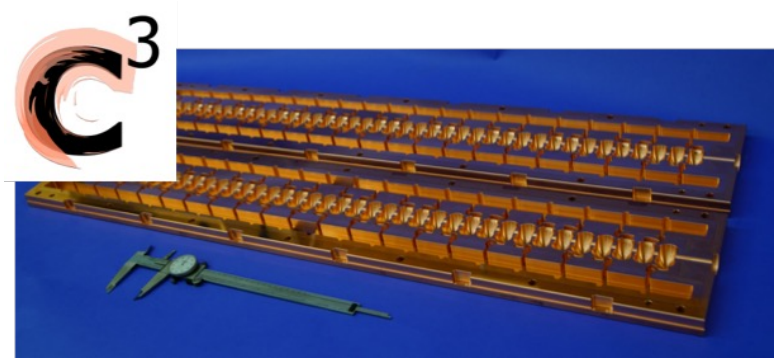
Cost/size of high energy colliders beyond LHC unsustainable!

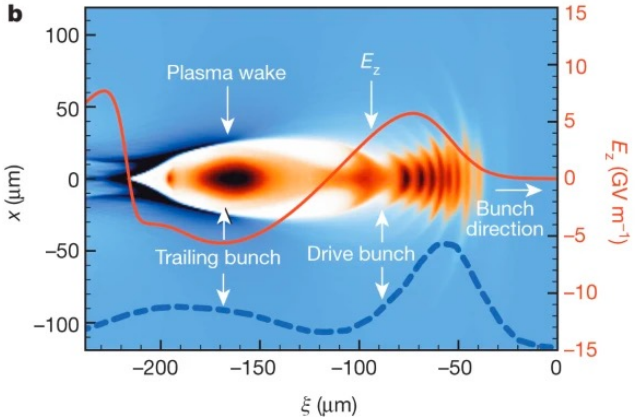



physicsworld.com


phys.org

Next generation of colliders will require radically new technology



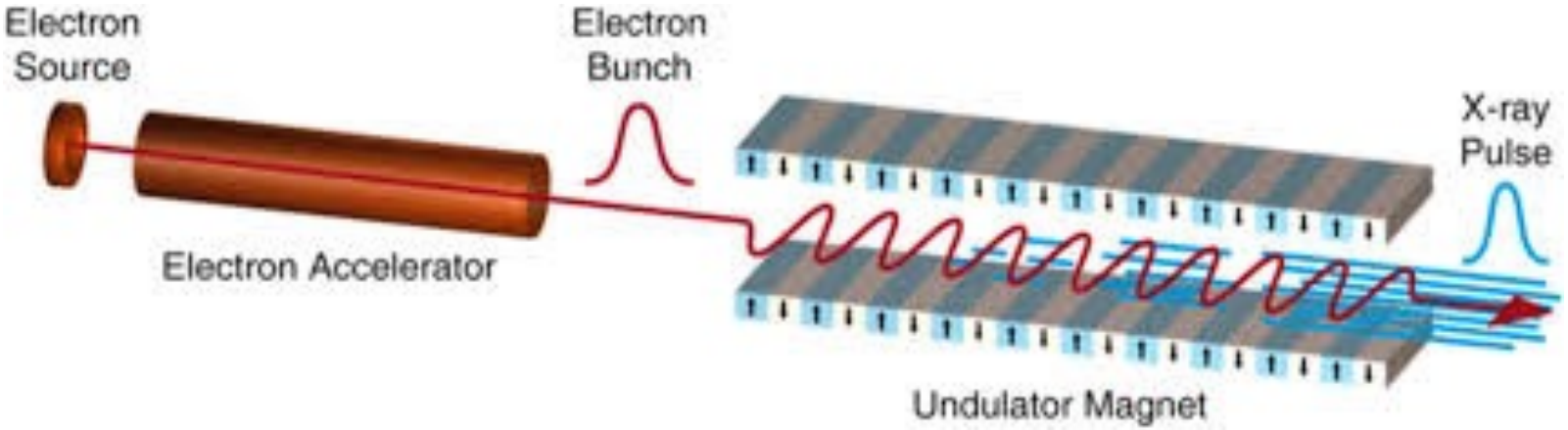

*Nature volume 515, pages 92–95(2014)*

**Cryo-cooled RF accelerators**
10 x state of the art,
based on existing technology…

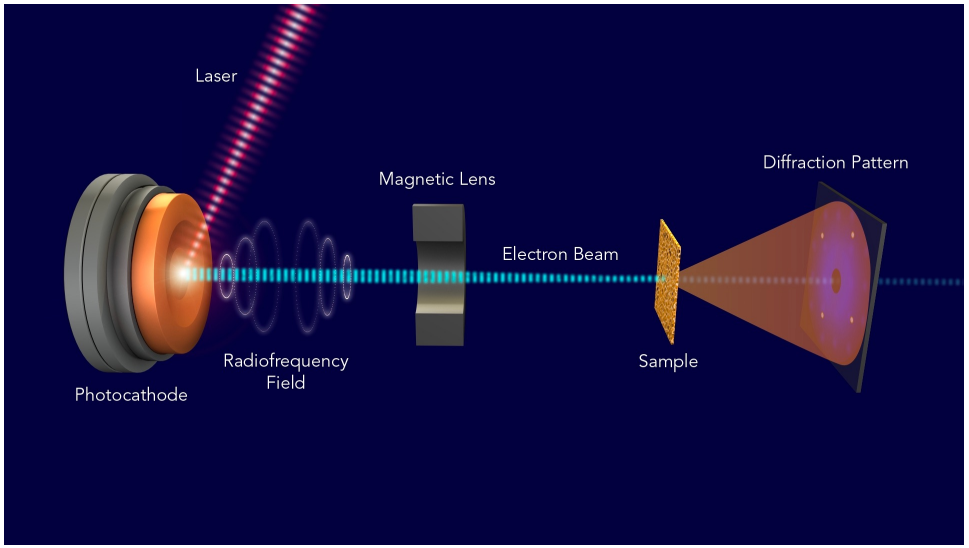
**Plasma-wakefield accelerators**
~100 x state of the art!
Long-term research effort…

# Ultrafast Probes of Matter

## X-ray free-electron lasers




## Ultrafast electron diffraction

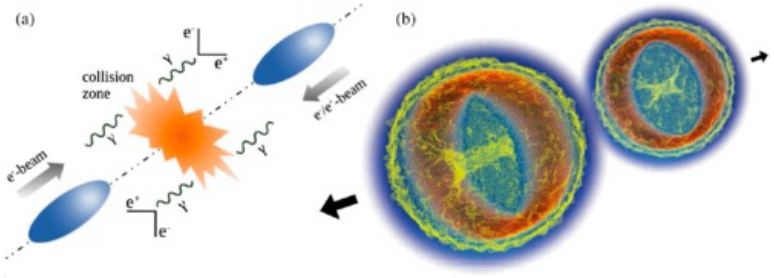



Atomic-scale diffraction
~fs timescale
Compact setup

# Extreme Scales Physics

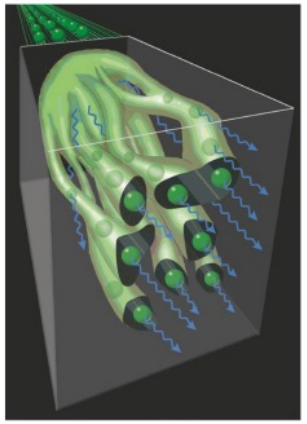
FACET-II e-beam ~10 atomic units of field,
Future upgrades could increase this number by ~100!
Combine all of this with a 200 TW laser…

Non-linear QED

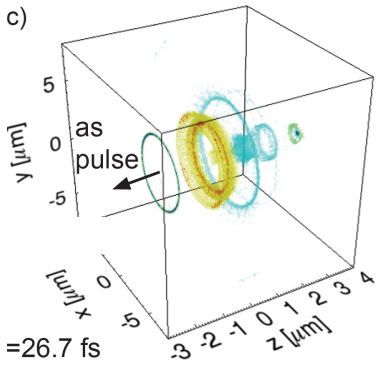



V. Yakimenko et al. Phys. Rev. Lett. **122**, 190404

Extreme light sources from
Beam-plasma interaction



Nature Photon. 12, 314 (2018)



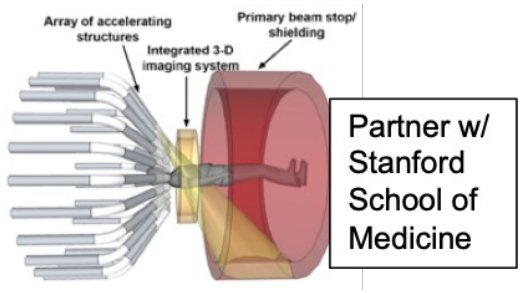

X. Xu *Physical Review Letters* 126.9 (2021): 094801.

# Societal Applications

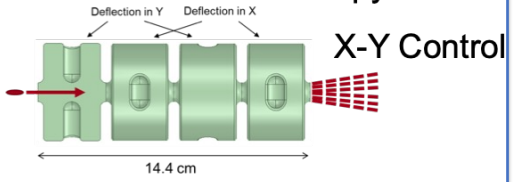
## Medical Accelerators

**Accelerators for high dose radiation therapy and medical imaging**

Research involves:
- Accelerator physics
- Radio-Biology




Rapid 3D Scanner for Proton Radiation Therapy

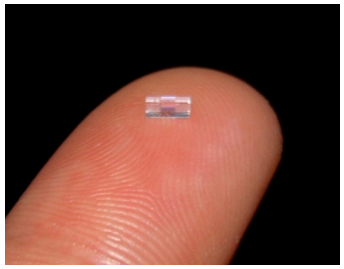



- 3D *RF control* of dose deposition over <1 s

## Compact Accelerators

**Laser-driven acceleration in dielectric microstructures**

Research involves:
- Photonic structures
- Nanofabrication
- Electron beam optics

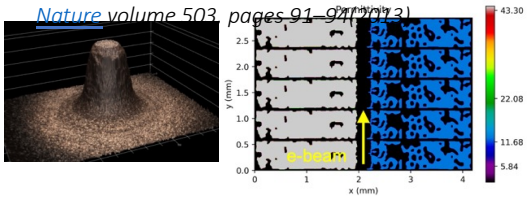


*Nature volume 503, pages 91–94(2013)*

**THz Accelerators**

Research involves:
- Photonic structures
- Nonlinear optics
- Electron beam dynamics

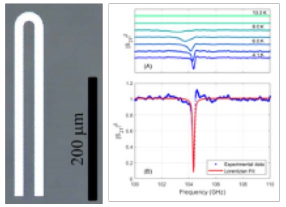
*Nature volume 503, pages 91–94(2013)*



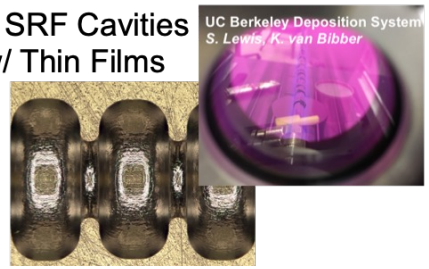

## Quantum Information Science

Research involves:
- Photonic structures
- Nanofabrication
- Superconducting RF cavities

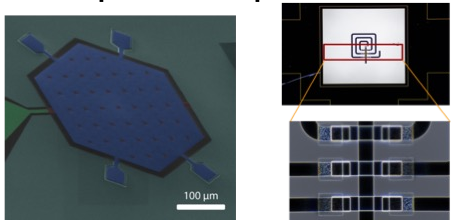
First mm-wave superconducting resonators




3D SRF Cavities w/ Thin Films



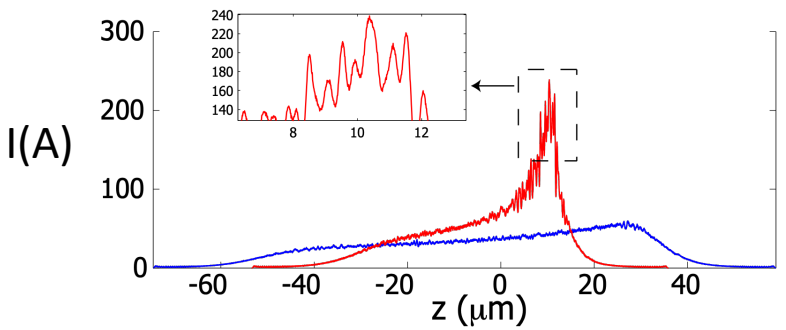

**Developing microwave vacuum-gap capacitor and spiral inductors**

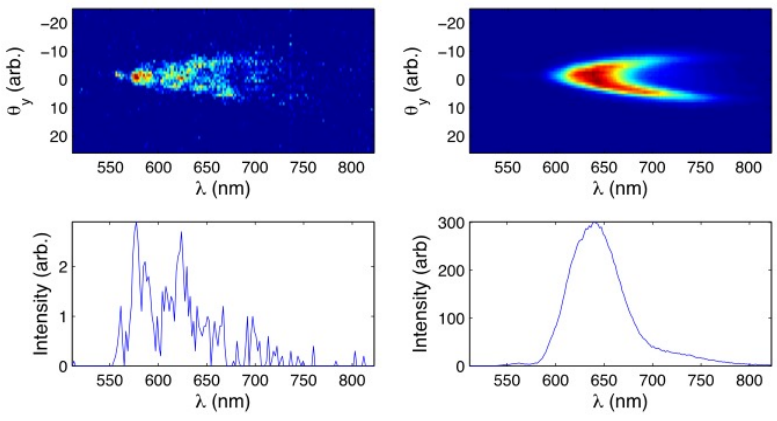


# Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results

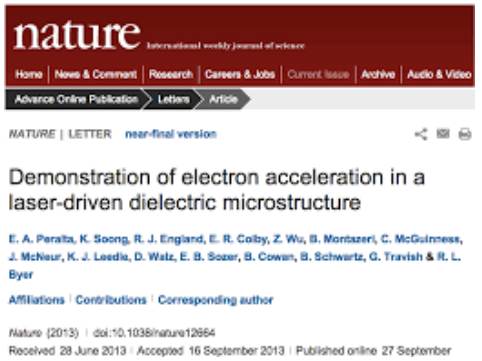
$$\left(\frac{1}{D^2}\nabla_\perp^2 - 1\right) E_z = -\int E_z(\vec{X}')\Pi(\vec{X},\vec{X}')d^2\vec{X}'$$



# Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results
- Advanced R&D initiatives leading to publications in high-impact journals



**Tunable isolated attosecond X-ray pulses with gigawatt peak power from a free-electron laser**

Joseph Duris[1,12], Siqi Li[1,2,12], Taran Driver[1,3,4], Elio G. Champenois[3], James P. MacArthur[1,2], Alberto A. Lutman[1], Zhen Zhang[1], Philipp Rosenberger[1,3,5,6], Jeff W. Aldrich[1], Ryan Coffee[1], Giacomo Coslovich[1], Franz-Josef Decker[1], James M. Glownia[1], Gregor Hartmann[7], Wolfram Helml[6,8,9], Andrei Kamalov[2,3], Jonas Knurr[3], Jacek Krzywinski[1], Ming-Fu Lin[1], Jon P. Marangos[4], Megan Nantel[1,2], Adi Natan[3], Jordan T. O'Neal[2,3], Niranjan Shivaram[1], Peter Walter[1], Anna Li Wang[3,10], James J. Welch[1], Thomas J. A. Wolf[3], Joseph Z. Xu[11], Matthias F. Kling[1,3,5,6], Philip H. Bucksbaum[1,2,3,10], Alexander Zholents[11], Zhirong Huang[1,10], James P. Cryan[1,3*] and Agostino Marinelli[1*]

# Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results
- Advanced R&D initiatives leading to publications in high-impact journals
- Excellent mentors and room for individual growth

C. Pellegrini
2015 Fermi Award

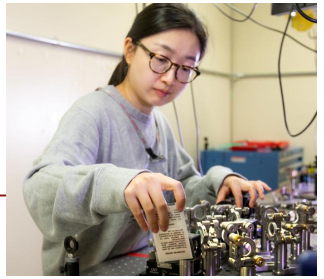
Among others:

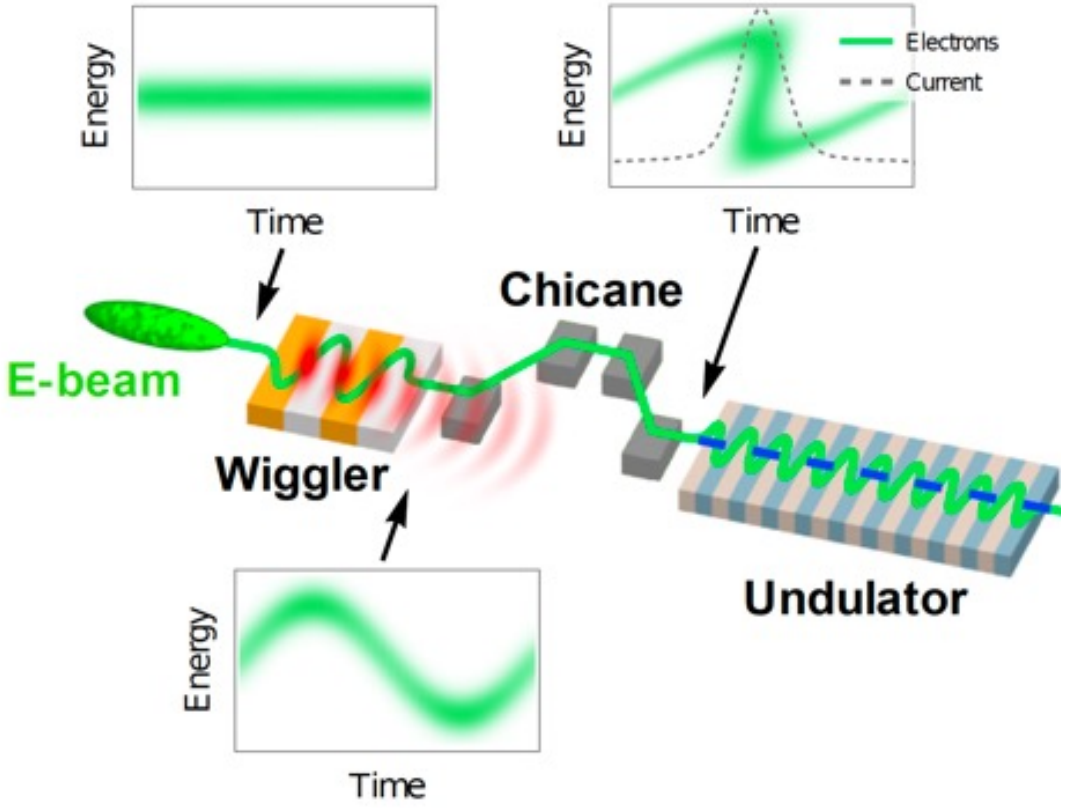
2009, 2012, 2014,2019 FEL Prize
2011-15, 2019 Young FEL Prize
2013 Wilson Prize
2014 Frank Sacherer Prize
2016/2019 M. Oliphant Prize
12 APS thesis prizes!!
(Siqi Li most recent winner)

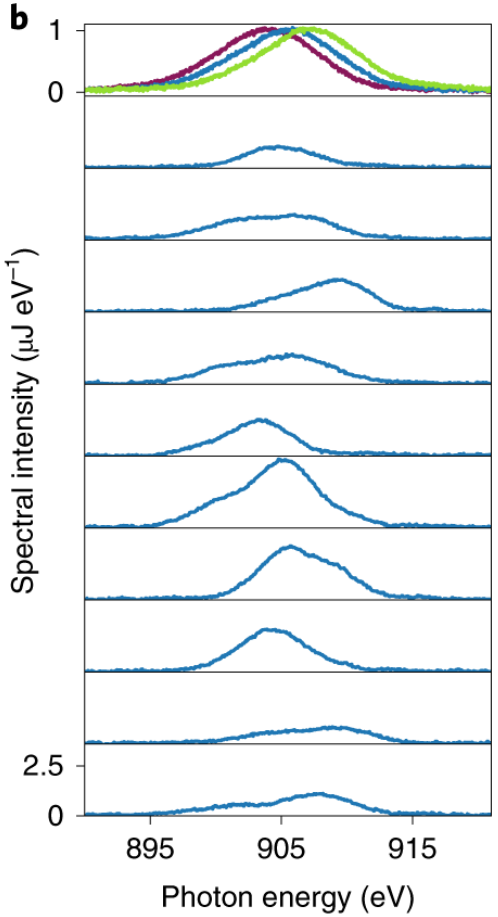
# Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results
- Advanced R&D initiatives leading to publications in high-impact journals
- Excellent mentors and room for individual growth
- Large availability of funding in and beyond graduate school!

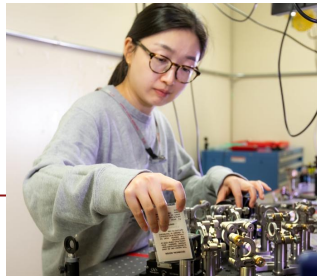
# Examples of Recent PhDs

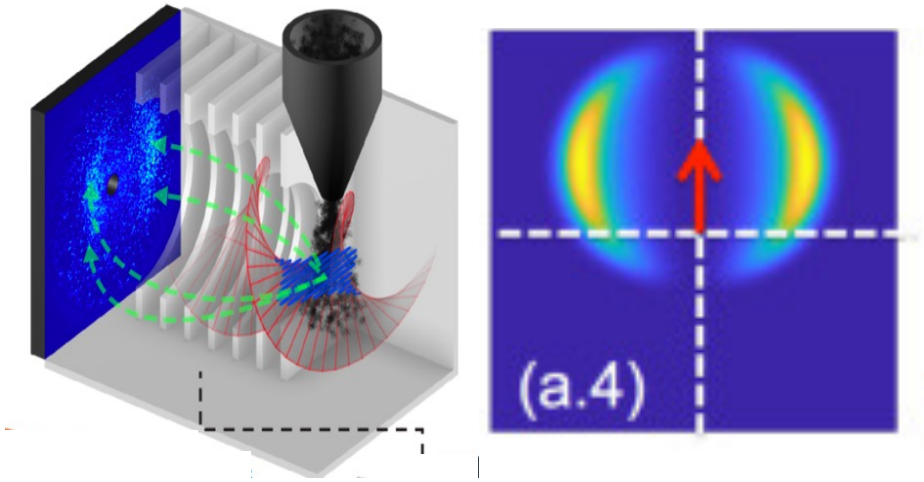




# Examples of Recent PhDs






*Optics express* 26.4 (2018): 4531-4547

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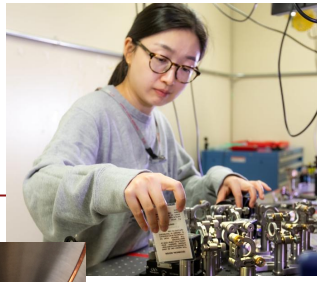
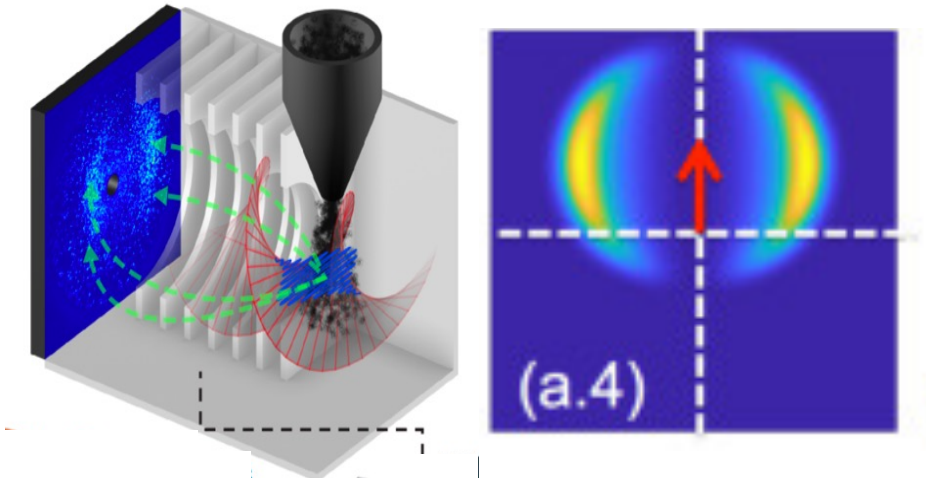
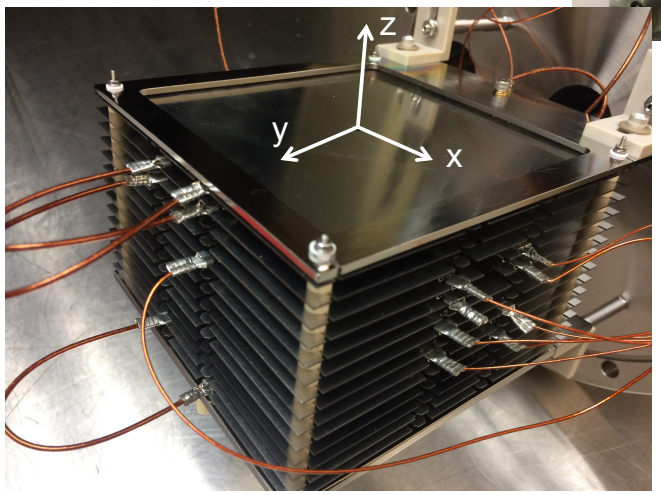





*Optics express* 26.4 (2018): 4531-4547




*AIP Advances* 8.11 (2018)

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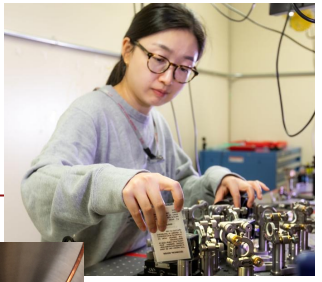
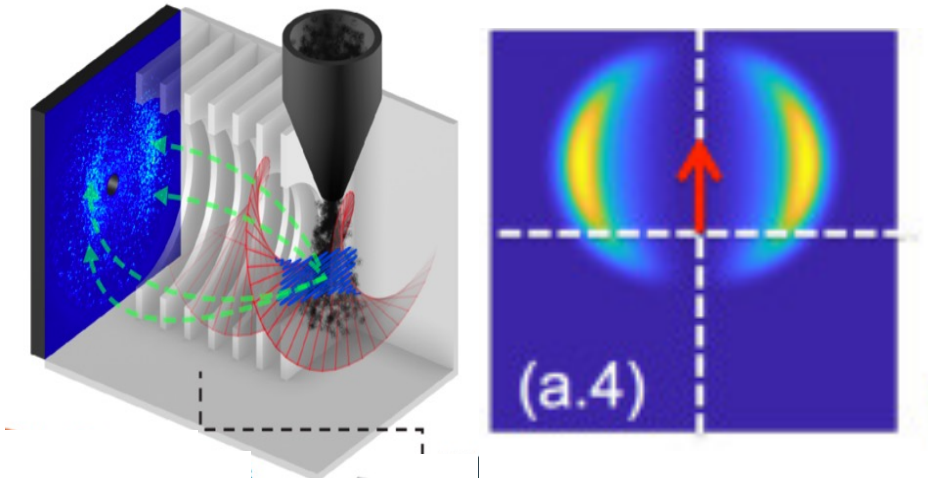
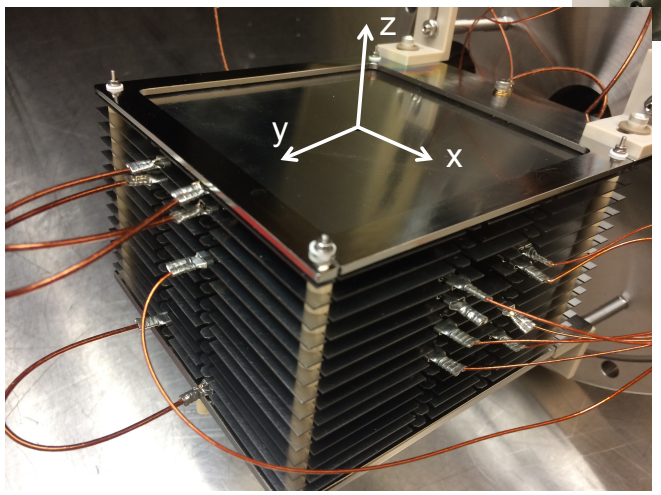
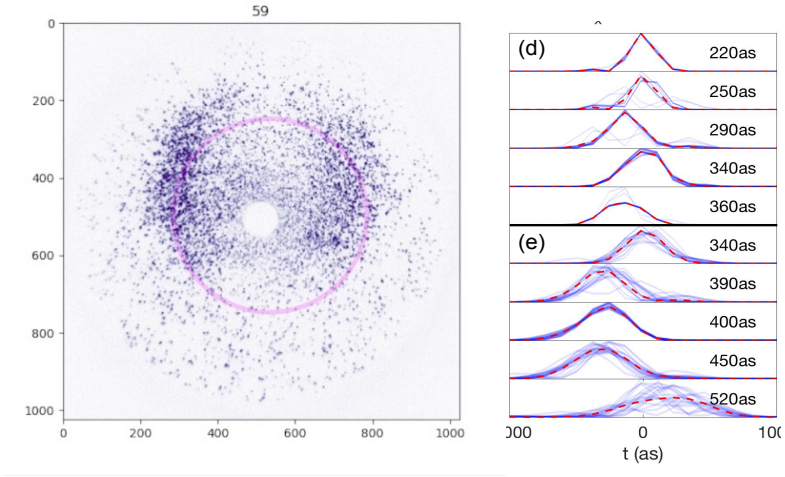





*Optics express* 26.4 (2018): 4531-4547

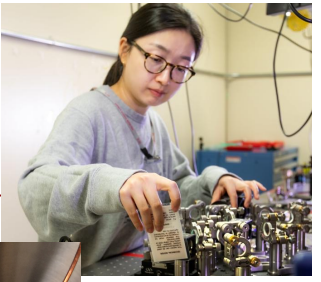


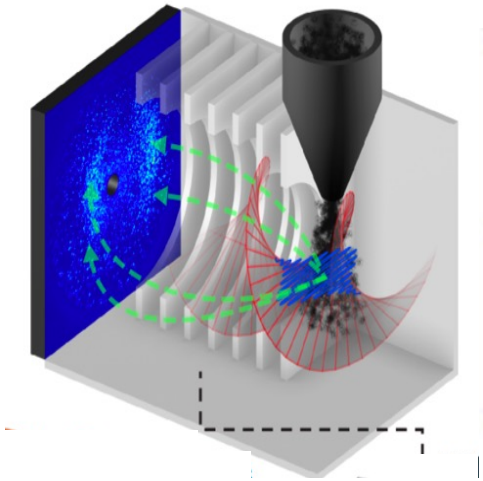

*AIP Advances* 8.11 (2018)

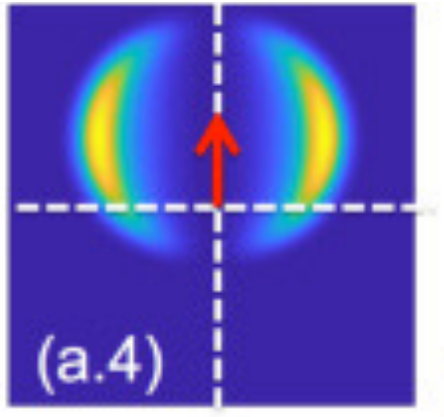



*Nature Photonics* 14.1 (2020): 30-36.

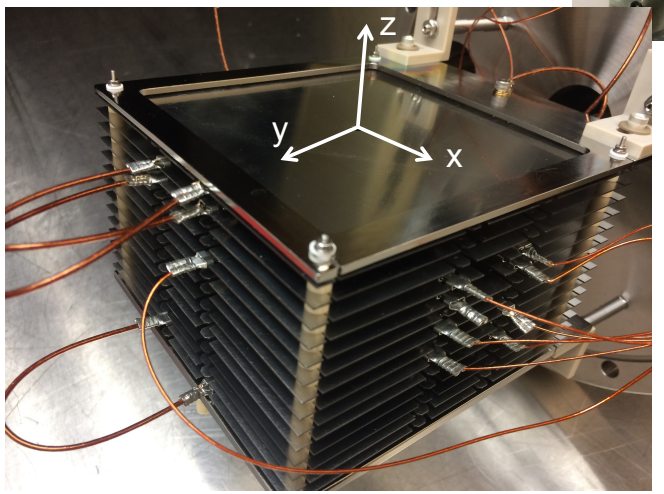
# Examples of Recent PhDs








*Optics express* 26.4 (2018): 4531-4547

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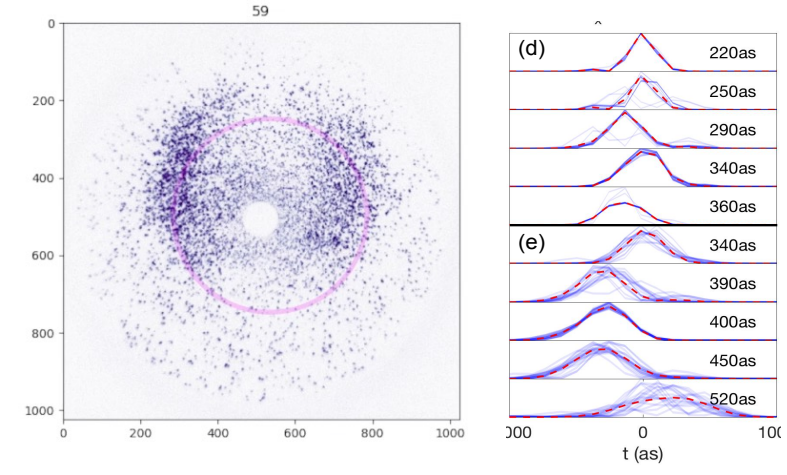
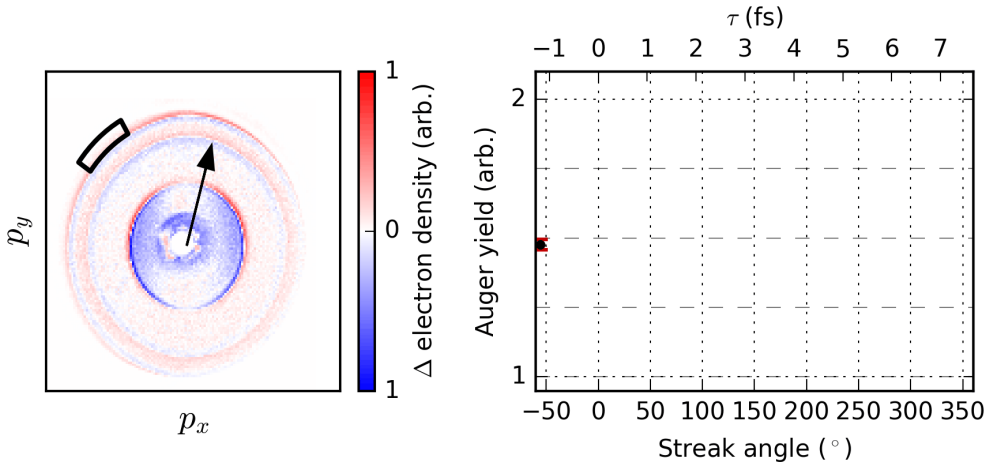
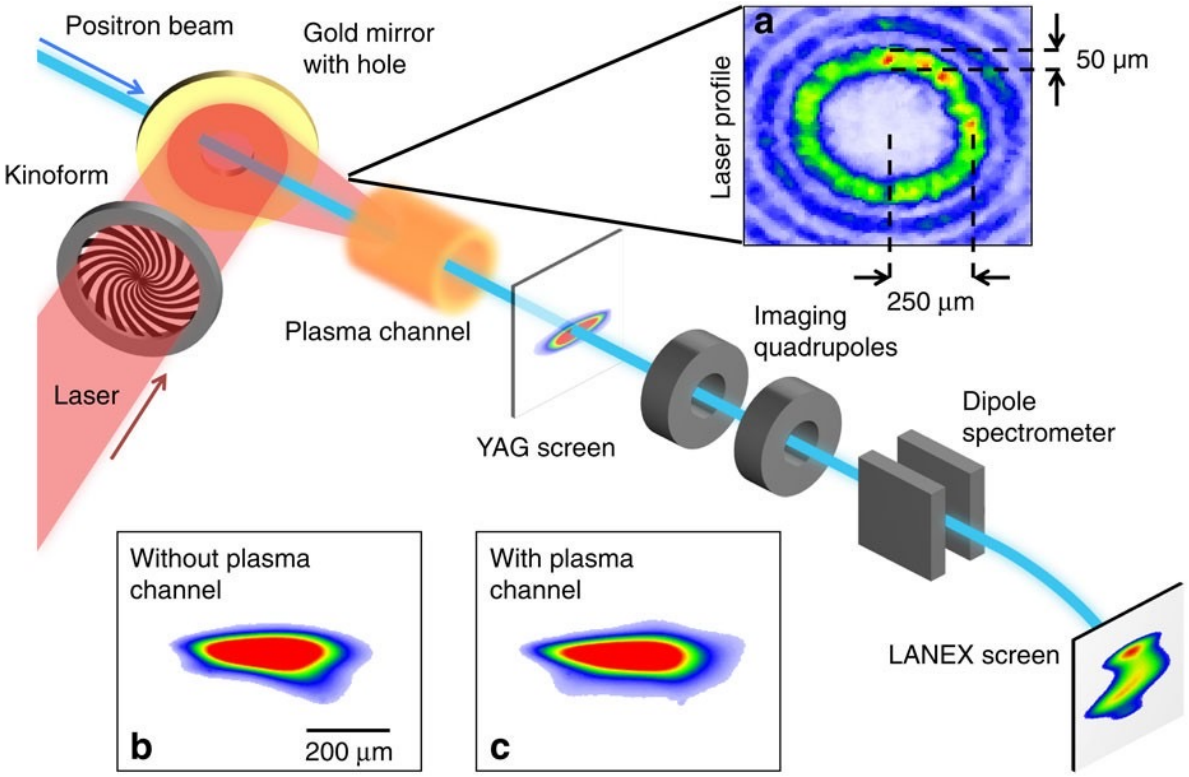



*Nature Photonics* 14.1 (2020): 30-36.

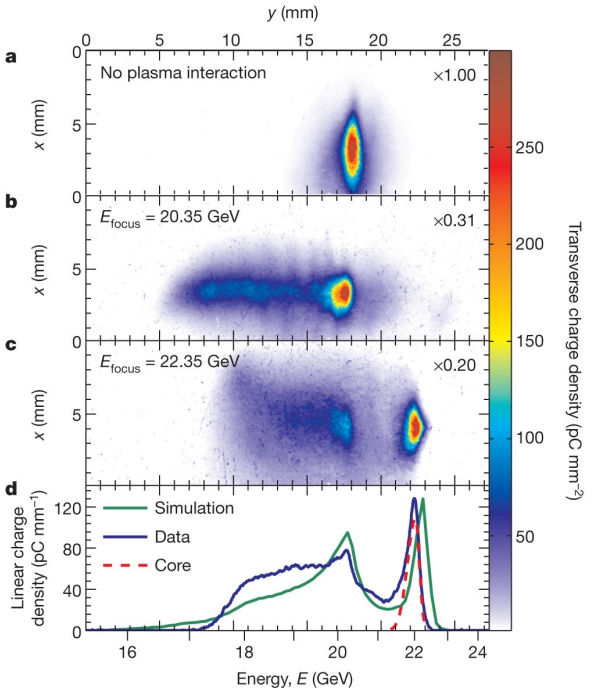



*Science* 375.6578 (2022): 285-290.

# Examples of Recent PhDs



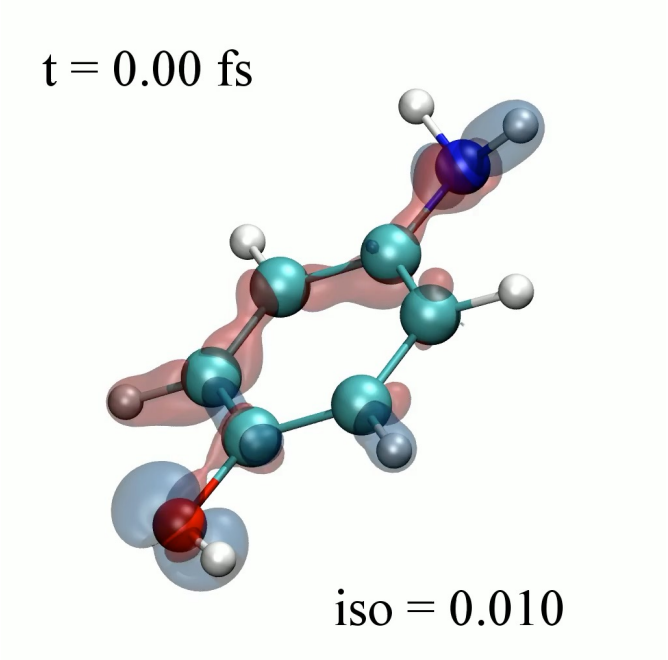

*Nature communications* 7.1 (2016): 11785

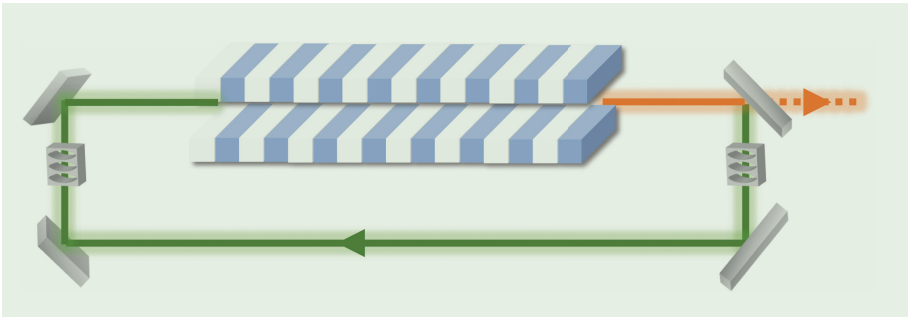


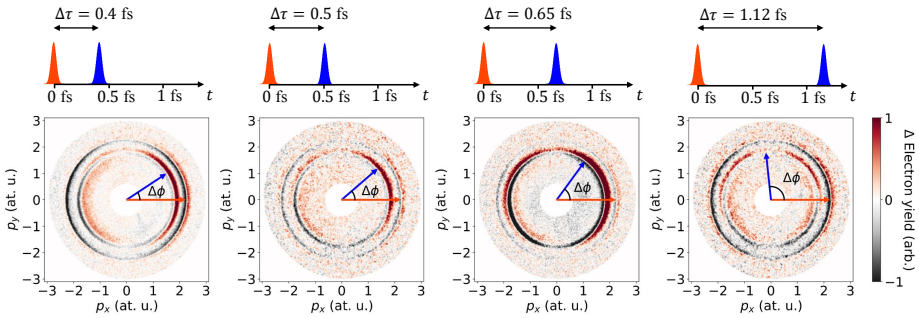

*Nature* 515.7525 (2014): 92-95.

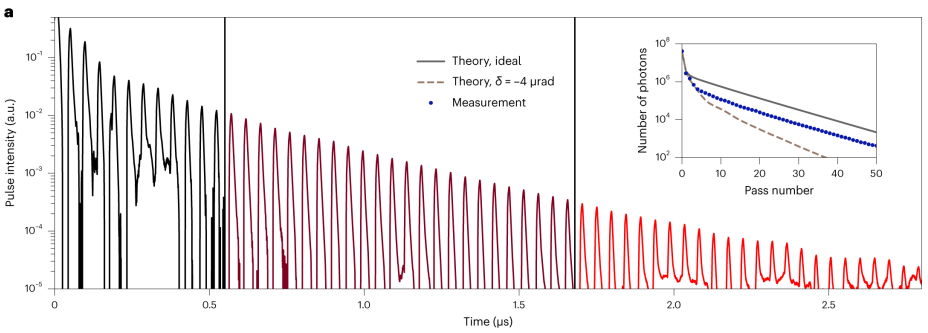
*Nature* 524.7566 (2015): 442-445

# Available Projects: XFEL R&D



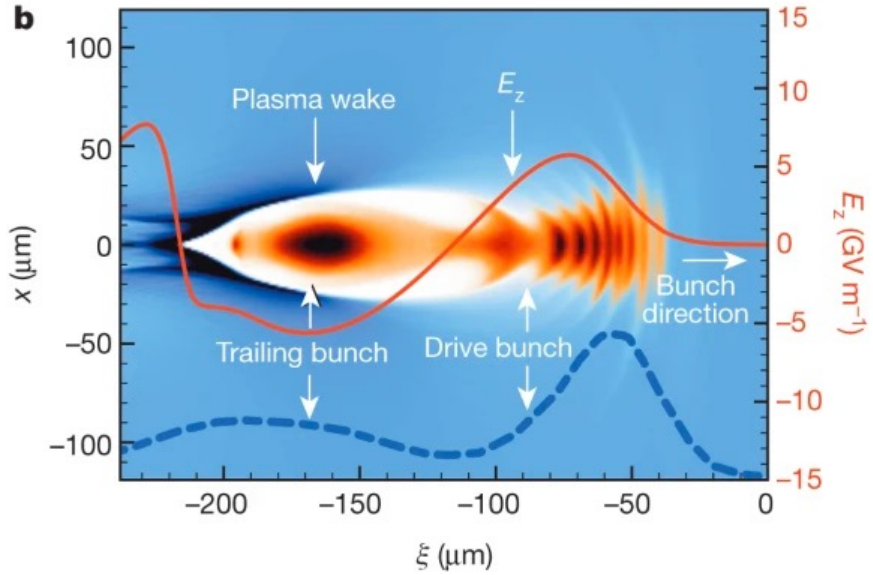





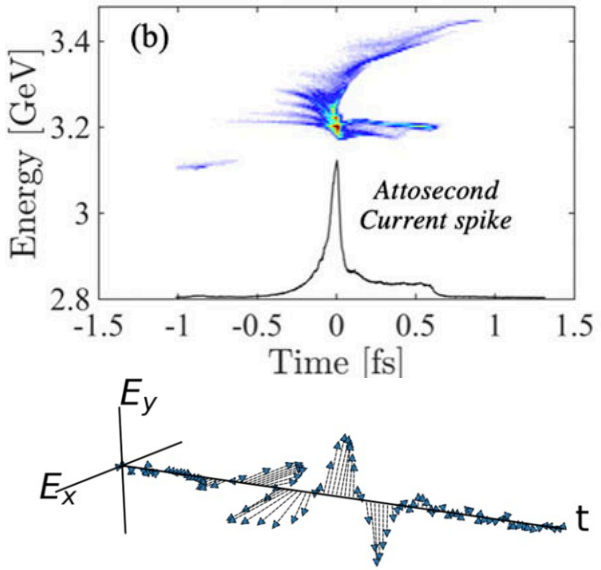




*R. Margraf et al. Nat. Photon.* (2023). https://doi.org/10.1038/s41566-023-01267-

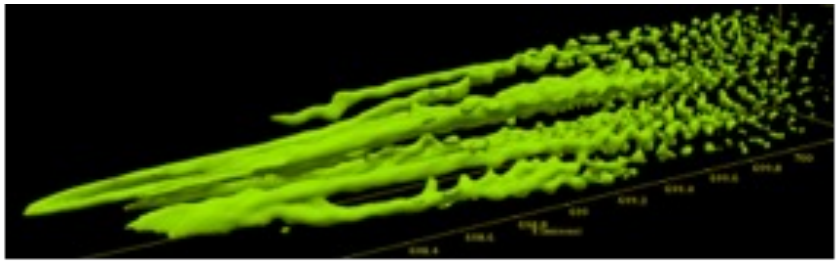
# Available Projects: FACET-II



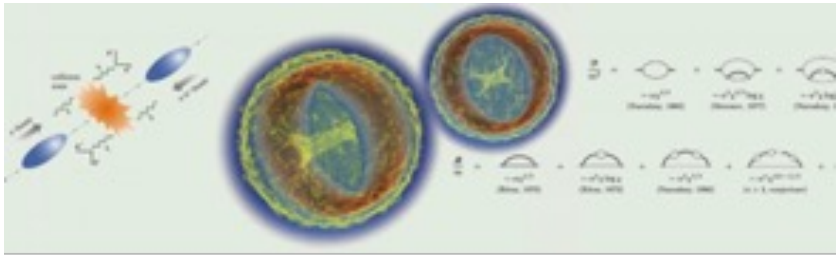

Plasma-wakefield acceleration




Plasma-based light-sources

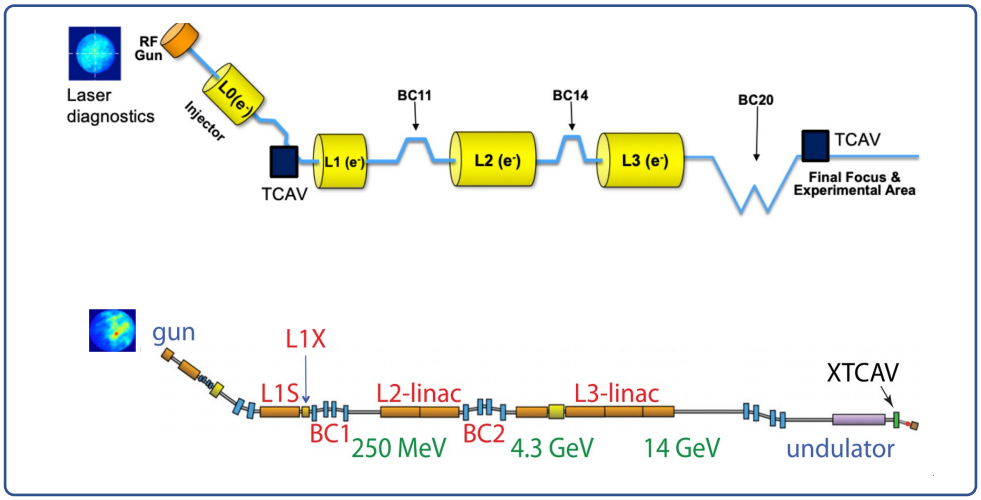


High-intensity gamma-rays



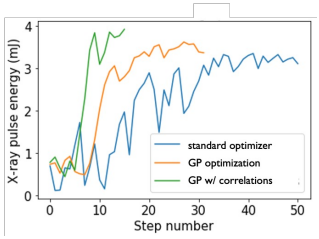
Non-linear QED

# ML/AI

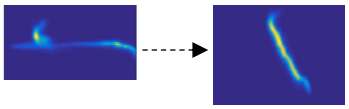

RF Gun
Laser diagnostics
Injector
L0(e-)
TCAV
L1 (e-)
BC11
L2 (e-)
BC14
L3 (e-)
BC20
TCAV
Final Focus & Experimental Area
gun
L1X
L1S
BC1
L2-linac
250 MeV
BC2
4.3 GeV
L3-linac
14 GeV
XTCAV
undulator

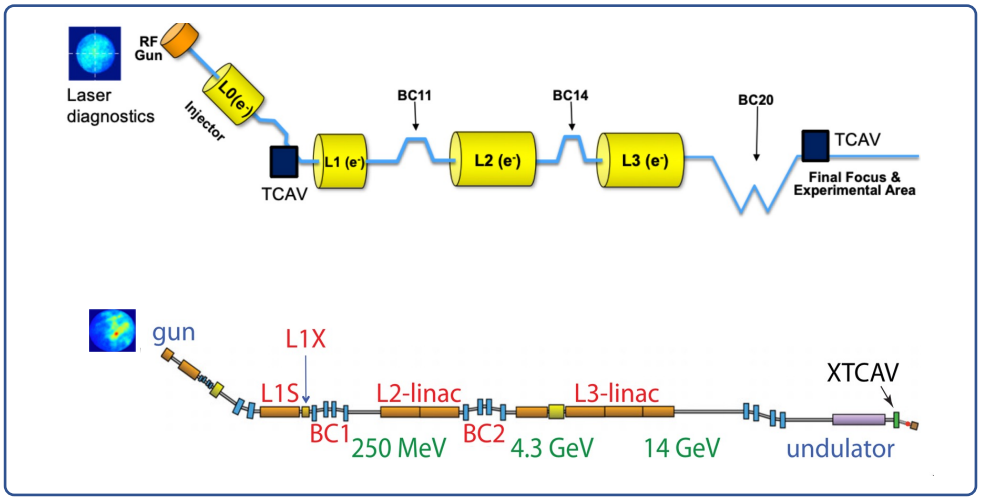
# ML/AI

**automated control + optimization**

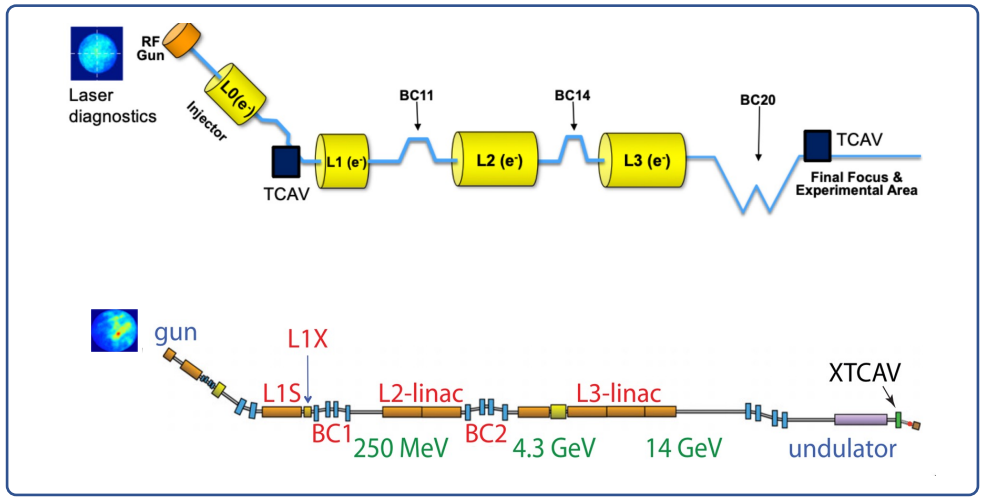


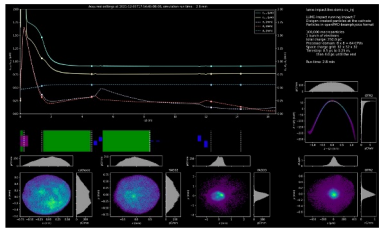

*J. Duris et al., PRL, 2020*

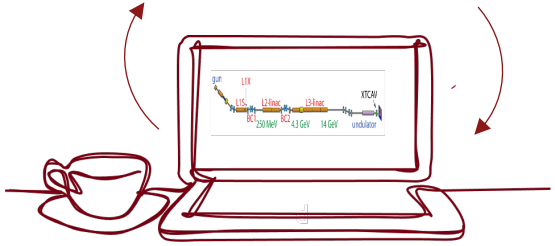




# ML/AI



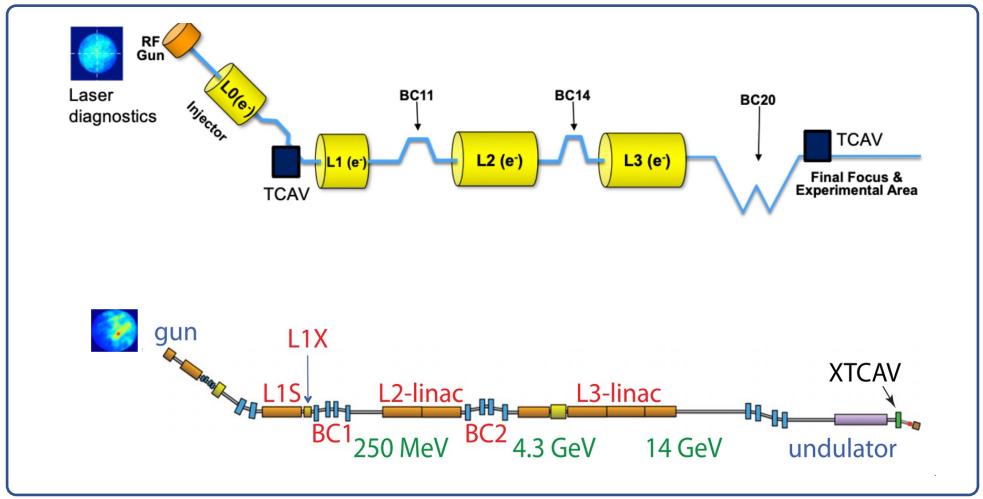


**digital twins + online modeling**

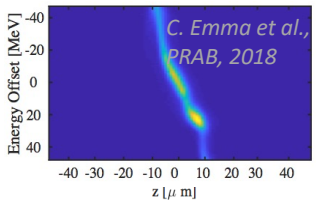
*(fast sims, differentiable sims, model calibration, model adaptation)*

# ML/AI

**Data reduction/rejection** *(kHz/MHz data streams)*
**Event triggering**

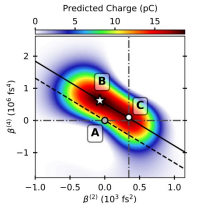



**ML-enhanced diagnostics**
*(provide insight at faster rate, at higher resolution, non-invasively)*




**anomaly detection**
**failure prediction**
*(plan maintenance; alert to changes in machine; alert to interesting science)*

**extract unknown relationships + correlations**
*(feed into future control / design)*




*R. Shaloo et al.*
arXiv:2007.14340

**+ need uncertainty quantification for all**
**+ can incorporate physics information in all**

# Who Are We?

## Accelerator Physics Faculty

Ago Marinelli

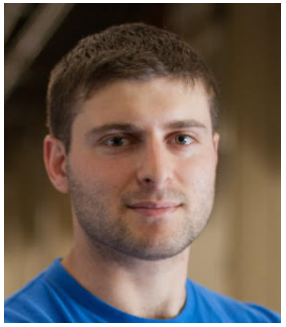
Zhirong Huang

Emilio Nanni

Sami Tantawi

## Some of the staff scientists you will work with…

Auralee Edelen



Spencer Gessner

Mark Hogan

Brendan O'Shea

# THANK YOU FOR YOUR ATTENTION!

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY