Laser plasma accelerators

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US-Japan HEP Collaboration
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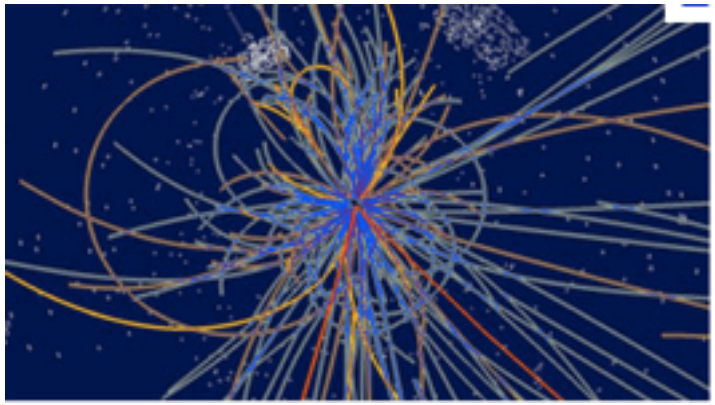
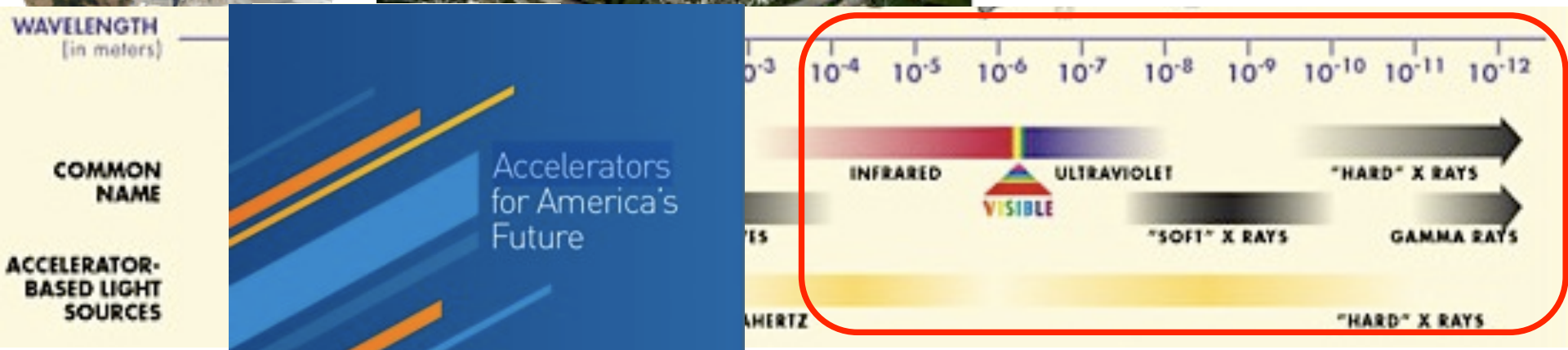
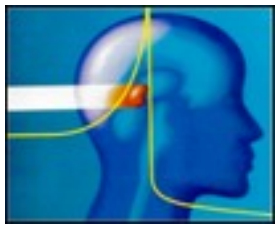
http://loasis.lbl.gov/

Accelerators: drivers for science

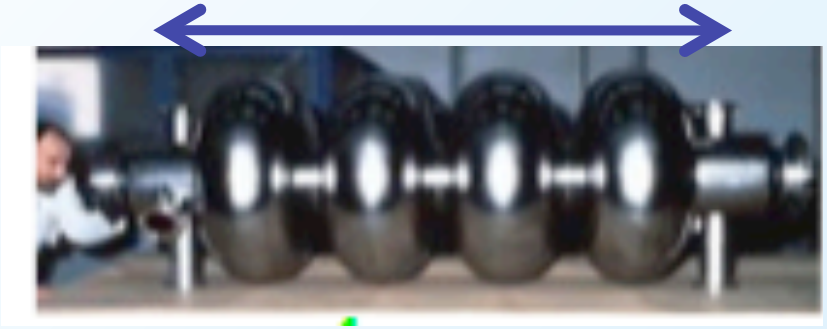






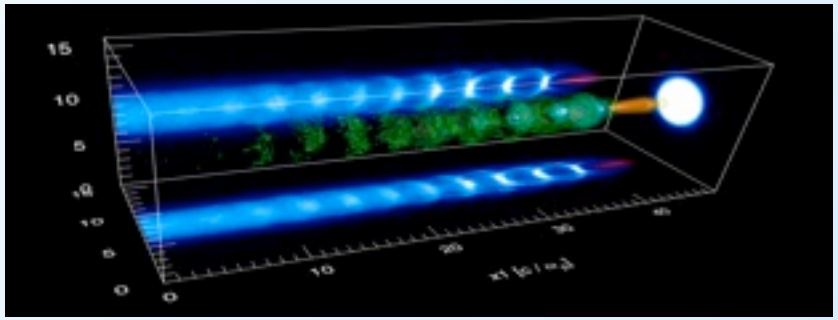
Laser plasma acceleration enables development of “compact” accelerators

m-scale



10 – 40 MV/m

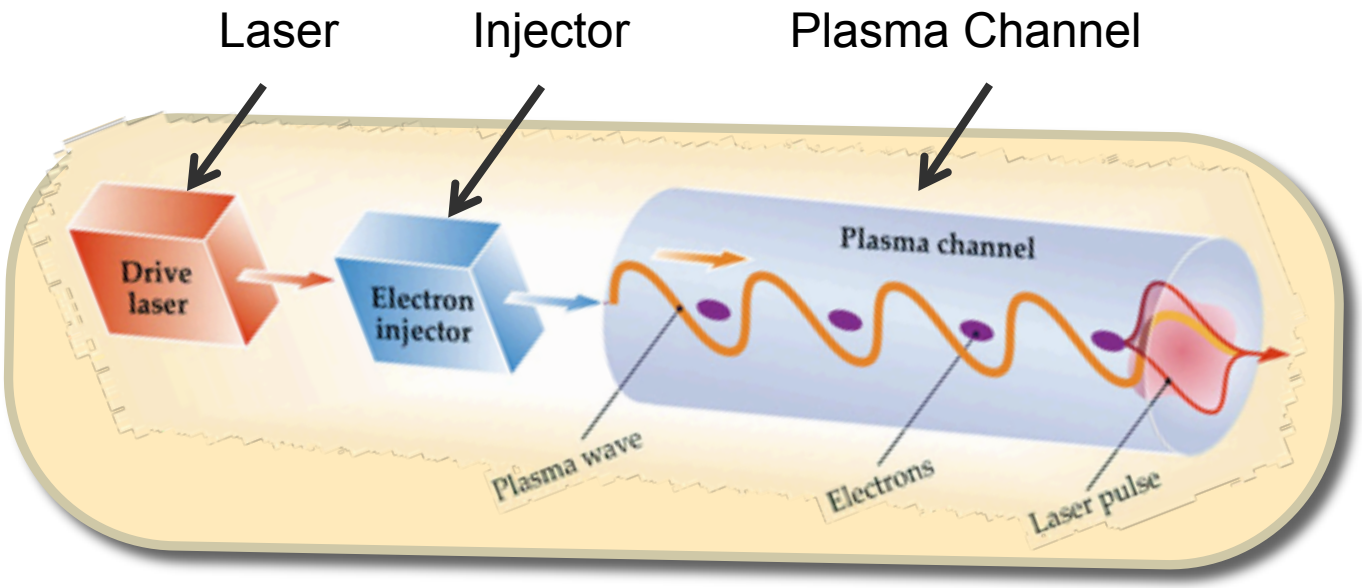
100 micron-scale



10 – 100 GV/m

Plasmas sustain extreme fields => compact accelerators
Can this technology be developed for energy frontier machines, light sources, medical or homeland security applications?

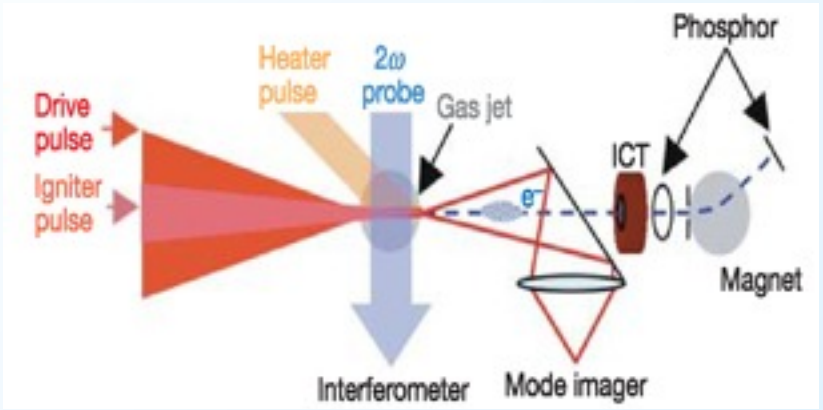
Building a laser plasma accelerator following conventional linac paradigm

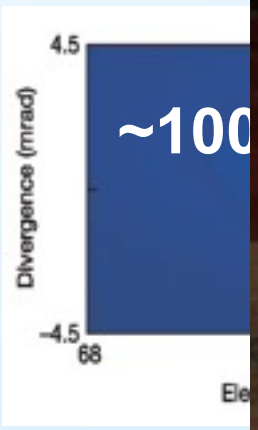


Leemans et al., IEEE Trans. Plasma Science (1996), Phys. Plasmas (1998)
Leemans and E. Esarey, Physics Today, March 2009
Esarey, Schroeder and Leemans, Rev. Mod. Phys (2009)

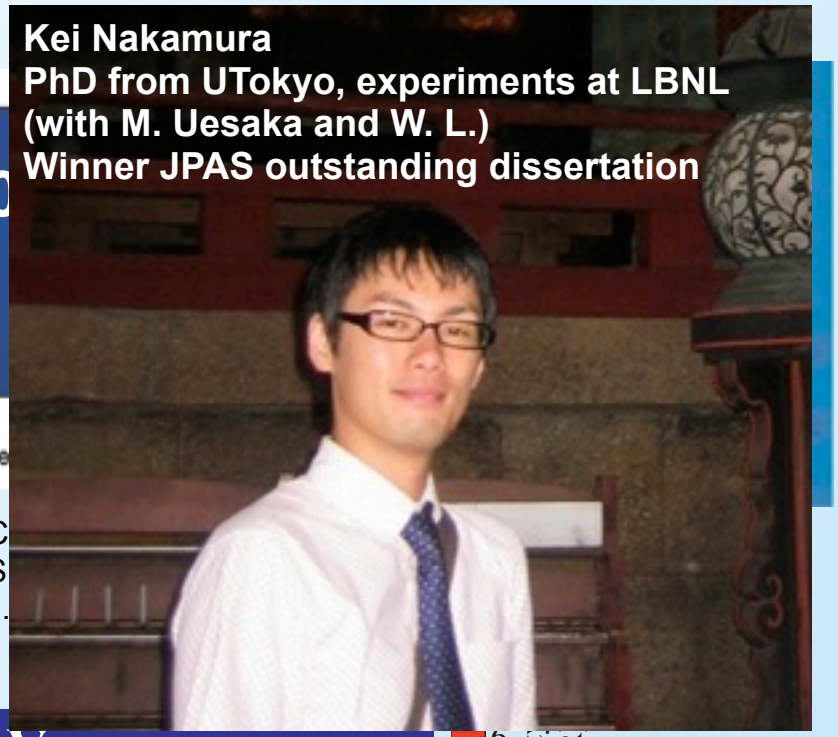
Channel guided laser plasma accelerators achieve high quality, up to GeV beams

2004 result: 10 TW laser, mm-scale plasma

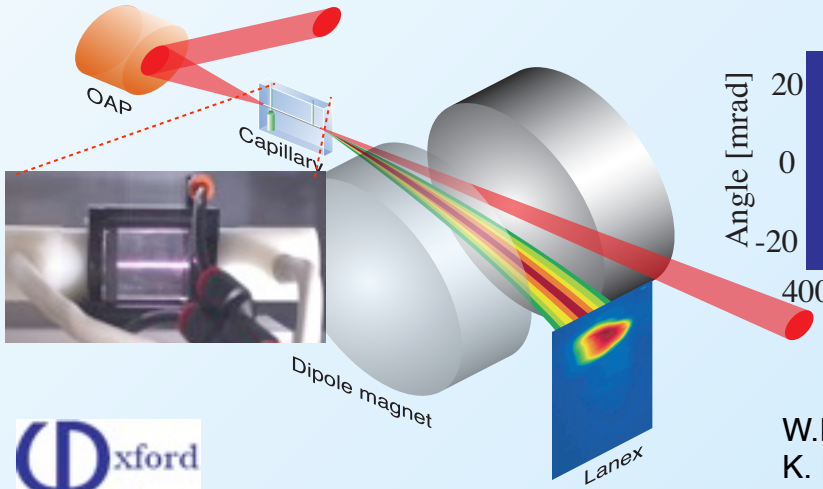


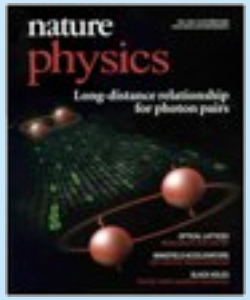


Kei Nakamura
PhD from UTokyo, experiments at LBNL (with M. Uesaka and W. L.)
Winner JPAS outstanding dissertation



2006 result: 40 TW laser, cm-scale plasma

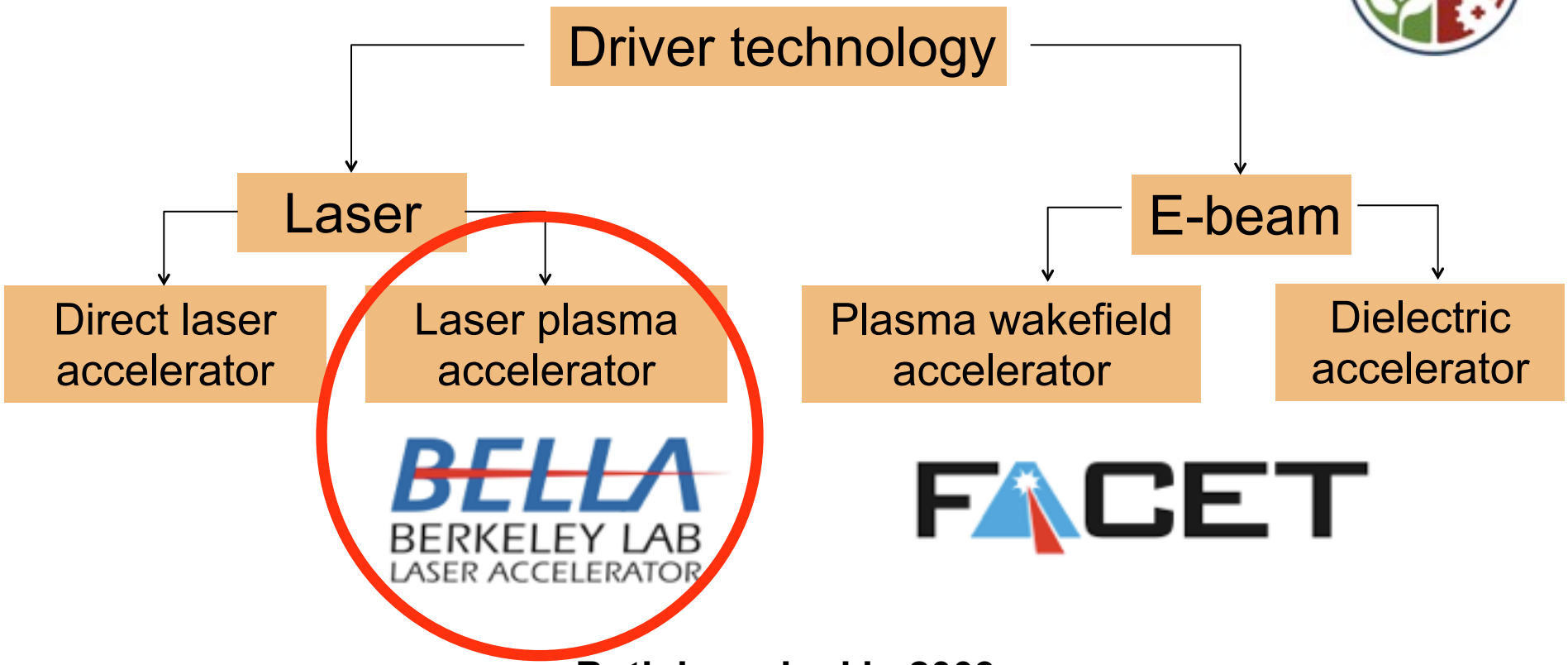




W.P. Leemans et. al, *Nature Physics* **2**, p696 (2006)
K. Nakamura et al., Phys. Plasmas **14,** 056708 (2007)

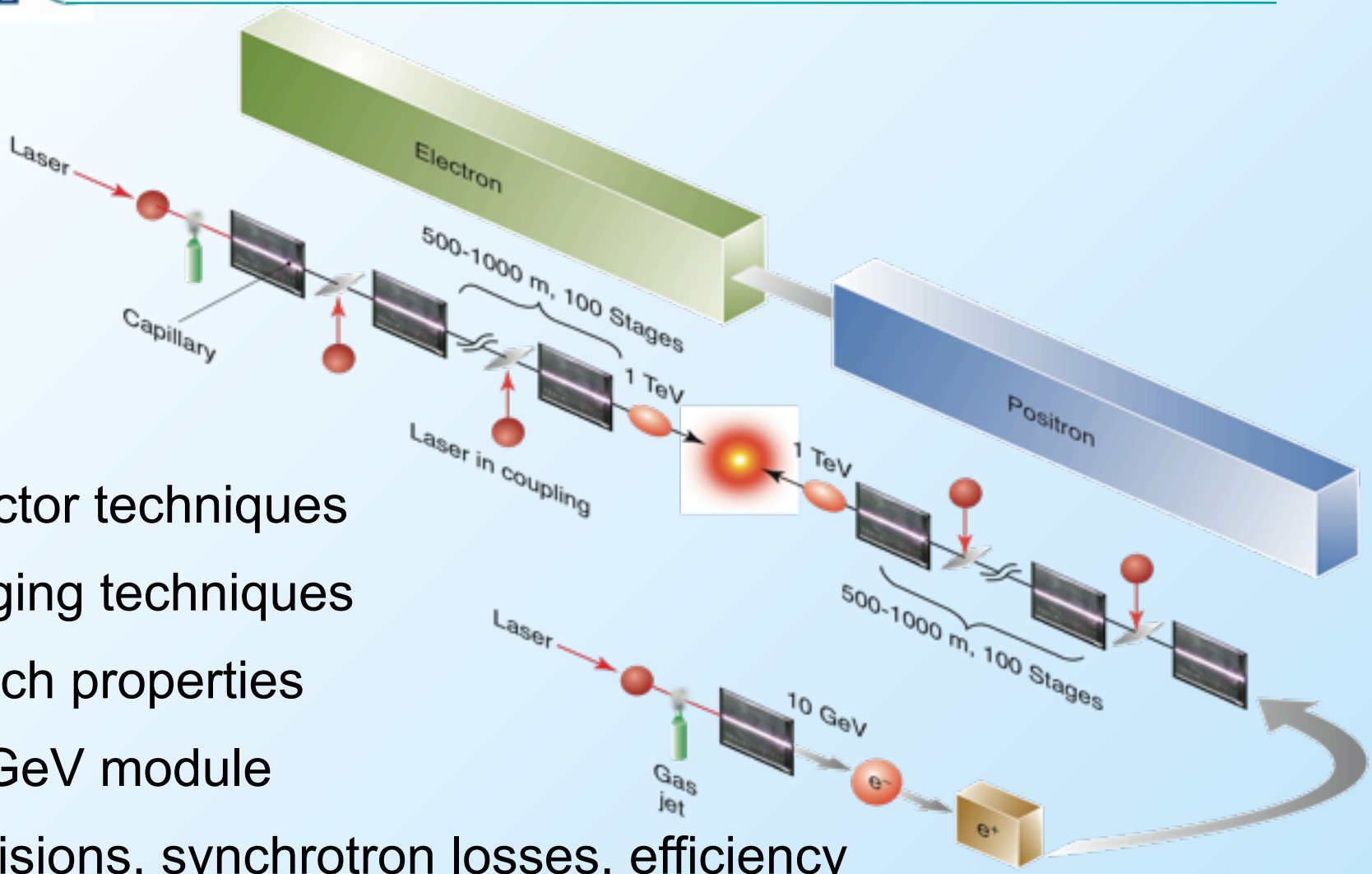
Major investments are being made in advanced plasma based accelerators

- Example: DOE-HEP has funded two facilities to explore high gradient acceleration



Both launched in 2009

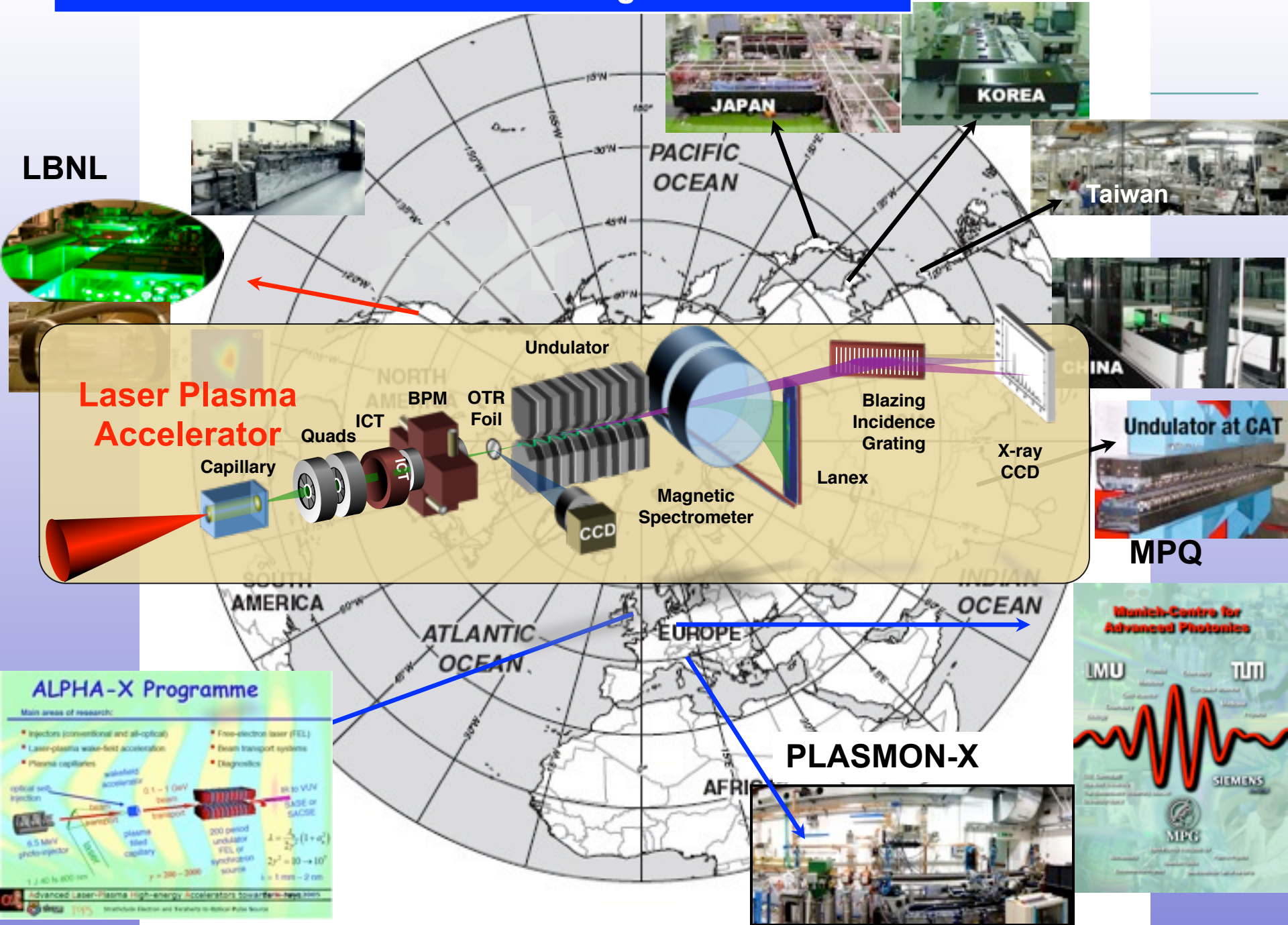
Concepts are being explored towards a Laser Plasma Linear Collider



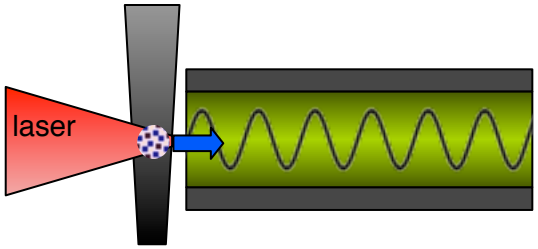
- Injector techniques
- Staging techniques
- Bunch properties
- 10 GeV module
- Collisions, synchrotron losses, efficiency

W. Leemans and E. Esarey, Physics Today (2009); C.B. Schroeder et al., PRST-AB 2010

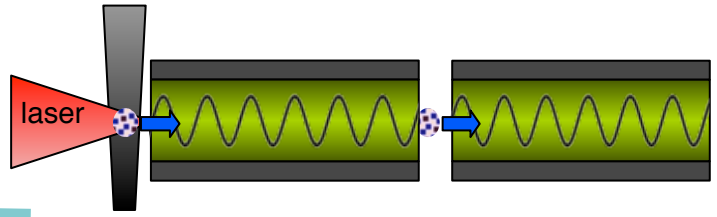
World-wide effort aimed at FEL using laser accelerator



Key technical challenges for Laser Plasma Accelerators



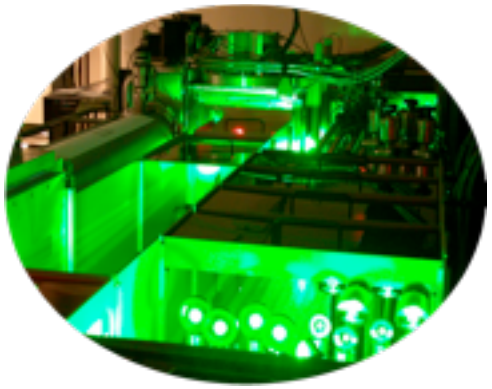
High quality beams



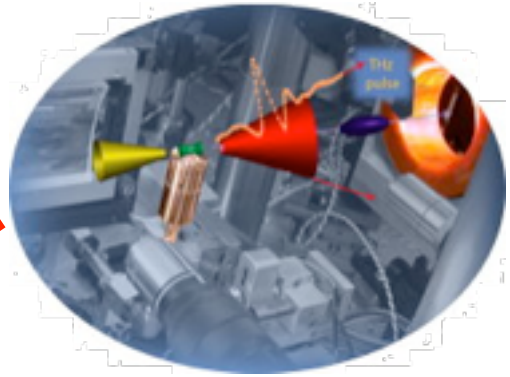
Staging, optimized structures

10-100 TW

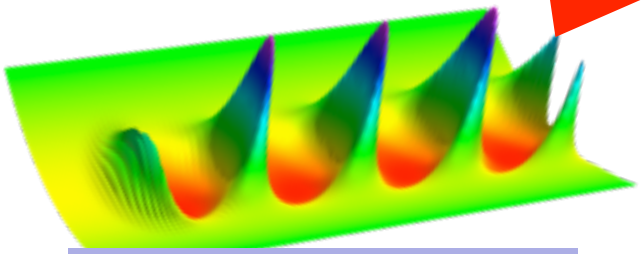
PW-class



Lasers: high average power



Diagnostics/Radiation sources



Modeling

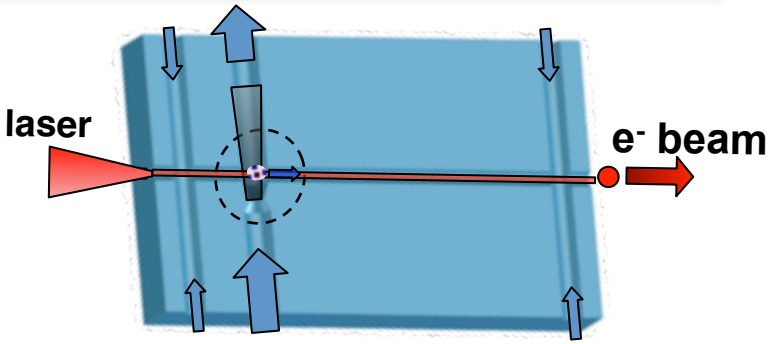
Multi-GeV beams

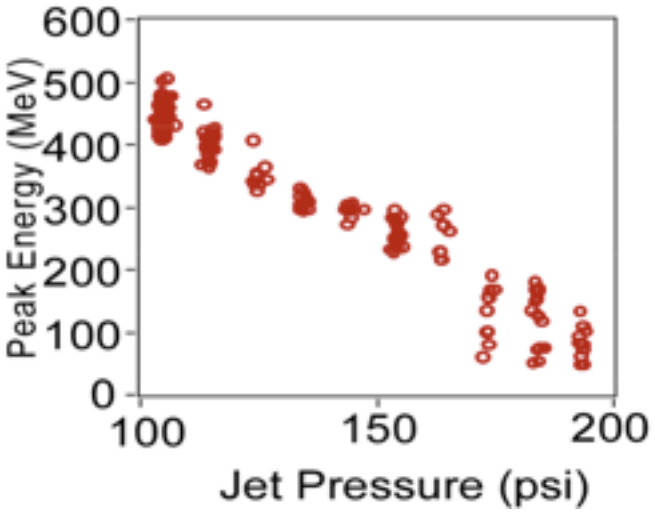
Electrons surfing on a wave: controlled injection

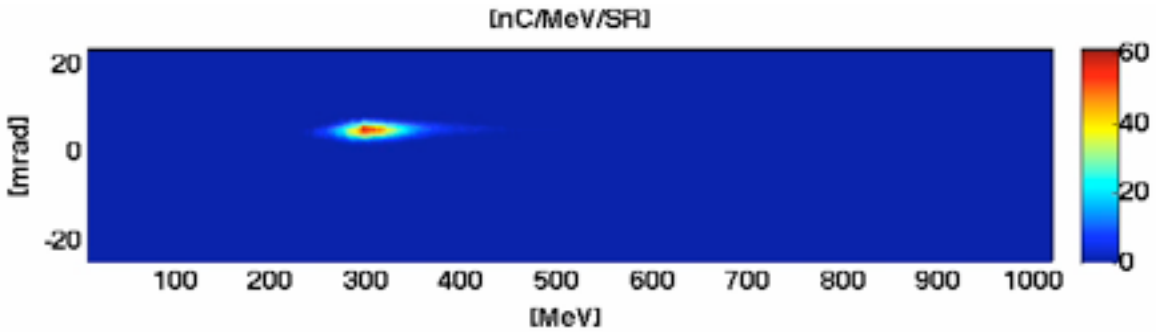
Since we are in Hawaii...

Techniques for improving beam quality, reproducibility, control being improved

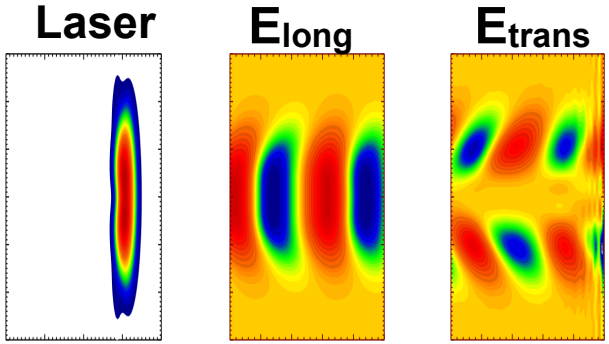
- Tunable energy, low ΔE/E



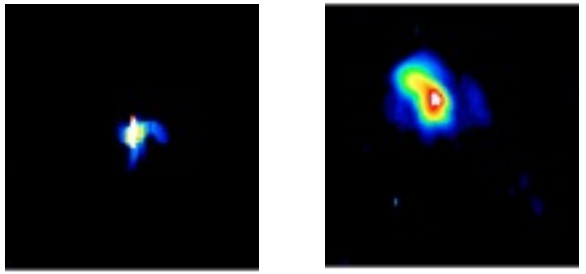




- Emittance control via laser mode

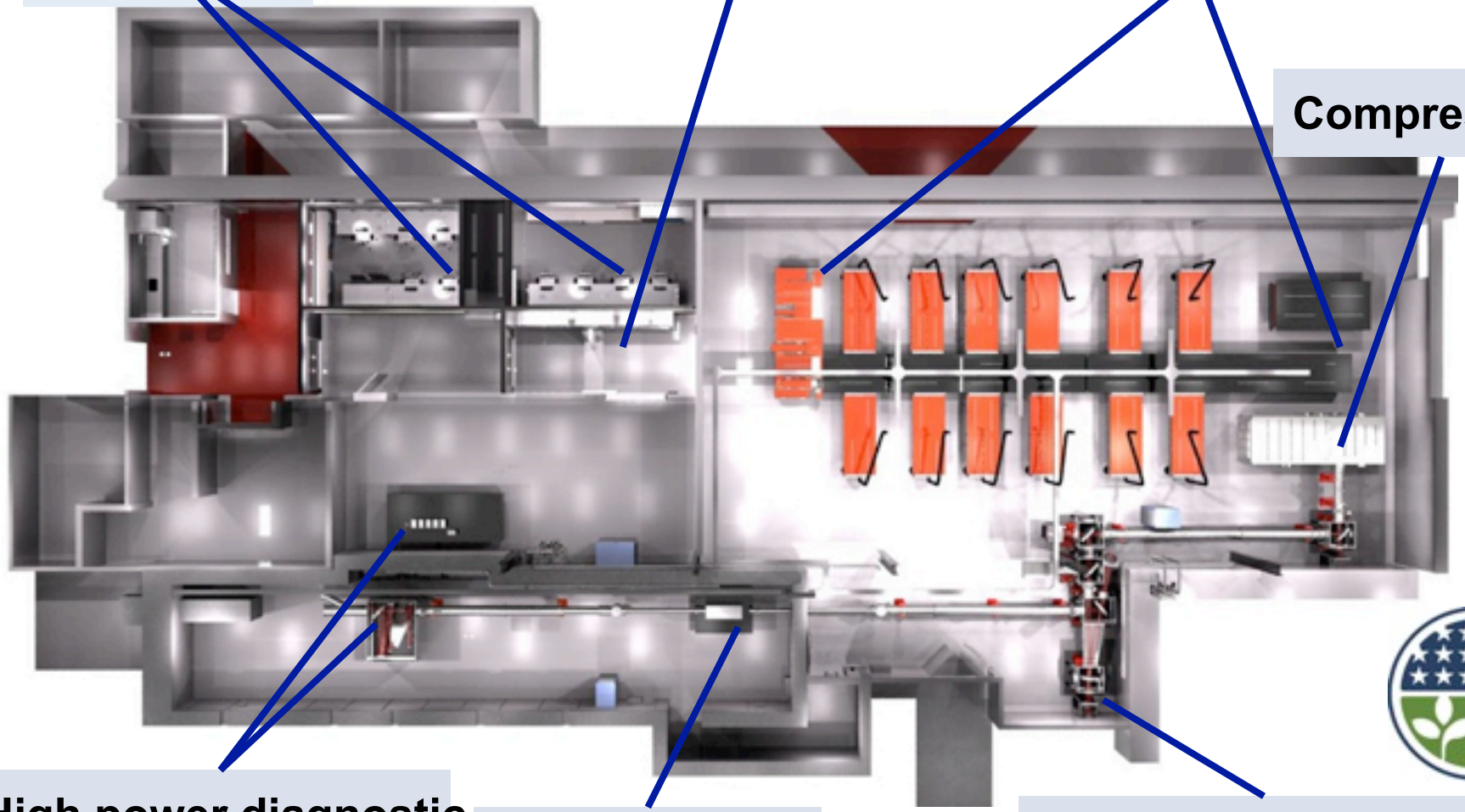


- Beam detection and transport



Coherent Optical Transition Radiation

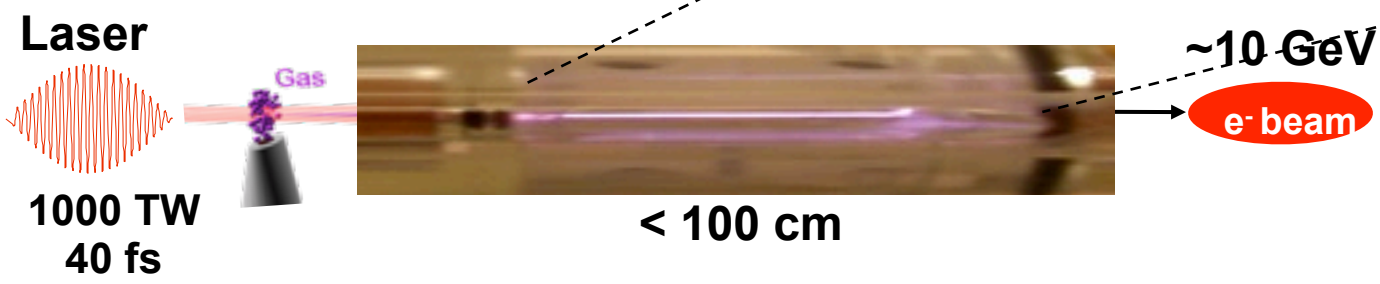
BELLA Facility: state-of-the-art PW-laser for laser accelerator science



BELLA laser opens significant opportunities

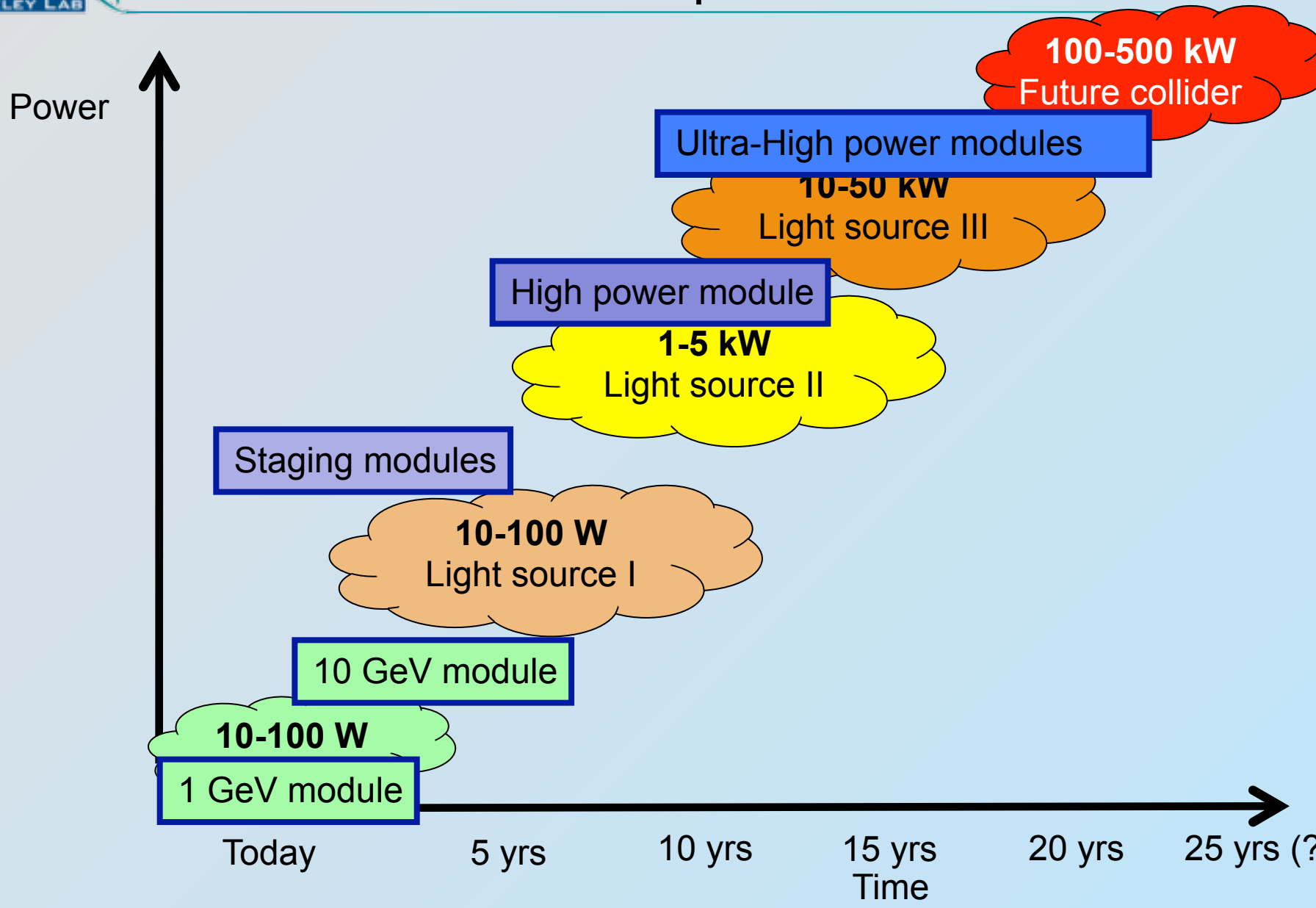
Lorentz boosted frame simulation
Full 1 m BELLA stage -- major advance
Courtesy of J.-L. Vay

2013 Experiments



- Accelerator science studies
  - 10 GeV Module for collider, (10 GeV, beam optimization, efficiency etc…)
  - Positron production; plasma wakefield acceleration, etc...
- Applications:
  - Hyperspectral radiation: coherent THz; X-ray FEL driver
  - Detector testing; Non-linear QED

Laser average power increase will enable more advanced laser plasma accelerator



Laser technology: key component for sustained progress

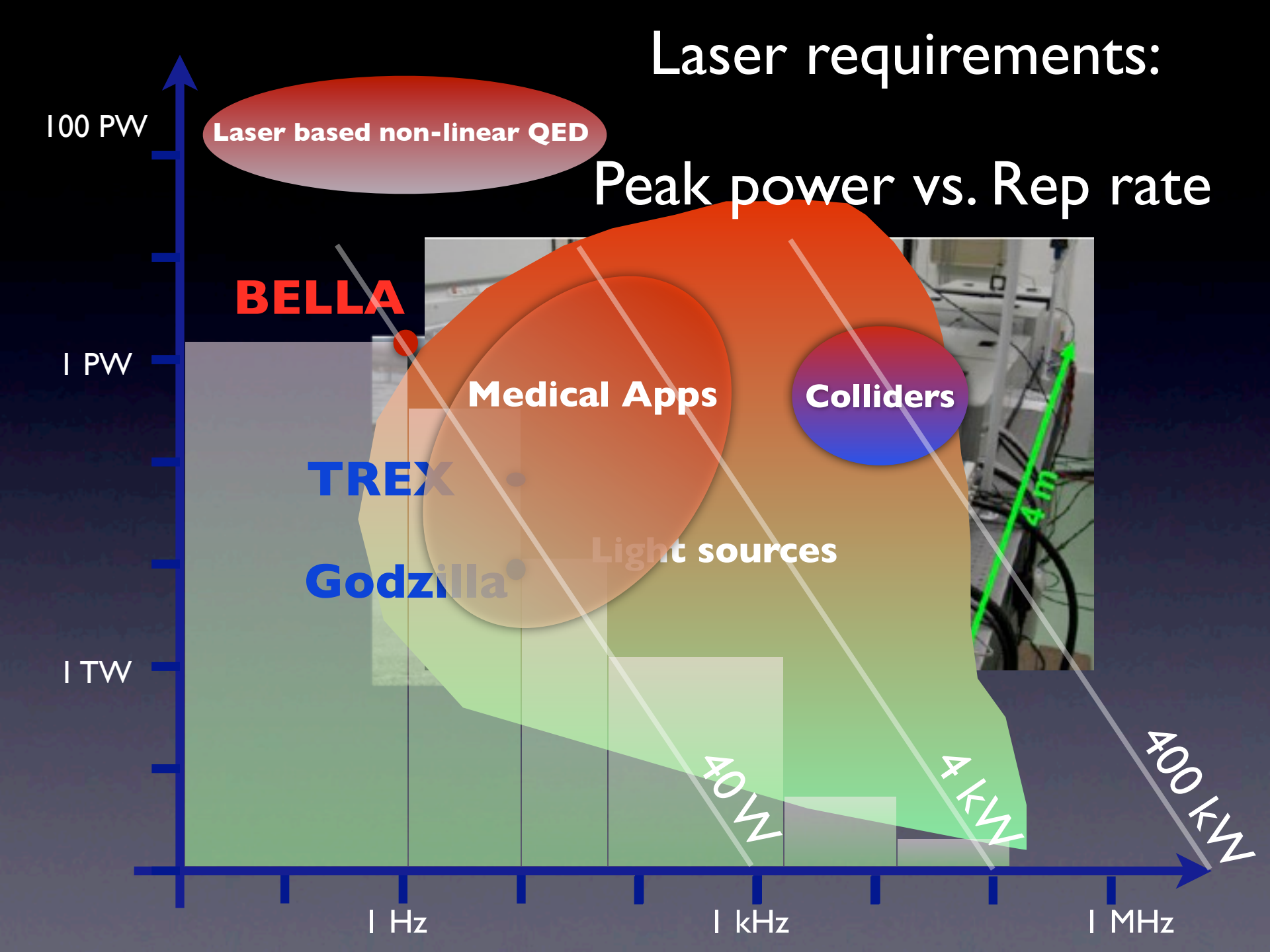
- How to reach laser average power levels needed for science?
- Develop roadmap for science and technology to develop next generation lasers:
  - Important for accelerators (see Accelerators for America's Future document)
  - Unique differences between lasers for defense and for science
  - Will require major research investment at National Labs, Universities and Industry with potential for international collaborations

ICFA-ICUIL Joint Task Force for Laser Technology: engaging two communities

- Joint ICFA-ICUIL taskforce on "**Roadmap for high average power laser technology for future accelerators**"
  - Leadership: Chou (ICFA-BD), Uesaka (ICFA-ANA), Leemans (JTF Chair, ICFA-ANA&ICUIL), Barty (ICUIL), Sandner (ICUIL)
- First Workshop by JTF held @ GSI, Darmstadt, April, 2010
  - 47 experts from accelerator and laser communities
  - Requirements on lasers for colliders, light sources, medical applications
  - Identifying promising laser technologies and bottlenecks
  - Developing strategic roadmap
  - Report in progress

Laser requirements:

Peak power vs. Rep rate



Novel lasers and materials are being developed

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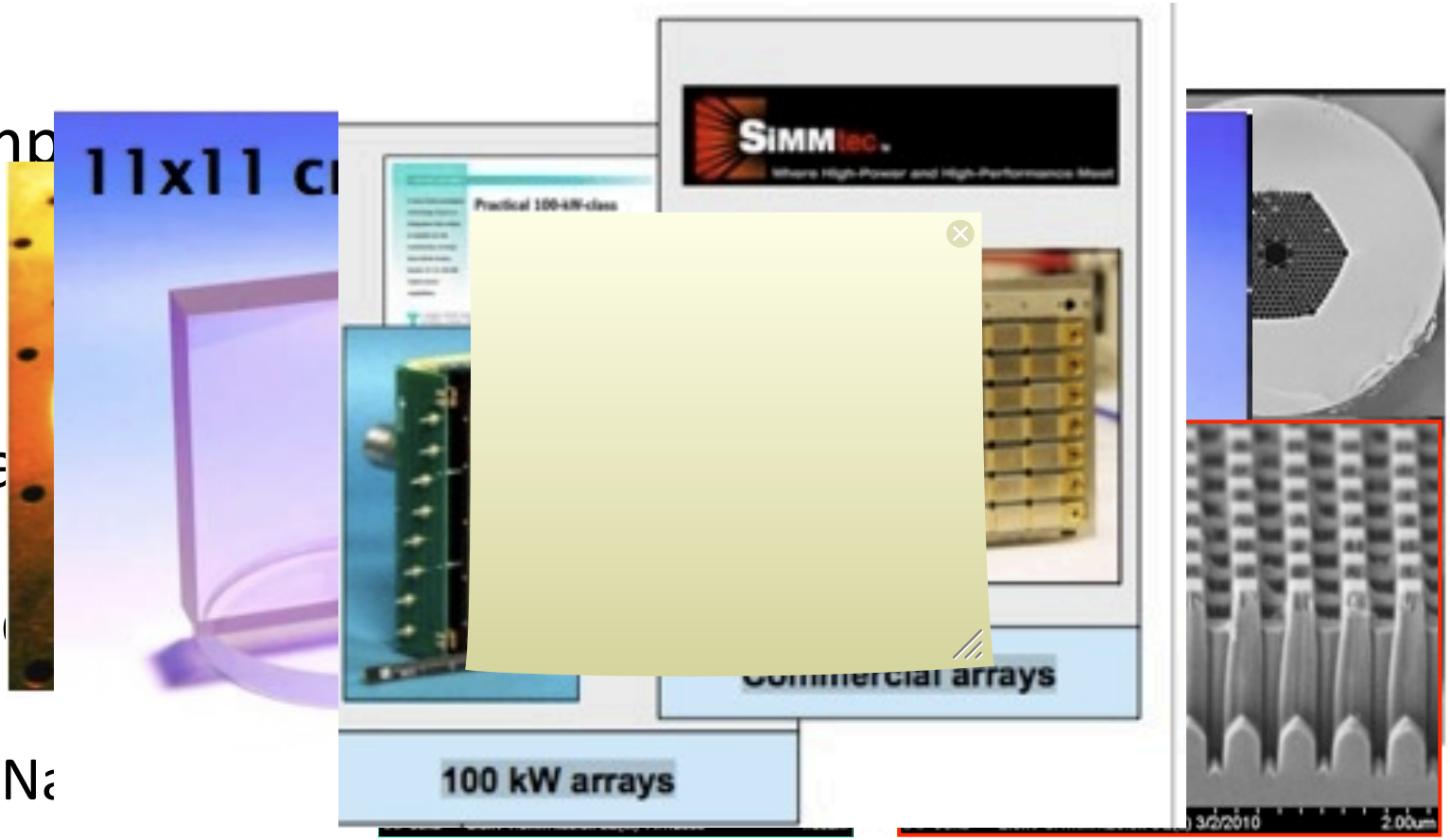
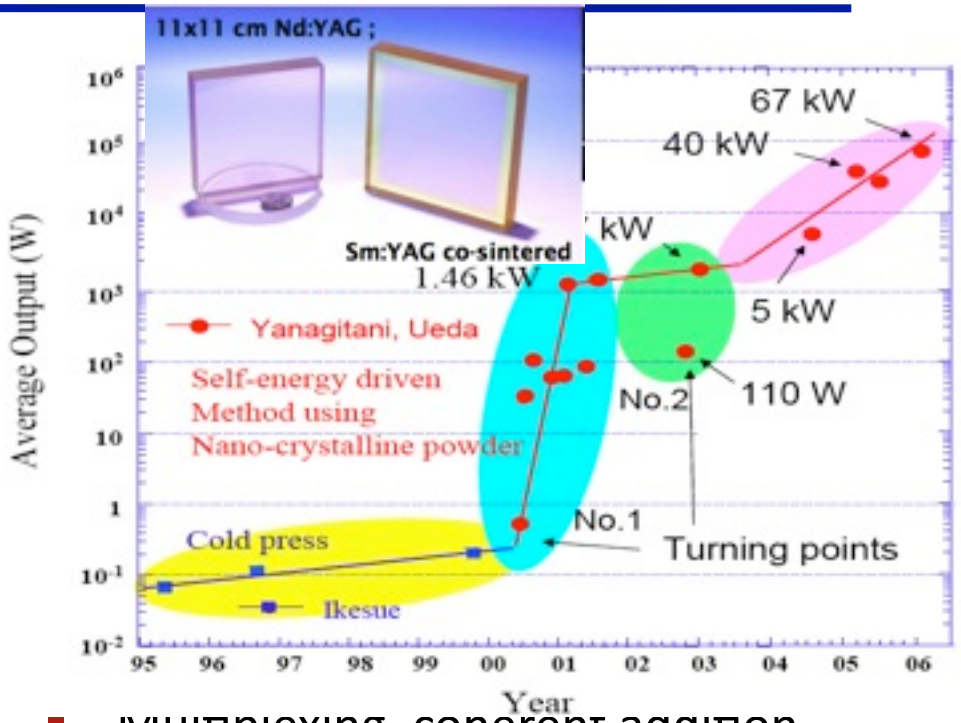


atings

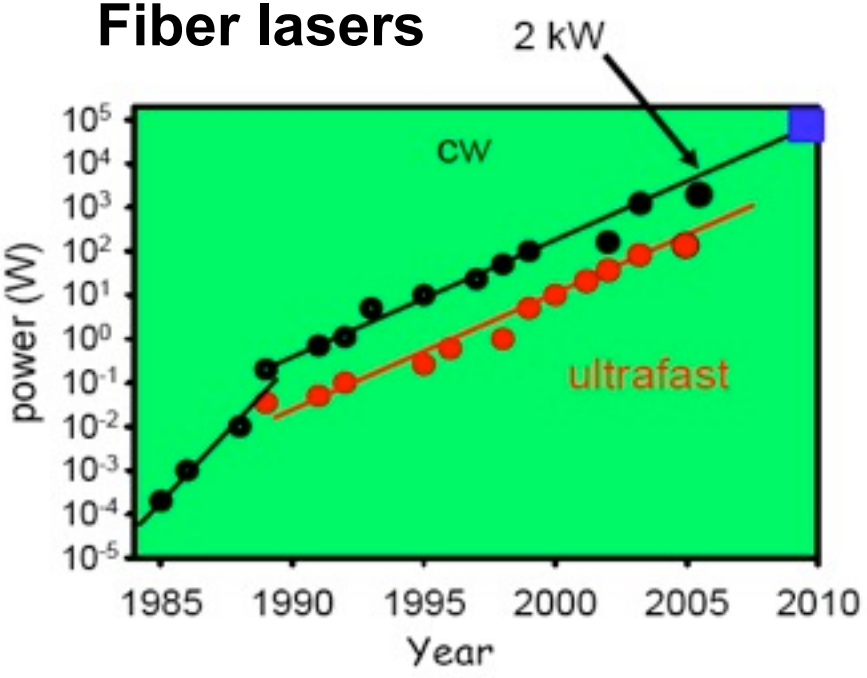
- Diodes and small quantum defect materials

Critical Technology:
Multi-kW lasers are being developed

Ceramic materials:
- Japan leading the world
- Promise for large scale sintered, engineered gain media

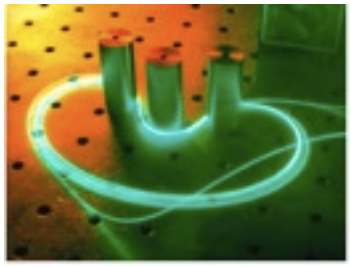


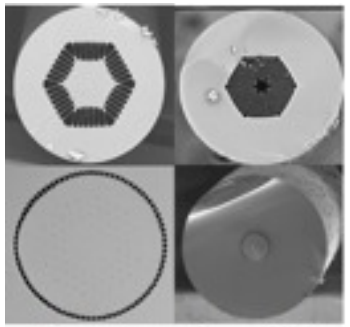
Fiber lasers



- Multiplexing, coherent addition

★ Two fibers recently demonstrated





Novel fiber designs, PCF

Courtesy: B. Byer and C. Barty

Major investments

- Example: European Extreme Light Infrastructure

- Four pillars (three funded at 790Meuro):

1. attosecond and XUV science: Hungary
2. High-brightness x-ray and particle sources: Czech Republic
3. Photo-nuclear science, transmutation,...: Romania
4. Ultra-high intensity science (non-lin QED): ???

www.eli-laser.eu

Conclusion

- Laser plasma accelerator science is vibrant
  - 10 GeV, high quality beams towards collider applications
  - FEL proof-of-principle experiments towards Light Source Facility
  - Gamma-ray sources
  - Medical and other applications
  - Attracting many students, postdocs into field
- Very significant investments being made around world:
  - Example: USA, Europe, Japan, China, Korea,…with collaborations
- “Big science” apps will require major investment in high average power laser technology
  - multi-kW (light sources, medical) to 100’s of kW (colliders), Petawatt lasers needed
  - Sustained, long range R&D needed for accelerator relevant lasers -- similar to klystron effort, 50 yrs ago
- Opportunities for US-Japan collaborative efforts