The Explosion of Intense Laser Activities Around the World and Related PW Activities at LLNL

10th DOE Laser Safety Workshop
Lawrence Livermore National Laboratory
August 19, 2014

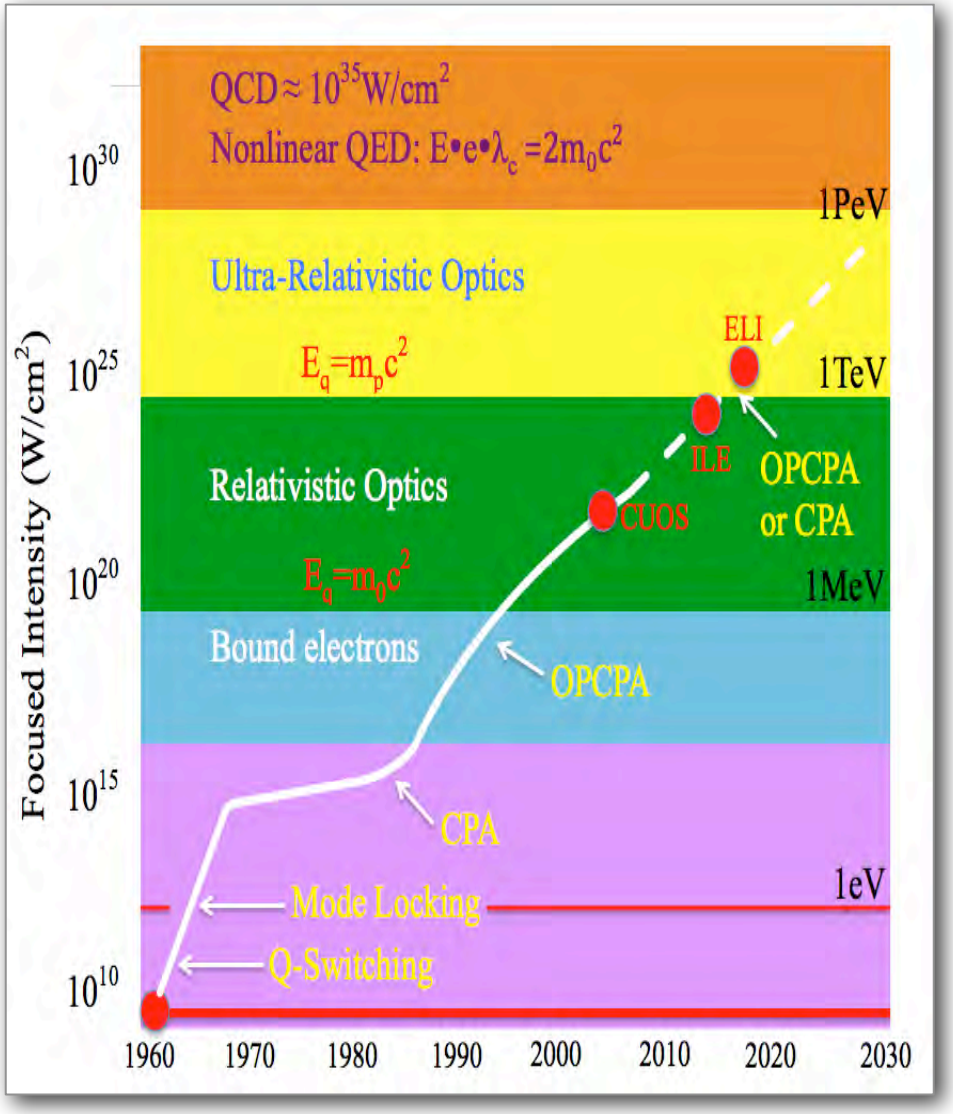
Dr. C. P. J. Barty

Chief Technology Officer
National Ignition Facility and Photon Science Directorate
Lawrence Livermore National Laboratory

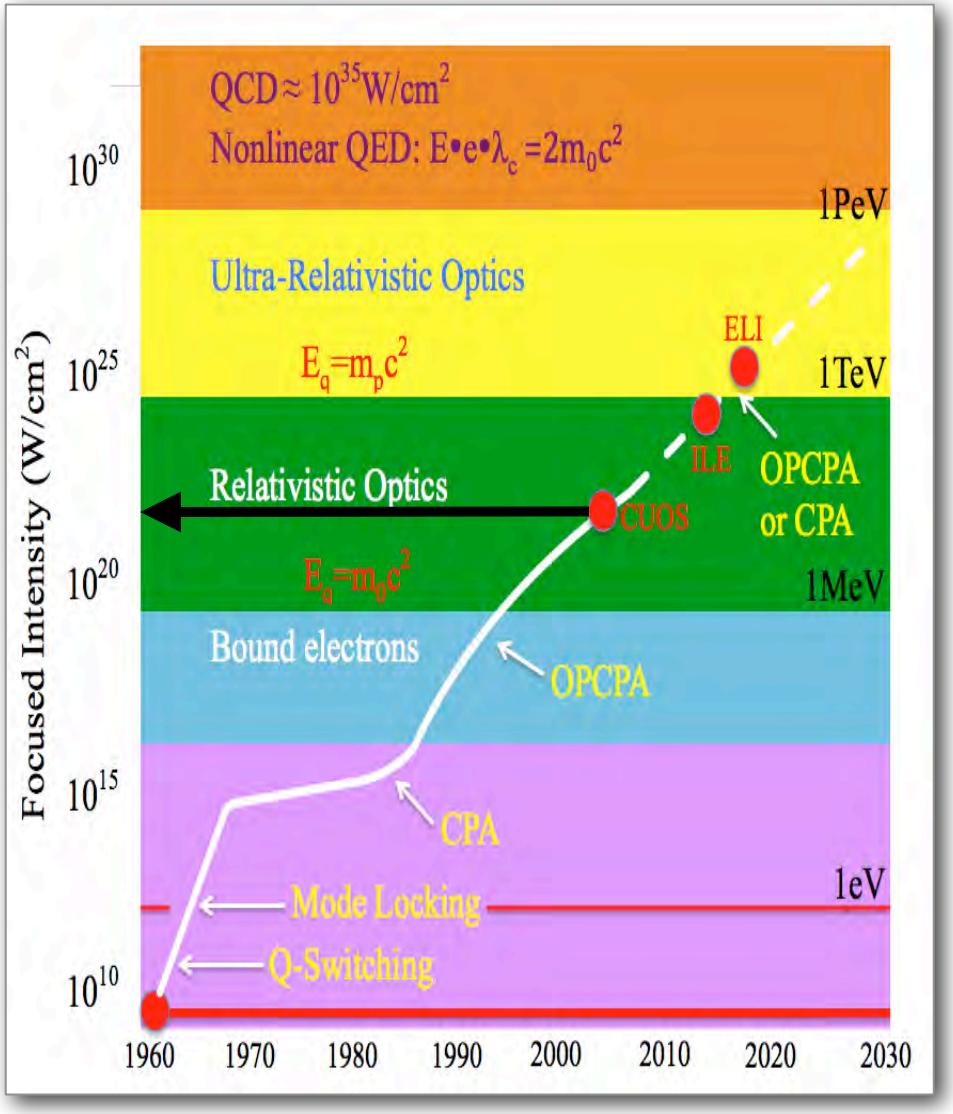
Co-chair
International Committee on Ultrahigh Intensity Lasers

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

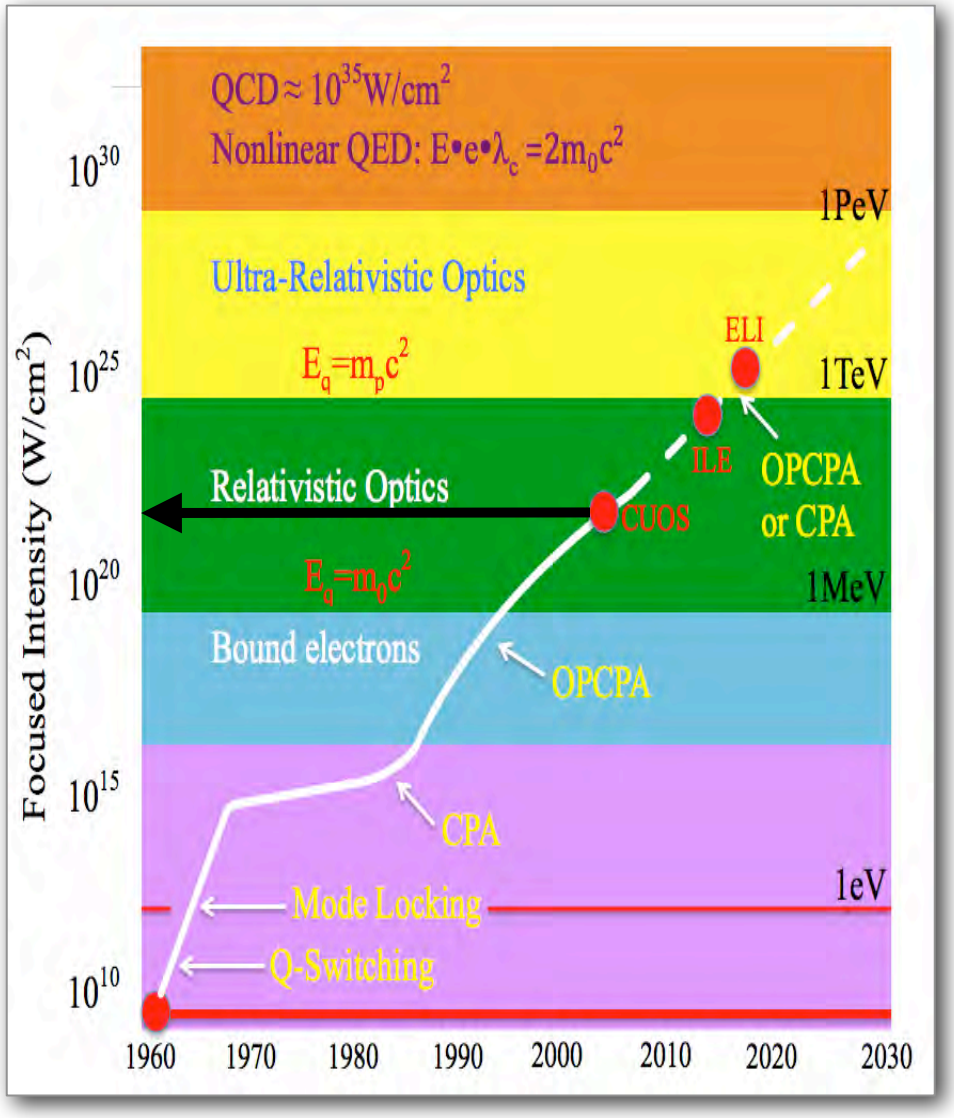
The pursuit of ultrahigh intensity science & apps is driving a world wide development of new capabilities



The pursuit of ultrahigh intensity science & apps is driving a world wide development of new capabilities



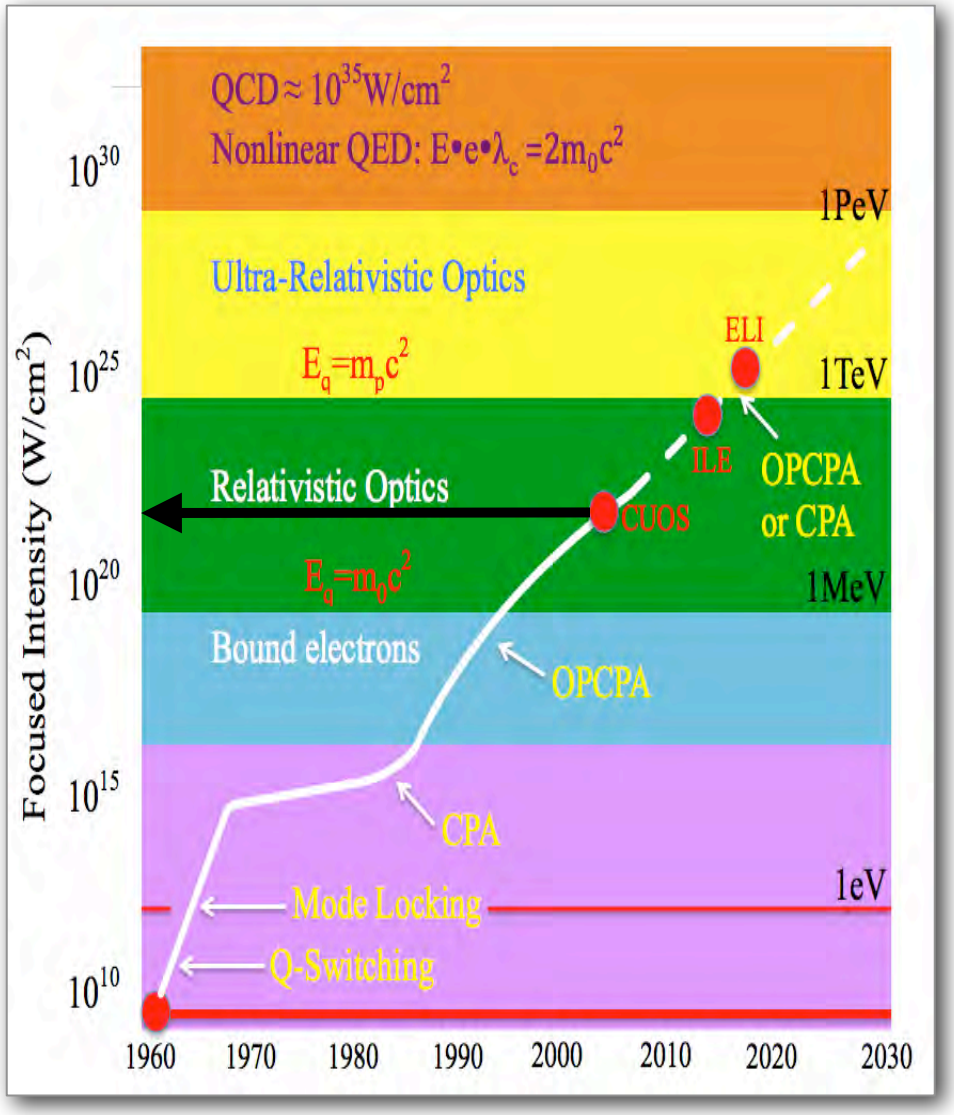
The pursuit of ultrahigh intensity science & apps is driving a world wide development of new capabilities



Opportunities at > 10^{23} W/cm^2

- **3.3x10^{12} J/cm^3 = 600 TonsTNT/cm^3 = 33 TBar photon pressure**
- **10-GeV unguided laser plasma accelerators**
  - **— table top x-ray FELS**
- **Relativistic proton and muon interactions**
  - **— compact hadron therapy**
- **Ultrafast ionization**
  - **— complete ionization through Zinc**
  - **— U^{82+} and Pu^{85+}**
- **Cluster fusion**
  - **— fusion materials lifetime testing**
- **Multi-GeV quiver energy and nuclear excitations**
- **e^+/e^-, p^+/p^-, pion production**
- **Relativistic vacuum nonlinear optics**
  - **— blue photons from “nothing”!**

The pursuit of ultrahigh intensity science & apps is driving a world wide development of new capabilities



Opportunities at > 10^{23} W/cm^2

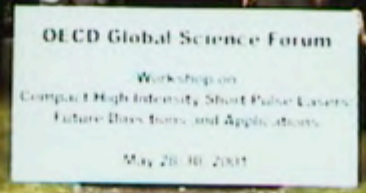
- **3.3x10^{12} J/cm^3 = 600 TonsTNT/cm^3 = 33 TBar photon pressure**
- 10-GeV unguided laser plasma accelerators
  — table top x-ray FELS
- Relativistic proton and muon interactions
  — compact hadron therapy
- Ultrafast ionization
  — complete ionization through Zinc
  — U^{82+} and Pu^{85+}
- Cluster fusion
  — fusion materials lifetime testing
- Multi-GeV quiver energy and nuclear excitations
- e^+/e^-, p^+/p^-, pion production
- **Relativistic vacuum nonlinear optics**
  — blue photons from "nothing"!

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”

May 28-30, 2001, JAERI, Kyoto, Japan

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”

2002 Jan - Proposal to Establish OCED GSF Coordinating Committee on “CHISP” Lasers



May 28-30, 2001, JAERI, Kyoto, Japan

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”

2002 Jan - Proposal to Establish OCED GSF Coordinating Committee on “CHISP” Lasers

2002 Dec - OCED GSF Coordinating Committee on “CHISP” Lasers meets at LLNL

May 28-30, 2001, JAERI, Kyoto, Japan

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”

2002 Jan - Proposal to Establish OCED GSF Coordinating Committee on “CHISP” Lasers

2002 Dec - OCED GSF Coordinating Committee on “CHISP” Lasers meets at LLNL

2003 Sept - OCED GSF Coordinating Committee on “CHISP” Lasers defines ICUIL Charter

May 28-30, 2001, JAERI, Kyoto, Japan

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”

2002 Jan - Proposal to Establish OCED GSF Coordinating Committee on “CHISP” Lasers

2002 Dec - OCED GSF Coordinating Committee on “CHISP” Lasers meets at LLNL

2003 Sept - OCED GSF Coordinating Committee on “CHISP” Lasers defines ICUIL Charter

2003 Oct - Proposal is made to IUPAP Executive Council to form ICUIL (patterned after ICFA)

May 28-30, 2001, JAERI, Kyoto, Japan

2001 May - OECD GSF Workshop on “Compact, High Intensity, Short Pulse Lasers”
2002 Jan - Proposal to Establish OCED GSF Coordinating Committee on “CHISP” Lasers
2002 Dec - OCED GSF Coordinating Committee on “CHISP” Lasers meets at LLNL
2003 Sept - OCED GSF Coordinating Committee on “CHISP” Lasers defines ICUIL Charter
2003 Oct - Proposal is made to IUPAP Executive Council to form ICUIL (patterned after ICFA)
2004 Feb - ICUIL Kickoff Meeting (10 laser lab members, 6 user community members)

The International Committee on Ultra-High Intensity Lasers

About ICUIL

Objectives

The International Committee on Ultra-High Intensity Lasers (ICUIL) is an organization concerned with international aspects of ultra-high intensity laser science, technology and education.

History

Charter

Committee

The objectives of ICUIL

- To provide a venue for discussions among representatives of high-intensity laser facilities and members of user communities, on international collaborative activities such as the development of the next generation of ultrahigh intensity lasers, exploration of new areas of fundamental and applied research, and formation of a global research network for access to advanced facilities by users.
- To promote unity and coherence in the field by convening conferences and workshops dedicated to ultrahigh intensity lasers and their applications.
- To accelerate progress in the field by sharing information, exploring opportunities for joint procurement, and exchanging equipment, ideas and personnel among laser laboratories world-wide.
- To attract students to high-field science by promoting their education and training, their interactions with prominent scientists, and access to the latest equipment, results and techniques.
- To strengthen and exploit synergy with other relevant fields and techniques, notably accelerator-based free electron lasers.

The International Committee on Ultra-High Intensity Lasers

About ICUIL

Objectives

The International Committee on Ultra-High Intensity Lasers (ICUIL) is an organization concerned with international aspects of ultra-high intensity laser science, technology and education.

History

Charter

Committee

The objectives of ICUIL

- To provide a venue for discussions among representatives of high-intensity laser facilities and members of user communities, on international collaborative activities such as the development of the next generation of ultrahigh intensity lasers, exploration of new areas of fundamental and applied research, and formation of a global research network for access to advanced facilities by users.
- To promote unity and coherence in the field by convening conferences and workshops dedicated to ultrahigh intensity lasers and their applications.
- To accelerate progress in the field by sharing information, exploring opportunities for joint procurement, and exchanging equipment, ideas and personnel among laser laboratories world-wide.
- To attract students to high-field science by promoting their education and training, their interactions with prominent scientists, and access to the latest equipment, results and techniques.
- To strengthen and exploit synergy with other relevant fields and techniques, notably accelerator-based free electron lasers.

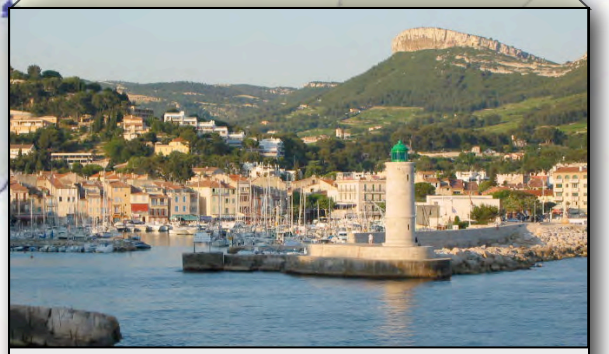
Biennial International Conference on Ultrahigh Intensity Lasers

ICUIL 2010 Watkins Glen

ICUIL 2012 Mamaia

ICUIL 2008 Tongli

ICUIL 2004 Lake Tahoe



ICUIL 2006 Cassis

ICUIL 2014 Goa

The International Committee on Ultra-High Intensity Lasers

About ICUIL

Objectives

The International Committee on Ultra-High Intensity Lasers (ICUIL) is an organization concerned with international aspects of ultra-high intensity laser science, technology and education.

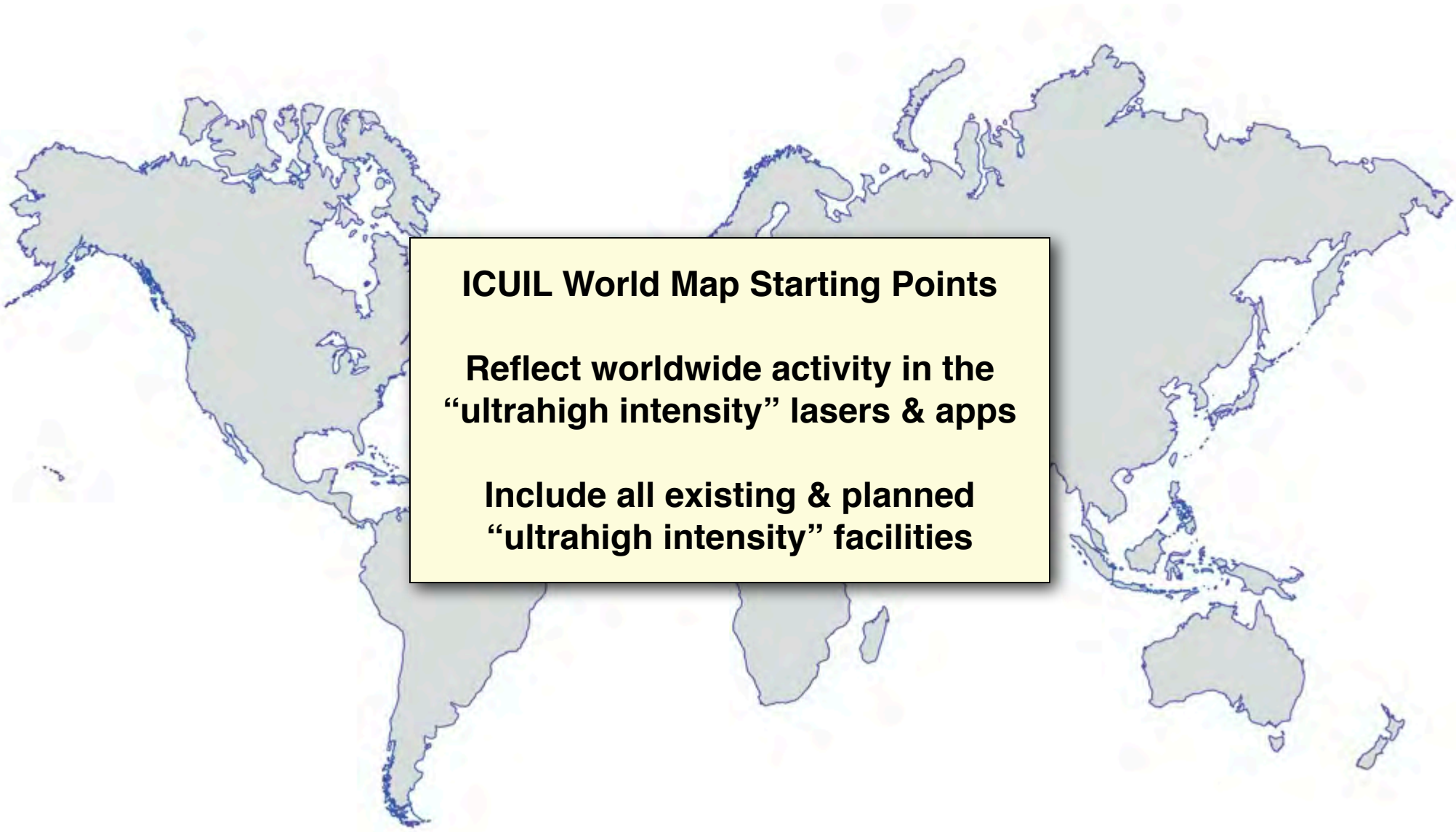
History

Charter

Committee

The objectives of ICUIL

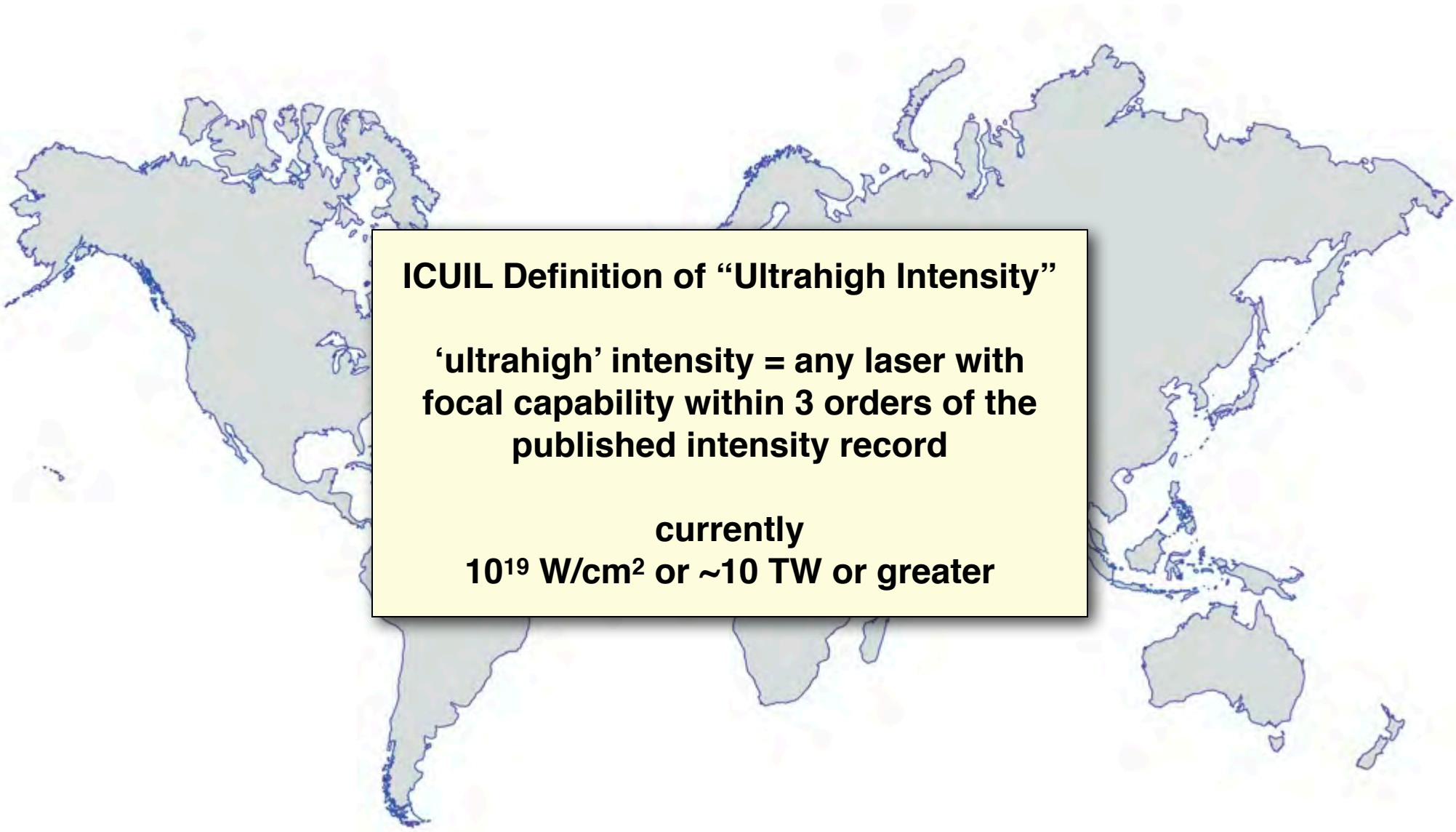
- To provide a venue for discussions among representatives of high-intensity laser facilities and members of user communities, on international collaborative activities such as the development of the next generation of ultrahigh intensity lasers, exploration of new areas of fundamental and applied research, and formation of a global research network for access to advanced facilities by users.
- To promote unity and coherence in the field by convening conferences and workshops dedicated to ultrahigh intensity lasers and their applications.
- To accelerate progress in the field by sharing information, exploring opportunities for joint procurement, and exchanging equipment, ideas and personnel among laser laboratories world-wide.
- To attract students to high-field science by promoting their education and training, their interactions with prominent scientists, and access to the latest equipment, results and techniques.
- To strengthen and exploit synergy with other relevant fields and techniques, notably accelerator-based free electron lasers.



ICUIL World Map Starting Points

Reflect worldwide activity in the "ultrahigh intensity" lasers & apps

Include all existing & planned "ultrahigh intensity" facilities

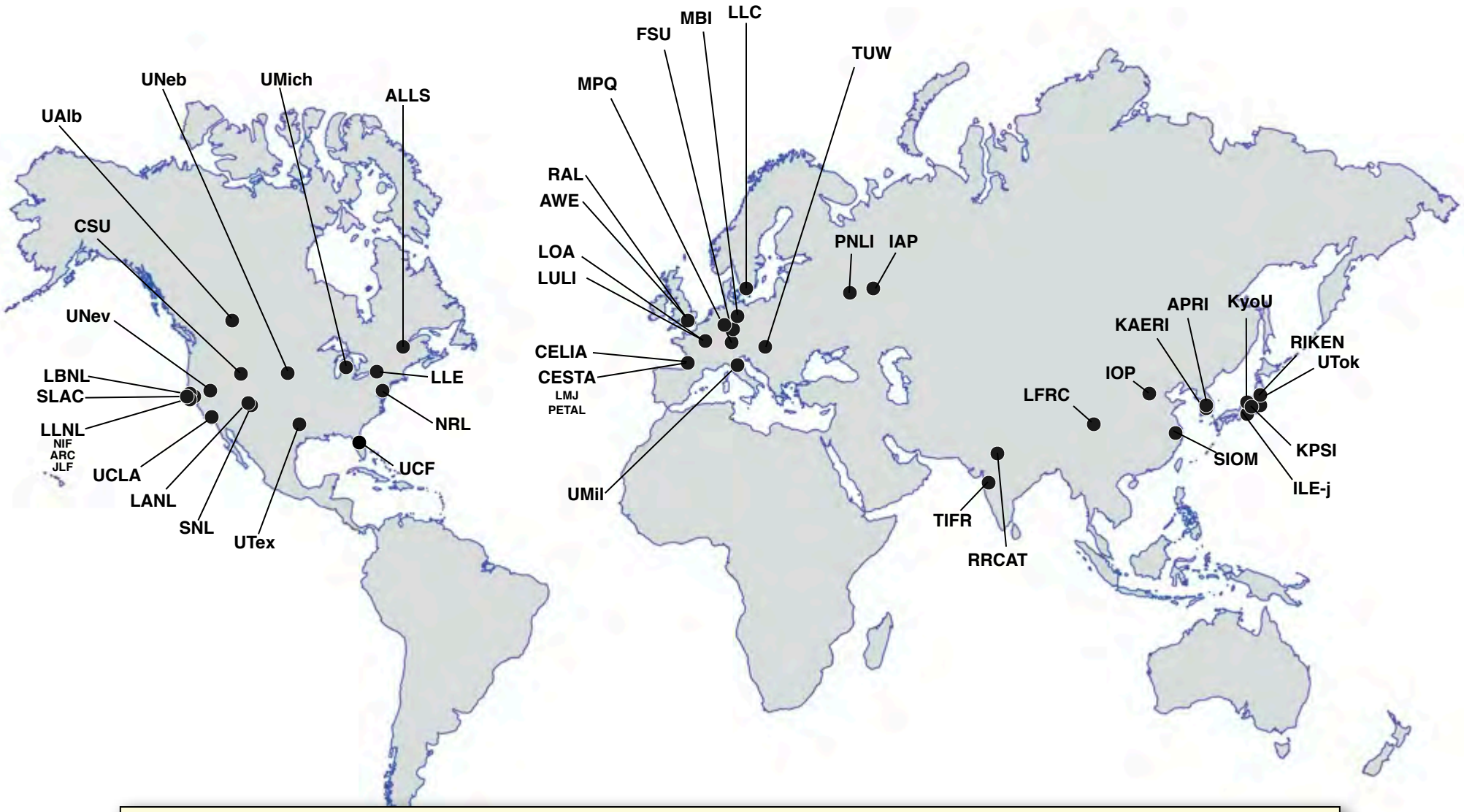


ICUIL Definition of "Ultrahigh Intensity"

'ultrahigh' intensity = any laser with focal capability within 3 orders of the published intensity record

currently
10^{19} W/cm^2 or ~10 TW or greater

2009 ICUIL World Map of Ultrahigh Intensity Laser Capabilities



Labels represent the establishments with physical and administrative responsibility for the ultrahigh intensity laser system or facility

ICUIL world map label	full name	country	city	region	tact	contact first name	contact last name	ta	email	email y/n	reply y/n	file y/n	photo y/n/w	info y/n/w	map y/n	web site	comments	present status	planned capability
ALLS	Advanced Laser Light Source	Canad	Varenn	North Ame	Dr.	Tsuneyuk	Ozaki	D	ozaki@emt.ir	y	y	y	y	y	y	http://lmn.emt.ir	limited we	200 TW 10 Hz	200 TW
ALLS	Advanced Laser Light Source	Canad	Varenn	North Ame	Dr.	Jean-Cla	Keiffer	D	none	n	n	n	n	y	y	http://lmn.emt.ir	from Canc	200 TW 10 Hz	200 TW
APRI	Advanced Photon Research Institute	Korea	Gwang	Asia	rof.	Jongmin	Lee	D	leejm@gist.a	y	y	y	y	y	y	http://apri.gist.a	good mat	00 TW and 1 PW	
APRI	Advanced Photon Research Institute	Korea	Gwang	Asia	Dr.	Tae Moor	Jeong	D	jeongtm@gis	y	n	n	n	n	y	http://apri.gist.a	no respon	00 TW and 1 PW	
APRI	Advanced Photon Research Institute	Korea	Gwang	Asia	Dr.	Chul Min	Kim	D	chulmin@gis	y	n	n	n	n	y	http://apri.gist.a	no respon	00 TW and 1 PW	
APRI	Advanced Photon Research Institute	Korea	Gwang	Asia	Dr.	Do-Kyeor	Ko	D	dkko@gist.ac	y	y	y	y	y	y	http://apri.gist.a	good mat	00 TW and 1 PW	
AWE	Atomic Weapons Establishment	Englan	Alderm	Europe	Dr.	David	Hillier	D	david.hillier@	y	n	n	n	n	y	www.awe.co.uk	orion lase	1 PW	
AWE	Atomic Weapons Establishment	Englan	Alder													w.awe.co.uk	10 long pu	1 PW	
AWE	Atomic Weapons Establishment	Englan	Alder													w.awe.co.uk	orion lase	1 PW	
BARC	Bhabha Atomic Research Centre	India	Mum													://www.barc	relatively l	<1 TW	1 TW
CELIA	Centre Lasers Intenses et Applicatio	France	Bord													://www.celia	info from E	5 TW	50 TW
CELIA	Centre Lasers Intenses et Applicatio	France	Bord													://www.celia.u-bordeau		5 TW	50 TW
CESTA	CEA le Commissariat à l'énergie ato	France	Bord													://www.cea.fr/le_cea/le		<1 PW	multi PW
CLPU	Centro de Laseres Pulsados (Pusec	Spain	Salan													://campus.u	from Canc	100 TW 10 Hz	
CREIPI	Central Research Institute of Electri	Japan	Yoko													://criepi.den	from Andr	40 TW	
ELI ALPS	Extreme Light Infrastructure Attosec	Hunga	Szeg													://www.eli-hungary.hu/		0 TW	PW few Hz
ELI ALPS	Extreme Light Infrastructure Attosec	Hunga	Szeg													://www.eli-hungary.hu/		0 TW	PW few Hz
ELI Beams	Extreme Light Infrastructure Czech I	Czech	Pragu													://www.eli-beams.eu/		0 TW	PW few Hz
ELI EF	Extreme Light Infrastructure Extrem	EU	TBD													://www.extreme-light-in		0 TW	200 PW
ELI NP	Extreme Light Infrastructure Nuclea	Romar	Buch													://www.eli-np.ro/		0 TW	2x 10 PW
ELI NP	Extreme Light Infrastructure Nuclea	Romar	Buchar	Europe	Dr.	Dan	Dumitras	D	dan.dumitras	y	y	y	y	y	y	http://www.eli-np.ro/		0 TW	2x 10 PW
FSU	IOQ/Friedrich Schiller University of	Germa	Jena	Europe	Dr.	Joachim	Hein	D	joachim.hein	y	y	y	y	y	y	http://www.phys	polaris A4	30 TW	350 TW
FSU	IOQ/Friedrich Schiller University of	Germa	Jena	Europe	Dr.	G.G.	Paulus	D	none	n	n	n	n	y	y	http://www.phys	from Canc	100 TW 10 Hz	
GSI	GSI-Helmholtzzentrum fuer Schweri	Germa	Darmst	Europe	Dr.	Thomas	Kuehl	D	t.kuehl@gsi.c	y	y	y	y	y	y	http://www.gsi.d	currently a	300 TW	600 TW
GSI	GSI-Helmholtzzentrum fuer Schweri	Germa	Darmst	Europe	Dr.	Vincent	Bagnoud	D	v.bagnoud@g	y	y	y	y	y	y	http://www.gsi.d	no respon	300 TW	600 TW
HHU	Heinrich-Heine-University Dusseldo	Germa	Dussel	Europe	Dr.	Fabian	Budde	D	f.budde@uni	y	n	n	n	n	y	http://www.uni-c	no respon	TW & 200 TW 10 Hz	
HHU	Heinrich-Heine-University Dusseldo	Germa	Dussel	Europe	Dr.	O.	Willi	D	none	n	n	n	n	y	y	http://www.uni-c	2 beam fa	TW & 200 TW 10 Hz	
HZDR	Research Center Dresden-Rossend	Germa	Dresde	Europe	rof.	Roland	Sauerbrey	D	r.sauerbrey@	y	y	n	n	y	y	www.fzd.de/fwt	200 TW 1(	200 TW 10 Hz	
HZDR	Research Center Dresden-Rossend	Germa	Dresde	Europe	Dr.	Ulrich	Schramm	D	u.schramm@	y	y	y	y	y	y	www.fzd.de/fwt	claims sin	150 TW 10 Hz	500 TW 1 PW
IAMS	Institute for Atomic and Molecular S	Taiwar	Taipai	Asia	Pro	Szu-yuan	Chen	D	none	n	n	n	w	w	y	http://www.iams	from web	10 TW	
IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Efim	Khazanov	D	khazanov@a	y	y	y	y	y	y	http://www.ipfra	910 nm O	560 TW	10 PW
IAP	Russian Academy of Sciences	Russia	Nizhny	Europe	Dr.	Arkady	Gonoskov	D	arkady.gonos	y	n	n	n	n	y	http://www.ipfra	see claims	560 TW	10 PW

Update to ICUIL World Map

130 individuals poled

100+ responses

100+ ppt, pdf and jpeg files sent

300+ pages of info and pictures received

IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Artem	Korzhiman	D	kav@ufp.app	y	n	n	n	n	y	http://www.ipfra	see claims	560 TW	10 PW
IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Igor	Kostyukov	D	kost@appl.sc	y	n	n	n	n	y	http://www.ipfra	see claims	560 TW	10 PW
IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Alexande	Sergeev	D	ams@ufp.ap	y	y	y	y	y	y	http://www.ipfra	same as a	560 TW	10 PW
IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Igor	Kostyukov	D	kost@appl.sc	y	n	n	n	n	y	http://www.ipfra	see claims	560 TW	
IAP	Institute of Applied Physics Russian	Russia	Nizhny	Europe	Dr.	Alexande	Sergeev	D	ams@ufp.ap	y	y	y	y	y	y	http://www.ipfra	same as a	560 TW	
IHCE	Institute of High Current Electronics	Russia	Tomsk	Europe	Dr.	Leonid	Mikheev	D	mikheev@sci	y	y	y	y	y	y	http://www.hcei.	475 nm Xe	0 TW	100 TW
IHCE	Institute of High Current Electronics	Russia	Tomsk	Europe	Dr.	Leonid	Mikheev	D	mikheev@sci	y	y	y	y	y	y	http://www.hcei.	475 nm Xe	0 TW	
ILE-f	Institut de Lumiere Extreme	France	Saclay	Europe	Dr.	Jean Pau	Chambare	D	jean-paul.cha	y	y	y	n	s	y	none	10 PW is t	0 TW	10 PW
ILE-j	Institute for Laser Engineering, Osal	Japan	Osaka	Asia	Dr.	Junji	Kawanaka	D	kawanaka@il	y	y	y	y	y	y	http://www.ile.o	sent mate	2.5 PW x4	>100 TW
ILE-j	Institute for Laser Engineering, Osal	Japan	Osak													://www.ile.o	no respon	2.5 PW x4	>100 TW
ILE-j	Institute for Laser Engineering, Osal	Japan	Osak													://www.ile.o	LFEX is cl	2.5 PW x4	>100 TW
ILE-j	Institute for Laser Engineering, Osal	Japan	Osak													://www.ile.o	2 beams c	2.5 PW x4	>100 TW
INFLPR	National Institute for Laser, Plasma	Romar	Buch													://www.inflp	claim is 20	20 TW	1 PW
INFLPR	National Institute for Laser, Plasma	Romar	Buch													://www.inflp	from the v	20 TW	1 PW
IOP	Institute of Physics, Chinese Acader	China	Beijin													://english.iop.cas.cn/		700 TW	Multi PW
IOP	Institute of Physics, Chinese Acader	China	Beijin													://english.iop	viewgraph	700 TW	Multi PW
IOP	Institute of Physics, Chinese Acader	China	Beijin													://english.iop	700 TW in	700 TW	Multi PW
KAERI	Korean Atomic Energy Research Ins	Korea	Daejo													ne	no respon	100 TW	
KAERI	Korean Atomic Energy Research Ins	Korea	Daejo													ne	no respon	100 TW	
KPSI	Kansai Photon Science Institute, Ad	Japan	Kizug													e not active	good phot	0 TW and 800 TW	
KPSI	Kansai Photon Science Institute, Ad	Japan	Kizug													e not active		10 TW and 800 TW	
KPSI	Kansai Photon Science Institute, Ad	Japan	Kizug													e not active	no eviden	0 TW and 800 TW	
KPSI	Kansai Photon Science Institute, Ad	Japan	Kizug													e not active		10 TW and 800 TW	
KyoU	Kyoto University	Japan	Kyoto	Asia	rof.	Shuji	Sakabe	D	kyoto-u.ac.jp	n	y	n	w	y	y	http://laser.kuicr	forwarded	10 TW	
LANL	Los Alamos National Laboratory, Tri	USA	Los Ala	North Ame	Dr.	Manuel	Hegelich	D	hegelich@lar	y	y	y	y	y	y	http://trident.lan	manuel cla	200 TW	
LANL	Los Alamos National Laboratory, Tri	USA	Los Ala	North Ame	Dr.	Juan	Fernandez	D	juanc@lanl.g	y	n	n	n	n	y	http://trident.lan	no respon	200 TW	
LBNL	Lawrence Berkeley National Labora	USA	Berkele	North Ame	Dr.	Csaba	Toth	D	ctoth@lbl.gov	y	n	n	n	n	y	http://loasis.lbl.gov/		12 TW and 65 TW	1 PW
LBNL	Lawrence Berkeley National Labora	USA	Berkele	North Ame	Dr.	Wim	Leemans	D	WPLeemans	y	y	y	y	y	y	http://loasis.lbl.g	basic syst	12 TW and 65 TW	1 PW
LFRC	Laser Fusion Research Center CAE	China	Mianya	Asia	rof.	Zhu	Qiuhua	D	qihzh@163.c	y	n	n	n	n	y	none	no respon	300 TW	
LFRC	Laser Fusion Research Center CAE	China	Mianya	Asia	Dr.	Zheng-Mi	Sheng	D	zmsheng@a	y	y	y	y	y	y	none	SILEX 300	300 TW	
LLC	Lund Laser Center	Swede	Lund	Europe	Dr.	Claes-Go	Wahlstrom	D	claes-goran.	y	n	n	n	n	y	http://www-llc.fy	doubling t	40 TW	100 TW 25
LLC	Lund Laser Center	Swede	Lund	Europe	Dr.	Anders	Persson	D	anders.perss	y	y	y	y	y	y	http://www-llc.fy	point stab	40 TW	100 TW 25
LLE	Laboratory for Laser Energetics	USA	Roches	North Ame	Dr.	Terry	Kessler	D	jude@lle.roch	y	y	y	y	y	y	http://www.lle.r	omega EP	260 TW & 30 TW	1 PW
LLE	Laboratory for Laser Energetics	USA	Roches	North Ame	Dr.	David	Meyerhofe	D	ddm@lle.roc	y	y	y	y	y	y	http://www.lle.r	meyerhofe	500 TW	1 PW
LLNL	Lawrence Livermore National Labor	USA	Livermo	North Ame	Dr.	John	Crane	D	crane1@llnl.g	n	n	n	y	y	y	https://lasers.llr	informatio	1 TW	multi PW

Update to ICUIL World Map

130 individuals poled

100+ responses

100+ ppt, pdf and jpeg files sent

300+ pages of info and pictures received

LLNL	Lawrence Livermore National Labor	USA	Livermo	North Ame	Dr.	Bob	Cauble	D	cauble1@llnl.	y	y	y	y	y	y	https://lasers.llr	calisto Ti:s	200 TW & 300 TW	
LLNL	Lawrence Livermore National Labor	USA	Livermo	North Ame	Dr.	Chris	Barty	D	barty1@llnl.g	n	n	y	y	y	y	https://lasers.llr	E23 would	1 TW	fs PW at 10
LOA	Laboratoire d'Optique Appliquée-EN	France	Palaise	Europe	Dr.	Antoine	Rousse	D	none	n	n	n	w	w	y	http://loa.ensta.	get materi	100 TW	
LOA	Laboratoire d'Optique Appliquée-EN	France	Palaise	Europe	Dr.	Rodrigo	Lopez-Mar	D	rodrigo.lopez	n	n	n	n	n	y	http://loa.ensta.	no evidence that the email was sent		
LULI	Laboratoire pour l'Utilisation des Las	France	Palaise	Europe	Dr.	Catherine	LeBlanc	D	catherine.leb	y	y	y	y	y	y	http://www.luli.p	LULI 2002	200 TW & 100 TW	
MBI	Max Born Institute for Nonlinear Opt	Germa	Berlin	Europe	rof.	Wolfgang	Sandner	D	sandner@mb	y	n	n	n	n	y	http://www.mbi-	70 laser sy	100 TW	500 TW
MBI	Max Born Institute for Nonlinear Opt	Germa	Berlin	Europe	Dr.	Ingo	Will	D	will@mbi-ber	y	n	n	n	n	y	http://www.mbi-	no respon	100 TW	500 TW
MPQ	Max Planck Institute for Quantum O	Germa	Garchir	Europe	Dr.	Laszlo	Veisz	D	Laszlo.Veisz(	y		y	y	s		http://www.mpq	8 fs 16 TW	16 TW	100 TW
NIF	Lawrence Livermore National Labor	USA	Livermo	North Ame	Dr.	John	Crane	D	crane1@llnl.g	n	n	n	n	n	y	https://lasers.llr	over all sy	200 TW in the UV	
NRL	Naval Research Laboratory	USA	Wash													p://other.nrl.r	info from web		
OSU	The Ohio State University	USA	Colur													p://www.phy	good info	40 TW	0.5 PW
PNLI	PN Lebedev Institute Russian Acade	Russia	Mosc													p://lebedev.ru	475 nm X	0 TW	30 TW
PNLI	PN Lebedev Institute Russian Acade	Russia	Mosc													p://lebedev.ru	deferred t	0 TW	30 TW
RAL	Rutherford Appleton Laboratory	Englan	Didco													p://www.clf.rl.	pw glass a	1 PW	10 PW
RFNC	Russian Federal Nuclear Center - TI	Russia	Sarov													p://en.vniief.r	operationa	1 PW	
RIKEN	RIKEN (from concatenation of Rikaç	Japan	Tokyo													p://www.riker	below 10 T	1 TW and 7 TW	
RRCAT	Raja Ramanna Centre for Advanced	India	Indor													p://www.cat.g	from Canc	10 TW	150 TW 5 Hz
RRCAT	Raja Ramanna Centre for Advanced	India	Indor													p://www.cat.g	from Canc	10 TW	150 TW 5 Hz
SIOM	Shanghai Institute of Optics and Fin	China	Shan													p://english.si	no respon	890 TW	
SIOM	Shanghai Institute of Optics and Fin	China	Shan													p://english.si	no respon	890 TW	
SIOM	Shanghai Institute of Optics and Fin	China	Shan													p://english.si	30 fs 890 T	890 TW	
SJTU	Shanghai Jiao Tong University	China	Shan													p://www.sjtu	building a	0 TW	200 TW
SLAC	MECI Matter in Extreme Conditions	USA	Stanf													p://www6.sla	matter und	4 TW	100 TW
SLAC	MECI Matter in Extreme Conditions	USA	Stanf													p://www6.sla	MECI end	4 TW	100 TW
SLIC	CEA le Commissariat à l'énergie ato	France	Saclay	Europe	Dr.	D.	Normand	D	none	n	n	n	n	y	y	http://www-femt	from Canc	100 TW 10 Hz	
SLIC	CEA le Commissariat à l'énergie ato	France	Saclay	Europe	Dr.	Pascal	d'Oliveira	D	pascal.dolive	n	n	n	n	y	y	http://www-femt	lead from	100 TW 10 Hz	
SNL	Sandia National Laboratory	USA	Albuqu	North Ame	Dr.	Patrick	Rambo	D	prambo@sar	y	y	y	y	y	y	http://www.z-be	200 TW ta	200 TW	1 PW
SNL	Sandia National Laboratory	USA	Albuqu	North Ame	Dr.	Ian	Smith	D	icsmith@san	y	n	n	n	n	y	http://www.z-be	good web	200 TW	1 PW
SNL	Sandia National Laboratory	USA	Albuqu	North Ame	Dr.	John	Porter	D	jlporte@sand	y	n	n	n	n	y	http://www.z-be	good web	200 TW	1 PW
TIFR	Tata Institute of Fundamental Resea	India	Mumba	Asia	Dr.	M	Krishnamu	D	mkrishm@tifr	y	n	n	n	y	y	http://www.tifr.re	purchasin	20 TW	100 TW
TIFR	Tata Institute of Fundamental Resea	India	Mumba	Asia	Dr.	G. Ravinc	Kumar	D	grk@tifr.res.in	y	y	y	y	y	y	http://www.tifr.re	have a 20	20 TW	100 TW
TIFR	Tata Institute of Fundamental Resea	India	Mumba	Asia	Dr.	Amit	Lad	D	amitlad@tifr.r	y	n	n	n	n	y	http://www.tifr.re	no respon	20 TW	100 TW
TIFR	Tata Institute of Fundamental Resea	India	Mumba	Asia	Dr.	Rajeev	Rajendran	D	rajeev.tifr@gr	y	n	n	n	n	y	http://www.tifr.re	no respon	20 TW	100 TW
TIFR-h	Tata Institute of Fundamental Resea	India	Hydera	Asia	Dr.	G. Ravinc	Kumar	D	grk@tifr.res.in	y	n	y	y	y	y	http://www.tifr.re	note from	0 TW	1 PW
TUW	Technical University of Vienna	Austria	Vienna	Europe	rof.	Andrius	Baltuskus	D	none	n	n	n	n	n	y	http://www.tuwie	based on	few TW	
UAlb	University of Alberta	Canad	Edmon	North Ame	rof.	Robert	Fedosejevs	D	rfed@ee.ualt	y	y	n	n	y	?	http://www.ece.engineerir		0 TW	PW few Hz

Update to ICUIL World Map

130 individuals poled

100+ responses

100+ ppt, pdf and jpeg files sent

300+ pages of info and pictures received

UCLA	University of California at Los Angel	USA	Los An	North Ame	rof.	Chan	Joshi	D	cjoshi@ucla.(	y	n	n	n	n	y	http://www.ee.u	based on	10 TW	
UEC	University of Electro-Communicatior	Japan	Tokyo	Asia	Dr.	Ken-ichi	Ueda	D	ueda@ils.uec	y	n	n	w	w	y	http://www.ils.u	based wel	TW KrF, 2 TW Ti:Sa	
UMed	Université de la Méditerranée, Labo	France	Marseil	Europe	Dr.	M.	Sentis	D	none	n	n	n	w	w	y	http://www.lp3.u	from Canc	0 TW	TW (march 2
UMich	University of Michigan	USA	Ann Arl	North Ame	Dr.	Victor	Yanovski	D	vpy@umich.e	y	y	y	y	y	y	http://www.engi	also have	300 TW	5 PW
UMil	University of MIlan	Italy	Milan	Europe	rof.	Sandro	DiSilvestri	D	sandro.desilv	n	n	n	n	n	y	http://www.fisi.p	based on	10 TW	?
UNeb	University of Nebraska	USA	Lincoln	North Ame	rof.	Donald	Unstadter	D	dpu@hfsserv	y	y	y	y	y	y	http://www.unl.e	diocles ex	100 TW	1 PW
UNev	University of Nevada at Reno	USA	Reno	North Ame	Dr.	Piotr	Wiewior	D	pwiewior@ur	y	y	y	y	y	y	http://www.ntf.u	got to the	10 TW	
UStr	University of Strathclyde	Scotla	Glasgo	Europe	Dr.	Dino	Jaroszynsk	D	none	n	n	n	n	y	y	http://silis.phys.	from Canc	100 TW 10 Hz	
USze	University of Szeged	Hunga	Szeged	Europe	rof.	Karoly	Osvay	D	osvay@phys	y	y	y	y	y	y	www.tewati.hu	2 TW will	2 TW	10 TW
UTex	University of Texas at Austin	USA	Austi													://www.ph.u	1.1 PW hy	1.1 PW	
UTex	University of Texas at Austin	USA	Austi													://www.ph.u	also have	1.1 PW	
UTok	University of Tokyo	Japan	Tokyo													ne	from mem	100 TW	
Amplitude	Amplitude	France	Palais																
Thales	Thales Optronique SA	France	Palais																

Update to ICUIL World Map

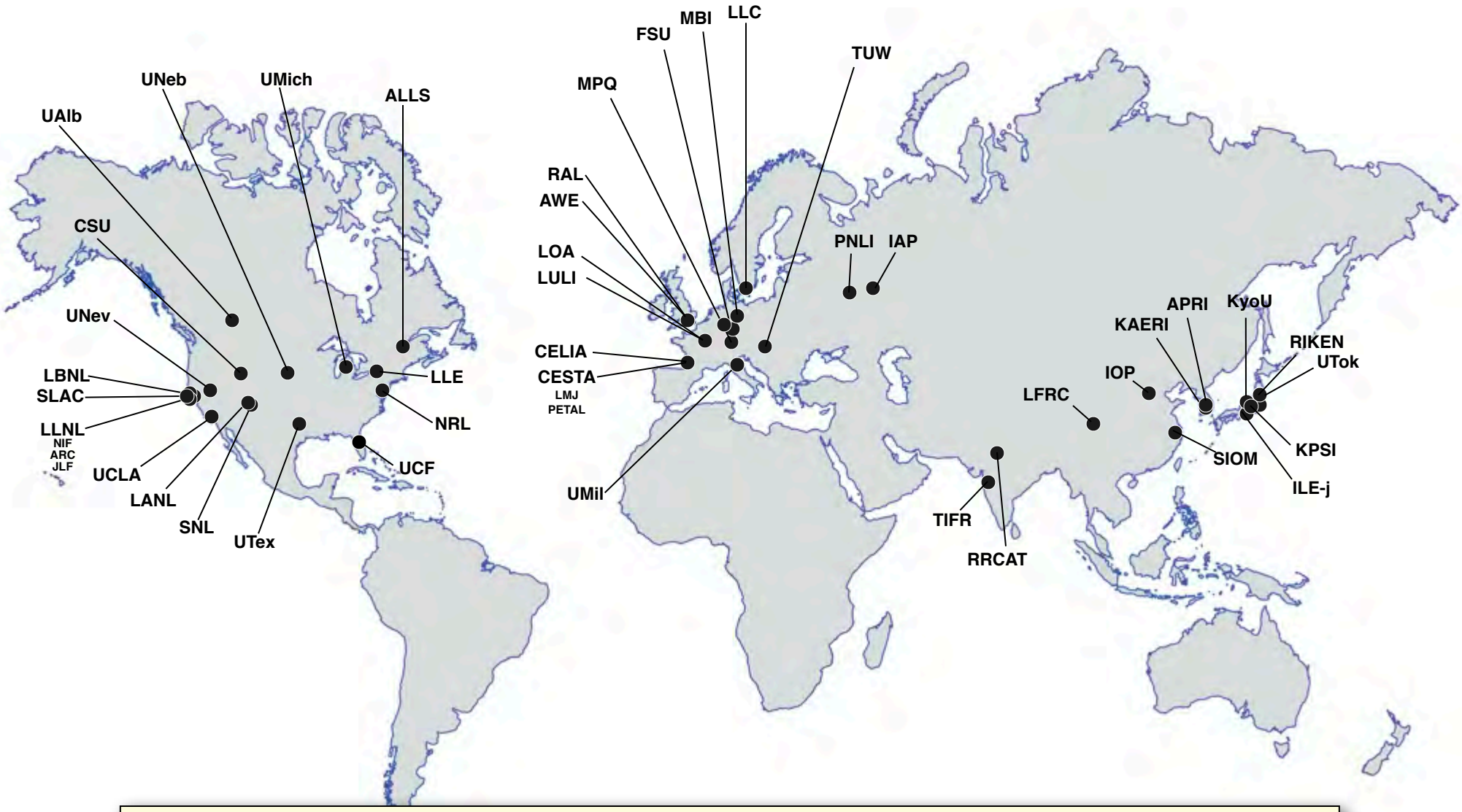
130 individuals poled

100+ responses

100+ ppt, pdf and jpeg files sent

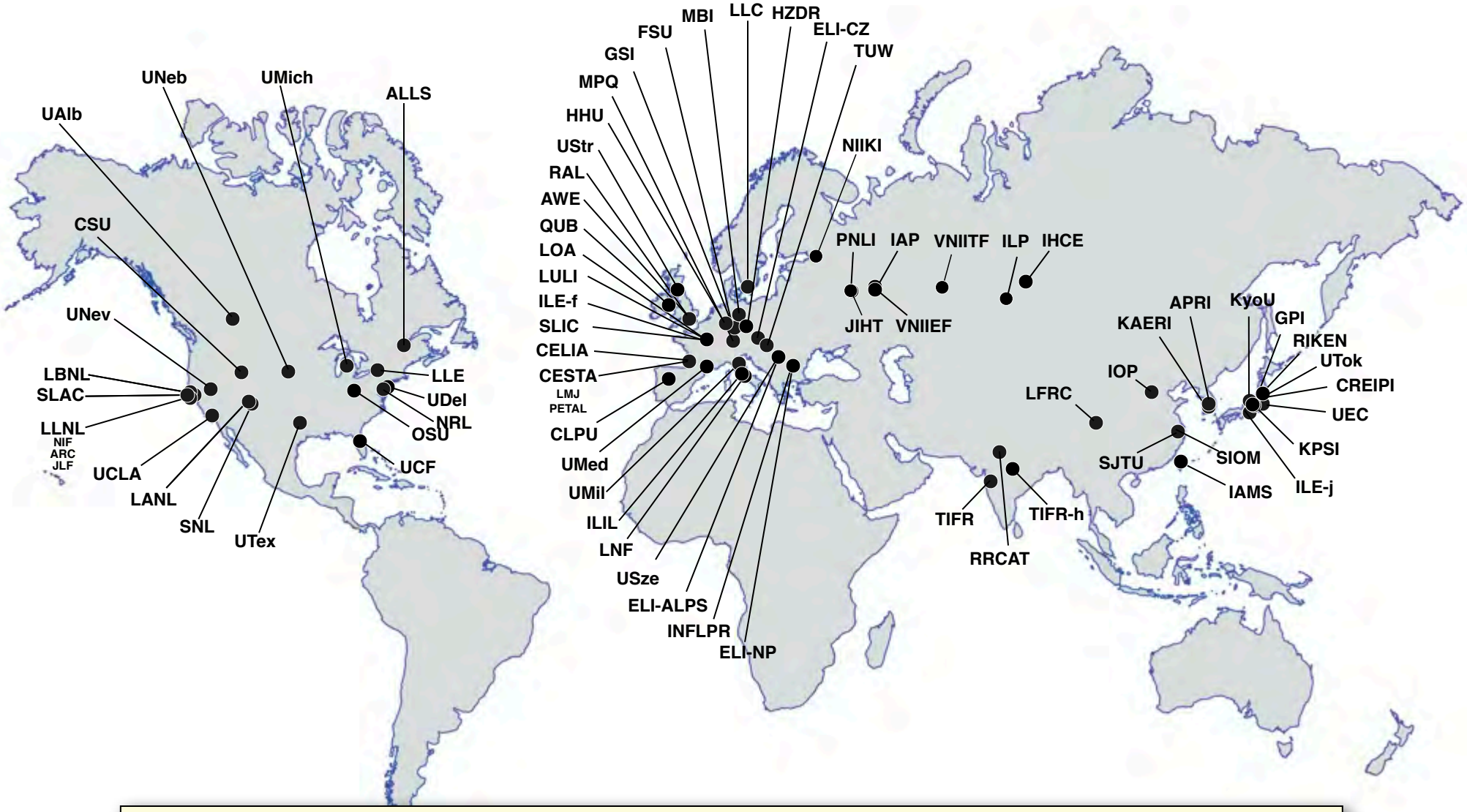
300+ pages of info and pictures received

2009



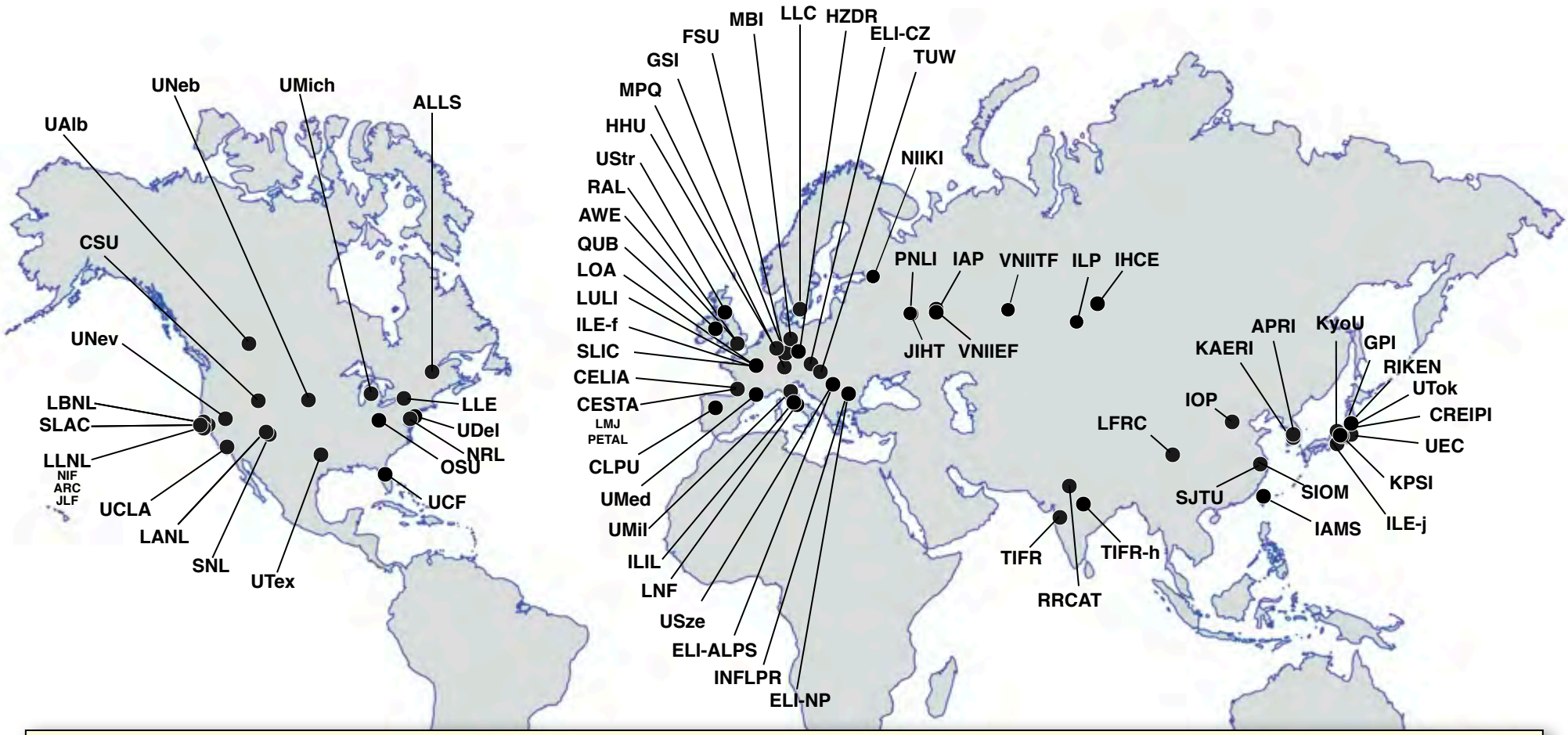
Labels represent the establishments with physical and administrative responsibility for the ultrahigh intensity laser system or facility

Today



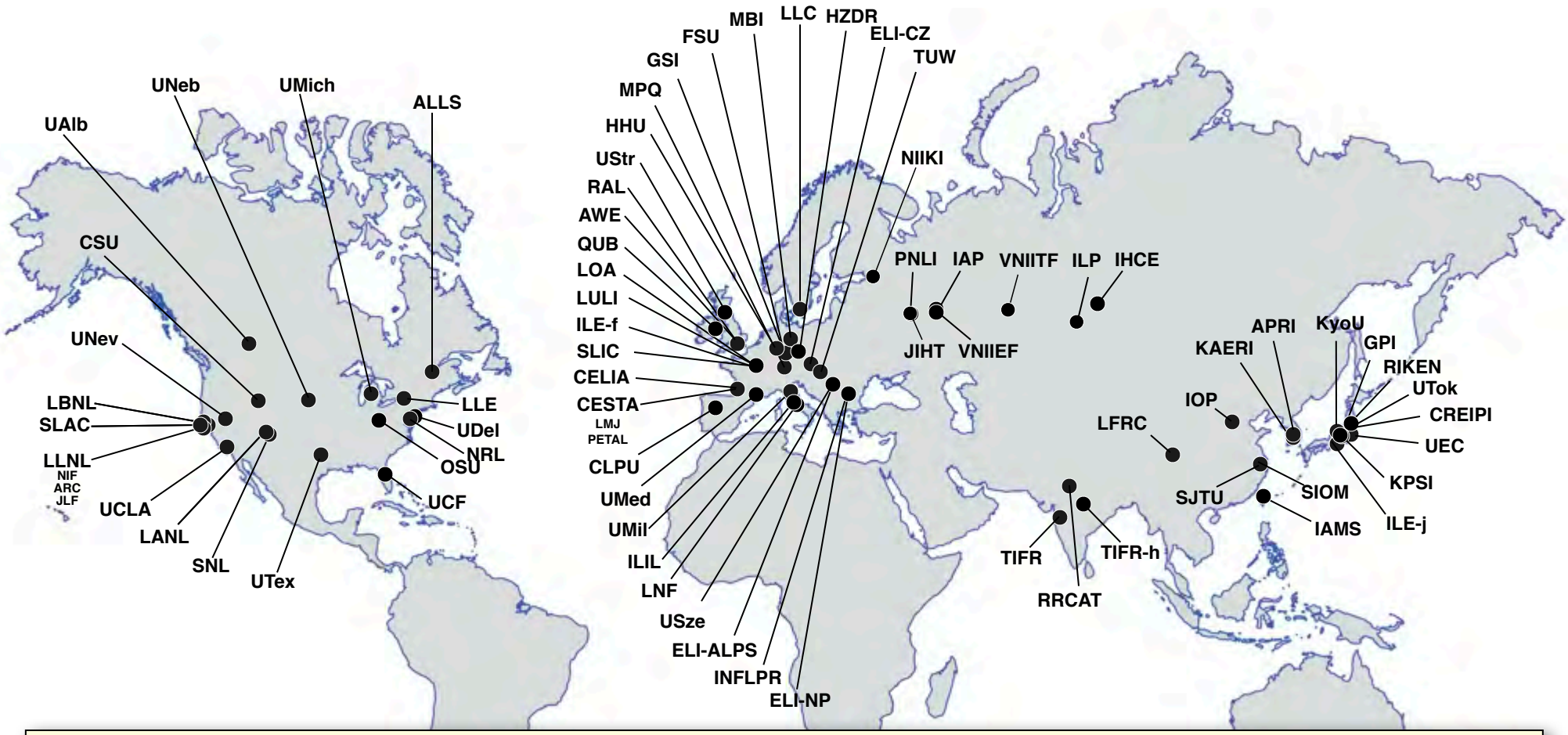
Labels represent the establishments with physical and administrative responsibility for the ultrahigh intensity laser system or facility

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities



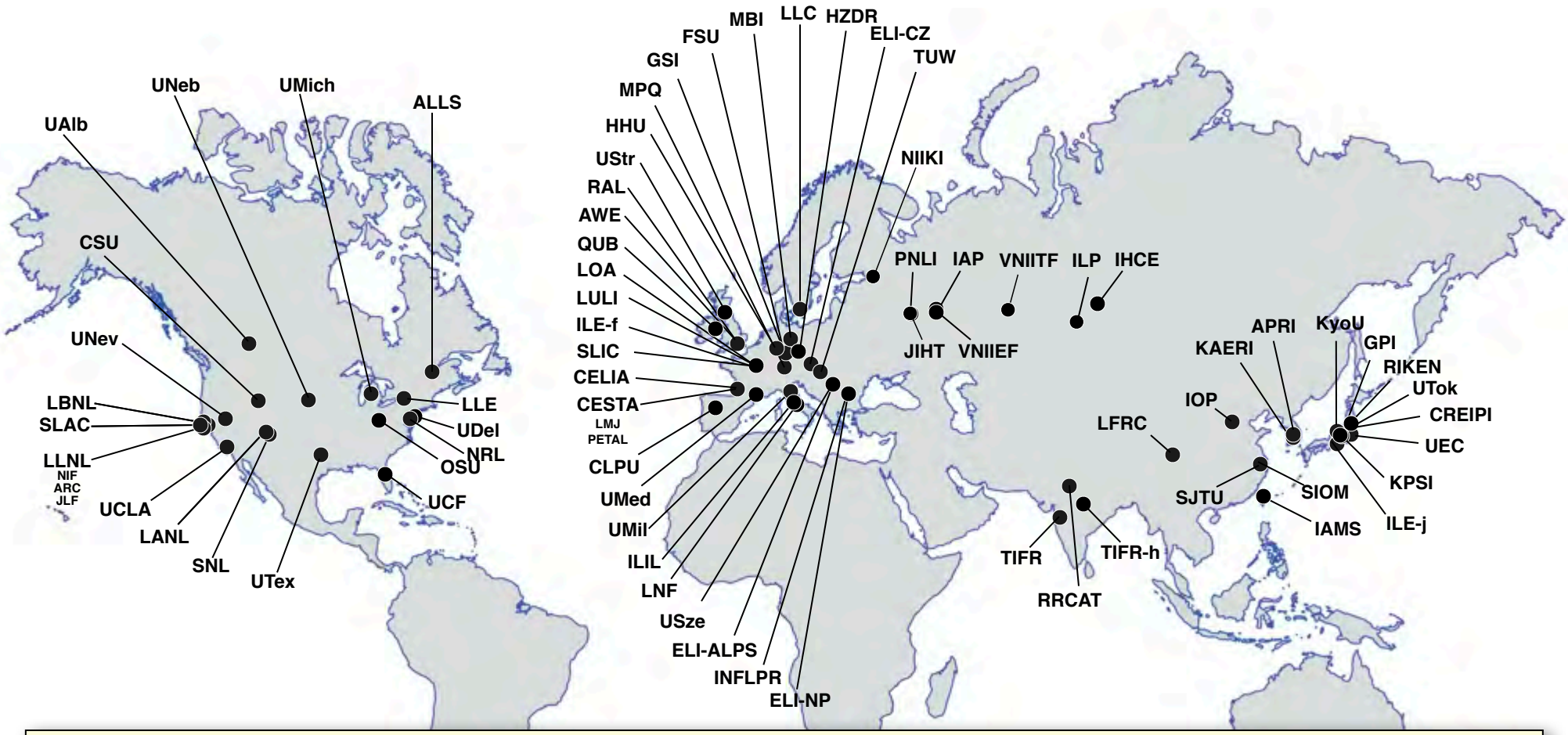
- The total peak power of all the intense systems operating in 2010 was ~11.5 PW

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities



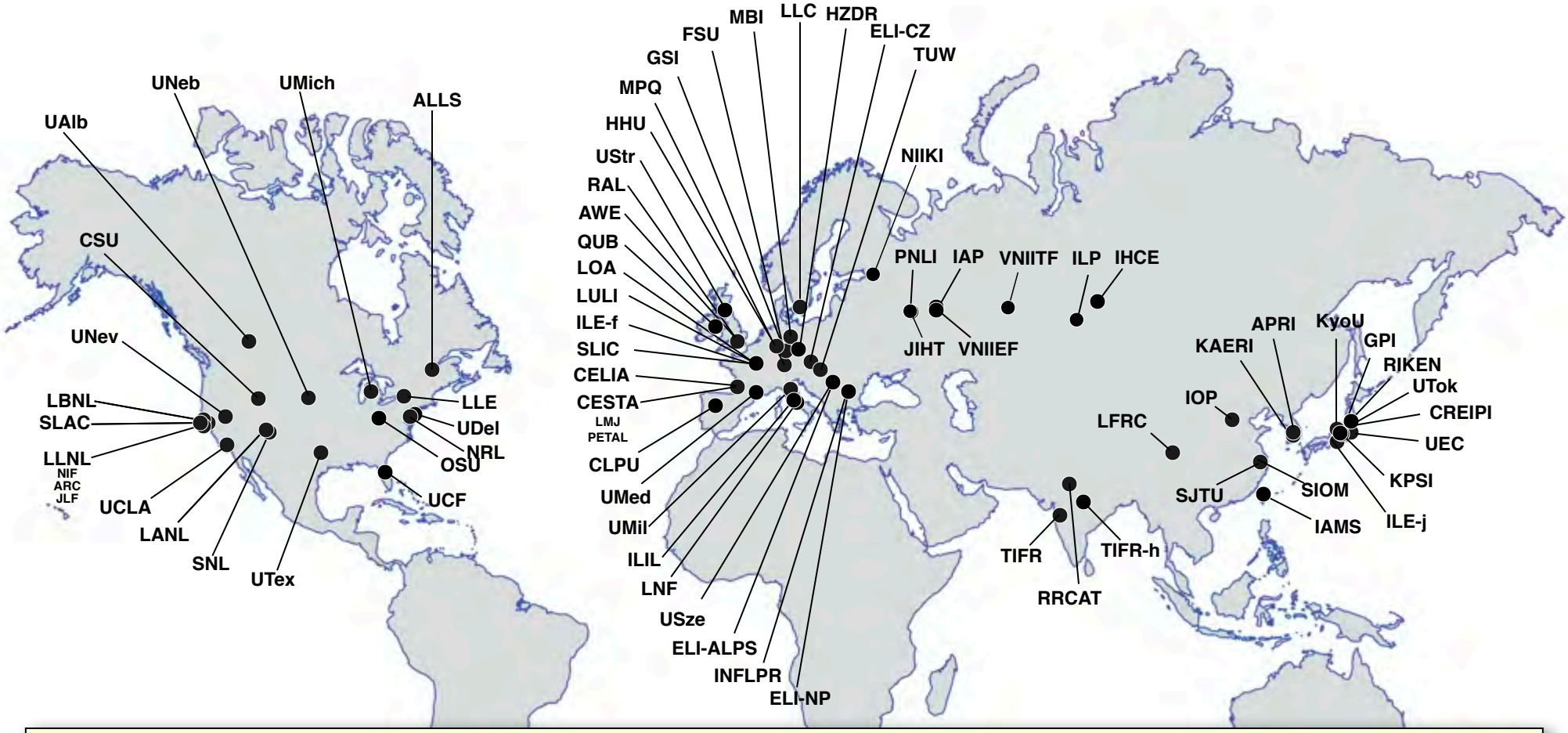
- The total peak power of all the intense systems operating in 2010 was ~11.5 PW
- By the end of 2017 planned intense laser projects will total to ~127 PWs

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities



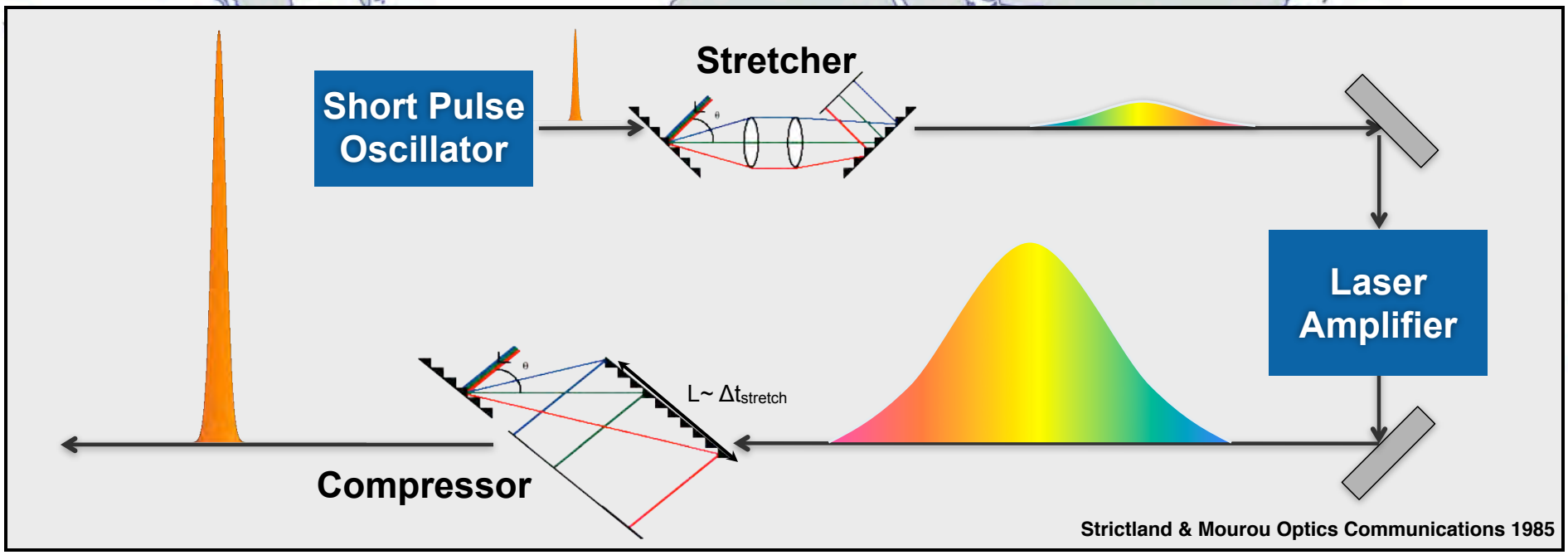
- The total peak power of all the intense systems operating in 2010 was ~11.5 PW
- By the end of 2017 planned intense laser projects will total to ~127 PWs
- These CPA projects represent ~$4.3B of effort by ~1600 people

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

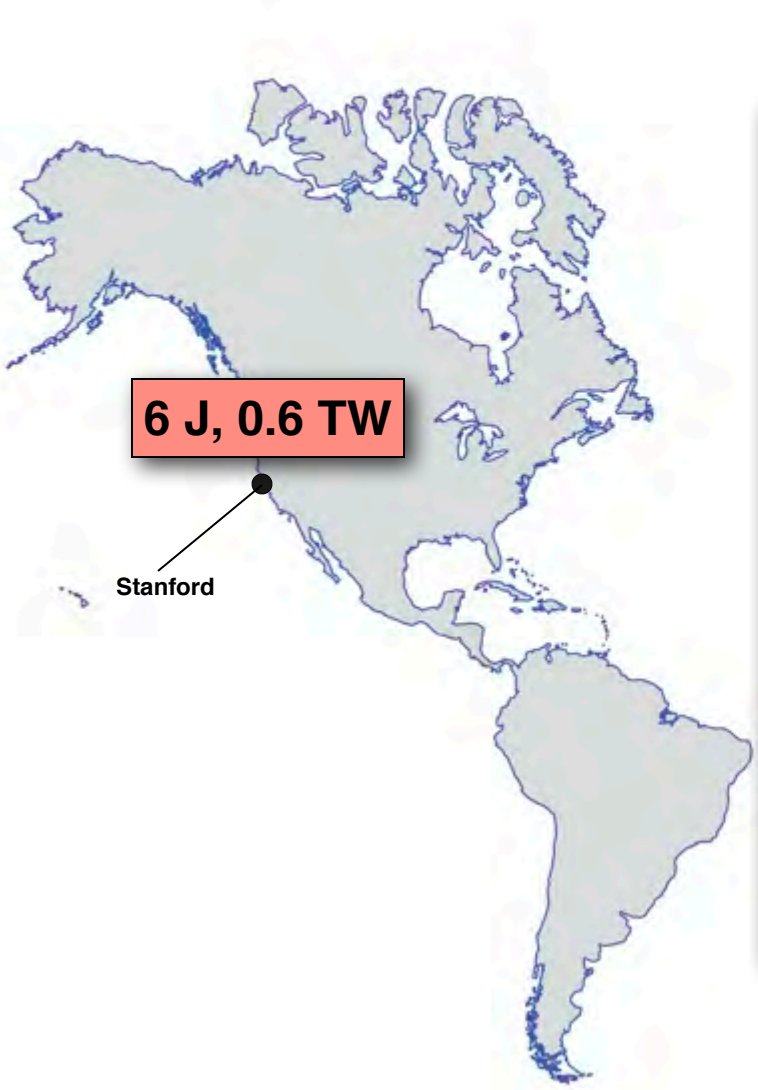


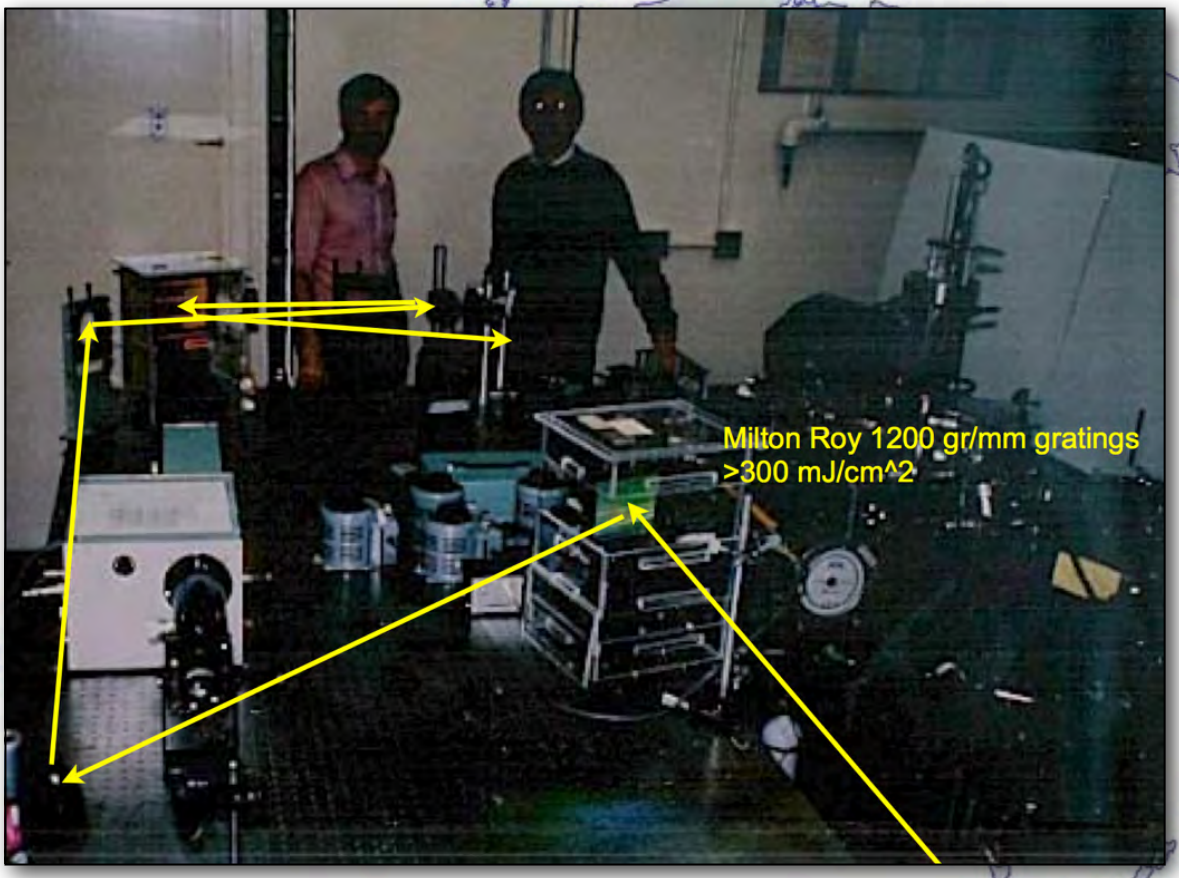
- The total peak power of all the intense systems operating in 2010 was ~11.5 PW
- By the end of 2017 planned intense laser projects will total to ~127 PWs
- These CPA projects represent ~$4.3B of effort by ~1600 people
- These estimates did not include MJ systems or planned Exawatt-scale projects

It started in 1985 with the invention of chirped pulse amplification

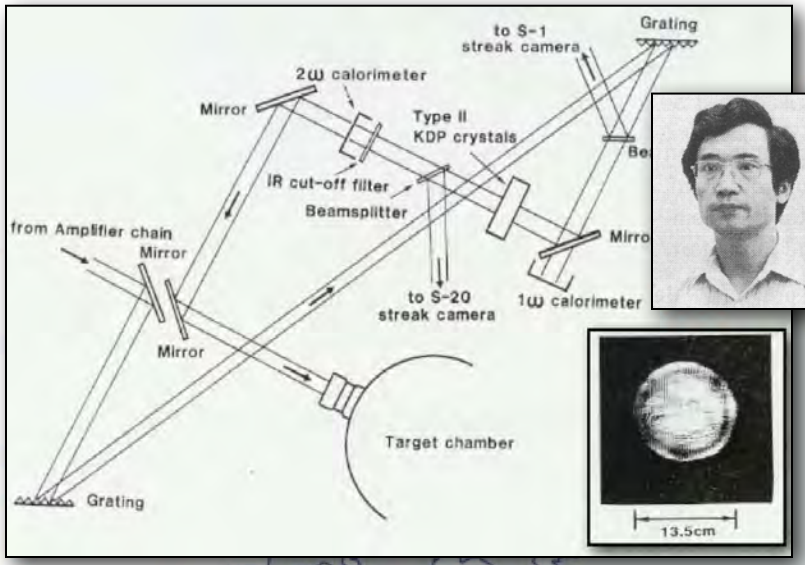


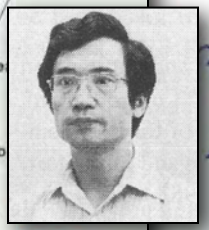
1987 - Stanford University





1989 - Institute for Laser Engineering @ Osaka University



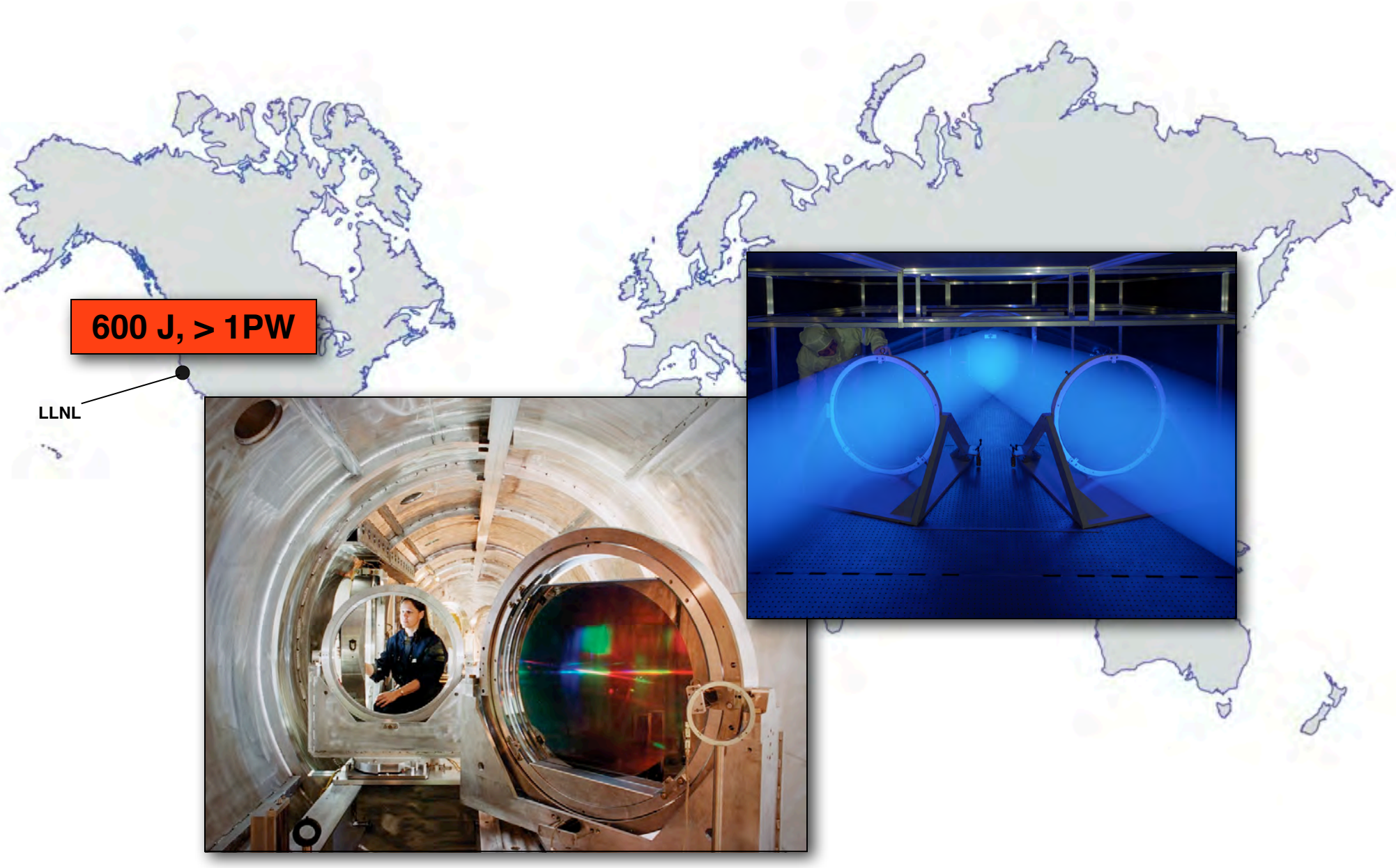


30 J, 30 TW

ILE-j

1996 - Lawrence Livermore National Laboratory

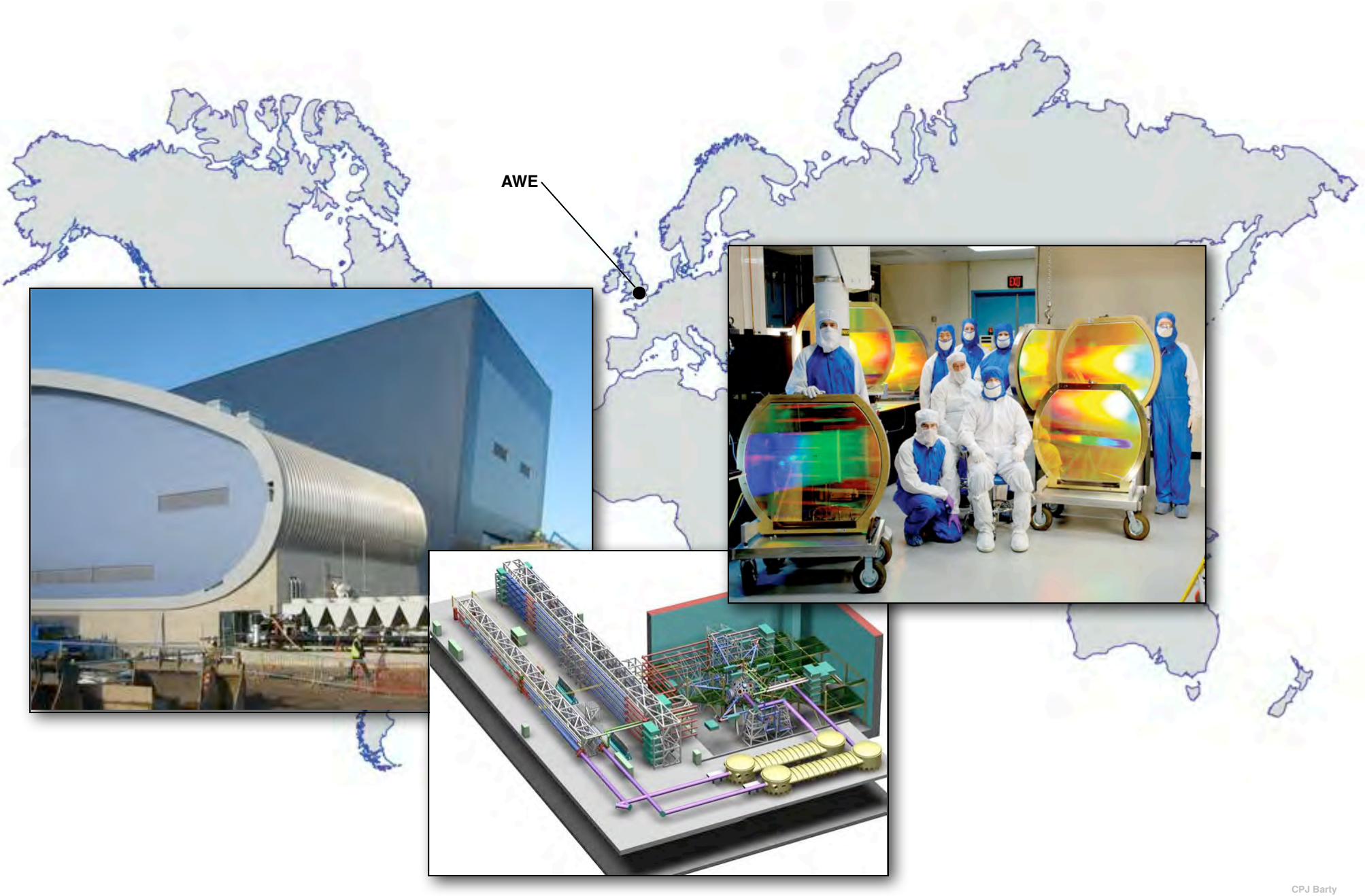
1996 - Lawrence Livermore National Laboratory



1996 - Lawrence Livermore National Laboratory

Today - Rutherford Appleton Laboratory

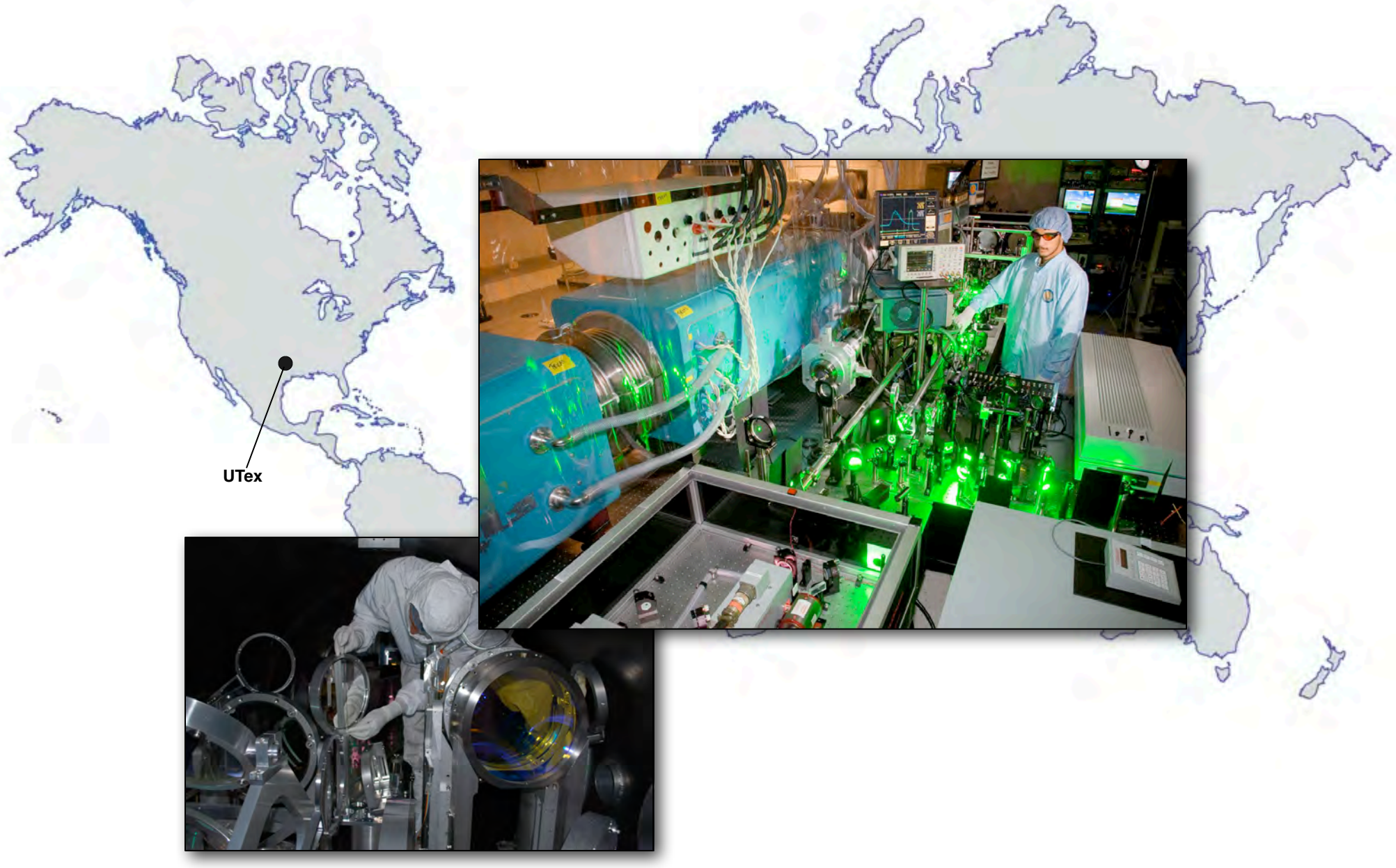
Today - Atomic Weapons Establishment



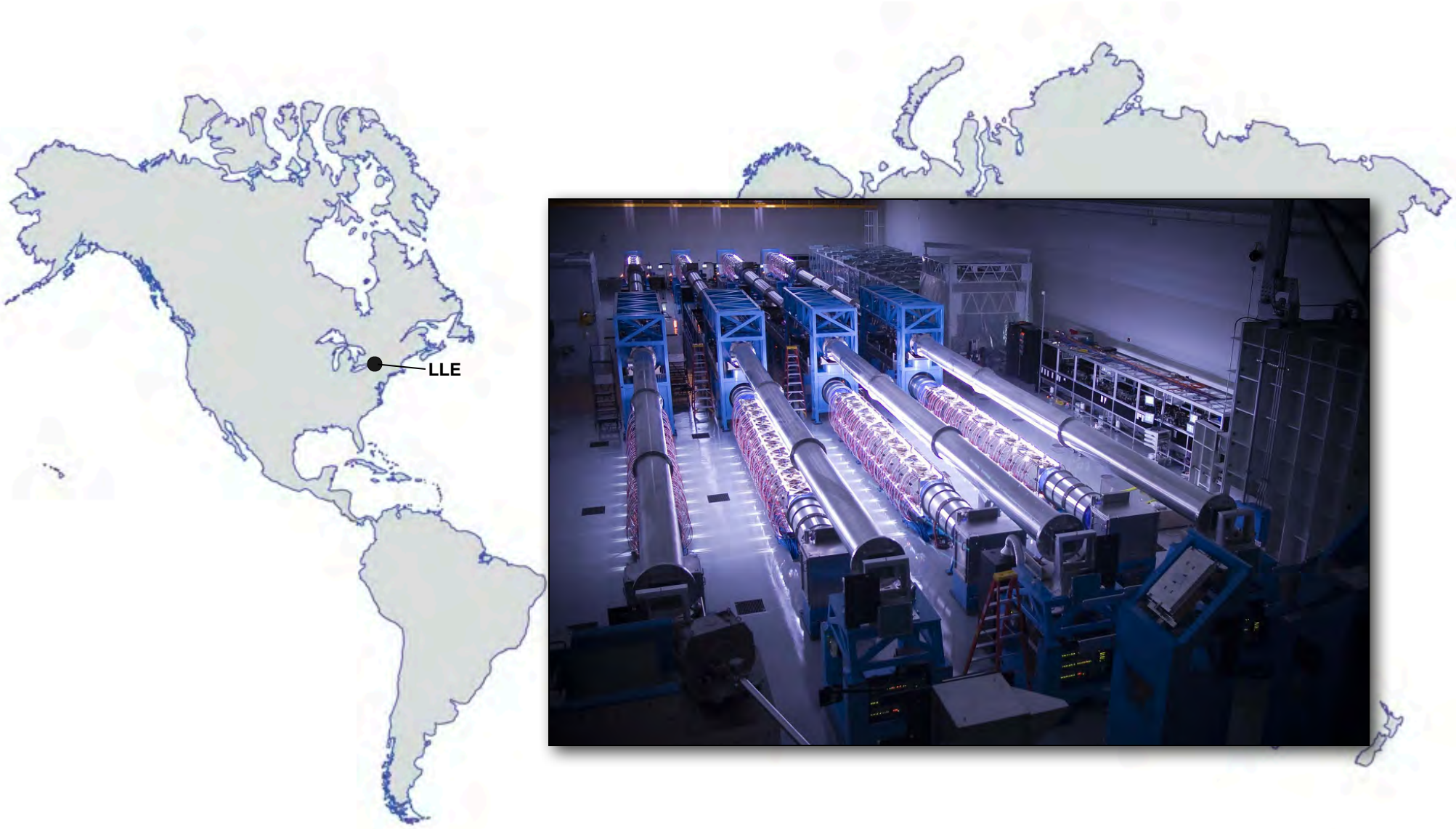
CPJ Barty

Today - GSI Germany

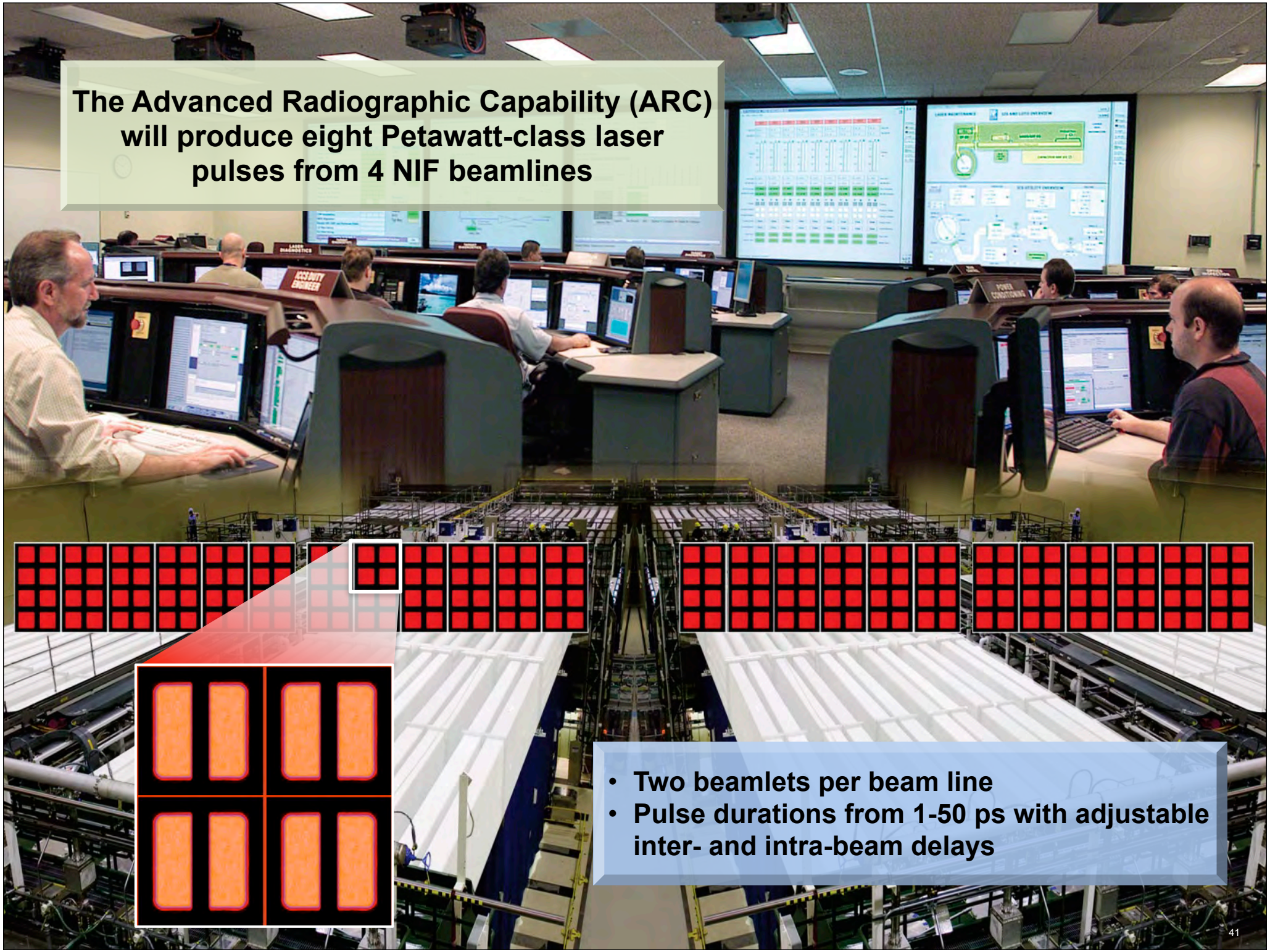
Today - UT Austin Texas PW



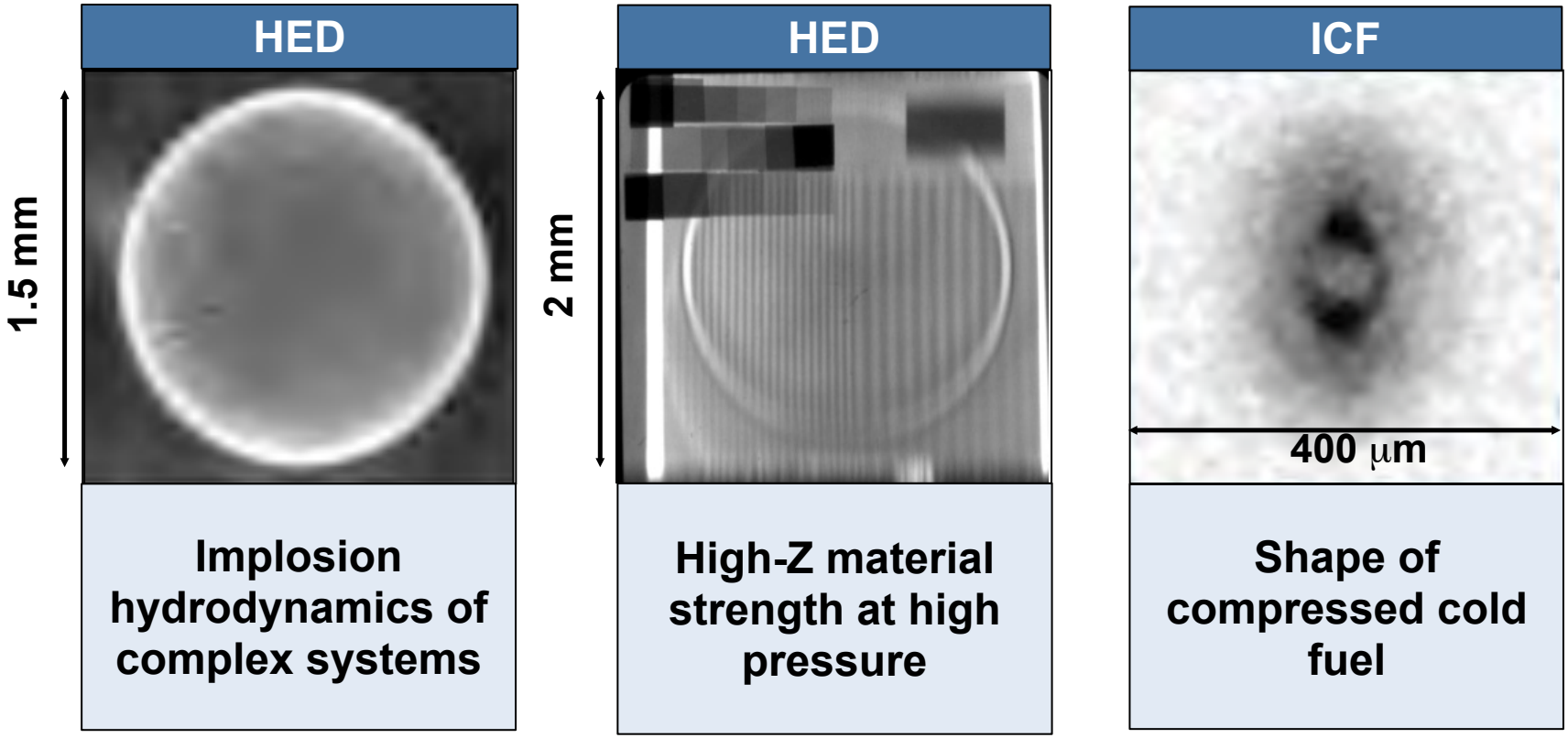
Today - Omega EP at LLE



Tomorrow - “ARC” 10 kJ in 10 ps at the NIF

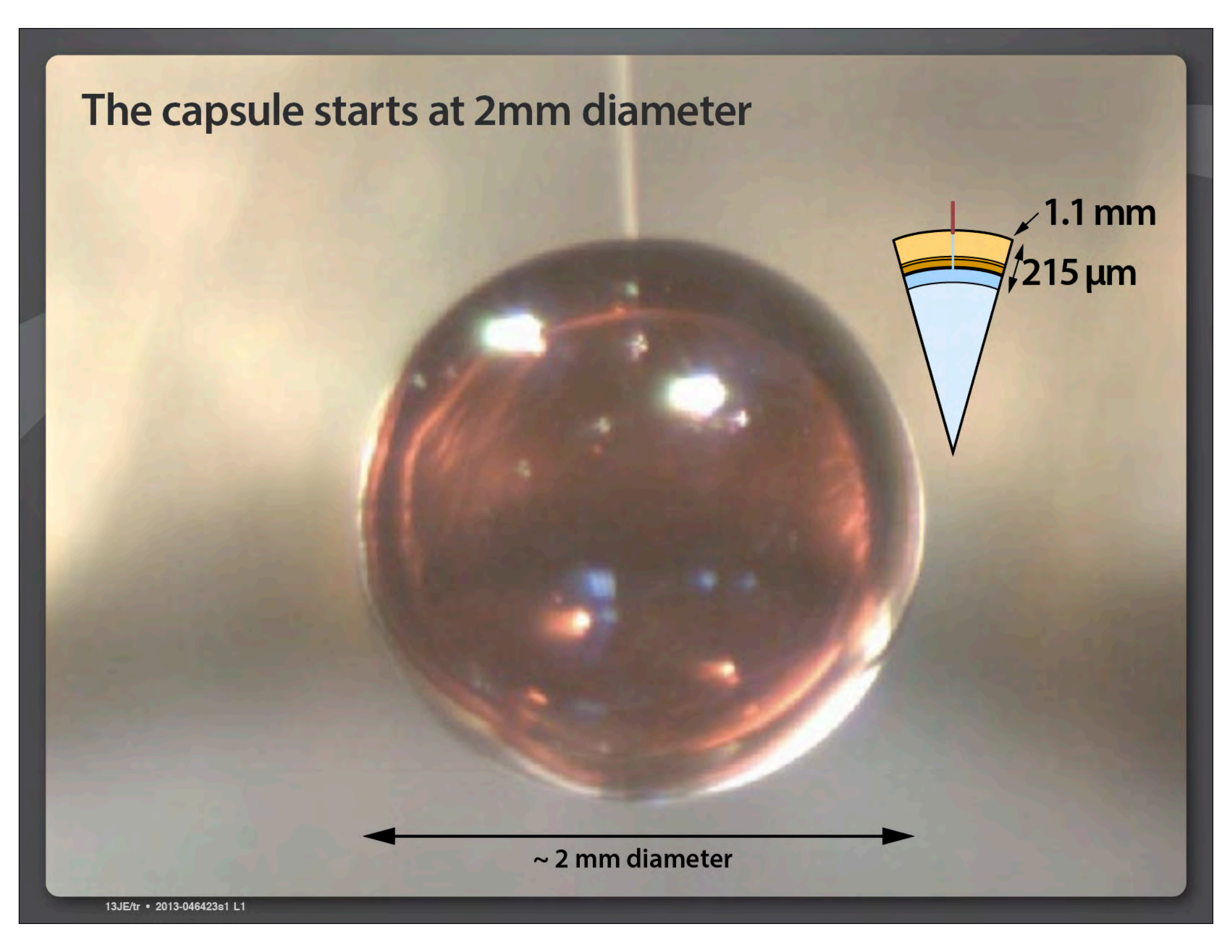

The Advanced Radiographic Capability (ARC) will produce eight Petawatt-class laser pulses from 4 NIF beamlines
• Two beamlets per beam line
• Pulse durations from 1-50 ps with adjustable inter- and intra-beam delays

ARC high energy backlighting capability is required for the high energy density science & ICF programs



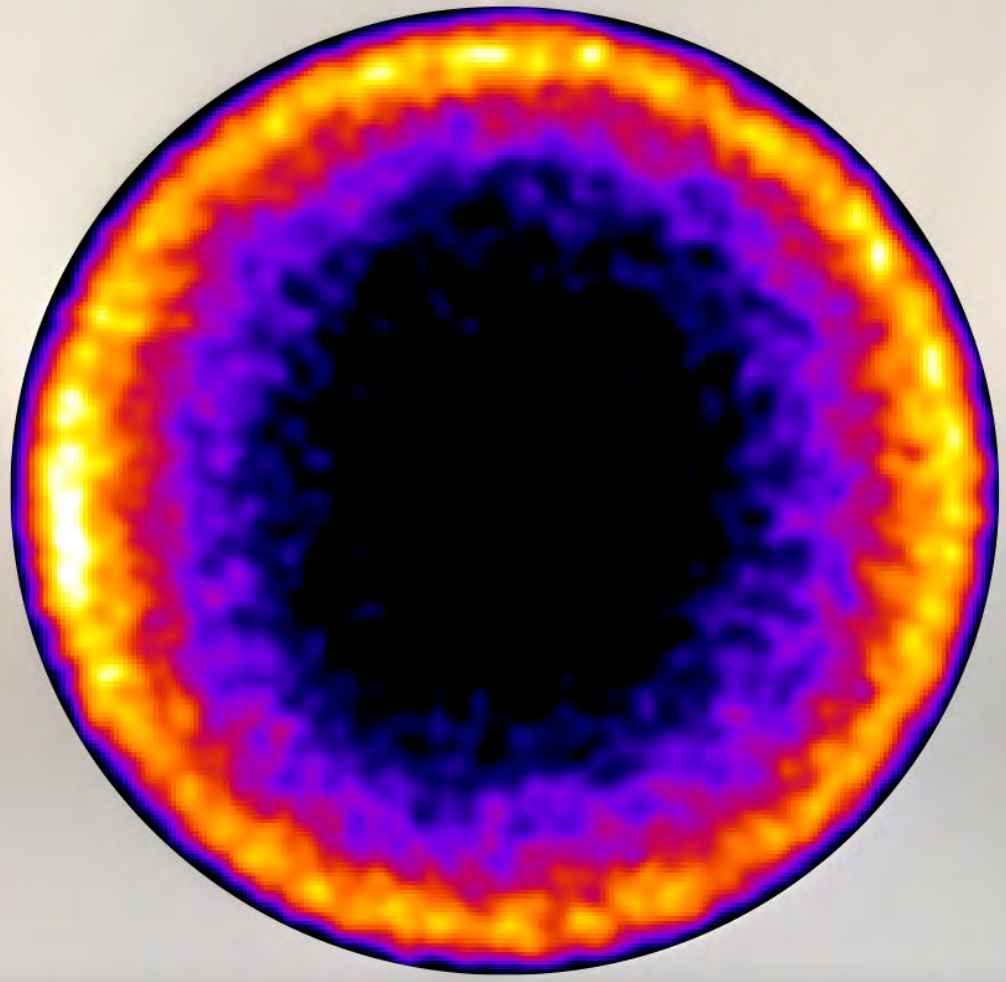
Planned NIF experiments will use ARC to produceback lighters at energies up to 100 keV

The capsule starts at 2mm diameter



Re-emmission sphere measures early time x-drive symmetry

Bang time – 19 ns



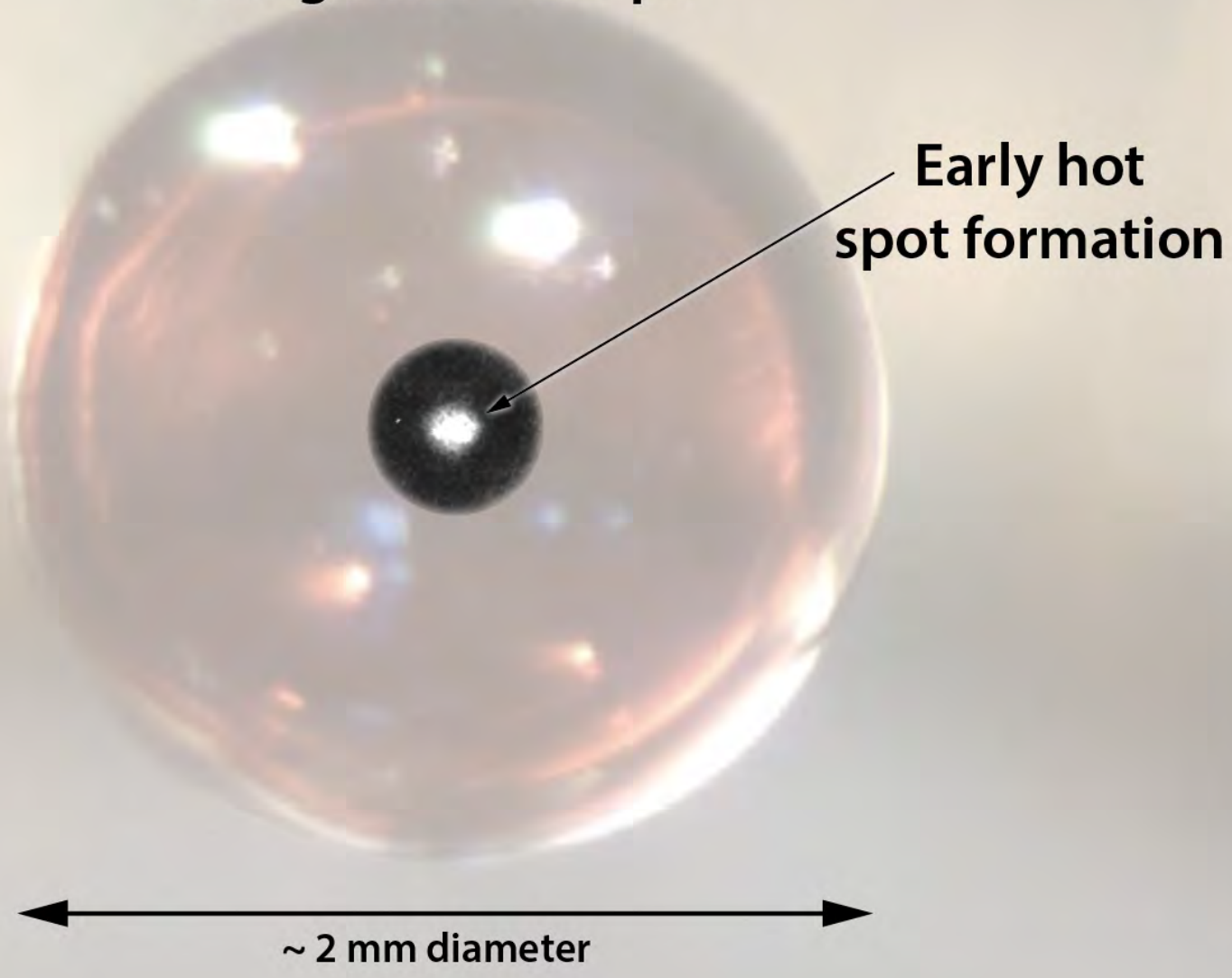
1 billionth of a second into the laser pulse

Radiography measures the shape of the capsule in-flight

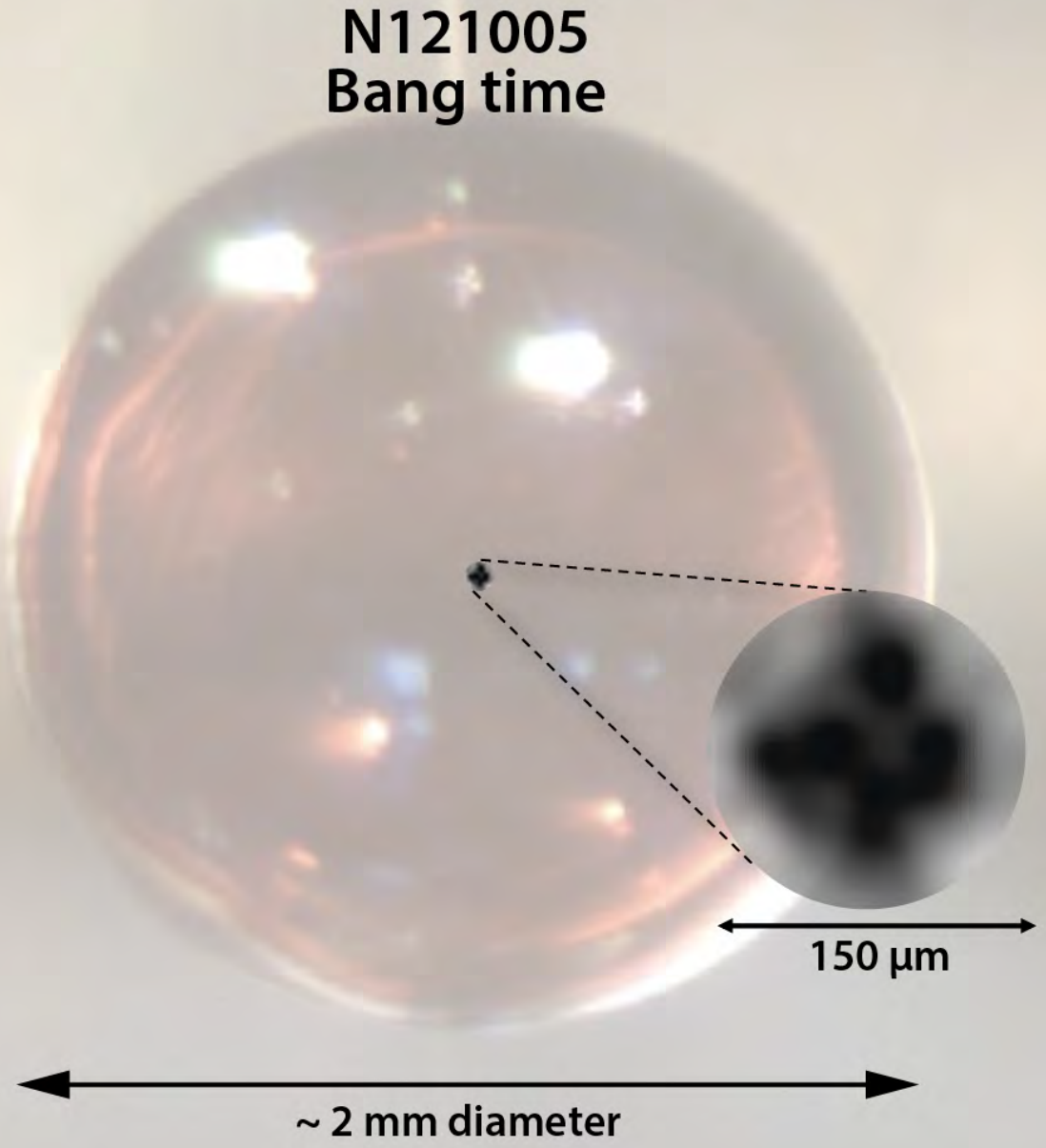
N121004
Bang time – 600 ps

~ 2 mm diameter

Radiography measures the shape of the capsule in-flight

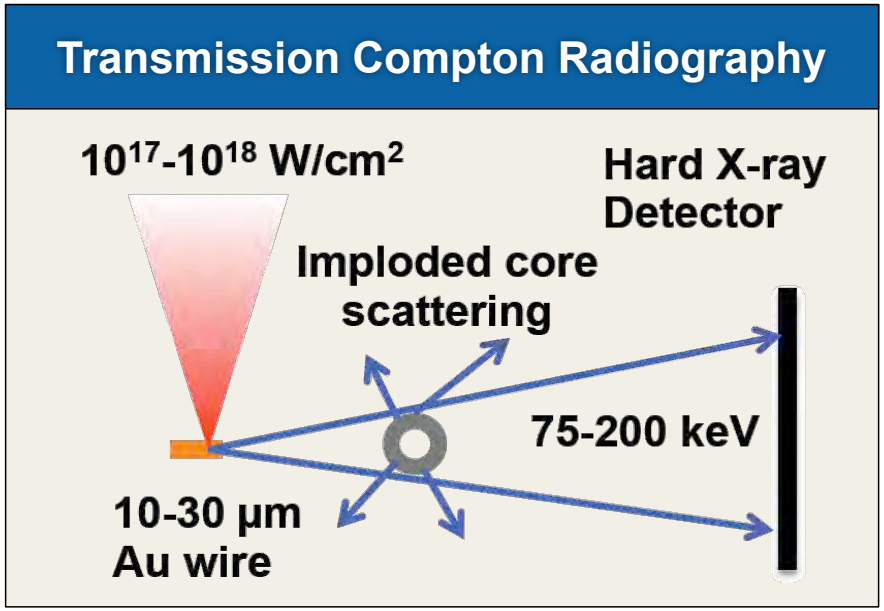


Compton radiography probes fuel shape at stagnation

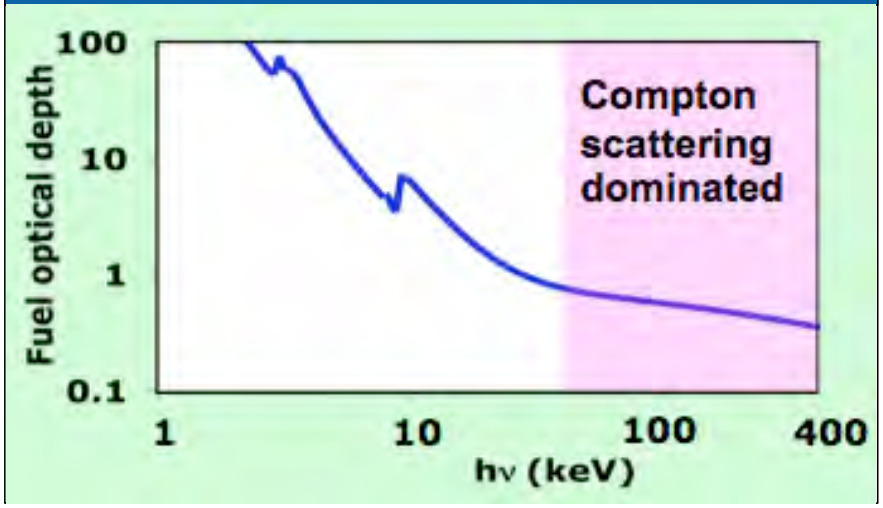


Point projection high energy (>75keV) radiography is ideally suited to probe fuel shape and uniformity

Transmission Compton Radiography



Optical depth of the fuel and ablator

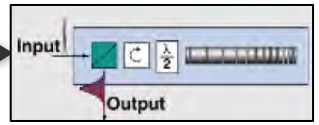


- Compton radiography is sensitive to n_e (not Z): ideal for probing DT fuel shape and density uniformity inside ablator
- Allows broadband operation as Compton cross section that dominates at high energy isweakly dependent on photon energy
- Radiography source is independently timed, in contrast to burn products
- Would require up 60 long pulse beam lines to do the same job!

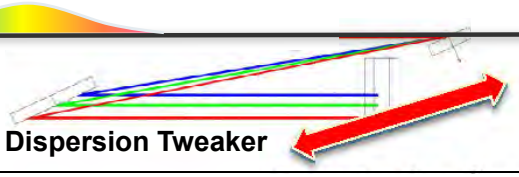
Each ARC beamlet uses chirped-pulse amplification to produce ps-timescale, laser pulses w/ > kJ energy

NIF master oscillator room

Short Pulse Oscillator

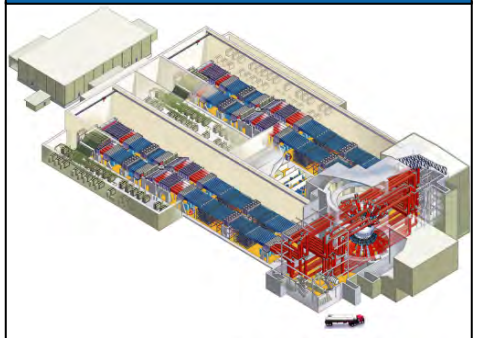


CFBG stretcher

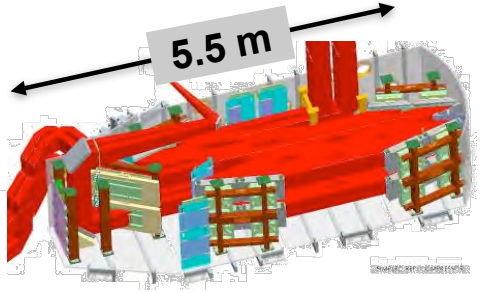


Dispersion Tweaker

NIF Laser Bay

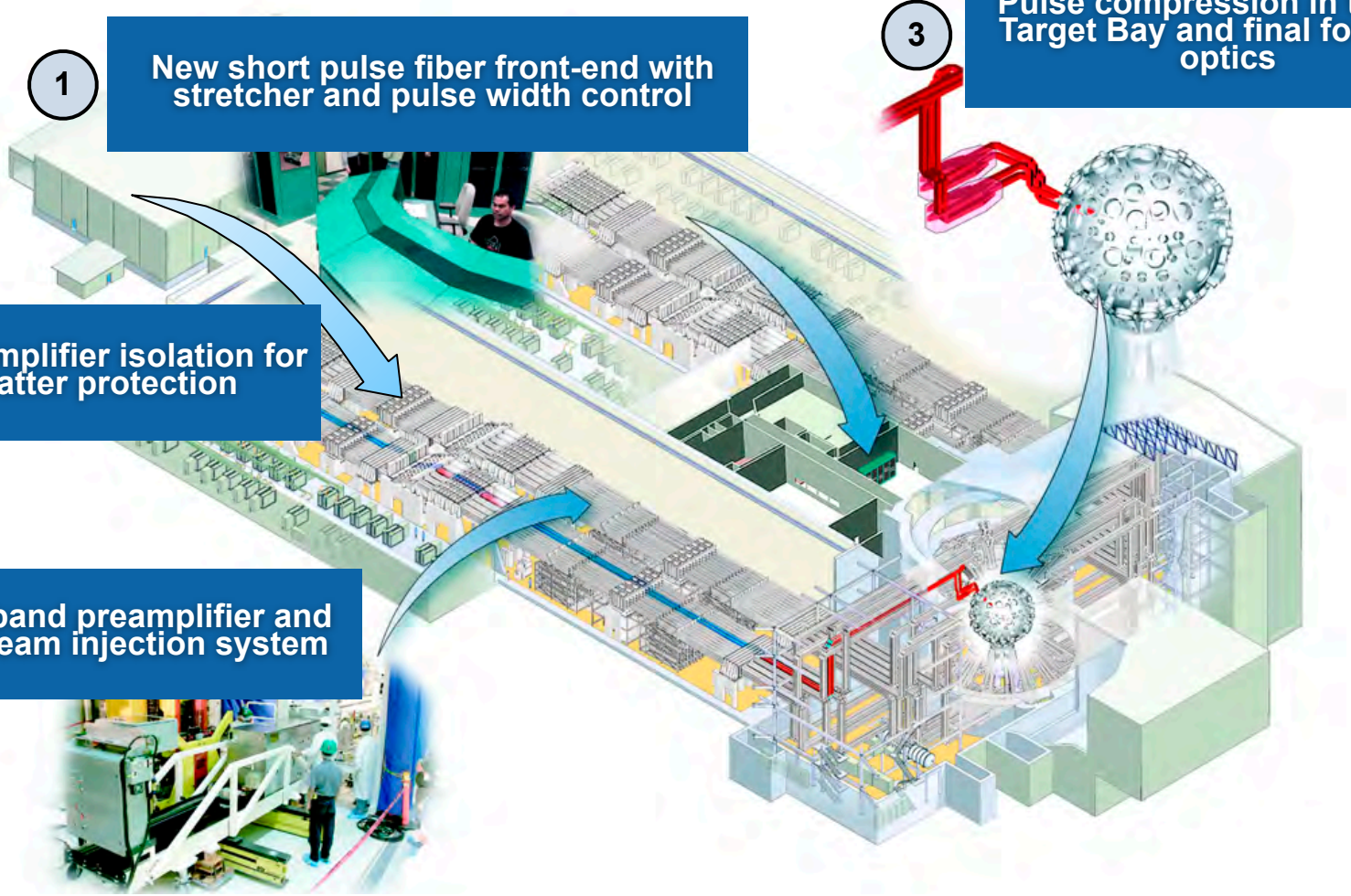


NIF target bay



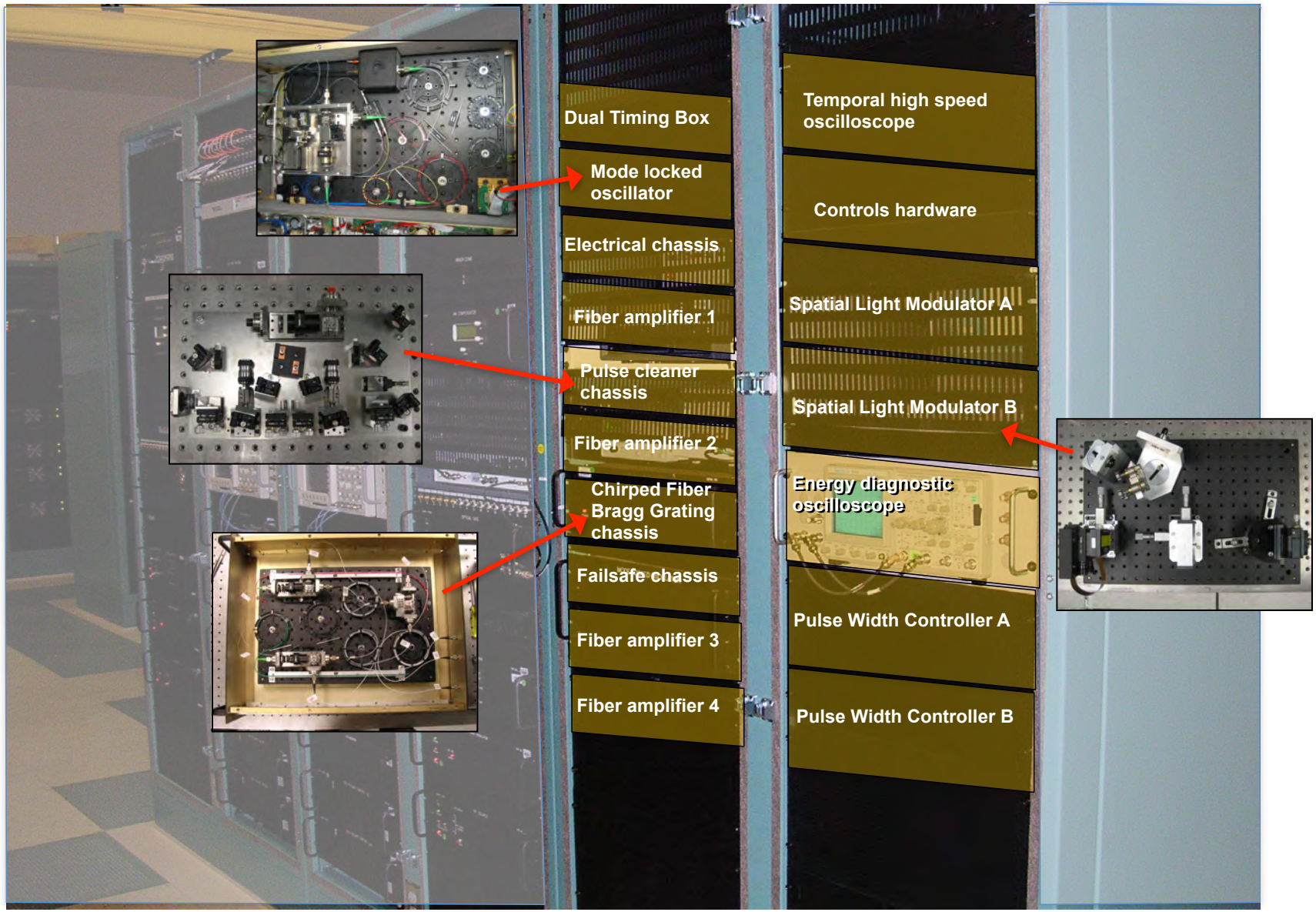
Compact, high efficiency, pulse compressor

Conversion of NIF beam lines to high-intensity, picosecond operation requires 4 top level changes

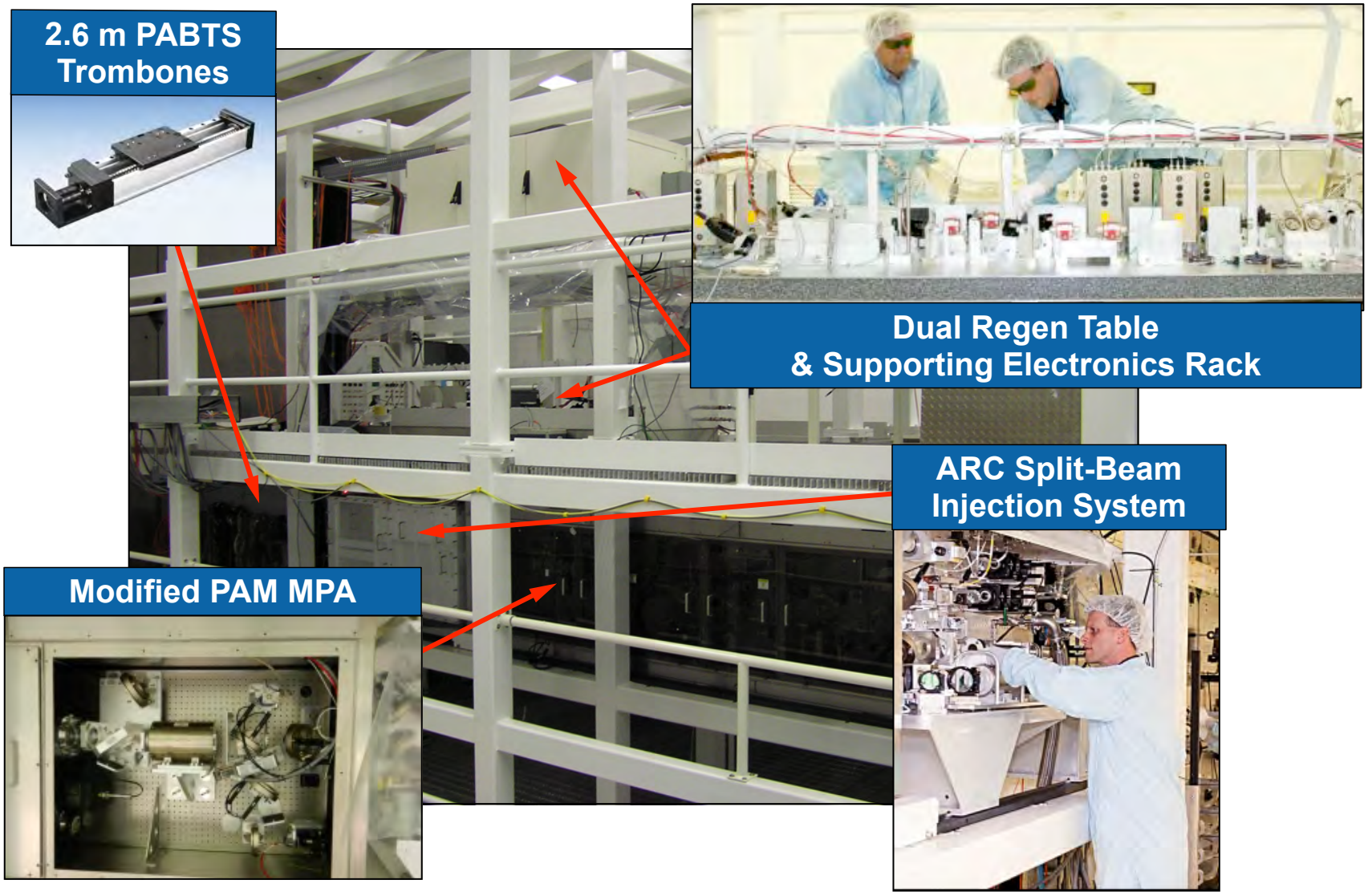


1. New short pulse fiber front-end with stretcher and pulse width control
2. Broadband preamplifier and split-beam injection system
3. Pulse compression in the NIF Target Bay and final focusing optics
4. Improved amplifier isolation for backscatter protection

ARC requires a new master oscillator to propagate wide bandwidth pulses through NIF

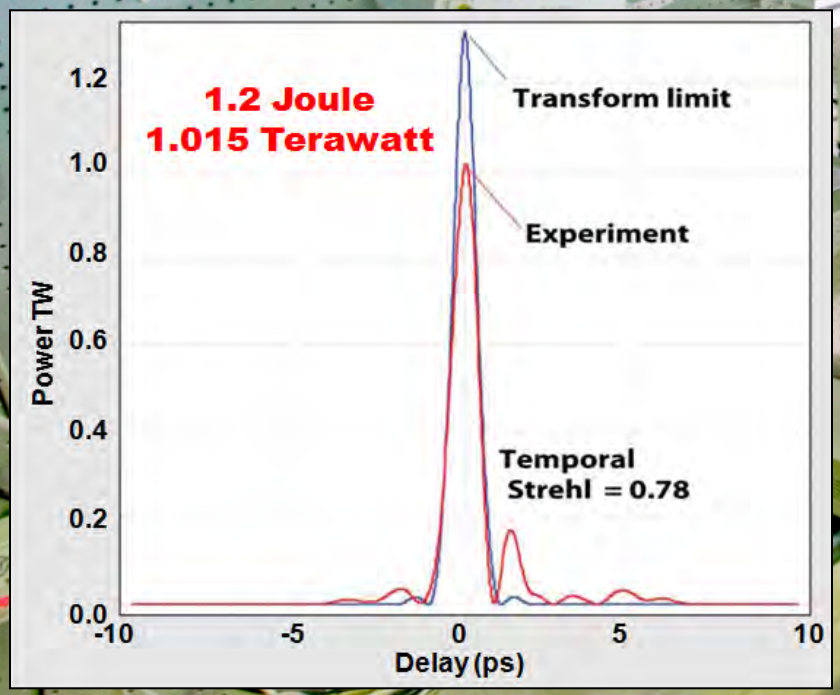


ARC injection laser hardware amplifies and injects the master osc. room pulse into the NIF main laser

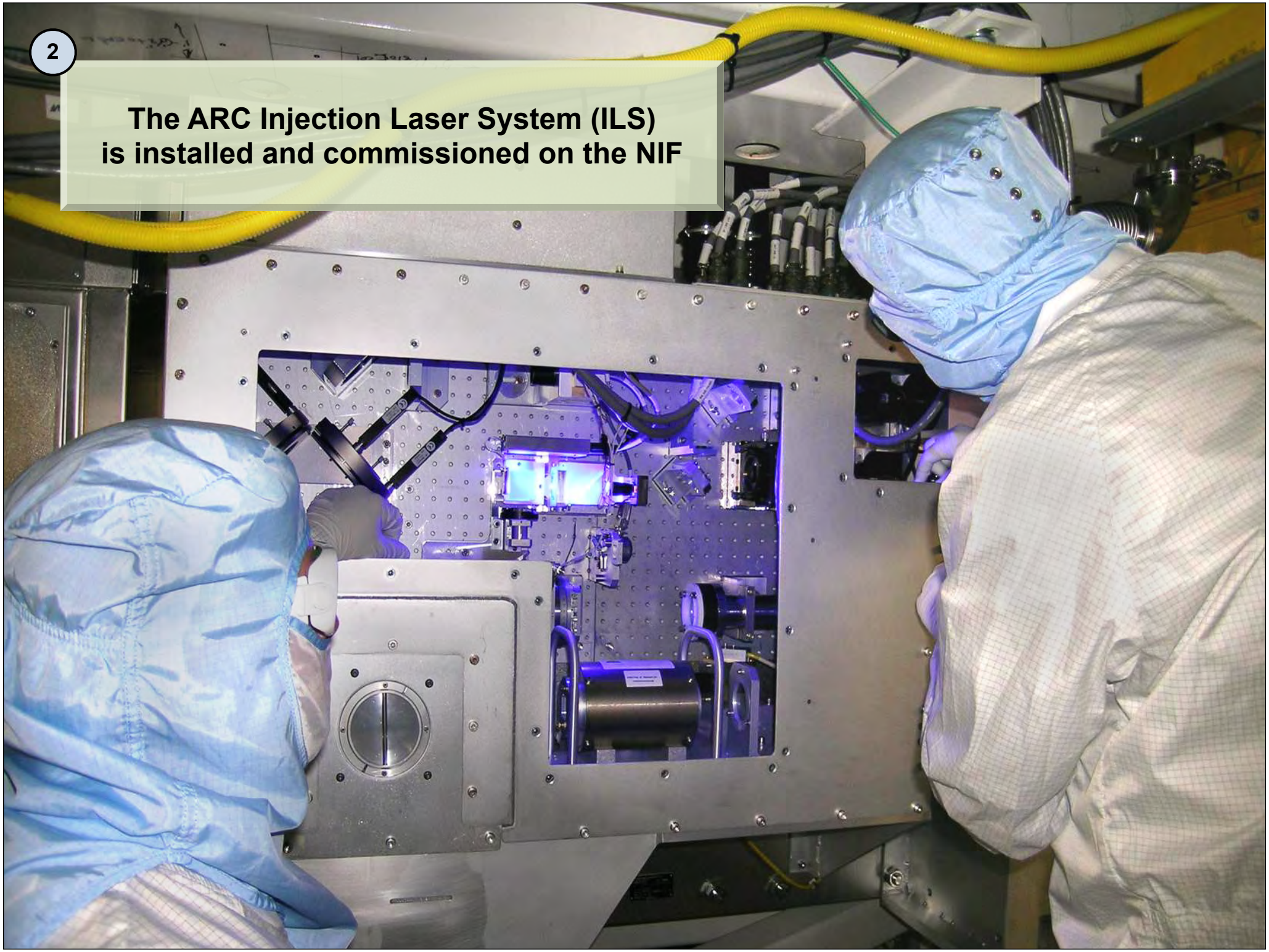


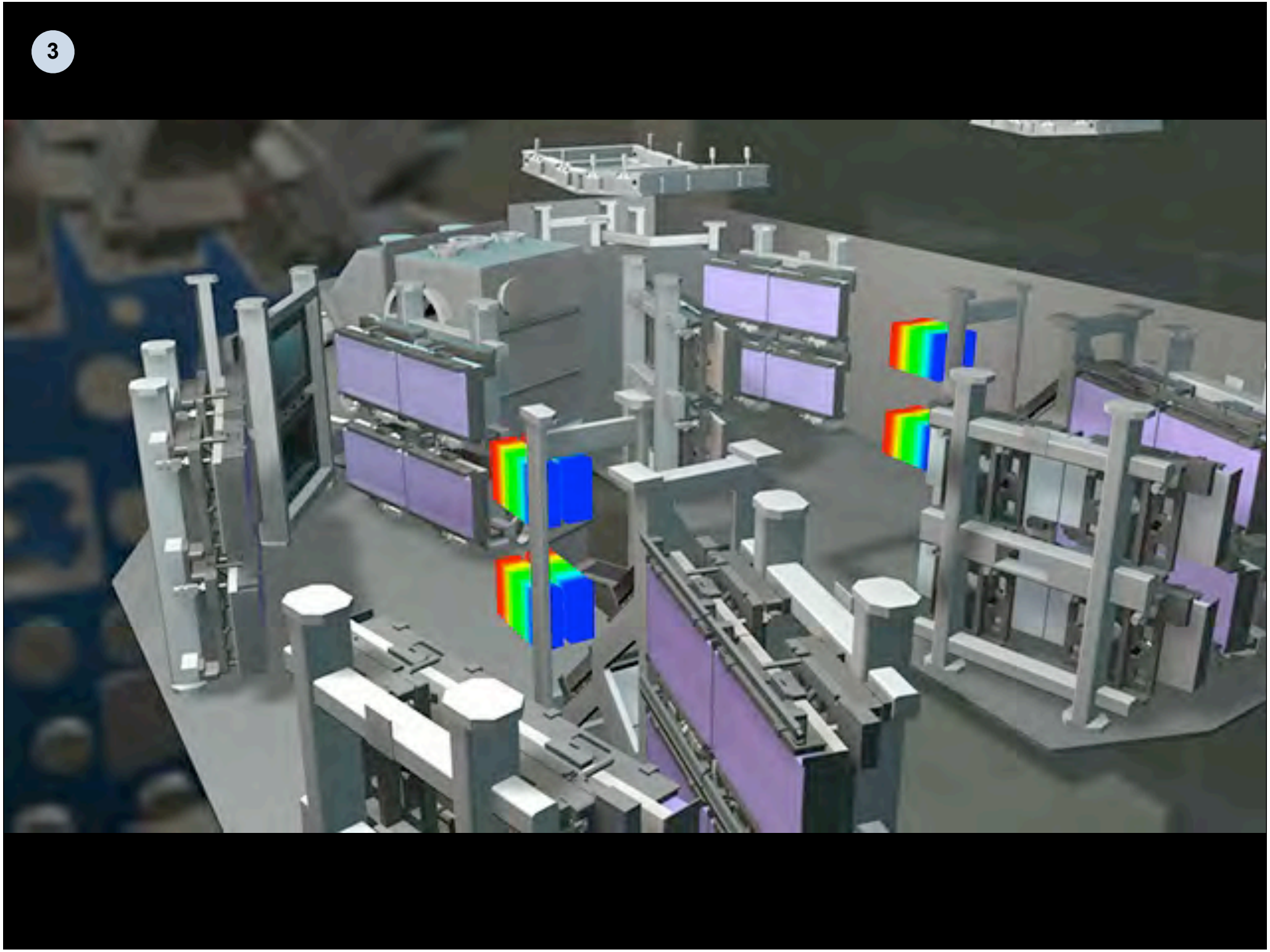
2

The ARC injection laser system has been performance tested in the ARC testbed facility

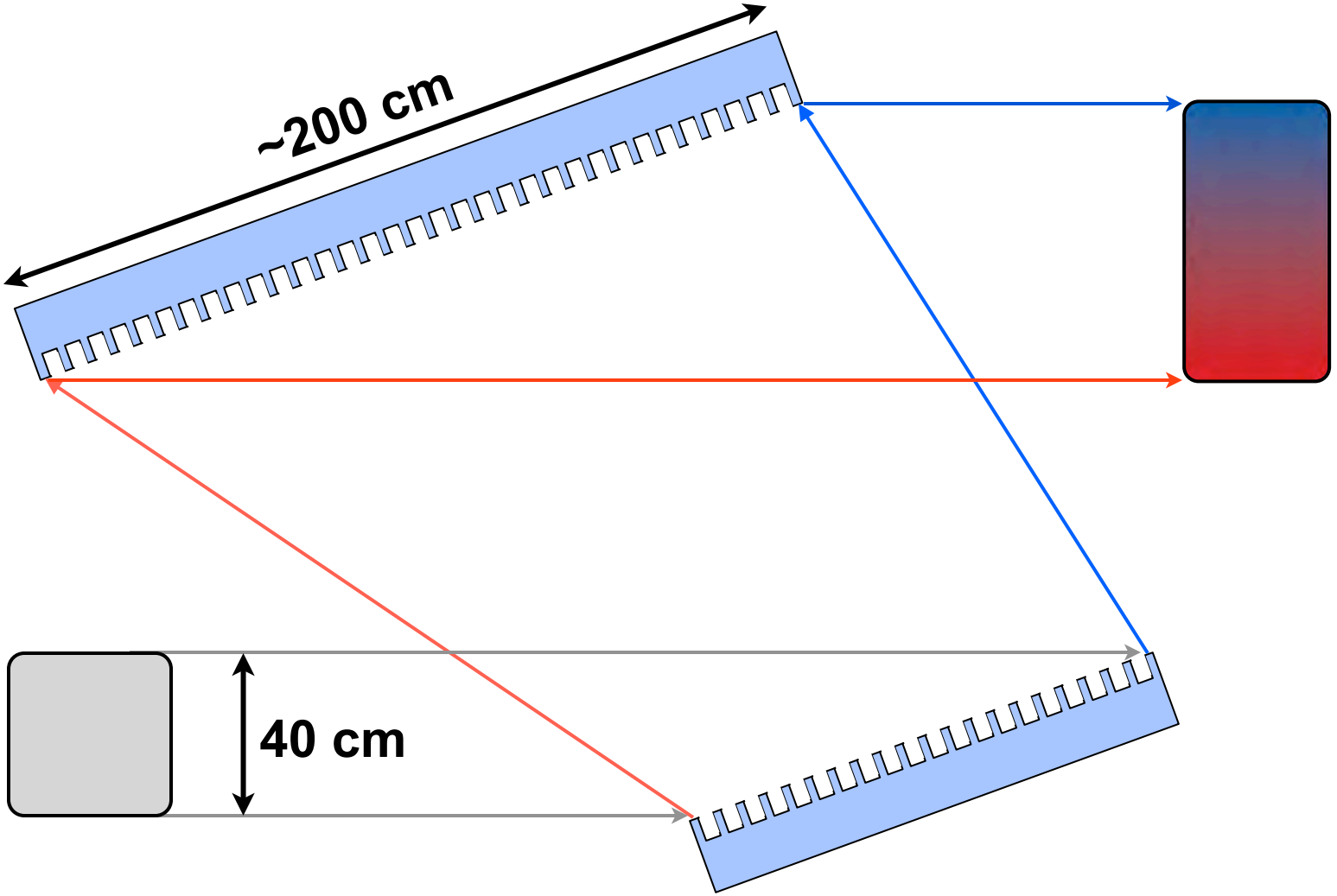


The ARC Injection Laser System (ILS) is installed and commissioned on the NIF

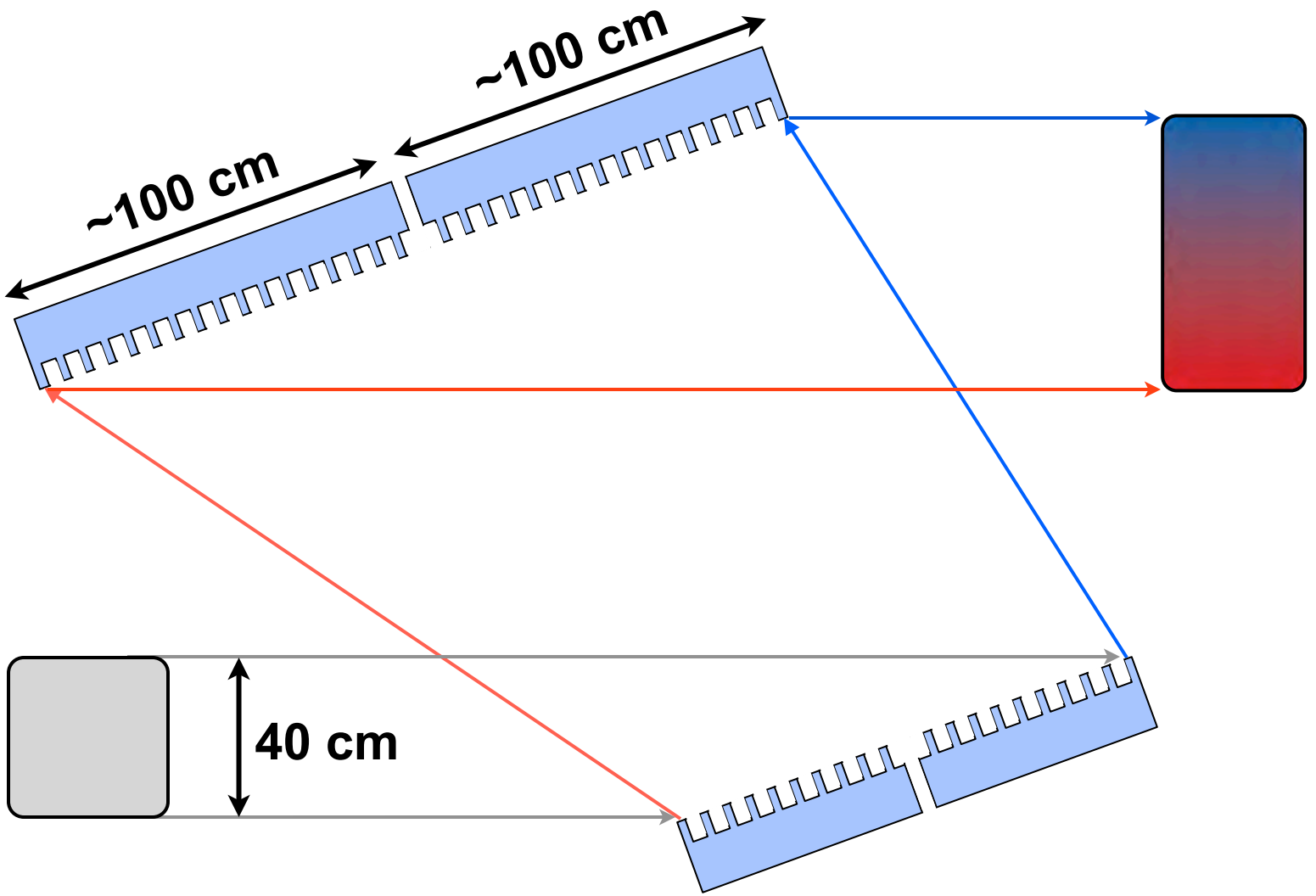




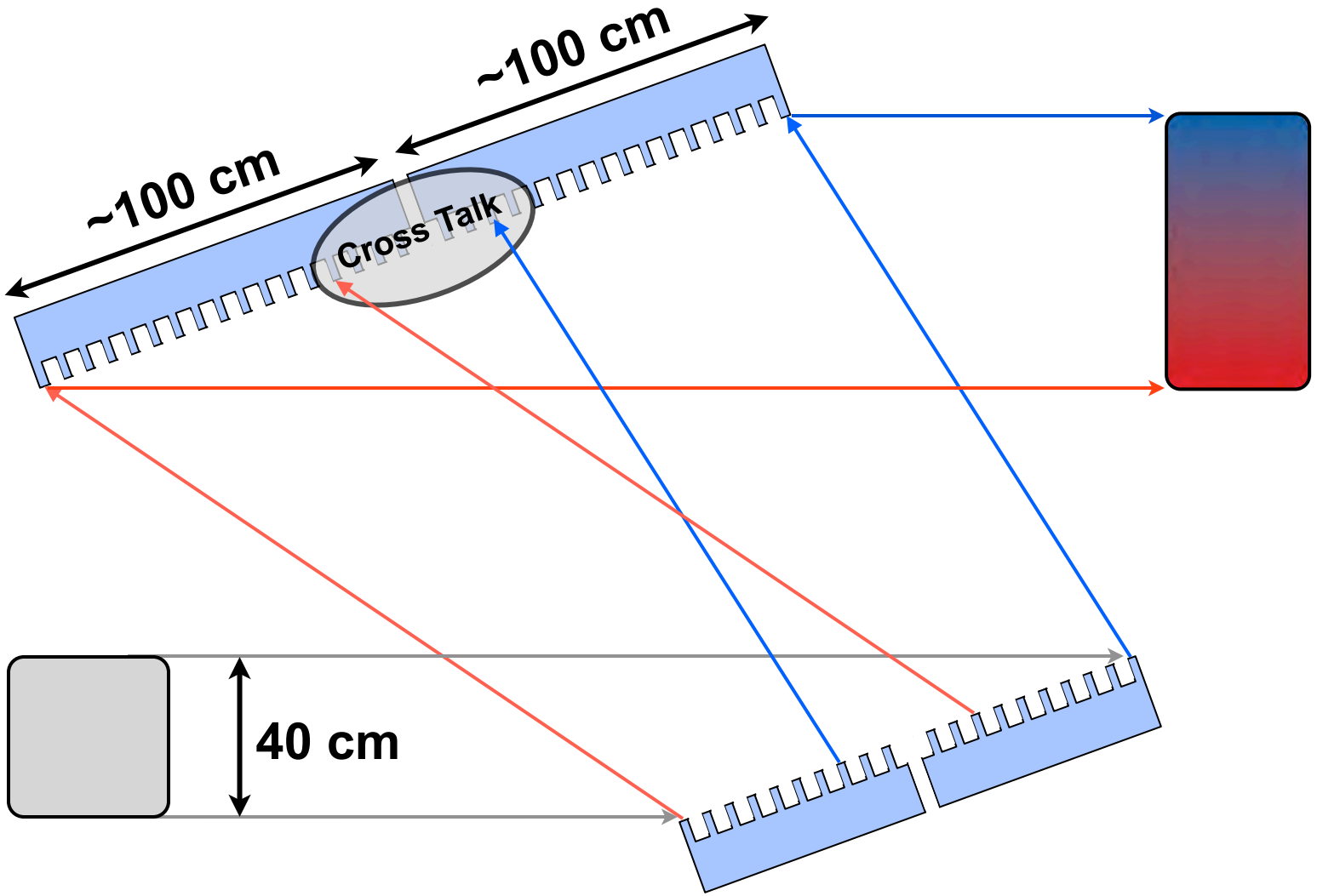
Pulse compression of 40-cm wide beams would require ~2 m gratings



Pulse compression of 40-cm wide beams would require ~2 m gratings OR “tiling of smaller gratings

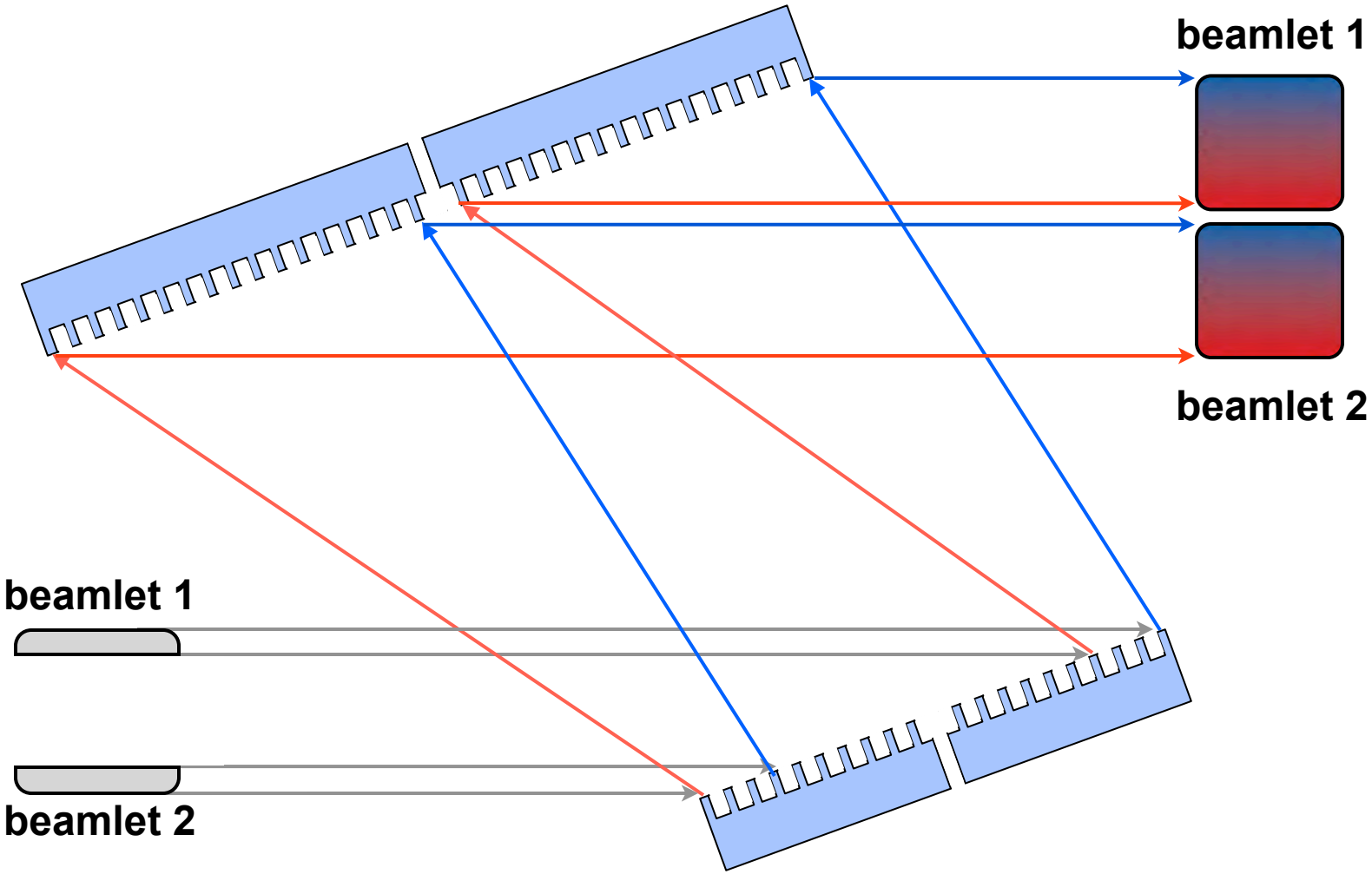


Pulse compression of 40-cm wide beams would require ~2 m gratings OR "tiling of smaller gratings



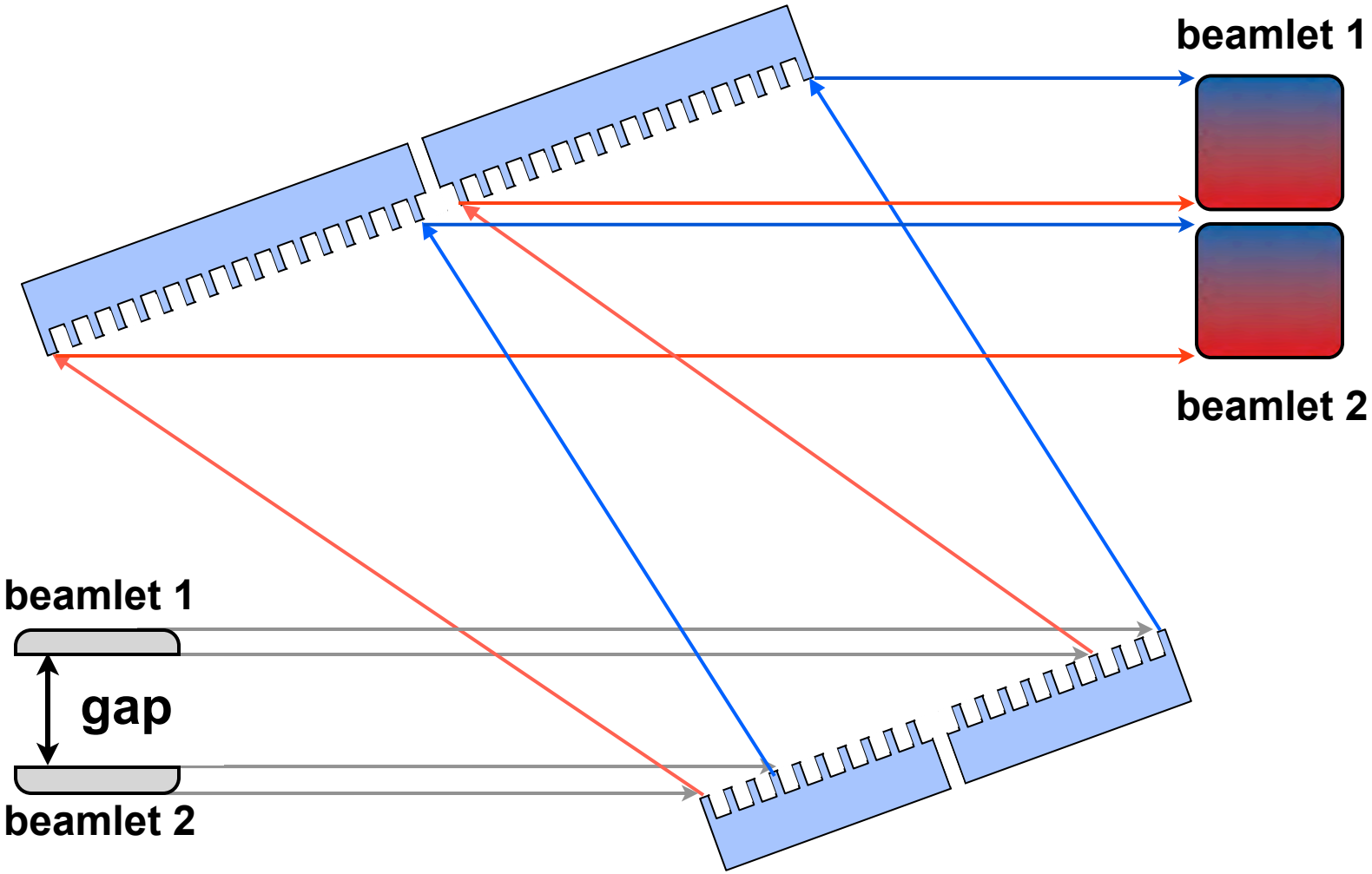
Tiling must be done "coherently" to avoid cross talk issues

The NIF beam is split prior to amplification to avoid cross talk & the need to coherently "tile" gratings,



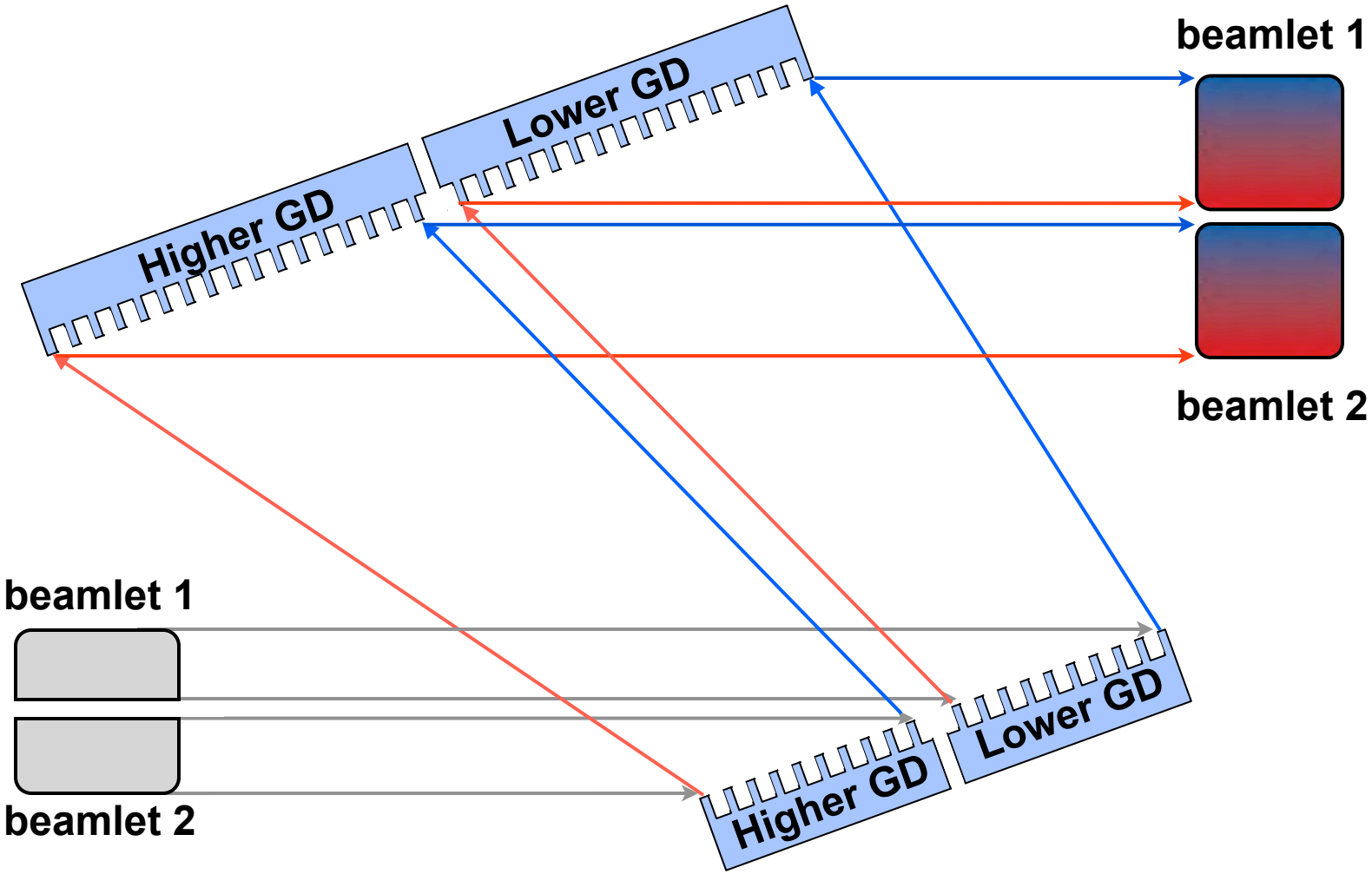
Two independent pulse compressors with double the outputs for back lighting

The NIF beam is split prior to amplification to avoid cross talk & the need to coherently "tile" gratings,

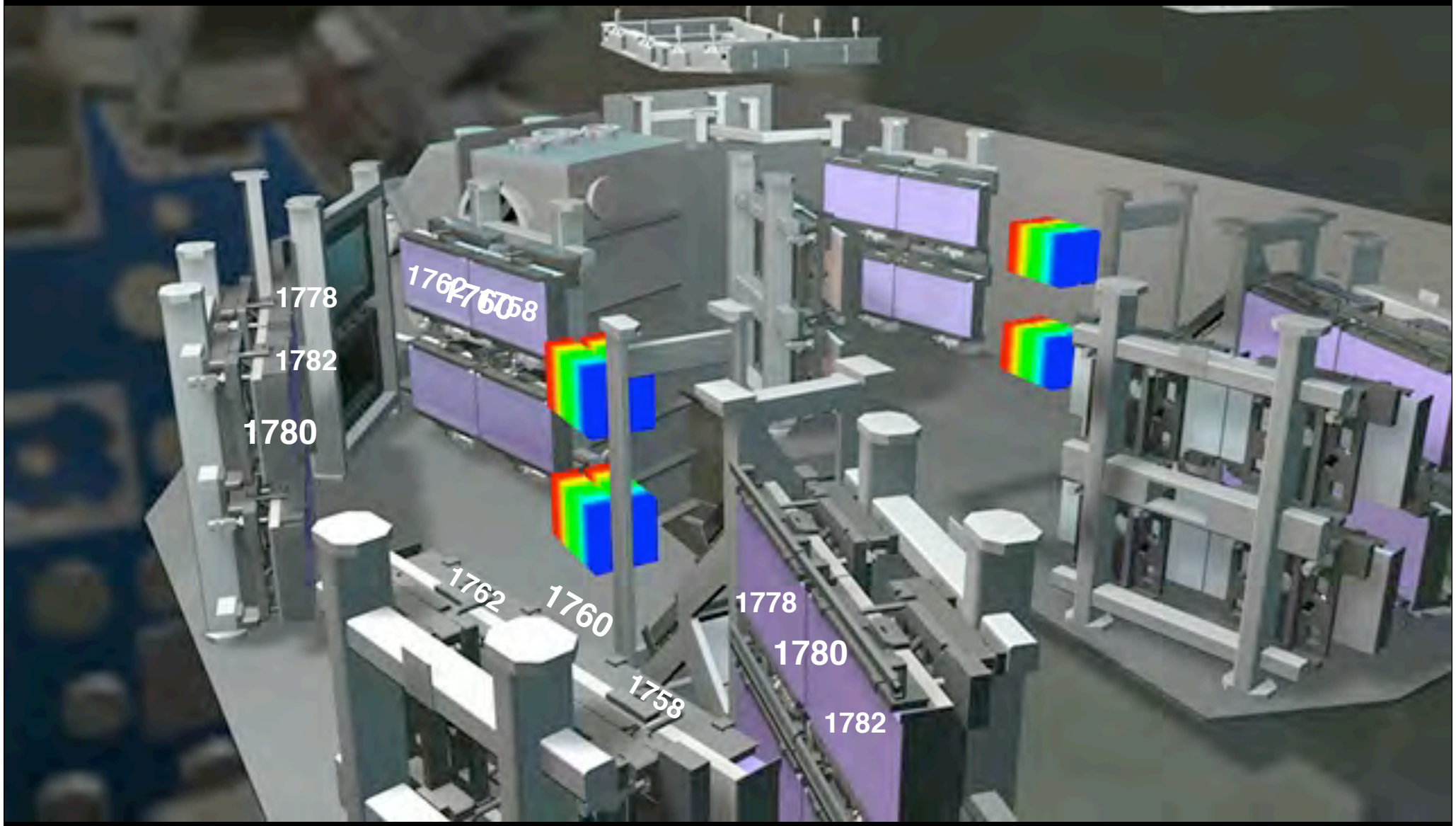


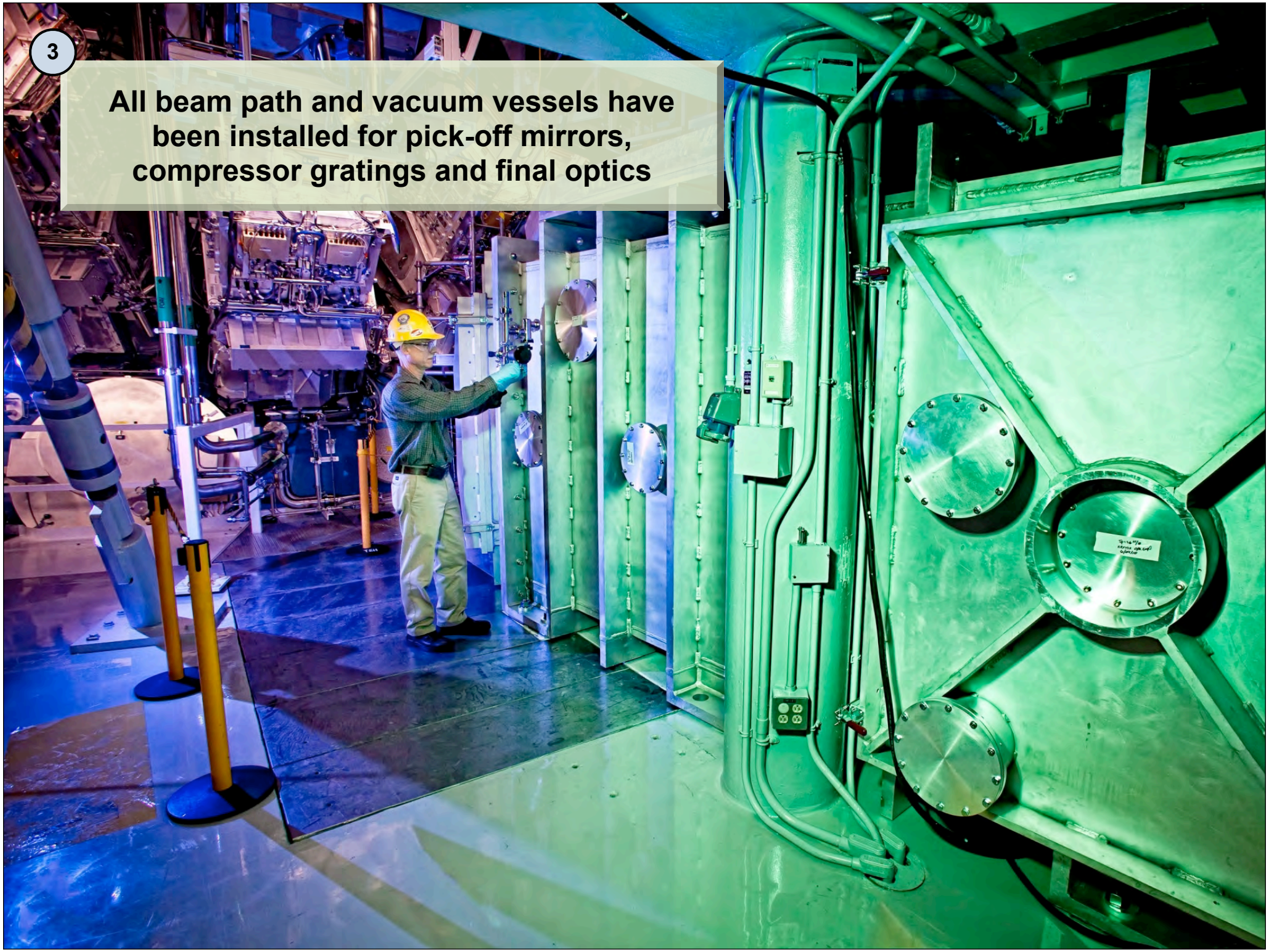
However the gap between the beams corresponds to an unwanted loss of energy

To avoid cross talk & the need to coherently "tile" gratings, the NIF beam is split prior to amplification

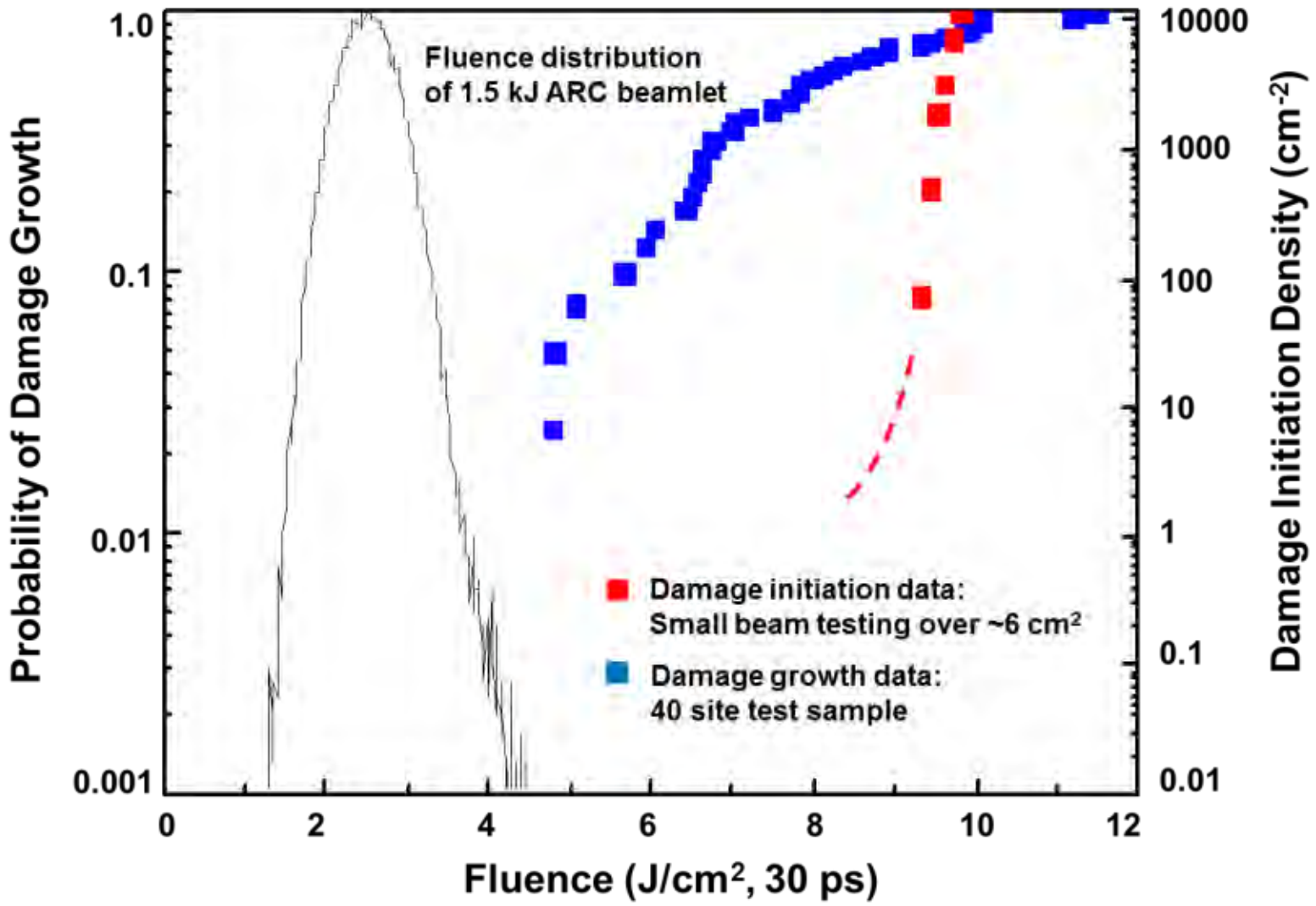


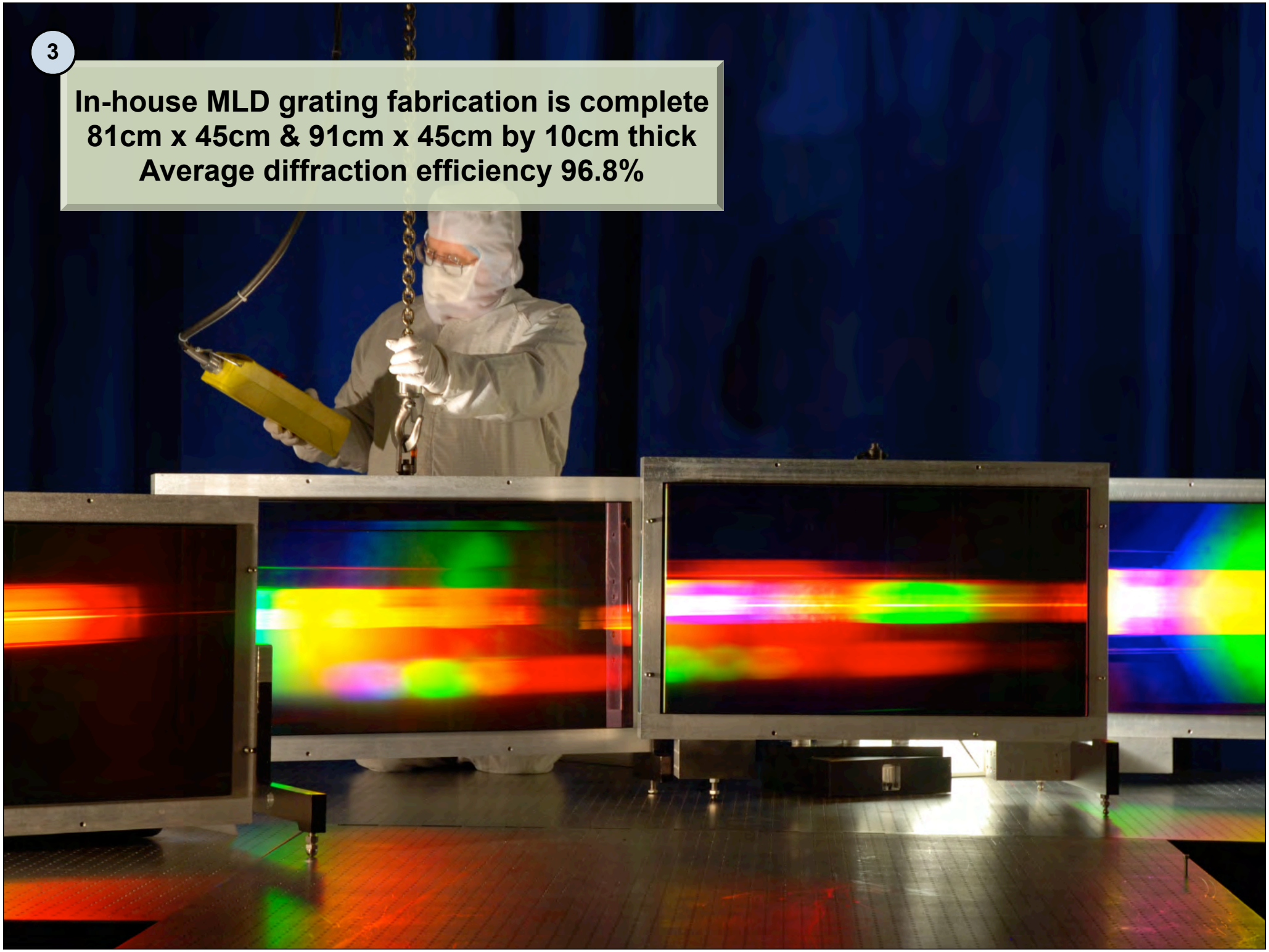
Beamlet energy is increased by slight modification of the left & right grating pairs


1778
1782
1780
1762
1760
1758
1778
1780
1782

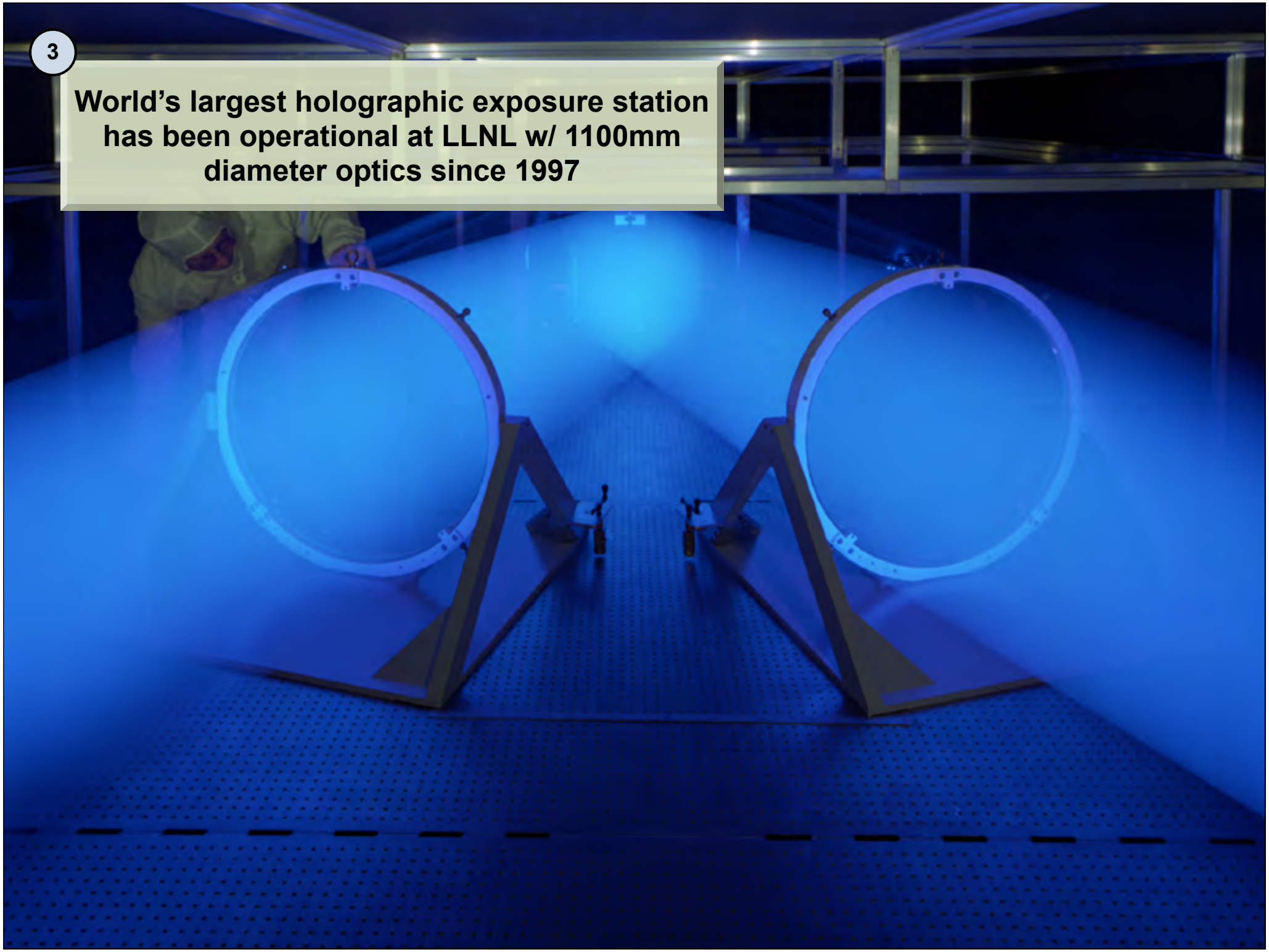

3
All beam path and vacuum vessels have been installed for pick-off mirrors, compressor gratings and final optics

Damage test data of ARC multi-layer dielectric grating samples supports >1.5 kJ per beamlet

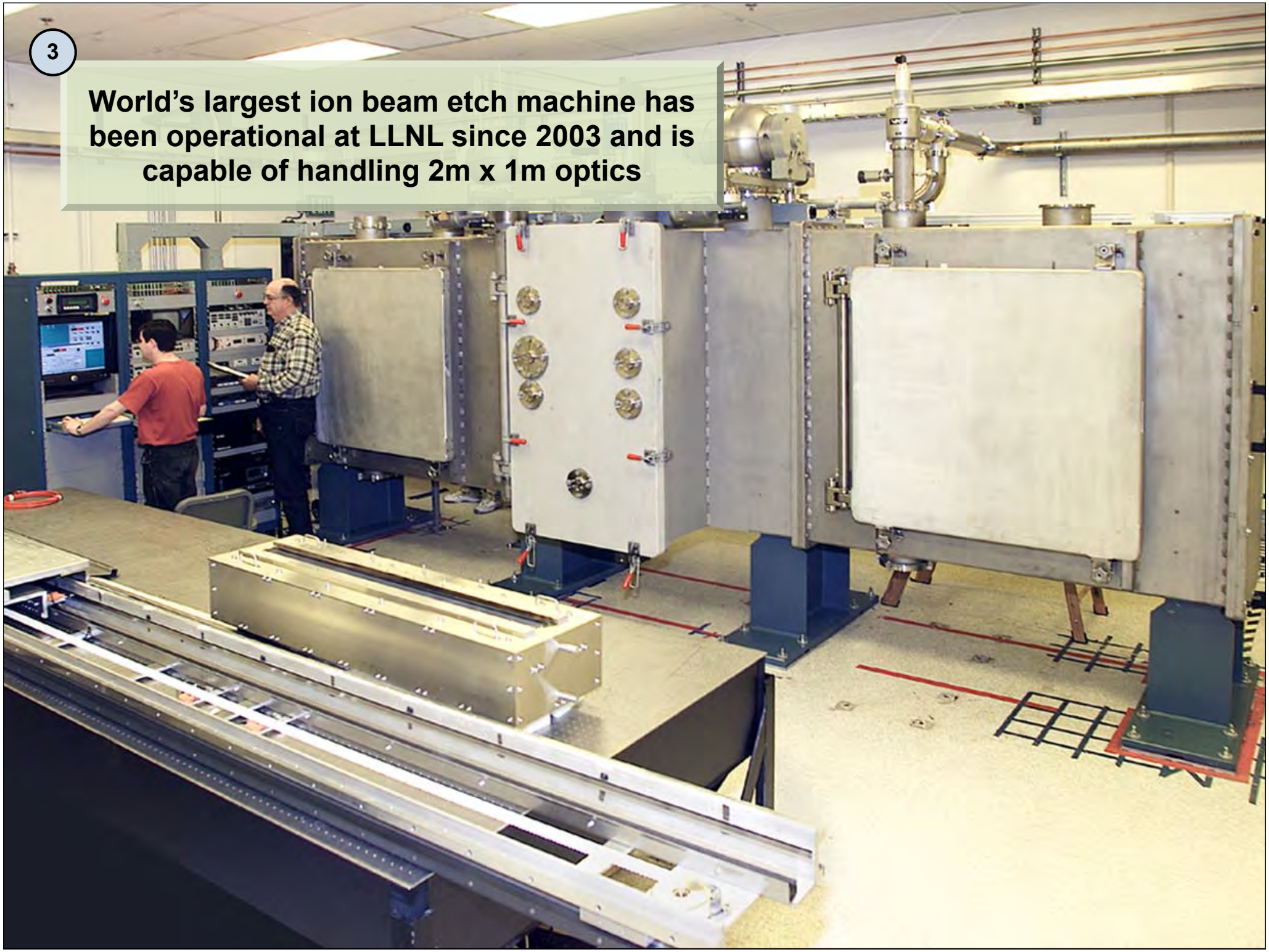



3
In-house MLD grating fabrication is complete
81cm x 45cm & 91cm x 45cm by 10cm thick
Average diffraction efficiency 96.8%

World's largest holographic exposure station has been operational at LLNL w/ 1100mm diameter optics since 1997

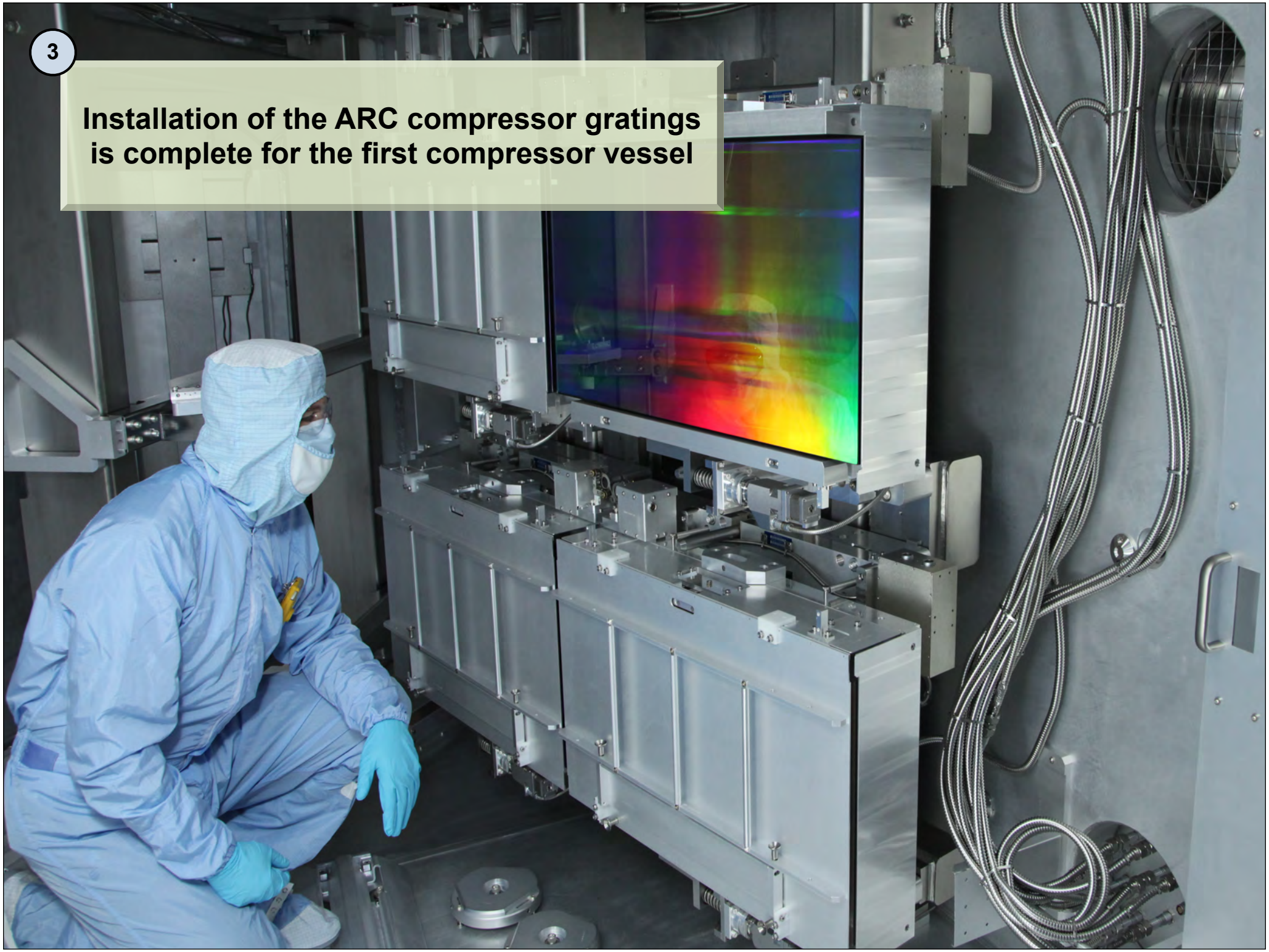


World's largest ion beam etch machine has been operational at LLNL since 2003 and is capable of handling 2m x 1m optics

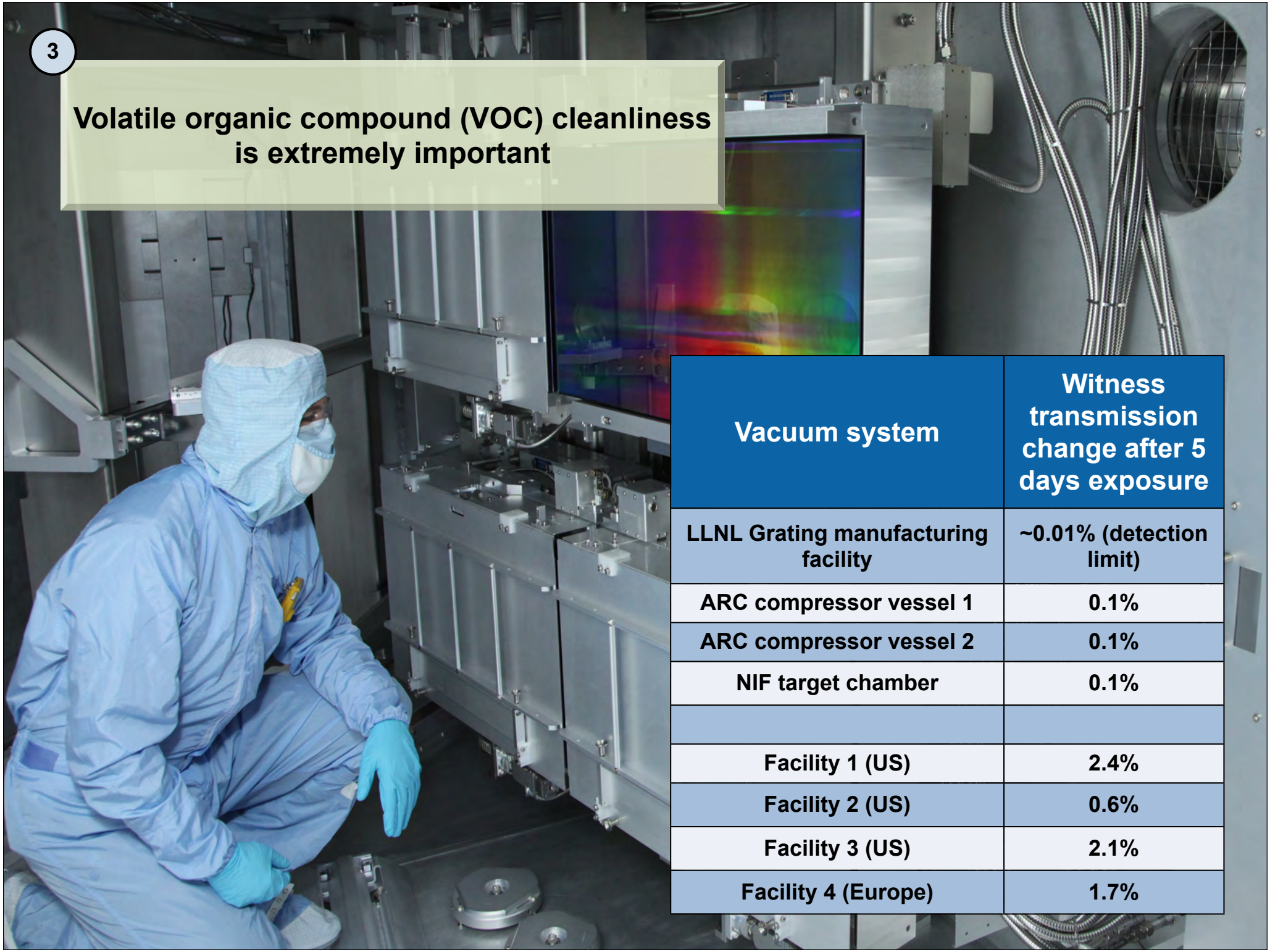


3

Installation of the ARC compressor gratings is complete for the first compressor vessel



Volatile organic compound (VOC) cleanliness is extremely important

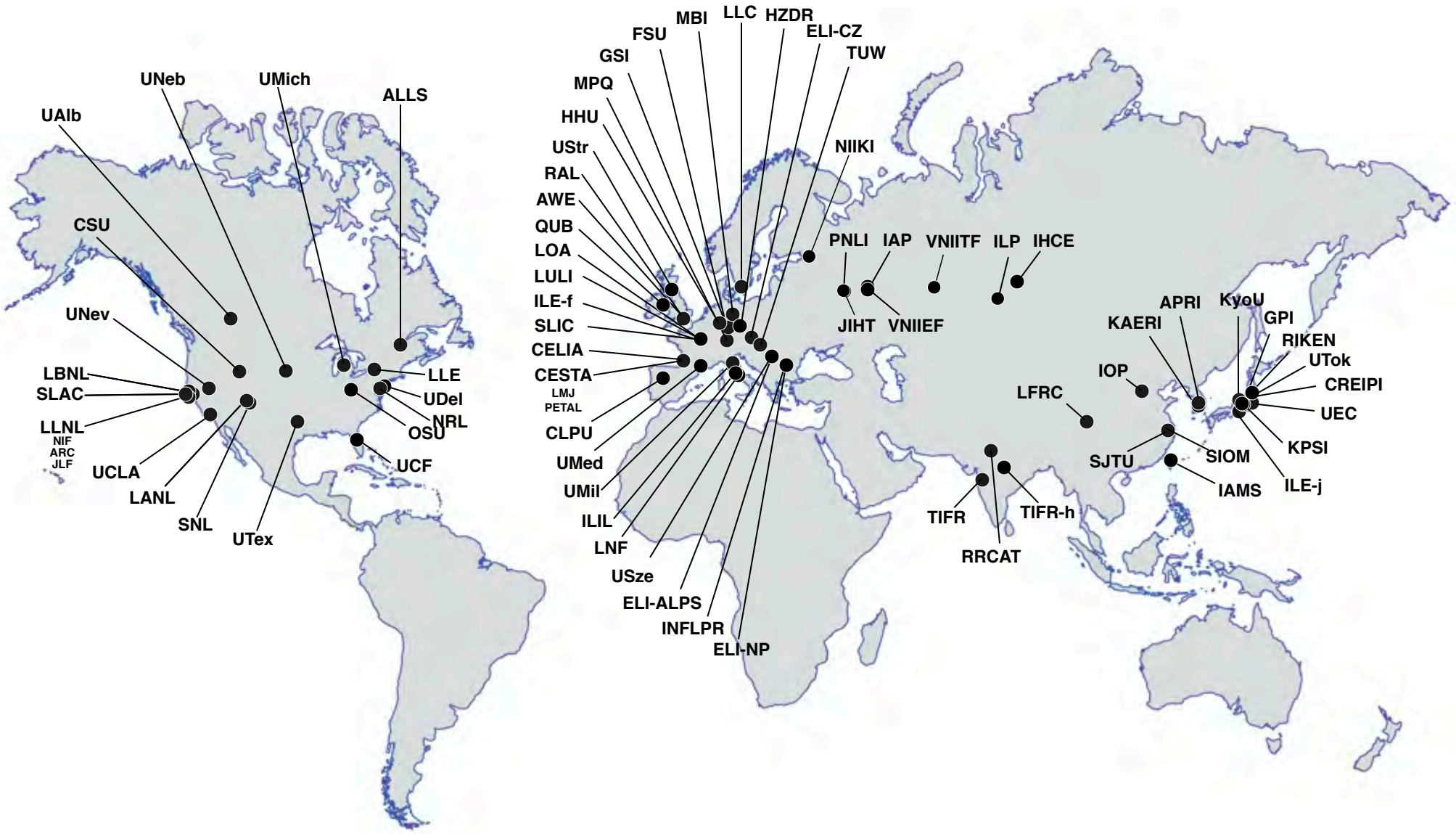


Vacuum system	Witness transmission change after 5 days exposure
LLNL Grating manufacturing facility	~0.01% (detection limit)
ARC compressor vessel 1	0.1%
ARC compressor vessel 2	0.1%
NIF target chamber	0.1%
Facility 1 (US)	2.4%
Facility 2 (US)	0.6%
Facility 3 (US)	2.1%
Facility 4 (Europe)	1.7%

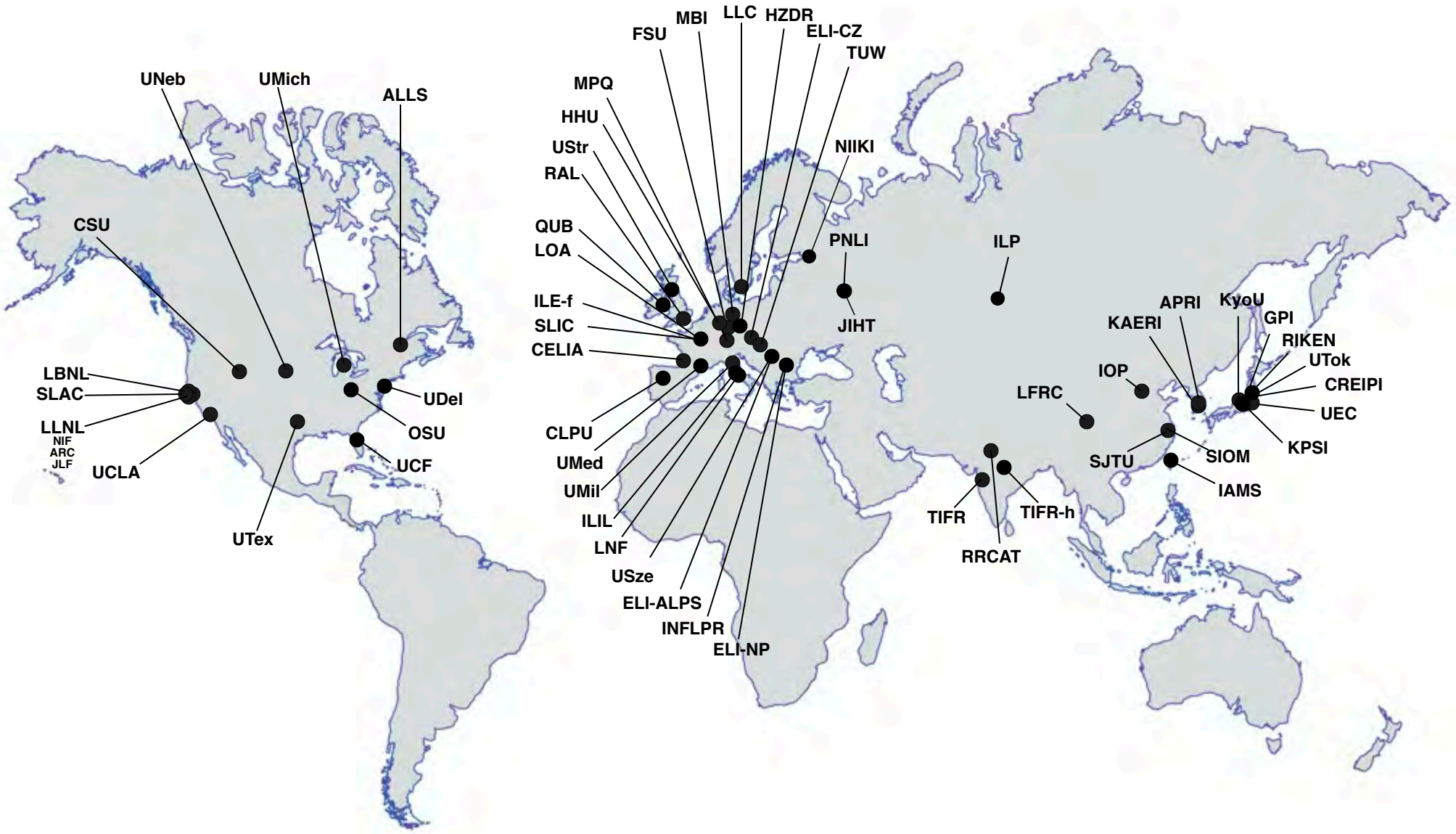
Present ICUIL World Map - Nd:Glass

CPJ Barty

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

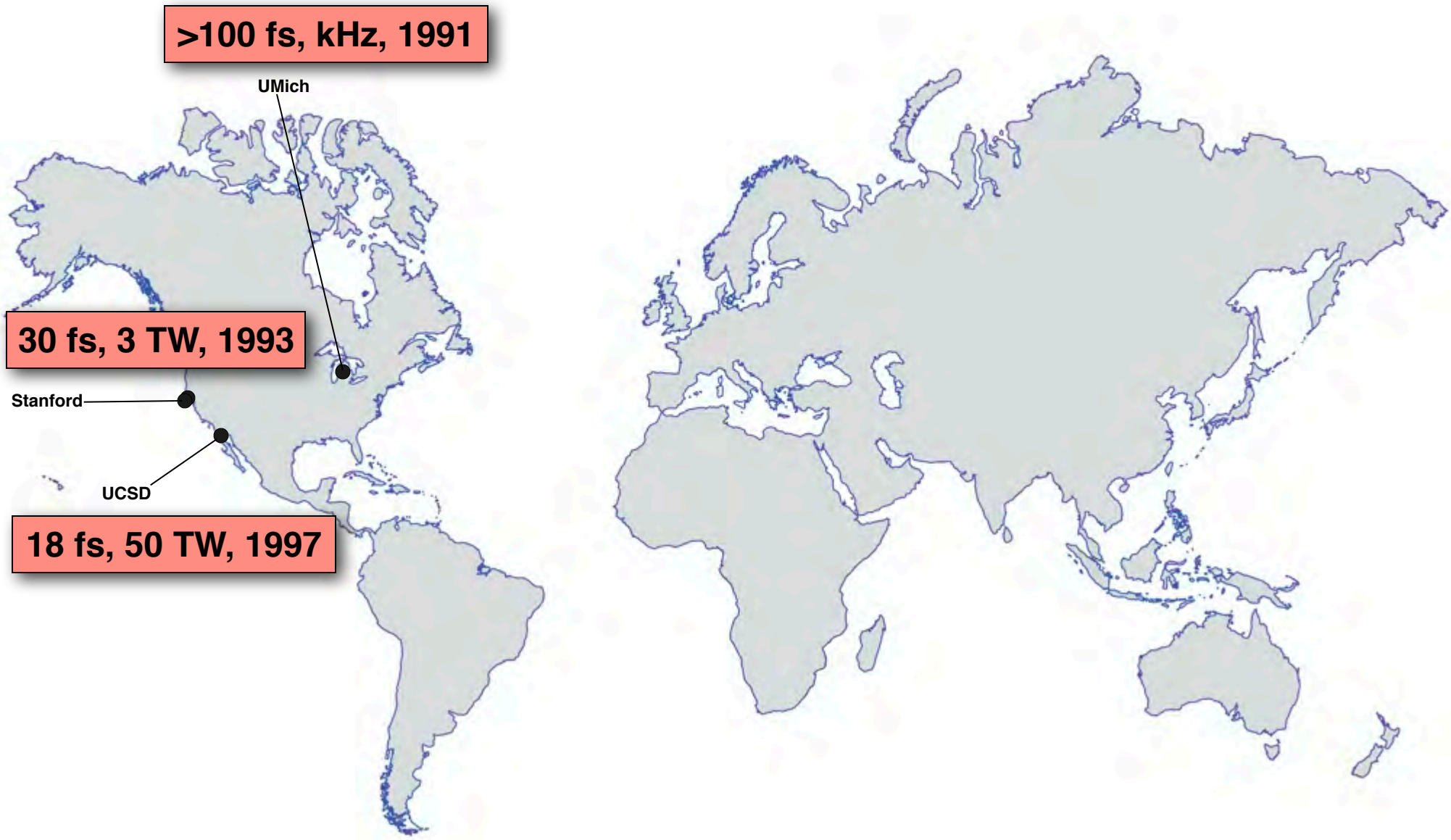


Present ICUIL World Map - Ti:sapphire Systems



CPJ Barty

The Early Days of Ti:sapphire



CPJ Barty

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

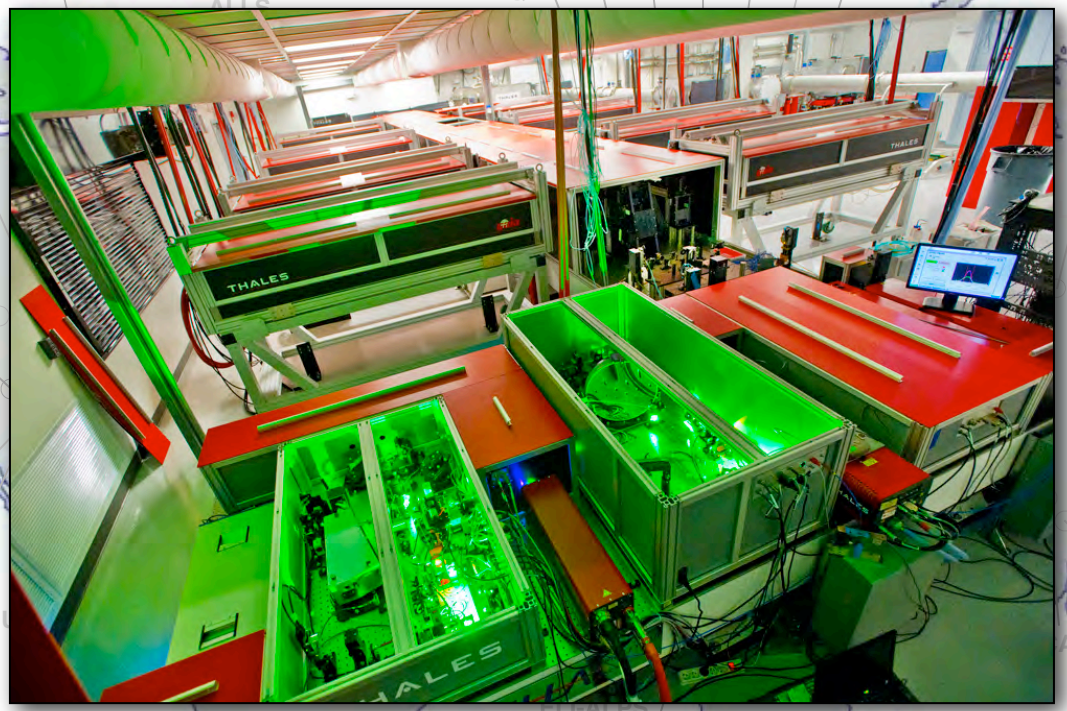
MBI LLC HZDR FSU ELI-CZ GSI TUW UNeb UMich UAlb CSU UNev LBNL SLAC LLNL NIF ARC JLF UCLA LANL SNL UTex GPI RIKEN UTok CREIPI UEC KPSI IAMS ILE-j UMil ILIL LNF USze ELI-ALPS INFLPR TIFR TIFR-h RRCAT

Japan's $600M Kansai Photon Science Institute created the 1st PW-scale fs system

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

S. Korea has invested ~$0.5B to create a multi-beam line, PW laser user facility

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities



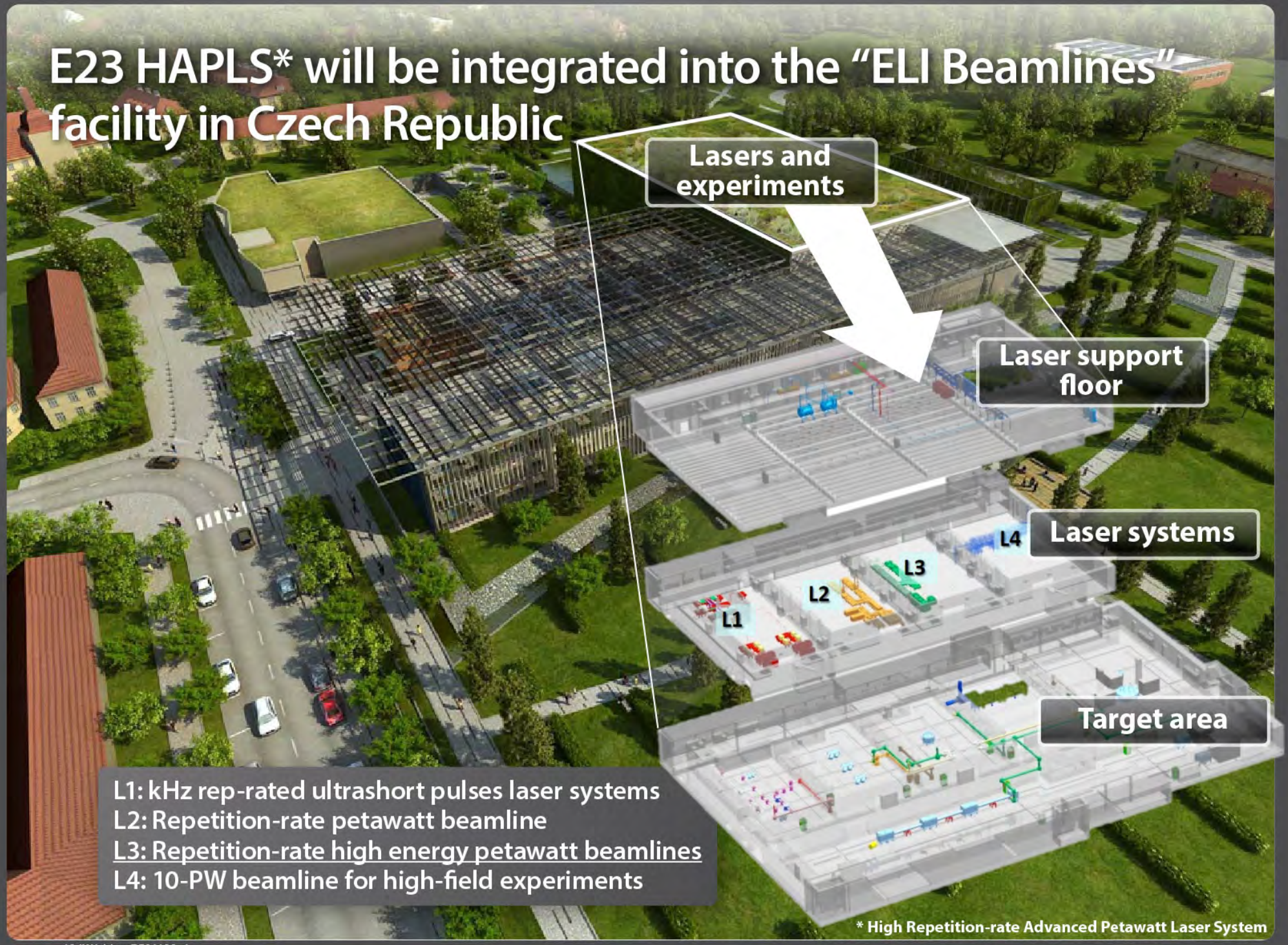
LBNL's BELLA 1 Hz, 1 PW laser system for laser-based particle acceleration

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

UNeb
UMich
ALLS
UAlb
MBI
LLC
HZDR
FSU
ELI-CZ
GSI
TUW
MPQ
HHU
NIIKI
UStr
RAL
AWE
PNLI
JIHT
VNIIEF
APRI
KAERI
GPI
RIKEN
UTok
CREIPI
UEC
KPSI
SIOM
IAMS
ILE-j
LBNL
SLAC
LLNL
NIF
ARC
JLF
LFRC
IOP
SNL
UTex
ILIL
LNF
USze
ELI-ALPS
INFLPR
ELI-NP

800M euros will be invested in the Extreme Light Infrastructure Project in Europe

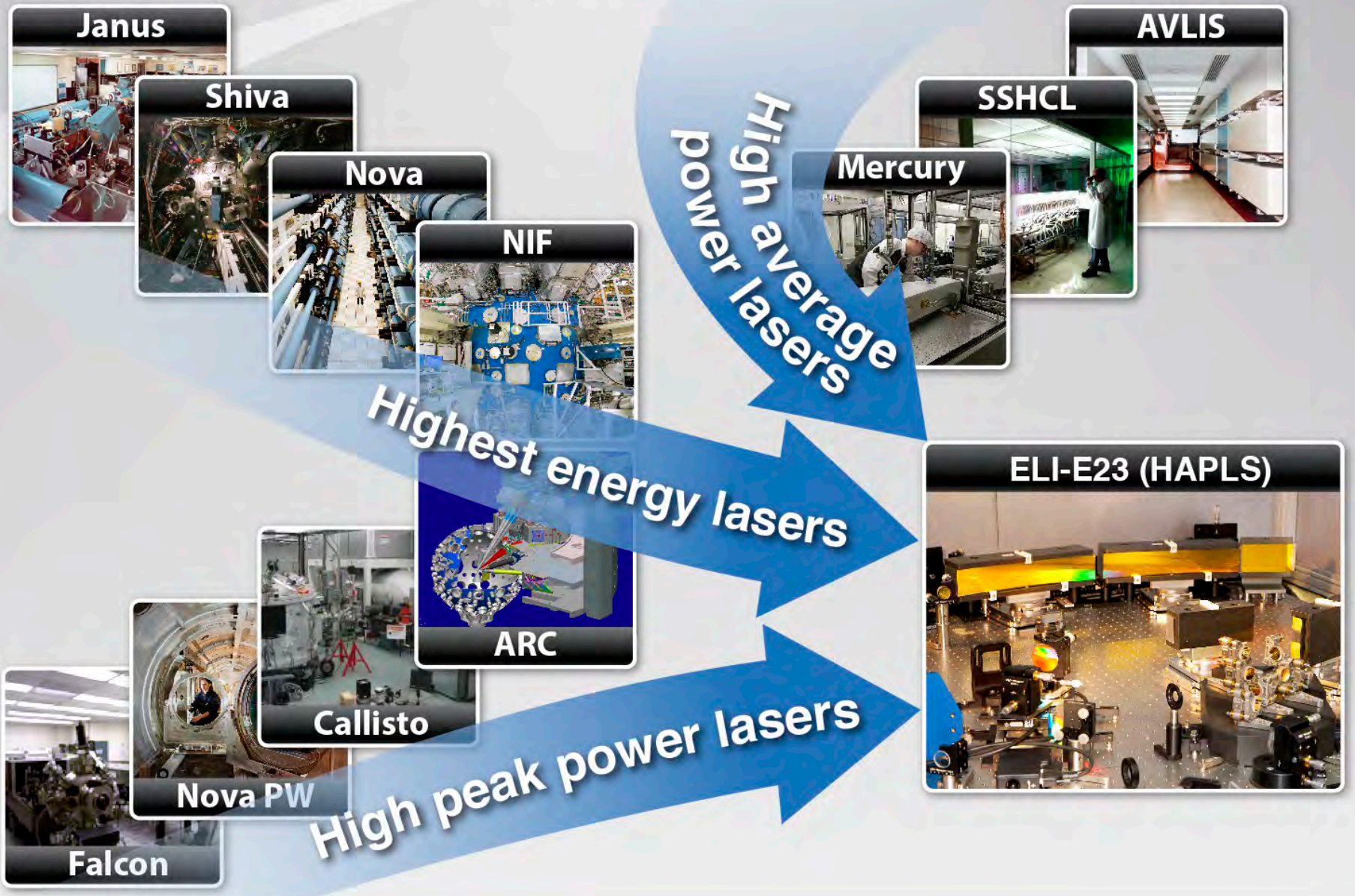
E23 HAPLS* will be integrated into the "ELI Beamlines" facility in Czech Republic



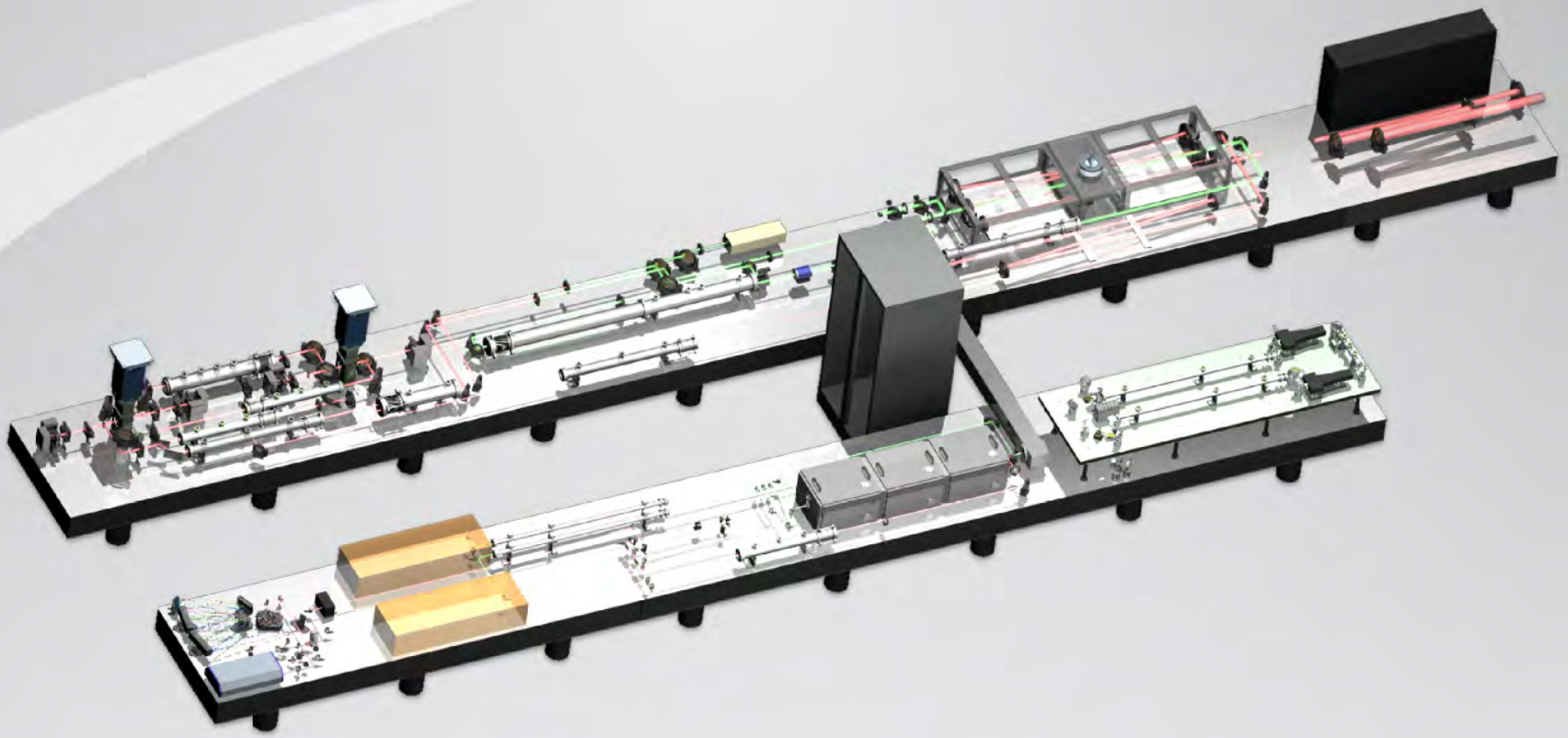
L1: kHz rep-rated ultrashort pulses laser systems
L2: Repetition-rate petawatt beamline
L3: Repetition-rate high energy petawatt beamlines
L4: 10-PW beamline for high-field experiments

* High Repetition-rate Advanced Petawatt Laser System

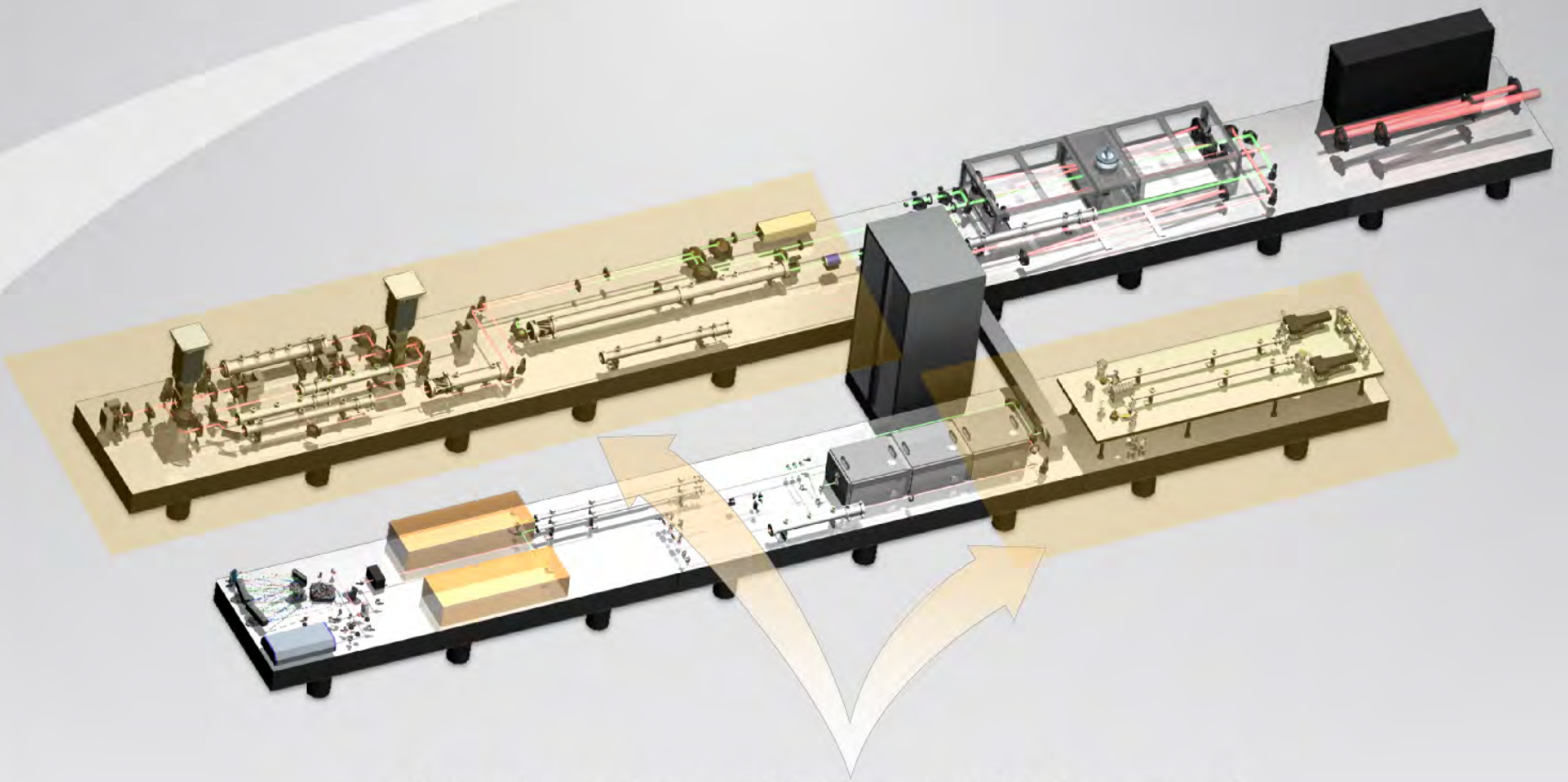
E23 builds on our expertise in high power and high-energy laser systems



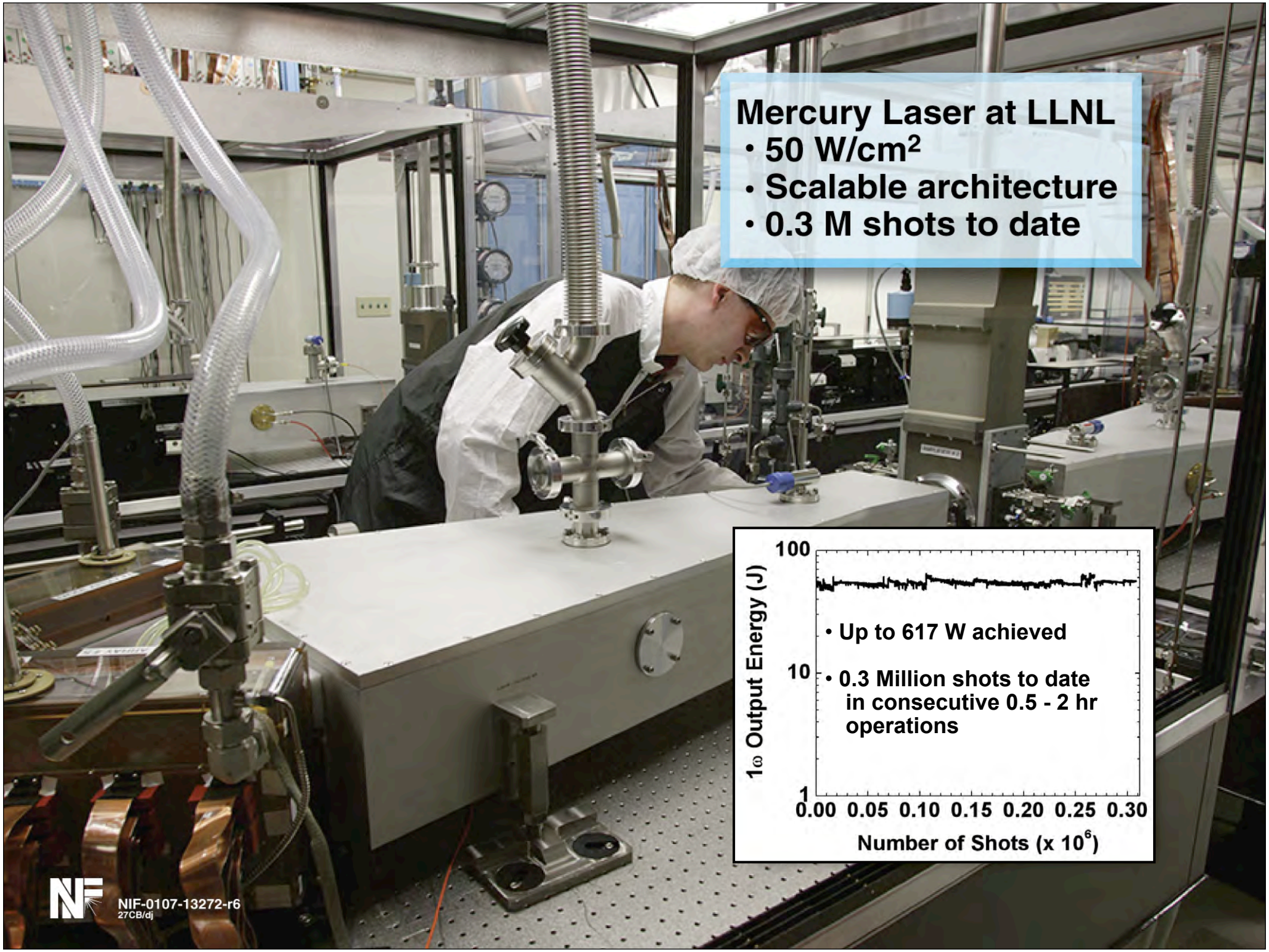
The E23 Laser System contains two major subsystems



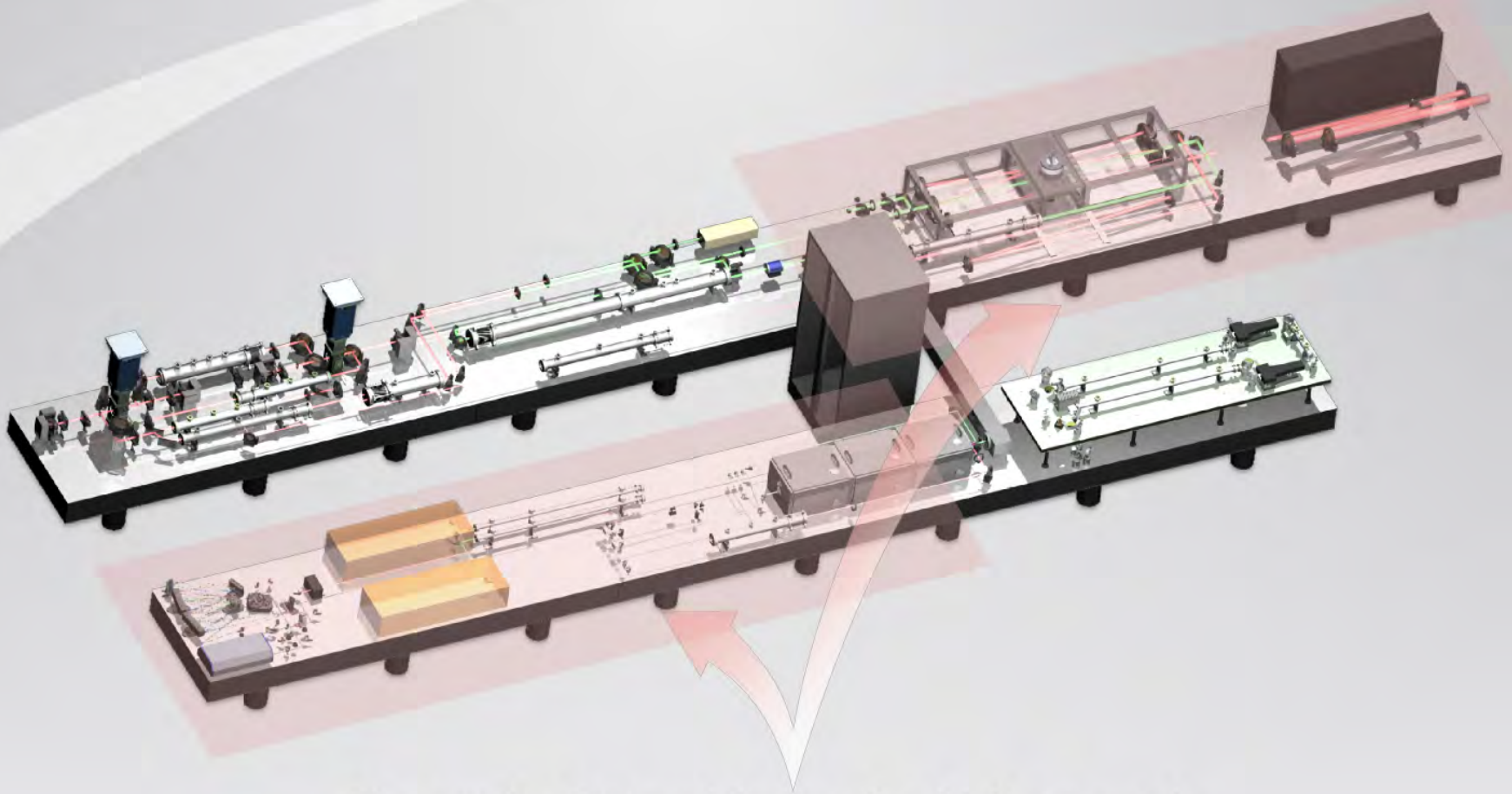
The E23 Laser System contains two major subsystems



Pump Laser System (high energy, high rep-rate)

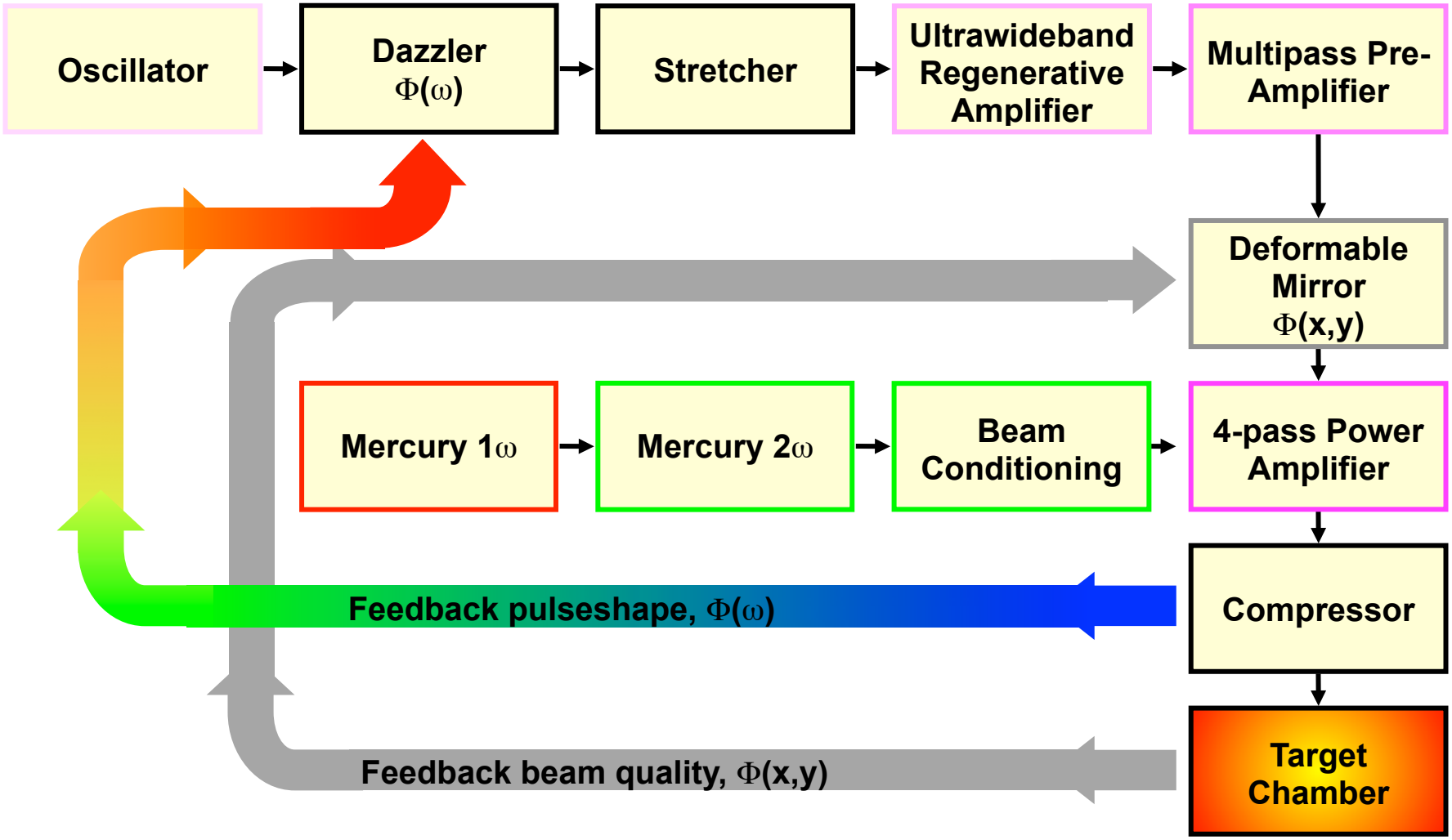

Mercury Laser at LLNL
• 50 W/cm²
• Scalable architecture
• 0.3 M shots to date
1ω Output Energy (J)
100
10
1
• Up to 617 W achieved
• 0.3 Million shots to date in consecutive 0.5 - 2 hr operations
0.00 0.05 0.10 0.15 0.20 0.25 0.30
Number of Shots (x 10⁶)
NIF-0107-13272-r6
27CB/dj

The E23 Laser System contains two major subsystems



Short-pulse System (short pulse, high rep-rate)

10 Hz operation enables real time feedback for dispersive and spatial control of petawatt pulses



A diffraction-limited PW laser can produce intensities in excess of 10^{23} W/cm^2

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

UAlb
UNeb
UMich
ALLS
OSU
UNev
LBNL
SLAC
LLNL
NIF
ARC
JLF
UCLA
LANL
SNL
UTex
LLE
UDel
NRL
OSU
MBI
LLC
HZDR
FSU
GSI
MPQ
HHU
UStr
RAL
AWE
QUB
LOA
LULI
ILE-f
SLIC
CELIA
CESTA
LMJ
PETAL
CLPU
UMed
UMil
ILIL
LNF
USze
INFLPR
ELI-CZ
TUW
NIIKI
ELI-ALPS
ELI-NP
GPI
RIKEN
UTok
CREIPI
UEC
KPSI
ILE-j
SIOM
IAMS

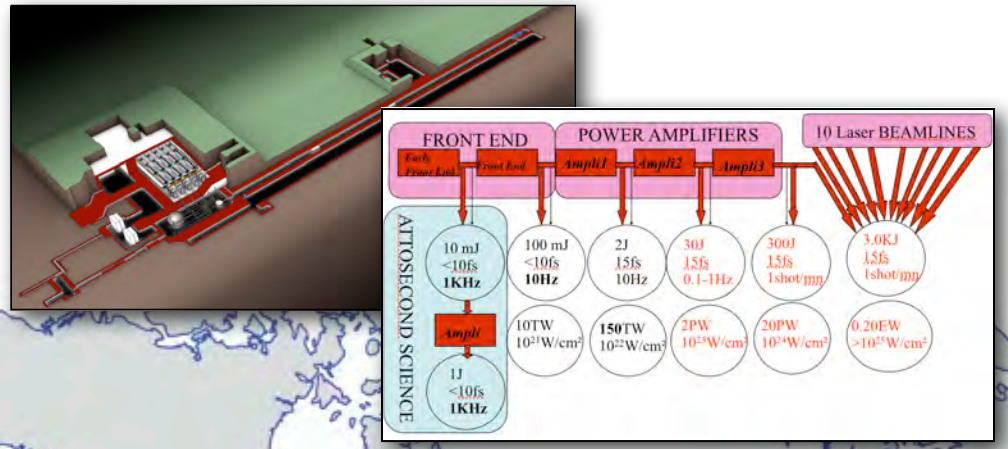
The ELI-Nuclear Physics facility has funded construction of 2, 10PW laser systems

Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

UAlb
UNeb
UMich
ALLS
CSU
UNev
LBNL
SLAC
LLNL
NIF
ARC
JLF
UCLA
MBI
LLC
HZDR
FSU
ELI-CZ
GSI
TUW
MPQ
HHU
UStr
NIIKI
RAL
AWE
QUB
LOA
LULI
PNLI
IAP
VNIITF
ILP
IHCE
VNIIEF
KAERI
APRI
GPI
RIKEN
UTok
CREIPI
UEC
KPSI
SIOM
IAMS
ILE-j
LFRC
IOP
TIFR
TIFR-h
RRCAT

The Tata Institute is considering systems beyond 10 PW for its Hyderabad facility

Concepts for Exawatt capability at large facilities are being formulated



IAP

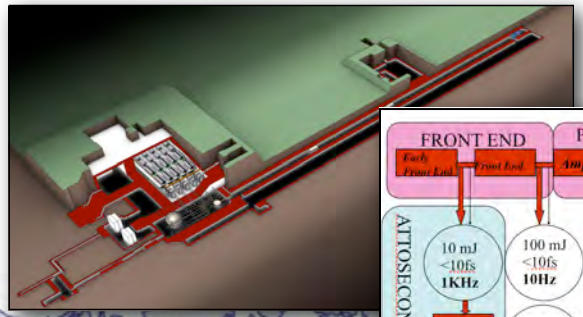
ILE-f

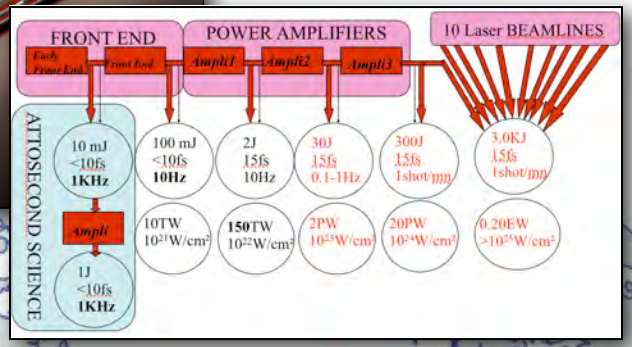
CESTA
LMJ
PETAL

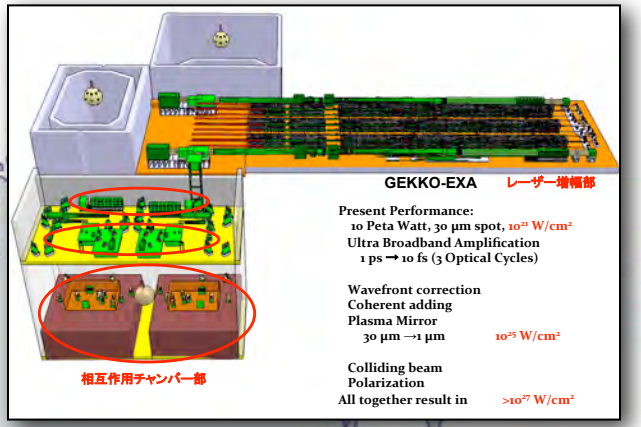
LLNL
NIF
ARC
JLF

ILE-j

Concepts for Exawatt capability at large facilities are being formulated







IAP

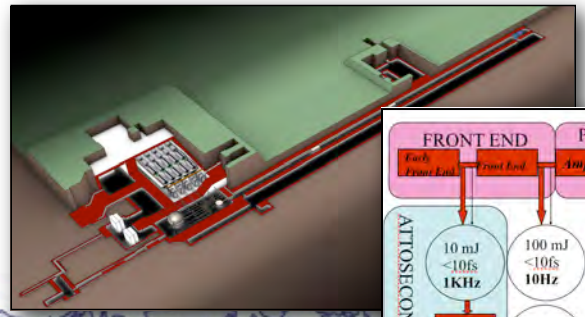
ILE-f

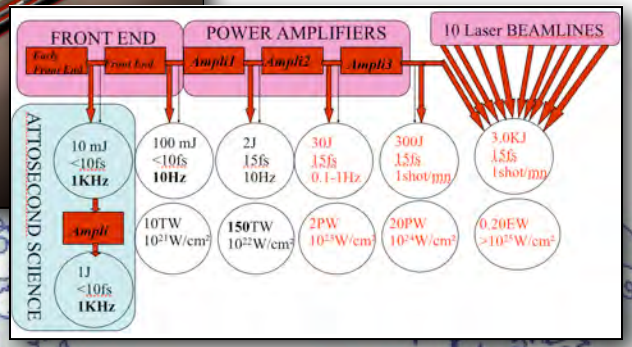
CESTA
LMJ
PETAL

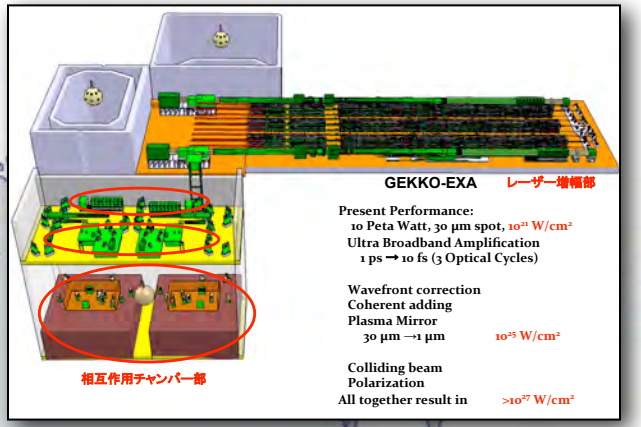
LLNL
NIF
ARC
JLF

ILE-j

Concepts for Exawatt capability at large facilities are being formulated







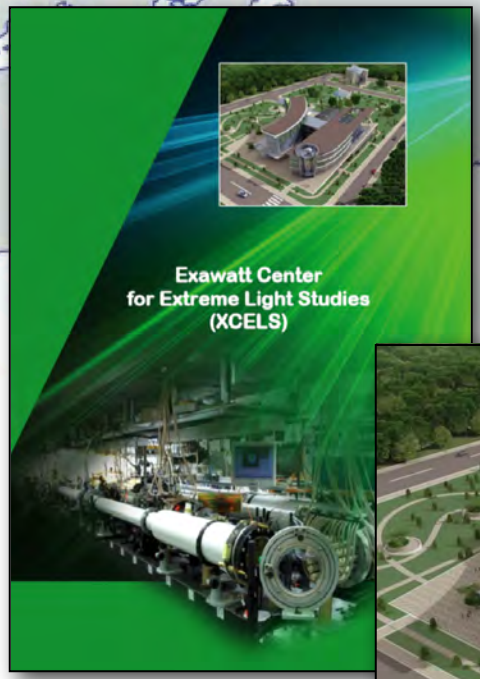
IAP

ILE-f

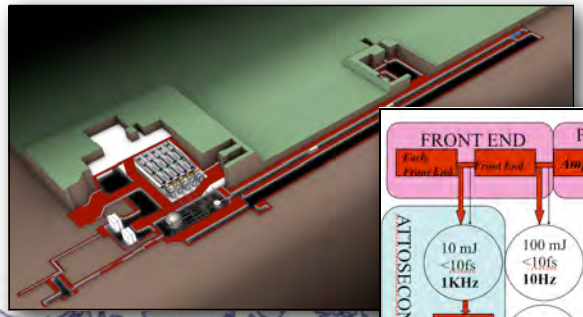
CESTA
LMJ
PETAL

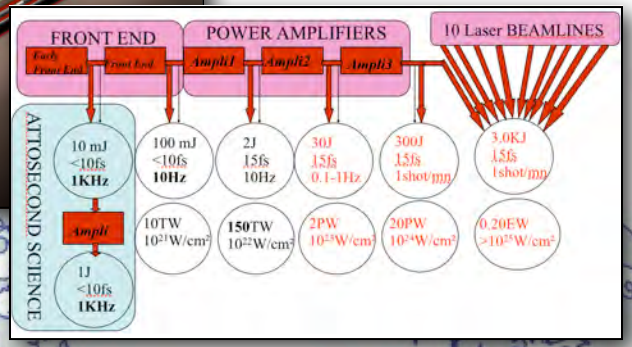
LLNL
NIF
ARC
JLF

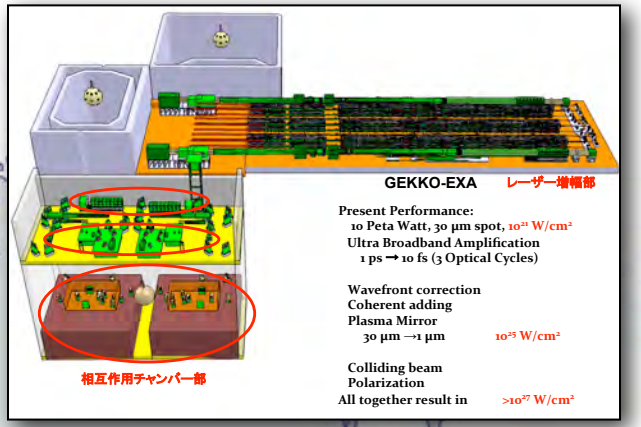
ILE-j



Concepts for Exawatt capability at large facilities are being formulated







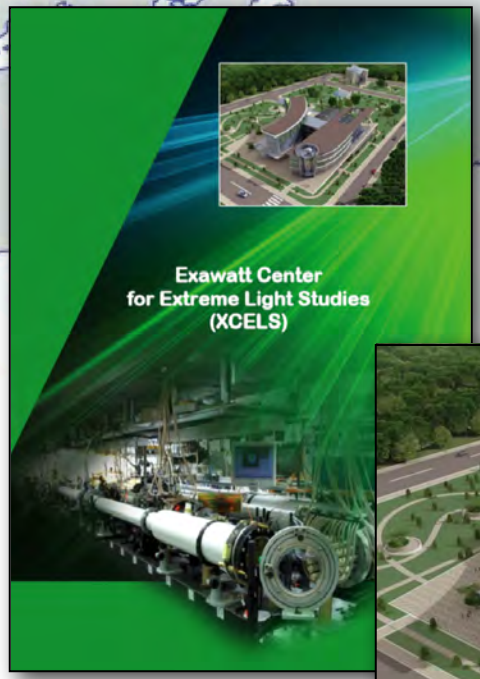
IAP

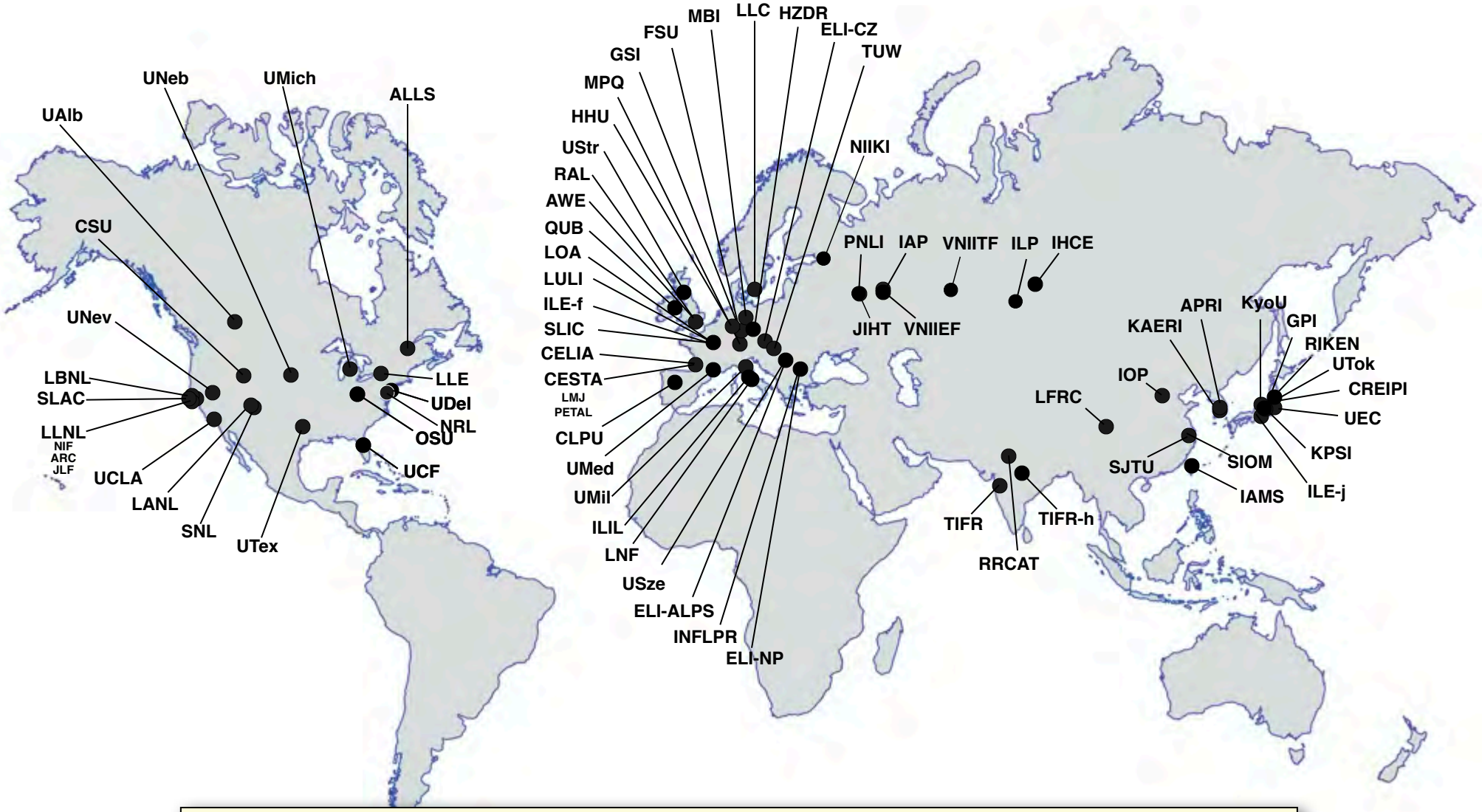
ILE-f

CESTA
LMJ
PETAL

LLNL
NIF
ARC
JLF

ILE-j





If you wish to see more of world of ultrahigh intensity lasers, visit www.icuil.org and explore the "interactive" world map

CPJ Barty