Development of 10PW Super Intense Laser Facility at Shanghai

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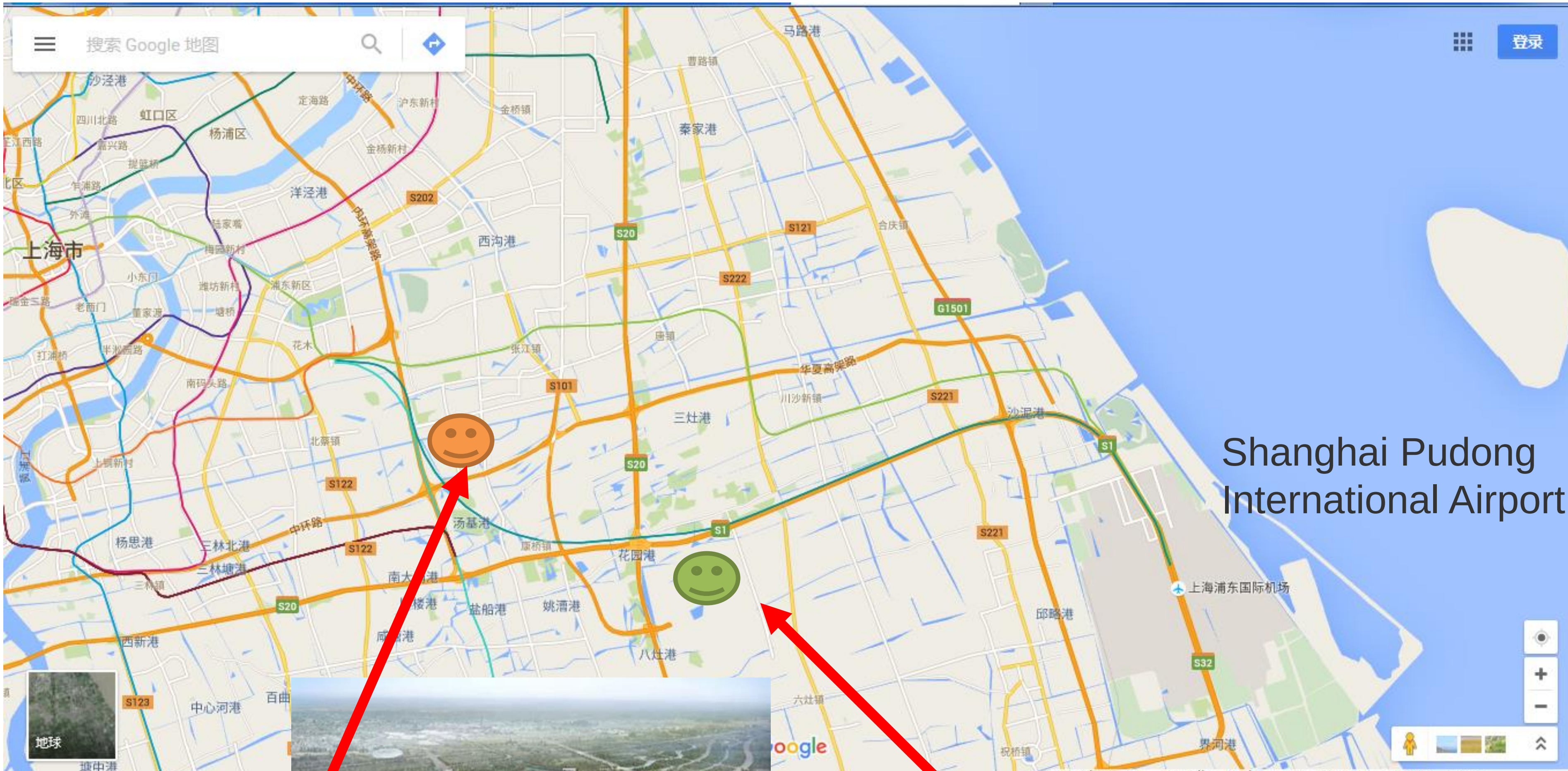
IZSET Conference
Paris, Nov.28-29, 2016

Outline

- Background
- The 10PW laser project at shanghai
- Applications: LWFA towards high quality electron beams
- Summary

Location of SULF (Shanghai Superintense Ultrafast Laser Facility)

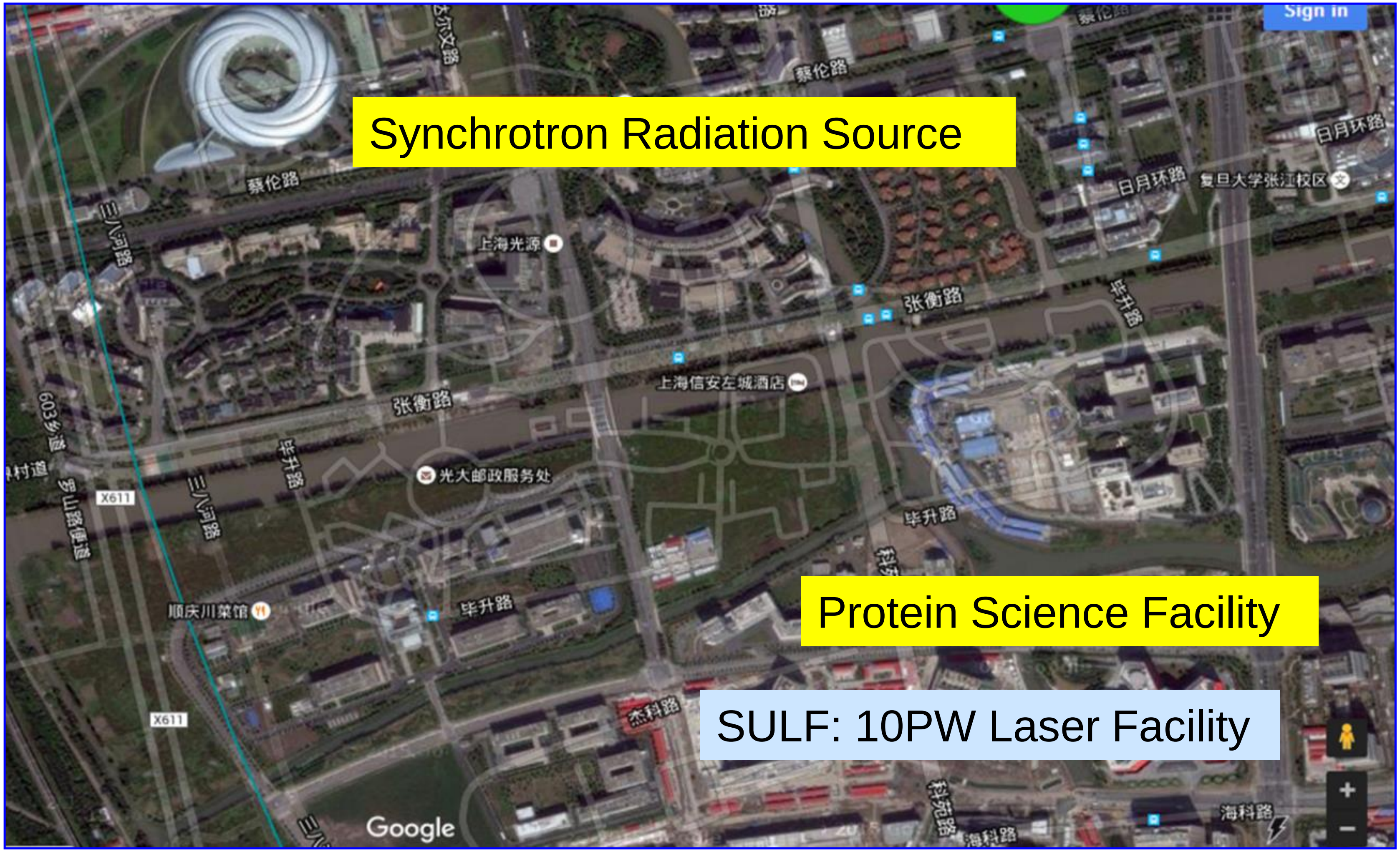


ShanghaiTech University

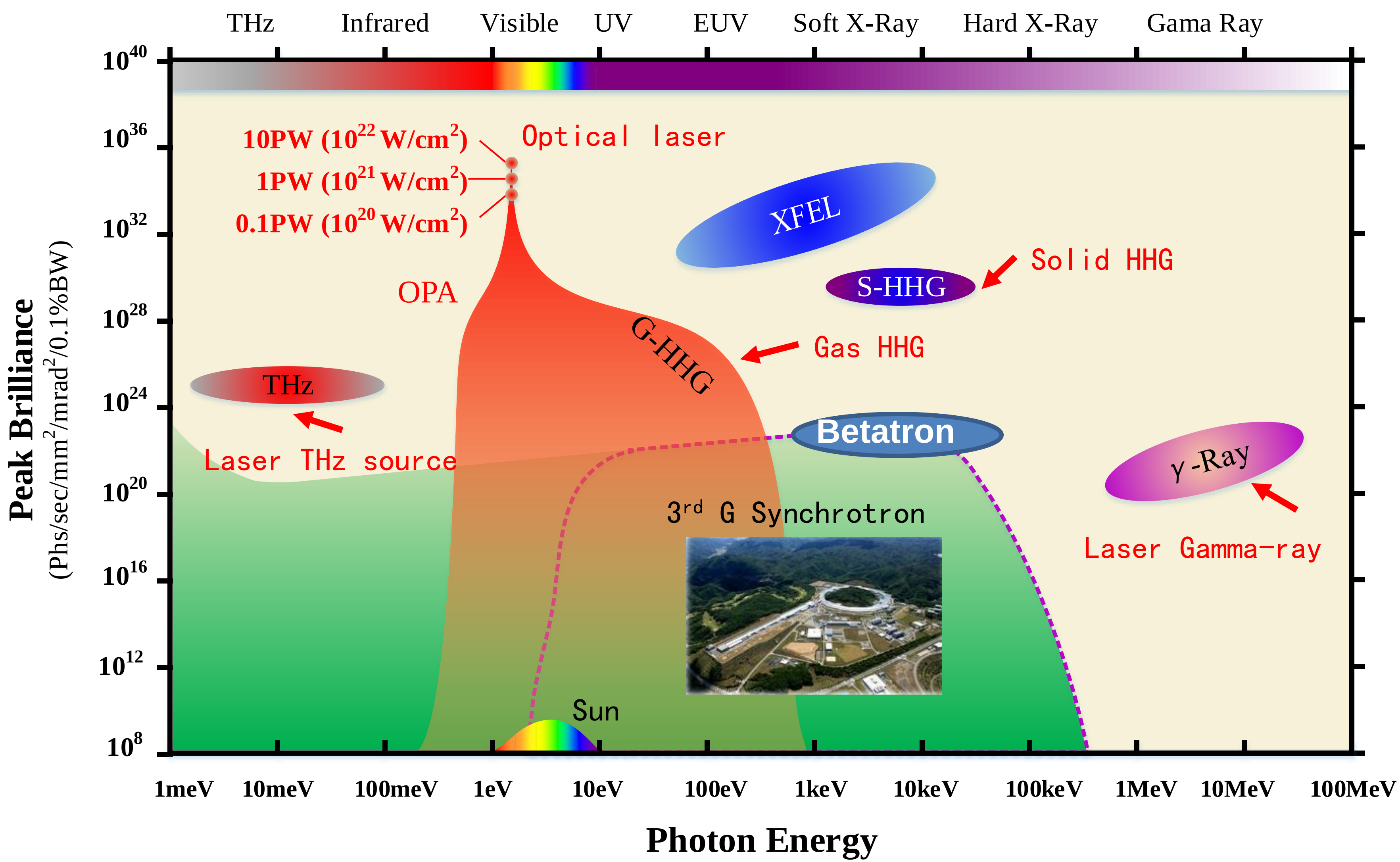
~15km

Disneyland of Shanghai

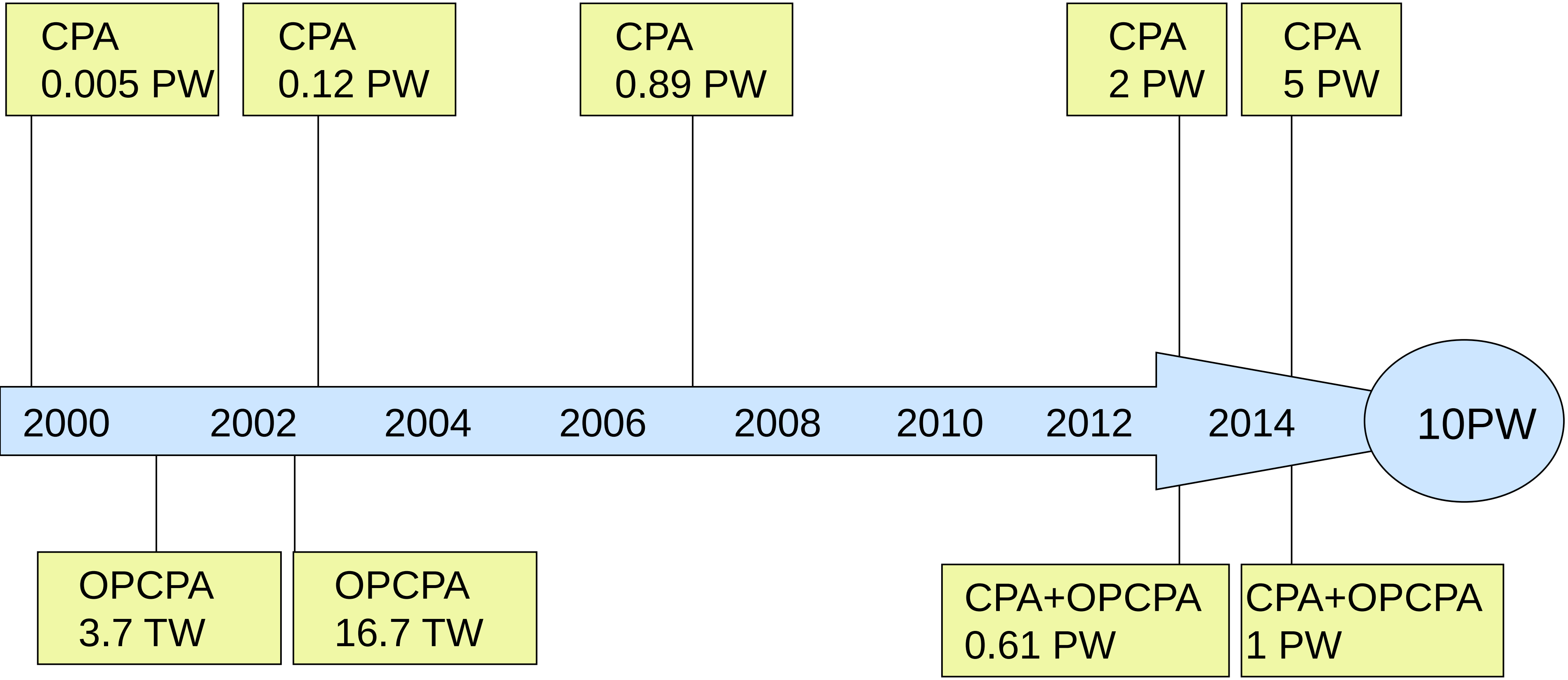
Location of SULF (SULF and other research infrastructure at Shanghai)



Petawatt laser / secondary rays vs SR and XFEL



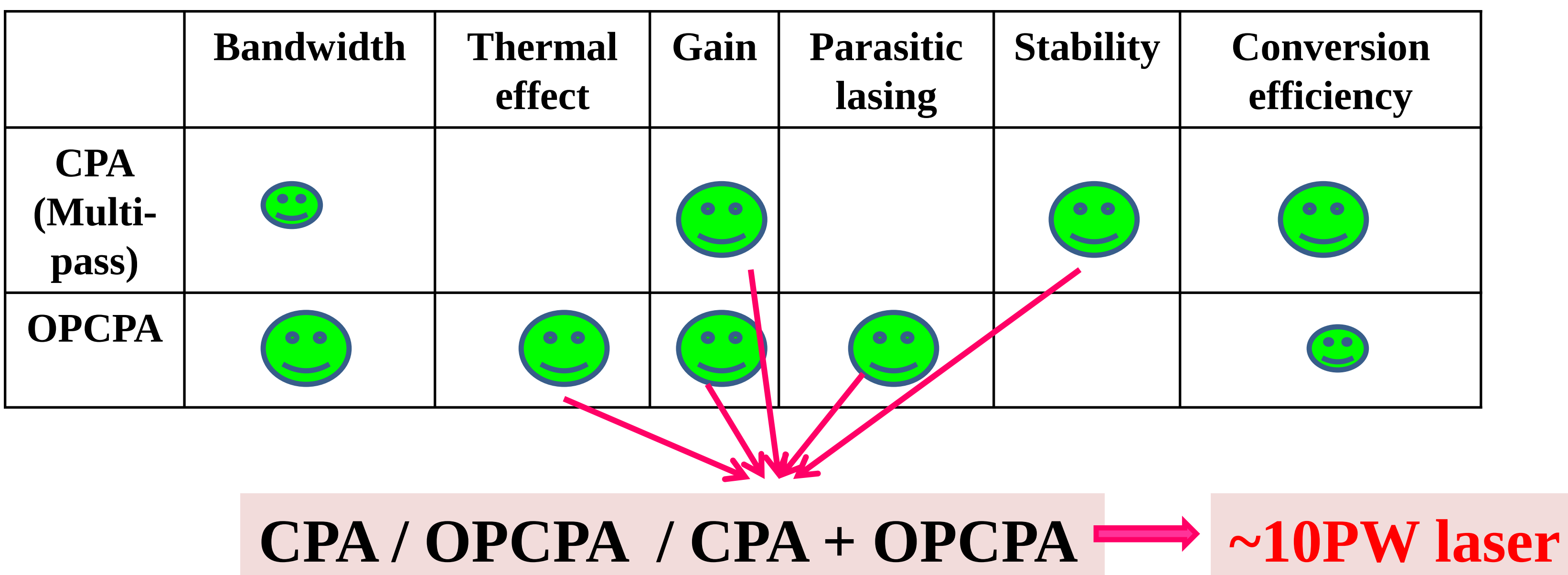
Towards a 10PW laser facility @ Shanghai



Shanghai Superintense Ultrafast Laser Facility (SULF):
The 10 PW Laser system: main parameters & approaches

Main parameters:

- Centeral wavelength: ~800nm
- Pulse energy: ~300 J
- Pulse duration: ~30 fs
- Contrast ratio: ~10^{11}
- Focused intensity: >10^{22}W/cm^2



SULF: The booster amplifier for 10PW pulses @ 800nm

	Bandwidth	Thermal effect	Gain	Parasitic lasing	Stability	Conversion efficiency
CPA (Multi-pass)						
OPCPA						

Challenges:

1: CPA: to obtain high gain with a large aperture Ti:saphhire

2: OPCPA: large aperture OPA crystals and high efficiency to support 10PW at 800nm central wavelength

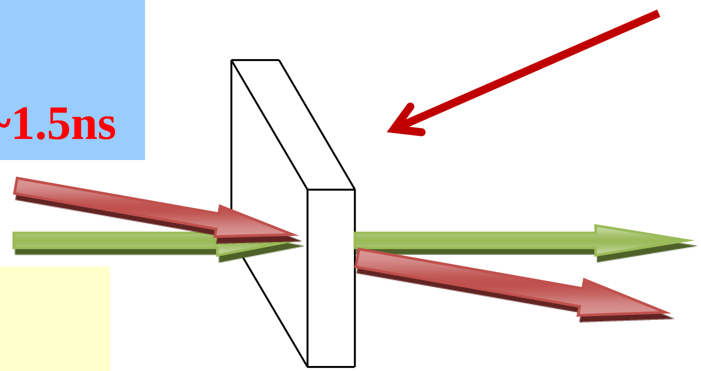
10PW OPCPA booster amplifier @ 800nm

Signal pulse (o):
λs: ~770nm - 830nm
Pulse Energy: 40J - 50J
Pulse width (FWHM): ~1.5ns

G~10

LBO or YCOB

Booster amplifier



Pump pulse (e):
λp: 527nm
Pulse energy: 2000J
Pulse width: ~2.5ns

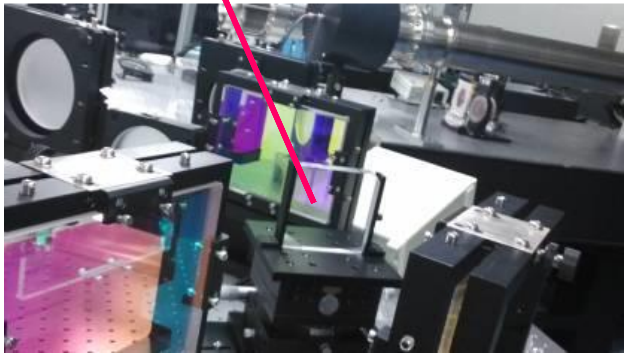
η=~25%

Amplified energy: ~ 500J
FWHM: ~1.5ns
Full width: ~2.0ns

Need to verify the conversion efficiency > 25% from the pump to the signal.

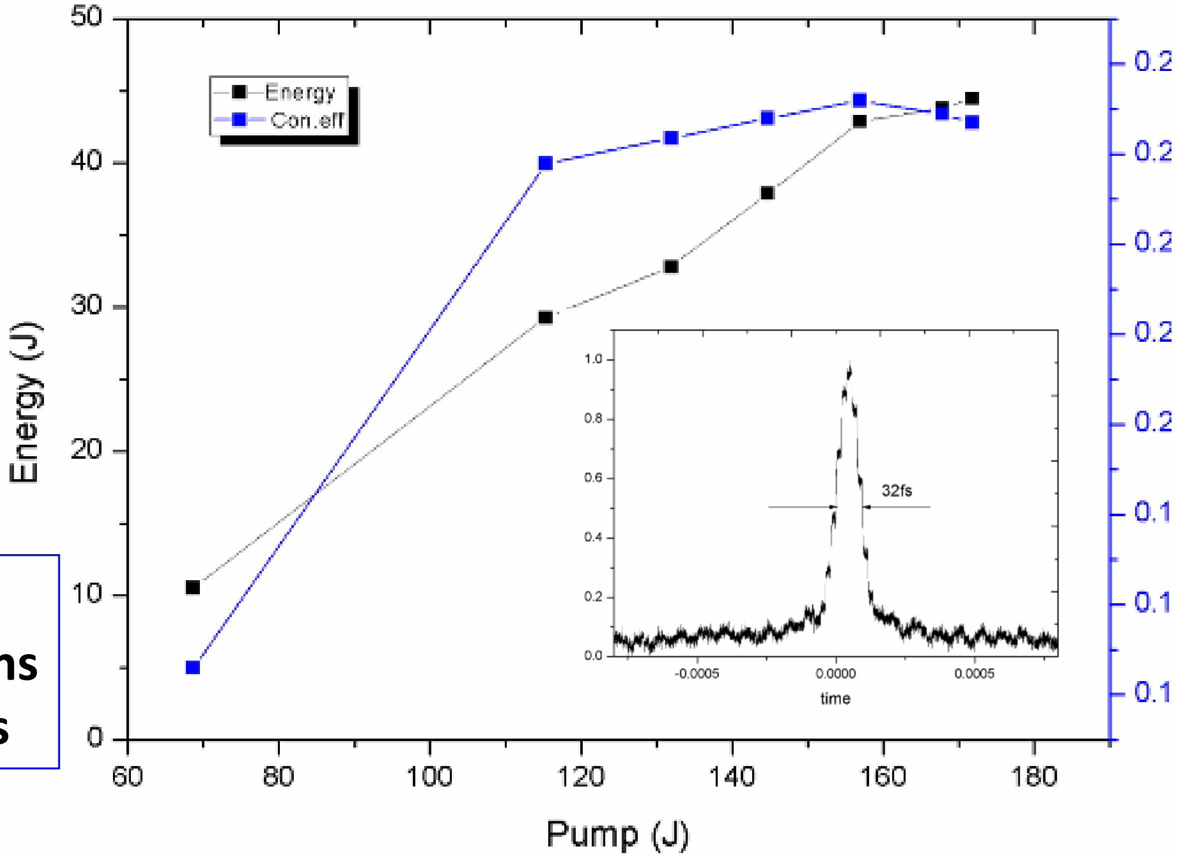
1PW OPCPA amplifier using 100mm LBO (2014)

LBO：
100mm×100mm×17mm



Beam size：
pump： 84mm
signal： 82mm

Pulse width：
pump： 2.89ns
signal： 1.9ns



Compressor Effi： 72%
Output Energy： 32.0J
Pulse Width： 32.0fs
Peak Power： 1.0PW

Laser Energy： 44.5J
Pump Energy： 167J
Pump fluence： 1.06GW/cm^2
Conversion Efficiency： 26%

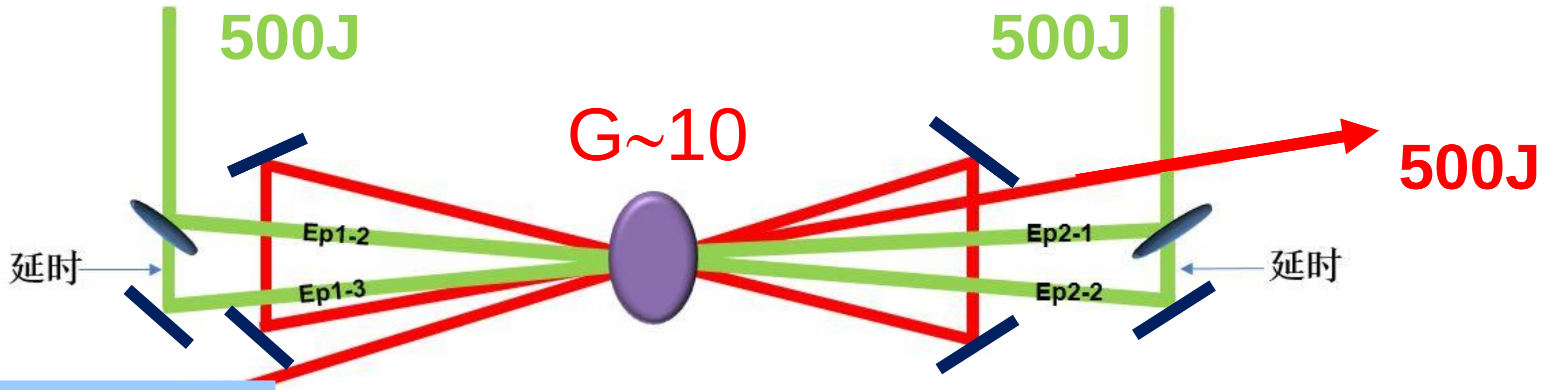
L. Yu et al. Opt. Lett. 40, 3412(2015)

10PW CPA booster amplifier @ 800nm

Pump pulse:
λp: 527nm
energy: ~1000J (2 beams)
width: ~10ns

η = ~ 50%

Amplified energy: ~ 500J
FWHM: ~1.5ns
Full width: ~2.0ns

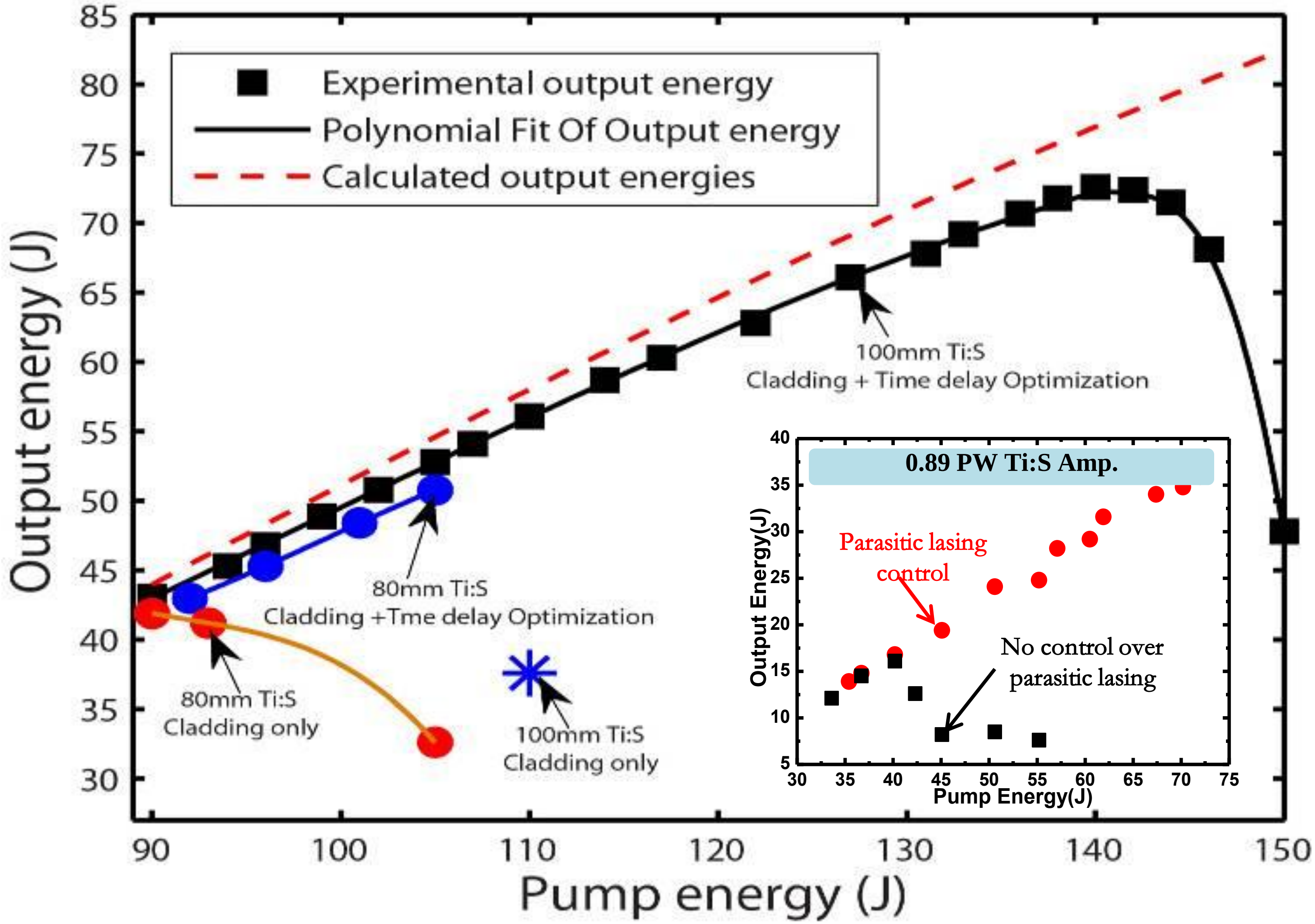


Signal pulse:
λs: ~770nm - 830nm
Energy: 40J - 50J
width (FWHM): ~1.5ns

Ti:sapphire
Booster amplifier

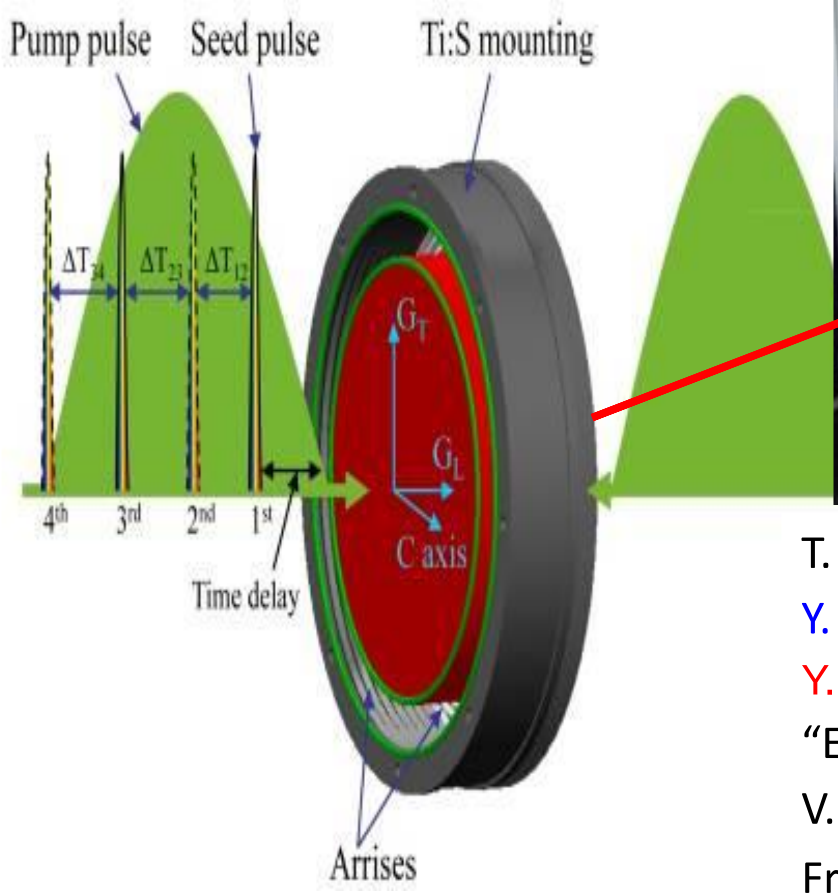
The required pump laser energy is < 1000J, with each pump laser beam of only 1/4 of the pump energy for OPCPA. But we need to verify the high gain for large size Ti:sapphire amplifier.

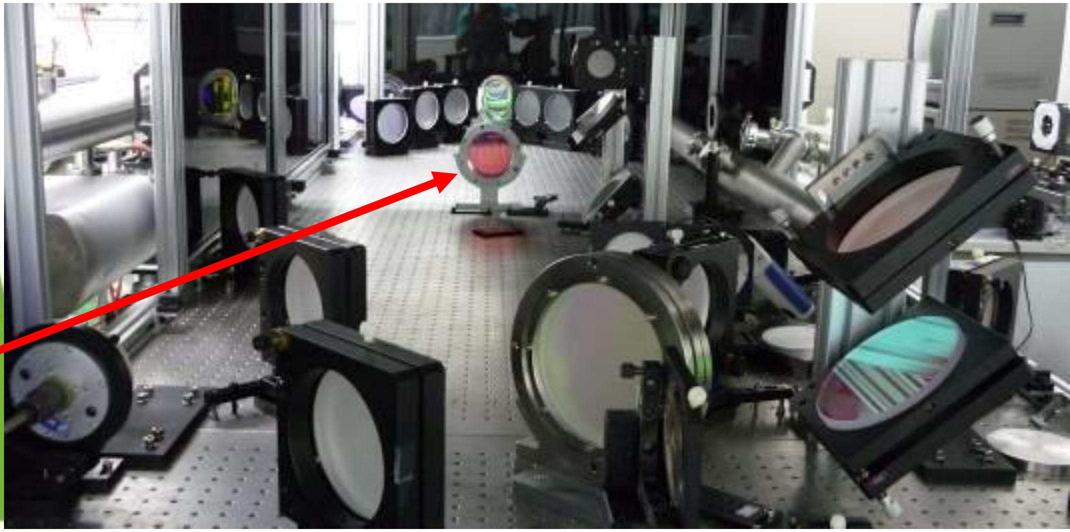
The output from a Ti:sapphire amplifier turns to decrease due to the onset of parasitic lasing



Optics Express, 15(23): 15335-15341 (2007) (Patent: ZL200710039733.6); Laser Physics Letters 10, 055302 (2013) ; Optics Express, 21(29): 29231-29239 (2013) (patent: 201310043867.0)

Active and passive control over the parasitic lasing in large aperture Ti:S amplifiers





T. Yu, et al., Opt. Express. 20, 10807(2012), 1.5PW

Y. Chu et al., Opt. Express. 21, 29231(2013), 2PW

Y. Chu et al., Optics Letters 40, 5011 (2015), 5PW

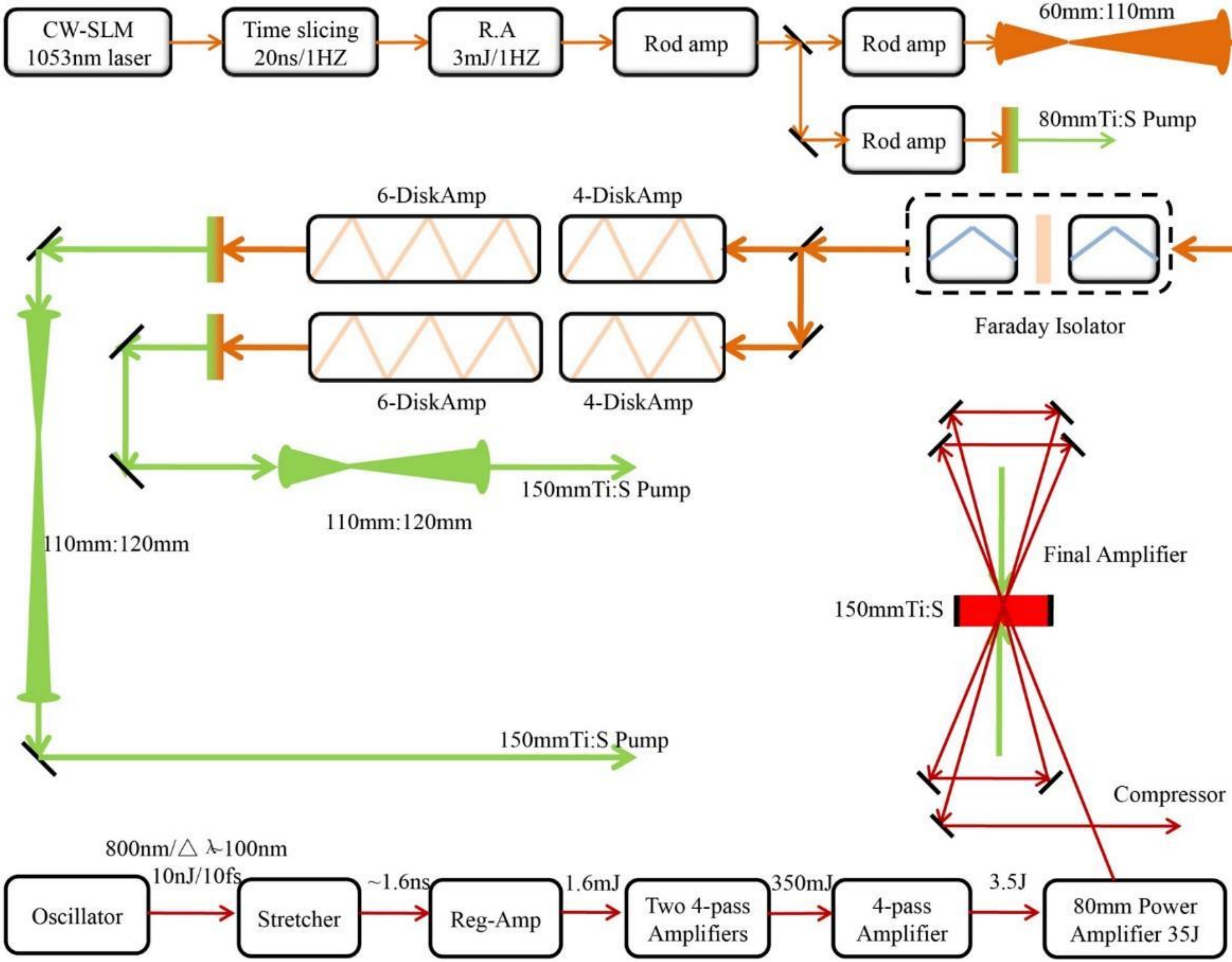
“Extraction During Pumping” termed by

V. Chvykov and co-workers

Frontiers in Optics 2012/Laser Science XXVIII, OSA Technical Digest (online) (Optical Society of America, 2012), paper FM4G.4, doi:10.1364/FIO.2012.FM4G.4

Opt. Commun. 312, 216 (2014).

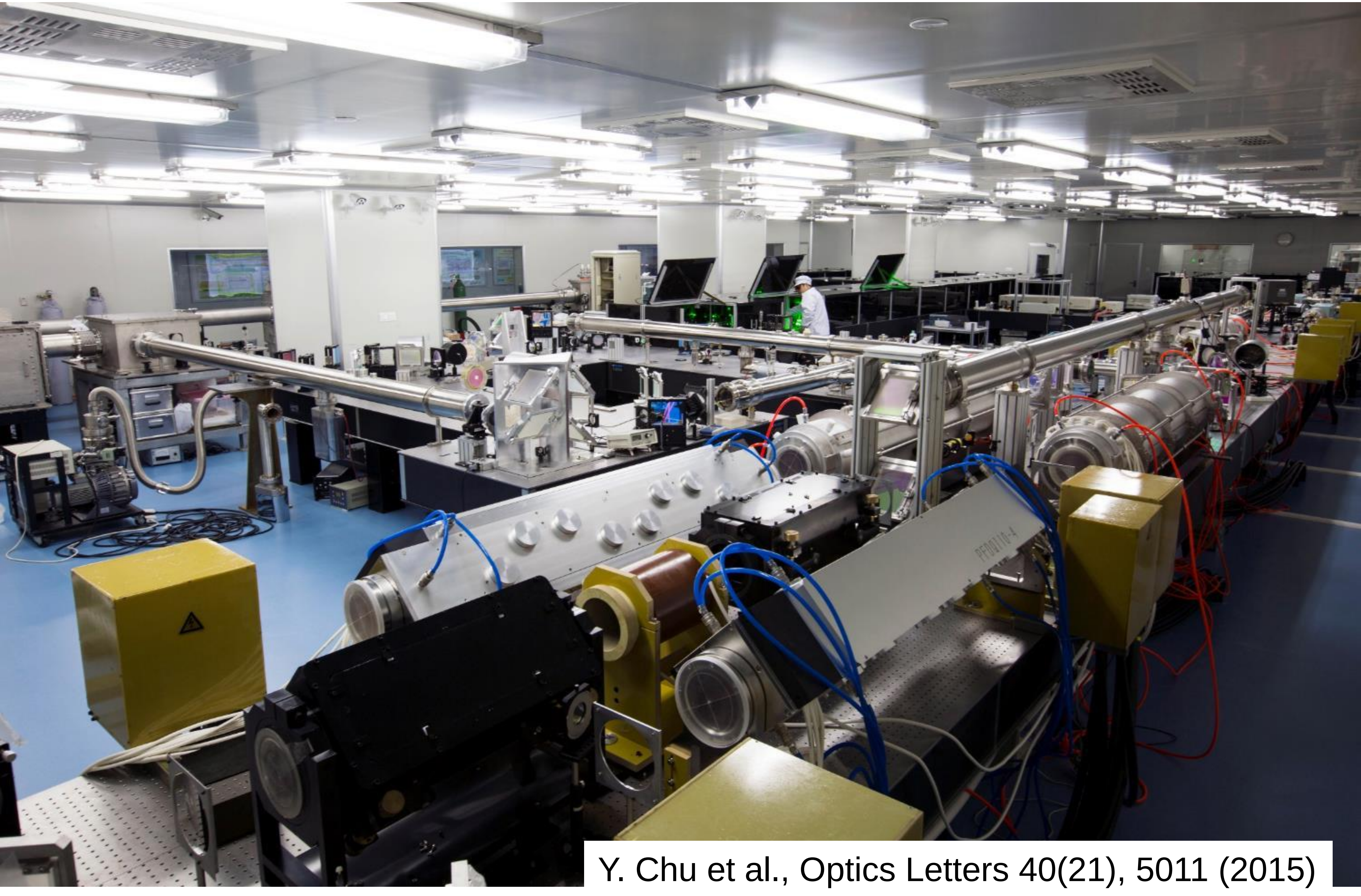
Schematic layout for the 5 PW amplification experiment



Output Energy: 192.3J

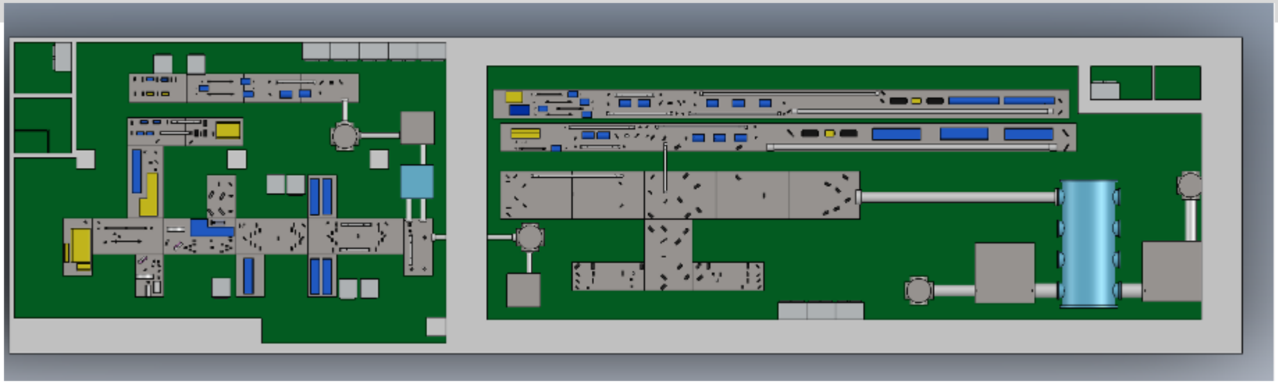
Y. Chu et al., Optics Letters 40(21), 5011 (2015)

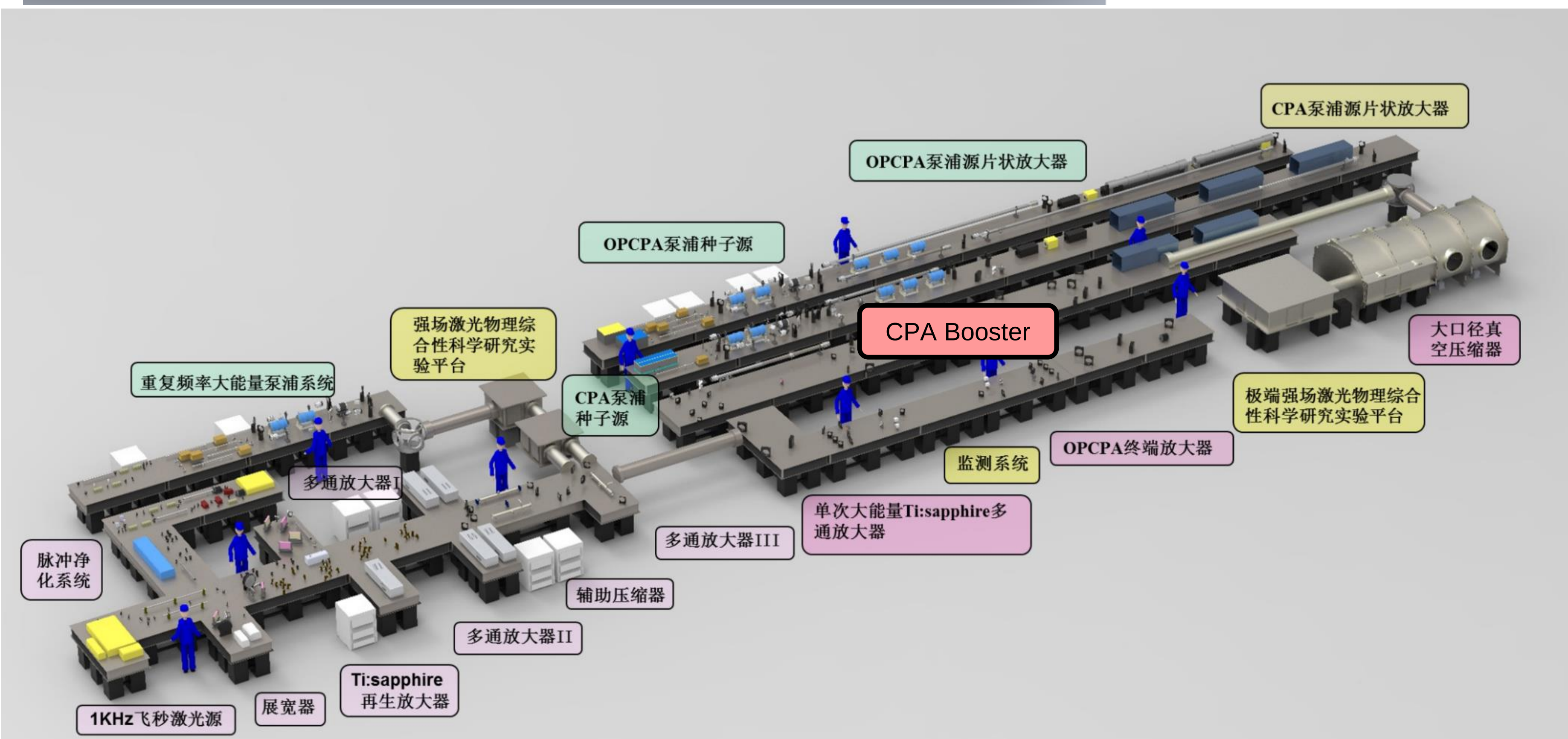
The 5PW CPA amplifier (2014)



Y. Chu et al., Optics Letters 40(21), 5011 (2015)

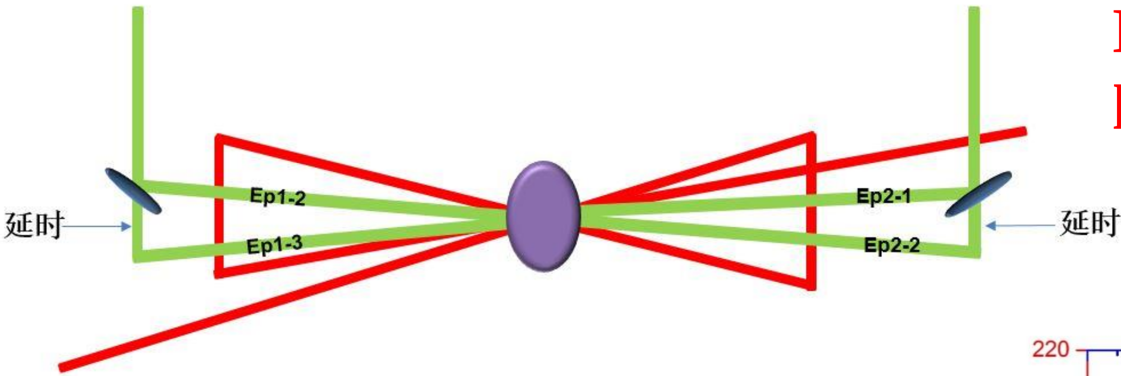
SULF implement the 10PW laser in a new lab. (2015-)



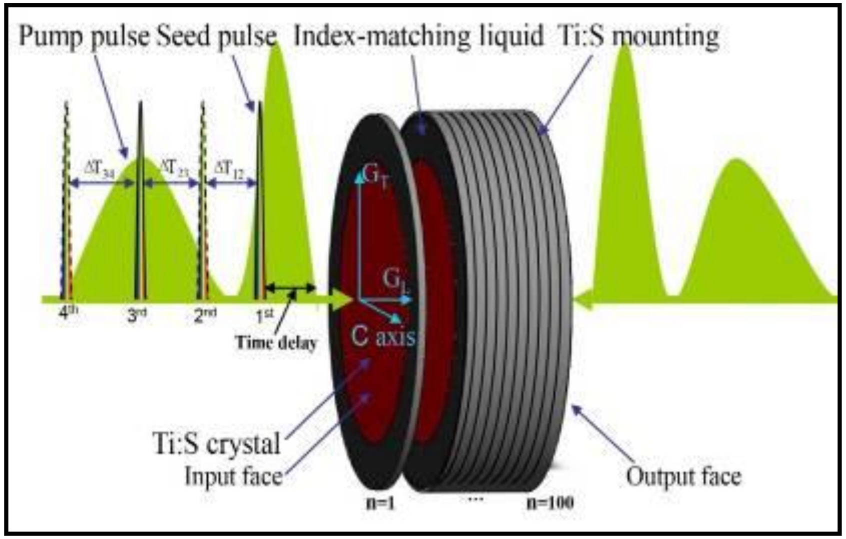


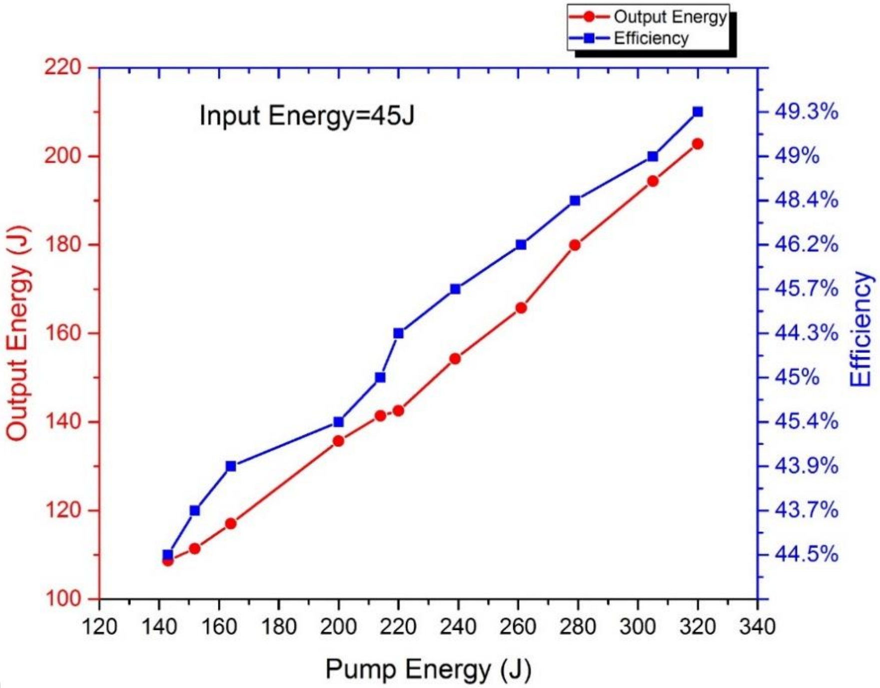
SULF The layout as of 2016/08

SULF 202J, 70nm Ti:sapphire amplifier



Demonstration of >200J large band (70nm) output





Y. Chu et al., Optics Comm. Vol.38, 67-73(2014)

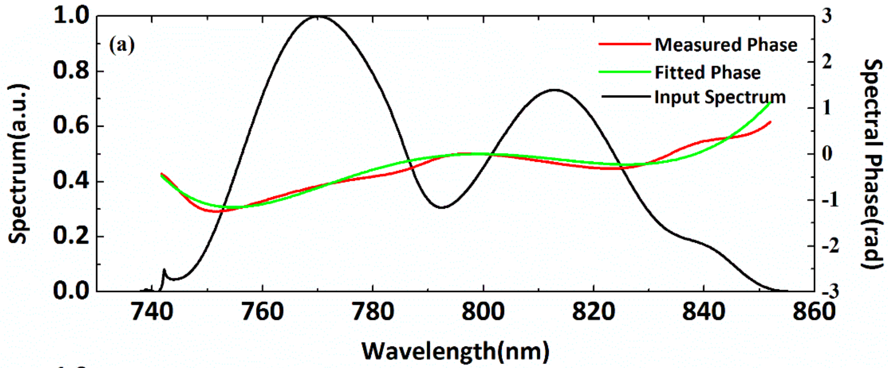
See, L. Yu et al., Poster 17

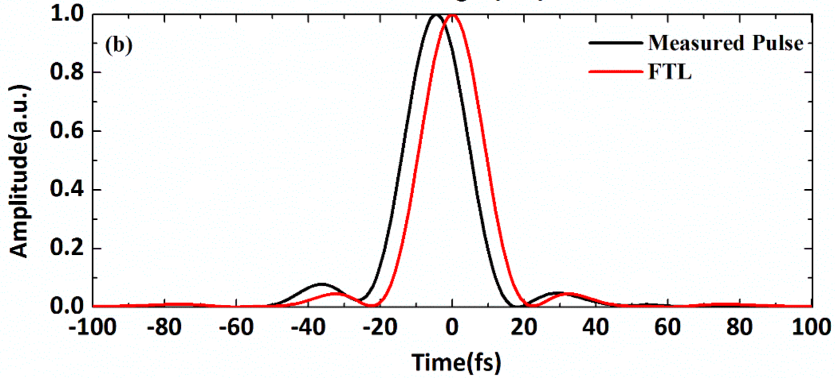
Output energy: 202.8J, conversion efficiency: 49.3%

SULF Compressor and Pulse Width

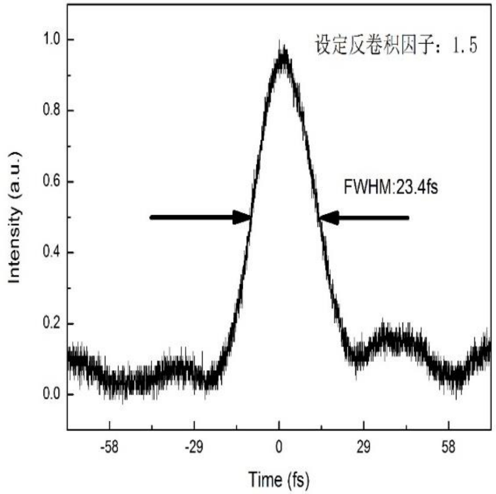
Total transmission efficiency ~ 70%

Low energy pulses at 10Hz





Single shot measurement



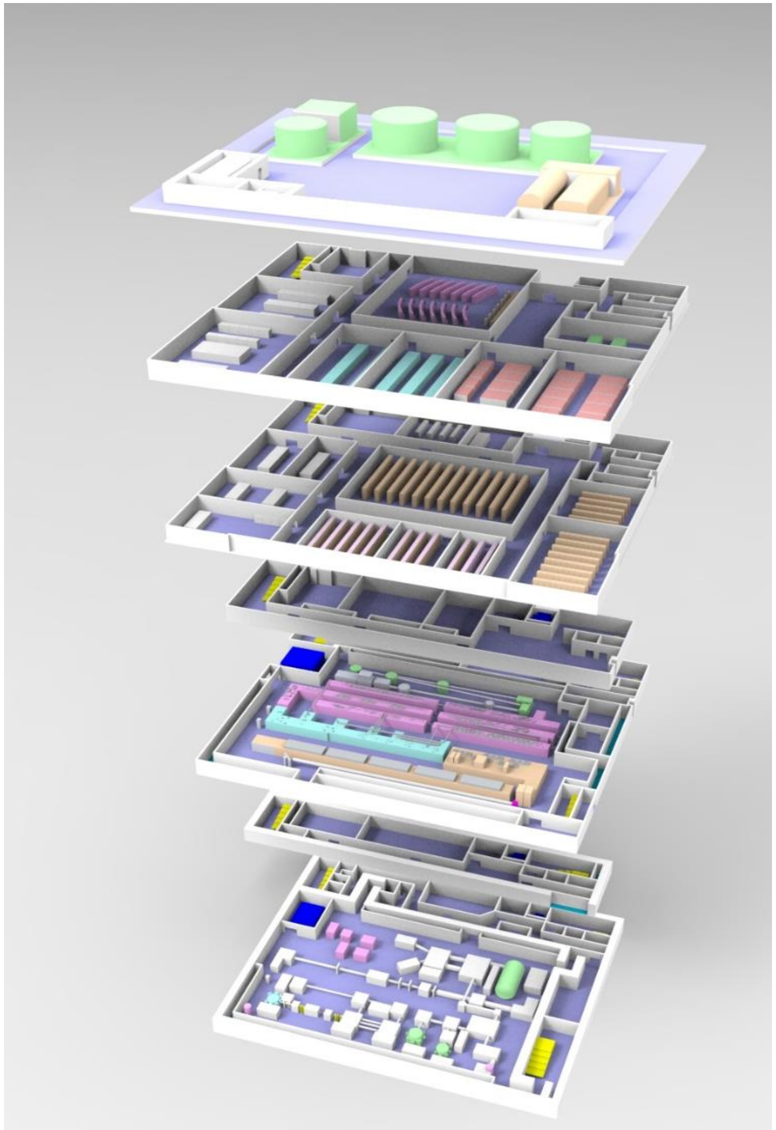
24fs@127J
5.3PW pulse

Measured to be 20fs, very close to the transform limited width of 19fs (The spectral width is 70nm FWHM)

See, S. Li et al., Poster 8

Land acquired

New building for user facility (available in 2019)



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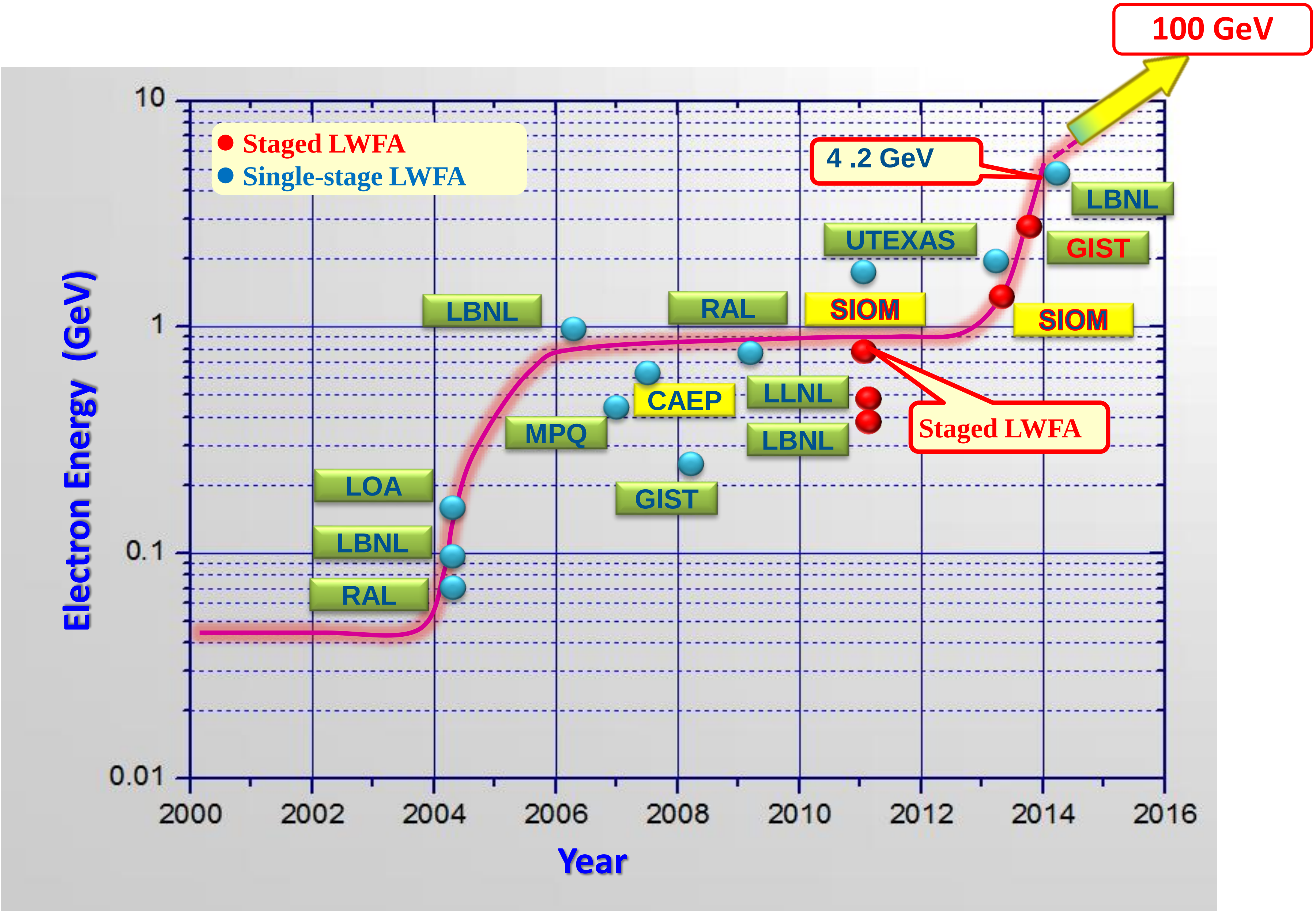
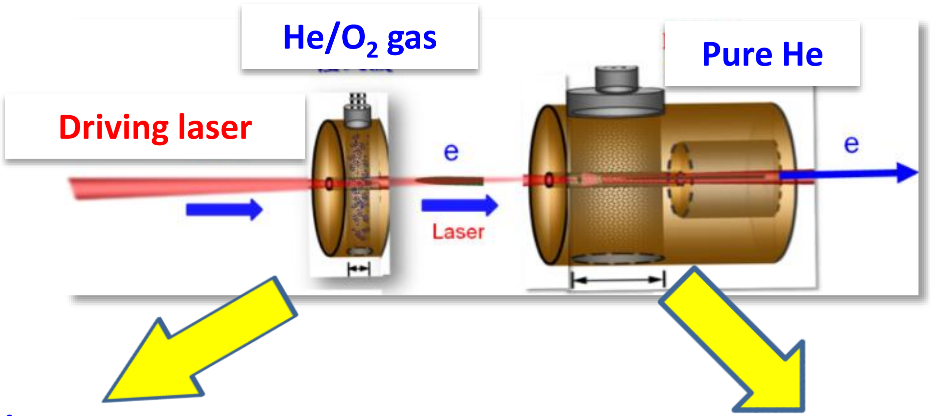
Progress in Laser Wakefield Acceleration of Electrons



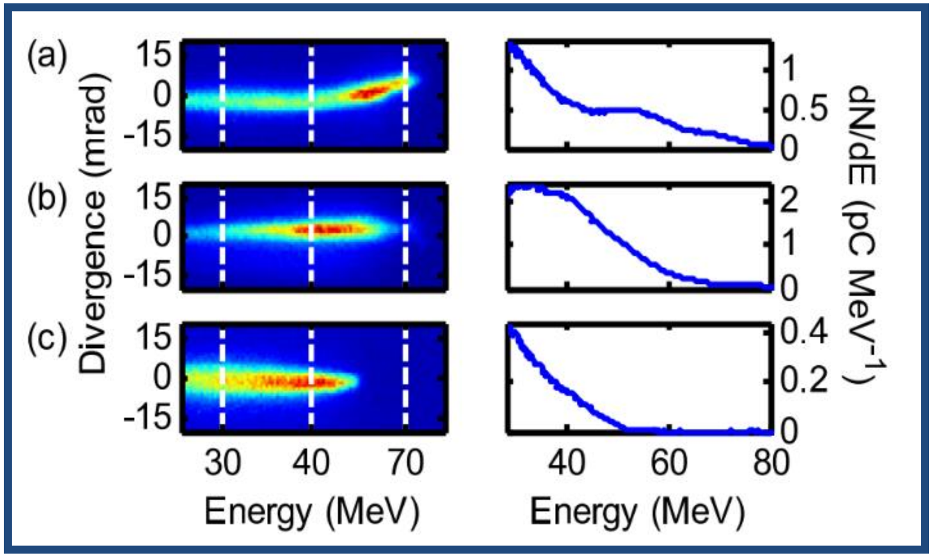
Demonstration of a GeV-class cascaded laser wakefield accelerator

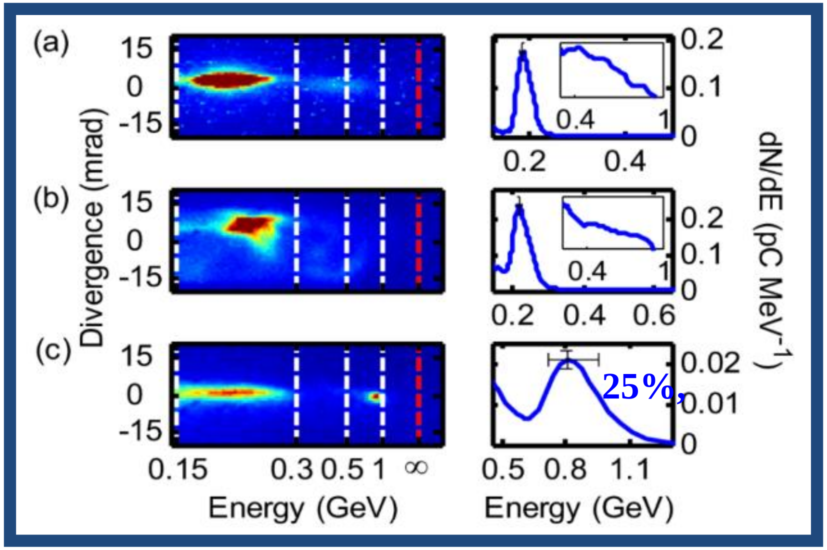
(SIOM, 2010)



Injector

Injector + Accelerator



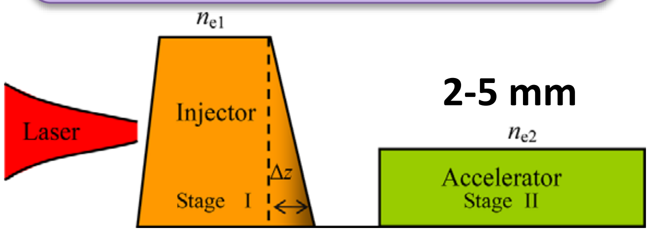


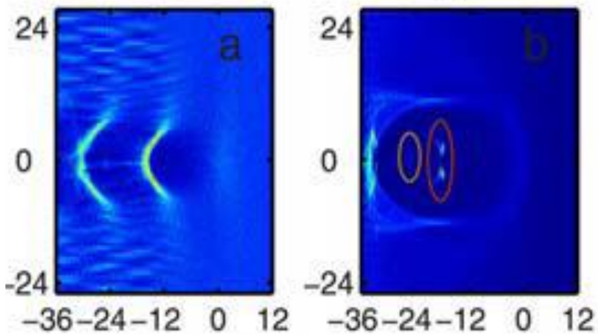
J. Liu, et al., Phys. Rev. Lett. 107, 035001 (2011)

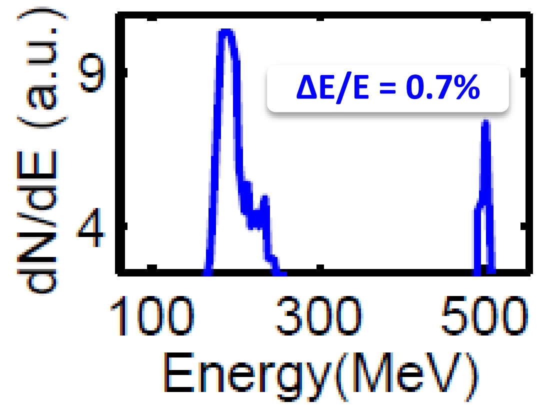
Demonstration of a two-stage LWFA beyond 1 GeV using gradient injection
SIOM (2012)

By optimizing the seeding phase of electrons into the second stage, electron beams beyond 0.5 GeV with a 3% rms energy spread were produced over 2 mm. Peak was further extended beyond 1 GeV by lengthening the second acceleration stage to 5 mm.[Appl. Phys. Lett.103, 243501(2013), Phys. Plasmas 19,023105(2012)]。

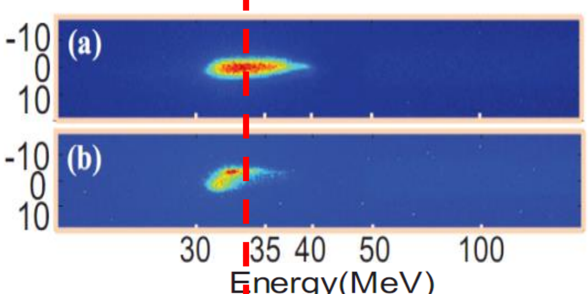
Cascaded LWFA (Gradient injection)

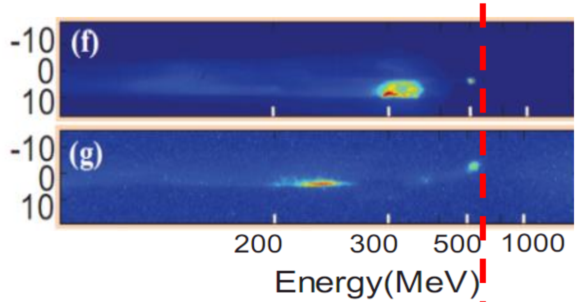


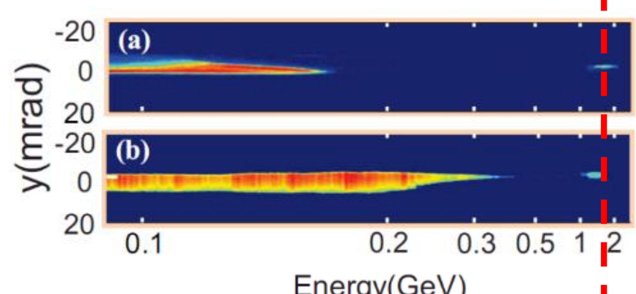




Experimental realization





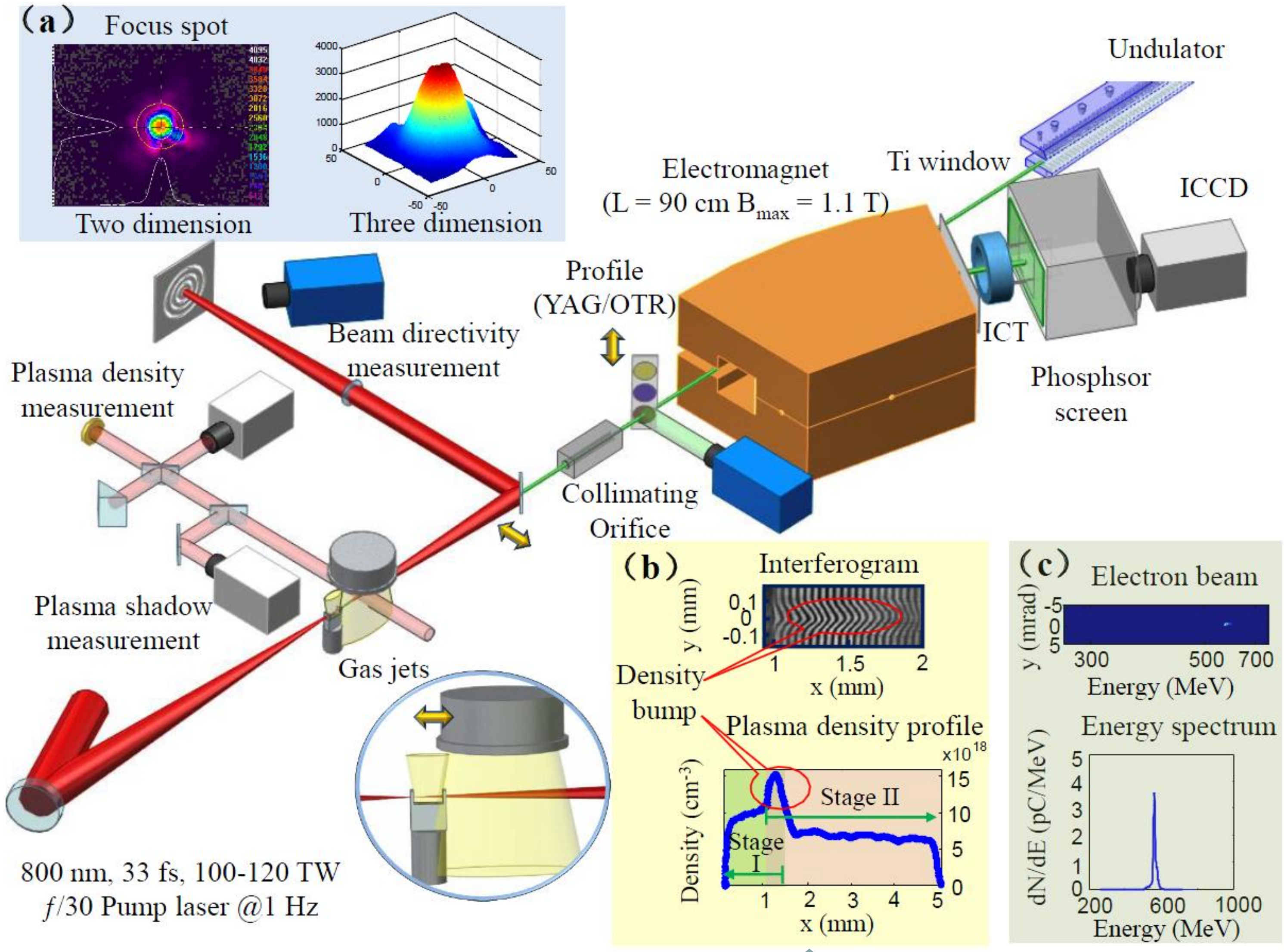


Electron injector
~32 MeV

Cascaded LWFA (1+2 mm)
530 MeV, ΔE/E ~ 3%

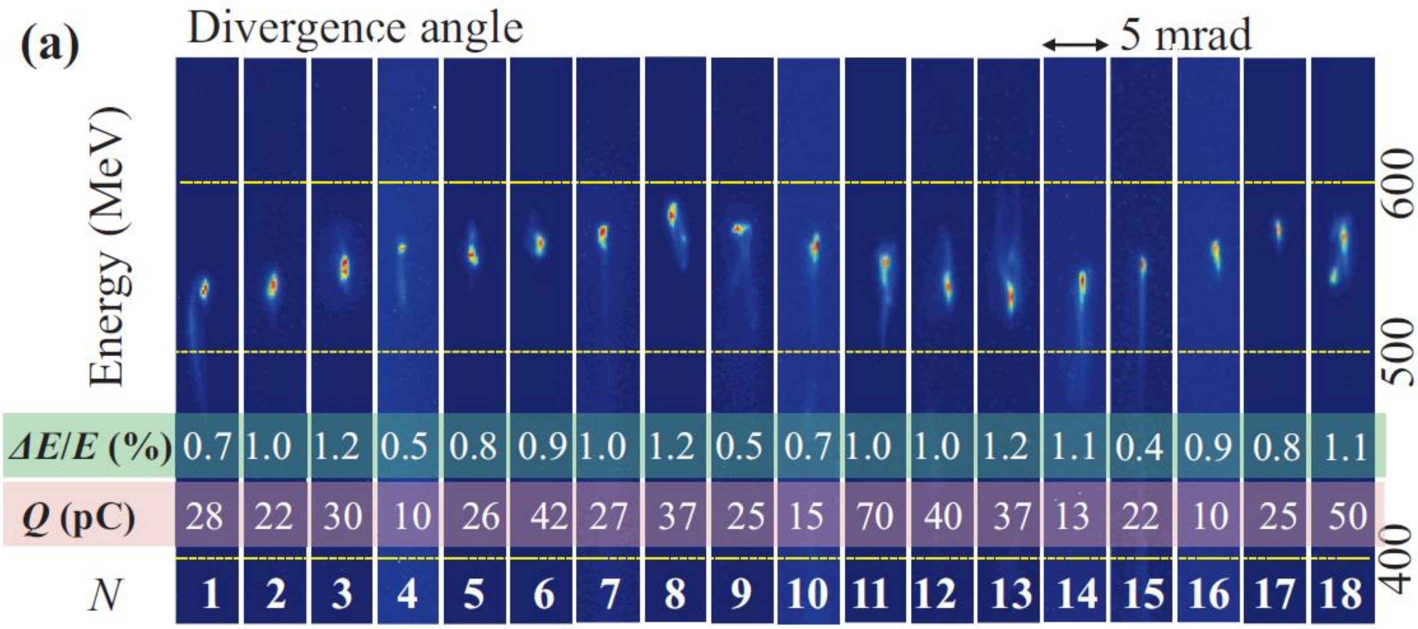
Cascaded LWFA (1+5 mm)
~1.3 GeV

High-Brightness High-Energy Electron Beams from a Laser Wakefield Accelerator via Energy Chirp Control



W. Wang et al., PRL 117,124801(2016)

High-Brightness High-Energy Electron Beams



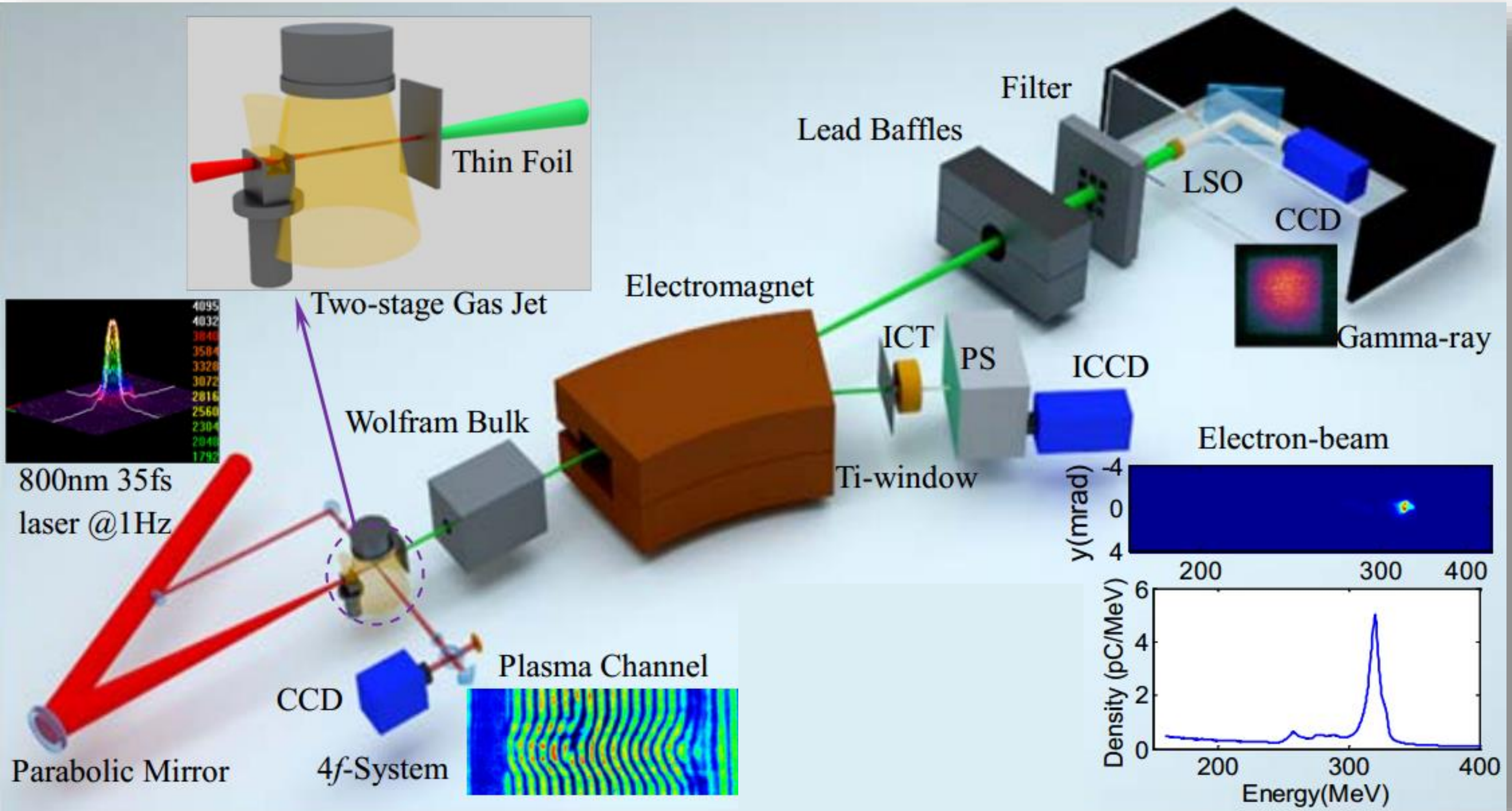
Minimum energy spread ~0.4%

Maximum 6-D Brightness ~6.5×10^{15} A/m^2/0.1%, **is comparable with the state of the art LINAC drivers**

rms energy spread 0.4-1.2%, charge 10-80 pC, rms divergency ~0.2 mrad） in the energy region（200~600 MeV）

W. Wang et al., PRL 117,124801(2016)

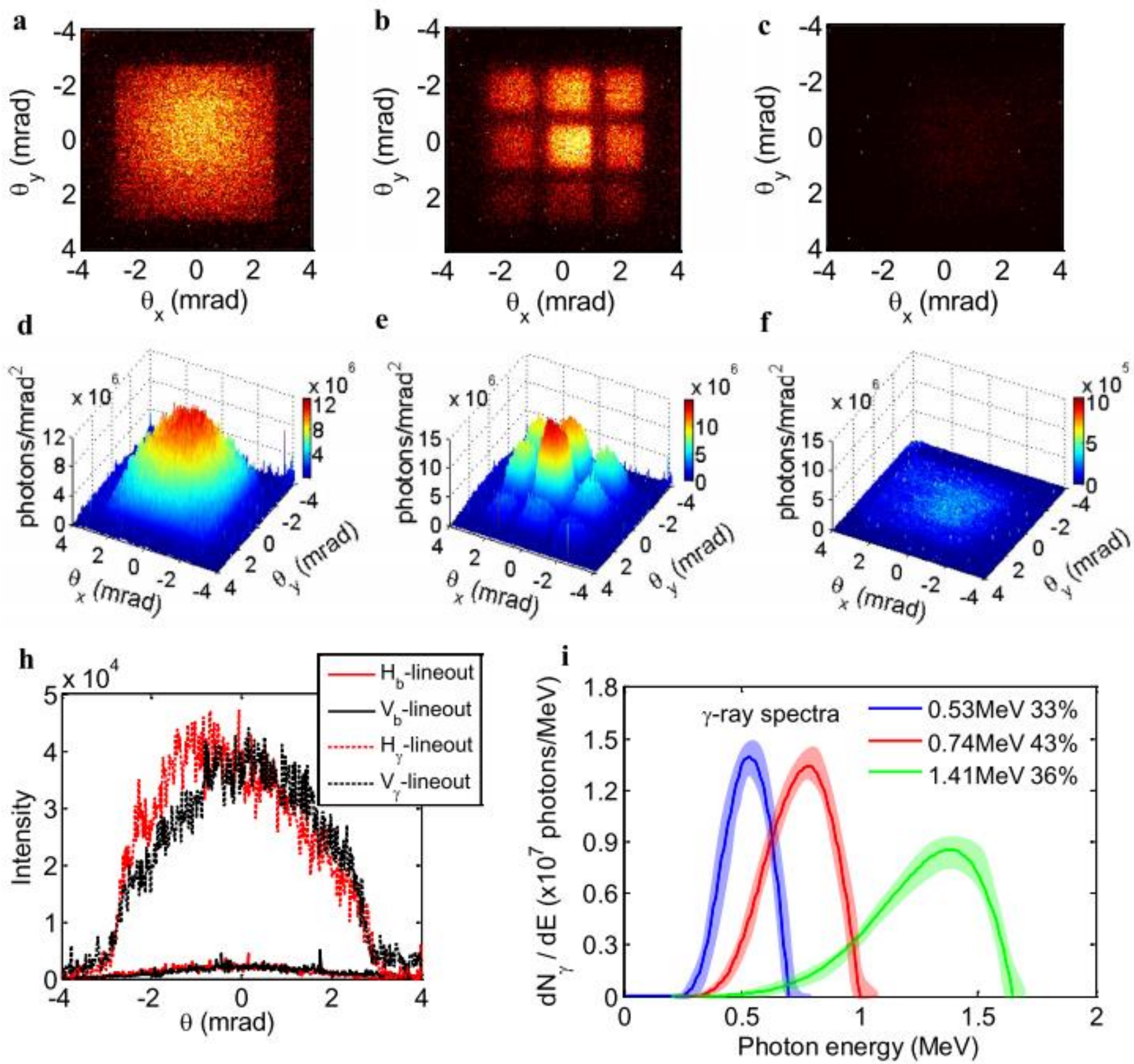
Compton scattering γ-rays based on high quality e beams



Previous works: Ta Phuoc et al., Nat. Photonics 6, 308 (2012)
Tsai et al., Physics of Plasmas 22, 023106 (2015)

This work: C. Yu et al., Scientific Reports, 6, 29518 (2016)]

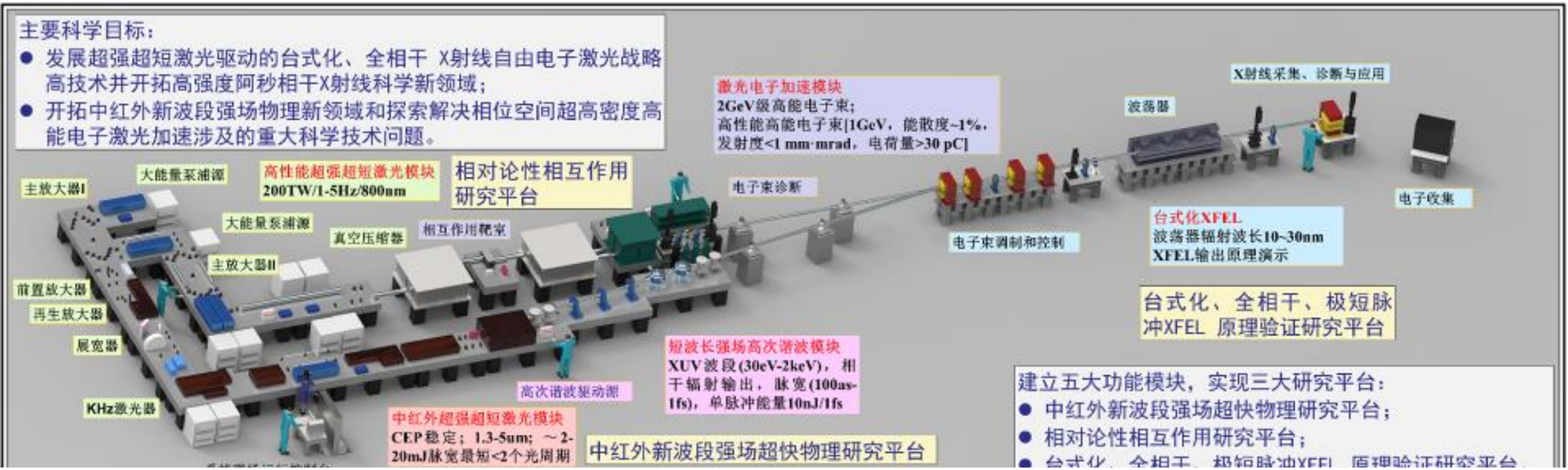
High brightness Compton scattering γ radiation

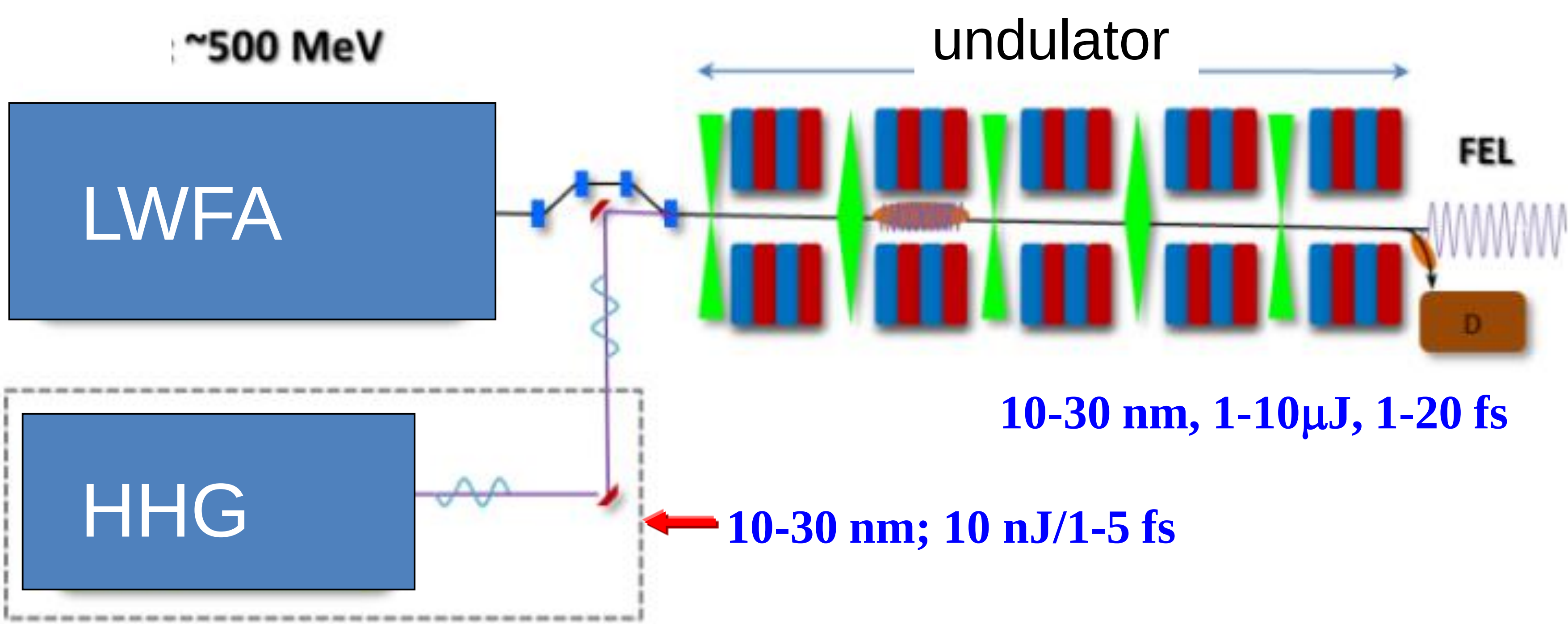


We measured quasi-monochromatic γ-rays from 0.3 to 2 MeV, with ~5×10^7 photons per-shot with a typical bandwidth of ~33% (FWHM) and a divergence of ~4 mrad. A peak brilliance of ~3 × 10^{22} photons s^{-1} mm^{-2} $mrad^{-2}$ 0.1% BW at 1 MeV is deduced.

[C. Yu et al., Scientific Reports, 6, 29518 (2016)]

HHG seeded LWFA based XFEL





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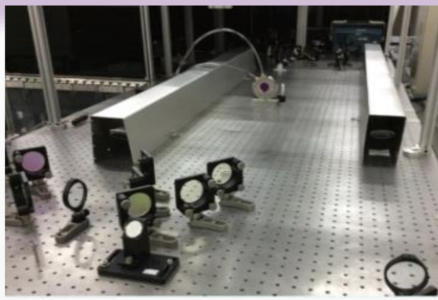
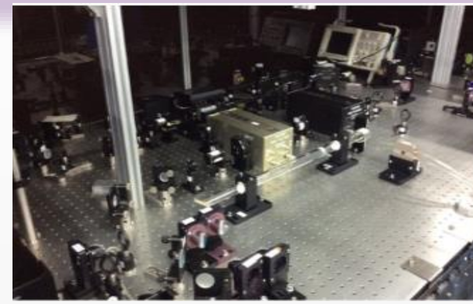
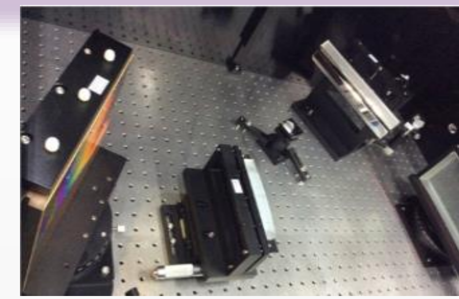
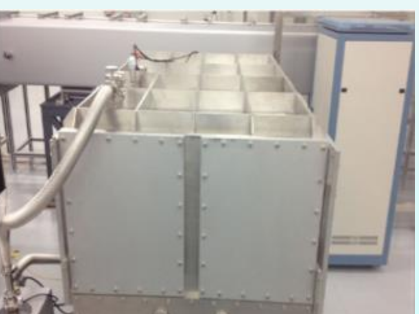
中国科学院上海光学精密机械研究所

Home-made 200TW / 5Hz Laser System



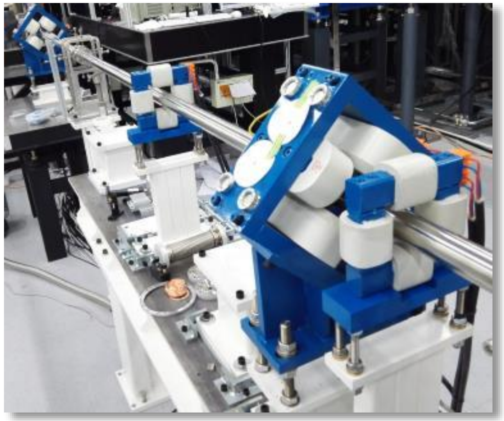


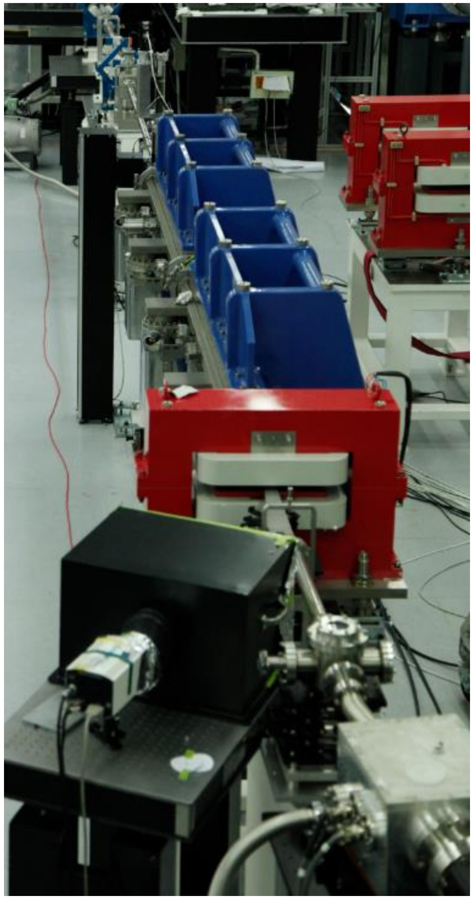


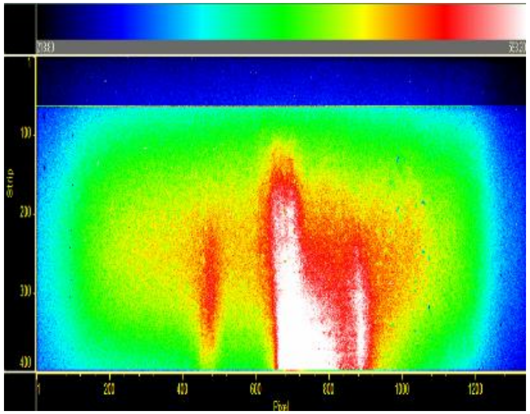


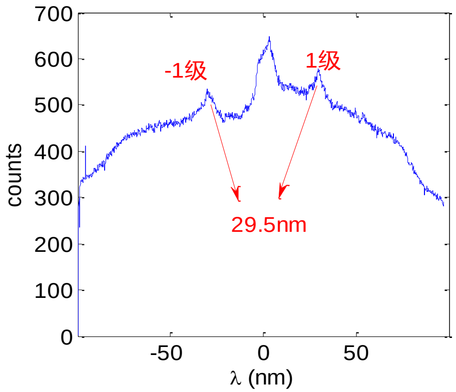
HHG-seeded LWFA-based XFEL

Electron Optics Installed





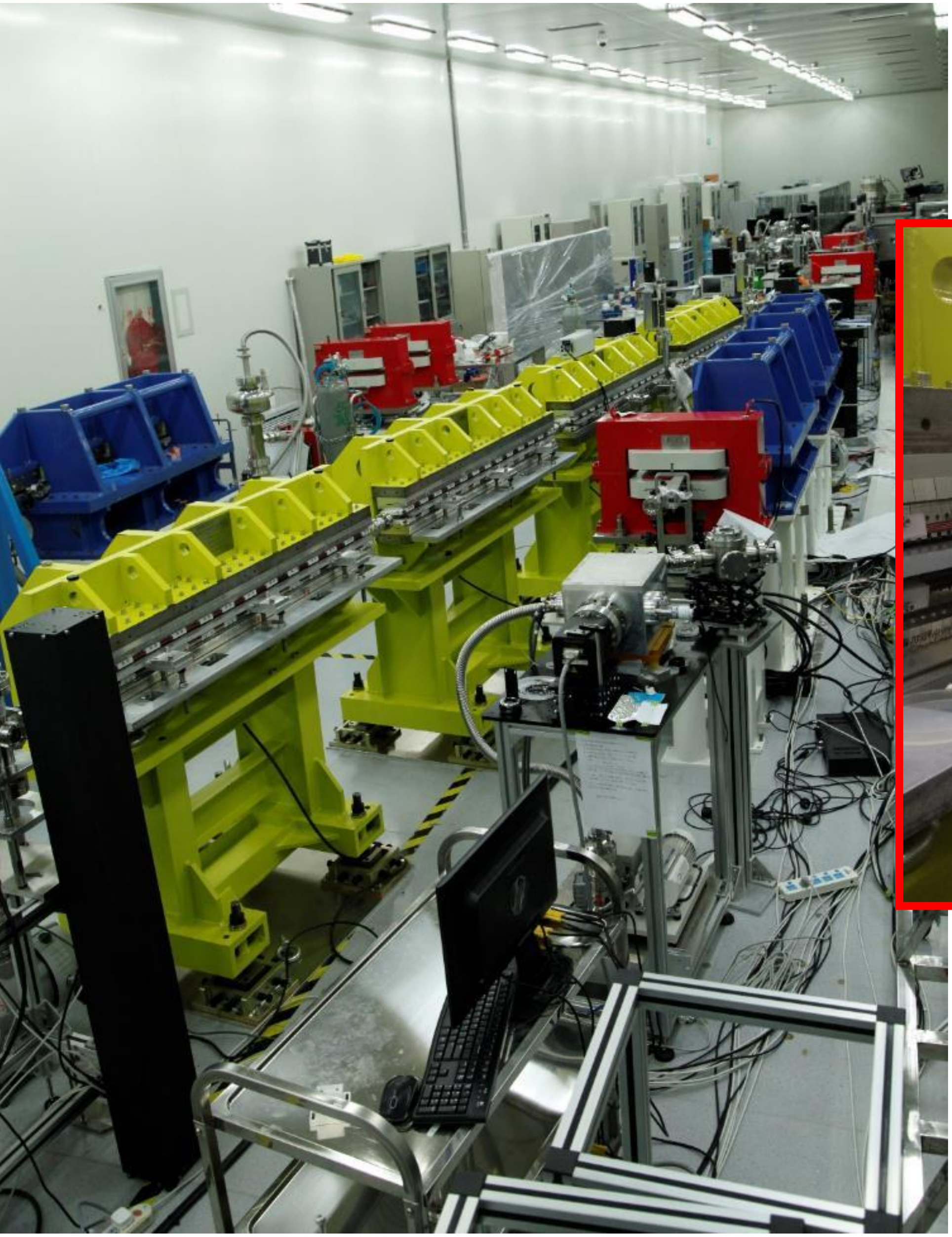


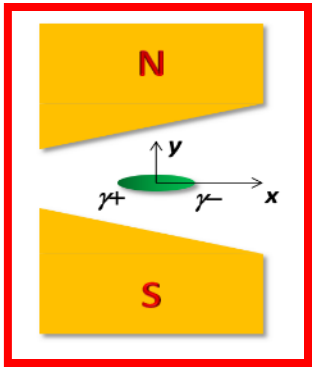


29.5 nm undulator emission

Standard undulator

Transverse gradient undulator (TGU) installed

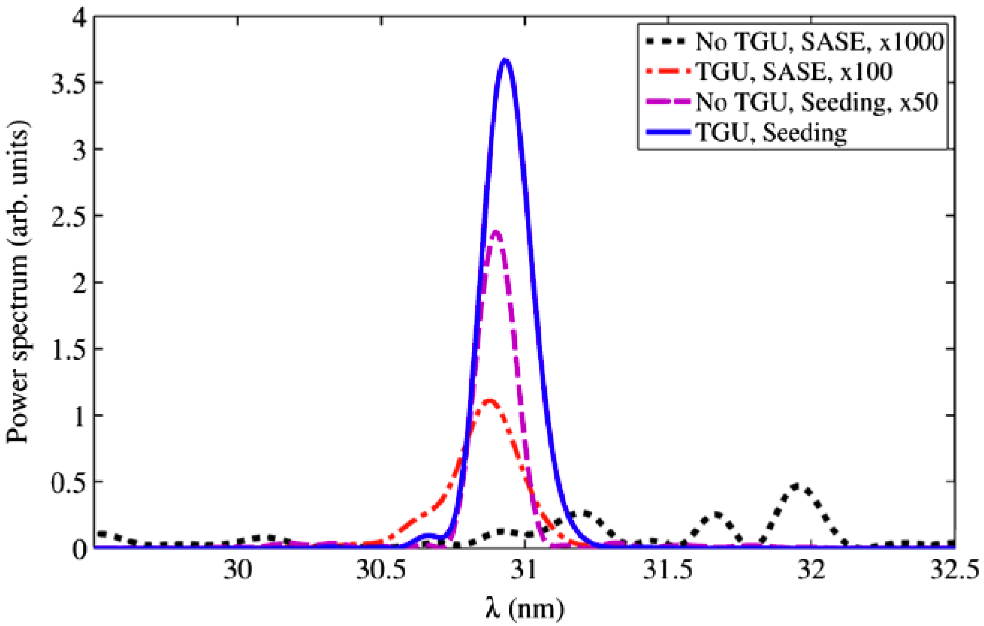


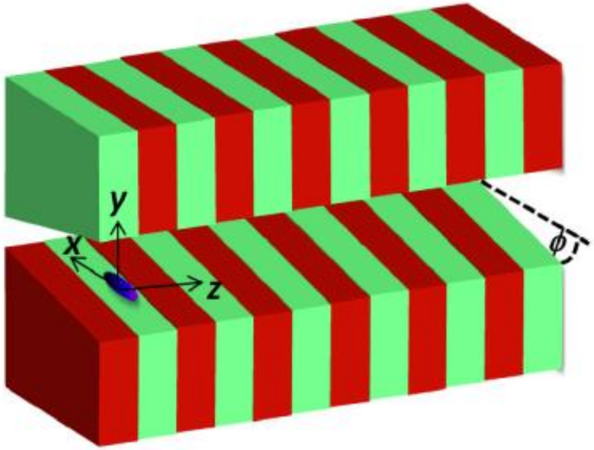


PRL 109, 204801 (2012) PHYSICAL REVIEW LETTERS week ending 16 NOVEMBER 2012

Compact X-ray Free-Electron Laser from a Laser-Plasma Accelerator Using a Transverse-Gradient Undulator

Zhirong Huang,[1] Yuantao Ding,[1] and Carl B. Schroeder[2]
[1]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*





TGU = ~ 20 ×
Seeding = ~ 100×
TGU + Seeding = ~ 7000 ×

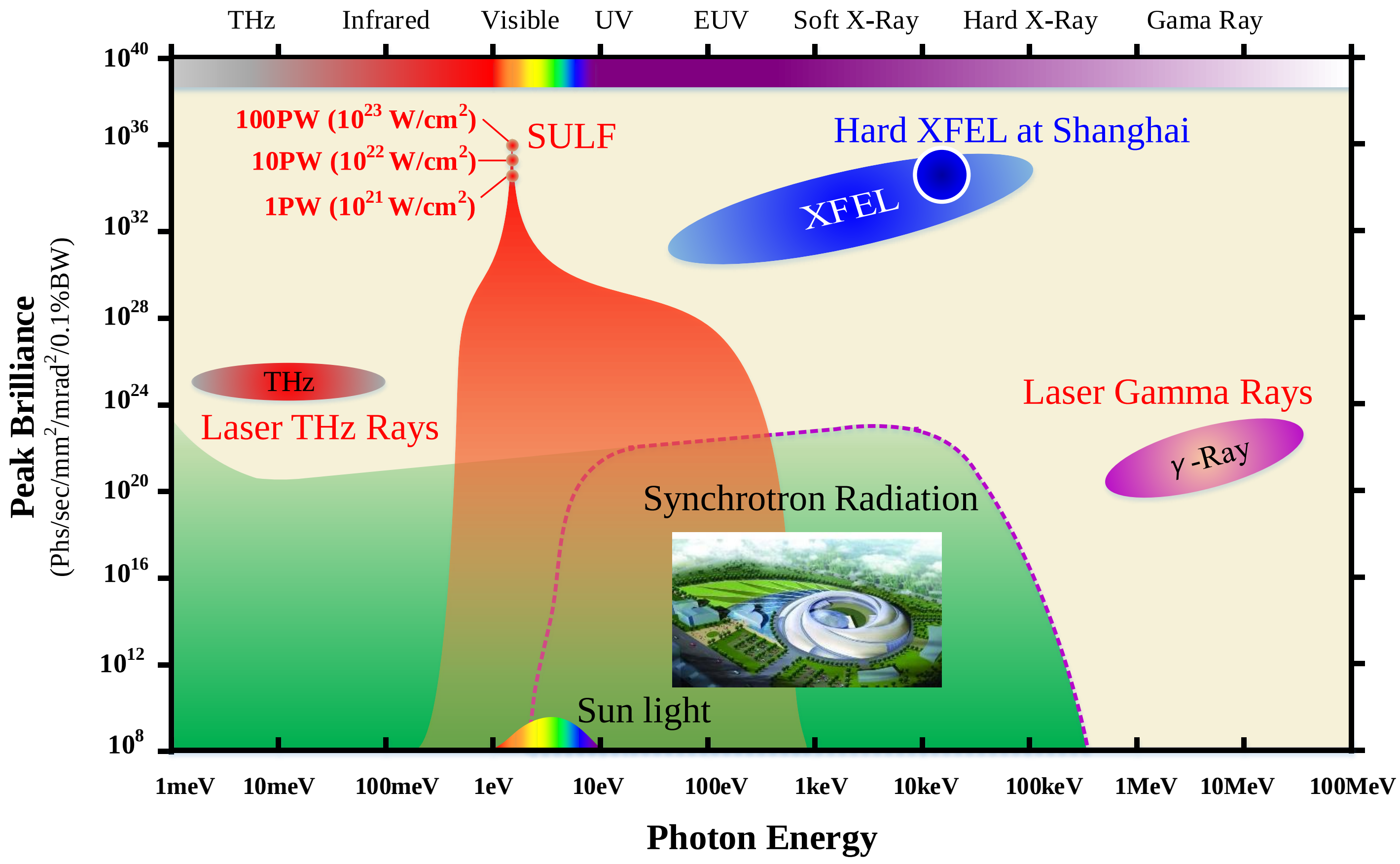
Summary

- **We have demonstrated the generation of 5.3PW, 24fs 800nm laser pulses from a CPA laser system where a high gain 150 mm Ti:sapphire amplifier with 202J, 70nm (FWHM) output is measured.**
- **We have demonstrated the generation of high-brightness e beams from a 2-stage LWFA via energy chirp control, the maximum 6-D brightness ~6.5×10^{15} $A/m^2/0.1\%$, is comparable with the state of the art LINAC drivers.**
- **Based on the high quality e beams, we have obtained high brightness Compton scattering gamma-ray source, a peak brilliance of ~3×10^{22} photons s^{-1} mm^{-2} $mrad^{-2}$ 0.1% BW at 1 MeV is deduced.**
- **LWFA-based FEL at 30nm is in progress with undulator emission measured and a 6-m long TGU installed.**

Station of Extreme Light Science (SEL) at XFEL

The marriage of two most intense light sources:

0.1nm XFEL + 100PW laser at 800nm



Similar stations at leading XFEL facilities

Facilities	LCLS	European XFEL	SACLA	**Shanghai XFEL**
Station	MEC (Matter in Extreme Conditions)	HIBEF (Helmholtz International Beamline for Extreme Fields)	BL2 (Beam Line 2)	SEL (Station of Extreme Light Science)
Laser Peak Power	0.2PW	0.2PW	2×0.5PW	100PW
Intensity	10^{20} W/cm^2	10^{20} W/cm^2	10^{21}W/cm^2	>10^{23} W/cm^2
Energy	7J	5J	--	1500J
Pulse width	35fs	25fs	--	15fs
Status	Finished	Under development	Under development	Proposal
Future Plan	0.4PW	1PW	10PW ?	--

Thank you for your attention !

Better Laser, Better Life !