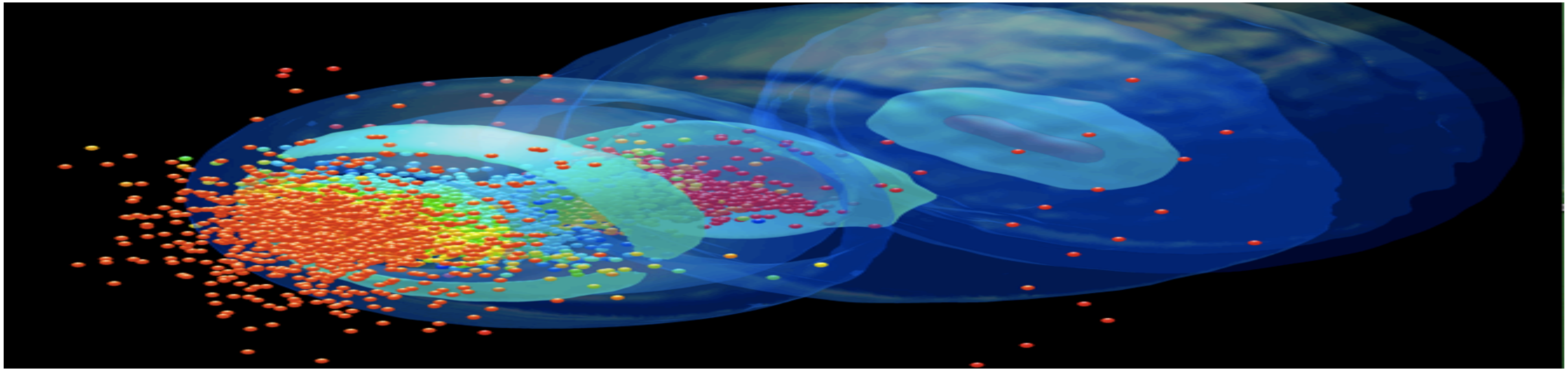


Overview of Advanced Accelerator Development in Asia

Wei Lu
Tsinghua University,China

The 2nd EAAC

La Biodola, Isola d'Elba

13-19 September 2015

Acknowledgement

Many thanks for people who provide materials in this talk:

J. Wang (NCU),C.H. Nam(IBS), M. Kondo(KPSI)

Z.T. Zhao (SINAP),Z.M. Sheng (SJTU),R.X. Li(SIOM), Y.T. Li(IOP),L.M. Chen(IOP),X.Q. Yan(PKU),Y.C. Du(Tsinghua),J.R. Shi(Tsinghua),Y.Q. Gu(LFRC)

Outline

- **Major Laser Facility for AAC in Asia (9 in this talk)**

- **Recent research progress (some highlights)**

  - ◆ **LWFA (energy gain, energy spread, staging, advanced diagnostics such as electron snapshot of wakefield, programmable plasma structures)**

  - ◆ **Theory and simulation (injection phase space dynamics, controlled injection for super bright beam generation, phase space matching for staging)**

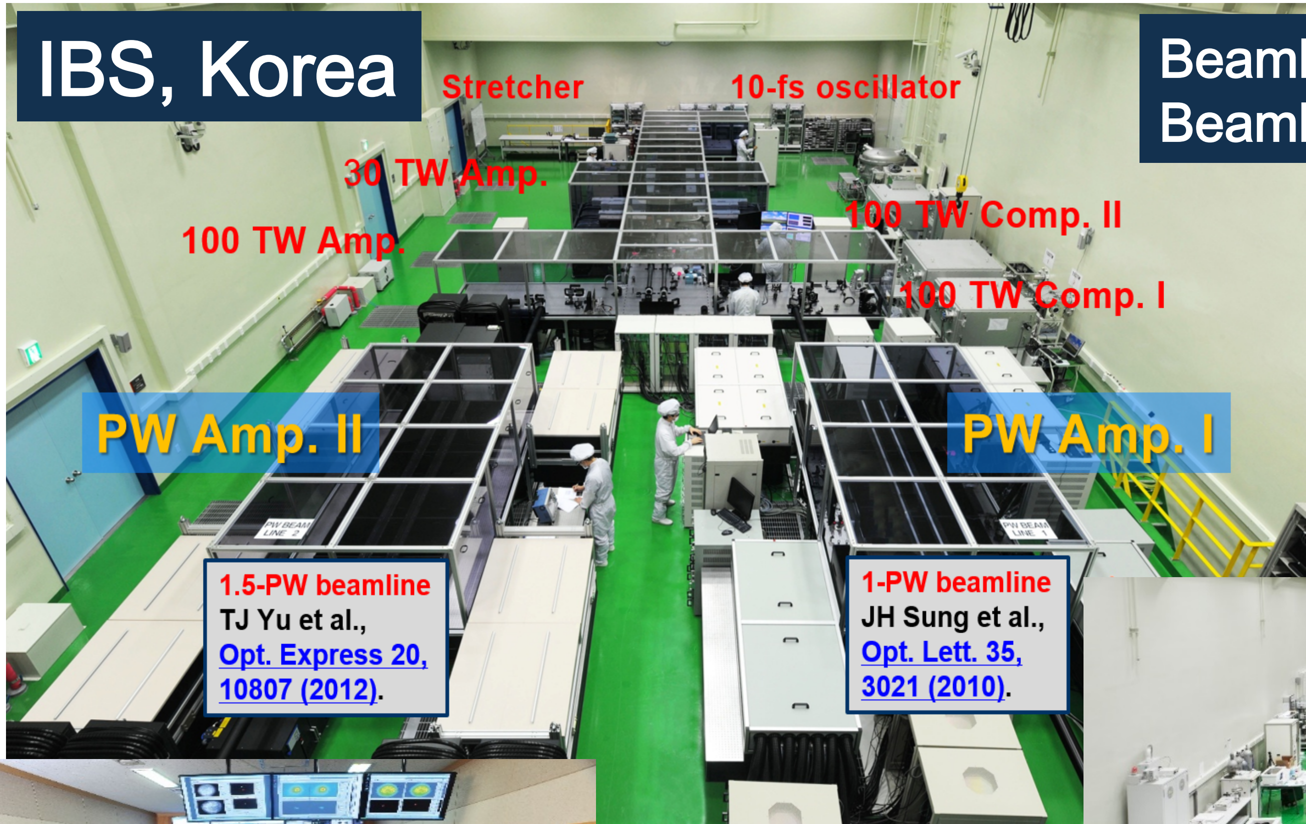
  - ◆ **Radiation source (Betatron, Thomson scattering source,THz, see Kim's talk on Friday)**

  - ◆ **Ion acceleration (energy gain, RPA, proton imaging)**

  - ◆ **C-X band high gradient structure (KEK/SINAP/Tsinghua, see Valery's talk tomorrow)**

- **Future Perspective**

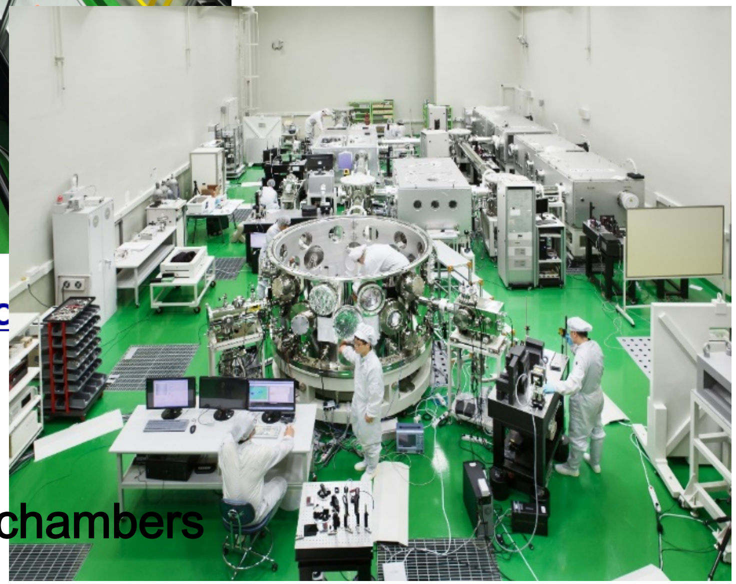
PW Laser at Center for Relativistic Laser Science



Beamline I: 30 fs, 1 PW
Beamline II: 30 fs, 1.5 PW

장의 세기 : ~ 5 x 10^{21} W/c

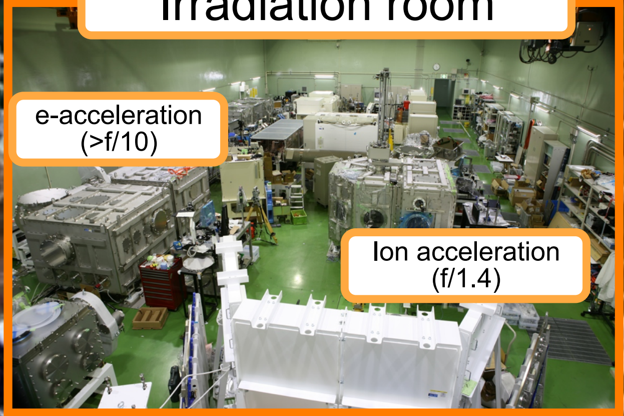
Control room



PW target chambers

Kansai Photon Science Institute
JAPAN ATOMIC ENERGY AGENCY

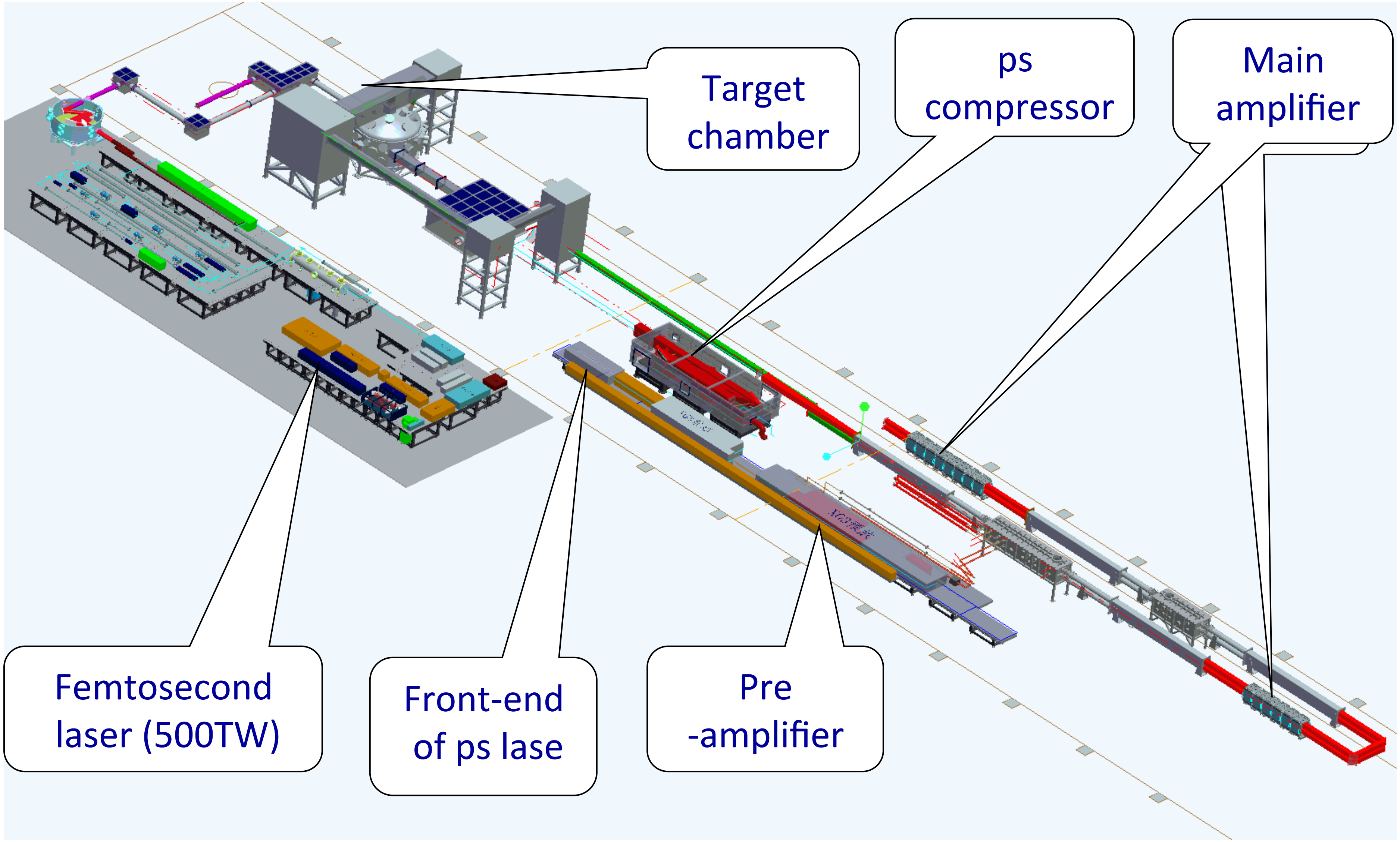
(since 1999)



	Previous (~2013)	New (2015)
Repetition Rate	0.00056 Hz	**0.1 Hz**
Beam diameter	150 mm	**250 mm**
Pulse Energy	8 J	**30 J**
Pulse Duration	30-40 fs	**30-40 fs**
Peak Power	0.2 PW	**>800 TW**
Nanosecond Contrast	$\sim 10^{11-12}$	**$\sim 10^{12}$**
Focusing	f/2.1	**f/1.4**
Peak Irradiance	2×10^{21} W/cm^2	**$\sim 10^{22}$ W/cm^2**

Current Members:
M. Kando, S.V. Bulanov, T. Zh. Esirkepov, Y. Fukuda, Y. Hayashi, H. Kiriyama, J. K. Koga, M. Kishimoto, A. Kon, K. Kondo, H. Kotaki, Y. Mashiba, Y Y. Miayasaka, M. Mori, M. Nishiuchi, K. Ogura, A. S. Pirozhkov, A. Sagisaka, H. Sakaki, H. Tanaka
Collaborators:
A. Faenov, T. Pikuz, M. Kanasaki

XG-III facility (ns/ps/fs)at LFRC of China

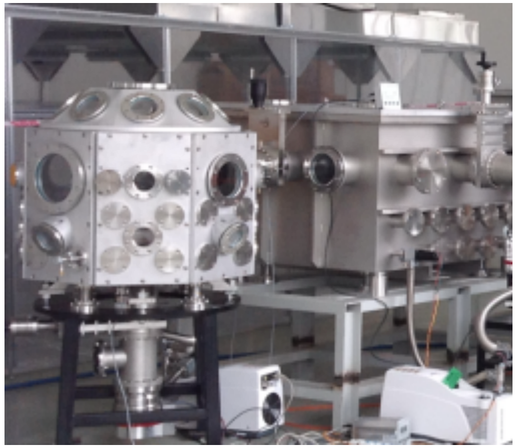


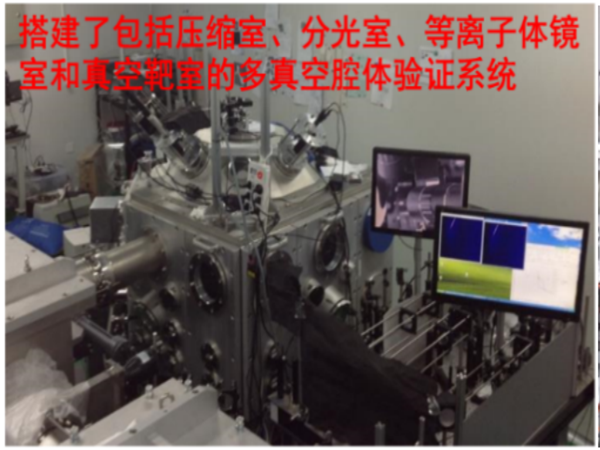
HHG-seeded LWFA-based XFEL (SIOM) Shanghai

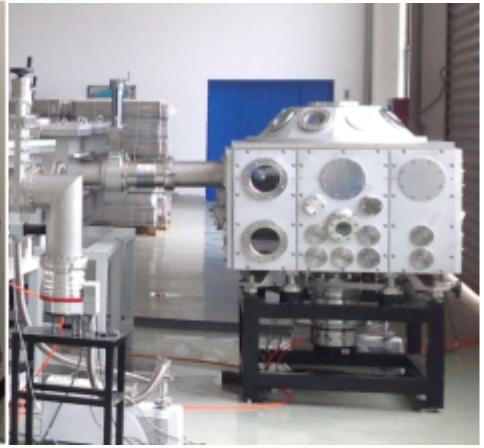
200TW Laser System and Chambers

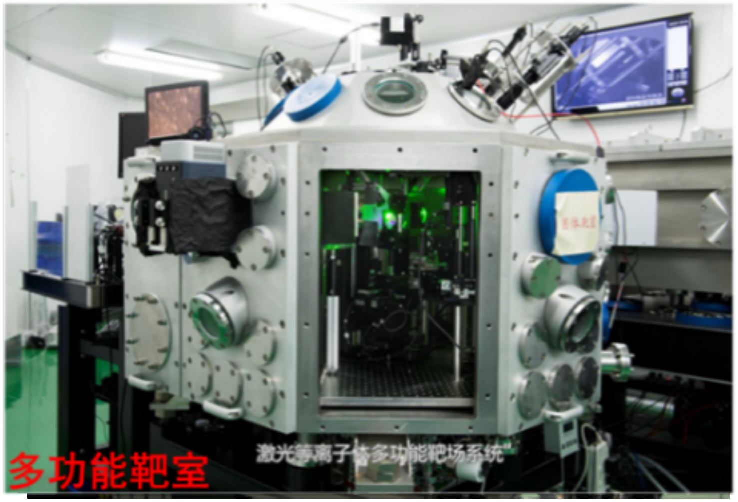
Laboratory for Laser Plasmas (LLP)

Shanghai Jiao Tong University (SJTU)









Energy/pulse ~5 J
Pulse duration ~25 fs
Peak Power ~200 TW

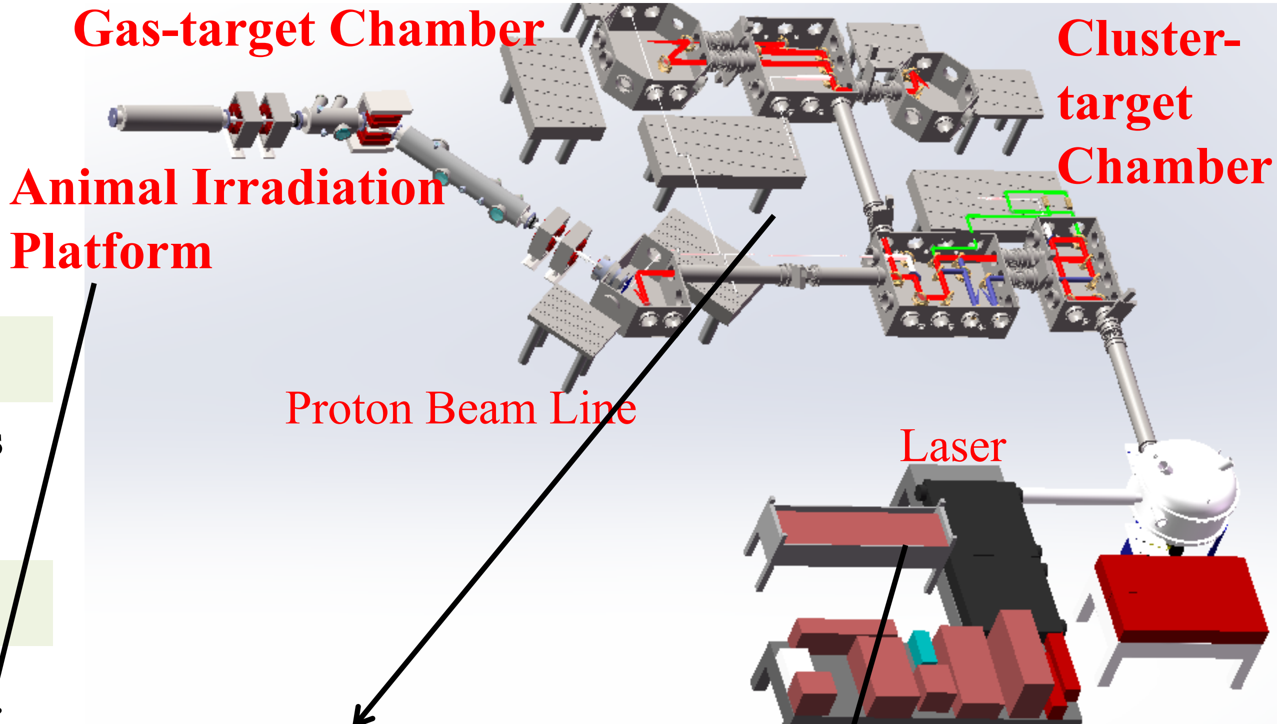
Laser Facility @IOP Beijing

20TW/100TW/1PW systems with 3 target chamber

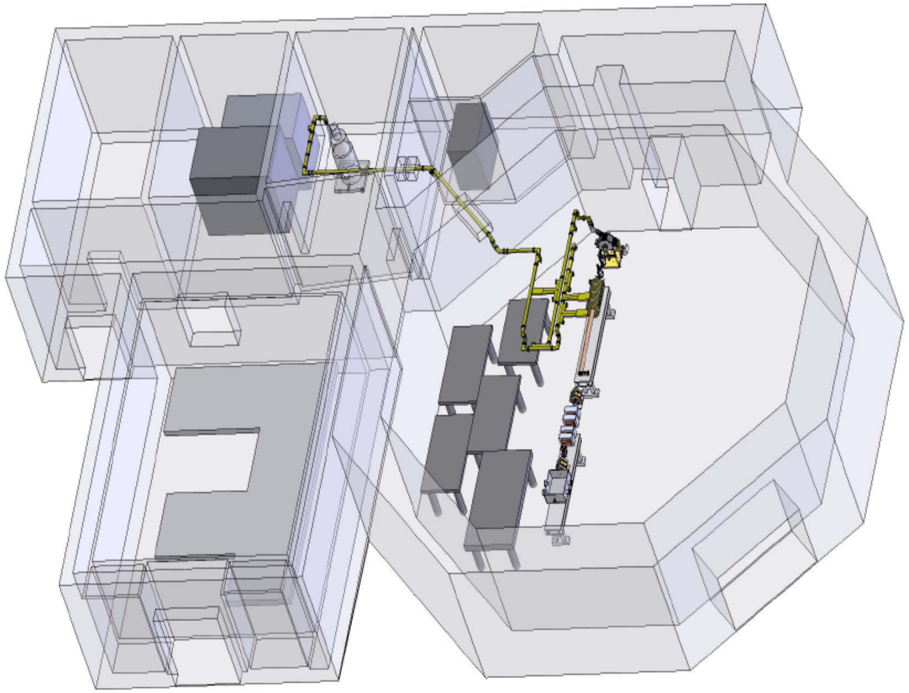
Compact LAser Plasma Accelerator @Peking Uni.

CLAPA Laser Parameters

Pulse Energy:	5 J
Pulse Duration:	< 25 fs
Wavelength:	800 nm
Contrast Ratio:	10^{10}:1 @ 100 ps 10^{9}:1 @ 20 ps
	10^{6}:1 @ 5 ps
	10^{3}:1 @ 1 ps



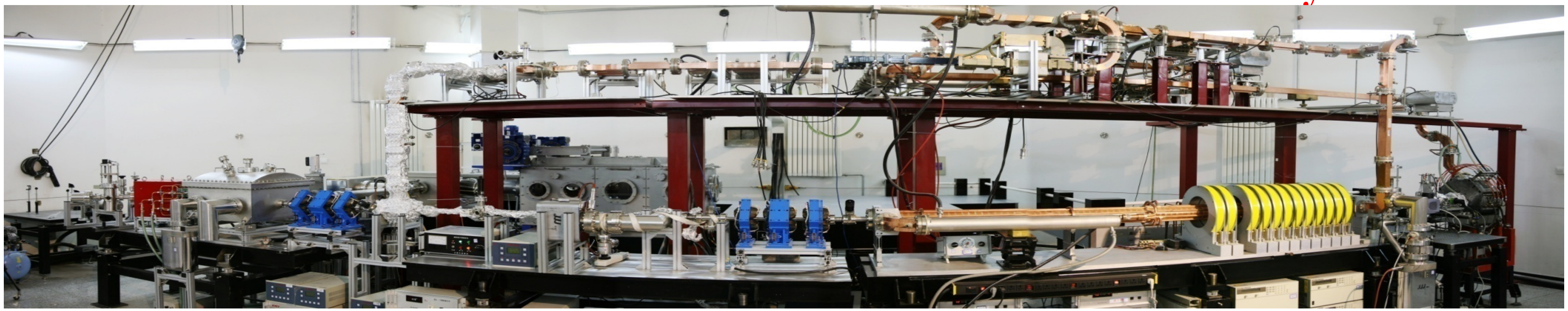
Advanced Acceleration Platform @ Tsinghua Univ



40TW Laser ＋45MeV Linac

45MeV LINAC

25fs 40TW Laser System



Sub 50fs high current (>5kA) electron beam obtained through hybrid compression

L^2PA

Laboratory of Laser Plasma Physics and Advanced Accelerator Technology at Tsinghua University

Current Research Focus

Key physics of high quality plasma based accelerators

- **Stable and efficient acceleration structure**

➢Matched self-guiding、fully optical channel generation、channel assisted matched guiding…

- **High quality controlled injection and 6D phase space manipulation**

➢ultralow emittance、high brightness、high charge and current、low energy spread、short pulse duration、controllable profile、phase space matching …

- **Diagnostics of beams with special space and time structures**

➢ultralow emittance、low energy spread、phase space structures…

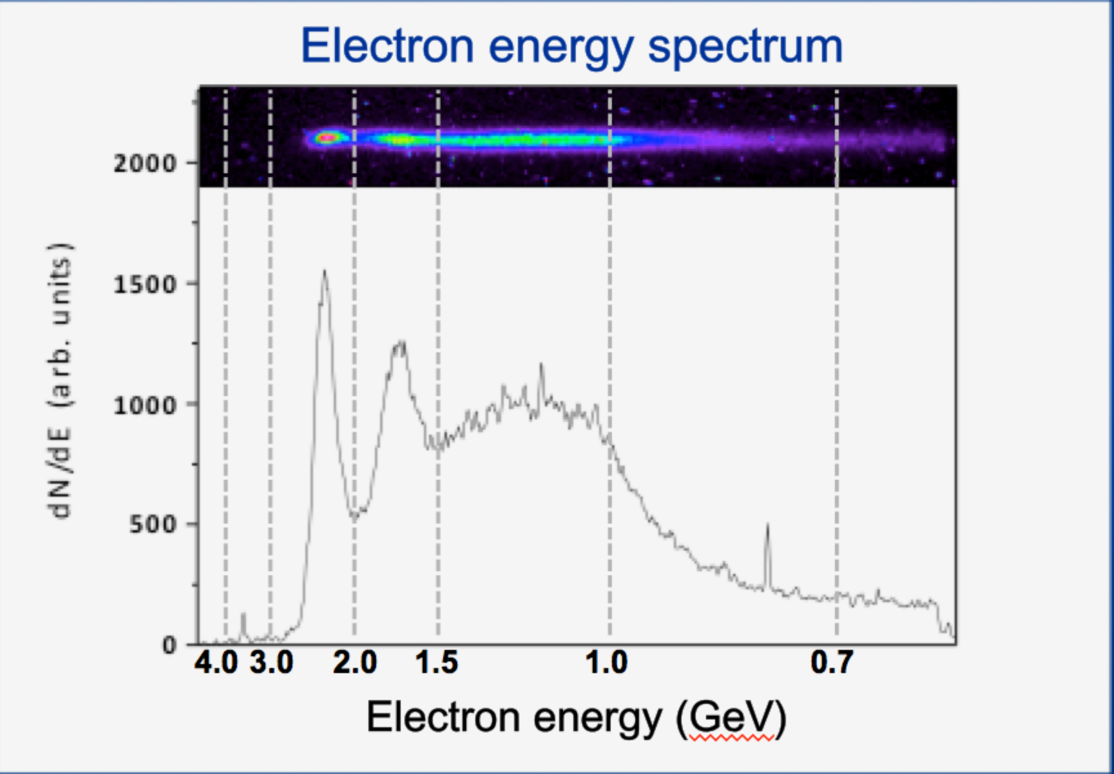
- **Diagnostics for acceleration structure and dynamic processes**

➢Optical probe、 electron probe …

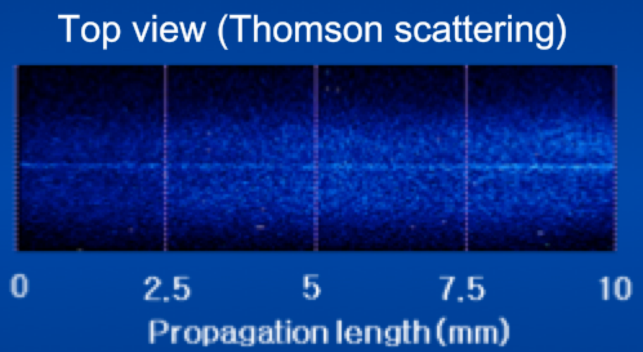
NCU 100TW Multi-Pulses Facility @ Taiwan (Prof. J. Wang)

Electrons over 2 GeV from a 1-cm gas cell

Gas cell length = 10 mm
Positively chirped 61 fs
Intensity = 2×10^{19} W/cm^2 (a_0=3.1)



Electron energy > 2 GeV

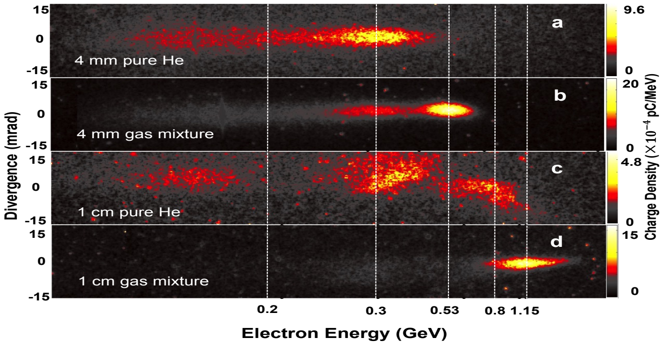


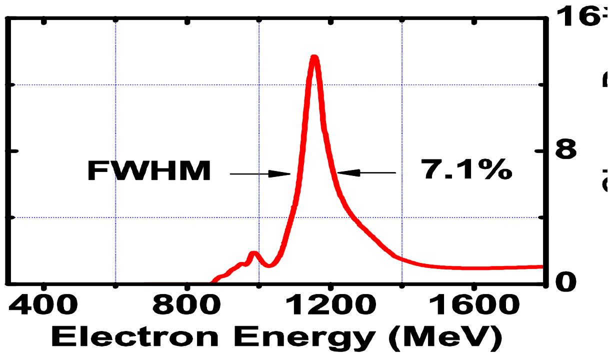
Smooth propagation over the whole medium length of 10 mm

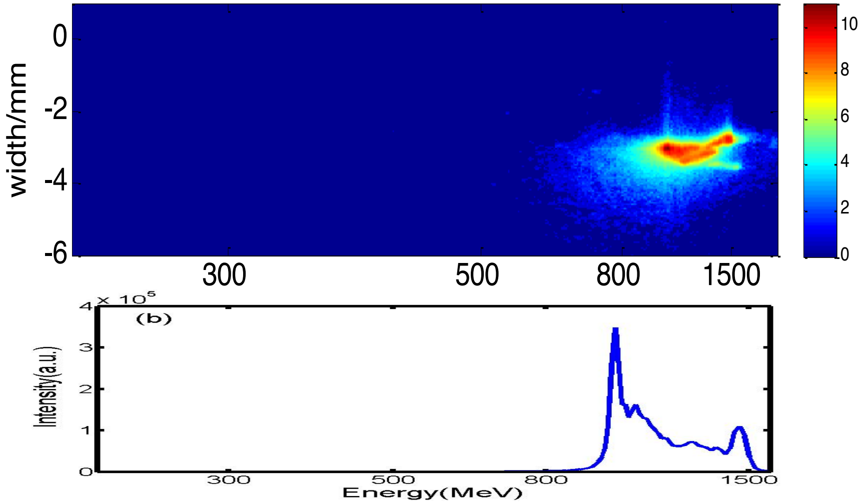
ibs CoReLS GIST

SJTU

LFRC







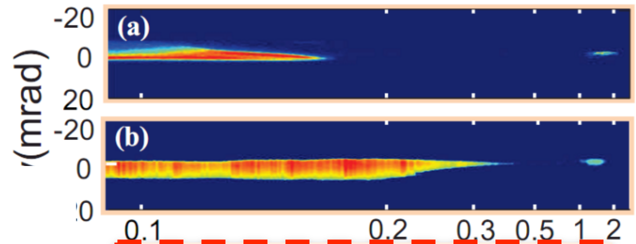
300TW self-injection

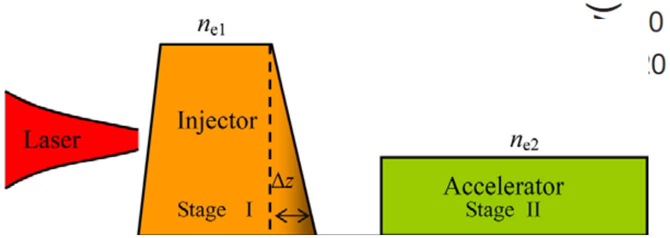
Self-truncated ionization injection

Mirzaie et al. Scientific Reports (2015)

SIOM

Appl. Phys. Lett.103, 243501(2013)





Cascaded LWFA (1+5 mm)

~1.3 GeV

Very low energy spread (absolute and relative) electron beams via self-injection @ Tsinghua

10-30MeV pC electron beam generation by a 60fs 5TW laser

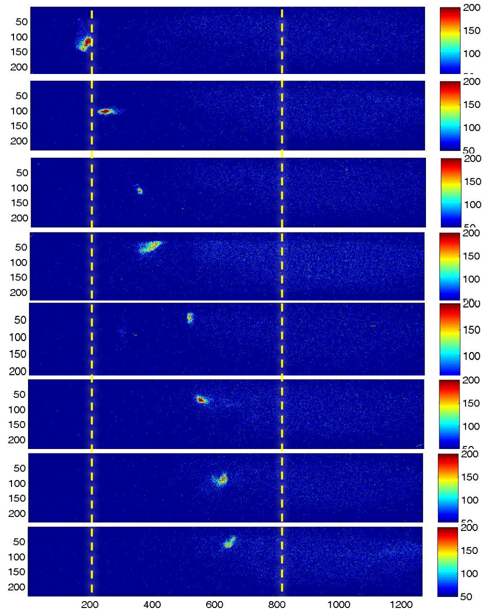
Very low absolute energy spread (AES) and relative energy spread (RES) observed under proper conditions :

On many shots, AES below 0.5MeV (rms), with the lowest 0.18MeV

On many shots, RES around 1-2% (rms), with the lowest 0.8%

Small divergence of a few mrad, with the smallest 1.2mrad

27.1MeV 11.38MeV

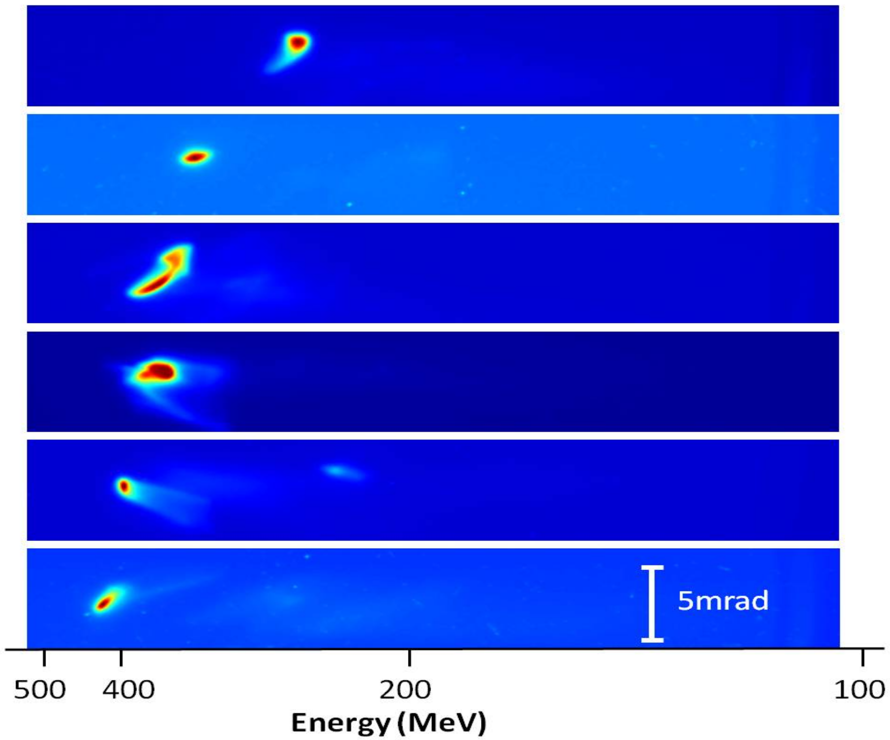


Energy (MeV)	Absolute energy spread(rms) (MEV)
27.6	0.53
25.7	0.77
22.1	0.18
21.0	0.87
17.5	0.20
16.5	0.53
14.7	0.45
14.3	0.39

By J.F. Hua, C.H. Pai et al.

300-430MeV low energy spread (2-5%) electron beams using a 50TW laser@NCU (Tsinghua/NCU/UCLA)

Single stage self-guided LWFA via self-injection



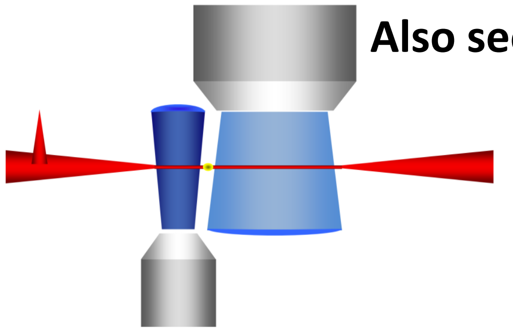
Energy (MeV)	RMS energy spread	Divergence angle (mrad)
265	2.1%	1.3
334	2.3%	0.83
367	5.2%	1.0
377	5.5%	1.6
408	2.3%	1.0
435	3.6%	1.6

By C.H. Pai et al.

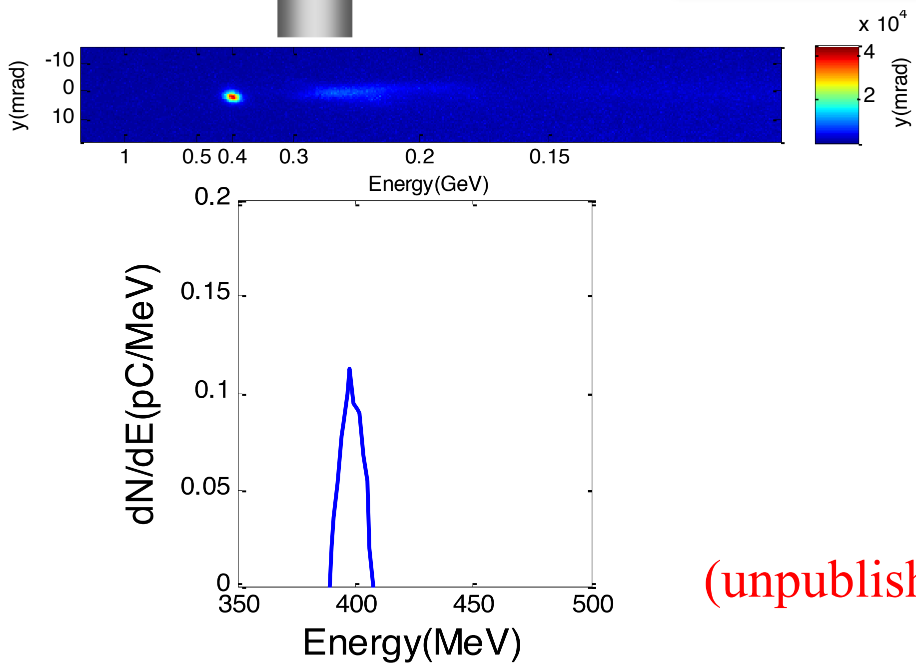
SIOM:High-quality electron beams by two stage LWFA

Also see two talks from Japan colleagues on Thursday and Friday

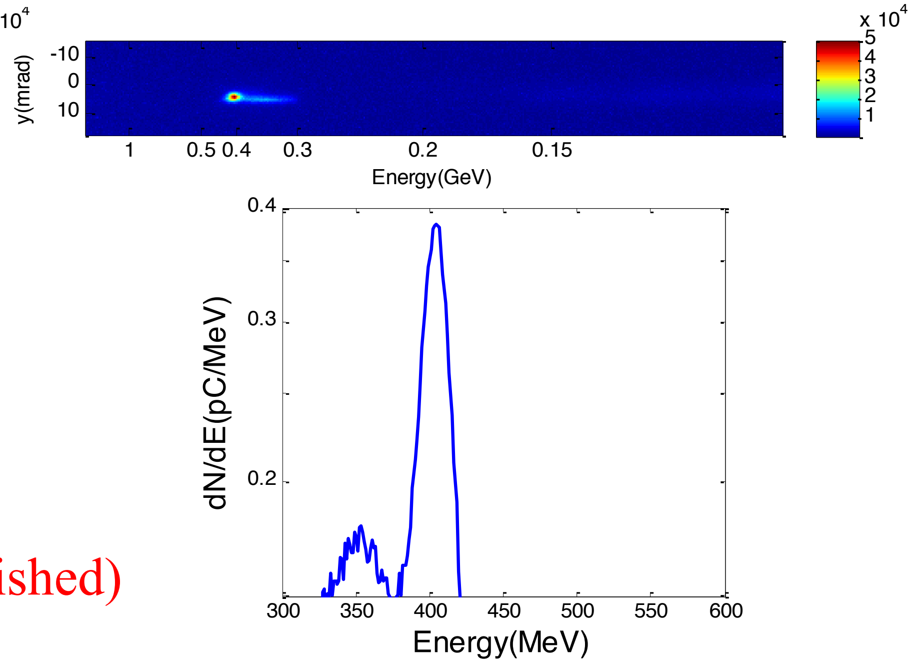
100 TW,
30 fs
5 Hz



Peak Energy: 0.4-0.6 GeV **Energy spread:** ~1%
Beam charge : up to 82.5 pC **Divergence:** ~1.0 mrad



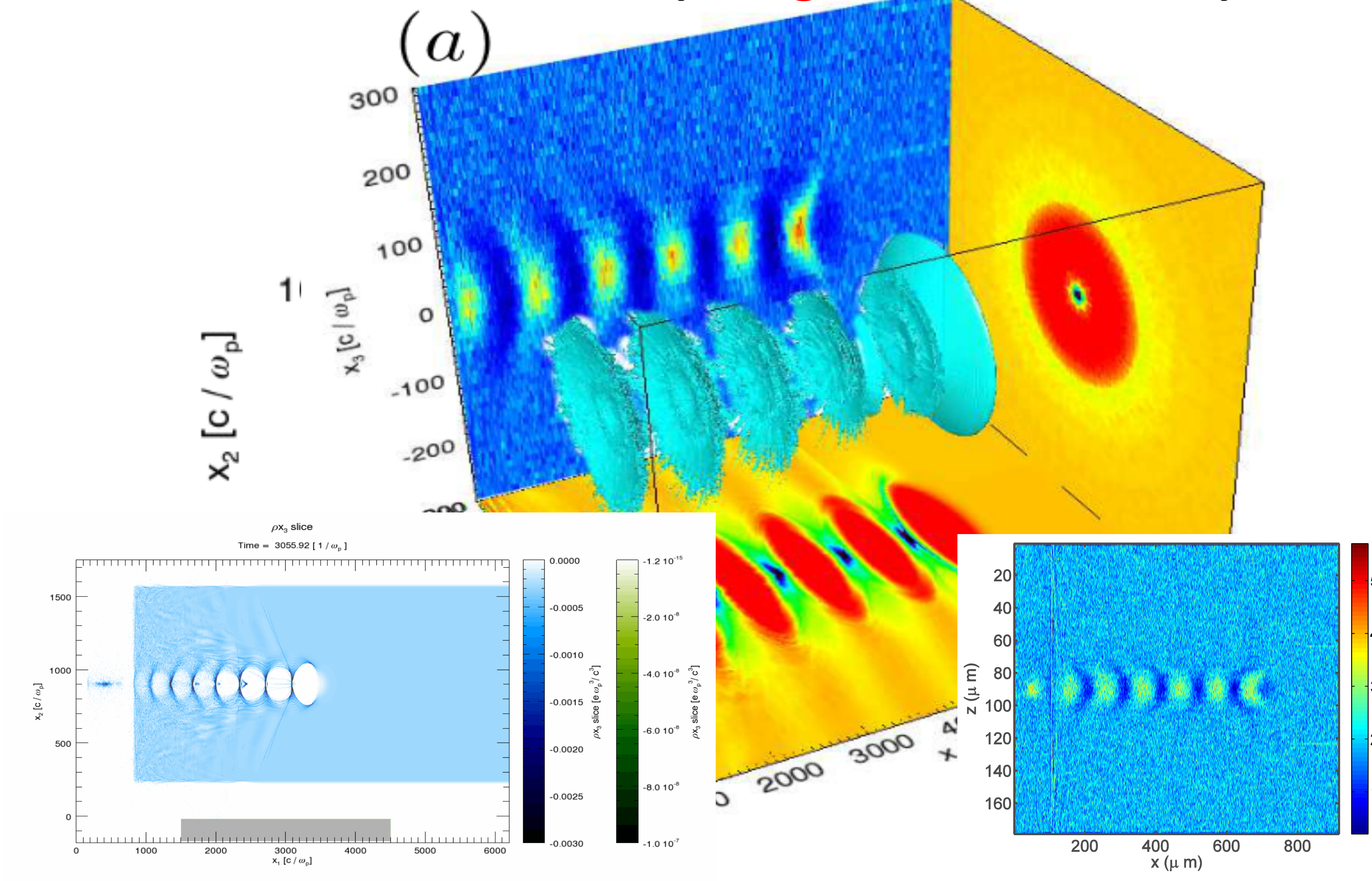
(unpublished)

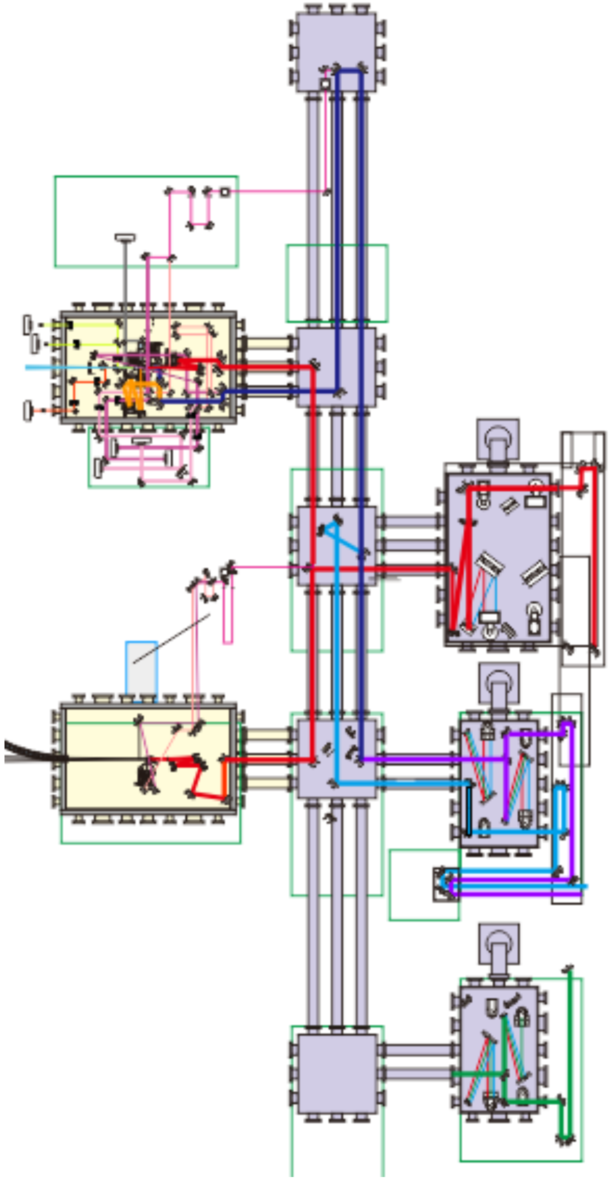


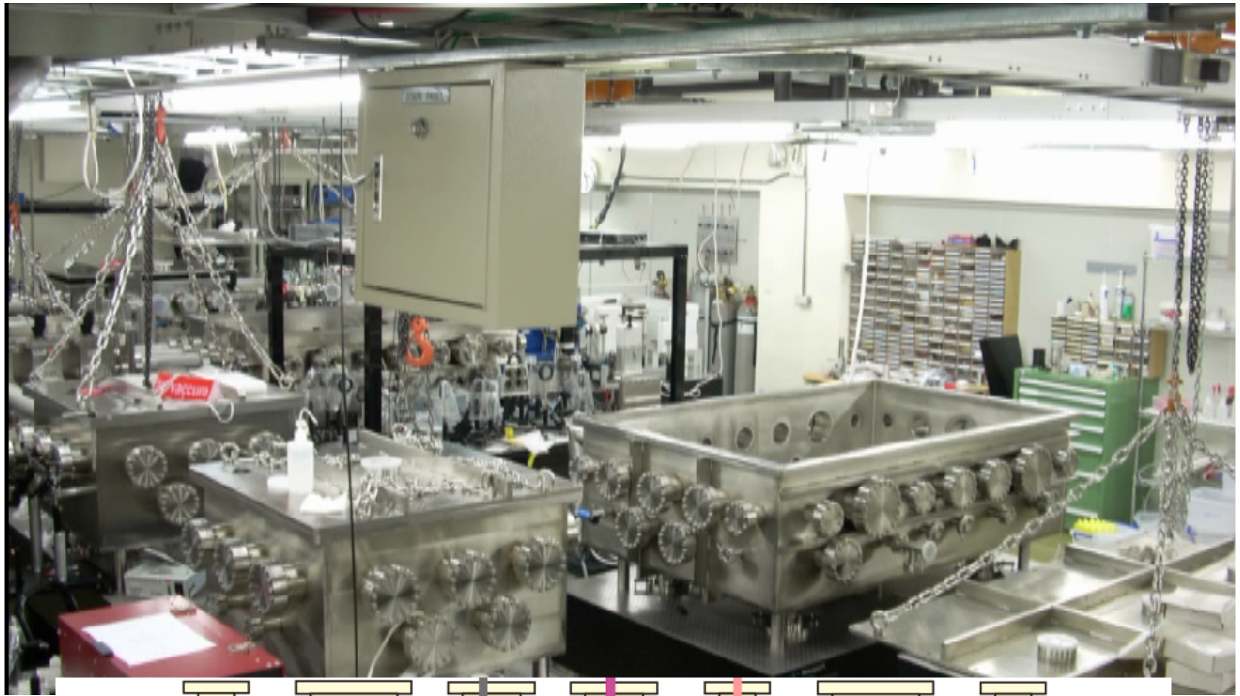
Peak energy	398 MeV
Energy spread (rms)	0.8%
Divergence (rms)	0 .8 mrad
Beam charge	82.5 pC

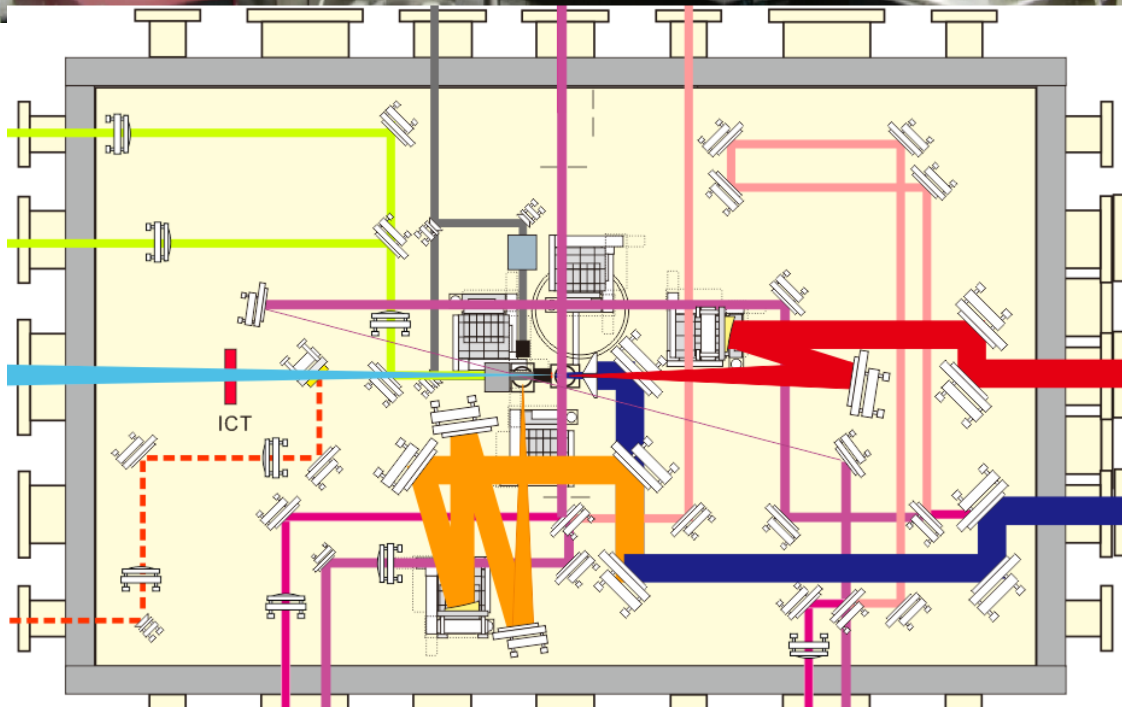
Peak energy	405 MeV
Energy spread (rms)	0.9%
Divergence (rms)	0.9 mrad
Beam charge	79.9 pC

The 1st demonstration of electron Snapshot of Wakefield @NCU (Tsinghua/NCU/UCLA)








ICT

Experimental observation of Wakefield

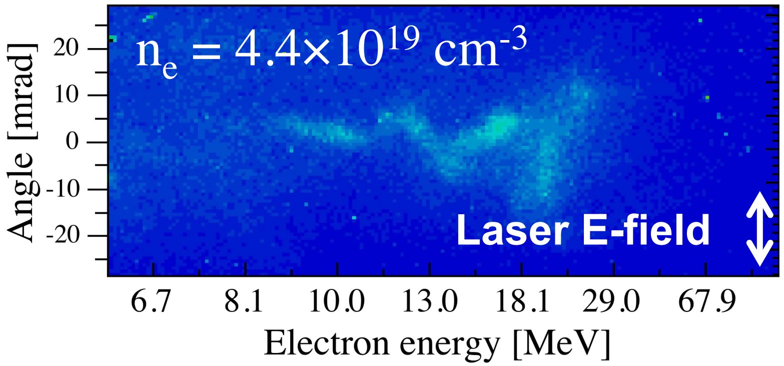
TO BE RELEASED WHEN PUBLICATION IS ACCEPTED

Wakefield propagation

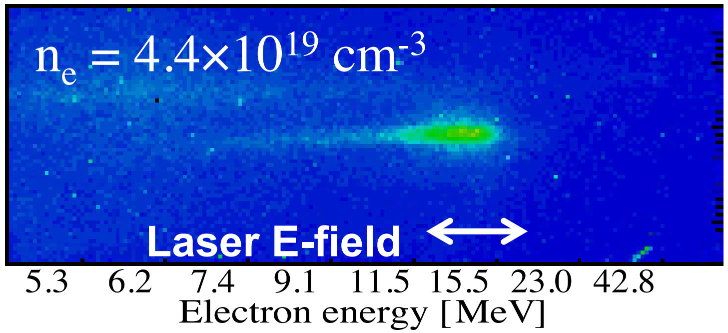
TO BE RELEASED WHEN PUBLICATION IS ACCEPTED

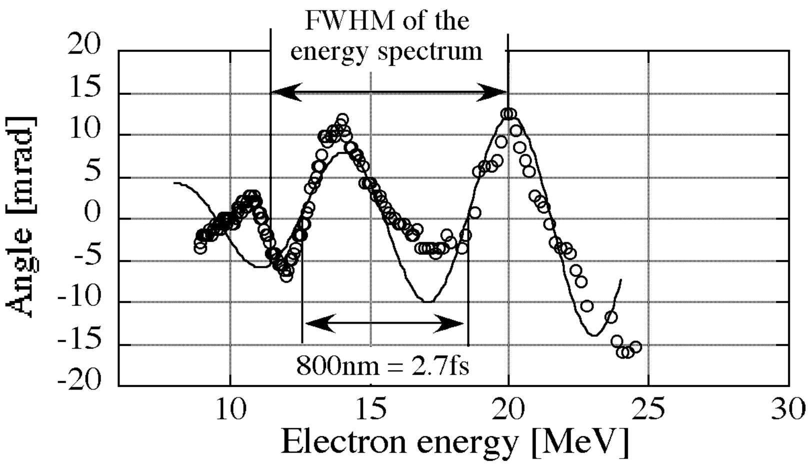
Electron pulse duration estimation by sinusoidal oscillation by laser field

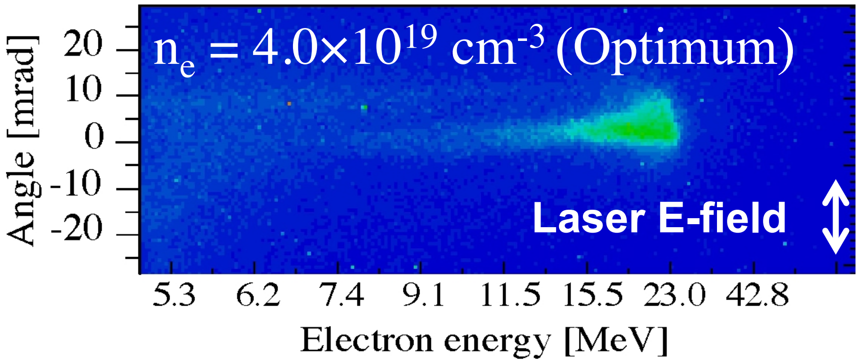
130 mJ/40 fs
f/22, N_2-gas
I=7.3×10^{17} W/cm^2



No oscillation is observed when the laser polarization is rotated.





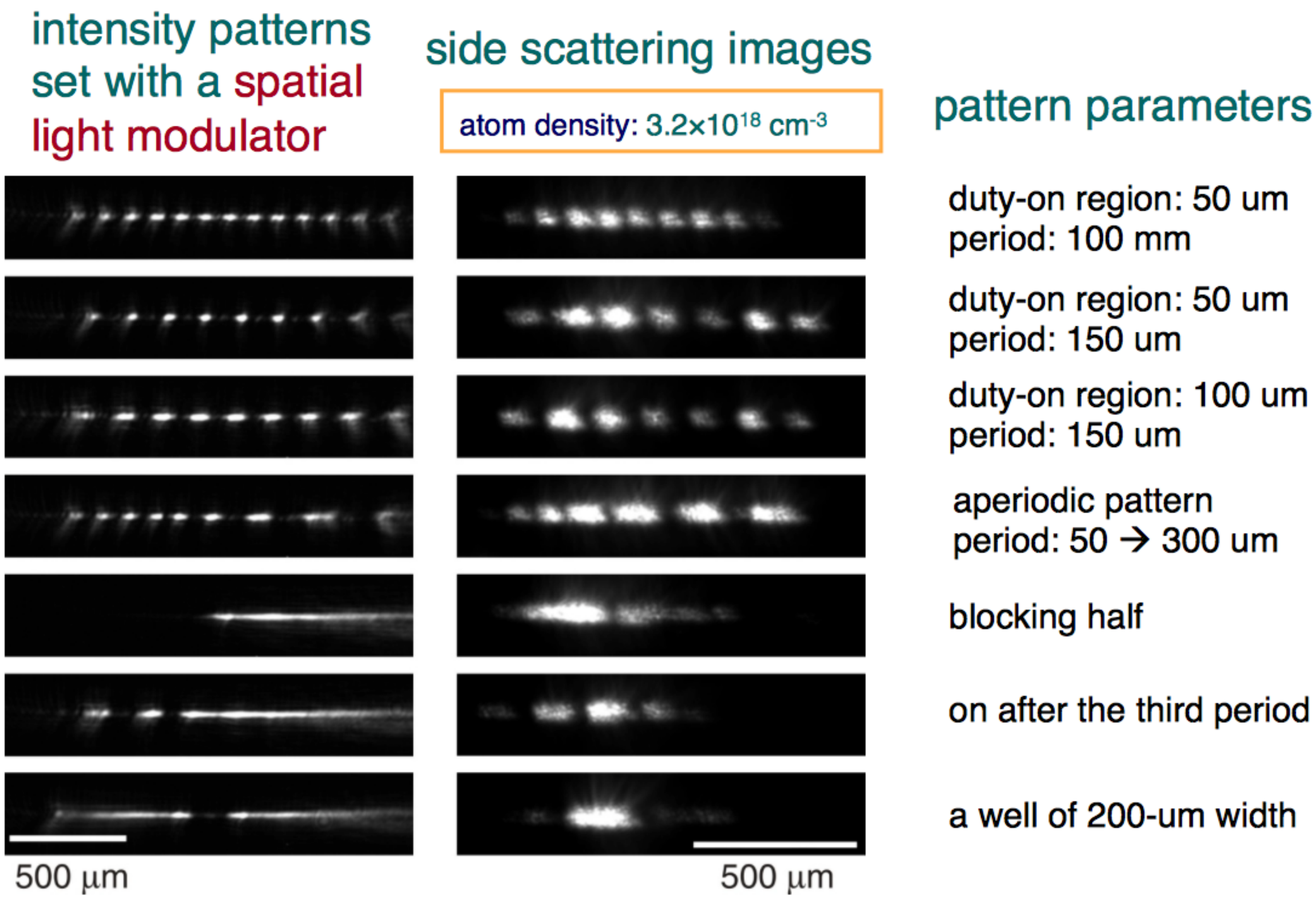


by tuning plasma density
electron feels the transverse kick by laser

Compact laser based XFEL project
has been started! (FY2014~2018)
See talks by M. Kando and T. Hosokai

H. Kotaki et al., J. Phys. Soc. Jpn., **84**, 074501 (2015).

Programmable fabrication of plasma structure using SLM@NCU/Tsinghua



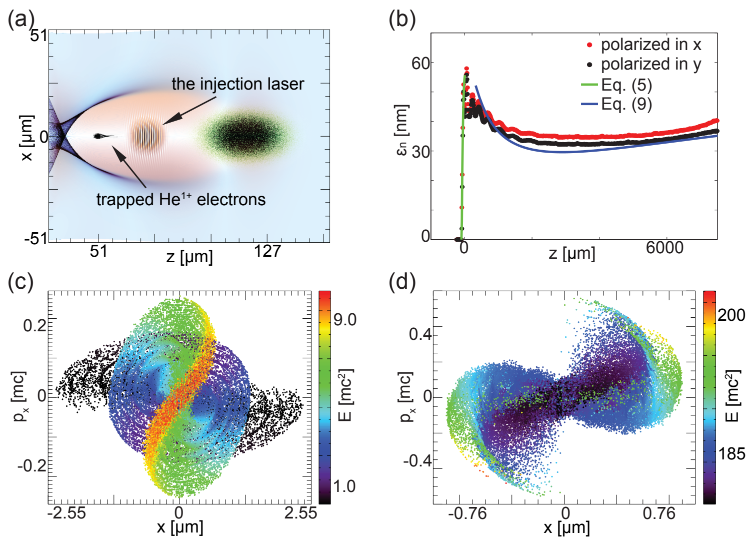
Structures with features about 10um can be fabricated

Density range: 10^18cm-3 to 10^20cm-3

PHYSICS OF PLASMAS 13, 110701 2006

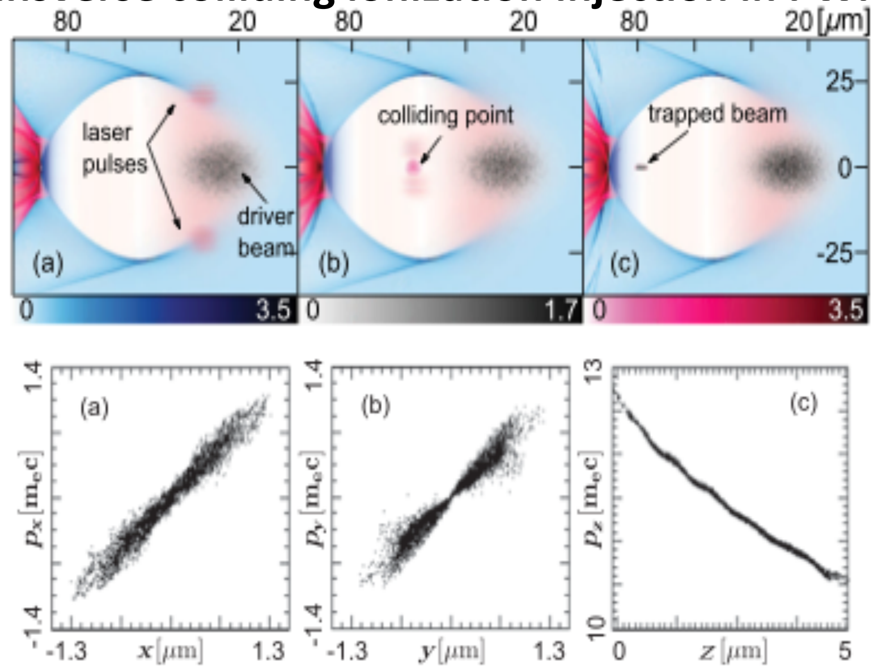
Theory and Simulation

Phase space dynamic of ionization injections



X.L. Xu et al., PRL 112, 035003 2014

Ultra-bright beam generation
Transverse colliding ionization injection in PWFA

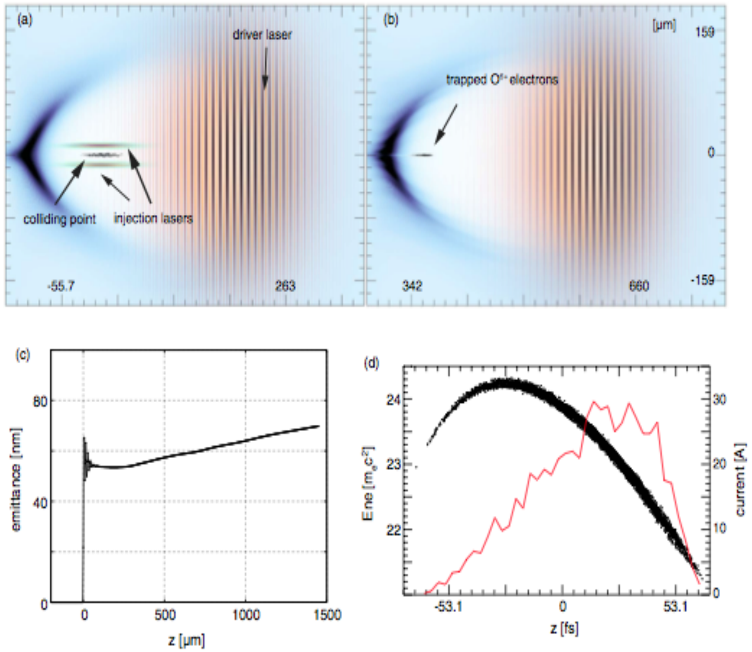


F. Li et al., PRL 111,015003 (2013)

Tsinghua/UCLA

Theory and Simulation

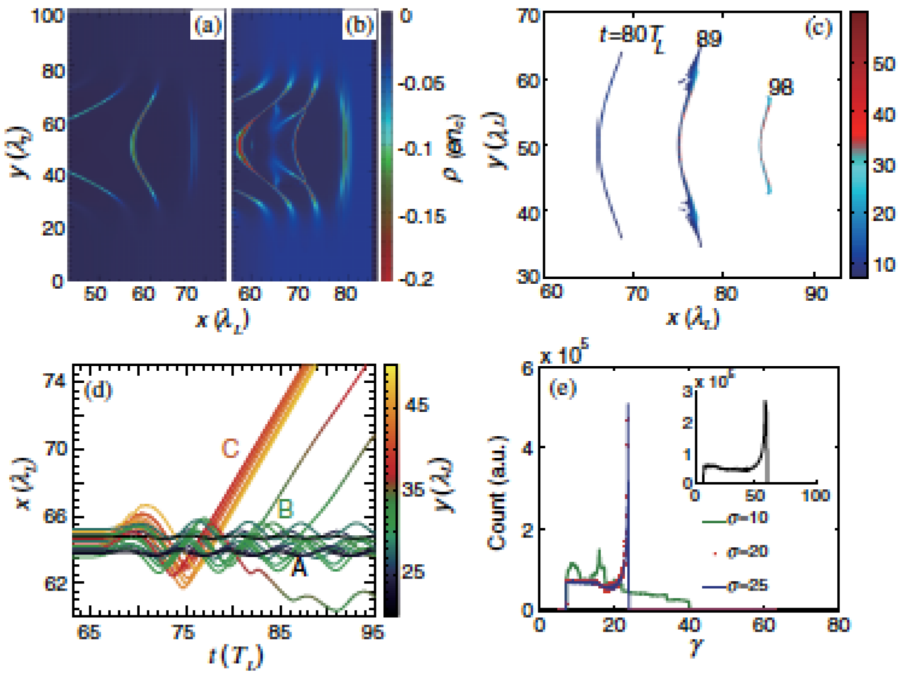
Two color ionization injection



L.L. Yu et al., PRL. 112, 125001 (2014)
LBNL/SJTU

Xu et al., PRSTAB 17,061301 2014
Tsinghua/UCLA

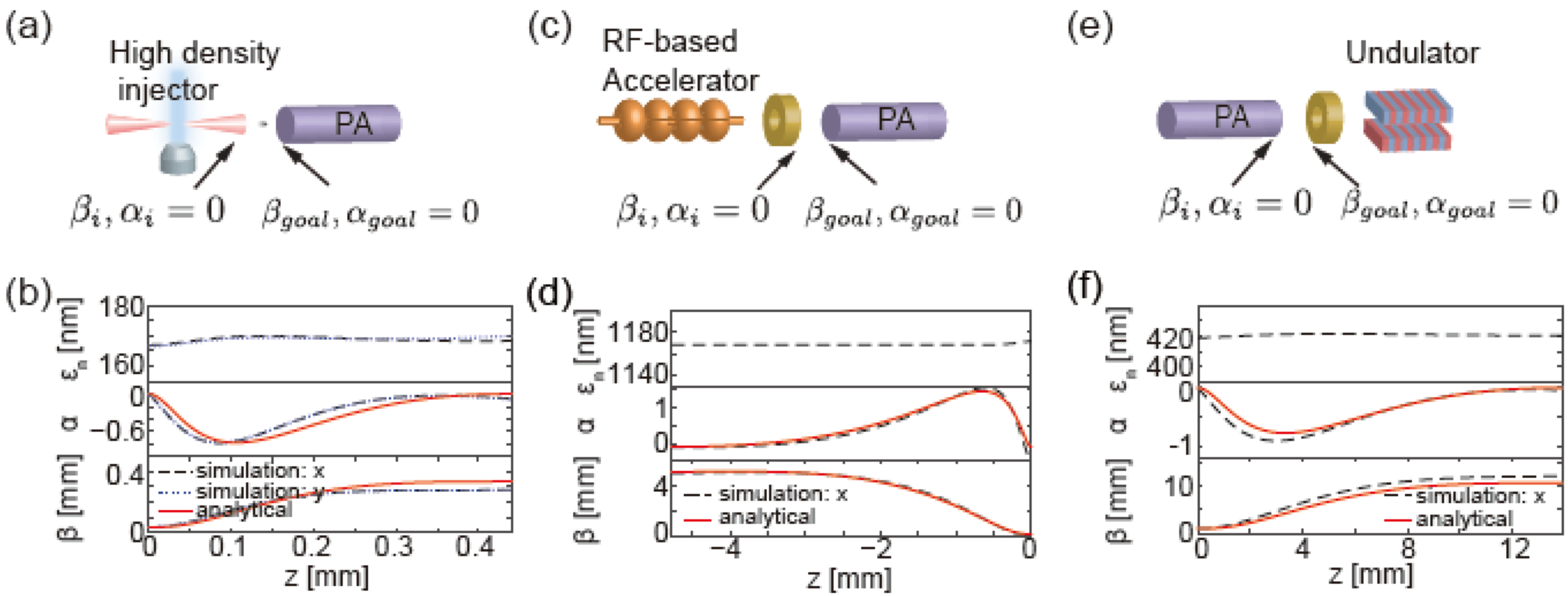
Dense attosecond electron sheets using up-ramp density transition



F.Y.Li et al., PRL 110, 135002 (2013)
SJTU/MPQ/UCLA/Tsinghua

Also see M. Chen's talk on ionization injection

Exact phase space matching for staging plasma and traditional accelerator components using longitudinally tailored plasma profiles

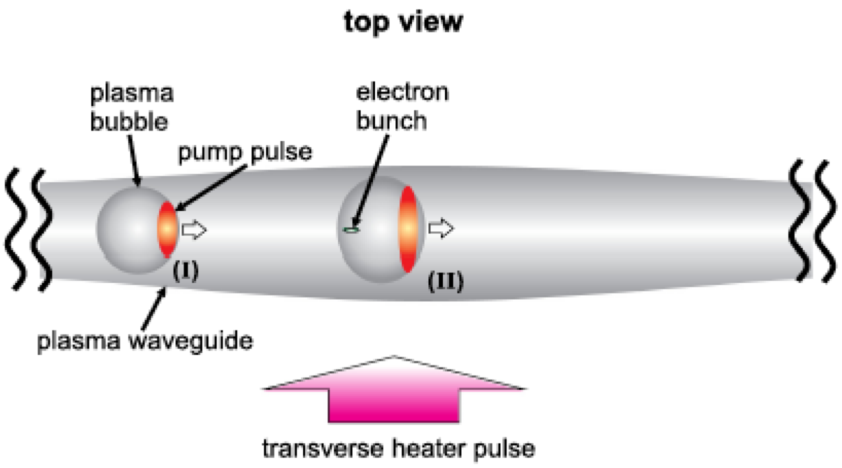


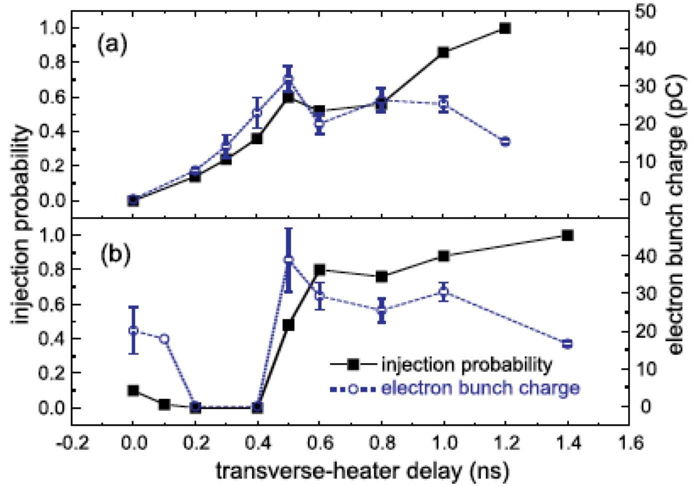
XU et al., Tsinghua/UCLA/SLAC

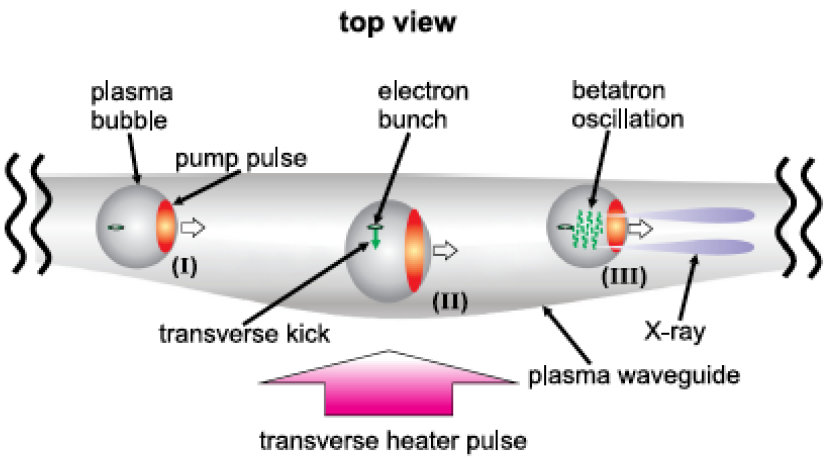
arXiv:1411.4386v2 (2014)

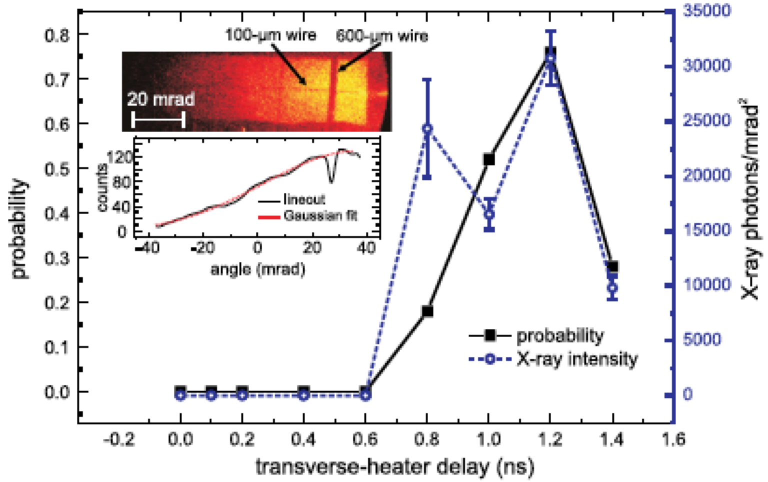
Betatron enhancement by plasma waveguide structure modification

Y.C.Ho et al., Phys. Plasmas 20, 083104 (2013) **NCU**



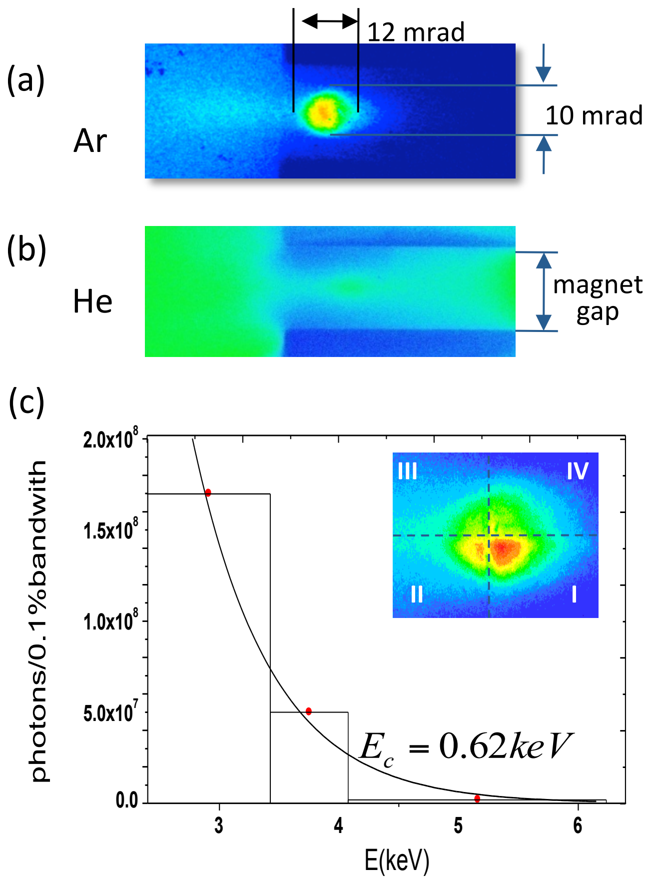


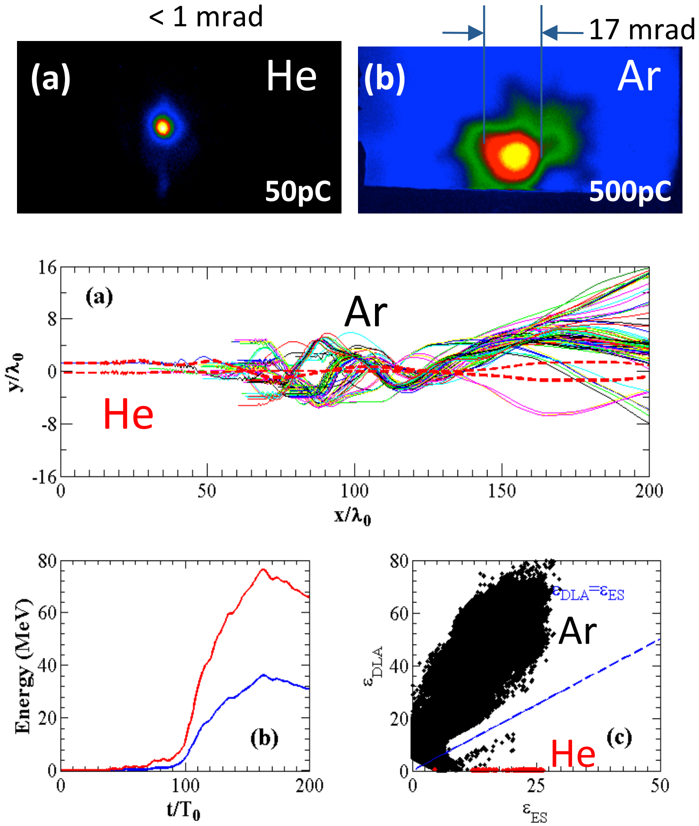




Betatron enhancement using cluster target

L. M. Chen. Sci. Reports 3, 1912(2013)   **IOP**

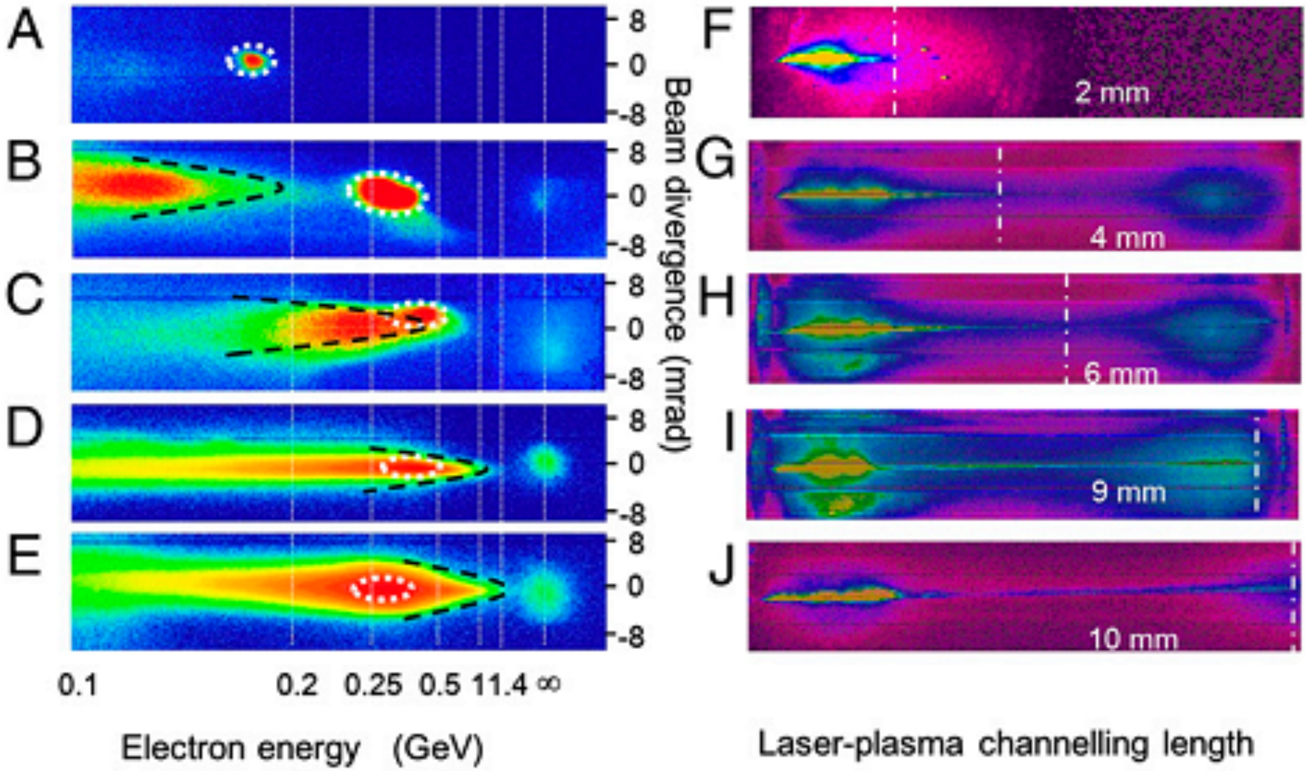


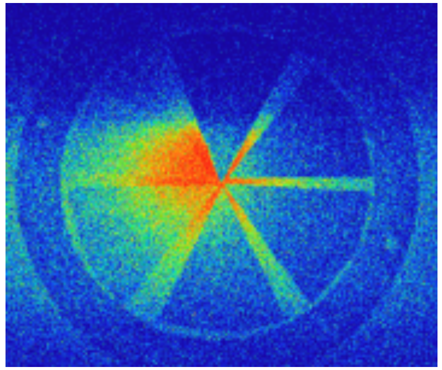


3TW laser through DLA to generate 2*10^8 X ray photons

Strong Betatron enhancement due to the second injection in LWFA

Yan, Chen*, PNAS 111, 5825 (2014) **IOP/LLNL**





Single shot image

Betatron E_{cri}= 15 keV

Photon = 4.5×10^{8}

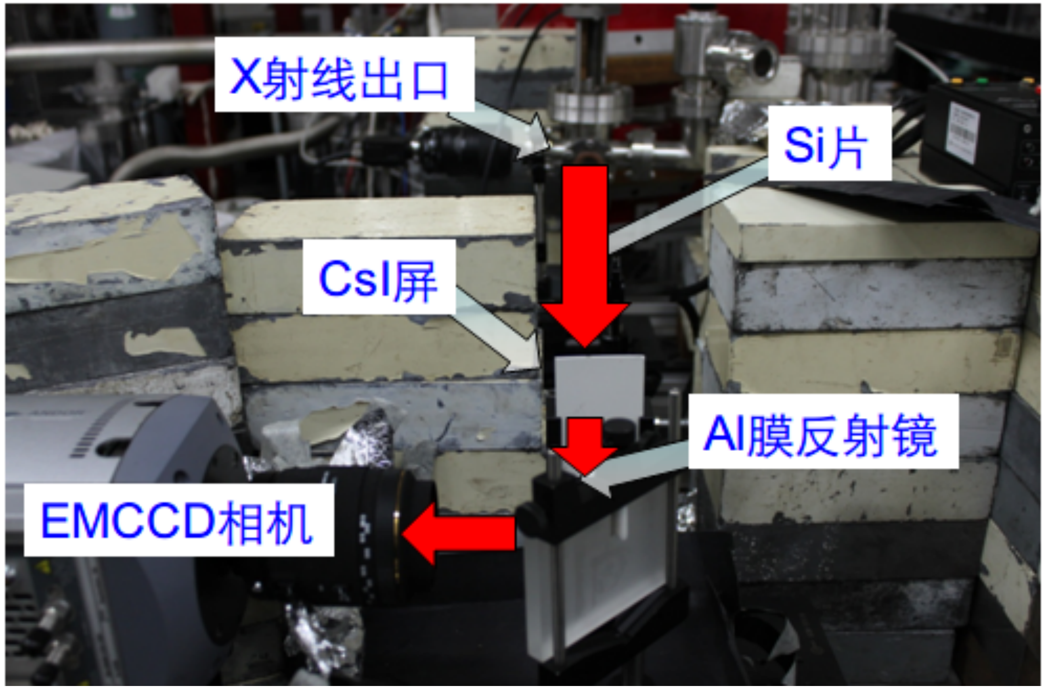
Divergence = 6 mrad

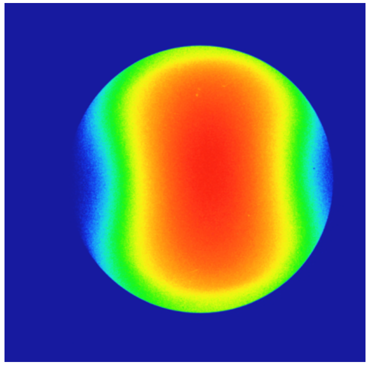
Size=4 μm

Duration=10 fs

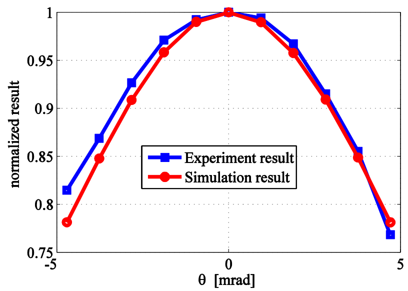
Thomson/Compton source

China (Tsinghua TTX)

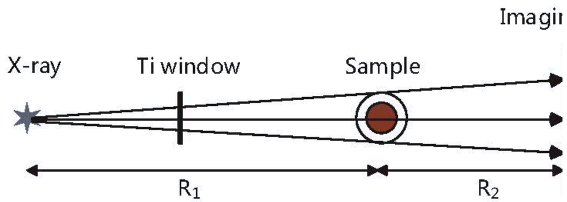


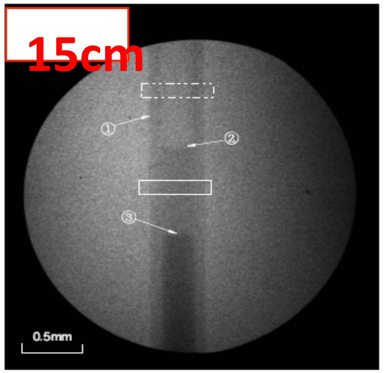


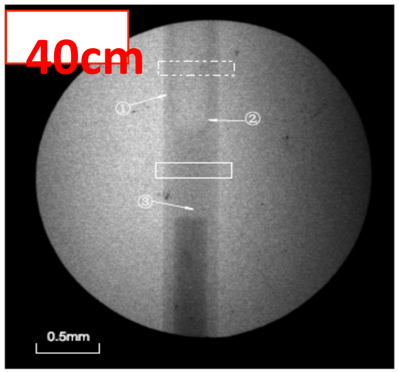
X-ray profile

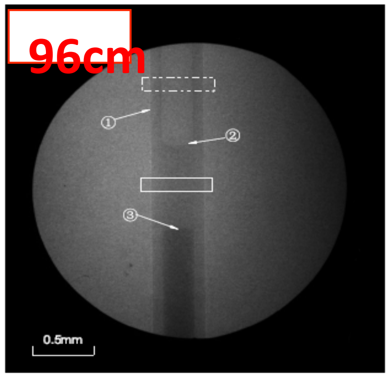


Phase Contrast Image









Powerful Terahertz Radiation from Relativistic Plasmas

Plasmas:

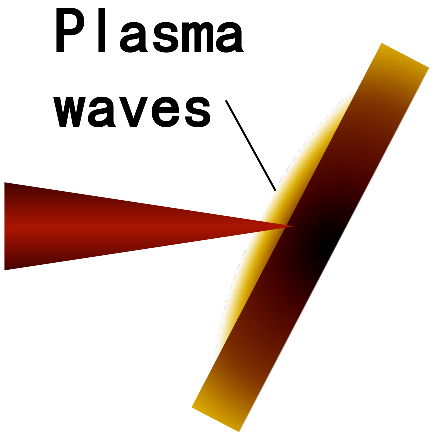
- no damage limit/ Arbitrarily high laser intensity

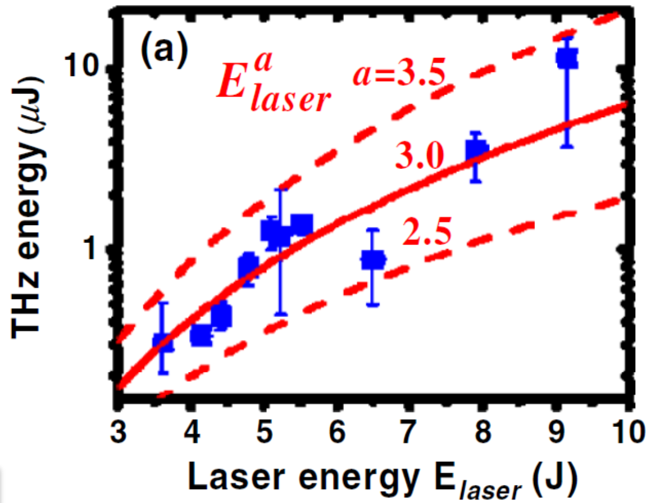
IOP

Laser waves → **Plasma waves** → **THz waves**

- **Wakefield**
- **Stimulated Raman Scattering (SRS)**

Linear Mode Conversion (LMC)



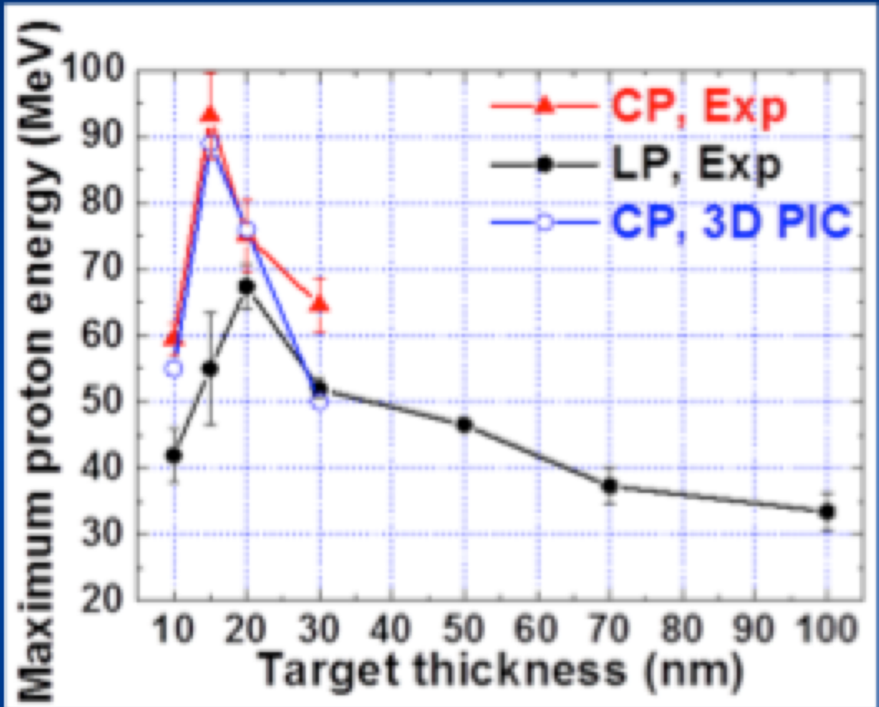


>0.24 mJ/sr

PRL 114, 255001 (2015)

Radiation pressure acceleration of protons with CP PW laser

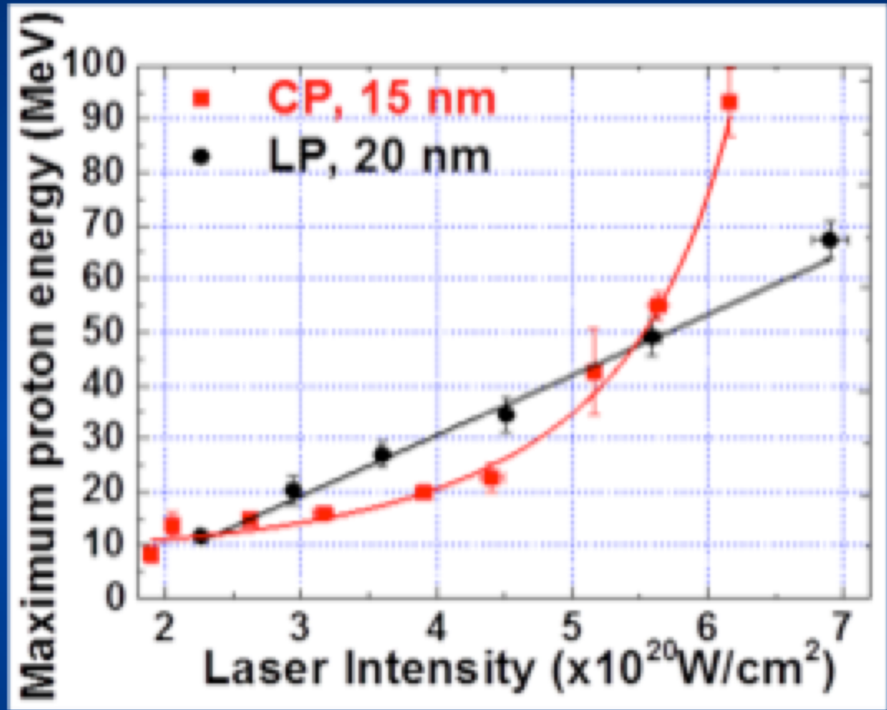
Optimization of target thickness ♪



Target: polymer
Laser polarization: circular or linear♪

$a_o = \pi\sigma = \pi\,(n_e/n_c)\cdot(d/\lambda)$ = 15 nm ♪

Maximum energy scaling ♪



quadratic energy scaling for CP

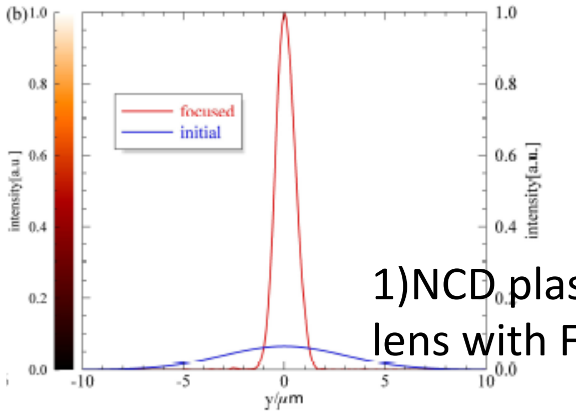
⇩

generation of 93-MeV proton beams ♪

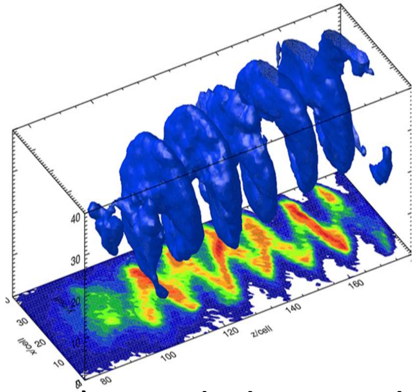
I J. Kim et al. arXiv:1411:5734 (2014)

ibS CoReLS GIST

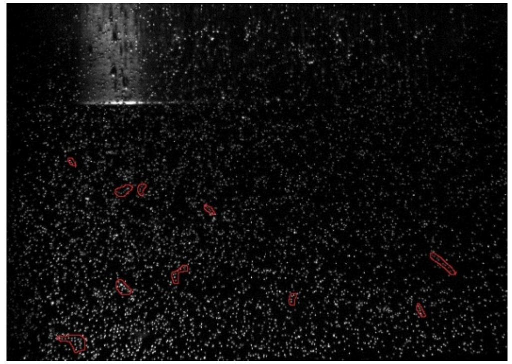
NCD Plasma lens for particle acceleration &&radiation



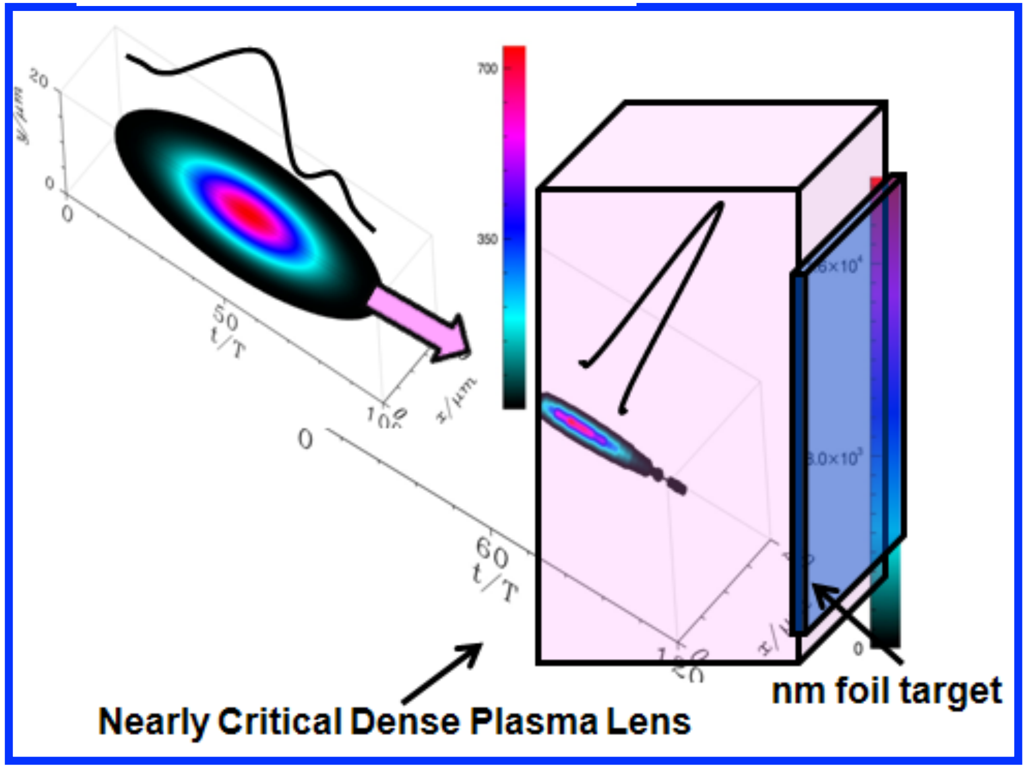
1)NCD plasma lens with F<2

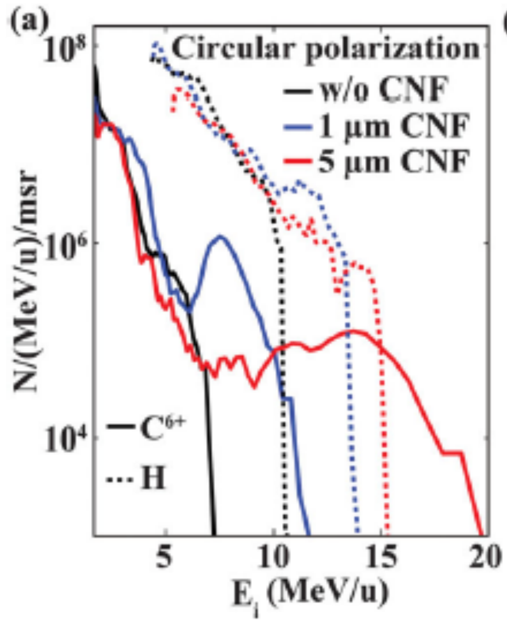


2) spiral electron beam



3)γ beam ~3MeV



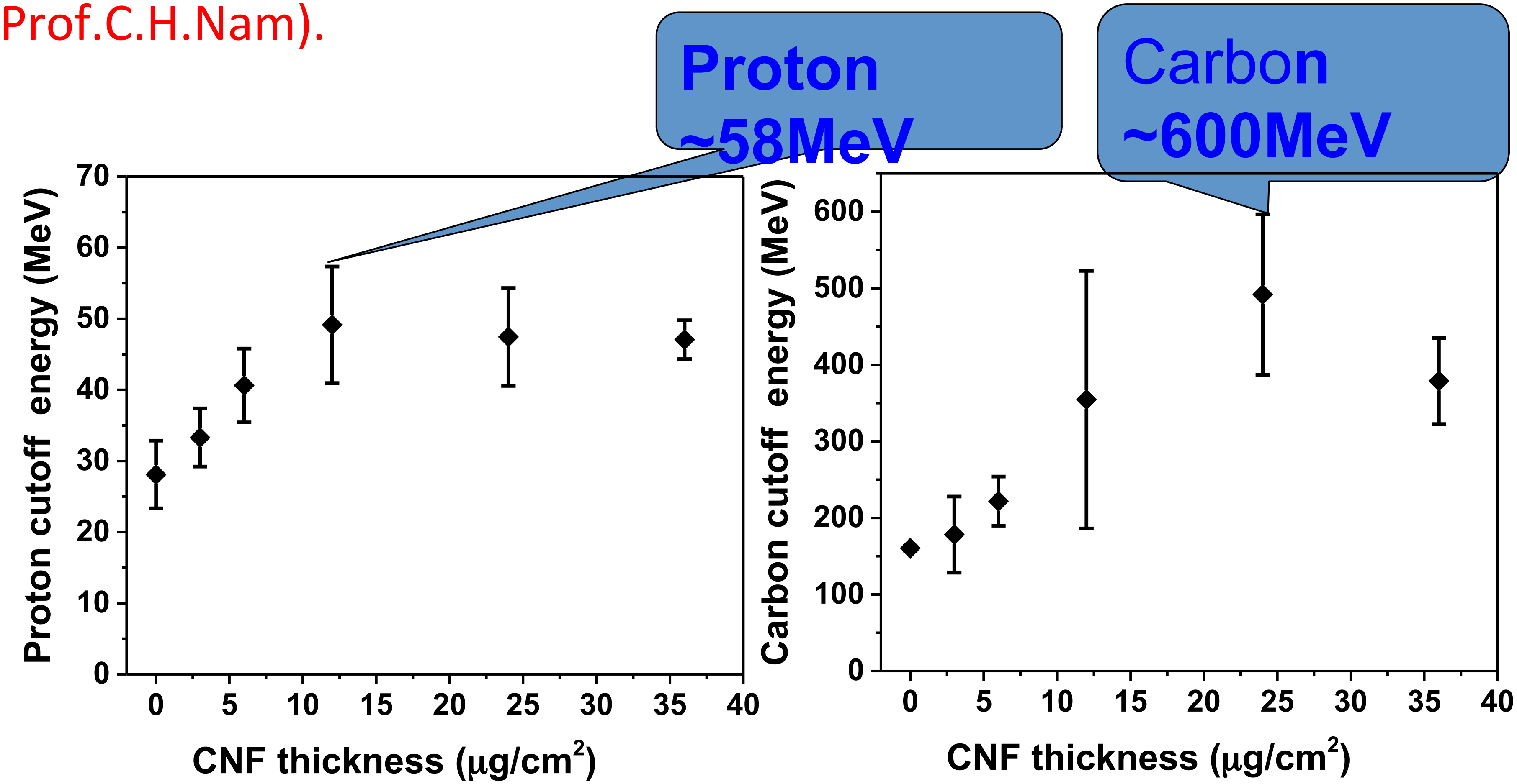


4) C6+ from 70MeV to 220MeV
Demonstrated by LMU/PKU/Jena

PRL107, 265002 (2011); 110, 045002 (2013); 115, 064801, 2015; PoP, 20, 013101 (2013); PoP22, 080704 (2015)

Carbon Nano-Tube (as NCD lens) + DLC foil

Experiments were performed using the CoReLS PW Laser in Korea (Prof.C.H.Nam).

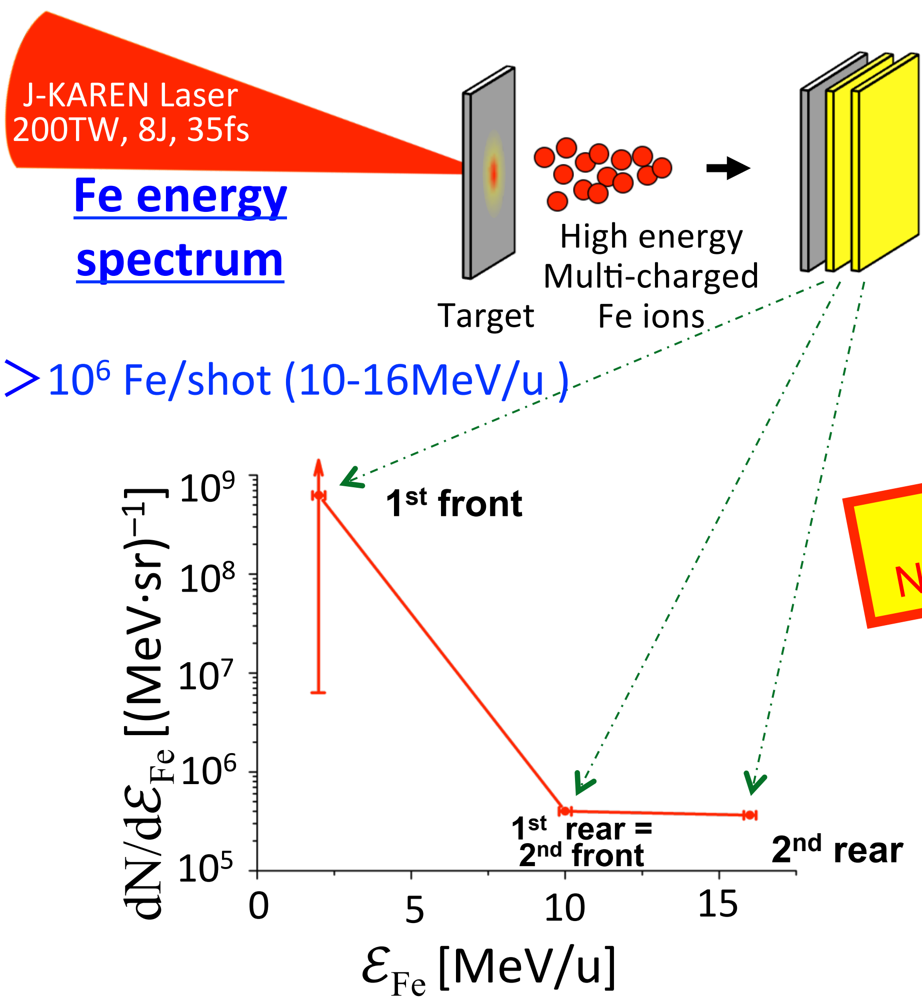


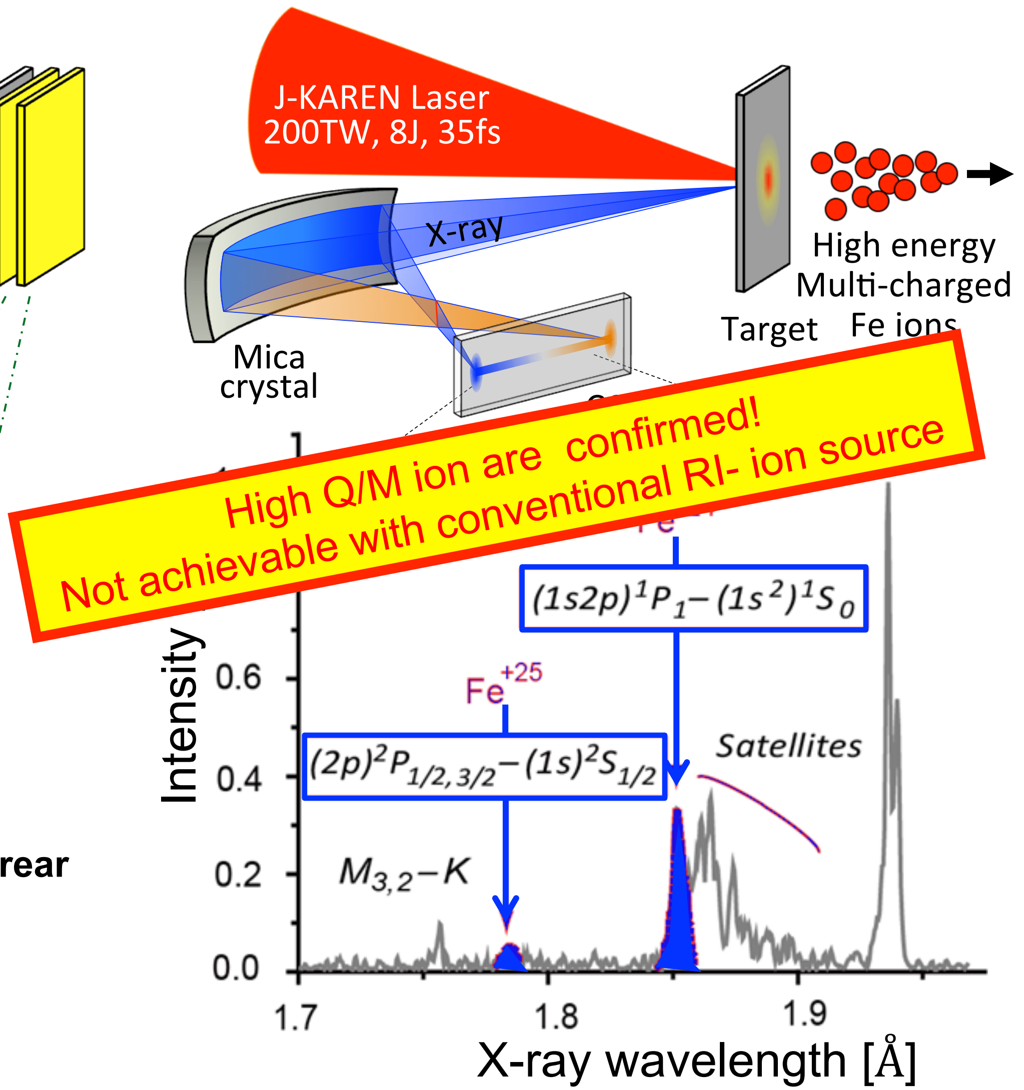
Cutoff energy of protons/carbons for linear polarization

By Yan, Ma, Lin, Schreiber, Zepf, Kim && Nam et al.,

See Wenjun Ma's Talk

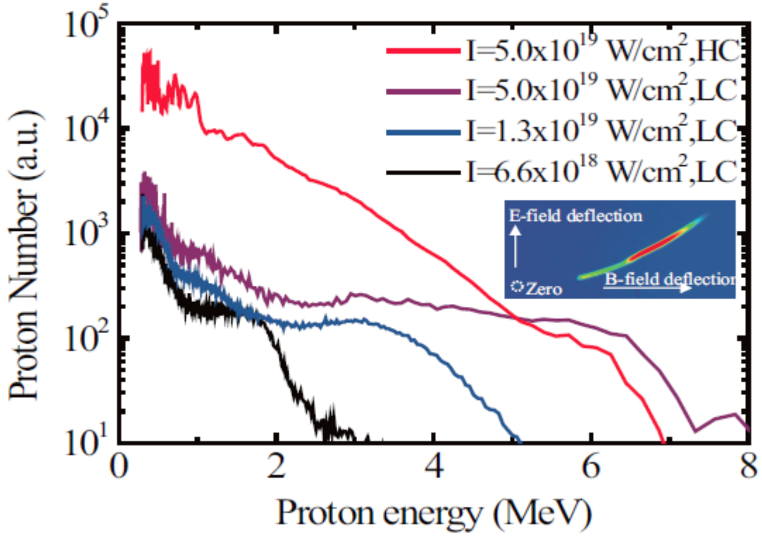
Fully-stripped Fe ion generation





M. Nishiuchi et al., Rev. Sci. Instrum. **85**, 02B904 (2014)
M.Nishiuchi et al., PoP **22** 033107 (2015)

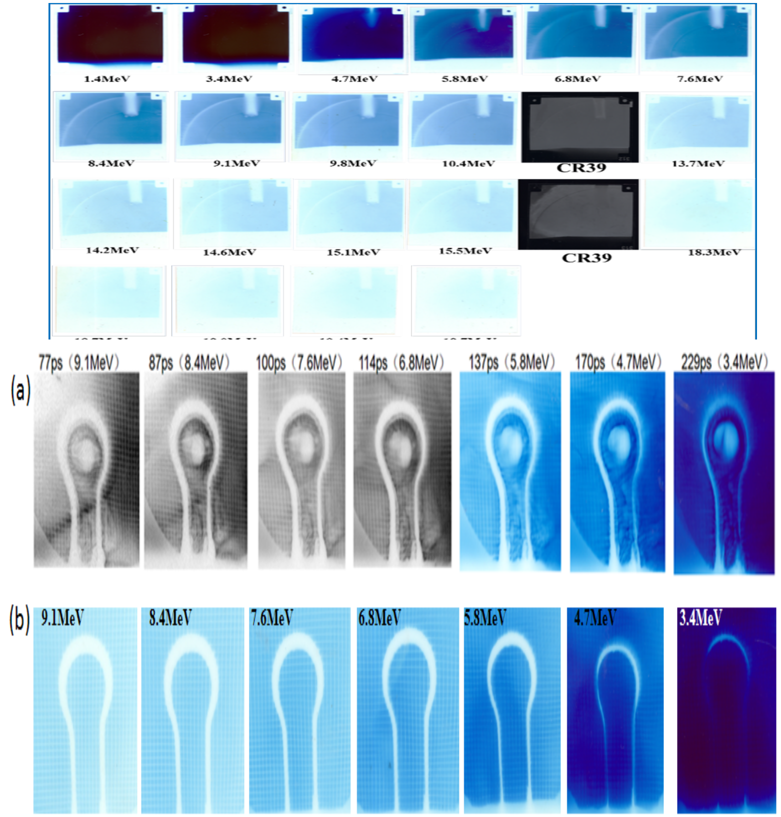
SJTU



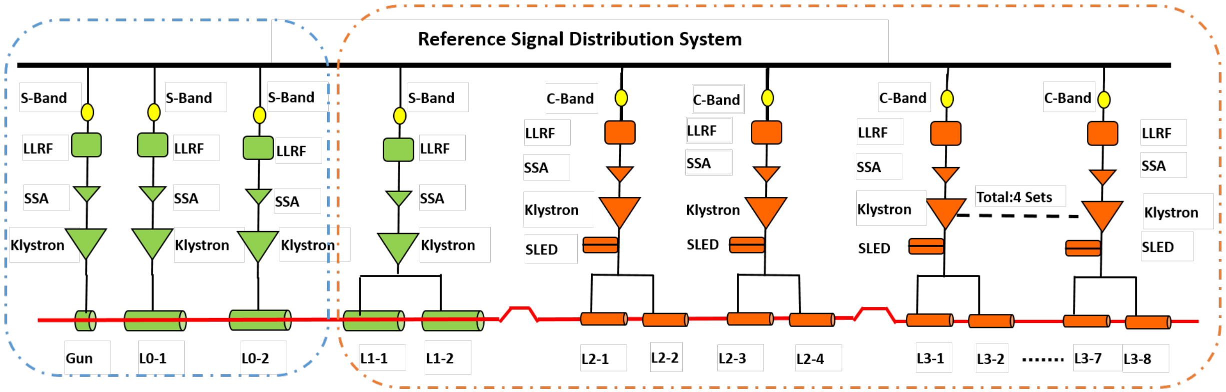
Ion energy spectra with plateau profiles: evidence of collisionless shock wave acceleration (submitted)

LFRC

20MeV (TNSA) proton imaging



C-band R&D for SXFEL at SINAP

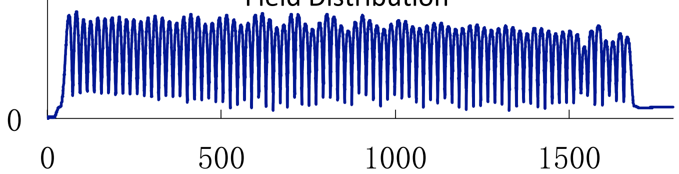


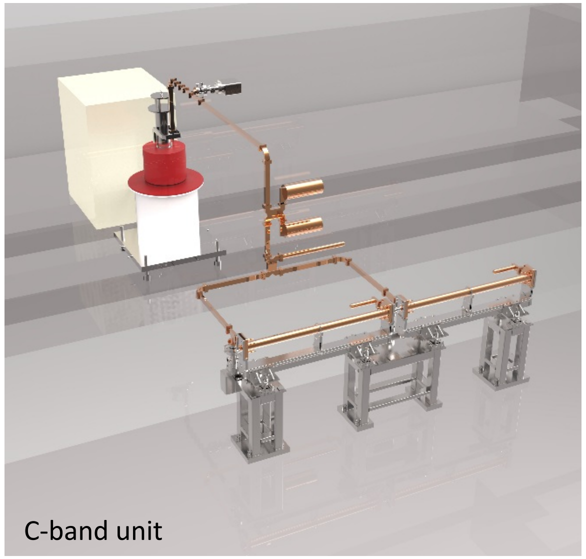
Injector

Linac

1. 40MV/m gradient
2. 6 sets C-band units for SXFEL
3. 12 C-band accelerating structures.
4. 6 pulse compressors
5. High amplitude and phase stability, 0.04% and 0.18 degree
6. Beam energy from 200MeV to 840MeV.

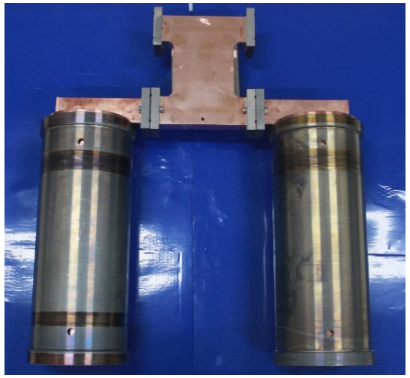
Field Distribution

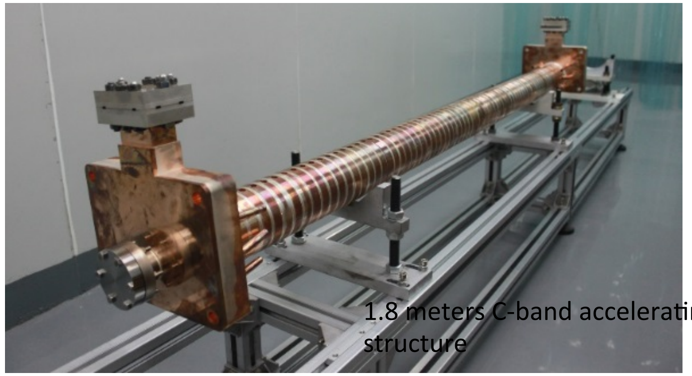




C-band unit

Pulse compressor



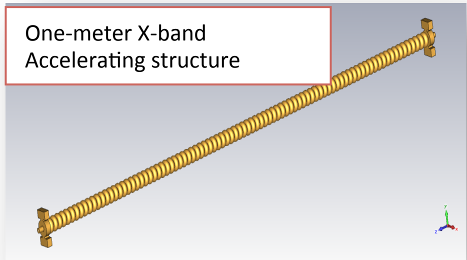


1.8 meters C-band accelerating structure

X-band plan at SINAP

1. Specific one-meter X-band accelerating structure has been designed and optimized for FEL, and one X-band deflecting cavity has been carried out at SINAP, and it's important beginning for X-band accelerating structure plan.
2. X-band RF unit based on 50MW klystron is also proposed for X-band Accelerator Test Facility (XATF) at SINAP, which gradient target is about 80MV/m.
3. The XATF at SINAP is the key plan in the future, and 80MV/m gradient and beam test will be verified in this facility, and many key parameters will be tested.

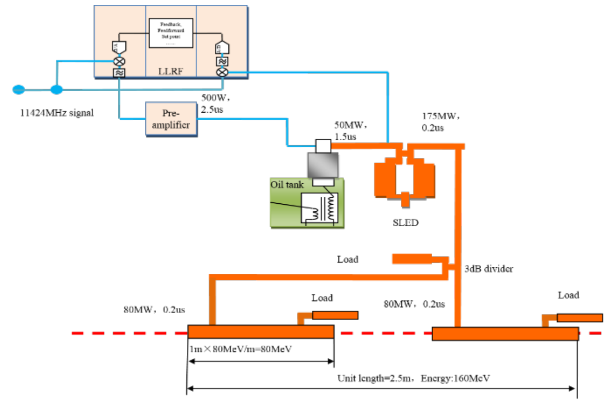
X-band deflecting cavity

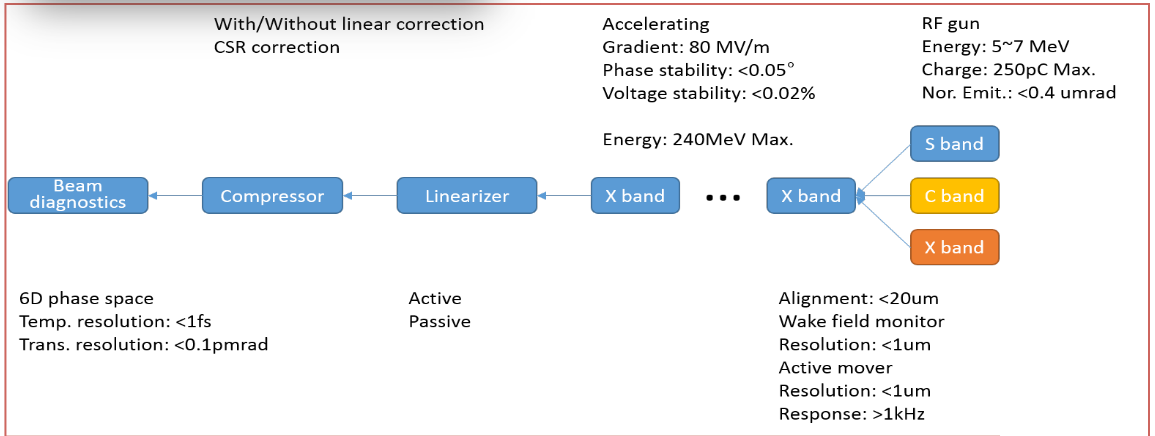


One-meter X-band Accelerating structure

Frequency	11424MHz
Phase advance	4π/5
Cell No.	89+2
Effective length	944.73mm
Cell length, d	10.497mm
Iris thickness, 2a	1.5 mm
Ratio of elliptic radius, b_a	1.8
Aperture, a_r	4.3~3.05.mm
Group velocity, Vg/c	3.45%~1.12%
Shunt impedance, R	86.7~108.7MΩ/m
Attenuation factor, τ	0.61
Filling time, t_f	150 ns
Sc	4.14~2.33 MW/mm^2
Emax/E0	2.68~2.02
Hmax/E0	2.68~2.39 mA/V
Input power, P_{in}	52MW @65MV/m 80MW @80MV/m

X-band unit proposal for 80MV/m





X-band Accelerator Test Facility plan at SINAP

Future Perspective

- The AAC community in Asia is growing fast! Many institutes invest heavily into this area

- The quality of the work is getting better and better, and there will be more leading results from Asia in the future

- More work will focus on how to build an accelerator: using the language of accelerator physics,such as phase space, matching ……

- It is an exciting time for AAC community, Asia as well

Thank you for your attention!