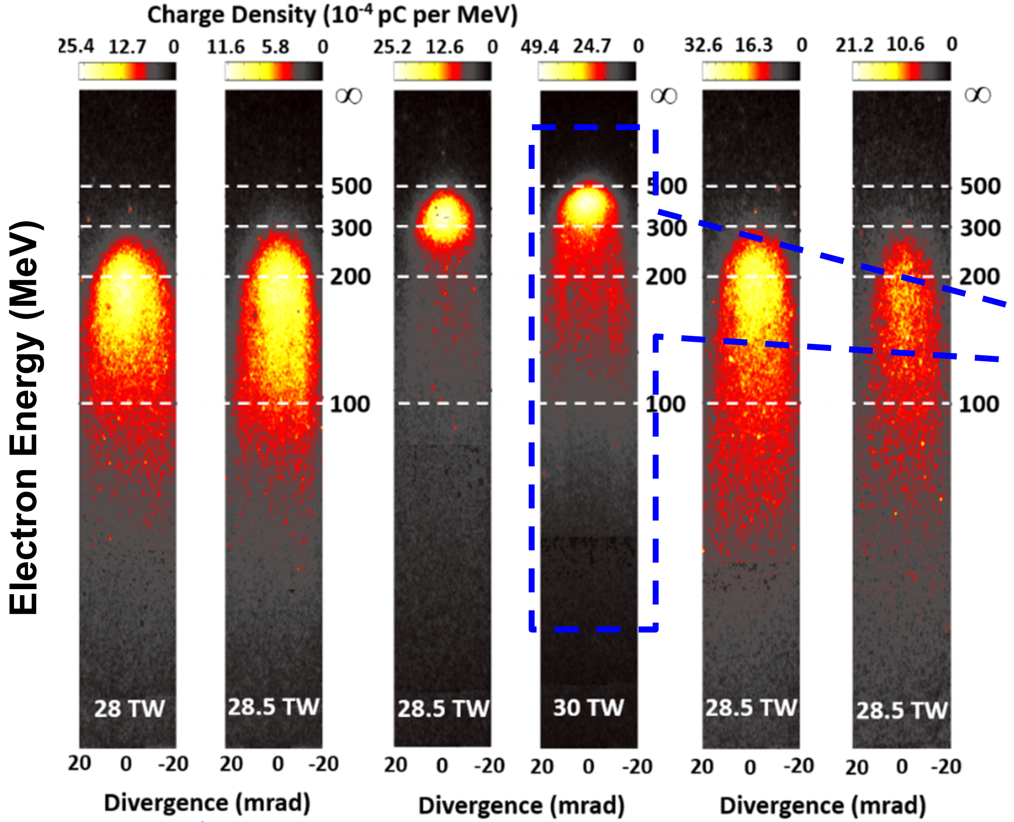
WG4 : Innovative Accelerator Techniques

Number of talks : 12
- China : 2
- Japan : 2
- Taiwan : 1
- Korea : 7

Main Research Subjects
- Electron acceleration
- Ion acceleration
- Radiations

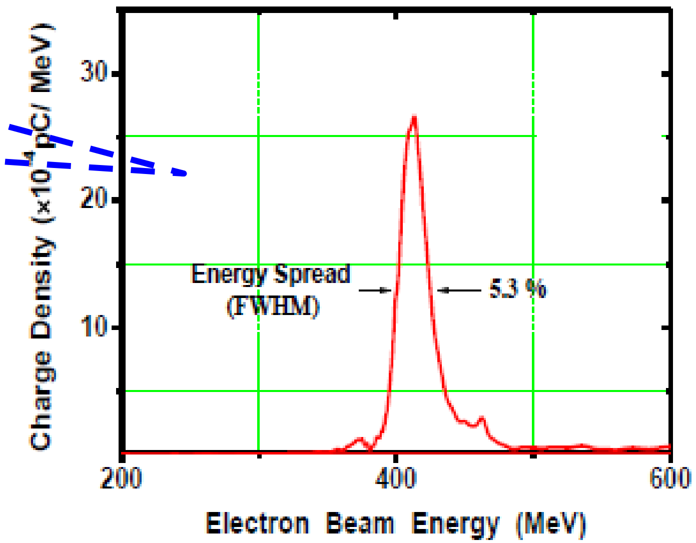
上海交通大學 Controlling energy-spread via the N_2 concentration

He+0.3%N_2 He+0.5%N_2 He+1%N_2



30 TW & 4 mm-long gas jet

Single stage



Self-injection dominates

Optimum ionization injection

nitrogen is too much

Li, Hafz* Opt. Express 22, 29578 (2014)

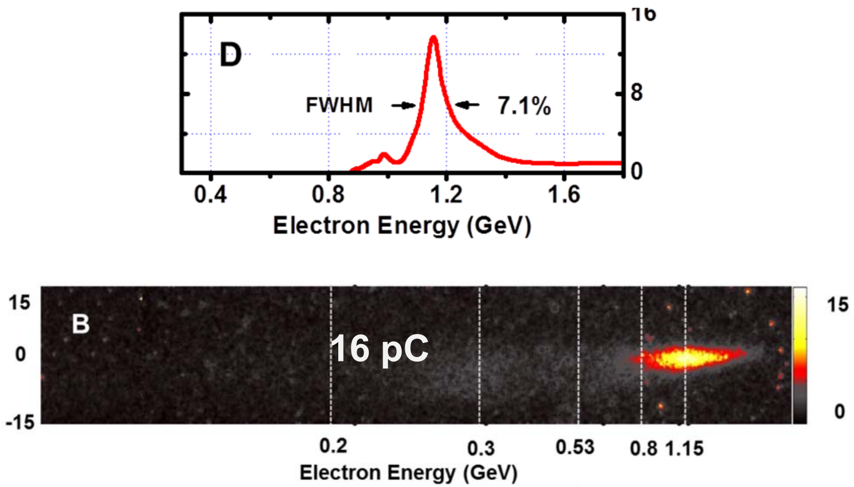
Mirzaie, Li, Hafz* et al., Scientific Reports 5, 14659 (2015)

Demonstration of STII for GeV electron beams

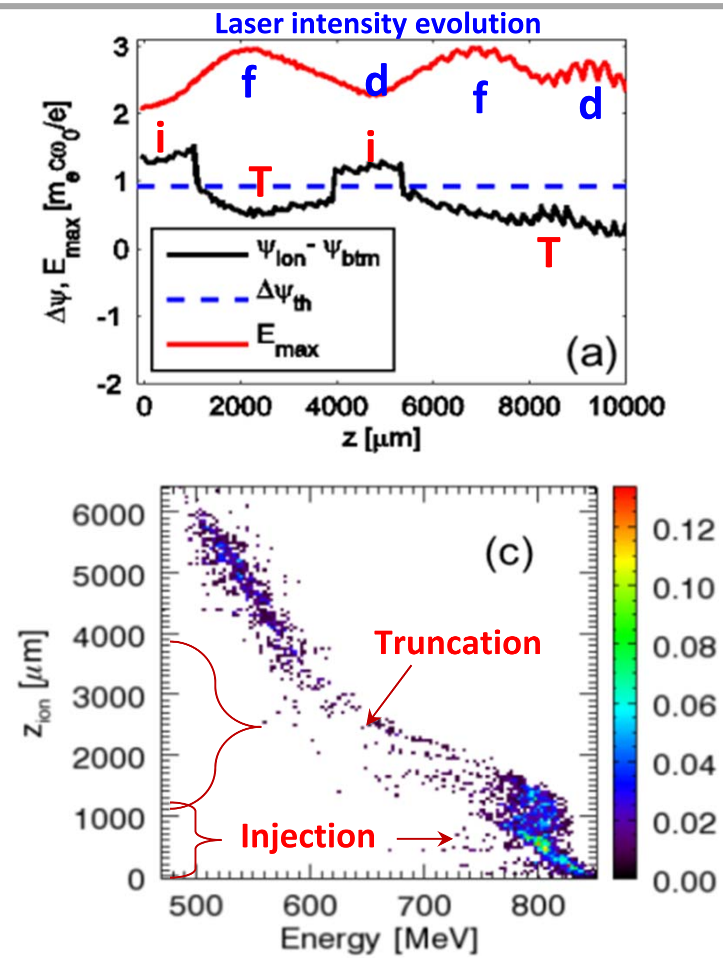
118 TW & 1 cm gas jet | **Single stage**

Experimental results

Ionization-injection in He+0.3% N_2



2D–PIC-Simulations



Li, Hafz* Opt. Express 22, 29578 (2014)

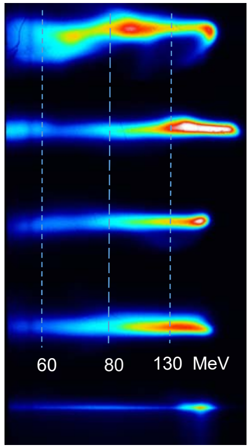
Mirzaie, Hafz* Scientific Reports 5, 14659 (2015)

STII: self-truncated ionization injection

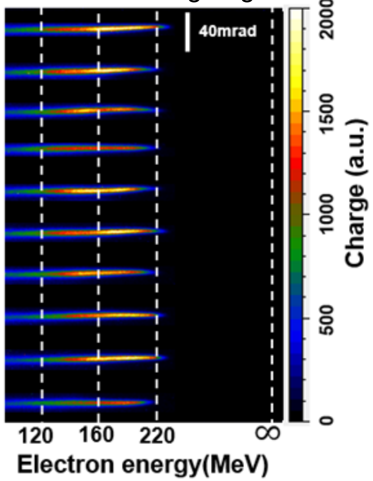
IHEP

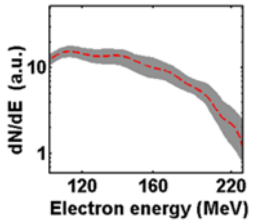
Stable electrons and application on 20TW laser at IOP, CAS

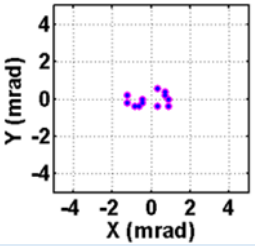
Pure Helium gas



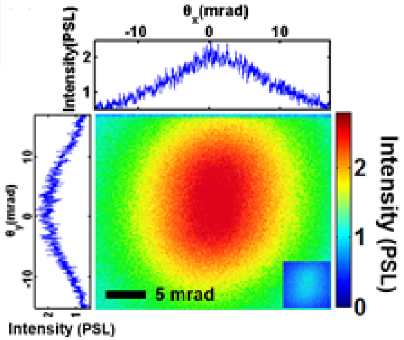
Pure Nitrogen gas

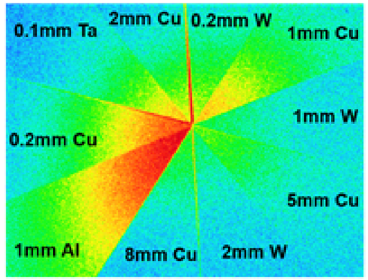


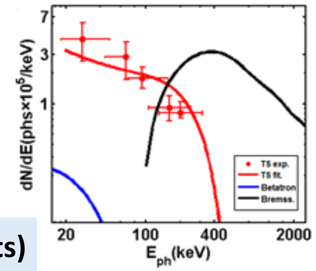


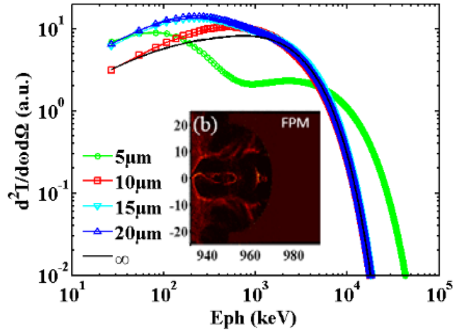


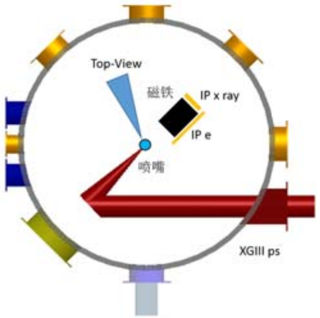
Divergence: **5.0 mrad** Pointing: **0.5 mrad (30 shots)**











SILEX-III @ Mianyang: 100J/1ps

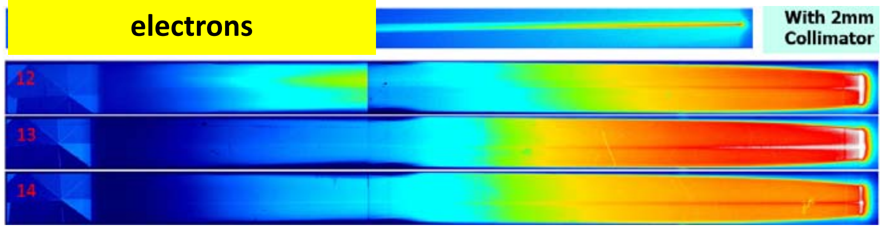
Well collimated electrons

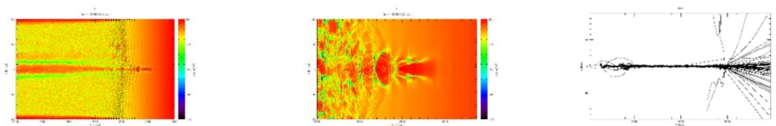
1Mpa N_2

1Mpa N_2

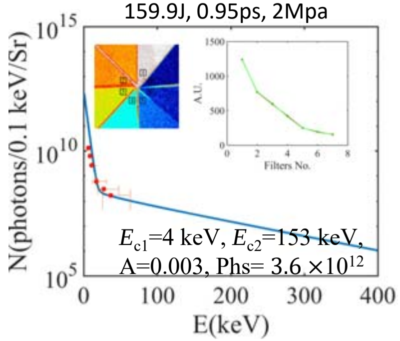
2Mpa N_2

3Mpa N_2



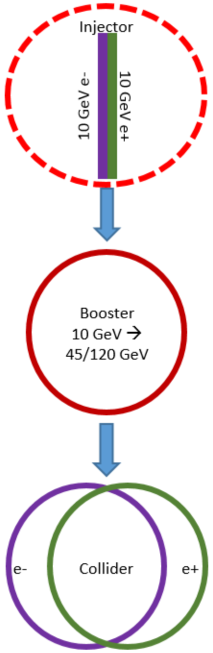


159.9J, 0.95ps, 2Mpa

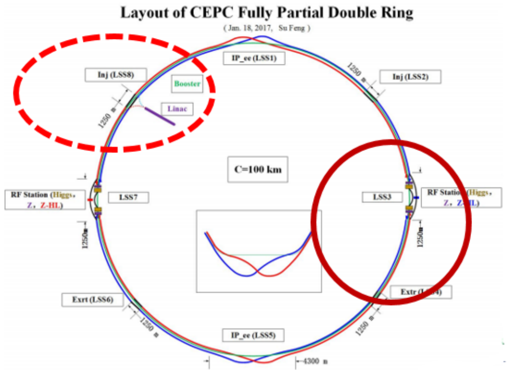


IHEP

Plasma-based CEPC Injector design (collaborated with Dr. Wei Lu's team in Tsinghua Univ.



CEPC Conceptual Design

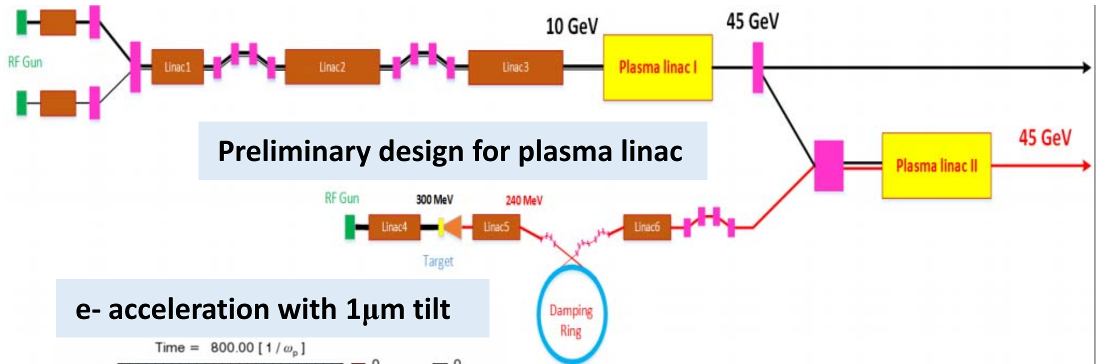


CEPC Baseline Design

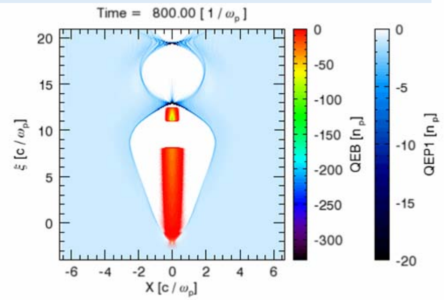
Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost

Booster ring may have low field problems due to extremely large energy increase.

Add a several meters plasma linac between original linac and booster ring



e- acceleration with 1μm tilt

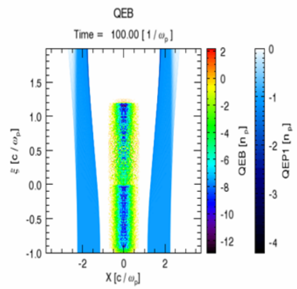


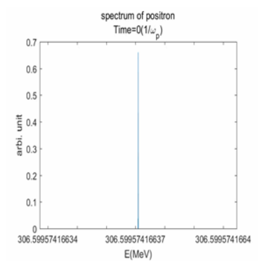
E_{driver}	$10GeV$
$E_{trailor}$	$2GeV \rightarrow 40.5GeV$
TR	3.8
Energy spread	1.8%
efficiency	58.8%

e+ acceleration

Output parameters

Trailor energy $E_t(GeV)$	45.5
Trailor normalized emittance $\epsilon_{nt}(mm\,mrad)$	100
TR	1
Energy spread $\delta_E(\%)$	1.3
Efficiency (driver -> trailor)	46.9%





KEK Project1: Overall Configuration @ LWFA Platform

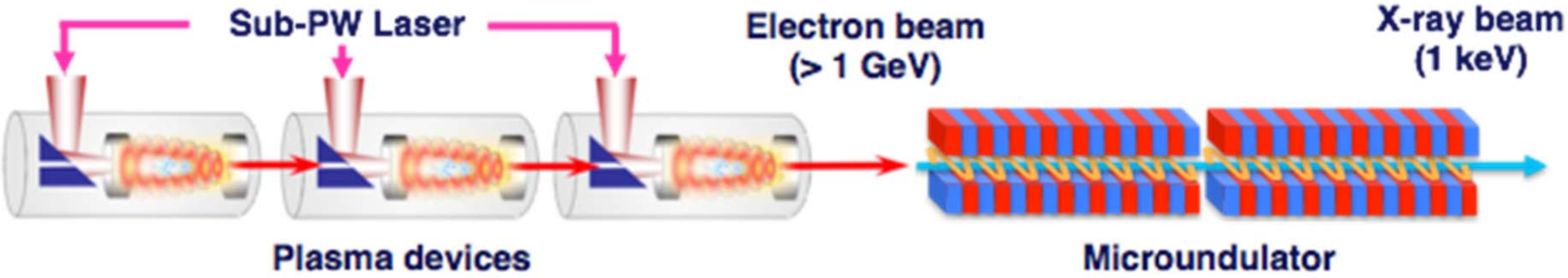
- Development of elemental technologies for future laser-driven XFEL -

PM: Yuji Sano
JST, TOSHIBA Corp.

Repeatable laser-driven GeV-class accelerator.

Criteria：Acc.length < 10cm、Energy Gain >1GeV,　Energy Spread <1%, beam divergence <1 mm-mrad、Pulse duration ~10fs

Project 1B: Integrated platform for laser acceleration
Issue: Multi-stage acceleration and generation of 1 keV X-ray beam by a microundulator with a length of 10 m or less/platform development



Project 1A: Laser acceleration elemental technologies
Issue: Electron acceleration exceeding 1 GeV and modularize it as a plasma device

Project 1D: Beam measurement and control
Issue: Control of laser and electrons, and injection of electron to undulator

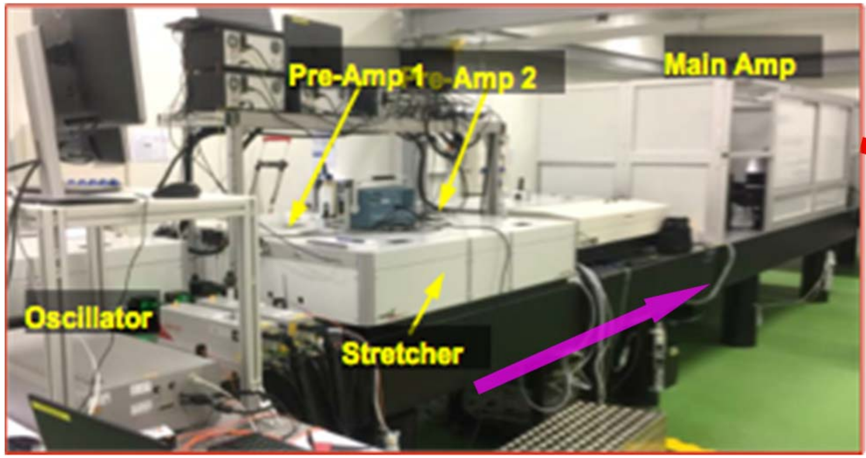
Project 3J: XFEL demonstration assessment
Issue: User demonstrations of laser acceleration XFEL.

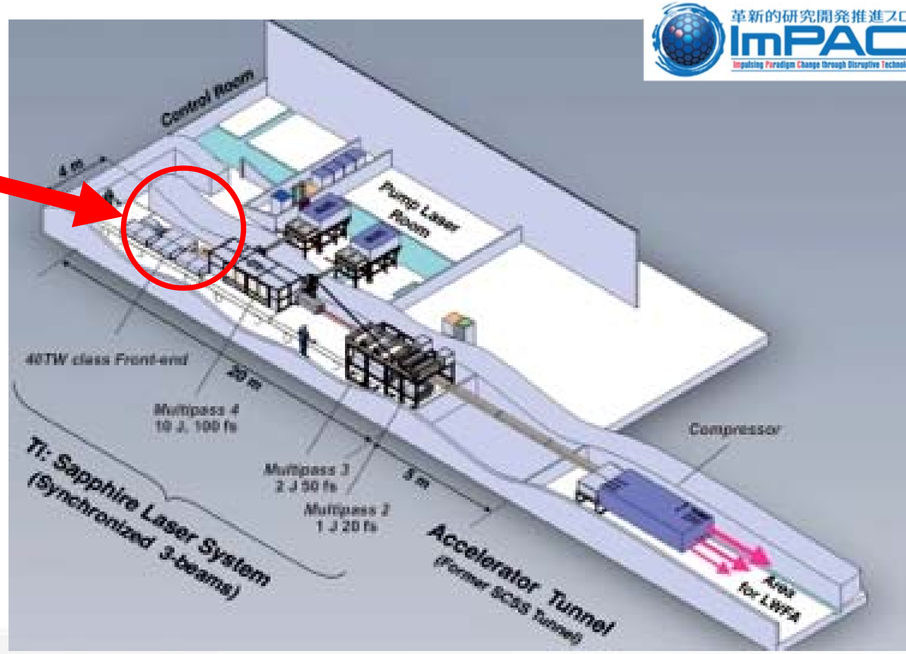
Project 1C: Microundulator
Issue: Ultra-compact undulatory generating 1 keV X-ray beam

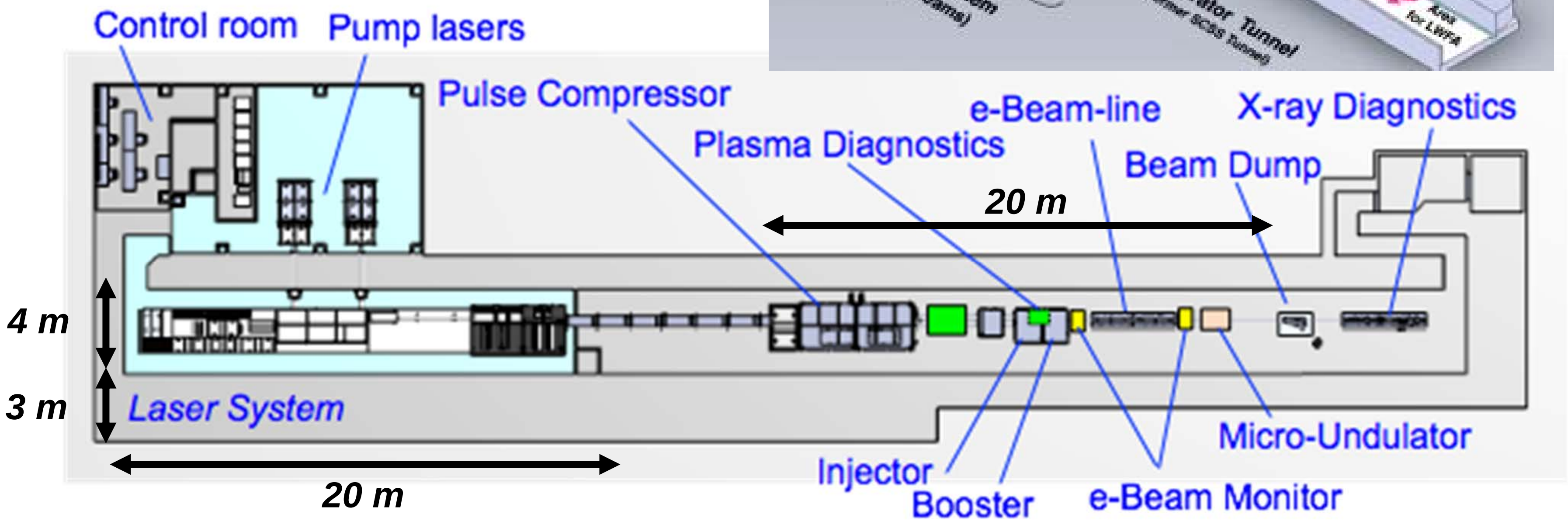
Project 3L: Evaluation of Microundulator

平成 29 年度レーザー核融合とレーザー加速研究会2018年 月15～16日@光産業創成大学院大学

KEK LWFA Platform Laser & Acc Tunnel @ SPring-8 Campus





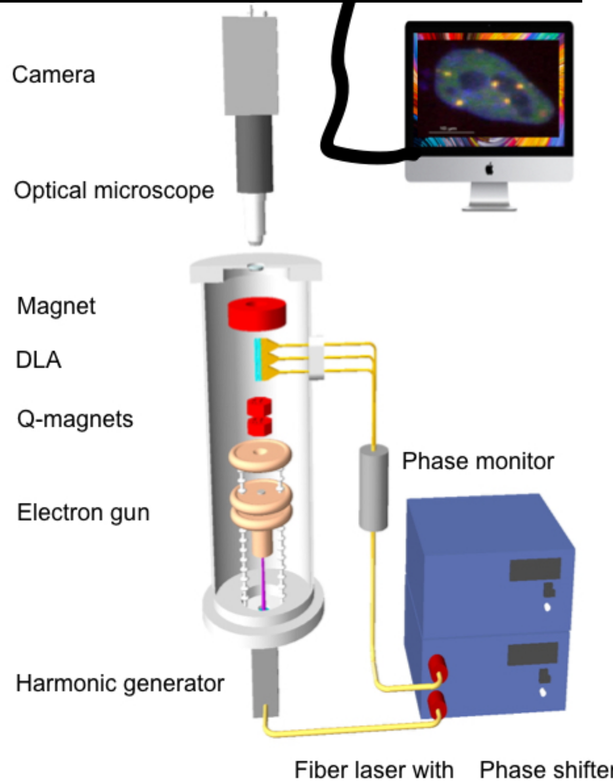


KEK Application of DLA to the radiotionbiology research

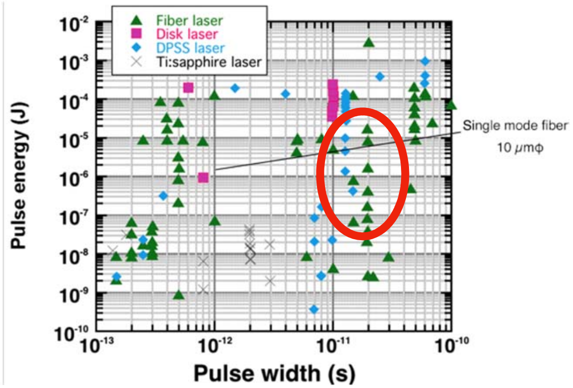
A tabletop micro-beam machine makes it possible to irradiate a target site in a living cell.

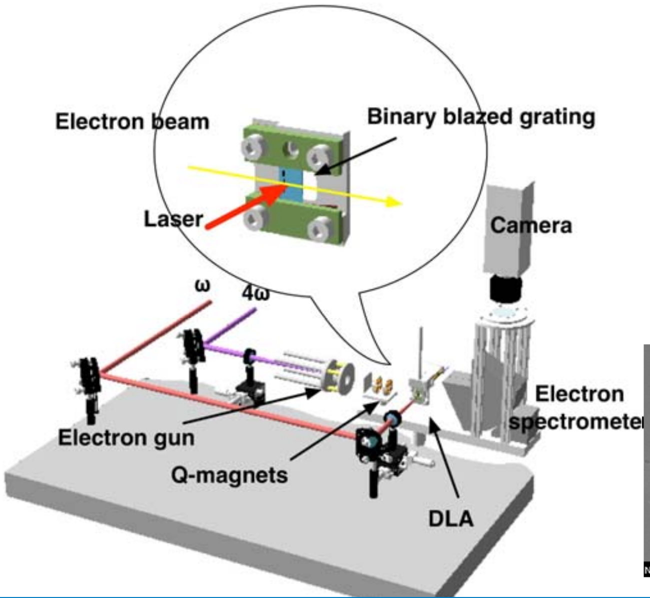
>100 electrons
A few MeV energy

Concept view of the microbes system

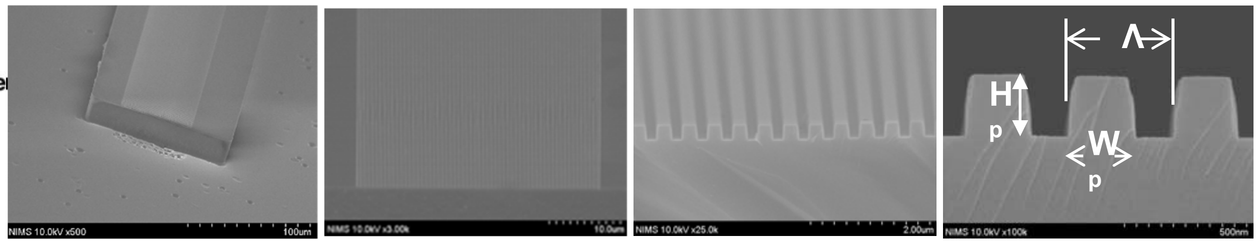


The DLA with high Q resonator enables to realize a compact system.





Grating for the experiment



NTHU

Dielectric laser accelerator (DLA) - accelerator on a chip (ACHIP)

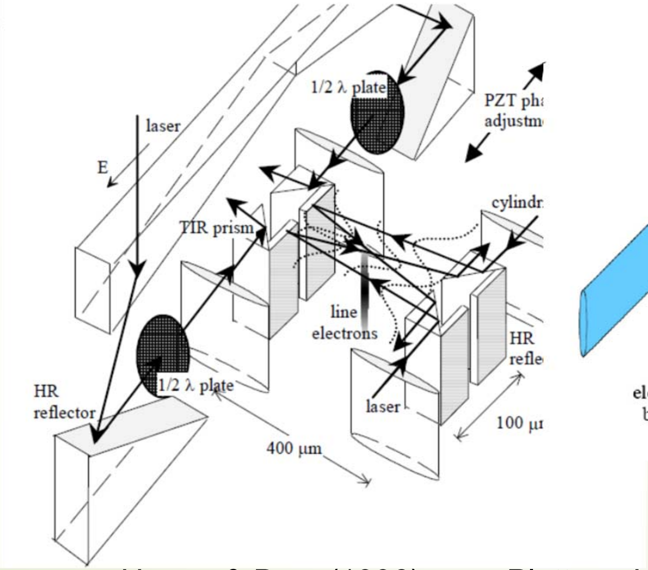
(laser wavelength ~ 1 μm)

$$E_{//} \approx \frac{-j}{k} \nabla_{\perp} E_{\perp} \sim 1\,\mathrm{GV/m}$$

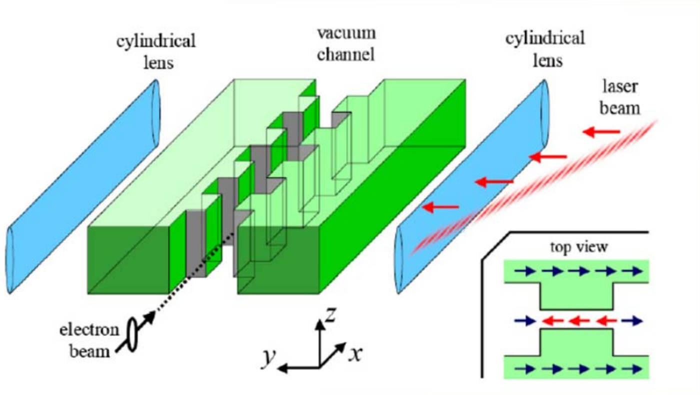
1. Solid state → **stable**

2. High damage field on dielectric and thus high acceleration gradient (up to ~ GeV/m)

3. Fabrication compatible to semiconductor lithographic patterning technique



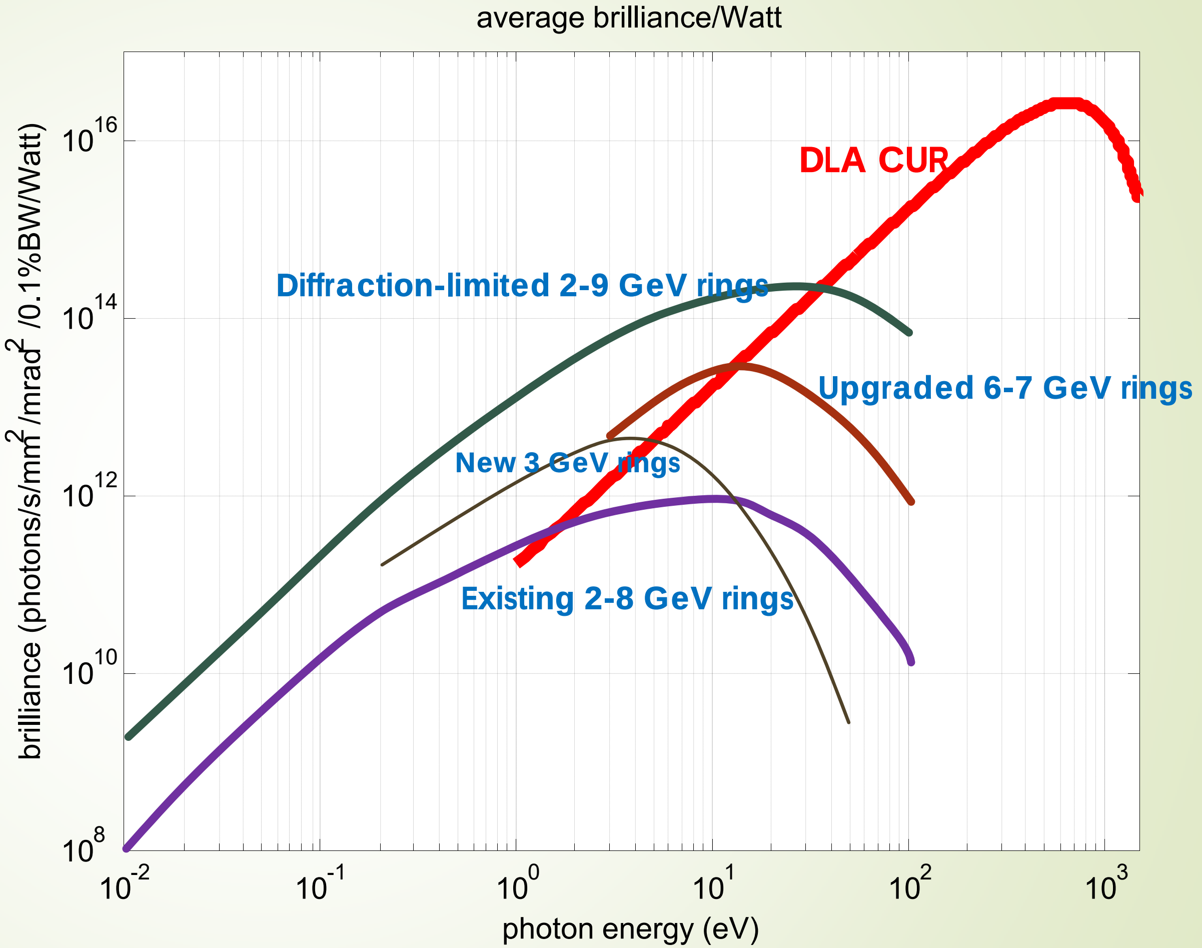
Huang & Byer (1996)



Plettner, Lu, Byer, Phy. Rev. ST AB 9, 111301 (2006)

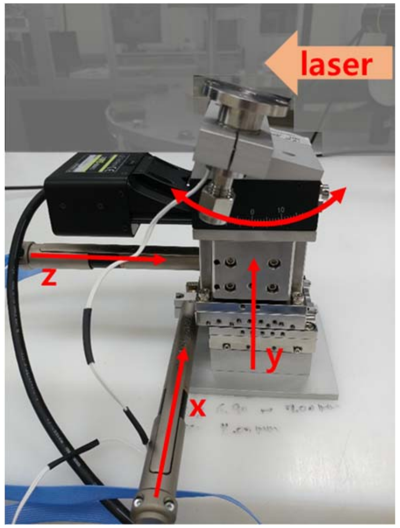
NTHU

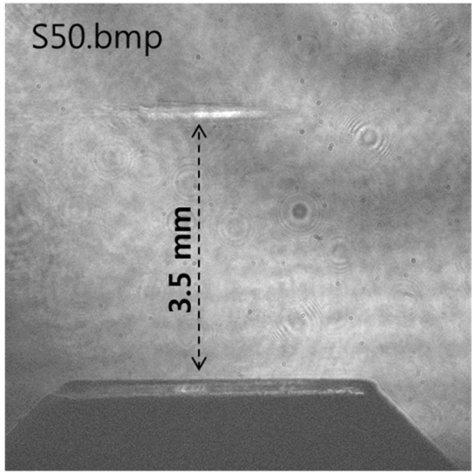
Normalized to average beam power (DLA average beam power is much smaller)

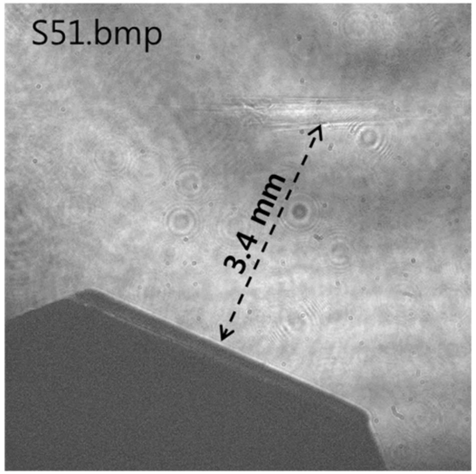


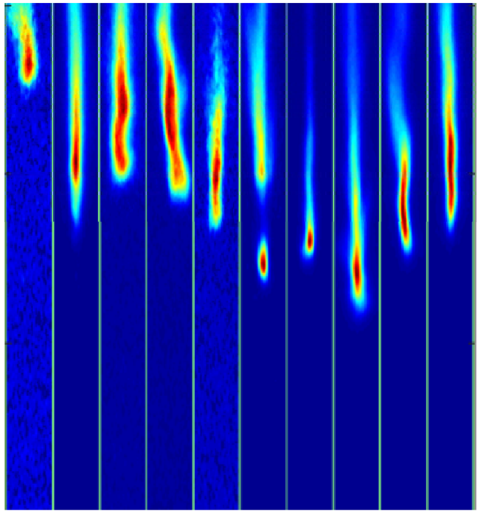
*Curves other than DLA CUR are adapted from Zirong Huang, SLAC-PUB-15449.

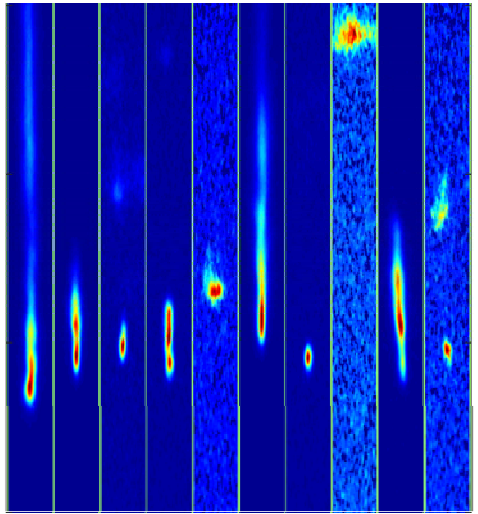
Beam from tapered density











Energy enhancement by the tapered density

Parallel nozzle : 140 MeV

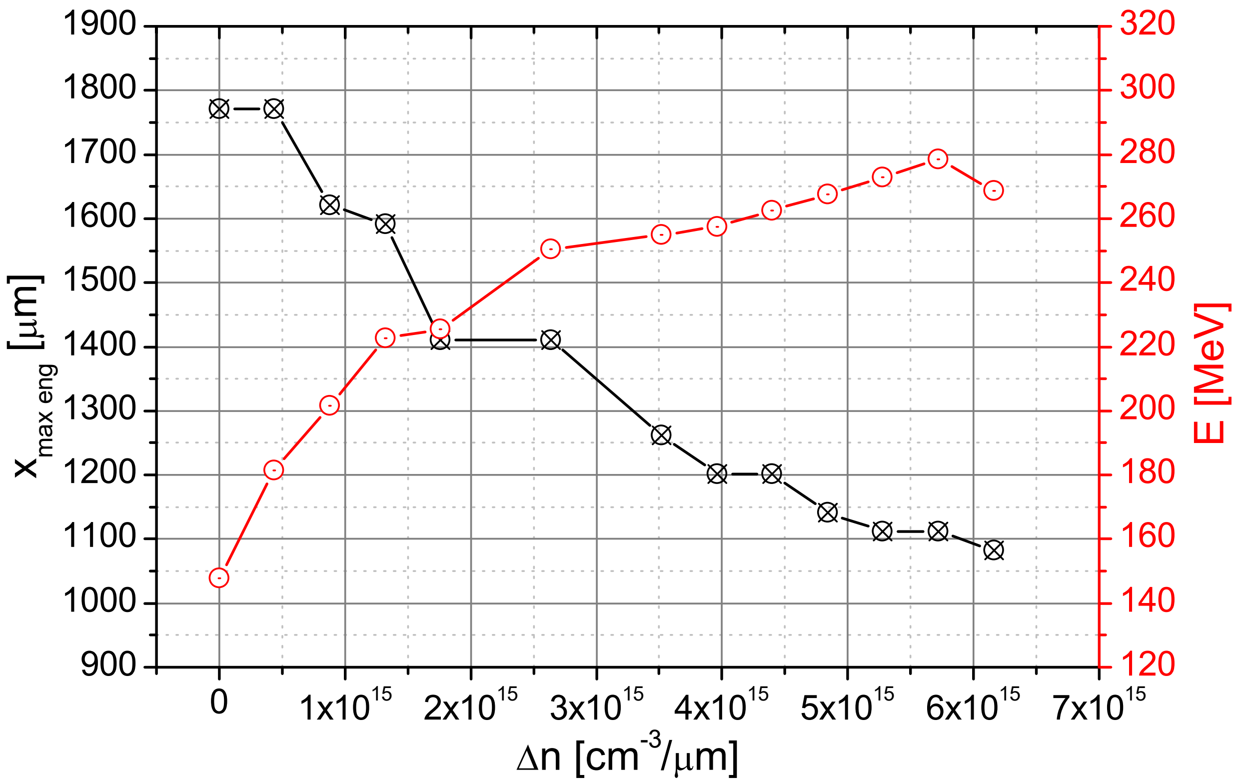
Tilted nozzle : 210 MeV

(calculated maximum energy

For parallel : 148 MeV,

tilted : 279 MeV)

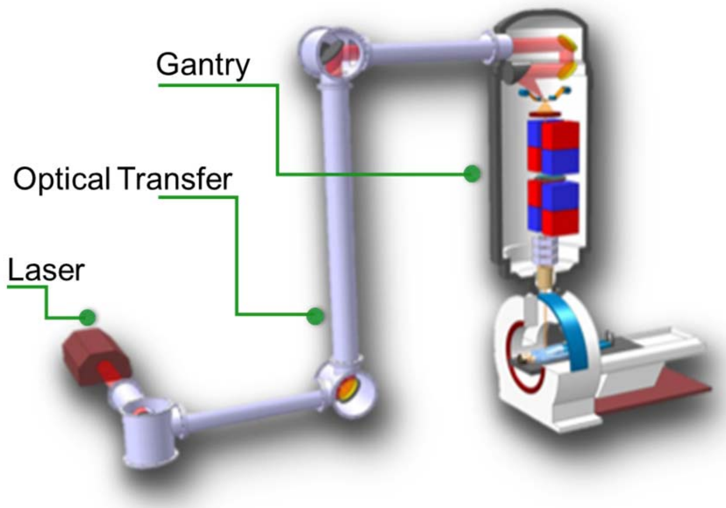
KERI Energy with linear upward density ramp



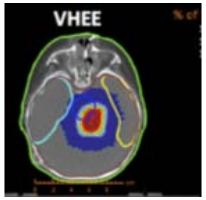
	uniform	$\Delta n = 5.7\times10^{15}$ ㎝$^{-3}$/㎛	
Acc. Length [㎛]	1771	1112	63 %
Max. energy [MeV]	148	279	187 %

Laser-Plasma Acceleration: Applications

Cancer Therapy

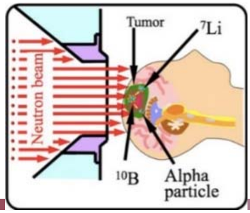


50 TW Laser system
Protons – ILEF target
Electrons – Gas or Metal target

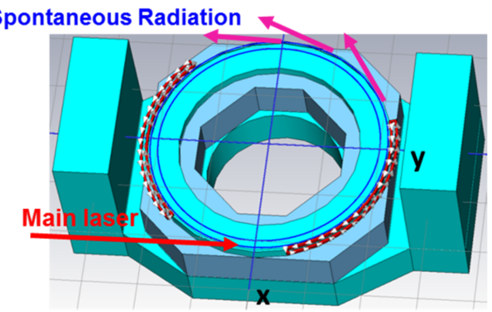


High Energy Electron Beam Therapy:
50 – 250 MeV Electrons

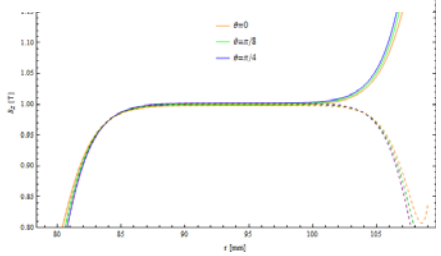
Boron Neutron Capture Therapy:
Epithermal neutrons + Boron :
Proton → Neutron → BNCT



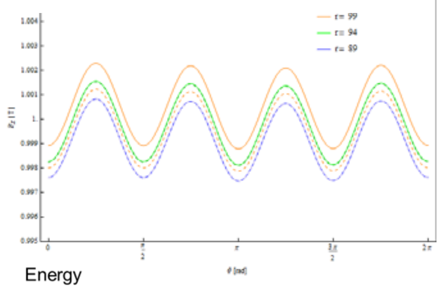
Compact Storage Ring



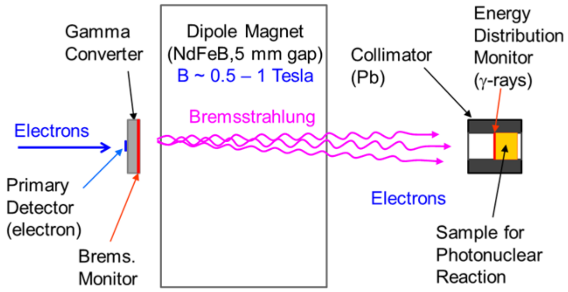
B filed in the radial direction B(r)



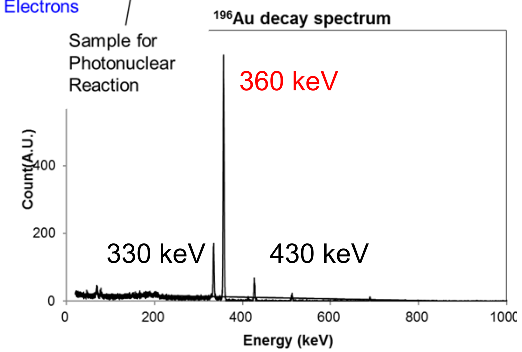
B filed along the trajectory B(θ)



Gamma-ray source: Bremsstrahlung



Decay spectrum of activated Au

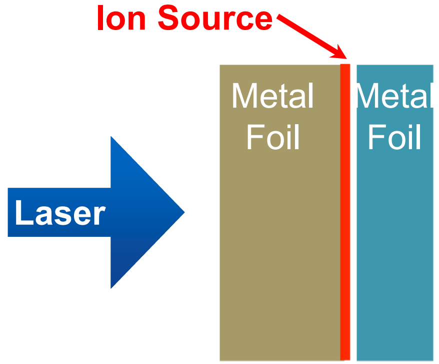


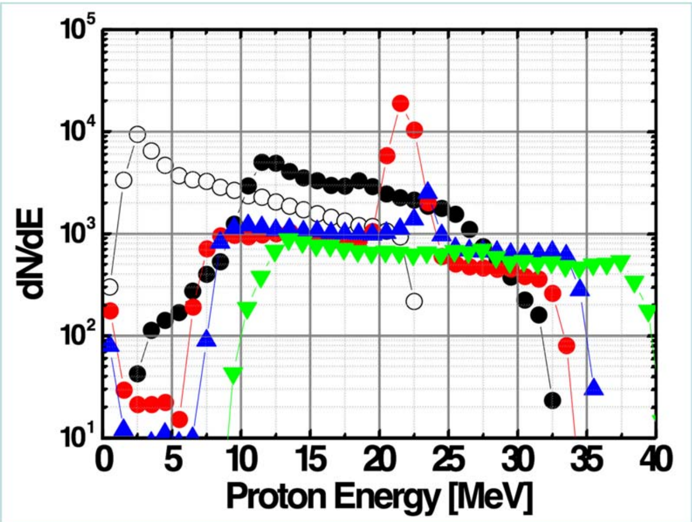
Korea Univ./KAERI

Laser-Plasma Acceleration: Ions & Electrons

Laser Proton Acceleration

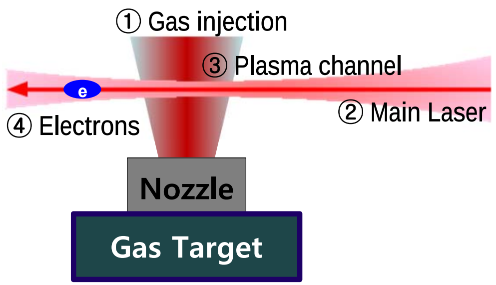
ILEF (Ion Layer Embedded Foil)



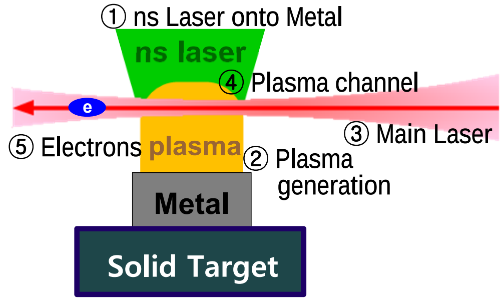


ref. K. N. Kim et al., POP 23, 033119 (2016)

Laser Electron Acceleration



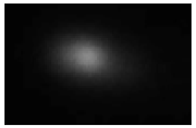
Easy to operate



High Vacuum, high rep. rate
Easy to shape plasma density

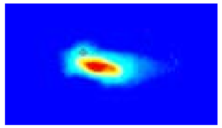
Laser : 20 TW, 27 fs,
He gas: 2x3 mm nozzle
Plasma density: ~10^{19} cm^{-3}

Electron beam:
Energy : ~110 MeV
Energy spread : ~ 30%
Charge : 50~100 pC
Divergence : ~ 4 mrad
Pointing jitter : ~ 6 mrad
Vacuum: < 10^{-2} torr



Laser : 29 TW, 27 fs,
Al: ~0.15x2 mm foot-print
Plasma density: ~10^{19} cm^{-3}

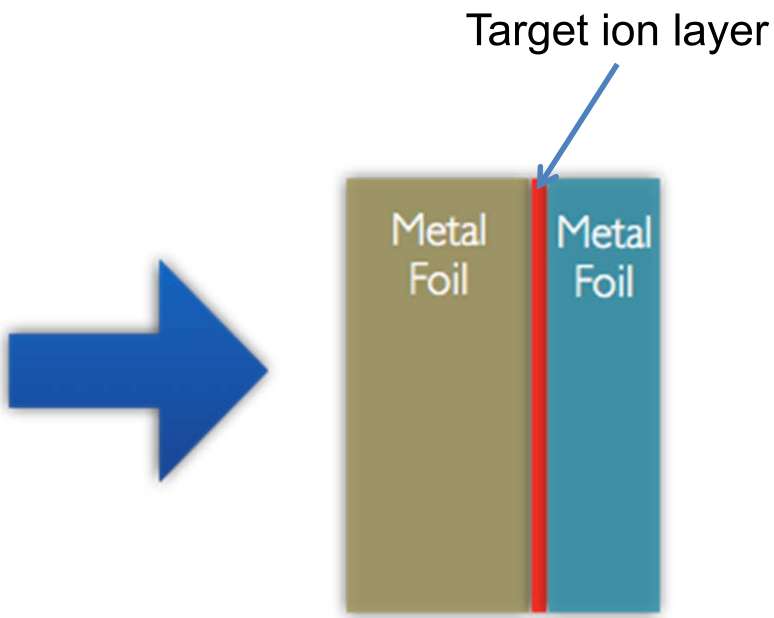
Electron beam:
Energy : 40~70 MeV
Energy spread : ~ 40%
Charge : ~ 60 pC
Divergence : < 12x6 mrad
Pointing jitter: ~3 mrad
High Vacuum: < 10^{-5} torr



KAERI

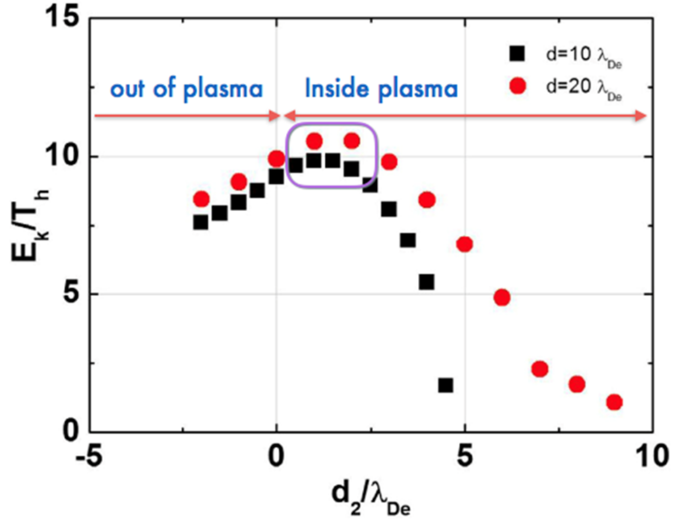
Layered Target

- For the generation of an energetic proton beam with narrow energy spread
- By utilizing a Bulk electrostatic field in the plasma

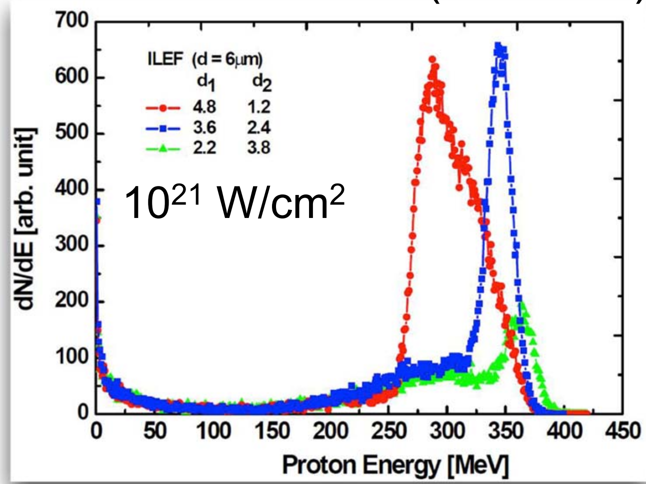


Ion Layer-Embedded Foil target

1D Fluid Simulation



2D PIC Simulation (XOOPIC)



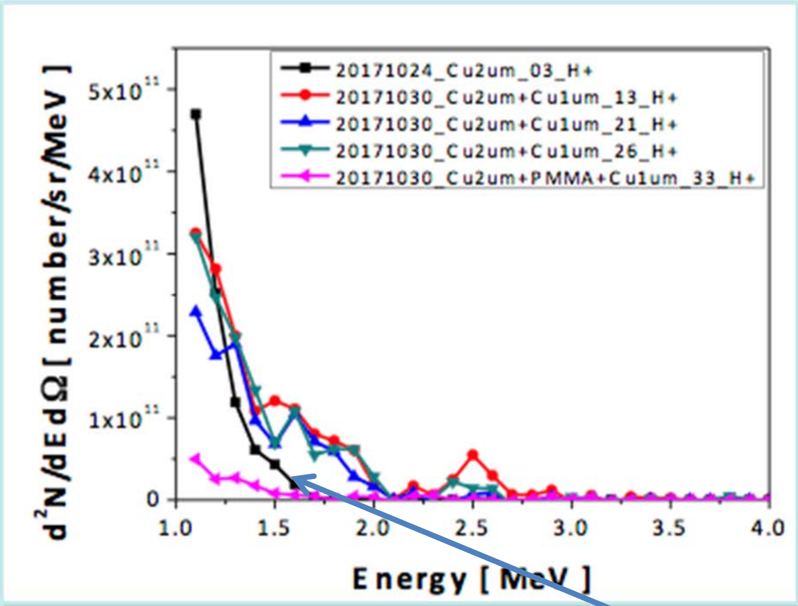
KAERI

Enhanced ion beams with peaked energy from layered targets

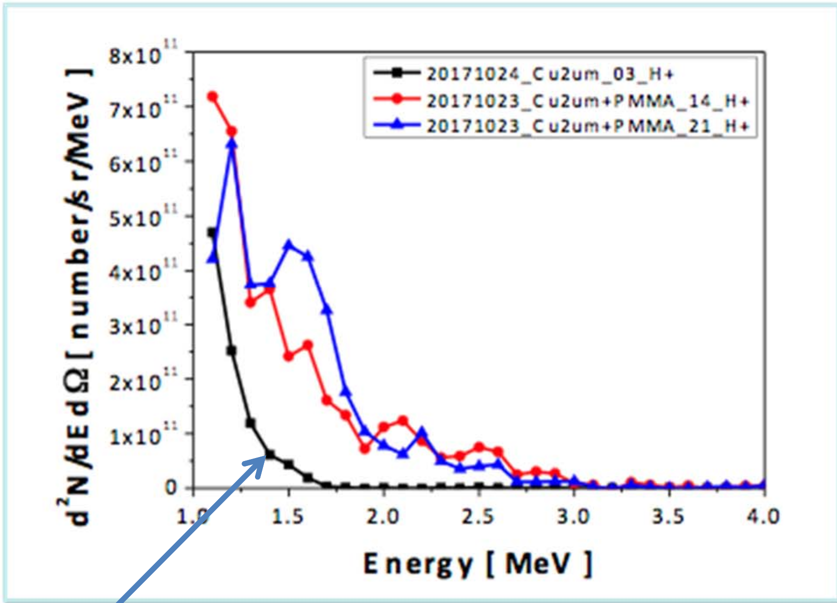
Demonstrated at CoReLs, IBS

High contrast laser of 10^{20} W/cm^2

ILEF (Cu 2 + 1 μm)



Double Layer (Cu 2 + PMMA)

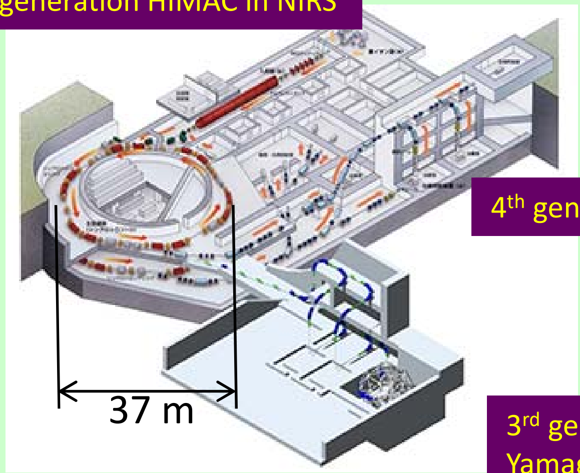


Single foil for comparison

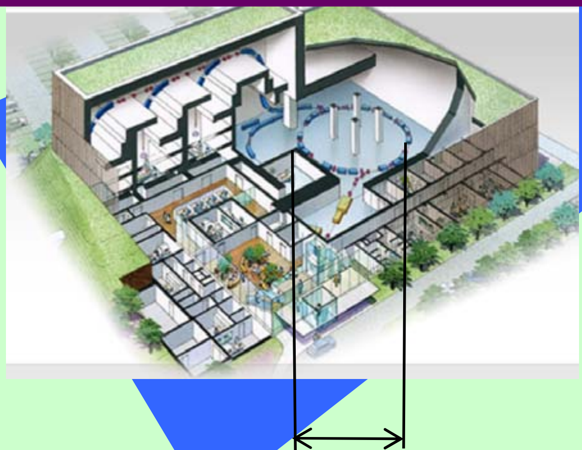
5th generation heavy ion cancer therapy machine Ⅰ

QST

1st generation HIMAC in NIRS

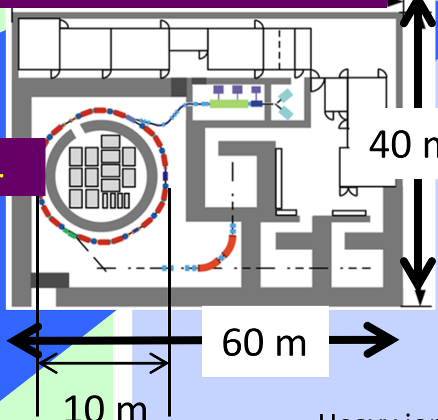


2nd generation: Gunma Univ., Heidelverg Univ.



Present status

3rd generation:
Yamagata Univ, Kanagawa, etc.

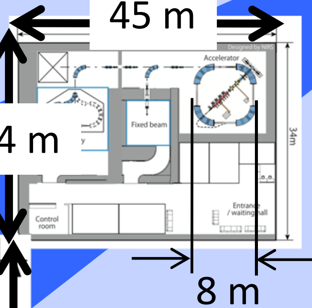


Under development now

NIRS found that there is a positive effect with using multi-ion speices for curing cancer.
→ Multi-ion irradiation cancer therapy

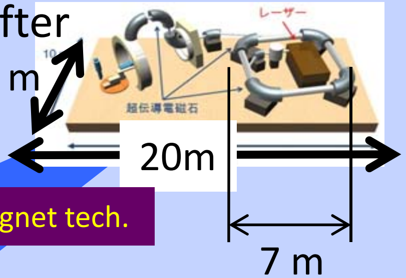
With using a super conducting magnet, it can be packed in 45 m x 34 m size building with a gantry.

4th generation: multi-ion irradiation effect and super conducting magnet tech.



5th generation: using laser driven ion accelerator

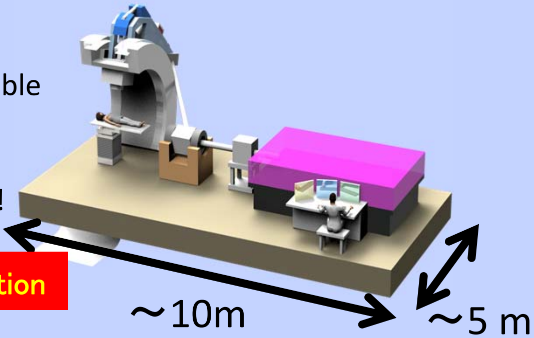
10 years after



With using a super conducting strong magnet and **laser driven ion injector**, it can be packed in 20 m x 10 m size building with a gantry.
Laser driven ion injector should be placed inside the main synchrotron accelerator ring.
This machine can be put in a big hospital. → An extra building is not necessary.

Future: Compact inexpensive machine with all optical

Heavy ion cancer therapy available at any time at anywhere, for anybody!
GeV/u accelerator at anywhere!



Generation of Destructive Innovation

Future status

20 years after

5th generation heavy ion cancer therapy machine Ⅱ

5th generation ion cancer therapy machine（This could be realized 10 years after.）

Compact Quantum Scalpel with a power laser technology which can be placed on one floor in a big hospital.

Ion species ： Helium, Nitrogen, Carbon, Oxygen, Neon etc.

Synchrotron： ～7m in dim., Building size： 20m x 20m （in hospital）

Irradiation device： Gantry scanning

Laser driven injector should be placed inside the synchrotron ring.

Spec requirement to laser driven ion injector

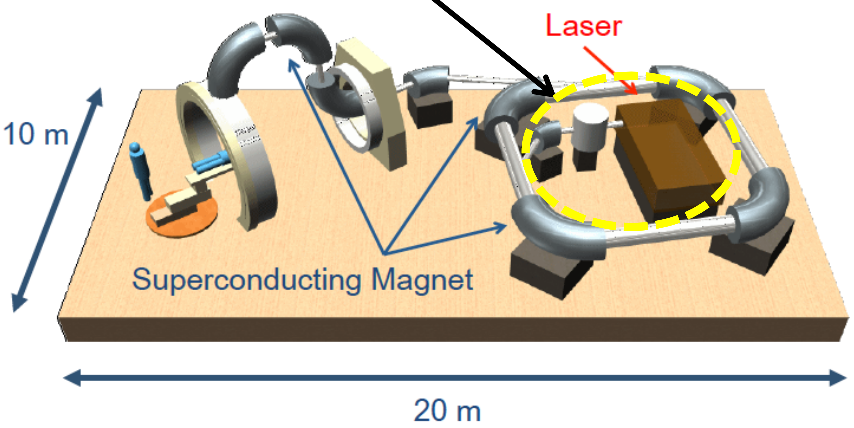
Ex.：Ion energy: > 4 MeV/u

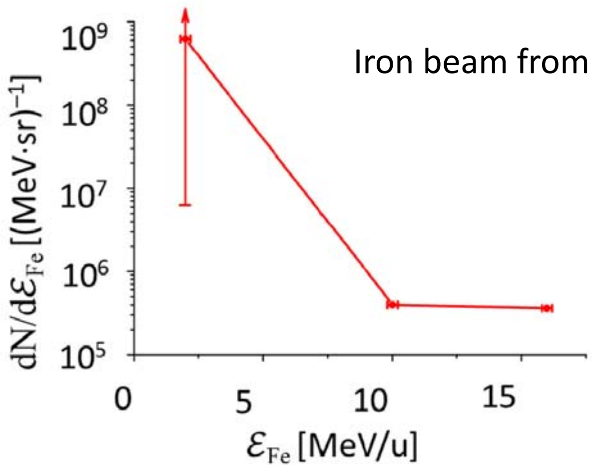
Rep. rate: > 1 Hz, < 1 kHz → **10 Hz**

Number in 1 % b.w. : >10^9 in 2 sec

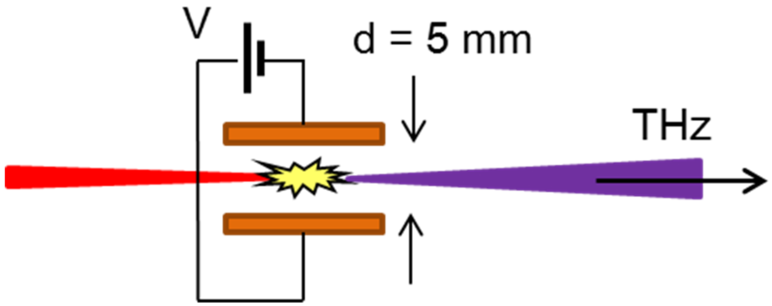
10 Hz → >10^8/shot in 10 % b.w.

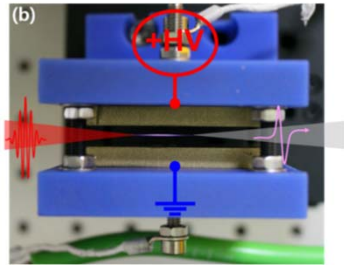
→ >10^8/shot in 1 % b.w. with Debancha

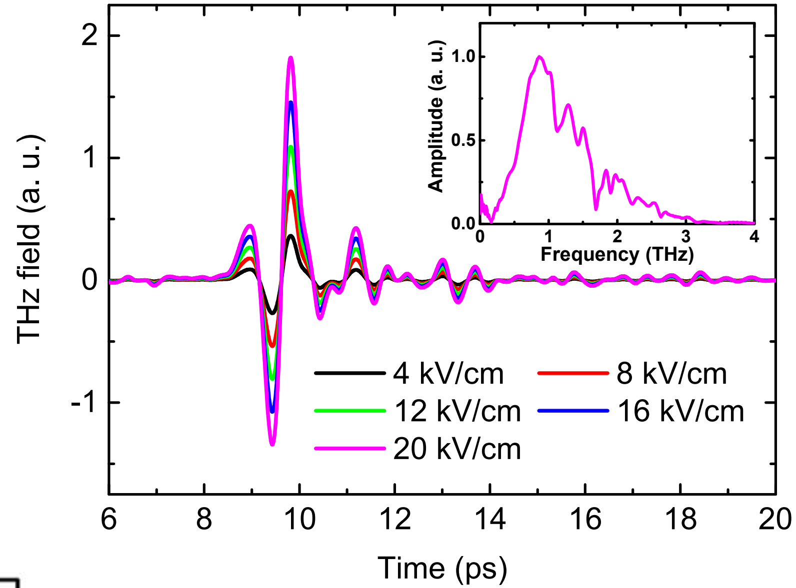


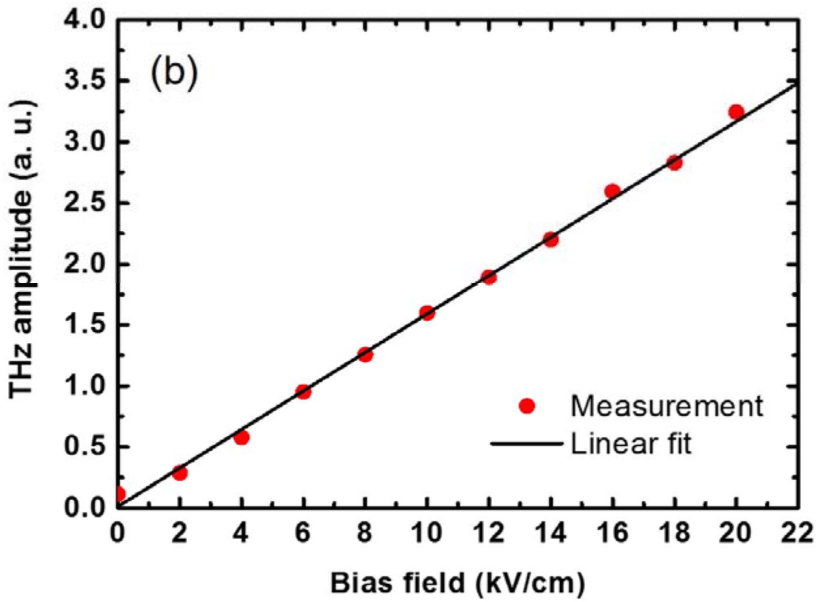


Enhanced THz Generation by DC Field







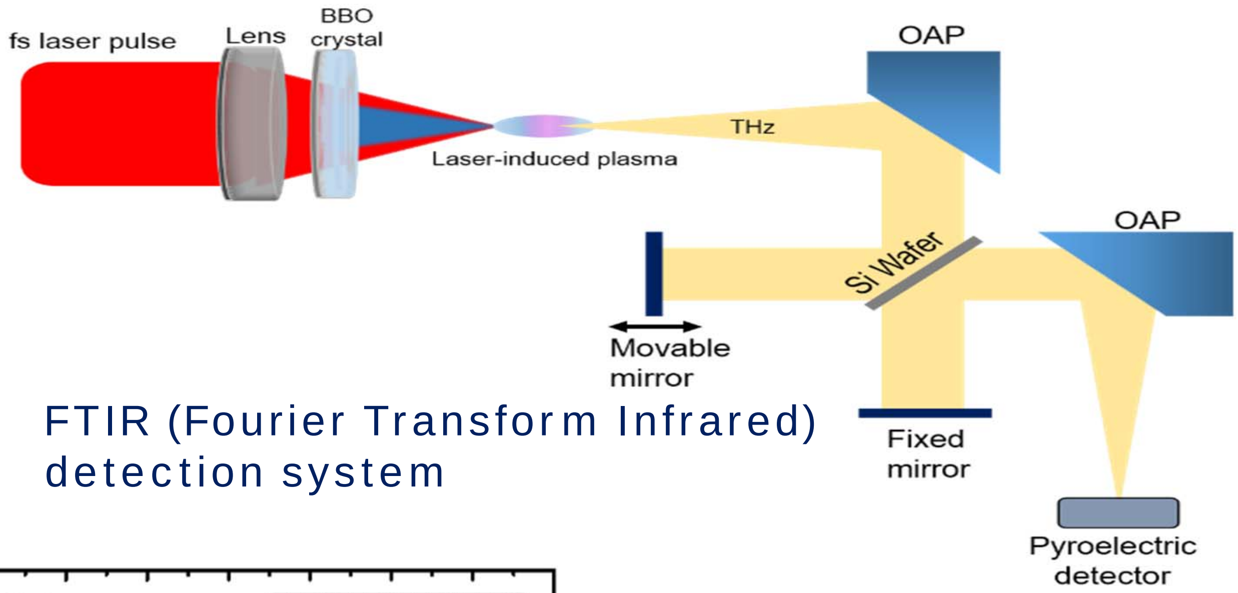


$$E_{THz} = E_{ext}\left[\cos\left(\omega_p t\right) - 1\right]\exp\left(-\nu_c^2 t^2\right)$$

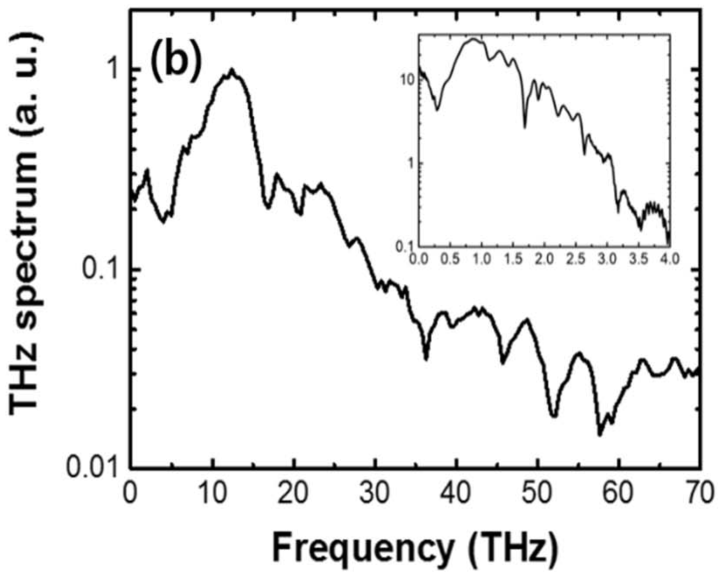
E_{ext} **: external DC electric field**

ν_c **: e-neutral collision frequency**

Two-color Method : broader bandwidth

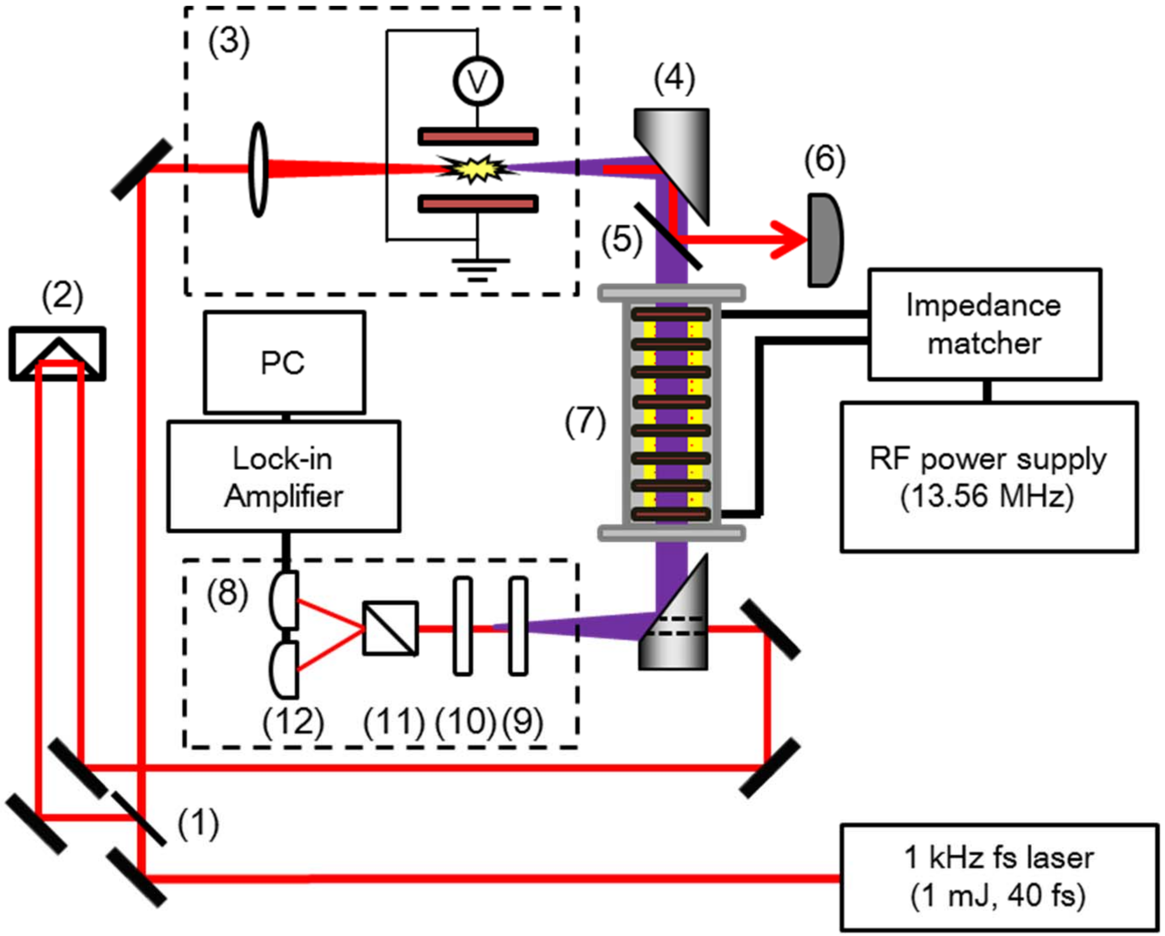


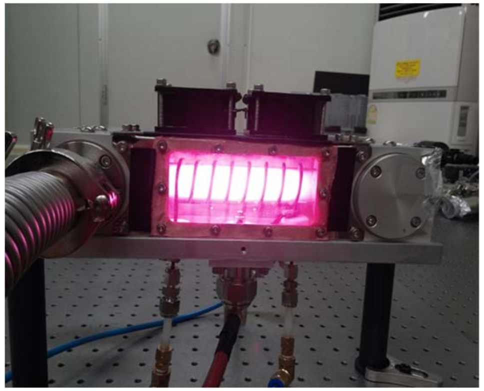
FTIR (Fourier Transform Infrared) detection system

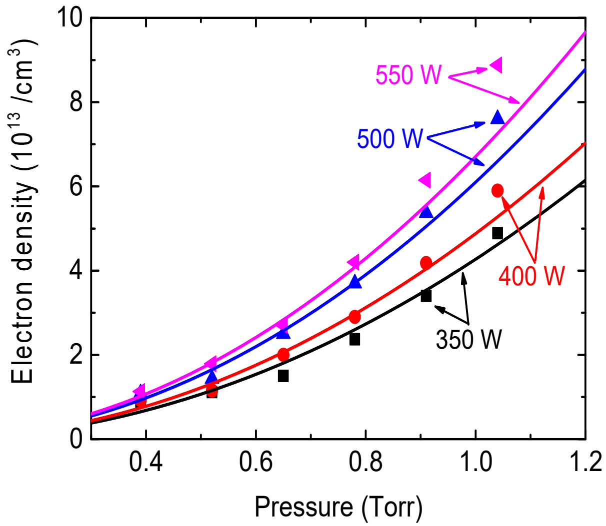


Broader bandwidth THz pulse can cover higher densities

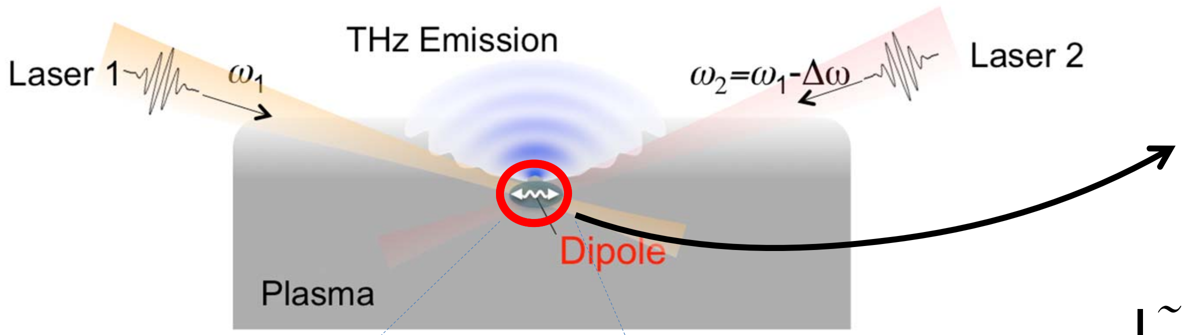
Schematic for the Experiment







PDO by Trapped Particles

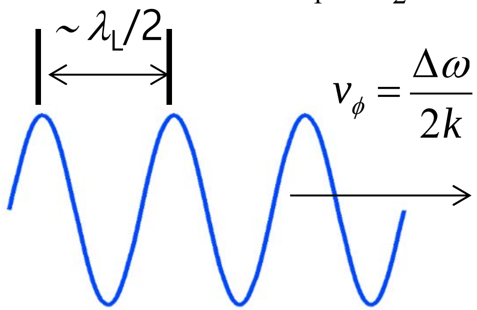


Moving Potential Train

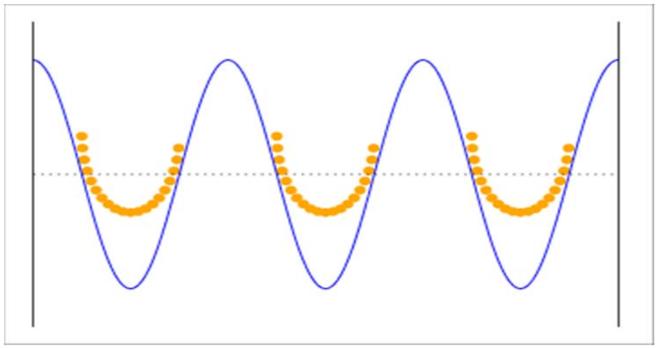
$$\Phi_{PM} \sim I_{laser} e^{2ikz-i\Delta\omega t}$$

$$\Delta\omega = \omega_1 - \omega_2 << \omega_{1,2}$$

$$2k \equiv k_1 + k_2$$



$$v_\phi = \frac{\Delta\omega}{2k} = \frac{\omega_1 - \omega_2}{k_1 + k_2} << c$$



Electrons riding on the potential train are displaced in a block to the right

Velocity of the displacement is determined by the laser detuning $\Delta\omega$

Two-dimensional PIC simulation – stronger field with higher frequency