General overview of THz project

2012.8.14 at Tomsk Polytechnic University
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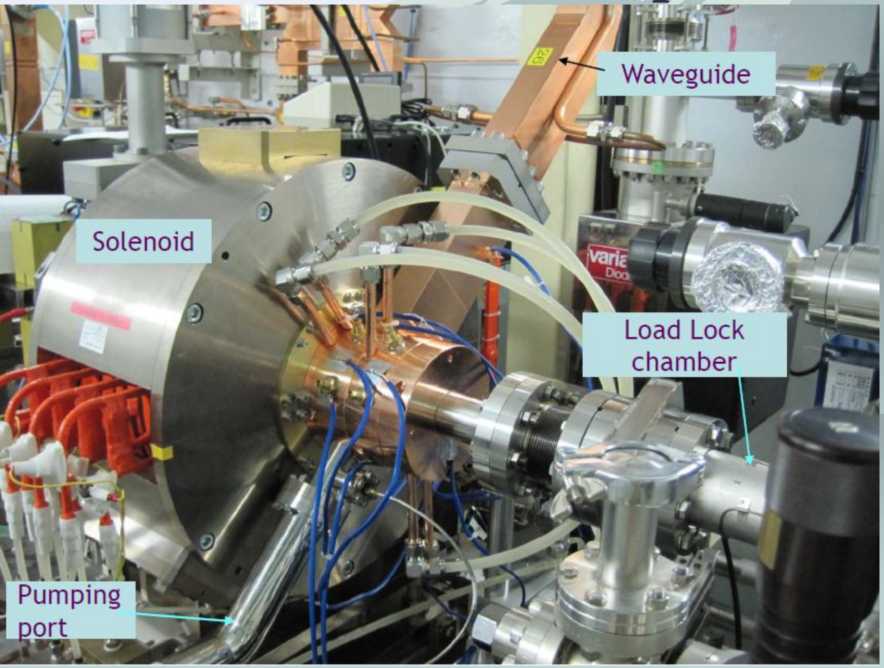
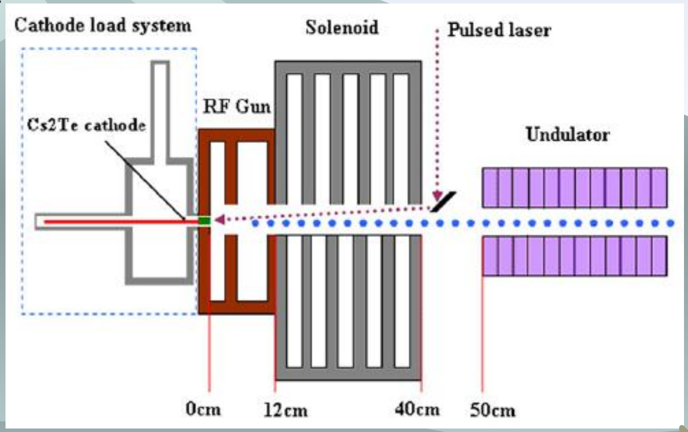
Contents :

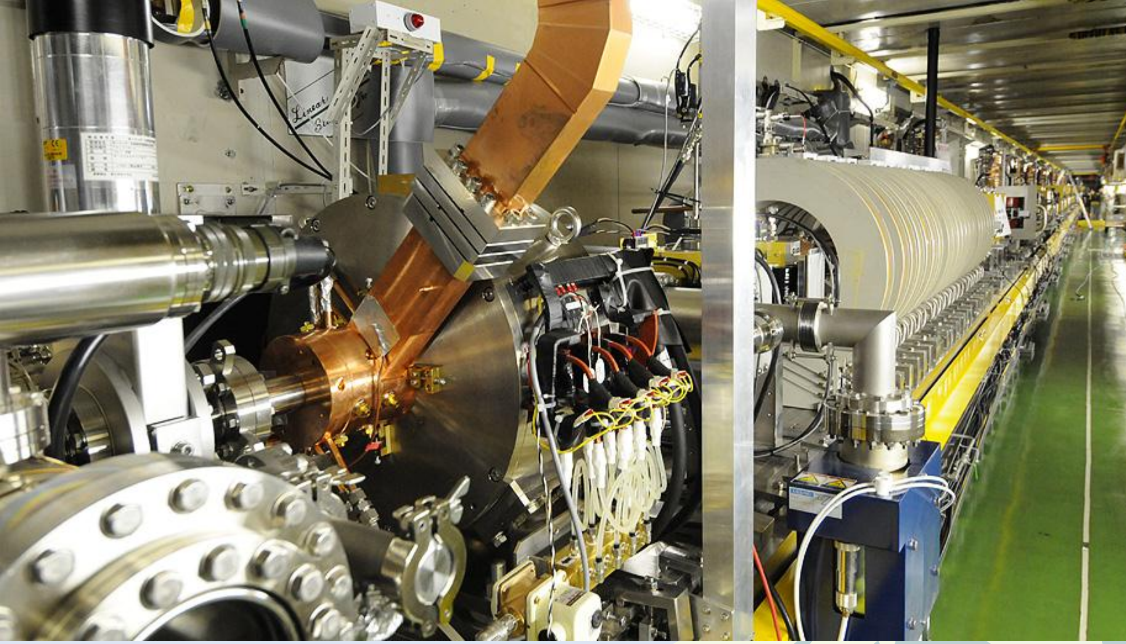
1. Introduction : Compact THz Source

Terahertz radiation is an electromagnetic wave in the frequency interval from 0.3 to 10THz.
A THz-FEL is a good candidate due to its characteristics of high peak brightness, short duration, and tunable wave length.
However, the need for a huge facility and substantial funds limit THz-FEL development.
Two important goals are to make the THz-FEL facility compact and to increase its output radiation power.





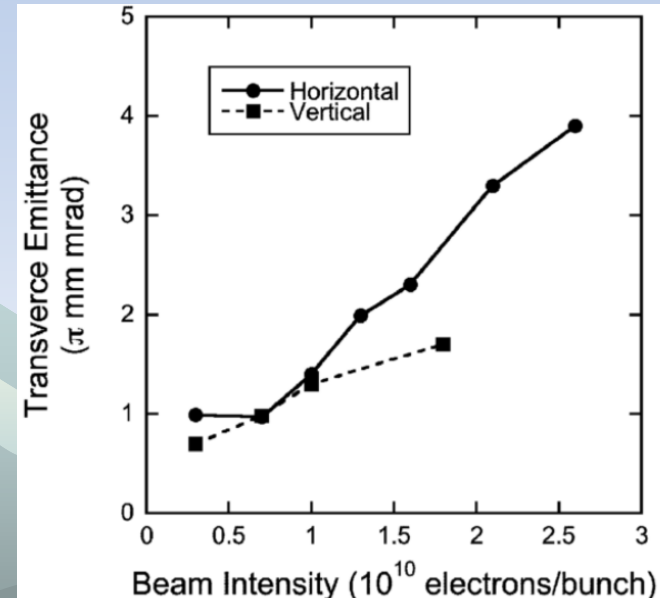
Less than 2m
THz Peak power :10MW to 100MW



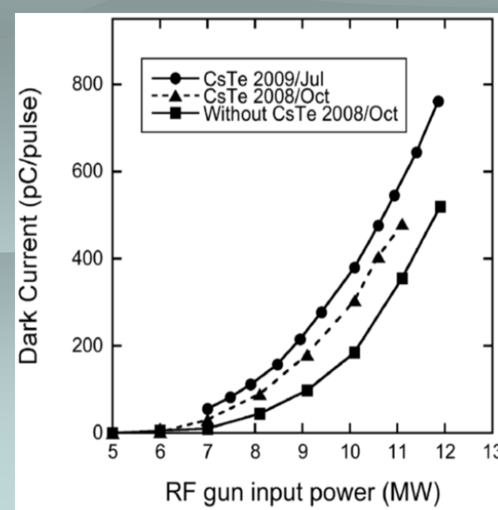
2. Basic Technologies

2-1. High Gradient S-band RF Gun

1.3GeV ATF Linac, results at 80MeV beam.



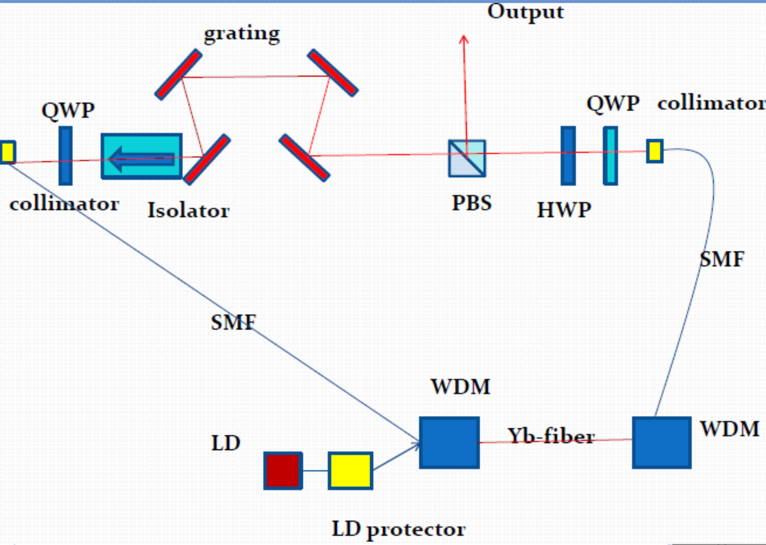
A laser-driven RF gun with a **Cs_2Te photocathode** has been developed at KEK **since 2002**. This gun has been operated as an electron source for the ATF and generates a beam with an operational intensity of up to **2×10^{10} electrons per bunch**. In 2008, a new gun incorporating all of the earlier modifications was produced for the ATF. Tests have confirmed a significant improvement of the Q value of the latest model. A typical transverse emittance of **1.3 π mm·mrad at 80 MeV** has been obtained under the following conditions: solenoid field of 0.18 T, beam intensity of **1×10^{10} electrons per bunch**, and **RF power of 9 MW**.

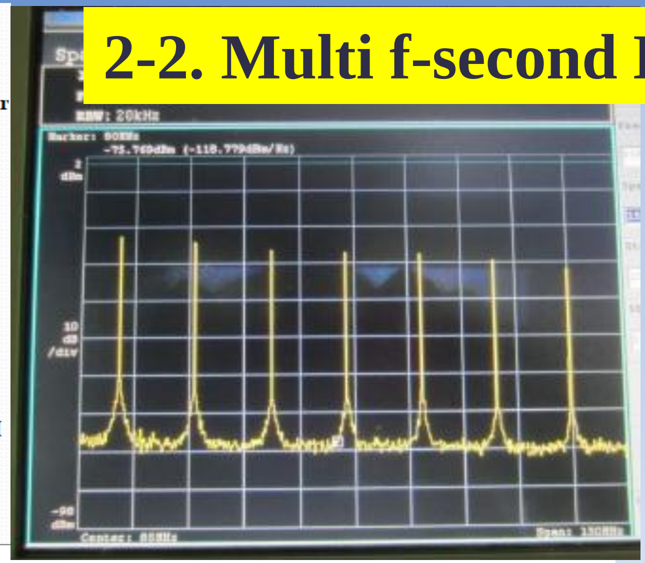


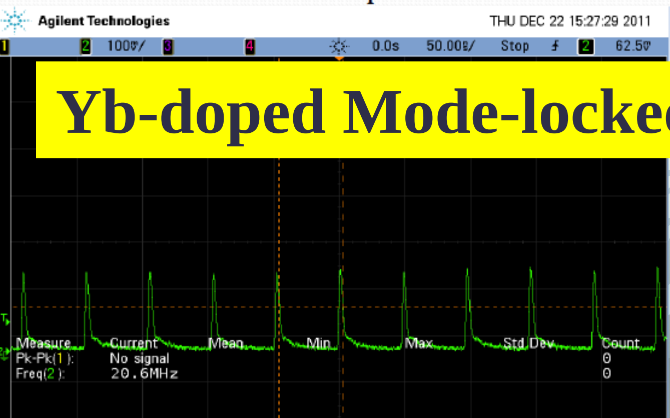
2-2. Multi f-second Laser Pulse Train

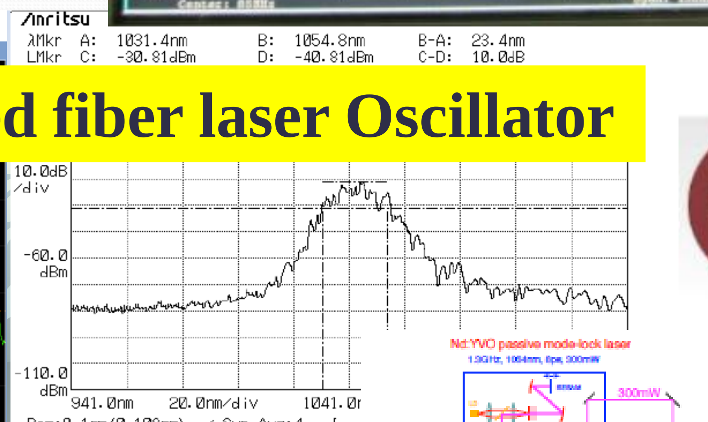
Pulse duration less than 100fs.
Output power more than 20mW.
Pulse energy more than 10μJ.
Burst amp.

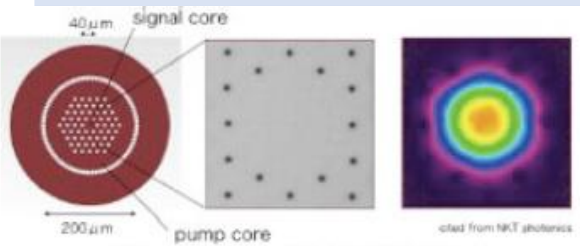
Yb-doped Mode-locked fiber laser Oscillator

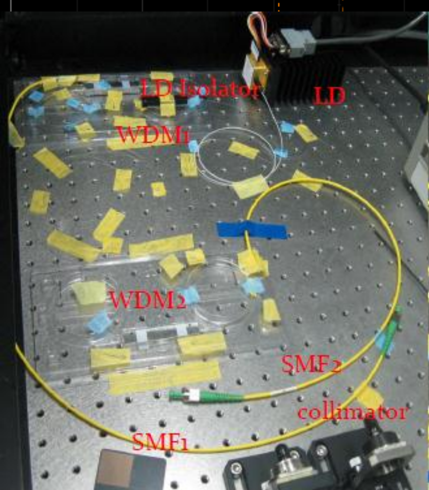


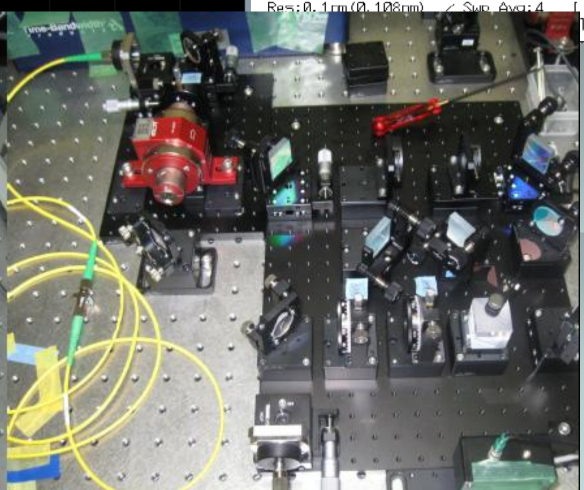


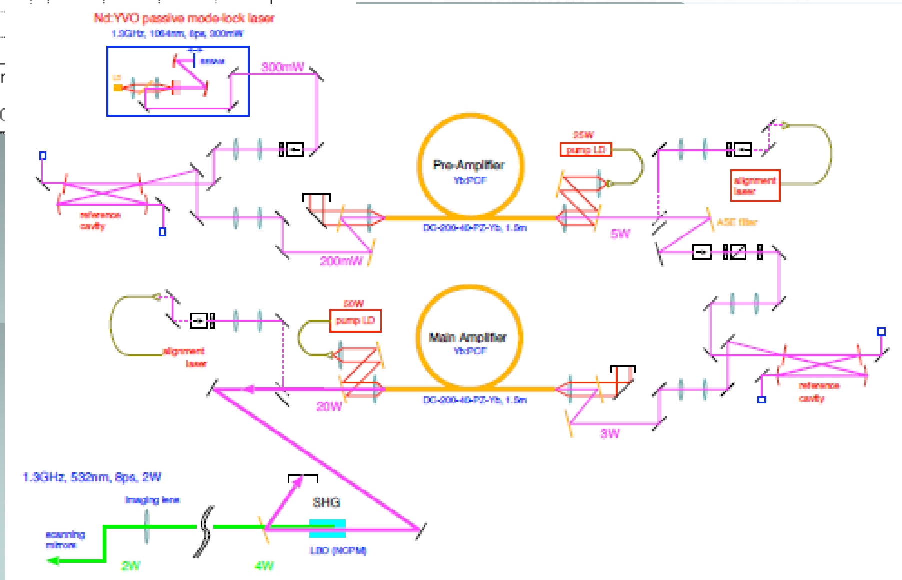




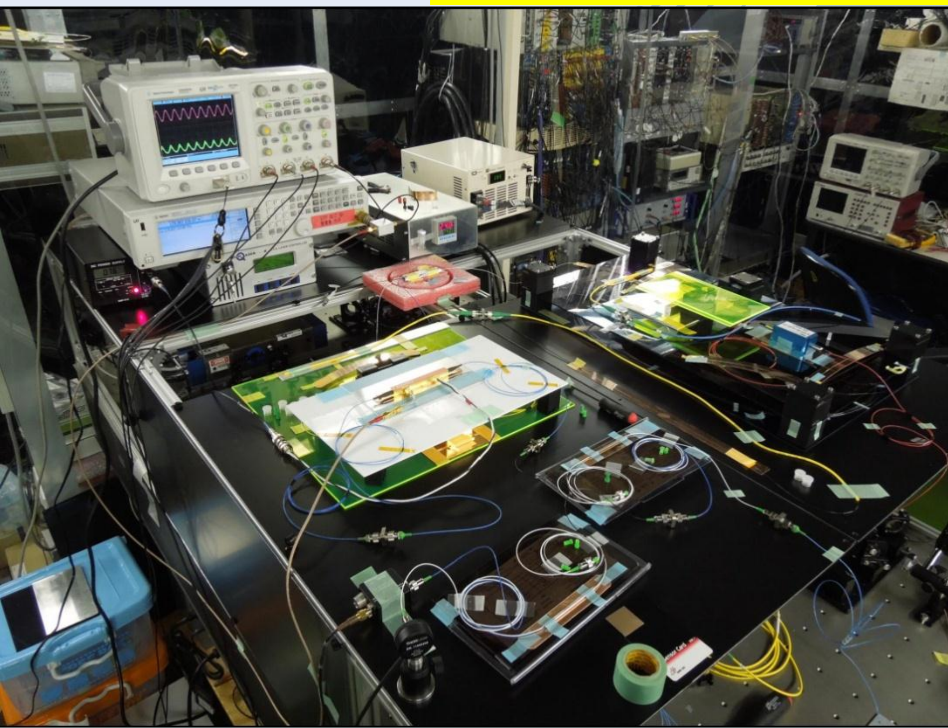


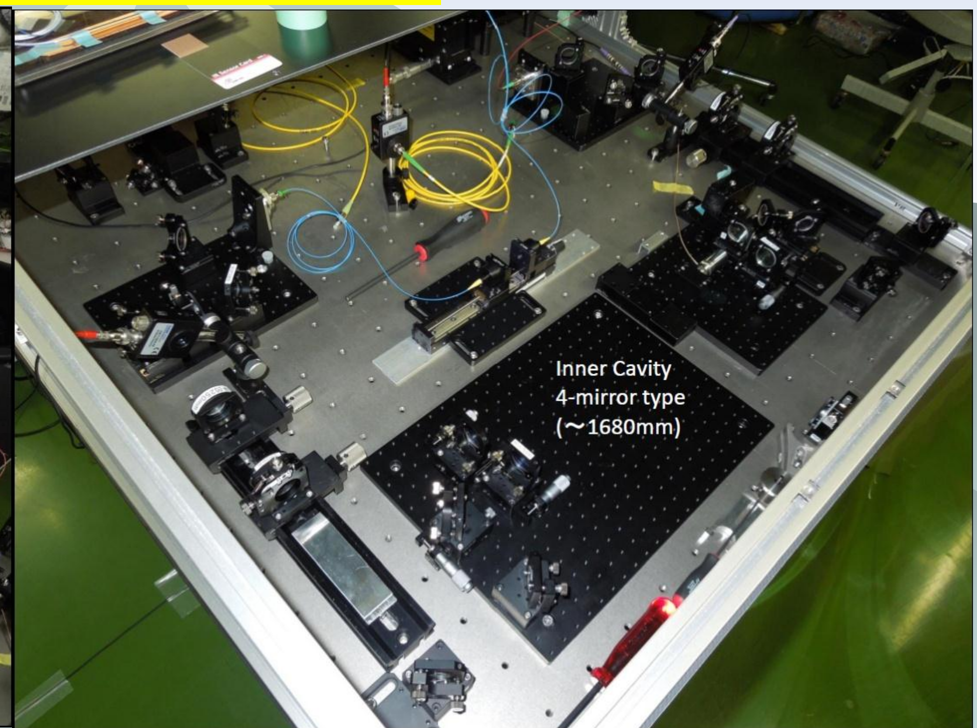






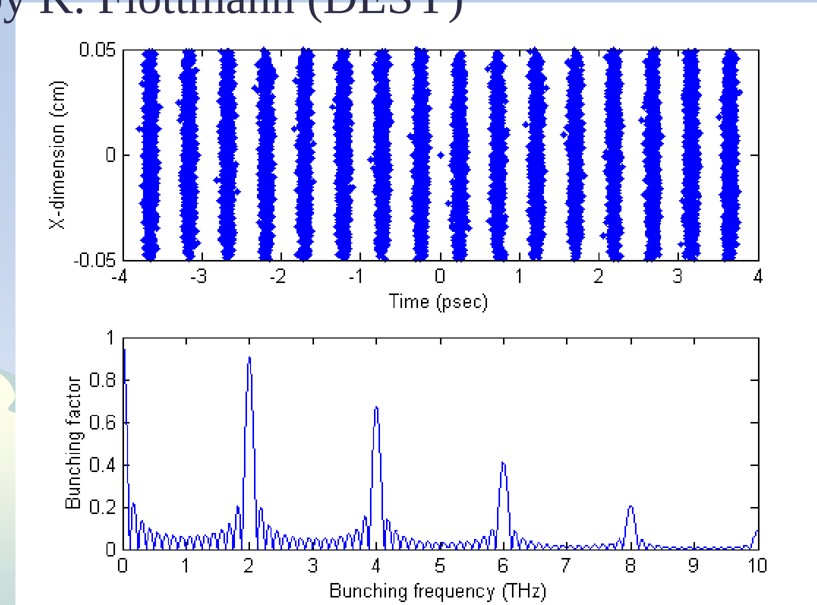
Fiber Laser System Development





3. Rough Evaluation by ASTRA and Genesis

Astra (**A** **S**pace Charge **Tr**acking **A**lgorithm) by K. Flottmann (DESY)
Genesis by Sven Reiche (PSI)

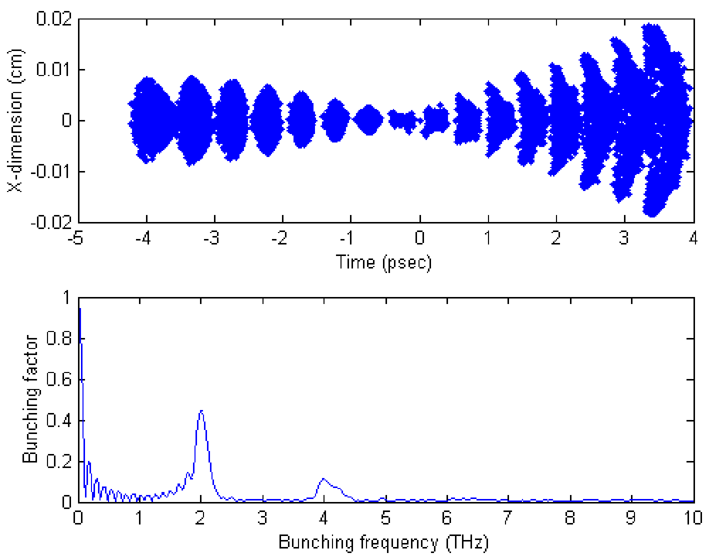


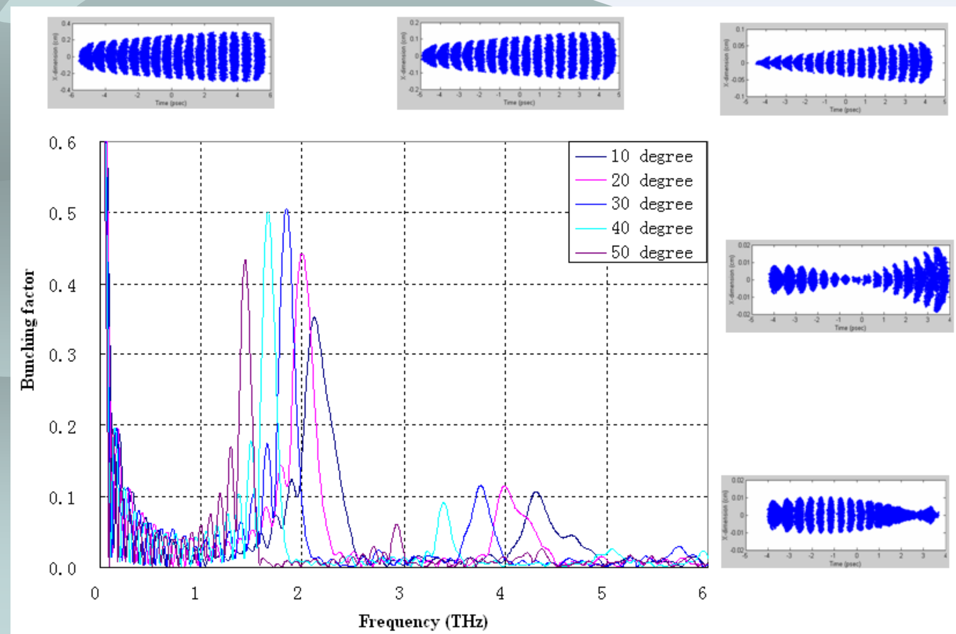
We assume the peak RF field gradient at the cathode surface is 100MV/m, 200pC and the laser injection phase is 20 degree.
The bunching factor at 2THz is still high ,0.446 at the wiggler entrance, see next figure.

$P=P_1[N_e + N_e(N_e-1)B(f)]$,

$B(f)=\sum \exp(i2\pi f z_j/c)/N_e$,

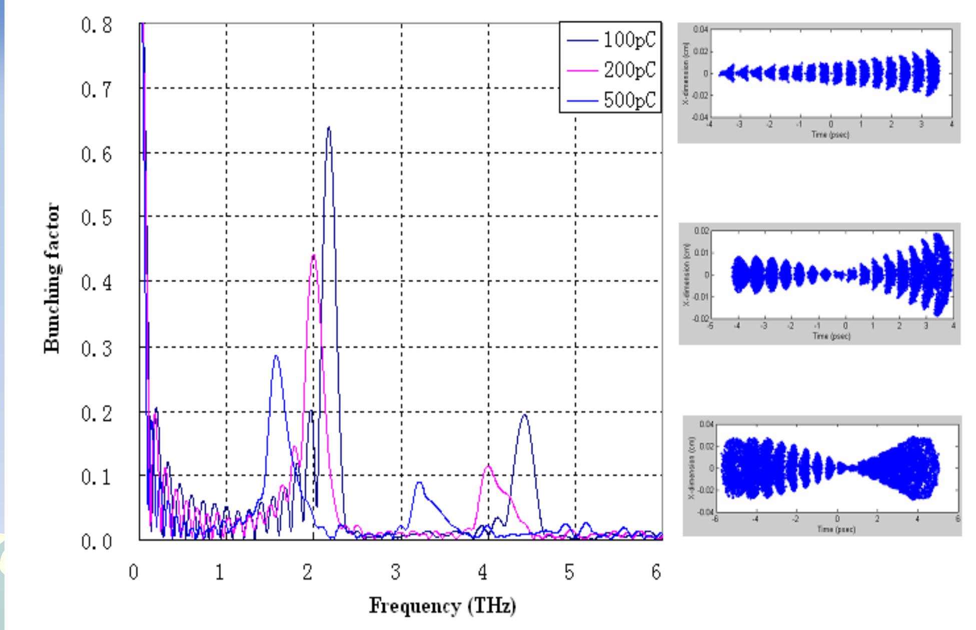
$\lambda_r=\lambda_w(1+K^2)/(2\gamma^2)$



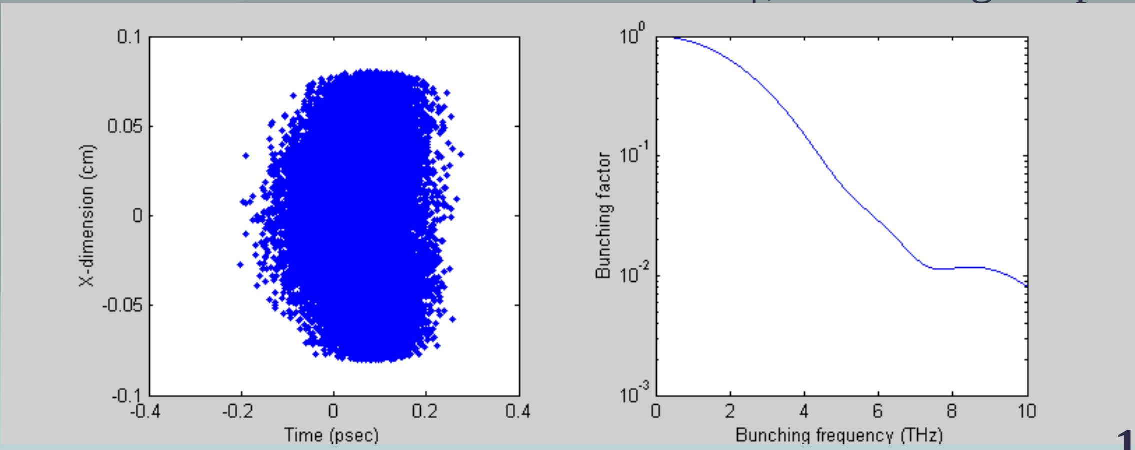


Above shows bunching factor dependence at the wiggler entrance on laser injection phase.

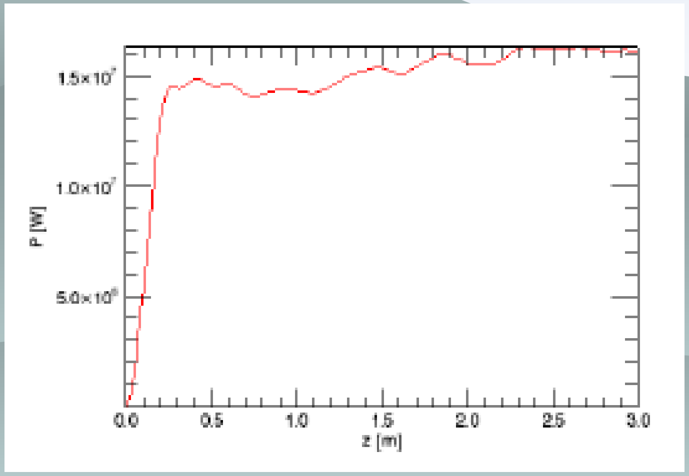
Right figure shows bunching factor dependence on total charge assuming Micro-bunch charge is uniform.
We need higher gradient acceleration, lower total charge and about 20 degree laser injection phase to keep a high bunching factor.



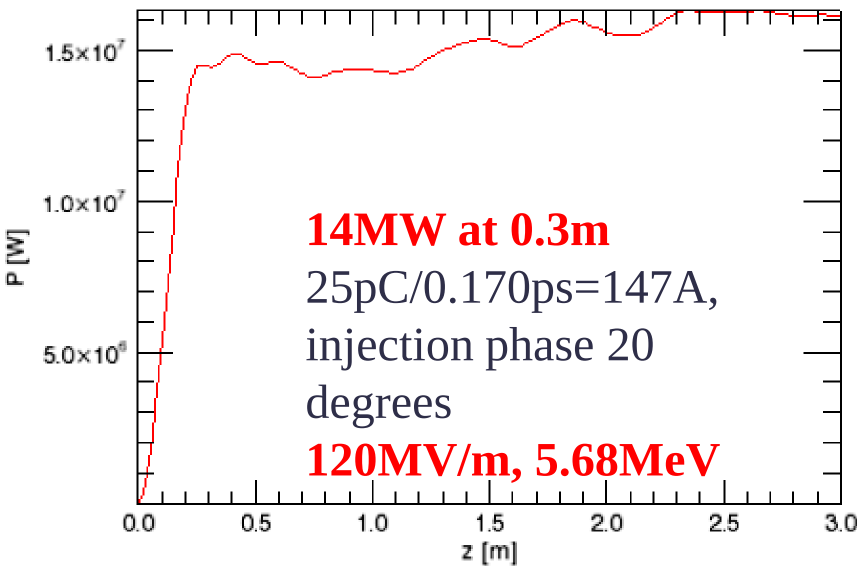
For example, we assume the peak field gradient at the cathode surface is 120MV/m and laser injection phase 20 degree. Then, electron beam energy is 5.68MeV.
Also, we consider the wiggler period length 30mm and 2THz radiation (wave length 150μm).
γ=12, K=0.873.
Uniform laser size on cathode 1.0mmϕ, total charge 25pC

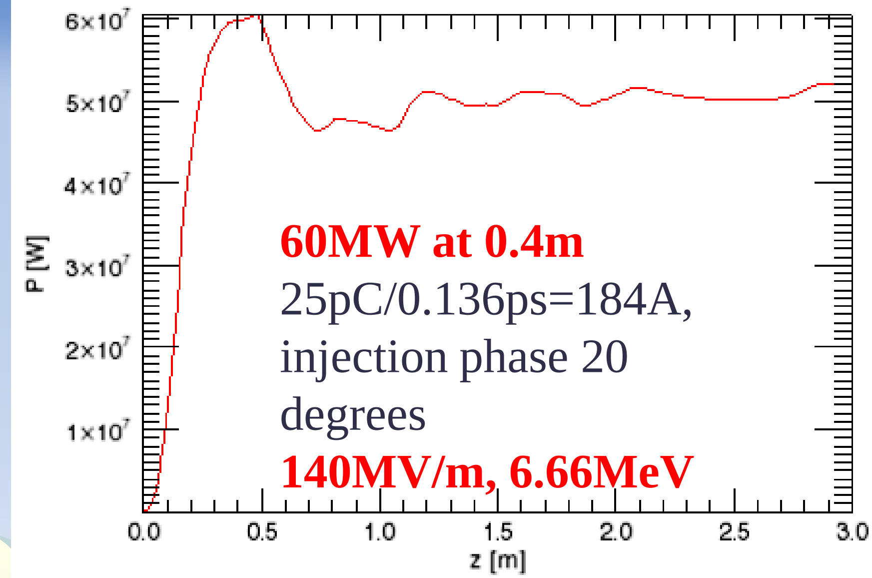


170 fs (FWHM), peak current=147A



14 MW peak power at 0.3m position





$P=P_1[N_e + N_e(N_e-1)B(f)]$, $B(f)=\sum \exp(i2\pi f z_j/c)/N_e$,

$\lambda_r=\lambda_w(1+K^2)/(2\gamma^2)$, K: tune the gap to make the resonance.

High gradient acceleration: shorter bunch length

(100MV/m-→140MV/m)

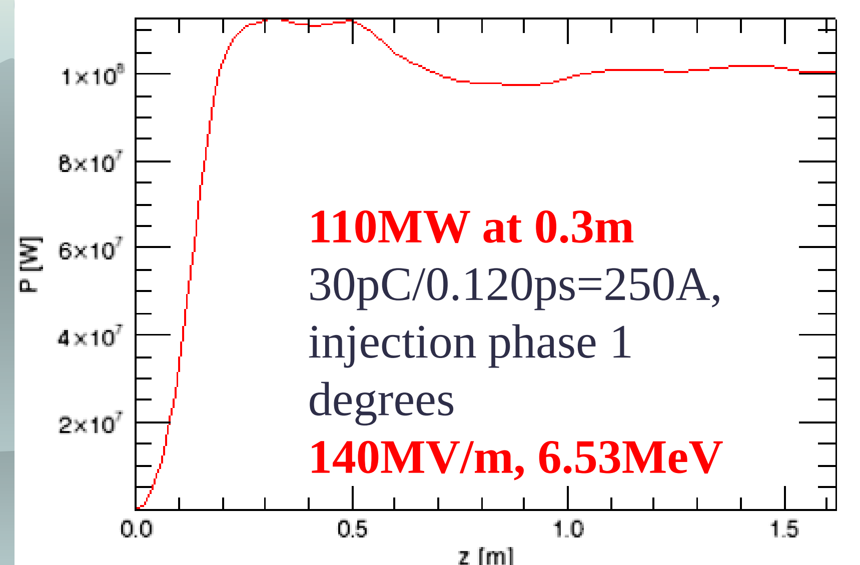
earlier laser injection phase: high bunching factor

High Peak Power radiation(20-→10-→1)

THz peak power 100MW generation will be possible.

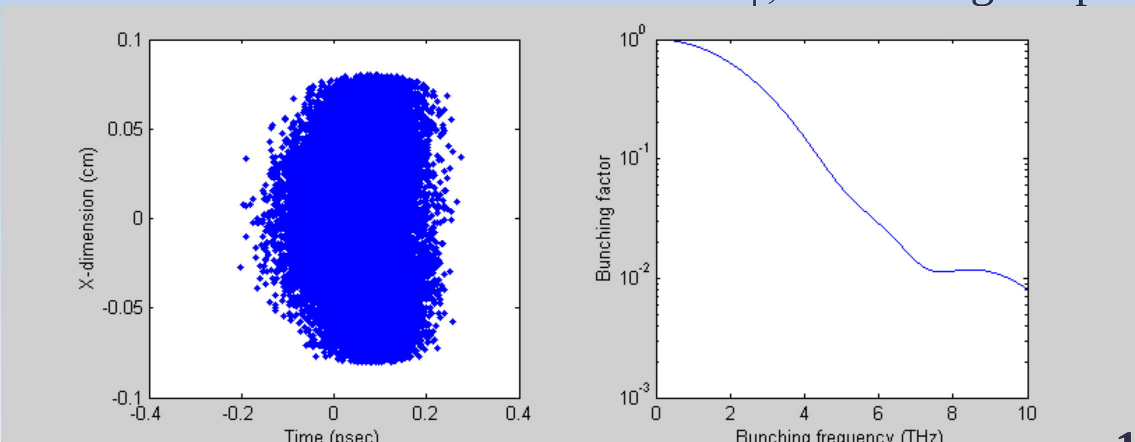
High gradient acceleration gun is essential.

100μJ/pulse THz source will be 1mJ-fs laser

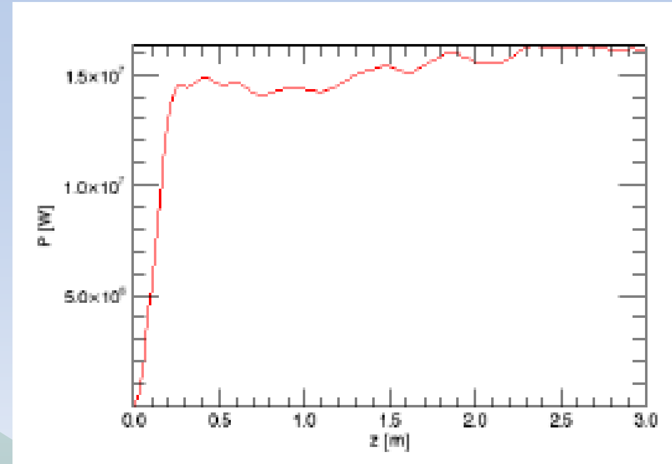


We have to take care the shielding effect to CSR, maybe.

For example, we assume the peak field gradient at the cathode surface is 120MV/m and laser injection phase 20 degree. Then, electron beam energy is 5.68MeV.
Also, we consider the wiggler period length 30mm and 2THz radiation (wave length 150μm).
g=12, K=0.873
Uniform laser size on cathode 1.0mmϕ, total charge 25pC



170 fs (FWHM), peak current=147A



14 MW peak power at 0.3m position

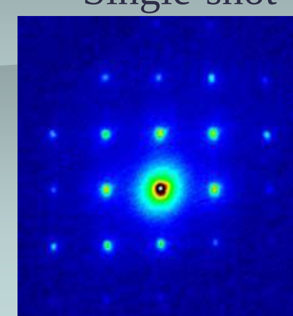
My colleague, Prof. Yan of Osaka University, demonstrated the generation of 100fs single electron bunched beam and obtained the single-shot Ultrafast Electron Diffraction (UED) using our RF gun cavity. In this experiment, the time resolution was 20fs in sigma.

Electron beam:
3 pC, 3 MeV,
10 Hz operation

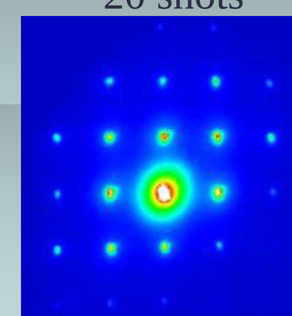
Sample:
~180nm-thick
single-crystal Si

The single-shot measurement was succeeded

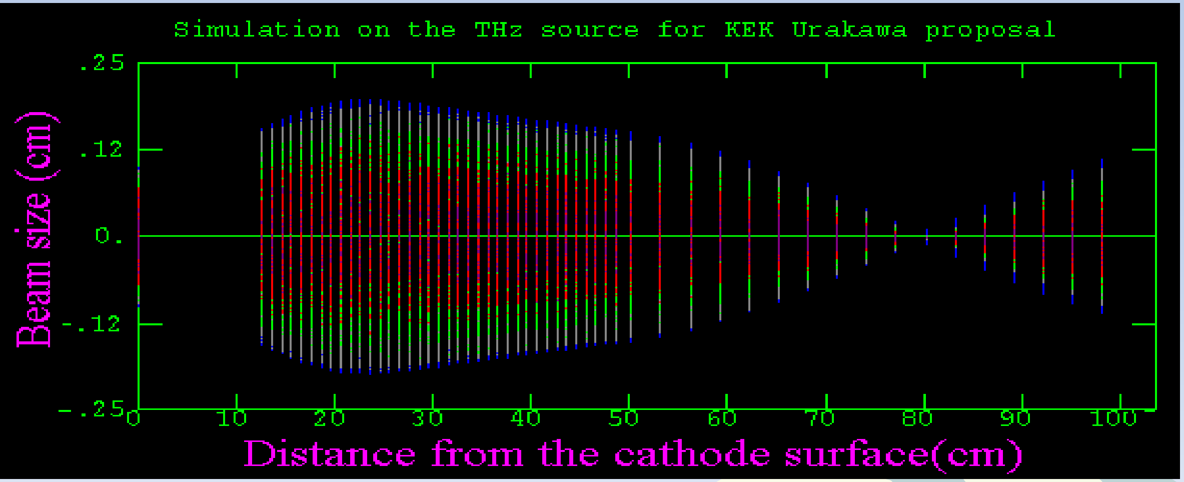
Single-shot

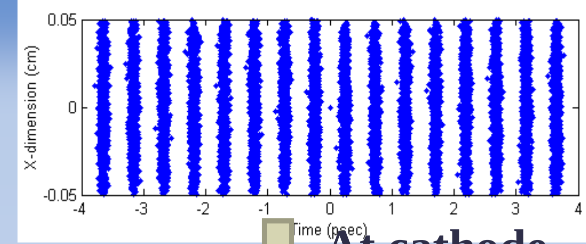


20 shots



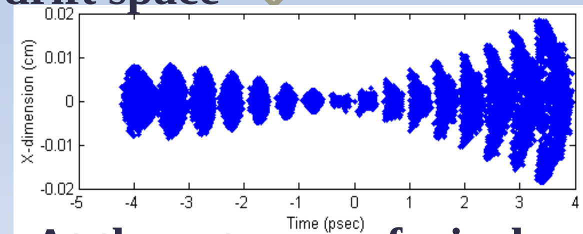
Simulation results



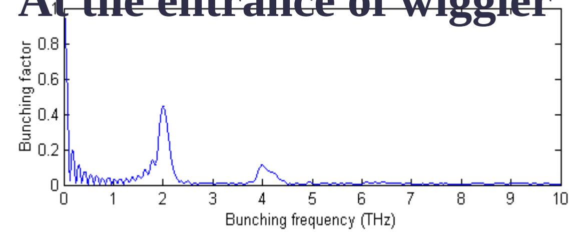


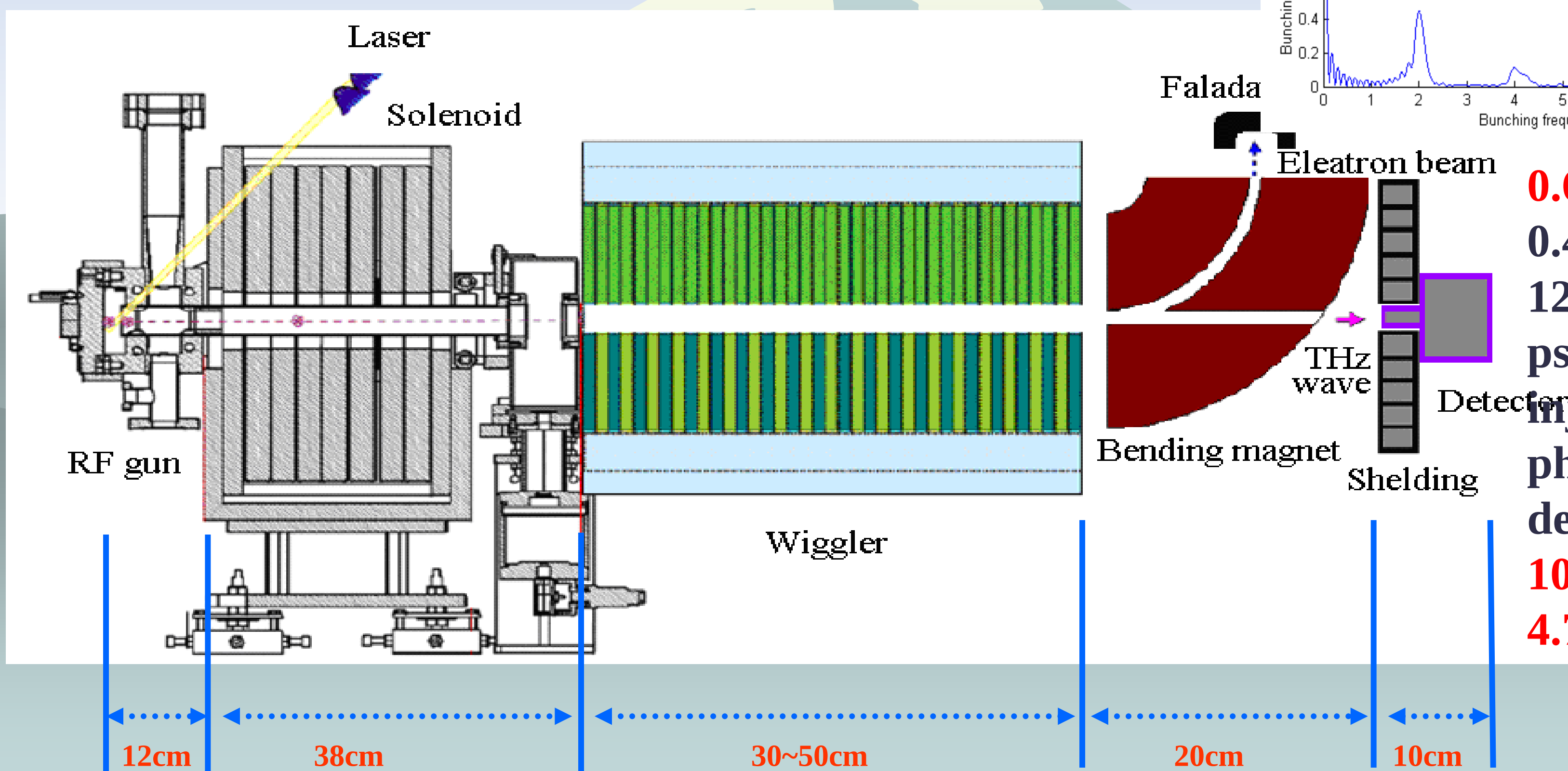
At cathode

38cm drift space



At the entrance of wiggler



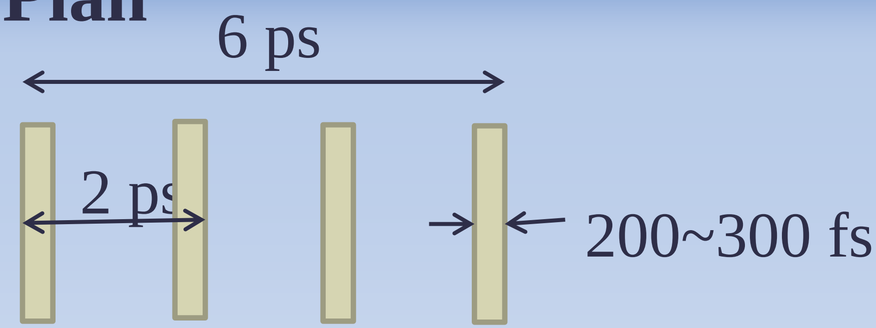


0.68MW at 0.4m 12.5pC/0.214 ps=58A, injection phase 20 degrees, **100MV/m, 4.7MeV**

4. Development Plan

Essential points :

Pre-bunched FEL,
Dynamical bunching in RF gun cavity which means faster laser injection phase less than 20 deg.,
Micro-bunch spacing should be matched to wavelength,
Late micro-bunch makes the bunching of former micro-bunches in resonated Undulator.



Time structure of 4 micro laser train for 500GHz super radiation from Undulator

500GHz microwave generation

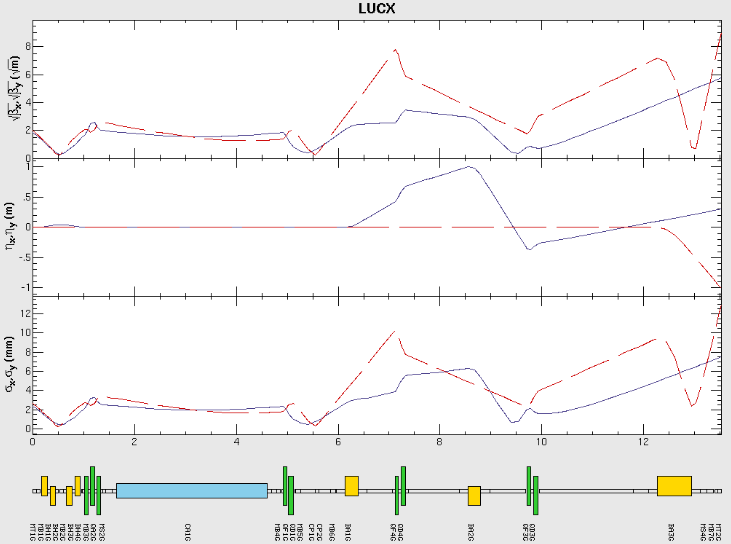
Generation of Comb beam in the RF Gun Cavity

Problem: beam loading effect due to multi micro-bunch and tuning on undulator field by pole-gap which makes the FEL resonance.

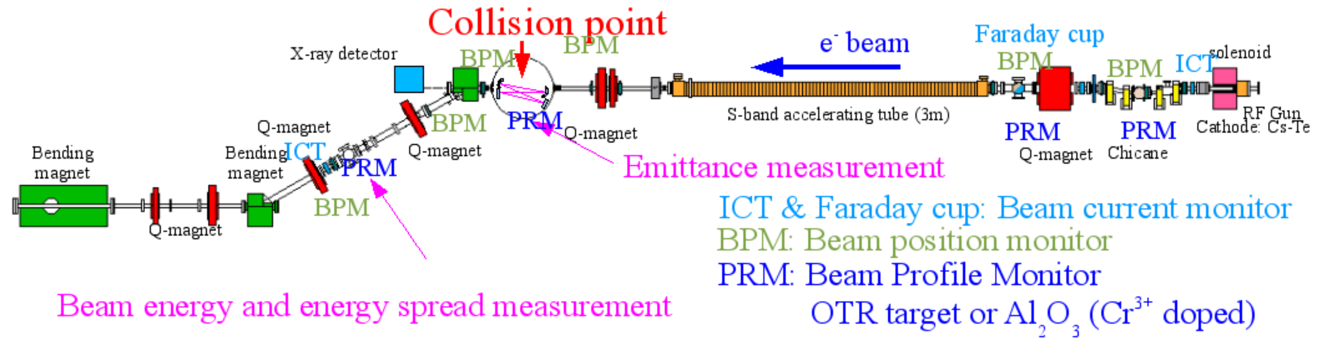
If we accept low micro-bunch charge, say 100pC or less, and not many micro-bunch, say 10 or less, above problems can be overcame.

50MeV S-band accelerator LUCX

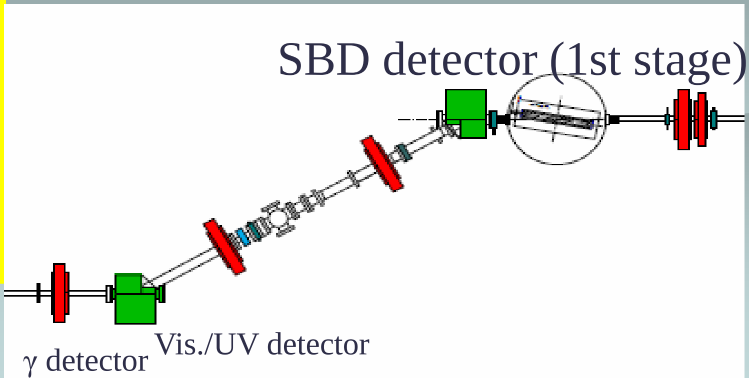
THz Detector and Imaging Developments



Advanced Accelerator Facility from 2008 to 2012 for Quantum Beam R&D



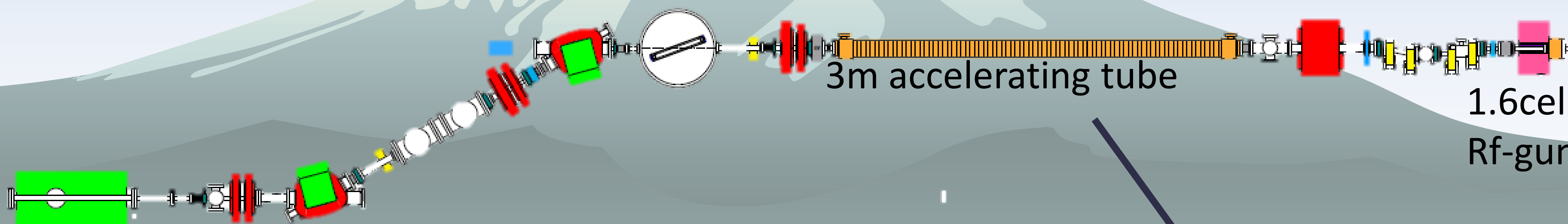
Maximum Energy 50MeV
Maximum Beam Power 156.26MeV μA

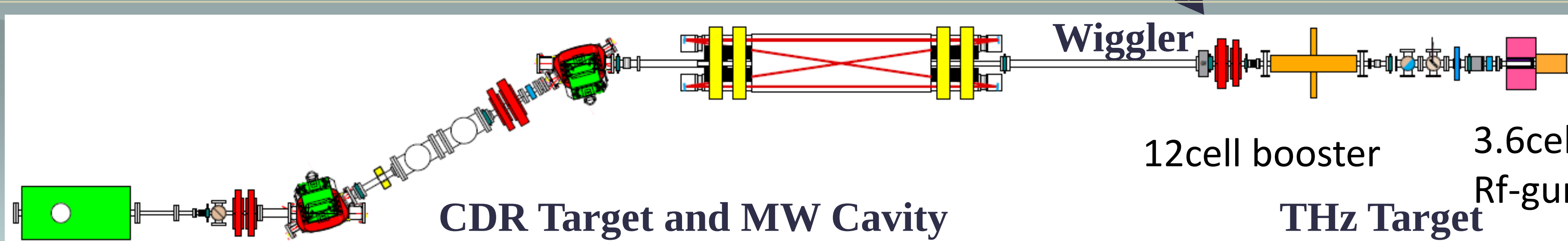


SBD detector development at LUCX : Measuring micro-wave around 300GHz

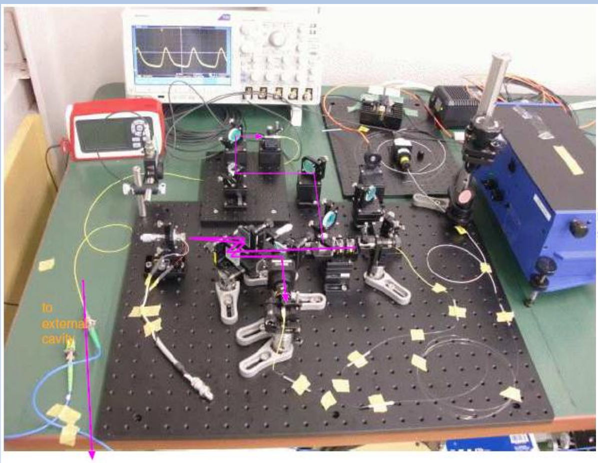
Recent plan for LUCX accelerator

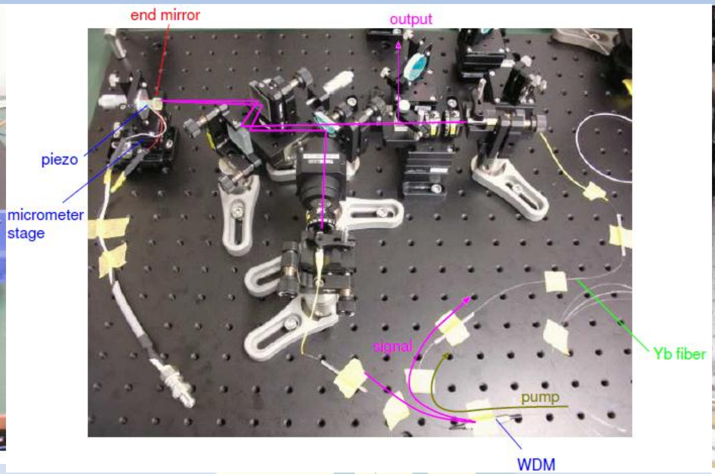
- To downsize the accelerator, we have planed to install a 3.6cell rf-gun and a 12cell booster.
  - 3.6cell rf-gun
    - Beam test has been started from Jan 2012.
  - 12cell booster
    - This booster is installed now.

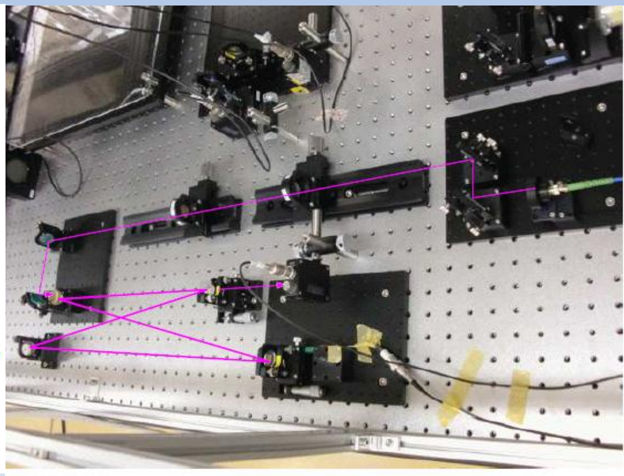




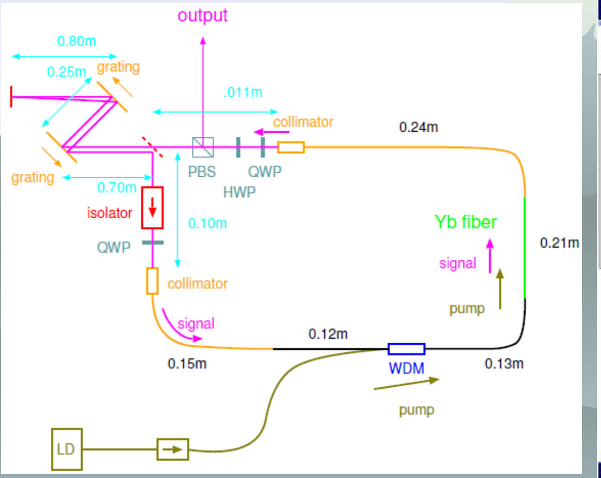
LUCX Facility, FSTB

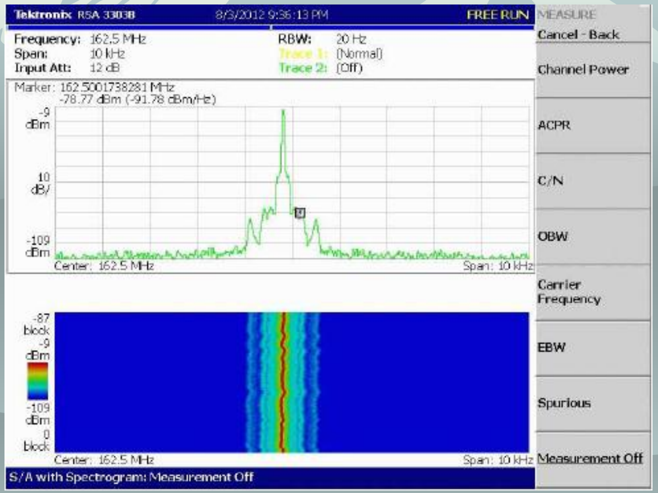


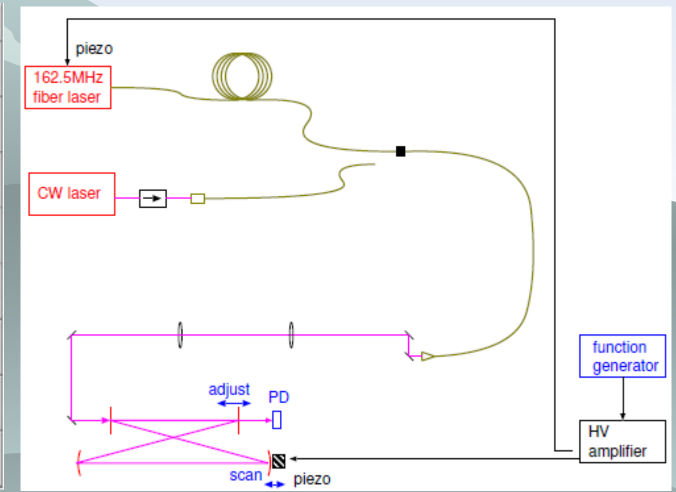




NLPR passive mode lock oscillator (162.5MHz)

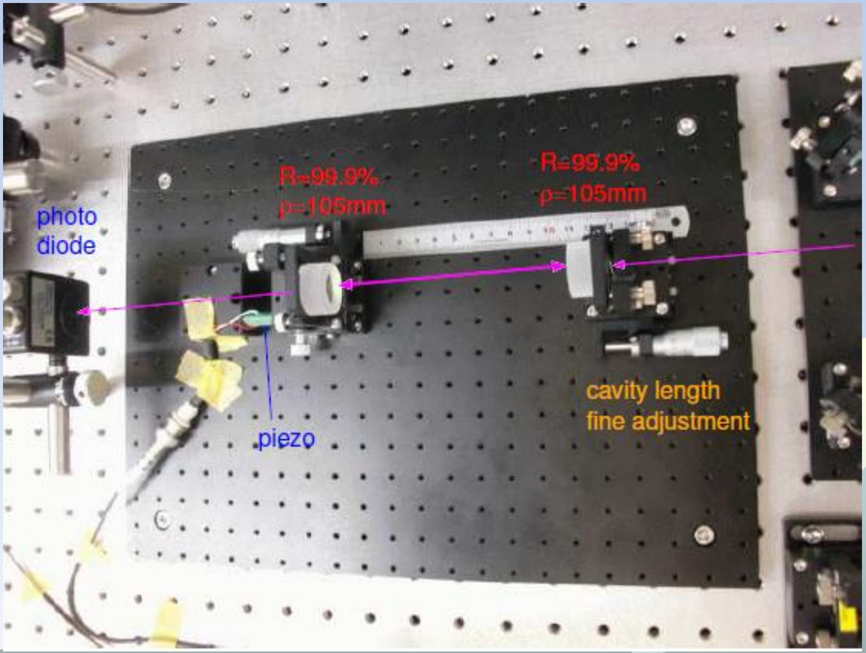


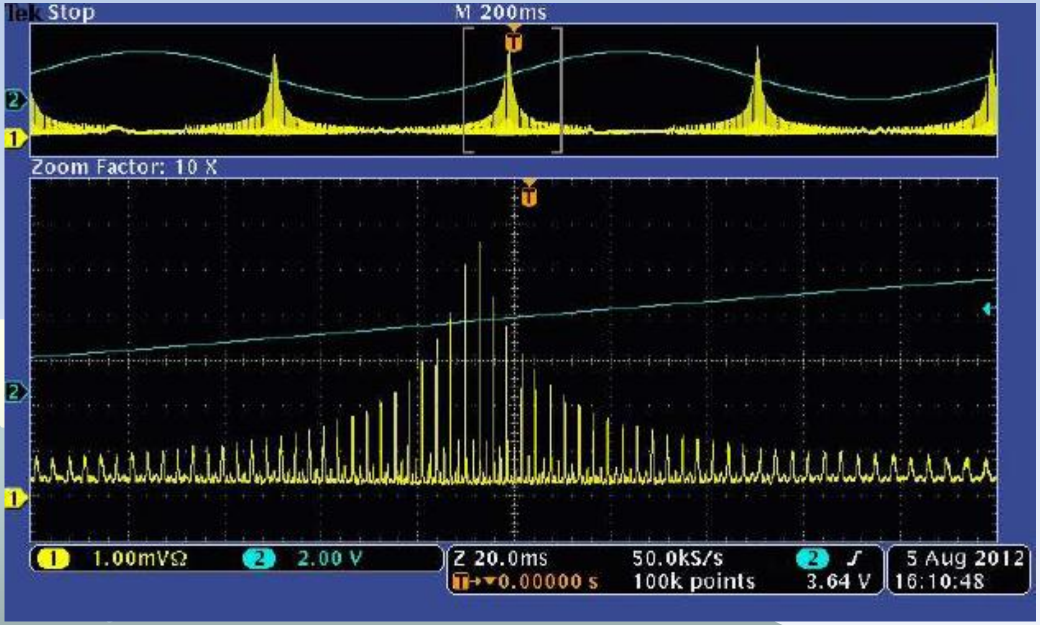




162.5MHz, 350fsec pulse duration, 43mW

1.3GHz seed laser produced by optical resonator and fiber oscillator.

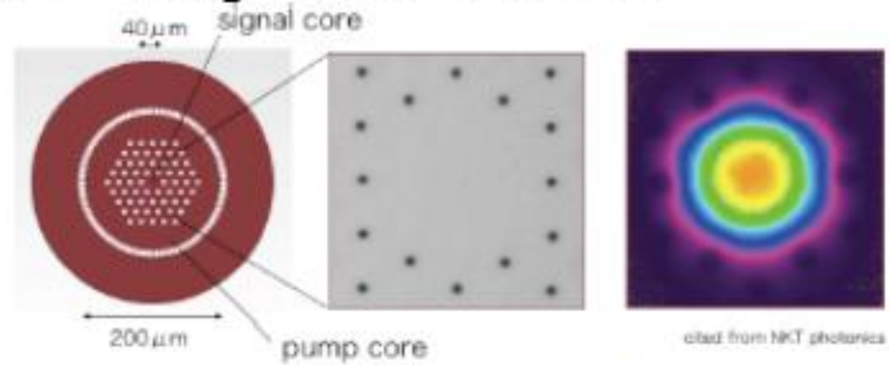




If we use high finesse thin optical cavity, we can generate micro bunches train within 8psec.

For example, two mirror cavity with the distance of 300μm can generate laser pulse train with pulse spacing of 2psec.

Yb doped Photonic Crystal Fiber



- Fiber based amplifier has been chosen for
  - high efficiency
  - easier heat treatment
  - good mode quality
- As a first choice
  - DC-200-40-PZ-Yb: most popular one
  - 976nm pump: for efficiency
- Test items
  - Test amplification at 1064nm, this wavelength is not optimal for Yb.
  - Model and understand the system. Optimize the length of fiber.
  - Non linearity at high power.

型番	DC-200-40-PZ-Yb-03
Signal Core	
Mode properties	Single mode
M^2	<1.3
Mode Field Diameter	29 ± 2 μm
Mode Field Area	650 ± 100 μm^2
NA @1060 nm	~0.03
Multimode Pump Core	
NA @950 nm	0.55 ± 0.05
Pump absorption @920nm	~3 dB/m
Pump absorption @976nm	~10 dB/m
Polarization Parameters	
Birefringence Δn	$1\cdot10^4$
Polarization Extinction Ratio	>15 dB
Physical Properties	
Signal core diameter	40 ± 2 μm
Inner cladding diameter	200 ± 5 μm
Outer cladding diameter	450 ± 20 μm
Coating diameter	620 ± 30 μm
Outer and inner cladding material	Pure silica
Coating material	HT acrylate

Pump optics

- Pump light used for test. (we used this because we got this for free.)
- Fiber output 75W LD (Jenoptik)
- Fiber core is 400μm, this should be input to PCF 1st crad of 200μm.
- Imaging lens system designed for x0.46 magnification.
  - acceptance : 3-σ in NA, 2-σ in area. seems ok.
- Feeling 200μm LD should be better if available. (now ordering at LIMO and DILAS)

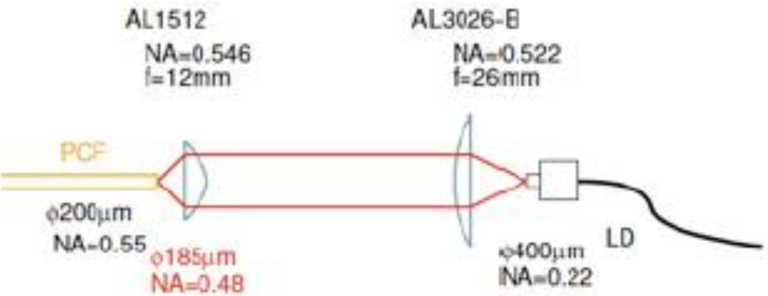


図 1: 設計した光学系

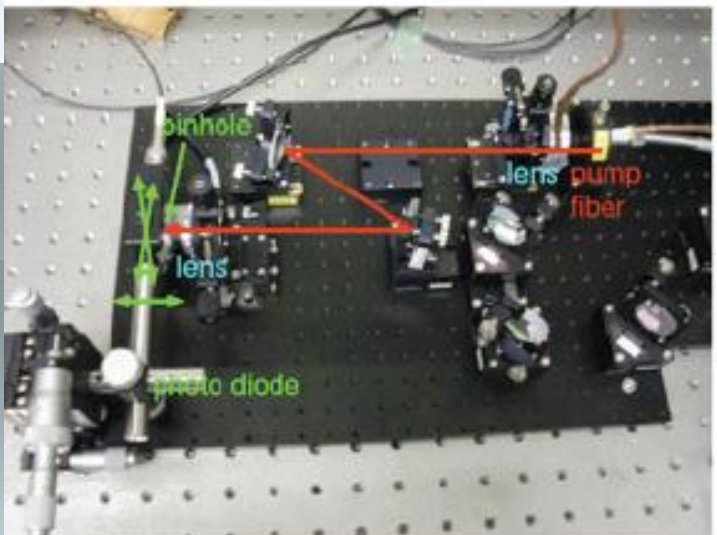
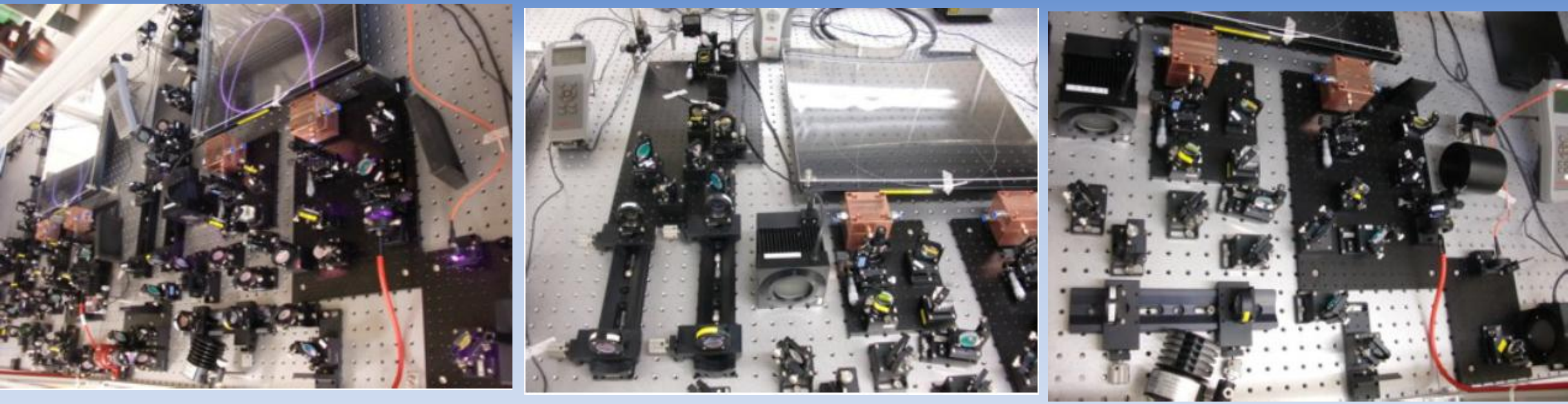
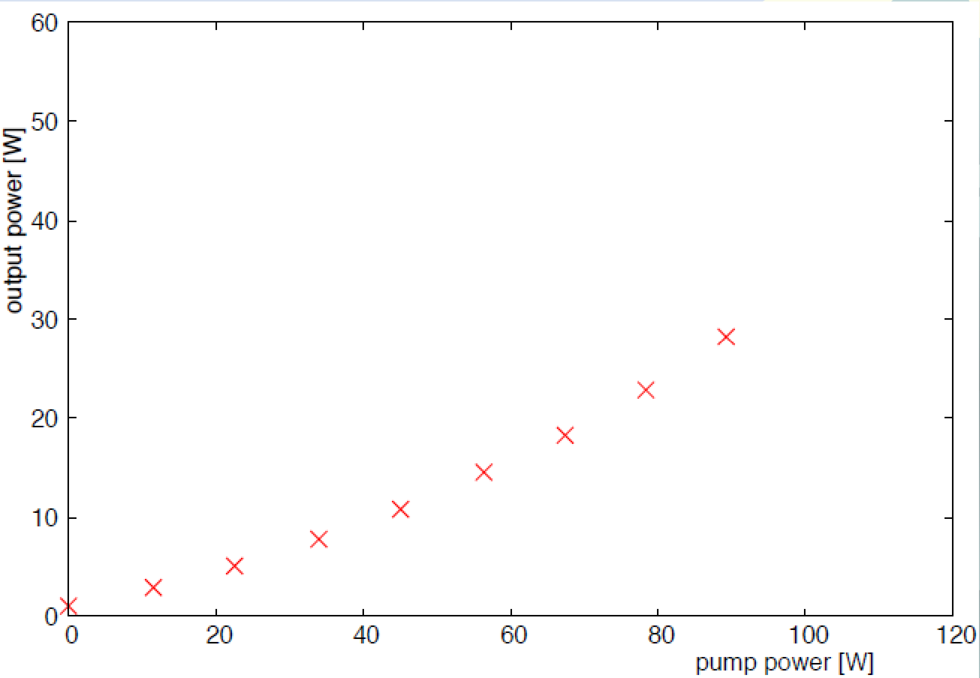


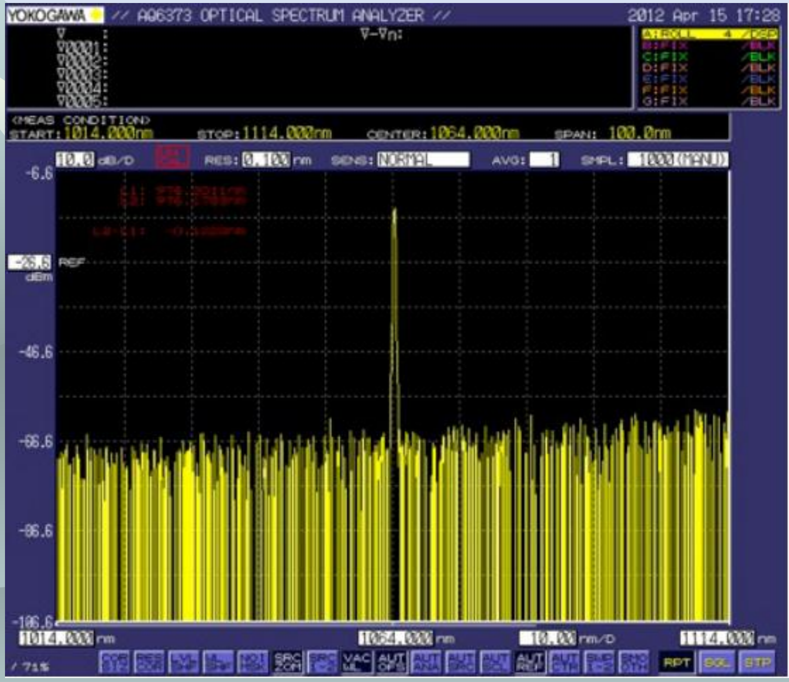
図 5: ビーム径測定のセットアップ

LD 型番	JOLD-75-CPXF-2P
ファイバコア直径	400 μm
ファイバ NA	0.22
ファイバコネクタ	F-SMA 905
PCF 型番	DC-200-40-PZ-Yb-01
励起光コア直径	200 μm
励起光 NA	0.55



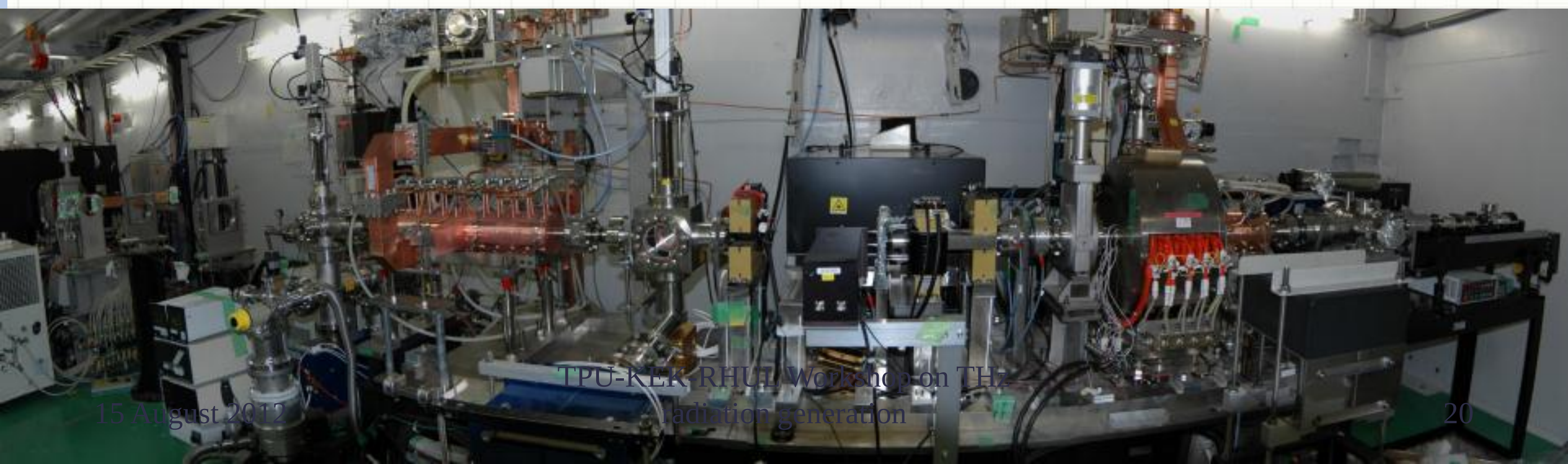
Set-up for fiber amplification test





Pulse duration from 100fs to 400fs using fiber laser is generated by simple system.

LUCX "2012 UPGRADE": THZ, 12-CELL BOOSTER



THz collaboration