Single-bunch Operation, Generation of Ultra-short Pulses at Storage Ring
And their Applications *(KEK International Center, Feb.28-Mar.1, 2005)*

Introduction on Single Bunch Mode and Ultra-Short X-Ray Plan at SSRF

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SSRF/SINAP

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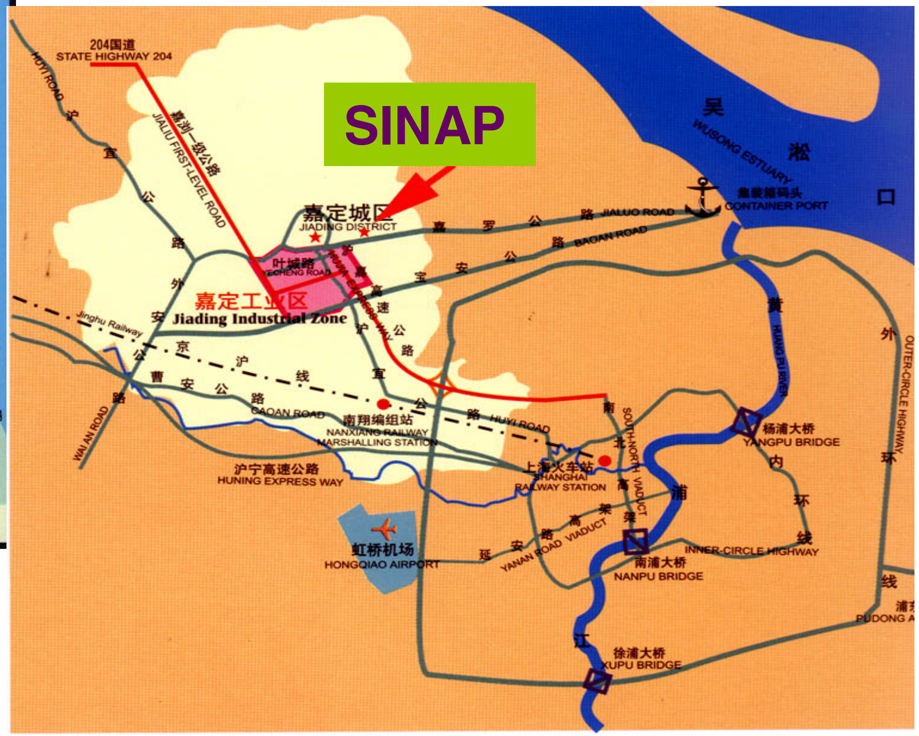
Outline

- Introduction
- Single Bunch Mode
- Ultra-Short X-Ray

I. Introduction



Map of Shanghai

- ❍ Rings Based:
- ●2nd ~ 3rd Generation SR
- ●Electron Beam Slicing
- ●X-ray SASE-FELs

- ❍ Linacs Based:
- ●FELs/X-ray FELs
- ●ERLs
- ●SPPS

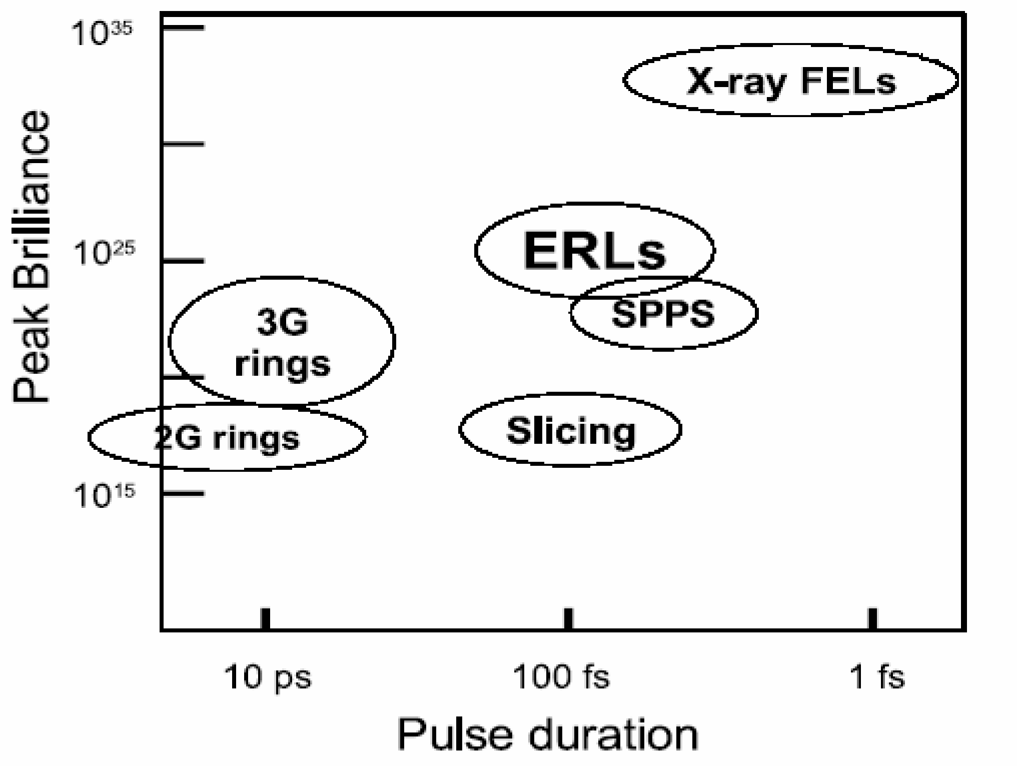


Fig. Peak Brightness versus pulse width for various X-ray sources (H. Winick)

❍ Light Based:

- Light microscopic
- Fluorescence
- XPS
- XRM
- Raman-micrscopic
- IR-micrscopic
- SMART project at BESSY-II
- Pump probe techniques

❍ Electron Beam Based:

- STM/AFM
- TEM
- SEM

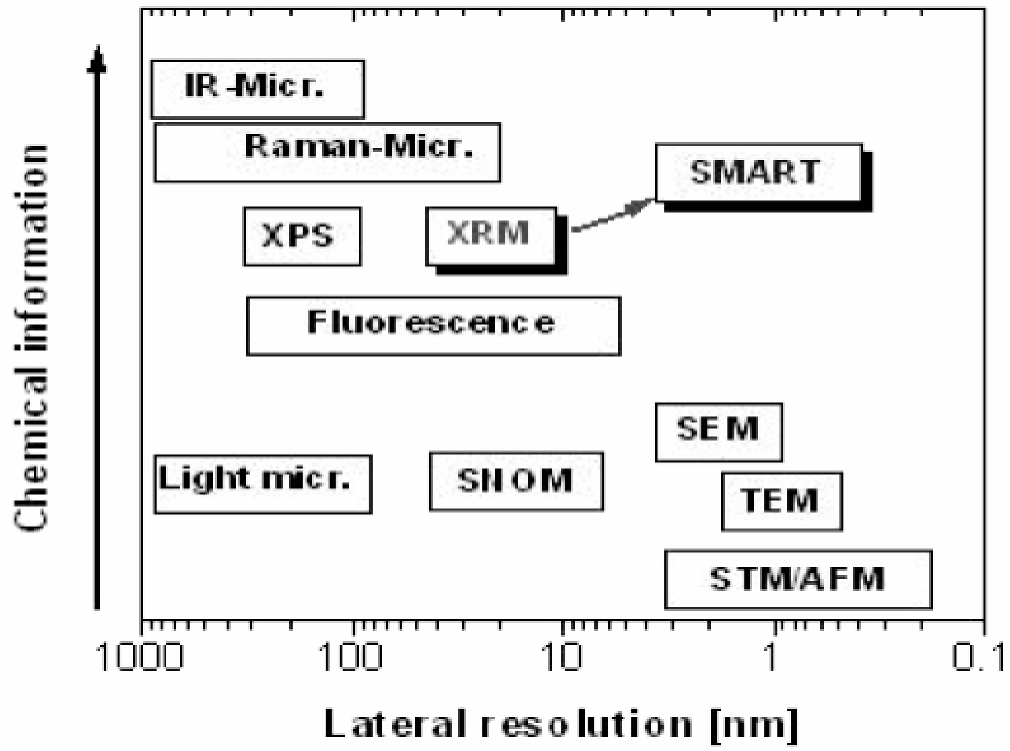


Fig. Chemical information provided by different spectromicroscopic probes versus their lateral resolution (A. Hitchcock et al)

SSRF (Shanghai Synchrotron Radiation Facility)

- SSRF 3rd generation SR:
  - E ~ 3.5 GeV, Emittance ~ 3.9 nm-rad
  - I_b ~ 5 mA, Beam Pulse width ~ 36 ps
  - Circumeference ~ 432 m

- 6-10GeV Linac for X-ray FEL (future plan)

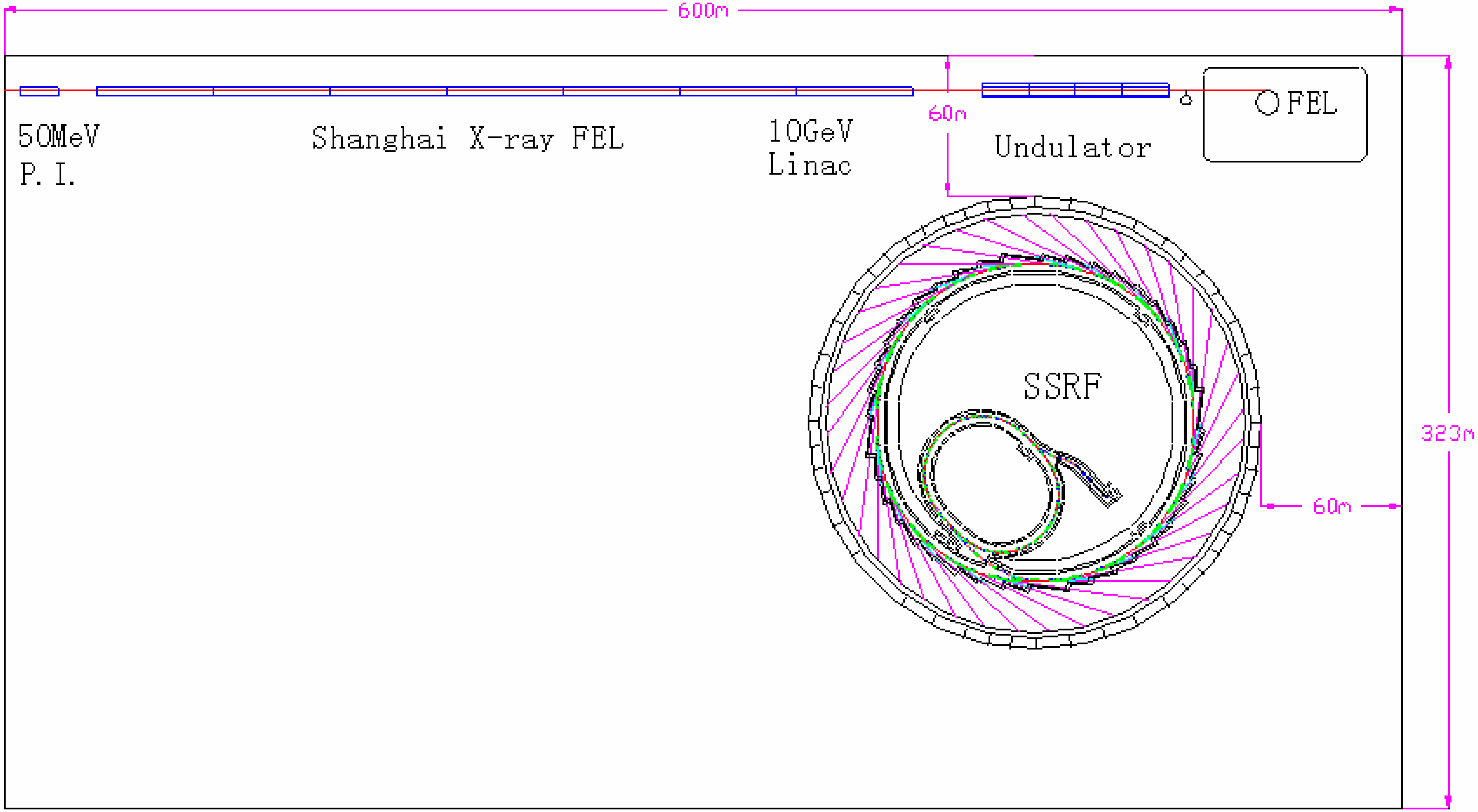


Fig. Layout of SSRF with X-ray FEL (Z. Zhao et al)

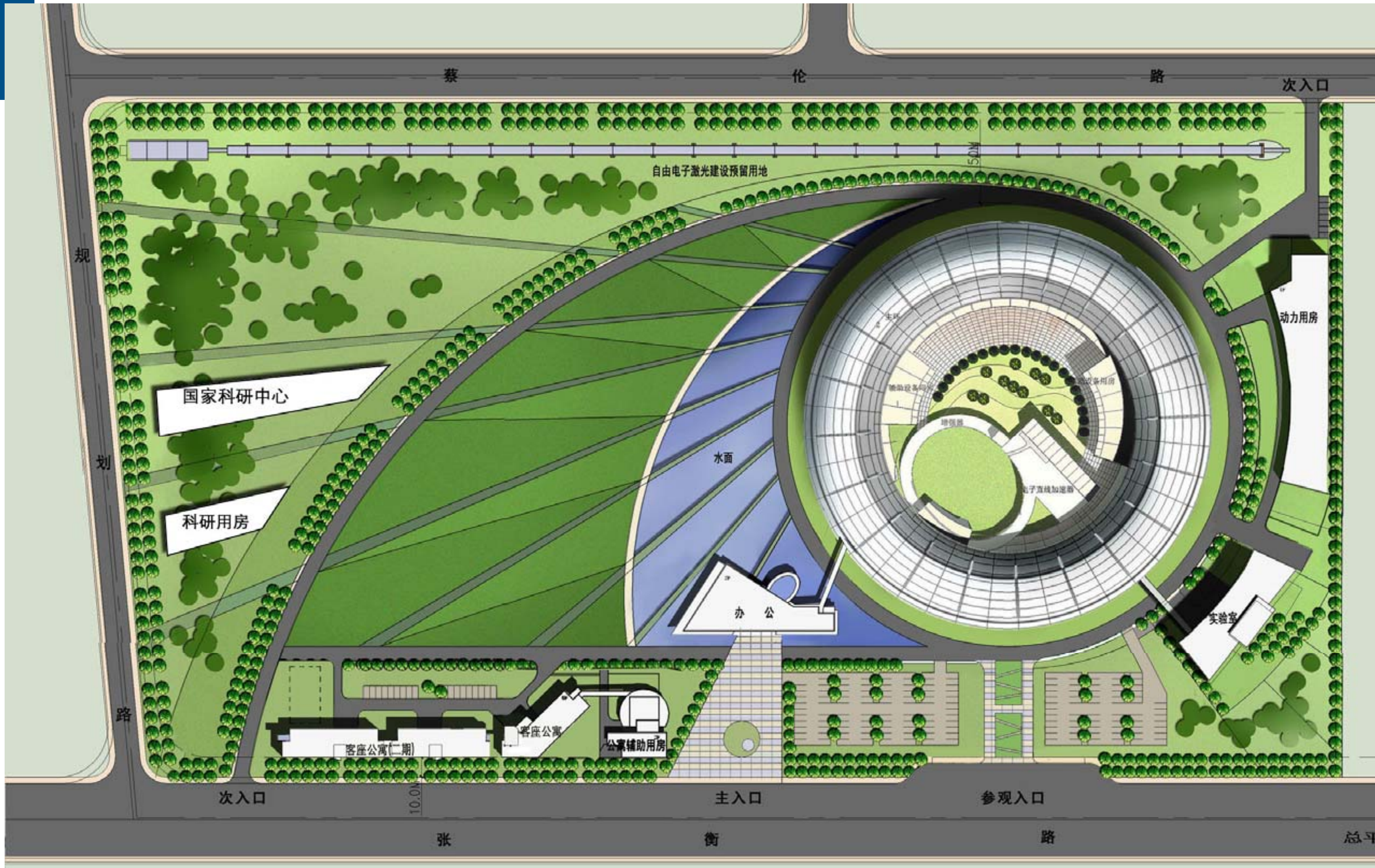
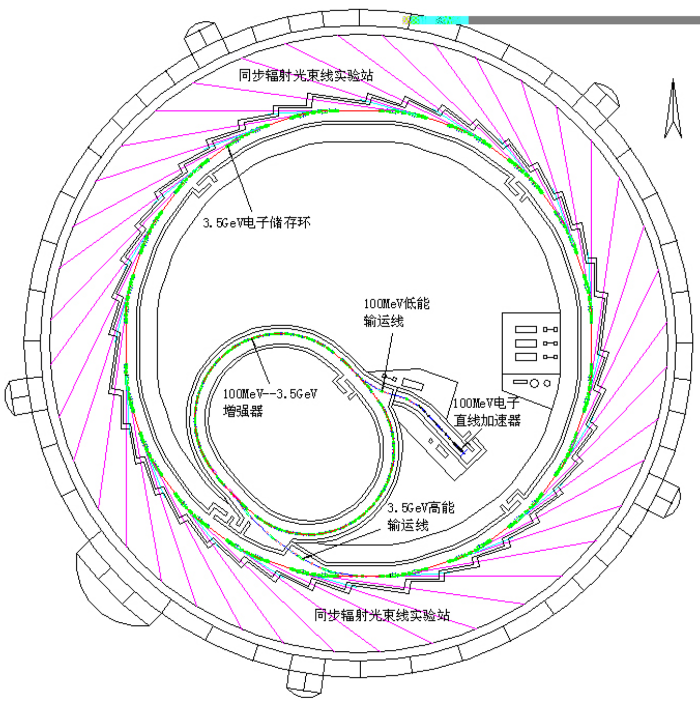
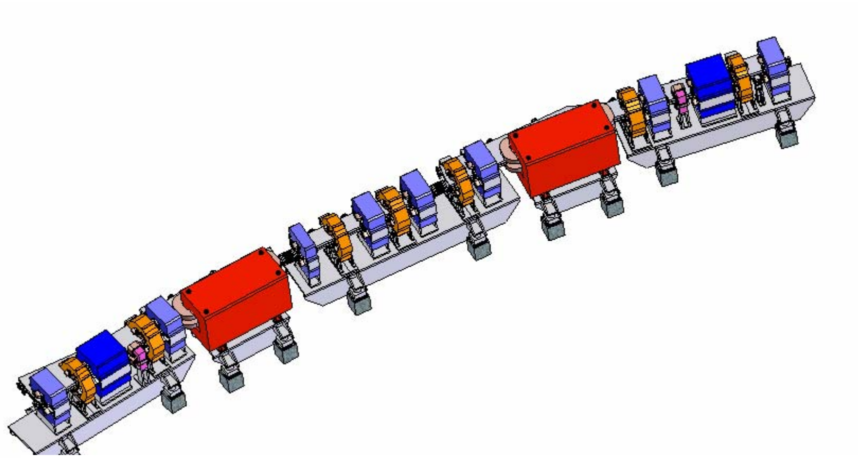


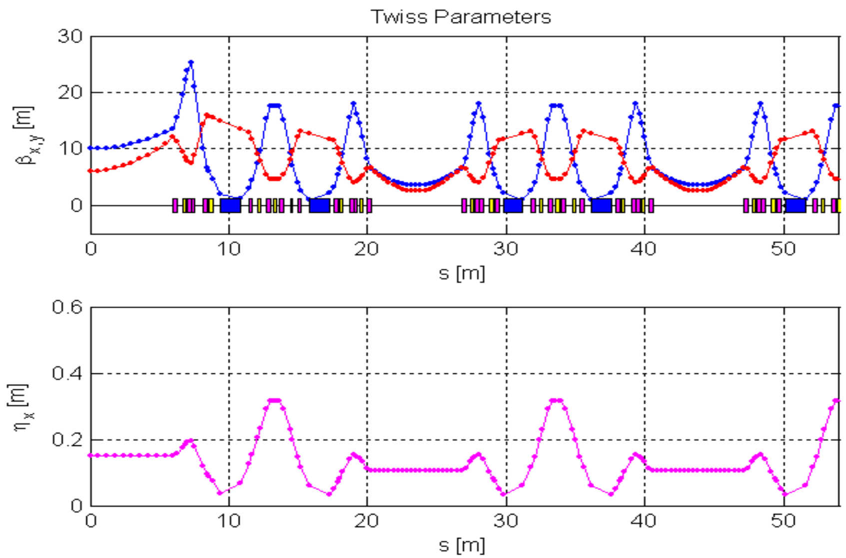
Fig. Bird view of SSRF with X-ray FEL plan

II. Single Bunch Mode

- ❑100MeV Electron Linac
- ❑3.5GeV Booster
- ❑3.5GeV Storage Ring







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SSRF Storage Ring Parameters

Lattice Structure	DBA	Low-emittance mode	Normal Mode
Enenrgy	GeV	3.5	3.5
Circonference	m	432	432
Natural Emittance	nm· rad	3.9	7. 97
Current：Multi-bunch Single bunch	mA	200~300 5	200~300 5
Number of Cells		20	20
Straights: Length×Number	m	12×4、6.5×16	12×4、6.5×16
$\beta_x/\beta_y/\eta_x$ in middle of long straight	m	10.0/6.0/0.15	10.0/6.0/0.05
$\beta_x/\beta_y/\eta_x$ in middle of standard straight	m	3.6/2.5/0.12	3.6/2.5/0.04
Betatron Tune Q_x/Q_y		22.22/11.32	22.22/11.32
Bunch Length	mm	4.0	4.3

The Pulse Structure of SSRF

- **Harmonic number h=720 (potential buckets in the ring), which may be filled with electrons in various ways.**

- **These pattern differ in total current, electron bunch structures and lifetime.**

- **Single bunch, two and few bunches, Beam Pulse width ~ 36 ps**

- **Beam Lifetime ~ 4.0 hrs, Top-up Injection needed.**

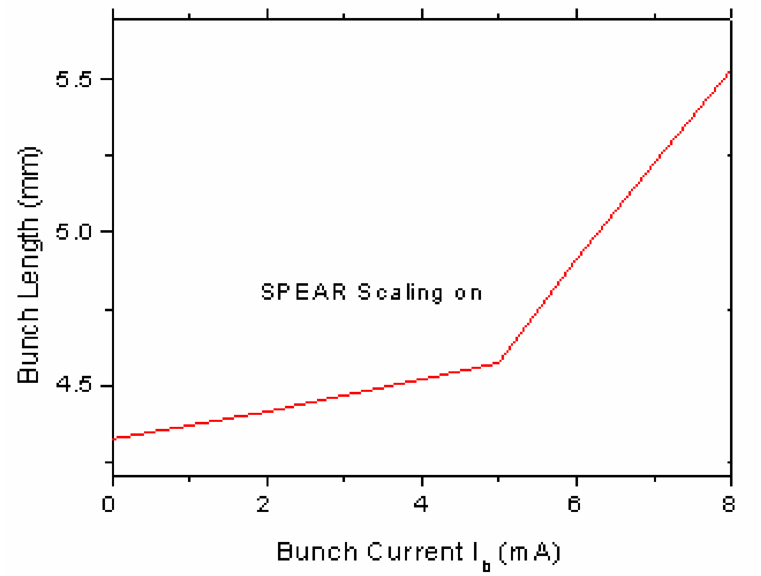


Fig. Bunch Length Vs Bunch Current, $Z_{//}$=0.4Ω

The High Speed Chopper System and its Synchronisation for picosecond experiments

- **The chopper was originally built for single bunch selection from the single bunch mode and hybrid mode at the ESRF.**

- **The main challenge was the extremely short time between pulses from the synchrotron. For example, in the multi-bunch mode, x-rays arrive every 2.0 ns, impossible to isolate mechanically.**

- **The only usable modes at present are the 1-bunch, the 8-bunch mode and the hybrid mode. The time between pulses is 1.44 μs, 0.18μs and 0.32 μs respectively.**

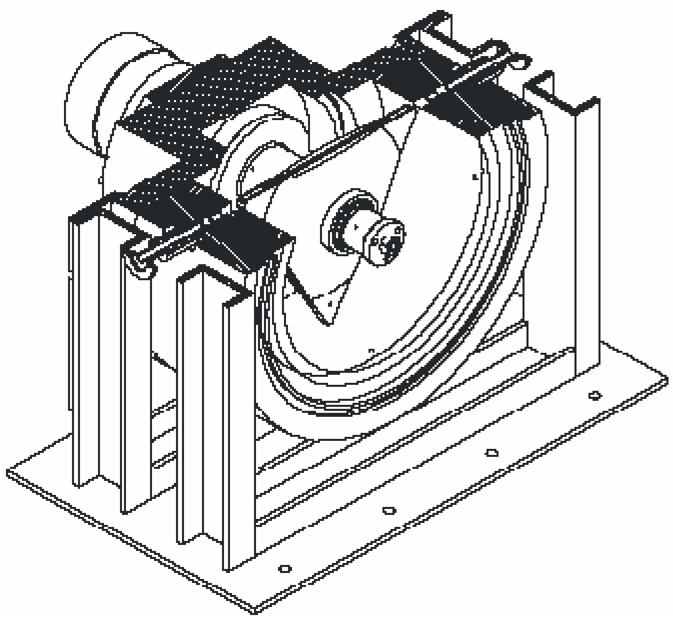


Fig. A three dimensional picture for the Mechanical chroper. Minimum opening time is 0.10 **μs**, Maximum opening time is 0.17 **ms**, Phase jitter 10 **ns**. (a fast rotating shutter).

Generation of Femtosecond Synchrotron Pules ----- Electron Beam Slicing

- The laser-induced energy modulation can be more than five times larger than the rms beam energy spread,

- Only a thin slice of electrons (temporally overlapped with the laser pulse) experience this modulation.

- The energy-modulated electrons are spatially separated from the rest of the electron bunch, in a dispersive section of the storage ring, by a transverse distance that is several times larger than the horizontal size of the electron beam

Ultrafast X-ray Science Facility at the Advanced Light Source

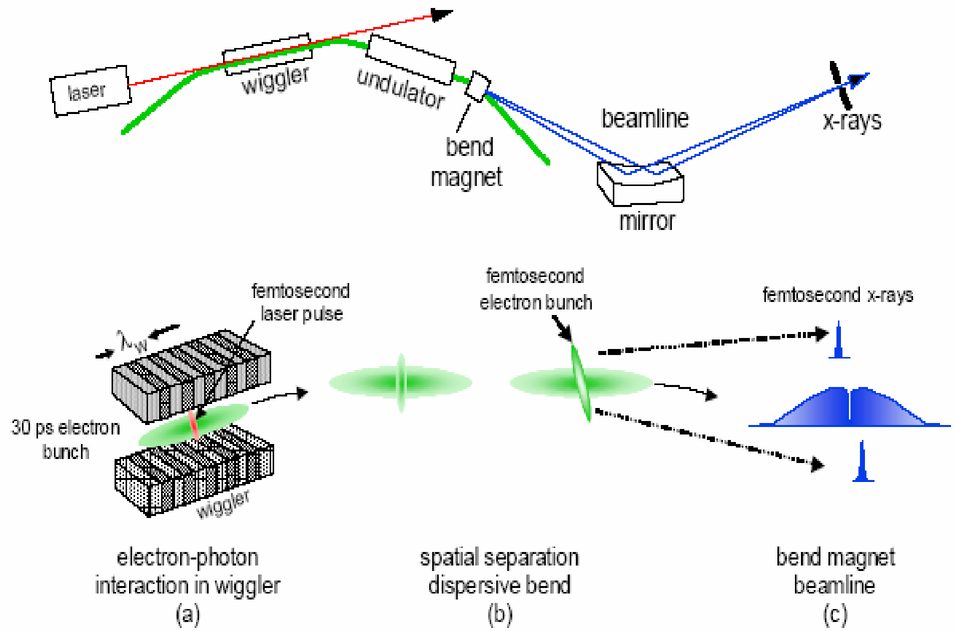


Figure 17. Schematic illustration of the technique for generating femtosecond synchrotron pulses, (a) laser/electron beam inter-action in resonantly-tuned wiggler, (b) separation of accelerated femtosecond electron slice in a dispersive section, (c) generation of femtosecond x-rays at an undulator or bend-magnet beamline.

The beam slicing method employs a femtosecond laser to modulate the energy of an electron bunch over the distance of the laser pulse length. To achieve a sufficient separation of the sliced electrons, the energy modulation must be several times larger than the energy spread of the electron beam ($E \geqslant 5E' \approx 13$ MeV at the SLS). Therefore,using state-of-the-art lasers, the electron beam energy cannot be much higher than 2.5 GeV.

For intermediate energy storage rings such as the SLS, this opens a unique avenue for time-resolved experiments: For the production of short photon pulses, the combined effect of the electron beam slicing method and the use of higher undulator harmonics means that high brightness sub-picosecond X-rays up to 18 keV are accessible at undulator beamlines specially developed at user facilities with a beam energy of about 2.5 GeV.

- Slicing method generates tipically 10^2 to 10^4ph/0.1BW per bunch, because the repetition rate of high power laser's repetition rate is limited to 1-4kHz, this is a serious drawback:

- But it can be implemented now at BESSY-II, ALS, SLS, SOLEIL(planned).

- The most favourable geometry is one in which the modulator (Wiggler) and the radiator (Undulator) are positioned in the same straight section of the ring.

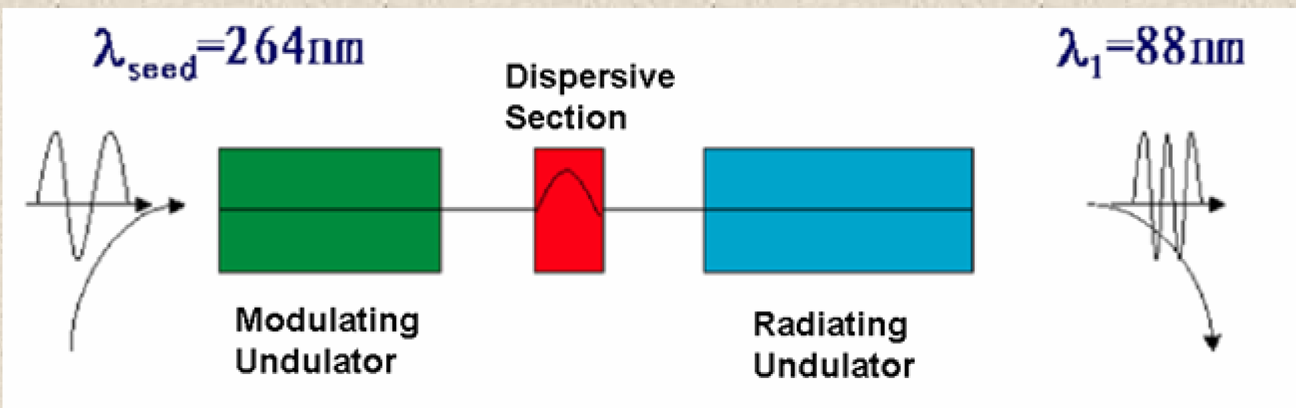
III. Ultra-Short X-ray FEL Plan

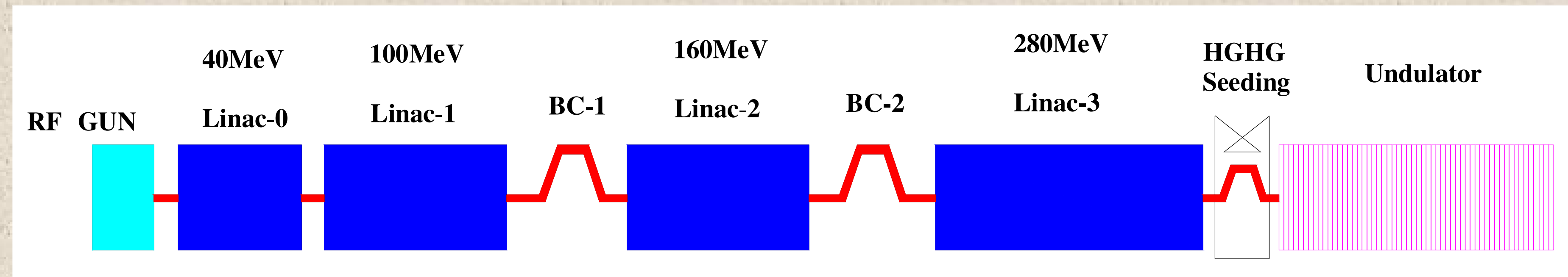
- SDUV-FEL
- Femtosecond/THz source
- Furture Shanghai X-ray FEL

SDUV-FEL Program

- SDUV-FEL (Shanghai Deep-UV Free-electron Laser)
- A Partly funded research program on FEL
  - R&D for high gain X-ray FEL
  - Develop an DUV-FEL test facility at SSRF/SINAP
  - Funded by CAS, MOST and NSF since 2000
  - 100~160MeV Linac under construction
- A joint research program of CAS
  - SSRF/ Shanghai Institute of Applied Physics
  - BFEL/ Institute of High Energy Physics
  - HLS/ NSRL, Univ. of Science and Technology of China

SDUV-FEL HGHG Scheme



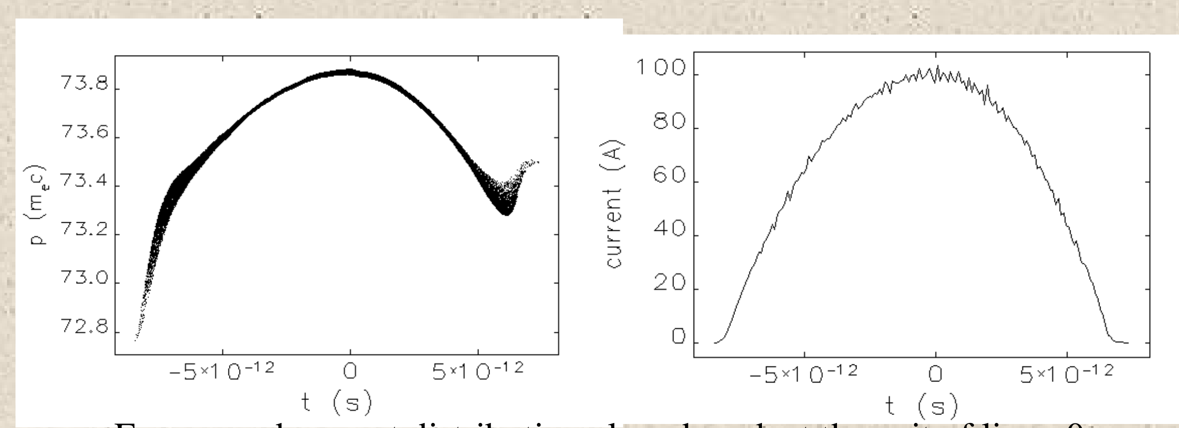


Phase I **Phase 2**

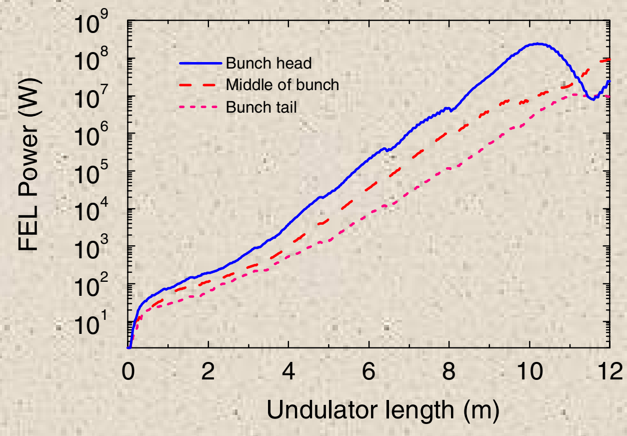
SDUV-FEL Performance

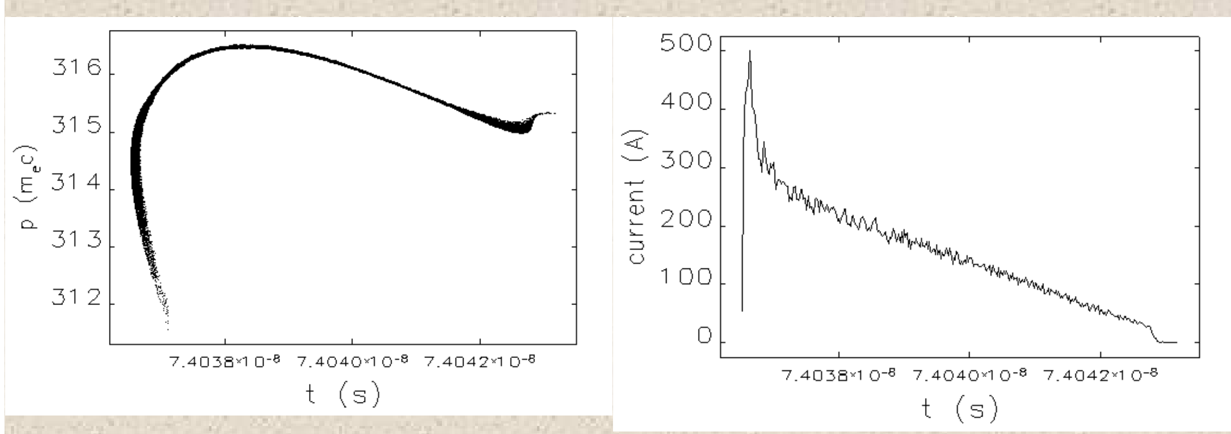
	Phase I	Phase II
FEL Parameters		
Wavelength (nm)	264	88
Output Power (MW)	~80	~140
Gain Length (m)	~0.7	~0.8
Electron Beam Parameters		
Energy (MeV)	~159	~276
Peak Current (A)	300	400
Emittance (mm-mrad)	6	4
Local Energy Spread (rms)	<0.1%	
Undulator Parameters		
Period (cm)	2.5	
Gap (cm)	1.0	
Length (m)	~10	

Start-to-End Simulation (260nm SASE)

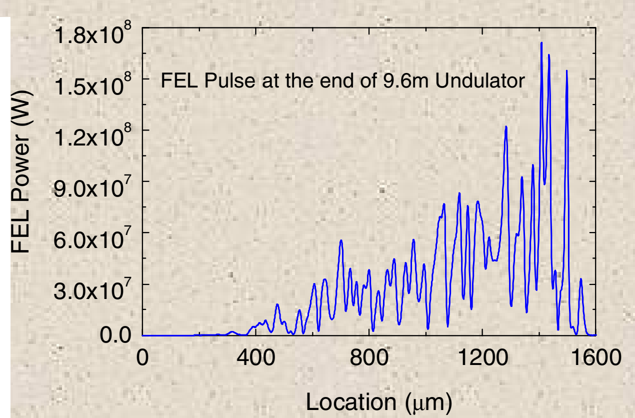


Energy and current distribution along bunch at the exit of linac-0



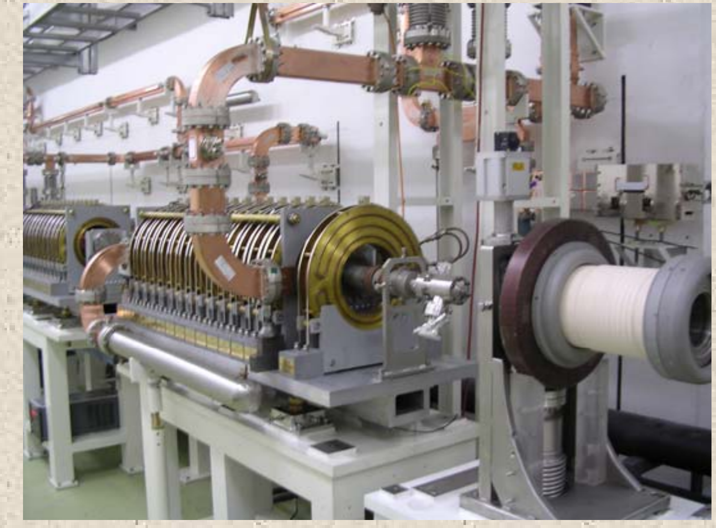


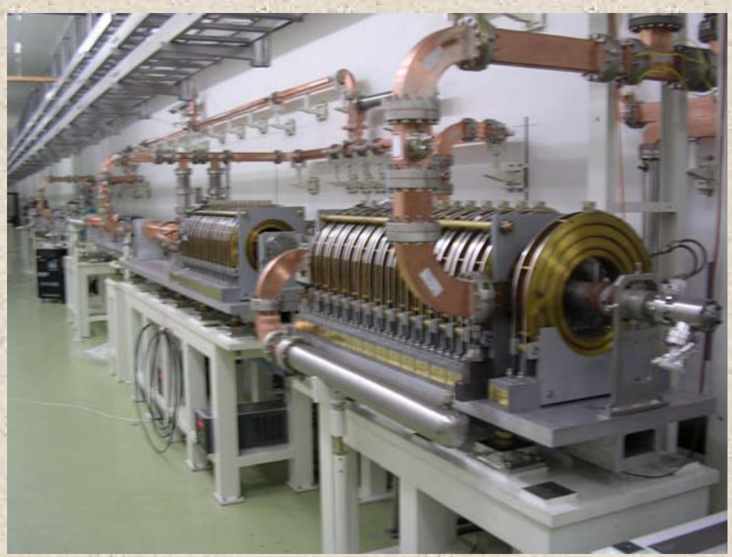
Energy and current distribution at the entrance to undulator



SASE FEL at 260nm

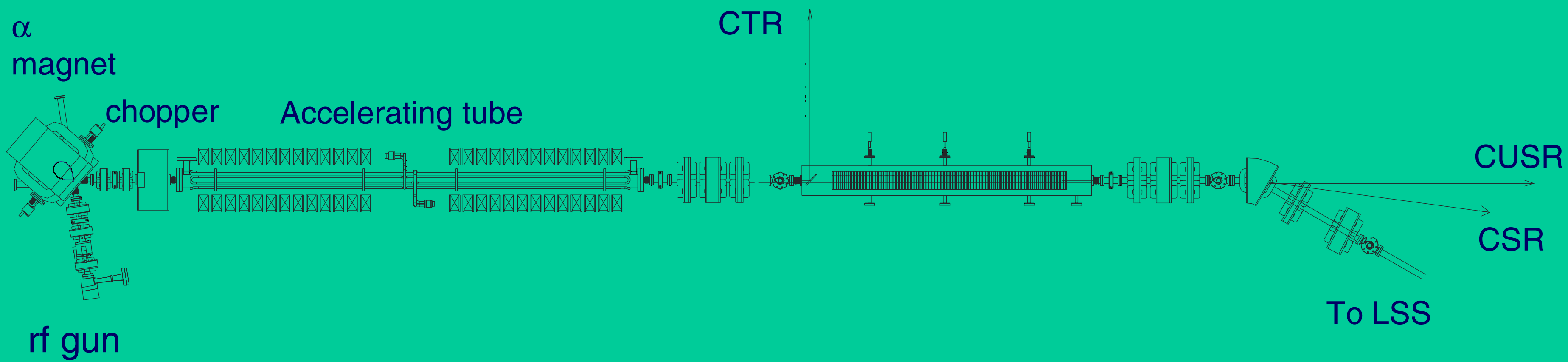
SDUV-FEL Linac





Femtosecond/THz source

- Femto-second electron facility.
- Coherent THz source — Coherent transition radiation and synchrotron radiation.

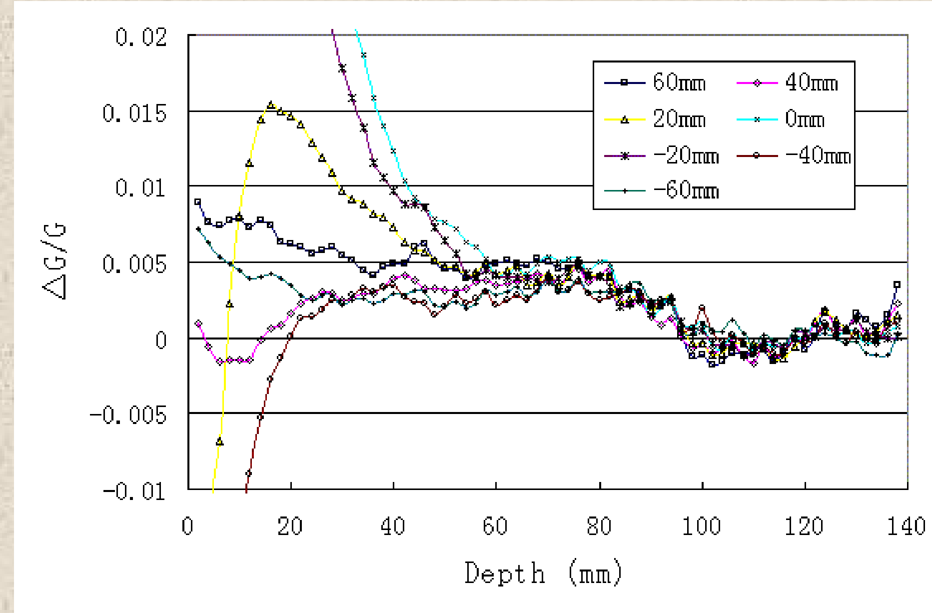


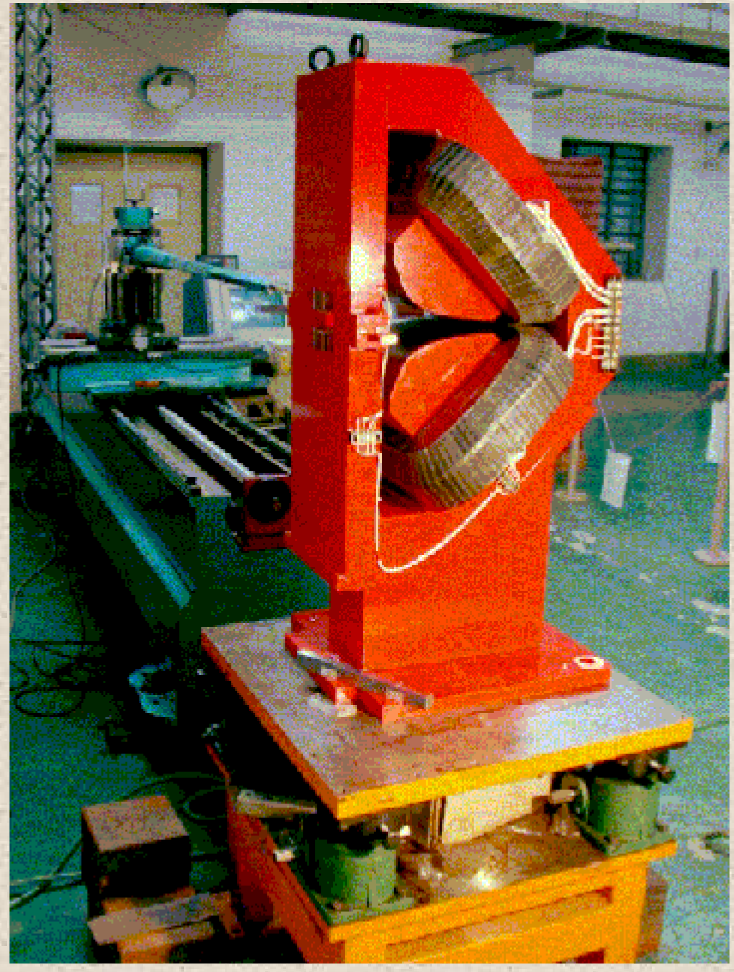
Parameters of the Coherent FIR Source (designed)

Frequency	THz	0.3~5
Pulse flux	photons/(pulse·1%bw)	10^8~5×10^{14}
Radiation power per pulse	μJ/(pulse·1%bw)	10^{-7}~0.1
Average flux *	photons/(s·1%bw)	10^{12}~10^{19}
Angular divergence	mrad	10~50

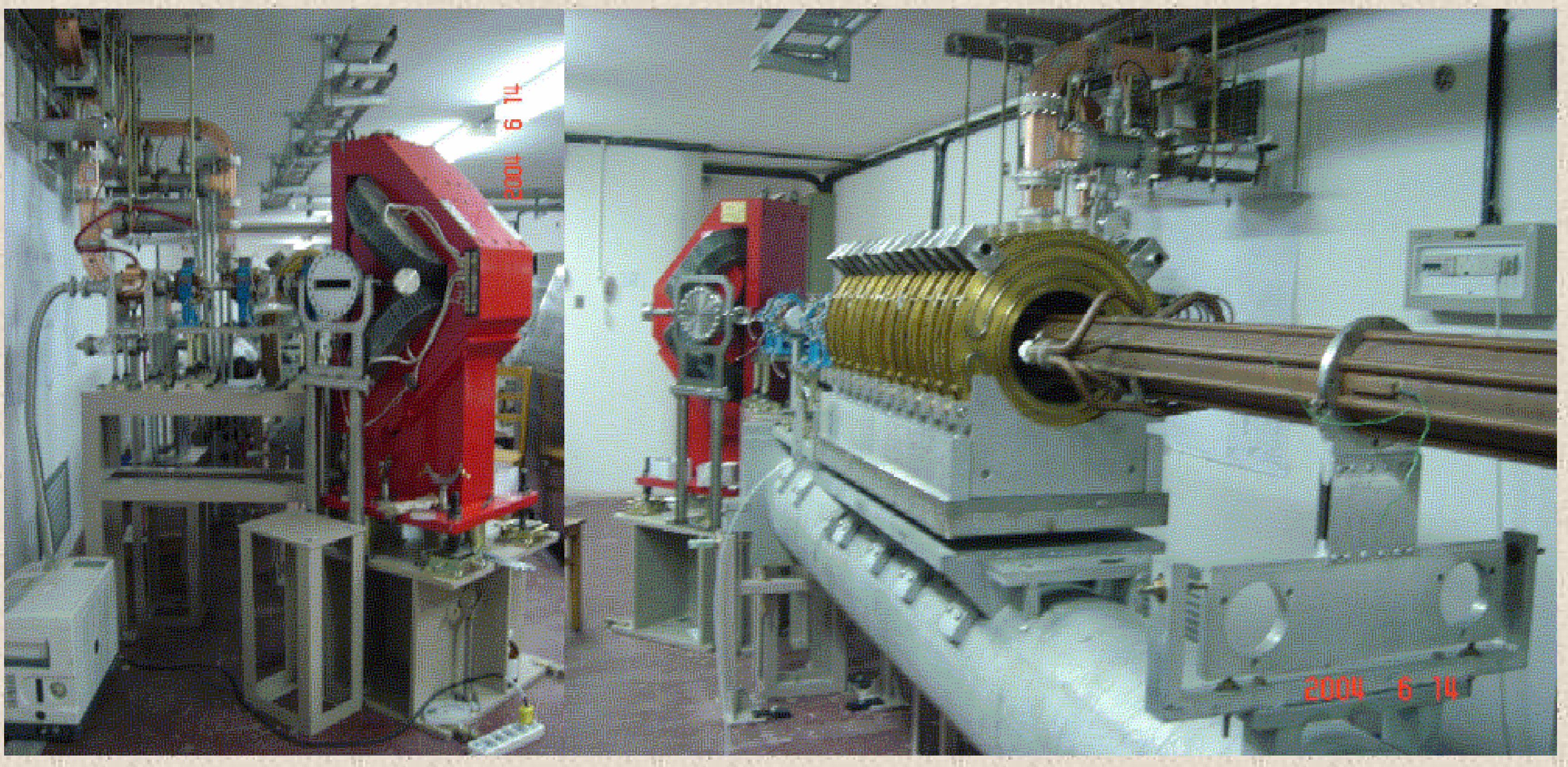
* 10 macropulse per second. One marcopulse contains more than 1000 micropulse.

Alpha Magnet

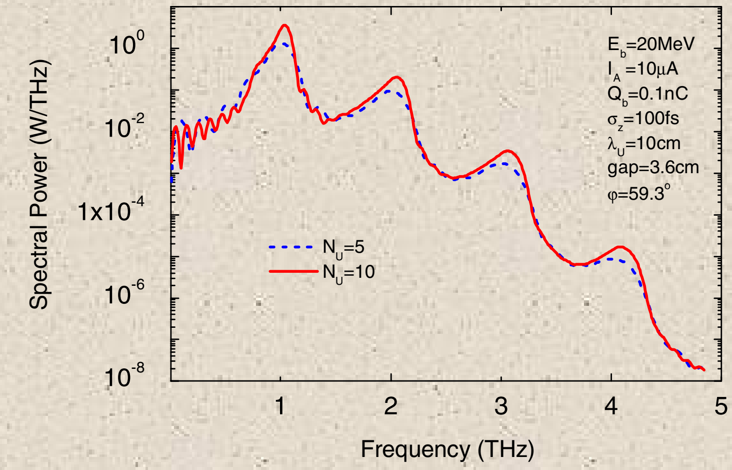




fs-Linac



EPU for THz



Beam Energy	**20 MeV**
Period Length	**100 mm**
Period Number	**5**
Gap	**36 mm**
Vertical Peak Magnetic Field	**0.59 T**
Horizontal Peak Magnetic Field	**0.35 T**

Furture Shanghai X-ray FEL

- 100~300 MeV DUV (70~300nm) FEL
- 540 MeV soft X-ray (3 ~ 10nm) FEL
- 6~10 GeV X-ray FEL (Future Plan)


Thanks