The FEL programs at Shanghai Institute of Applied Physics (SINAP)

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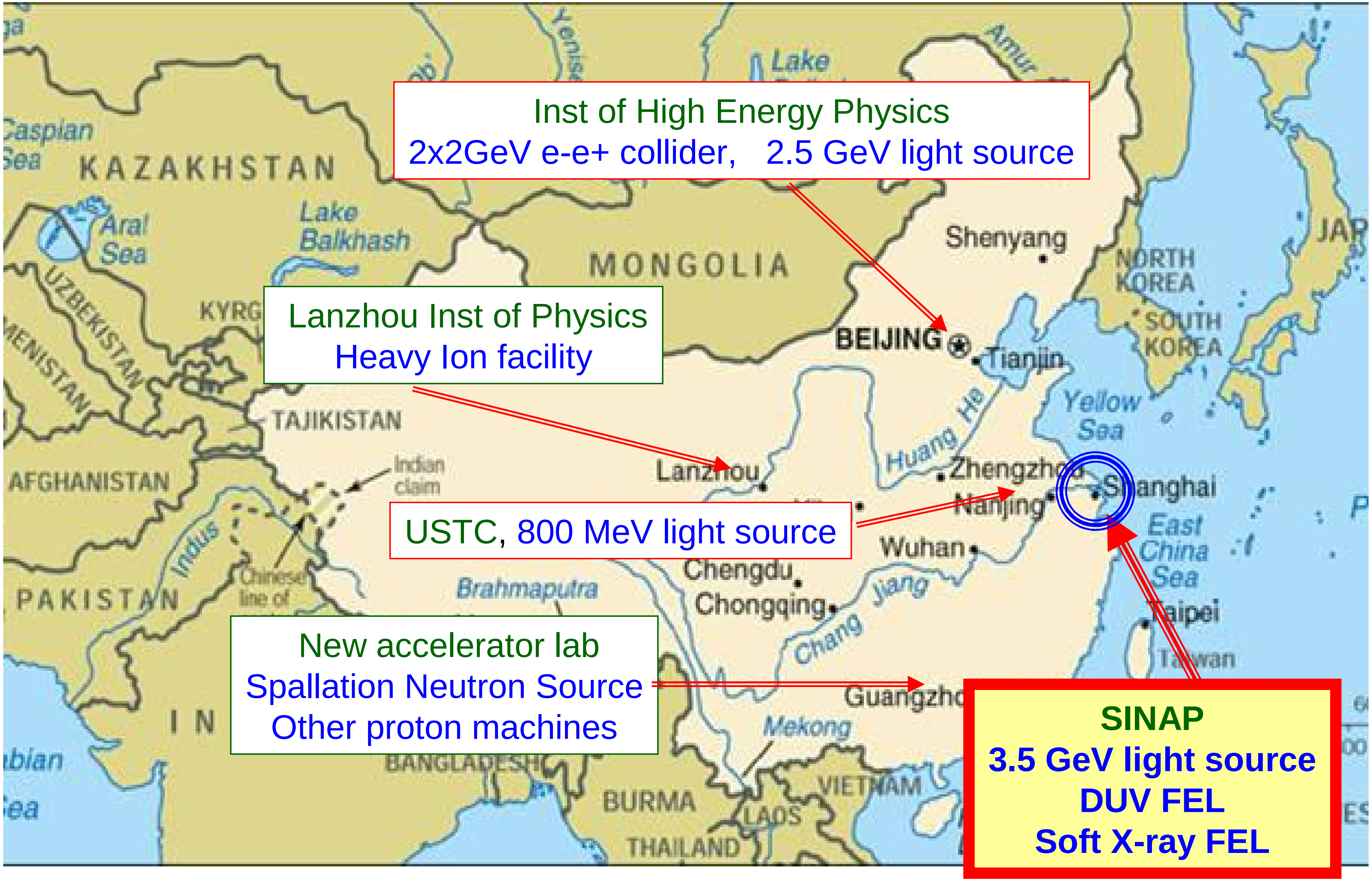
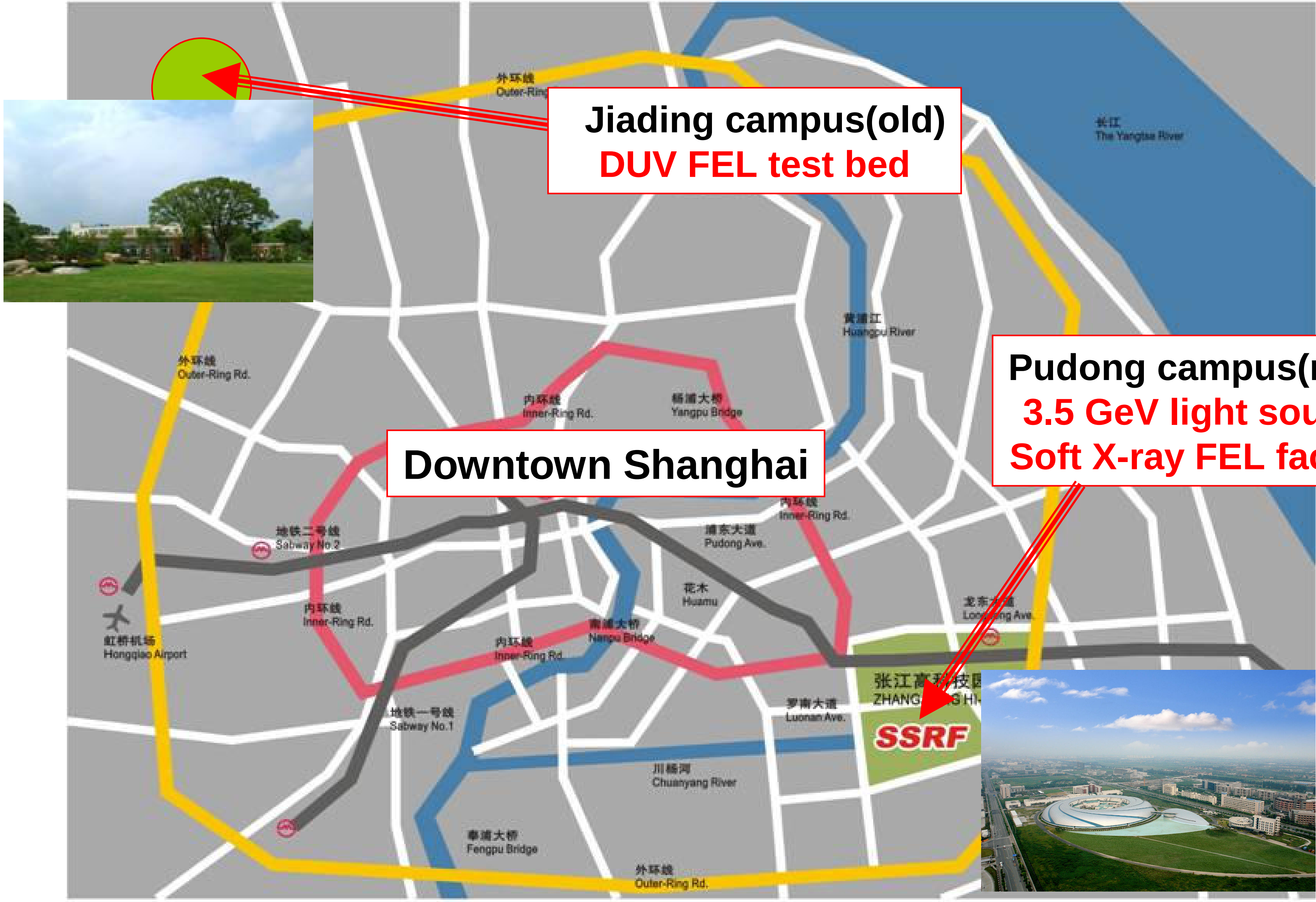
Outline

- About SINAP
- DUV FEL test bed
- Soft X-ray FEL test facility
- Summary

Major accelerator labs in mainland China



Shanghai Inst of Applied Physics (SINAP): old and new campus



Brief history

Before 1998: no significant research/facility
on high energy accelerators

1998: proposal of a medium energy light source,
R&D starts(100 MeV prototype linac, etc)

2001: light source project pending,
proposal for **a DUV FEL test bed**

2004□3.5 GeV light source approved,
construction starts on 12/25

2007: ring commissioning, beam stored on 12/24□
location of a **soft X-ray FEL** decided to be at
SINAP

New SINAP

Ultimate goal:

Accelerator-based Photon Science Center

Medium Energy Light Source &
Linac-based (hard) X-ray FEL

Shanghai Light Source at a glance

Light source: 3.5 GeV, cir=432m, 3.9nm emittance, 20 straights(4x12m), superconducting RF cavities

Current status of light source, briefly

- Injector chain meets design goals
- Ring commissioning: fast and smooth

    300 mA@3.5 GeV

    emittance: ~3.9 nm@3.5 GeV, lifetime >20 hrs

    orbit stability: ~1um level with slow FB

- Open to users since May, 2009
- Seven beamlines in use, 20 more in next 5 years

What's next? →

Free Electron Laser

FELs in SINAP

- Commissioning:

  XUV FEL test bed, 160 MeV linac,

  Seeded FEL experiments, like

  HGHG (High Gain Harmonic Generation) ,

  Echo, HHG, etc.

  2009-2012

- Design:

  Soft X-ray FEL test facility, 840MeV-1.3 GeV linac,

  Seeded FEL, waiting for government approval.

- Ultimate goal:

  Hard X-ray FEL user facility, 6-8 GeV warm linac,

  L-S-C-band, HGHG or SASE? To be decided.

DUV FEL test bed in SINAP

- Located in old campus
- Based on an existing proto-type linac injector for the light source
- Slow progress due to funding/manpower issues
- Boosted by progress on soft X FEL and LS
- Now most hardware ready for stage 1
- Beam test begins
- First FEL in 2009

Main parameters for Shanghai Deep UV FEL

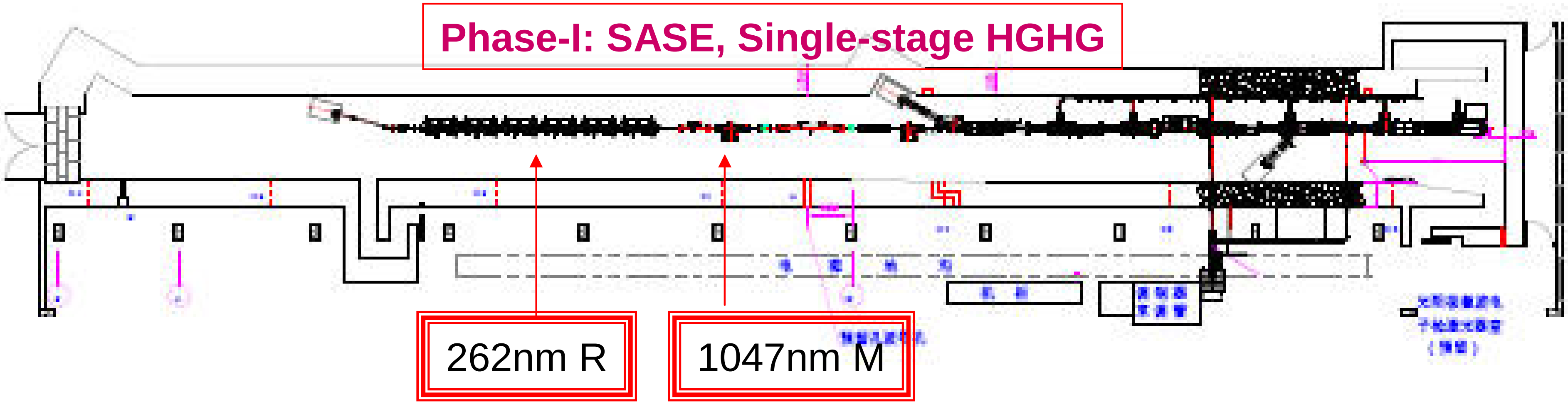
- **Electron beam**□
  E **= 160 MeV, *I*p > 300 A, *ε* < 6.0 mm-mrad,**
  energy spread< 0.02%, bunch length: 2~3 ps
- **Seed laser**□
  ***λ*s=786nm(1047nm), *τ*=*1*00fs(a few ps), *P*s : 1~100 MW**

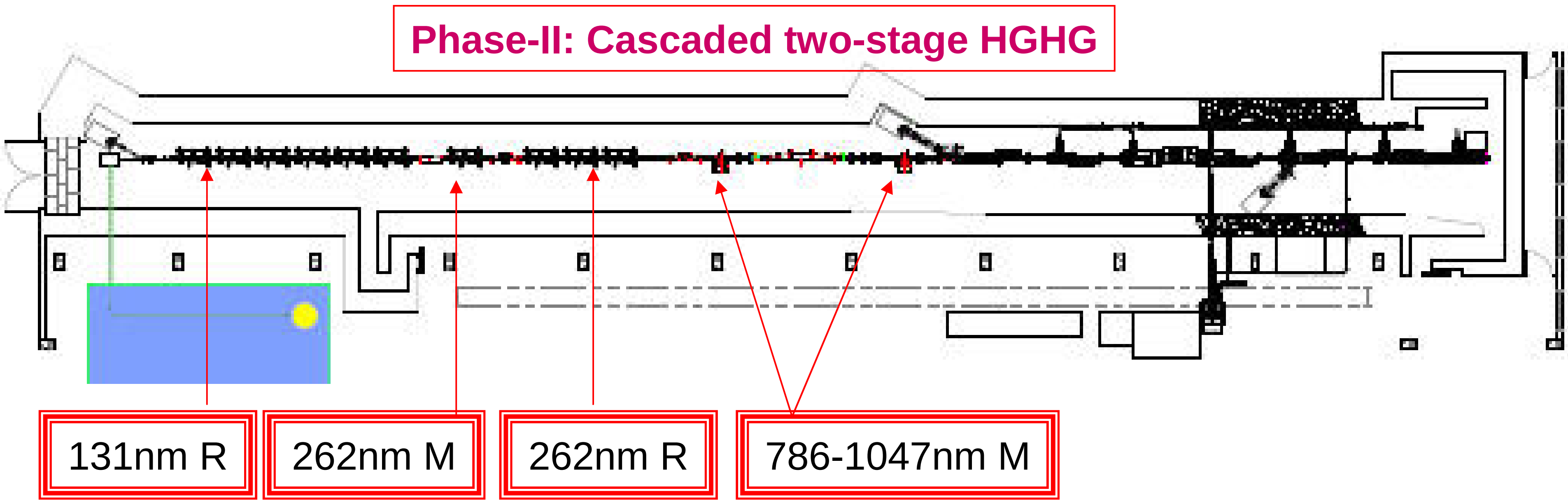
	stage-1	stage-2
Modulators:	**stage-1**	**stage-2**
***λ*u (mm)**	**50**	**25**
***a* u**	**1.45**	**1.02**
***L*m (m)**	**0.5**	**1.5**
Radiators:	**stage-1**	**stage-2**
***λ*u (mm)**	**25**	**18**
***a* u**	**1.02**	**0.65**
***L*r (m)**	**9**	**9**
***β* (m)**	**3**	**3**
***λ-fel*□nm□**	**262**	**131**

SDUV: 6th High Gain FEL user facility in world

Project	Type	Location	Country	e-Beam(GeV)	Photon (nm)	Status	
LEUTL	SASE	APS	USA	0.22	660-130	Since 2001	
TTF I	SASE	DESY	Germany	0.3	125-85	Since 2002	
SDL DUV-FEL	HGHG	SDL/NSLS	USA	0.145	400-100	Since 2002	1
FLASH (TTF)	SASE	DESY	Germany	1.0	12 - 6	Since 2006	2
SCSS Prototype	SASE	SPring-8	Japan	0.25	150-50	Since 2006	3
LCLS	SASE	SLAC	USA	15	0.15	In 2008	4
SCSS XFEL	SASE	SPring-8	Japan	8	0.1	In 2011	
Euro XFEL	SASE	DESY	Germany	25	0.1	(in 2014)	
Soft X-ray FEL	HGHG	BESSY	Germany	2.3	64 - 1.2	proposal	
SPARC	SASE	INFN Frascati	Italy	0.15	500	in 2007	
FERMI	HGHG	Trieste	Italy	1.2	10	In 2009	5
SDUV	**HGHG**	**Shanghai**	**China**	**0.2**	**262-44**	**in 2009**	6
ARC-EN CIEL	HHG	Saclay	France	0.7	1	proposal	
PAL XFEL	SASE	Pohang	Korea	3.7	0.3	proposal	
PSI XFEL	SASE	PSI	Swiss	3.7	1	proposal	

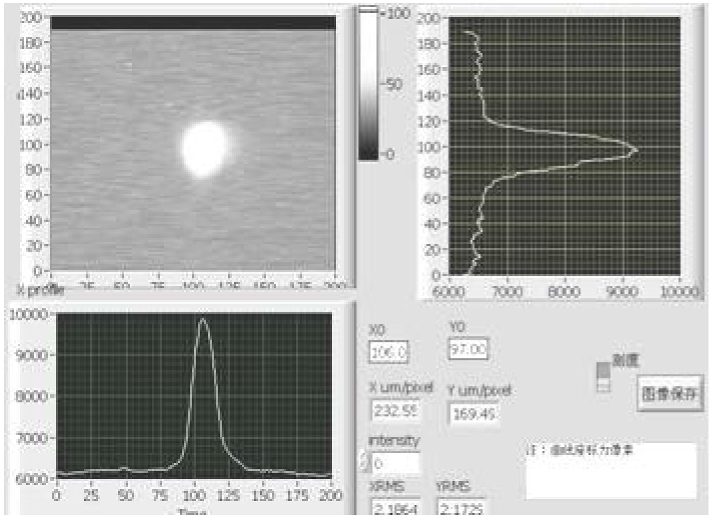
SDUV□ Phase-I (2009) and phase-II (2010)





100 MeV linac proto type for light source

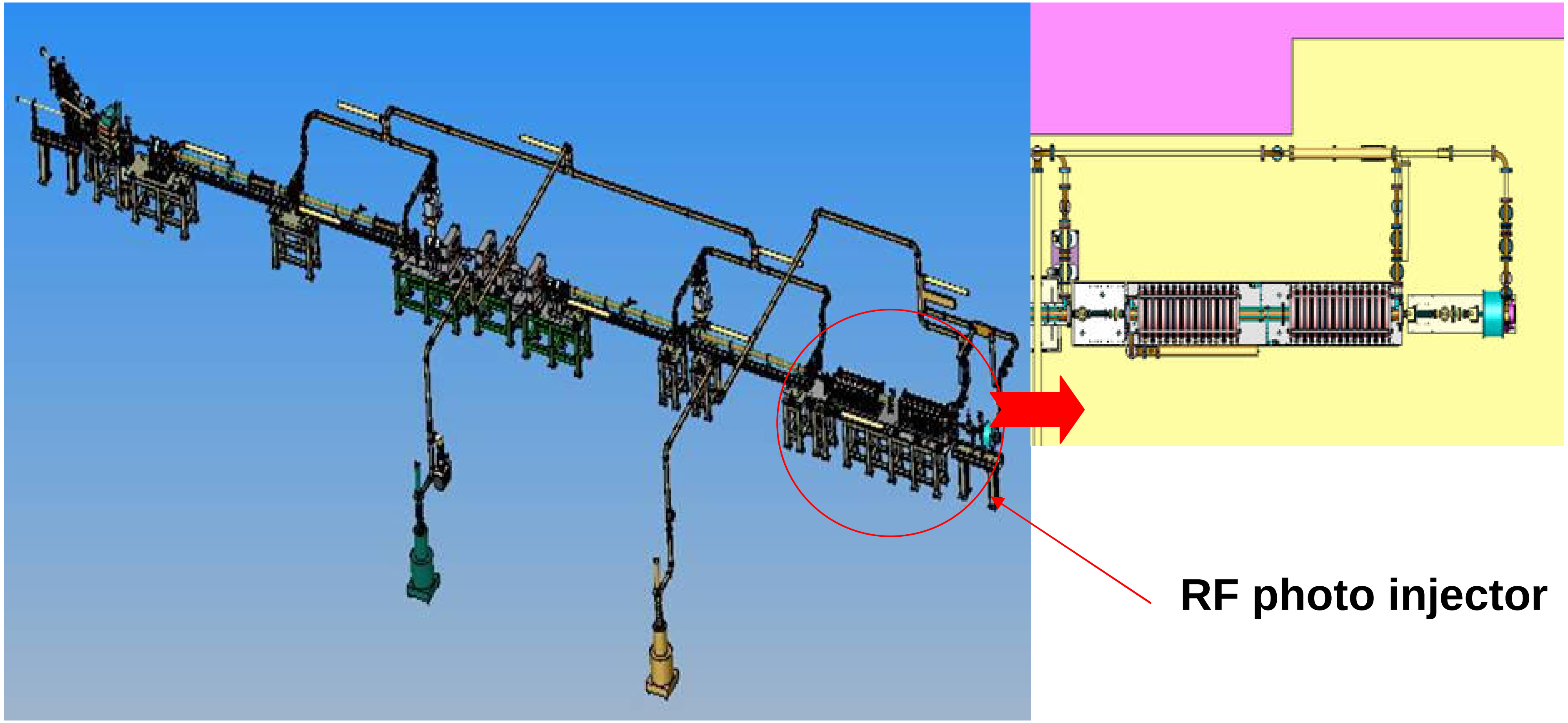
Parameters	Unit	Single bunch	Multi bunch
Energy	MeV	110	100
Energy spread (rms)	%	0.5	0.9/0.5
Normlized emittance (rms)	mm·mrad	60	140/80
Pulse length(FWHM)	ns	1.0	324/175
Beam current (rms)	mA	1280 (peak)	323/292 (peak)



Linac was commissioned in 2005

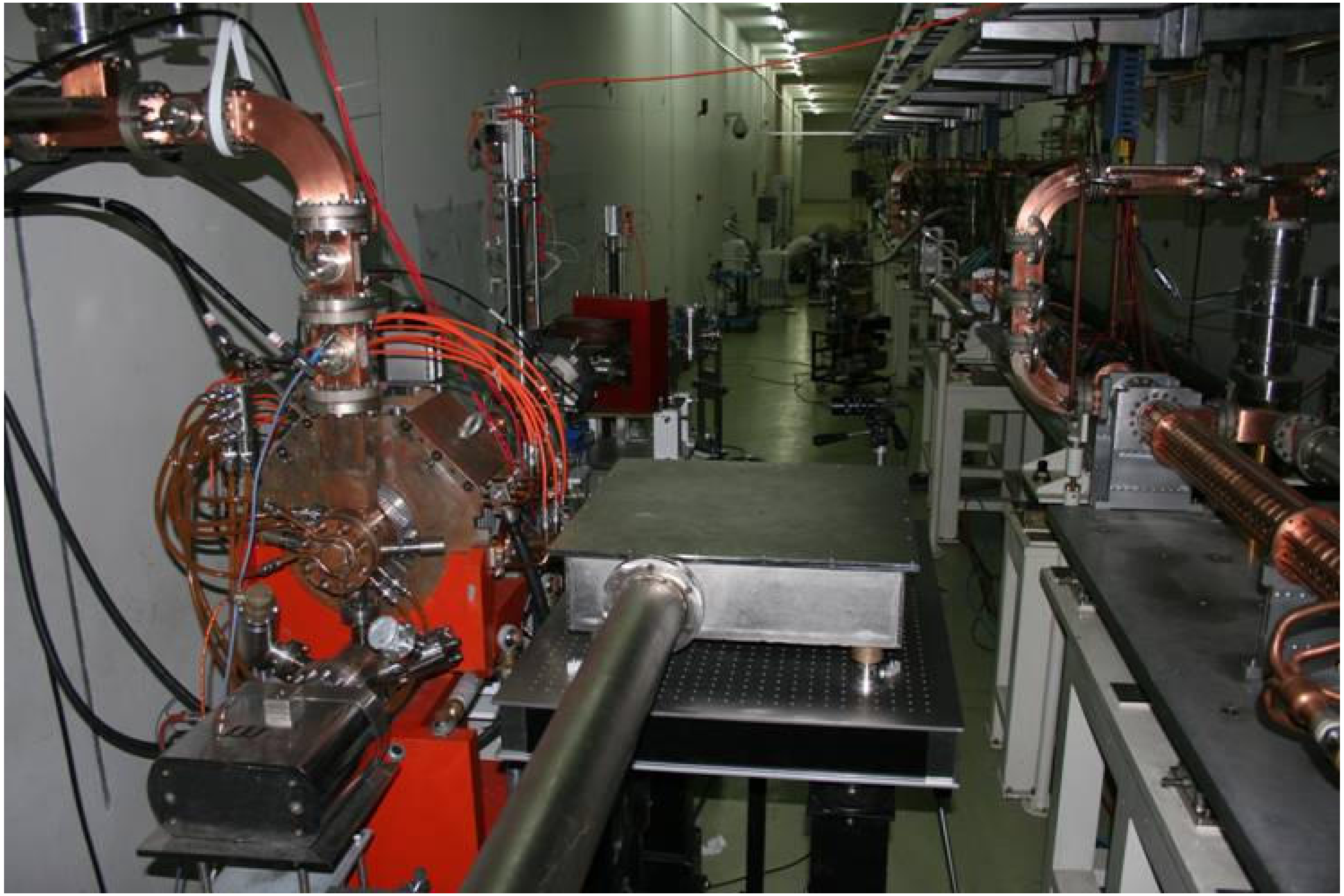
Upgrade to 160 MeV

100kV-ns grid gun and 15 MeV buncher of the existing 100MeV Linac is replaced by a 40MeV injector consisting of photo-cathode rf gun and an accelerating section.



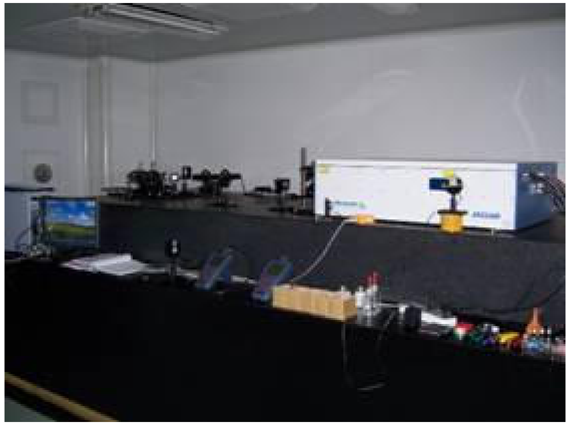
RF photo injector

Photo-injector on test bench till this fall



SDUV: Laser system for photocathode RF gun

- **Jaguar-QCW-1000 Laser (+FHG) and Synchronizer CLX-1100 (Switzerland Time-Bandwidth Products□Inc) has been chosen**
- **Commissioning since 2007**



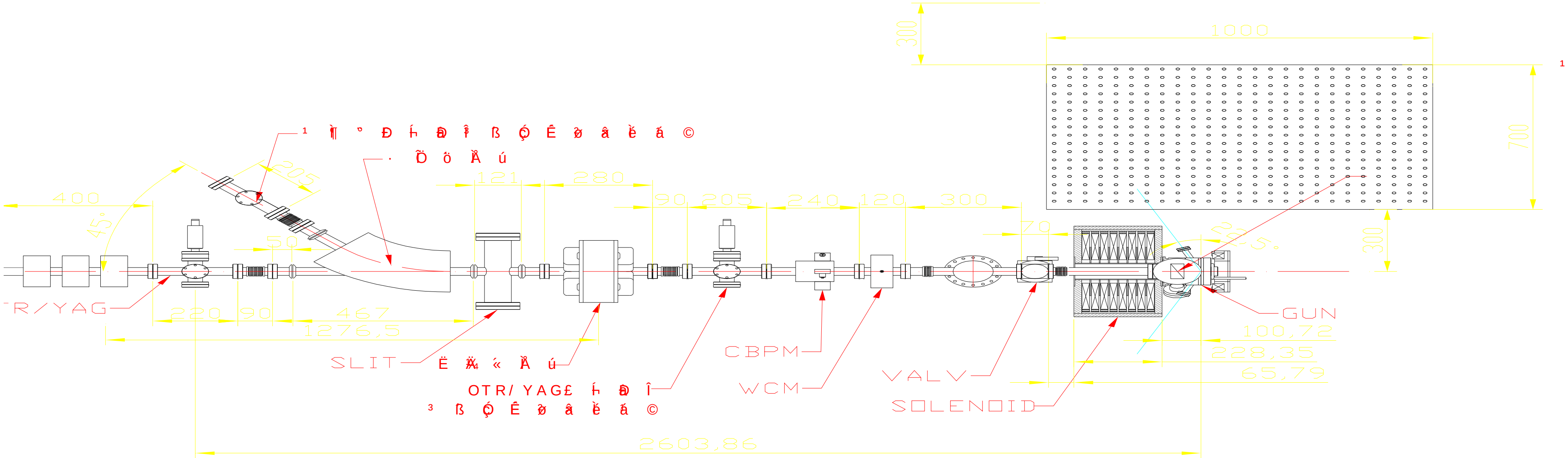
Main parameters

Laser medium	Nd:YLF
Wavelength□	1047nm/262nm
Pulse length□	12ps/8ps
Repetition frequency□	0□100Hz
Energy/pulse□	1mJ/0.25mJ
Energy stability(p-p)□	1□rms
Time stability□	0.5ps rms

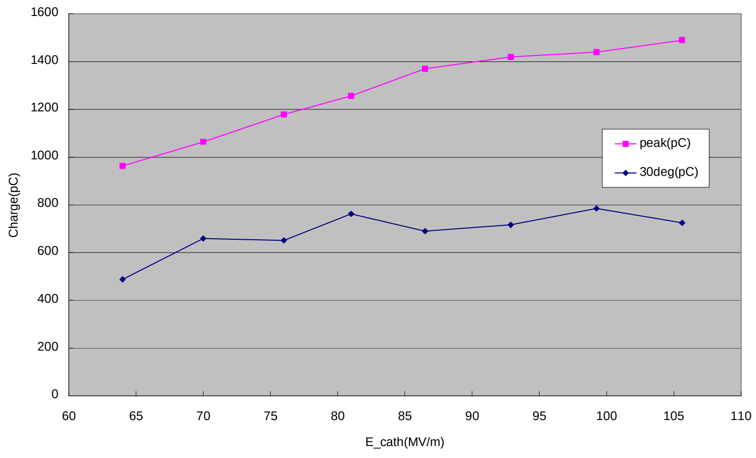
Laser parameters

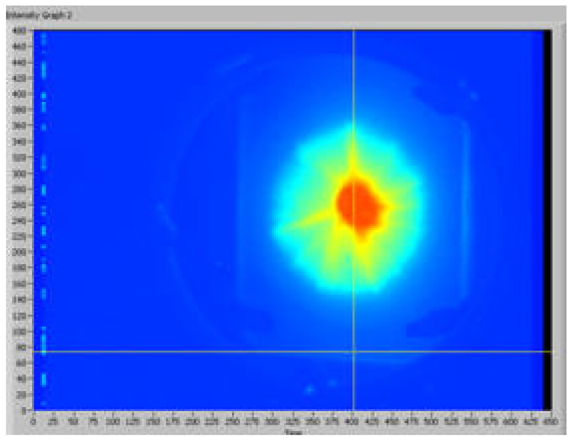
	Drive laser (since 2006)	Seed laser (2009)
Type	Nd-YLF	Ti□Sa
Wavelength	1047 / 262 nm	786 / 262 nm
Pulse energy	1.2mJ / 0.2mJ	6mJ / 0.6mJ
Pulse duration	8-10 ps	2ps/100fs/(30fs)
Power as IR seed	~20MW(split)	3~50 GW
Company	Time-bandwidth	Coherent
Repetition rate_max.	100 Hz	50 Hz
Bandwidth	~0.1nm	~10nm
Pulse shapes	Gaussian	Gaussian
Energy stability	<2%	<2%

Gun commissioning underway



Grad.: 100 MV/m, E: ~4 MeV, Bunch Charge: 700pC@50uJ, emit: ~ 5mm.mrad





Bunch compressor
install this fall

Main parameters

- **Beam energy□ 100 MeV**
- **Energy spread□1%**
- **Bunch length: 8~9/3~4ps**
- **Compression ratio□2~3**
- **Bend angle□ 7°~ 14°**
- **Maximum field□4000 Gs**
- **R_{56}(Max.)□ -100 mm**

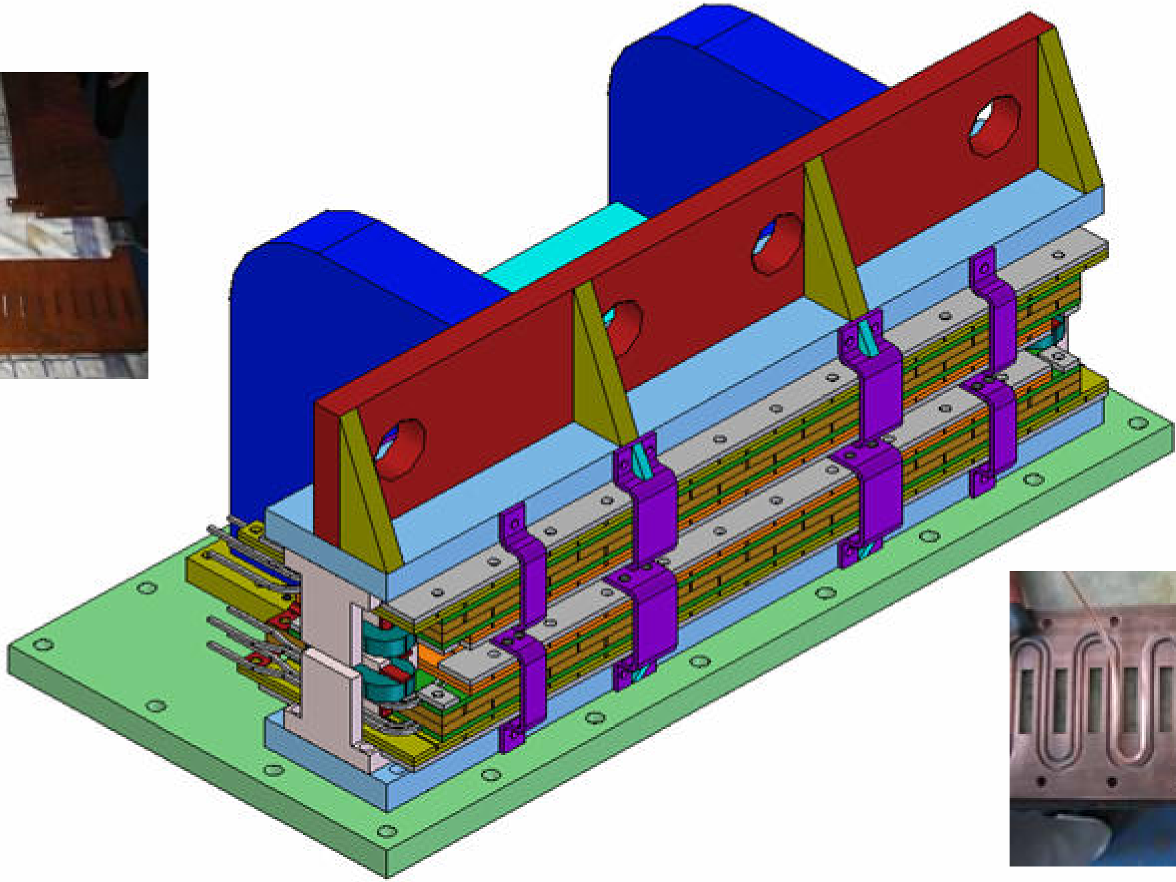
Undulator System

Developed by NSRL and SINAP, install this fall

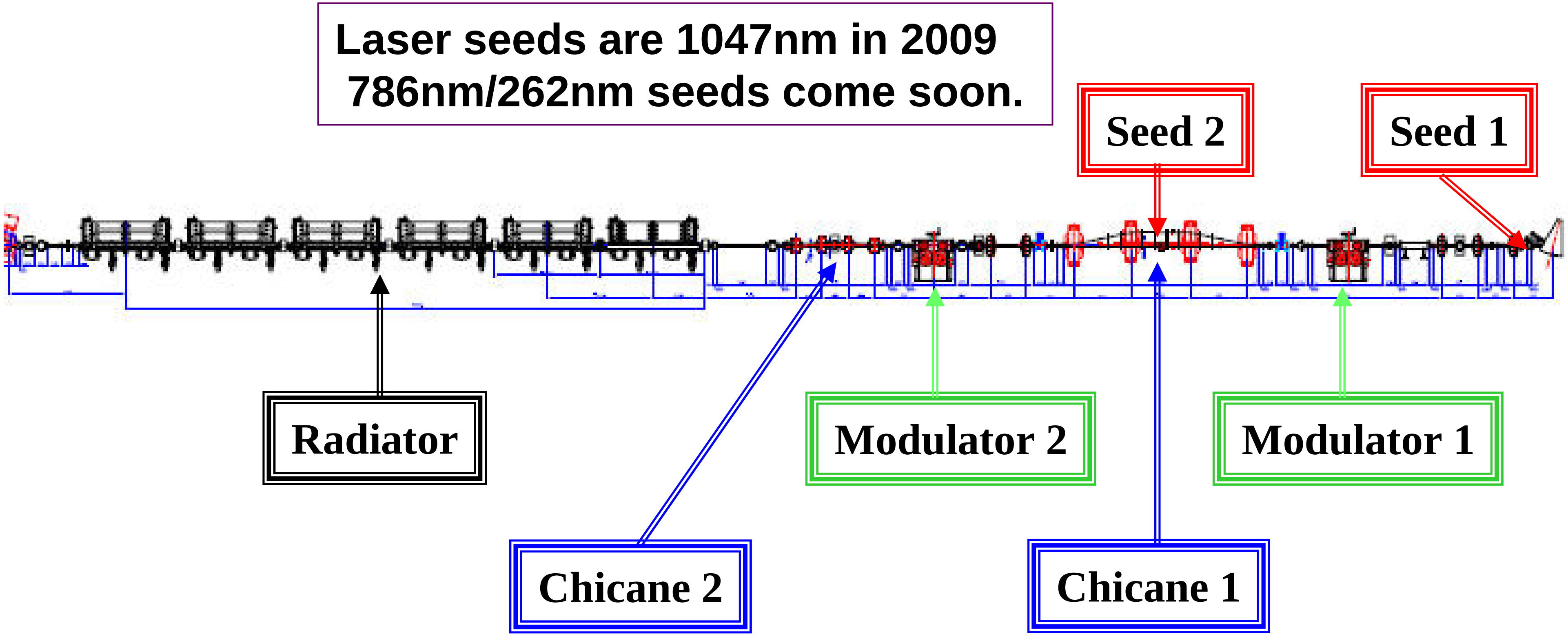
Main parameters

Period length	25mm
Gap	10mm
Peak Field	0.6T
K	1.4
Type	hybrid/Nd-Fe-B
Segment length	1512.5mm
Space between segments	250mm
Segment number	6
First field integral	0.1T-mm
Second field integral	10T-mm*mm

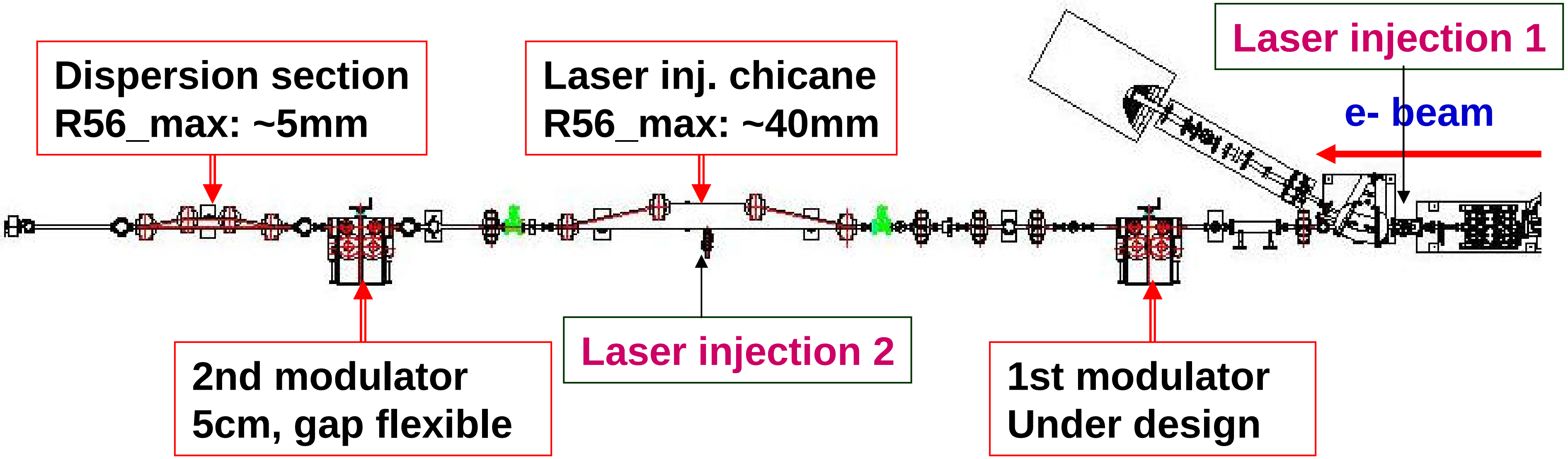
New 10x6.5cm EM undulator
as 2nd modulator (1st modulator is 5cm PM)



FEL layout (August, 2009)



Newly designed dual-modulator section



Goals:

- Double modulators
- Double chicanes(R56)
- Double lasers, etc.

Capabilities of doing a set of FEL experiments:

de-modulator type, laser-modulation type, etc.

Experiment programs on SDUV

- **Phase 1: SASE and HGHG at 262 nm.**
  EEHG (echo) at 4th harmonics
- **Phase 2: try to test cascading (262 nm → 131 nm)**
- **Other possible experiments:**
  laser heater, seeding with HHG (collaborate with a laser institute), etc

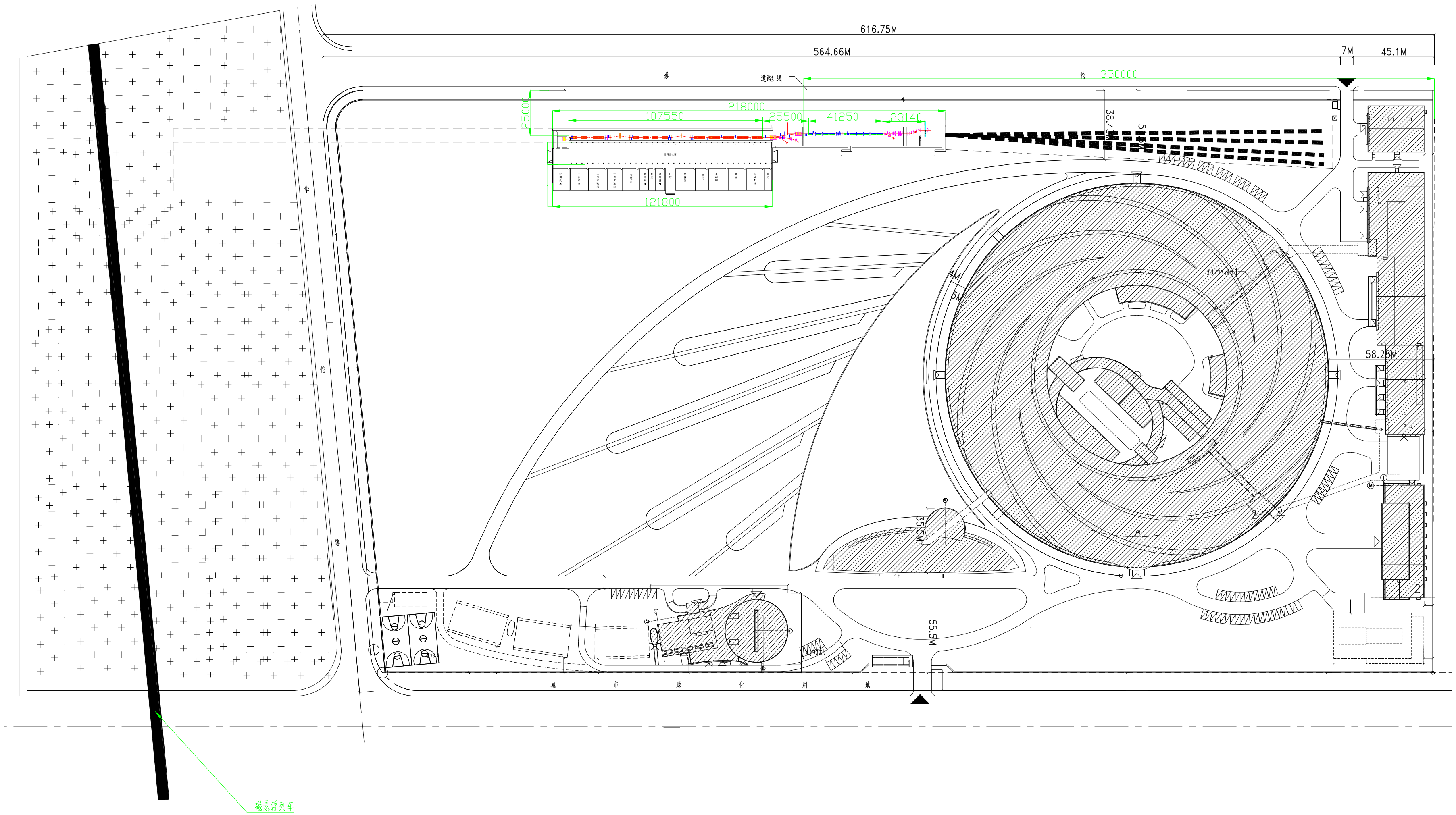
Schedule:

Sept.-Oct., 2009: commissioning of accelerator

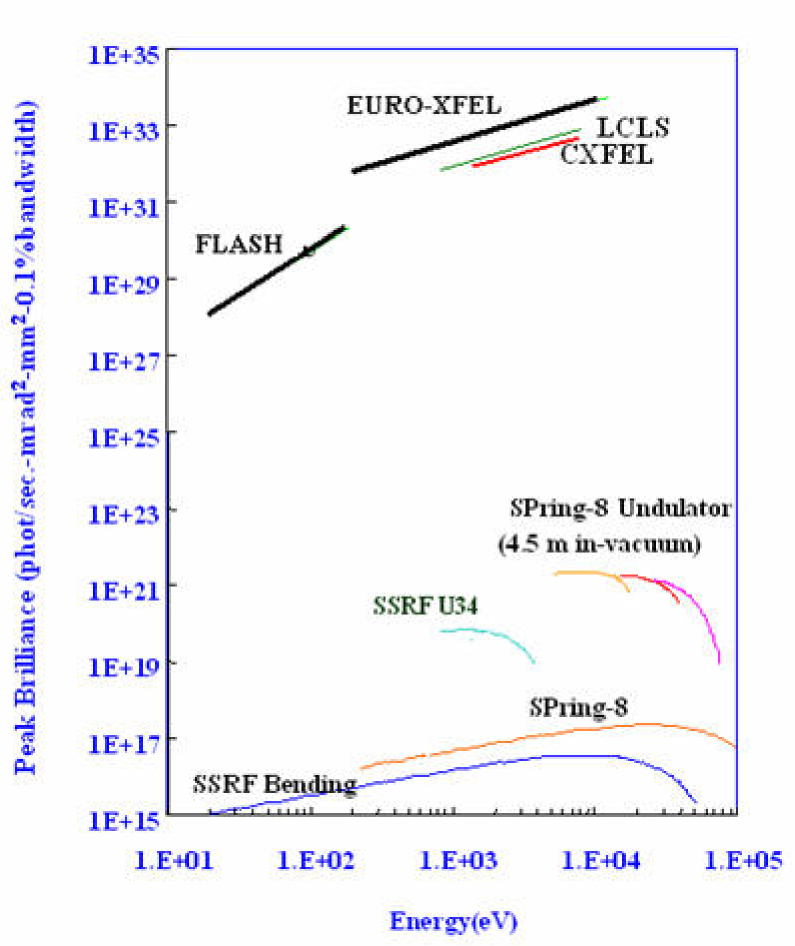
Nov., 2009: FEL experiment, SASE&HGHG at 262nm, echo, etc.

2010-11: cascading, HHG

Soft & hard X-ray FEL at SINAP



Why a soft X-ray FEL test facility?



- **Ultimate goal is to build a hard X-ray FEL user facility around 2015 or so in China**

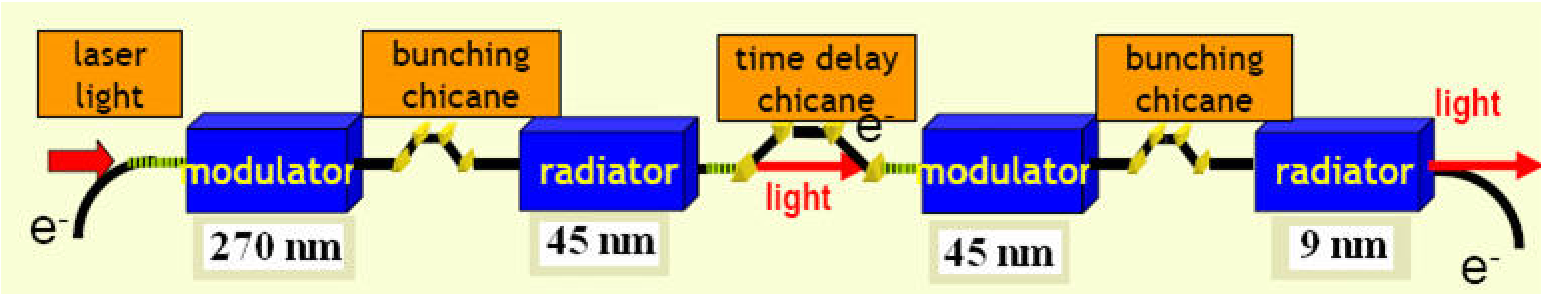
Accelerator: R&D is necessary

photo injector
main accelerator (sc or copper)
timing/synchronization
diagnostics
undulator, etc.

FEL type: crucial question

cascading HGHG or SASE?

Main parameters of SXFEL



Seed laser	λ_s=270nm□ P_{max}=200MW, τ_s=100fs				
Electron parameter	E=0.84GeV□I_p=600A□ε_n=2.0 mm·mrad, δE/E=0.1% , τp=1.6ps, rep rate: 10 Hz				
	parameter	1^{st} stage		2^{nd} stage	
undulator	λ_u (cm□	5.8	3.8	3.8	2.5
	g (cm)	~1.2	~1.1	~1.1	~1.0
Disp. sec	dψ/dγ	2.1		5.9	
FEL parameter	λ (nm)	270	45	45	9
	L_G (m)	0.78	0.88	0.88	1.32
	L_U (m)	1.0	6	1.0	18
	P (MW)		≥100		≥100

SXFEL vs. Fermi

Similarities:

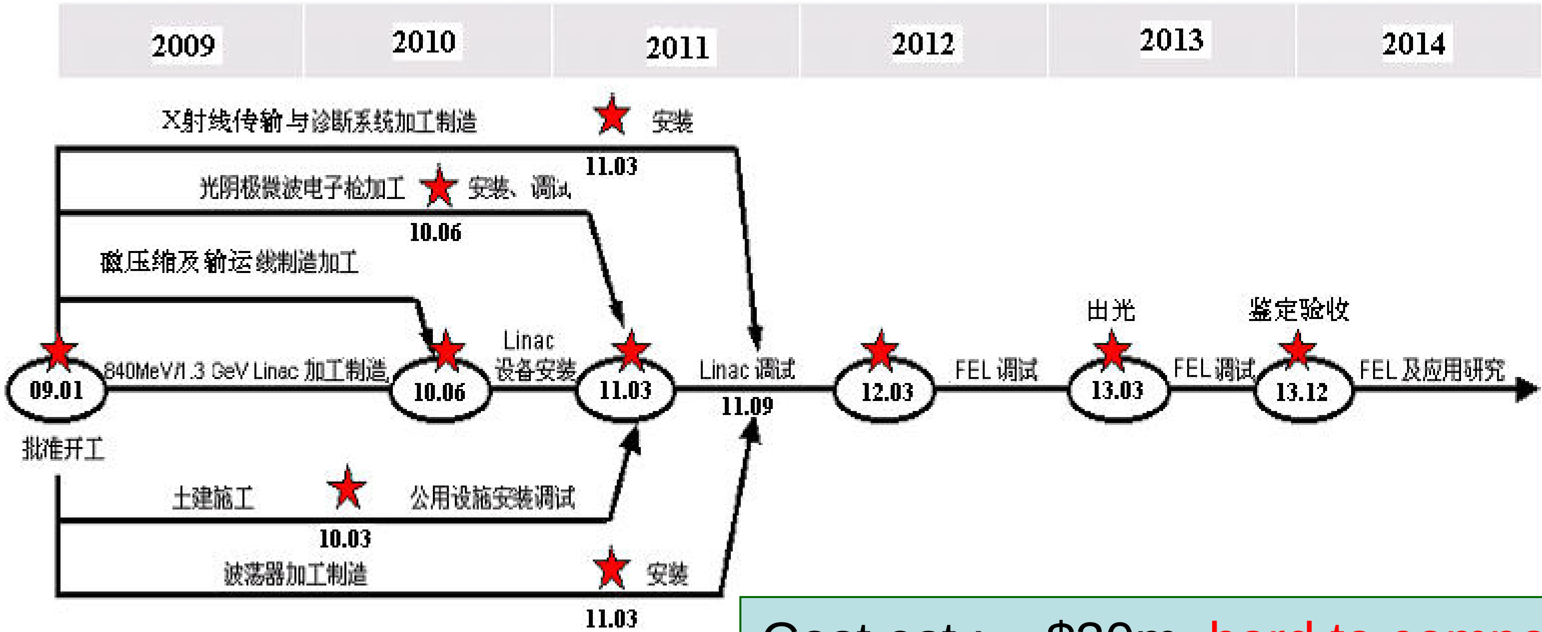
- seeded HGHG
- ~1GeV s-band copper linac
- In site of a light source, etc.

Differences:

- Test facility vs. user facility
- Cascading (primary goal) vs. single stage (optional cascading for FEL2)
- New linac vs. use of some existing linac sections, etc

Schedule

2007.2	approval of the project
2008.7	technical optimization study starts
2009.1	construction starts
2011.9	linac commissioning
2012.9	FEL experiments



Cost est.: ~$30m, hard to compare!

Domestic collaboration

- The soft X-ray FEL project is assumed to be carried out by a domestic collaboration:

  SINAP: lead the project (manager: Zhentang Zhao)

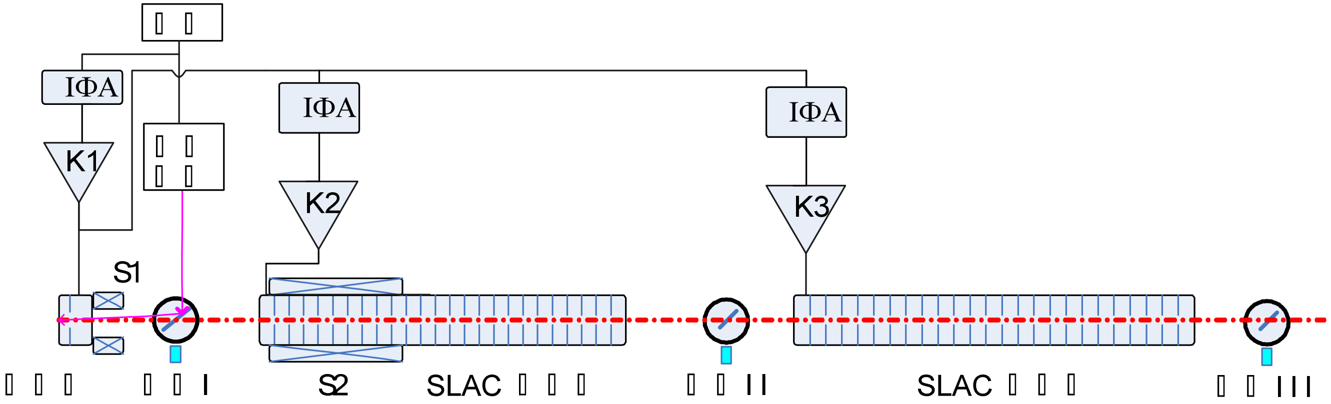
  IHEP: participate linac construction

  Tsinghua Uni.: photo-injector

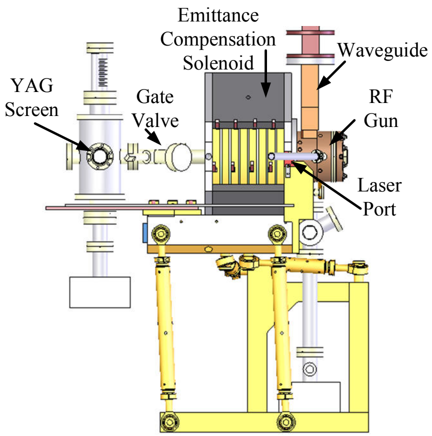
  Peking Uni.: superconducting module

- ‘Technical Optimization Study (TOS)’ starts now at SINAP.

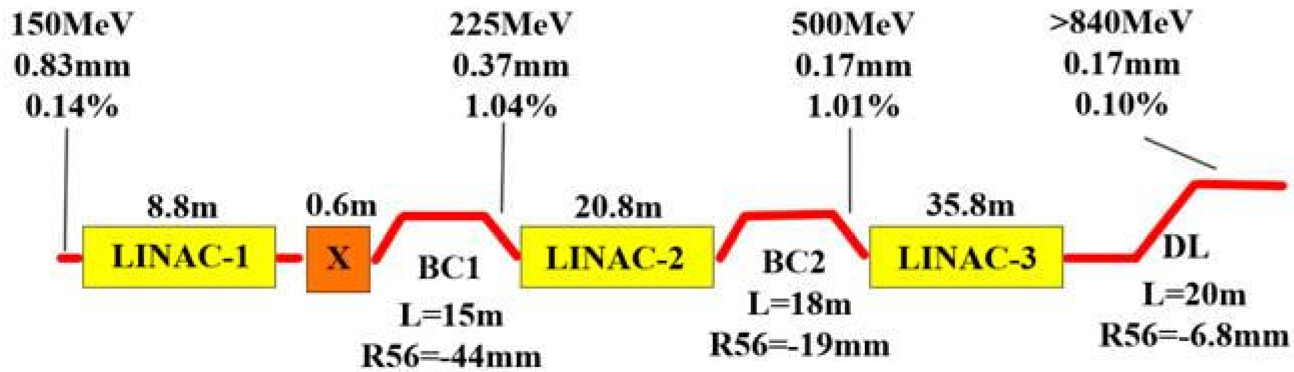
Photo injector: BNL/SLAC/UCLA type



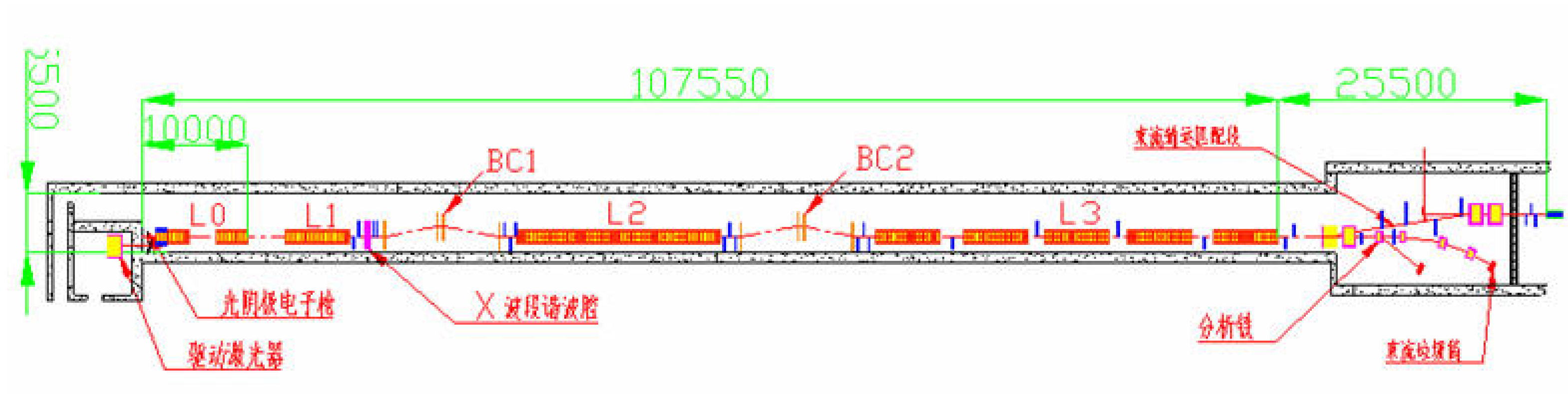
Bunch charge □nC□	1.0
Energy □MeV□	□150
Pulse length □FWHM, ps□	10
RMS emittance □mm·mrad□	1.5
Relative RMS energy spread	0.2%
Timing jitter	0.3ps
Rep rate □Hz□	1-10



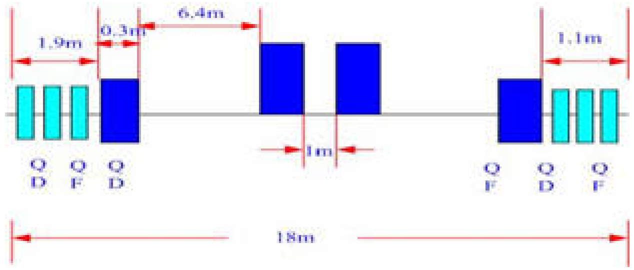
Main accelerator

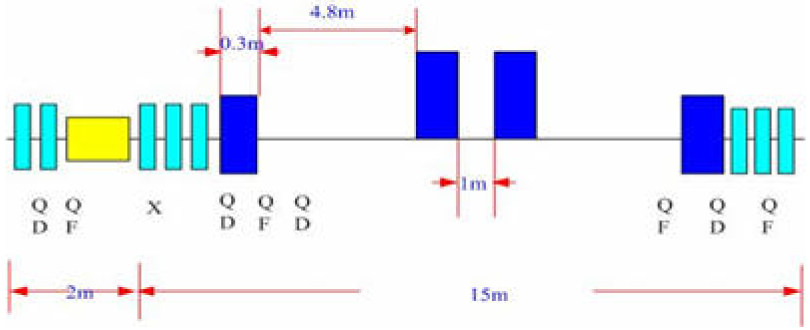


- S-band structures + x-band
- Two compressors
- 0.84 GeV / 1.3 GeV w/wt SLEDs



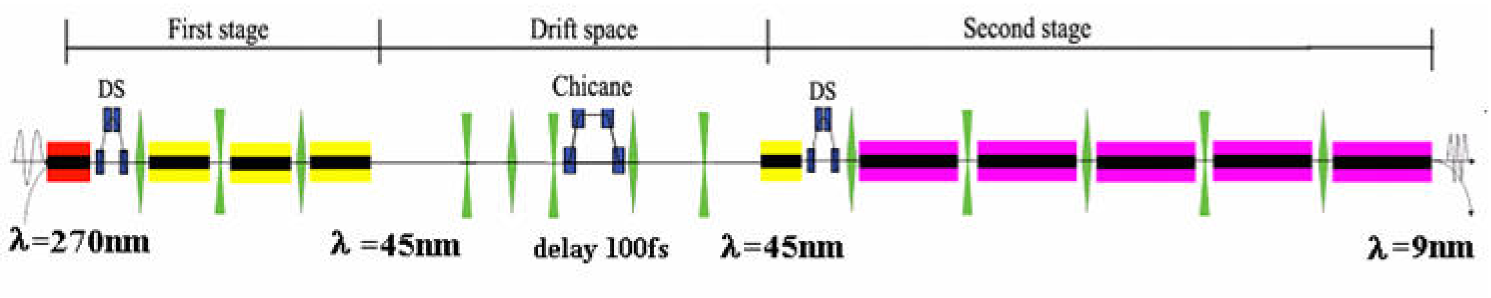
Bunch compressor



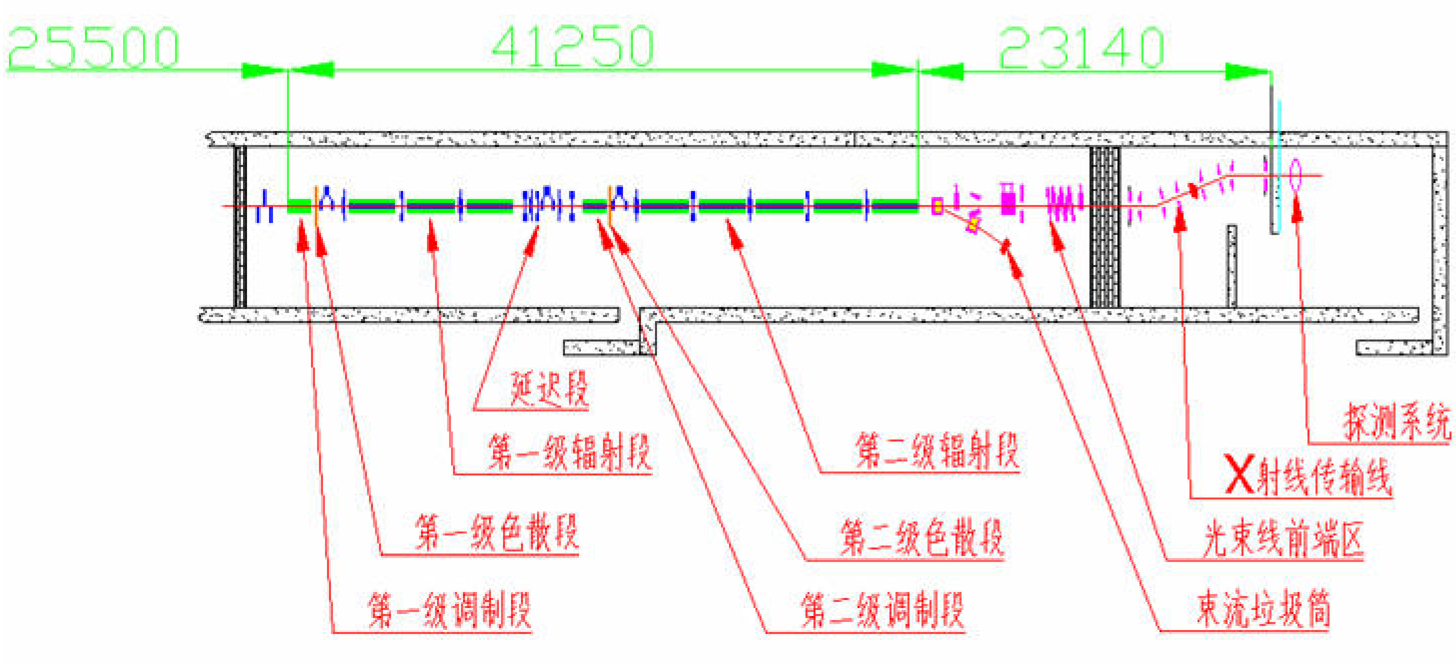


Parameters	BC1		BC2	
	parameter	unit	parameter	unit
Energy	225	MeV	500	MeV
Energy spread(rms)	1.04	%	1.01	%
Compression ratio(rms)	3		2	
R_{56}	~-44	mm	~-19	mm
Length	11.8	m	15	m
Length of dipole	0.3	m	0.3	m
Bending angle	3.8	degree	2.2	degree
CSR emittance growth	2.4	%	3.4	%

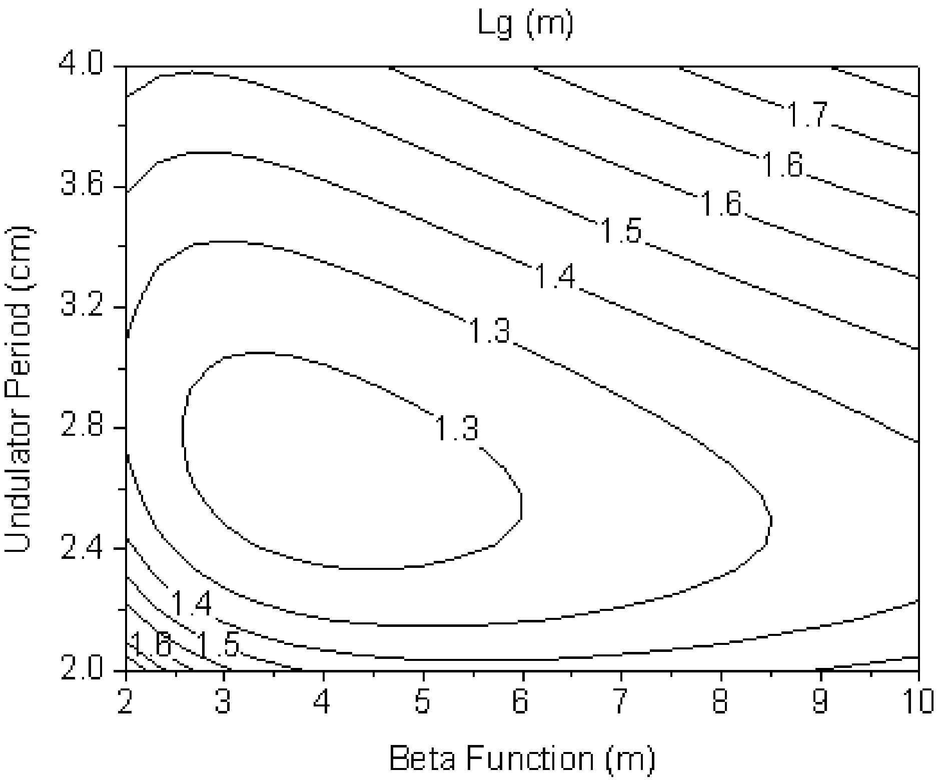
Undulators for 2 stages of HGHG



42 m total length, hybrid type



Preliminary FEL simulations



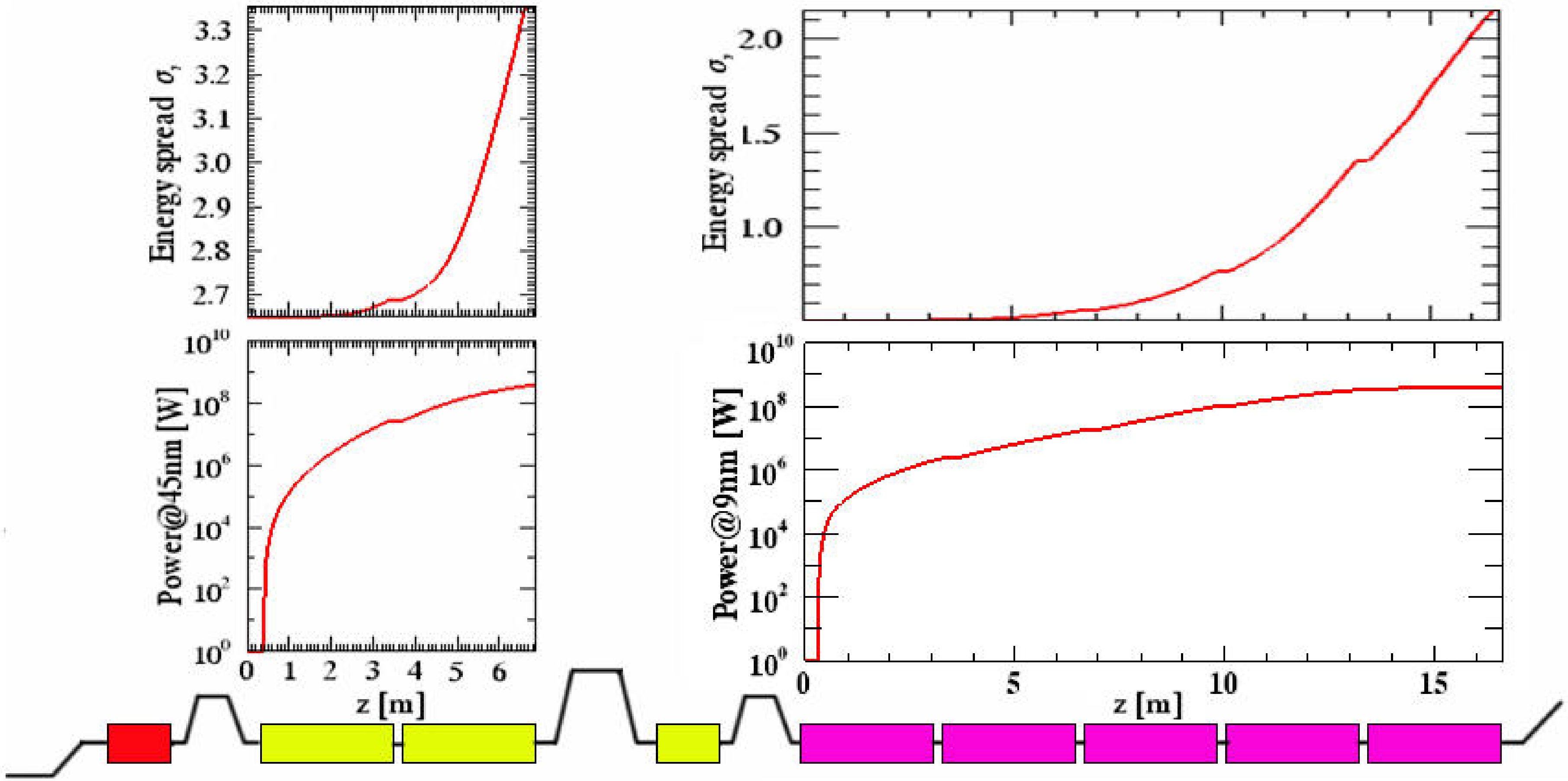
HGHG at 9nm

Period: 2.5 cm

Beta: ~5 m

Gap: 10 mm

FEL output



Energy spread σ,
3.3
3.2
3.1
3.0
2.9
2.8
2.7
Power@45nm [W]
10^10
10^8
10^6
10^4
10^2
10^0
0 1 2 3 4 5 6
z [m]
Energy spread σ,
2.0
1.5
1.0
Power@9nm [W]
10^10
10^8
10^6
10^4
10^2
10^0
0 5 10 15
z [m]

A soft X-ray FEL user facility?

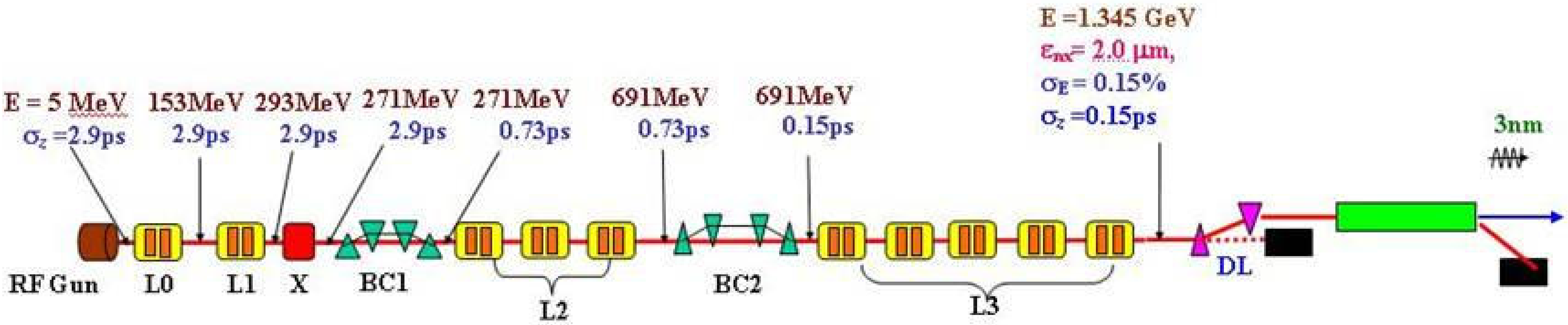
- Questions raised during review in May.
- Several possibilities:

  HGHG at 9-45 nm, straightforward

  SASE at 3 nm, 1.3 GeV (envisioned in current design),

  HGHG at 3 nm, may need 1.5 GeV energy + low emittance, according to Fermi preliminary studies

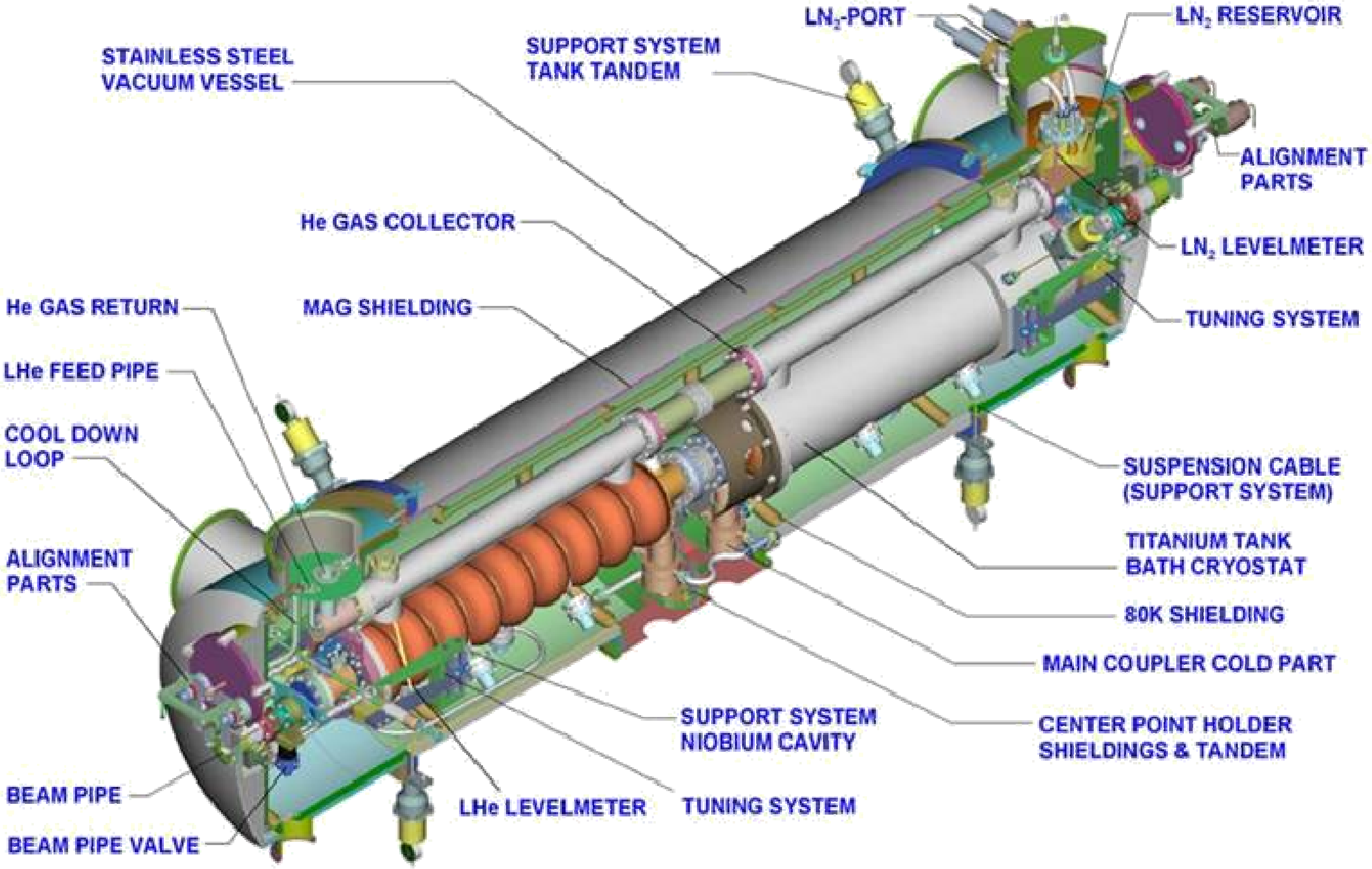
Potential SASE operation mode (3nm, linac is operated with SLED)



Beam parameters	HGHG / SASE
e- energy (GeV)	0.84 / 1.3
FWHM bunch length (ps)	~1.0 / ~0.5
Gradient (MV/m)	18 / 27 (SLED)
Peak current (kA)	0.6 /~2.0

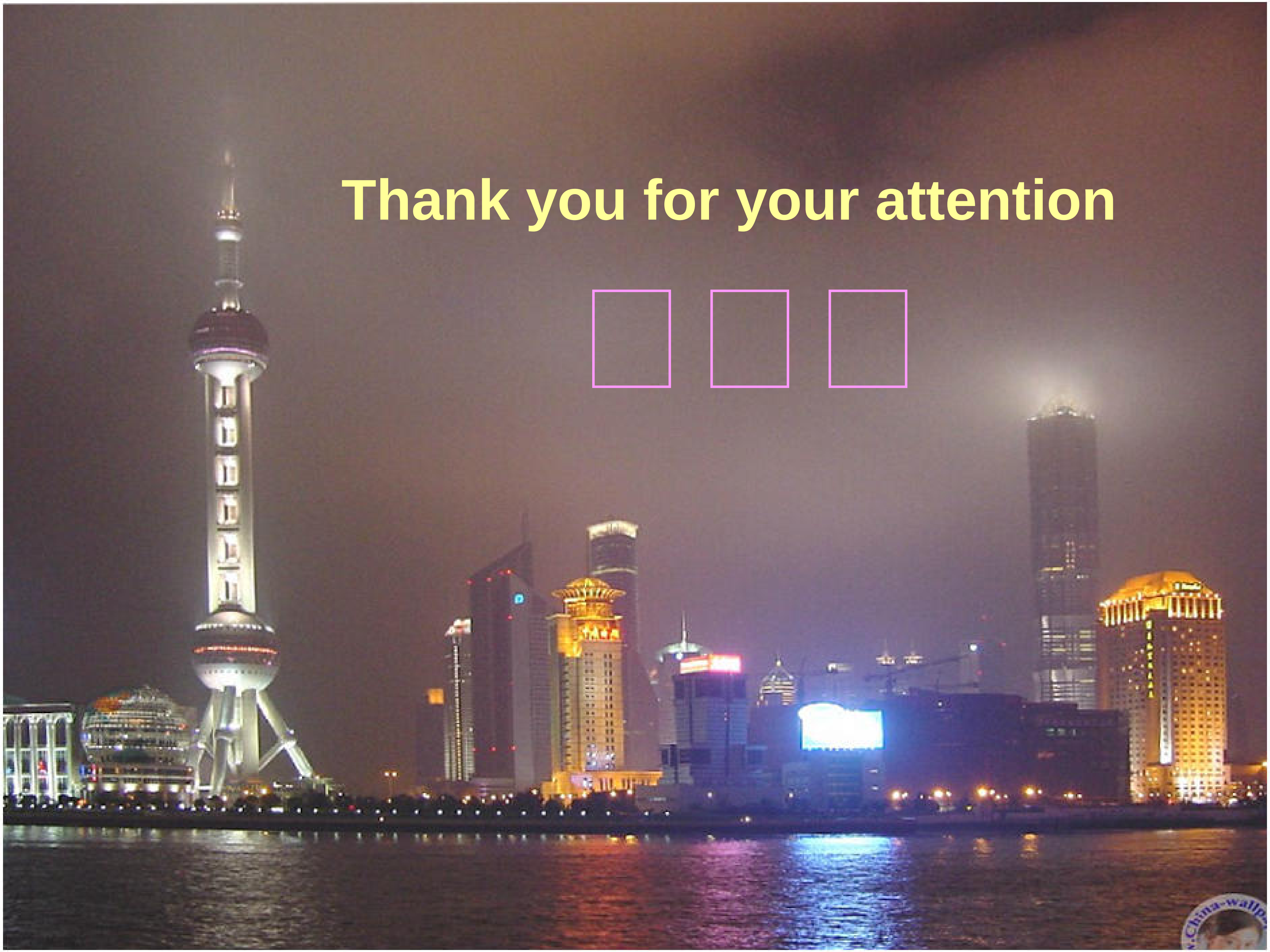
Undulators for SASE mode need extra funding

A rather independent part of the SXFEL project:
sc linac cavity R&D, by Peking University



Summary

- **The FEL researches will be the next focus in SINAP after the 3.5GeV light source.**
- **A DUV FEL test bed starts commissioning, ready for FEL experiments in early 2009.**
- **A soft X-ray FEL test facility (SXFEL) is funded and will be built in site of Shanghai Light Source. TOS is starting now.**
- **The experimental programs of two FEL test facilities have ample room for the input from the community. A lot of opportunities for collaborations.**


Thank you for your attention