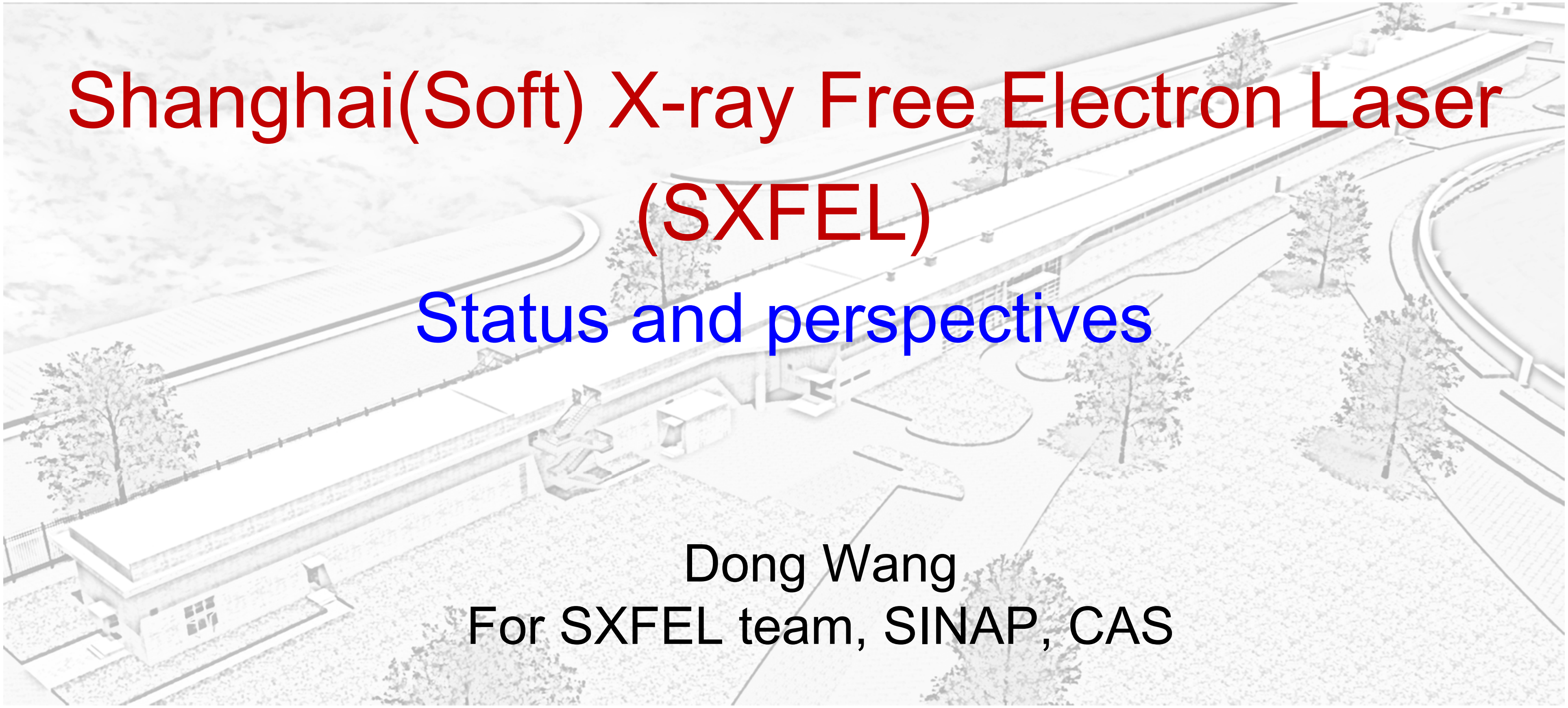


# Shanghai(Soft) X-ray Free Electron Laser (SXFEL)

## Status and perspectives

Dong Wang
For SXFEL team, SINAP, CAS

IPAC2016, Busan, Korea
May 10, 2016

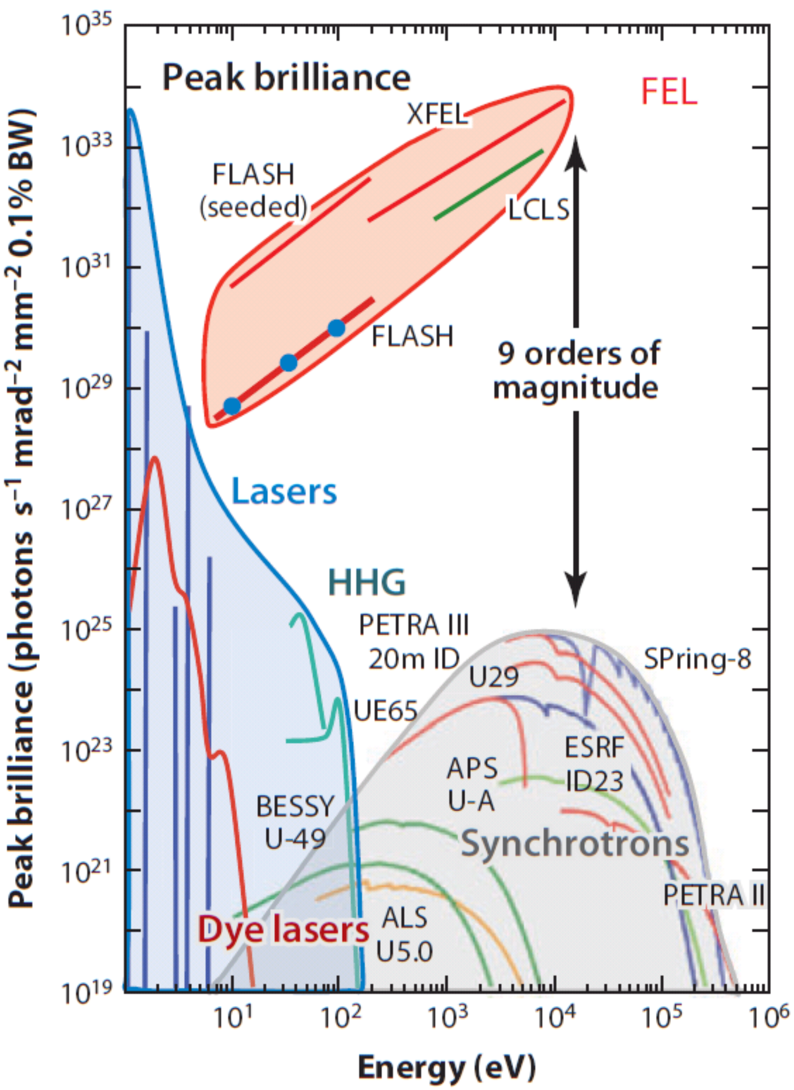
SINAP
中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

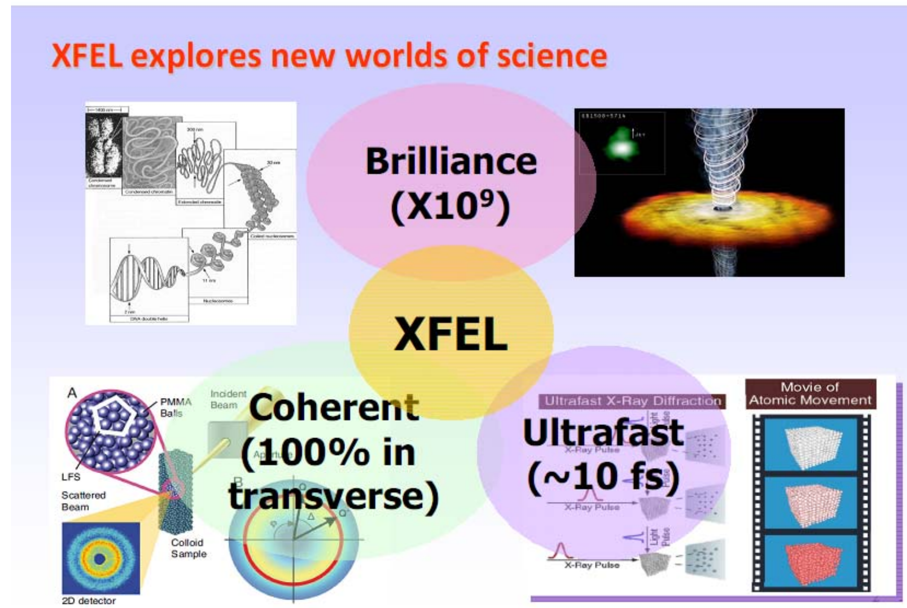
# Outline

- Introduction
- SXFEL, Test Facility
- SXFEL, User Facility Project
- Remarks

# Introduction

# XFEL and SR: complementary




J. Ullrich, A. Rudenko, R. Moshammer
Ann. Rev. Phys. Chem. 63, 635 (2012)

XFEL vs. 3rd gen. SR light source

- Brightness: 10 orders of m. higher
- Pulse length: ~1-100fs
- Coherence: fully


DESY, Germany
Linac Coherent Light Source at SLAC
X-FEL based on last 1-km of existing linac
1.5-15 Å
Injector (35º)
Existing 1/3 Linac (1 km)
(with modifications)
New e⁻ Transfer Line (340 m)
Undulator (130 m)
Near Experiment Hall
(underground)
Far Experiment
SLAC, USA
ELETTRA, Italy
SINAP, China
SACLA
Spring-8, Japan
PAL, Korea
PSI, Switzerland

# SXFEL: Project Scope

- 'phased' project

## 1, SXFEL Test Facility

Schedule: 2014.12 ~ 2017.12, under construction
Budget: $35M
Design goals: ~300m tunnel, 840 MeV linac, 8.8nm seeded FEL
Source: national funding agency

## 2, SXFEL User Facility (soft x-ray)

Schedule: 2016.7 ~ 2018.12, officially approved
Budget: ~$110M (80M for SINAP)
Design goals: add 250mx50m FEL and experiment halls,
upgrade to1.6 GeV, ~2 FELs, 4~5 stations
Source: local and national funding agencies

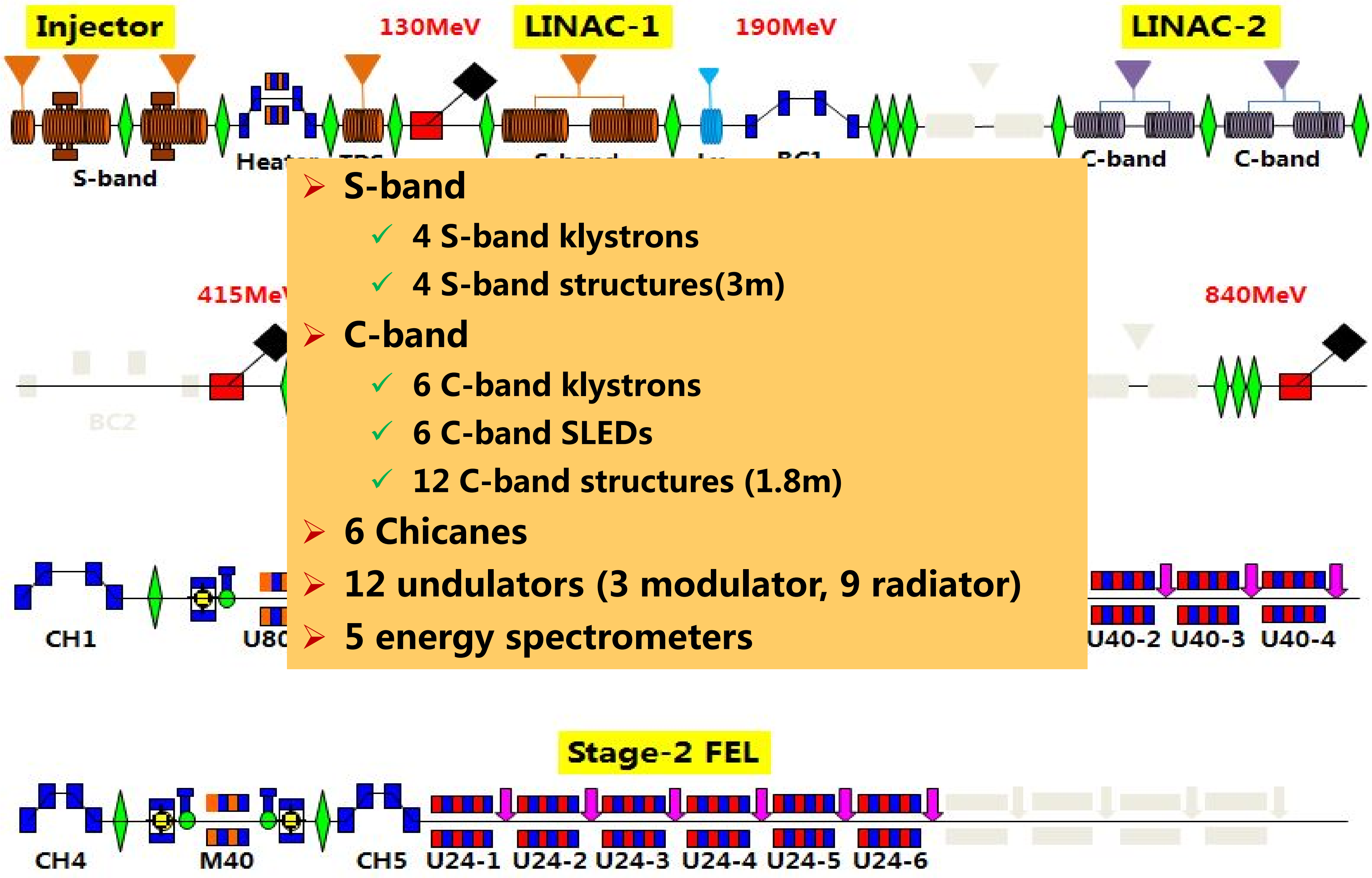
## 3, SXFEL extend to hard x-ray

Design goals: 5~6 GeV linac, multi-FELs cover 0.1nm ~ 10nm

# Goals of Test Facility

- Prototype for (hard) x-ray FEL user facility
  - key technologies and components
- Novel XFEL principle/operation-mode researches
  - mainly seeded FEL (HGHG, EEHG, cascade, etc. )
- As part of future XFEL (linac tunnel)

# Linac and FEL layout




- **S-band**
  - ✓ **4 S-band klystrons**
  - ✓ **4 S-band structures(3m)**
- **C-band**
  - ✓ **6 C-band klystrons**
  - ✓ **6 C-band SLEDs**
  - ✓ **12 C-band structures (1.8m)**
- **6 Chicanes**
- **12 undulators (3 modulator, 9 radiator)**
- **5 energy spectrometers**

# Test Facility parameters

## Photo-injector

| | |
|---|---|
| Bunch charge (nC) | 0.5 |
| Beam energy (MeV) | 129.4 |
| Pulse length (ps, FWHM) | 9 |
| Normalized emittance (mm.mrad, rms) | <0.95 |
| Energy spread (rms) | < 0.14% |
| Rep-rate (Hz) | 1-10 |

## Main linac

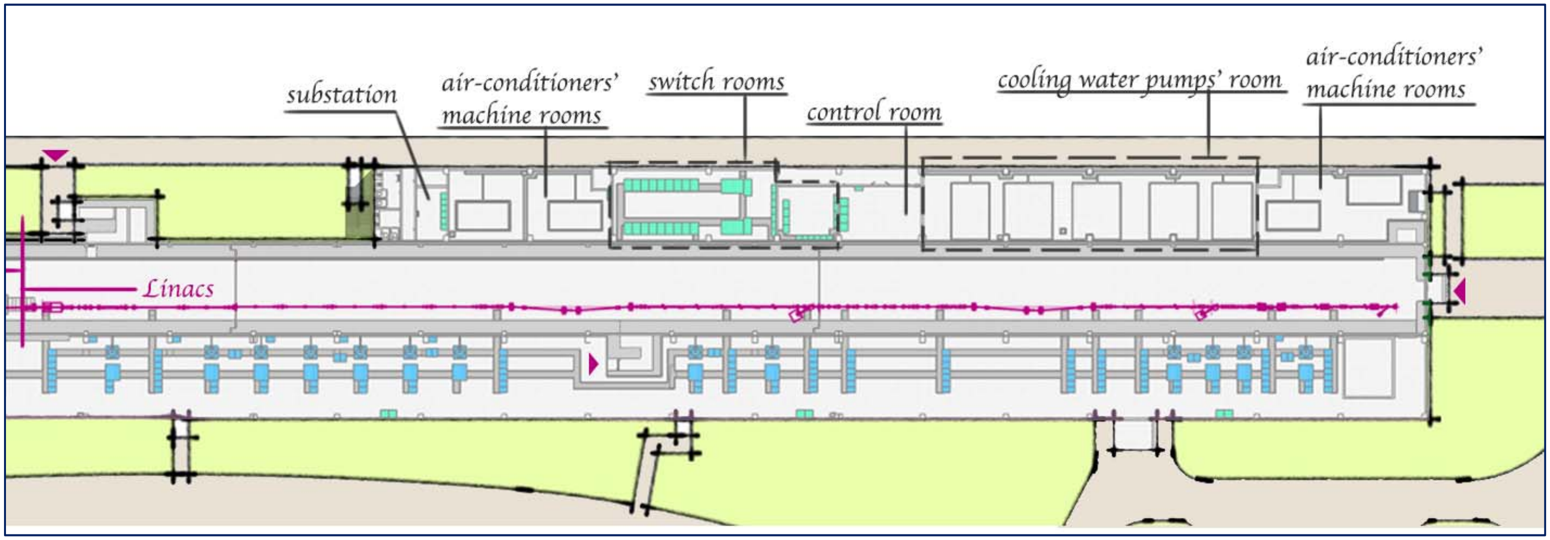
| | |
|---|---|
| Bunch charge (nC) | 0.5 |
| Beam energy (GeV) | 0.84 |
| Bunch length (ps, FWHM) | ≤ 1.0 |
| Norm. emittance (mm.mrad) | < 2.0 |
| Energy spread (rms) | < 0.15% |
| Rep-rate (Hz) | 1-10 |
| Peak current (A) | ≥ 500 |

## FEL

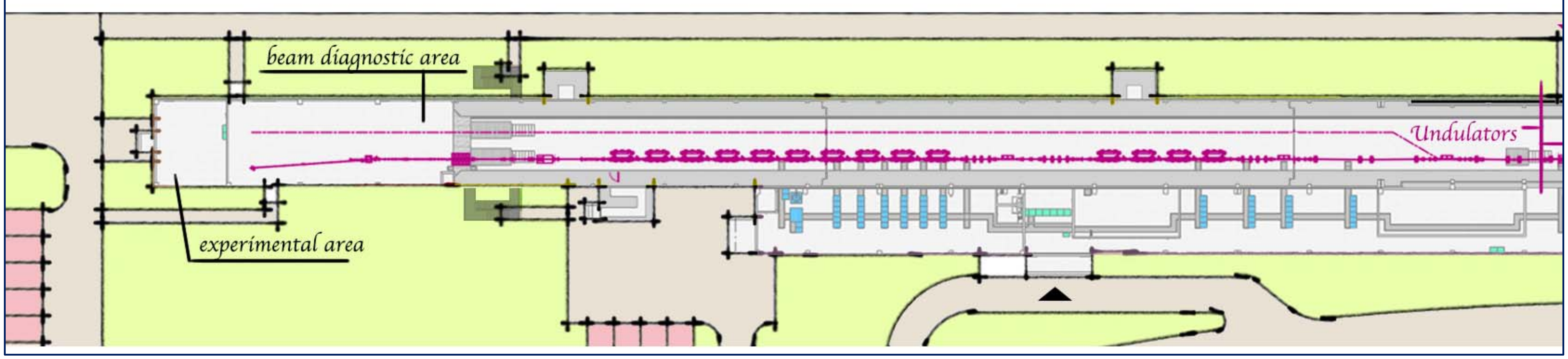
| | Baseline (8.8nm) | | Water-window (~2 nm) |
|---|---|---|---|
| **Scheme** | **HGHG-HGHG** | **EEHG-HGHG** | **HGHG-HGHG** |
| **Harmonics** | **6 × 5** | **6 × 5** | **14 × 6** |
| **Beam energy** | **840MeV** | **840MeV** | **1600MeV** |
| **FEL wavelength** | **8.8nm** | **8.8nm** | **~3nm** |
| **FEL pulse** | **< 100fs** | **<100fs** | **< 100fs** |
| **FEL power** | **>100MW** | **>100MW** | **~ 100MW** |

# Machine layout in tunnel

## Linac section (~140m)

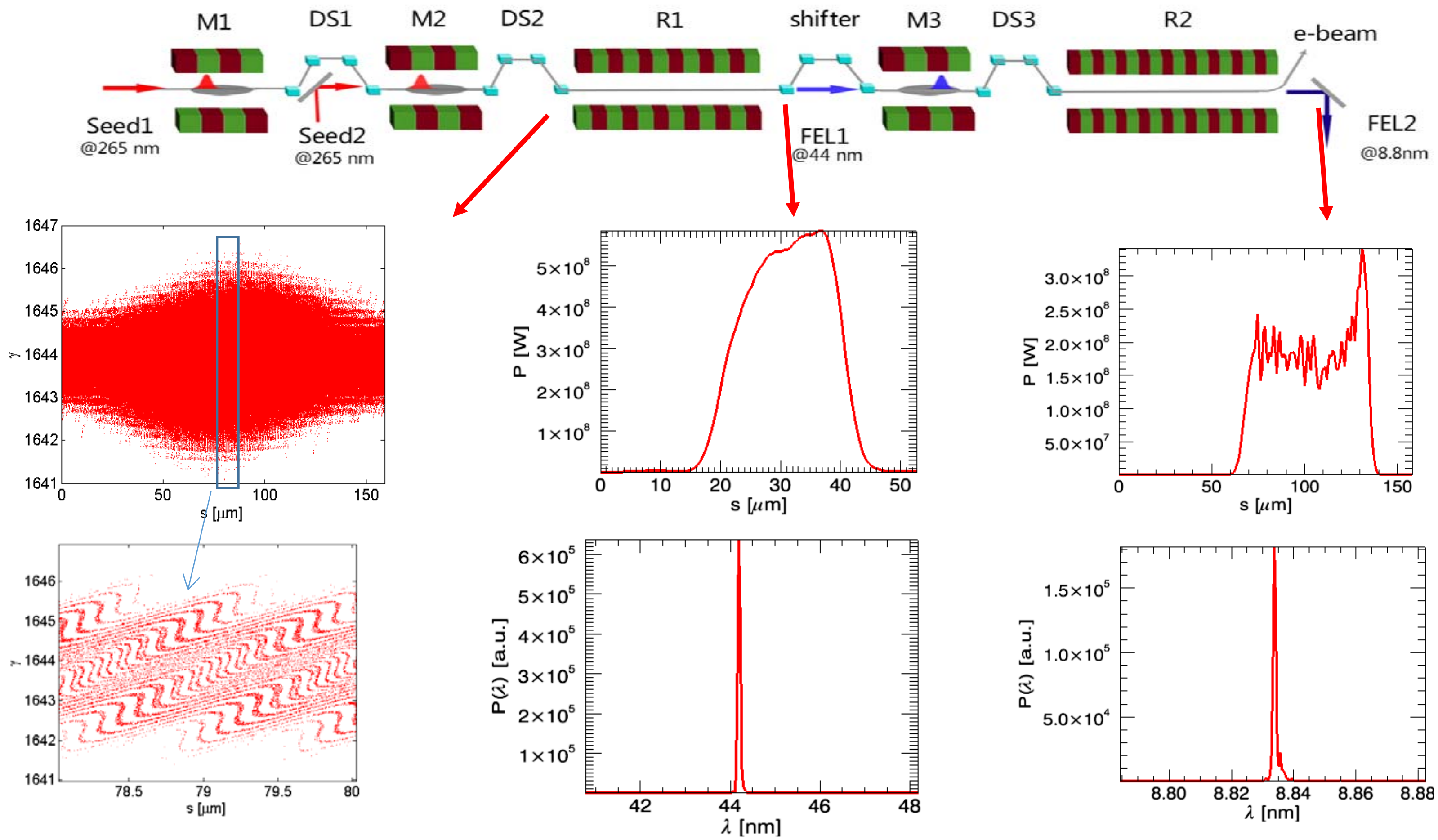



## Undulators/Diagnostics section (~155m)

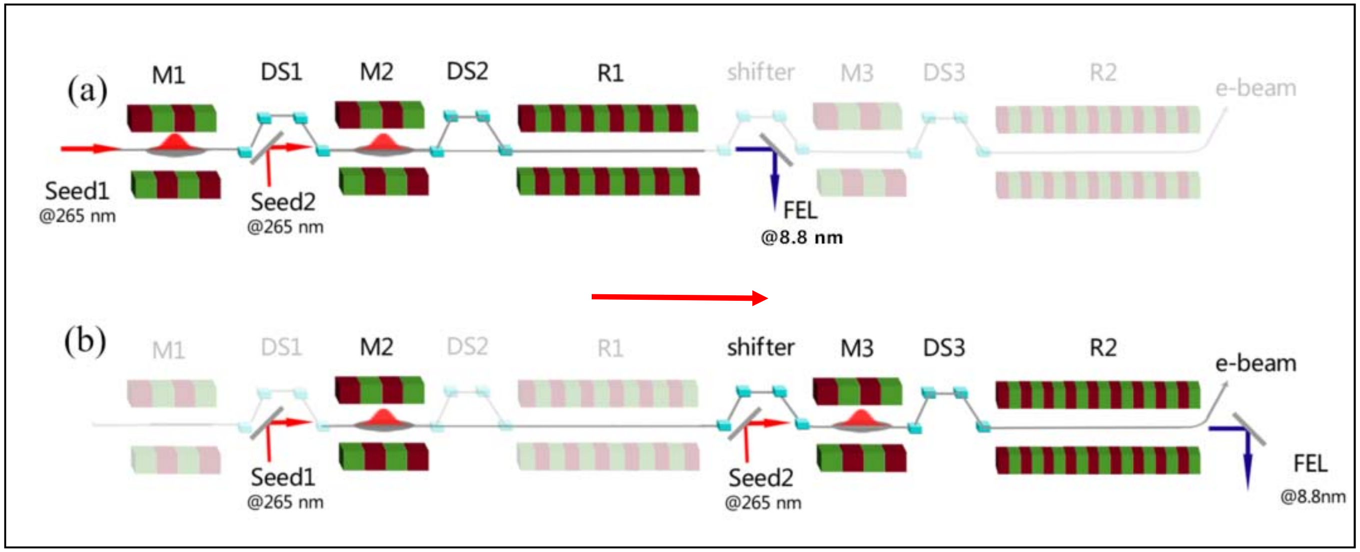


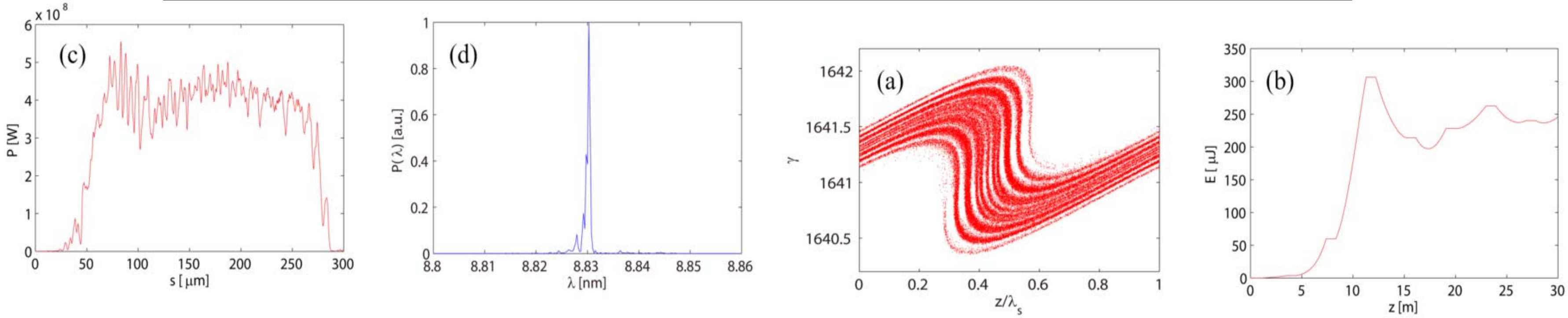
# EEHG-HGHG cascade @SXFEL test facility

- POP experiments for the EEHG-HGHG cascade
- Improve the coherence of output radiation pulse



# Echo(EEHG)-30 @ test facility

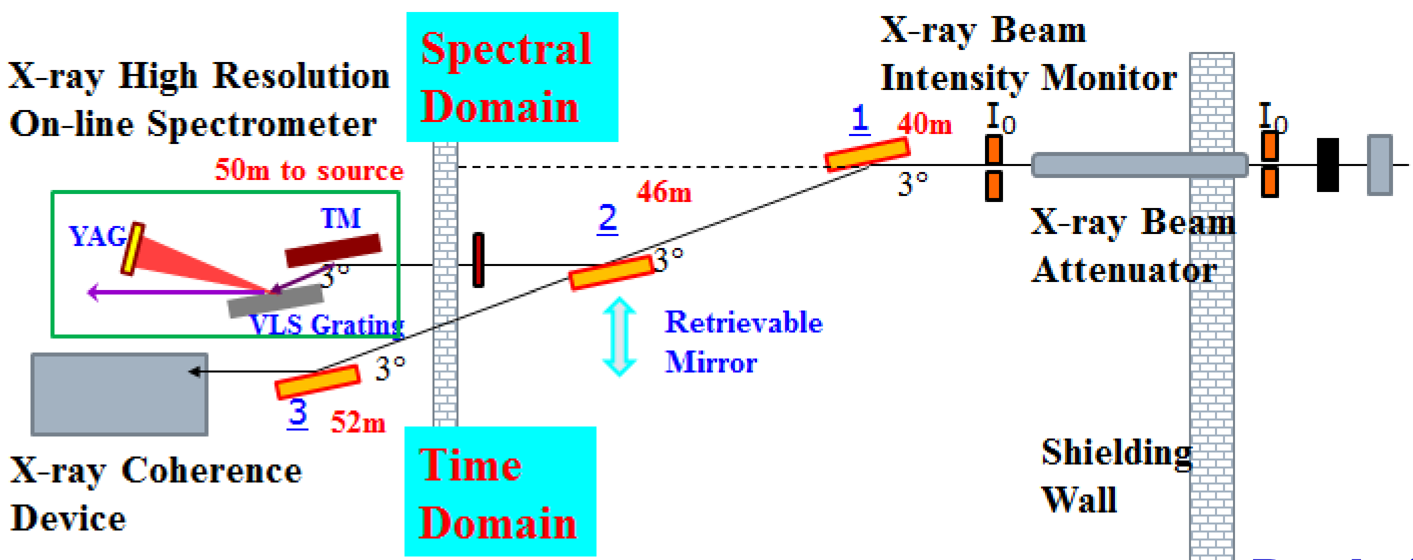


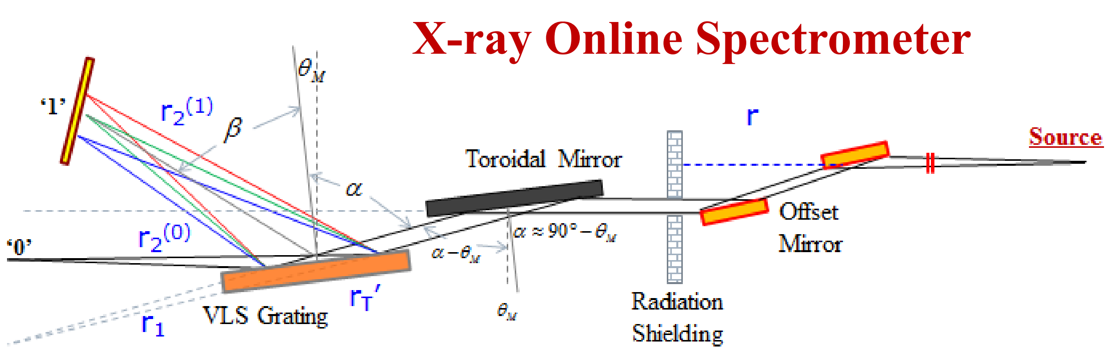



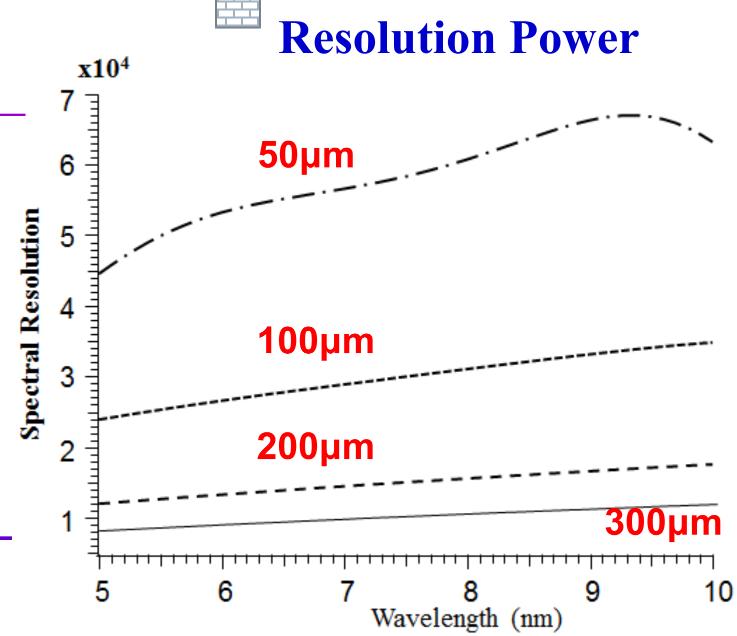

- ☐ Mitigate the jitter problem and improve the output stability
- ☐ More photons per pulse
- ☐ Narrower bandwidth


• *C. Feng and Z.T. Zhao, Chin. Sci. Bull. 55, (2010) 221*

# Diagnostic beamline



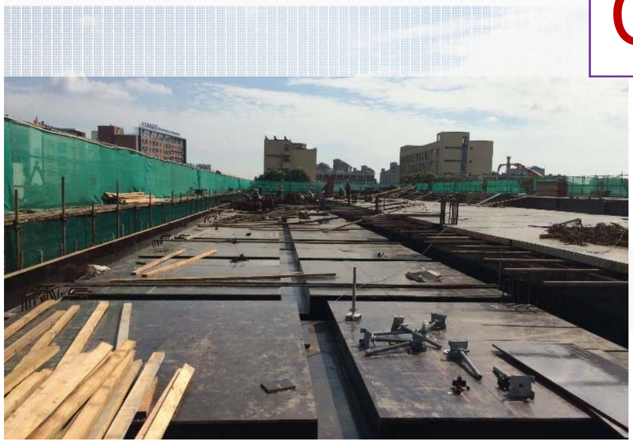
# Civil construction of SXFEL

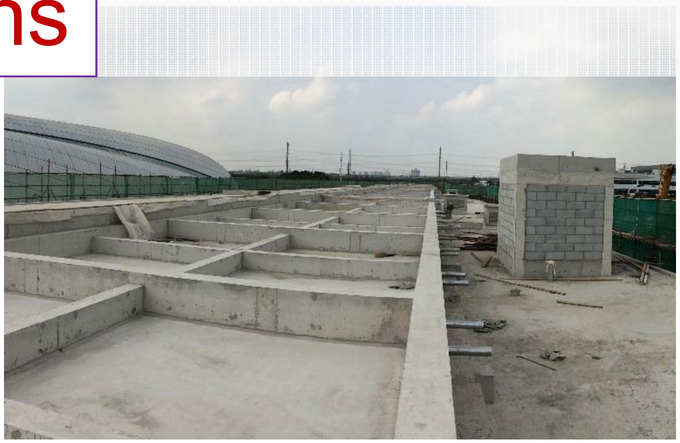






# Civil constructions





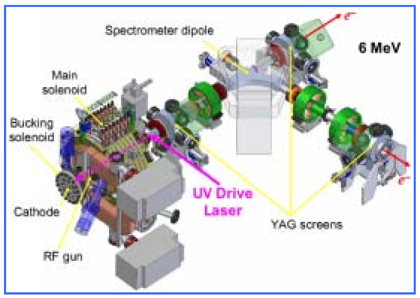



SXFEL Tunnel, 2016.4
Building and utility are ready for installation

# Main components

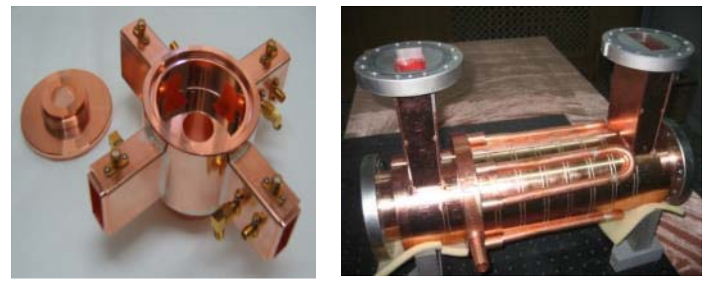
- A series of prototypes were carried out in past year.
- Now most components are under mass production.

## Injector



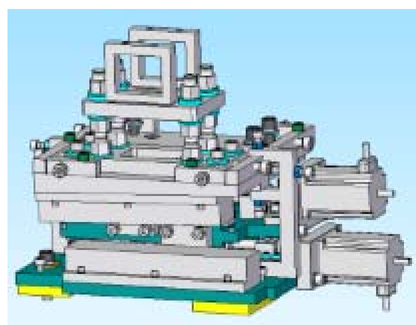

## Undulator

## Beam diagnostics

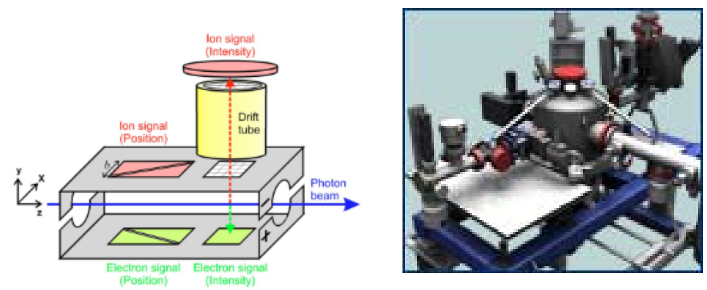


## Accelerating tube

## Mechanical & Vacuum



## Diagnostics beam line



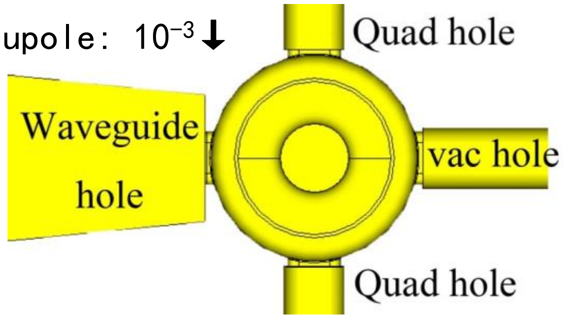

• • • • • •

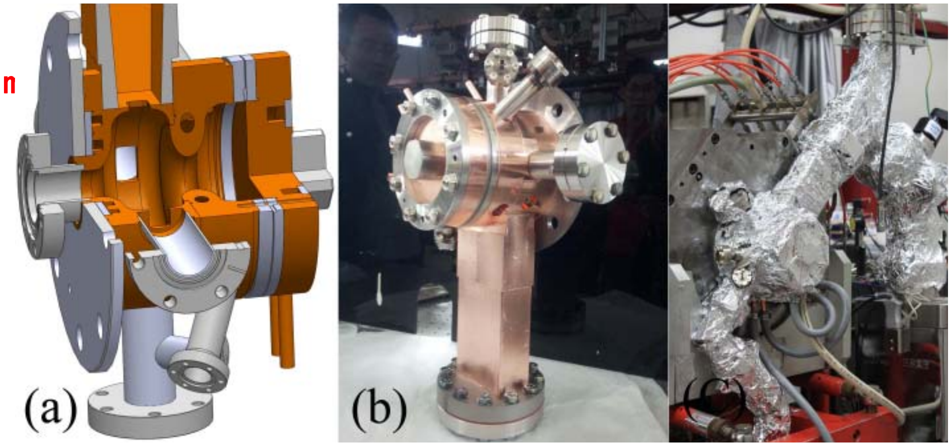
# Photo-cathode gun (by Tsinghua University)

- New cathode sealing to reduce RF breakdown
- Asymmetric vac port and quad port to reduce m

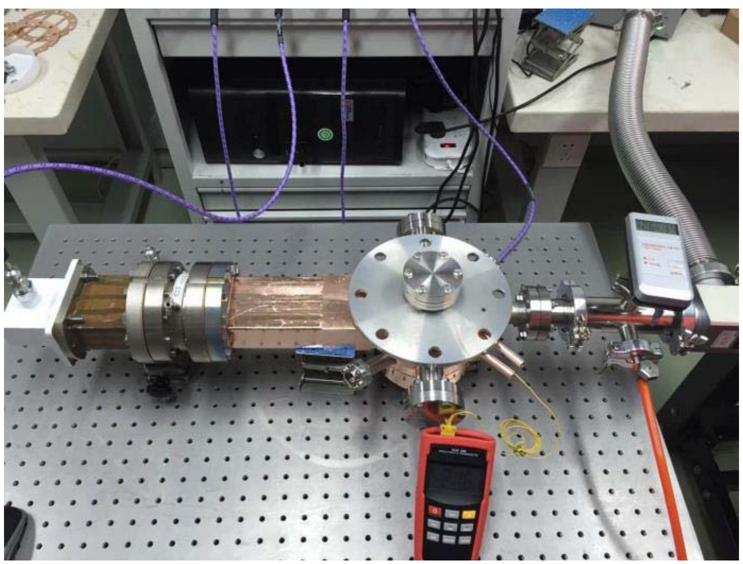
Dipole: $10^{-2}$ ↓

Quadrupole: $10^{-3}$ ↓



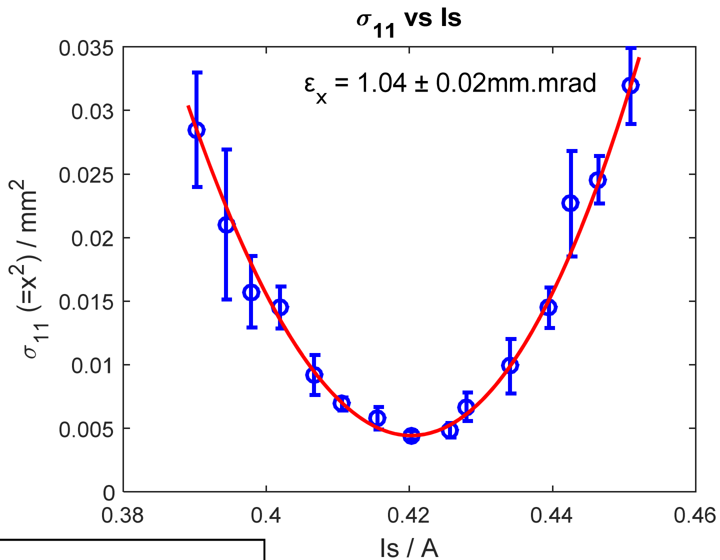

- Higher Q0, RF heating lowered by 20%
- Larger mode separation, zero mode reduction by



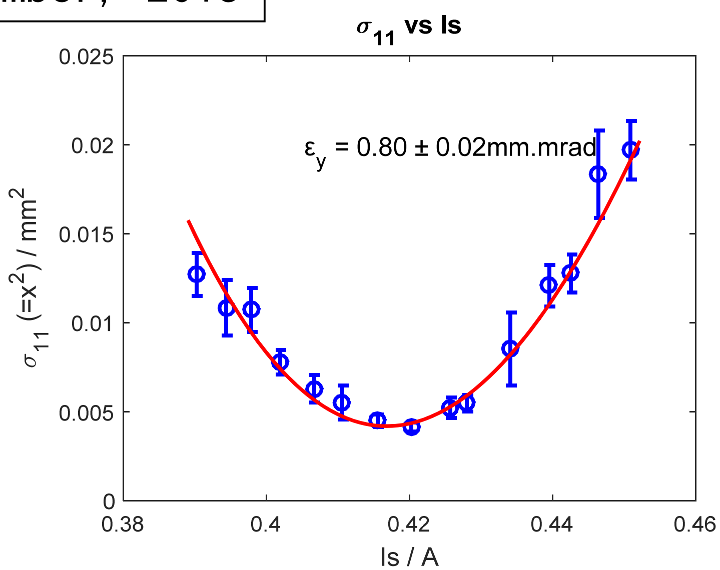
| Parameters | Value | Unit |
|---|---|---|
| PI mode frequency | 2856 | MHz |
| Quality factor $Q_0$ | 14000 | |
| Coupling factor $\beta$ | 1.3 | |
| Electric field on cathode | 120 | MV/m |
| RF pulse width | 1.7 | μs |
| Repetition rate | 10 | Hz |
| Peak power of wall heat loss | 9.4 | MW |
| Input RF peak power | 11.3 | MW |
| Cathode material | Copper | |
| QE | $4 \times 10^{-5}$ | |
| dark current at 120 MV/m | < 250 | pC/pulse |

# Gun test result, drive laser hutch

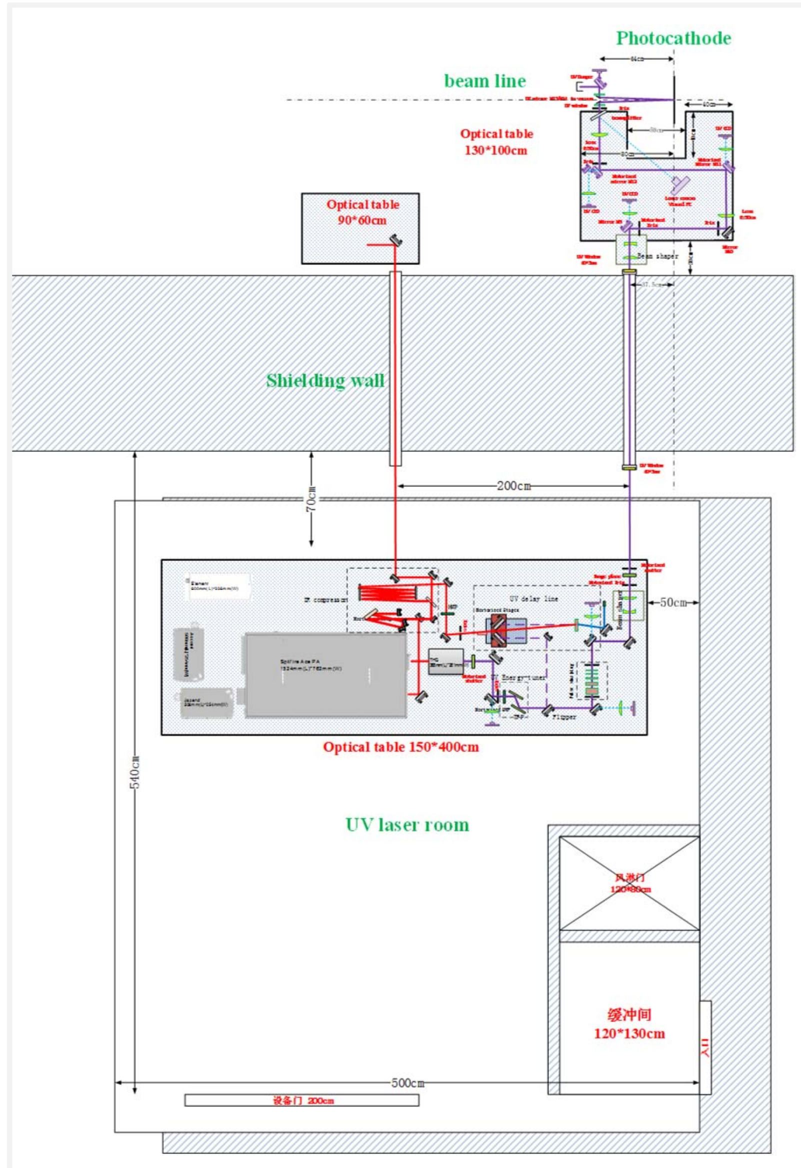
500pC




November, 2015

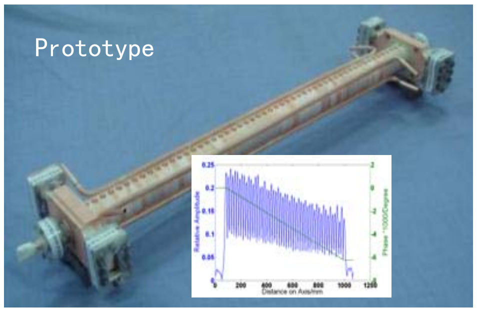


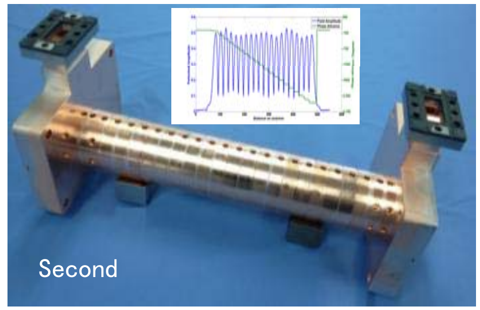

50MeV



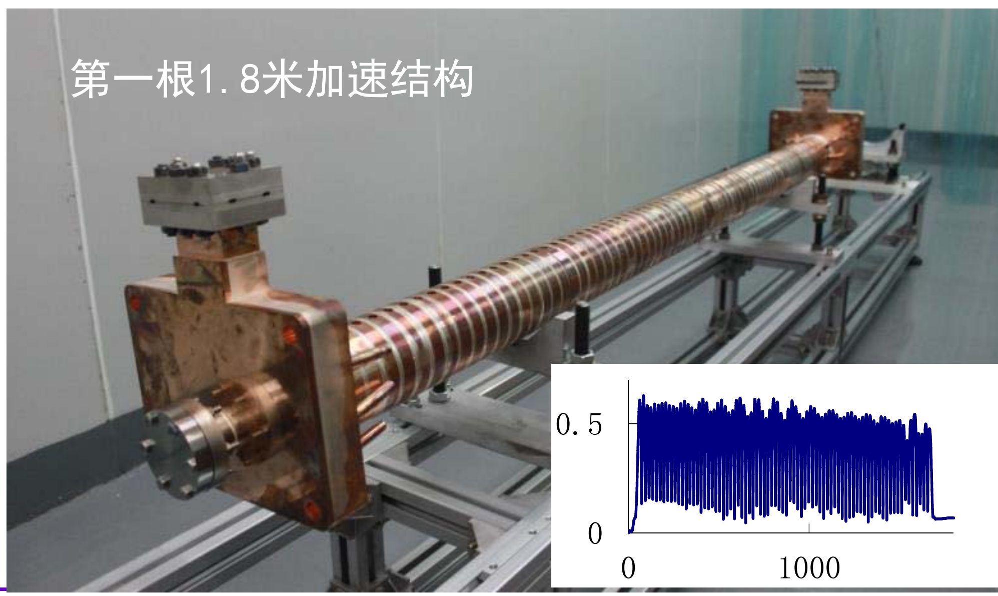
# C-band structure

## C-band prototype:   1.8m structure and SLED





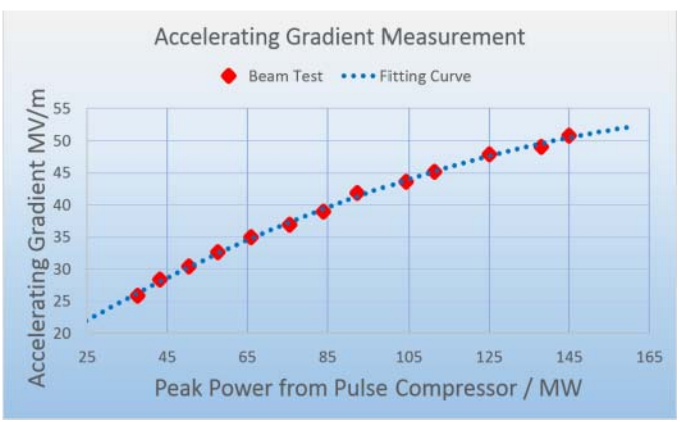


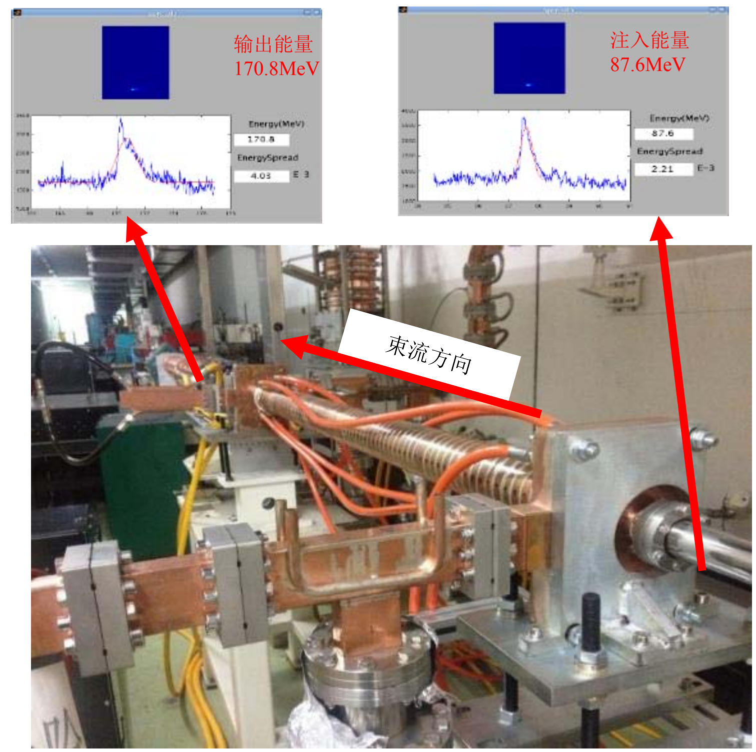

# Beam test for c-band unit

## High power test with e- beam at SDUV：~50 MV/m

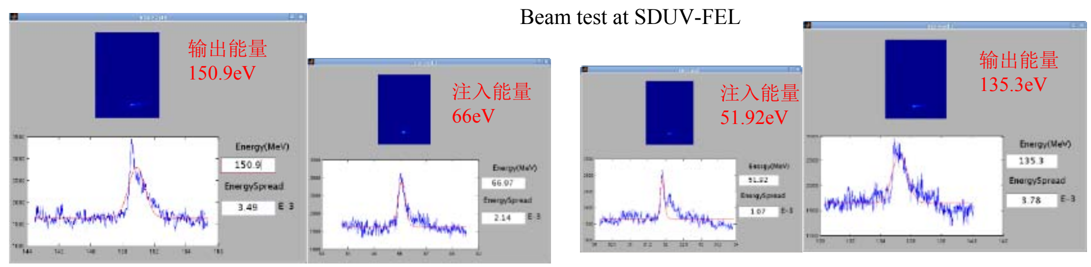
1. 束流注入C波段加速管能量为87.6MeV，最大输出能量为170.8MeV，能量增益83.2MeV，加速结构有效加速长度为1.638米，因此最大加速梯度为50.8MV/m.
2. 通过扫描充电电源25kV至37kV，SLED功率输出对应为63MW至145MW，实际束流测量获得的加速梯度为25.9MV/m至50.8MV/m，与高功率测试结果基本吻合。
3. 为防止出现高能量初出现分析铁饱和现象，导致测量误差，故将注入能量分别降低至66MeV和51.92MeV，分别测量145MW峰值功率束流能量，分别为150.9MeV和135.3MeV，分别对应能量增益为84.83和83.38，与之前的测量结果一致，因此可以证明之前的170.8MeV没有进入饱和区，测量结果是有效的。

$$E(^{MV}/_{M}) = 4.27\sqrt{Peak\ Power\ (MW)}$$



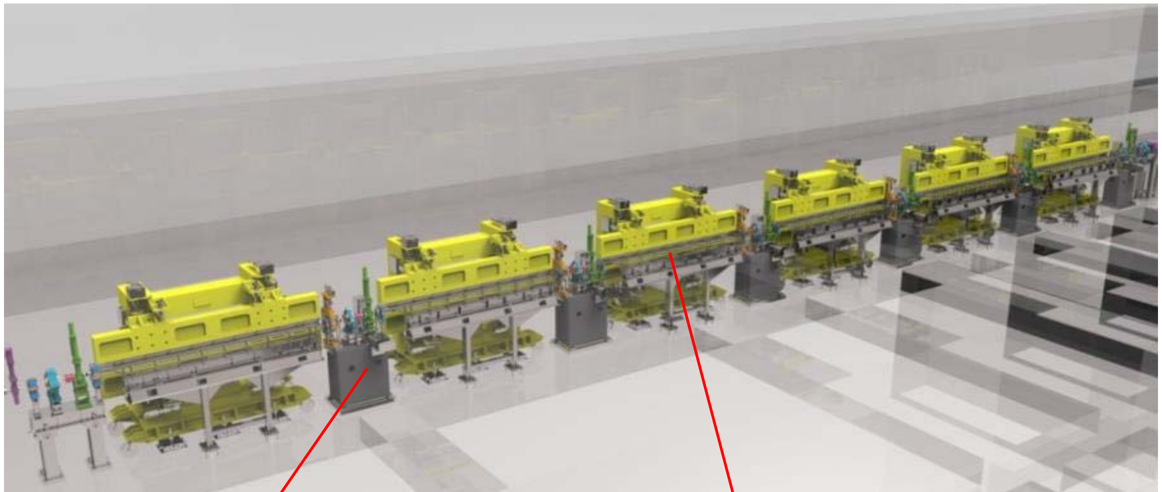

Beam test at SDUV-FEL

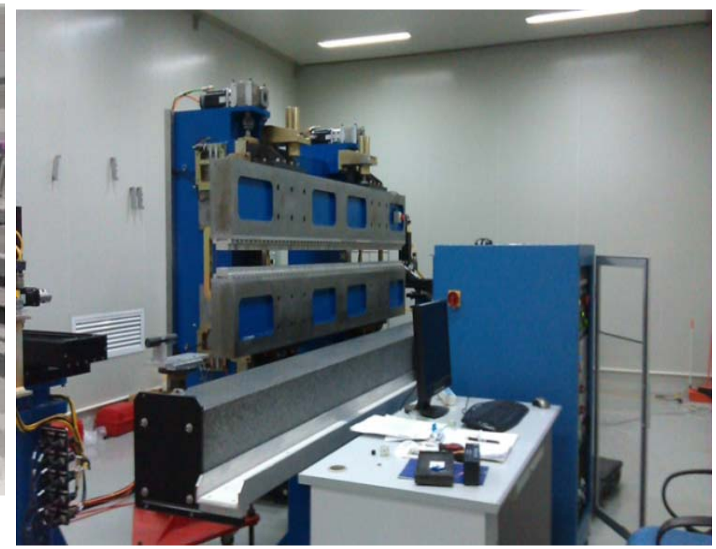


# Movable chicane in linac

- 0~7 degrees bending angles
- Rotating frame & movable platform
- Dipole、Profile、slit、SBPM、correctors、ion pump、bellows, flanges and supports

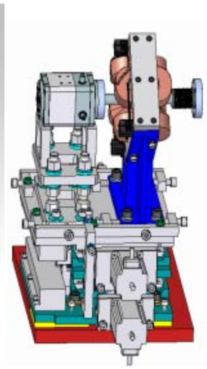
# Undulator unit

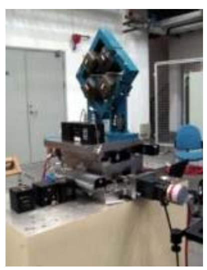


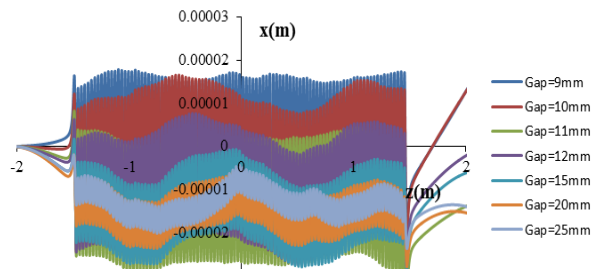


BBA unit

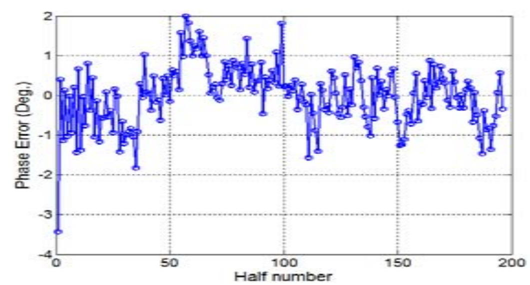
Vaccum chamber








BBA movable platform



# Undulator & magnets productions

Undulator

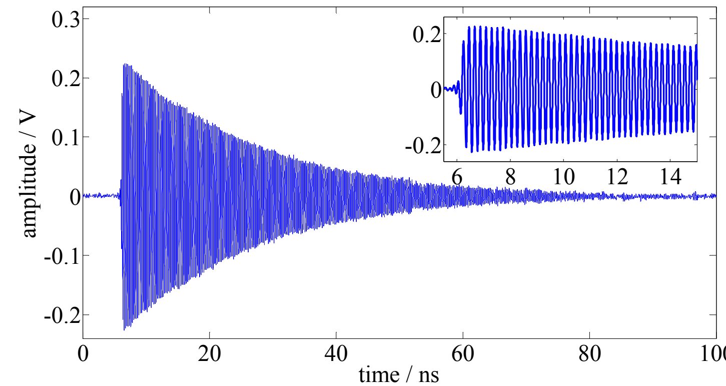
Phase shifter

Quads

Focusing coil

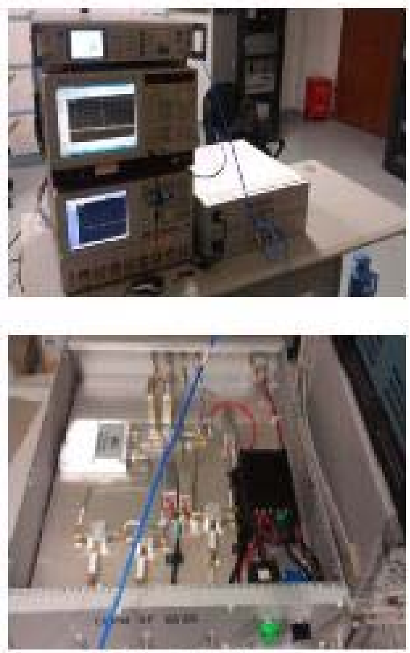
# Cavity BPM（CBPM）

CBPM束流实验@SDUV FEL

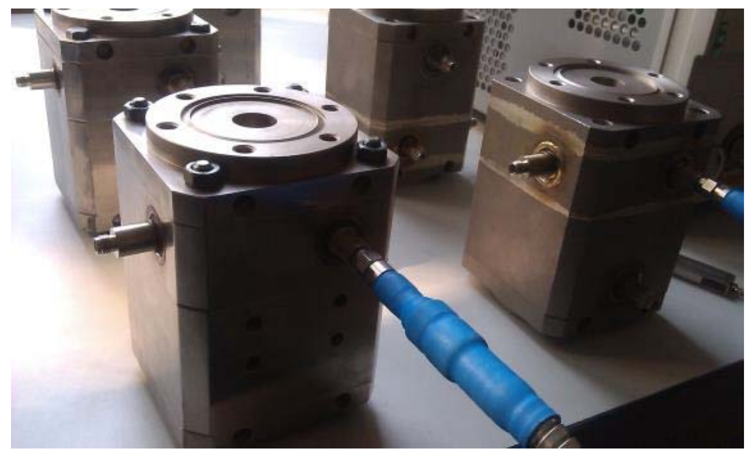



RF signals

探头结构及工艺设计



RF 前端



Productions

# Magnet supports

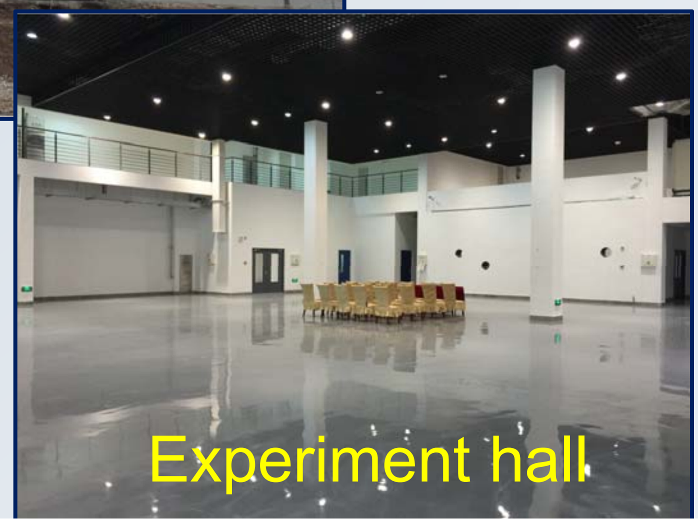





# Issues: overlaps with DCLS project

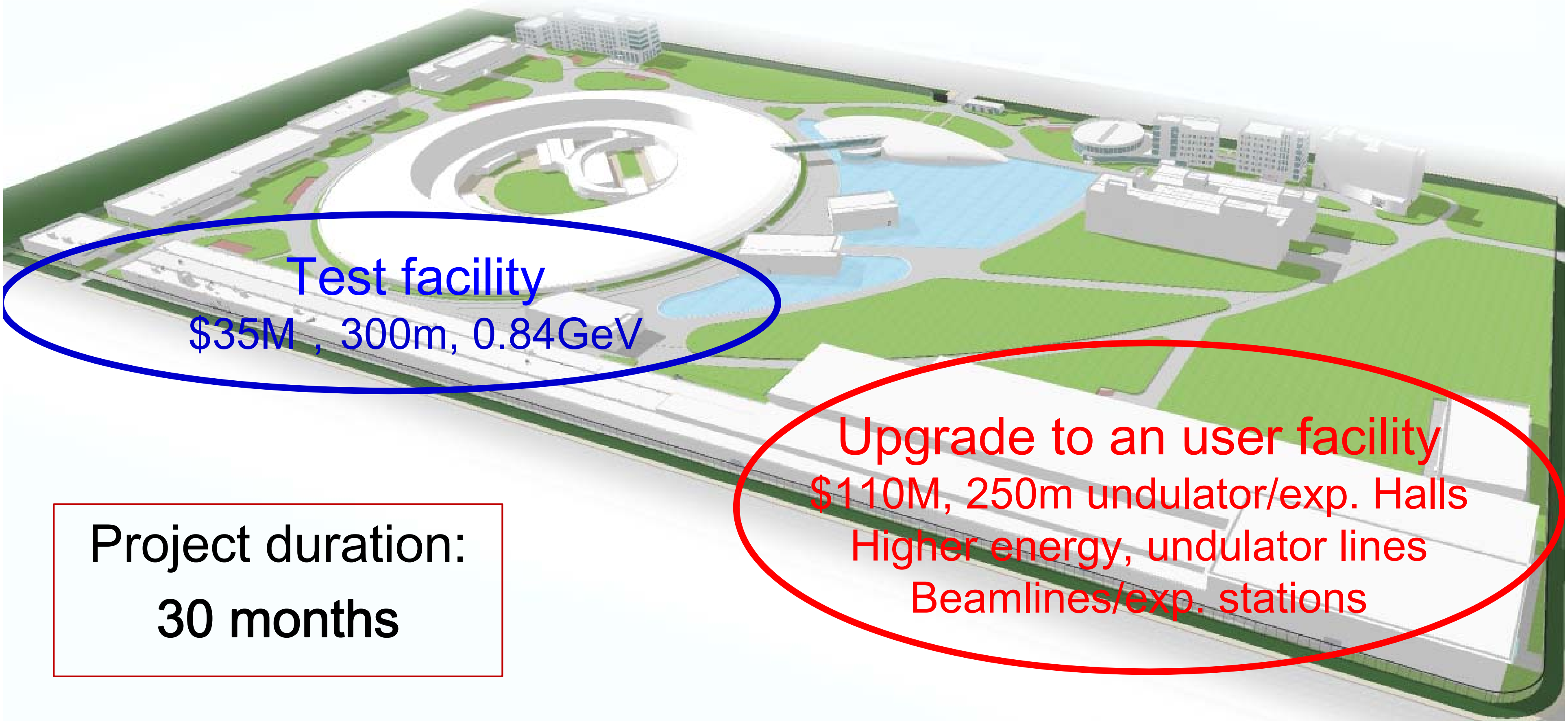



Courtesy:
G.L. Wang, DCLS

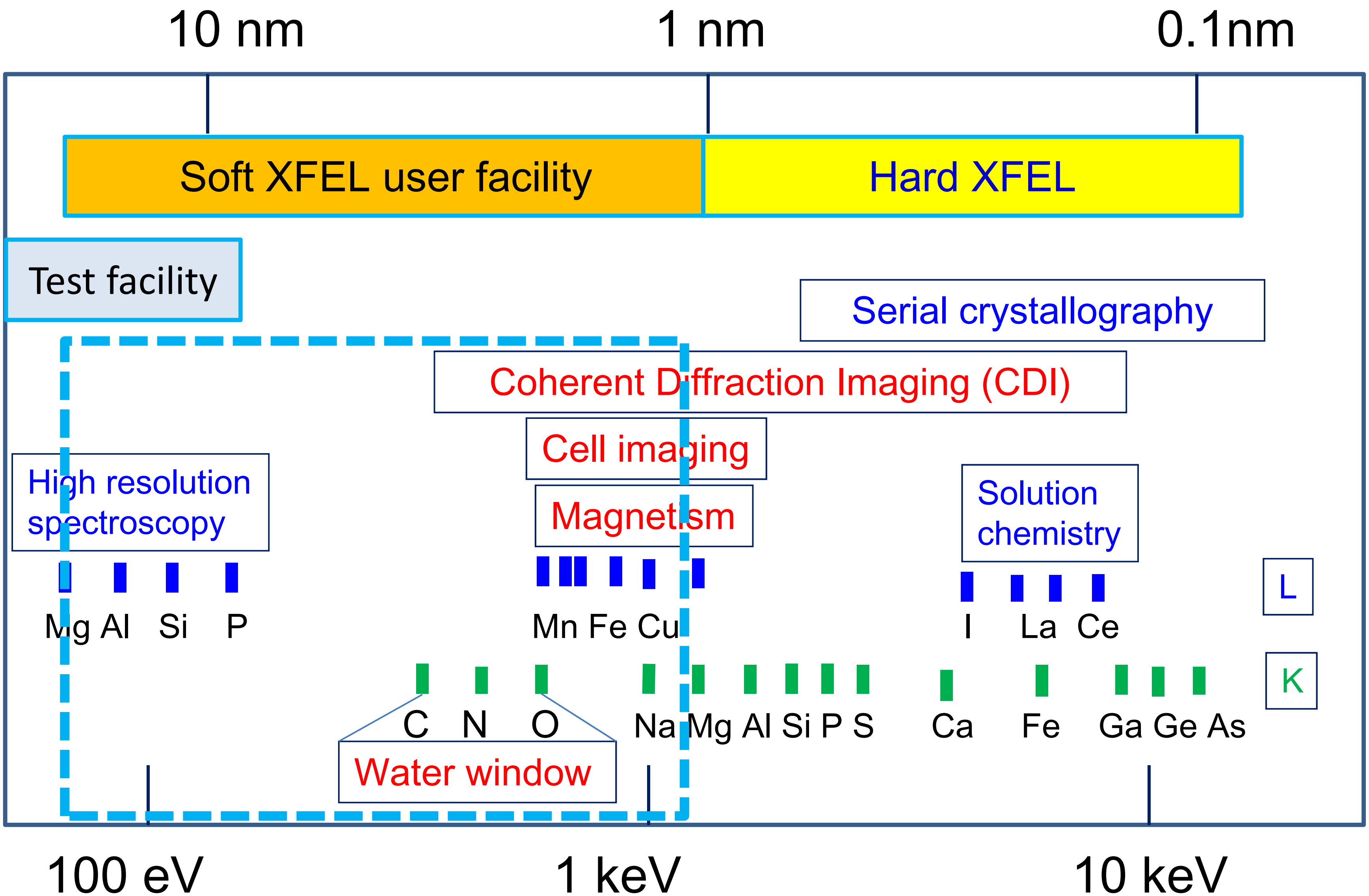
# SXFEL user facility project: Just approved

- New funding for upgrade to user facility with $110M.
- Build undulator/experiment halls and increase beam energy.
- Jointly with Shanghai Tech Uni.( responsible for user stations)

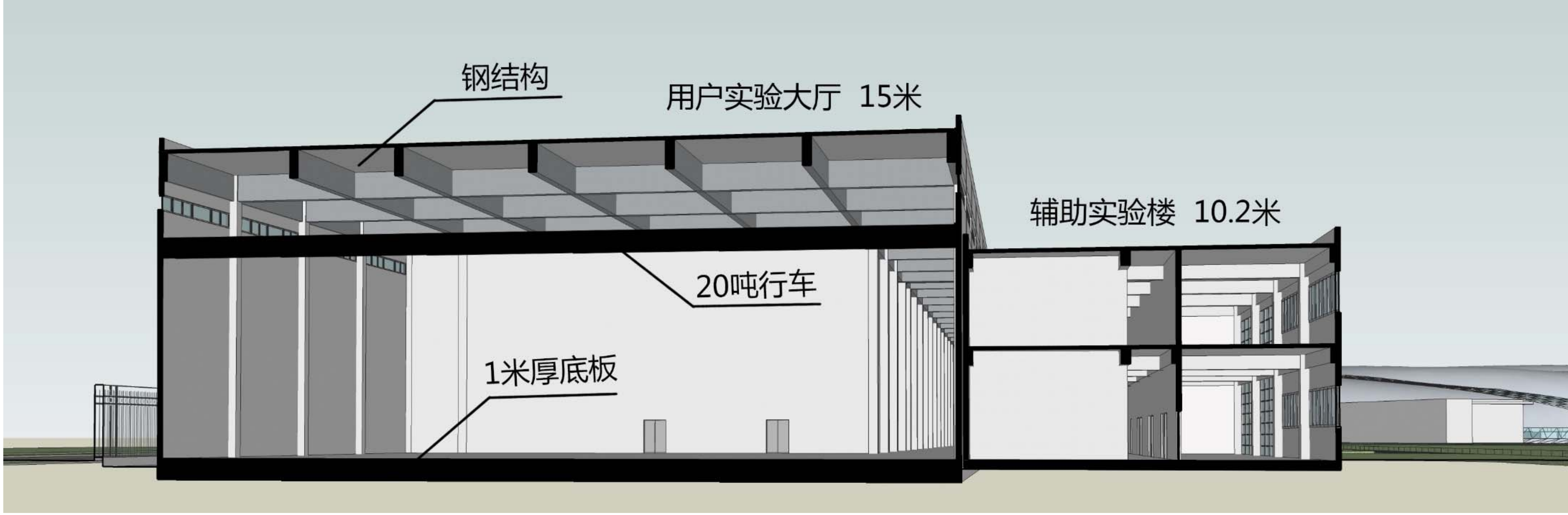



Project duration:
30 months

# SXFEL user facility:
# Strongly pushed by scientific community



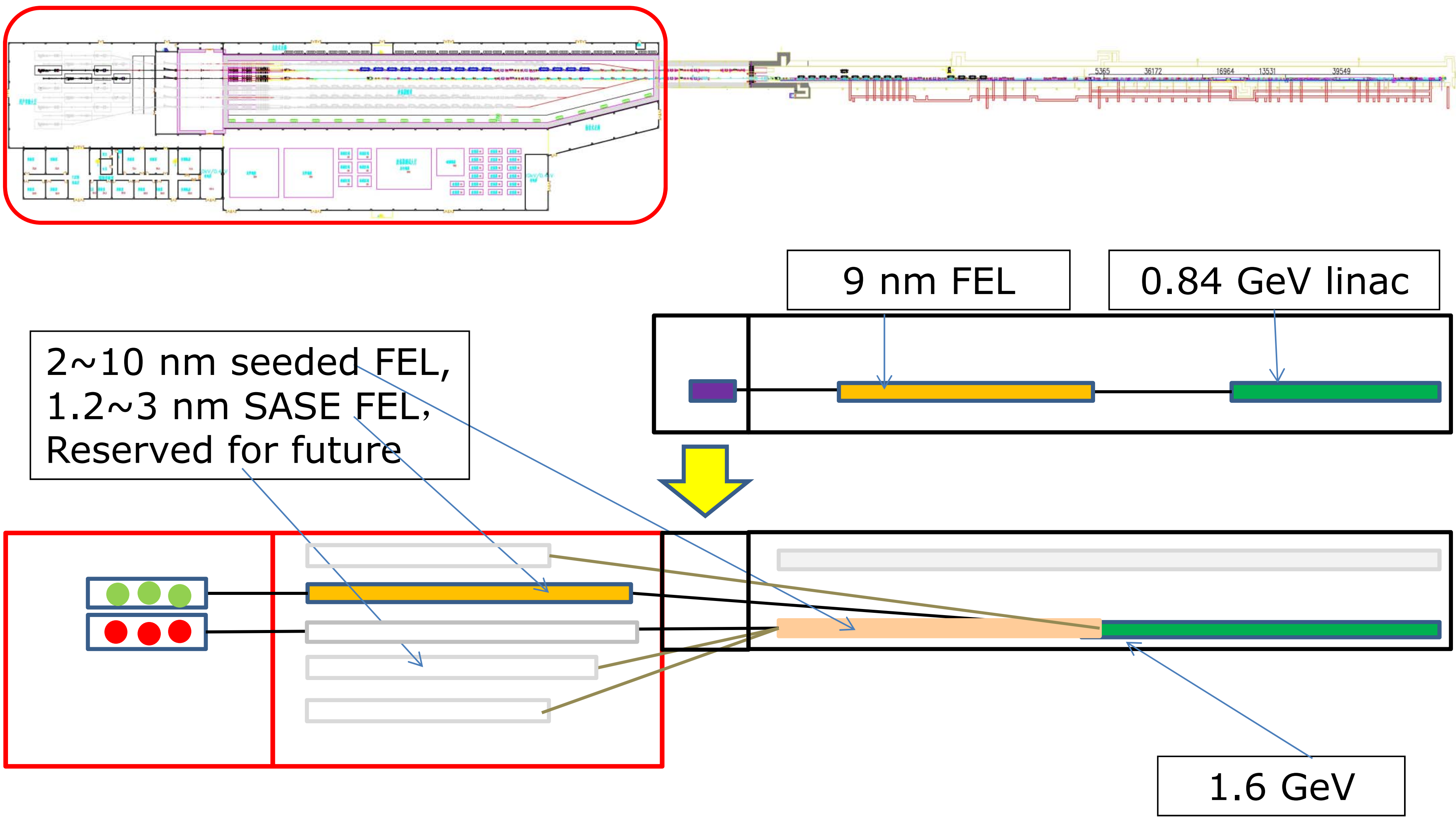
# New buildings for user facility



# User Facility Parameters

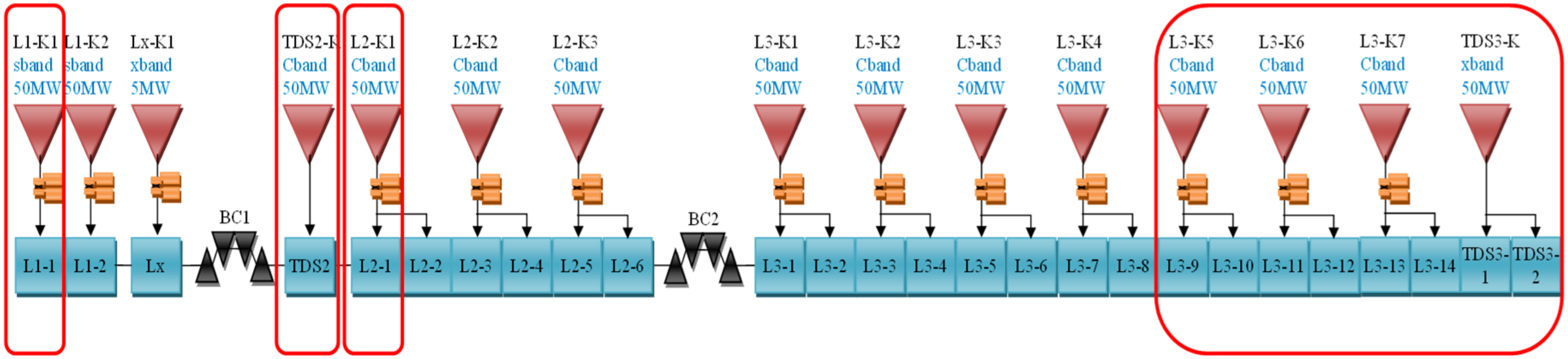
| Parameters | Test Facility | User FEL1 | User FEL2 | Unit |
|---|---|---|---|---|
| Output Wavelength | 9 | 2~10 | 1.2-3 | nm |
| FEL type | HGHG-EEHG | HGHG-EEHG | SASE Self-seeding | |
| Bunch charge | 0.5~1 | ~0.5 | ~0.2 | nC |
| Beam Energy | 0.84 | 1.0-1.6 | 1.0-1.6 | GeV |
| Energy spread | 0.1~0.15% | 0.1~0.15% | 0.1~0.15% | |
| Energy spread (sliced) | 0.02% | 0.02% | 0.02% | |
| Normalized emittance | <2.0 | <1.0 | <0.5 | mm.mrad |
| Pulse length (FWHM) | ~0.5 | 0.03 -1 | 0.03-1 | ps |
| Peak current | ~0.5 | 0.7 | 0.7 | kA |
| Rep. rate | 1~10 | 10-50 | 10-50 | Hz |

# Machine layout:  test facility to user facility

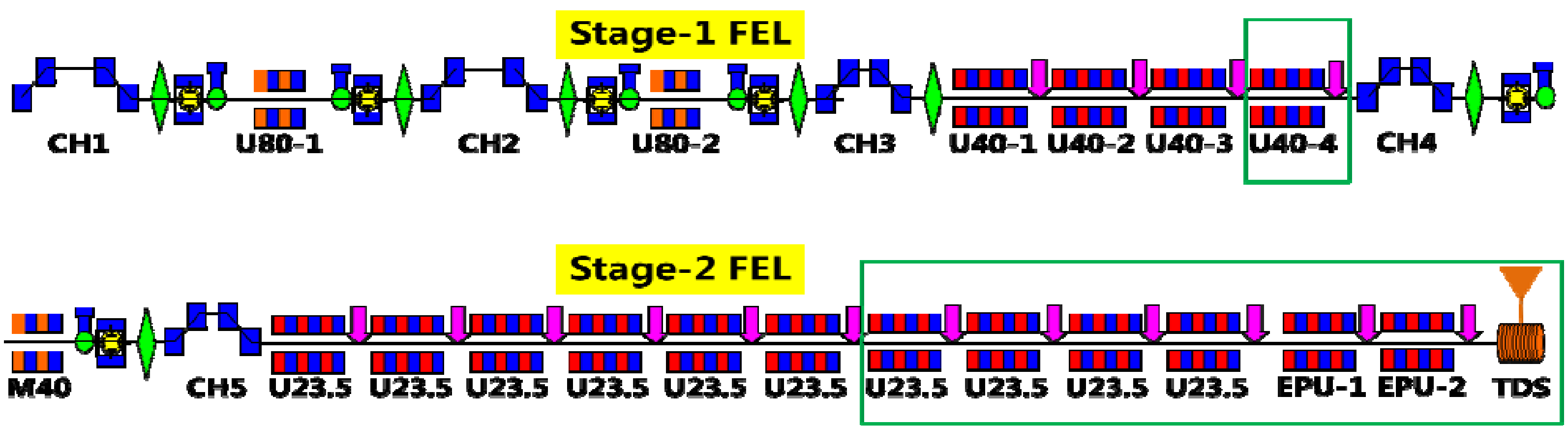


# Machine upgrade for user facility

Linac, add 6 c-band units and 1 s-band klystron

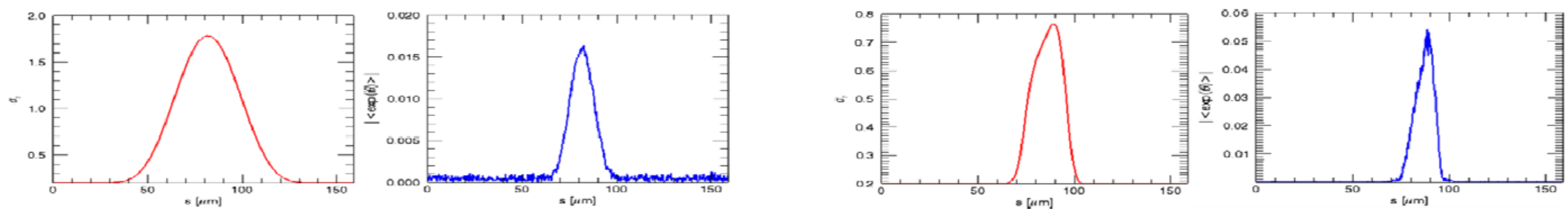



Seeded FEL line: add 7 undulator units

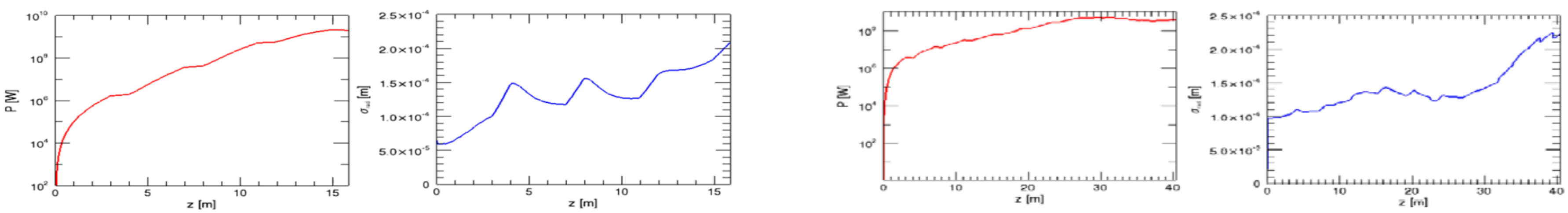


# FEL1: seeded @2~3nm

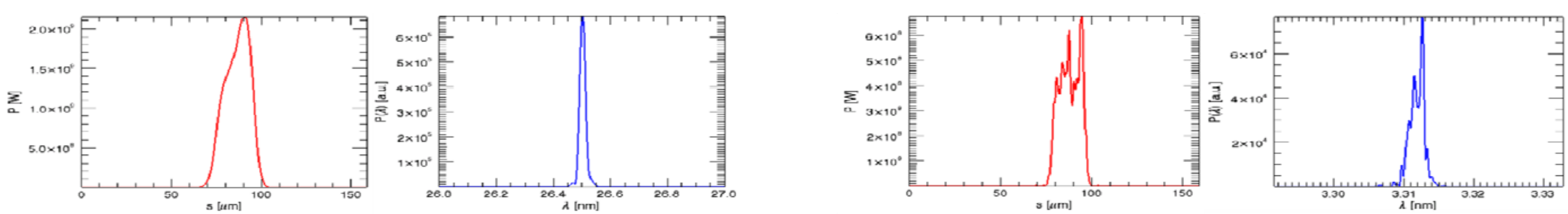
First stage | Second stage



Energy spread ( red ) and bunching factor ( blue )



Gain curve ( red ) and bunching evolution ( blue )

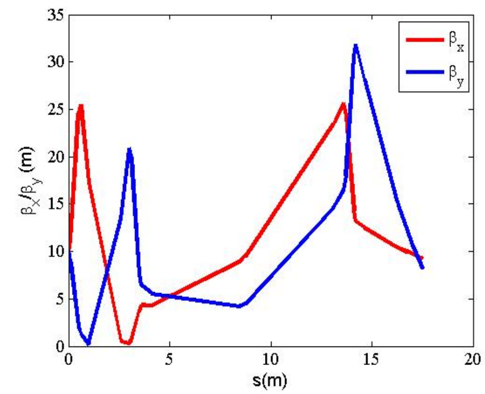


Output ( red ) and spectrum ( blue )

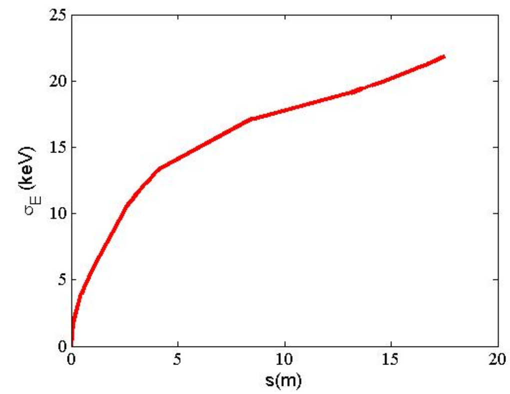
# Possible echo-150 @SXFEL user facility

- To generate coherent radiation in the "water window" and beyond
- Test the harmonic up-conversion limit of a single stage EEHG

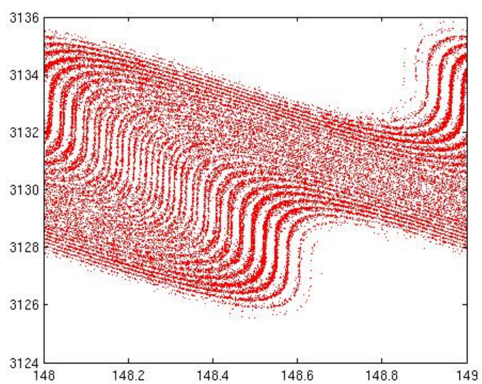
| Main parameters | |
|---|---|
| Beam energy | 1.6 GeV |
| Peak current | 1 kA |
| Energy spread | 160 keV |
| Emittance | 0.4 μm |
| Charge | 0.2 nC |
| Seed wavelength | 265 nm |
| Radiation wavelength | 1.78 nm |
| High-order mode | n=-4 |

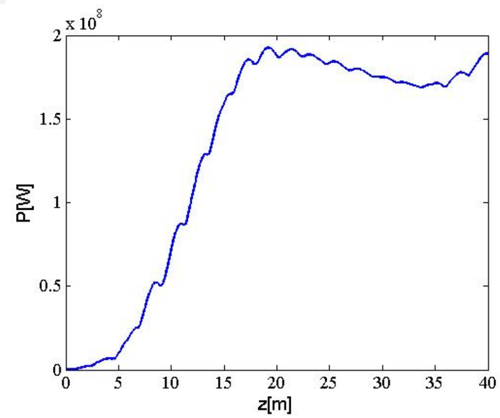


Lattice design from the linac exit to the entrance of the radiator

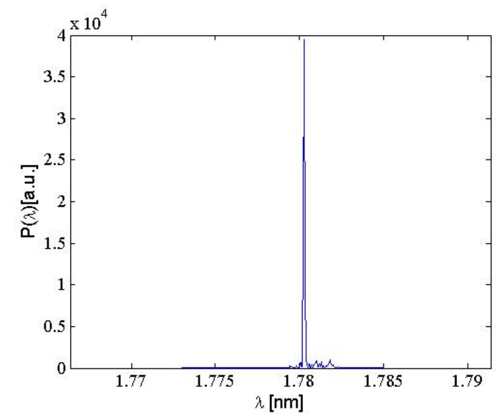


Calculation of the IBS effect


Phase space



Gain curve

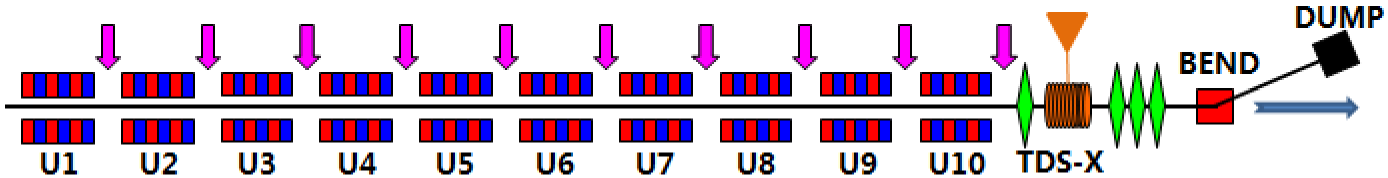


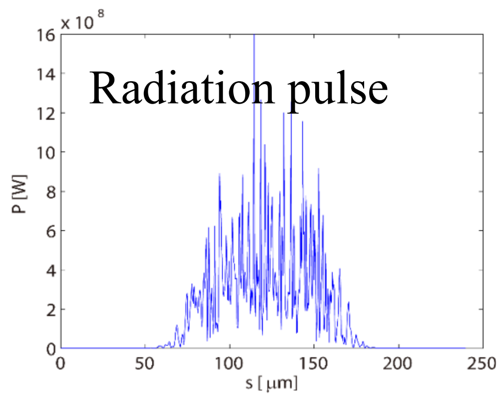
Spectrum

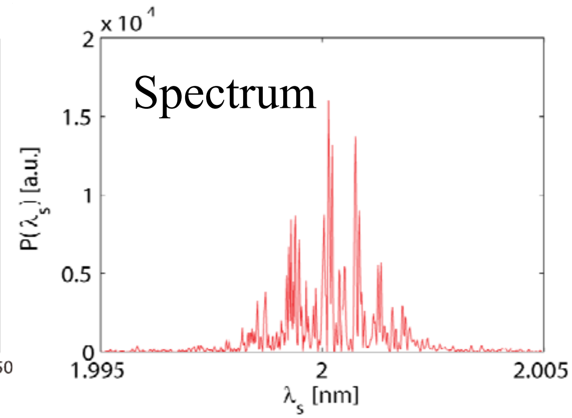
- *K.S. Zhou, C. Feng and D. Wang, to be submitted.*

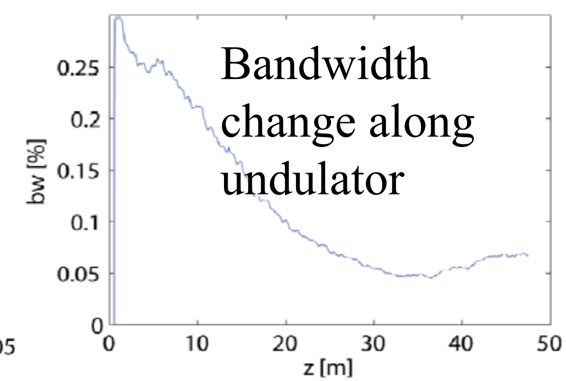
# FEL2: SASE@1~2nm, newly built

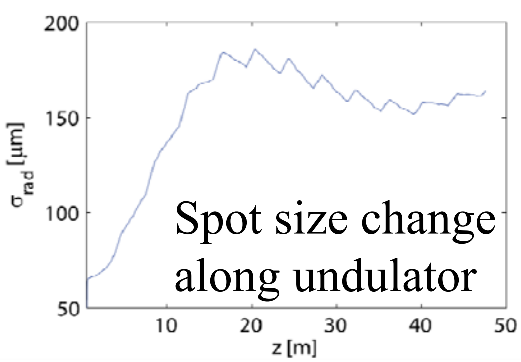
## self-seeding and other schemes being considered

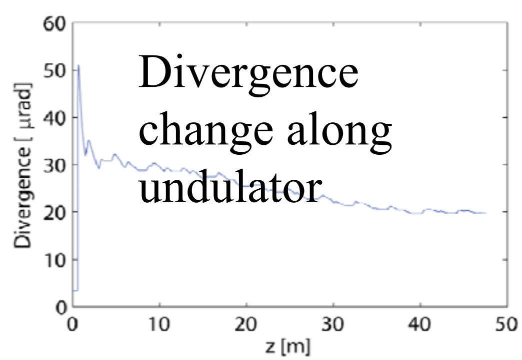


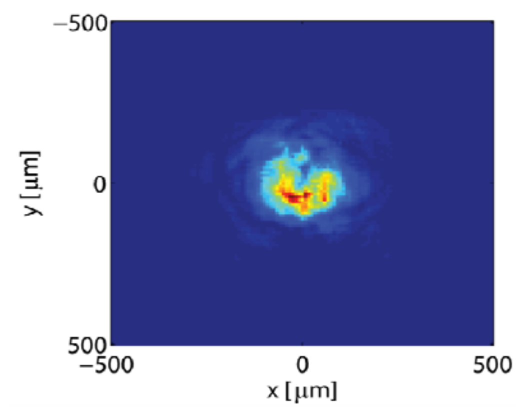



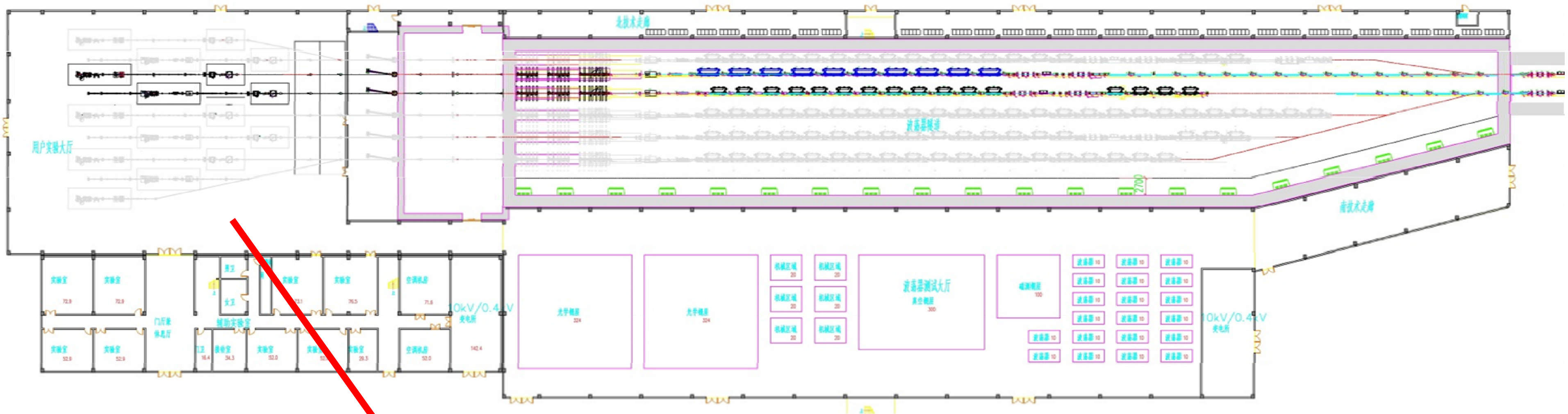



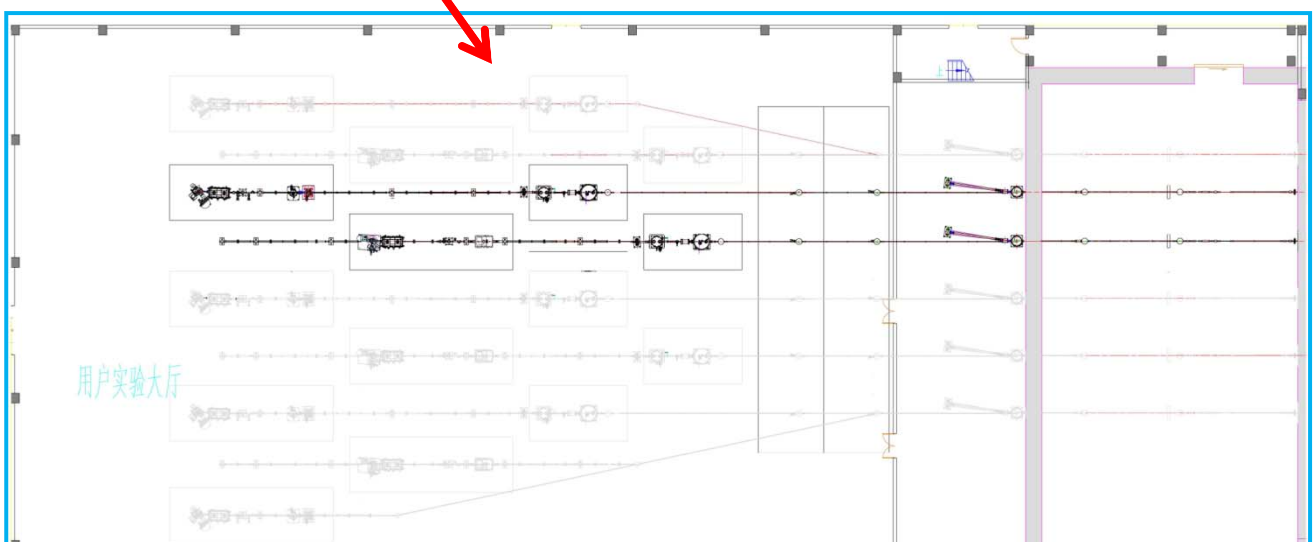




Output spot (near field)

# New buildings (undulator & exp. Halls)






Experiment hall

4 to 5 stations

CDI
AMO
Ultrafast physics
Surface chem.
TBD
(led by STU )

# Remarks

- SXFEL Test Facility project is going OK so far despite of very tight budget and schedule.
- Still tough challenges ahead in installation and commissioning stages for interferences with other projects.
- Soft x-ray FEL user facility got approved, which is a major step forward and foundation for the future.


Thank you！