X-ray FEL facilities at Shanghai

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Chinese Academy of Sciences

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Casa Marina Resort, Key West, FL

13th International Computational Accelerator Physics Conference (ICAP 18)

SIOM

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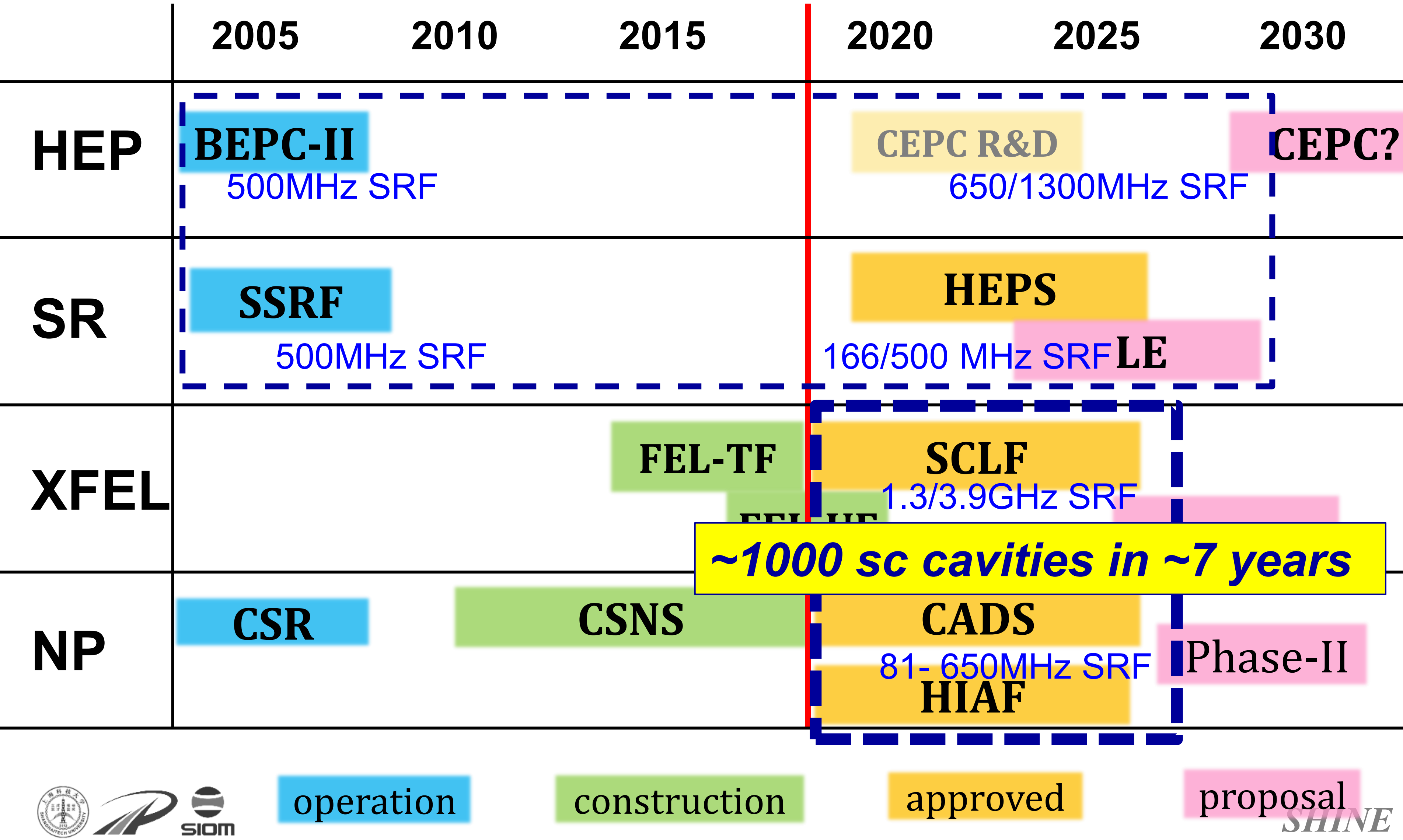
Outline

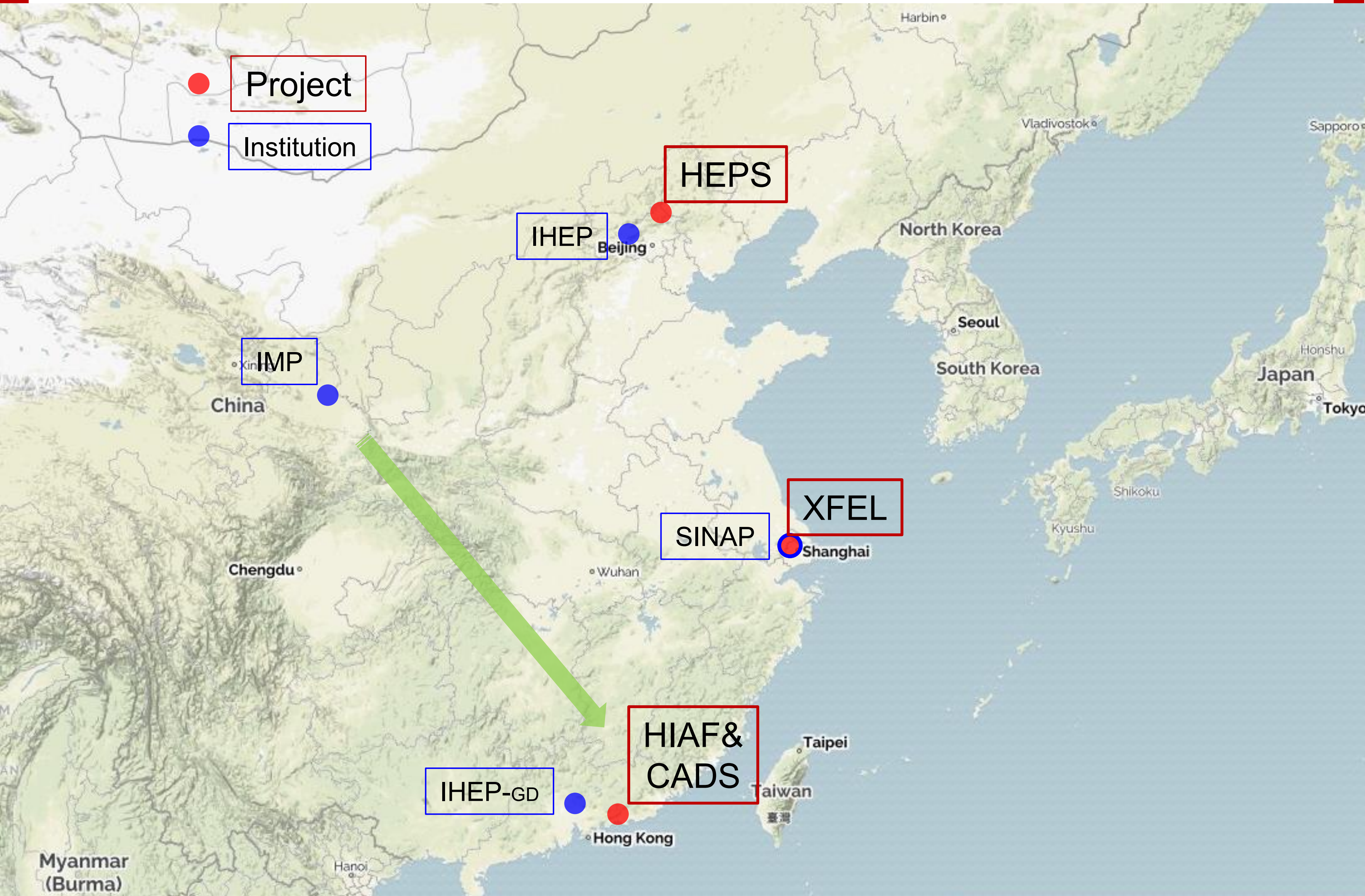
- Introductions
- General layout and parameters
- Key sub-systems
- Infrastructure and R&D for future
- Summary

Large Accelerator Projects in China

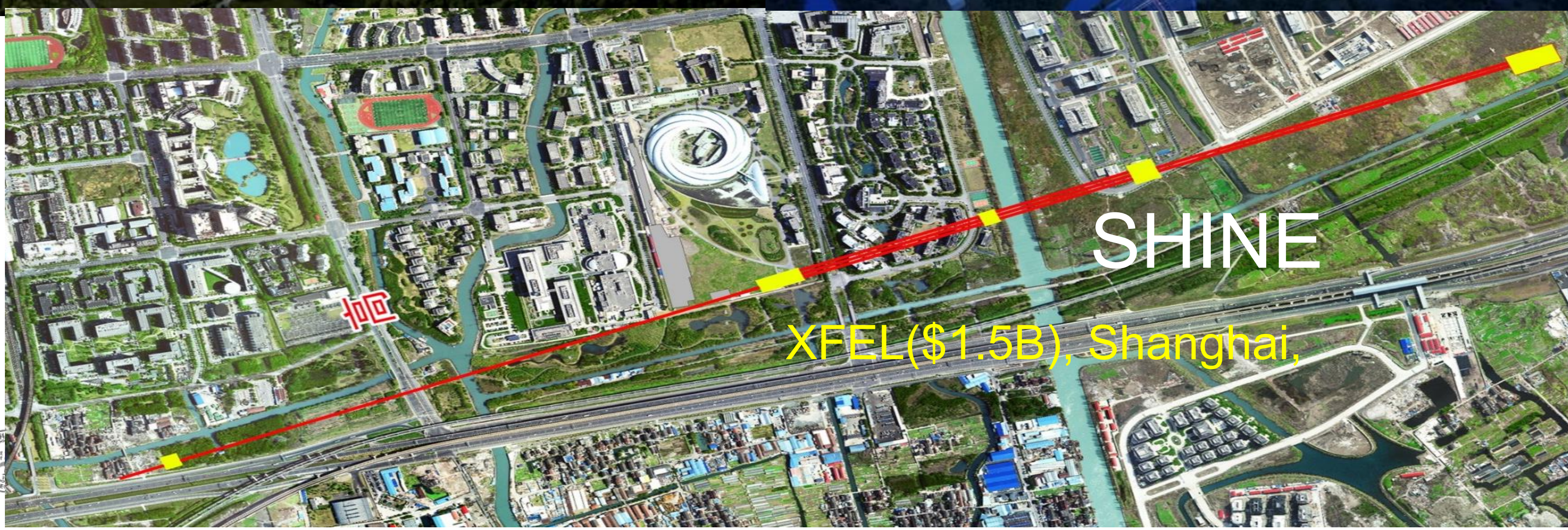
(2005-2025)



Maps of new accelerator projects in China



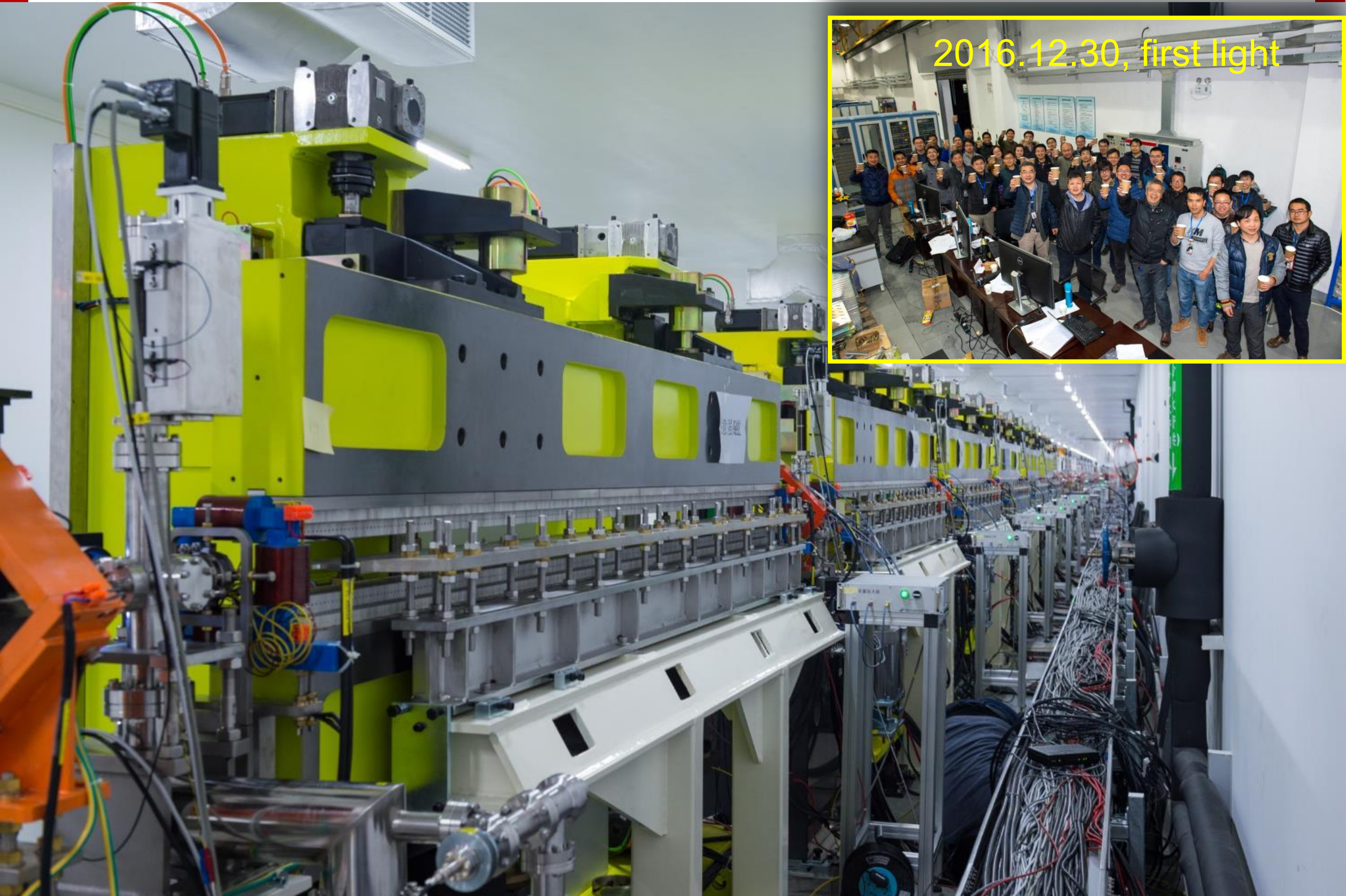
Major accelerator projects in China 2018-25



SINAP/SARI Zhangjiang Campus, Shanghai

X-ray FEL Test Facility：0.84GeV warm linac

XFEL Test Facility



Photon science complex at Shanghai

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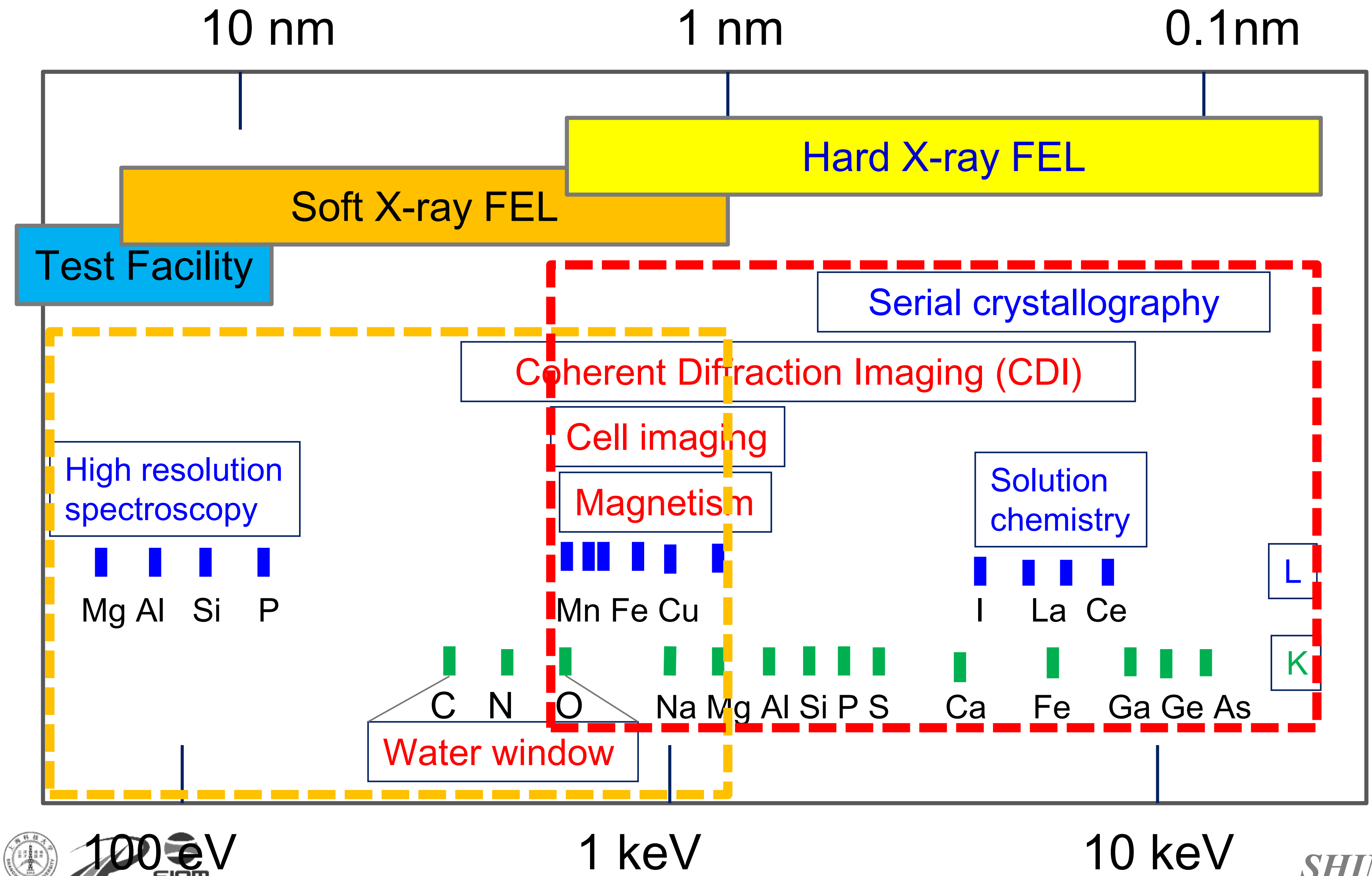
Decision making on next XFEL project

- Initial plan: low rep-rate XFEL with warm linac,
  - PROS: low cost/compact/early operation
  - CONS: quite limited performance
- CW option: high rep-rate XFEL with cw scRF linac
  - PROS: high performance, much more potentials
  - CONS: expensive/late operation/technical challenge

Finally, with strong support by local government (75% of total cost and 100% R&D funding), **cw option** was chosen. Approval by national/local funding agency: April 28, 2017

Scientific needs for XFELs at SINAP



Scope of Hard X-ray FEL at Shanghai

- Officially approved April 2017, groundbreaking in 2018
- ~3km long, 8GeV cw linac, 1MHz rep-rate, 3 FEL lines
- 3 beamlines, 0.4-25keV, ~10 stations, 100PWs laser
- Cost: ~ $1.4B, (~80% by local government)
- Schedule: 7 years (2018-25)
- Joint project team: STU, SINAP, SIOM
- Potentials: >6 undulator/beamline, ~30 stations, 100PW laser vs. XFEL collisions, gamma ray physics, etc.

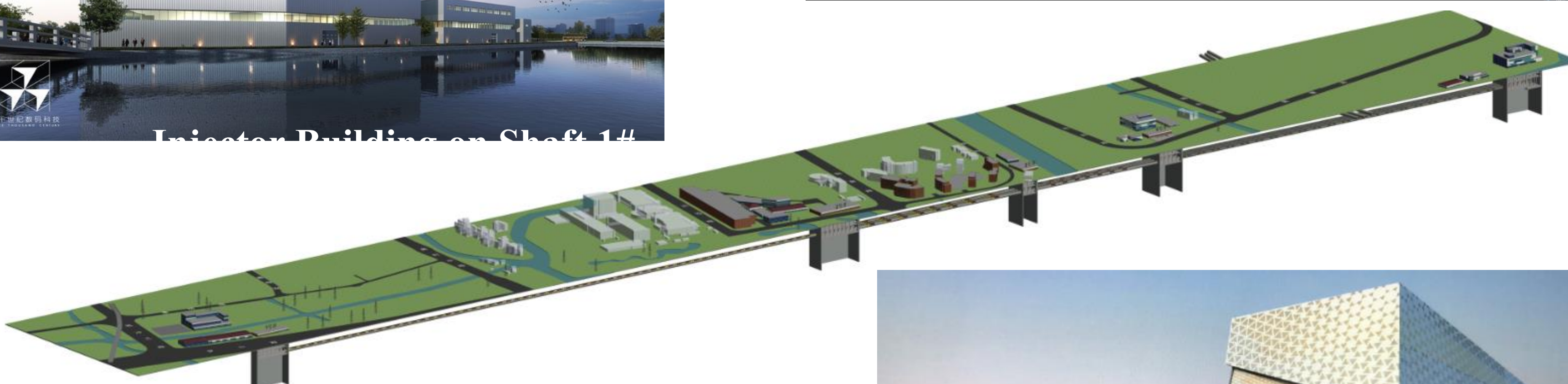
SHINE: cornerstone of new science center

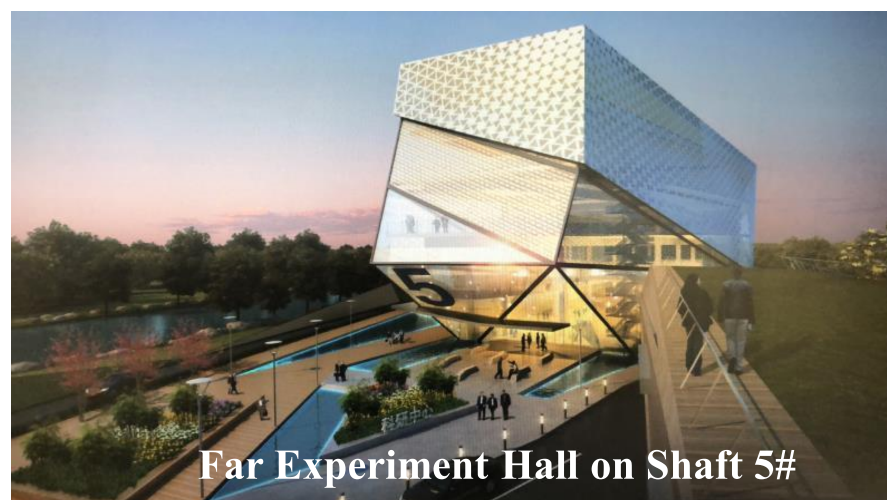
N
Shanghai Hard X-ray FEL
Injector
Linac
Switchyard
SINAP
S
STU
Far Hall
SARI
Near Hall
Beam Dump
Undulator

Buildings and tunnels

Building on Shaft 3#

Injector Building on Shaft 1#



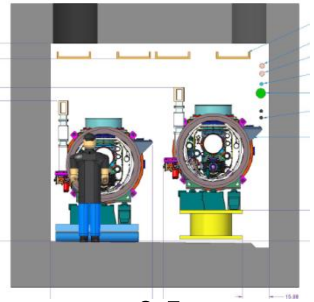


Far Experiment Hall on Shaft 5#

EXFEL，LCLS-II and Shanghai XFEL

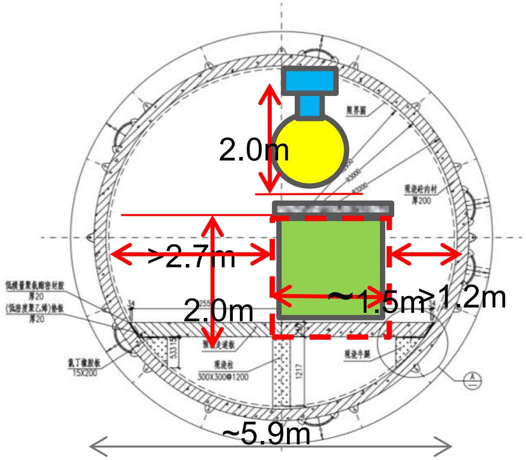
~5.2m

European XFEL



~3.5m

LCLS-II



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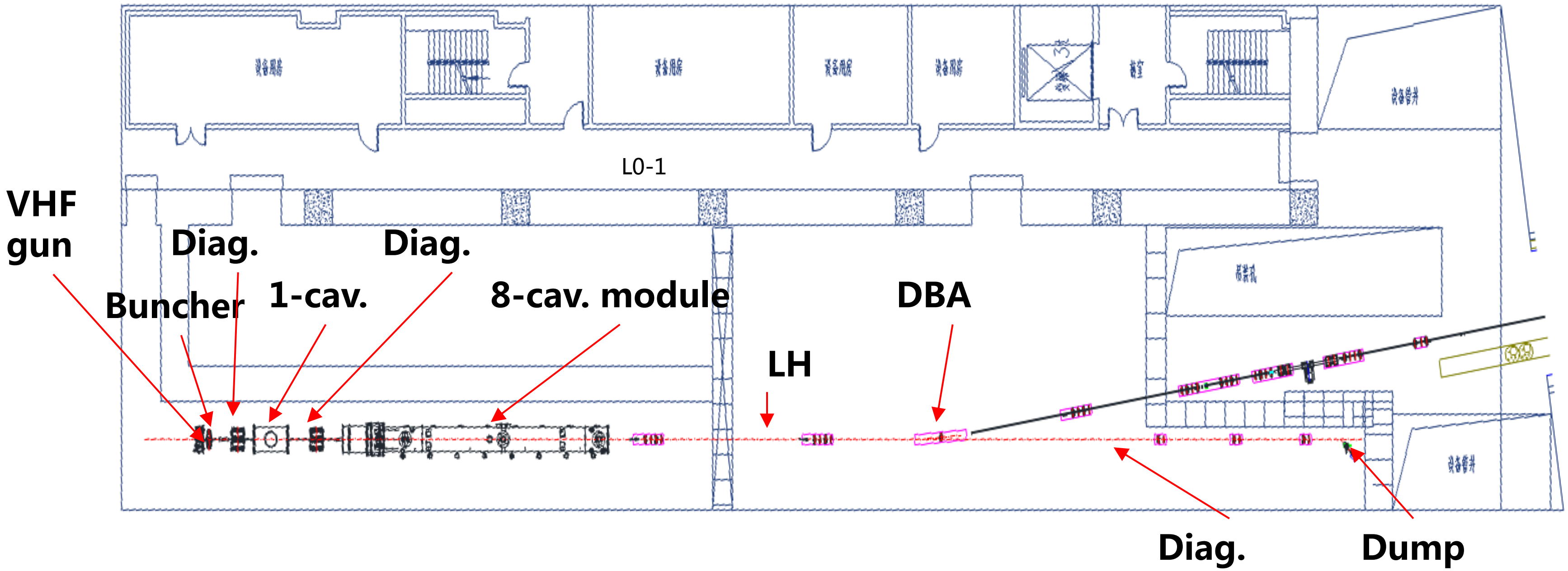
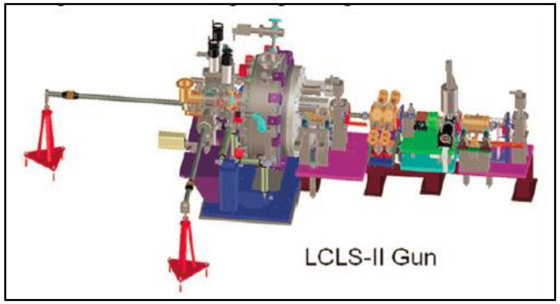
	EuropeanXFEL	LCLS-II（HE）	Shanghai XFEL
RF mode	Pulsed	CW	CW
Power source	Klystron	SSA	SSA
Accelerator	Single Tunnel	Tunnel + Gallery	Single Tunnel
2K heat load/CM	~20w/CM	~80w/CM	~80w/CM
Tunnel slope	~	0.5%	~
N of modules	~100	~35（+19）	~75
2K capability	~3kW	~ 2 x 4kw	~3x4 or 4x3 kw

Shaft #1: Injector



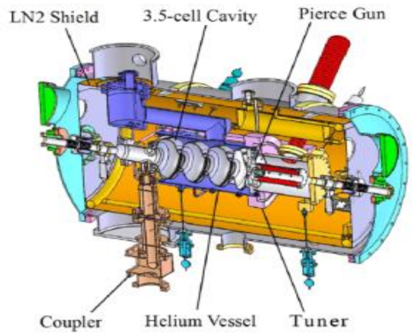
- 2 injectors in parallel possible
- allow independent commissioning

High rep-rate gun：VHF as baseline

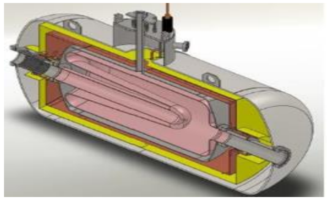


APEX-VHF

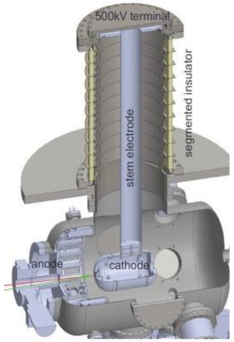
SINAP-VHF



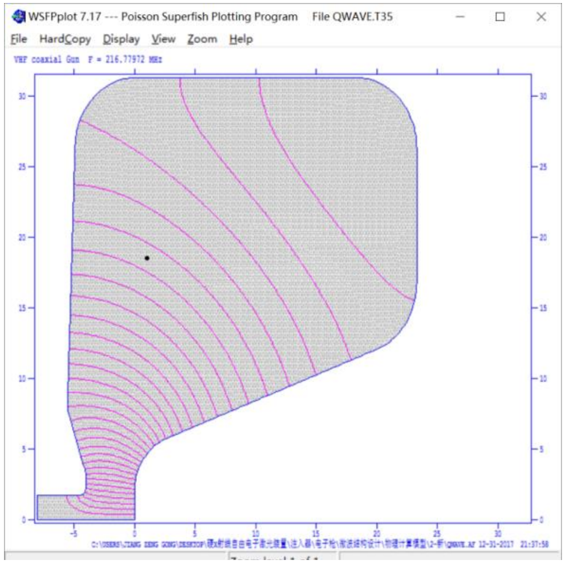
PKU-SC-DC



Wis-BNL-SC
KEK-SC



CU-DC
KEK-DC



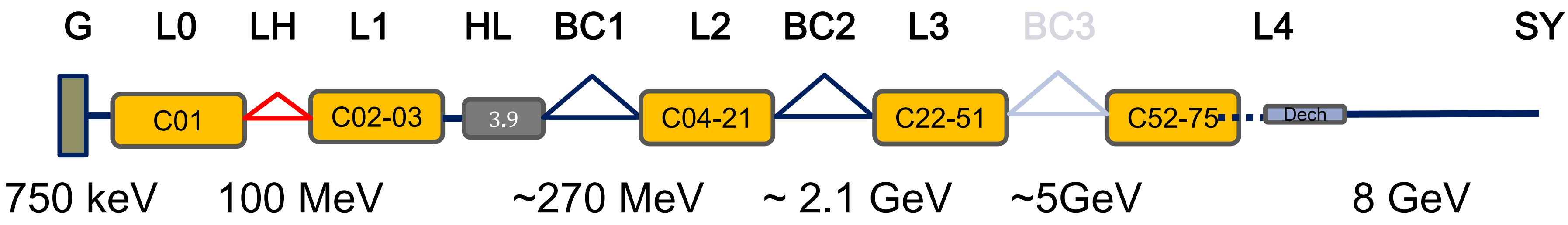
Field calculations

Main parameters of SINAP VHF gun

Frequency	162.5 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.6 MV/m
Q_0 (ideal copper)	29439
Shunt impedance	5.76 MΩ
RF Power @ Q_0	100 kW
Stored energy	2.16 J
Peak wall power density	30.9 W/cm^2
Accelerating gap	4 cm

SHINE

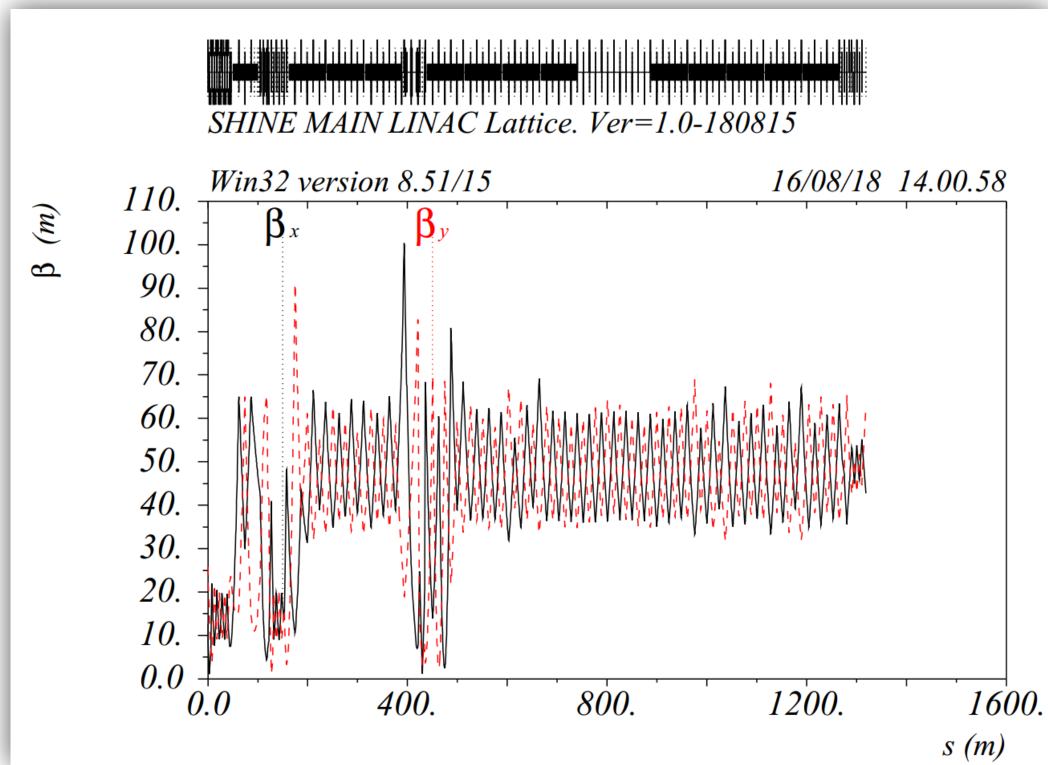
8GeV Linac

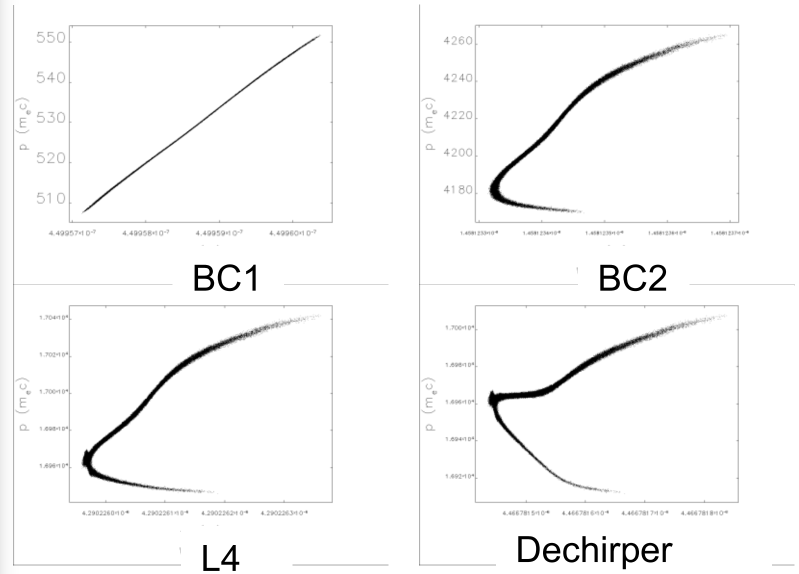


	CMs	Cavities	Powered*	Gradient (MV/m)	Energy(MeV)	σ_z (mm)	σ_δ (%)	ϕrf	R56 (mm)
L0	1	8	7	16.3	100	1	0.04	0	-
L1	2	16	15	14.8	326	1	0.383	-12.7	-
HL	2	16	15	12.5	269	1	1.433	-150	-
BC1	-	-	-	-	269	0.14	1.433	-	-61
L2	18	144	135	15.5	2148	0.14	0.365	-30	-
BC2	-	-	-	-	2148	0.007	0.365	-	-36.5
L3	24	192	180	15.5	5235	0.007	0.085	0	-
L4	30	240	224	15.5	8653	0.007	0.085	0	-

* 6% spare

Lattice of linac





Phase spaces

Linac tunnel:	1430m
Warm section:	4 (DBA + 3BC)
Bunch compression:	2 BCs, 3rd possible
De-chirper:	needed

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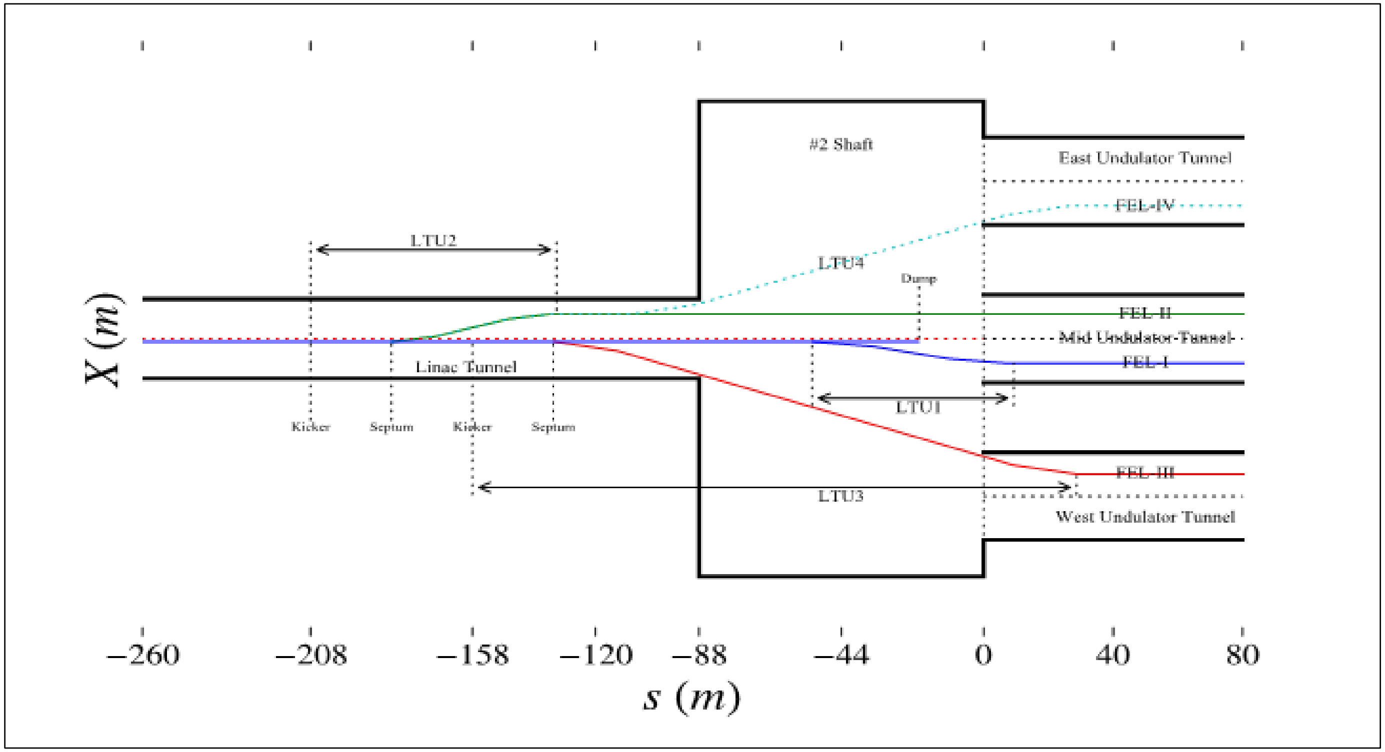
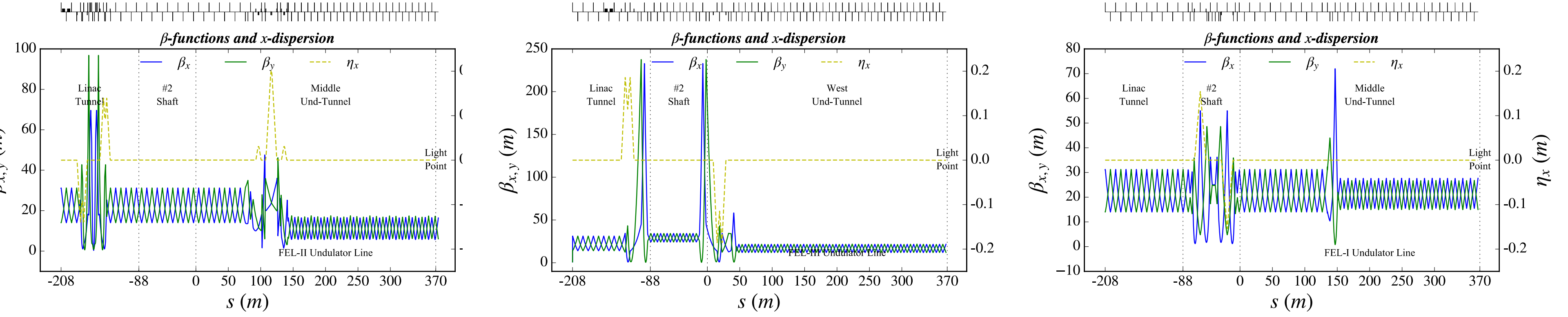
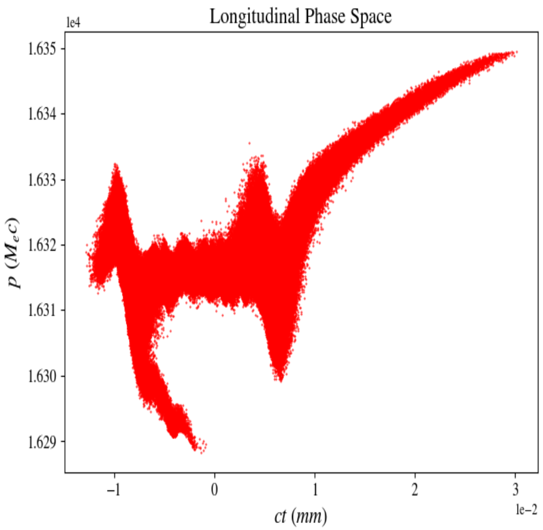
Beam distributions

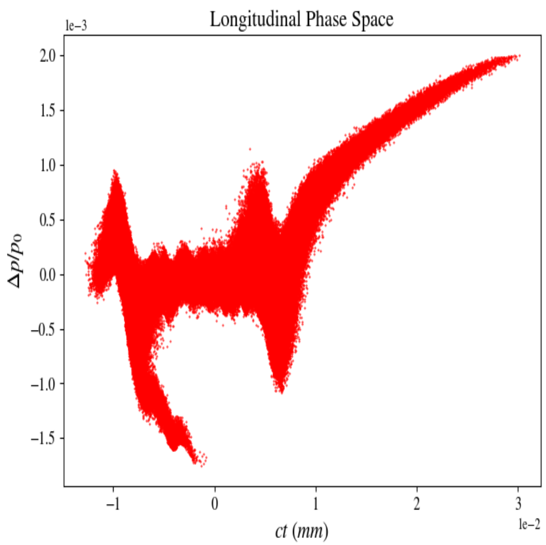




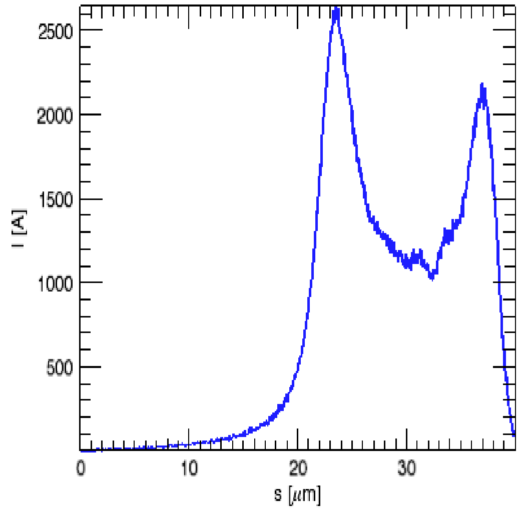
FEL performance

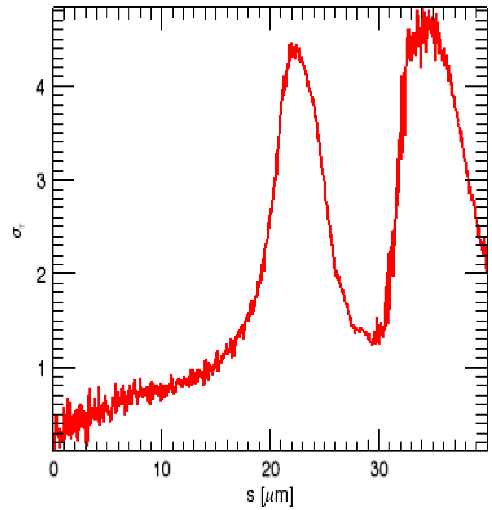
(shown is FEL-I, SASE)



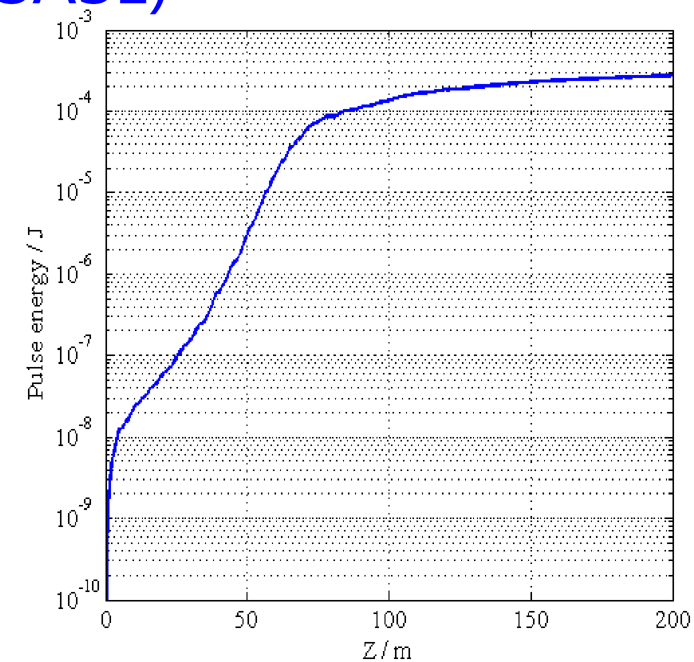


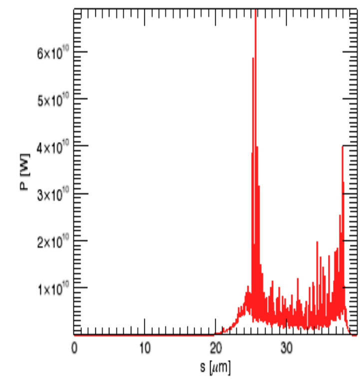
Electron beam profiles

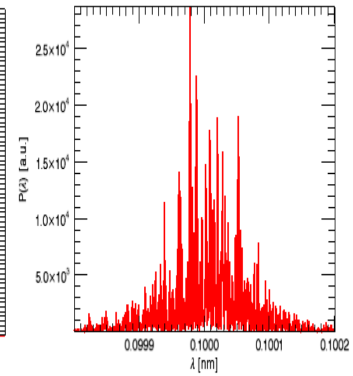




Peak current
Energy spread

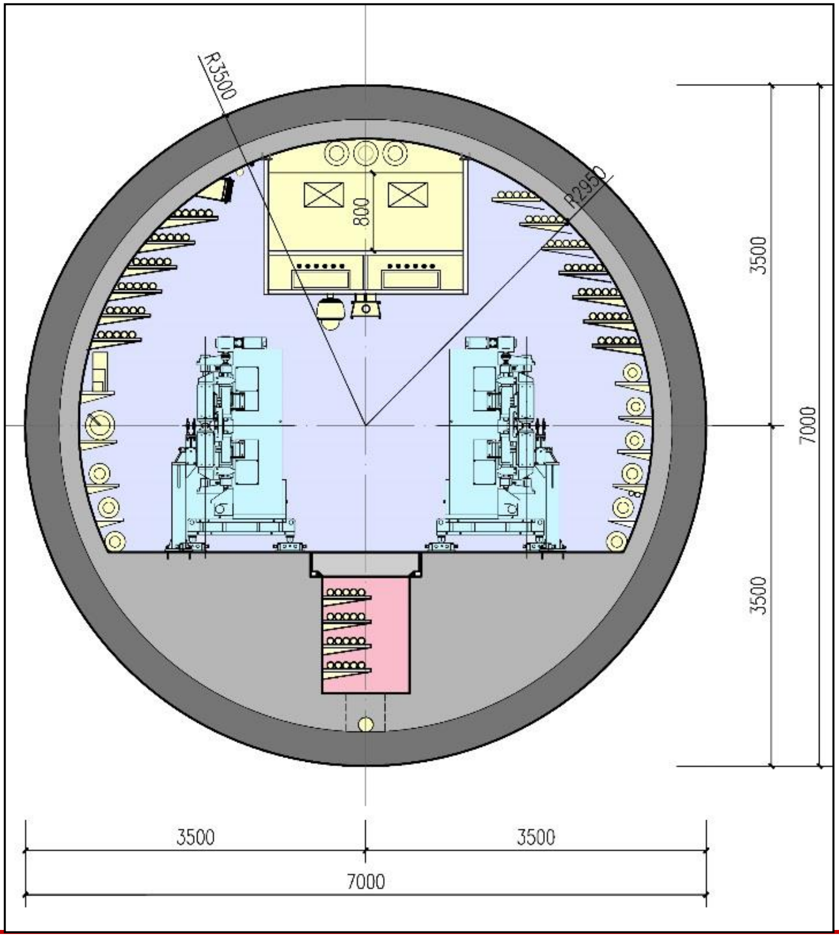






FEL-I performance
(12.4keV，300μJ)
Gain/temporal

Undulators in tunnel



- Left：EXFEL, single FEL line per 4.5m tunnel
- Right：SHINE, two FEL lines per 6.0 m tunnel

Infrastructures and R&Ds for future

- From low to high rep. rate: **a huge step** (warm to SC)
- Y770M (~100M Euros) granted to project since 2017
- Priority: SRF infrastructures/R&D
- Also cw guns, new undulator, kickers, etc
- Prototypes underway
- Team (integrated to construction): STU, SINAP, SIOM
- Collaborations w/ domestic and international institutions: Crucial!

Groundbreaking: April 27, 2018

Civil construction: Shaft #1 and #5

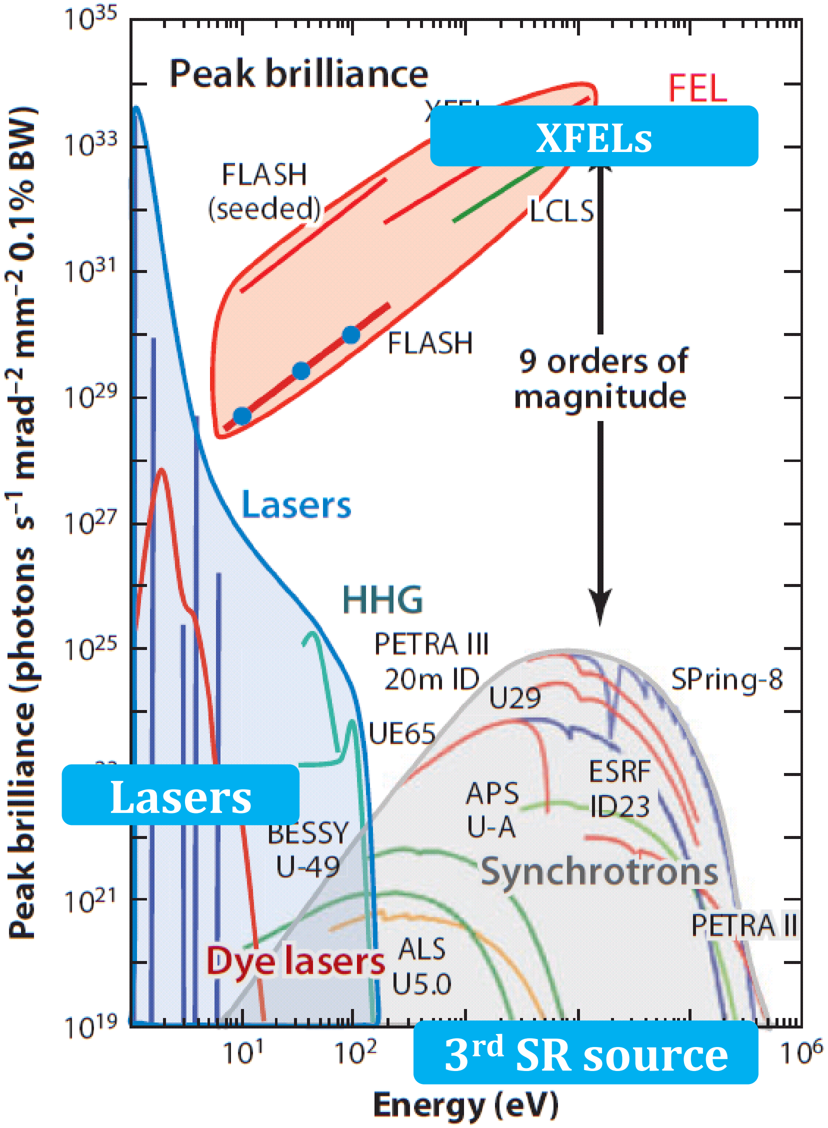
Summary

- Next major facility at Shanghai will be hard X-ray FEL based on superconducting technologies despite of huge technical challenges.
- The main parameters and general layout have been preliminarily explored to meet the requirements by the XFEL performance.
- We are determined to greatly strengthen our sc related capabilities through the intense R&D programs and actively seek the co-operations domestically and internationally to accomplish the project and eventually contribute to the community.


Thank you !

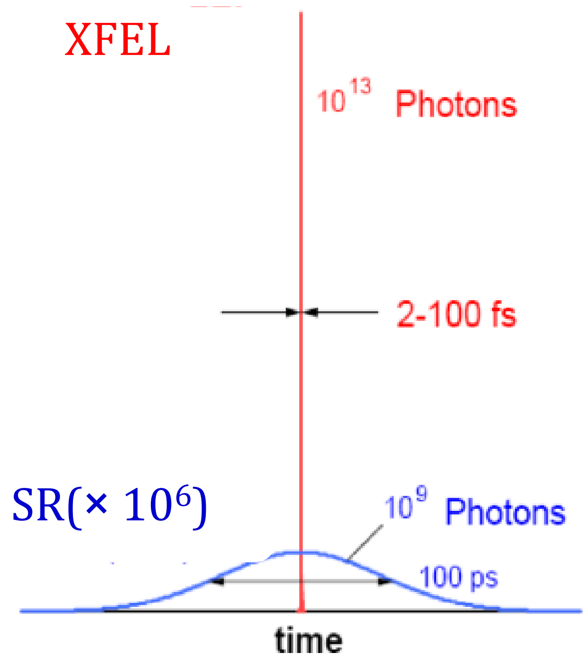
Backup slides

XFEL: new generation



XFEL

- Coherent
- <10 fs ultra fast
- ~10^{12} photons/pulse ultra right

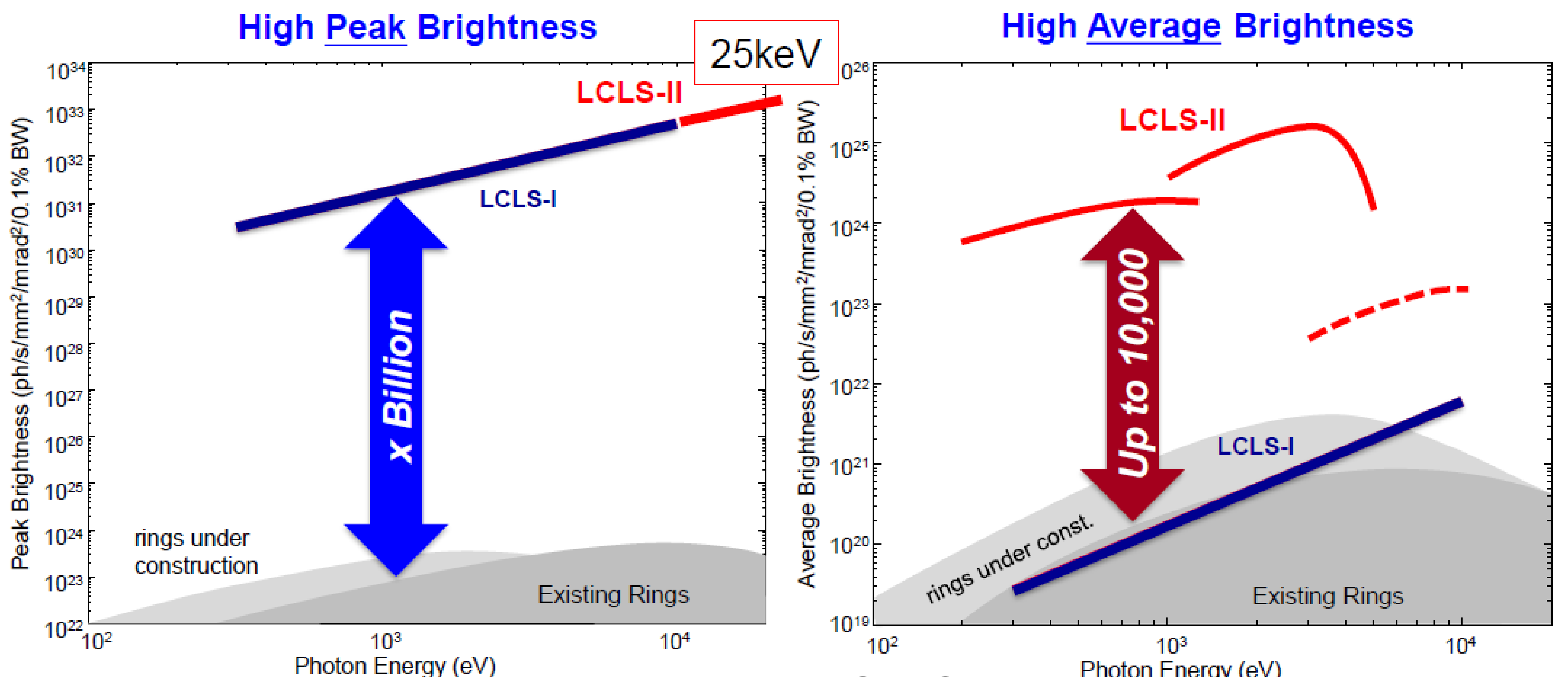


Lots of XFEL are being built/ designed including one in Lund

Why scRF-based XFELs?

LCLS-II provides a factor >10^3 in average brightness (to 5 keV), and extends the reach of the Cu linac to 25 keV

SLAC



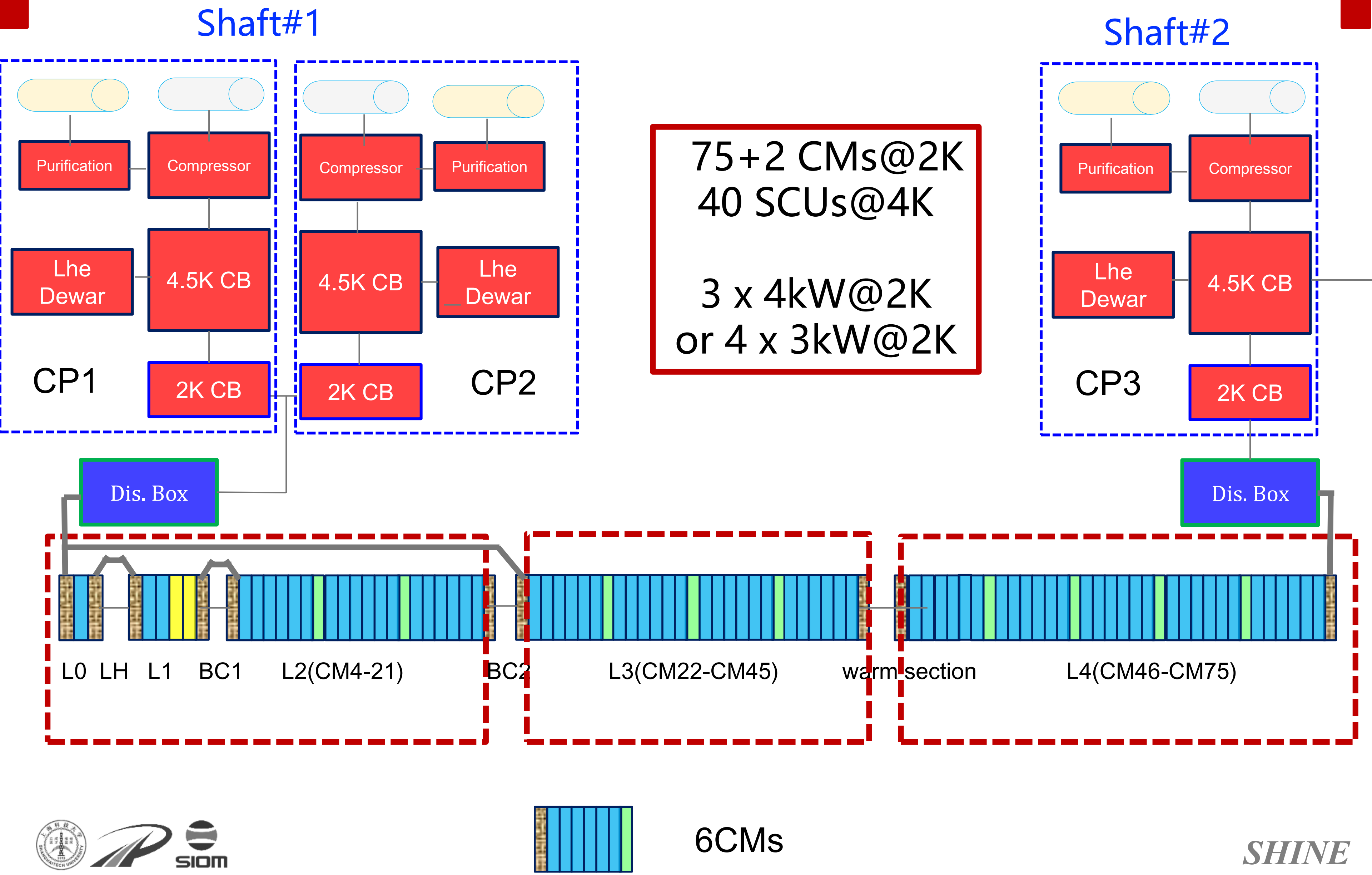
Brachmann, SLAC


Hard X-ray FELs, SC linac, 3~4 km
FLASH
EuropeanXFEL
Linac Coherent Light Source at SLAC
X-FEL based on last 1-km of existing linac
1.5-15 Å
Injector (35°)
Existing 1/3 Linac (1 km)
(with modifications)
New e⁻ Transfer Line (340 m)
LCLS
Undulator (130 m)
LCLS-II
Near Experiment Hall
(underground)
Far Experiment


Hard X-ray FEL, warm linac, 700m-1100m
SACLA
SACLA
PAL-XFEL
SwissFEL


Soft X-ray FEL, warm linac, 400m-500m
FERMI
SXFEL

CMs and cryogenic system



75+2 CMs@2K
40 SCUs@4K

3 x 4kW@2K
or 4 x 3kW@2K

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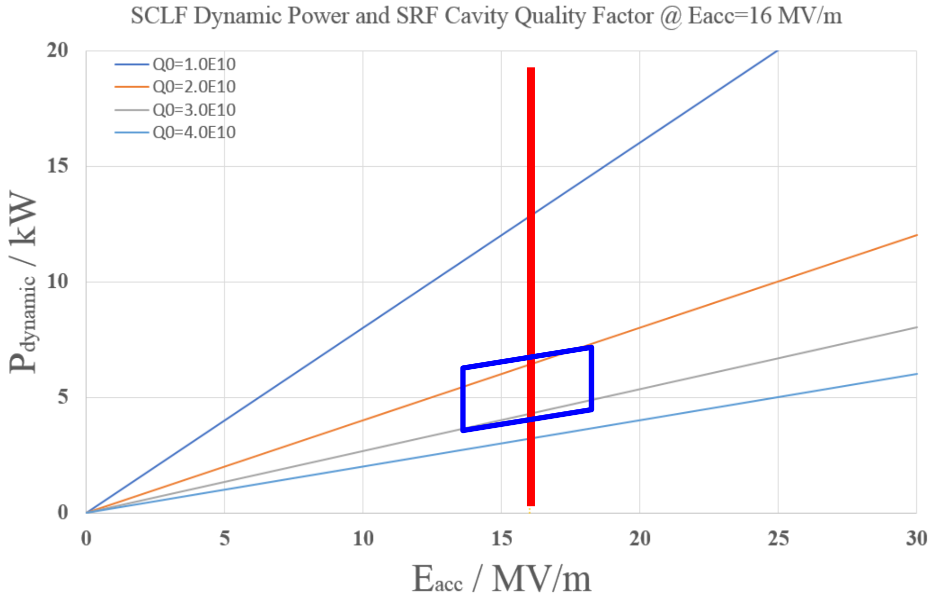
600 RF cavities: ~12kW@2K heat load



Operating points
in considerations

Gradient: 14~18MV/m
Qo: 2.0~3.0E10
Load_d: 4~8kW@2K
Plant: ~12 kW@2 K

- For Q0 ≥3E10 @ 16 MV/m

Surface treatment : N-doping, infusion

Lots prototyping ahead

- For Q0 ≥2E10 @ 16 MV/m

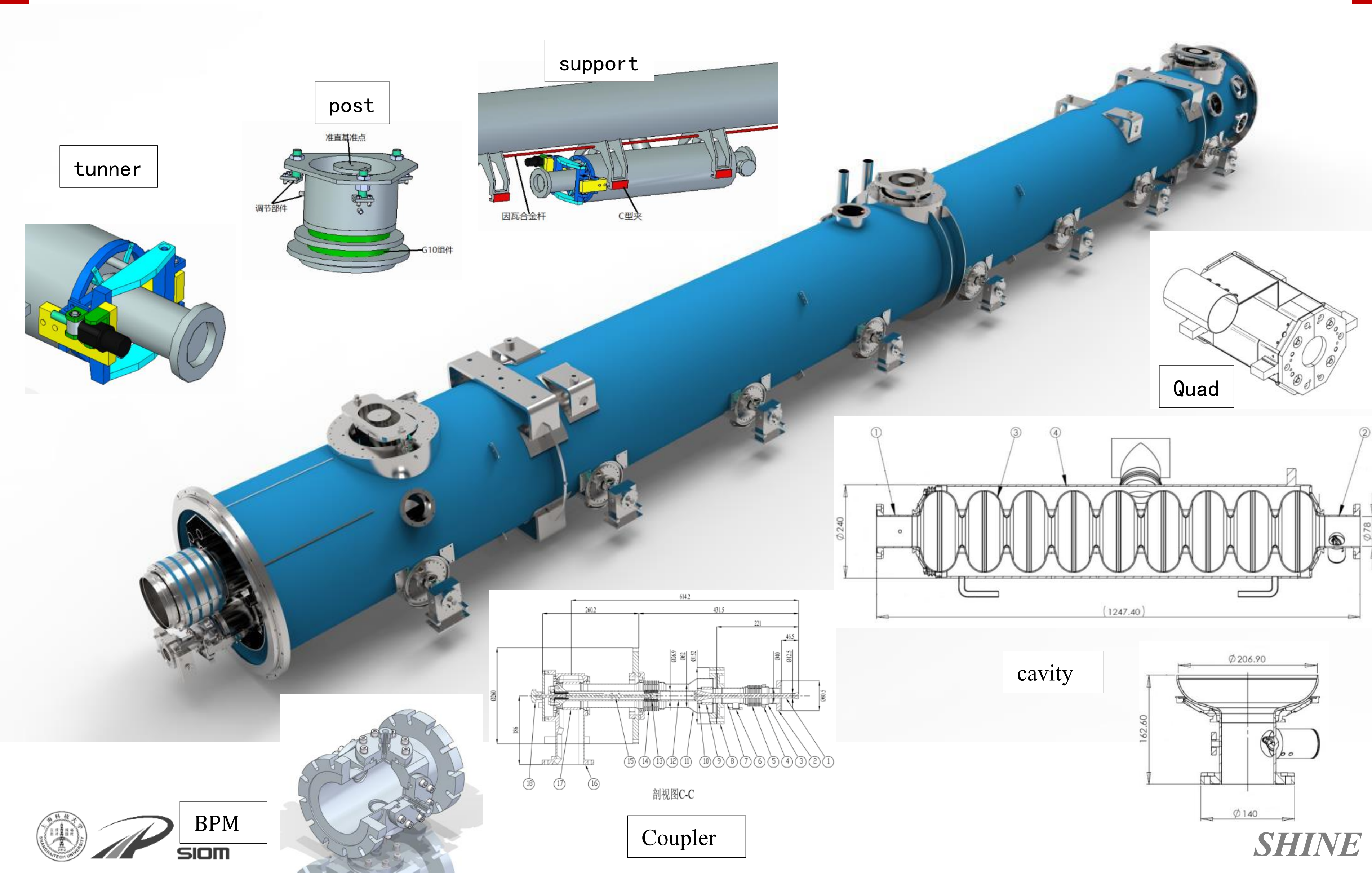
State-of-art non-doping cavities

Large grain materials

2.0 K→1.8K operating

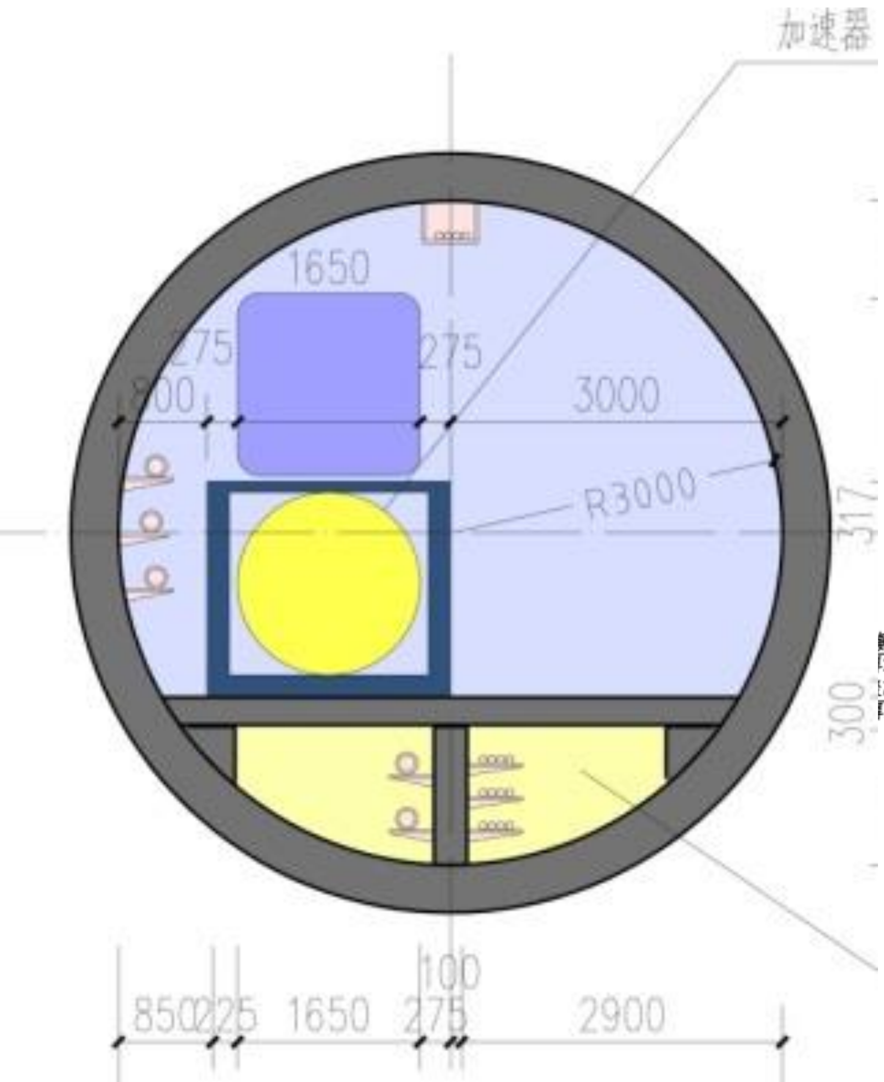
TESLA 9-cell 1.3GHz cavity

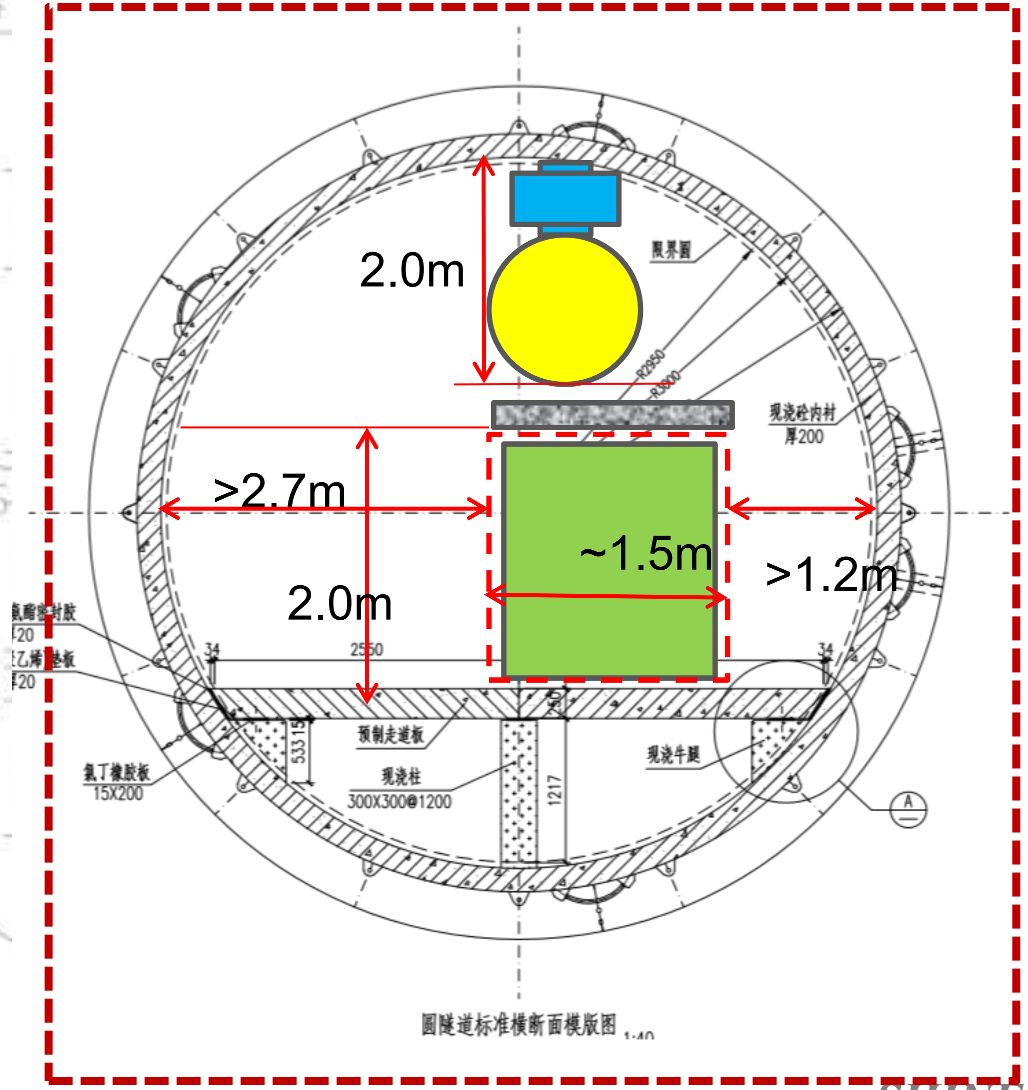
Cryomodule



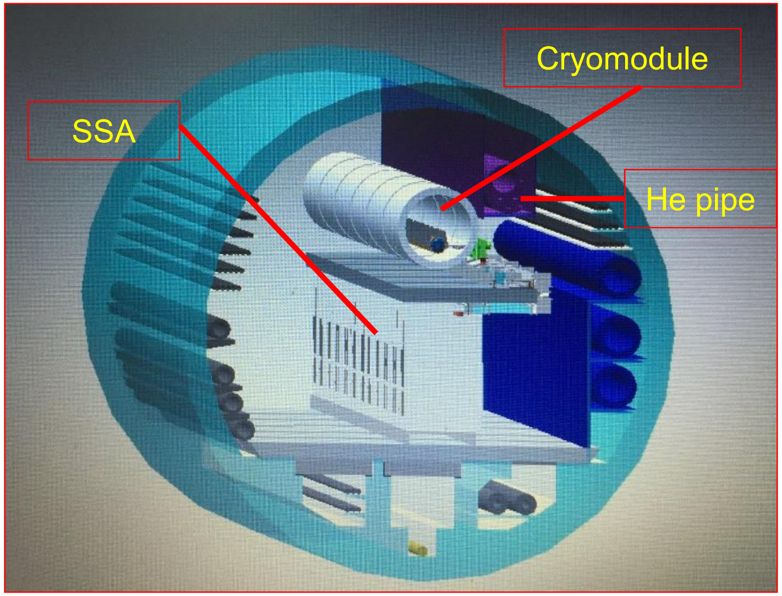
tunner
post
准直基准点
调节部件
G10组件
support
因瓦合金杆
C型夹
Quad
cavity
1247.40
Ø240
Ø78
Ø206.90
162.60
Ø140
Coupler
614.2
260.2
431.5
221
46.5
剖视图C-C
BPM

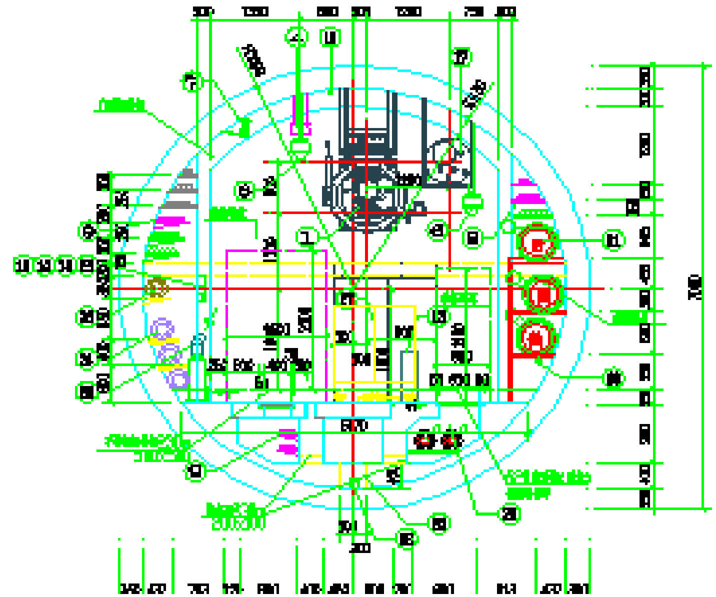
SHINE tunnels: all with 6m diameter

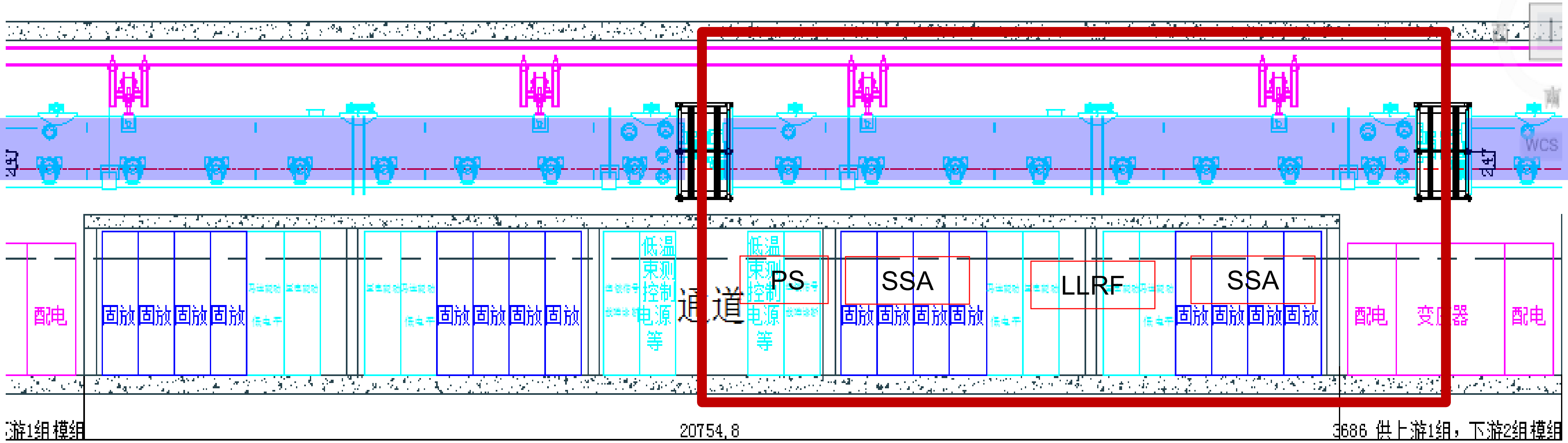




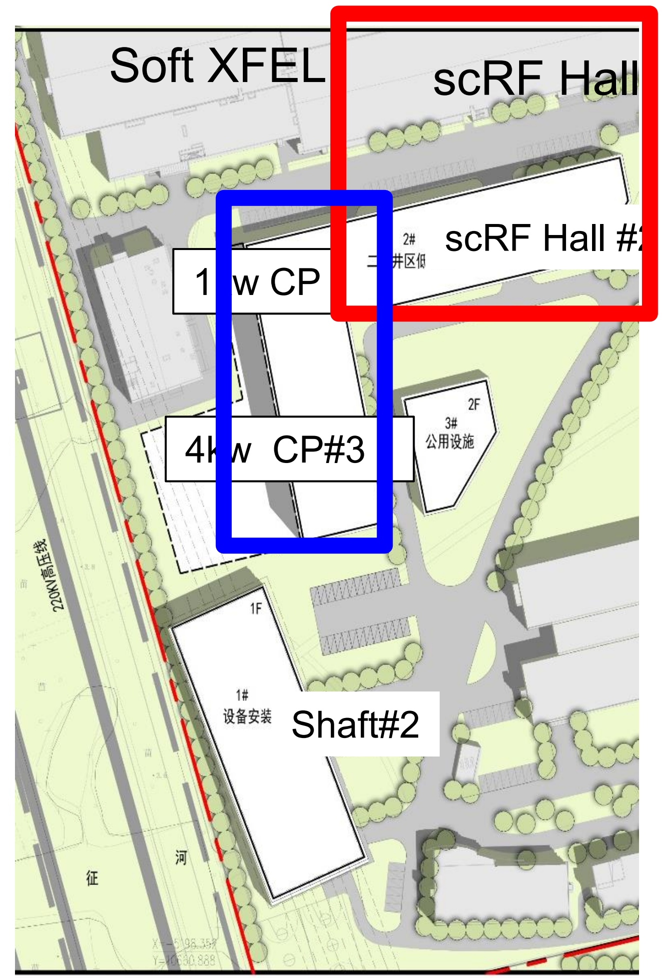
SHINE cryomodule layout



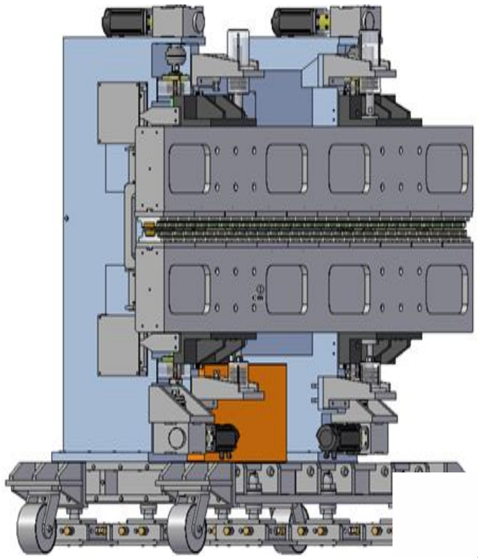




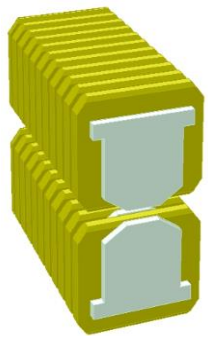
Shaft #2 (at SINAP): switchyard

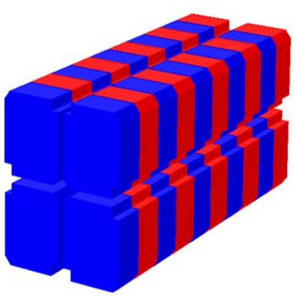


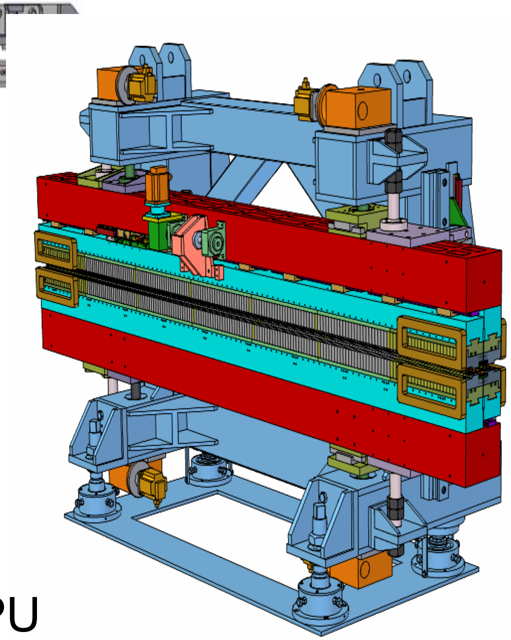
Undulators



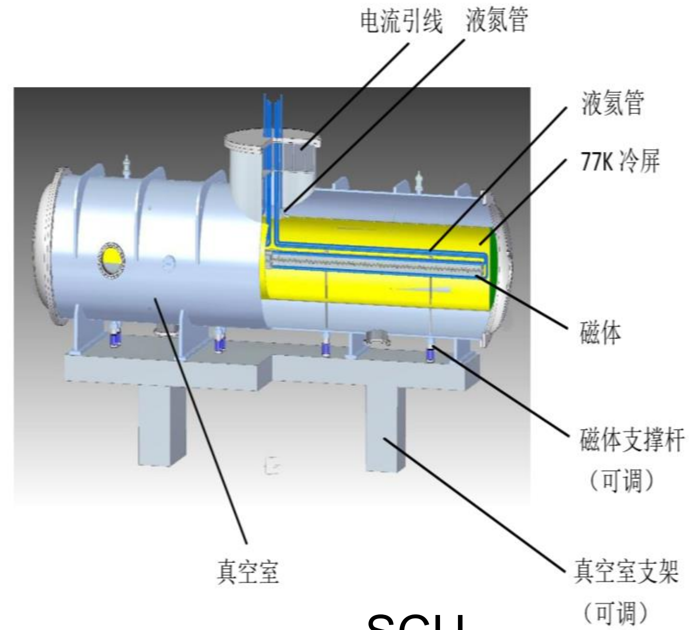
Planar U



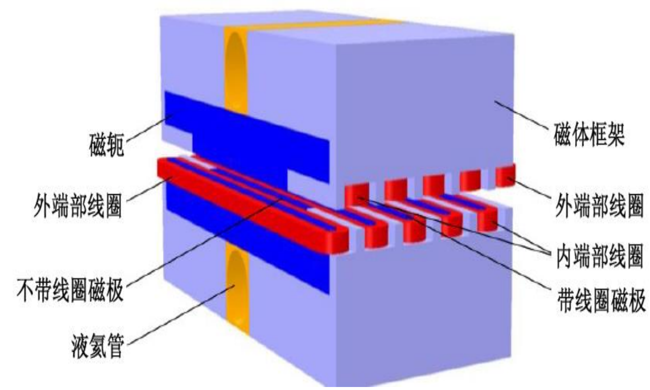




EPU



SCU



Polarization Control: VP and more

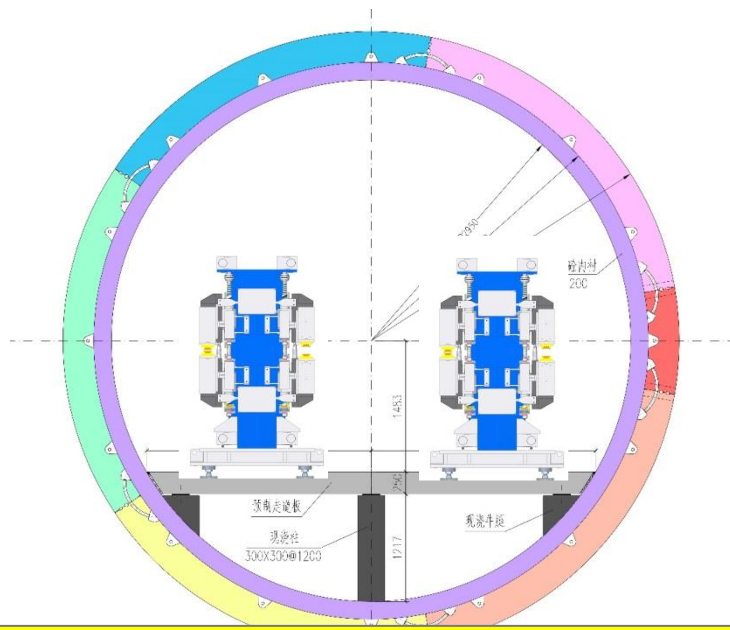
likely VP for FEL-I(warm) and –III(sc) as baseline

Left：LCLS-II VP undulator　　Right: SINAP stackable VP undulator

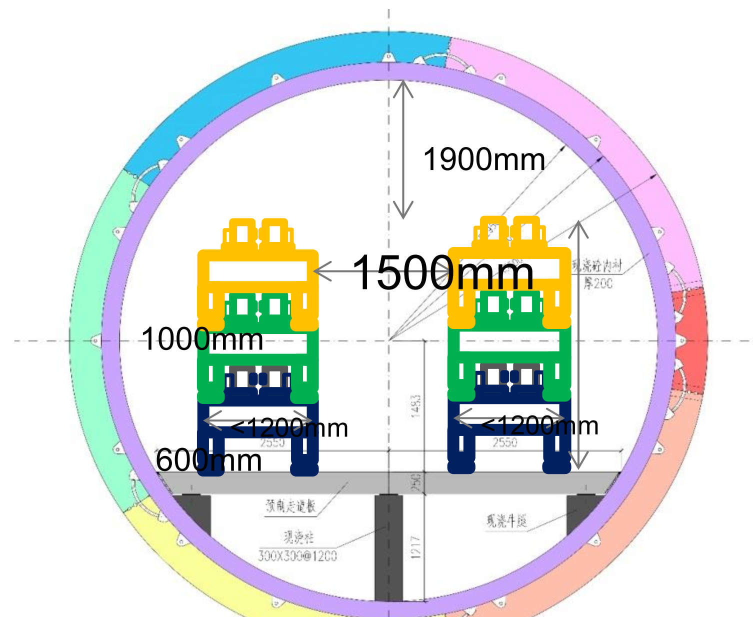
Future: more FEL lines in a tunnel

Typical，1 FEL / 4.5m tunnel，EXFEL

2 FELs in 6m tunnel, LCLS-II，SHINE

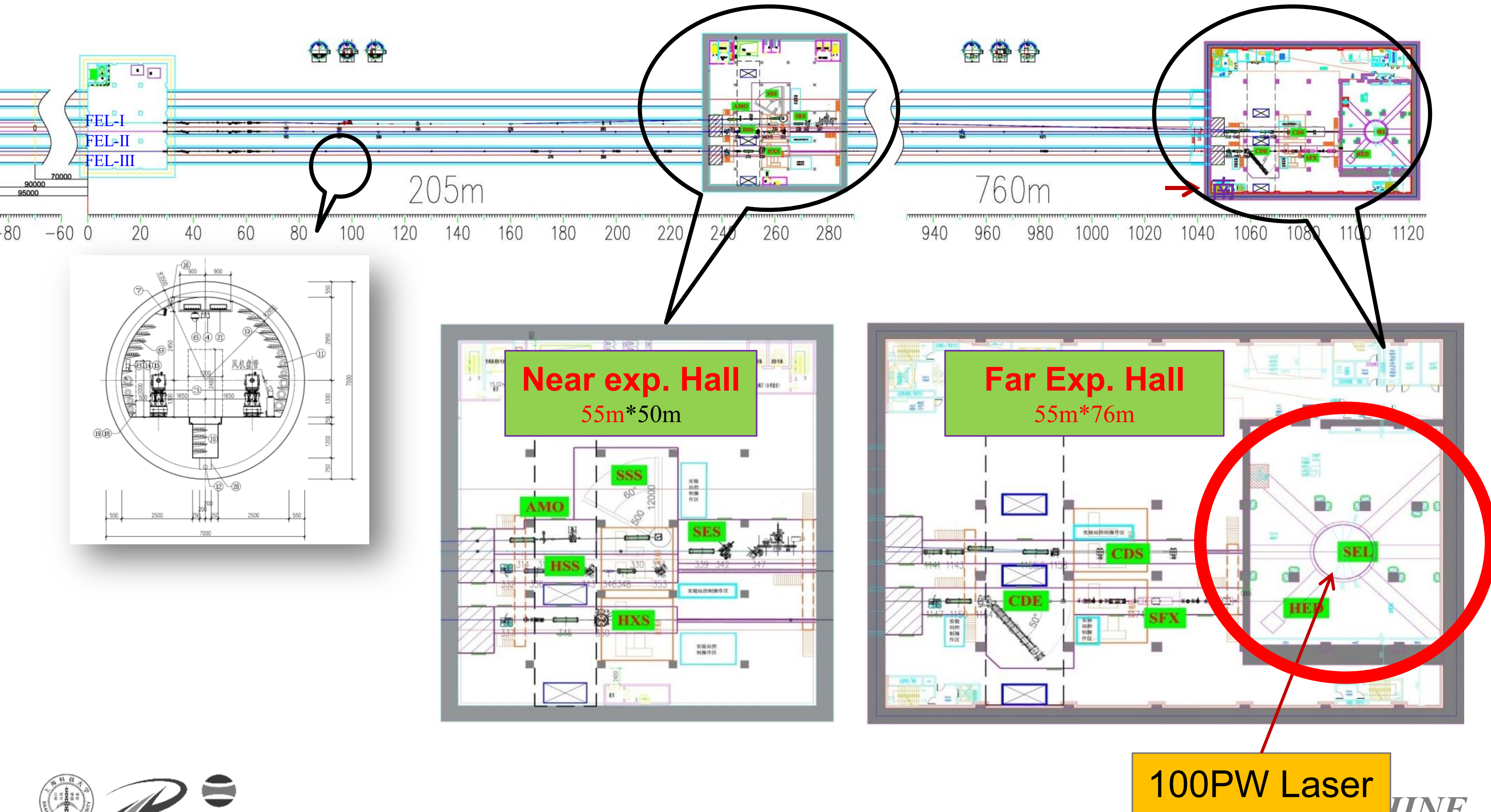


Two-in-one HPU，4 FELs/ 6m tunnel



Stackable VPU，6 FELs / 6m tunnel

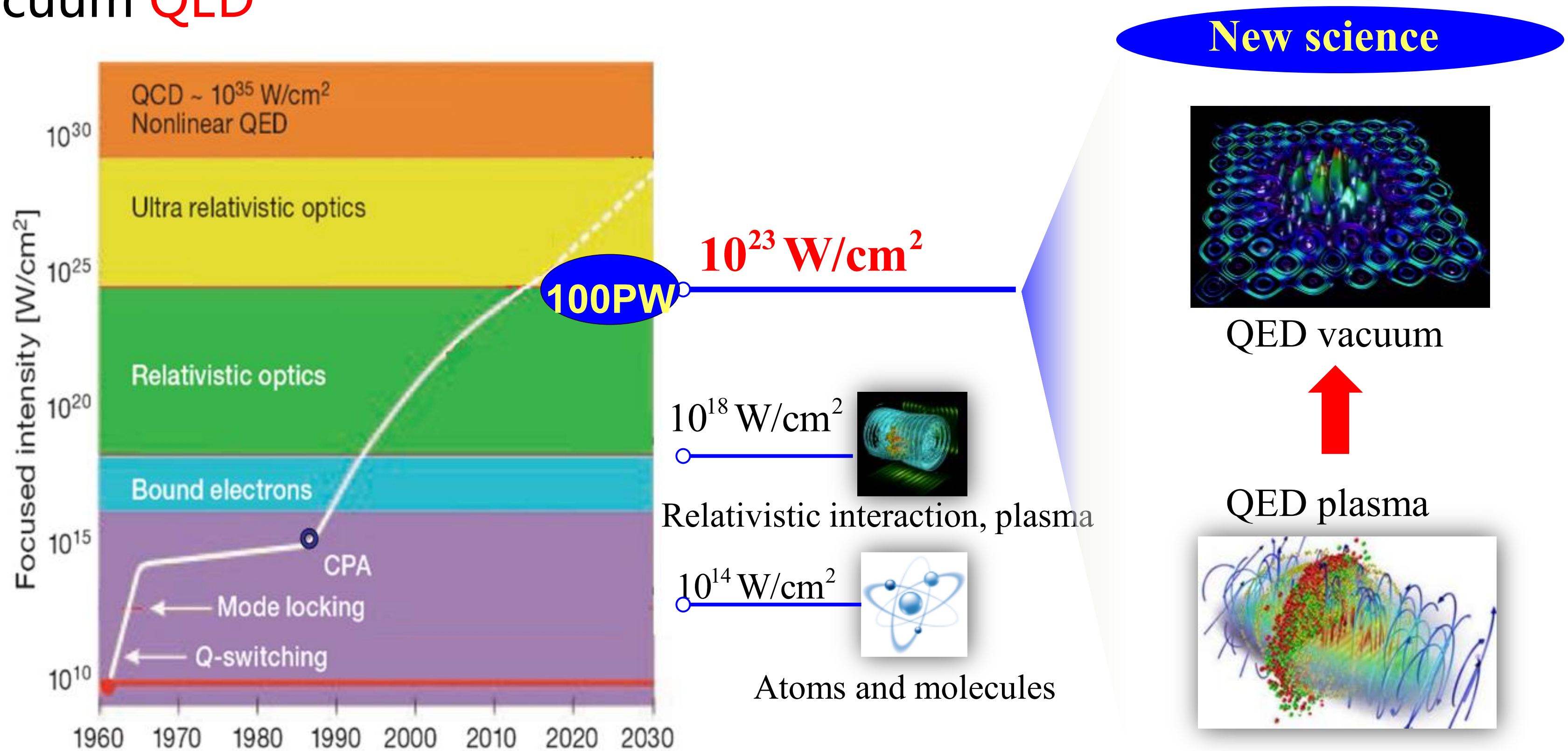
Photon beamlines /end-stations



SHINE

Extreme Light: 100 PW Laser System

The marriage of optical laser pulse with the intensity of $10^{23} W/cm^2$ and intense XFEL will open the gate for the investigation of high field vacuum QED

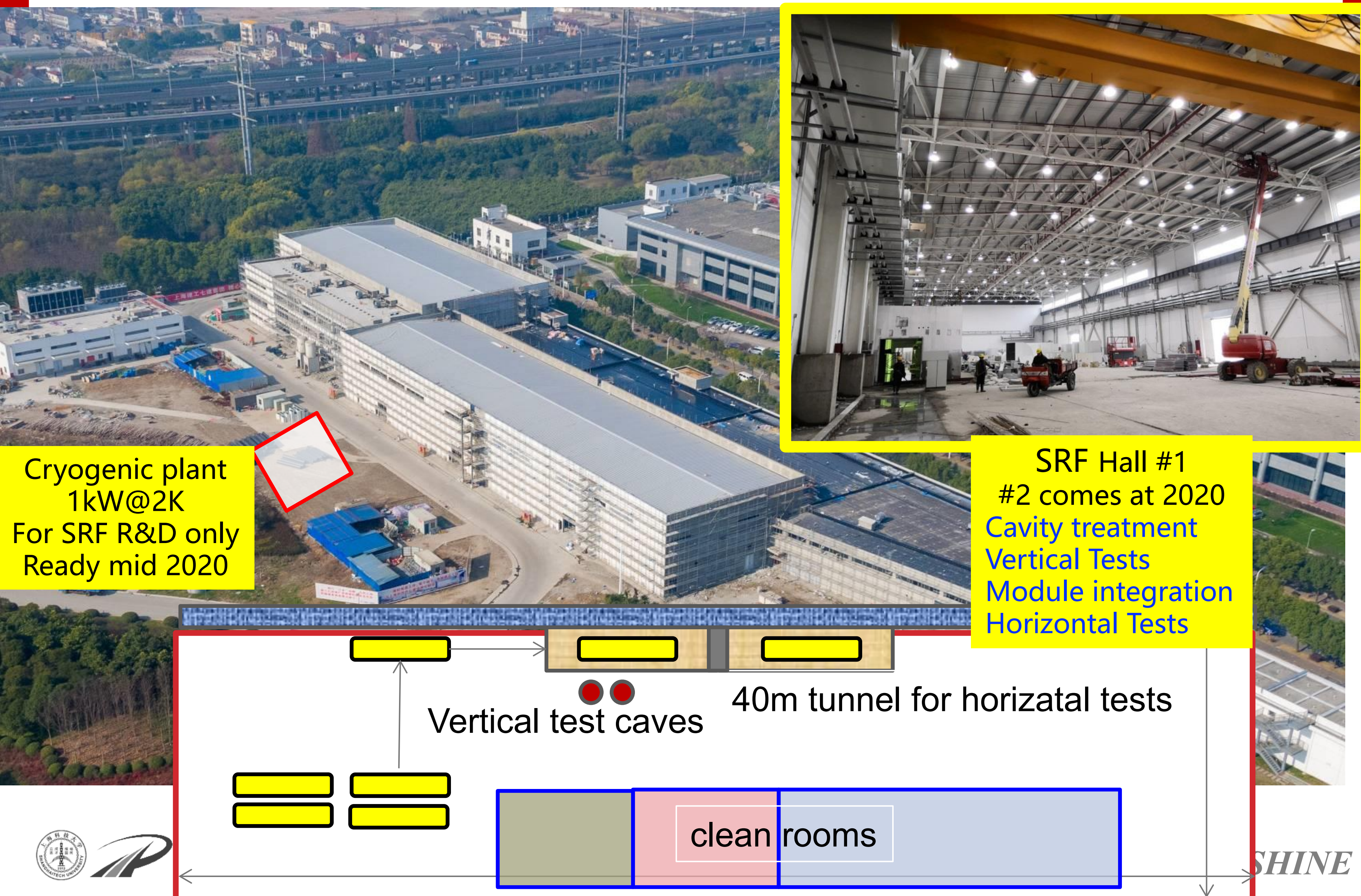


G. Mourou and T. Tajima

SHINE strategy on SRF

- TESLA type cavity/cryomodule technology are well established, thanks to the continues global efforts especially by TTC and EXFEL/LCLS-II project.
  - join and cooperate with community, hopefully make contributions
- Major components have been industrialized.
  - multi commercial suppliers (to deal with tendering/bidding procedures of funding agencies)
- Novel technologies (N-Doping, infusion, etc.) are of great importance to project for cost-effective performance and future potentials.
  - all for it since now, while keep other options going
- CM Integration/SRF-testing need to be taken care of on-site to a large extent unless good partners found
  - build up full capabilities while look for collaborating institution/industry

SRF R&D Halls and cryogenic plant at SINAP

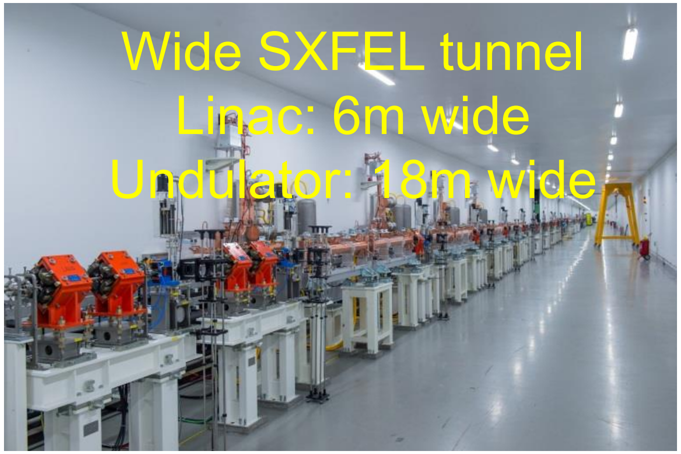


New SRF infrastructure at SINAP

- 2 SRF Halls + CM storage : total 8000m^2
- SRF treatments/CM integrations
- 1kW@2K cryogenic plant
- 4 VT caves
- 2x40m bunkers: 4 HT stations

Different scenarios envisioned

- 4x4-cavity and 4xCM tests max.
- 2-CMs HT with interconnect
- gun + 1-2 CMs = beam test
- SXFEL wide tunnels for several CMs (~ a SC VUV FEL)



SIOM

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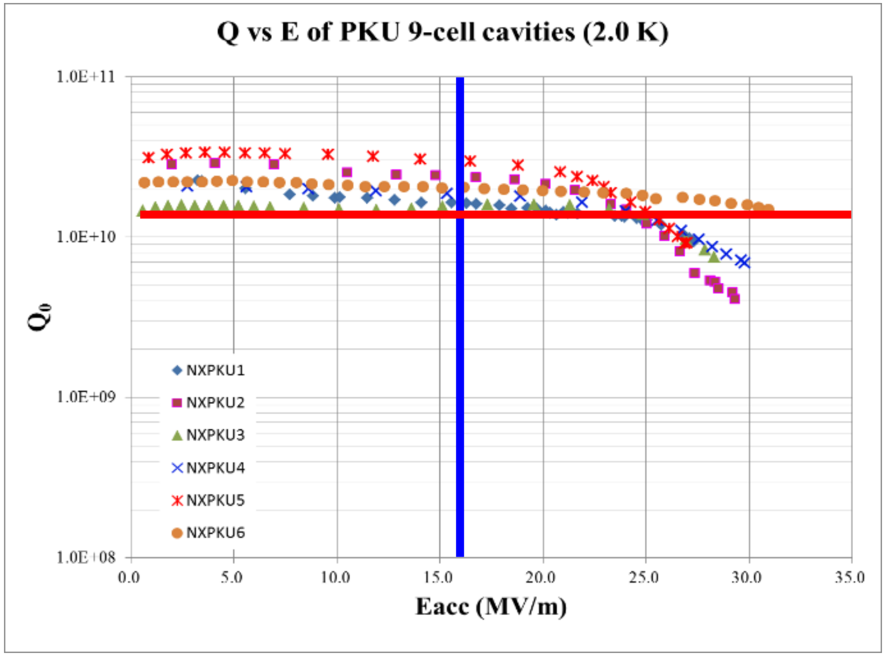
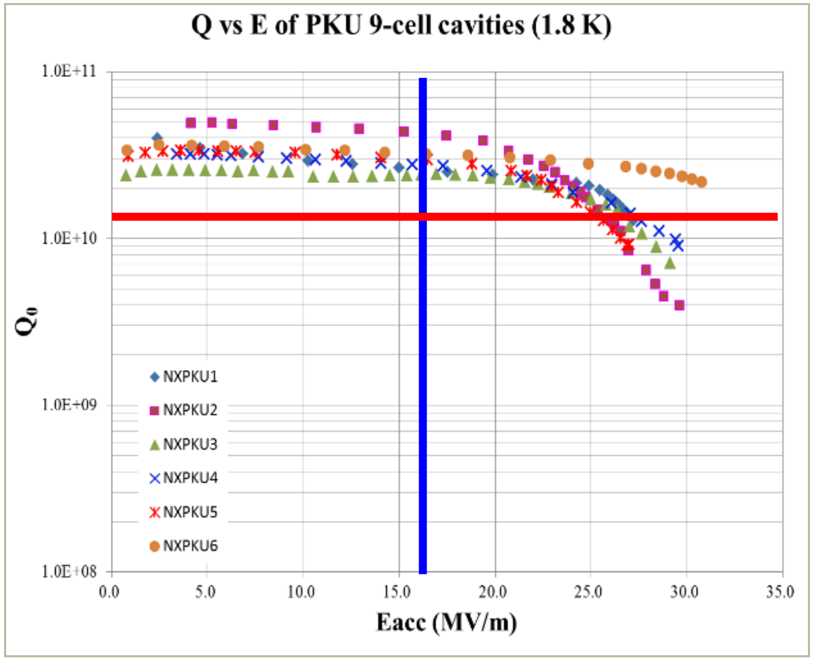
SXFEL project includes sc cavity R&D

6 Large Grain 1.3GHz cavities made in OTIC

Large grain cavities: VT results by PKU

- E_{acc} >25 MV/m (SCLF baseline : 16MV/m , blue)
- Q_0 ~ 1.6-2.4E10 @ 2K , at 16 MV/m, ~3.5E10 @1.8K





- Q_0(1.8K)/Q_0(2.K) = 1.50-1.79 (@~16 MV/m)
- Operation @1.8 K could be an option

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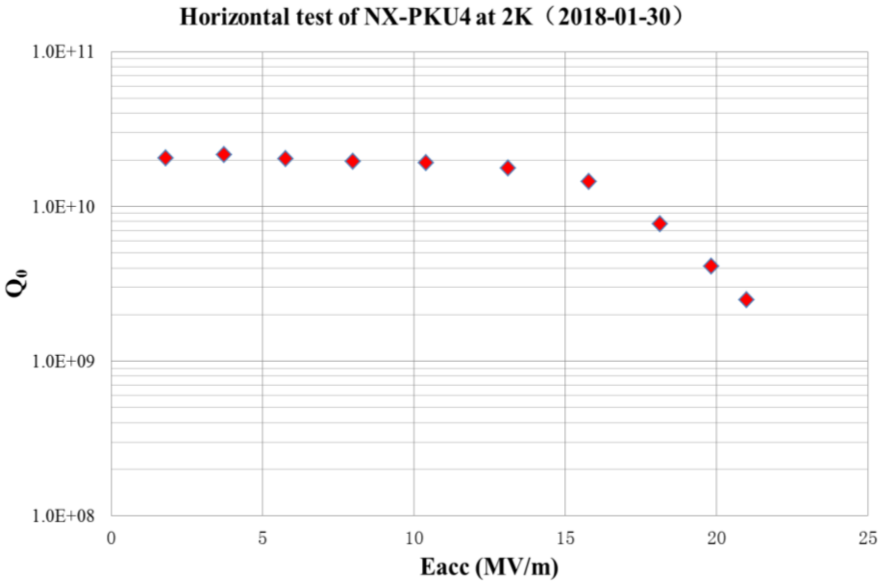
Horizontal tests of 1.3 GHz CM (2-LG cavities) at PKU



Horizonal test setup:

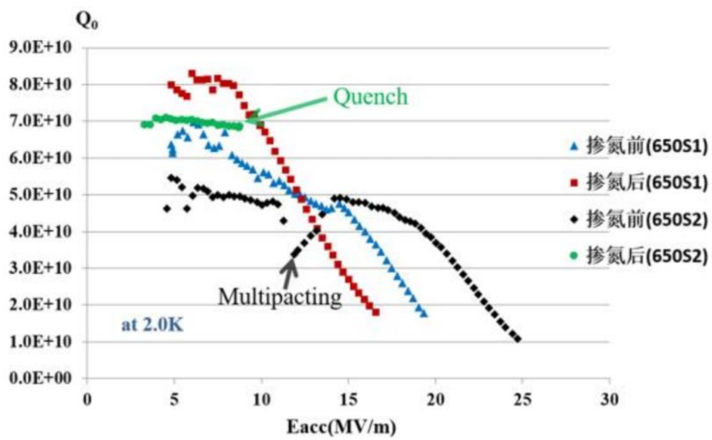
- Pulse mode: 0.5 Hz, 700 ms
- Qe~6×10^8 for Q-E measurement

E_{acc} >20 MV/m without quench

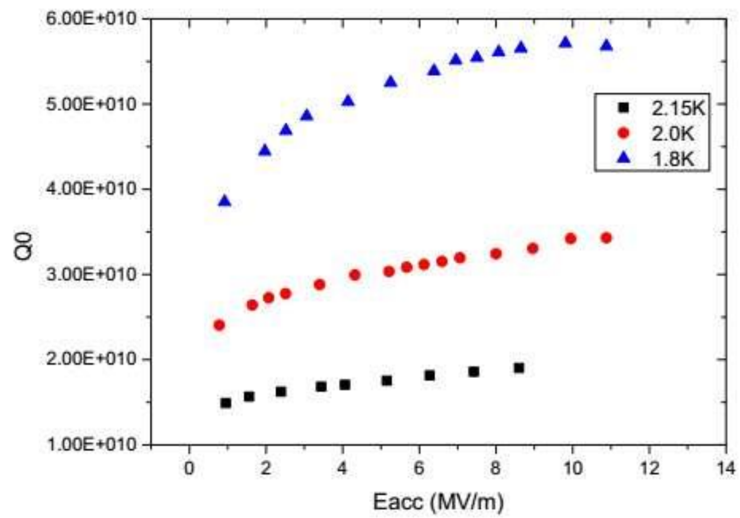
Q-drop after 15 MV/m:

Caused by Cryogenic capacity limitation (~55 W at 2 K for cooling down both 3.5-cell injector and 2×9-cell cryomodule) and probably field emission

N-doping: initial results by IHEP and PKU



CEPC 掺氮超导腔垂直测试结果（2.0K）



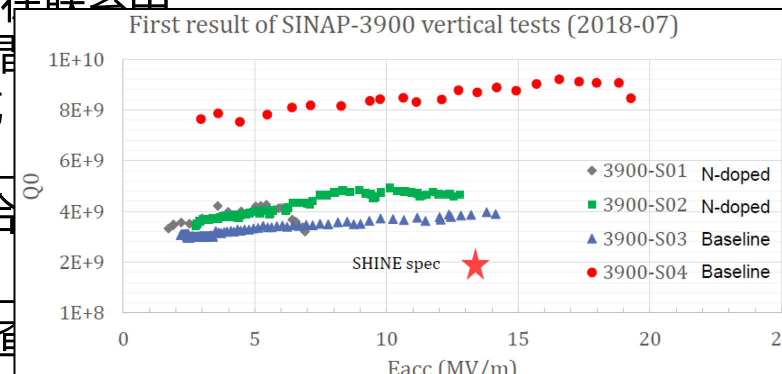
IHEP 650MHz single-cell cavity N-doping

PKU N-doped 1.3GHz cavity

IHEP/PKU/SINAP to have 9-cell cavity EP/N-doping in 2018

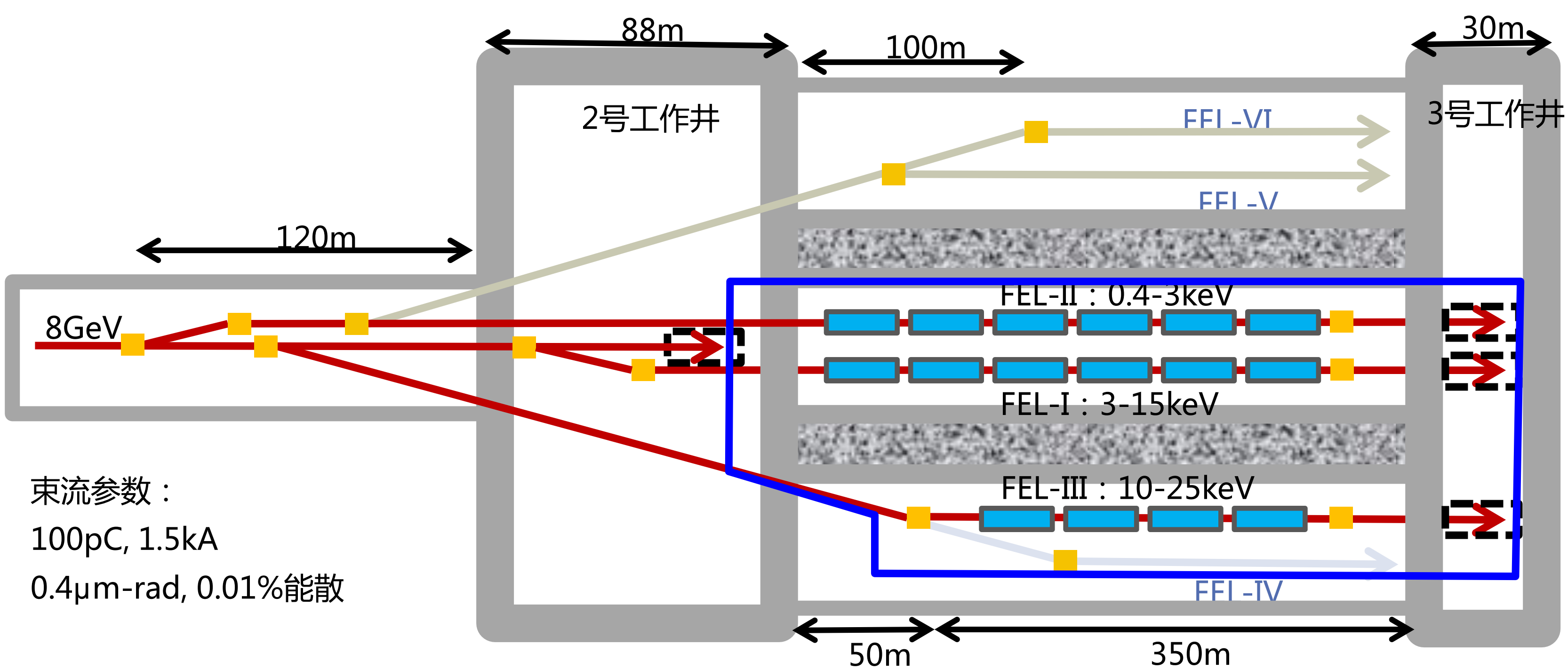
SHINE SRF R&D

系统	工作进展
1.3GHz 超导腔	铌材料、三组腔和三组耦合器样机，单一来源已经 始启动合同谈判。
3.9GHz 超导腔	3.9GHz单cell腔：已完成4只3.9GHz细晶单cell腔的 步：对测试系统进 正在联系中 晶 式 计划
低温传输	合 行工艺 中。
真空系统	屏蔽门阀，已完成招标预备会/审查
超导磁铁	完成了超导四极磁 体科技有限公司，21日 合同谈判。
机械系统	完成1.3GHz模组 撑台招标预备会/审查 会， 已发出标书。慢调 中。
测试大厅	超净间：已完成招 超纯水装置：技术 采购工作。



Undulator lines

- FEL-I（3-15keV）：SASE、Self-seeding、
- FEL-II（0.4-3keV）：EEHG/HGHG、SASE、self-seeding
- FEL-III（10-25keV）：SASE、self-seeding, with SC undulators



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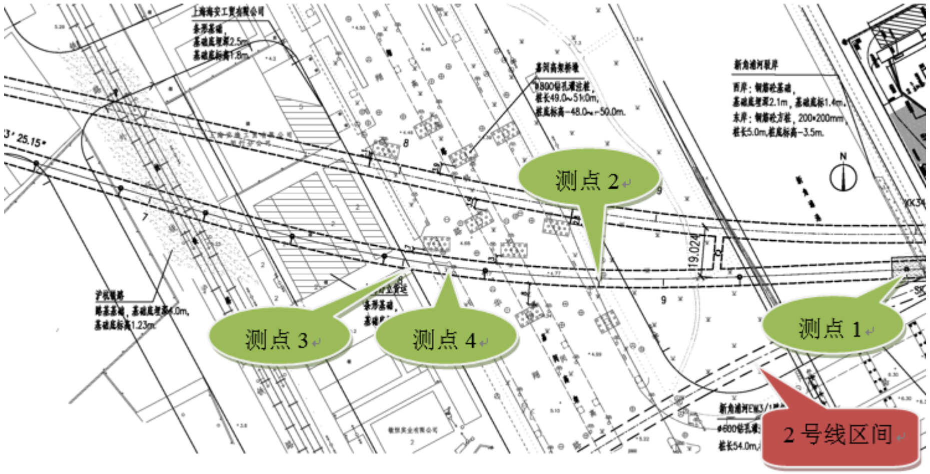
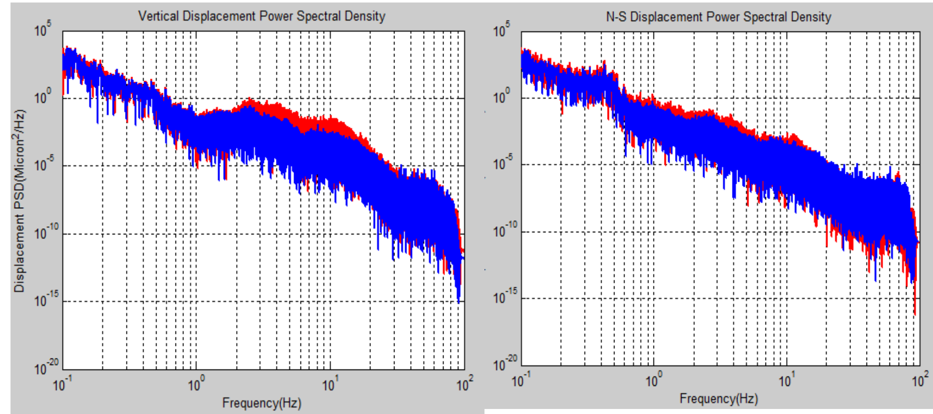
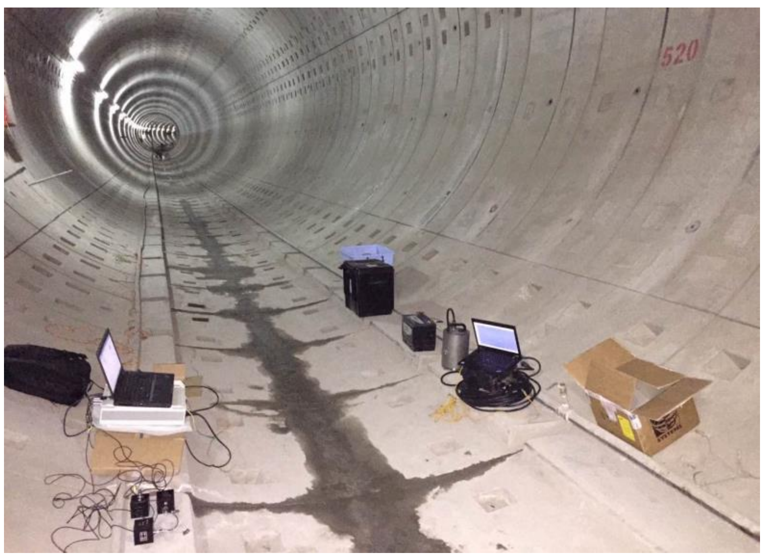
Tunnel vibration measurements

R. Deng, J. Wang, et al





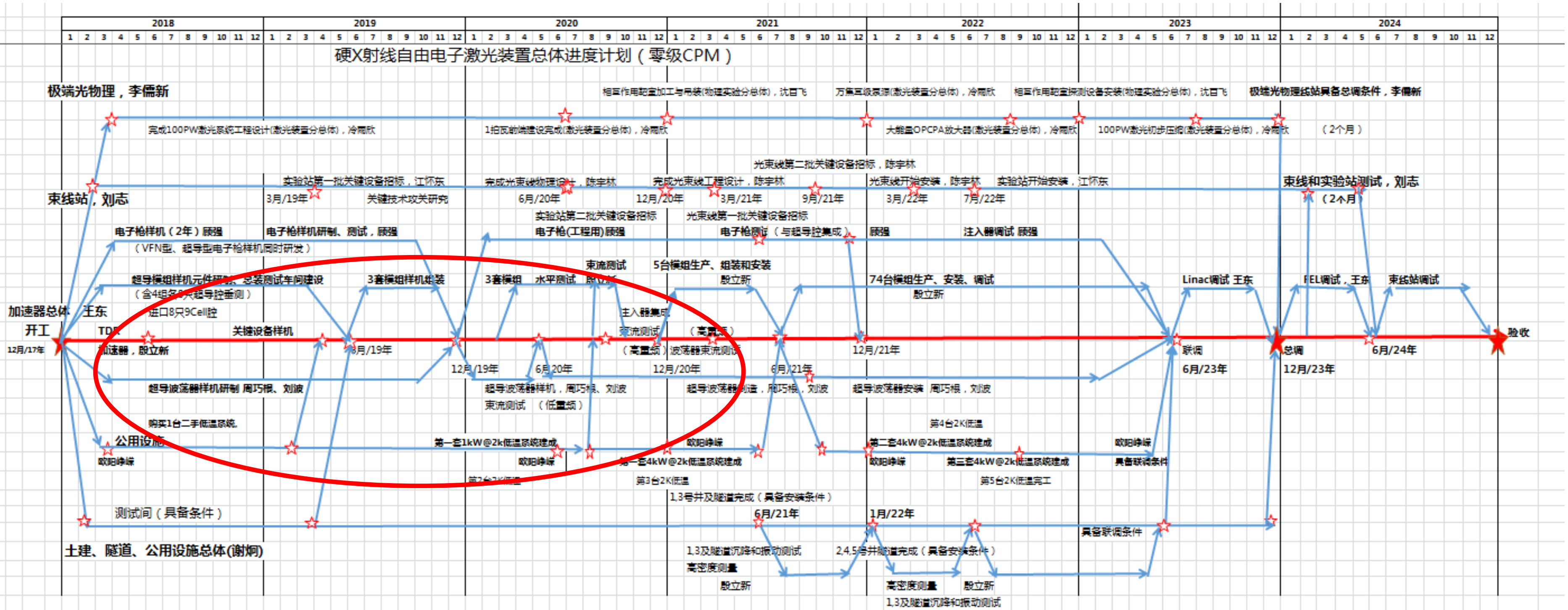


20170122				1-100Hz rms movements		
Pts	Position	Depth	Time	Vert.	N-S	W-E
3	Ground		13:40-13:50	0.4111	0.2338	0.2407
4	Tunnel	24.3m		0.1962	0.1549	0.1404
4	Tunnel	24.3m	03:00-03:10	0.0629	0.0927	0.0649

Measurements of vibrations in similar tunnels

Schedule

Duration:	7 years (2018-2025)
Prototyping:	starting 2017(separate funding)



Cryo-module design/fabrications and cryo-plant are critical.