Advancing PWFA and PWFA-FEL research in China, including FEL Lasing……

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7th European Advanced Accelerator Conference
Isola d'Elba, Italy September 26, 2025

A Joint effort of IHEP, THU, SARI, BAQIS, ZZU and Qifeng

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

清華大學
Tsinghua University

中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

BAQIS

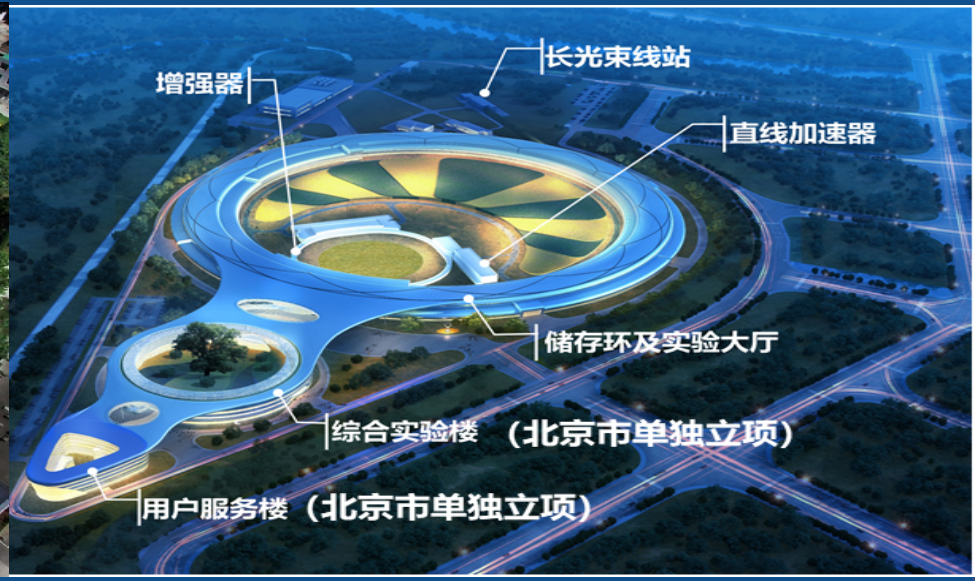
Newlight Source
QiFeng Technology

Outline

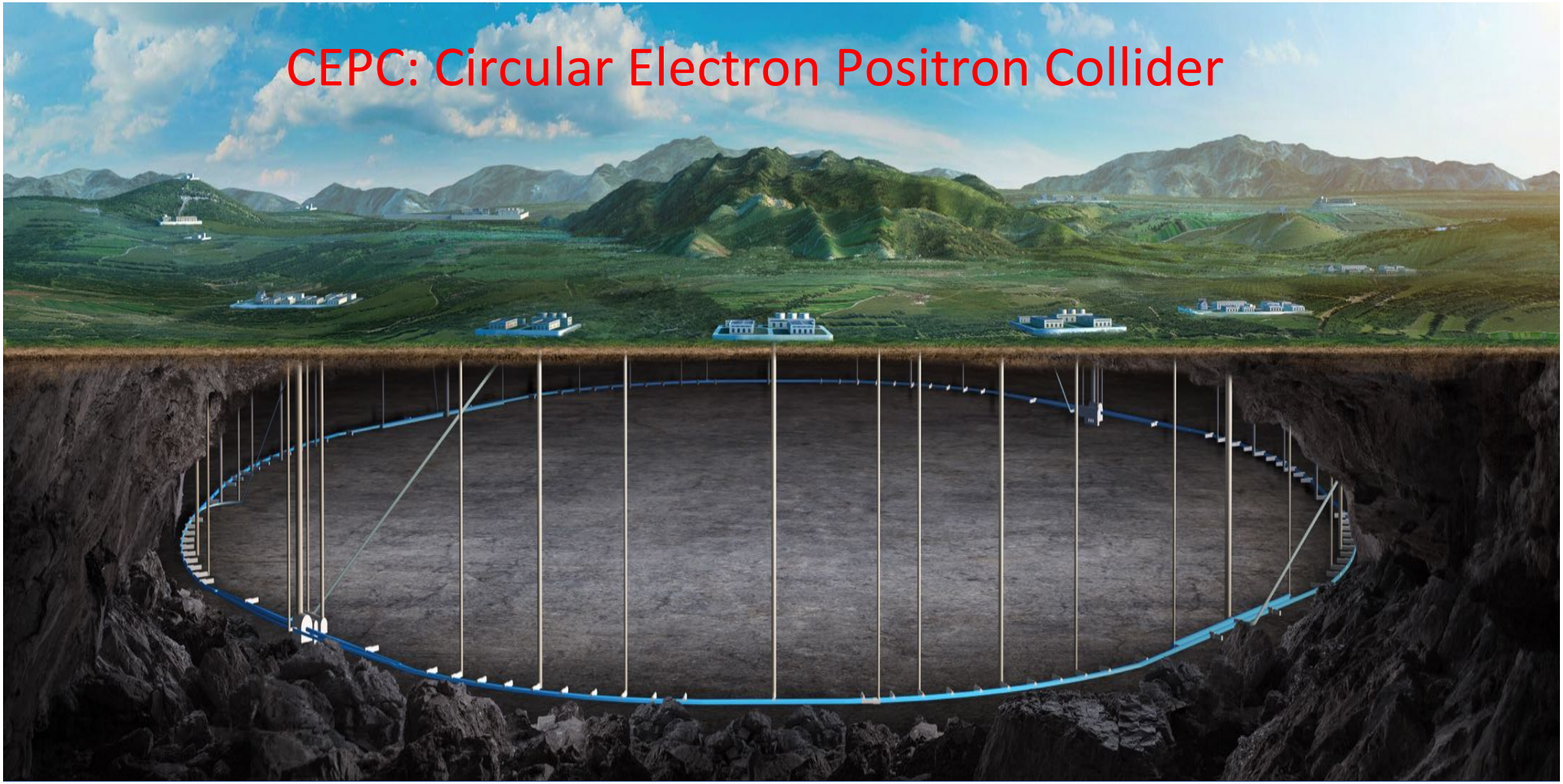
- PATH: Plasma Accelerator towards TeV Horizon
- Progress of PWFA-FEL on SXFEL platform
- Laser Plasma Accelerator for Applications

Institute of High Energy Physics: IHEP
Chinese Academy of Science

Beijing Electron Positron Collider (BEPC II)

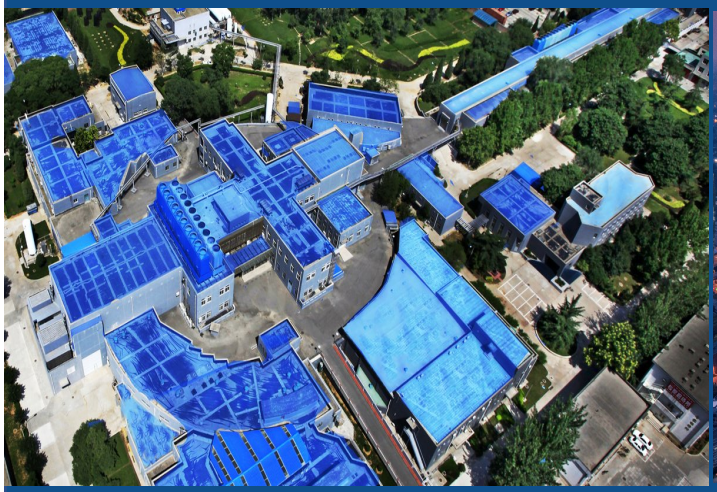


High Energy Photon Source (HEPS)


CEPC: Circular Electron Positron Collider

PATH: Plasma Accelerator towards TeV Horizon

A China initiated effort towards future light source and collider



PWFA/LWFA platform at BEPCII
IHEP, Beijing

PWFA/LWFA platform at SXFEL
SARI, Shanghai

LPA application platform: CCLS
ZZU, Zhengzhou, Henan

PATH: A roadmap with 4 phases…

Phase I: 2024-2028
- PWFA/LWFA platforms based on BEPCII and SXFEL
- tabletop LPA applications

Phase II: 2029-2033
- A full energy plasma injector for BEPCII
- PWFA/LWFA driven FELs for applications

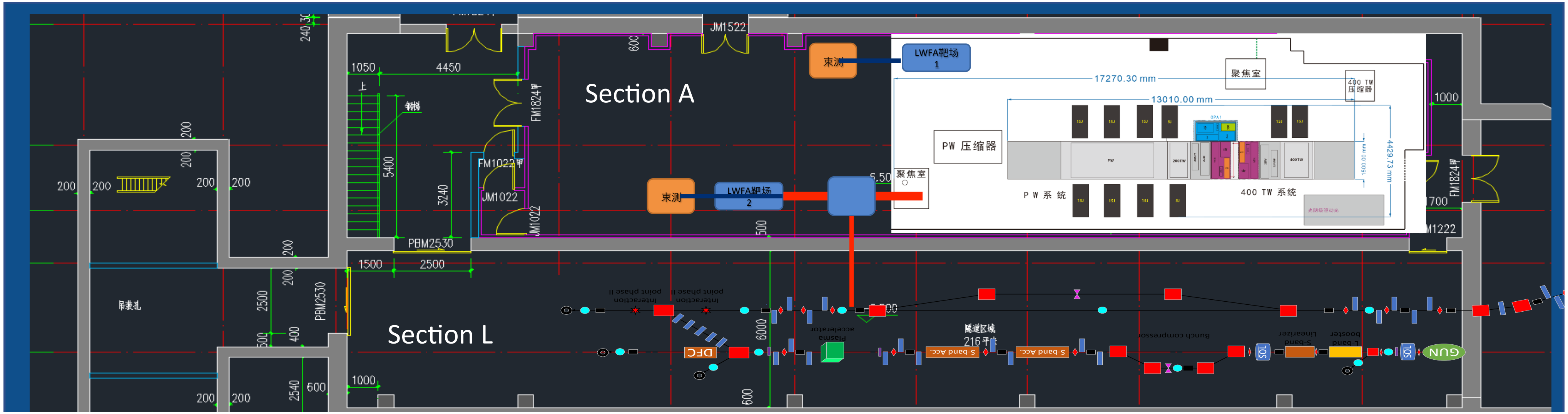
Phase III: 2034-2038
- A full energy plasma injector for CEPC or FCC-ee

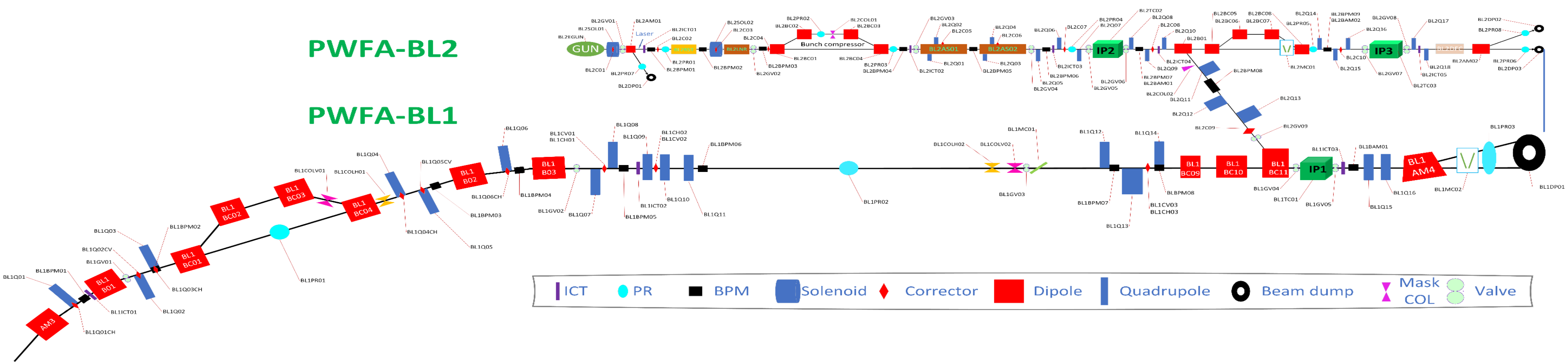
Phase IV: 2039-…
- 1-10TeV Linear collider technology becoming mature……

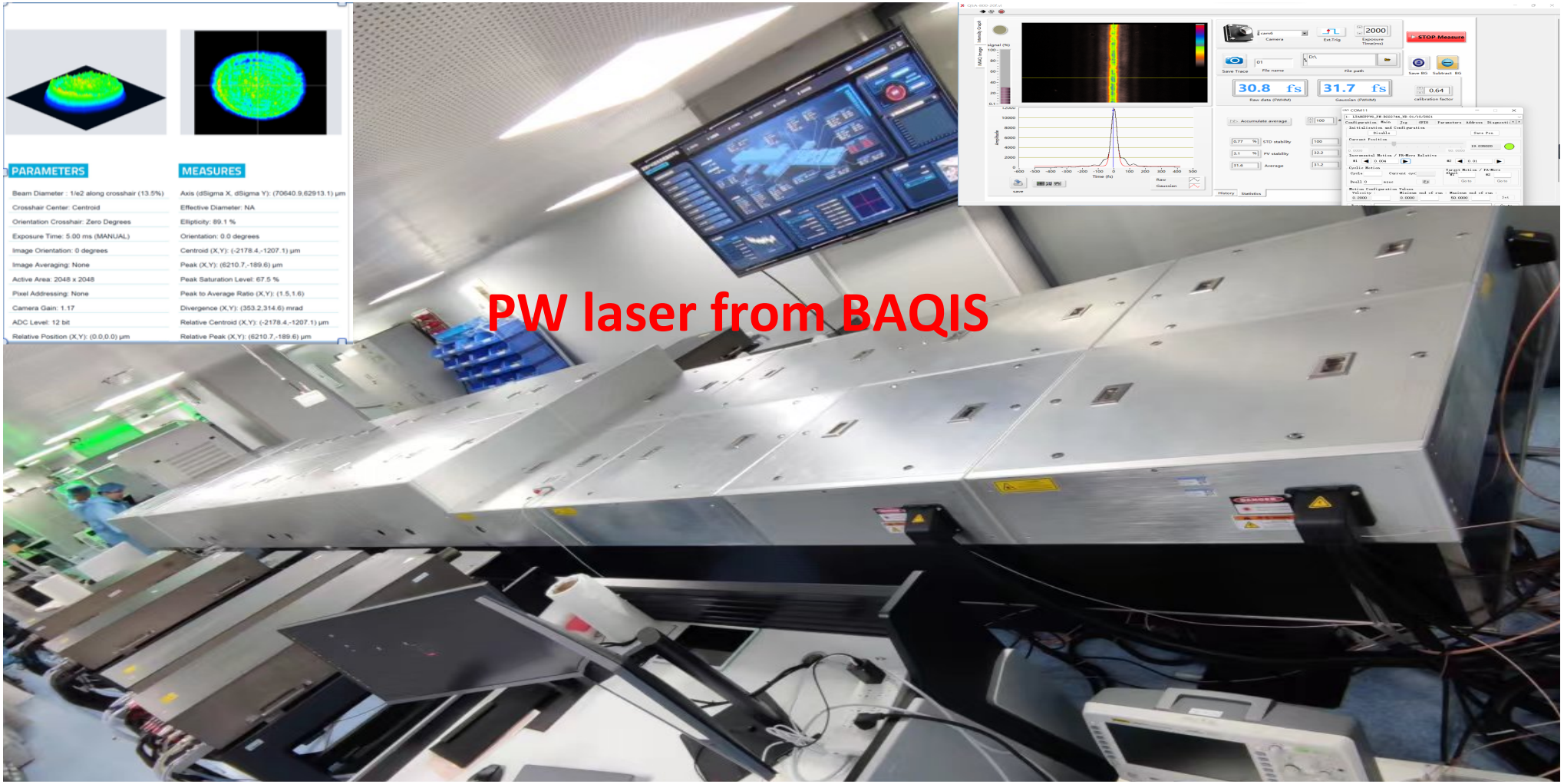
A PWFA/LWFA platform at #10 Hall of BEPCII

CAS Leading project (2023-2028) for Basic Science

”Beam Driven Advanced Acceleration and Application ”


Section A
Section L
束测
LWFA靶场 1
LWFA靶场 2
17270.30 mm
13010.00 mm
聚焦室
400 TW 压缩器
PW 压缩器
P W 系 统
400 TW 系统
JM1522
FM1824甲
FM1022甲
JM1022
PBM2530
GUN
DFC
隧道区域 216平米
S-band Acc.

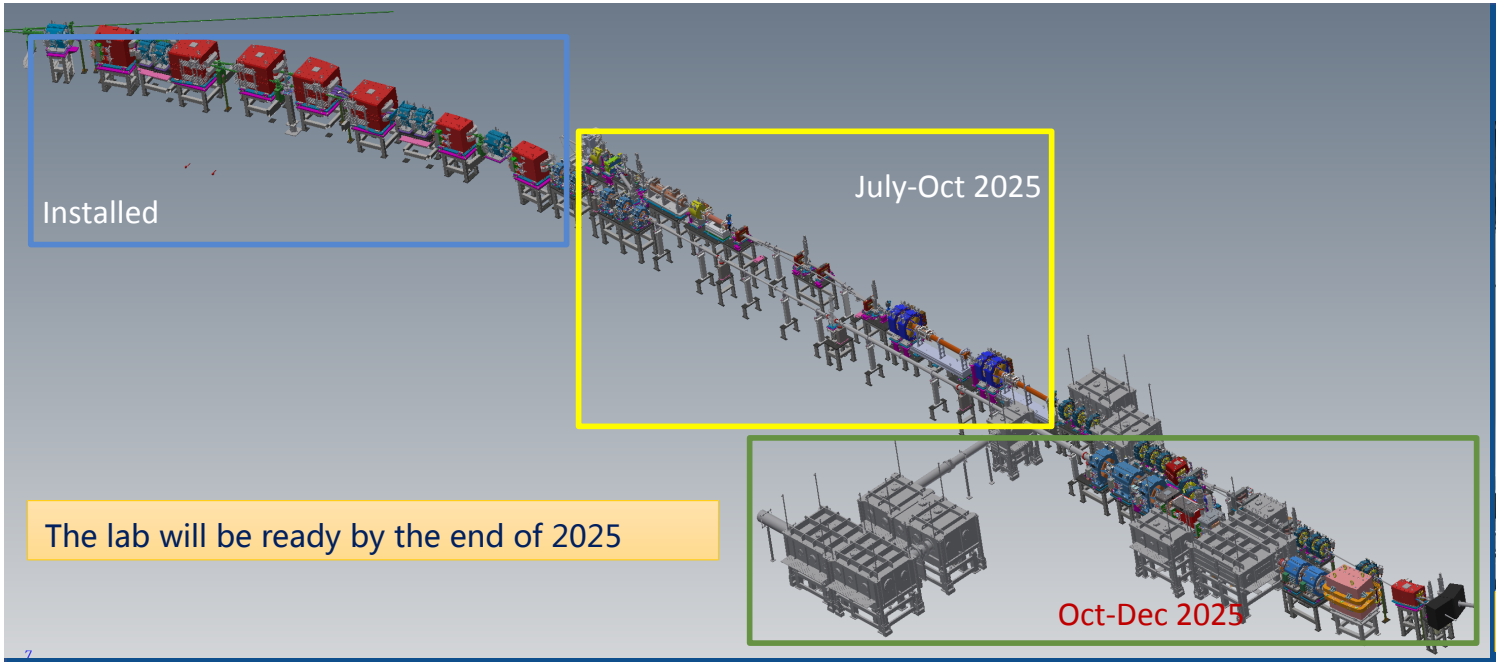

PWFA-BL2
PWFA-BL1
GUN
Bunch compressor
IP1
IP2
IP3
ICT
PR
BPM
Solenoid
Corrector
Dipole
Quadrupole
Beam dump
Mask
COL
Valve


PARAMETERS
MEASURES
Beam Diameter : 1/e2 along crosshair (13.5%)
Crosshair Center: Centroid
Orientation Crosshair: Zero Degrees
Exposure Time: 5.00 ms (MANUAL)
Image Orientation: 0 degrees
Image Averaging: None
Active Area: 2048 x 2048
Pixel Addressing: None
Camera Gain: 1.17
ADC Level: 12 bit
Relative Position (X,Y): (0.0,0.0) µm
Axis (dSigma X, dSigma Y): (70640.9,62913.1) µm
Effective Diameter: NA
Ellipticity: 89.1 %
Orientation: 0.0 degrees
Centroid (X,Y): (-2178.4,-1207.1) µm
Peak (X,Y): (6210.7,-189.6) µm
Peak Saturation Level: 67.5 %
Peak to Average Ratio (X,Y): (1.5,1.6)
Divergence (X,Y): (353.2,314.6) mrad
Relative Centroid (X,Y): (-2178.4,-1207.1) µm
Relative Peak (X,Y): (6210.7,-189.6) µm
STOP Measure
30.8 fs
31.7 fs
PW laser from BAQIS

- **BLI**: BEPCII 2GeV e-/e+ beams with compression (~1ps)
- **BLII**: A new 1-5nC 150MeV Linac with 2 IPs
- **PW laser**: 1PW 30fs 1Hz compact laser from BAQIS

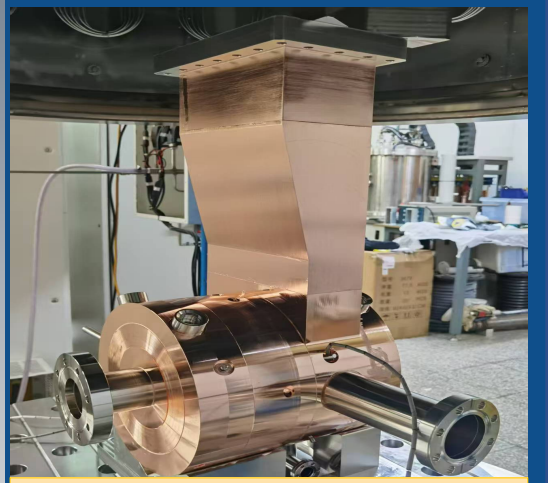
3 systems are synchronized and combined in IP1

- Positron acceleration in electron beam driven PWFA
- External injection to a PWFA
- PWFA staging
- External injection to a LWFA (e-/e+)

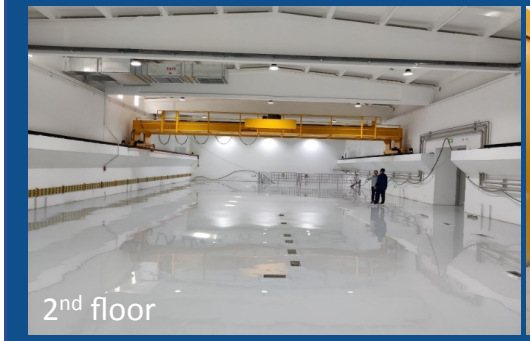


The lab will be ready by the end of 2025

中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences



L-band Photo-injector



2nd floor

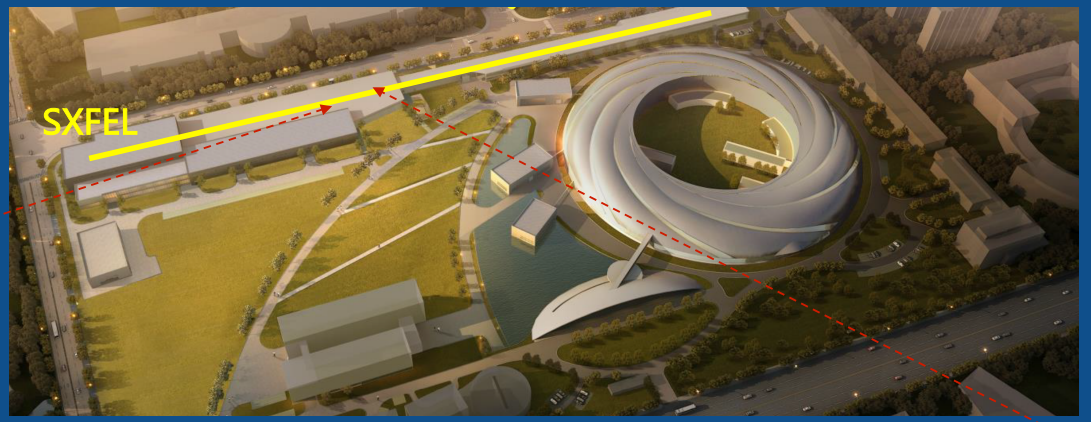
Accelerator tunnel

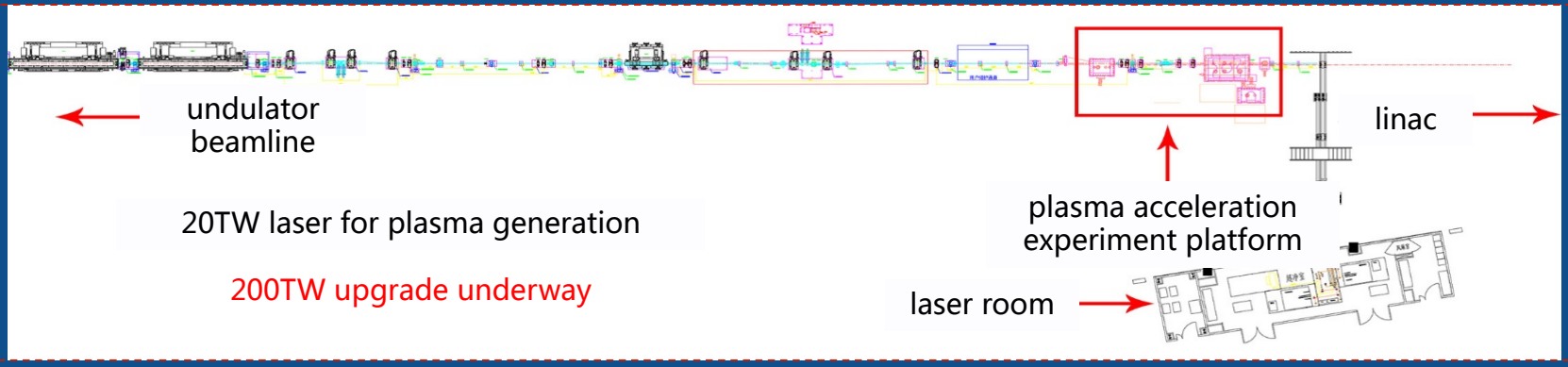
Clean room for PW

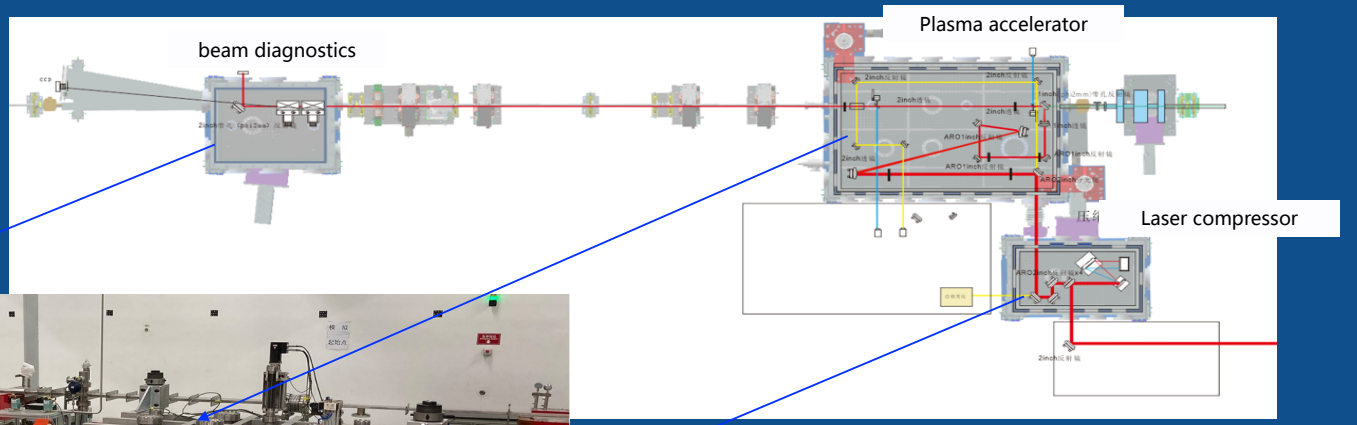
BEPCII tunnel（installed）

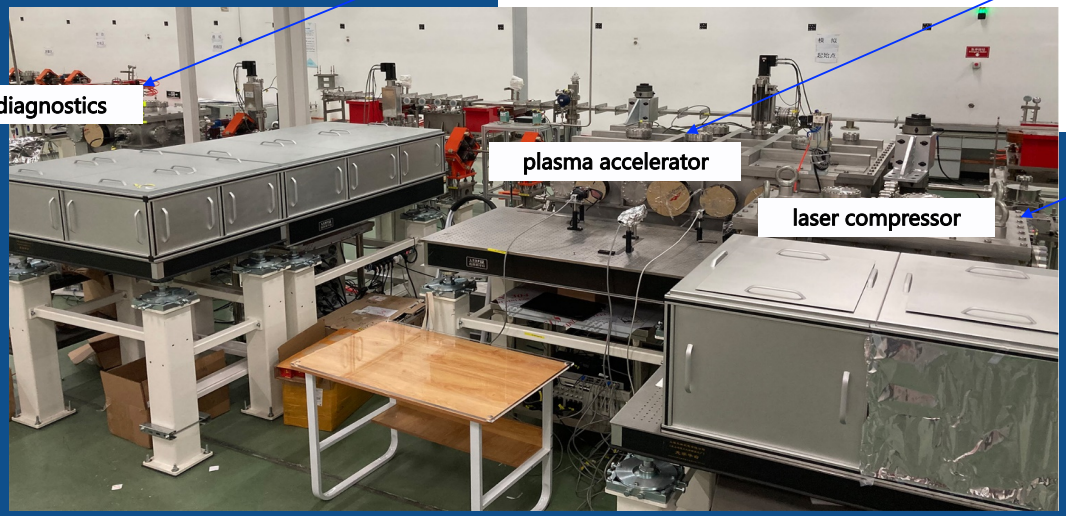
A PWFA/LWFA platform at SXFEL of SARI

- Collaboration with Prof. Zhentang Zhao since 2017.
- Supported by CAS leading project of Basic Science (2023-2028)
- SXFEL: 1.5GeV Linac + 40m Undulator, an ideal test bed for PWFA-FEL and LWFA-FEL



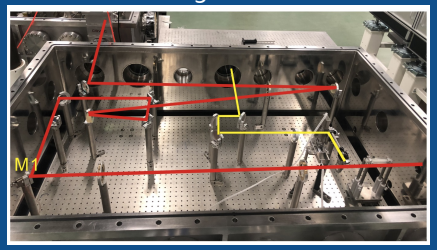






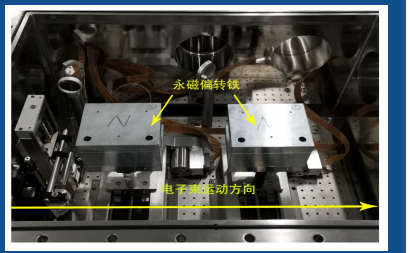
Plasma acceleration chamber

- 10~20cm gas cell
- Laser focusing
- Laser-beam coupling
- Plasma diagnostics

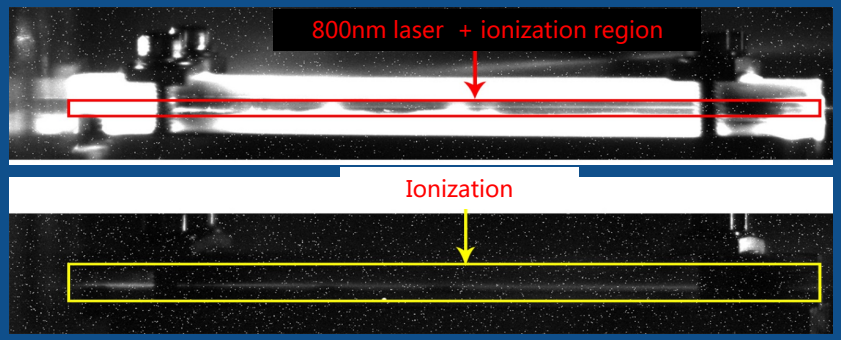


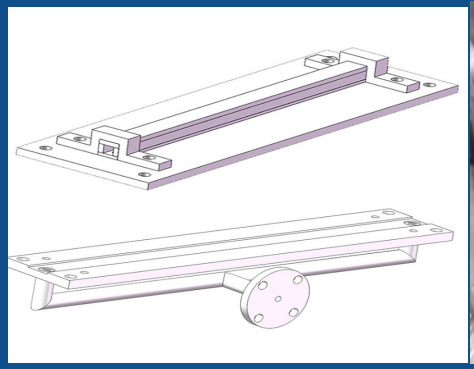
Beam diagnostics chamber

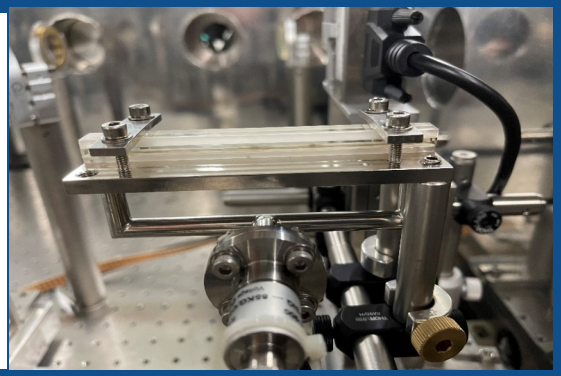
- Energy spectrometer (PM)
- Beam spot monitor



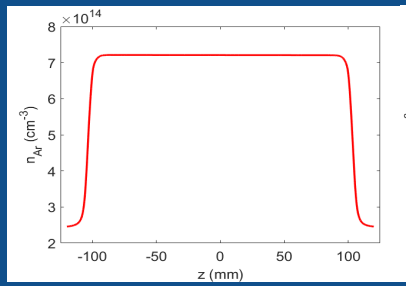
Plasma Source (20cm)

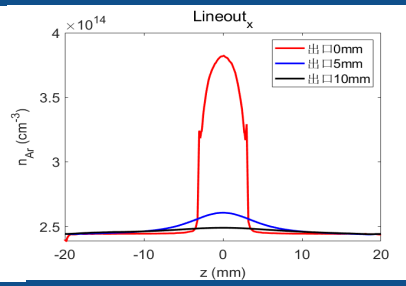


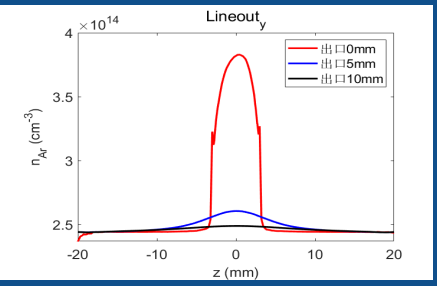




- 10~20cm length
- reliabe and uniform plasma density profile
- operated at 2Hz@0.1MPa
- backing pressure 0~5MPa

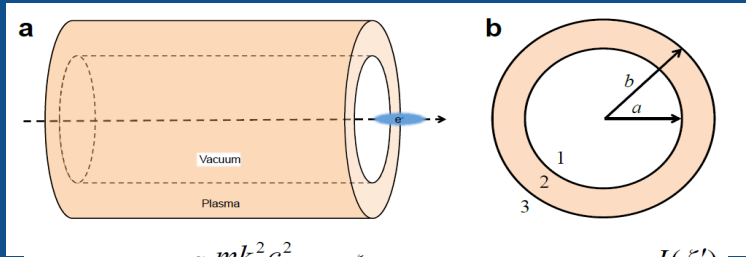




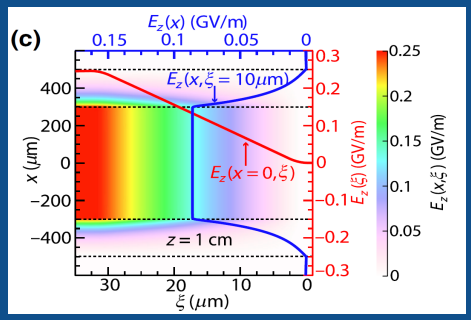


Beam Phasespace Manipulation based on HPC

Hollow Plasma Channel (HPC)

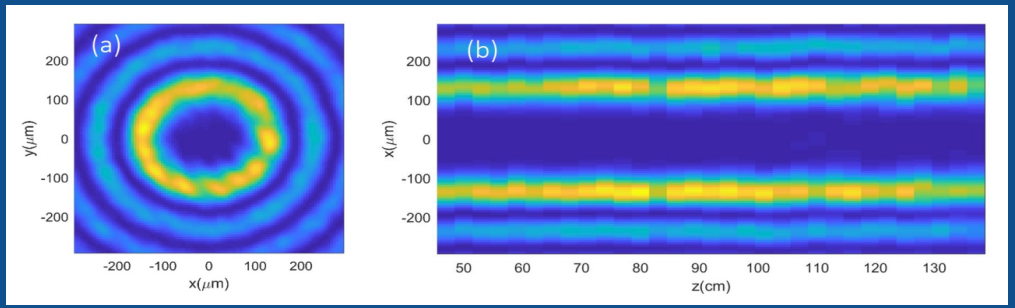


$$E_z(r,\xi) = -\frac{q}{e}\frac{mk_p^2c^2}{\varepsilon_0}A_0\int_{-\infty}^{\xi} d\xi' \cos[\Omega_0 k_p(\xi-\xi')]\frac{I(\xi')}{I_A}$$



hollow plasma channel generated by a high-order Bessel beam.
(radius~100um, ~10cm long)

- **Advantages**
  - Acceleration field is independent of radial position, slice energy can be preserved.
  - Nearly zero focusing force, slice emittance can be preserved.

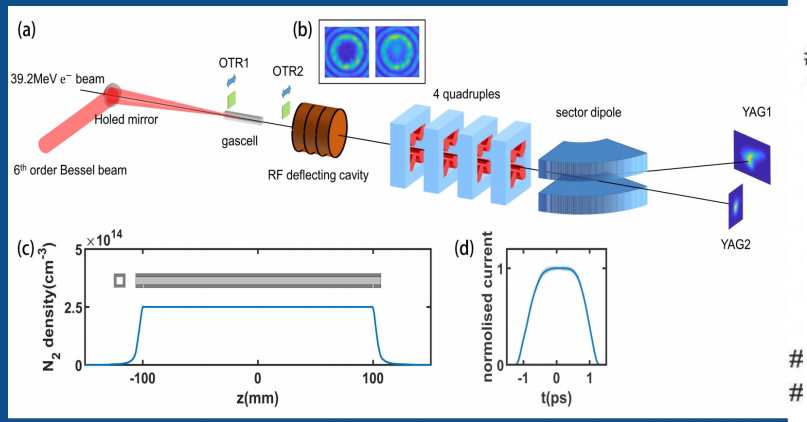


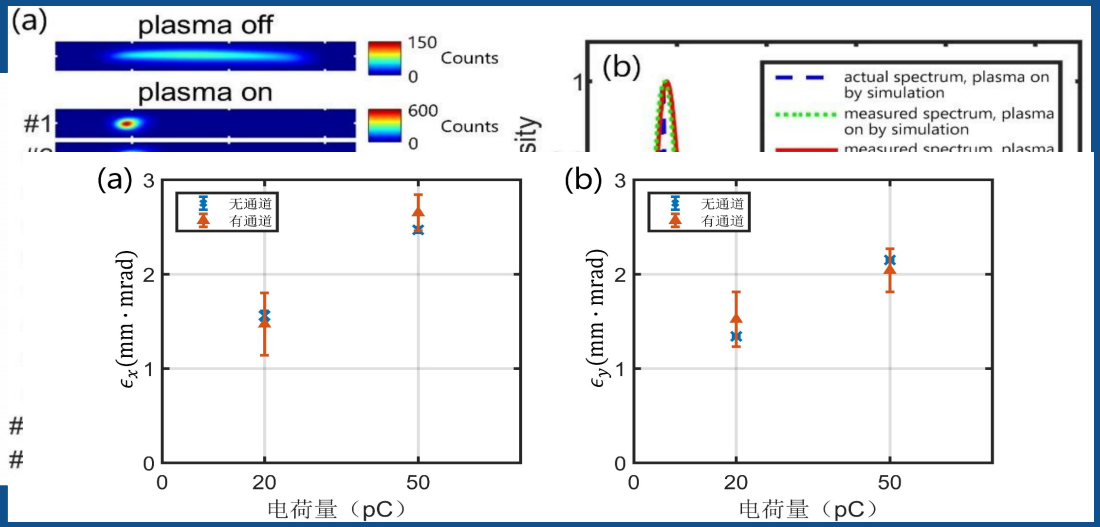
Y. P. Wu et al, PHYSICAL REVIEW APPLIED 12, 064011 (2019)

Spencer J. Gessner, PHD thesis, Standford University (2016)

HPC Phasespace Manipulation as dechirper

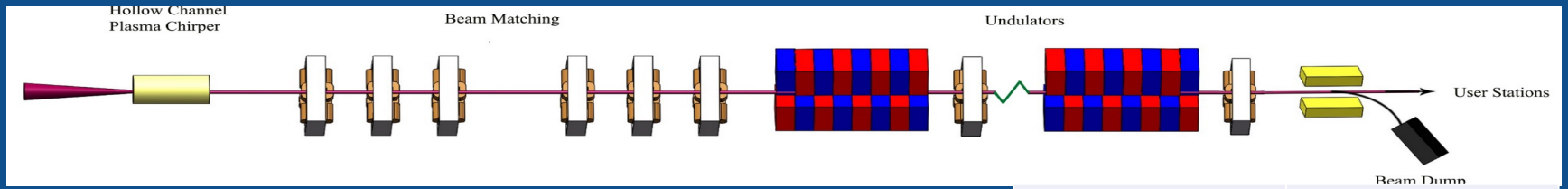
- A HPC dechirper demonstrated : energy chirp from ~1% to ~0.1%
- Emmittance conservation confirmed through measurement





S. Liu et al, Phys. Rev. Lett. 133, 175001 (2024)

PWFA-driven Broadband FEL scheme

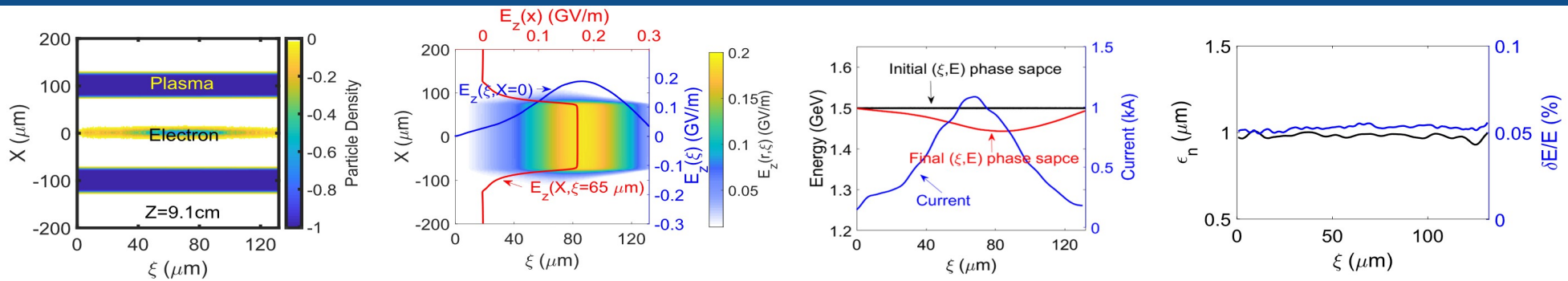


Peng, B., et al. Physical Review Applied **19(5) 2023**

Increasing the energy chirp while maintain the slice beam quality → Increasing radiation bandwidth

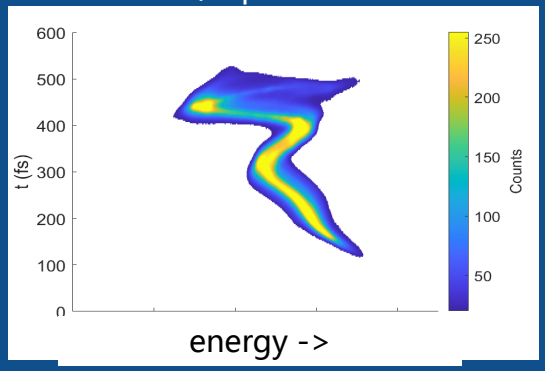
Beam energy	**1.5 GeV**
Charge	**250 pC**
Beam length	**210 fs**
Emittance	**1 mm mrad**
Plasma density	**5e16 cm^{-3}**
Length	**0.3 m**
Inner radius	**75 um**

Slice energy spread and emittance can be well-preserved



Phase Space Modulation in HPC

w/o plasma



backing pressure 21bar + laser energy 90 mJ

energy ->

energy ->

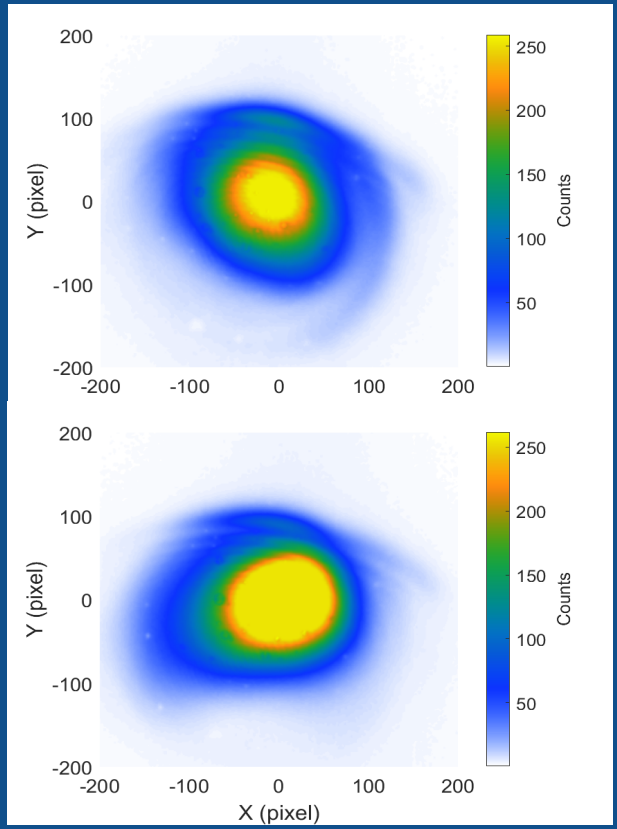
backing pressure 7.2bar + laser energy 90 mJ

energy ->

energy ->

paras.	value
beam energy	670MeV
FEL wavelength	~9.8nm
Charge	500pC
beam length	~400fs
beam spot size (rms)	80μm

XFEL lasing with good probability



7.2bar @90mJ

13.6bar @90mJ

Saturated Amplification of XFEL

- Exponential gain of the FEL was observed, and **saturation gain** was achieved under certain parameter conditions.
- FEL output enegy is estimated **>50 uJ**.

Demonstration of XFEL saturated amplification using phase space manipulation based on PWFA.

Redshift of XFEL spectra

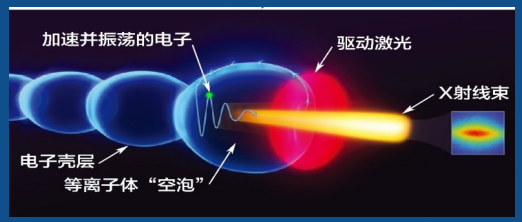
FEL spectrum exhibits a significant redshift, with a maximum redshift of 2.61 eV (~2%), demonstrating a certain degree of tunability.

Spectrum Broadening of XFEL

- **The spectrum exhibits a clear, single-spike distribution. The multiple peak feature of SASE is suppressed.**
- **The average bandwidth is ~3 times of the original spectra**

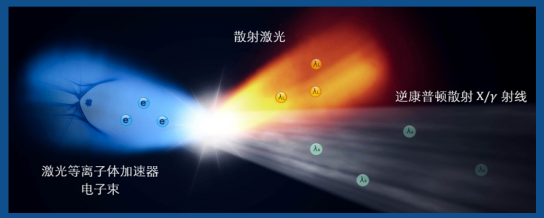
Applications with table-top LWFA

Betatron X rays



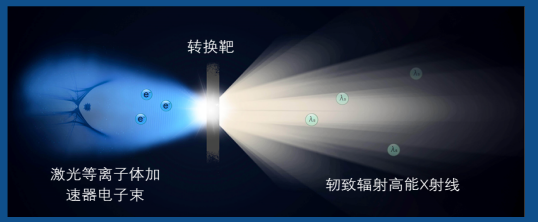
- 0.1~20 keV
- 10^{8}~10^{10}phs/shot
- Source size：1~5μm
- Imaging、XAFS

ICS X-gamma ray



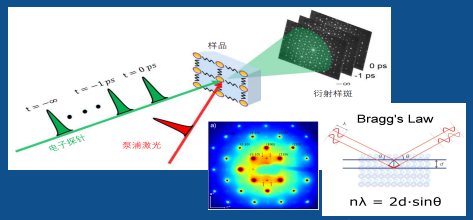
- 10keV~5MeV
- 10^{7}~10^{9}phs/shot
- Source size：1~5μm
- Imaging, nuclear physics

Gamma ray with a convertor



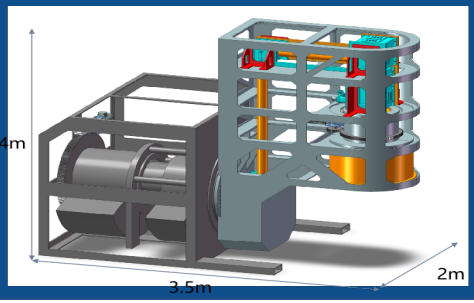
- 0.5~100MeV
- ： 5~10cGy/min@1m
- Source size：10~50μm
- High resolution Defects detection

~MeV UED



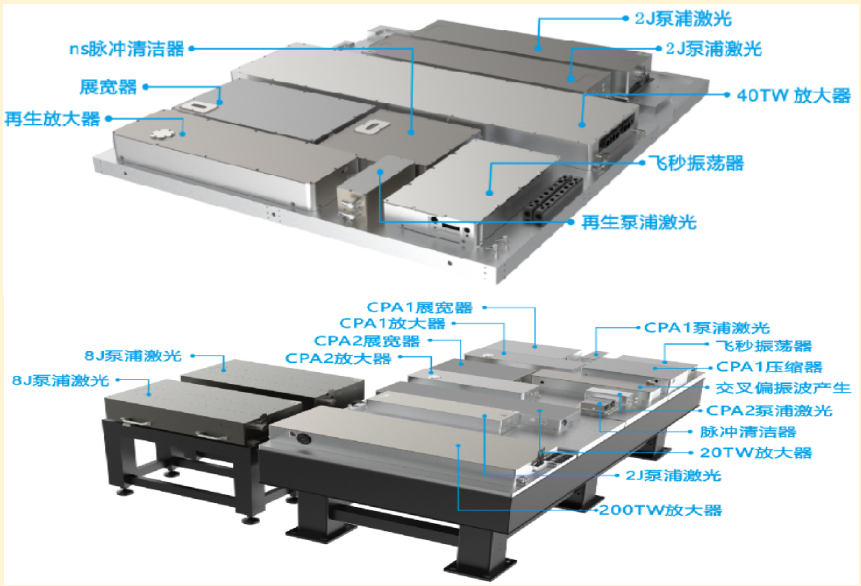
- Time resolution：10-50fs
- charge：3-20fC/shot

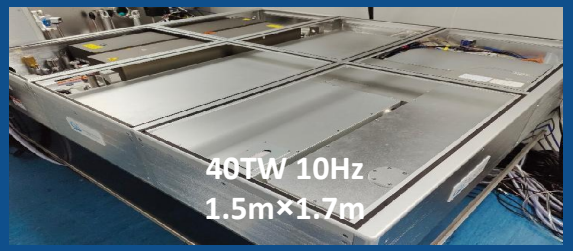
VHEE



50-200MeV
~500pC/shot

Compact Robust Laser Development for Application





Newlight Source
QiFeng Technology

BAQIS

Table top ultrafast synchrotron source

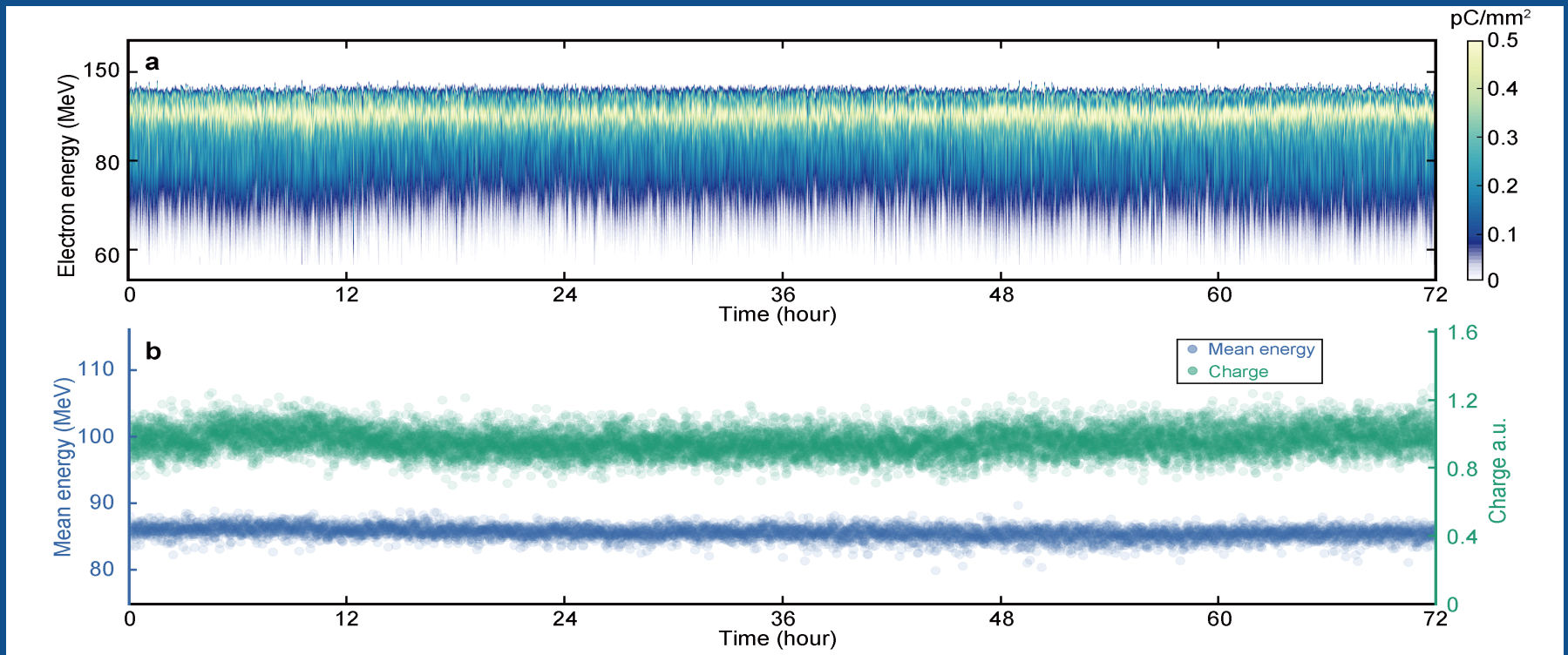
Movable LWFA system in a container

running over 180 days, 5day/week, 10-12h /day)

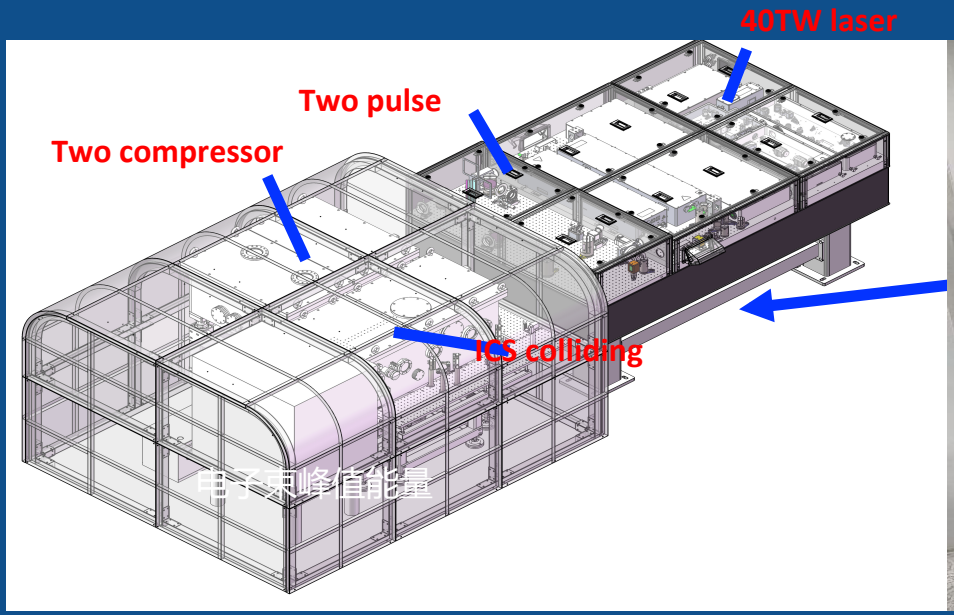
Temperature (outside) :
25.5~29.5℃

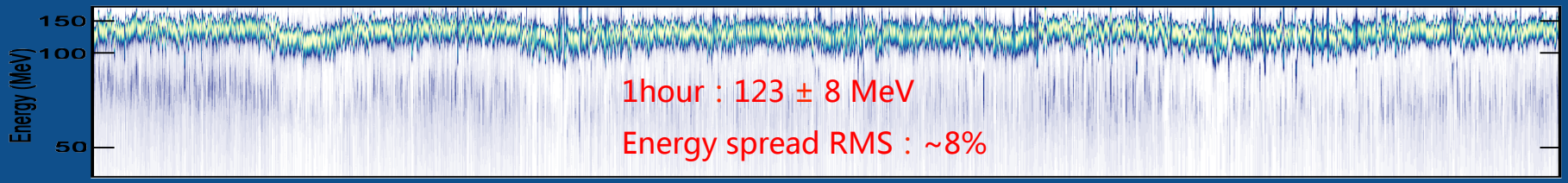
Energy
1.3%@72hrs

Charge
12% (>60MeV@72hrs)



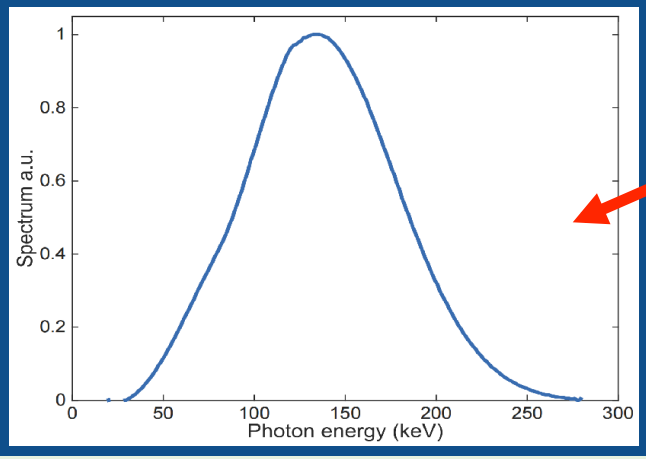
Compact Hard X ray ICS by two pulses

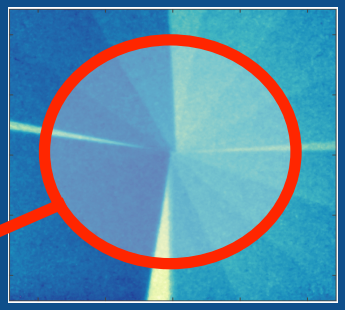




High Flux Quasi-mono Hard X Ray

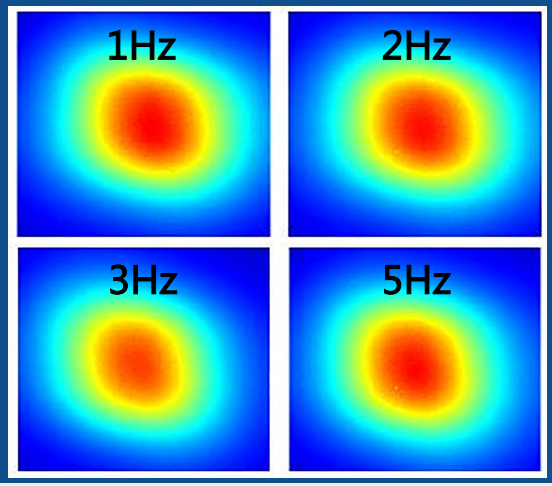
- Quasi-mono spectra

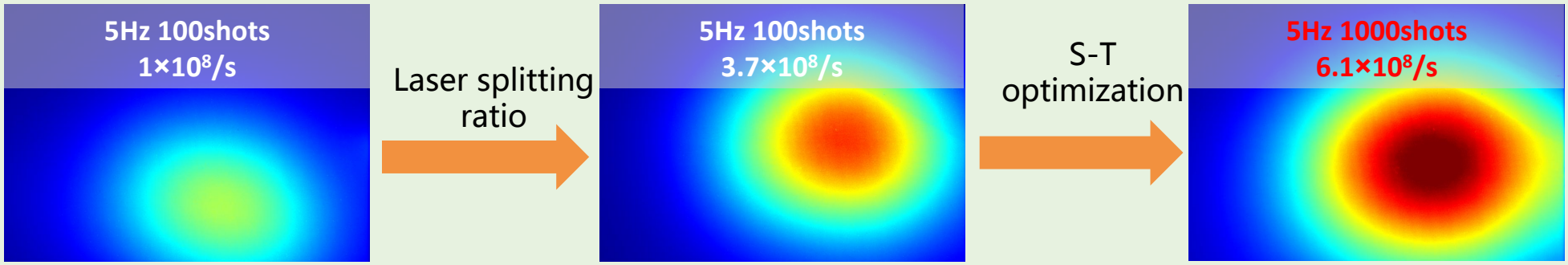




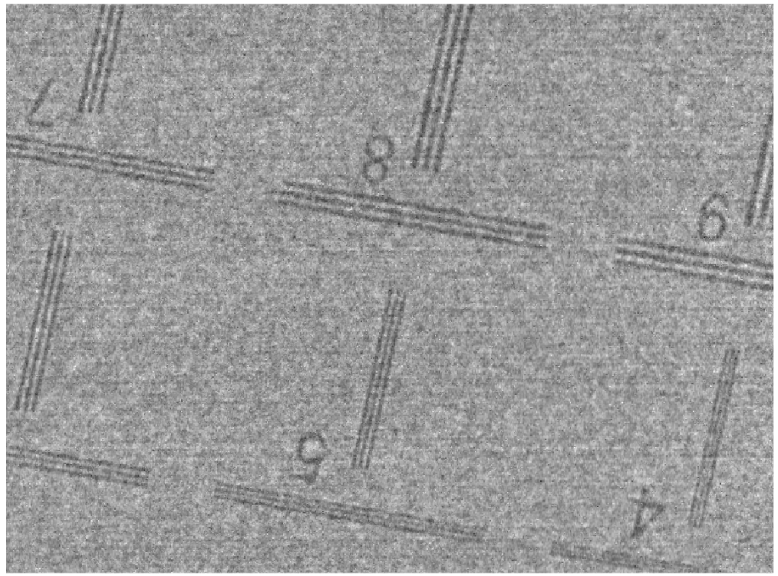
X ray energy : ~150keV

Rms bandwidth : ~25%

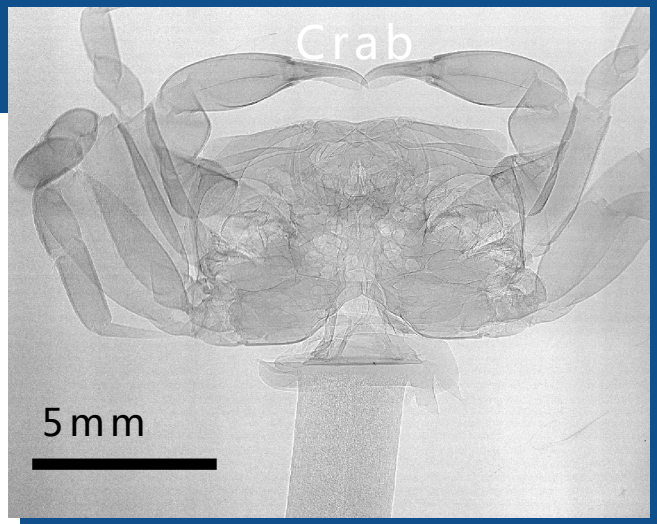


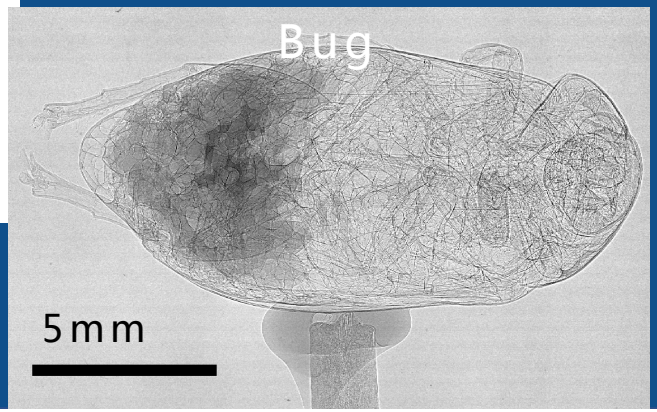


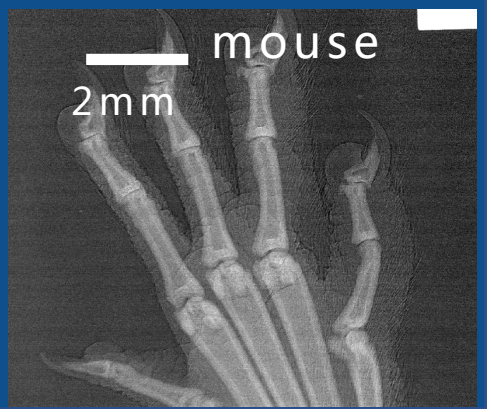
■ JIMA resolution



Resolution <4μm

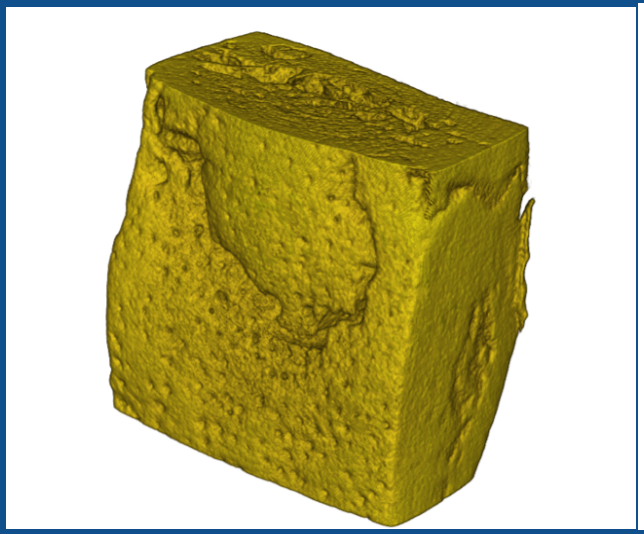




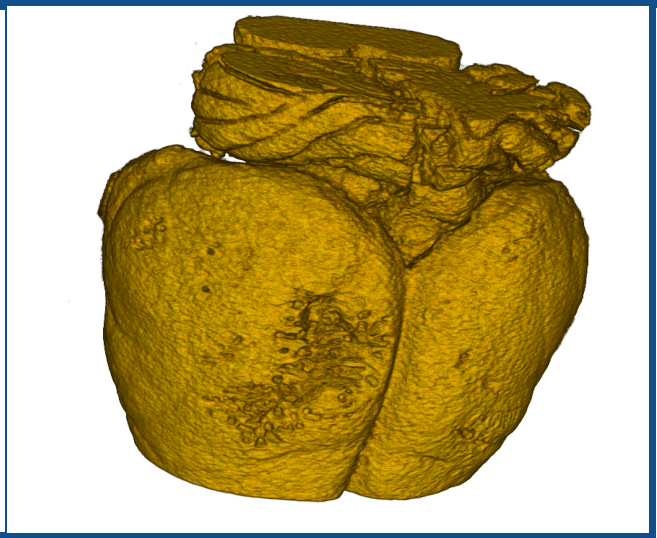


High resolution Phase-contrast CT

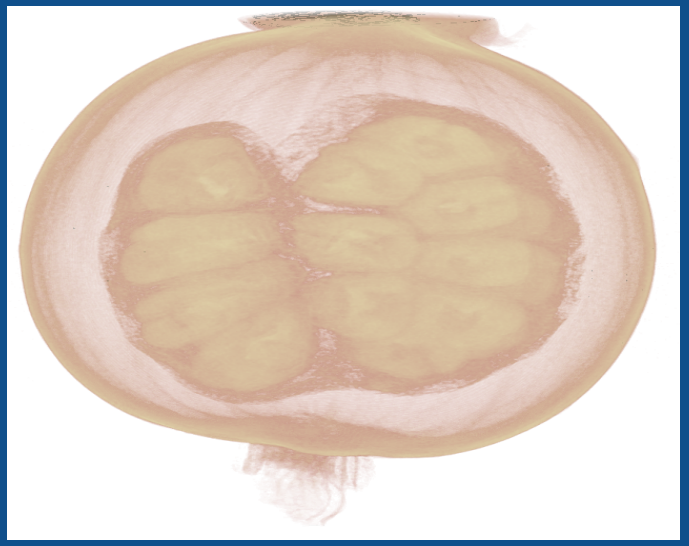
- Head bone



- Mouse brain

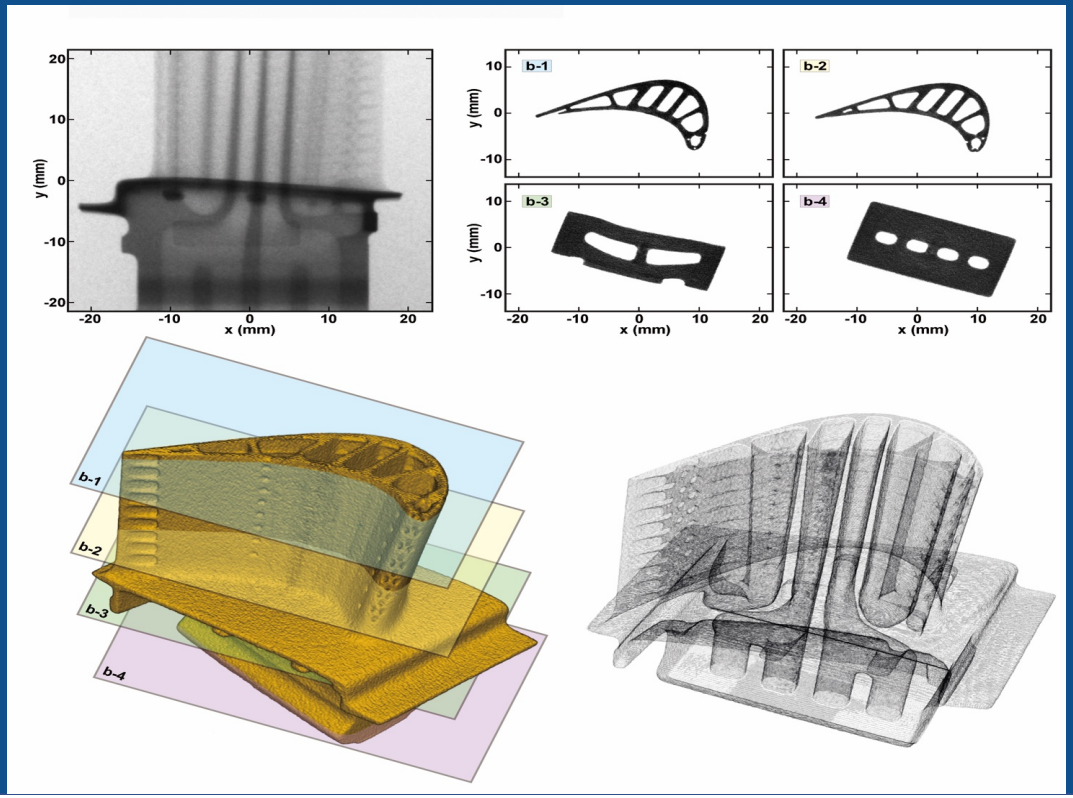


- Nut

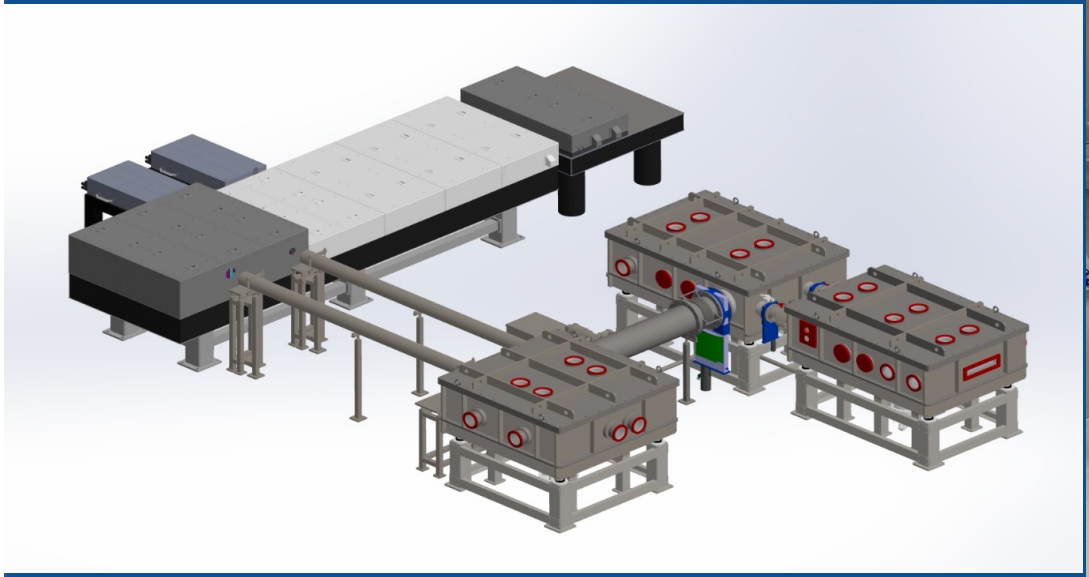


High energy Gama-ray CT for turbine blade

Resolution <50μm

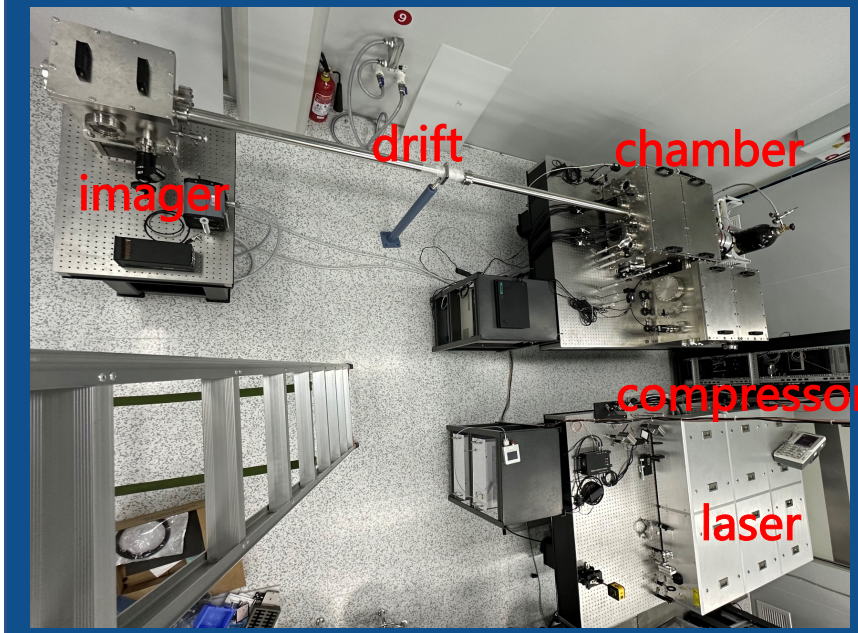


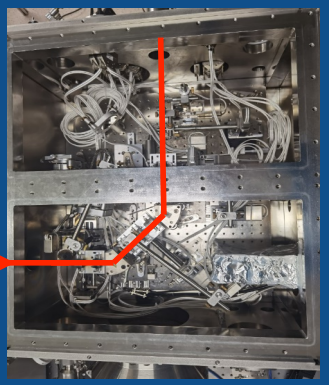
300TW ICS system at Fudan University

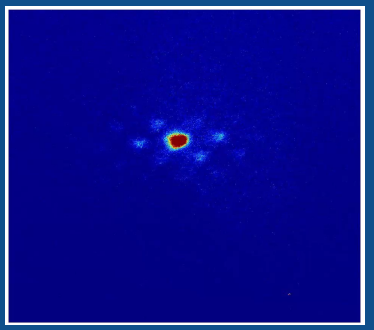


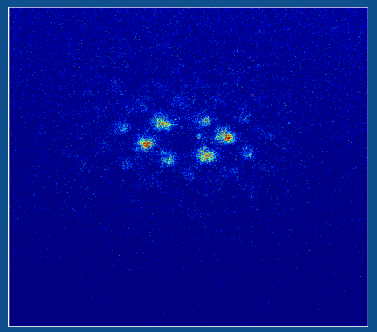
Fudan University Shanghai

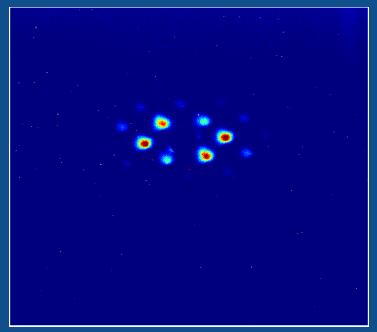
MeV UED based on table-top LWFA (~57fs)











arXiv:2210.12093 [physics.acc-ph]

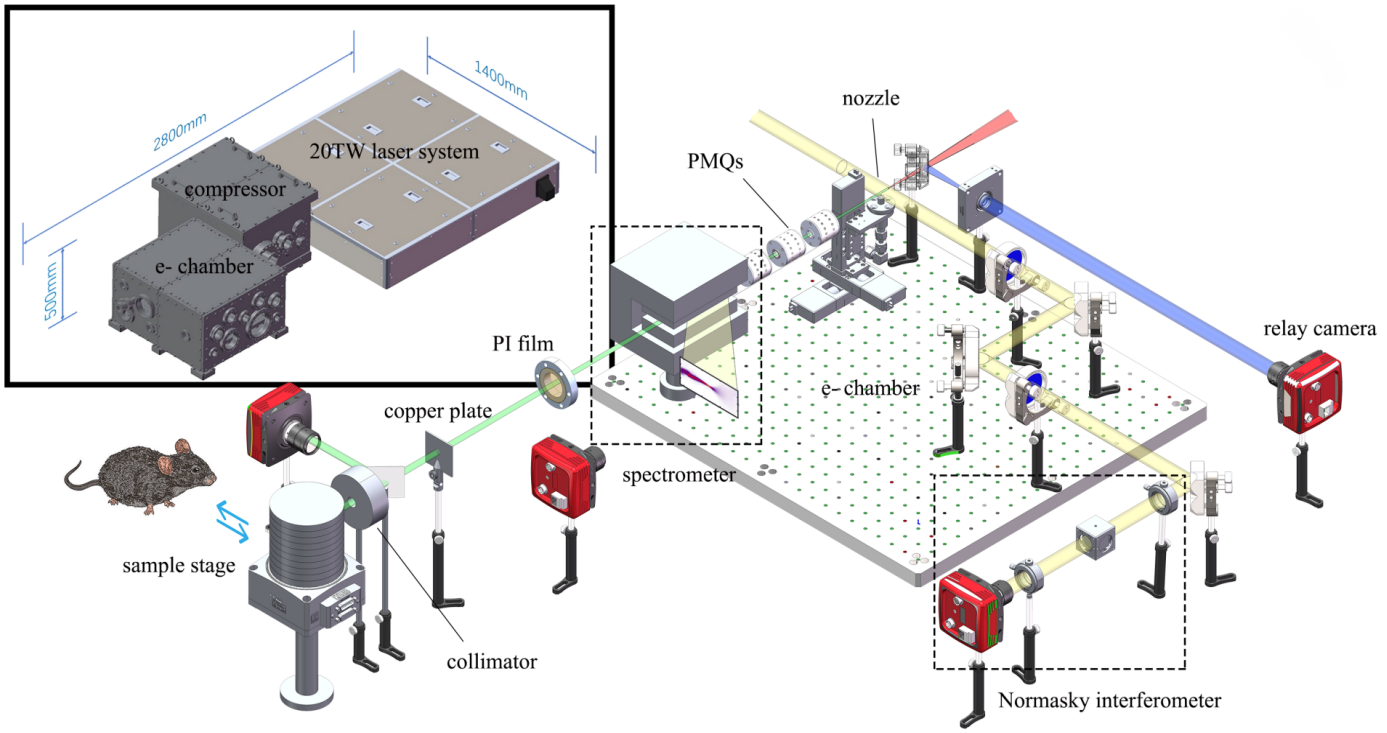
Patent: CN114975050A

Single shot 11fC

100shots

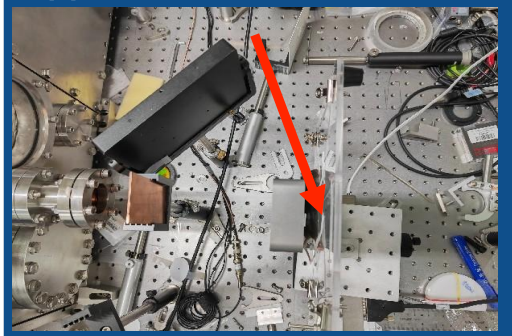
LWFA driven VHEE for small animals

Size: 3m*1.5m



Water body+RCF

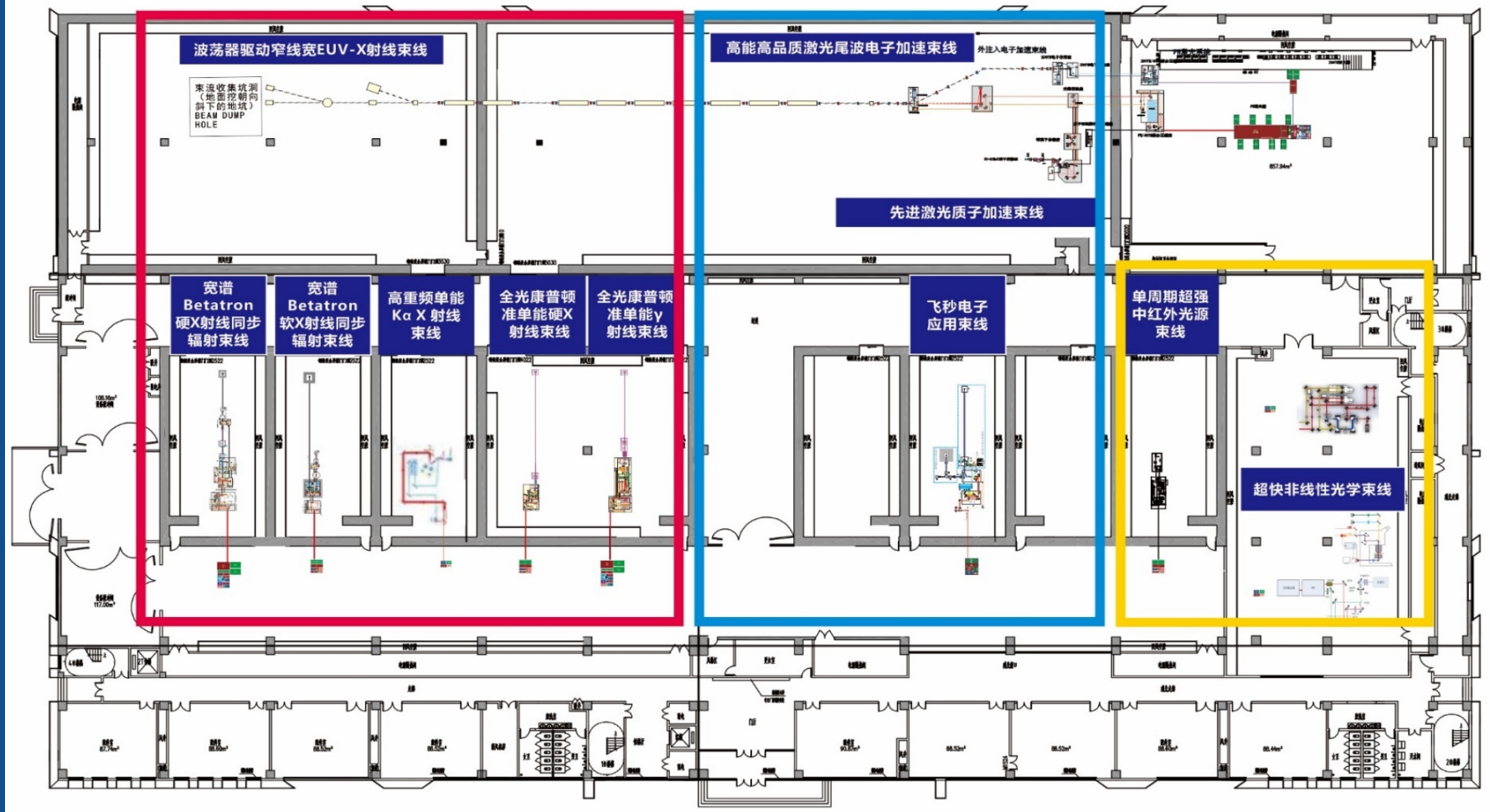
Support for mouse



A Laser Plasma Accelerator Application Facility

CCLS

Zhenzhou U., Zhenzhou, Henan


波荡器驱动窄线宽EUV-X射线束线
束流收集坑洞（地面挖朝向斜下的地坑）
BEAM DUMP HOLE
高能高品质激光尾波电子加速束线
外注入电子加速束线
先进激光质子加速束线
宽谱 Betatron 硬X射线同步辐射束线
宽谱 Betatron 软X射线同步辐射束线
高重频单能 Kα X 射线束线
全光康普顿准单能硬X射线束线
全光康普顿准单能γ射线束线
飞秒电子应用束线
单周期超强中红外光源束线
超快非线性光学束线

Thank you for your attention

High efficiency high quality LWFA is possible

For a 1.4 kJ PW laser:

Electron beam:
energy gain >140 GeV
charge ~ 2 nC
energy spread <1%
Efficiency: > 20%

Shuang Liu, Fei Li, Shiyu Zhou, Jianfei Hua, Warren B. Mori, Chan Joshi, Wei Lu*. A Scalable, High-Efficiency, Low-Energy-Spread Laser Wakefield Accelerator Using a Tri-Plateau Plasma Channel. Research, 2024, 7:0396

Case	*1*	*2*	*3*	*4*	*5 (uniform channel)*
Scaling factor F	1	2	4	16	16
Averaged energy gain (GeV)	0.57	2.28	9.88	145.9	51
Laser peak power (TW)	15.3	61.2	245	3917	3917
Pulse length (fs)	21.5	43.0	86.0	344	344
w_0 (μm)	10.7	21.3	43.0	171	171
Laser pulse energy (J)	0.34	2.76	22.1	1393	1393
Plasma density of first plateau (cm^{-3})	2e18	5e17	1.25e17	7.81e15	7.81e15
Plasma length (mm)	6.1	48.8	390	2.5e4	3.3e4
Electron beam charge (pC)	125	250	492	2000	2000
Energy spread (FWHM)	0.42%	0.65%	0.63%	<1%	~15%
Energy efficiency	21.1%	21.2%	21.1%	~21.1%	~7.4%