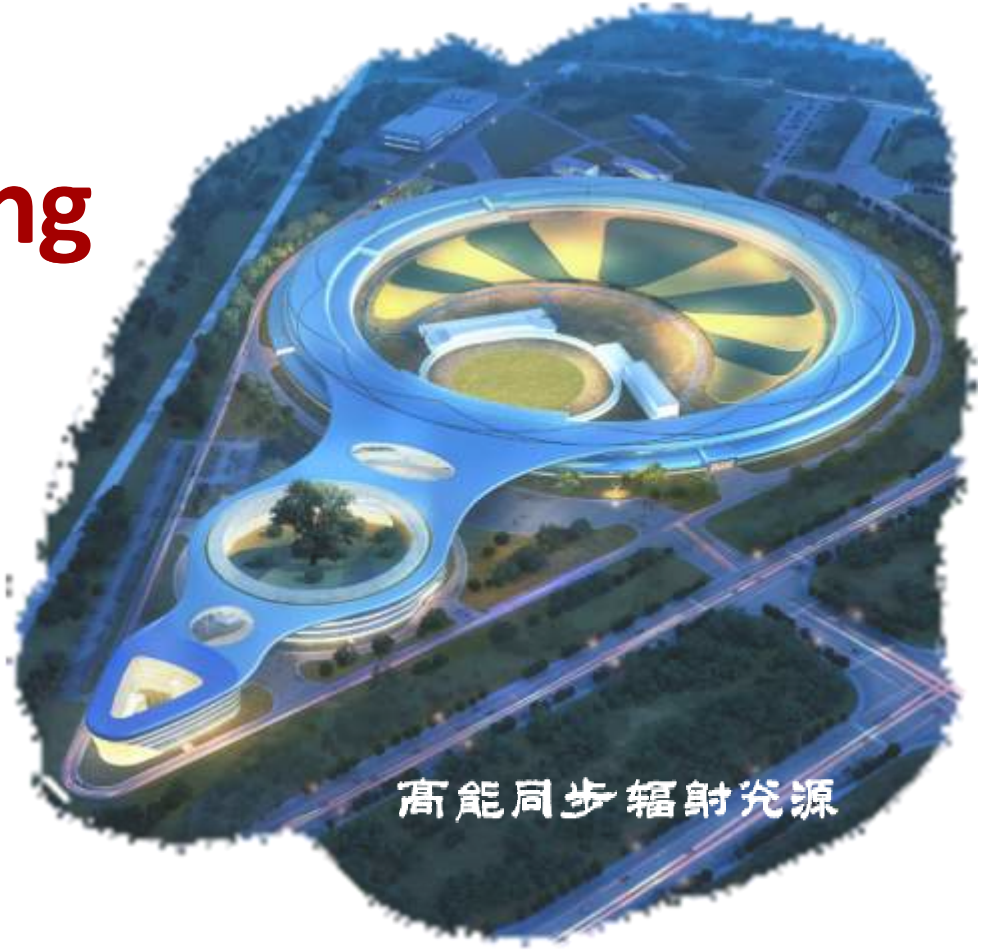
Status of the High Energy Photon Source (HEPS) at Beijing



Yi Jiao
IHEP, CAS, Beijing

2021-03-17

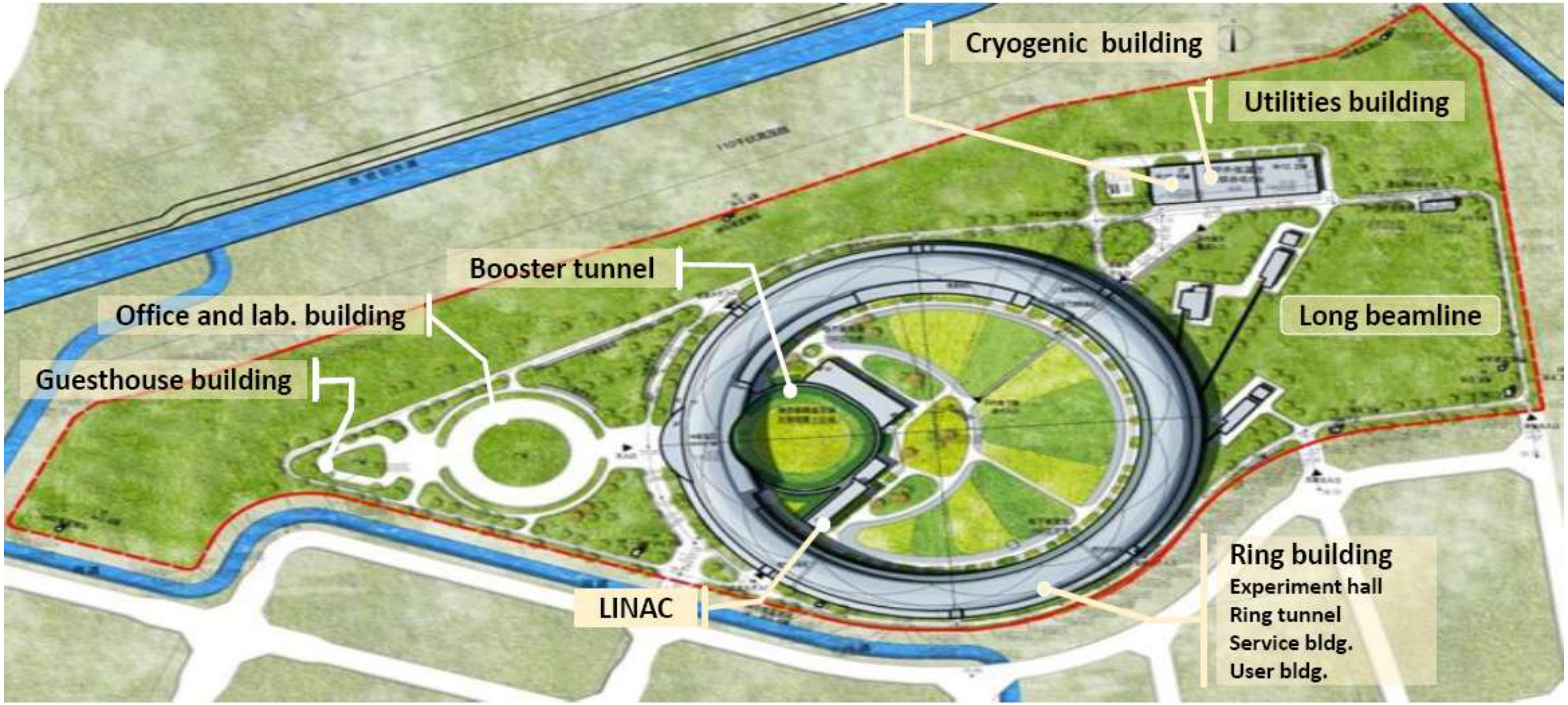
AFAD2021 (online) · BINP, Novosibirsk, Russia

Outline

Brief introduction

High Energy Photon Source (HEPS)

- HEPS is a 4th generation, 6 GeV, ultralow emittance synchrotron light source.
- It is currently under construction in the northeast suburb of Beijing, China.



Project management

- The new project management was announced on Feb. 20,2020.

Project manager Weimin PAN

Executive deputy manager Yuhui DONG

Deputy manager Gang XU， Jian LIANG， Sheng WANG

Chief engineer Huamin QU

Deputy engineer Weifan SHENG, Jing ZHANG

Chief technologist Guoping LIN

Deputy technologist Jianshe CAO, Haijie QIAN

Chief economic manager Ya ZHOU

5 Divisions (52 systems)

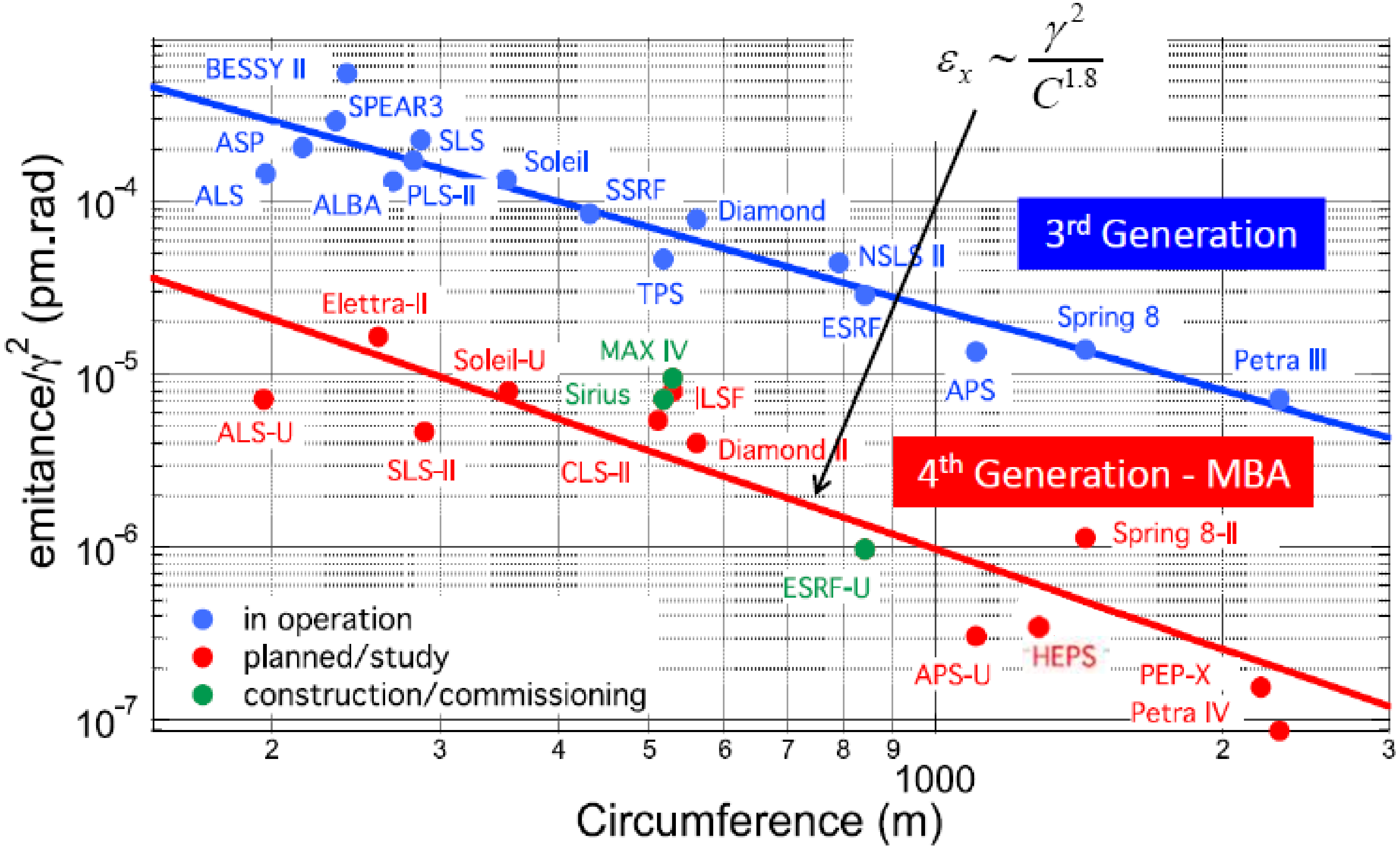
Brief history of the HEPS

- Preliminary design studies (2008~2016)
  - Lattice design iterated and finally came to hybrid-7BA lattice
  - Injector design studies and related physics studies carried on at the same time

- HEPS-Test Facility (2016 – 2018)
  - R&D on the accelerator and beam line techniques for a DLSR
  - Developed key hardware techniques that are essentially required for constructing a diffraction-limited storage ring light source and completed the physics design for the HEPS project.

- HEPS project (2019 – 2025)
  - About 6.5 years, budget ~ 4.8 billion RMB (manpower excluded)
  - The civil construction started in June 2019, expected to be finished at mid-2021.

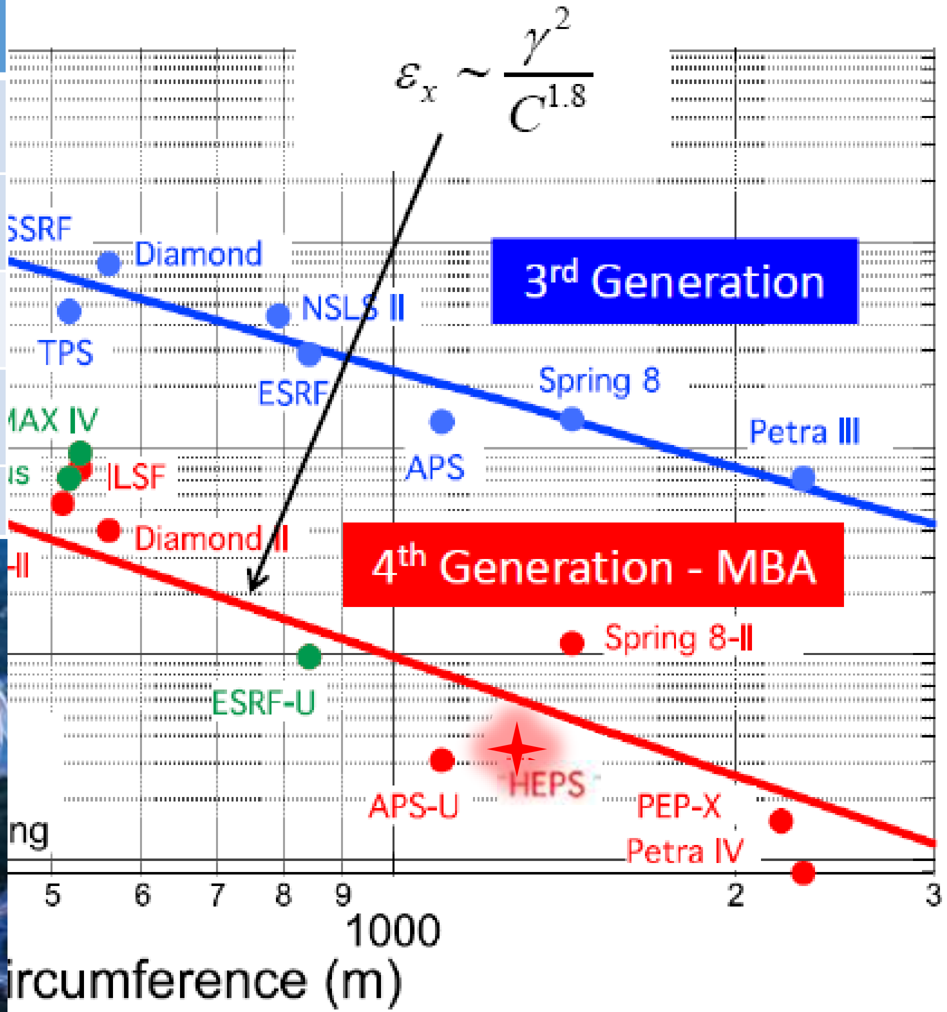
Design goals of the HEPS



Courtesy of R. Walker, L. Liu

Design goals of the HEPS

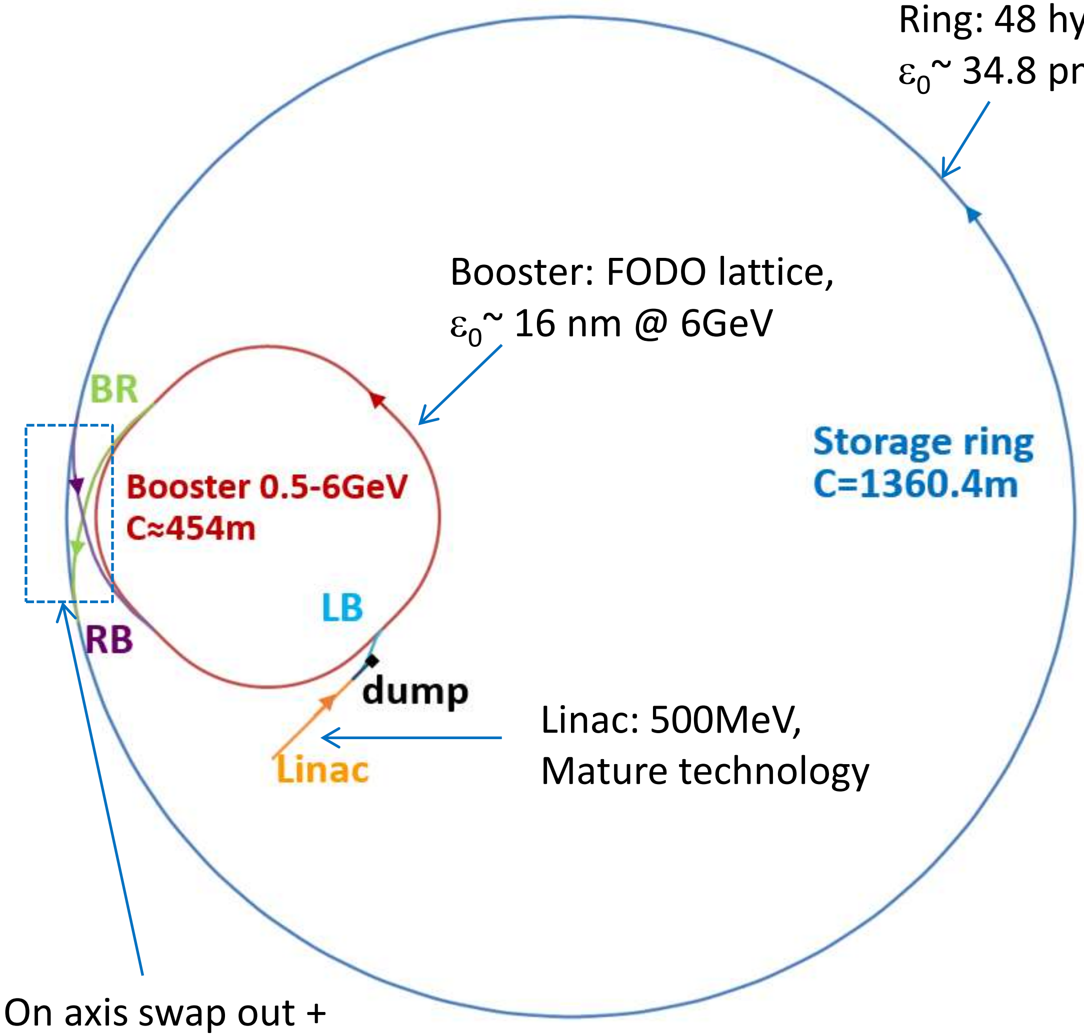
Parameters	Value	Unit
Beam energy	6	GeV
Natural emittance	≤ 60	pm·rad
Brightness	$> 10^{22}$	$phs/s/mm^2/mrad^2/0.1\%BW$
Beam current	200	mA
Injection	Top-up	



Courtesy of R. Walker, L. Liu

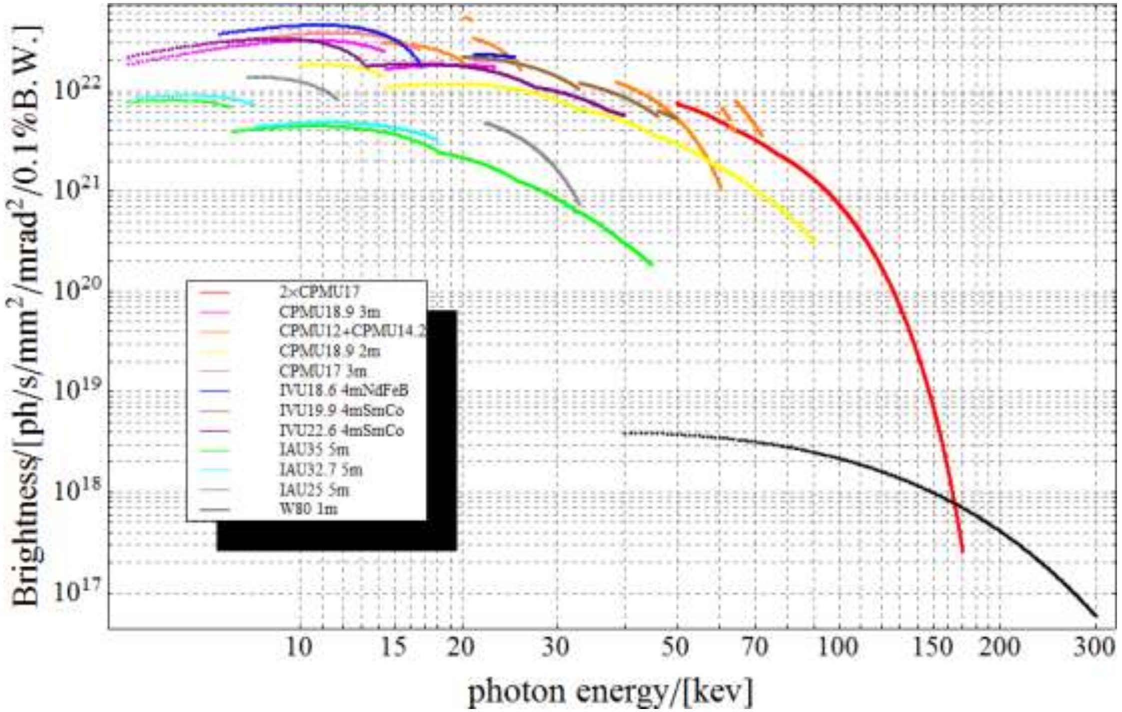
Design of the light source

Schematic layout [1]



On axis swap out +
High energy accumulation (in booster)

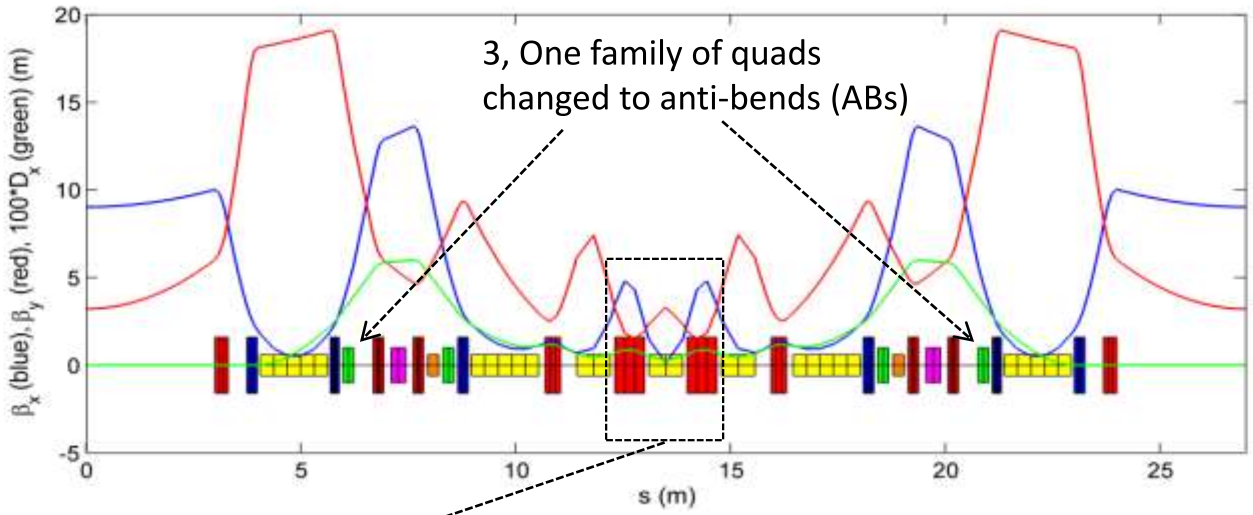
In phase one, 14 beam lines will be built.
Brightness of above $4*10^{22}$ at 200mA expected.



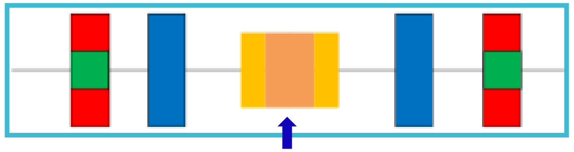
[1] Y. Jiao, G. Xu, X. Cui, Z. Duan, Y.Y. Guo, P. He, D. Ji, J.Y. Li, X.Y. Li, C. Meng, Y.M. Peng, S.K. Tian, J.Q. Wang, N. Wang, Y.Y. Wei, H.S. Xu, F. Yan, C.H. Yu, Y.L. Zhao, Q. Qin*, “The HEPS project”, J. Synchrotron Rad. (2018). 25, 1611-1618. https://doi.org/10.1107/S1600577518012110.

Modified hybrid-7BA lattice

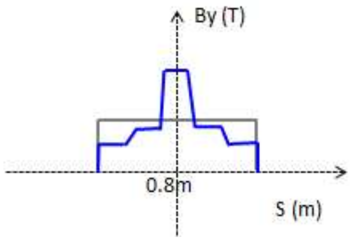
- Evolved over more than 10 years [1]. Candidate lattice structures include DBA [2], TBA [3], standard-7BA [4,5], hybrid-7BA [6-8], and modified hybrid-7BA [9-12].



1, Replace the middle cell with BLG/AB cell

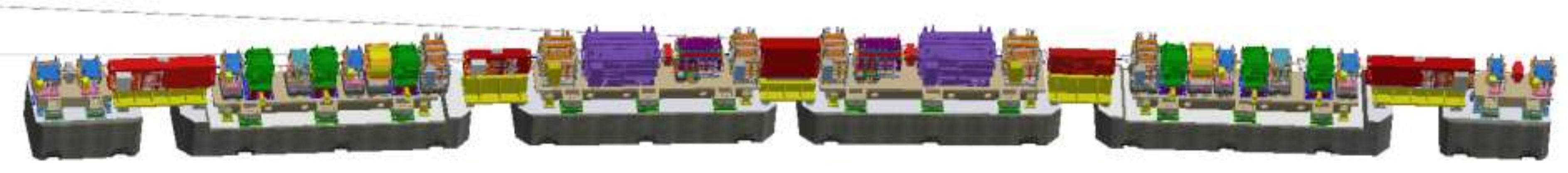


2, Central slice of BLG used for bending magnet beam line



Peak field (T)	Critical photon energy (keV)	Peak power density (W/mrad²)
0.5T	12.0	702
0.85T	20.3	1194
1T	23.9	1405
1.5T	35.9	2107
2T	47.9	2810
3T	71.8	4215
3PW(1.6T)	38.3	2349

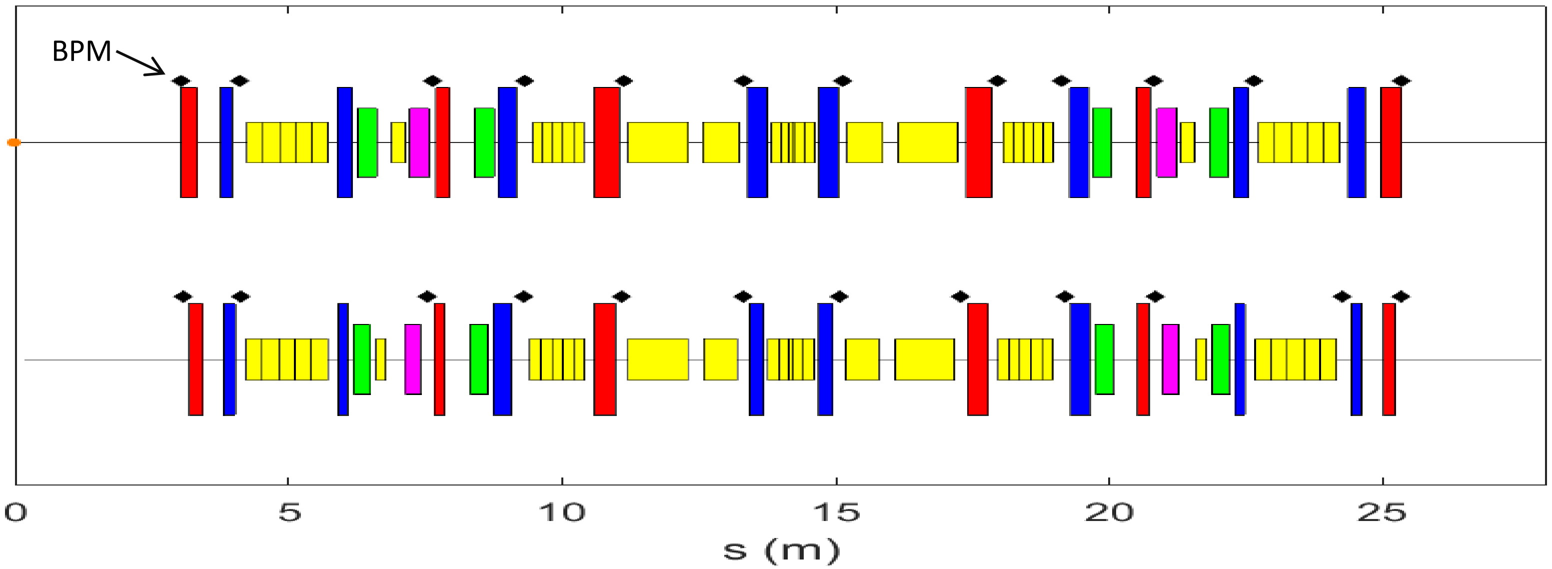
[1] Y. Jiao, *et al.*, IPAC'18, TUPMF049.
[2] X. Jiang, *et al.*, "BAPS Preliminary Design Report", internal report, 2012.
[3] G. Xu, Y.M. Peng, Chin. Phys. C, 39(3), 037005, 2015.
[4] Y. Jiao, G. Xu, D.H. Ji, SAP2014, THPMH1, 2014.
[5] Y. Jiao, G. Xu, Chin. Phys. C, 39(6), 067004, 2015.
[6] G. Xu, Y. Jiao, Y. Peng, Chin. Phys. C, 40(2), 027001, 2016.
[7] Y. Jiao, Chin. Phys. C, 40(7), 077002, 2016.
[8] Y. Jiao, G. Xu, Chin. Phys. C, 41(2), 027001, 2017.
[9] Y. Jiao, *et al.*, FLS2018, MOP2WB01.
[10] Y. Jiao, *et al.*, "The HEPS project", J. Synchrotron Rad. (2018). 25, 1611-1618.
[11] Y. Jiao, *et al.*, IPAC'19, TUZPLS2.
[12] Yi Jiao, *et al.*, Radiat Detect Technol Methods **4**, 415–424 (2020).

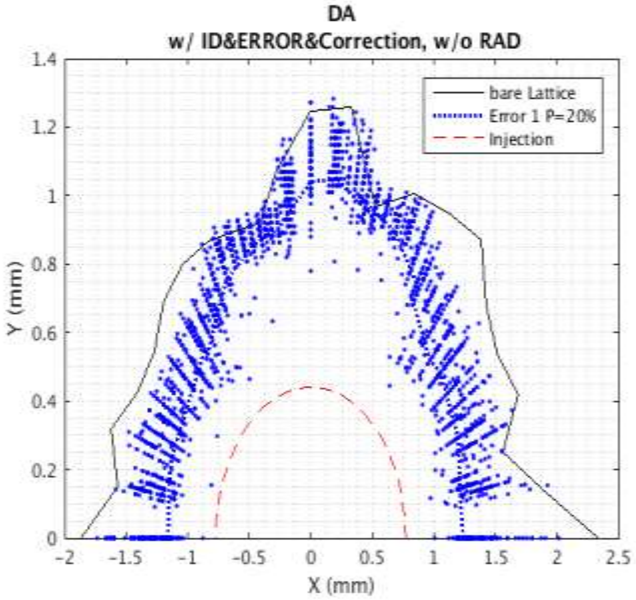


Courtesy of C. Li

Latest lattice modification

- Modified lattice to meet the challenges from hardware and engineering design
  - More space in arc area (~1.1 m per 7BA), and released requirements on some magnets [1]
  - Emittance almost recovered, dynamic aperture reduced but still enough for injection [2]

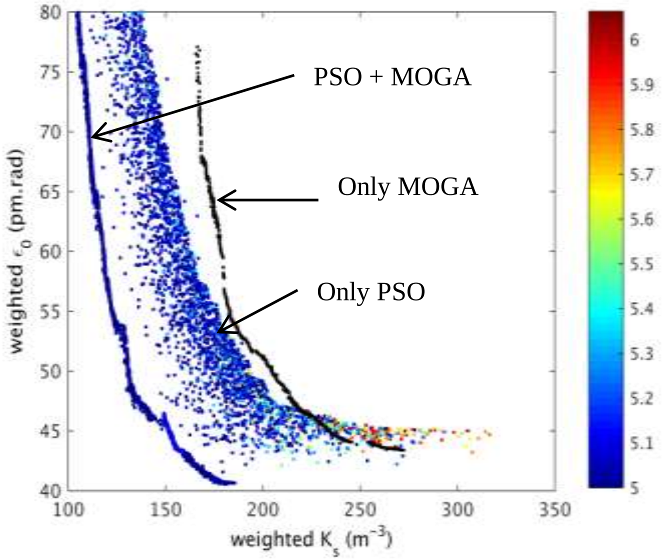




[1] Y. Jiao, *et al.*, Radiat Detect Technol Methods 4, 415–424 (2020).
[2] D.H. Ji, *et al.*, HEPS-AC-AP-TN-2021-003-V0, 2021.

Explore ultimate performance of the lattice

- Global optimization of the lattice with **stochastic optimization** methods
  - Iterative application of MOGA and PSO [1] allows much better performance than using either of them (e.g., [2])

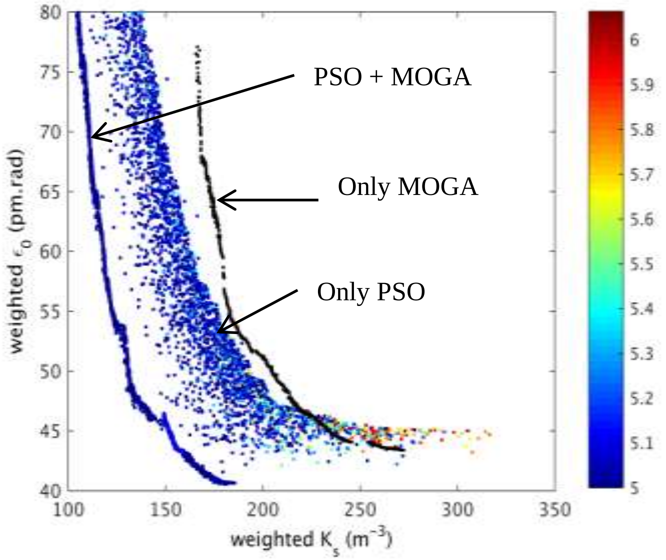


Better solutions w/ PSO + MOGA

[1] Y. Jiao, G. Xu, Chin. Phys. C, 41(2), 027001, 2017. [2] Y. Jiao, Chin. Phys. C, 40(7), 077002, 2016.
[3] J. Wan, *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A 946 (2019) 162683. [4] Jinyu Wan, *et al.*, Phys. Rev. Accel. Beams 23, 081601 (2020).

Explore ultimate performance of the lattice

- Global optimization of the lattice with **stochastic optimization** methods
  - Iterative application of MOGA and PSO [1] allows much better performance than using either of them (e.g., [2])
- **Machine learning** enhanced genetic algorithm [3,4] for nonlinear optimization
  - More efficient and better optimization performances



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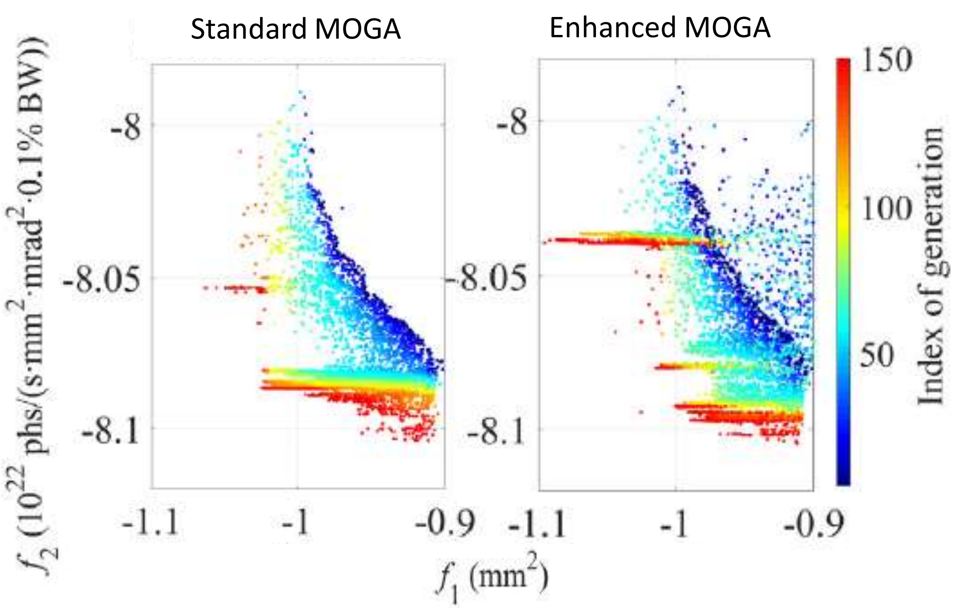
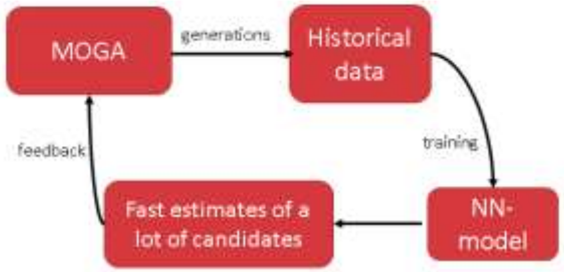
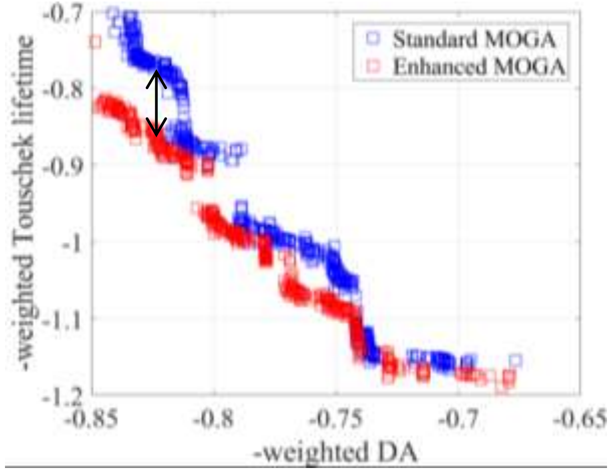


Generate more competitive candidates during the MOGA evolution with the aid of clustering methods



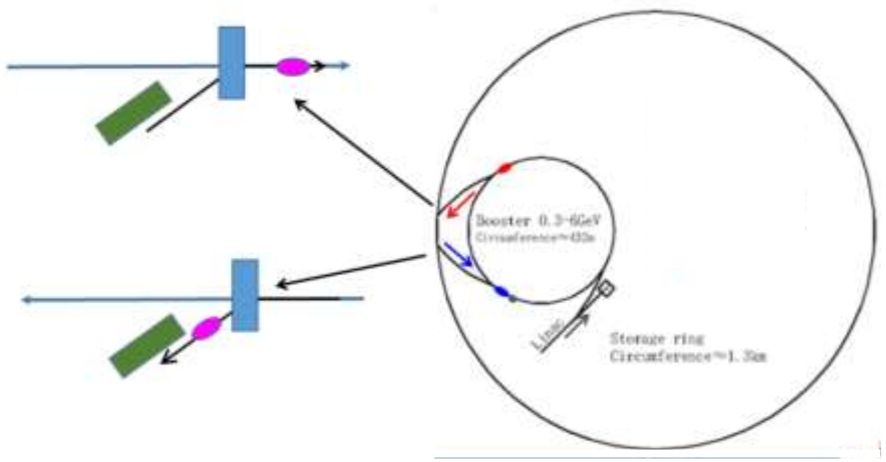


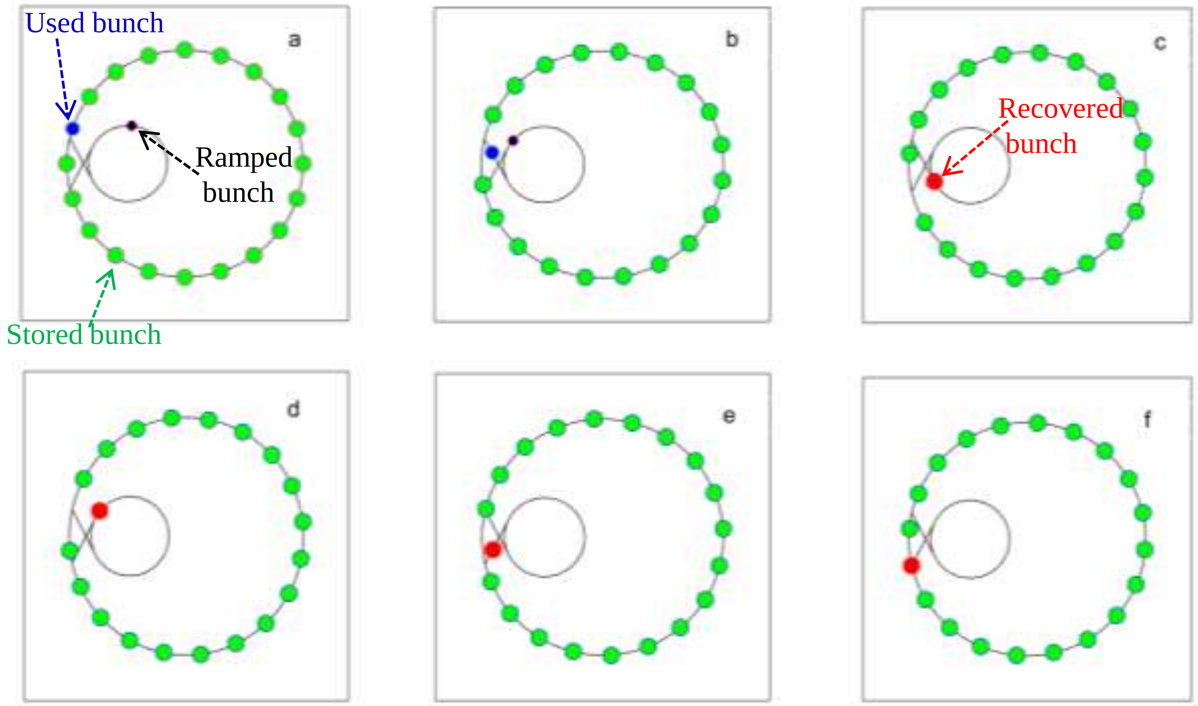
Neural network enhanced MOGA that allows 10% increase of lifetime

[1] Y. Jiao, G. Xu, Chin. Phys. C, 41(2), 027001, 2017.
[2] Y. Jiao, Chin. Phys. C, 40(7), 077002, 2016.
[3] J. Wan, *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A 946 (2019) 162683.
[4] Jinyu Wan, *et al.*, Phys. Rev. Accel. Beams 23, 081601 (2020).

On-axis swap out + high-energy accumulation in booster

- It requires: one more transfer line, and extraction section in the ring [1,2]





Charge accumulation in Booster at 6 GeV [1]:
(a) Used bunch extracted from the ring, (b) passing through a transport line, (c) Injected to booster, merged with an existing bunch, (d) after about 10 thousands' revolutions in booster, extracted from the booster, (e) passing through another transport line, (f) re-injected to the ring

[1] Z. Duan *et al*., Proc. IPAC'18, pp.4178-4181, THPMF052.
[2] Y. Guo, *et al*.,. Radiat Detect Technol Methods 4, 440–447 (2020).
[3] Y. Peng, *et al*., Radiat Detect Technol Methods 4, 425–432 (2020).
[4] C. Meng, *et al*., Radiat Detect Technol Methods 4, 497–506 (2020).

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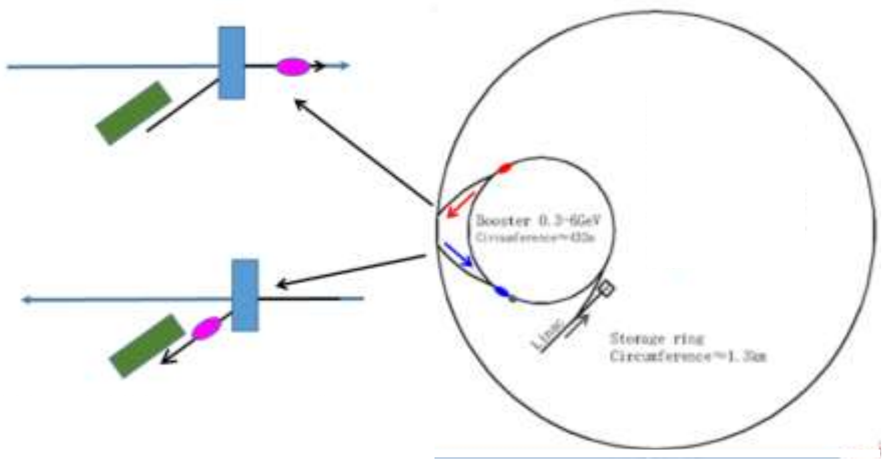

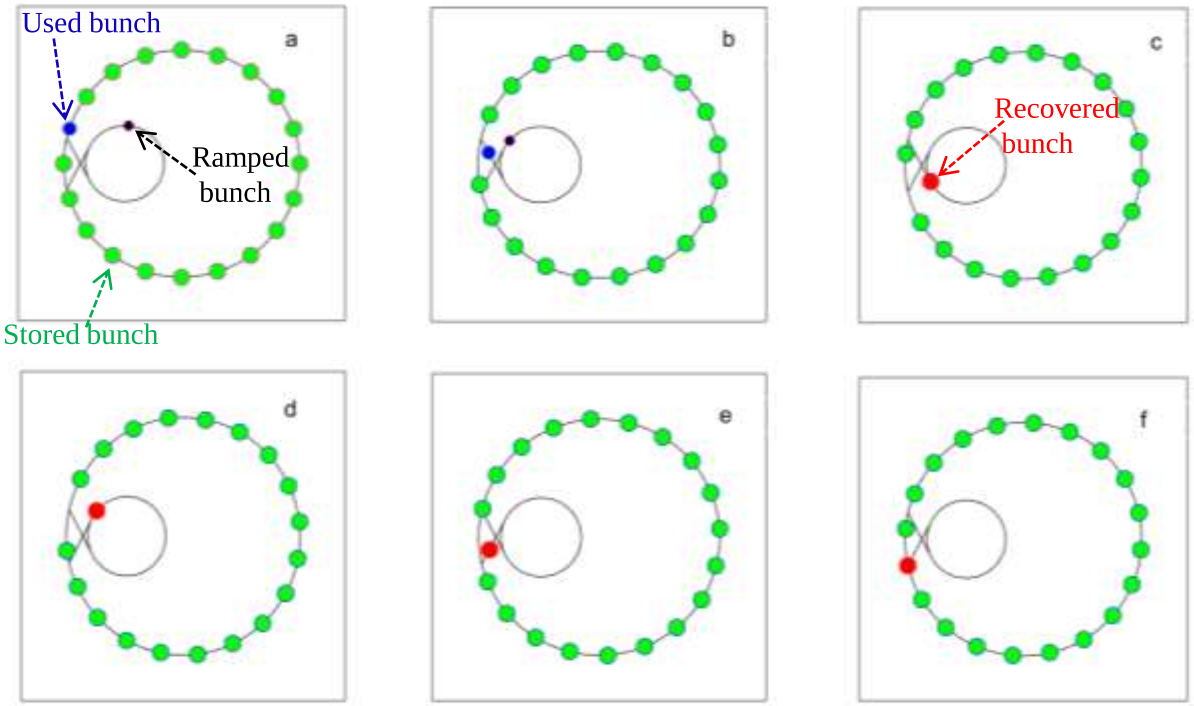

- Less single bunch charge requirement [3,4]

	Swap-out only	Swap out + accum.
Max. Q from Linac	> 16 nC	7 nC
Max. Q from Booster	> 14.4 nC	5 nC

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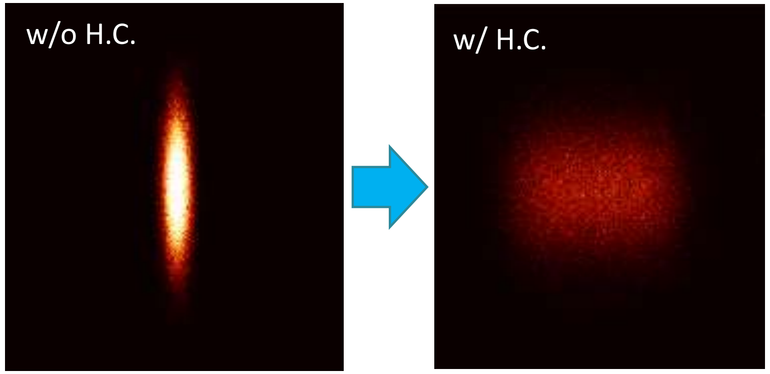
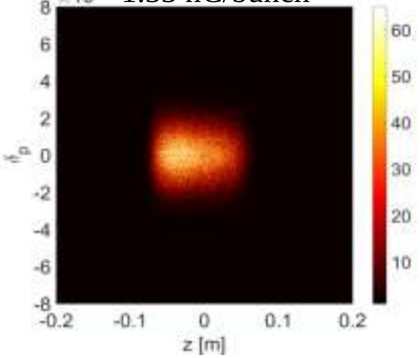
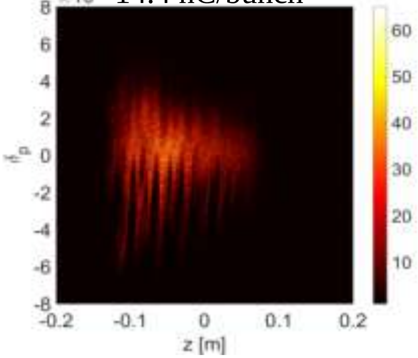
[3] Y. Peng, *et al*., Radiat Detect Technol Methods 4, 425–432 (2020).
[4] C. Meng, *et al*., Radiat Detect Technol Methods 4, 497–506 (2020).

Studies to ensure 200 mA operation

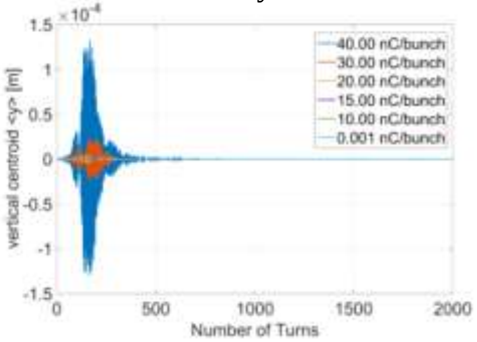
- Detailed impedance modeling
  - Impedance contributions were evaluated and optimized based on iteration with hardware designs[1-2]
- Numerical simulation on single and multi-bunch instabilities
  - Harmonic cavities (500 MHz) and fundamental cavities (166.6 MHz) are used to lengthen the bunches, so as to increase beam lifetime [3] and especially to mitigate IBS effect and collective beam instabilities [4]
  - With the aid of feedback system and positive chromaticity, it is feasible to control the multi-bunch instabilities (coupled bunch instability [2], and ion instability [5,6,7]) for 200 mA operation
  - No beam loss at the max. target single bunch charge (14.4 nC/bunch, 63 bunches & 200 mA), however, brightness reduction (10~20%) is unavoidable [2]; also, injection transient instability should be careful [8,9]







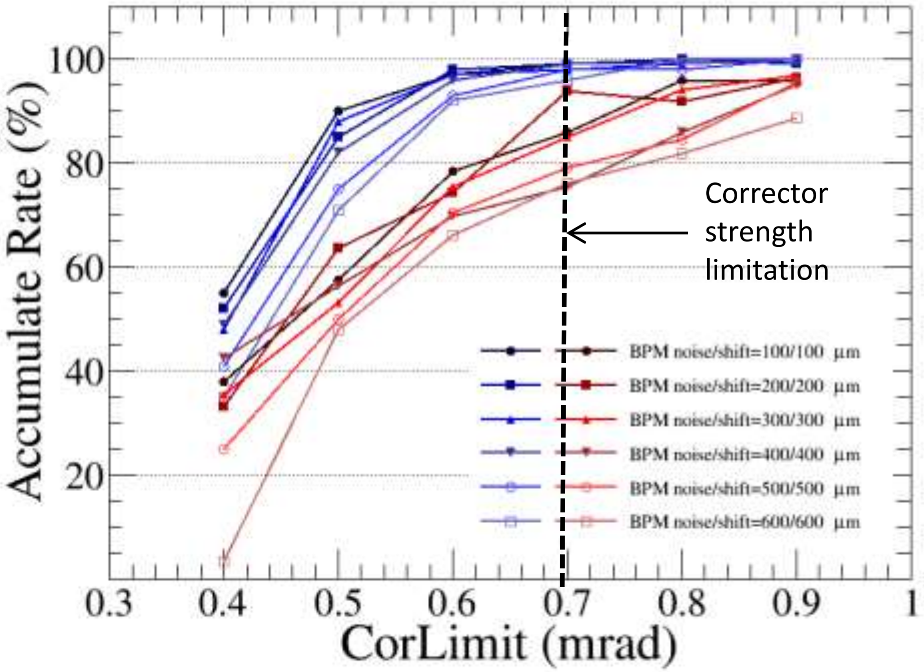
+5 chromaticity to cure TMCI



[1] N. Wang, *et al*., IPAC17, WEPIK078. [2] N. Wang, *et al*., Atom Energ Sci Technol 2019, 53(9): 1601-1606. [3] S.K. Tian, *et al*., IPAC2017, TUPAB067.
[4] H. Xu, N. Wang, FLS2018, WEP2PT024. [5] N. Wang, *et al*., IPAC2018, THPAK014. [6] S.K. Tian, *et al*., IPAC2018 THPMF055.
[7] C. Li, *et al*., Phys. Rev. Accel. Beams 23, 074401 (2020). [8] Z. Duan, *et al*., IPAC19, TUPGW053. [9] H. Xu, *et al*., Nucl. Instr. Meth.. A 986 (2021) 164658..

Initial commissioning simulation under way

- Considering large initial field and alignment errors, and using the response matrix of the bare lattice, simulation of the first turn trajectory correction of the ring has been done [1,2]
  - The probability of successful first turn trajectory correction is higher than 80%
- Next, include more practical considerations, and simulate the whole process of the initial commissioning process (from first turn around to a few mA storage).



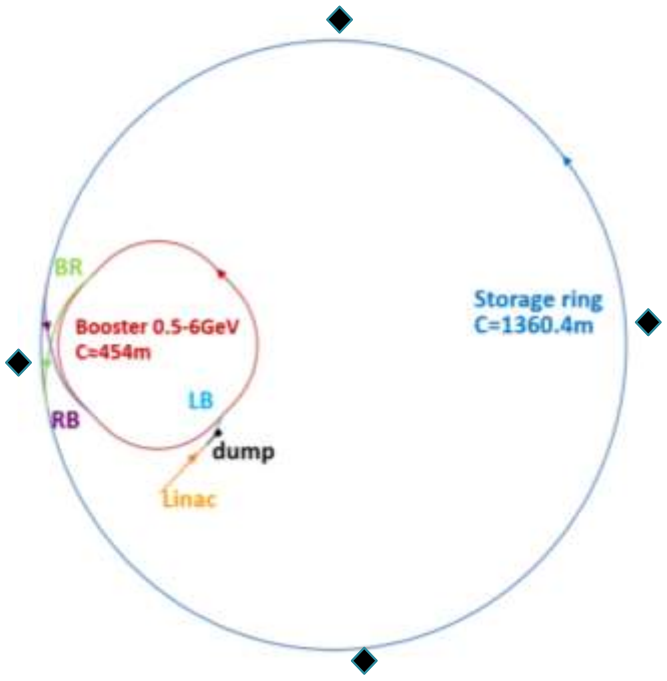
误差	值
Quadrupole Δx	30μm
Quadrupole Δz	150μm
Quadrupole ΔΦ	200μrad
Quadrupole ΔG/G	2e-4
Dipole Δx	200μm
Dipole Δz	150μm
Dipole ΔΦ	100μrad
Dipole ΔG/G	3e-4
BPM Noise/Shift	100μm/100μm

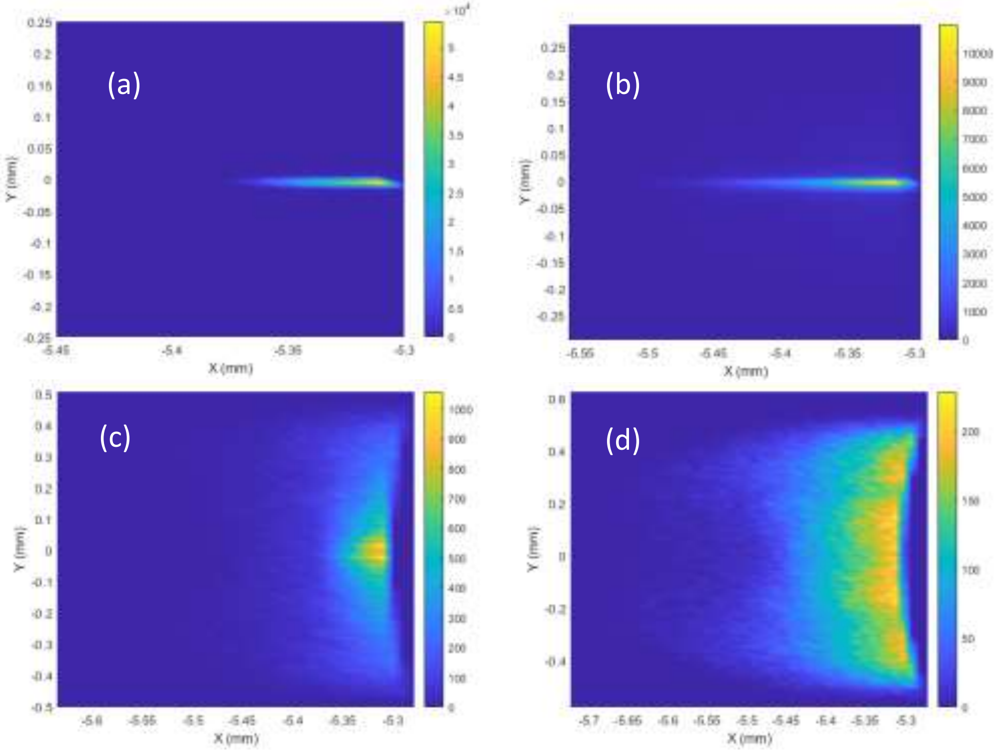
Blue curves: w/o physical aperture
Red curves: w/ physical aperture

[1] Y.L. Zhao, *et al.*, “First Turn Around Strategy for HEPS”, IPAC2017, MOPIK082.
[2] B. Wang, *et al.*, HEPS-AC-AP-TN-2021-004-V0.

Beam loss control in the ring

- Use collimators to localize the beam loss (due to Touschek effect and active beam dump) in the ring
- Found the beam deposition would be destructive on collimators in the cases of active beam dump, and other components (e.g., Lambertson septum in the case of extraction failure)
- Plan to use pre-kickers [1, 2] (before active beam dump or beam extraction) to increase the beam size and decrease the energy intensity on collimators and other components





Electron beam distribution at the collimator after active beam dump

(a) w/o pre-kicker
(b) w/ horizontal pre-kicker
(c) w/ vertical pre-kicker
(d) w/ horizontal and vertical pre-kickers

The max. beam intensity at collimators reduced by about 200 times with pre-kickers

4 collimators at the 2nd dispersion bumps of the 1st, 13th, 25th, and 37th 7BA.

[1] Y.L. Zhao, *et al.*, HEPS-AC-AP-TN-2020-024-V0.
[2] Z. Duan, *et al.*, HEPS-AC-AP-TN-2020-031-V0.

Construction status

Ground breaking ceremony on 2019 June, 29

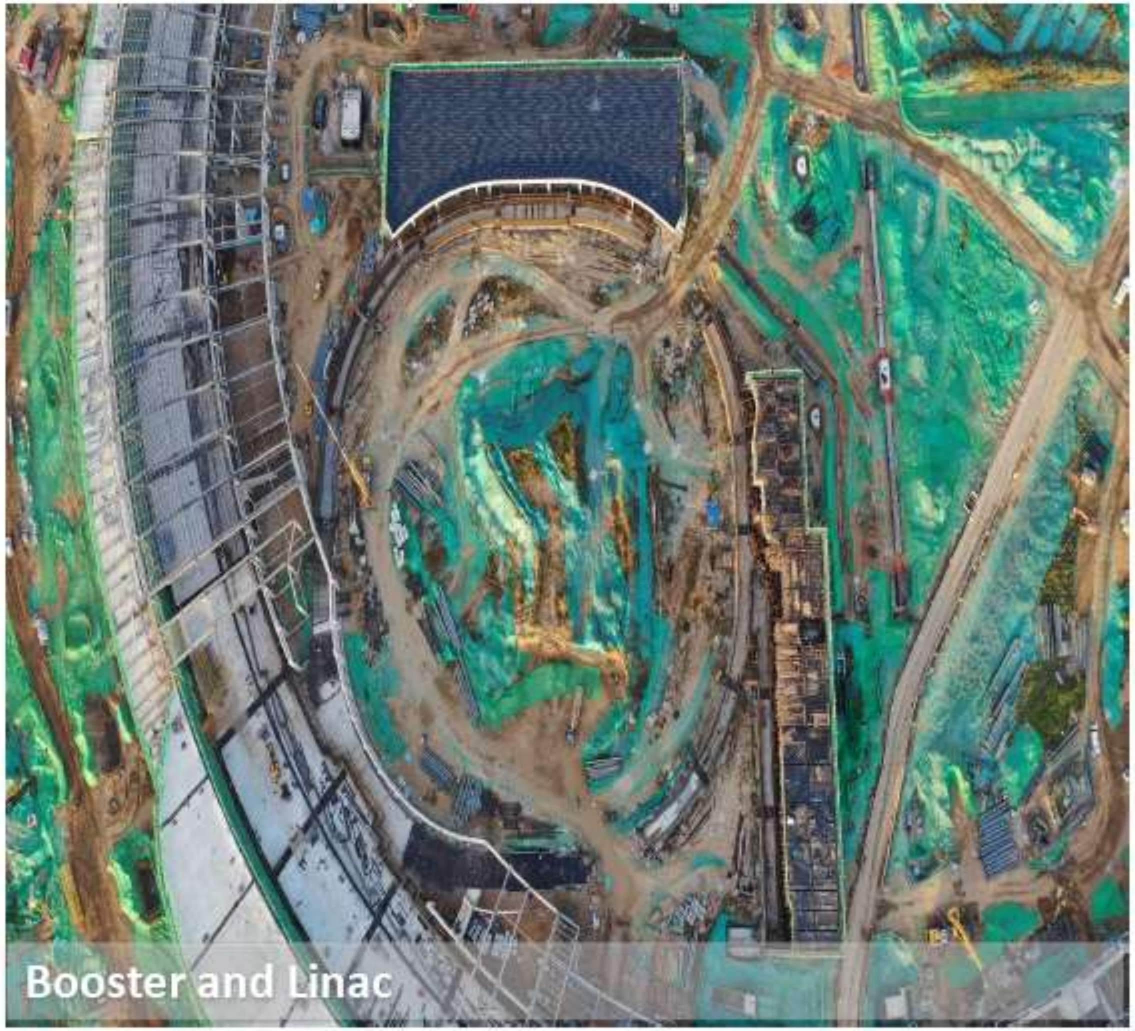
Site evolution in 2019-2020

Construction status

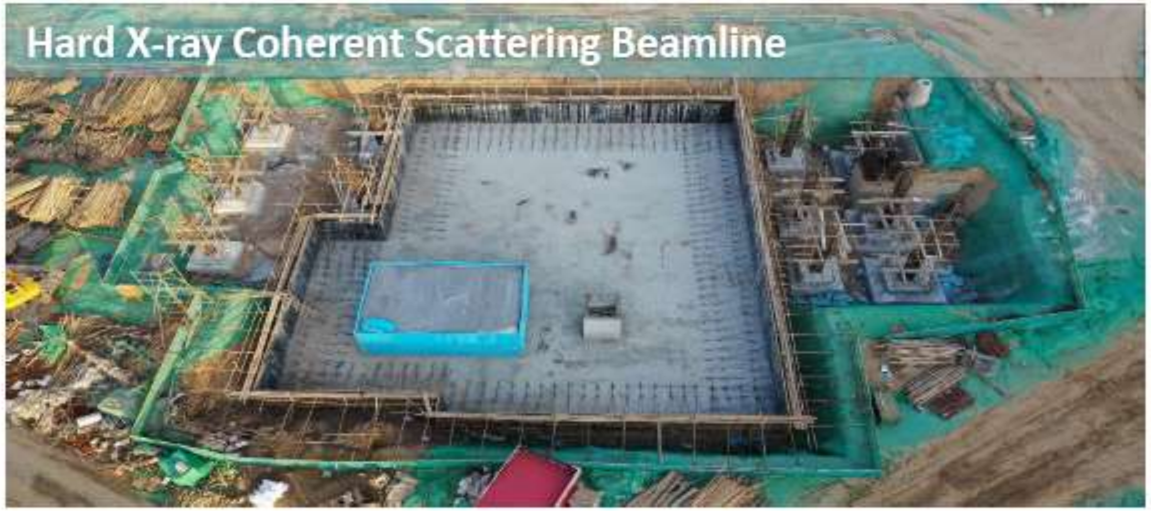
- Up to date,
  - 80% of the total earthwork in the park area had been completed (~ 210,000 cubic meters);
  - Roof-topping works for the utility building and the booster RF hall had been completed;
  - Outdoor construction works had been started.

Construction status

Construction status



Construction status



Summary

Summary

- HEPS design has been basically frozen
  - On one hand, pursue as high brightness as possible
  - On the other hand, ensure high feasibility and stability
- In spite of pandemic, civil construction goes steadily
  - At the same time, hardware components, e.g., magnets, put into mass production
- A lot of work ahead
  - Make the installation and commissioning more smoothly and easier.


Thanks for your attention!