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

The 2026 Asian Forum for Accelerators and Detectors

Kicker development at SARI

Time：2026/10/14

Yongfang LIU for Pulsed Technology Group

SHINE

SSRF

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CONTENTS

01 Background

02 Kicker system at SSRF

03 Kicker system at SXFEL

04 Kicker system at SHINE

05 Summary

Synchrotron Radiation and FEL Facilities in Shanghai

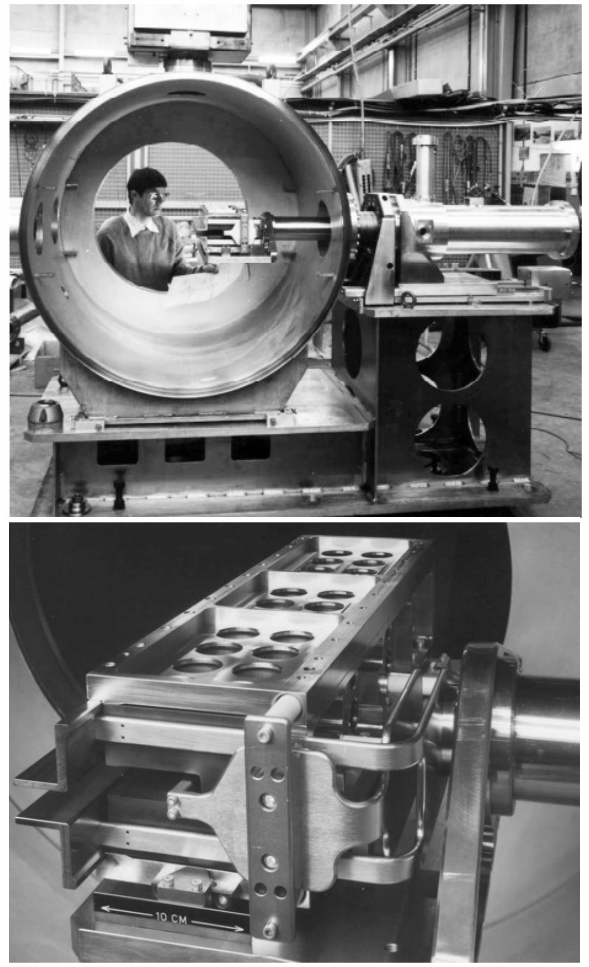


Kicker Magnet

Kicker is a magnet generates transient pulsed magnetic fields to kick a selected bunch and rapidly deflecting their trajectory at a specific timing while leaving neighboring bunches undisturbed

KEY FEATURES

- Fast-pulsed electromagnetic devices operating in nanosecond to microsecond.
- Coils must be placed inside the vacuum chamber, or ceramic vacuum chambers shall be adopted with coils mounted externally.
- Co-design and integrated consideration of kicker magnet and pulsed power supply



Kicker magnet from CERN(1970's)

Kicker Type

pulse waveform

•Half-sine wave: Half-sine pulse generator + kicker magnet

•Trapezoidal wave:

- Tube-based: Pulse-forming network / pulse-forming line
- Solid-state: Solid-state switches + energy-storage capacitor

Coil structural parameters

•Lumped-parameter type: Air-core coil, ferrite window-frame magnet, slotted-pipe type

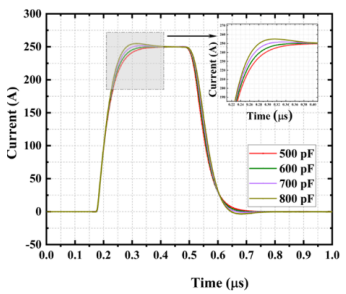
•Distributed-parameter type: transmission line kicker, strip-line kicker

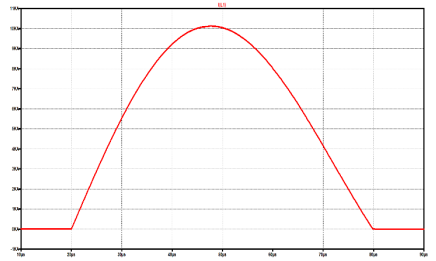
Magnetic pole order

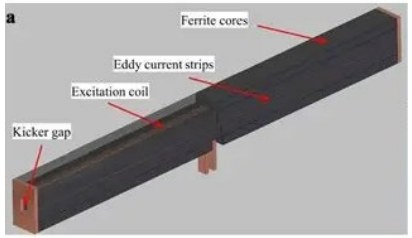
•Pulsed dipole magnet

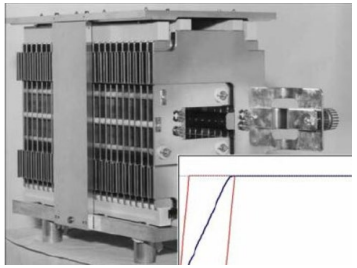
•Pulsed multipole magnet (sextuple, octupole, etc.)

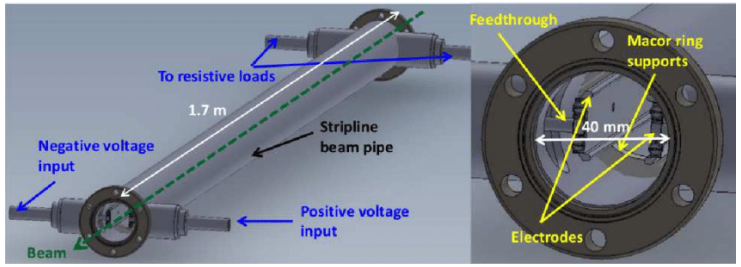
These types are independent, choosing a kicker is a multi-factor design rather than a single choice.

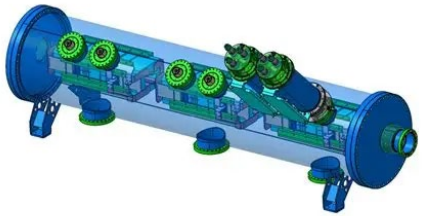


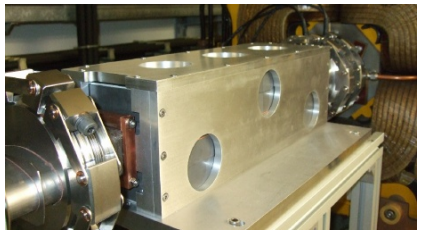












Kicker system at SSRF

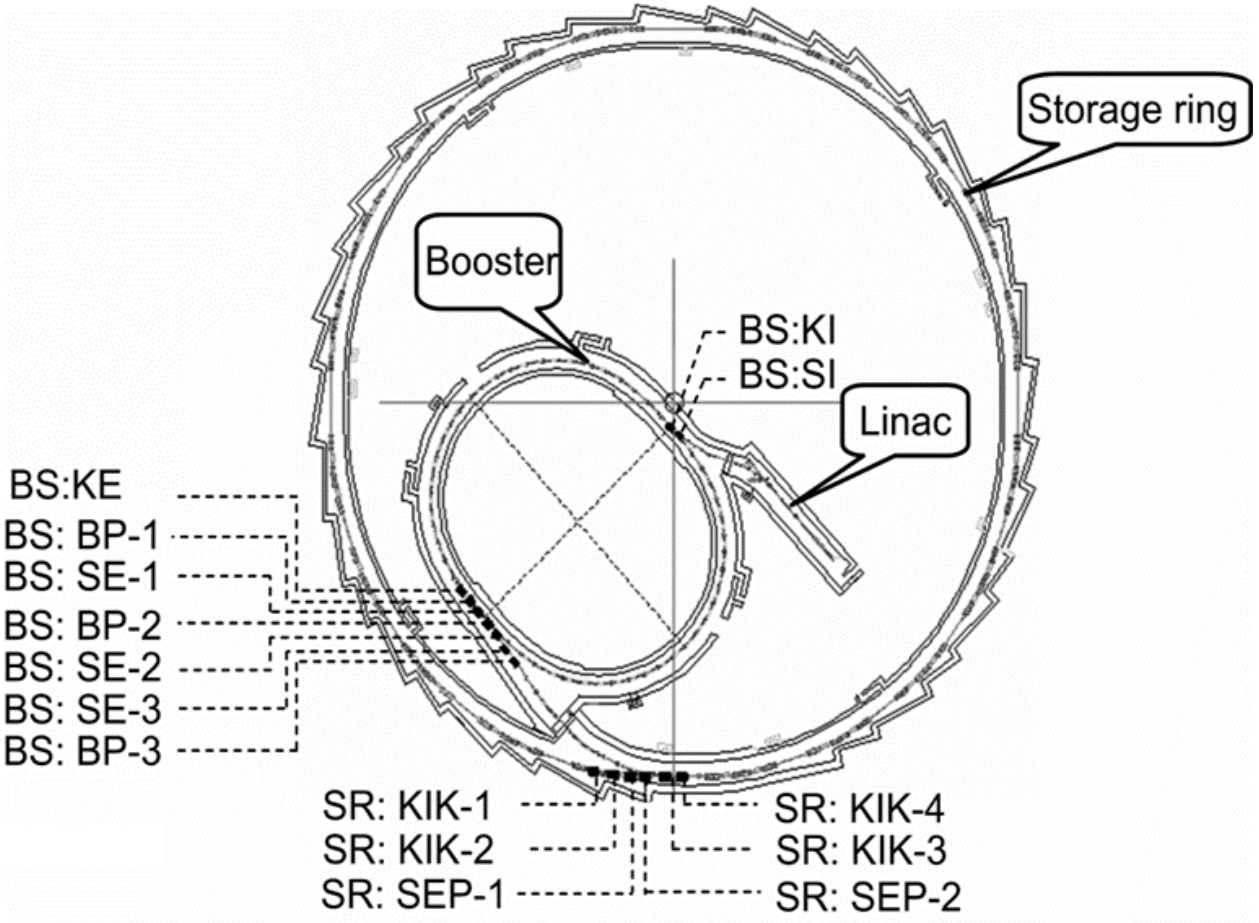


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Kicker system at SSRF

The Shanghai Synchrotron Radiation Facility (SSRF) comprises a 150 MeV electron linear accelerator, a 3.5 GeV booster and a 3.5 GeV electron storage ring.

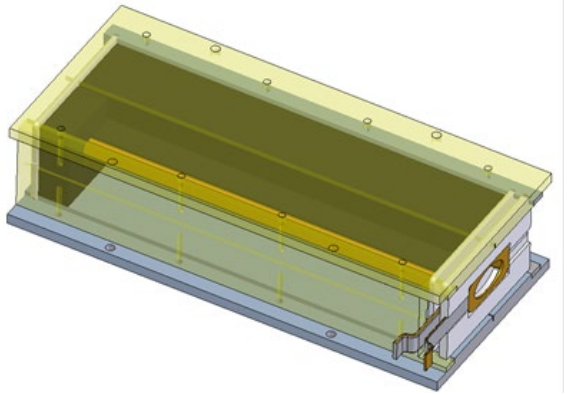
- The booster beam injection system uses one septum magnet and one kicker magnet.
- The booster beam extraction system is realized by one kicker magnet, three septum magnets and three bump magnets.
- The storage ring injection system comprises four kicker magnets and two septum magnets.



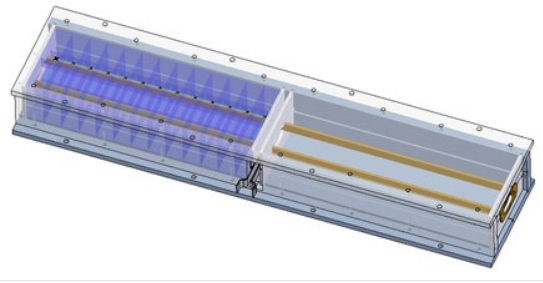
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Kicker for SSRF Booster Injection and Extraction

	Booster Injection	Booster Extraction
Beam energy	150 MeV	3.5 GeV
Deflection angle	9.26 mrad	1.64 mrad
Effective length	0.4 m	0.8 m
Magnetic field	116 Gauss	240 Gauss
Gap size(H×V)	50mm×26mm	50mm×26mm
Repetition rate	2 Hz	2 Hz
Current shape	Trapezoidal	Trapezoidal
Flat-top duration	>250 ns	>250 ns
Rising/Fall time	<250ns(F)	<250 ns(R)
Jitter	< ±5 ns	< ±5 ns
Magnetic stability	0.5%	0.5%



Injection Kicker



Extraction Kicker

- Single-turn coil configuration, oxygen-free copper
- The same gap design
- In-vacuum magnet design
- Ferrite cores
- Feedthrough for excitation connection

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Kicker for SSRF Booster Injection and Extraction

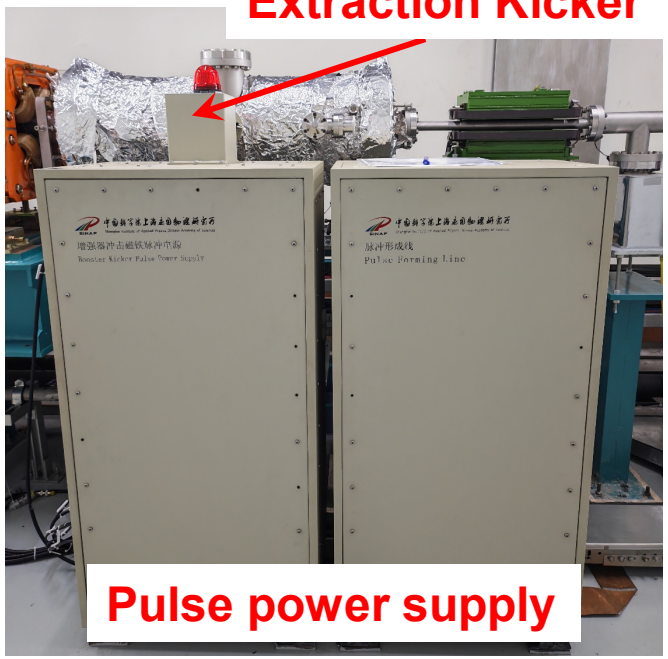
Item	Booster Injection	Booster extraction
Pulse current	240 A	500 A
P-P stability	0.5%	0.5%
Timing jitter	±5 ns	±5 ns
Kicker inductance	1.2 μH	2.3 μH
Stray inductance	0.8 μH	0.8 μH
Coil resistance	7 mΩ	14.1 mΩ

- PFL(pulse-forming-line) configuration
- 50 Ω characteristic impedance for injection
- 25 Ω characteristic impedance for extraction
- CCPS charging the PFL
- Max voltage ＜15kV
- Thyratron switch (CX1154L)
- The same design for both injection and extraction

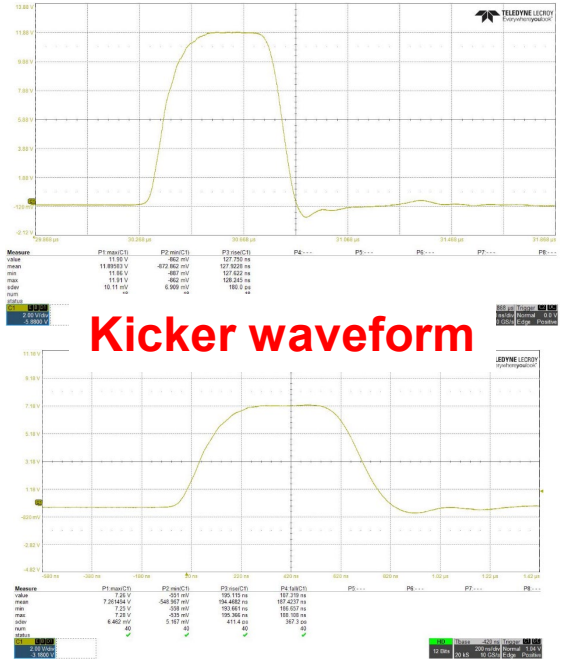
Injection Kicker



Extraction Kicker



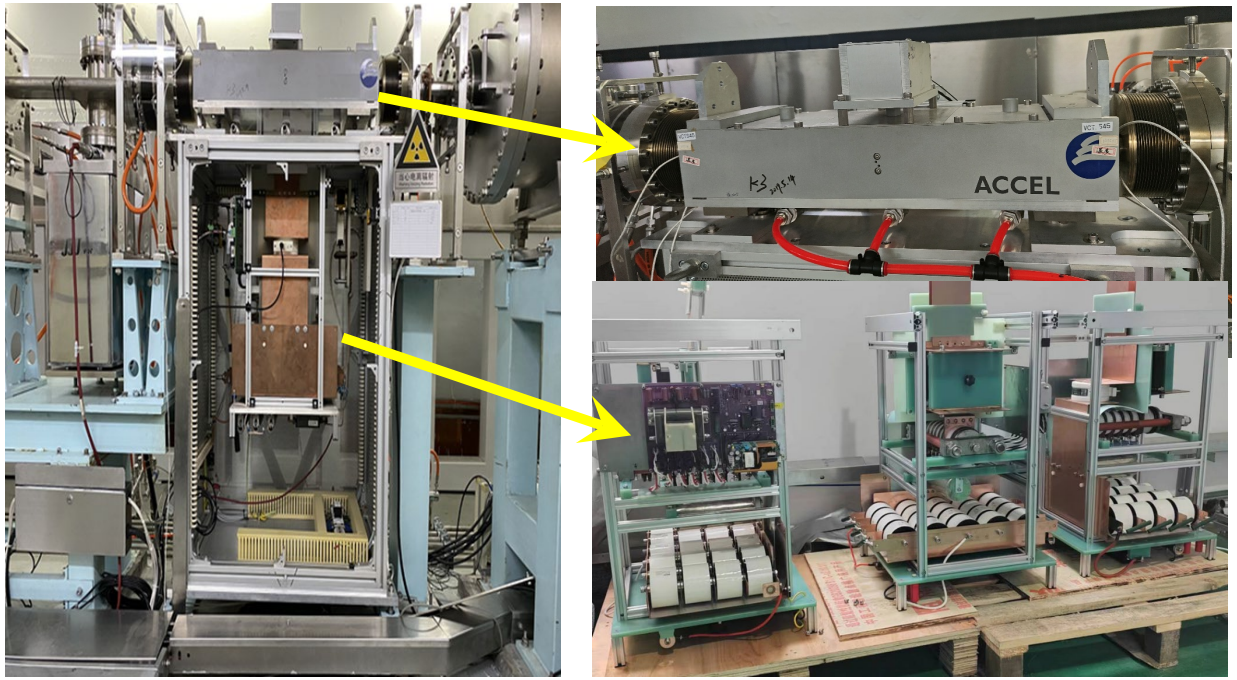


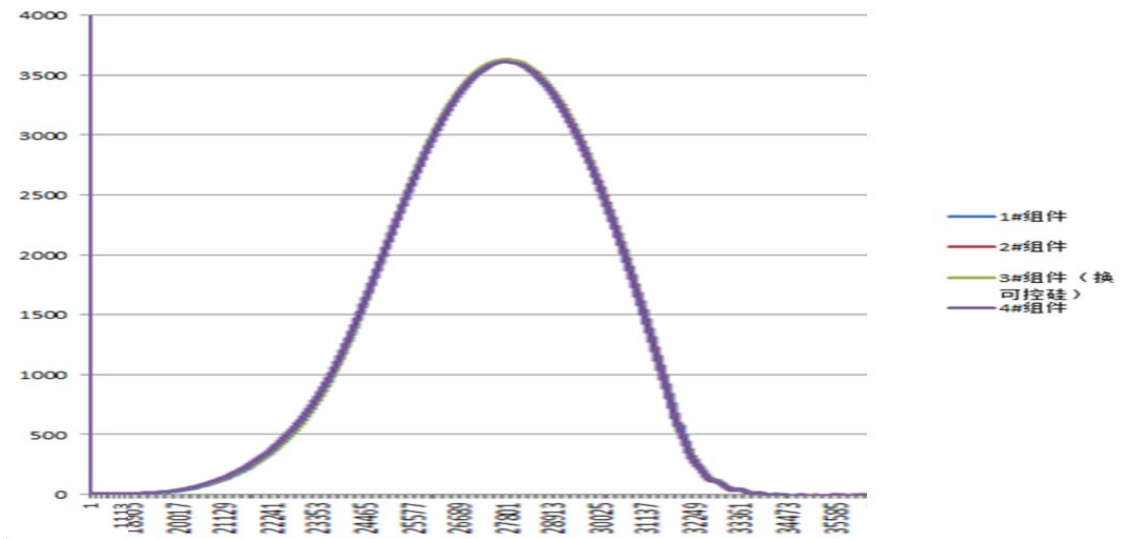


Kicker for SSRF Storage Ring Injection

Beam energy	3.5 GeV	Repetition rate	2 Hz
Effective length	0.6 m	Integrated field error	±0.1%
Deflection angle	4.83 mrad	Field uniformity	0.5%
Magnetic field	93.9 mT	Pulse current	3146 A
Gap size (H×V)	60 mm×4 mm	Jitter	10 ns
Kicker inductance	2 μH	Charging voltage	7.5 kV
Half-sine base width	4 μs	Timing stability	±2 ns

- window-type ferrite magnetic cores
- Titanium-coated ceramic vacuum chamber
- LC resonant discharge configuration
- CCPS charging the PFL
- Max voltage ＜8kV
- Thyristor switch



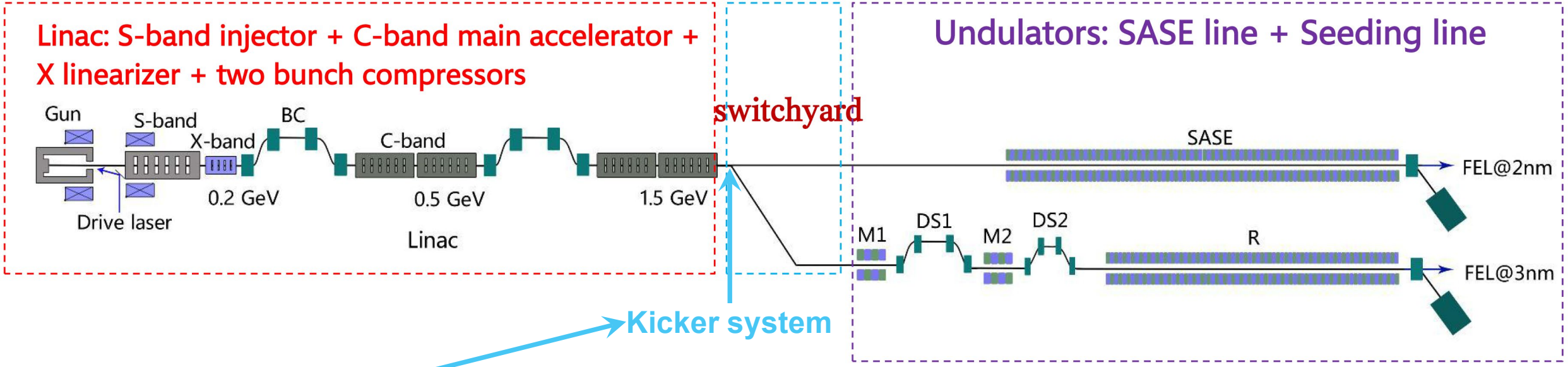


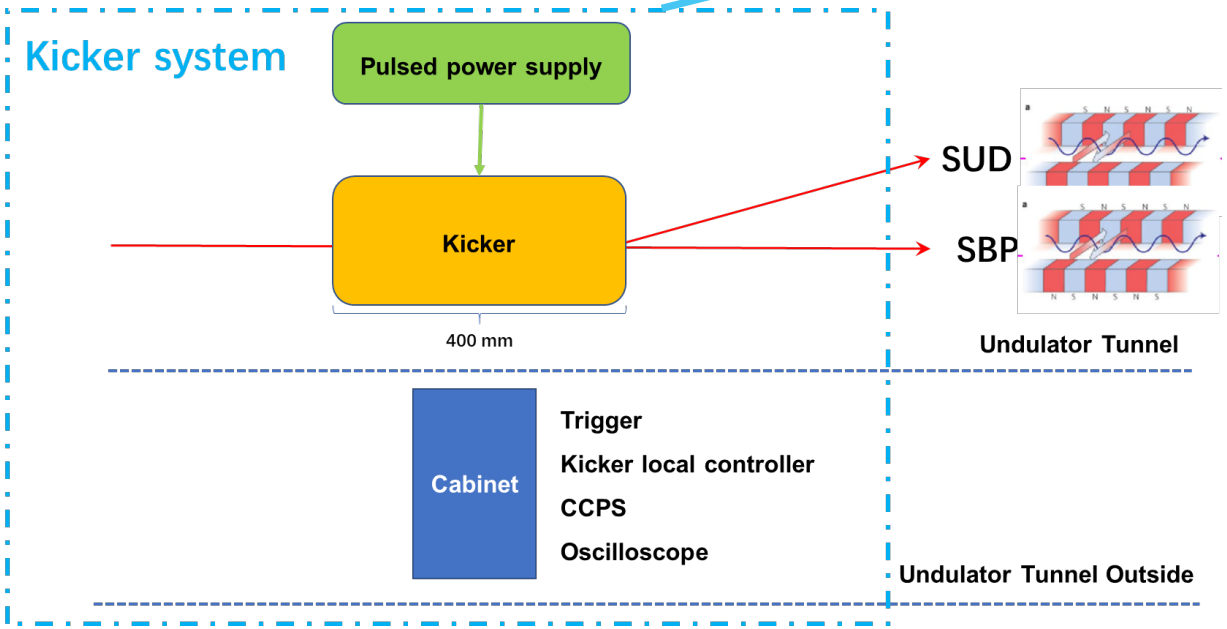
Kicker system at SXFEL



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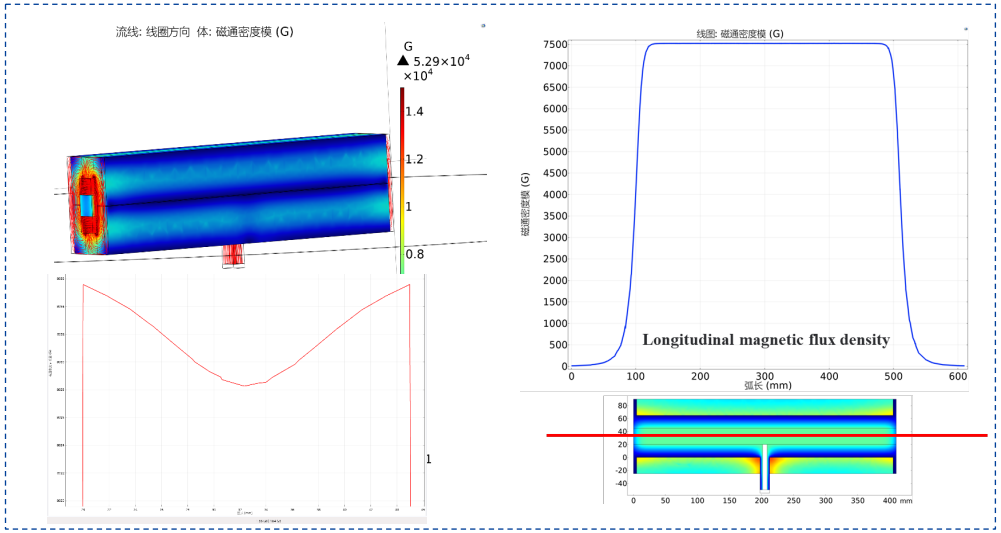
Kicker system at SXFEL





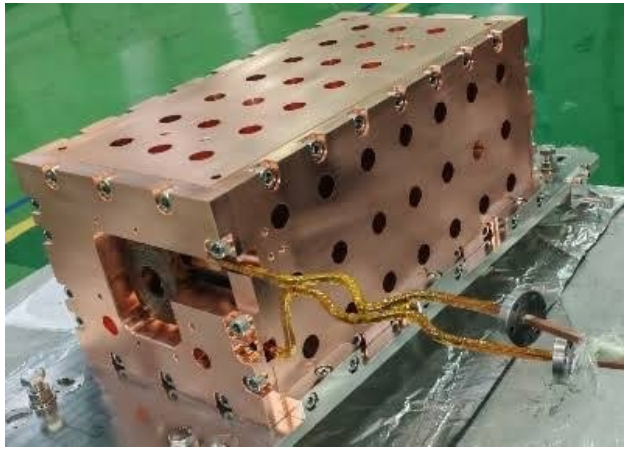
SXFEL kicker technical specification	
Beam energy	1.5 GeV
Deflection angle	54 mrad
Effective length	400 mm
Gap size	25mm*25mm
Repetition rate	25 Hz
Magnetic field	7500 G
Pulse current	1300 A
Half-sine base width	250 μs
P-P stability	100 ppm

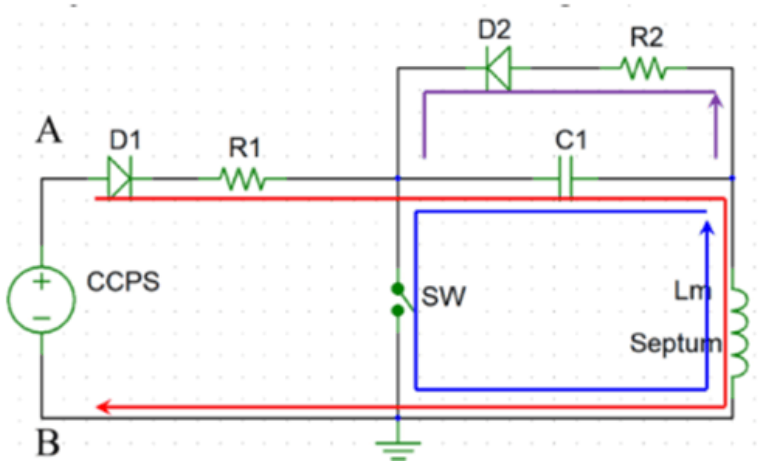
Kicker system at SXFEL

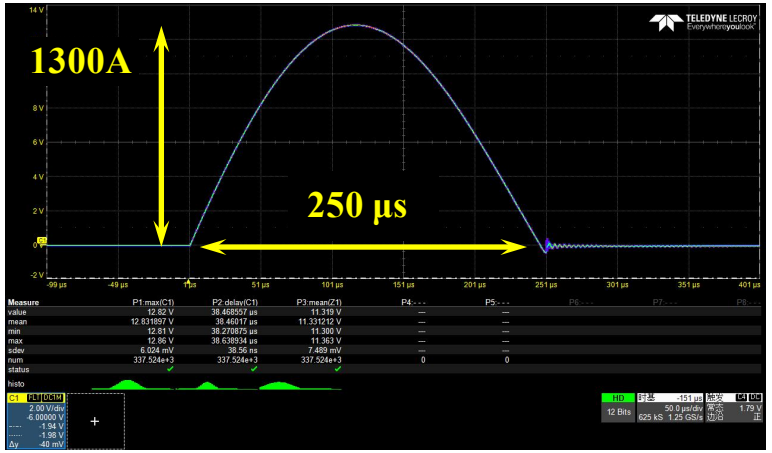


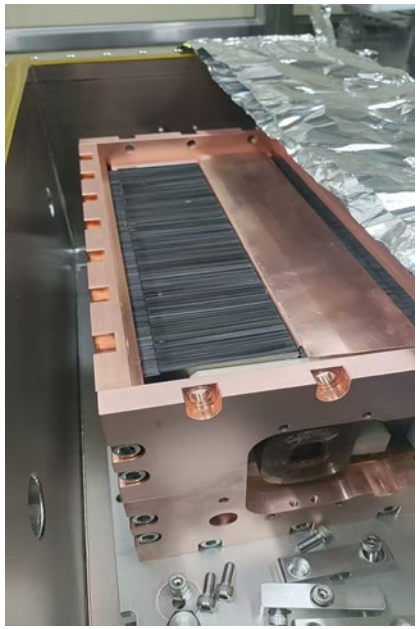








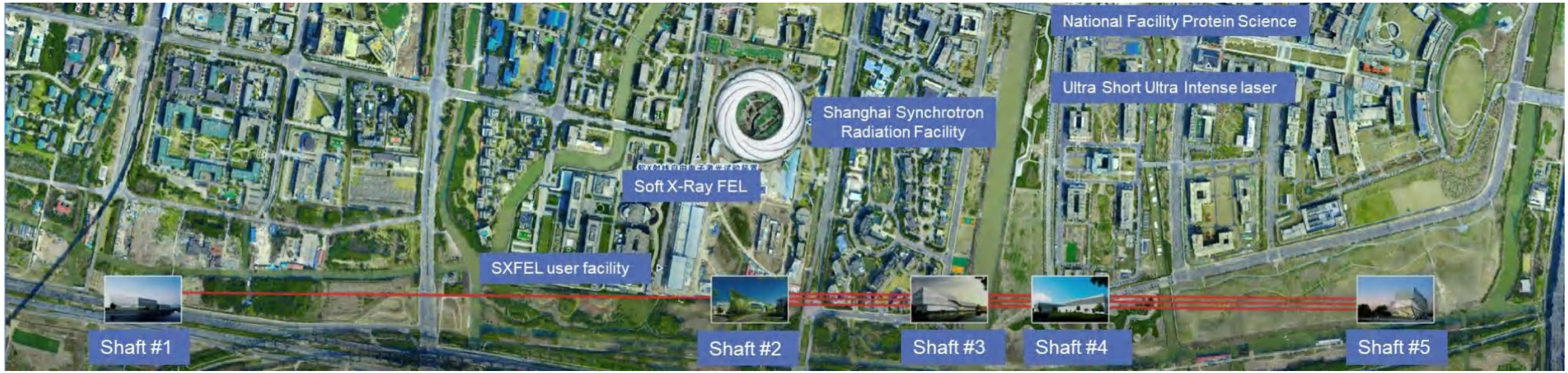




- In-vacuum multi-turn coil kicker magnet
- Half-sine current waveform with large pulse width (250 μs)
- LC resonant and IGBT based pulse power supply

SHINE

Kicker system at SHINE



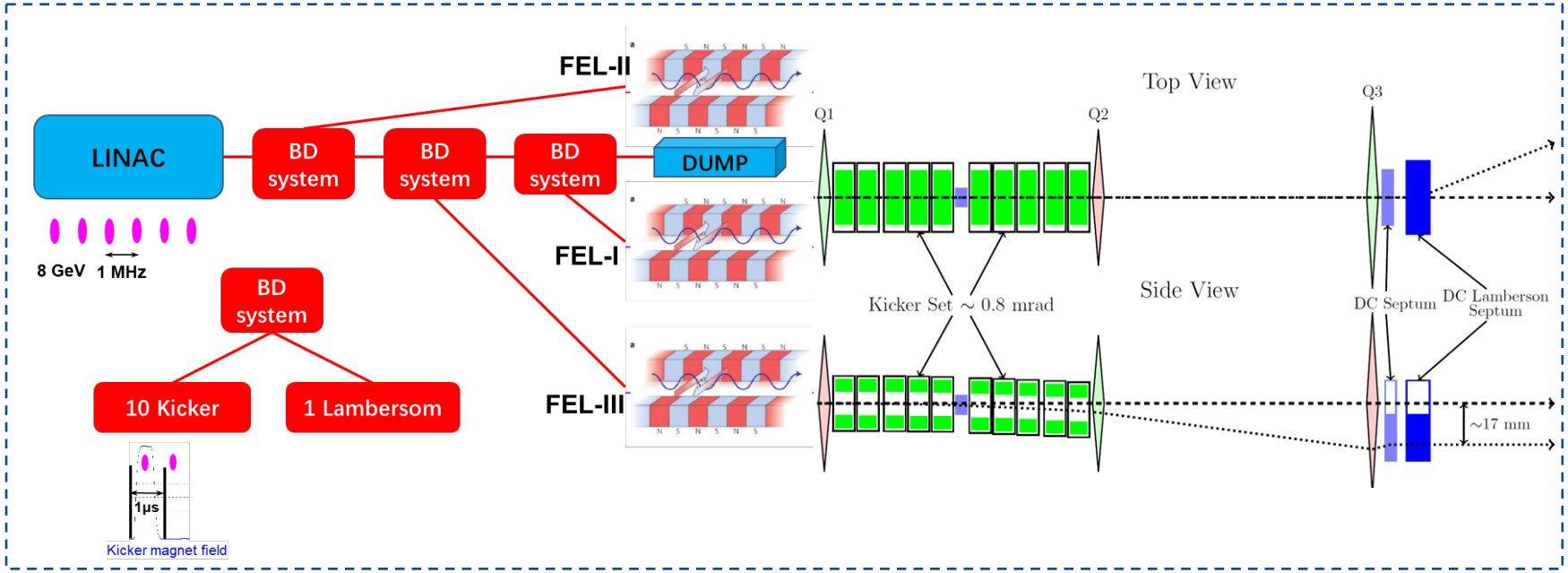
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Kicker requirement at SHINE

The switchyard is located between the endpoint of the LINAC and the entrance of the undulator lines, and distribute electron bunches into three different undulator lines in a bunch-by-bunch mode.

Total 3 switchyard
Each one includes

- 5/10 kicker in series to deflected in the vertical direction to achieve bunch-by-bunch beam separation.
- A DC vertical septum magnet flattens the vertical deflection angle of the beam
- A Lamberson magnet separates the beam in the horizontal, enter different undulator beamlines.



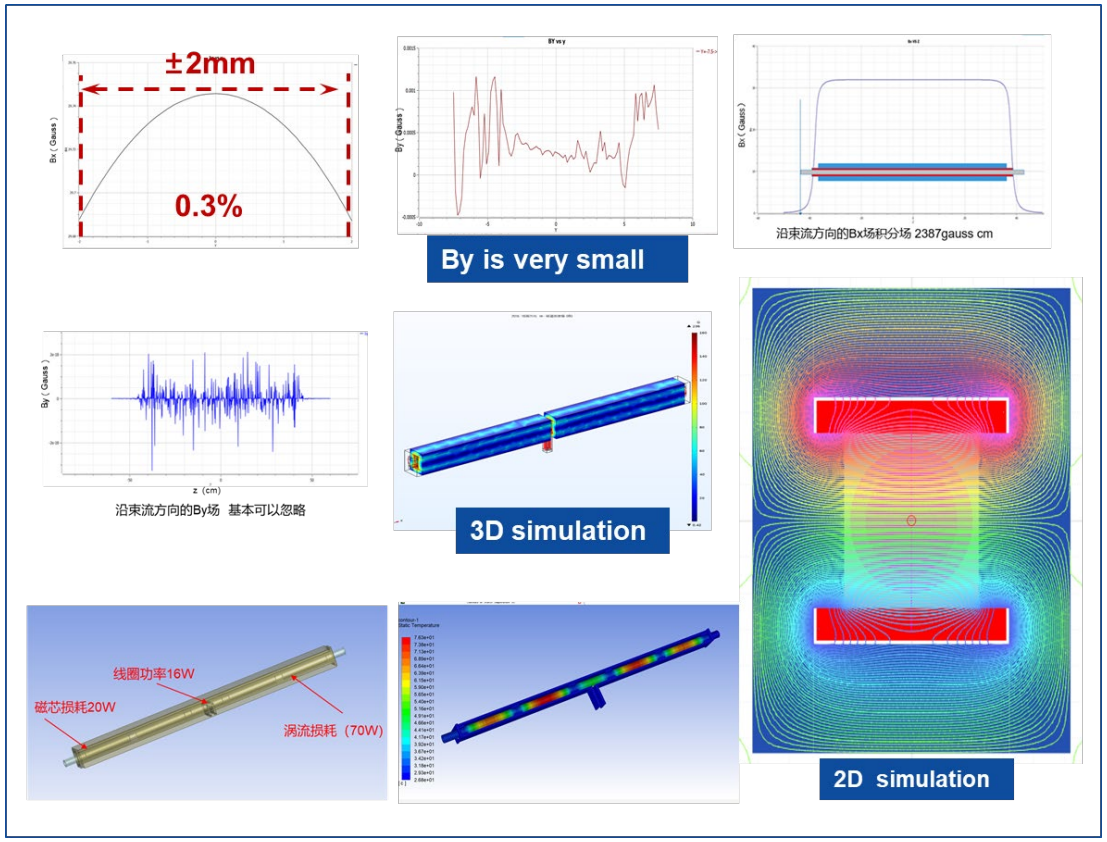
Kicker requirement	
Beam energy	8 GeV
Deflection angle	80 μrad
Mechanical length	< 1m
Repetition rate	1-1MHz
Gap size	Φ14
Pulse width	< 1μs
Stability	< 100 ppm

SHINE

Kicker Scheme Selection

Implementation

In air lumped-inductance kicker with Ti-coated ceramic vacuum chamber



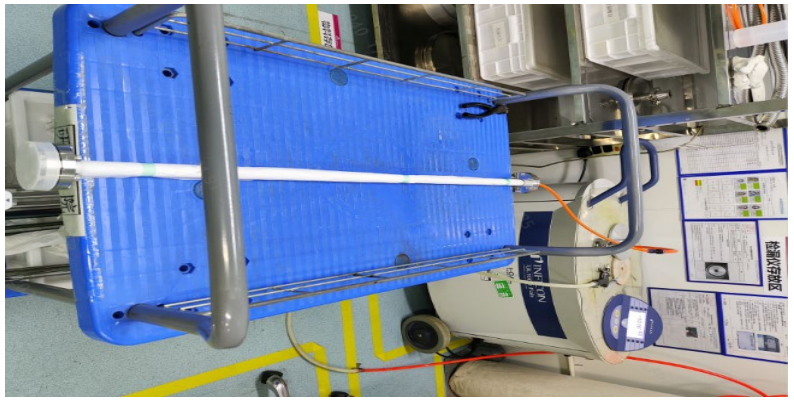
Key parameters of the Kicker			
Beam energy	8 GeV	Bending angle	0.08 mrad
Effective length	0.75 m	Max. Rep. rate	1 MHz
Aperture(H)	22 mm	Field intensity	3mT
Aperture(V)	24 mm	Peak current	57 A
beampipe	Φ14	coating	200nmTi

1. 2D simulation of cross-sectional field distribution
2. 3D simulation of longitudinal field distribution
3. Coil loss16W taking into account of skin effect
4. Core loss 20W
5. The induced eddy current loss is related to the thickness of the coating, estimate 70W
6. Thermal simulation ensures the temperature of vacuum pipe
7. The coil is cooled with water to lower the temperature

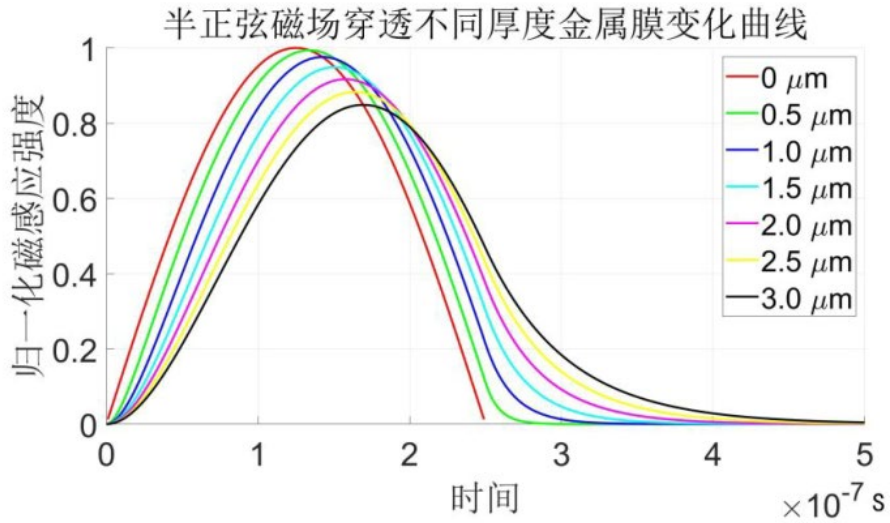
SHINE

Ceramic vacuum chamber

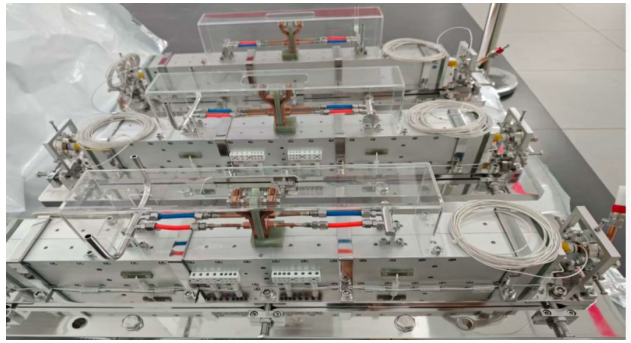
Ceramic vacuum chamber



Length:950mm;
Inner diameter:14mm;
Thickness:3mm;
Ti-coating thickness:200nm



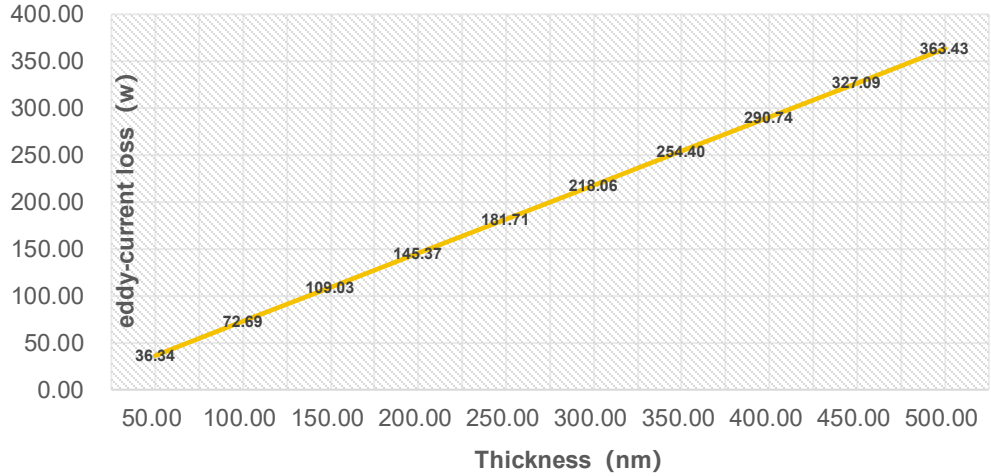
Kickers



Uninstalled

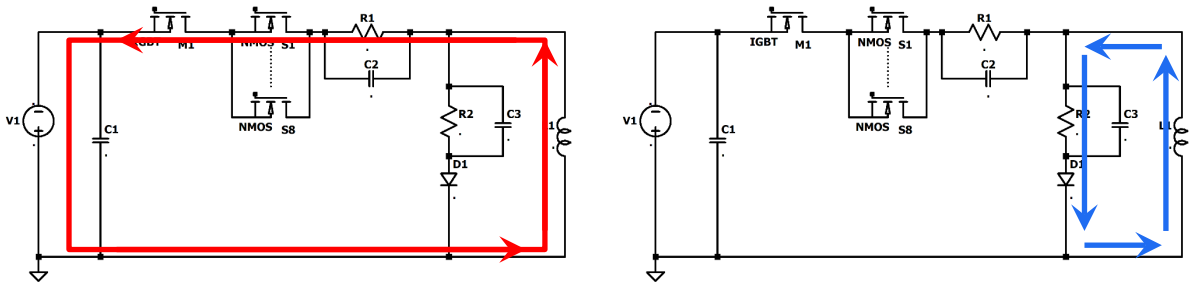


Installed

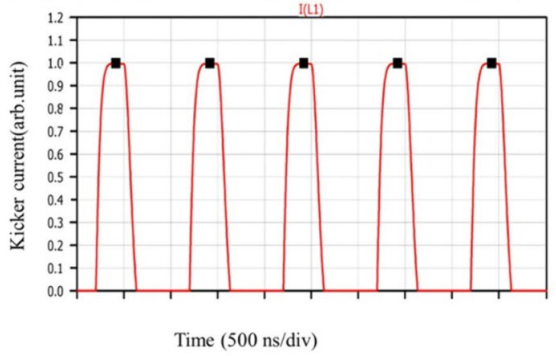


Pulse power supply design

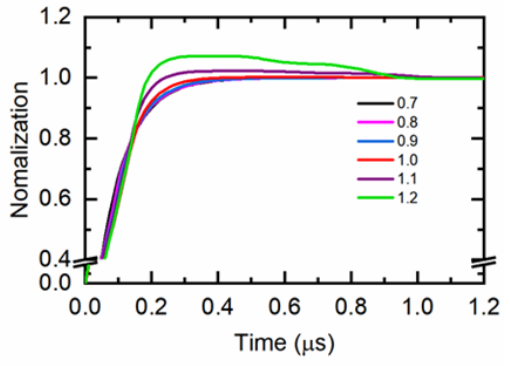
Pulse Forming Principle



Current simulation



Damping point tuning

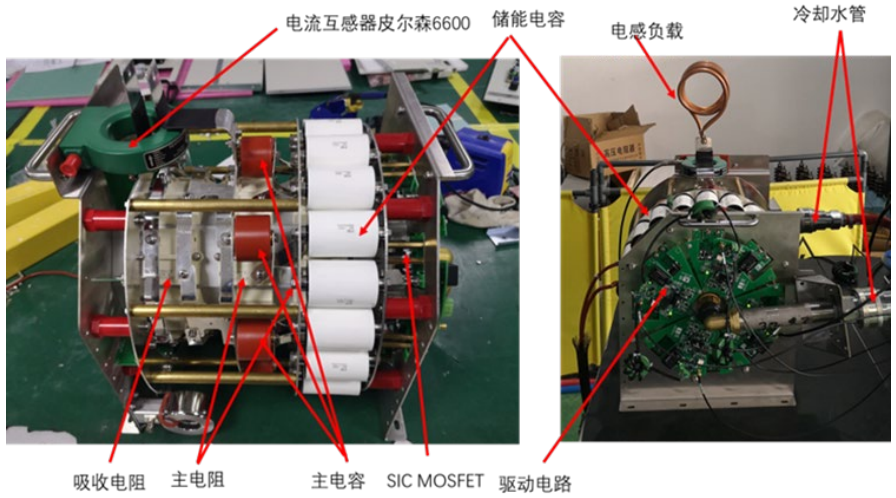


Time constant and peak current

$$t = \frac{\pi - \beta}{\omega_d} = \frac{2(\pi - \beta)}{\sqrt{\frac{4}{LC} - \frac{1}{R^2C^2}}}$$

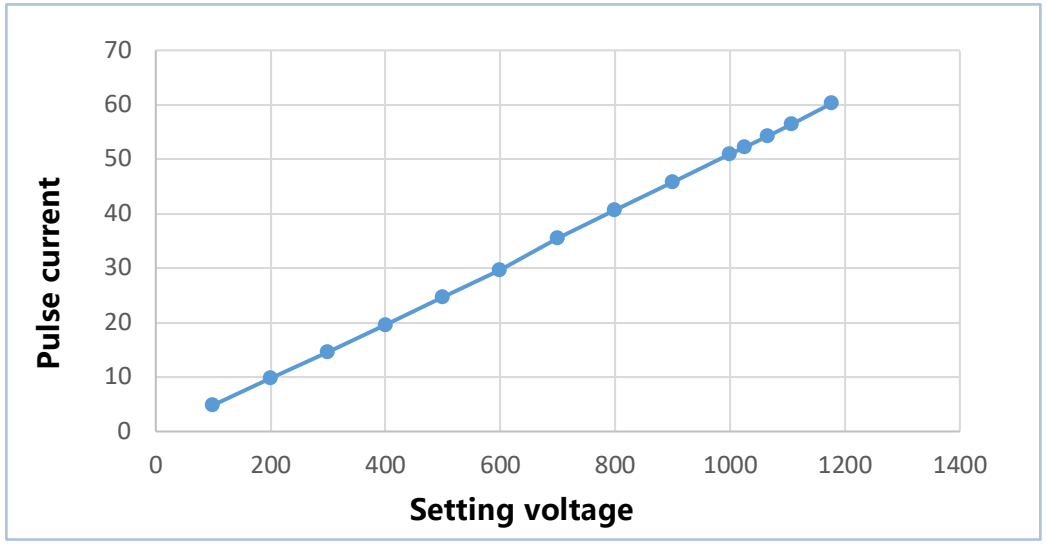
$$i_L = V\sqrt{\frac{C}{L}} * e^{-\frac{\sigma(\pi-\beta)}{\sqrt{1-\sigma^2}}} + \frac{V}{R}$$

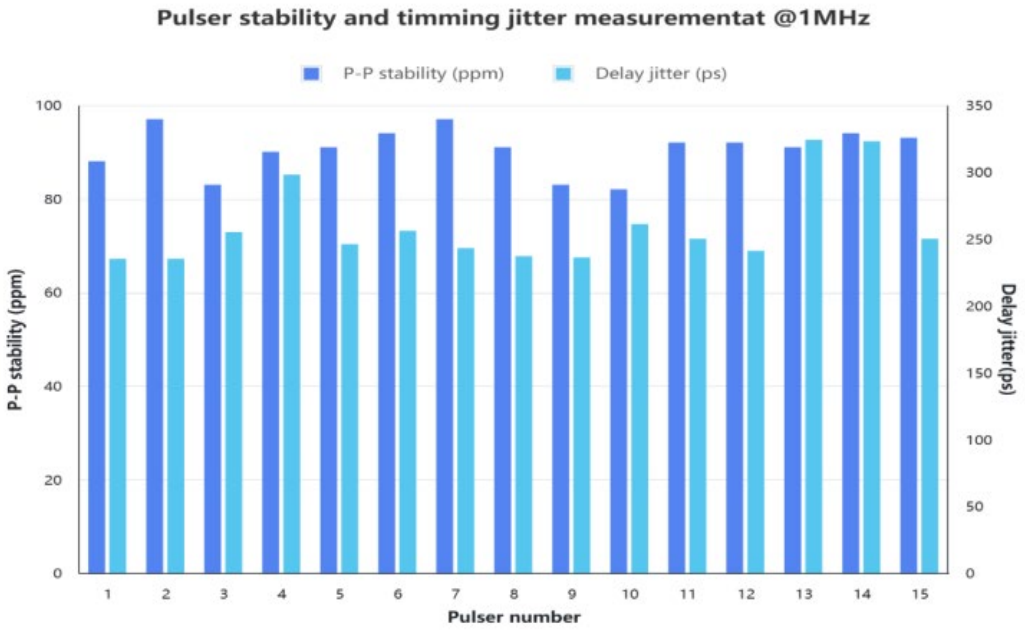
R1	25 Ω	C2	400 pF
R2	50 Ω	D1	3300V SIC
NMOS	3300V SIC	C1	10 mF
V1	-1250 V	Kicker	1.4 μH



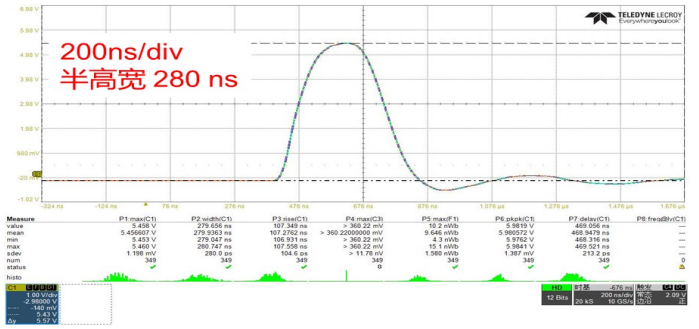
Liu, Yongfang, Gu Ming. et al. Development of a MHz Pulsed Power Supply for Kicker Magnet in SHINE IEEE Transactions on Power Electronics, vol. 39, no. 4, pp. 4291-4300, April 2024.

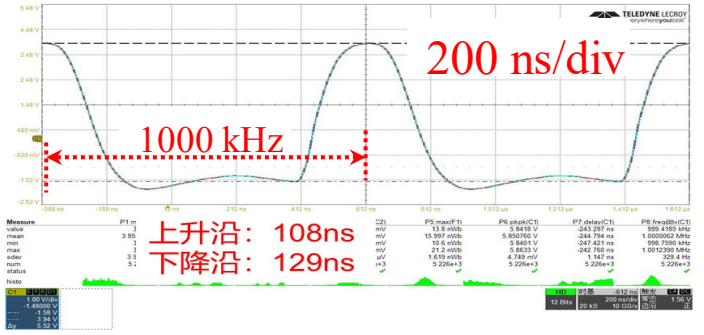
Test result


Pulse current
Setting voltage
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400


Pulser stability and timming jitter measurementat @1MHz
P-P stability (ppm)
Delay jitter (ps)
P-P stability (ppm)
Delay jitter(ps)
Pulser number


5 µs/div
60 A
100 kHz


200ns/div
半高宽 280 ns


200 ns/div
1000 kHz
上升沿：108ns
下降沿：129ns

Summary



- Total 6 kicker used in SSRF injection and extraction system

  Both In air and in vacuum kicker are used

- A in-vacuum multi-turn coil kicker is applied in SXFEL to beam distribution

- Total 25 lumped inductance kicker is applied in SHINE to beam distribution

- Non linear kicker and Higher repetition rate kicker are under R&D

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THANK YOU FOR WATCHING