Septum kicker and pulse generator for injection and extraction

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Injection group

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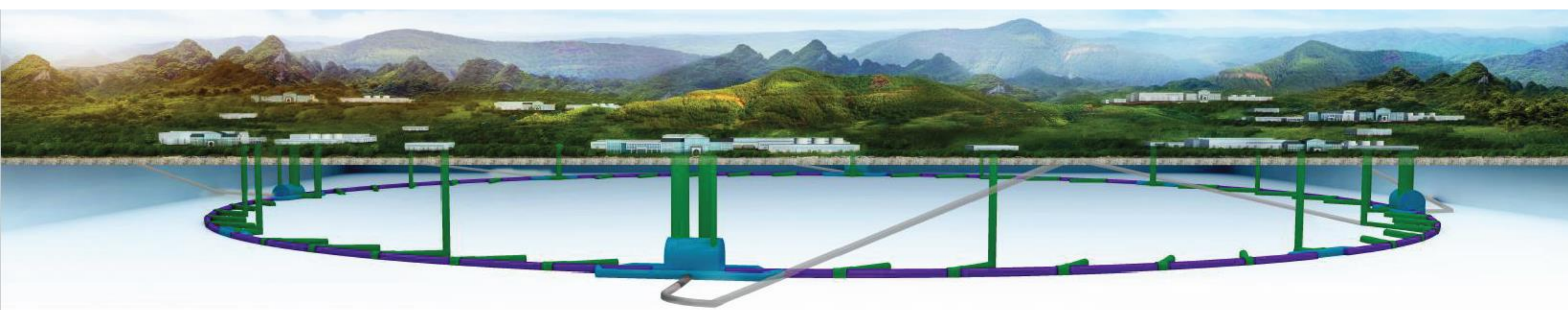


Outline

Overview of the CEPC injection and extraction systems

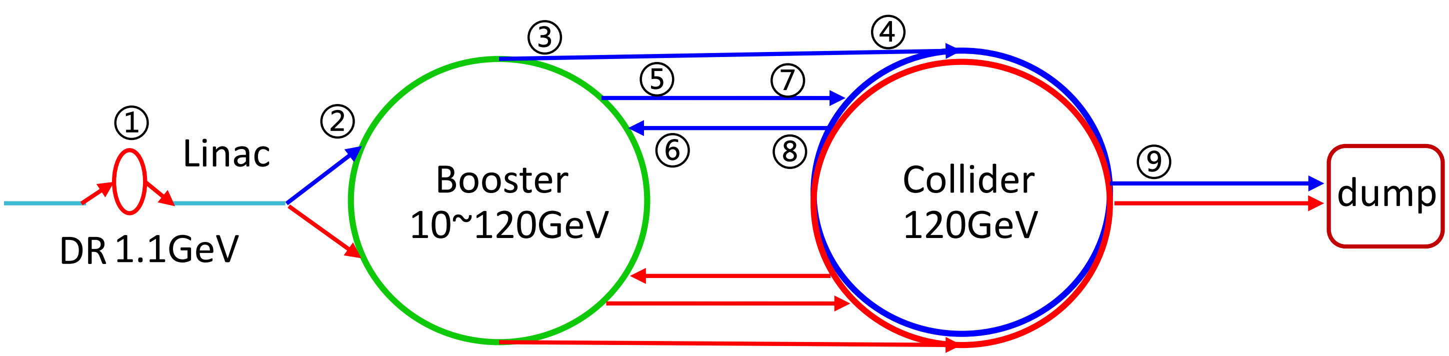
CEPC injection and extraction systems

In CEPC accelerator complex, there are 9 injection and extraction sub-systems, including:

① DR injection and Extraction system(e+)
② Booster LE injection system (e+,e-)
③ Booster Extraction system1 (e+,e-)
④ Collider off-axis injection system (e+,e-)
⑤ Booster Extraction system2 (e+,e-)
⑥ Booster HE injection system (e+,e-)
⑦ Collider swap out injection system (e+,e-)
⑧ Collider swap out extraction system (e+,e-)
⑨ Collider beam dump system(e+,e-)

③–④ → Off-axis injection (in W and Z mode)

⑤–⑧ → On-axis injection (only in Higgs mode)



Main types of inj. & ext. hardware

	Sub-system	Kicker		Septa	
		Kicker Type	Kicker waveform	Septa Type	Stored beam pipe aperture /Thickness of septum
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine or trapezoid/250ns	Horizontal in air LMS	ϕ22/3.5mm
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal in air LMS	ϕ55/5.5mm
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical in air LMS	Φ55/6mm
4	Collider off-axis inj.	Delay-line NLK kicker	Trapezoid /440-2420ns	Vertical in vacuum LMS	Φ75x56/2mm
5	Booster ext. for CR on-axis inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical in air LMS	Φ55/6mm
6	Booster HE inj. for CR on-axis inj.	NLK or Pulsed sextupole	Half-sine/0.333ms	Vertical in air LMS	Φ55/6mm
7	Collider swap out inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical in air LMS	Φ75x56/6mm
8	Collider swap out ext.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical in air LMS	Φ75x56/6mm
9	Collider beam dump	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical in air LMS	Φ75x56/6mm

Hardware R&D plans

- One team is in charge of both HEPS and CEPC inj. & ext. system. A part of hardware R&D for 2 projects are overlapping.
- Hardware R&D activities:
  - Lambertson septa magnets
    - Outside vacuum magnet: Septum thickness ≥3.5 mm
    - Half in vacuum magnet: Septum thickness =2 mm
  - Kicker systems
    - Strip-line kicker and super fast pulser（PW=10~50ns）
    - Slotted-pipe kicker and fast pulser（PW=250~300ns）
    - Ferrite core kicker （in-air with metallic coated ceramic vacuum chamber) and pusler
      - Lumped parameter dipole kicker（PW=1.36us half-sine）
      - Distributed parameter (delay-line) dipole kicker（ PW=440~2420ns trapezoid）
      - Distributed parameter (delay-line) Nonlinear kicker（ PW=440~2420ns trapezoid）

Overlapping part (Lambertson septa magnets: outside vacuum and half in vacuum magnets; strip-line and slotted-pipe kickers)

Lambertson magnet

Typical requirements for CEPC LSM

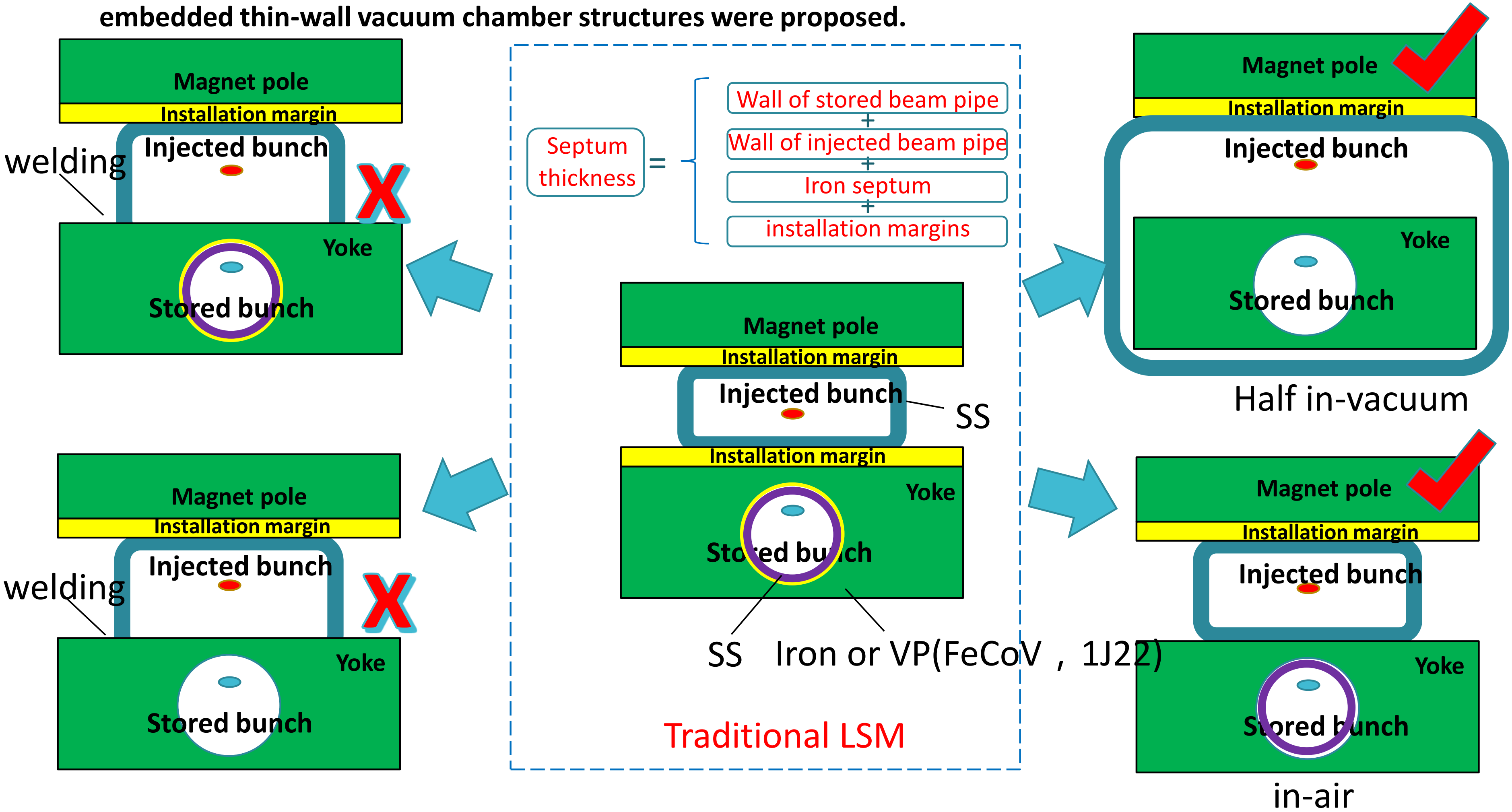
Parameters	Unit	DR-LSM	BST-LEI-LSM	CR-LSM-2
Quantity	-	2	2	2×5
Energy	GeV	1.1	10	120
Deflection angle	mrad	120	22	0.35
Insertion length	m	0.5	0.8	1.75
Magnetic field strength for injected/extracted beam	T	0.883	0.9175	0.08
Min. Septum thickness（including septum board, inj./ext. beam pipe wall, installation gap)	mm	3.5	5.5	2
Field uniformity	-	<±0.05%	<±0.02%	<±0.05%
Leakage field	-	$\leq 1\times10^{-3}$	$\leq 1\times10^{-3}$	$\leq 1\times10^{-3}$
Clearance of stored beam at lambertson（H×V）（refer to stored beam orbit）	mm	36.4×22	30×50	-
Clearance of inj.&ext. beam at lambertson（H×V）（refer to inj.&ext. beam orbit）	mm	22×11	18×29	-
Physical aperture of stored beam vacuum chamber	mm	22×22	55×55	75x56

In-air

Half in vacuum

Lambertson Magnet Design Consideration

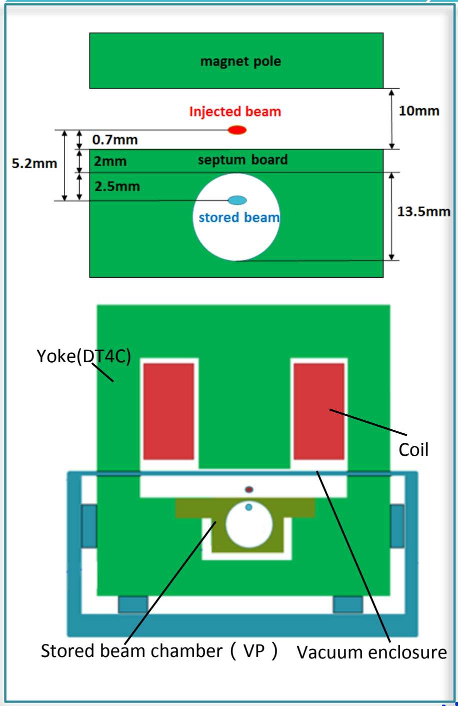
- In order to decrease the septum thickness, higher Bs magnetic shielding material, VP， is adopt for septum board. Thinner wall of beam pipe, or sharing wall of beam pipe structure is preferred.
- To reduce difficulty on small aperture vacuum chamber machining and welding, half-in-vacuum and embedded thin-wall vacuum chamber structures were proposed.

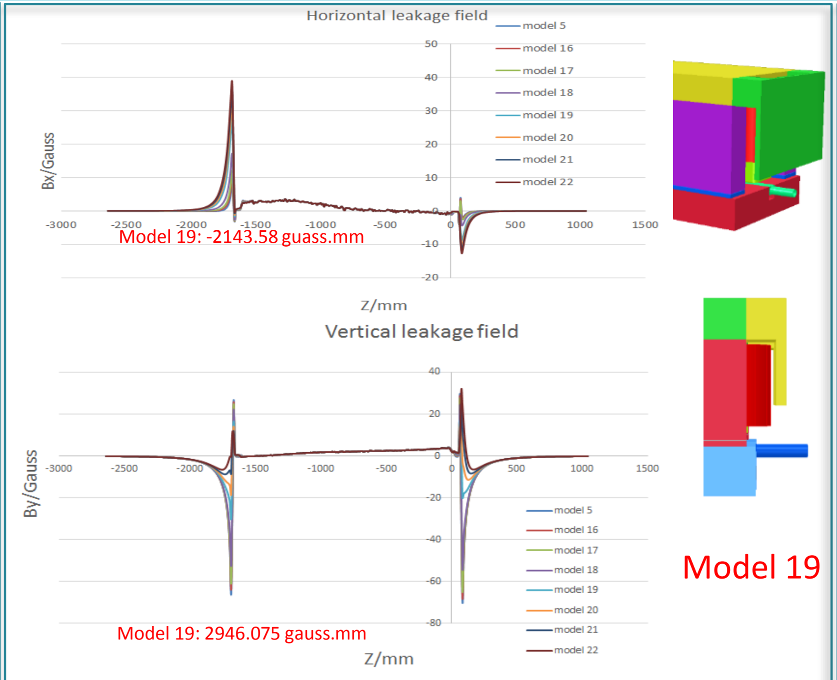


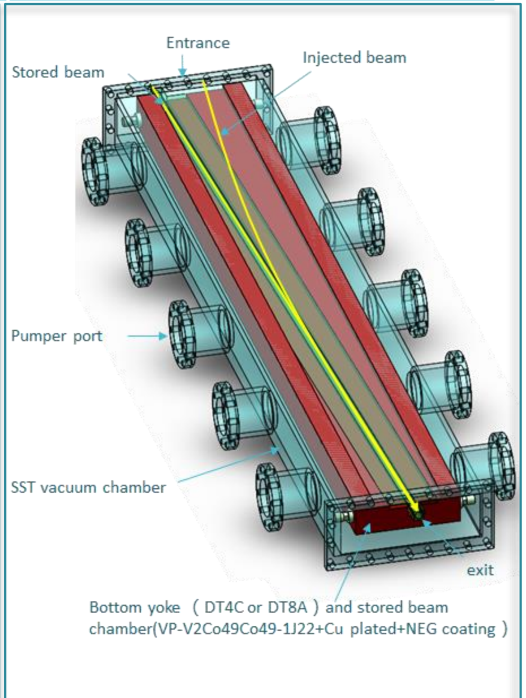
Half In-Vacuum LSM for HEPS SR

- Feature：Partial magnet is located in the vacuum; total septum thickness=2mm; VP(1J22) is adopt for septum

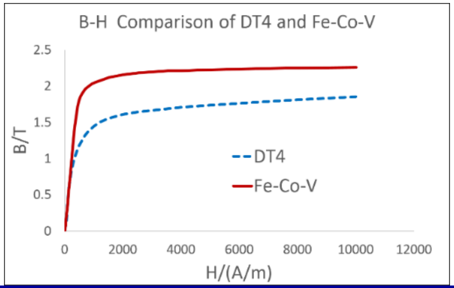
New idea was proposed in 2019 | Physical design optimization result: Leak field<0.02% | Mechanical design and prototype R&D

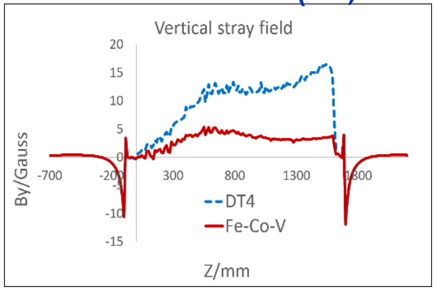


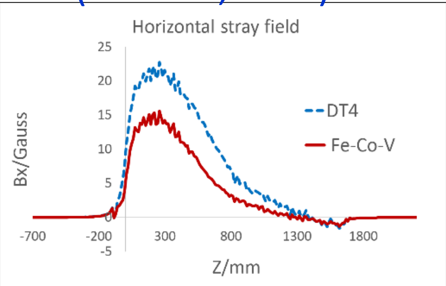




magnetic shielding material: Pure iron (Fe, DT4) Vs. VP(Fe-C0-V, 1J22)

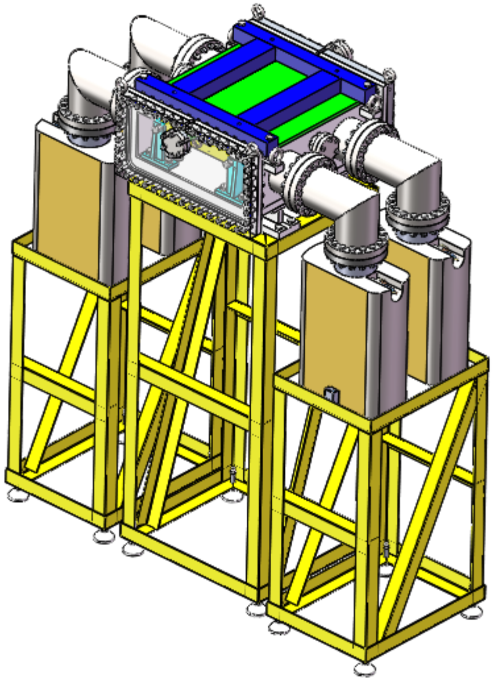




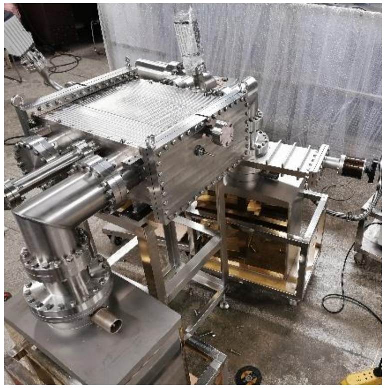


Half in-vacuum LSM R&D for HEPS SR

- Prototype progress:
  - ¼ prototype was completed in 2021
  - To verify the mechanical structure, machine and welding processing, NEG coating.



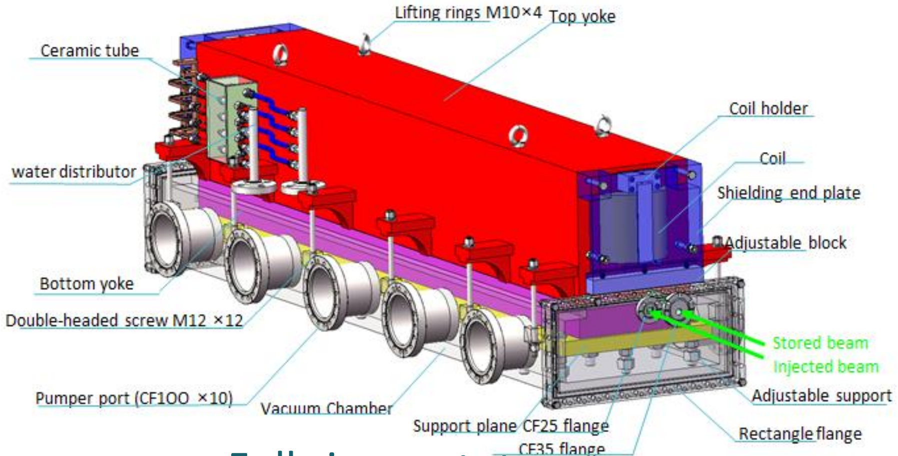
¼ prototype



NEG coating R&D

Half in-vacuum LSM R&D for HEPS SR

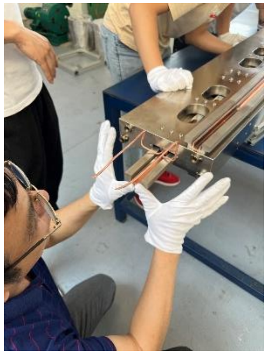
- Full size prototype:
  - Started in 2021
  - All the mechanical component processing was completed
  - The biggest challenge is magnetic shielding block machining because the VP is hard and brittle. Although it can be segmented processing by EDM, but annealing deformation is hard to control.

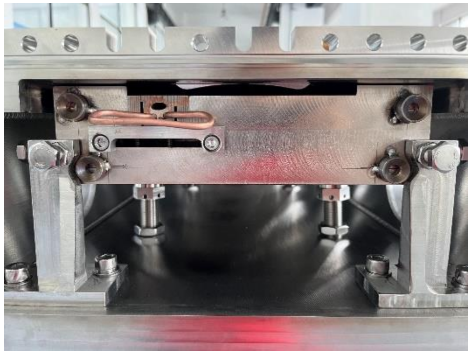


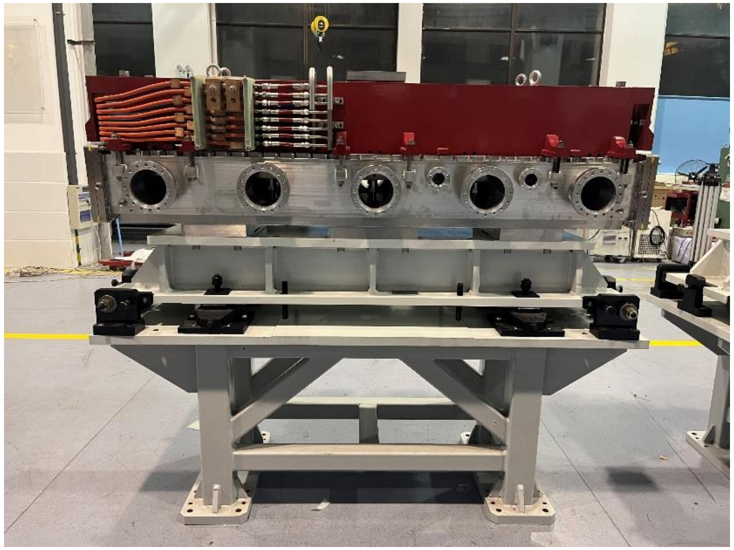
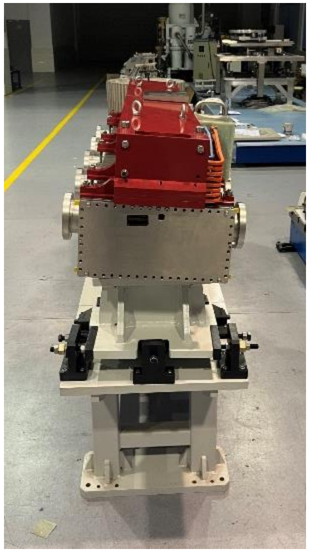
Full size prototype

Half in-vacuum LSM prototype for HEPS

- Latest progress: Pre-assembling has completed and entered final assembling phase

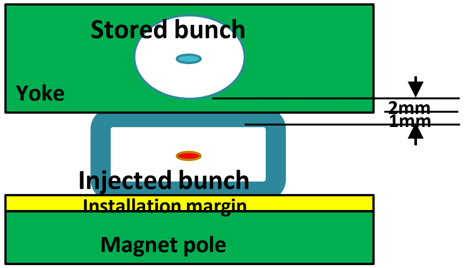


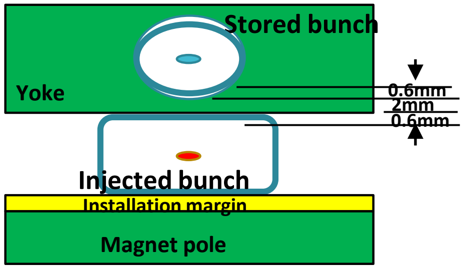



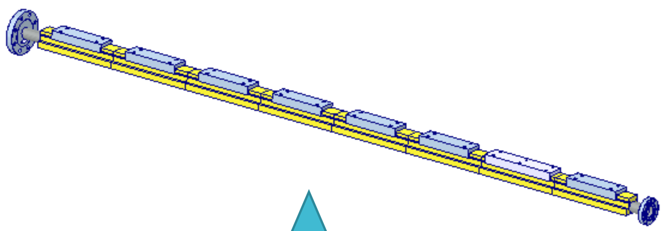



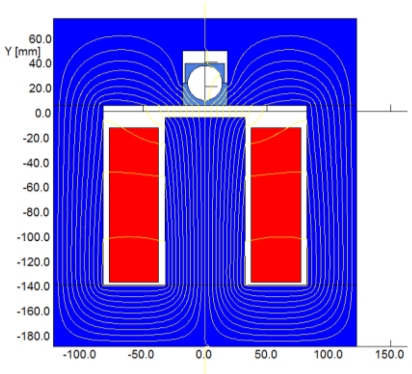

In-air LSM R&D for HEPS BST

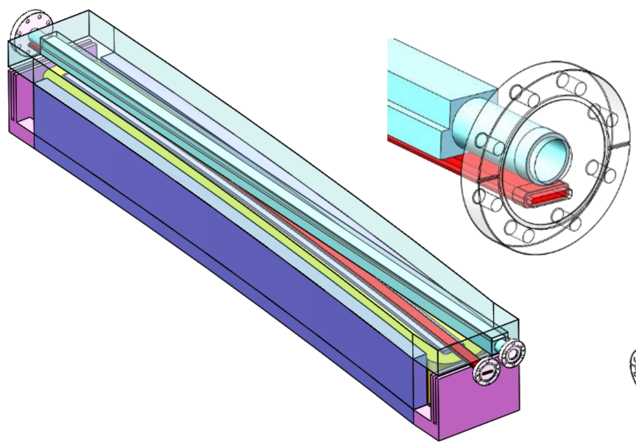
- Feature：magnet is located in the air; total septum thickness=3.5mm， Length=1.6m
- Because FeCoV（1J22，Co50）is hard to machine, the magnetic shielding blocks must segmented processing by EDM . And that, the embedded thin wall SST vacuum chamber for stored beam is needed.

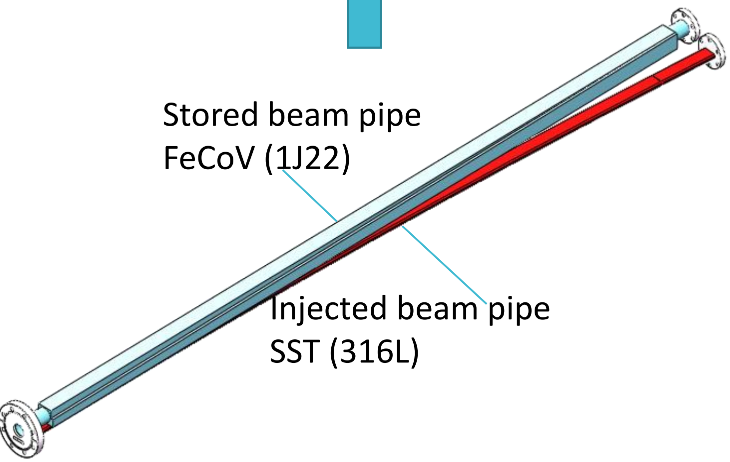






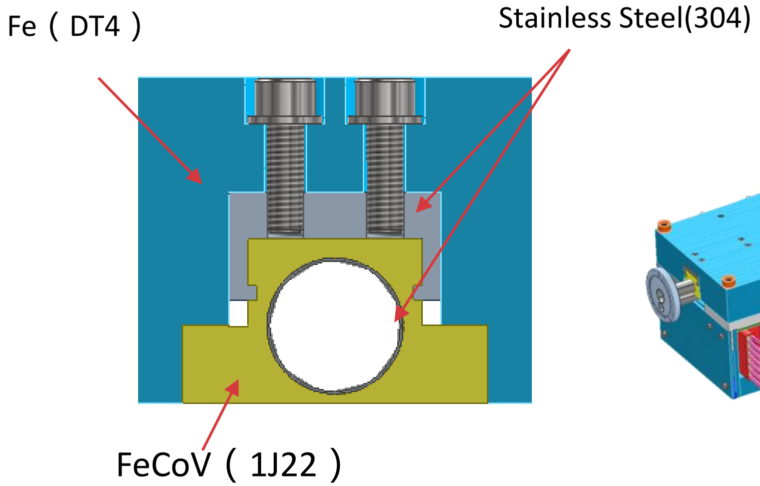


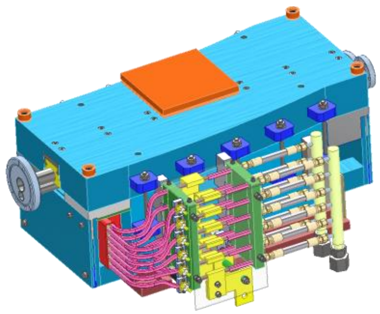


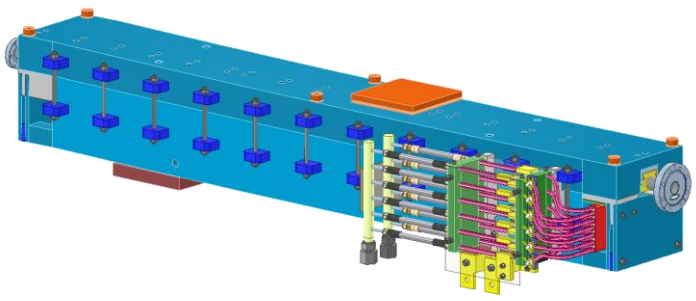


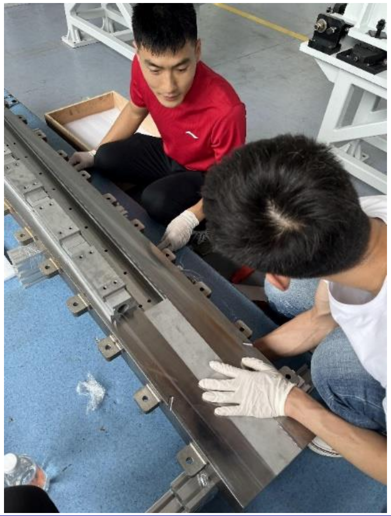
In-air LSM R&D for HEPS BST

- The latest progress: the prototypes are being assembled







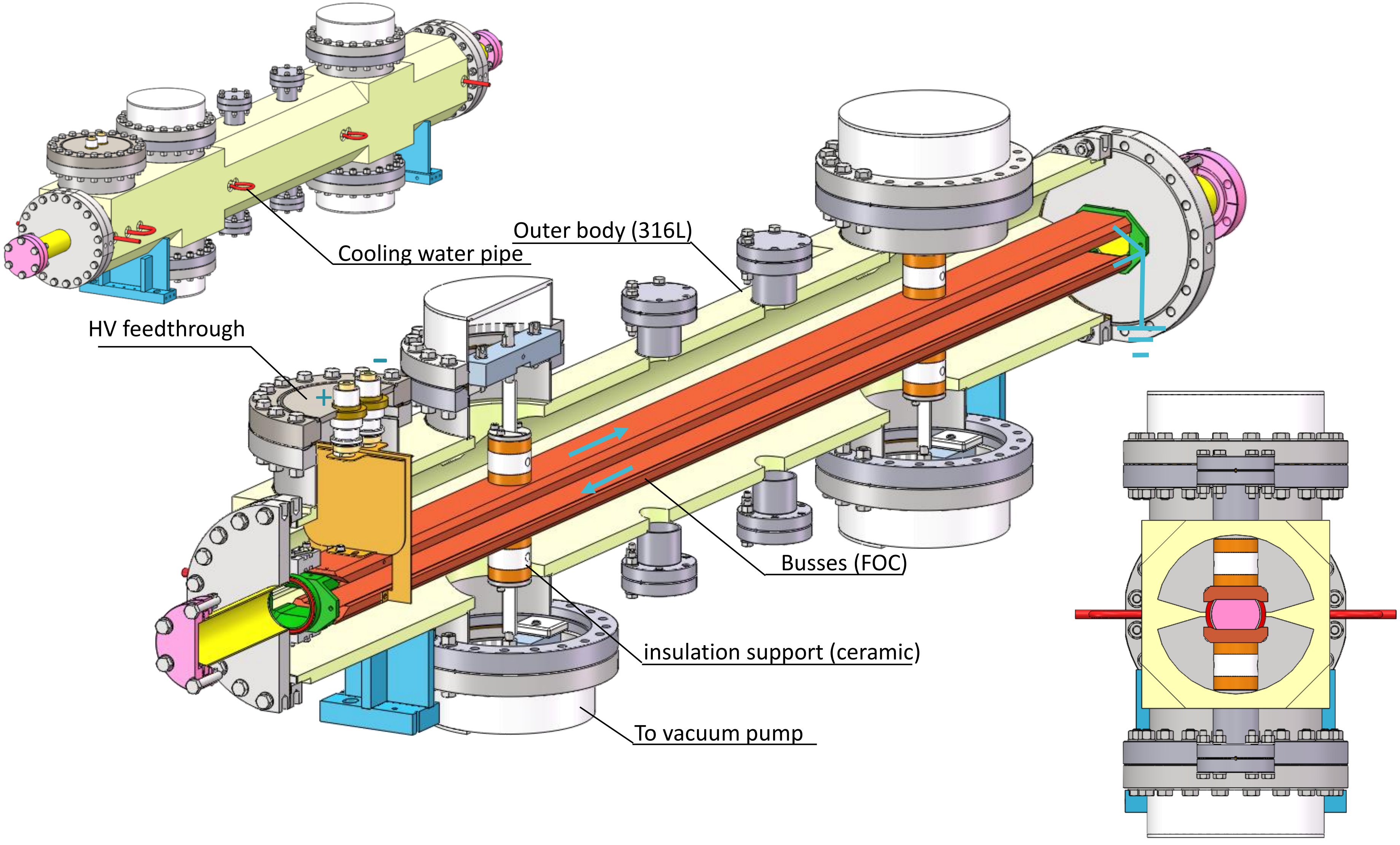


Slotted-pipe Kicker system

DR inj./ext. kicker design parameters

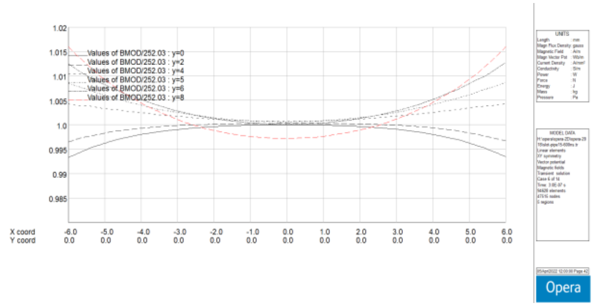
parameter	Unit	DR-kicker
Quantity	-	2
Type	-	Slotted-pipe kicker
Deflect direction	-	Vertical
Beam Energy	GeV	1.1
Deflect angle	mrad	10.7
Magnetic effective length	m	1.4
Magnetic strength	T	0.0281
Integral magnetic strength	T·m	0.03934
Clearance region(H×V)	mm	32.8×26.6
Good field region(H×V)	mm	19.8×16
Field uniformity in good field region	-	±1.5%
Repetition rate	Hz	100
Amplitude repeatability	-	±0.5%
Pulse jitter	ns	≤5
Bottom width of pulse(5%-5%)	ns	< 250

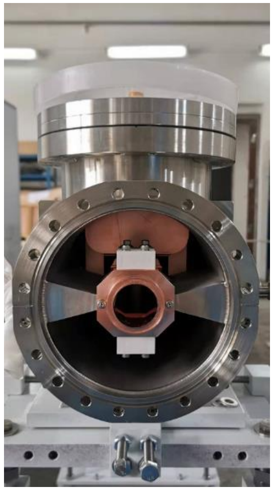
Slotted-pipe kicker engineer design

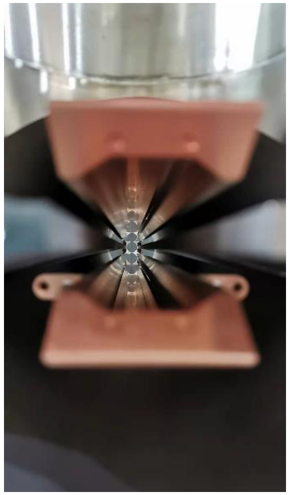


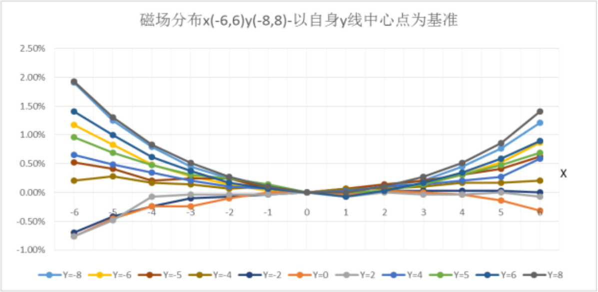
Prototype kicker for HEPS BST

- The latest progress: the kicker prototype is pass the vacuum assembling test and the magnetic field measurement have completed. The field distribute performance meet the requirements.



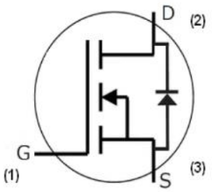


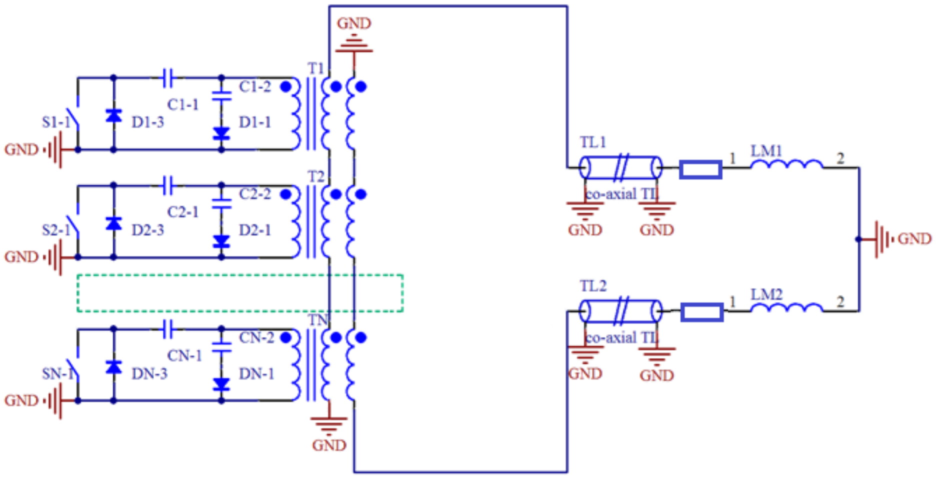


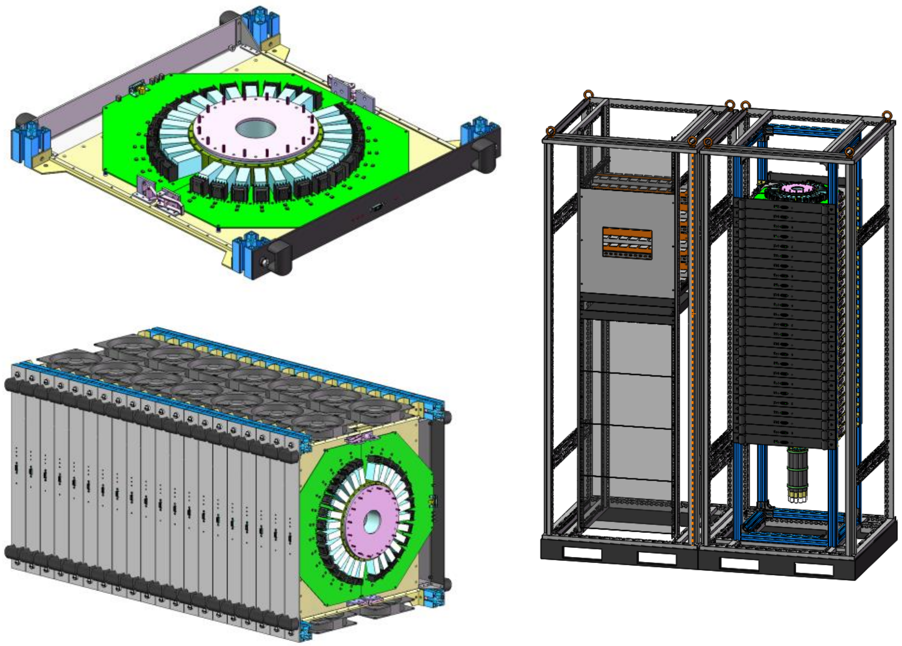


250ns-fast kicker pulser design

- Scheme: 20-stage inductive adder based on SiC-MOSFETs.
- The co-axial transformer is configured as bipolar output.
- The pulser is located outside tunnel and 10 50 Ω cables with length more than 30m are applied to connect with kicker.
- Matching terminal resistor is 10Ω.



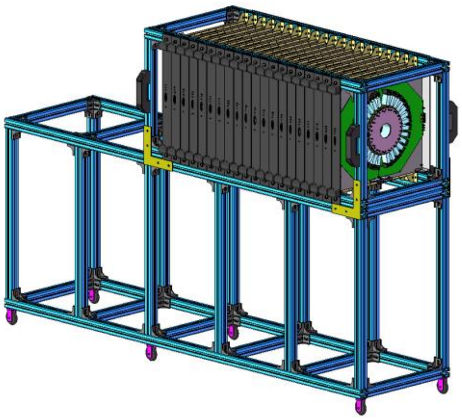


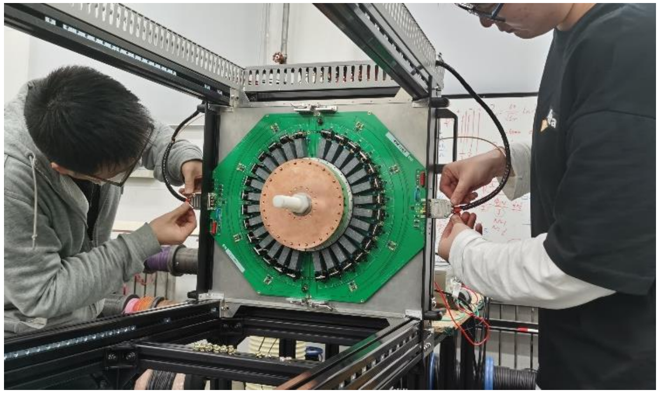


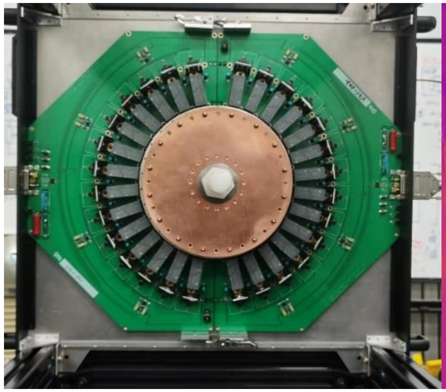
20-stage inductive adder

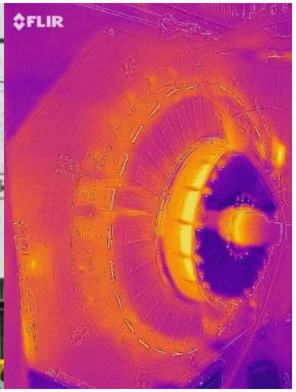
Pulser prototype for HEPS

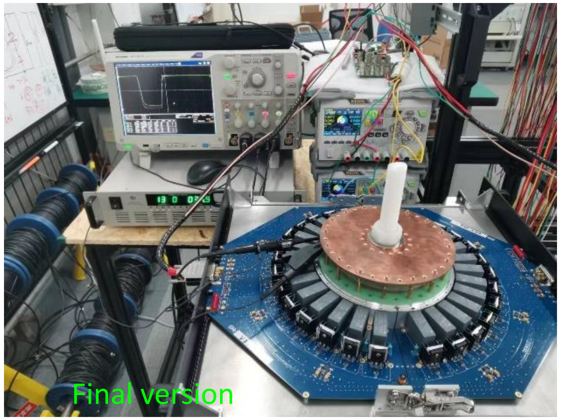
- Latest Progress：Single stage and double stages full power test has been completed（1400V into 0.5Ω）. Mass production and test is on going.

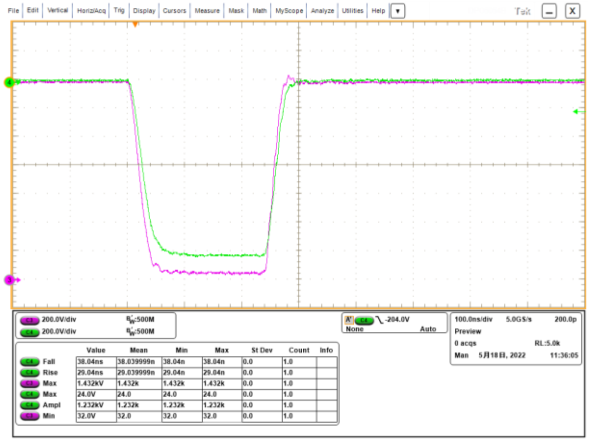










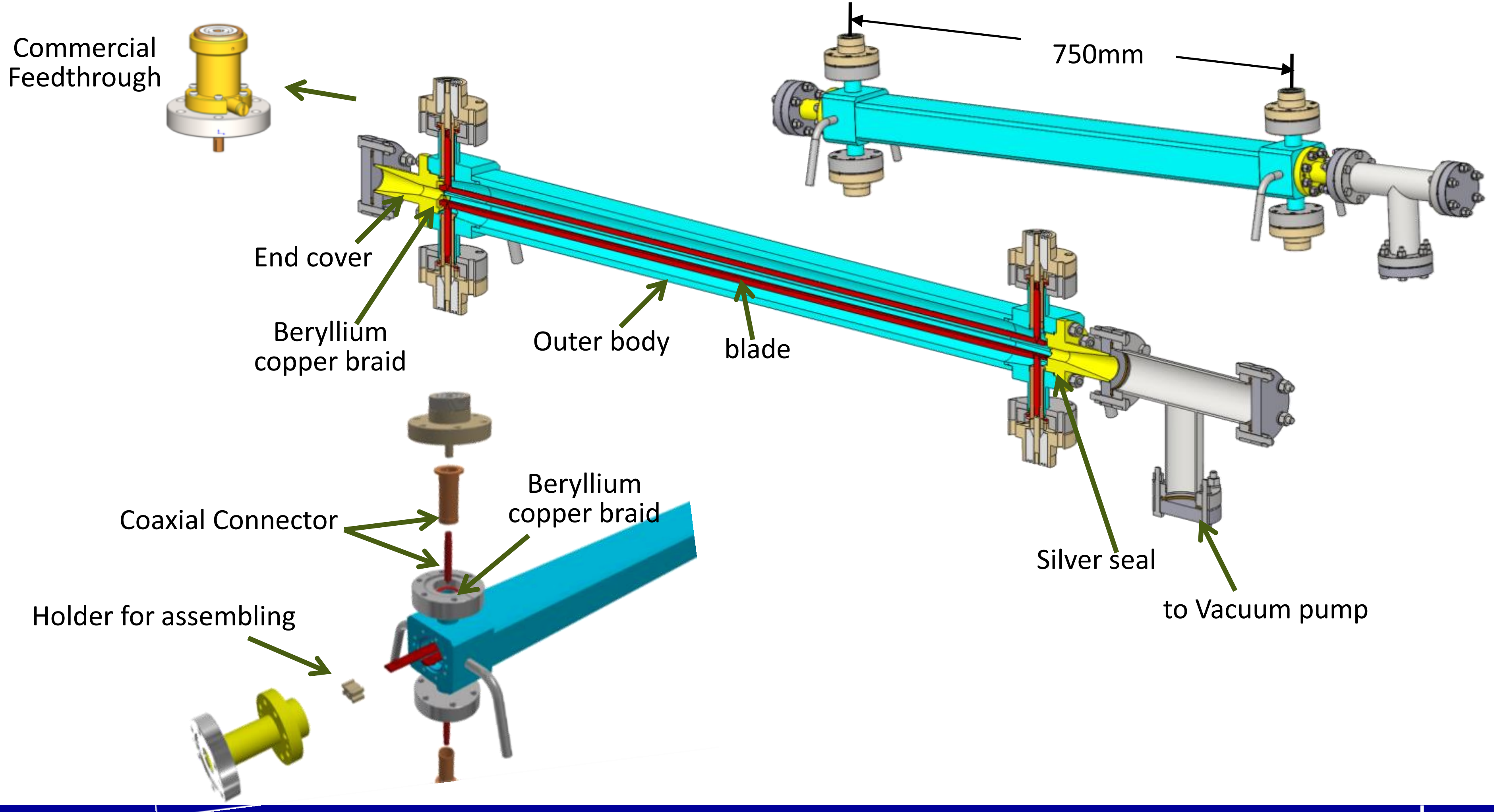


Mass production and test

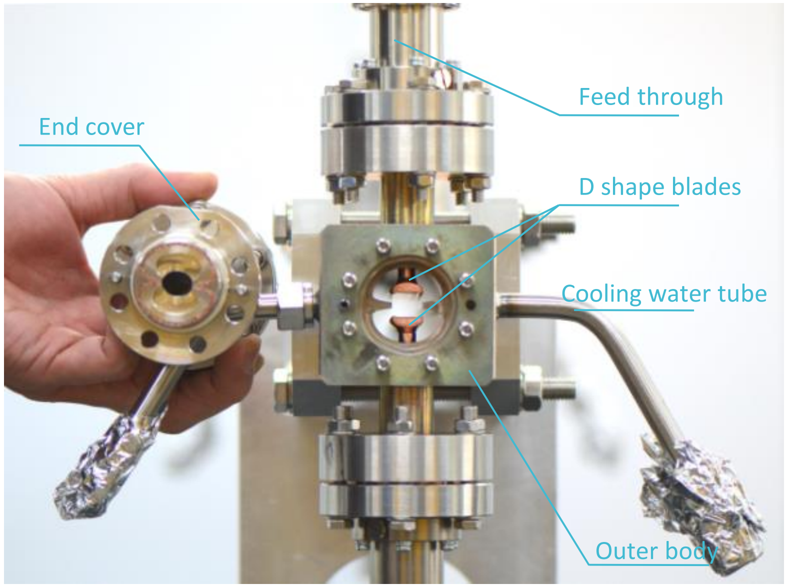
Strip-line kicker system

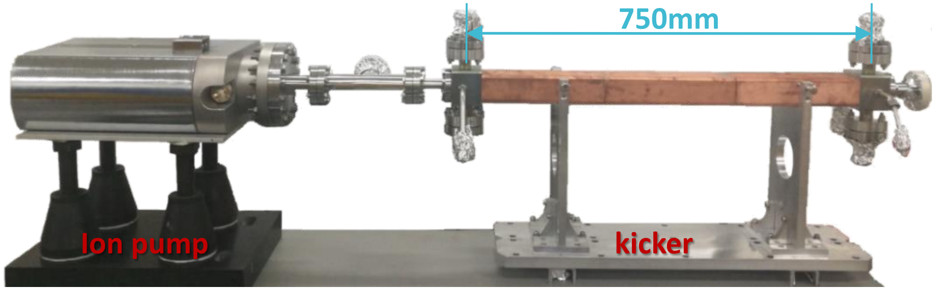
Prototype I: 750mm-long Strip-line Kicker

- The strip-line kicker system R&D started from 2016 for HEPS-TF, including 2 kind of prototypes:750mm-long and 300mm long.

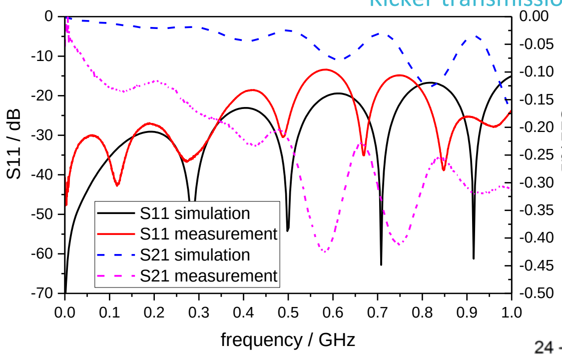


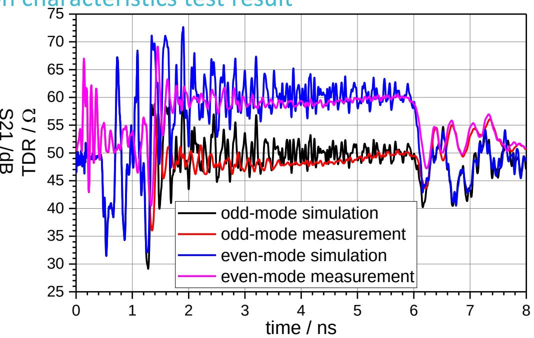
Prototype kicker passed acceptance test of HEPS-TF

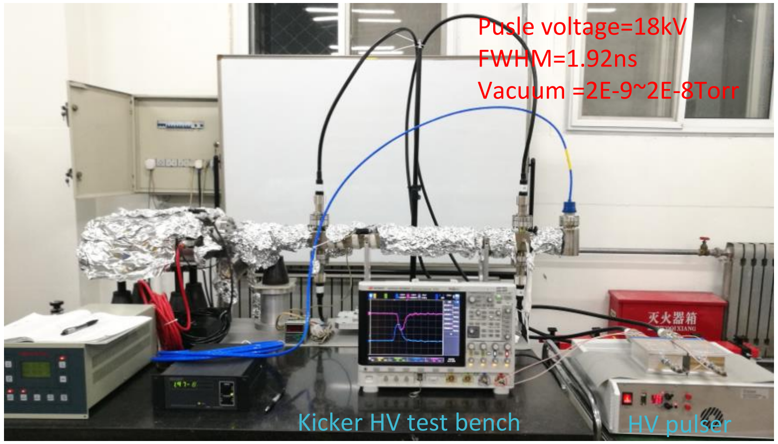




Kicker transmission characteristics test result







Kicker HV test reult：

- Kicker electrical pulse：

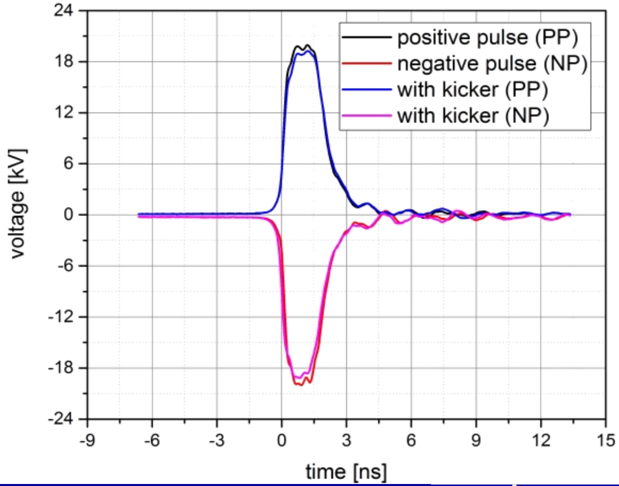
Rise time（10%-90%）<641ps，

Fall time（90%-10%）<1.5ns。

- pluse edge slowing down due to kicker insertion：

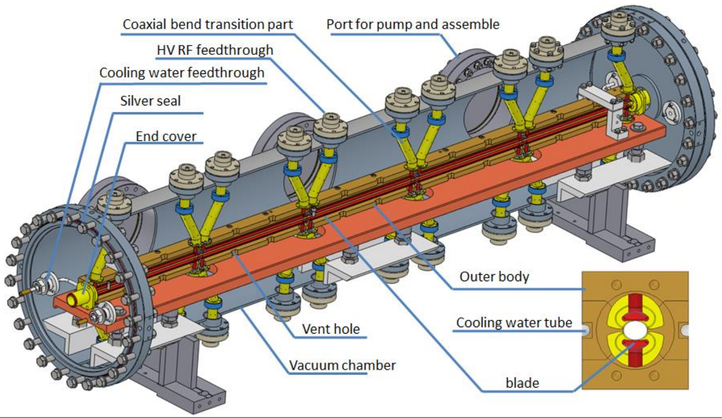
rise time (10%-90%)≈86.6ps,

Fall time (90%-10%) ≈ 35ps。

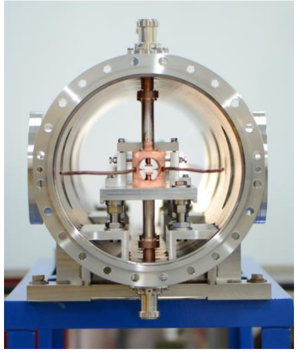


The strip-line kicker prototype R&D completed

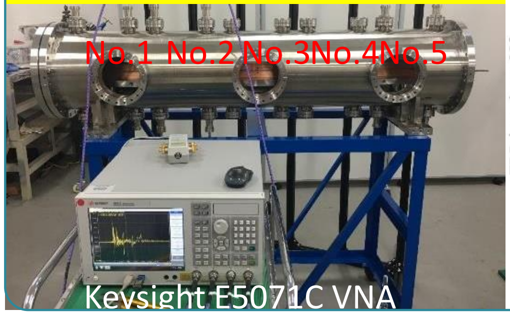
- Feature：5 sets of 300mm strip-line kicker in a single module to save the straight section space.

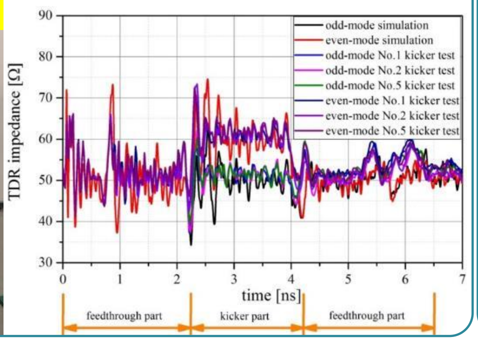


L. Wang, J.H. Chen, A 300mm long prototype strip-line kicker for the HEPS injection system, IPAC2019

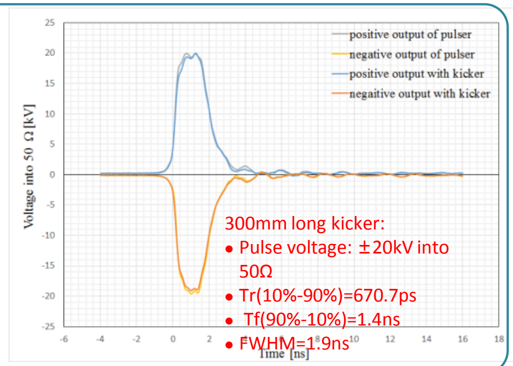


TDR measurement



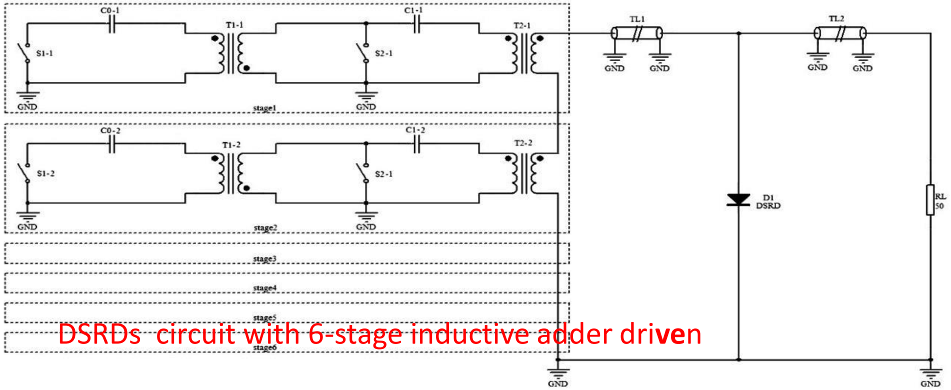


HV pulse testing at ± 20kV

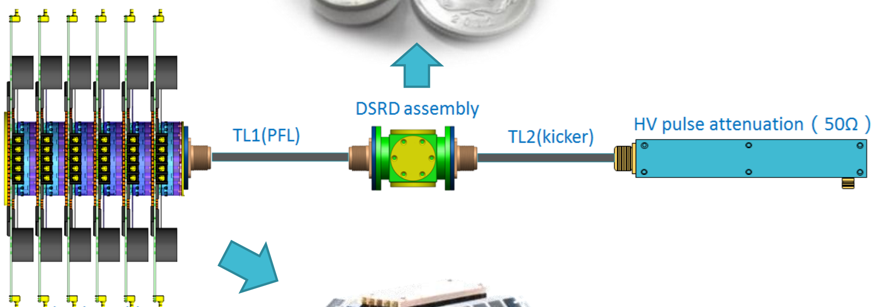


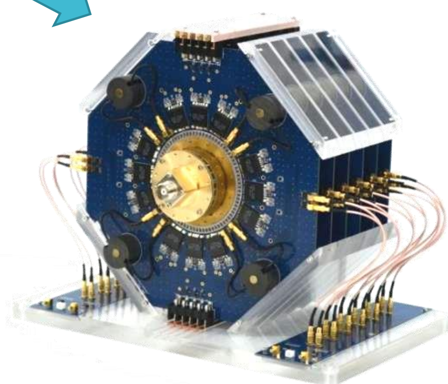
10ns-fast puler R&D

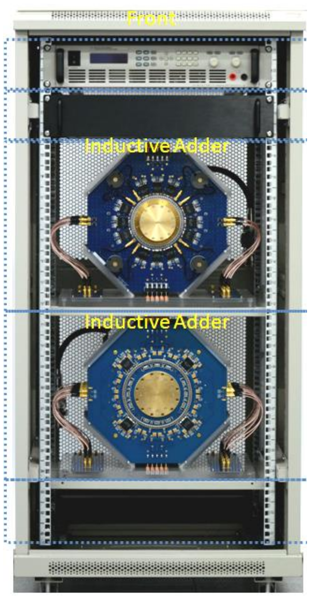
- Scheme: pulser based on DSRDs driven by 6-stage inductive adder;

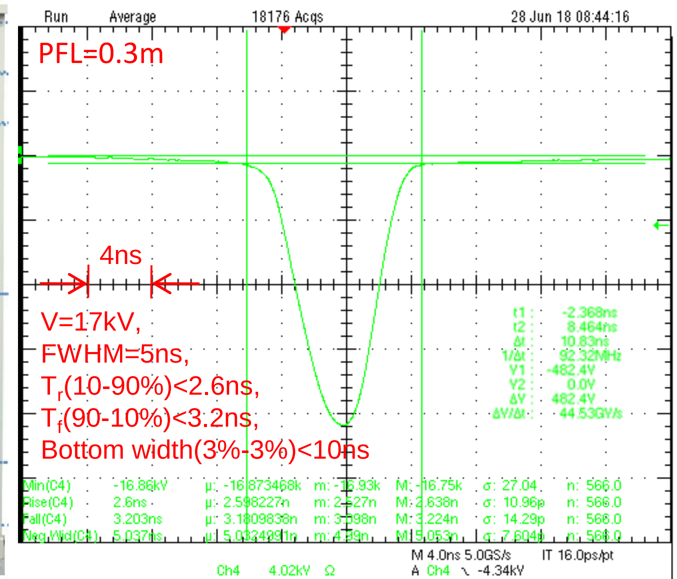


Drift Step Recovery Diode







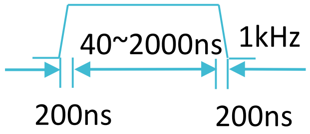


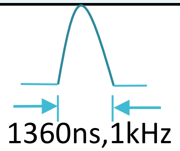
J.H. Chen, Strip-line kicker and fast pulser R&D for the HEPS on-axis injection system, NIMA 920(2019)1-6

Ferrite core kicker magnet

BST EXT kicker design parameters

parameter	Unit	BST-EXT-kicker1 (for CR off-axis inj.)	BST-EXT-kicker2 (for CR on-axis inj.)
Quantity	-	2	2
Type	-	In-air delay-line dipole kicker	In-air lumped parameter dipole kicker
Deflect direction	-	Horizontal	Horizontal
Beam Energy	GeV	120	120
Deflect angle	mrad	0.2	0.1
Magnetic effective length	m	1.4	0.7
Magnetic strength	T	0.06	0.06
Integral magnetic strength	T·m	0.08	0.04
Clearance region(H×V)	mm	55×55	55×55
Good field region(H×V)	mm	?	?
Field uniformity in good field region	-	±1.5% ?	±1.5% ?
Repetition rate	Hz	1k	1k
Amplitude repeatability	-	±0.5%	±0.5%
Pulse jitter	ns	≤5	≤5
Bottom width of pulse(5%-5%)	ns	Trapezoid：440~2420	Half-sine： 1360
Tr/Tf(5%-95%)	ns	<200	<680



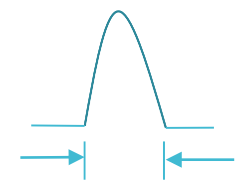


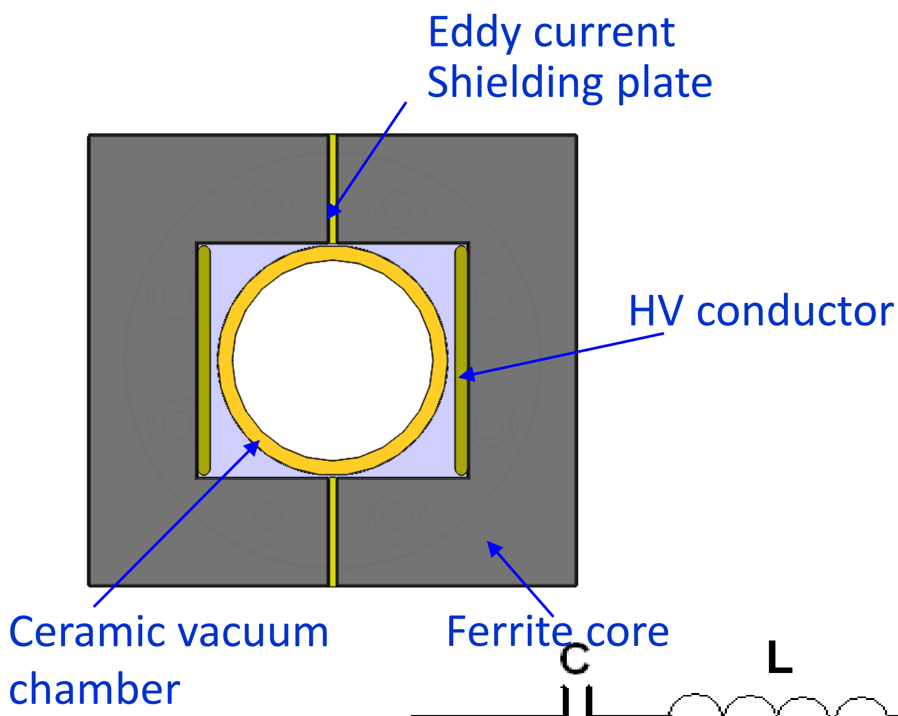
Lumped parameter dipole kicker system

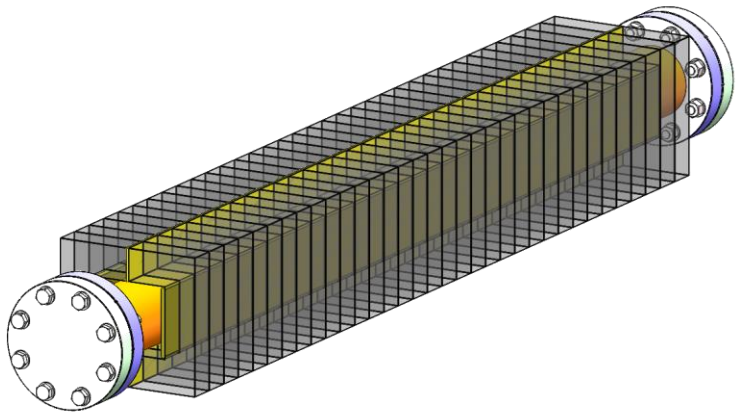
- **For 1.3us half-sine kicker, a Lumped parameter dipole kicker is fit.**

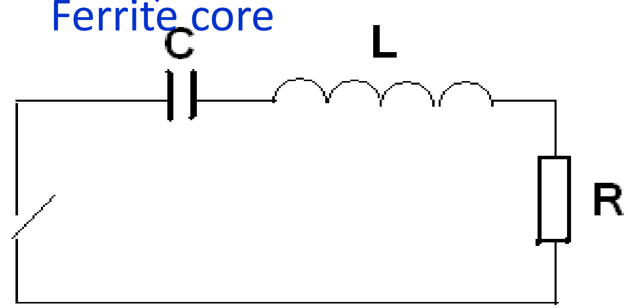
Features:

- Out-vacuum **kicker** with metallic coating ceramic vacuum chamber





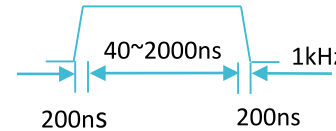




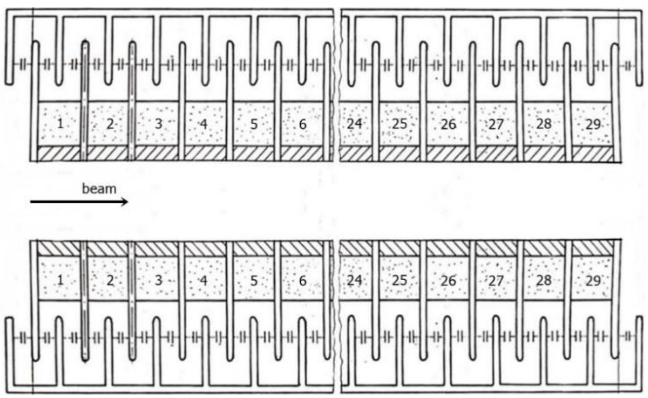
$$\begin{cases} Z = \sqrt{\frac{L}{C}} \\ I = \frac{U}{Z} \\ T = 2\pi\sqrt{LC} \end{cases}$$

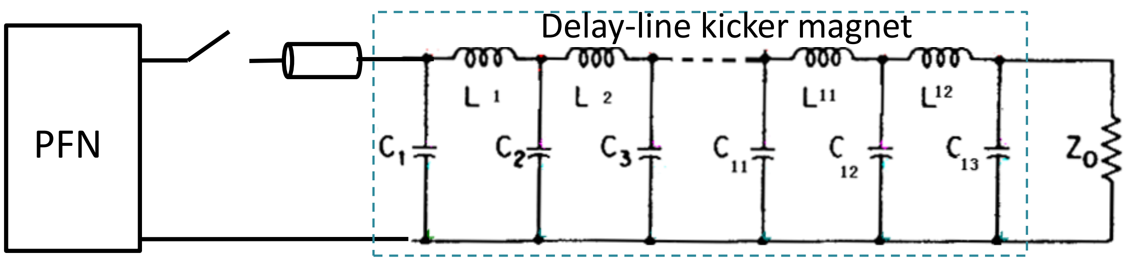
Delay-line dipole kicker system

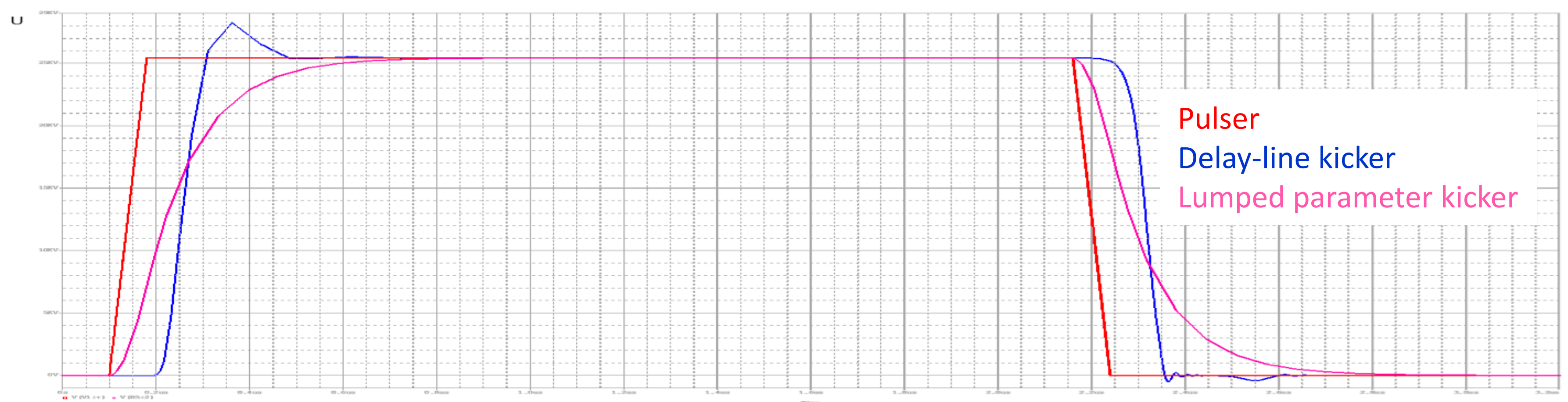
- **For trapezoid kicker system, a delay-line dipole kicker is preferred, because it can helps to achieve ideal trapezoid waveform. While, its structure is complicated.**



challenges



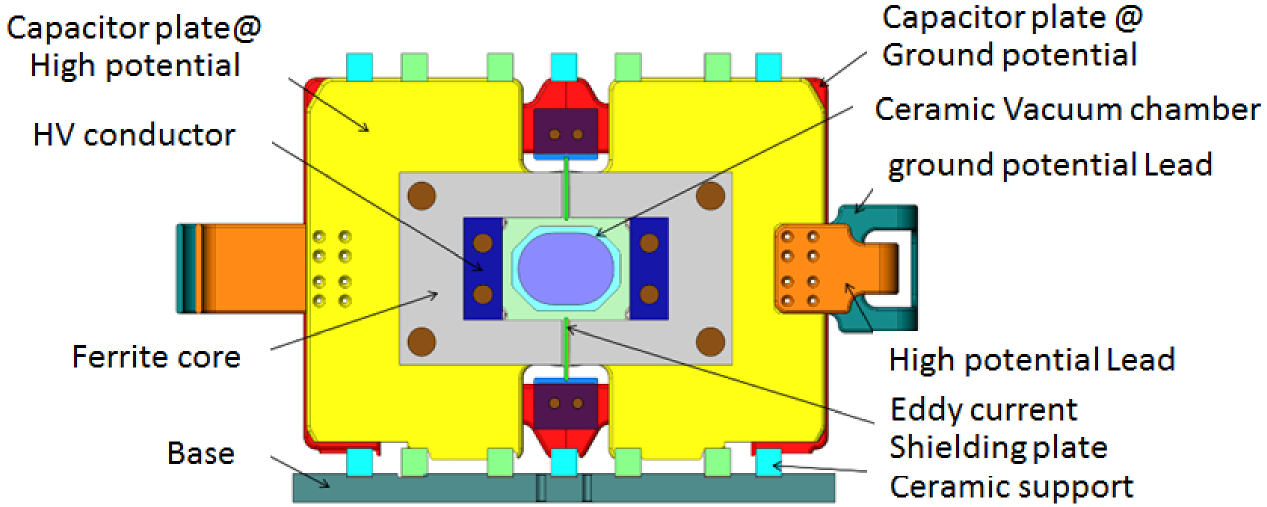


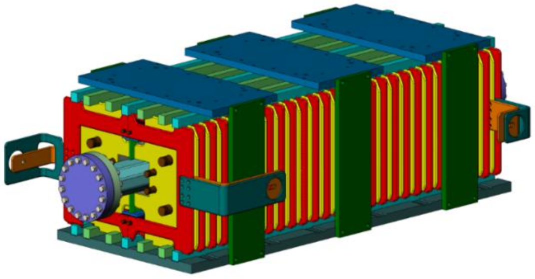


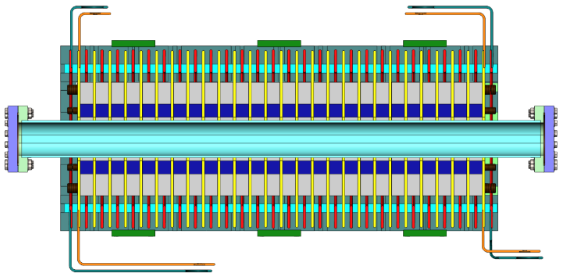
Dual-C type delay-line dipole kicker R&D

Latest progress: We have finished a dual-C delay-line kicker prototype engineer design.

The R&D was initiated at the end of last year.

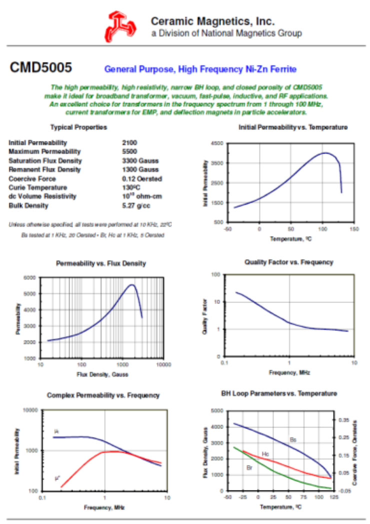


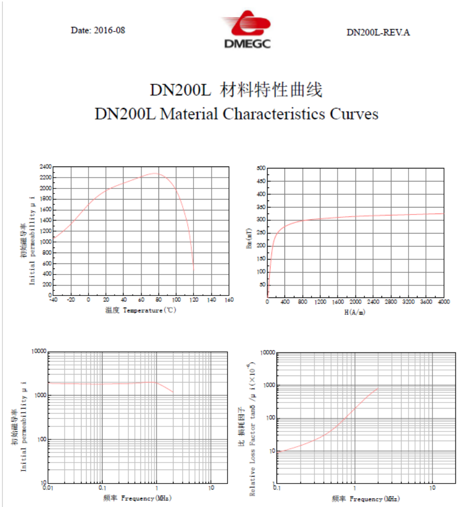


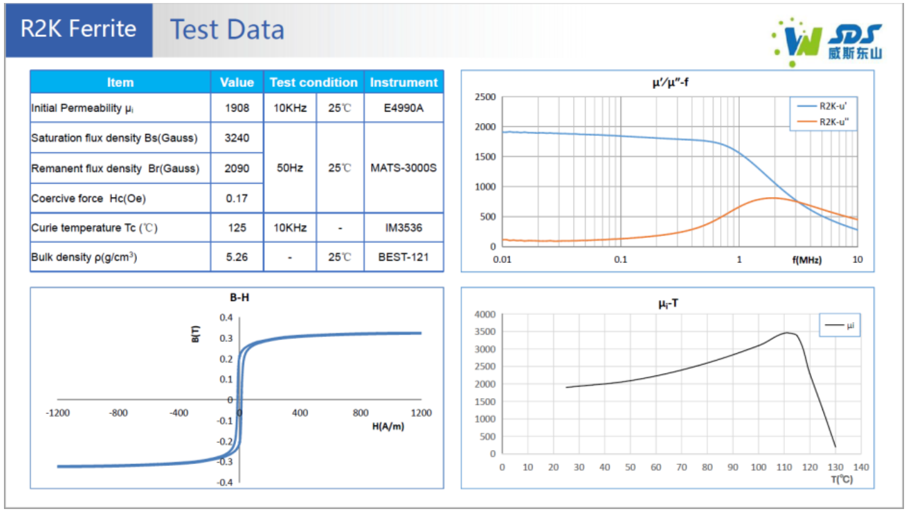


Ferrite core for delay-line kicker prototype

- Investigating the domestic ferrite core manufacturers

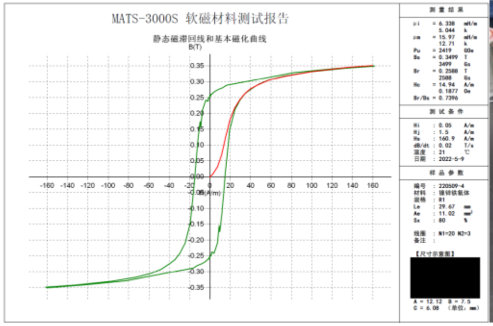


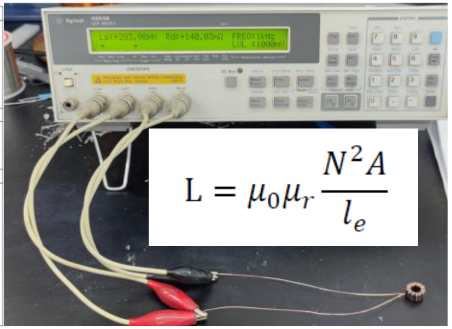




Item	Value	Test condition		Instrument
Initial Permeability μi	1908	10KHz	25℃	E4990A
Saturation flux density Bs(Gauss)	3240	50Hz	25℃	MATS-3000S
Remanent flux density Br(Gauss)	2090			
Coercive force Hc(Oe)	0.17			
Curie temperature Tc (℃)	125	10KHz	-	IM3536
Bulk density p(g/cm³)	5.26	-	25℃	BEST-121

- Ni-zn ferrite sample core test



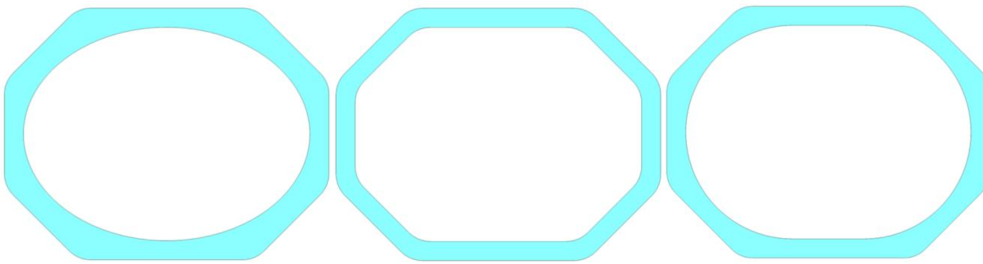


$$L = \mu_0 \mu_r \frac{N^2 A}{l_e}$$

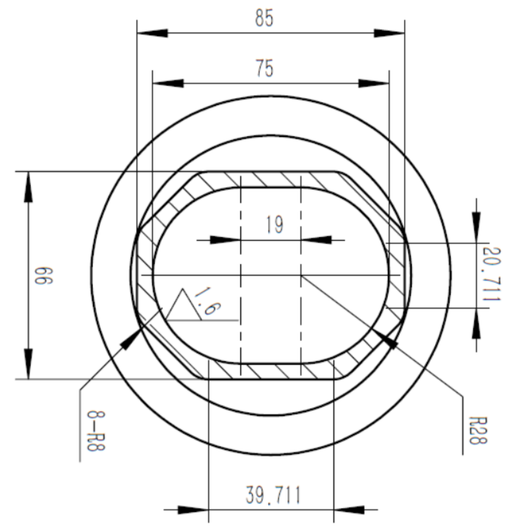
L(uH)/μr	100Hz	1kHz	10kHz	100kHz
200mV	421.7/1841	275.4/1202	279.28/1279	262.98/1148
400mV	609.7/2662	280.85/1226	280.17/1223	260.17/1136
600mV	871.9/3806	283.18/1236	278.73/1217	259.02/1131
800mV	1139.4/4974	287.91/1257	281.26/1228	259/1131
1000mV	1290.7/5635	295.22/1289	280.5/1225	259.92/1135

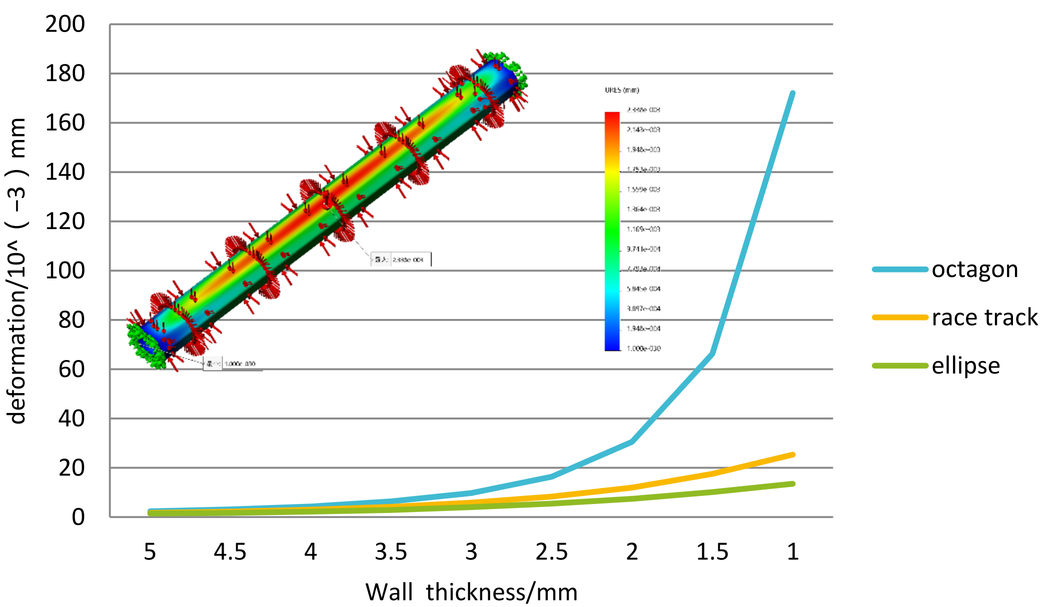
Ceramic vacuum chamber R&D

- ceramic vacuum chamber with special pattern metallic coating is key component for outside-vacuum kicker magnet.
- Latest progress: the prototype is in fabrication phase



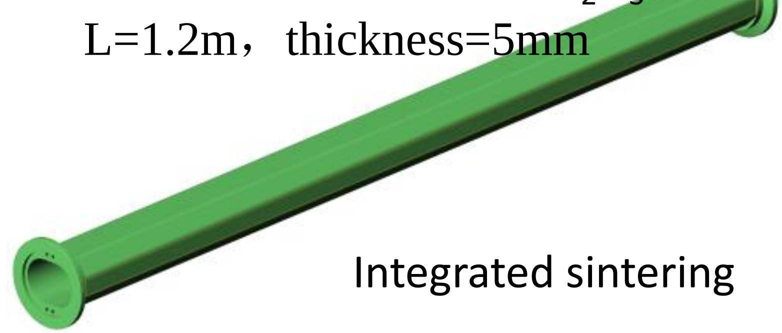
ellipse octagon Race track √





Ceramic material: 99% AL_2O_3

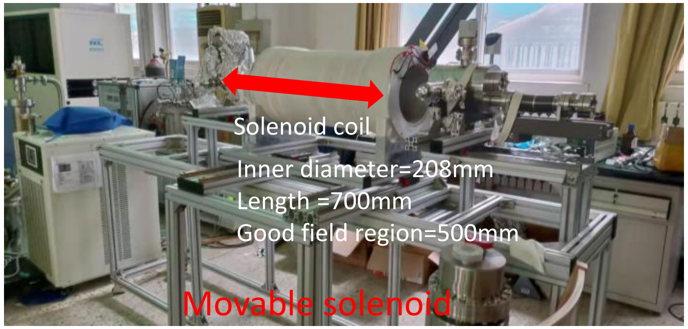
L=1.2m， thickness=5mm

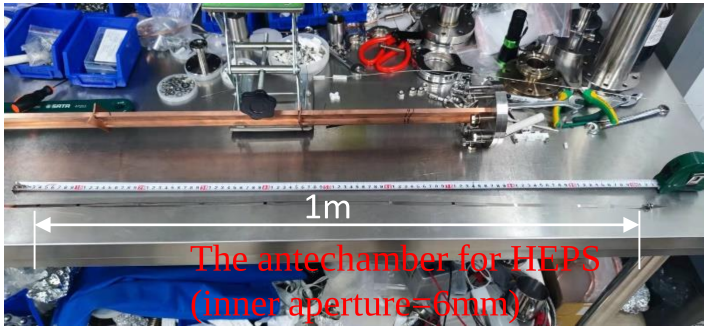


Integrated sintering

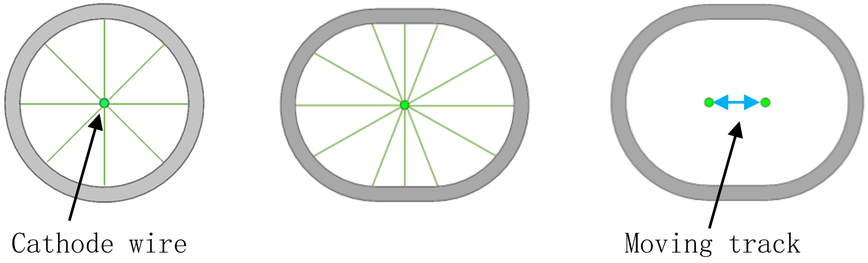
Magnetron sputtering coating prepare

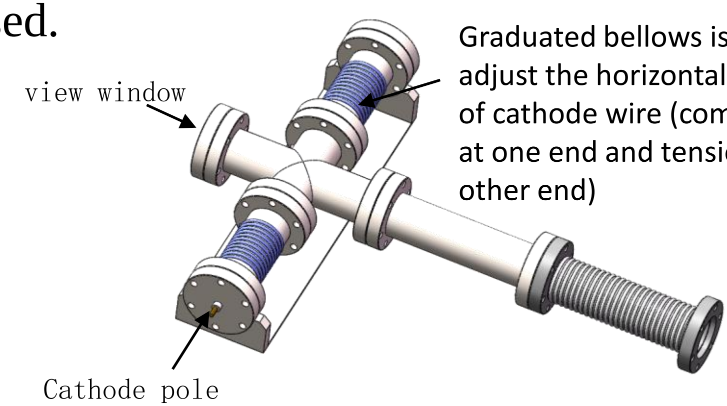
- **As for metallic coating, a set of magnetron sputtering coating platform was set up.**





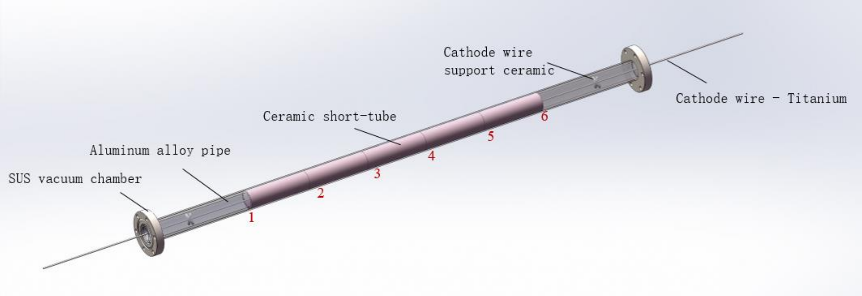
- Horizontal coating system have been setup. It can support 700mm long pipe coating one-time or 1400mm long pipe sectional coating.
- In order to obtain uniform coating inner racing track shape vacuum chamber, a horizontal movable cathode wire target solution is proposed.

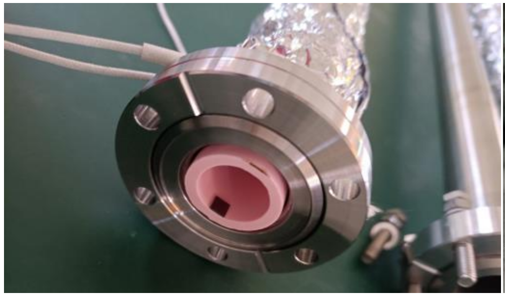


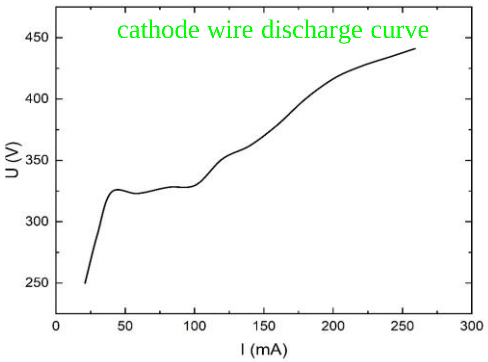


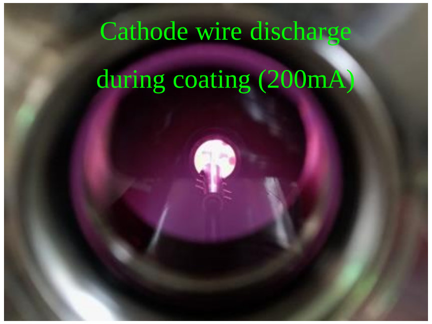
TiN coating test

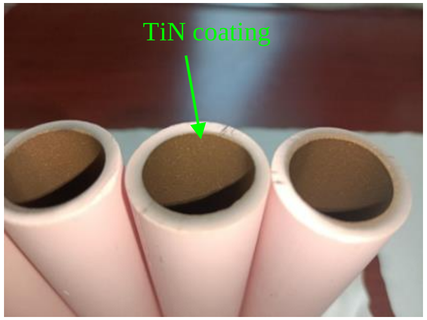
- And we have achieved TiN (Titanium nitride) film sampling on a shorter ceramic vacuum chamber.

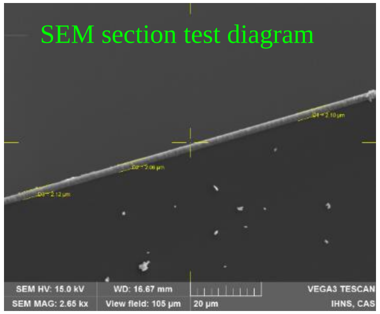


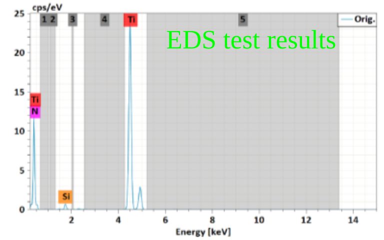








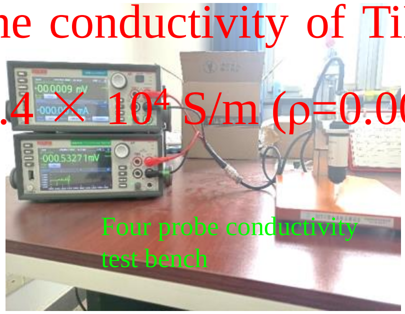




No7-1 1

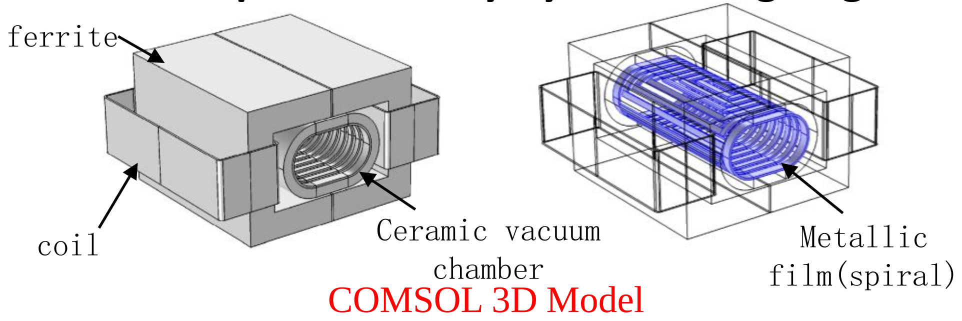
元素	原子数	线	净值	质量 [%]	归一化质量 [%]	原子 [%]	abs. error [%] (1 sigma)	abs. error [%] (2 sigma)	abs. err (3 sig
N	7	K-Serie	60186	22.83	22.51	49.83	0.95	1.89	
Ti	22	K-Serie	402816	78.57	77.49	50.17	1.59	3.19	
			总计：	101.40	100.00	100.00			

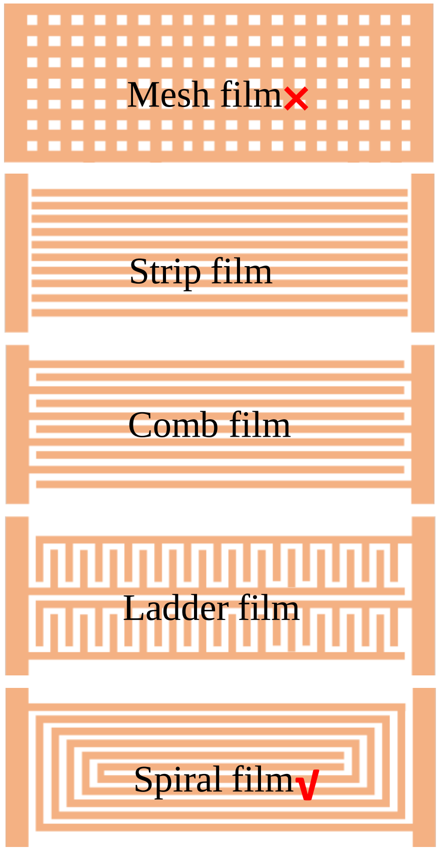
- the conductivity of TiN film is about 5.4×10^4 S/m (ρ=0.0018 $\Omega \cdot$cm)



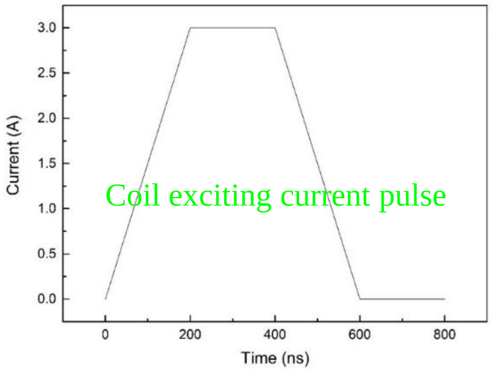
Film pattern study

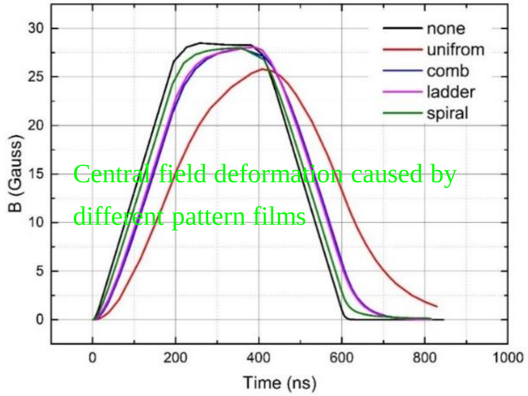
- **The film pattern study by PCB is ongoing.**



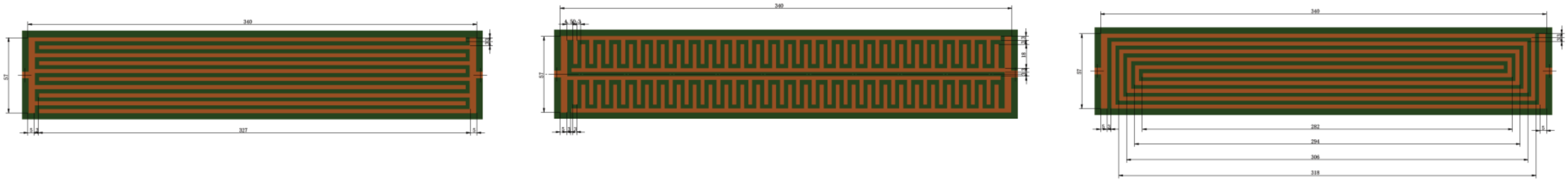


- the film square resistance is set to 0.2 Ω (equivalent to 86nm copper film or 1.1 µm TiN film)
- Material conductivity is set to 5000S / m, and the corresponding thickness is 1mm.





- The coating pattern on PCB research by Vector network analyzer(VNA).



Summary

- The types of all inj./ext. components are determined. The hardware designs towards TDR are being carried out. One team is in charge of both HEPS and CEPC inj. & ext. system. A part of hardware R&D for 2 projects are overlapping.
- The Lambertson septa prototypes for HEPS are in assembling phase.
- The slotted-pipe kicker prototype has completed. The pulser full power prototype is in mass production and assembling process.
- Strip-line kicker and fast pusler prototypes has completed for 3 years.
- R&D of delay-line kicker including ceramic chamber with TiN coating has started.

END

Thank you for attentions!!!

abstract

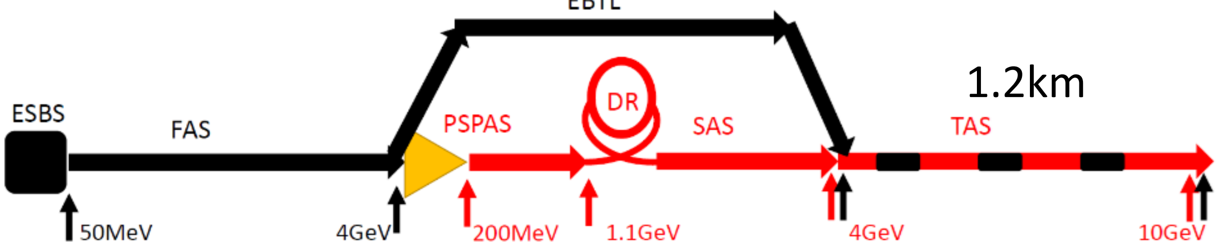
The type of CEPC injection and extraction hardware including Lambertson septa，strip-line kicker，slotted-pipe kicker, Lumped parameter ferrite core kicker，and delay-line fast kicker.

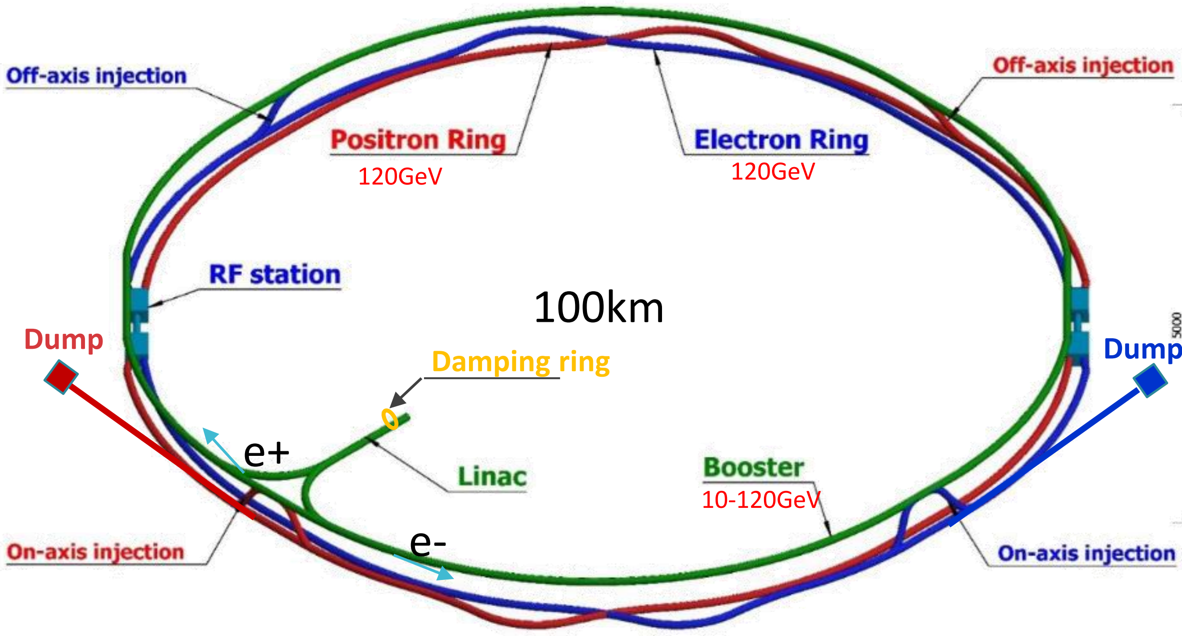
The hardware designs towards TDR are being carried out. One team is in charge of both HEPS and CEPC inj. & ext. system. Some hardware R&D are overlapping.

Backup slides

Layout of the accelerator complex

The CEPC accelerator complex consists of a **Linac**, which including a small **damping ring** for positron beams, several **transport lines**, a **booster ring** and 2 **storage rings**, all of which are in a single tunnel.





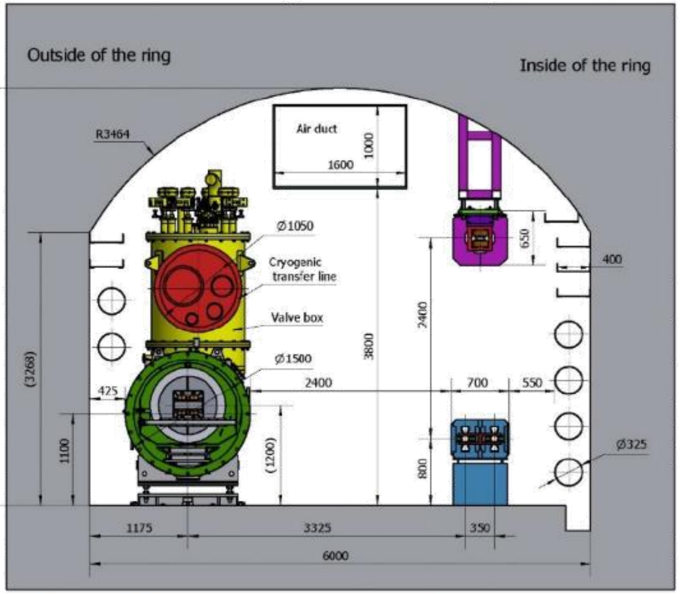


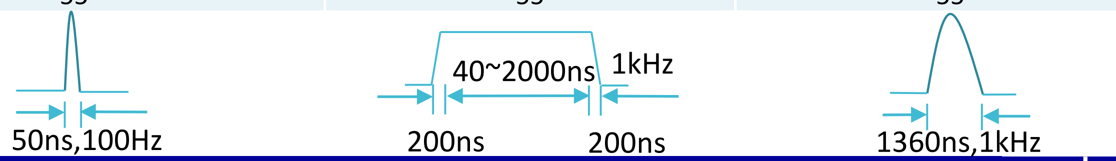
Figure 2.1: Tunnel cross section in the arc region

Booster Ring

Booster operating mode	Higgs			W		Z	
Beam energy（GeV）	10	120		10	80	10	45.5
Function	Injection（both）	Extraction（off-axis）	Inj./Ext.（on-axis）	Injection（off-axis）	Extraction（off-axis）	Injection（off-axis）	Extraction（off-axis）
Bunch number	242（in half ring）		7（in half ring）	1524（uniform）		6000	
Min. bunch spacing （ns）	680		23800	220		25	
Bunch number per train× train number	-		-	-	-	80×75	
Train spacing （ns）	-		-	-	-	2460	
Injection（extraction）mode	Bunch by bunch			Bunch by bunch		Bunch by bunch	Train by train
Kicker repetition rate (Hz)	100	1000		100	1000	100	1000
Kicker pulse width (ns)	1360			440		50	<6900
Kicker flat top （ns）	-			-		-	>1980
Kicker rise（fall）time (ns)	<680			<220		<25	<2460
Timing delay(ns)	<680		<23800	<220		<2460	<4400
injection（extraction）period (s)	2.42	0.242	0.007	15.24	1.5	60	0.075
Kick angle (mrad)	0.11	0.2	0.1	0.11	0.2	0.11	0.2
Kick Integral field strength (Tm)	0.004	0.08	0.04	0.004	0.05	0.004	0.03
Beam pipe aperture Φ（mm）	55						

Considering the compatibility of three operating modes:

Function	LE-Injection（both）	HE-Extraction（off-axis）	HE-Inj./Ext.（on-axis）
Kicker repetition rate (Hz)	100	1000	1000
Kicker pulse width (ns)	50	440~2420(Adjustable)	1360
Kicker flat top （ns）	-	0~1980(Adjustable)	-
Kicker rise（fall）time(ns)	<25	<220	<680
injection（extraction）period (s)	60	1.5	0.007
Kick angle (mrad)	0.11	0.2	0.1
Kick Integral field strength (Tm)	0.004	0.08	0.04
Beam pipe aperture Φ（mm）	55	55	55

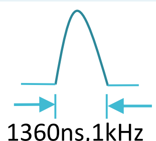


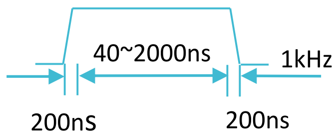
Collider ring

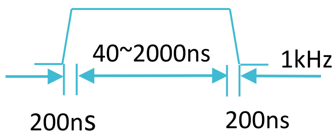
Booster operating mode	Higgs			W		Z	
Beam energy（GeV）	120			80		45.5	
Function	Injection（off-axis）	Injection（on-axis）	Extraction（dump）	Injection（off-axis）	Extraction（dump）	Injection（off-axis）	Extraction（dump）
Bunch number	242（in half ring）- 7			1524（uniform）		12000	
Min. bunch spacing （ns）	680			220		25	
Bunch number per train× train number	-			-		80×150	
Train spacing （ns）	-			-		245	
Injection（extraction）mode	Bunch by bunch			Bunch by bunch		Train by train	
Kicker repetition rate (Hz)	1000			1000		1000	
Kicker pulse width (ns)	1360			440		<2460	
Kicker flat top（ns）	-			-		>1980	
Kicker rise（fall）time (ns)	<680			<220		<245	
Timing delay(ns)	<680	<23800	<680	<220		<4400	
injection（extraction）period (s)	0.242	0.007	0.242	1.5		0.15	
Kick angle (mrad)	0.1	0.2	0.2	0.1	0.2	0.1	0.2
Kick Integral field strength (Tm)	0.04	0.08	0.08	0.027	0.05	0.015	0.03
Beam pipe aperture HxV（mm）	75×56						

Considering the compatibility of three operating modes:

Function	Injection（on-axis）	Injection（off-axis）	Extraction（dump）
Kicker repetition rate (Hz)	1000	1000	1000
Kicker pulse width (ns)	1360	440~2420(Adjustable)	440~2420(Adjustable)
Kicker flat top（ns）	-	0~1980(Adjustable)	0~1980(Adjustable)
Kicker rise（fall）time(ns)	<680	<220	<220
injection（extraction）period (s)	0.007	1.5	1.5
Kick angle (mrad)	0.2	0.1	0.2
Kick Integral field strength (Tm)	0.08	0.04	0.08
Beam pipe aperture HxV（mm）	75×56	75×56	75×56

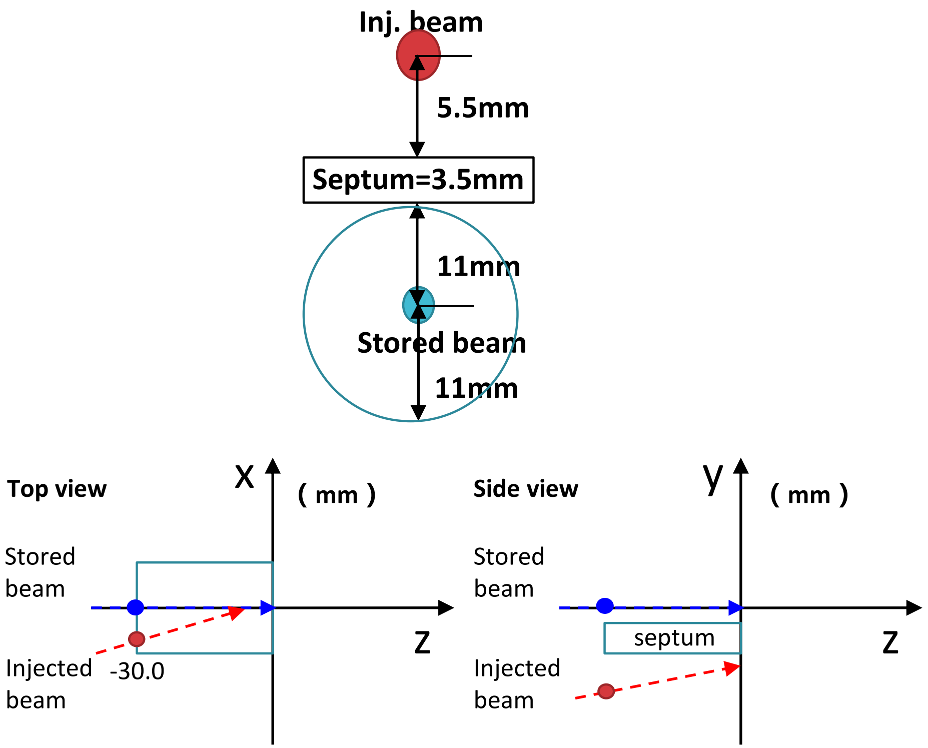




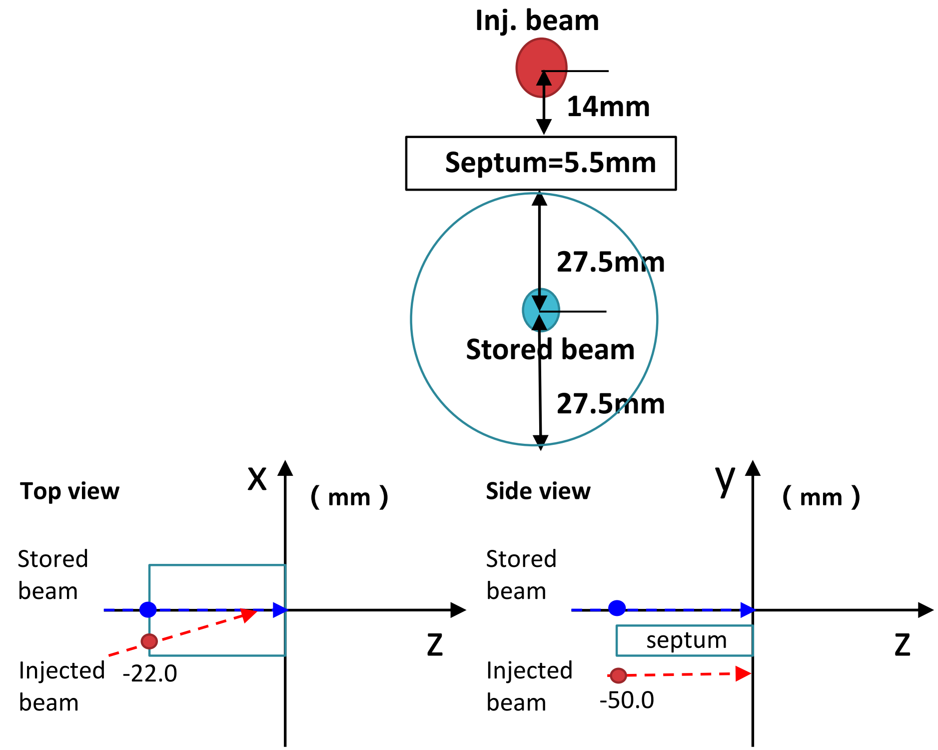


DR and BST LE inj.

DR inj. & ext.



BST LE inj.



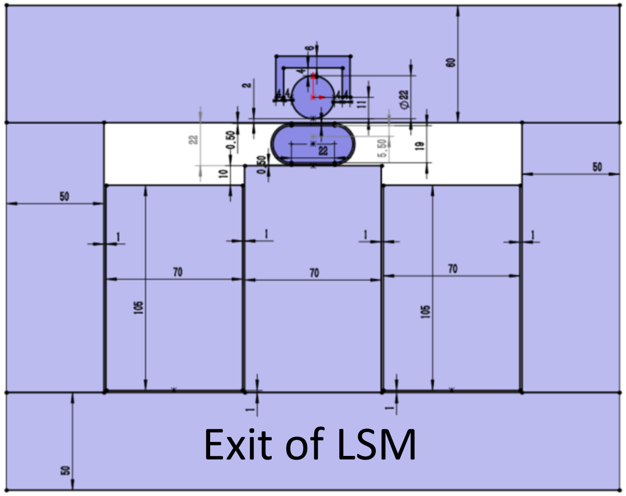
Injected beam	X(mm)	Y(mm)	Z(mm)
LSM in	-30.0	-23.75	-500.0
LSM out	0	-20	0

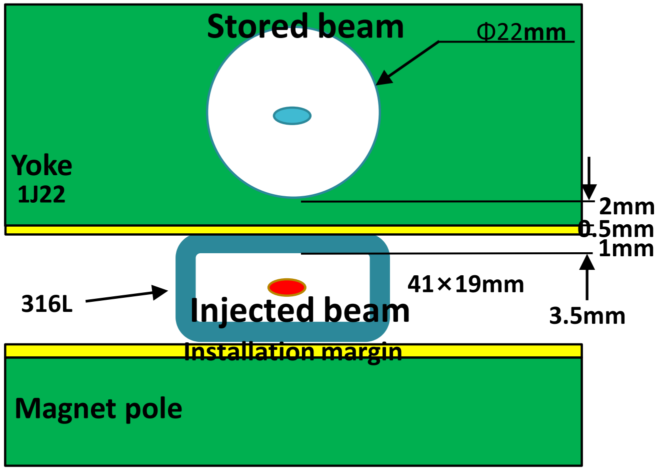
Stored beam	X(mm)	Y(mm)	Z(mm)
LSM in	0	0	-500.0
LSM out	0	0	0

Injected beam	X(mm)	Y(mm)	Z(mm)
LSM in	-22.0	-50	-800.0
LSM out	0	-50	0

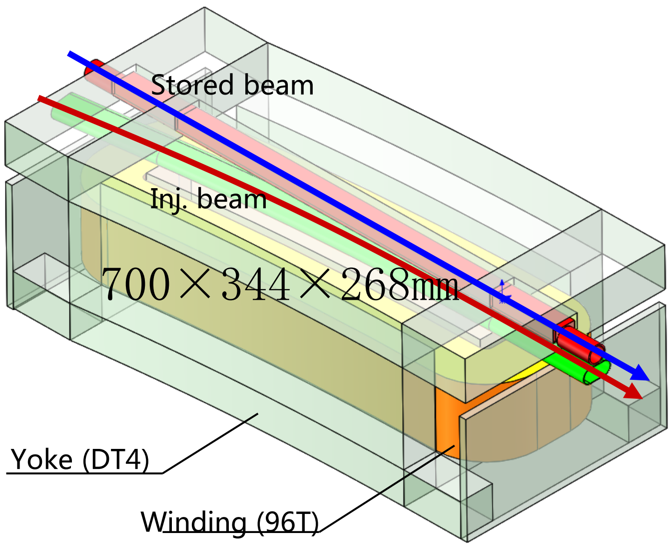
Stored beam	X(mm)	Y(mm)	Z(mm)
LSM in	0	0	-800.0
LSM out	0	0	0

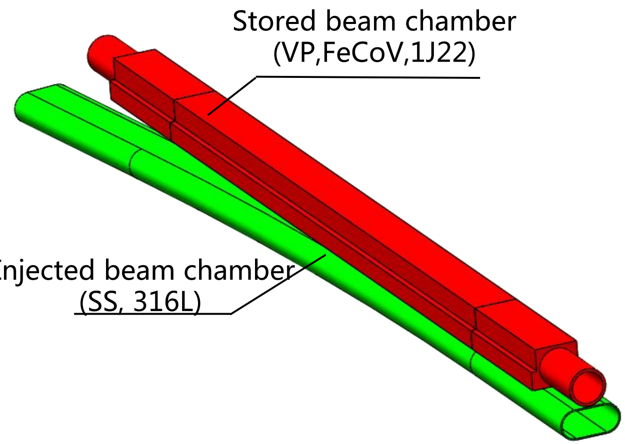
LSM physics design for DR



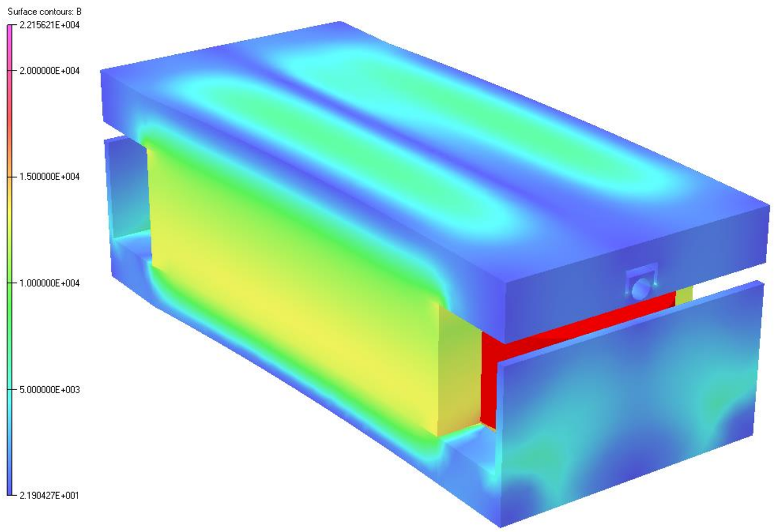


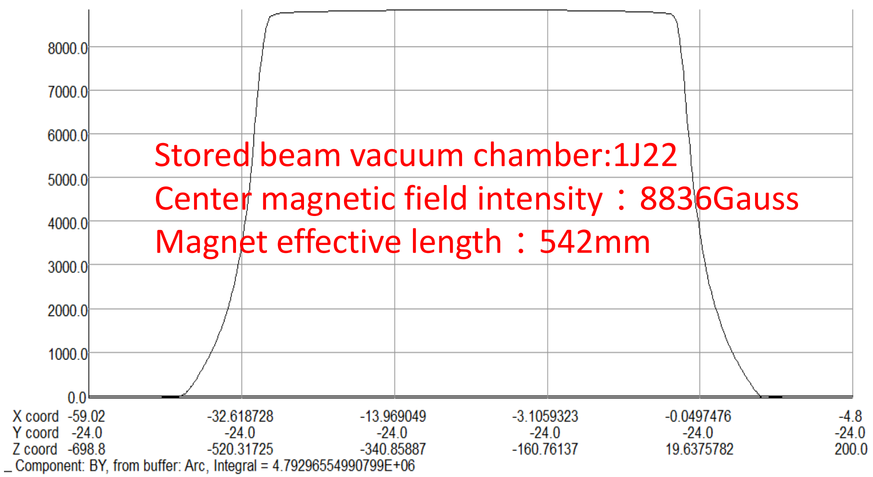
- Stored beam pipe(VP) inner diameter= ø22mm, Thickness=2mm
- Injected beam pipe (SS): W=41mm, H=19mm, Thickness=1mm
- Septum Thickness=2+1+0.5=3.5mm
- Magnet gap: 22mm
- Winding: W=70mm,H=105mm,T=96
- Exciting current=166A
- Inductance=0.0228H

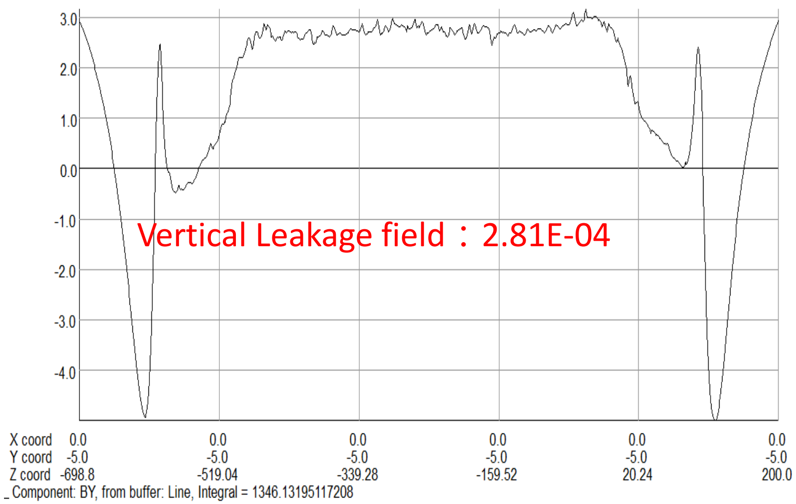


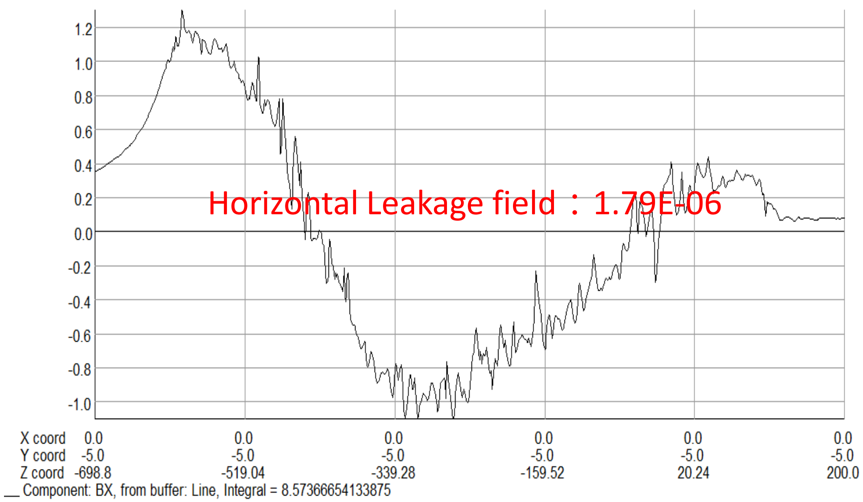


3D simulation

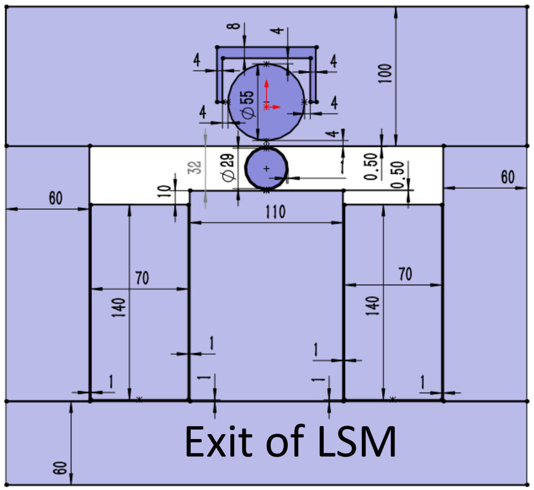


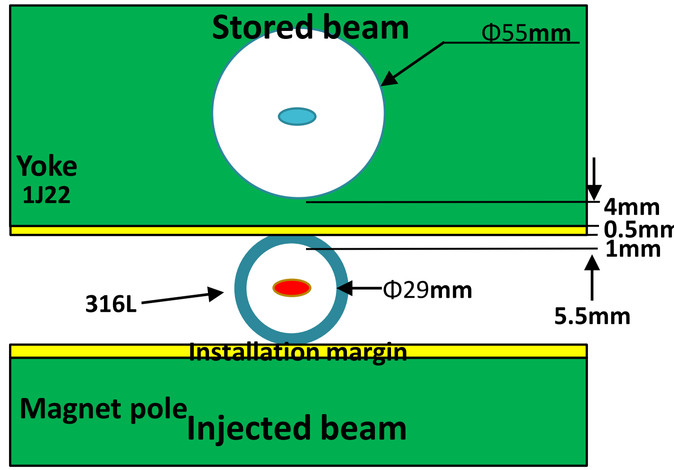




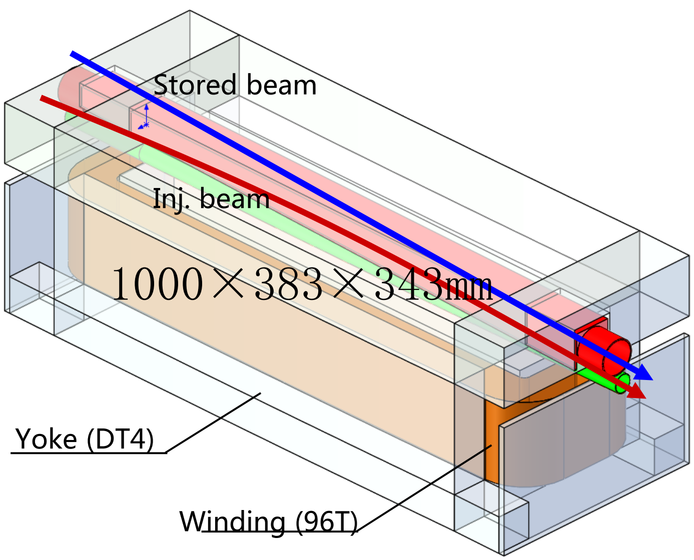


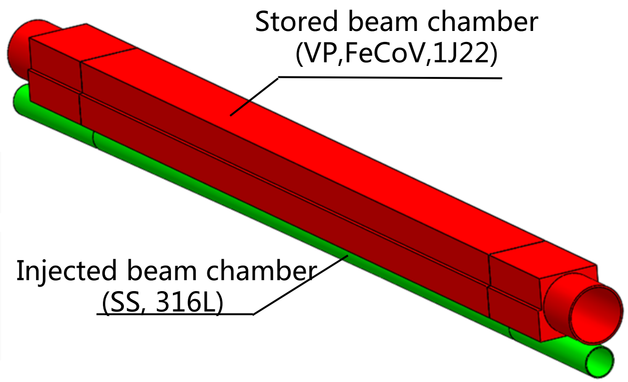
LSM physics design for BST LE-Inj.



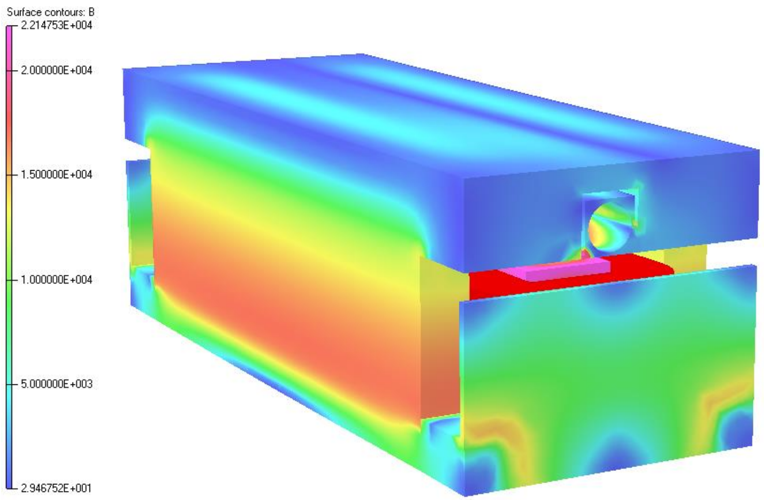


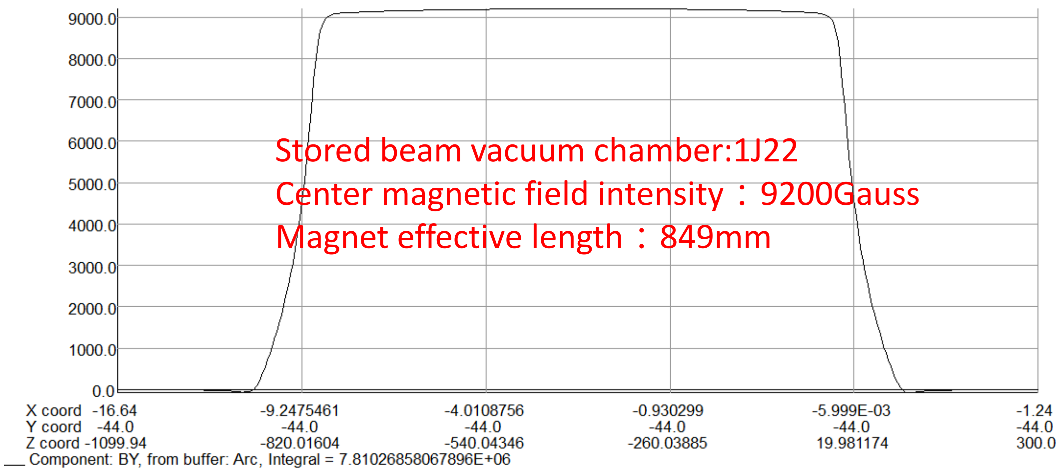
- Stored beam pipe(VP) inner diameter= ø55mm, Thickness=4mm
- Injected beam pipe (SS): inner diameter=ø29mm, Thickness=1mm
- Septum Thickness=4+1+0.5=5.5mm
- Magnet gap: 32mm
- Winding: W=70mm,H=140mm,T=128
- Exciting current=188A
- Inductance=0.0682H

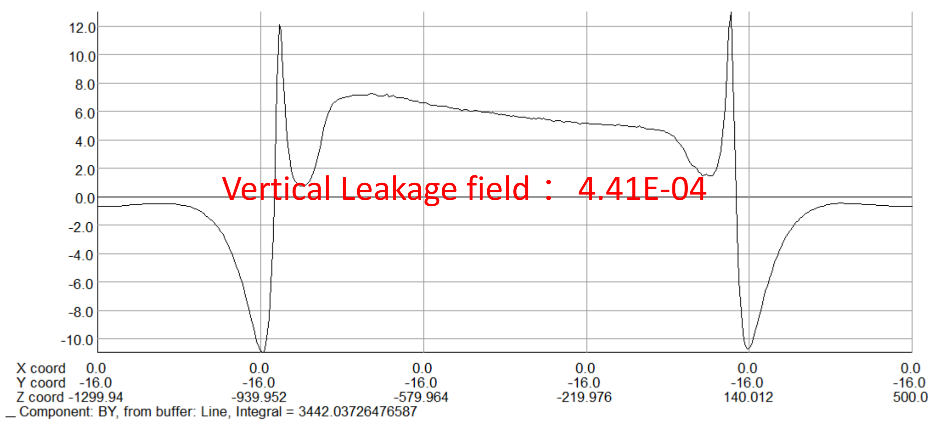


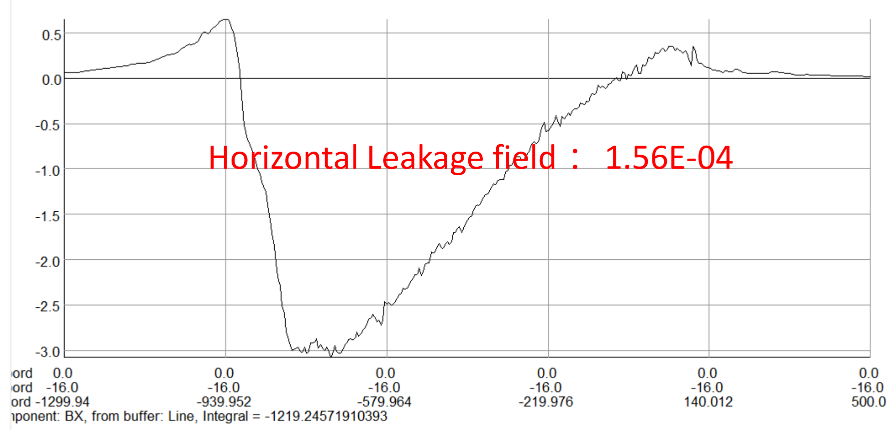


3D simulation



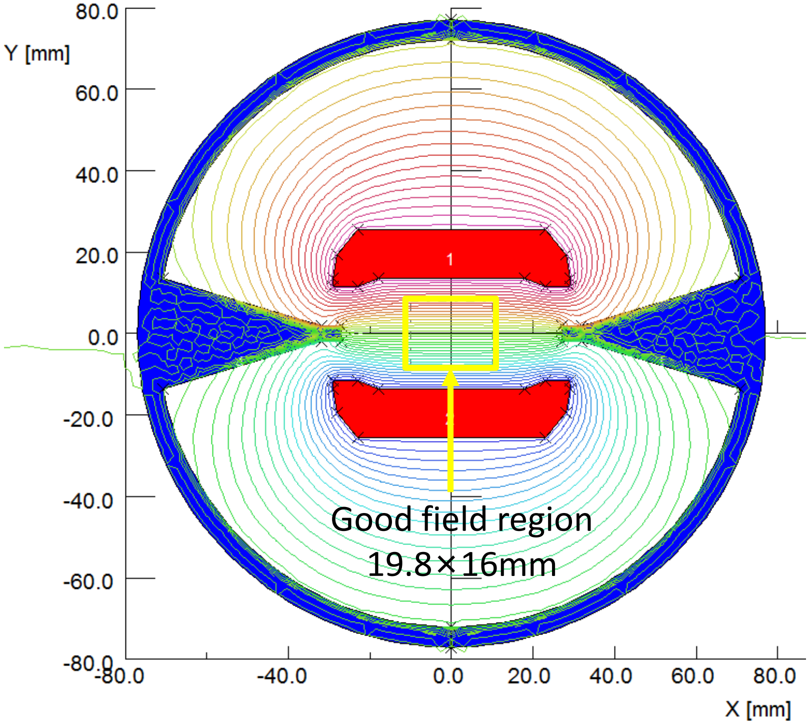


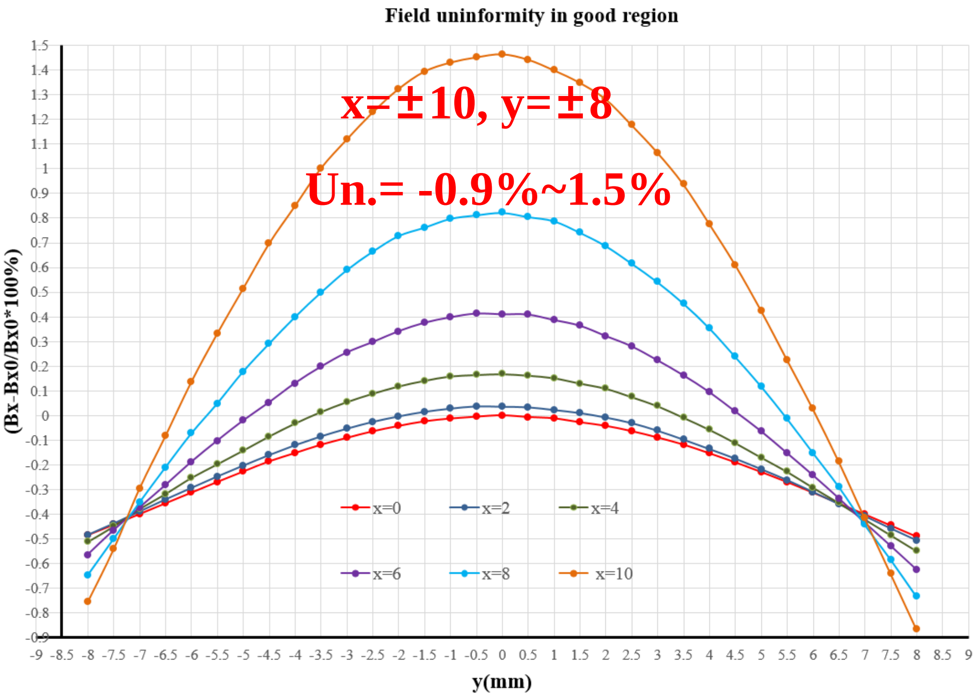




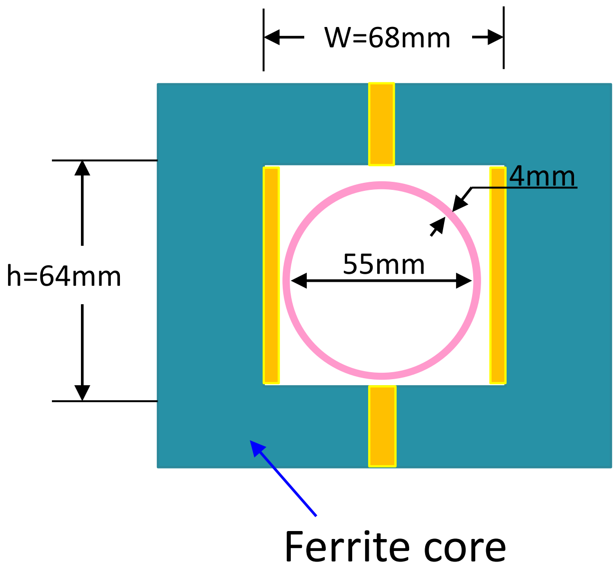
Magnet physics design

- 2D simulation model
- Max. voltage of coil: Umax=10622V
- Max. exciting current: Imax=2400A
- Magnet coil inductance=387nH
- Good field region: 19.8×16mm
- Field uniformity: -0.9%~1.5%





Kicker magnet physics design



$$L=\mu_0 \frac{w}{h} l = 4\pi \times 10^7 \times \frac{68}{64} \times 1.4 = 1.8683\mu H$$

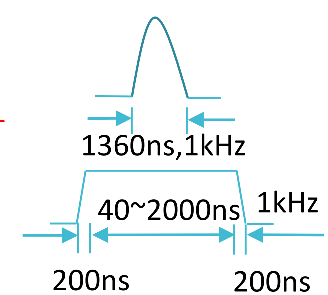
$$I=\frac{B}{\mu_0} h = \frac{0.06}{4\pi\times10^{-7}} \times 0.064 = 3.056kA$$

$$Z = 10\Omega$$

$$U=I\cdot Z = 3000 \times 10 = 30kV$$

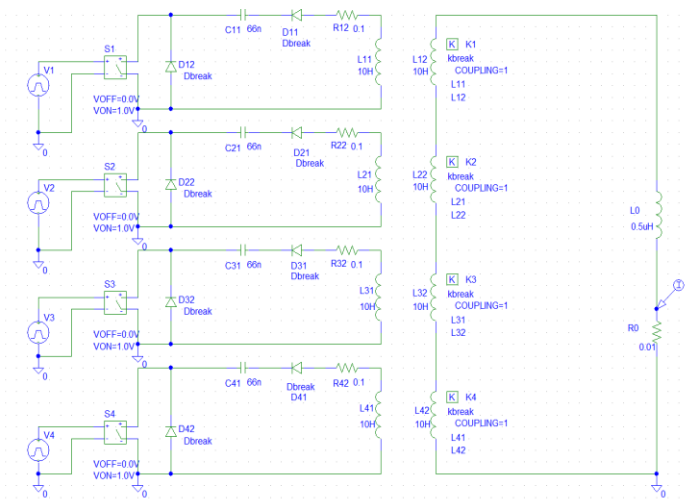
$$\tau = \frac{L}{R} = \frac{1.87 \times 10^{-6}}{10} = 187ns$$

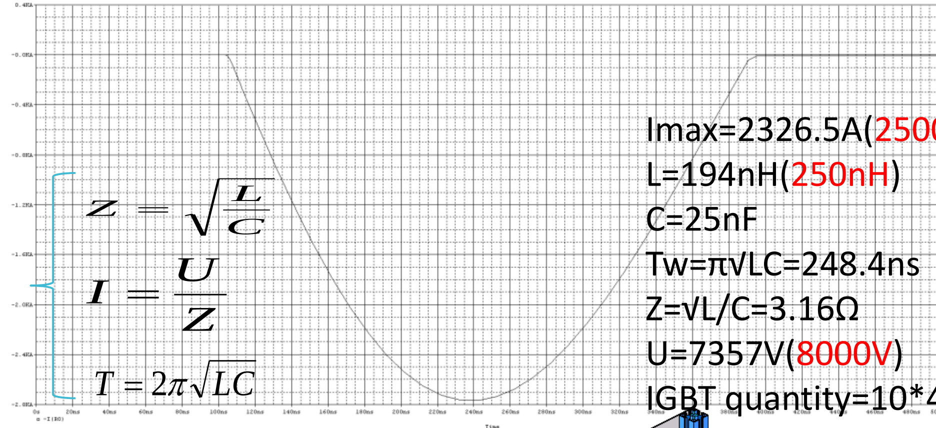
Kicker magnet type	Pulse discharge mode	Magnetic field rise time Tr (5%-95%)
Lumped parameter	Shorted end	3τ=561ns
Lumped parameter	Matching	3τ/2=280.5ns
Delay-line	Matching	τ=187ns



Novel half-sine wave pulser

- Inductive adder + LC resonance discharge circuit (IGBT+SBD)



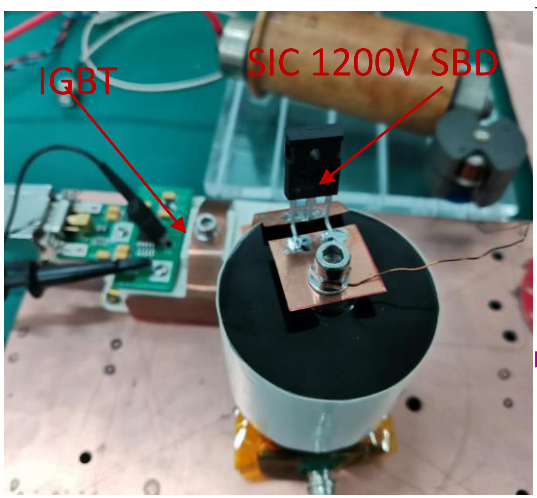


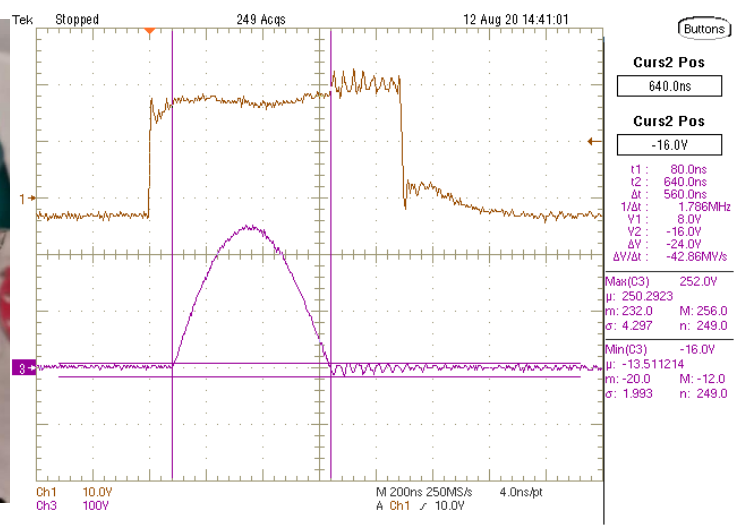
$$Z = \sqrt{\frac{L}{C}}$$

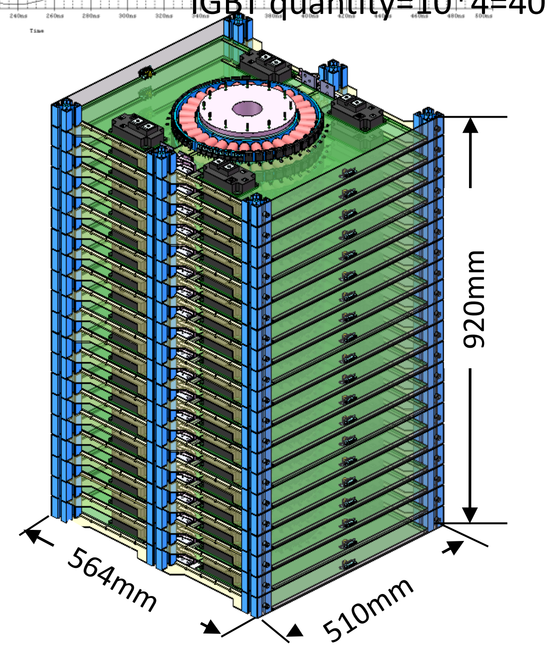
$$I = \frac{U}{Z}$$

$$T = 2\pi\sqrt{LC}$$

Imax=2326.5A(2500A)
L=194nH(250nH)
C=25nF
Tw=π√LC=248.4ns
Z=√L/C=3.16Ω
U=7357V(8000V)
IGBT quantity=10*4=40

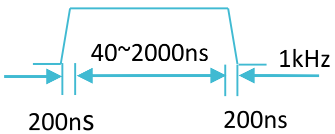




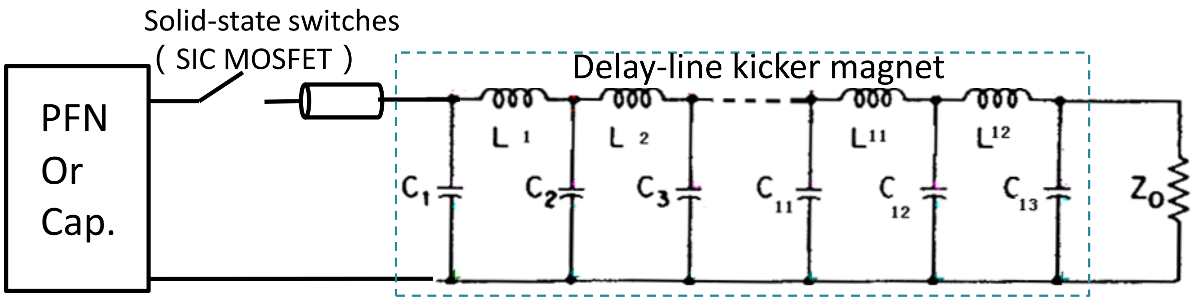


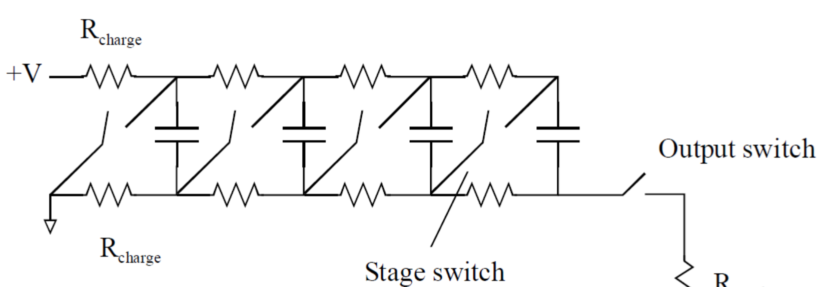
Trapezoid wave pulser

- Adjustable pulse width trapezoid waveform pulser based on SiC MOSFET
- Energy storage component
  - Capacitor ： Flat-top dropping compensate topology
  - PFN ：low impedance
- Power stacking topology
  - inductive adder: not fit for long pulse
  - Marx generator: hard to control structure impedance

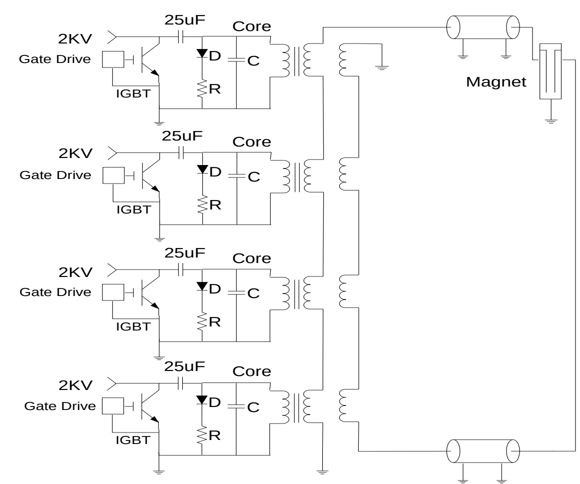


challenges





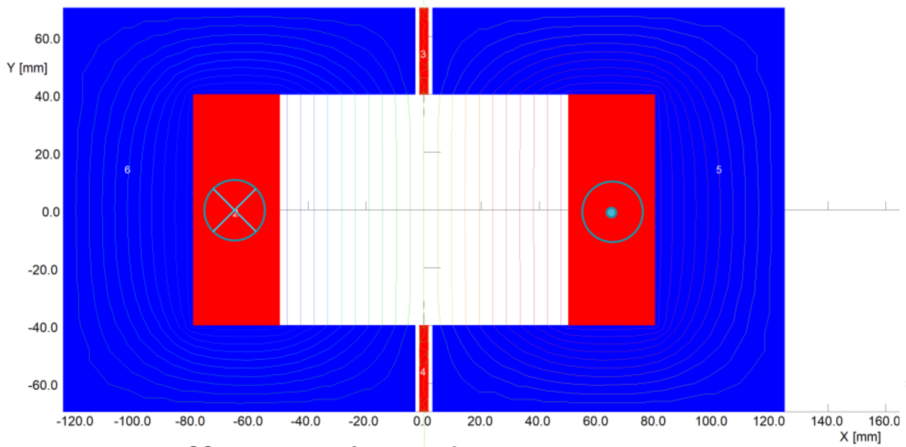
Marx generator



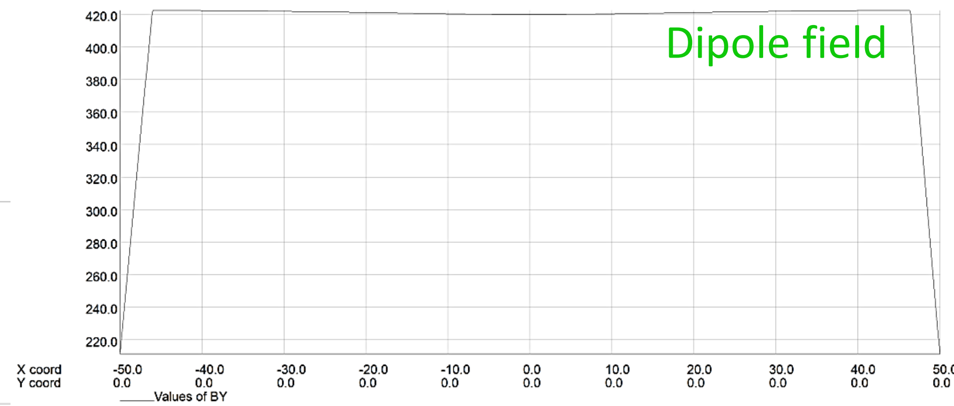
Inductive adder

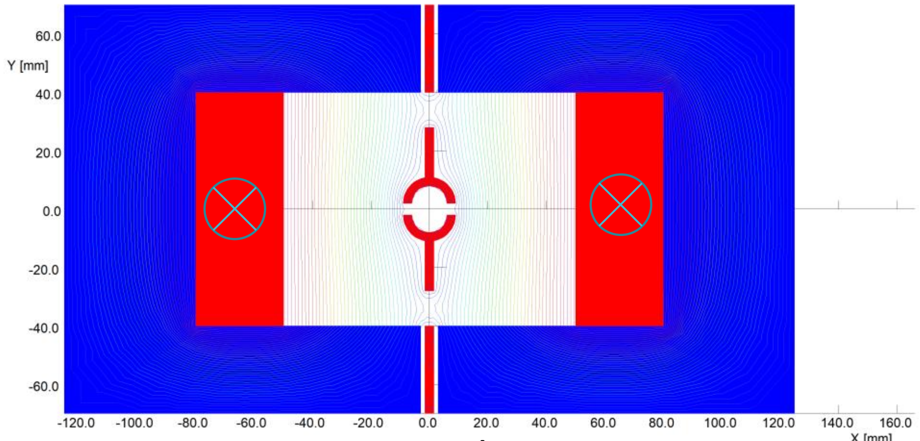
Delay-line Nonlinear Kicker (NLK)

- Thinking about if the nonlinear kicker injection is possible for CEPC, after all this top-up injection scheme should loose the requirement of DA.

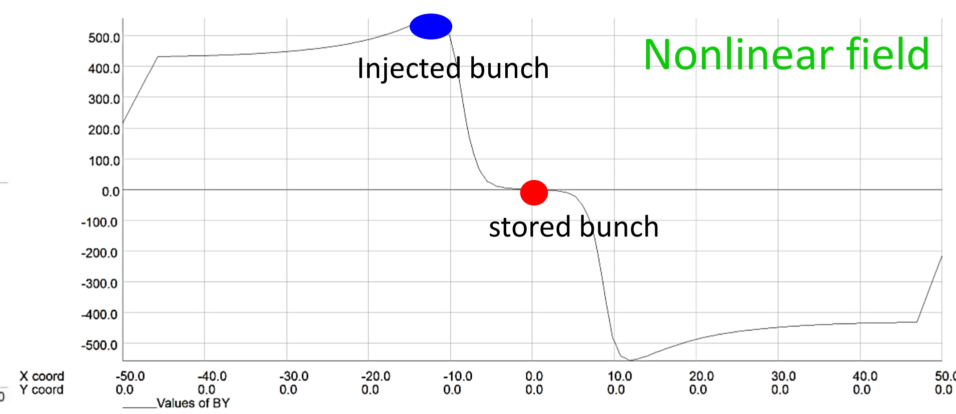


Differential mode exciting

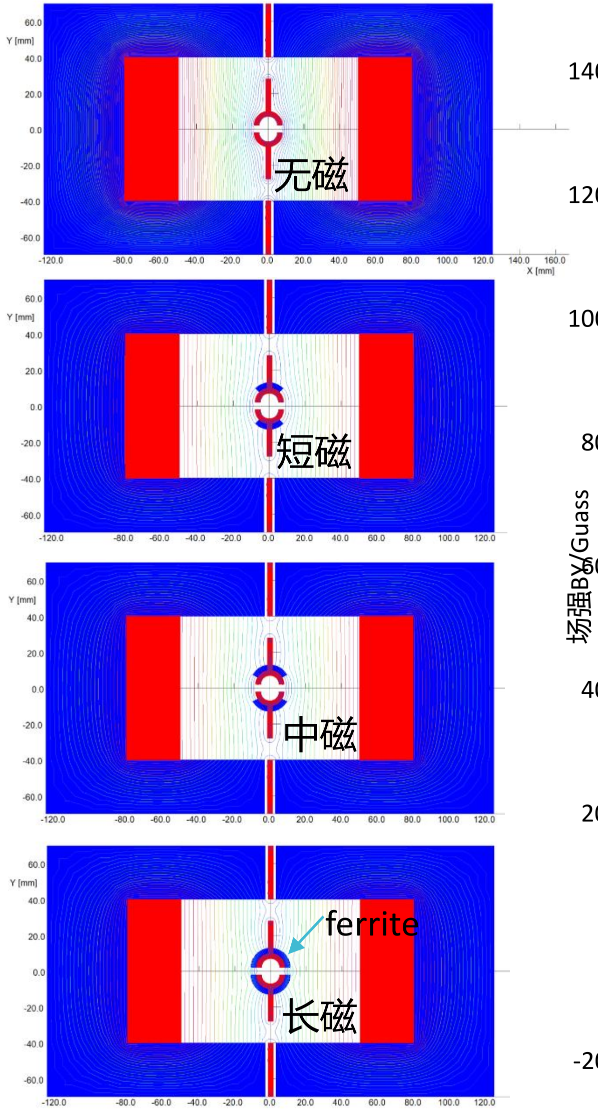


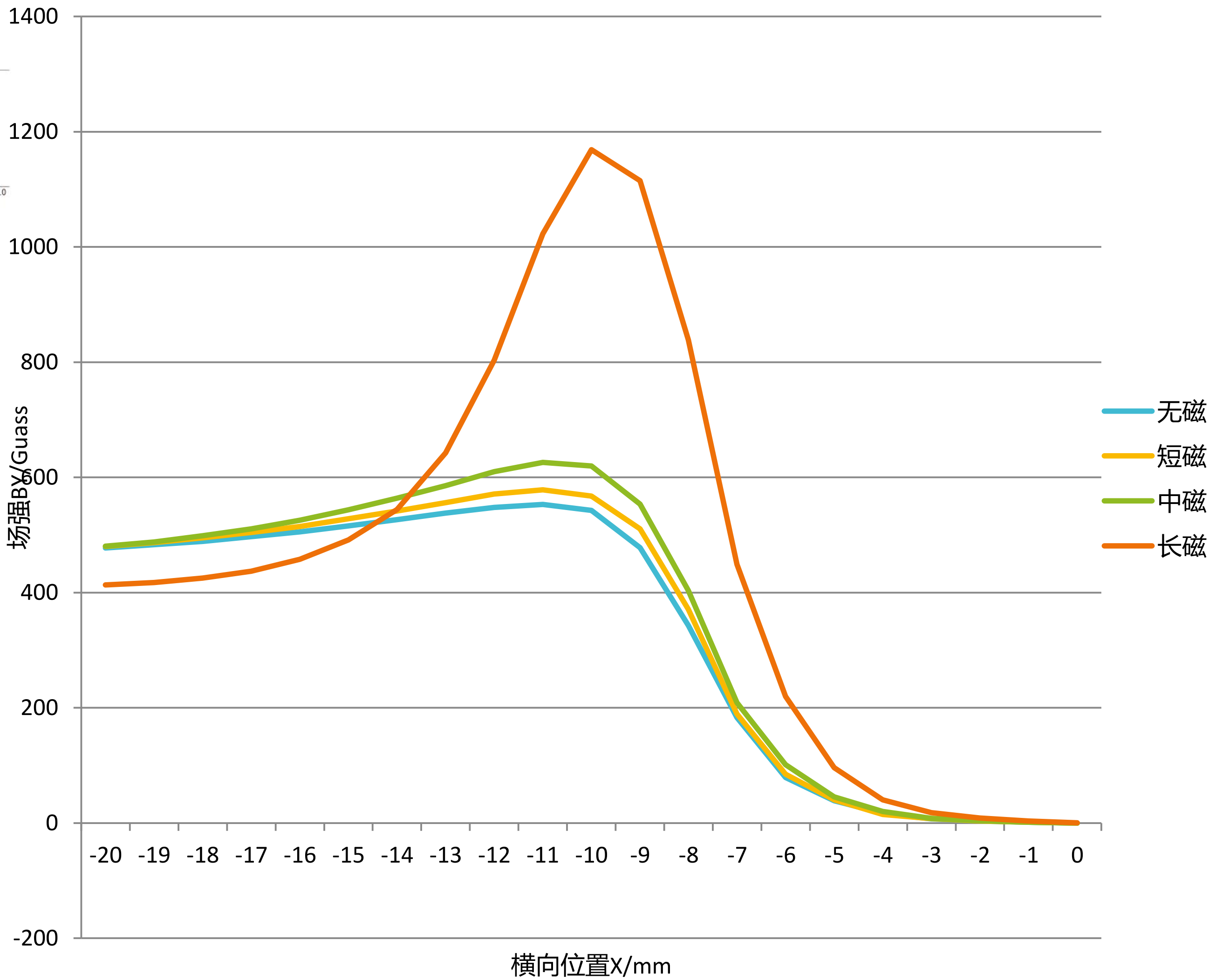


Common mode exciting



NLK physical design optimization





Delay-line NLK preliminary design