NSRL 中国科学技术大学 国家同步辐射实验室 NATIONAL SYNCHROTRON RADIATION LABORATORY

Overview of Hefei Advanced Light Facility

- HALF Project

Faya Wang

On behalf of entire project team

National Synchrotron Radiation Lab,

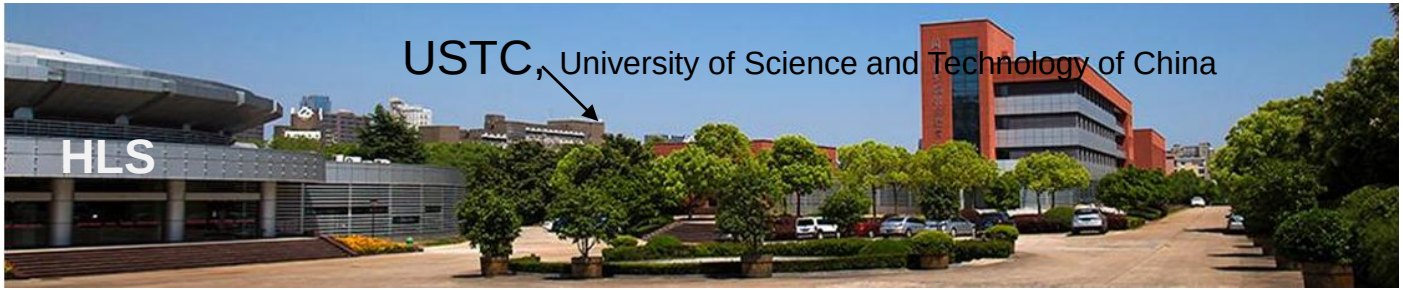
University of Science and Technology of China

2020-10-26

- National Synchrotron Radiation Lab (NSRL)
- Hefei Advanced Light Facility (HALF)
  - Needs
  - Approach
  - R&D Progress
- Summary

NSRL - National Synchrotron Radiation Lab

- **Host Hefei Light Source, HLS**
- **1st synchrotron facility in China**
- **1st light in 1984**
- **HLS has been operated over 35 years.**
- **10 beamlines**
- **There are ~ 150 staff scientists and engineers in NSRL.**



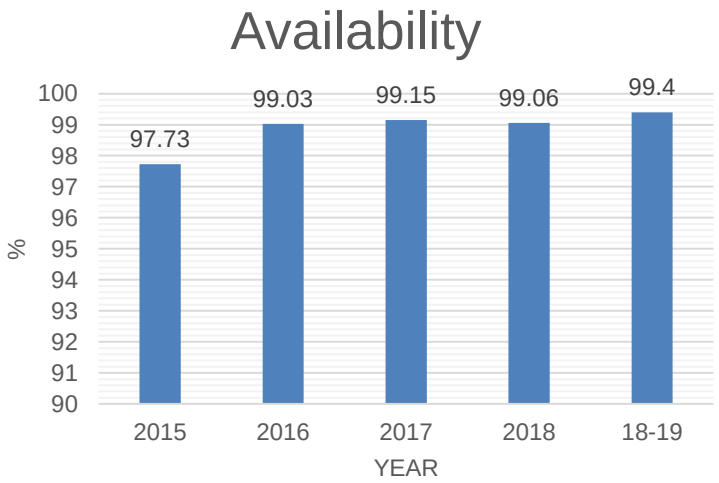
HLSI
（1984-1991）

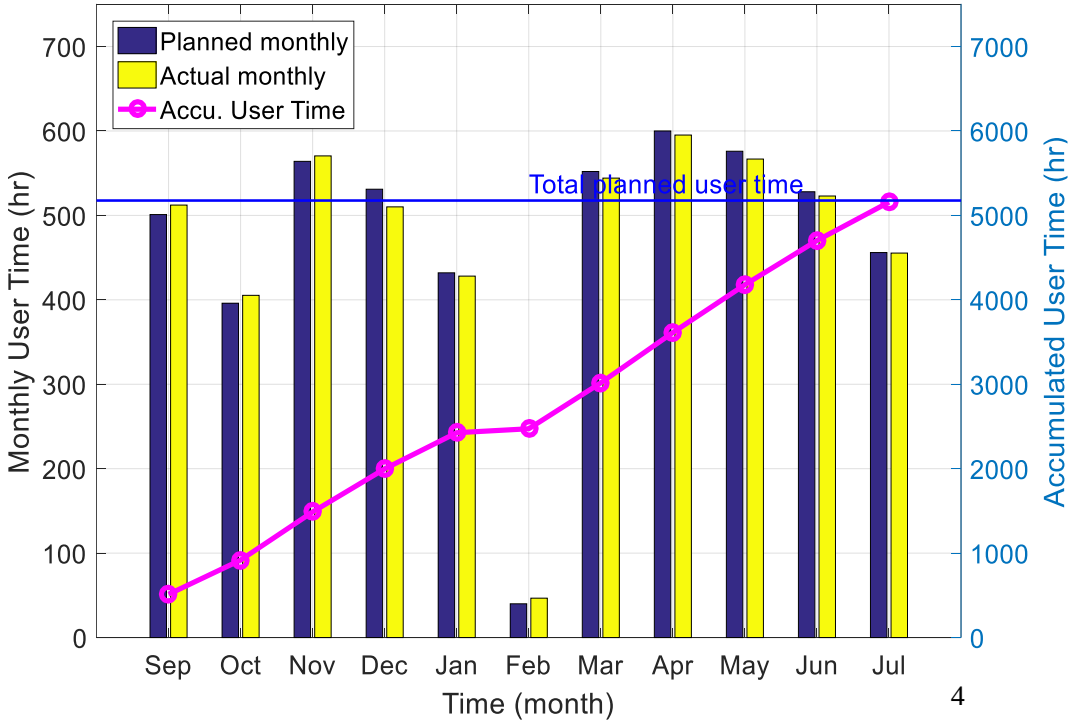
HLSII
（1998-2004）

major upgrade
（2010-2014）

Hefei Light Source (HLS) in NSRL

- **Top-off mode from Jul. 25 2018**
- **360 mA** ±1.5%
- **Total user time > 5000 hrs @2019**





Synchrotron Light Sources in Mainland China

	Energy（GeV）	Perimeter（m）	I（mA）	Natural emittance（nm rad）	Beamlines
高能同步辐射光源 (HEPS) – 4th GLS	6	1360.4	100~200	0.05-0.1	14/48SS
上海光源 (SSRF) – 3rd GLS	3.5	432	260	3.9	15
北京同步辐射装置 (BSRF) – 1st GLS	2.5	/	250	/	14
合肥光源 (HLS-II) – 2nd GLS	0.8	66.13	300	<40	10

- Total 40 available beamlines
- 7 VUV，10 soft-x

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Hefei Advanced Light Facility - HALF

4th GLS	Photon	Energy (VUV-SX)	Average brightness 10^{21} phs/mm^2/mrad^2/0.1%BW/s	Beamlines > 30
	Accelerator	A low energy diffraction limited storage ring.		

- >2800 attendees
- >100 institutes

HALF – Key Performance Parameters

Energy:

2.2 GeV

- Natural emittance $\propto E^2$
- Magnetic gradient $\propto E^1$
- Lattice radiation loss $\propto E^4$
- Equilibrium emittance (IBS) $\propto E^{-4}$
- Instability growth rate $\propto E^{-1}$
- Radiation wavelength $\propto \lambda_p/E^2$

Emittance:

< 100 pm

- Undulator radiation (opt@max. Brigthness): $\varepsilon_r \approx \lambda/2\pi$
- ebeam emittance: $\lesssim \frac{1}{2}\varepsilon_r = \lambda/4\pi \approx 100[pm]/E_P[keV]$
- Spatial coherence: ~ 44%

Size:

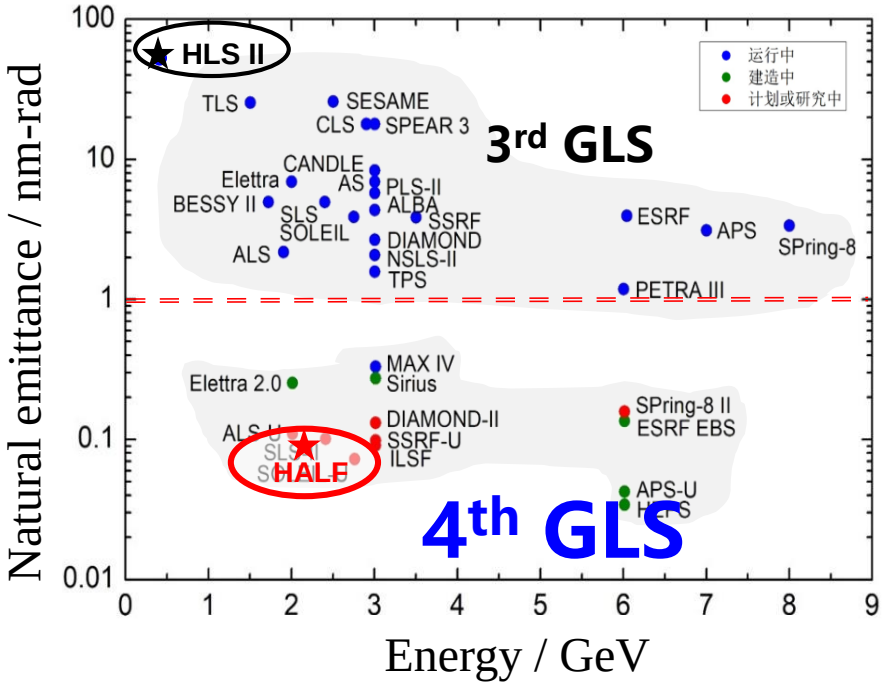
~ 500 m

- greatly depends on energy and emittance
- beamlines, cost, feasibility → long straight section + mid-ss

HALF – Key Performance Parameters

- **An Advanced Lower Energy 4th Generation Light Source.**

Parameters	ALS-U	SLS-2	Elettra 2.0	HALF
Eng/GeV	2.0	2.4	2.0	2.2
Perimeter/m	196	290	259	480
Periods	12	12	12	20
SS	12	12	12	40
Natural emittance/pm·rad	110	120	250	< 100
Current/mA	500	400	400	350
Average brightness/10^{21}	~4	1	2	> 1

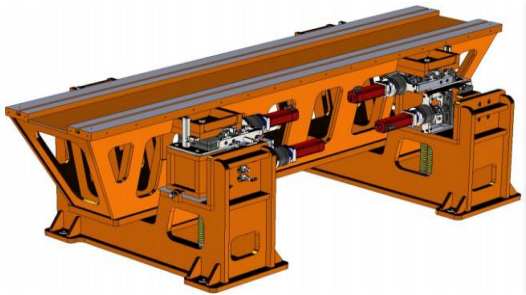


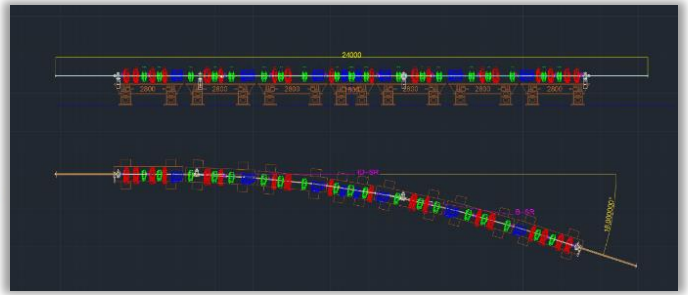
HALF - R&D Scope

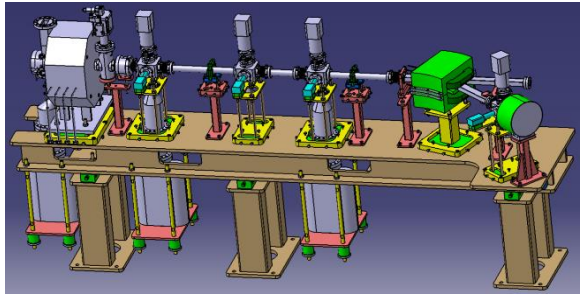
- **Timeline: 2017/12 – 2020/12**
- **Goal: to develop essential technologies**

  ✓ **Storage ring： lattice design, magnet, RF, vacuum, beam diagnostics, magnet support and alignment system, control system et al；**

  ✓ **injector： physics design, high quality electron source**







HALF - R&D Scope

High brightness photons： high brightness electrons

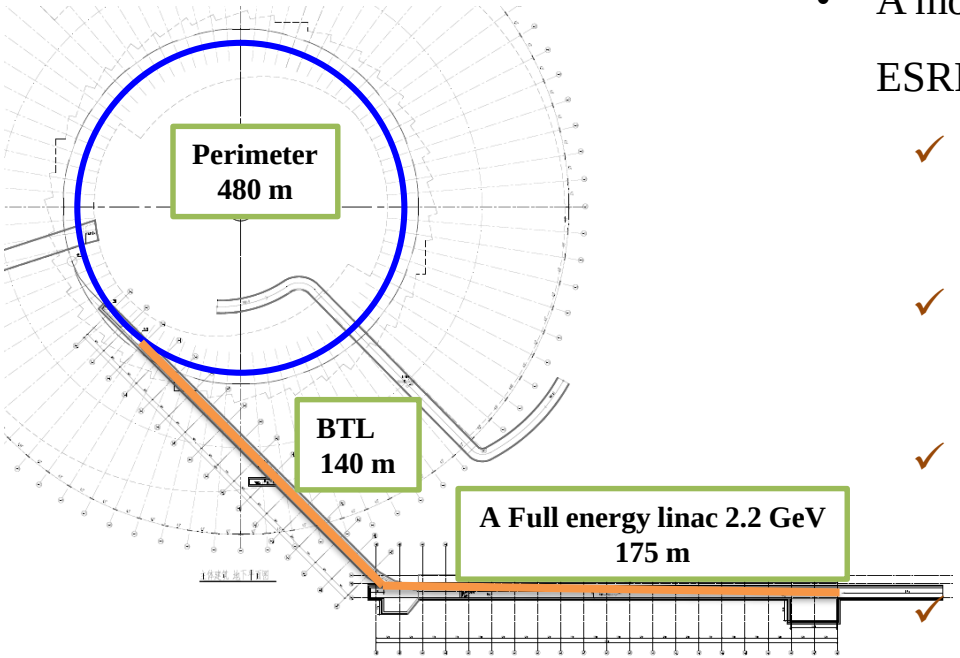
- **Design**
  - Single particle dynamics
  - Collective effects
  - Error study
  - Injection scheme
    - Hybrid 6BA Lattice (fulling coupling)
    - SCRF 500 MHz
    - Active HHC, 1500 MHz
    - Damping wiggler for IBS and IDs
    - Off-axis injection w/ nonlinear kicker
    - A full energy S-band linac w/ photo rf gun
- **Implement**
  - Magnet
  - Girder
  - Power supply
  - Alignment
  - Vacuum
  - RF
  - Injection
  - Injector
- **Maintain**
  - Work point: WP feedback
  - Orbit stability： SOFB + FOFB
  - Instability： Bunch by bunch feedback
  - Rf: LLRF

Low emittance @high current

$$B_{ph} \propto B_e \propto \frac{I_e}{\varepsilon_x \varepsilon_y}$$

HALF - Global Design Approach

Lattice Highlights:

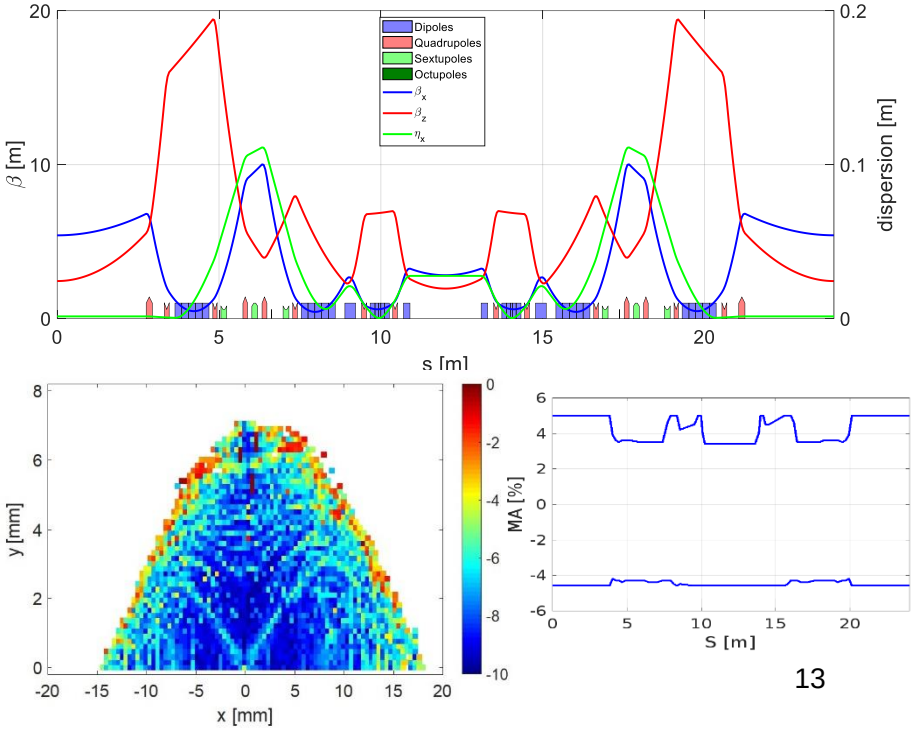


- A modified hybrid MBA lattice with advantages of both ESRF-EBS and SLS-2 lattices, which
  - ✓ has low emittance while still preserve good nonlinear beam dynamics.
  - ✓ has a reasonable damping time for a such a low energy and large footprint storage ring.
  - ✓ has a very high ratio of up to 32% of straight section to the ring perimeter.
  - ✓ needs only moderate magnetic field strength and gradient.

HALF – Lattice

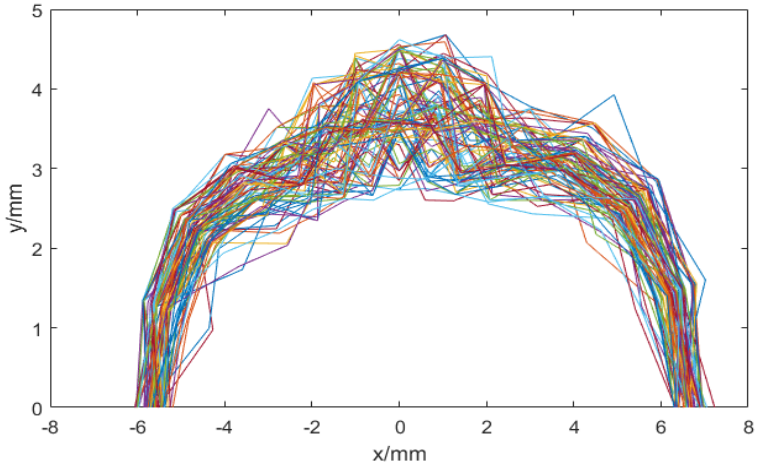
- **A modified Hybrid MBA: 6BA**
- **Has 40 straight sections and very large DA**

Parameters	value	Unit
Energy	2.2	GeV
Natural em	85.1	pm·rad
Perimeter	480	m
Work point	48.175/17.175	-
Natural energy spread	6.6e-4	-
Natural chromaticity	-75/-59	-
Energy loss	217.5	keV
Momentum compaction factor	6.3e-5	-
Damping time (H/V/L)	22/32.4/21.2	ms
LSS length	5.5	m
MSS length	2.2	m

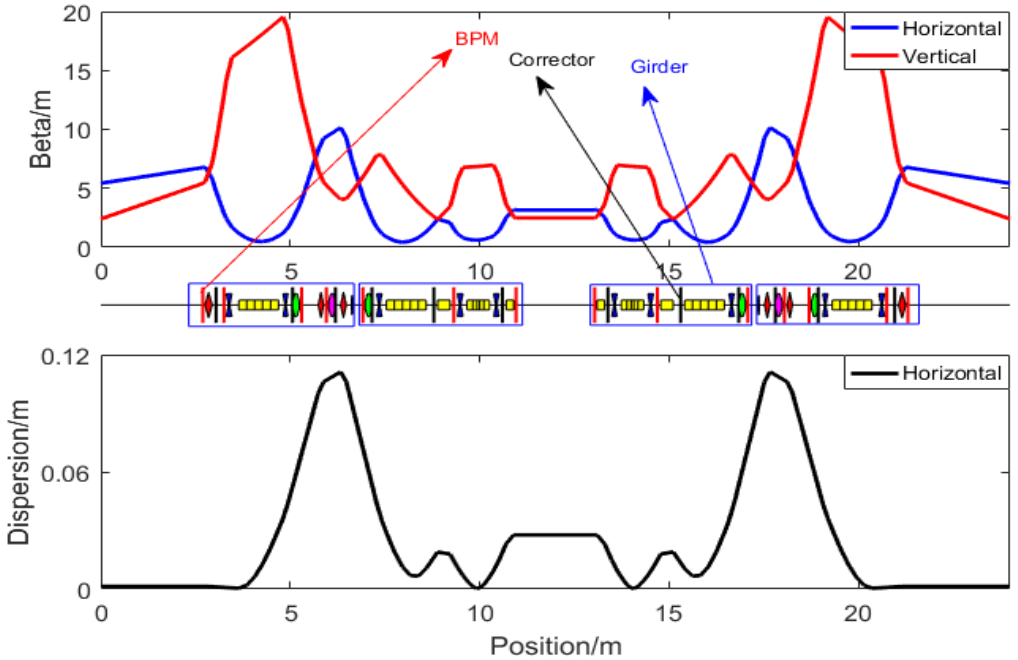


HALF – Lattice

Error list	value
Between girder （T/L）	50/150 um
Q, S, O(T/L)	30/150 um
Diploe (LGB)	200 /150um
D, Q, S, O angle	0.4 mrad
D,Q,S,O integral field (gradient)	1e-3

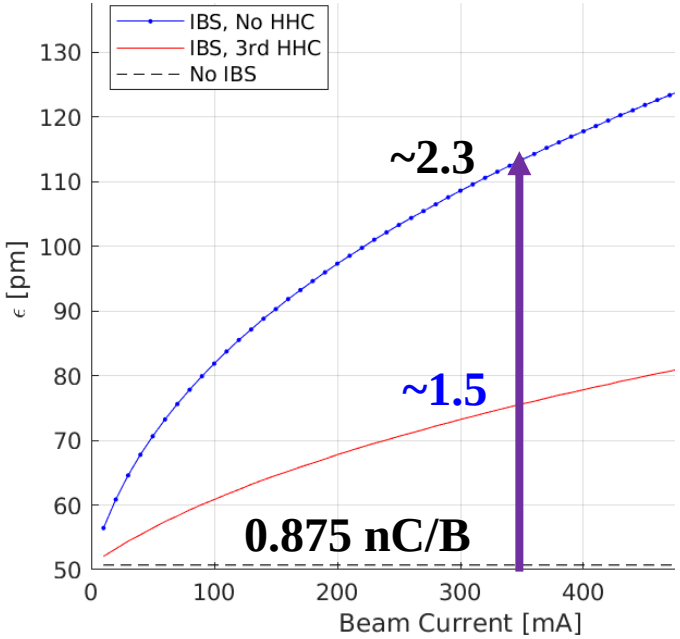


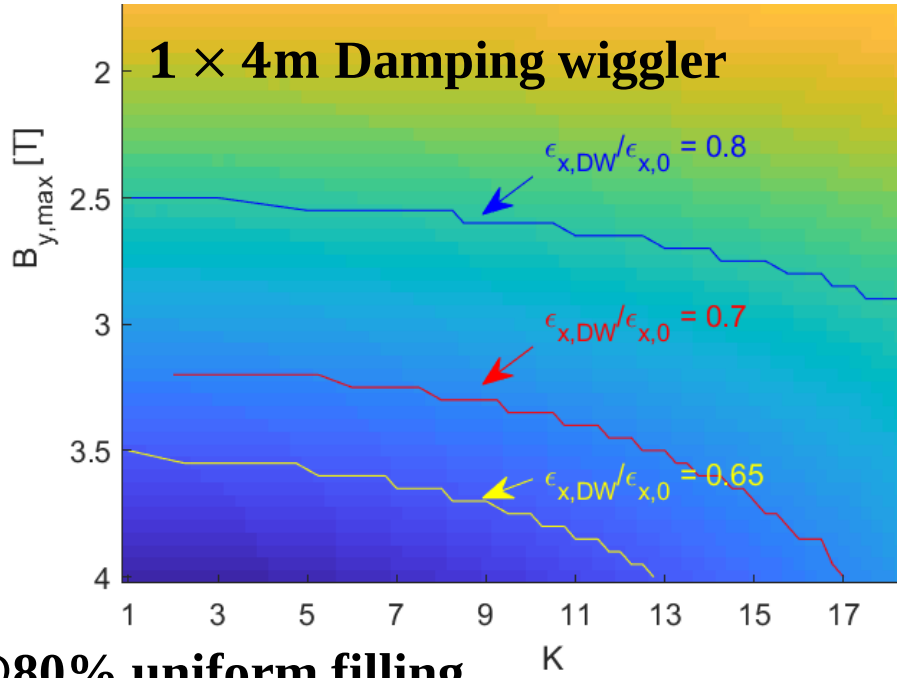
- Corrector strength (H/V)： < 0.3 mrad
- 14 BPMs and 12 correctors per cell



HALF – Lattice

- **IBS suppression: 3HHC + Damping Wiggler ($\lambda_p = 80\ mm$)**





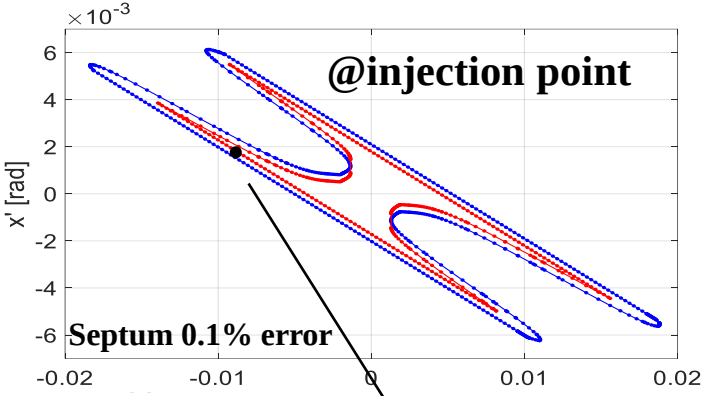
5x lengthening @ full coupling@80% uniform filling

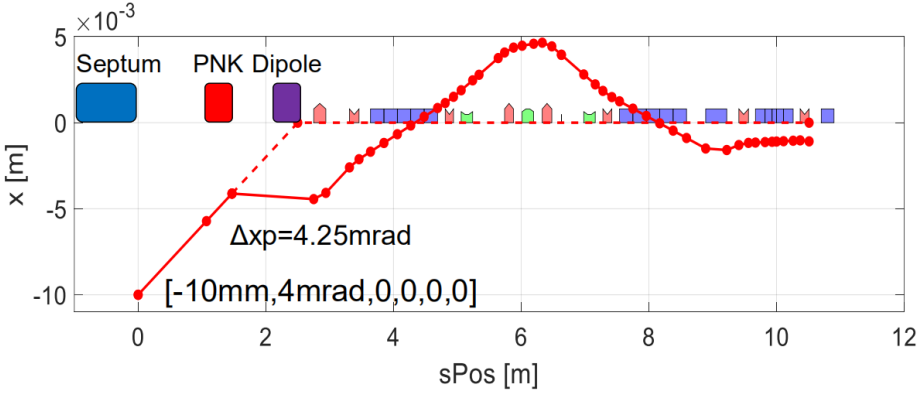
Injection

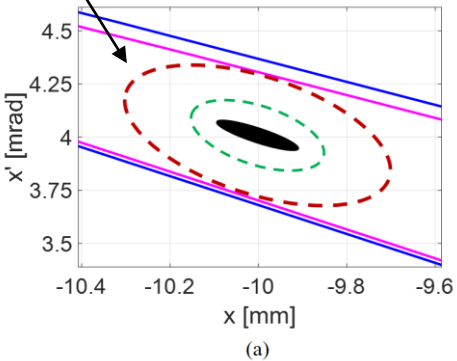
- **Off-axis injection : a full energy linac + Septum + NLK**

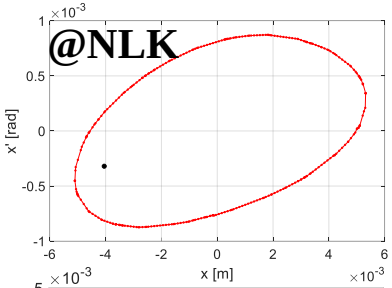
S-band Linac

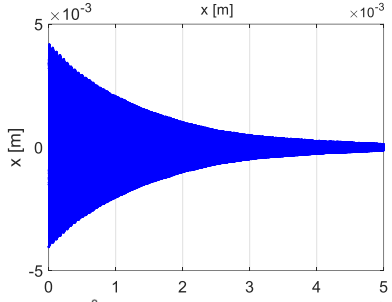
Parameters	
Energy	2.2 GeV
Emittance	< 0.5 nm
Energy spread	<0.05%

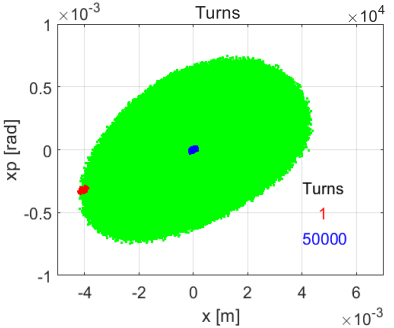












Ring RF system

❖ Main rf: 500 MHz, ~1 MV

- **SCRF: 1/2 MV, 1 cavity, ~4m, a long straight section**
- **NCRF: 1/2 MV, 2 cavities, 2m, a middle straight section**

	cavities	RF power: kW （350mA, 2U0)	RF power: kW （500 mA, 3U0)	SS
SCRF	2	173	428	2L
NCRF	4	200	448	1L
SCRF+NCRF	**1+2**	**173/2+200/2**	**438**	**1L+1M**

❖ HHC: 1500 MHz, ~1/3 MV, 3 NCRF cavities

Essential Technologies

Magnet

Girder

Power Supply

Alignment

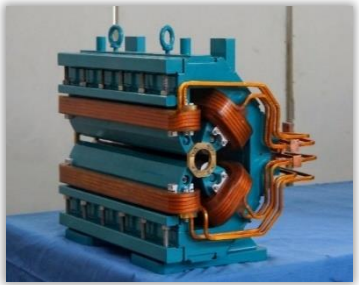
Vacuum

RF system

Injection

Injector

- **High gradient quadrupole and sextrupole**
- **Longitudinal gradient bending magnet**

	LGB	Combined D/Q	Quadrupole	Sextrupole
Field/gradient	0.29~0.69 T /7	0.27 T，25 T/m	>=80 T/m	>3000 T/m2
Good field	± 5 mm			
Aperture	≥26 mm			
Integral field err	$<5\times10^{-4}$			

Essential Technologies

Magnet

Girder

Power Supply

Alignment

Vacuum

RF system

Injection

Injector

- 6D freedom
- Range[H/V]：≥ 6 mm
- Resolution：< 2 μm (20% beam size)
- Precision：< 10 μm (50% beam size)
- Amplification factor：~ 1
- Lowest resonance：> 30 Hz

Measurement：

- **Range [H/V]:+/- 9mm**
- **Precision: 4 μm**
- **Resolution: 1 μm**

Essential Technologies

Magnet

Girder

Power Supply

Alignment

Vacuum

RF system

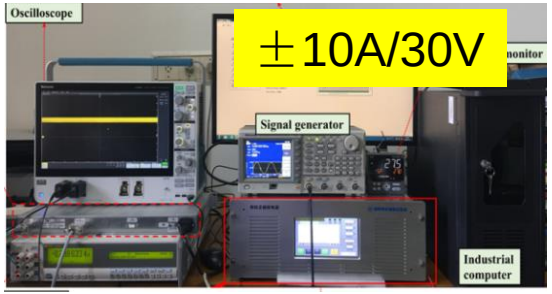
Injection

Injector

- **High current polarized DC power supply: long term stability below 10 ppm / 2 vendors.**
- **Low current bi-polar DC power supply: long term stability around 20 ppm and small signal bandwidth of 5 kHz / 3 vendors.**

800A/200V

200A/40V



±10A/30V

Essential Technologies

Magnet

Girder

Power Supply

Alignment

Vacuum

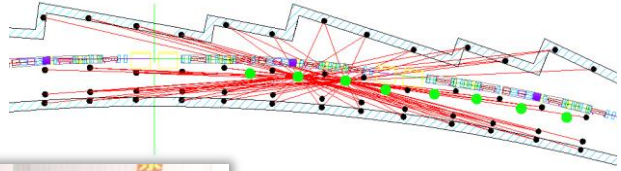
RF system

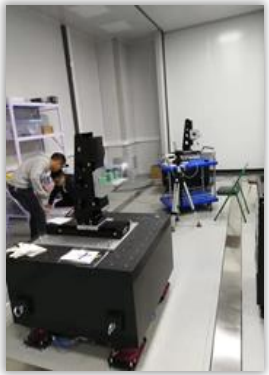
Injection

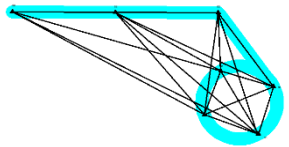
Injector

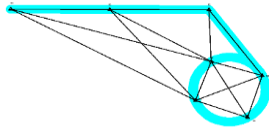
Requirement：30 um/50 um (within girder/in between)

- **Surface network: 7 control points with absolute precision of 2~3 mm**
- **Tunnel control network: 5 pts/4m with relative precision of 0.2 mm**
- **Pre alignment： stretched wire (10 um)**
- **In field：laser tracker （50 um）**









Essential Technologies

Magnet

Girder

Power Supply

Alignment

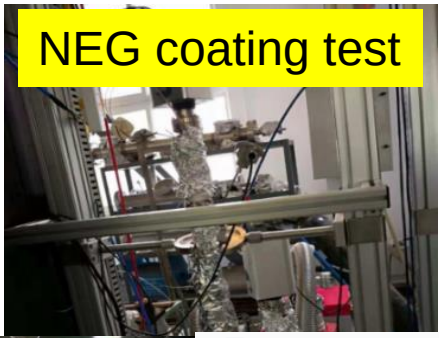
Vacuum

RF system

Injection

Injector

- **Small aperture and large dimension**: **NEG coating**
  - **Dynamic < 10E-7 Pa**
  - **Static < 10E-8 Pa**
- **"Special care" components**： **flange, bellows, photon absorber et al.**



Essential Technologies

Magnet

Girder

Power Supply

Alignment

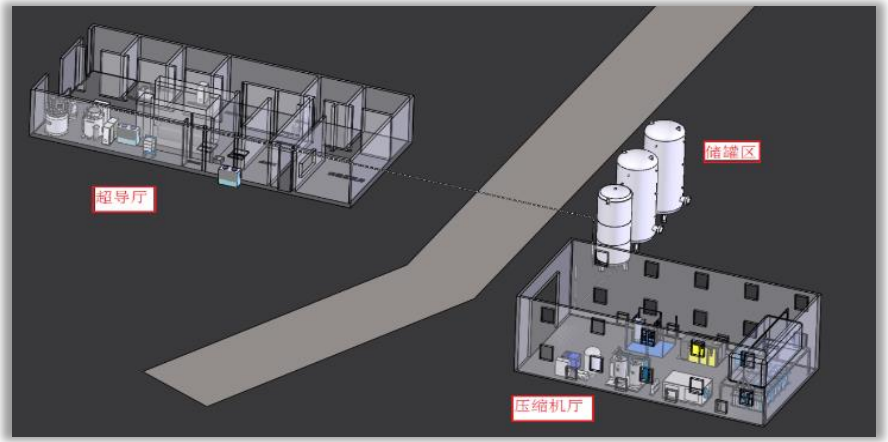
Vacuum

RF system

Injection

Injector

- **A cryogenic system of 250 watts cooling capacity is on the way.**



Essential Technologies

Magnet

Girder

Power Supply

Alignment

Vacuum

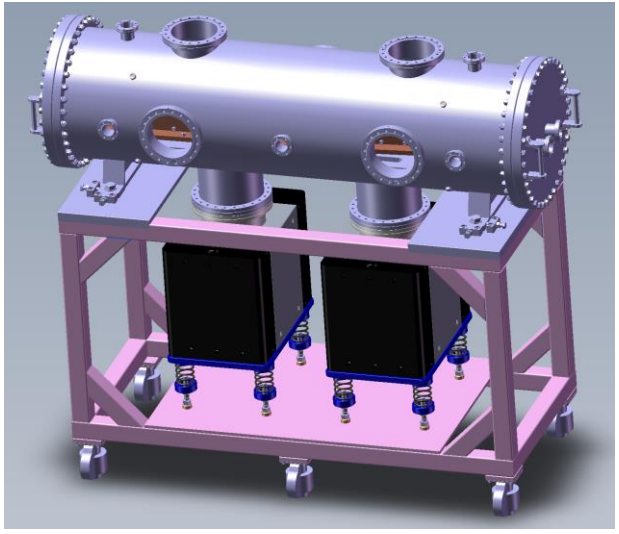
RF system

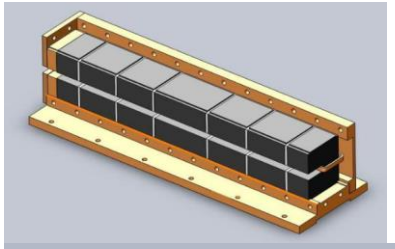
Injection

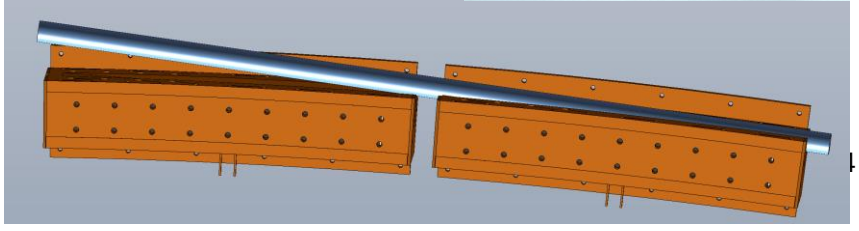
Injector

- **Septum**
- **Non linear faster kicker**

Total length	**2×650 mm**
Magnetic field method	Eddy current, in-vacuum
Septum plate	2 mm
Total deflection	120 mrad
Aperture	30mm×12mm (H, V)
Magnetic field	0.73T@7.0kA
Stray field	~5e-4



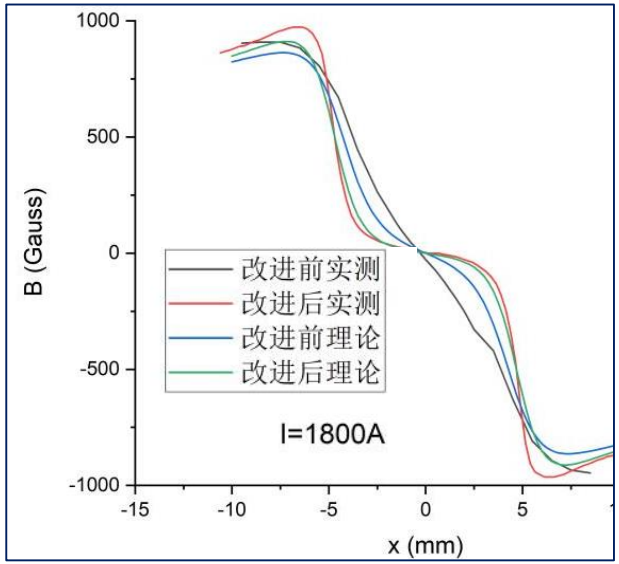


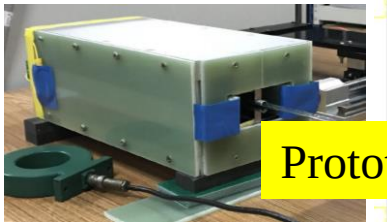


Essential Technologies

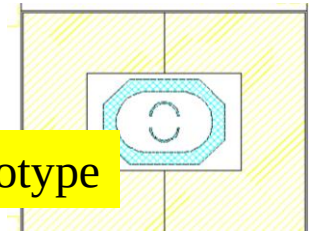
- **Septum**
- **Non linear faster kicker**

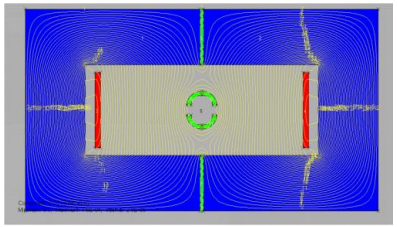
Main parameters	
Aperture (mm×mm)	85×36
Length (mm)	300
Gap between the two shields (mm)	12
Magnet inductance (μH)	9.83
Peak B field location (mm)	6

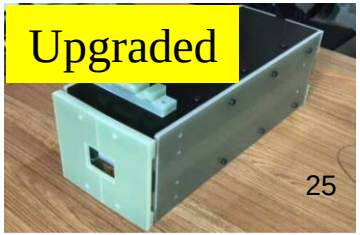




Prototype







Upgraded

Essential Technologies

Magnet

Girder

Power Supply

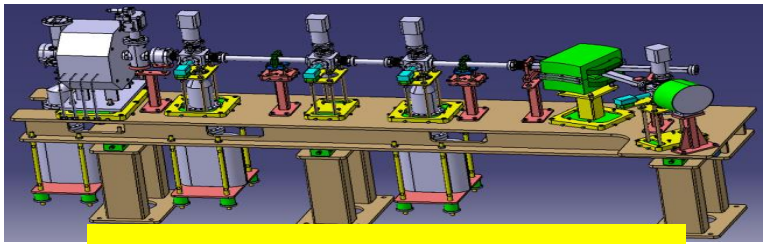
Alignment

Vacuum

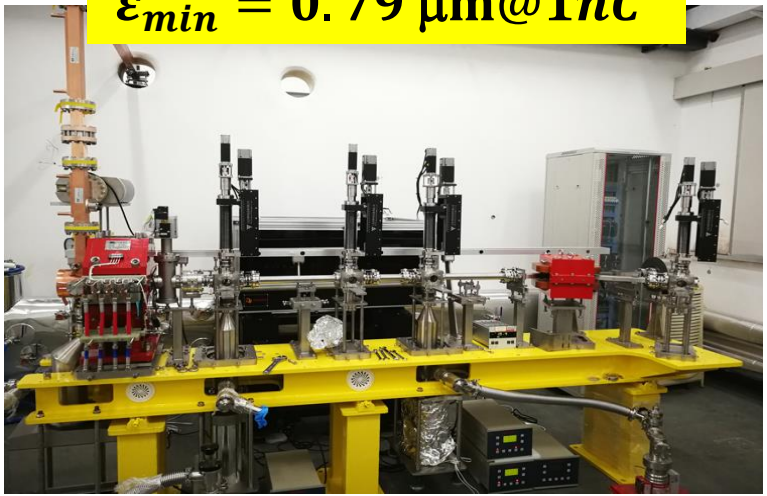
RF system

Injection

Injector



$\varepsilon_{min} = 0.79\ \mu m@1nC$



Main parameters	Requirement	Simulation
Energy	2.2GeV	2.2GeV
Normalized em (H/V)	2.0mm ·m rad	1.2/1.1mm · mrad
Maximum bunch charge	1nC	1nC
dE/E	<0.05%	0.0415%
Energy stability	<0.05%	0.0172%
dX	<20 μm	<1 μm
dY	<20 μm	<1 μm
length		175m

Summary

- **Design:**

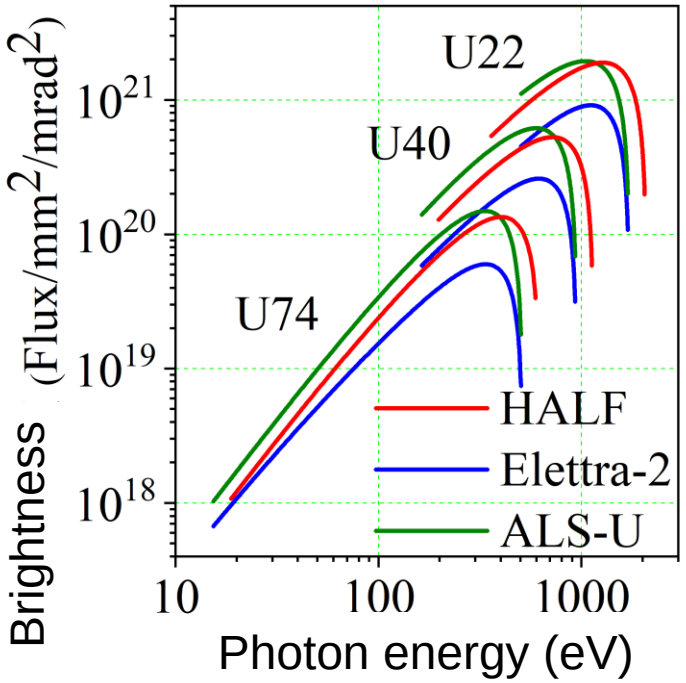
  1）high ratio of SS/C(32%)

  2）high usability of SS sections（~35/40， 5 = 1injection + 2SRF + 1DW + 1HHC）

  3）large DA: high injection efficiency

  4）large MA: long beam life time

- **Engineering:** a technically feasible project.



Thanks

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