(Alternative) Design for BEPCII Upgrade

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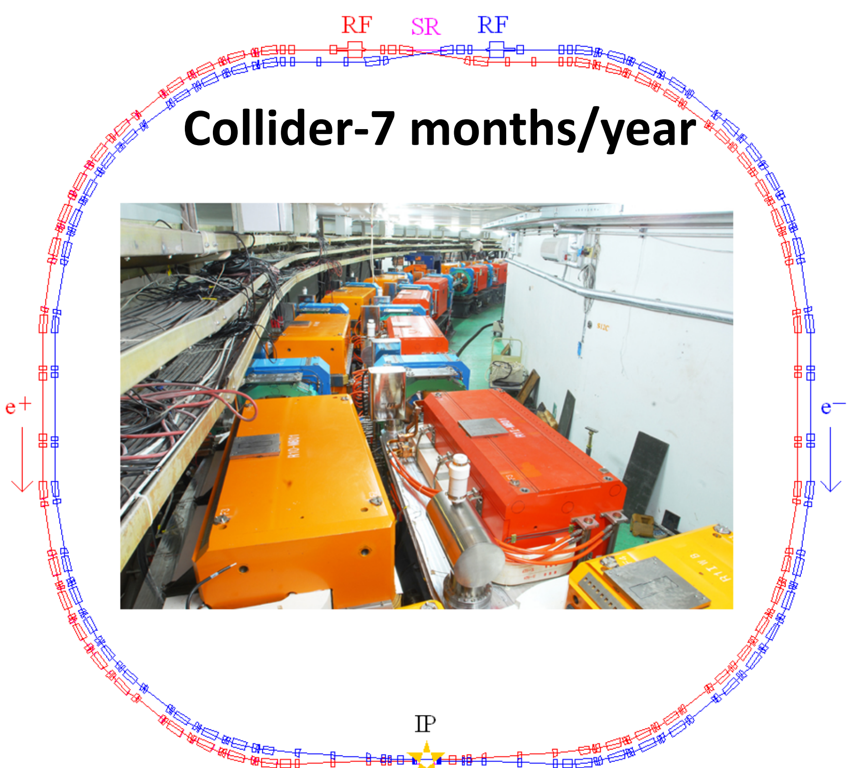
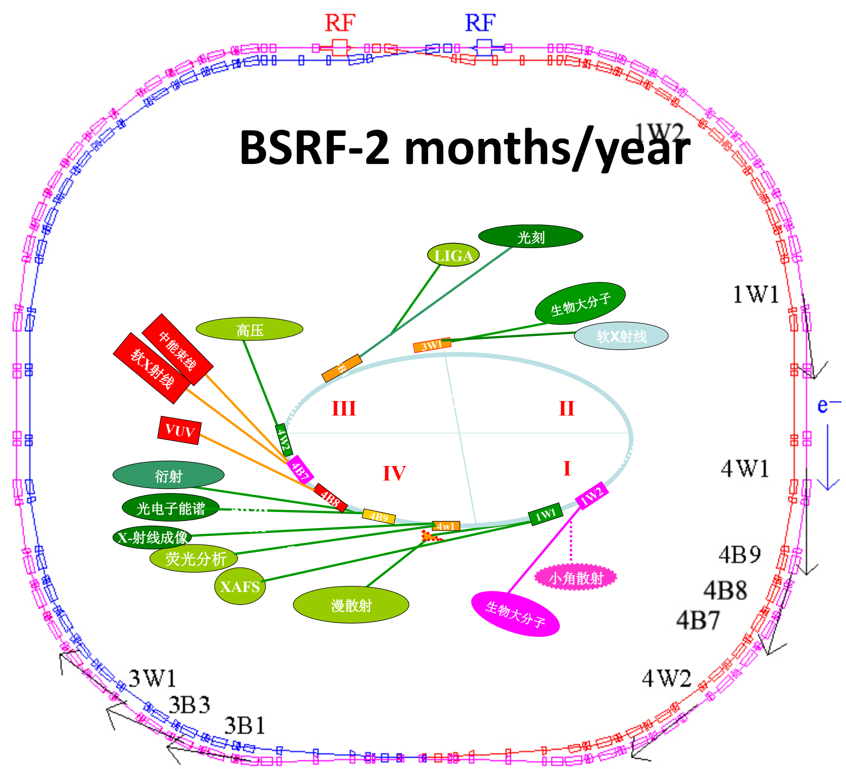
Outline

- Introduction to BEPCII
- The upgrade program
- Lattice design
- Key hardware upgrade
- Schedule
- Summary

Introduction to BEPCII

- BEPC II is a two-ring e+e- collider running in the tau-charm energy region (Ecm = 2.0-4.2 GeV)
- The collider consists of two 237.5 m long storage rings, one for electrons and one for positrons. They collide at the interaction point with a horizontal crossing angle of 11*2 mrad
- The machine also provides a high flux of synchrotron radiation at a beam energy of 2.5 GeV, known as Beijing Synchrotron Radiation Facility.





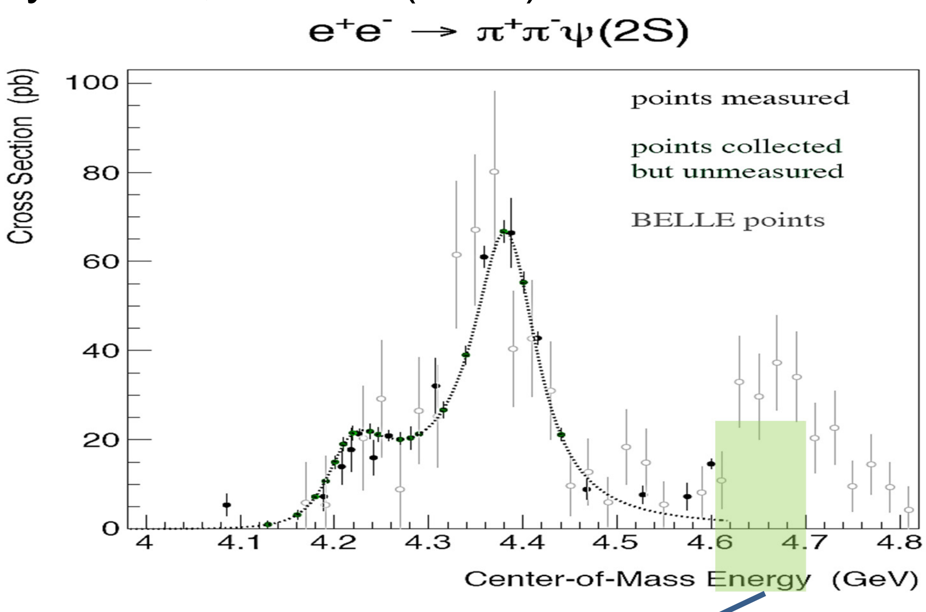
Why the upgrade

- In 2020, the proposed remainder samples for future physics was released by BESIII. They are mostly in higher energy than the maximum designed energy of BEPCII
- Assuming current BEPCII luminosity performance, another 12 years will be required to complete the remainder data taking
- So, an upgrade to enhance the luminosity performance and enlarge the energy range is expected

Future Physics Program of BESIII, Chin. Phys. C 44, 040001 (2020)

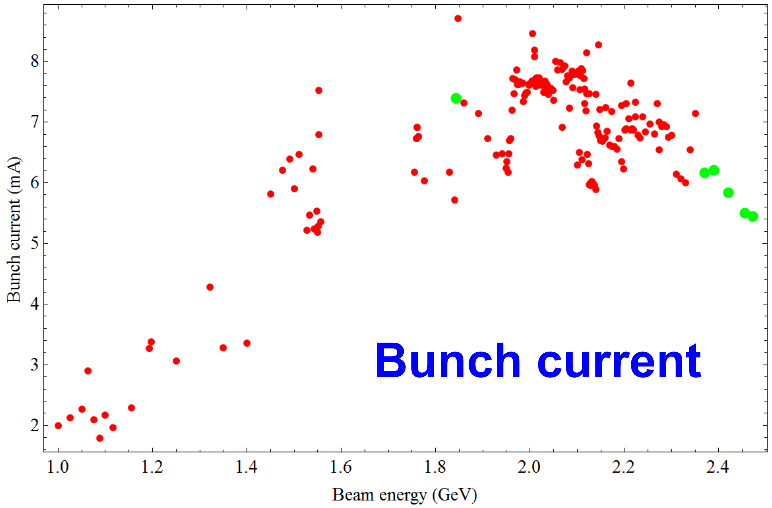
Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

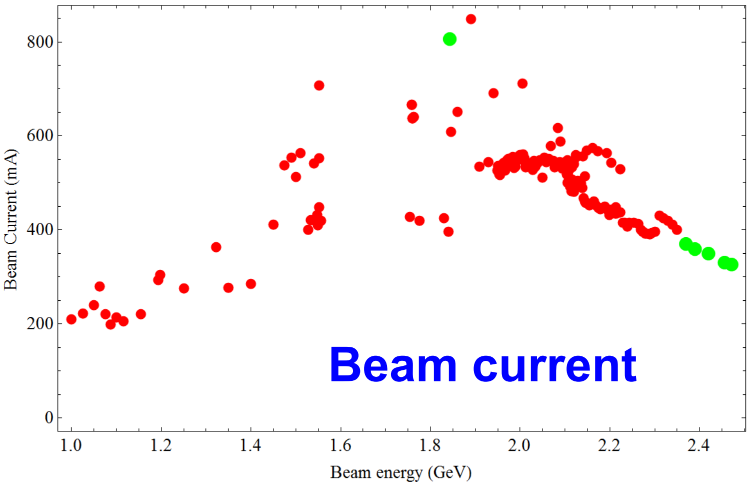
Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days



3.6 fb^{-1} in 2020 (186 days)

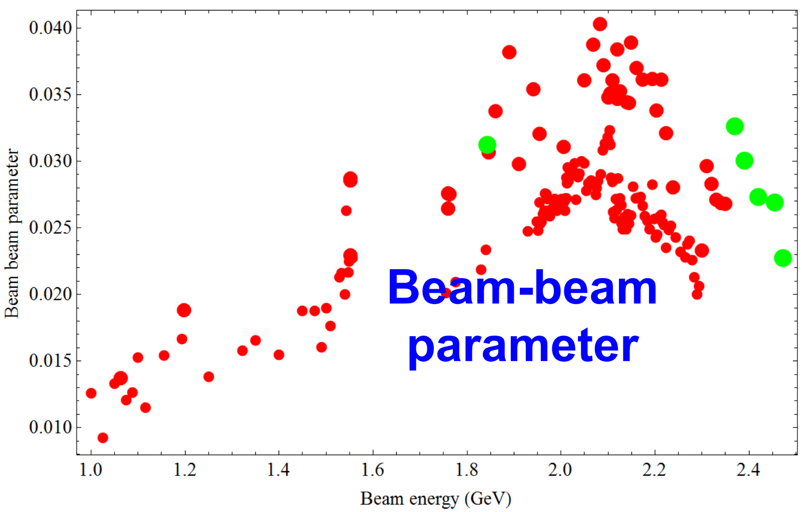
Status of Beam performance at BEPCII

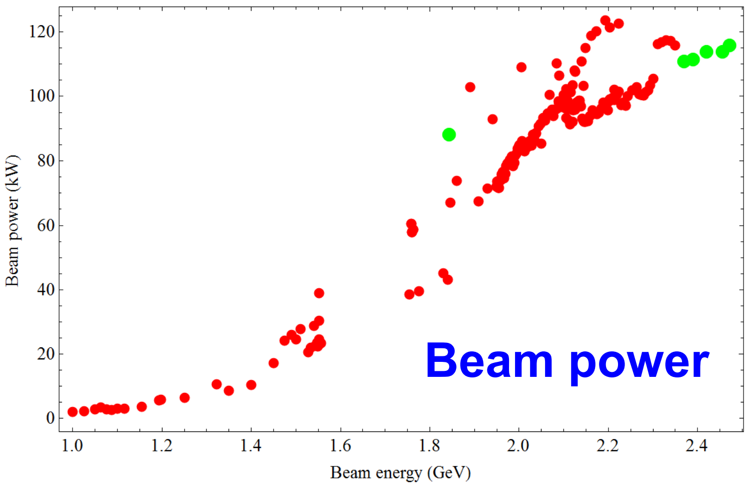




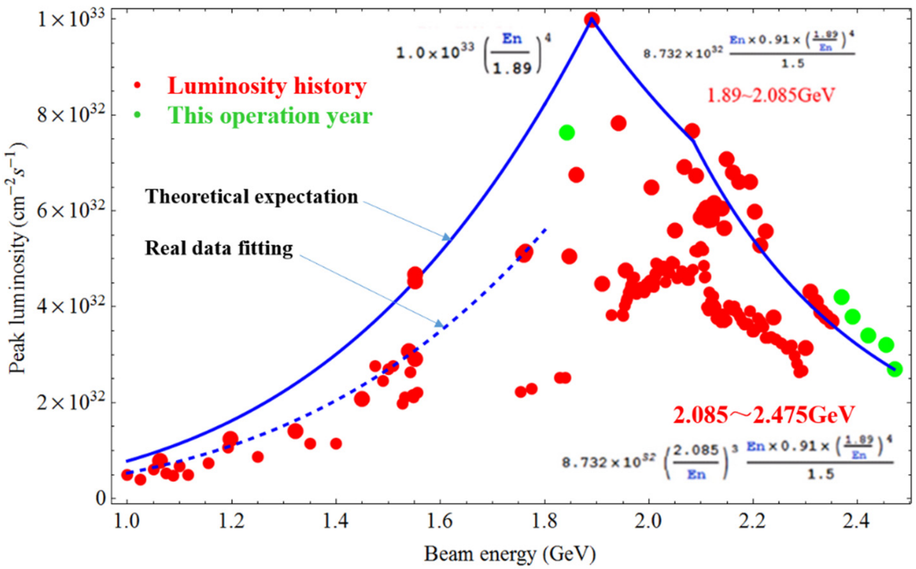
Limited by RF voltage

Limited by SR power

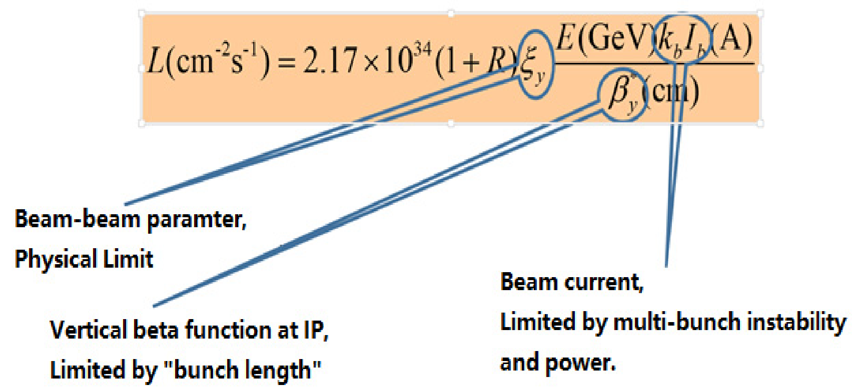




How to increase luminosity at BEPCII



- **Luminosity drops at high energy**
- **Beam-beam performance drops at higher energy**



Schemes that have been studied:

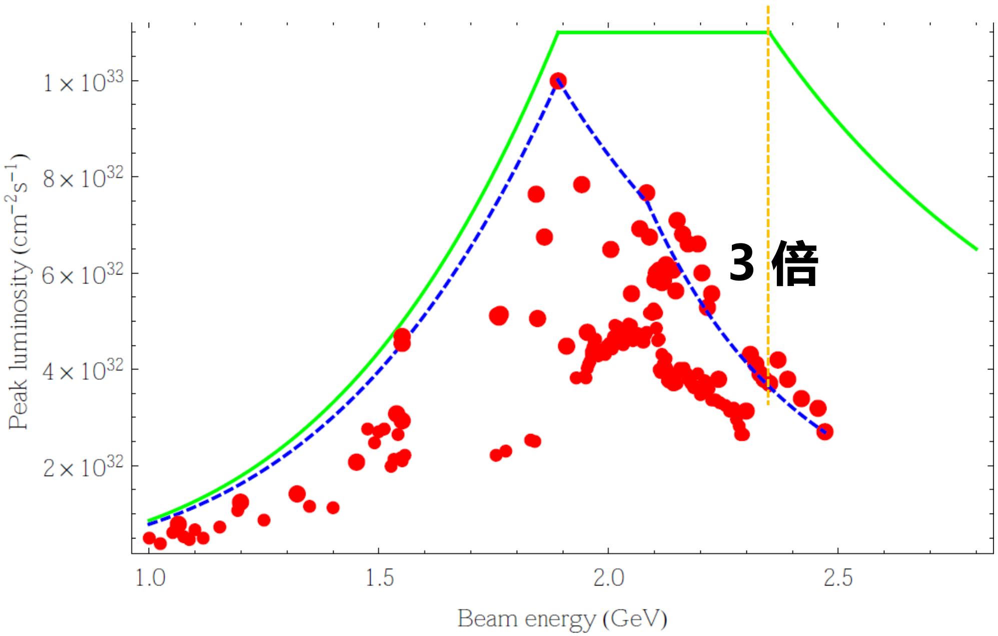
- Crab-Waist Collision: needs both the detector and accelerator to be upgraded, has technical crisis and heavy workload, not realistic in near future
- Conventional scheme: Squeeze bunch length and β_y^* by increasing RF voltage + Increase beam current (SR Power)

Design parameters before/after upgrade

Beam Energy：2.35GeV

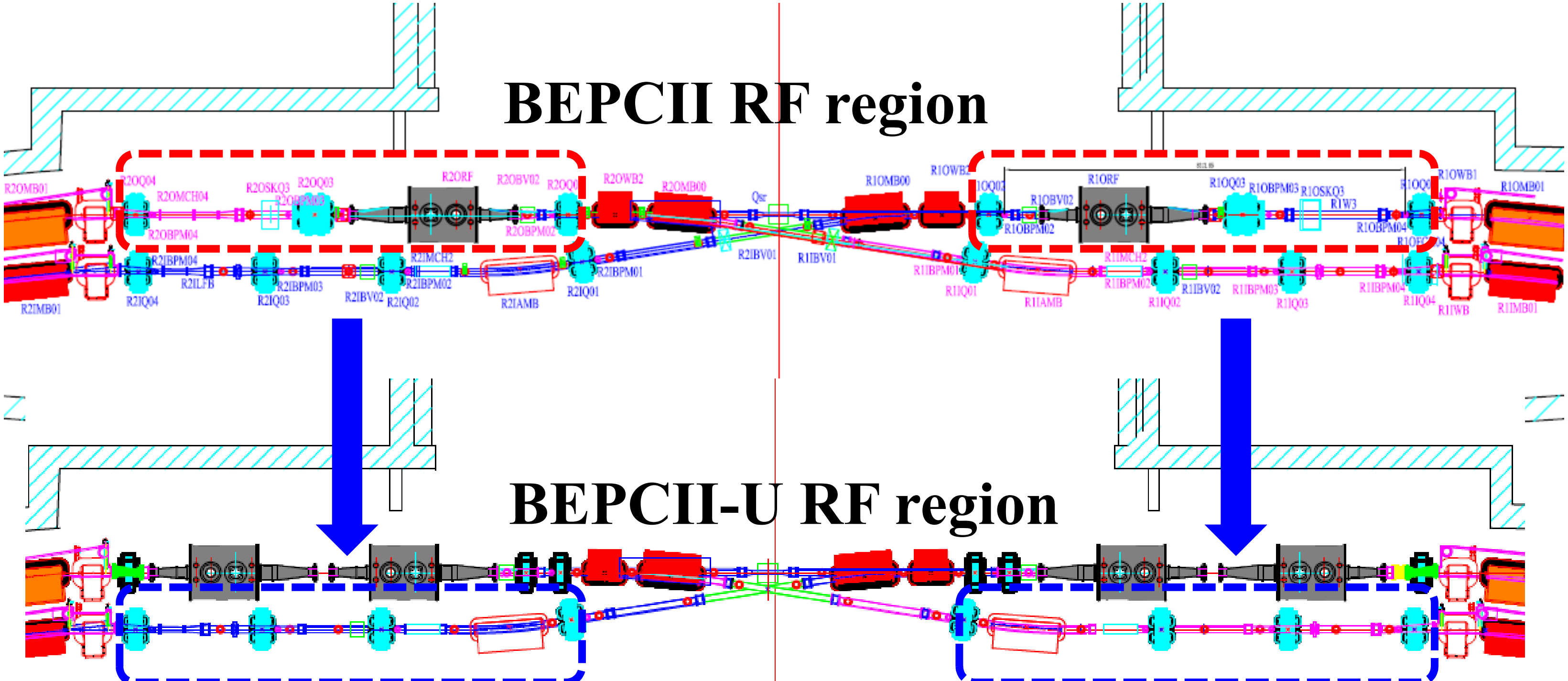
	BEPCII	BEPCII-U
Lum [$10^{32}cm^{-2}s^{-1}$]	**3.5**	**11**
β_y^* [cm]	**1.5**	**1.3**
Bunch Current [mA]	7.1	7.5
Bunch Num	56	120
SR Power [kW]	**110**	**250**
$\xi_{y,\mathrm{lum}}$	**0.029**	**0.036**
Emittance [nmrad]	147	152
Coupling [%]	**0.53**	**0.35**
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.04
σ_z [cm]	**1.69**	**1.3**
RF Voltage	**1.6 MV**	**3.3 MV**

BEPCII-U vs BEPCII



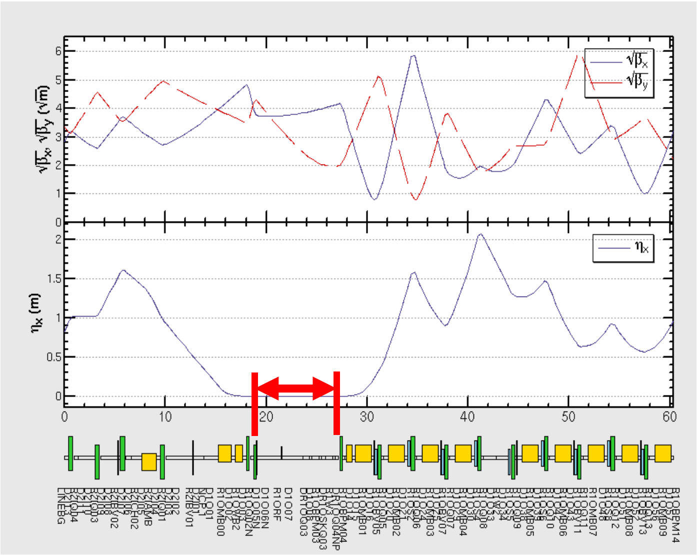
- **Luminosity is increased by a factor of 3 @2.35GeV**
- **Maximum beam energy is increased from 2.1GeV to 2.8GeV.**

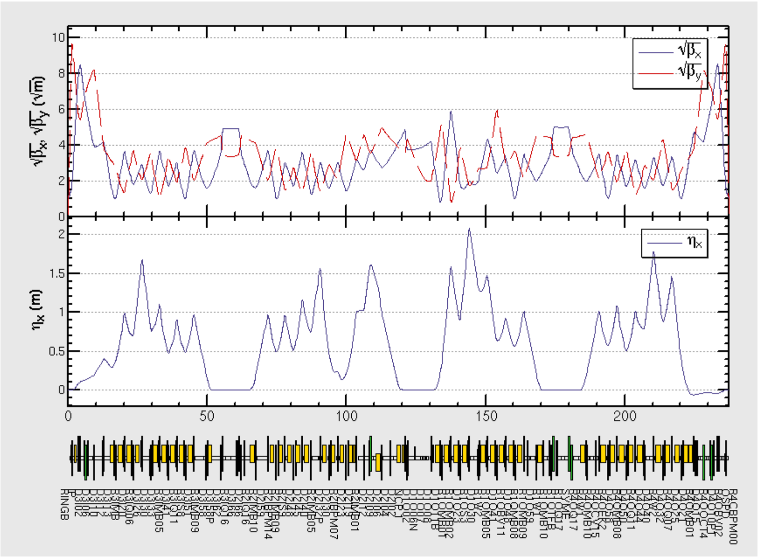
RF region modification



- 1 existing + 1 new RF Cavity/ per ring
- Space saved for new cavity by replacing existing Q-magnets with smaller ones and move the feedback system、 collimator and vacuum valve to other proper places in the ring
- The survey will be kept exactly the same as BEPCII

Baseline lattice

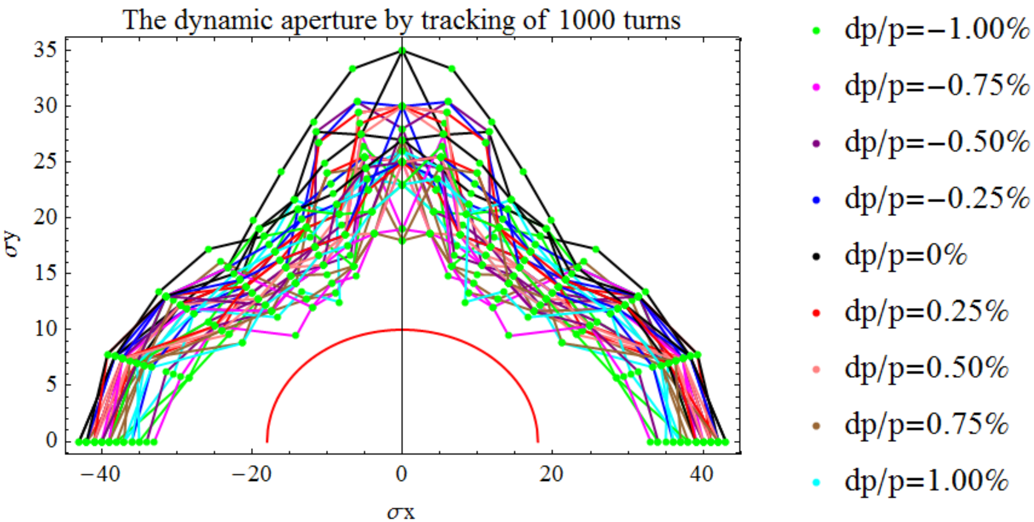


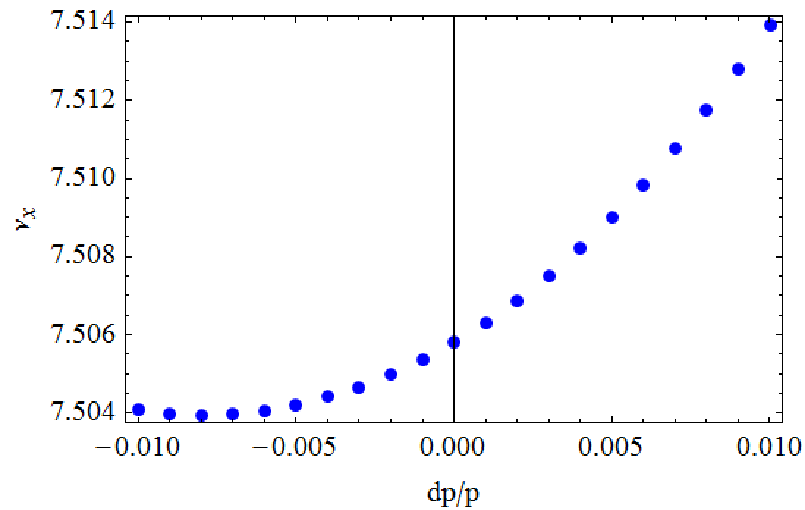


Linear lattice：

- ➢ Local optics design at the RF region
- ➢ Global tuning to minimize the emittance by controlling the H-function
- ➢ Keep working point near the half integer to ensure high luminosity

DA of baseline lattice



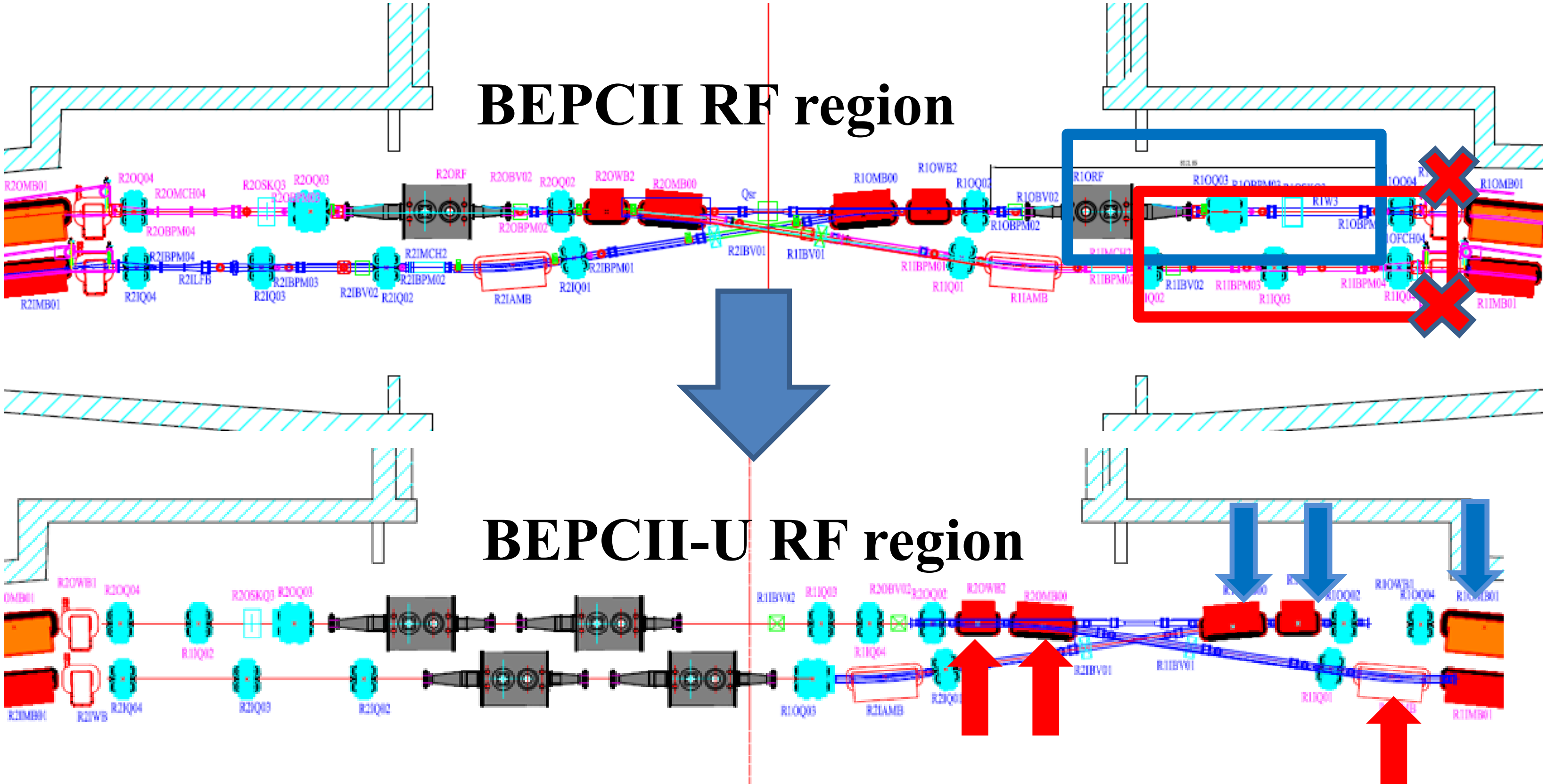


DA after optimization:

Within ±15σe， DA meets the following requirements:

- Injection requirements
- Careful tuning of nx vs dp
- The aberration of beta function is within ±15 %
- Luminosity performance due to lattice nonlinearity is evaluated considering weak strong beambeam (SAD)

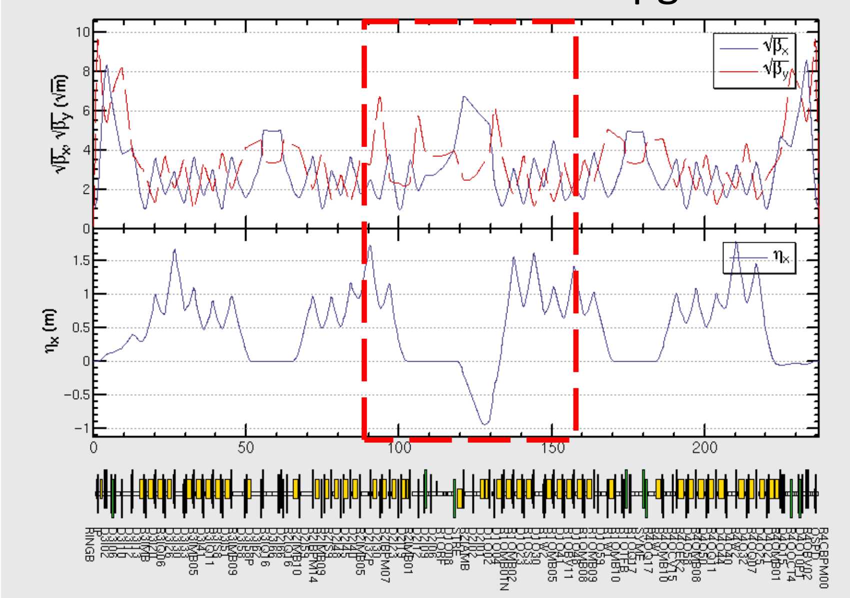
Alternative design of RF region



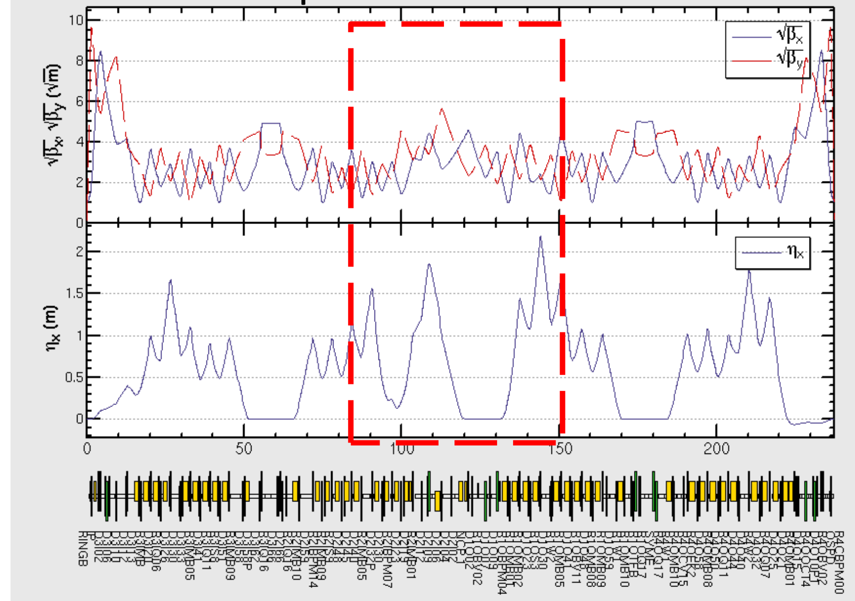
- Two cavities at the outer ring and the other two at the inner ring
- One weak bend was removed in each ring to have enough longitudinal space
- Survey is recovered by tuning three adjacent bends

Alternative lattice design

Alternative BER lattice for upgrade



Current operational BER lattice



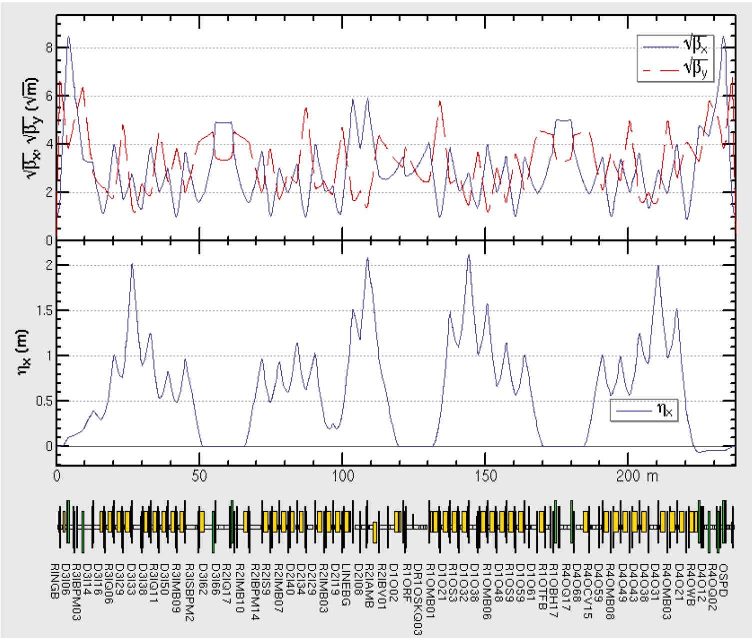
Linear lattice：

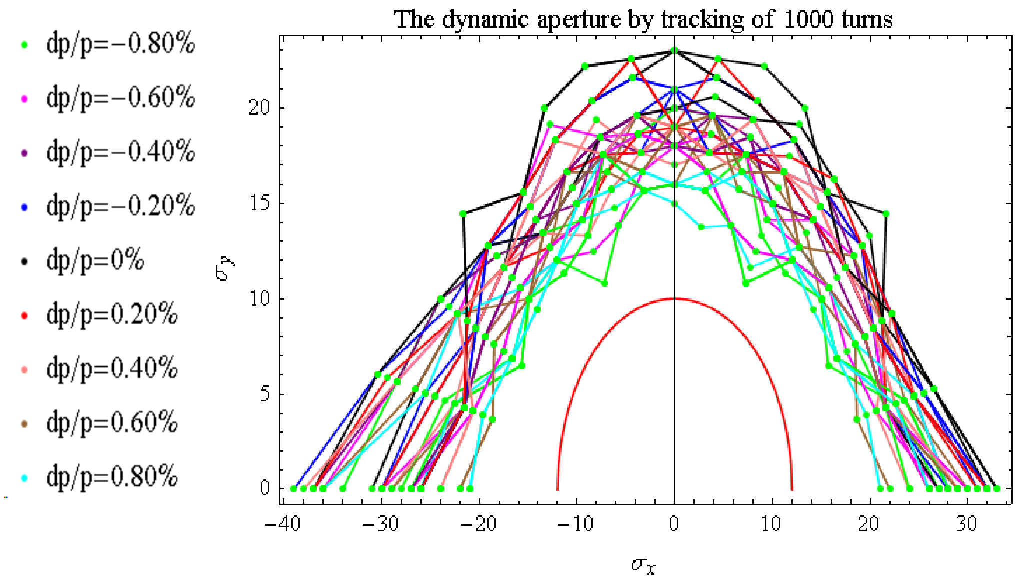
- ➢ Local lattice design at the RF region and global Minimize the emittance by controlling the H-function
- ➢ Careful dynamic aperture optimization and chromatic effect tuning
- ➢ Luminosity performance due to lattice nonlinearity evaluated

Pros and cons of two designs with different RF region

	Baseline design	Alternative design
Survey	Same	Locally changed
Commissioning	Easy	May need a little effort
Space	Tight	Relatively spacious
Cavity maintenance	Offline	Online

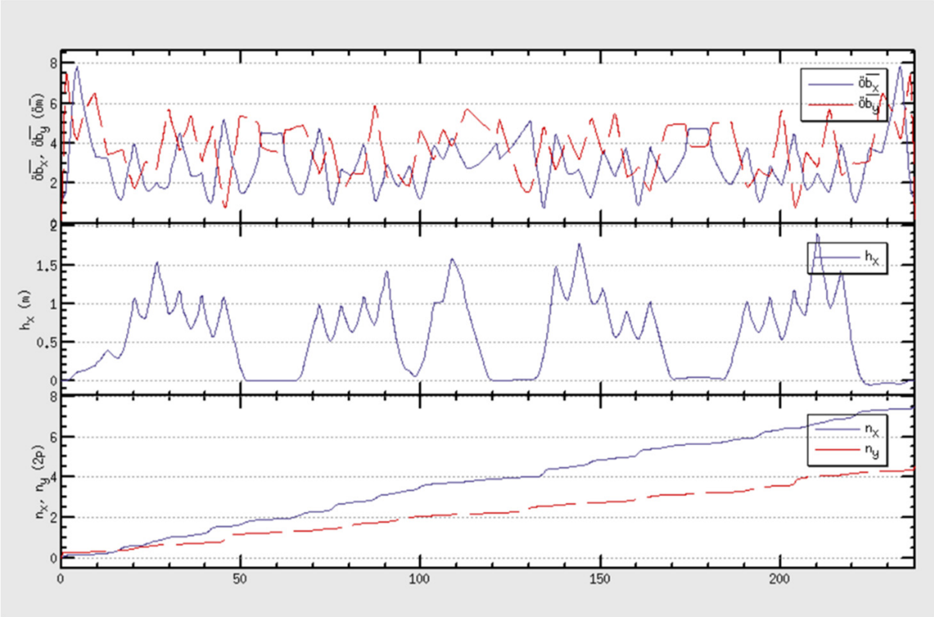
Baseline lattice design@2.8GeV

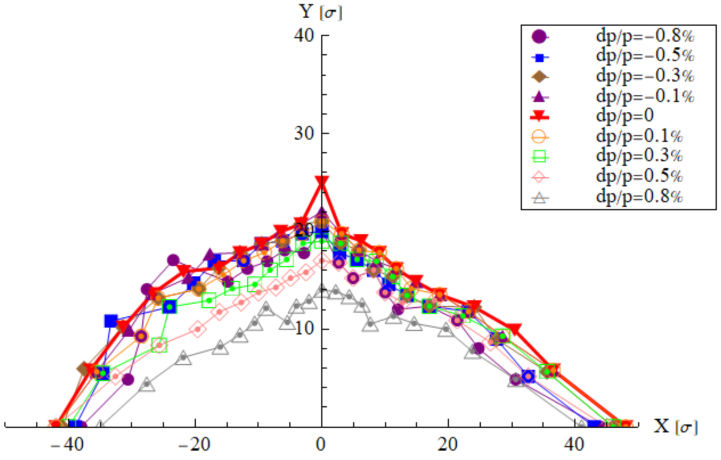




- New SCQ with higher gradient assumed
- βy* is increased to 3cm to compensate the limitation of sextuple strengths
- Global tuning to reduce the strengths of Q-magnets and ensure present magnets could work
- Optimization of beam emittance to have enough physical aperture

Alternative lattice design@2.8GeV





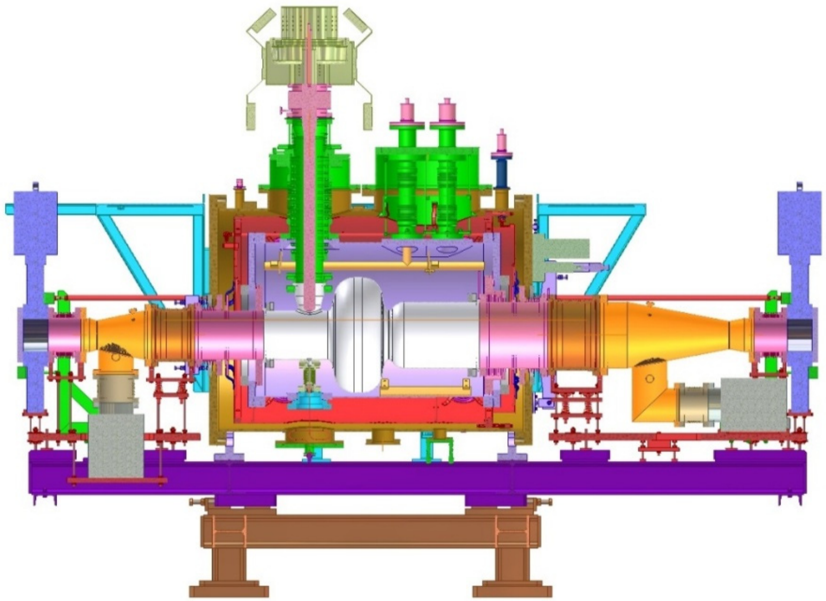
Courtesy of D. Wang

- New SCQ with higher gradient assumed
- Global tuning to further reduce the strengths of Q-magnets by reducing the vertical tune from 5.57 to 4.57
- βy^* can be reduced to 2.5cm
- Chromatic effects are under investigation

Hardware upgrade ----RF system

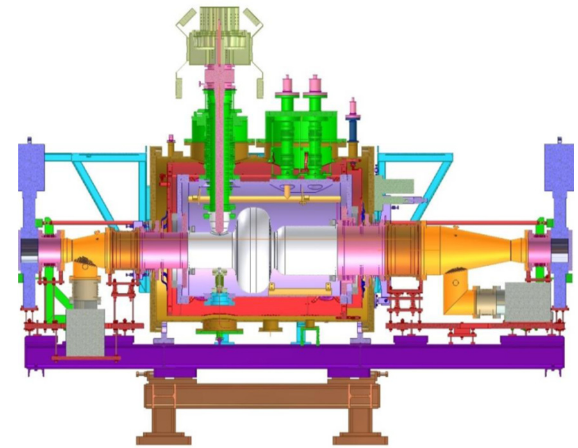
RF system is one of the core part of the upgrade:

- There will be four cavities after upgrade: two cavities that are under operation, one backup cavity, and one newly manufactured cavity
- Two sets of 500MHz, 200kW solid state power source will be installed
- Digital LLRF control system which has been independently developed at IHEP will be used



Hardware upgrade ----cryogenic system

BEPCII 500W@4.5K

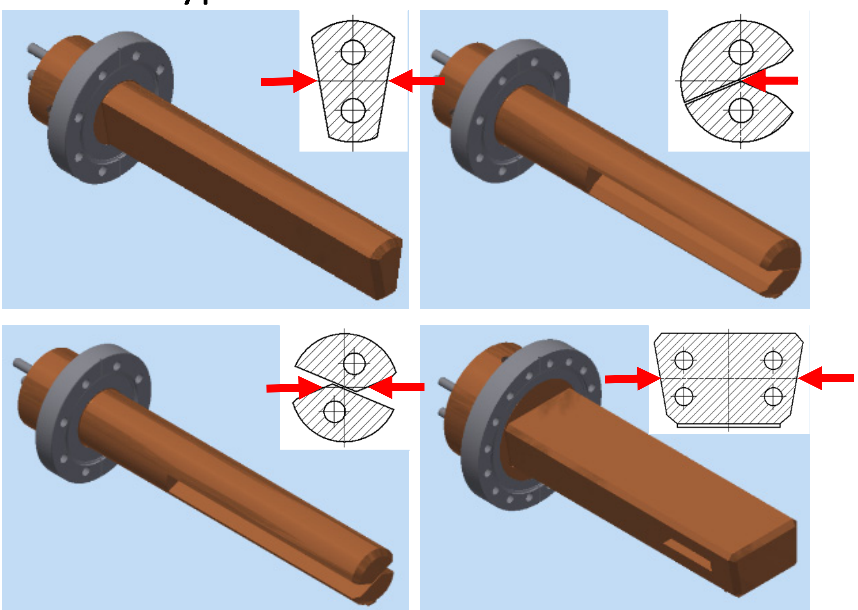


Cryogenic system will be upgraded to meet the cooling requirement of two additional RF cavities:

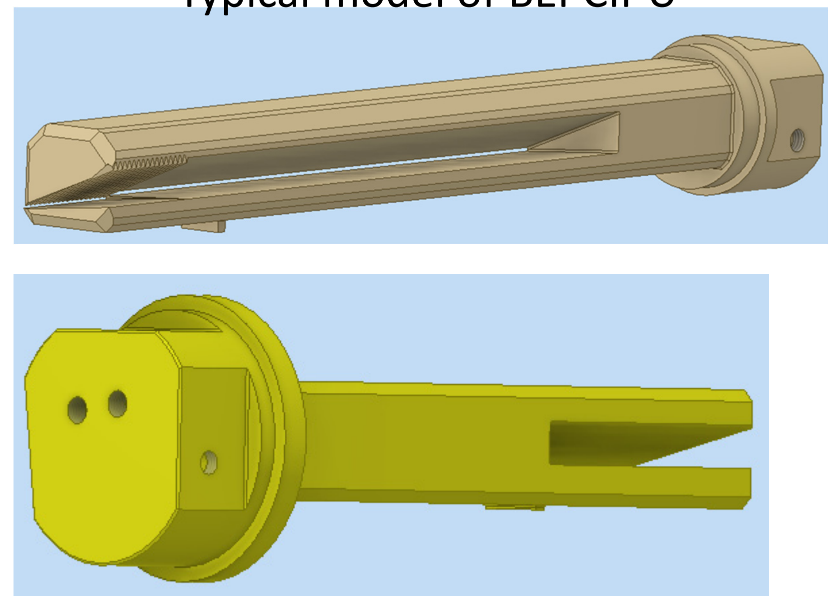
- A new refrigerator with 1000W@4.5K cooling capacity will replace the old 500W@4.5K one
- The compressor, cryostat and manifold box will be upgraded accordingly
- Both local and remote control system will be replaced

Hardware upgrade ----photon absorber

Typical model of BEPCII



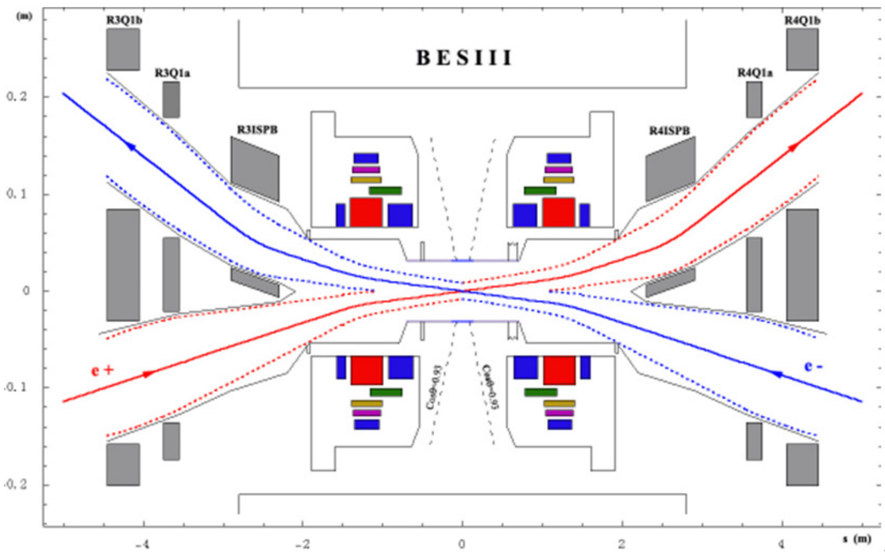
Typical model of BEPCII-U

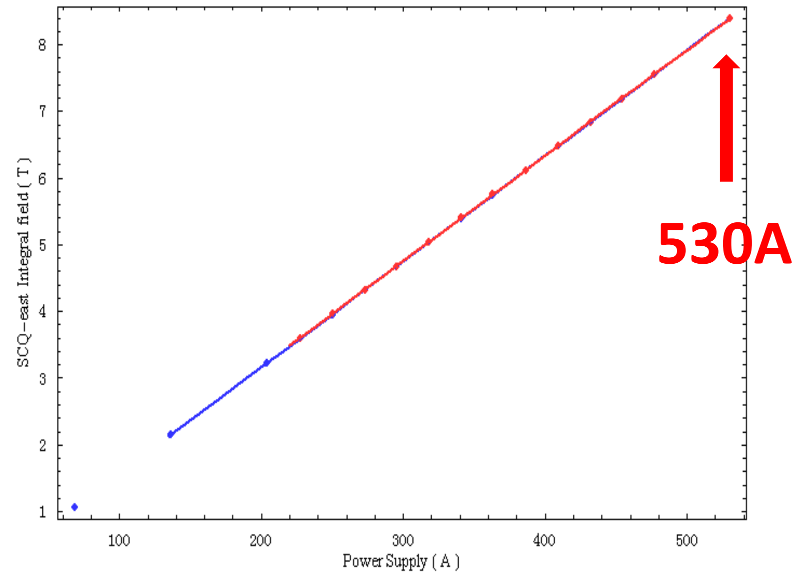


Photon absorbers bear ~85% of the synchrotron radiation power:

- The SR power increases from 110kW to 250kW after upgrade
- To reduce the power density, the incident angle is decreased and sawtooth structure is added
- Dual water pipes are used to cool the absorber down
- Eliminate double sides absorber design (no Synchrotron radiation-specific mode available)

Hardware upgrade ----SCQ

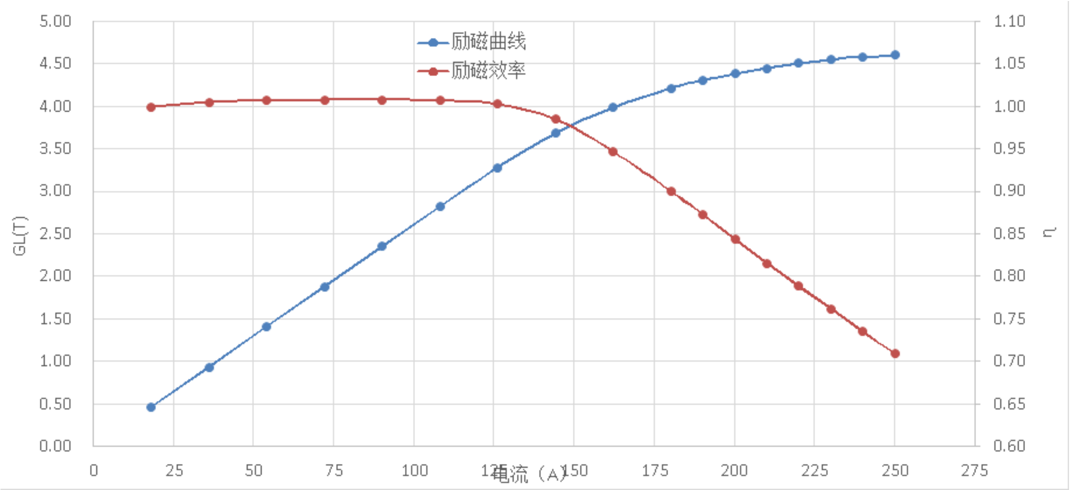




One of the bottleneck to higher energy of 2.5-2.8GeV is the strength of SCQ:

- It is know that the quench current of the present SCQ is 580A
- It requires the SCQ to work at 625A@2.8GeV, which is beyond the quench current
- New SCQs have to be design and manufactured to have a high luminosity at 2.8GeV

Hardware upgrade ----magnets



Simulated 105Q excitation curve

About ¼ quadrupoles of the ring will work at the saturation region @2.8GeV :

- ➢ Careful lattice design to reduce the strengths of quadrupoles
- ➢ Sacrifice the excitation efficiency to use present magnets instead of dismantle so many magnets and install new ones
- ➢ Modification of the power supply to higher excitation current

Hardware upgrade ----other systems

- Injection: new kicker with slotted pipe structure and solid state pulsed power supply to meet the requirement of higher current and higher power
- LINAC: add new klystrons to boost the beam energy to 2.8GeV
- Background: add new collimators to reduce the background from both the injection and the circulating beam
- Utility: the corresponding cooling water, electricity, air conditioning upgrade

……

Schedule

- 2024 .7-12, Shut down for hardware dismantling and installation
- 2025-2028, Operation at 2.3~2.5GeV, and prepare for energy upgrade
- 2028.6-9, Energy upgrade to 2.8GeV
- 2028.9~2030, Operation at 2.5~2.8GeV

Summary

- Detailed design for BEPCII upgrade has been finished
- The upgrade is optimized at 2.35GeV with tripled luminosity, and the maximum beam energy will be increased to 2.8GeV
- It is expected to reduce the remaining BESIII data taking time from 12 years to 3-4 years after upgrade

Thank you !