High Energy Photon Source
--- Overview & Status

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on behalf of the HEPS team

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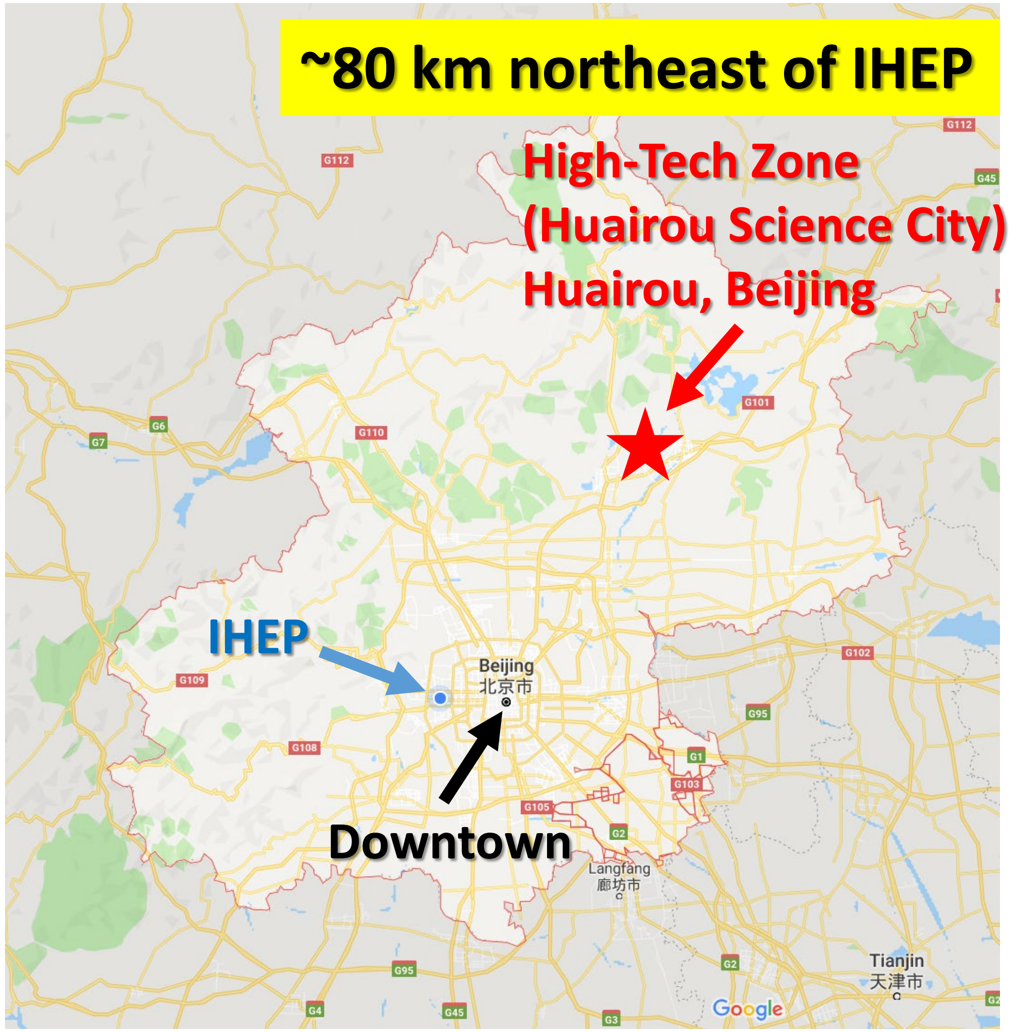
Acknowledgements

- The presented work was done by HEPS team.
- Thank Prof. Q. Qin and Dr. Y. Jiao for providing information.

Outlines

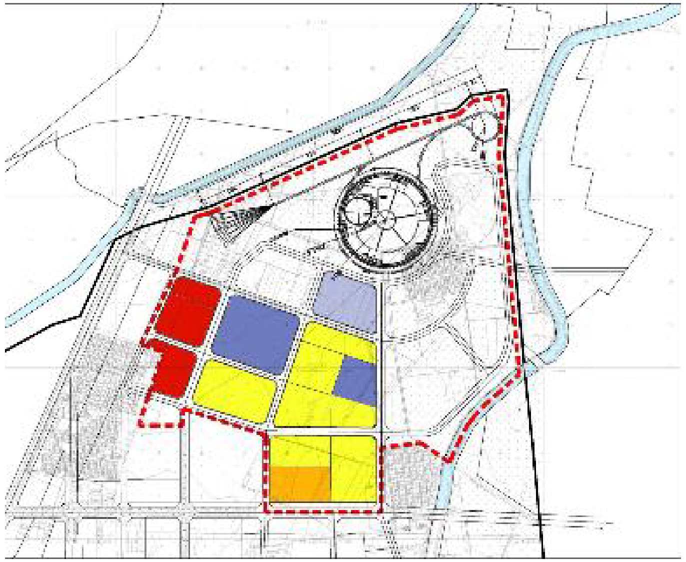
1. Introduction
2. Brief Overview of HEPS Design
3. Brief Plan and Status of HEPS Project
4. Summary

Site of HEPS



BASIC: An area of ~ 1 km^2, including:

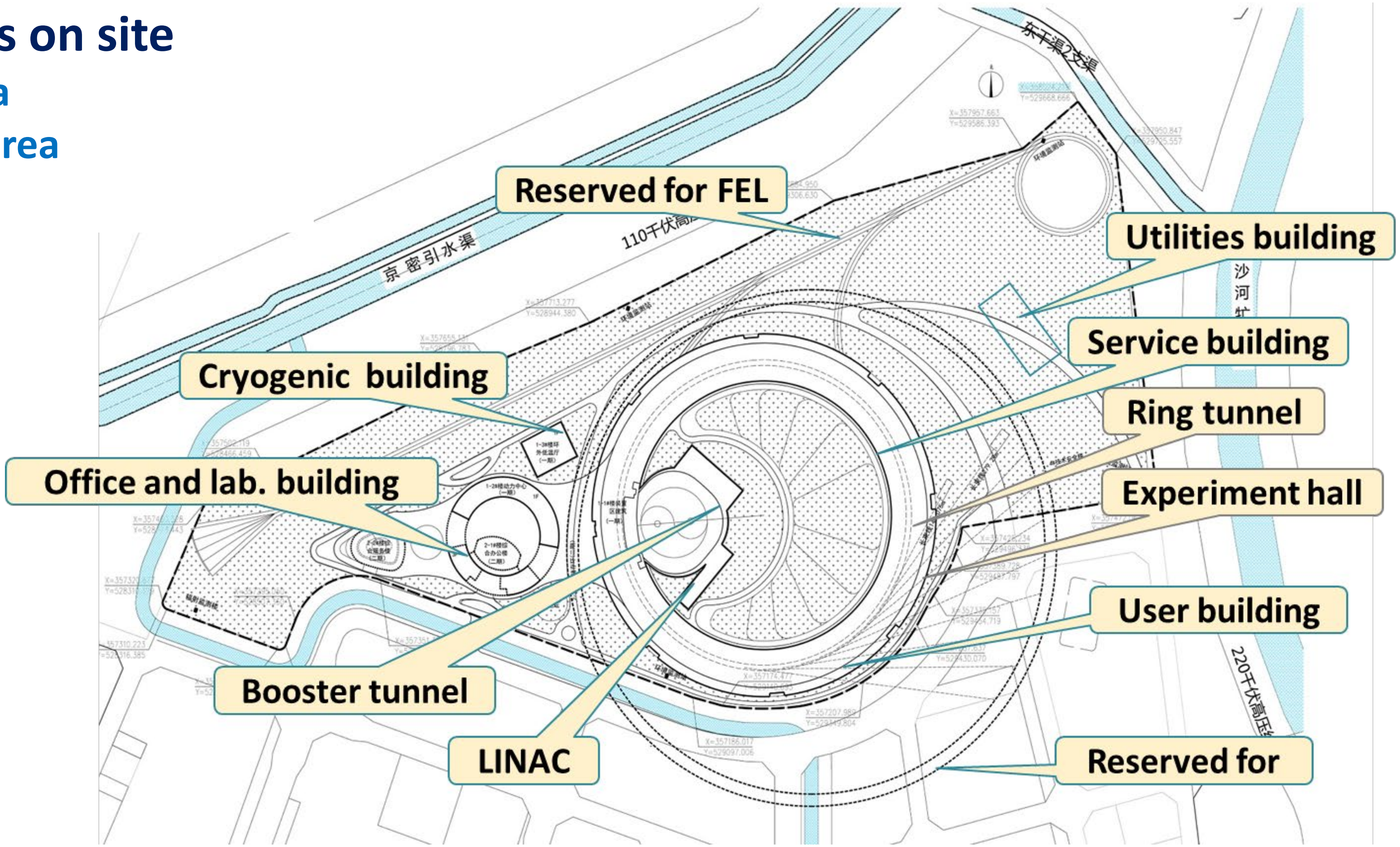
- HEPS
- SECUF (Synergized Extreme Condition User Facility)
- Simulation Facility for the Earth
- Research platforms of energy, environment, biology, materials, etc.



Site of HEPS

Three areas on site

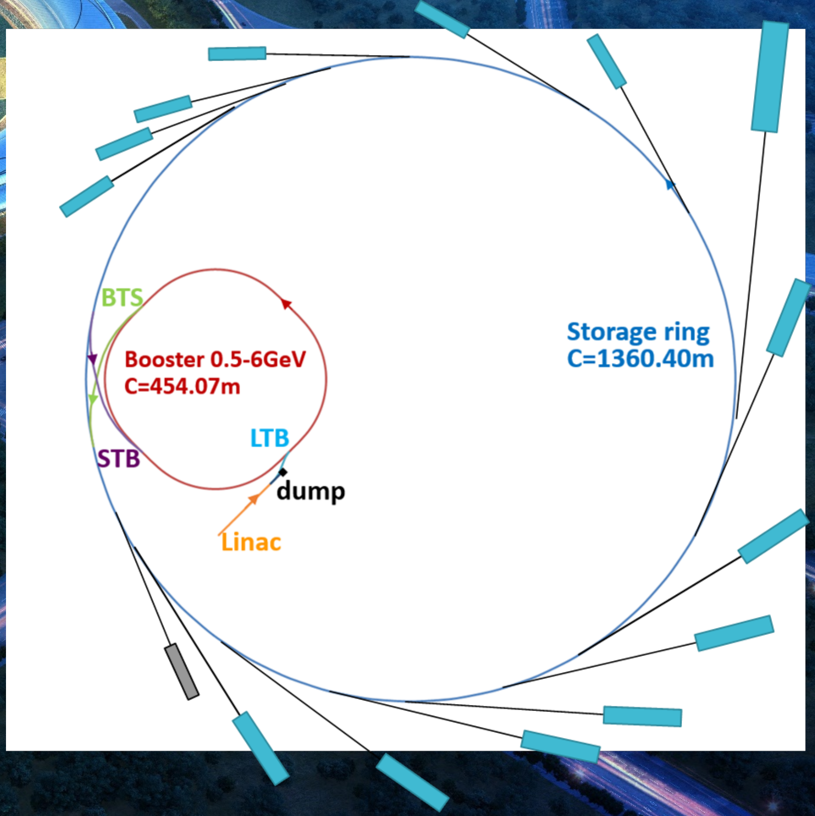
- Office area
- Machine area
- Aux. area



Design Goals

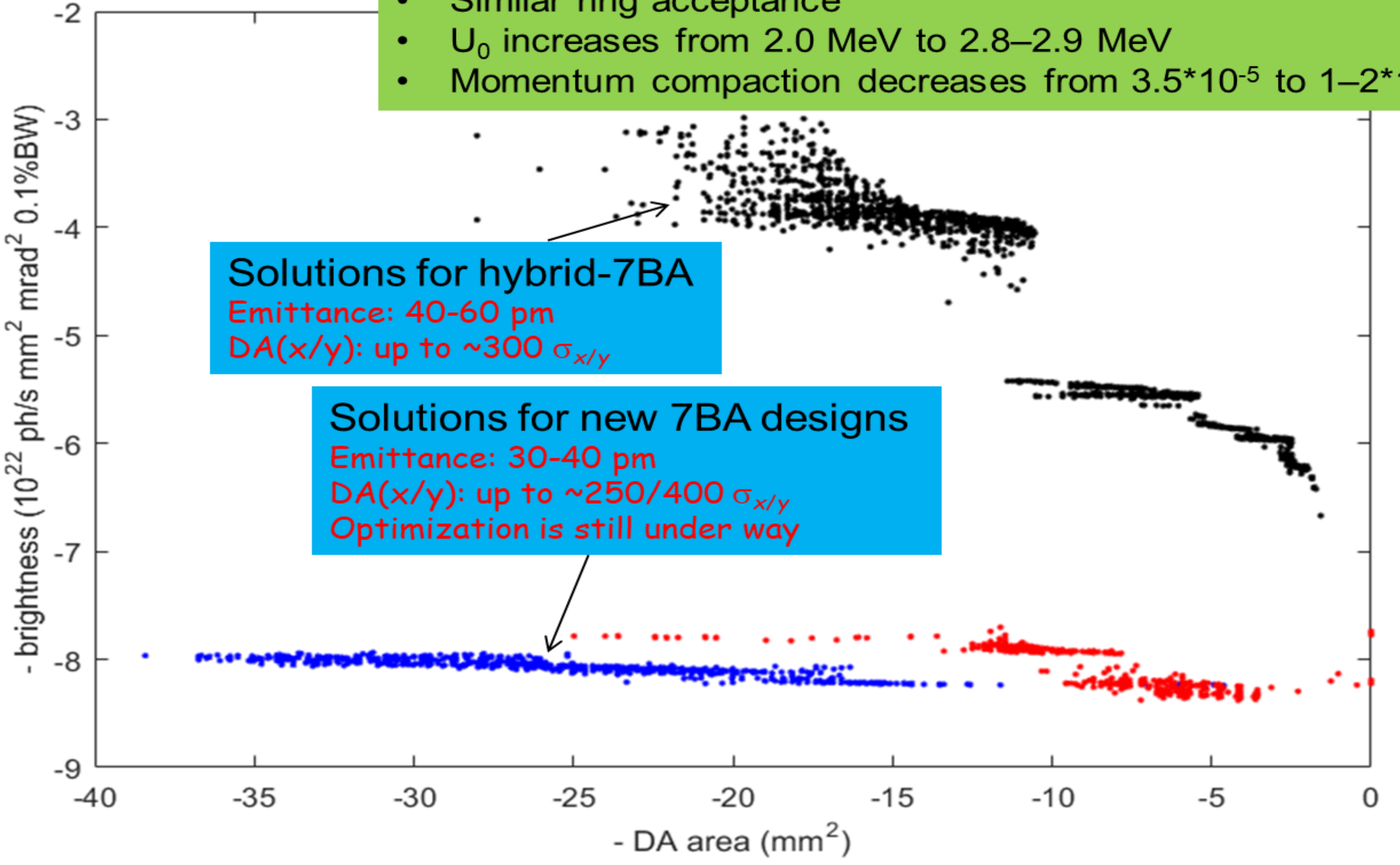
- **High Energy Photon Source (HEPS) is going to be the next synchrotron light source in China.**

Main parameters	Unit	Value
Beam energy	GeV	6
Circumference	m	1360.4
Emittance	pm·rad	< 60
Brightness	phs/s/mm²/mrad²/0.1%BW	$>10^{22}$
Beam current	mA	200



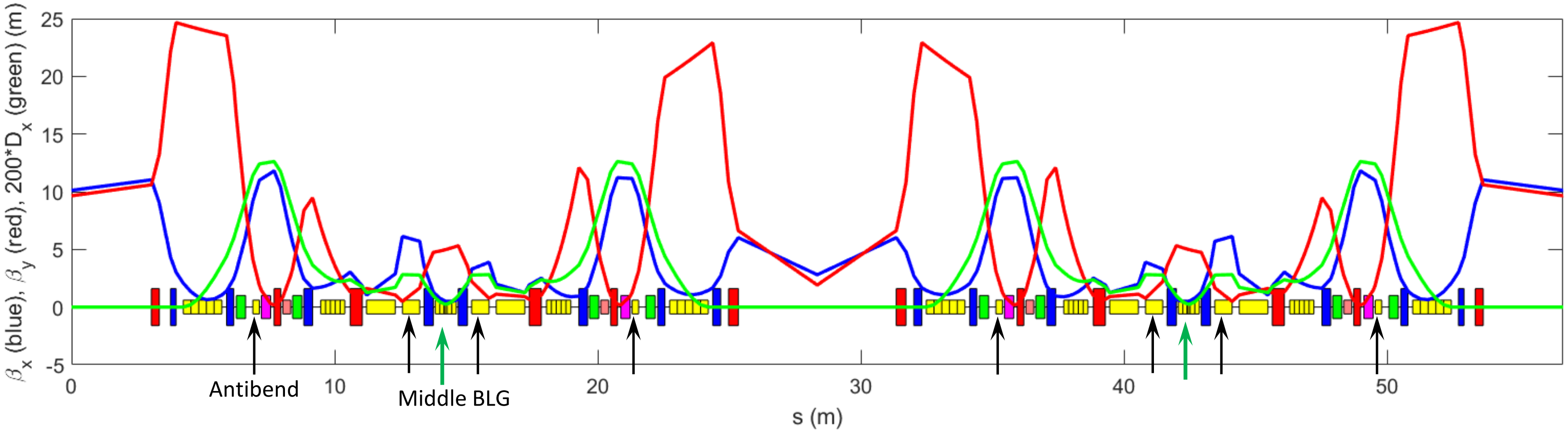
Explore Better Lattices

Hybrid 7BA lattice with **antibend & superbend**
- Natural emittance: 30–40 pm
- More than 30% higher brightness than 48 period hybrid-7BA lattice
- Similar ring acceptance
- U_0 increases from 2.0 MeV to 2.8–2.9 MeV
- Momentum compaction decreases from $3.5*10^{-5}$ to $1–2*10^{-5}$



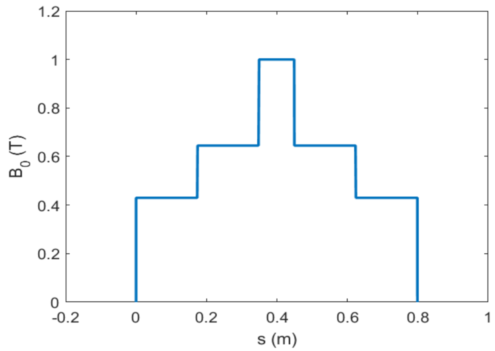
DA area: $\textit{Objective}(2) = \text{Effect. DA(x)*Effect. DA(y)*MA/3\%*}\textit{weight function}$

Baseline Lattice: 1360.4 m, 34 pm @ 6 GeV



- **BLG used in the middle of 7BA**
  - Help to reduce emittance
  - Central slice (1 T, 5 mrad) used for bending magnet beam line
  - If necessary, it is feasible to replace the magnet. Once keeping the total length and bending angle the same, changing the magnet will cause only little perturbation to ring performance.

Field profile of middle BLG magnet



Change critical energy by changing the field of central slice

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

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More Considerations in Lattice Optimization

- More practical lattice model
  - with insertion devices and RF cavities
  - with impedance and intra-beam scattering model
- Lattice calibration simulation
  - Develop automatic first-turns commissioning program
  - Investigate dependence of ring performance on kinds of errors
  - Identify tolerance for magnetic field error and misalignment errors
  - Specify critical error source and develop methods to recover expected ring performance
- Collective effects study
  - Evaluate impedance budget by considering as many vacuum elements of different sizes as we can
  - Evaluate threshold of single bunch and multi-bunch instabilities
  - Focus on the RF high-order-mode induced coupled bunch instabilities

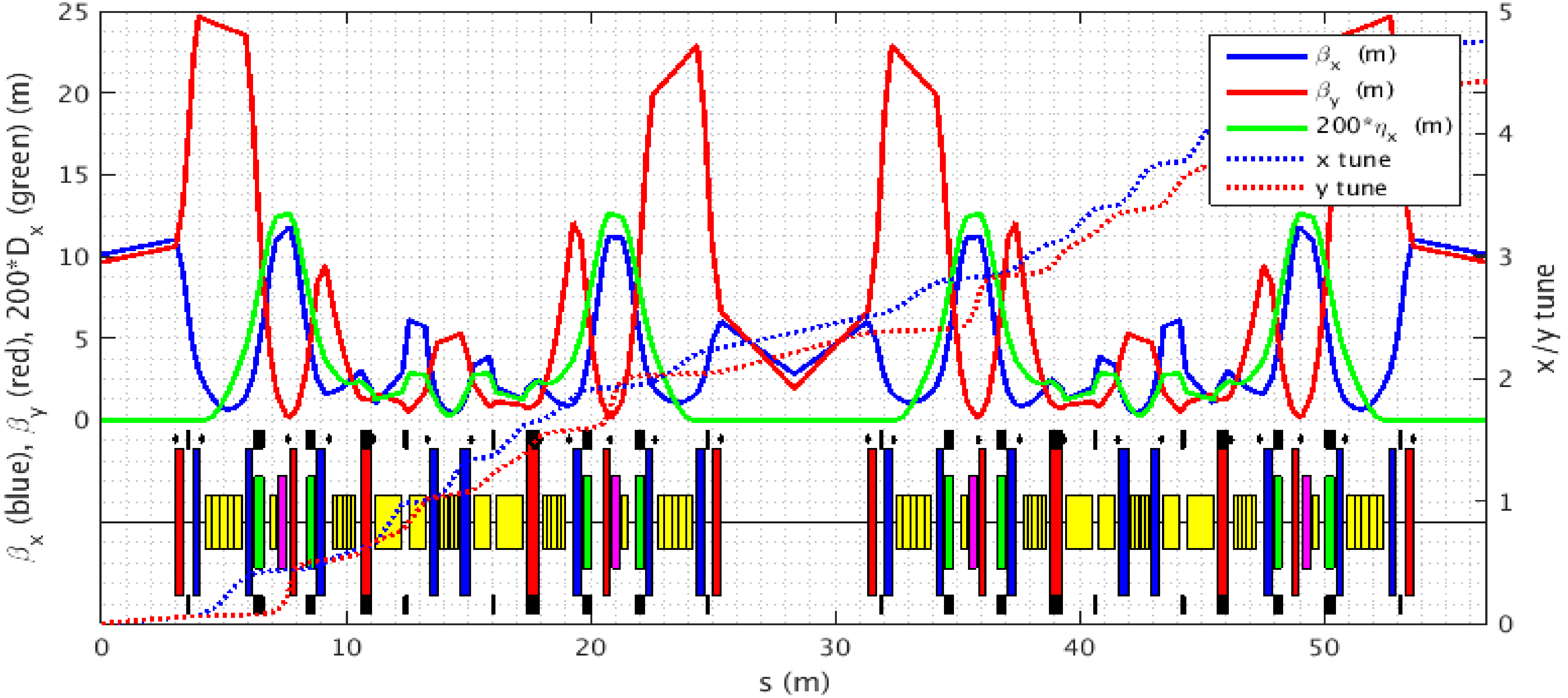
Error Correction Considerations

Courtesy of D. H. Ji

- H/V phase advance=2π* (4.7560/4.4264) per cell(2*7BA)
- 8 + 8 + 4(4) orbit correctors each cell
  - 8: Dedicated skew quadrupole-like correctors: windings supply H/V orbit correction and fast orbit feedback,
  - 8: Auxiliary windings on SD sextupole magnets for orbit correction
  - 4(4): Auxiliary windings on quadrupole magnets for orbit correction
    - 4 on QF3 used in Orbit Correction
    - (4) on QF1 enables transfer of the DC components of nearby faster correctors
- 8 skew quadrupole knobs each cell
  - 4 dedicated skew quadrupole-like correctors between QF1 and QD1, dispersion-free region
  - 4 octupoles with skew quadrupole windings, dispersion region
- 24 BPMs each cell

Error Correction Considerations

Courtesy of D. H. Ji



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Commissioning Simulation Scheme

Courtesy of D. H. Ji

	Stage 0	Stage 0.5	Stage 1	Stage 2
Target	Beam accumulation;	Transition stage for stage 1 foundation	Good Beam Performance	Joint Commissioning w/ ID
Foundation	Low charge; No Orbit; Unpredictable hardware status(BPM~500μm; hardware Abnormity);	Beam accumulated; Hardware w/o calibration;	Enough current&life time; Calibrated hardware;	Well calibrated beam performance;
Tools/Key	Hardware Abnormity Diagnosis; Trajectory correction; tune adjust; RF on; Sextupole on;	BBA @Quad/Sext; TBT Optics Correction(AC LOCO/MIA); injection efficiency; Life time;	Orbit correction; Optics Correction; Coupling adjust; High current study; Feedback	Local orbit correction; Local optics correction…

Sextupole Movers for Orbit Corrections

Courtesy of D. H. Ji

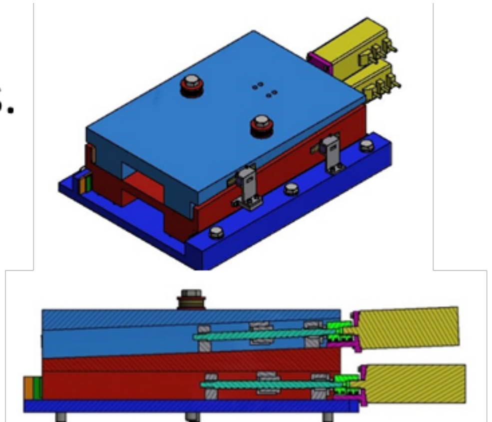
Sextupole movers enable X/Y offset adjustment of sextupoles. using LOCO algorithm to realize beam-based sextupole alignment.

Bad: online adjust mover is difficult to keep the stiffness and will introduced beam vibration.

Good: Improve obviously the flexibility and accuracy of the optics correction.

Sextupole rms offset: H: 100 µm -> 20 µm, V: 80 µm -> 50 µm,

vertical correction less effective due to the worse S/N ratio in cross-plane RM measurement.

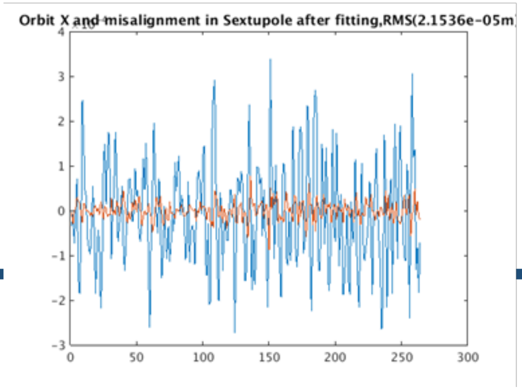


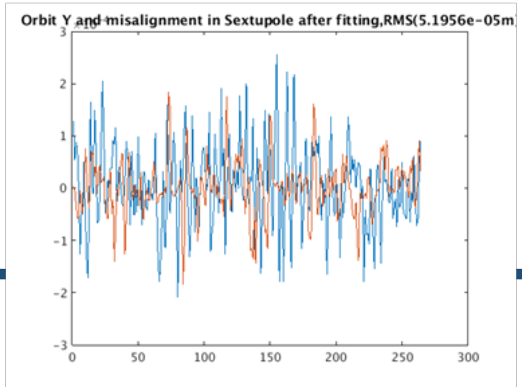
sextupole movers for HEPS

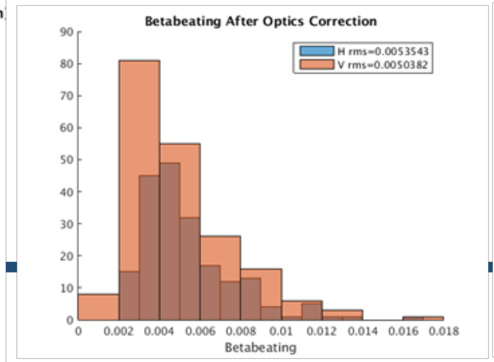
accuracy: 5 µm rms

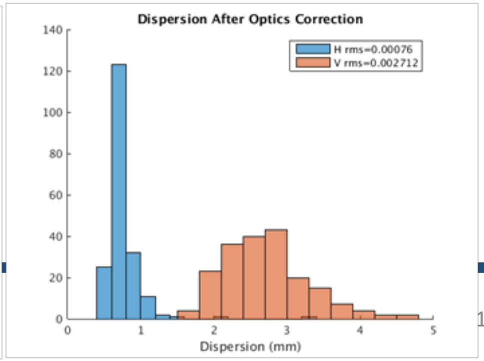
Range: 300 µm

grating-rule sensor









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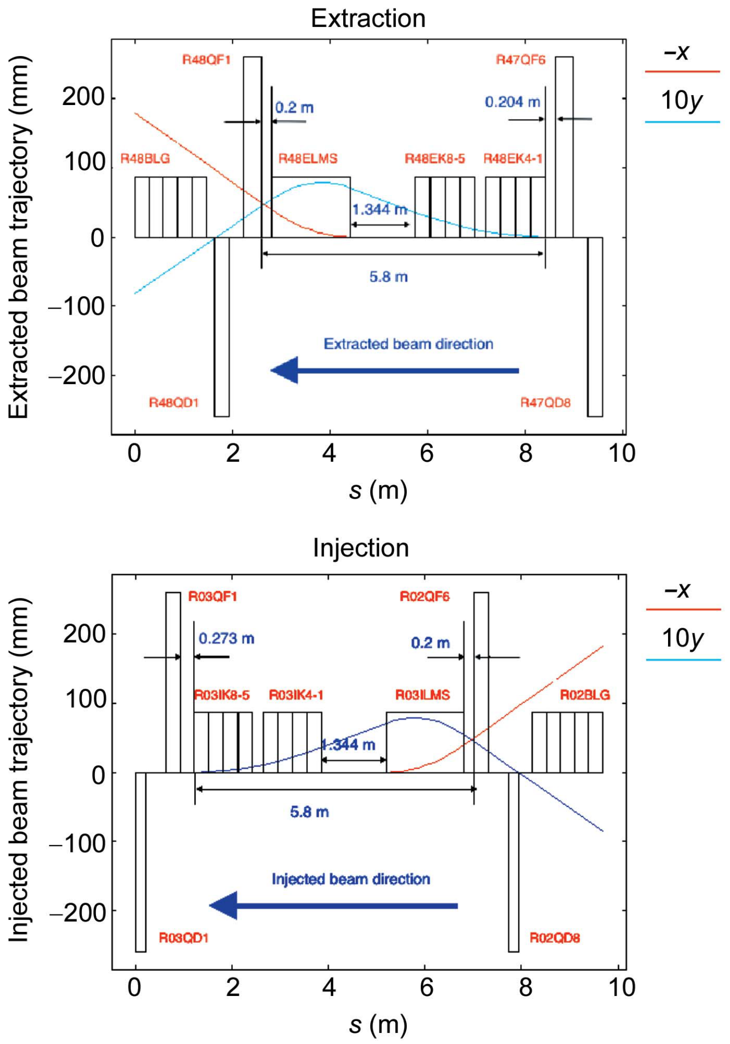
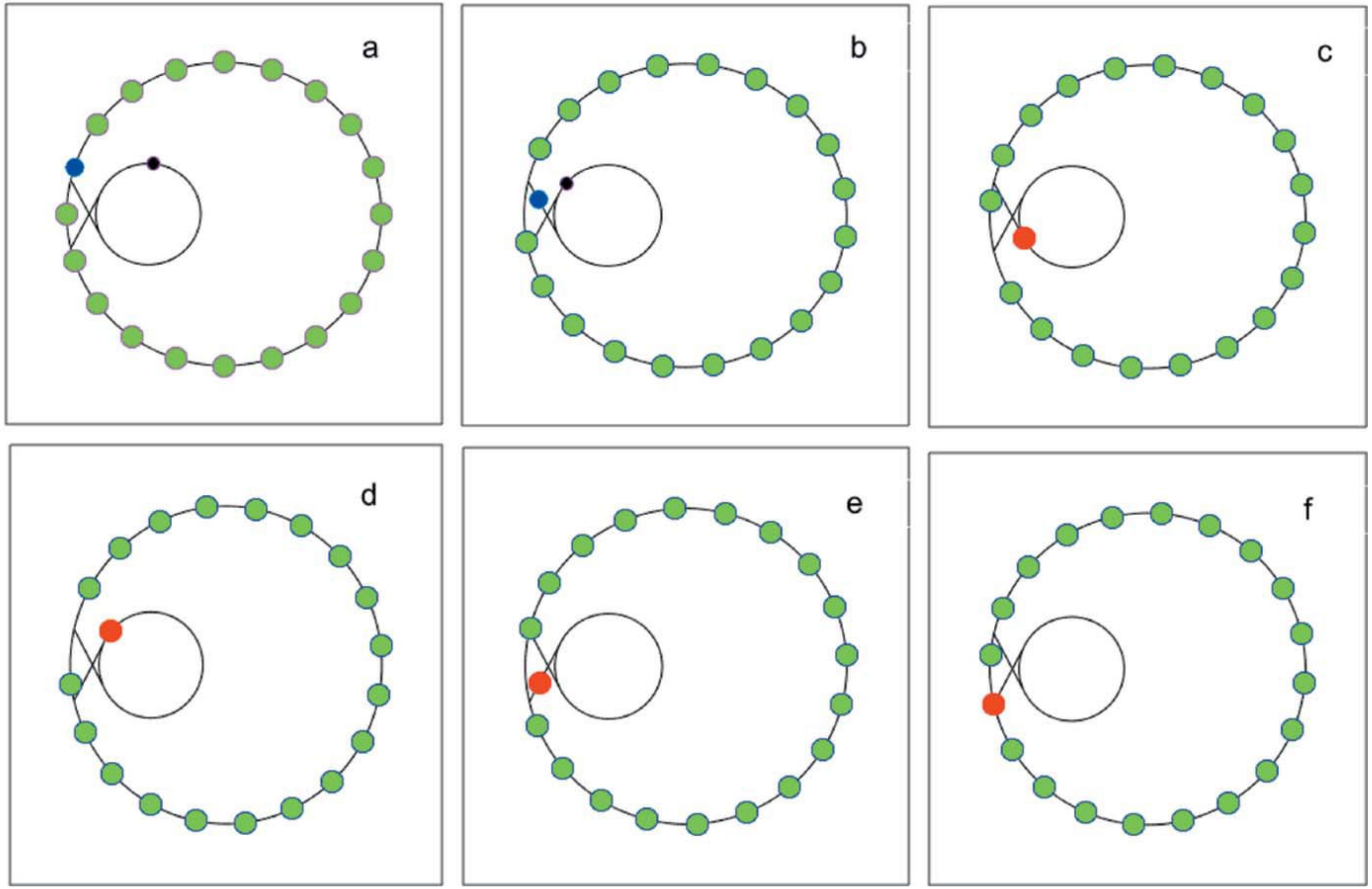
Courtesy of Z. Duan

On-Axis Swap-Out Injection with "High-Energy Accumulation" Scheme





Y. Jiao et.al., The HEPS Project, J. Synchrotron Rad. (2018). 25

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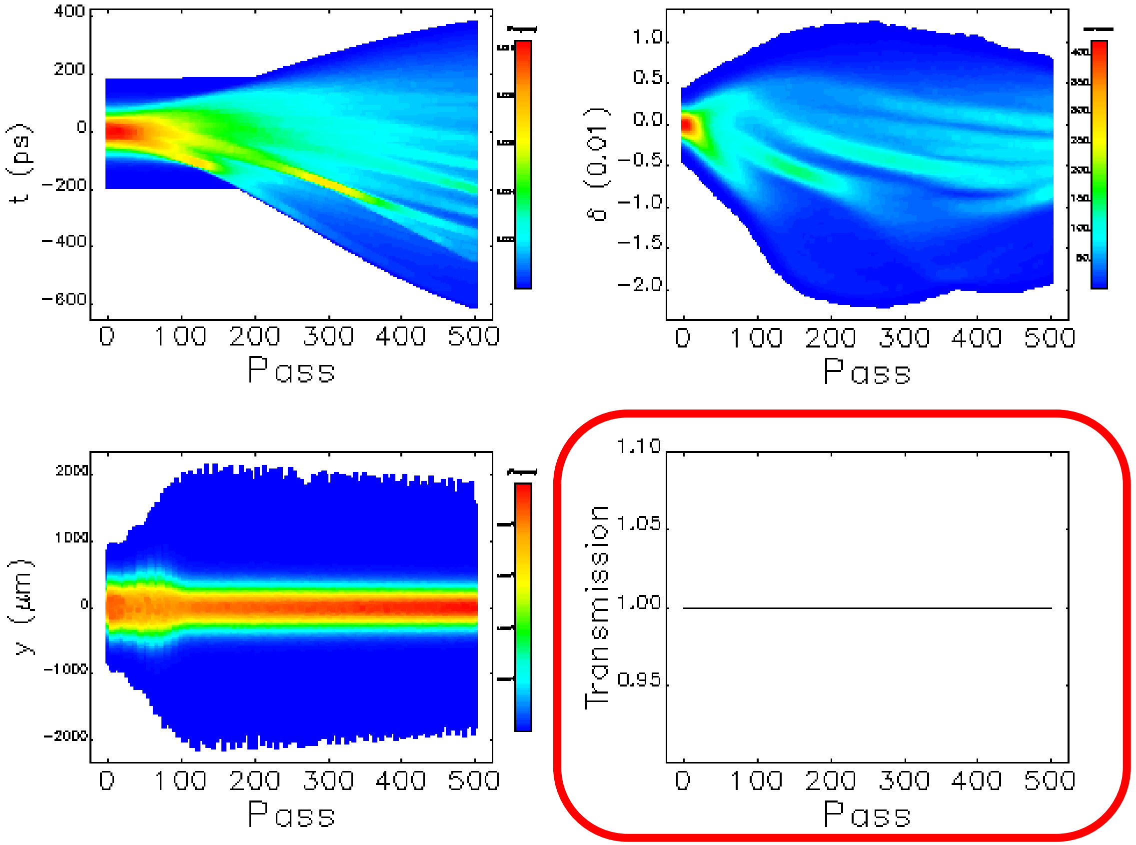
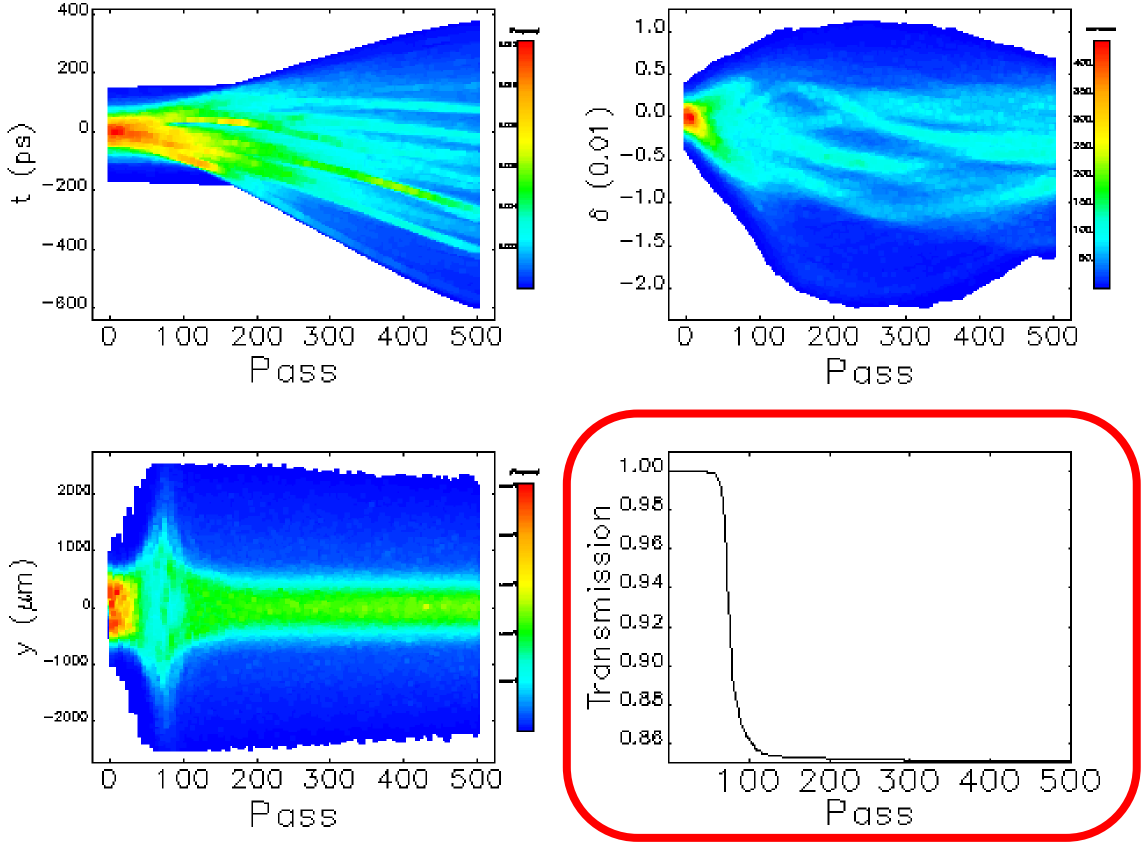
Courtesy of Z. Duan

High-Charge Limit in the transient process after injection

- Single-bunch 15 nC, initial vertical offset $y_{ini} = 300\mu m$, initial bunch length $\sigma_{t-ini} = 40\ ps$, initial energy spread $\sigma_{\delta-ini} = 0.001$



Linear One-Turn Map



Element-By-Element

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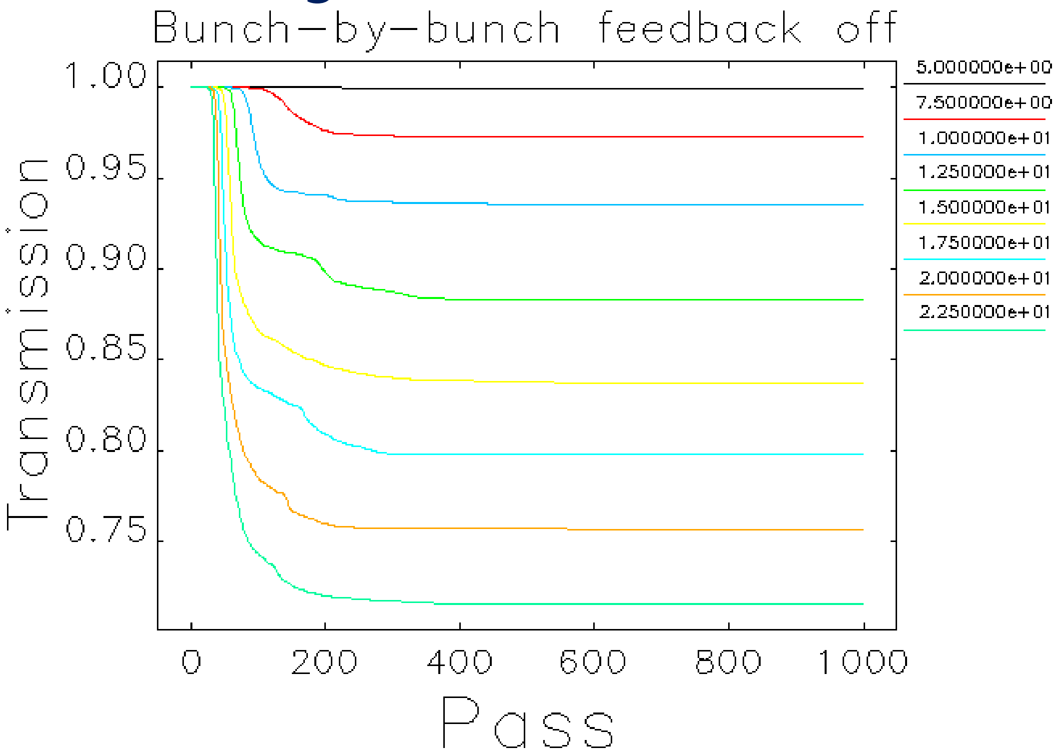
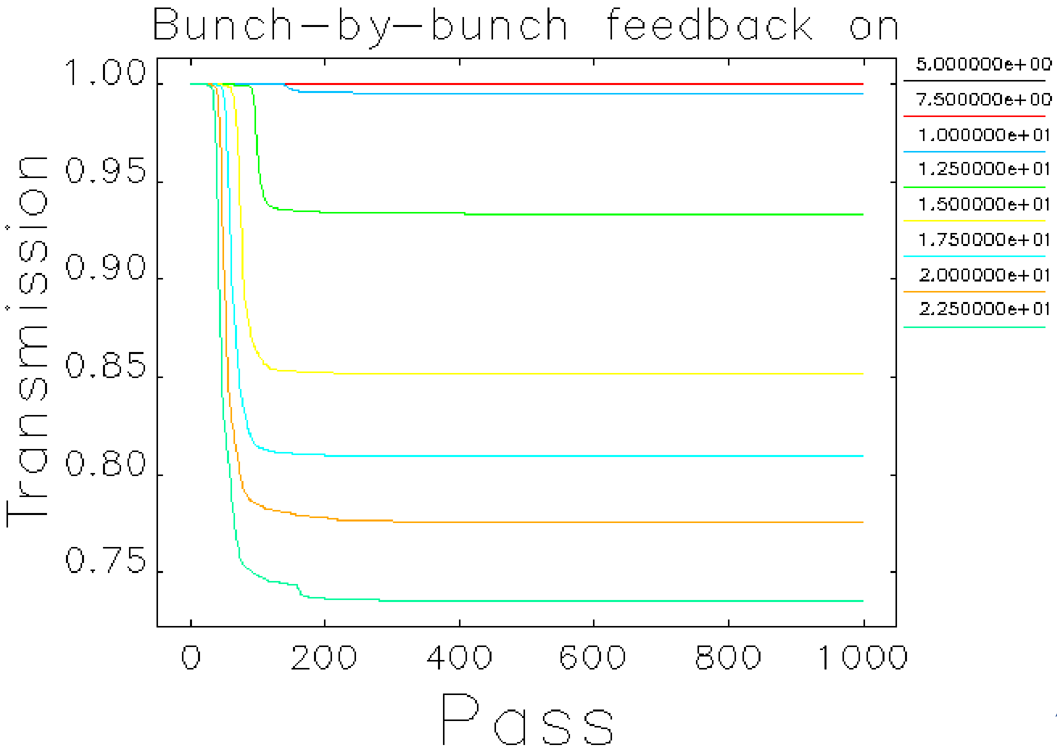
Courtesy of Z. Duan

High-Charge Limit in the transient process after injection

- Initial vertical offset $y_{ini} = 300\mu m$, initial bunch length $\sigma_{t-ini} = 40\,ps$, initial energy spread $\sigma_{\delta-ini} = 0.001$, element-by-element tracking.
- Two different situations w/ and w/o bunch-by-bunch feedback system.
- Further systematic calculations are needed to optimize the injection efficiency at high bunch charge.





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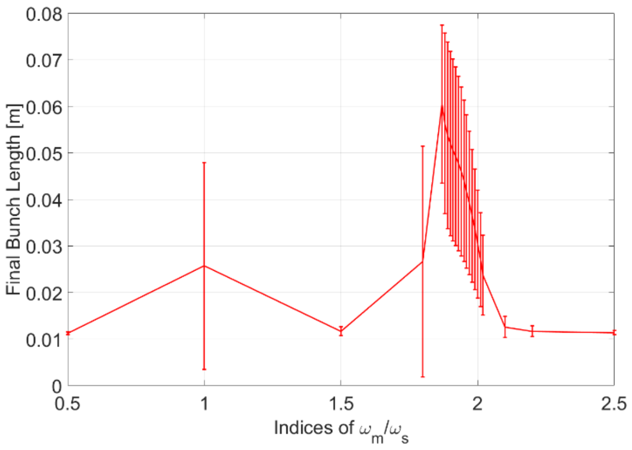
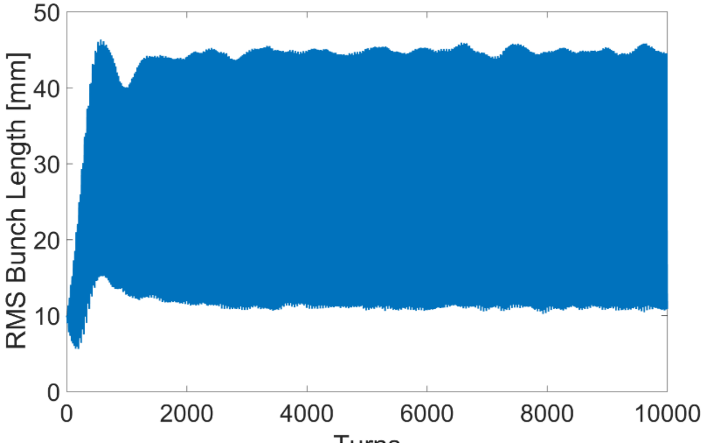
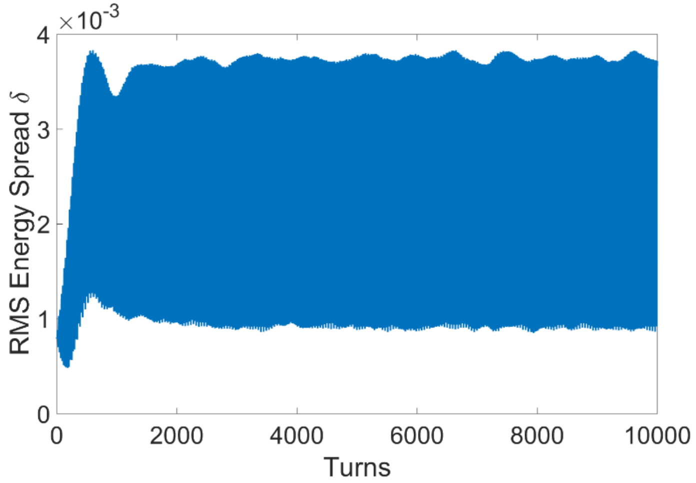
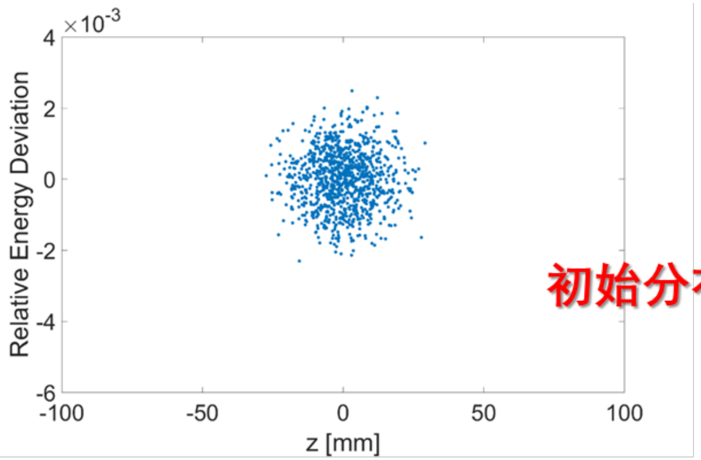
Idea of implementing RF Modulation in Booster

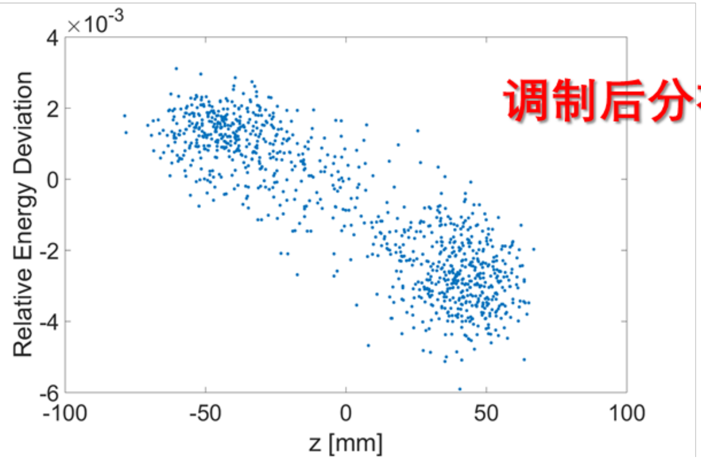
- Preliminary simulations prove the effectiveness of RF modulation on increasing injection efficiency.



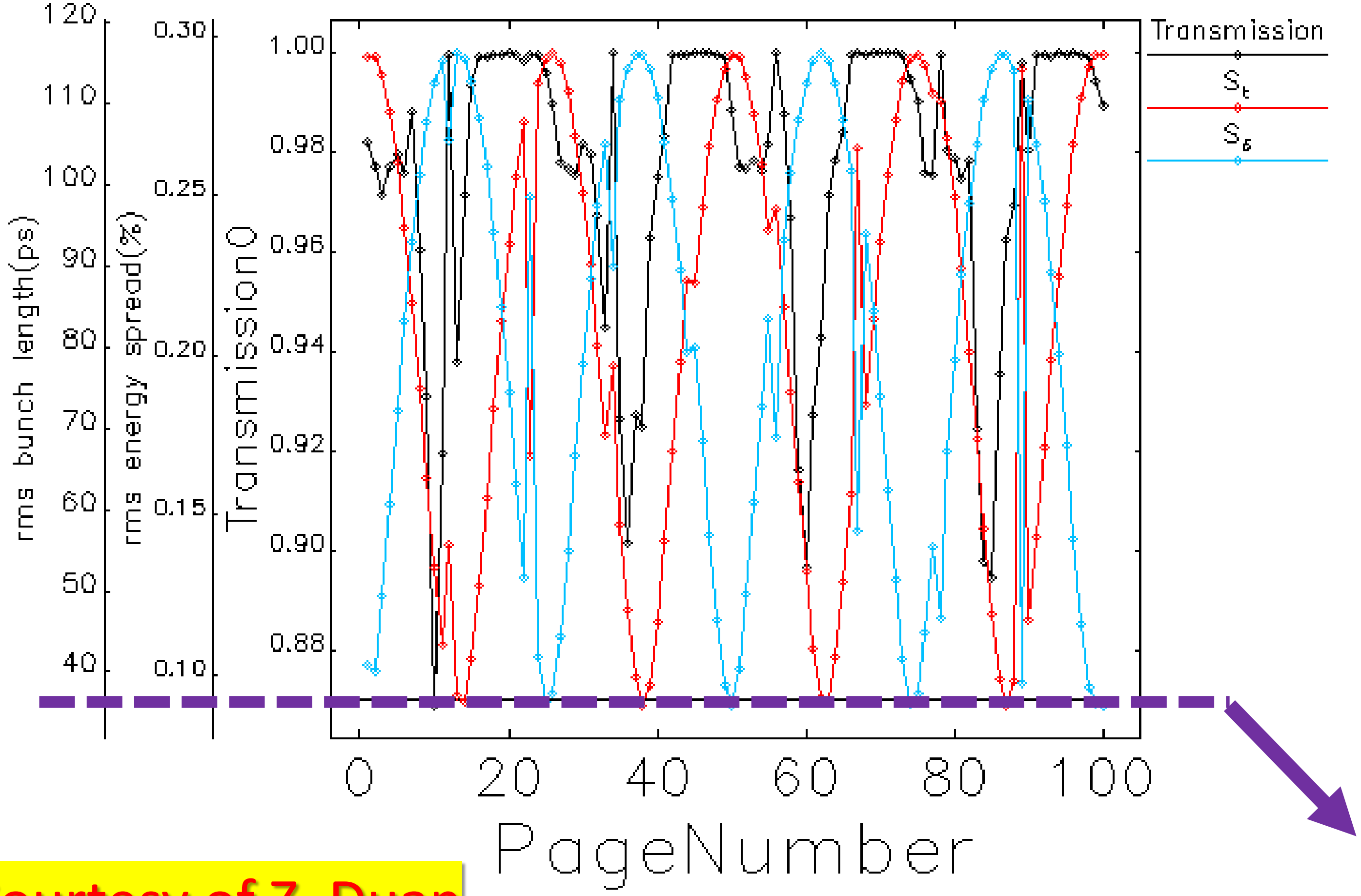








Idea of implementing RF Modulation in Booster



- **BLACK**: Injection Efficiency w/ RF Phase Modulation;
- **RED**: Initial Bunch Length;
- **Cyan**: Initial Energy Spread;

Injection Efficiency w/o RF Modulation

Courtesy of Z. Duan

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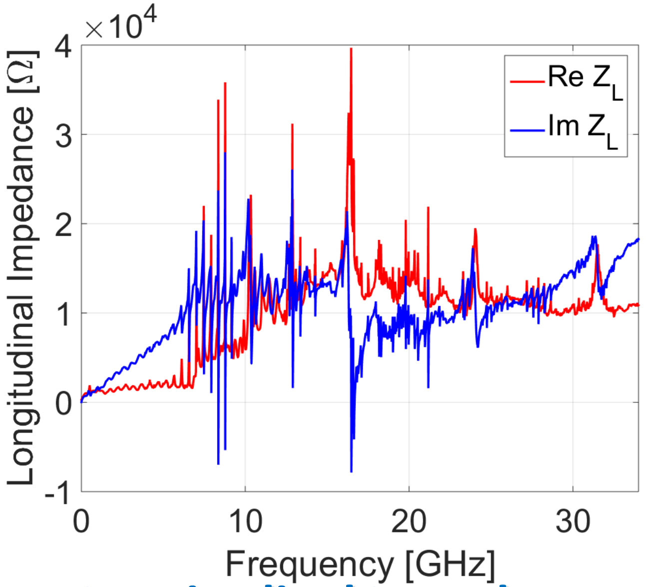
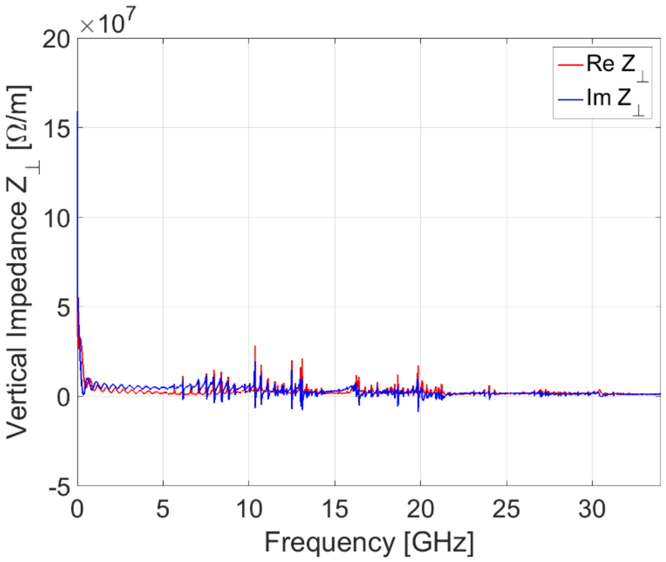
Impedance Modeling

- Total impedance spectrum has been used in the calculations of the charge limit.
- Update of the impedance model is still on-going since the more detailed engineering designs of components is on-going.



Longitudinal Impedance



Transverse Impedance

Elements	Number	Elements	Number
Resistive wall	-	In-vacuum IDs	7
Primary RF cavities	5	Tapers of Out-vacuum IDs	14
Harmonic cavities	2	BPMs	576
Vacuum transitions	240	Injection kickers	10
Bellows	1500	Extraction kickers	10
Flanges	2064	Longitudinal Feedback kicker	1
In-line absorbers	600	Transverse Feedback kicker	1
Vacuum pumping ports	288		

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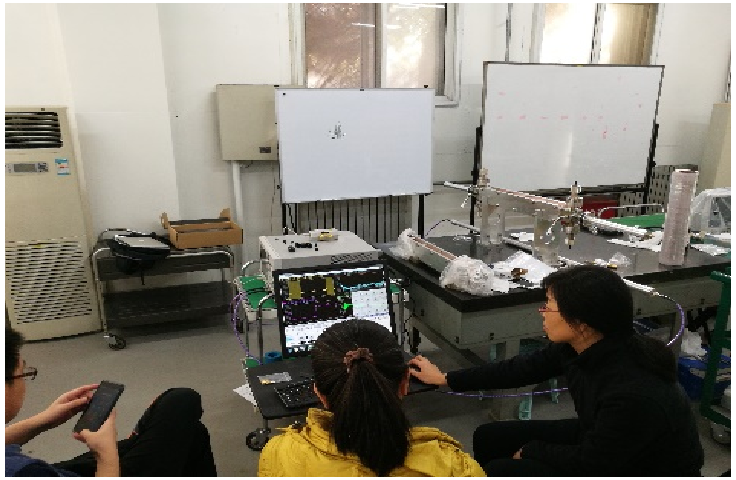
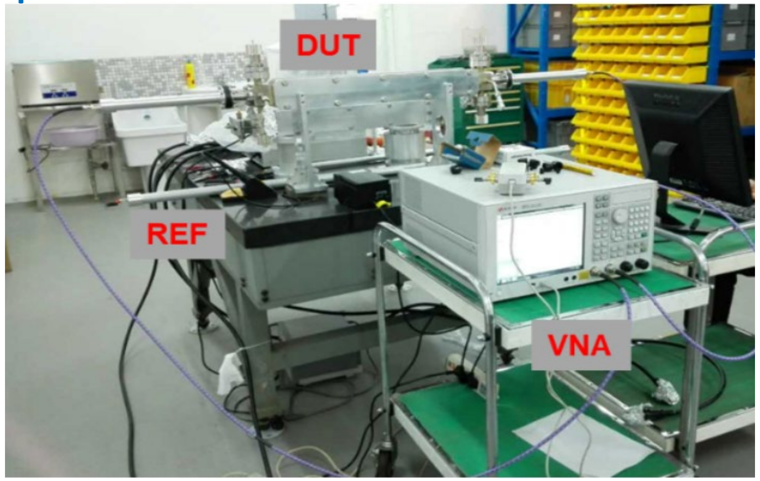
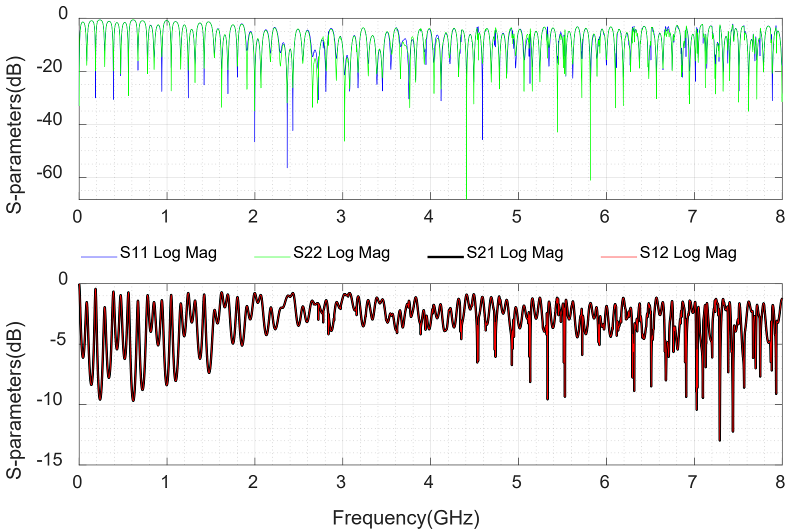
Impedance Measurements

- Traditional coaxial-wire technique

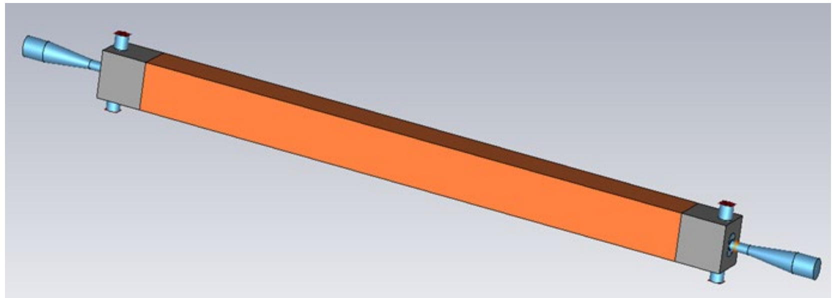


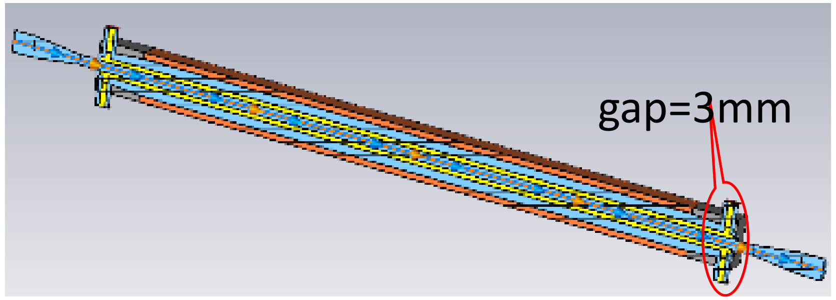




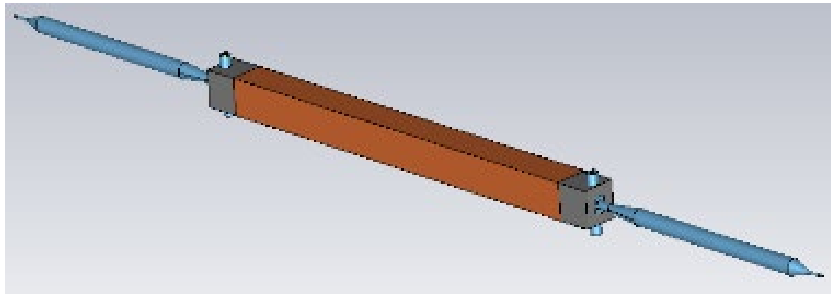
- Frequency space between ripples in transmission is ~96 MHz (λ=3.12m).
- The high peaks above 4 GHz are supposed to be introduced by the poor matching at the feedthroughs or higher modes other than TEM.

- Wakefield simulation with CST



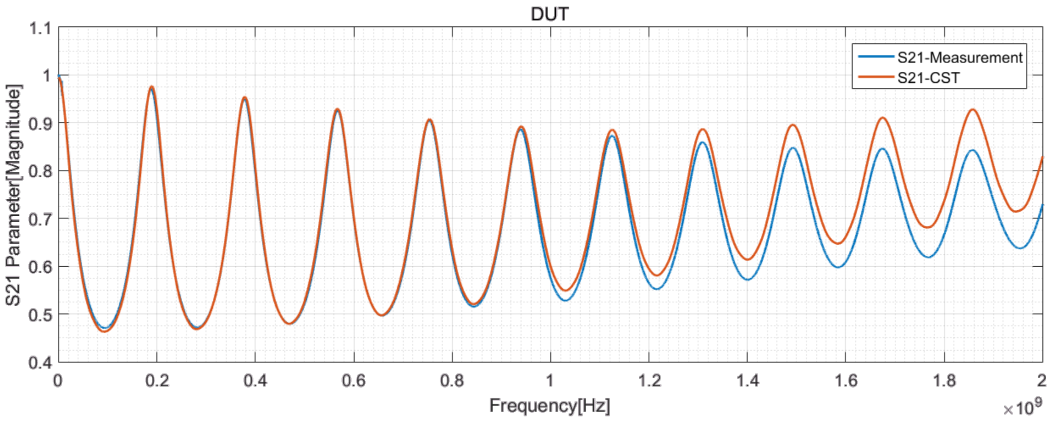


- S-parameter simulation with CST

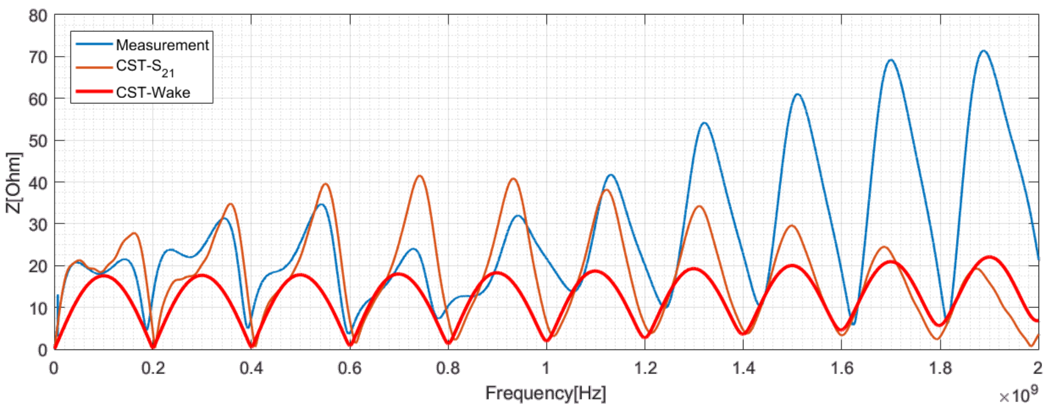


Impedance Measurements

S-parameter simulation



Comparison between measurement and simulations



- The agreement between simulation and measurement are reasonably good.
- The S parameter simulation shows the same frequency characteristic compare to the coaxial measurement, but with lower amplitude.
- The wake-field simulation gives much lower amplitude compare to the measurement or S-parameter simulations, and the repetition period of the resonances is larger.
- The difference can be explained by the additional cavity structure introduced by the drift transition.

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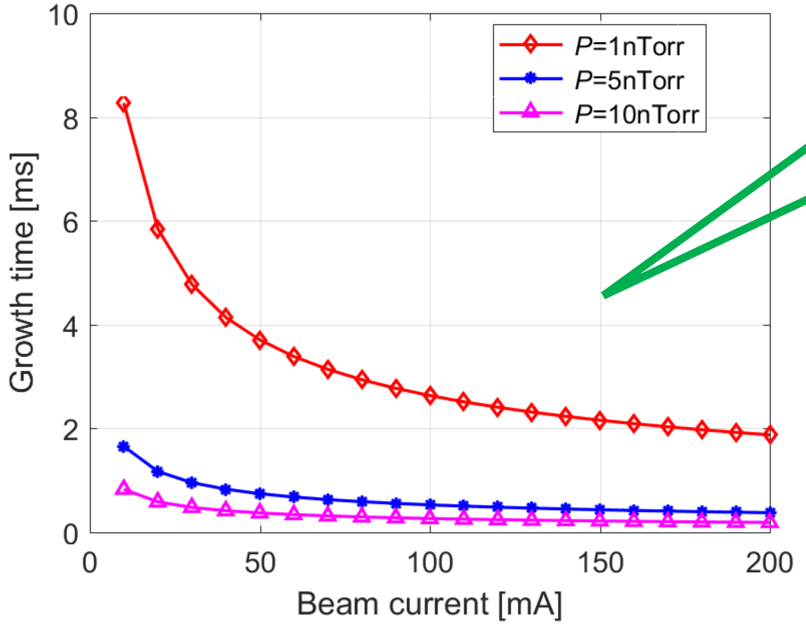
Fast-Beam Ion Instability

- Analytic estimations have been carried out by assuming different beam currents and different vacuum pressures:
  - $\tau_y \approx 18$ ms



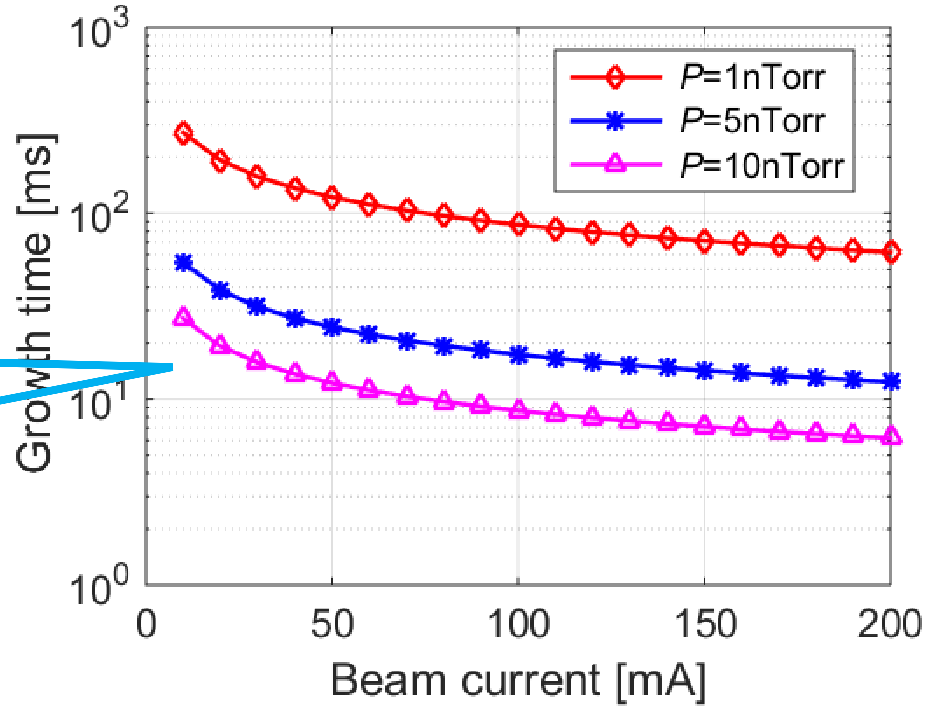
$y \ll \sigma_y$

$$\frac{1}{\tau_e} \approx \frac{1}{\tau_c} \frac{c}{4\sqrt{2}\pi L_{sep} n_b a_{bt} f_i}$$

$y \gg \sigma_y$

$$\frac{1}{\tau_H} \approx \frac{1}{\tau_c} \frac{c}{2\pi f_i L_{sep} n_b^{3/2}}$$

$$\frac{1}{\tau_c} = \frac{4 d_{gas} \sigma_{ion} \beta N_e^{3/2} n_b^2 r_e r_p^{1/2} L_{sep}^{1/2} c}{3\sqrt{3}\gamma \sigma_y^{3/2} \left(\sigma_y + \sigma_x\right)^{3/2} A^{1/2}}$$



T.O. Raubenheimer and F. Zimmermann, Fast Beam-Ion Instability I: Linear Theory and Simulations, SLAC-PUB-6740, Phys. Rev. E, Vol. 52, 5, pp. 5487–5498 (1995).

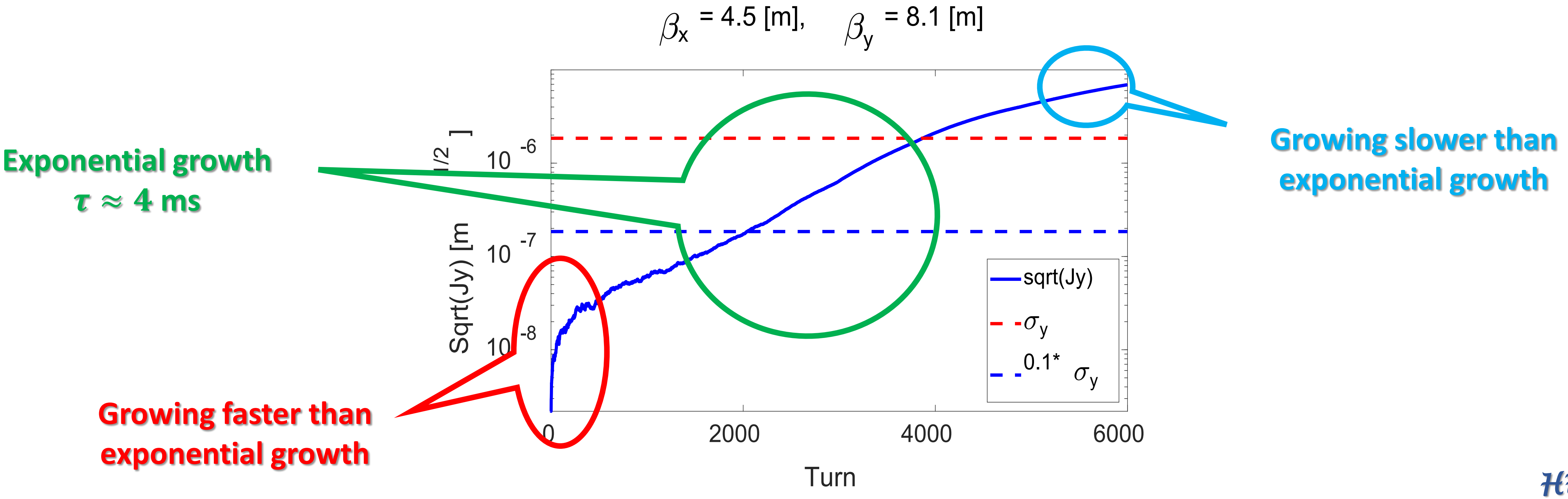
G.V. Stupakov, T.O. Raubenheimer and F. Zimmermann, Fast Beam-Ion Instability II: Effect of Ion Decoherence, SLAC-PUB-6805, Phys. Rev. E, Vol. 52, 5, pp. 5499–5504 (1995).

G.V. Stupakov, A Fast Beam-Ion Instability, Proceedings of the International Workshop on Collective Effects and Impedance for B-Factories (CEIBA95), KEK Proceedings 96-6, August 1996, p. 243 (1996).

Fast-Beam Ion Instability

Systematic Studies,
Code development,
& Simulations
By C. Li

- Simulation by implementing weak-strong model:
  - 200 mA, 680 continuous bunches;
  - 'weak' : each electron bunch is represented as 1 macroparticle;
  - 1 nTorr;
- Bunch-by-Bunch feedback system is foreseen to cure the FBII.



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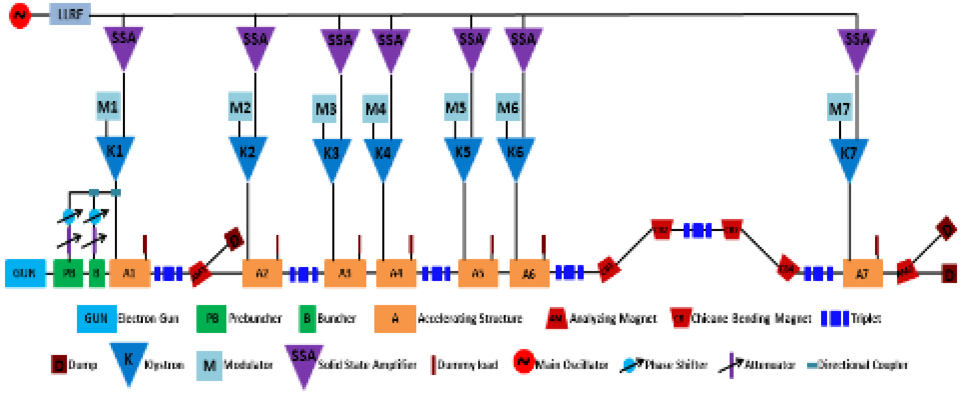
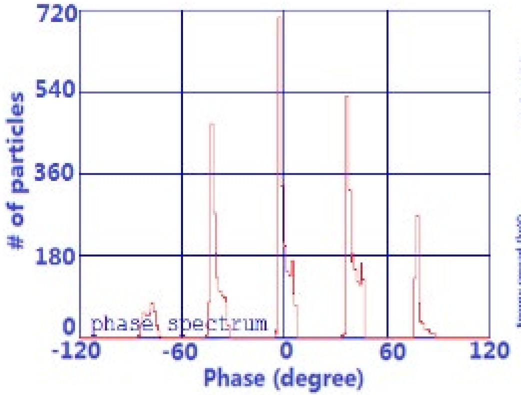
Design of the Injector of HEPS

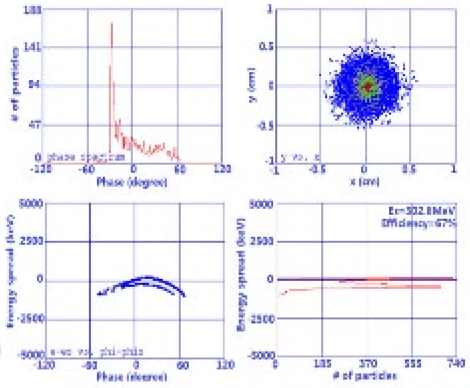
- Linac design

  Electron gun, buncher, accelerating tube, etc.

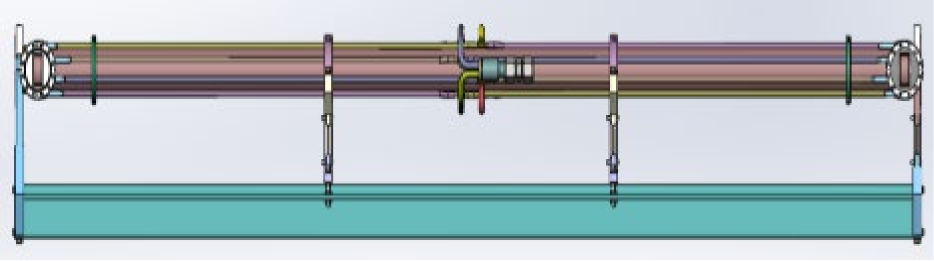


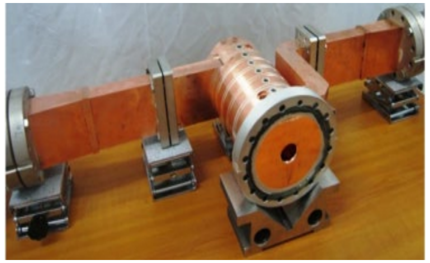


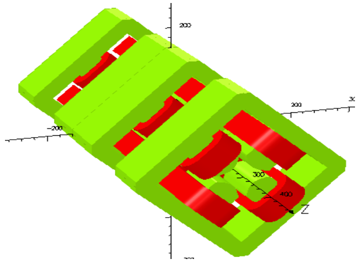
Bunch distribution at the linac exit



Phase & position distribution of central bunch



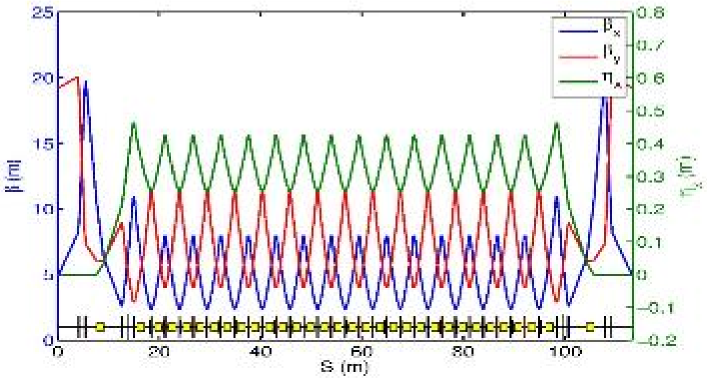


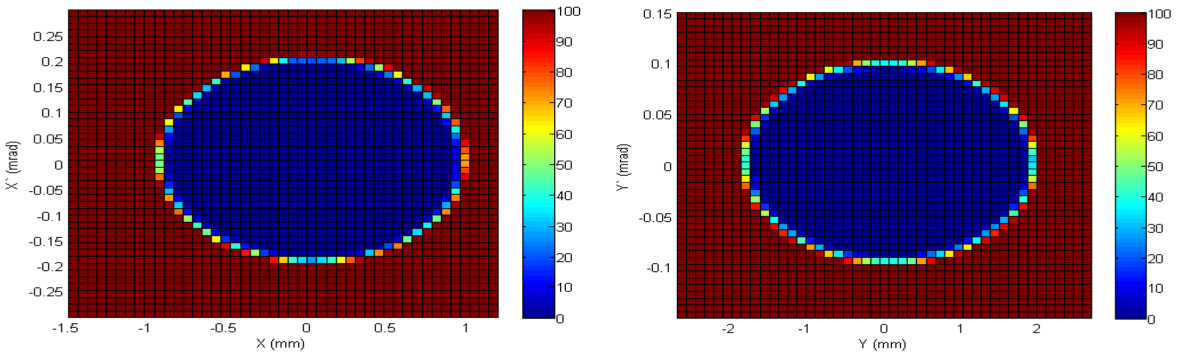


- Beam dynamics simulation & AP design
- Design of accelerating structure & MW element
- Physics design of various kind of magnets
- Design of other systems of linac

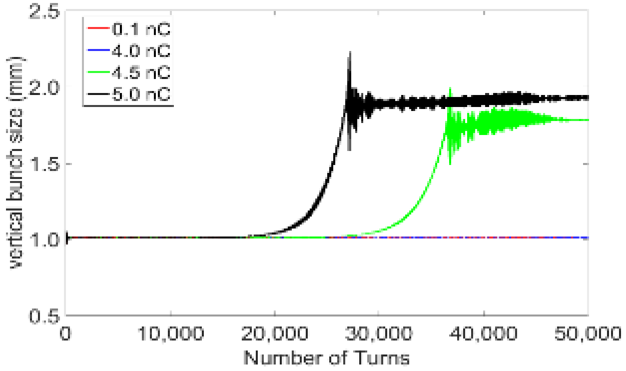
Design of tl

• Booster design

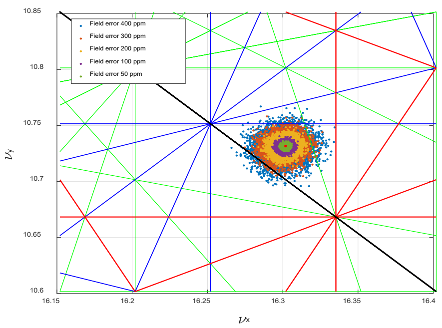




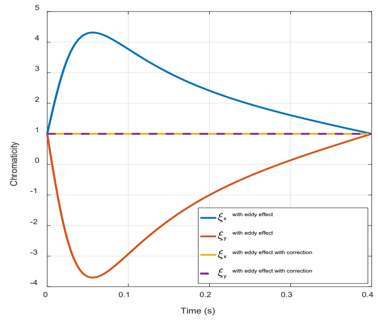
Effect on orbit error at low energy to injection



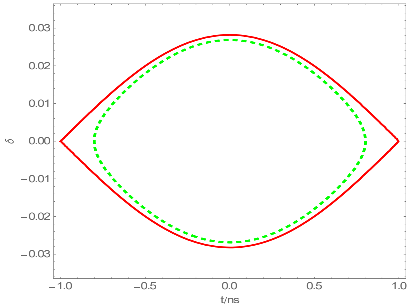
Single bunch current limit



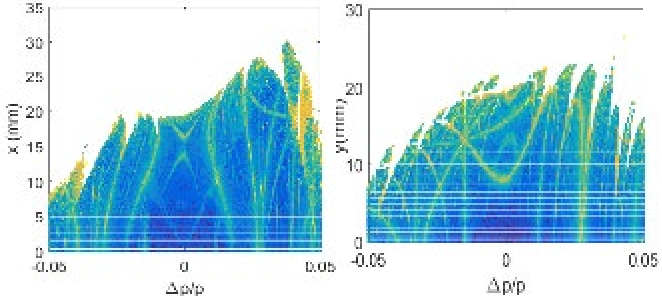
Effect of magnetic errors to tunes



Chromaticity variation due to ripple



Mom. Acceptance @low energy

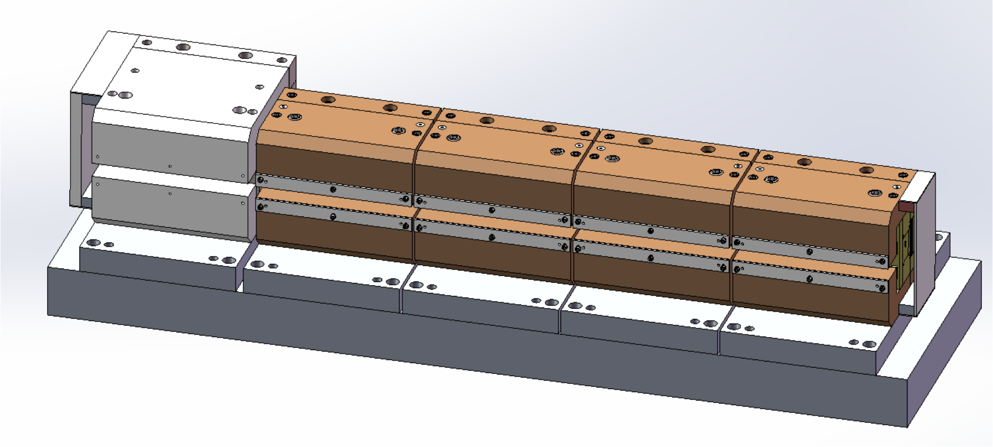


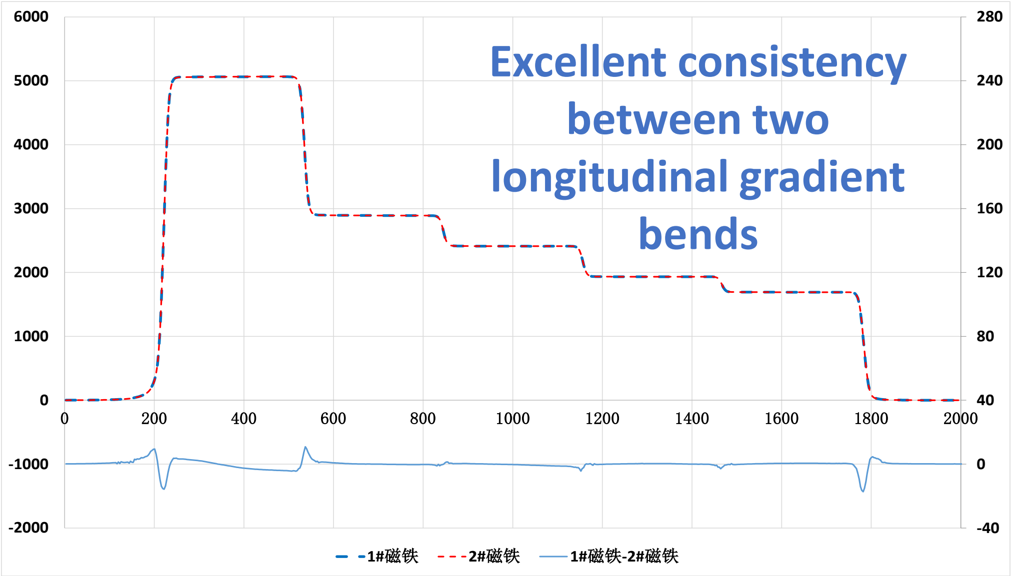
Dynamic aperture study

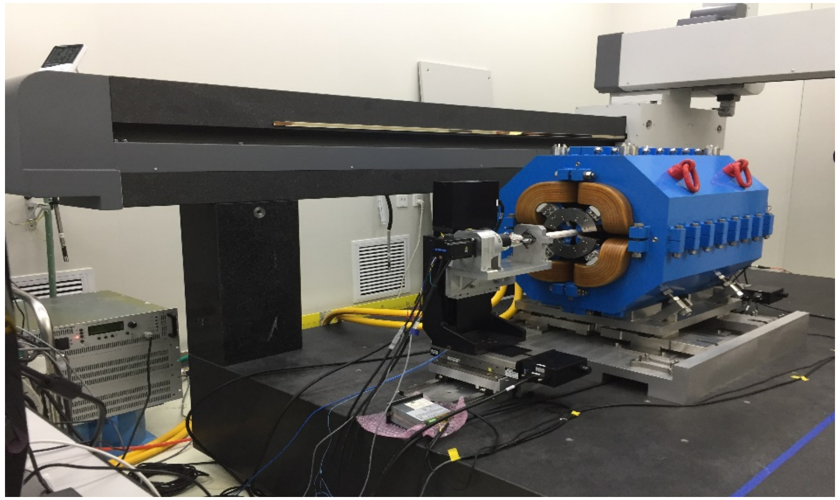
- Lattice design & nonlinear tracking study
- Magnetic errors effects to injection and beam store
- Simulation on impedance, modification of AP parameters to get required bunch charge
- Fit to the swap-out & longitudinal on-axis injection

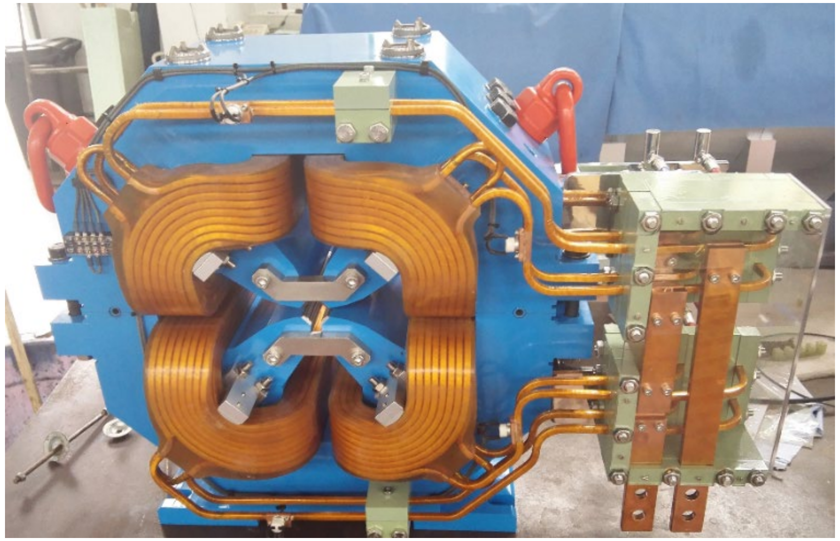
HEPS

Hardware Progress





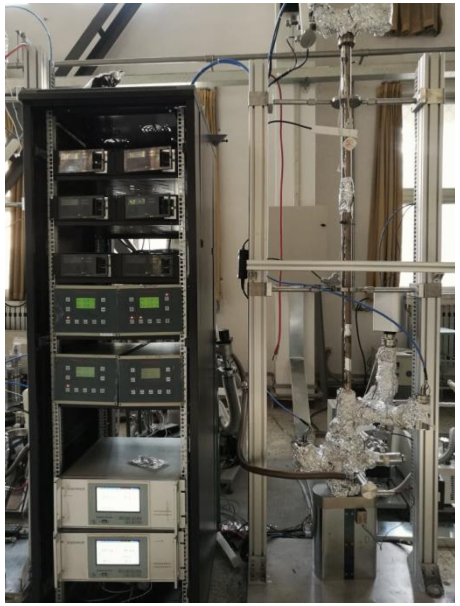


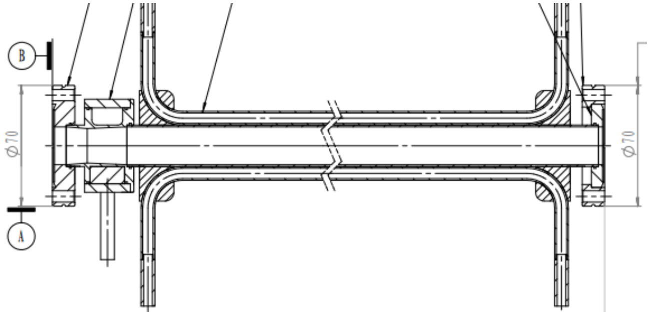


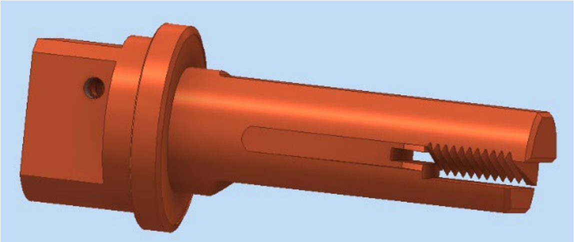
Magnets prototypes

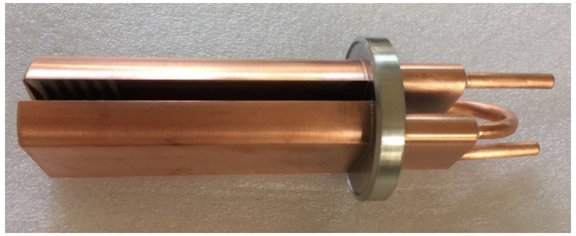
HEPS

Hardware Progress



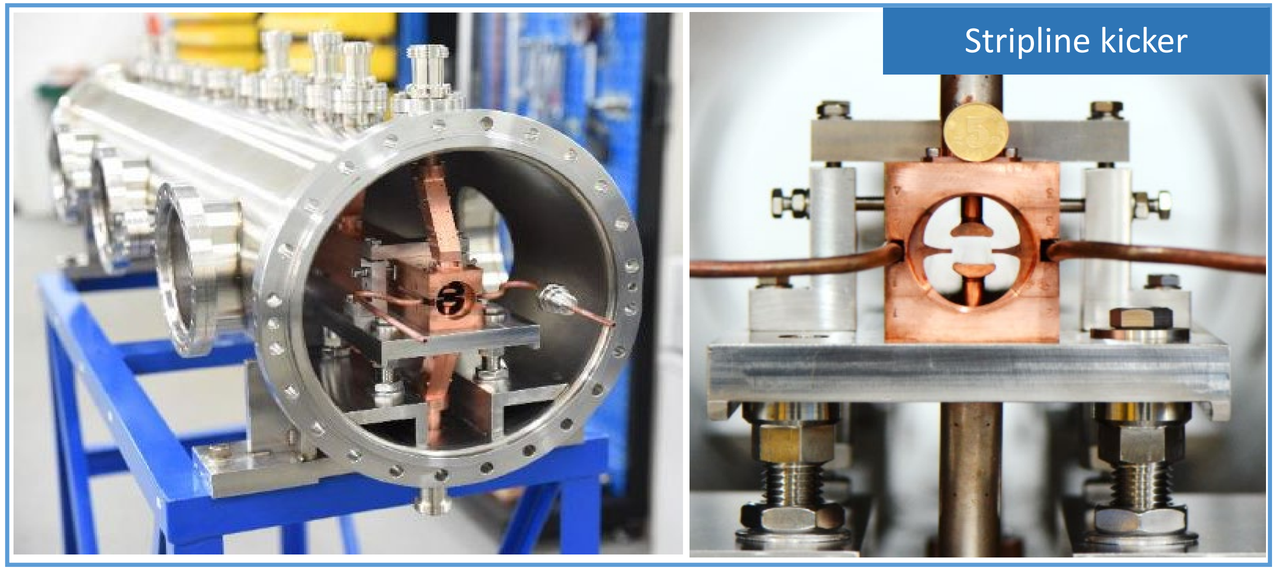




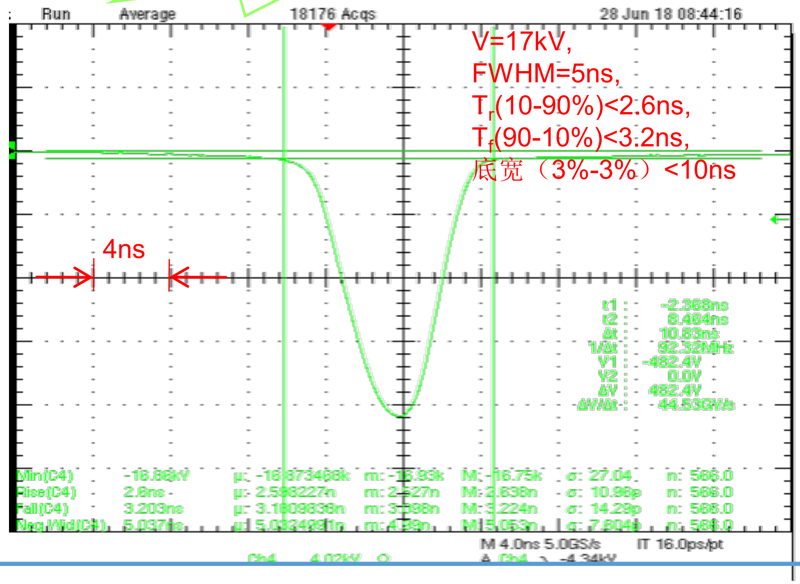


Kicker and Pulser

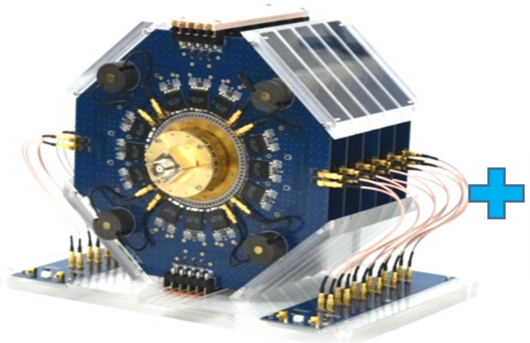
Stripline kicker



Bench test



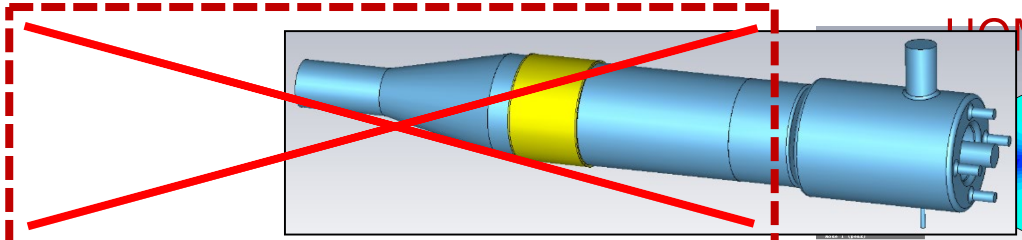
HV fast pulser



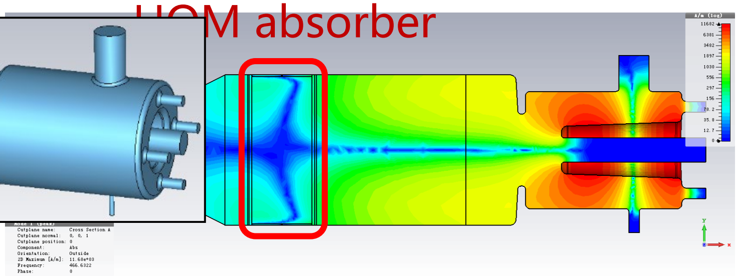
Inductive adder

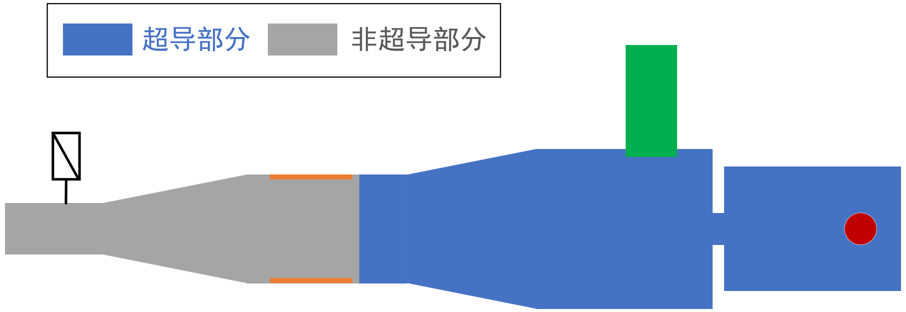
Drift Step Recovery Diodes

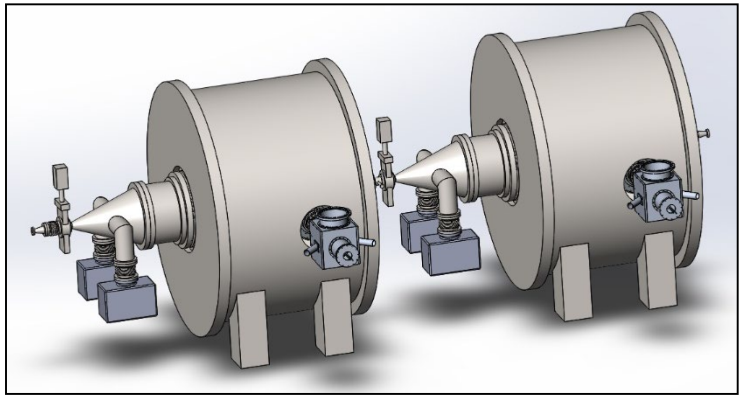
166.6 MHz Superconducting RF Cavity with heavy HOMs Damping

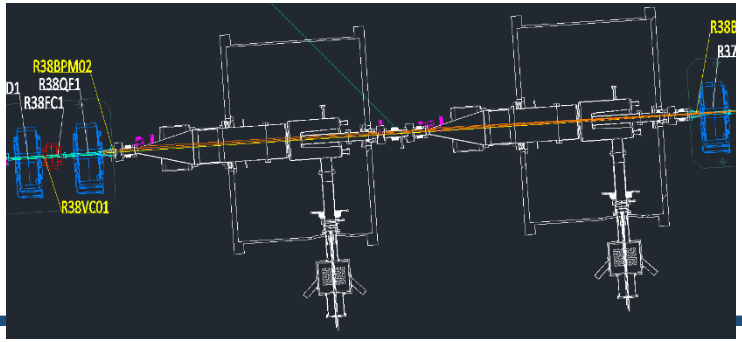


“HOM tuning” given up

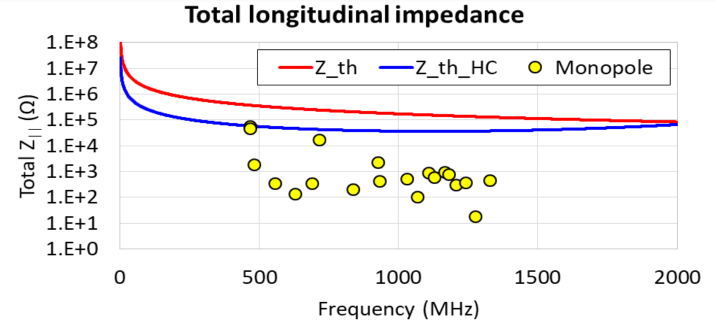


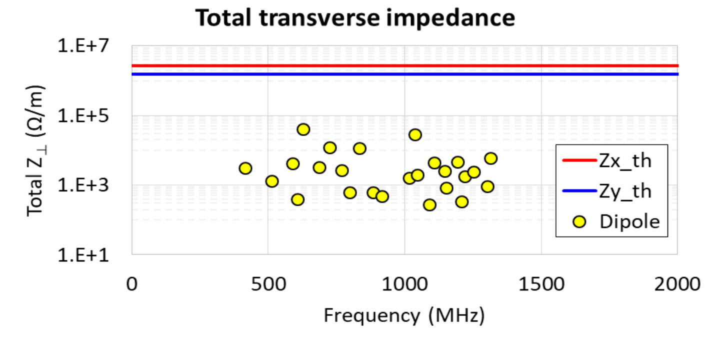




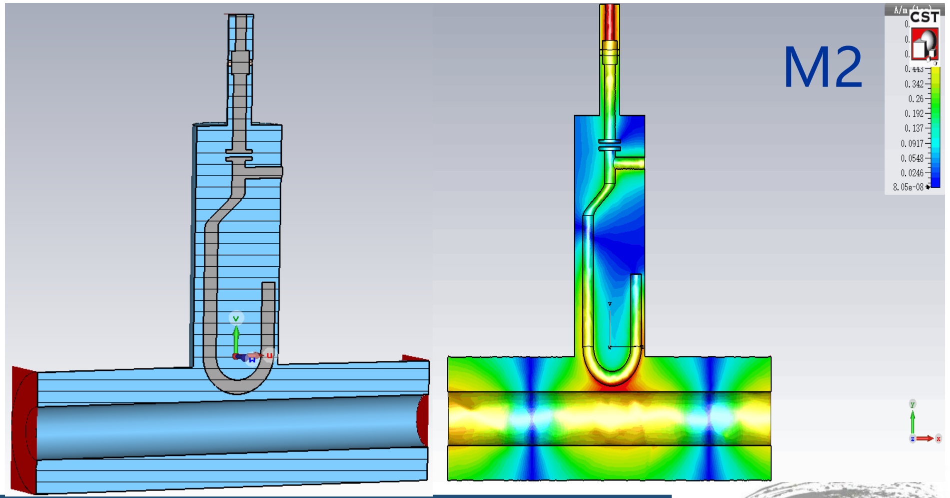


New Baseline





- Hybrid HOMs Suppression
  - HOM Coupler;
  - HOMs Absorber;



Brief Overview of Beamlines

B1 Engineering Materials Beamline	60-170keV
B2 Hard X-ray Multi-analytical Nanoprobe (HXMAN) Beamline	< 10nm; in situ nanoprobe; 200m long
B3 Structural Dynamics Beamline (SDB)	Single shot for irreversible; 200m long
B4 Hard X-ray Coherent Scattering Beamline	CDI, XPCS
B5 Hard X-ray High Energy Resolution Spectroscopy Beamline	NRS, Raman and RIXS
B6 High Pressure Beamline	Diffraction; 150nm, ultrahigh pressure
B7 Hard X-Ray Imaging Beamline	Up to 300keV, 300mm beam size, 350m long
B8 X-ray Absorption Spectroscopy Beamline	sub micron, quick XAFS
B9 Low-Dimension Structure Probe (LODISP) Beamline	surface and interface
B10 Biological Macromolecule Microfocus Beamline	1μm, serial crystallography
B11 pink SAXS	pink, least optics
B12 High Res. Nanoscale Electronic Structure Spectroscopy Beamline	ARPES, 200-2000eV
B13 Tender X-ray beamline	Spectroscopy, BM beamline
B14 Transmission X-ray Microscope Beamline	Nano imaging and spectroscopy
B15 Test beamline	X-ray optics test

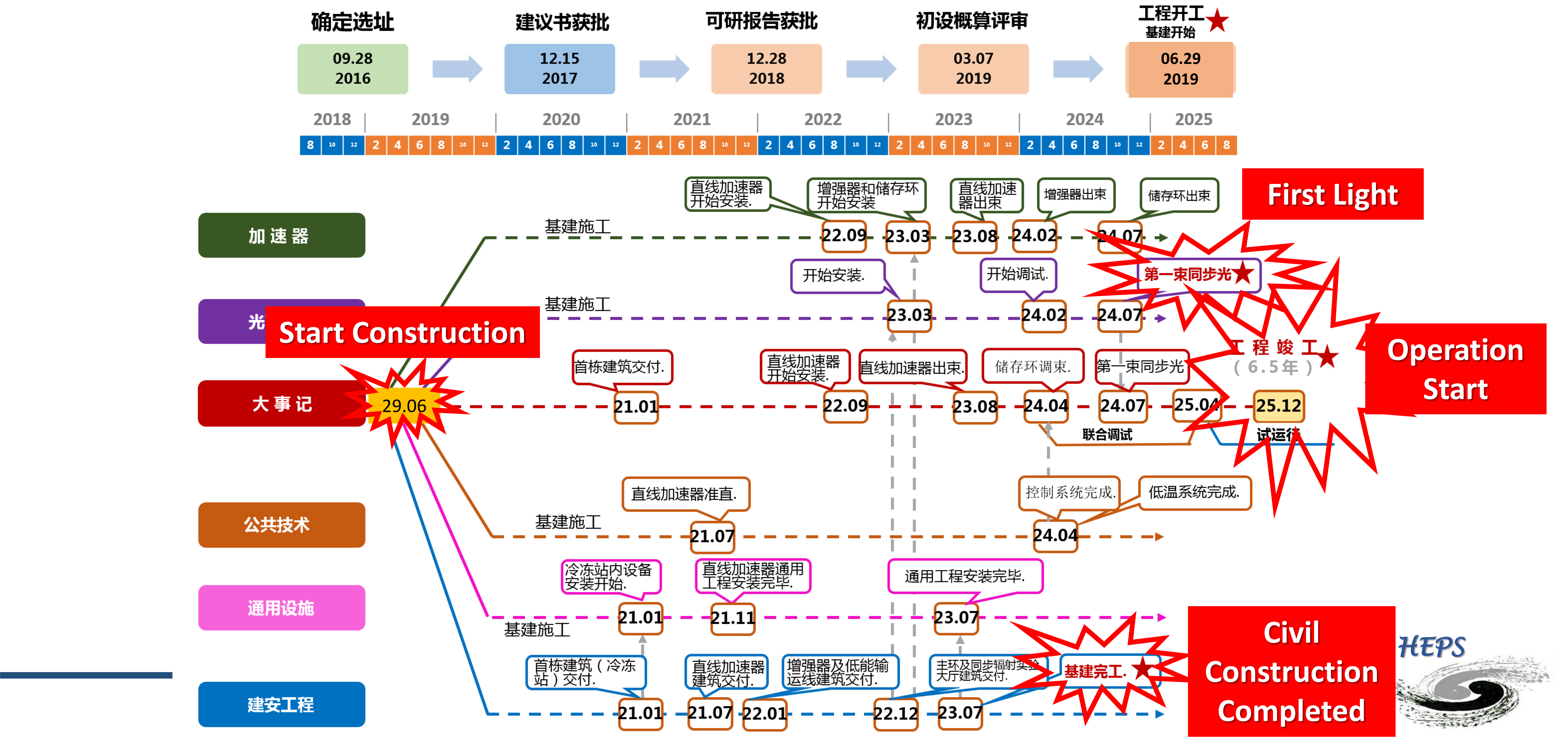
Brief Introduction of the Plan and Status of the HEPS Project

- **Contents of construction**
  - **Accelerator (Linac, booster, transport lines, storage ring)**
  - **14 beamlines + 1 diagnostics line**
  - **Global support systems (control, cryogenics, alignment, radiation protection)**
  - **Conventional utility**
  - **Buildings for machine and other auxiliary facility**
- **Budget**
  - **4.68 B CNY (~600 M Euro)**
- **Construction period: 6.5 years including commissioning**

Milestones of HEPS project

- 01/2016, Conceptual Design Report study finished
- 02/2017, Project Proposal Report completed & submitted to CAS
- 03/2017, internal review of Project Proposal Report
- 05/2017, modified PPR submitted to the National Development & Reform Commission
- 26/06/2017, national review of PPR
- 15/12/2017, PPR approved by government
- 01/2018, Feasibility Study Report submitted to CAS
- 11/06/2018, national review of Feasibility Study Report
- 31/08/2018, national review of Preliminary Design Report
- 28/12/2018, Feasibility Study Report approved
- 22/05/2019, Preliminary Design Report approved
- 29/06/2019, Construction started, and will be completed in 6.5 years

Milestones of HEPS project



Start of the Construction of HEPS! 29-June-2019


Thank you for your attention!