Future projects for next generation Tau-charm Factories

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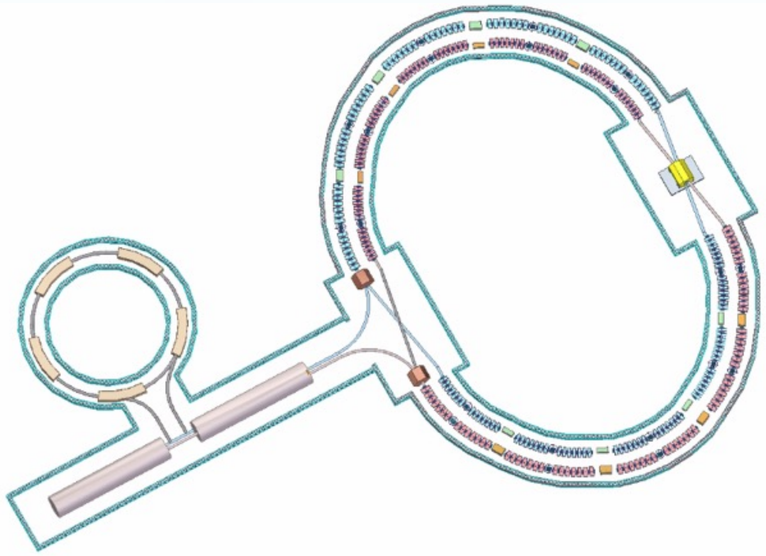
Outline

- What's a Super Tau Charm factory?
- Major challenges for super Tau Charm accelerators
- Super Charm Tau Factory at BINP
- Super Tau Charm Facility at USTC
- Conclusion

What's a Super Tau Charm?

- A e+e- collider with c.m. energy around 4 GeV
  - i.e. 2-7 GeV for Chinese STCF, 3-7 GeV for Russian SCTF
    - Achieve main luminosity goal at 4 GeV
  - Dual Ring, one interaction point
  - A peak luminosity of $10^{35}cm^{-2}s^{-1}$, 100 times as scientists had achieved at BEPC II
  - Do we need polarization?



❍ Large Piwinski Angle and Crab Waist (P. Raimondi 2006)

Luminosity $L = \frac{\gamma}{2er_e} \cdot \frac{I_{tot}\xi_y}{\beta_y^*} R_H$

Large Piwinski angle: $\phi = \frac{\sigma_z}{\sigma_x} \tan\left(\frac{\theta}{2}\right)$

Transverse beam separation in parasitic IPs

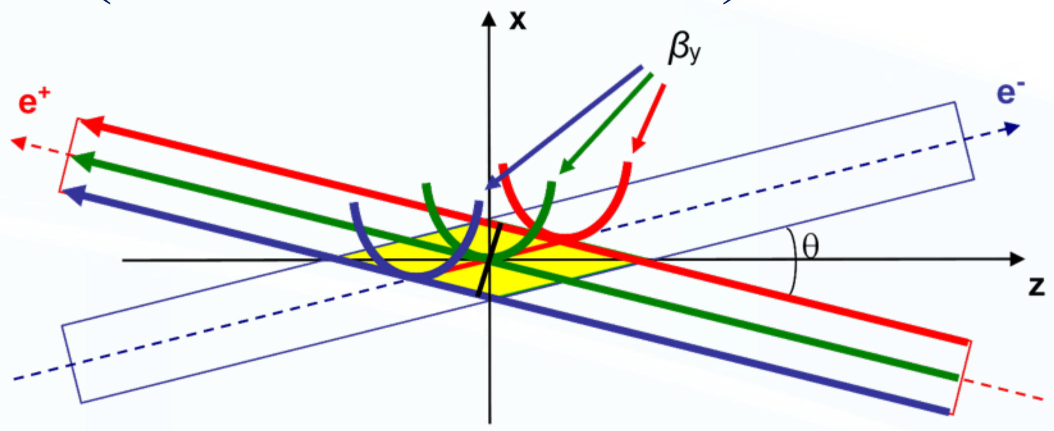
- distance between bunches is not limited by beam-beam

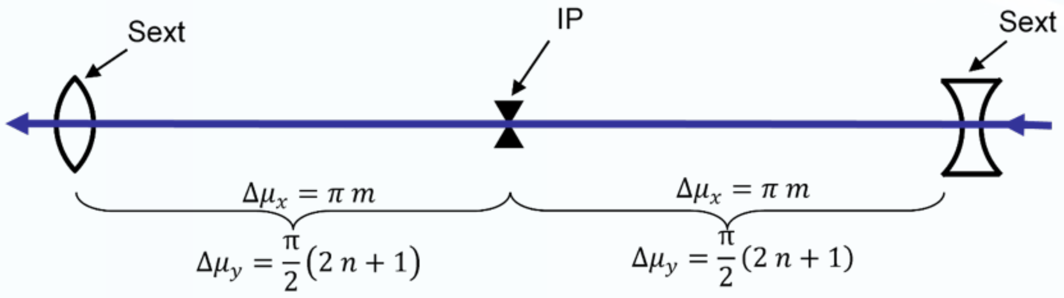
Interaction area length $L_i \ll \sigma_z$

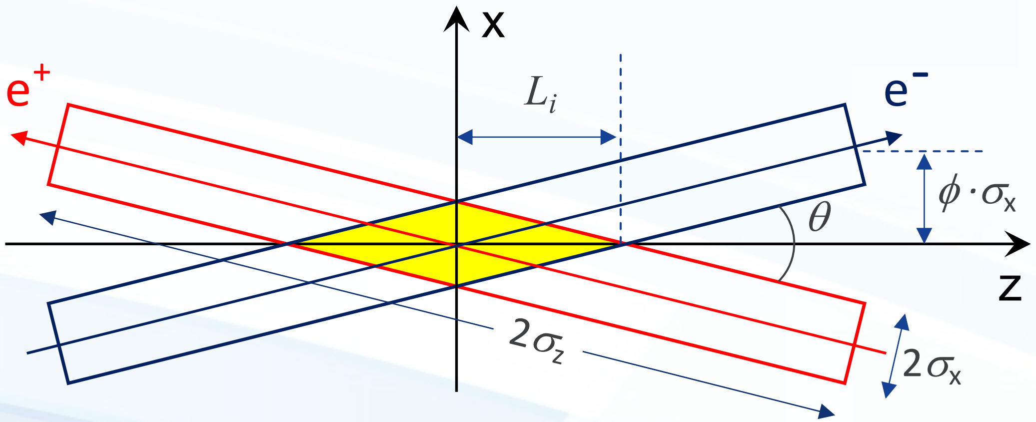
- $\beta_y^* \approx L_i \ll \sigma_z$ no hour-glass

CRAB waist (CRAB sextupoles) suppresses betatron and synchro-betatron resonances

- $\xi_y \sim 0.2$ (Theoretically)







K. Hirata PRL 1995

Test of ‘‘Crab-Waist’’ Collisions at the DAΦNE Φ Factory, PRL 2010

Slide by courtesy of A. Bogomyagkov, Workshop on future Super c-tau factories 2021, 15-17 November

Major challenges for accelerators

- Accelerator design physics
  - *High current, small bunches at IP*
    - Collective effects ↑↑， Instability ↑↑
  - Focusing↑↑ -> Negative chromaticity↑↑ -> Chromatic correcting sextupoles
    - Chromatic correcting sextupoles + crab waist sextupoles， more non-linearity
  - *Smaller dynamic aperture and energy aperture*
    - Also, much shorter Touschek lifetime （Bremsstrahlung is not decisive）
  - *Lower bending angle per dipole in arc cells*
    - Strong focusing, lower emittance
    - Smaller maximum values of the dispersion function, provide adequate momentum acceptance -> not optimum for chromaticity correction but can use DLSR experience

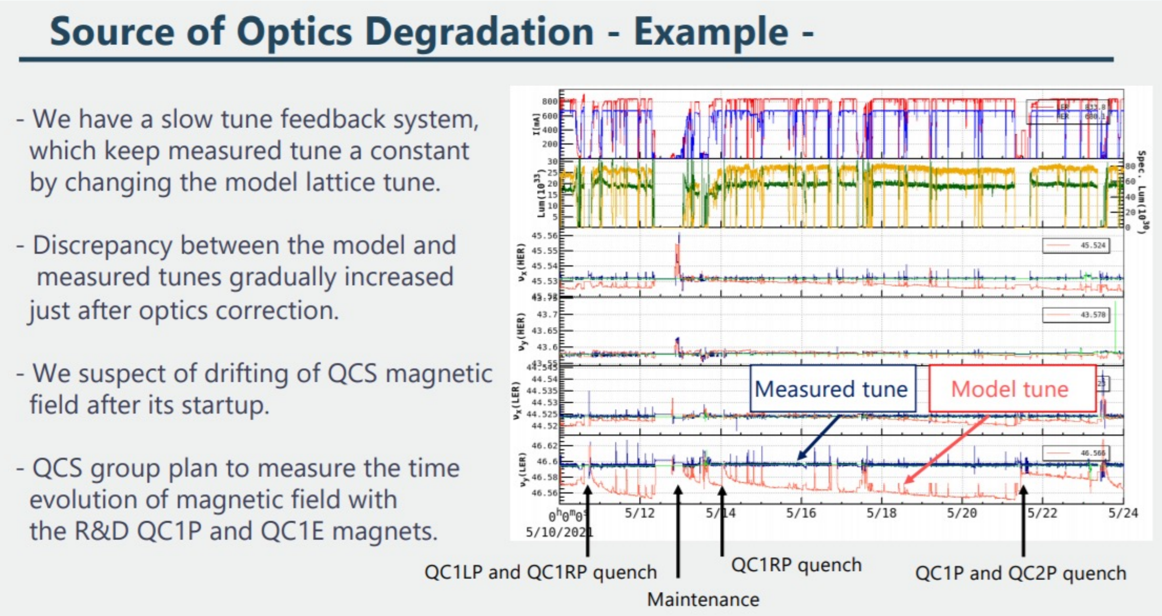
❍ Key Technologies for Accelerators

- Technologies for high peak luminosity: Interaction Region Misc.
  - Superconducting magnets for final focus
  - Correcting the focusing magnets leakage, cancelling the detector solenoid, etc.
  - Collimator, cryostat, chamber, etc.
- Technologies for high integrated luminosity: Beam instrumentations and so on
  - Monitoring beam parameters, suppressing the instabilities, optimizing collision, etc.
- Beam sources and injection
  - Electron and positron source with high current and high quality
    - Very low lifetime -> High current top-up injection, sufficient injection efficiency is needed
    - Low quality (especially emittance and bunch size) may result in perturbations and irradiations
  - On-axis injection may be required
    - Due to lower aperture

❍ Experience from SuperKEKB*

- Reach a high beam-beam parameter (tune shift) is essential, but difficult
  - 0.0881/0.0807 (design); 0.046/0.030 (June 2021)
- Current may be lower than expected
  - The measured threshold can be much lower than expected (i.e. limited by TMCI due to the impedance of narrow beam collimators
- Beam blow up significantly contribute to luminosity loss

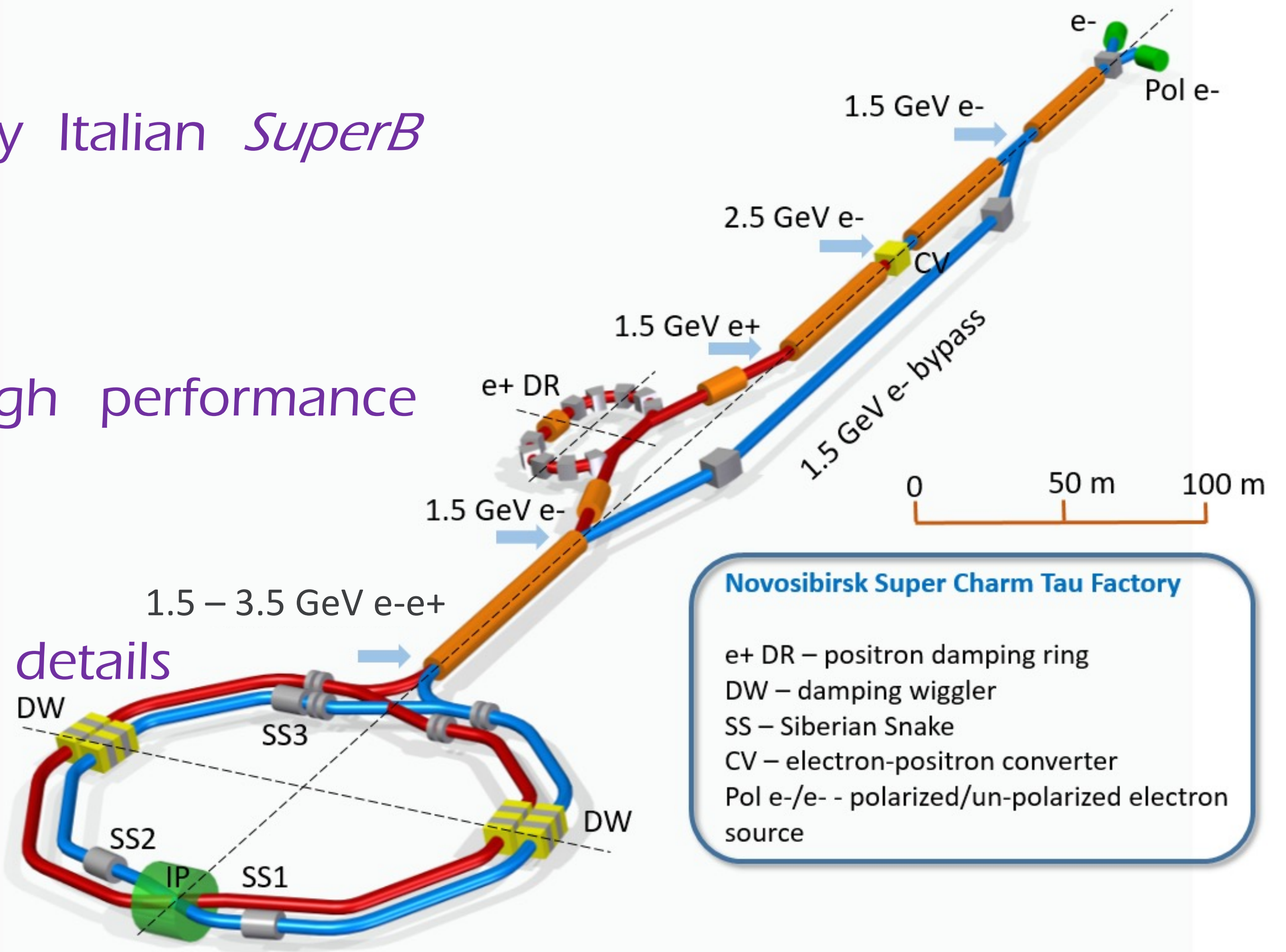
*Courtesy of H. Sugimoto, Workshop on future Super c-tau factories 2021, 15-17 November



We can see that advanced beam instrumentations , feedback systems and carefully commissioning are required

SCTF @ BINP

- Work started since 2008
  - Design and parameters inspired by Italian *SuperB* Factory project
- 2011 CDR ver1.0
  - With MDI, lattice optimization, high performance operation at all energies
- 2018 CDR ver2.0
  - Upgraded design and more technical details
- From 2019 to Now
  - Shorter ring, better dynamics
  - Snakes
  - Realistic design of MDI, lens and injection facility



❍ Design parameters

E(MeV)	1500	2000	2500	3000	3500
Π(m)	632.94				
F_{RF}(MHz)	350				
2θ(mrad)	60				
$\varepsilon_y/\varepsilon_x$(%)	0.5				
β_x^*/β_y^* (mm)	100/1				
I(A)	2	2	2	2	2
$N_{e/bunch}\times 10^{-10}$	9	9	8	9	[illegible]
N_b	292	292	328	29[illegible]	[illegible]
U_0(keV)	130	260	465	773	1220
V_{RF}(kV)	1600	2000	2500	3500	5000
ν_s	0.0164	0.0159	0.0158	0.017	0.019
δ_{RF}(%)	1.9	1.8	1.7	1.7	1.9
$\sigma_e\times 10^3$ (SR/IBS+WG)	0.28/1	0.4/1.1	0.5/1.1	0.6/1.1	0.7/1.1
σ_s(mm) (SR/IBS+WG)	4/15	7/15	7/15	[illegible]	[illegible]
ε_x(nm) (SR/IBS+WG)	2.7/8.8	5/5.5	7/4.6	[illegible]	[illegible]
$L_{HG}\times 10^{-35}(cm^{-2}s^{-1})$	0.8	1	1	1	1
ξ_x/ξ_y	0.007/0.15	0.005/0.14	0.003/0.1	[illegible]	[illegible]
$\tau_{Touschek}$ (s)	1600	1600	2300	4000	8300
$\tau_{Luminosity}$ (s)	2000	1600	1700	1600	1600

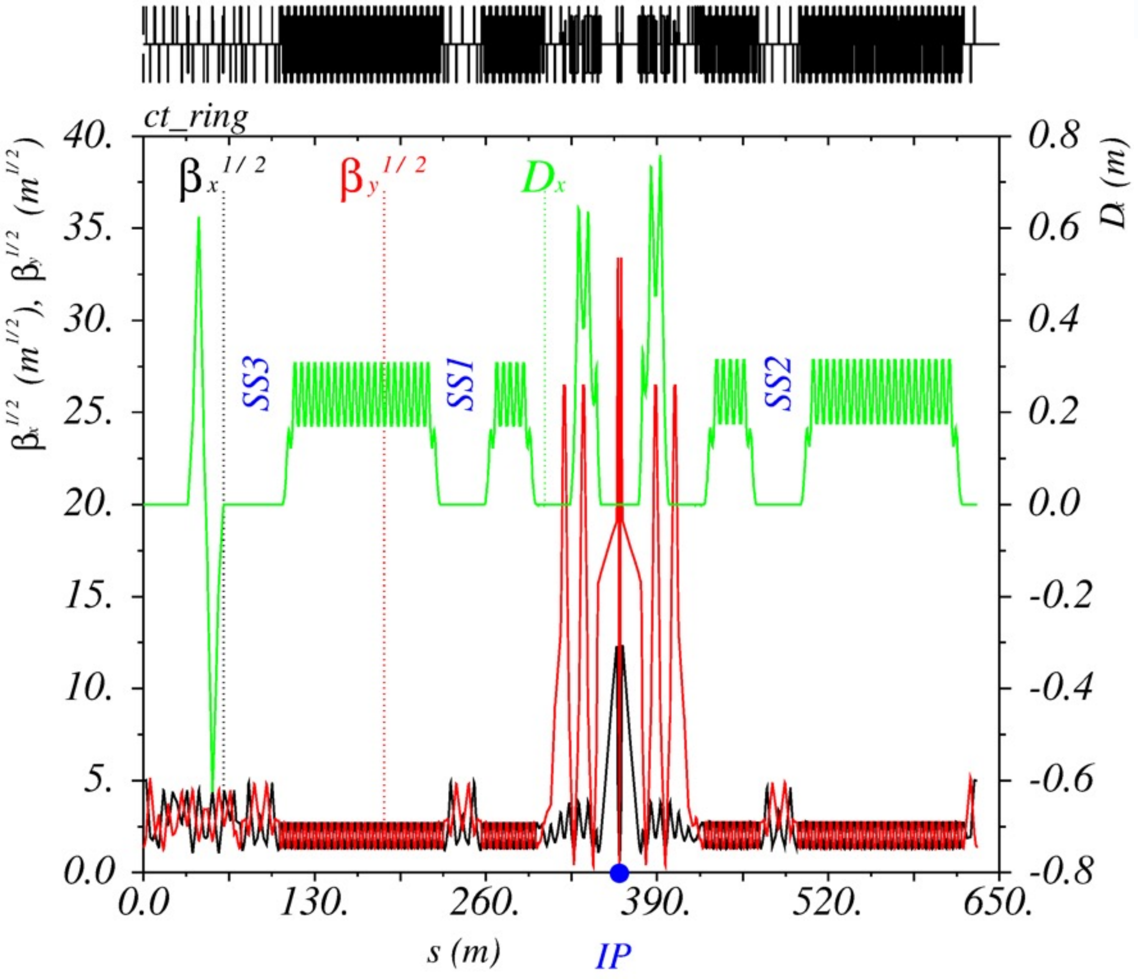
SuperKEKB 03.12.2019 $\beta_y^* = 1\ mm$

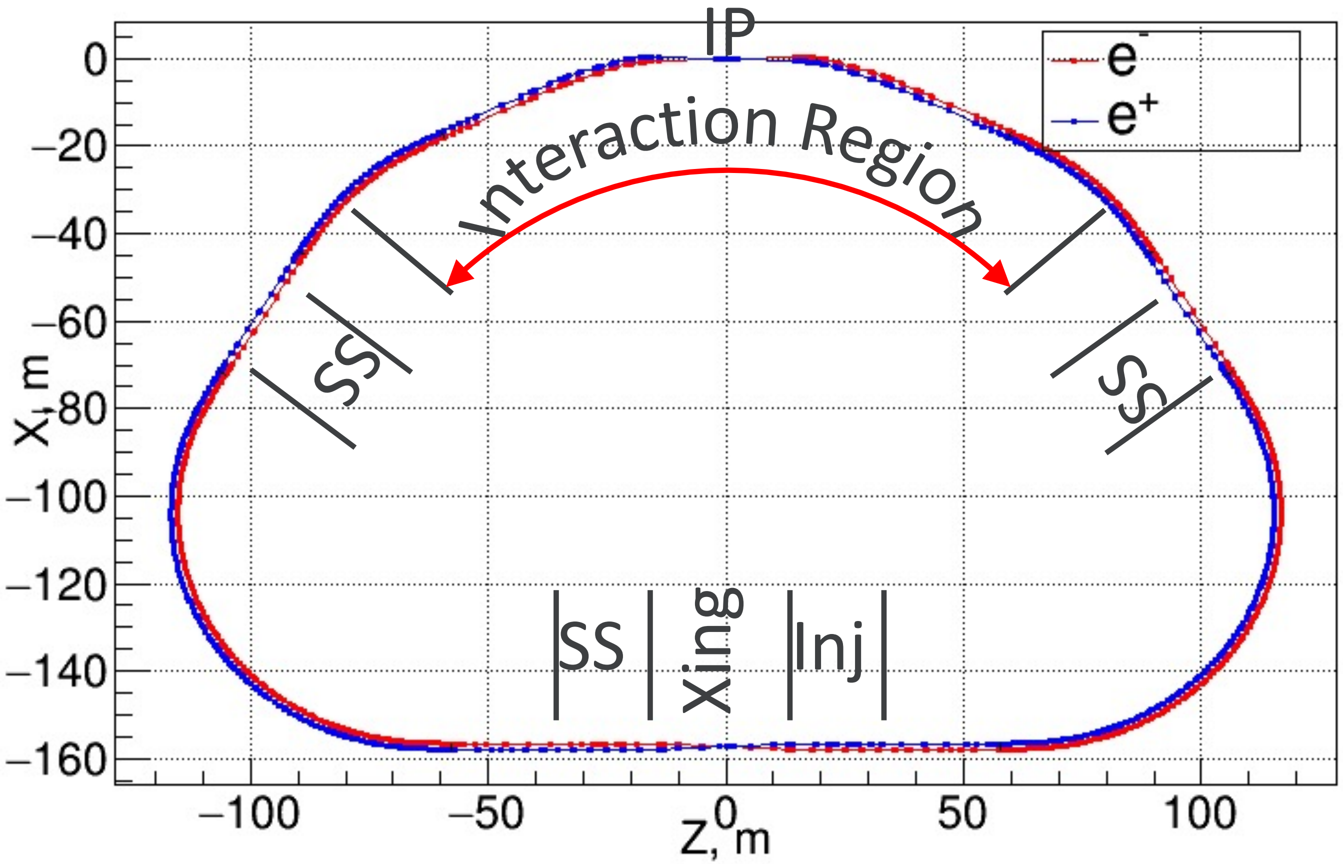
PEPII: I(e+)=3.2 A PEPII
DAFNE : I(e-)=2.45A

SuperKEKB: $L = 3.1\times 10^{34}$

SuperKEKB(LER): $\tau = 360\ s$

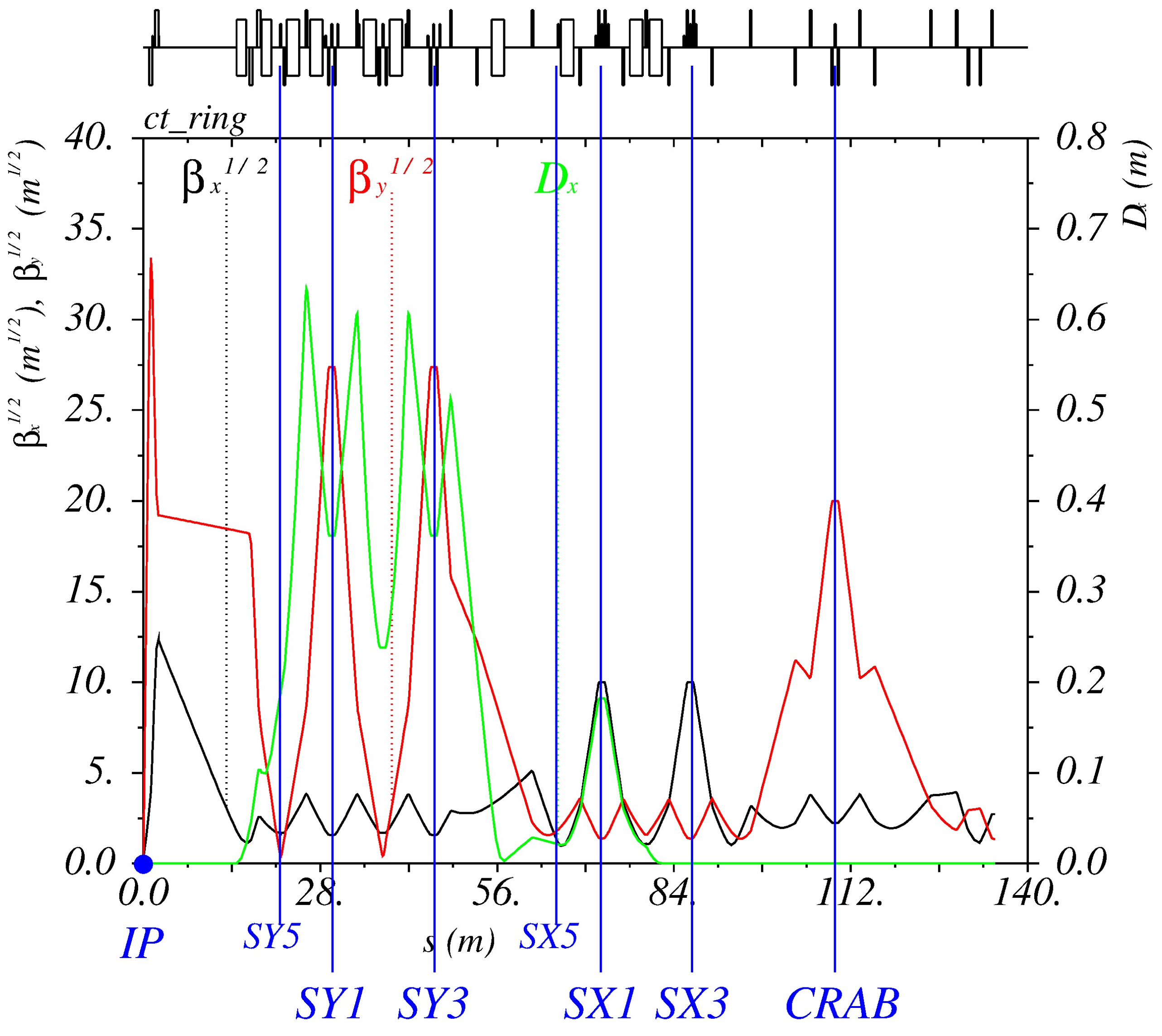
❍ Lattice and layout 2021



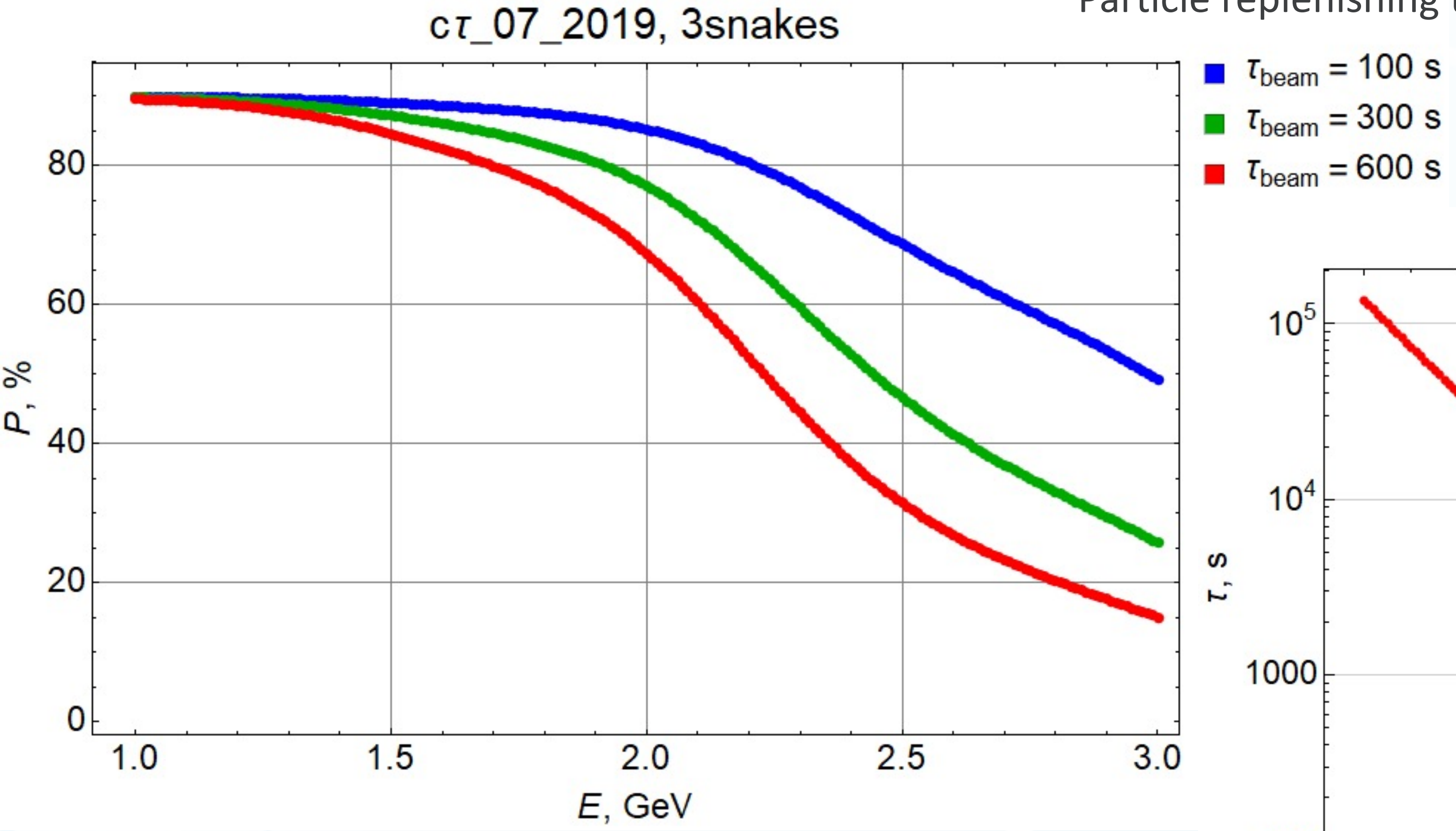


❍ Interaction region

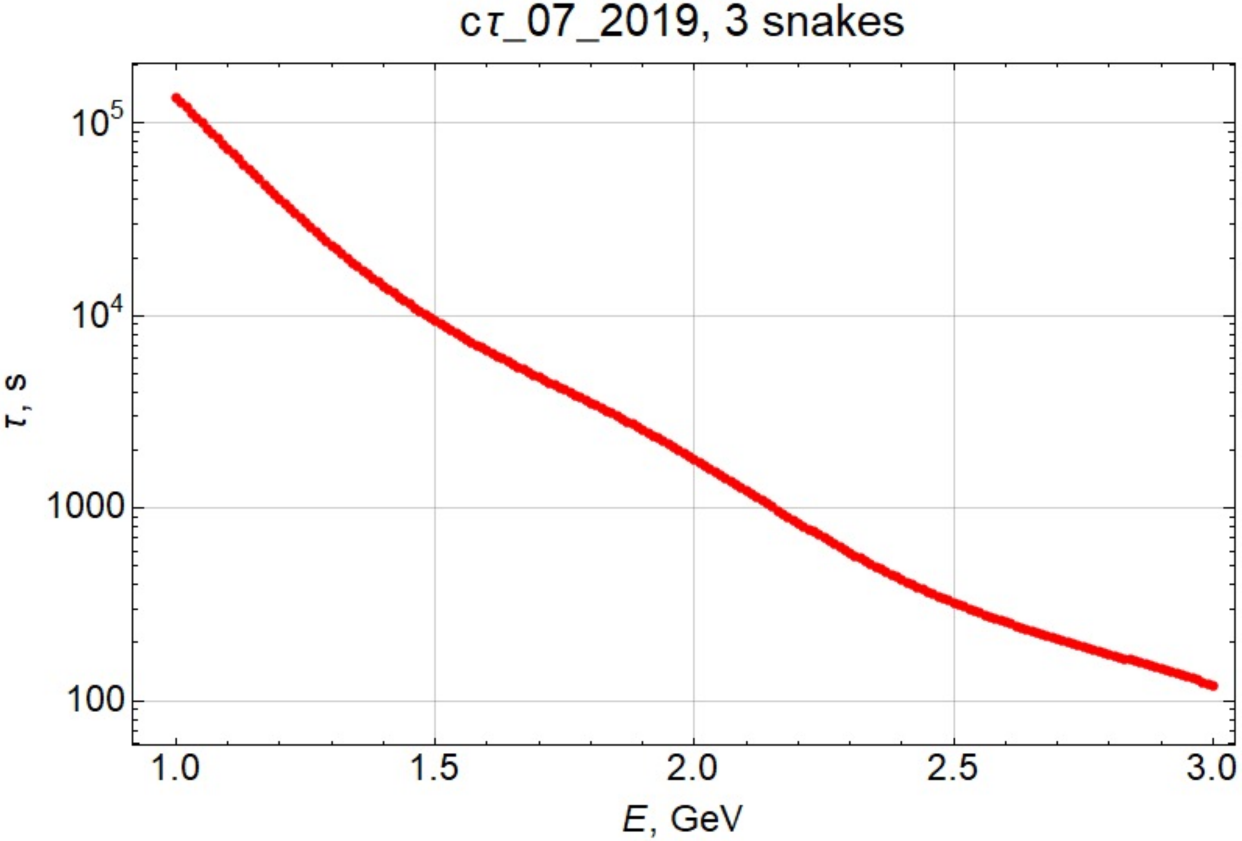
CRAB: $\mu_x = 7\pi$ $\mu_y = 5.5\pi$



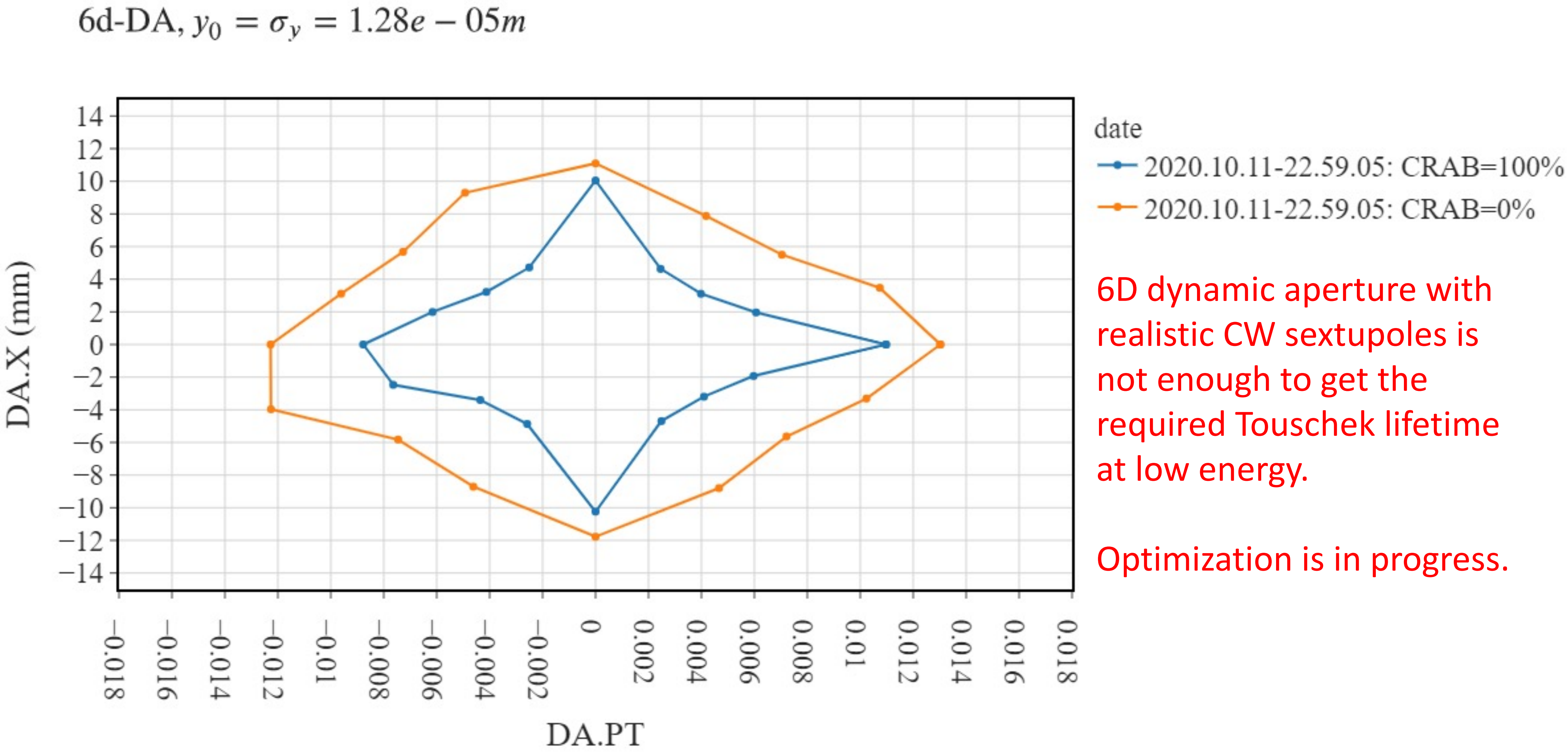
❍ Longitudinal Polarization



Particle replenishing time



❍ CRAB sextupole influence: 6d-DA



6D dynamic aperture with realistic CW sextupoles is not enough to get the required Touschek lifetime at low energy.

Optimization is in progress.

❍Status

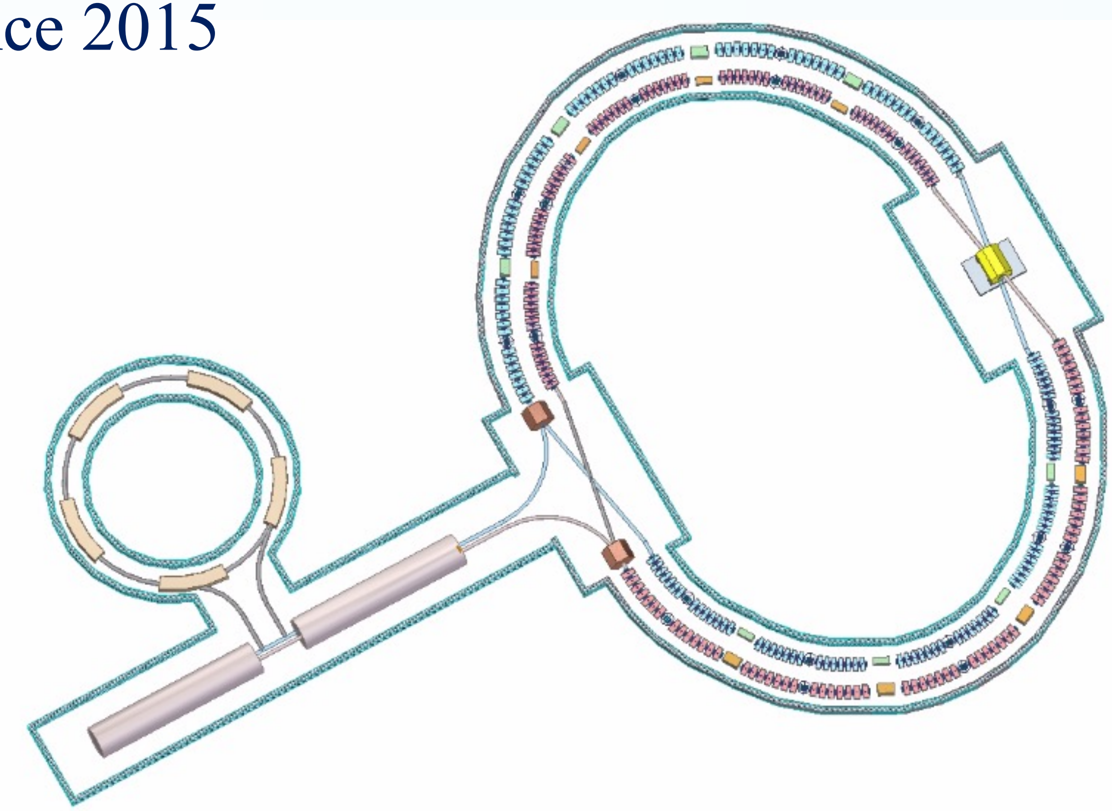
- The linear lattice and parameters provide desired luminosity and polarization
- Realistic design of new injection facility $2\times10^{11}\ e^{+}/s$ for 200 s of beam life time
- Detailed design of interaction region and MDI, 3d design of FF quadrupoles, maximum strength is reduced from 100 T/m to 40 T/m
- Siberian snakes sections provide sufficient longitudinal polarization
- On momentum dynamic aperture is sufficient for injection and beam-beam effects
- Off momentum dynamic aperture with CRAB ON is insufficient at 1.5-2.5 GeV to provide necessary Touschek lifetime (work is in progress)

❍Nearest future plans

- Several powerful organizations, labs and institutes as supporters and our united team steadily push the Government to approve the project
- In spite the whole budget is still under discussion by Russian Government, there was a decision to start with R&D and prototypes and money were allocated for 2022-2023 for key components including:
  - FF technical design and 40 T/m FF quad prototype of CCT technology
  - Polarized e- source design and key elements development with photo-gun prototype
  - Optimization and design of positron converter
  - etc..
- SuperKEKB experience show that there are still problems with implementation of the SW collision in real life, BINP consider a test facility in the range of 1-1.5 GeV beam energy with all main CW features (large Piwinski angle, small emittance, large current, low β_y, complicated IR, etc.). Reduce risks for large super charm-tau.

STCF @ USTC

- Topic started since 2013
- First open discussed on Xiangshan Conference 2015
- Accelerator work began from 2018
  - Set goals for two stage construction
  - 3 faculties and 3 graduate students
- From 2019 to Now, preliminary CDR stage
  - Preliminary lattice design
    - Published in JINST, 2021
  - Several key technologies discussed
  - Optimization work in progress



- Supported by local authority and Hefei Comprehensive National Science Center

○ Parameters and accelerator physics design

Parameters	Phase 1	Phase 2
Circumference/m	800~1000	800~1000
Optimized Beam Energy/GeV	2	2
Energy Range/GeV	1-3.5	1-3.5
Current/A	2	2
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	6/0.06	5/0.05
β Function @ IP (β_x^*/β_y^*)/mm	90/0.9	50/0.5
Collision Angle(full θ)/mrad	60	60
Tune Shift ξ_y	0.06	0.08
Hour-glass Factor	0.9	0.9
Lifetime	600	900
Luminosity/$\times 10^{35}$cm^{-2}s^{-1}	≥0.5	~1.0

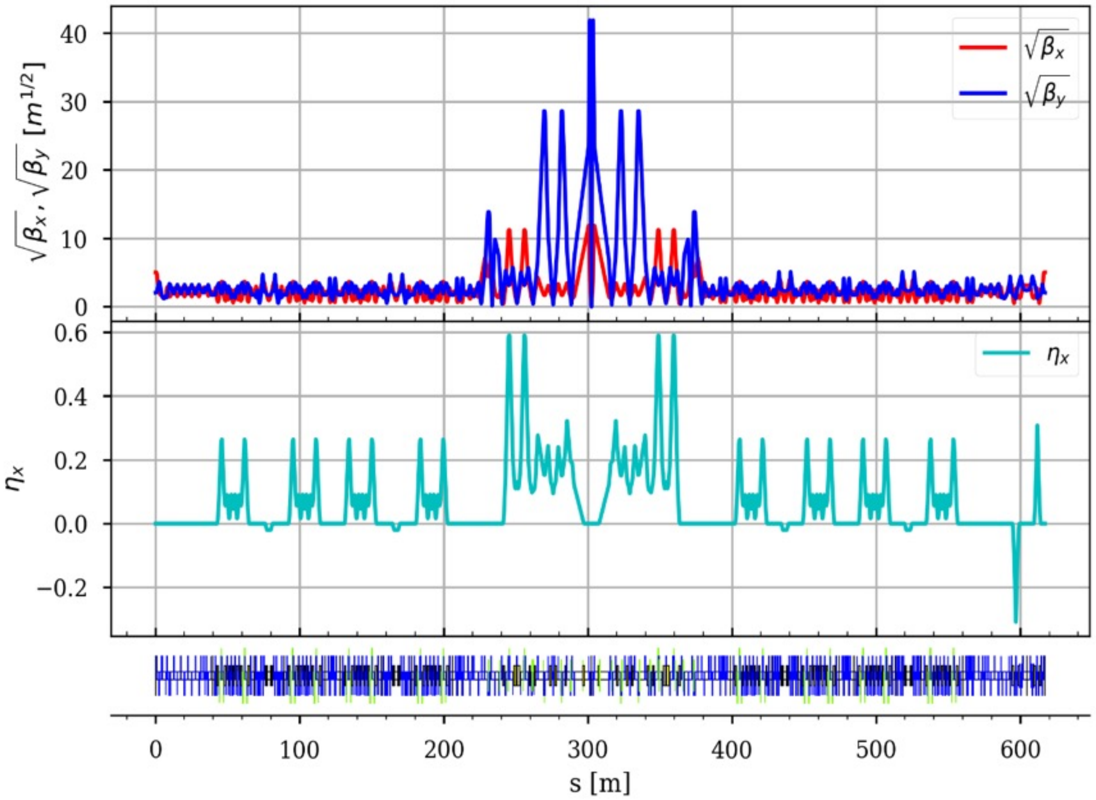
- For realistic project
- Stage 1, half luminosity and no polarization
- Stage 2, after operation for some time, upgrade to high luminosity with polarized electron beam

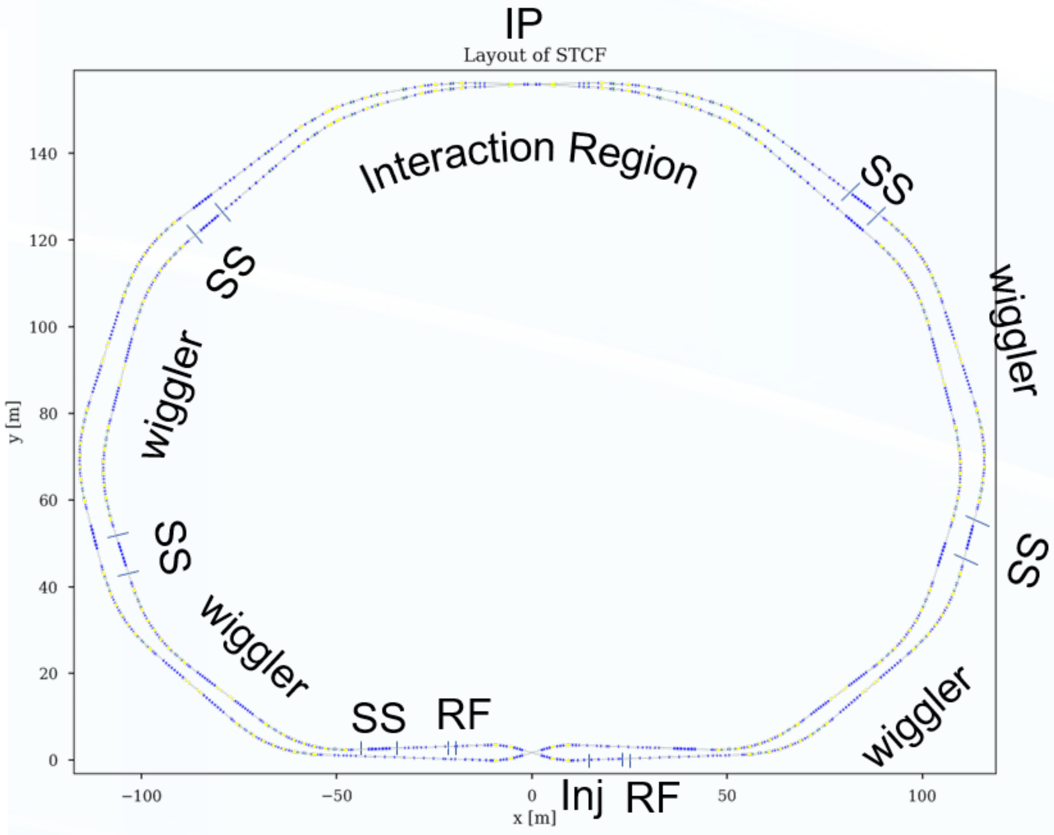
❍ Parameters and accelerator physics design

Parameters	Value	Unit
Optimize energy E	2.0	GeV
Circumference Π	617.06	m
f_{RF}	500	MHz
2θ	60	mrad
$\varepsilon_y/\varepsilon_x$	0.5	%
β_x^*/β_y^*	90/0.6	mm
I	2.0	A
$N_{e/bunch}$	5	10^{10}
N_b	512	-
U_0	157.3	keV
V_{RF}	3.0	MV
$\nu_x/\nu_y/\nu_s$	40.552/24.571/0.016	-
δ_{RF}	1.8	%
σ_e (w.o/w IBS)	0.56/0.74	10^{-3}
σ_x(w.o/w IBS)	15.9/19.4	μm
σ_y(w.o/w IBS)	0.09/0.11	μm
σ_s (w.o/w IBS)	6.7/10	mm
ε_x (w.o/w IBS)	2.8/4.2	nm
L_{HG}	$0.5\sim1\times10^{35}$	$cm^{-2}s^{-1}$
ξ_x/ξ_y	0.004/0.10	-
$\tau_{Touschek}$	200	s
Damping time $\tau_x/\tau_y/\tau_s$	52/52/26-> (36/36/18)	ms
Momentum compact factor α_c	5.26×10^{-4}	-

- Similar to BINP results, short Touschek lifetime project
- We want to use damping wigglers to suppress the damping time so as to reach high luminosity, but still under study

❍ Lattice and layout 2022



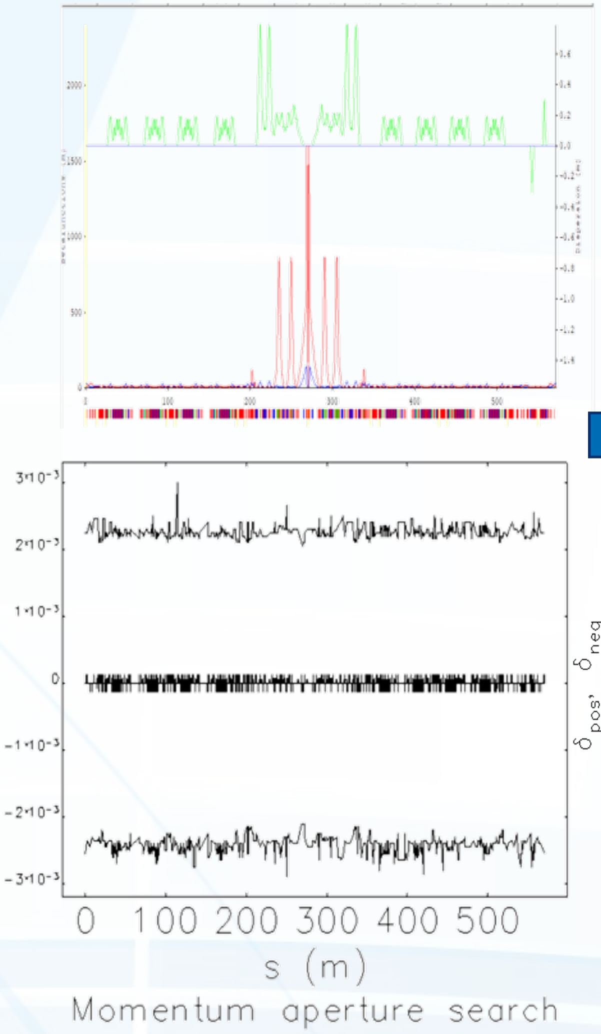


➢ Compared to 2021:

- Hybrid 7BA (H-7BA) -> High order achromat H-7BA, Larger dynamic aperture and momentum aperture
- Tuning the tune between CCY and final doublet(FD), with additional sextupoles at small β position, to get large momentum aperture

❍ Optimization of touschek lifetime

<35s



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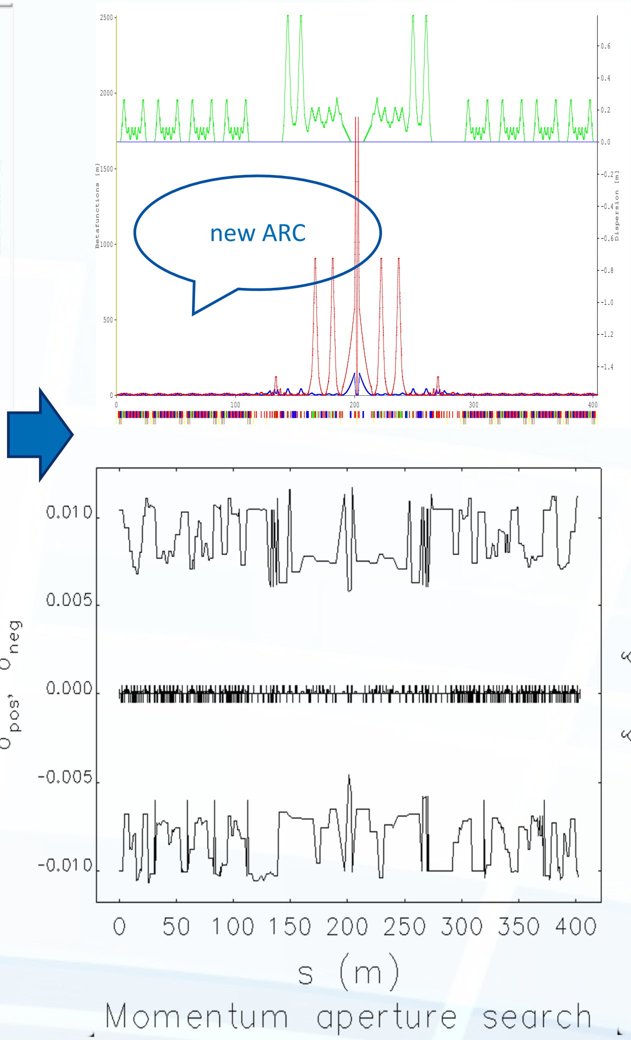

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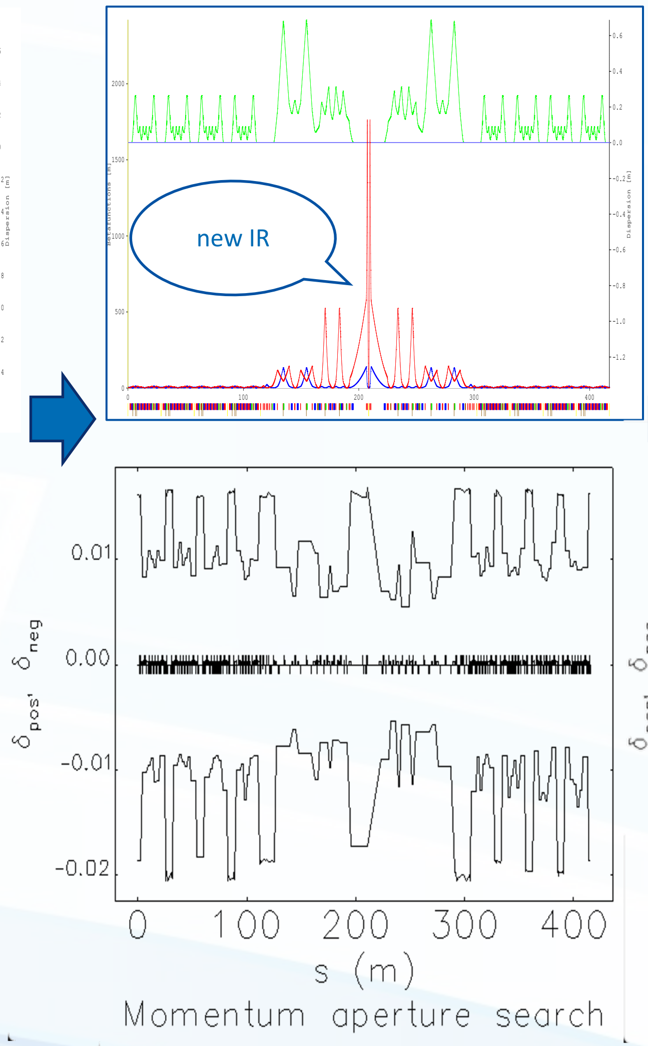
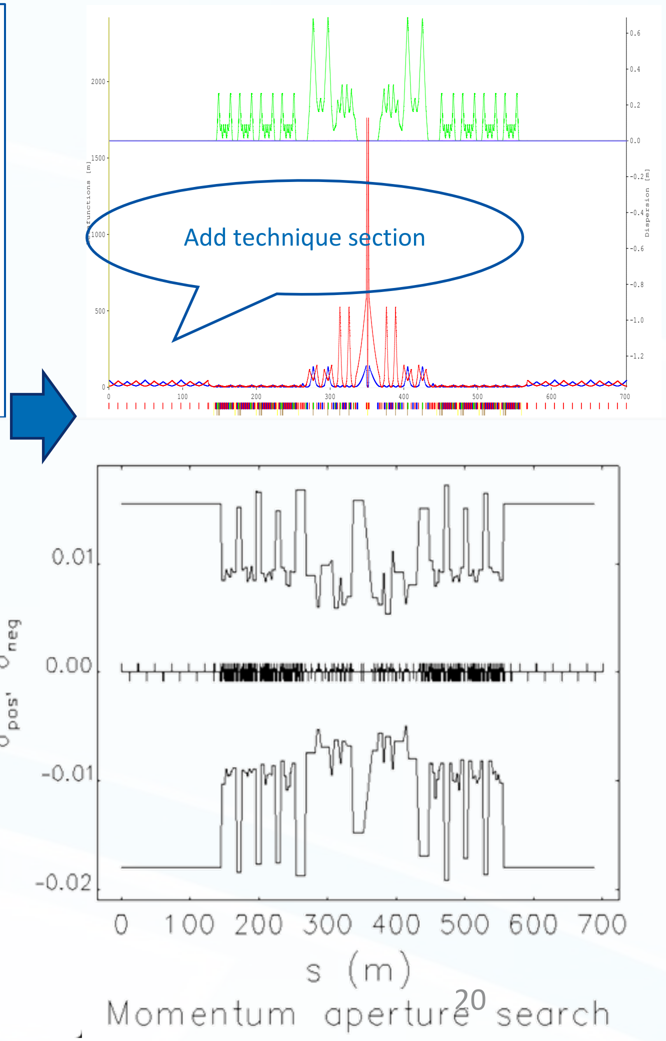


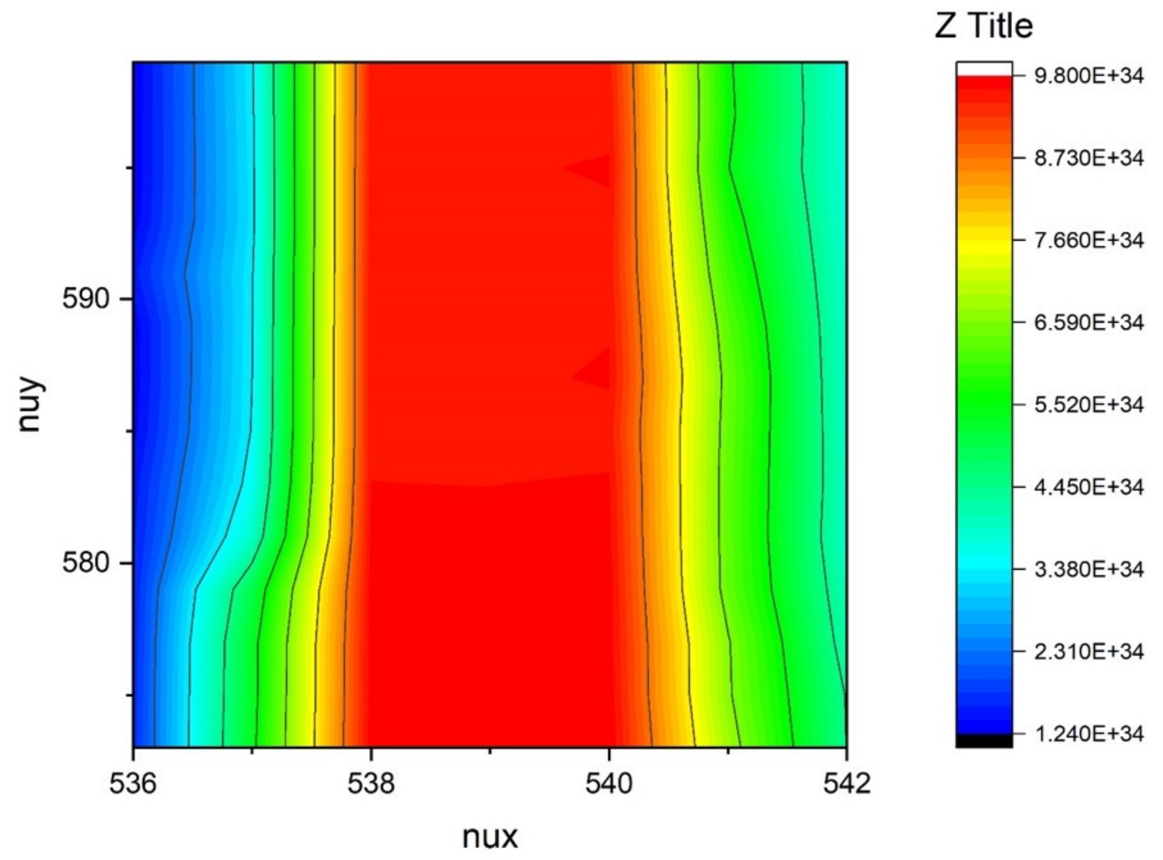
200s



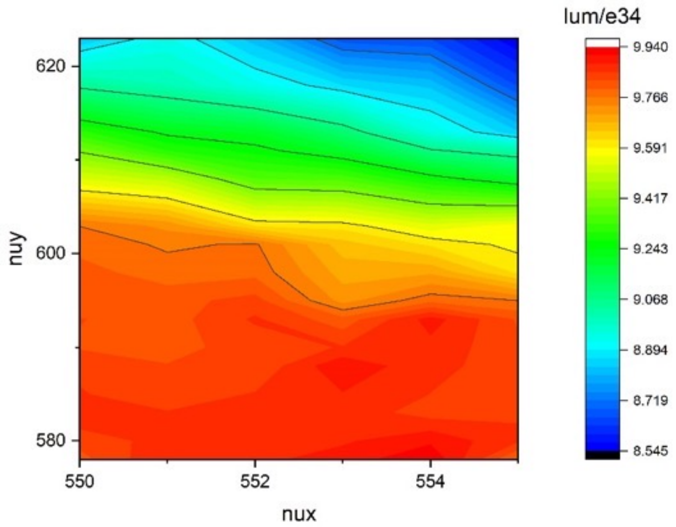
❍ Beam-beam simulation

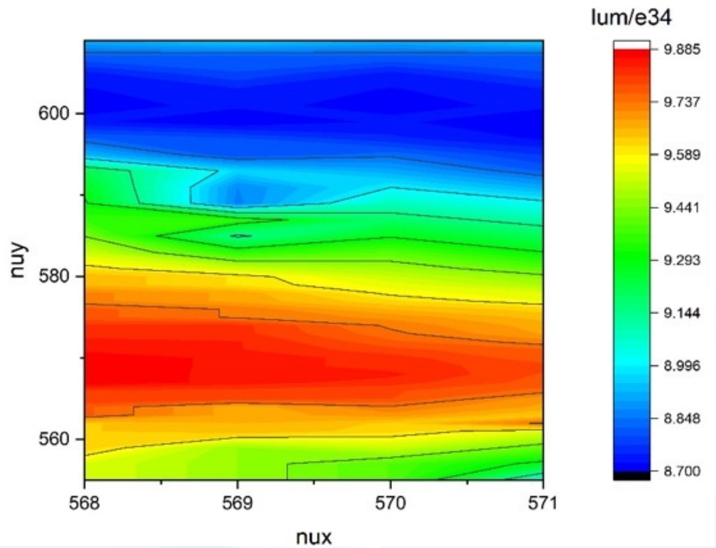
- *Several new effects become important for the collider performance such as beamstrahlung, coherent X-Z instability and 3D flip-flop.*
- *When the X-Z instability is excited, the horizontal emittance increases.*

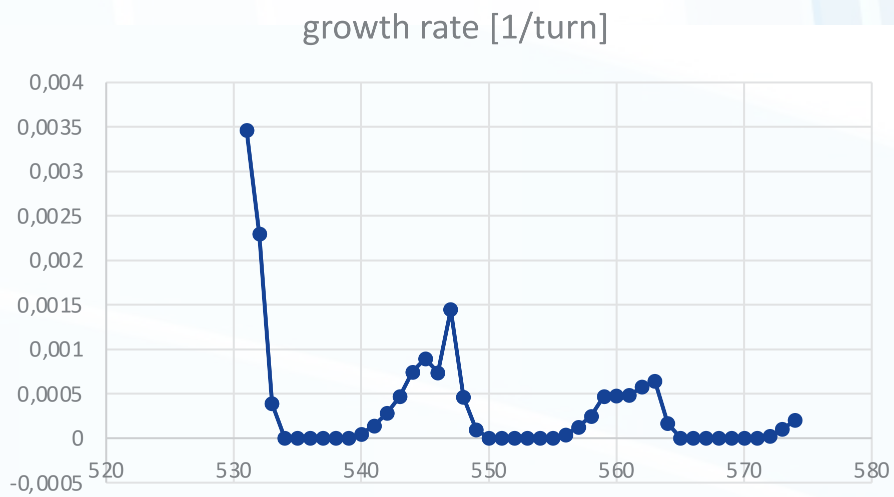
- The instability would exist near the resonance:
- ν_x = 0.5 + k*νz, the stable horizontal tune area would shift due to the change of synchrotron tune (ν_z).
- At first, we set ν_z =0.012 (~3ξ_x), we gain a really small safe area, which the width is only 0.002~0.003

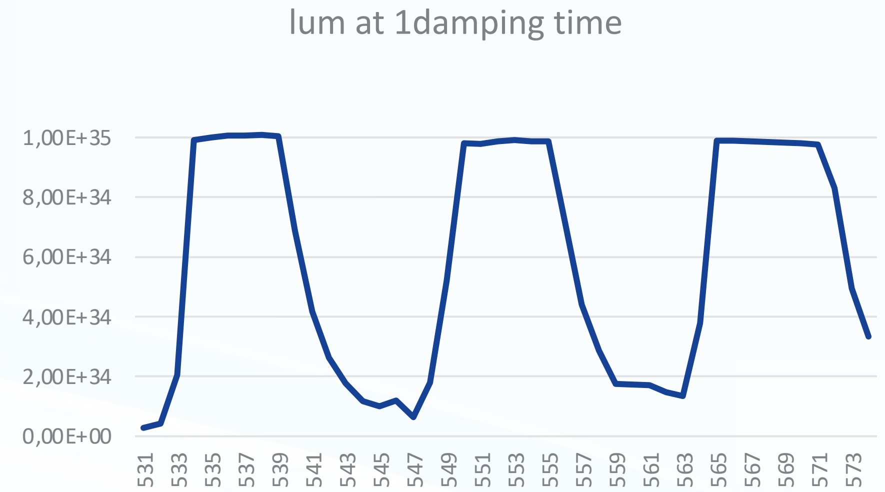


- We use the ratio of beam size blowup in horizontal direction to identify the instability.
- Due to the beam-beam effects and beamstrahlung effect, the peak of emittance growth will be shifted and then the width of stable collision tune area would be reduced, for $\nu_z/\xi_x = 3$, it's less than ξ_x.
- Increase ν_z from 0.012($3\xi_x$) to 0.016($4\xi_x$), then we gain a wider safe area, which the width is 0.005-0.006.



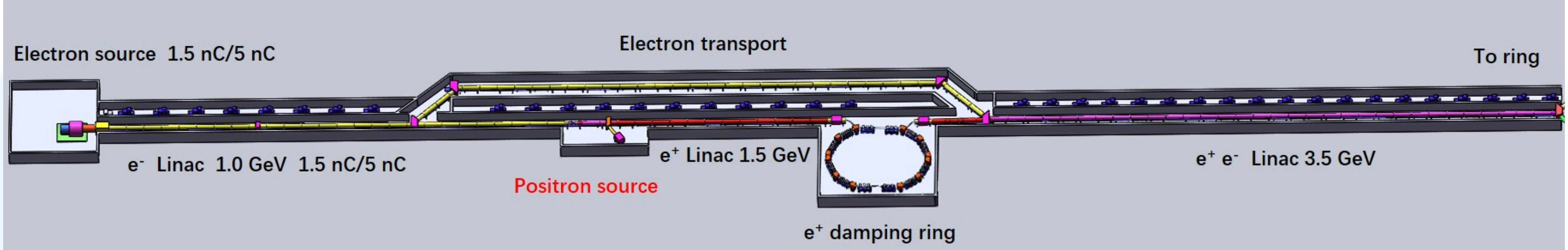


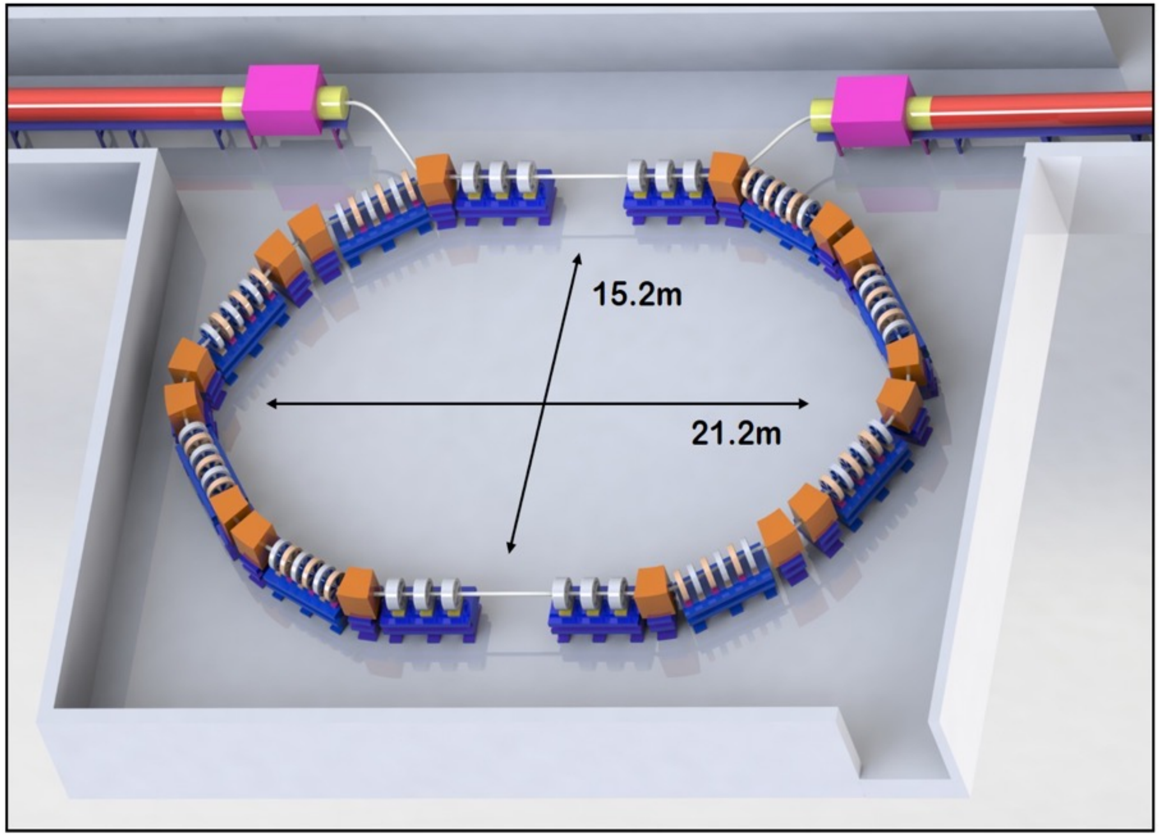




*vx = 0.5 + k*vz , vz=0.016; vy = 0.571*

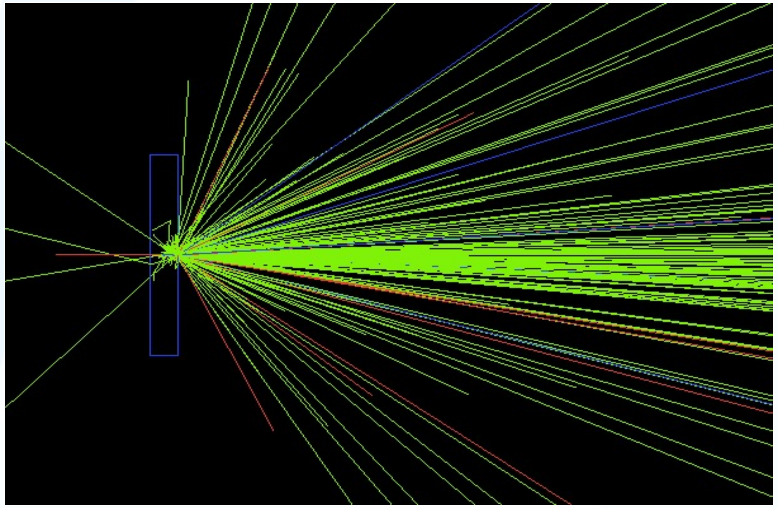
○ Injector

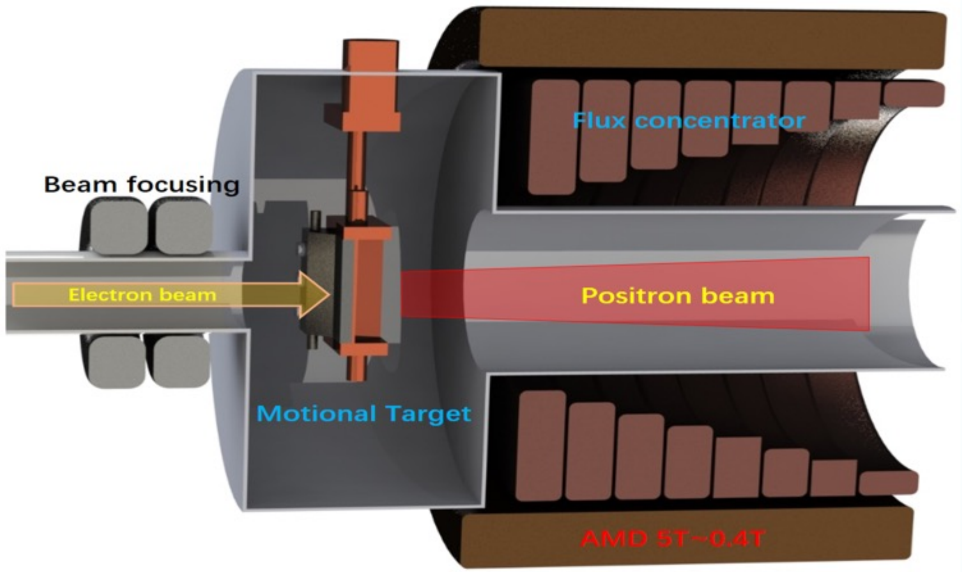


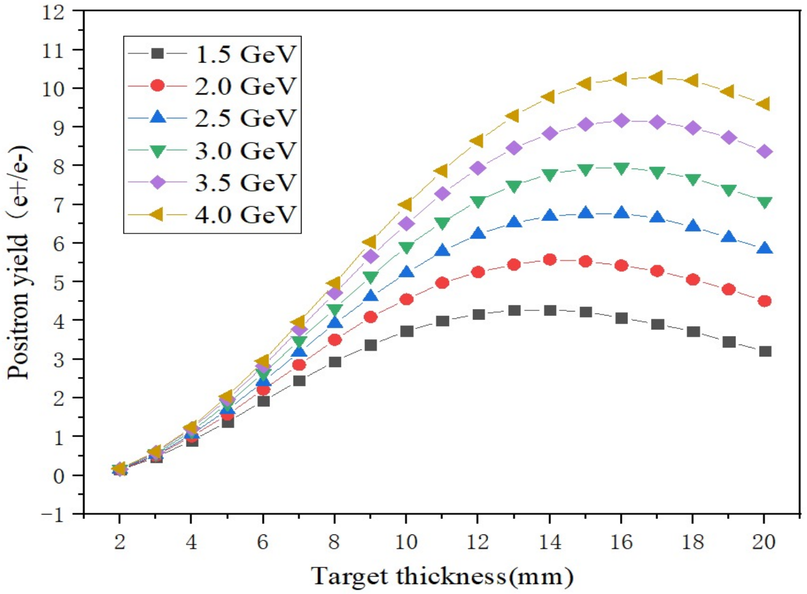


Parameter	Value
Energy	1.0 GeV
Perimeter	~58 mm
Repetition frequency	50 Hz
Bending radius	2.7 m
Dipole magnets, B_0	1.4 T
Momentum compression factor, α_c	0.076
U_0	35.8 keV
Damping time x/y/z	12/12/6 ms
δ_0	0.05%
ε_0	287.4 mm·mrad
Bunch length	7 mm
ε_{inj}	2500 mm·mrad
$\varepsilon_{ext\ x/y}$	704/471 mm·mrad
$\delta_{inj}/\delta_{ext}$	0.3/0.06
Divergence of energy	1%
f_{rf}	650 MHz
V_{rf}	1.8 MV

❍ Positron Source*







Parameter	Value
Electron bunch	5 nC
Electron energy	1.5 GeV
Rep. rate	50 Hz
Deposited power	532 W
Magnetic field	5↘0.4
Target thickness	13 mm
Target material	Tungsten
e^+ yield	0.25

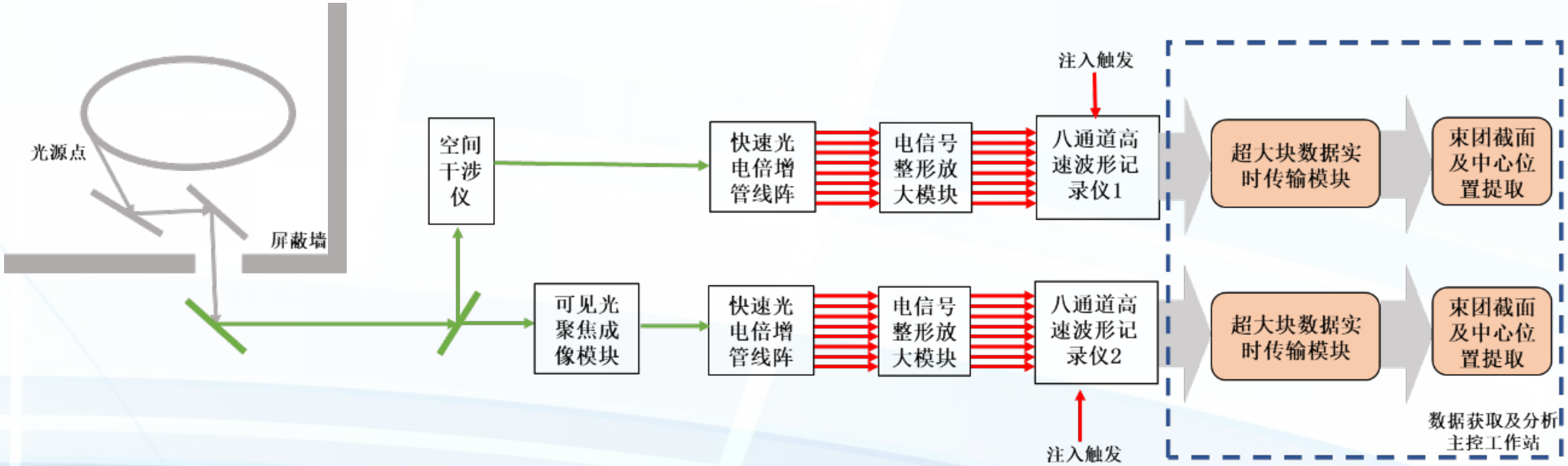
- Motional target with cooling system designed for STCF positron
- Experiments had been done on thermal research for single crystal-tungsten target

*Published in NIMA

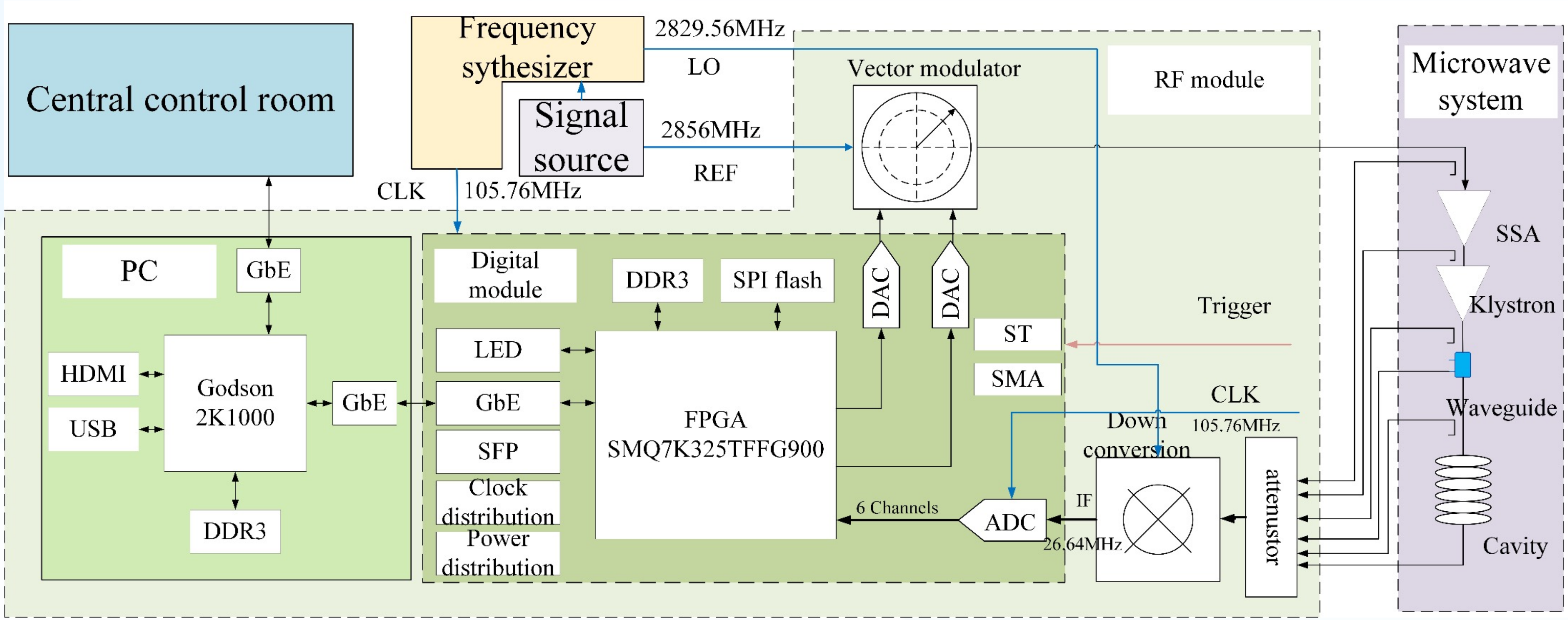
❍ Bunch size measurement for monitoring the blow-up

➢ *Use synchrotron radiation to monitor the bunch size*

- Use visible light to implement bunch by bunch, turn by turn 3D measurement bunch profile with high time resolution, like 2-4 ns
  - Key technology: signal processing
- Develop X-ray interferometer to measure the bunch transversal size with high space resolution, like µm to sub-µm
  - Key technology: X-ray optics

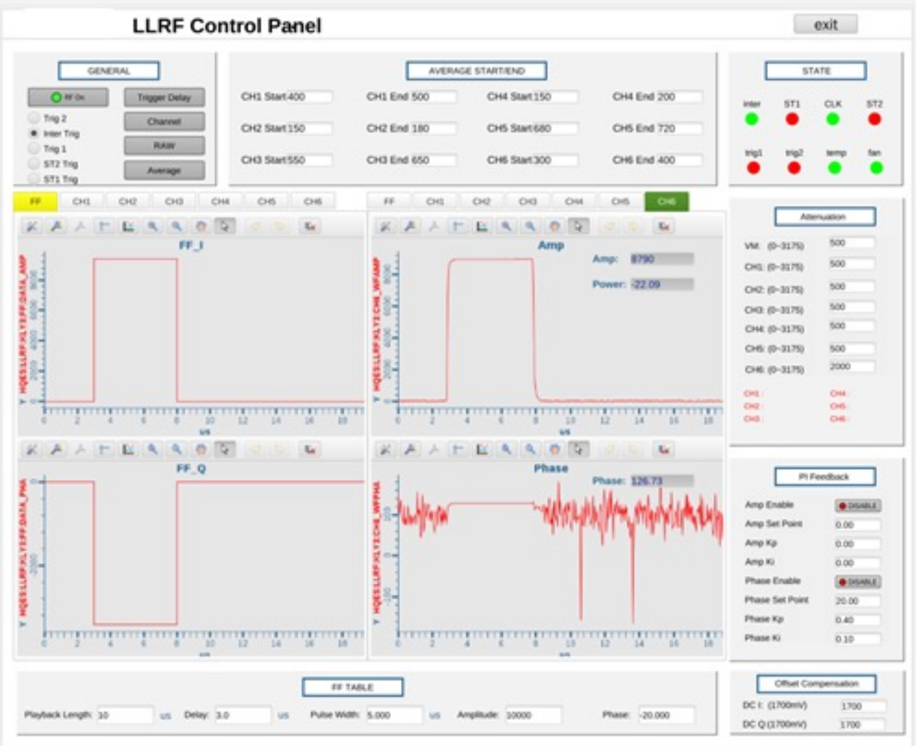


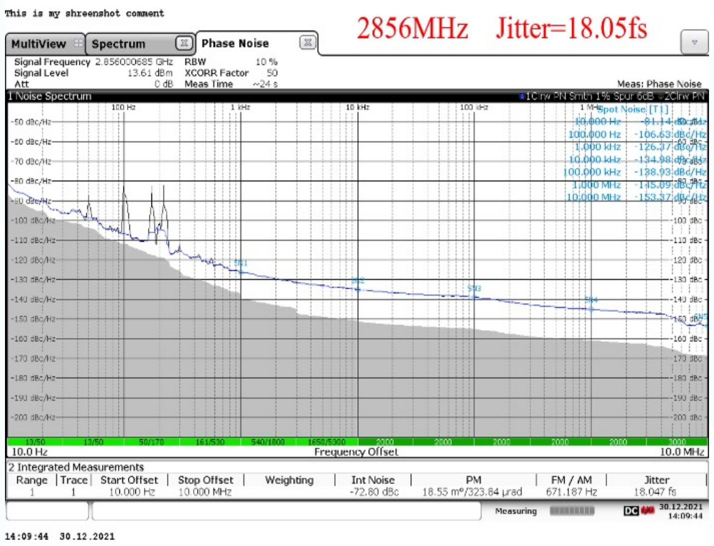
❍ Low Level RF system with domestic electronics

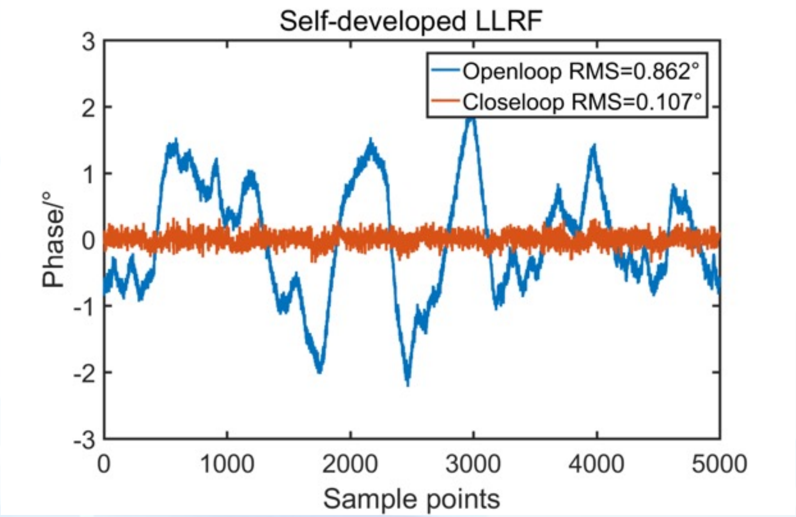


- **Hardware**
  - RF Source; Frequency Synthesizer; IF Signal processor
- **Software**
  - FPGA Firmware; Control Algorithms; EPICS Control

➢ Beam test results







- Signal source & frequency synthesizer have been developed.
- Close loop beam test result for S band LLRF system reached around 0.1° (rms).

Status and future plans

- In the last 5 years, USTC and CAS had given more than 20M RMB for preliminary study (including detectors, physics and accelerators)
- Several universities and institutes joined our plan as supporters, more are interested.
- Applying for Central Government R&D fund now, a decision will be made possibly by October.
- Local authority agreed to give R&D funds in 2022-2025
- A prototype of interaction region and a test facility for electron and positron source will be constructed by 2025.

Conclusion

- A consensus has been reached for collision scheme
  - Large Piwinski angle and CW
- More accelerator physics study and further technical experiments are required.
- We have noticed what some of the key problems are, and we may also known the direction where to find the answers.
- Experiences from BEPCII, SuperKEKB are very helpful.
- Test facilities will be very helpful.

Thank you for your attention