Summary (accelerator Physics)

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Accelerator Physics and Technology Parallel Session Program

- **General topic**
  - "**Summary of Mini Workshop on Polarization for Future Colliders**" by Yuhong Zhang (JLab)
- **CEPC: Design Optimization, Accelerator Physics and Technology**
  - "**CEPC Optimization Design Towards TDR**" by Yiwei Wang (IHEP)
  - "**CEPC Booster Optimization Design towards TDR**" by Dou wang (IHEP)
  - "**CEPC Orbit Correction Study**" by Yuanyuan Wei (IHEP)
  - "**CEPC Injection/Extraction Optics with Hardware Consideration**" by Xiaohao Cui (IHEP)
  - "**CEPC MDI towards TDR**" by Sha Bai (IHEP)
  - "**CEPC MDI SC Magnets R&D**" by Yingshun Zhu (IHEP)
  - "**CEPC SCRF R&D towards TDR**" by Jiyuan Zhai (IHEP)
  - "**CEPC Injector Damping Ring RF System Design and R&D**" by Dianjun Gong (IHEP)
  - "**Design of the Electrostatic-Magnetic Deflector for CEPC**" by Bin Chen (IHEP)
  - "**SCRF Infrastructure Development**" by Song Jin (IHEP)
  - "**CEPC Civil Engineering and Implementation (Qinhuangdao)**" by Yu Xiao (Yellow River Engineering Consulting Company Ltd)
  - "**CEPC Coordination Design System (Projectwise) and Installation Study**" Ke Huang (Huadong Engineering Corporation Ltd)
  - "**Green CEPC**" by Yunlong Chi (IHEP)
- **Other Colliders**
  - "**Technology R&D for SuperKEKB**" Collider" by Makoto Tobiyama (KEK)
  - "**RF System Challenges in Circular Colliders**" by Robert Rimmer (JLab)
  - "**eRHIC Overview with Technologies**" by Francois Meot (BNL)
  - "**JLEIC Overview with Technologies**" by Yuhong Zhang (JLab)
  - "**FCC MDI**" by Michael Koratzinos (MIT)

Beam Polarization for Future Collider Mini-Workshop

Yuhong Zhang

- **General topic**
  - "Polarized Beams: A Brief History and Future Prospect" by Yaroslav Derbenev (JLab)
- **Machine Overview**
  - "Introduction to CEPC " by Jie Gao (IHEP)
- **e+e- colliders at low to medium energy**
  - "BINP's Polarization Proposal for Tau-Charm Factory" by Ivan Koop (BINP)
- **e+e- collider at energy frontier**
  - "Resonant Depolarization at Z and W Beam Energy" by Ivan Koop (BINP)
  - "Polarized Electron and Positron Beams in CEPC" by Zhe Duan (IHEP)
  - "Preliminary Studies of Beam Polarization in CEPC" by Wenhao Xia (IHEP)
- **e-p and e-A colliders**
  - "Beam Polarization in Future Colliders (eRHIC and FCC-ee)" by Eliana Gianfelice-Wendt (FNAL)
  - "JLEIC Electron Beam Polarization" by Yuhong Zhang (JLab)
  - "Spin Matching in Electron (Positron) Rings" by Vadim Ptitsyn (BNL)
- **Electron/positron sources**
  - "ILC Polarized Electron and Positron Sources" by Kaoru Yokoya (KEK)
- **Polarimetry**
  - "Overview of Electron Polarimetry" by David Gaskell (Jlab)
  - "Design of the Beam Polarimeter for FCC-ee" by Nikolai Muchnoi (BINP)
- **Code development and simulations**
  - "Code Development and Simulation Studies of Polarized Beams" by Francois Meot (BNL)
  - "Re-evaluation of Spin-Orbit Dynamics of Polarized e+e- Beams in High Energy Circular Accelerators and Storage Rings: Bloch Equation Approach" by Klaus Heinemann (Univ. of New Mexico)

“Polarized Beams: A Brief History & Future Prospects” by Ya. Derbenev (JLab)

I. Foundations and problems

- *Polarization sources*
- Thomas – BMT spin equations
- Spin in conventional rings
- Compensated spin rotators
- Resonance depolarization
- Crossing the spin resonances
- ZGS + AGS proton spin acceleration
- BST radiative polarization
- Orlov’ depolarization

II. Polarization canonical theory

III. Siberian Snakes

- SS idea and demonstration
- SS techniques
- SS utilization and success in RHIC
- Multiple SS for SSC

IV. Spin-compensated quads

V. Figure 8 synchrotron

VI. Polarized EIC

- Fixed orbit e-spin rotator and snake

VII. Future polarized beams

- **Polarized LHC?**
- **Polarization ideas for CEPC:**

Snakes

Bending snakes

Achromatic snakes

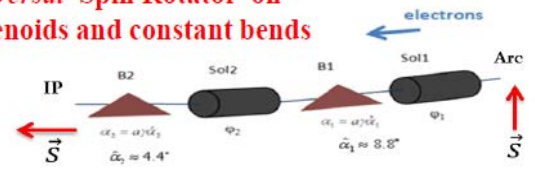
Flipping spin rotators

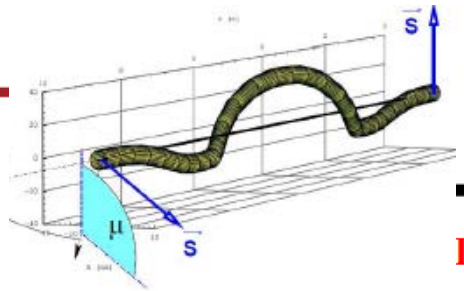
- **Polarization ideas for 75 TeV PPC**

Many snakes

Spin-compensated quads

Universal Spin Rotator on solenoids and constant bends



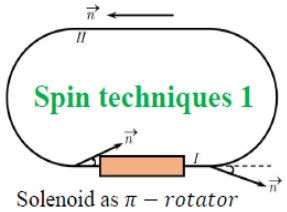


Spin Techniques 1

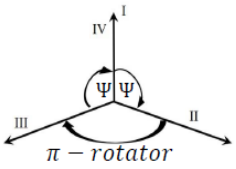
“Siberian Snakes”: making *Spin Echo* in racetracks…

Cancellation idea of spin global precession over the racetrack orbit:
instead of reversing the arcs, let us make *reverse of spin*…!
by inserting local spin flip about a horizontal axis

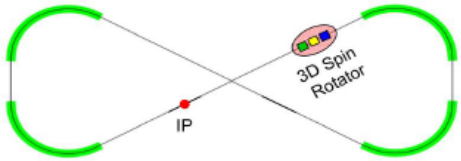
Topological compensation of spin precession over arcs



Spin echo effect is obviously extendable to any $\pi-$ *rotator* around ***an arbitrary horizontal axis***



Twisted Spin Synchrotron: *Spin Echo*



"Polarized Beams: A Brief History and Future Prospects" by Ya. Derbenev

Thoughts on Beam Polarization delivery in CEPC

Option I: Use Polarized e-gun (electrons only…)

- Stacking and accelerating for injection to collider ring
- Acceleration and maintenance of PEB in the Collider Ring

Option II : BST polarization in the Collider Ring

- Ta
- Lu

Thin

- Fi
- Sr

Options for the Collider Rings

Option I Many SS

- Sufficient large chain of SS to suppress depolarizing impact of the superperiodic misalignment harmonics
- Spin tune ½
- Compensation of tune spread associated with beam emittance
- Spin response function to suppress the beam-beam depolarization

Spin Rotators for CEPC.1.

Fixed orbit SR on dipoles and solenoids for CEPC

$(S_y = 1)$ α_{x1} α_{y1} φ_{z1} $\alpha_{x2} - \alpha_{x1}$ α_{y2} φ_{z2} $-\alpha_{x2}$ $(S_z = 1)$

Spin Rotators for CEPC. 2.

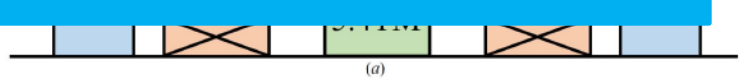
lds

1)

ms. 2.

Preconclusion

At this stage, our anticipation of successful design for future polarized beams is close to 100% optimism.



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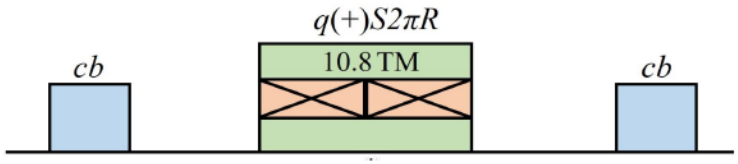

- **Two SS then will be enough to eliminate spin resonance crossing during the acceleration and stay away of the resonances through the luminosity run**
- **Think about spin flipping (if inquired); ideas on table…**

“Resonant Depolarization at Z and W Beam Energy” by I. Koop

Outline

- Resonance Depolarization studies by spin tracking
- Spin tracking code features
- Self-p
- Probl

Spin

Reso

- Beam emittances in CEPC/FCCee are so small that all resonances with betatron frequencies are suppressed and their influence on the spin motion is negligible
- Only static vertical orbit distortions and the longitudinal

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n Snake?

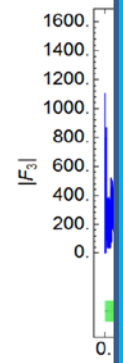
274

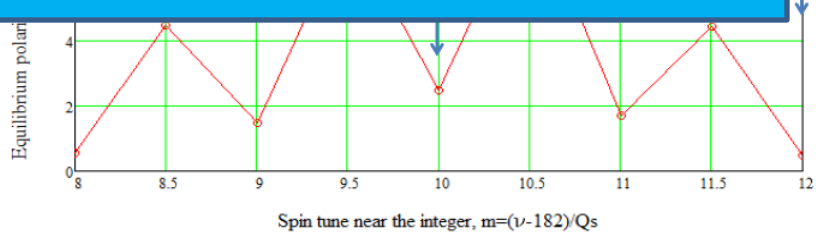
8.6

29

s=0.05

82.6





Conclusion

- Spin tracking of a motion of a single particle reveals the dependence of the spectrum line width from the synchrotron tune and other beam parameters.
- This width becomes very large for chosen synchrotron tune Qs=0.05 at W and the standard RD procedure becomes not applicable.
- The discussed above new RD procedure (by steps) works well even in cases when a width of the spin resonance became very large. That is just the case with Qs=0.05. Still the accuracy of a method needs to be studied further.
- Second order terms in orbital motion also contribute to the line width (I.Koop, Yu.Shatunov, in proc. EPAC 1988, Rome, p.738-739). See also the talk on systematic errors from A.Bogomyagkov: tomorrow, WG7.

Overview of Electron Polarimetry by Dave Gaskell (JLab)

Outline

- Overview of common electron polarimetry te
  - Mott scattering
  - Møller scattering
  - Compton Scattering

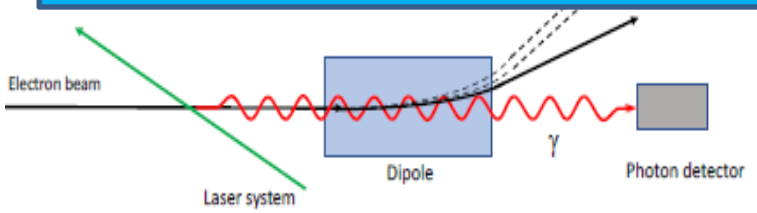
Electron Polarimetry Techniques

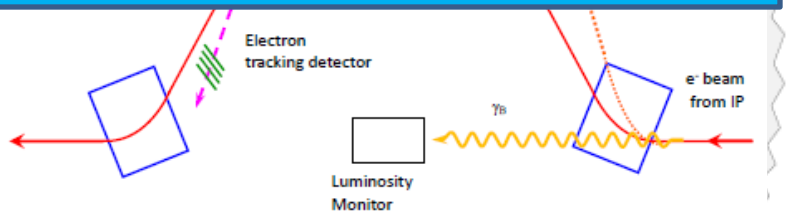
Common techniques for measuring electron beam polarization

- Mott scattering: $\vec{e} + Z \rightarrow e$, spin-orbit coupling of electron spin with (large Z) target nucleus
  - Useful at MeV-scale (injector) energies

Summary

- Several useful techniques for electron polarimetry
  - Compton polarimetry is commonly used in storage rings/colliders
  - Møller polarimetry may be possible using jet targets, but likely more R&D is required
- High precision has been achieved with Compton polarimetry with several devices in different accelerators
  - In general, highest precision has used electron detection for longitudinal polarization
  - High precision is possible for transverse Compton polarimeters, but less experience
- EIC will require precise measurements of both electron and hadron polarization
  - Compton polarimeter design for EIC will draw on experience from earlier devices
  - JLEIC (longitudinal) Compton polarimeter design based on successful JLab polarimeters
  - eRHIC Compton polarimeter will measure transverse polarization – important experience from HERA TPOL will prove valuable





Personal Impression and Prospect

- There is a theoretical framework of beam polarization and good understanding
- There were successful experiences in dealing beam polarizations in collider
  - Lepton beam polarization in HERA
  - Hadron beam polarization in RHIC
- Very challenging beam polarization requirements in future colliders
  - ~10% polarization for both e- and e+ beams in z (and even W) energy
  - >70% polarization for both electron and proton/light ion beams in EIC
- More challenges in delivering physics: spin flip
- Technical systems: polarized sources (ILAC, Super Tau-Charm, EIC)
- Technical system: polarimetry
- There are good simulation tools, still need improvements (physics and computing)
- A small community, international collaboration should be very helpful

Lattice Optimization of the CEPC Collider Ring Towards The TDR

Yiwei Wang (IHEP)

Outline

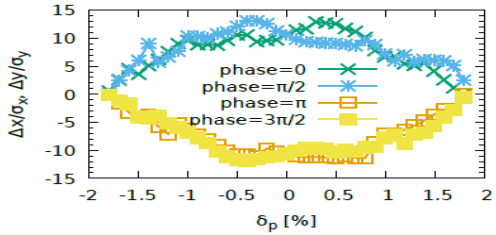
- The CEPC collider lattice design for CDR
- Optimization of the lattice towards the TDR
  - Error correction
  - Injection region
  - Separation region
  - Interaction region

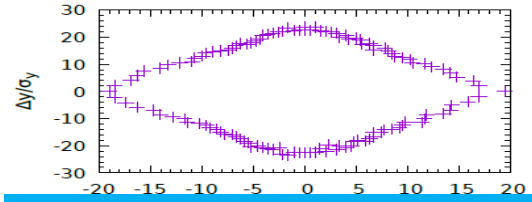
Dynamic aperture requirements

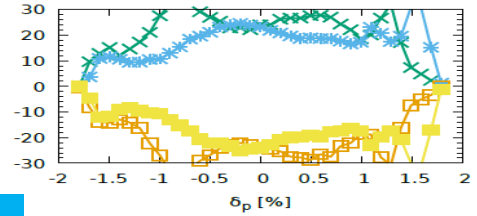
	Higgs	W	Z
with on-axis injection	$8\sigma_x \times 15\sigma_y \times 1.35\%$	-	-
with off-axis injection	$13\sigma_x \times 15\sigma_y \times 1.35\%$	$15\sigma_x \times 9\sigma_y \times 0.9\%$	$17\sigma_x \times 9\sigma_y \times 0.49\%$

Tracking in SAD w/ synchrotron radiation damping, fluctuation(100 samples), energy sawtooth and tapering, 145/475/2600 turns(H/W/Z, 2 damping times), 4 initial phases

Higgs

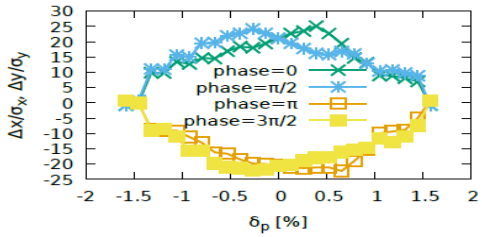


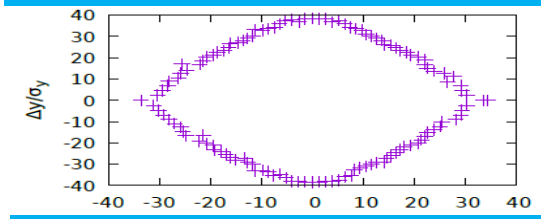


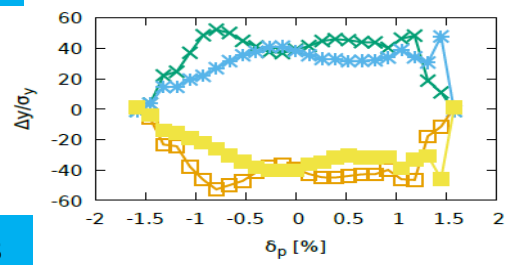


$20\sigma_x \times 23\sigma_y$ & 0.018 w/o errors

W

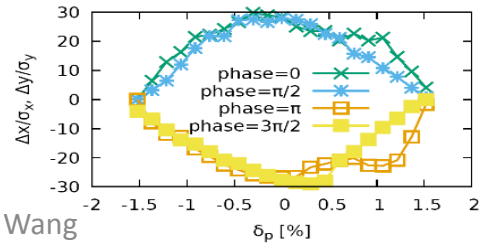


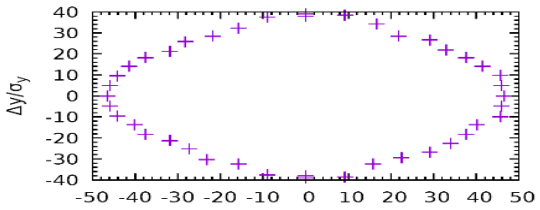


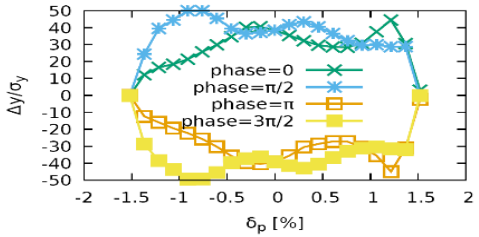


$32\sigma_x \times 40\sigma_y$ & 0.015 w/o errors

Z







$46\sigma_x \times 40\sigma_y$ & 0.015 w/o errors

Lattice Optimization of the CEPC Collider Ring Towards The TDR

Yiwei Wang (IHEP)

Performance with errors

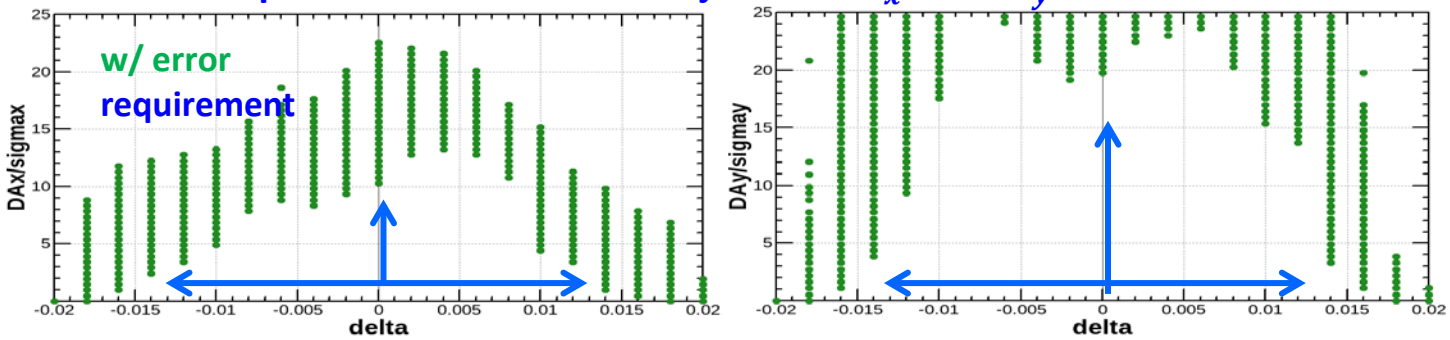
Component	Δx (um)	Δy (um)	$\Delta\theta_z$ (urad)
Arc quad	100	100	100
IR Quad (w/o FF)	50	50	50
Sextupole	100	100	100

Component	Field error
Dipole	0.01%
Arc quad	0.02%

Dynamic aperture result for **Higgs mode**

- Tracking in SAD w/ radiation damping/fluctuation, energy sawtooth & tapering, 145 turns (2 damping times)
- Horizontal dynamic aperture decreases significantly with errors, still fulfils the requirement of on-axis injection.

Requirement with on-axis injeciotn $8\sigma_x \times 15\sigma_y$ & 0.0135



Conclusions

- Optimization of CEPC collider lattice towards the TDR has been started.
  - Relaxed requirement of alignments and filed errors compared with CDR and stronger corrections made. It fulfils the dynamic aperture requirement of on-axis injection.
  - Larger βx at injection point was made in order to relax the dynamic aperture requirement of the off-axis injection scheme. DA are almost the same.
  - With longer QD0, the vertical dynamic aperture increased from 23 σy to 30 σy. Further optimization of the horizontal dynamic aperture and momentum acceptance is under going.
  - The radiation from the separation components is tolerable for SCRF cavities. Some collimators in the RF region will help.
- Further optimization of the arc quadrupole length, βy* and so on is undergoing.

CEPC Booster Optimization Design towards TDR

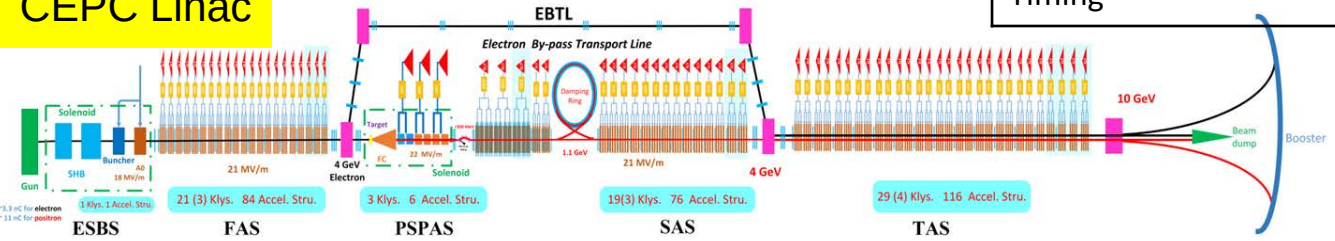
Dou Wang (IHEP)

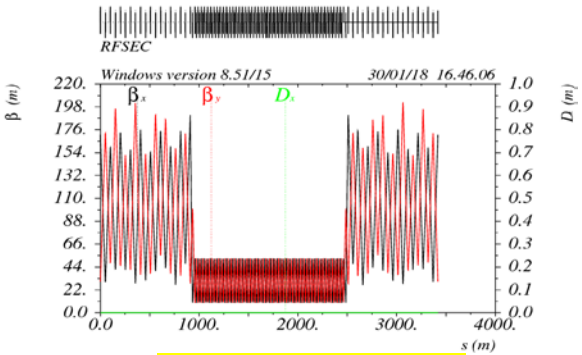
Outline

- Introduction
- Design requirements
- Geometry & optics
- Performance with errors
- Ramping curves & eddy current effect
- TDR plan
- Summary

Beam current (mA)	<1.0 (Higgs), 4.0 (W), 10 (Z)
Emittance@ 120GeV (nm rad)	<3.6
Dynamic aperture @10GeV(σ, normalized by linac beam size)	>4σ+5mm
Dynamic aperture @120GeV	>6σx+3mm, 49σx+3mm
Energy acceptance	>1%
Coupling	<0.5%
Booster transfer efficiency	>92%
Total transfer efficiency	>90% (99%*92%*99%)
Timing	Meet the top-up injection

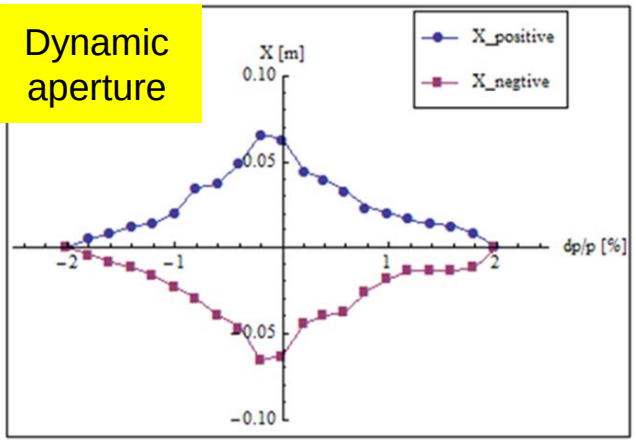
CEPC Linac

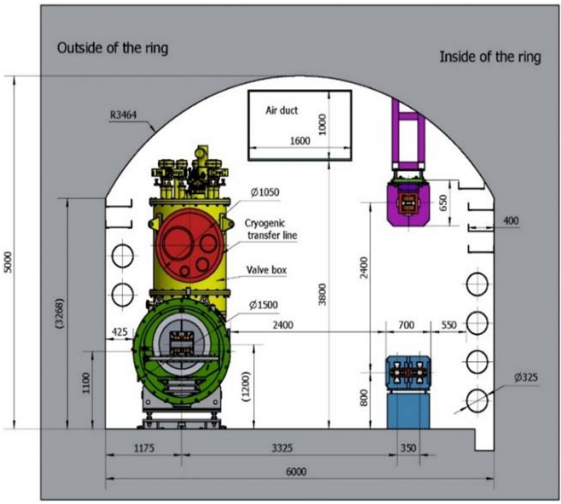


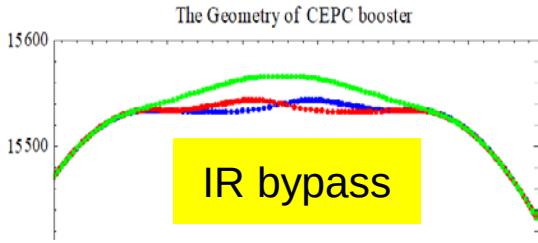


Booster optics

Dynamic aperture







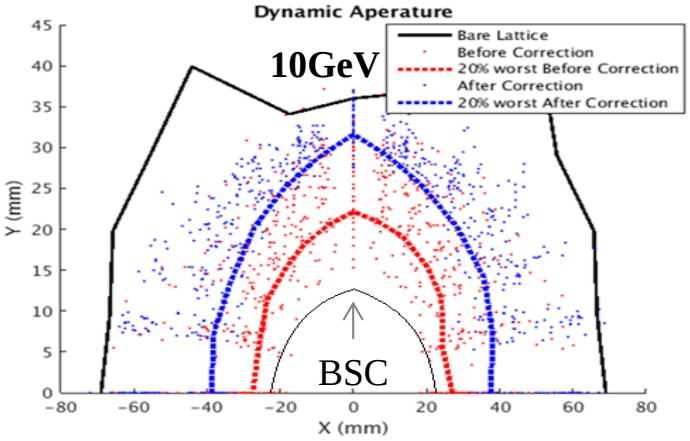
IR bypass

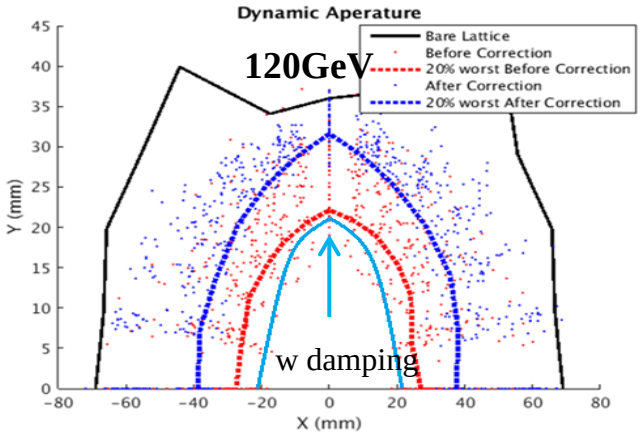
CEPC Booster Optimization Design towards TDR

Dou Wang (IHEP)

Dynamic aperture with errors

- With only COD corrections, DA is nearly two thirds of bare lattice
- At 120GeV, radiative damping and sawtooth was considered.
- DA requirement @ 10GeV determined by the beam stay clear region





	DA requirement		DA results	
	H	V	H	V
10GeV ($\varepsilon_x = \varepsilon_y$ =120nm)	$4\sigma_x$ +5mm	$4\sigma_y$ +5mm	$7.7\sigma_x$ +5mm	$14.3\sigma_y$ +5mm
120GeV (ε_x=3.57nm, $\varepsilon_y = \varepsilon_x$*0.005)	$6\sigma_x$ +3mm	$49\sigma_y$ +3mm	$21.8\sigma_x$ +3mm	$779\sigma_y$ +3mm

Summary

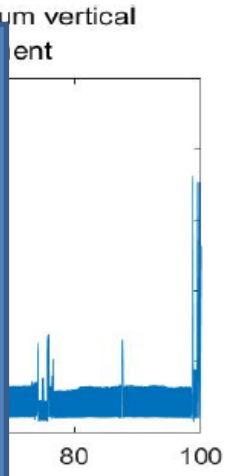
- The booster design can meet the injection requirements at all three energy modes.
- Accelerator physics design satisfies the requirements of geometry, beam dynamics and key hardware.
- DA reduction due to eddy current is serious and local correction with extra sextupole coils is designed.
- Low magnetic field in the booster is still a challenge. Technical solutions are studied continuously.
- Further optimization design → relax DA difficulty for collider
- Clear plan/goal for next step and ready to TDR phase

Imperfection and correction for CEPC

Yuanyuan Wei (IHEP)

Misalignment sensitivity

Orbit amplification factor



Conclusions

- CEPC lattice is sensitive to the imperfections. Therefore, the optics correction is very challenging.
- CEPC optics correction procedure was demonstrated to be effective.
- With the abovementioned imperfections, both DA and MA after correction are acceptable.

Towards TDR

- Study whether the tolerance of the imperfections can be relaxed.
- Optimize the correction strategy to achieve finer tuning of optics.
- Include imperfection of final focus (FF) quadrupoles.
- Include more types of imperfections.

Vertical
Orbit an
Quadrupole
Sextupole alig
Quadrupole

M

Co

qua
IR Q

Se

3 = 94

fectly aligned.

ld error

.01%

.02%

Corre

- COD
- Turn
- Dispe
- Beta
- Coupling and vertical dispersion correction (Local coupling parameter correction）.

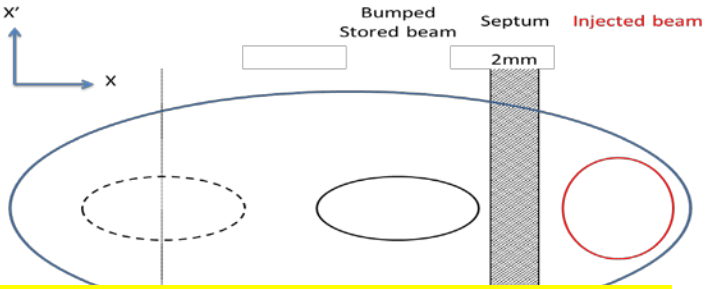
Injection/Extraction Optics of CEPC with Considerations of Kickers & Septa

Xiaohao Cui (IHEP)

Outline

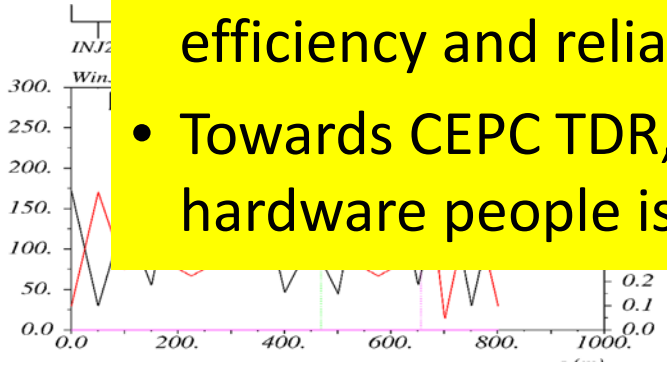
1. An introduction to CEPC
2. Injection to the damping ring
3. Injection to the booster
4. Extraction from the booster and Injection to the collider
5. injection process
6. Summary

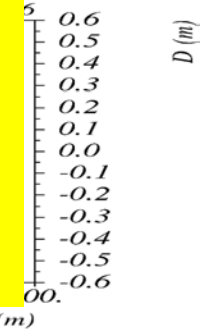
- A standard off-axis injection in the horizontal plane.



Linac

- Guiding
- Horizont
  bending





$\delta_E / p_0 c = 0.$

Table name = TW

Summary

- The optics of transport lines and some basic considerations of injection magnets are discussed.
- More optimization is needed to increase the injection efficiency and reliability.
- Towards CEPC TDR, more detailed discussions with the hardware people is needed.

Extraction

- The booster is 2.4 m above the collider.
- kick the beam horizontally, and the septa give a deflection in the vertical plane.

Component	Number	Septum width	Length (m)	Type	Deflection angle (mrad)	Field (T)
Septum	2	10 mm	15	Lambertson	26	0.69
Kicker	2		2		0.2	0.04

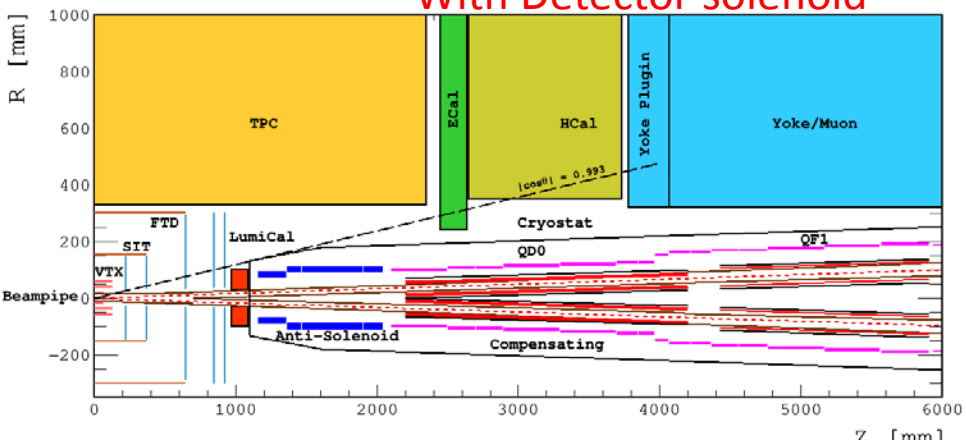
CEPC MDI towards TDR

Sha Bai (IHEP)

Outline

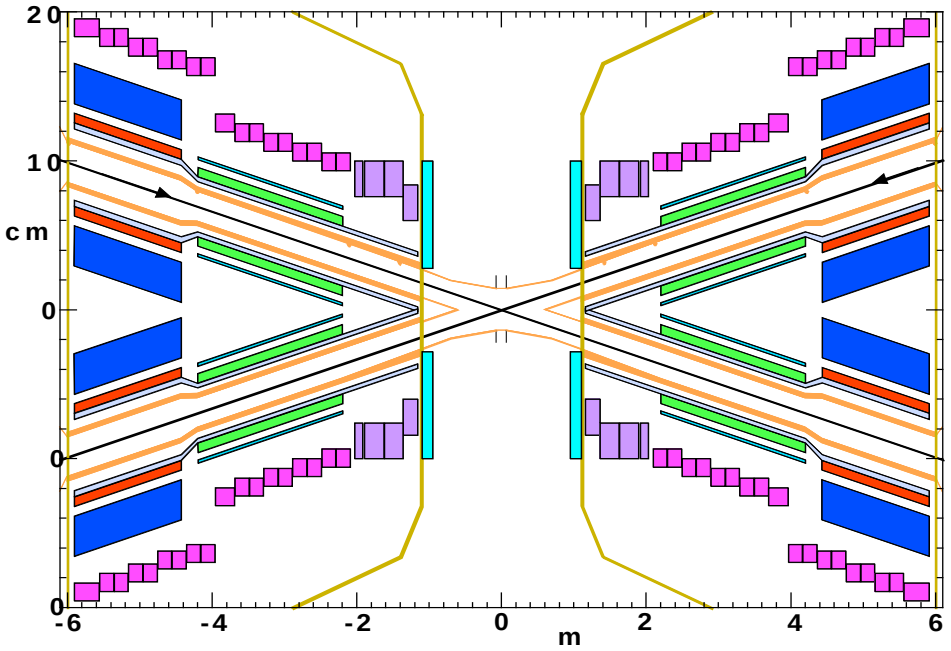
- MDI layout and IR design
- Synchrotron radiation and mask design
- Beam loss background & collimator design
- HOM absorber design
- Mechanics and assembly
- SC magnet supporting system
- IP BPM design
- Summary

With Detector solenoid

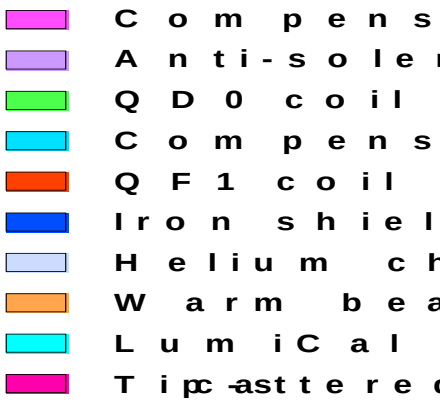


- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

Without Detector solenoid
~cryostat in detail



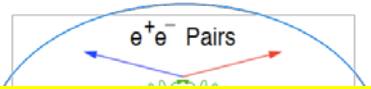
- The Machine Detector Interface (MDI) is about ±7m long from the IP
- The CEPC detector SC solenoid with 3T field and the length of 7.6m.



CEPC MDI towards TDR

Sha Bai (IHEP)

Beam loss



Summary

- The finalization of the beam parameters and the specification of special magnets have been finished. The parameters are all reasonable.
- The detector solenoid field effect to the beam can be compensated.
- HOM of IR beam pipe has been simulated, water cooling was considered and HOM absorber is under design.
- Beam lifetime of CEPC double ring scheme is evaluated.
- The most importance beam loss background is radiative Bhabha scattering and beamstrahlung for the Higgs factory.
- Collimators are designed in the ARC which is about 2km far from the IP to avoid other backgrounds generation. Beam loss have disappeared in the upstream of IP for both Higgs and Z factory.
- Preliminary design of Remote Vacuum Connection(RVC) is finished. And preliminary procedures of mechanics assembly are under studying.
- Towards TDR, many of the MDI components are under development.

Be

ution

Beam-Thermal photon scattering	50.7 h
Radiative Bhabha scattering	74 min
Beamstrahlung	80 min

- RBB and BS loss with collimators for Higgs
- HOM absorber
- IR mechanics assembly
- Luminosity monitoring

CEPC MDI SC Magnets R&D

Yingshun Zhu (IHEP)

Outline

- Introduction
- Design progress of CEPC MDI SC Magnets
- TDR plan
- R&D status
- Summary

R&D status

- In the R&D stage of CEPC project, superconducting prototype magnets for the MDI will be developed in three consecutive steps:

1) Development of double aperture superconducting quadrupole prototype magnet QD0.
2) Development of short combined function superconducting prototype magnet including QD0 and anti-solenoid.
3) Development of long combined function superconducting prototype magnet including QD0, QF1 and anti-solenoid.

➢ Supported by "Wang Yifang scientist studio", **the Step 1 of the R&D has started:** Development of double aperture superconducting quadrupole prototype magnet QD0.

Summary

- MDI superconducting magnets are key devices for CEPC. Conceptual design of superconducting magnets in CEPC MDI has been finished.
- Field cross talk effect between two apertures of QD0 can be reduced to be acceptable using iron yoke.
- The anti-solenoid is divided into a total of 29 sections with different inner coil diameters, with a max central field of 7.0 T.
- TDR plan of superconducting magnets in CEPC MDI is formed.
- Prototypes superconducting magnets are proposed, and the R&D has started .

CEPC SCRF R&D Towards

Jiyuan Zhai(IHEP)

Outline

- CDR design of CEPC SRF system
- SCRF TDR plan and R&D status
- Summary

CEPC Collider Ring SRF Parameters

Collider parameters: 20180330	H	W	Z
SR power / beam [MW]	30	30	16.5
RF voltage [GV]	2.17	0.47	0.1
Beam current / beam [mA]	17.4	87.7	460
Bunch charge [nC]	24	19.2	12.8
Bunch number / beam	242	1524	12000
Bunch length [mm]	3.26	5.9	8.5
Cavity number (650 MHz 2-cell)	240	2 x 108	2 x 60
Idle cavities on line / ring	0	12	60
Cavity gradient [MV/m]	19.7	9.5	3.6
Q_0 for long term operation	1.5E10	1.5E10	1.5E10
Input power / cavity [kW]	250	278	275
Klystron power [kW] (2 cavities / kly)	800	800	800
HOM power / cavity [kW]	0.57	0.75	1.94
Optimal Q_L	1.5E6	3.2E5	4.7E4
Optimal detuning [kHz]	0.2	1.0	17.8

Challenging RF hardware and beam operation, but feasible

- HOM power up to 1 kW/coupler w/ safe fill patterns, within the technology reach.
- HOM CBI is OK with deeper TM011 mode damping (and large cavity frequency spread and fast bunch-by-bunch feedback), but critical. Better to have idle cavities off-line.
- FM CBI manageable by RF feedback. Parking cavities FM CBI mitigate by symmetry detuning.
- Phase shift is moderate for small gaps
- Multi-cavity HOM power propagation and CBI under investigation.

CEPC SCRF R&D Towards

Jiyuan Zhai (IHEP)

TDR Plan of CEPC SRF System

Time	TDR R&D Plan	Resources (in CNY)
2018 - 2020	• System Design and Optimization • Key Technology R&D • 650 MHz Test Cryomodule • High Q, high gradient, new material	• MOST CEPC 7 M (650 MHz, IHEP & PKU) • PAPS 15 M (650 MHz & 1.3 GHz) • SHINE R&D 13 M (1.3 GHz cavity and coupler) • New material research fund 12 M (2018-2022) • 4 FTEs now, 2 more FTEs needed
2020 - 2022	• Engineering Design • Full Cryomodule Prototyping • High Q, high gradient, new material	• 80 M (one 650 MHz & one 1.3 GHz module with power sources) • SHINE pre- and mass production ? M (1.3 GHz) • New material research fund 12 M (2018-2022) • 12 FTEs
2022 - 2023	• Industrialization and Pre-production • Cryomodule Beam Test	• 90 M (three 650 MHz modules + two 1.3 GHz modules) • SHINE mass production ? M (1.3 GHz) • 18 FTEs

CEPC SRF Technological Uncertainties

Uncertainty	Impact	Mitigation Method
High Q operation (long term)	Cryogenic capacity, Field emission	Practical Q target, Moderate gradient, Clean (tunnel) assembly
Power coupler (variable)	Window event or failure, RF trip	Limit coupler power, Stand-by cavities, Fast closing valves between modules
HOM coupler and bellow	RF heating, cable heating, bellow heating	High power test at 2 K Special designed rigid coaxial line Class 10, RF shielded bellow at 2 K
LLRF (hardware in RF power source system)	FM CBI, Parking cavities for W & Z, Booster RF ramp	Direct RF feedback, symmetry detuning, Booster cavity para-phase ramp

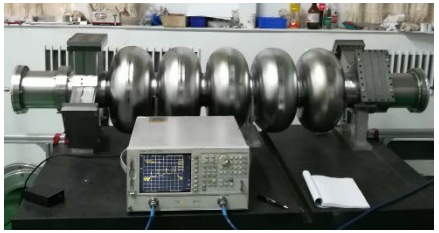
CEPC SCRF R&D Towards

Jiyuan Zhai (IHEP)

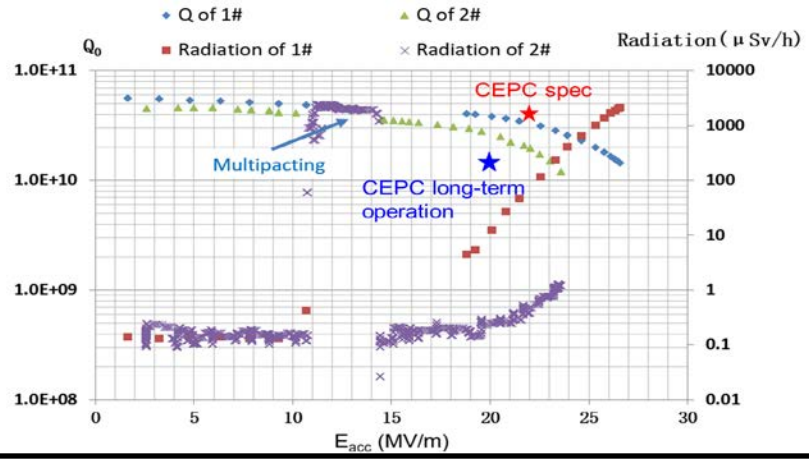
CEPC SRF Technology R&D Status

CEPC 650 MHz 2-cell cavity by OTIC

CEPC 650 MHz 2-cell cavity by HERT



CEPC 650 MHz 5-cell cavity with waveguide HOM coupler by HERT



- 650 MHz 2-cell cavity (BCP without Nitrogen-doping) reached 3.2E10 @ 22 MV/m (**nearly reached CEPC collider cavity vertical test spec 4E10 @ 22 MV/m**)
- Nitrogen-doping and EP on 650 MHz cavity under investigation.
- EP facility under commissioning.

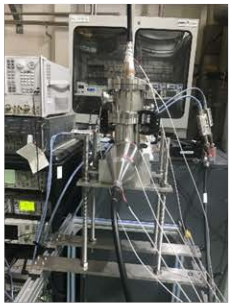
CEPC SCRF R&D Towards TDR

Jiyuan Zhai (IHEP)

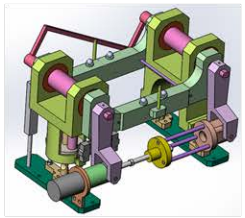
CEPC SRF Technology R&D Status

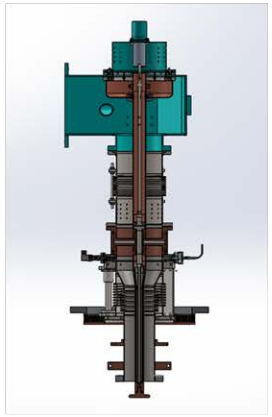
CEPC Collider HOM coupler (1 kW CW) by OTIC and HD

CEPC HOM absorber of SiC & AlN (5 kW CW)



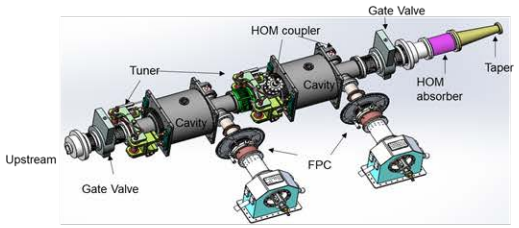
High power test of HOM coupler (left) and absorber (right) at room temperature. Up to 100 W transmitted power through the HOM coupler and 1 kW RF power absorbed by the HOM absorber.

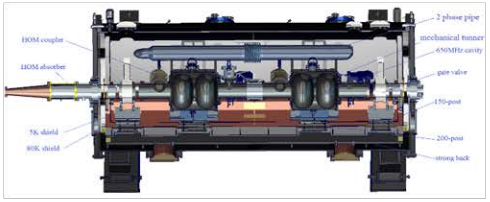


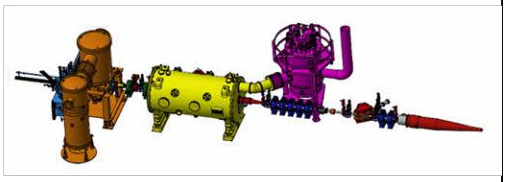


Tuner and input coupler (variable 300 kW CW) for CEPC 650 MHz cavity in fabrication

CEPC Booster 1.3 GHz TESLA 9-cell cavity mass production and variable double window coupler by HERT







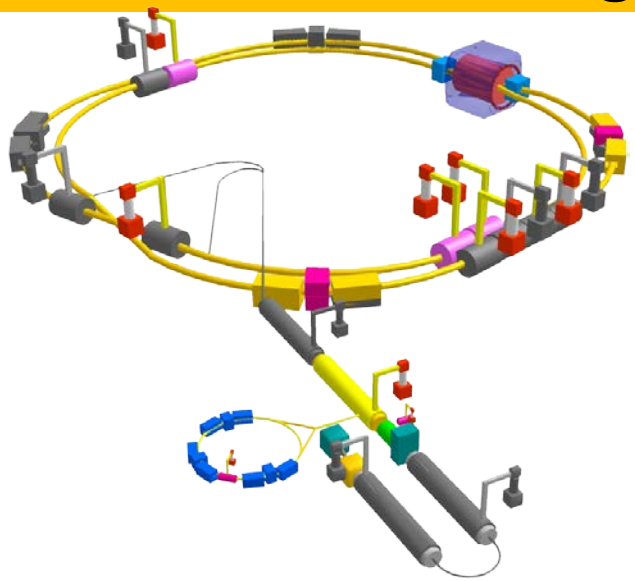
CEPC Collider Test Cryomodule with two 650 MHz 2-cell cavities and 10 mA CW beam.

Summary

- CDR design of CEPC SRF system completed with considerations on various operational requirements & scenarios and particular beam-cavity interactions and technical issues.
- SRF key components and test cryomodule design and R&D progress well, especially the world leading storage ring high Q cavity and high power SRF components.
- More resources needed to complete TDR R&D in 2019-2023.

Technology R&D for SuperKEKB Collider

Makoto Tobiyama (KEK)



- Circumference 3km
- LER:e^+ 4GeV 3.6A, HER:e^- 7GeV 2.6A
- f_{RF}=508.886 MHz, h=5120
- Low emittance 3.2/4.6nm with ~0.28% xy-coupling
- Bunch length 6/5 mm @1mA/bunch
- β^* at IP H/V 32/0.27mm 25/0.3mm
- Luminosity 80×10^{35} (x40 of KEKB)

Many difficulties to realize 40x luminosity

- Low emittance, low beam size at IP
  - Low emittance lattice (using existing components)
  - Large nonlinearity, much narrower dynamic aperture
  - Very strong, ultrafine-controlled superconducting final quadrupoles
  - High quality injection beam (small beam size, stable)
    - Positron damping ring to damp e+ injection beam, RF gun (e-)
  - Fast, and strong IP beam feedback systems
  - Beam instrumentation to measure beam qualities
- High beam current
  - Strong beam injector
  - Low impedance, high power-capacity vacuum components
  - Strong RF systems
  - Strong bunch feedback systems to suppress beam instabilities

Technology R&D for SuperKEKB Collider

Makoto Tobiyama (KEK)

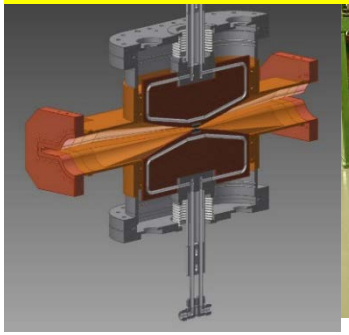
Development of beam collimators and their related instruments

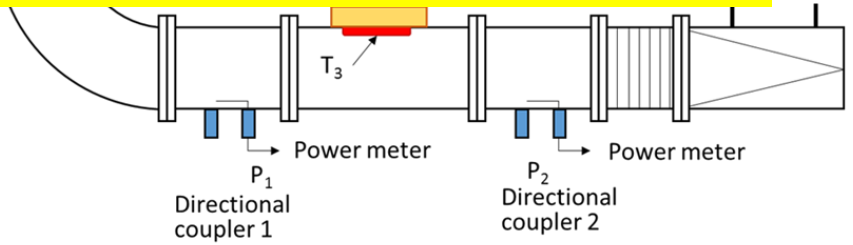
Beam collimator installed in the Supe
comm

Setup for a high power test of HOM

Summary

- SuperKEKB collider has stared the collision experiment.
  - Shown good performance of “nano-beam” collision scheme working with βy^*=3mm.
  - Instruments and tools developed for SuperKEKB collider have shown good performance.
- Difficulties found during phase-2 operation need to be solved soon.
  - Belle II background handling, including continuous injection.
  - QCS quench
  - Damage on beam collimators
  - Injection stabilities, including low emittance beam transport.
  - Optics correction for much smaller βy^*



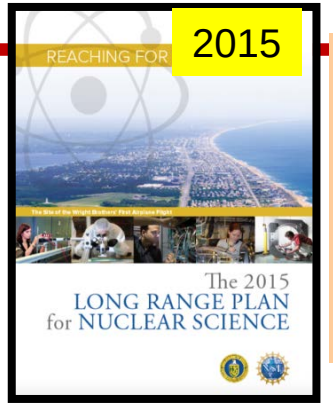


US EIC Milestones

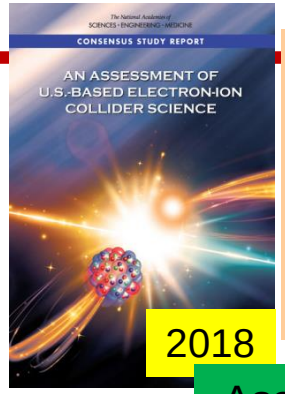
EIC White Paper

1st edition, 12/07/2012
2nd edition, 02/03/2013
3rd edition, 11/30/2014

2012 - 14



Recommendation 4: A high-energy high-luminosity polarized electron-Ion collider for new facility construction following the completion of FRIB



2018

"The realization of an EIC is absolutely crucial to maintaining the health of the field of nuclear physics in the U.S. and would open up new areas of scientific investigation."

Assessment Findings

Finding 1 (Science): An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms: How does the mass of the nucleon arise? How does the spin of the nucleon arise? What are the emergent properties of dense systems of gluons?

Finding 2 (Accelerator): These three high-priority science questions can be answered by an EIC with highly polarized beams of electrons and ions, with sufficiently high luminosity and sufficient and variable center-of-mass energy.

Finding 3: An EIC would be an unique facility in the world, and would maintain U.S. leadership in nuclear physics.

Finding 4: An EIC would maintain U.S. leadership in the accelerator science and technology of colliders, and help to maintain scientific leadership more broadly.

Finding 5: Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.

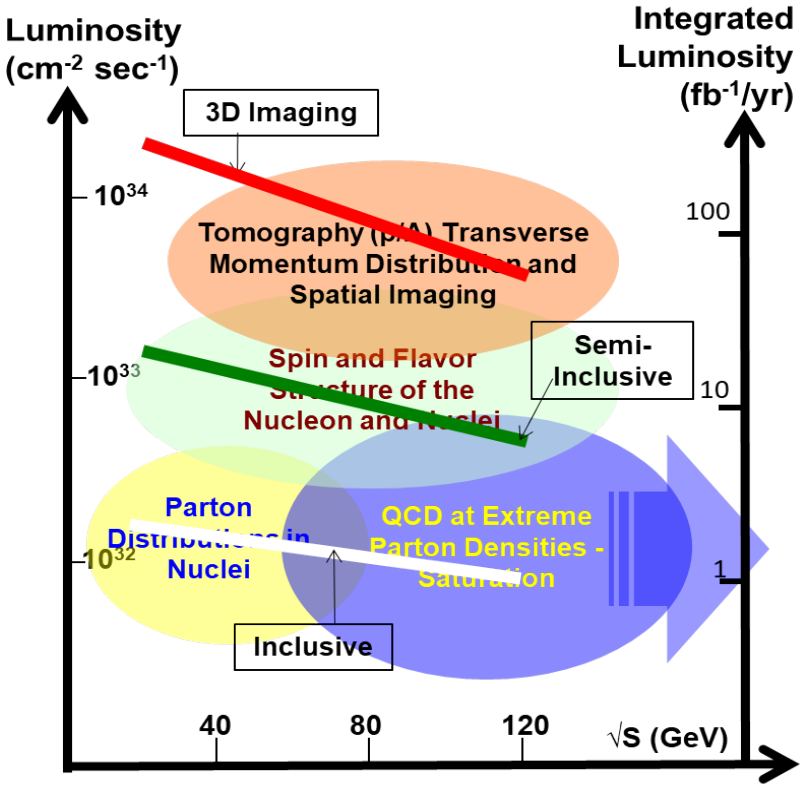
Finding 9: The broader impacts of building an EIC in the U.S. are significant in related fields of science, including in particular the accelerator science and technology of colliders and workforce development.

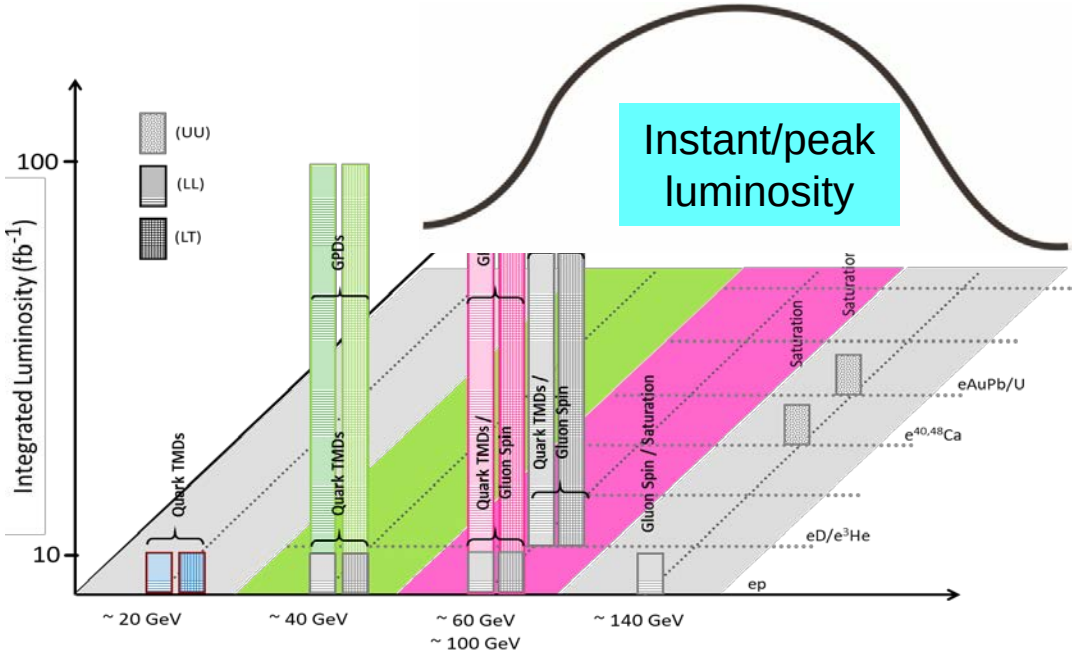
EIC Science

A Gluon Microscopy for Understanding the Glue that Binds Us All

A versatile range of *beam species, kinematics*, *polarizations*, *high luminosity* is required to

- *Precisely image sea quarks & gluons in nucleons & nuclei,*
- Explore the new QCD frontier of strong color fields in nuclei
- Resolve outstanding issues in understanding nucleons and nuclei in terms of fundamental building blocks of QCD





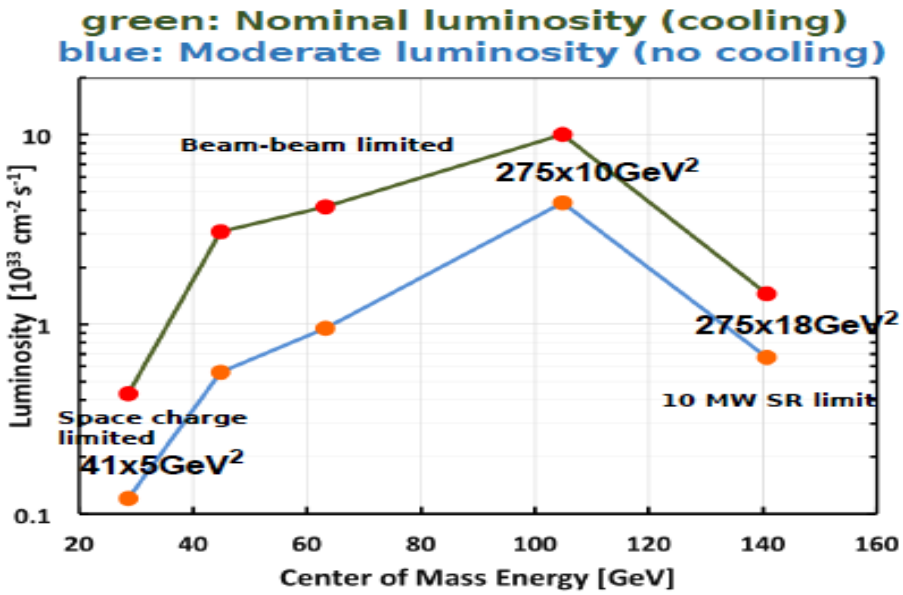
EIC Integrated luminosity needs vs. energy ranges and ion species for White Paper science program. Dual columns with different hashing represent different polarization (LL and LT) – each requiring integrated luminosity proportional to the height of the bar. Measurements that can be done concurrently are superimposed on taller columns.

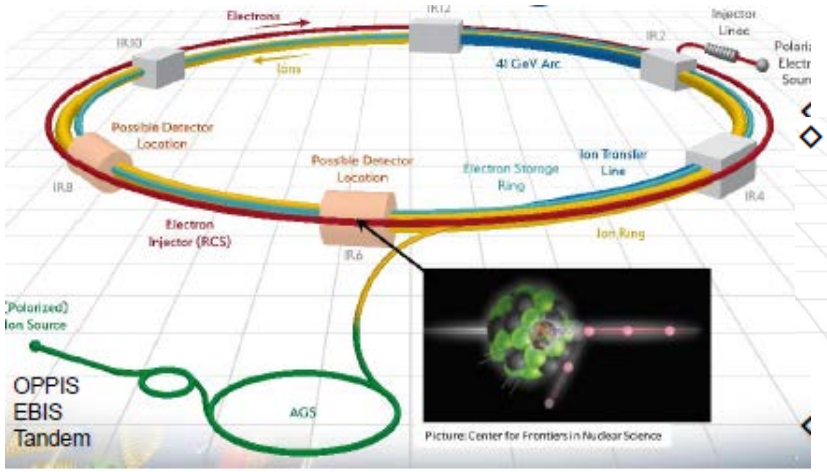
eRHIC Overview and Technologies

Francois Meot (BNL)

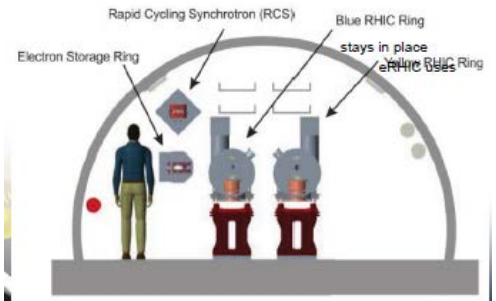
Design Goals

- Collision luminosity ~10^{33}-10^{34} $cm^{-2}s^{-1}$
  (exceeding HERA luminosity by 2 orders of magnitude)
- Electron, proton, ^{3}He and d polarization **>70%**;
  - *electrons: longitudinal at IPs;*
  - *hadrons: longitudinal and transverse;*
  - *complex e-h spin patterns*
- Large acceptance detector
  with elements integrated in the IR for forward particle detection
- Wide center-of-mass energy span: **29-140 GeV, e-p**
  29-89 GeV/n, e-ion

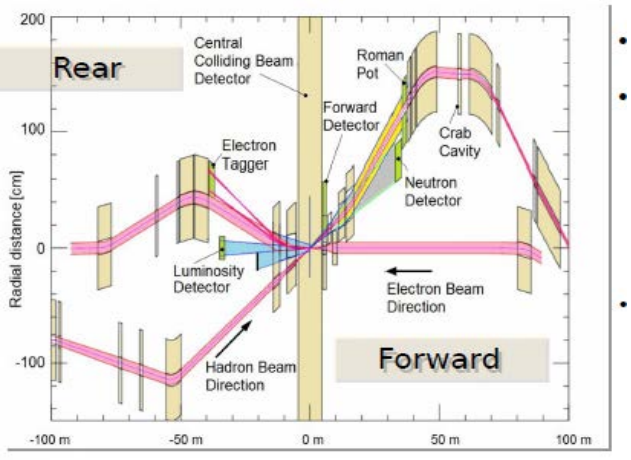




- **Based on RHIC ion complex:**
  - Polarized protons from OPPIS
  - Ions, polarized 3He and d, from EBIS
  - Booster and AGS injectors
  - Acceleration/storage in RHIC Yellow



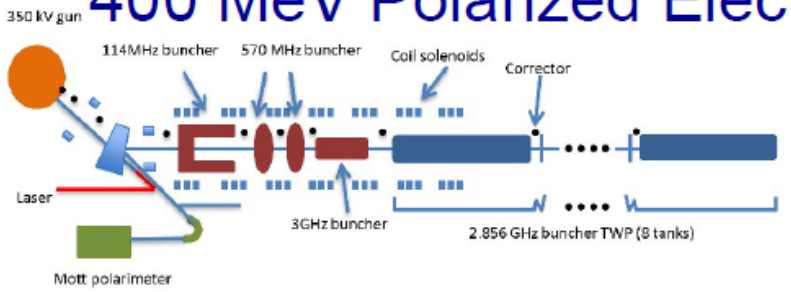
- **Adding an electron complex, in RHIC tunnel**
  - Polarized electron source
  - 400 MeV linac
  - Rapid-cycling synchrotron
  - 5 to 18 GeV storage ring



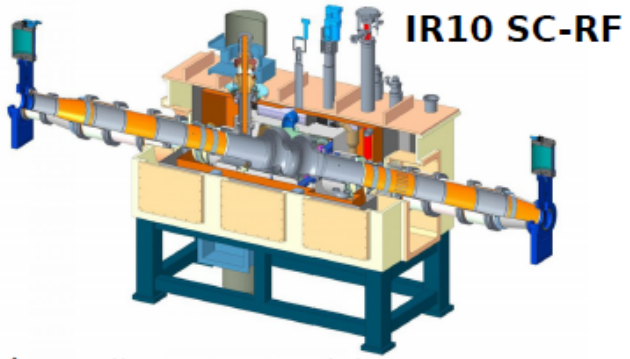
eRHIC Overview and Technologies

Francois Meot (BNL)

400 MeV Polarized Electron Injector



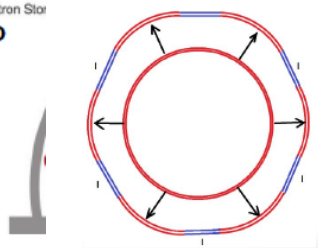
Parameter	Value
Charge [nC]	10
Frequency [Hz]	1
Energy [MeV]	400
Normalized emittance [mm-mrad]	55
Bunch length [psec]	6
dp/p	10^{-2}
polarization [%]	85



- 2-cell, 2K cryomodule, 563 MHz, 3MV/cell
- 12 cryomodules at 10 MW SR limit
- 2x 500 kW adjustable fundamental power couplers.
- 4x SiC Beamline HOM Absorbers
- Multibeam IOT power source.

RCS – Full Energy Injector

- **Accelerates 400 MeV, 10 nC bunches from the linac, to full collision energy, 5-18 GeV**
  100~200 ms acceleration ramp & 1 Hz repetition rate
- **RF system:**
  normal-conducting 563 MHz cavities (located at IR10), total voltage 72 MV.



*** Expand a circular 96-period ring, onto RHIC 6-fold footprint**

*** Choose [Qy]=51 to avoid resonances**
$a\gamma = kP \pm [Q_y]$

Helium-3 Source

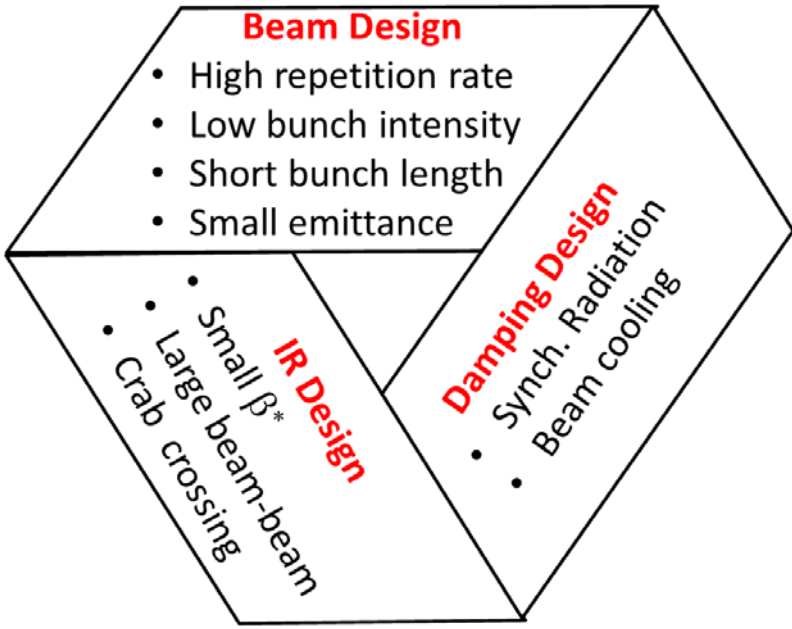
- Requirements:
  - 2×10^{11} $^3He^{2+}$ in a 10 μs pulse (~4.0 mA)
  - Polarization > 70%
  - Spin flip every pulse
  - Compatibility with EBIS operation for heavy ion physics.

JLEIC Overview and Technologies

Yuhong Zhang (JLEIC)

Concepts for High Luminosity

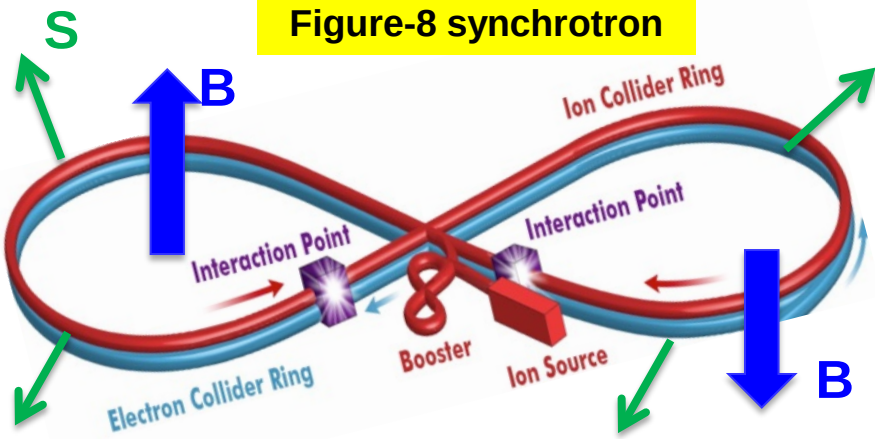
- *Conventional* approach for hadron colliders
  - Few colliding bunches ➔ low bunch frequency
  - High bunch intensity ➔ long bunch ➔ large β^*
- Approach: *high bunch rep-rate + short bunch beams* (standard for lepton colliders, KEK-B >2×10^{34}/cm^2/s)
- JLEIC is based on CEBAF, *already* up to 1.5 GHz
- *New green field* ion complex can be designed to deliver high bunch repetition rate



Concepts for High Polarization

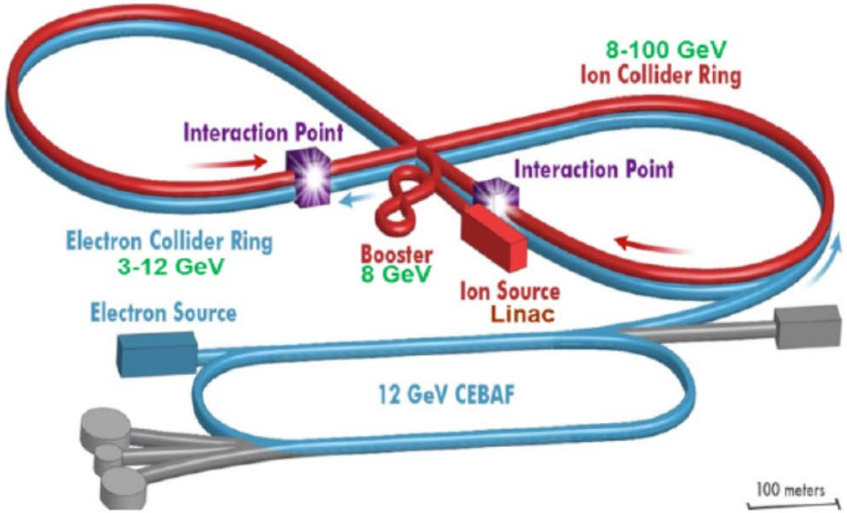
- Adopted a figure-8 topology for ion rings
  ➔ *Enabled by a **green field** collider ring design*
- Spin precessions in the left & right parts of a figure-8 ring ***exactly cancelled*** ➔ spin tune is ***zero***
- Does not cross spin resonance during energy ramp
- Spin can be controlled and stabilized by compact spin rotators, no need of Siberian Snakes
- The ***only way*** to accelerate/store polarized deuterons in medium energy range (gyromagnetic ratio *g-2* too small)

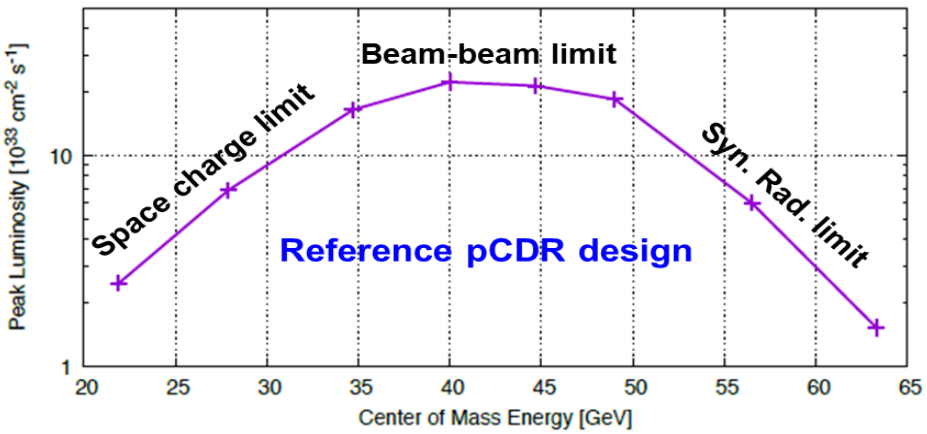
Figure-8 synchrotron



JLEIC Overview and Technologies

Yuhong Zhang (JLEIC)



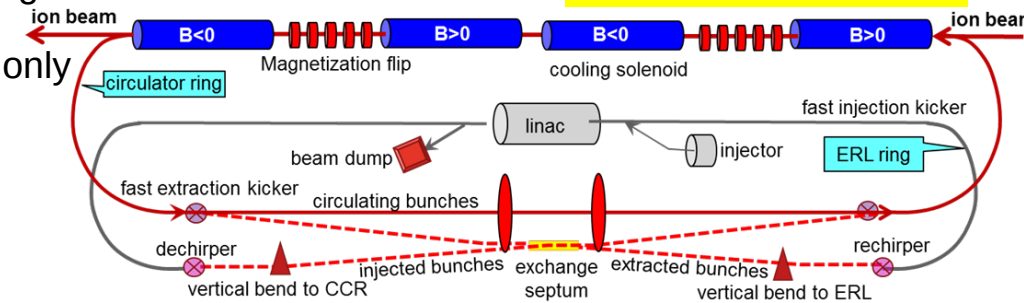


- **Energy**
  - Coverage of CM energy from 15 to **65** GeV
  - Electrons 3-12 GeV, protons 20-100 GeV, ions 12-40 GeV/u
- **Ion species**
  - Polarized light ions: p, d, ^{3}He, and possibly Li
  - Un-polarized light to heavy ions up to A above 200
- **Support 2 detectors**
  - Full acceptance capability
- **Luminosity**
  - 10^{33} to 10^{34} cm^{-2}s^{-1} / IP in a *broad* CM energy range
- **Polarization at IP**
  - Longitudinal for both beams, transverse for ions only
  - All polarizations >70%
- **Upgradable to higher CM energy ~ 140 GeV**

Multi-phased Cooling Scheme

Ring	Functions	Kinetic energy (GeV / MeV)			Cooler type
		Proton	Lead ion	Electron	
booster ring	Accumulation of positive ions		0.1 (injection)	0.054	DC
collider ring	Maintain emitt. during stacking	7.9 (injection)	2 (injection)	4.3 (proton) 1.1 (lead)	DC
	Pre-cooling for emitt. reduction	7.9 (injection)	7.9 (ramp to)	4.3	DC
	Maintain emitt. during collision	Up to 100	Up to 40	Up to 54.5	ERL

ERL Electron Coolers

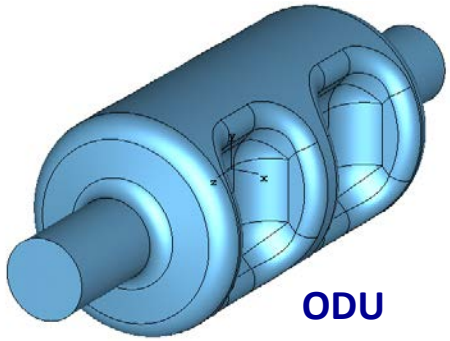


RF System Challenges in Circular Colliders

Bob Rimmer (JLEIC)

Outline

- High energy
  - Many cavities/cells
  - High synchrotron radiation power (e+e-)
- High currents, many bunches
  - High beam power
  - Detuning
  - Instabilities
  - High power couplers/windows
  - HOM damping/power
  - Coupled-bunch modes, BBU, feedback
- Gaps
  - Ion clearing or abort gaps
  - Transients
  - Complex beam spectrum
- Interaction regions
  - Impedance/heating
  - Crab crossing
- Conclusions



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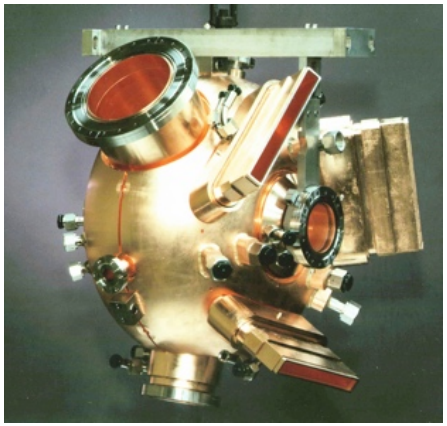
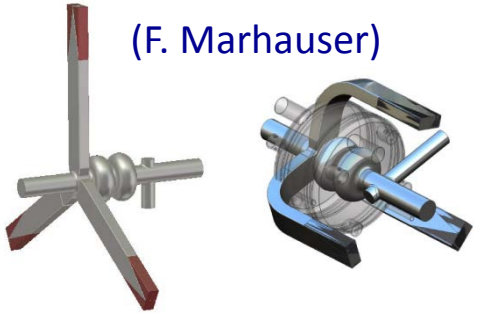


PEP II RF cavity in JLEIC e-Ring

476 MHz, single cell,
1 MV gap wwith 150 kW
strong HOM damping
>400 kW RF to beam

(F. Marhauser)



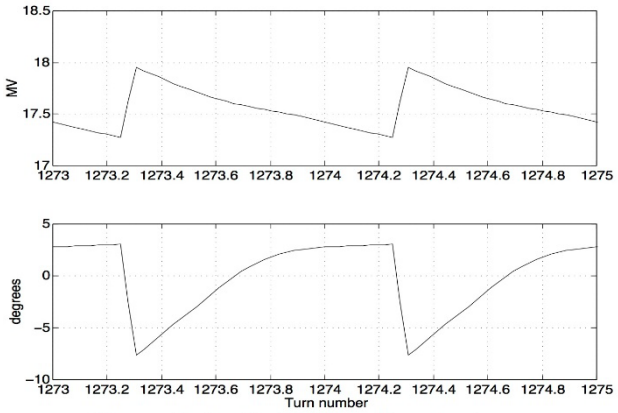
- 956 MHz 2-cell Cavity
- Waveguide HOM dampers
- Stable

- Electron and ion beams have to cross at an angle in an EIC
  - Create space for independent electron and ion IR magnets
  - Avoid parasitic collisions of shortly-spaces bunches
  - Improves detections
  - Improves detector background
- Without compensation, geometric luminosity loss is about a factor of 12 and there is potential for dynamic instabilities
- Crabbing restores effective head-on collisions
- Local compensation: set of crab cavities in both sides of IP
- Deflective crabbing: demonstrated at KEK-B, tested with ions at CERN SPS

RF System Challenges in Circular Colliders

Bob Rimmer (JLEIC)

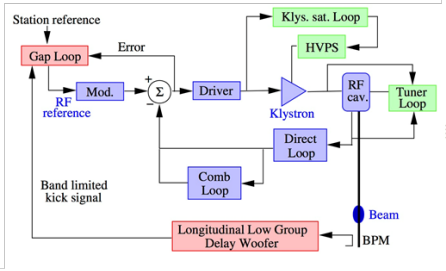
- Ion clearing or abort gaps
  - High stored beam energy requires abort gaps and special beam dump lines
  - Gap length is determined by kicker rise time
  - Gaps may also be needed for ion clearing or electron cloud
- Transients
  - Gaps cause transient beam loading
  - Can saturate klystron if high gain direct loop is used
    - Klystron small signal gain goes to zero, feedbacks stop working
  - Causes phase transient along the beam fill
  - Modulates arrival time of bunches at IP (and at crab cavities)
  - Introduces bunch length variation and synchrotron tune spread along the train
- Complex beam spectrum
  - Causes spectral lines at revolution harmonics in between RF lines
  - May induce significant power in some HOMs
  - May induce significant power in beam chamber components (bellows, IR chamber etc.)



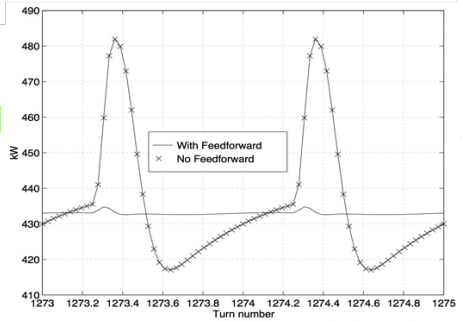
Gap transient mitigations

- SRF cavity has potential for higher stored energy, smaller transients
- Alternate Idea - used at KEKB - NC ARES energy storage cavity system
- Feed-forward, avoids saturating klystron due to direct feedback
- Match transients in both rings (PEP-II)
- Fill pattern shaping?

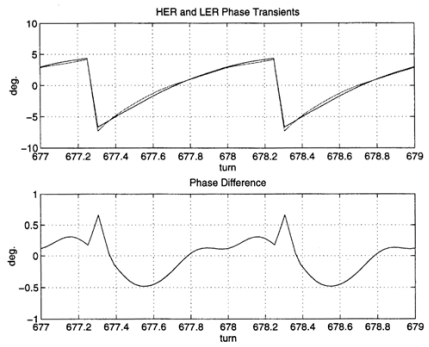
ARES cavity



System block diagram. Fast dynamics (modeled) appear in blue, slow dynamics (fixed parameters in simulation) in green, and not modeled components in red.



Forward Power Variation, with and without Feedforward.



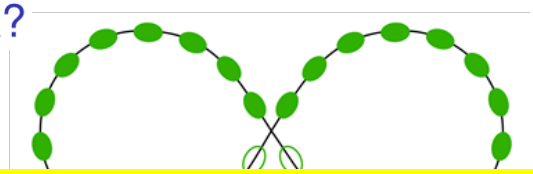
The gap induced transients in the two rings must be matched to prevent

Bob Rimmer (JLEIC)

Fill pattern modulation

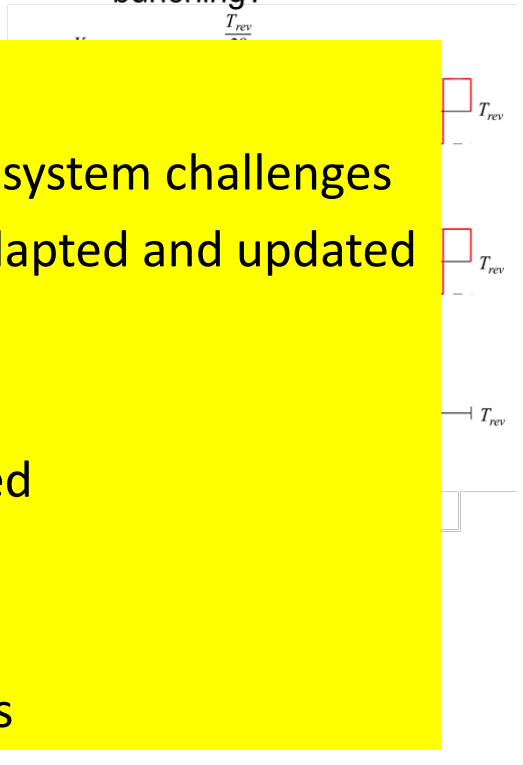
Add charge either side of the gap to reduce transient over most of the fill.

Does Fill Pattern Modulation Work?



What about ions?

Alternative: barrier bucket re-bunching?



Results in long gaps

Conclusions

- High current and high energy colliders provide many RF system challenges
- Techniques from light sources and “Factories” can be adapted and updated
- New SRF cavity designs can advance the state of the art
- RF power costs are significant
- Gap transients are challenging and not completely solved
- Crab crossing brings its own challenges
  - SPS test with protons very encouraging!
- These problems are common to all new circular colliders

FCC-ee MDI Magnetic Elements

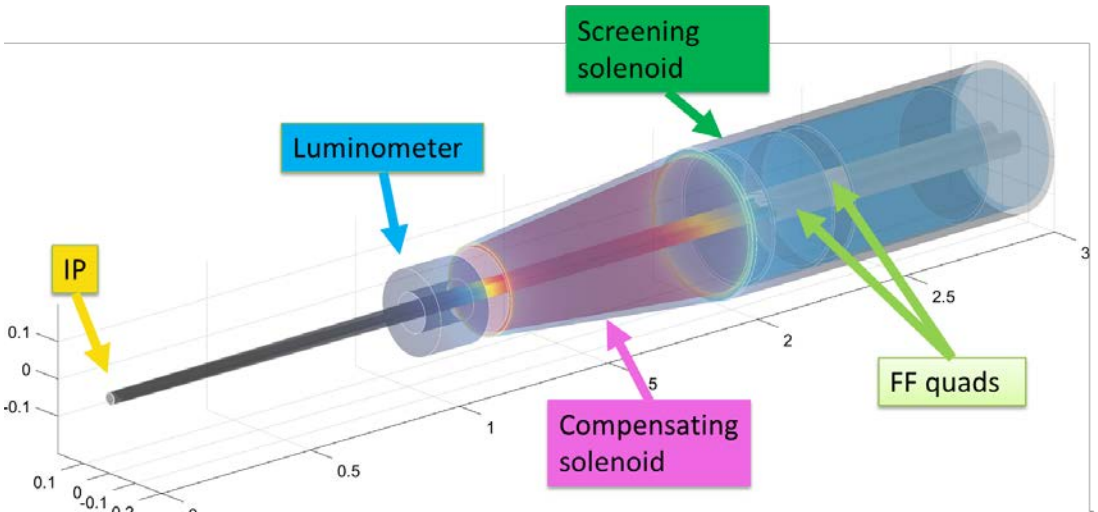
Michael Koratzinos
(CERN & MIT)

Requirements

1. Leave adequate space for the detectors: in the present design magnetic elements reach angles of up to ± 100 mrad. The luminosity counter sits unobstructed in front of all magnetic elements.
2. In order to minimise emittance blow-up due to coupling between transverse planes, the integrated field seen by the electrons and positrons crossing the IP should vanish. Field compensation should be better than 1% to avoid any noticeable increase in emittance (if the compensation is off by 0.1% then the resulting vertical emittance blow up would be 0.1 pm per IP – the effect is quadratic).
3. Vertical emittance blow-up due to fringe fields in the vicinity of the IP should be significantly smaller than the nominal emittance budget. Particular attention is given to the low energy working points where the emittance blow-up is worse, aiming at a fraction of the nominal vertical emittance of 1 pm for two IPs
4. The final focus quadrupoles should reside in a zero-field region to avoid transverse beam coupling; the maximum integrated solenoid field at the final focus quadrupoles should be less than about 50 mTm at each side of the IP.
5. The field quality of the final focus quadrupoles should have errors smaller than 1×10^{-4} for all multipoles.

The FCC-ee baseline solution

- A compensating solenoid must sit between the screening solenoid and luminometer to ensure an integral field of zero



FCC-ee MDI Magnetic Elements

Michael Koratzinos
(CERN & MIT)

- The stringent requirements of the final focus quadrupoles are satisfied by using a canted-cosine theta design. The proposed design features iron-free coils with crosstalk and edge

Conclusions

- We have satisfied all requirements related to magnetic elements close to the IP for a high-performance e+e- accelerator…
- …using a minimum number of magnetic elements (2 solenoids per side)
- We have designed a ultra-precise final focus quadrupole system that eliminates cross talk and has excellent field quality at the edges (and not only in the middle)
- This is based on the CCT technique
- Advantages are:
  - Excellent field quality
  - Able to correct cross talk
  - Excellent packaging advantages for correctors
  - Can be designed/manufactured at a fraction of the cost of traditional designs
- A prototype FCC-ee FF quadrupole is being constructed and will be tested soon (Suitable for: FCC-ee, CEPC, next generation SuperKEKb, next tau-charm factory?)

Racetrack

- But: more conductor for same field compared to conventional design

Four Interested Talks in This Afternoon Sesssion

- "**SCRF Infrastructure Development**" by Song Jin (IHEP)
- "**CEPC Civil Engineering and Implementation (Qinhuangdao**)" by Yu Xiao (Yellow River Engineering Consulting Company Ltd)
- "**CEPC Coordination Design System (Projectwise) and Installation Study**" Ke Huang (Huadong Engineering Corporation Ltd)
- "**Green CEPC**" by Yunlong Chi (IHEP)

Personal Reflections

- Many interesting talks
- Lots of progresses in CEPC Design Studies
- Many accelerator design issues and R&D are shared by present and future colliders (FCCee/CEPC, e+e-, EIC)
- Collaborations between these teams are important
- Finally, would like to thanks the host (IAS) for this conference and accelerator mini-workshop)