On the challenges of future e^+e^- colliders

M.E. Biagini, INFN-LNF

The 2024 International Workshop on the High Energy Circular Electron Positron Collider

Hangzhou, China, Oct. 23rd-26th 2024

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

The future of e^+e^- circular colliders

- Future e^+e^- colliders, aiming at high luminosity, will be facing both design and technical challenges. We call them indeed *Super-Factories*
- Two categories of colliders (circular, linear) and two frontiers (high energy and high precision) are in the design or R&D phase, aiming at taking data in the next decade and beyond
- Time (a decade at least) in this case is a benefit: solutions to technical issues can be found

Design/beam dynamics challenges (some)

- Beam parameter at IP
- Crab-waist collision
- IR design
- Solenoid compensation and ε_y growth
- Machine Detector Interface (MDI)
- IP orbit feedback and L tuning
- Low emittances
- Chromaticity and Non-Linearities
- DA & MA
- Errors handling → Optics/coupling
- High beam currents
- Lifetime
- Backgrounds in the IR
- Backgrounds in the rings
- Impedance → instabilities
- Ion-trapping/e^- cloud mitigation
- Fast injection (off/on/swap) & ramping
- Polarization (T and possibly L)

All are interconnected!

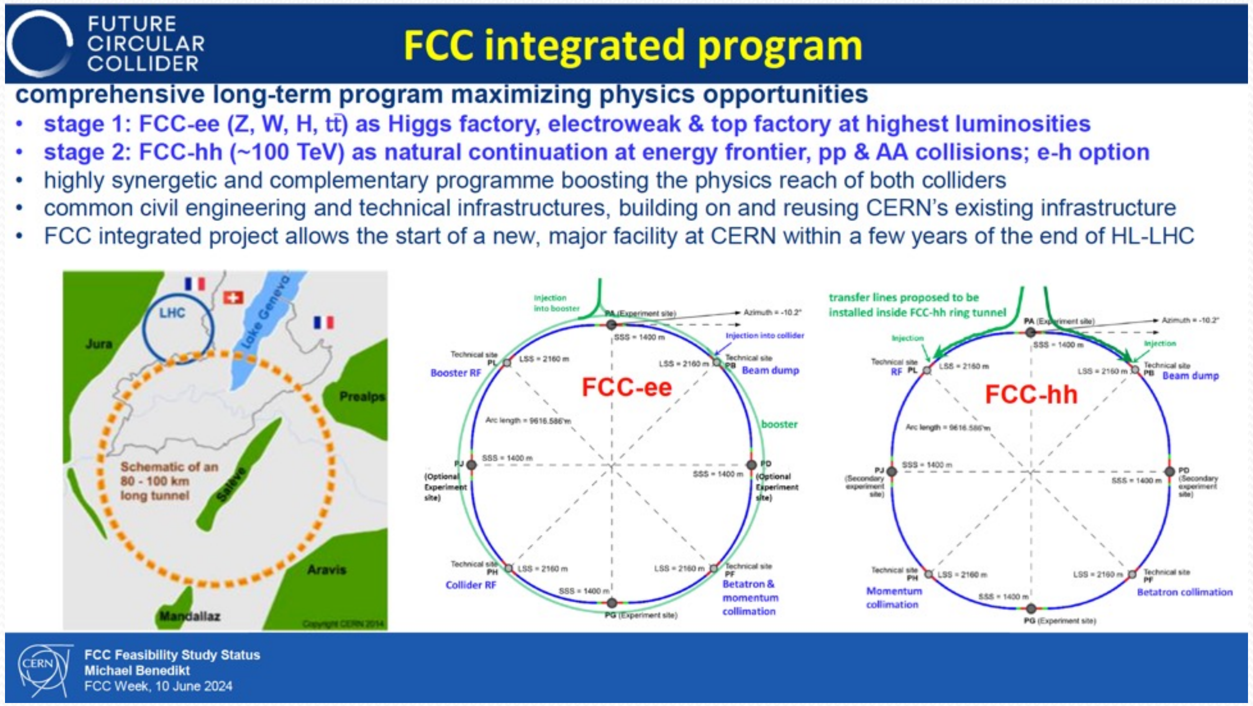
Technical challenges (some)

- IR SC quadrupoles
- IR engineering (MDI)
- HOMs in IR
- SC Magnets
- SC RF
- High efficiency RF sources
- Reliable injector
- Plasma injector
- Diagnostics & Controls
- Vacuum
- Collimators (NL?)
- Synchrotron losses (saw-tooth)
- Radiation hardness
- Alignment
- Installation
- Civil engineering

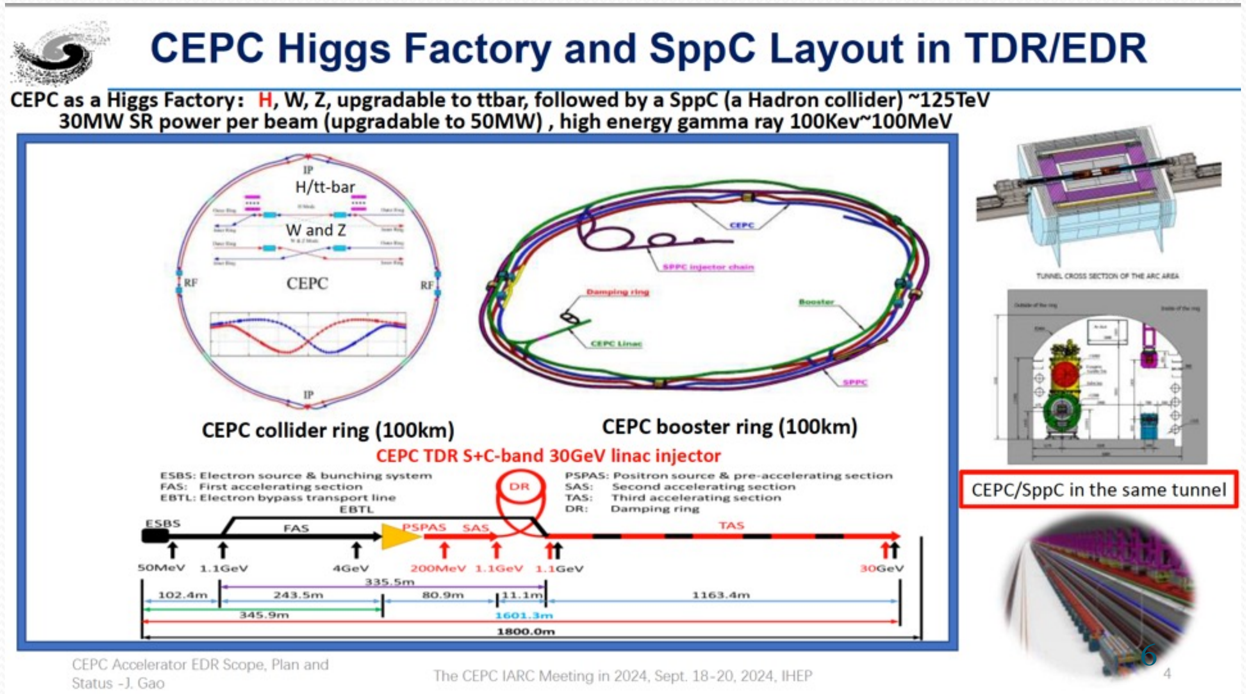
Other challenges…

- Money (construction & operation)
- Manpower (design, construction & operation)
- Time
- Availability of electronics/equipment in a few years, when required for mass production
- Accessibility → repairs in tunnel in case of failures
- Sustainability → green accelerator?
- …

Super Higgs (Z,W,ttbar) Factories



~100 Km, 3 rings, underground tunnel, ramping booster, high synchrotron losses
Alignment is nightmare...



Need for some "green" solution to be able to sustain a very costly operation
Efforts are going on in both projects, more to be done

FCCee Machine Detector Interface

- MDI is a crucial part of the collider
- It is important to choose the right beam pipe material and geometry, evaluate correctly the beam losses and chamber heating, design supports able to minimize vibrations overall in the IR, at the same time satisfying the detector requirements for space
- In parallel, backgrounds and particle losses need to be carefully studied
- Not forgetting the SC quadrupoles and their correction coils
- Luminosity performances will mostly depend on the IR design and engineering
- At FCCee intensive studies and R&D are in progress

FCCee MDI

M. Boscolo, FCCweek, June 2024

Main plans on key aspects of the MDI design

Talk on Friday by A. Ciarma

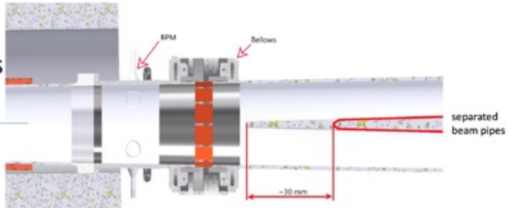
- ❑ IR magnet system & Cryostats
  - FF Quads & Correctors
  - Solenoid comp. scheme & anti-solenoid design
- ❑ IR Mechanical model, including vertex and lumical integration, and assembly concept
  - Services (i.e. air & water cooling for vertex and vacuum chambers) and cables
  - Anchoring to the detector
  - Accessibility & Maintenance
  - Vacuum connection
  - IR BPMs
  - Integrate in the design an alignment system
- ❑ Heat Loads from wakefields in IR region
  - In progress
- ❑ Beam induced backgrounds
  - Activity on the software and MDI model level, great effort done, to be continued in the next months.
    - Halo beam collimators implemented.
    - IP backgrounds evaluated.
    - Single beam effects (e.g. beam-gas, thermal photons, Touschek) being implemented in Xsuite.
    - SR backgrounds studied in different conditions and baseline/LCCO optics was compared.
    - Injection backgrounds
    - Study of IR radiation level & fluences started (Fluka)
  - Results to be used by the detectors to estimate their backgrounds, and feedbacks to MDI to optimize shieldings, masks and collimators.
  - Beamstrahlung dump with radiation levels

Steps towards the FS final report: MDI note written for the midterm report will be updated with the improvements made so far, and it will be expanded with new studies by September 2024.

Alexander Novokhatski (SLAC)

Optimization of the FCC-ee IR beam pipe elements

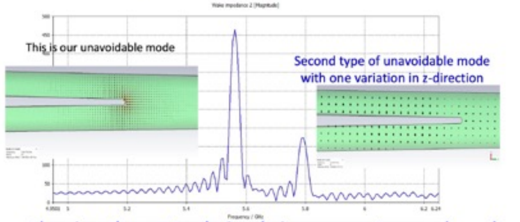
- Goal is to minimize IR heat-load due to impedances
- Low impedance vacuum chamber designed
- New evaluations of trapped modes for
  - different shape of SR masks
  - elliptical shaped BPM



Unfortunately we had to increase the length of the mutual chamber part in order to install these elements

Next steps

- Optimize gold thickness on the internal vacuum chamber
- Finalize IR bellow design
- Evaluate impedance for the global IR model (chambers, bellows, BPM, masks)



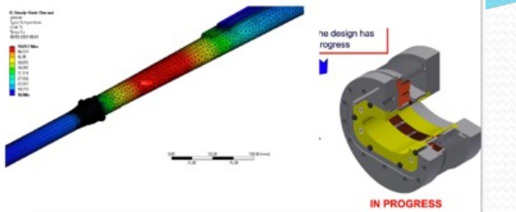
Lengthening the mutual pipe brings more trapped modes

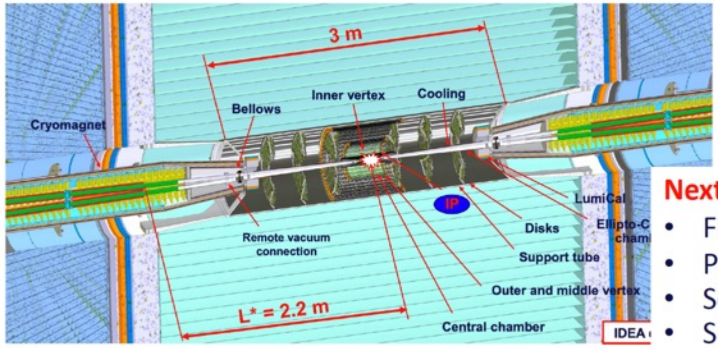
FCC 14/6/2024 FCC WEEK 24 MDI SUMMARY Manuela Boscolo

Francesco Fransesini (INFN-LNF)

Mechanical model of the MDI

- Progress on the central and conical chamber design
- Vacuum chambers material budget optimization
  - removal of copper manifolds
  - pure Beryllium vs AlBeMet: gain up to a factor 2
  - check paraffin safety → water?





Next steps

- Finalize IR bellows design
- Progress remote vacuum connection
- Services
- Supports

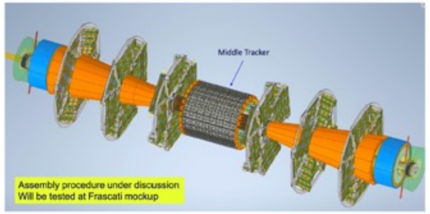
FCC 14/6/2024 FCC WEEK 24 MDI SUMMARY Manuela Boscolo

Fabrizio Palla (INFN-Pisa)

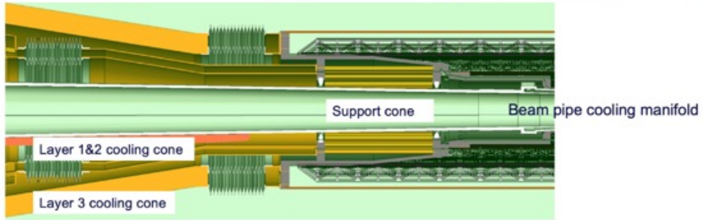
Vertex detector design and integration

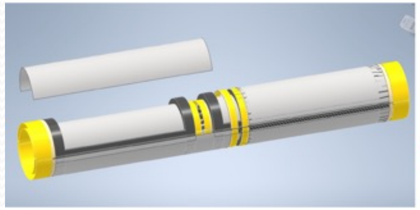
Integration with the machine elements being developed
Services integration and cooling being finalised:

$$\Delta T < 10^{o}C \;-\; 1.5\mu m \; RMS \; displacement$$



A mini-workshop on vertex detector technologies (including system integration and mechanical aspects) will be held at CERN on July 1 and 2: https://indico.cern.ch/event/1417976/





Lightweight layout using an ALICE ITS3 inspired design

A lighter concept with curved and stitched MAPS is being engineered

First layout done
Engineering drawings started, having in mind construction sequence
Cooling (air) and flex circuits routing will be addressed shortly

FCC 14/6/2024 FCC WEEK 24 MDI SUMMARY Manuela Boscolo

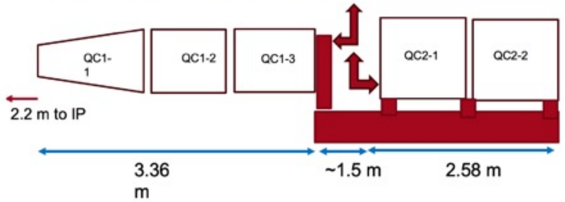
J. Seeman (SLAC)

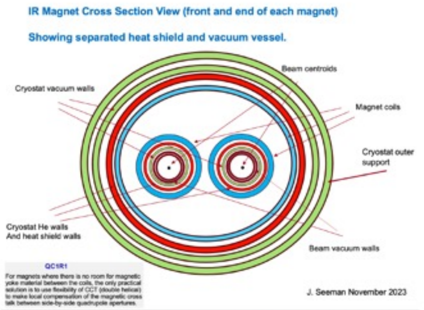
IR magnet system

Preferred option for the IR cryostat

IR QC1 and QC2 in different cryostats but one integrated raft (not to scale)

Need to make space for cryogens, leads, and cantilever supports.





Radial distance from detector solenoid axis to beam axis: conservative/less conservative approach

Alternative solenoid compensation scheme
https://doi.org/10.18429/JACoW-IPAC2024-TUPC68

Suggested focus topics for FCCee MDI and IR magnets for 2024-2025 SLAC

1) Add inner background shielding: W, Ta, or Cu inside magnets in cryostat (Δr?)
2) Resolve new IR lattice vs present: QC1,QC2 placement and anti-solenoids
3) Make initial cryostat design (4 or 7 m) by cryogenic/mechanical engineer(s)
4) Answer if IR magnets need higher-order trim coils
5) Confirm 100 mrad detector-accelerator cone angle
6) IR BPMs and other diagnostics
7) Full list of magnet, vacuum, and cryogenic specifications
8) Converge on background mask geometry
9) Make initial layout of magnet/cryogenic splice box
10) Construct a left and right CCT magnet pair for QC1 and test
11) Carry out warm test of CCT quadrupole for reduced left-right field cross-talk
12) Design remote vacuum flanges (need 6 flanges with 2 designs)
13) Radial differential movements during cool down

FCCee Definition of alignment strategy

CEPC Talk on Friday by X. Wang

Alignment should comply the need of keeping errors to a minimum for machine performances

General constraints
- Access (installation, alignment, maintenance)
- Space
- Radiation level
- Thermal stability
- Stability of the tunnel floor, ground motion

Alignment is a real concern

Project constraints
- Cost
- Manpower available
- Operation / maintenance time

Alignment of a component inside a tunnel

Component & support design
- Impact of vibrations
- Eigen frequencies
- Rigidity of component & support
- Weight

Beam requirements
- Fiducialisation requirements
- Component assembly on girder
- Girder alignment in the tunnel
- Relative / absolute alignment requirements

Alignment methods & instrumentation available

- **Takes several years!!!**
- **Different methods and solutions needed according to the area**

Hypotheses

- **Tolerances**

FCC-ee emittance tuning results
without BPM errors and without chromaticity correction

RMS misalignment and field errors tolerances:

Type	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	ΔS (μm)	ΔDTHETA (μrad)	ΔDPHI (μrad)
Arc quadrupole*	50	50	300	150	100	100
Arc sextupoles*	50	50	300	150	100	100
Dipoles	1000	1000	300	1000	-	-
Girders	150	150	-	1000	-	-
IR quadrupole	100	100	250	250	100	100
IR sextupoles	100	100	250	250	100	100

* misalignments relative to girder placement

Type	Field Errors
Arc quadrupole*	$\Delta k/k = 2 \times 10^{-4}$
Arc sextupoles*	$\Delta k/k = 2 \times 10^{-4}$
Dipoles	$\Delta B/B = 1 \times 10^{-4}$
Girders	-
IR quadrupole	$\Delta k/k = 2 \times 10^{-4}$
IR sextupoles	$\Delta k/k = 2 \times 10^{-4}$

Important to note:
BPM errors not included and chrom correction not included.

Radiation not included in correctors and trim and skew quads.

Also note:
Despite well corrected linear optics, the DA is still greatly reduced.

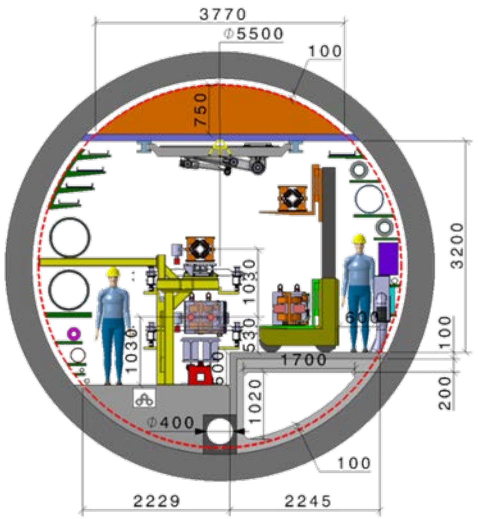
From Tessa Charles (FCC week, June 2022)

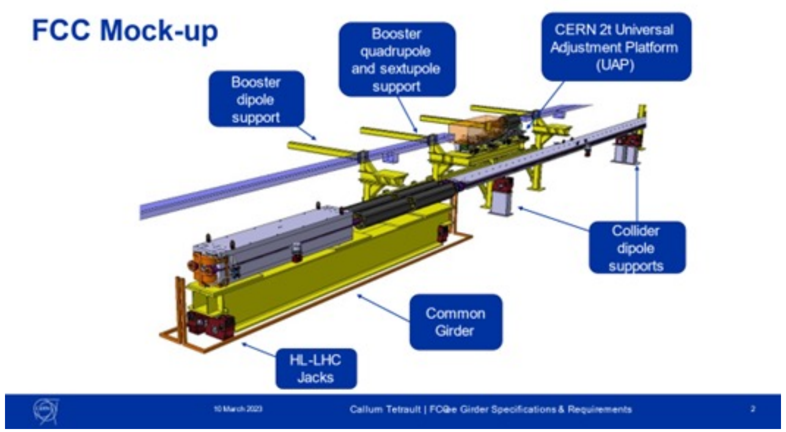
FCC Jean-Paul Burnet / Tor Raubenheimer

Recall, what need to be done to complete the feasibility study

Impact of alignment requirement
- Can change the design of accelerator supports
- Can bring additional equipment to be installed in the tunnel (motorized jack…)
- Can add a lot of cables
- Can increase the cost

Related to accelerator design





- **Number of components:**
  - In the arcs (Main Ring):
    - 2944 girders:
      - 2944 quadrupoles
      - 2944x2 sextupoles
    - 5888 dipoles
- In the arcs (booster):
  - 2944 girders
    - 2944 quadrupoles
    - 2944 sextupoles
  - 5888 dipoles
- In the LSS (???):
  - 2240 components booster
  - 2240 components (main ring)
- Injectors: 500 components ???
- Other components ???

CEPC SRF cavities & power sources

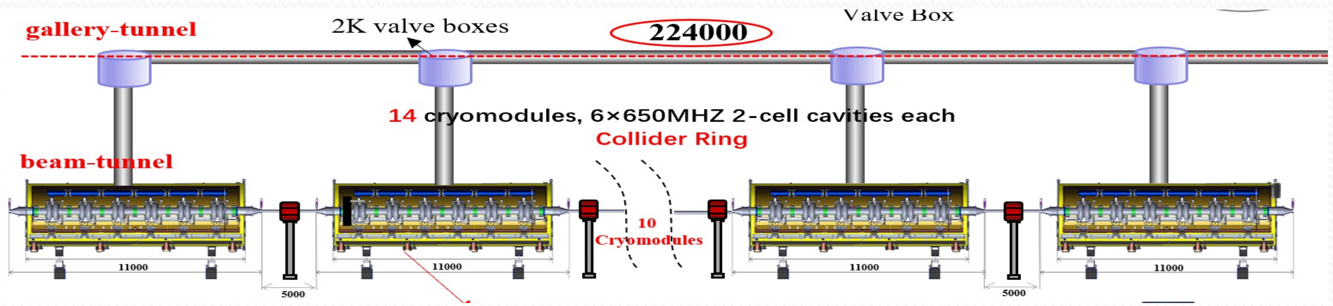
- More than 1000 cavities are needed, for booster (40%) and collider (60%)
- 1.3 GHz TESLA-like for the booster, built for DALS injector, 650 MHz for the collider, prototypes going-on on 2-cells cavity
- Significant results have been achieved on prototyping variable couplers, which are a key factor required for energy efficiency across the different collider modes
- New design of Cryo-Module (in series, not in parallel) → challenging but cost saving, strong collaboration between industry and institutions, test planned next year of a very large cold box of 18 kW @ 4.5 K
- High efficiency klystron → impressive result → recorded efficiency of 78.5% at CW 803 kW (aims at 90%!)
- Multi-beam klystron (MBK) and Energy Recovery MBK Klystrons tests by end 2024
- C-band pulsed klystron with 80 MW output power at 100 Hz repetition rate was designed and is ready for production

Several talks on Thursday by CEPC

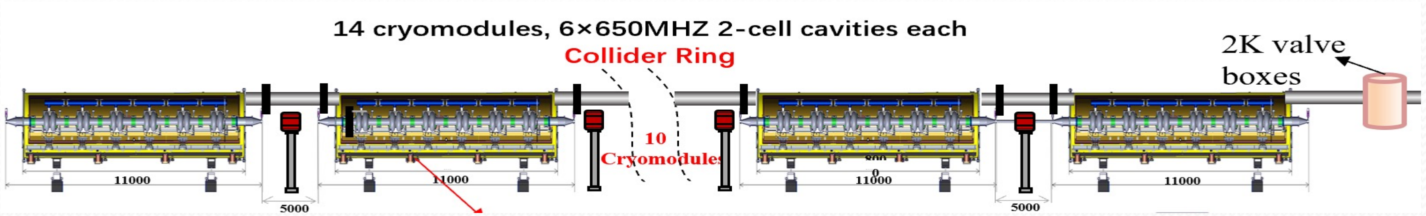
CEPC 650 MHz 6 x 2-cell Cryo-Module Design

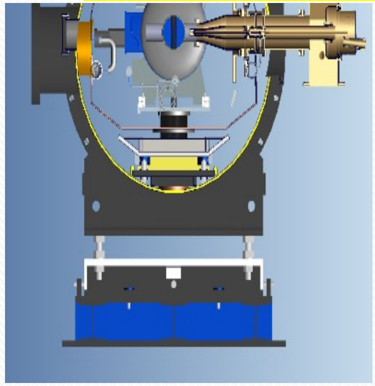
J. Zhai, CEPC EDR Review, Sep. 2024

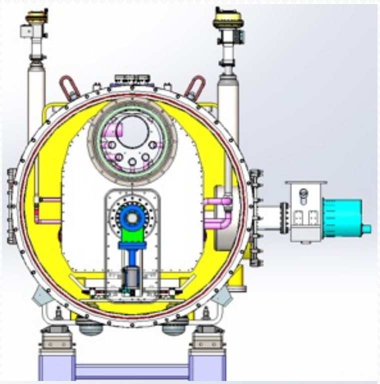
CDR

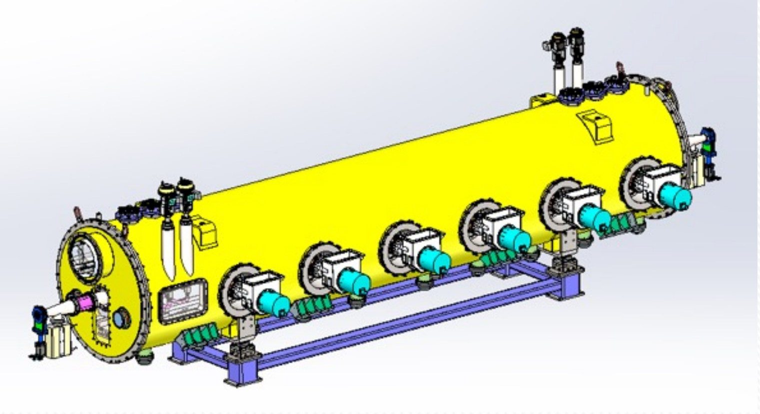


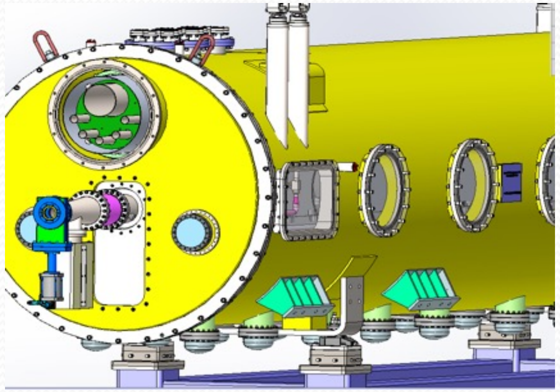
TDR









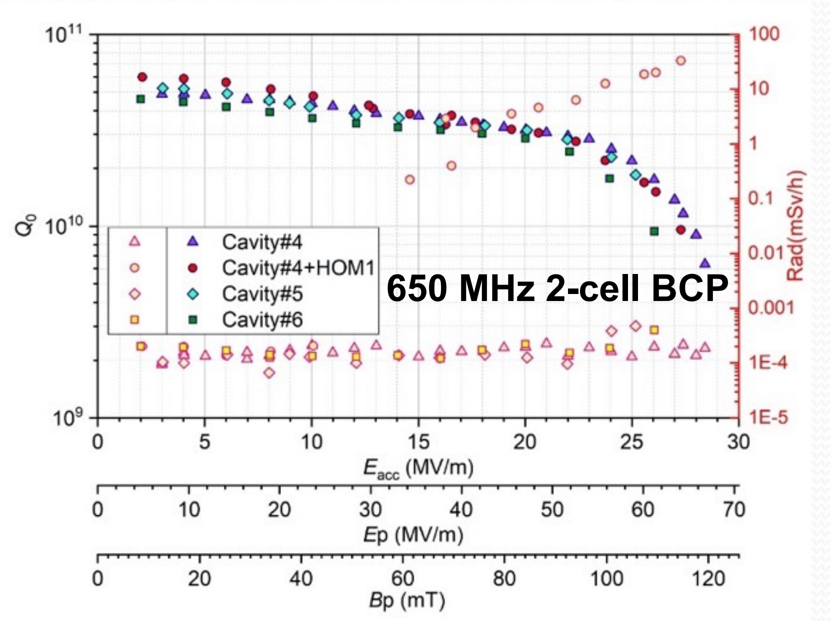


- Multi-channel cryogenic pipes inside the cryomodule
- Modified cavity strong-back support structure for better performance (based on ADS injector 325 MHz spoke module, CEPC 650 MHz 2x2-cell test module, PIP-II 650 MHz and CSNS-II 648 MHz module)
- Cryomodule combined with multi-channel cryogenic lines:
  - combines the features of cryomodule, valve box and cryogenic lines (under investigation)
  - shared vacuum, make full use of space, low cost
  - two 5 ~ 8 K Ø45 pipes for coupler, two 40 ~ 70 K Ø45 pipes for thermal shield, one 2 K Ø219 GRP, 3 Bara @ 5 K Ø45 pipe for supercritical supply

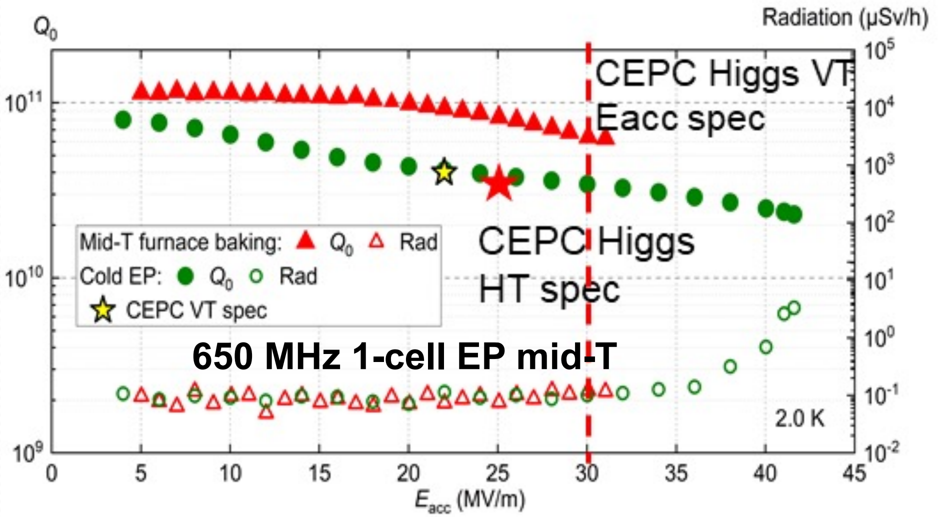
650 MHz 2-cell Cavity EDR R&D

CEPC 650 MHz CM		EDR Specification
650 MHz 2-cell cavity vertical test	$E_{acc.max}$	**30 MV/m**
	Q_0	**3.6E10 @ 25 MV/m**
Module horizontal test acceptance	$E_{acc.max}$	28 MV/m
	Q_0	3.3E10 @ 25 MV/m
Module long term operation	$E_{acc.max}$	28 MV/m
	Q_0	3.0E10 @ 25 MV/m

20 % margin from vertical test to operation spec.



- **BCP dressed 2-cell VT**: 2E10 @ 25 MV/m, max ~ 26.5 MV/m
- **BCP 2-cell module test**: 2E10 @ 8 MV/m (coupler cooling limited?)
- **EP + mid-T 1-cell VT**: 8E10 @ 25 MV/m, max 31.5 MV/m
- **Apply 1-cell recipe to 2-cell**



J. Zhai, CEPC EDR Review, Sep. 2024

Multi-beam klystron fabrication

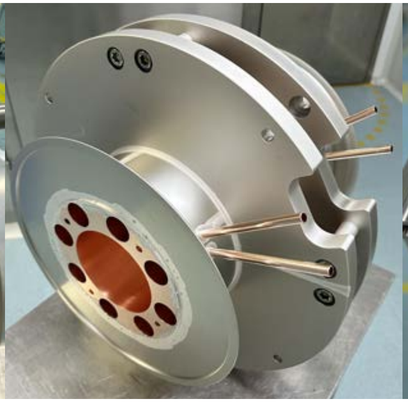
Z. Zhou, CEPC EDR Review, Sep. 2024

- MBK's cavity 3, 4, 5 and 6 have completed brazing, leak detection and tuning, while cavity 7 is still being processed and is expected to be completed this October
- Aims at 86% efficiency

The parameters of each cavities:

CAV. No.	2	3	4	5	6
Design Freq. (MHz)	651. 2	1296	1942. 5	670	671
Cold test before brazing (MHz)	651. 237	1303. 99	1936. 875	666. 9375	670. 3125
Cold test after brazing (MHz)	649. 375	1290. 5	1937. 4719	667. 21875	669. 7356
Cold test after tuning (MHz)	651. 1625	1295. 75	1942. 3249	669. 8125	670. 7325
Cold test after temperature and humidity correction (MHz)	651. 108	1295. 624	1941. 983	669. 819	670. 844
	18℃ RH% 45%	22℃ RH% 56%	21℃ RH% 52%	21. 5℃ RH% 47%	20℃ RH% 38%
	2023/2/17	2024/5/30	2024/7/23	2024/6/21	2024/5/6

CAV 3



CAV 4

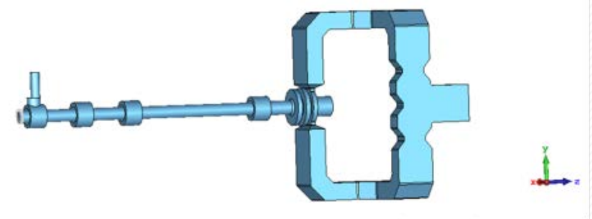
CAV 5

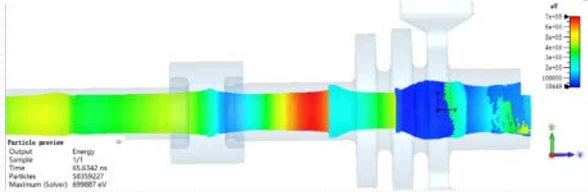
CAV 6

Design of a C-band 80 MW Klystron

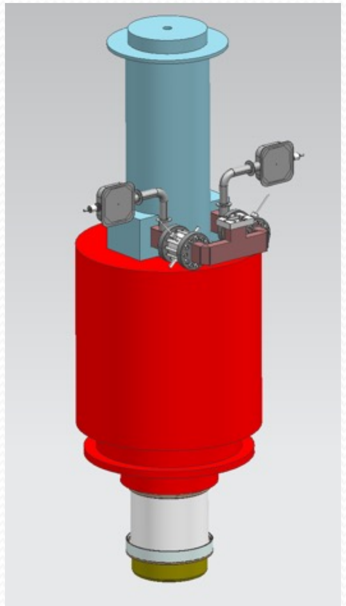
- Design review in May 2024 → reasonable and feasible, design results have achieved the expected goals

Parameters	Value	Cannon
Frequency	5720 MHz	5712MHz
Output Power	**80MW**	**50MW**
Repetition rate	**100Hz**	**50Hz**
Pulsed width	3us	3us
Efficiency	47%	42%
Beam voltage	420 kV	360kV
Beam current	403 A	320A





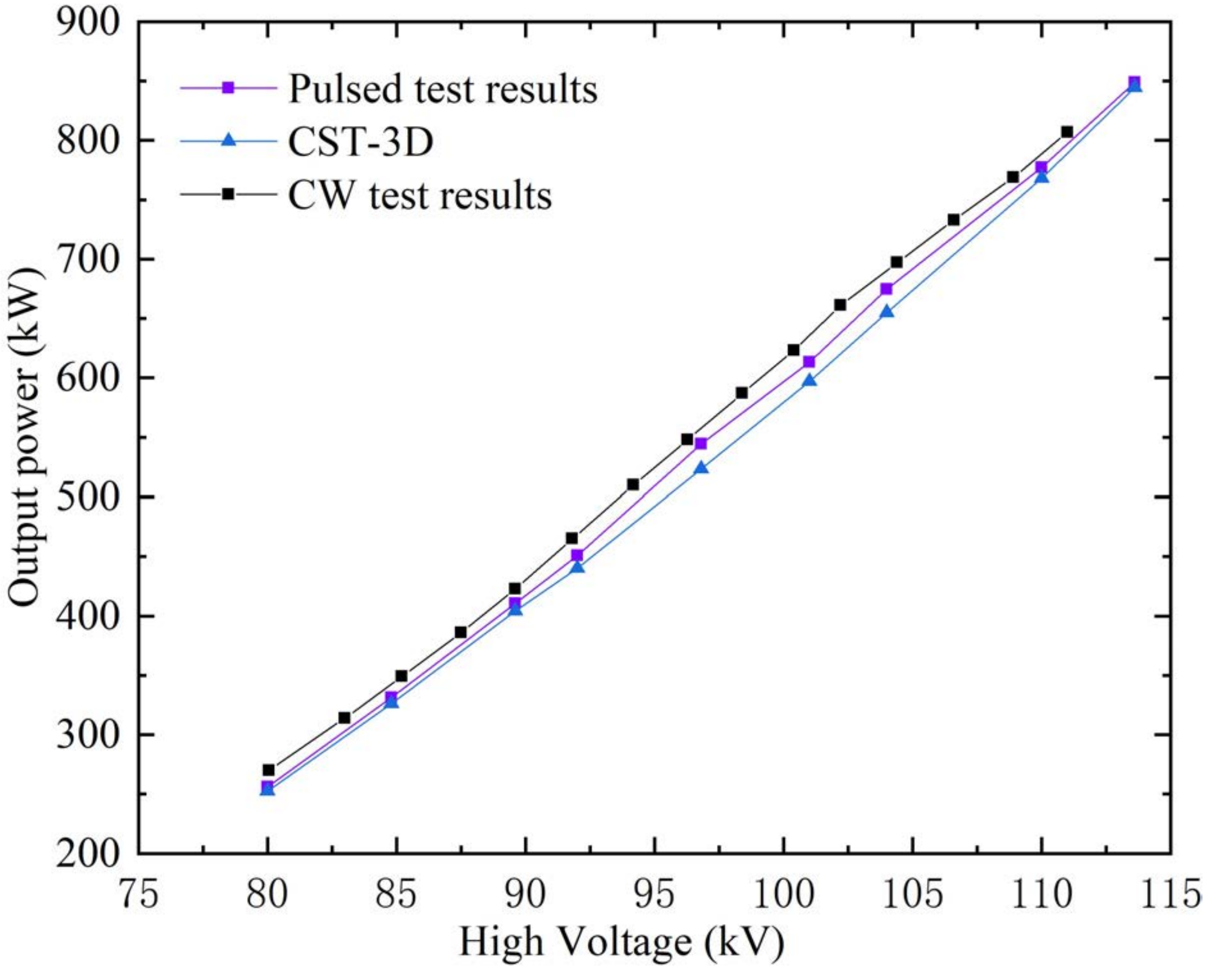
- Mechanical and process design review in August 2024 → design is feasible, meets technical specs, and has the conditions for production implementation → **enter the production stage**

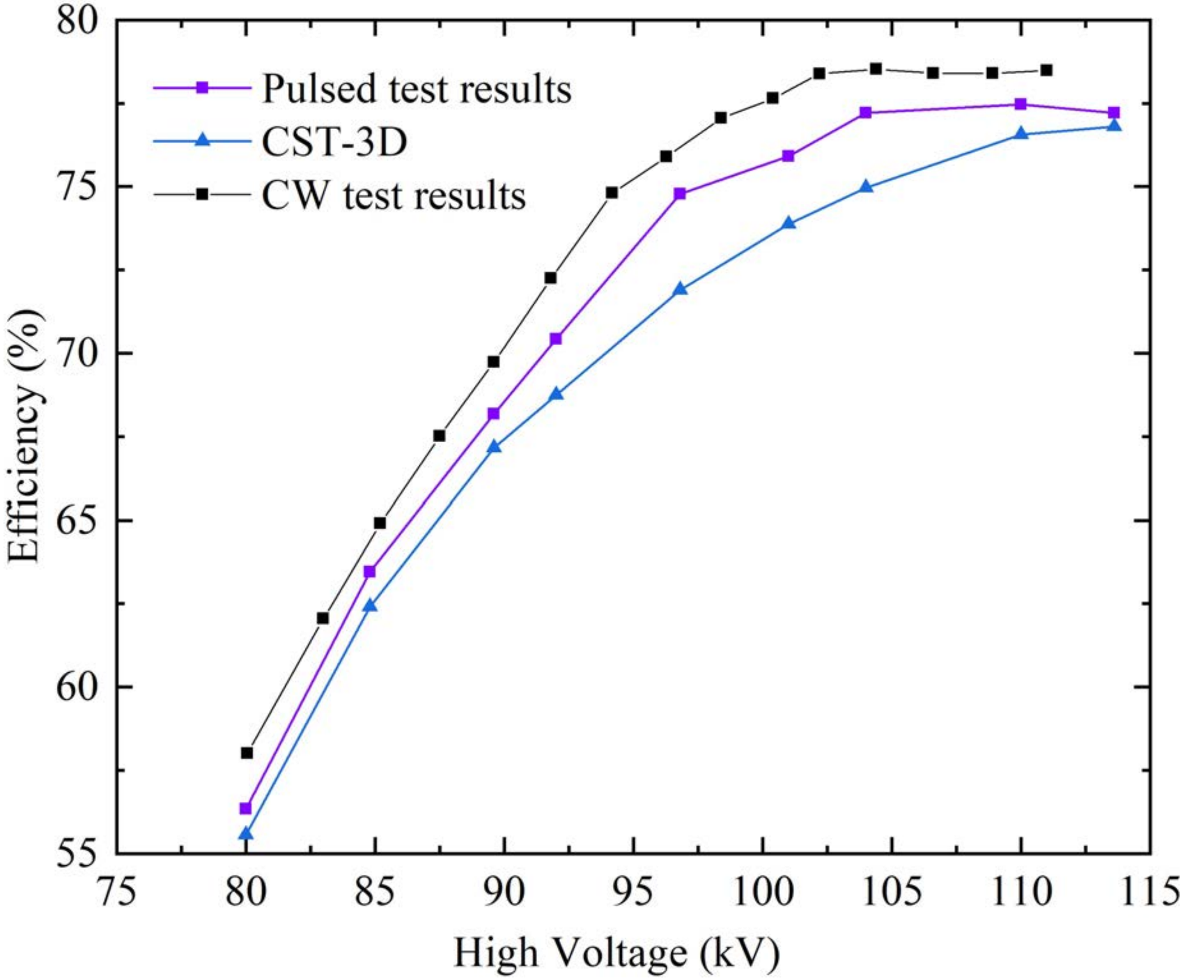


Z. Zhou, CEPC EDR Review, Sep. 2024

650MHz/800kW CW klystron test results

Z. Zhou, CEPC EDR Review, Sep. 2024





Super tau/charm Factories

- Two order of magnitude smaller in size
- In design study phase, going for some R&D
- Ambitious goals: large energy range, from 2 to 7 GeV c.o.m, with same or close luminosity
- Need for Damping Wigglers to deal with damping time at all energies
- Option to have longitudinal polarization at IP
- Crab-waist sextupoles, needed for reaching design luminosity are a challenge for the DA & MA
- Short Touschek lifetime is a serious issue
- Difficult to have enough Dynamic and Momentum Apertures for injection and lifetime → need for a ”new” lattice?
- *Smaller accelerator size does not always mean smaller challenges!*

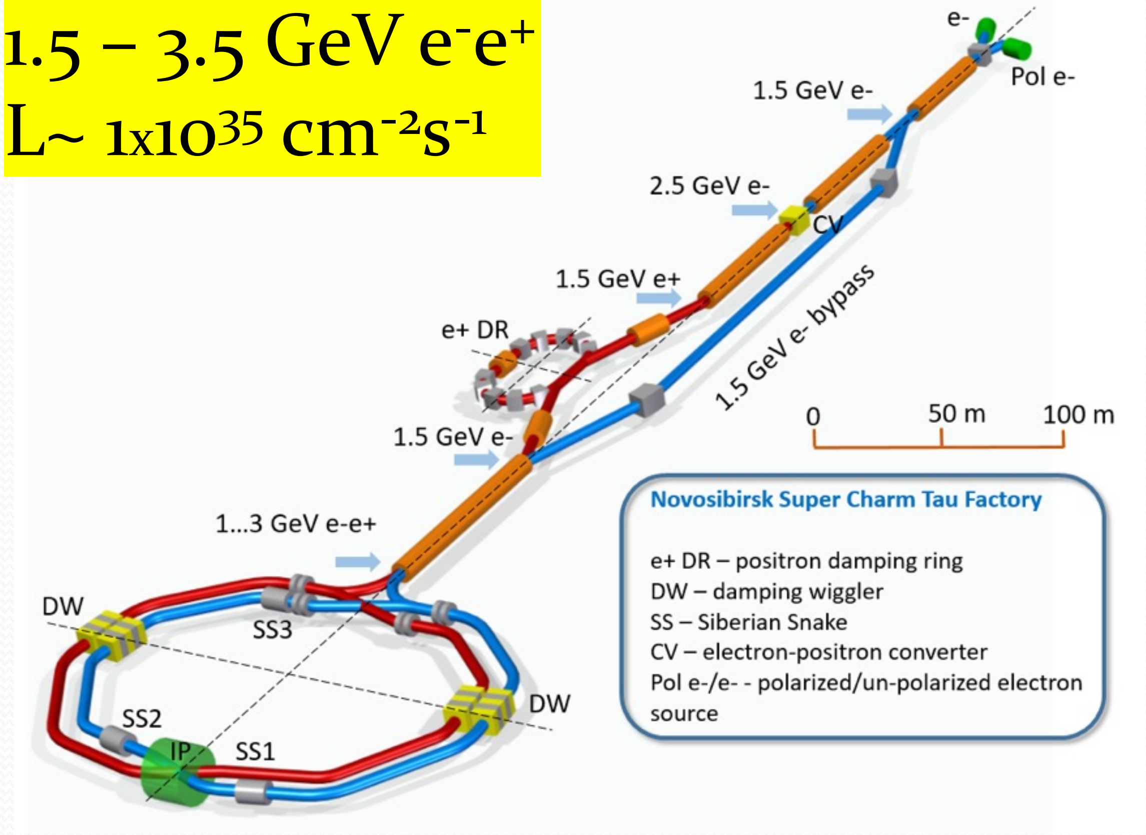
Super tau/charm Factories

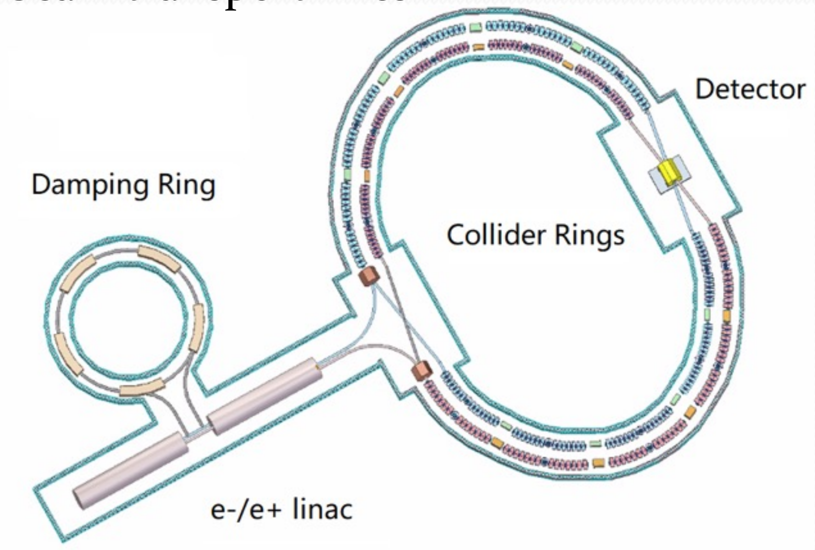
SCTF, BINP

STCF, USTC

- Core design goal:
  - **Energy: 2-7 GeV c.o.m**
  - **Luminosity: >5×10^{34} cm^{-2}s^{-1} @4GeV**
  - Upgrading potential: polarized beam, higher luminosity
- Accelerator structure
  - Double-ring collider: ~850m long, low emittance, high current, large Piwinski angle
  - Injector: full-energy linac, e+ damping ring or accumulator, beam transport lines

1.5 – 3.5 GeV e^-e^+
L~ 1x10^{35} cm^{-2}s^{-1}





BINP design parameters

A. Bogovmiakov, FTCF2024, Jan. 2024

E(MeV)	1500	2000	2500	3000	3500	1500	2000
Π(m)			935.874				
F_{RF}(MHz)			350				
2θ(mrad)			60				
β_x^*/β_y^* (mm)			100/1				
$\varepsilon_y/\varepsilon_x$(%)			0.5			**10**	0.5
I(A) / N_b	2.9	2.7	2.5	2.7	2.9	2.9	1.64
$N_{e/bunch}\times10^{-10}$	6	5.3	5	5.3	5.8	6	**3.25**
N_b / q	941/1093	983/1093	983/1093	983/1093	974/1093	941/1093	983/1093
U_0(keV) / V_{RF}(kV)	91 / 1500	288 / 2000	504 / 3000	820 / 3900	1266 / 5000	91 / 750	288 / 2000
ν_s	0.0153	0.0152	0.0166	0.0172	0.018	0.0108	0.0152
δ_{RF}(%)	1.98	1.83	1.97	1.97	1.98	1.3	1.83
$\sigma_e\times10^3$ (SR/IBS+WG)	0.27/1.1	0.36/1.2	0.5/1.2	0.5/1.2	0.6/1.3	0.27/0.9	0.36/1.1
σ_s(mm) (SR/IBS+WG)	3.6/14	4.7/15	6/14	7/14	8/14	3.6/17	4.7/15
ε_x(nm) (SR/IBS+WG)	2.0/6.4	3.5/3.8	5.5/3.2	7.9/4.1	11/5.7	2.0/2.9	3.5/3.5
$L_{HG}\times10^{-35}(cm^{-2}s^{-1})$	1	1	1	1	1	**0.29**	**0.4**
ξ_x/ξ_y	0.005/0.12	0.003/0.1	0.002/0.08	0.002/0.065	0.002/0.05	0.003/0.03	0.002/0.06
$\tau_{Touschek}$ (s)	125	208	302	560	1100	304	304
$\tau_{Luminosity}$ (s)	3500	3200	3000	3200	3500	12000	5000

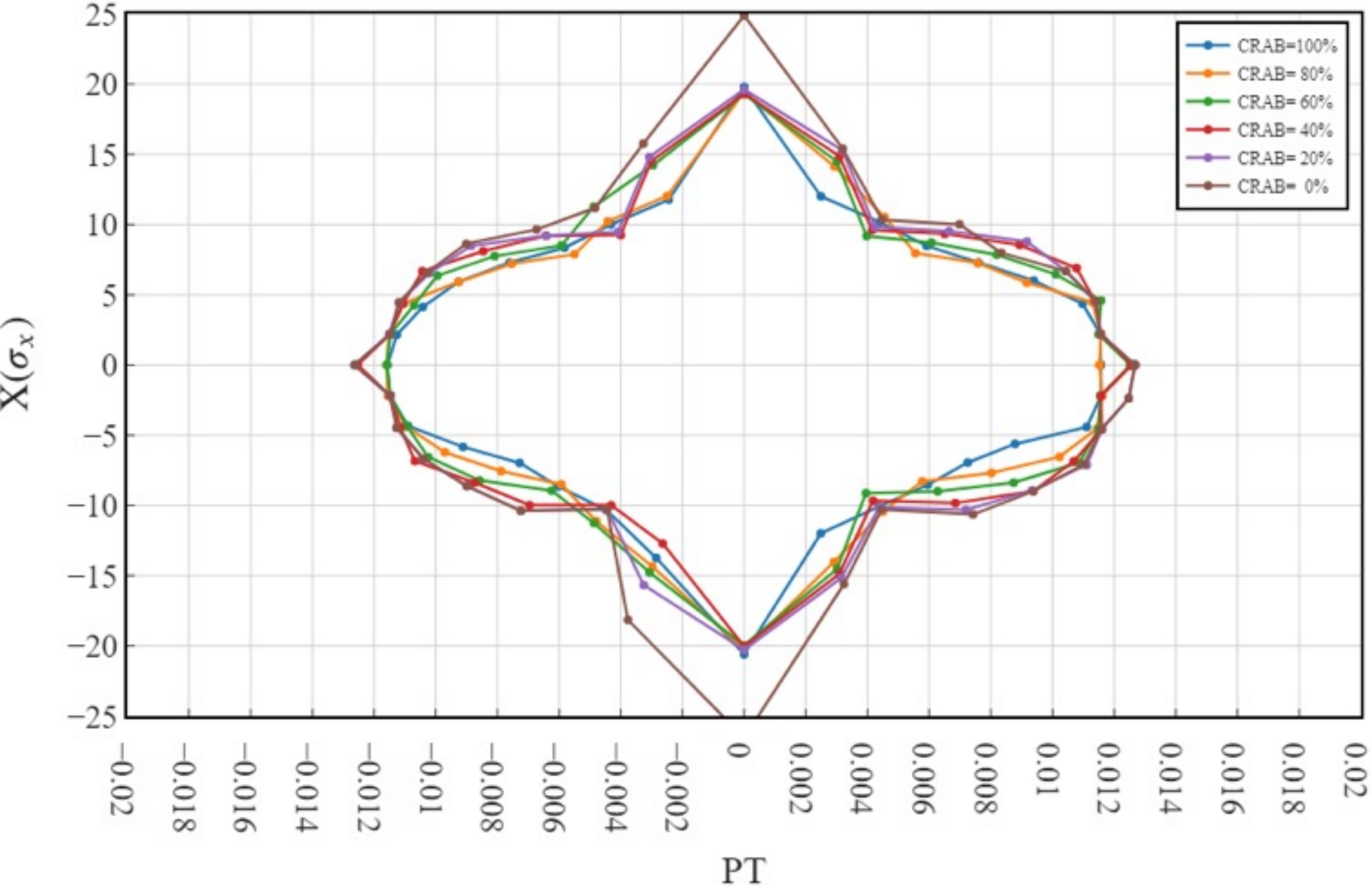
for $\mathcal{L} = 1\times10^{35}$

for $\tau_{Touschek} \geq 300\ s$

6d Dynamic Aperture

E = 1.5 GeV	CRAB=100 %	CRAB=60 %	CRAB=0%
N_{part}	6×10^{10}	6×10^{10}	6×10^{10}
$\tau_{Touschek}$(s)	125	104	118
$L_{HG}(cm^{-2}s^{-1})$	1×10^{35}		

6d-DA, $y_0 = \sigma_y, \sigma_x = 3.98e-04m, \sigma_e = 1.04e-03$



Sextupoles:
- IR: 5(Y) + 8(X)
- ARCS: 24(Y)+24(X)

Octupoles:
- IR: 2(Y)+2(X)

Energy aperture: ±1.1%
$\tau_{Touschek}$ = 125 s

A. Bogovmiakov, FTCF2024, Jan. 2024

USTC design Parameters

J. Tang, 2nd IAC meeting, Oct. 2024

Parameters	Units	Value	Value	Value	Value
Beam energy, E	GeV	2	1	1.5	3.5
Circumference, C	M	865.398			
Crossing angle, 2θ	mrad	60			
L*	m	0.9			
Relative gamma		3913.9	1956.9	2935.4	6849.3
Revolution period, T_o	ms	2.887			
Revolution frequency, f_o	kHz	346.42			
Coupling, k		0.50%			
Hor. emittance (SR), ε_x	nm	9.71	2.63	5.86	29.34
Hor. emittance (DW, IBS)	nm	6.08	12.46	7.12	29.35
Ver. Emittance (SR), ε_y	pm	48.55	13.125	29.3	146.7
Ver. emittance (DW, IBS)	pm	30.4	62.3	35.6	146.75
Hor. beta function at IP, β_x	mm	40			
Ver. beta function at IP, β_y	mm	0.6			
Hor. beam size at IP, σ_x	mm	15.59	22.32	16.88	34.26
Ver. beam size at IP, σ_y	mm	0.135	0.193	0.146	0.297
Betatron tunes, ν_x/ν_y		32.555/34.57			

Parameters	Units	Value	Value	Value	Value
Mom. compaction factor, α_p	10^{-4}	13.86	13.04	13.65	14.14
Energy spread (DW, IBS), σ_e	10^{-4}	7.9	5.61	7.64	10.03
Beam current, I	A	2	1.5	1.7	2
Bunch filling ratio		48%			
Bunch spacing, τ_b	ns	4.0			
Single-bunch current, I_b	mA	2.89	2.17	2.46	2.89
Single-bunch charge	nC	8.34	6.25	7.09	8.34
SR power per beam (Total)	MW	1.082	0.15885	0.45203	2.954
Trans. damping time, τ_x, τ_y	ms	21.34	54.52	32.57	13.68
RF frequency, f_{RF}	MHz	499.7			
RF voltage, V_{RF}	MV	3	1	2	6
Bunch length (0.1Ω, IBS),	mm	8.43	9.79	8.56	8.89
Piwinski angle, Φ_{piw}	rad	16.21	13.16	15.22	7.78
Ver. beam-beam parameter		0.105	0.095	0.108	0.026
Luminosity, L	$cm^{-2}s^{-1}$	1.3E+35	4.2E+34	8.7E+34	4.7E+34

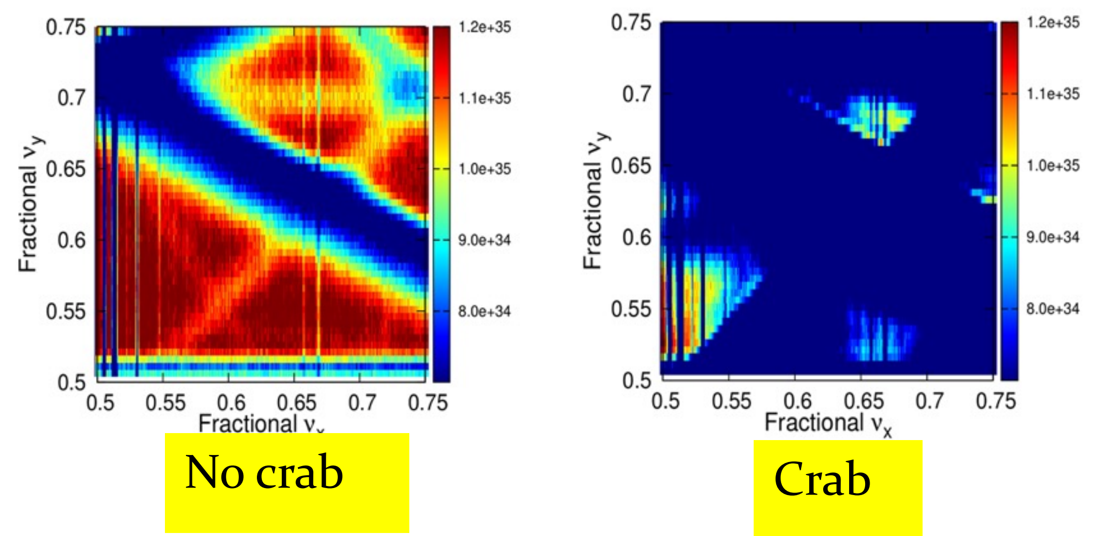
$\tau_{Touschek}$ ~150 s @ 2 GeV (small DA and MA)

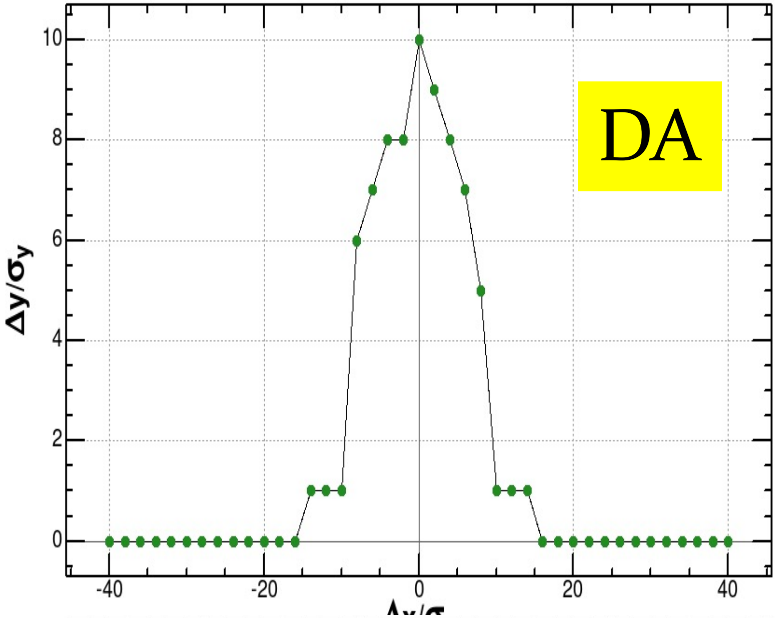
USTC collider ring design

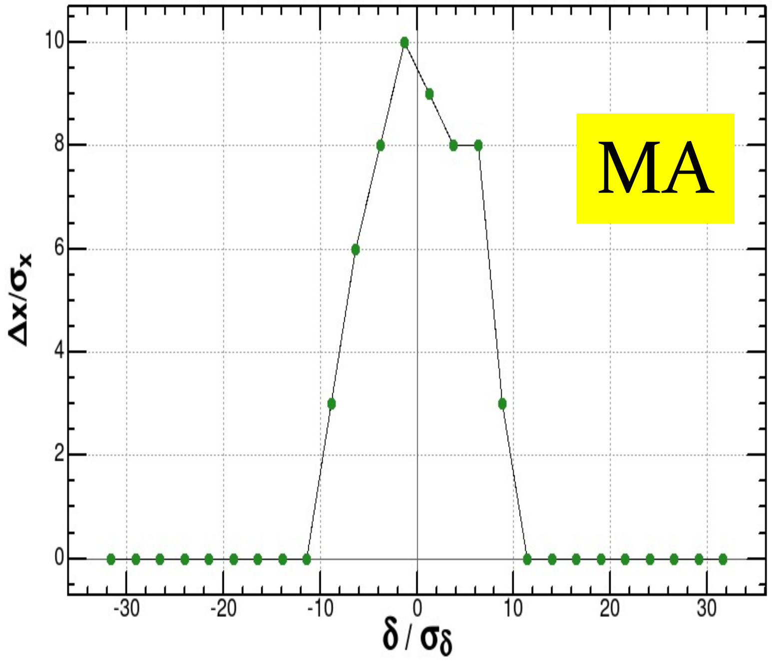
- Nonlinear dynamics
  - Very strong due to strong nonlinear effects and higher-order kinetic effects
  - Very limited DA: about 6 mm (X) and 1 mm (Y) @inj
  - Small LMA: ~1.5%
  - Intense optimization with simulations and

Need for swap-out injection?

- Touschek scattering
  - Simulations (Elegant, SAD)
  - Current: ~150 s @ 2 GeV (very small DA and LMA)





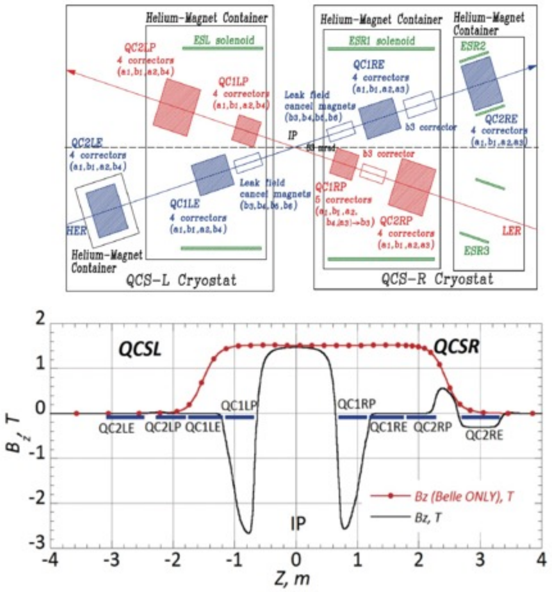


SuperKEKB

- SuperKEKB has already delivered 2 times the KEKB luminosity in just 4 years
- However, design luminosity is still not achieved
- IR design was made with exceptional attention to optics, magnets, cryogenics, mechanics, diagnostics → this seems not enough to account for the difficulty to reach the design luminosity
- Two effects have recently disrupted the performances, limiting the beam current:
  - TMCI and -1 mode instability, probably due to impedance
  - Dust events, causes not yet accounted for
- An IR upgrade is being studied:
  - larger DA → Touschek lifetime 260 → 420 sec
  - improved chromatic coupling
  - reduced emittance growth

Talk on Saturday by T. Okada

The present QCS configuration



Multipole components of leakage fields from QC1LP and QC1RP that have no yokes are canceled by other corrector magnets on the HER beam line.

To accommodate the local orbit plane rotation caused by the solenoid magnetic field, QCs(LER) is rotated.

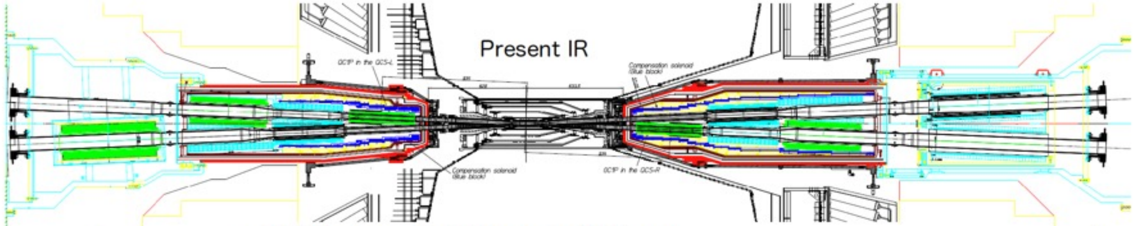
The magnets are placed with deliberate offsets.

Magnet	Int. field T	Z m	Δx mm	Δy mm	Δθ mrad
QC1LP	22.96	−935	0.0	−1.5	−13.35
QC1RP	22.96	935	0.0	−1.0	7.204
QC2LP	11.48	−1925	0.0	−1.5	−3.725
QC2RP	11.54	1925	0.0	−1.0	−2.114
QC1LE	26.94	−1410	0.7	0.0	0.0
QC1RE	25.39	1410	−0.7	0.0	0.0
QC2LE	15.27	−2700	0.7	0.0	0.0
QC2RE	13.04	2925	−0.7	0.0	0.0

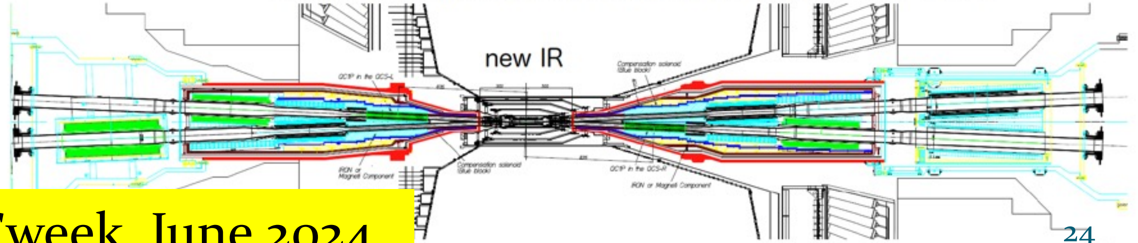
A very complicated system

25

3. Upgrade ideas



- QC1Ps from L*=935mm to 835mm
- Cover QC1Ps with the magnetic yoke
- Install new compensation solenoid coils between IP and QC1Ps



26

M. Masuzawa, FCCweek, June 2024

SuperKEKB issues & mitigations

Measure against Seven Major Issues

1. Sudden beam loss
   ➡ copper coating of collimator head, additional monitors (acoustic sensors, loss monitors, monitor of every bunches and every turns)
2. Beam-size blowup due to Beam-Beam interactions
   ➡ chromatic X-Y coupling correction, reduction of machine error in the IR, etc.
3. Beam-related background
   ➡ more IR radiation shields
4. Injection efficiency and emittance blowup in the beam transport line
   ➡ wider aperture at injection point, shielding effect to suppress coherent synchrotron radiation (CSR)
5. Difficulties to keep beam orbit stable and large vertical emittance
   ➡ Beam pipe deformation due to SR heating pushed quadrupole magnets via BPM. Isolation between them will be tested.
6. Short lifetime and narrow dynamic aperture with β_y^* squeezing
   ➡ sextupole and octupole optimization
7. Beam-size blowup due to -1 mode instability in the LER → reducing impedance and optimization of BxB FB

16

3.Fast Loss (Sudden Beam Loss)
3-1 What is "SBL(Sudden Beam Loss)" ?

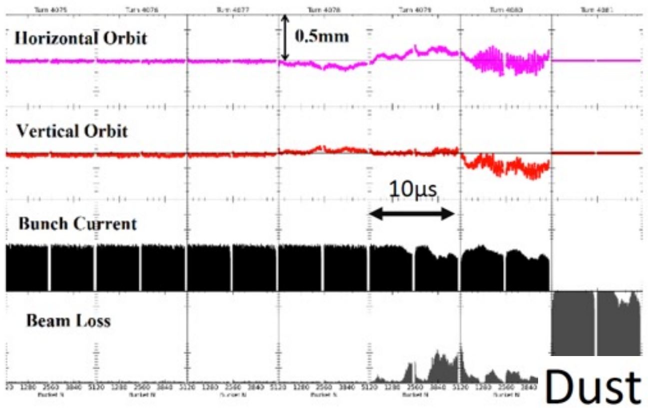
A lot of studies to understand the cause

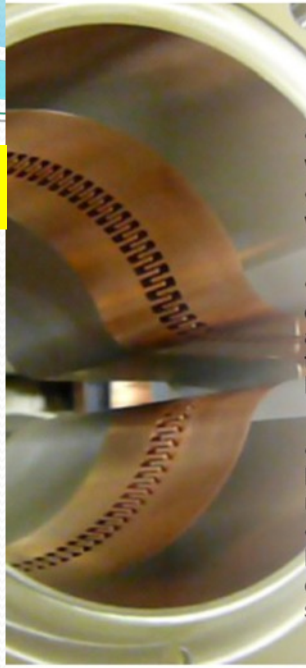
Beam loss that occurs suddenly within 1 turn (10μs) without precursory phenomena. ＝ Sudden Beam Loss（SBL）

- The cause of SBL had been unknown.
- A significant percentage of the beam is before the abort trigger is issued and stored beam is dumped

→ Harmful effects of SBL;
  - Damage to collimators and other accelerator components,
  - Quench of the final focusing superconducting magnets (QCS),
  - Large backgrounds to the Belle-II detector,
  - Inability to store high current due to beam abort.

Beam signal measured by
Bunch Oscillation Recorder(BOR) & Bunch Current Monitor(BCM)





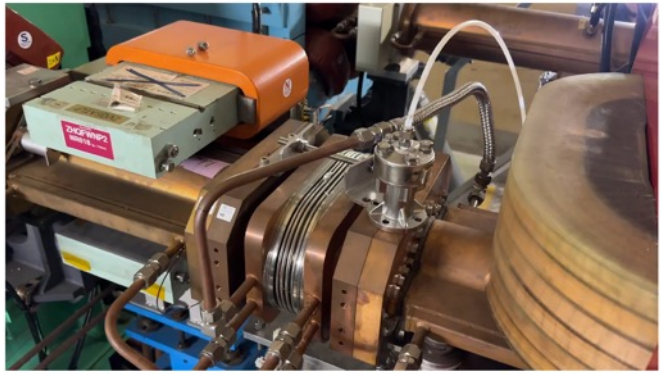
Can bellows be (also) dust source?

- ~ 90% of the bellows in the LER were replaced with new bellows (comb-tooth type).
- ~ 20% of the bellows in the HER were replaced with new bellows.
- It is true that the bellows rub against the RF contacts, so it is possible that small metal fragments are generated. But we have not seen any metallic fragments that could have been generated from the bellows.
- Some people seem to think that the newer model has a wider gap between the comb teeth, which makes it easier for dust to fall into the beam channel.
- However, the number of dust particles generated by the RF contacts seems to be small to begin with, dust will not fall into the beam channel as much as it should be a problem.

19

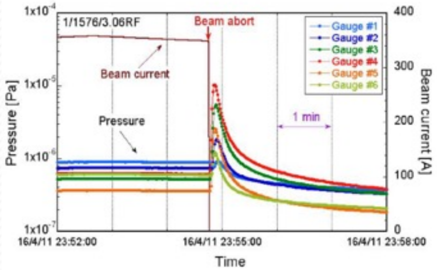
- We knocked the D10（almost）/D11(3) wiggler chamber with a knocker (about 100 times each) at maintenance day (5/29) to remove as much dust as possible.

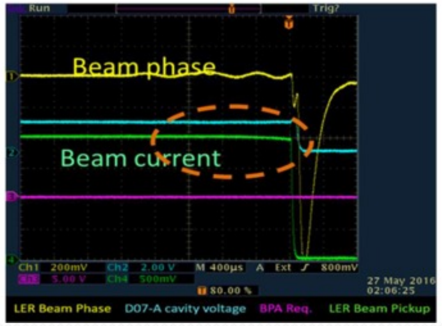
→If it works and we get less serious SBL, we may knock on other places too.

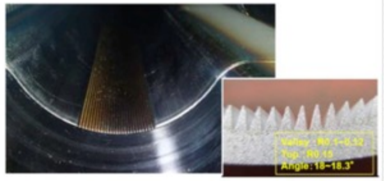


Dust event (our experience)

- At the Phase-1, pressure bursts with beam loss were frequently observed in the LER, which was an obstacle to beam current increase.
  - ➢ When a loss monitor was triggered and issued abort, the pressure momentarily jumps to the 10^{-7}-10^{-6} Pa range in some parts of the ring at the same time.
  - ➢ The beam was lost over several 100 μs, and oscillations in the beam phase were observed.
- Estimating the location of pressure bursts from the CCG indications, most of the pressure bursts occurred in the vicinity of the grooved aluminum beam pipes in the bending magnets.
- The beam current at which pressure bursts occurred increased with the maximum beam current at that time. The frequency of pressure bursts tended to decrease after a while of operation at the same maximum beam current (aging effect).



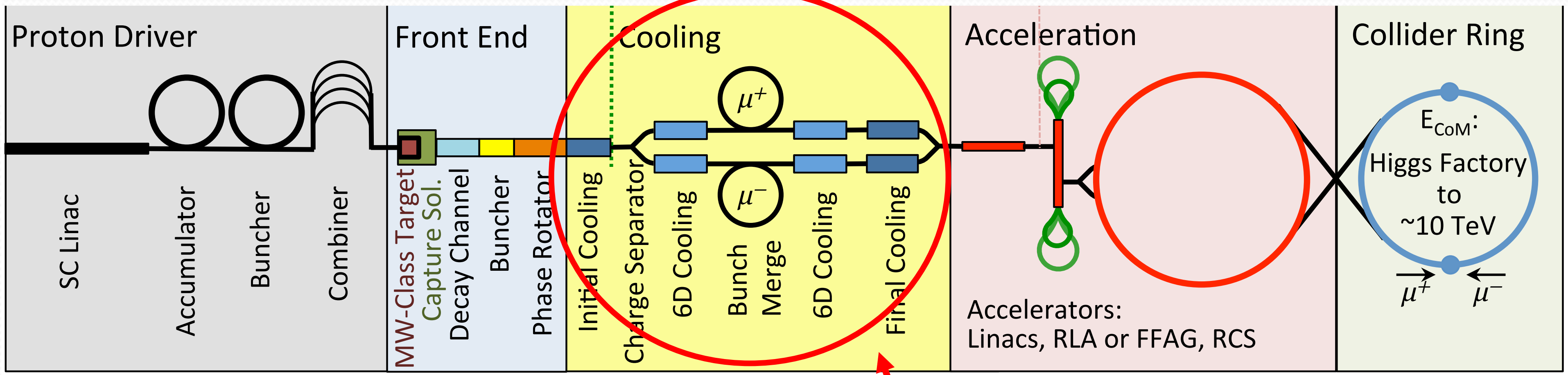




Conclusions

- The future of accelerators for Fundamental Physics research is paved by these daring projects
- Challenges are the salt of Physics & Technology
- Many of the technological results from the R&D efforts we do for fundamental research have an impact on everyday life
- We should pursuit more complex accelerators, hoping that Society, Governments, and General Public understand the benefit of such endeavors, and approval, money, and manpower will be provided

Muon Collider (proton source) ingredients



Proton driver: producing high-power multi-GeV bunched H-beam. For a conversion efficiency of about 0.013 **μ** per proton*GeV, a **proton** beam in the 1-4 MW power range at an energy of 6.75 GeV provides the number of **μ** required

Buncher: **Accumulator** (forms intense and short (~2 ns) proton bunches) **+** **Compressor** (rotates bunches 90° in longitudinal phase space)

Lines depending on **p** E

π prod. target: must stand **p** high power. Immersed in high solenoidal field to capture and guide **π** into the decay channel

Front-end: decay channel with solenoidal field and RF cavity, captures **μ** in a bunch train, time dependent acceleration (different E)

Initial cooling channel: ionization cooling to reduce 6D phase space by a factor of 50, so the muon beam is inside first acceleration stage acceptance

Other ionization cooling stages: to allow for MC high luminosity beam parameters

Fast muons acceleration stages, for example Recirculating Linear Accelerator (RLA), Fixed Field Alternate Gradient (FFAG), or Rapid Cycling Synchrotron (RCS)

Muon Collider Rings, 0.25 to 10 TeV c.o.m.

Thank you for your attention

International Muon Collider Collaboration (EU funded)

If you think YOUR machine is difficult...