Highlights of Accelerator Mini-workshop

(18-19, January 2024)

Yuhui Li (IHEP)

IAS-HEP 2024 Mini-Workshop: Accelerator

- Accelerator parallel, hybrid on-line and in-person meeting
- Tuesday-Friday, 2 days, 6 sessions, **16 talks**
  - 2 Switzerland (CERN)
  - 1 France (CEA, irfu)
  - 1 Japan (KEK)
  - 12 China (IHEP)

Jan 18, 2024 (Thu) [Day 1]	
Chair: Jie GAO (IHEP)	
Title	**Speaker**
Future Accelerator Projects in Asia/Australia	Jie GAO (IHEP)
EAJADE Sustainability Activities for Future Large Accelerators and Colliders	Maxim TITOV (CEA Saclay, Irfu)
CEPC Towards a Green Collider	Yuhui LI (IHEP)
Break	
Chair: Maxim TITOV (CEA Saclay, Irfu)	
Title	**Speaker**
Green ILC [Zoom]	Masakazu YOSHIOKA (KEK)
CO_2 Reduction Optimization with Future Colliders Design, Construction and Operation [Zoom]	Dou WANG (IHEP)
Energy Recover and Reuse Technology Studies for Large Green Accelerators	Rui GE (IHEP)
Self-arranged Lunch	
Chair: Michael KORATZINOS (CERN)	
Title	**Speaker**
High Q and High Field SC Cavity Studies and Applications in Green Accelerators	Jiyuan ZHAI (IHEP)
High Efficiency Klystron Studies and Development for Green Colliders	Zusheng ZHOU (IHEP)
Break	
Chair: Tohru TAKAHASHI (U of Hiroshima) [Zoom]	
Title	**Speaker**
Overview of the Xsuite Accelerator Simulation Framework [Zoom]	Giovanni IADAROLA (CERN)
IHEP C3 Technology Studies	Jingru ZHANG (IHEP)
Beam Drived Plasma Accelerator and Efficiency Study	Dazhang LI (IHEP)

Jan 19, 2024 (Fri) [Day 2]	
Chair: Jie GAO (IHEP)	
Title	**Speaker**
SC Magnets for FCCee Collider Ring	Michael KORATZINOS (CERN)
Permanent Magnets Applications in Accelerators	Mei YANG (IHEP)
Applications of High Field Superconducticity Technology	Qingjin XU (IHEP)
Break	
Chair: Yuhui LI (IHEP)	
Title	**Speaker**
HEPS Green Energy Applications	Jinshu HUANG (IHEP)
Economical and High Efficiency Industrial Production of Accelerator Components	Song JIN (IHEP)

An Introduction to Future Accelerator based Projects in Asia/Australia

Jie Gao

Institute of High Energy Physics

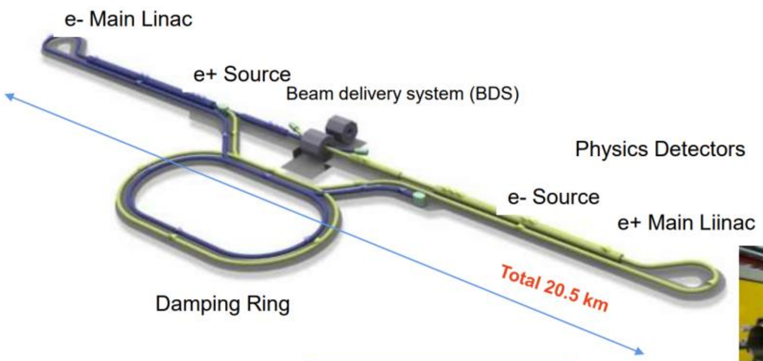
- Colliders for high energy physics
- Nuclear physics
- Photon and spallation neutron sources
- Proton and Carbon therapy
- Summary

Future accelerator facilities in Asia and Australia: ILC250 GeV

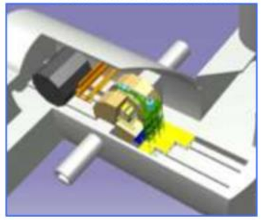
ILC250GeV as a Higgs Factory and Beyond

Parameters	Value
C.M. Energy	250 GeV
Peak luminosity	1.35 x10^{34} cm^{-2}s^{-1}
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	8012 (x 1.1)
# cryomodule	928
# Klystron	~200

Hong Kong, Jan. 18, 2024 J. Gao

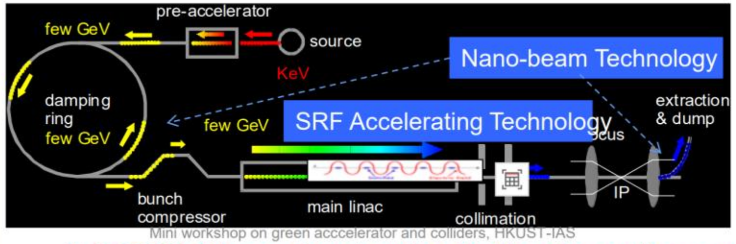


Shinichiro Michizono



Site: In Japan

Key Technologies



928 cryomodules are needed

8,012 SRF cavities will be used.

Mini workshop on green acccelerator and colliders, HKUST-IAS

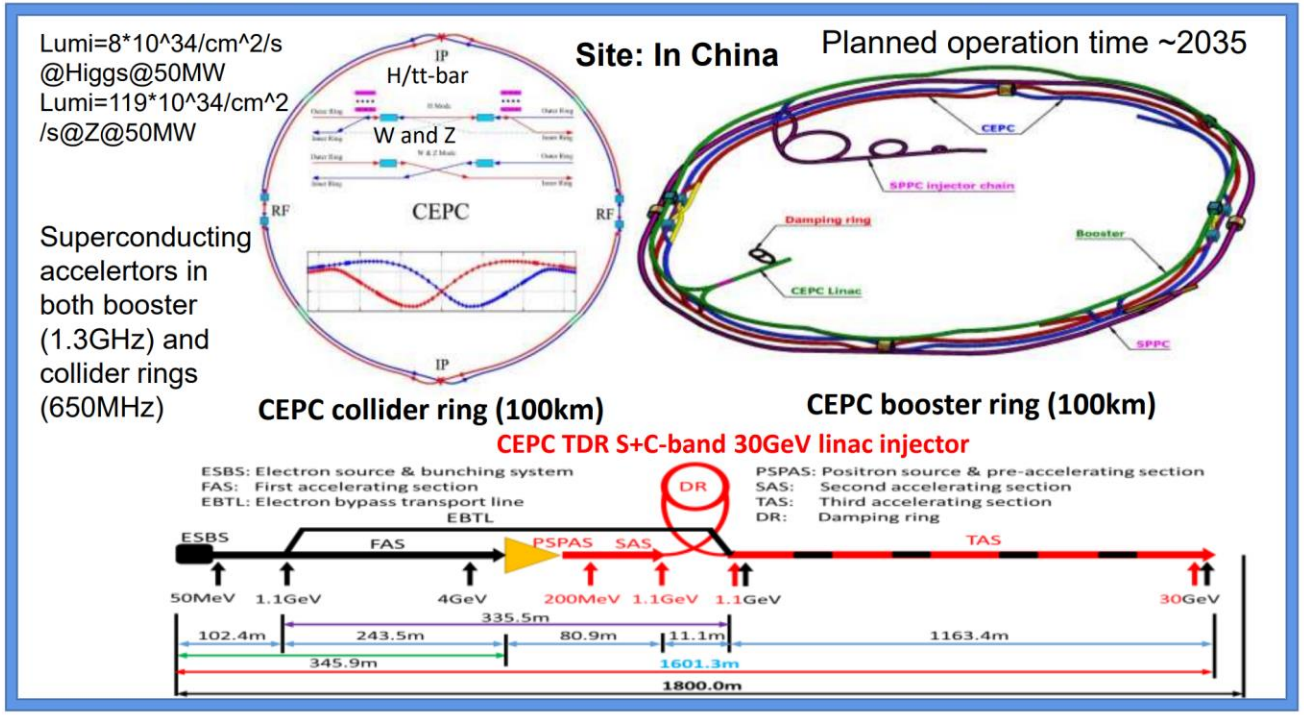
ILC250GeV accelerator (including tunnel) construction cost is ~5 B$.

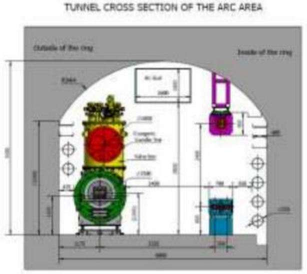
Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	E / $\mathcal{L}$ Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	10^{34}cm^{-2}s^{-1}	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_e	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_b	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	µs	727	961	727/961	727/961	961	897
Accelerating gradient	G	MV/m	31.5	31.5	31.5	31.5	31.5	45
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_z^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_x$	µm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_x^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_y^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power *	P_{site}	MW	111	138	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

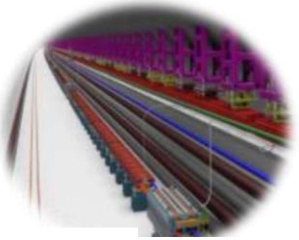
- **SRF technology** has been well **matured** for the realization of the ILC, including industrial participation, based on the very successful **Euro-XFEL** completion constructed and stable operation since 2017, and with **LCLS-II** being in commissioning.
- SRF technology **advances with high-G and -Q** highly **expected** for future upgrades:
  - **Nb-bulk, SW:** ~ **50 MV/m**, for ~ 1-TeV upgrade ,
  - **Nb3Sn, SW:** > **50 MV/m**, for > 1-TeV upgrade, and
  - **Nb-bulk, TW:** ~ **70 MV/m**, for further upgrade to reach beyond (up to ~ 3 TeV).

Future accelerator facilities in Asia and Australia:CEPC

CEPC as a Higgs Factory: H, W, Z, upgradable to tt-bar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradale to 50MW) CEPC TDR cost (2023) 36.4B RMB (~5B USD)







CEPC Civil Engineering

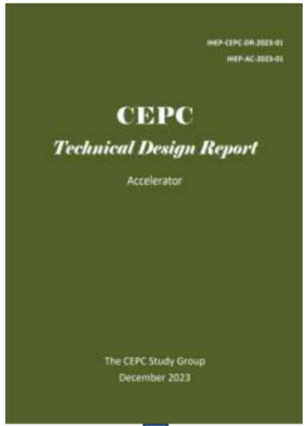
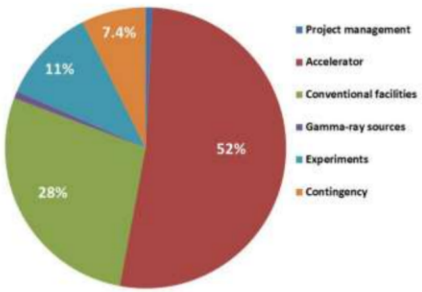


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

Total	364	100%
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Distribution of CEPC Project total TDR cost of **36.4B RMB**

CEPC accelerator TDR has been completed and formally released on December 25, 2023
CEPC accelerator TDR link: (arXiv: 2312.14363)
CEPC accelerator TDR releasing news:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

Linac

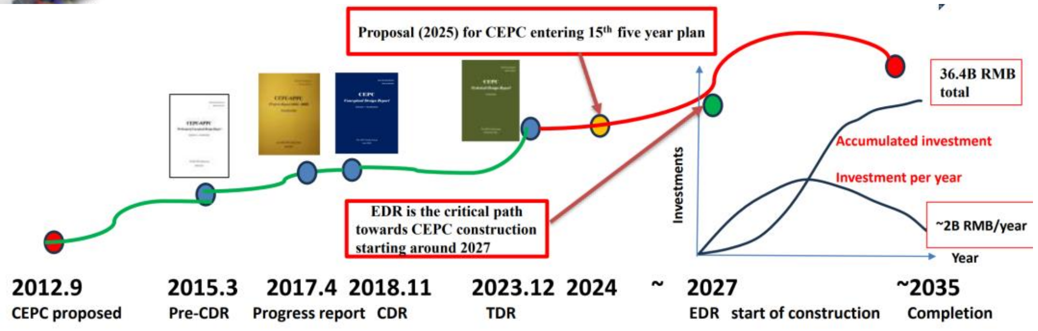
Parameter	Symbol	Unit	Baseline
Energy	E_e/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch number per pulse			1 or 2
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	100					
Injection energy	GeV	30					
Extraction energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

Collider

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	30			
Energy (GeV)	120	45.5	80	180
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	5.0	115	16	0.5



Future accelerator facilities in Asia and Australia: HIAF & CiADS

- **HIAF: High Intensity heavy ion Accelerator Facility**
- **CiADS: China Initiative Accelerator Driven System**
- **Being built by IMP in Huizhou of Guangdong Prov.**
- **Two of 16 large-scale scientific infrastructure facilities approved by China Government during the 12th 5-year-plan 2016-2020**

- **HIAF:** Nuclear physics research
- **Total budget:** 2.8 B CNY ¥(424 M USD $)
- **Schedule:** 2018-2025
- Construction started officially Dec. 2018

- **CiADS:** Nuclear waste transmutation
- **Total budget:** 4.0 B CNY ¥(606 M USD $)
- **Schedule:** 2021-2027
- Construction started officially July. 2021

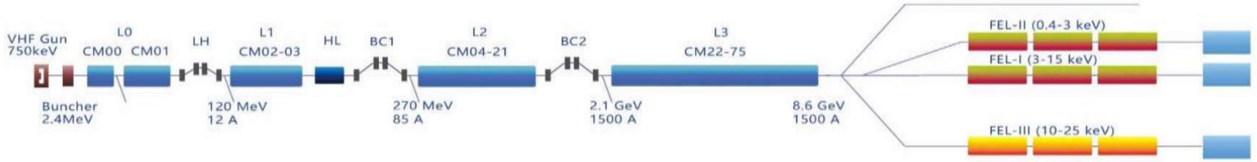
Future accelerator facilities in Asia and Australia: SHINE-FEL

Shanghai Hard X-ray FEL Facility (SHINE)

Zhentang Zhao

SHINE is based on 1.3GHz SC accelerator technology:

- 1.3GHz SRF cryomodules : 75
- 1.3GHz 9cell cavities: 600+16
- 3.9GHz SRF modules: 2

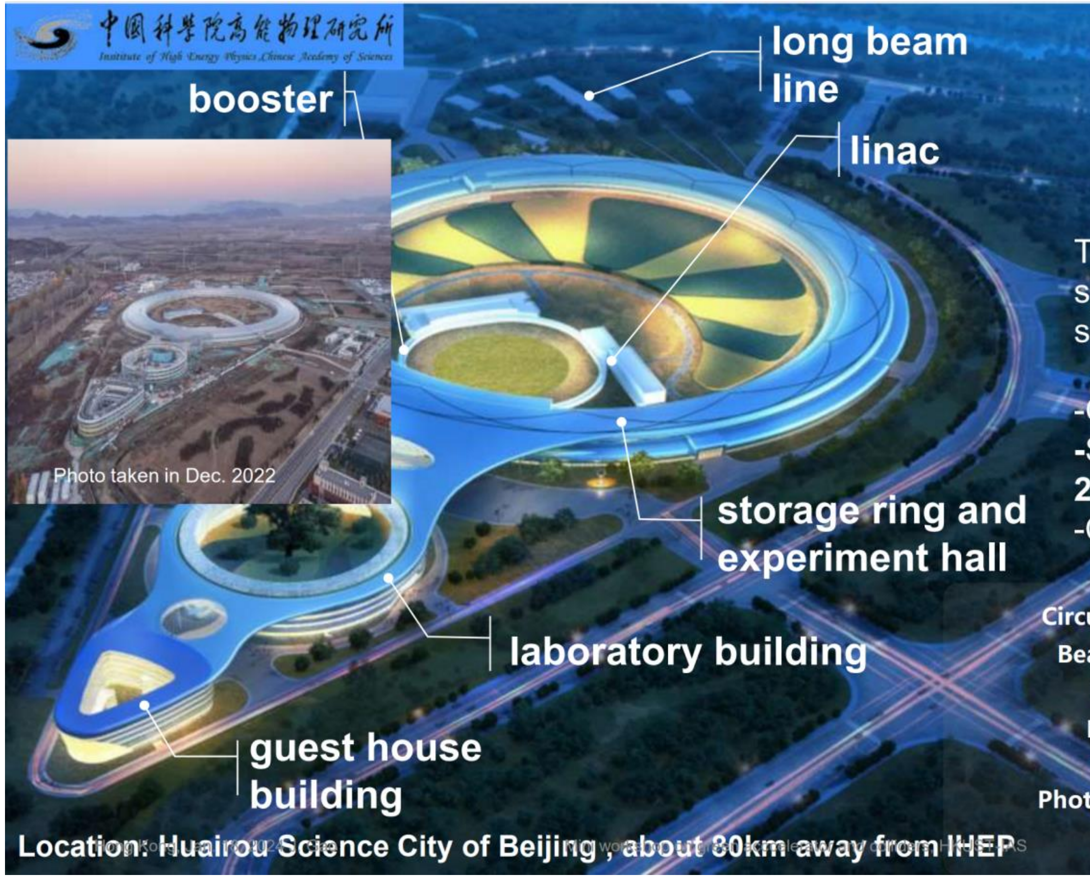


- SHINE groundbreaking in April, 2018, aiming at lasing in 2025.
- SHINE cost:~10B RMB or ~1.5B USD

	Nominal	Range
Beam energy/GeV	8.0	4-8.6
Bunch charge/pC	100	10-300
Max rep-rate/MHz	1	up to 1
Beam power/MW	0.8	0 - 2.4
Photon energy/keV	0.4-25	0.4-25
Pulse length/fs	20-50	5-200
Peak brightness	5×10^{32}	1×10^{31}-1×10^{33}
Average brightness	5×10^{25}	1×10^{23}-1×10^{26}
Total facility length/km	3.1	3.1
Tunnel diameter/m	5.9	5.9
2K Cryogenic power/kW	12	12
RF Power/MW	2.28	3.6

FEL Line	Nominal	Objective
FEL-I		
Photon energy/keV	3-15	3-15
Photon number per pulse @12.4keV	$>10^{10}$	$>10^{11}$
Max pulse repetition rate/MHz	0.66	1
FEL-II		
Photon energy/keV	0.4-3	0.4-3
Photon number per pulse @1.24keV	$>10^{12}$	$>10^{13}$
Max pulse repetition rate/MHz	0.66	1
FEL-III		
Photon energy/keV	10-25	10-25
Photon number per pulse @15keV	$>10^{9}$	$>10^{10}$
Max pulse repetition rate/MHz	0.66	1

Future accelerator facilities in Asia and Australia: HEPS



High Energy Photon Source (HEPS) of IHEP

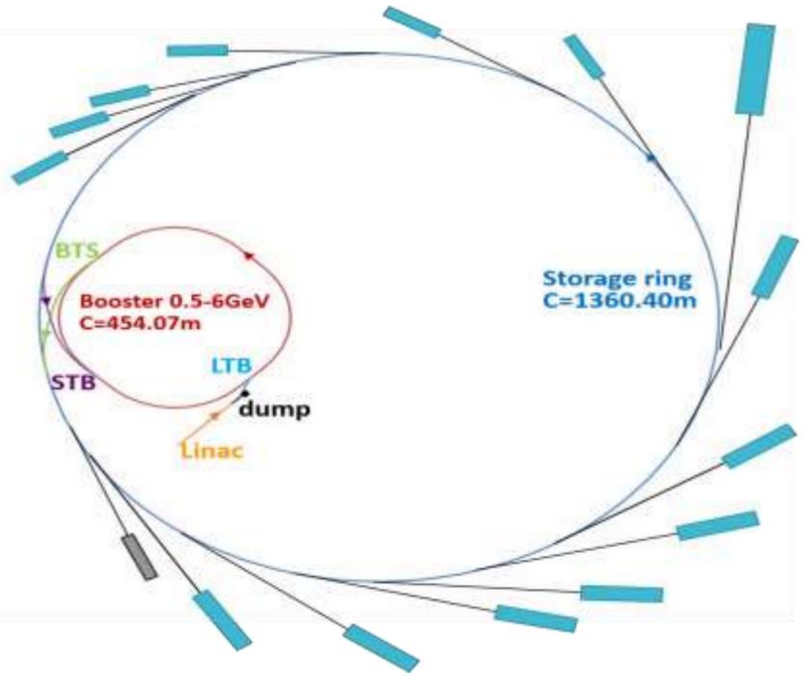
The first high-energy synchrotron radiation light source in China

-Groundbreaking: **Jun. 29, 2019**
-Scheduled completion in **Dec., 2025**
-Cost: **~5B RMB ~750M USD**

Area	650,658.21	m^2
Circumference	1360.4	m
Beam energy	6	GeV
Emittance	≤0.06	nm•rad
Brightness	$>1\times10^{22}$	phs/s/mm²/mrad²/0.1%BW
Beamlines	≥90	14 BLs in Phase I
Photon energy range	0.2-300	keV

Location: Huairou Science City of Beijing, about 80km away from IHEP

Weimin Pan



HEPS Booster

HEPS Linac

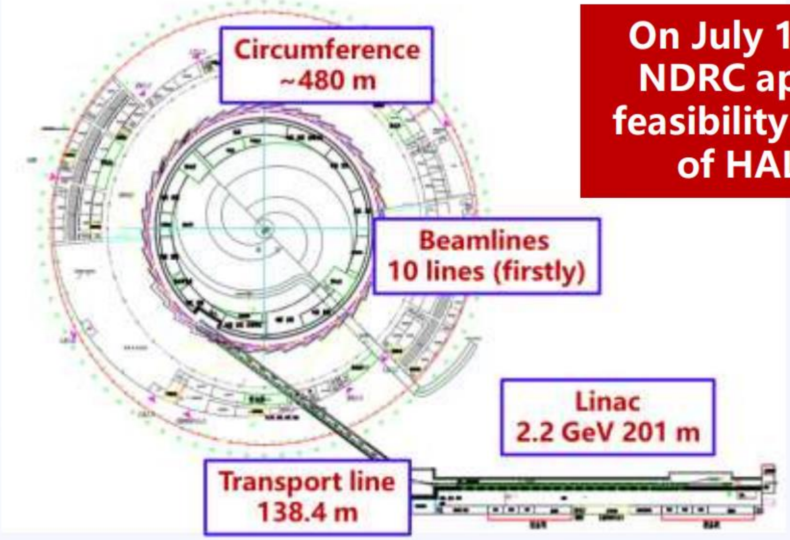
2400+ Magnets

700+ BPMs

~2000 vacuum chambers

Future accelerator facilities in Asia and Australia: HALF & SAPS

Hefei Advanced Light Facility (HALF)



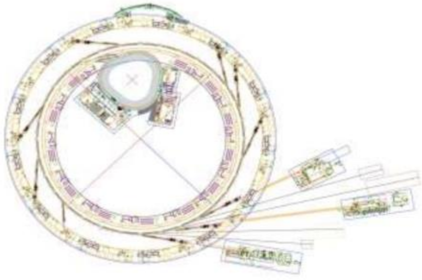
On July 12, 2022, the NDRC approved the feasibility study report of HALF project

Parameter	Design Metrics
Energy [GeV]	2.2
Beam current [mA]	350
Circumference [m]	479.86
Natural emittance [pm rad]	85.8
Lattice Structure	6BA
Number of straight sections	20×5.3 m+20×2.2 m
Maximum brightness [Flux/mm^{2}mrad^2]	1.15×10^{21}
Coherence ratio (@ 1 keV)	30%

The Southern Advanced Photon Source (SAPS) of IHEP in Dongguan

Sheng Wang

- The 4th generation （3.5GeV） diffraction-limited storage ring
- Brightness >10^{22}phs/s/mm^2/mrad^2/0.1%BW
- SAPS will be located adjacent to CSNS
- Planned to start construction around 2025
- Cost about 30B RMB ~450M USD



SAPS is located at IHEP, Dongguan campus, Guangdong Province, China

Future accelerator facilities in Asia and Australia: Korea

Accelerator Facilities in Korea
(Photon sources and nuclear physics)

Heavy ion radio-therapy

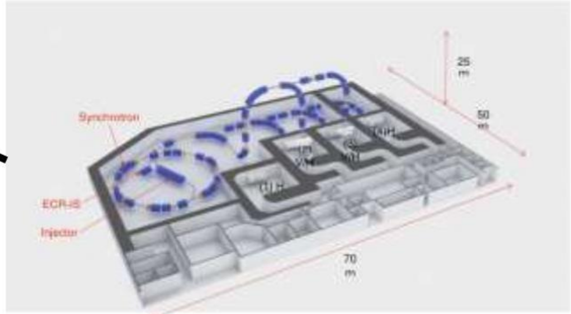
Korea-4GSR project (started)

Rare isotope accelerator

PLS-II & PAL-XFEL (PAL)

100 MeV Proton accelerator

Heavy ion radio-therapy



Future accelerator facilities in Asia and Australia: Austrilia

Recent Projects in Australia

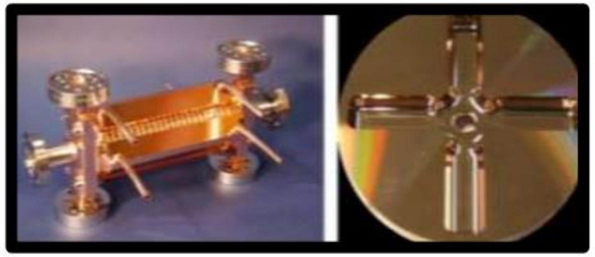
Rohan Down

X-band test laboratory at University of Melbourne: X-LAB

- The southern hemisphere's first X-band radio-frequency test facility
- Electron test beam to be developed in 2024

Australian Bragg Centre for Proton Treatment and Research in Adelaide

- Houses a Radiance 330 proton beam therapy system, manufactured by ProTom International
- Australia's first Proton therapy facility, due for operation 2023



X-LAB

Future Projects in Australia

National Particle Treatment and Research Centre (NPTRC)

- In advanced design, but not yet committed to by government.
- Designed for Proton and Carbon therapy, with a research branchline proposed.

More proton therapy facilities are also proposed.

NPTRC proposal

Bragg Centre December 2022

EAJADE workshop on sustainability & assessment of future Acc.

https://wsfa2023.huhep.org/ ; https://indico.desy.de/event/39980/

Four blocks (not limited to future Higgs Factores and to Linear Colliders):

I. Large-Scale Research Facilities & Sustainability/Life Cycle Assessment (LCA)

II. Sustainable Accelerator Technologies

III. Europe-Horizon and National Sustainability-Supporting Programmes

IV. Green ILC and Local Industries

Highlights of the EAJADE Workshop on Sustainability (WSFA2023) & European LDG Working Group on Sustainability Assessment of Future Accelerators

Maxim Titov

CEA Saclay / CERN

EAJADE workshop on sustainability & assessment of future Acc.

I. Large-Scale Research Facilities & Sustainability/Life Cycle Assessment (LCA)

- Objective Assessment of Sustainability Aspects of New Large Infrastructures
- Experience from ESS on Green Facilities
- A Life Cycle Assessment of the CLIC and ILC Linear Collider Feasibility Studies
- The ISIS-II Neutron And Muon Source Life Cycle Assessment: An Introduction
- The HElmholtz LInear ACcelerator HELIAC
- CERN Accelerates Sustainability
- Optimisation of the FCC Power Consumption and Next Steps for Sustainability Studies
- A Sustainability Roadmap for C3
- A Sustainability Outlook for CLIC / ILC

Power Purchase Agreement – Running on Renewables

Different approaches to reduce impact of large electric power consumption:

- *Reduce power (by higher efficiency)*
- *Re-use waste energy (heat)*
- *Modulate power according to availability (price)*
- *Use regenerative power*

A real implementation of renewable energy supply:

✓ A physical power purchase agreement (PPA) is a long-term contract for the supply of electricity at a defined, fixed price at the start and then indexed every year, and a consumer for a defined period (generally 20 years). Being considered for CERN, initially at limited scale. Advantages: price, price stability, green, renewable.

✓ *Must be a goal to run future accelerator at CERN primarily on green and more renewable energy with very low carbon footprint. However, energy costs will remain a concern.*

If we have energy available at 12.5 g CO_2/kWh = 12.5 kton CO_2/TWh (not unlikely in 2050):

- ***20km accelerator construction ~ 20 years of operation.***
- ***1 km accelerator construction ~ 1 TWh annual electricity (annual LC operation 0.6 TWh)***

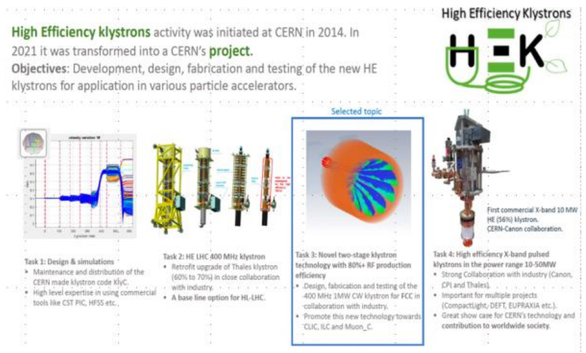
EAJADE workshop on sustainability & assessment of future Acc.

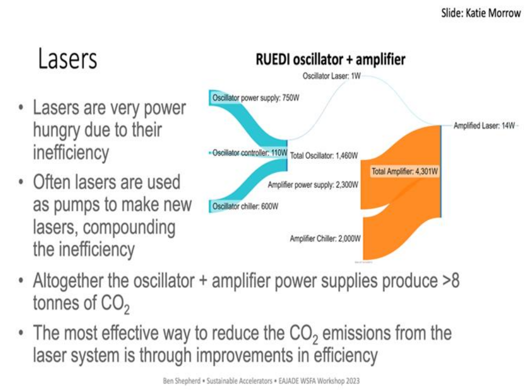
II. Sustainable Accelerator Technologies

- ✓ High-Efficiency Klystrons @ CERN
- ✓ Sustainable Accelerator R&D in the UK
- ✓ Experience from ESS on Green Facilities

III. Europe-Horizon & National Sustainability-Supporting Programs

- ✓ *EU-Horizon EAJADE (M. Titov)*
- ✓ *EU-Horizon iSAS (J. d' Hondt)*
- ✓ *Spanish Science Industry (E. Fernandez)*
- ✓ *EU-Japan Regional & Cluster Cooperation Heldesk (V. Fermaud)*





IV. Green ILC and Local Industries

- ✓ Scenarios toward 2050 Carbon Neutrality in Japan and ILC (M. Yoshioka)
- ✓ Efforts of Taiheiyo Cement towards Carbon Neutrality (Y. Ohgi)
- ✓ The Future of Construction: Carbon-Negative Concrete for a Greener Tomorrow (K. Avadh)
- ✓ Large-Scale Wooden Construction (Y. Shibuya)
- ✓ Sustainable Forestry in the Tohoku region (K. Shibata)
- ✓ Quantitative Evaluation of Forest CO2 Absorption in Ichinoseki City (H. Kikuchi)
- ✓ Creation of a sustainable society model utilizing IoT technology and local resources (Y. Komiya)
- ✓ Commercialization of Low-Grade Waste Heat Recovery (Y. Kouno)

Green ILC

Masakazu YOSHIOKA
(KEK)

Accelerator researchers are making following four efforts to achieve sustainable accelerator facilities

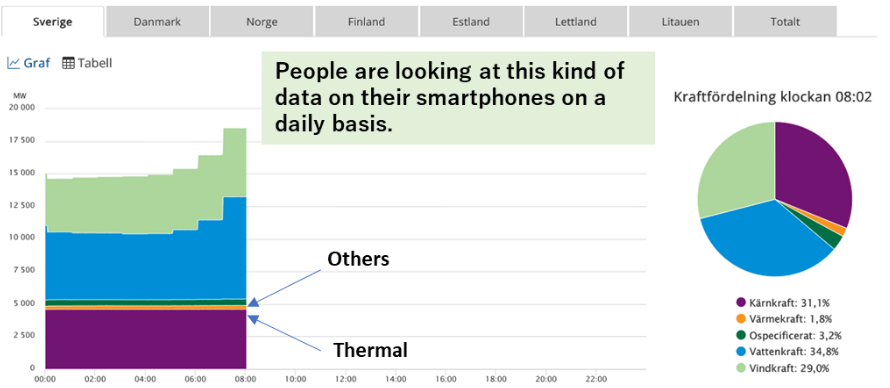
① Increasing the power efficiency and performance of accelerator components.

② Electricity used by accelerators should be provided by sustainable power sources instead of fossil fuels, and effective local use of the waste heat energy emitted from the accelerator.

③ To this end, we will help to increase the amount of sustainable electricity in the region and create regional energy management business using waste heat.

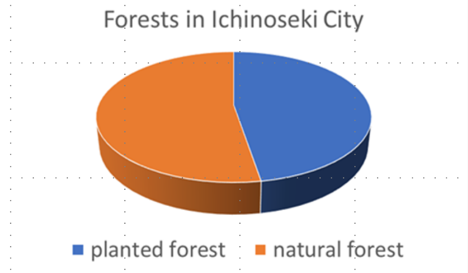
④ Cooperate to increase Green Carbon (from forests), Blue Carbon (from seaweed), and White Carbon (CO_2 fixation by increasing wooden buildings) in the region to increase CO_2 absorption.

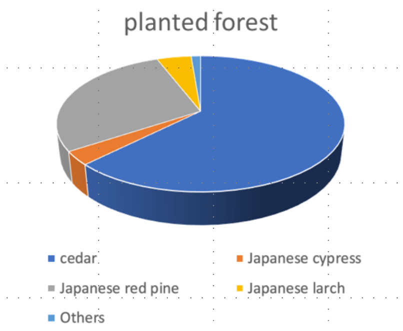
- **Sweden and Europe have liberalized their electricity markets and electricity is traded under free competition.**
- Electricity networks are interconnected and power is transmitted and distributed across borders.
- The objective of the electricity market is to use integrated resources as efficiently as possible to meet the demands of electricity users.
- The public can view the following electricity statuses at any time in real time (https://www.svk.se/om-kraftsystemet/kontrollrummet/)

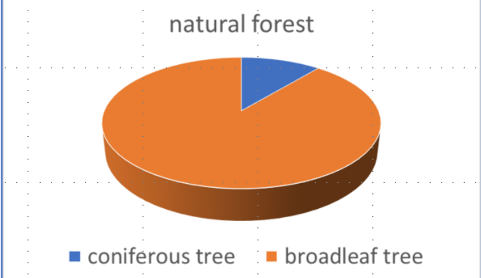


Green ILC

Green Carbon







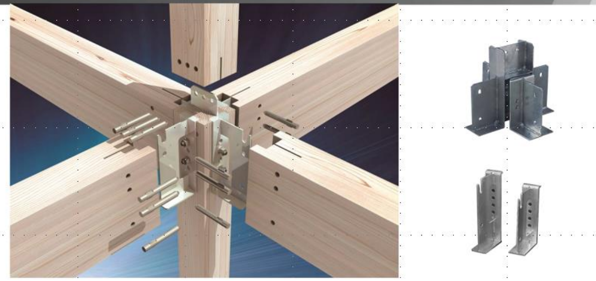
47% Planted Forest: 31465 ha
53% Natural Forest: 34895 ha
Total 66363 ha

In planted forests, cedar is the most abundant species, followed by red pine.

Natural forests are mostly broadleaf tree.

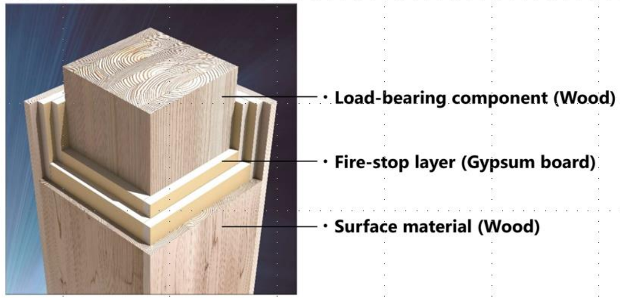
White Carbon

Metal Hardware Joining Method "KES System"



- Use of metal hardware in in the joints and connections of wooden components
- Drastic improvement in the performance of timber construction, including seismic resistance, durability, insulation, airtightness, and ease of construction.

Wooden Fireproof Components "COOL WOOD"



1-hour Fireproof COOL WOOD (Column)

Blue Carbon (CO_2 absorption by seaweed in coastal areas in the town of Hirono, northern Iwate Prefecture)

CO_2 absorption by seaweed is very promising because it is slightly better than that of forests.

SC Magnets for the FCCee Collider Ring

M. Koratzinos

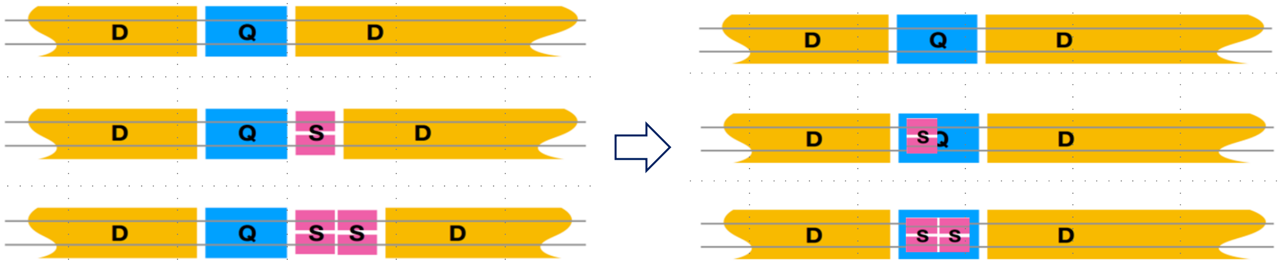
Storage Ring	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
Magnet current	25%	44%	66%	100%
Power ratio	6%	19%	43%	100%
Dipoles (MW)	0.8	2.6	5.8	13.3
Quadrupoles (MW)	1.4	4.3	9.8	22.6
Sextupoles (MW)	1.3	3.9	8.9	20.5
Power cables (MW)	1.2	3.8	8.6	20
Total magnet losses	4.8	14.7	33.0	76.4
Power demand (MW)	5.6	17.2	38.6	89

Cooling and ventilation		Z	W	H	TT
Beam energy (GeV)		45.6	80	120	182.5
Pcv (MW)	all	33	34	36	40.2

Magnet is the major electricity consumer after SRF, and we pay twice for normal conducting magnets: one through ohmic losses, and again for removing the heat with our cooling and ventilation (CV) system.

Total contribution of the collider ring magnets is therefore **~100MW** at the top, 76% of which comes from the quads and sextupoles

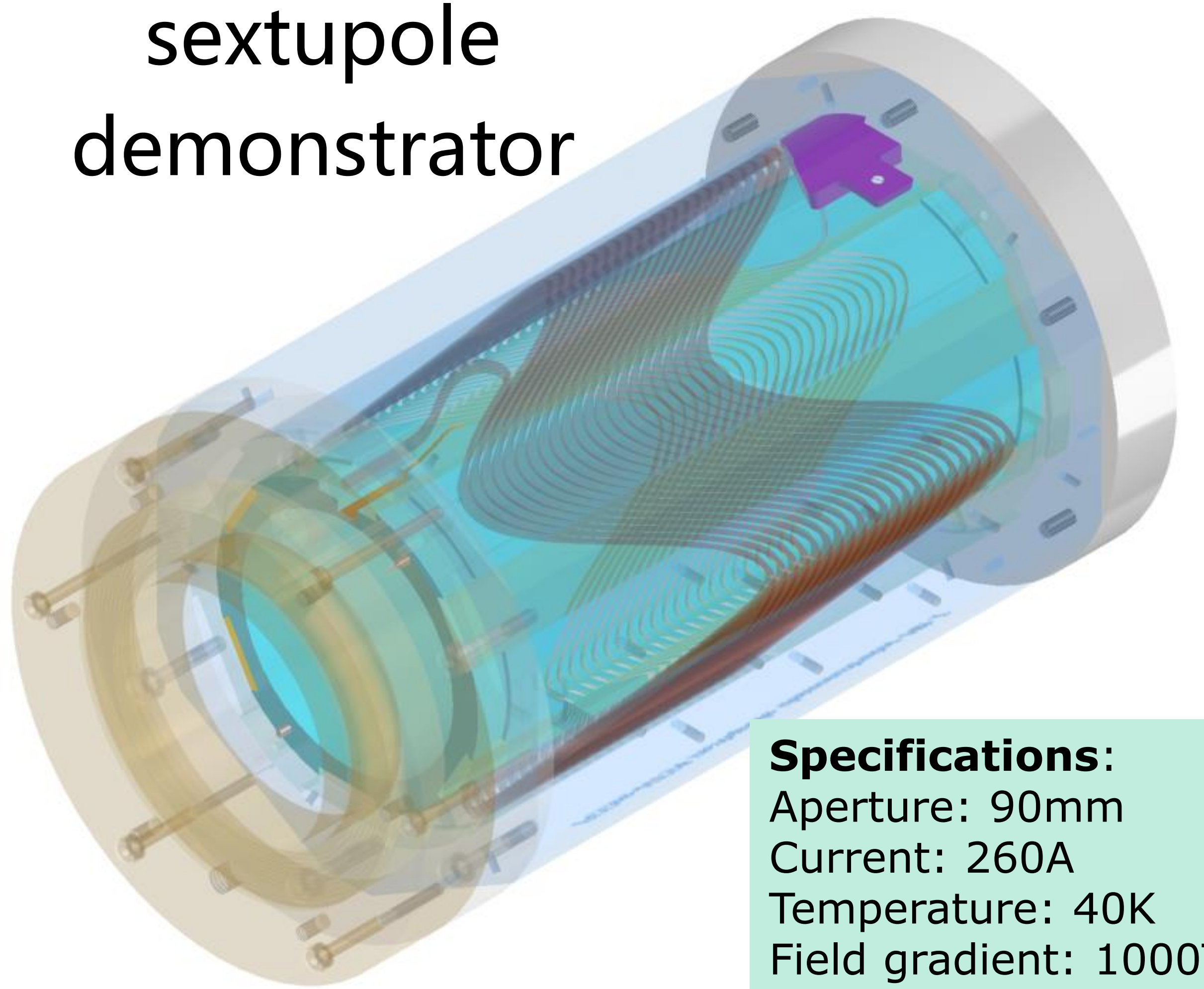
Replace the NC Q+S. by HTS Mag.: zero Ohmic loss + higher packing factor



Potential additional benefit: More space (~7%) for dipole and reduction of the RF power

SC for the FCCee collider

sextupole demonstrator

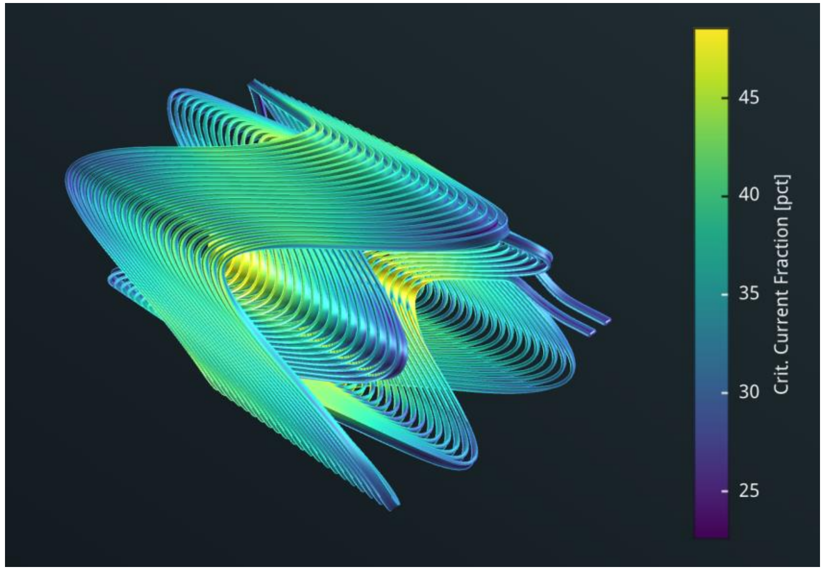


Choose a CCT magnet layout due to
- Ease of construction
- Good field quality
- Quick design cycle

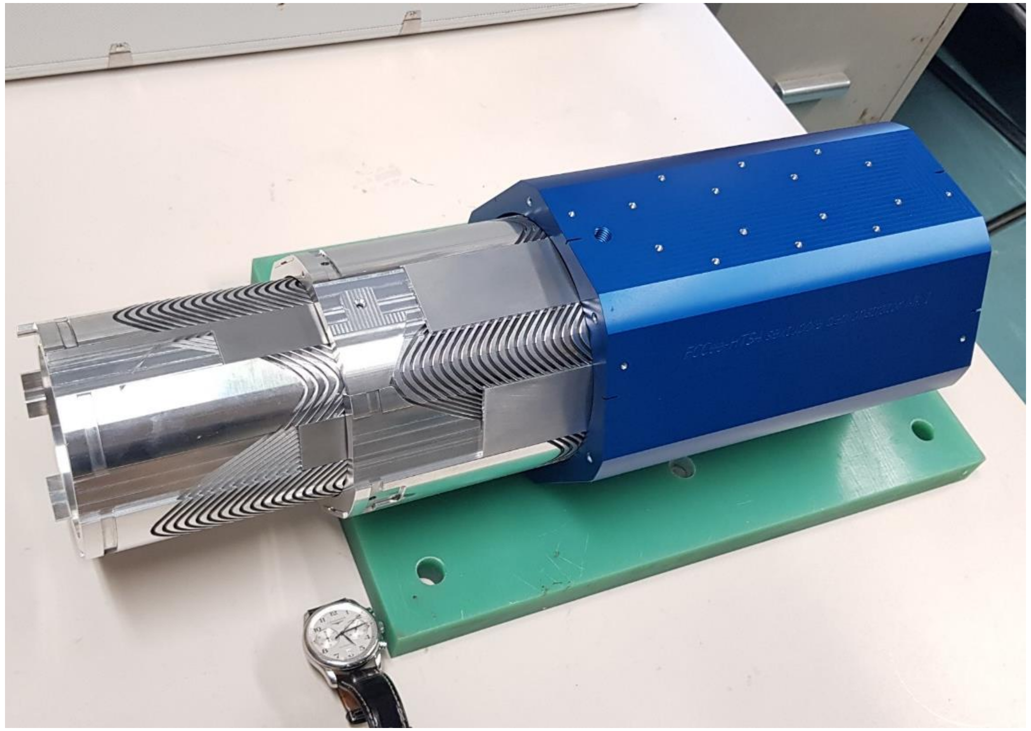
Other approaches (i.e. standard cosine-theta) will also be pursued

Demonstration of the HTS tape CCT magnet

Specifications:
Aperture: 90mm
Current: 260A
Temperature: 40K
Field gradient: 1000T/m2
Max. field @conductor:1.5T
Crit. Current fraction: 49%
Temp. margin: 14K

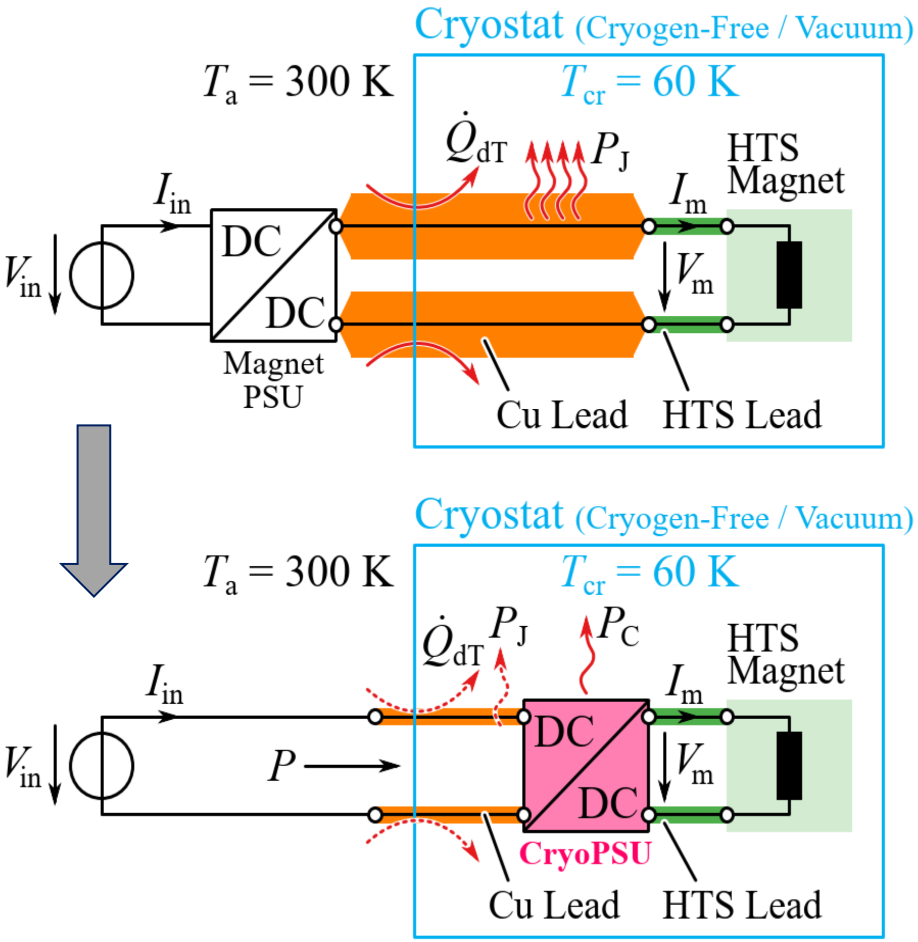


SC for the FCCee collider



CCT Formers manufactured

Further reduce the heat loss from the Cu leads by placing the power supply (250A) inside the cryostat



Giovanni IADAROLA (CERN)

Xsuite

An Integrated Beam Physics Simulation Framework

Who uses Xsuite and for which applications?

LHC and HL-LHC
- **Tracking for DA** - lattice only (M. Le Garrec, E. Maclean, C. E. Montanari , T. Pugnat, D. Veres)
- **Crab-cavity noise studies**(A. Fornara, Uni. Manchester)
- **Beam-beam weak-strong** (G. Sterbini, S. Kostoglou, C. Droin, E. Lamb, D. Christie Uni. Manchester)
- **Beam-beam strong-strong** (X. Buffat)
- **Wire compensation studies** (P. Belanger, D. Kalchev TRIUMF)
- **Collimation studies** (F. Van Der Veken, N. Triantafillou, B. Lindstrom, M. D'Andrea, P. Hermes)
- **Optics/orbit matching, including RDT matching** (B. Lindstrom, K. Paraschou, C. Droin, S. Kostoglou, Y. Angelis)
- **Non-linear corrections calculation** (J. Dilly)
- **Hollow e-lens studies** (P. Hermes + students)
- **Incoherent e-cloud effects** (K. Paraschou)
- **Beam instrumentation studies** (D. Alves, K. Lasocha, SY-BI)

Injector complex (PSB, PS, SPS, LEAR, AD, ELENA)
- **Space-charge studies** (F. Asvesta, T. Prebibaj)
- **Cooling studies** (D. Gamba, P. Kruyt)
- **Instabilities with wakes and space-charge** (X. Buffat)
- **Slow extraction studies at PS and SPS** (P. Arrutia Sota, T. Bass, F. Velotti, SY-ABT)
- **Ion studies** (E. Waagaard)
- **Beam transfer simulations** (F. Velotti, SY-ABT)
- **MTE simulations**, optics+tracking (A. Huschauer, starting)

Light sources (Petra IV, Elettra, Bessy III)
- **Tracking and DA**

FCC
- **FCC-ee optics matching, tapering + RF phasing** (M. Hofer, J. Keintzel, P. Kicsiny (L. Van Riesen-Haupt)
- **FCC-ee DA studies** (M. Hofer, L. Van Riesen-Haupt, EPFL)
- **FCC-ee and FCC-hh beam-beam-SS&WS** (P. Kicsiny, D. Di Croce, EPFL)
- **Beamstrahlung, Bhabha** (P. Kicsiny)
- **FCC-ee and FCC-hh collimation studies** (A. Abramov, G. Broggi)
- **FCC-ee vibration studies** (J.P. Salvesen, M.Hofer, LAPP Annecy collab.)
- **Compton scattering studies** (A. Abramov, I. Debrot, M. Hofer)
- **Collective effects** (M. Migliorati, A. Ghribi - Uni Sapienza, A. Rajabi – Desy)

GSI/FAIR
- **Space-charge** simulations (A. Oeftiger and team)
- **Slow extraction** simulations - SIS18 and SIS100 (P. Niedermayer, C. Cortes)
- **BTF studies** (C. Cortes)

Medical accelerators
- **Slow-extraction for PIMMS** (R. Tailor)
- **Slow-extraction for MedAustron** (F. Kuehteubl, E. Renner, et al.)

BNL - RHIC and EIC
- **Optics calculations and tracking**
- **Collimation studies**

Fermilab – Main Injector, Recycler, IOTA
- **Tracking studies**
- **Impedance + space-charge** simulations

Training (Universiy of Rome and EPFL)

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CERN has developed various **software tools :**

- **MAD-X**, lattice description, optics calculation and design, tracking
- **Sixtrack**, a **fast-tracking program**: long **single-particle simulations**
- **Sixtracklib**, a **C/C++library for single-particle tracking** compatible with Graphics Processing Units (GPUs)
- **COMBI**, simulation of **beam-beam** effects using **strong-strong modelling**
- **PyHEADTAIL**, a **Python** toolkit for **collective effects** (impedance, feedbacks, space charge, and e-cloud)

the Xsuite project since **2021**

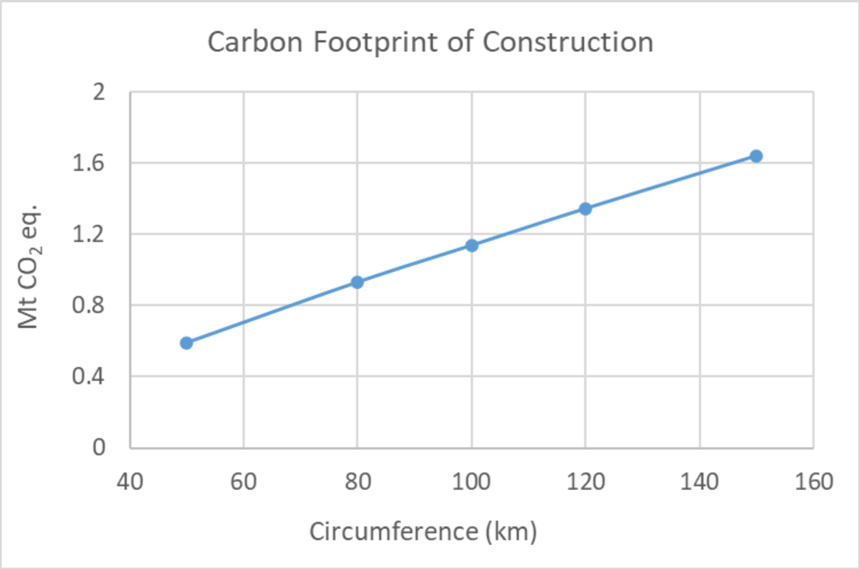
- **Main goal:** a **modern Python toolkit** the know-how built in developing and exploiting MAD, Sixtrack, COMBI, PyHEADTAIL etc.,
- Designed for **seamless integration** among the different components and for **extendability**
- Designed to support **different computing platforms**, including **multicore CPUs and GPUs** from different vendors

CO_2 Reduction Optimization with Future Colliders Design, Construction and Operation

Dou Wang, (IHEP)

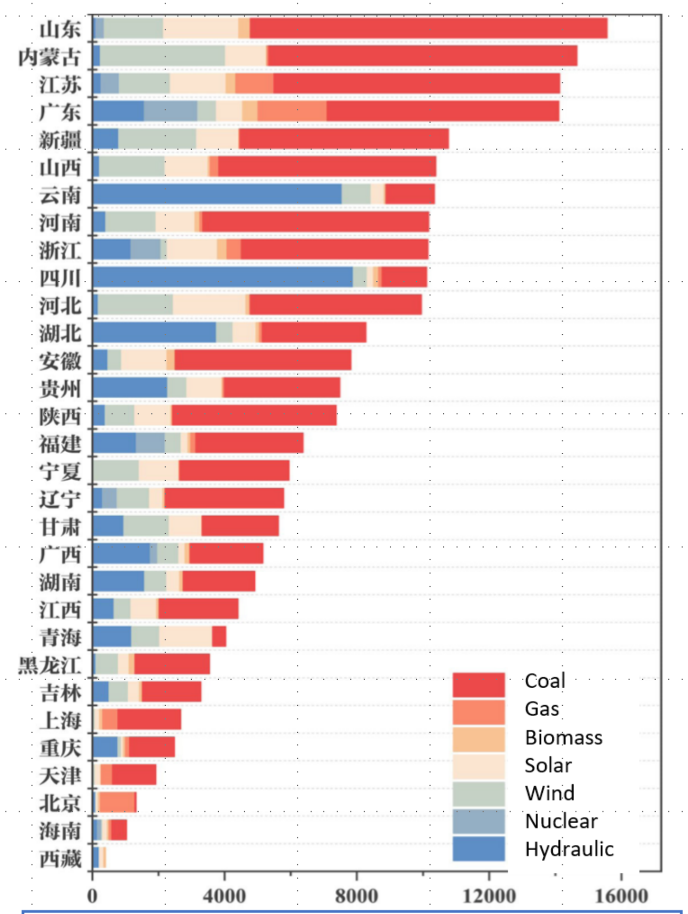
Calculation Model for CEPC Construction Impact

- **Environmental impact of construction**: raw material supply (A1), material transport (A2), material manufacture (A3), material transport to work site (A4), and construction process (A5)



- Main tunnel: 7.0 kton CO_2 e/km
- Carbon for construction: Main tunnel + other structures + transport (+25%)

CO2 Reduction Optimization with Future Colliders Design, Construction and Operation



Electricity Generating Capacity in China 2020 (10000 kW)

Carbon intensity (kgCO2/kWh)

省份	2010 年	2012 年	2018 年	2020 年
辽宁	0.836	0.775	0.722	0.91
吉林	0.679	0.721	0.615	0.839
黑龙江	0.816	0.797	0.663	0.814
北京	0.829	0.776	0.617	0.615
天津	0.873	0.892	0.812	0.841
河北	0.915	0.898	0.903	1.092
山西	0.88	0.849	0.74	0.841
内蒙古	0.85	0.929	0.753	1.000
山东	0.924	0.888	0.861	0.742
上海	0.793	0.624	0.564	0.548
江苏	0.736	0.75	0.683	0.695
浙江	0.682	0.665	0.525	0.532
安徽	0.791	0.809	0.776	0.763
福建	0.544	0.551	0.391	0.489
江西	0.764	0.634	0.634	0.616
河南	0.844	0.806	0.791	0.738
湖北	0.372	0.353	0.357	0.316
湖南	0.552	0.517	0.499	0.487
重庆	0.629	0.574	0.441	0.432
四川	0.289	0.248	0.103	0.117
广东	0.638	0.591	0.451	0.445
广西	0.482	0.495	0.394	0.526
海南	0.646	0.686	0.515	0.459
贵州	0.656	0.495	0.428	0.42
云南	0.415	0.306	0.092	0.146
陕西	0.87	0.769	0.767	0.641
甘肃	0.612	0.573	0.491	0.46
青海	0.226	0.232	0.26	0.095
宁夏	0.818	0.779	0.62	0.872
新疆	0.764	0.79	0.622	0.749

Qin Huang Dao (河北: 1.092)
Hu Zhou (浙江: 0.532)
Chang Sha (湖南: 0.487)
Shen Shan (广东: 0.445)

8

- **Peak Carbon Dioxide Emissions**: China has pledged to reach carbon peak by 2030,
- **Carbon neutrality:** achieve a relative "zero emissions" before 2060 by planting trees and forests, saving energy and reducing emissions

2021~ 2030: realize peak carbon emissions

↓

2031~ 2045: rapid reduction of carbon emissions

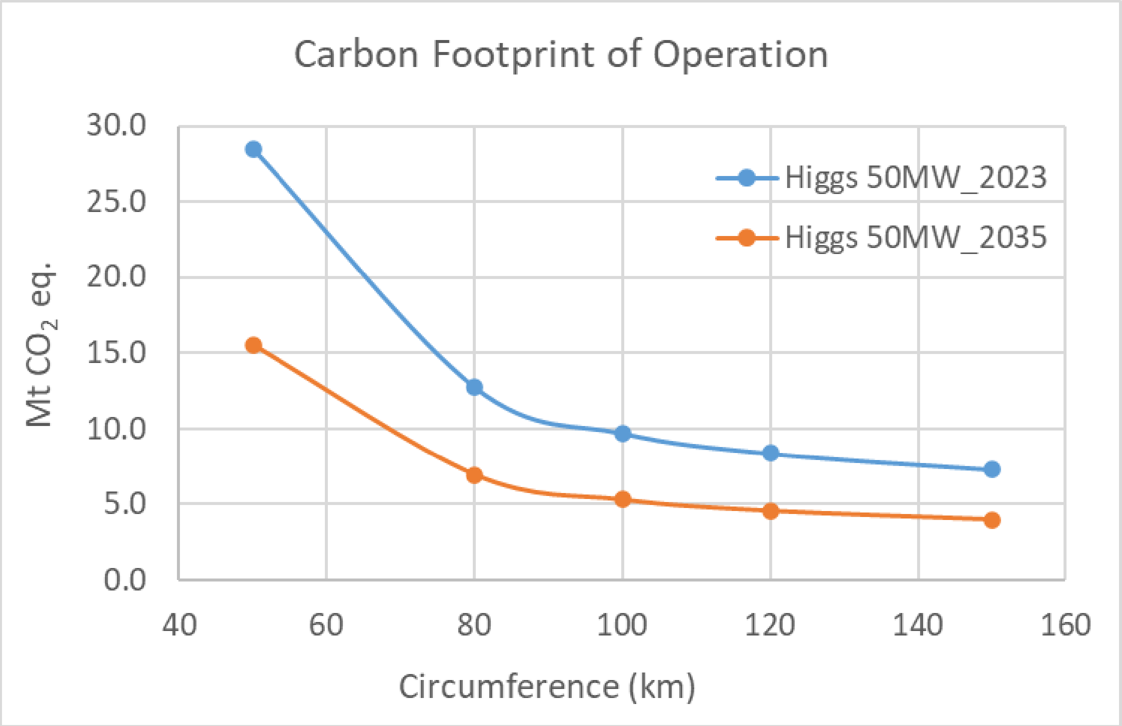
↓

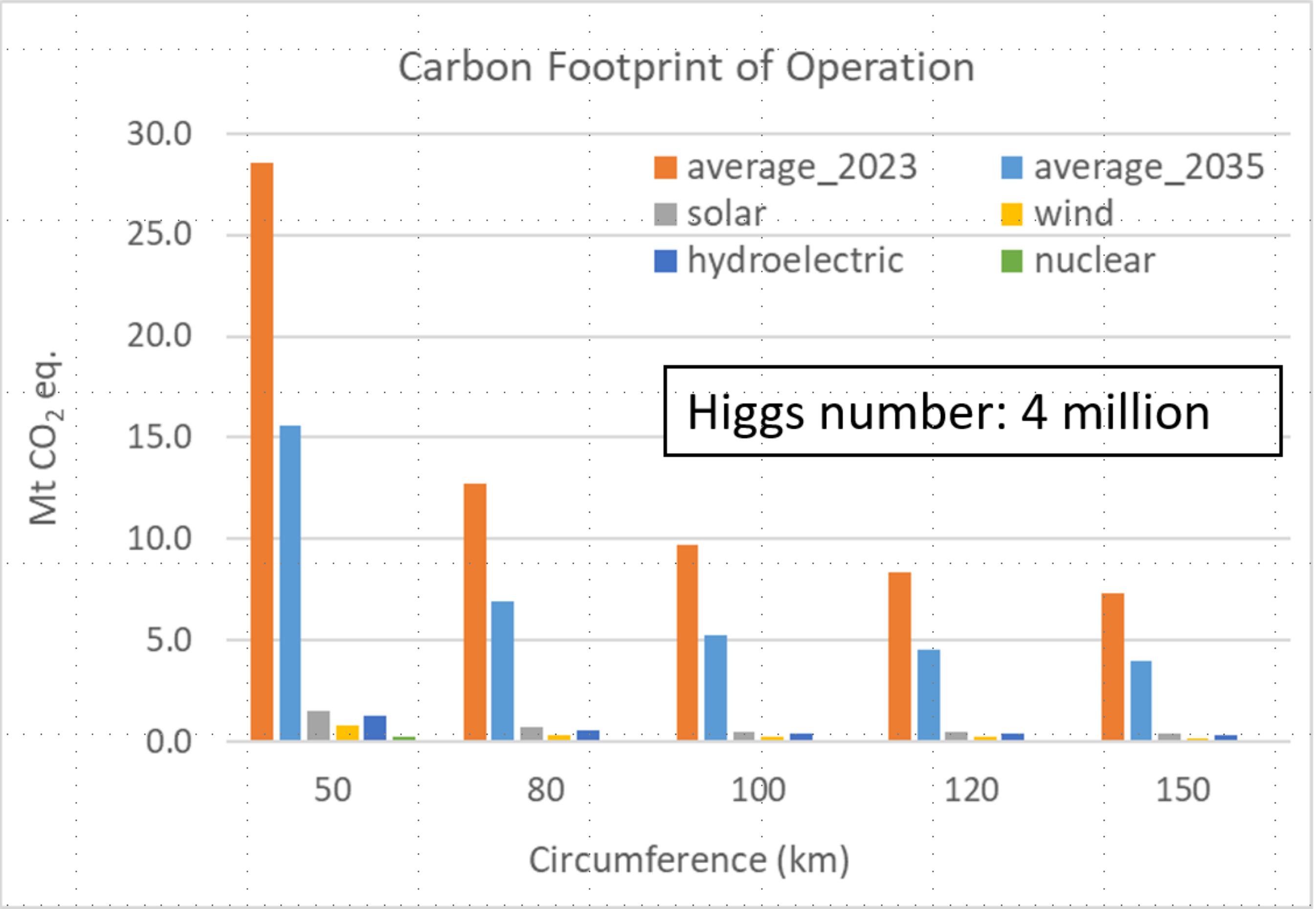
2046~ 2060: deep decarbonization, achieving carbon neutrality

CO2 Reduction Optimization with Future Colliders Design, Construction and Operation

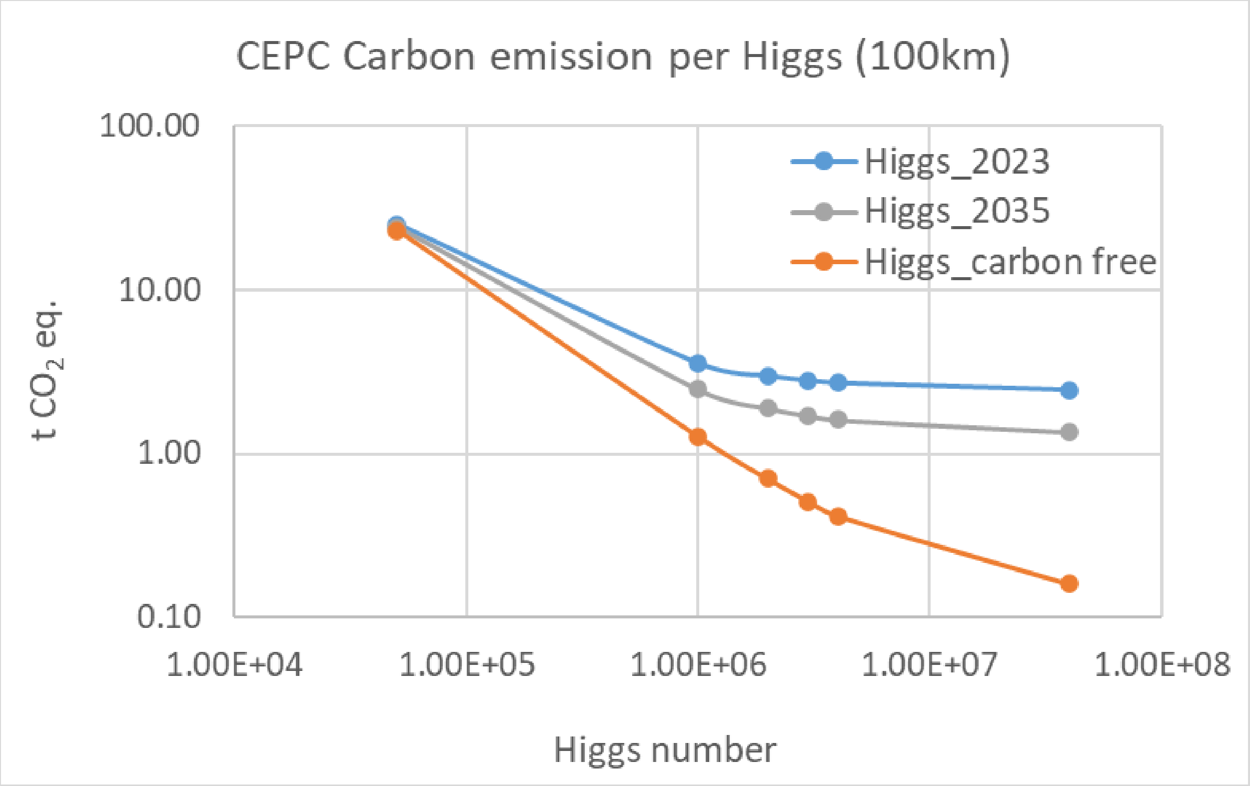
- Grid average carbon intensity in 2023:
  550 ton CO_2 e /GWh
- Grid average carbon intensity by 2035:
  300 ton CO_2 e /GWh

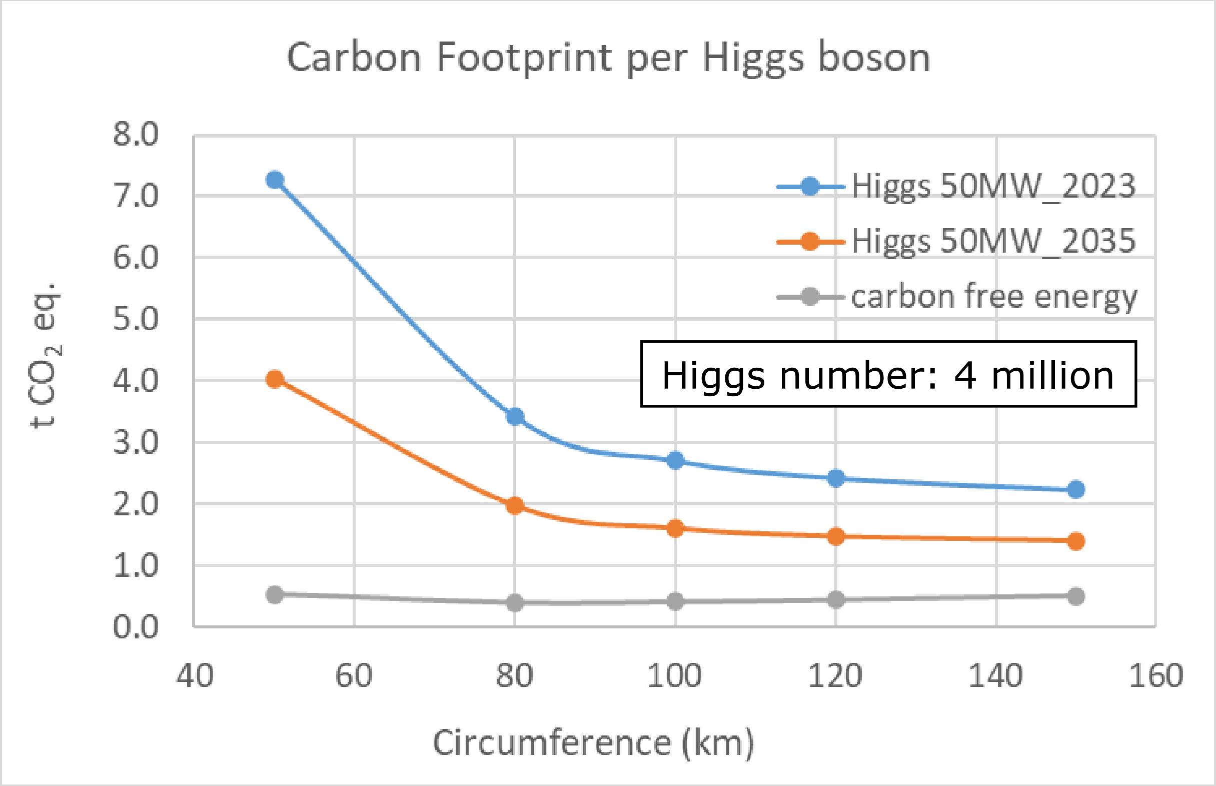
Solar (t CO2/GWh)	Wind (t CO2/GWh)	Hydroelectric (t CO2/GWh)	nuclear(t CO2/GWh)
30	15	25	5





CO2 Reduction Optimization with Future Colliders Design, Construction and Operation

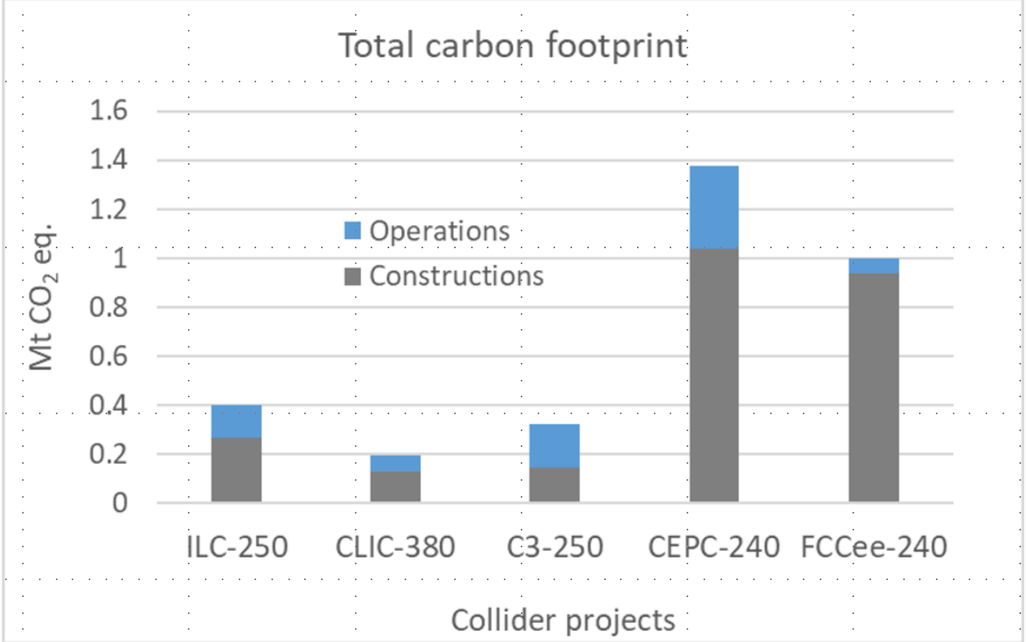


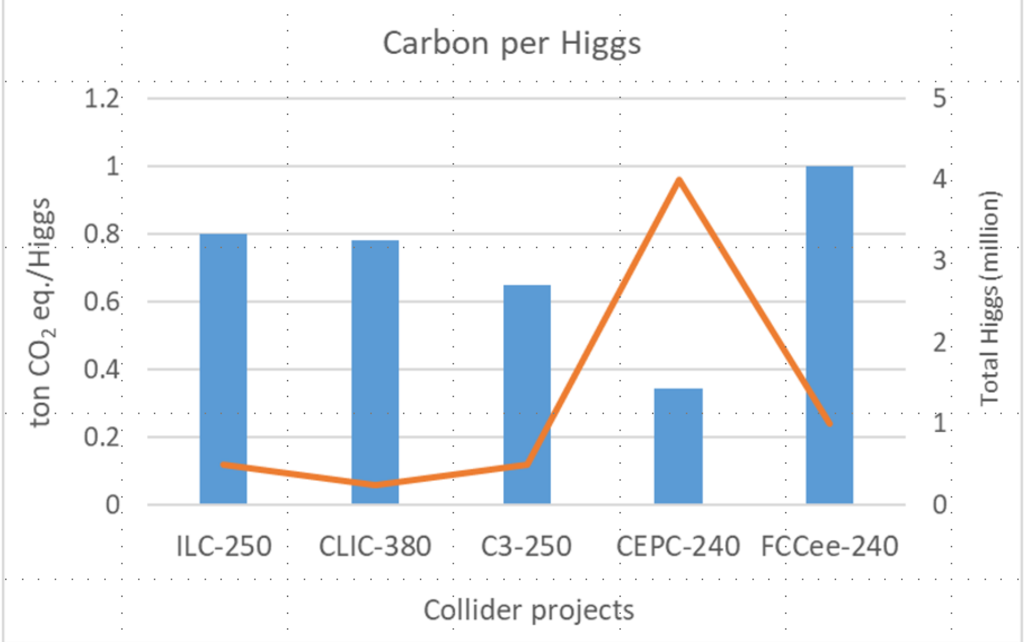


CO2 Reduction Optimization with Future Colliders Design, Construction and Operation

	ILC-250	CLIC-380	C3-250	CEPC-240	FCCee-240
Instantaneous power (MW)	111	110	150	340	290
Annual collision month	6.2	4.6	6.2	5.0	4.2
Annual collision time (E7 s)	1.6	1.2	1.6	1.3	1.1
Operational efficiency	0.75	0.75	0.75	0.57	0.75
Higgs operation time (years)	11.5	8	11.5	10	3
Higgs number (million)	0.5	0.25	0.5	4	1

Ref: Patrick JANOT and Alain BLONDEL, "The carbon footprint of proposed e^+e^- Higgs factories", arXiv:2208.10466v4 [hep-ph] 23 Sep 2022.





High Q and High Gradient SRF Cavity Studies and Applications in Green Accelerators

Jiyuan Zhai (IHEP)

Huge RF power decrease: Super-conducting (SC) vs Normal-conducting (NC)

650 MHz cavities for CEPC Collider Higgs mode:
2.2 GV RF voltage shared by two beams, 30 MW SR per beam

- **SC**: 3E10@25 MV/m, cell R/Q=107 Ω, 192 2-cell cavities
  ~ 4 kW RF wall loss , ~ 8 kW RF AC power, ~ 3 MW cryogenic AC power
- **NC**: 4E4@25 MV/m, cell R/Q=270 Ω, 77 5-cell cavities
  ~ 1200 MW RF wall loss , ~ 2000 MW RF AC power, ~ 180 MW cooling AC power
- **NC**: 4E4@2 MV/m, cell R/Q=270 Ω, 960 5-cell cavities
  ~ 100 MW RF wall loss , ~ 160 MW RF AC power, ~ 15 MW cooling AC power

Cryogenic power decrease with high Q Niobium cavities

- CEPC 650 MHz 2-cell cavity Q_0 at 2 K vs cryogenic AC power of total cavity wall loss: 1E10 ~ 9 MW, 3E10 ~ 3 MW, 6E10 ~ 1.5 MW, 1E11 ~ 1 MW

Gain from further-increasing Q is marginal!

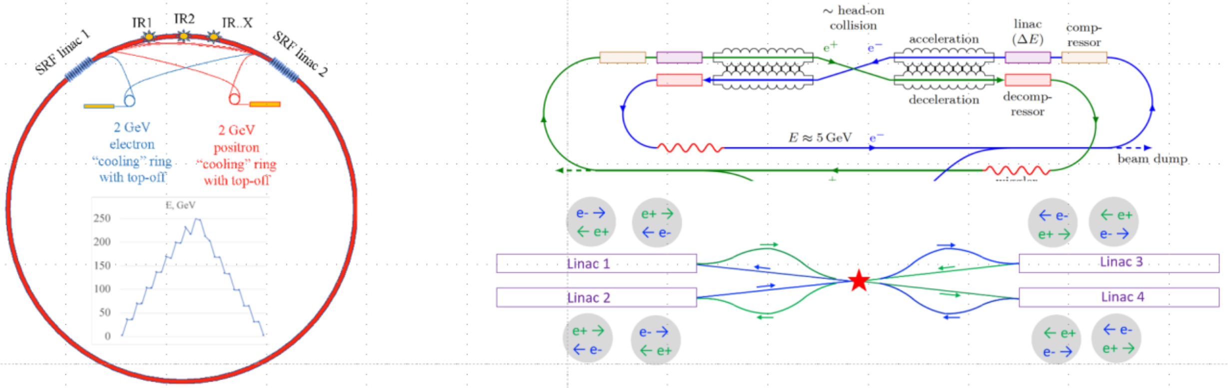
Cryogenic power decrease with high Q SRF Nb_3Sn cavities

- 650 MHz Nb_3Sn 2 K Q_0 at ~ 20 MV/m lower than Nb (no-doping or N/O doping)
- ~ 20 MV/ m Nb_3Sn 4.2 K cryo efficiency similar to Nb at 2 K, lower than high Q Nb at 2 K
- 650 MHz Nb cavity at 4.2 K Q_0 ~ 2E9. If use cryocooler at 4.2 K for industry application (~ 10 MV/m), Nb_3Sn is the only choice. COP of cryocooler not efficient for large accelerators.

ADS Using SRF Cavities

- 1 GW fission reactor, 15 MW proton beam (1.5 GeV, 10 mA CW), 30 MW for the SRF linac. If using normal conducting cavities, a large part of generated power goes to linac.

ERL based collider with SRF Cavity



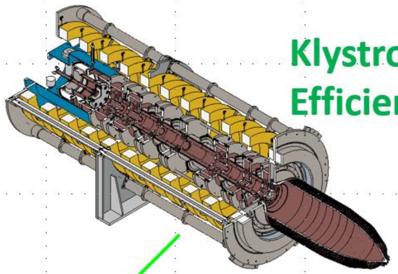
ERL-FEL: Ideal EUV Light Source

- Energy recovery linac (ERL) based Free Electron Laser (FEL) for high power EUV lithography (proposed by KEK, Japan)
- Many advantages over the current LPP source.

High-efficiency klystrons R&D status for CEPC

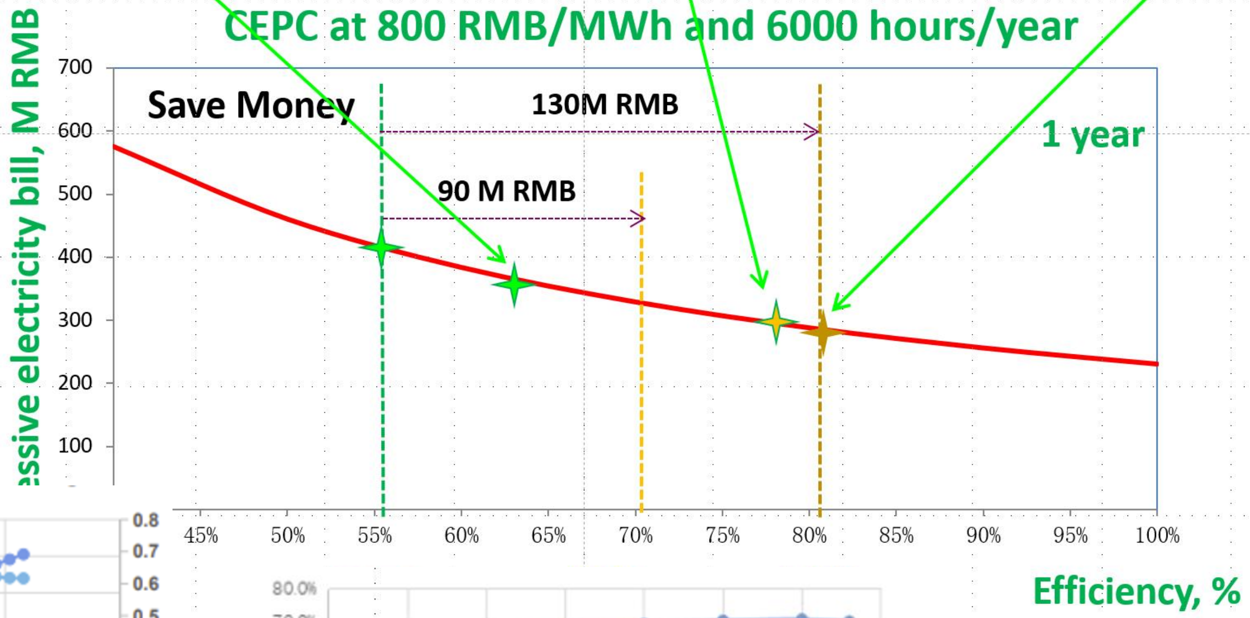
Zusheng Zhou

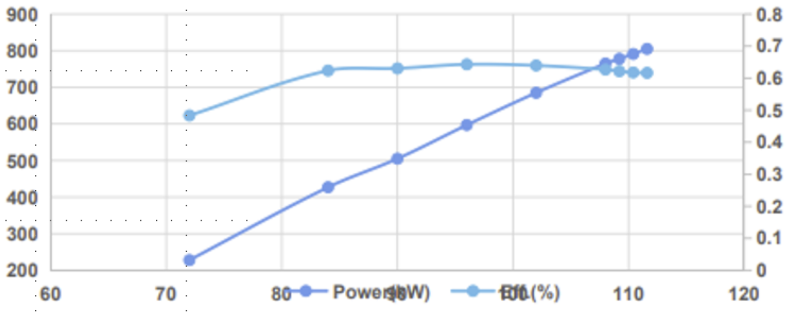
Klystron No. 2 aiming at efficiency 77%

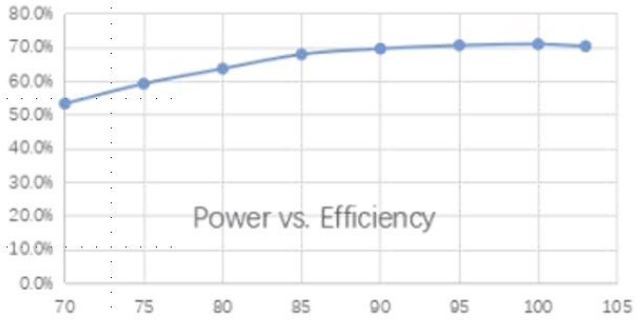


Klystron No. 3 Efficiency 80.5%

Klystron No. 1 Efficiency 62% (2020)

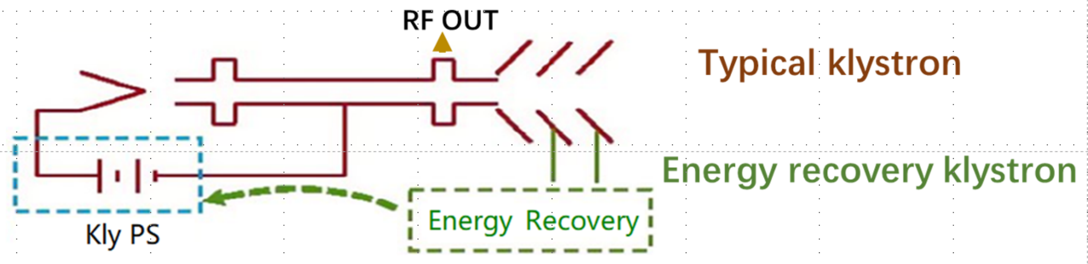


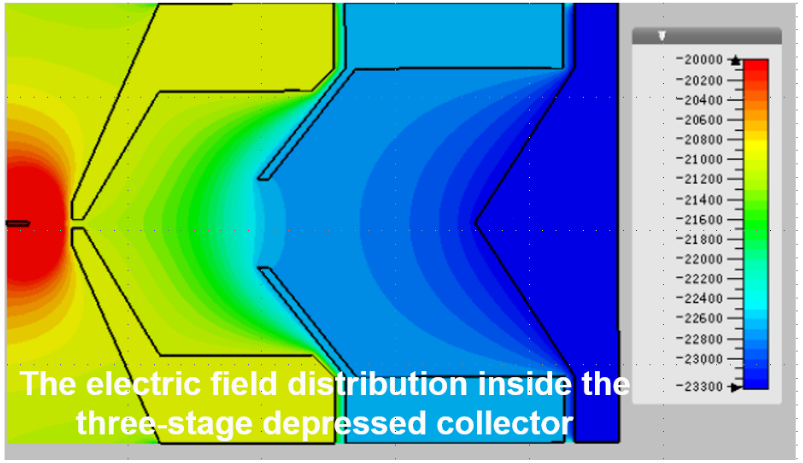




Increasing efficiency by decelerating the used beams at collector

- CPI (USA) has developed multiple models of multi-stages decelerating collector klystrons
- Many research institutes in Japan, UK and so on has conducted similar efforts.



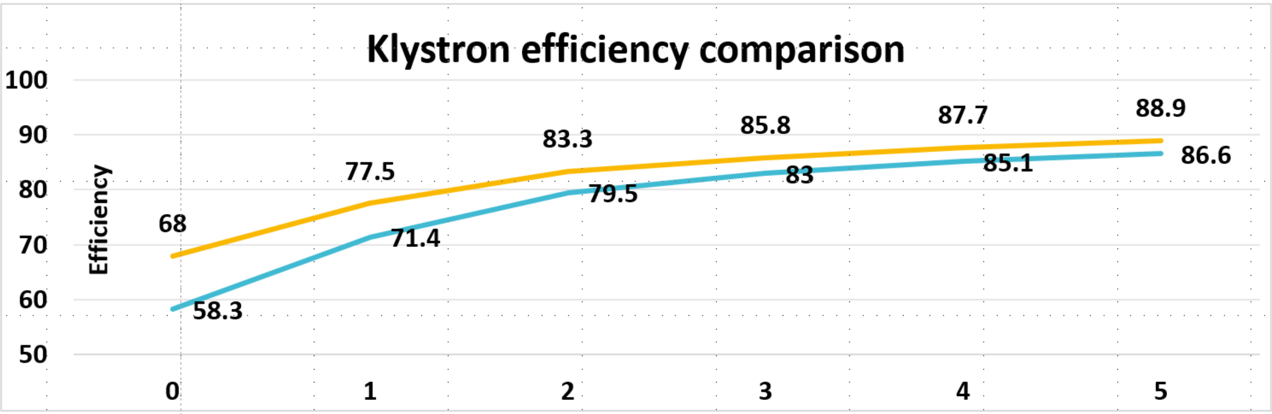


The electric field distribution inside the three-stage depressed collector

- CEPC will carry out the researches as well
  - Theoretical studies of efficiency v.s. collection stages for normal and high-efficient klystrons

CEPC high efficiency klystron prototype H.V. 113kV Cur. 9.5A		
Coll. Qty	Coll. Eff.	Kly. Eff.
0	0.0%	68.0%
1	29.8%	77.5%
2	47.7%	83.3%
3	55.6%	85.8%
4	61.4%	87.7%
5	65.2%	88.9%

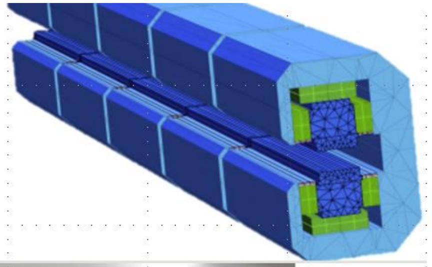
CEPC first prototype H.V. 81.5kV Cur. 15.3A		
Coll. Qty	Coll. Eff.	Kly. Eff.
0	0.00%	58.3%
1	31.4%	71.4%
2	50.9%	79.5%
3	59.2%	83.0%
4	64.3%	85.1%
5	67.9%	86.6%



Eco-friendly magnet R&D at IHEP

Mei Yang

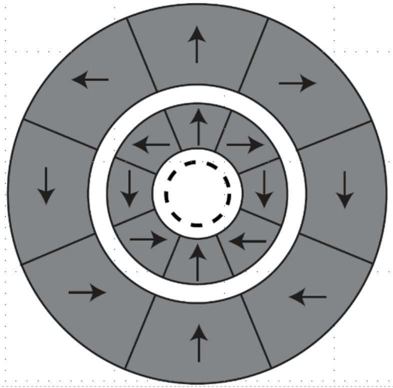
- Longitudinal-gradient dipole takes use of the permanent magnet at HEPS, which consumes zero electricity



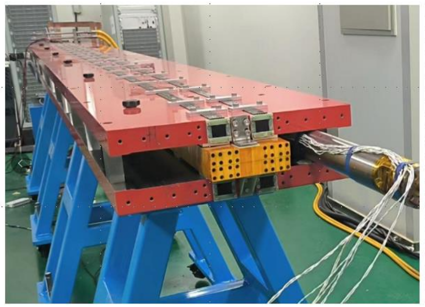
- Equivalent single excitation energy consumption of about 1.62kW.
- Equivalent cooling, power efficiency additional energy consumption of about 1.3kW
- 240 magnets in the whole ring
- Annual running time of 8000 hours

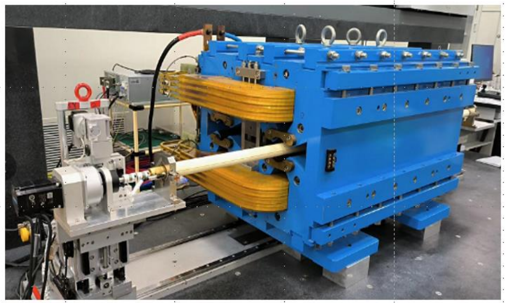
Annual saving electricity about **5.6 million kWh**

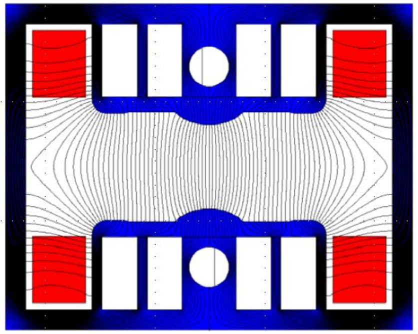
Dual-rings magnets enable field tenability in a large range



- **Dual aperture magnets prototypes for the CEPC Collider**





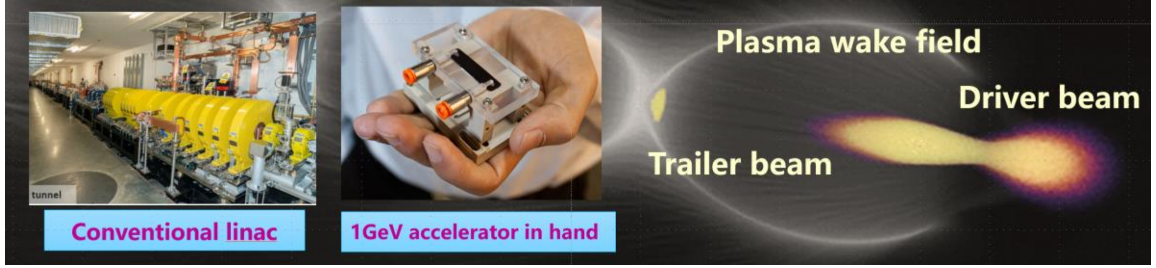


Develop plasma acceleration technology to improve the efficiency

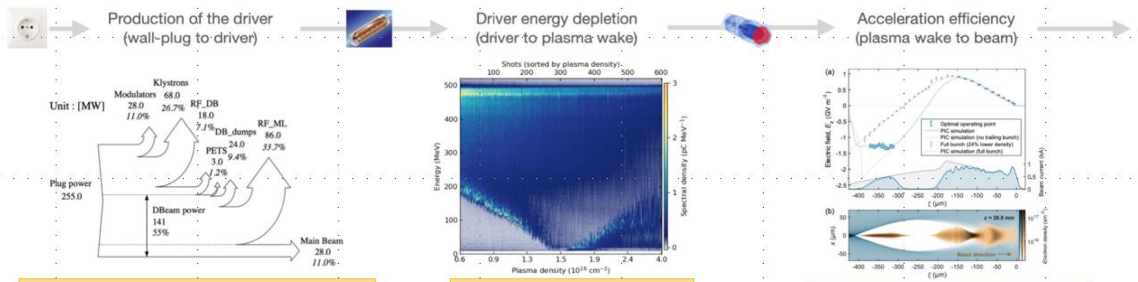
Dazhang Li

Proposal Name	c.m. energy [TeV]	Luminosity/IP $[10^{34}\ cm^{-2}s^{-1}]$	Yrs. pre-project R&D	Yrs. to 1st physics	Constr. cost [2021 B$]	Electr. power [MW]
FCC-ee[1,2]	0.24	7.7 (28.9)	0-2	13-18	12-18	290
CEPC[1,2]	0.24	8.3 (16.6)	0-2	13-18	12-18	340
ILC[3]-0.25	0.25	2.7	0-2	<12	7-12	140
CLIC[3]-0.38	0.38	2.3	0-2	13-18	7-12	110
CCC[3]	0.25	1.3	3-5	13-18	7-12	150
HELEN[3]	0.25	1.4	5-10	13-18	7-12	110
FNAL e^+e^- circ.	0.24	1.2	3-5	13-18	7-12	200
CERC[3]	0.24	78	5-10	19-24	12-30	90
ReLiC[1,3]	0.24	165 (330)	5-10	>25	7-18	315
ERLC[3]	0.24	90	5-10	>25	12-18	250
XCC $\gamma\gamma$	0.125	0.1	5-10	19-24	4-7	90
$\mu\mu$-Higgs	0.13	0.01	>10	19-24	4-7	200
ILC-3 **59 km**	3	6.1	5-10	19-24	18-30	~400
CLIC-3 **50 km**	3	5.9	3-5	19-24	18-30	~550
CCC-3	3	6.0	3-5	19-24	12-18	~700
ReLiC-3	3	47(94)	5-10	>25	30-50	~780
$\mu\mu$Collider[1]-3	3	2.3(4.6)	>10	19-24	7-12	~230
LWFA-LC-3 **1.3 km**	3	10	>10	>25	12-80	~340
PWFA-LC-3 **14 km**	3	10	>10	19-24	12-30	~230
SWFA-LC-3	3	10	5-10	>25	12-30	~170

- **High gradient:** ~10-100GV/m, ~**1000times higher than conventional Acc.**
- **High energy conversion rate**
- **High repetition rate possibility**
- **Focus on PWFA acceleration**



AC → Driver, Driver → Wakefield, Wakefield → Trailer

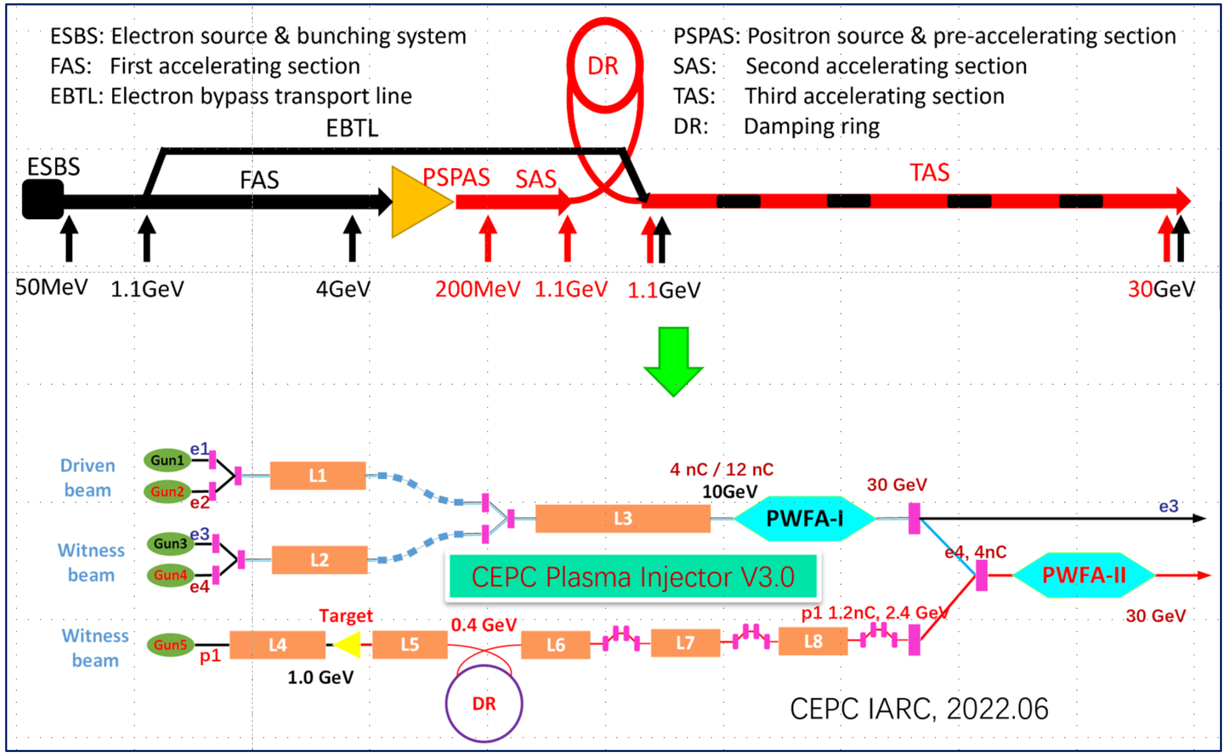


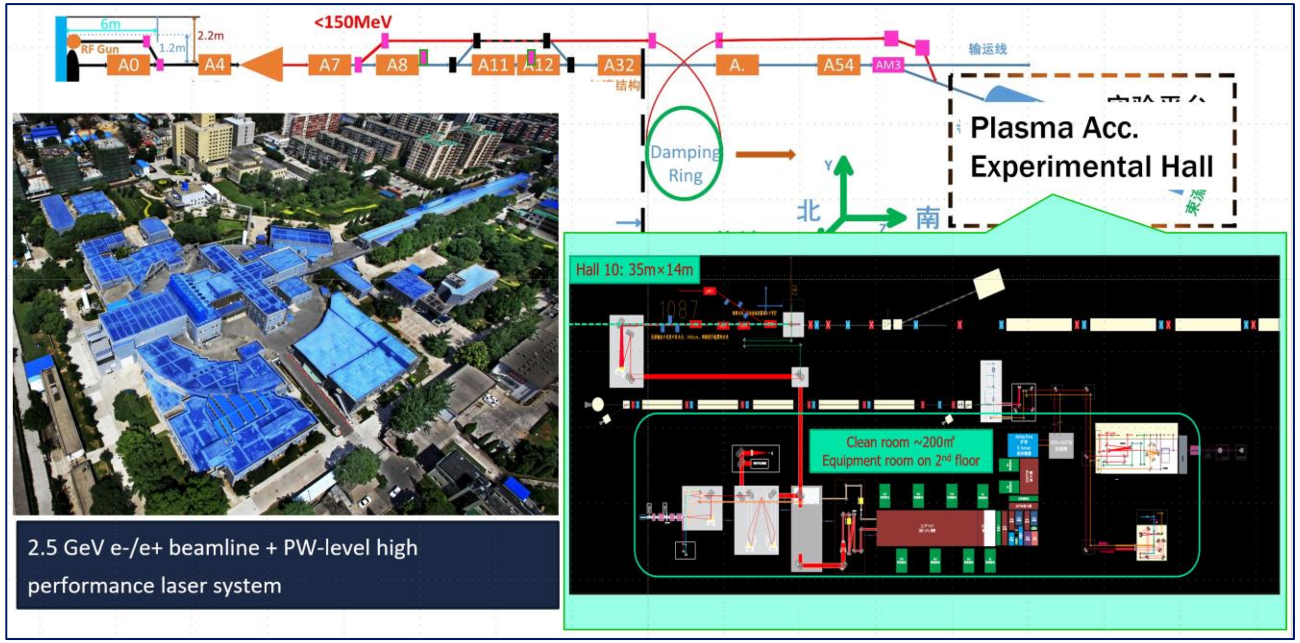
50-60% for PWFA
~ 10% for LWFA

50% (exp.)
90% (sim.)

40% (exp.)
90% (sim.)

CEPC & Test facility for developing Plasma-acceleration at IHEP





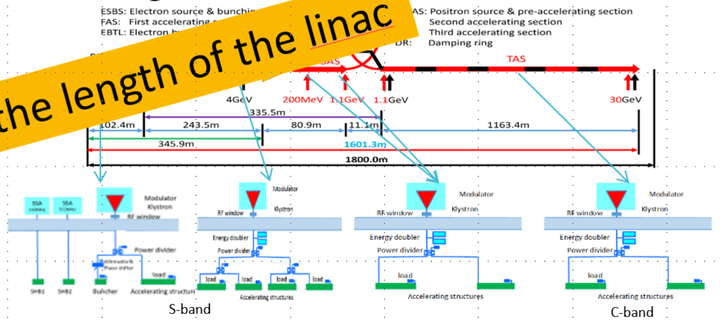
Cold C-band acceleration R&D activities and challenges

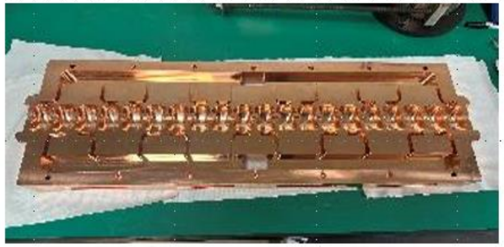
Jingru Zhang

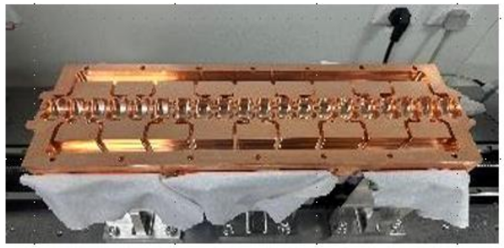
- The gradient of the 30 GeV linac normal conducting structures
  - S-band, 80 MW klystron
    - 1-1(ESBS), 1 accelerating structure, 22MV/m
    - 1-4 (FAS), 21 sets(6+15), 84 standard accelerating structures, 22MV/m
    - 1-2(PSPAS), 8 sets, 16 big hole accelerating structures, 22MV/m
    - 1-2(SAS), 4 sets, 8 accelerating structures, 27MV/m
  - C-band, 50 MW klystron
    - 1.1GeV-30GeV, 1-2(TAS), 235 sets, 470 accelerating structures, [illegible]/m

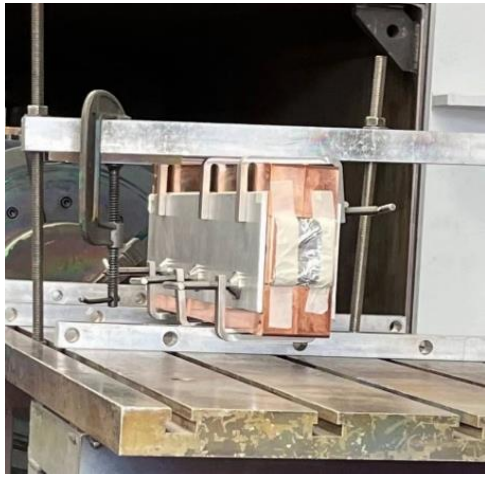
High gradient C3 reduces the length of the linac

Parameter	Unit	S-band		C-band
Frequency	MHz	2860		5720
Length	m	3.1	2.0	1.8
Cavity mode		2π/3		[illegible]
Aperture	mm	[illegible]		[illegible]
Gradient	[illegible]	[illegible]		40
Cells (include couple[illegible]	[illegible]	[illegible]	55	89
Number of Acc. Str[illegible]	[illegible]	93	16	470
Number of Klystron		33		236
Klystron Power	MW	80		50

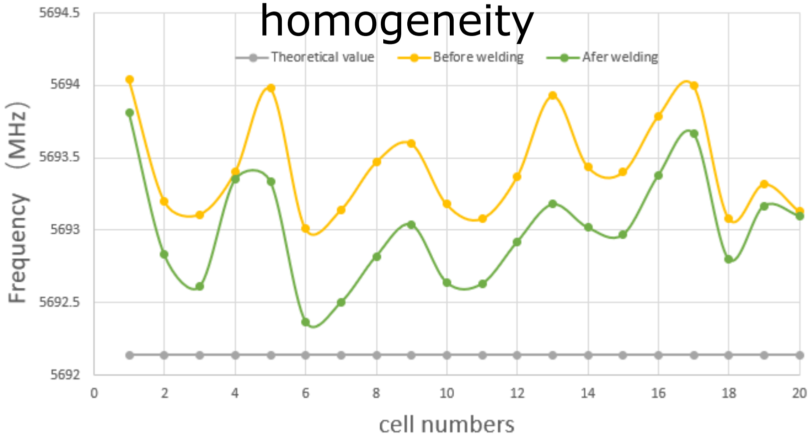




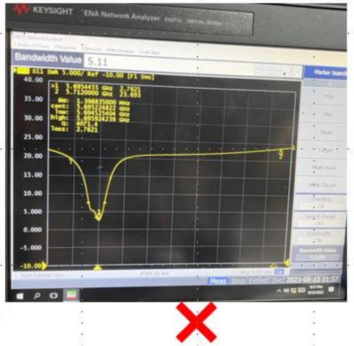


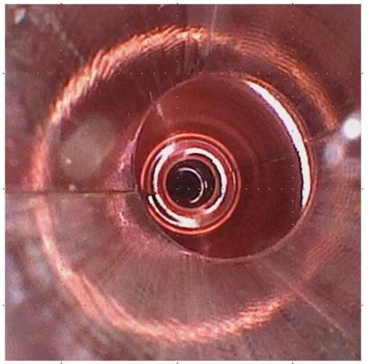


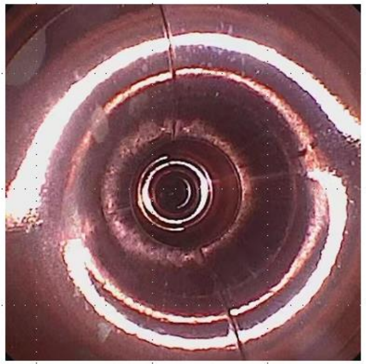
Acceptable in-air frequency homogeneity



Vacuuming the cavity breaks the good frequency distribution





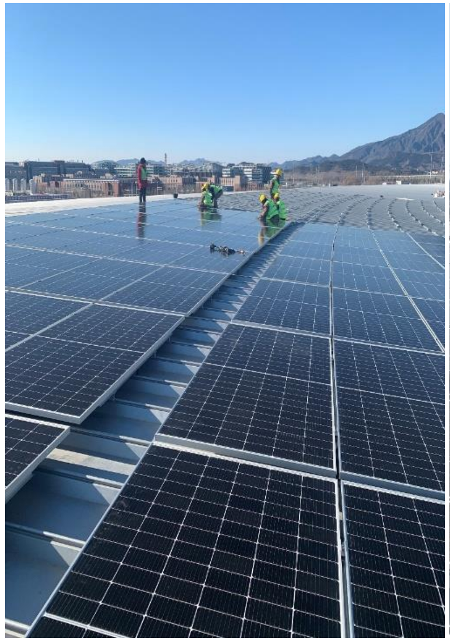


Exploring the inner of a cavity using an endoscope

Solar panels on-top of the roof at HEPS

Jinshu Huang

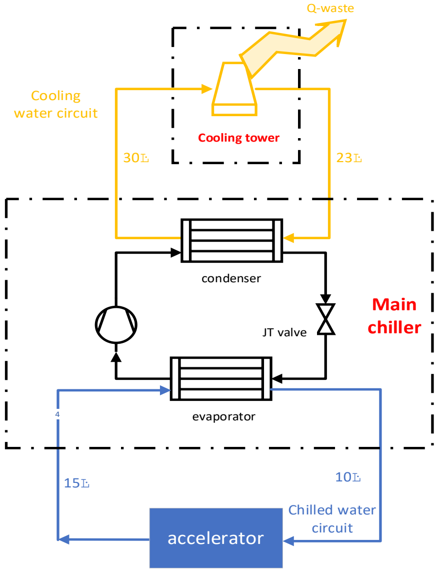
- Photovoltaic (PV) power generation systems are installed on the roofs of HEPS building complex
- Adopting 465Wp/550Wp monocrystalline silicon photovoltaic modules, the first phase has a total installed capacity of 9,950.92 kWp. The average annual power generation is expected to be 10.31 million kWh, and the equivalent average annual utilization hours will be 10,035.85h.
- Phase I was connected to the grid on 2023.10.30.
- The second phase is planned to lay PV modules on the ground inside the storage ring with an installed capacity of 7314.45kWp



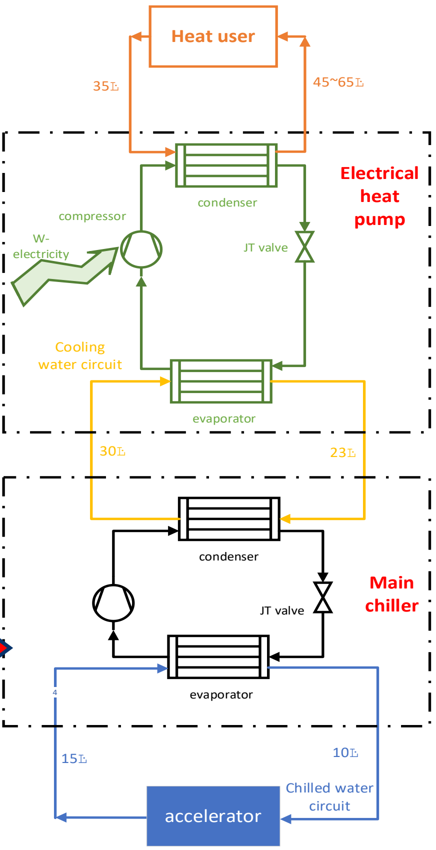
AHP serves to recover the waste heat

Rui Ge

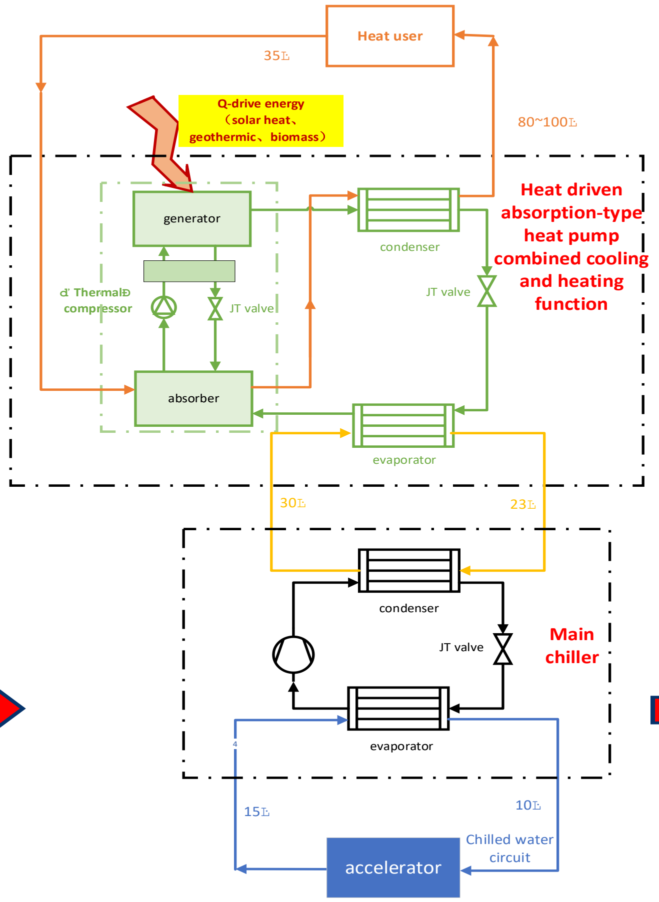
- As the rapid development of photovoltaic and heat storage technology, AHP can be served the new possible scheme to recover the waste heat.



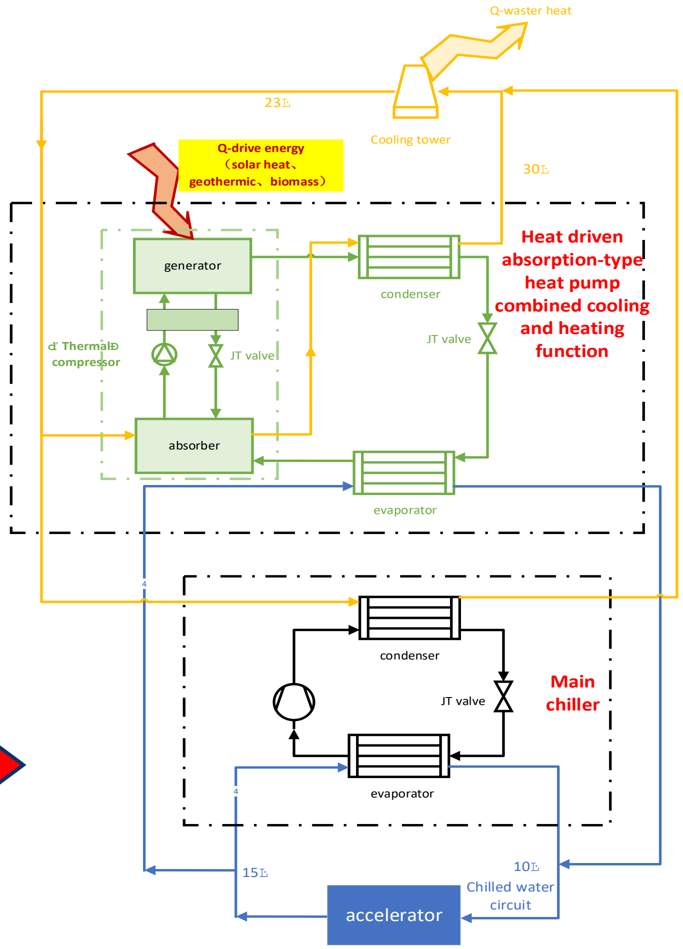
1. Conventional waste heat discharged through cooling towers in accelerator



2、Recovery the waster heat using the electrical heat pump



3、Heating condition-absorption type HP-recovery of waste heat Machine from the main cooling unit for heating



4、 Refrigeration condition - absorption Type HP - to produce part of the chilled water, can reduce the main cooling unit energy consumption (energy saving)

Summary

- Novel concept to improve the power efficiency, recycle energy, and generate renewable energy are addressed as comprehensive measures for sustainable operation.
- There are many common challenges to achieve a green & high efficiency machine
- Substantial collaborations can provide many benefits