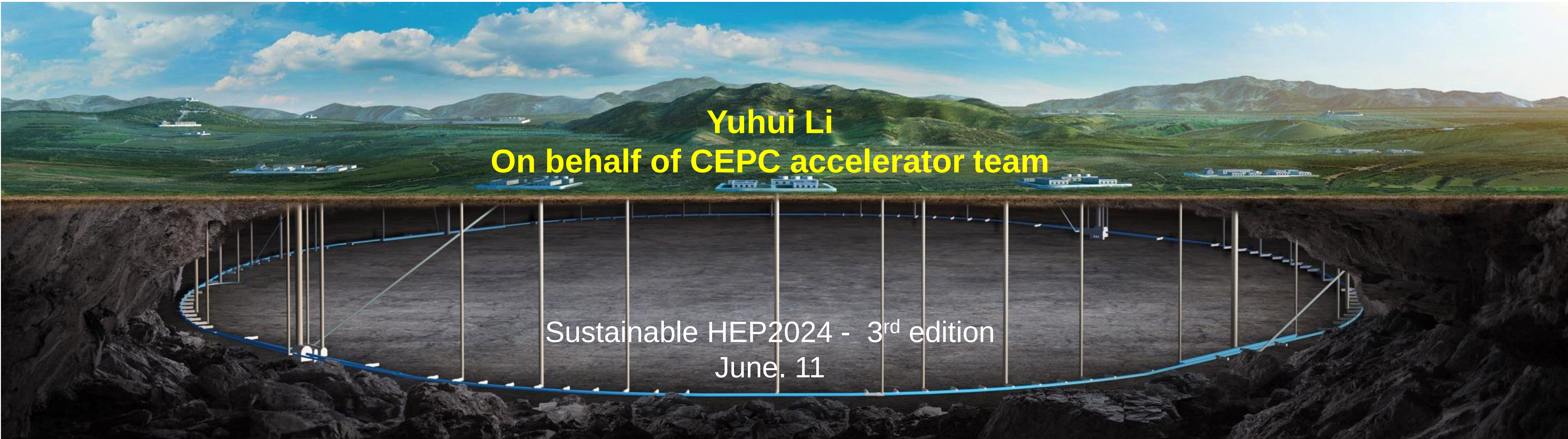
Efforts to make CEPC a green machine



Yuhui Li
On behalf of CEPC accelerator team

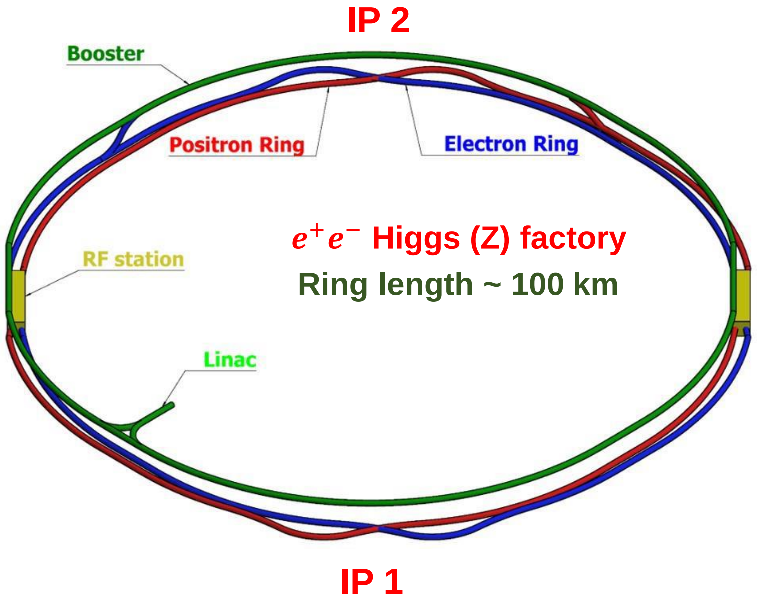
Sustainable HEP2024 - 3rd edition
June. 11

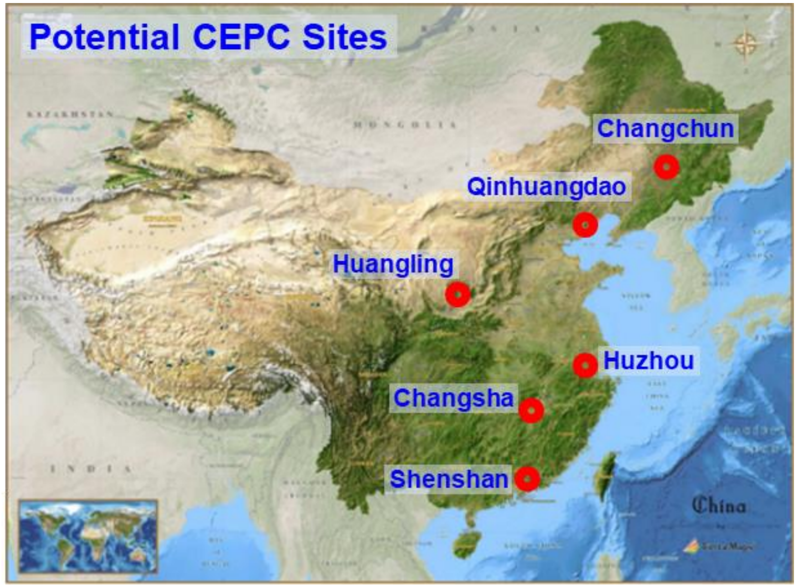
Approaches to a green machine/sustainability operation

- Brief introduction to CEPC
- CO2 footprint life-cycle assessment
  - Civil construction
  - Footprint of construction and operation
- Improving the key technology energy efficiency
  - Superconducting technology: High Q SRF cavity and cooling system; HTS magnets
  - High performance & efficiency RF source
  - Novel magnets: dual aperture magnet, permanent magnet
  - Application of revolutionary new acceleration technology, i.e. Plasma acceleration
  - Coating for the vacuum system, SST for magnet power supply
- Clean energy implement and utility
  - Solar panel
- Energy/non-renewable resource recovery
  - Waste energy recovery from cooling water and utility in civilization
  - Energy recovery from klystron
  - Helium recovery

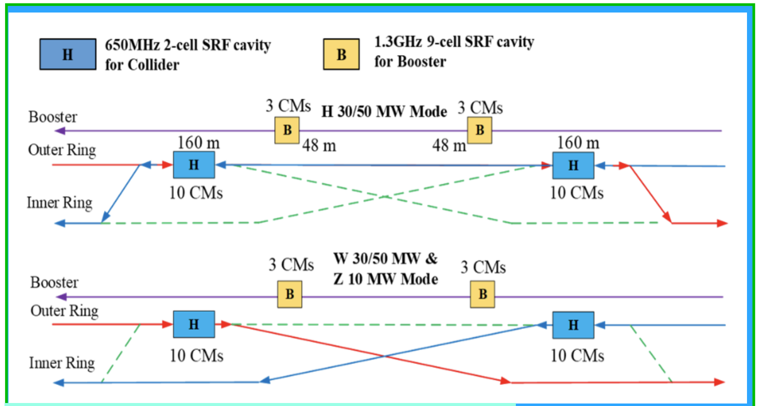
A brief introduction to CEPC

- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ≥1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and then $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the far future.

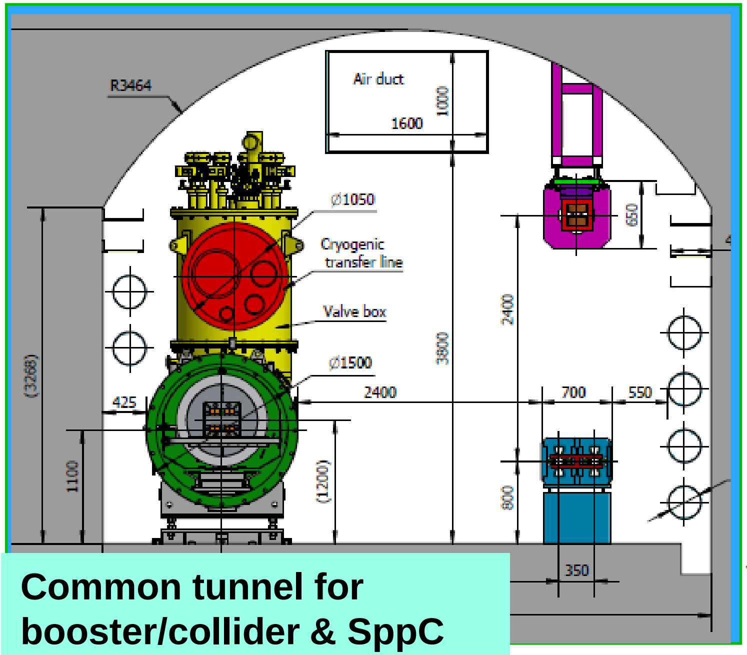




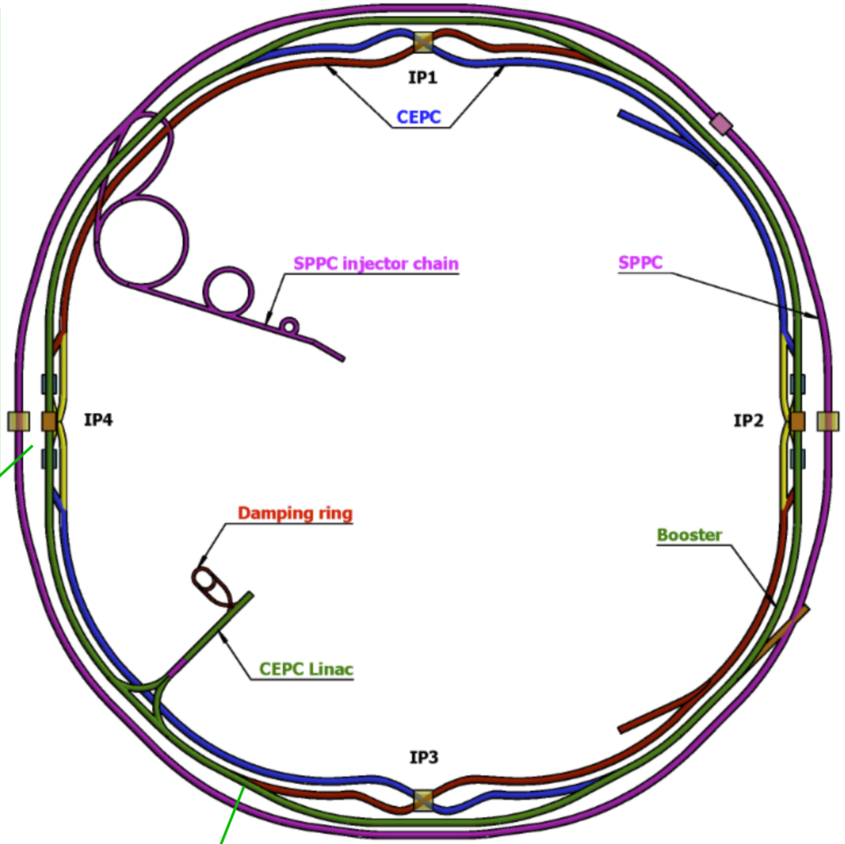
CEPC Layout and Design Essentials



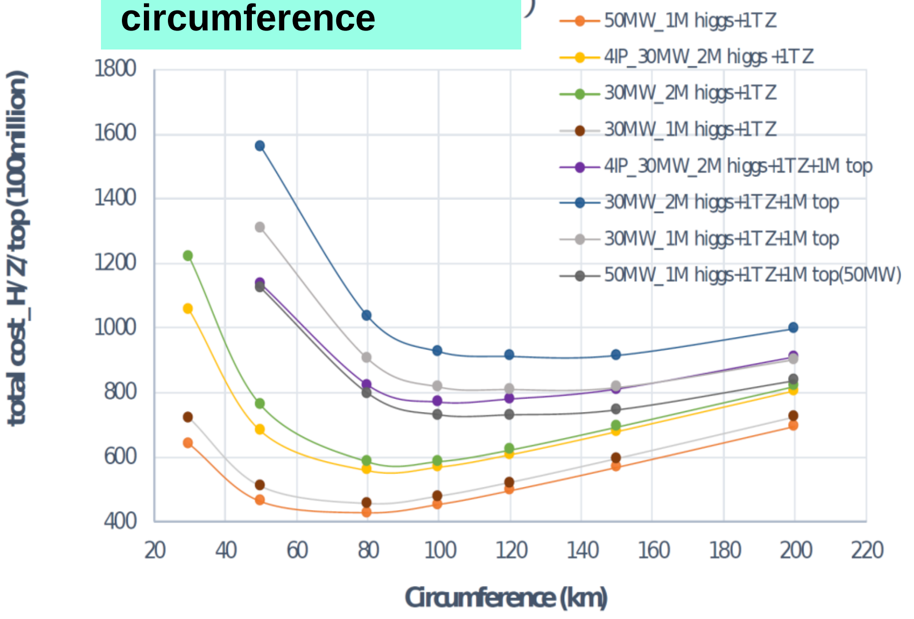
Switchable operation for Higgs W and Z



Common tunnel for booster/collider & SppC



Cost optimization v.s. circumference



D. Wang *et al* 2022 *JINST* **17** P10018

Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

- **Circular collider**: Higher luminosity than a linear collider
- **100km circumference**: Optimum total cost
- **Shared tunnel**: Compatible design for CEPC and SppC
- **Switchable operation**: Higgs, W/Z, top

CEPC operation plan

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. /IP ($10^{34} cm^{-2}s^{-1}$)	Integrated Lumi. /yr (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

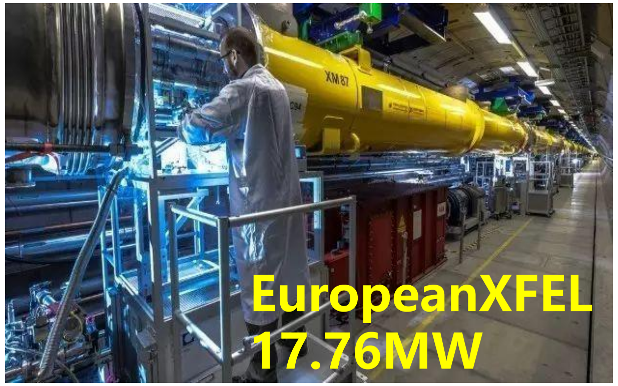
* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

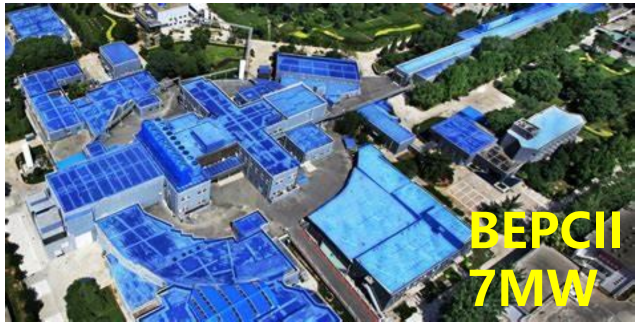
** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

Motivation and obligations to pursue a green machine

- China national dual-carbon strategy: CO_2 emission peak before 2030 and carbon neutrality before 2060)
- The modern high-performance accelerator complex consumes a significant amount of energy: LHC, ILC, CEPC…





Energy consumption breakdown @ 30MW SR power

Table A3.11: Total facility power consumption in Higgs mode (30 MW/beam)

	System for Higgs (30 MW /beam)	Location and power Requirement (MW)						Total (MW)
		Collider	Booster	Linac	BTL	IR	Surface building	
1	RF Power Source	96.90	0.15	12.26				109.31
2	Cryogenic System	9.72	1.71			0.16		11.59
3	Vacuum System	5.40	4.20	0.60				10.20
4	Magnet System	42.16	8.46	2.15	4.89	0.30		57.96
5	Instrumentation	1.30	0.70	0.20				2.20
6	Radiation Protection	0.30		0.10				0.40
7	Control System	1.00	0.60	0.20				1.80
8	Experimental Devices					4.00		4.00
9	Utilities	37.80	3.20	1.80	0.60	1.20		44.60
10	General Services	7.20		0.30	0.20	0.20	12.00	19.90
	Total	201.78	19.02	17.61	5.69	5.86	12.00	261.96

CEPC-TDR p965

- The total electricity consumption is **262MW** for the operation of SR power **30MW**
- The major energy consumer systems:
  - RF power (109 MW)
  - Magnet (58 MW)
  - Cryogenics (11.6 MW)
- Auxiliary power:
  - Instrumentation(2.2) + Radiation Protection (0.4) + Control (1.8) + Experimental device (4) +Utility(44.6) +General Service(19.9) = **73 MW**

Energy consumption breakdown @ 50MW SR power

Table A3.15: Total facility power consumption in Higgs mode (50 MW/beam)

	System for Higgs (50 MW /beam)	Location and power Requirement (MW)						Total (MW)
		Collider	Booster	Linac	BTL	IR	Surface building	
1	RF Power Source	161.60	1.73	14.10				177.43
2	Cryogenic System	9.17	1.77			0.16		11.10
3	Vacuum System	5.40	4.20	0.60				10.20
4	Magnet System	42.16	8.46	2.15	4.89	0.30		57.96
5	Instrumentation	1.30	0.70	0.20				2.20
6	Radiation Protection	0.30		0.10				0.40
7	Control System	1.00	0.60	0.20				1.80
8	Experimental Devices					4.00		4.00
9	Utilities	46.40	3.80	2.50	0.60	1.20		54.50
10	General Services	7.20		0.30	0.20	0.20	12.00	19.90
	Total	274.53	21.26	20.15	5.69	5.86	12.00	339.49

CEPC-TDR p967

The total power at other operation modes are listed in TDR

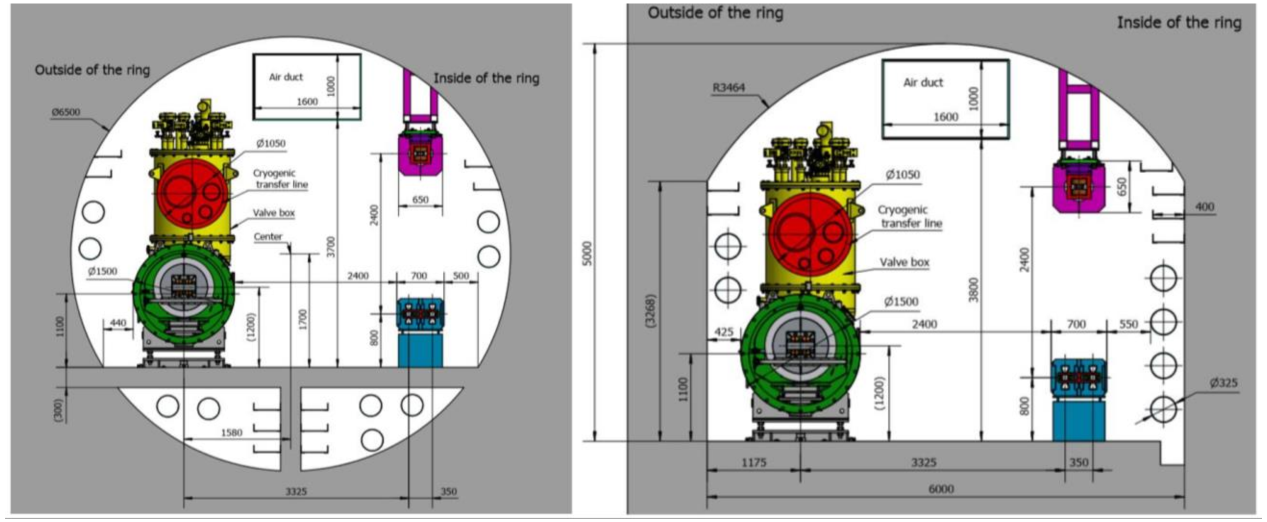
- The total electricity consumption is **340MW** for the operation of Higgs, SR power **50MW**
- The major energy consumer systems:
  - RF power (177MW)
  - Magnet (58MW)
  - Cryogenics (11 MW)
- Auxiliary power:
  - Instrumentation(2.2) + Radiation Protection(0.4) + Control(1.8) + Experimental device (4) + Utility(54.5) + General Service(19.9) = **78 MW**

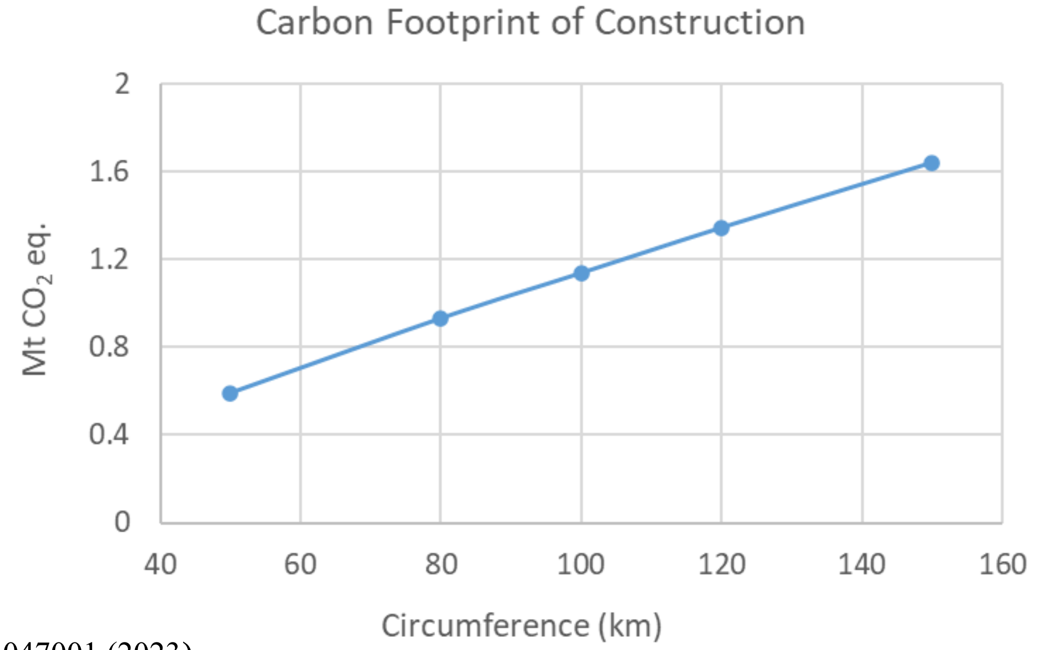
CO2 footprint of civil construction (preliminary)

● Tunnel cross section and CO2 footprint

- ILC: 7.34 kton CO_2/km (9.5 m diameter)
- CLIC: 6.38 kton CO_2/km (5.6 m diameter)

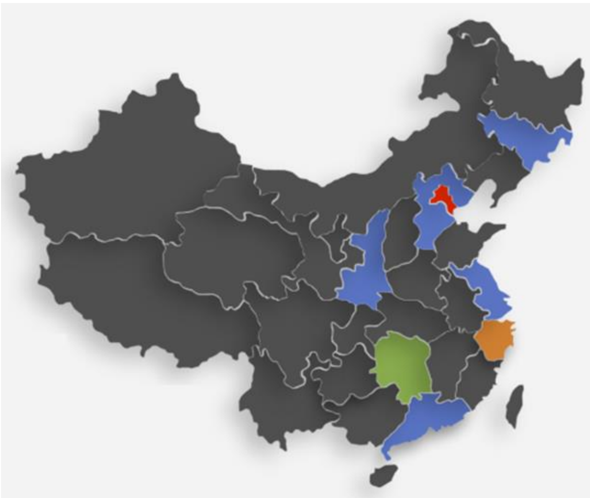
- Main tunnel: 7.0 kton CO_2 e/km
- Auxiliary civil construction: ~30% of emissions (klystron gallery, access shafts, alcoves, and caverns) , referring to 100km circumference
- transport and construction process emissions*: ~25% emission, proportional to the tunnel lengh





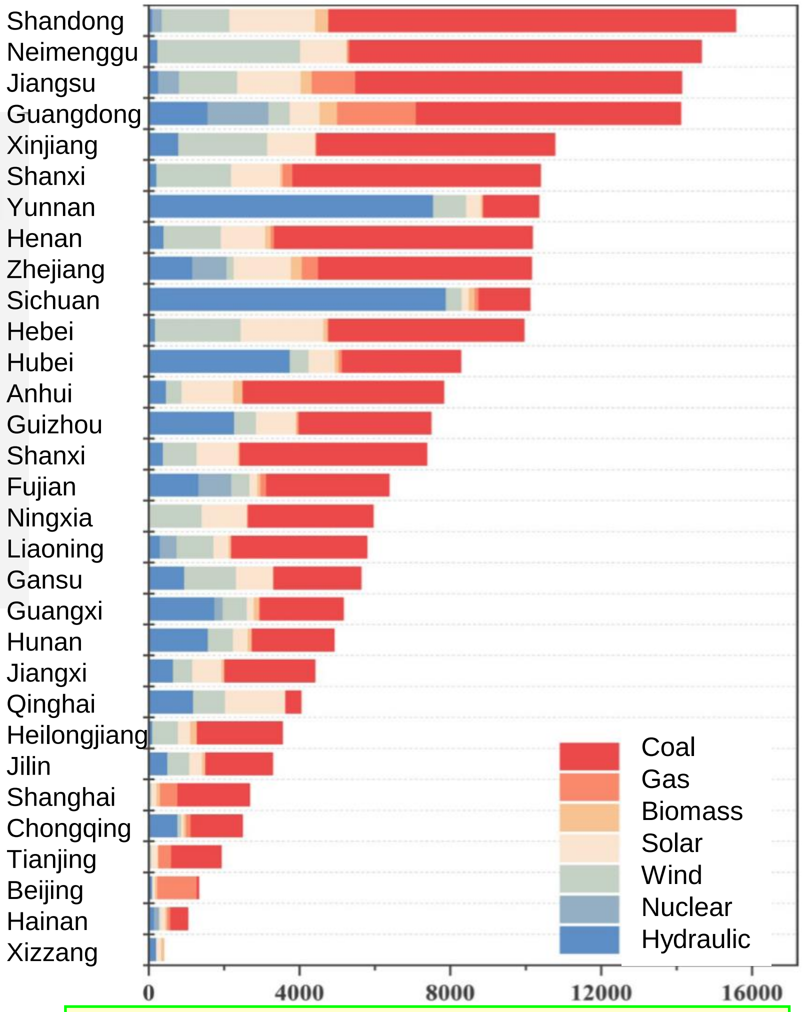
* Martin Breidenbach et. al., "Sustainability Strategy for the Cool Copper Collider", PRX Energy 2, 047001 (2023)

Electricity carbon intensity map



Electricity Transport:

- North-to-South
- West-to-East



Electricity Generating Capacity in China 2020 (10000 kW)

Carbon intensity (kgCO2/kWh)

省份	2010 年	2012 年	2018 年	2020 年
Liaoning	0.836	0.775	0.722	0.91
Jilin	0.679	0.721	0.615	0.839
Heilongjiang	0.816	0.797	0.663	0.814
Beijing	0.829	0.776	0.617	0.615
Tianjin	0.873	0.892	0.812	0.841
Hebei	0.915	0.898	0.903	1.092
Shanxi	0.88	0.849	0.74	0.84
Neimenggu	0.85	0.929	0.753	1.0
Shandong	0.924	0.888	0.861	0.742
Shanghai	0.793	0.624	0.564	0.548
Jiangsu	0.736	0.75	0.683	0.695
Zhejiang	0.682	0.665	0.525	0.532
Anhui	0.791	0.809	0.776	0.763
Fujian	0.544	0.551	0.391	0.489
Jiangxi	0.764	0.634	0.634	0.616
Henan	0.844	0.806	0.791	0.738
Hubei	0.372	0.353	0.357	0.316
Hunan	0.552	0.517	0.499	0.487
Chongqing	0.629	0.574	0.441	0.432
Sichuan	0.289	0.248	0.103	0.117
Guangdong	0.638	0.591	0.451	0.445
Guangxi	0.482	0.495	0.394	0.526
Hainan	0.646	0.686	0.515	0.459
Guizhou	0.656	0.495	0.428	0.42
Yunnan	0.415	0.306	0.092	0.146
Shanxi	0.87	0.769	0.767	0.641
Gansu	0.612	0.573	0.491	0.46
Qinghai	0.226	0.232	0.26	0.095
Ningxia	0.818	0.779	0.62	0.872
Xinjiang	0.764	0.79	0.622	0.749

Qinhuangdao

Huzhou

Changsha

Shenshan

Carbon intensity expectation (2025-2035)

省份	2025 年	2030 年	2035 年
Liaoning	0.578 (0.528-0.664)	0.496 (0.432-0.571)	0.371 (0.342-0.408)
Jilin	0.564 (0.559-0.594)	0.43 (0.384-0.472)	0.216 (0.210-0.281)
Heilongjiang	0.654 (0.648-0.683)	0.599 (0.590-0.621)	0.504 (0.467-0.528)
Beijing	0.595 (0.573-0.612)	0.519 (0.476-0.532)	0.289 (0.208-0.299)
Tianjin	0.688 (0.668-0.709)	0.536 (0.53-0.584)	0.418 (0.413-0.448)
Hebei	0.736 (0.714-0.784)	0.683 (0.666-0.733)	0.544 (0.512-0.571)
Shanxi	0.707 (0.69-0.738)	0.7 (0.684-0.738)	0.598 (0.583-0.633)
Neimenggu	0.8 (0.791-0.836)	0.792 (0.783-0.836)	0.673 (0.665-0.714)
Shandong	0.546 (0.536-0.56)	0.498 (0.489-0.506)	0.383 (0.36-0.386)
Shanghai	0.333 (0.321-0.464)	0.325 (0.312-0.432)	0.281 (0.259-0.349)
Jiangsu	0.601 (0.579-0.639)	0.512 (0.489-0.539)	0.411 (0.386-0.435)
Zhejiang	0.418 (0.412-0.427)	0.386 (0.381-0.402)	0.307 (0.289-0.314)
Anhui	0.755 (0.725-0.758)	0.694 (0.65-0.757)	0.596 (0.546-0.644)
Fujian	0.363 (0.346-0.379)	0.33 (0.322-0.358)	0.27 (0.266-0.293)
Jiangxi	0.474 (0.451-0.498)	0.436 (0.414-0.444)	0.354 (0.334-0.359)
Henan	0.599 (0.553-0.621)	0.49 (0.462-0.512)	0.389 (0.356-0.409)

省份	2025 年	2030 年	2035 年
Hubei	0.31 (0.307-0.317)	0.254 (0.247-0.316)	0.202 (0.19-0.261)
Hunan	0.453 (0.447-0.46)	0.409 (0.397-0.422)	0.312 (0.3-0.331)
Chongqing	0.363 (0.231-0.396)	0.256 (0.193-0.304)	0.179 (0.131-0.226)
Sichuan	0.104 (0.103-0.107)	0.075 (0.073-0.075)	0.04 (0.04-0.04)
Guangdong	0.369 (0.359-0.382)	0.332 (0.318-0.351)	0.276 (0.269-0.295)
Guangxi	0.336 (0.316-0.363)	0.334 (0.317-0.373)	0.279 (0.26-0.308)
Hainan	0.326 (0.312-0.332)	0.224 (0.188-0.236)	0.115 (0.11-0.143)
Guizhou	0.398 (0.393-0.408)	0.276 (0.26-0.278)	0.204 (0.146-0.206)
Yunnan	0.1 (0.093-0.102)	0.062 (0.05-0.075)	0.025 (0.022-0.03)
Shanxi	0.607 (0.533-0.623)	0.601 (0.528-0.619)	0.515 (0.446-0.53)
Gansu	0.443 (0.433-0.469)	0.407 (0.391-0.439)	0.279 (0.223-0.285)
Qinghai	0.067 (0.048-0.078)	0.032 (0.027-0.041)	0.01 (0.01-0.013)
Ningxia	0.724 (0.703-0.758)	0.665 (0.643-0.714)	0.459 (0.452-0.551)
Xinjiang	0.720 (0.601-0.745)	0.713 (0.595-0.745)	0.573 (0.516-0.599)

- The carbon intensity will be reduced rapidly until 2035 in China.
  - Qing Hai: 0.01 kgCO2/kWh (hydroelectric, wind and photovoltaic dominate)
  - Hu Nan: 0.312 kgCO2/kWh (hydroelectric and coal dominate)

CEPC Higgs CO2 footprint (preliminary)

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

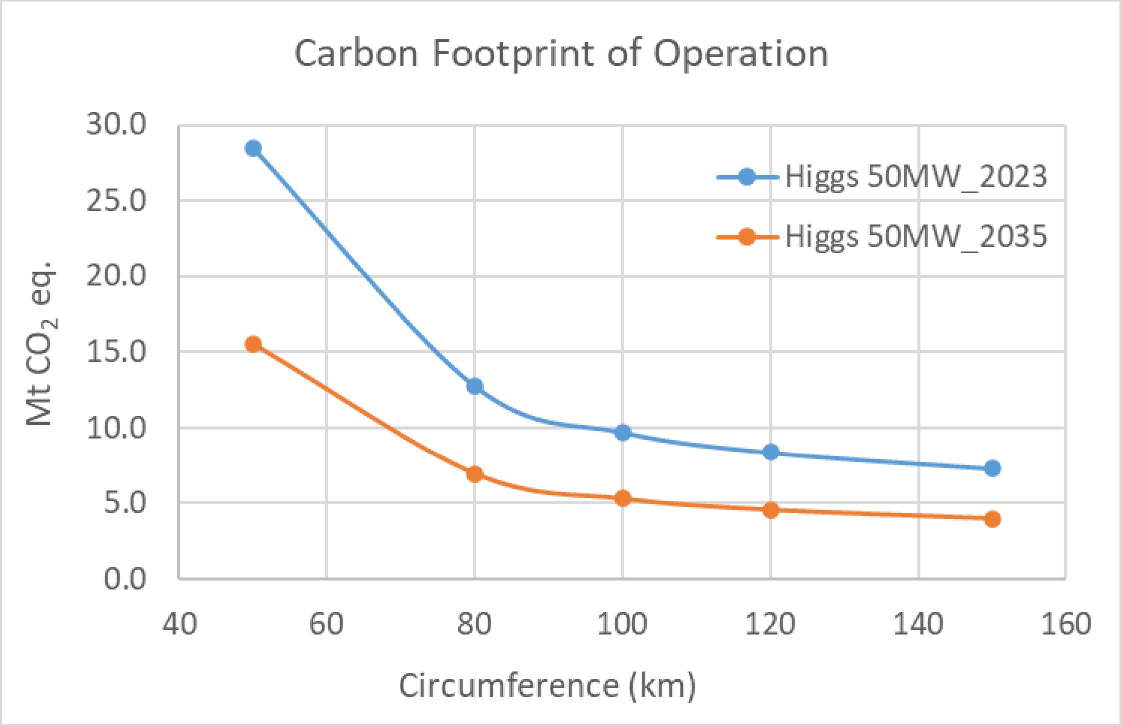


Table: CEPC parameters*

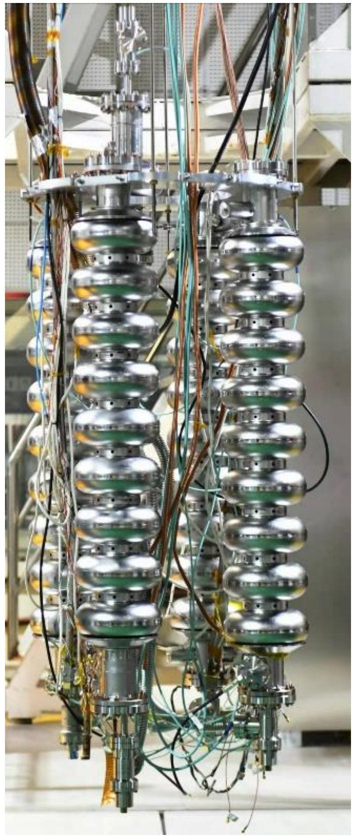
Circumference(km)	50	80	100	120	150
L /IP (50MW) (10^{34} $cm^{-2}s^{-1}$)	2.83	6.33	8.33	9.7	11.1
Total Higgs particle (million)			4		
Collision time/year (month)			5		
Running time (years)	30	14	10	9	8
Instantaneous power (MW)			**340**		

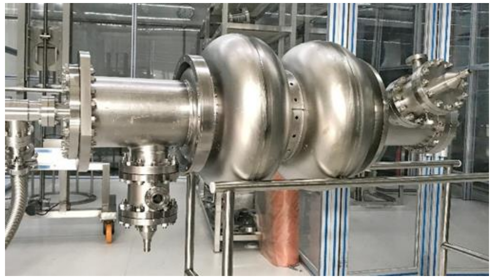
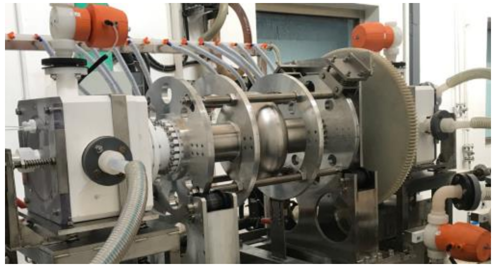
*Dou Wang, et al., “CEPC cost model study and circumference optimization”, *Journal of Instrumentation*, (2022)17 P10018.

These evaluations are entirely based on the success of key technologies R&D, as well as stable fabrication and operation.

SRF cavity using Mit-T baking

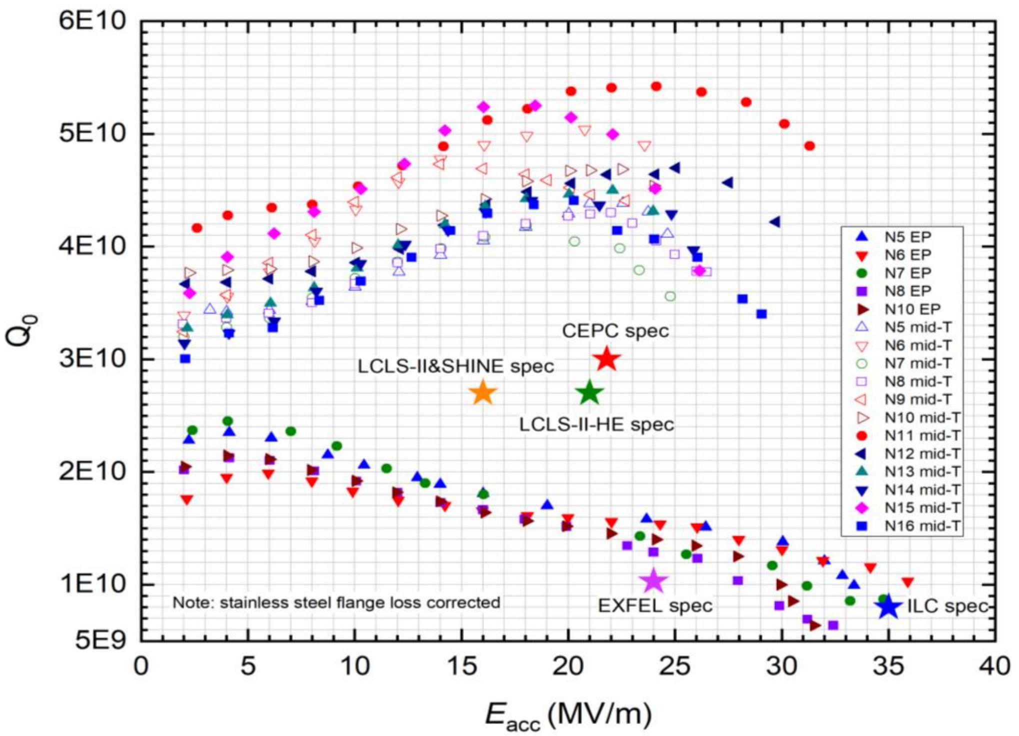
- Mid-T baking (O-doping) vs. N-doping: higher E_{acc} & Q, simple process, less EP
- Excellent results obtained, exceeding requirements of CEPC, SHINE, LCLS-II, etc.
- ILC-type cavities with higher E_{acc} is also under development



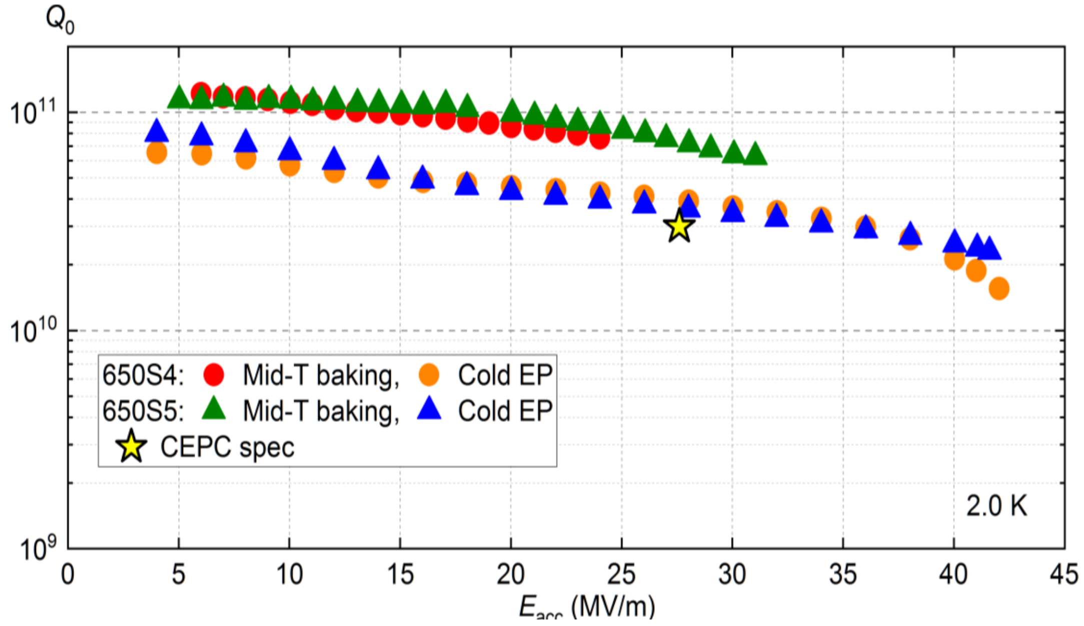




Mid-temp baking SRF cavity test results

1.3GHz 9-cell cavity VT



650 MHz 1-cell cavity VT



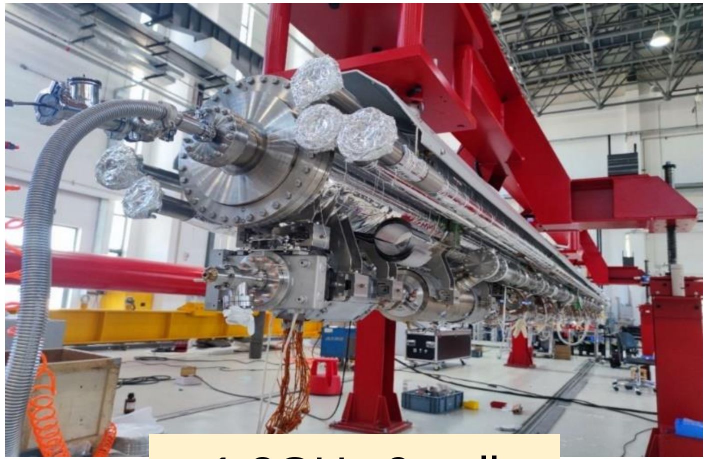
- Mid-T baking applied to 1.3GHz/650MHz cavities, resulting in High Q SRF cavity that meets the CEPC specification;
- Completed SRF modules for both 1.3GHz and 650MHz cavities were assembled;

SRF cryo-module horizontal test results

- 650 MHz test cryomodules including cavities, couplers, HOM absorbers, tuners..., was built and tested OK
- A full eight 1.3 GHz 9-cell cavities with input couplers, tuners, SC magnet, BPM, cryostat, module cart, feed/end-cap, volve-box ... was built and tested OK

Parameters	Horizontal test results	CEPC Booster Higgs	LCLS-II, SHINE	LCLS-II-HE
Average Q_0 @ 21.8 MV/m	3.6×10^{10}	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average CW E_{acc} (MV/m)	23.1			

650MHz 2-cell



1.3GHz 9-cell

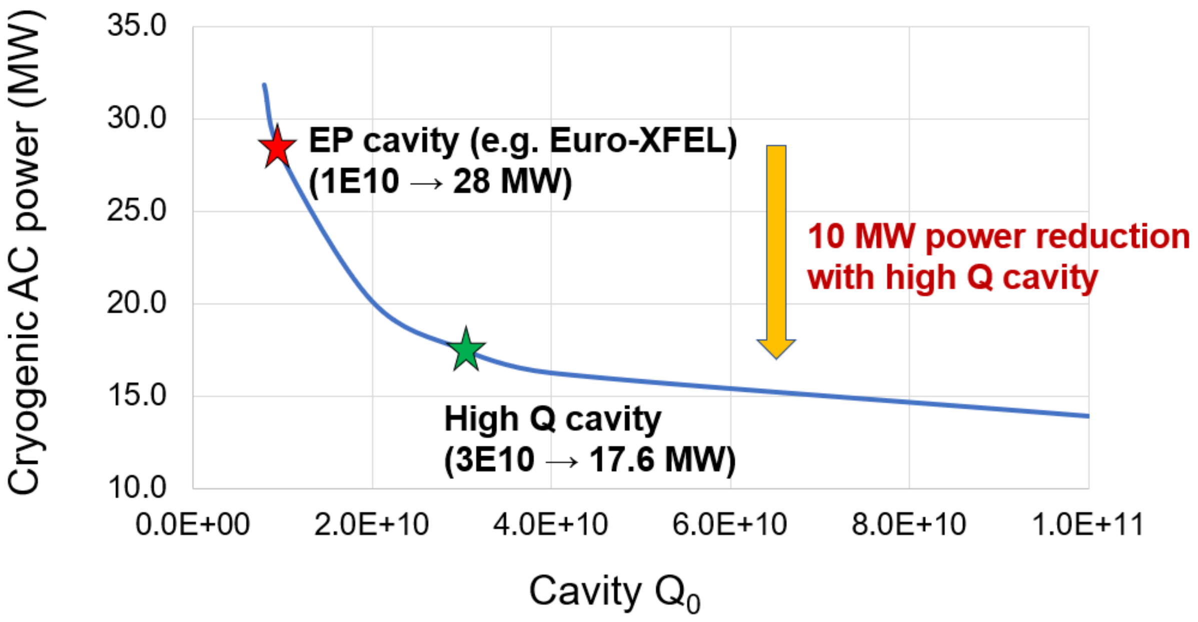
1.3GHz 9-cell

166MHz QW

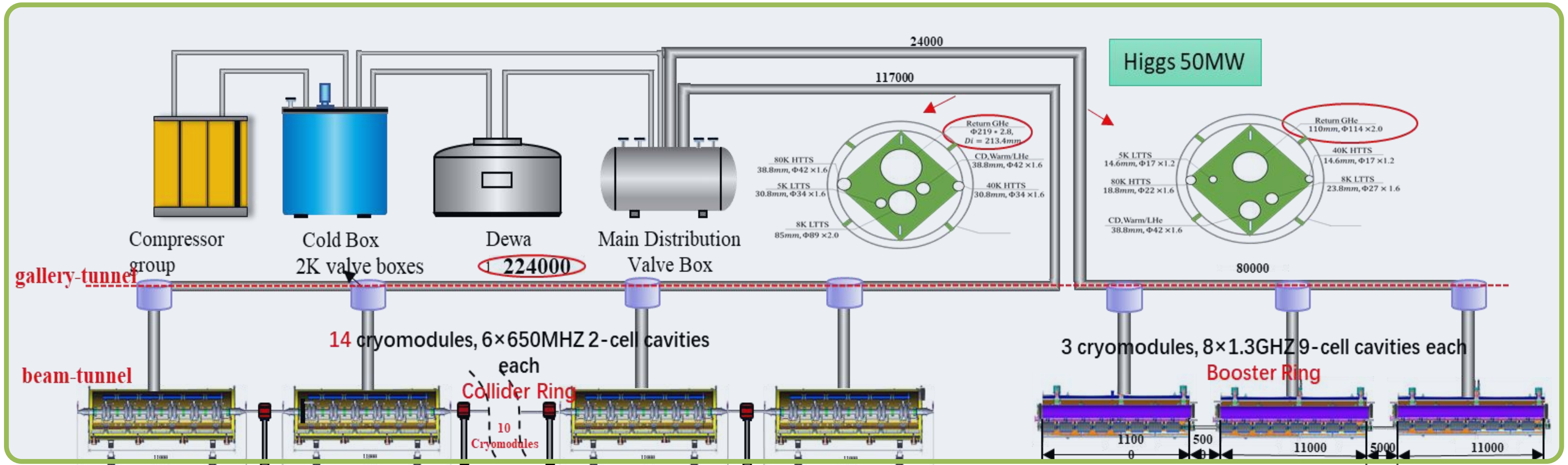
High Q SRF significance for a green machine

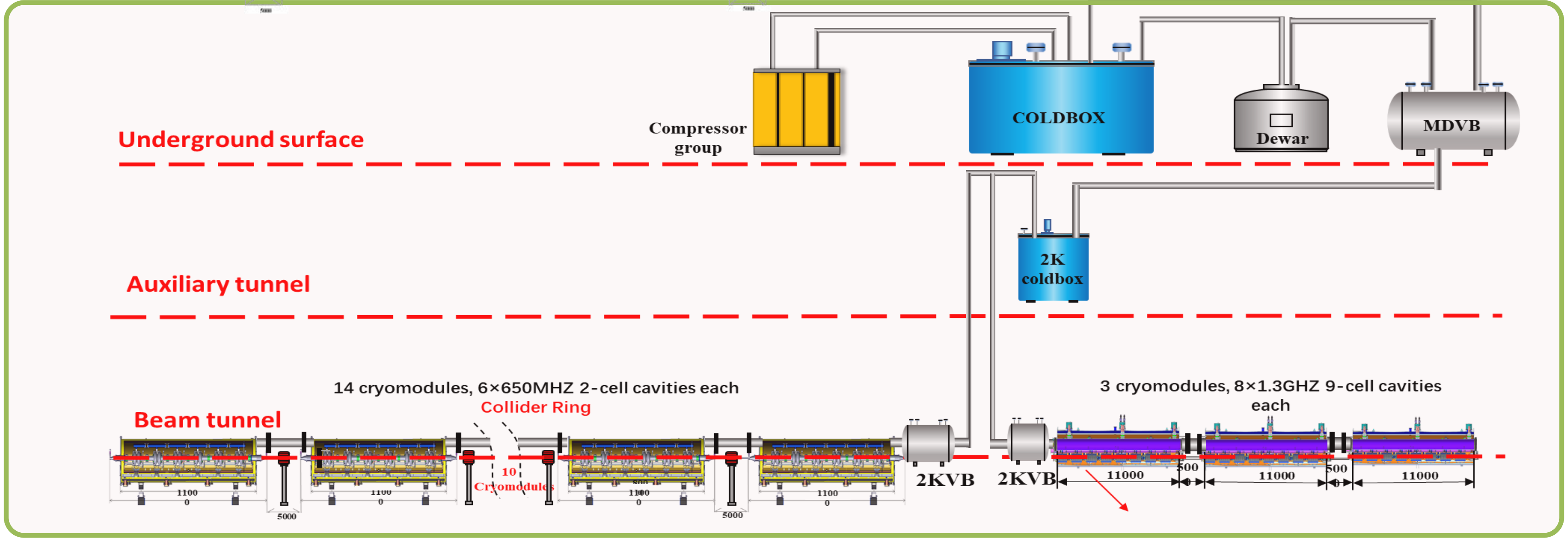
- The SRF system, along with its cryogenic auxiliaries, is one of the major electricity consumers. High Q-factor SRF cryo-modules effectively reduce the heat load, resulting in lower energy consumption
- The CEPC 1.3GHz SRF cavities adopt the mid-temp baking technology, which enhances the Q factor by 5 times compared to the EP technique.
- Using the high-Q SRF in CEPC may reduce the operational power by 10MW, which could result in an electricity savings of approximately 60M kWh per year.

Power consumption with respect to the cavity Q-factor
CEPC 50MW Higgs operation



Optimization to the cryogenic system





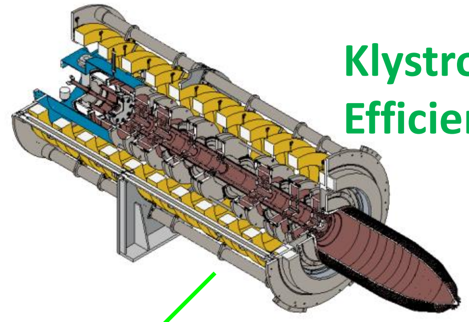
CDR

TDR

- Eliminate many small valve boxes;
- Process flow looks more easier;
- Reduce the cryogenic cost;

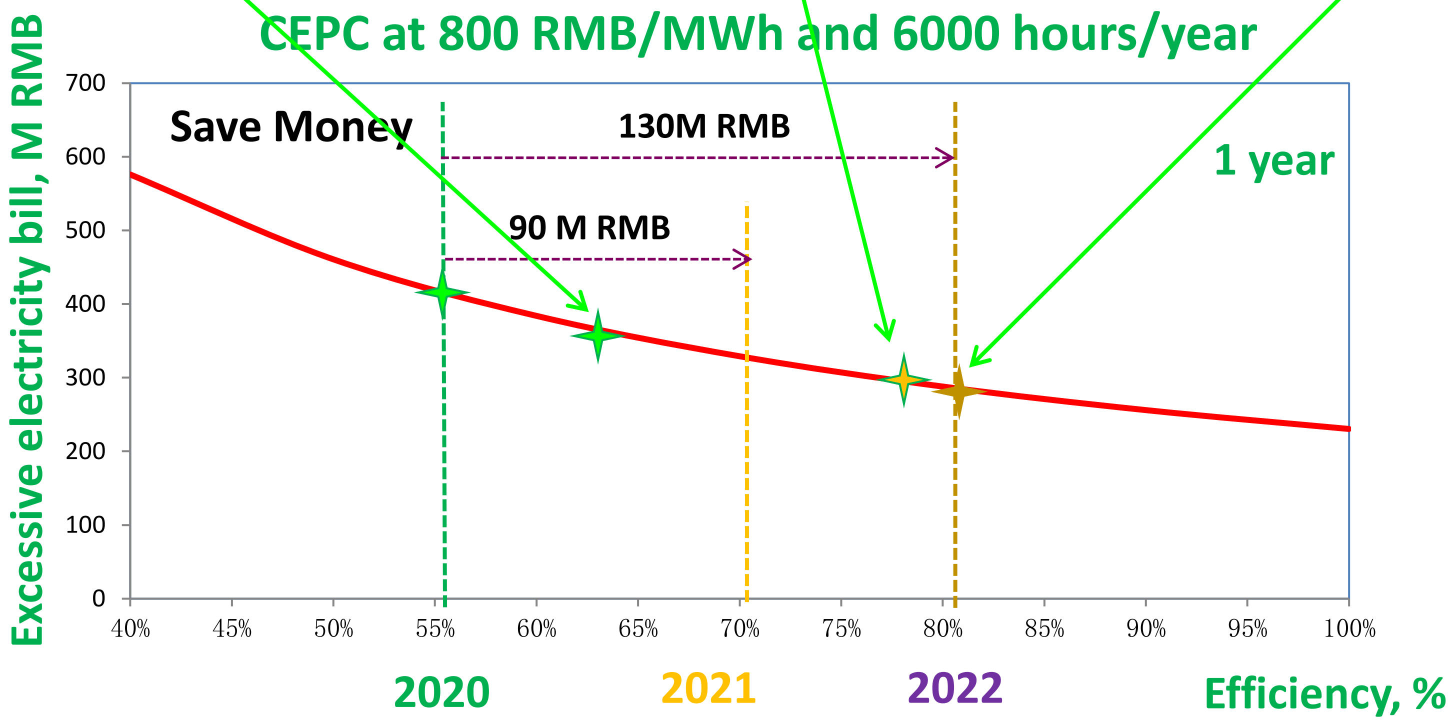
Endeavors for a high-efficient klystron

Klystron No. 2
aiming at
efficiency 77%



Klystron No. 3
Efficiency 80.5%

Klystron No. 1
Efficiency 62%
(2020)

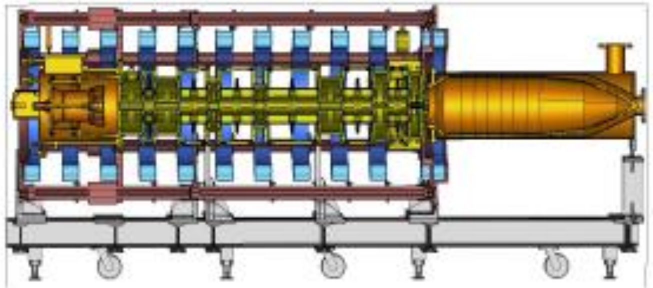


Efficiency impact on operation cost (Only considering operation efficiency of 650MHz klystrons)

Research status of the klystron

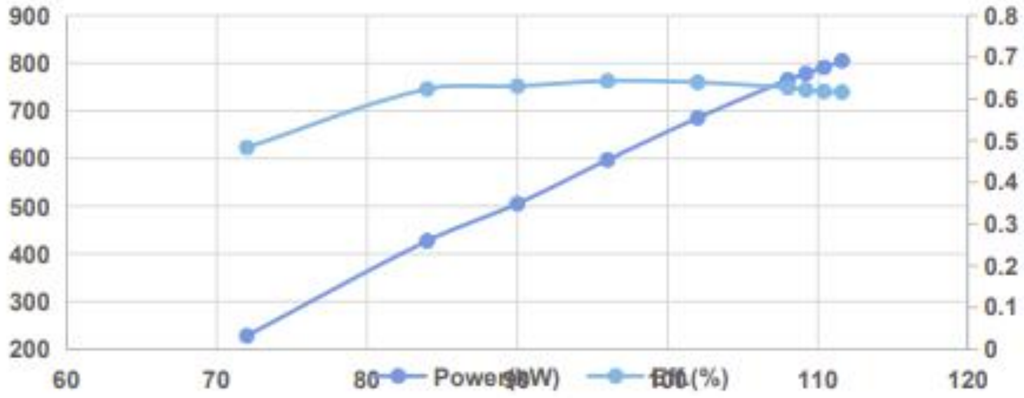
Klystron No. 1
Efficiency 65%
(2020)

Klystron No. 2
Efficiency 77%
(2021)



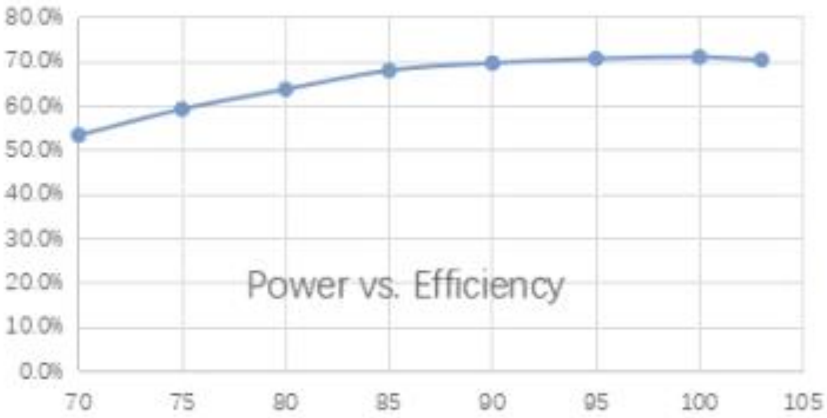
Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

Pulsed RF Mode (30% duty factor, 60ms/5Hz)

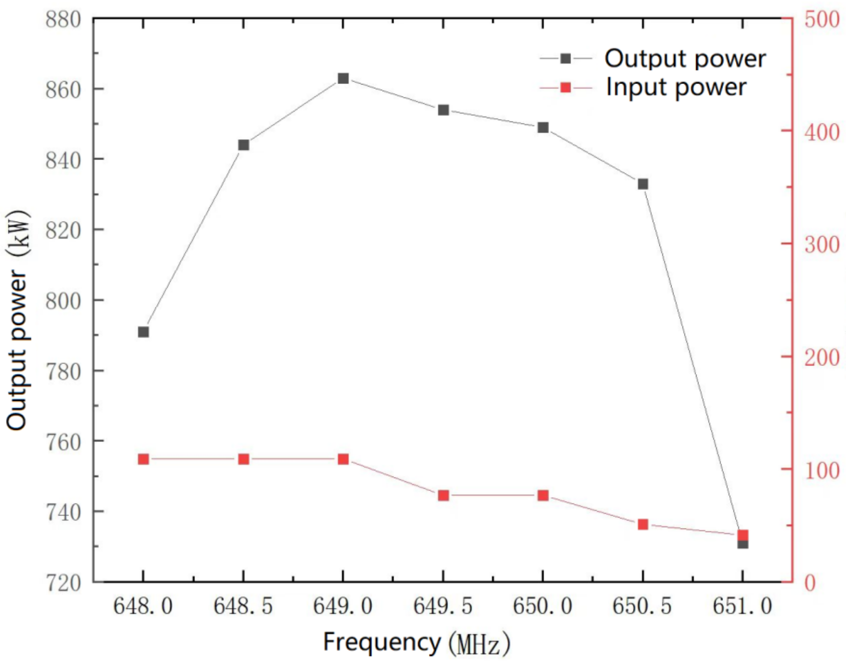


2022

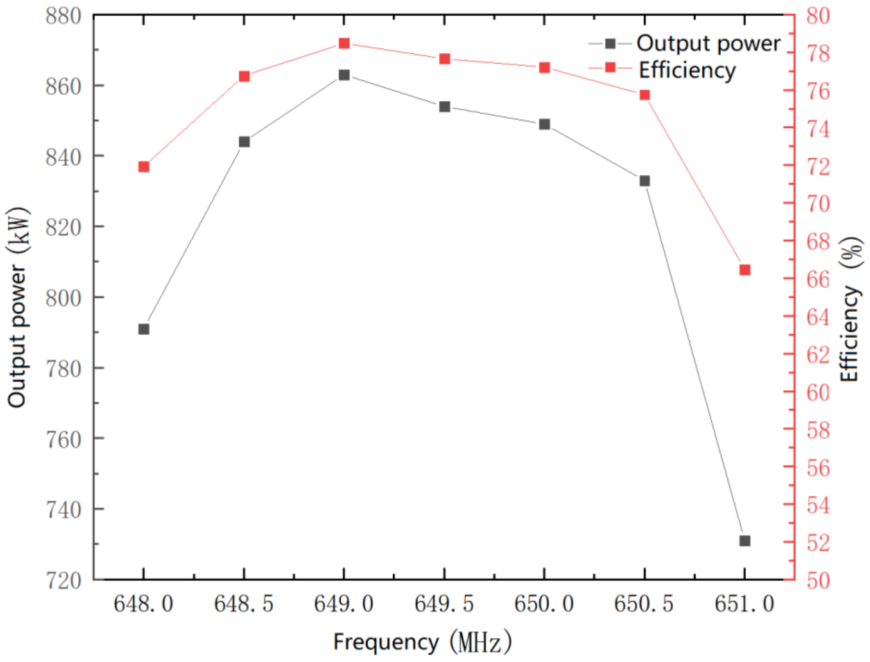
70.5% @ 630kW



2nd round test is on-going



Output power vs. input power



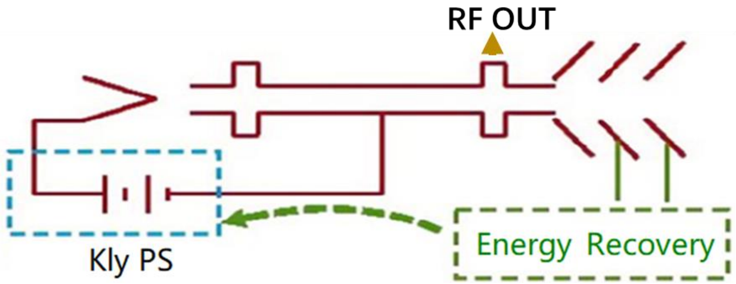
Output power vs. Efficiency

- 2nd round test since January of 2023, 77.2% @849 kW was achieved in pulse mode
- Further test is on going for wider pulse and CW mode

A Multi-Beam Klystron will be completed soon, with the high power test scheduled in 2024

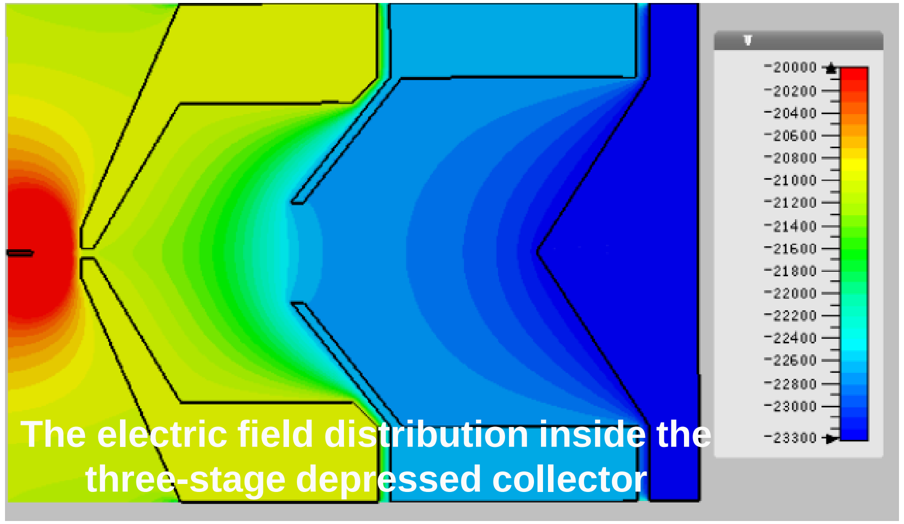
Energy recovery by decelerating the used beams

- 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.



Typical klystron

Energy recovery klystron

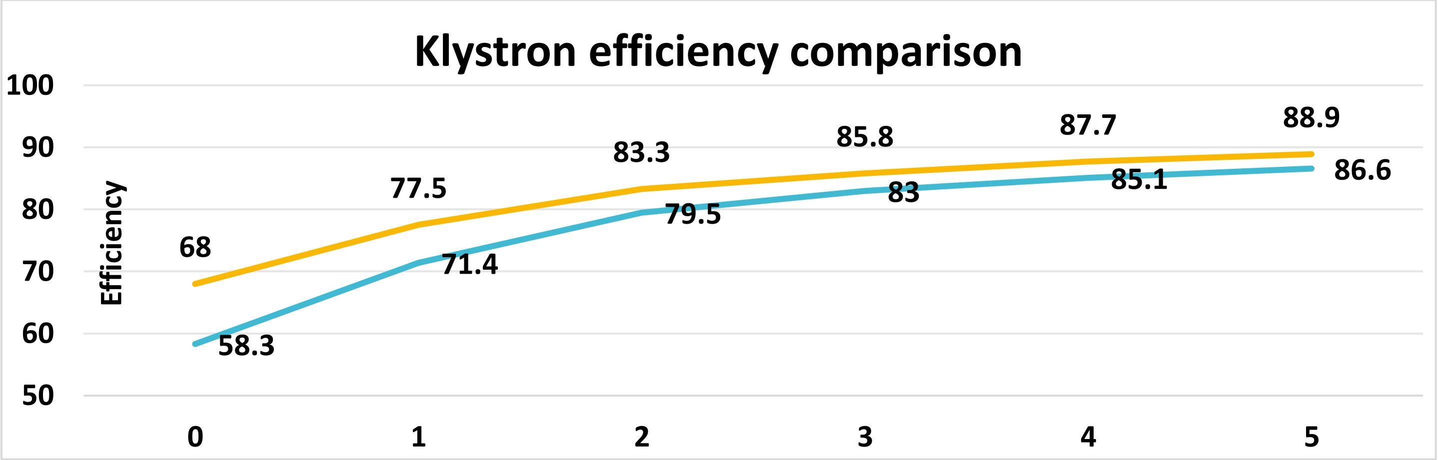


The electric field distribution inside the three-stage depressed collector

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

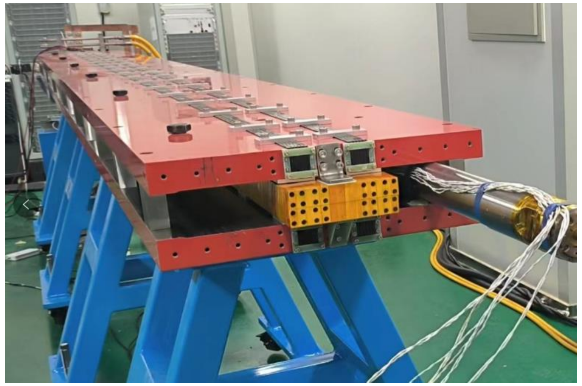
CEPC high efficiency klystron prototype H.V. 113kV Cur. 9.5A		
Coll. Qty	Coll. Eff.	Kly. Eff.
0	0.0%	68.0%
1	29.8%	77.5%
2	47.7%	83.3%
3	55.6%	85.8%
4	61.4%	87.7%
5	65.2%	88.9%

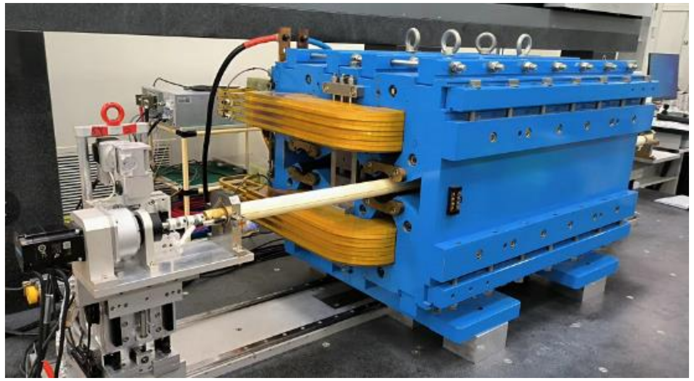
CEPC first prototype H.V. 81.5kV Cur. 15.3A		
Coll. Qty	Coll. Eff.	Kly. Eff.
0	0.00%	58.3%
1	31.4%	71.4%
2	50.9%	79.5%
3	59.2%	83.0%
4	64.3%	85.1%
5	67.9%	86.6%

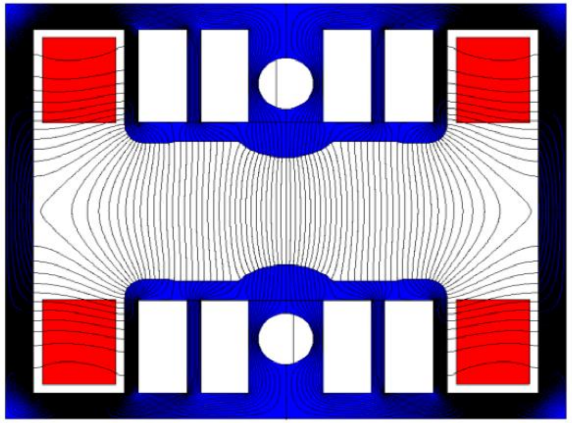


Novel design and prototypes for the room-temperature magnet

- **Dual aperture magnets prototypes for the CEPC Collider**
  - Following the proposal of dual-aperture magnets with common coils from CERN, the CEPC team has developed prototypes for dipoles and quadrupoles. Both prototypes meet the specified requirements.
  - Large amount of dual-aperture magnets will be used in CEPC: 7574 sets of magnets cover about **84.67 km**
  - Compare to the conventional separated-aperture magnets, the dual-aperture magnets will save **50% electricity**, roughly **40 MW**

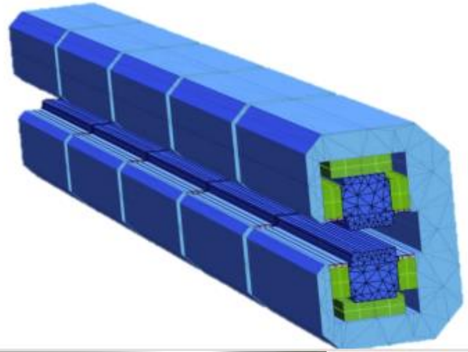






- **Combine-function dipole- sextuple design for the CEPC Booster, eliminating a lot of sextuples and resducing their energy consumption**

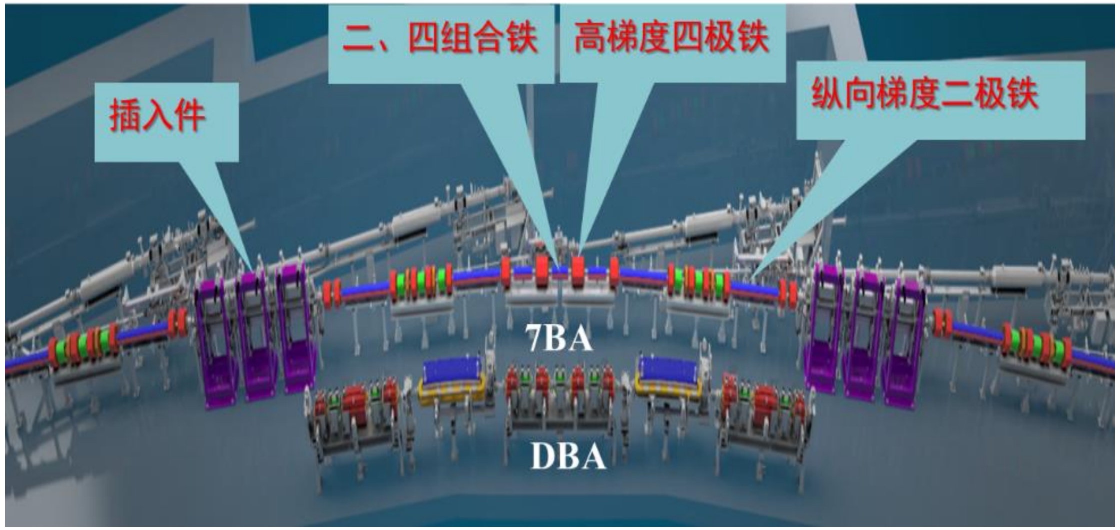
HEPS employs permanent dipole magnets



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

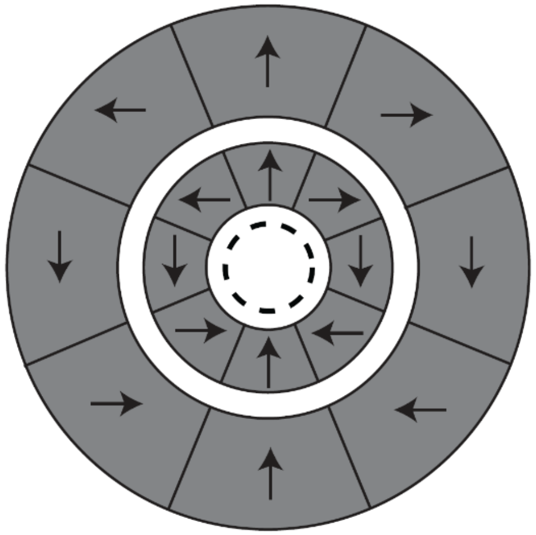
- Equivalent single excitation energy consumption of about 1.62kW.
- Equivalent cooling, power efficiency additional energy consumption of about 1.3kW
- 240 magnets in the whole ring
- Annual running time of 8000 hours

Annual saving electricity about **5.6 million kWh**



Field adjustable PM quadrupole

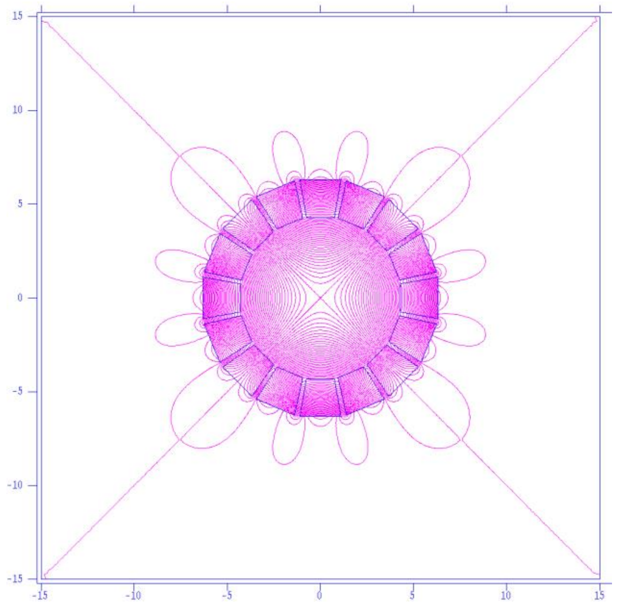
- **Dual-rings magnets enable field tenability in a large range**
- **Challenges:**
  - Movement synchronizing for ceaselessly field cancellation
  - Shimming technology for good field quality at all operation modes
  - Radiation shielding



- **The CEPC uses permanent magnets (dipole, quadruple) for**
  - Damping ring
  - Transport line

CEPC				
Storage Ring	Z	W	H	TT
Beam Energy (GeV)	45.5	80.0	120.0	180.0
Current ratio	25%	44%	67%	100%
Power ratio	6%	20%	44%	100%
Dipoles (MW)	0.76	2.35	5.29	11.90
Quadrupoles (MW)	2.13	6.58	14.81	33.31
Sextupoles (MW)	1.28	3.96	8.91	20.04
Correctors (MW)	0.04	0.12	0.28	0.62
Power cables (MW)	1.26	3.90	8.77	19.74
Total magnet losses	5.47	16.91	38.05	85.62
Power demand (MW)	**6.40**	**19.78**	**44.51**	**100.14**

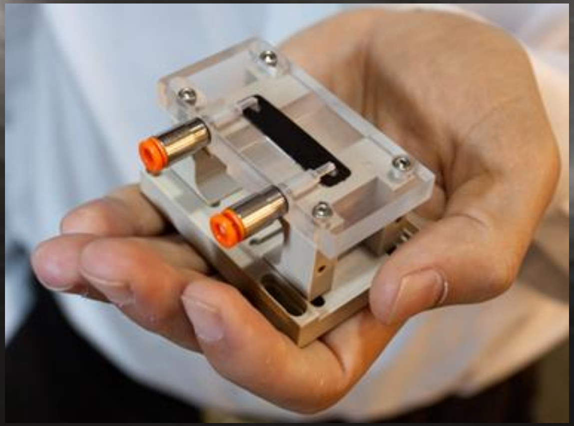
- **Explore novel ideas for collider QUAD**



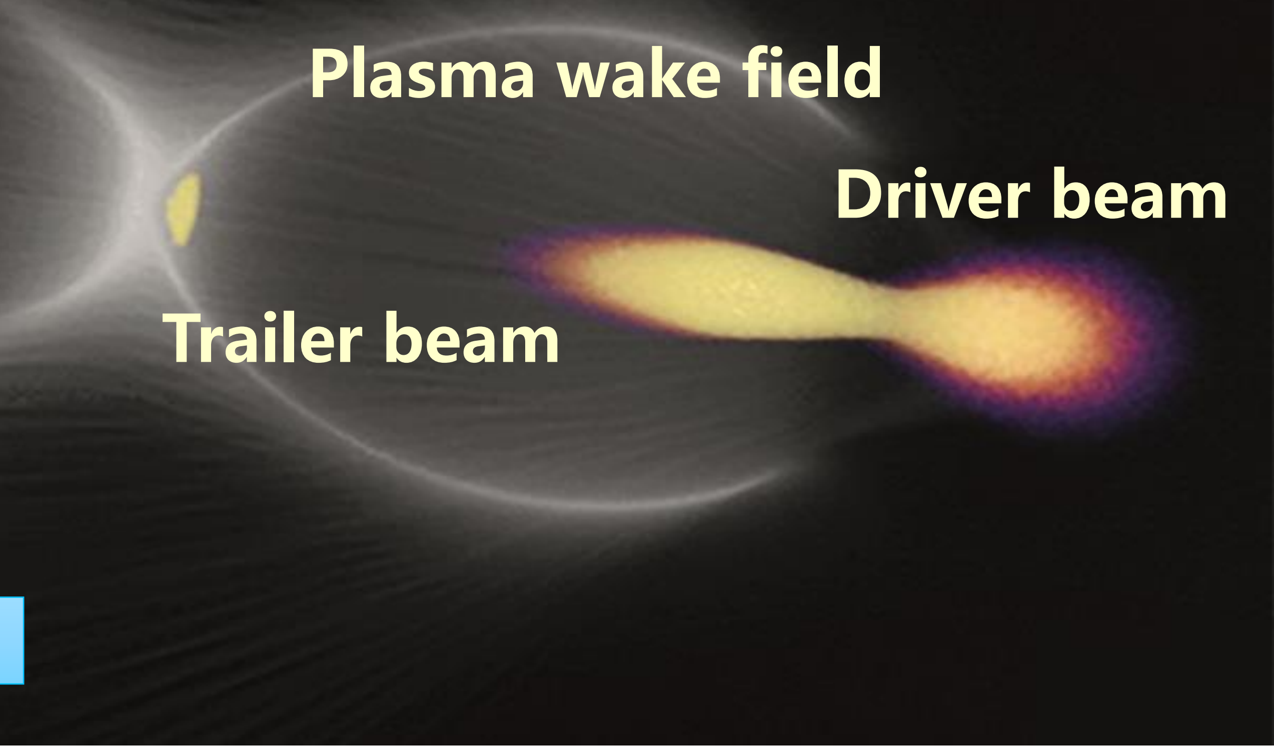
Plasma wake field acceleration

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

Conventional linac



1GeV accelerator in hand



Conventional collider vs. plasma collider

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

Snowmass'21 Accelerator Frontier Report

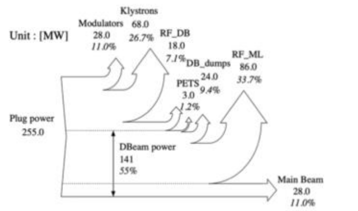
- Size:
  - LWFA LC << PWFA LC << LC
  - But NOT 1000 times smaller due to beam deliver section
- Power consumption
  - Plasma LC < LC, smaller size means smaller vacuum, magnet, SC ……
  - PWFA LC < LWFA LC, due to higher $\eta_{\text{wall plug}\rightarrow\text{driver}}$ and $\eta_{\text{driver}\rightarrow\text{trailer}}$
  - Plasma acclerator estimation is not as accurate as conventional LC, and should be overestimated / based on future technology
- Construction
  - Plasma accelerator cost is in a big range due to technique uncertainty
  - May not be ready in the next 20 yrs

Single stage plasma acceleration efficiency

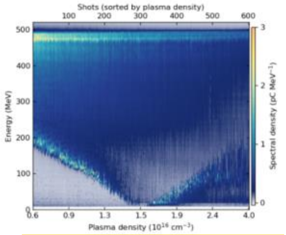
Hosing instability

AC → Driver, Driver → Wakefield, Wakefield → Trailer

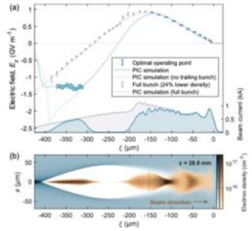
Production of the driver (wall-plug to driver) → Driver energy depletion (driver to plasma wake) → Acceleration efficiency (plasma wake to beam)



50-60% for PWFA
~ 10% for LWFA



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



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

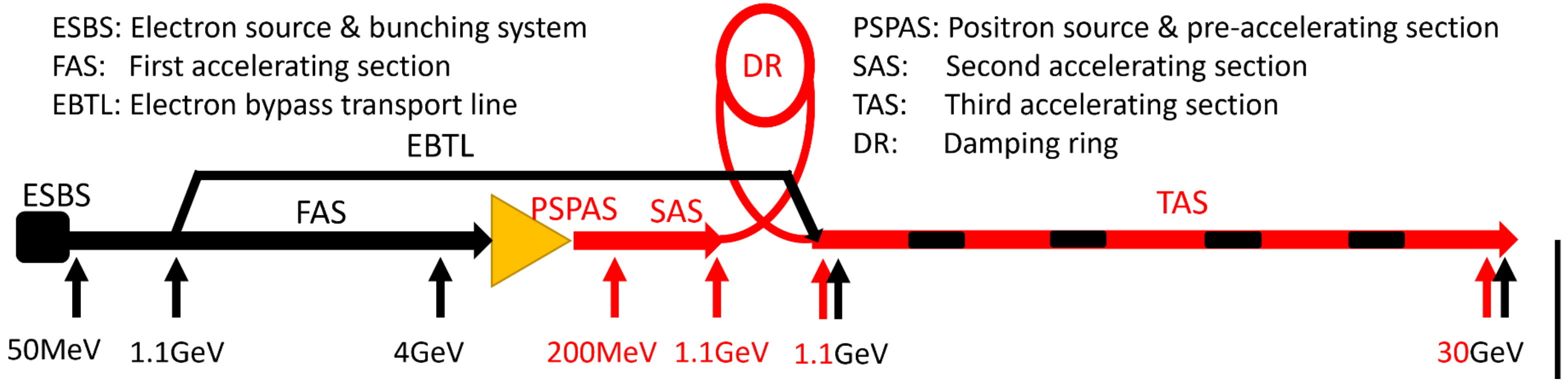
	Plasma accelerator	ilc	clic
Inter-bunch separation	*O*(100 ns)	554 ns	0.5 ns
Bunch-train length	???	726 µs	156 ns
Macro-pulse separation	???	100 ms	20 ms
Max. # of bunches per second	**???**	**13120**	**15600**

Right now < 10 or even < 1

High rep. rate plasma source and lasers (for LWFA)

CEPC drives PWFA study @ IHEP

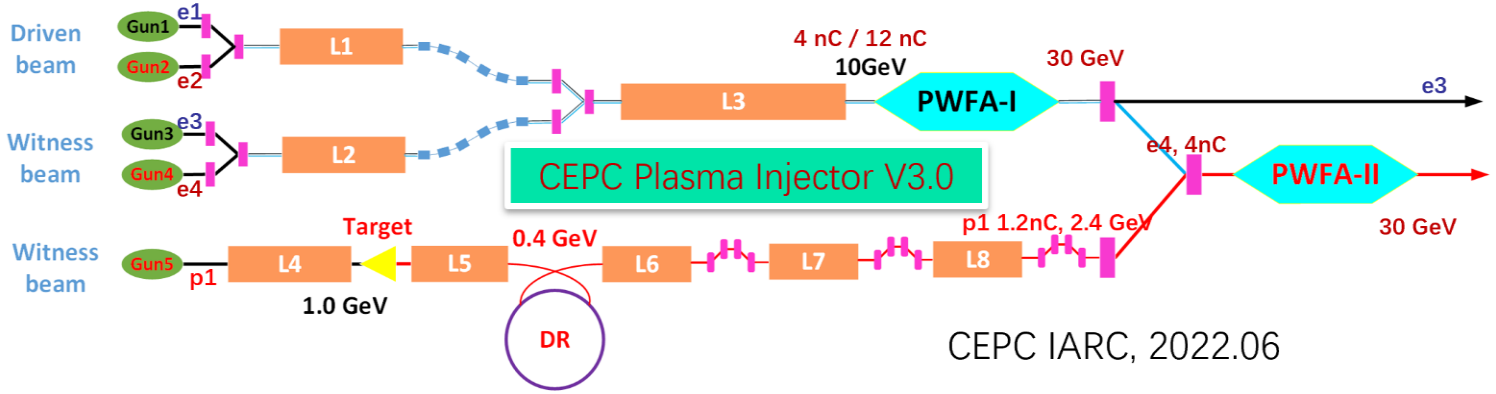
- Backup solution for CEPC linac, conceptual design based on simulation shows that the scheme is feasible



Conventional technology as the baseline design:

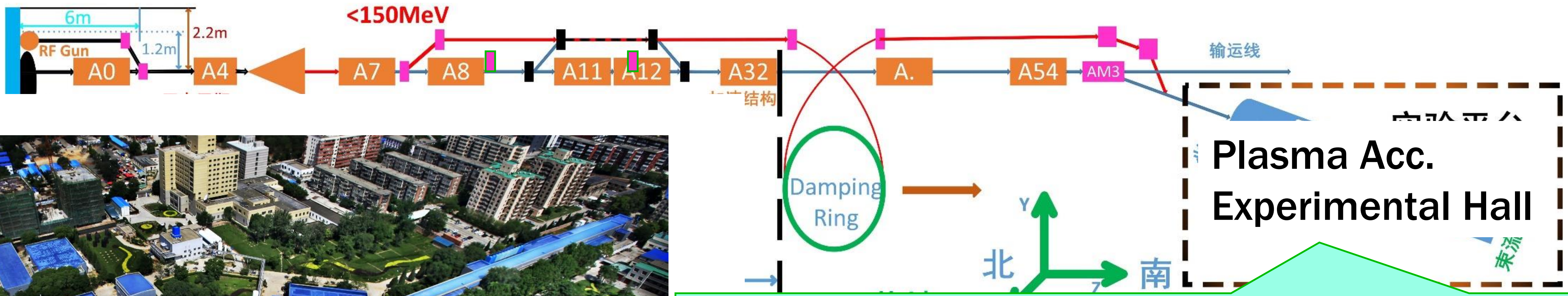
PWFA backup design:

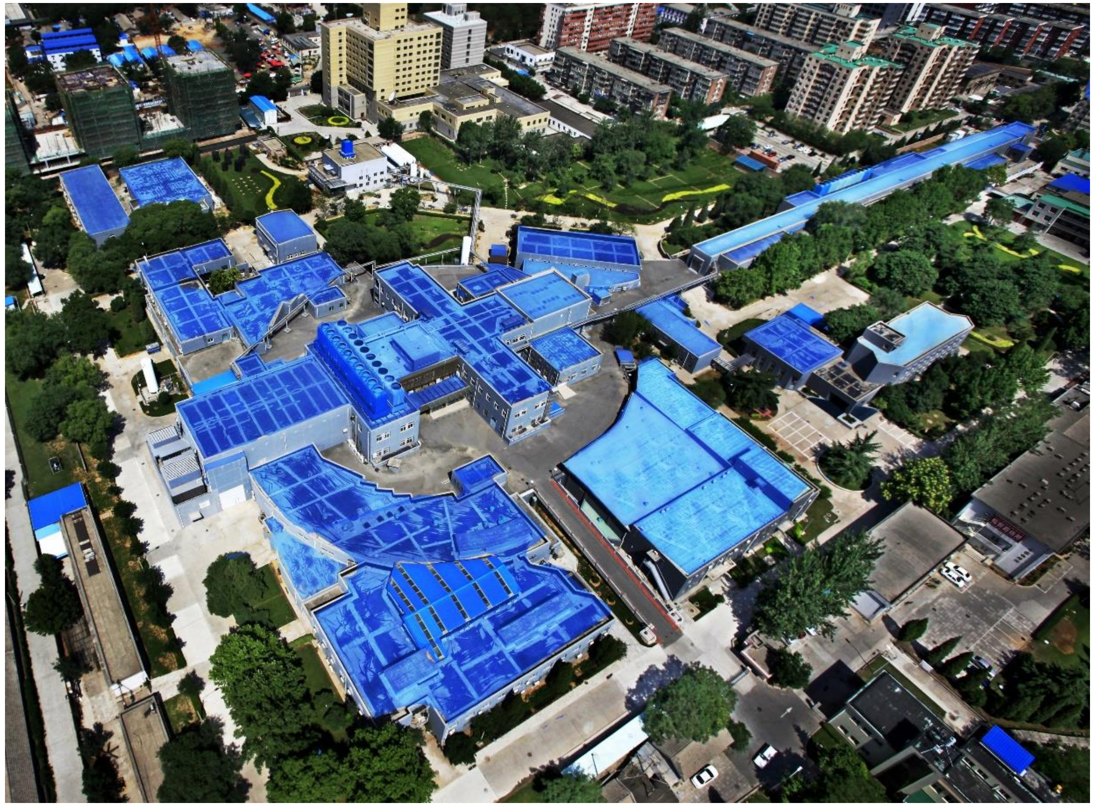
- **Main linac: 10GeV S-band**
- **L-band (10+ nC) and S-band (≤5nC) RF guns**
- **Compression and combination**
- **Different e+ acc. scheme**
- **e+ PWFA need to be cascaded**
- **e- PWFA with TR ~ 3.5**

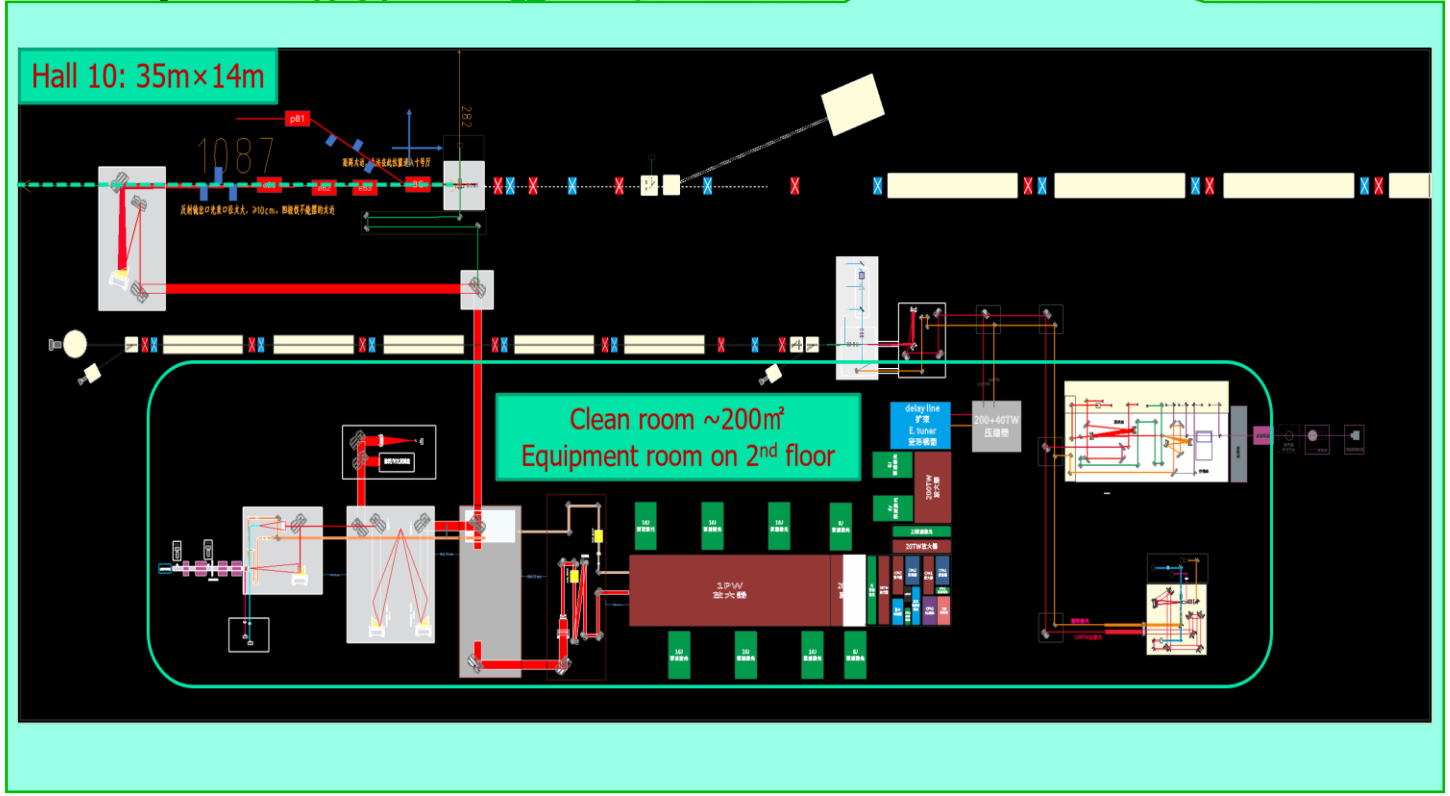


CEPC IARC, 2022.06

Test facility to be built at BEPCII



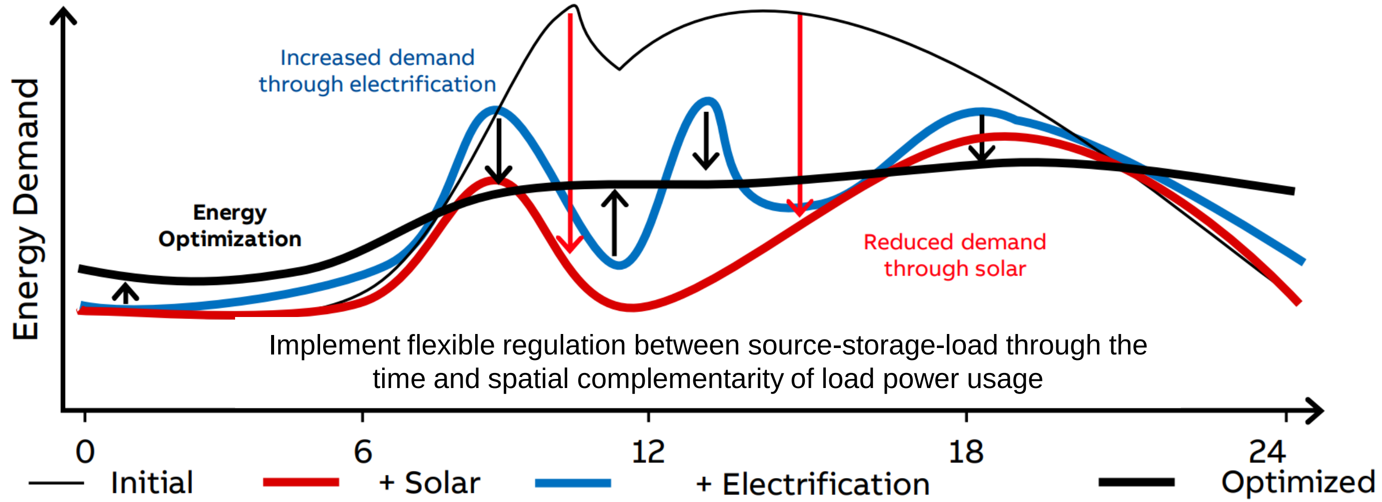


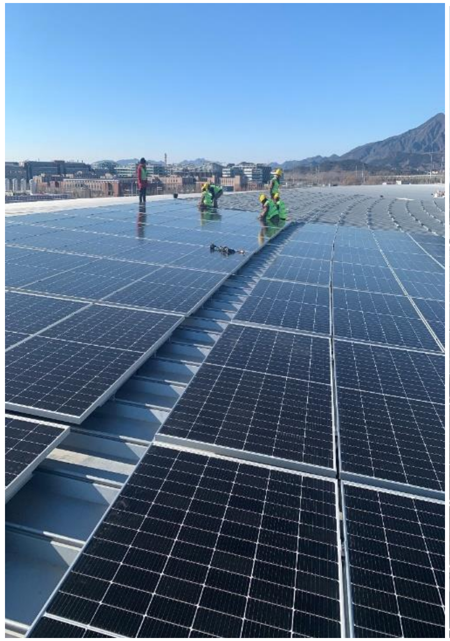


2.5 GeV e-/e+ beamline + PW-level high performance laser system

Solar panels on-top of the roof at HEPS

- 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 10.30766 million kWh, and the equivalent average annual utilization hours will be 1035.85h.
- 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.

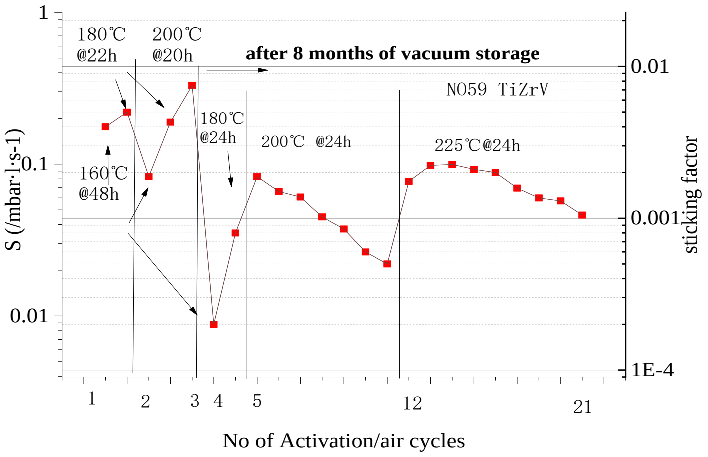




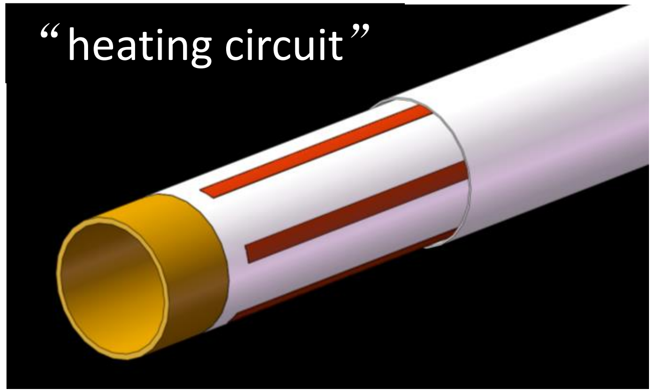
NEG coating for vacuum chambers

● NEG coating instead of pumps and automatic production

- The NEG coating is used to suppress the e-cloud of the positron ring. It also provides distributed pumping speed for both the positron and electron rings simultaneously.
- Sputter ion pumps will be employed to maintain pressure and pump off CH_4 and noble gases that cannot be pumped off by the NEG coating.
- Compare to the conventional way, it will save **50% sputtering ion pumps (about 10,000) and** counterpart of **electricity**, roughly **1 MW** to pumping system of collider.



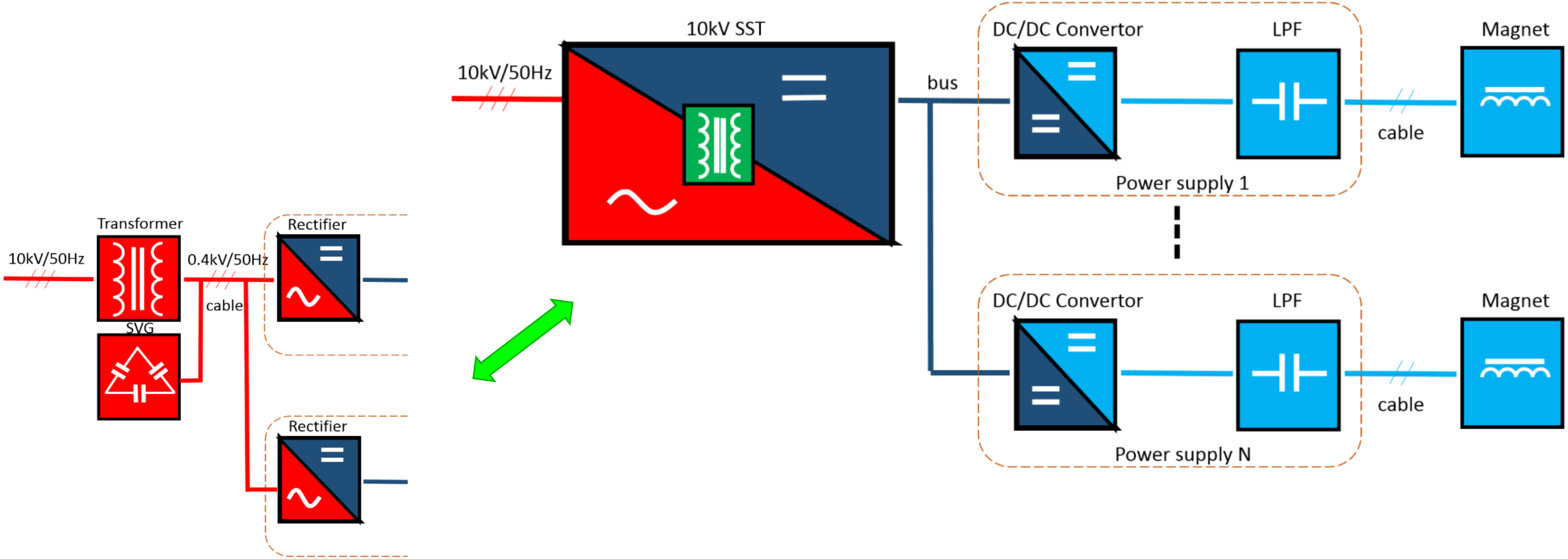
Automatic production



Spraying heating film

- Multilayer of ceramic and metal spraying heating film will be coated outside of the vacuum chamber instead of the kapton heating film.
- Automatic and intelligent manufacturing will introduce to components fabrication of vacuum system for massive production which could efficiently increase the efficiency and decrease the processing carbon.

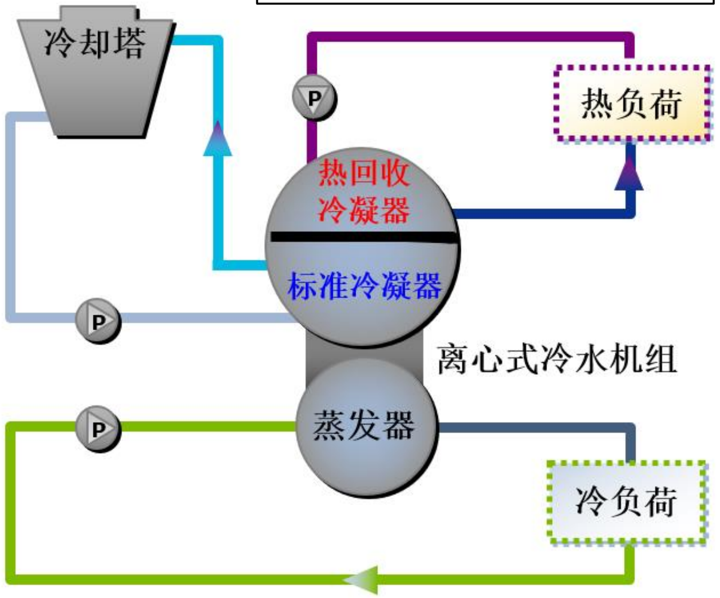
Novel concept of power supply based on 10kV SST



- Numerous media/small magnet power supplies are needed: Quadrupole, Sextupole, corrector, … Lots of cables are needed, resulting in energy lost
- SST can eliminate the need for 10kV transformer and SVG, which directly converts the AC power from 10kV to DC 200V – 1000V DC200V~1kV, with voltage tenability
- Rectifier is not needed in the power supplies, reducing the cost, space occupation and power consumption

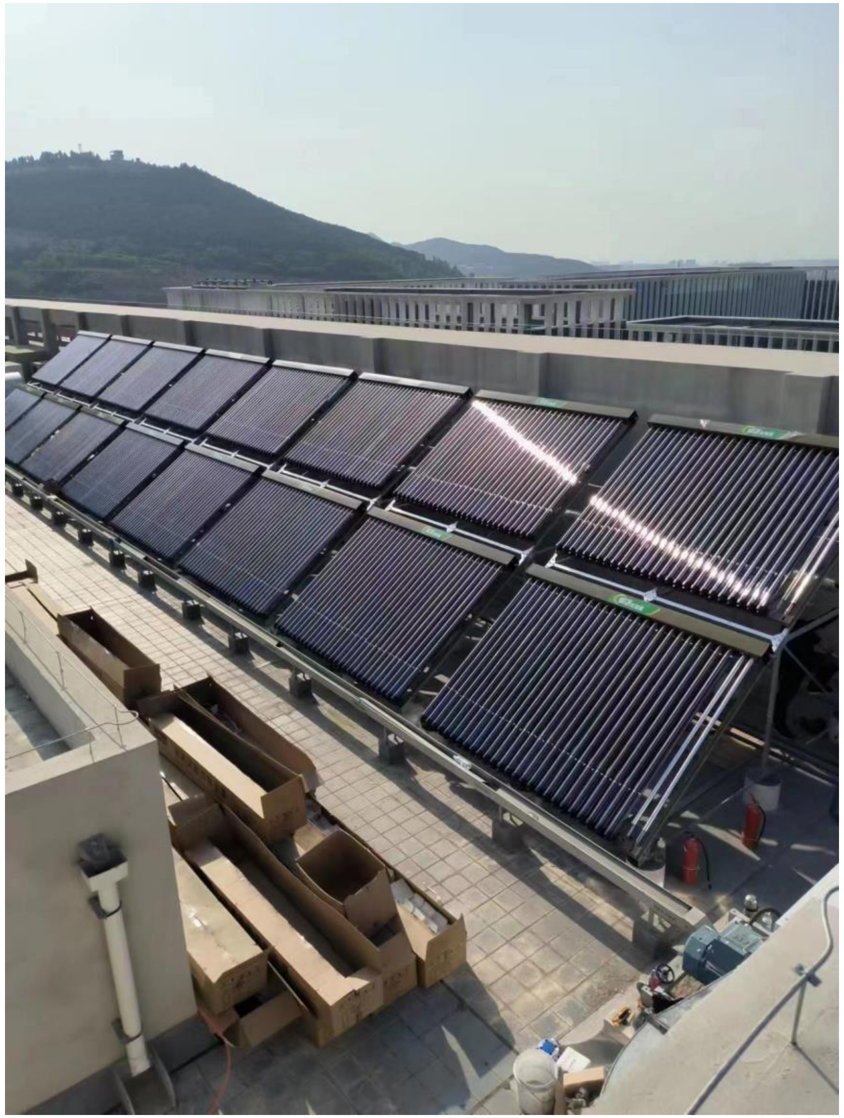
HEPS Waste Heat Sources Utilization

Installation the heat recovery condenser



- A heat recovery chiller unit is used to recover waste heat.
- HEPS installs four heat recovery chiller units: 2 * 5500 kW and 2 * 2800 kW. In the normal operation, maximum of about 13 MW waste heat can be recovered in the form of 42°C water
- The heat load of HEPS is about 10,413 kW in winter and 4,117 kW in summer. When the system is running, the recovered heat source can fully replace municipal heat sources

solar-electricity efficiency vs. solar-thermal efficiency: AHP for higher efficiency



Electrical heat pump

solar energy→electricity→EHP enhance T

15%*3=45%

Absorption heat pump

solar energy→heat→AHP enhance T

50%*1.8=90%

- 1. 《光伏发电效率技术规范》

Technical Specification for Photovoltaic Power Generation Efficiency

- 2.《蒸气压缩循环冷水（热泵）机组国家标准GB/T 18430》

National Standard for Vapor Compression Cycle Chilled Water (Heat Pump) Units GB/T 18430

- 3. 《真空管型太阳能集热器国家标准 GB/T 17581-2021》

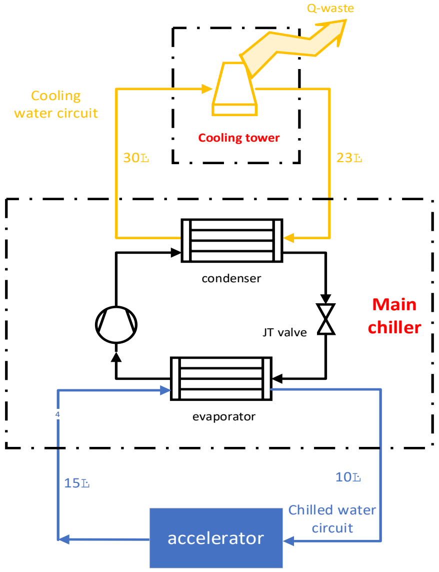
National Standard for Vacuum Tube Solar Collectors GB/T 17581-2021

- 4. 《第一类溴化锂吸收式热泵机组国家标准GBT 34620-2017》

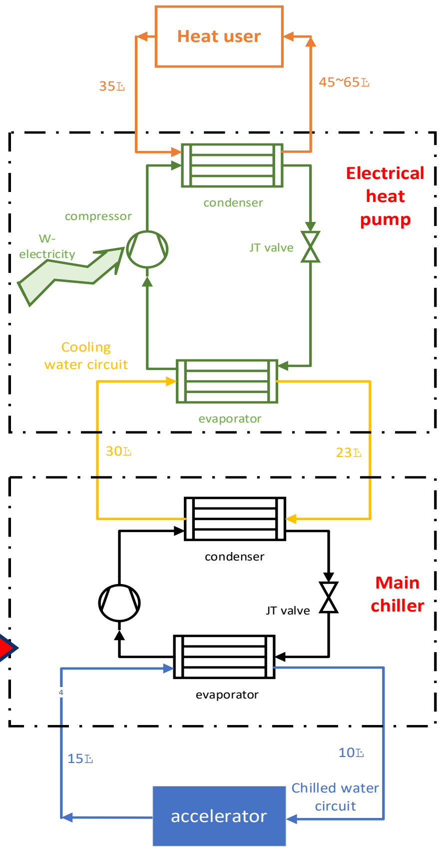
National Standard for Type I Lithium Bromide Absorption Heat Pump Units GBT 34620-2017

Advanced heat-pump technology applications for CEPC

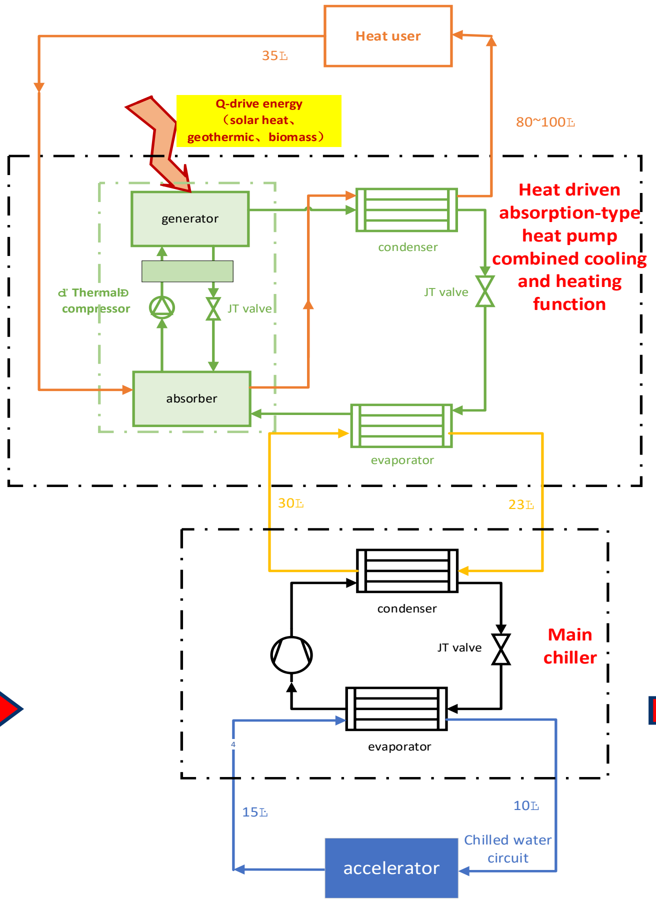
- **As the rapid development of photovoltaic and heat storage technology, AHP can be served the new possible scheme to recover the waste heat.**



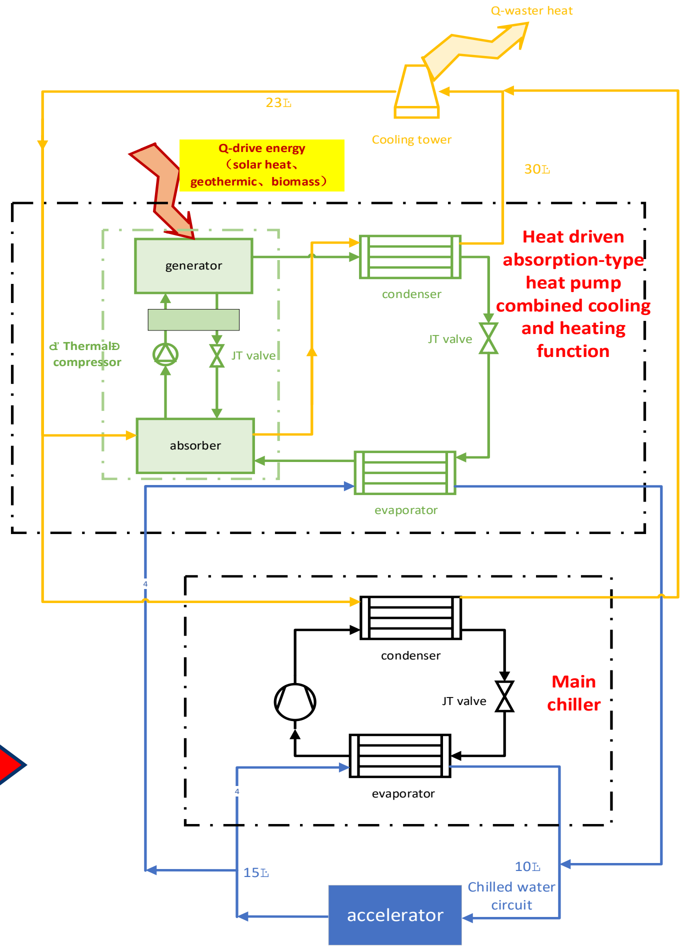
1. Conventional waste heat discharged through cooling towers in accelerator



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

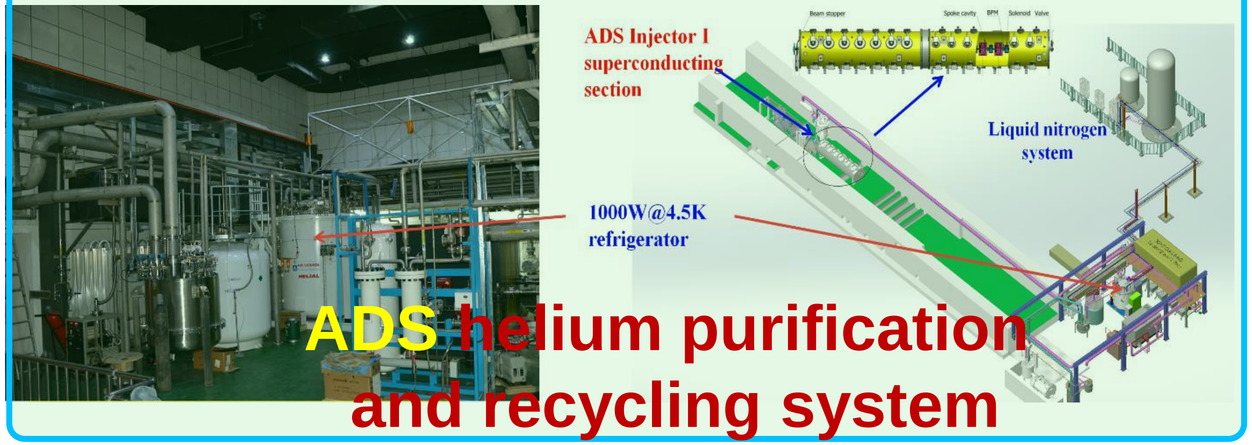


4、 Refrigeration condition - absorption Type HP - to produce part of the chilled water, can reduce the main cooling unit energy consumption (energy saving)

Full recovery/recycling of helium for sustainability operation

- Helium gas is a non-renewable resource. Therefore, helium recycling is essential for sustainable operations.
- IHEP has implemented a helium gas recovery system, specifically the liquid helium recovery and purification system of BEPCII(ADS)/PAPS, many years ago. This system has been operating stably.
- **Recovery capacity ≥210NM³/h; purification capacity ≥105NM³/h;**

PAPS helium purification and recycling system



ADS helium purification and recycling system

BEPCII cryogenic system

Summary

- Prototypes have been developed and key technology breakthrough has been achieved, with many of them addressing green collider technologies
- Power efficiency, energy recycling, and clean energy generation are addressed as comprehensive measures for sustainable operation
- More endeavors are needed for a comprehensive life-cycle CO_2 footprint assessment

Thank you for your attention