https://www.physics.ox.ac.uk/confs/CEPC2019/index.asp

Impressions from the Workshop

Benno List
(I)LC Project Meeting, 26.4.2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

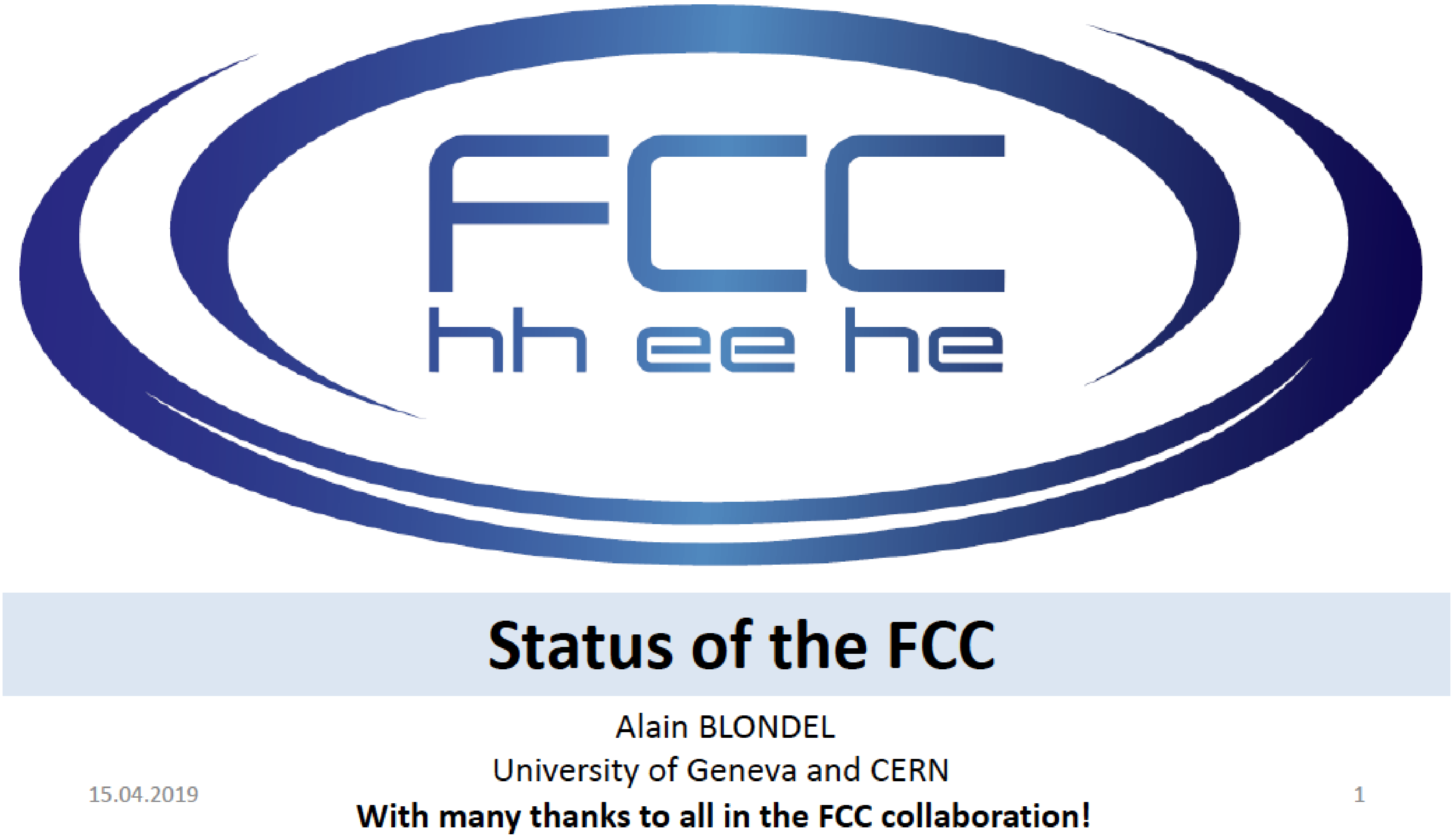
DESY.

Introduction

- Workshop in Oxford, April 15-17
- 4 Tracks: Physics, Detectors, **Accelerators**, Tools & Performance – I went to Accelerator parallel sessions
- Mixed attendance: ~50% from China,
  large overlap with FCC-ee and CLIC, ILC communities for non-accelerator sessions

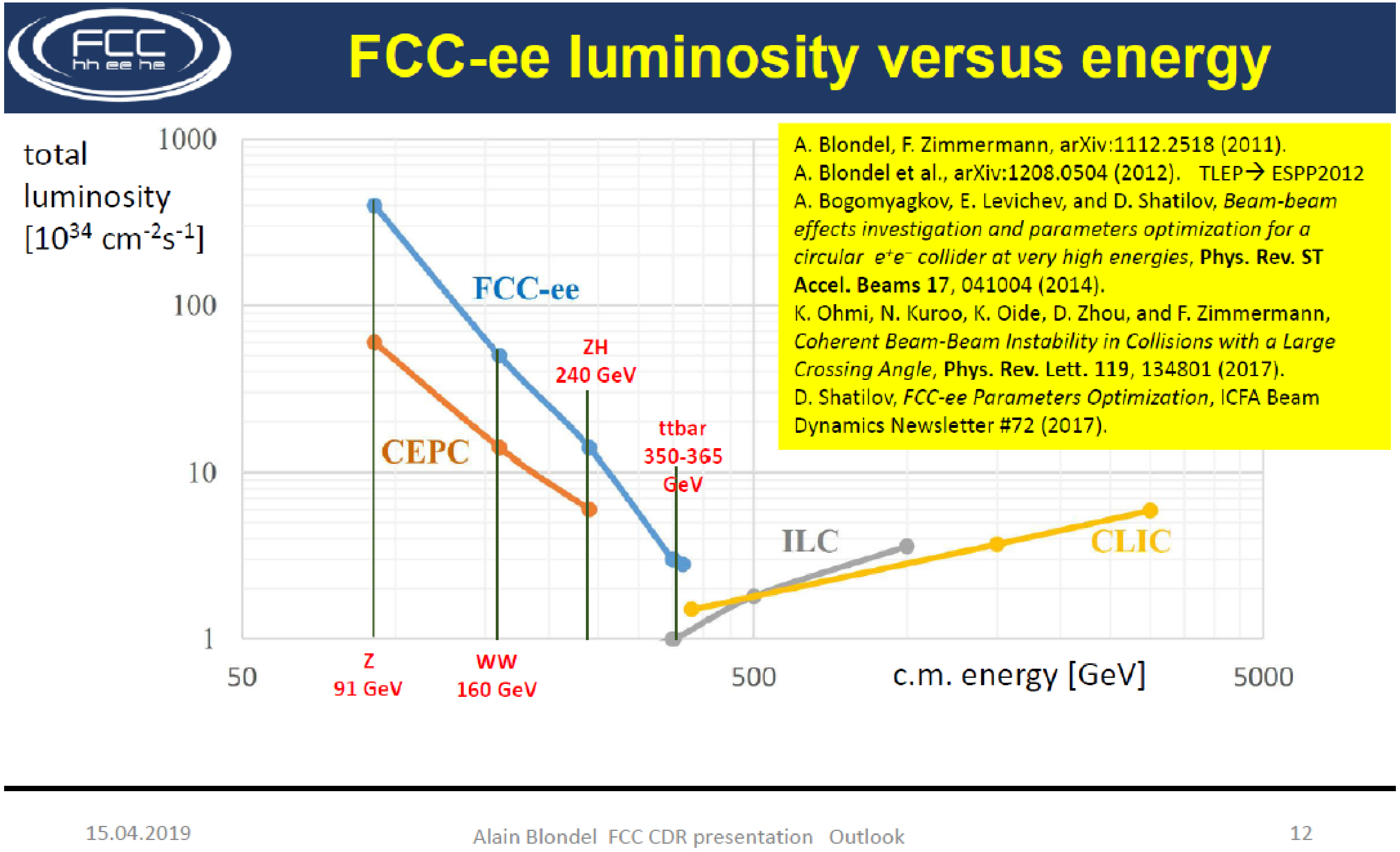
- Note: I stole many slides from Brian‘s accelerator summary.
  Look at the full talk at https://indico.cern.ch/event/783429/contributions/3306683/

Start with FCC



FCC vs LC

As seen by FCC



integrated luminosity per construction cost

for the H running, **with 5 ab^{-1} accumulated over 3 years**, the total investment cost corresponds to
10 kCHF per produced Higgs boson

for the Z running with **150 ab^{-1} accumulated over 4 years** the total capital investment cost corresponds to
10 kCHF per 5×10^{6} Z bosons
= the number of Z bosons collected by each experiment during the entire LEP programme !

construction cost per luminosity dramatically decreased compared with LEP !

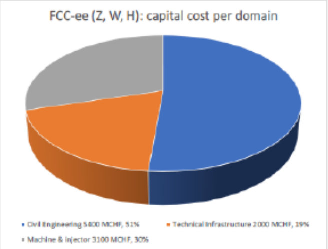
FCC costs

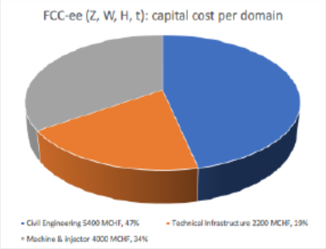
FCC-ee cost estimate

Total construction cost phase1 (Z, W, H) amounts to 10,500 MCHF

- 5,400 MCHF for civil engineering (51%)
- 2,000 MCHF for technical infrastructure (19%)
- 3,100 MCHF accelerator and injector (20%)

most of this to be recuperated for FCC-hh!



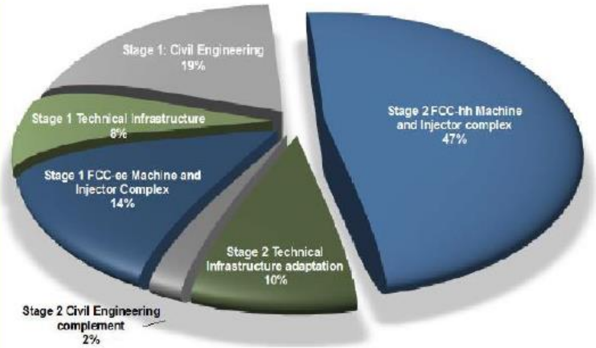


Complement cost for phase2 (tt) amounts to 1,100 MCHF

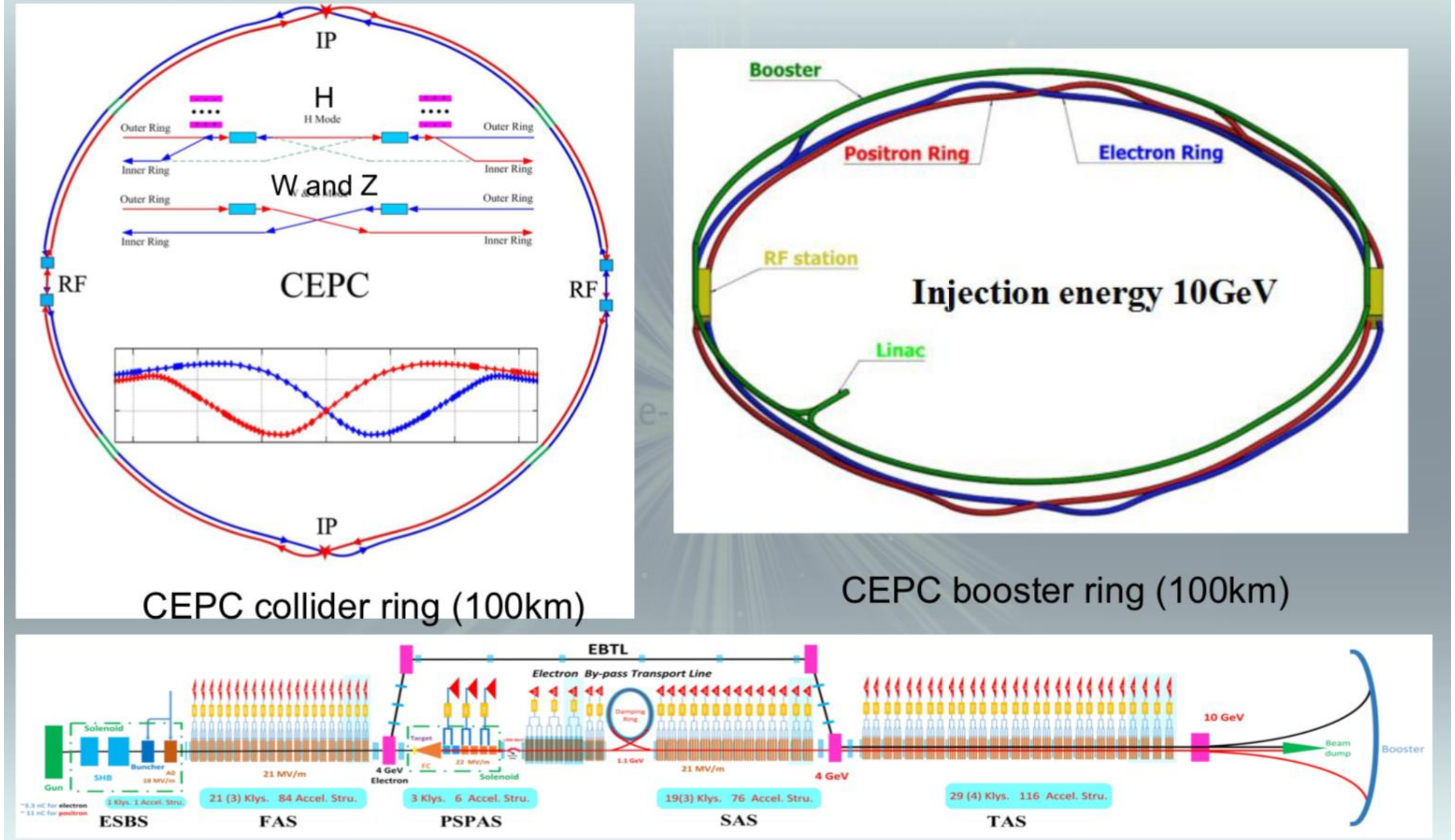
- 900 MCHF for RF, 200 MCHF for associated technical infrastructure

FCC-integrated cost estimate

Domain	Cost in MCHF
Stage 1 - Civil Engineering	5,400
Stage 1 - Technical Infrastructure	2,200
Stage 1 - FCC-ee Machine and Injector Complex	4,000
Stage 2 - Civil Engineering complement	600
Stage 2 - Technical Infrastructure adaptation	2,800
Stage 2 - FCC-hh Machine and Injector complex	13,600
TOTAL construction cost for integral FCC project	28,600



CEPC Accelerator



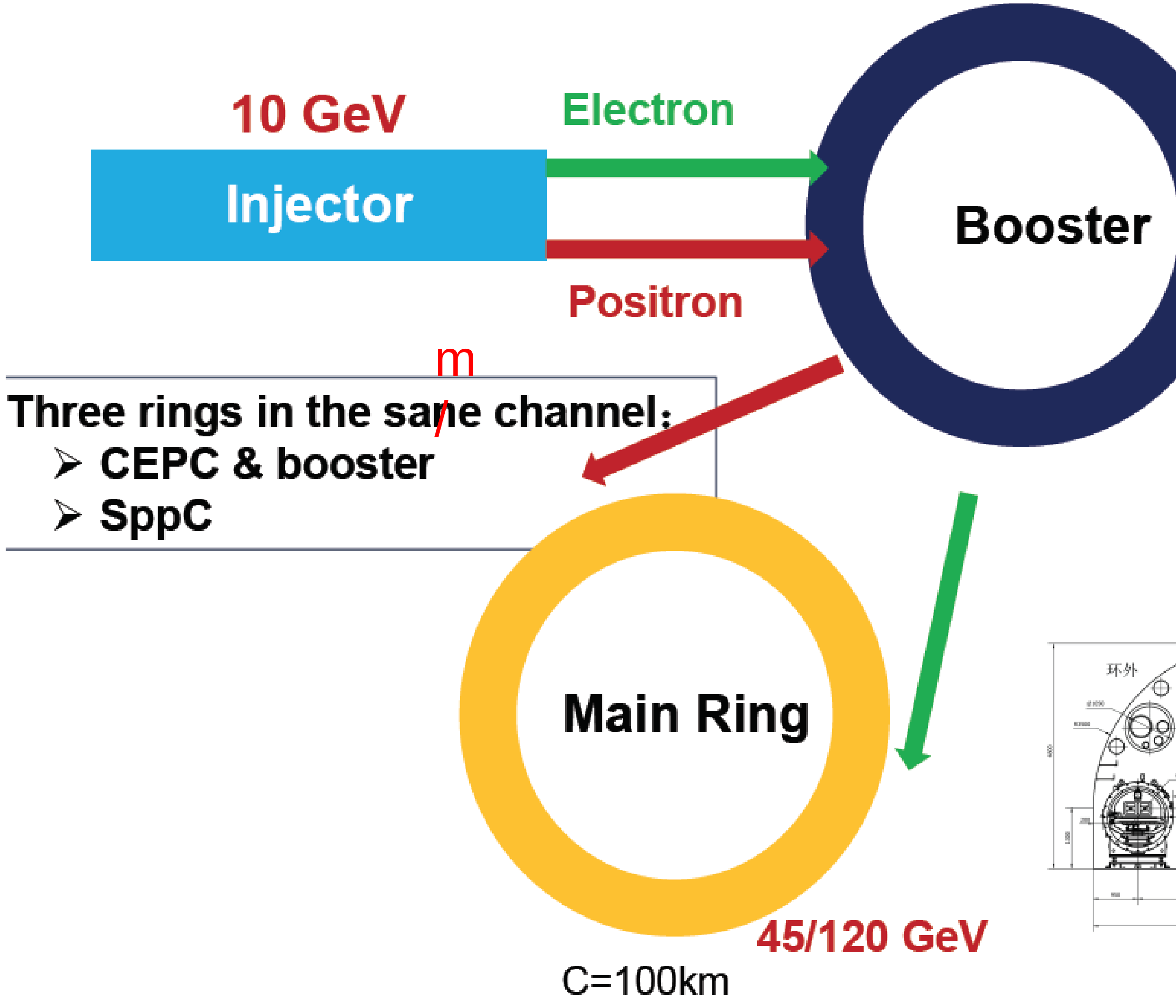
CEPC collider ring (100km)

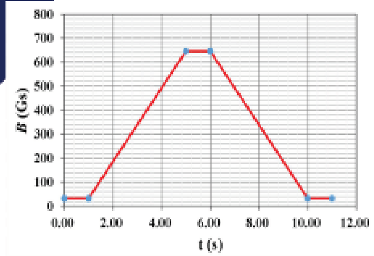
CEPC booster ring (100km)

CEPC Linac injector (1.2km, 10GeV)

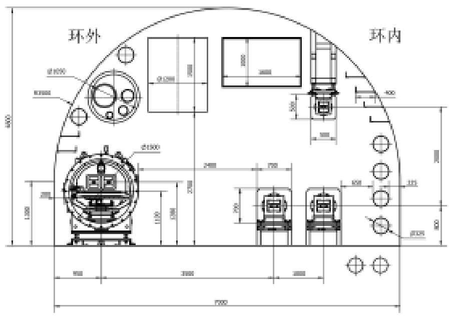
CEPC

CEPC Accelerator CDR Status and Perspectives towards TDR
Jie Gao (Institute of High Energy Physics, Chinese Academy of Sciences)





Booster Cycle (0.1 Hz)



New Parameters

Parameters updated since CDR

CEPC CDR Parameters
D. Wang

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^*/β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

CEPC High Lumi Parameters@Higgs
D. Wang

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.68	0.33	0.035	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	3.78	8.5	27.7	
Number of particles/bunch N_e (10^{10})	17.0	12.0	8.0	
Bunch number (bunch spacing)	**218 (0.76μs)**	**1568 (0.20μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.8	90.4	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	0.91			
β function at IP β_x^*/β_y^* (m)	**0.33/0.001**	**0.33/0.001**	**0.2/0.001**	
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	0.89/0.0018	0.395/0.0012	0.13/0.003	0.13/0.00115
Beam size at IP σ_x/σ_y (μm)	17.1/0.042	11.4/0.035	5.1/0.054	5.1/0.034
Beam-beam parameters ξ_x/ξ_y	0.024/0.113	0.012/0.1	0.004/0.053	0.004/0.085
RF voltage V_{RF} (GV)	2.4	0.43	0.082	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.2	2.98	2.42	
Bunch length σ_z (mm)	3.93	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.58	0.77	**1.94**	
Energy spread (%)	0.19	0.098	0.080	
Energy acceptance requirement (%)	**1.7**	**0.90**	**0.49**	
Energy acceptance by RF (%)	3.0	1.27	1.55	
Photon number due to beamstrahlung	0.104	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime* (min)	30/50	>400		
Lifetime (hour)	**0.22**	**1.2**	**3.2**	**2.0**
F (hour glass)	0.85	0.92	0.98	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**5.2**	**14.5**	**23.6**	**37.7**

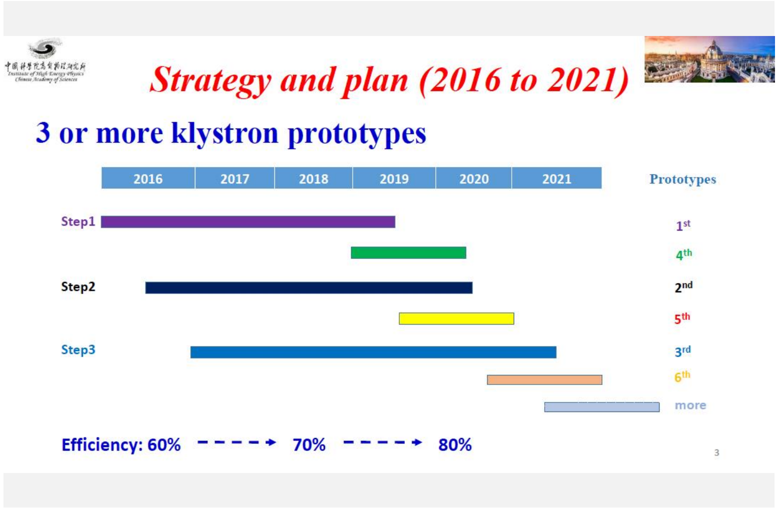
*include beam-beam simulation and real lattice

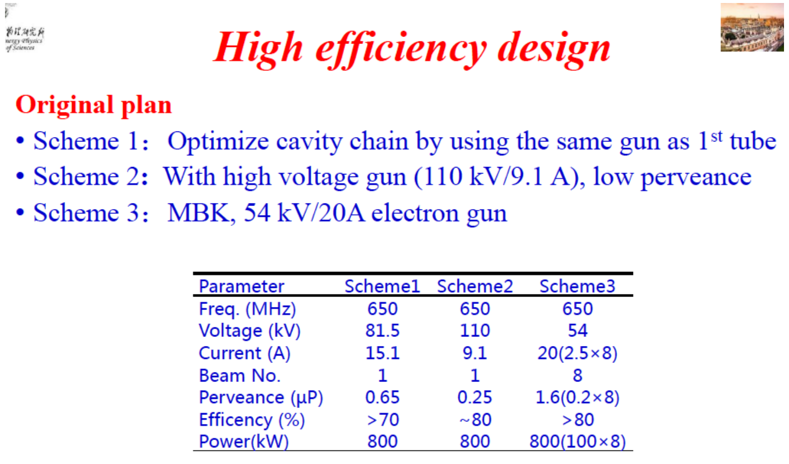
Klystron R&D

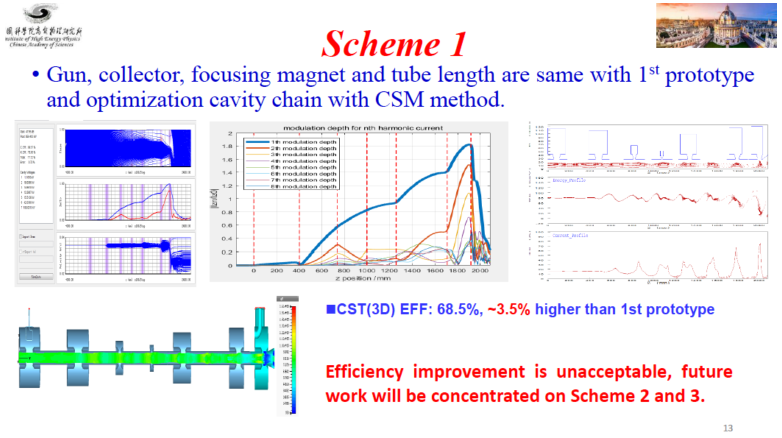
Development of an 80% efficient Chinese klystron

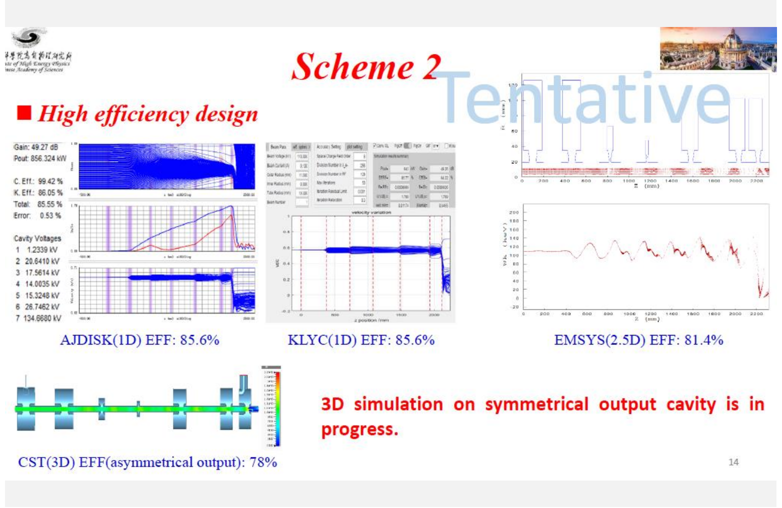
Approach:

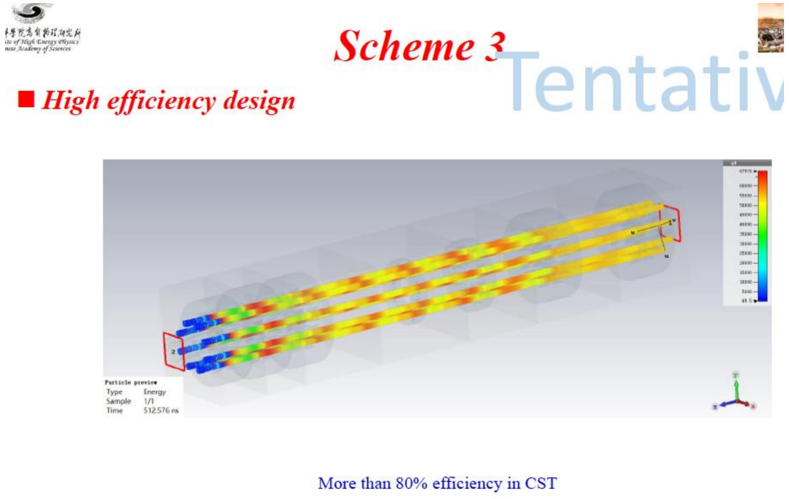
Pursue 3 designs in parallel











Klystron R&D

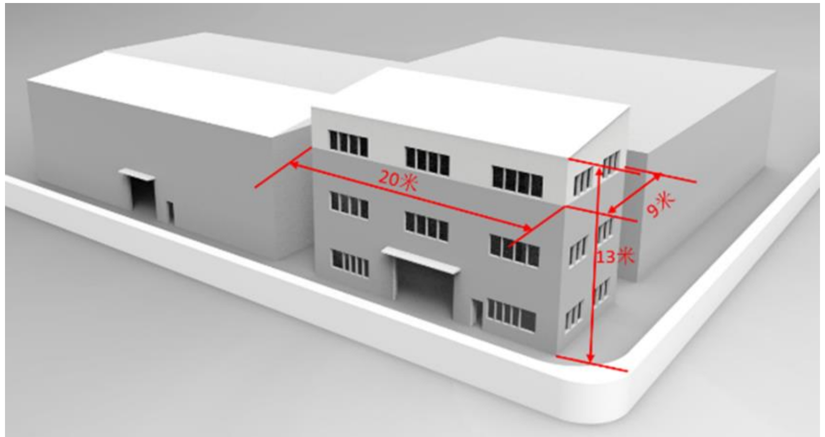
650MHz/800kW meets CEPC project demands

80% efficiency

◆1st prototype tube

Mechanical design and manufacture

Plant and infrastructure preparation



Dimension of new building

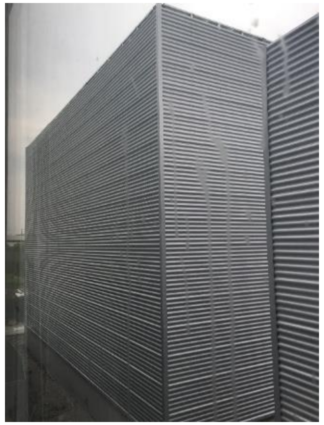
Dec. 29, 2018

Jan. 10, 2019

Jan. 28, 2019

Mar. 3, 2019

Mar. 27, 2019



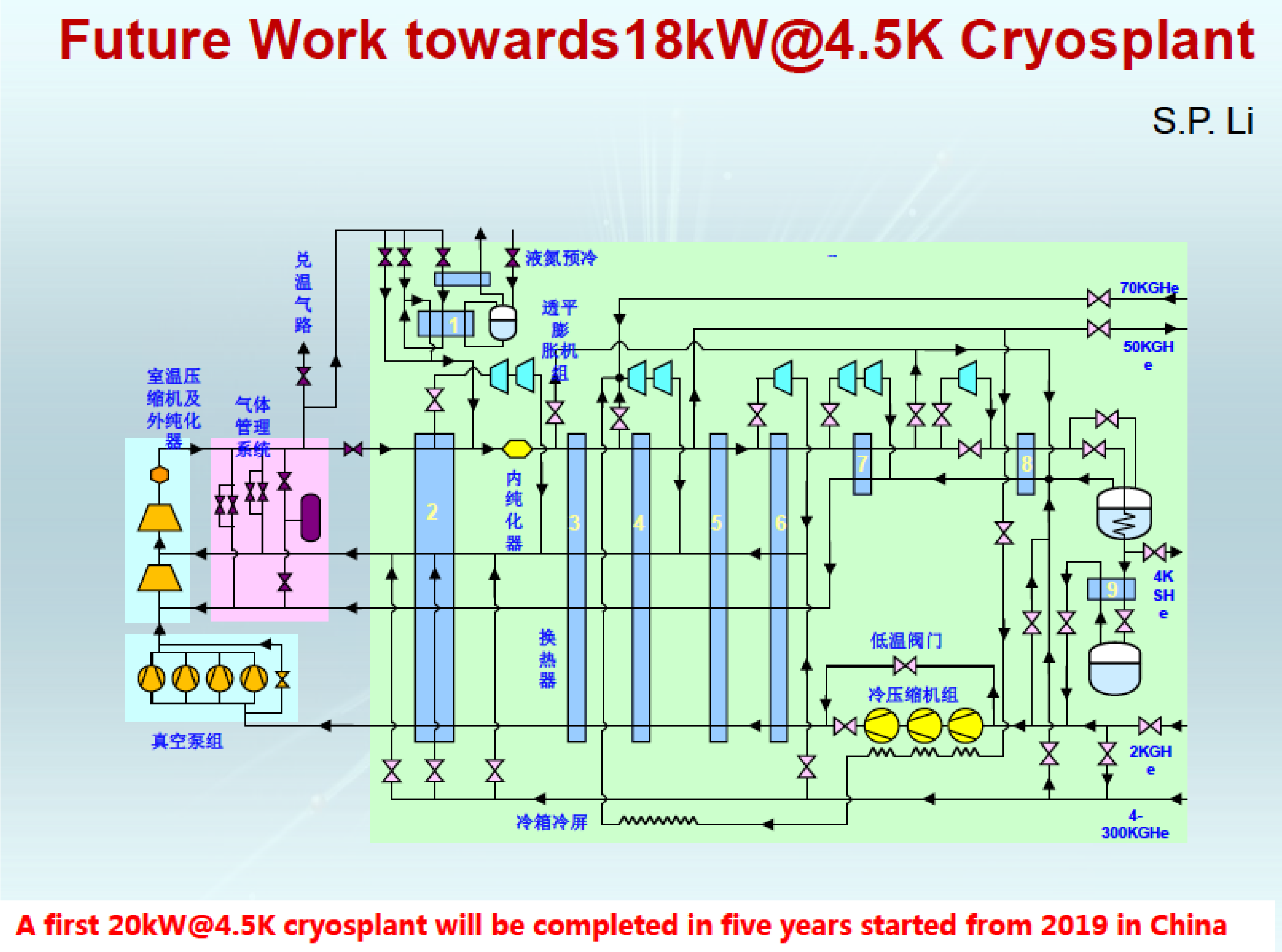
Apr. 12, 2019

◆**High efficiency design**

2nd prototype optimization Multi-beam klystron consideration

Chinese Cryo Plant

Plans for a Chines Cryo Plant (~18kW@4.5K – typical plant size for ILC, XFEL, LHC)



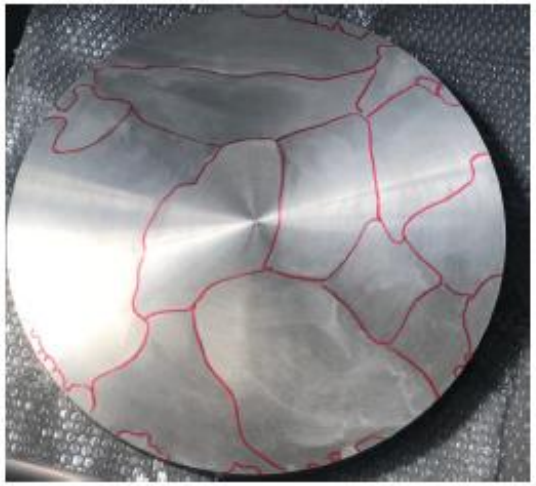
SCRF Developments

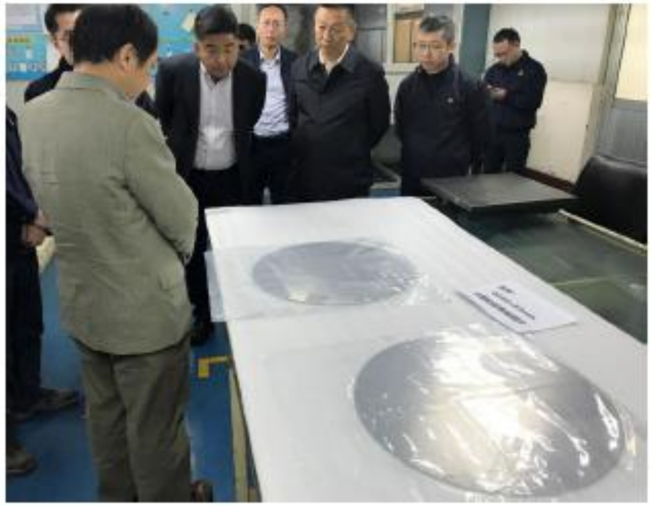
Target: Q0 of 5E10 at 42MV/m at 2K -> World Record

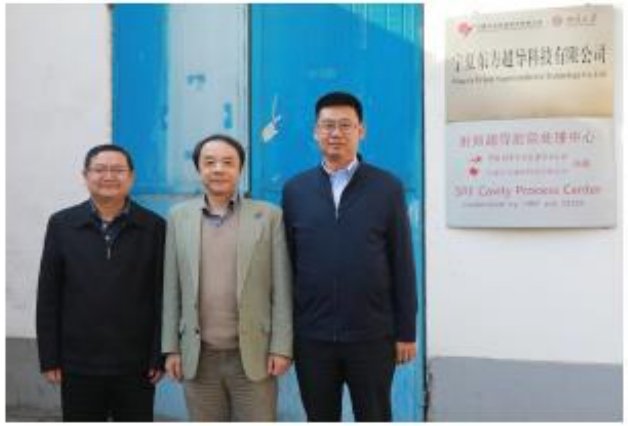
650 MHz 1-cell cavity (large grain)

P. Sha

- 650 MHz 1-cell cavity (large grain) is favorable for HL-Z, which have higher Q and gradient than fine grain.
- Target of Vertical test: **5E10 @ 42MV/m at 2.0 K**.
- Four cavities are under fabrication now, which will be tested in the middle 2019.







Large grain Nb sheets made by OTIC

New Parameters

CEPC New Parameters @Z

20190226	Z (2T) - CDR W/O ante-chamber	Z (2T) - new1 W/O ante-chamber	Z (2T) - new2 W ante-chamber	Z (2T) - new3 W ante-chamber
Beam energy (GeV)	45.5			
Synchrotron radiation loss/turn (GeV)	0.036			
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	23.8	27.9	27.9	33.0
Number of particles/bunch N_e (10^{10})	8.0	12.0	12.0	15.0
Bunch number (bunch spacing)	12000 (25ns+10%gap)	8570 (35ns+10%gap)	14564 (20.6ns+10%gap)	1682 (26ns+10%gap)
Beam current (mA)	461.0	494.3	839.9	842.2
Synchrotron radiation power /beam (MW)	16.5	17.7	30	30
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	0.2/0.001			
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	0.18/0.0016			
Beam size at IP σ_x/σ_y (μm)	6.0/0.04			
Beam-beam parameters ξ_x/ξ_y	0.004/0.079	0.004/0.093	0.004/0.093	0.004/0.098
RF voltage V_{RF} (GV)	0.10			
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.42			
Bunch length σ_z (mm)	8.5	10.0	10.0	11.8
HOM power/cavity (kw)	1.94 (2cell)	1.35 (1cell)	2.29 (1cell)	2.45 (1cell)
Energy spread (%)	0.080	0.1	0.1	0.115
Energy acceptance requirement (%)	0.49	0.6	0.6	0.7
Energy acceptance by RF (%)	1.7			
Photon number due to beamstrahlung	0.023	0.03	0.03	0.032
Lifetime (hour)	2.5	2.0	2.0	1.8
F (hour glass)	0.99	0.97	0.97	0.97
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	32.1	43.9	74.5	79.2

Choose *Z(2T) - new2* to explore the high current potential (~ 800 mA) of CEPC SRF system with 1-cell cavities (this talk) or other better schemes (to be studied in the future).

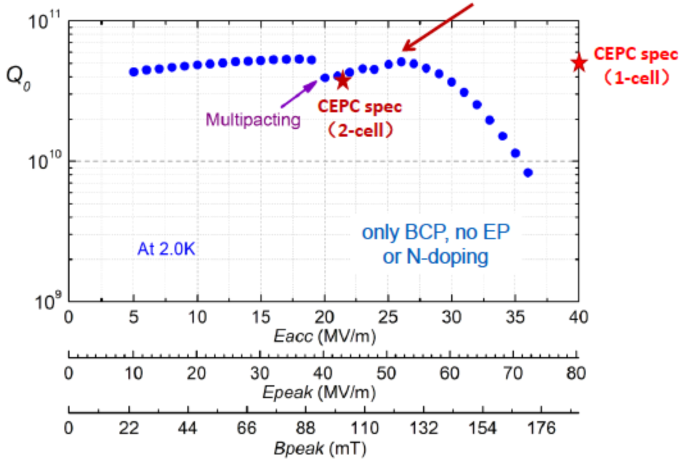
1-Cell cavities for Z running

650 MHz 1-cell cavity

Accelerating gradient (Eacc) reach 36.0 MV/m, **Q = 5.1E10 @ Eacc = 26 MV/m。**

Next, increase the Q and Eacc through N-doping, EP, etc. Target: **5E10@42MV/m** for vertical test.

Record highest Q-factor in China



650 MHz 1-cell cavity

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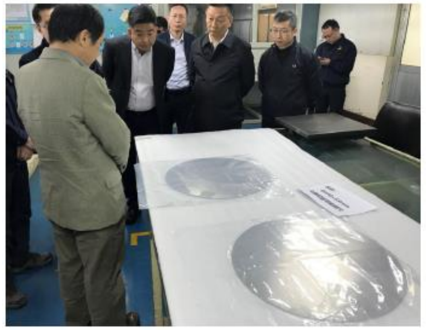
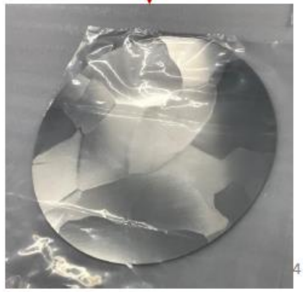
650 MHz 1-cell cavity (large grain)

- Then, OTIC made a new Nb ingot (Φ480mm) for us, which was processed to qualified Nb sheet.
- Four cavities are under fabrication now, which will be tested in the middle 2019. Target of Vertical test: **5E10 @ 42MV/m** at 2.0 K.



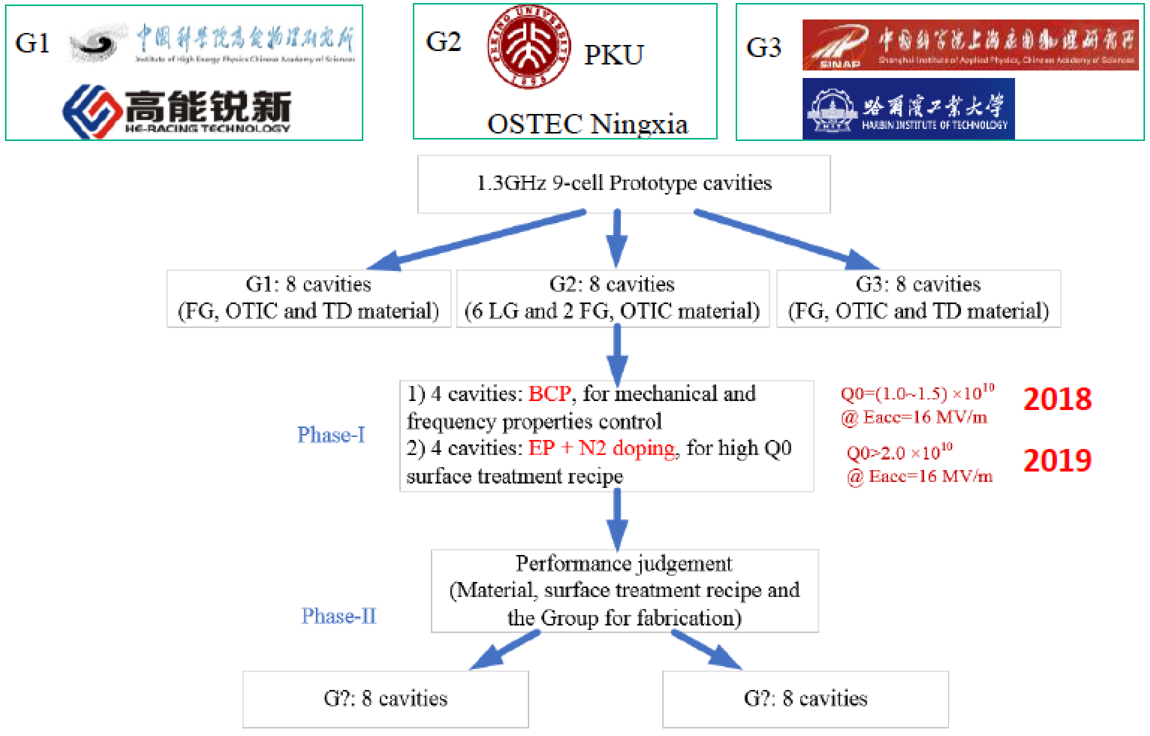
Large grain Nb sheets made by OTIC

Nb ingot (Φ480mm)



TESLA-Shape 1.3GHz Cavities for SHINE

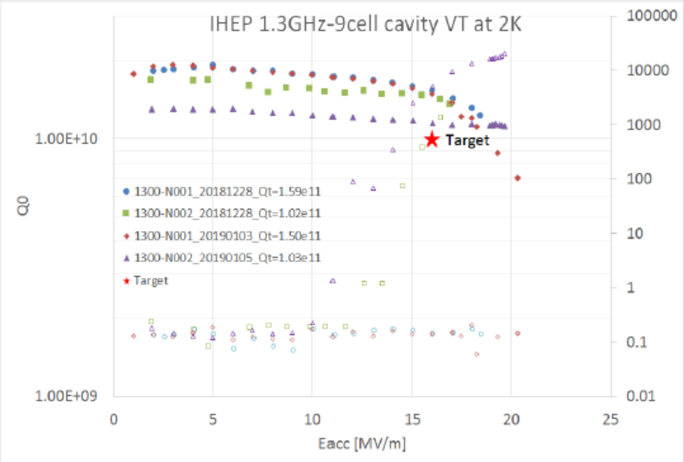
1.3 GHz cavities for SHINE

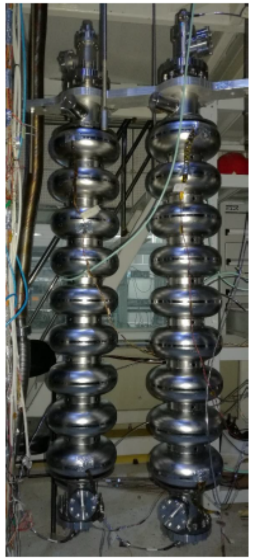


Phase-II: Meet all specifications and build surface treatment recipe

1.3 GHz 9-cell cavity

- Two 1.3 GHz 9-cell cavities has been made and tested by IHEP for SHINE, which received BCP (no EP or N-doping).
- #1 Q=1.5E+10 @ 16 MV/m, #2 Q=1.3E+10 @ 16 MV/m, Maximum gradient ~ 20.3 MV/m
- Target in 2019: Q=2.0E+10 @ 16 MV/m with N-doping + EP.





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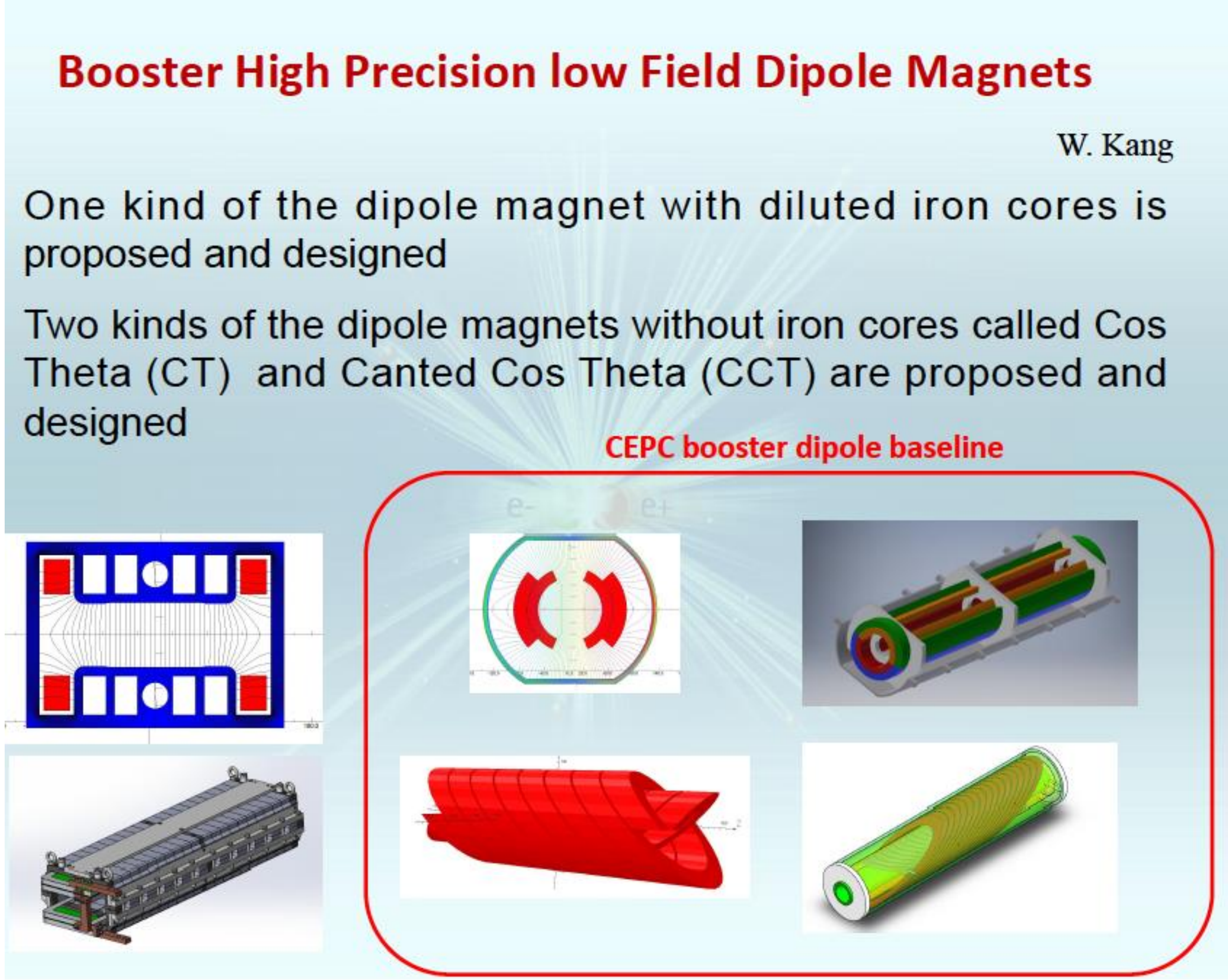
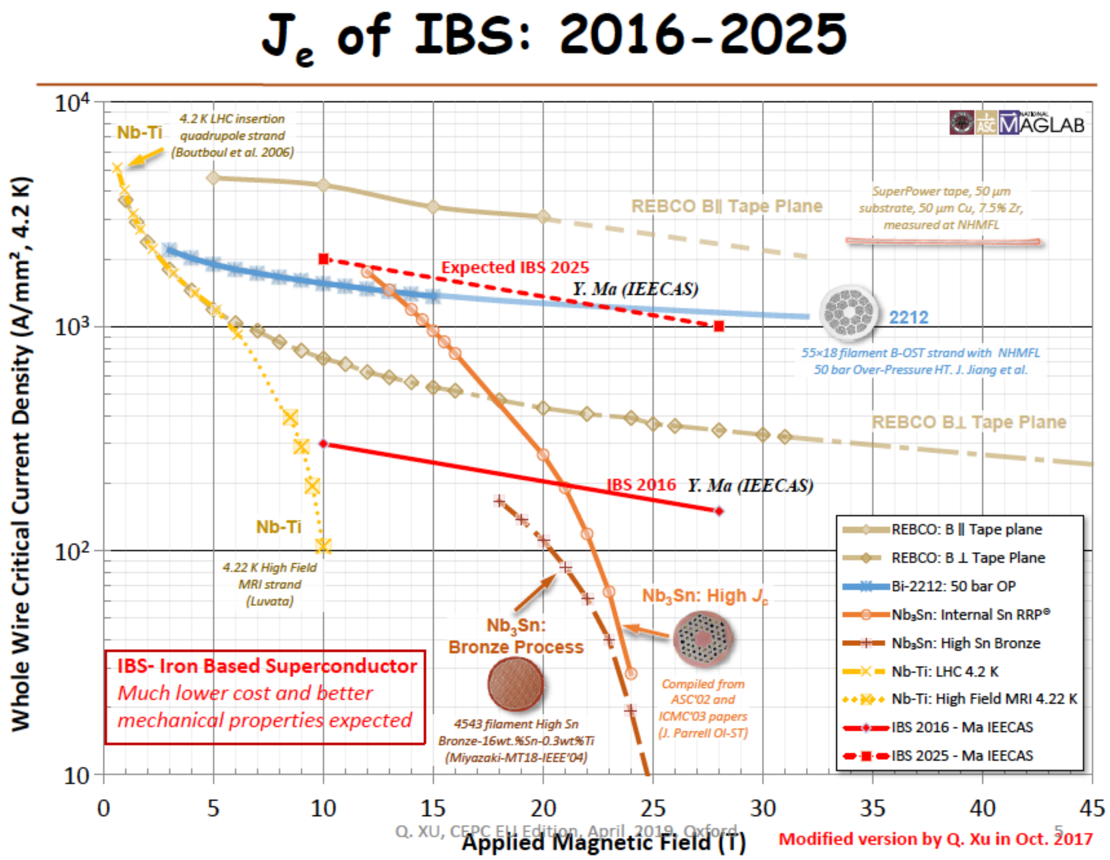
Booster Magnets

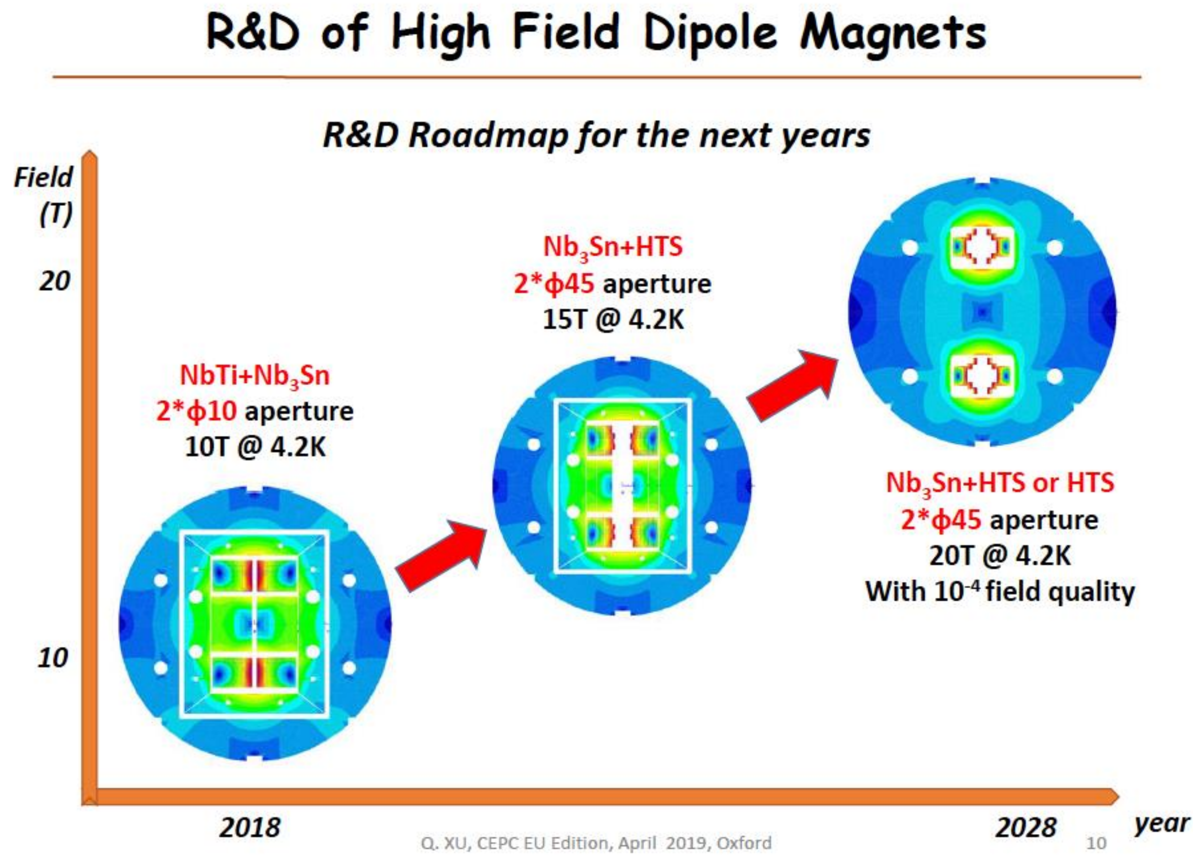
New, increased ramp rate requires air coil magnets to avoid remnant fields



Superconductor Research

China goes for IBS: Iron-Based Superconductors





Iron-Based Superconductors

A fascinating discovery

Japanese scientists use alcoholic drinks to induce superconductivity

7 March 2011

Japanese researchers have been immersing iron-based compounds in hot alcoholic beverages such as red wine, sake and shochu to induce superconductivity.

Scientists from the National Institute for Materials Science, Japan, found that immersing pellets of an iron-based compound in heated alcoholic beverages for 24 hours greatly increase their superconducting ability.

Iron-based compounds can become superconductive after being exposed to air. This process however can take up to several months. This study demonstrated that superconductivity can be induced in just one day.

Due to the variety of technological applications of superconducting materials, there has been a scramble for substances that may induce and enhance superconductivity in iron-based compounds.

The alcoholic beverages used were red and white wine, beer, Japanese sake, shochu, and whisky. Samples of the iron-based compound were immersed in each beverage, heated at 70oC for 24 hours, and then analysed.

Red wine was shown to induce the best superconducting properties; however beverages with the same alcohol concentration showed a significant difference. This suggests that it may not be the alcohol contributing to the creation of superconductivity but instead another component present in the beverages.

http://www.iop.org/news/11/march/page_50051.html

Superconductor Science and Technology

Alcoholic beverages induce superconductivity in $FeTe_{1-x}S_x$

K Deguchi[1,2,3], Y Mizuguchi[2,3], Y Kawasaki[1,2,3], T Ozaki[1,3], S Tsuda[1,3], T Yamaguchi[1,3] and Y Takano[1,2,3]

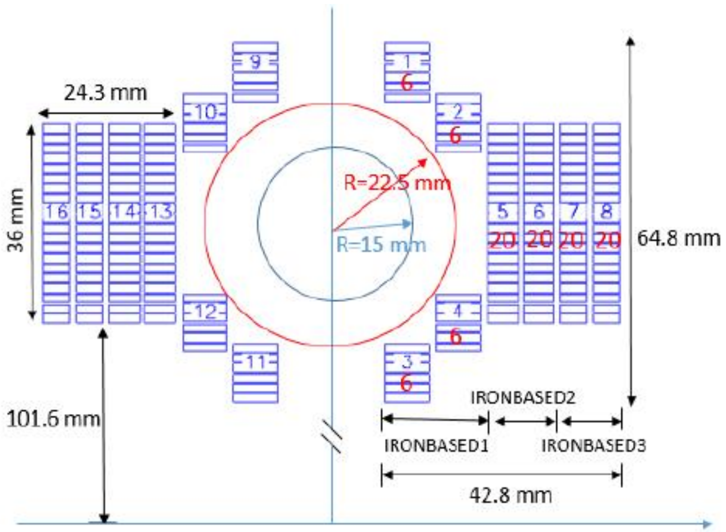
Published 7 March 2011 • IOP Publishing Ltd
Superconductor Science and Technology, Volume 24, Number 5

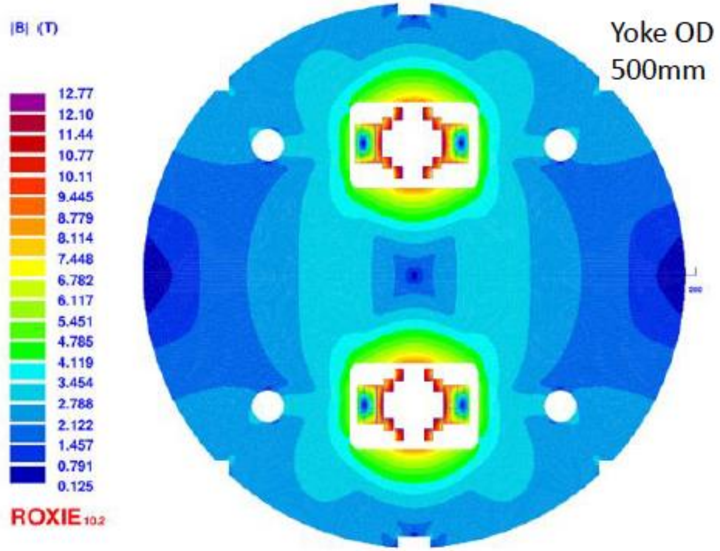
the cutting of the pellet, we immediately carried out the measurement using one of the pieces to obtain the as-grown data. Other pieces (~ 0.15 g) obtained from same pellet were put into a glass bottle (20 ml) filled with alcoholic beverage, beer (Asahi Super Dry, Asahi Breweries, Ltd.), red wine (Bon Marche, Mercian Corporation), white wine (Bon Marche, Mercian Corporation), Japanese sake (Hitorimusume, Yamanaka shuzo Co., Ltd.), shochu (The Season of Fruit Liqueur, TAKARA Shuzo Co., Ltd.) or whisky (The Yamazaki Single Malt Whisky, Suntory Holdings Limited). We also performed a control experiment using a set of samples immersed in pure water, a mixed solution of water and ethanol, and anhydrous ethanol. Although the water-ethanol and alcoholic beverage sets of samples were cut from separate pellets, reproducible results of the control samples, as described below, indicated a small pellet-to-pellet variation. The samples in various liquids were heated at 70 °C for 24 hours.

doi:10.1088/0953-2048/24/5/055008

SPPC 12T Fe-based Magnets

C. Wang, E. Kong (USTC), Q. Xu et al.





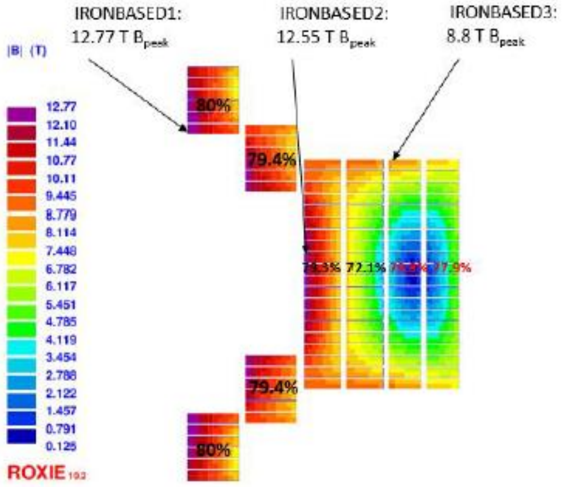


Table 1: Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Filament	Insulation
IRONBASED1	8	1.5	1.5	20	IRON-BASED	FE-BASED	0.15
IRONBASED2	5.6	1.5	1.5	14	IRON-BASED	FE-BASED	0.15
IRONBASED3	5	1.5	1.5	12	IRON-BASED	FE-BASED	0.15

Table 2: Main parameters of the strand

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IRON-BASED	0.802	1	200	4.2	10	4000	111

For per meter of such magnet, the required length of the iron-based strand: 6.08 Km

Civil Engineering & Site Selection

Factors affecting site selection：

1、Social factors:

National planning, Regional economic conditions, Cultural environment, Immigration, Environmental protection.

2、Natural conditions and engineering factors:

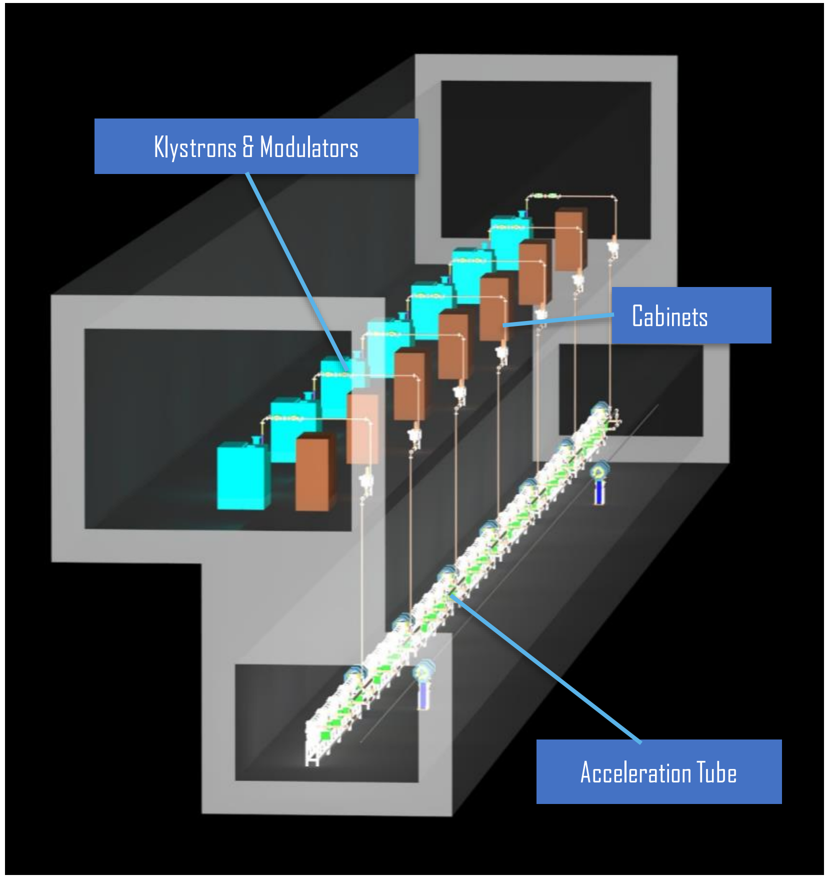
Climate, Traffic, Topographical geology, Engineering layout, Construction Conditions, Engineering investment.

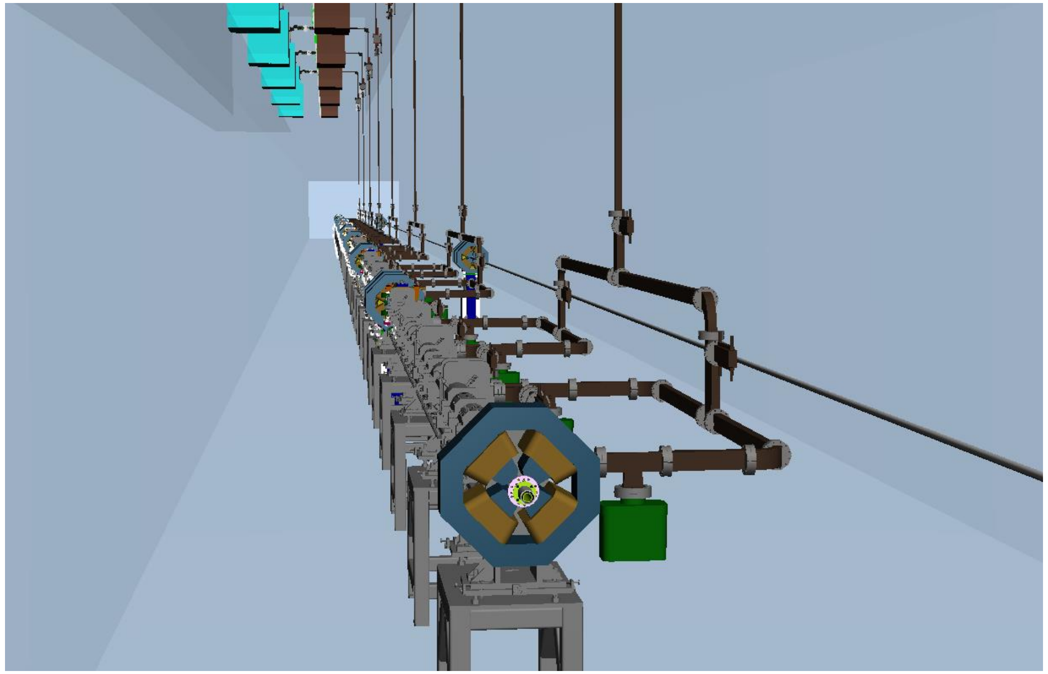
3、Operating factor:

Water supply, power supply, operating costs

In China, there are many sites that meet the construction conditions.

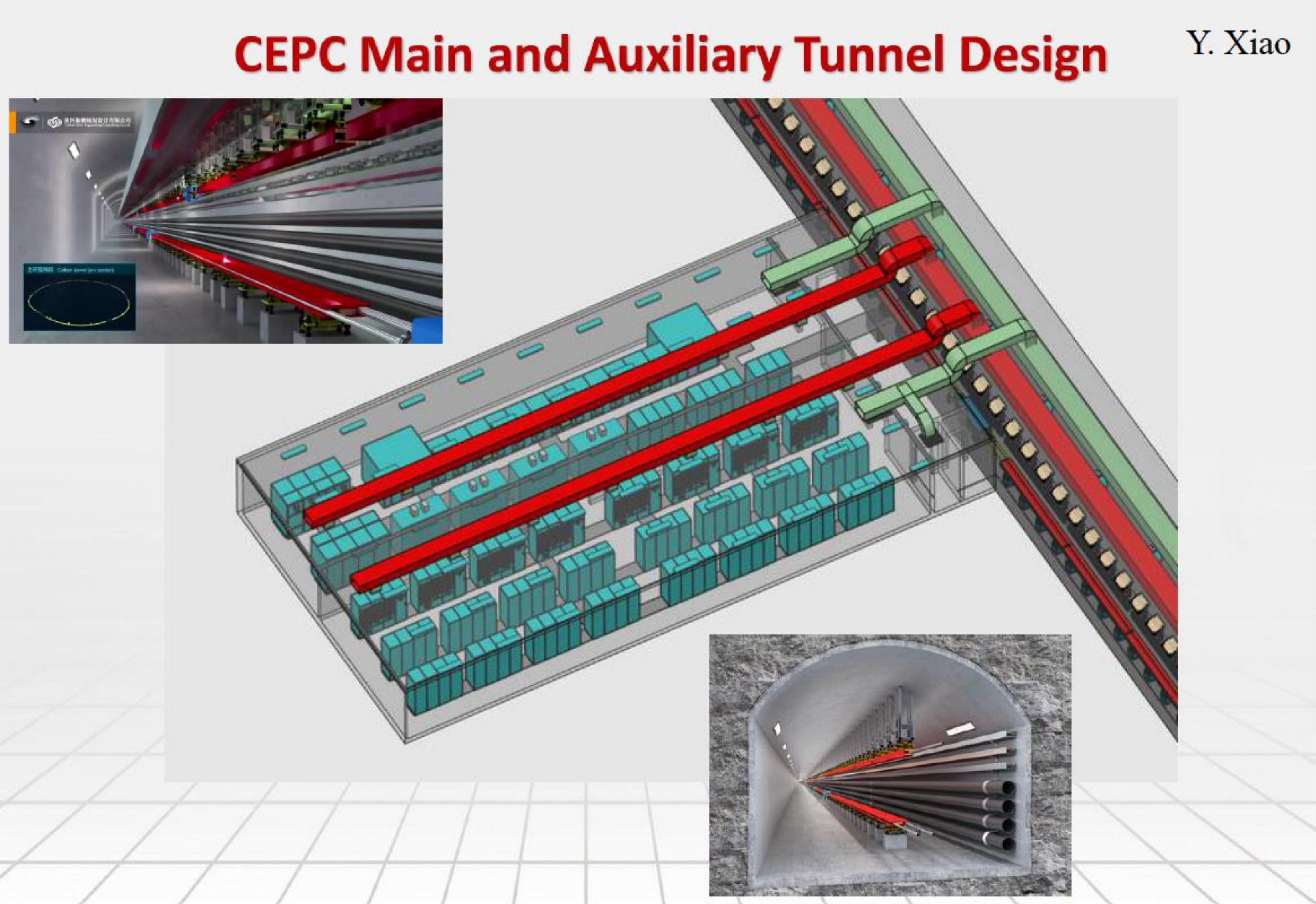
Linac segment CAD





Inside the linac tunnel

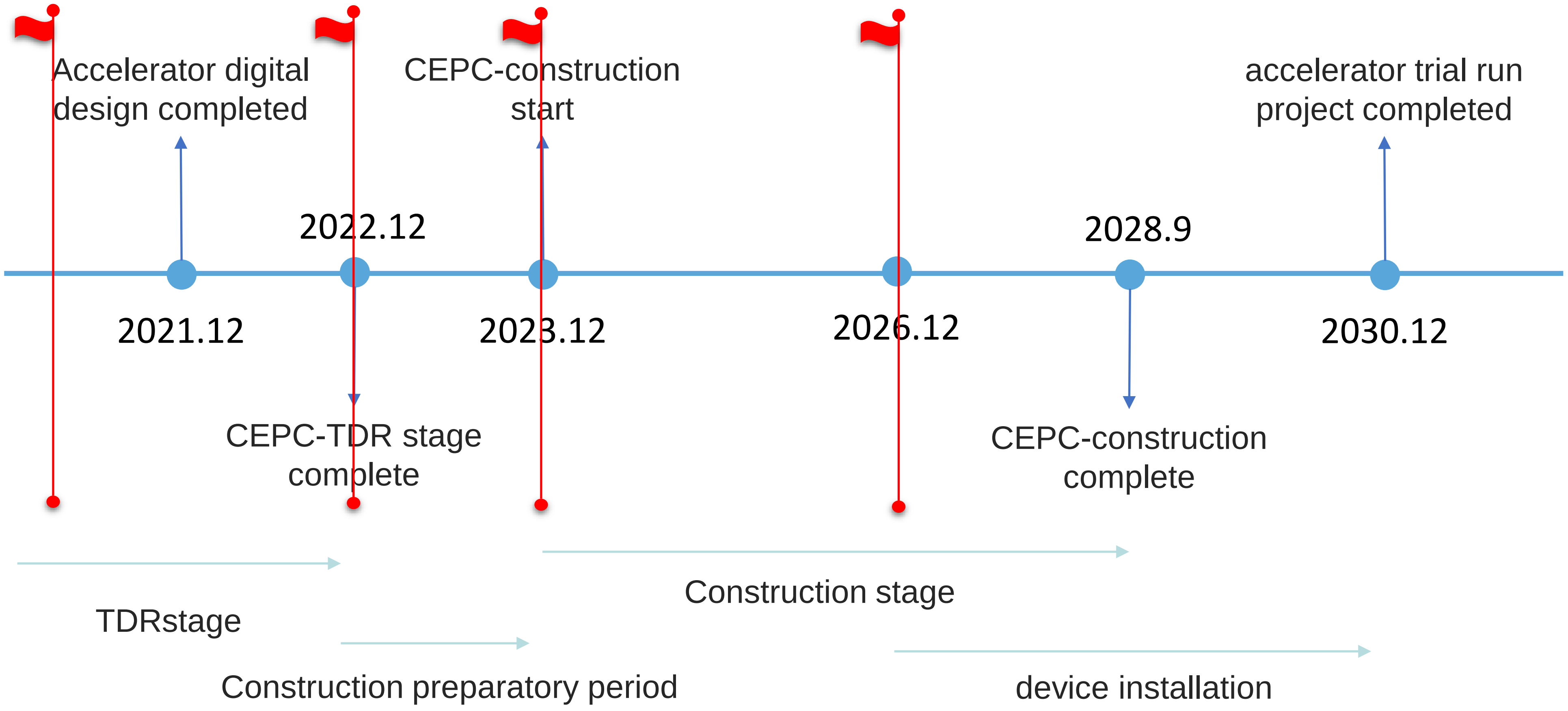
Main & Auxiliary Tunnel Design



International Science City

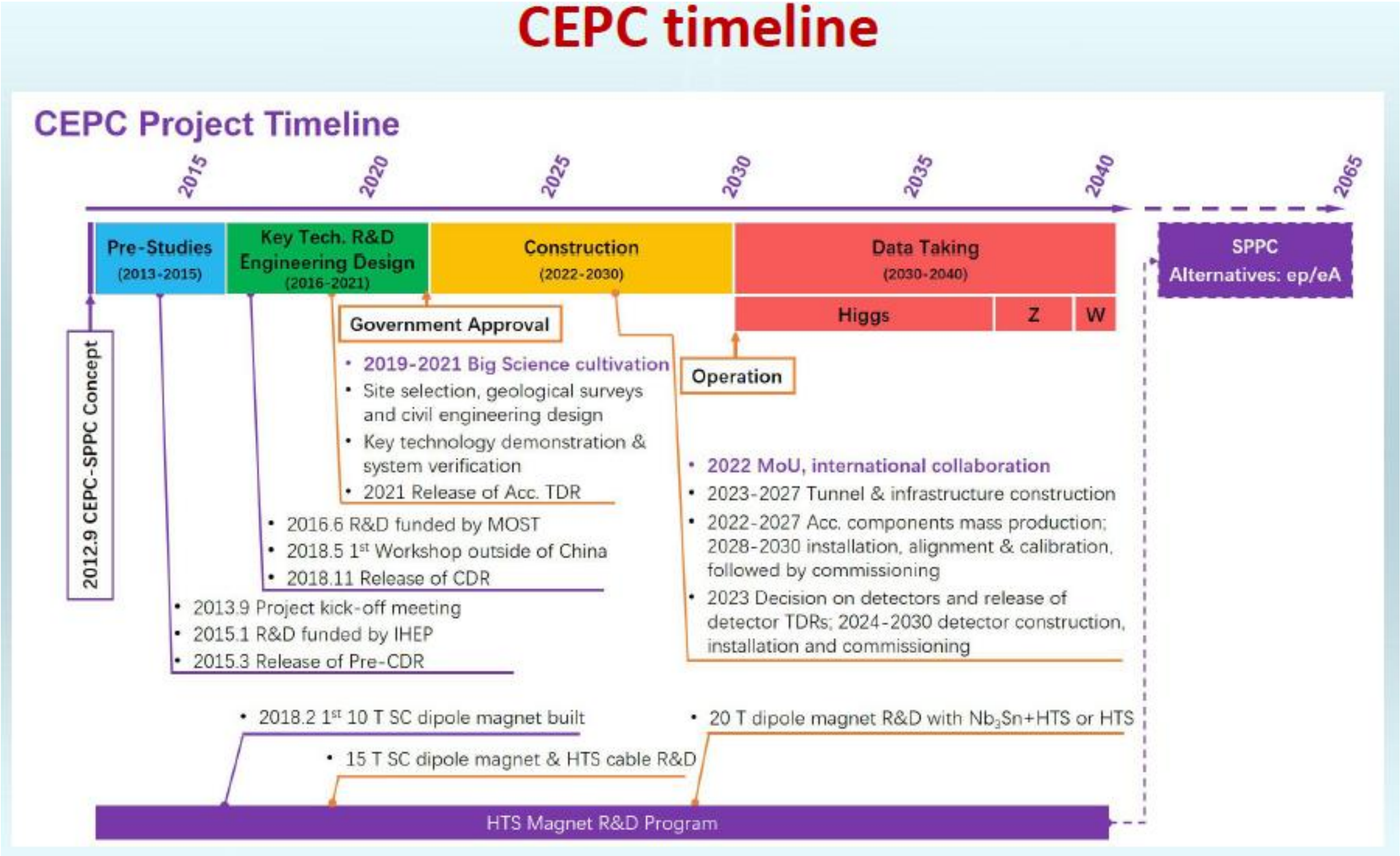
Overall Scale : 3.3km² of construction area for short-term use & 6.7km² for future use.

Construction Schedule



Timeline

From Jie Gao's talk



Polarized Beams

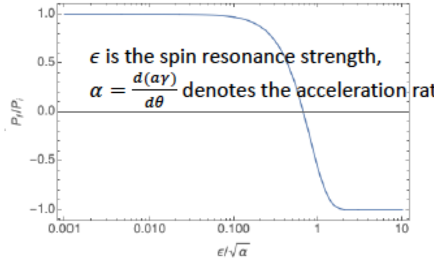
Take a ambitious design and make it harder

Polarized lepton acceleration in the booster

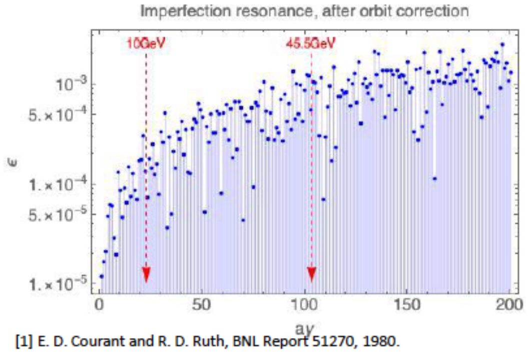
In a planar ring, the closed orbit spin tune $\upsilon_s \approx a\gamma$, two families of important spin resonances:

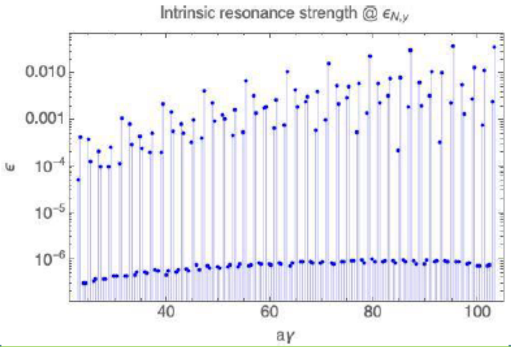
- Imperfection resonance $a\gamma = K$, K is integer
- Intrinsic resonance $a\gamma = K \pm \nu_y$, K is integer

Polarization change after linearly ramping through a single isolated spin resonance



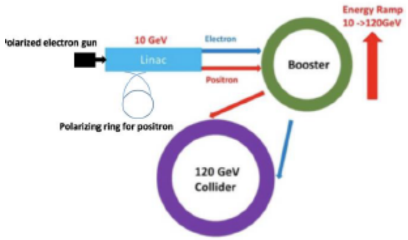
Spin resonance strengths for CEPC booster lattice (w/ DEPOL[1])



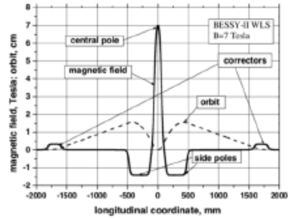


[1] E. D. Courant and R. D. Ruth, BNL Report 51270, 1980.

Alternative option w/ polarized positron beam



An asymmetric wiggler @BESSY-II as WLS[2] .



The e+ damping ring as a e+ polarizing ring (PPR).

- Asymmetric wigglers dominate synchrotron radiation effects[1].
- e+ bunches gain > 50% polarization after 20 seconds.
- To keep continuous injection and a beam lifetime of 2 hour (high luminosity) @Z in the storage ring
  - ~200 bunches, ~600 mA current required in the PPR
  - ns-level rise/fall time inj/ext kickers.
- One possible operation scenario
  - Initial injection of non-polarized positron beam.
  - Then continuous injection with polarized e+ beam, beam polarization build-up within hours.
- The requirement for PPR from CEPC-W is less challenging.

A tentative parameter table

Parameter	value
Beam energy (GeV)	2.5
Circumference (m)	200
Wiggler total length (m)	22
B+/B- (Tesla)	15[3] / 1.5
U0 (MeV)	4
Polarization build-up time (s)	17
rms energy spread	~0.3%
Natural emittance (nm)	~10
Radiation damping time (ms)	~1

[1] A. Blonde and J. Jowett, LEP Note 606, 1988. [2] A. M. Batrakov, et al, APAC 2001, pp 251-253.
[3] G. Sabbi "15 T at 4.5 K, which can be considered as a practical limit for accelerator quality designs using state of the art Nb3Sn conductor." in Handbook of Accelerator Physics and Engineering, 2nd Edition, 2013, p 599.

My personal uptake

- CepC is extremely ambitious, everywhere:
  - Ultra-short construction schedule (5 years)
  - New Z0 parameters (to match FCC) -> new 1-cell cavities needed (because of HOMs)
  - Ambitious cavity goals: Q0=5E10 at 42MV/m (in vertical test)
  - Increased ramp rate – difficult boster design
  - Idea: Produce polarised beams (positrons: polarise in damping rings) and inject them
  - 2 linac concepts: 10-20GeV conventional, or 45GeV plasma
  - For SppC: High-temperature superconductors, 12-24(!!!) T
  - Concentrate on domestic industry: cavities, cryomodules, cryo plants, klystrons
  - Enormous human ressources already now available
- Competition with FCC is very visible, parameters are ever increased to match FCC – 350GeV next?
- Clearly a Chinese-centric project, international collaborators could harly keep pace
- What about the detectors? [P. Collard: Making the coil alone takes 9 years...]