Preliminary Conceptual Design of the CEPC-SPPC

Weiren Chou
For the CEPC-SPPC Study Group

Exploring the Physics Frontier with Circular Colliders
January 26 – February 1, 2015, Aspen, Colorado, USA

CEPC-SPPC Timeline (preliminary)

CEPC

1st Milestone: Pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

SPPC

2014 Visitors

Name	**Institution**	**Specialty**	**Dates**
Dmitry Shatilov	BINP (Russia)	Beam-beam	April 1 - 16
Dick Talman	Cornell U. (USA)	General	April 13 - May 15
Yoshihiro Funakoshi	KEK (Japan)	Parameters, injection, background	April 1 - 15
Kazuhito Ohmi	KEK (Japan)	Beam-beam, e-cloud	April 13 - 25
Armen Apyan	Northwestern U. (USA)	CAIN/Guinea-Pig, polarized e+, beam dump	March 31 - April 30
Yunhai Cai	SLAC (USA)	Lattice, interaction region	April 15 - 30
Yuhong Zhang	Jlab (USA)	ep collider	April 13 - May 10
John Skaritka	BNL (USA)	Warm and SC magnet	July 12 - 26
Kazuhito Ohmi	KEK (Japan)	Beam-beam	July 16 - 30
Carlo Pagani	INFN (Italy)	SRF	July 21 - August 1
Sergey Belomestnykh	BNL (USA)	SRF	September 16 - 27
Ramesh Gupta	BNL (USA)	SC magnet	September 16 - 23
Mei Bai	BNL (USA)	Polarization	October 13 - 18
Mike Sullivan	SLAC (USA)	IR and MDI	October 13 - 18
Kazuhito Ohmi	KEK (Japan)	Beam-beam	October 13 - 15
Sergey Belomestnykh	BNL (USA)	SRF	October 13 - 18
Dave Rice	Cornell (USA)	e+e- collider	October 13 - 14
Frank Zimmermann	CERN (Switzerland)	General	October 13 - 15
John Seeman	SLAC (USA)	General	October 13 - 18
Michiko Minty	BNL (USA)	Instrumentation	October 13 - 18
Yuhong Zhang	Jlab (USA)	e-p	October 13 - 18
Carlo Pagani	INFN-Milan (Italy)	SRF	October 19 - November 6
Marica Biagini	INFN-LNF (Italy)	e+e- collider	October 13 - 22
Yunhai Cai	SLAC (USA)	Lattice	October 13 - 16
Mike Koratzinos	U. Geneva (Switzerland)	General	October 13 - 16
Hiroshi Sugimoto	KEK (Japan)	Lattice	October 8 - 17
Ernie Malamud	Fermilab (USA)	Editing	December 3 - 17

55th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders – Higgs Factory (HF2014)

October 9 – 12, 2014, Hotel Wanda Realm, Beijing, China

Program (draft as of 09/27/2014)

	Thursday, October 9 (at Hotel)	Friday, October 10 (at Hotel)	Saturday, October 11 (at IHEP)	Sunday, October 12 (at Hotel)
Morning 08:30 – 10:00	**Plenary session 1** Theory talk 1 (Nima Arkani-Hamed, IAS) Theory talk 2 (Shouhua Zhu, Peking U.)	**Parallel session 2** WG 1 – Parameters WG 2 – Optics	**Parallel session 6** WG 3 – IR and MDI WG 4 – SR and shielding	**Parallel session 10** WG 7 – Orbit and beam stability (an open slot)
10:00 – 10:30	**Coffee break**	**Coffee break**	**Coffee break**	**Coffee break**
10:30 – 12:00	**Plenary Session 2** Experiment talk 1 (Alain Blodel, U. Geneva) Experiment talk 2 (Yuanning Gao, Tsinghua U.)	**Parallel session 3** WG 1 – Parameters WG 2 – Optics	**Parallel session 7** WG 3 – IR and MDI WG 5 – SRF	**Parallel session 11** WG 8 – Polarization WG 9 – Instrumentation and control
Lunch 12:00 – 14:00			IOC lunch meeting	
Afternoon 14:00 – 15:30	**Plenary session 3** Overview: FCC-ee (Frank Zimmermann, CERN) Overview: CEPC (Qing Qin, IHEP)	**Parallel session 4** WG 2 – Optics WG 3 – IR and MDI	**Parallel session 8** WG 5 – SRF WG 6 – Injectors and injection	**Summary session**
15:30 – 16:00	**Coffee break**	**Coffee break**	**Coffee break**	
16:00 – 17:30	**Parallel session 1** WG 1 – Parameters WG 2 – Optics	**Parallel session 5** WG 3 – IR and MDI WG 4 – SR and shielding	**Parallel session 9** WG 6 – Injectors and injection WG 7 – Orbit and beam stability	
18:00 – 19:45	**Special joint session with LCWS2014** WG 10 – "Green" accelerators (Higgs factory, ILC, CLIC, etc.)			
Evening	Reception at 20:00		Banquet	

Working Group Conveners:

WG 1: Eugene Levichev (BINP), Frank Zimmermann (CERN)
WG 2: Katsunobu Oide (KEK), Yunhai Cai (SLAC)
WG 3: Mike Sullivan (SLAC), Yoshihiro Funakoshi (KEK)
WG 4: John Seeman (SLAC), Marica Biagini (INFN-LNF)
WG 5: Yoshiyuki Morita (KEK), Sergey Belomestnykh (BNL)
WG 6: Dave Rice (Cornell U.), Yannis Papaphilippou (CERN)
WG 7: John Byrd (LBNL), Gang Xu (IHEP)
WG 8: Ivan Koop (BINP)
WG 9: Michiko Minty (BNL), Hermann Schmickler (CERN)
WG 10: Steve Peggs (BNL)

Informal Mini-Review of CEPC-SPPC Pre-CDR

October 13 – 17, 2014, IHEP

Agenda (October 11, 2014)

	Monday, October 13 Room A415	Tuesday, October 14 Room C407	Wednesday, October 15 Room C407	Thursday, October 16 Room A415	Friday, October 17 Room C407
Morning 09:00 – 12:00 (Coffee break at 10:30)	**Ch 3: Layout & performance** (*Weiren Chou*) **Ch 4.1: Parameters** (*Yuanyuan Guo*) **Ch 4.2: Lattice** (*Huiping Geng*)	**Ch 4.6: Synchrotron radiation** (*Yadong Ding*) **Ch 4.7: Injection & beam dump** (*Xiaohao Cui*) **Ch 4.8: Beam loss, background and collimation** (*Hongbo Zhu*) **Ch 4.9: Polarization** (*Zhe Duan*)	**Ch 5.1: SRF** (*Yi Sun / Jiyuan Zhai*) **Ch 5.2: RF power source** (*Zusheng Zhou*) **Ch 5.3: Cryogenic system** (*Shaopeng Li*) **Ch 5.6: Vacuum** (*Haiyi Dong*) **Ch 5.7: Instrumentation** (*Junhui Yue*)	**Ch 9: Conventional facilities** (*Guoping Lin*) Discussion in small groups	Discussion in small groups
Lunch 12:00 – 14:00					
Afternoon 14:00 – 17:00 (Coffee break at 15:30)	**Ch 4.3: IR and MDI** (*Yiwei Wang*) **Ch 4.4: Beam instabilities** (*Na Wang*) **Ch 4.5: Beam-beam effects** (*Yuan Zhang*)	**Ch 6.1: Linac and sources** (*Guoxi Pei / Xiaoping Li*) **Ch 6.2: Booster** (*Chuang Zhang*) **Ch 7: SPPC** (*Jingyu Tang*) **Ch 11.15: SC magnet R&D** (*Qingjin Xu*) **Ch 8: e-p and e-A colliders** (*Yuemei Peng*)	**Ch 5.4: Magnets** (*Wen Kang*) **Ch 5.5: Power supplies** (*Fengli Long*) **Ch 5.8: Control** (*Dapeng Jin*) **Ch 5.9: Mechanical system** (*Haijing Wang*) **Ch 5.10: Radiation shielding** (*Zhongjian Ma*) **Ch 5. 11: Survey & alignment** (*Xiaolong Wang*)	Discussion in small groups	Discussion in small groups

Invited Reviewers:

Mei Bai (BNL)
Dave Rice (Cornell)
Yuhong Zhang (Jlab)
Mike Koratzinos (CERN)

Mike Sullivan (SLAC)
Frank Zimmermann (CERN)
Carlo Pagani (INFN-Milan)
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Reviewers Reports (13 reports, 28 pages)

Reviewers' Comments from the CEPC_SPPC Pre-CDR Mini-Review

(October 13-17, 2014, IHEP)

1. Dave Rice (Cornell University, USA)

Dear Weiren and Qing,

The few days spent working with IHEP staff in reviewing the draft pre-CDR work last week was most pleasant an interesting. The hospitality and high level of competence and dedication of the group there makes visits most enjoyable and productive.

My comments follow more or less the outline you suggested.

What is missing in the Pre-CDR?

With only a top-level TOC one cannot go too much into detail, but a few items come to mind:

1. It may (or may not!) be useful to have a discussion of overall operations from injection cycle to yearly schedule showing how 250 fb-1 will be conservatively achieved with the luminosity & lifetimes quoted. I didn't see an obvious heading where this might go other than Injection or Machine Layout and Performance.
2. The separators for the pretzel will have some challenging design aspects, specifically the synchrotron radiation environment (photo currents) and HOM losses. Some up-front engineering/design would be appropriate.
3. Beam stability analysis for the booster was not shown. The higher frequency RF and long damping times raise concerns for 50 bunch operation (even though lower current). HOM impedances are significantly higher for the 1.3 GHz system.
4. There was fleeting discussion of Z-pole operation but no serious attention impact. I assume that the plan is to ignore for now. However, the closer bunch spacing will require rethinking both booster and ring beam stability and injection scheme. Could science/political pressure generated by CERN plans bring this to the forefront?

CEPC-SPPC:Pre-CDR

February 2015

The CEPC-SPPC Study Group

IHEP-AC-2015-001

CEPC-SPPC

Preliminary Conceptual Design Report

February 2015

The CEPC-SPPC Study Group

CEPC-SPPC

Preliminary Conceptual Design Report

February 2015

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1 The Science of the CEPC and the SPPC

1.1 Introduction

The Standard Model (SM) of elementary particle physics has withstood extensive experimental tests and has proven to be very successful in describing the subatomic world. The Higgs boson, recently discovered at the Large Hadron Collider (LHC), is consistent with the long awaited SM Higgs. Further measurement of its properties, including its couplings to fermions, other bosons and its self-interaction, will refine this picture. Any deviations from the SM will open the door to new physics beyond the Standard Model.

While the SM has been remarkably successful in describing experimental phenomena, with the discovery of the Higgs boson completing the last missing piece, it is likely that the SM is only an effective theory at the electroweak scale. In particular, the SM does *not predict* the parameters in the Higgs potential, nor does it provide a description of the nature of the electroweak phase transition. The vast difference between the Planck scale and the weak scale still remains a mystery. The discovery of a spin zero Higgs boson, the first elementary particle of its kind, only sharpens these questions. In addition, there is no particle candidate for dark matter in the SM. It is clear that any effort to address these questions will involve new physics beyond the SM. Therefore, the Higgs discovery marks the beginning of a new era of theoretical and experimental explorations. The search for such new physics will remain the critical objectives of current and future experimental particle physics programs.

The LHC will resume operation in 2015 at a 13 TeV center-of-mass (cm) energy after the current shutdown for upgrades. The LHC, as well as the ALTAS and CMS detectors, are scheduled to undergo additional upgrades in 2018 and 2022, and will enter the High Luminosity LHC (HL-LHC) phase at the design cm energy of 14 TeV. Experiments at the LHC will maximize the physics potential which will eventually be limited by the collider cm energy and the large background present in the pp collision data.

In the longer time scale, lepton colliders, including the ILC, CEPC and FCC (ee), may be built and be in operation prior to the completion of the HL-LHC phase. They will provide a clean environment to study the Higgs boson. The results would be complementary to the LHC and among themselves. The envisioned high energy pp colliders FCC (hh) and SPPC will extend the cm energies far beyond that of the LHC. The energy frontiers accessible through the LHC, HL-LHC, ILC, CEPC-SPPC and FCC will push the experimental e^+e^- and pp programs up to 1 TeV and nearly 100 TeV in cm energies, respectively.

1.2 Physics with the e^+e^- Collider

The CEPC e^+e^- collider is envisioned to be operated with a cm energy of 240 GeV where the Higgs events are produced primarily through the interaction $e^+e^- \rightarrow ZH$. With a nominal luminosity of 2×10^{34} $cm^{-2}s^{-1}$ about 1 million clean Higgs events will be produced by CEPC over a period of 10 years at each of the two interaction points.

lead to observable deviations in the Higgs couplings from the SM expectations. Typically, such deviations can be parameterized as

$$\delta = c\,\frac{v^2}{M_{NP}^2} \qquad (1)$$

where v and M_{NP} are the vacuum expectation value of the Higgs field and the typical mass scale of new physics, respectively. The size of the proportionality constant, *c*, depends on the model, but it should not be much larger than *O* (1). The current and upcoming LHC runs will directly search for new physics from a few hundreds of GeV to at least a TeV. Eq. (1) implies that probing new physics beyond the LHC reach would require the measurement of the Higgs couplings at least to the percent level accuracy.

The ATLAS and CMS experiments at the LHC will continue to improve the measurement of the Higgs boson properties including couplings to gauge bosons, Yukawa couplings and self-couplings. The current level of precision in the Higgs coupling measurements are at about *O* (15%) in most cases. They will be significantly improved in the coming decades through the on-going LHC program, as documented in several studies [1, 2]. Precision of a few percent are achievable for some of the couplings. However, to achieve the sub-percent level of precision will need new facilities. A lepton collider operating as a Higgs factory is a natural next step.

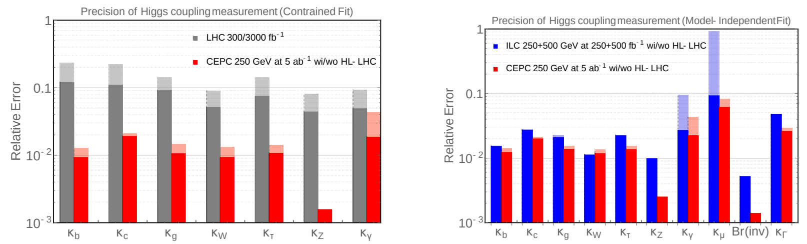


Figure 2.1: Projections of the precision of Higgs coupling measurements at CEPC. The y-axis is the percentage accuracy of the ratio between the measured size of the couplings and the Standard Model predictions. Left panel: The projections for the LHC (300 fb^{-1}, lighter grey) and HL-LHC (3 ab^{-1}, darker grey) are shown together with those for the CEPC (5 ab^{-1}, lighter red) and the combination of CEPC and HL-LHC (darker red). Right panel: The projections for the CEPC are shown together with those for the ILC (250+500 GeV with 250+500 fb^{-1}, lighter blue) and the combination of ILC and HL-LHC (darker blue).

The CEPC collider will allow the measurement of the rates of production of the Higgs boson in e^+e^- annihilations. The SM predicts those cross sections for a Standard Model Higgs. The leading production at ~240 GeV is the Higgsstrahlung process $e^+e^- \rightarrow Z^* \rightarrow ZH$, supplemented by the WW and ZZ fusions $e^+e^- \rightarrow \nu\nu\,(W^*W^*) \rightarrow \nu\nu$ H and $e^+e^- \rightarrow (Z^*Z^*) \rightarrow e^+e^-$ H, respectively. Data from CEPC can help identify the nature of the Higgs boson with these measurements.

A strong advantage of the CEPC experiment over the LHC is that the Higgs can be detected through the recoil mass method by reconstructing only the Z boson without including the recoiling Higgs boson in the event reconstruction. Therefore, Higgs production can be disentangled from its decay in a model independent way. Moreover,

CEPC Design – Top Level Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	240 GeV
Integrated luminosity (per IP per year)	250 fb^{-1}
No. of IPs	2

⇒ one million Higgs from 2 IPs in 10 years

SPPC Design – Top Level Parameters

Parameter	Design Goal
Particles	p, p
Center of mass energy	70 TeV
Integrated luminosity (per IP per year)	(TBD)
No. of IPs	2

A Note on the *pp* Luminosity

B. Richter, RAST, volume 7, p.1 (2014)

Parameter	HL-LHC	LHC-100 8T	LHC-100 16T
Beam Energy (TeV)	7	100	100
Circumference (km)	27	190	95
L ($cm^{-2}sec^{-1}$)	$5x10^{34}$	$2.5x10^{36}$	$2.5x10^{36}$
Bunch Spacing (ns)	25	25	25
Bean Current (Amp)	1.09	7.7	7.7
Synchrotron Rad Power (Mw)	0.0075	2.6	10.3
β * (cm)	15	15	15
ε_n (micron)	2.5	2.5	2.5
Particles per Bunch	$2.2x10^{11}$	$1.5x10^{12}$	$1.5x10^{12}$
Events per bunch collision	140	7000	7000
Events per mm	1.3	0.0025	0.0025

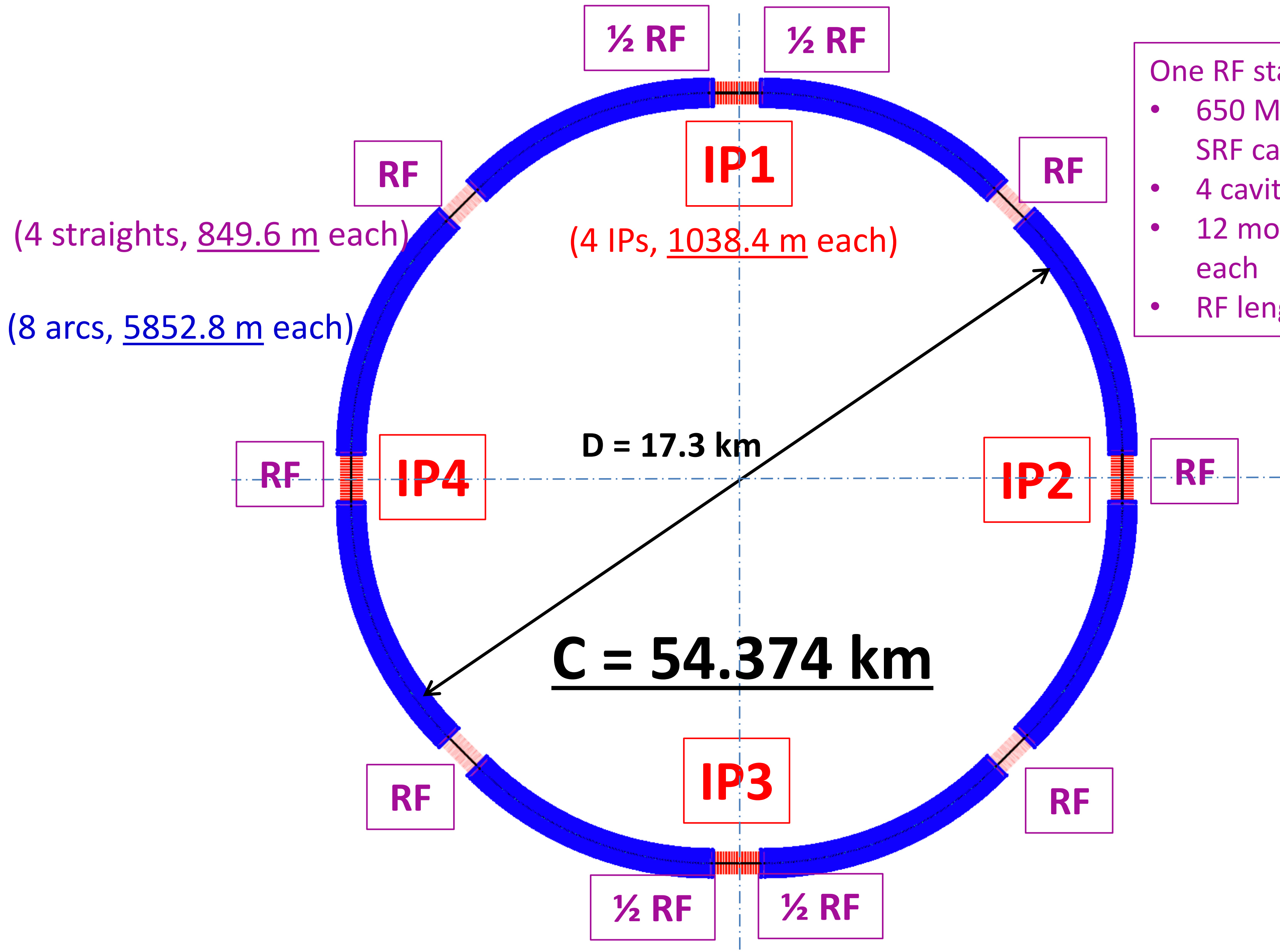
Discussion last week in Hong Kong

- 1e32 is good enough to start
- 1e36 or bust!

Continued discussion this week here in Aspen

- Liantao's quantitative analysis
- Michelangelo's talk tomorrow

CEPC Lattice Layout (September 24, 2014)



One RF station:

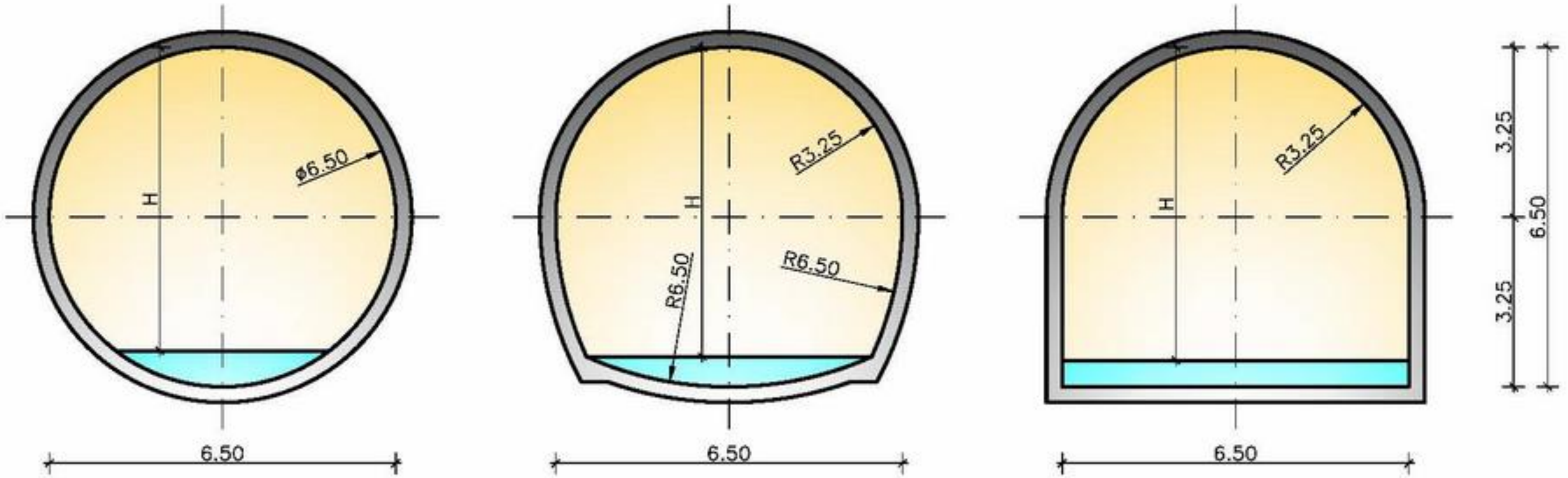
- 650 MHz five-cell SRF cavities;
- 4 cavities/module
- 12 modules, 10 m each
- RF length 120 m

结构及防水初步方案

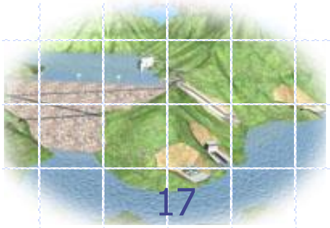
黄河设计公司
YREC

断面型式选择

圆型　　马蹄型　　城门洞型

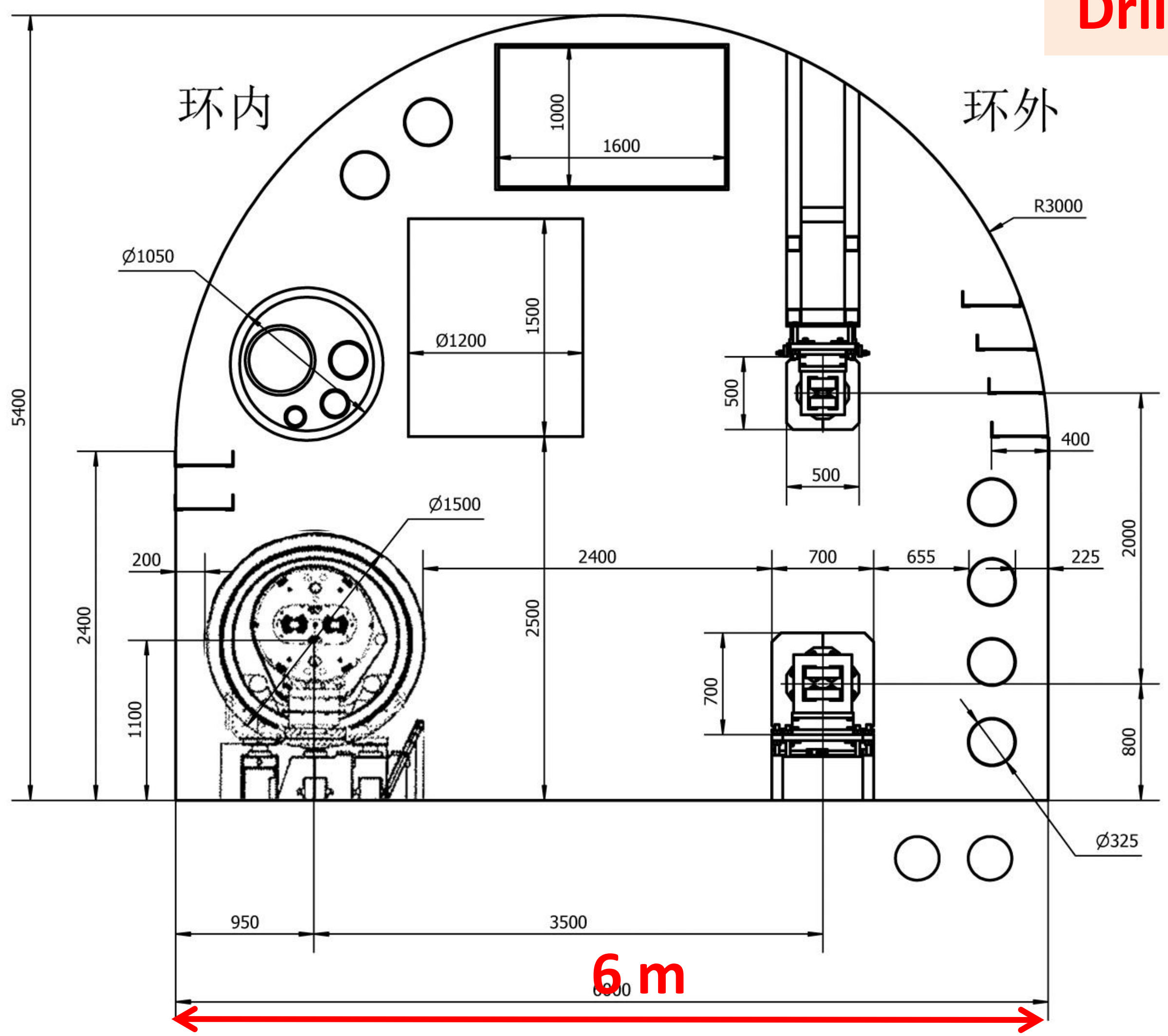


使用面积比约为：1 ： 1.05 ： 1.10



Tunnel Cross Section – SPPC + CEPC Magnets

Drill/Blast Method



LHC Tunnel – Magnet Section

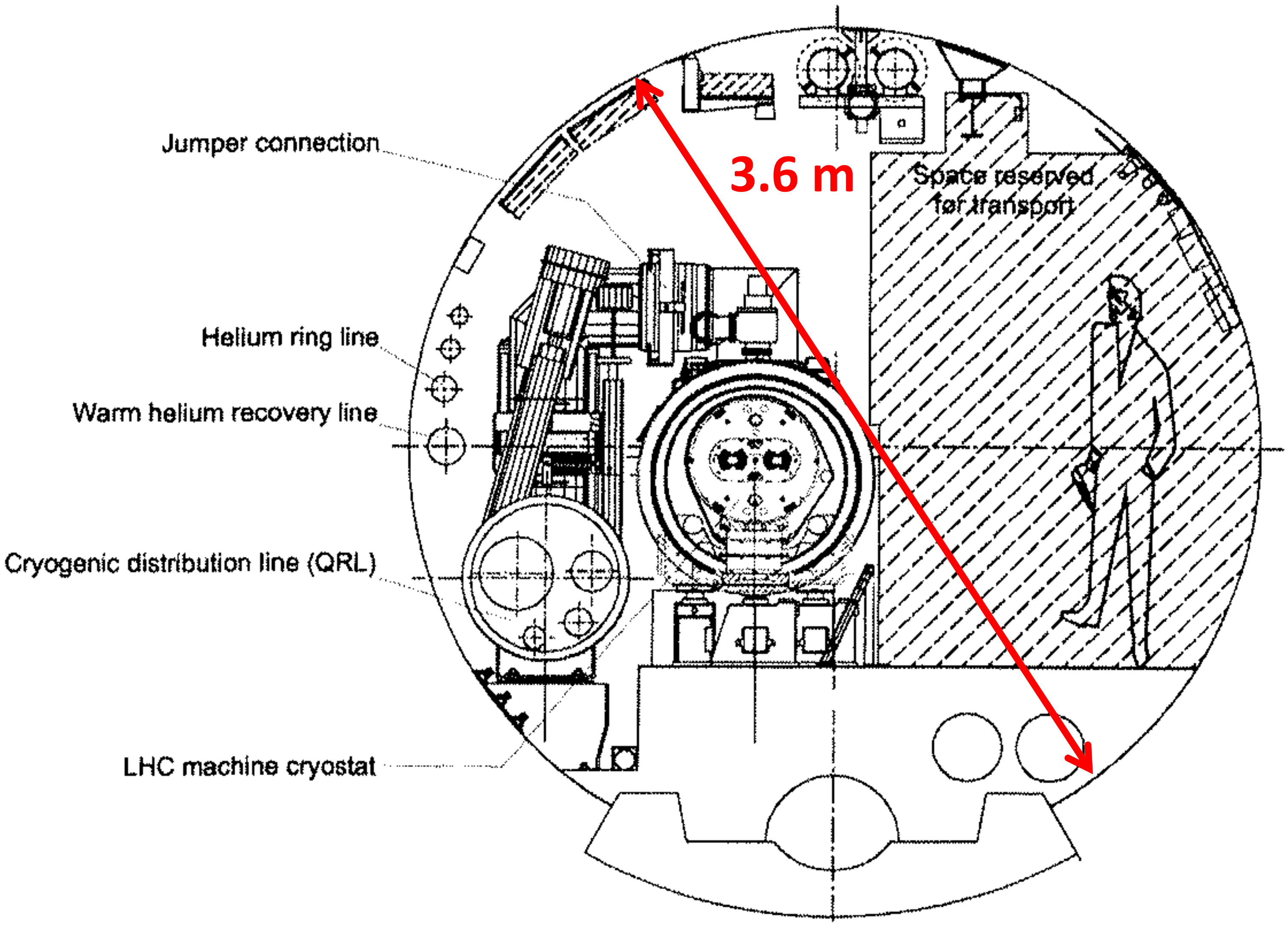
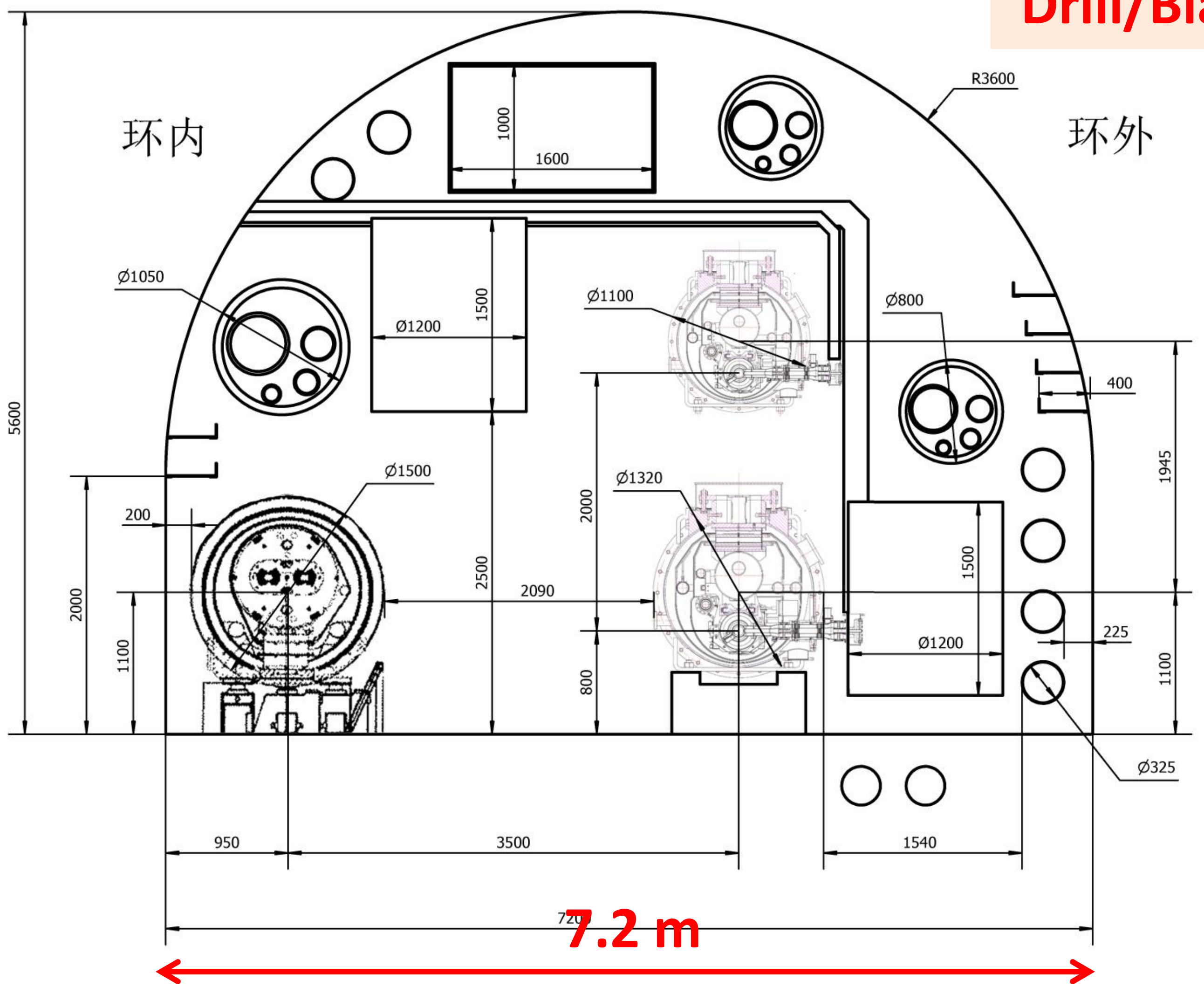


Figure 11.1: Transverse cross-section of the LHC tunnel

Tunnel Cross Section – RF Sections

Drill/Blast Method

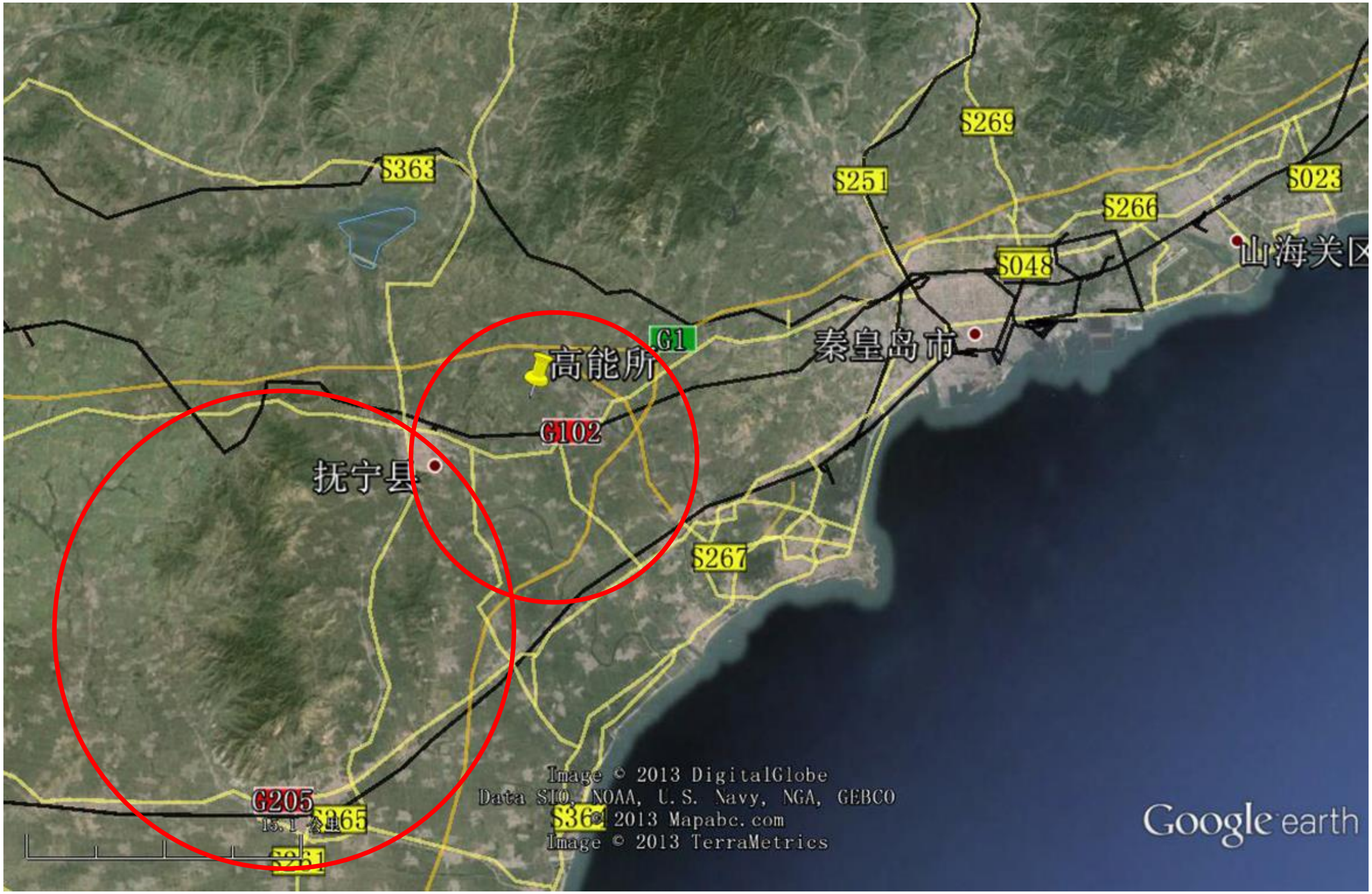


CEPC – Site Investigation

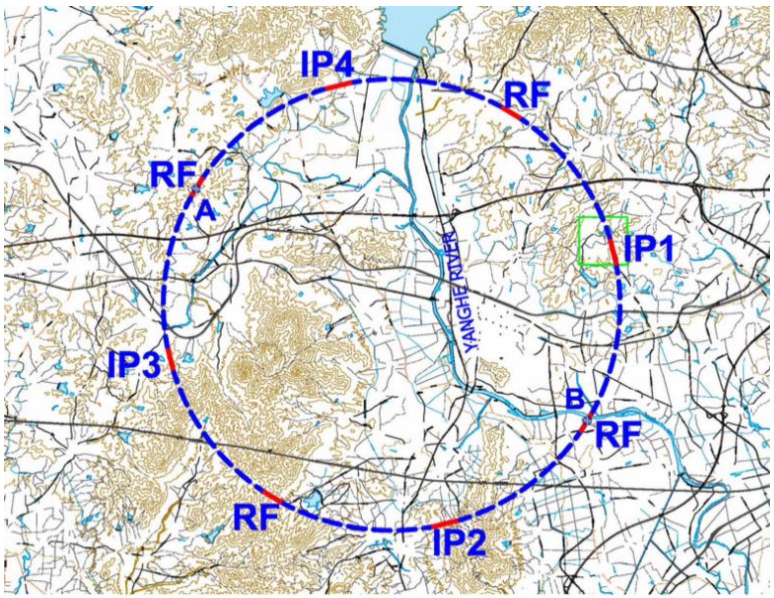
A good example is 秦皇岛:

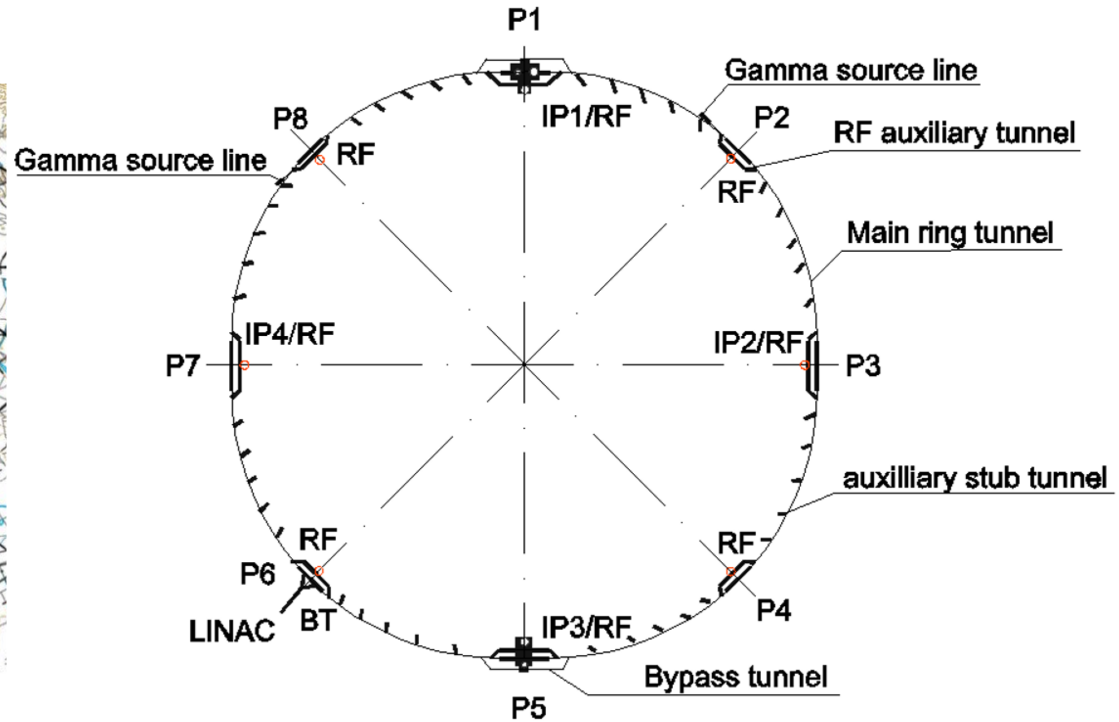
300 km from Beijing

3 hours by car; 1 hours by high speed train

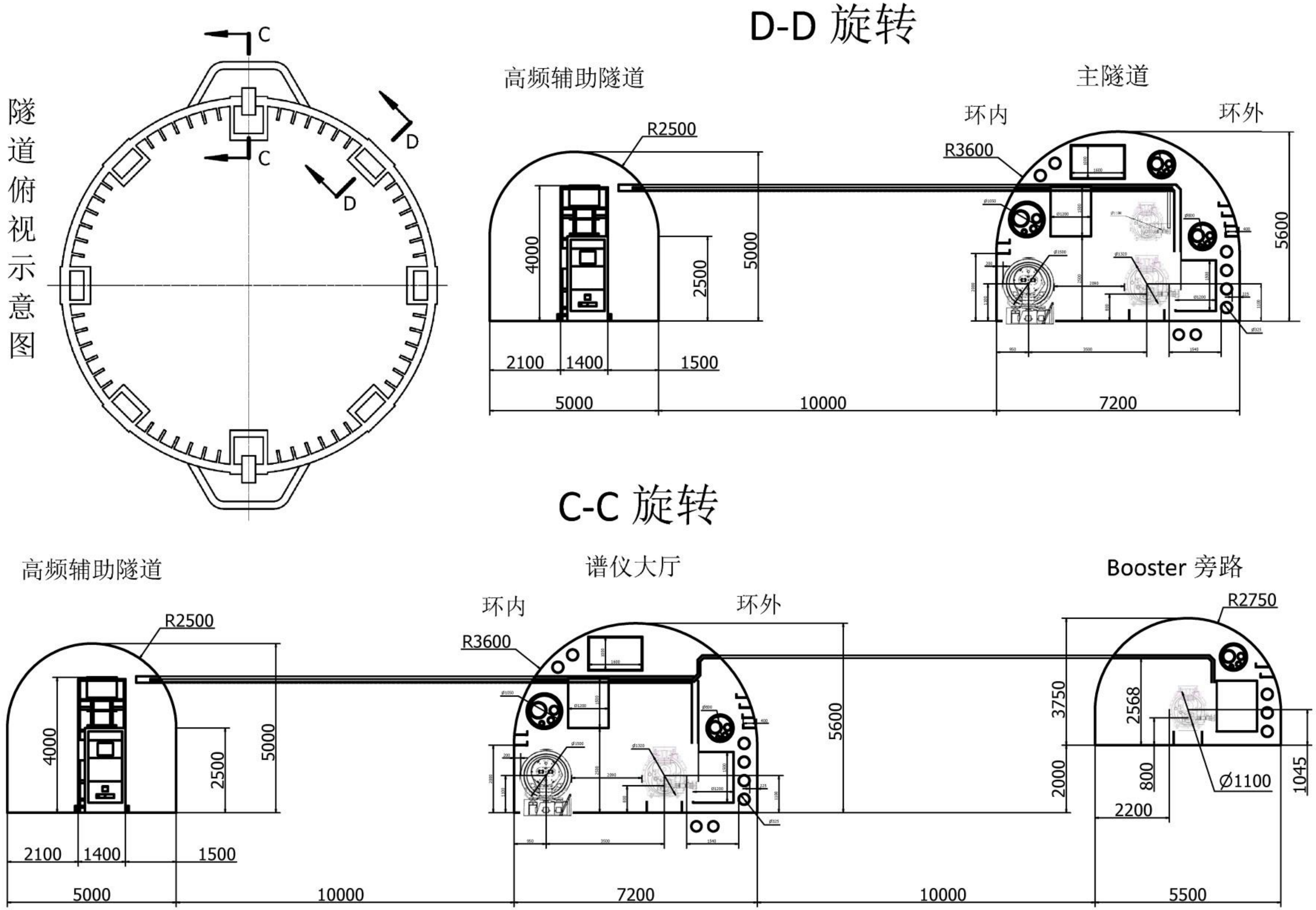


Civil Construction





Main Tunnel, Auxillary Tunnel & Bypass Tunnel



Circular Lepton Colliders (K. Oide, RAST, volume 7)

Table 1. Electron-positron circular colliders in the world. S/D = single/double ring.

Collider	Location	Scheme	Beam Energy (GeV)	Luminosity (10^{30}cm^{-2}s^{-1})	Year
AdA	Frascati	S	0.25	$\sim 10^{-5}$	1962
ACO	Orsay	S	0.5	0.1	1966
Adone	Frascati	S	1.5	0.6	1969–1993
SPEAR	SLAC	S	4	12	1972–1990
VEPP-2/2M	BINP	S	0.7	13	1974–
DORIS	DESY	D	5.6	33	1974–1993
DCI	Orsay	D	1.8	2	1976–2003
PETRA	DESY	S	19	30	1978–1986
VEPP-4M	BINP	S	7	50	1979–
CESR	Cornell	S	6	1,300	1979–2002
PEP	SLAC	S	15	60	1980–1990
TRISTAN	KEK	S	32	37	1986–1994
BEPC	IHEP	S	2.2	13	1989–2005
LEP	CERN	S	46	24	1989–1994
DAΦNE	Frascati	D	0.7	150	1997–
LEP2	CERN	S	105	100	1995–2000
PEP-II	SLAC	D	3.1 / 9	12,000	1999–2008
KEKB	KEK	D	3.5 / 8	21,100	1999–2010
CESR-c	Cornell	S	1.9	60	2002–2008
VEPP-2000	BINP	S	0.5	120	2006–
BEPCII	IHEP	D	2.1	710	2007–

CEPC Design – Guidelines

- Build an underground tunnel for a Higgs factory
- Use the same tunnel for a future *pp* collider:
  - The tunnel cross section should be big enough to accommodate an *e+e-* collider, a booster and a *pp* collider
  - The straight sections should be long enough to accommodate large detectors and complex collimation systems of a *pp* collider
  - It should allow to run both *e+e-* and *pp* experiments simultaneously
  - Within the budget limit, the tunnel circumference should be made as large as possible
- Keep options open for:
  - Super Z
  - *e-p* and *e-A* colliders
  - Light source
  - FEL
- A possible timeline:
  - A Preliminary Conceptual Design Report (Pre-CDR) this year
  - Get ready for R&D to start in 2016 in the government's 13th Five-Year Plan (2016-2020)
  - Get ready for construction to start in 2021 in the 14th Five-Year Plan (2021-2025)
  - Get ready for experiments to start in 2028 in the 15th Five-Year Plan (2026-2030)

CEPC Design - Baseline

- Tunnel circumference: ~54 km
- Tunnel size: 6.0 m (LEP tunnel: 3.6 m)
- 8 arcs and 8 straight sections: 4 straight for IPs and RF, another 4 for RF, injection and beam dump, etc.
- A 6 GeV linac on the surface (with the option for an FEL in the future)
- A full-energy 120 GeV Booster in the tunnel
- A 240 GeV e+e- Collider in the same tunnel underneath the Booster
- A single beam pipe for both e+ and e- beams (similar to LEP, CESR)
- Synchrotron radiation budget: 50 MW per beam
- Two SRF systems:
  - Booster: 1.3 GHz 9-cell cavity, similar to the ILC, XFEL, LCLS-II
  - Collider: 650 MHz 5-cell cavity, similar to the ADS, PIP-II

CEPC Design – Main Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54752
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Bunch population [Ne]**		3.79E+11
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
Bending radius [ρ]	m	6094	**momentum compaction factor [α_p]**		3.36E-05
Revolution period [T_0]	s	1.83E-04	**Revolution frequency [f_0]**	Hz	5475.46
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**$\xi_{x,y}$/IP**		0.118/0.083
Bunch length SR [$\sigma_{s.SR}$]	mm	2.14	**Bunch length total [$\sigma_{s.tot}$]**	mm	2.65
Lifetime due to Beamstrahlung	min	47	**lifetime due to radiative Bhabha scattering [τ_L]**	min	51
RF voltage [V_{rf}]	GV	6.87	**RF frequency [f_{rf}]**	MHz	650
Harmonic number [h]		118800	**Synchrotron oscillation tune [ν_s]**		0.18
Energy acceptance RF [h]	%	5.99	**Damping partition number [$J\varepsilon$]**		2
Energy spread SR [$\sigma_{\delta.SR}$]	%	0.132	**Energy spread BS [$\sigma_{\delta.BS}$]**	%	0.096
Energy spread total [$\sigma_{\delta.tot}$]	%	0.163	**n_γ**		0.23
Transverse damping time [n_x]	turns	78	**Longitudinal damping time [n_ε]**	turns	39
Hourglass factor	Fh	0.68	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.04E+34

Main Technical Challenges for CEPC

Common for both CEPC and FCC-ee:

1. IR optics with appropriate dynamic aperture for off-momentum up to ±2%
2. Machine-detector interface (L* = 1.5 m)
3. HOM damper for the RF cavity
   - High average beam current: 2 x 16.6 mA
   - High HOM loss: 2 x 2.3 kW per cavity

	40 K to 80 K	5 K to 8 K	2K
Efficiency in W/W	16.4	197.9	703.0

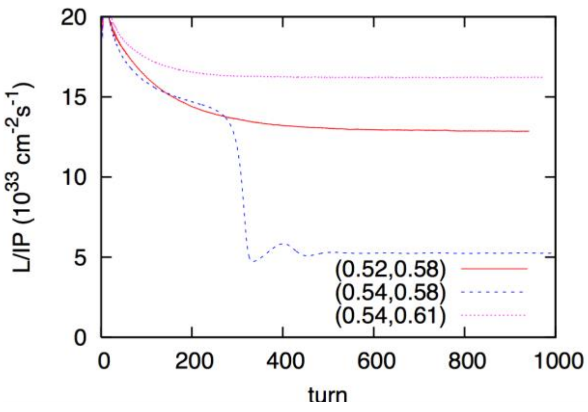
	40 K to 80 K	5 K to 8 K	2 K
HOM heat load distribution	3%	0.3%	0.1%

Specific to CEPC (due to budget constraint):

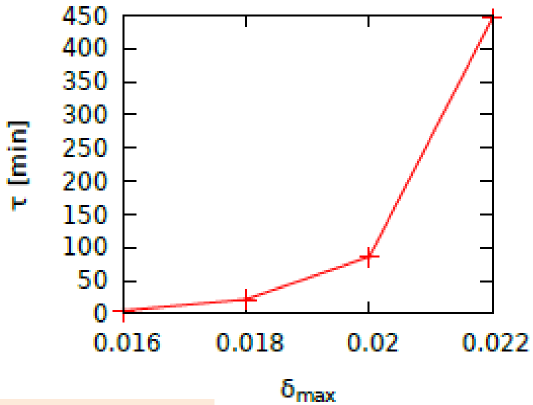
4. Pretzel orbit (single beam pipe)
5. Low energy injection (6 GeV) to the Booster:
   - Earth field effect: bend field ~30 Gs, measured earth field ~0.5 ± 0.03 Gs

Beam-Beam Effect

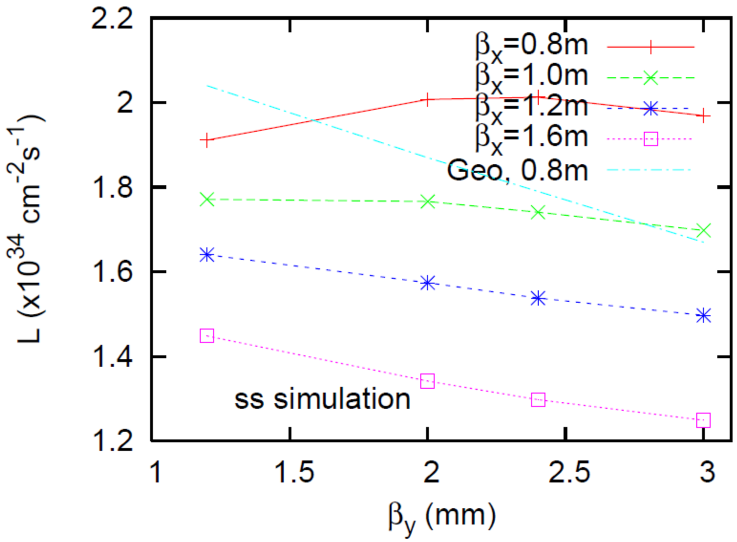
Luminosity *vs.* Working point



Momentum acceptance *vs.* Beam lifetime

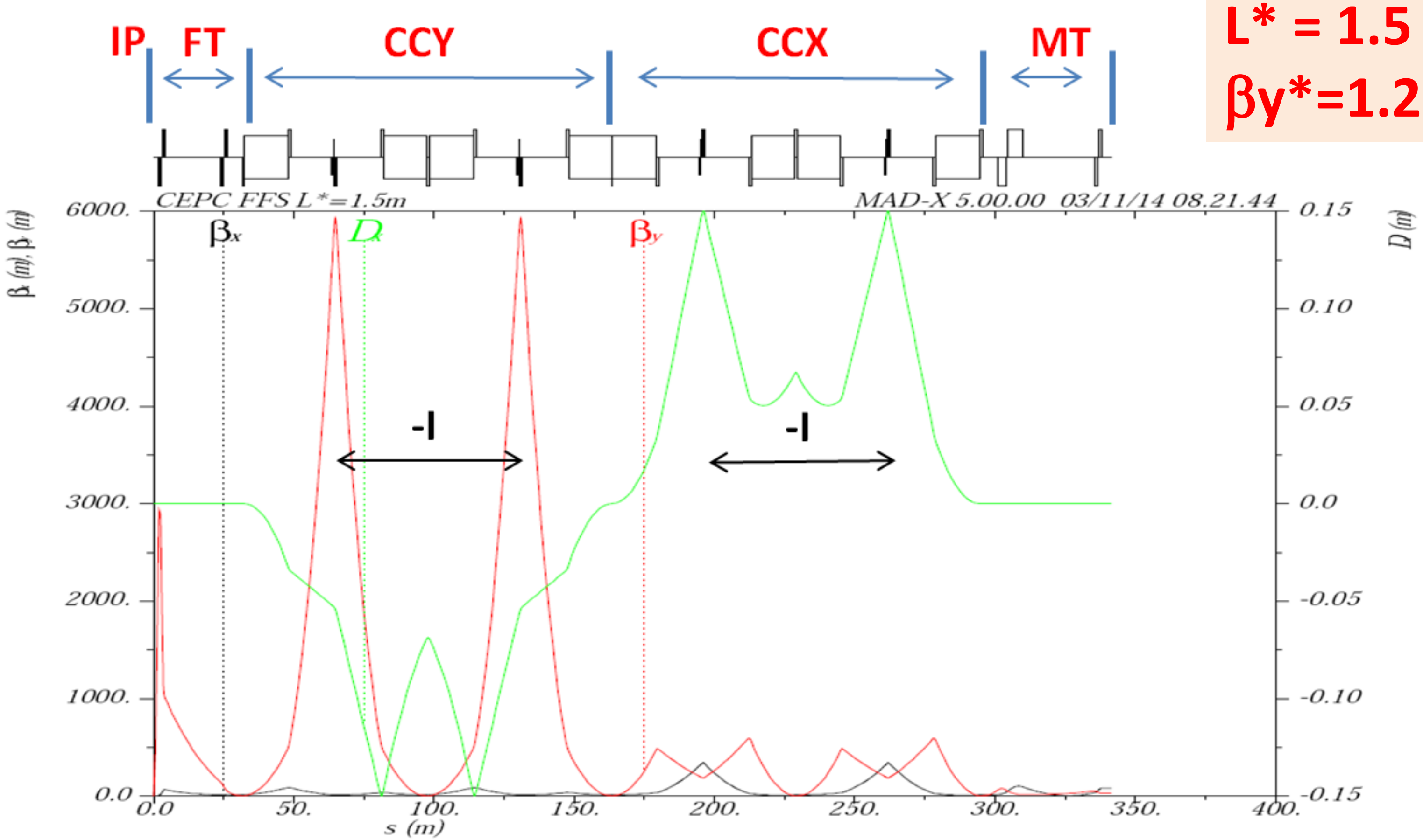


Luminosity *vs.* Beta*

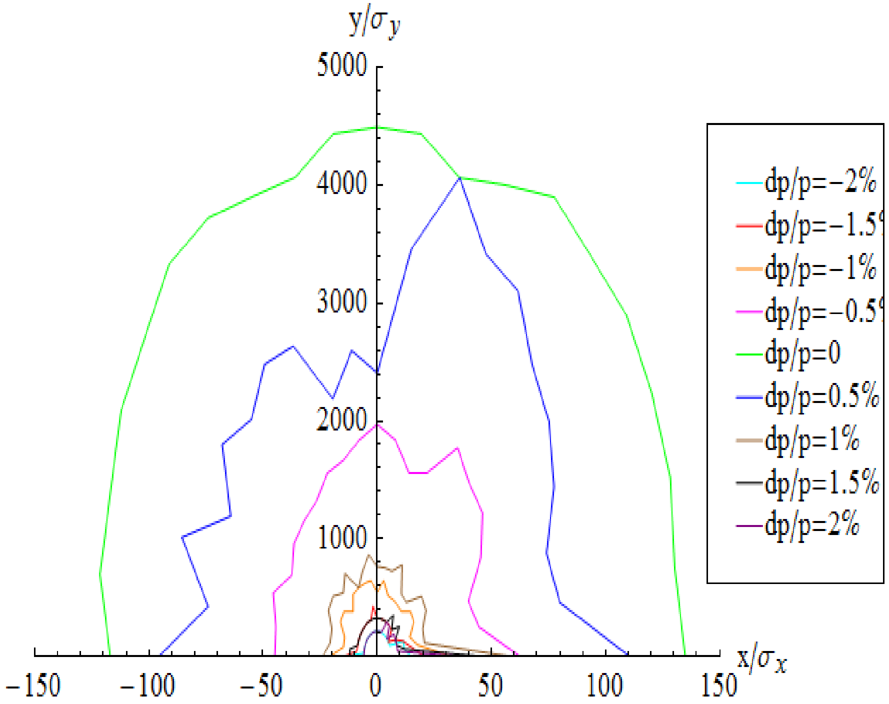


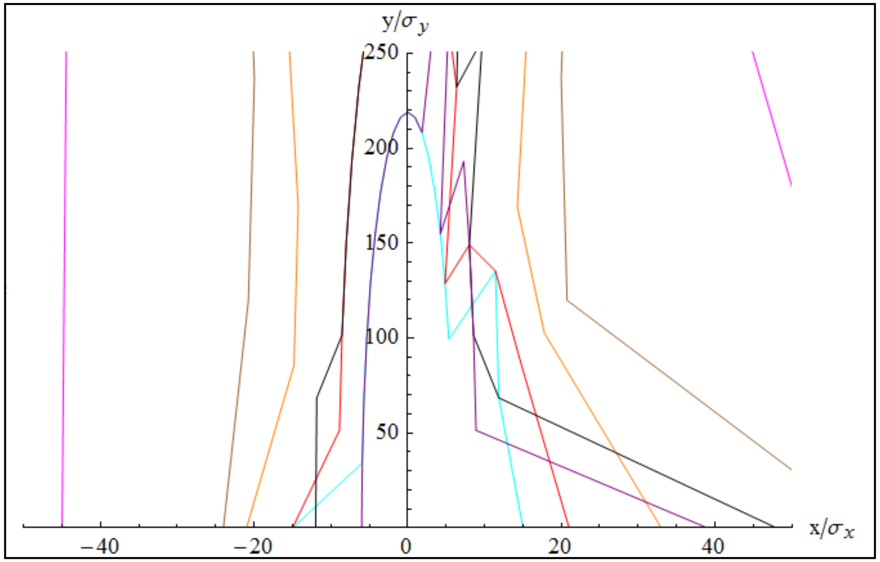
IR Optics

L* = 1.5 m
βy*=1.2mm

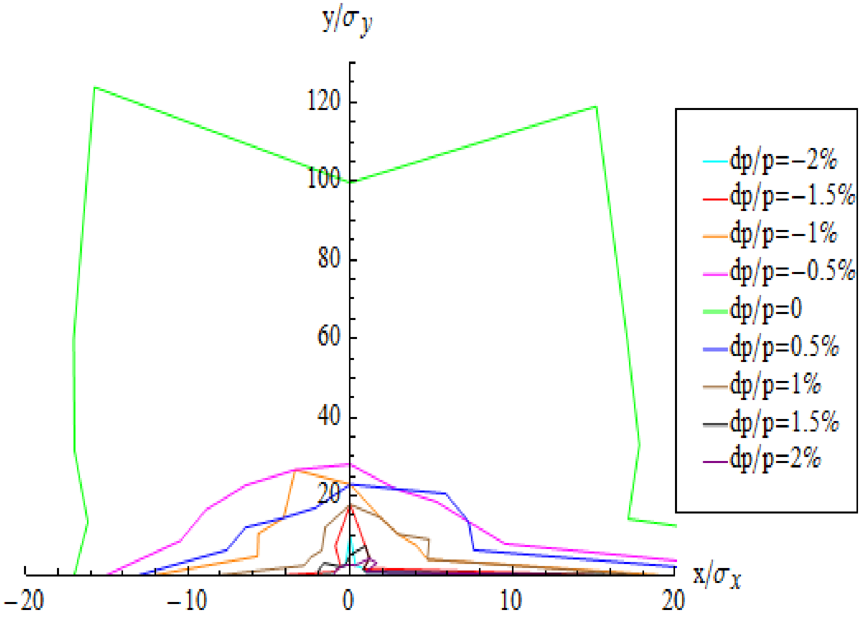


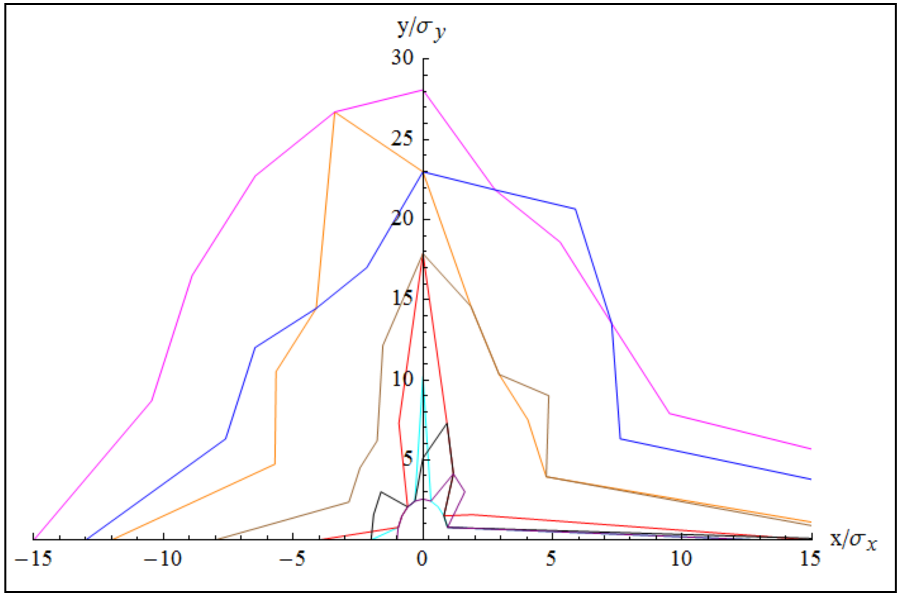
Dynamic Aperture of IR + Arc Linear Matrix



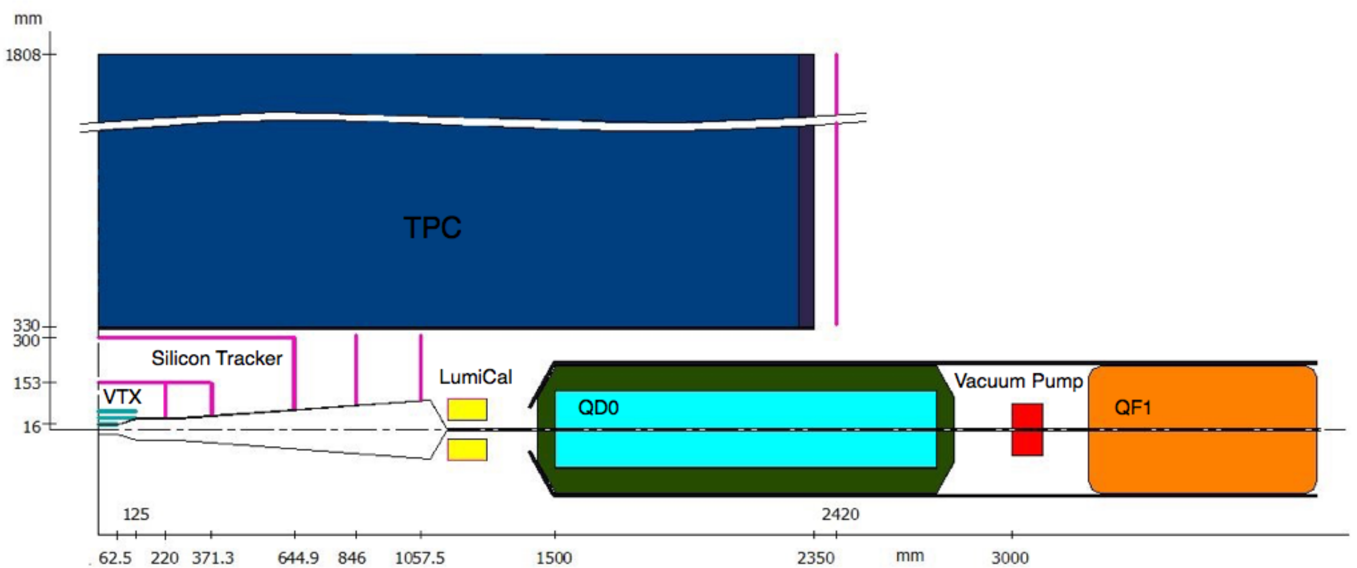


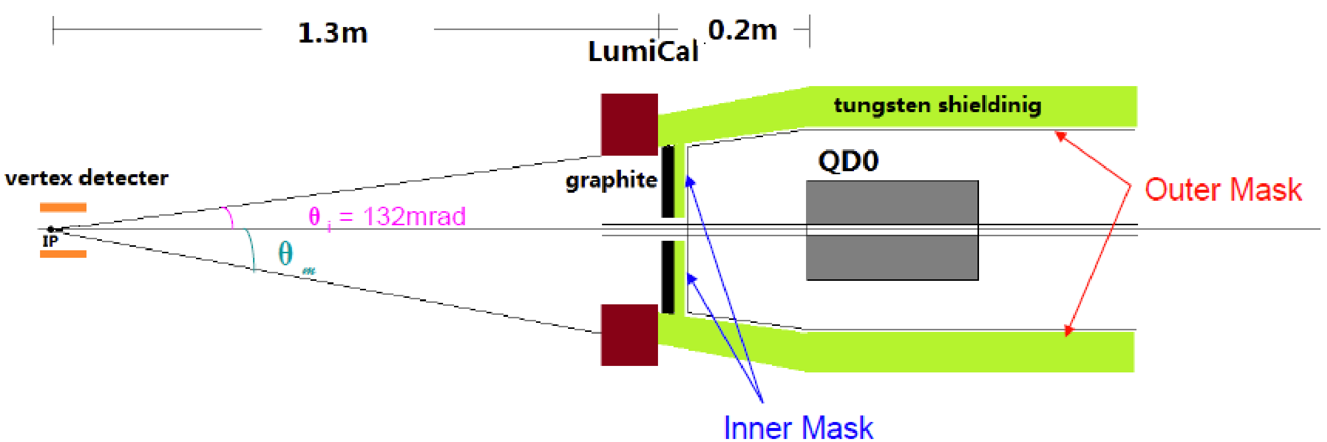
Dynamic Aperture of the Entire Ring



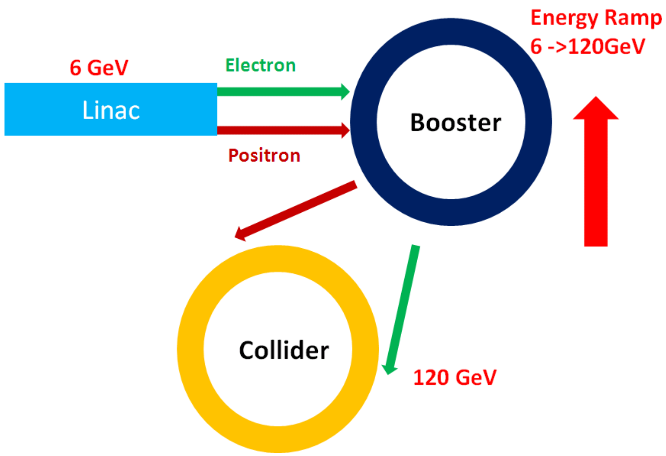


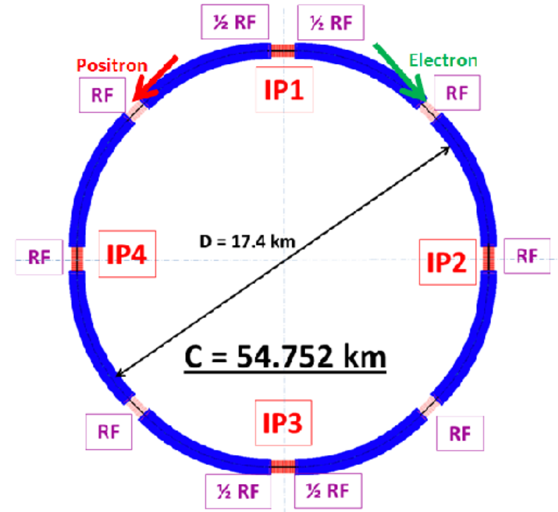
Machine Detector Interface



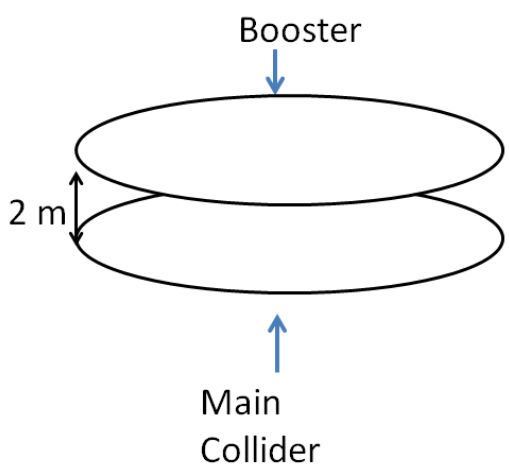


Injectors

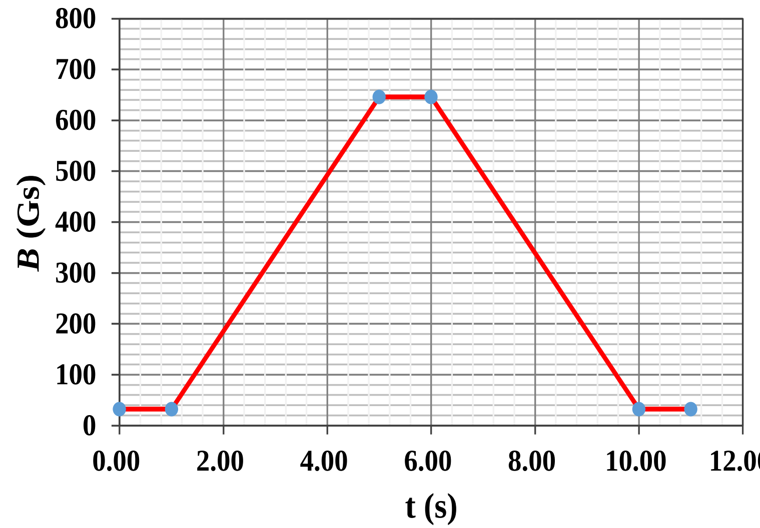




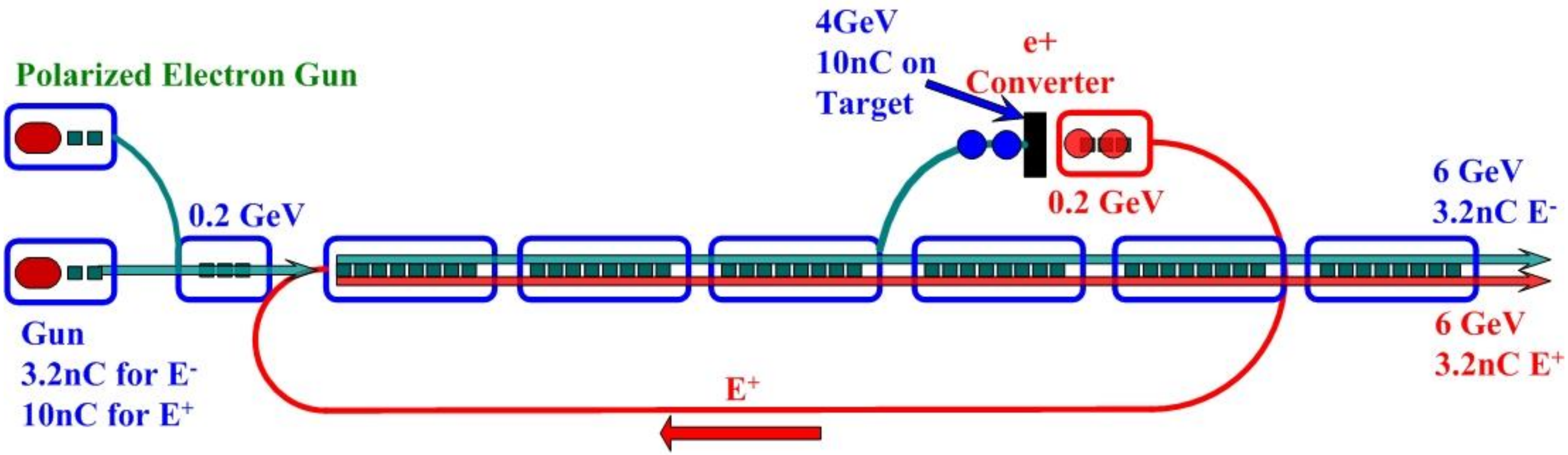
Top-up Full-energy Injection



Booster Cycle (0.1 Hz)



Injectors (cont…)



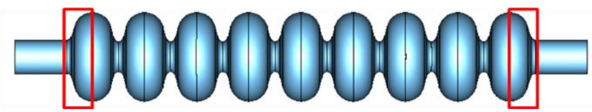
Totally 6GeV Linac

CEPC Cryomodule Layout

CEPC Booster 1.3 GHz Cryomodule

Euro-XFEL/ILC/LCLS-II type

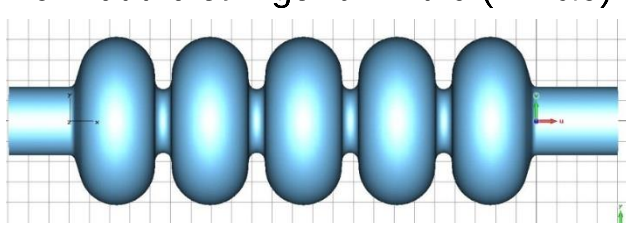
- 8 1.3 GHz 9-cell cavities per module
  2 HOM couplers per cavity
  1 beamline HOM absorber at 70 K
- module length: 12 m (no SCQ)
- 4 modules per module string
  connect without cryo & vac interval
- module string length: 48 m
- 8 module strings: 6+4x0.5 (IR1&3)

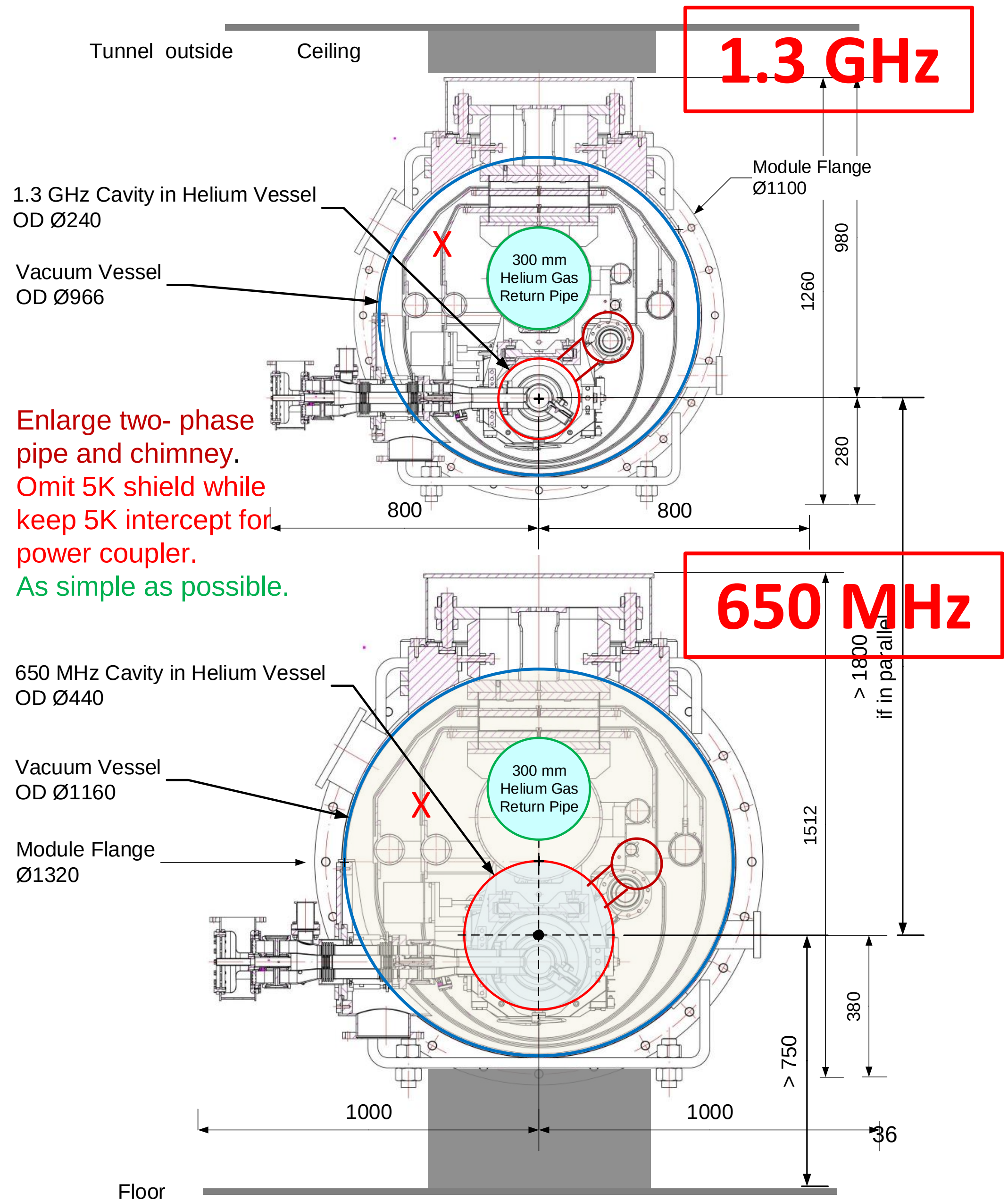


CEPC Collider 650 MHz Cryomodule

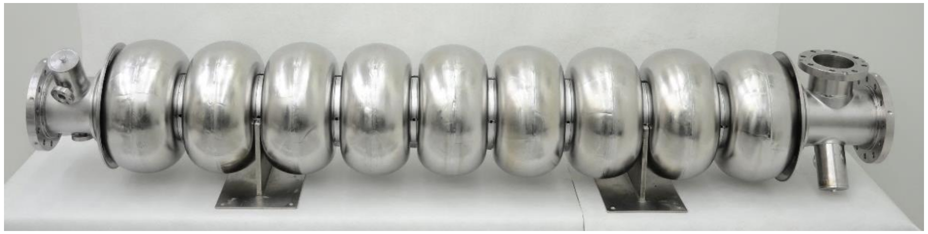
scaled from 1.3 GHz cryomodule

- 4 650 MHz 5-cell cavity per module
  2 HOM couplers per cavity
  2 beamline HOM absorbers at RT
- module length: 10 m
- 12 modules per module string
- module string length: 120 m
- 8 module strings: 6+4x0.5 (IR1&3)





IHEP 1.3 GHz and 650 MHz Cavity



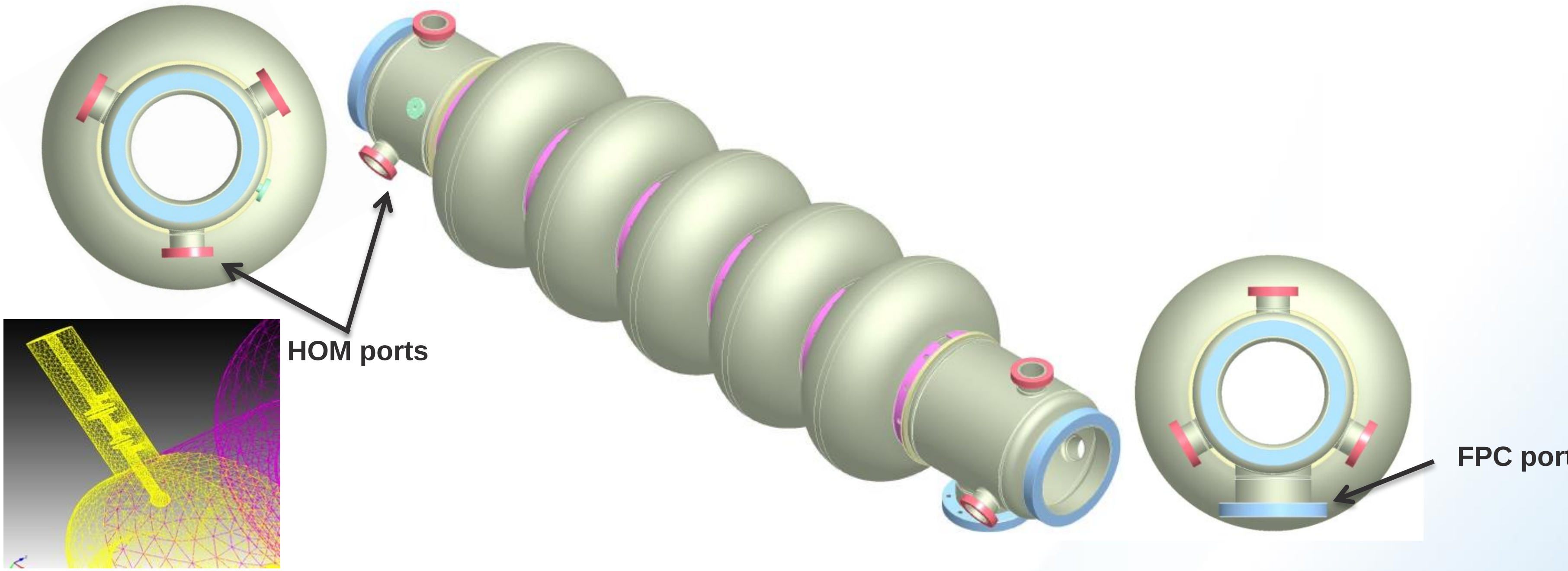
1.3 GHz 9-cell cavity vertical test (VT) in 2013. In module horizontal test (HT), the cavity performance will have degradation.

	ILC TC-1	CEPC
VT E_{acc}	20 MV/m	**22 MV/m**
VT Q_0	1.4E10	**3E10**
HT E_{acc}	18 MV/m	20 MV/m
HT Q_0	1E10	2E10

ADS 650 MHz β=0.82 5-cell cavity
Vertical test soon

IHEP Cryomodules for XFEL
(58 modules, 12 m long each)

Five-cell cavity with strong HOM damping



- Six antenna-type couplers will be attached to the large diameter beam pipes and will provide strong HOM damping while maintaining good fill factor for the linac.
- Two HOM filters are currently under consideration: a high pass filter made of lumped elements and a ridge waveguide filter.
- Total HOM power to be extracted in eRHIC is about 7.3 kW per cavity.

SRF R&D Plan for the Project Timeline

- The critical path of the project is to have a successful R&D for the SRF
- CEPC will require two large SRF systems:
  - Collider: 650 MHz, 384 cavities in 96 cryomodules
  - Booster: 1.3 GHz, 256 cavities in 32 cryomodules
- This would be the largest SRF installation in the world. To succeed with designing, fabricating, commissioning and installation of such a system, a significant investment in R&D, infrastructure and personnel is necessary.
- The R&D has two parts:
  - Prototyping as well as technology development for several critical components, in particular, the HOM damper
  - Pre-series production:
    - ✓ 15-20 1.3 GHz cavities and 30-35 650 MHz cavities
    - ✓ A large RF facility similar to that in Jlab, Fermilab and DESY for cavity inspection and tuning set ups, RF lab, several vertical test stands, clean rooms, HPR systems, FPC preparation and conditioning facility, cryomodule assembly lines, horizontal test stations, high power RF equipment, a cryogenic plant, etc.
    - ✓ Capable to assemble 1 Booster modules and 2 Collider module each month
    - ✓ To have at least two vendors for each type of RF
    - ✓ Personnel development

SRF R&D Program on CEPC Timeline

2015 — 2020 — 2027

Pre-studies (2013-2015)

R&D Engineering Design (2016-2020, 5 yrs.)

Construction (2021-2027, 7 yrs.)

SRF Pre-design

SRF Initial Technology R&D (2016-2020, 5 yrs.)

HOM damping, high Q_0 cavity, coupler window, heat load

SRF Pre-Production R&D (2019-2022, 4 yrs.)

SRF Production and Installation (2023-2027, 5 yrs.)

IHEP site infrastructure

Large scale SRF lab (infrastructure) on CEPC site and in industry (2018)

CEPC SRF Team (~6)

CEPC SRF Core Team (main ring 10 + booster 10 in parallel) (start from 2017)

SRF ~ 200 FTEs (start from 2020), engineers and technicians

Facility upgrade, additional space

Components Prototyping & Performance Demonstration:
Cavity (four for each), helium vessel, vertical test
Power coupler (four for each), HOM dampers, tuners
Short (two-cavity) module for each type, horizontal test

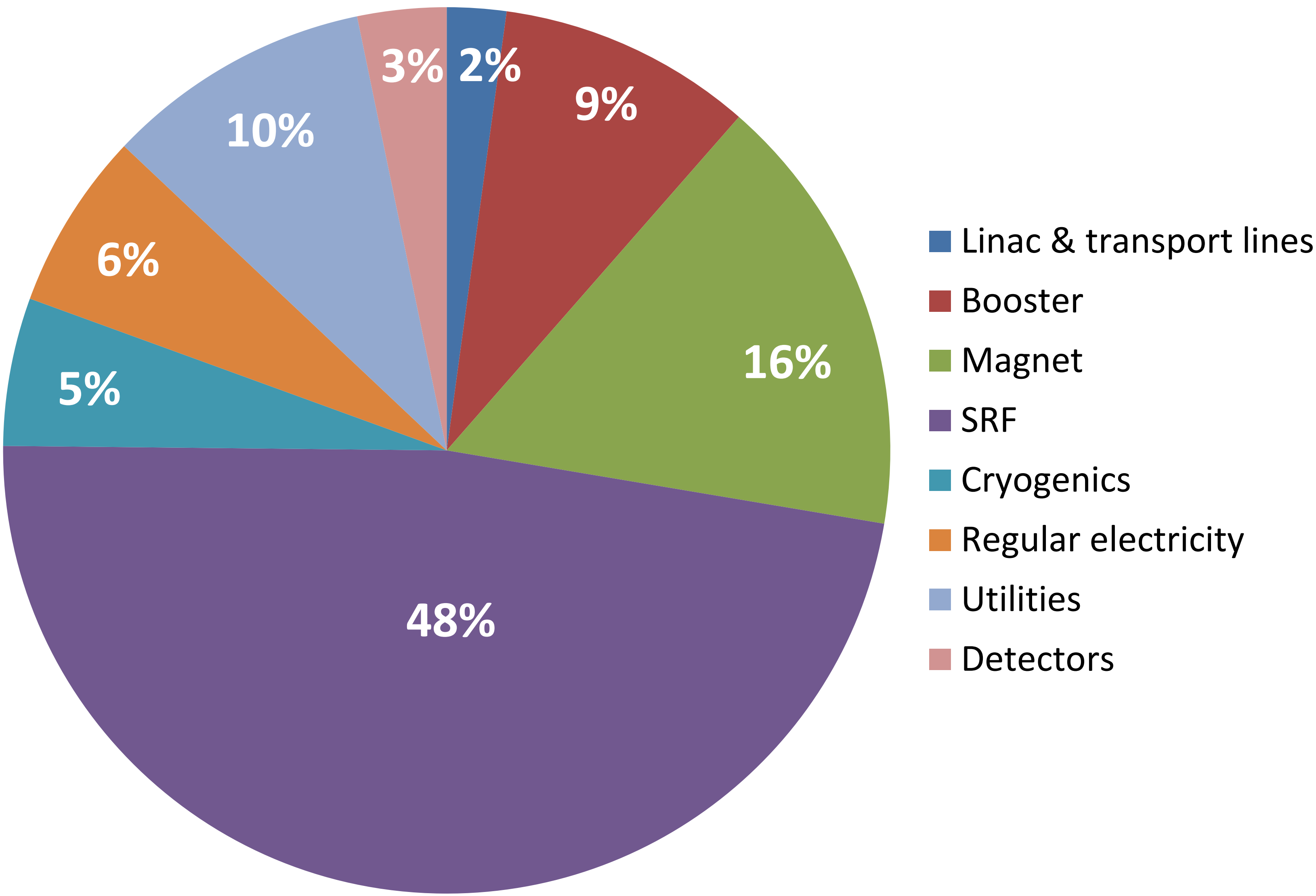
Demonstrate Robustness of Fabrication and Assembly Processes of Cryomodule and its Components. Establish procedures, quality control steps, test set ups, assembly sequences, etc. for the production run. Build and test two booster cryomodules and three main ring cryomodules.

Booster SRF in three years (2023-2025):
test two 1300 MHz cavities per week
assemble and test one cryomodule per month
Main ring SRF in four years (2023-2025):
test two 650 MHz cavities per week
assemble and test two cryomodules per month

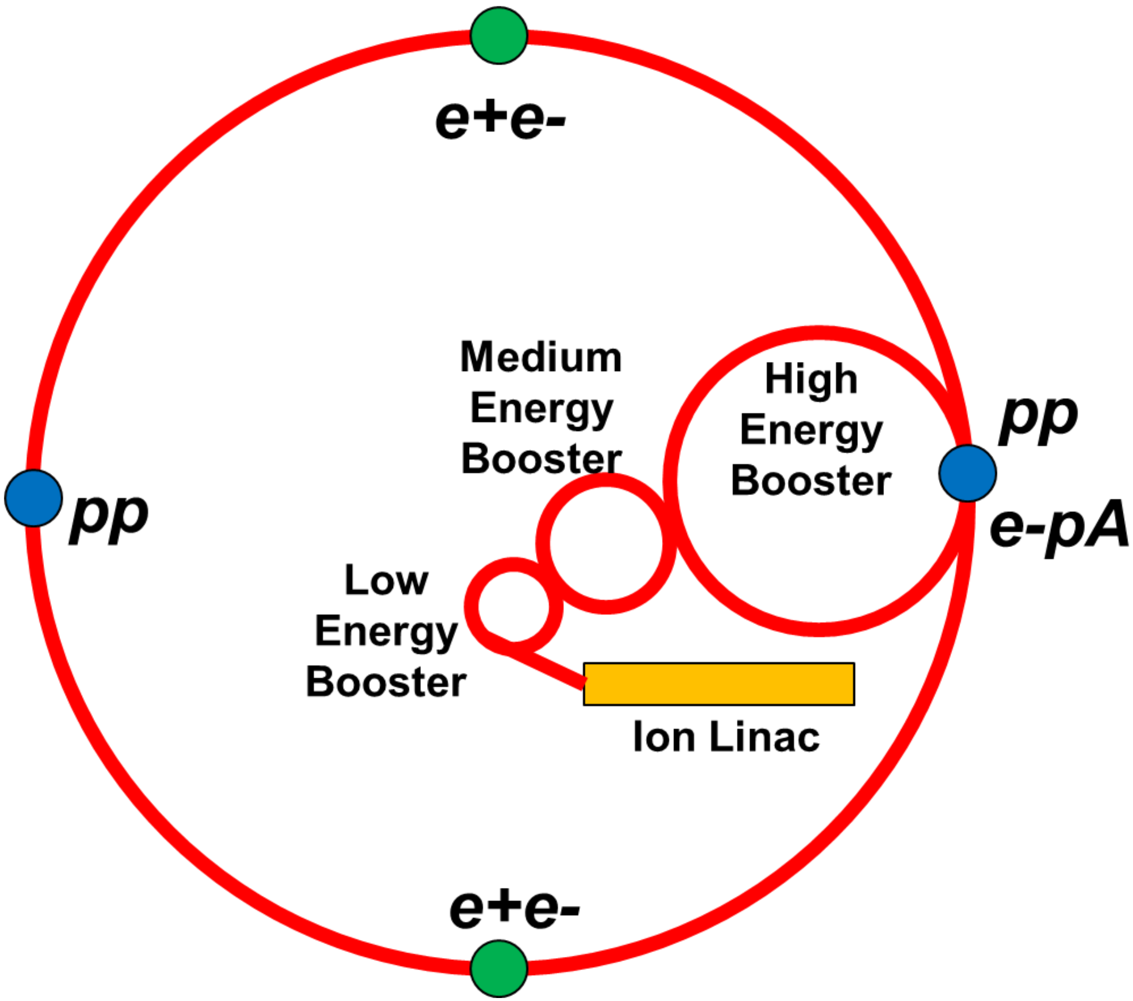
Power Consumption

system	location and electrical loads(MW)					Total
	ring	Booster	Linac	BT	IP	
power source	230	15	2.1			247.1
cryogenics	16	2			1	19
power converter for magnets	60.5	13.2	1.2	1	1	76.9
experimental devices					14	14
dedicated services	15	5	1	1	2	24
utilities	55	10	2.5	1	2	70.5
general services	15		1	1	1	18
campus						30
Total	391.5	45.2	7.8	4	21	499.5

Relative Power Consumption



Upgrade to SPPC



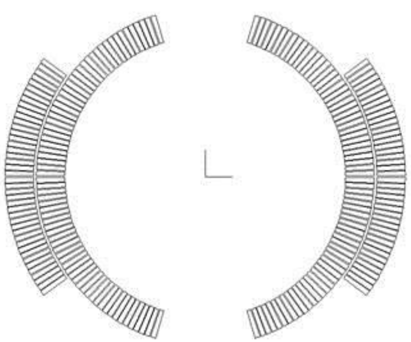
Main Technical Challenges for SPPC

- Accelerator technology
  - SC magnet (increasing performance and decreasing costs)
  - Synchrotron radiation and beam screen (reducing power consumption)
  - Collimation (machine protection)
- Accelerator physics
  - IR design, low β_y^*, dynamic aperture
  - Synchrotron radiation, heat load and radiation damage lifetime
  - Beam-beam
  - e-cloud
  - Impedance and instabilities
  - Ground motion
  - MDI and background
  - Machine reliability
  - Cooling
- Non-technical:
  - Government strategic plan for S/T investment
  - Support from both HEP and non-HEP scientists

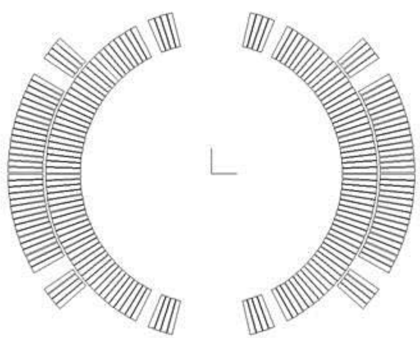
Four Colliders using SC Magnets

	E (GeV)	B (T)	Length (m)	First beam
Tevatron	980	4.3	6280	7 1983
HERA	920	5.0	6336	4 1991
RHIC	100/n	3.5	3834	6 2000
LHC	7000	8.3	26659	9 2008

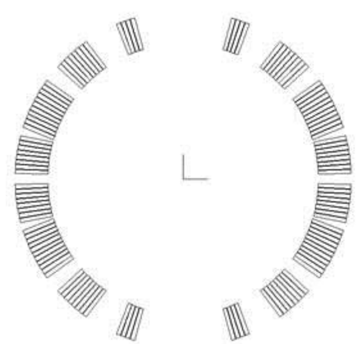
Tevatron



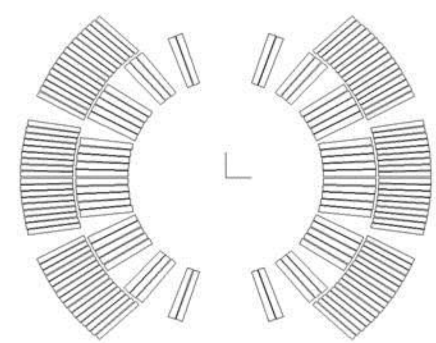
HERA



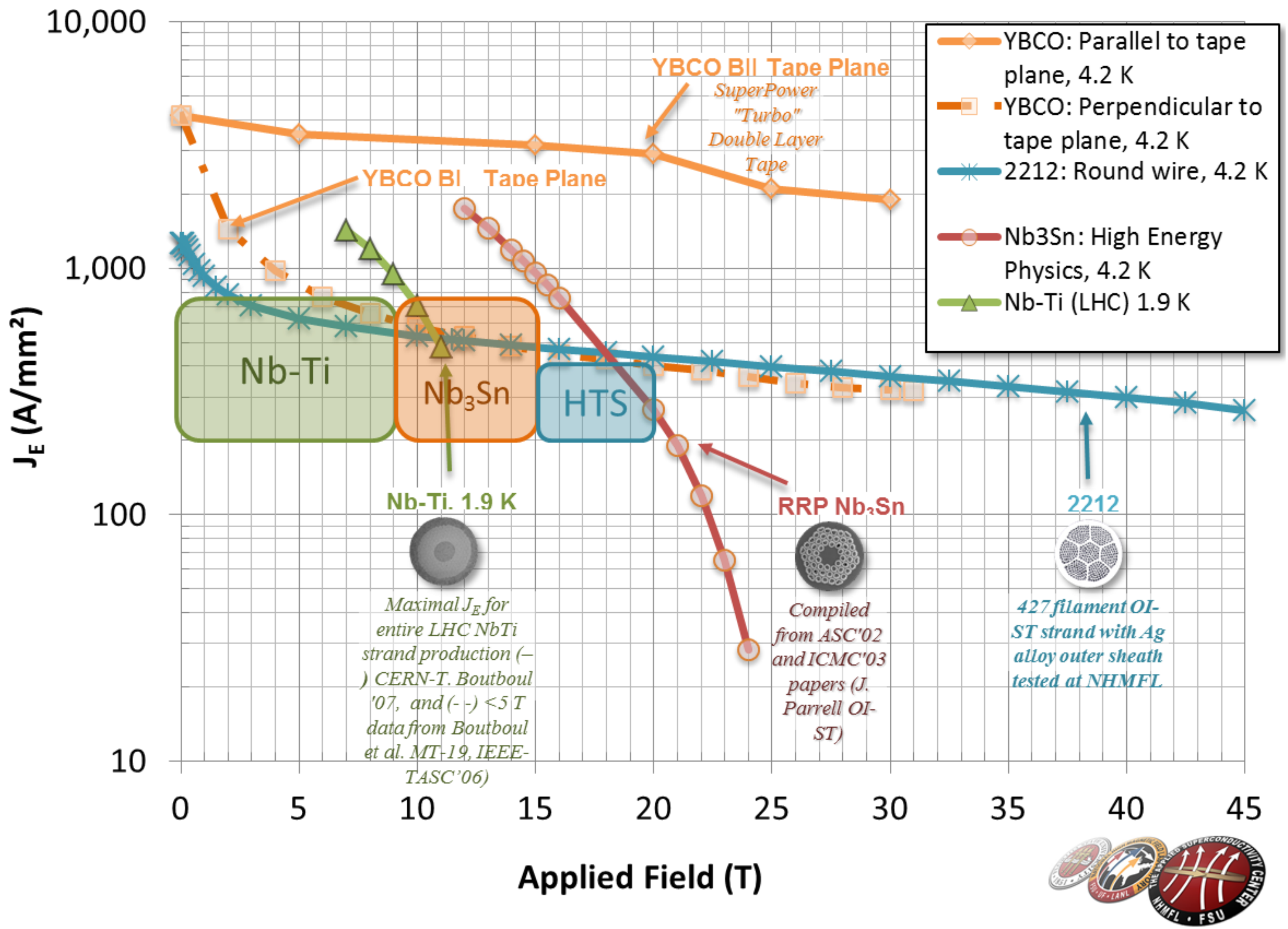
RHIC



LHC



All cosine theta, all NbTi

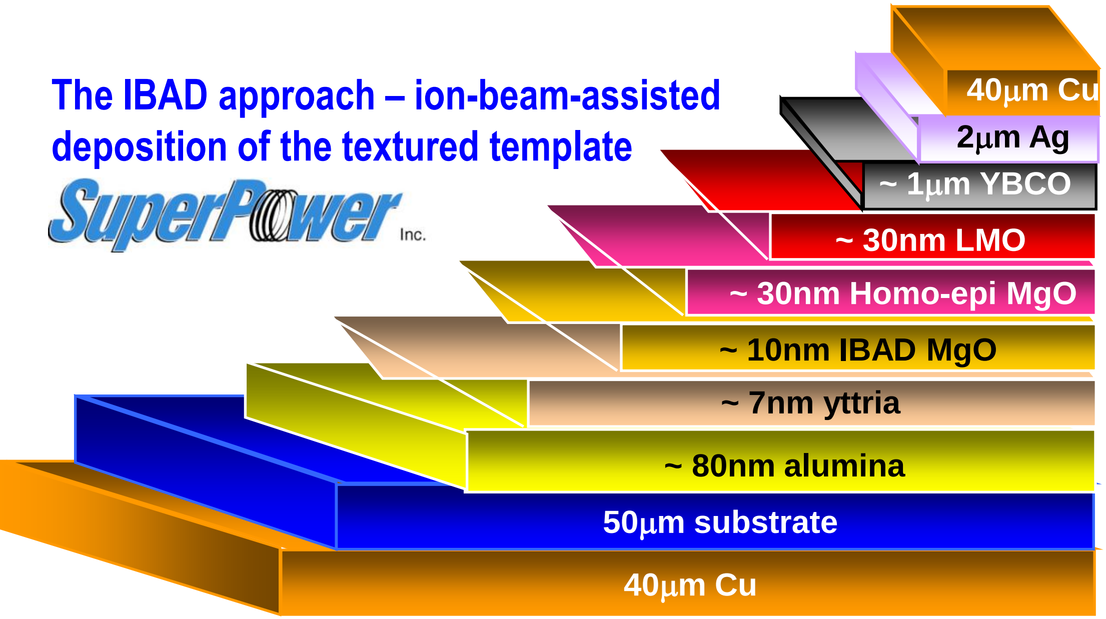


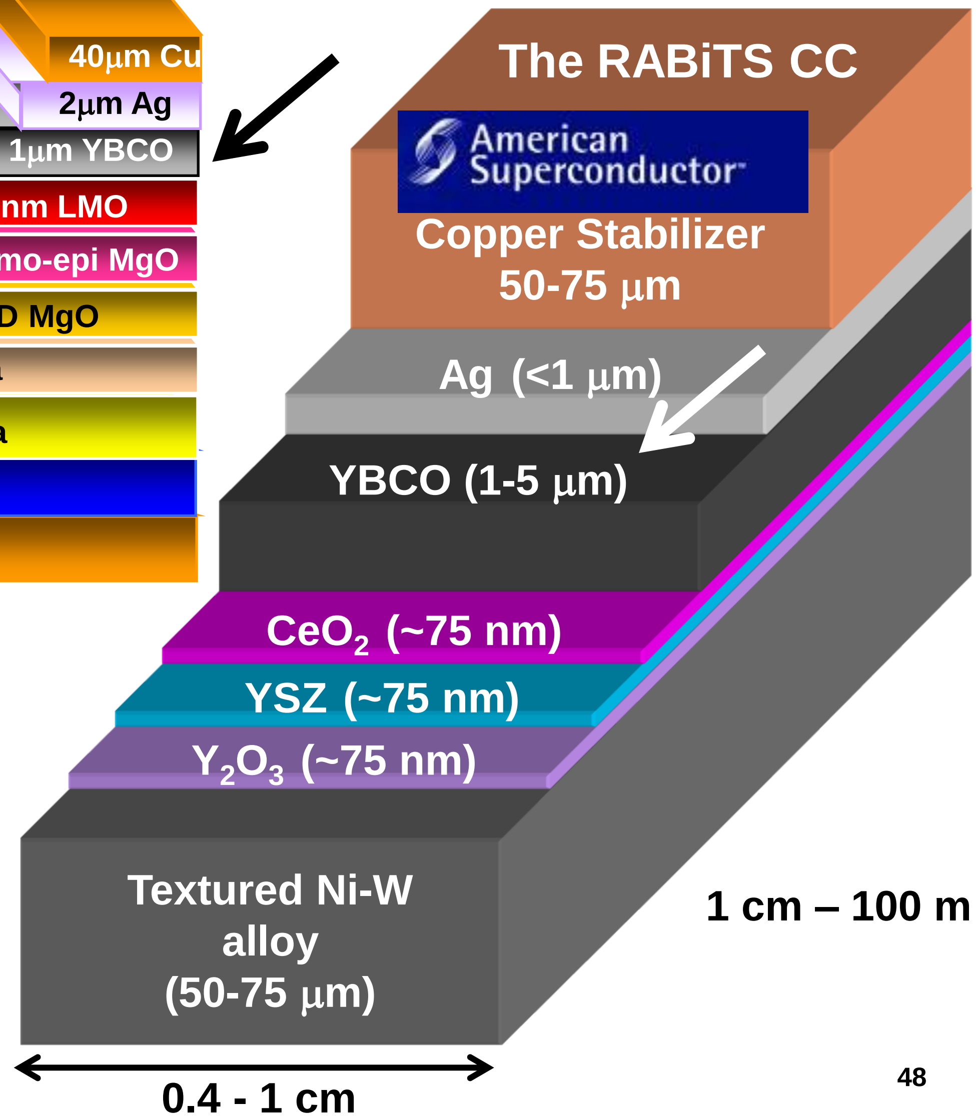
(courtesy of Peter Lee, Applied SC Center of FSU)

And coated conductors of YBCO which approximate single crystals by the mile…….

The IBAD approach – ion-beam-assisted deposition of the textured template

SuperPower Inc.





Pilot production of 100-500 m lengths. Now approaching 1km

Metallurgical Texture introduced here (RABiTS)

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Superconductor Price Comparison

Steve Gourlay – Superconductor price paid by LBNL to the US companies:

NbTi ~ \$300/kg

Nb_3Sn ~ \$2000/kg

Bi-2212 ~ \$20,000/kg

Superconductor price quoted by the Chinese companies:

- Bi-2223: RMB 15,000/kg ⇔ USD 2,400/kg
- YBCO: RMB 20,000/kg ⇔ USD 3,300/kg

SJTU HTS Research Institute 上海超导联合研究院

New System

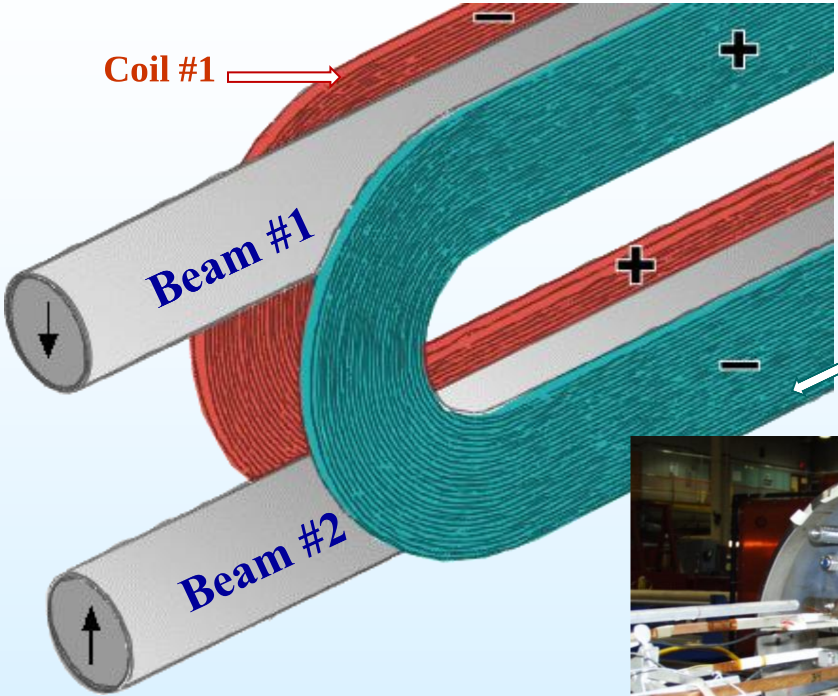
- Management committee and Department Dean in charge
- Management committee: 4 persons from Shanghai Superconductor, 3 persons from SJTU
- Infrastructure and operating funds sponsored by Shanghai Superconductor,
- Company-like talent employment, promotion and reward system
- Research fund and job title fully supported by SJTU

新体制
新机制

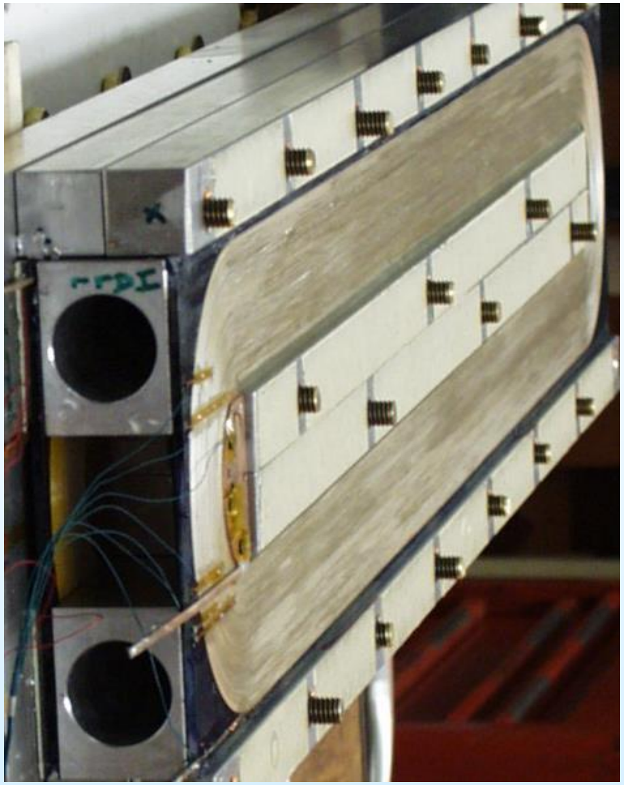
- 研究院实行管理委员会领导下的院长负责制
- 管理委员会超导公司四席、交通大学三席
- 基础设施由超导公司捐建，运行经费由超导公司划拨
- 实行公司化的人员聘用、晋升、奖惩及薪酬制度
- 交通大学在经费和职称等方面给予超导研究院全面支持

联系方式：洪智勇，zhiyong.hong@sjtu.edu.cn

High Field 2-in-1 Common Coil Dipole Design for Colliders



Highest field R&W Nb3Sn dipole



HTS tape common coil dipole

A conductor friendly design

✓ Suitable for HTS coils – Roebel cable?

- Unfavorable orientation wrt field
  - However, think long term. Will Ic remain so anisotropic forever?

Seeking Solution for Severe SR

	7TeV(LHC)	16.5TeV(HE-LHC)	50TeV(FCC)	31.7TeV(SPPC)
SR power W/m	0.17w/m	4.35w/m	28.4w/m(100km) 44.3w/m(83km)	45.8w/m(50km)
Critical energy (keV)	0.044	0.575	4.3(100km) 5.5(83km)	2.15

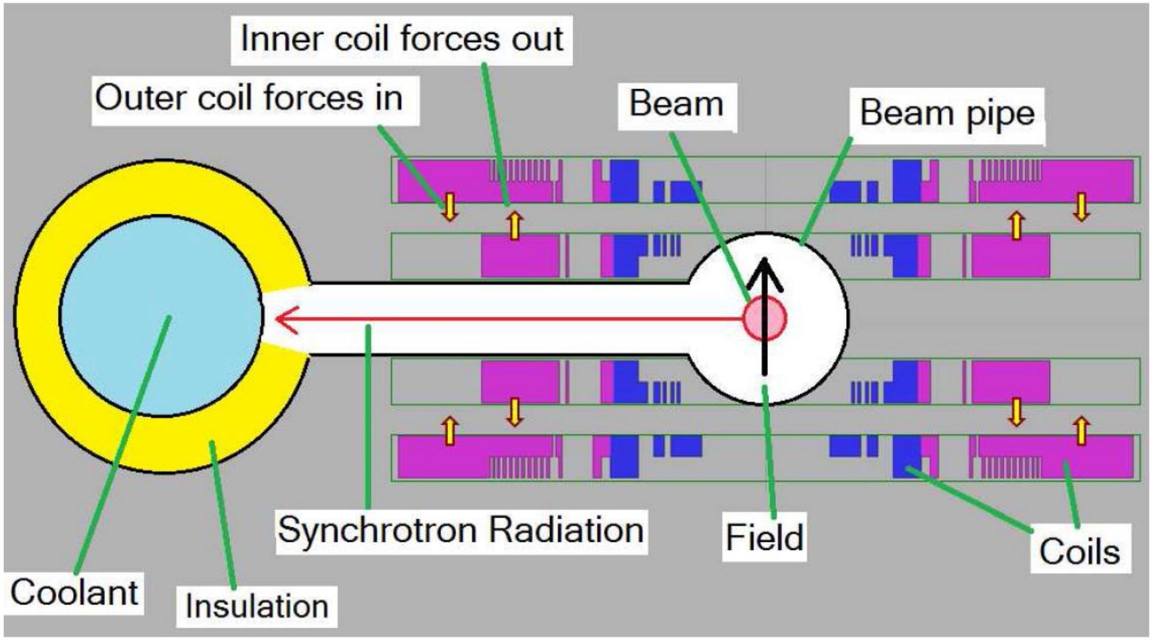
SR of 100 TeV protons ⇔ 50 GeV electrons

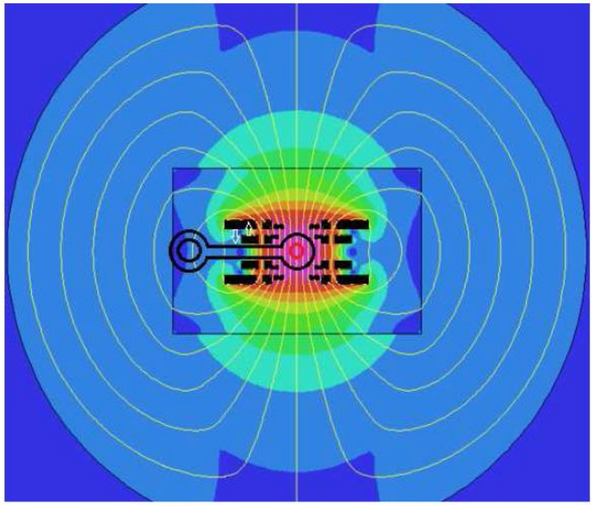
	40 K to 80 K	5 K to 8 K	2K
Efficiency in W/W	16.4	197.9	703.0

- Possible solutions:
  - High temperature beam screen (50 K)
  - Open mid-plane dipole
  - Anti-chamber in dipole
  - Photon stops

Open Mid-plane Dipoles

Magnet Division R. Gupta's design[13] for 13.5 T





- Coils shown give very good field uniformity
- The sketched idea of the dump allows cooling at 77 K and space for good thermal insulation to 1.8 K yoke
- The open plane design will be easier at lower dipole fields.

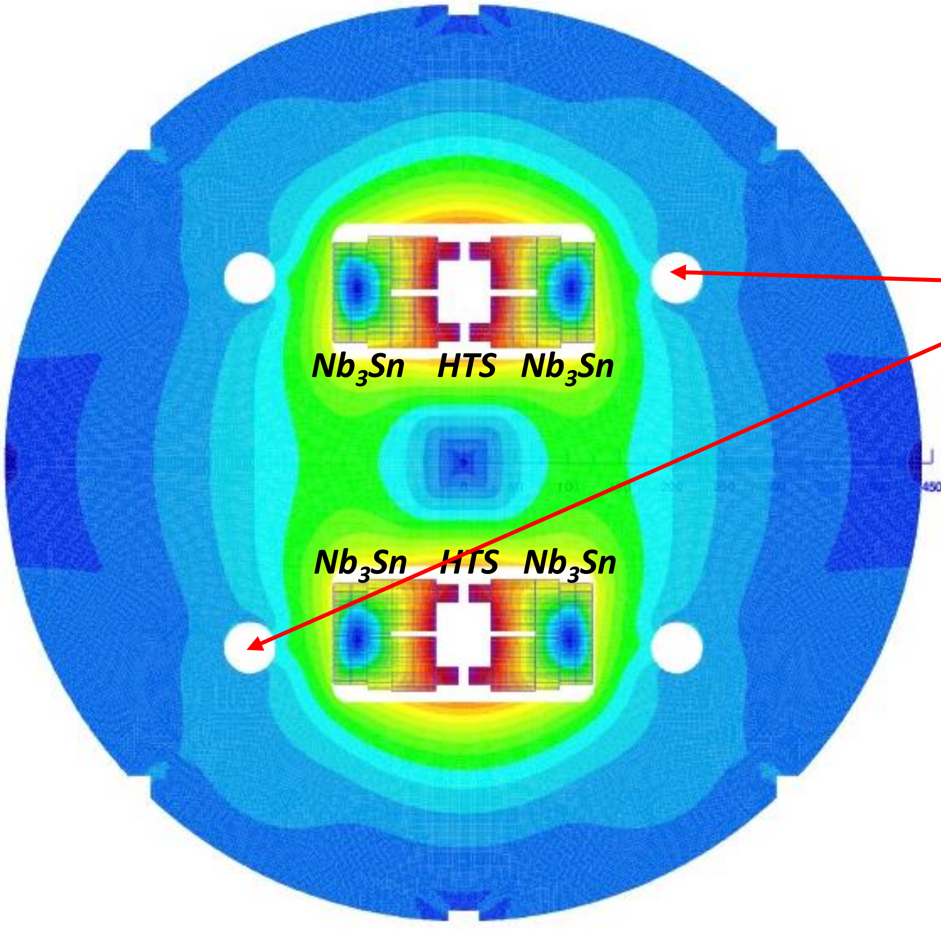
(Bob Palmer, BNL, this workshop)

Conceptual design study of the 20-T dipole

(Preliminary)

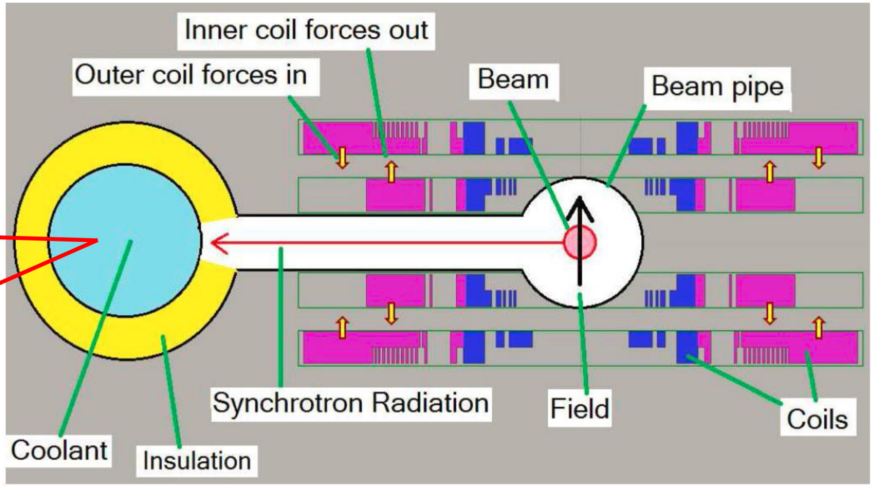
20-T Nb_3Sn + HTS dipole for SppC

Maximum space for beam pipes: 2 * Φ50 mm, with the load line ratio of 85% @ 4.2K and the diameter of 900mm



Open-plane design is under consideration

To remove the synchrotron radiation heat load at higher temperature



Proposed by Ramesh Gupta, BNL

Decay particles will deposit energy in a warm absorber that is sufficiently away from the superconducting coils or support structure.

R&D plan of the 20 T accelerator magnets

(Preliminary)

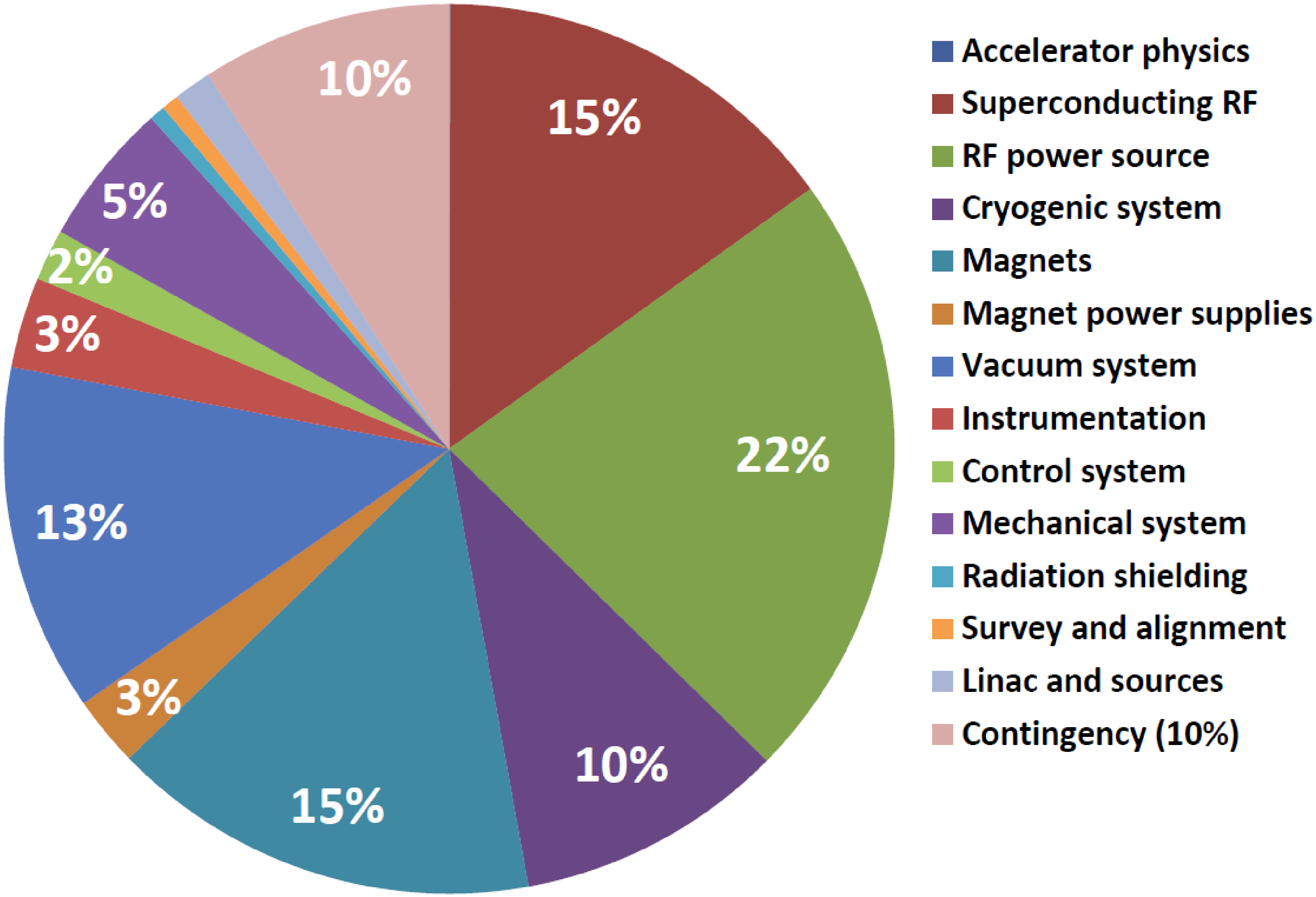
- **2015-2020**: Development of a 12-T operational field Nb_3Sn twin-aperture dipole with common coil configuration and 10^{-4} field quality; Fabrication and test of 2~3 T HTS (Bi-2212 or YBCO) coils in a 12-T background field and basic research on tape superconductors for accelerator magnets (field quality, fabrication method, quench protection).
- **2020-2025**: Development of 15-T Nb_3Sn twin-aperture dipole and quadrupole with 10^{-4} field uniformity; Fabrication and test of 4~5 T HTS (Bi-2212 or YBCO) coils in a 15-T background field.
- **2025-2030**: 15-T Nb_3Sn coils + HTS coils (or all-HTS) to realize the 20-T dipole and quadrupole with 10^{-4} field uniformity; Development of the prototype SppC dipoles and quadrupoles and infrastructure build-up.

Work Breakdown Structure (WBS)

1	合计
2	加速器 Accelerators
2.1	加速器物理
2.2	高频系统
2.3	低温系统
2.4	磁铁系统
2.5	电源系统
2.6	机械系统
2.7	真空系统
2.8	束测系统
2.9	准直
2.10	控制系统
2.11	辐射防护
2.12	直线加速器
2.13	功率源
2.14	增强器
2.15	超导加速器磁铁（SPPC）R&D
2.16	不可预见费10%
3	探测器 Detectors
3.1	径迹探测器（TPC）
3.2	顶点探测器（VTX）
3.3	量能器（电磁+强子）
3.4	Muon探测器
3.5	探测器磁铁
3.6	物理模拟与软件组
3.7	计算资源系统
3.8	触发与数据获取系统
3.9	不可预见费10%

4	同步辐射装置 Light Sources
4.1	光束线站
4.2	不可预见费10%
5	土建 Civil Construction
5.1	地下建筑工程(钻爆法、6.5m)
5.2	地面建筑
5.3	独立费用
5.4	其他费用
5.5	不可预见费10%
6	通用设施 Utilities
6.1	供配电系统
6.2	水冷系统
6.3	通风空调系统
6.4	压缩空气
6.5	独立费用
6.6	其他费用
6.7	不可预见费10%

CEPC Relative Cost Estimate



Global HEP Strategy

ICFA statement in February, 2014 at DESY

ICFA encouraged the two studies (FCC and CEPC-SPPC) to work as close together as possible, with the following statement:

ICFA supports studies of energy frontier circular colliders and encourages global coordination.

ICFA statement in July, 2014 at Valencia

ICFA endorses the particle physics strategic plans produced in Europe, Asia and the United States and the globally aligned priorities contained therein. Here, ICFA reaffirms its support of the ILC, which is in a mature state of technical development and offers unprecedented opportunities for precision studies of the newly discovered Higgs boson. In addition, ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

Summary

- A Preliminary Conceptual Design Report (Pre-CDR) is completed. There will be a review next month by an international committee chaired by Prof. Oide (KEK). The report will be released after the review.
- It is by no means an optimized design. Rather, it provides a baseline design that is consistent and able to reach the design goal.
- The design is focused on the CEPC, but it is compatible to an upgrade to the SPPC.
- The critical R&D items have been identified.
- The next steps:
  - ➢ To submit the report to the government and get into the 13^{th} Five-Year Plan (2016-2020).
  - ➢ To carry out an R&D plan for key technical systems.
  - ➢ To form international collaboration with other HEP laboratories and institutions.
  - ➢ To organize a series of mini-workshops, each to address a specific subject (SC magnet, SRF, IR optics, MDI, pretzel, etc.).

Questions?