Future e+e- and Hadron Colliders

J. Gao

IHEP

LHCP Conference, May 16, 2022

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- Introduction

- Electron-positron linear colliders: ILC, CLIC, C3

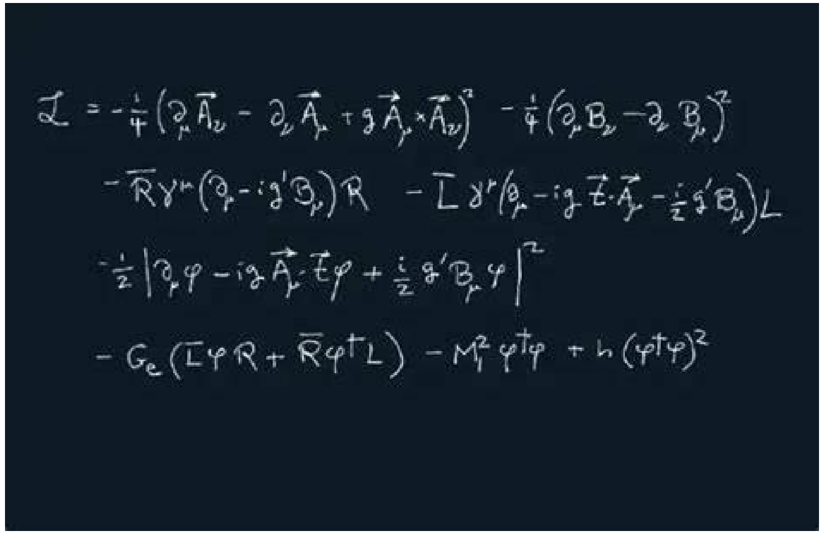
- Electron-positron circular colliders and hadron colliders: CEPC+SppC, FCCee+FCChh

- ICFA Statement regarding Higgs Factory development and the ILC

- Conclusions

Physics goals of e+e- and hadron colliders

- Electron-positron colliders (91, 160 , 240, 360-380, 550, 3000GeV)
  - Higgs Factory (>10^6 Higgs) :
    - Precision study of Higgs(m_H, J^{PC}, couplings) , Similar & complementary to e+e- Linear colliders
    - Looking for hints of new physics, DM…
  - Z & W factory (>10^{12} Z^0) :
    - precision test of SM
    - Rare decays ?
  - Flavor factory: b, c, t and QCD studies
- Proton-proton collider(~100 TeV)
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., h^3 & h^4 couplings

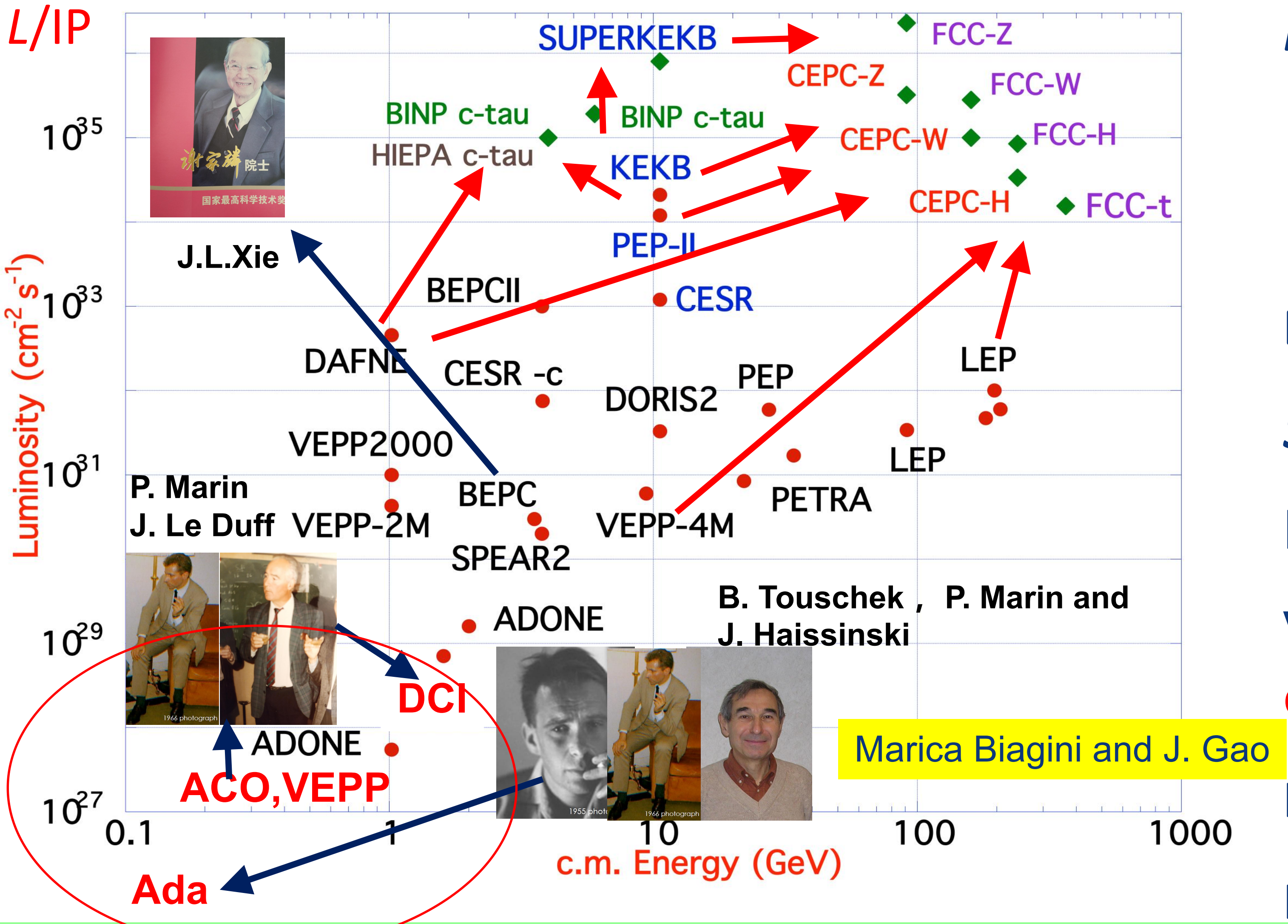


$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{4}\left(\partial_\mu \vec{A}_\nu - \partial_\nu \vec{A}_\mu + g\vec{A}_\mu \times \vec{A}_\nu\right)^2 - \frac{1}{4}\left(\partial_\mu B_\nu - \partial_\nu B_\mu\right)^2 \\
& - \bar{R}\gamma^\mu\left(\partial_\mu - i g' B_\mu\right)R - \bar{L}\gamma^\mu\left(\partial_\mu - i g \vec{t}\cdot\vec{A}_\mu - \frac{i}{2} g' B_\mu\right)L \\
& - \frac{1}{2}\left|\partial_\mu\varphi - i g \vec{A}_\mu\cdot t\varphi + \frac{i}{2} g' B_\mu \varphi\right|^2 \\
& - G_e\left(\bar{L}\varphi R + \bar{R}\varphi^\dagger L\right) - M_1^2\varphi^\dagger\varphi + h\left(\varphi^\dagger\varphi\right)^2
\end{aligned}
$$

Have a better and deeper understanding
of the fundamental laws of Universe as a whole

Precision measurement + searches: Complementary with each other !

Future circular lepton factories based on proven concepts and techniques from past colliders and light sources



Marica Biagini and J. Gao

B-factories: **KEKB & PEP-II:**
double-ring lepton colliders,
high beam currents,
top-up injection

DAFNE: crab waist, double ring

Super B-factories, **S-KEKB: low β_y^***

LEP: high energy, SR effects

VEPP-4M, LEP: precision E calibration

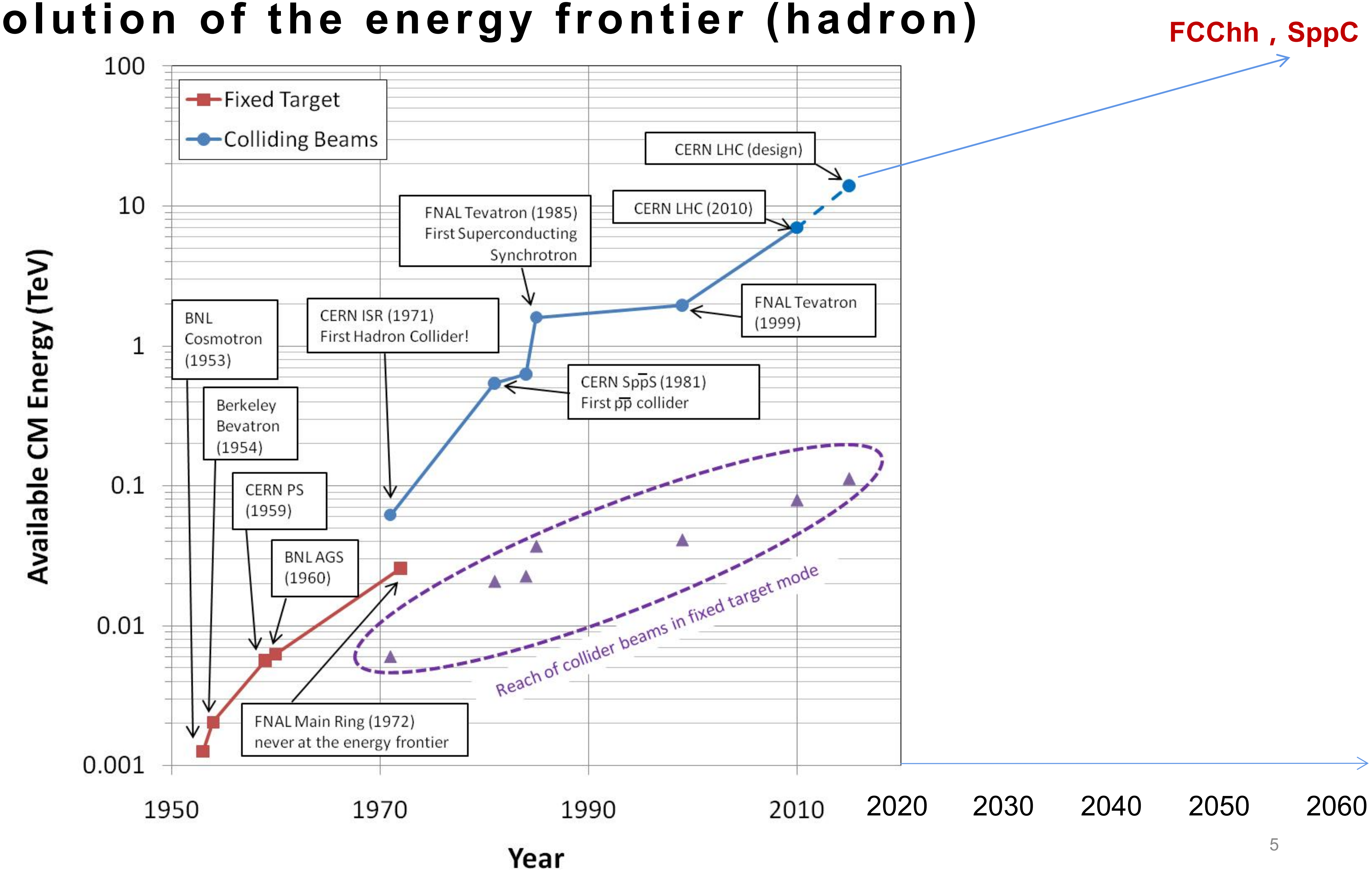
KEKB: e^+ source

In addition:
linear collider,
SLC at SLAC

HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

Evolution of the energy frontier (hadron)



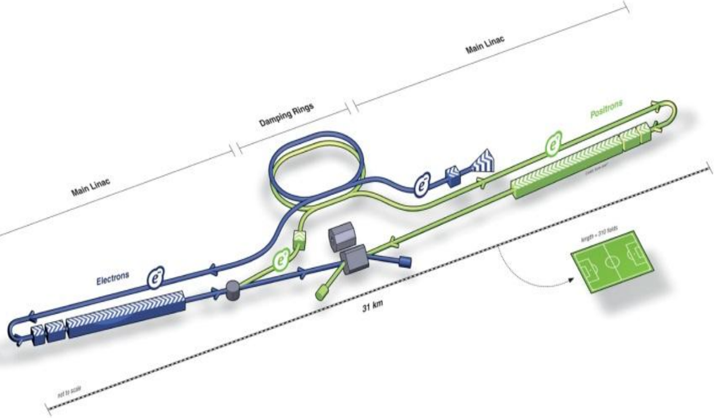
Proposals of future e+e- and hadron colliders

ILC,CLIC, C3, CEPC-SppC: FCC(ee,hh):

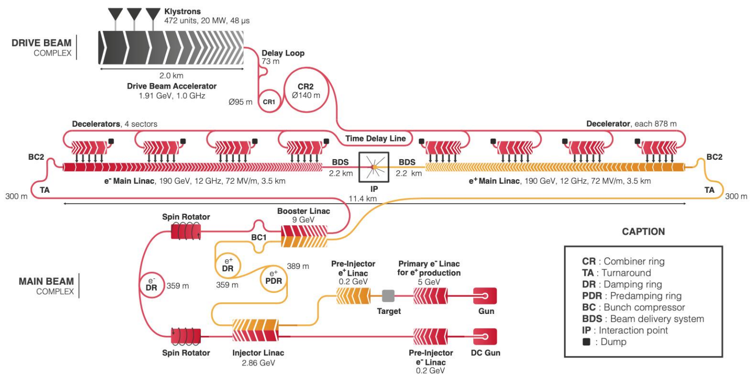
1） Linear colliders：ILC, CLIC, C3
from Higgs energy upto 3TeV

2） Circular Colliders (e+e- and pp):

- CEPC-SppC kick-off meeting in Sept. 2013
- CERN FCC (ee,hh) kick-off meeting in Feb., 2014



ILC250

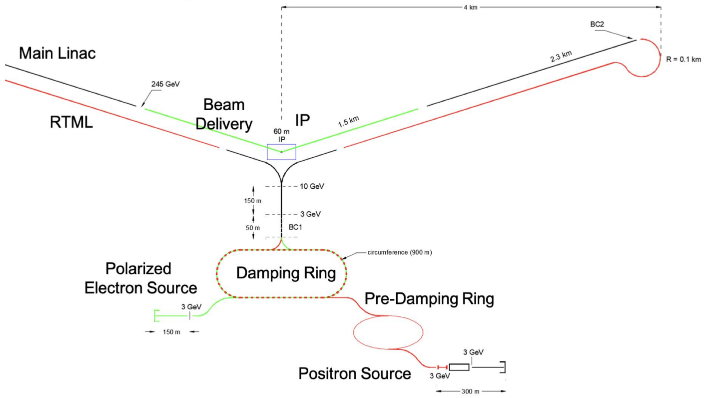


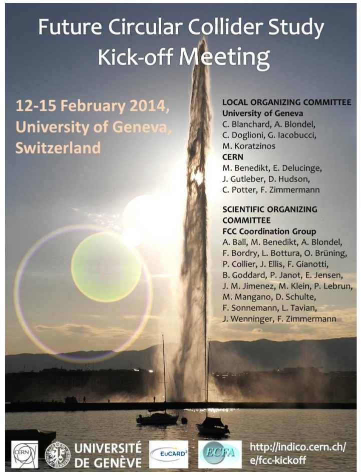
CLIC

3 e+e− Linear Collider

A proposal from USA to Snowmass21

C³ - 8 km footprint for 250/550 GeV





Future Circular Collider Study
Kick-off Meeting

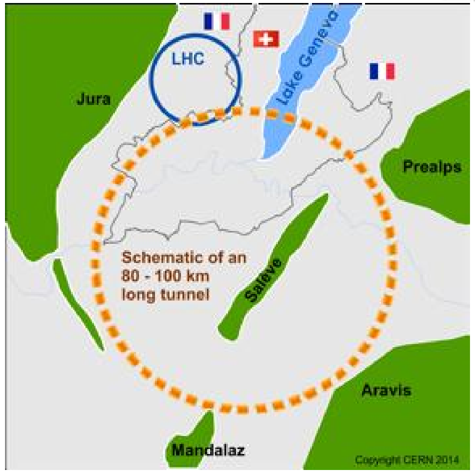
12-15 February 2014,
University of Geneva,
Switzerland

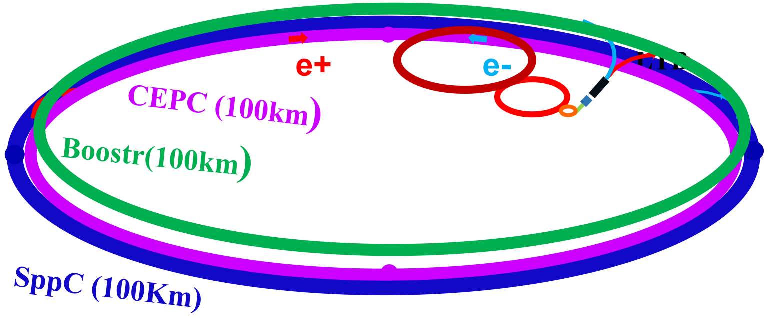
LOCAL ORGANIZING COMMITTEE
University of Geneva
C. Blanchard, A. Blondel,
C. Doglioni, G. Iacobucci,
M. Koratzinos
CERN
M. Benedikt, E. Delucinge,
J. Gutleber, D. Hudson,
C. Potter, F. Zimmermann

SCIENTIFIC ORGANIZING COMMITTEE
FCC Coordination Group
A. Ball, M. Benedikt, A. Blondel,
F. Bordry, L. Bottura, O. Brüning,
P. Collier, J. Ellis, F. Gianotti,
B. Goddard, P. Janot, E. Jensen,
J. M. Jimenez, M. Klein, P. Lebrun,
M. Mangano, D. Schulte,
F. Sonnemann, L. Tavian,
J. Wenninger, F. Zimmermann

UNIVERSITÉ DE GENÈVE
http://indico.cern.ch/e/fcc-kickoff

ILC Scheme | © www.form-one.de





CEPC-SppC

s [m]

250GeV ILC

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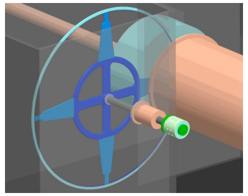
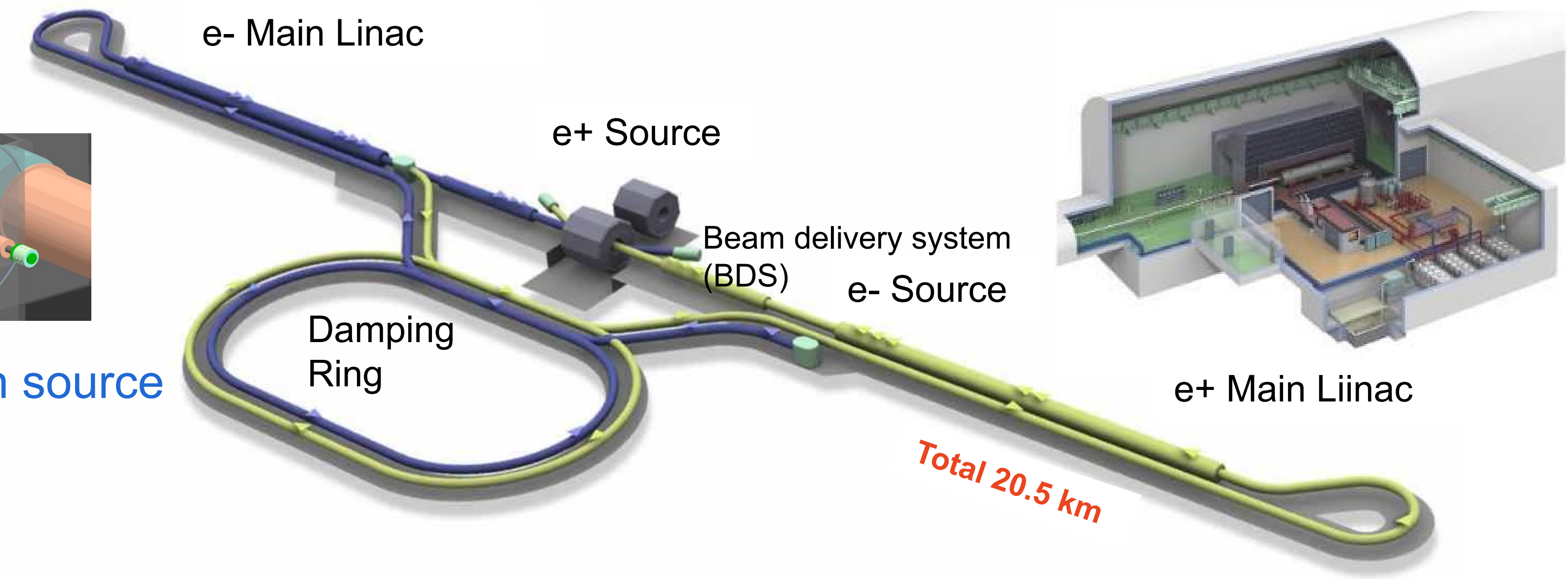
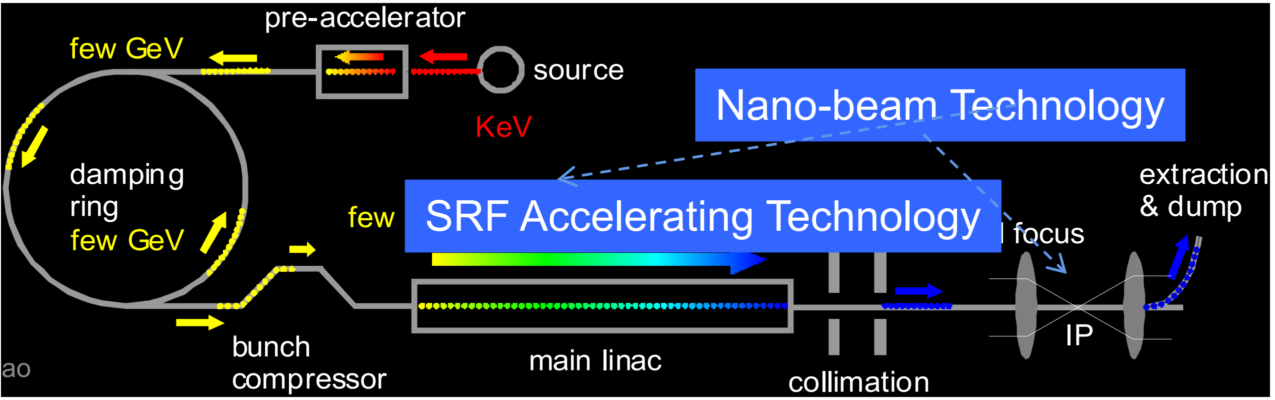


Positron source



8,000 cavities

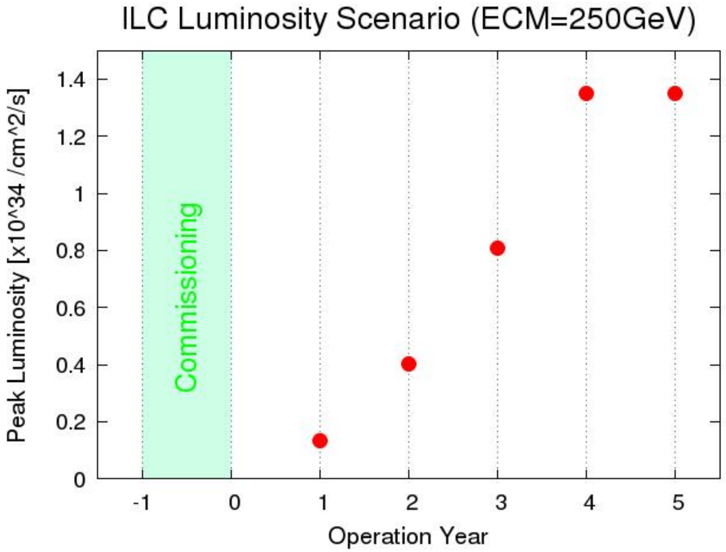
Key Technologies

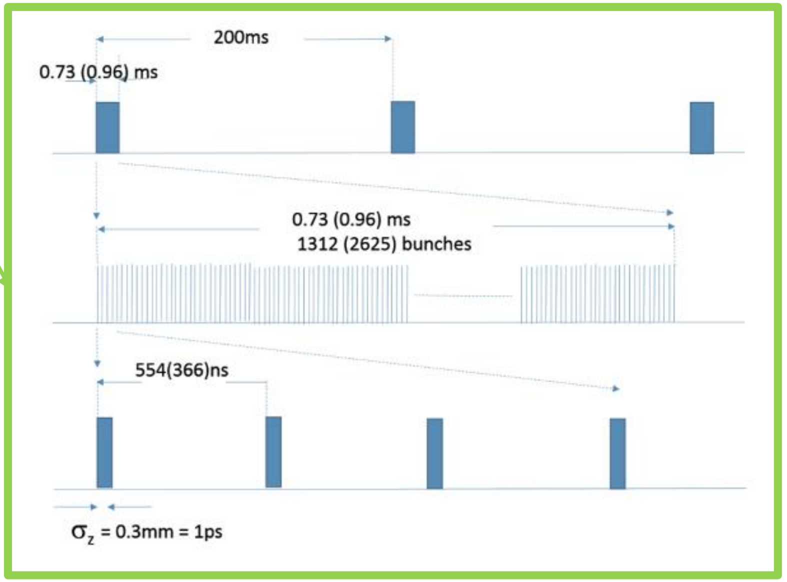


Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} cm^{-2}s^{-1}
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G. Q_0	31.5 MV/m (35 MV/m) Q_0 = 1x10 ^{10}

ILC machine parameters

ILC	electron/positron	ILC250
Beam Energy	GeV	125 (e-) and 125 (e+)
Peak Luminosity (10^34)	cm-2 s-1	1.35
Int. Luminosity	ab-1/yr	0.24* ** 5,000-hour operation at peak luminosity*
Beam dE/E at IP		0.188% (e-), 0.150% (e+)
Transv. Beam sizes at IP x/y	nm	515/7.66
Rms bunch length /	cm	0.03 (σ_z)
beta*	mm	bx*=13mm, by*=0.41mm
Crossing angle	mrad	14
Rep./Rev. frequency	Hz	5
Bunch spacing	ns	554
Bunch population		2x10^{10}
# of bunches		1,312
Length/Circumference	km	20.5
Facility site power	MW	111
Cost (value) range	$B US	~5 (tunnel and accelerator)
Timescale till operations	years	(~1) + 4(prep.) + 9(construction)





Shinichiro Michizono

ILC potential for upgrades

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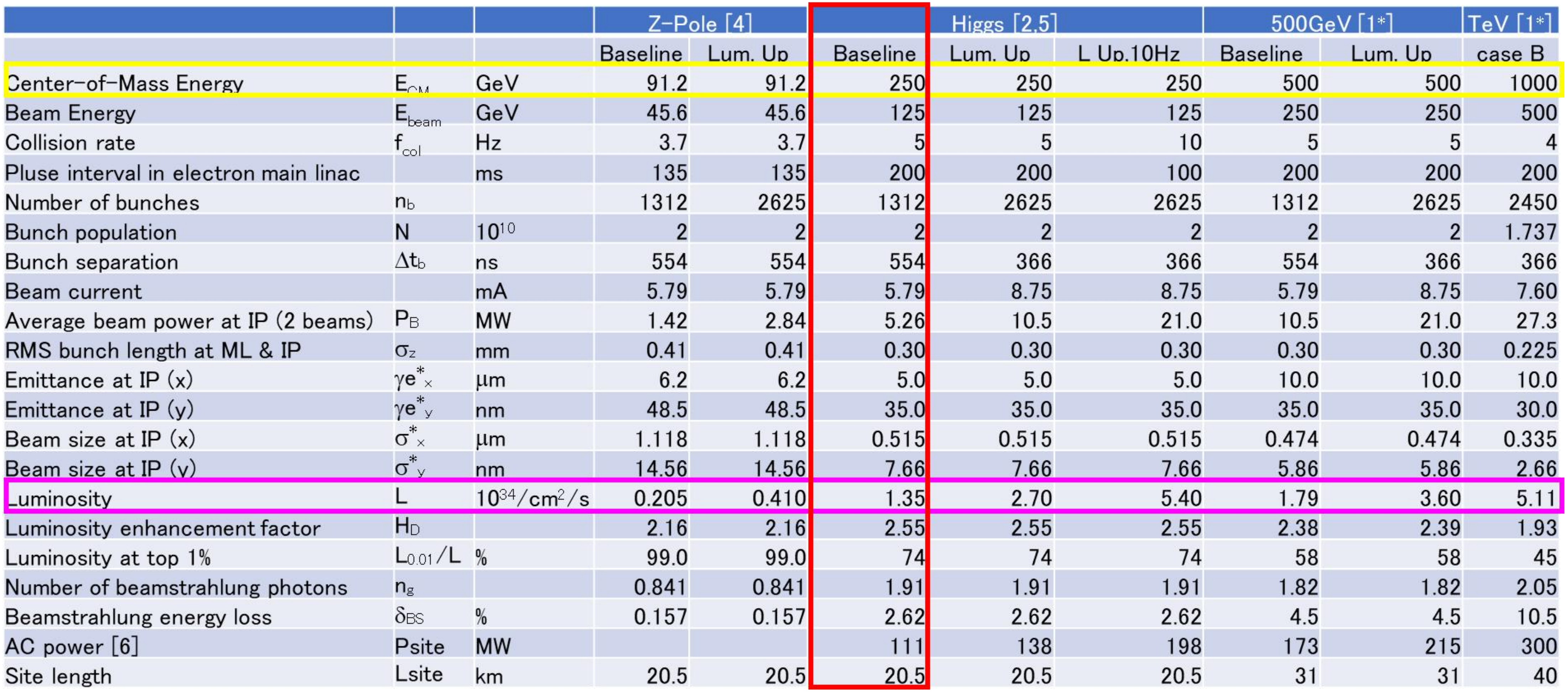
Michizono

The ILC can be upgraded to higher energy and luminosity.



			Z-Pole [4]			Higgs [2,5]		500GeV [1*]		TeV [1*]
			Baseline	Lum. Up	Baseline	Lum. Up	L Up.10Hz	Baseline	Lum. Up	case B
Center-of-Mass Energy	E_{CM}	GeV	91.2	91.2	250	250	250	500	500	1000
Beam Energy	E_{beam}	GeV	45.6	45.6	125	125	125	250	250	500
Collision rate	f_{col}	Hz	3.7	3.7	5	5	10	5	5	4
Pluse interval in electron main linac		ms	135	135	200	200	100	200	200	200
Number of bunches	n_b		1312	2625	1312	2625	2625	1312	2625	2450
Bunch population	N	10^{10}	2	2	2	2	2	2	2	1.737
Bunch separation	Δt_b	ns	554	554	554	366	366	554	366	366
Beam current		mA	5.79	5.79	5.79	8.75	8.75	5.79	8.75	7.60
Average beam power at IP (2 beams)	P_B	MW	1.42	2.84	5.26	10.5	21.0	10.5	21.0	27.3
RMS bunch length at ML & IP	σ_z	mm	0.41	0.41	0.30	0.30	0.30	0.30	0.30	0.225
Emittance at IP (x)	γe^*_x	µm	6.2	6.2	5.0	5.0	5.0	10.0	10.0	10.0
Emittance at IP (y)	γe^*_y	nm	48.5	48.5	35.0	35.0	35.0	35.0	35.0	30.0
Beam size at IP (x)	σ^*_x	µm	1.118	1.118	0.515	0.515	0.515	0.474	0.474	0.335
Beam size at IP (y)	σ^*_y	nm	14.56	14.56	7.66	7.66	7.66	5.86	5.86	2.66
Luminosity	L	$10^{34}/cm^2/s$	0.205	0.410	1.35	2.70	5.40	1.79	3.60	5.11
Luminosity enhancement factor	H_D		2.16	2.16	2.55	2.55	2.55	2.38	2.39	1.93
Luminosity at top 1%	$L_{0.01}/L$	%	99.0	99.0	74	74	74	58	58	45
Number of beamstrahlung photons	n_g		0.841	0.841	1.91	1.91	1.91	1.82	1.82	2.05
Beamstrahlung energy loss	δ_{BS}	%	0.157	0.157	2.62	2.62	2.62	4.5	4.5	10.5
AC power [6]	Psite	MW			111	138	198	173	215	300
Site length	Lsite	km	20.5	20.5	20.5	20.5	20.5	31	31	40

Energy

Lumi.

Technical preparation

Shinichiro Michizono

IDT-WG2 summarized the technical preparation as work packages (WPs) in the technical preparation document.

ILC Pre-lab

Actual cavity /CM manufacturing

SRF
~41MILCU
285 FTE-yr
- WP-1 Cavity production
- WP-2 Cryomodule assembly
- WP-3 Crab cavity

e- source
~2.5MILCU, 6 FTE-yr
- WP-4 Electron source

e+ source
~6MILCU, 15FTE-yr

Undulator scheme
- WP-5 Undulator
- WP-6 Rotating target
- WP-7 Magnetic focusing

e-Driven scheme
- WP-8 Rotating target
- WP-9 Magnetic focusing
- WP-10 Capture cavity
- WP-11 Target replacement

DR
~2.5MILCU, 30FTE-yr
- WP-12 System design
- WP-13 Collective effect
- WP-14 Injection/extraction

BDS
~2MILCU, 16FTE-yr
- WP-15 Final focus
- WP-16 Final doublet

Dump
~3MILCU, 12FTE-yr
- WP-17 Main dump
- WP-18 Photon dump

For detail,
http://doi.org/10.5281/ zenodo.4742018

SRF technology is energy-efficient, and its applications are increasing around the world.
These WPs will contribute to the promotion of SRF accelerators in each region.

- The technical preparation document was reviewed by the international review committee (chair:Tor Raubenheimer (SLAC)).
- The total global cost of the project is about 60 MILCU* and about 360 FTE-year. (This does not include the cost of the infrastructure for the WPs.)
- The cost will be shared internationally as in-kind contribution.

1MILCU=1M$(2012)

ILC construction/operation cost

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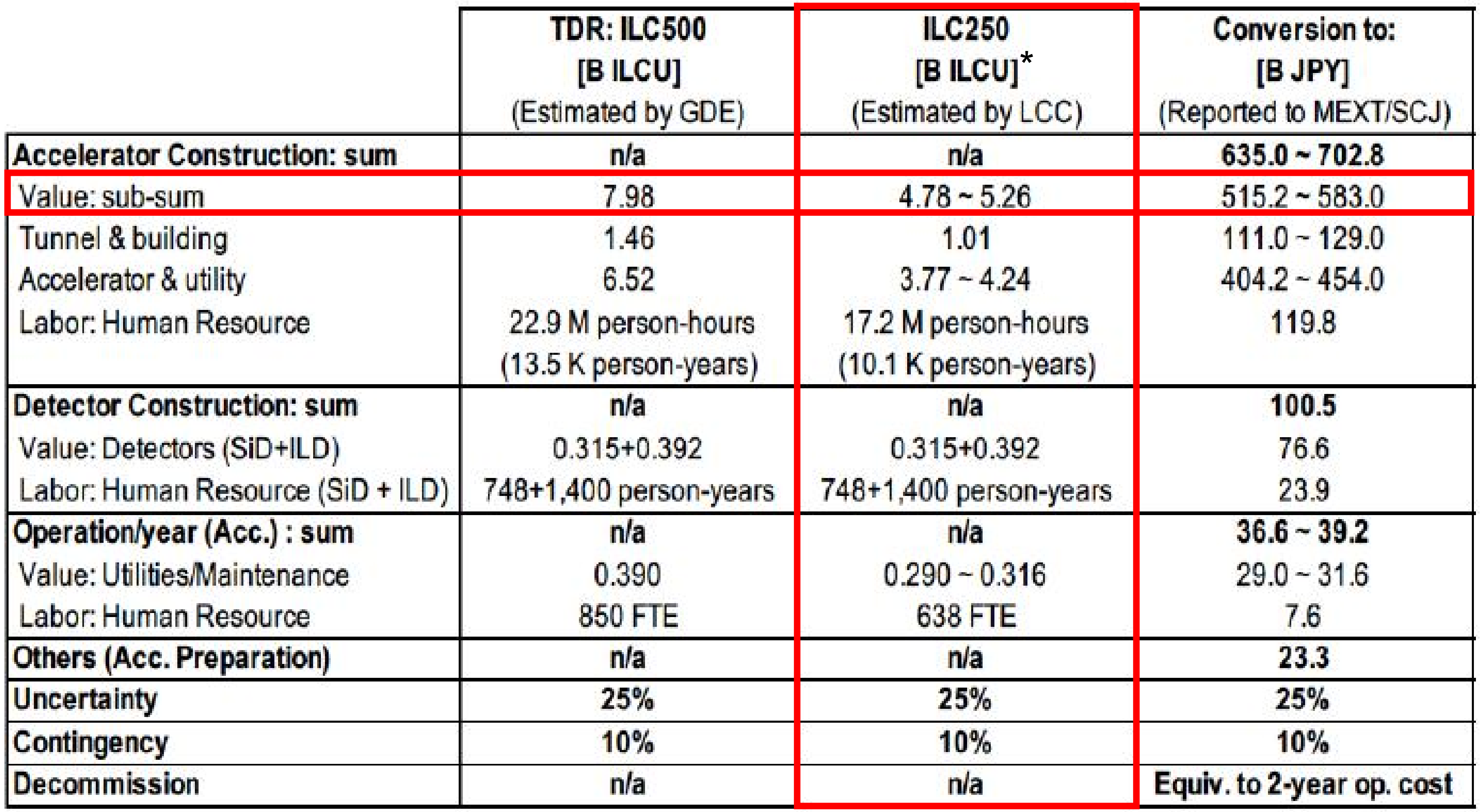
ILC accelerator (including tunnel) construction cost is ~5 B$.



	TDR: ILC500 [B ILCU] (Estimated by GDE)	ILC250 [B ILCU]* (Estimated by LCC)	Conversion to: [B JPY] (Reported to MEXT/SCJ)
Accelerator Construction: sum	**n/a**	**n/a**	**635.0 ~ 702.8**
Value: sub-sum	7.98	4.78 ~ 5.26	515.2 ~ 583.0
Tunnel & building	1.46	1.01	111.0 ~ 129.0
Accelerator & utility	6.52	3.77 ~ 4.24	404.2 ~ 454.0
Labor: Human Resource	22.9 M person-hours (13.5 K person-years)	17.2 M person-hours (10.1 K person-years)	119.8
Detector Construction: sum	**n/a**	**n/a**	**100.5**
Value: Detectors (SiD+ILD)	0.315+0.392	0.315+0.392	76.6
Labor: Human Resource (SiD + ILD)	748+1,400 person-years	748+1,400 person-years	23.9
Operation/year (Acc.) : sum	**n/a**	**n/a**	**36.6 ~ 39.2**
Value: Utilities/Maintenance	0.390	0.290 ~ 0.316	29.0 ~ 31.6
Labor: Human Resource	850 FTE	638 FTE	7.6
Others (Acc. Preparation)	**n/a**	**n/a**	**23.3**
Uncertainty	**25%**	**25%**	**25%**
Contingency	**10%**	**10%**	**10%**
Decommission	**n/a**	**n/a**	**Equiv. to 2-year op. cost**

*1 ILCU= 1 US$ in 2012 prices

ILC timeline

Now we are at pre-preparation phase (waiting for the preparation phase).
Four years preparation (@ILC Pre-Lab) and ~10 years construction (@ ILC Lab.).

2022

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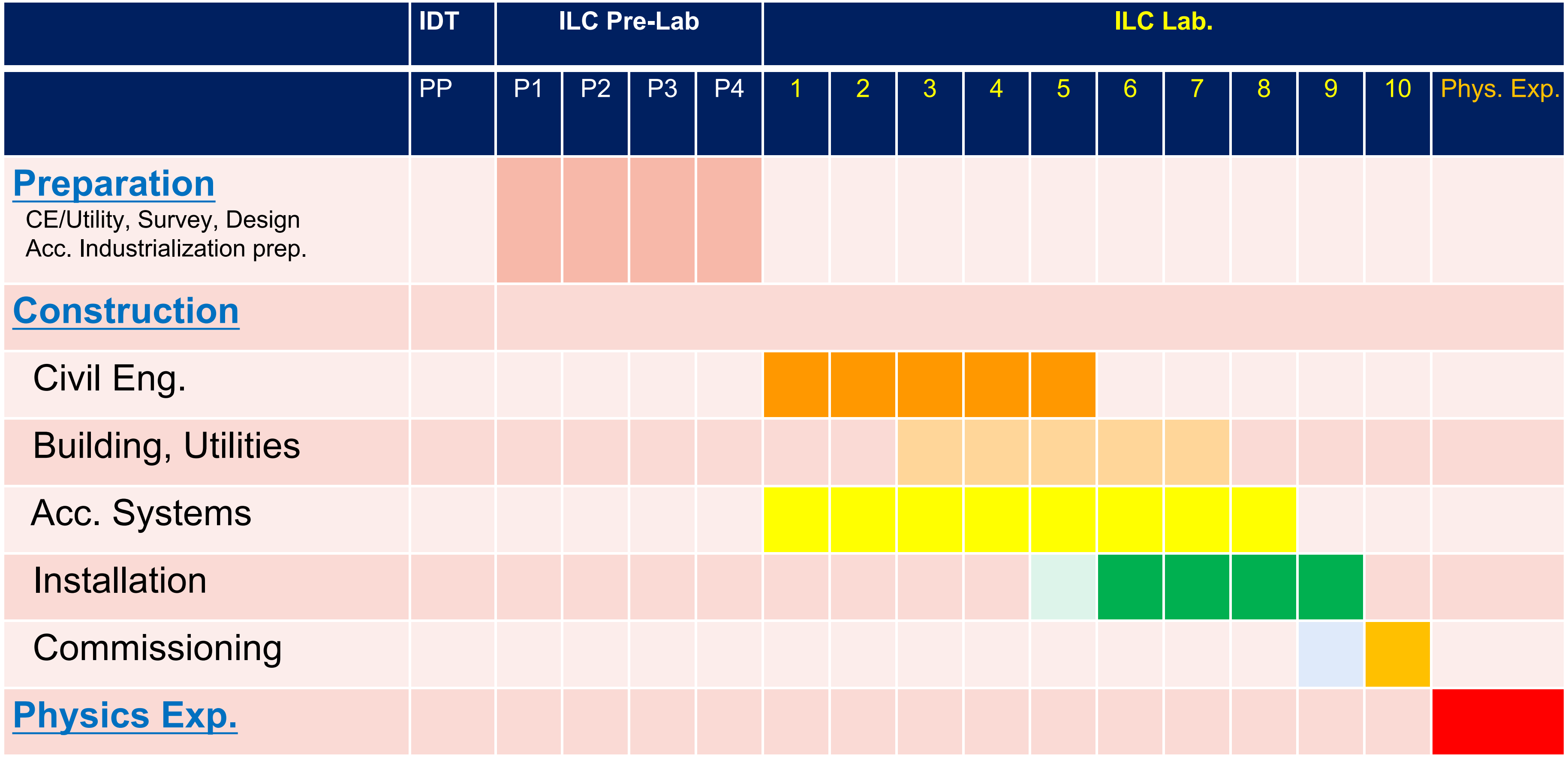


	IDT	ILC Pre-Lab				ILC Lab.										
	PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.
Preparation CE/Utility, Survey, Design Acc. Industrialization prep.		■	■	■	■											
Construction																
Civil Eng.						■	■	■	■	■						
Building, Utilities								■	■	■	■	■				
Acc. Systems						■	■	■	■	■	■	■	■			
Installation										▨	■	■	■	■		
Commissioning														▨	■	
Physics Exp.																■

IDT

ICFA

ILC International Development Team

Executive Board

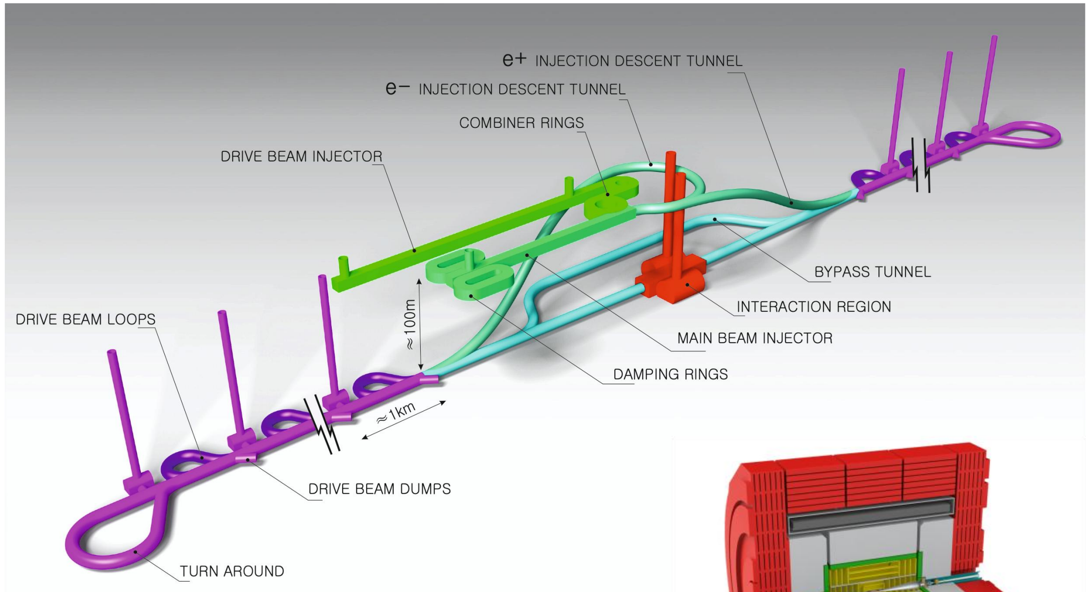
Americas Liaison	Andrew Lankford (UC Irvine)
Working Group 2 Chair	Shinichiro Michizono (KEK)
Working Group 3 Chair	Hitoshi Murayama (UC Berkeley/U. Tokyo)
Executive Board Chair and Working Group 1 Chair	Tatsuya Nakada (EPFL)
KEK Liaison	Yasuhiro Okada (KEK)
Europe Liaison	Steinar Stapnes (CERN)
Asia-Pacific Liaison	Geoffrey Taylor (U. Melbourne)

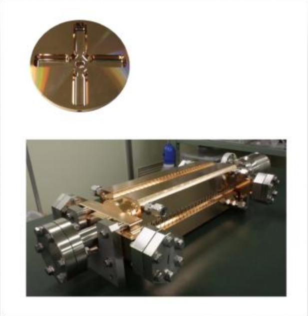
Working Group 1
Pre-Lab Setup

Working Group 2
Accelerator

Working Group 3
Physics & Detectors

The Compact Linear Collider (CLIC)





Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)

- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20'500 structures at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision energies from 380 GeV (Higgs/top) up to 3 TeV (Energy Frontier)

- CDR in 2012 with focus on 3 TeV. Updated project overview documents in 2018 (Project Implementation Plan) with focus 380 GeV for Higgs and top.

- **Cost:** 5.9 BCHF for 380 GeV (stable wrt 2012)
- **Power:** 110 MW at 380 GeV corresponding to ~50% of CERN's energy consumption today

- Comprehensive **Detector and Physics** studies

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Snowmass (https://arxiv.org/abs/2203.09186)

CLIC parameters

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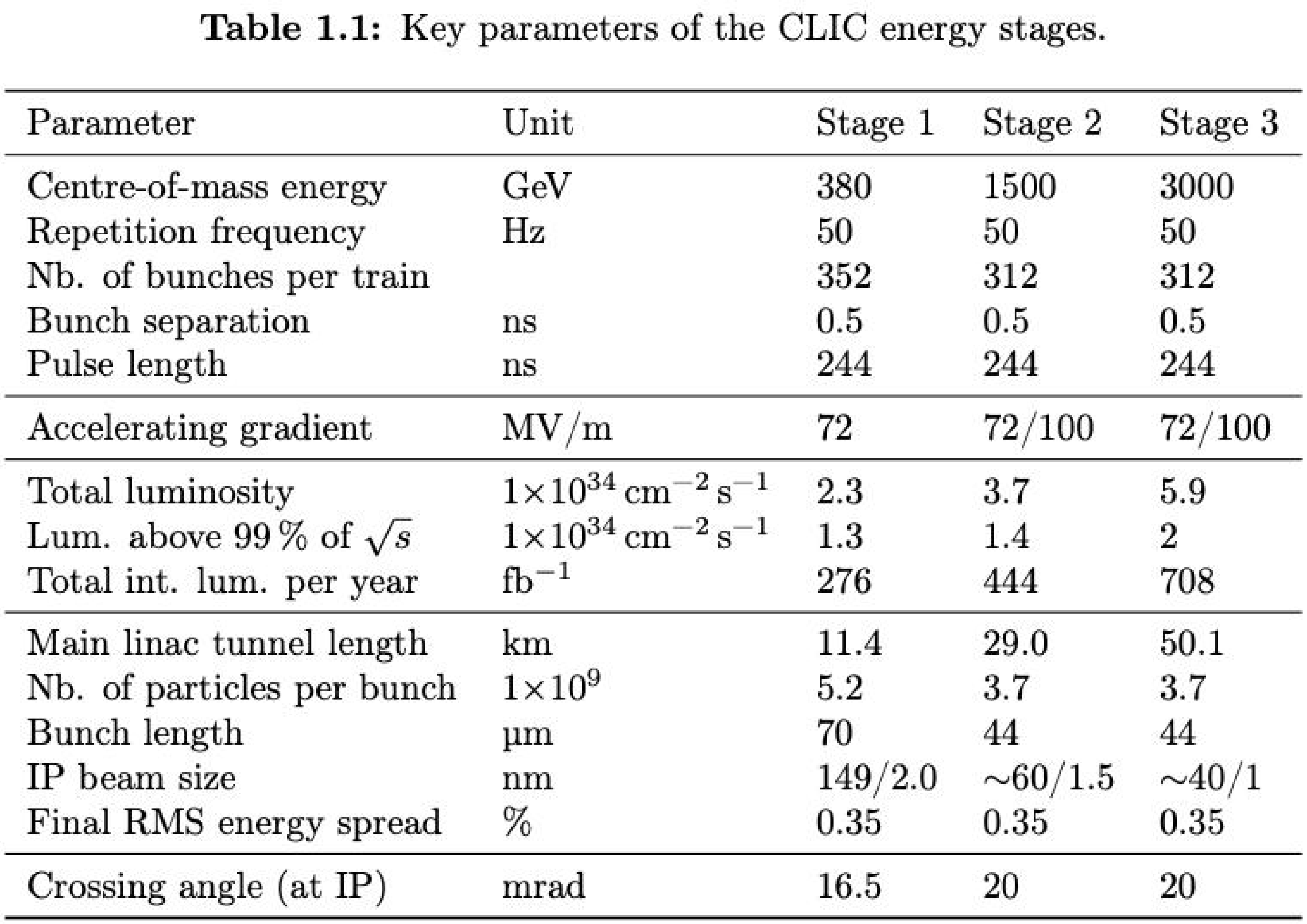

Table 1.1: Key parameters of the CLIC energy stages.

Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	1.3	1.4	2
Total int. lum. per year	fb^{-1}	276	444	708
Main linac tunnel length	km	11.4	29.0	50.1
Nb. of particles per bunch	1×10^{9}	5.2	3.7	3.7
Bunch length	µm	70	44	44
IP beam size	nm	149/2.0	~60/1.5	~40/1
Final RMS energy spread	%	0.35	0.35	0.35
Crossing angle (at IP)	mrad	16.5	20	20

CLIC is a mature design/study

Steinar Stapnes

The CLIC accelerator studies are mature:

Optimised design for cost and power

Many tests in CTF3, FELs, lightsources and test-stands

Technical developments of "all" key elements

Cost – I

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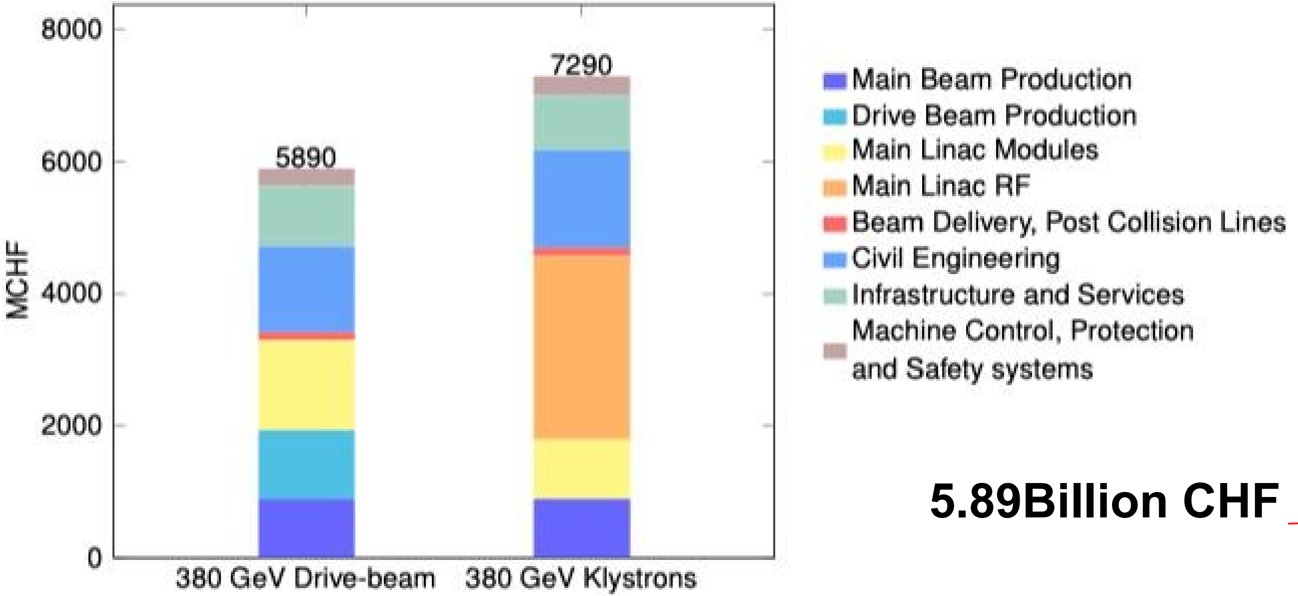
Machine has been re-costed bottom-up in 2017-18

- Methods and costings validated at review on 7 November 2018 – similar to LHC, ILC, CLIC CDR
- Technical uncertainty and commercial uncertainty estimated



Domain	Sub-Domain	Cost [MCHF]	
		Drive-Beam	Klystron
Main Beam Production	Injectors	175	175
	Damping Rings	309	309
	Beam Transport	409	409
Drive Beam Production	Injectors	584	—
	Frequency Multiplication	379	—
	Beam Transport	76	—
Main Linac Modules	Main Linac Modules	1329	895
	Post decelerators	37	—
Main Linac RF	Main Linac Xband RF	—	2788
Beam Delivery and Post Collision Lines	Beam Delivery Systems	52	52
	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
Civil Engineering	Civil Engineering	1300	1479
Infrastructure and Services	Electrical distribution	243	243
	Survey and Alignment	194	147
	Cooling and ventilation	443	410
	Transport / installation	38	36
Machine Control, Protection and Safety systems	Safety system	72	114
	Machine Control Infrastructure	146	131
	Machine Protection	14	8
	Access Safety & Control System	23	23
Total (rounded)		**5890**	**7290**

5.89Billion CHF → CLIC 380 GeV Drive-Beam based: 5890^{+1470}_{-1270} MCHF;

7.29Billion CHF → CLIC 380 GeV Klystron based: 7290^{+1800}_{-1540} MCHF.

CLIC power and energy

CLIC power at 380 GeV: 110 MW.

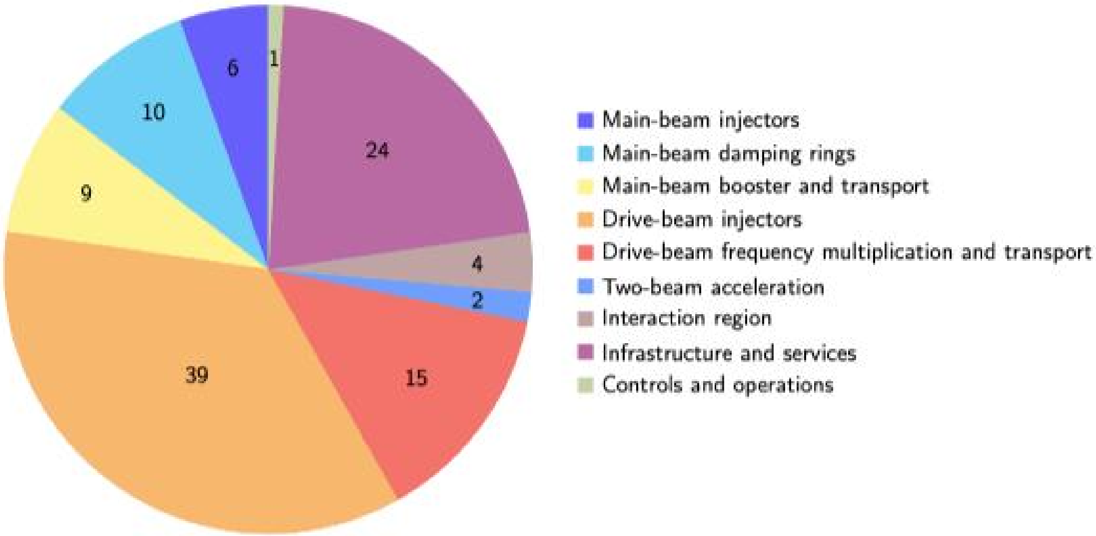


Fig. 4.8: Breakdown of power consumption between different domains of the CLIC accelerator in MW at a centre-of-mass energy of 380 GeV. The contributions add up to a total of 110 MW. (image credit: CLIC)

Table 4.2: Estimated power consumption of CLIC at the three centre-of-mass energy stages and for different operation modes. The 380 GeV numbers are for the drive-beam option and have been updated as described in Section 4.4, whereas the estimates for the higher energy stages are from [57].

Collision energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	110	25	9
1500	364	38	13
3000	589	46	17

Steinar Stapnes

The CLIC project

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April 4, 2022

Abstract

The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear e^+e^- collider under development by the CLIC accelerator collaboration, hosted by CERN. The CLIC accelerator has been optimised for three energy stages at centre-of-mass energies 380 GeV, 1.5 TeV and 3 TeV [21]. CLIC uses a novel two-beam acceleration technique, with normal-conducting accelerating structures operating in the range of 70 MV/m to 100 MV/m.

The report describes recent achievements in accelerator design, technology development, system tests and beam tests. Large-scale CLIC-specific beam tests have taken place, for example, at the CLIC Test Facility CTF3 at CERN [39], at the Accelerator Test Facility ATF2 at KEK [53, 67], at the FACET facility at SLAC [35] and at the FERMI facility in Trieste [36]. Crucial experience also emanates from the expanding field of Free Electron Laser (FEL) linacs and recent-generation light sources. Together, they demonstrate that all implications of the CLIC design parameters are well understood and reproducible in beam tests and prove that the CLIC performance goals are realistic. An alternative CLIC scenario for the first stage, where the accelerating structures are powered by X-band klystrons, is also under study. The implementation of CLIC near CERN has been investigated. Focusing on a staged approach starting at 380 GeV, this includes civil engineering aspects, electrical networks, cooling and ventilation, installation scheduling, transport, and safety aspects. All CLIC studies have put emphasis on optimising cost and energy efficiency, and the resulting power and cost estimates are reported. The report follows very closely the accelerator project description in the CLIC Summary Report for the European Particle Physics Strategy update 2018-19 [22].

Detailed studies of the physics potential and detector for CLIC, and R&D on detector technologies, have been carried out by the CLIC detector and physics (CLICdp) collaboration. CLIC provides excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors. The physics potential at the three energy stages has been explored in detail [2, 3, 17] and presented in submissions to the European Strategy Update process.

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

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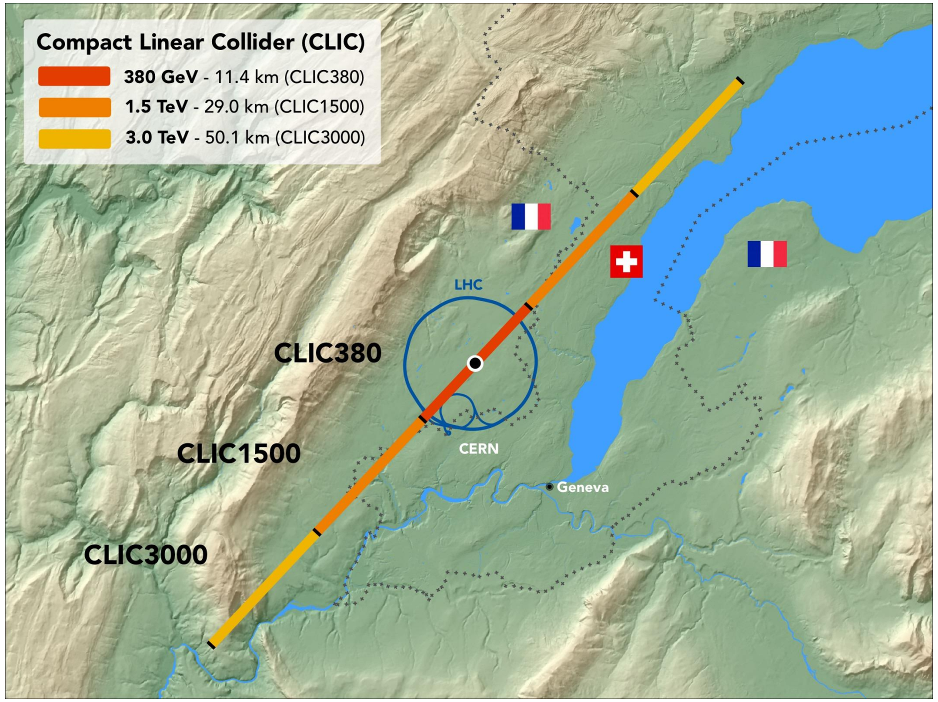
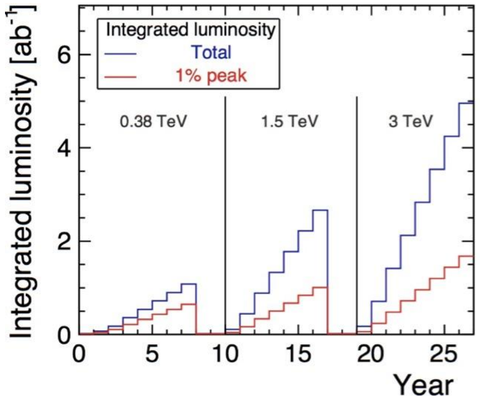
*Compiled and edited by the CLIC Accelerator Steering Group on behalf of the CLIC Accelerator Collaboration, corresponding author: `steinar.stapnes@cern.ch`

Submitted to Snowmass21 (https://arxiv.org/abs/2203.09186)

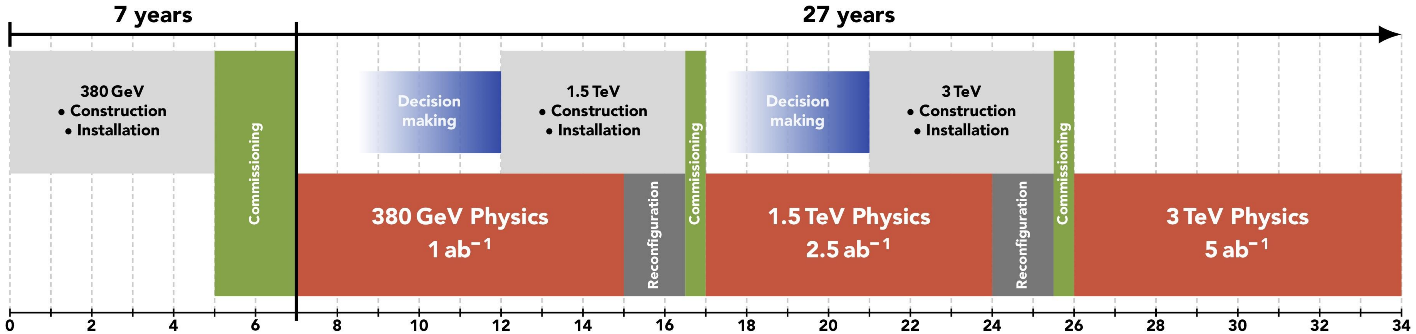
CLIC CE, timeline and schedules

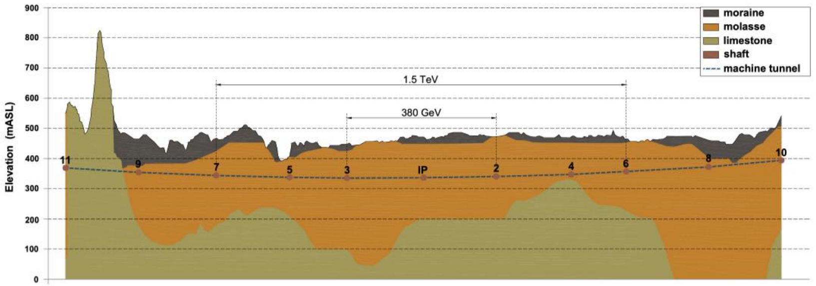




Steinar Stapnes

Ramp-up and up-time assumptions: arXiv:1810.13022, Bordry et al.





Project Readiness Report as a step toward a TDR – for next ESPP
Assuming ESPP in 2026, Project Approval ~ 2028, Project (tunnel) construction can start in ~ 2030.

The CLIC study is mature: (https://arxiv.org/abs/2203.09186)

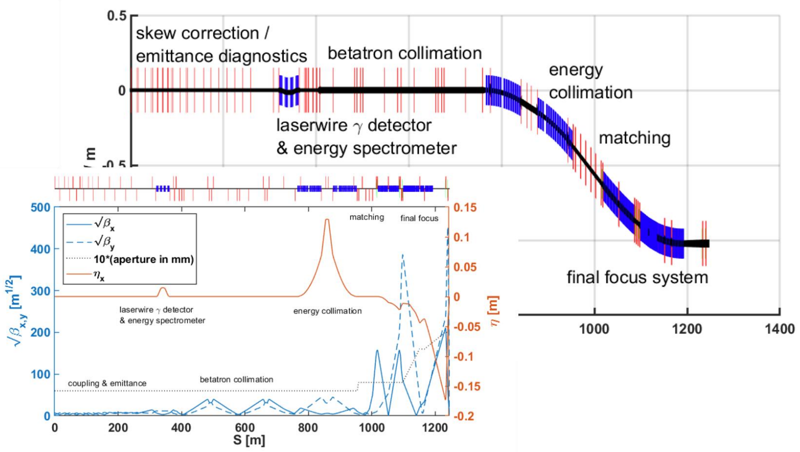
Accelerator Complex

More Details See: ArXiv 2110.15800 (2021)

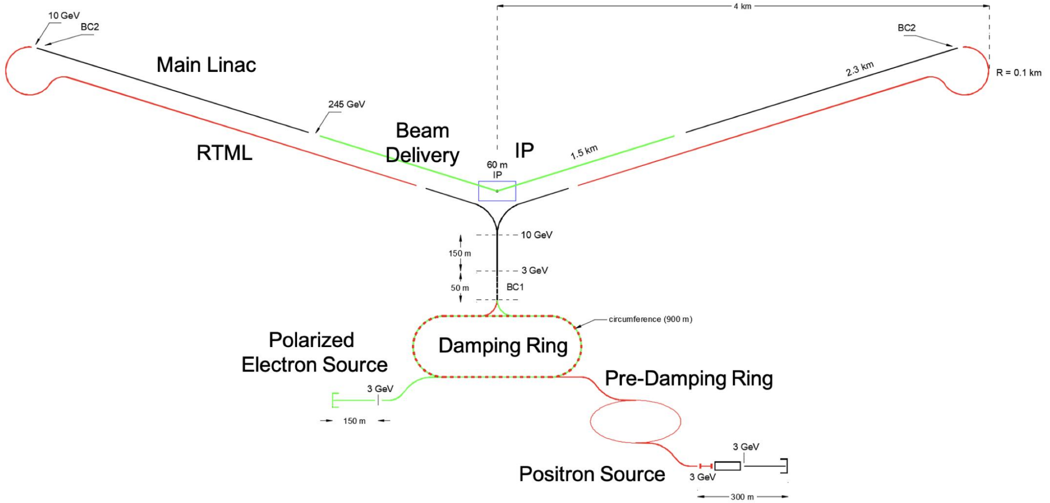
Emilio Nanni

- 8 km footprint for 250/550 GeV CoM - > 70/120 MeV/m
  - ***7 km footprint at 155 MeV/m for 550 GeV CoM – present Fermilab site***
- Large portions of accelerator complex are compatible between LC technologies
  - Beam delivery and IP modified from ILC (1.5 km for 550 GeV CoM)
  - Damping rings and injectors to be optimized with CLIC as baseline
  - Costing studies use LC estimates as inputs

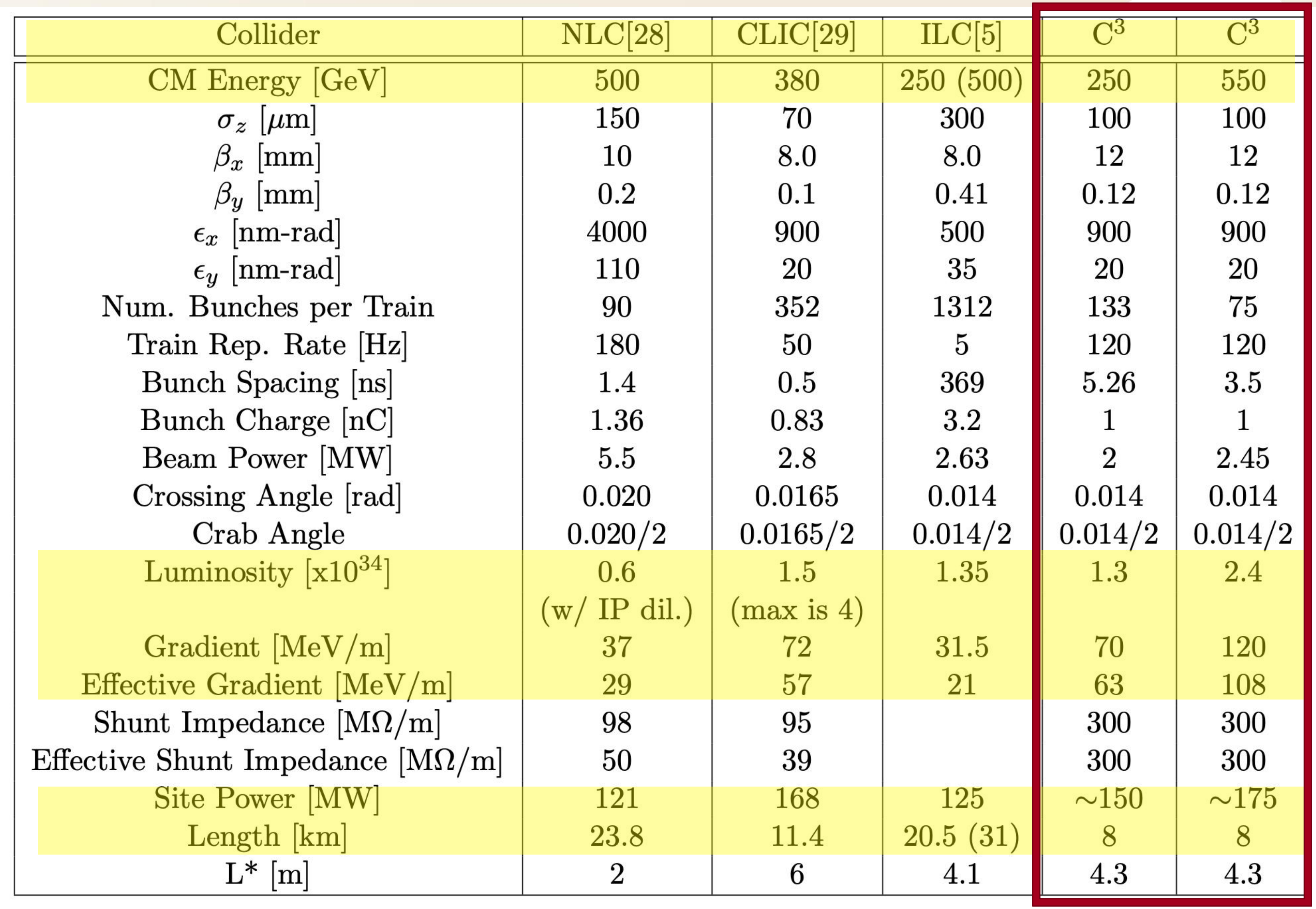
C³ - Investigation of Beam Delivery Adapted from ILC/NLC



C³ - 8 km footprint for 250/550 GeV



C3 linear collider table of parameters

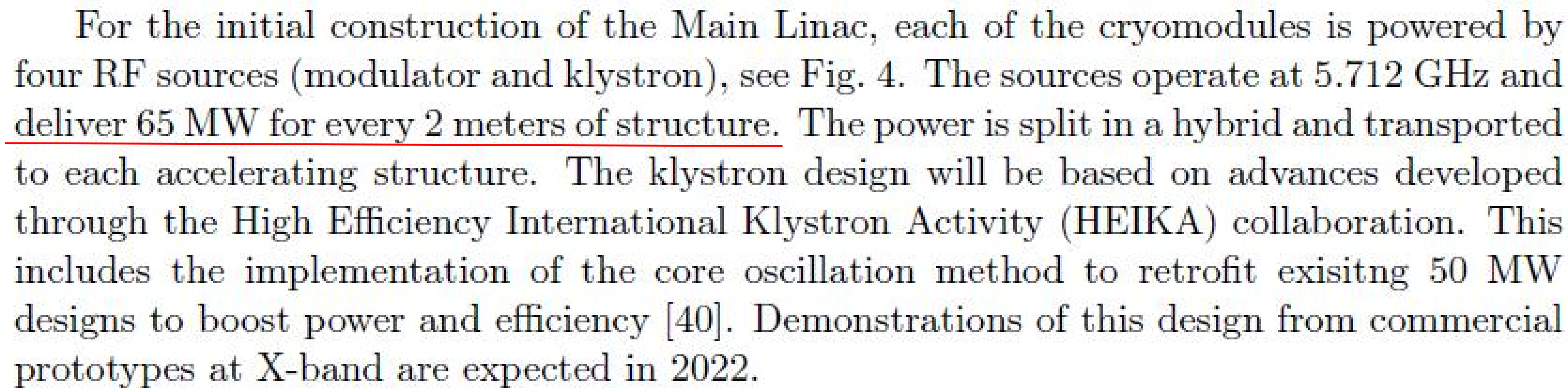


Collider	NLC[28]	CLIC[29]	ILC[5]	C^3	C^3
CM Energy [GeV]	500	380	250 (500)	250	550
σ_z [μm]	150	70	300	100	100
β_x [mm]	10	8.0	8.0	12	12
β_y [mm]	0.2	0.1	0.41	0.12	0.12
ϵ_x [nm-rad]	4000	900	500	900	900
ϵ_y [nm-rad]	110	20	35	20	20
Num. Bunches per Train	90	352	1312	133	75
Train Rep. Rate [Hz]	180	50	5	120	120
Bunch Spacing [ns]	1.4	0.5	369	5.26	3.5
Bunch Charge [nC]	1.36	0.83	3.2	1	1
Beam Power [MW]	5.5	2.8	2.63	2	2.45
Crossing Angle [rad]	0.020	0.0165	0.014	0.014	0.014
Crab Angle	0.020/2	0.0165/2	0.014/2	0.014/2	0.014/2
Luminosity [x10^{34}]	0.6 (w/ IP dil.)	1.5 (max is 4)	1.35	1.3	2.4
Gradient [MeV/m]	37	72	31.5	70	120
Effective Gradient [MeV/m]	29	57	21	63	108
Shunt Impedance [MΩ/m]	98	95		300	300
Effective Shunt Impedance [MΩ/m]	50	39		300	300
Site Power [MW]	121	168	125	~150	~175
Length [km]	23.8	11.4	20.5 (31)	8	8
L* [m]	2	6	4.1	4.3	4.3

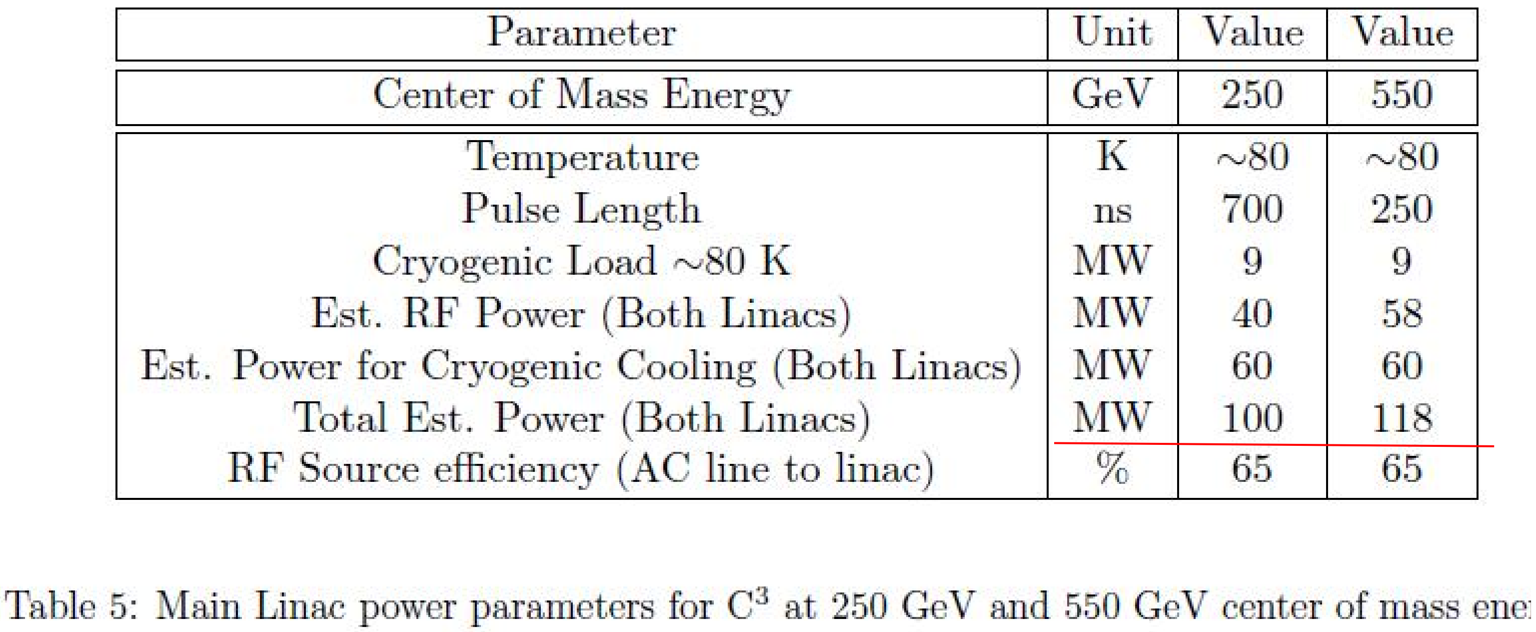
Emilio Nanni

C3 linear collider power consumption

Emilio Nanni

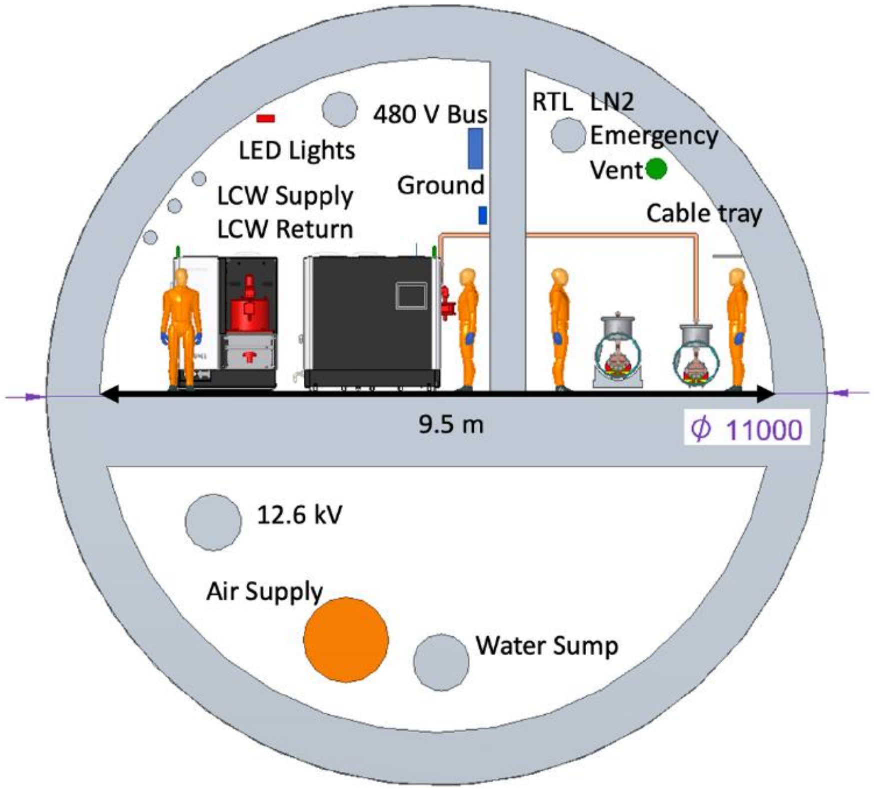


For the initial construction of the Main Linac, each of the cryomodules is powered by four RF sources (modulator and klystron), see Fig. 4. The sources operate at 5.712 GHz and deliver 65 MW for every 2 meters of structure. The power is split in a hybrid and transported to each accelerating structure. The klystron design will be based on advances developed through the High Efficiency International Klystron Activity (HEIKA) collaboration. This includes the implementation of the core oscillation method to retrofit exisitng 50 MW designs to boost power and efficiency [40]. Demonstrations of this design from commercial prototypes at X-band are expected in 2022.



Parameter	Unit	Value	Value
Center of Mass Energy	GeV	250	550
Temperature	K	~80	~80
Pulse Length	ns	700	250
Cryogenic Load ~80 K	MW	9	9
Est. RF Power (Both Linacs)	MW	40	58
Est. Power for Cryogenic Cooling (Both Linacs)	MW	60	60
Total Est. Power (Both Linacs)	MW	100	118
RF Source efficiency (AC line to linac)	%	65	65

Table 5: Main Linac power parameters for C^3 at 250 GeV and 550 GeV center of mass ene



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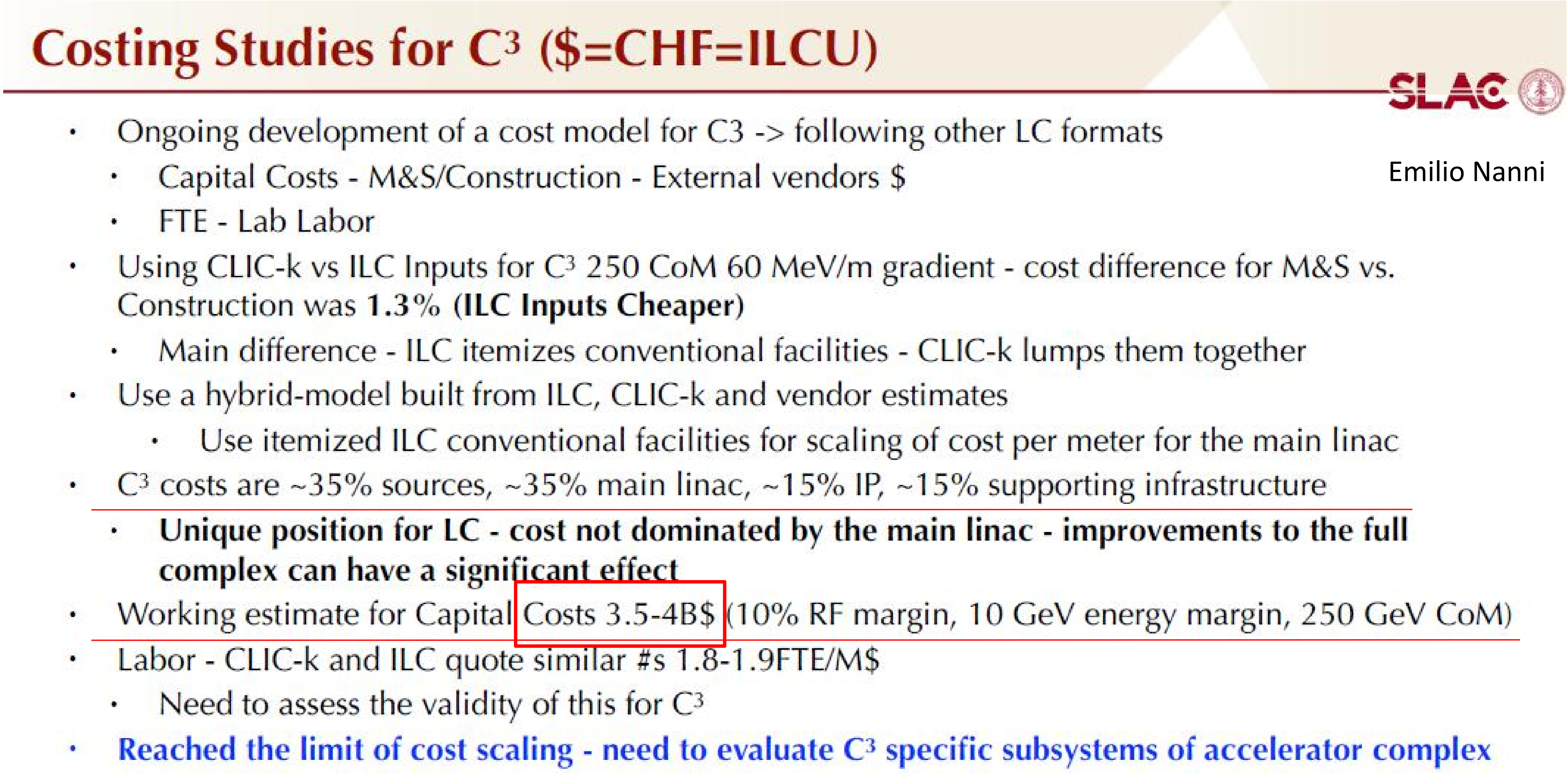
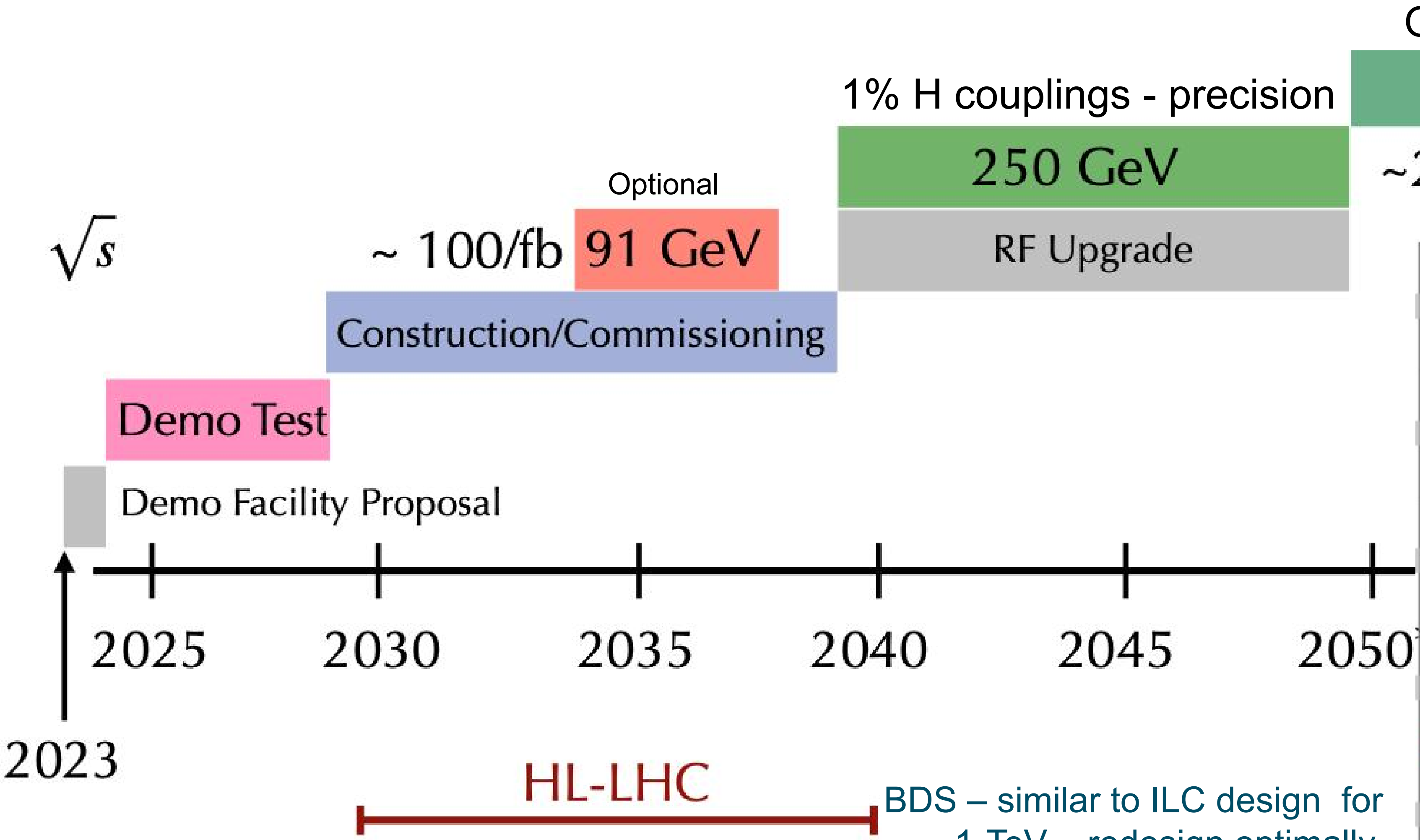


Costing Studies for C^3 ($=CHF=ILCU)

- Ongoing development of a cost model for C3 -> following other LC formats
  - Capital Costs - M&S/Construction - External vendors $
  - FTE - Lab Labor
- Using CLIC-k vs ILC Inputs for C^3 250 CoM 60 MeV/m gradient - cost difference for M&S vs. Construction was **1.3% (ILC Inputs Cheaper)**
  - Main difference - ILC itemizes conventional facilities - CLIC-k lumps them together
- Use a hybrid-model built from ILC, CLIC-k and vendor estimates
    - Use itemized ILC conventional facilities for scaling of cost per meter for the main linac
- C^3 costs are ~35% sources, ~35% main linac, ~15% IP, ~15% supporting infrastructure
  - **Unique position for LC - cost not dominated by the main linac - improvements to the full complex can have a significant effect**
- Working estimate for Capital Costs 3.5-4B$ (10% RF margin, 10 GeV energy margin, 250 GeV CoM)
- Labor - CLIC-k and ILC quote similar #s 1.8-1.9FTE/M$
  - Need to assess the validity of this for C^3
- **Reached the limit of cost scaling - need to evaluate C^3 specific subsystems of accelerator complex**

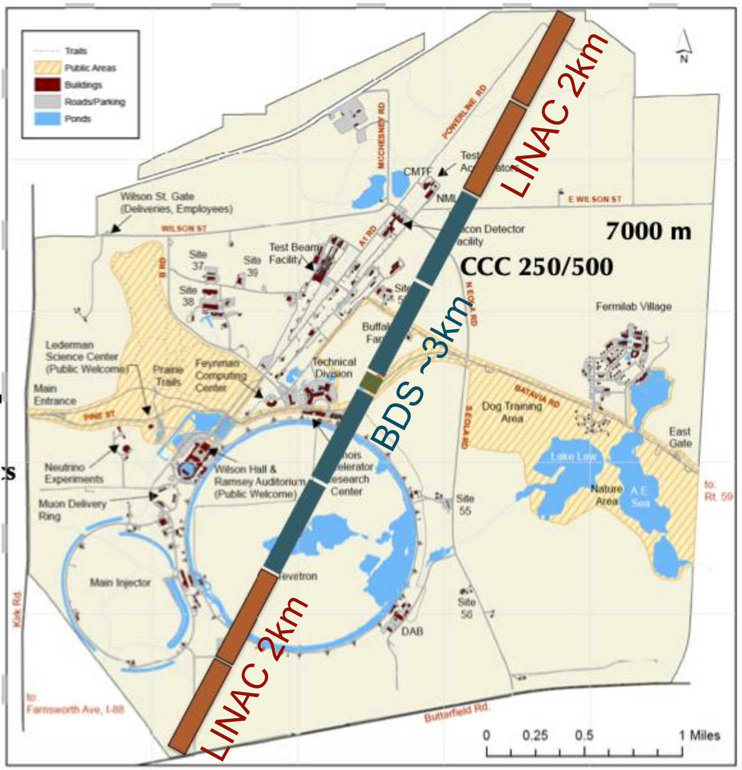
Sridhara Dasu

C^3 – $\sqrt{s} = 250 - 550$ GeV – Potential Coordinates



BDS – similar to ILC design for 1-TeV – redesign optimally.

C3 Fermi site

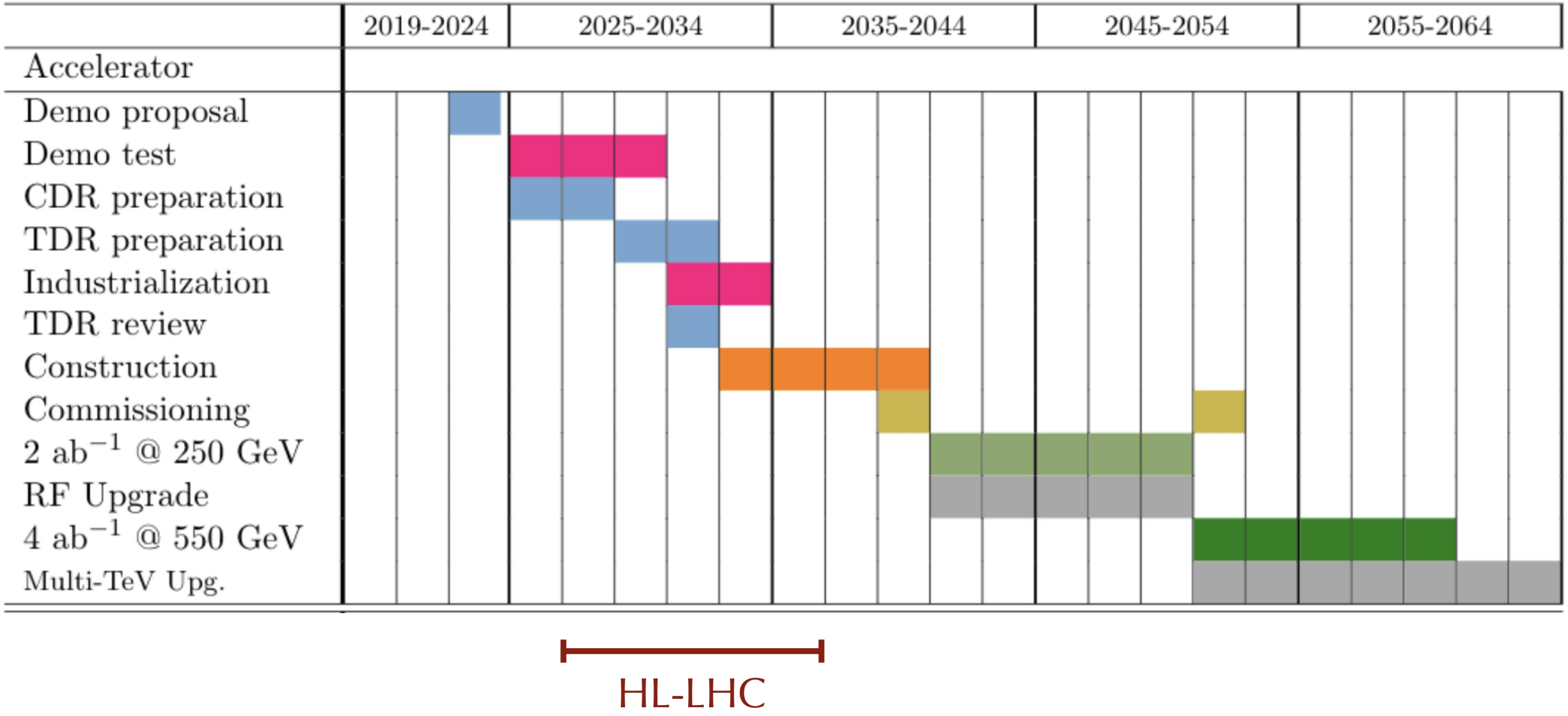


Can fit in FNAL site with BDS improvements

Timeline for C³ 250/550

- Technically limited timeline following community engagement through the full Snowmass process to define the parameters of the C^3 proposal

Emilio Nanni

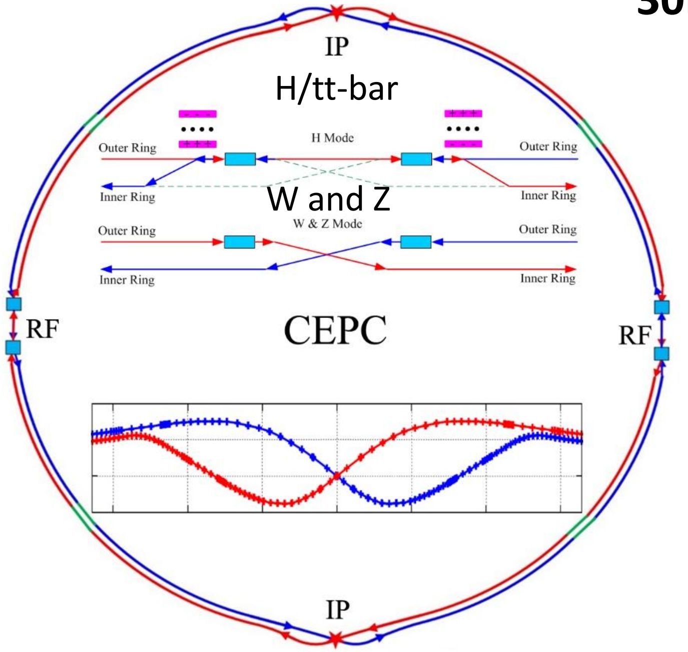


	2019-2024			2025-2034					2035-2044					2045-2054					2055-2064				
Accelerator																							
Demo proposal			🟦																				
Demo test				🟥	🟥	🟥																	
CDR preparation				🟦	🟦																		
TDR preparation						🟦	🟦																
Industrialization							🟥	🟥															
TDR review							🟦																
Construction								🟧	🟧	🟧	🟧												
Commissioning											🟨						🟨						
2 ab^{-1} @ 250 GeV												🟩	🟩	🟩	🟩	🟩							
RF Upgrade												▨	▨	▨	▨	▨							
4 ab^{-1} @ 550 GeV																	🟩	🟩	🟩	🟩	🟩		
Multi-TeV Upg.																	▨	▨	▨	▨	▨	▨	▨

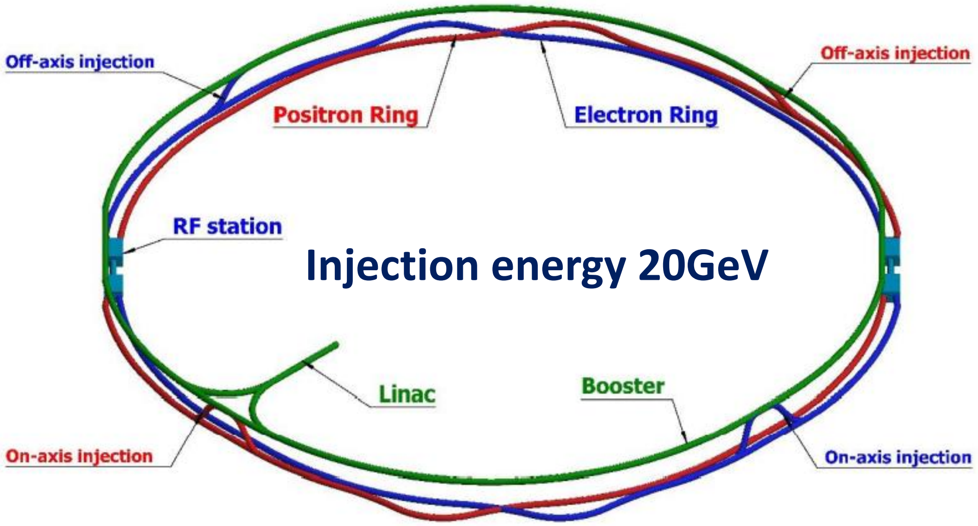
CEPC TDR layout

CEPC as a Higgs Factory：H, W, Z, upgradable to tt-bar, followed by a SppC ~125TeV

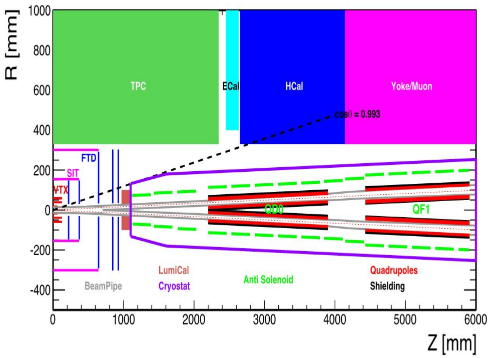
30MW SR power per beam (upgradale to 50MW)



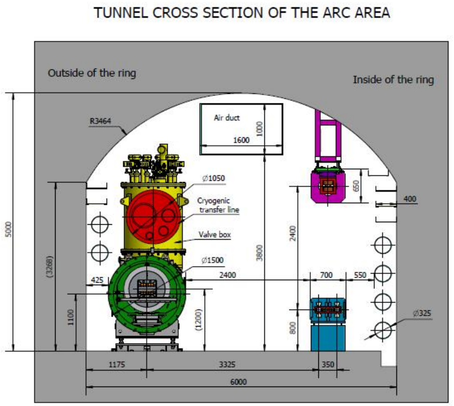
CEPC collider ring (100km)



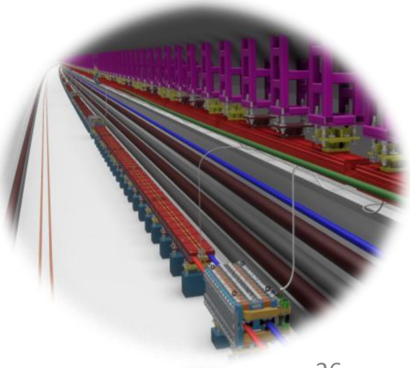
CEPC booster ring (100km)



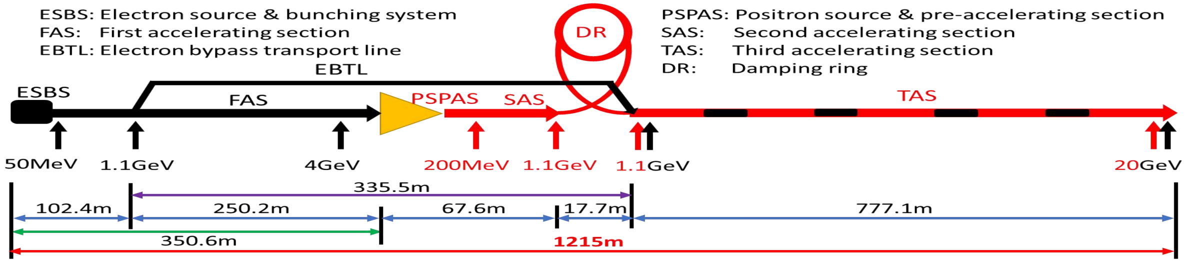
CEPC MDI



CEPC Civil Engineering



CEPC TDR S+C-band 20GeV linac injector



CEPC TDR parameters

Dou Wang

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	**30**			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	249	1297	11951	35
Bunch spacing [ns]	636	257	23 (10% gap)	4524
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	16.7	84.1	803.5	3.3
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	**5.0**	**16.0**	**115.0**	**0.5**

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

The AC power is 270MW

CEPC TDR parameters (upgrade)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
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RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

Dou Wang

This parameter table is used by US Snowmass21 for CEPC physics performance potential evaluation

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

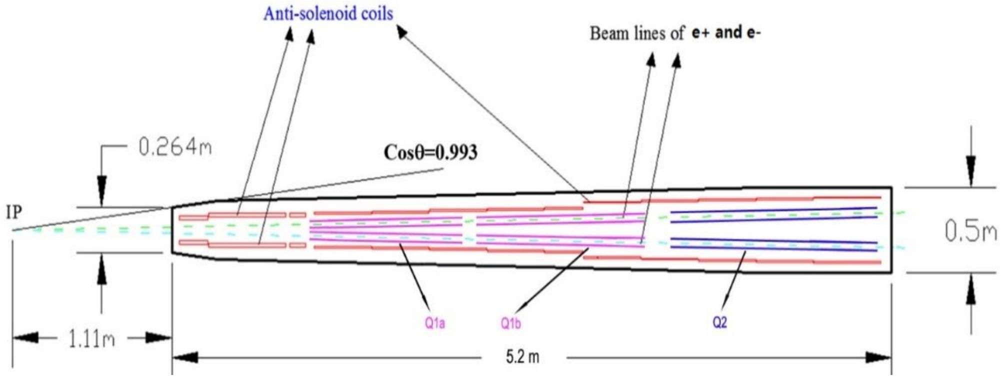
The AC power is 350MW

CEPC collider ring IR for all energies

(Higgs, W, Z and tt-bar)

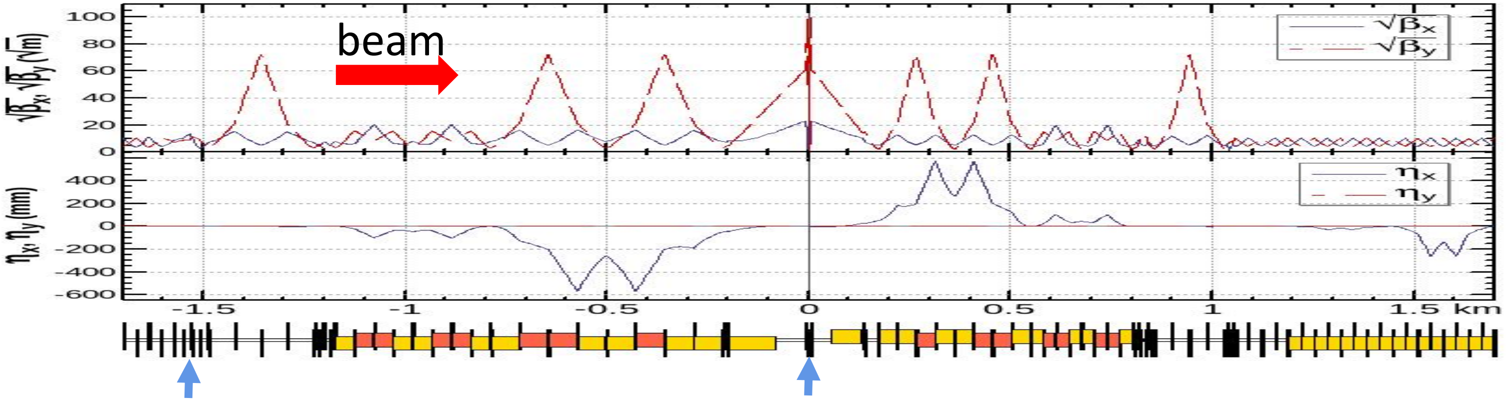
For the interaction region, the IP beta functions are refitted with the different combination of final doulets and the matching quadruples.

Yiwei Wang



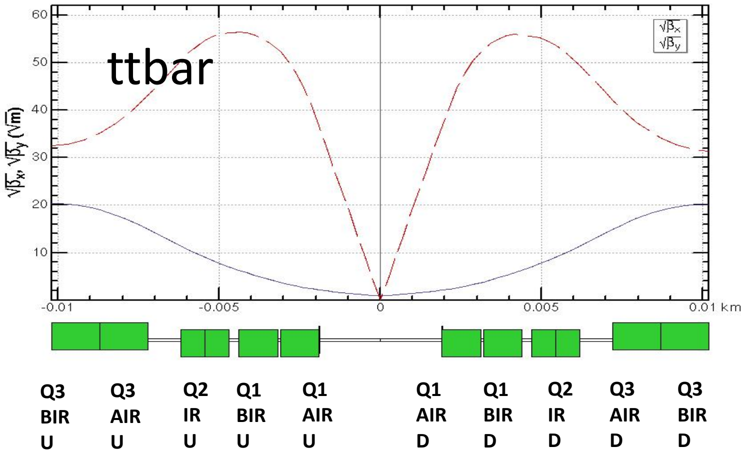
	QD	QF
Z	Q1A	Q1B
W/H	Q1A+Q1B	Q2
ttbar	Q1A+Q1B+Q2	add quad Q3A and Q3B

Higgs: L*=1.9m, LQ1A=1.22m, LQ1B=1.22m, LQ2=1.5m, d=0.3m, GQ1A=142T/m, GQ1B=96T/m, GQ2=56T/m



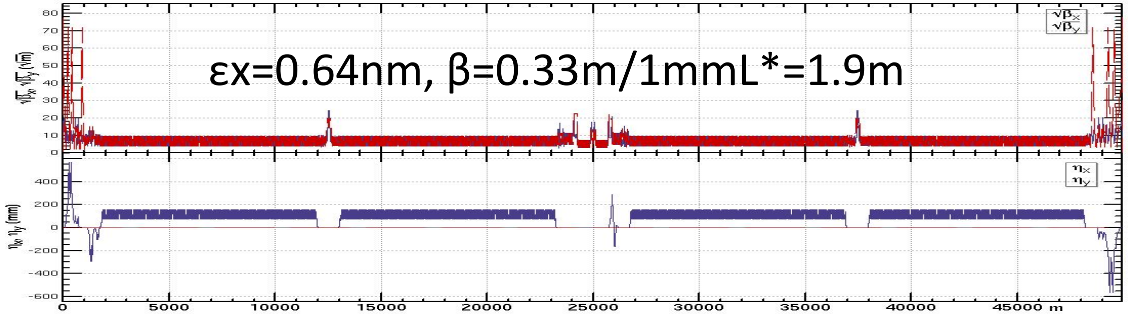
matching section

Final doublet



CEPC collider ring TDR lattice dynamic apertures with errors for Higgs energy

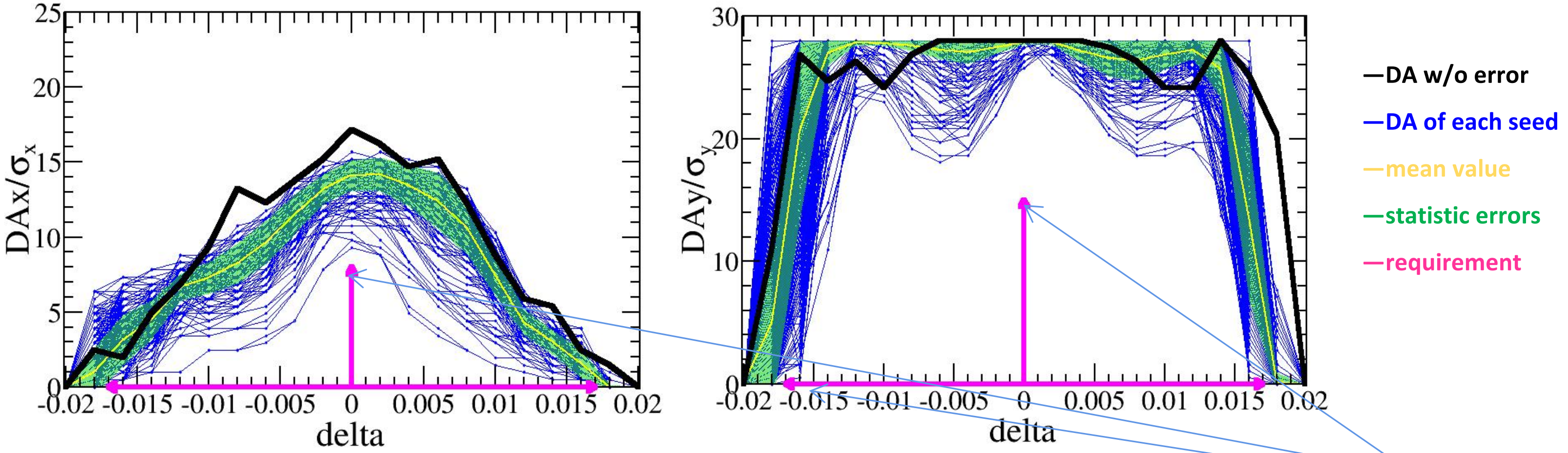
Yiwei Wang
Bin Wang



εx=0.64nm, β=0.33m/1mmL*=1.9m

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	

Effects included in tracking
Synchrotron motion
Radiation loss in all magnets
Tapering
Crab waist sextupole
Maxwellian fringes
Kinematic terms
Finite length of sextupole



DA design goal
$8\sigma_x \times 15\sigma_y \,\&\, 0.017$

Lattice version cepc.lat.diff.8713.346.2p used

The DA with erros of TDR lattice satisfiy the design goal

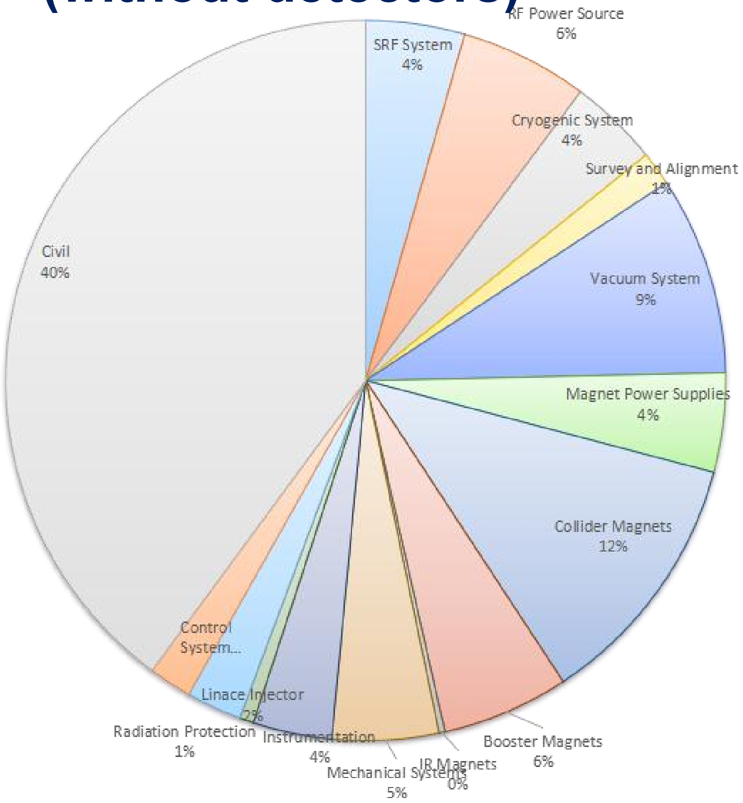
Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
IR Quadrupole	**0.1**	**0.1**	**0.01**	

CEPC CDR power consumption cost estimate as a Higgs Factory

	System for Higgs (30MW)	Location and electrical demand(MW)						Total (MW)
		Ring	Booster	LINAC	BTL	IR	Surface building	
1	RF Power Source	103.8	0.15	5.8				109.75
2	Cryogenic System	11.62	0.68			1.72		14.02
3	Vacuum System	9.784	3.792	0.646				14.222
4	Magnet Power Supplies	47.21	11.62	1.75	1.06	0.26		61.9
5	Instrumentation	0.9	0.6	0.2				1.7
6	Radiation Protection	0.25		0.1				0.35
7	Control System	1	0.6	0.2	0.005	0.005		1.81
8	Experimental devices					4		4
9	Utilities	31.79	3.53	1.38	0.63	1.2		38.53
10	General services	7.2		0.2	0.15	0.2	12	19.75
	Total	213.554	20.972	10.276	1.845	7.385	12	266.032

266MW

CEPC CDR Cost Breakdwon (without detectors)



The total cost of CEPC~35Billion RMB~5Billion US$ (Accelerator+2 Detectors+Civil+Contigence)

CEPC TDR parameters (upgrade)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
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Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

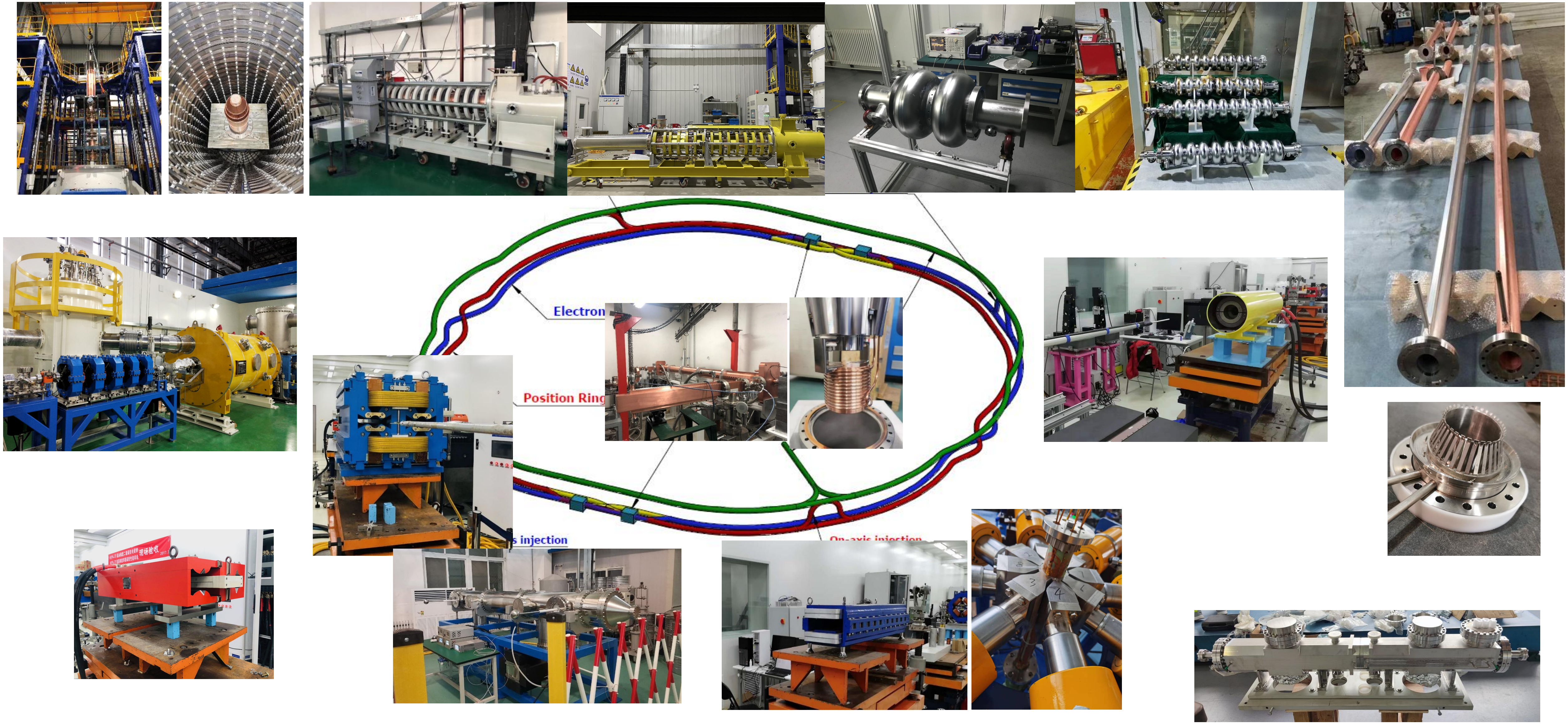
Dou Wang

This parameter table is used by US Snowmass21 for CEPC physics performance potential evaluation

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

The AC power is 350MW

CEPC TDR R&D of key technologies



CEPC CDR-Higgs

Peak Luminosity = $3\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Ingetrated Luminosity = 5.6 ab^{-1}

Higgs annual luminosity =0.8 ab^{-1}

CEPC TDR-Higgs

Peak Luminosity = $5\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Ingetrated Luminosity = 9.3 ab^{-1}

Higgs annual luminosity =1.3 ab^{-1}

CEPC TDR-Higgs (upgrade)

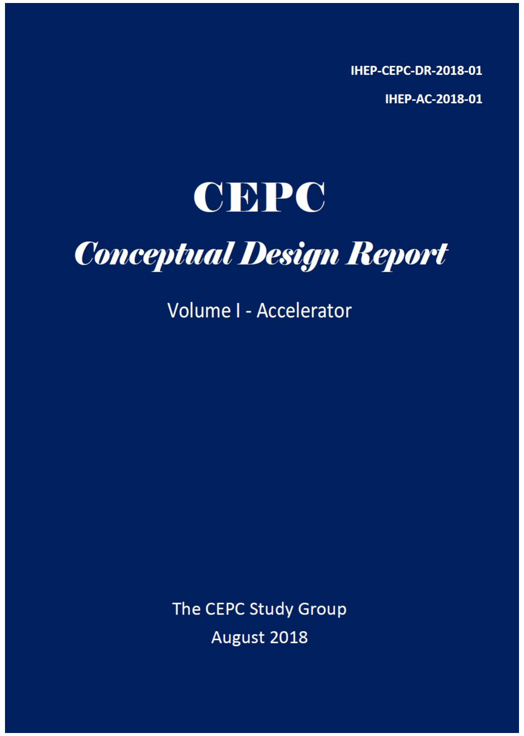
Peak Luminosity = $8.3\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Ingetrated Luminosity = 15.4 ab^{-1}

Higgs annual luminosity =2.2 ab^{-1}

These parameters are used for Snowmass21

CEPC CDR Vol. I, Accelerator



IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC
Conceptual Design Report
Volume I - Accelerator

The CEPC Study Group
August 2018

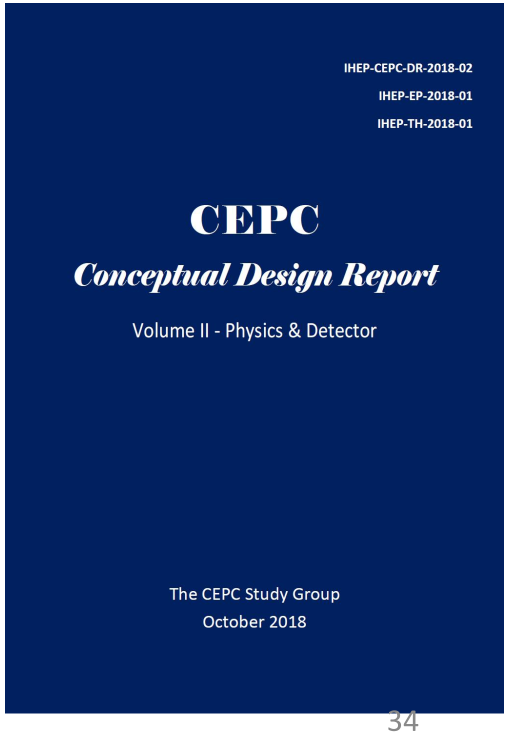
CEPC Accelerator Snowmass 21
AF White Paper

1) CEPC Accelerator white paper to Snowmass21, arXiv:2203.09451

2) CEPC CDR Vol. I, Accelerator ,http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

3) CEPC CDR Vol. II, Physics and Detector, http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf

CEPC CDR Vol. II, Physics/Detector



IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

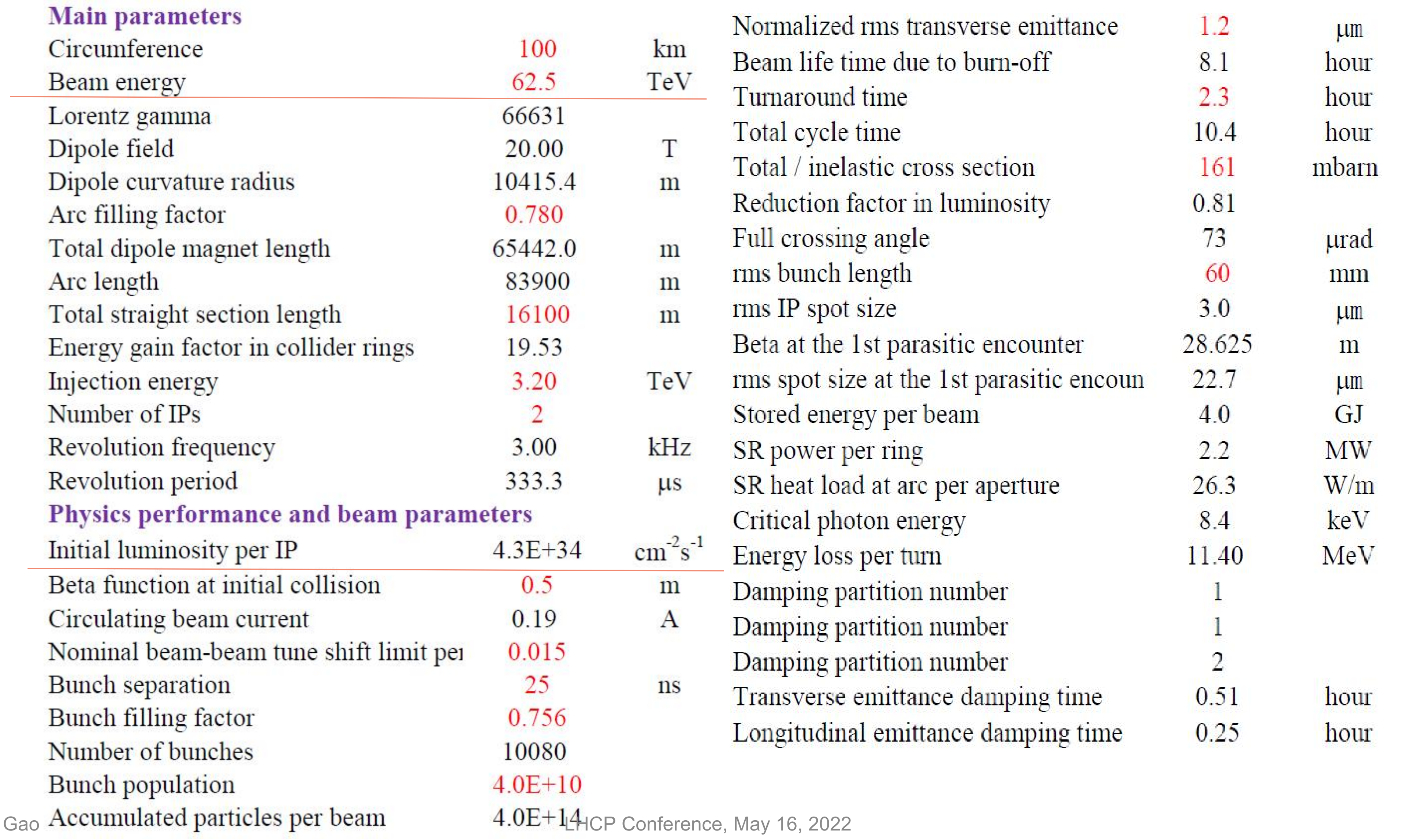
CEPC
Conceptual Design Report
Volume II - Physics & Detector

The CEPC Study Group
October 2018

SppC Collider Accelerator Physics

-Parameter list (updated Feb. 2022)

Jingyu Tang
Haocheng Xu

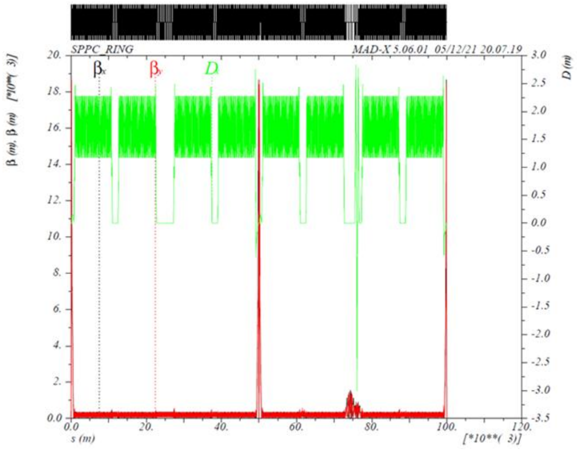


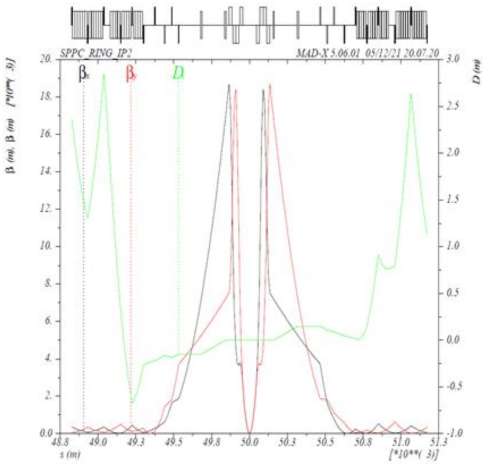
Main parameters		
Circumference	100	km
Beam energy	62.5	TeV
Lorentz gamma	66631	
Dipole field	20.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	19.53	
Injection energy	3.20	TeV
Number of IPs	2	
Revolution frequency	3.00	kHz
Revolution period	333.3	µs
Physics performance and beam parameters		
Initial luminosity per IP	4.3E+34	$cm^{-2}s^{-1}$
Beta function at initial collision	0.5	m
Circulating beam current	0.19	A
Nominal beam-beam tune shift limit pe	0.015	
Bunch separation	25	ns
Bunch filling factor	0.756	
Number of bunches	10080	
Bunch population	4.0E+10	
Accumulated particles per beam	4.0E+14	
Normalized rms transverse emittance	1.2	µm
Beam life time due to burn-off	8.1	hour
Turnaround time	2.3	hour
Total cycle time	10.4	hour
Total / inelastic cross section	161	mbarn
Reduction factor in luminosity	0.81	
Full crossing angle	73	µrad
rms bunch length	60	mm
rms IP spot size	3.0	µm
Beta at the 1st parasitic encounter	28.625	m
rms spot size at the 1st parasitic encoun	22.7	µm
Stored energy per beam	4.0	GJ
SR power per ring	2.2	MW
SR heat load at arc per aperture	26.3	W/m
Critical photon energy	8.4	keV
Energy loss per turn	11.40	MeV
Damping partition number	1	
Damping partition number	1	
Damping partition number	2	
Transverse emittance damping time	0.51	hour
Longitudinal emittance damping time	0.25	hour

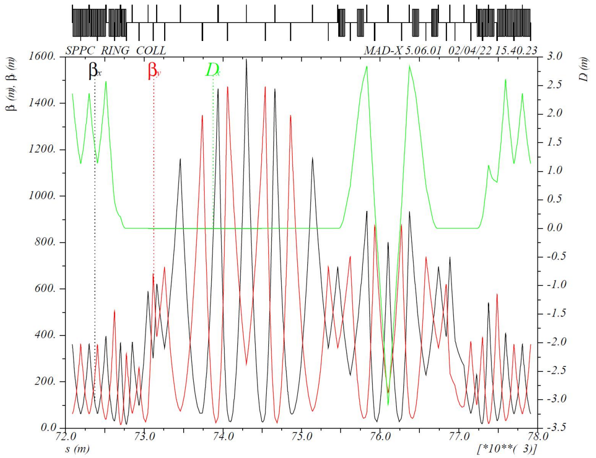
SppC lattice design

Haocheng Xu
Yiwei Wang

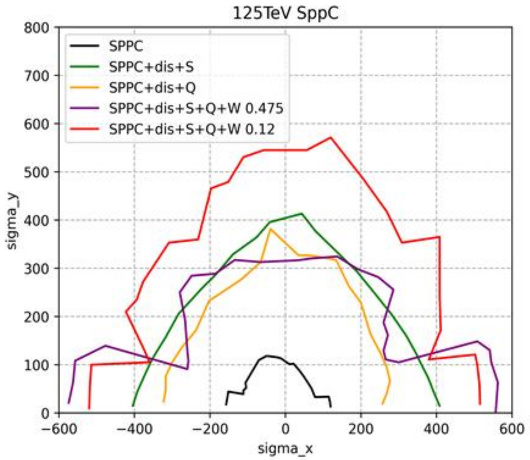
- Lattice of SPPC ring, IP and collimator section

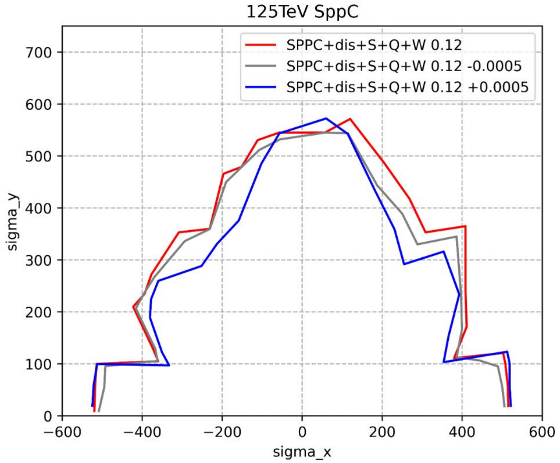






- Dynamic Aperture Optimization





High field SC dipoles R&D with HTS for SppC

Qingjin Xu

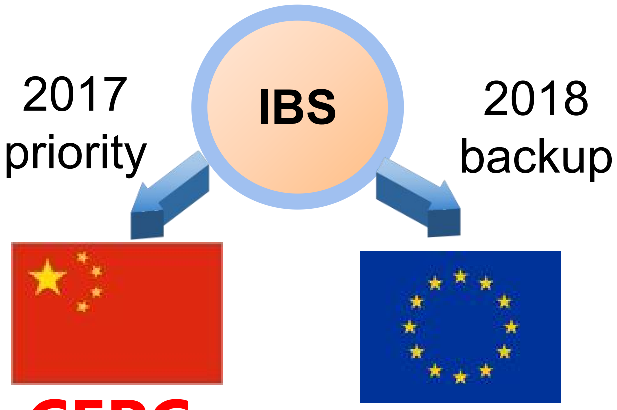
Scientific merit

-Even high collision energy is expected with the CEPC tunnel : SppC

-Energy is proportional to the dipole field

$$E[GeV] = 0.3 \times B[T] \times \rho[m]$$

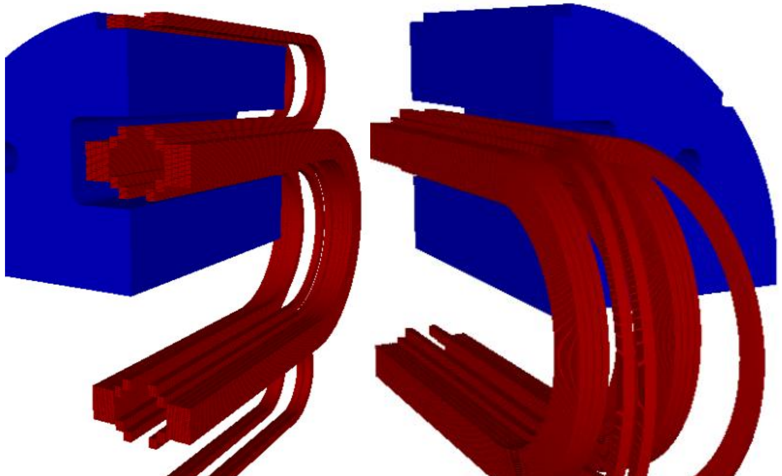
HTS Magnet is the only measure for ultra high field（12～24 T）、IBS has a bright prospect。



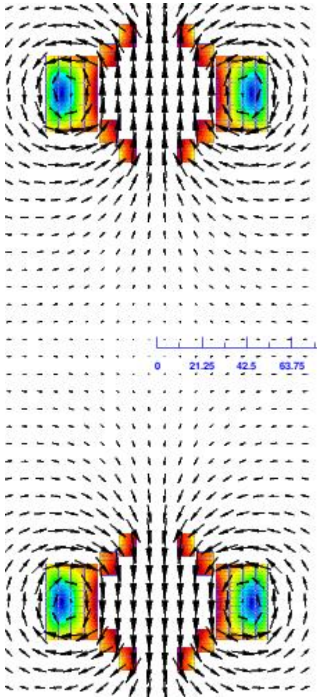
CEPC SppC

FCC

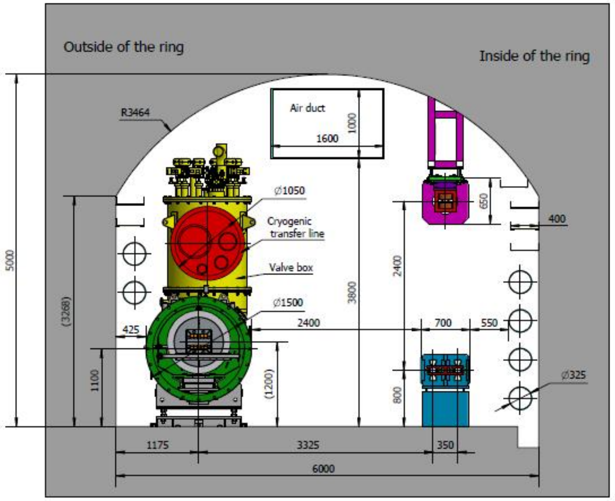
Thousands of HTS magnet are needed for SPPC or FCC



SPPC高场超导磁体概念设计



TUNNEL CROSS SECTION OF THE ARC AREA

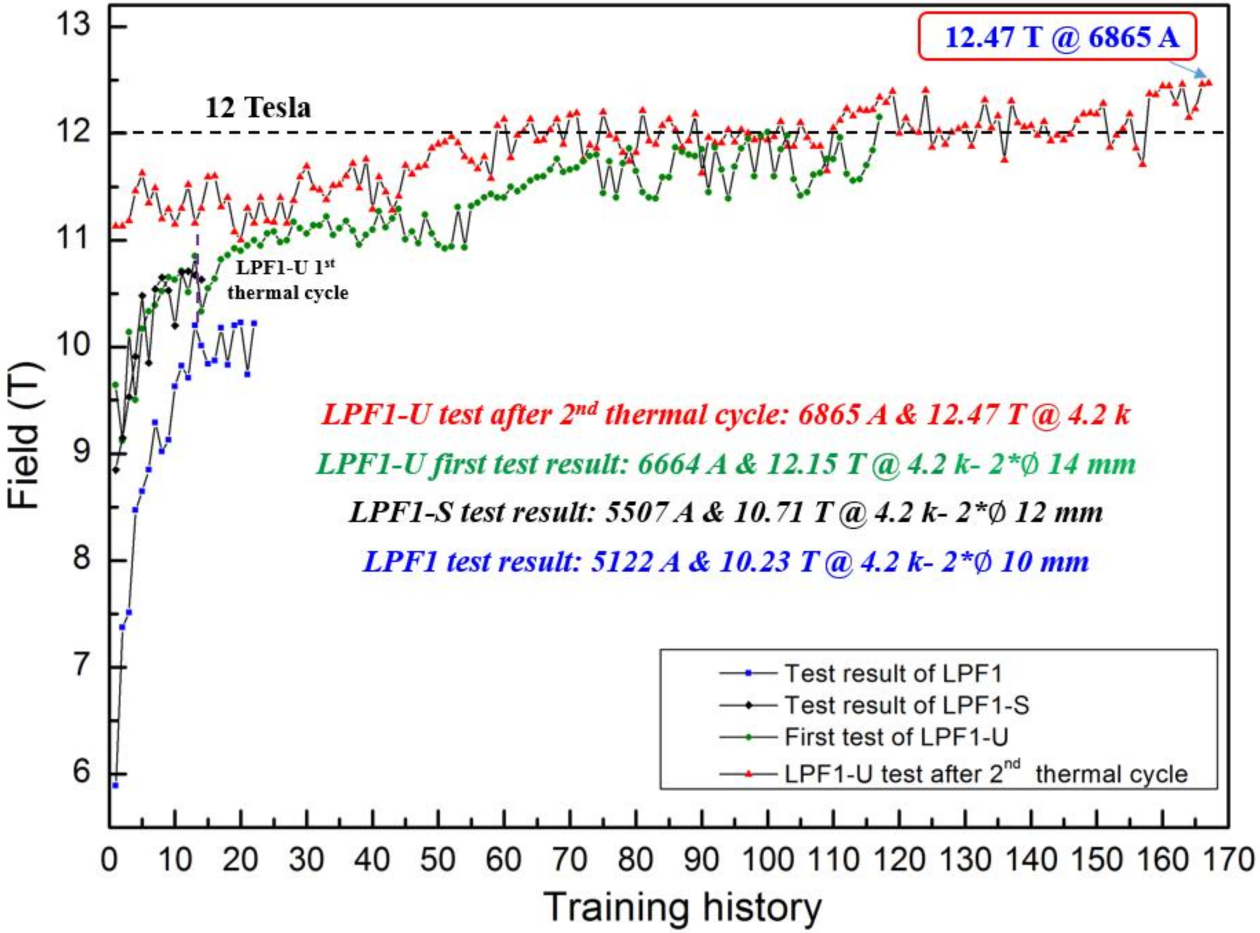


CEPC-SPPC tunnel

Latest performance of LPF1-U (SppC)

Qingjin Xu

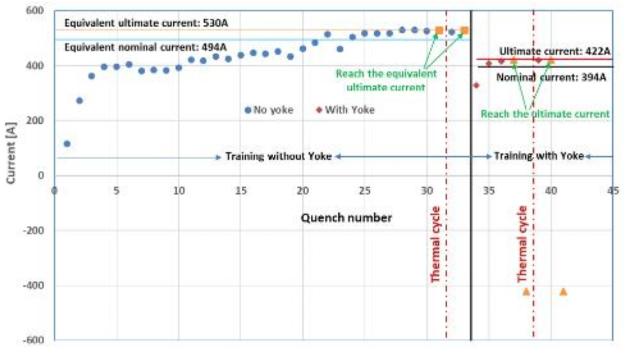
Picture of LPF1-U

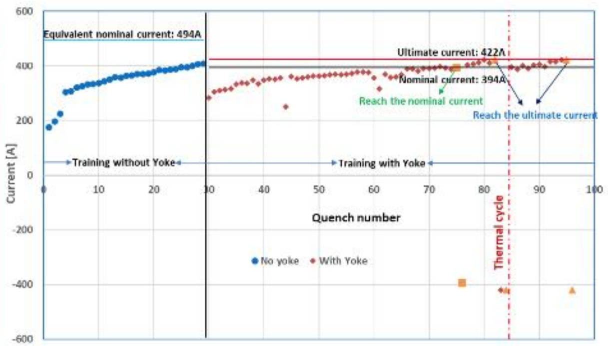


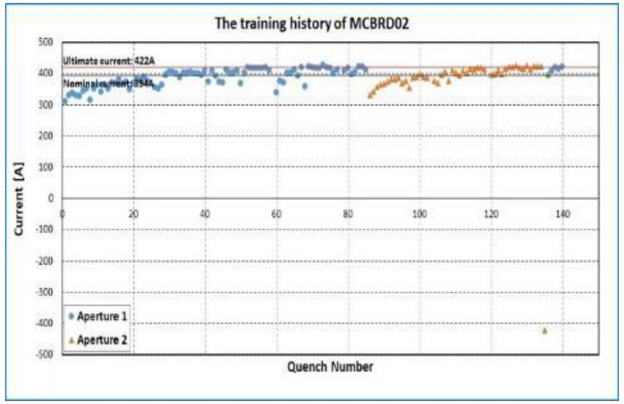
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-19T field

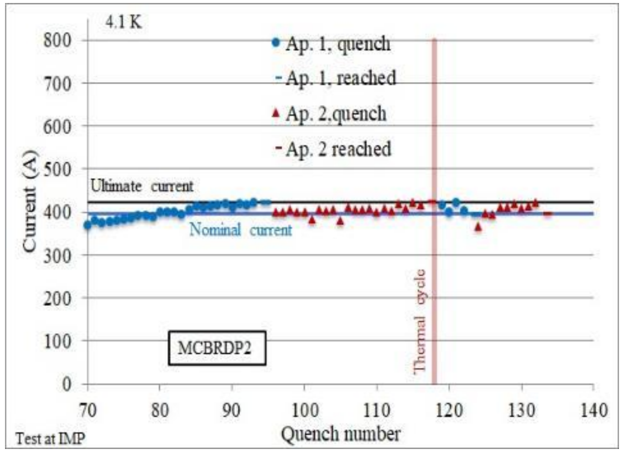
Development of CCT dipole magnets for HL-LHC by IHEP

Qingjin Xu



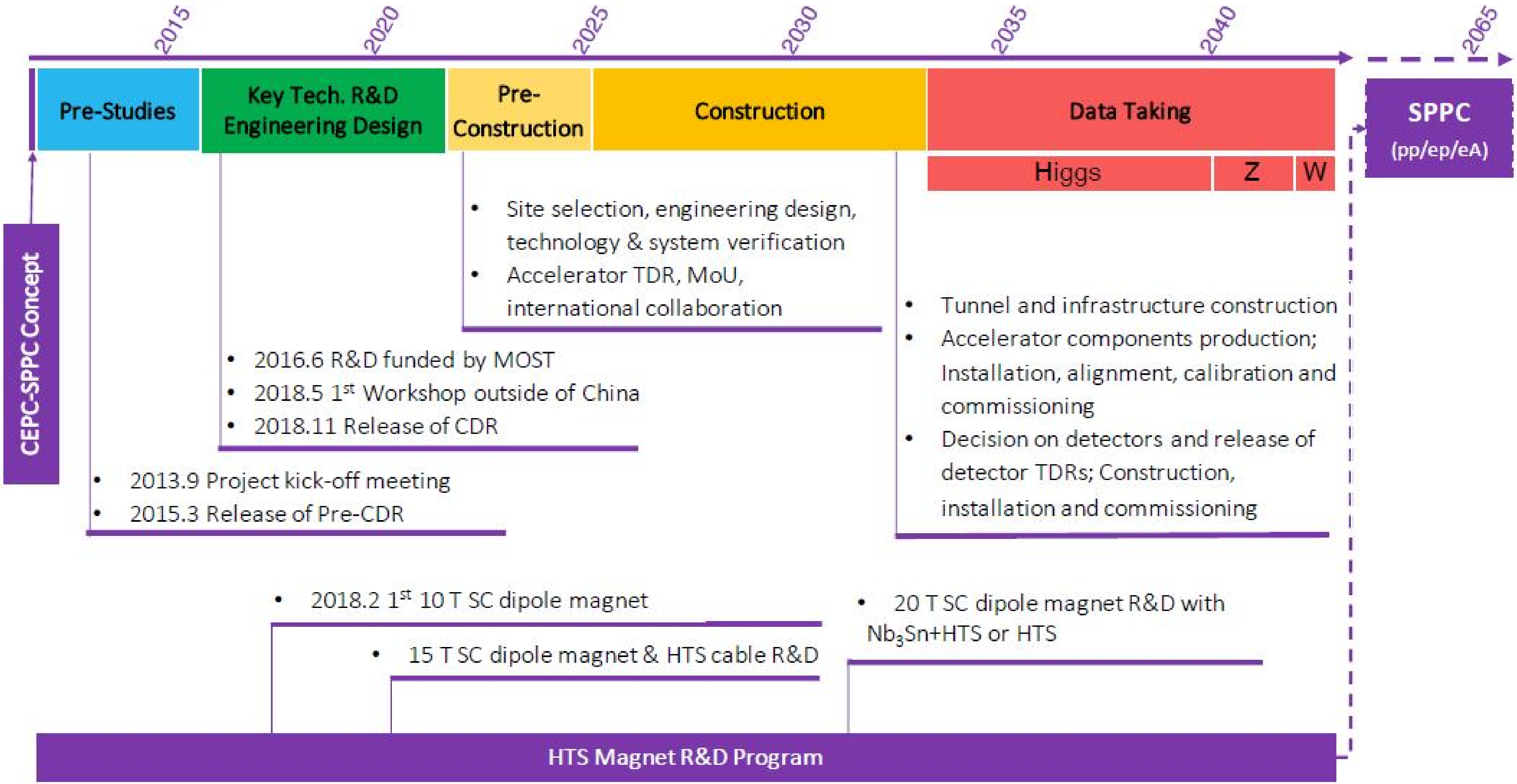






- The first set of CCT superconducting magnets MCBRD01 with satisfactory field strength and field quality, has been shipped to Europe in October, 2021.
- The assembly of the 2nd set of HL-LHC CCT superconducting magnets has been finished in Jan, 2022, and now the magnet is tested at IMP
- Fabrication of a full size prototype magnet MCBRDP2 was completed in May, 2020. Both apertures reached the ultimate current.

CEPC Project Timeline



Pre-Studies

Key Tech. R&D Engineering Design

Pre-Construction

Construction

Data Taking

Higgs | Z | W

SPPC
(pp/ep/eA)

CEPC-SPPC Concept

- Site selection, engineering design, technology & system verification
- Accelerator TDR, MoU, international collaboration

- Tunnel and infrastructure construction
- Accelerator components production; Installation, alignment, calibration and commissioning
- Decision on detectors and release of detector TDRs; Construction, installation and commissioning

- 2016.6 R&D funded by MOST
- 2018.5 1st Workshop outside of China
- 2018.11 Release of CDR

- 2013.9 Project kick-off meeting
- 2015.3 Release of Pre-CDR

- 2018.2 1st 10 T SC dipole magnet

- 15 T SC dipole magnet & HTS cable R&D

- 20 T SC dipole magnet R&D with Nb_3Sn+HTS or HTS

HTS Magnet R&D Program

Perspective for accelerator TDR and EDR plans

- **CEPC Accelerator TDR completion time: Dec. 2022**
  - -Consistent TDR high luminosity parameter design as Higgs factory
  - -Key components with prototyping, techincal feasibility demonstrated, no technical show stopper
  - -Design and R&D technical documentation (Data, drawings, etc.)
  - -CEPC accelerator TDR document release in 2023

- **CEPC Accelerator EDR Phase Plan:Jan. 2023-Dec. 2025**
  - -CEPC site study converging to one or two with detailed feasibility studies (tunnel and infrastructures, environment)
  - -Engineering design of CEPC accelerator systems and components towards fabrication in an industrial way
  - -Site dependent civil engineering design implementation preparation
  - -EDR document completed for government's approval of starting construction around 2026 (the starting of the "15th five year plan")

CEPC Video (BIM design)

1) http://cepc.ihep.ac.cn/Qinhuang_Island.mp4
2) http://cepc.ihep.ac.cn/Huzhou.mp4
3) http://cepc.ihep.ac.cn/Changsha.mp4

FUTURE
CIRCULAR
COLLIDER

FCC-ee collider parameters (stage 1)

K. Oide

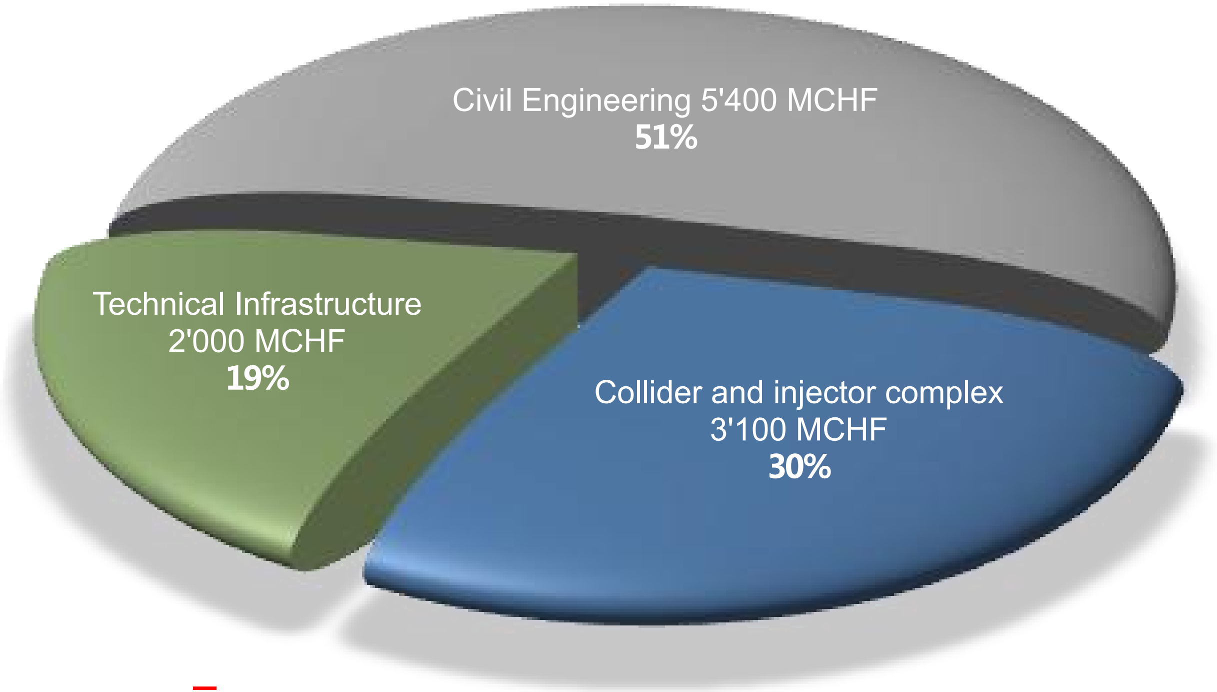
Parameter [4 IPs, 91.2 km, T_{rev}=0.3 ms]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1400	135	26.7	5.0
number bunches/beam	8800	1120	336	42
bunch intensity [10^{11}]	2.76	2.29	1.51	2.26
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.48/0	4.0/7.67
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	10	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
beam-beam parameter ξ_x / ξ_y	0.004/ .159	0.011/0.111	0.0187/0.129	0.096/0.138
rms bunch length with SR / BS [mm]	4.32 / 15.2	3.55 / 7.02	2.5 / 4.45	1.67 / 2.54
luminosity per IP [10^{34} cm^{-2}s^{-1}]	181	17.3	7.2	1.25
total integrated luminosity / year [ab^{-1}/yr]	86	8	3.4	0.6
beam lifetime rad Bhabha / BS [min]	19 / ?	20 / ?	10 / 19	12 / 46

Frank Zimmermann

Cost estimate from FCCee CDR (2018)

Total construction cost: ~10,500 MCHF (for Z, W and H working points)

Frank Zimmermann



Cost estimates for the accelerators (collider and injector complex) and technical infrastructure are based on machine and system inventories.
Cost estimate for civil engineering is based on an analysis of construction methods for underground and surface structures, the associated material quantities and unit prices, derived from several recent large-scale tunnel and civil engineering projects in Central Europe.
Precision of the overall cost estimate is at ±30% level.

Operation at the $t\bar{t}$ working point will require later installation of additional RF cavities and associated cryogenic cooling infrastructure with a corresponding total cost of 1,100 MCHF.

Changes that might affect cost: fewer surface sites (12 → 8), reduced size of experimental caverns, perhaps 4 instead of 2 exp.'s, …

FCC-hh (pp) collider parameters (stage 2)

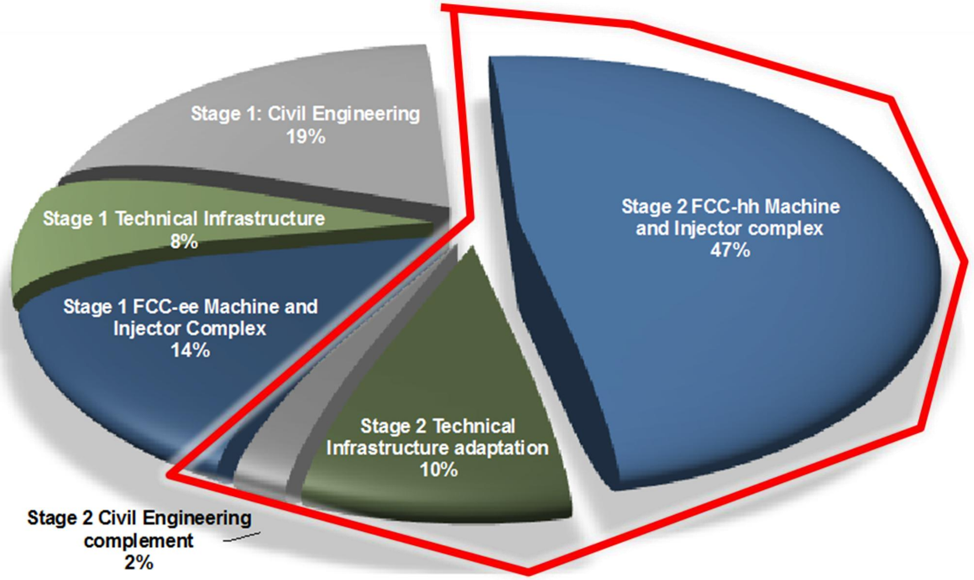
Frank Zimmermann

parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	**100**		27	14	14
dipole field [T]	**17 (16 c.f.)**		16	8.33	8.33
circumference [km]	**91.17**		26.7	26.7	26.7
beam current [A]	0.5		1.1	1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	2.2	1.15
bunch spacing [ns]	25	25	25	25	25
synchr. rad. power / ring [kW]	**2700**		100	7.3	3.6
SR power / length [W/m/ap.]	32.1		4.6	0.33	0.17
long. emit. damping time [h]	0.45		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.45	0.15 (min.)	0.55
normalized emittance [mm]	2.2		2.5	2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	**5**	**30**	16	5 (lev.)	1
integr. luminosity / yr [fb^{-1}/yr]	**≥ 250**	**≥ 1000**	500	≥ 300	55
events/bunch crossing	**170**	**1000**	460	132	27
average turnaround time [h]	5	4	5	4	5
optimum run time [h]	11.6	3.7	5.3	13 - 18	10
stored energy/beam [GJ]	7.8		1.4	0.7	0.36

FCC-hh cost estimate as part of FCC-integrated project cost estimate

Frank Zimmermann

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**



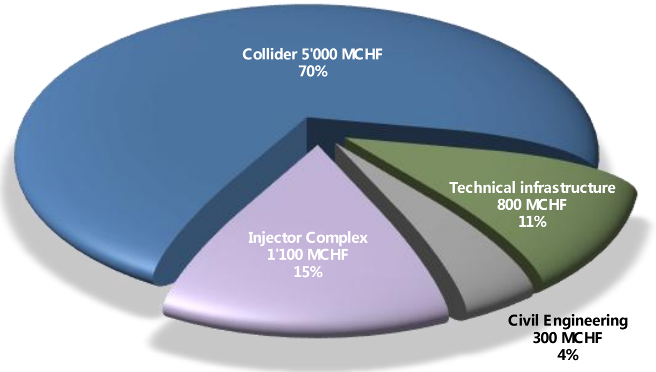
Total construction cost FCC-ee (Z, W, H) amounts to 10,500 MCHF & 1,100 MCHF (tt).

Total construction cost for subsequent FCC-hh amounts to 17,000 MCHF.

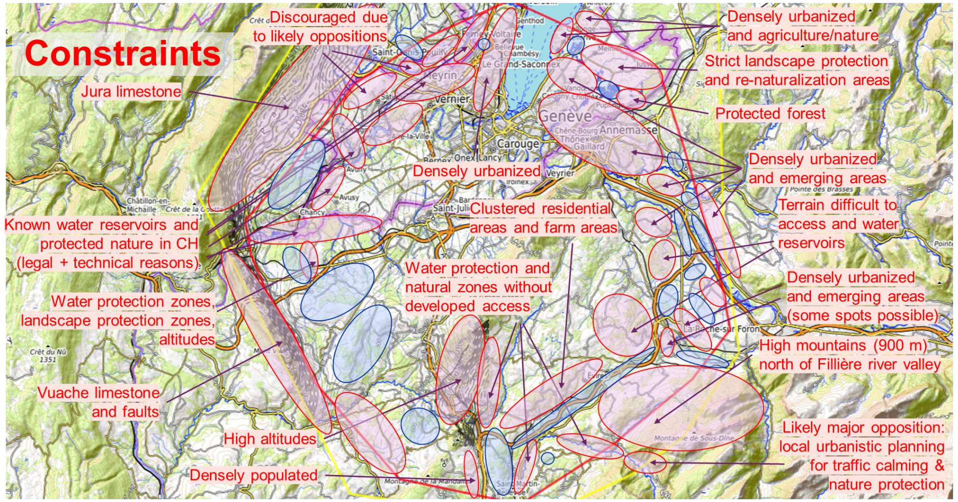
(FCC-hh stand alone cost would be 25 BCHF); cost target 2 MCHF/ dipole magnet

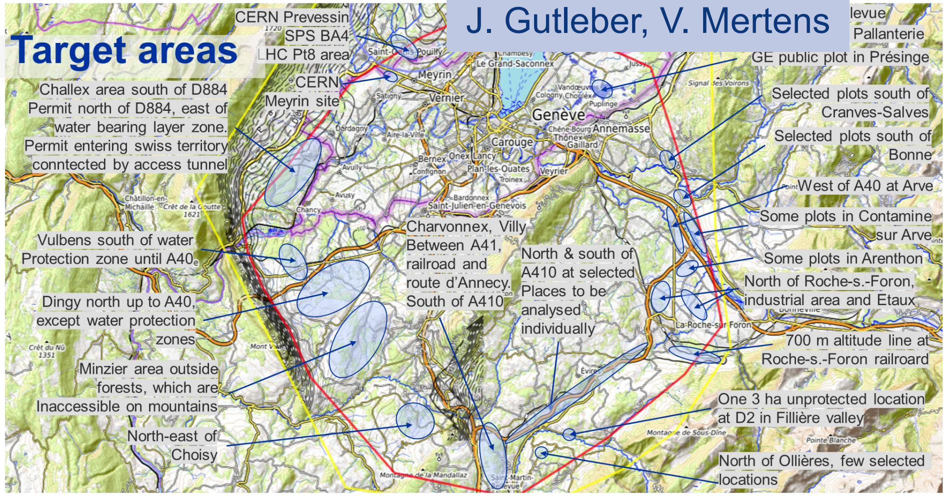
HE-LHC cost estimate

Total construction cost HE-LHC amounts to 7,200 MCHF (of which 1,1 MCHF for injector); cost target 2.3 MCHF / dipole magnet



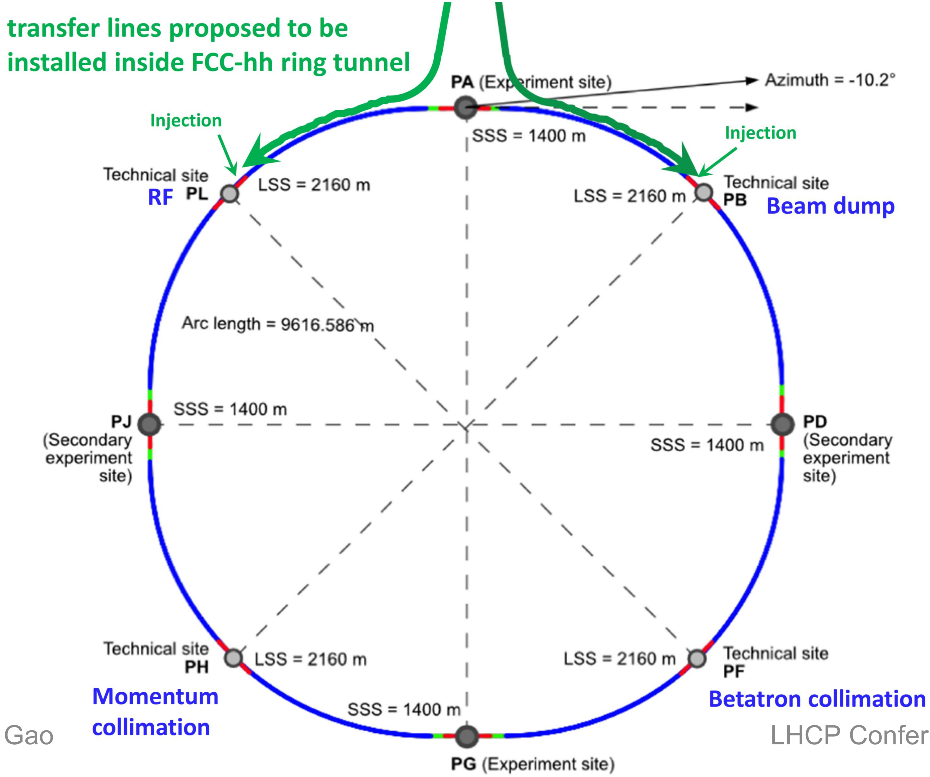
FCC"low risk" placement & layout (2021)





J. Gutleber, V. Mertens

Frank Zimmermann



Double ring pp and heavy-ion collider

Common footprint with FCC-ee, except near IPs

Main experiments in PA & PG, secondary experiments in PD & PJ

Extraction & β collimation in PB & PF (2.16 km each); 400 MHz RF in PL as for FCC-ee, momentum collimation in PH

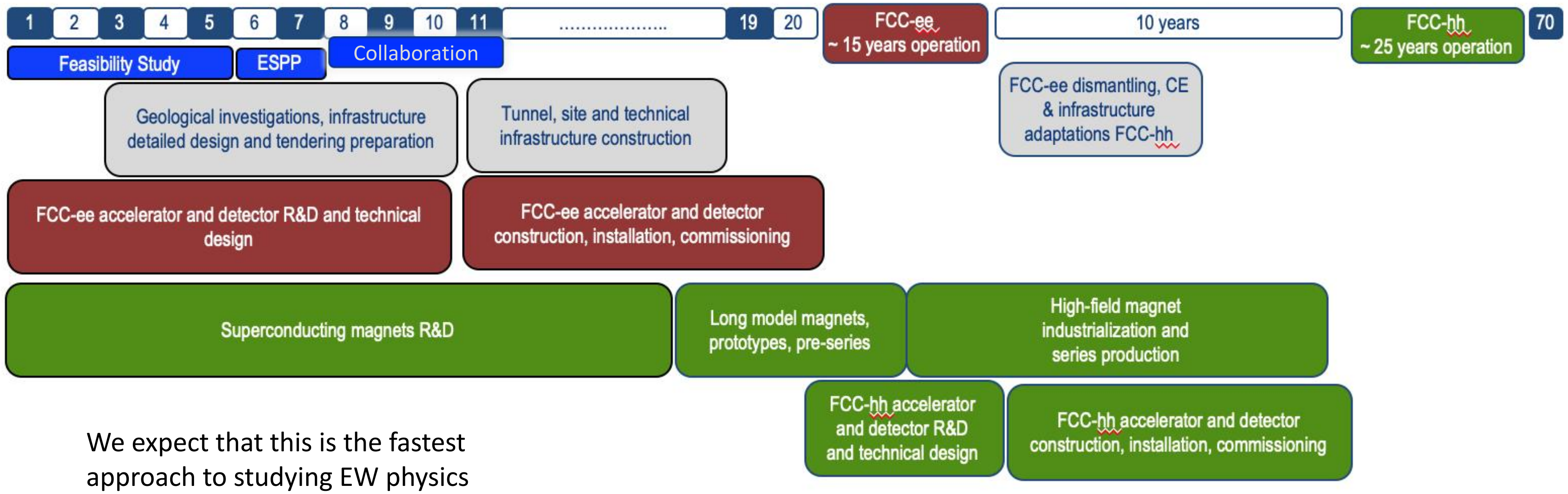
Injection tunnel shared with FCC-ee; **hadron injection** may require transfer lines in collider tunnel from PA till PL and PB;

FUTURE
CIRCULAR
COLLIDER

Timeline of FCC integrated programme

Technical schedule

Frank Zimmermann



1 2 3 4 5 6 7 8 9 10 11 ……………….. 19 20

FCC-ee
~ 15 years operation

10 years

FCC-hh
~ 25 years operation

70

Feasibility Study

ESPP

Collaboration

Geological investigations, infrastructure detailed design and tendering preparation

Tunnel, site and technical infrastructure construction

FCC-ee dismantling, CE & infrastructure adaptations FCC-hh

FCC-ee accelerator and detector R&D and technical design

FCC-ee accelerator and detector construction, installation, commissioning

Superconducting magnets R&D

Long model magnets, prototypes, pre-series

High-field magnet industrialization and series production

FCC-hh accelerator and detector R&D and technical design

FCC-hh accelerator and detector construction, installation, commissioning

We expect that this is the fastest approach to studying EW physics

	$\sqrt{s}$	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- **FCC-ee**	~90 GeV Z 160 WW 240 H ~365 top	230 x10^{34} 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp **FCC-hh**	100 TeV	5 x 10^{34} 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb **FCC-hh**	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep **Fcc-eh**	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb **Fcc-eh**	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

Realistic timeline matched to HL-LHC:

- ❑ Feasibility Study: 2021-2025
- ❑ If project approved before end of decade → construction can start beginning 2030s
- ❑ FCC-ee operation ~**2045-2060**
- ❑ FCC-hh operation **2070-2090++**

F. Gianotti

ICFA Statement Regarding Higgs Factory Development and the ILC

https://icfa.hep.net/wp-content/uploads/ICFA_Statement_April2022_Final.pdf

ICFA Statement Regarding Higgs Factory Development and the ILC

The International Committee for Future Accelerators (ICFA) recently met to review global progress and plans in high-energy physics. ICFA reconfirms the international consensus on the importance of a Higgs Factory as the highest priority for realizing the scientific goals of particle physics. This view has only strengthened over time based on results from the world's particle physics facilities. Various design studies based on different technologies are in progress, including both circular colliders (FCC-ee and CEPC) and linear colliders (ILC and CLIC). ICFA follows with great attention the development of Higgs Factory proposals worldwide and recognizes the importance of advancing such concepts.

ICFA also reaffirms the importance of the regional planning activities that have recently been completed and those underway, which for decades have underpinned the global strategy for the field. Indeed, following the 2020 update to the European Strategy for Particle Physics, Europe is now undertaking a feasibility study for FCC. ICFA eagerly awaits the results of ongoing strategic planning activities in the U.S., China and elsewhere.

Concerning the International Linear Collider (ILC), ICFA reaffirms its position that the concept for the ILC is technically robust and has reached a level of maturity which supports its moving forward with the engineering design study toward its timely realization. Indeed, recent accelerator projects across the globe confirm the readiness of the foundational superconducting accelerator technology.

ICFA commits to continuing efforts within the International Development Team (IDT) over the next year to coordinate the global research community's activities toward further developing and realizing the ILC in Japan. In particular, the IDT will work to further strengthen international collaboration among institutes and laboratories, and to expand the broad support from various stakeholders. ICFA will monitor developments over the next year to assess availability of resources and progress in international discussions.

ICFA continues to encourage inter-governmental discussion between Japan and potential partner nations to advance international collaboration toward important research and development activities as well as coordination toward realization of an ILC.

April 10, 2022

Various design studies based on different technologies are in progress, including both circular colliders (FCC-ee and CEPC) and linear colliders (ILC and CLIC). ICFA follows with great attention the development of Higgs Factory proposals worldwide and recognizes the importance of advancing such concepts.

Conclusions

- The discovery of Higgs boson in on July 4, 2012 on LHC at CERN marks the most important milestone for the human being in understanding the fundamental laws of Universe
- Electron positron Higgs factories are the most demanded near term colliders for precision studies and discoveries both within and beyond SM
- Proton proton colliders as long term projects permit our exploring new energy frontiers
- Ambisious proposals from Asia (ILC, CEPC-SppC), Europe (CLIC, FCCee,hh) and America (C3...) have demonstrated their strong willingness and abilities towards future
- We will have a fruitful future in providing new kowledges and technologies for the good of the world with extensive collaborations

Acknowledgements

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