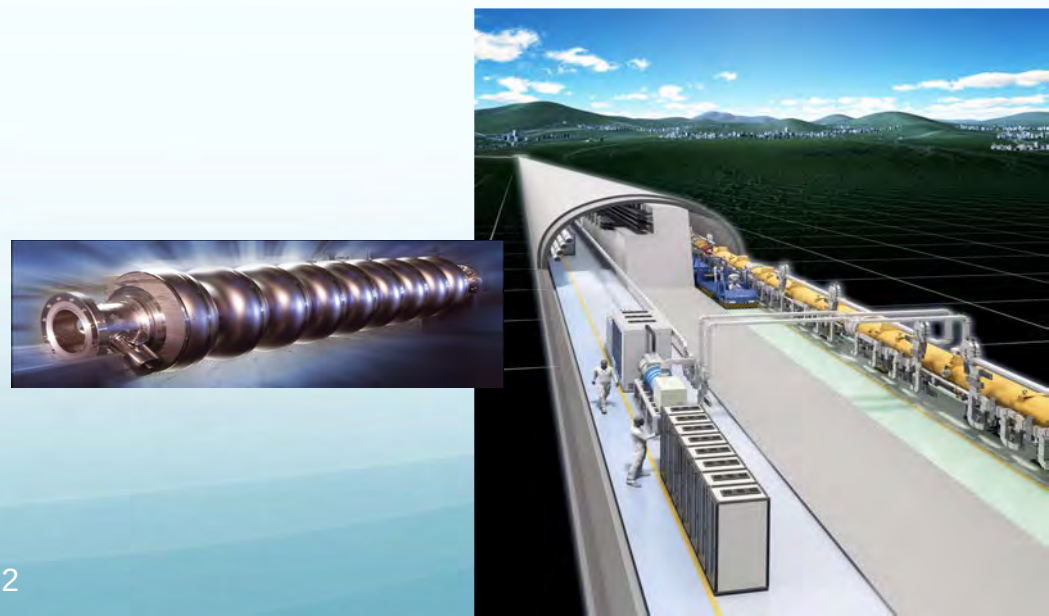
accelerator latest developments

A. Faus-Golfe

On behalf ILC –IDT WG2



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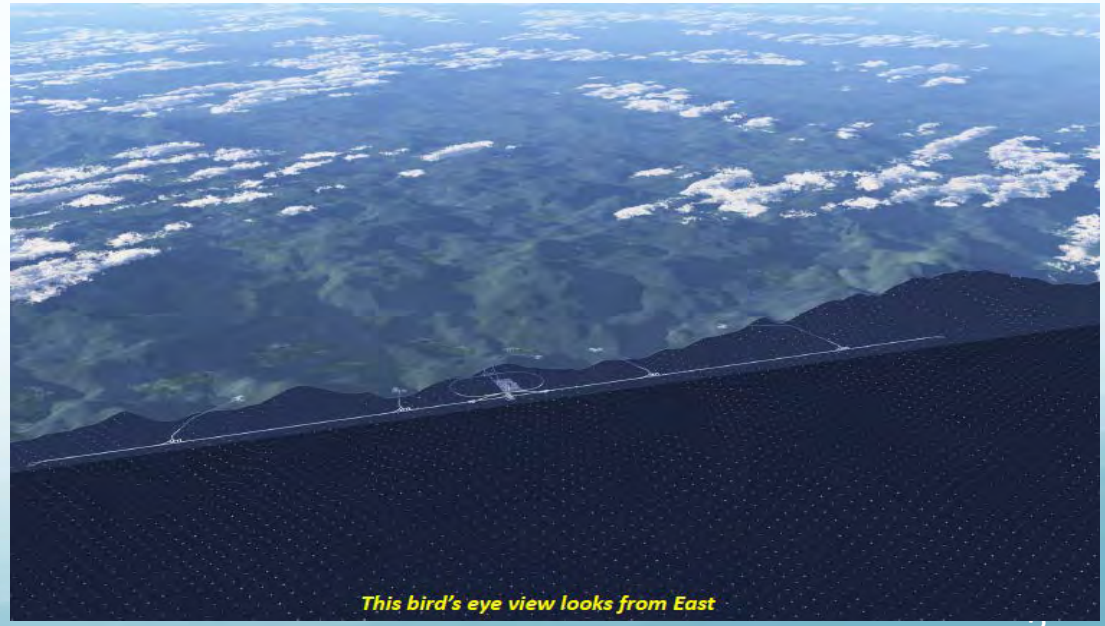

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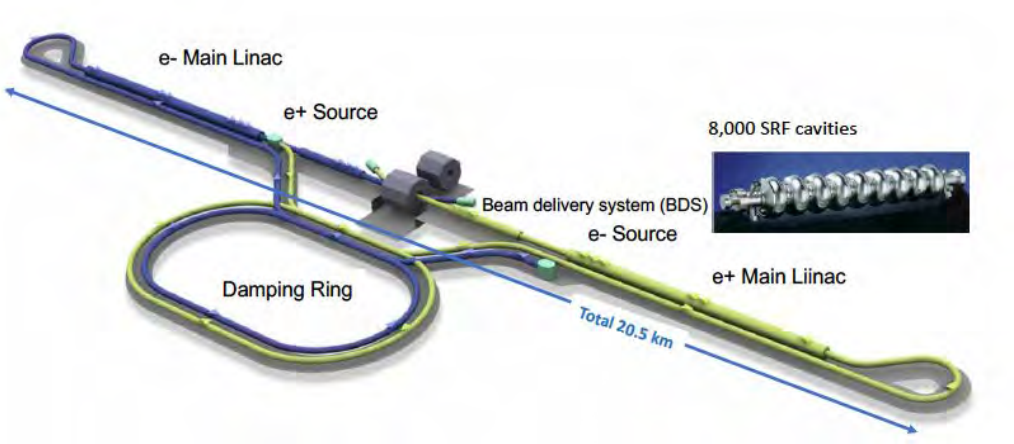

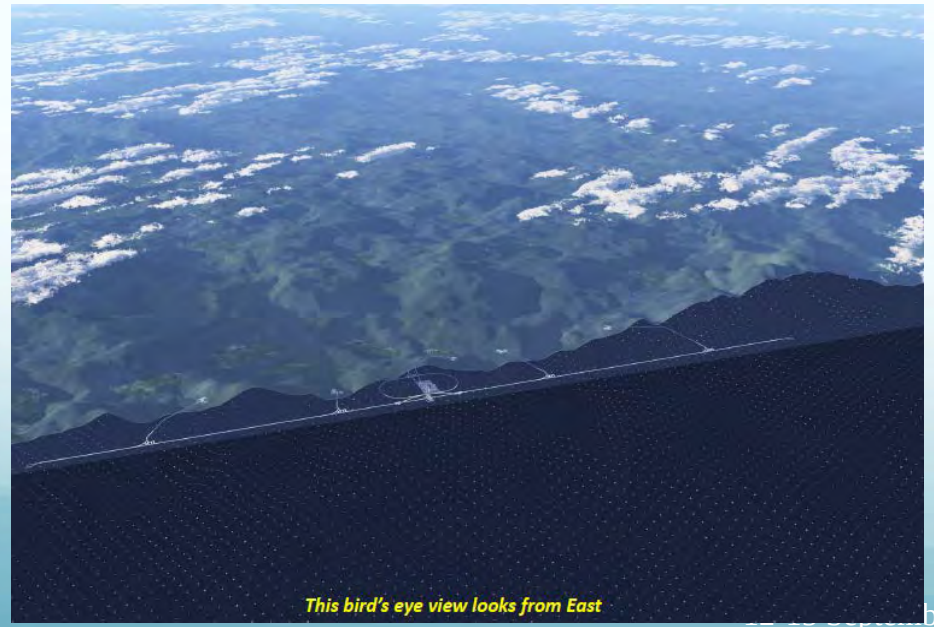

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Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_e	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_b	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_z^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_x$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_x^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_y^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	128	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

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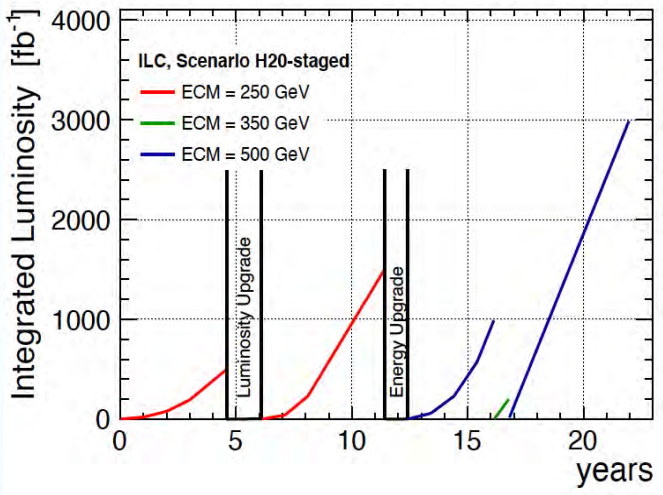

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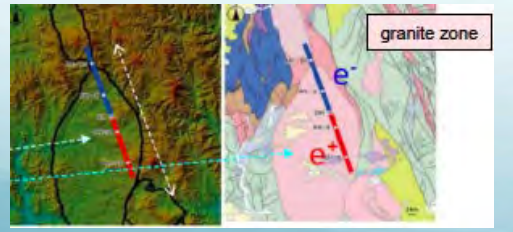
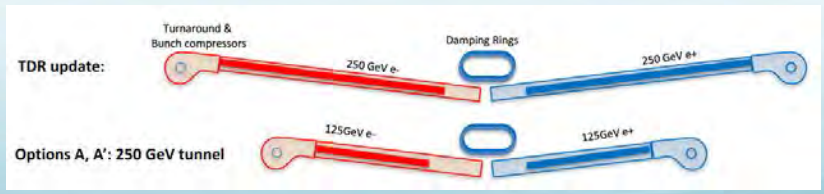
granite zone





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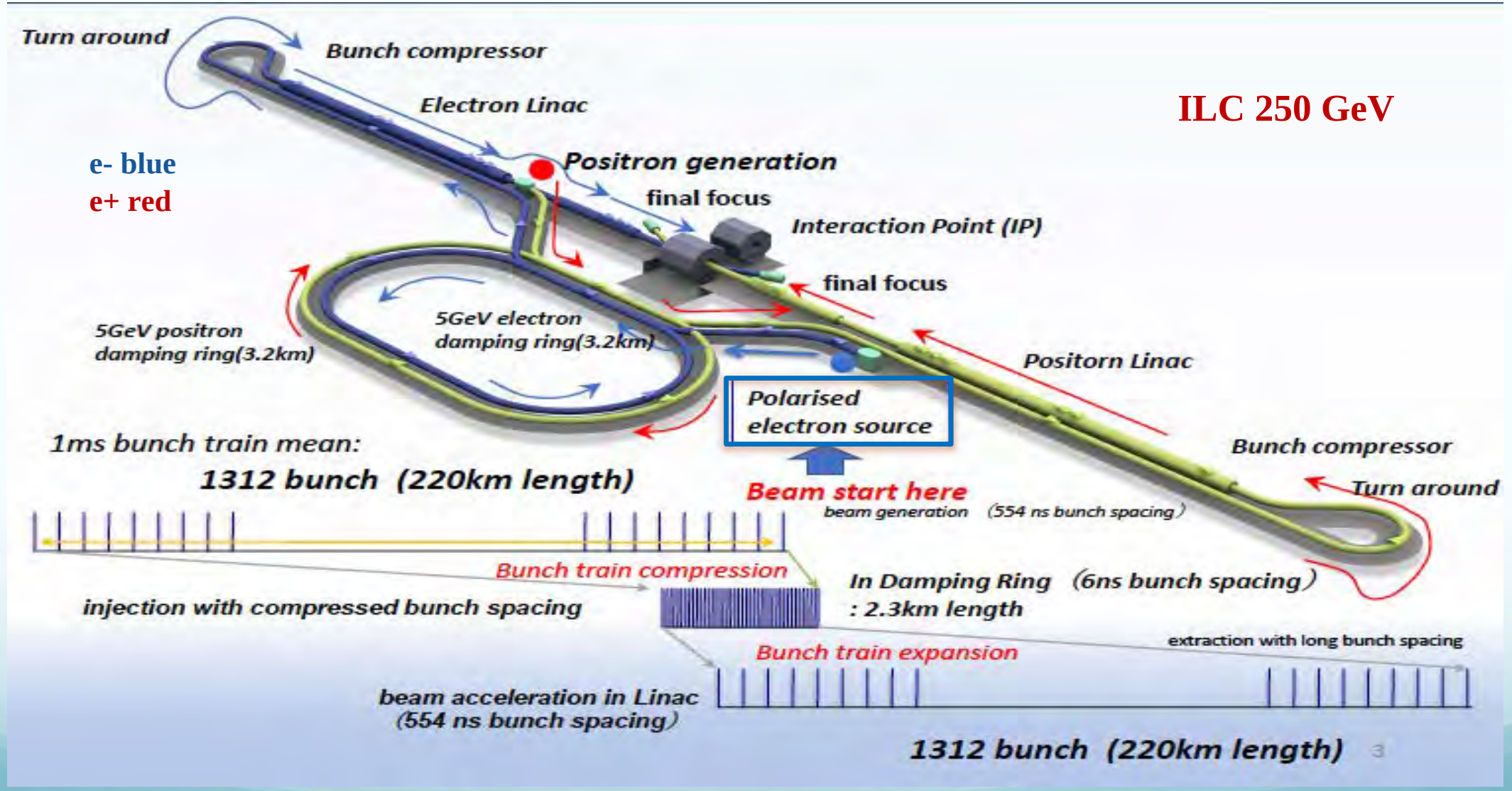
ILC 250 GeV
e- blue
e+ red
Turn around
Bunch compressor
Electron Linac
Positron generation
final focus
Interaction Point (IP)
final focus
5GeV positron damping ring(3.2km)
5GeV electron damping ring(3.2km)
Positorn Linac
Polarised electron source
1ms bunch train mean:
1312 bunch (220km length)
Bunch compressor
Turn around
Beam start here
beam generation (554 ns bunch spacing)
Bunch train compression
In Damping Ring (6ns bunch spacing)
: 2.3km length
injection with compressed bunch spacing
extraction with long bunch spacing
Bunch train expansion
beam acceleration in Linac
(554 ns bunch spacing)
1312 bunch (220km length)

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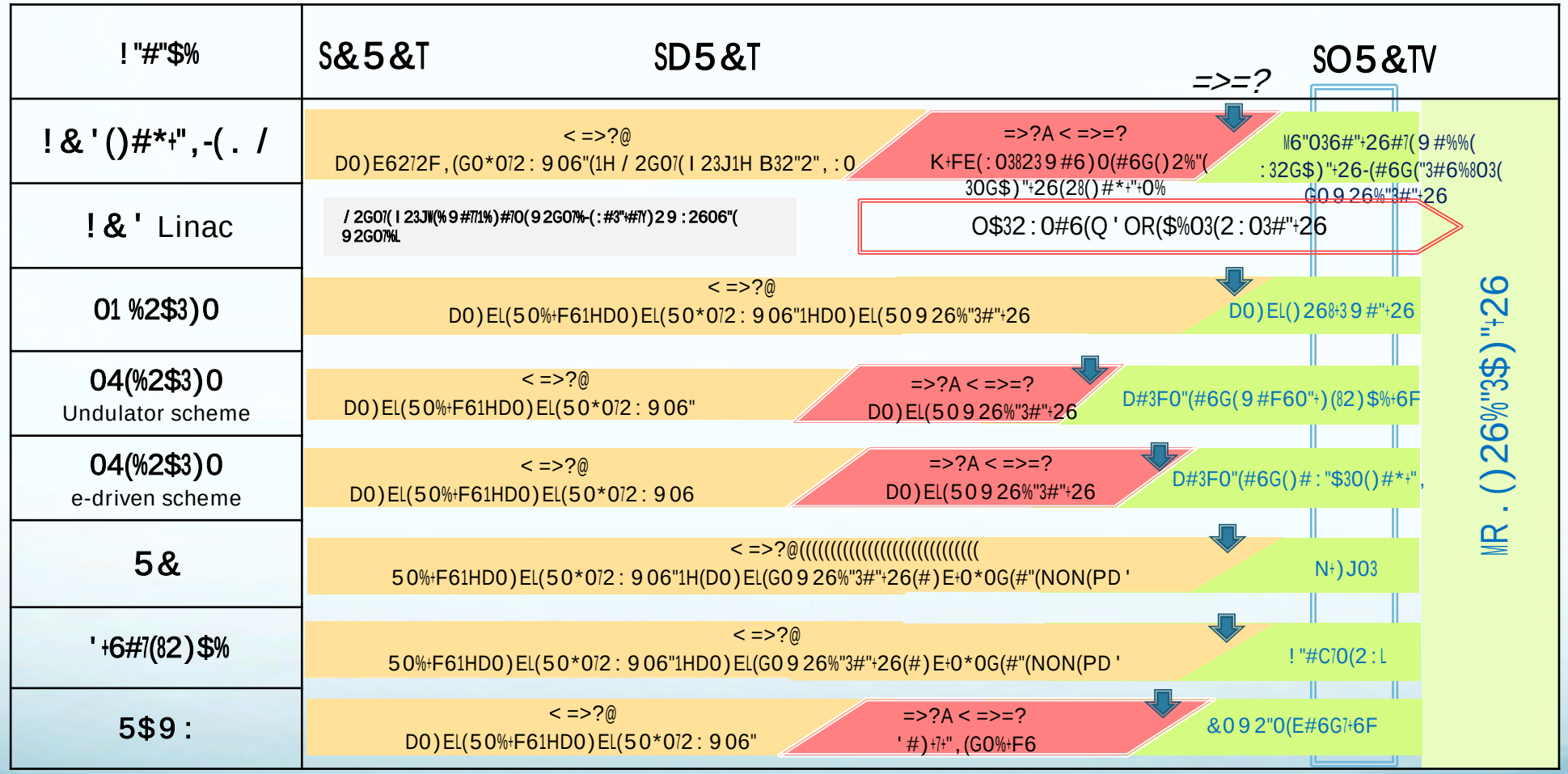

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Progress in SRF

~2017 | 2018~2021 | Pre-lab

Cavity

Yield evaluation of cavities based on TDR

The mass production of European XFEL has reached ≥ 83% of the ILC specification yield (90%).

European XFEL: 29 ± 5.1 MV/m

LCLS-II: 18-21 MV/m Q>2.7 10^{10}

Euro-XFEL Operation (Europe) ~800 cavities/ ~100 Modules

LCLS-II Construction (USA) ~280 cavities/ ~35 Modules

Realized through international cooperation and procurement

High performance and cost reduction

US-Japan: high performance with new surface treatment, etc.

ILC

Germany-Japan: Improving Efficiency in Cavity Manufacturing. Final design is underway to comply with "High Pressure Gas Safety".

Cavity manufacturing, performance demonstration (Yield demonstration in three areas)

Cryomodule

Eng. design

Module assembly

Demonstration of cryomodule assembly, transfer, and performance

Accelerator performance verification at KEK-STF2

France-Japan: Automation of cavity cleaning

Progress in positron source

Plan A:Undulator scheme
Plan B:e-driven scheme (same tunnel)
Plan C:e-driven scheme (extra tunnel)

~2017 technical design | 2018~2021 technical verification | Pre-lab

Baseline Undulator scheme to obtain polarization

Optics design

Undulator prototype

Photon dump design

High-speed rotating positron target, Technology Design

Target before and after radiation:

Ti target beam test

Long undulator operation at European XFEL

Practical Operation of Superconducting Helical Undulator (Alternate Periodic Structure)

Pulse solenoid design

Next Steps: evaluate both schemes by international cooperation

Target maintenance

Alternative: Conventional e-Driven

Optics design

Target thermal simulation

Mag. focusing

Paricle simulation

Target Prototyping Vacuum characteristics Testing

Loading compensation

Thermal analysis

APS cavity

RF stability test

Technology selection

Progress in beam dump

~2017 | 2018~2021

Basic design (by researchers abroad)

Design revalidation and specific facility design

Designed with 500GeV beam
Absorber: Water(10 atm)

Confirmation of safety by simulation
- Heat and stress in beam window, heat and shock waves in water
- Evaluation of activation and shielding

Heat analysis

Shock wave

Specific design of radiation shield

Beam Dump Water Circulation System Design (2020)

Design for shielding of muon particles generated by beam dump

Consultations with beam target/dump experts from around the world beyond ILC

LHC beam dump

RADIATE collaboration

Civil Design of Beam Dump Cavity (2019) (including muon shielding)

Pre-lab

Remote Maintenance

- Testing of main components of circulating water system
- Beam window replacement device
- Leakage countermeasures for radiating dump water
- Earthquake resistant design

Detailed system design (pursuit of safety design)

Progress in DR

~2017 | 2018~2021 | Pre-lab

DR

Eng. design

Design based on experience with circular accelerators (4th generation SR) around the world

3.2 km circumference
H/V 4 μ / 20 nm in 100 ms

e+e- shared a common tunnel

Beam pipes (NEG)

BPMs

Maturing technology for beams in the latest ring accelerators such as SuperKEKB

Permanent magnets

Final design

Inj./Ext.

Eng. Design Equipment verification

Beam extraction demonstrated.

LBNL

CERN-CLIC

Fast kicker technology

Stable operation

Progress in Final Focus

~2017 | 2018~2021 | Pre-lab

Tech. design completed Spec. almost achieved

Wakefield effects

Detailed design Stable operation demonstration

Distribution of bunch positions measured at IPB, with two-BPM FB off (green) and on (purple)

ATF: achieved 41nm (2016) (37nm=ILC (7.7nm))

High-speed beam position control technology was also demonstrated.

FONT feedback system

ATF2 wakefield knobs system be-tween BPM QD10BFF and QD10AFF

Wakefield effect was evaluated at ATF.
-confirm no serious problem at ILC
-demonstrate a technique to reduce the wakefield effect

ATF International Review (Committee)*
-The committee highly evaluated the achievements of ATF so far.
-The committee pointed out the importance of continuing research to contribute to the detailed design of the ILC final convergence.

*https://agenda.linearcollider.org/event/8626/

Ultra low-β* studies

Modify the beam monitor system, etc. at ATF to demonstrate stable operation.

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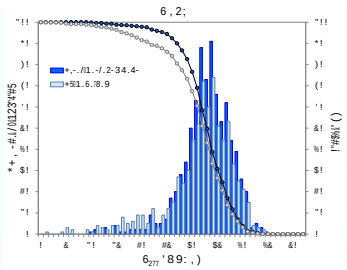

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LCLS-II: 18-21 MV/m
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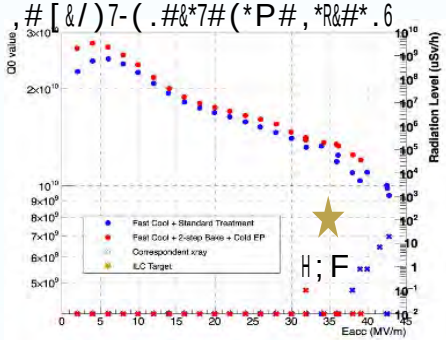

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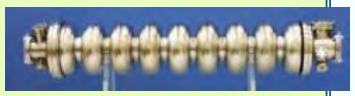

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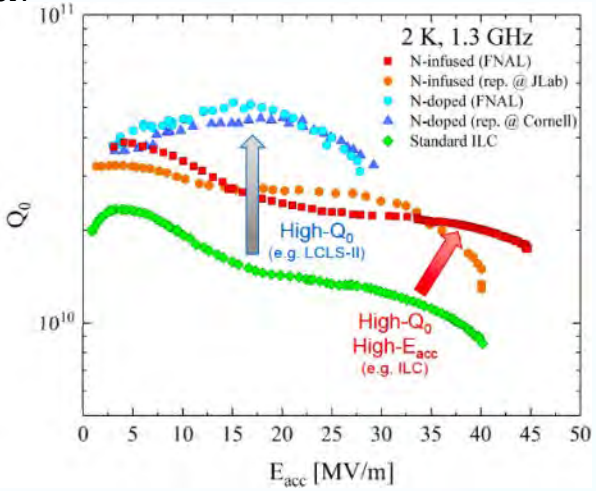

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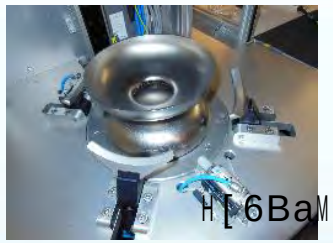

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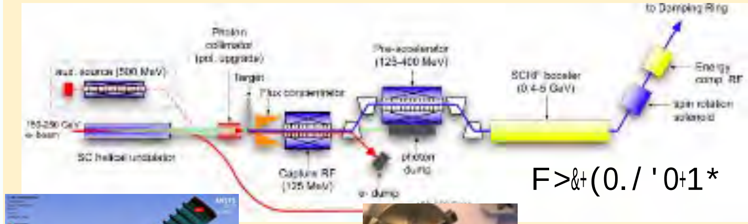

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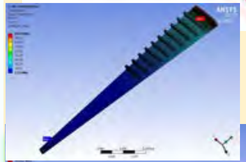

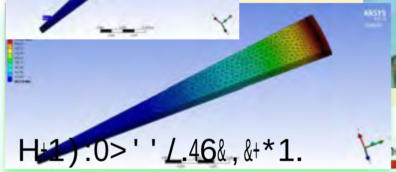

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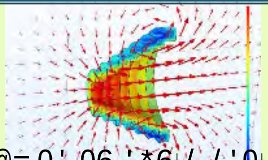

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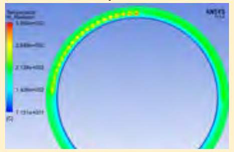

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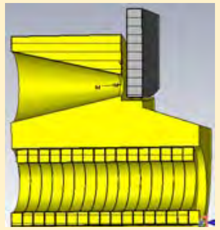

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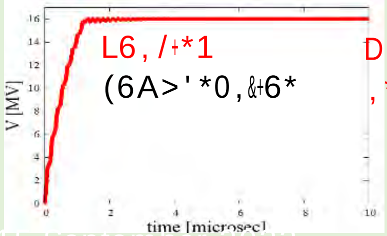

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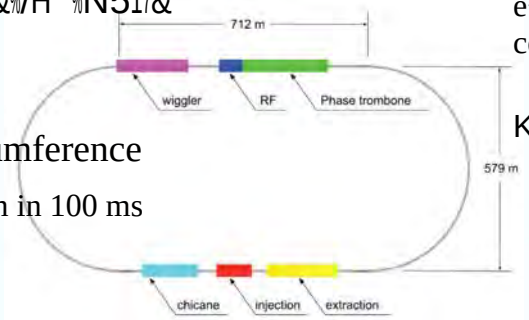
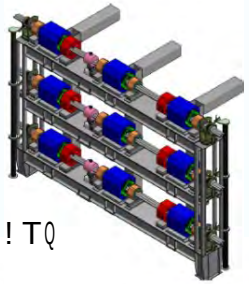


3.2 km circumference

H/V 4 ! / 20 nm in 100 ms

e+e- shared a common tunnel



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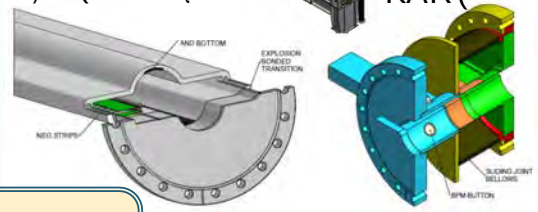

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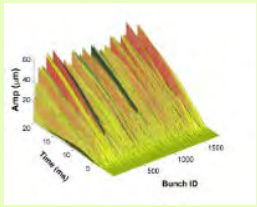

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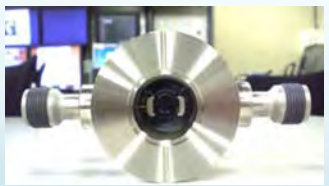
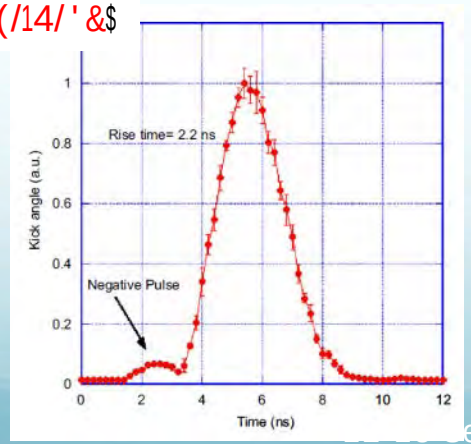
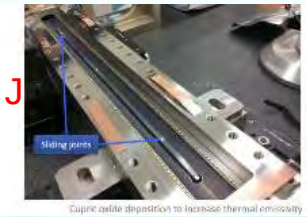
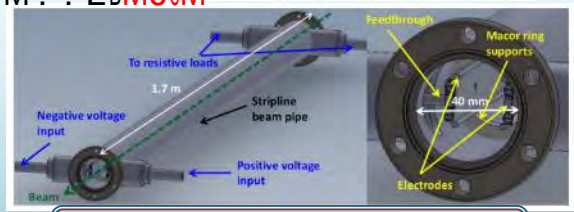




JKLJ



M ! : LBMJCM



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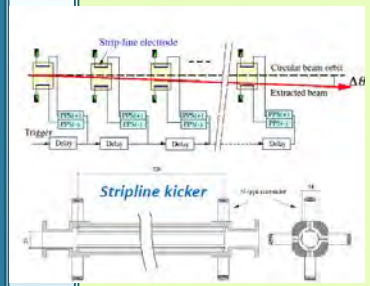

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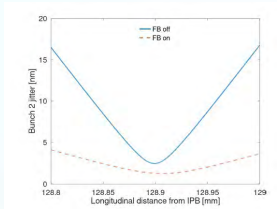
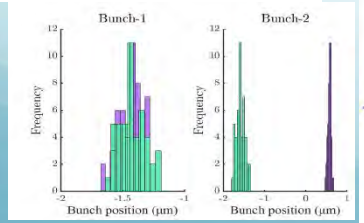
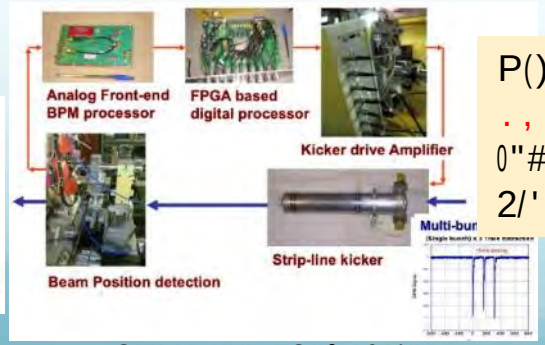


Distribution of bunch positions measured at IPB, with two-BPM FB o ! (green) and on (purple)





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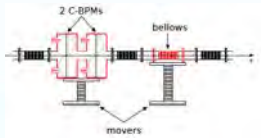

ATF2 wake ! eld knobs system be-tween BPM QD10BFF and QD10AFF

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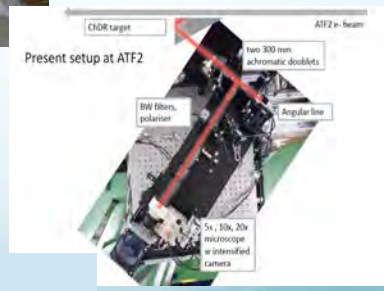

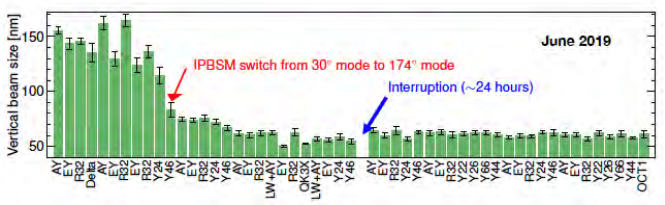

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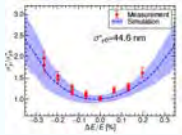

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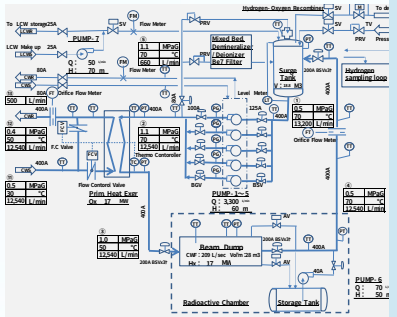
Specific design of radiation shield

Beam Dump Water Circulation System Design (2020)



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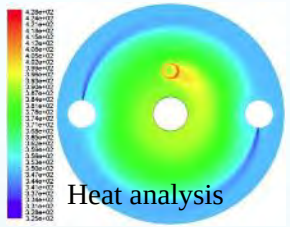

Heat analysis

Shock wave

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65,-0A.: (USA+Canada)	C/.-/2*@2A*1:/-;A/0*12*@2E&EC3FFG2<,B,>*+5,1/2*@2.2 1,H2C(82A.B0/=2/-,./5,1/25,/I*<2@*-2E&EC3FFG2 <,B,>*+5,1/2*@2.2A-.42A.B0/=2@*-2JE3EJ&K	LC3M.+.12collaboration on SRF cavity performance improvement and cost reduction, assembly and installation of cryomodules for LCLS-II.Production began for in-kind contributions of the RFD crab cavities and cryomodules to the HL-LHC by the US & Canada
8-.1A,	'N+,-0,1A,2012.::,54>=2*@2C(8201+;/2A*;+>,-:2.1<2 cryomodule assembly at XFEL in Europe, cooperation with Nanobeam at ATF	F13O01<2A*1/-04;/0*1:2/*2/I,2';-*+,.12),;/-*12C*;-A,2 PESS), the US PIP-II project, cavity performance improvement at SRF, nanobeam collaboration at ATF.
Q,-5.1=	7'CE62P+-,>0501.-=2:/.D,2*@2FE&R2+>.1101D2:/;<=92 S8'E2A*1:/-;A/0*12:/./-/,<2012"##T92C(82A*:/2,:/05./,2 @*-27U(K	U,5*1:/-./0*12*@2>.-D,2C(82.AA,>,-./*-2H0/I2stable operation of XFEL, and improvement of SRF cavity performance
F/.>=	&ontribution to ILC-TDR for cryomodules, cavities and reference Blade tuners, in-kind contribution to half of the cavities and cryomodules at XFEL in Europe.	F13O01<2A*1/-04;/0*1:2/*2/I,2';-*+,.12),;/-*12C*;-A,2 PESS), the US PIP-II project, cavity tuner design at the VSR Upgrade of BESSY storage ring HZB
C+.01	).1*4,.52A*».4*-./0*12./26789201 3O01<2A*1/-04;/0*1:2 :;AI2.:2:;+,-A*1<;A/01D25.D1,/:2./2';-*+,.12S8'E92 013O01<2A*1/-04;/0*1:2/*2F8VF82012M.+.1	F13W01<2A*1/-04;/0*12/*2/I,2';-*+,.12),;/-*12C*;-A,2 PESS), CIEMAT was awarded a budget for the R&D of the ILC superconducting magnet.
LW	).1*4,.52A*».4*-./0*12./2678K2&*1/-04;/0*1:2/*2 7U(2@*-2<.5+01D2-01D:92+*:0/-*12:*;-A,:924,.52 <,>0B,-=2:=:/,592(82:*;-A,:92.1<24,.52<;5+K	F13O01<2A*1/-04;/0*1:2/*2/I,2';-*+,.12),;/-*12C*;-A,2 PESS) and the US PIP-II projects, design of the LHC crab cavity.

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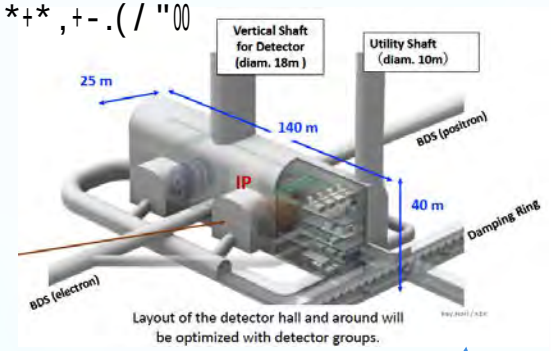
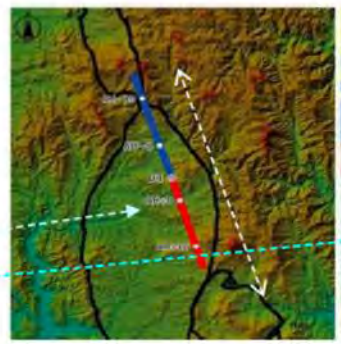


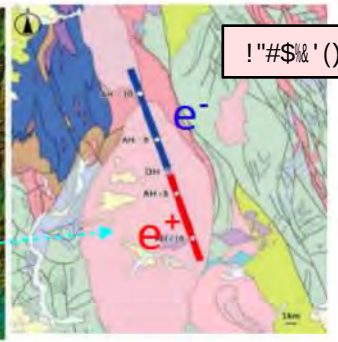
Layout of the detector hall and around will be optimized with detector groups.

3&'-4-5& 5+6,'-&,7

① ILC Location

ILC accelerator area : inside the granite rock bodies
→ inside black curves (left)
→ in the pink color (right)
→ possible up to 50 km

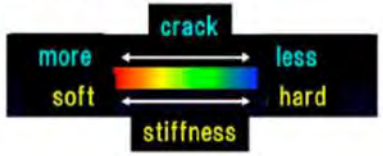


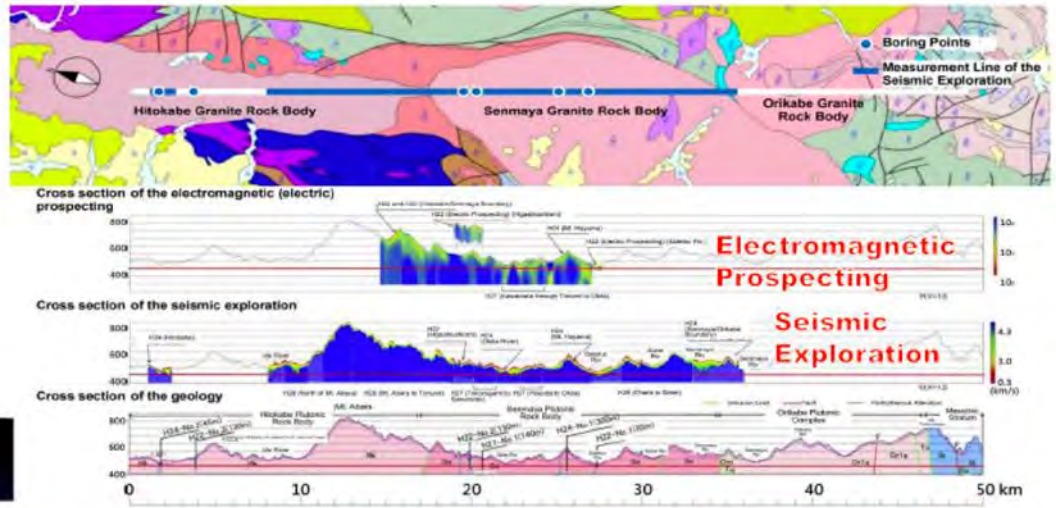


→ On-going jobs : Optimal accelerator placement, considering surface environment, land-use and land-acquisition

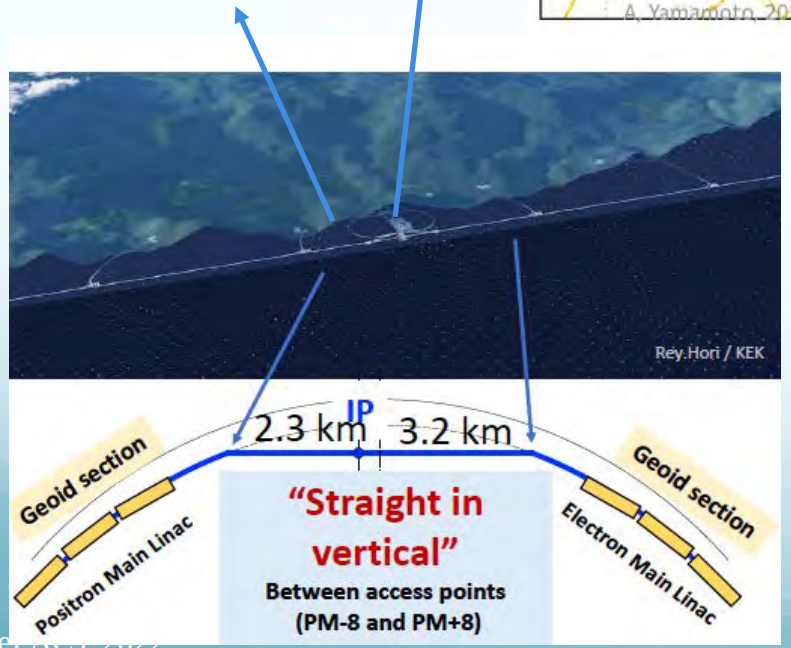
② Geological Surveys

- Electric Prospecting (crack)
- Seismic Exploration (stiffness)
- Boring Survey
- Borehole Camera
- Measurement of Initial Stress of the Ground





→ no issues from previous surveys
→ requiring : additional surveys around access tunnel head and access tunnel inside for detailed designing



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Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_e	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_b	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_z^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_x$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_x^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_y^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	128	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Green-ILC AAA-2014 Report

Green ILC Studies in Tohoku Area

- Studies conducted on
  - Exhaust heat recovery from the ILC and the creation of business derived from it
  - Connecting the ILC with the local forestry industry
  - Utilization of solar heat
  - The "Green ILC" concept and community development and planning - building an energy recycling society based on the Global Village Vision

320ktonCO2/year

M. Yoshioka: https://agenda.linearcollider.org/event/9211/contributions/49408/
M. Yoshioka et al.: https://www.pasj.jp/web_publish/pasj2020/proceedings/PDF/WEPP/WEPP57.pdf

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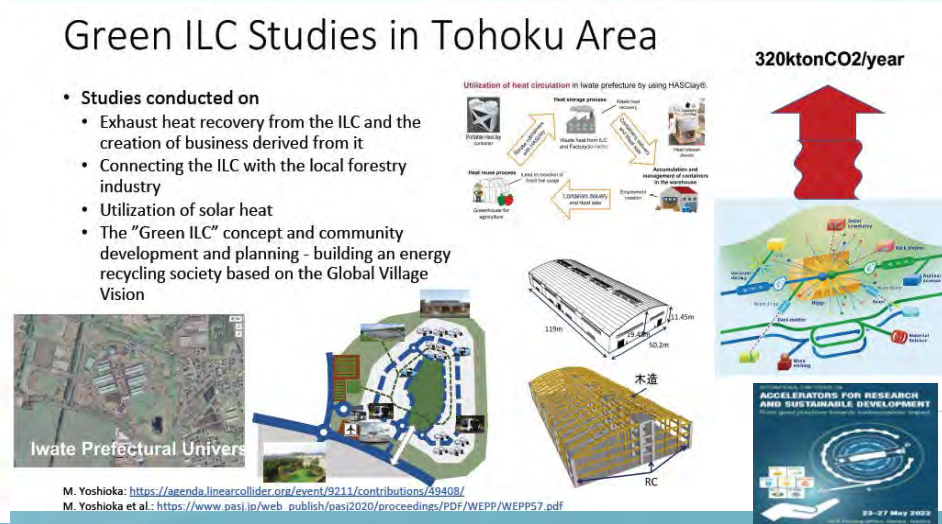

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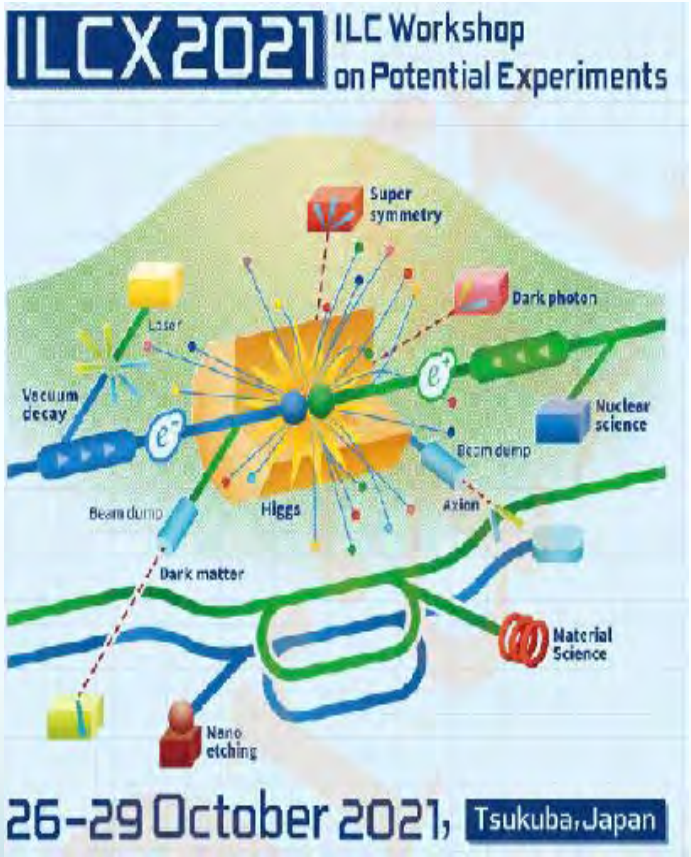

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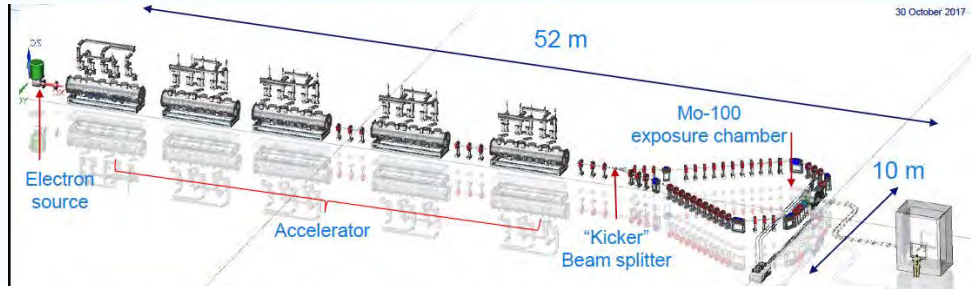
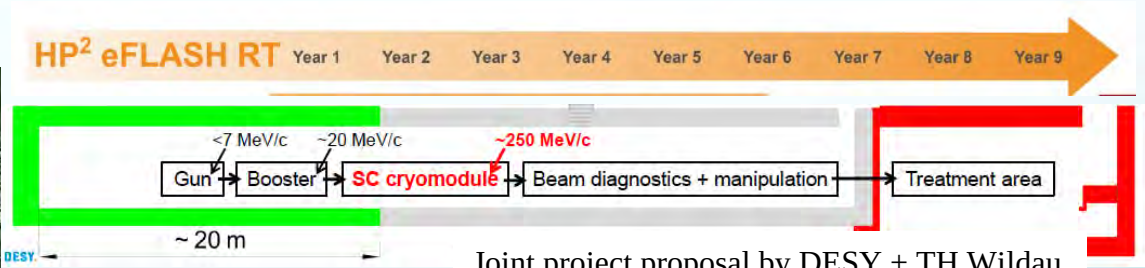
1.3GHz 9 cell cavity

SCRF compact for water treatment



LightHouse : SC linac Isotope production. ASML-IRE-RI GMbh



Joint project proposal by DESY + TH Wildau

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SHINE under construction

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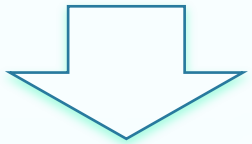
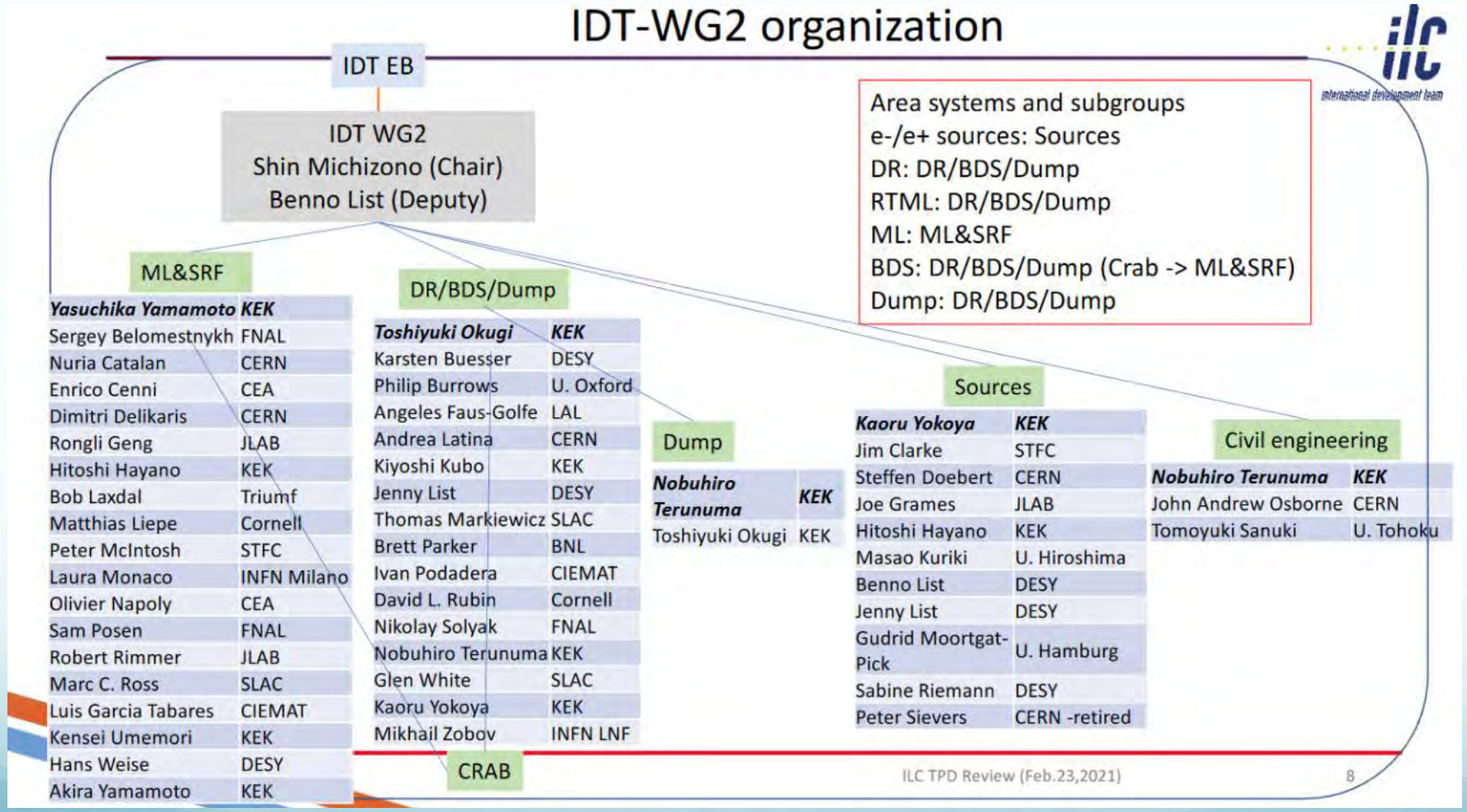


	IDT	ILC Pre-Lab				ILC Lab.										
	PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.
Preparation CE/Utility, Survey, Design Acc. Industrialization prep.																
Construction																
Civil Eng.																
Building, Utilities																
Acc. Systems																
Installation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

Following a four-year ILC Pre-Lab phase, ILC construction will continue for about 9 years + 1 commisioning

ILC International Development Team

IDT Working Group 2 - Accelerator



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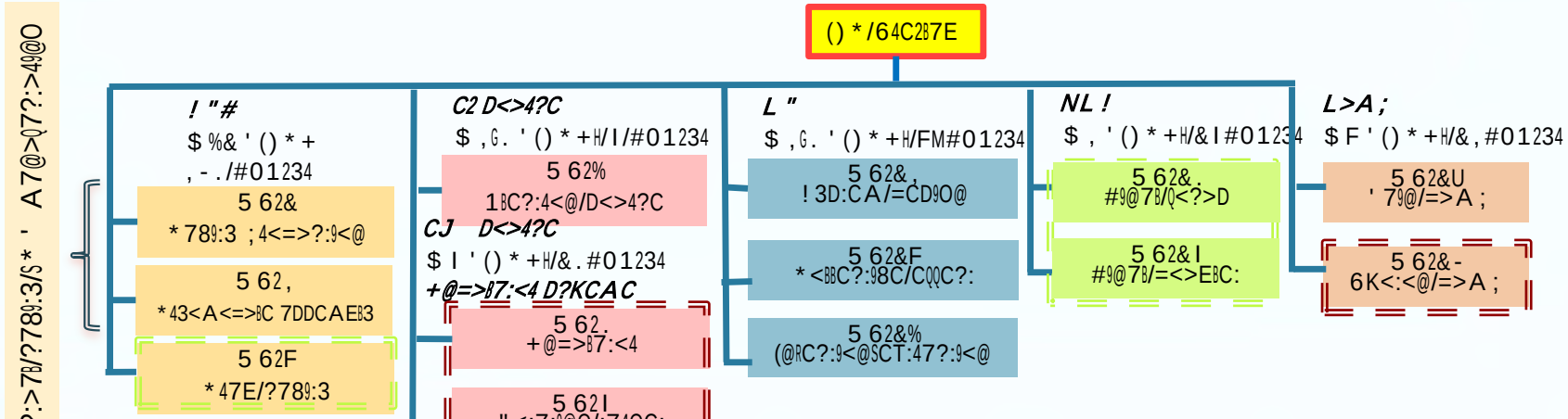

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MEXT review: ILC Advisory Panel

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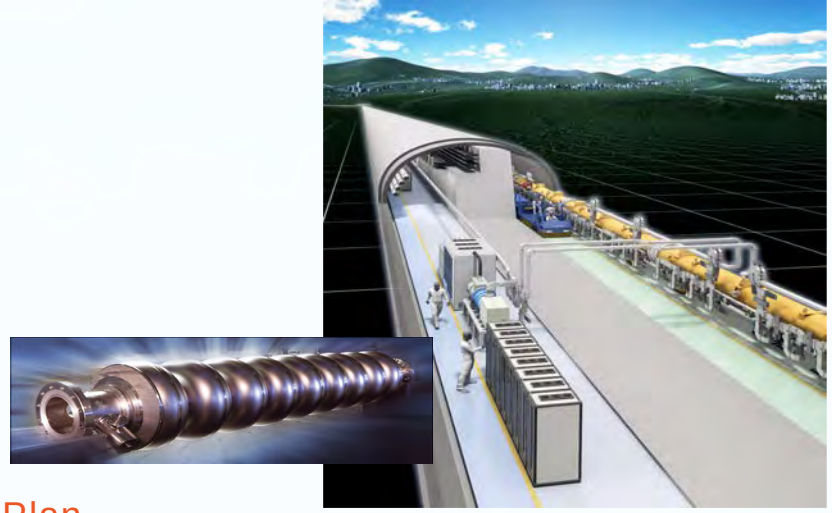
https://icfa.hep.net/wp-content/uploads/ICFA_Statement_April2022_Final.pdf



Medium Term Plan

EPPSU Snowmass EPPSU

2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037

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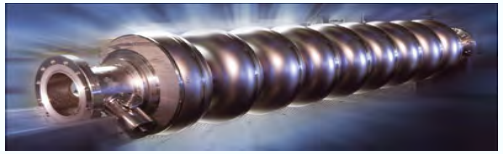

Thanks for your attention

Special thanks to:

Shin Michuzono, Steinar Stapnes Phil Burows and Benno List

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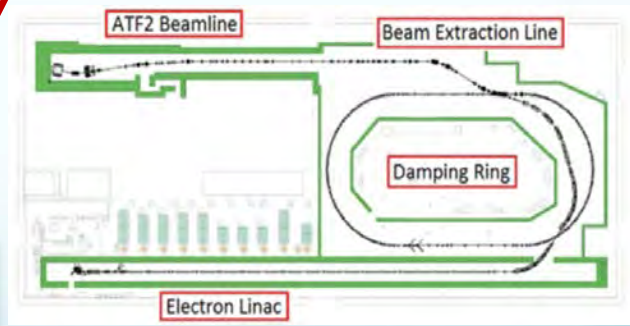

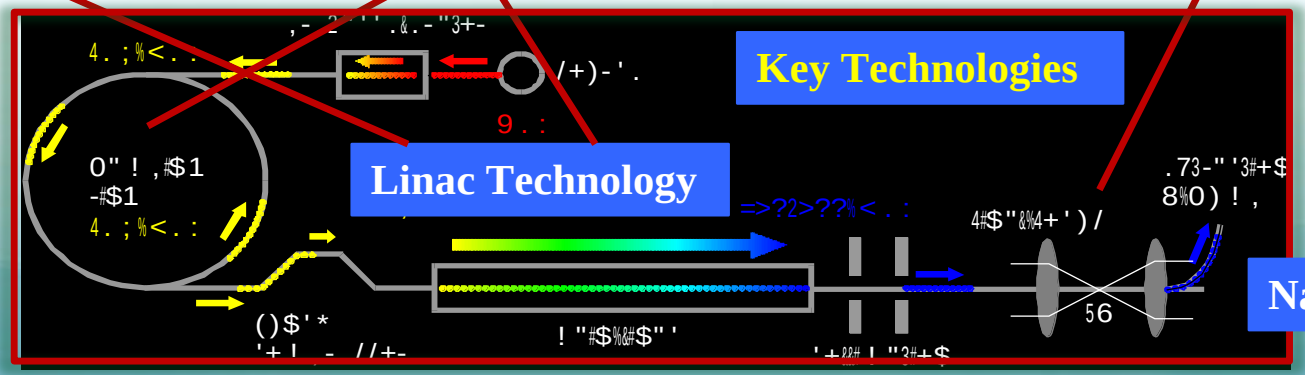

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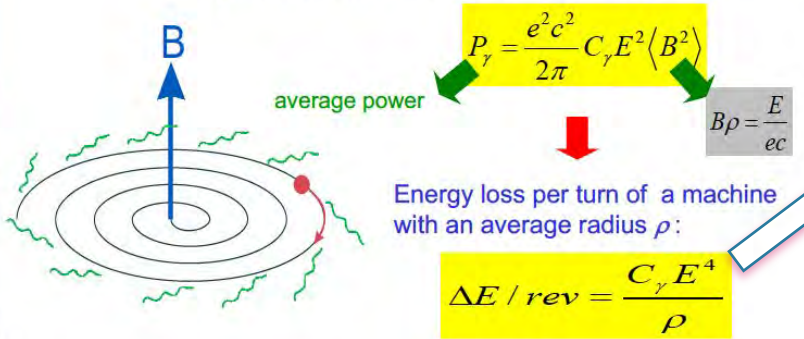
Why a Linear Collider, and not just build a bigger storage ring ?

Synchrotron radiation from an e⁻ in a magnetic field:



average power $P_\gamma = \frac{e^2c^2}{2\pi} C_\gamma E^2 \langle B^2 \rangle$

$B\rho = \frac{E}{ec}$

Energy loss per turn of a machine with an average radius ρ:

$$\Delta E / rev = \frac{C_\gamma E^4}{\rho}$$

Energy loss per turn has to be be replaced by the RF system, which is the major cost factor for a collider.

LC

Why a Linear Collider ? some cost reasons…

tunnel, vacuum systems,magnets..

$\$_{lin} \propto \rho$

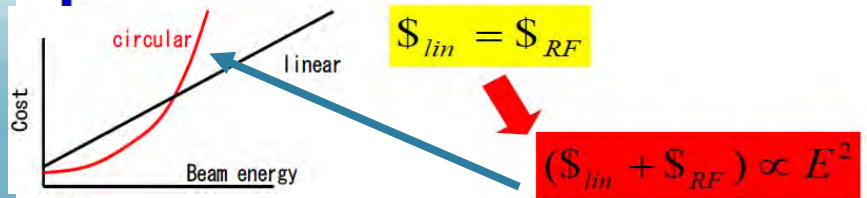
RF system

$\$_{RF} \propto \frac{E^4}{\rho}$

Optimum when

$\$_{lin} = \$_{RF}$

$(\$_{lin} + \$_{RF}) \propto E^2$



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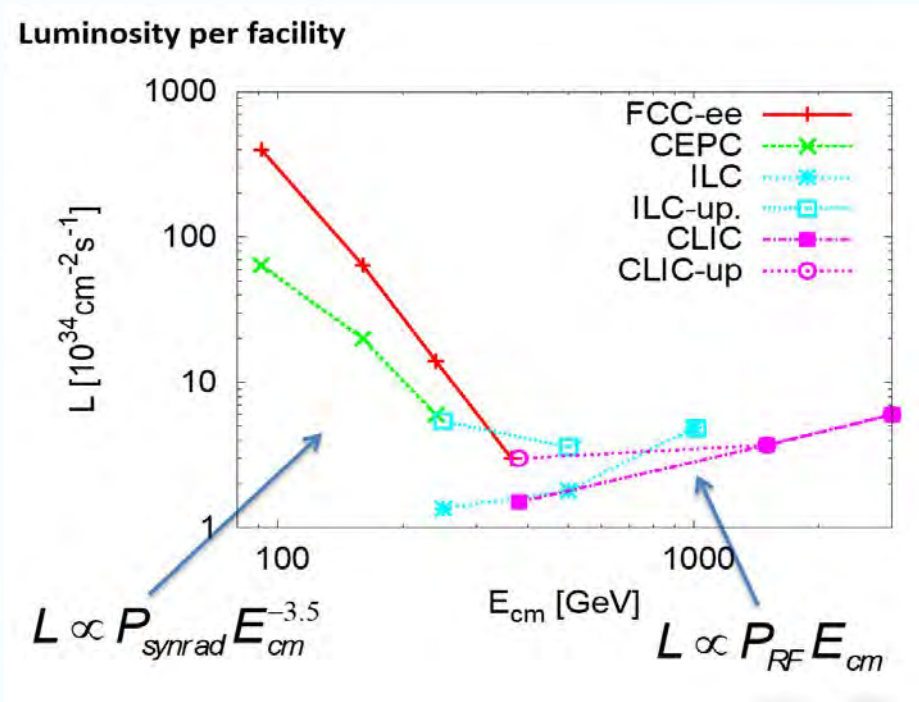

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	Units	ATF2	ILC	CLIC
E_{cm}	[GeV]	1.3	250	380
$\mathcal{L}$	[10^{34} cm^{-2} s^{-1}]		1.35	1.5
f_{rep}	[Hz]	3.12	5	50
$n_{bunches}$	1	1 - 20	1312	352
N_e	[10^{10}]	1.0	2.0	0.52
$!_b$	[µm]	7000	300	70
$!t_b$	[ns]	154	554	0.5
$"_x$ / $"_y$	[nm]	5000 / 30	5000 / 35	950 / 30
$!_x^*$ / $!_y^*$	[nm]	9000 / 37	516 / 7.7	149 / 2.9
$IP_{Stabilization}$	$!_y^*$	< 0.05	< 0.2	< 0.08
L^*	[m]	1	4.1	6
$!_x^*$ / $!_y^*$	[mm]	40 / 0.1	13 / 0.41	8 / 0.1

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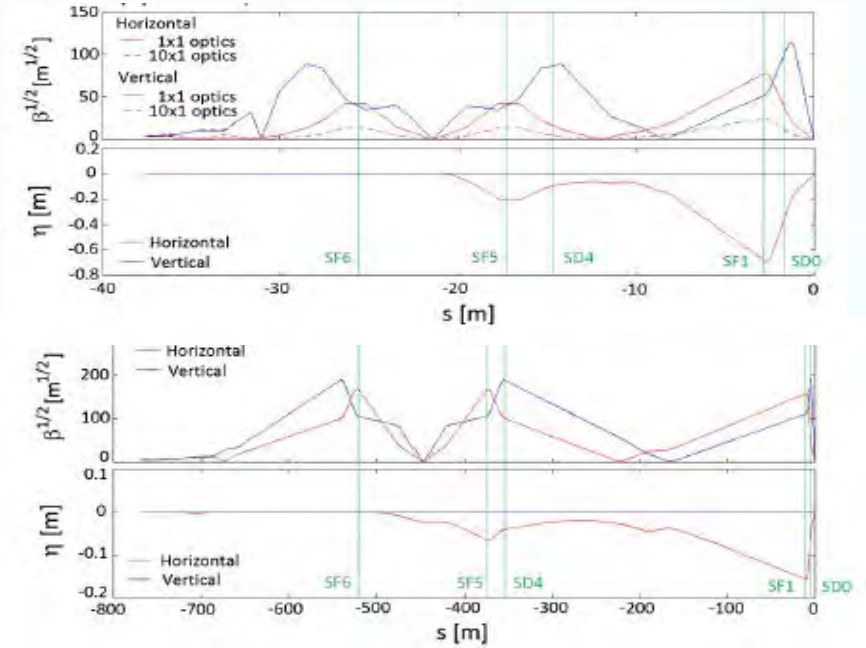

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Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

- ATF2 Goal : **37** nm → ILC **7.7** nm (ILC250)
  - Achieved **41 nm** (2016)

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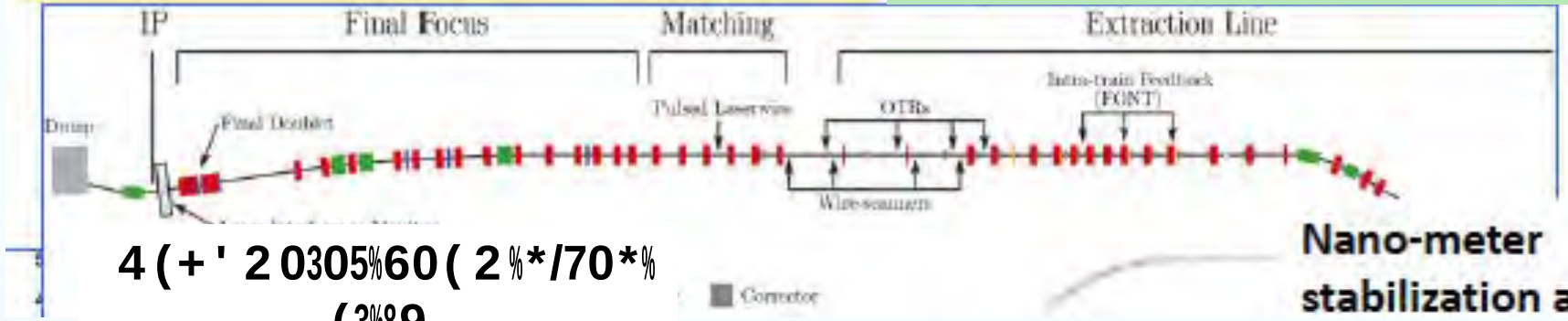

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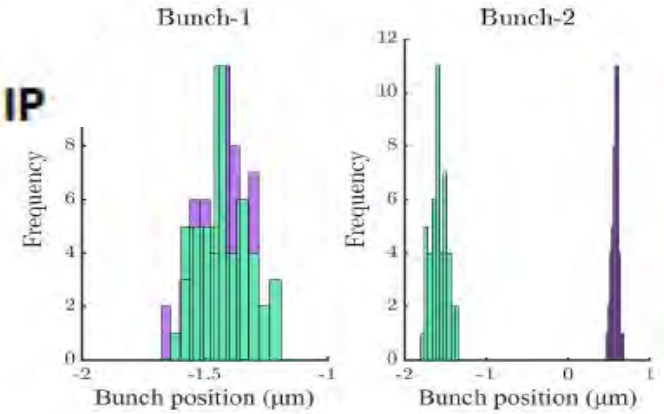
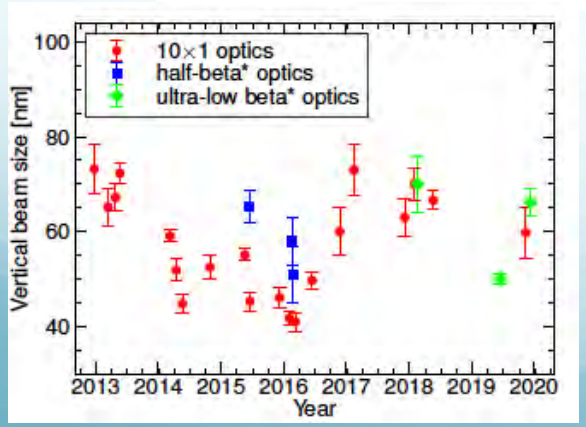
Nano-meter stabilization at IP

Distribution of bunch positions measured at IPB, with two-BPM FB o! (green) and on (purple)





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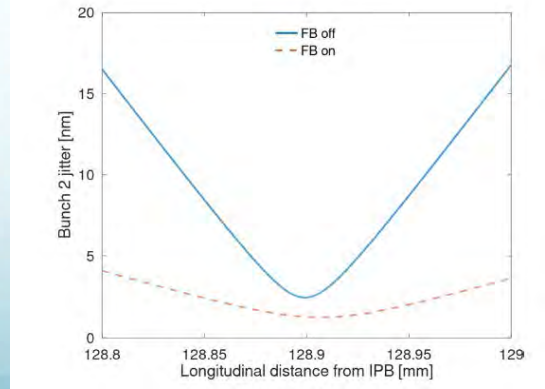
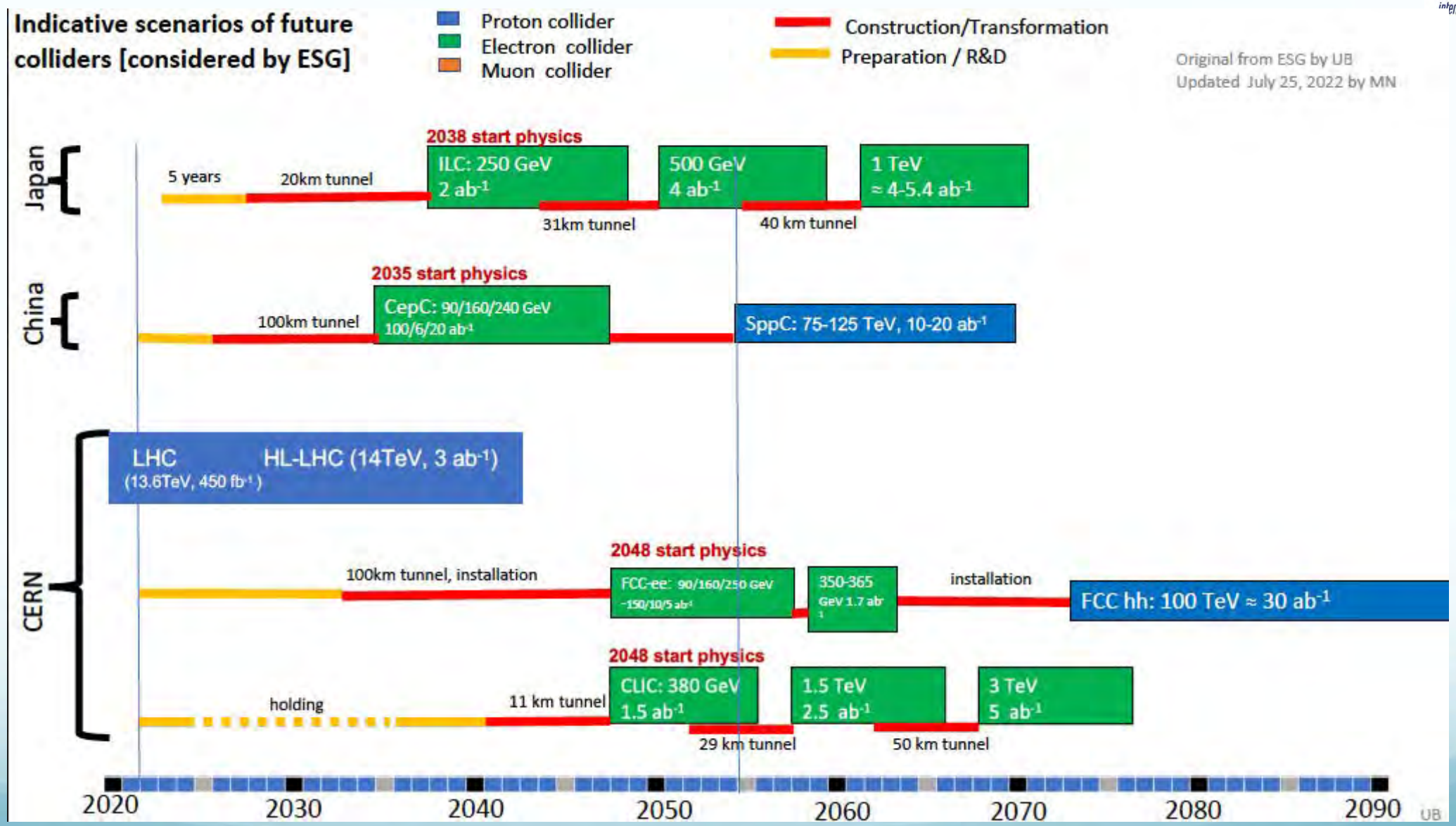
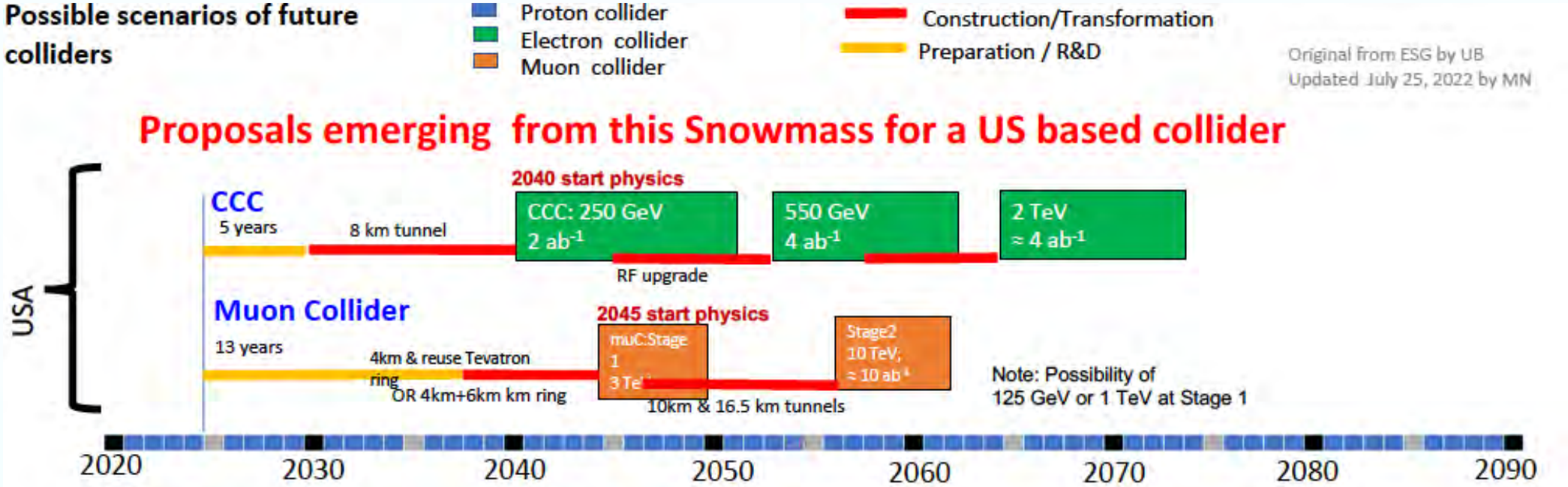


Predicted vertical position jitter with FB on-off


Indicative scenarios of future colliders [considered by ESG]
Proton collider
Electron collider
Muon collider
Construction/Transformation
Preparation / R&D
Original from ESG by UB
Updated July 25, 2022 by MN
Japan
2038 start physics
5 years
20km tunnel
ILC: 250 GeV
2 ab-1
31km tunnel
500 GeV
4 ab-1
40 km tunnel
1 TeV
≈ 4-5.4 ab-1
China
2035 start physics
100km tunnel
CepC: 90/160/240 GeV
100/6/20 ab-1
SppC: 75-125 TeV, 10-20 ab-1
CERN
LHC
(13.6TeV, 450 fb-1)
HL-LHC (14TeV, 3 ab-1)
2048 start physics
100km tunnel, installation
FCC-ee: 90/160/250 GeV
~150/10/5 ab-1
350-365
GeV 1.7 ab-1
installation
FCC hh: 100 TeV ≈ 30 ab-1
2048 start physics
holding
11 km tunnel
CLIC: 380 GeV
1.5 ab-1
29 km tunnel
1.5 TeV
2.5 ab-1
50 km tunnel
3 TeV
5 ab-1
2020
2030
2040
2050
2060
2070
2080
2090
UB



- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - International Cost Sharing

- Consider proposing hosting ILC in the US.