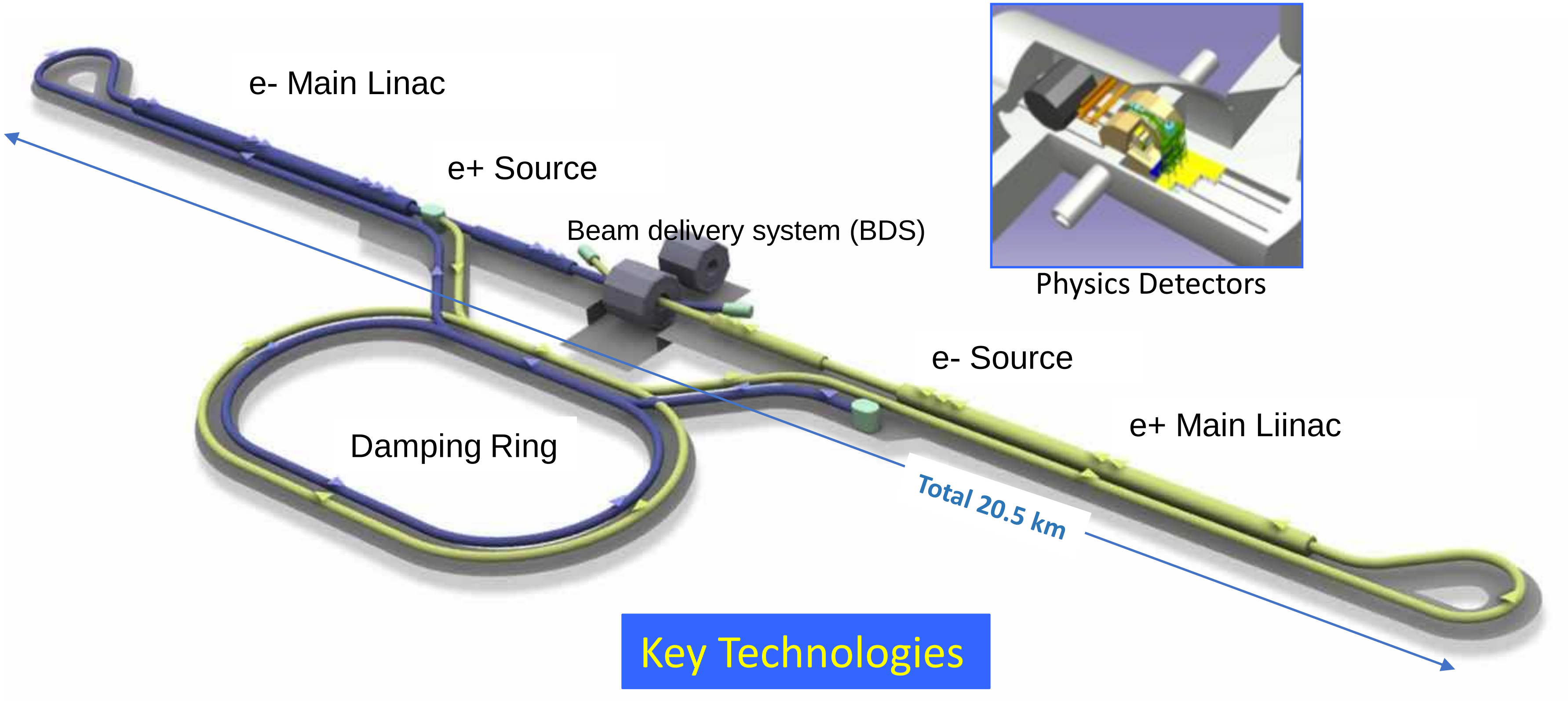
ILC250 accelerator

Speaker: Shin MICHIZONO
Linear Collider Collaboration (LCC)/KEK

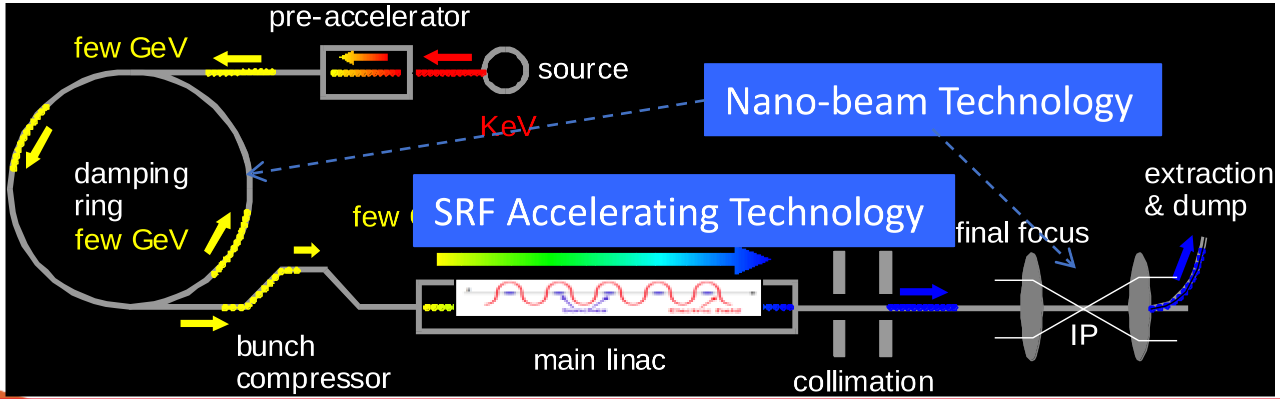
- *ILC250 accelerator overview*
- *ILC250 beam parameters and possible upgrades*
- *Main advantages, technical maturity*
- *Construction cost and schedule*
- *Summary*

ILC250 accelerator facility



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}

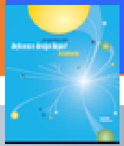
Key Technologies



ILC R&D organization, TDR

2004

2006 ‘07 ‘08 ‘09 ‘10 ‘11 ‘12 ‘13 ‘14 ‘15 ‘16 ’17 ’18 ’19 ’20



SC Technology selected

ILC-GDE

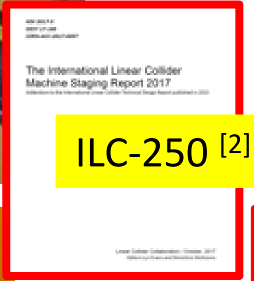
TDR

LCC

RDR)

Technical Design Phase

TDR [1] :
49 countries
392 institutions
>2400 researchers

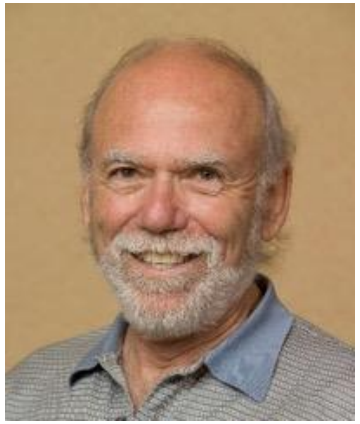

The International Linear Collider Machine Staging Report 2017

ILC-250 [2]

International Development Team


Recommendations on ILC Project Implementation
High Energy Accelerator Research Organization (KEK)
October 1, 2019

Recommendations on ILC Project Implementation [3]



Barry Barish
GDE director
(the Nobel Prize winner for physics in 2017)

Lyn Evans
LCC director
(former LHC project manager)

LHC

European XFEL

LCLS-II

LINEAR COLLIDER COLLABORATION

ILC machine parameters

Facility "Standard Table"

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*
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
# of IPs		1
# 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)

* 5,000-hour operation at peak luminosity

IP parameters and conditions

The BDS is designed such that it can be upgraded to a maximum beam energy of 500 GeV; components necessary for 125 GeV beam operation are installed and space for a later upgrade is reserved.

To bring the beams to collision with the necessary nano-meter accuracy requires a continuous compensation of drift and vibration effects. Along the ILC, the pulse length and bunch separation (727 μs and 554 ns, respectively) are large enough to allow corrections between pulses as well as within a bunch train (intratrain feedback).

Finally, the 3.9 GHz crab cavities close to the interaction point are incorporated that rotate the bunches to compensate for the 14 mrad beam crossing angle.

Parameter			Z-pole [4]	Higgs [2]	500 GeV [1]	TeV [1]
Beam size at IP (x)	σ^*_x	μm	1.118	0.515	0.474	0.335
Beam size at IP (y)	σ^*_y	nm	14.56	7.66	5.86	2.66
Luminosity (baseline)	L	$10^{34}/cm^2/s$	0.205	1.35	1.79	5.11
Luminosity at top 1%	$L_{0.01}/L$	%	99	74	58	45
Number of beamstrahlung photons	n_γ		0.841	1.91	1.82	2.05
Beamstrahlung energy loss	δ_{BS}	%	0.157	2.62	4.5	10.5

Nano-beam is well studied at ATF2 in KEK.

Potential for upgrades

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

Main advantages

- A linear accelerator is more advantageous for accelerating electron and/or positron beams to higher energies.
- The spin of the electron and/or positron beam can be maintained during the acceleration and collision. This can help significantly improve measurement precision.
- The efficient power transfer from the AC power source to the beam owing to the small surface resistance of the accelerating structure (cavity) made of Nb.
- Further energy efficiency improvements are considered as part of the of Green ILC concept [8], which aims to establish a sustainable laboratory.

Technical Maturity

- ILC based on superconducting radiofrequency (SRF) technology started its R&D from 2005 (GDE). Reference Design Report (RDR) was published in 2007 and TDR was published in 2013.
- More than 2,400 researchers contributed to the TDR.

- The SRF technology's maturity was proven by the operation of the European X-ray Free Electron Laser (X-FEL) in Hamburg, where 800 superconducting cavities (1/10 of ILC SRF cavities) were installed.
- In addition to European XFEL, LCLS-II at SLAC, SHINE in Shanghai are under construction.

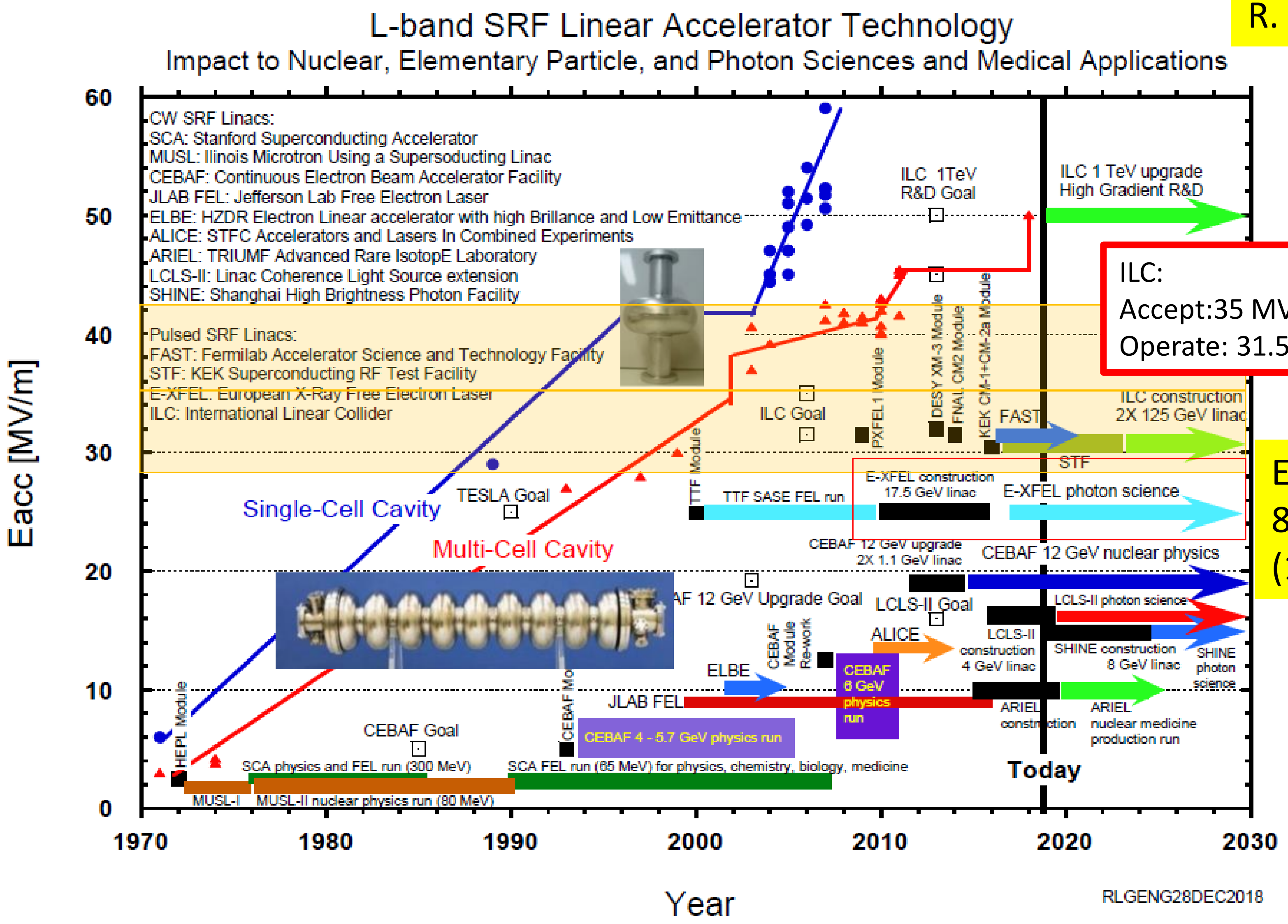
- Nano-beam technology has been demonstrated at ATF hosted in KEK under international collaboration and almost satisfied the requirements of the ILC.

- Remaining technical preparation (such as mass-production of SRF cavities, positron source, beam dump) can be carried out during the preparation phase before ILC construction. These are listed in "Recommendations on ILC Project Implementation" [7].

ILC : 3 – Shovel-ready

Matured SRF technologies

R. Geng (JLAB)



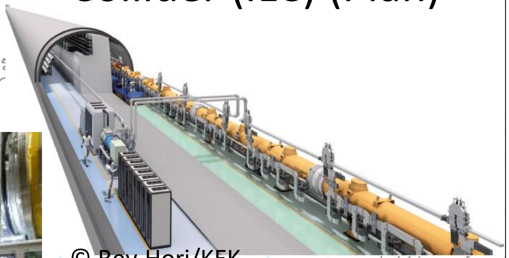
ILC:
Accept:35 MV/m +/-20%
Operate: 31.5MV/m +/-20%

European XFEL
800 cavities
(10% of ILC ML)

Worldwide large scale SRF accelerators

European XFEL

International Linear Collider (ILC) (Plan)



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Euro-XFEL
Operation started from 2017
- **-100 cyromodules**
- **-800 cavities**
- **-17.5 GeV (Pulsed)**

LCLS-II + HE (under construction)
- **-35 + 20 cyromodules**
- **-280 + 160 cavities**
- **- 4 + 4 GeV (CW)**

ILC
- **-900 cyromodules**
- **-8,000 cavities**
- **-250 GeV (Pulsed)**

DESY

LAL/Sacray

INFN

SLAC

FNAL

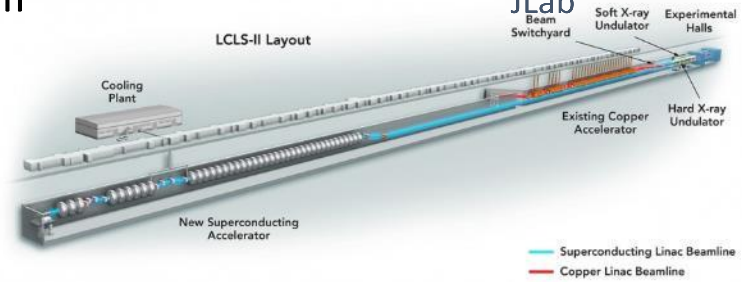
Cornell

JLab

KEK

SINAP

LCLS-II



SHINE (under construction)
- **-75 cyromodules**
- **-~600 cavities**
- **- 8 GeV (CW)**

1.3GHz 9 cell cavity

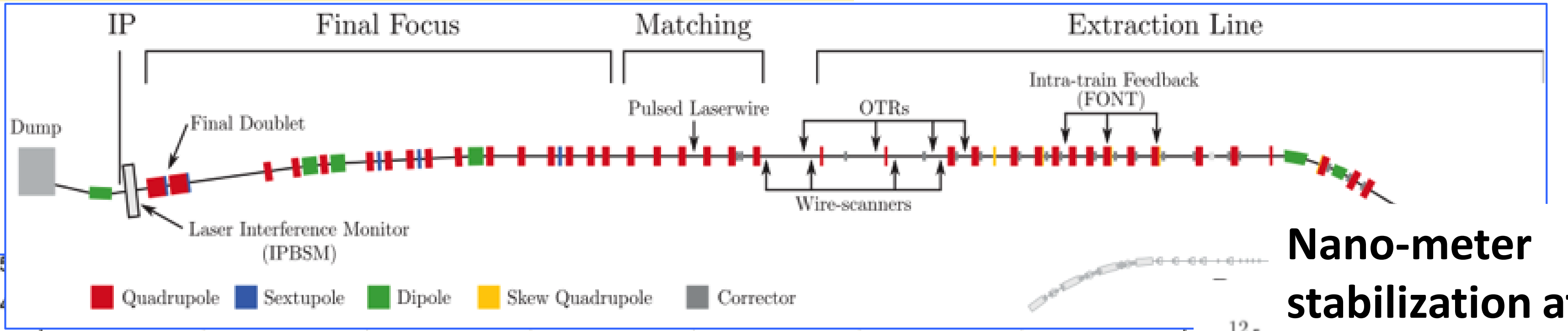
Nano-beam R&D

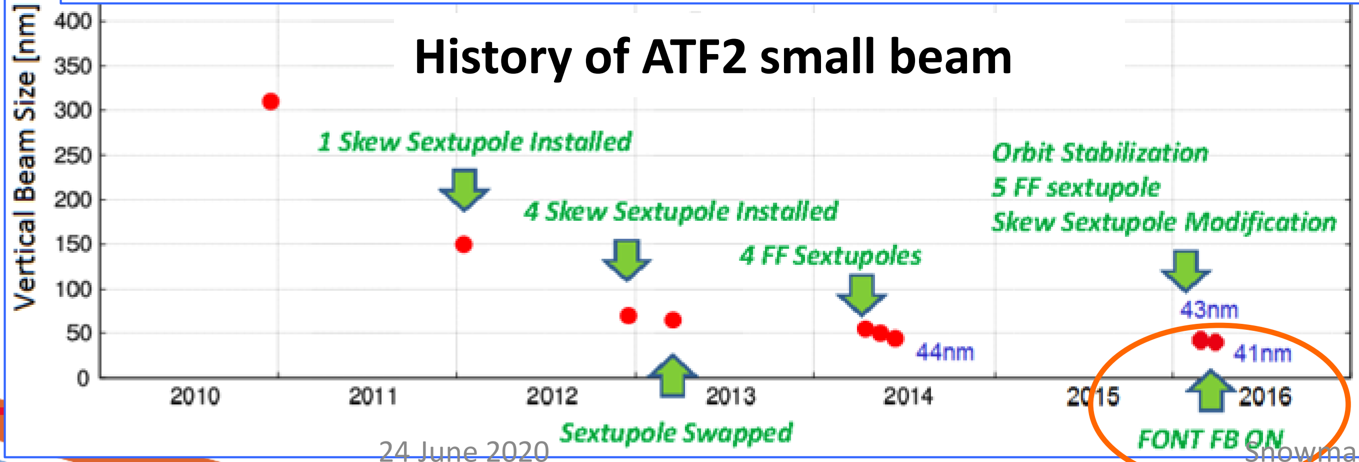
Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

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

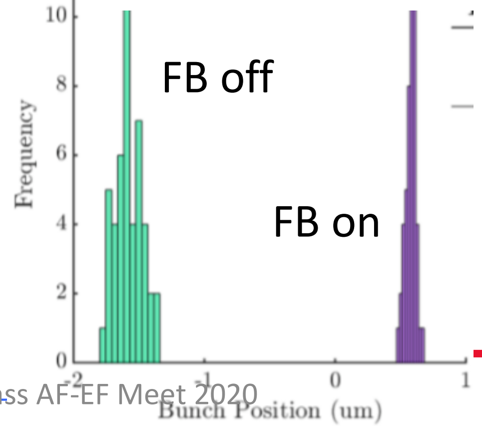
Goal 2: Develop a few nm position stabilization for the ILC collision

- **FB latency 133 nsec achieved** (target: < 366 nsec)
- **positon jitter at IP: 106 → 41 nm (2018)** (limited by the BPM resolution)





Nano-meter stabilization at IP (2018)



Construction cost

ILC accelerator (including tunnel) construction cost is ~5 B$ [1,2,7,8].

	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**

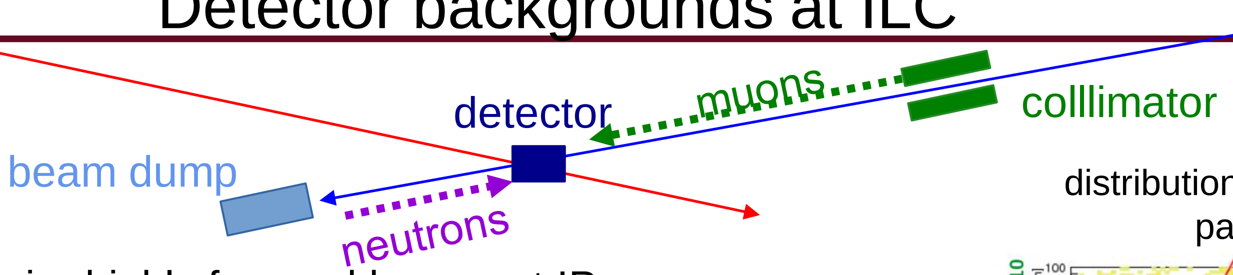
*1 ILCU= 1 US$ in 2012 prices

Timeline

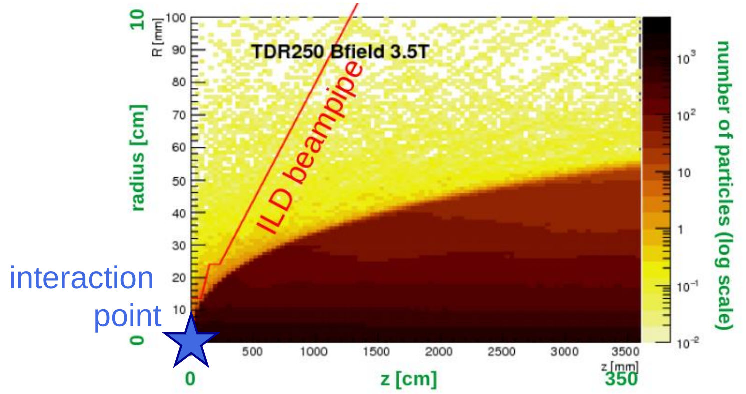
Now we are at pre-preparation phase (waiting for the preparation phase).
Four years preparation and 9 years construction.

	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.															

Detector backgrounds at ILC



distribution of beamstrahlung pairs near IP



single pass collisions require highly focused beams at IP

→ **beamstrahlung**

radiation emitted while bunches cross

→ many low energy electron-positron pairs

constrained by detector's strong B-field (3.5~5 T)

→ beampipe designed to contain vast majority,
small fraction intersects inner tracking detectors

collimators used to reduce beam halo & confine synchrotron radiation within beampipe

→ **high energy muons** can be produced,

particularly in final focus system where beam energy is highest

→ muons can reach detector hall (up to a few per bunch-crossing)

at linear collider, detector is in line-of-sight of linac

mitigated by upstream magnetized iron shielding

distinctive signature in detector, rather easy to identify

beams dumped in pressurized water tank a few 100m downstream of IP

neutrons can drift back into the detector hall

→ not expected to have a significant effect on the ILC detector

no serious beam gas background expected, even at modest vacuum pressure [10^{-6} Pa]

Summary

- *ILC250 is 20 km long e-/e+ collider for the Higgs factory.*
- *The ILC is upgradable in energy and luminosity.*
- *International collaborations (GDE, LCC and IDT(International Development Team from summer 2020)) have been leading the R&Ds of the ILC since 2005.*
- *TDR was published in 2013 and these technologies are matured.*
- *Key technologies at the ILC are superconducting rf (SRF) and nano-beam.*
  - *SRF technology has been widely adopted at XFELs such as European XFEL.*
  - *Nano-beam technology has been demonstrated at ATF hosted by KEK*
- *Construction cost (value) is ~5 B$ and we assume 4-year preparation and 9-year construction.*

References

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Thank you for your attention