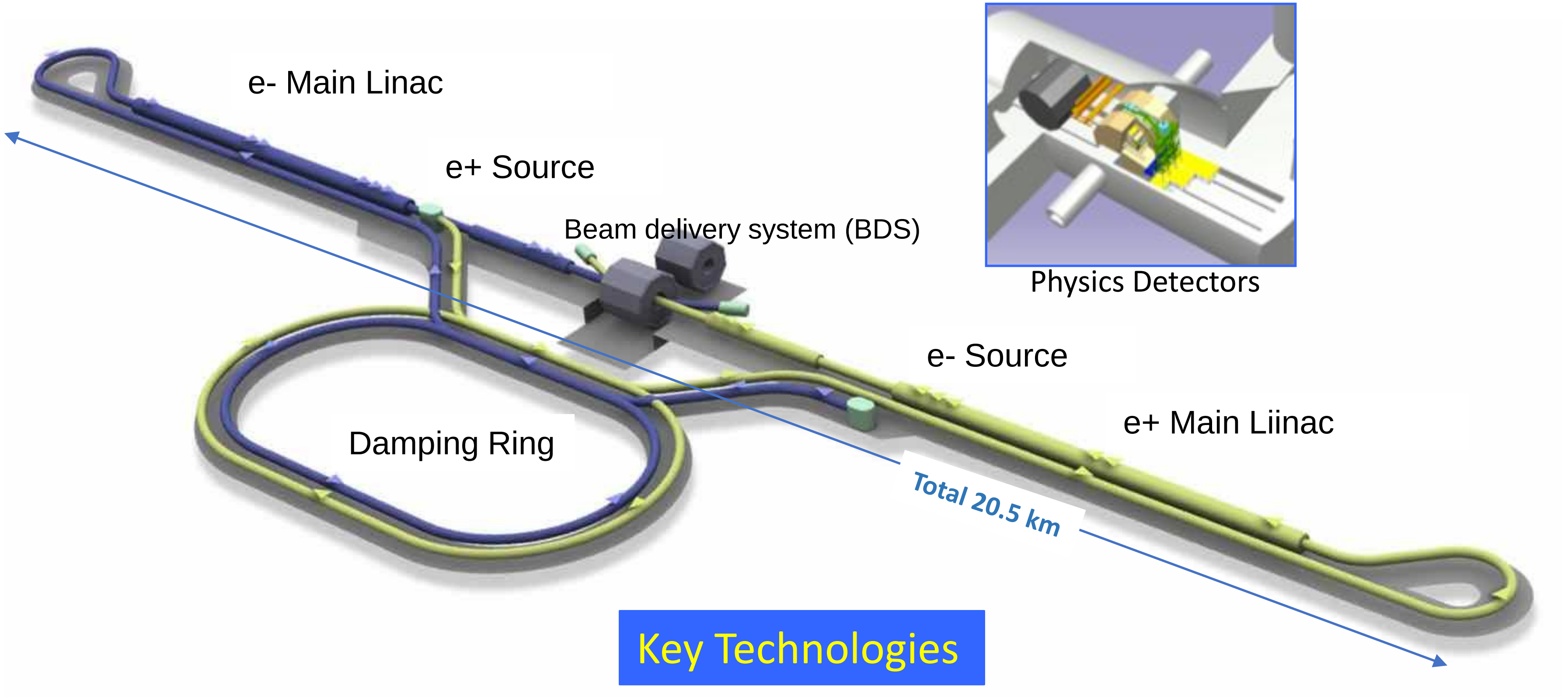
ILC250 accelerator

Speaker: Shin MICHIZONO
International Development Team (IDT) WG2/ KEK

- *ILC250 accelerator overview*
- *ILC250 beam parameters and possible upgrades*
- *Main advantages, technical maturity*
- *Key technologies*
  - *SRF*
  - *Nano-beam*
  - *Positron source*
  - *Beam dump*
- *Construction cost and schedule*
- *ILC Pre-Lab activity*
- *Summary*

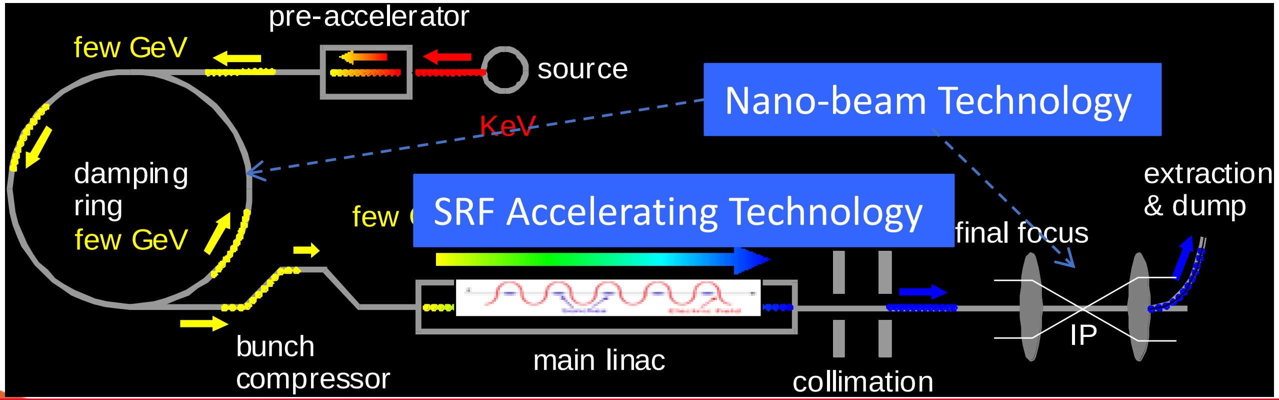
ILC250 accelerator facility



Physics Detectors

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

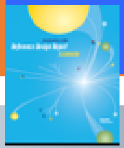


8,000 SRF cavities will be used.

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

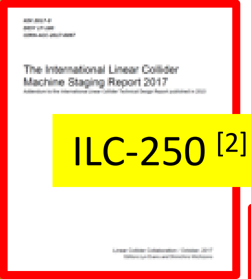
TDR

LCC

RDR)

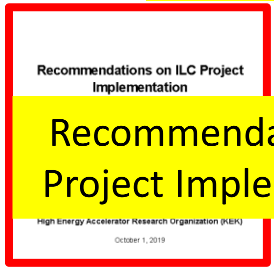
Technical Design Phase

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

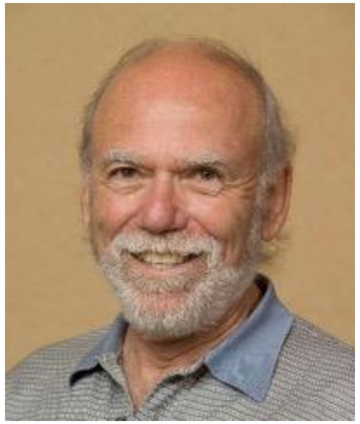


ILC-250 [2]

International Development Team



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

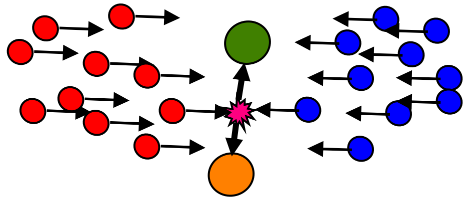
European XFEL

LCLS-II

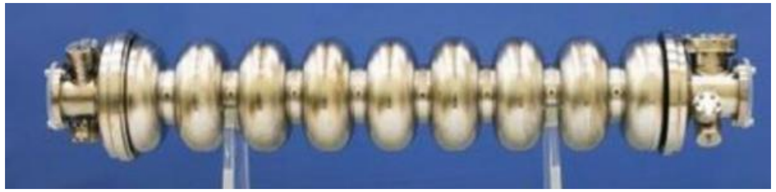
Area systems of the ILC

bunch, consisting of ~10^10 e+/e−

- Creating particles ***Sources***
  - polarized elections/positrons
- High quality beams ***Damping ring***
  - Low emittance beams
    - Small beam size (small beam spread)
    - Parallel beam (small momentum spread)



- Acceleration ***Main linac***
  - superconducting radio frequency (SRF)



- Getting them collided ***Final focus***
  - nano-meter beams
- Go to ***Beam dumps***

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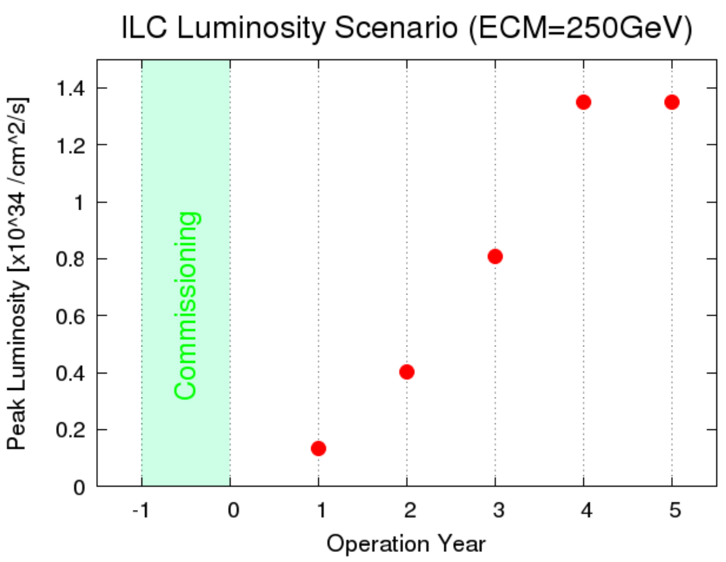
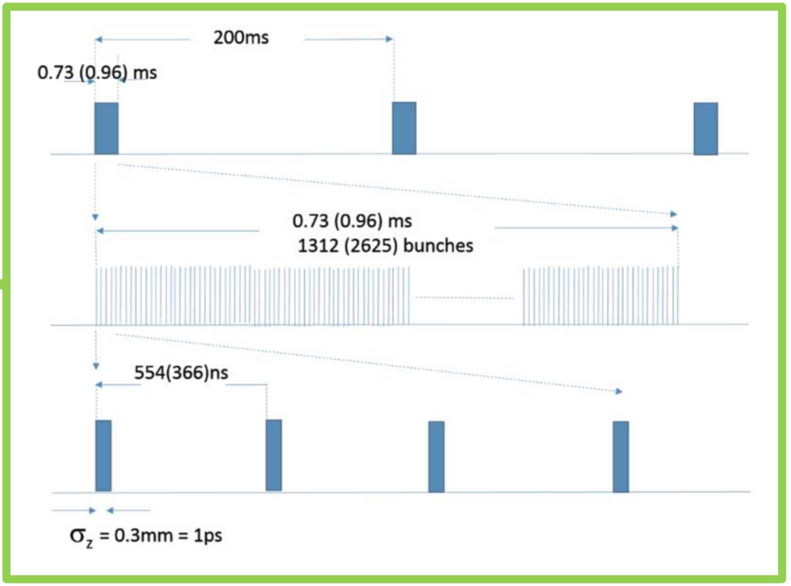
ILC machine parameters

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*
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 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*





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

Energy

Lumi.

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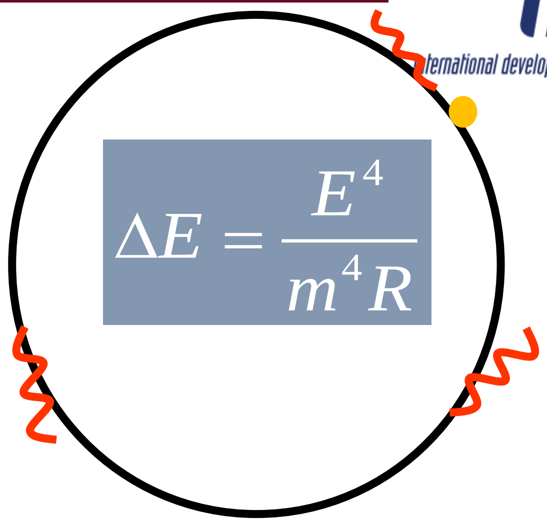
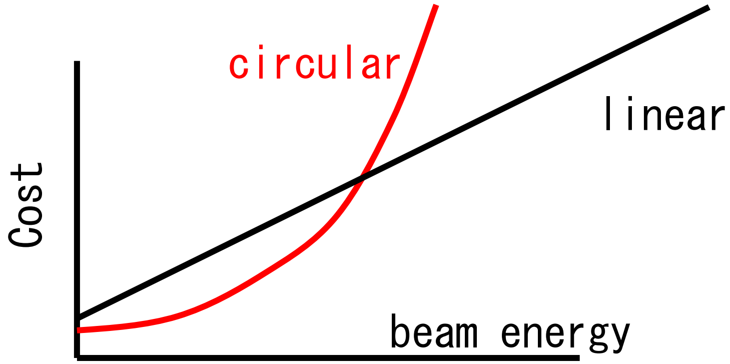
Main advantages

- 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 small surface resistance of the SRF accelerating structure (cavity) made of Nb enables the efficient power transfer from the AC power source to the beam.
- Further energy efficiency improvements are considered as part of the of Green ILC concept [7], which aims to establish a sustainable laboratory.



$$\Delta E = \frac{E^4}{m^4 R}$$

Circulating beam loses energy by synchrotron radiation.
Linear collider can extend its collision energy by longer tunnel/ higher gradient.



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 at Pre-lab before ILC construction. These are listed in "Recommendations on ILC Project Implementation" [3].

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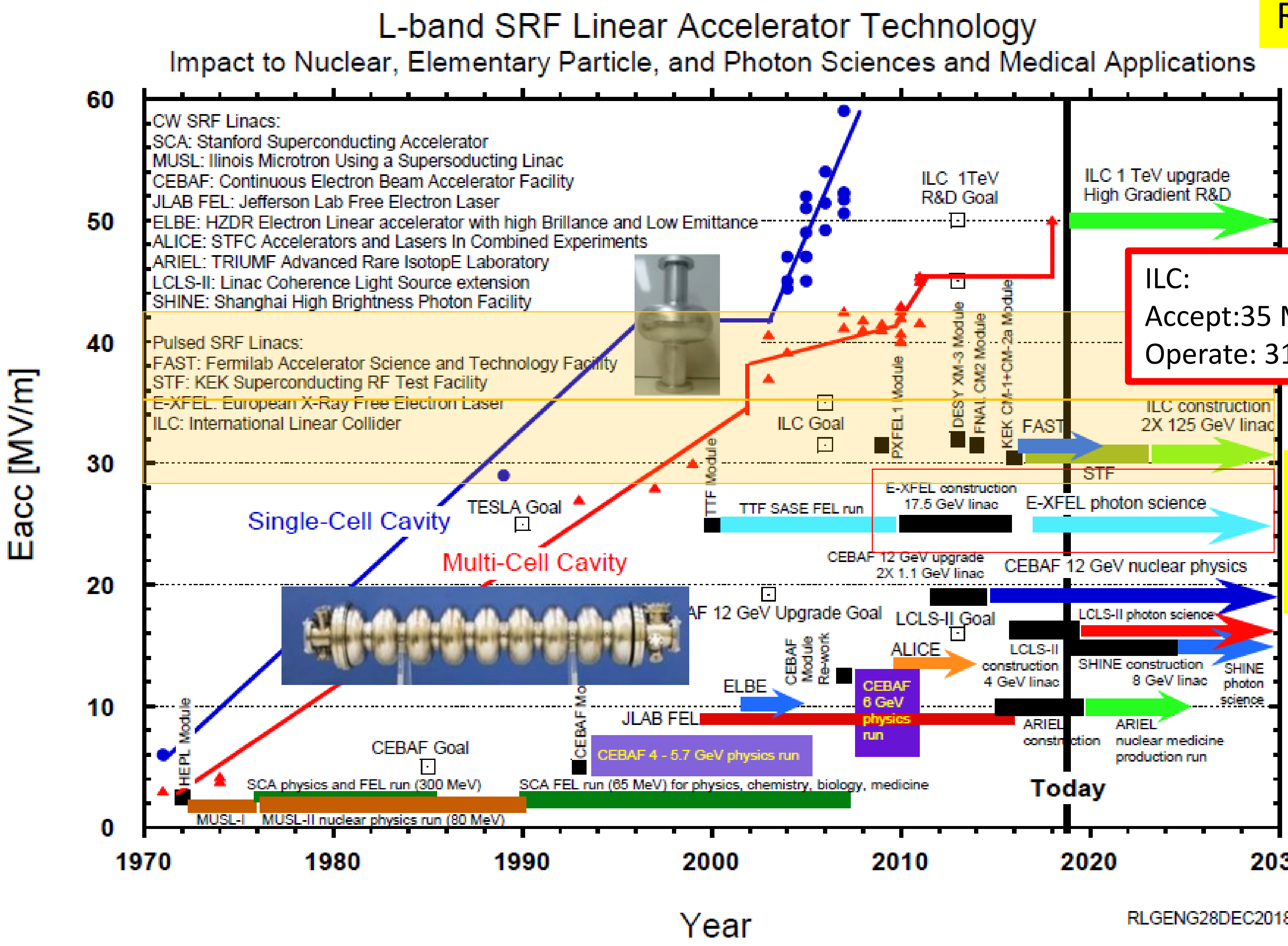
Matured SRF technologies

R. Geng (JLAB)



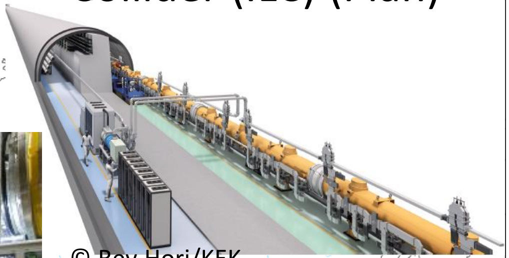
ILC:
Accept:35 MV/m +/-20%
Operate: 31.5MV/m +/-20%

European XFEL
800 cavities
(10% of ILC ML)

Worldwide large scale SRF accelerators

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

International Linear Collider (ILC) (Plan)



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

DESY

LAL/Sacray

INFN

SLAC

FNAL

Cornell

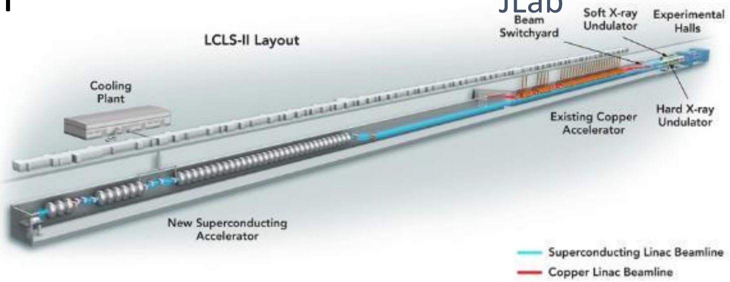
JLab

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

KEK

SINAP

LCLS-II



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

1.3GHz 9 cell cavity

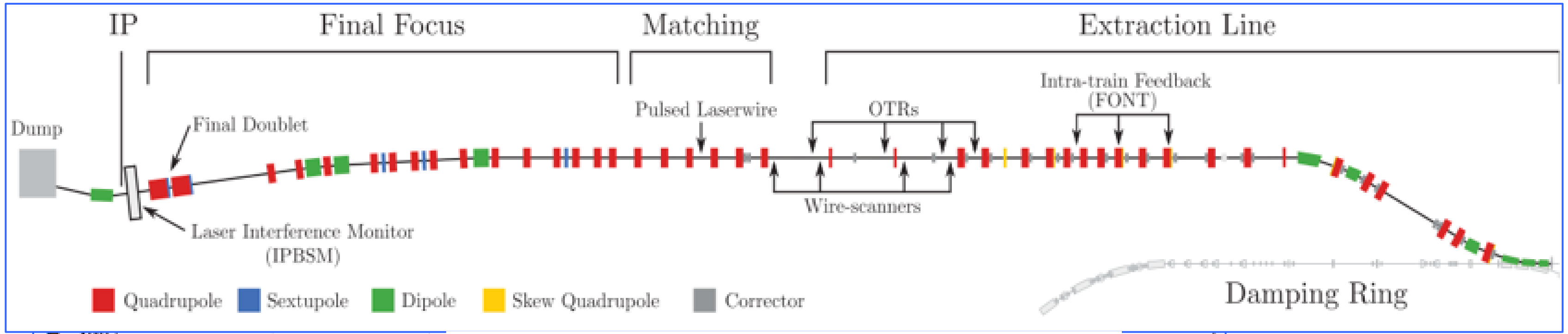
Nano-beam R&D at ATF2

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

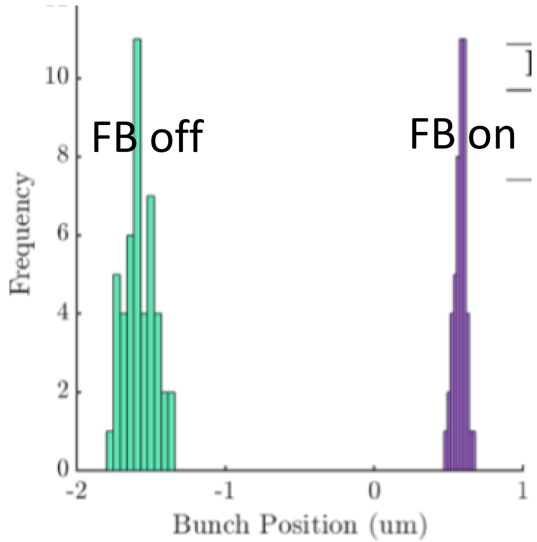
ATF2 Goal : **37** nm → ILC **7.7** nm (ILC250); achieved **41 nm** (2016)

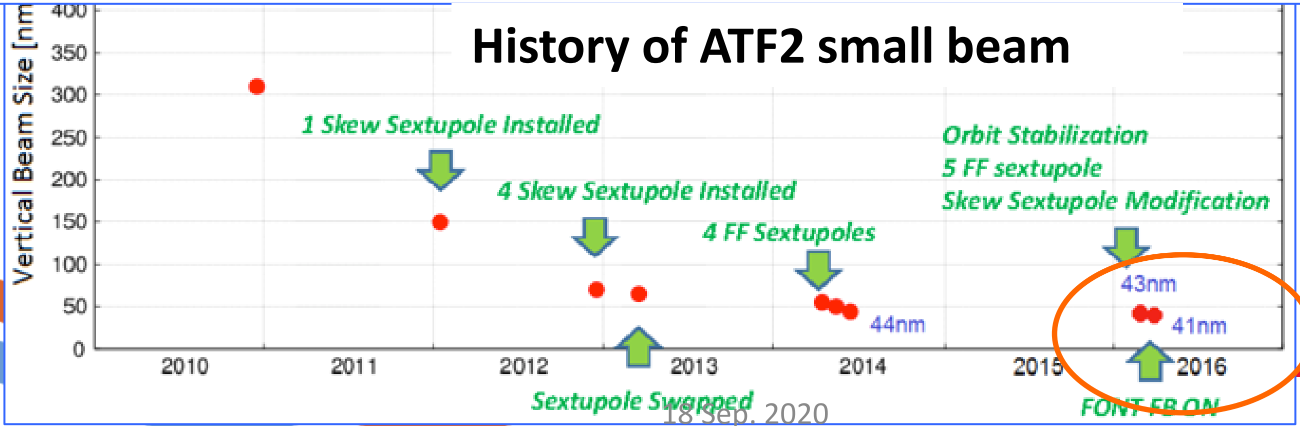
Goal 2: Develop the position stabilization for the ILC collision

- **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)



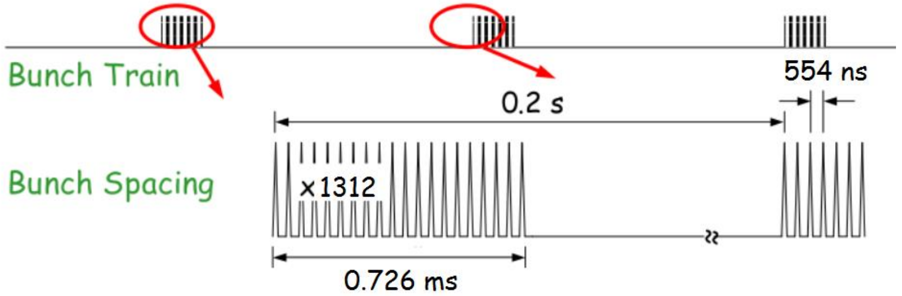


FONT* Bunch train feedback at final focus

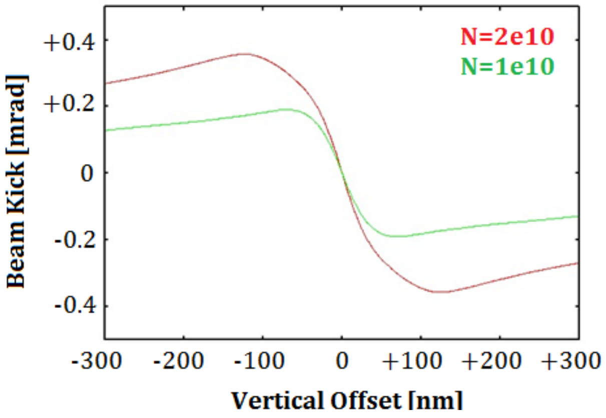
*Feedback On Nanosecond Timescales by Oxford University

https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.21.122802

ILC bunch structure

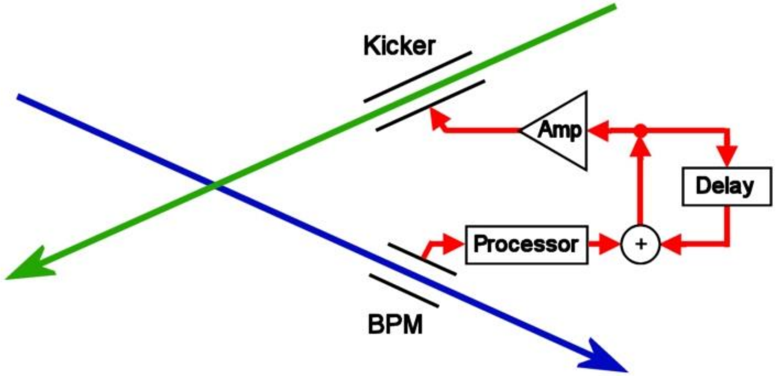


CAIN simulation



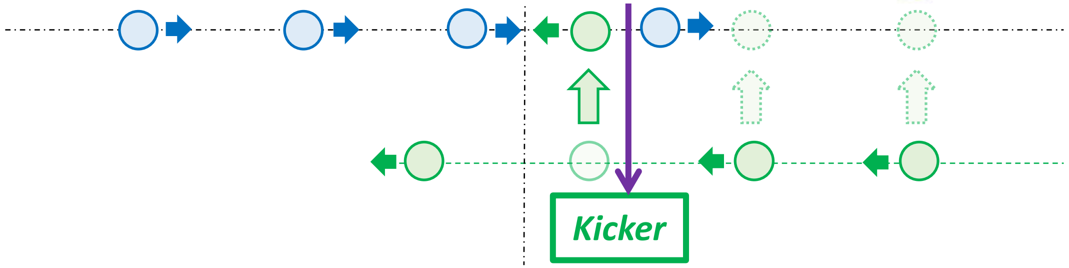
Depending on the relative position of the beam, beams are greatly scattered by the beam-beam effect.

The position of the beam between pulses shifts due to ground vibrations and equipment noise.
On the other hand, the position of the beam does not change significantly inside the bunch train.



Efficient beam collision can be achieved with high-speed feedback that measures the initial beam position of the bunch train and corrects the position of subsequent bunches in the train.

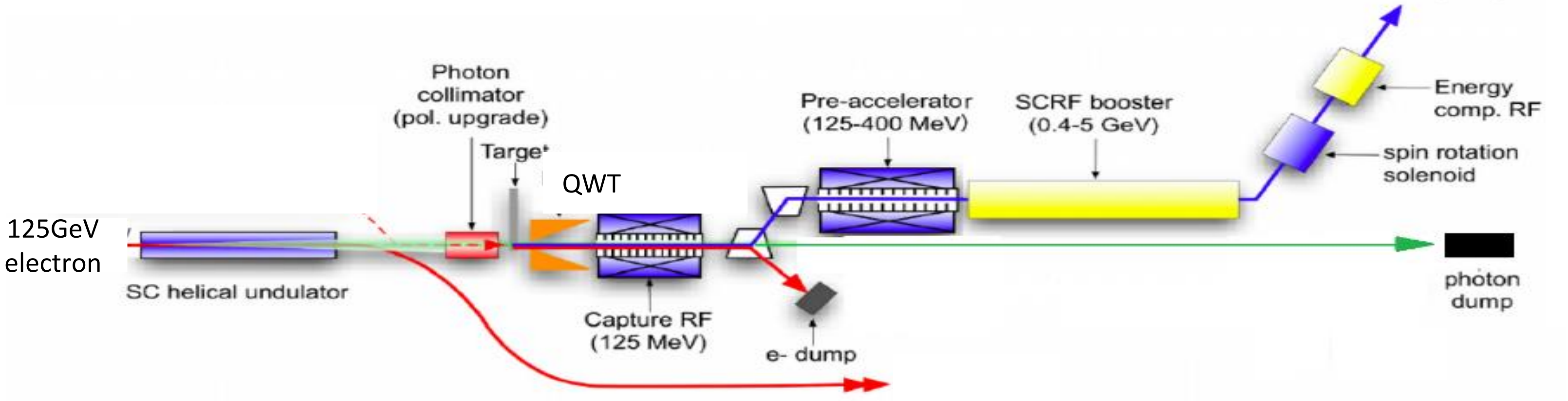
Feedback latency should be less than bunch space.

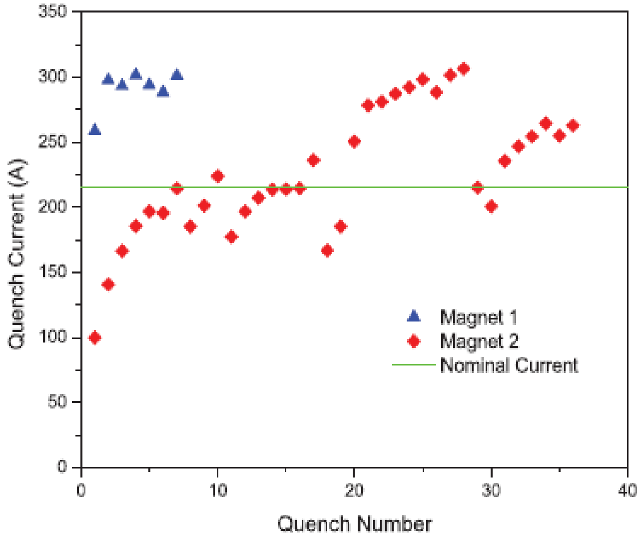


The first bunch does not collide, but the second and subsequent bunches will collide.

Positron Source (Undulator)

125 GeV electrons are injected to the helical undulator. The photons produced at the undulator is used for the electron/positron pair creation at the rotating target. Polarized positrons can be generated.





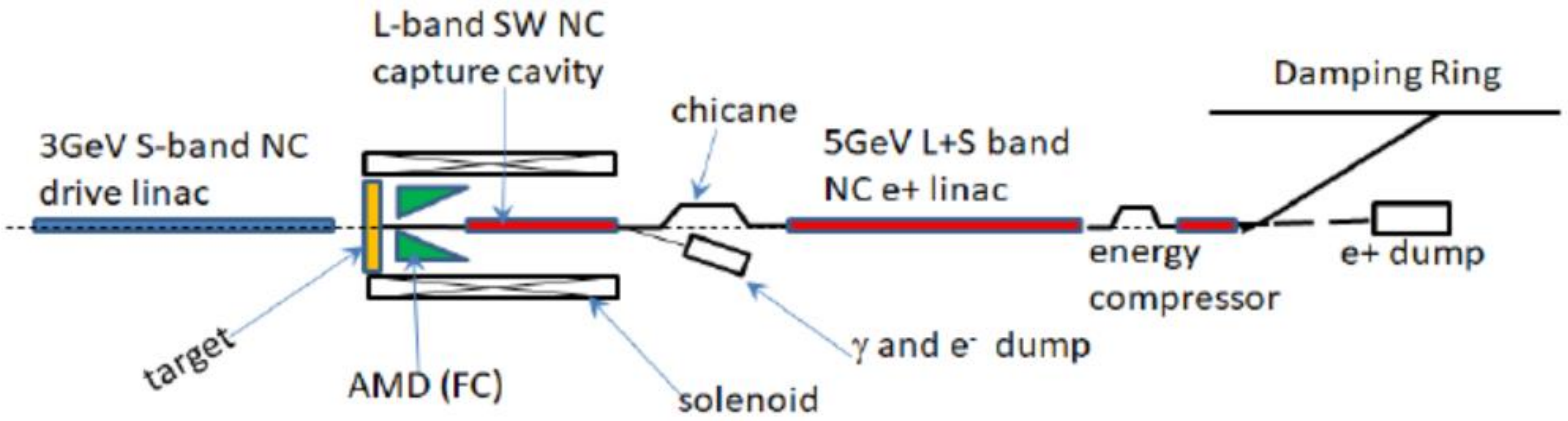
test at Daresbury

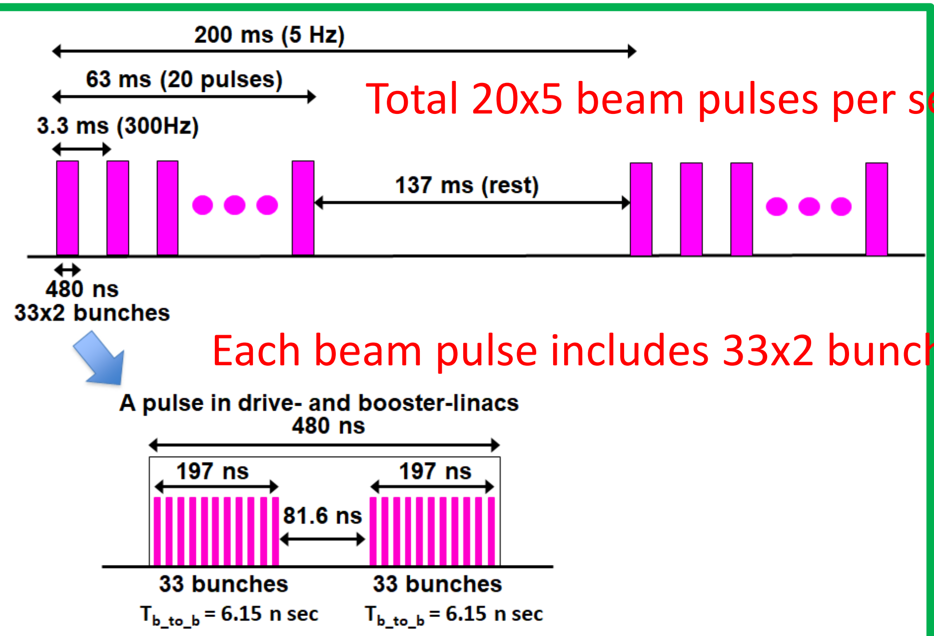
PHYSICAL REVIEW LETTERS 107 (2011) 174803

Two undulators in one cryomodule were tested. Both achieved nominal magnetic fields.

Positron Source (e-Driven)

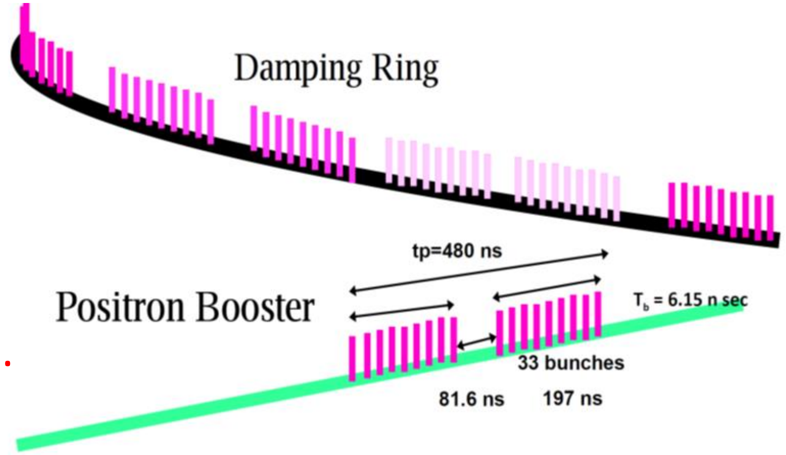
Extra 3GeV linac is used for the positron generation. High energy electrons are not necessary. (Electron independent commissioning is possible. However, polarization is not available.)



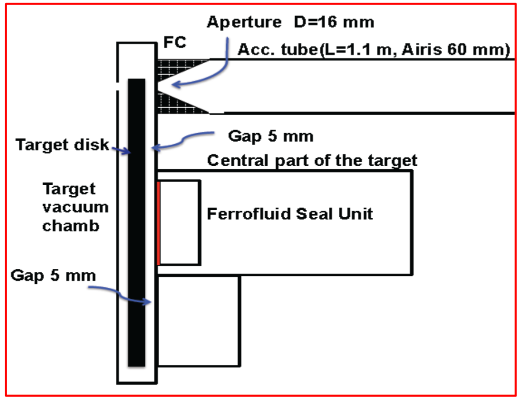


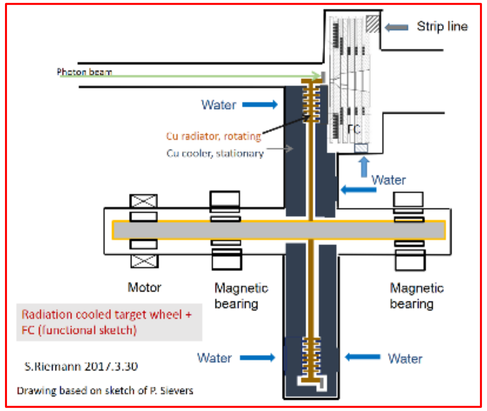
Total 20x5 beam pulses per sec.

Each beam pulse includes 33x2 bunches.



Positron rotating target





	undulator	E-Driven	Existing X-ray generator
Cooling/Seal	Radiation/ magnetic levitation	water/magnetic fluid	water/magnetic fluid
radius（ｍｍ）	500	250	160
weight（kg)	50*	65*	17
Tangential velocity（m/s)	100	5	160
rotation (rpm)	2,000	200	10,000
Beam heat load(kW)	2	20	90
Vacuum pressure（Pa)	10^{-6}	10^{-6}	10^{-4}

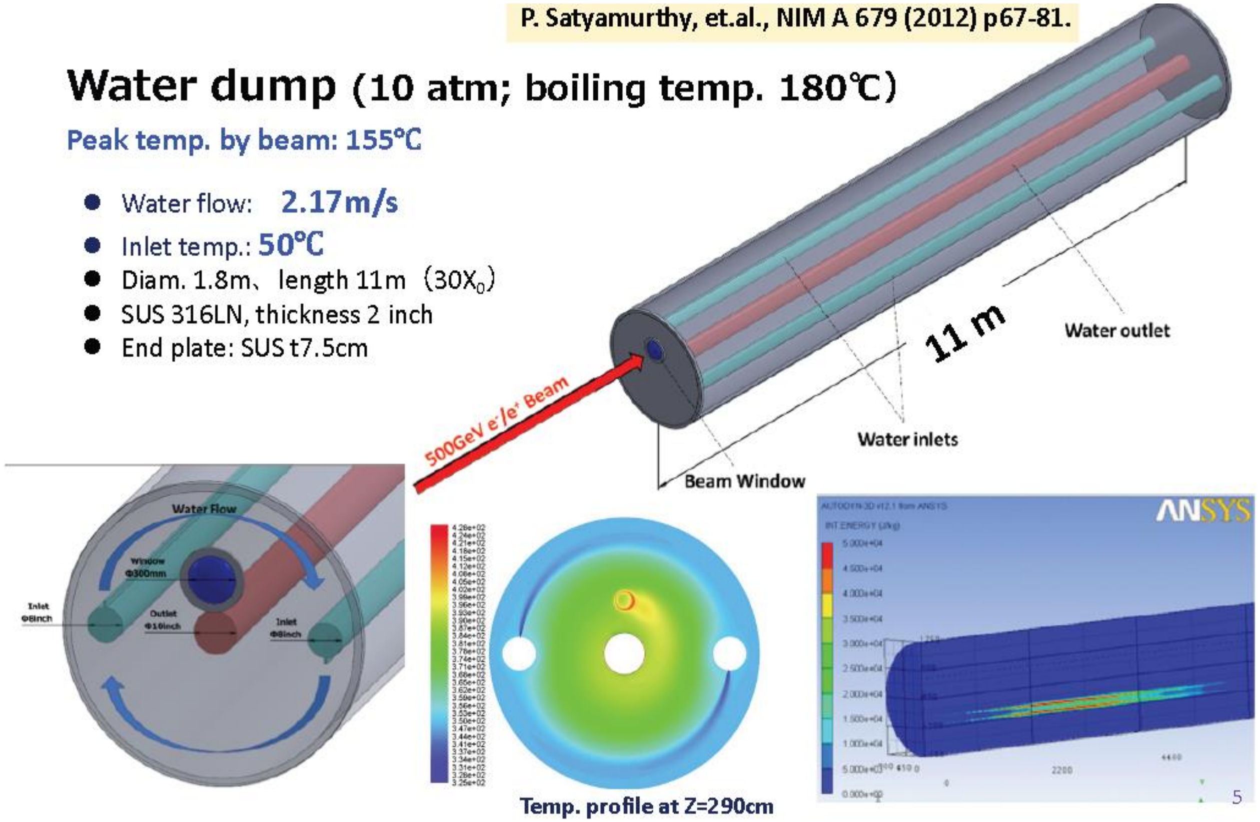
*The weight depends on the design of the disk part and the material

- Reliable rotating target
- Replacement of rotating target

Technical preparation at Pre-lab phase

Beam dump

- ILC beam dump is designed for 1TeV collision energy, and ILC250 has enough margin.



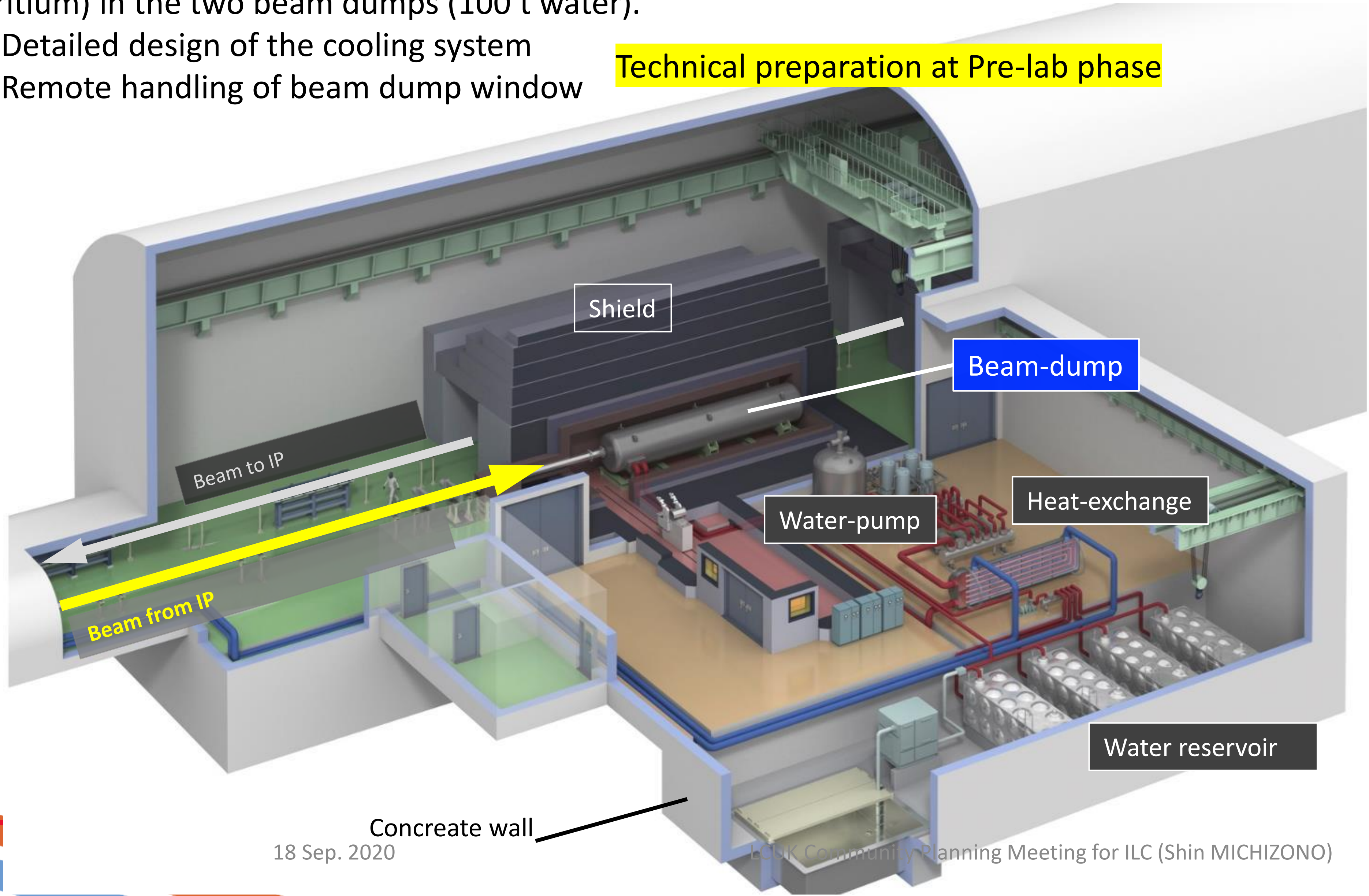
Water beam dump	Req.	Des.	Achieved	unit	Comment
ILC 250GeV	2.6	17	-	MW	Designed for 500GeV beam
SLAC 2mile LINAC	-	2.2	0.75	MW	**ILC beam dump prototype**
CEBAF	0.9	1.0	0.73	MW	In operation at Jefferson Lab from the 90s to the present. 2 units (2 beam lines). Composite type with aluminum plates arranged in water.

Beam dump system

Tritium is generated in the water beam dump. Saturated value is expected ~100 TBq (~0.3g tritium) in the two beam dumps (100 t water).

- Detailed design of the cooling system
- Remote handling of beam dump window

Technical preparation at Pre-lab phase



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Construction cost

ILC accelerator (including tunnel) construction cost is ~5 B$ [1,2,8,9].

	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**

Accelerator construction

Operation cost

Preparation cost

*1 ILCU= 1 US$ in 2012 prices

Timeline

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

	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.																

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Accelerator activities at ILC Pre-lab phase

Technical preparations /performance & cost R&D [shared across regions]

- SRF performance R&D
- Positron source final design and verification
- Nanobeams (ATF3 and related): Interaction region: beam focus, control and Damping ring: fast kicker, feedback
- Beam dump: system design, beam window, cooling water circulation
- Other technical developments considered performance critical

Technical preparation

Final technical design and documentation [central project office in Japan with the help of regional project offices (satellites)]

- Engineering design and documentation, WBS
- Cost confirmation/estimates, tender and purchase preparation, transport planning, mass-production planning and QA plans, schedule follow up and construction schedule preparation
- Site planning including environmental studies, CE, safety and infrastructure (see below for details)
- Review office
- Resource follow up and planning (including human resources)

Engineering Design Report (EDR)

Preparation and planning of deliverables [distributed across regions, liaising with the central project office and/or its satellites]

- Prototyping and qualification in local industries and laboratories, from SRF production lines to individual WBS items
- Local infrastructure development including preparation for the construction phase (including Hub.Lab)
- Financial follow up, planning and strategies for these activities

Mass-production

CE, local infrastructure and site [host country assisted by selected partners]

- Engineering design including cost confirmation/estimate
- Environmental impact assessment and land access
- Specification update of the underground areas including the experimental hall
- Specification update for the surface building for technical scientific and administrative needs

Civil engineering

ILC250 accelerator

Speaker: Shin MICHIZONO
International Development Team (IDT) WG2/ KEK

- *ILC250 accelerator overview*
- *ILC250 beam parameters and possible upgrades*
- *Main advantages, technical maturity*
- *Key technologies*
  - *SRF*
  - *Nano-beam*
  - *Positron source*
  - *Beam dump*
- *Construction cost and schedule*
- *ILC Pre-Lab activity*
- *Summary*

Summary

- *ILC250 accelerator 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.*
- *Preparation phase activities are*
  - *Technical preparation*
  - *Final engineering design*
  - *Preparation for mass production, …*

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Thank you for your attention