Accelerating Electrons

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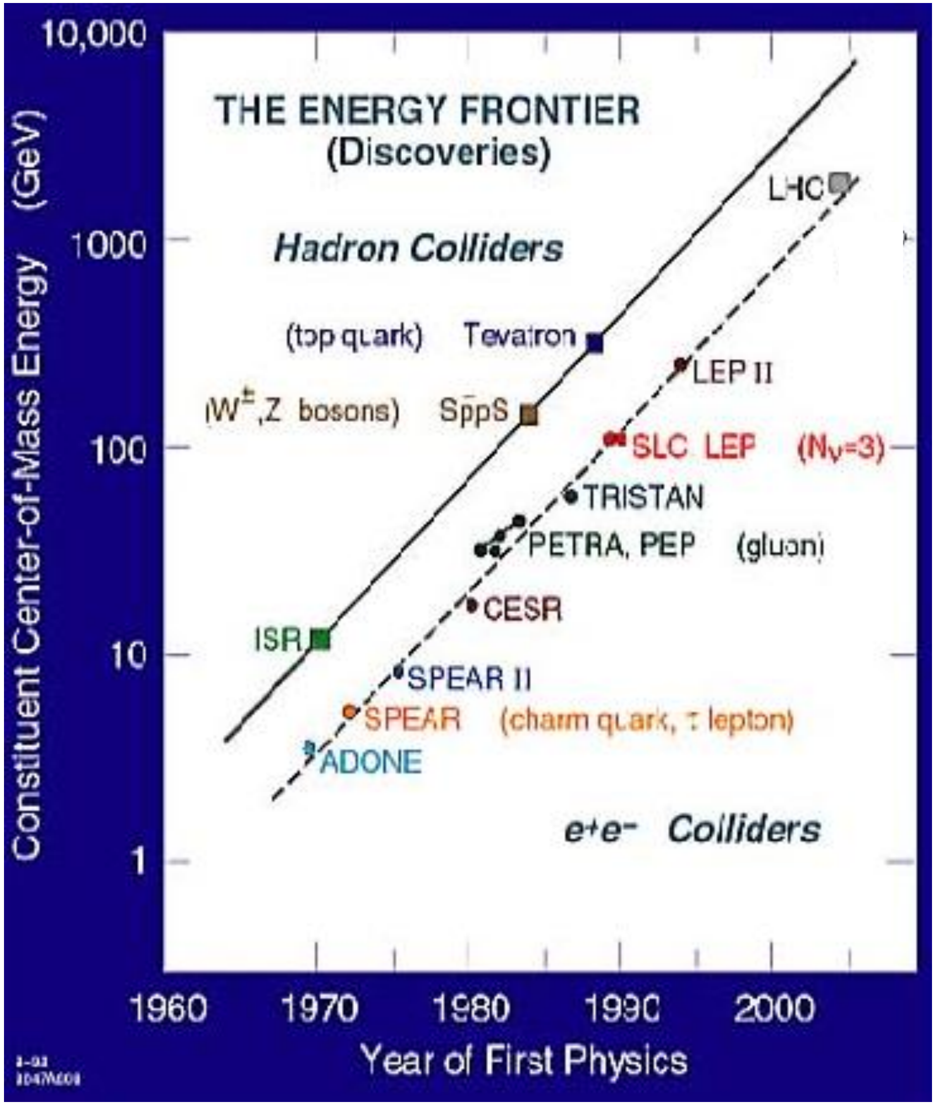
2013 SLAC Summer Institute

10 July 2013

Energy Frontier e+e- Colliders

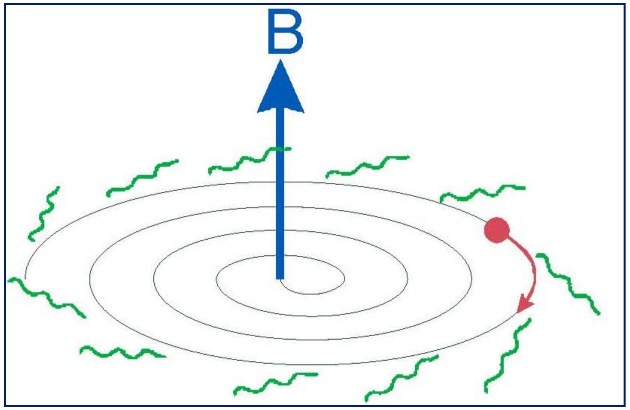


LEP-II at CERN
E_{cm} = 209 GeV
P_{rf} = 30 MW

Why a Linear Collider?

Synchrotron Radiation from an electron in a magnetic field

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



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

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

Energy loss must be replaced by RF system

Cost scaling $$

* Linear Costs: (tunnel, magnets, etc.)

$$\$_{lin} \sim \rho$$

* RF costs:

$$\$_{RF} \sim \Delta E \sim E^4 / \rho$$

* Optimum at

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

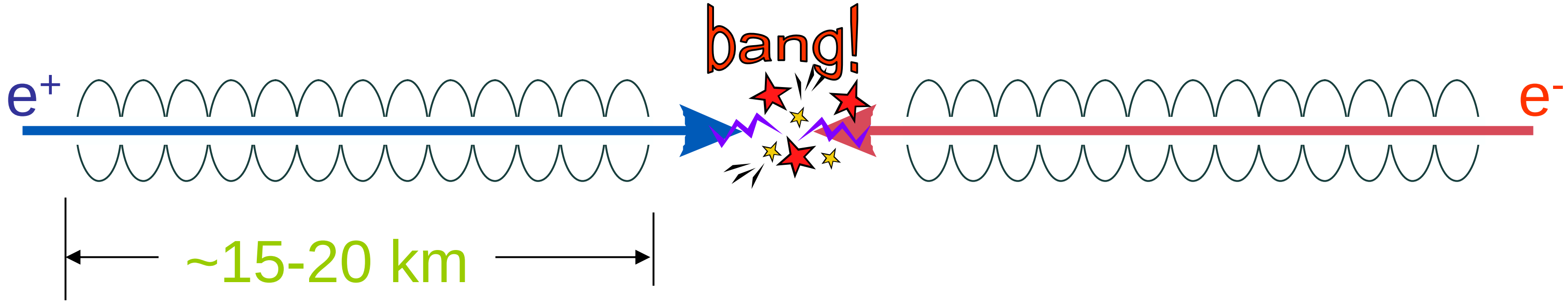
Optimized cost ($\$_{lin} + \$_{RF}$) scales as E^2

The bottom line $$$

		LEP-II	TLEP-350 GeV	Hyper - LEP
E_{cm}	GeV	209	350	2000
L	km	27	80	3200
ΔE	GeV	3.4	9.2	240
$\$_{tot}$	10^9 SF	2	10	240

Solution: Linear Collider

Two Linacs, No Bends!



For a E_{cm} = 1 TeV machine:

Effective gradient G = 500 GV / 15 km

= 34 MV/m real-estate gradient

Cost scaling: storage ring $\$_{tot} \propto E^2$

linear collider $\$_{tot} \propto E$

The Beginning – *an idea*

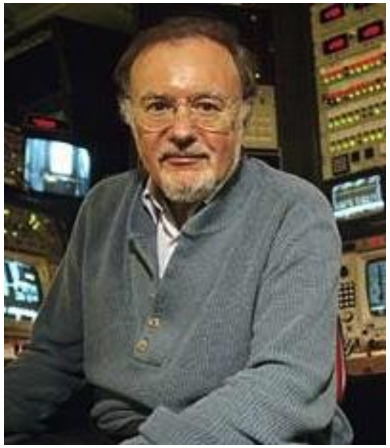
A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

M. Tigner,
Nuovo Cimento 37 (1965) 1228

"While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable."



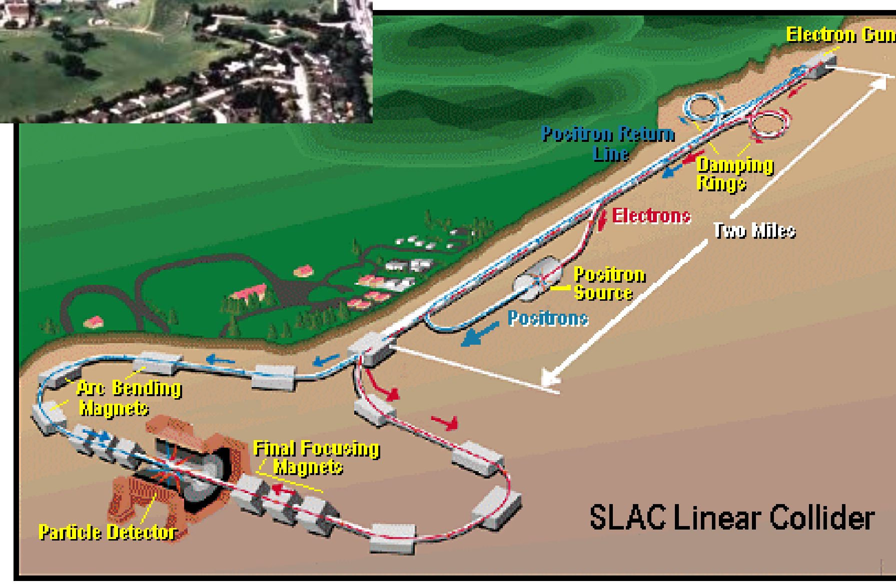
The real Beginning was at SLAC

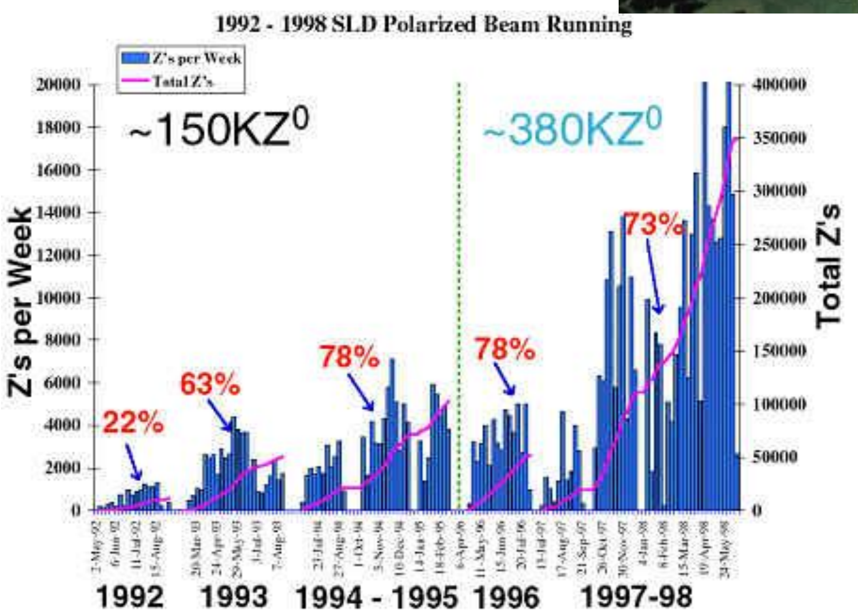
Burt Richter

SLAC Linear Collider (SLC)

1988-1998

A proof of principle





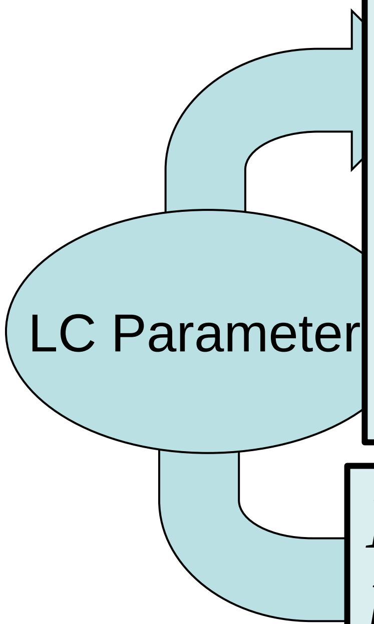
Achieved $\sigma^x \times \sigma^y$ = 1/3 of design

Linear Collider History (1988-2013)

* SLC (SLAC, 1988-98)
* FFTB (SLAC, 1992-1997)
* NLCTA (SLAC, 1997-)
* SBTF (DESY, 1994-1998)
* TTF (DESY, 1994-, now FLASH)
* CLIC CTF 1,2,3 (CERN, 1994-)
* ATF (KEK, 1997-)
* STF (KEK, 2006-)
* ATF-II (KEK, 2007-)
* NML/ASTA (FNAL, 2007-)

More than 25 Years of Linear Collider R&D

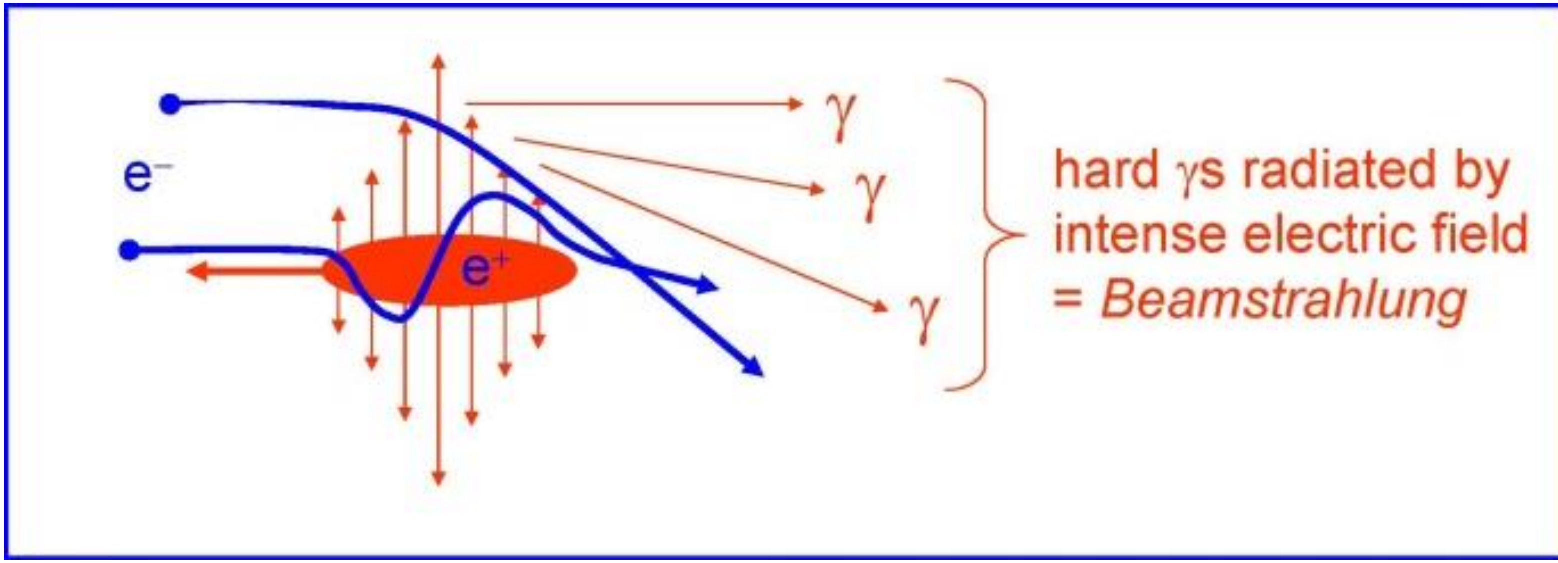
Linear Collider Design Issues



L – Luminosity: Effectiveness of collider
N – particles in a bunch
n_b – bunches in a machine pulse
f_{rep} – pulses per second
$\sigma_{x,y}$ – x (and y) beam sigma at IP
H_D – disruption of one beam caused by the fields of the other

E_{CM} – collision Center of Mass Energy
$b_{\_fill}$ – the fraction of the machine length actually used for acceleration
$L_{\_linac}$ – the length of the linac
$G_{\_RF}$ – the average accelerating gradient

Another Luminosity Issue: Beamstrahlung



RMS relative energy loss $\delta_{BS} \approx 0.86 \frac{e r_e{}^2}{2 m_0 c^2} \left(\frac{E_{cm}}{\sigma_z}\right) \frac{N^2}{(\sigma_x + \sigma_y)^2}$

Need $\sigma_x * \sigma_y$ small to maximize luminosity

but $(\sigma_x + \sigma_y)$ large to reduce δ_{BS}

=> "flat beams" with $\sigma_x \gg \sigma_y$ and σ_y as small as possible

Luminosity Scaling Law

RF→beam power efficiency

$$L \mu \frac{hP_{RF}}{E_{CM}} \sqrt{\frac{d_{BS}}{e_{y}}}$$

Beamstrahlung (physics)

Vertical emittance

The *Luminosity* Issue

* High Beam Power
  * High current (n_b N)
  * High efficiency ($P_{RF} \rightarrow P_{beam}$)

* Small IP vertical beam size
  - Small emittance ε_y
  - strong focusing (small β^*_y , σ^*_y ~ nm)

The *Luminosity* Issue

Superconducting RF Linac Technology

(SCRF)

* High current (n_b N)
* High efficiency ($P_{RF} \rightarrow P_{beam}$)

- Small emittance ε_y
- strong focusing (small β^*_y)

1^{st} LC Technology Review - 1994

Only one scheme (of 8) was superconducting

E_{cm}=500 GeV

	TESLA	SBLC	JLC-S	JLC-C	JLC-X	NLC	VLEPP	CLIC
f [GHz]	1.3	3.0	2.8	5.7	11.4	11.4	14.0	30.0
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	6	4	4	9	5	7	9	1-5
P_{beam} [MW]	16.5	7.3	1.3	4.3	3.2	4.2	2.4	~1-4
P_{AC} [MW]	164	139	118	209	114	103	57	100
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	100	50	4.8	4.8	4.8	5	7.5	15
σ_y^* [nm]	64	28	3	3	3	3.2	4	7.4

International Technology Review Panel

International Committee for Future Accelerators (ICFA) representing major particle physics laboratories worldwide convened a panel to choose between SC and X-band for the collider technology.

In Beijing 2004, they chose SCRF accelerator technology and in 2005, formed the Global Design Effort (GDE) for the ILC

By late 2004: only ILC and CLIC

E_{cm}=500-1000 GeV

	ILC	SBLC	JLC-S	JLC-C	JLC-X/NLC	VLEPP	CLIC
f [GHz]	1.3						30.0
$L\times10^{33}$ [$cm^{-2}s^{-1}$]	≥20						21
P_{beam} [MW]	5-23						4.9
P_{AC} [MW]	140-300						175
$\gamma\varepsilon_y$ [$\times10^{-8}$m]	3-8						1
σ_y* [nm]	3-8						1.2

the Big Jump from SLC to ILC

In Beam Power (P_{beam}) X 100,

collision beam size (σ^*_y) 1/100

and Luminosity (***L***) X 10^4

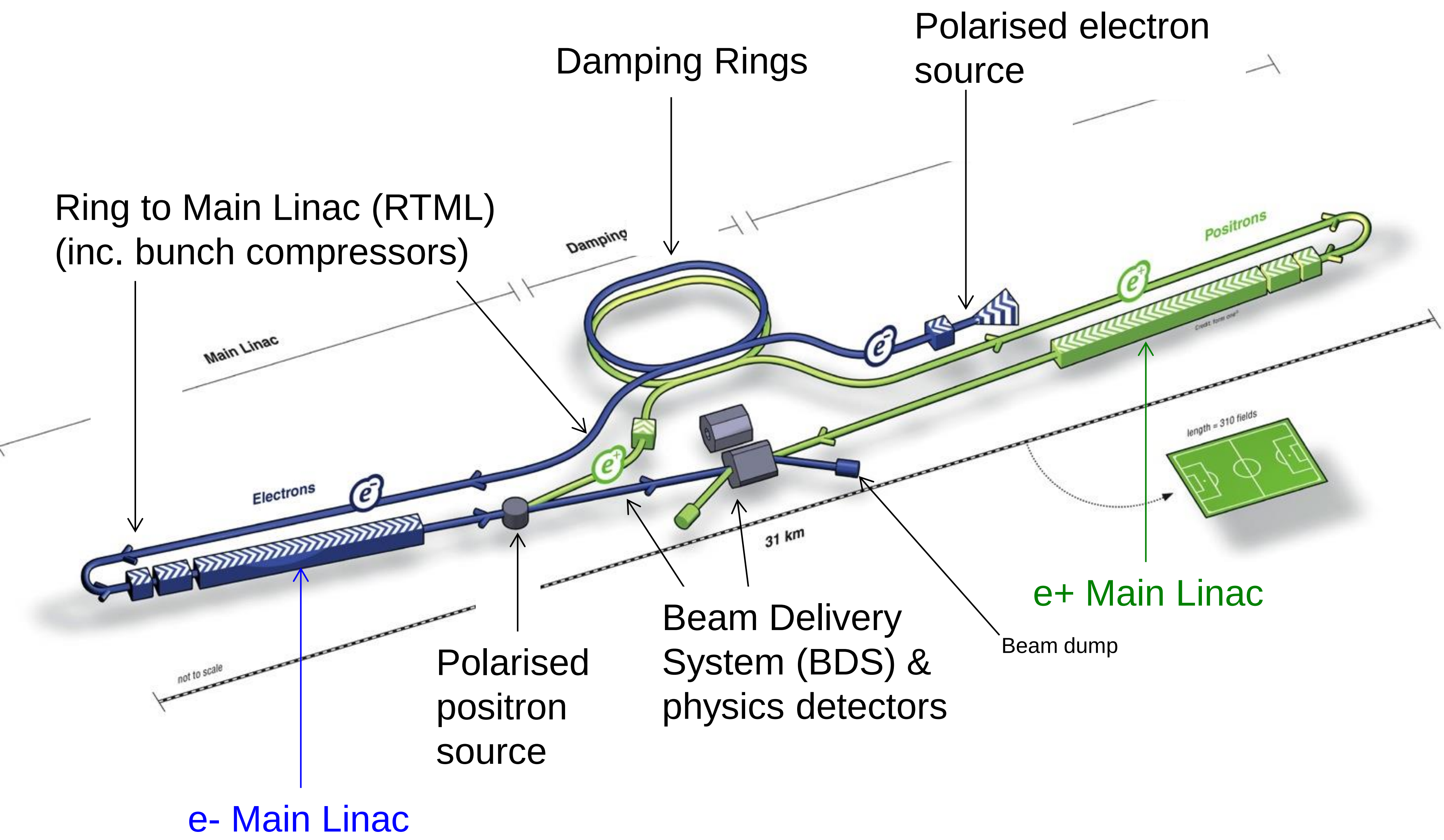
SLC / ILC Comparison

	SLC	ILC	
E_{cm}	100	500	GeV
P_{beam}	0.04	5	MW
σ^*_y	500	6	nm
$\delta E/E_{\mathrm{bs}}$	0.03	4	%
$\boldsymbol{L}$	**3×10^{-4}**	**1.8**	**10^{34} cm^{-2}s^{-1}**

ILC

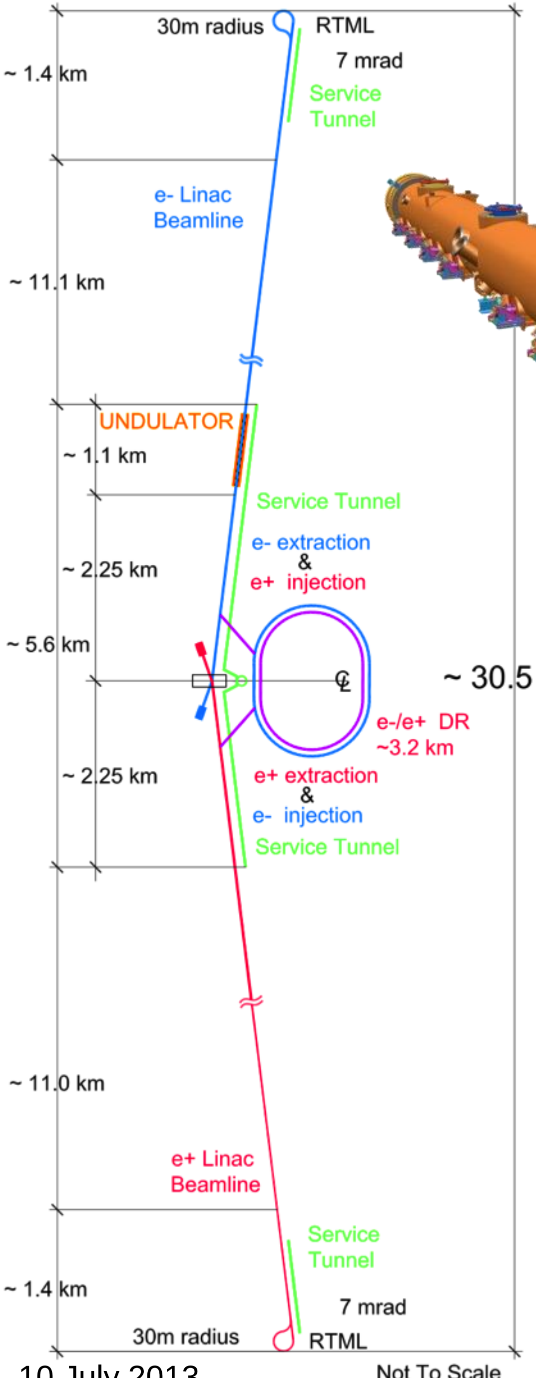
Slides courtesy of Nick Walker, Marc Ross and Akira Yamamoto

ILC in a Nutshell

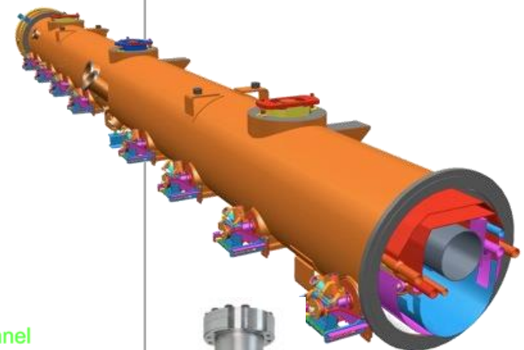


not to scale

ILC Scheme | © www.form-one.de



The ILC

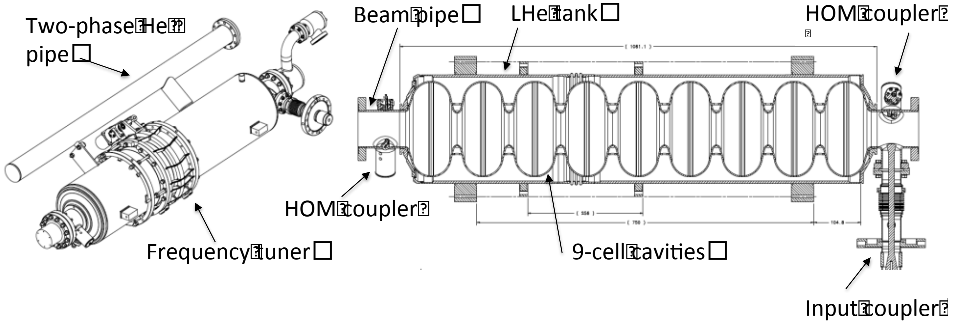


* 200-500 GeV E_{cm} e^+e^- collider
  L ~2×10^{34} $cm^{-2}s^{-1}$
  – upgrade: ~1 TeV
* SCRF Technology
  – 1.3GHz SCRF with 31.5 MV/m
  – 17,000 cavities
  – 1,700 cryomodules
  – 2×11 km linacs
* Developed as a truly global collaboration
  – **G**lobal **D**esign **E**ffort – **GDE**
  – ~130 institutes
  – http://www.linearcollider.org

500 GeV Parameters

Physics	Max. E_{cm}	500 GeV
	Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
	Polarisation (e-/e+)	80% / 30%
	δ_{BS}	4.5%
Beam (interaction point)	σ_x / σ_y	574 nm / 6 nm
	σ_z	300 μm
	$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
	β_x / β_y	11 mm / 0.48 mm
	bunch charge	2×10^{10}
Beam (time structure)	Number of bunches / pulse	1312
	Bunch spacing	554 ns
	Pulse current	5.8 mA
	Beam pulse length	727 μs
	Pulse repetition rate	5 Hz
Accelerator (general)	Average beam power	10.5 MW (total)
	Total AC power	163 MW
	(linacs AC power	107 MW)

SCRF Linac Technology

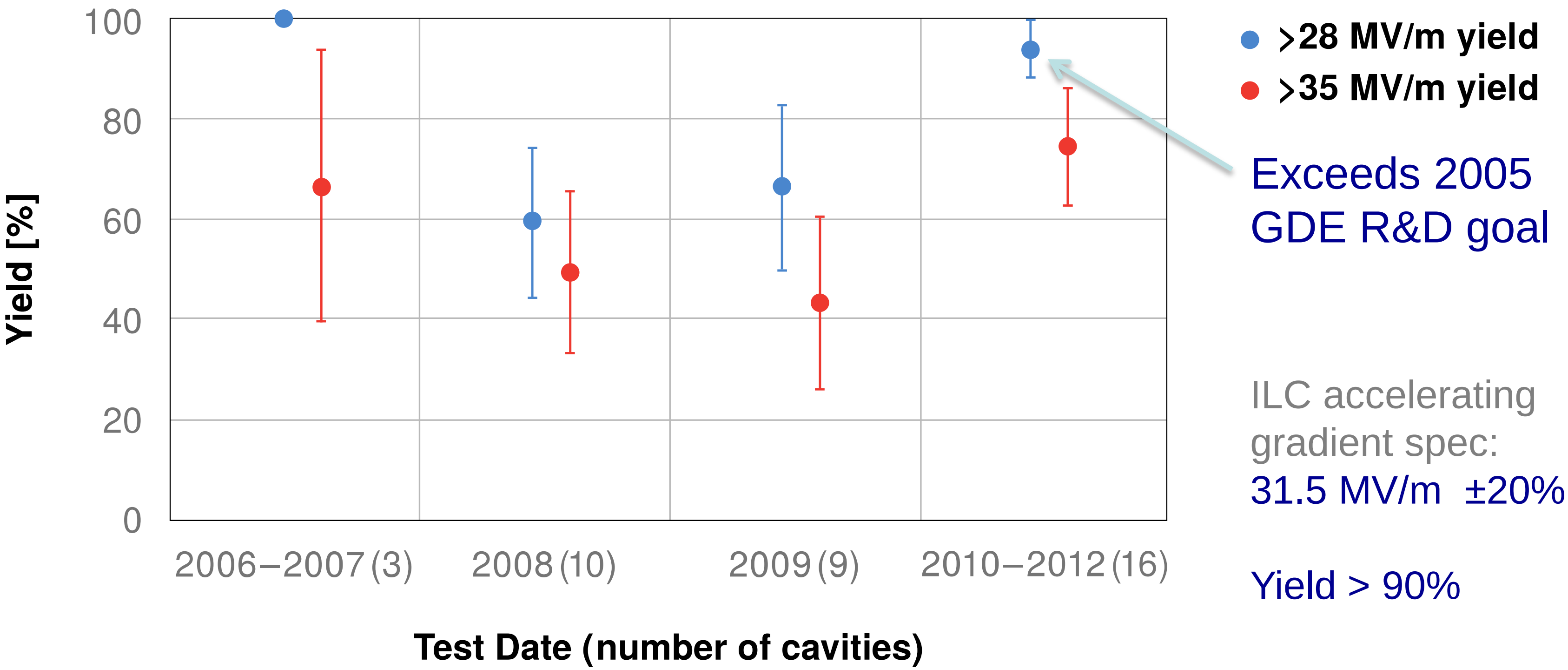


1.3 GHz Nb 9-cellCavities	16,024
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436 / 471 *

* site dependent

Approximately 20 years of R&D worldwide
→ Mature technology, overall design and cost

Progress in SCRF Cavity Gradient

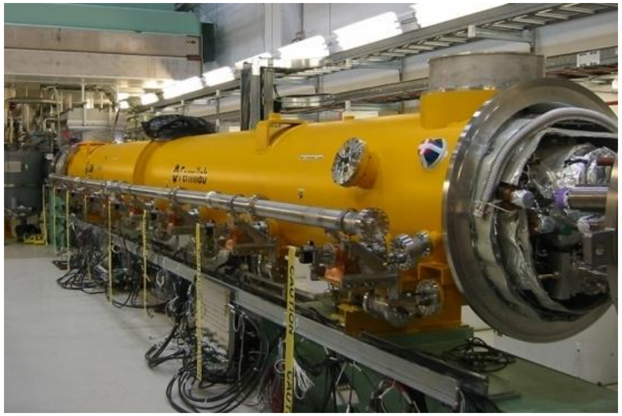


ILC accelerating gradient spec:
31.5 MV/m ±20%

Yield > 90%

GDE global database — Asia – KEK; Europe – DESY; US – JLab, FNAL, ANL
Qualified cavity vendors — Asia – 2; Europe – 2; US – 1

Worldwide Cryomodule Development

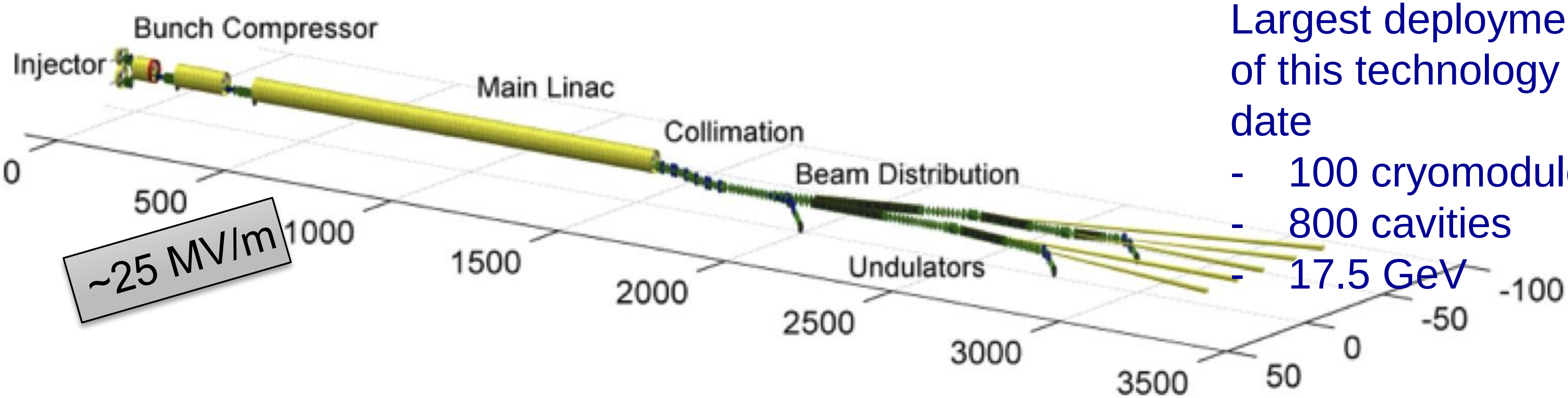


CM1 at FNAL NML module test facility

S1 Global at KEK SRF Test Facility (STF)

PXFEL 1 installed at FLASH, DESY, Hamburg

European XFEL @ DESY



Largest deployment of this technology to date

- 100 cryomodules
- 800 cavities
- 17.5 GeV

Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

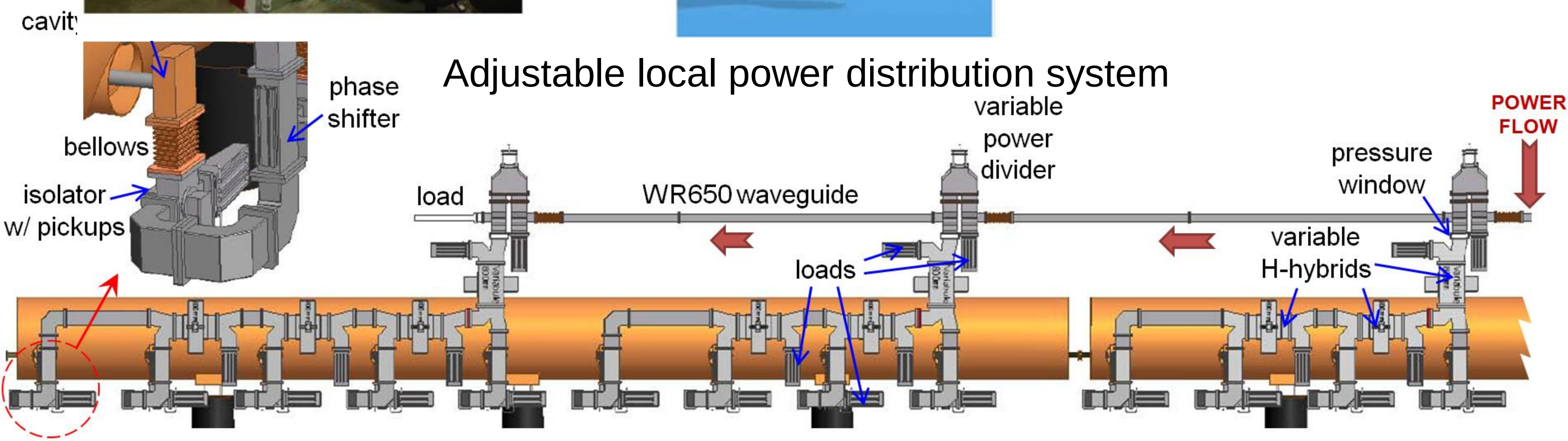
The ultimate 'integrated systems test' for ILC. Commissioning with beam 2nd half 2015

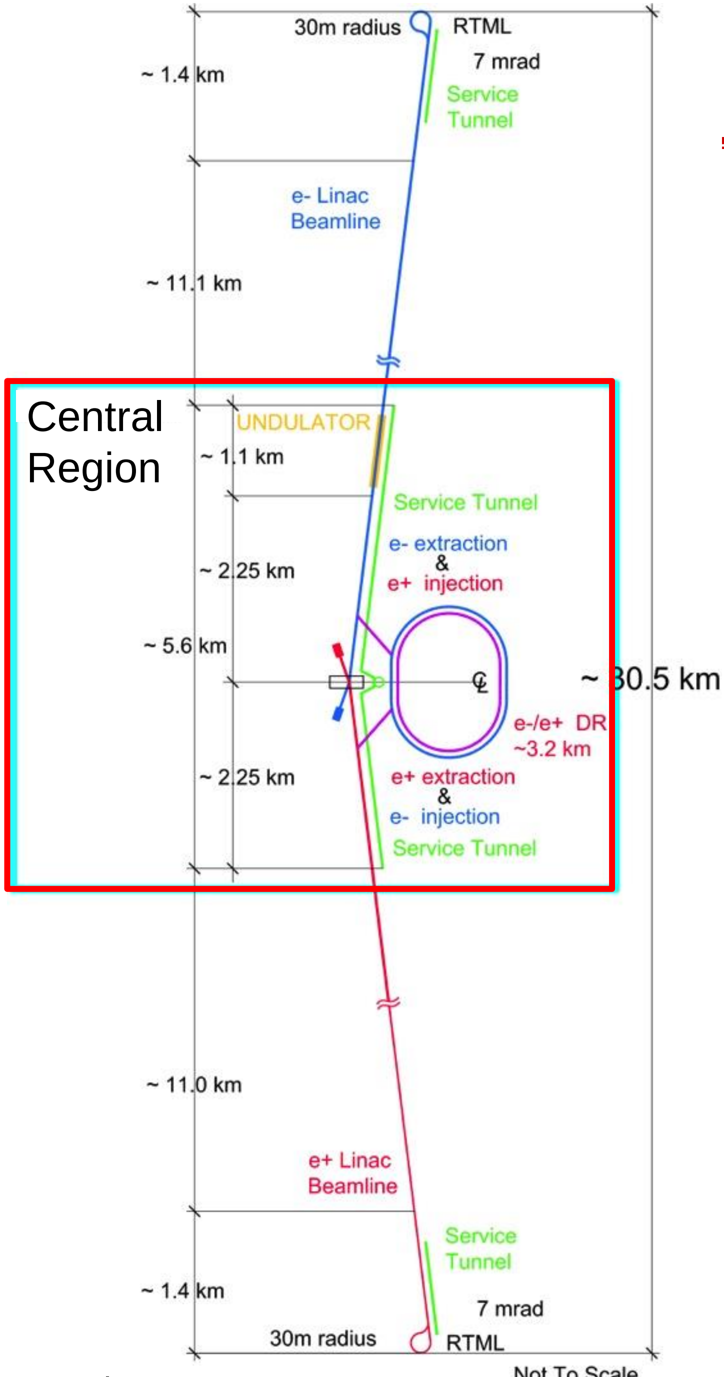
RF Power Source and Distribution

Marx modulator

10MW MB Klystron

Adjustable local power distribution system

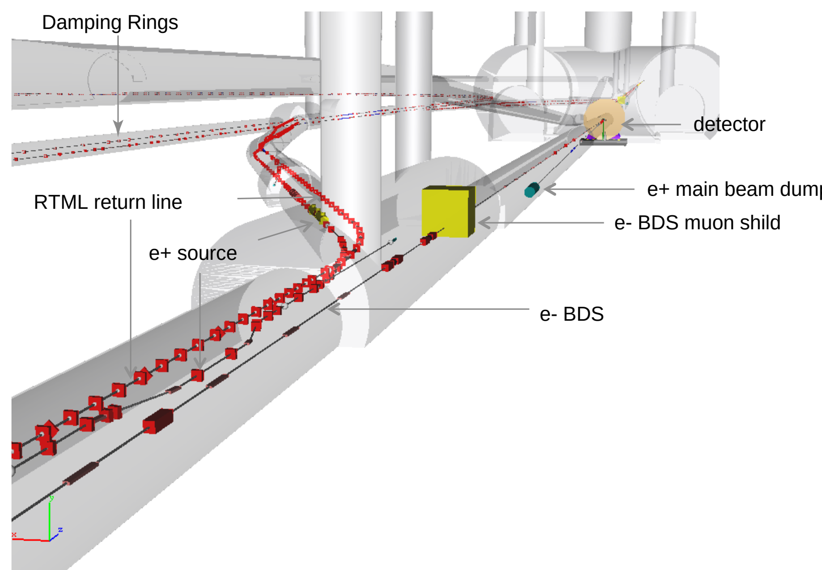




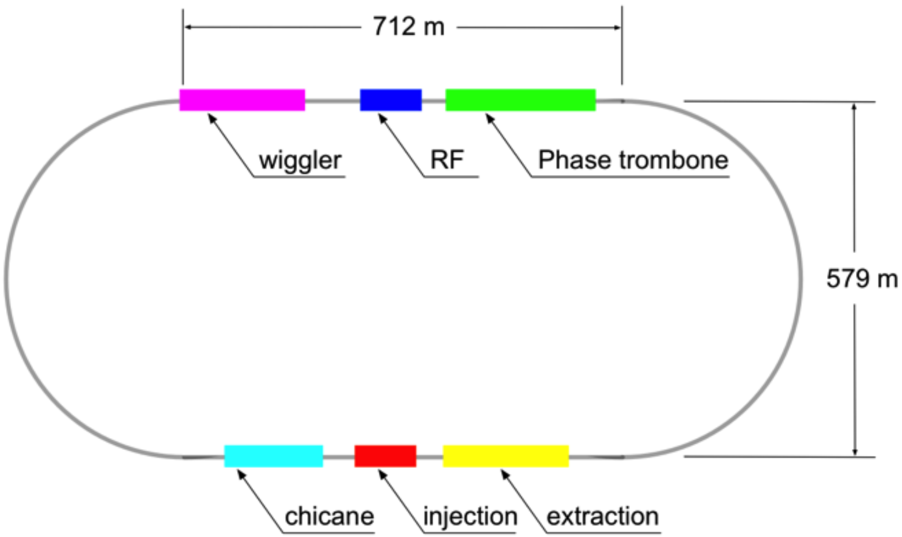
Central Region

- 5.6 km region around IR
- Systems:
  - electron source
  - positron source
  - beam delivery system
  - RTML (return line)
  - IR (detector hall)
  - damping rings
- Complex and crowded area

common tunnel



Damping Rings

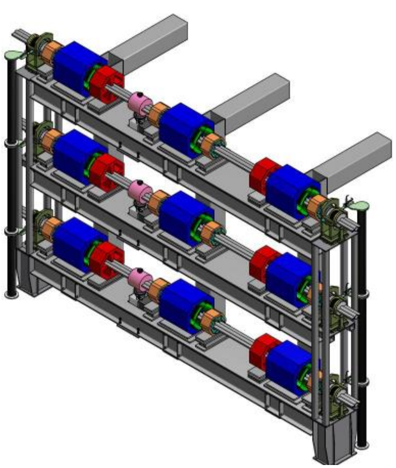


Circumference		3.2	km
Energy		5	GeV
RF frequency		650	MHz
Beam current		390	mA
Store time		200 (100)	ms
Trans. damping time		24 (13)	ms
Extracted emittance	x	5.5	µm
(normalised)	y	20	nm
No. cavities		10 (12)	
Total voltage		14 (22)	MV
RF power / coupler		176 (272)	kW
No.wiggler magnets		54	
Total length wiggler		113	m
Wiggler field		1.5 (2.2)	T
Beam power		1.76 (2.38)	MW

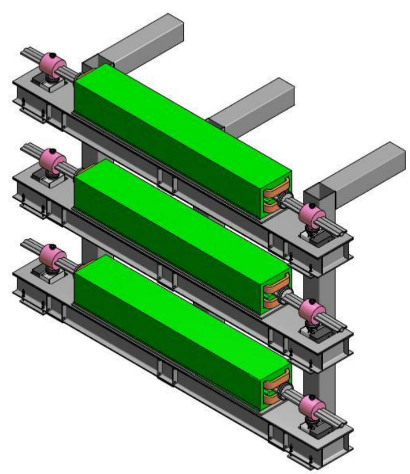
Positron ring (upgrade)

Electron ring (baseline)

Positron ring (baseline)



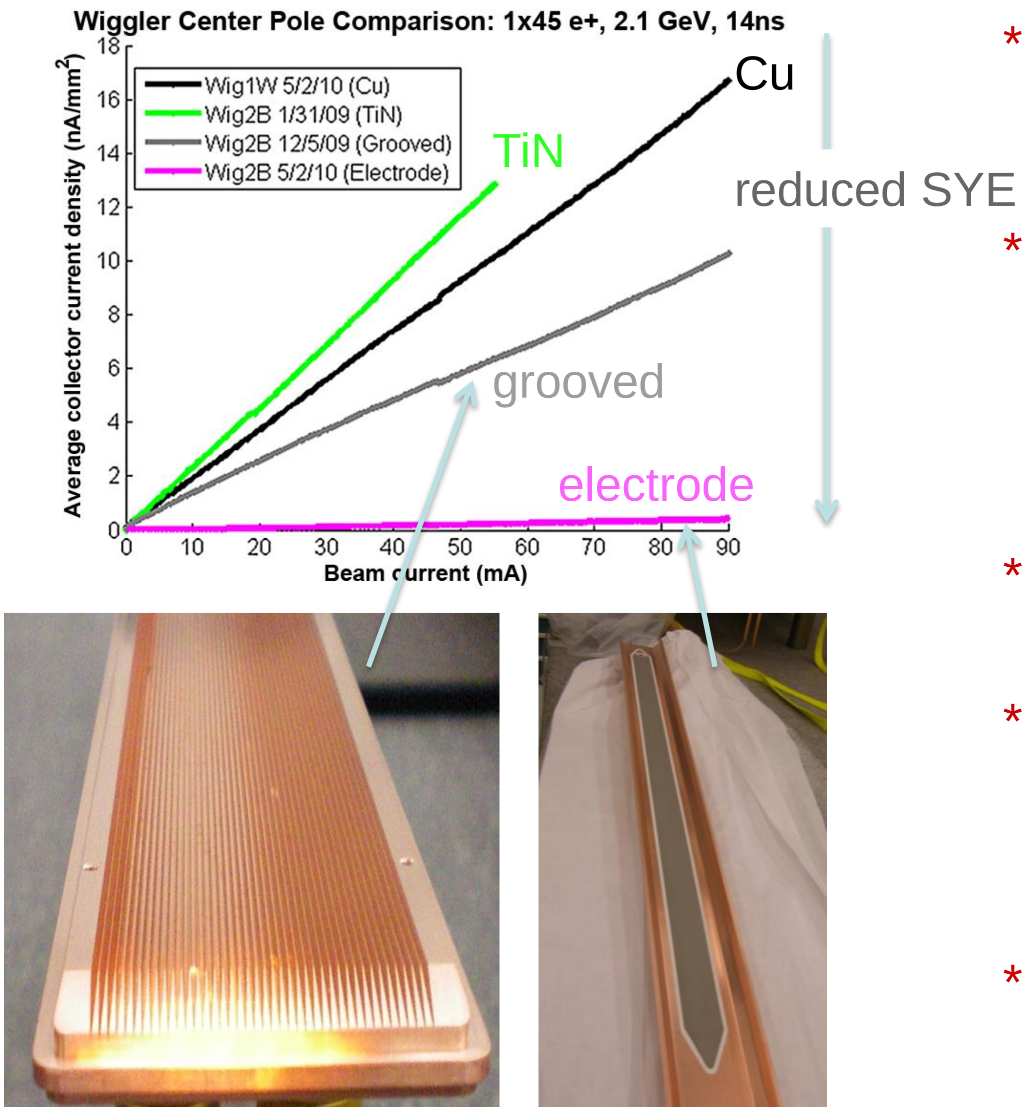
Arc quadrupole section



Dipole section

Many similarities to modern 3rd-generation light sources

Critical R&D: Electron Cloud



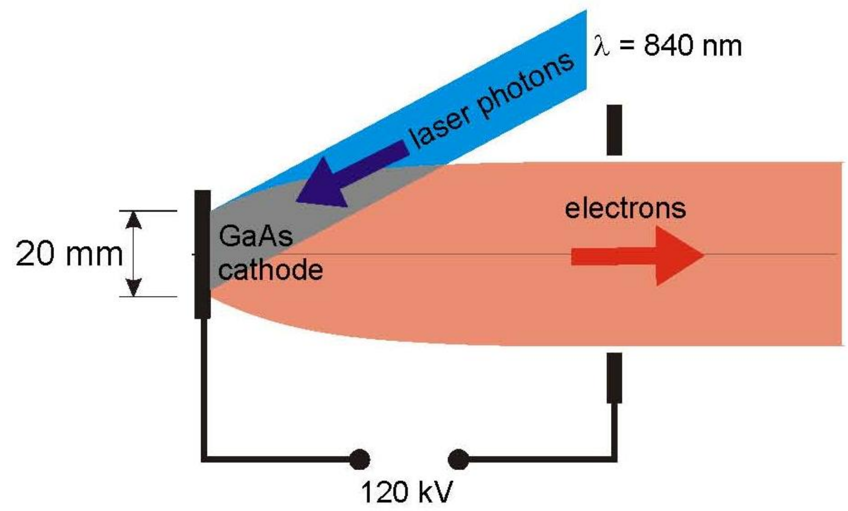
* Extensive R&D programme at CESR, Cornell (CesrTA)
* Instrumentation of wiggler, dipole and quad vacuum chambers for e-cloud measurements
  – RFA
* low emittance lattice
* Benchmarking of simulation codes
  – cloud build-up
  – beam dynamics (head-tail instabilities)
* Example: wiggler vacuum chamber

e- Source: DC Gun for Polarization

* No RF guns available to produce polarized beams

* Laser-driven photo injector
* Circularly-polarized photons on GaAs cathode

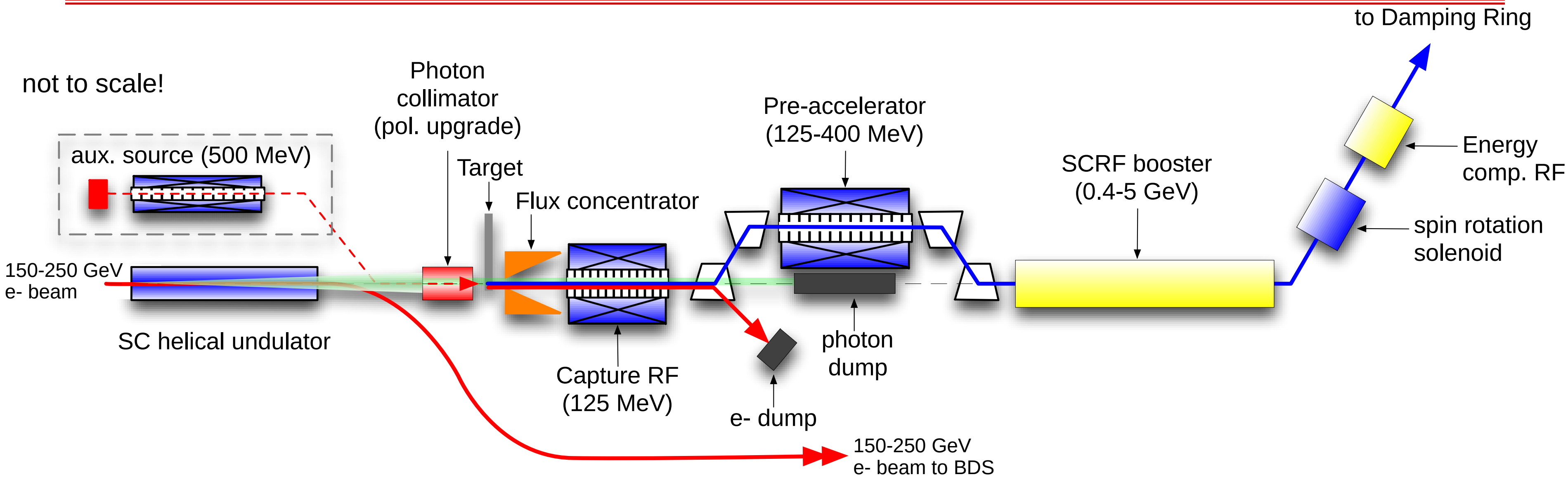
  → longitudinally polarized e-
* Laser pulse modulated to give required time structure
* Very high vacuum requirements for GaAs (< 10-11 mbar)
* Beam quality dominated by space charge



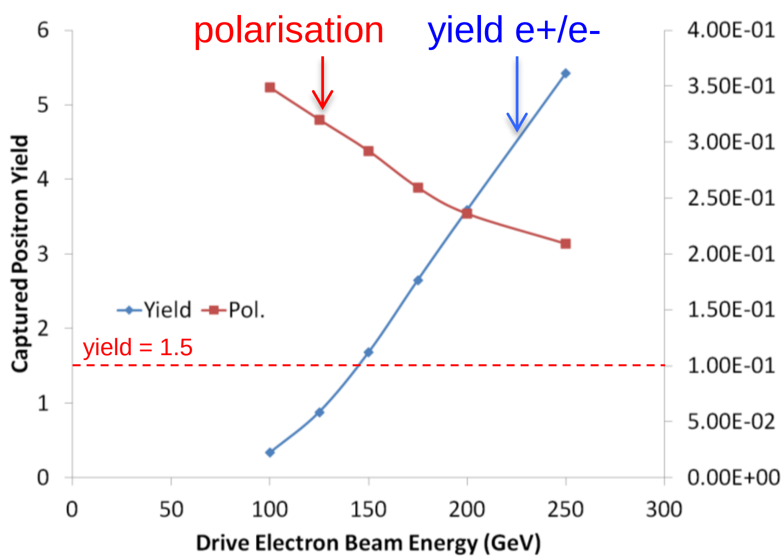
$\varepsilon_n \approx 10^{-5}$ m

factor 10 in x plane
factor ~ 500 in y plane

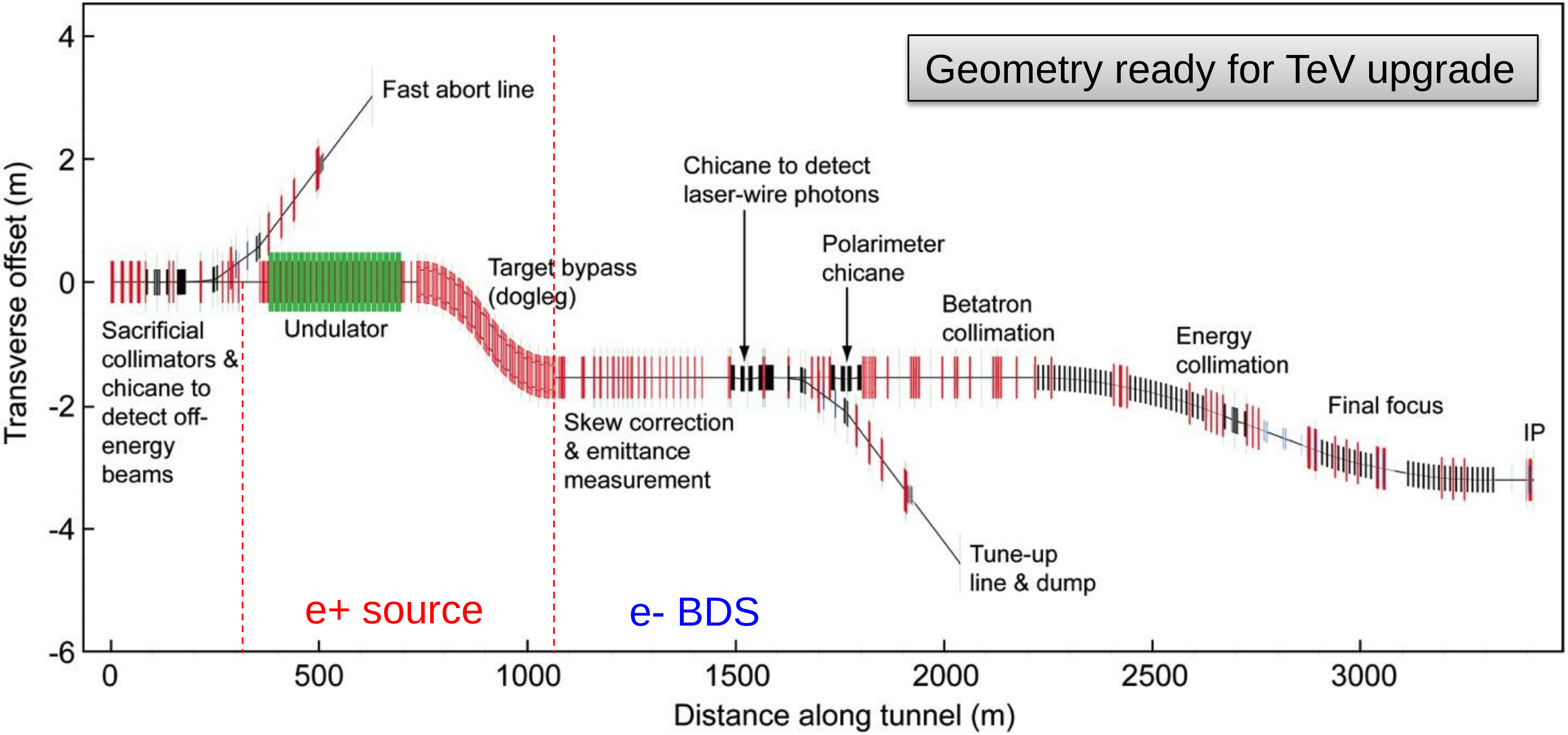
Positron Source (central region)



* located at end of electron Main Linac
* 147m SC helical undulator
* driven by primary electron beam (150-250 GeV)
* produces ~30 MeV photons
* converted in thin target into e+e- pairs



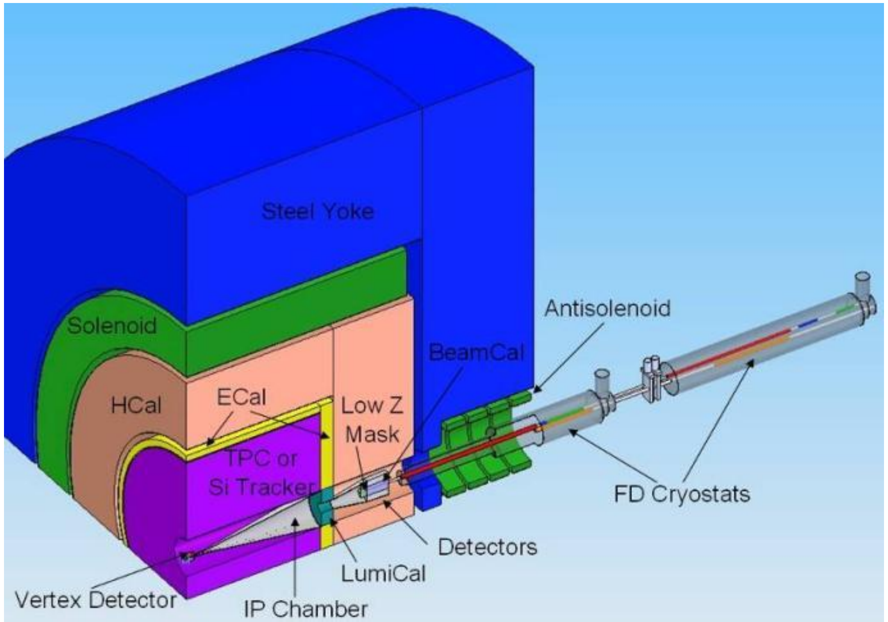
Beam Delivery System and MDI

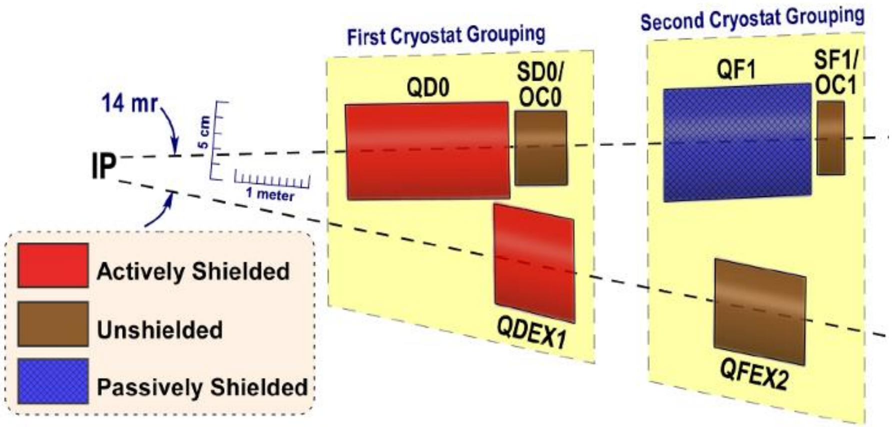


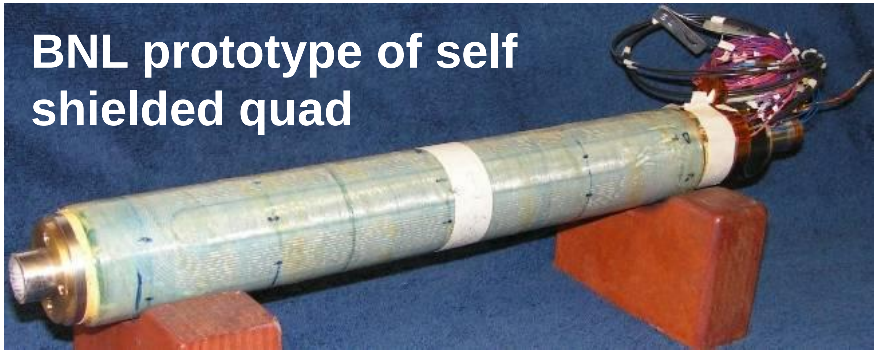
electron Beam Delivery System

IR region (Final Doublet)

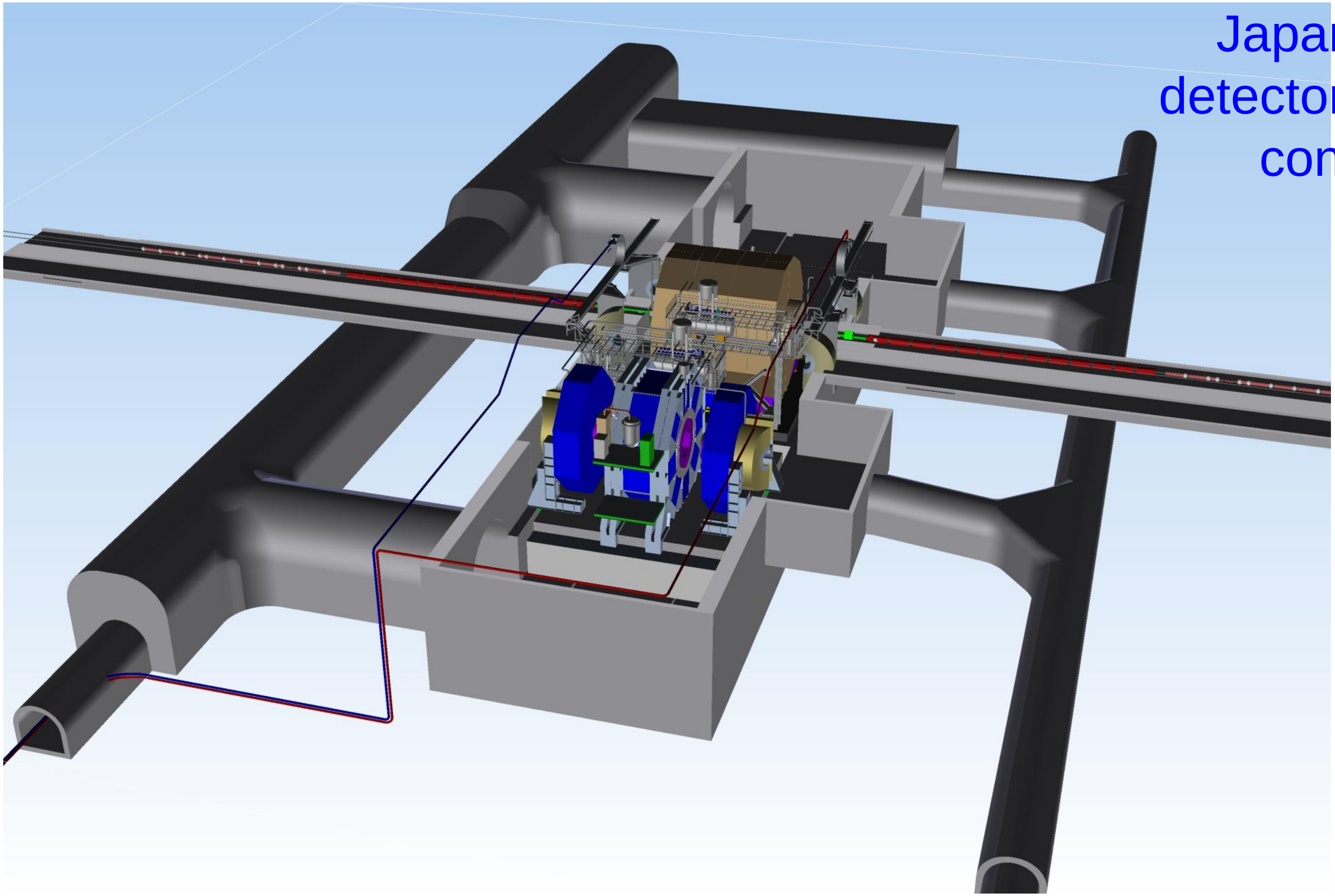
- FD arrangement for push pull
  - different L*
  - ILD 4.5m, SiD 3.5m
- Short FD for low E_{cm}
  - Reduced β_x*
    - increased collimation depth
  - "universal" FD
    - avoid the need to exchange FD
    - conceptual - requires study
- Many integration issues remain
  - requires engineering studies beyond TDR
  - No apparent show stoppers





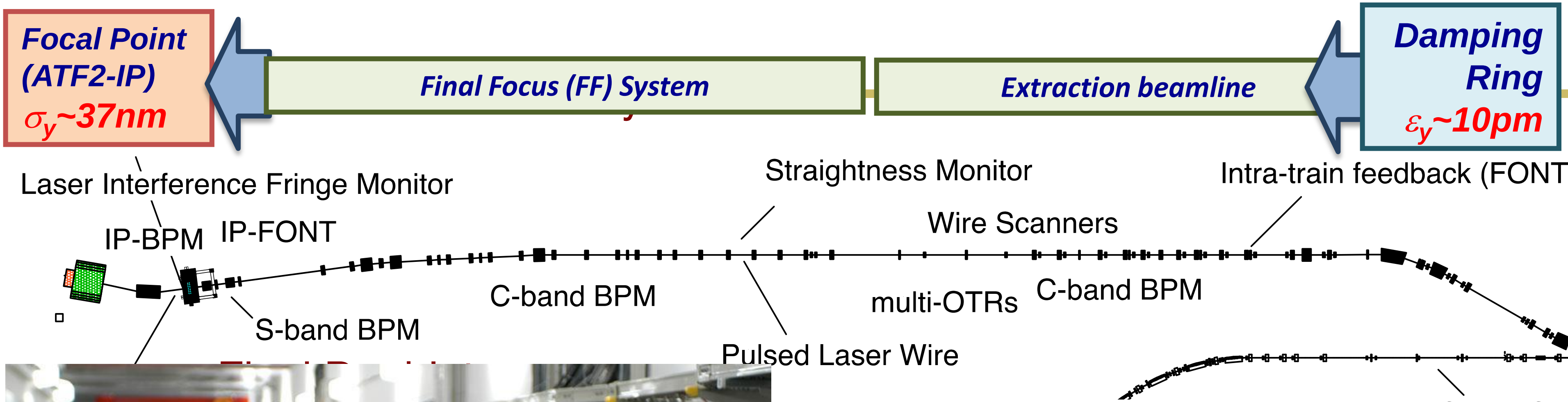


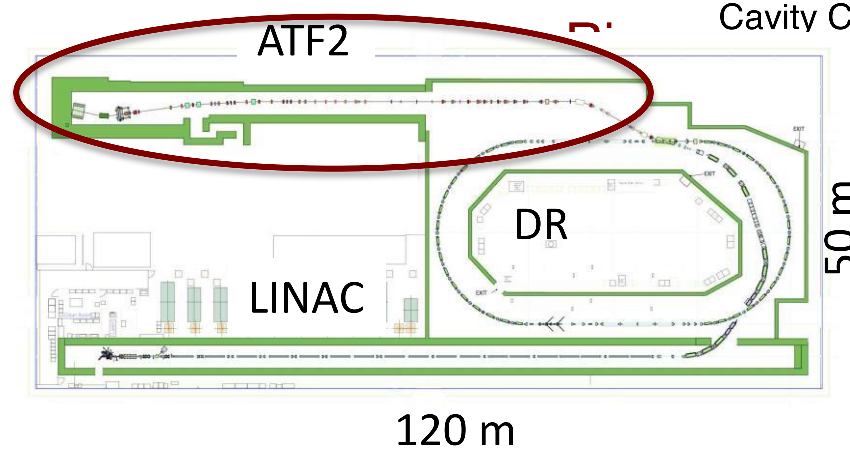
MDI (Detector Hall)



Japanese detector hall concept

Final Focus R&D: ATF-II @ KEK



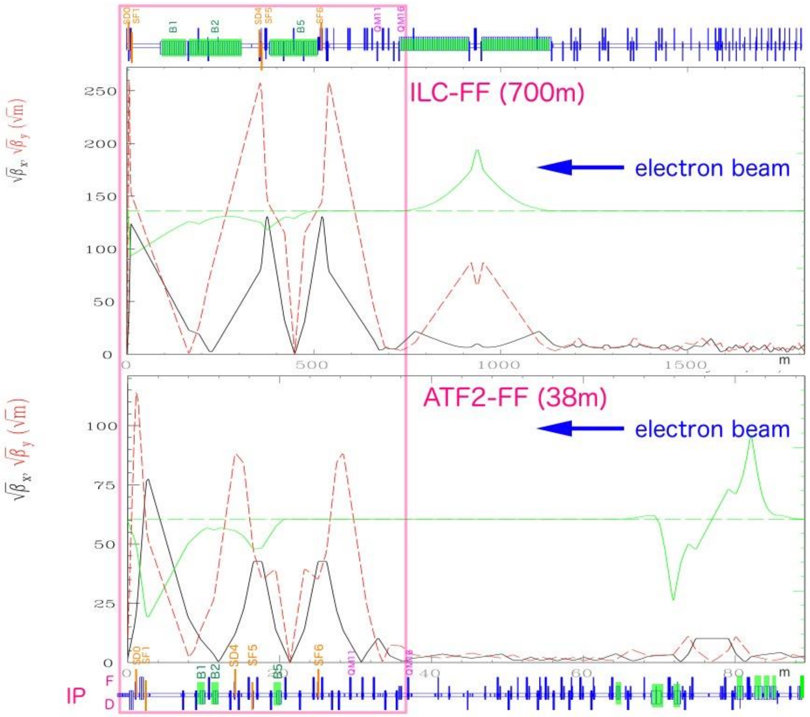


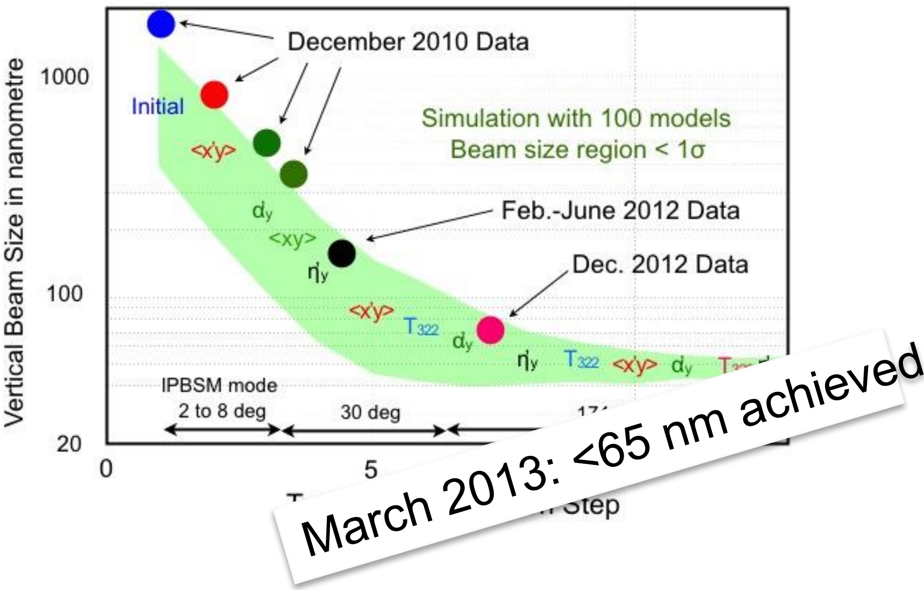
Formal international collaboration

Final Focus R&D: ATF-II @ KEK

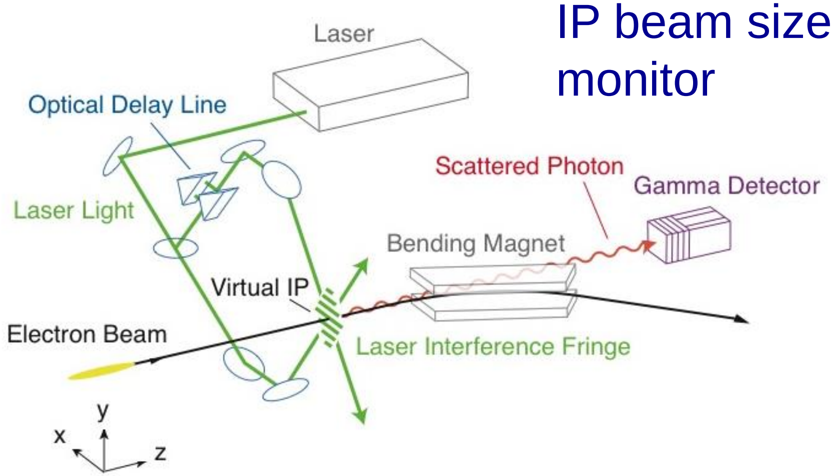
Test bed for ILC final focus optics

- strong focusing and tuning (37 nm)
- beam-based alignment
- stabilisation and vibration (fast feedback)
- instrumentation





IP beam size monitor



Global Effort for ILC Beam Demonstration

TTF/FLASH (DESY) ~1 GeV
ILC-like beam ILC RF unit
(* lower gradient)

STF (KEK) operation/construction
ILC Cryomodule test：S1-Global
Quantum Beam experiment

CesrTA (Cornell)
electron cloud
low emittance

DESY

INFN Frascati

KEK, Japan

SLAC

FNAL

Cornell

NML facility ILC RF unit test
Under construction

DA^{f}NE (INFN Frascati)
kicker development
electron cloud

ATF & ATF2 (KEK)
ultra-low emittance
Final Focus optics
KEKB electron-cloud

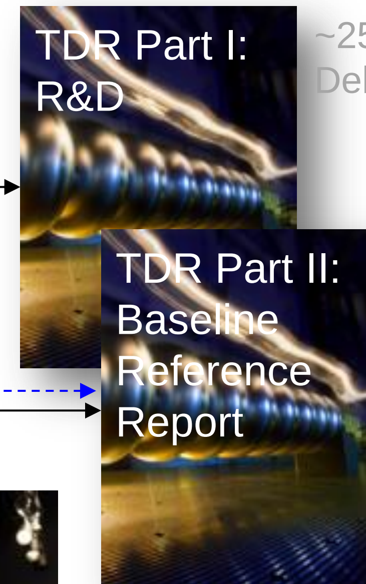
SLAC RF sources
test stands

Technical Design Report Completed

2007 **2011** **2013***

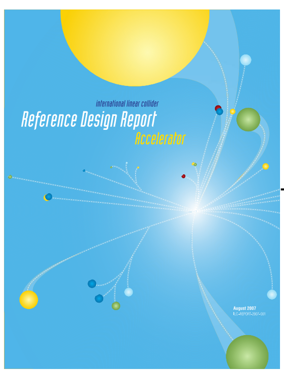
ILC Technical Progress Report
(“*interim report*”)

AD&I



~250 pages
Deliverable 2

~300 pages
Deliverables
1,3 and 4

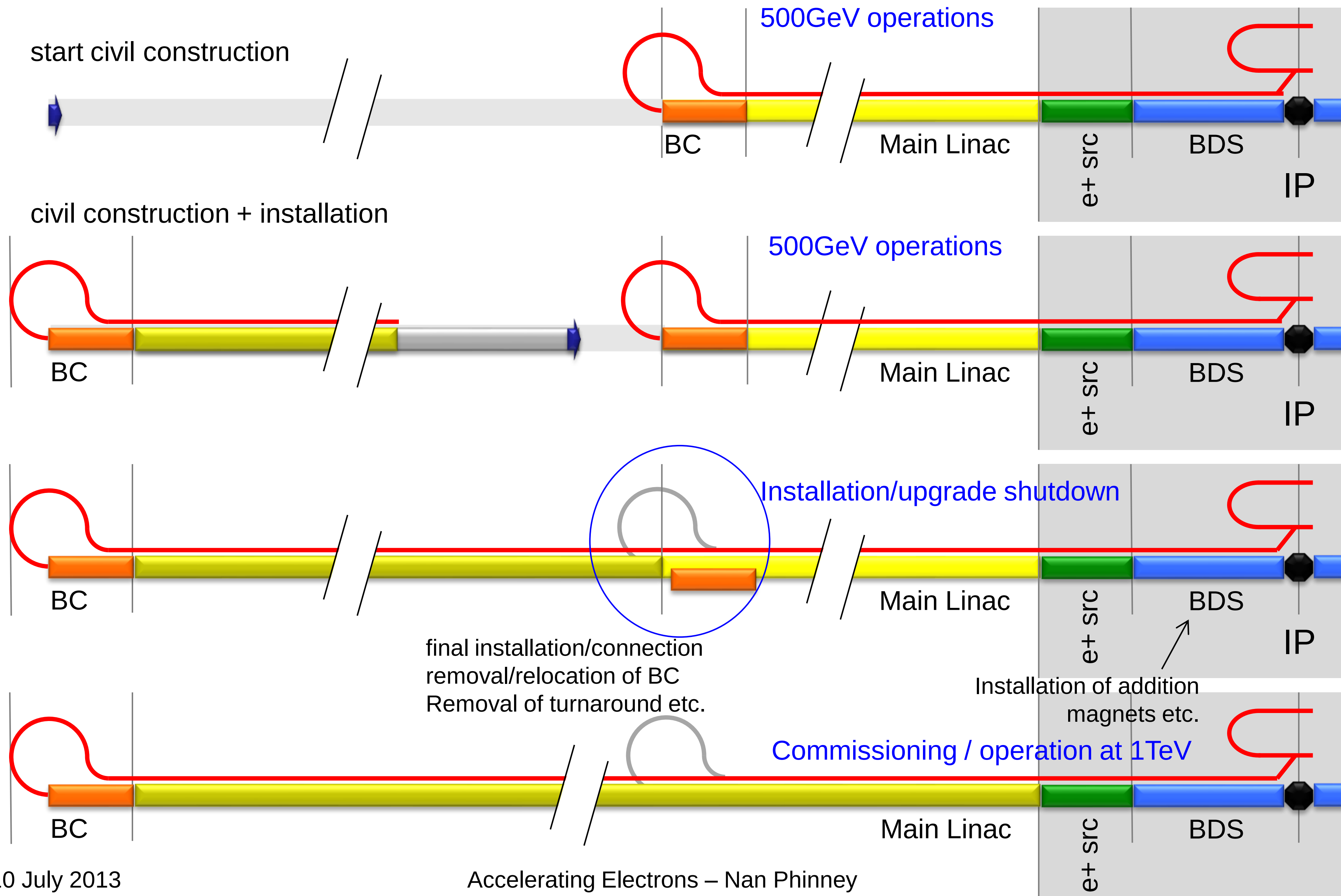


Reference Design Report

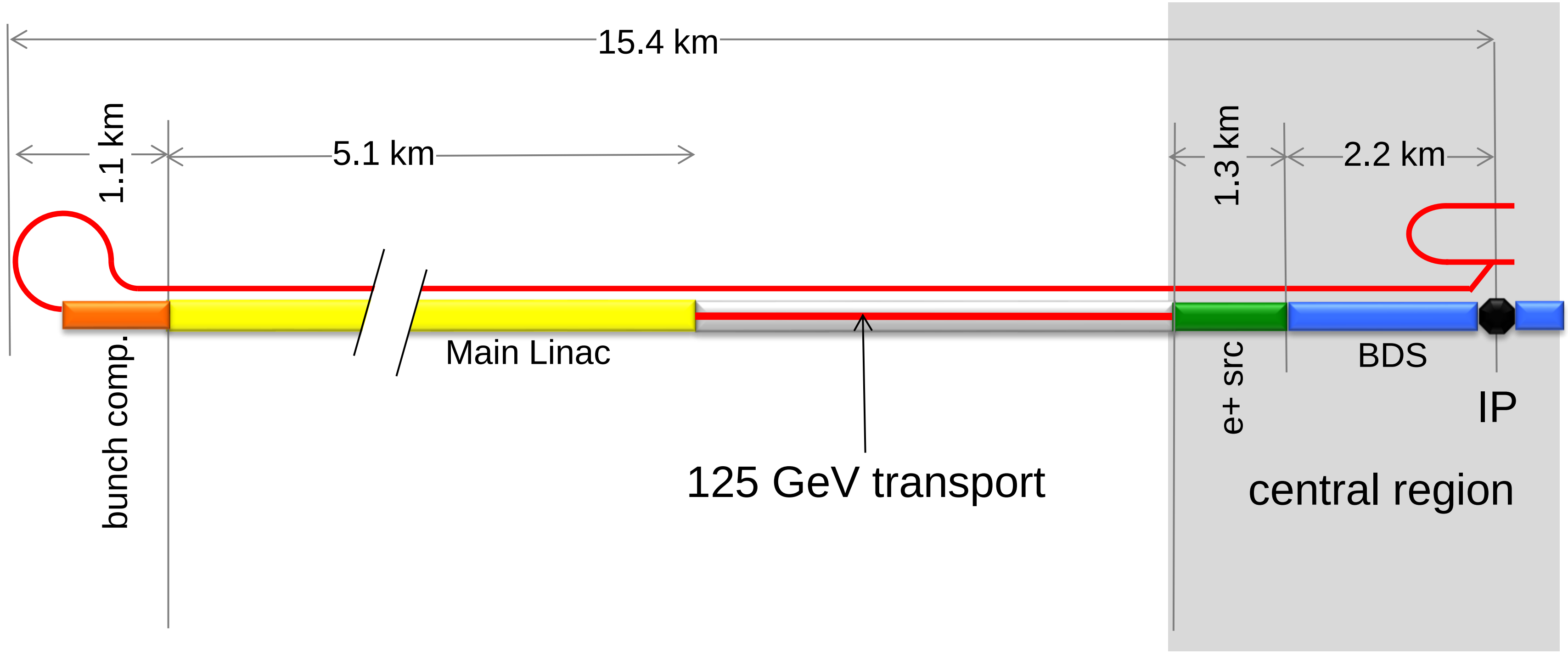
Technical Design Report

* end of 2012 – formal publication early 2013

500 GeV Upgradeable to 1 TeV



Higgs Factory @ 250 GeV



Half the linacs
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
5km 125 GeV transport line

quasi-adiabatic energy upgrade?

Japanese plans for a "Science City"

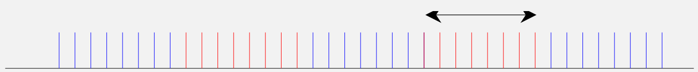
CLIC

Slides courtesy of Steinar Stapnes and Daniel Schulte

CLIC Layout at 3 TeV

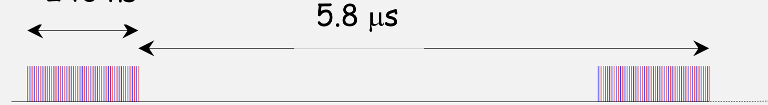
Drive Beam Generation

Drive beam time structure - initial

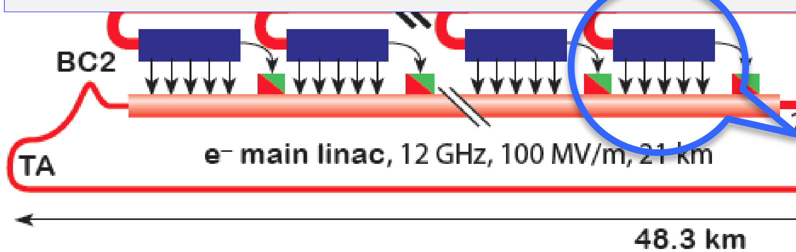


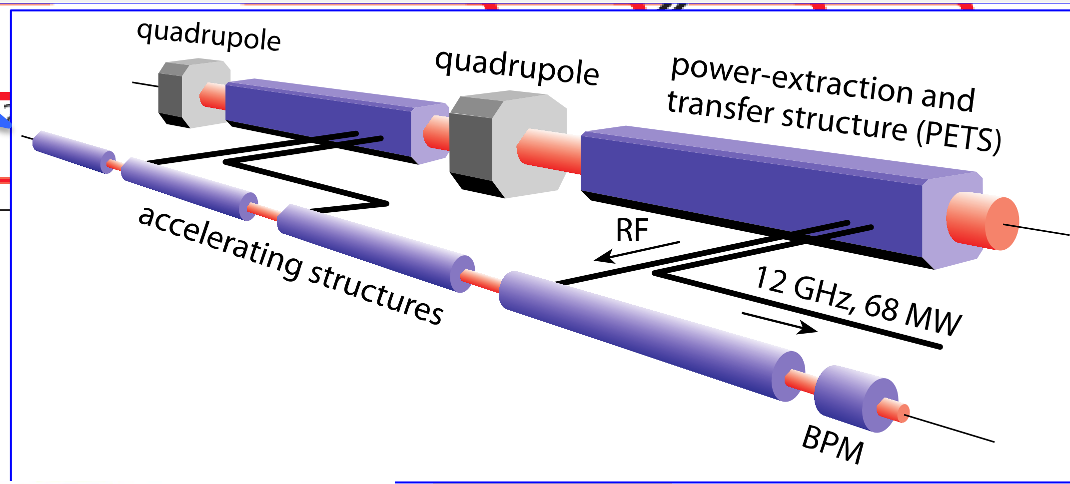
140 μs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final



24 pulses – 101 A – 2.5 cm between bunches

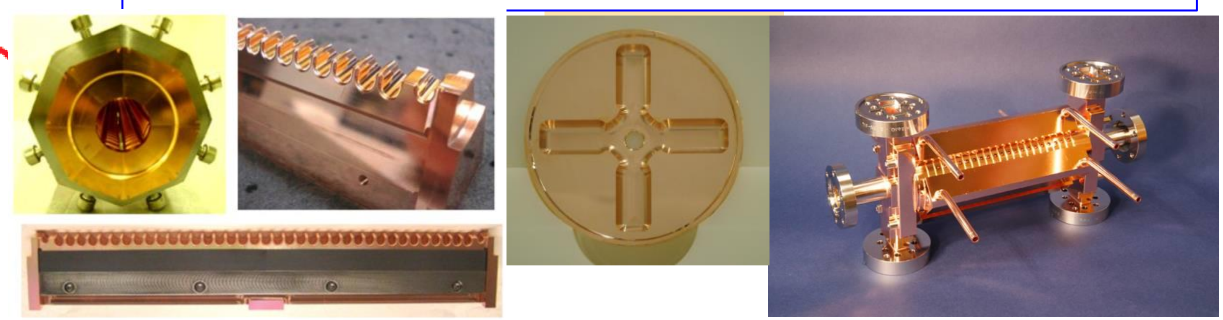




CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

e⁻ injector,
2.86 GeV

Main Beam Generation Complex

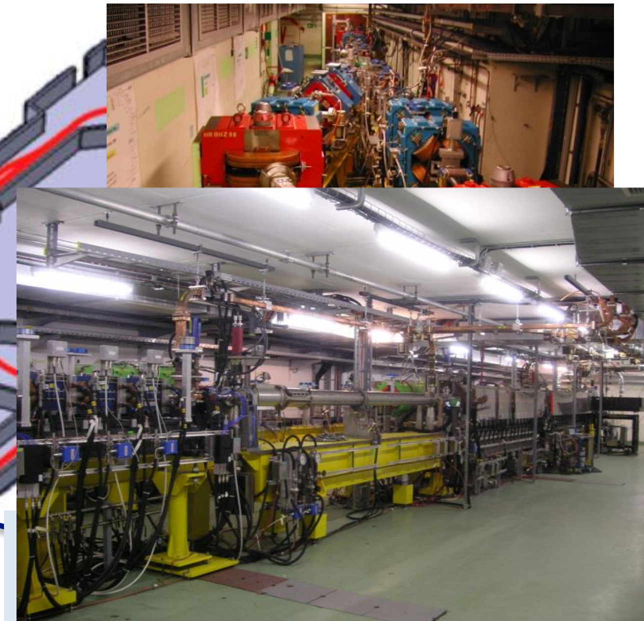


CLIC Parameters

Parameter	Symbol	Unit			
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Luminosity	$\mathcal{L}$	$10^{34} \cdot \mathrm{cm}^{-2}\mathrm{s}^{-1}$	2.3	3.2	5.9
Luminosity in peak	$\mathcal{L}_{0.01}$	$10^{34} \cdot \mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.4	1.3	2
Gradient	G	MV/m	80	80/100	100
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	μm	72	44	44
IP beam size	σ_x/σ_y	nm	≈ 200/2.3	≈ 60/1.5	≈ 40/1
Norm. emittance (end of linac)	ϵ_x/ϵ_y	nm	—	660/20	660/20
Norm. emittance (IP)	ϵ_x/ϵ_y	nm	2400/25	—	—
Nom. beta-functions (IP)	β_x/β_y	mm	8/0.1	4/0.07	4/0.07
Bunches per pulse	n_b		354	312	312
Distance between bunches	Δ_b	ns	0.5	0.5	0.5
Repetition rate	f_{rep}	Hz	50	50	50
Estimated power consumption	P_{wall}	MW	272	364	589

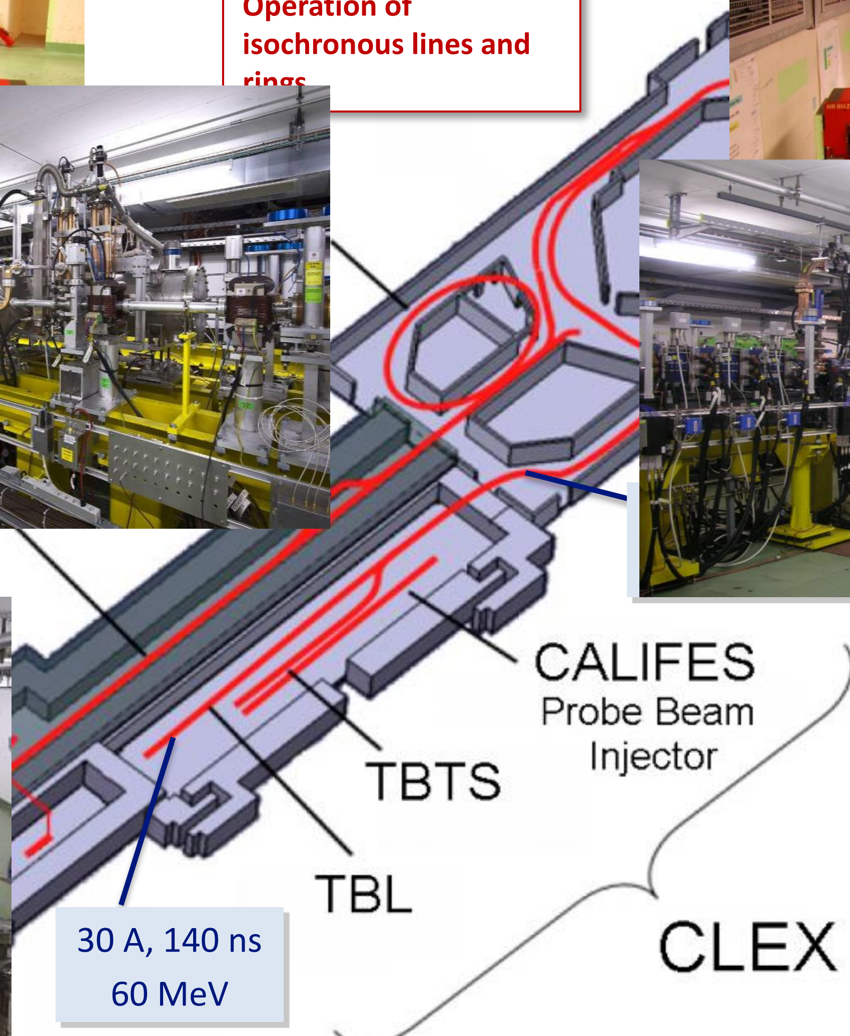
CLIC Test Facility (CTF3)

Operation of isochronous lines and rings



and current multiplication by RF deflectors

High current, full



30 A, 140 ns
60 MeV

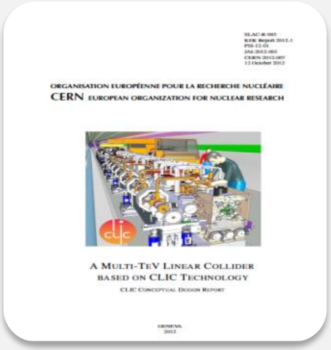
12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

CDR Conclusion on Key Issues

Main linac gradient	– Ongoing test close to or on target – Uncertainty from beam loading
Drive beam scheme	– Generation tested, used to accelerate test beam, deceleration as expected – Improvements on operation, reliability, losses, more deceleration (more PETS) to come
Luminosity	– Damping ring like an ambitious light source, no show stopper – Alignment system principle demonstrated – Stabilisation system developed, benchmarked, better system in pipeline – Simulations seem on or close to the target
Operation Machine Protection	– Start-up sequence defined – Most critical failure studied – First reliability studies – Low energy operation developed

The CLIC CDR Documents

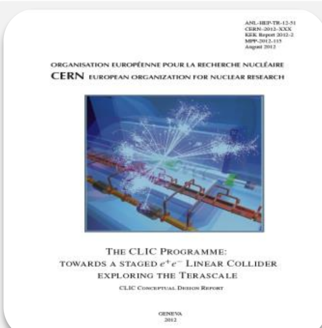


Vol 1: The CLIC accelerator and site facilities (H.Schmickler)

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- Complete, presented in SPC in March 2011, in print: https://edms.cern.ch/document/1234244/

Vol 2: Physics and detectors at CLIC (L.Linssen)

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- Completed and printed, presented in SPC in December 2011 http://arxiv.org/pdf/1202.5940v1



Vol 3: "CLIC study summary" (S.Stapnes)

- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- Completed and printed, submitted for the European Strategy Open Meeting in September http://arxiv.org/pdf/1209.2543v1

CLIC Timeline

Steinar Stapnes

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.

2017-22 Preparation Phase

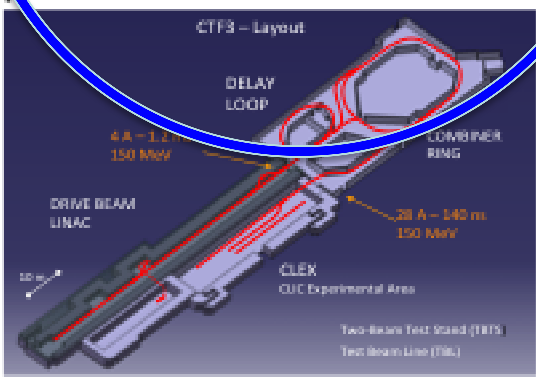
Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

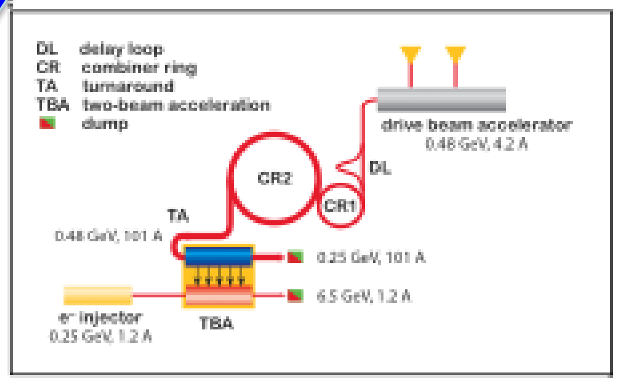
Prepare detailed Technical Proposals for the detector-systems.

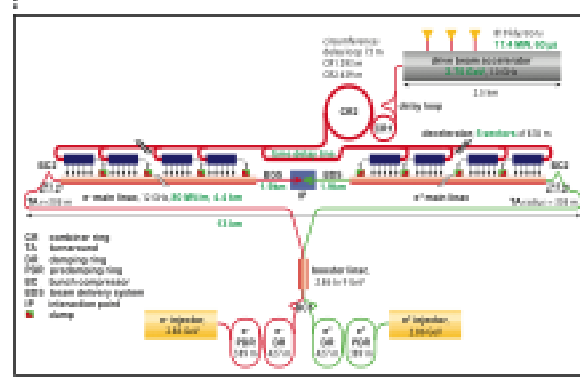
2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.







2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2022-23 Construction Start

Ready for full construction and main tunnel excavation.

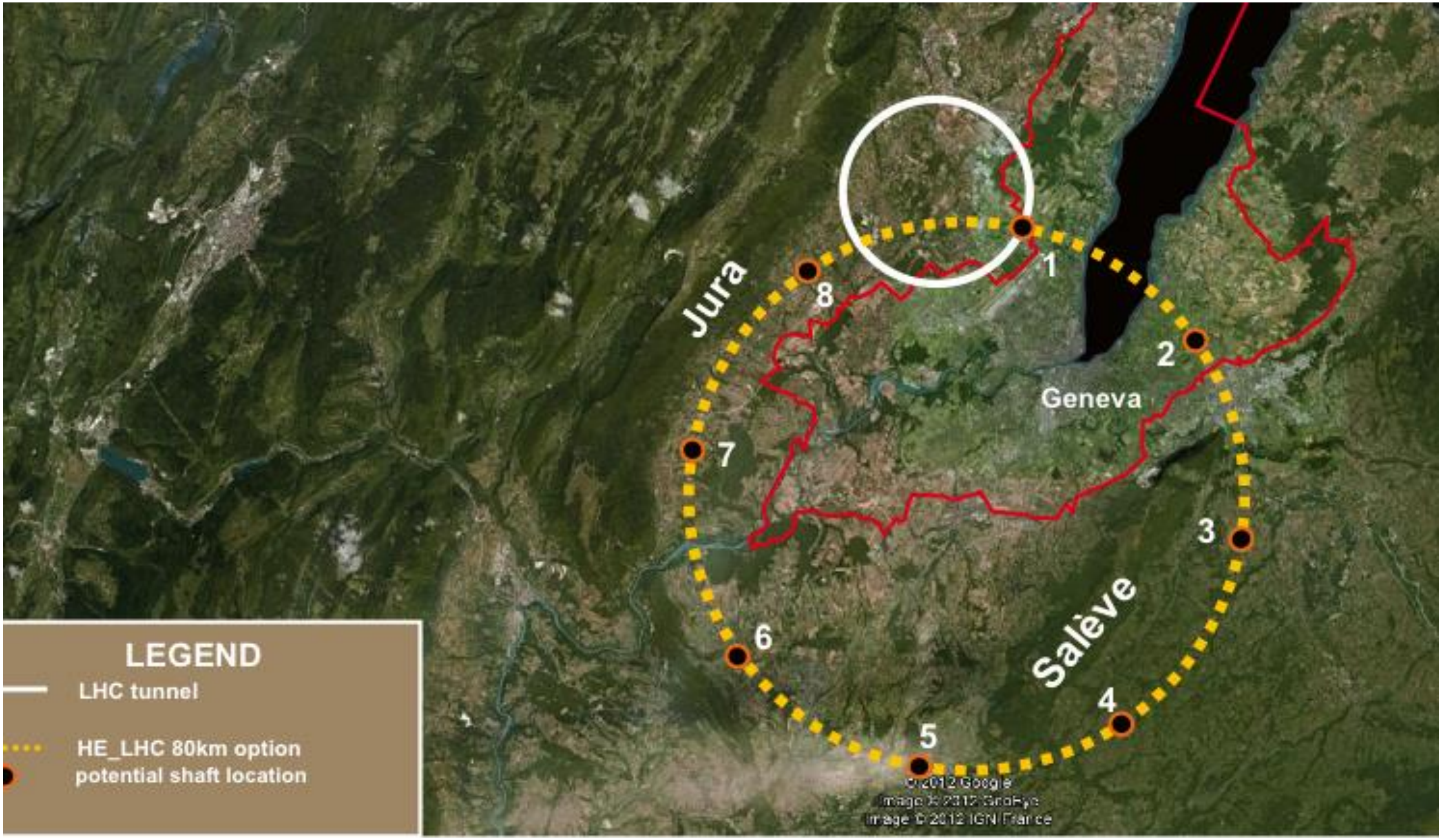
2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

TLEP

Slides courtesy of Alain Blondel, Marc Ross, Kaoru Yokoya

80 km version of TLEP



Geology concerns >> now considering 100 km ring

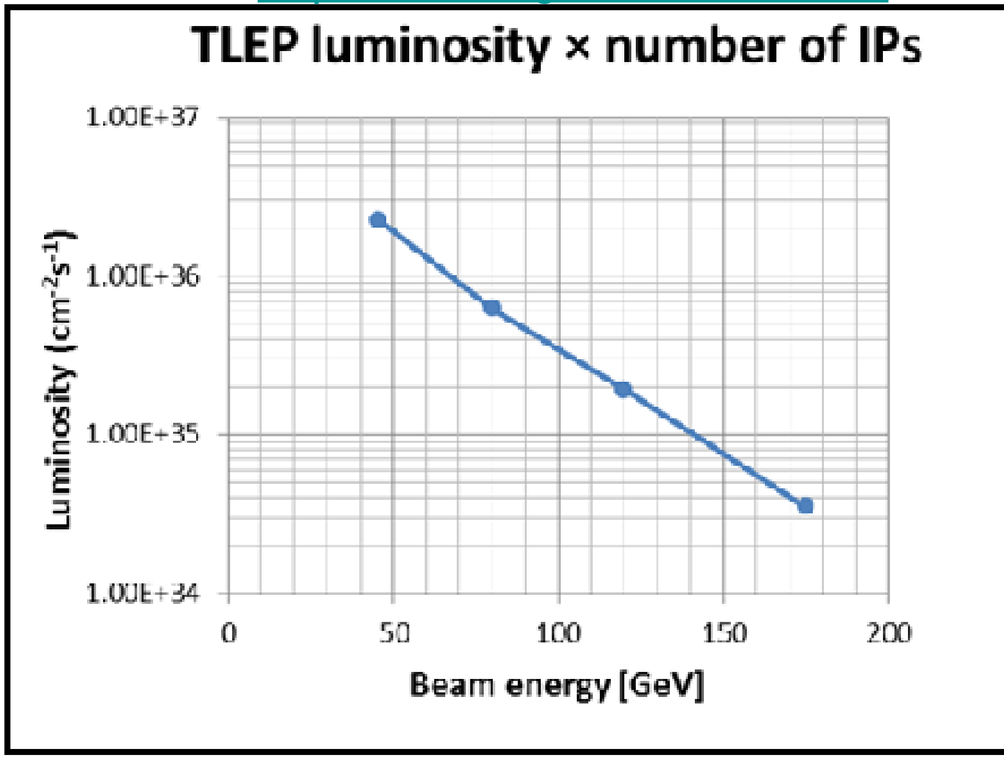
Table 1: TLEP parameters at different energies

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
circumf. [km]	80	80	80	80
beam current [mA]	1180	124	24.3	5.4
#bunches/beam	4400	600	80	12
#e−/beam [10^{12}]	1960	200	40.8	9.0
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
bending rad. [km]	9.0	9.0	9.0	9.0
κ_ε	440	470	470	1000
mom. c. α_c [10^{-5}]	9.0	2.0	1.0	1.0
$P_{loss,SR}$/beam [MW]	50	50	50	50
β^*_x [m]	0.5	0.5	0.5	1
β^*_y [cm]	0.1	0.1	0.1	0.1
σ^*_x [μm]	124	78	68	100
σ^*_y [μm]	0.27	0.14	0.14	0.10
hourglass F_{hg}	0.71	0.75	0.75	0.65
E^{SR}_{loss}/turn [GeV]	0.04	0.4	2.0	9.2
V_{RF}, tot [GV]	2	2	6	12
$\delta_{max,RF}$ [%]	4.0	5.5	9.4	4.9
ξ_x/IP	0.07	0.10	0.10	0.10
ξ_y/IP	0.07	0.10	0.10	0.10
f_s [kHz]	1.29	0.45	0.44	0.43
E_{acc} [MV/m]	3	3	10	20
eff. RF length [m]	600	600	600	600
f_{RF} [MHz]	700	700	700	700
δ^{SR}_{rms} [%]	0.06	0.10	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	0.19	0.22	0.17	0.25
$\mathcal{L}$ /IP[10^{32}cm^{-2}s^{-1}]	5600	1600	480	130
number of IPs	4	4	4	4
beam lifet. [min]	67	25	16	20

TLEP: A HIGH-PERFORMANCE CIRCULAR e^+e^- COLLIDER TO STUDY THE HIGGS BOSON

M. Koratzinos, A.P. Blondel, U. Geneva, Switzerland; R. Aleksan, CEA/Saclay, France; O. Brunner, A. Butterworth, P. Janot, E. Jensen, J. Osborne, F. Zimmermann, CERN, Geneva, Switzerland; J. R. Ellis, King's College, London; M. Zanetti, MIT, Cambridge, USA.

http://arxiv.org/abs/1305.6498.



Set of Parameters for an Early Stage of Design

Design Issues for HE e+e- Ring Colliders

* Synchrotron radiation power O(100MW)
  – Must be replaced with SC RF → kms of cavities
  – Must be absorbed in beam pipe → heat load
  – High critical energy of photons → risk of activation
  – Limits the maximum beam current
* Beamstrahlung radiation in collisions
  – Luminosity requires low emittance lattice, small β*
  – Small beam size at IP → large beamstrahling
  – Large energy loss → large momentum aperture
  – Difficult to achieve with small β* even for 1 IP
* Short beam lifetimes
  – Requires top-up injection – another ring $$
  – Bunch trains require 2 rings for e+ and e- $$

Marc Ross

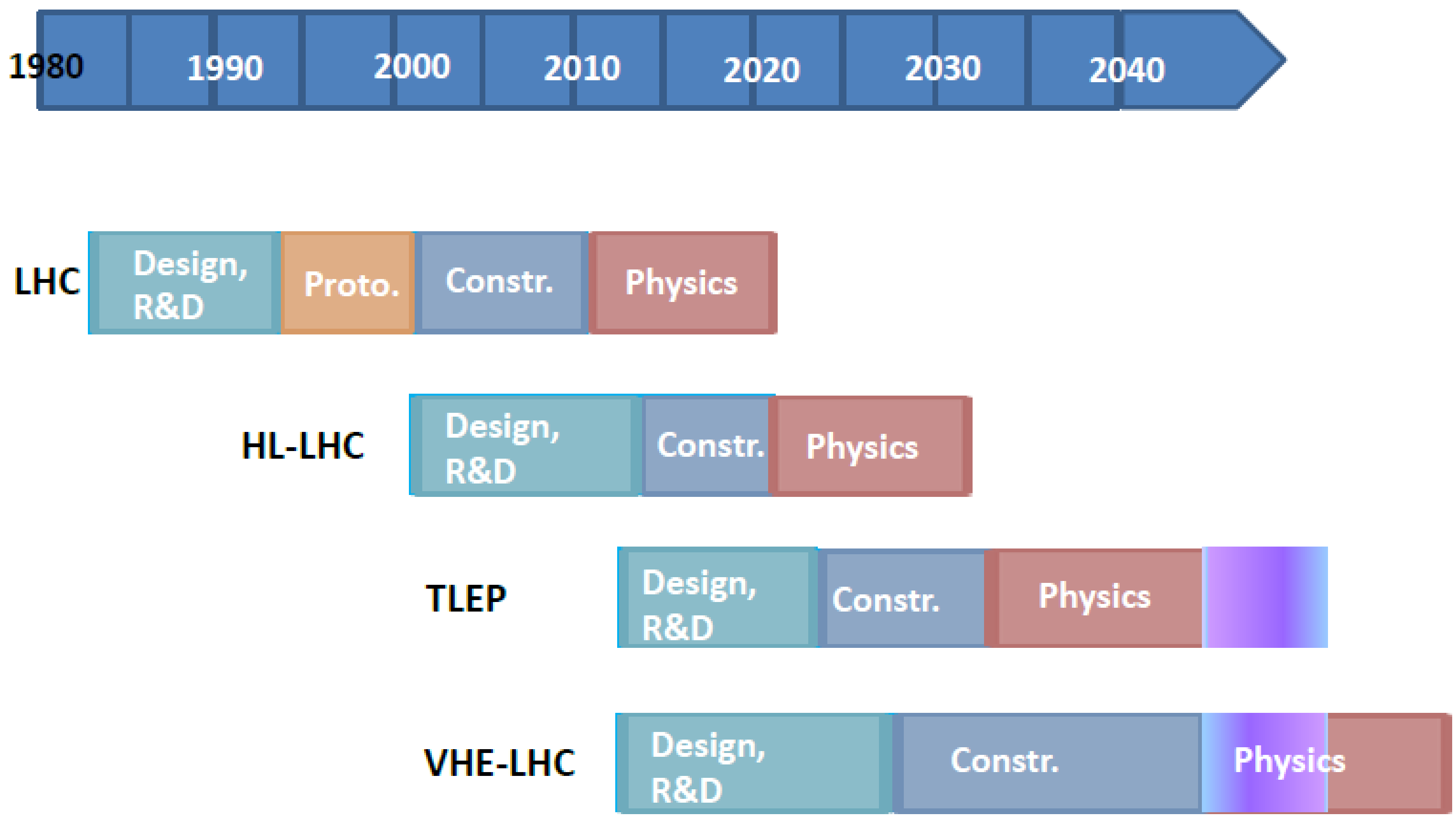
Collider 'Wall Plug' AC Power use:

ILC and 80 km ring:	ILC -H	ILC-nom	Ring - H	Ring - t
E_cm (GeV)	250	500	240	350
SRF Power to Beam (MW)	5.2	10.5	100	100
Eff. RF Length (m)	7,837	15,674	600	1200
RF klystron peak efficiency (%)	65	65	65	65
klystron operating margin, HVPS, Klystron Aux and klystron water cooling (% inefficiency)	→ 30 + 20 Additional inefficiency due cavity fill-time		20*	20
Overall system RF efficiency (%)	10	14	45	45
Cryo (MW)	16	32	20	40
Normal Conducting (exc. Injector complex) (MW)	6	10	120**	120
Injector complex	32	32	16***	16
Conventional (Air, lighting, ..)	6	6****	18	18
Total (exc. detector)	**112**	**153**	**396**	**416**

* 5% for operating margin, 2% for auxiliaries, 3% for HVPS and 10% for water cooling
** assume 1.5 kW / m tunnel inclusive (ILC avg. 3 kW / m)
*** from SSC / Fermilab injector (linac + LEB + MEB); assumes LHC not needed
**** 6 MW for 30 km beam tunnel complex; ~3x more for 80 ring

Assume two separate collider rings – similar to B Factories

possible long-term time line



Zimmermann

Conclusion

* If Physics Demands a Higgs Factory soon

* ILC is the most mature design
  - Critical R&D is successfully completed
  - Still requires serious site-specific engineering
  - Japanese are interested in a bid to host

  It would be the opportunity of a generation

* CLIC can potentially reach higher energy

* TLEP limited to lower energy but provides tunnel for P-P
  - CERN focused on Hi-Lumi LHC through late 2020s
  - Both projects are > 20 years off