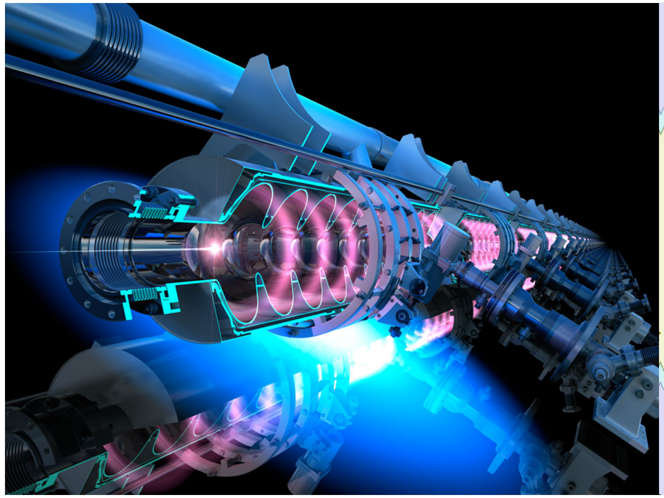
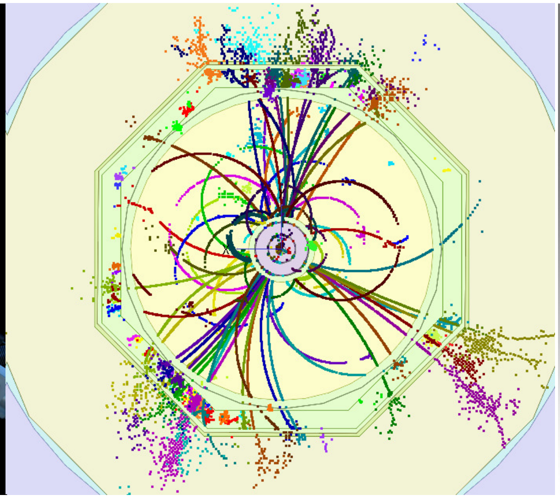
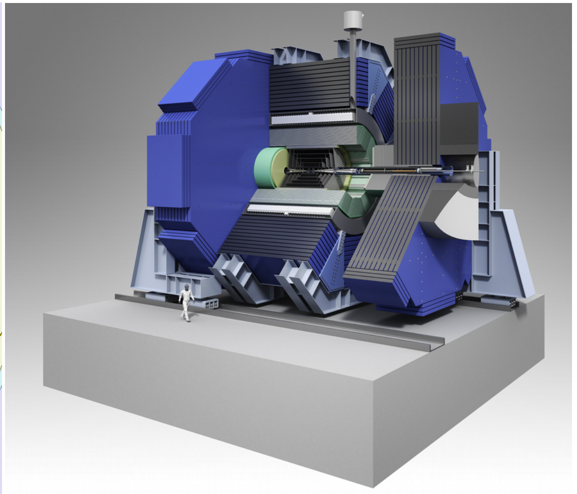
The International Linear Collider

Status Report





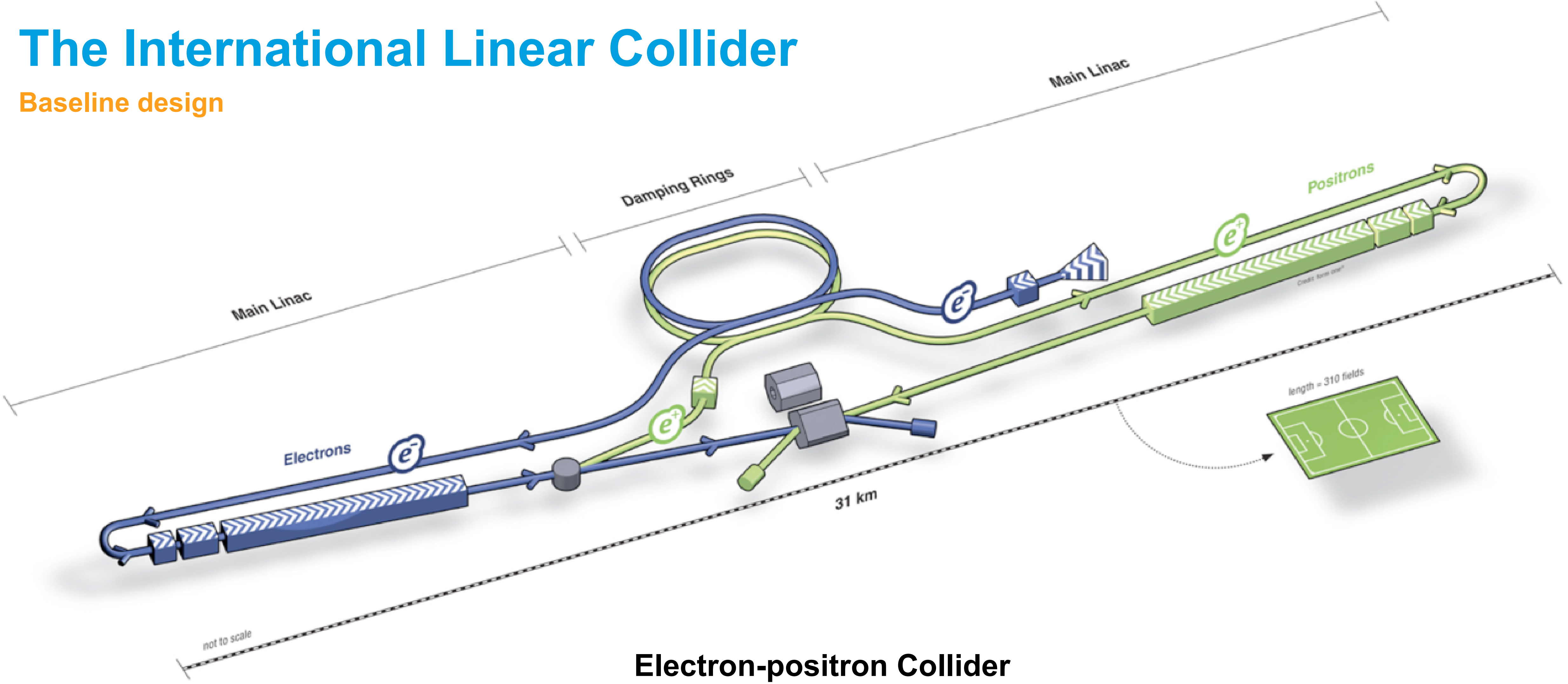


Marcel Stanitzki
CERN, 16/November/2018

Introduction

The International Linear Collider

Baseline design



Electron-positron Collider

- Center-of-mass energy 250 GeV (Higgs factory)
  Extendable to higher energies (1 TeV)
- Based on superconducting RF niobium cavities
- Polarized beams
- One interaction region, two detectors

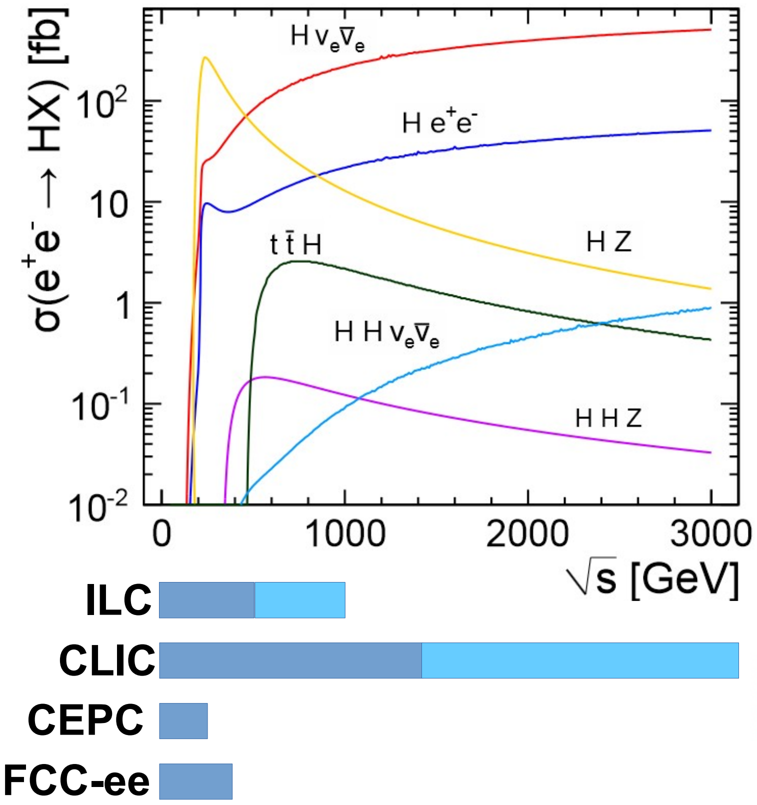
The ILC Physics Case

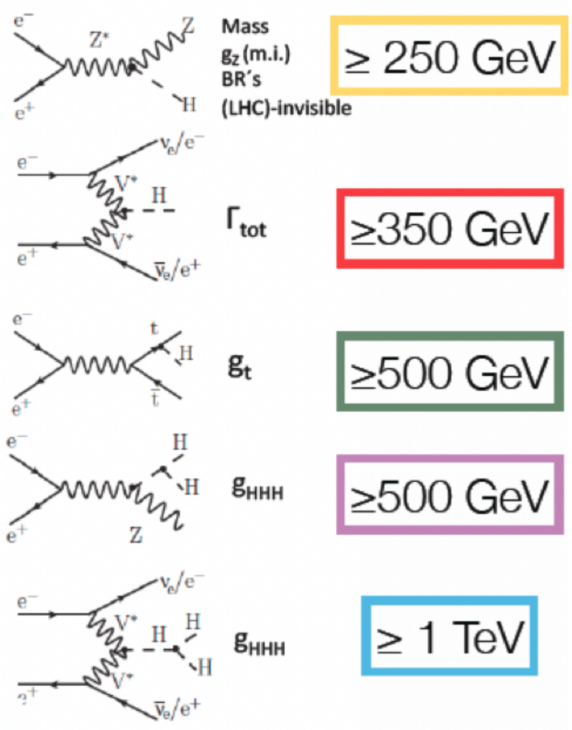
Higgs, Top, BSM

ILC: a rich physics program @ 250Gev - 1TeV
Higgs precision physics, top-quark physics, physics beyond the standard model

Discovery of a Higgs boson in 2012
Higgs as new window into physics beyond the Standard Model

So far absence of new physics at the LHC
➔ precision is key to BSM physics; deviations of e.g. SM Higgs couplings are O(%)

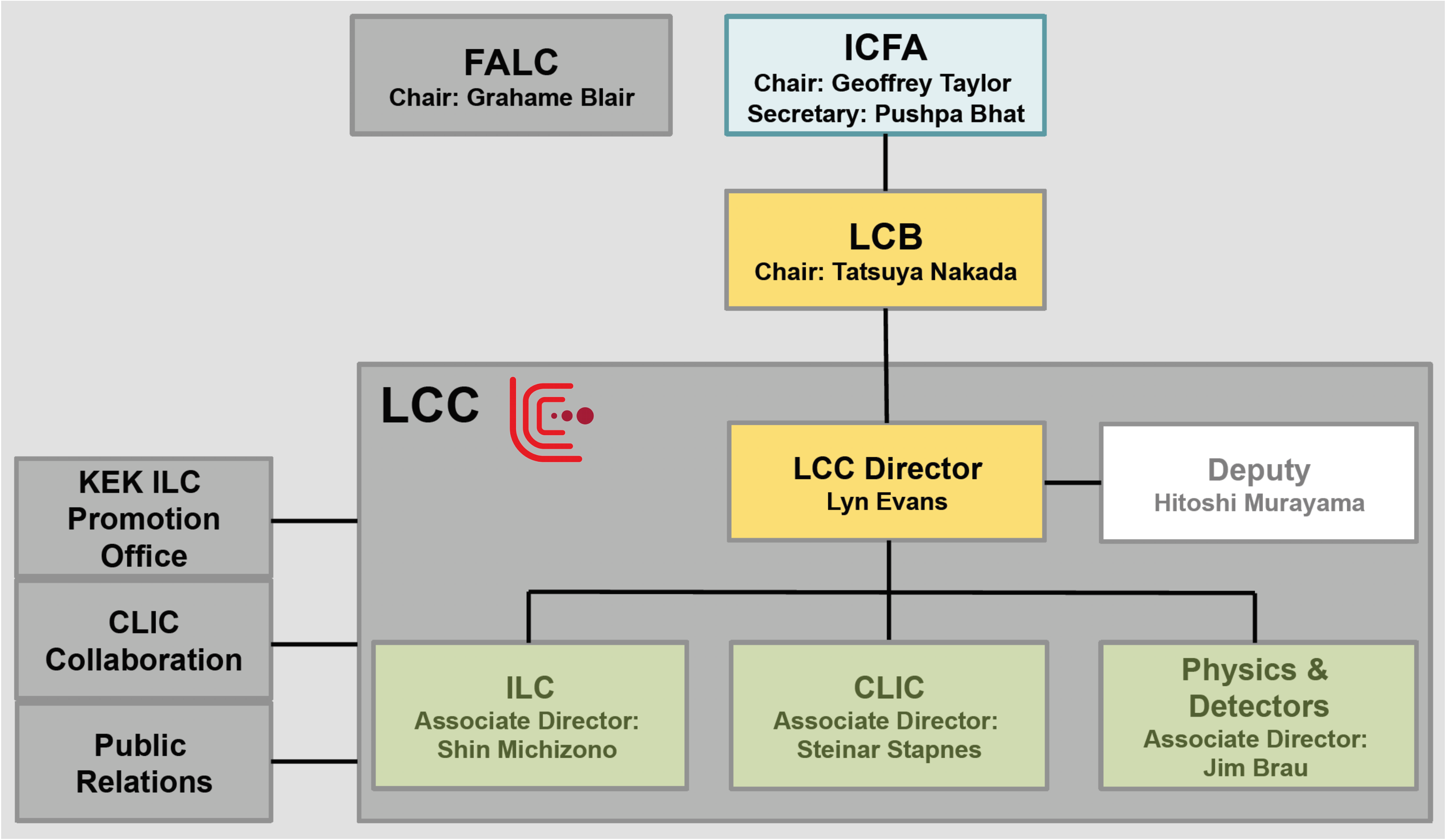




The ILC is a Higgs factory at all energies!
At 250 GeV: Very clean and easy to reconstruct HZ final state. Precision access to many Higgs properties

The Linear Collider Collaboration

Established in 2013



ILC Technical Design Report

Published May 2013

The TDR

- 500 GeV ILC
- Five Volumes
  - Physics, Accelerator & Detectors
  - Culmination of 8 years of effort
  - Available here
- Wide Community support
  - 2400 people sign the TDR
- Global Handover Event
  - Tokyo, Geneva, Chicago

The Update of the European Strategy

European strategy update 2013 – outcome

a) *Europe should preserve this [European organisational] model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to the wider society.*

b) *The European Strategy takes into account the worldwide particle physics landscape and developments in related fields and should continue to do so.*

c) *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030.*

d) *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures […]*

e) ***There is a strong scientific case for an electron-positron collider, complementary to the LHC … The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.***

f) *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

Re-baselining the ILC

Moving the initial energy from 500 GeV to 250 GeV

The ILC250

- A Higgs factory that defines an entire project which should be justified by its own scientific case
- Significant reduction of the initial costs expected
- Seen as a first step towards the full ILC

Re-Baselining

- Discussed at LCWS in Morioka 2016
- Fully supported by JAHEP & ICFA
- Adopted as the new baseline in 2017
- See Report on Arxiv

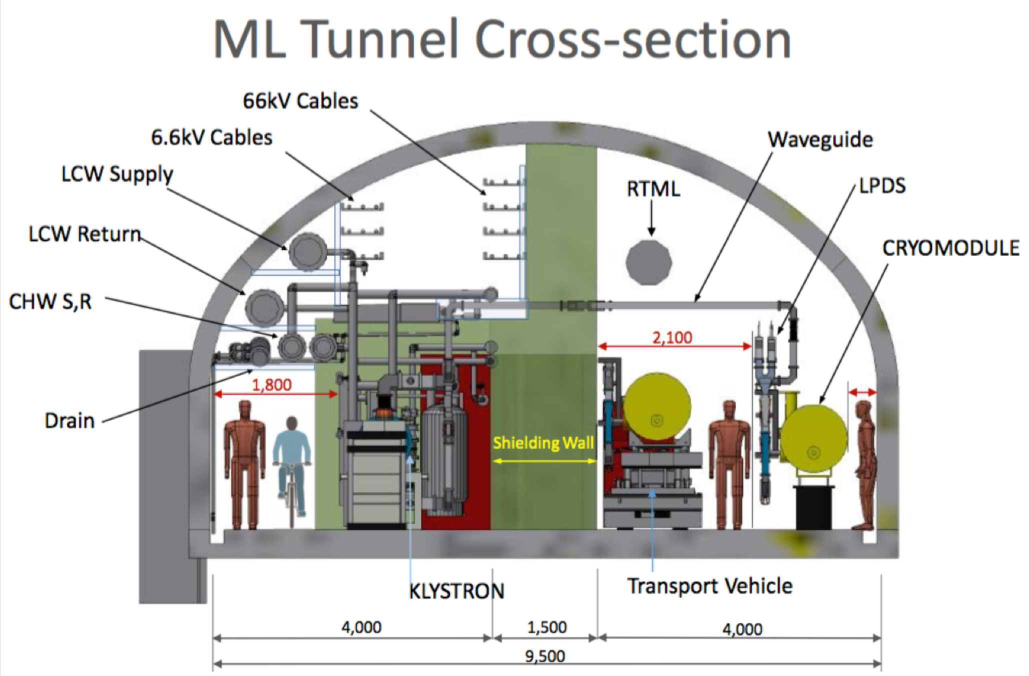
The ILC Accelerator

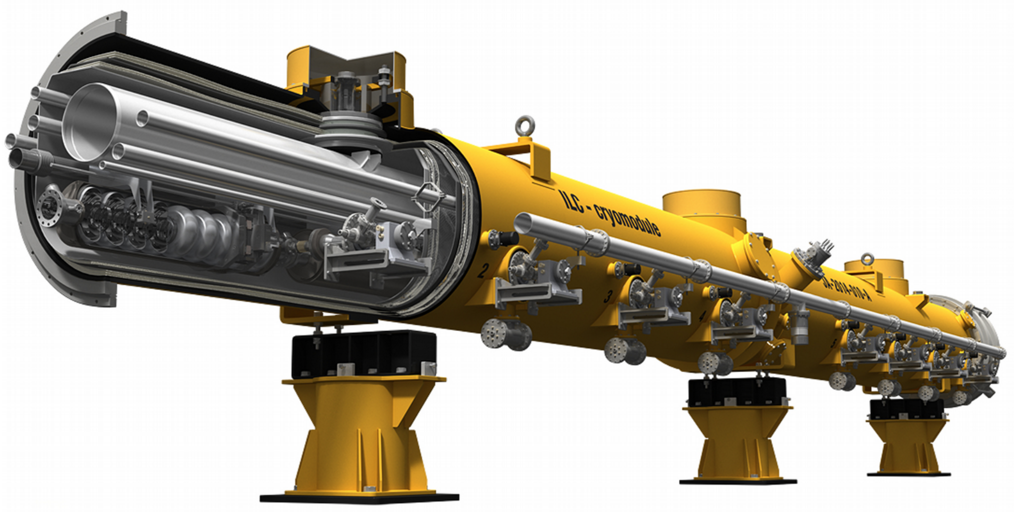
The ILC Accelerator

ILC250 Baseline Design

ILC250

- 20 km long
- Acceleration
  - 8370 superconducting cavities in 930 cryo-modules
  - Gradient 31.5 MV/m (35 MV/m)
  - 1.3 GHz RF
- 129 MW power consumption
- Beam parameters
  - 2×10^{10} particles/bunch
  - 554 ns spacing
  - $L = 1.8 \times 10^{34}\ cm^{-2} s^{-1}$
  - Beam polarization 80/30 (e^-/e^+)

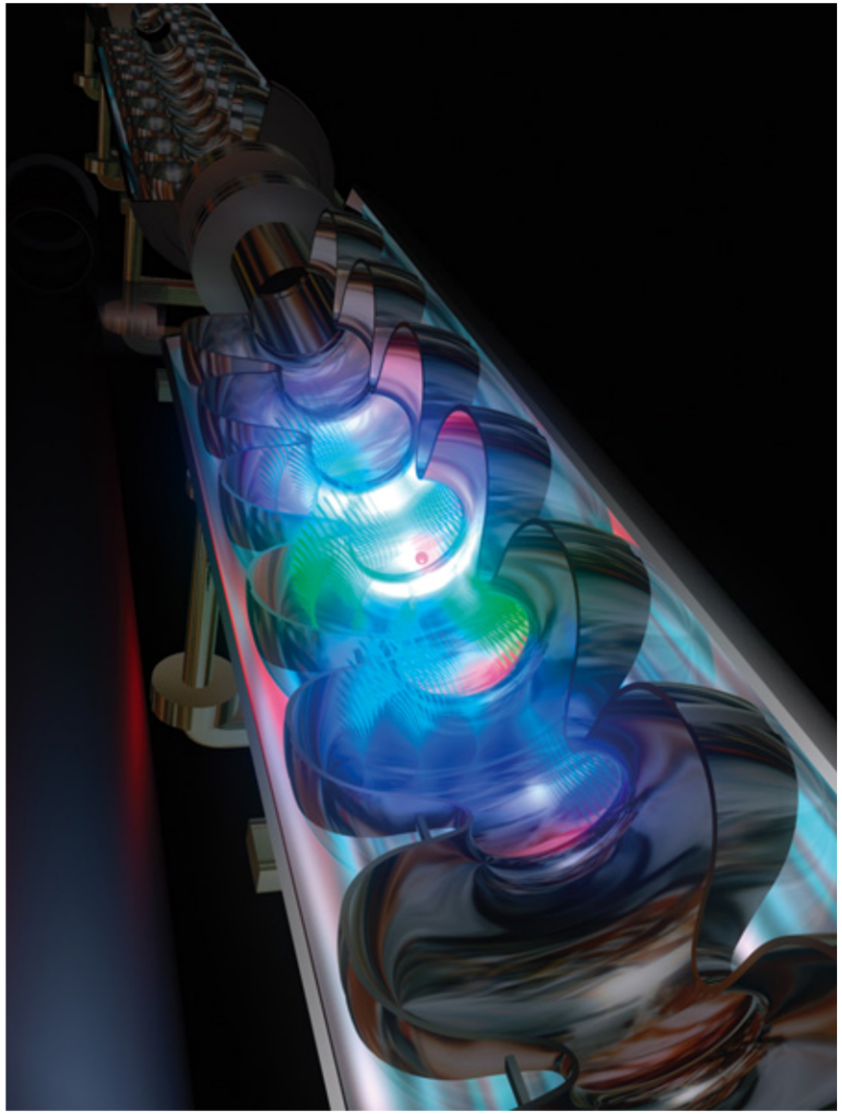




ILC Machine Parameters

Baseline Configuration

Quantity	Unit	ILC250	ILC500	ILC1000
Centre-of-mass energy	GeV	250	500	1000
Luminosity	$10^{34}cm^{-2}s^{-1}$	1.35	1.8	4.9
Repetition frequency	Hz	5	5	4
Bunches per pulse	1	1312	1312	2450
Bunch population	10^{10} e-	2	2	1.74
Linac bunch interval	ns	554	554	366
Beam current in pulse	mA	5.8	5.8	7.6
Beam pulse duration	s	727	727	897
Average beam power	MW	5.3	10.5	27.2
Norm. hor. emitt. at IP	µm	5	10	10
Norm. vert. emitt. at IP	nm	35	35	35
RMS hor. beam size at IP	nm	516	474	335
RMS vert. beam size at IP	nm	7.7	5.9	2.7
Site AC power	MW	129	163	300
Site length	km	20.5	31	40



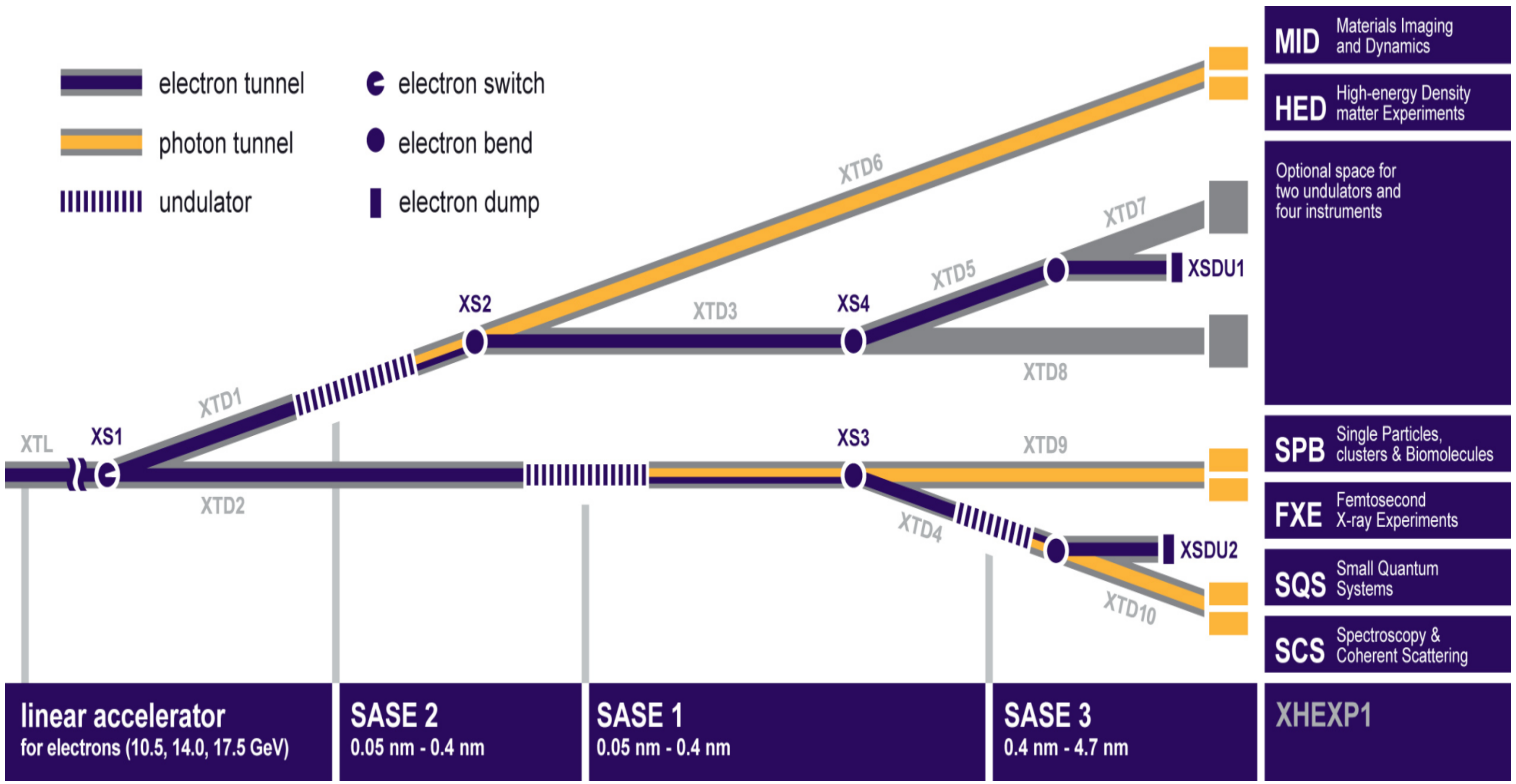
Luminosity Upgrades by doubling the number of bunches

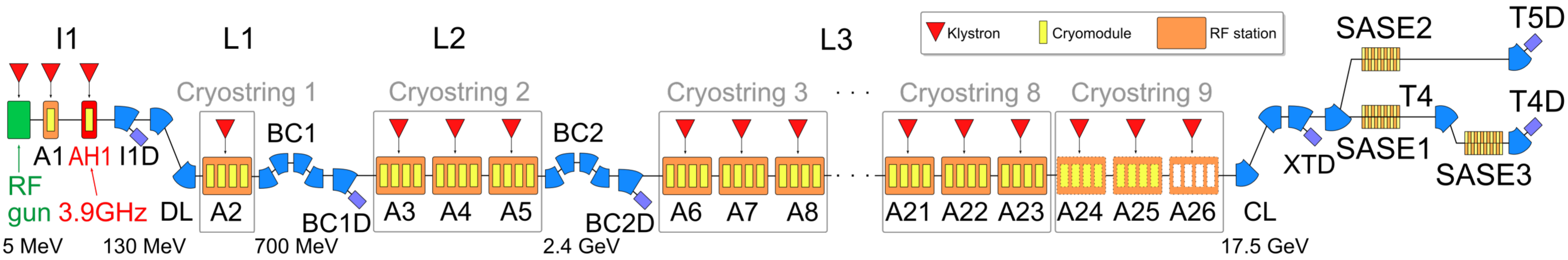
The European XFEL

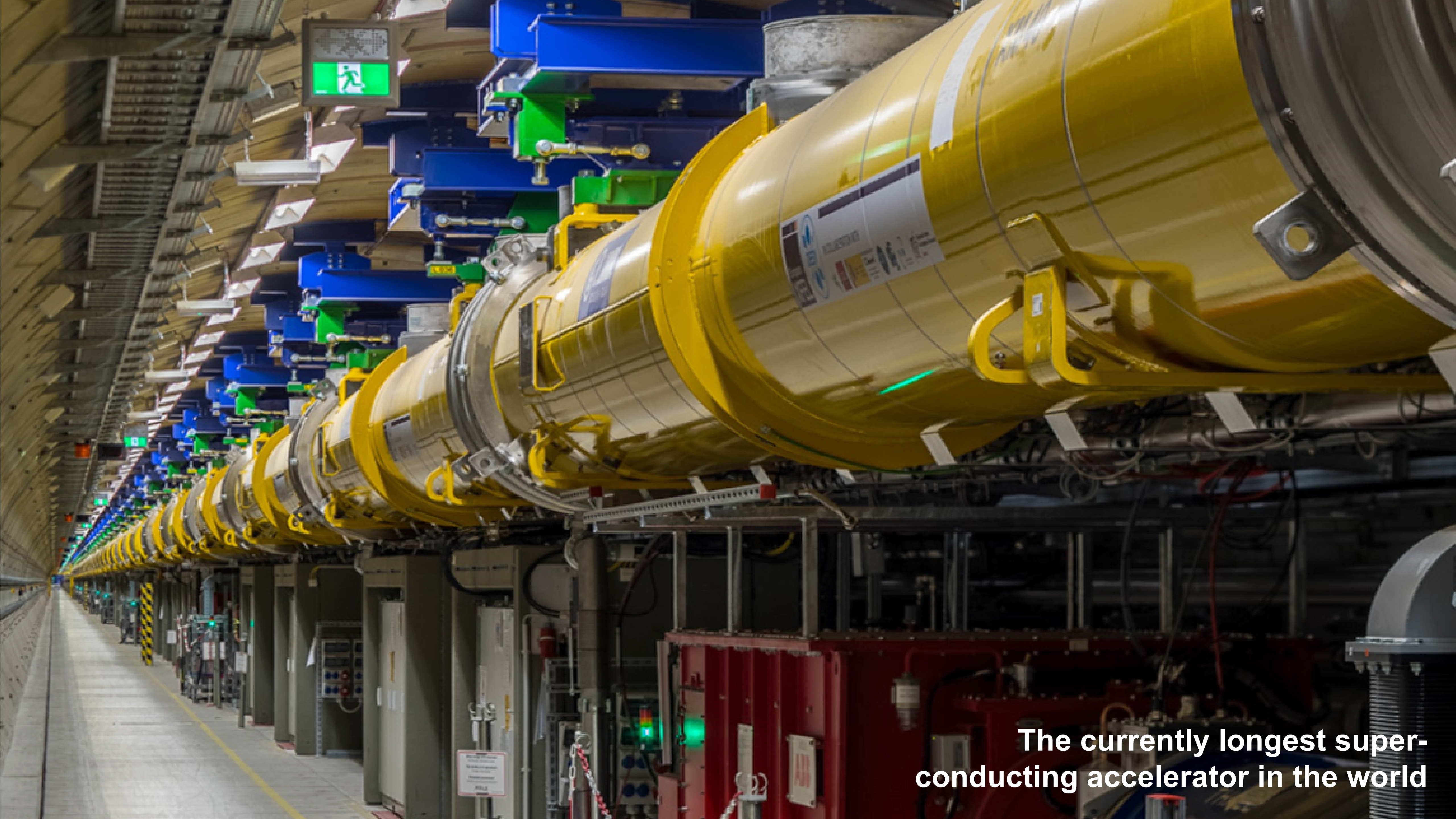
10% of the ILC Main Linac

Soft and hard X-ray light experiment

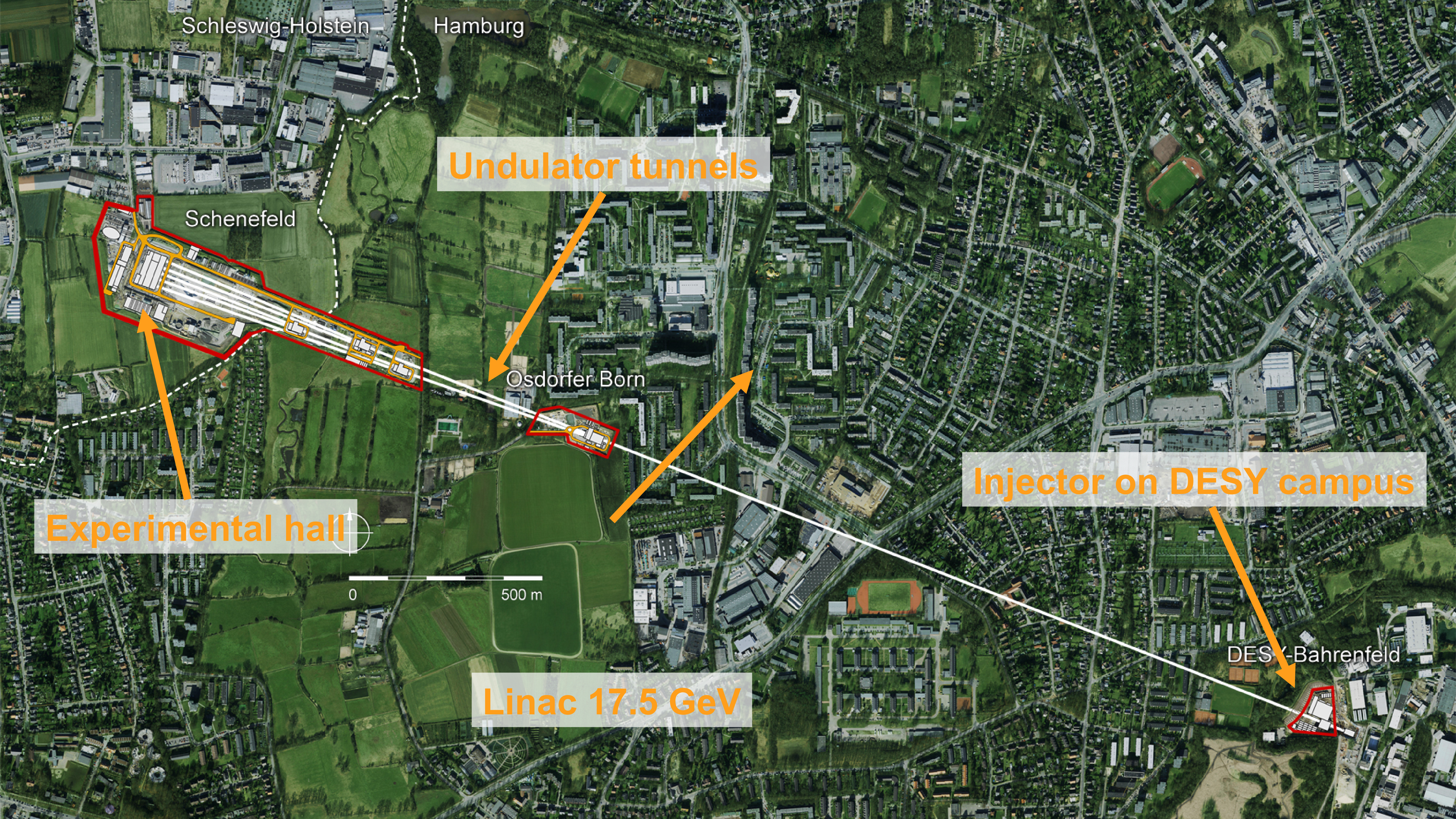
- ~800 TESLA-type cavities
- Resonance frequency 1.3 GHz
- 32 cavities per XTL RF station
- Design energy 17.5 GeV
- Pulsed operation 10 Hz
- Routine user operation at several stations





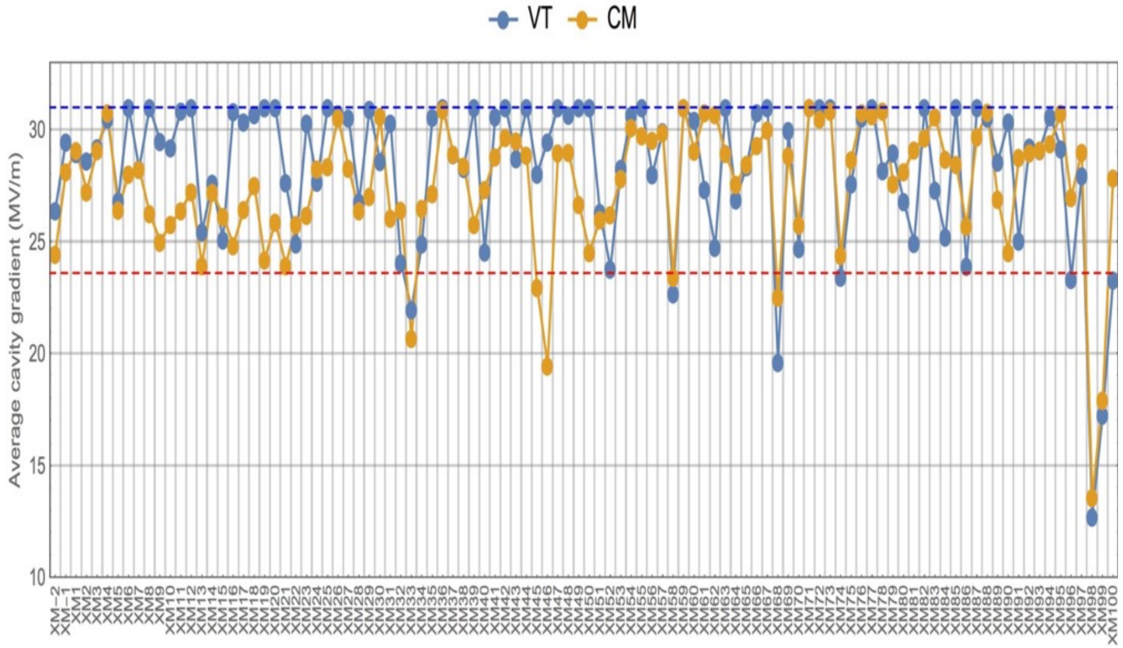


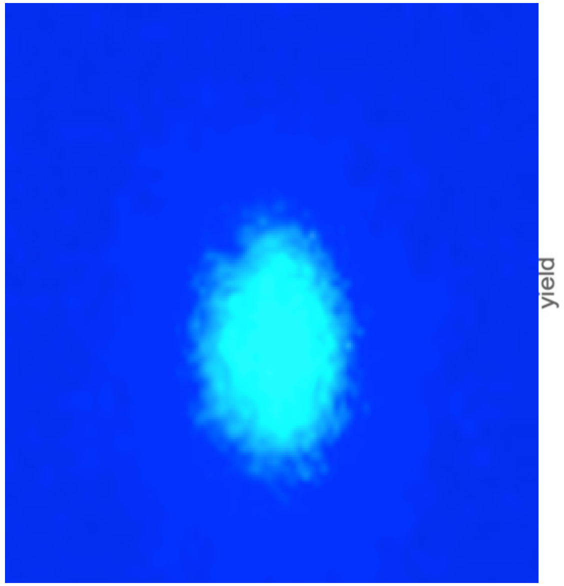
The currently longest super-
conducting accelerator in the world

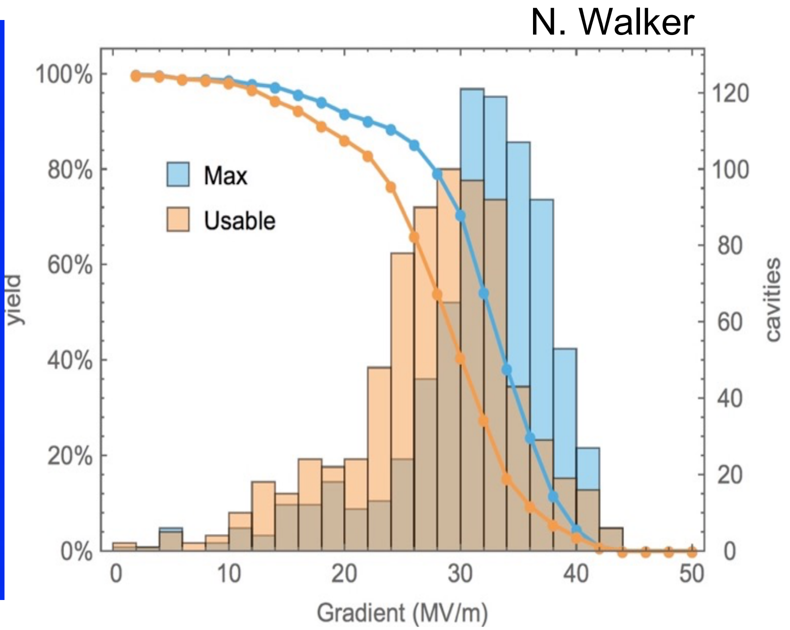

Schleswig-Holstein
Hamburg
Undulator tunnels
Schenefeld
Osdorfer Born
Experimental hall
Injector on DESY campus
0
500 m
DESY-Bahrenfeld
Linac 17.5 GeV

European XFEL Cavity and Module Performance

Showcasing ILC technology







Cavity and cryomodule tests for XFEL

- Tests of cavities („VT“) up to 31 MV
- Cryomodule tests („CM“)
- XFEL specifications easily achieved; extrapolation to ILC possible.

First lasing: May 2017

- User operations have started
- Design energy achieved on 12 July 2018
- First operation with 2700 bunches/train in October 2018

Cavity results:

- 31.5 MV/m @ 90% yield
- XFEL goal: 23.6 MeV/m
- ILC goal: 35 MeV/m
- Shown: „As received“ tests of XFEL cavities

Demonstrating Nano-Beams

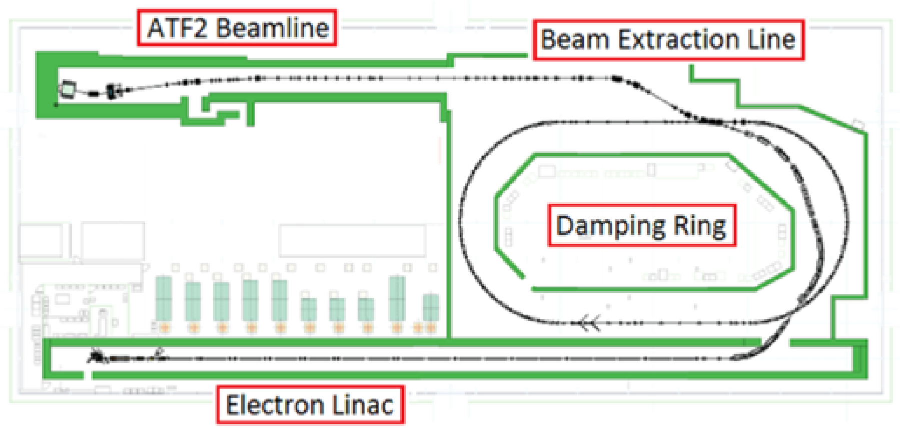
ATF2 Facility at KEK

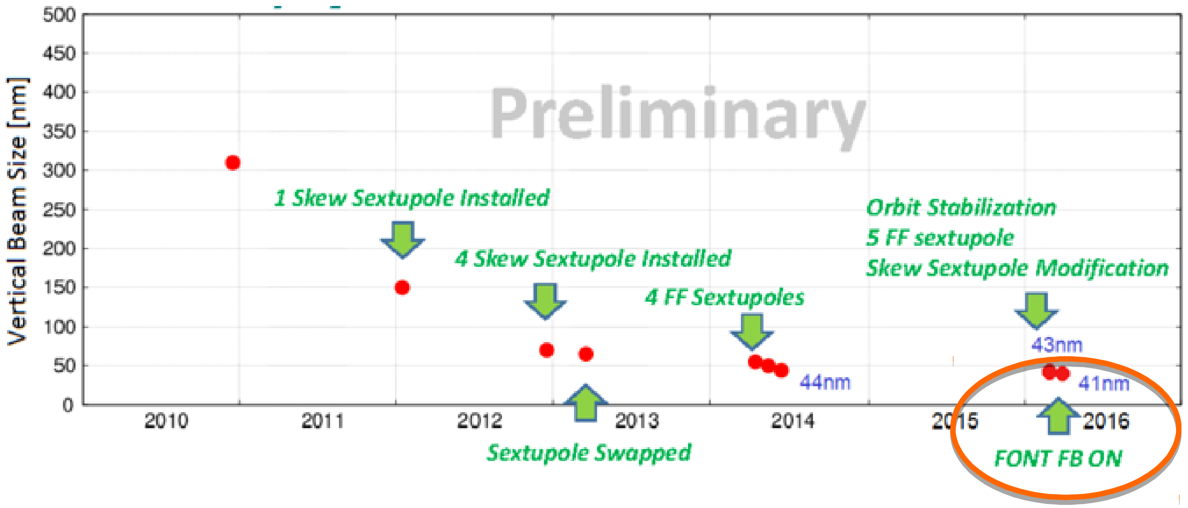
Latest Achievements

- World Record : 41 nm beam spot size
- Design goal 37 nm (corresponds to 5 nm at ILC)

Reproducible

- ~32 hrs recovery from a 3 week shutdown
- ~16 hrs recovery from weekend beam-off

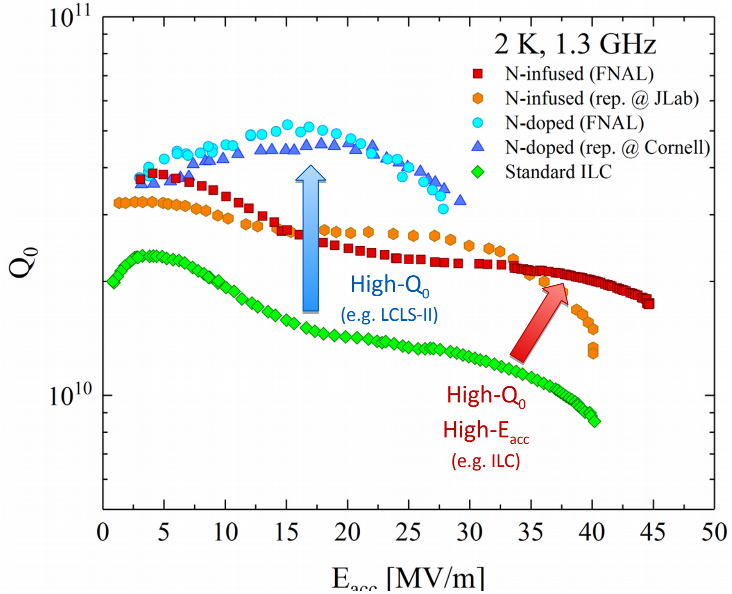


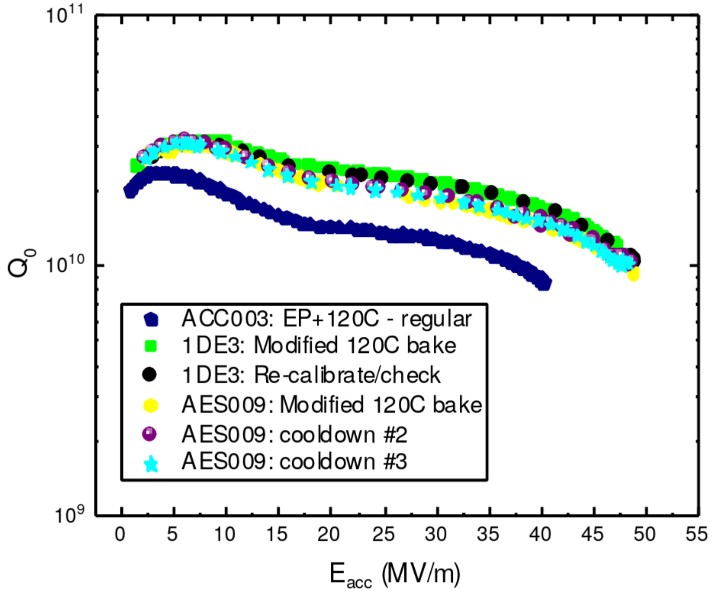


Continuous Progress on SCRF

Super Conducting RF R&D world-wide

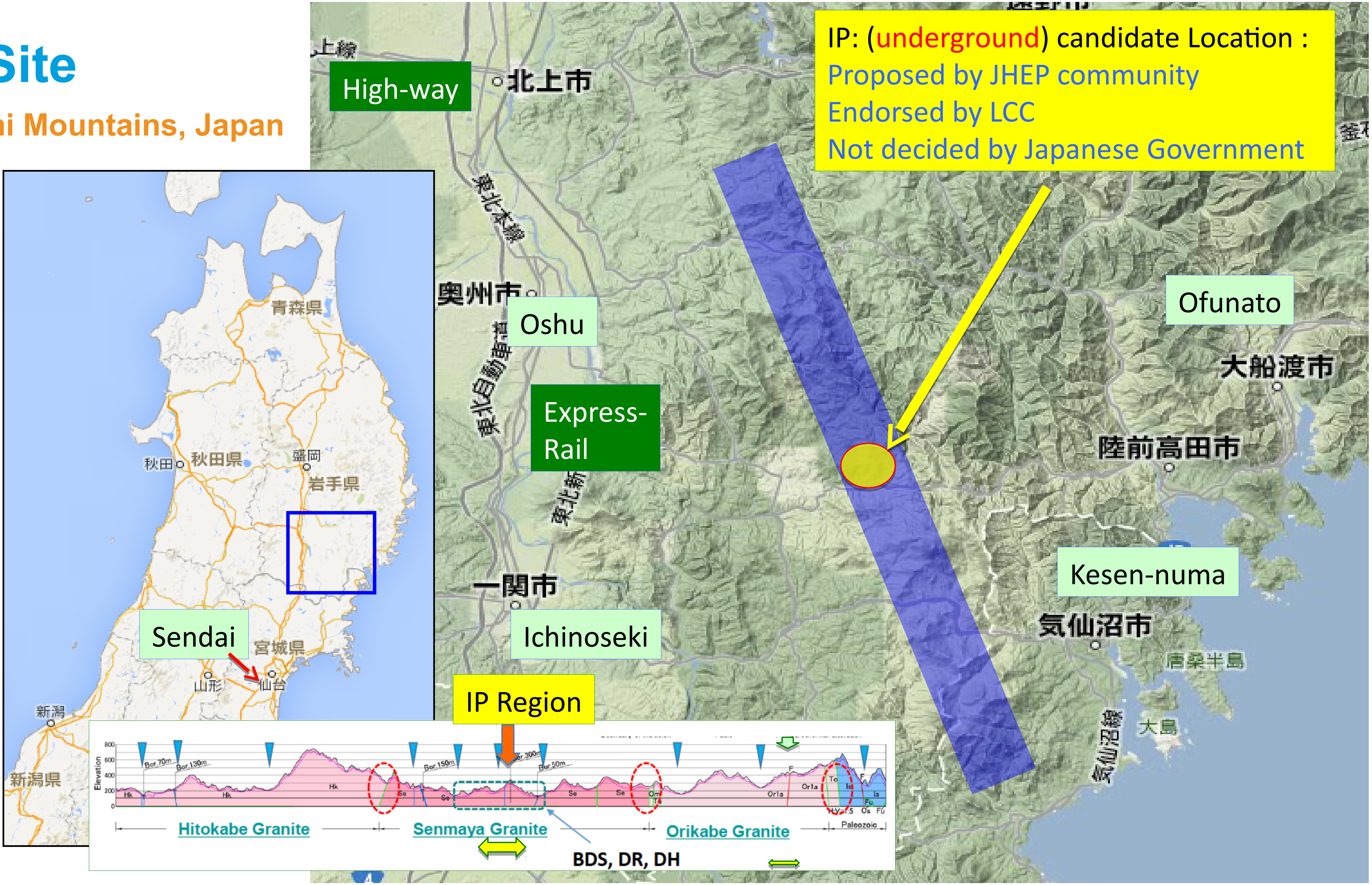
- Cavity specifications
  - 35 MV/m ±20% (‘vertical test’)
  - Corresponds to~ 31.5 MV/m operation (TDR)
  - 90% yield achieved
- Still improving
  - e.g. N_2 doping & N_2 infusion
  - Higher Gradient and Q_0
  - 35 MV/m operation realistic
  - And things keep improving 49 MV/m in single-cell cavity achieved
- Benefits
  - Fewer cavities & less cryogenic power





ILC Site

Kitakami Mountains, Japan

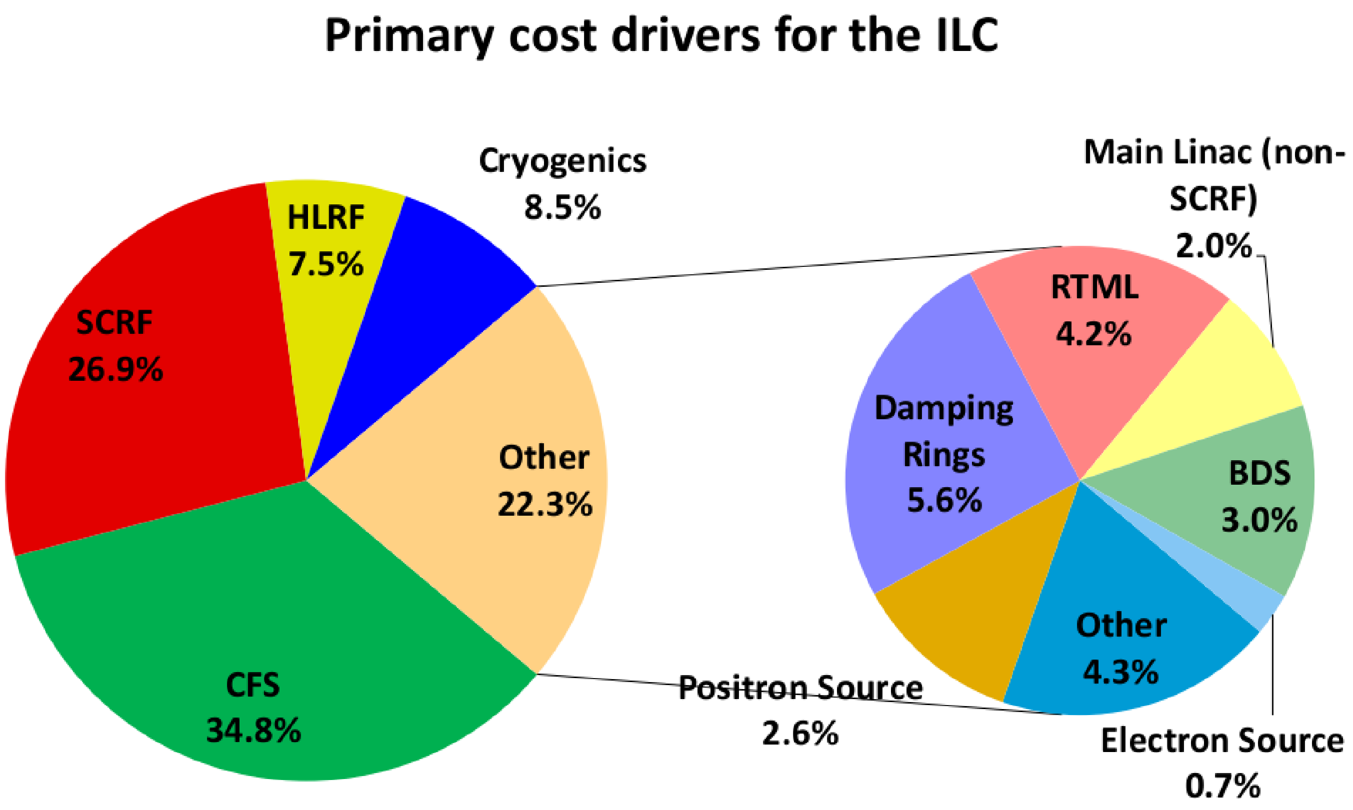


Accelerator Costing

ILC250 Baseline

ILC costing model

- Established for the TDR
  - Including set-up and learning curves
- TDR (500 GeV)
  - 7.98 Billion US-$
- Updates since
  - All experiences from the E-XFEL, ESS, LCLS-II
  - Higher Gradient Cavities
- ILC 250 baseline
  - 40% cost reduction
  - 1/3 Construction (CFS)



Extendability built-in

Going fom 250 GeV to 1 TeV

ILC Site & Infrastructure

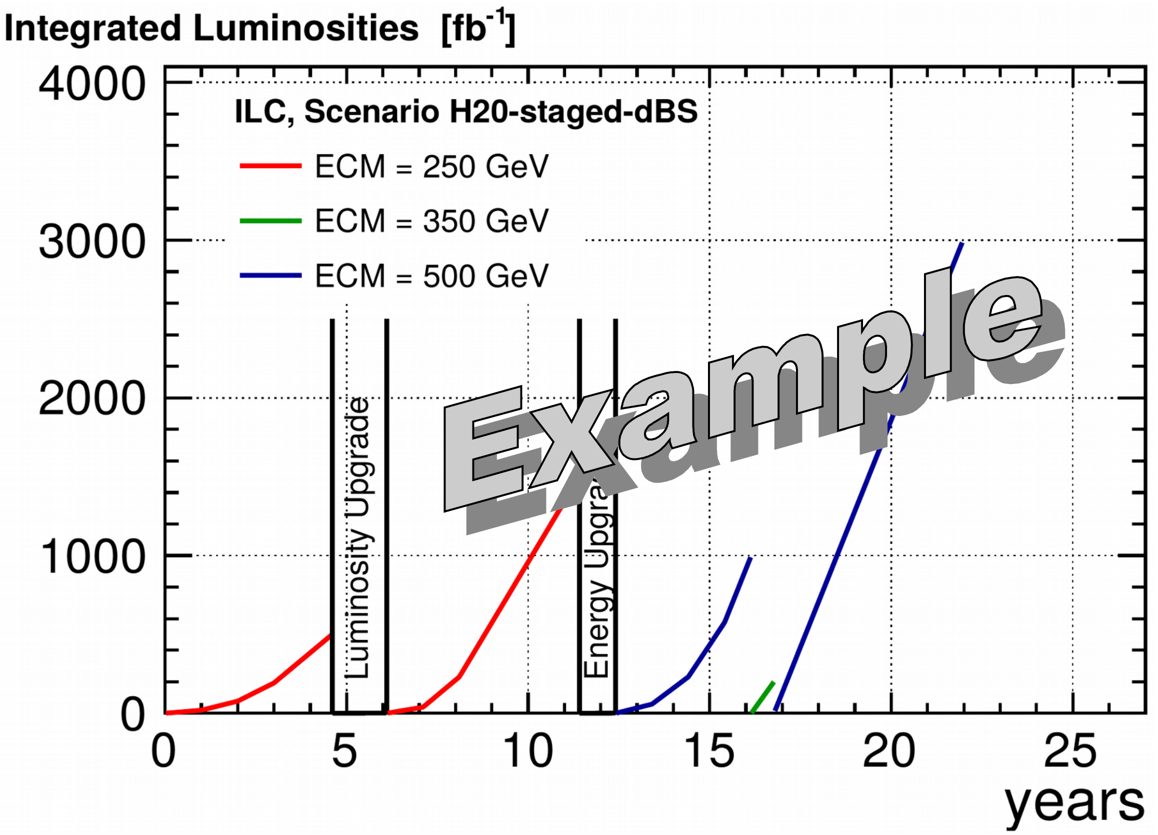
- 67 km maximal length of tunnel
- Beam dumps, etc designed for 1 TeV operation
- Overall recommended ILC power limit for the 1 TeV ILC : 300 MW

Luminosity upgrades

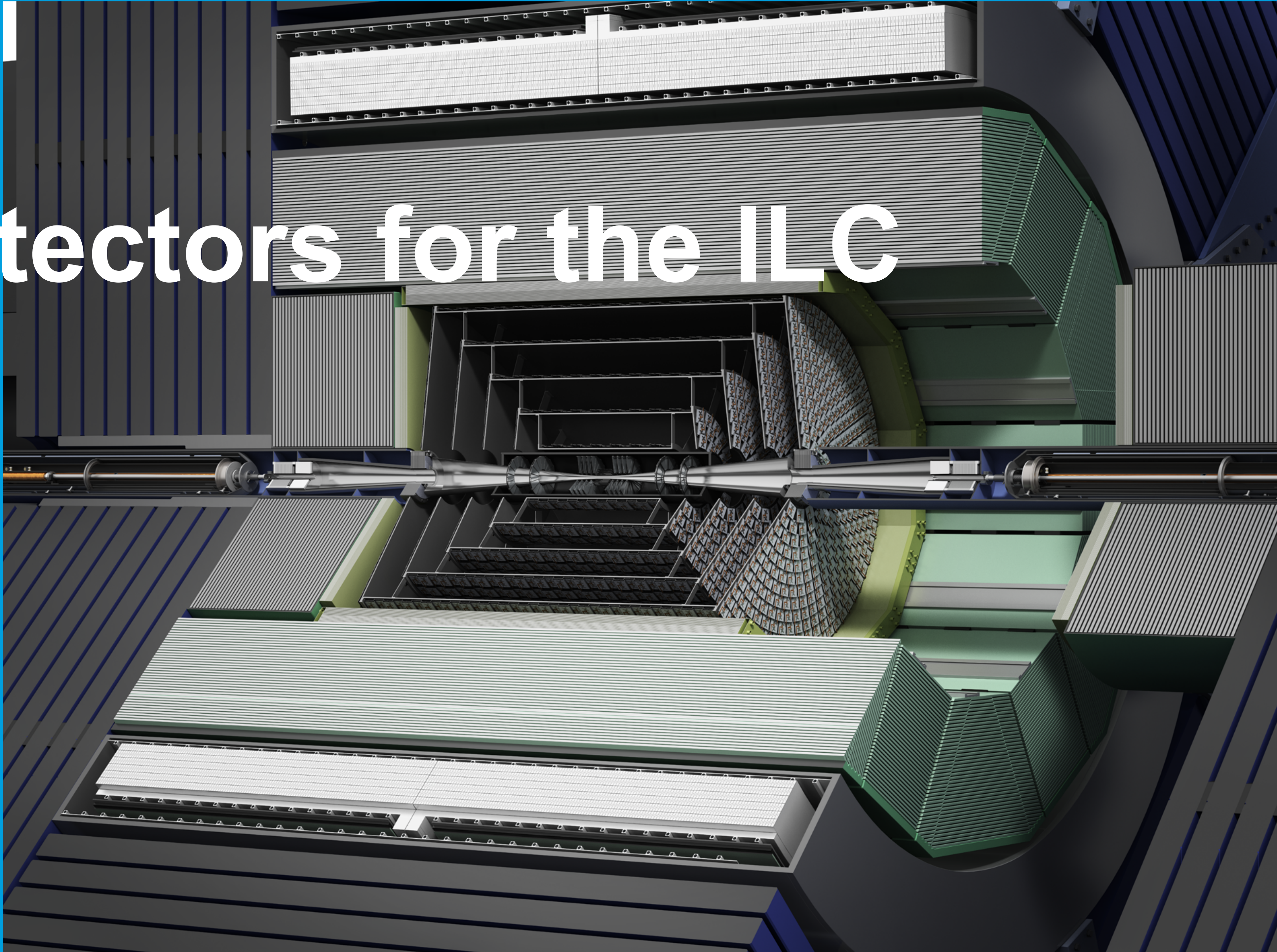
- Straightforward: Increasing the number of bunches from 1312 to 2624
- Power Increase 129 MW → 164 MW

Energy upgrades

- Energy upgrades to 350 GeV ($t\bar{t}$ threshold) and ~500 GeV being discussed
- 1 TeV for longer-term plan



The Detectors for the ILC

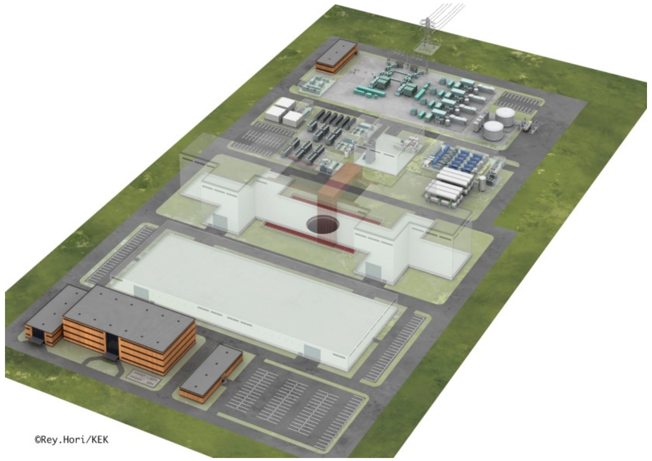


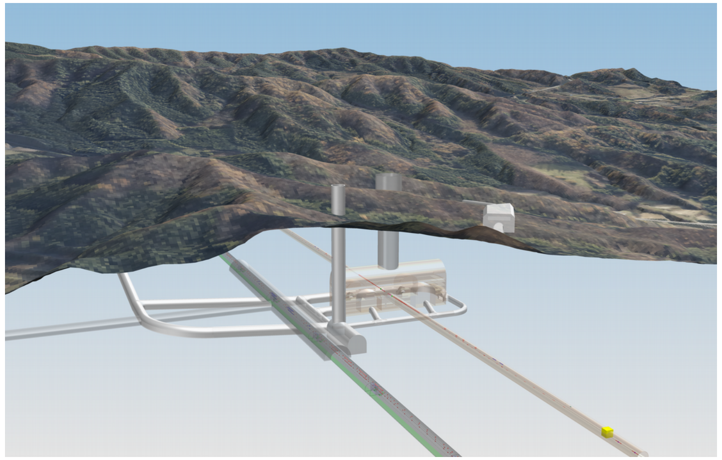
ILC Interaction Region

Kitakami Mountain

Interaction Region Campus

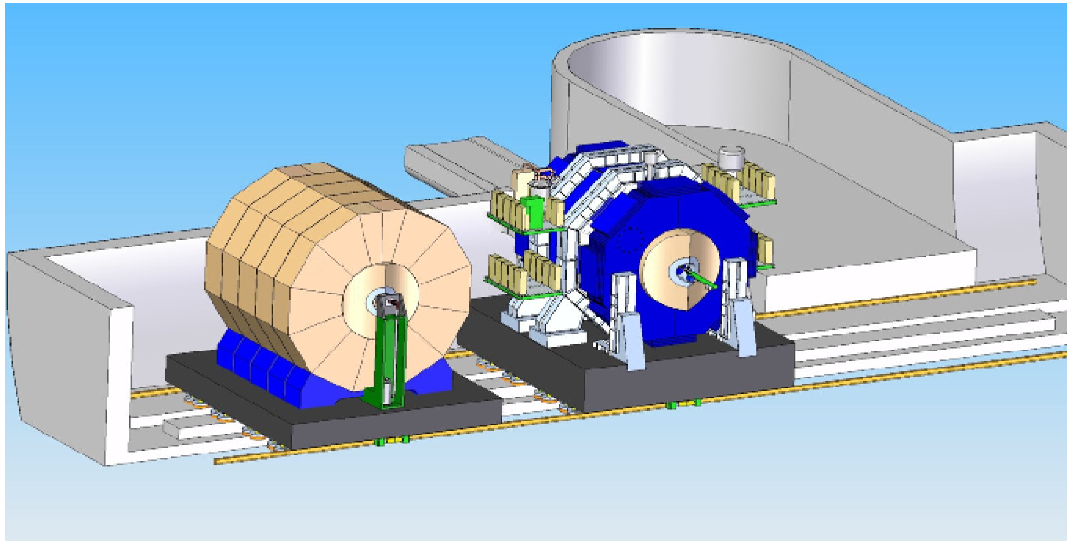
- Campus located in the Kitakami mountains
- Assembly hall, service buildings
- Access to IP using vertical shafts





1 IP - 2 Detectors

- The ILC has only one interaction region
- Two detectors share the IP in a push-pull configuration
  - Detectors on platforms
  - Swap-over in 48-72 hours

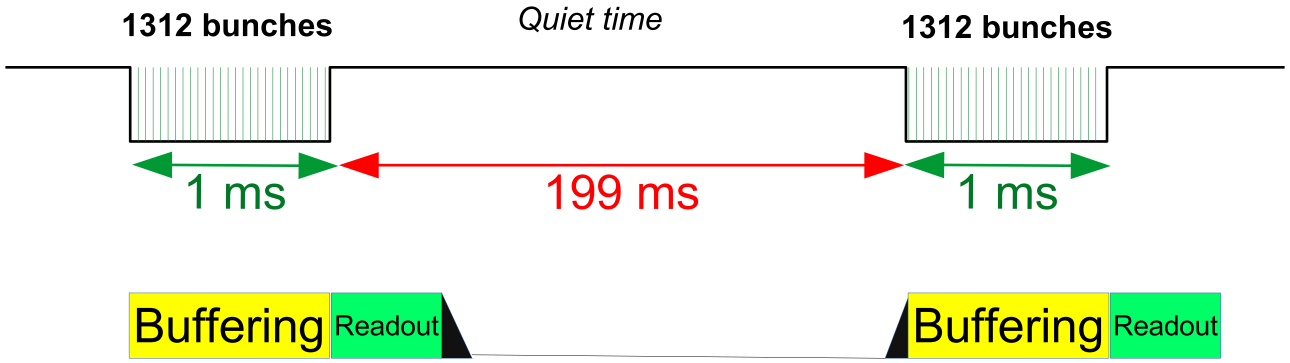


ILC Bunch Train Structure

Bunches, Bunch trains & Power Pulsing

ILC Timing

- Bunch Structure at the ILC is very different compared to a synchrotron
  - Bunch spacing of 554 ns
  - 1 Train has 1312 bunches in ~ 1 ms
  - Then 199 ms quiet time until the next train
- Huge Impact on the Detector design
  - Occupancy dominated by beam background & noise
  - Triggerless Readout
  - Buffering on front-end &Readout after the last bunch
  - Powering off the front-ends during the quiet time
  - Power saving of a Factor 100 → No Active cooling



Particle Flow Paradigm

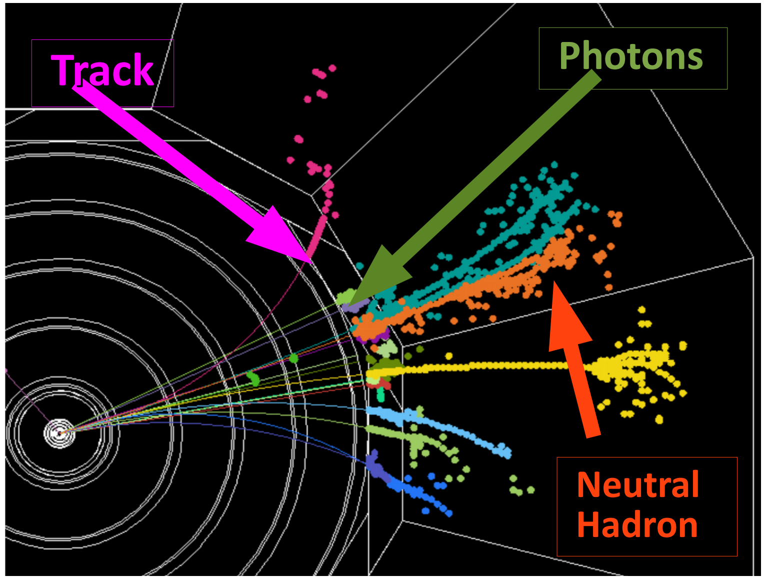
Driver for ILC Detector Design

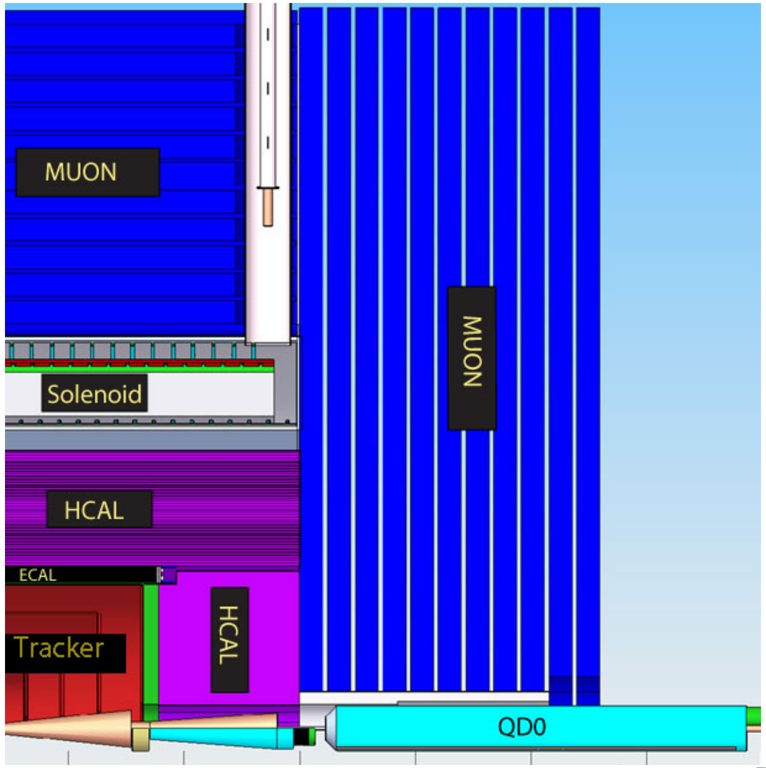
Particle Flow Algorithms

- PFA has been used before at LEP, HERA and LHC
- Novel Approach at the ILC→ PFA drives design of the detector

Impact on the detector design

- Highly granular calorimetry
- Low-mass tracking
- Calorimetry inside the superconducting solenoid





Detector Requirements

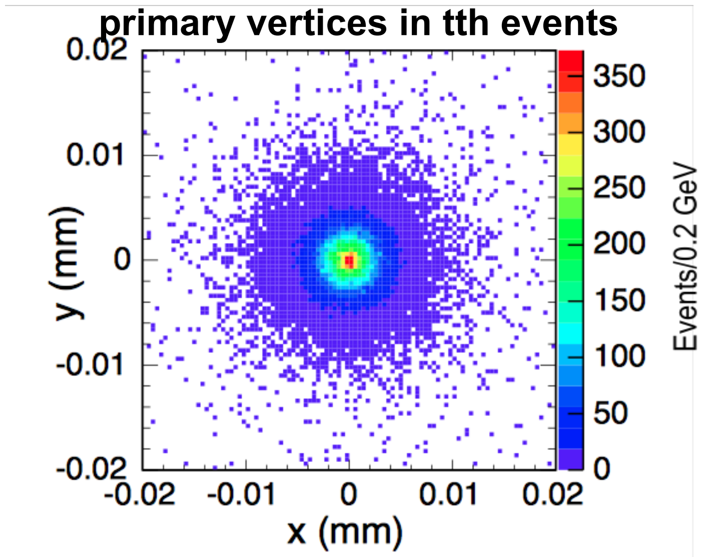
ILC requires precision detectors

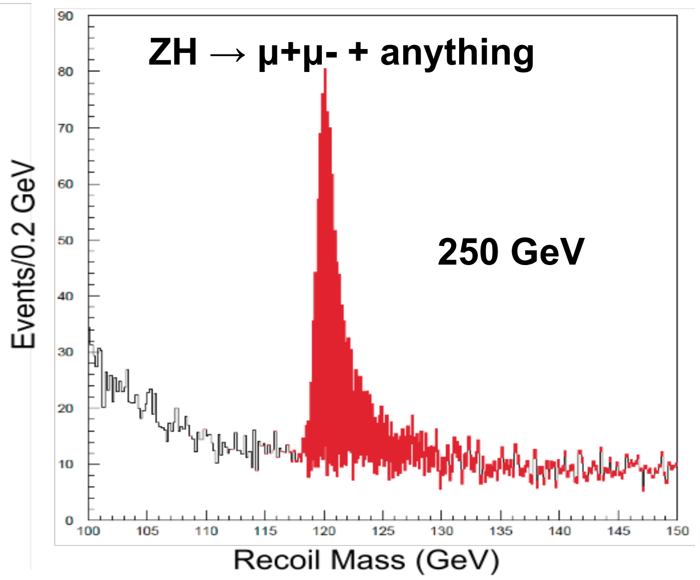
ILC detector design cornerstones

- Particle Flow
- Power Pulsing

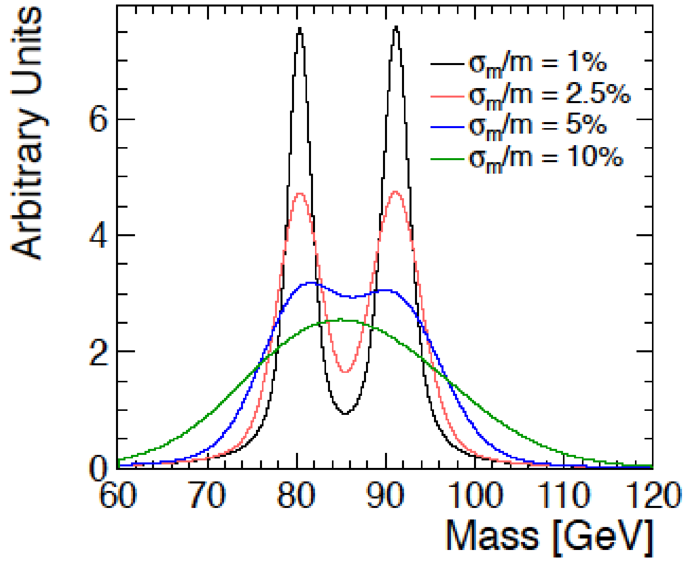
Performance Requirements

- Time stamping
  - Single Bunch resolution
- Vertex detector
  - < 4 μm precision
  - $\sigma_{r\phi} \approx 5\ \mu m \oplus 10\ \mu m / p \sin^{(\frac{3}{2})}(\theta)$
- Tracker
  - $\sigma(1/p) \sim 2.5 \times 10^{-5}$
- Calorimeter
  - $\frac{\sigma_{E_{Jet}}}{E_{Jet}} = 3-4\%, E_{Jet} > 100\ GeV$





W-Z separation



SiD and ILD

Detector concepts for the ILC

Common Aspects

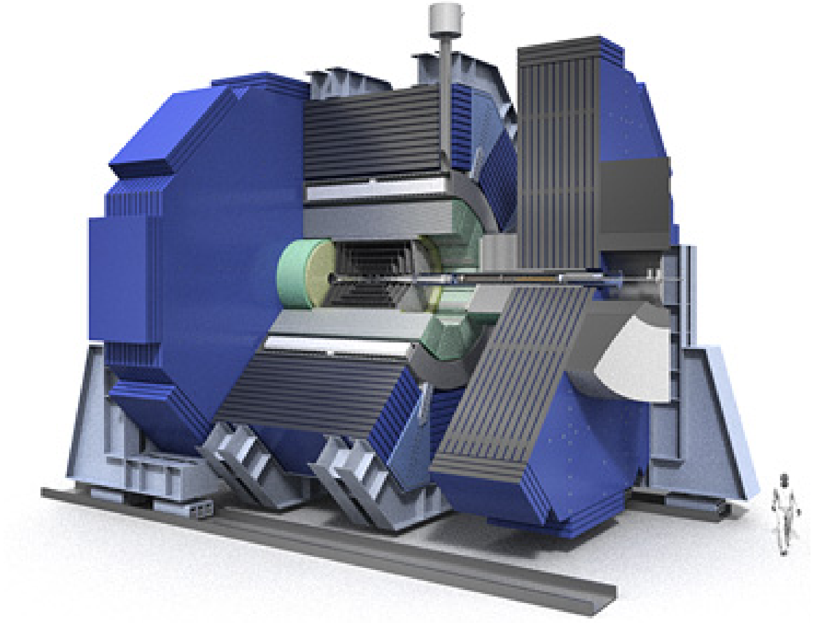
- Designed for Particle Flow
- Highly granular calorimetry
- Designed for easy Push-Pull operation

SiD

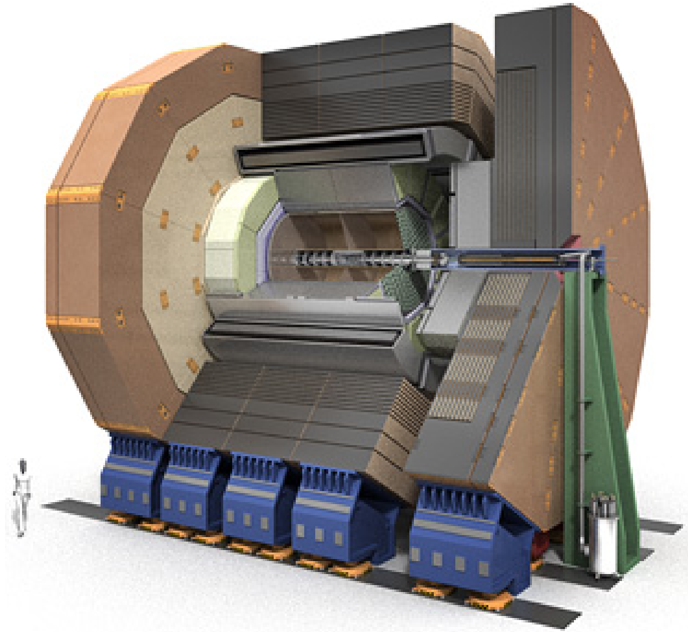
- Compact high-field design
- All-Silicon tracking
- B Field 5 T, r_{ECAL}=1.25 m

ILD

- Large medium-field design
- TPC as main tracking device
- B Field 3.5 T, r_{ECAL}=1.7 m



SiD



ILD

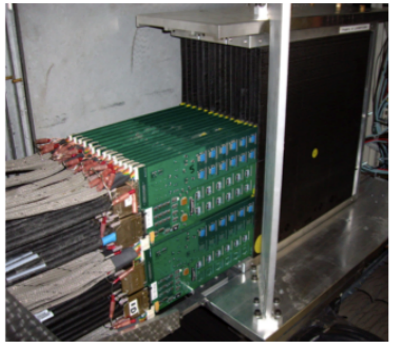
R&D Highlight: CALICE

Establishing Highly Granular Calorimetry

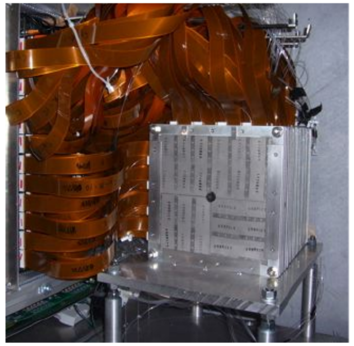
CALICE Collaboration

- R& D for highly granular calorimeters started in 2001
- CALICE collaboration started in 2005
- CALICE today:
  - 55 institutes in 19 countries (4 continents)
  - 350 members
- Various technologies approaching technological readiness
  - SiW, Scintillator+SiPM, GEM, RPC
- Game-changing impact on detector designs:
  - ILC, CLIC, CEPC, CMS, DUNE

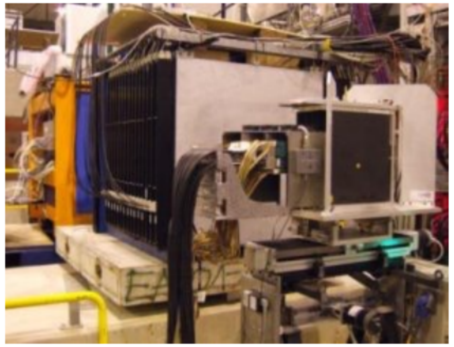
SiW ECAL



ScintW ECAL

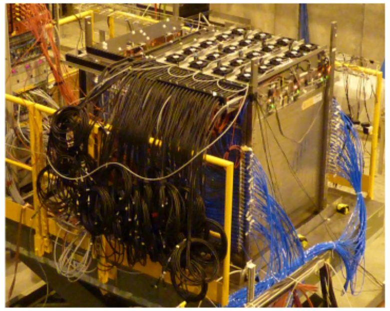


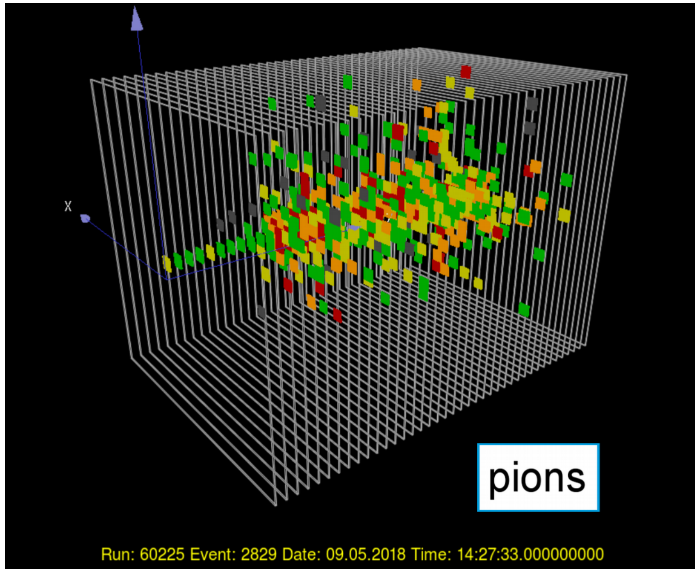
Scint AHCAL, Fe & W



RPC DHCAL, Fe & W

RPC SDHCAL, Fe





Detector R&D for the ILC

The LCC Detector R&D Report

Summarizing the state of detector R&D relevant for linear collider detectors

- Current version Nov. 9th, 2018 (living document)
- Third version prior to December 18th, 2018 that can be used as supporting documentation to the update of the European Strategy for Particle Physics.

- You can download the latest version from
  - http://www.linearcollider.org/P-D/Working-groups/Detector-R-D-liaison

LINEAR COLLIDER COLLABORATION

Detector R&D Report

VERSION 2018.2

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November 9, 2018

LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

Linear Collider software

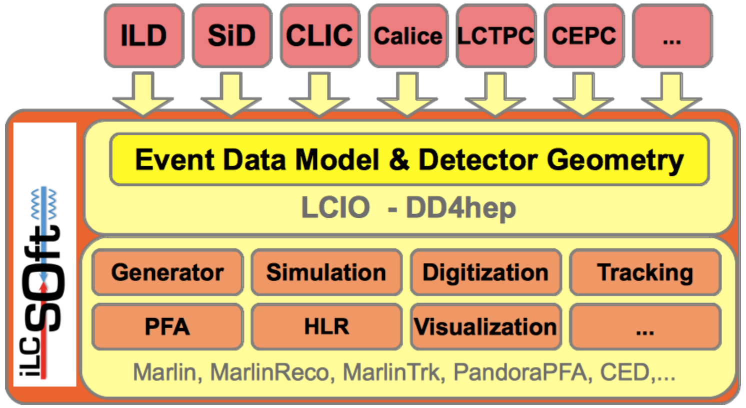
Used ILC, CLIC, CEPC, CALICE

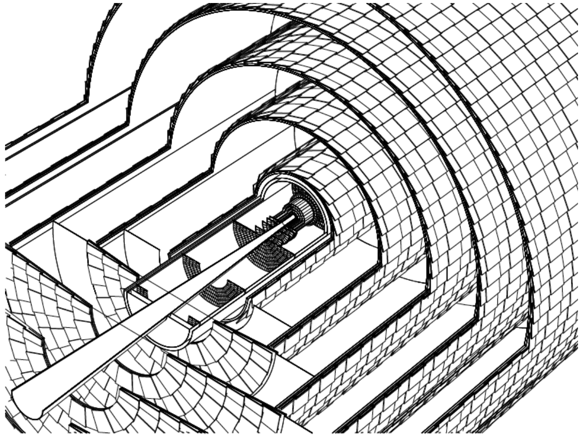
ILCSoft

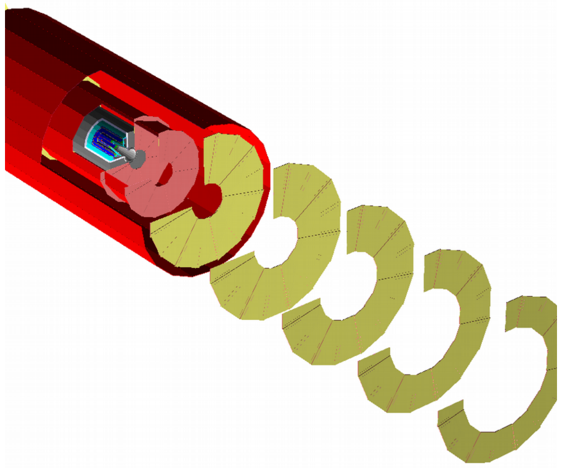
- ILC community has a long tradition of using and developing common software tools
  - started in 2003 with LCIO common EDM -
  - since 2010 common detector description DD4hep
- Used by ILC, CLIC and test beams and others

SiD & ILD

- Both concepts use full simulation for detector performance studies and physics analyses
- Detailed simulation models with electronics, gaps and imperfections, cables and services
- Realistic detector and physics performance aided by common software

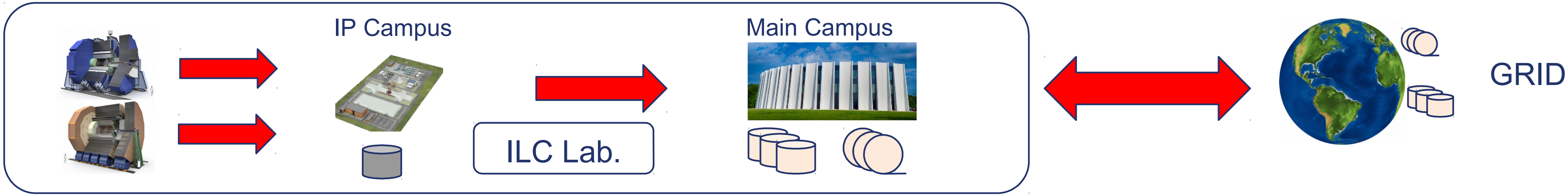






ILC Computing

Overall Concept



Role of each facility

IP Campus: Event building & Monitoring

- Main Campus: Data storage, Event(BX) selection,
- GRID Computing: Data Analysis &Simulation

Challenges

- Trigger less readout. O(1000) BXs per 1 train of 5 Hz.
- Efficient event selection using full reconstruction
- GRID infrastructure for data and CPU sharing

Resource Requirements

- Raw data rate ~ 1.5GB/s. Annually 10~15 PB
- CPU : 200 ~ 300kHepSpec06 for simulation, reconstruction and analysis
- Resources ~ 1 order of magnitude less than LHC requirements

Physics Performance

Higgs Precision

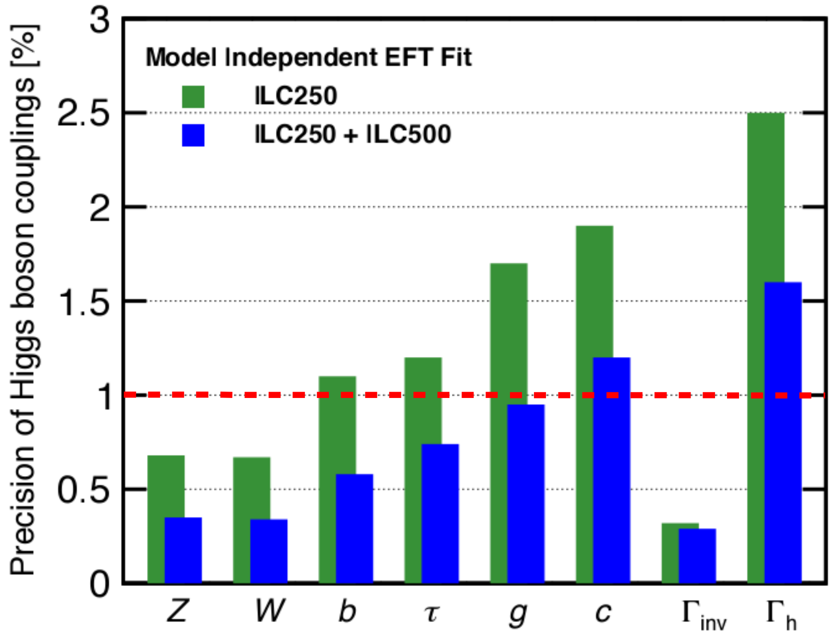
Model-independent EFT Fit

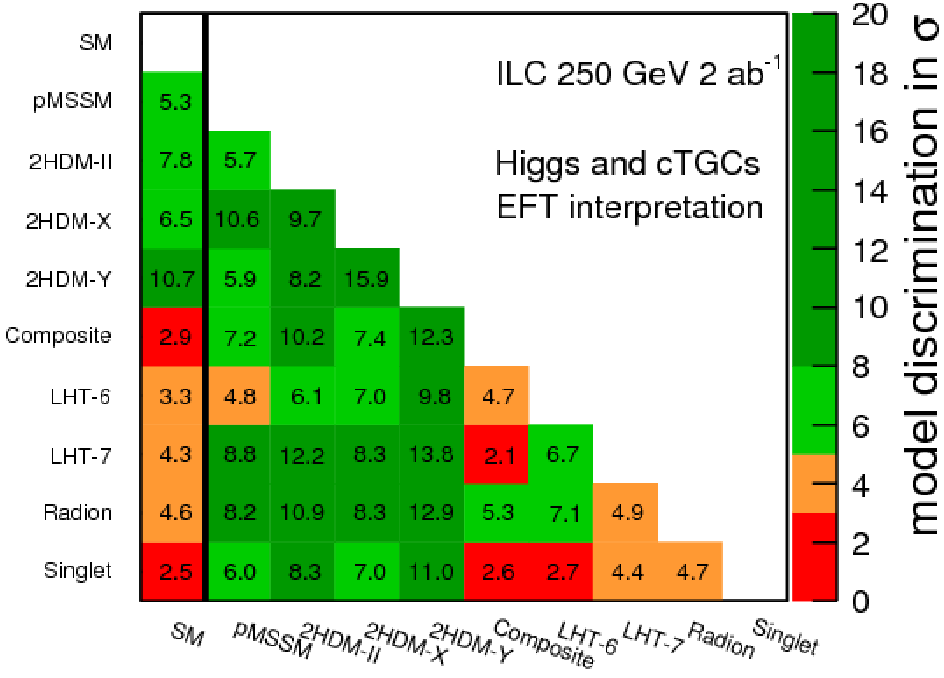
The EFT Fit

- 250 GeV 2 ab^{-1} / 500 GeV 4 ab^{-1}.
- Based on an EFT analysis, but highly model-independent.
- Polarization of ILC beams provides crucial inputs

Results

- ILC250 will reach ~ 1% level for W, Z, b couplings and can distinguish between many models (Arxiv)
- Any new physics effect discovered at 250 GeV can be confirmed with an independent data set after the upgrade to higher energies.
- A detailed comparison to the new projections for HL-LHC will appear once these numbers are available





Top Quark physics

Rich program at 350 GeV and beyond

350 GeV

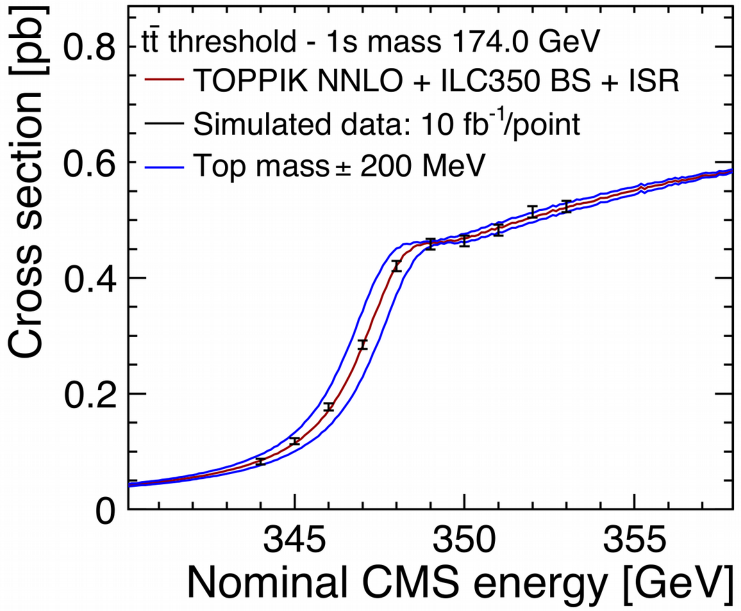
- Top-threshold scans
- Top mass with 40 MeV accuracy

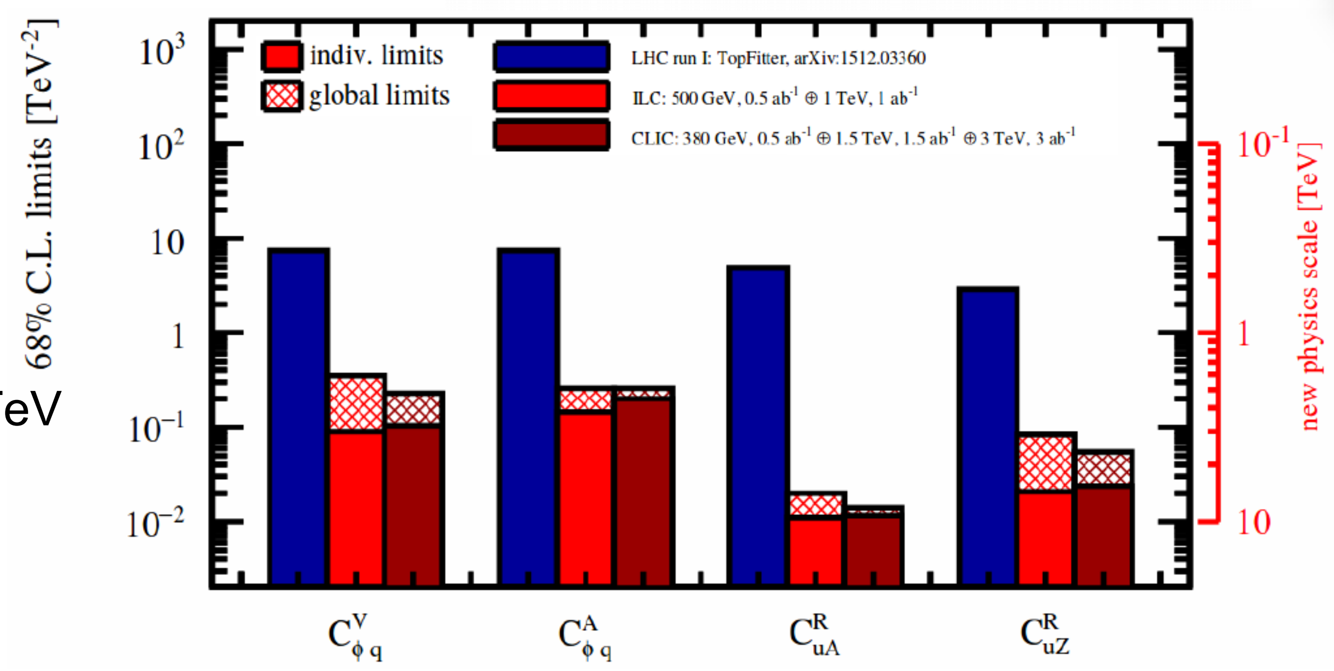
500 GeV

- Top-EW couplings
- ttH

TOP EFT fit

- Physics reach of ILC for new physics up to 10 TeV
- Polarization adds crucial information
- [Arxiv]





Double Higgs & Higgs Self-Coupling

At ILC250 and ILC500

Double Higgs Production

- Multiple diagrams contributing with/without Higgs self-coupling λ
- Interference terms

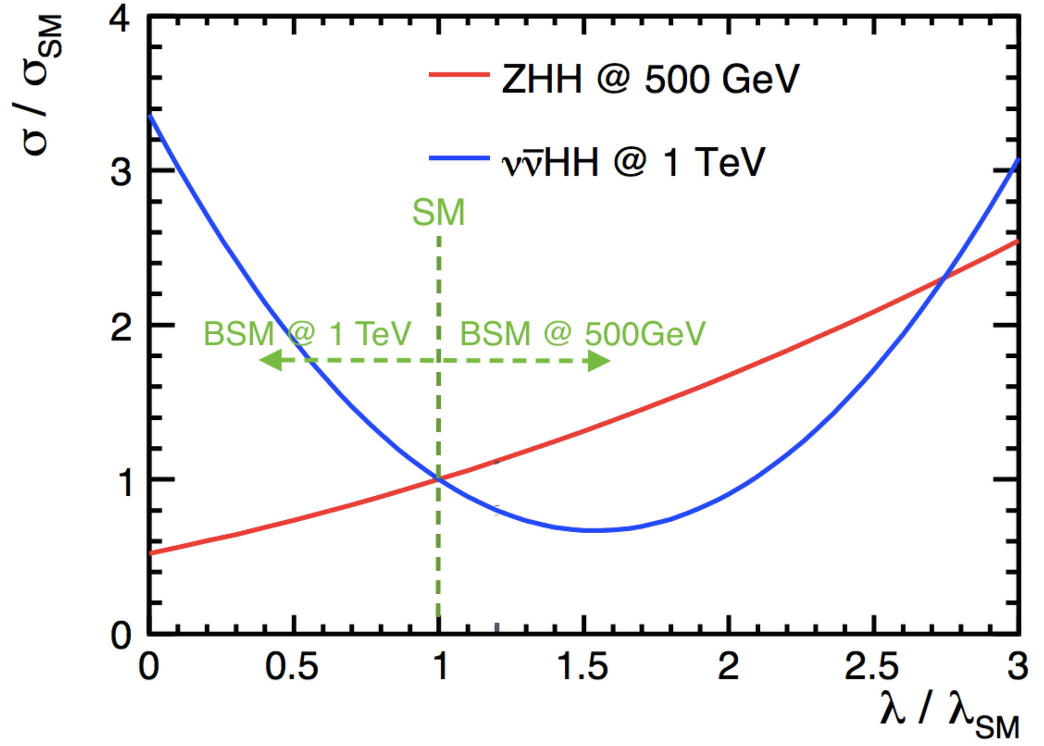
ILC250

- Higher Order Correction to σ_{ZH}
- Not entirely model-independent

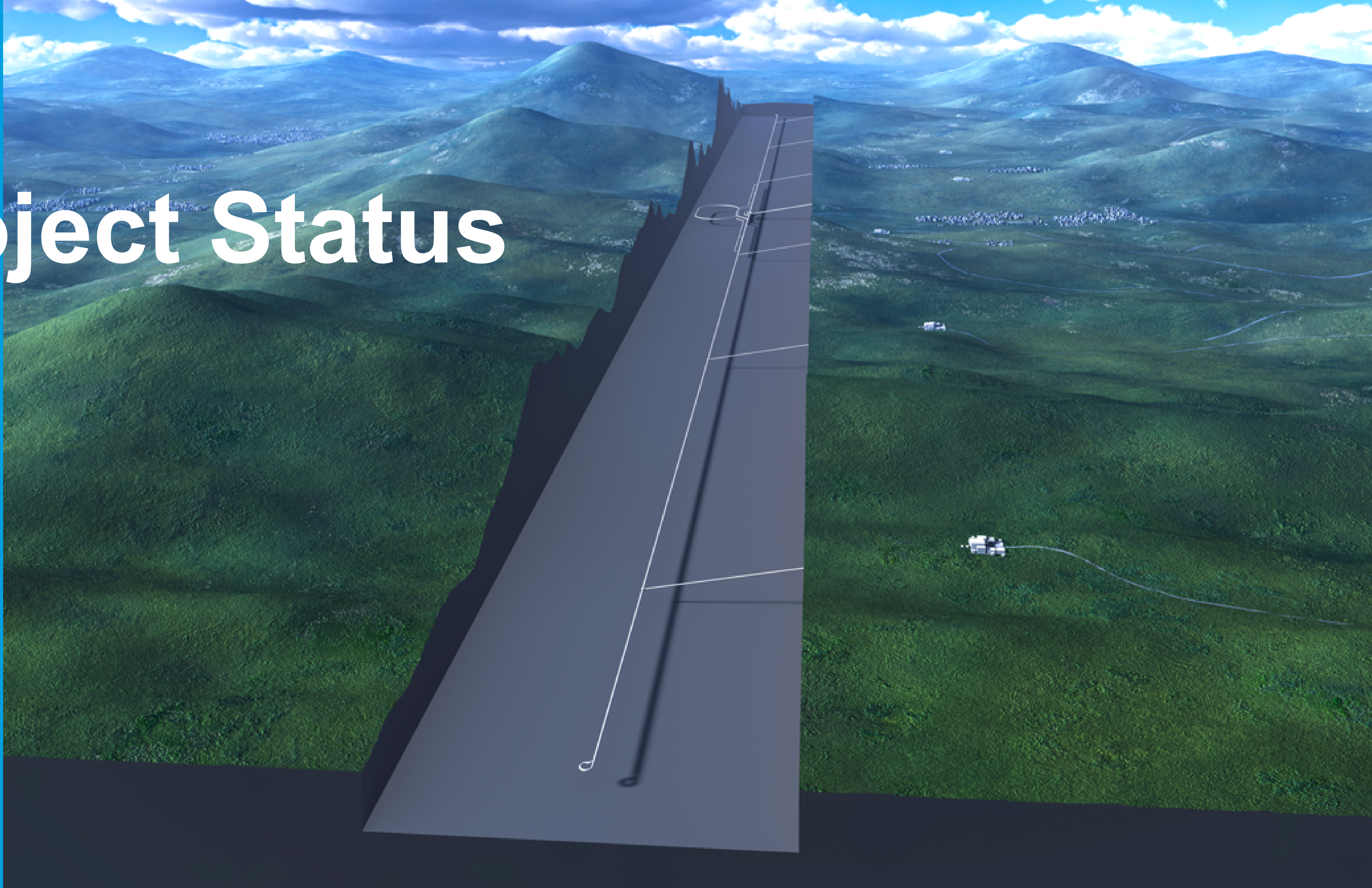
ILC500

- Establish Double Higgs Production with 8σ
- Measurement with ~ 27% accuracy

$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$



Project Status

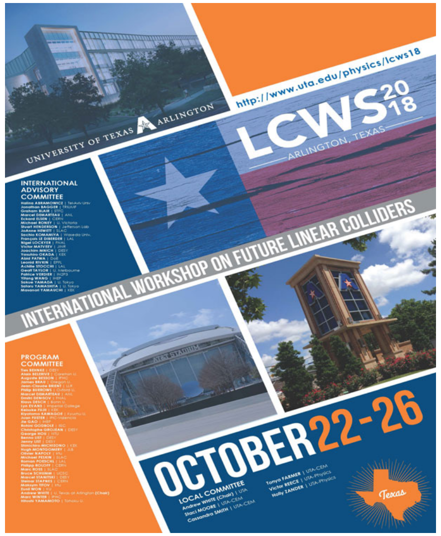


Meetings and Communities

Carrying the ILC project forward

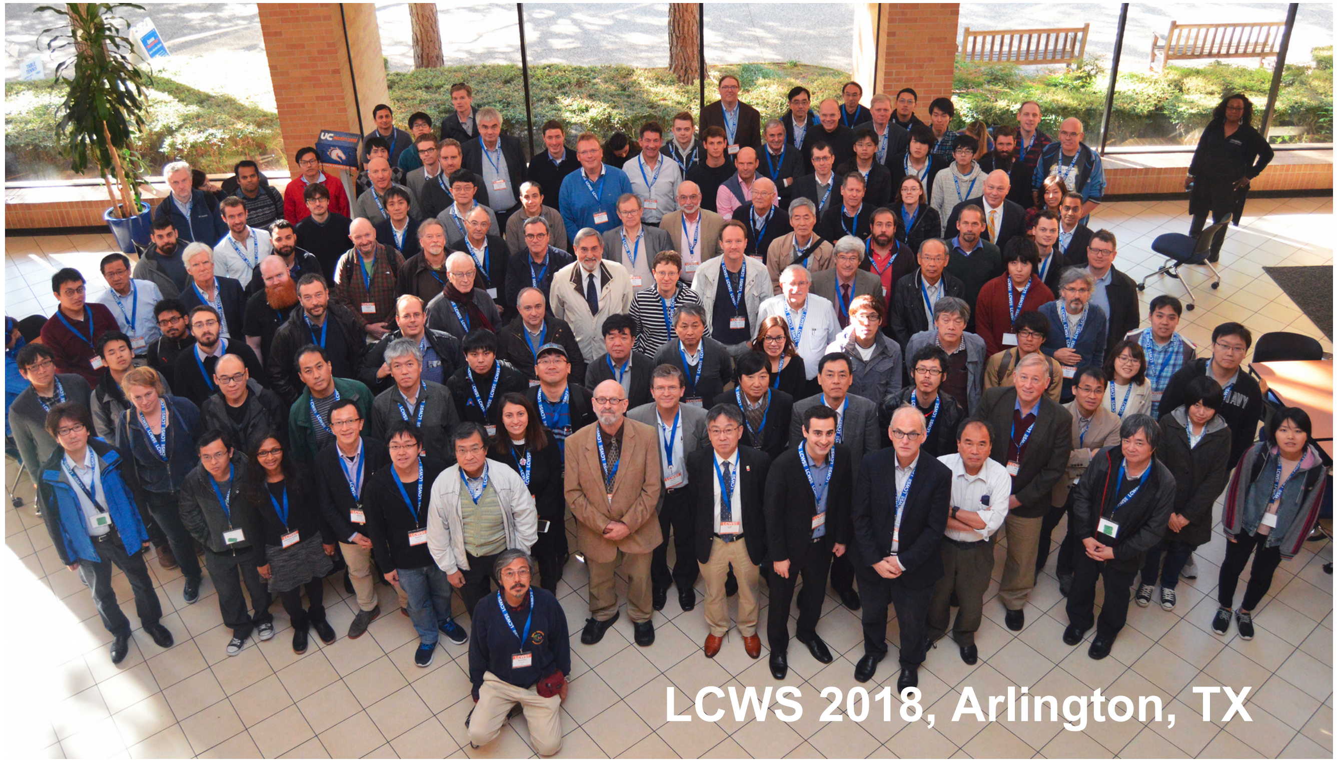
LC NEWSLINE

THE NEWSLETTER OF THE LINEAR COLLIDER COMMUNITY



Linear Collider Workshops

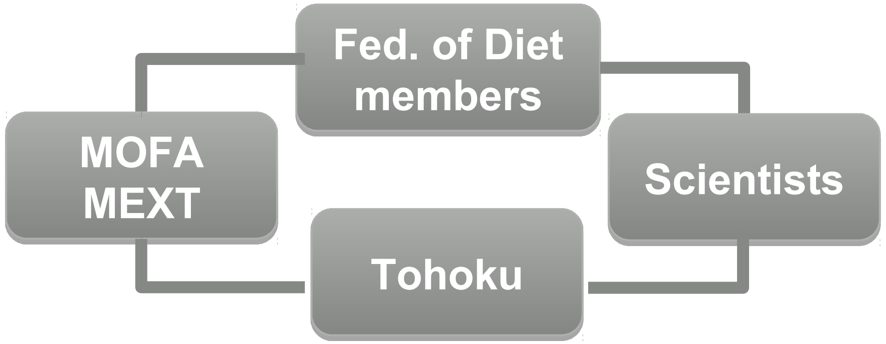
- Community very active despite limited funding
- Two meetings/ year with 200-300 people attending
- Additional meetings/workshops on dedicated issues
  - MDI, Polarization, Detector R&D, Software
- Great support from Horizon2020 Projects
  - AIDA2020, E-JADE
- Regular Newsline



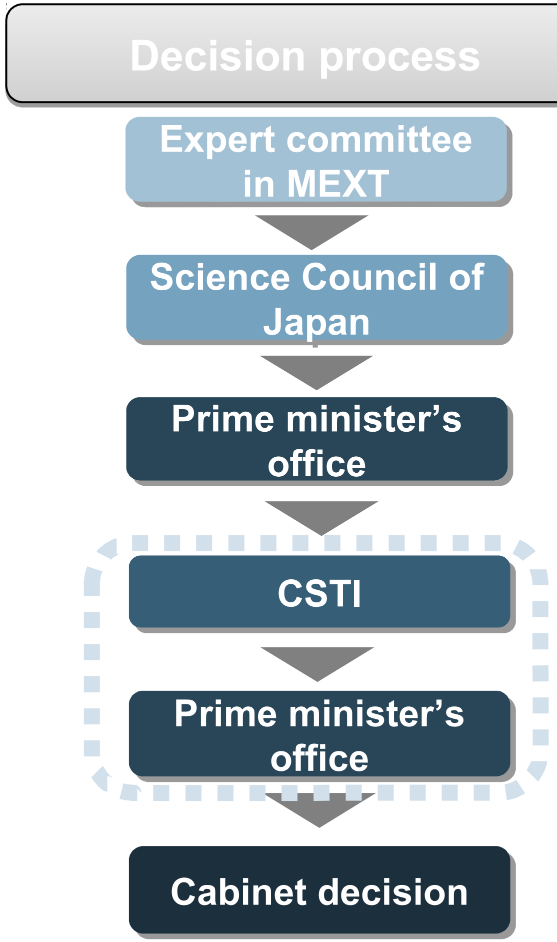
LCWS 2018, Arlington, TX

ILC Decision Timeline in Japan

From S. Yamashita (FCCJ)



2013 2017	US ・ EU ・ Labs. in the world Support ILC in Japan
2018	Japan-France ・ Japan-Germany Established Government – Politic- Academic Body July 2018 Expert Committee in MEXT by fall 2018 Discussion in Science Council of Japan by the end of Dec. 2018 Expression of Interest from Japanese government
2019	Japan-US intergovernmental discussion Discussion of 5 year European Strategy



Political Developments

In Japan and around the world

- Prime Minister Abe and his cabinet briefed on ILC in August 2018
- Federation of Diet Members (150+ MP) continues to strongly support ILC
- Delegation visits to Paris, Berlin, Washington, D.C.

Potential ILC Timeline

Excluding Political Consideration

Pre-Preparation Phase

- End 2018 “ Statement from Japan”

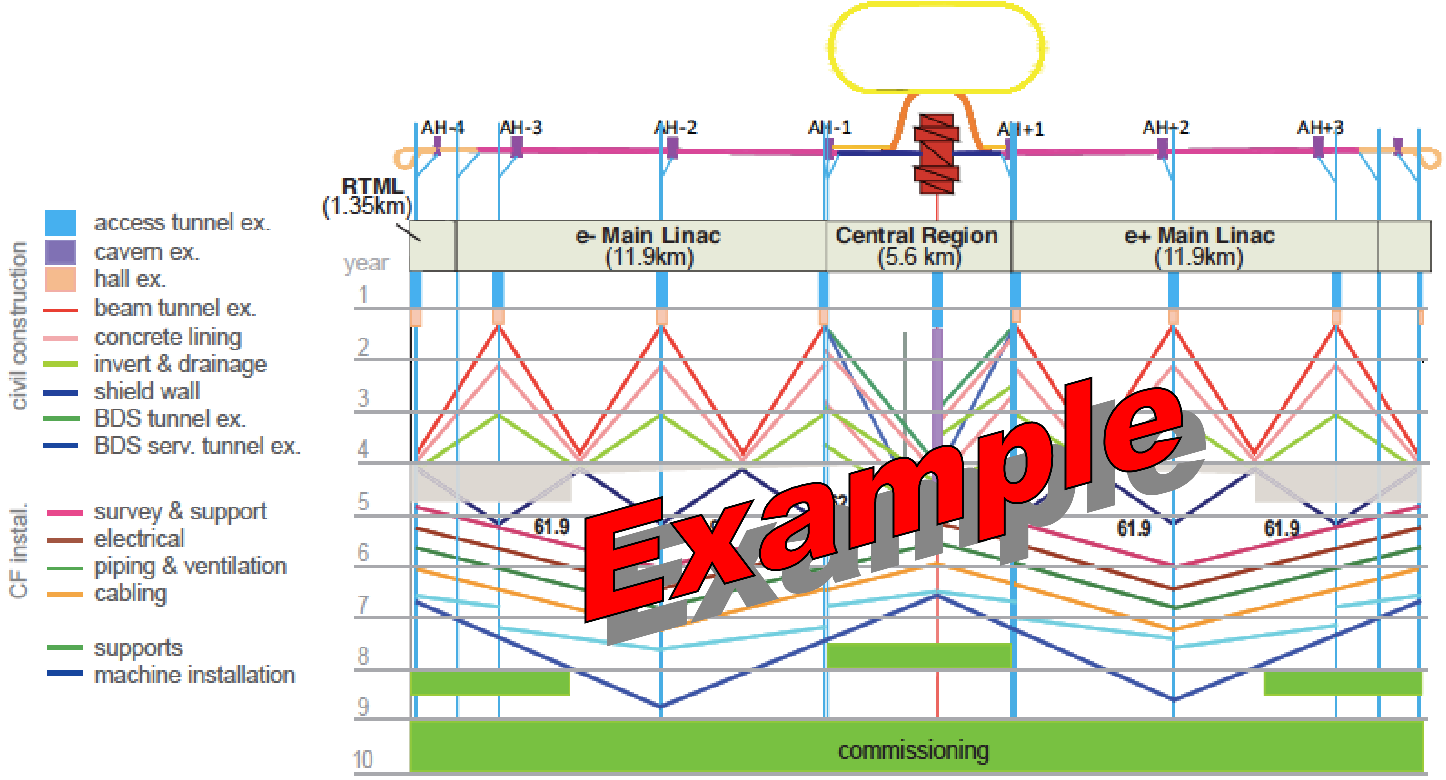
Project Preparation Phase - 4 years

- International Agreements,
- Construction Preparations
- Collaboration Formation

Construction Phase – 8 years

- Begin of Construction

Commissioning & Physics



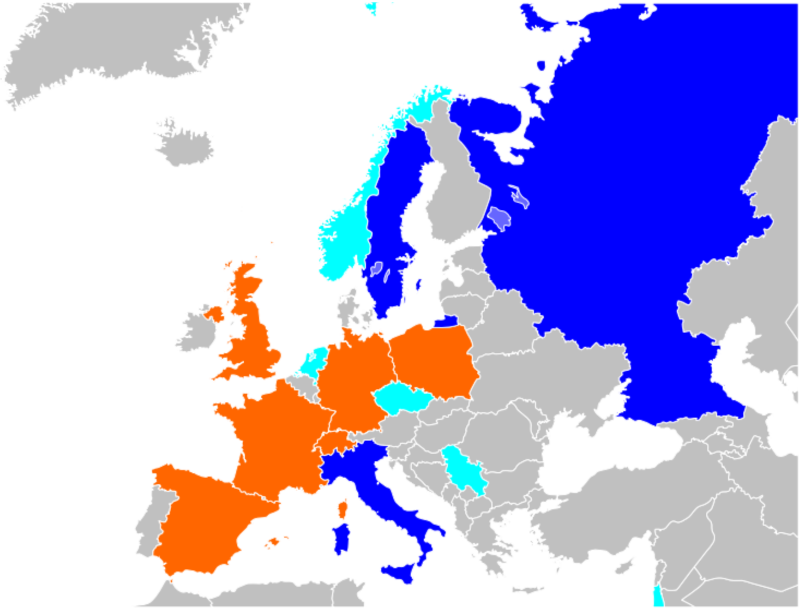
European Involvement

Preparation Plan for European Participation in the ILC

E-JADE
Europe -Japan Accelerator Development Exchange Programme

EIPP Report

- Prepared by the E-JADE Consortium upon a request from the KEK Directorate
- Contents
  - Summary on past and present European Activities relevant for the ILC
  - ILC Preparation Phase & Europe
  - Potential European In-kind contributions
  - Possible involvement forms of Europe
- Presented to CERN Counci in June 2018
- Available here



European Strategy Inputs

From the ILC Community

ILC Input documents to the European Strategy process

- Main Inputs
  - Document 1: “The ILC project general description”
  - Document 2: “The European effort/participation”

Main supporting documents

  - ILC TDR documents
  - ILC project overview, being specifically produced for ESU
  - European ILC Preparation Plan (EIPP), produced under E-JADE project
  - LC Detectors R&D Liasion Report
  - ILD Detector Input for the ESU

Industry Workshops

Industries from Asia, Europe, Americas

1 Day Mini-Workshops with Industry

- Since LCWS 2016
- All three regions (Asia, Europe, Americas)
- Well-attended
  - Extensive activities in all regions fairly directly related to eventual ILC construction
    - cost reduction through performance improvement based
  - Interactions between (scientific) clients and industry demands excellent communications and frequent understanding of goals on both sides

Upcoming Meetings

Linear Collider Community Town Meeting

Town Meeting

- Recommendation from the Linear Collider Board (LCB)
  - The Linear Collider Community should form a unique position to be presented at the Open Symposium for the update of the European Strategy for Particle Physics taking place in Granada for May 13-16, 2019
  - LCC and relevant people are charged organise a community town meeting in Spring 2019
- The tentative plan is
  - **8-9 April 2019 at Swisstech Convention Centre @ EPFL,in Lausanne**

Town Meeting Inputs & Goals

- Inputs
  - European Strategy Inputs(ILC and CLIC)
  - Statement (or no statement?) from the Japanese government
  - Assessment of the situation by LCB/ICFA made at their meetings on 7-8 March 2019
- Goals
  - Agree on a unique future strategy for the international linear collider activities.
  - Prepare the case for the meeting in Granada
  - Address the future organization of the international linear collider activities beyond LCC.

Summary

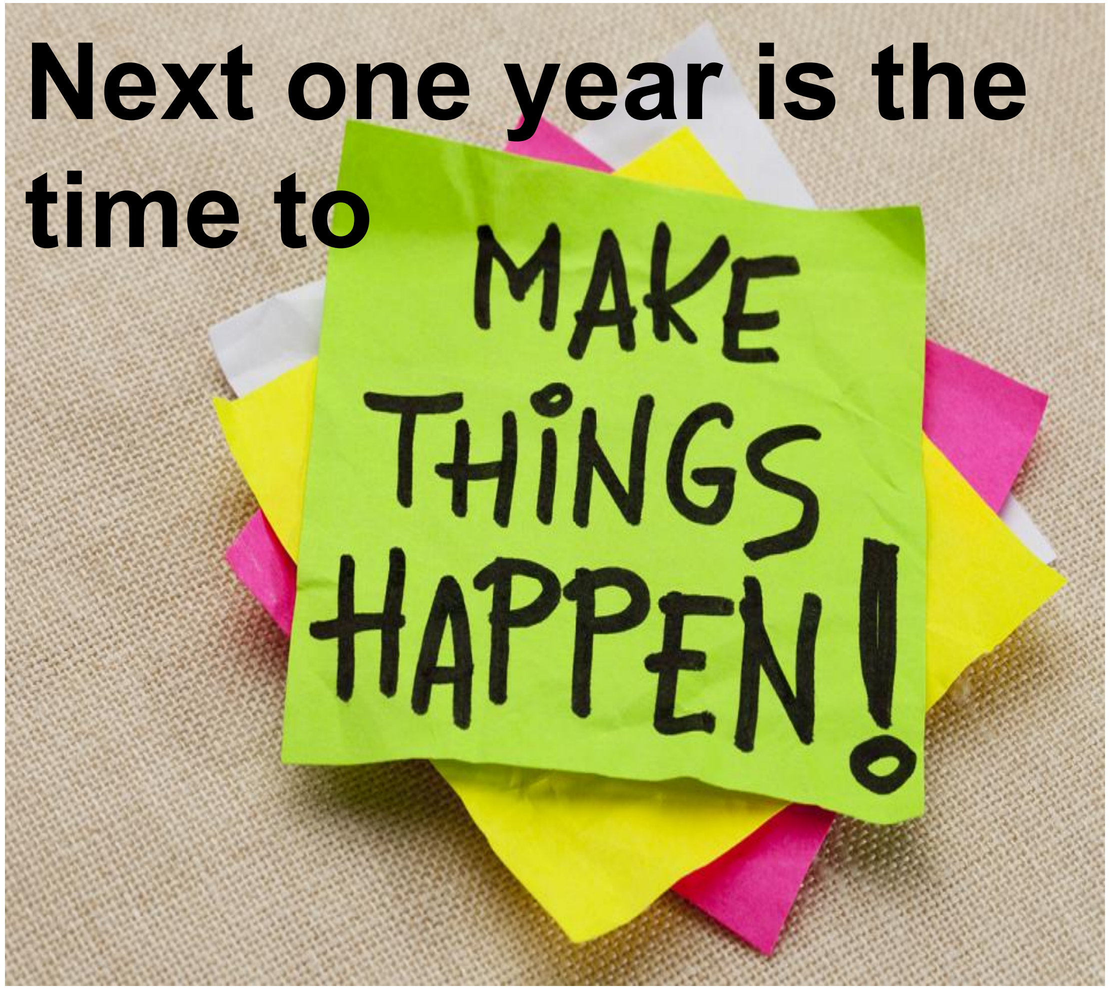
International Linear Collider

The ILC is ready to go

- Physics case well established
- Accelerator technology proven and ready
- Detector designs are very advanced
- Global community active and united
- Good Synergy with CLIC

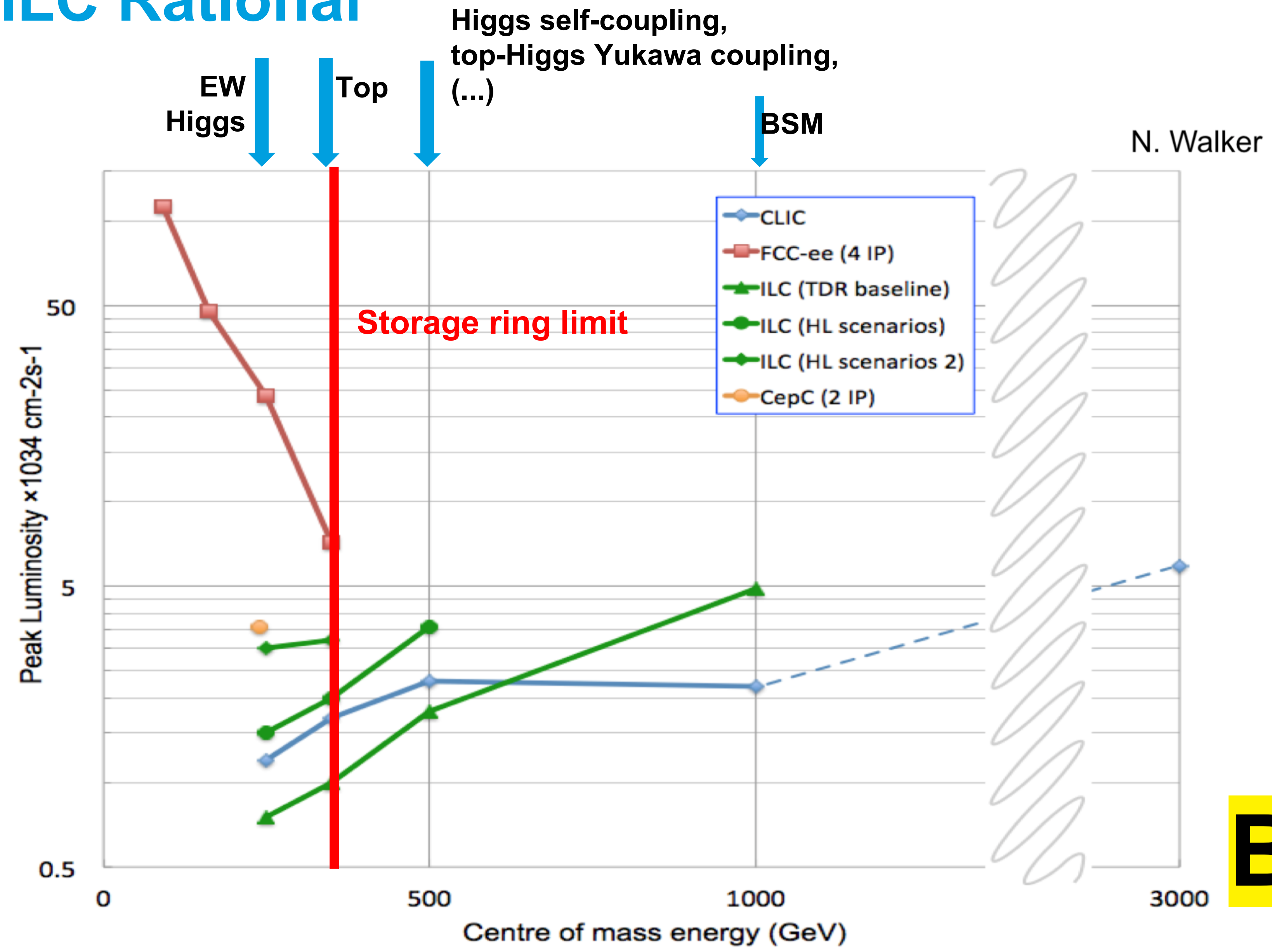
Project Status

- Inputs to ESU by December 2018
- Community meeting in April 2019
- Statement expected from Japan by End 2018



Thank you

ILC Rational



- **Circular:**
  - Energy limited by fundamental physics
  - Energy loss ∝ E4
- **Linear:**
  - Energy limited by acceleration gradient
  - today: SCRF O(35 MeV/m)
  - future: drive beam O(100 MeV/m)
- **Costs**
  - linear ∝ E
  - circular ∝ E2

Backup

The European XFEL

History

2000:

First laser light (109 nm) at the Tesla Test Facility (TTF); today known as FLASH

2001 / 2002 / 2006:

TESLA Linear Collider TDR with XFEL Appendix (2001)
TESLA TDR Supplement with stand-alone XFEL (2002)
European XFEL TDR (2006)

2009:

Foundation of the European XFEL GmbH
Start civil construction

2010:

Foundation of the **Accelerator Consortium**
16 institutes coordinated by DESY

2012:

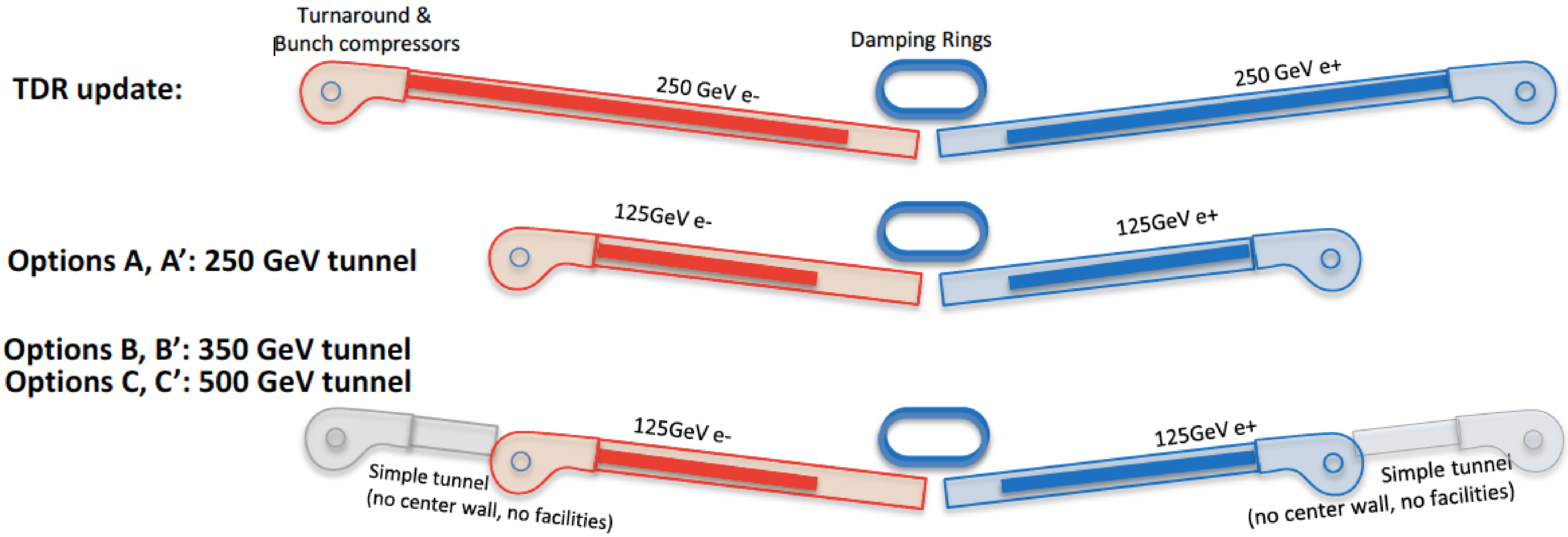
Tunnel finished
Start infrastructure installation

2016:

Accelerator finished
Start commissioning with cool down

ILC Costing

Moving to 250 GeV Higgs Factory



Staging Options

- Options A, B, C : Assume 31.5 MV/m (TDR)
- Options A', B', C' : Assume 35 MV/m