ILC Status Update
and the latest from CLIC

Marcel Stanitzki

The Future of Particle Physics: A Quest for Guiding Principles

KIT 01/Oct/2018

The Case for e^+e^-

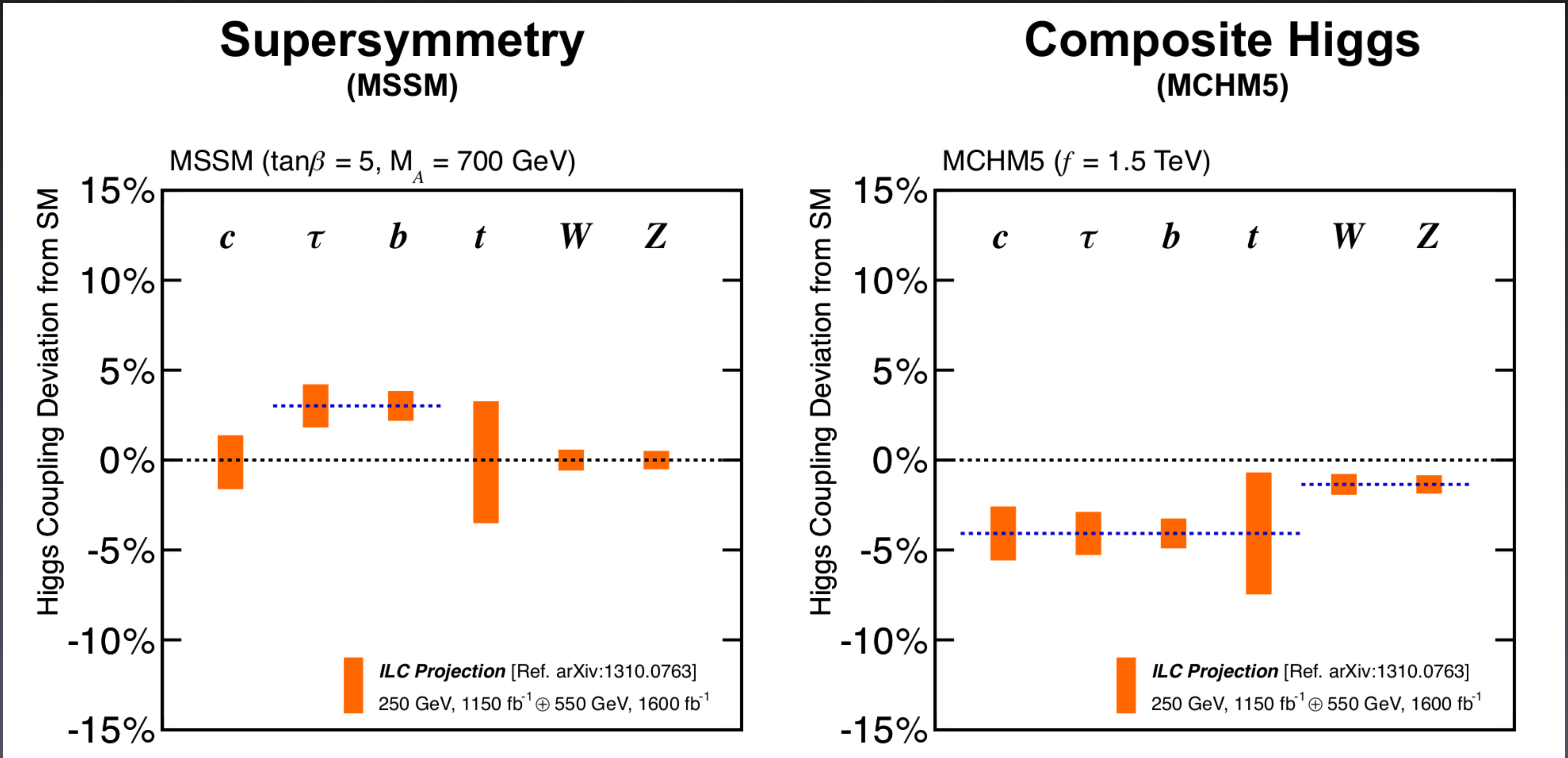
What precision is needed

- LHC has not discovered evidence for new physics yet
  - A big surprise to many …
- If new physics exists and is out of reach for the LHC
  - Small deviations to SM processes
  - ~ 1/(Energy scale)
  - e.g. Higgs Branching Ratios are very sensitive
- Need 1% or better accuracy to fingerprint new physics

Precision for the Terascale

- To complement the LHC/HL-LHC a precision machine is required
  - Only e^+e^- colliders offer the required precision
- e^+e^- Advantages
  - Well defined initial state and tunable E_{CMS}
  - Clean environment, no large backgrounds from QCD like in $pp/p\bar{p}$
  - Monte-Carlo simulations with high precision
  - Very low radiation environment

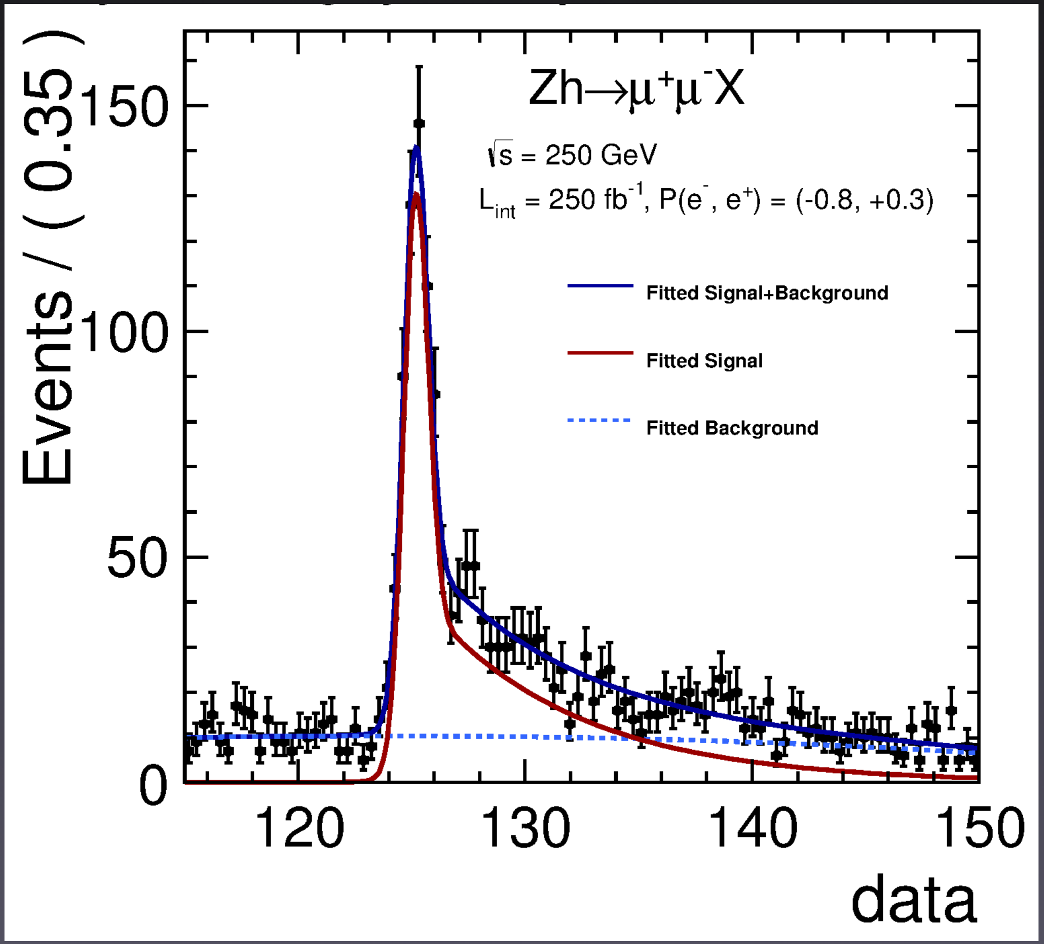
Probing new physics



Percent-level accuracy on Higgs Couplings essential !

Higgs Precision Physics

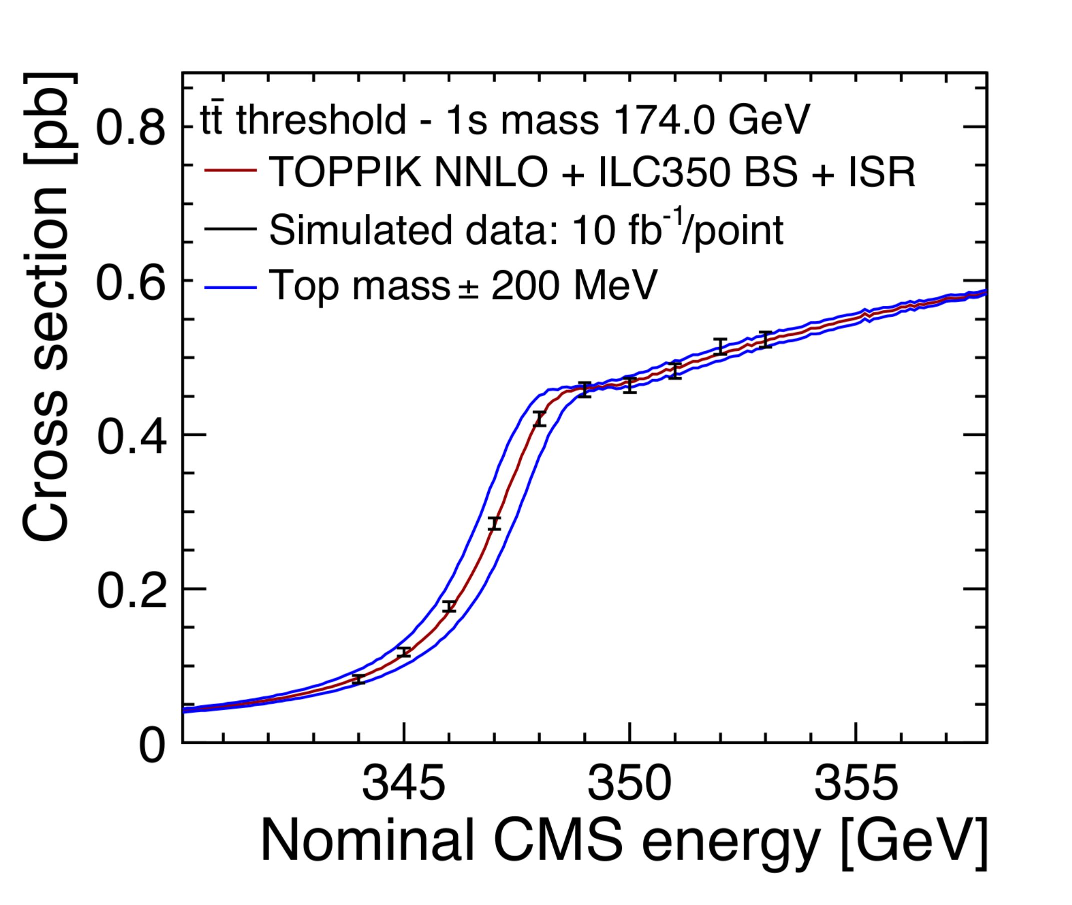
- e^+e^- will do everything the LHC/HL-LHC does
  - Couplings, Mass, Spin
- But e^+e^- does Model-independent measurements
  - No dependence on theory
- Unique at the ILC
  - Total Higgs Width
  - $H \to c\bar{c}/gg$



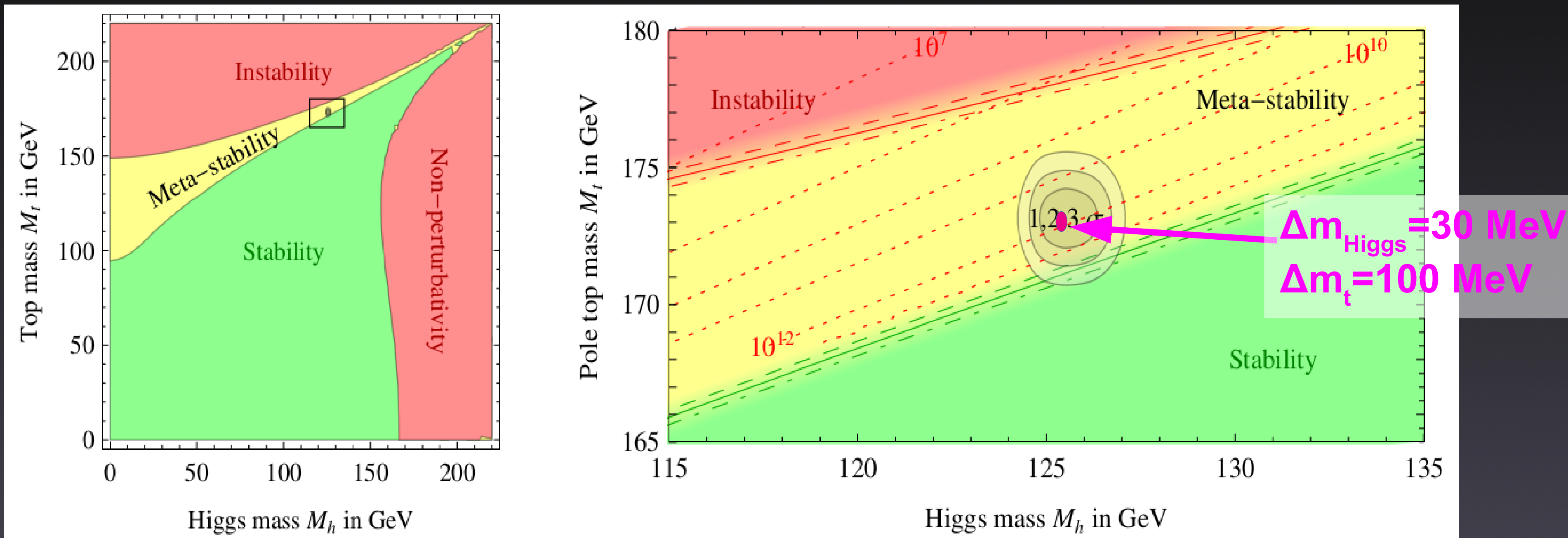
Model-independent Measurement of σ_{HZ} at 250 GeV

A Top Factory

- Top Threshold scans
  - Δm_{top}< 40 MeV
- Conversion to $\overline{\text{MS}}$ scheme
  - Measured top mass at ILC can easily be converted to $\overline{\text{MS}}$ mass
  - This yields an total error of Δm_{top}~50 MeV
  - Theory/ α_s limited
- Compared to LHC
  - Accuracy ~ 500-800 MeV
  - Mass is Monte-Carlo Mass
  - Conversion is non-trivial



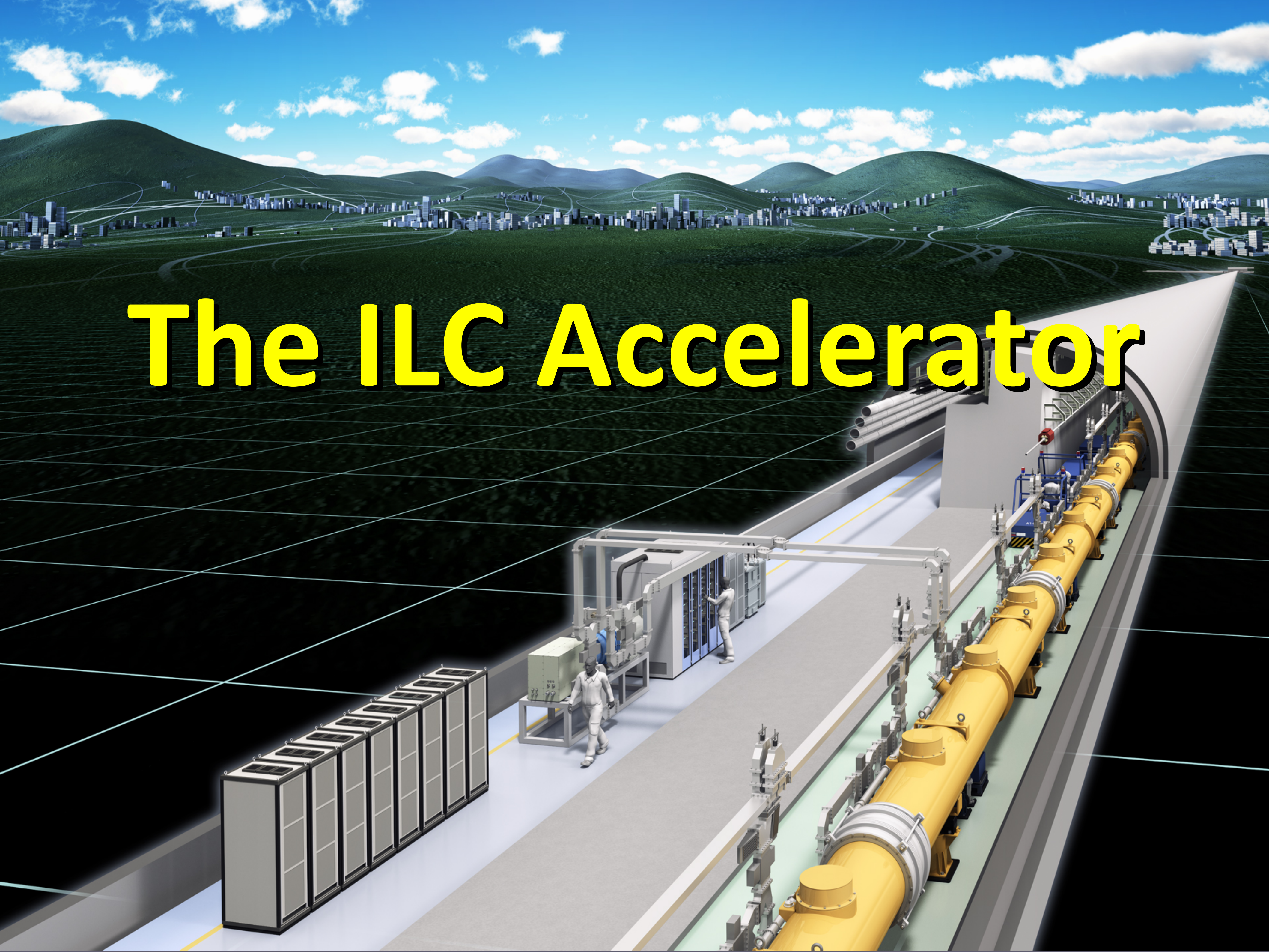
Probing SM Vacuum Stability



- m_{Higgs}=125 GeV (LHC)
  - Quite close to the minimum M_{Higgs} value that ensures absolute vacuum stability within the Standard Model
- e^+e^- will settle this question

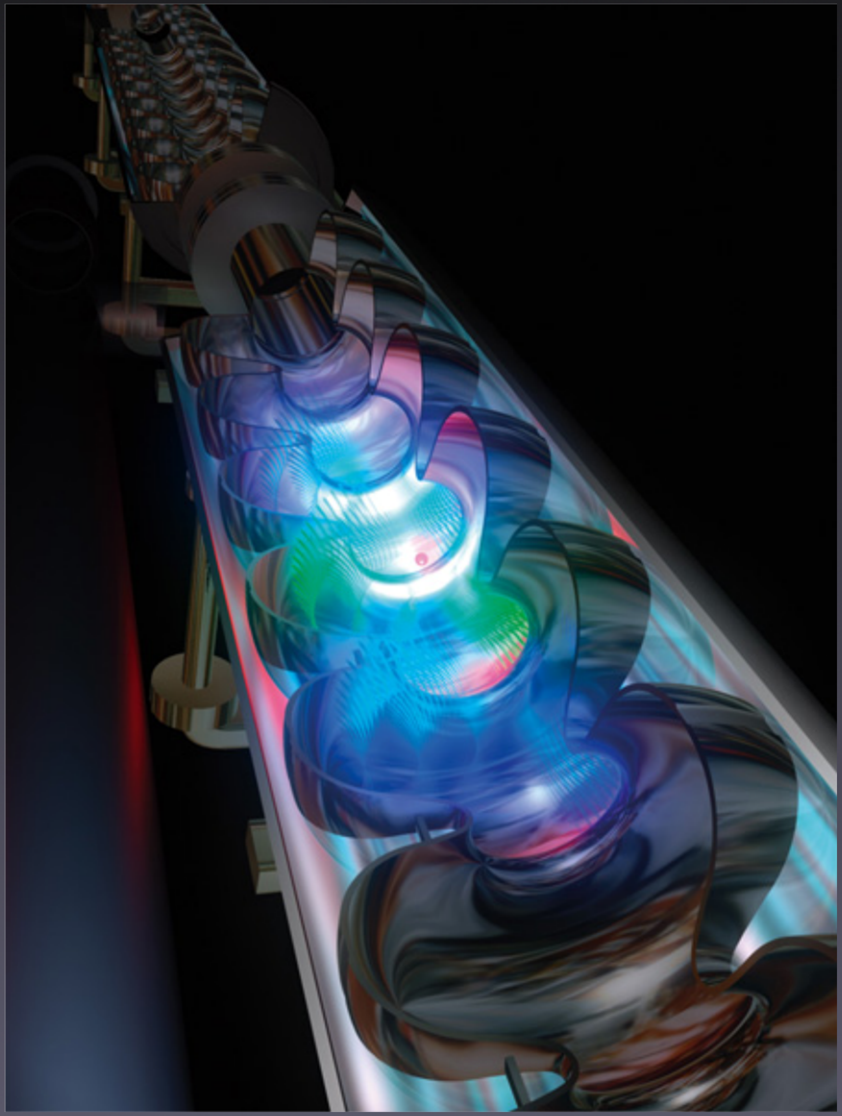

The International
Linear Collider

The ILC Accelerator



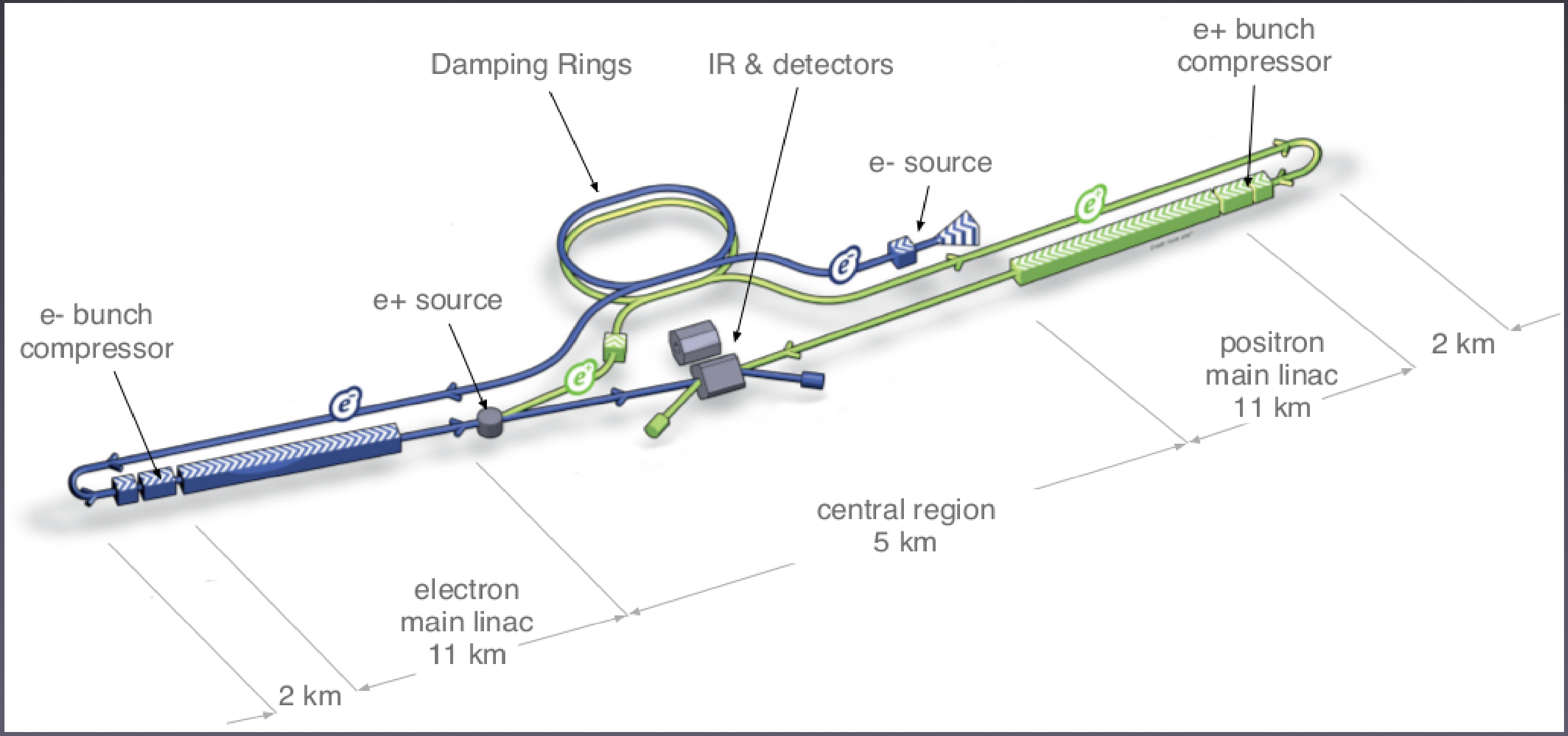
Why a Linear Accelerator ?

- Basic Limitations of all e^+e^- synchrotons
  - Synchrotron radiation loss ~ E^4/r
  - Synchrotron cost ~ quadratically with Energy (B. Richter 1980)
    - E_{CMS}=~ 200 GeV as upper limit for warm RF
    - E_{CMS}=~ 300 GeV as upper limit for cold RF
  - Power consumption becomes prohibitive
- Linear Accelerators offer a clear way to higher energy
  - Not limited by synchrotron radiation
  - Cost ~ linear with Energy
  - Polarization of both beams
  - "nano beamspot" allows detectors close to the IP → key ingredient for c-tagging



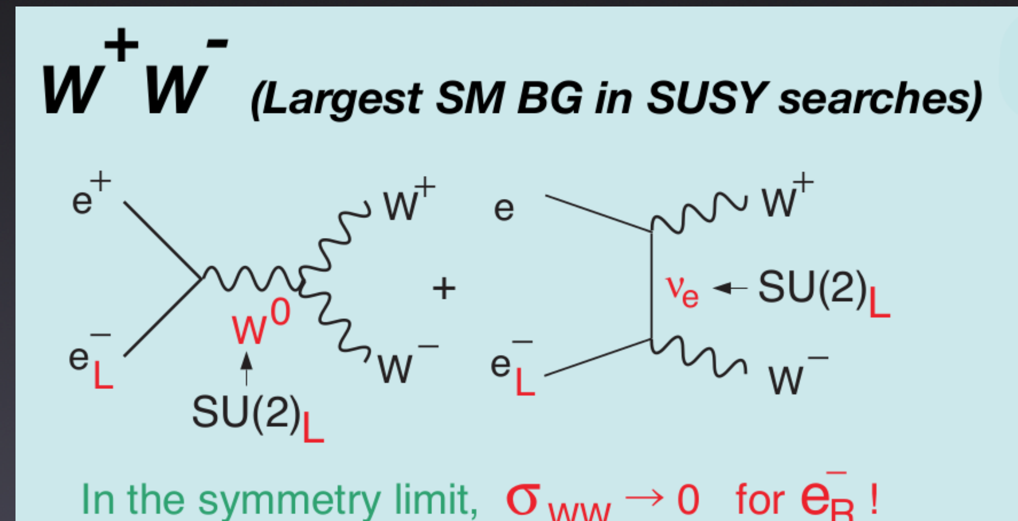
The ILC Project

- The ILC (International Linear Collider)
  - A 500 GeV (baseline) GeV e+e- Linear Collider
  - Clear Upgrade Path to 1 TeV
  - Beam Polarization
- Interaction Region with two detectors

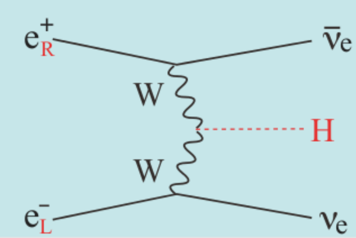


Power of polarization at the ILC

- The ILC offers polarized e^+/e^- beams
  - Extremely difficult for circular colliders
- Baseline
  - 80 % polarization for e^-
  - 30 % polarization for e^+
- Upgrades possible
- Unique capabilities
  - Controlling Backgrounds
  - Enhancing Signal



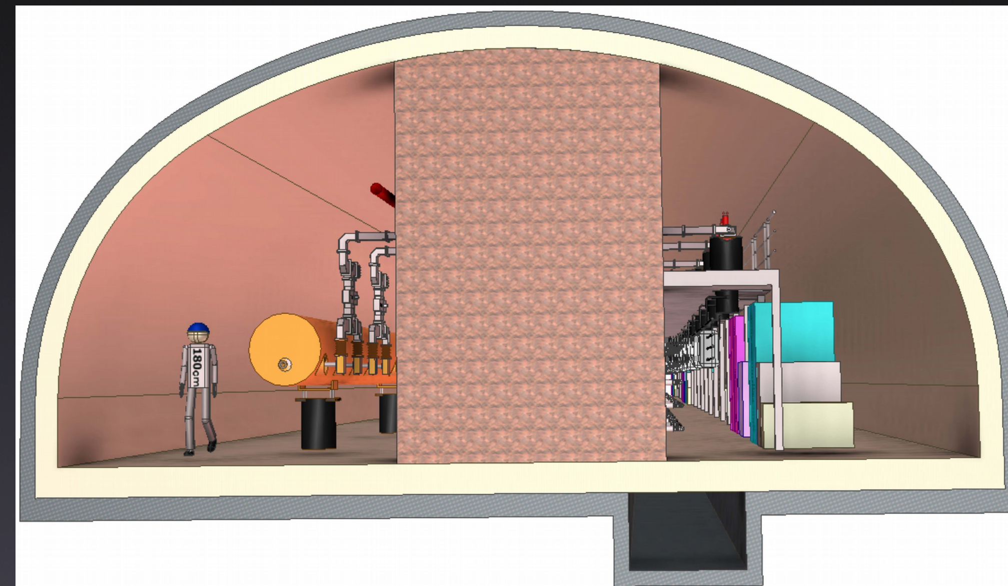
WW-fusion Higgs Prod.



	ILC
Pol (e-)	-0.8
Pol (e+)	+0.3
(σ/σ	1.8x1.3=2.34

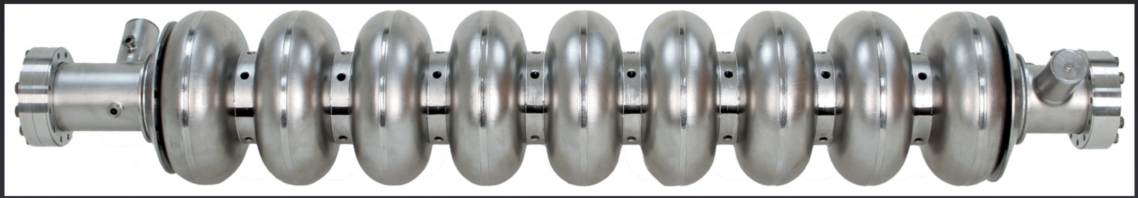
The TDR ILC Machine

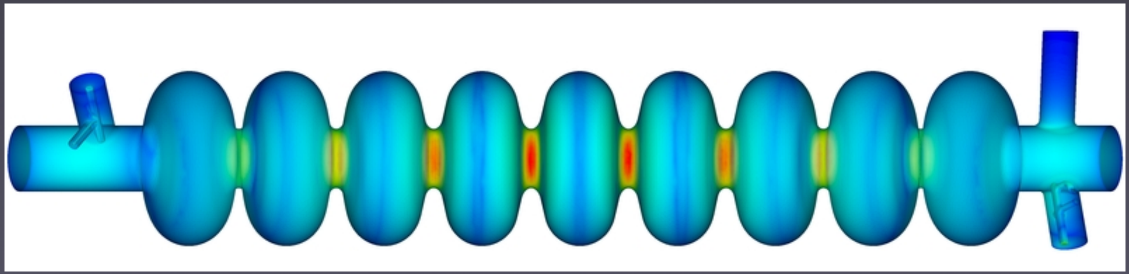
- 500 GeV Linear collider
  - 31 km long
- Acceleration
  - 7400 superconducting Cavities in 850 Cryo Modules
  - Gradient 31.5 MV/m
  - 1.3 GHz RF
  - 163 MW power consumption
- Beam parameters
  - 2×10^{10} particles/bunch
  - 554 ns spacing
  - $L=1.8\times10^{34}\ cm^{-2}s^{-1}$
  - Polarization 80/30 (e^-/e^+)
  - Nanometer-scale beam spot



Why going cold?

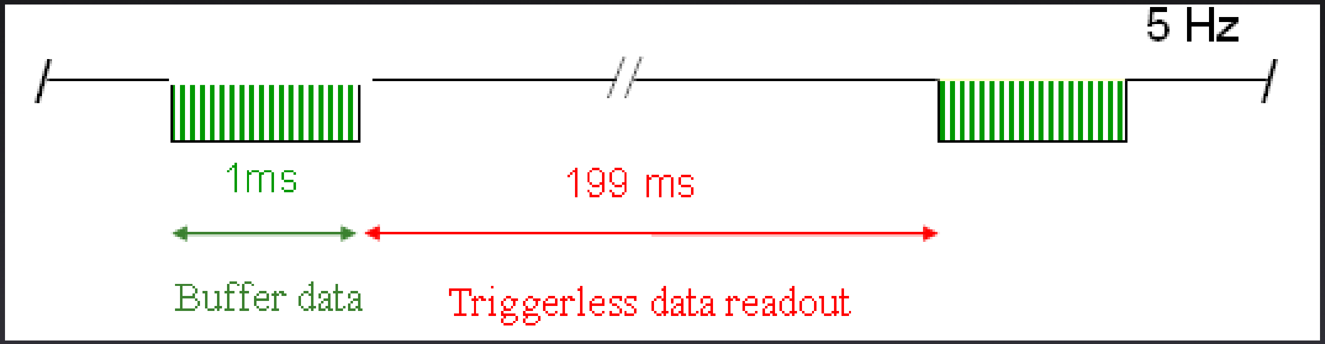
- High RF ->Beam-power efficiency
  - low-loss cavities
- Ease of RF power generation
  - low frequency (1.3 GHz)
  - Long pulses / fill time (1 ms / 0.6 ms)
  - Long pulses allow intra-train feedback
- Emittance preservation
  - Large cavity iris
  - low transverse and longitudinal wakefields





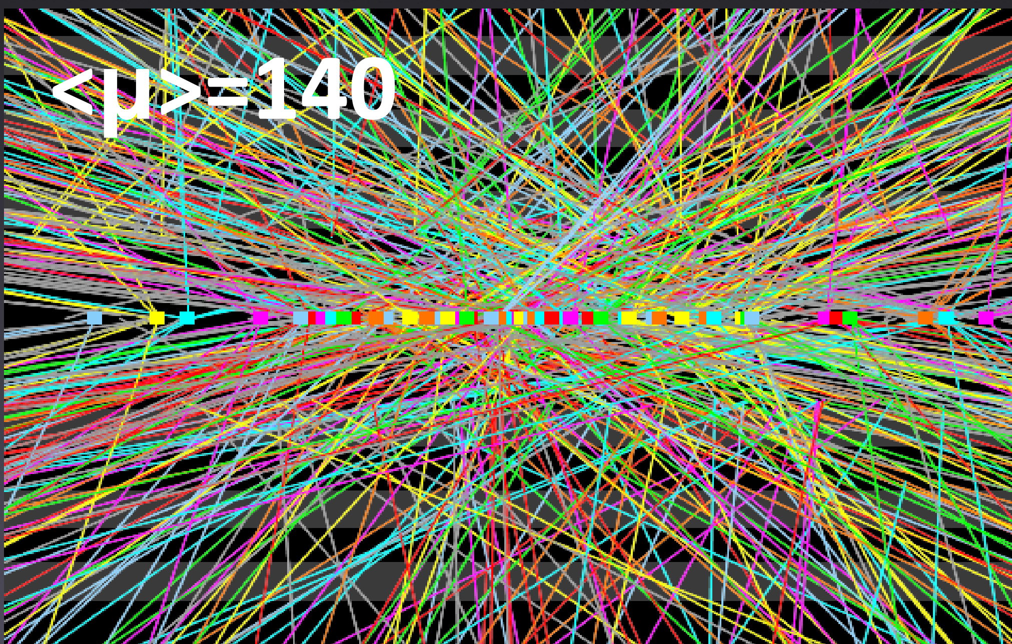
The ILC Detectors

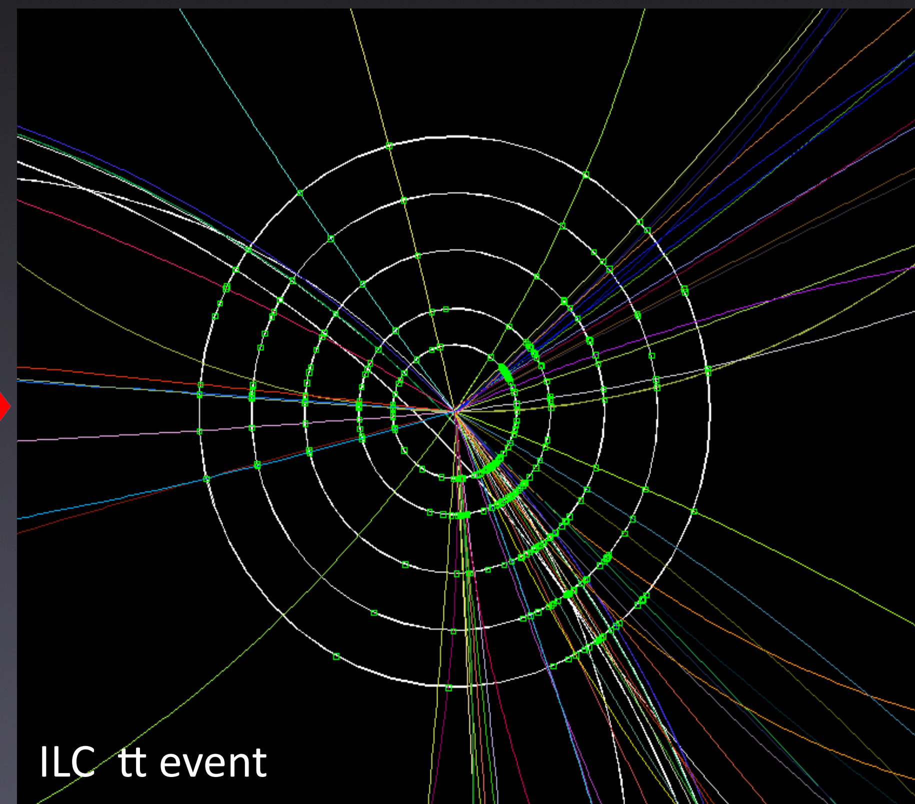
ILC Environment



- ILC environment is very different compared to LHC
  - Bunch spacing of ~ 554 ns (baseline)
  - 1312 bunches in a 1 ms long pulse (train)
  - 199 ms quiet time
- Occupancy dominated by beam background & noise
  - ~ 1 hadronic Z ($e^+e^- \rightarrow Z \rightarrow q\bar{q}$) per train ...
- Readout during quiet time possible

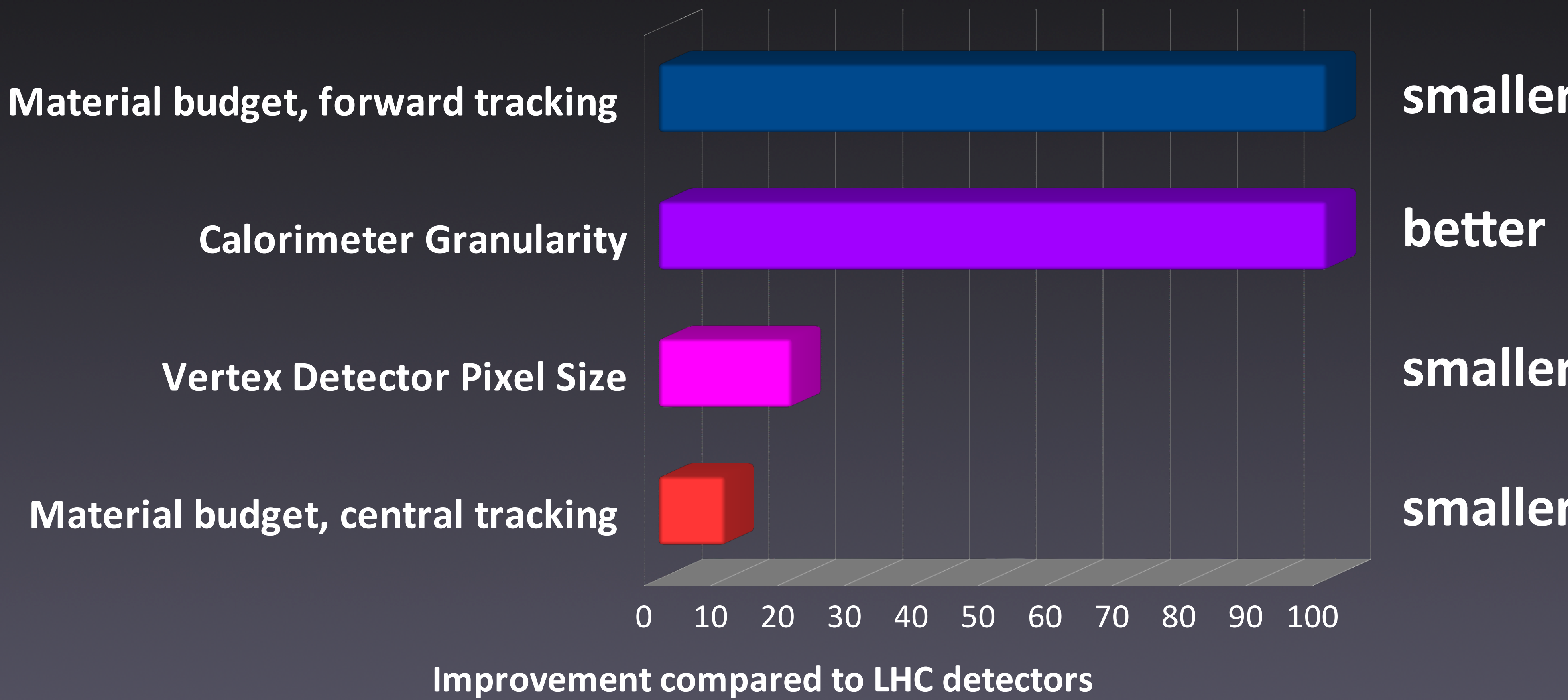
From HL-LHC to ILC





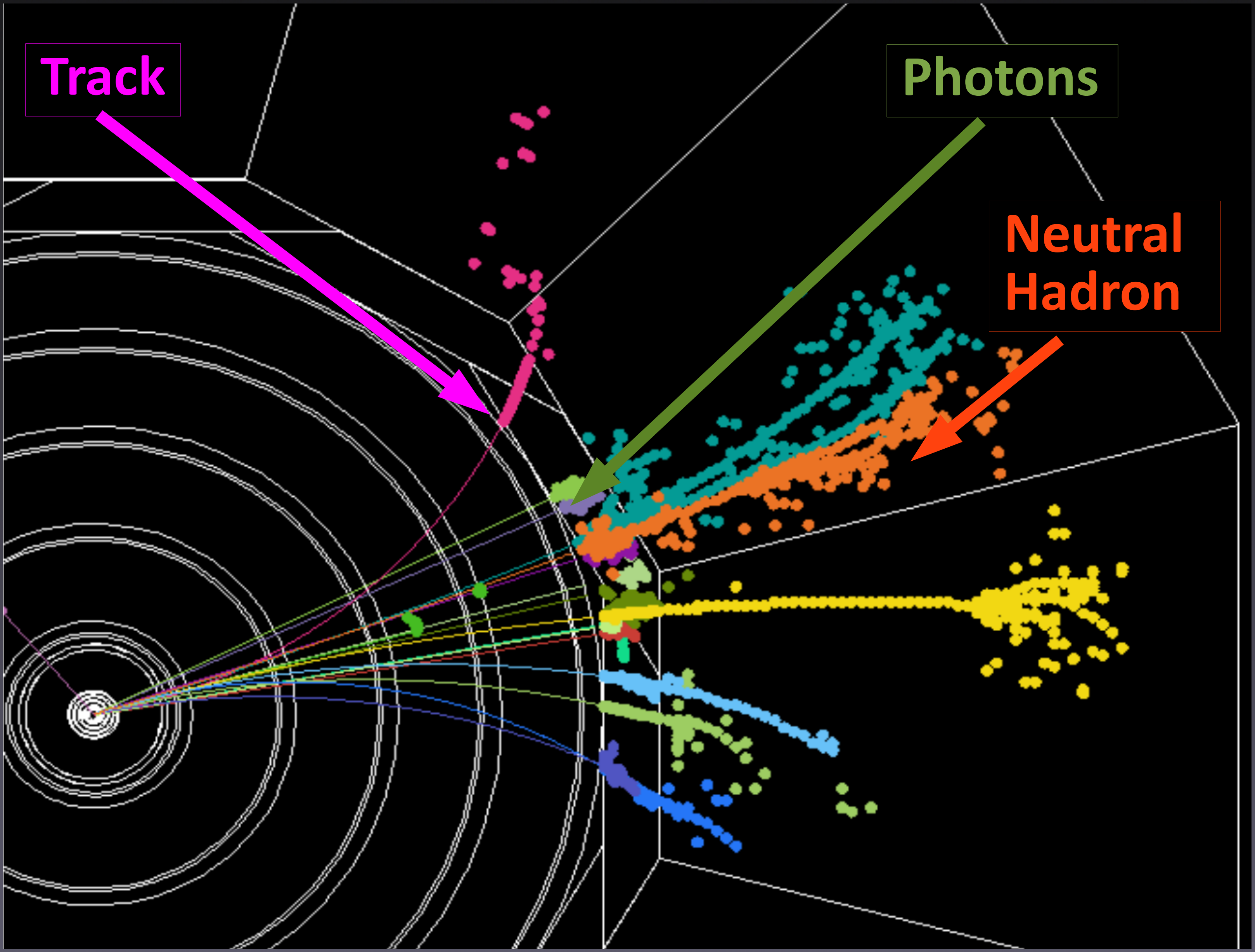
Moving from 140 interactions per crossing to ~1 event/train

Comparison with LHC detectors



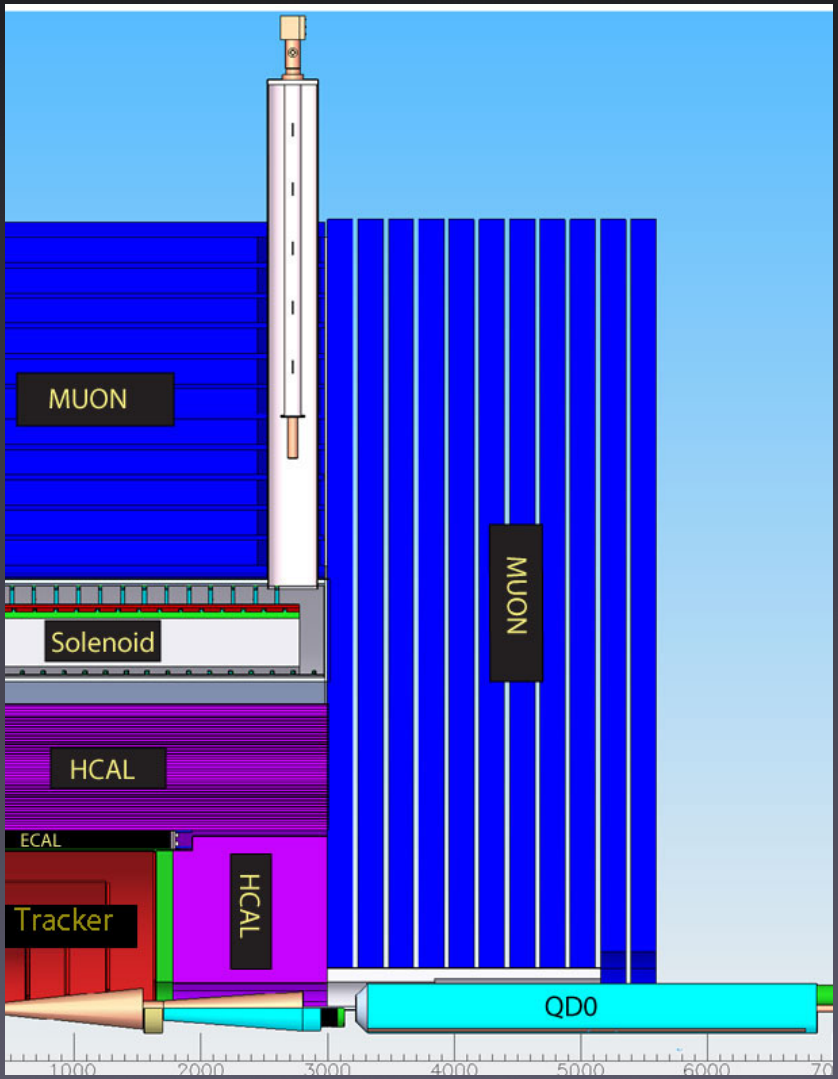
ILC Requirements for Timing, Data rate and Radiation hardness are very modest compared to LHC

PFA Reconstruction

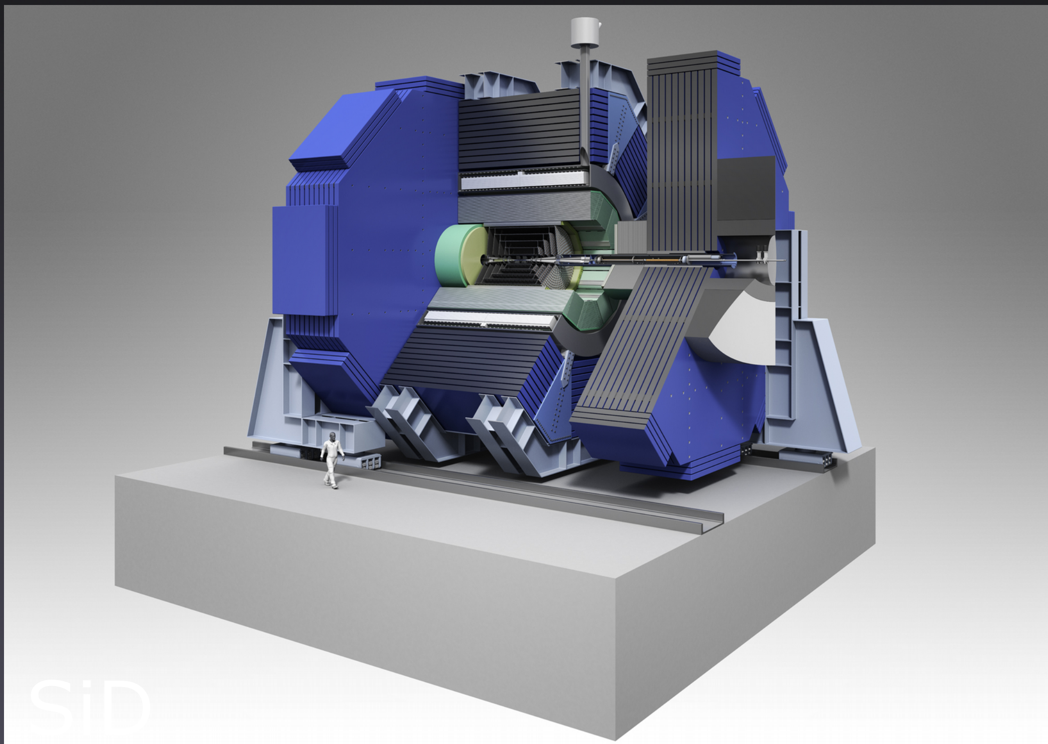


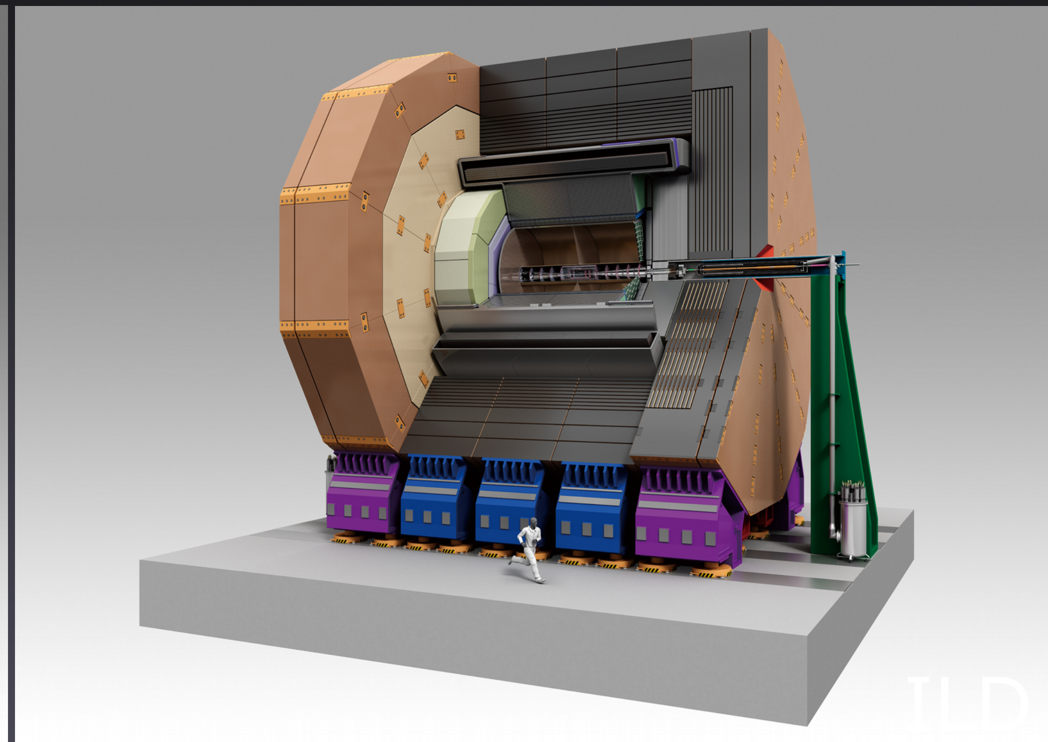
ILC Detectors

- PFA has been used at LEP, HERA and LHC before
- Novel Approach at the ILC
  – PFA drives design of the detector
- Consequences
  – Calorimetry inside the superconducting solenoid
  – Highly granular calorimetry
  – Low-mass tracking



SiD & ILD





- SiD
  - $r_{tracker}$= 1.25 m
  - B = 5 T
  - All-silicon tracking
- ILD
  - $r_{tracker}$= 1.8 m
  - B = 3.5 T
  - Time Projection Chamber

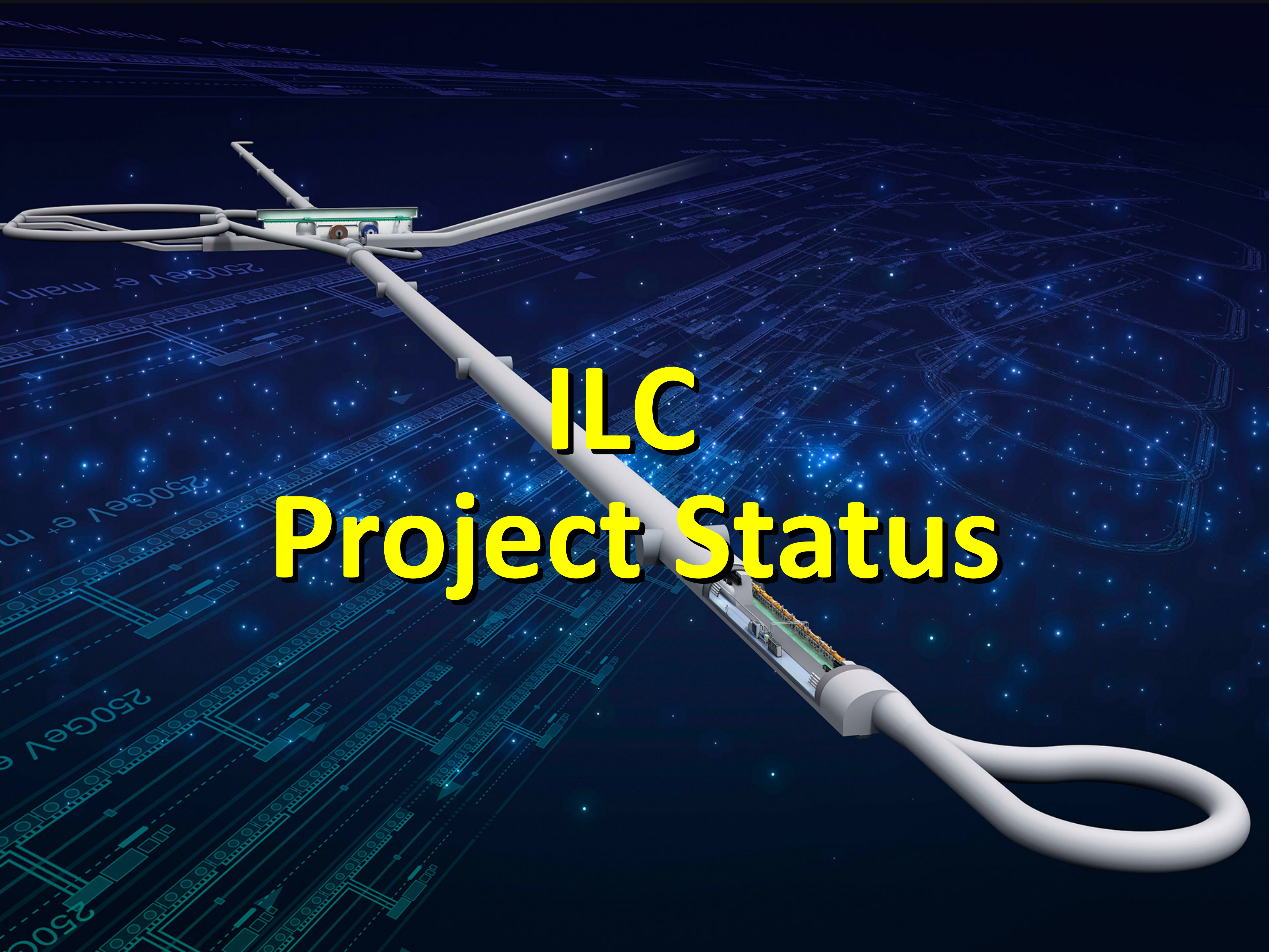
The ILC TDR

"As compared to other projects of similar scale (ITER, LHC, ATLAS, CMS, ALMA, XFEL, FAIR, ESS, SSC) the quality of the documentation presented by the GDE team is equal or superior to that utilized to launch into a similar process."

The ILC is good to go!

- ILC TDR
  - Five Volumes covering
  - Physics, Accelerator & Detectors
  - Culmination of 8 years of effort
- Very favorable review
- Wide Community support
  - 2400 people sign the TDR
- Global Handover Event
  - Tokyo, Geneva, Chicago

ILC
Project Status

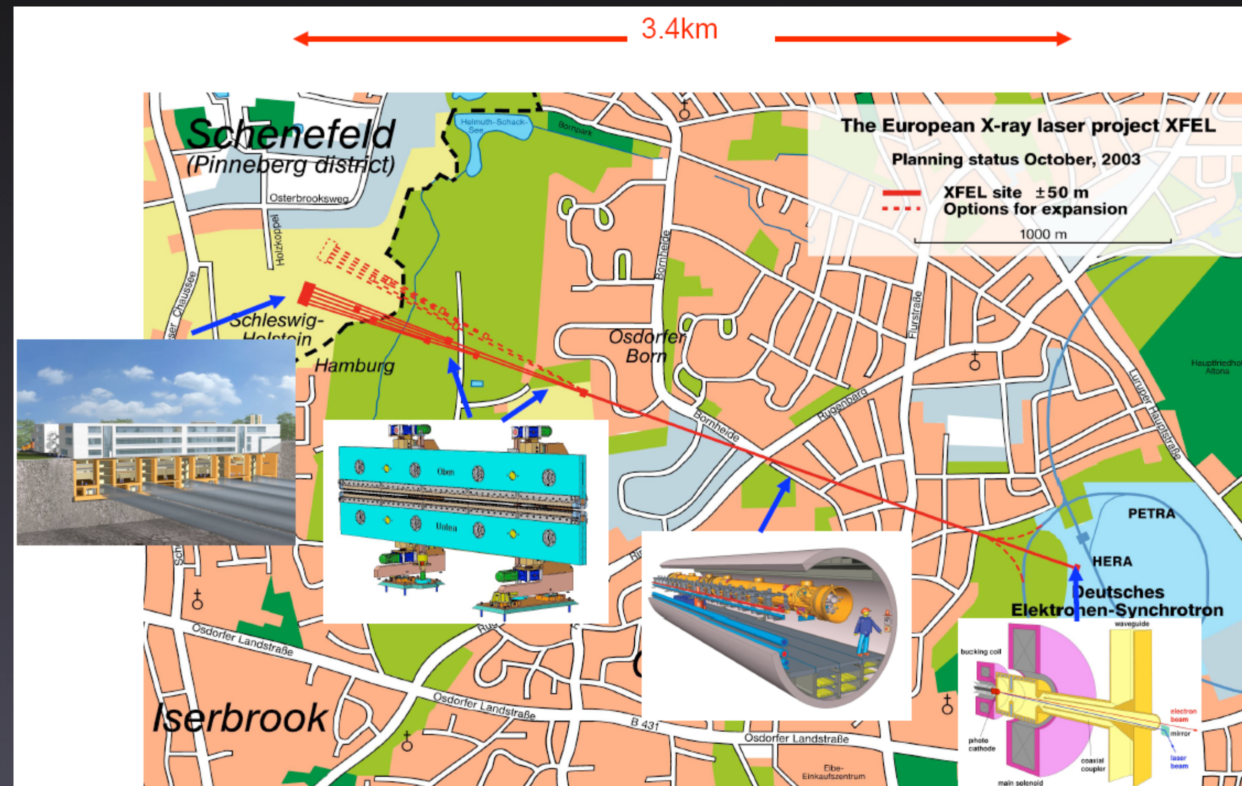


Making it real

- May 2013
  - European Strategy supports ILC participation
- May 2014
  - US P5 Strategy fully supports ILC
- ILC Community now focuses on making the ILC a reality

The European XFEL

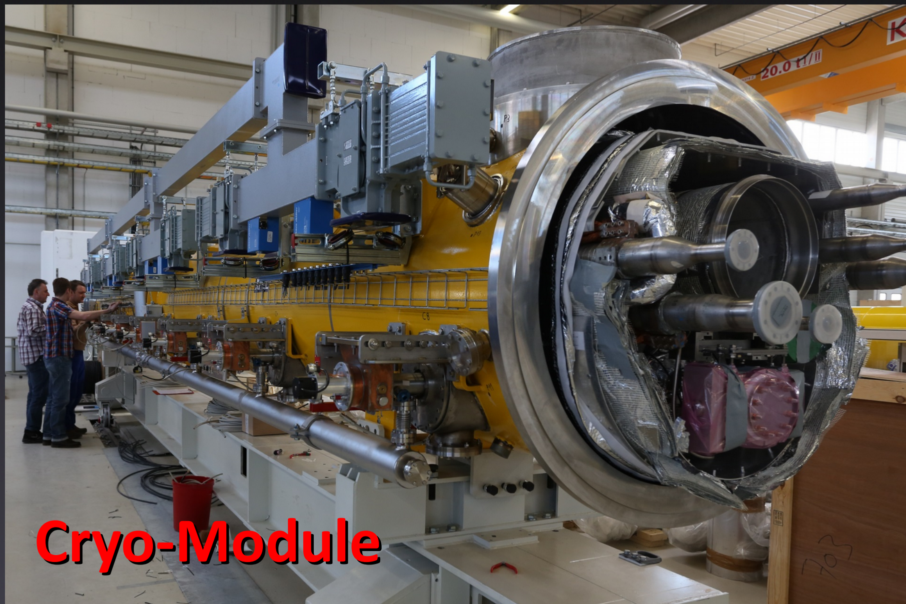
- Free Electron Laser
  - Photon energy 0.3 - 24 keV
  - Pulse duration ~ 10 - 100 fs
  - Pulse energy few mJ
- Superconducting linac. 17.5 GeV
  - 10 Hz (27 000 b/s)
- 5 beam lines / 10 instruments
- Start version with 3 beam lines and 6 instruments
- First electron beam December 2016
- User Operation September 2017
- Design Energy May 2018



European XFEL

The European XFEL
Built by Research Institutes from 12 European Nations

European XFEL Construction

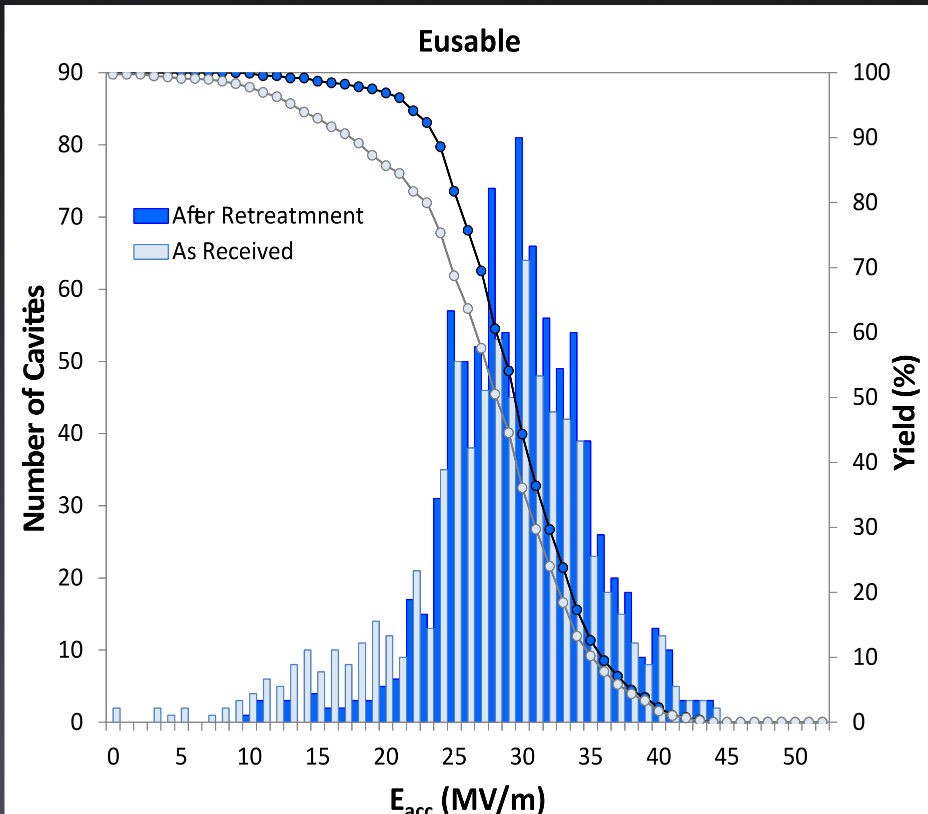

Cryo-Module

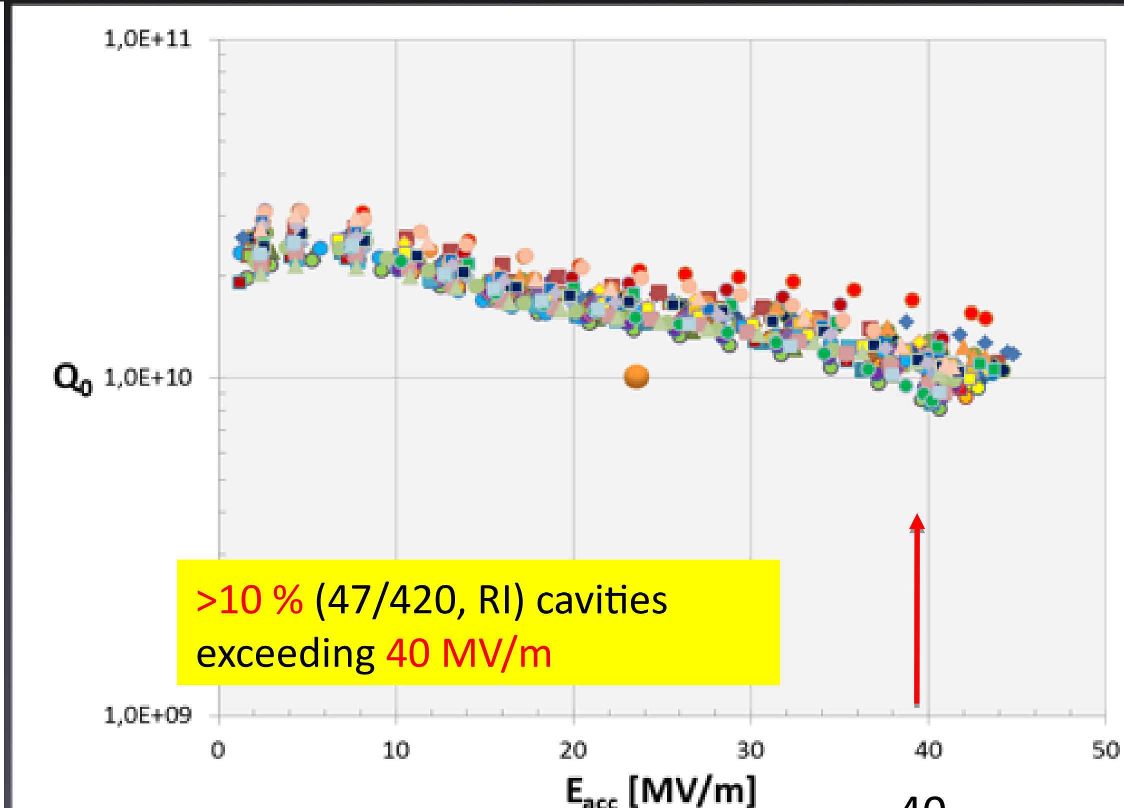

Cavity Production


AMTF Hall at DESY


XFEL Tunnel

European XFEL: SRF Cavity Performance





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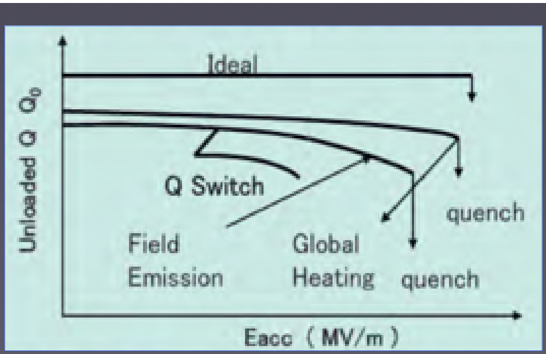
After Retreatment:

E-usable: 29.8 ± 5.1 [MV/m]

(RI): E usable 31.2 ± 5.2 [MV/m]), w/ 2nd EP

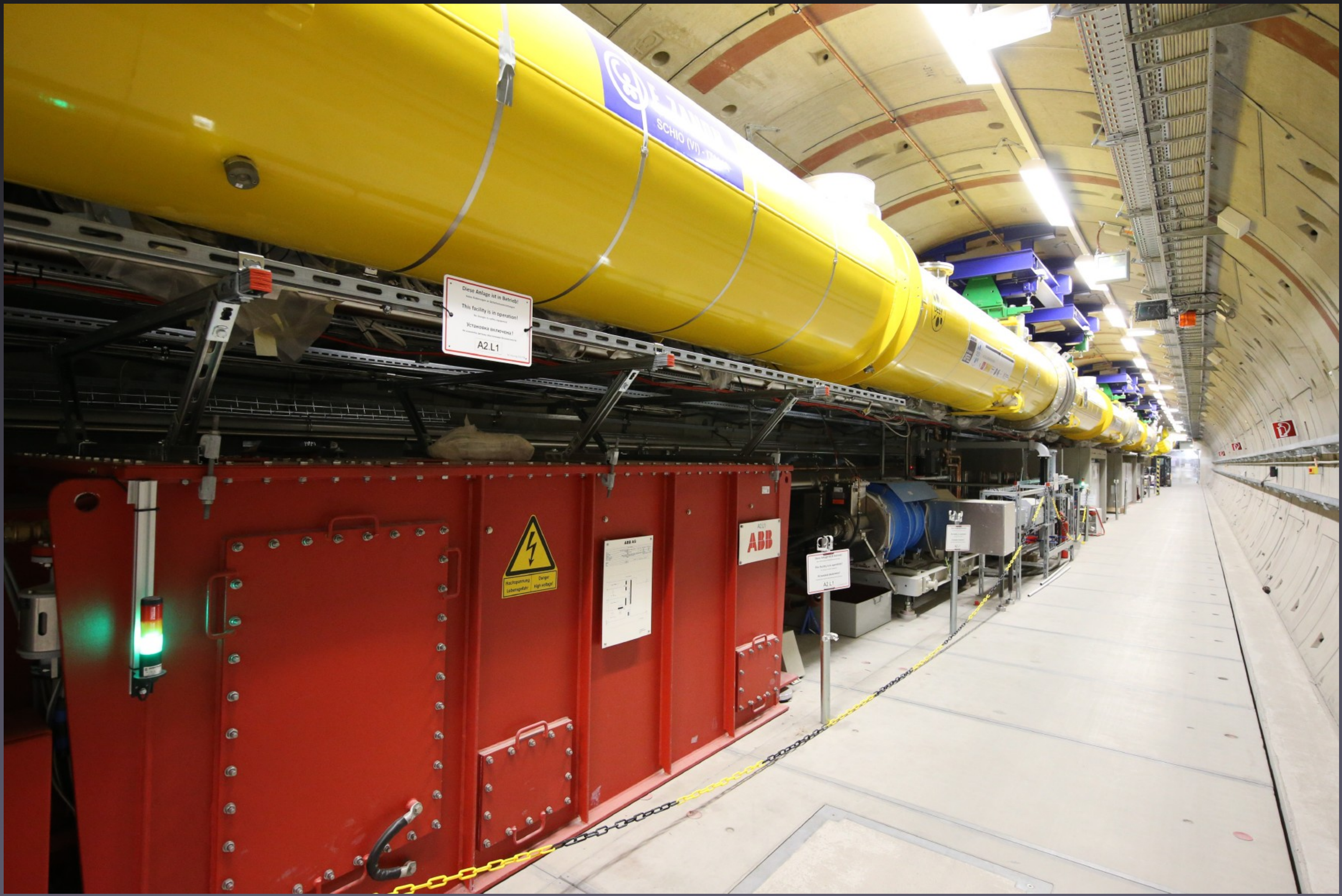
(EZ): E usable 28.6 ± 4.8 [MV/m]) , w/ BCP (instead of 2nd EP)



Courtesy, D. Reschke , N. Walker, C. Pagani

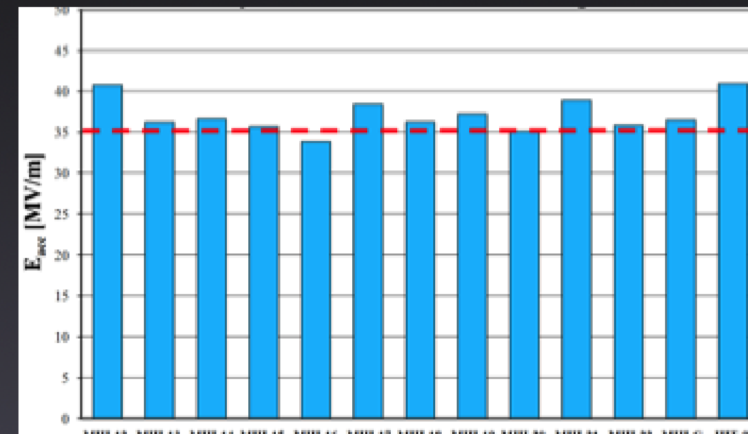
Marcel Stanitzki

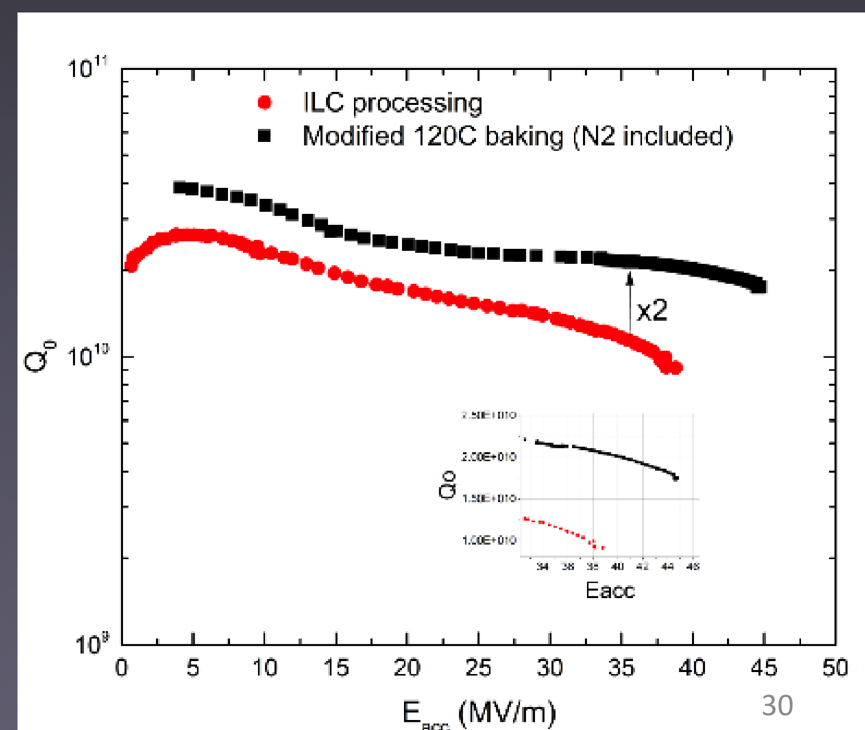
XFEL Tunnel


Diese Anlage ist in Betrieb!
This facility is in operation!
A2.L1
ABB

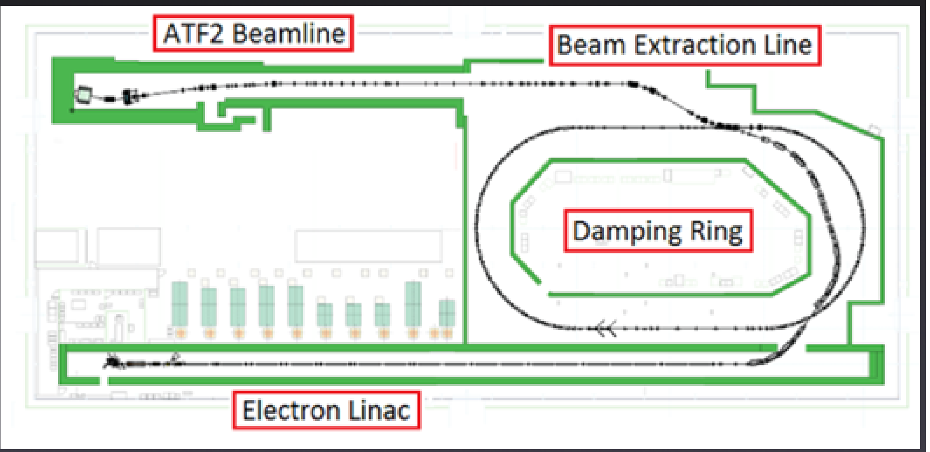
Superconducting RF cavities

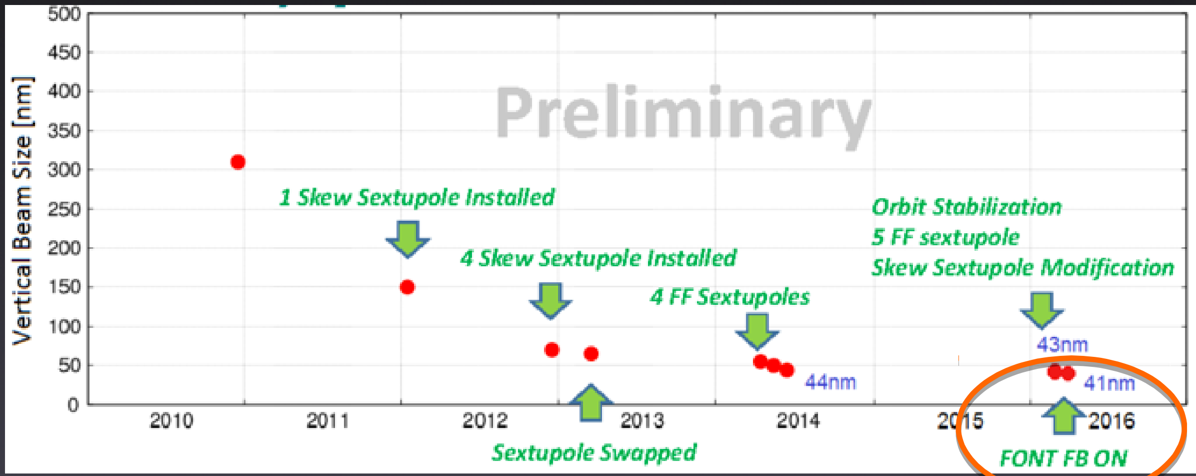
- Cavity spec:
  - 35 MV/m ±20% (‘vertical test’)
  - Corresponds to~ 31.5 MV/m operation
  - 90% yield achieved
- Still improving
  - e.g. N_2 doping
    - Higher gradient
    - 35 MV/m operation realistci
    - TDR: 31.5 MV/m
  - Benefit
    - Fewer cavities
    - Higher Q Less cryogenic power





Achieving the ILC Beamspot size





ATF2 Test Facility at KEK

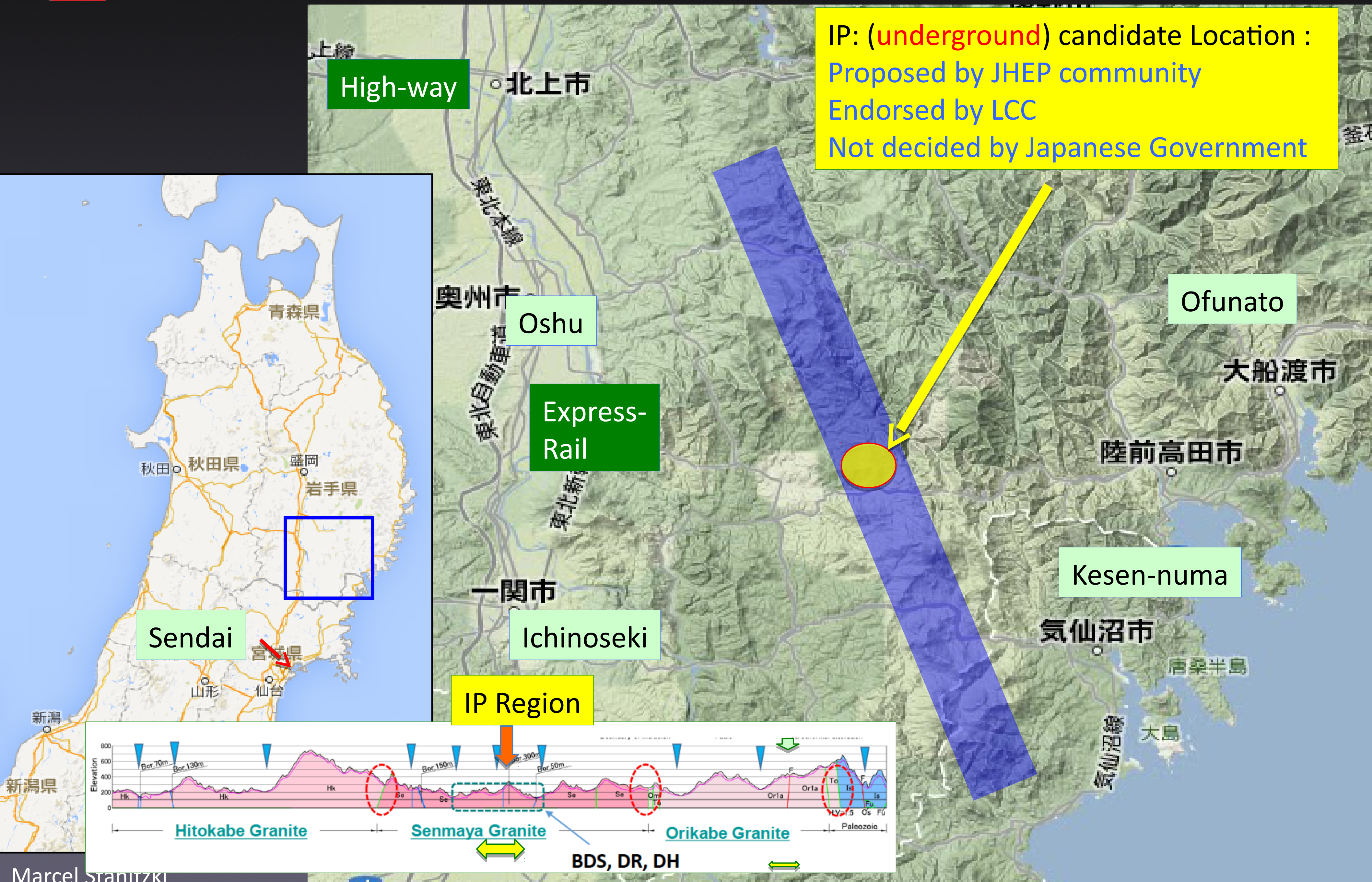
- World Record : 41 nm beam spot size
  - Design goal 37 nm (corresponds to 5 nm at ILC)
- Reproducibility
  - ~32 hrs recovery from a 3 week shutdown
  - ~16 hrs recovery from weekend beam-off

ILC Site Selection

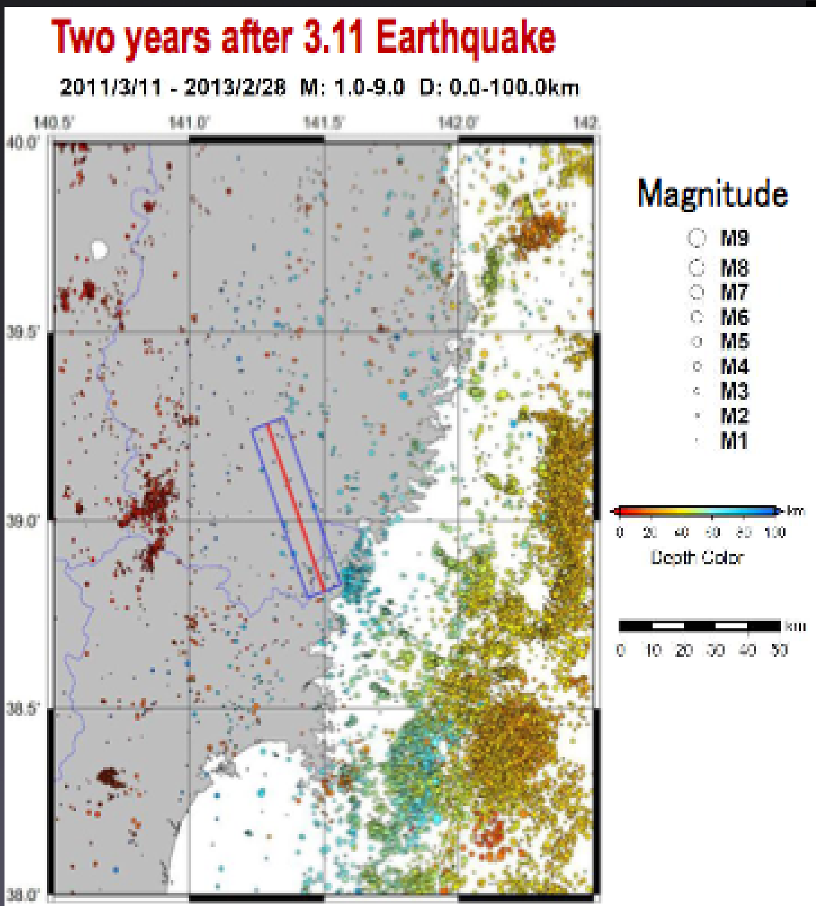
- Japan proposed two sites
  - Kitakami, Honshu “Northern Site”
  - Sefuri, Kyushu “Southern Site”
- Expert Panel Review on Scientific merits of each site
  - Geology, Infrastructure
  - Economic impact

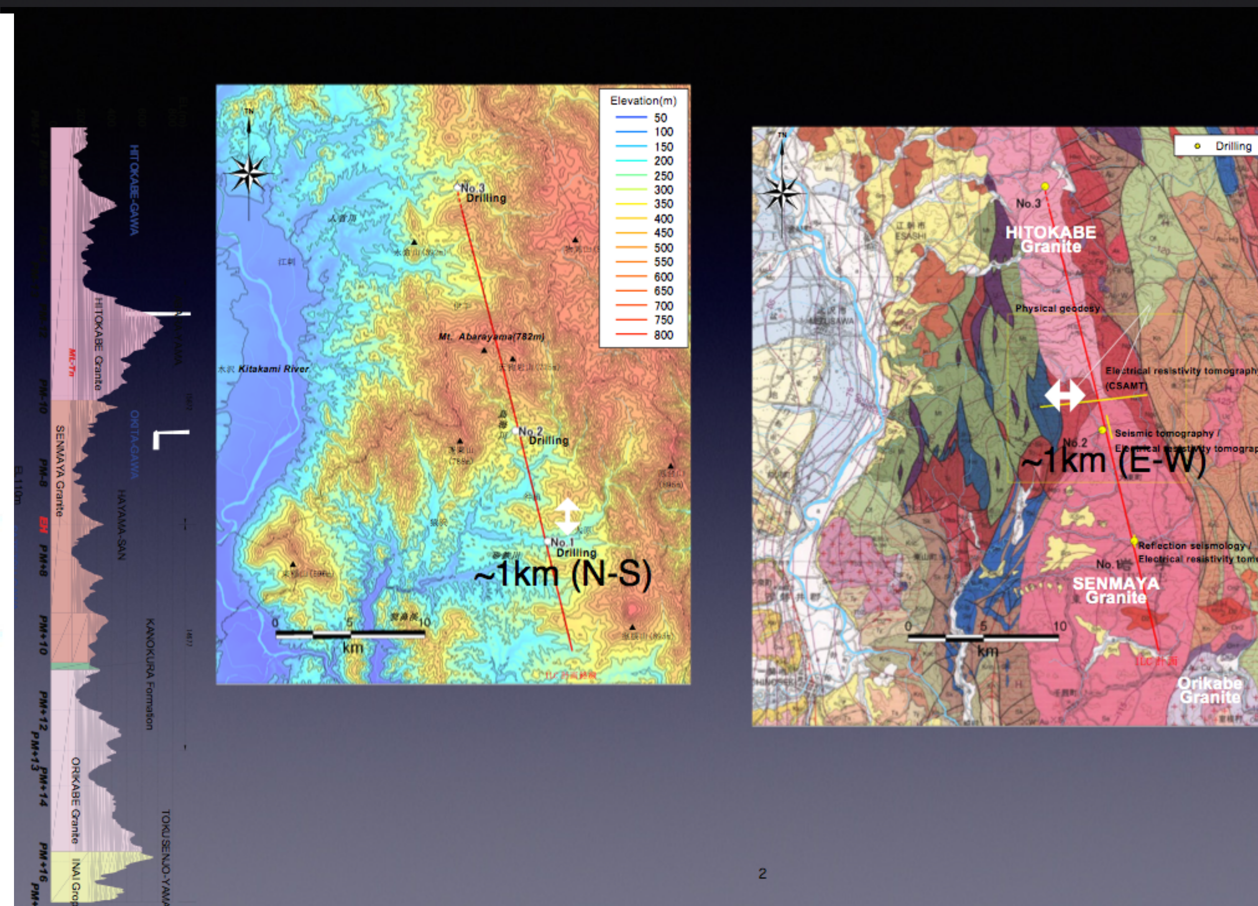
ILC Site – Kitakami Mountains

IP: (underground) candidate Location :
Proposed by JHEP community
Endorsed by LCC
Not decided by Japanese Government

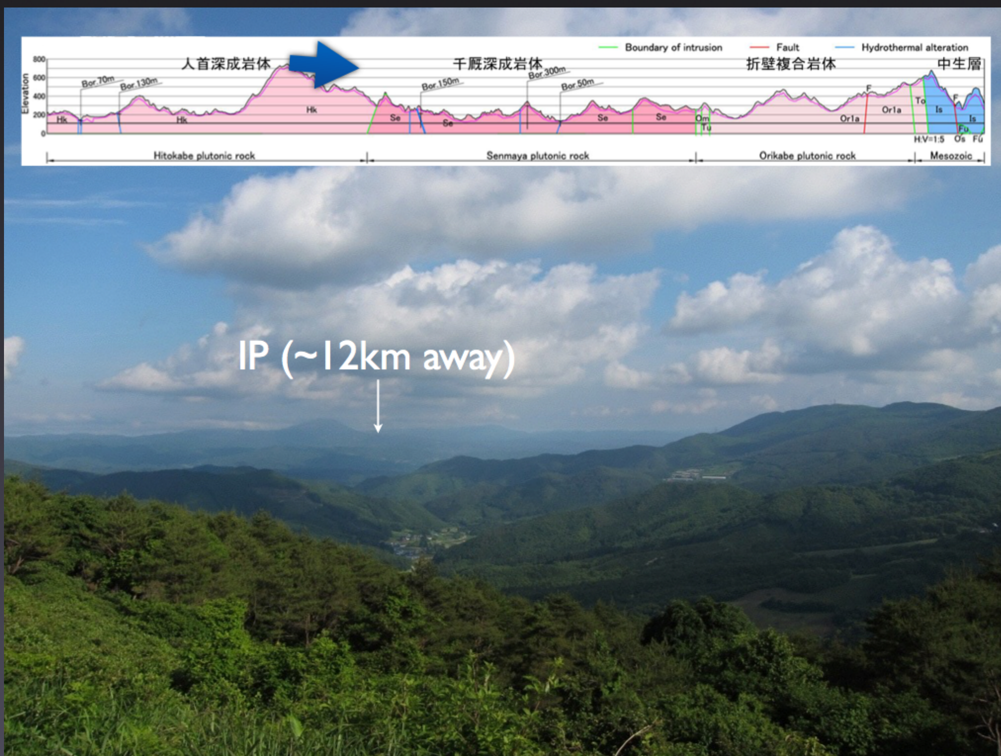


Some more details



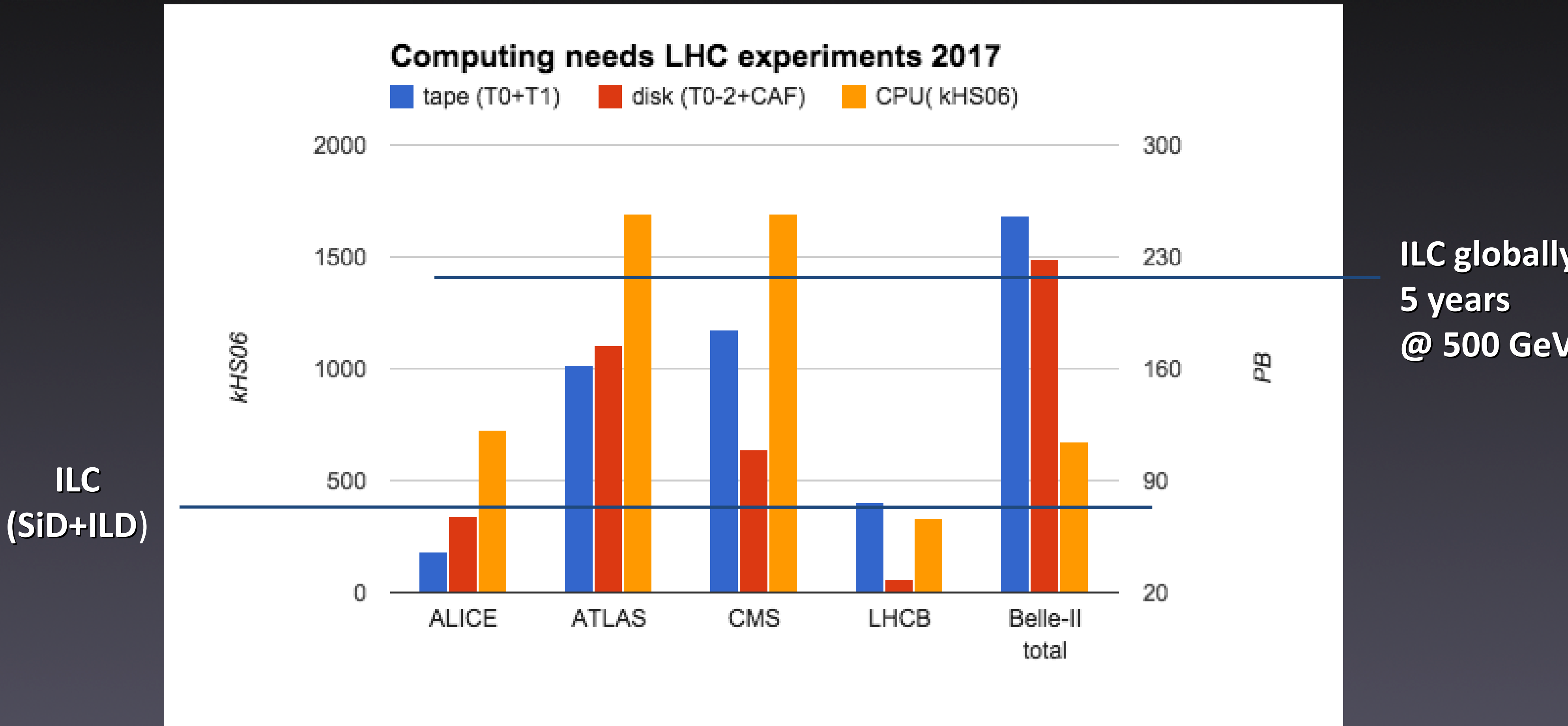


Kitakami Mountains



ILC Detector and Machine experts Visit September 2014

ILC Computing Needs

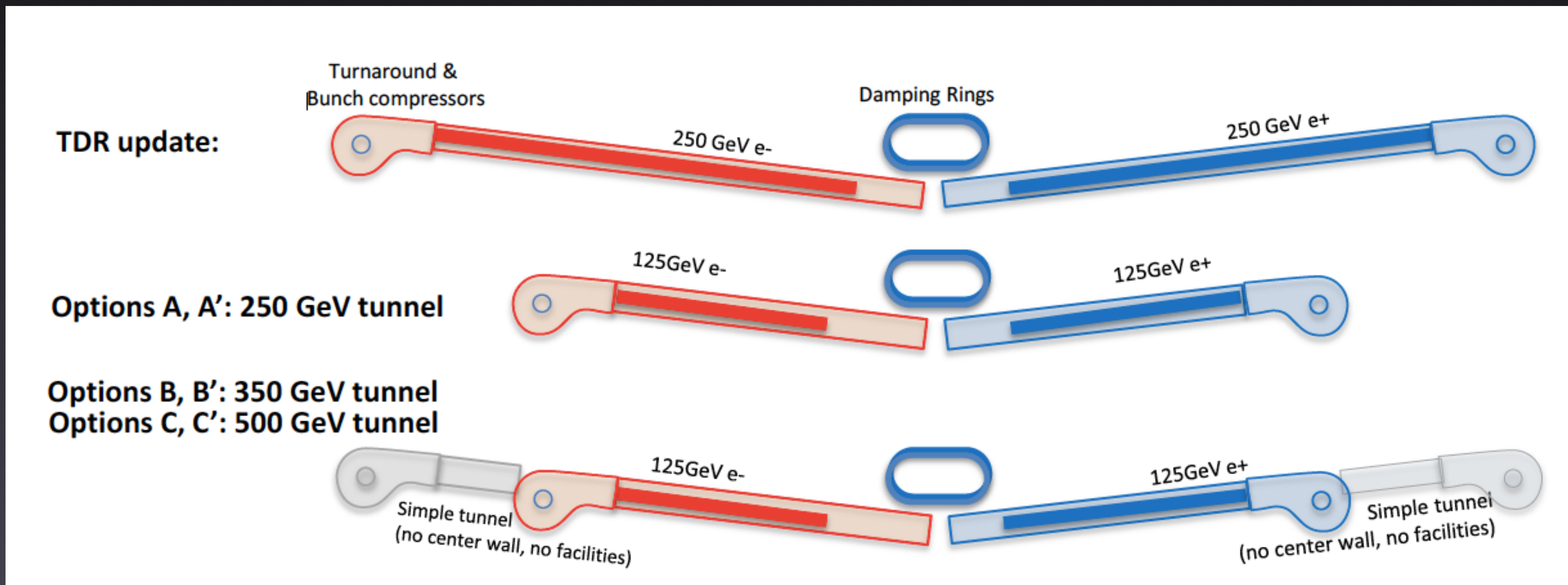


- For comparison: ILC 500 GeV
  - 9 PB / yr / experiment raw data; 220 PB for 5 years ,incl. Monte Carlo, analysis
  - 415 kHS06 total

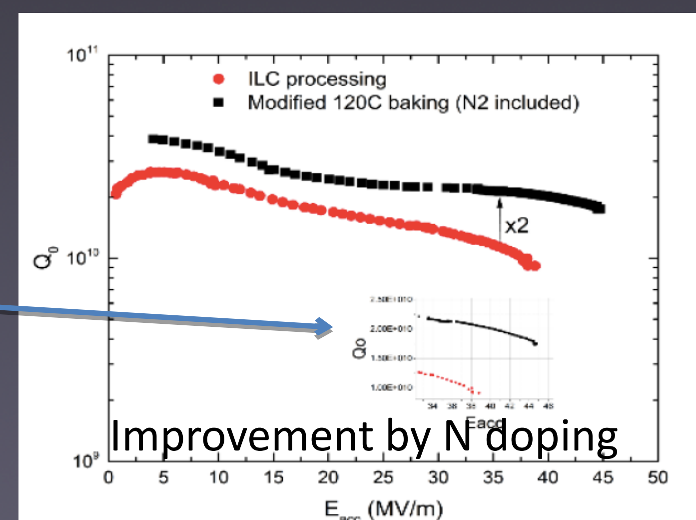
Proposal for ILC250 Higgs Factory

- As a first step towards the full ILC
- LCWS2016 Morioka
  - Proposed a first stage at 250 GeV as a Higgs factory that defines one whole project which should be justified by its own scientific case.
- The idea was discussed and a general agreement was obtained.

Staging Options



Options A, B, C : Assume 31.5 MV/m (TDR)
Options A', B', C' : Assume 35 MV/m
Now realistic, e.g.



Cost Reduction TDR → ILC250

Table 6-1: Summary of the staging cost

	e+/e- collision [GeV]	Tunnel Space for [GeV]	Value Total (MILCU)	Reduction [%]
TDR	250/250	500	7,980	0
TDR update	250/250	500	7,950	-0.4
Option A	125/125	250	5,260	-34
Option B	125/125	350	5,350	-33
Option C	125/125	500	5,470	-31.5
Option A'	125/125	250	4,780	-40
Option B'	125/125	350	4,870	-39
Option C'	125/125	500	4,990	-37.5

Up to 40% cost reduction compared to ILC500 (TDR)
Power consumption down from 164 MW→ 125 MW

Scientific Significance of ILC and Proposal of its Early Realization in light of the Outcomes of LHC Run 2

Japan Association of High Energy Physicists, July 22, 2017

- …As discussed above, the scientific significance and importance of ILC has been further clarified considering the current LHC outcomes. ILC250 should play an essential role in precision measurement of the Higgs boson and, with HL-LHC and SuperKEKB, in determining the future path of new physics. Based on ILC250's outcomes, a future plan of energy upgrade will be determined so that the facility can provide the optimum experimental environment by considering requirements in particle physics and by taking advantage of the advancement of accelerator technologies. It is expected that ILC will lead particle physics well into the 22st century.
- To conclude, in light of the recent outcomes of LHC Run 2, JAHEP proposes to promptly construct ILC as a Higgs factory with the center-of-mass energy of 250 GeV in Japan.

International Committee for Future Accelerators (ICFA)

Statement on the ILC Operating at 250 GeV as a Higgs Boson Factory Nov 2017

…ICFA considers the ILC a key science project complementary to the LHC and its upgrade.

ICFA welcomes the efforts by the Linear Collider Collaboration on cost reductions for the ILC, which indicate that up to 40% cost reduction relative to the 2013 Technical Design Report (500 GeV ILC) is possible for a 250 GeV collider.

ICFA emphasizes the extendibility of the ILC to higher energies and notes that there is large discovery potential with important additional measurements accessible at energies beyond 250 GeV. ICFA thus supports the conclusions of the Linear Collider Board (LCB) in their report presented at this meeting and very strongly encourages Japan to realize the ILC in a timely fashion as a Higgs boson factory with a center-of-mass energy of 250 GeV as an international project, led by Japanese initiative.

MEXT ILC Advisory Panel on ILC250

- Established in May 2014.
  - ‘Re-activated’ to evaluate the ILC 250 GeV ‘Higgs factory’.
- ‘Re-activated’ two working groups:
  - Particle and nuclear physics working group
  - To evaluate the scientific case for ILC250
  - First mtg: Jan 18, 2018
- TDR working group
  - evaluate design maturity and costing
  - First mtg: Jan 30
- The ILC advisory panel has produced its final report on July 4, 2018
  - Supportive and no surprises

Science Council of Japan Committee on the Revised ILC

- Five years ago, the SCJ committee on ILC issued a report:
  - … the government of Japan should
    - (1) secure the budget required for the investigation of various issues to determine the possibility of hosting the ILC, and
    - (2) conduct intensive studies and discussions among stakeholders, including authorities from outside high-energy physics as well as the government bodies involved for the next two to three years.
  - … Upon completion of the above investigations, SCJ is prepared to contribute to the government's decision by presenting scientific and academic perspectives.
- Now that MEXT experts' committee finished its report
  - SCJ committee was re-Established on Jul 26, 2018
  - Final Report by ~ end of October
  - European Strategy sets the deadline

Political Developments

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

Potential Timeline

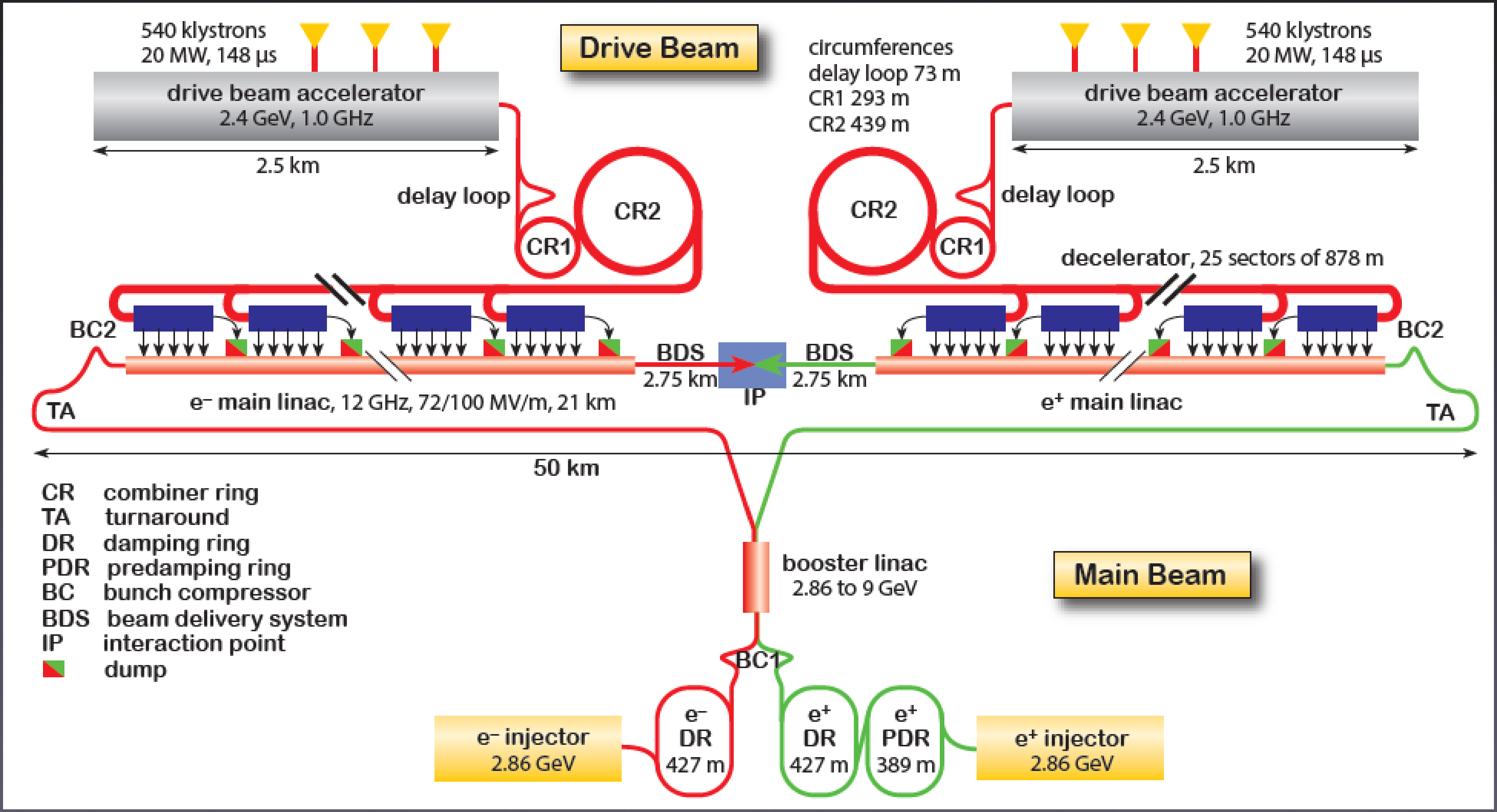
- Technically Viable, Political Possible
- 2018 " Green Light from Japan"
- 2019-2022 Project Preparation Phase
  - Agreements, Construction Preparations
- 2023
  - Begin of Construction
- 2032
  - First Beams

ILC Summary

- The ILC is technology-wise ready to go
- ILC250 Higgs Factory reduces the cost by up to 40%.
- ILC has the potential to reach 500 GeV or 1 TeV
  - Luminosity is limited by power consumption considerations

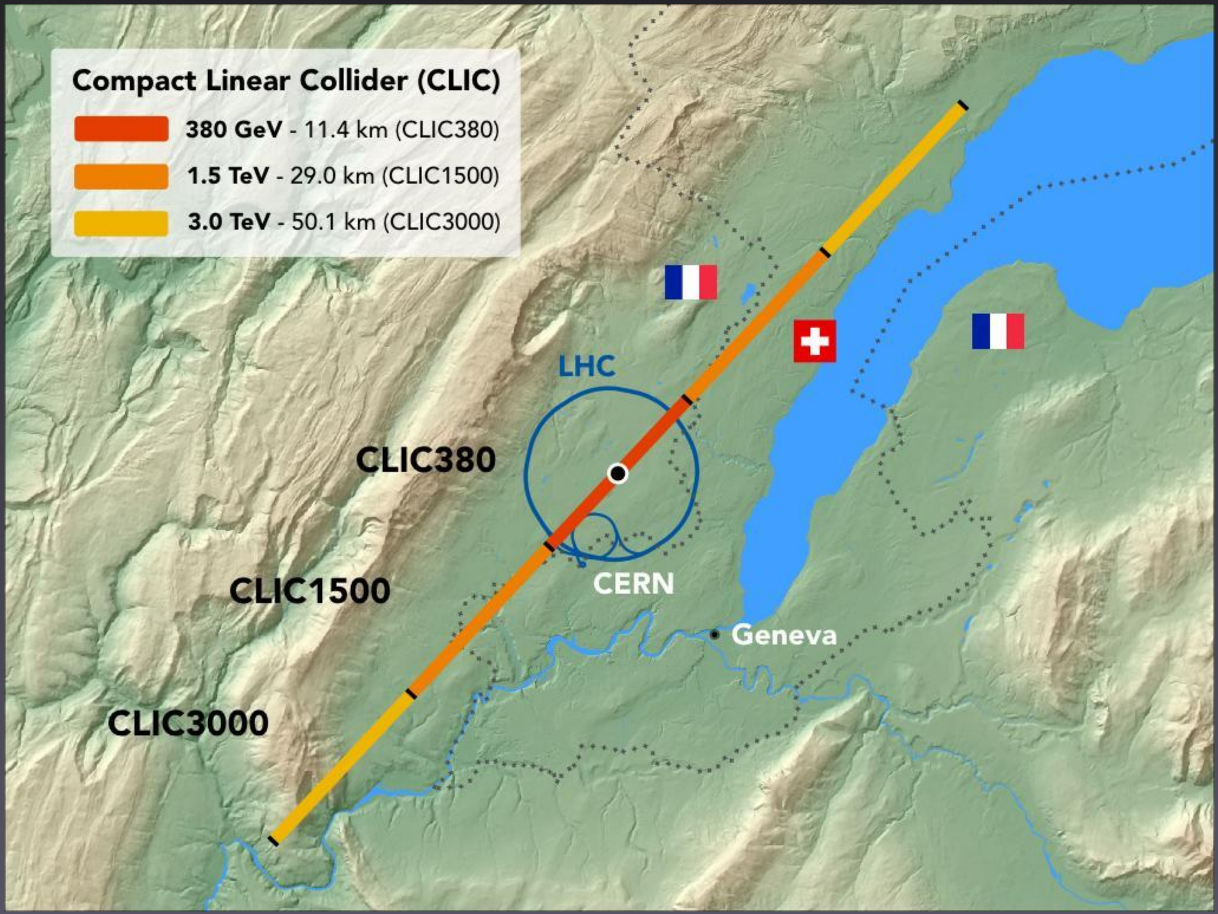
  Japanese government is about to finish evaluating the case for ILC (ILC 250 Higgs Factory)
  - Only project that has reached that level
- The deadline for inputs to the European Strategy Discussion is the end of this year – important that a positive statement comes from Japanese government in that time scale.

The CLIC Concept



The CLIC Project

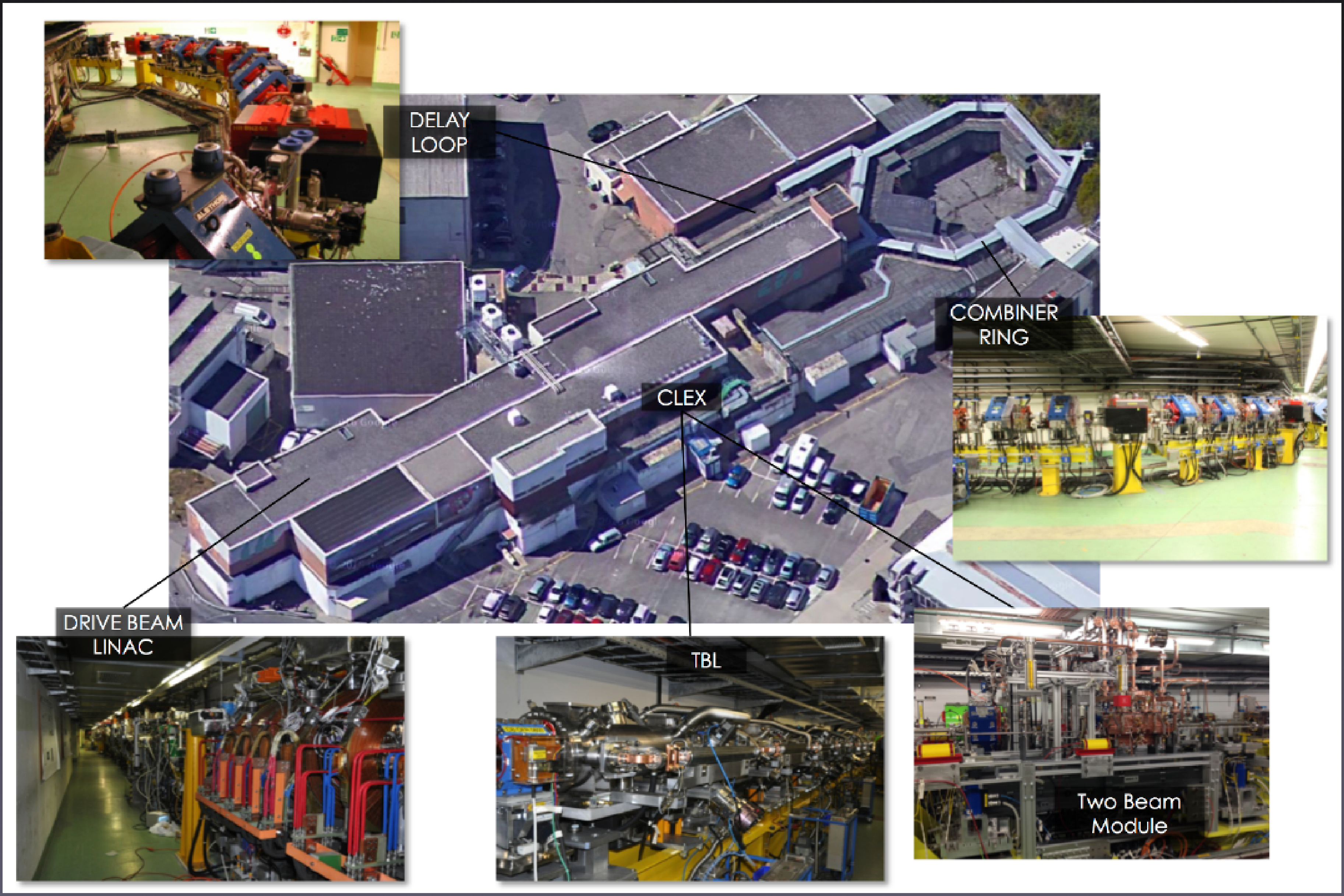
- Optimize machine design w.r.t. cost and power for a staged approach to reach multi-TeV scales:
  - 380 GeV (optimized for Higgs + top physics)
  - 1500 GeV
  - 3000 GeV
- Adapting appropriately to LHC + other physics findings
- Possibility for first physics no later than 2035 (technology-driven)
- Project Plan to include accelerator, detector, physics



The Three Stages

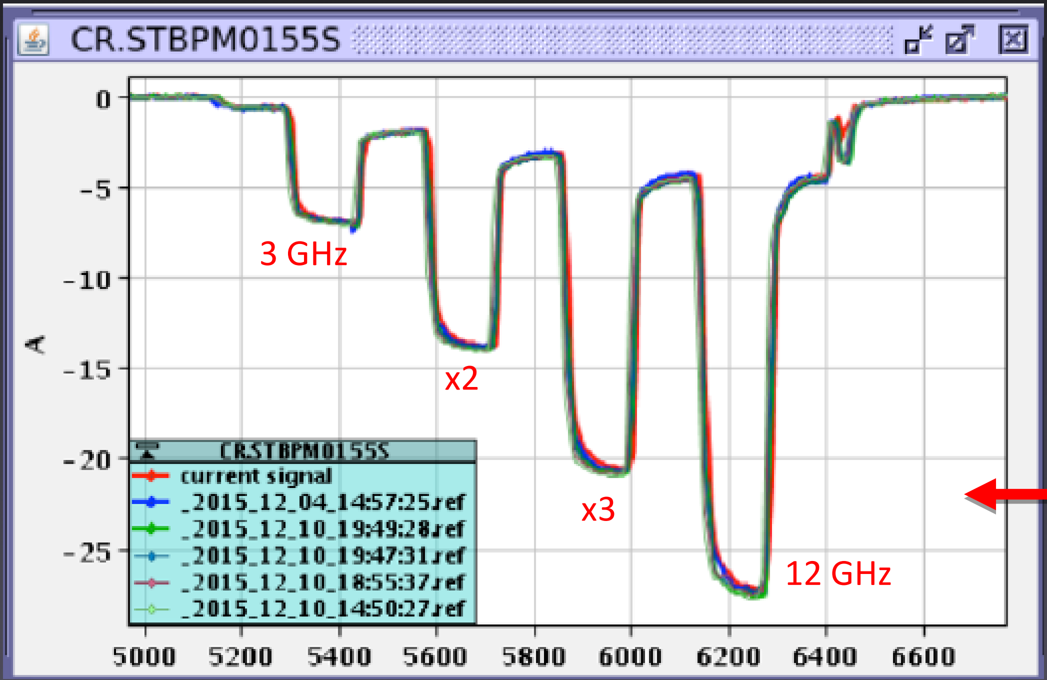
Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.9	1.4	2
Main tunnel length		km	11.4	29.0	50.1
Number of particles per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	μm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	920/20	660/20	660/20
Normalised emittance (at IP)	$\varepsilon_x/\varepsilon_y$	nm	950/30	—	—
Estimated power consumption	P_{wall}	MW	252	364	589

CLIC Test Facility (CTF3)



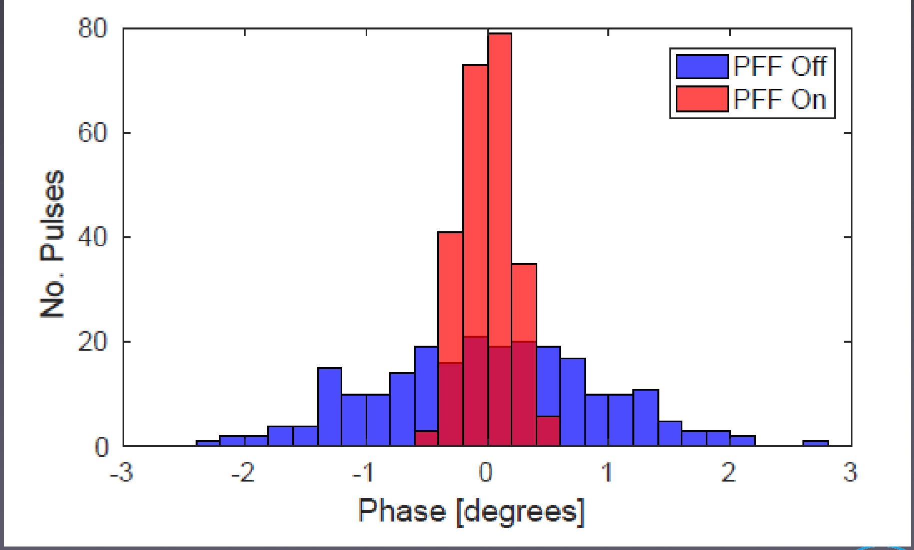
CTF Status

Produced high-current drive beam bunched at 12 GHz



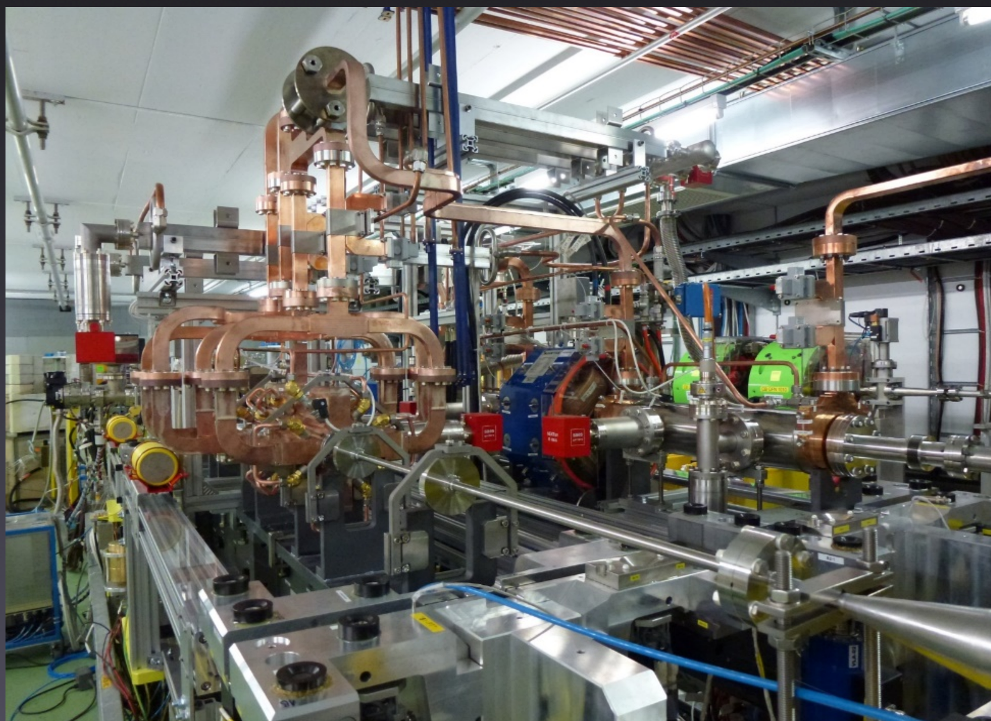
28 A

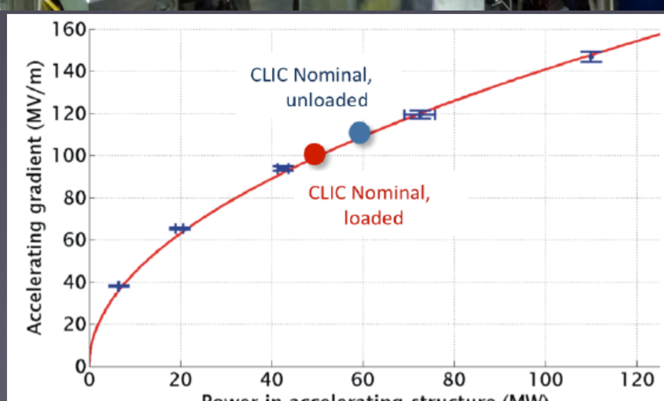
Arrival time stabilised to 50 fs



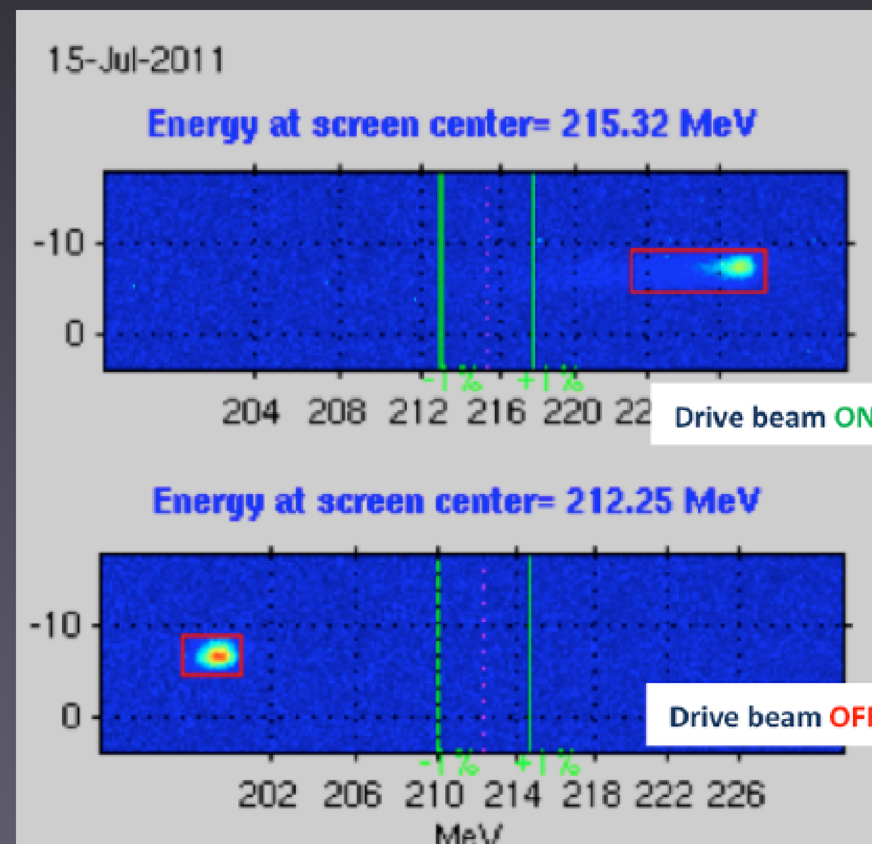
Status

- Demonstrated two-beam acceleration



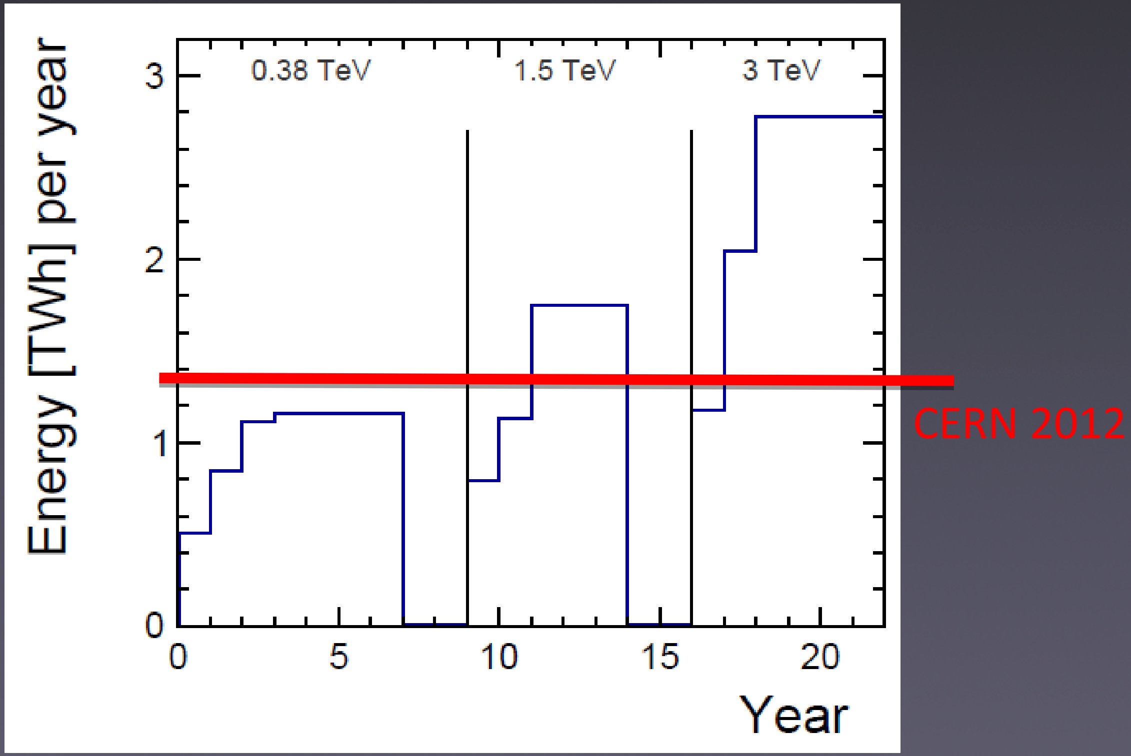


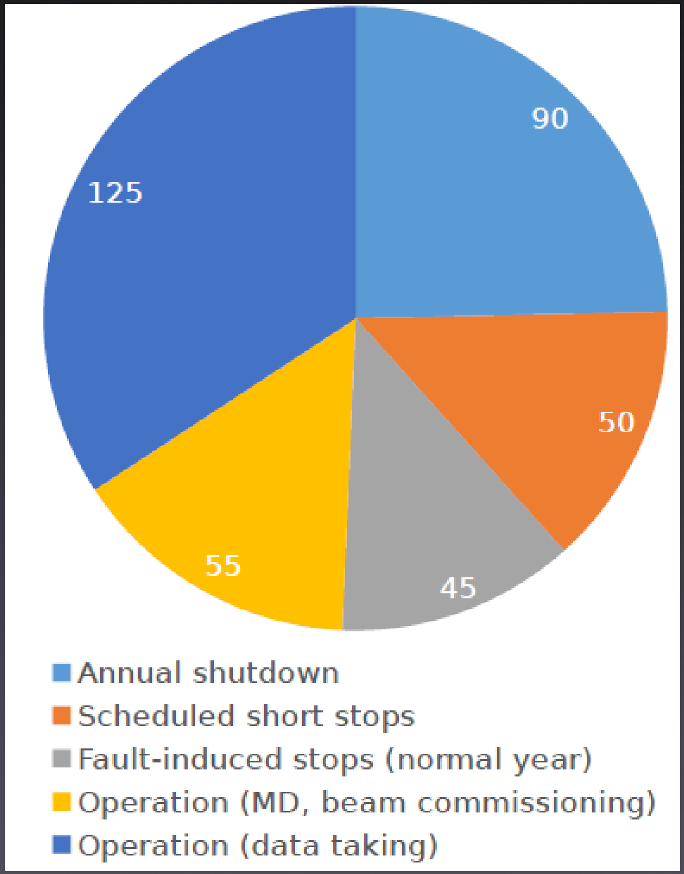
31 MeV = 145 MV/m



AC Power budget

$\sqrt{s}$ [TeV]	$P_{nominal}$ [MW]	$P_{waiting\ for\ beam}$ [MW]	P_{stop} [MW]
0.38	252	168	30
1.5	364	190	42
3.0	589	268	58





R&D to reduce Power at 380 GeV from 250→ 200 MW

CLIC Project Preparation Plan

- Preparing CLIC Project Plan + supporting documents for input to European Strategy Update (ESU)
- Staged approach, starting at 380 GeV with costs and power not excessive compared with LHC
- Upgrade path in stages over 20-30 year horizon → 3 TeV
- Update costings, for both baseline and a klystron-based 380 GeV first stage
- Maintain flexibility and align with LHC physics outcomes
- Next step > 2020 is a ~5-year project preparation phase: critical parameters, detailed site layout, value engineering, risk mitigation … → plans to be presented to ESU
-

Short Summary

- Two linear collider projects are being pursued (ILC and CLIC) – with large collaborative effort.
  - Both have reached a remarkable level of mature, have a clear physics case, are (each) affordable – and it is likely one will be built.
  - The European XFEL as a 10% Prototype of the ILC→ Unique advantage
  - Within 1-2 year the landscape in Japan and Europe can be expected to be clearer.
- **Future accelerators in particle physics are today cost and power limited – don't scale energy unless you can scale down cost/GeV and maintain or increase luminosities**
  S. Stapnes (CERN, 2018)

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  - For hosting the SiD Optimization Workshop
  - Supporting SiD and the ILC
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Discussion Time

Backup !

Reviews …

European Strategy for Particle Physics 2013

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. 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.

US P5 Statement 2014

"Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds."

Higgs Self-coupling

- One of the most difficult measurements at both LHC and ILC
  - Key measurement for understanding the Higgs
- Cross-section at the ILC
  - 10^4 smaller than the Higgs cross-section
- ILC at 500 GeV will be able to establish its existence
  - <30% accuracy predicted
  - 1 TeV upgrade really valuable (<10 %)