Connecting Particles with the Cosmos

LEXI LANDESEXZELLENZINITIATIVE HAMBURG

UHH DESY

# The Energy Frontier

Ties Behnke, DESY

11.10.2012

# What I will discuss

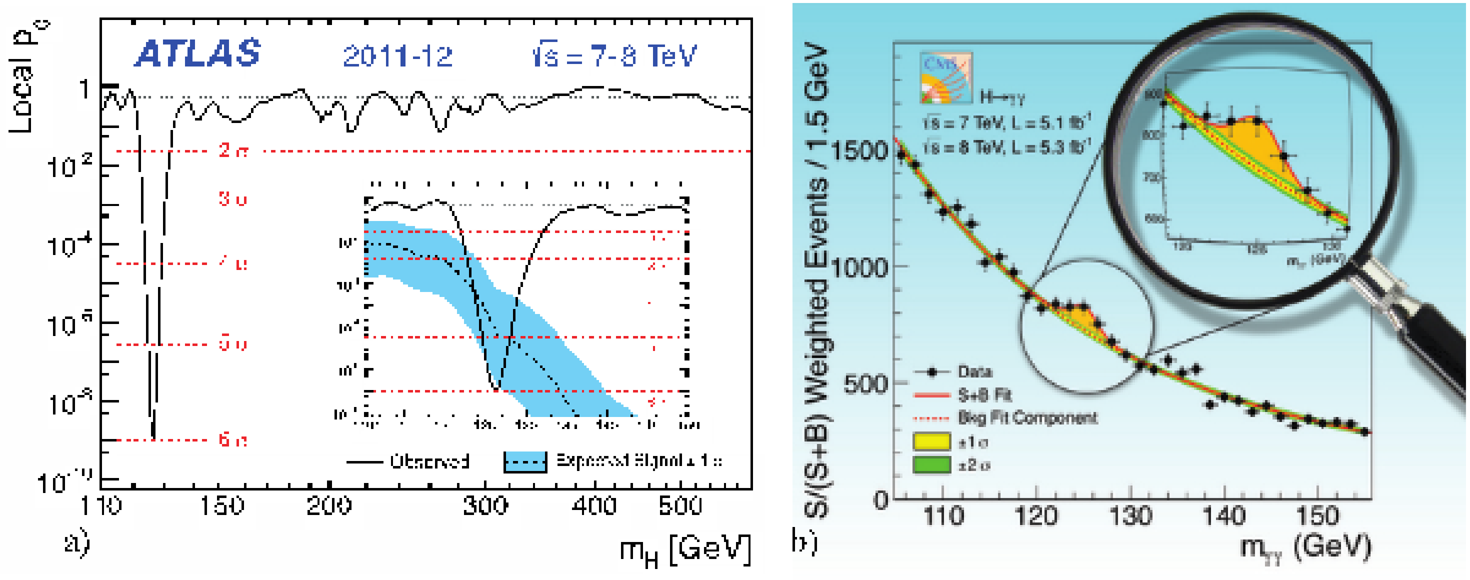
The energy frontier

How to we get there: Facilities we might want to use

What can we realistically expect: Folding in the realities of life

DESY

# The Energy Frontier




- LHC is the only machine at the energy frontier for the moment

- Incredible success already now
    - O(300) papers already
    - “Higgs” discovery
    - Enormous physics output

See many talks at this meeting

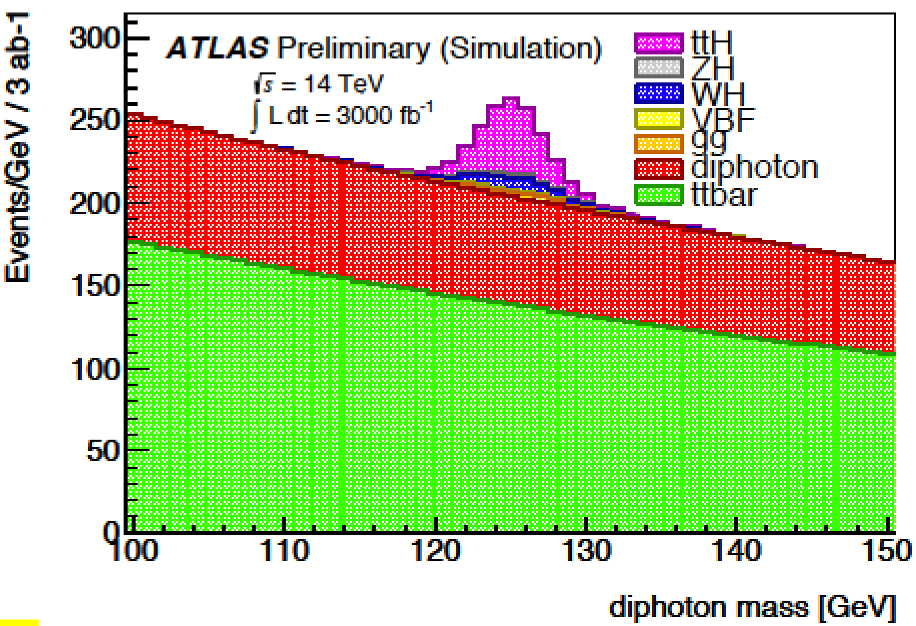
# Physics at the LHC

… is incredibly broad.

- Hadron colliders do precision physics
- Any collider does more than originally planned and anticipated

But hadron colliders have certain limitations:

- Many decay channels are for realistically invisible
- Often only the ratio of couplings can be measured

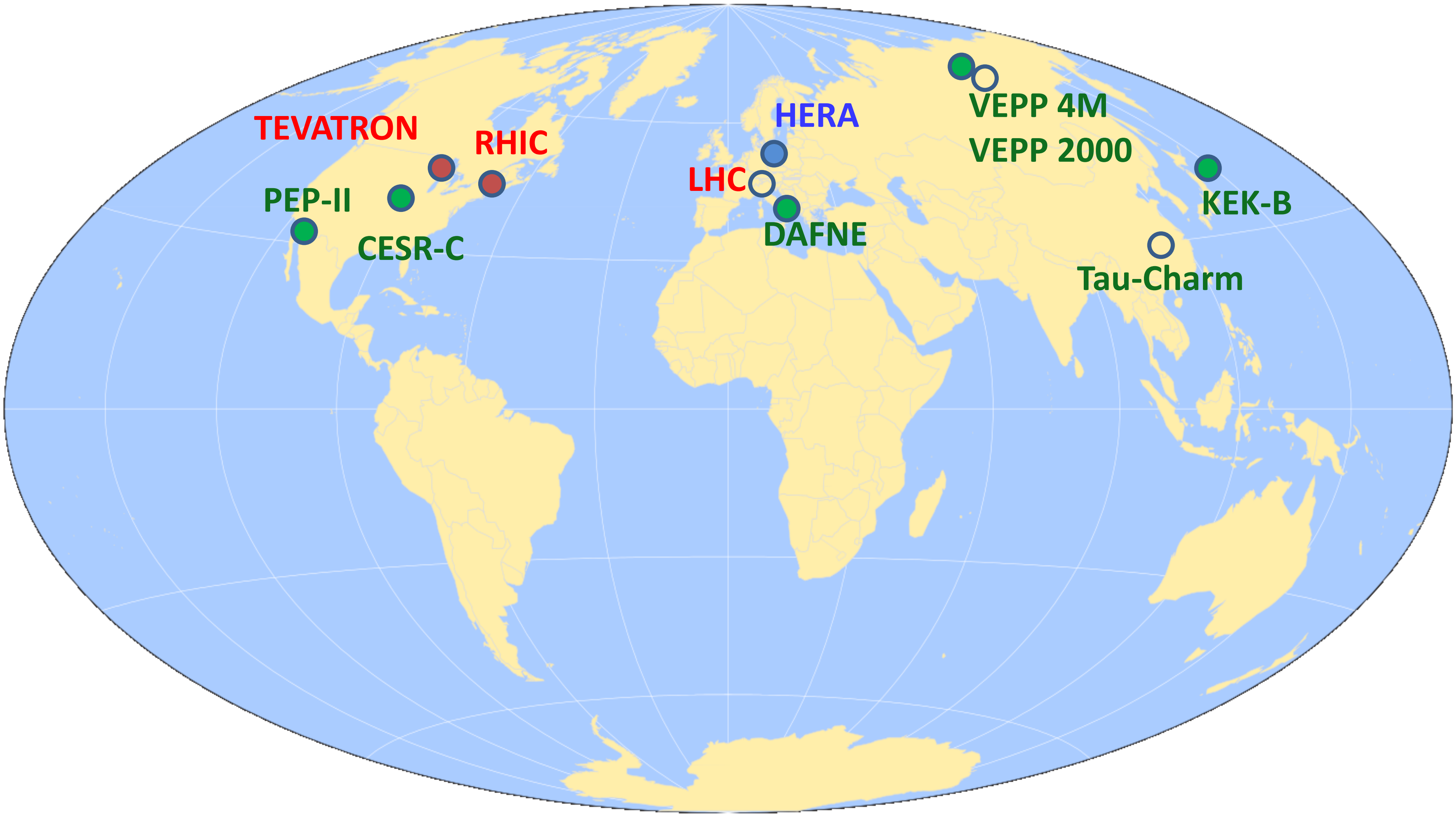



But: is there a future beyond the LHC?

# Colliders 2006

- In operation
- Under construction

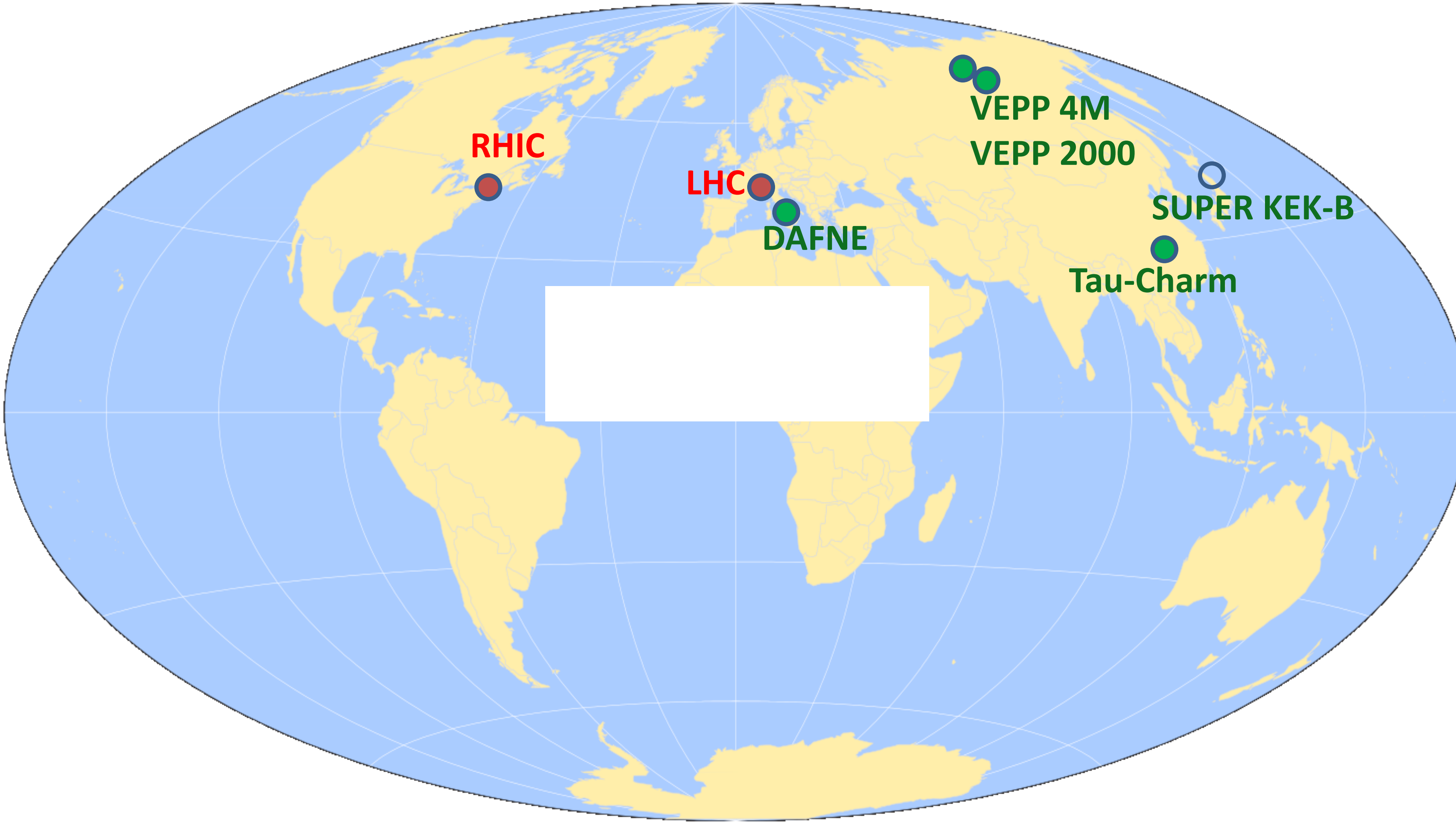
Hadrons
Leptons
Leptons-Hadrons



# Colliders Today

- In operation
- Under construction

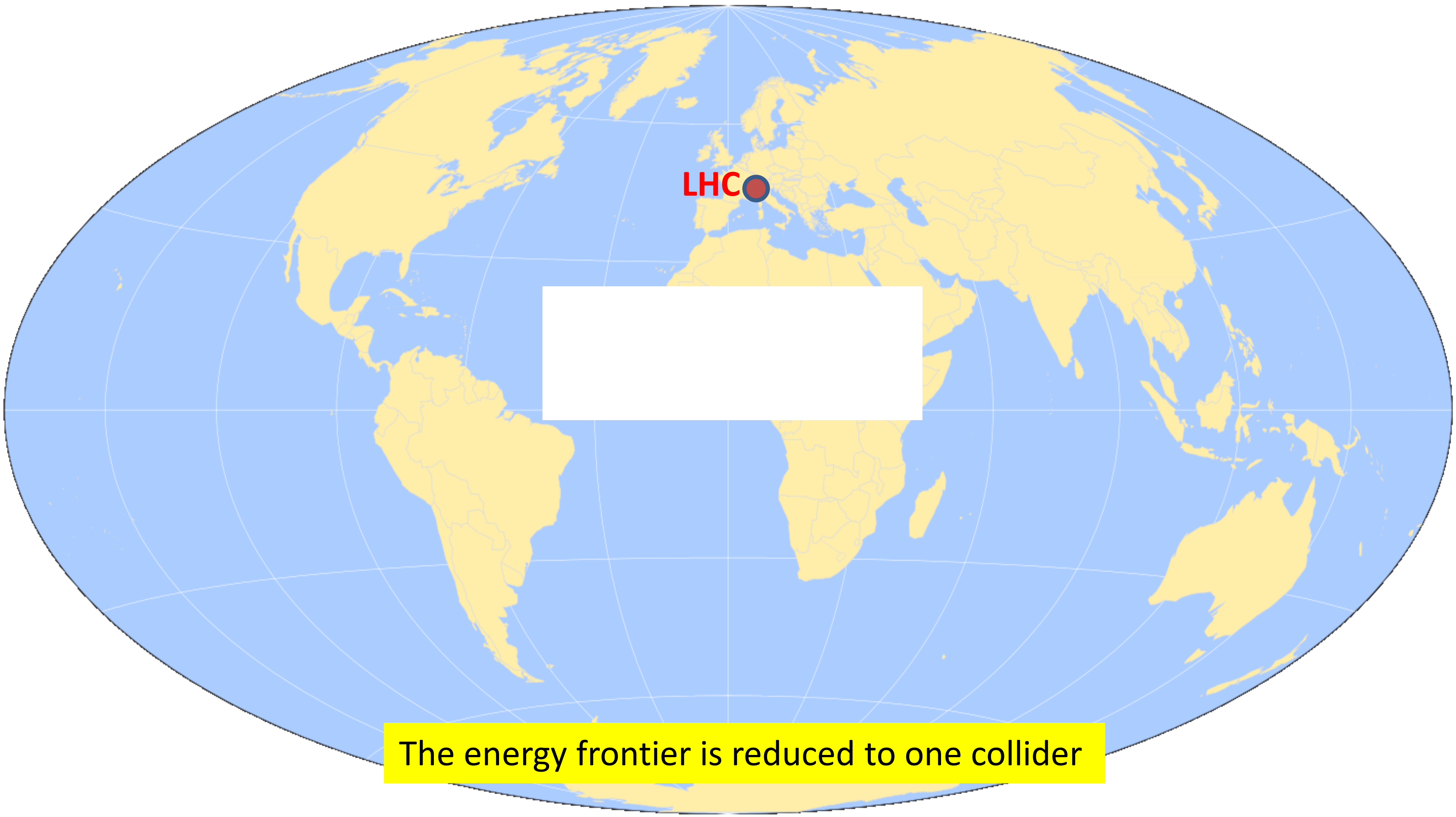
**Hadrons**
**Leptons**
**Leptons-Hadrons**



# HE Colliders Today

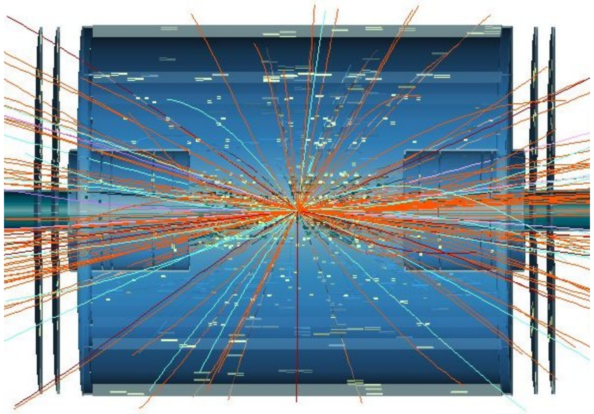
In operation
Under construction

Hadrons
Leptons
Leptons-Hadrons

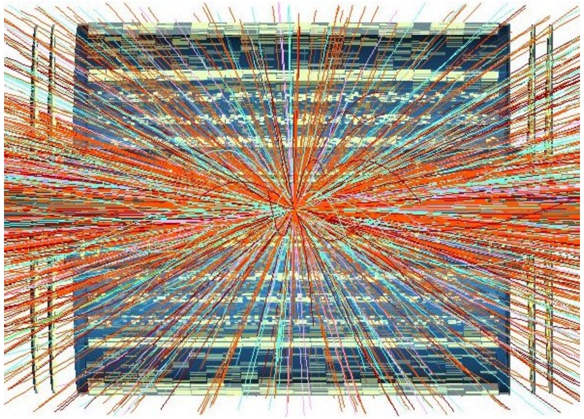



The energy frontier is reduced to one collider

# The Future of the LHC Program



Increase
luminosity
by a factor of 10



- Program to consolidate and upgrade the accelerator chain at CERN
- Ambitious program to upgrade the detectors in several stages to cope with the increased luminosity and radiation levels

# The LHC at CERN: a scenario

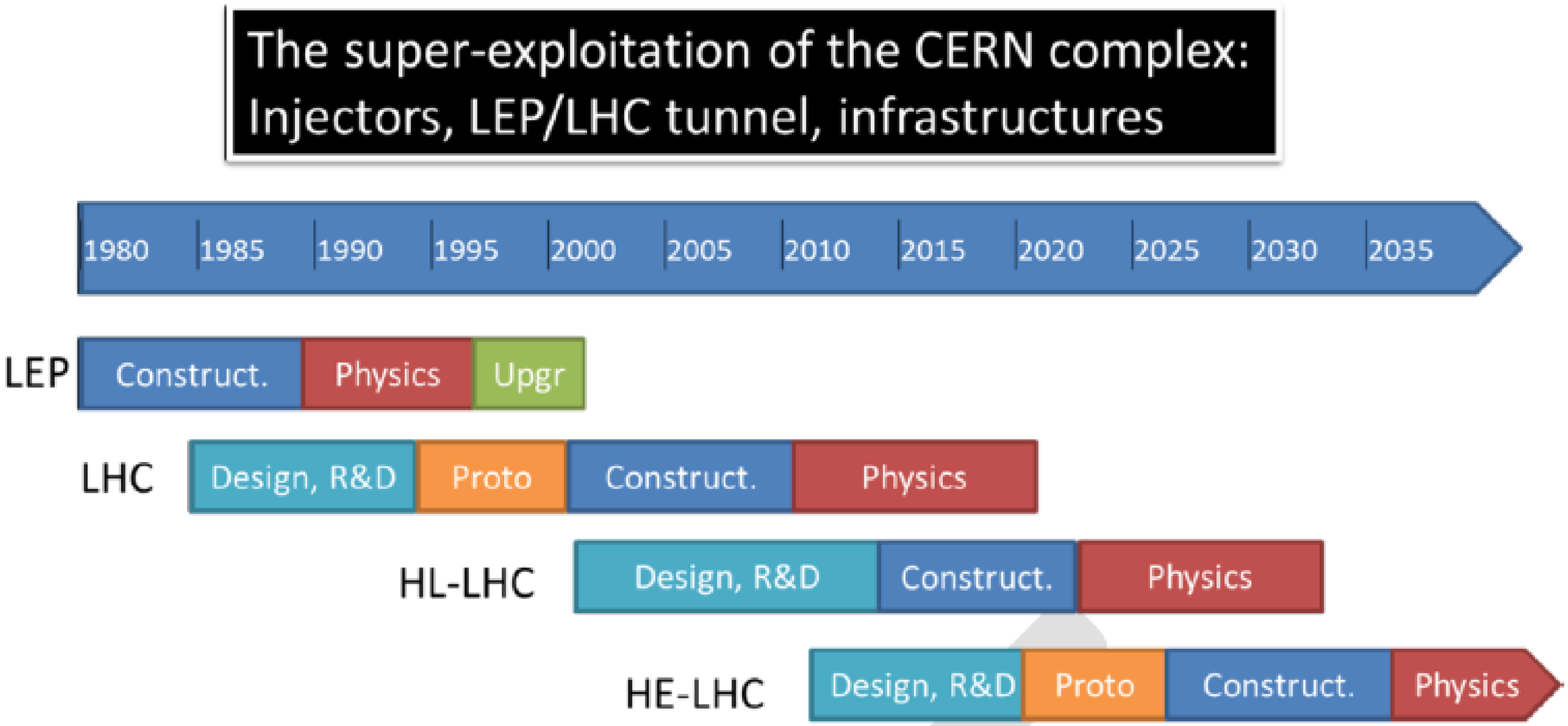


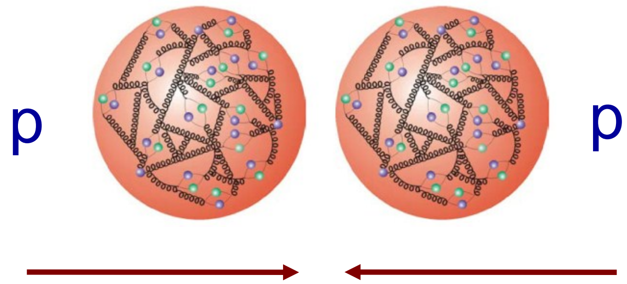

*Figure 10. The possible timeline of LHC and its upgrades.*

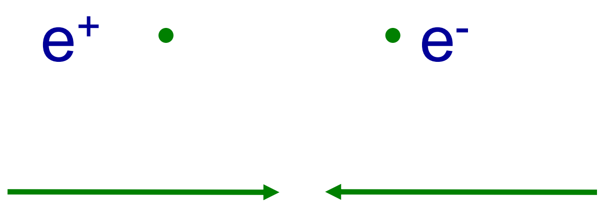
# Beyond HE-LHC : new tunnels in Geneve area

1) 42 TeV c.o.m. with 8.3 T (present LHC dipoles)
2) 80 TeV c.o.m. with 16 T (high field based on Nb3Sn)
3) 100 TeV c.o.m with 20 T (very high field based on HTS)


*Figure 9. Two possible location, upon geological study, of the 80 km ring for a Super HE-LHC (option at left is strongly preferred)*

# Hadron and Lepton Colliders



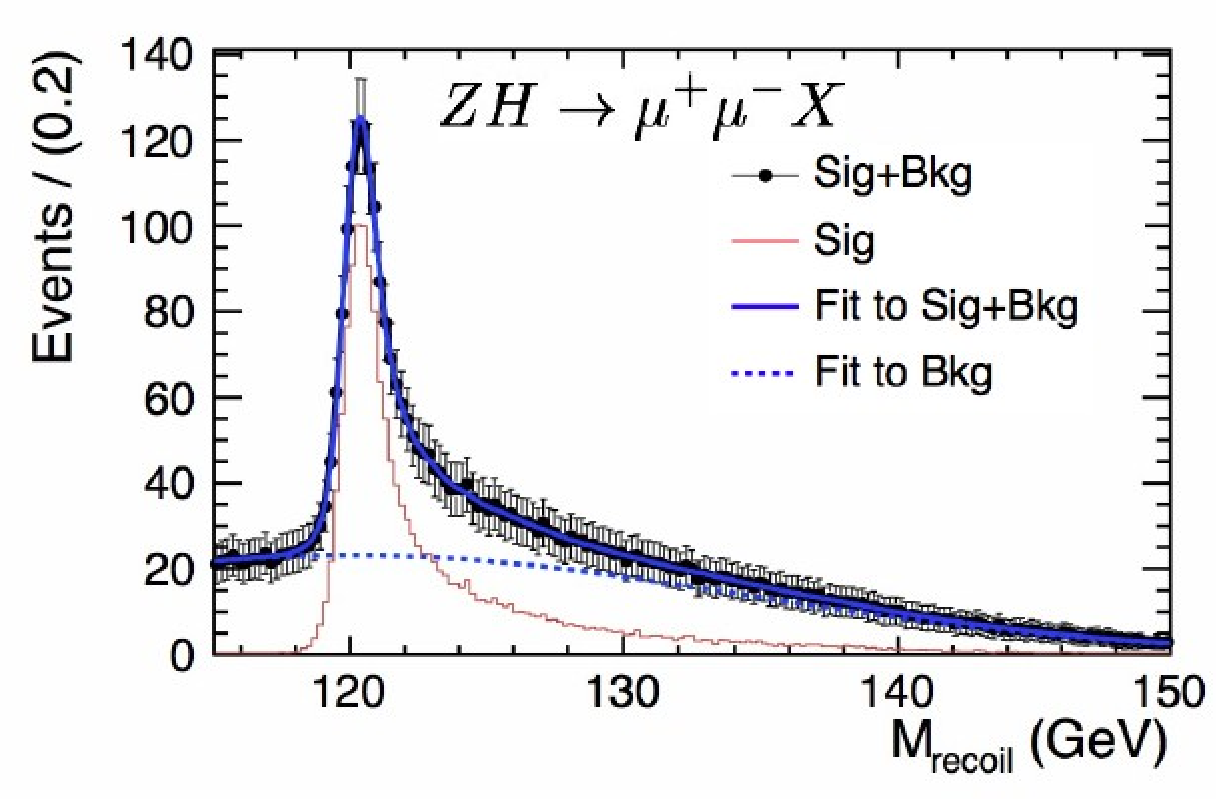

- Proton (anti-) proton colliders:
  - Energy range high (limited by bending magnets power)
  - Composite particles, different initial state constituents and energies in each collision
  - Difficult hadronic final states
- Discovery machines
- Precision measurement potential

- Electron positron colliders:
  - Energy range limited (by RF power)
  - Pointlike particles, well defined initial state quantum numbers and eneries
  - Easier final states
- Precision machines
- Discovery potential

# Physics at a Lepton Collider

Higgs physics: 126 GeV is “perfect” for LC

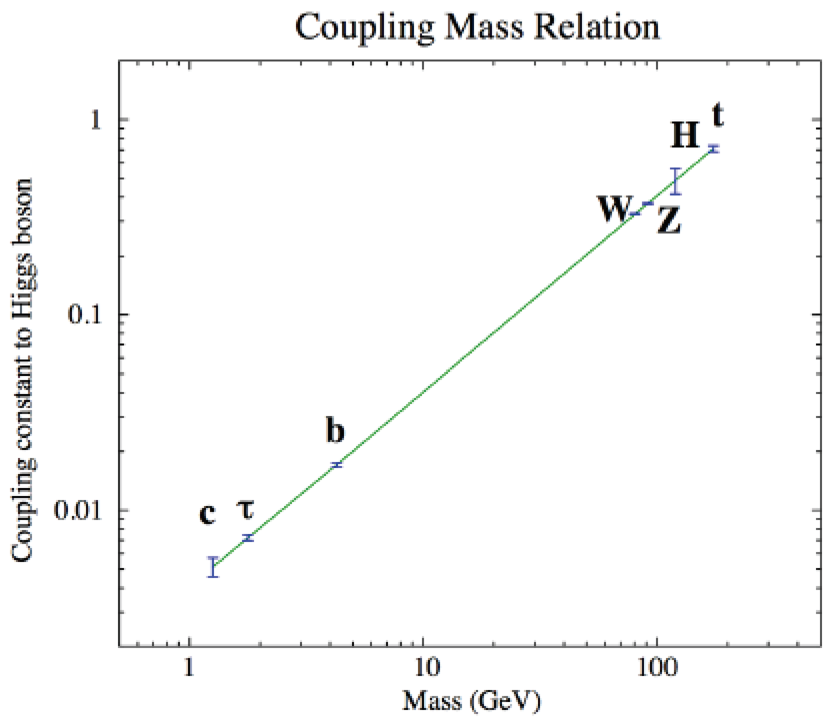
Very clean, model independent signal using the recoil method



# Physics at a Lepton Collider

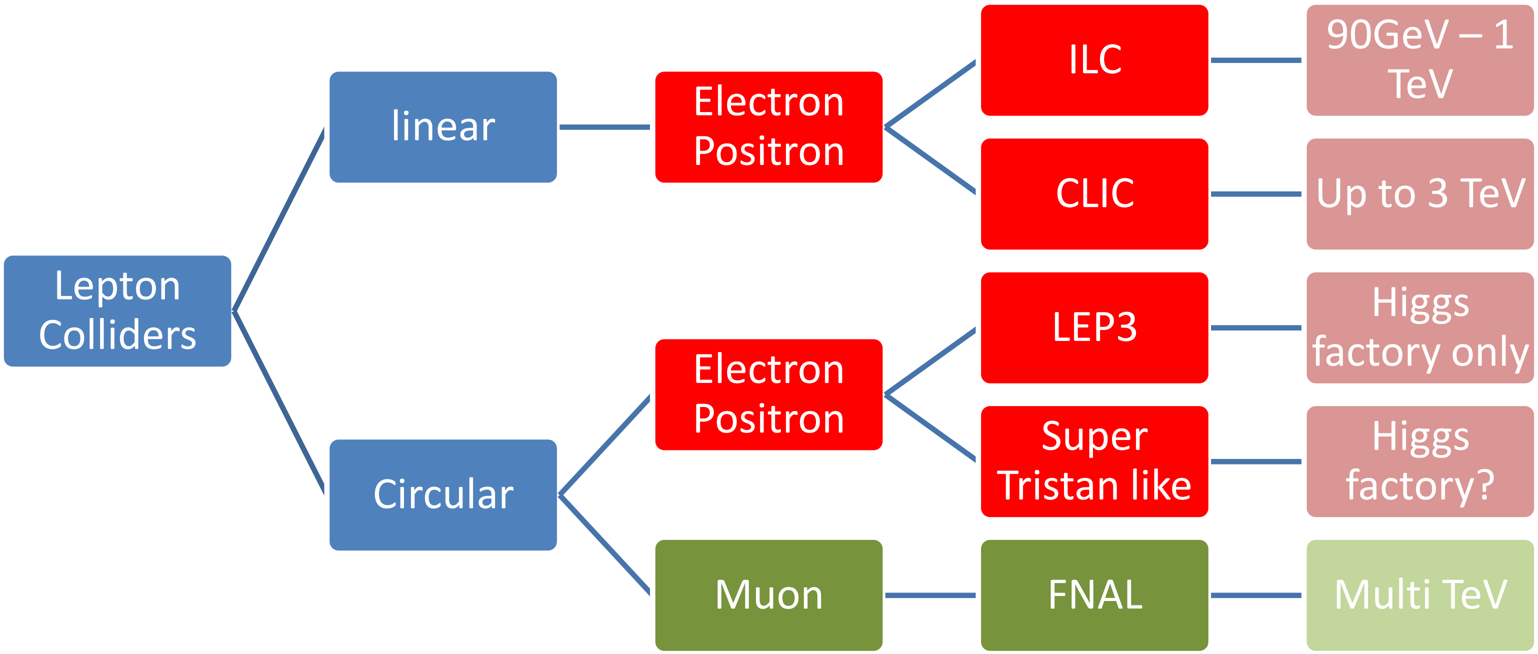
Higgs physics: 126 GeV is "perfect" for LC

| | 250 | 350 | 500 | >1.5 TeV |
|---|---|---|---|---|
| $g_{HWW}$ | ? | ? | 1.2 % | ? |
| $g_{HZZ}$ | 1.5 % | 1.8 % | | |
| $g_{Hbb}$ | 1.3 % | 1.1 % | | |
| $g_{Hcc}$ | 4.5 % | 3.2 % | | 1.5 % |
| $g_{H\tau\tau}$ | ~3 % | ~3 % | | ? |
| $g_{Htt}$ | - | - | 10 % | ? |
| $g_{H\mu\mu}$ | - | - | | 8 % |
| $\lambda_{(HHH)}$ | - | - | <50 % | <20 % |



# Lepton Colliders

Large number of options how to realise a HE lepton facility



# Multi-TeV Circular Colliders

| | LEP-II | Super-LEP | HYPER-LEP |
|---|---|---|---|
| $E_{cm}$ | 180 GeV | 500 GeV | 2 TeV |
| $L$ | 27 km | 200 km | 3200 km |
| $\Delta E$ | 1.5 GeV | 12 GeV | 240 GeV |
| €$_{tot}$ | 2 billion | 15 billion | 240 billion! |

Table by James Jones

- Very high energy circular lepton colliders are not realistic
- $€_{LC} \sim E + \text{const.}$

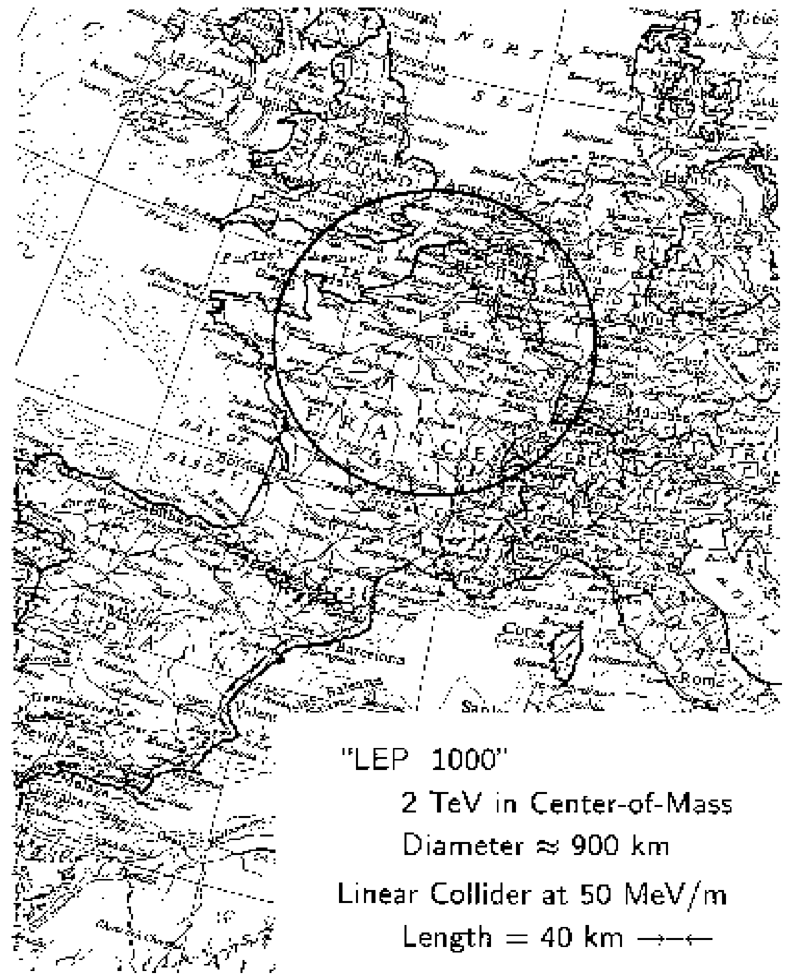
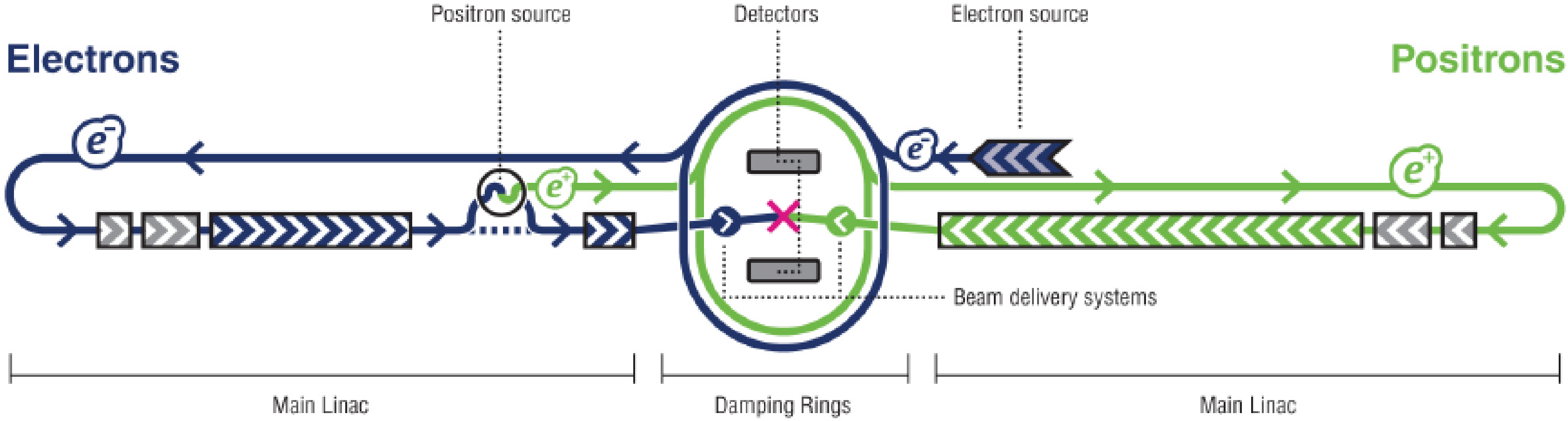



Figure by Gregory Loew

# ILC

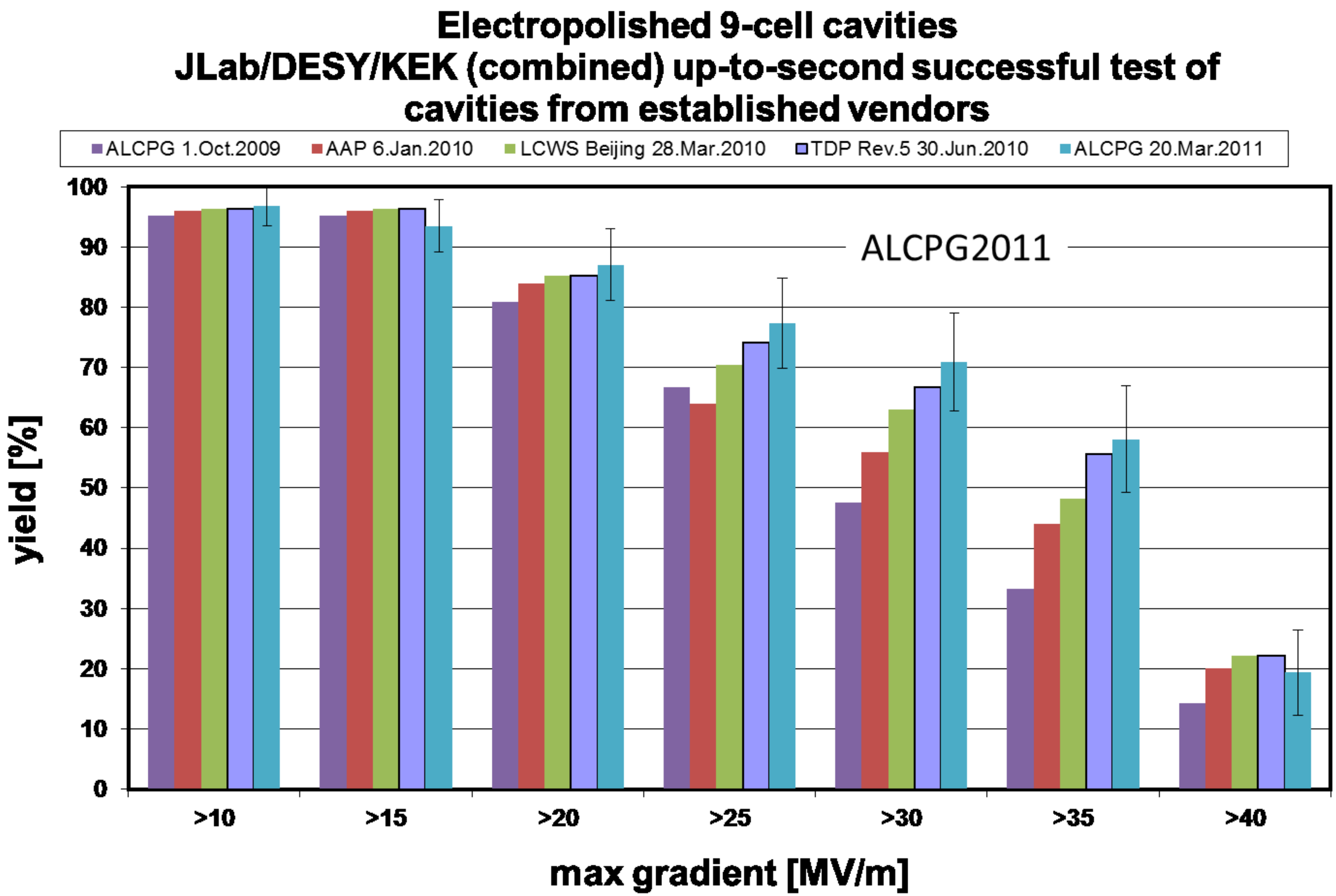
Two single-beam linacs with superconducting RF accelerating cavities ~40 MV/m




Schematic layout of the ILC complex

- For $\sqrt{s}$ = 500 GeV total length of facility ~30 km
- Established technology
  - Industrial production of high field superconducting cavities now well established

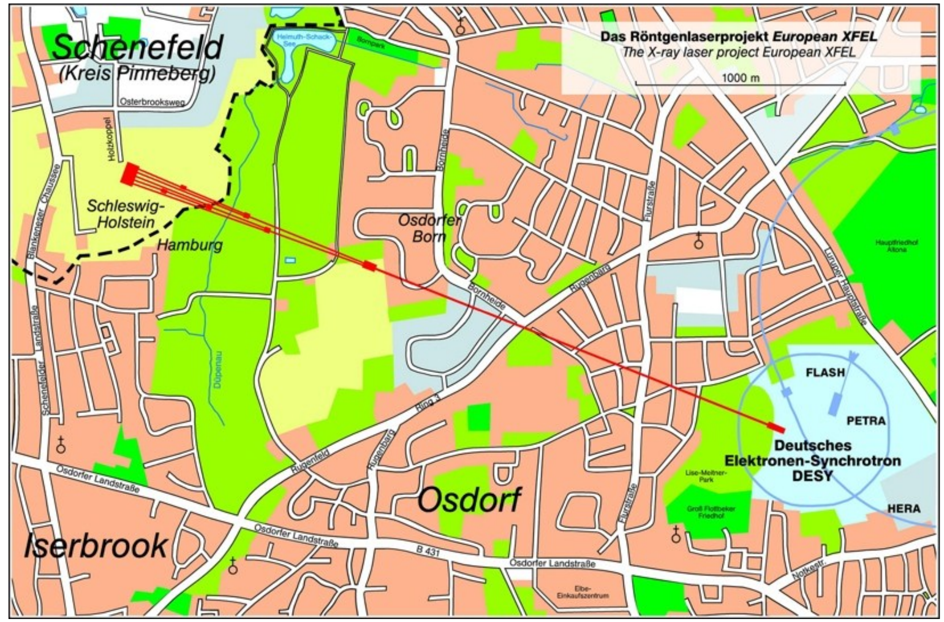
# ILC: Gradient



# The European XFEL

X-Ray Free Electron Laser

- ILC technology
- Length: 3,4 km
- Beam energy: 17,5 GeV
- Laser wavelength: 0,085 - 6 nm
- Laser pulse length: < 100 fs
- Construction start: 2009
- First beam: 2014
- Very broad physics program fr
quantum-level studies to applie
research
- Linac: 10% prototype for ILC...

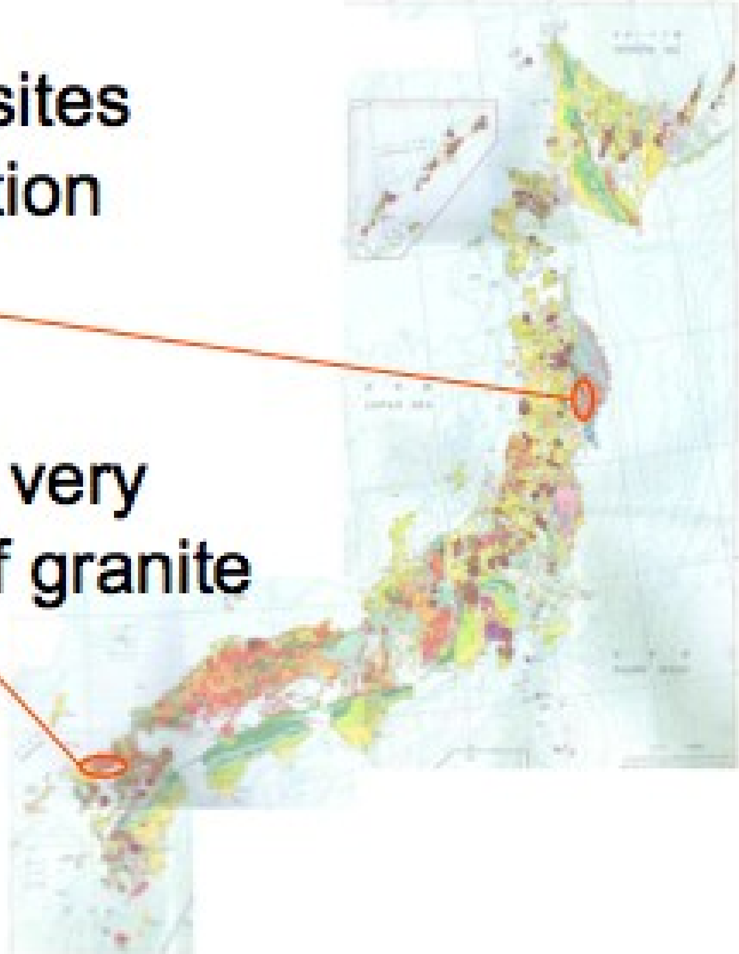




# ILC Siting: current developments

## Japanese candidate sites

- Two candidate sites under investigation
  - Kitakami
  - Sefuri
- Both sites have very good geology of granite



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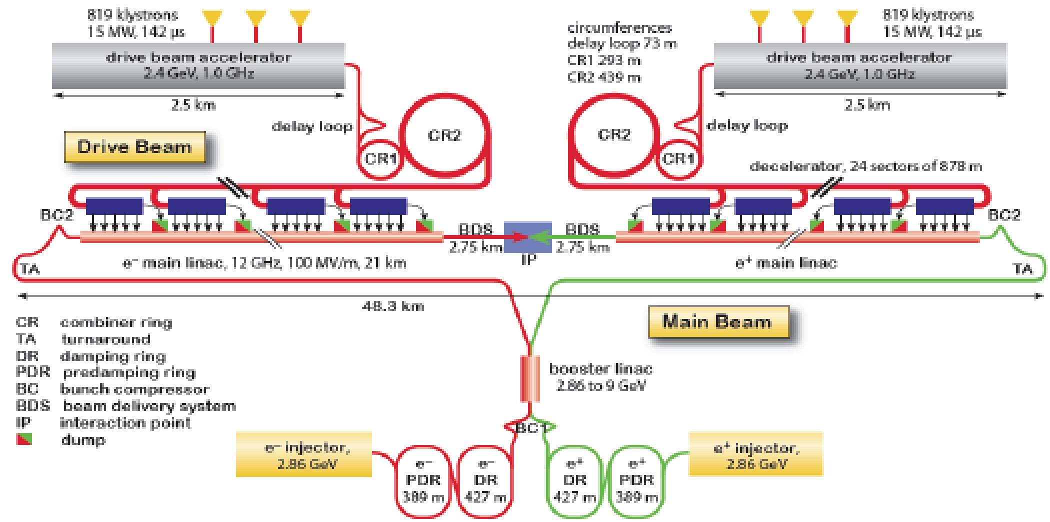
# Sefuri Mountain

# CLIC

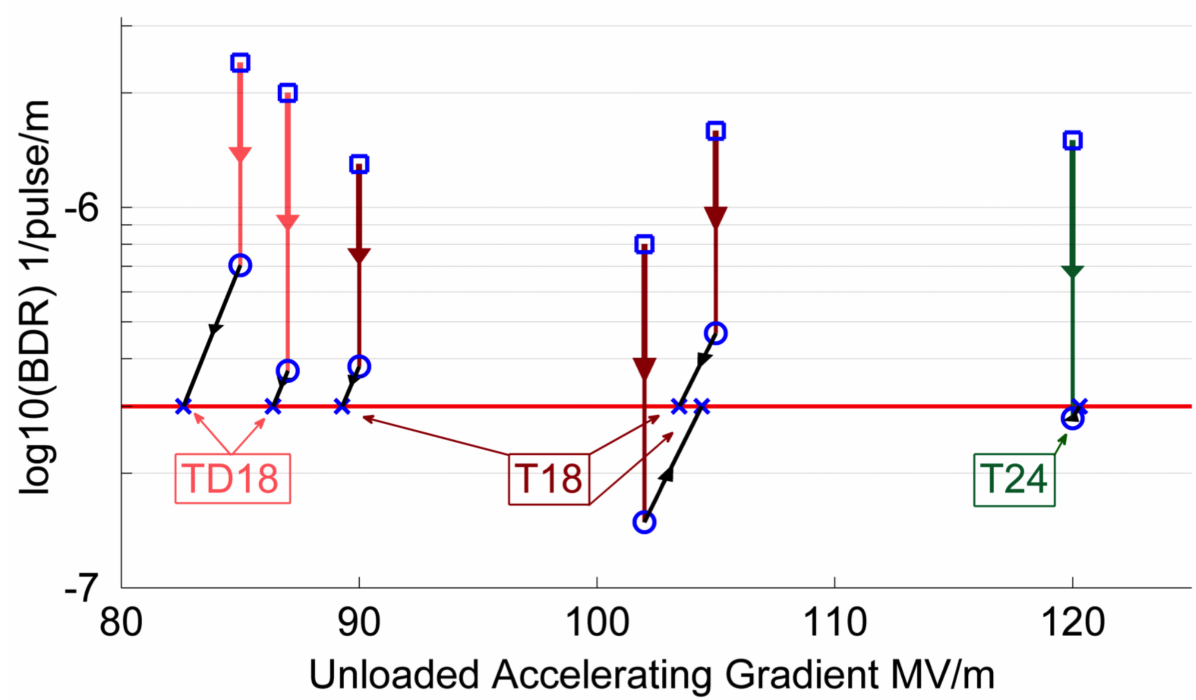
## Overview of the CLIC layout at $\sqrt{s}$ = 3 TeV




Two double-beam linacs

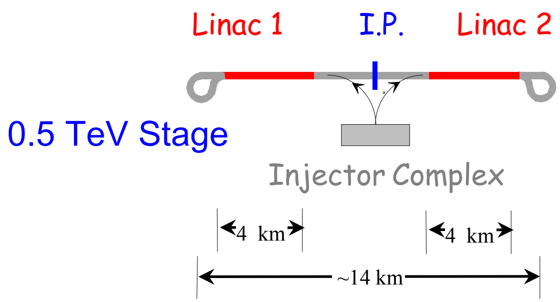
- Low energy, high current drive beam powers ~100 MV/m RF cavities in main linac

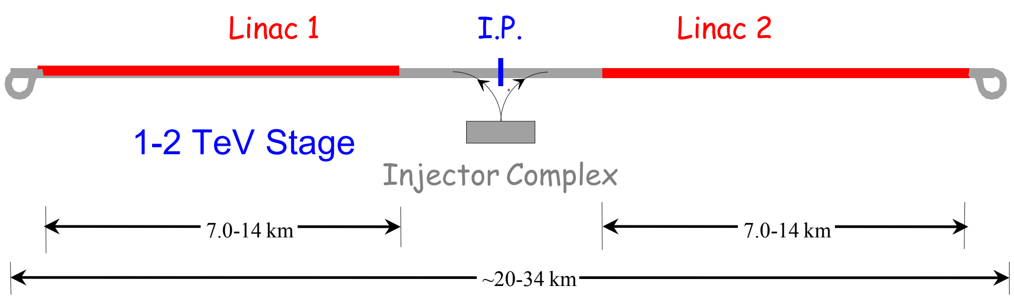
- CLIC R&D ongoing at CERN
  - Gradient
  - Stability
  - Beam handling
  - …

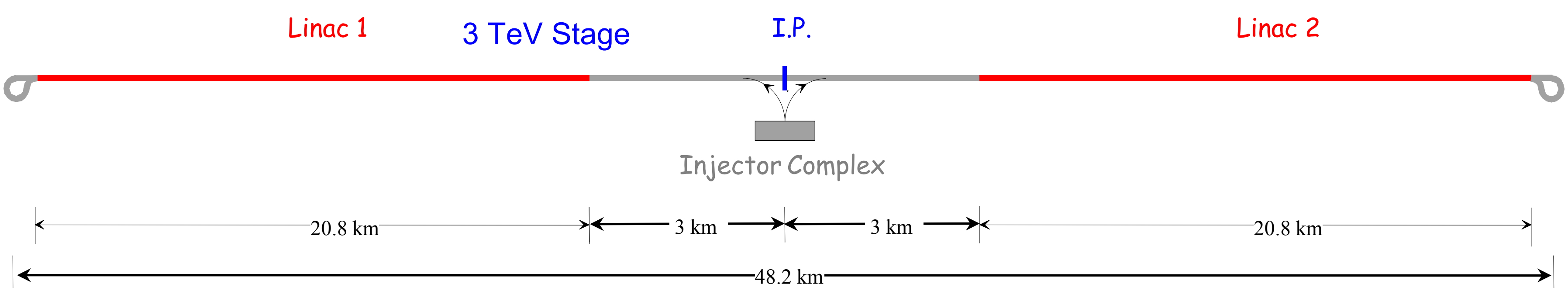


# CLIC staging

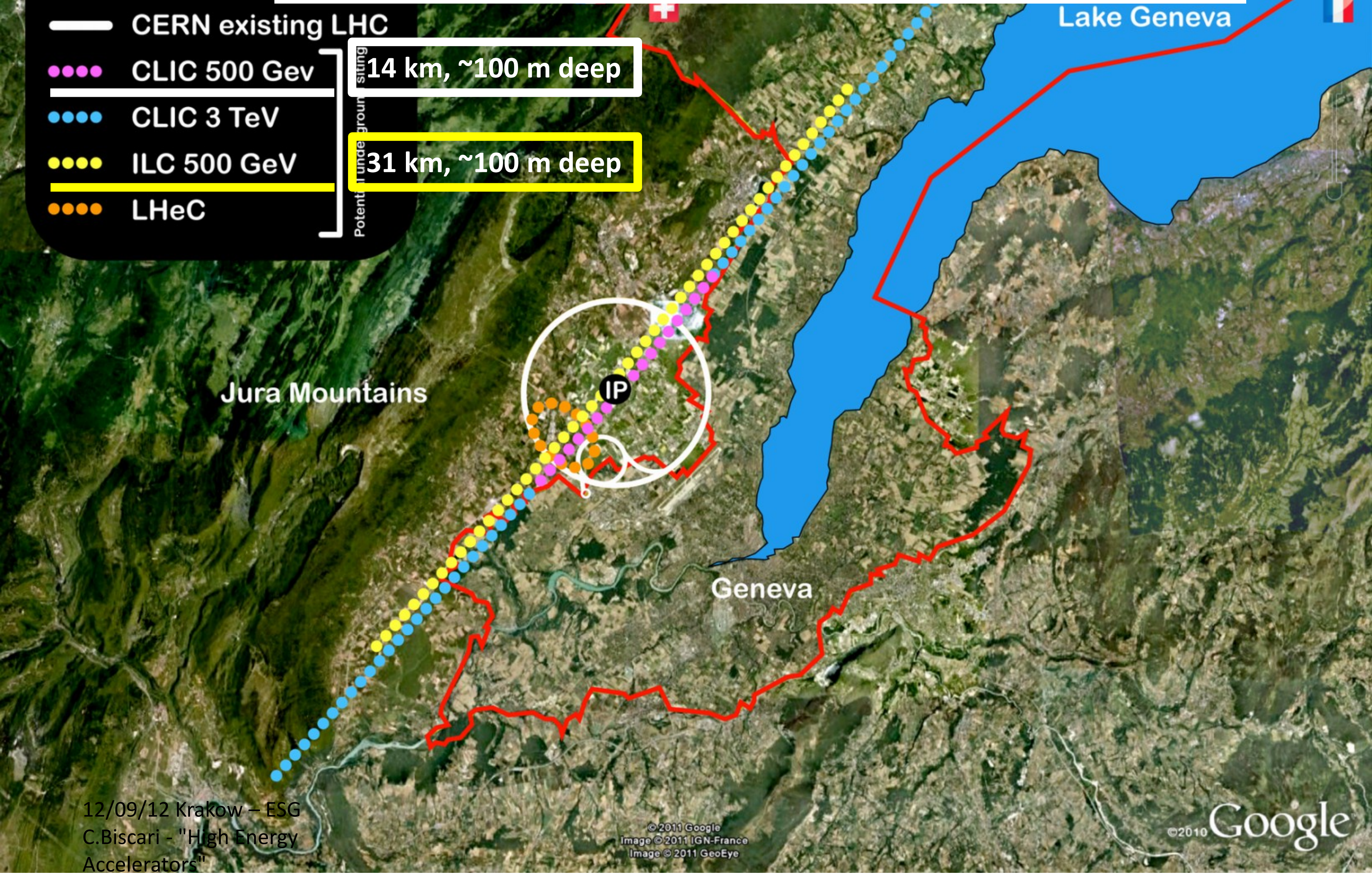
A linear collider
can be realised in stages
to increase its
energy reach.



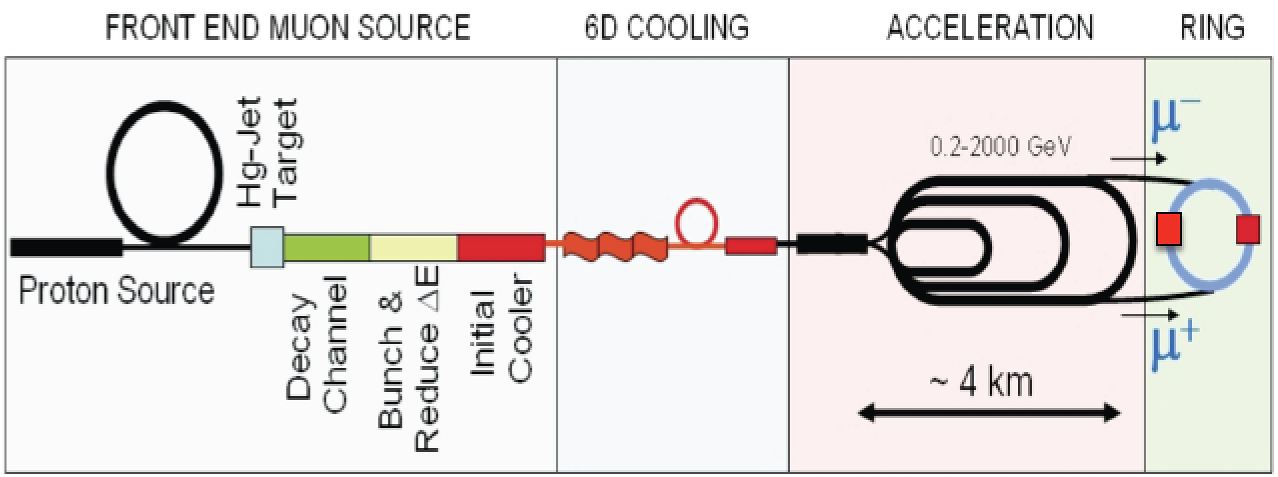



# A linear collider at CERN



# Muon Collider




- Potential advantages wrt. $e^+e^-$
- Smaller facility size
  - Synchrotron radiation losses ~ $E^4/m^4r$
- Smaller energy spread
  - Beamsstrahlung ~ $E^4/m^4$
- s-channel Higgs production ~$m^2$

- Target L = $10^{34}$ $cm^{-2}s^{-1}$ per IP
- Many technical challenges to be faced
  - Intense proton source
  - Muon cooling
  - Can detectors survive muon decay rate and still do the physics?
- Could be a follow-on from (or precursor to) a ν-factory

# Muon Collider Conceptual Layout

**Project X**
Accelerate Hydrogen ions to 8 GeV using SRF technology.

**Compressor Ring**
Reduce size of beam (2±1 ns).

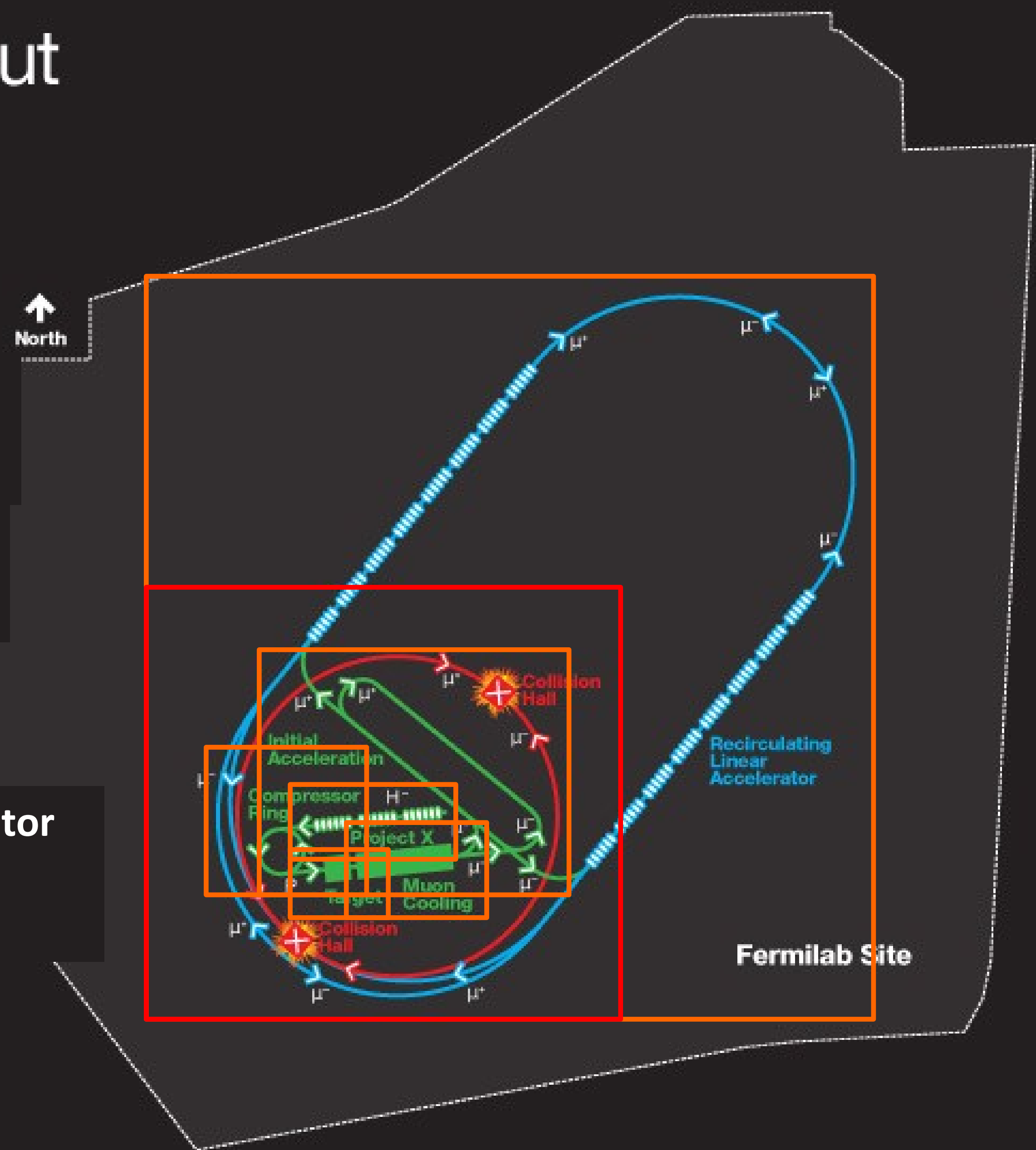
**Target**
Collisions lead to muons with energy of about 200 MeV.

**Muon Capture and Cooling**
Capture, bunch and cool muons to create a tight beam.

**Initial Acceleration**
In a dozen turns, accelerate muons to 20 GeV

**Recirculating Linear Accelerator**
In a number of turns, accelerate muons up to Multi-TeV using SRF techlnology.

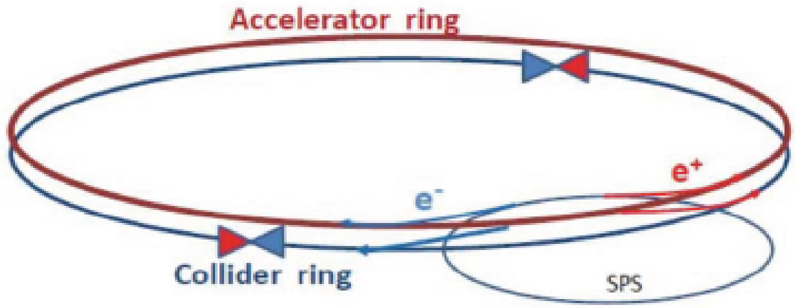
**Collider Ring**
Bring positive and negative muons into collision at two locations 100 meters underground.




www.fnal.gov/pub/muon_collider

Katsuya Yonehara @ IPAC12

# Circular "Higgs factory"




E.g., LEP3:

- $\sqrt{s}$ = 240 GeV in the LHC tunnel to produce $e^+e^- \rightarrow ZH$ events
- Short beam lifetime (~16 mins) requires two ring scheme
  - Top up injection from 240 GeV "accelerator ring"
  - "Collider ring" supplying 2-4 interaction points $L = 10^{34}\,cm^{-2}s^{-1}$ per IP
    - Re-use ATLAS and CMS and/or install two dedicated LC-type detectors
- Current design uses arc optics from LHeC ring
  - Dipole fill factor 0.75 (smaller than for LEP)
  - increased synchrotron energy loss (7 GeV per turn)
  - redesign possible?
- $e^{\pm}$ polarization probably not possible at $\sqrt{s}$ = 240 GeV
- In principle space is available to install compact $e^+e^-$ facility on top of LHC ring
  - Is this really feasible?
  - Alternatively wait until completion of LHC physics programme and removal of LHC ring?
- SuperTRISTAN is a proposal for a similar machine in Japan

E.g., TLEP:

- $\sqrt{s}$ = 350 GeV in 80 km LHC tunnel to reach thresholds for top pair and $e^+e^- \rightarrow \nu\nu WW \rightarrow \nu\nu H$

# Where do we go from here?

My personal point of view:

Physics calls for a lepton collider to supplement the LHC

- Clear case for a Higgs factory
- Top, W physics equally convincing
- Higher energies depend on LHC findings

With ILC we have at our disposal a mature technology to built a LC

With CLIC we have an exciting possibility to extend the reach into the muti-TeV range in the future

Circular machines are less attractive

cost-benefit analysis
Extensibility

The current political climate in Japan might be a unique chance to realise such machine. Lets profit from this!

# DESY

DESY is a strong player in the LHC and in the LHC upgrade

- Participation in both Atlas and CMS
- We intend to play an important role in both the ATLAS and the CMS upgrade

DESY is a strong player in the ILC world

- Large body of know-how on SCRF
- XFEL is world-unique SCRD LA facility under construction

Strategically detector development know-how and detector integration know-how will be a strong and common foundation for DESY's continued HEP involvement.

Close cooperation with the University of Hamburg is an important asset.

# Backup

# University HH - DESY

DESY and UHH have been strong partners since the founding of DESY

We profit mutually from each other

- Close integration into the university is a key advantage for DESY to maintain and strengthen a vibrant scientific life
- Uni HH profits from the DESY infrastructure and capabilities

# Parameters Example

| | TRISTAN | KEKB | LEP2 | LEP3 | DLEP | SuperTRISTAN | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 40 | 60 | |
| Beam Energy | 32 | 8 / 3.5 | 105 | 120 | 120 | 120 | 120 | GeV |
| Circumference | 3 | 3 | 27 | 27 | 53 | 40 | 60 | km |
| Beam Current / beam | 7 | 1400 / 1700 | 4 | 7.2 | 14.4 | 8.6 | 8.6 | mA |
| Bunches / beam | 2 | 1600 | 4 | 3 | 60 | 12 | 18 | |
| β* x / y | 2000 / 40 | 1200 / 6 | 1500 / 65 | 150 / 1.2 | 200 / 2 | 80 / 2.5 | 80 / 2.5 | mm |
| Emittances x / y | | 18 / 0.1 | 48 / 0.25 | 20 / 0.15 | 5 / 0.05 | 23.3 / 0.09 | 24.6 / 0.09 | nm |
| Bunch length | 10 | 6 | 3 | 3 | 1.5 | 3 | 3 | mm |
| Beam-beam parameters | 0.02<br>0.025 | 0.05<br>0.09 | 0.025<br>0.065 | 0.126<br>0.13 | 0.1<br>0.1 | 0.05<br>0.156 | 0.045<br>0.155 | |
| Radiation loss / turn | 300 | 4 / 2 | 2750 | 6900 | 3470 | 3420 | 2150 | MV |
| RF Voltage | 400 | 10 / 5 | 3640 | 9000 | 4600 | 5000 | 3300 | MV |
| RF frequency | 508 | 509 | 352 | 1300 | 1300 | 1300 | 1300 | MHz |
| Total SR Power | 4.2 | 5.6 / 3.4 | 22 | 100 | 100 | 59 | 37 | MW |
| Luminosity / IP | 0.04 | 21 | 0.13 | 13 | 16 | 10 | 10 | /nb/s |