# FUTURE LINEAR COLLIDERS

– focusing on clic

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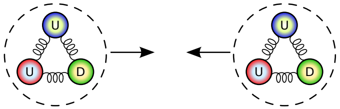
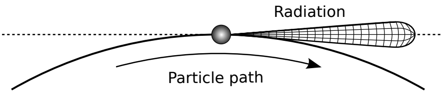
- Hadron colliders (protons, antiprotons, ions)
  - Consist of quarks and gluons (valence and sea partons) with different energy
  - "Discovery machine"
- Lepton colliders (electrons/positrons, muons)
  - Fundamental particles
  - Precision physics at a chosen energy
- Photon colliders




Hadron and lepton colliders complement each other.

It is difficult to build a new circular electron machine because of energy loss from synchrotron radiation (bremsstrahlung). The energy loss per revolution is

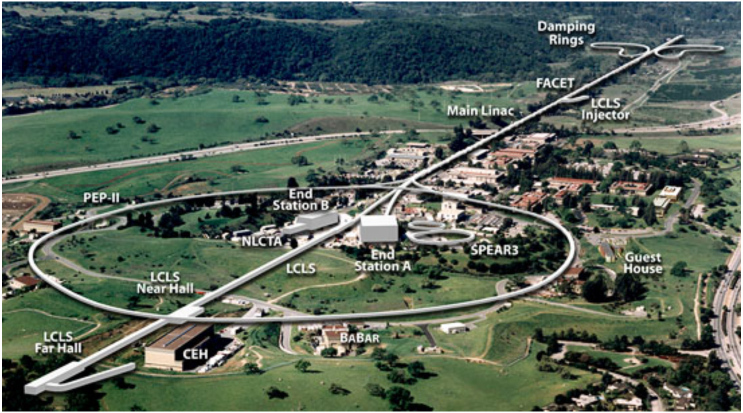
$$\Delta E \propto \frac{1}{m_0^4}\frac{E^4}{\rho} f_{\text{rev}}.$$




- Electrons have $10^{13}$ more losses than protons
- A higher energy needs a much larger ring
  - An upscaled version of LEP from $\sqrt{s} = 0.2$ to 1 TeV would require a circumference of 670 km!
  - The TLEP project is already talking about an 80 km ring at $\sqrt{s} = 350$ GeV

The general consensus is that the next generation collider should be a **linear $e^+e^-$ collider.**

# SLAC – with the largest linear accelerator/collider to date

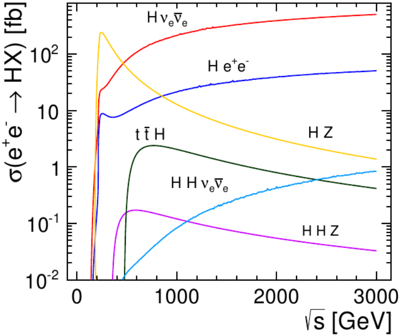



- In operation since 1966
- 3.2 km long
- Used as a $e^+e^-$ collider at $\sqrt{s} = 90$ GeV
- Not used for particle physics today

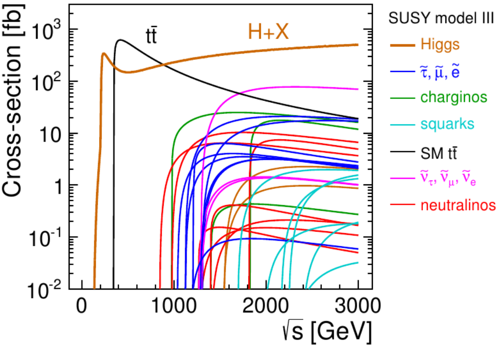
# Physics potential for $e^+e^-$

- Standard model electroweak precision physics
  - Higgs (cross-section, mass, self-coupling)
  - Top quark
- Beyond standard model physics
  - More Higgs particles
  - Supersymmetry
  - Heavy gauge bosons
  - Extra dimensions
  - ...

SM Higgs production cross-section

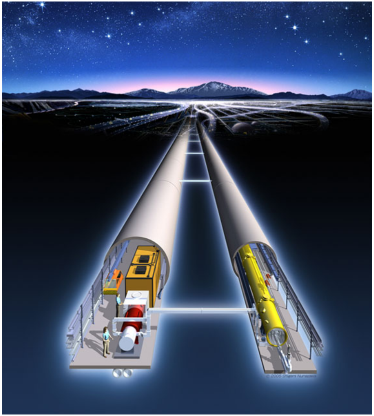



Cross-section of a specific mSUGRA model (SUSY)



## ILC

- Center-of-mass energy $\sqrt{s} = 0.5$ TeV
- 31 km long
- Superconducting niobium rf cavities for acceleration
- Accelerating gradient: 31.5 MV/m
- 369 ns bunch spacing

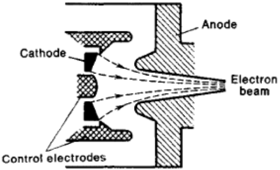


## CLIC

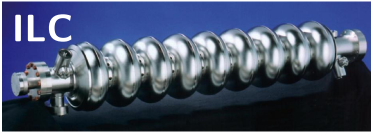
- Center-of-mass energy up to $\sqrt{s} = 3.0$ TeV
- 48 km long
- Two-beam acceleration (normal-conducting)
- Accelerating gradient: 100 MV/m
- 0.5 ns bunch spacing $\Rightarrow$ more pile-up in the detector

# Traditional particle acceleration

1. **Static acceleration:**
   - Static voltage between an anode and a cathode
   - Used in CRT TVs, and also in modern $e^-$ sources and in klystrons
   - Problem: Electric breakdown at 3 MV/m in air

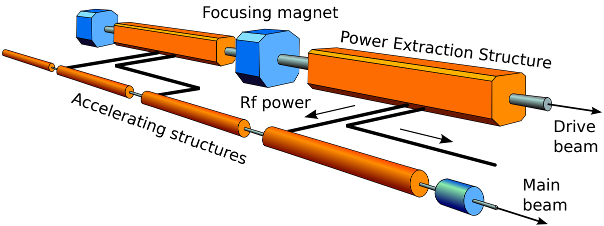


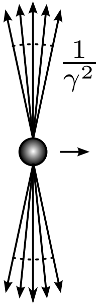

2. **Standing/travelling electric waves (radio frequency):**
   - Particles can 'ride' on the wave
   - Necessary to use particle bunches
   - Typical acceleration: ∼20–35 MV/m (more is possible, but this is inefficient)
   - Room-temperature or superconducting


# 'New' concept: Two-beam acceleration

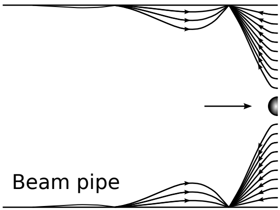
- Instead of one beam in each direction, we use two beams.
- Electromagnetic energy is extracted from a low energy, high current drive beam, which loses kinetic energy (it is decelerated). This is done by a special microwave structure called PETS (Power Extraction and Transfer Structure).
- The energy is transferred to a high energy, low current main beam for acceleration.
- This allows a quite efficient acceleration at 100 MV/m.
- We can in principle have an even higher acceleration, but are limited by the electric breakdown rate in the structures. For luminosity reasons this must be lower than $10^{-7}$ per structure.



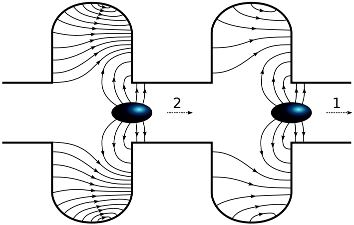


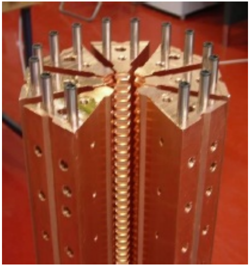

A relativistic particle has a length contracted field. Close to the speed of light it will have a 'pancake' field.

When going through a beam pipe that is not perfectly conducting, the particle and the image current will feel the impedance of the beam pipe and produce a wake field. The field vanishes ahead of the beam due to causality.



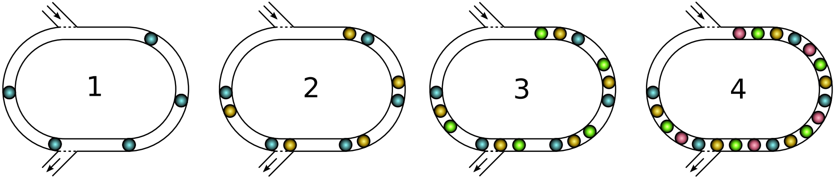
- If particle bunches go through a cavity, some of the wake field will be left behind and can ring for a short time.
- By sending bunches at the correct frequency and by including several cavities, we can build up a large field constructively.
- The energy in the field travels with a group velocity of 0.5$c$, and is extracted in waveguides at the end of the structure.
- To maximize the produced field, we need a high bunch charge and a short bunch spacing.
- In the CLIC design, the instantaneous field depends on the wakefield from 11 bunches, and corresponds to 135 MW rf power.

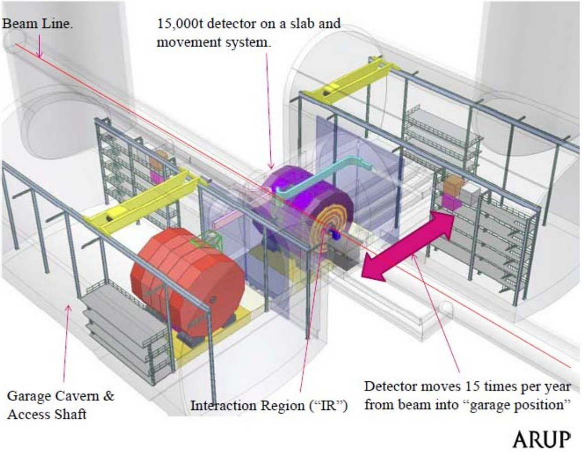


# Bunch combination

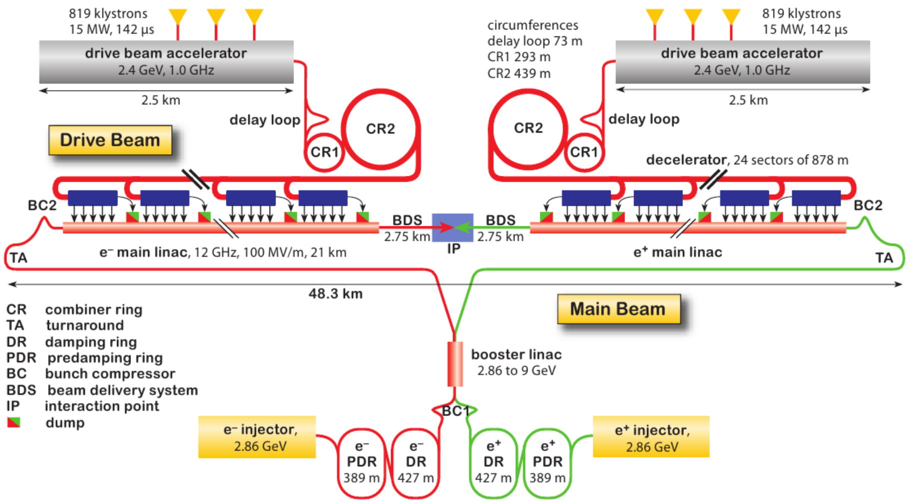
- The power produced in a PETS strongly depends on the beam current, as $P \propto I^2$.
- Therefore we combine bunches to create an intense beam
  - 1 delay loop combines bunches by a factor 2
  - 1 combiner ring combines bunches by a factor 3
  - 1 combiner ring combines bunches by a factor 4
- In total we have a factor $2 \times 3 \times 4 = 24$ bunch combination



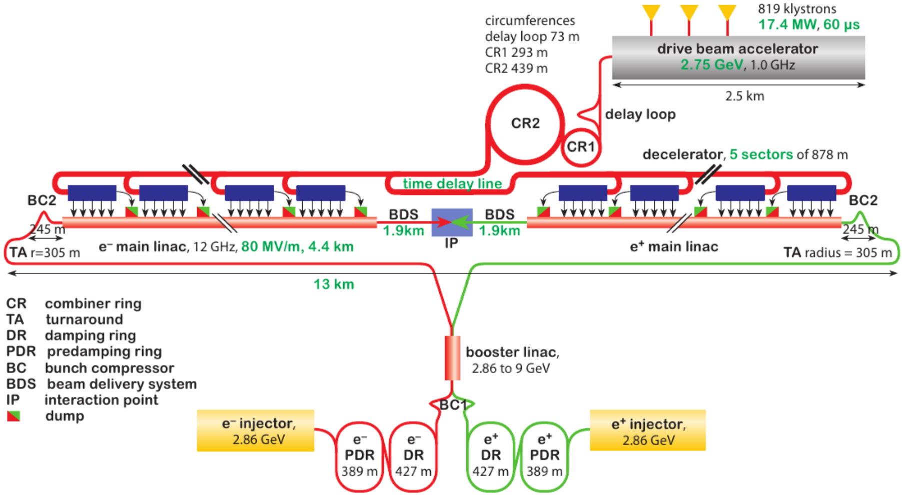



- Two general purpose detectors that can be exchanged
- ILD and CLIC_ILD: Large calorimeters optimized for jet reconstruction (comparable to CMS)
- SiD and CLIC_SiD: Compact, cost-optimized detector with a higher magnetic field

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



# CLIC layout at $\sqrt{s} = 500$ GeV

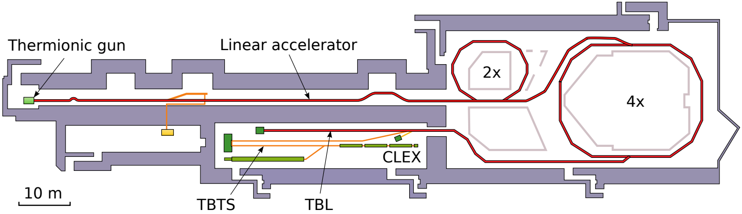



| | |
|---|---|
| CR | combiner ring |
| TA | turnaround |
| DR | damping ring |
| PDR | predamping ring |
| BC | bunch compressor |
| BDS | beam delivery system |
| IP | interaction point |
| ■ | dump |

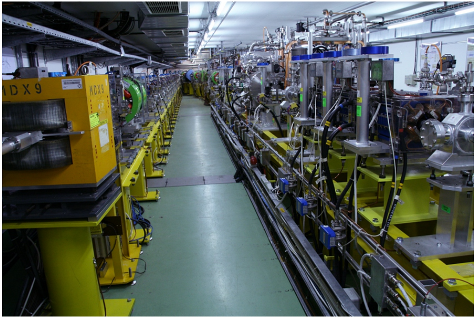
# CLIC Test Facility 3 (CTF3) – Concept

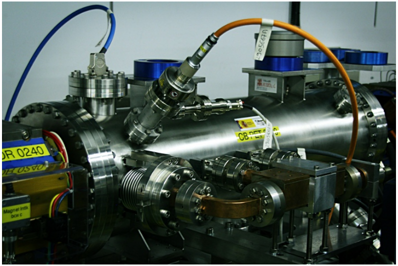
**Verification and demonstration of CLIC technology**

- 1 *delay loop* – factor 2 bunch combination
- 1 *combiner ring* – factor 4 bunch combination
- Testing of *Power Extraction and Transfer Structures*
- Two-beam acceleration and testing of accelerating structures in the Two-Beam Test Stand
- High energy extraction/deceleration in the Test Beam Line

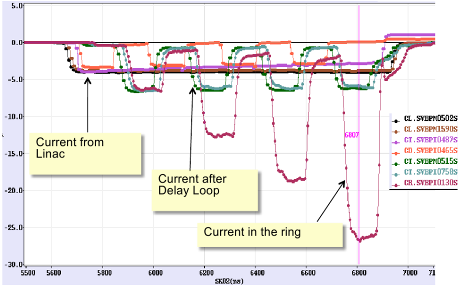


# CLIC Test Facility 3 (CTF3) – Pictures

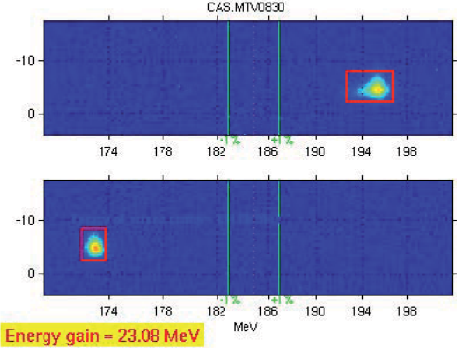




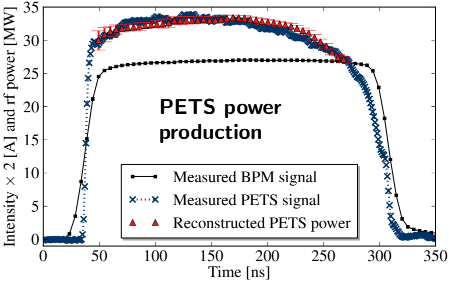
**Factor 8 bunch combination**

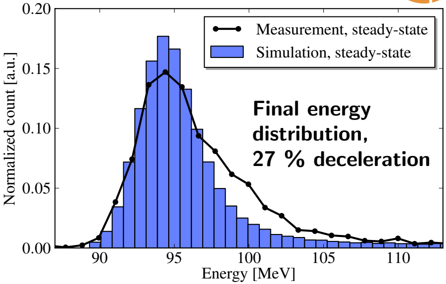


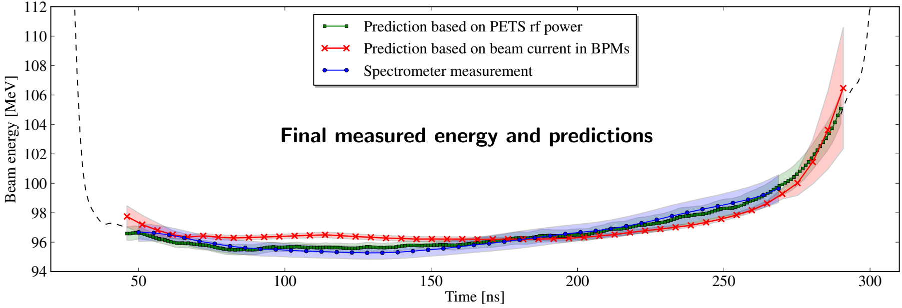

**Two-beam acceleration – 106 MV/m**



# CLIC Test Facility 3 (CTF3) – Results (ii)



Thank you!