Main sources: talks by Shin Michizono, Akira Yamamoto, Phil Allport – and my old slides from various talks also full of “extractions” from many LC colleagues
More information for most topics will be given in your lectures the next two weeks
Accelerators
  - Luminosity, energy, quantum numbers, physics goals

Detectors
  - Efficiency, speed, granularity, resolution, physics goals

Trigger/DAQ
  - Efficiency, compression, through-put, physics models

Offline analysis
  - Signal and background, physics studies

The primary factors for a successful experiment are the accelerator and detector trigger system, and losses there are not recoverable.

At all steps above simulations and real data are used.
Particle type to accelerate

Not so many choices:
- Need stable charges particles: protons, electrons, (muons), ions – most used: electrons and protons
- Secondary beams: photons, pions, kaons, neutrons, neutrinos, ..... 

Proton collisions: compound particles
- Mix of quarks, anti-quarks and gluons: variety of processes
- Parton energy spread
- QCD processes large background sources

Electron/positron collisions: elementary particles
- Collision process known
- Well defined energy
- Background from other physics limited

proton mass ≈ 2000

electron mass
“Unknowns”:
- Flavour structure
- Matter-antimatter
- Why is the Higgs so light
- Neutrino sector
- Forces merging?
- Gravity
- …
Limitations - synchrotron radiation

We want $E_{\text{cm}}$ as high as possible for new particle accelerators
Circular colliders $\Rightarrow$ synchrotron radiation loss:

$$P_s = \frac{e^2 c}{6\pi \varepsilon_0 (m_0 c^2)^4} \frac{E^4}{R^2}$$

For electrons a severe limitation, size and costs explode – go linear

Less of a problem with protons (size of ring driven by magnet technology but radiation losses also there becoming significant for the components)

There are other reasons why linear colliders are pursued:
- Scalable (lengthen or shorten) and upgradable with new technology
- Very linked the main invest-area in accelerator construction – light-sources/FELs
- Affordable covering (most of) the Standard Model precision physics
Outline:

- Generic elements and challenges of a Linear Colliders
- Focus on CLIC (380 GeV) and ILC (250 GeV) status
- Smaller Linear Accelerators for material characterization, medical applications, etc
- Key points
The critical steps (in next slides):

1) Create low emittance beams (sources, injector, damping rings, ring to main linac - RTML)
2) Acceleration in main linac (energy increase per length)
3) Supply energy as efficient as possible to beam (high power at 1, 1.3 and 12 GHz)
4) Nano-beams: Squeeze the beam (Beam Delivery System - BDS), i.e. reduce $\beta$

\[ \mathcal{L} = H_D \frac{N^2}{4\pi \sigma_x \sigma_y} n_b f \]

\[ \sigma_{x,y} = \sqrt{\frac{\beta_{x,y} \epsilon_{x,y}}{\gamma}} \]
The damping rings reduce the phase space (emittance $\varepsilon_{x,y}$) of the beam – wigglers to stimulate energy losses (SR)

Light-sources need similar beams (picture: ALBA)

The RTML (ring-to-main linac transport) reduces the bunch length
Maximize acceleration per meter

Below left: A high-gradient “warm” accelerating structure, 12 GHz for CLIC
Above: A superconducting 1.3 GHz Rf structure for ILC

Limitations by electrical and magnetic fields on surfaces, field emission and heating (key technology optimisation)

Different pulse lengths and bunch structure (ILC and CLIC):

<table>
<thead>
<tr>
<th>Bunches per pulse</th>
<th>$n_b$</th>
<th>1312</th>
<th>312</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between bunches</td>
<td>$\Delta z$ [mm]</td>
<td>554</td>
<td>0.5</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>$f_r$ [Hz]</td>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>

... has ramifications for acc. size, beam dynamics, instrumentation, detectors, etc, ....

However, physics, cost, power, luminosities remarkably similar in the end (for similar collision energies)
Example: CLIC 20 MW L-band (1 GHz) Multi-beam pulsed klystron.

- Modulator ($\eta=0.9$)
  - Energy storage: 150 kW + 88 kW
  - Switch
  - HV transformer

- Cathode

- RF circuit ($\eta=0.7$)
  - Collector 60 kW
  - Solenoid 4 kW

- Depressed collector ($\eta=0.5$)

- Lower (<60kV) voltage:
  - 40 mini-cathodes
  - No oil tank (cost)
  - Shorter tube (cost)
  - Faster switching (efficiency/cost)

- Permanenct Magnets:
  - No power consumption
  - Potential cost reduction
  - Vs. SC solenoid:
    - More expensive solution

- New klystron RF circuit ($\eta=0.8$)
  (+) Reduced Collector dissipation (16 kW)

- Power from grid: 200 MW
  - Gated mini-cathode:
    - No switches (cost)
    - Modulator efficiency $\approx 1.0$
    (+) Improved stability

$\eta_{Total} = 0.62$

$\eta_{Total} = 0.9$
Nano-beams

Very small beams (example from ILC 500 GeV and CLIC 3 TeV)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol [unit]</th>
<th>ILC</th>
<th>CLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre of mass energy</td>
<td>$E_{\text{cm}}$ [GeV]</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L$ [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]</td>
<td>1.8</td>
<td>6</td>
</tr>
<tr>
<td>Luminosity in peak</td>
<td>$L_{0.01}$ [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Gradient</td>
<td>$G$ [MV/m]</td>
<td>31.5</td>
<td>100</td>
</tr>
<tr>
<td>Particles per bunch</td>
<td>$N$ [$10^9$]</td>
<td>20</td>
<td>3.72</td>
</tr>
<tr>
<td>Bunch length</td>
<td>$\sigma_z$ [$\mu$m]</td>
<td>300</td>
<td>44</td>
</tr>
<tr>
<td>Collision beam size</td>
<td>$\sigma_{x,y}$ [nm/nm]</td>
<td>474/5.9</td>
<td>40/1</td>
</tr>
<tr>
<td>Vertical emittance</td>
<td>$\varepsilon_{x,y}$ [nm]</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Bunches per pulse</td>
<td>$n_b$</td>
<td>1312</td>
<td>312</td>
</tr>
<tr>
<td>Distance between bunches</td>
<td>$\Delta z$ [mm]</td>
<td>554</td>
<td>0.5</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>$f_r$ [Hz]</td>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>

The CLIC strategy:
- Align components (10$\mu$m over 200m)
- Control/damp vibrations (from ground to accelerator)
- Measure beams well – allow to steer beam and optimize positions
- Algorithms for measurements, beam and component optimization, feedbacks
- Tests in small accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)
To develop nano-beam tech.
• Key for the luminosity
• 6 nm beam at IP (ILC)

**ATF2: Final Focus Test Beamline**
Goal 1: establish “small beam” tech.
Goal 2: stabilize “beam position”

1.3 GeV S-band Linac (~70 m)

Damping Ring (~140 m)
Low emittance electron beam

**Progress in FF Beam Size and Stability at ATF2**

<table>
<thead>
<tr>
<th>Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ATF2 Goal: 37 nm → ILC 6 nm</td>
</tr>
<tr>
<td>• Achieved 41 nm (2016)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal 2: Develop a few nm position stabilization for the ILC collision by feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>• FB latency 133 nsec achieved (target: &lt; 300 nsec)</td>
</tr>
<tr>
<td>• Position jitter at IP: 410 → 67 nm (2015) (limited by the BPM resolution)</td>
</tr>
</tbody>
</table>

**Layout of ILC**

Nano-beams
ILC Candidate Location: Kitakami, Tohoku
### ILC Layout

![ILC Layout Diagram](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.M. Energy</td>
<td>500 GeV</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$1.8 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>Beam Rep. rate</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>0.73 ms</td>
</tr>
<tr>
<td>Average current</td>
<td>5.8 mA (in pulse)</td>
</tr>
<tr>
<td>E gradient in SCRF acc. cavity</td>
<td>31.5 MV/m +/- 20% $Q_0 = 1E10$</td>
</tr>
</tbody>
</table>
ILC: SCRF

- **Ultra-high** $Q_0 \left(10^{10}\right)$
  - Almost zero power (heat) in cavity walls (in SC RF the main efficiency issues related to fill factors and cryogenics)
- Standing wave cavities with low peak power requirements
- Long beam pulse (~1 ms) - favorable for feed-backs within the pulse train

**Low impedance**
- beam generates low “wakefields”
- relatively large structures (1.3 GHz)
<table>
<thead>
<tr>
<th>Project</th>
<th>Notes</th>
<th># cavities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEBAF-JLAB (US)</td>
<td>Upgrade 6.5 GeV =&gt; 12 GeV electrons</td>
<td>80</td>
</tr>
<tr>
<td>XFEL-Hamburg (EU)</td>
<td>18 GeV electrons – for Xray Free Electron Laser – Pulsed</td>
<td>840</td>
</tr>
<tr>
<td>LCLS-II – SLAC (US)</td>
<td>4 GeV electrons – CW XFEL (Xray Free Electron Laser)</td>
<td>300</td>
</tr>
<tr>
<td>SPIRAL-II (France)</td>
<td>30 MeV, 5 mA protons -&gt; Heavy Ion</td>
<td>28</td>
</tr>
<tr>
<td>FRIB – MSU 8US)</td>
<td>500 kW, heavy ion beams for nuclear astrophys</td>
<td>340</td>
</tr>
<tr>
<td>ESS (Sweden)</td>
<td>1 – 2 GeV, 5 MW Neutron Source ESS - pulsed</td>
<td>150</td>
</tr>
<tr>
<td>PIP-II–Fermilab (US)</td>
<td>High Intensity Proton Linac for Neutrino Beams</td>
<td>115</td>
</tr>
<tr>
<td>ADS- (China, India)</td>
<td>R&amp;D for accelerator drive system</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>Globally Int. Effort</td>
<td></td>
<td>&gt; 2000</td>
</tr>
</tbody>
</table>
Worldwide SRF Collaboration

European XFEL

ILC-SRF technology

Asia,
PAPS@IHEP  CFF/STF@KEK

Americas,  LCLS-II

A. Yamamoto, 171106
European XFEL, SRF Linac Completed

**Progress:**
- **2013:** Construction started
- **2016:** E-XFEL Linac completion
- **2017:** E-XFEL beam start

1.3 GHz / 23.6 MV/m
800+4 SRF acc. Cavities
100+3 Cryo-Modules (CM)
: ~1/10 scale to ILC-ML

**European XFEL: SRF Cavity Performance**

After Retreatment:

- **E-useable:** \(29.8 \pm 5.1 \text{ [MV/m]}\)
- **Q₀:** >10% (47/420, RI) cavities exceeding 40 MV/m
## ILC Parameters demonstrated

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Parameter</th>
<th>Unit</th>
<th>Demonstrated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nano-bam:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATF-FF equiv. beam size (y)</td>
<td>37 (reaching 41)</td>
<td>nm</td>
<td>KEK-ATF</td>
</tr>
<tr>
<td>ILC-FF beam size (y)</td>
<td>5.9 (correspond. 7)</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td><strong>SRF:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average accelerating gradient</td>
<td>31.5 (±20%)</td>
<td>MV/m</td>
<td>DESY, FNAL, JLab, Cornell, KEK,</td>
</tr>
<tr>
<td>Cavity $Q_0$</td>
<td>10$^{10}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Cavity qualification gradient)</td>
<td>35 (±20%)</td>
<td>MV/m</td>
<td></td>
</tr>
<tr>
<td>Beam current</td>
<td>5.8</td>
<td>mA</td>
<td>DESY-FLASH, KEK- STF</td>
</tr>
<tr>
<td>Number of bunches per pulse</td>
<td>1312</td>
<td></td>
<td>DESY</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>3.2</td>
<td>nC</td>
<td></td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>554</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Beam pulse length</td>
<td>730</td>
<td>ms</td>
<td>DESY, KEK</td>
</tr>
<tr>
<td>RF pulse length (incl. fill time)</td>
<td>1.65</td>
<td>ms</td>
<td>DESY, KEK, FNAL</td>
</tr>
<tr>
<td>Efficiency (RF$\rightarrow$beam)</td>
<td>0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>5</td>
<td>Hz</td>
<td>DESY, KEK</td>
</tr>
</tbody>
</table>
ILC SC RF global integration model

Industry: manufacturing components w/worldwide contracts

Hub-lab: regionally hosting integration & Test

ILC Host/Hub-Lab

Hub-Lab

Industry worldwide
ILC since the TDR in 2012-13: Technical focus and changes

Site specific studies

Technical developments for most accelerator systems - high Q improvements for example

E-XFEL at DESY successfully constructed and put into operation – a key technology demonstration

Recent proposal to start with an initial energy of 250 GeV (physics impact report) – key issues:
- Higgs precision depends significantly on HiLumi performance and theory assumptions (link)
- Below ttbar threshold
- Reduced search capabilities

Nevertheless, provides impressive precision, and remains upgradable.

TDR costs of ~8 BILCU for 500 GeV (ILCU = 2012 US$ estimate used in the TDR) can be reduced by up to ~40%

---

**Options for ILC Staging at 250GeV**

<table>
<thead>
<tr>
<th>Options</th>
<th>Gradient [MV/m]</th>
<th>ECM [GeV]</th>
<th>Total ECM Margin</th>
<th>n</th>
<th>Space margin</th>
<th>Reserved tunnel</th>
<th>Total tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDR update</td>
<td>31.5</td>
<td>500</td>
<td>2%</td>
<td>10</td>
<td>1,473 m</td>
<td>0 m</td>
<td>33.5 km</td>
</tr>
<tr>
<td>Option A</td>
<td>-</td>
<td>250</td>
<td>6%</td>
<td>6</td>
<td>583 m</td>
<td>0 m</td>
<td>20.5 km</td>
</tr>
<tr>
<td>Option B</td>
<td>-</td>
<td>6 &amp; 8</td>
<td>6 &amp; 10</td>
<td>6</td>
<td>0 m</td>
<td>20.5 km</td>
<td></td>
</tr>
<tr>
<td>Option C</td>
<td>-</td>
<td>35</td>
<td>6%</td>
<td>6 &amp; 8</td>
<td>1,049 m</td>
<td>3,238 m</td>
<td>27 km</td>
</tr>
<tr>
<td>Option A'</td>
<td>-</td>
<td>6 &amp; 10</td>
<td>3,477 m</td>
<td>33.5 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option B'</td>
<td>-</td>
<td>6 &amp; 10</td>
<td>3,477 m</td>
<td>33.5 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option C'</td>
<td>-</td>
<td>6 &amp; 10</td>
<td>3,477 m</td>
<td>33.5 km</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Status and Prospect for ILC

We are here, in 2018

(~2+) 4 year (Pre-Preparation and) Preparation Phase

ICFA
ILCSC
Work Sharing
GDE/RD
RDR/DBD Activities
Site-dependent design

ILC Organization (ILC Lab.)
Construction
Operation
(9 year)

European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire
CLIC layout, power generation

Drive-beam (low energy, high intensity, long pulses) created by klystrons

Drive beam time structure - initial

- 240 ns
- 140 s train length - 24 sub-pulses
- 4.2 A - 2.4 GeV - 60 cm between bunches

Drive beam time structure - final

- 240 ns
- 5.8 s
- 24 pulses - 101 A - 2.5 cm between bunches
First stage energy \( \sim 380 \) GeV

Let us look at three challenges:

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- \( \sim 100 \) MV/m gradient in main-beam cavities
CLIC Test Facility (CTF3)
Status

- Produced high-current drive beam bunched at 12 GHz

Arrival time stabilised to 50 fs
• Demonstrated two-beam acceleration

31 MeV = 145 MV/m
Achieved 100 MV/m gradient in main-beam RF cavities
Acc. Structures TD24&26 – new baseline optimised and alternatives for manufacturing and cost

Baseline: Machines disks, damping structures, bonding steps

3 TeV structure CLIC G* (optimised)

Rectangular (manufacturing)

SwissFEL Assembly (brazing)

Halves: SLAC/CERN
- 104 x 2m-long C-band structures (beam $\rightarrow$ 6 GeV @ 100 Hz)
- Similar um-level tolerances
- Length ~ 800 CLIC structures
Industrial considerations (example)

- Bodycote (FR)
- Reuter (DE)
- TMD (UK)
- SWISSto12 (CH)
- LT-Ultra (DE)
- Concept Laser (DE)
- INITIAL (FR)
- Protoshop (DE)
- VDL (NL)
- Yvon Boyer (FR)
- DMP (ES)
- Morikawa (JP)
- KERN (DE)
- Thermocompact (FR)
- BACMI (FR)
- Multivalent (NL)
- CINEL (IT)
- VDL (NL)
- BACMI (FR)
- CECOM (IT)
- Reuter (DE)
- Nihon (JP)
- COMEB (IT)
- Viztrotech (KR)
- Scandinova (SE)
- Jema (ES)
- Picatron (CH)
- Thales (FR)
- CPI (US)
- Toshiba (JP)
A cost of ~6 BCHF and power ~200 MW are “reasonable” values
→ Continue work on modules, RF and CE for costs; for power RF and magnets
CLIC roadmap

2013 - 2019 Development Phase
Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators.

2020 - 2025 Preparation Phase
Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation.

2026 - 2034 Construction Phase
Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning.

2019 - 2020 Decisions
Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC).

2025 Construction Start
Ready for construction; start of excavations.

2035 First Beams
Getting ready for data taking by the time the LHC programme reaches completion.
Technical activities – examples

Technical Developments are motivated by several possible reasons – and are now quite mature:

- Key components for system-tests (example magnets, instrumentation, modules)
- Critical for machine performance (example alignment, stabilization, damping ring studies)
- Aimed at cost or power reduction (example magnets, klystrons, modules)
Information about some relevant suppliers and subcontractors participating to prototypes procurement for the CLIC Magnets R&D phase

Note: majority of coils and of other components manufacturing, magnet assembly, was done by CERN apart for the DBQ magnets (EM and PM versions).

1) Main Beam Quadrupoles. **4 prototypes** procured: 3 Type1 (the shorter), 1 Type4 (the longer)

**Relevant procurements:**
- Coils: TESLA Engineering LTD, Storrington, West Sussex - UK
- High Precision quadrants machining:
  - DMP 20850 Mendario, Gipuzkoa - ES

2) Drive Beam Quadrupoles (EM version): **8 prototypes** procured:

**Relevant manufacturers:**
- Complete manufacturing:
  - Danfysik A/S 2630 Taastrup, DK
- High Precision Quadrants machining:
  - DMP 20850 Mendario, Gipuzkoa - ES
- PM blocks:
  - EMPEROR International GmbH, Hanau - D
  - VDL Groep BV, Eindhoven - NL
  - Röttgers Værktøj A/S Odense - DK

3) Drive Beam Quadrupoles (PM version): **2 prototypes** procured by Daresbury Laboratory

4) Main Beam Steering Dipoles: **2 prototypes** procured

5) Final Focus Quadrupole QD0: **1 prototype** procured

**Relevant manufacturers:**
- PM blocks:
  - EMPEROR International GmbH, Hanau - D
  - VDL Groep BV, Eindhoven - NL
  - Röttgers Værktøj A/S Odense - DK

6) Final Focus Sextupoles SD0: (**1 prototype procurement on-going**)

**Relevant manufacturers:**
- Permendur and PM blocks procurement:
  - VDL Groep BV, Eindhoven - NL
  - Röttgers Værktøj A/S Odense - DK

7) Octupoles for ATF facility at KEK, Japan: **2 magnets** procured

**Relevant manufacturers:**
- Coils: S.E.F Sarl, Labège - F
- Iron Yokes EDM Machining:
  - Röttgers Værktøj A/S Odense - DK
Towards TeV beams with new technology?

A possible witness beams:
Electrons: $10^{10}$ particles @ 1 TeV
~few kJ

Existing driver beams options:
Lasers: up to 40 J/pulse
Electron driver: up to 60 J/bunch
Proton driver: SPS 19 kJ/bunch, LHC 300 kJ/bunch

1.7 GeV energy gain in 30 cm of pre-ionized Li vapor plasma.
2% energy spread
Up to 30% wake-to-bunch energy transfer efficiency (mean 18%).

While GeV acceleration in plasmas has been demonstrated for with both lasers and electron beams, reaching TeV scales requires staging of many drivers and plasma cells. Challenging.

Current focus on “small scale” applications – for LCs a long way to go:
Electrons and Positrons, staging, energy efficiency, suitable beam-parameters and luminosity
However – disruptive technologies so (always) very important to pursue (and cost in this case likely less)

Mostly from E.Adli
Free electron lasers and Linear Colliders

User community in many fields of science (LCLS 2013)

**LCLS Facts**
- 594 scientists conducted experiments in 2013
- 4,580 operating hours in 2013
- 277 publications since LCLS began in 2009
- 15 collaborators, on average, per experiment proposal
- 6 experimental stations

LCLS I and II, SACLA, E-XFEL, SwissFEL ... many more (from soft to hard X-ray)
Ex. links LCs and FELs for CLIC (ILC shown already)

<table>
<thead>
<tr>
<th>Location</th>
<th>Facility Type</th>
<th>Power</th>
<th>Status or Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN</td>
<td>XBox-1 test stand</td>
<td>50 MW</td>
<td>Operational, connection to CLEAR planned</td>
</tr>
<tr>
<td></td>
<td>XBox-2 test stand</td>
<td>50 MW</td>
<td>Operational</td>
</tr>
<tr>
<td></td>
<td>XBox-3 test stand</td>
<td>4x6 MW</td>
<td>Operational</td>
</tr>
<tr>
<td>Trieste</td>
<td>Linearizer for Fermi</td>
<td>50 MW</td>
<td>Operational</td>
</tr>
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<td>S-band test stand</td>
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Eindhoven University led SMART*LIGHT Compton Source
Two linear collider projects are being pursued (ILC and CLIC) – with large collaborative effort.

- Both are mature, have a clear physics case, are (each) affordable – and it is likely one will be built.
- Within 1-2 year the landscape in Japan and Europe can be expected to be clearer.

The developments (design, technical developments, tests of single elements or systems, industrial (pre)-productions – and also civil engineering, conventional systems, power and cost optimizations, are done by international teams/collaborations, usually led a major lab with special interest in the project but with world-wide participation since the technology developments and knowledge are transferable to other and/or local projects.

**Linear accelerator** technology and development are currently strongly taking part outside particle physics – very beneficial in both directions and easy to show societal impact

Any linear collider facility is likely to host many future machines. It can be extended – and/or equipped with new technology in the future ... but still a long way to go

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