ILD, a Detector for the
International Linear Collider

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On behalf of the ILD Concept Group
July 31, 2020

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**International Linear Collider**

**Tohoku (Northeast), Japan**

"Higgs factory": 250 GeV

Future upgrades: 1 TeV and beyond

Energy extendibility:

- P(e⁻) = 80% ; P(e⁺) = 30% (nominal)

**Physics: Higgs, EW, Top, BSM**

**#1 Higgs (Jul 31)**
M. Peskin: Expectations for precision tests of the Standard Model at the ILC
D. Jeans: Precision Higgs physics at the ILC and its impact on detector design
J. Tian: A new way of understanding the role of each measurement in SMEFT

**#3 BSM (Jul 31)**
M. Núñez Pardo de Vera: ILC as a SUSY discovery and precision instrument

**#4 Top/EW (Jul 28, Jul 31)**
G. Wilson: Improving electroweak precision observables and TGCs with the ILD
A. Irles: Heavy quark production in high energy electron positron collisions

**Polarized beams**: 80% (e⁻) ; 30% (e⁺) (nominal)

**#11 Accelerators (Jul 30)**
J. List: Polarized beams at future e+e- colliders
**Japanese Government: “Interest in the ILC project”**
Mar. 7, 2019: Ministry of Education, Culture, Sports, Science and Technology (MEXT) “will continue to discuss the ILC project with other governments while having an interest in the ILC project” (update on Feb. 20, 2020)

**European Strategy for Particle Physics Update (Jun. 2020)**
“The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.”

**Support from the United States**
Jim Siegrist (DOE/HEP), HEPAP Meeting (Jul. 9, 2020):
- Current support from the U.S. to enable Japan move forward with the ILC
- To strengthen the long-standing U.S.-Japan cooperation in science and technology, concerted effort during last 12-15 months by the U.S. Government — DOE, U.S. State Department, The White House Office of Science & Technology Policy, and the National Security Council — to support a Japanese initiative to move forward to the proposed ILC “Pre-Laboratory” phase of the project

**Proposed timeline for ILC project:**
- LCC: 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, ...
- LCB
- ILC Pre-Lab: 4 yrs
- ILC Laboratory (Construction): 10 yrs
- ILC Lab (Operation): 20+ yrs

ILC International Development Team expected to start Aug. 2020 (1-1.5 yr)

- Detector design should be ready around the start of ILC Laboratory.
ILD Concept Group

ILD: “International Large Detector”
Currently 64 institutes, 30 countries

ILD Executive Team (ILD-ET)
Spokesperson: Ties Behnke <Ties.Behnke@desy.de>
Deputy spokesperson: Kiyotomo Kawagoe
Physics coordinator: Keisuke Fujii (deputy Jenny List)
Technical coordinator: Claude Vallee (deputy Karsten Buesser)
Software/reconstruction coordinator: Frank Gaede (deputy Akiya Miyamoto)

Elected members of the ILD executive Team:
Alberto Ruiz, Yasuhiro Sugimoto, Henri Videau, Graham Wilson

ILD Institute Assembly
Each member institute is represented by one vote in the ILD institute assembly.
Chair: Marc Winter <marc.winter@iphe.cnrs.fr>
If you are interested to join ILD please send a mail to the chair of the institute assembly and to the spokesperson.

ILD Meeting 2019 at KEK
ILD welcomes new people and new ideas!

ILD website:
https://www.ilcild.org

ILD Interim Design Report (IDR):
most recent comprehensive document about ILD (Mar. 2020)
ILD Subdetectors

**Tracking:**
- Vertex Detector (VTX)
- **Time Project Chamber (TPC)**
- Silicon Trackers (SIT, SET)
- Forward Tracking Disks (FTD)

**Calorimeters:**
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)
- Forward Calorimeters (FCAL)

All inside solenoidal coil of 3-4 T

General-purpose 4π detector

ILD Cost Fraction (IDR-L, 2020)

Total 379 M€
ILD Design Goals

Features of ILC: low backgrounds, low radiation, low collision rate
These allow us to pursue more aggressive detector designs:

**Detector Requirements**

- Impact parameter resolution
  \[ \sigma(d_0) < 5 \times 10^{-3} / (p[\text{GeV}] \sin^{3/2}\theta) \mu\text{m} \]
- Transverse momentum resolution
  \[ \sigma(1/p_T) = 2 \times 10^{-5} \text{ GeV}^{-1} \oplus 1 \times 10^{-3} / (p_T \sin^{1/2}\theta) \]
- Jet energy resolution
  3-4% (around \( E_{\text{jet}} \sim 100 \text{ GeV} \))
- Hermeticity
  \( \theta_{\text{min}} = 5 \text{ mrad} \)

**Physics Studies**

- Total \( \sigma(e^+e^- \rightarrow ZH) \)
- \( H \rightarrow bb, cc, \tau\tau \)
- \( Z/W/H \rightarrow jj; H \rightarrow \text{invisible} \)
- \( H \rightarrow \text{invisible}; BSM \)

ILD is optimized around **particle flow**:

- Highly granular calorimeters
- Low-mass trackers
- Software reconstruction
- Separation of clusters at particle level

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**Physics Studies**

- **Higgs recoil** against \( Z \rightarrow \mu\mu \)
- **p_T resolution**
- **dijet mass** \( \nu\nu WW & \nu\nu ZZ \)
- **Bhabha rejection** vs. polar angle coverage
  - [PRD 101, 075053 (2020)]
  - [arXiv:2003.01116]
Impact of Bunch Structure on Detector Design

ILC 250 Bunch Structure

- 200 ms
- ~1 ms
- ~0.5 μs
- 1312 bunches

→ Suggests “power pulsing” (5-10 Hz) of subdetectors with a duty cycle of ~a few %

Power Pulsing

ON OFF ON OFF ...

Being studied for Vertex, TPC, ECAL, HCAL, …

e.g.) Vertex: Power consumption expected to be reduced by a factor ~20

Also: implications for readout and cooling strategies.
- Trigger-less readout of the detector
- Per-bunch offline processing
- Minimizes cooling needs and associated material budget
Vertex Detector

- Final subdetector to be installed, R&D to continue until ~2030
- 3 double layers, $r_{\text{min}}=16$ mm, 3 $\mu$m point resolution
- Main challenges: beam backgrounds, power consumption, material budget (0.2-0.3% $X_0$ per layer)
- Technology options: CPS, FPCCD, DEPFET

**PLUME-2:** material budget
- Cu wire: 0.42% $X_0$
- Al wire: 0.35% $X_0$

**BELLE II beam commissioning with PLUME CMOS**

**CMOS pixel development path**

<table>
<thead>
<tr>
<th>DETECTOR:</th>
<th>STAR-PXL (ULTIMATE)</th>
<th>ALICE-ITS (ALPIDE)</th>
<th>CBM-MVD (MIMOSIS)</th>
<th>ILD-VXD (PSIRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology (AMS):</td>
<td>0.35 $\mu$m</td>
<td>0.18 $\mu$m</td>
<td>0.18 $\mu$m</td>
<td>&lt; 0.18 $\mu$m</td>
</tr>
<tr>
<td>Pixel size ($\mu$m$^2$):</td>
<td>20.7 x 20.7</td>
<td>27 x 29</td>
<td>22 x 33</td>
<td>22 x 22 or 18 x 18</td>
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<tr>
<td>Readout mode:</td>
<td>rolling shutter</td>
<td>data driven</td>
<td>data driven</td>
<td>data driven</td>
</tr>
<tr>
<td>Time resolution ($\mu$s):</td>
<td>135</td>
<td>5-10</td>
<td>5</td>
<td>1-4</td>
</tr>
<tr>
<td>Power (mW/cm$^2$):</td>
<td>150</td>
<td>35</td>
<td>200</td>
<td>50-100</td>
</tr>
<tr>
<td>Material ($X_0$/layer):</td>
<td>0.39%</td>
<td>0.3%</td>
<td>-</td>
<td>0.15%</td>
</tr>
</tbody>
</table>

**FPCCD thinner wafer**

60mm x 9.7mm x 50$\mu$m
Time Projection Chamber

- ILD uses a Time Projection Chamber (TPC) as the central tracker
- Drift time of ionized electrons $\rightarrow$ longitudinal position
- Gaseous detector: low material budget (~0.05 $X_0$ barrel region)
- Particle identification with $dE/dx$ (next page)
- Readout options: GEM, Micromegas, pixel
- Field distortion due to ion backflow mitigated using gating device to collect positive ions in-between bunch trains.

Test beam data

Tracker mass $\theta$ / degrees

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Particle Identification

TPC dE/dx only:

Combine dE/dx with ECAL time-of-flight (100ps):

Proof of concept.  
100 ps needs to be demonstrated in test beam prototype.

$A_{FB}(b)$ from $\text{e}^+\text{e}^- \rightarrow \text{bb}$ @ 250 GeV  
Vertex charge reconstruction corrected using Kaon ID and detector acceptance:

$#4 \text{Top/EW (Jul 31)}$
A. Irles: Heavy quark production in high energy electron positron collisions

$\rightarrow$ Particle identification capabilities offer unique physics opportunities
**ECAL**

V. Boudry: “Implementation of large imaging calorimeters”

Silicon tiles (5x5mm²)

or Scintillator strips (5x45mm²)

with Tungsten absorber

Ultra-granular calorimeter:

10-100 million readout channels

**HCAL**

W. Ootani: “Exploring the structure of hadronic showers and the hadronic energy reconstruction with highly granular calorimeters”

Scintillator tile (3x3 cm²)

or Gas RPC (1x1 cm²)

with Steel absorber

Highly granular calorimeter
Forward Calorimeters

LumiCal prototype (DESY)

M. Borysova: Development and performance of a compact LumiCal prototype calorimeter for future linear collider experiments

BeamCal simulation / reconstruction

energy deposition integrated over 1 bunch crossing

erm Calorimetric hermeticity down to 6 mrad

Hermeticity and BSM

- Hermeticity crucial for missing momentum reconstruction
- Bhabha, $e\gamma$, $\gamma\gamma$ processes can be major backgrounds to BSM searches with missing

Example: Mono-photon WIMP search

Bhabha vs. Hermeticity [PRD 101, 075053 (2020)]

→ Every mrad coverage counts for Bhabha rejection
Summary and Outlook

• ILC is a proposed Higgs factory with energy extendibility of 1 TeV and beyond.

• ILD is optimized around particle flow, with highly granular calorimeters, low mass trackers, and software reconstruction.

• Lots of efforts made for detector R&D, but there are still many opportunities and open questions:
  ➢ Need detailed design for many subdetectors
  ➢ Use of timing information
  ➢ Calibration/alignment
  ➢ Reconstruction software and physics studies
  ➢ New technologies!

• ILD welcomes new people and new ideas!