International Large Detector for the International Linear Collider

Jean-Claude Brient
Laboratoire Leprince-Ringuet
CNRS- IP Paris

on behalf of ILD collaboration
There is now a large consensus for an e+e- machine (Higgs factory) as the next particles large collider

- **ILC (250)** is an e+e- machine for the detailed study of EW symmetry breaking … W, Z, Higgs … e+e- → WW, ZZ, ZH.

- Following machine experts, the design of this machine is well advanced and it could be ready for construction within few years.

- **WITH MODEL INDEPENDENT** measurement Higgs coupling to Z e+e- → ZH → ee,μμ +X (using **Missing Mass**…. Need **VERY PRECISE** tracker devices)

**HOWEVER**

<table>
<thead>
<tr>
<th>Z to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ℓ⁻</td>
<td>6%</td>
</tr>
<tr>
<td>qq (jets)</td>
<td>70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ν</td>
<td>32%</td>
</tr>
<tr>
<td>qq' (jets)</td>
<td>68%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H (close to SM) to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ℓ⁻</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>qq (jets), WW, ZZ</td>
<td>&gt;85%</td>
</tr>
</tbody>
</table>
There is now a large consensus for an e+e- machine (Higgs factory) as the next large particles collider

- **ILC (250)** is an e+e- machine for the detailed study of EW symmetry breaking … W, Z, Higgs … e+e- → WW, ZZ, ZH .

- Following machine experts, the design of this machine is well advanced and it could be ready for construction within few years

- **WITH MODEL INDEPENDENT** measurement Higgs coupling to Z e+e- → ZH → ee,μμ +X (using Missing Mass*…. Need VERY PRECISE tracker devices)

## HOWEVER

<table>
<thead>
<tr>
<th>Z to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ℓ⁻</td>
<td>6%</td>
</tr>
<tr>
<td>qq (jets)</td>
<td>70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ν</td>
<td>32%</td>
</tr>
<tr>
<td>qq’ (jets)</td>
<td>68%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H (close to SM) to</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ⁺ ℓ⁻</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>qq(jets) ,WW,ZZ</td>
<td>&gt;85%</td>
</tr>
</tbody>
</table>

Optimal use of luminosity needs to reconstruct and tag the bosons through their hadronic decays

Particle Flow Algorithm (PFA)

Imaging calorimetry

\[ M_{REC} = (\sqrt{s} - E_{ll})^2 - |P_{ll}|^2 \]

This conclusion has also been adopted by CLIC, FCCee and CEPC for at least one detector option
From G4 simulation, the expected performances are a convolution of the detector design and recons. software !!!
Detector design

From key requirements from physics: (GOALS of the design concept)

- **Tracking resolution**
  \[ \sigma(1/pt) = 2 \times 10^{-5} \text{ GeV}^{-1} \oplus 1 \times 10^{-3} / (\text{pt} \sin^{1/2}\theta) \]

- **vertexing** \((H \to bb/cc/\tau\tau)\)
  \[ \sigma(d0) < 5 \oplus 10 / (p[\text{GeV}] \sin^{3/2}\theta) \mu\text{m} \]

- **PFA capability**
  
  **jet energy resolution** 3-4%  
  \((H \to \text{invisible/bb/cc/}\tau\tau, \text{WW, ZZ tagging})\)

  **Tau as a polarimeter** (Higgs CP, search for \(Z'\), …)

- **hermeticity** \(\theta_{\text{min}} = 5 \text{ mrad} \) and no escape area  
  \((H \to \text{invis, BSM})\)

Consequences for the detector

- **low mass tracker:**
  - main device: **Time Projection Chamber** \((dE/dx !) \rightarrow V0 \) and tracks recons. efficiency in jet !!
  - add. silicon: eg VTX: 0.15% rad. length / layer)

- **high granularity calorimeters**
  optimised for particle flow  (Pattern recognition of hadronic, em showers)
What to do to go for such a detector

Design (G4 and Reconstruction)

Prototypes, tests beam, G4 based design

- Industrial design
- Costing
- Engineering
- Organization at the stage of pre-construction

We are here

PANDORA ARBOR

Color code
Well advanced
In progress
Not really started

CONSTRUCTION
Organisation, resp. sharing,
Risks mitigation, industrial constraints,
Final design, etc…
A large effort has been made on the organization in such a way that ILD is ready to be a real collaboration.

**ILD spokesperson**: Ties Behnke (DESY)
Deputy spokesperson: Kiyotomo Kawagoe (Kyushu Univ.)

Physics Coordinator: Keisuke Fujii (KEK)
Technical coordinator: Claude Vallée (DESY)
Software/recons: coordinator: Frank Gaede (DESY)

**ILD executive team**:  
Alberto Ruiz (Spain-Santander), Yasuhiro Sugimoto (Japan-KEK), Henri Videau (France-LLR), Graham Wilson (USA-Kansas)

**ILD institute assembly**:  
Chair: Marc Winter (IPHC Strasbourg)

---

**ILD technical convenors**

- **Technical Coordinator**: Claude Vallée  
  Deputy: Karsten Buesser

- **Central Design & Integration**
  - Karsten Buesser (DESY)  
  - Roman Poeschl (LAL)  
  - Toshiaki Tauchi (KEK)

- **Trigger & Data Acquisition**
  - Taikan Suehara (Kyushu)  
  - Matthew Wing (UCL)

- **Vertex**
  - Auguste Besson (IPHC)  
  - Akimasa Ishikawa (Tohoku)  
  - Marcel Vos (Valencia)

- **Tracker**
  - Paul Colas (IRFU)  
  - Akira Sugiyama (Saga)  
  - Ivan Vila (Santander)

- **Calorimeter**
  - Jean-Claude Brient (LLR)  
  - Imad Lakhtineh (IPNL)  
  - Wataru Ootani (Tokyo)

- **Very Fwd System**
  - Yan Benhammou (Tel Aviv)  
  - Sergey Schuwalow (DESY)

- **Iron Instrumentation**
  - Strahinja Lukic (Belgrade)  
  - Valeri Saveliev (IAM Moscow)

---

**Working Group boundaries**

- **Technical Coordination**
  - **Vertex**  
    - Vertex reconstruction and flavor tagging.
  - **Tracker**  
    - Charged track momentum measurement and identification.
  - **Calorimeter**  
    - Barrel+Endcap electromagnetic and hadronic calorimeters.
  - **Very Fwd System**  
    - Very forward calorimeters and beam monitors.
  - **Iron Instrumentation**  
    - Yoke instrumentation for muon tracking and calorimetry tail catching.

---

**SUBDETECTOR SOFTWARE CONTACTS**

- **Technical Coordination**
  - **Vertex**  
    - Marcel Vos (Valencia)
  - **Tracker**  
    - Si: Marcel Vos  
    - TPC: Oliver Schäfer (DESY)
  - **Calorimeter**
  - **Central Design & Integration**
  - **Trigger & Data Acquisition**
  - **Very Fwd System**
  - **Iron Instrumentation**

  - Daniel Jeans (Tokyo)
  - Bogdan Pawlik (Krakow)
  - Nicola d’Ascenzo (IAP Moskow/Huazhong)
Choices of technology

Magnet 3-4 T ("a la CMS")

VDET: pixel … CMOS, DEPFET, etc…

Trackers: TPC (GEM, micromegas, Pixels)
silicon pixels/strips

ECAL: silicon or scintillator – Tungsten –
Pixels: 5x5 mm² or 5x45 scint. strip
O(50M) channels → Stability, S/N, etc…

HCAL: Scint. Tile or gas RPC – Stainless steel
Pixels: 1x1 cm² (Gas RPC) or 3x3 cm² (Tile)
Constraints on the design

Material budget
Constraint from PFA

Mechanical constraint from geography

**Constraints on the design**

- Material budget
- Constraint from PFA

**Mechanical constraint from geography**

**Constraints on UGCAL**

- S/N in calorimetry
- Stability response
- Compactness

**Acceleration response spectrum**

- Earthquake peak: 2-6 Hz (maximum stresses)

**Maximum displacement:** 24.9 mm

**Smallest gap between ECAL rings along z:** 0.98 mm

**Smallest gap between ECAL module along phi:** 2.29 mm
Forward silicon tracker

Low angle devices

TPC

TRACKERS

![Forward silicon tracker image]

![Low angle devices image]

![TPC image]

![Graph image]
Ultra Granular ECAL

Silicon ECAL

Tungsten
Silicon diode
5x5 mm²
26-30 layers

costing

Scintillator strip ECAL

Tungsten
Scintillator strips- SiPM
45x5 mm²
26-30 layers

Test beam @DESY/CERN

MIP signal

Scintillator strips - SiPM
45x5 mm²
26-30 layers

Mip signal

EBU threshold

APS-DPF meeting - Boston July 2019
High Granular HCAL

Gas/RPC HCAL

- Mylar layer (50μ)
- PCB (1.2mm)
- PCB support (FR4 or polycarbonate)
- Readout pads (1cm x 1cm)
- Gas gap
- Mylar (175μ)
- Ceramic ball spacer (1.2mm)
- Cathode glass (1.1mm) + resistive coating
- Glass fiber frame (1.2mm)
- Anode glass (0.7mm) + resistive coating

Test beam @ CERN

1x1 cm²
Glass RPC
Stainless steel
Readout semi-digital

Tiles HCAL

3x3 cm²
SiPM
Stainless steel
Analog readout
45 layers

Robot for tiles HCAL construction
A HUGE EFFORT has to be made for the optimization of the detector, the reconstruction, the engineering, the relations with industry, the cost…
More precisely:

• Establish the performances versus a physics benchmarks list

• Establish the best efficient design versus cost (see next slide)

• Make technological choices (ECAL, HCAL, VDET, TPC-endplate) and establish the final design for construction

• Make the best use of the detector (i.e. Fractal dimension for PID in calorimeter) improving the reconstruction

• Integrate all possible improvements (i.e. PID with TOF, timing in shower, 5D PFA, … )
“LARGE” versus “SMALL”
• e+e– collider is the future machine for Higgs precision (and more)

• **ILC** is still alive !!

• **ILD** is a design well understood for 10 years of works, and it improves continuously (Intermediate Design Report will be released by the end of the year)

There is a lot of **opportunities in the ILD collaboration**

• Reconstruction (i.e. 5D PFA, Lepton ID with TOF, etc…)
• Engineering (from proto to real detector- industrial “product”)
• Analysis, software, hardware, etc…

CMS or ATLAS was built by > 1000 active researchers, engineers …. 

ILD is today about 100 active people … it is OK for this stage, but clearly not to proceed to the next step
Visible energy resolution with PFA
TESLA Report - 2001

The resolution is about 3.1 GeV !!
A factor 2 better than LHC experiments
ZH final state at 250 GeV centre of mass energy

4 jets

2 jets + 2 l
Carbon fiber-Tungsten structure with Alveola to slide in the active layers.
Invariant Mass from $\tau$ decays

<table>
<thead>
<tr>
<th>$\tau \rightarrow \pi \nu$</th>
<th>$\tau \rightarrow \rho \nu$</th>
<th>$\tau \rightarrow a_1 \nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet mass &lt; 0.2</td>
<td>90.2 %</td>
<td>1.7 %</td>
</tr>
<tr>
<td>Jet mass in 0.2-1.1</td>
<td>1.7 %</td>
<td>87.3 %</td>
</tr>
<tr>
<td>Jet mass &gt;1.1</td>
<td>8.1 %</td>
<td>7.4%</td>
</tr>
</tbody>
</table>

Thanks you to granularity and segmentation !!

Full Simulation GEANT4 & Reconstruction with PFA
Hadron-EM separation: 30+10 GeV $\pi^+ - e^+$ (TB+MC), $\pi^+ - \gamma$ (MC)

Probability to reconstruct exactly one $\gamma$ & one $\pi^+$ for Pandora or one $\gamma$ for Garlic (which does not reconstruct hadrons), Arbor not used for AHCAL.

Good agreement between TB and MC.

Amount of material in ATLAS and CMS inner trackers

- **ATLAS**
  - Services
  - TRT
  - SCT
  - Pixel
  - Beam Pipe

- **CMS**
  - Beam Pipe
  - Sensitive
  - Electronics
  - Support
  - Cooling
  - Cable
  - Outside

Weight: 4.5 tons
Weight: 3.7 tons