Conclusions from Detectors

Joachim Mnich (DESY)
October 2010
Geneva
Outline

Disclaimer:
• not a summary of all sessions and talks on LC detector R&D
• impossible to give justice to all the many results and developments presented here

Instead:
• pick a few highlights
• personal selection with a few personal remarks
• outlook
Looking back…

EUDET project 2006-2010:

• collaboration in Europe & beyond
  > 30 institutes

• well defined structure

• plus additional funds
  7 M€ in total
Pre-EUDET
(Vienna 2005)

Small TPC prototypes

+ many other examples

Conclusion:
continue collaborative spirit → AIDA

Today
(Geneva 2010)

Large TPC prototype
EUDET - before / after

- From proof-of-principle to technology prototypes:
  - compact mechanics, power-pulsed ASIC family, scalable DAQ

- ECAL

- aHCAL

- dHCAL: (nothing)
A few selected highlights…
**LC Vertex Detector**

Measure impact parameter, charge for every charged track in jets, and vertex mass.

**Need:**
- Good angular coverage with many layers close to vertex.
- Efficient detector for very good impact parameter resolution
- Material ~ 0.1% $X_0$ per layer.
- Capable to cope with the LC beamstrahlung background (higher for CLIC)
- Single point resolution better than 3 μm.
- Small pixels, thin sensors, thin r/o electronics, low power (gas cooling).
- CLIC requires better timing resolution.

**Figure of merit for the VXD:**

$$\sigma_{r\phi} \approx \sigma_{rz} \approx a \oplus b/(\sin^{3/2} \theta)$$

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>a (μm)</th>
<th>b (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEP</td>
<td>25</td>
<td>70</td>
</tr>
<tr>
<td>SLD</td>
<td>8</td>
<td>33</td>
</tr>
<tr>
<td>LHC</td>
<td>12</td>
<td>70</td>
</tr>
<tr>
<td>CLIC</td>
<td>&lt;5</td>
<td>&lt;15</td>
</tr>
<tr>
<td>ILC</td>
<td>&lt;5</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>
Technology Advances

- Diversified R&D on pixels continues
- Substantial progress achieved on several fronts during the last year even if at reduced speed
- Great achievements partly because the relevant accessible industrial technologies have made sometimes striking progress

- Some pixel technologies is now even at the level where it is expected to meet all ILD vertex detector specifications by 2011, i.e. within the DBD timeline
3D Vertical Integration

Stacking of multiple layers of chips
- optimise pixel performance
- simplify integration
- possibility to develop novel monolithic pixel sensors
- Important for CLIC developments

Substantial number of teams contributing to this effort
- progress slower than expected
- but considerable progress recently

Vertically Integrated Pixel VIP2a (FNAL)
Integration Issues

• R&D on system integration issues have picked up speed
• Achieving ultra-light pixelated systems (like double-sided, or monolithic or unsupported ladders)

Thinned DEPFET sensor

Mimosa18 thinned to 30 um embedded in kapton < 0.15% $X_0$

Fully equipped ladder with 50 µm sensors by 2012 ~ 0.3% $X_0$

Silicon Carbide for novel mechanical vertex structures
**LC technologies in real experiments**

- Important: integration of sensors in real experiments
  - Smaller projects: beam telescopes (i.e. EUDET BT)
  - Real vertex detectors!
- Leads to concrete applications of > 10 years of R&D
- Allows to assess various emerging technologies in real experimental HEP conditions for the first time
- Even if they are not yet all pushed to the performances needed for the ILC.

Belle II VXD with DEPFET (2014)

STAR@RHIC with Mimosa (2012)
MC Simulation CLIC-VXD

- Layout optimisation for the vertex and forward tracking region started from validated ILC tracking-detector designs: ILD and SiD
- Adaptations for CLIC (background-) conditions: forward region, distances to IP
- Where applicable: complementary choices, to study influence on performance
- Fully implemented in Geant-4 simulation frameworks Mokka (ILD) and SLIC (SiD)

Resulting designs
CLIC_ILD_CDR and CLIC_SiD_CDR will be used for large-scale full-simulation MC studies towards a Conceptual Design Report (CDR), to be submitted in 2011

\[ \sim 20\text{-}30\% \text{ worsening for x2 more material w.r.t. (optimistic) default} \]
Gaseous Tracking

- TPC is main tracker for the ILC concept, as option under evaluation by CLIC
- Active R&D effort within the LC-TPC collaboration
- Focus of the past few years:
  - demonstrate feasibility and performance in prototypes
  - develop an realistic overall concept including integration in the ILD detector
  - major test beam effort by many groups using DESY beam

Micromegas based measurements

- 80 µm resolution at 2m in B=3.5 T!
- Major achievement

First momentum measurement:
Only Factor 2 worse than required

Asian GEM module

$\sigma_0 = 60.8 \pm 0.5$
$N_{\text{eff}} = 39.0 \pm 0.4$
TPC at ILC & CLIC

- Requirements at ILC and CLIC are very different:
  - ILC: 369 ns vs CLIC: 0.5 ns (30 mm vs 40 µm)

Studies of detector integration have started

- Simulation: bunch crossing ID within +5 CLIC bunches: TPC not immediately excluded

Studies of mechanics and integration into ILD have started
Silicon Tracking

- Silicon tracking is central to both ILC and to CLIC concepts
- Main challenges:
  - material budget in sensors and support structures
  - level of integration of readout and services
  - power supply, power cycling
  - alignment methods

Example: edgeless sensors could simplify overall construction significantly and reduce material budget

Test (edgeless) detectors on 6” wafer (SOI technology)
Silicon Tracking

Internal alignment is critical for success of tracking:

- True for any of the concepts
- Particular challenge for the large outer Silicon layer in ILD

Principle: shine laser beam through Si-layer (a la CMS)
But: develop more transparent sensors (20% → 60% transmission)

Readout: very wide field.

Development of mixed analogue-digital 128 channel ASCIC (SiTR chip)
Integrate the pitch adapter on the sensor
Sophisticated infrastructure and test benches developed
(in Europe within EUDET)

Mechanics:
Develop integrated concept for SI tracking integration into ILD and SiD
Main Challenges in Tracking

Technologies:
  • Have at least one technology per system which fulfills all requirements
    Might well be different for ILC and CLIC
  • Have a concept on how to get data from the sensor to the DAQ

  • System aspects:
    • Move from test to system aspects:
      • Large scale systems
      • System integration within sub-detector
      • System integration with other parts of the detector

Engineering aspects:
  • Develop engineering concept for technology
  • Develop powering and cooling concepts for system

TPC endplate design
TPC material budget
Si material budget
Support structures
Power pulsing
Cabling, services
Calorimeter: PFLOW with test beam data

- The “double-track resolution” of an imaging calorimeter
- Small occupancy: use of event mixing technique possible
- Apply full Pandora clustering algorithm
- Important: agreement data - simulation
- Strong support for full detector simulations to be done with photons, too
DHCAL test beam started at FNAL

• cubic metre steel instrumented with RPCs
• Argonne led US effort in CALICE
• using existing Fe stack and infrastructure, DAQ, tail catcher

• first very clean muon events
• hadrons expected today

• combined run with SiW ECAL physics prototype in spring 2011

• possible continuation with W

• Testbeam started this week
Power pulsing at 3 T

- sDHCAL technological prototype with integrated electronics and ASICs
Calorimetry @ CLIC

- higher jet energy - deeper HCAL
- tungsten is cost-competitive with a larger coil
- but slower (nuclear) response may be in conflict with time stamping needs

- CALICE test beam started @ CERN
  - first use existing scintillator aHCAL
  - later: gaseous dHCAL
  - and 2nd generation aHCAL with timing electronics

### Pandora on ILD-CLIC

<table>
<thead>
<tr>
<th>$E_{\text{JET}}$</th>
<th>RMS$_{90}/E_J$</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 GeV</td>
<td>3.6 %</td>
</tr>
<tr>
<td>100 GeV</td>
<td>2.9 %</td>
</tr>
<tr>
<td>250 GeV</td>
<td>2.8 %</td>
</tr>
<tr>
<td>500 GeV</td>
<td>3.0 %</td>
</tr>
<tr>
<td>1 TeV</td>
<td>3.2 %</td>
</tr>
<tr>
<td>1.5 TeV</td>
<td>3.2 %</td>
</tr>
</tbody>
</table>
Calo: Towards DBD

- Physics with gaseous HCAL
  - understand operational stability uniformity, calibration, energy and topological resolution, use of amplitude information
- Electronics integration demonstrators with all candidate technologies
- System performance of a full size 2nd generation
  - sDHCAL module
- Make it work!

Calorimetry
First Design of the Forward Region of a CLIC detector

- LumiCal is designed to measure the Luminosity with a precision of $10^{-2}$ at 3 TeV
- BeamCal feasible, improves hermeticity
Succesful test-beam

Sensor plane Prototypes for LumiCal (Silicon) and BeamCal (GaAs) have been manufactured, connected to ASICs and studied in the 4 GeV electron beam at DESY (Most components supported by EUDET).
Succesful test-beam

- Several millions of trigger taken, Data analysis ongoing
- Preliminary results, impact point measured with the telescope correlated with the signal of a certain pad
In Progress

8 Channel ASIC chips tested (UST Cracow)

Static and dynamic parameter as expected, working up to 50 MHz
Will be used in the next beam-test for a full system test
Power pulsing

FPGA based DAQ (UST Cracow, INP Cracow, Tel Aviv Univ.)

Xilinx Virtex5FXT FPGA with embedded PowerPC 440

2012: performance measurements of a fully assembled sensor plane
> 2012: towards a calorimeter prototype (AIDA supported)
DAQ and Software

DAQ:
- Many efforts (test beam driven)
  EUDET telescope, LCTPC, CALICE,…
- Overall concept(s) needed
- Learn from LHC detectors
  integrated concepts
  Result: DAQ efficiency > 90%

Software:
- Common tools used by ILC & CLIC
- New models for DBD/CDR
- Simulation and reconstruction are making good progress towards optimisation
Summary

• Very rich detector R&D programme for a Linear Collider
• Very good progress in many projects
• Good collaboration ILC-CLIC

• LC detector R&D has impact on other projects, e.g.
  • LHC
  • B-factories
  • and beyond HEP

• Funding is critical

• Define plans until 2012 and beyond
  • Priorities
  • Integration & „low tech“ issues
Backup slides
EUDET Telescope

Generally applicable:
- Main use from small pixel sensors to larger volume tracking devices
- Movement of device under test (DUT) to scan larger surface
- **Easy to use:** well defined/described interface
- Very high precision: <3 µm precision even at smaller energies; < 2µm for high energy hadrons

- Mimosa26 sensor
- 663 kpixels with 18.4 µm pitch
- column parallel binary readout

- Telescope is travelling back and forth between DESY and CERN since 2007 (84 test beam weeks so far)
- All together 29 user groups from LC and LHC (also combined running)