Worldwide Linear Collider
Calorimeter R&D
Test Beam Effort

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DESY
CALICE Collaboration

LCWS 2004, Paris
April 22, 2004
Outline

- Calorimeter R&D challenges
- Test beam requirements
- Past and present activities
- Preparations for the next steps
LC calorimetry challenge

- **Jet energy resolution**: separate W and Z in their hadronic mode
- Dijet masses in \( e^+e^- \rightarrow WW\nu\bar{\nu}, \ e^+e^- \rightarrow ZZ\nu\bar{\nu} \)

**LEP-like detector**

**LC design goal**

![Graphs showing jet energy resolution](image)

- 60%\(\sqrt{E}\) vs. 30%\(\sqrt{E}\)
Particle flow

• Maximum tracking - minimum calorimetry

• Each particle should be reconstructed and measured separately

• For the jet energy measurement spatial resolution / particle separation power is more important than energy resolution
Calorimeter design

- small Moliere radius
- high granularity

- “large” radius and length
- large magnetic field
- “no” material in front

Moliere Radius for W:
\[ r_M = 0.9\text{cm} \]
- effectively a factor \((1 + \text{Gap} / 2.5\text{mm})\) more
- technology challenge: thin readout gap

Cost:
need \(~3000\text{ m}^2\)
expect 2$/cm^2$ Silicon in 2010
still ECAL = 50% of total detector

follow alternative options: scintillator or hybrid
Hadron calorimeter concepts

• The HCAL must be imaging, too
• Readout options:
  - Analogue: classical scintillator - but pushing the granularity
  - Digital: radically imaging; counting hits
High granularity

- new photodetectors allow individual readout of smallest scintillator tiles

*Si Photo-Multiplier*

- optimize granularity for shower separation

Two showers: $\pi^+ 10\text{GeV}$, $K^0 10\text{GeV}$

Events/1GeV

Energy of Neutral Shower [GeV] (A.Raspereza)
Calorimeter R&D challenges

ECAL:
• Optimize overall detector geometry
• SiW: thin sampling layer technology
• alternatively: (hybrid) sampling structure
• photon reconstruction / separation

HCAL:
• Pattern recognition of shower “trees”
• large area chambers, low cost electronics
• novel readout technologies

PFLOW:
• need fully developed algorithms to evaluate basic design configurations
Goals of the test beam program

- **Technologies**: demonstrate the feasibility

- **Algorithms**: tune particle separation, PFLOW with real data

- **Simulations**: test and validate or improve hadronic shower models
  - together with well-measured hadronization of $W$ or $Z$ boson, optimize overall detector for jet reconstruction
  - even better, but more ambitious: collect a shower library

- **Note**: this can **not** be done with existing coarse granularity data
Required sensitivity

- 10'000 particles, compare Geant 3 (histo) vs. Geant 4 (points)

• differences vary with energy, particle type, detector material,…

(study by D. Ward)
Energies and angles

- mean energies around 10 GeV
- but need 5-50 GeV
- better 1-100 GeV

- 90 degrees never occurs!

(V. Morgunov)
More beam requirements

- Electrons and photons, pions and protons, muons
- energy spread <2%
- rate ~1kHz (<100 Hz for RPCs)
- tracking (need ~1mm: wire chambers or Si telescope)
- particle ID (Cerenkov)
- infrastructure (crane, cooling, gas, computing & network)
- space (6m wide)
- magnet? (4T @ DESY, cosmics only, for small ECAL or RPCs)

- several phases of running time
- $O(10^2)$ configurations * $O(10^4)$ events * $O(10^2)$ bins = $10^8$ events
  = 1-10 days running time = several weeks real time each
Test beam detector requirements

- a cubic metre size
- plus tail catcher to measure leakage
- possibilities for wide angular scans

- flexibility to test different configurations
  - with, w/o ECAL
  - different active media (scintillator, RPCs, GEMs)
  - different sampling structures, absorber thickness and types, and gap widths

- DAQ for few $10^4$ or even few $10^5$ ch.
## R&D groups worldwide

<table>
<thead>
<tr>
<th>Calorimeter</th>
<th>Technology</th>
<th>Groups</th>
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<tbody>
<tr>
<td>Electromagnetic</td>
<td>Silicon-Tungsten</td>
<td>BNL, Oregon, SLAC</td>
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<tr>
<td></td>
<td>Silicon-Tungsten</td>
<td>Britain, Czech, France, Korea, Russia</td>
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<td></td>
<td>Scintillator/Silicon-Lead</td>
<td>ANF, Padova</td>
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<td></td>
<td>Scintillator/Silicon-Tungsten</td>
<td>Kansas, Kansas State</td>
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<tr>
<td></td>
<td>Scintillator-Lead</td>
<td>KEK, Kobe, Konan, Niigata, Shinshu, Tsukuba</td>
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<tr>
<td></td>
<td>Scintillator-Tungsten</td>
<td>Colorado</td>
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<tr>
<td>Hadronic (analog)</td>
<td>Scintillator-Steel</td>
<td>DESY, Dubna, ITEP, LPI, MEPHI, Charles, IPAS</td>
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<tr>
<td></td>
<td>Scintillator-Lead</td>
<td>KEK, Kobe, Konan, Niigata, Shinshu, Tsukuba</td>
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<tr>
<td>Hadronic (digital)</td>
<td>Gas Electron Multipliers-Steel</td>
<td>UTA</td>
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<td></td>
<td>Scintillator-Steel</td>
<td>NICADD</td>
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<td>Resistive Plate Chambers-Steel</td>
<td>IHEP (Russia), JINR</td>
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<tr>
<td></td>
<td>Resistive Plate Chambers-Steel</td>
<td>ANL, Boston, Chicago, FNAL</td>
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<tr>
<td>Tail catcher</td>
<td>Scintillator-Steel</td>
<td>FNAL, NICADD</td>
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<tr>
<td></td>
<td>Resistive Plate Chambers-Steel</td>
<td>INFN</td>
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Previous studies: Asia

- long series, just finishing (spring 2004)
- example:
  - electrons and hadrons @ KEK and FNAL
- see calo session

HCAL studies with test beam (1996-1999)

- Good energy resolution and linearity thanks to hardware compensation

(slide from Hiroyuki Matsunaga)
Joint European /Asian tests

- 6 GeV electrons

Shower MAX. det. at DESY

DESY Beam Test with mini-CAL
Sep./2003

(slide from Tohru Takeshita)
Scintillator HCAL (CALICE)

- pre-prototype, 50-100 channels
- Compare different photodetectors: SiPMs, MA-PMs and APDs (underway)
- see calo session
Hybrid ECAL (Italy)

- at Frascati
- and CERN

S. Miscetti

LCWS, Paris, April 22, 2004
Felix Sefkow, LC Calorimeter R&D Test Beam Effort
Plans in Asia, US, Europe

- Asian groups were planning to finalize ECAL tests in spring 2004
  - report at this conference
  - further plans being discussed

- US groups plan to start with ECAL options at SLAC in 2005,
  - all HCAL options till 2008

- Forward calorimeter groups plan
  - high intensity e beam at Frascati 2005-06
  - high energy e beam > 2008 (CERN?)
CALICE plans

164 Physicists, 28 Institutes, 9 Countries: 3 Regions

• CALICE prepares beam test series in 2005-06
• ECAL and HCAL together, different options
  – SiW ECAL
  – HCAL with scintillators, RPCs or GEMs
ECAL preparations

- PCB with Si sensors and VFE being commissioned with DAQ in Paris these days
HCAL preparations

- cubic metre prototype (based on scintillator minical experience) presently moving from design to construction phase
  - high granularity to test analogue and (semi-)digital options

- flexible mechanical structure (stack and moving table)
  - being built at DESY

- square metre RPCs and GEMs in preparation (US, Russia)
Tail Catcher

- HCAL inside coil is thin - need to recover 10-20% for 20 GeV pion
- scintillator strip tail catcher / muon system being prepared

(NIU, with DESY)
• ECAL and HCAL (8-10’000 channels each) are aiming at using unified (ECAL) DAQ system
  - conceptual solutions for HCAL front end electronics exist

• common testbeam simulation and reconstruction framework
  - effort centred at DESY, NIU, and Paris
Schedule, near, medium term

- start with ECAL end 2004 at DESY
- then integrate (scintillator) HCAL with ECAL
- goal: move both to hadron beam in 2005
  - and high energy e beam, ...
- vary readout options: 2006 +
- possible scenario:

<table>
<thead>
<tr>
<th>Year</th>
<th>Calorimeter</th>
<th>Beam time request</th>
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<tbody>
<tr>
<td>2005</td>
<td>ECAL (CALICE)</td>
<td>3 weeks (electrons)</td>
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<td>Analog HCAL</td>
<td>4 weeks (hadrons, muons)</td>
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<tr>
<td>2006</td>
<td>Digital HCAL (RPCs)</td>
<td>4 weeks (hadrons, muons)</td>
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<td></td>
<td>ECAL + Analog HCAL + Tail catcher</td>
<td>5 weeks (hadrons)</td>
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<tr>
<td></td>
<td>ECAL + Digital HCAL + Tail catcher</td>
<td>5 weeks (hadrons)</td>
</tr>
<tr>
<td></td>
<td>ECAL (US)</td>
<td>3 weeks (electrons)</td>
</tr>
<tr>
<td>2007</td>
<td>ECAL + Analog HCAL + Tail catcher</td>
<td>5 weeks (hadrons)</td>
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<tr>
<td></td>
<td>ECAL + Digital HCAL + Tail catcher</td>
<td>5 weeks (hadrons)</td>
</tr>
<tr>
<td></td>
<td>Digital HCAL (different active media)</td>
<td>8 weeks (hadrons, muons)</td>
</tr>
<tr>
<td>2008</td>
<td>ECAL + Digital HCAL + Tail catcher</td>
<td>5 weeks (hadrons, muons)</td>
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Conclusion

• R&D proto-collaborations work:
• prototype construction in task sharing mode ongoing
• common systems (mechanics, DAQ, tail catcher), infrastructure and software

• clock is running for basic design choices in few year's time
• first round in 2005

• FNAL and Protvino beam facilities both meet basic calorimeter requirements
• practicability to be checked: need to further sharpen our plans