LC Detector R&D

- International LC R&D Committee Report -

(presented by H. Yamamoto, Santa Cruz 2002/6)

draft: blueox.uoregon.edu/~jimbrau/LC/LCrandd.ps

Still not complete. Soliciting comments.

Following a suggestion by LC Worldwide Study Commitee,
a committee was formed in 2001 to draft a report to

- Describe the R&D needed for LC.
- List R&D's currently performed.
- Point out areas missing or not well-covered.

To help newcomers find R&D work (and get funded),
to avoid unnecessary duplications,
and to make sure no big holes are left.

In short, to maximize the effectiveness of R&D's worldwide.

Committee members

Asia: Yoshiaki Fujii, Hwanbae Park, Hitoshi Yamamoto
Europe: Chris Damerell, Rolf-Dieter Heuer, Ron Settles
N. America: Jim Brau, Gene Fisk, Keith Riles

- Held meetings at LC workshops (Kracow, Beijing, Chicago) and communicated by E-mail.
- Basic structure of the draft decided at the Beijing ACFA meeting 2001.
- Actual dividing up of drafting works at the Chicago LC workshop, Jan. 2002.

Early on ($\sim$ Beijing meeting), we decided:

- Not prescriptive or exhaustive.
- Innovative R&D's not listed are encouraged.
- Only software efforts directly related to hardware designs are included.
- LHC-specific R&D's not included.
- Set up one cross-region website for each sub-detector maintained by corresponding experts. (to keep the global organization effective).

It does not prescriptively list up areas of needed R&D's.
(let readers decide on their own)

The report will be undoubtedly incomplete,
but may be useful if not taken too seriously.
(was useful to me)

Brief Description of the Report

Where LC is

- Compete with LHC (in a broad sense).
- Need to make full use of the available luminosity.
- Performances far better than LHC in each subdetector taking advantages of the lower rates and radiation. (Detector R&D efforts that match those of the machine are warranted.)

Detector performance goals

- vertexing: $\sigma_{r\phi,z}(ip) \leq 5\,\mu\mathrm{m} \oplus \frac{10\,\mu\mathrm{m\,GeV/c}}{p\sin^{3/2}\theta}$,
  (1/5 r_{beampipe}, 1/30 pixel size, 1/30 thin w.r.t LHC)

  (Example)
  b, c tagging. ($H \longrightarrow b\bar{b}$ vs $c\bar{c}$)
  $t \longrightarrow$ 3jets reconstruction.

- central tracking: $\sigma(\frac{1}{p_t}) \leq 5 \times 10^{-5}(\mathrm{GeV/c})^{-1}$
  ($\sim 1/10$ LHC. 1/6 material in tracking volume.)

  (Example)
  M_H by $e^+e^- \longrightarrow ZH \longrightarrow \ell^+\ell^- X$
  $M_{\tilde{\ell}}$ by $e^+e^- \longrightarrow \tilde{\ell}\tilde{\ell} \longrightarrow \ell^+\ell^-\chi^0\chi^0$

Detector performance goals (cont'd)

- forward tracking: $\sigma(\frac{1}{p_t}) \leq 3 \times 10^{-4}(\mathrm{GeV/c})^{-1}$, $\sigma(\delta\theta) \leq 2\mu$rad to $|\cos\theta| \sim 0.99$.

  (Examples)
  SUSY t-channel production.
  $d\mathcal{L}/dE$ by forward Bhabha.

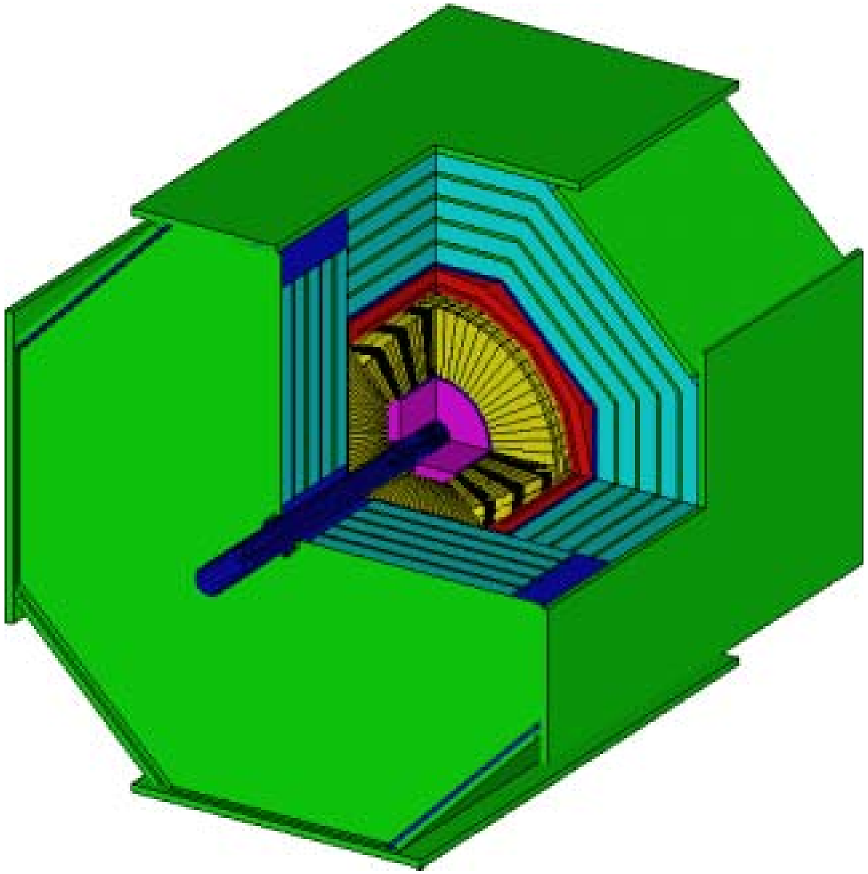
- energy-flow: $\frac{\sigma_E}{E} \simeq 0.30 \frac{1}{\sqrt{E(\mathrm{GeV})}}$
  (1/200 calorimeter granularity w.r.t. LHC)

  jet 4-momentum measurement.
  (e.g. $Z, W, H \to 2$jets, $t \to 3$jets)

- hermeticity
  (only ~ 10mrad hole along beamline)

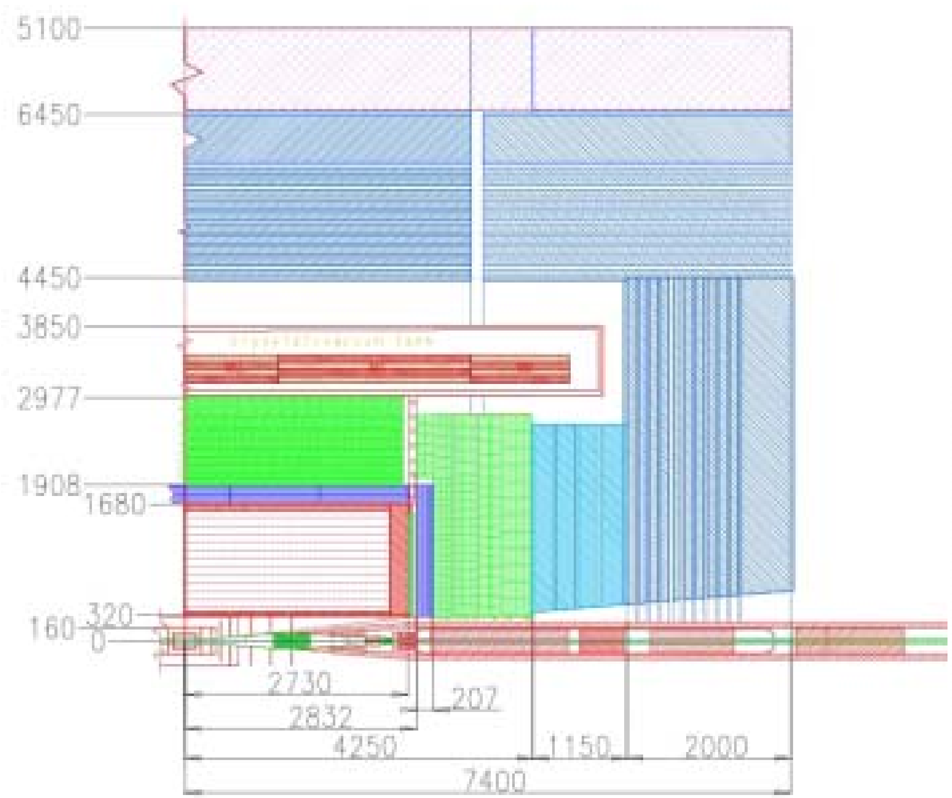
  Missing energy measurement.

Generic LC detector

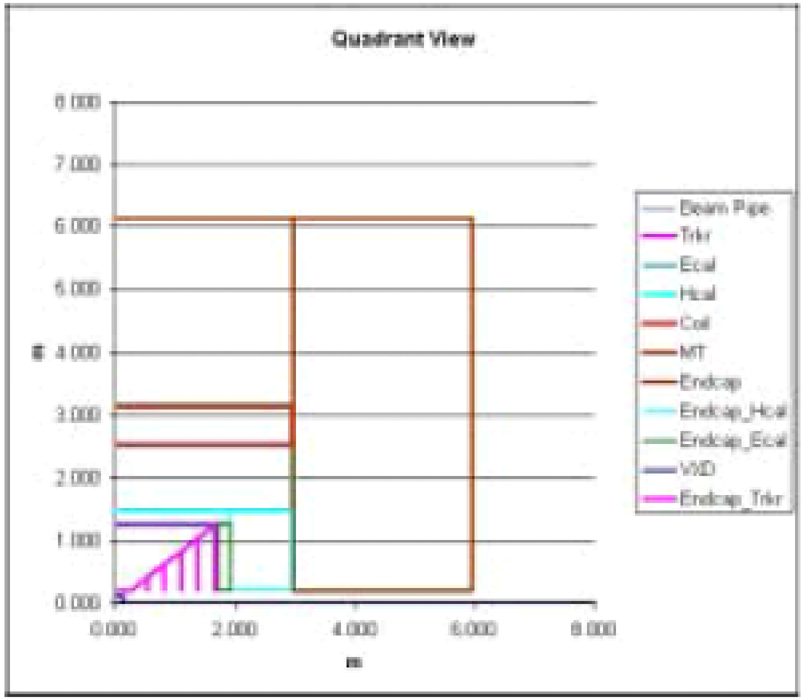


- Instrumented IP mask.
- Pixel-based vertex detector.
- High B-field ($\geq 3T$)
  (For p-resolution.
  Also,squeeze pair background)
- ECAL&HCAL within B-field.
- Flux-return as muon detector.
  (catches hadronic shower tail)

‘Large’ design
(gas-based central tracker)



‘Small’ design
(Silicon-based central tracker)



R&D Presently Performed

1. Tracking System

Vertex Detector

Tradeoffs:

Radius $\leftrightarrow$ background (e^+e^- pairs)

Spacial resolution/material $\leftrightarrow$ readout speed/radiation hardness

- Pair background: stay-clear $\propto 1/B$.
- Neutron $\sim 3\times10^8$/cm^2/yr:
  $\ll$ LHC, but with a large uncertainty.
- Readout speed: particularly important for Tesla.
  occupancy $\sim$4% if taken for a full 1ms train.

Vertexing Options

Charge-Coupled Devices (CCD's) (default)

Pros: proven performance at SLD
Small pixel size $\sim(20\mu\text{m})^2$
Good spacial resolution ($< 5\mu$m)
Relatively easy to thin

Cons: slow readout
modest radhardness
probably needs to be cooled

- LCFI (LC Flavour Identification) collaboration: UK (Bristol,Glasgow,Lancaster,Liverpool,Oxford,RAL)
- US collaboration (Oregon, Yale)
- Japanese collaboration (KEK, Niigata, Tohoku, Saga)

Charge-Coupled Devices (CCD's)

R&D items

- Thinning Si bulk to ~100μm (0.1%X_0/lyr)
- Mechanical: e,g, tension support (eliminate ribs)
- Radhadening: instrinsic radhardness
  + damage control (trap filling)
- Faster clock speed and/or parallel readout.
  Greater integration of readout electronics.
- Room-temperature operation.

Active Pixel Sensors (APS)

- Hybrid pixel sensors (i.e. bump-bonded readout/sensor)
  (CERN, Helsinki, INFN, Krakow, Warsow)
  R&D items
  - material reduction
  - smaller pitch
  - capacitively-coupled readout to reduce #channel
- Monolithic active pixel sensors (MAPS).
  CMOS image sensor technology. Pixel size ∼CCD
  Commercial fab process. Readout/sensor on one chip.
  (Strasbourg, RAL)
  R&D items
  - large-area sensor
  - fast readout
  - thinning
- DEPFET (depleted FET)
  (MPI-Munich)

Central Tracker

Global optimization study (simulation)
(Colorado, Michigan, Indiana, Santa Cruz, Wayne State)
tradeoffs: track finding, background, material budjet,
bunch discrimination, calorimetry interface.

Two basic types:

- Gaseous
  large, many samplings/trk
  dE/dx π/K separation promissing.
  - Jet chamber
  - TPC
- Silicon
  small, $\sim$5 samplings/trk
  No dE/dx π/K separation.
  (may be useful for new long-life heavy particles)

Jet Chamber

(KEK)

R&D items

- Controling/monitoring wire sag.
- Gas gain saturation (dE/dx and 2-track separation)
- Cell design for Lorentz angle (3 Tesla).
- Gas mixture study.
- Neutron background ($\sim$2khits/train).
- Maintenance of resolution (85μm) and 2-track separation (2mm) over the volume and time.

TPC (Time Projection Chamber)

Europe (Aachen, DESY/Hamburg, Karlsruhe, Krakow, MPI-Munich, NIKHEF, Novosibirsk, Orsay/Sacley, Rostok)

N. America (Carleton,/Montreal, LBNL, MIT)

TPC R&D items

- **Novel readouts:** GEM, MicroMEGAS, silicon-based.
  Avoid high-tension wires (reduce material of endplate).
  High-granurarity wire readout as backup.

- **Gas mixture**
  (resolution vs speed tadeoff)
  (quenching vs neutron background tradeoff)

TPC R&D items (cont'd)

- **Electronics**
  integration for 10^6 pads, high-speed sampling (> 20MHz), neighbouring pads.

- **Mechanical design:** Cooling, material reduction.

- **Space charge:** distortion correction.

- **Calibration:** laser, "z"-type chamber.

- **Readout simulation:** compare with prototype devices.

Si Tracker
(NLC S option)

A 5-layer Si tracker as the central tracking device in high-B field (5Tesla) ($r_{\max} = 1.25$m, $L/2 = 1.67$m)

- **Si drift detector**
  (Wayne State)
  - Thin substrates/mechanical support.
  - Improve spacial resolution ($< 10\mu$m).
  - Increase drift length (reduce channels).
  - Lower-mass front-end readout.

- Si microstrip
  (Santa Cruz, SLAC)
  - Thinner substrates/mechanical support.
  - Long ladders (longer shaping time for low noise).
  - Power switching (to match trains).
  - Lorentz angle effect.
  - Double-sided readout.
  - Pulse-height information (time walk, dE/dx)

Alignment

Could reduce the requirement on mechanical rigidity.
based on the interferometer scheme of ATLAS

Forward Tracker

Silicon microstrip disks to cover down to $|\cos\theta| = 0.99$ (8 deg)
First few layers could be pixel sensors (TESLA TDR)

(Santa Cruz, SLAC)
simulation and protyping together with the Si tracker R&D.

Intermediate Tracker

Place between the vertex detector and the central tracker
to aid track matching between them
and to improve momentum resolution.

Relevant R&D's by
(LPNHE-Paris, Santa-Cruz/SLAC, Wayne State)

Additional Trackers

- Silicon External Tracker (SET)
  Just after TPC (endcap and barrel)
  (LPNHE-Paris)
  R&D: Cost reduction.

- Straw chambers (behind TPC endcap)
  (DESY)
  R&D: spacial resolution, material thickness,
  bunch tagging, calorimeter sprashback.

- Sicintillating fibre tracker
  between Vertexing and TPC
  (Indianna)
  R&D: timing precision, material thickness.

2. Calorimeters

Plays important roles in jet 4-momentum reconstruction

EFA (Energy-flow algorithm):
Combine information from the trackers,
the calorimeters, and also the muon system,
avoid double counting,
assign appropreate weights
$\longrightarrow$ jet 4-momentum.

Simulation studies:
CALICE collaboration,
KEK, Colorado, Oregon/SLAC.

ECAL

- Si-W calorimeter
  High granurarity ($\sim$1cm^2), but expensive.
  (CALICE, Oregon/SLAC)
  R&D items:
  - Segmentation optimization (cost reduction).
  - Prototype construction/test (CALICE 2004).
- Tile-fibre calorimeter
  Modest granurarity (4×4cm^2)
  (KEK, Niigata, Tsukuba)
  R&D items:
  - Segmentation optimization.
  - fibre configuration.
  - Prototype construction/test.

ECAL (cont'd)

- **Showermax detector (for tile-fibre)**
  Inserted near showermax to aid granurarity.
  - scintillator strips (Shinshu/Konan)
  - silicon pads.
- **Shashlik calorimeter**
  Fibres run londitudinally.
  Londitudinal segmentation is an issue.
  (TESLA TDR)
  R&D items:
  - Londitudinal segmentation
    - scintillating fibres of different decay times
    - photodiodes to readout the front part.
- **Scintillator strip calorimeter**
  Orthogonally arranged. (Tsukuba)

HCAL

- Tile-fibre calorimeter

  Larger granurarity than the ECAL version.

  Fe: good for effective Moliere radius.

  Pb: hardware compensation at 4mm/1mm sampling.

  (CALICE, KEK, Kobe/Konan)

  R&D items:

  - Granurarity optimization.
  - Optimization of absorber material.
    (hardware compensation)
  - Prototype construction (also tested with ECAL)
  - Photon detectors in high B field:
    APD, HPD, HAPD, MRD, EBCCD.

HCAL (cont'd)

- Digital calorimeter
  Very-high granurarity (~ 1cm^2) with 1-bit readout.
  Use granurarity also for compensation.
  ('software compensation')
  (CALICE, U. Texas)
  Read out: RPC or wires as default.

  R&D items:
  - Prototype (tile/digital interchangeable)
  - New readouts (GEM, VLPC).

3. Muon Detector

Muon ID + hadron shower tail

Fe as flux return
RPC, Scintillation counter strips, wires as readout.
(INFN-Frascati, Kobe, Tohoku, N. Illinois, FNAL)

R&D items needed:

- Mechanical design.
  Support system of the large heavy detector.

- Simulation studies.
  Tracking algorithms
  EFA
  Beam backgrounds
  Hadron punch-throughs

- Hardware R&D's
  Prototype design and beam tests.

4. Particle ID (hadrons)

dE/dx will be available for gaseous cental trackers.
(if care is taken not to sacrifice dE/dx)
Do we need a Cerenkov device?

In general, vertexing is a powerful flavor id at LC.
How useful is additional hadron id?
(is this a settled question?)

Giga-Z B-physics may need such device.
($B^- \to D_{1,2}K^-$, $B_s \to D_s^+ K^-$)

DELPHI/SLD types occupy a large valume before ECAL.
$\to$ DIRC type - focusing. (Colorado State)

5. IP Instrumentation

- Beam energy.
  10^{-4} needed in general: possible with
  an improved beam spectrometer of SLC/LEP.
  10^{-5} needed for Giga-Z: Possible?
- Differential luminosity
  Critical in m_t threshold scan etc.
  Low-angle Bhabha accolinearity.
- Polarization.
  Giga-Z: 10^{-3} polarization determination needed.
- Beam profile.
  Hit pattern near Lum. Mon. of pairs.
  Pixel-based disk system R&D
  (Hawaii, KEK, Tohoku).

6. Detectors for the $\gamma\gamma$ Collider

$\gamma\gamma$ collider events $\sim e^+e^-$ collider events.

$\gamma\gamma$ specific:

- Laser system.
  Inside(NLC) or outside(Max Born) the detector
  Interference with low-angle detectors.

- Large beam disruption.
  Outgoing path.
  Beam background (10^{11} neutrons/cm^2/yr at IP)
  $\rightarrow$ needs to be improved (dose or CCD)

- 'Resolved photon' events ($\gamma \rightarrow q\bar{q}$)
  High rate - every random trigger has a track.
  (LLNL)

Items Currently Missing in the Report

Low-angle calorimeters
(lum.mon., instrumented mask etc.)

Trigger

. . .

Challenges are in front of us to design/build
a detector that takes full advantage of the luminosity of LC.
They seem certainly be achievable if we put all forces together.