NLC Detectors
by C. Damerell
Introduction

Accelerator options: influence on detector

Interaction region, machine backgrounds and masks

Vertex and Tracking

Particle ID

Calorimetry

Muon Detection

Trigger and DAQ

Summary and Suggestions
Introduction

- Sub-system detector design and R&D is generally carried out under umbrella of a regional overall detector concept

  JLC
  TESLA
  LCD-S
  LCD-L

- Some tension between those who see these as evolving into a design one would want to build, as opposed to straw-man studies which will be changed drastically when the international collaborations eventually start to form.

- All are proving very useful in establishing boundary conditions which can firmly exclude some sub-system options (eg silicon microstrip devices for vertex detector) and can point the way to R&D requirements for the surviving options (eg controlling ion feedback in a TPC at TESLA).

- No evidence that detector issues will influence the choice of accelerator (the dog will not be wagged by its tail) but:

  each accelerator design is responding to detector issues which influence the physics reach (eg minimal angle for electron detection)

- One of the strongest lessons from LEP and SLC was that machine energy and luminosity aren’t the only important parameters.

  \[ e^- \text{ beam polarization} \quad \text{and} \quad \text{minimal vertex detector radius} \] can be of vital importance

- For the future, possibly also \( e^+ \) polarization, special running with reduced energy spread, etc. All these need physics and detector studies.

- The interaction between the LC accelerator, physics and detector issues is very strong. The timely pursuit of all is necessary if we are to develop a system which will be well matched to the challenging physics requirements, such as

\[ e^+e^- \rightarrow \text{HA} \quad \text{12 jets, 4 b-flavoured} \]
Small detector with 6 T Solenoid

Large detector with 3T Solenoid
Accelerator Options: Influence on Detector

- Main issue is different time structure between superconducting and room-temperature RF machines.

Examples:

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Bunch Train</th>
<th>Rep Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLC</td>
<td>95 at 2.8 ns</td>
<td>120 Hz</td>
</tr>
<tr>
<td>JLC-X (new)</td>
<td>190 at 1.4 ns</td>
<td>120 Hz</td>
</tr>
<tr>
<td>TESLA (new)</td>
<td>2820 at 337 ns</td>
<td>5 Hz</td>
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</tbody>
</table>

- TESLA briefly broke away from the competition with luminosity on offer, but they may be catching up fast:

500 GeV

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Luminosity</th>
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<tbody>
<tr>
<td>TESLA (new)</td>
<td>$7 \times 10^{33} \rightarrow 3.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>NLC</td>
<td>$7 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>JLC-X (new)</td>
<td>$9 \times 10^{33} \rightarrow 1.8 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ (Tauci / Yokoya)</td>
</tr>
</tbody>
</table>

N. Phinney reminded listeners of the SLC learning curve.

- TESLA backgrounds have recently been improved greatly, permitting vertex detector inner layer at 12 mm radius, as for NLC.

- Consequences of the machine differences:
  - Untriggered TPC suffers serious ion feedback at TESLA, necessitating a novel readout technology
  - CCD vertex detector also needs novel readout at TESLA. Desirable for other applications.

- Generally no reasons to strongly prefer either accelerator design for physics.
Interaction Region, Machine Backgrounds and Masks

- Main detector-related issues are:
  - minimum radius for vertex detector (flavour ID)
  - minimum polar angle for tracking (hermeticity for multi-jet events)
  - minimum polar angle for E-cal (electron veto to reduce 2-γ background)

- Accelerator scientists in all regions have made tremendous progress in these topics

- Disrupted beam, synchrotron radiation, beamstrahlung need to be efficiently transported to the remote beam dump

Solutions found for all options

Problem will increase with energy (eg CLIC)

- Consequence of premature energy deposition (eg on previous version of TESLA collimators) can be excessive neutron flux at the detector (vertex, TPC tracker, ...)

- Current designs have neutron flux in range
  - $< 2 \times 10^4$ 1 MeV n/cm$^2$.yr (TESLA) to
  - $\sim 1.5 \times 10^9$ 1 MeV n/cm$^2$.yr (NLC)

  Why the discrepancy? This covers the range 'comfortable' to 'challenging' for a CCD detector!

A (minor) challenge for CCD-based vertex detector

- What cannot be dumped remotely on the $e^+e^-$ pairs from the beam-beam interaction.

- These can hit the vertex detector directly or by backscattering

- They also define the small-angle limit for calorimetry which could plausibly detect single electrons from 2γ background processes (eg for SUSY searches)

- All designs envisage conical tungsten masks (with front-end probably instrumented) over angular range $\sim 50-80$ mrad partly equipped with an internal luminosity monitor/calorimeter down to $\sim 25$ mrad
Graphite plug or ring may be effective in attenuating flux of backscattered electrons

Higher solenoid field permits smaller vertex detector radius, though the quantitative relationship is not too clear

Discrepancy in hit rates may be due to absence of graphite plug in LCD designs (LCD dominated by backscattering, TESLA dominated by primary electrons)

Tentative Conclusions

Generation of beamstrahlung, pairs, beam-beam bremsstrahlung are under control

There is significant background from pairs and radiative Bhabhas in the detector

Vertex detector at R=12 mm seems possible with solenoid field \( \geq 3 \) Tesla

Neutron flux is under control (but not much safety margin for CCDs)

Still room for surprises?

• Beam-beam physics relies entirely on simulation programs

• X-ray specular reflection effects can be serious.
Energy Distribution

$\sqrt{s} = 1 \text{ TeV}$

Disrupted beam

Beam-Beam Pairs

Rad. Bhabhas

Energy (GeV)
Extraction Line

quads  

bends  

quads

Tracking in GEANT3

Disrupted Beam (E< 250 GeV)
Spent Beam

- beam has large transverse emittance after collision
- energy spread is very large
$e^+ e^- \text{ Pair Background from Beam-Beam Interaction}$

Maximum Radius of Pairs vs. $Z$

6 Tesla

No crossing angle
LCD Small Detector in GEANT3
JIM based on GEANT3

$E_e > 200$ keV

$E_\gamma > 10$ keV
x-y Distribution of Pair e⁻, e⁺ at z = 2 m

1 TeV, 6 Tesla Field Map

\[ \sim \frac{1}{2} \text{ Watt DC} \rightarrow 10^9 \text{ rad/year} \]
$e^+e^- \text{ Bad NaI Vertex Detector}$

$R = 12 \text{ mm}$

**TESLA**

$\nu s = 500 \text{ GeV} \quad L = 3 \times 10^{-34} \quad B = 4 \text{ Tesla}$

$240 \text{ hits/mm}^2/\text{trian} \rightarrow 1200 \text{ hits/mm}^2/\text{s}$

Correcting to $L = 0.7 \times 10^{-34}$

$\rightarrow 280 \text{ hits/mm}^2/\text{s}$

**LCD-5**

$\nu s = 1 \text{ TeV} \quad L = 0.7 \times 10^{-34} \quad B = 6 \text{ Tesla}$

$10 \text{ hits/mm}^2/\text{trian} \rightarrow 1200 \text{ hits/mm}^2/\text{s}$

Correcting to $\nu s = 0.5 \text{ TeV}$

$\rightarrow 600 \text{ hits/mm}^2/\text{s}$

$2.1 \times \text{ TESLA}, \: \text{Despite Higher B Field}$

- Mostly Backscatter, Not So For TESLA

$\Rightarrow \text{ Potential Benefit Of Grainsite Or Polyethylene Plug For LCD?}$
Neutron Bad at Vertex Detector

$R = 12\ mm$

**Tesla**

$V_S = 500\ GeV \quad L = 3 \times 10^{34}$

$< 0.8 \times 10^8 \ \text{1MeV n/cm}^2/\text{yr}$

(Nila Factor $\approx 0.7$, since
Ant. Energy $\approx 0.5\text{MeV}$)

**LCDF - S**

$V_S = 1\ \text{Tev} \quad L = 0.7 \times 10^{34}$

• Pairs are main source of neutrons

$1.7 \times 10^9 \ \text{n/cm}^2/\text{yr}$

$\Rightarrow 1.7 \times 10^9 \times \frac{0.5}{1.0} \times \frac{3}{0.7} \times 0.7 \Rightarrow 2.5 \times 10^9$

? \quad ?

$30 \times \text{Tesla}$

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Vertex and Tracking Detectors

- **Vertex Detector**

  - Physics importance of optimal performance has been established in several studies (eg Higgs branching ratios)

  - This relies on

    - optimal spatial precision (eg 3.5 µm)
    - minimal layer-1 radius (eg 12 mm)
    - minimal layer thickness (eg 0.12% X₀)
    - sufficient layers for internal tracking and alignment (eg 5 layers)

- Solenoid field of 3T may suffice. Higher fields degrade the impact parameter resolution (Bruce Schumm)

- Since 1993, all agree on **pixel-based** detectors (due to hit density in jets, and backgrounds). But there remain several options …

- **CCDs**

  - SLD experience puts them in a strong position

  - Need faster readout, particularly for TESLA (column parallel architecture)

  - Need thinner ladders (0.4% → 0.12%X₀)

  - Need improved radiation hardness due to neutron background (maybe)

  - 1 Gpixel detector design looks feasible, but R&D is only beginning

- **Hybrid APS (Active pixel sensor)**

  - Small detector pixels may work, with charge-sharing to large readout pixels, to improve spatial precision

  - Thinning of detector and readout chips may yield thicknesses 0.3%–1%X₀

  - No problem of radiation hardness (LHC)
Higgs Branching Ratio Determination for \( m_H = 120 \text{ GeV}/c^2 \) and 500 fb\(^{-1}\)

<table>
<thead>
<tr>
<th>Channel</th>
<th>( \frac{\delta(BR(H \rightarrow X)/BR)}{BR(H \rightarrow \text{hadrons})} )</th>
<th>( \delta(BR(H \rightarrow X)/BR) )</th>
</tr>
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<tbody>
<tr>
<td>( H^0/h^0 \rightarrow bb )</td>
<td>( \pm 0.011 )</td>
<td>( \pm 0.008 )</td>
</tr>
<tr>
<td>( H^0/h^0 \rightarrow cc )</td>
<td>( \pm 0.134 )</td>
<td>( \pm 0.080 )</td>
</tr>
<tr>
<td>( H^0/h^0 \rightarrow gg )</td>
<td>( \pm 0.050 )</td>
<td>( \pm 0.050 )</td>
</tr>
<tr>
<td>( H^0/h^0 \rightarrow \tau^+\tau^- )</td>
<td>( \pm 0.060 )</td>
<td>( \pm 0.051 )</td>
</tr>
</tbody>
</table>

- SM BR's and uncertainties estimated from HDECAY program:
  - \( m_b = (4.82 \pm 0.10) \text{ GeV}/c^2 \), \( m_b - m_c = (3.40 \pm 0.04) \text{ GeV}/c^2 \)
  - \( \alpha_s(m_Z) = 0.1164 \pm 0.0025 \), \( m_{top} = (175 \pm 0.3) \text{ GeV}/c^2 \)
CENTRAL TRACKING AND IMPACT
PARAMETER ERRORS

North American 'S' Detector (6 Tesla)

\[ \cos \theta = 0 \]

Decoupled \* means infinite multiple scattering layer between VTX and Central Tracker (so that only momentum measurement is meaningful)

*
Monolithic APS

- Deep depletion: pioneering work by Hawaii group. Scale up? Currently limited by available foundries
- Low resistivity: recent idea of Renato Turchetta
- Could achieve 100% mip efficiency
- Problem of scaling to large area, or material overheads of a multi-tile assembly with many electrical connections inside the tracking volume
- Both APS options are helped by low duty cycle at linear collider, so low power dissipation compared with LHC

R&D on all pixel detectors is being pushed hard for numerous application areas

Multivariate analysis can further extend the physics potential (Richard Hawkings)
Monolithic Pixel Detector

Readout electronics and sensor on the same chip

Hawaii-Stanford monolithic pixel detectors
Fabricated at CIS, Stanford

- Thickness 300µm
  - Collection electrode: \( p^+ \) (i.e. collects holes)
  - Bulk: \( p \)
  - Backside: \( n^+ \)-diffusion

- One PMOS readout circuit in \( n \)-well for each pixel.

- Operated with full depletion at \( \sim 60 \) V.
EXEMPLE DE DISPOSITIFS. 6.

Dispositif de 386*290 pixels = 10^5
14 µm de coté
Technologie 0.5 µm CMOS
Power consumption:
50 mW --> 0.4 µW/pixel
Readout speed 8 MHz
Epaisseur de la couche epitaxiale: 17 µm

Pixel fill factor (facteur de remplissage): 70% pour lumière visible (partie métallique opaque) --> 100% pour MIP
ZVTOP/NN charm tagging performance, $\cos \theta < 0.9$

- mass tag, 1cm CCD
- NN tag, 1cm CCD
- mass tag, 2cm CCD
- NN tag, 2cm CCD
- mass tag, 2cm APS
- NN tag, 2cm APS

C-tagging purity

C-tagging efficiency

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- Tracking Detector (Central Region)

- Gaseous Tracking Detectors

  TPC favoured by TESLA and LCD-L
  (large CDC favoured by JLC, but hit density a challenge)

- Advantages of TPC

  > 100 points/track (large redundancy)
  3D reconstruction
  Thin (but ~ 0.5X₀ in each endcap)
  \( \frac{dE}{dx} (K / \pi \text{sep} > 3\sigma \text{to} 5 \text{GeV/c}) \)

- Disadvantages of TPC

  Poor 2-track resolution
  For TESLA, need to run ungated (see trigger section) implies novel readout technology to suppress positive ion feedback (GEM OK to 90%; adequate?)

- Performance goal \( \sigma(1/p) = 7 \times 10^{-3} \)

  permits \( Z^0 \) invariant mass reconstruction with better than its intrinsic width (2.4 GeV/c²)

- TESLA worse than NLC: for backgrounds:

  1 \( e^+e^- \) event
  3 \( \gamma\gamma \) events (rejected by trk pointing)
  15000 background hits

  Trk finding and reconstruction 'not a problem'

- Losses due to 2-track resolution in jets, and \( R_{\text{min}} \)?
- General concept: Large detector, gaseous tracking, large acceptance
- main tracking components:
  - high precision vertex detector (4-5 layers)
  - large TPC tracking chamber

configuration:

\[
\begin{align*}
  z &= \pm 250 \text{ cm} \\
  R_i &= 32 \text{ cm} \\
  R_o &= 170 \text{ cm} \\
  N_{hit} &= 118 \\
  \text{Gas} &= \text{Ar/CH}_4 \text{ 90-10}
\end{align*}
\]
- physics drives the required momentum resolution: e.g.
  recoil mass measurement in $e^+e^- \rightarrow Z^0H, Z^0 \rightarrow \mu^+\mu^-$

- goal: better than intrinsic width of the $Z$ ($2.49\text{GeV}/c^2$)

\[
\sigma(1/p) = 7 \times 10^{-5}
\]

LC TPC alone: $2.8 \times 10^{-4}$
LC ALEPH $12 \times 10^{-4}$
• **Silicon Tracking Detectors**

• **Silicon Microstrips**

One option for LCD-S

• Advantages

  Compact (with high B field)
  Robust against backgrounds
  Inner layer can be close to vertex detector (good 2-trk resolution)
  (occupancy $3 \times 10^{-3}$ at $R = 30$ cm)

• Disadvantages

  May *prefer* E-cal on larger radius
  Poorer momentum resolution at low momentum (this *could improve* with R&D)

• Shaping time options (in all cases, pulsed power for short duty cycle eliminates need for active cooling: wonderful!)

  • *Short shaping time*

    $\times 30$ background suppression (overkill?)

  • *Long shaping time*

    No background suppression through bunch train (OK?)
    L (ladder) $> 150$ cm possible
    Thinner detector $0.11\% - 0.32\% X_0$ possible (approach low-mom performance of gaseous detector)

• Maybe long $\tau_4$ for barrel
  short $\tau_s$ for forward disks
  (Need for further simulations to decide)
Silicon Drift Detector (SDD)

- Build on STAR experience (0.7 m²). Current LCD-S baseline
- R&D:
  - improve resolution to 5 μm
  - reduce detector thickness to 150 μm (aim for 0.5% X₀/layer)
  - improve 2-track resolution to 200 μm

\[ \frac{\sigma_p}{p} = 6 \times 10^{-5} \pm 0.0022 \] LCD-S (3 double layers SDD)

\[ \frac{\sigma_p}{p} = 5 \times 10^{-5} \pm 0.00065 \] LCD-L (TPC: 144 points)

- How important is superior TPC performance at low momentum?
- How much can the silicon tracker performance be improved at low momentum?
• **Tracking Detector (Forward Region)**
  
  • LCD-S only has explicit plans at present, but clearly essential for all, up to mask edge (and *within* mask for energetic electrons; see calorimetry)
  
  • 5-layer Si strip system suggested
  
  • **Tracking Performance Overview** (momentum resolution only)
    
    • LCD-L and TESLA similarly excellent
    
    • LCD-S worse at low $p$ (but catching up?)
    
    • Forward tracking is good for sign determination of highest momentum tracks down to mask edge
    
    (Be careful not to mess this up with vertex detector electronics: should be OK for CCDs)
Calorimetry

- Around 6 options under study, but only one combines excellent transverse and longitudinal granularity, with potential for measuring jet energy by the energy flow method pioneered by ALEPH

- W-Si for ECAL, various options for H CAL
  Fine granularity and high density are the key requirements

- c/π ratio is not important

- Only disadvantage seems to be cost, which by comparison with the LC is certainly modest, even for a TESLA- or LCD-L-scale detector
Electromagnetic Calorimeter

- Jean-Claude Brient (for TESLA) proposes pads
  
  1.5 cm x 1.5 cm x 1X_{e}\nu
  25 depth segments (25 X_{e} total)
  on inner radius of 1.7 m (15 x 10^6 channels)

  Same technology for endcaps outside the mask

- VOXEL-based calorimetry, with 3-D cluster reconstruction and deletion of track-associated energy deposition

- Richard Dubois:
  
  Simulation show ~20% reduced response in endcap (6T field). Effective sampling fraction changes with B?
  
  Use of thin sensitive medium in high magnetic field is a new issue, needing R&D
  (Effect observed by CMS in test beam)

Small Angle ECAL

- Hermetic calorimetry is even more important than hermetic tracking
  
  \[ \rightarrow \text{instrumented mask (nose)} \]
  \& \text{calorimeter/luminosity monitor inside mask}

  Small-angle calorimetry to veto energetic electrons from \[ ee \rightarrow eey \]
  and 2-photon background

- At \( \sqrt{s} = 1 \text{TeV} \), if cannot veto below 50 mrad, SUSY search for \( \tilde{t} \rightarrow \tilde{\chi}c \)
  will not work for \( \Delta M < 25 \text{ GeV} \)

- TESLA sees:

  Tungsten plug radius 0.9 cm \( \rightarrow \) 5.4 cm \( -26 \text{ TeV/BX} \)
  In-mask calorimeter radius > 5.4 cm (23.5 mrad) \( 6 \text{ GeV/BX} \)

  Conclusion: Fine-grained detector in mask for \( \theta > 23.5 \text{ mrad} \)
  is possible, to detect and veto energetic electrons

  Can also provide useful information re beam-beam conditions
CALOR. BARREL - View XY

- Coil cryostat
- ECAL
- HCAL
- Output signal
- Electronic
Response vs Angle
○ **Hadronic Calorimeter**

- Need to reconstruct EFLOW objects
  Eg neutral hadron and charged hadron showers to be disentangled with good efficiency

- Fine granularity (including depth segmentation) and good energy resolution are again important

- One example (Brient)
  
  Cells 1.5 cm $\times$ 1.5 cm $\times$ 0.2, $\lambda_1$
  Si-Cu or Si-Fe (Stainless Steel)

- Simulations are suspect (Yoshiaki Fujii)
  
  Individual shower shapes can be very different from the average.
  Often, a charged pion generates a fake $\gamma$ in the ECAL.
  (Further arguments in favour of EFLOW approach)

- Effect of coil in front of HCAL may be pretty bad (Korbel)
  
  $\frac{\sigma E}{E}$
  0.38$/\sqrt{E}$  0.43$/\sqrt{E}$  0.52$/\sqrt{E}$

  (Also ALEPH Experience)
Calorimetry: Performance

- For multi-jet environment, calorimeter-alone approach to jet energy measurement will be degraded even beyond present simulations:

  For $R_{\text{cal}} = 170$ cm and 3T

  $7\%$ charged energy of central jets spirals into the endcaps

- Energy Resolution

  **Electromagnetic**

  LCD-S and TESLA Si-W

  \[
  \frac{16\%}{\sqrt{E}} \oplus 0.2\%
  \]

  SiCAPO test beam results: \( \frac{\sigma E}{E} = 18\% \sqrt{(t / E)} \)

  \( t \) : thickness in \( X_o \)

  **Hadronic**

  Isolated charged hadrons

  LCD-S  Cu-Scint outside coil  \( \frac{45\%}{\sqrt{E}} \)

  LCD-L  Pb-Scint inside coil  \( \frac{32\%}{\sqrt{E}} \)

  Large constant term -- $7\%$ due to leakage (?)

  These simulations are in an early stage, and can be trusted only after careful tuning using test-beam data

- Jet Reconstruction

  - Depends critically on separation of EFLOW objects. 3-D simulations are only just beginning

  - Preliminary indications:

    With respect to charged pion, reconstruct low energy photon at 1-2 cm
reconstruct neutral hadron at 2-4 cm

(good rejection of hadronic fake photons)

- \( \frac{\sigma(E_{\text{jet}})}{E_{\text{jet}}} \approx 42\% /\sqrt{E_{\text{jet}}} \)
  for TESLA + EFLOW (Brient)

• Dijet Mass Resolution

Jet direction resolution is very important
Quick simulation without background (Y Fujii)

\[ \sigma_{m_{\ell}} \sim 1.3 \text{ GeV in } ZH \text{ mode} \]
\[ \sigma_{m_{\ell}} \sim 3.2 \text{ GeV in } W^- W^+ \text{ mode} \]

More complex events, and corresponding \( E_{\text{FLOW}} \) reconstruction would be interesting.

Closing Remark

Numerous options for calorimetry are under study

• Strong impression that as the simulations progress to multi-jet events with realistic hadron shower development, the advantages of the energy flow approach will be overriding.

⇒ High density with excellent transverse granularity and fine depth segmentation (voxel structure)
3D view $\pi^+$ 10 GeV

J.-C. Brient
<table>
<thead>
<tr>
<th>Beam Table</th>
<th>Detector Efficiency</th>
<th>Mass before EM</th>
<th>EM - 10%</th>
<th>EM ~ 50%</th>
<th>EM ~ 10%</th>
<th>EM ~ 5%</th>
<th>EM ~ 1%</th>
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<th>Other Options</th>
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- Cost optimization may be difficult. Expensive.
- R-field effect be investigated. Speed is.
- Position measured at each layer.

Resonance Measurement Limited

- Mechanical
  - Investigation
  - 3-fold effect investigated
  - Position measurement at many detectors. Fast

General Comments on Detector Options

1. Open
Particle ID ($K - \pi$ separation)

- Many issues have yet to be studied

- Strongest arguments are likely to be associated with the information from the vertex detector
  (eg distinguishing $b / \bar{b}$ and $c / \bar{c}$ jets)

- Linked to choice of tracking detector. If TPC, $K - \pi$ separation to 5 GeV/c can cover a good part of the range

- Space required, and material before the ECAL, will discourage gaseous focusing Cerenkov systems like CRID/RICH

- Focusing DIRC may be very interesting. Momentum range may be adequate. Needs serious study.
Muon Detection

- **Scale** ~ BaBar or Belle

- Several options:
  - Resistive plate chambers (RPC)
  - Scintillator bars and WLS fibres
  - Thin-gap chambers (MWPCs) (TGC)
  - Single-cell drift chambers

- Need $\sigma \sim 1$ cm

- Well-established technologies
  
  Large area, so cost is the driving factor.
Trigger and DAQ

- Only the LC will be able to cope with degenerate scenarios:
  \[ M_1 \sim M_2 \]
  eg \[ m_{\tilde{\chi}_1^0} \]
  \[ \text{given tag} \]
  char

- GMSB signatures
  \[ \tilde{\chi}_1^0 \rightarrow \tilde{\psi} \gamma \]
  non-pointing \( \gamma \) in calorimeter

- LC at \( \sqrt{s} = 1 \) TeV has less discovery range than LHC, but leaves no \textit{blind regions}

- All depends on very inclusive trigger

- Recent suggestions (Ralf Gerhards and Partick le Du) is to operate all detector elements in \textit{untriggered} mode

- Take advantage of long interval between bunch trains (8 ms at NLC/JLC, 200 ms at TESLA) to process data in \textit{generic general purpose processors}

- TESLA NLC
  
  Per Train 335 MB 13.5 MB
  Per Second 13 Gbit 16 Gbit

- Filtering such data volumes with \textit{multiple processors} and \textit{high bandwidth networks} is believed to be technically feasible. Many ideas being explored.

  \( \text{Vertex detector \& TPC \rightarrow Continuous read mode} \)
  
  \[ \text{Large} 1 \sim 5 \text{ms (NLC/JLC)} \]
  \[ \sim 75 \mu \text{s (TESLA)} \]
Summary and Suggestions

- Future LC has discovery potential complementary to LHC
- New physics may be seen as
  - multi-jet events (many jets being b- or c- flavoured)
  - modest energy clusters (degenerate scenarios)
  - non-pointing Js (GMSB)
  - novel particles with measurable lifetimes
- Physics backgrounds, specially from 2 – γ process, can be severe
- Machine backgrounds, specially from e+e- pairs produced by the beam-beam interaction, need careful handling (moderately high field solenoid certainly helps)
- Machine conditions (well-separated bunch trains) provide special opportunities:
  - Almost cable-free detector (as at SLD) → phenomenal hermeticity
  - low average power even with 10⁹ detector elements (vertex detector) → very low material budgets
  - untriggered readout with comprehensive event filters
- World-wide studies have revealed numerous options for all sub-detector systems:

  **Vertex**: CCD Hybrid APS Monolithic APS
  **Tracking**: CDC TPC Si μstrip Si drift
  **Calorimetry**: Si-W Scint tile Shashlik Crystal
- Numerous important open questions, eg:

  \[ r = 1 \text{ cm and } B = 3 \text{T OK?} \]
  
  \[ \text{L detector with fine-grained calorimeter OK? (cost)} \]
  
  \[ \theta_{\text{min}} \text{ for veto of energetic electrons?} \]
  
  \[ \text{intermediate tracker?} \]

  \[ \text{How robust is EFLOW in multi-jet environment?} \]

- **Simulations** are advancing rapidly

- **Detector R&D** is so far mainly parasitic on other projects, but this is beginning to change

- Physicists from the 3 regions are getting to know each other and sharing information and ideas

- **Convergence on one project by 2002/3** will be possible without trauma to the participating particle physicists. (For the accelerator scientists,...?)

- Setting aside the \( \gamma \gamma \) option (fading?) there will still be two detectors. Should encourage **complementary features, not necessarily** L and S.

  _Unlike LHC, with care the future LHC can be made a highly physics-friendly machine. Need to build it to find out what this will deliver in discoveries inaccessible to LHC._