Luminosity Calorimeter Technologies

- **SiW** - Silicon-tungsten sampling calorimeter (current Si tech)
- **Quartz Fiber** – Cerenkov longitudinal sampling (CMS HF)
- **Gas Cerenkov** – Cerenkov longitudinal sampling (new)
- **Parallel Plate Avalanche Ch** – gas sampling (current)
- **PbWO$_4$** – Continuous scintillating (CMS ECAL)
The Problem

- Bunch crossing (warm) 1.4 ns
- (cold) 337 ns
- Radiation dose ~100 MRad/y
- Pairs produced / crossing ~ 200 TeV
  \(<E> \sim 4 \text{ GeV}\)
  \(<x,y> \sim \text{several cms}\)
- Must see 250 GeV Bhabha e+e-
- Must veto 2-gamma background events
IP background calculation:
Takashi Maruyama, SLAC

With Current NLC IP Beam
Parameters:
# e+ or e- = 49,000/bunch
\(<E> = 4.1 \text{ GeV}
E_{\text{total}} = 199,000 \text{ GeV}

\(<E> = 4.1 \text{ GeV}

Energy (GeV)
Signal path: calorimeter to behind yoke

Only take signals out the back....
Si-W: 50 layers 2 mm W + 0.3 mm Si  
(M.Breidenbach, T.Maruyama, …)

**Strengths:** known technology, fine granularity, well simulated and well understood.

**Weaknesses:** Si may be radiation-soft, electron-hole drift is slow; recovery time long (compared to 1.4 ns).

- Zeuthen r-φ segmentation
- Rin = 1.0 cm
- Rout = 2.0 cm
SiW dose

Max $\sim 70$ MRad/y

20 April 2004

John Hauptman, Linear Collider Meeting, Paris, 19-23 April 2004
Results from RD50: Si is OK up to 1 Grad  (M. Moll, RD50/2003/001)

Most remarkable fact: oxygenated Si is impervious to electromagnetic radiation damage, i.e., OK for LC, and not OK for p’s and π’s, i.e., not OK for LHC.

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Quartz Fiber Calorimetry
(Spanier, Bugg & Onel, Winn)

**Strengths:** well understood (CMS-HF), fast and radiation-hard.

**Weaknesses:** time spread of signal ~ 1ns (almost OK); radiation hardness ~ 1 Grad (almost OK).

“Rapunzel”
The quartz fiber Hadronic Forward (HF) calorimeter of CMS is completely understood. Energy resolution, spatial resolution, radiation damage, Cerenkov light budget at all stages, uniformity, etc.

Fast for the 25-ns LHC
Slow for the 1.4-ns warm LC
Detailed understanding of everything in HF

Cerenkov photon budget at every physical stage of this new quartz fiber calorimeter

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Quartz Transmission vs. Dose & Dose Rate

Ray Thomas, Texas Tech University – using an electron accelerator

\[
\frac{1}{\lambda_{\text{atten}}} = \alpha D^\beta
\]

D (MRad), \(\alpha, \beta \sim 0.3\)

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And, at two more wavelengths
And, for each wavelength at two dose rates
Gas Cerenkov: Basic idea

- Shower particles generate Cerenkov light in gas between highly reflective metallic walls.
- Gas refractive index $n = 1 + \delta$, where $\delta \sim 0.001$ for most gases at STP.
- Cerenkov angle is small: $\sin \theta_C \approx \sqrt{2\delta} \approx 0.05$
- Cerenkov threshold is high: $E_{th} \approx \frac{m_e}{\sqrt{2\delta}} \approx 11.2$ MeV
- Cerenkov photons co-move with $e^{+/-}$ in a $15$ ps pancake

Very radiation-hard: only gas and metal.

Does not “see” IP $\gamma, e$ backgrounds nor radioactivation below $10-20$ MeV
Hex simulation
Parallel Plate Avalanche Chamber (PPAC)
(Onel, Norbeck)

- Low pressure gas, ~ 20 torr
- Plates at ~ 700 V
- Signal generation ~ 3 ns
- Positive ions take ~ 1 μs

PPACs are well understood and, for non-organic gases, would suffer little radiation damage.
PbWO$_4$ Crystals: CMS ECAL

- Well understood, tested.
- Signal generation $\sim 10$ ns
- Signal recovery $\sim 25$ ns
- QA problems during manufacture solved.
- Radiation hardness undergoing testing for time dependence of signal and signal loss.

(Note Bene: these dose rates are far below the 10 Rad/s for a LC luminosity monitor).
“Study of Radiation Damage in Lead Tungstate …”, ibid., Batarin, V.A., et al.,

27 GeV e- beam
Radiation hardness: \( \text{PbWO}_4 \) compared to quartz fiber

27 GeV e-
Batarin, et al.

Dose Rate Comparison at 450nm

Heavy Lines Represent Data

- 25 kRad/s
- 18 Rad/s
- 12 kRad/s
- 592 Rad/s
- 2.5 kRad/s

Transmission (%)

Accumulated Dose (Rad)
## Time scales (ns)

<table>
<thead>
<tr>
<th></th>
<th>Si-W</th>
<th>Quartz fiber</th>
<th>Gas Cerenkov</th>
<th>PPAC</th>
<th>PbWO4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal generation</td>
<td>3</td>
<td>~0</td>
<td>~0</td>
<td>1.65</td>
<td>10</td>
</tr>
<tr>
<td>Signal transmission</td>
<td>3</td>
<td>1</td>
<td>.3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Recovery time</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1000</td>
<td>25</td>
</tr>
<tr>
<td>DAQ time</td>
<td></td>
<td>1</td>
<td>1</td>
<td>?</td>
<td>1</td>
</tr>
</tbody>
</table>

20 April 2004  
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## Radiation Hardness

<table>
<thead>
<tr>
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<th>Quartz fiber</th>
<th>Gas Cerenk</th>
<th>PPAC</th>
<th>PbWO4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose-to-Death</strong></td>
<td>1 GRad</td>
<td>10 GRad</td>
<td>100 GRad</td>
<td>?</td>
<td>0.1 GRad</td>
</tr>
<tr>
<td><strong>Signal loss per 0.1 GRad</strong></td>
<td>1%</td>
<td>12%</td>
<td>1%</td>
<td>?</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Other potential signal losses</strong></td>
<td>on-wafer circuitry</td>
<td>-</td>
<td>R&lt;1.0 10%</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Main weakness</strong></td>
<td>defect generation</td>
<td>optical damage</td>
<td>optical transport</td>
<td>positive ions</td>
<td>optical damage</td>
</tr>
</tbody>
</table>
# Grade A, B, ..., → F

<table>
<thead>
<tr>
<th></th>
<th>Si-W</th>
<th>Quartz fiber</th>
<th>Gas Cerenkov</th>
<th>PPAC</th>
<th>PbWO4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>F</td>
<td>C</td>
</tr>
<tr>
<td>Radiation hardness</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>Physics strength</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Risk = 1/success</td>
<td>B</td>
<td>A</td>
<td>D</td>
<td>D</td>
<td>B</td>
</tr>
</tbody>
</table>
### Necessary R&D and beam tests...

<table>
<thead>
<tr>
<th>Material</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si-W</td>
<td>(1) radiation damage tests – see TTU work above</td>
</tr>
<tr>
<td></td>
<td>(2) expose a few Si layers to 1.4 ns test beam</td>
</tr>
<tr>
<td>Quartz fiber</td>
<td>(1) test in 1.4 ns test beam</td>
</tr>
<tr>
<td></td>
<td>(2) test sensitivity to low energy e’s in IR</td>
</tr>
<tr>
<td>Gas Cerenkov</td>
<td>(1) manufacture smooth metallic surfaces</td>
</tr>
<tr>
<td></td>
<td>(2) test in 1.4 ns test beam</td>
</tr>
<tr>
<td>PPAC</td>
<td>(1) test multilayer PPAC in “hot” source, first. If Δt&lt;5ns,</td>
</tr>
<tr>
<td></td>
<td>(2) expose to 1.4 ns test beam</td>
</tr>
<tr>
<td>PbWO$_4$</td>
<td>(1) radiation hardness at 100 MRad level – see TTU work</td>
</tr>
<tr>
<td></td>
<td>(2) test for time scale of recovery in fast beam</td>
</tr>
</tbody>
</table>
Summary

• Good ideas, but any contender must be dosed (at SLAC or elsewhere) at high rate and to high dose levels.

• Proponents must produce a “dose-to-death” number. This is not easy.

• We need an estimate of the additional dose to the luminosity monitor not associated with bunch crossings.

• For the warm LC, signal generation and recovery times should allow integration over only 1-2 bunches, not more, for the critical early stages of tuning the linac beams. The luminosity made depend on bunch number …

• Timing constraints are largely absent for the cold machine with 337 ns bunch spacing.