Heavy Flavour Identification at Linear Colliders

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Linear Collider Flavour Identification

- Has been focusing on ILC

- Bristol
- Edinburgh
- Glasgow
- Liverpool
- Nijmegen
- Oxford
- RAL
Flavour Physics

- Precision detectors close to interaction point
- Distinguish tracks from secondary vertices
  - Identify, separate $b$, $c$ quarks and $\tau$ leptons
  - Measure charge
Flavour Tagging

- $b$-tagging fairly robust at the ILC
- $c$-tagging more detector dependent
  - Measure Higgs branching ratios
  - ...

![Diagram 1](image1.png)

- $ee \rightarrow Z \rightarrow qq$ @ 91 GeV
- Full Monte Carlo - LDC01_05Sc
- Full reconstruction

![Diagram 2](image2.png)

- Coupling constant to Higgs Boson, $g_x$
- Typical precisions at ILC
- $H^+$, $W$, $Z$
Vertex Charge

- Add charge of all tracks in vertex
- Identify charge of flavoured hadron
  - Can distinguish quark/antiquark
  - Measure hadronic asymmetries
  - Anomalous couplings, LEDs...

Forward – Backward Asymmetry of reconstructed bbar

- Sensitive to detector parameters
  - Acceptance
  - Material
  - Geometry...
ILC Vertex Detector

- 800M 20×20µm² pixels
- 5 layers, inner radius ~ 1.5 cm
- Gas cooling
  - 0.1% $X_0$ per layer in active region
  - Uniform material distribution
Mechanics

Material target equivalent to 100 μm silicon

- Thinning silicon to 50-100 μm becoming routine
- Thinning to epitaxial possible

- Ladders with bulkheads
  1. Unsupported silicon
     - can’t control lateral curl
  2. Laterally stiffened silicon
  3. Rigid structures
Thin Substrates

- Longitudinal stiffness from tensioning
- Lateral stiffness from thin substrate
  - Beryllium: good specific stiffness but bad CTE
  - Carbon fibre good candidate
    - 0.09% $X_0$ test model
    - laterally stability insufficient

profile of silicon along the length of a ladder

Deviation in z (um)

- SI on CF (at 20 deg C)
- SI on CF (at -50 deg C)
- SI on Steel (at 20 deg C)
- SI on Steel (at -50 deg C)
Foam Ladders

- 25 micron silicon on 1.5mm 8% SiC
  - Very rigid
  - Achieved 0.14% $X_0$

- 20 micron silicon sandwiching 1.5mm 2% carbon
  - Could be double-sided
  - Achieved 0.07% $X_0$

More exotic rigid structures possible
RVC Foam

- Reticulated Vitreous Carbon
  - 2-3% relative density
  - Not stiff enough for one-sided
RVC Results

- Shape due to fabrication technique
  - New fixtures look promising
  - Difficult to control behaviour
SiC Foam Ladder

- Processed 8% SiC Foam
  - A fraction of initial shape left
  - 30% over material budget
  - Now have 3-4% foams
- Minimally constrained
  - Eliminate stiction in mountings

Negligible deformation over 70 degrees!
Foam Future

- SiC seems extremely promising
  - Lower density now in hand
  - Learning how to process
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The ILC Challenge

ILC bunch structure:
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- Once per train ~200 hits/mm²: *too slow*
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- And gas cooled!
Sensor R&D

- **Column Parallel CCDs**
  - Focus so far - building on past experience
  - Readout during bunch train

- **Image Sensor with In-situ Storage**
  - Increased robustness
  - Reduced driver requirements
CP CCDs

- Separate readout for each column
- 50 MHz clock rate
- Clock drive is real challenge

Column Parallel CCD
Readout time = (N+1)/F_{out}
• RAL-designed ASIC
  ▸ Bump-bonded on 20µm pitch
  ▸ Latest has cluster finding
High Speed CPCCDs

- Two metal layers
- Distributed clocks
  - Faster
  - More uniform
- Old and new ASICs
CPC-2

- 1, 4, 10 cm long variants
- Custom clock driver ASIC
- Tested up to 45 MHz

Noise $\sim 75e^-$
• Store charge in CCD register within each pixel
• Orders of magnitude increased resistance to RF
• Much reduced clocking requirements \((\text{readout} \sim 1 \text{MHz})\)
• Combination of CCD and CMOS technology on small pitch
ISIS-1

- Proof-of-principle in CCD process
  - 16×16 array
  - 5 time samples
isis-1 Tests

- Tested with $^{55}\text{Fe}$ and 6 GeV $e^{-}$
- X-rays and MIPS clearly seen
- Position resolution $\sim 12\mu$m
ISIS-1 at CERN

- Testing in CERN 120 GeV pion beam
• Custom CMOS process
• 800µm² pixels
• 20 time samples
  ‣ Close to targets
  ‣ Wafers being diced
Summary

- Complete ILC vertex detector package
- Good progress in
  - Software and physics studies
  - Mechanics
  - Sensors
- Applicability beyond ILC
  - Continue much as generic R&D