Track Timing at $e^+e^-$ Linear Collider with the Silicon Drift Detector Main Tracker

R. Bellwied, D. Cinabro, V. L. Rykov
Wayne State University
Detroit, Michigan

Introduction

Technology options for the central Main Tracker (MT);
Collision time structure and event pile-up;
Track time-stamping with the TPC.

Silicon Drift Detector (SDD) based central MT

Track selection

Track timing

Conclusion
Introduction: Options for the technology of Main Tracker

Projective

- Drift Chamber
- Silicon Microstrips

3D pixel

- Time projection chamber (TPC): Maximum drift time ~ 40-60 μs
- Silicon Drift Detectors (SDD): Maximum drift time ~ 6-8 μs

Event pile-up: How serious is this problem?
Introduction: Collision time-structure and event pile-up

Train or Rf-pulse

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NLC</th>
<th>JLC</th>
<th>TESLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train length, $\mu s$</td>
<td>0.265</td>
<td>0.265</td>
<td>950</td>
</tr>
<tr>
<td>Number of bunches/Train</td>
<td>190</td>
<td>190</td>
<td>~2800</td>
</tr>
<tr>
<td>Bunch separation, $ns$</td>
<td>1.4</td>
<td>1.4</td>
<td>337</td>
</tr>
<tr>
<td>Repetition rate, $Hz$</td>
<td>120</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Background $\gamma\gamma$-events in TPC</td>
<td>2-3</td>
<td>2-3</td>
<td>3-5</td>
</tr>
<tr>
<td>Background $\gamma\gamma$-events in SDD</td>
<td>2-3</td>
<td>2-3</td>
<td>~0.5</td>
</tr>
</tbody>
</table>

\[ L = (2-3) \cdot 10^{34} cm^{-2}s^{-1} \]

For NLC/JLC, it is expected ~2.2 hadronic $\gamma\gamma$-events per train, in addition to the trigger, with the average number of tracks ~17 and energy deposit in the calorimeter ~100 GeV per such an event. 

* T. Abe et al, Physics Resource Book for Snowmass 2001 and ref. therein
Track time stamping with the TPC

- It is recognized that, if the time stamping for the tracks in the TPC or SDD is not done, it could seriously impact the detector performance, particularly its missing mass resolution.

- Sorting out tracks, using the Main Tracker only is always the most desirable option.

- The suggested solution for the TPC was to place, at some TPC depth, fast intermediate tracker, made from scintillating fibers and/or silicon intermediate tracking layer inside the TPC.

(Physics Resource Book, 2001)
5 SDD barrels at radii from 20 to 125 cm.

~56 m² area covered with ~5600 SDD-wafers of the size 10x10 cm².
STAR Silicon Vertex Tracker (SVT)

- **3 SDD barrels at radii ~ 6.5, 10.5, and 14.5 cm.**
- **~0.86 m² area covered with ~216 SDD wafers (double-SDD) of the size 6.3x6.3 cm².**
- **Drift along azimuth (local ϕ-axis).**

Drift along magnetic field (z-axis) is preferable for better P_T-resolution.
Correct timing: 
Hit positions are determined correctly, and fit to a track with a good $\chi^2$.

Wrong timing with some hit SDDs drifting in the opposite directions to the others (probability $15/16^{th} = 93.75\%$): 
Hit positions are determined incorrectly, and do not fit to a track, i.e. $\chi^2$ is bad.

Wrong timing with all hit SDDs drifting the same direction (probability $1/16^{th} = 6.25\%$): 
Hit positions are determined incorrectly, but still fit to a shifted track with a good $\chi^2$. 

Track time stamping: All SDD drifting along same axis
Vertex Detector (VXD):
- 5 CCD layers of the thickness $0.12\% X_0$ each
  - at the distances of 1.2, 2.4, 3.6, 4.8 and 6.0 cm
- Spatial resolution (both directions), $\sigma_{\text{vxd}} = 5 \mu m$
- Vertex position assumed to be known at $\sigma_{\text{vtx}} = 2 \mu m$

Central Main Tracker (MT):
- 5 flat SDD layers of the thickness $0.5\% X_0$ each
  - at the distances of 20, 46.25, 72.5, 98.75 and 125 cm
- High voltage = 2500 V/5 cm = 50 V/mm
- Drift velocity = 6.75 mm/µs
- Spatial resolution along anodes, $\sigma_{\text{anode}} = 7 \mu m$
- Spatial resolution along drift, $\sigma_{\text{drift}} = 10 \mu m$

Other simulation parameters and characteristics:
- Solenoidal magnetic field, $B = 5 T$
- Phase space: $-0.8 < \cos \theta < 0.8; \quad 0 < \varphi < 2\pi$
- Multiple scattering in beam pipe, VXD & MT, cryostat, air, etc. was accounted in the both, helical track generation and reconstruction procedures.
- More details on the SD-option geometry for the LC detector are at:
  
  http://www-mhp.physics.lsa.umich.edu/~keithr/LC/baselines_mar01.html
Track selection: All MT layers drifting along z-axis

Examples of track separation

- Various options for drift directions.

- $\Delta t = 10$ ns

- The best separation is with the drift directions alternated from layer to layer.

- In the MT only, no time separation for $\sim 6\%$ of tracks, which hit SDDs, drifting the same direction.
Track selection: Drift in MT layers - \( \ldots \)

Examples of track separation

Tracking system for SD-MAR01 detector

- Silicon (SDD or \( \mu \)-strip) barrel
- Si \( \mu \)-Strip
- Disk Tracker
- CCD Vertex Detector (+ cryostat)

\( \cos(\theta) = 0.80 \)
\( \cos(\theta) = 0.90 \)
\( \cos(\theta) = 0.99 \)
Various drift axis combinations in MT layers

Examples of track separation

Randomly Distributed drift directions

$\Delta t = 10 \text{ ns}$

The best separation is with the drift axes alternated from layer to layer:
$z\phi z\phi z$ and $\phi z\phi z\phi$
Various drift axis combinations in MT layers

Impact on $P_T$-resolution:

\[ \sigma_{\text{anode}} = 7 \ \mu m \]
\[ \sigma_{\text{drift}} = 10 \ \mu m \]

- In the options $\varphi z \varphi z$ (the best for time stamping), momentum resolution at high $P_T$ deteriorates by $\sim 10\%$, compared to $zzzzz$ (the best for $P_T$ resolution).

- There is virtually no worsening of momentum resolution for $zzz\varphi z$ drift.
One more step forward: **Track timing**

Introducing one more parameter: track generation time, in the fits of hit sets, which are tried as potential tracks.
With the SDD based main tracker, Track Timing is possible at nanosecond and, at high-$P_T$, even at sub-nanosecond level.

The best drift combinations are $z\phi z\phi z$ (and $\phi z\phi z\phi$) and $z z z z \phi z$ with no worsening of $P_T$- resolution compared to $z z z z z z z$ (ultimately the best for $P_T$).
Conclusion

- It is shown that, with the SDD based central Main Tracker for the detector at e+e- Linear Collider, the track selection and timing is possible at the \textit{nanosecond} and even \textit{sub-nanosecond} level.

- This means that, even at the NLC and/or JLC with the bunch spacing at 1.4 ns, each high-P_T track can be assigned to a particular bunch crossing at the confidential level of up to \( \sim 2\sigma \).

- For the considered here 5-layer central Main Tracker, it is suggested to make layers 1, 2, 3 and 5 drifting along z-axis, but layer 4 drifting along the azimuth (\( \phi \)-axis) with effectively no negative impact on the tracker’s momentum resolution. In other words, all the above is just \textit{for free} with the SDD Main Tracker.