The CDF Silicon Vertex Trigger

Vertex 2002

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The Silicon Vertex Trigger was designed and built for the CDF collaboration by people from the following institutions:

- INFN – Pisa
- INFN – Trieste
- University of Chicago
- Université de Genève
CDF r-z view

- CDF
- SVT

Diagram of the CDF r-z view showing various components such as the SVX II, Intermediate Silicon Layers, and other calorimeters.
Why and how?

• Trigger on B hadronic decays
  – B physics studies, eg. CP violation in B decays, Bs mixing
  – new particle searches, eg. Higgs, Supersymmetry
• A b-trigger is particularly important at hadron colliders
  – large B production cross section for B physics
  – high energy available to produce new particles decaying to b quarks
  – overwhelming QCD background
    • need to improve S/B at trigger level

• Detect large impact parameter tracks from B decays using the fact that \( \tau(B) \approx 1.5 \) ps

Technical challenge!
SVT: Silicon Vertex Trigger

Inputs:
- L1 tracks from XFT ($\phi$, $p_T$)
- SVX II digitized pulse heights from SVX II

Functionalities:
- Hit cluster finding
- Pattern recognition
- Track fitting

Outputs:
- Reconstructed tracks ($d$, $\phi$, $p_T$)

Additional notes:
- COX track (2 parameters)
- Impact parameter (transverse projection)
- Beam spot coordinates
Triggering in Run 2

Dataflow of CDF "Deadtimeless" Trigger and DAQ

Detector

7.6 MHz Crossing rate
132 ns clock cycle

L1 Storage Pipeline:
42 Clock Cycles Deep

L1 Accept

L1 Trigger

Level 1:
7.6 MHz Synch. pipeline
5544 ns latency
45 kHz

L1 Accept

L2 Buffers:
4 Events

L2 Accept

L2 Trigger

Level 2:
Asynch. 2 stage pipeline
~20 µs latency
300 Hz

L1+L2 rejection: 20,000:1

DAQ Buffers

L3 Farm

Mass Storage

60 Hz
~20 MB/s

Central Tracker (Pt, φ)
EM + HAD/EM + Track
EM+HAD (Jet)
Muon + Track
Missing E_T, Σ E_T

Si Secondary vertex
EM shower max, ISO
Jet Clustering
Multi object triggers

Farm of ~200 PC's running fast versions of Offline Code ➔ more sophisticated selections
CDF Run II trigger architecture

- Tracking system
  - central outer tracking (COT)
  - silicon tracking (SVX II & ISL)

- three-level trigger
  - L1: 5.5 μs pipeline
    - XFT: L1 2D COT track
  - L2: ~20 μs processing time
    - two stages of 10 μs

- SVT at stage 1 of L2
  - SVX II readout
  - hit cluster finding
  - pattern recognition
  - track fitting
Finding tracks in the silicon
Building the “Pattern Bank”

\[ f(x_1, x_2, x_3, \ldots) = 0 \]

1. Build a database with all patterns corresponding to “good” tracks
2. Compare hits in each event with all patterns to find track candidates

In this example:
Straight lines, 5 layers, 12 bins/layer

Total number of patterns \( \sim (12)^2 \times (5-1) = 576 \)
AM chip internal structure

- **AB<6:0>** (R/W MODE)
- **SEL<2:0>**
- **SELECT PLANE DECODER**
- **DATA BUS MULTIPLEXER**
- **DB<11:0>**
- **OPC<3:0>**
- **ENP**
- **SEL**
- **CLKB**
- **CLKA**
- **OR**

**ADDRESS DECODER**

- **pattern 0**
  - layer0
  - layer1
  - layer2
  - layer3
  - layer4
  - layer5

- **12 bits word**
- **12 bits compar.**
- **HIT BIT**

- **HIT COUNTER**
- **MATCH BIT**

- **ADDRESS ENCODER**
- **pattern 1**
  - 12 bits word
  - 12 bits compar.
  - HIT BIT

- **pattern 127**
  - 12 bits word
  - 12 bits compar.
  - HIT BIT

- **HIT BIT**
- **COUNT SHIFT**
AMchip

SVT
Amplug: mezzanine board
128 Amchips
x 128 patterns each
= 16K pattern board
SVT basic architecture

- Pattern recognition and track fitting done separately and pipelined

Pattern recognition with Associative Memory (AM)
highly parallel algorithm using coarser resolution to reduce memory size

Fast track fitting with linear approximation using full resolution of the silicon vertex detector
Non-linear geometrical constraint for a circle:

\[ F(x_1, x_2, x_3, \ldots) = 0 \]

But for sufficiently small displacements:

\[ F(x_1, x_2, x_3, \ldots) \approx a_0 + a_1 \Delta x_1 + a_2 \Delta x_2 + a_3 \Delta x_3 + \ldots = 0 \]

(First order expansion of)

With constant \( \Delta x_i \)
Constraint surface

6 coordinates: $x_1, x_2, x_3, x_4, x_5, (P_T), x_6 (\phi)$

3 parameters to fit: $P_T, \phi, d$

3 constraints

Tangent plane:

$$\sum_{i=1}^{d} a_i x_i = b$$

Track parameters:

$$d \approx c_0 + \sum_{i=1}^{c} c_i x_i$$

Linear approximation is so good that a single set of constants is sufficient for a whole detector wedge ($30^\circ$ in $\phi$)
SVT Wedges
SVT system architecture

raw data from SVX front end

Hit Finders

COT tracks from XTRP

Sequencer

Associative Memory

Track Fitter
to Level 2

12 fibers

x 12 phi sectors

Merger

Hit Buffer

hits

roads

hits
<table>
<thead>
<tr>
<th>Component</th>
<th>Count</th>
</tr>
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<tbody>
<tr>
<td>Hit Finders</td>
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<tr>
<td>Mergers</td>
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<td>XTFC</td>
<td>6</td>
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<tr>
<td>Ghostbuster</td>
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</tr>
</tbody>
</table>

**TOTAL** 136 + spares
SVT: board and crate layout

- CPU
- Tracer
- Spy Control
- Hit Finder
- Sequencer
- Associative Memory
- Merger
- Hit Buffer
- Track Fitter
- XTFA
- XTFB
- XTFC

SVT: board and crate layout

- b0svt00
- b0svt07
- b0svt06
- b0svt05
- b0svt01
- b0svt02
- b0svt03
- b0svt04
Hit Buffer board
Merger board
SVT crates in CDF counting room
Impact parameter vs. phi

\[ d = y \cos(\phi) - x \sin(\phi) \]
SVT: beam profile

Impact parameter distribution

This distribution is interpreted as the convolution of the actual transverse size of the beam spot with the impact parameter resolution of the SVT.

\[ \sigma \approx 50 \text{ um} \approx 43 \text{ um} \pm 25 \text{ um} \]

SVT resolution beam spot size
Beam center at beginning of store normally stable within 20 microns.

Drift during the duration of a store of 20 to 30 microns in x,y (often correlated)

Beam slope more stable (variation <20 microradians)

TeV store ~12 hours
Hadronic B decays with SVT

@ 3 x 10^{31} \text{cm}^{-2} \text{s}^{-1}

~ 3 \text{ KHz}

~ 5 \text{ Hz}

Two paths

\begin{itemize}
\item L1:
  \begin{itemize}
  \item Two XFT tracks
  \item \( P_t > 2.5 \text{ GeV}; \; P_{t1} + P_{t2} > 6.5 \text{ GeV} \)
  \item \( \Delta \phi < 135^\circ \)
  \end{itemize}
\item L2:
  \begin{itemize}
  \item \( d_0 > 100 \mu\text{m} \) for both tracks
  \item Validation of L1 cuts with \( \Delta \phi > 2^\circ \)
  \item \( L_{xy} > 200 \mu\text{m} \)
  \item \( d_0(B) < 140 \mu\text{m} \)
  \end{itemize}
\end{itemize}

Two body decays

\begin{itemize}
\item L1:
  \begin{itemize}
  \item Two XFT tracks
  \item \( P_t > 2.5 \text{ GeV}; \; P_{t1} + P_{t2} > 6.5 \text{ GeV} \)
  \item \( \Delta \phi < 135^\circ \)
  \end{itemize}
\item L2:
  \begin{itemize}
  \item \( d_0 > 120 \mu\text{m} \) for both tracks
  \item Validation of L1 cuts with \( \Delta \phi > 2^\circ \)
  \item \( L_{xy} > 200 \mu\text{m} \)
  \item \( d_0(B) < 140 \mu\text{m} \)
  \end{itemize}
\end{itemize}

Many body decays
CDF as a Charm factory?

CDF Run II Preliminary

$D^0 \rightarrow K\pi$

$N_{D^0} = 56320 \pm 490$

CDF Run 2 Preliminary

$D^\pm \rightarrow K\pi\pi$

$N_{D^\pm} = 25570 \pm 160$
Fully Hadronic B decays

CDF Run 2 Preliminary

$L = 11 \text{ pb}^{-1}, 18 \text{ June 2002}$

$B \rightarrow h^+h^-$

33$\pm$9 signal events

Mean $5.215 \pm 0.013 \text{ GeV/c}^2$

Width $0.053 \pm 0.011 \text{ GeV/c}^2$

CDF Run II Preliminary

$L = 10 \text{ pb}^{-1}$

$B^\pm \rightarrow D^0 \pi \rightarrow K\pi\pi$

Events per 20 MeV/c$^2$

B Mass [GeV/c$^2$]
The design and construction of SVT was a significant step forward in the technology of fast track finding.

We use a massively parallel/pipelined architecture combined with some innovative techniques such as the associative memory and linearized track fitting.

SVT is now fully commissioned and we have shown we can handle all the technical challenges related to detector and beam alignment in real time.

Performance of SVT is as expected.

CDF is triggering on impact parameter and collecting data we hope will soon lead to significant physics results.