The CDF Silicon Vertex Trigger

Vertex 2002

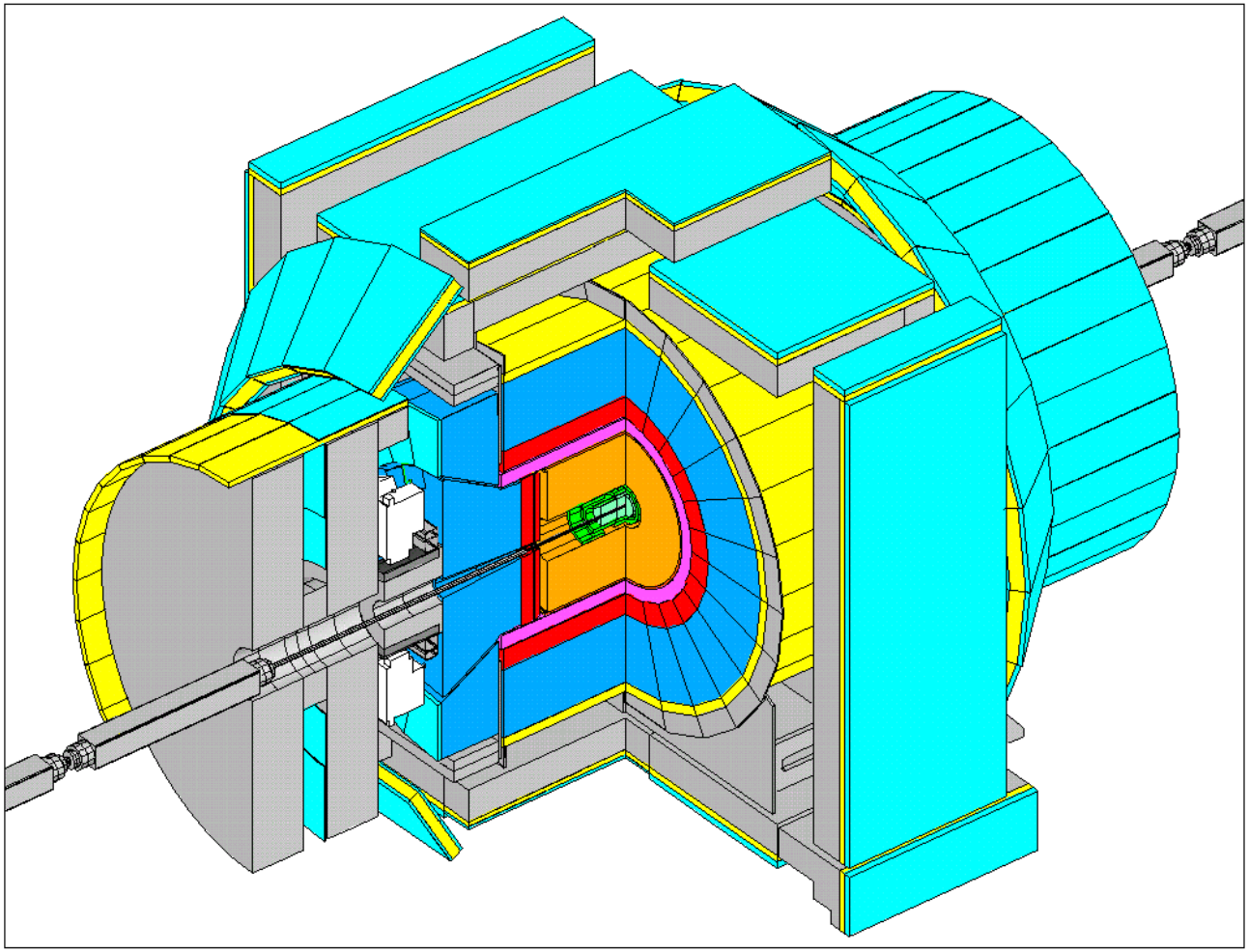
Luciano Ristori
Istituto Nazionale di Fisica Nucleare
Pisa – Italy

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

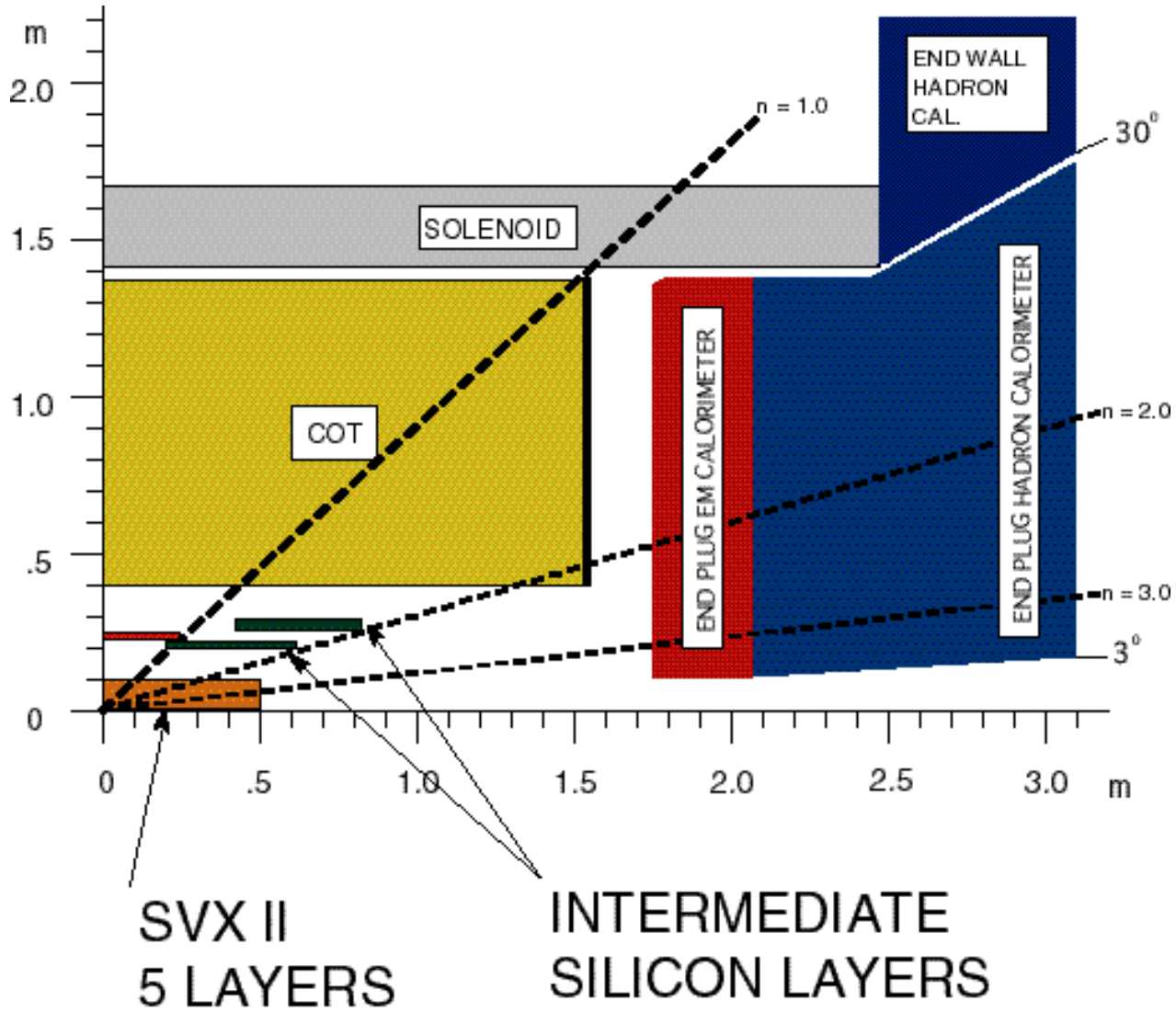
- INFN – Pisa
- INFN – Trieste
- University of Chicago
- Université de Genève

CDF DETECTOR

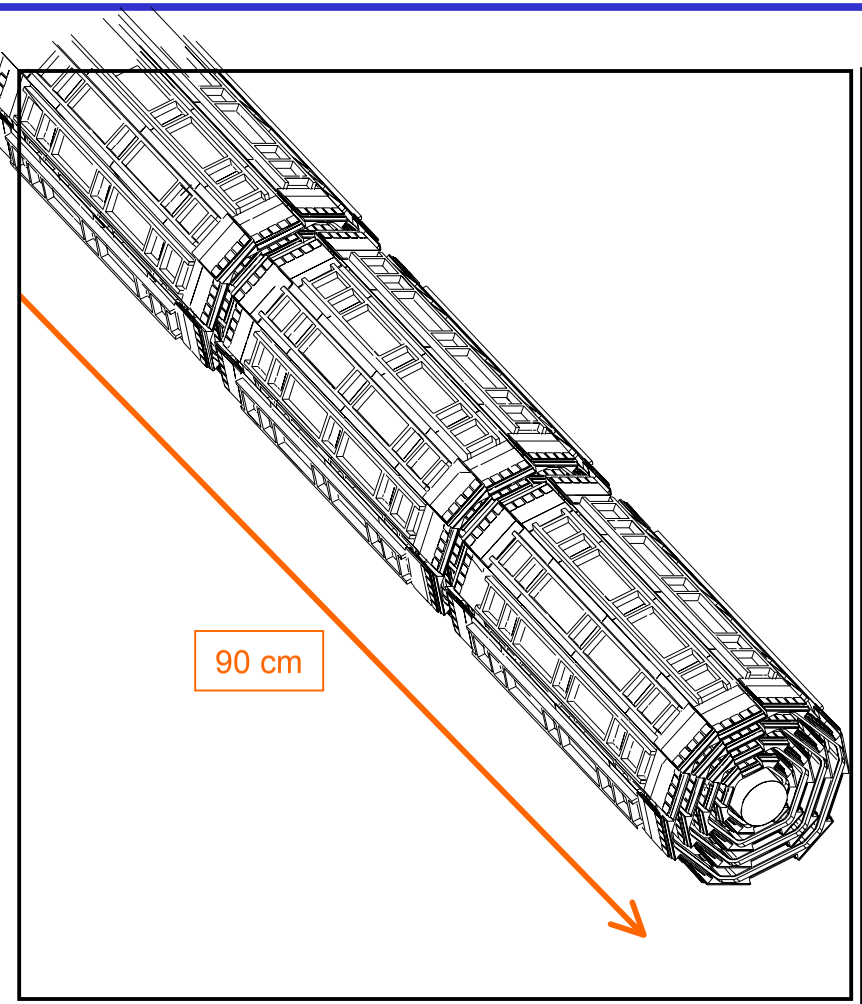
SVT

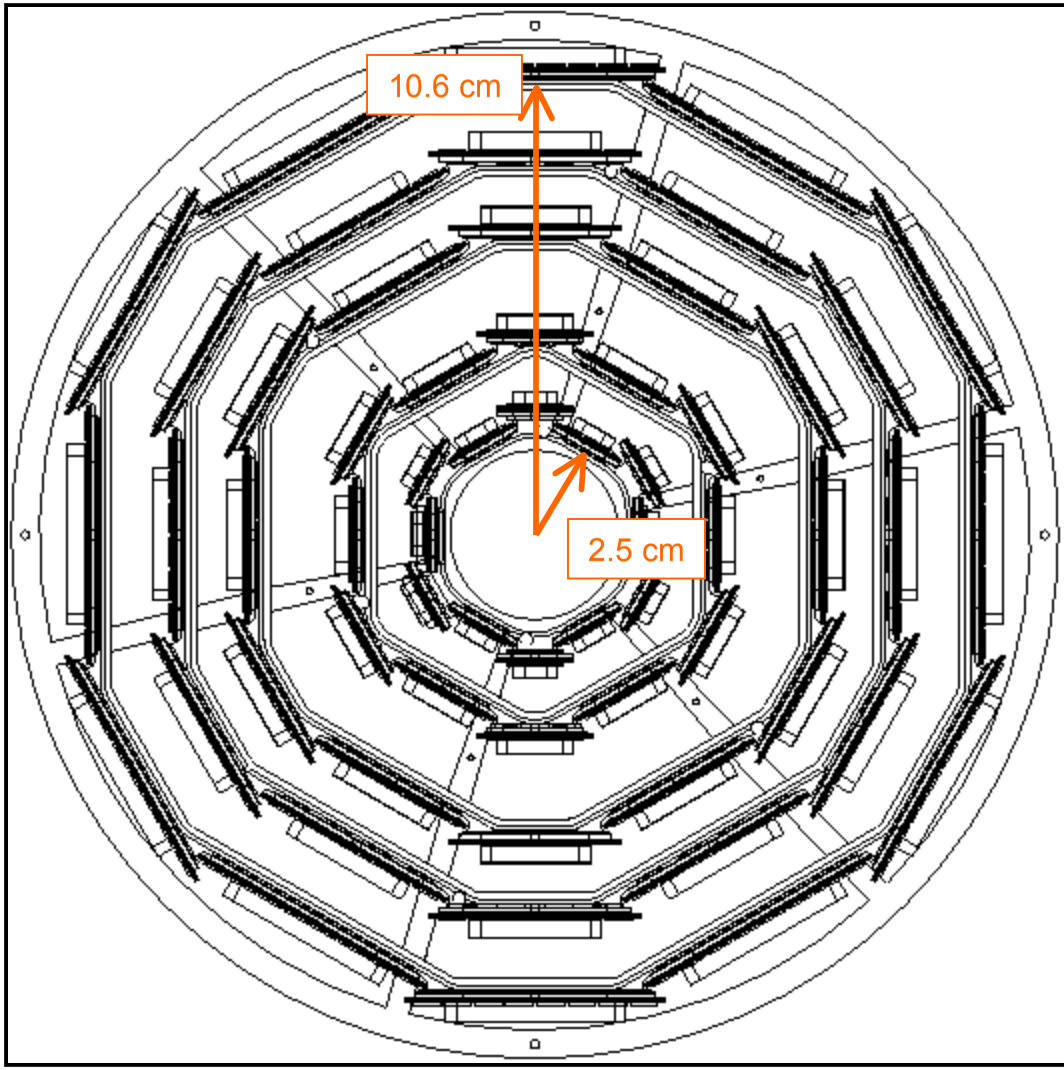


CDF r-z view


m
2.0
1.5
1.0
.5
0
0
.5
1.0
1.5
2.0
2.5
3.0
m
n = 1.0
n = 2.0
n = 3.0
30°
3°
END WALL
HADRON
CAL.
SOLENOID
COT
END PLUG EM CALORIMETER
END PLUG HADRON CALORIMETER
SVX II
5 LAYERS
INTERMEDIATE
SILICON LAYERS

SVX II



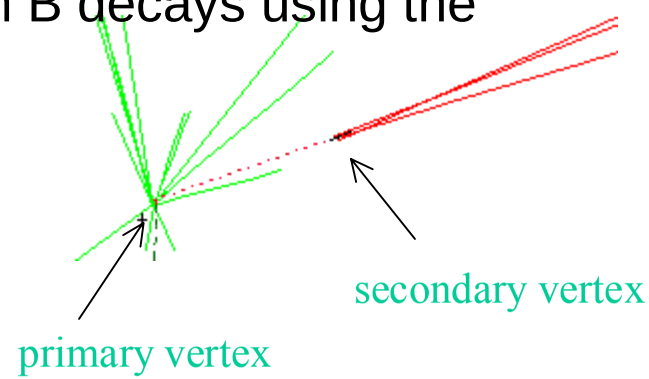


Why and how?

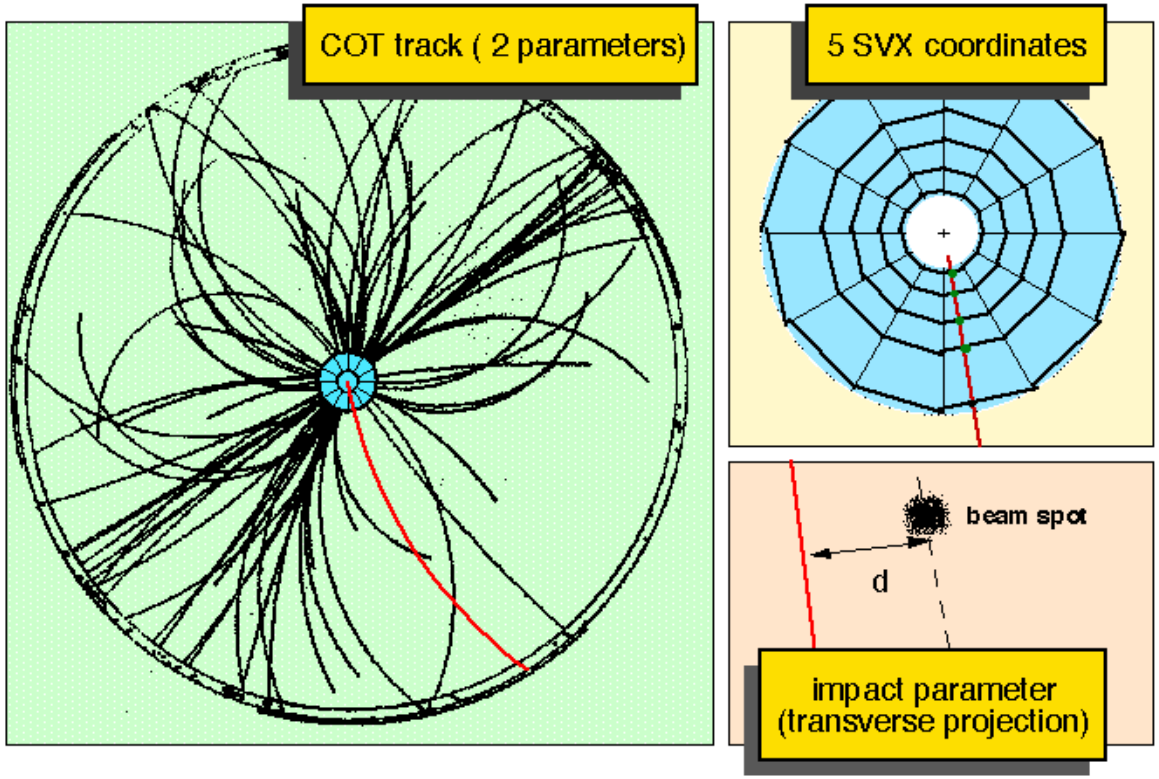
- Trigger on B hadronic decays
  - B physics studies, eg. CP violation in B decays, Bs mixing
  - new particle searches, eg. Higgs, Supersymmetry
- A b-trigger is particularly important at hadron colliders
  - large B production cross section for B physics
  - high energy available to produce new particles 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 (ϕ, p_T)
- digitized pulse heights from SVX II

Functionalities:

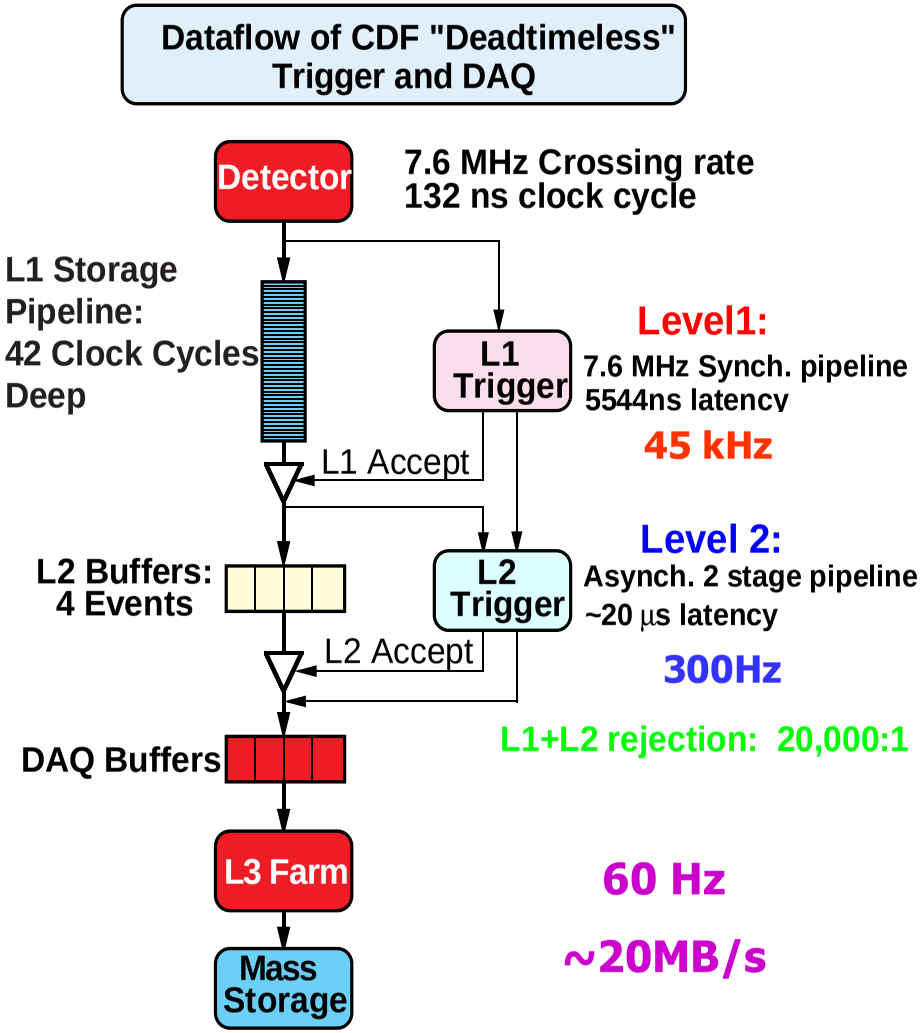
- hit cluster finding
- pattern recognition
- track fitting

Outputs:

- reconstructed tracks (d, ϕ, p_T)

Triggering in Run 2

SVT

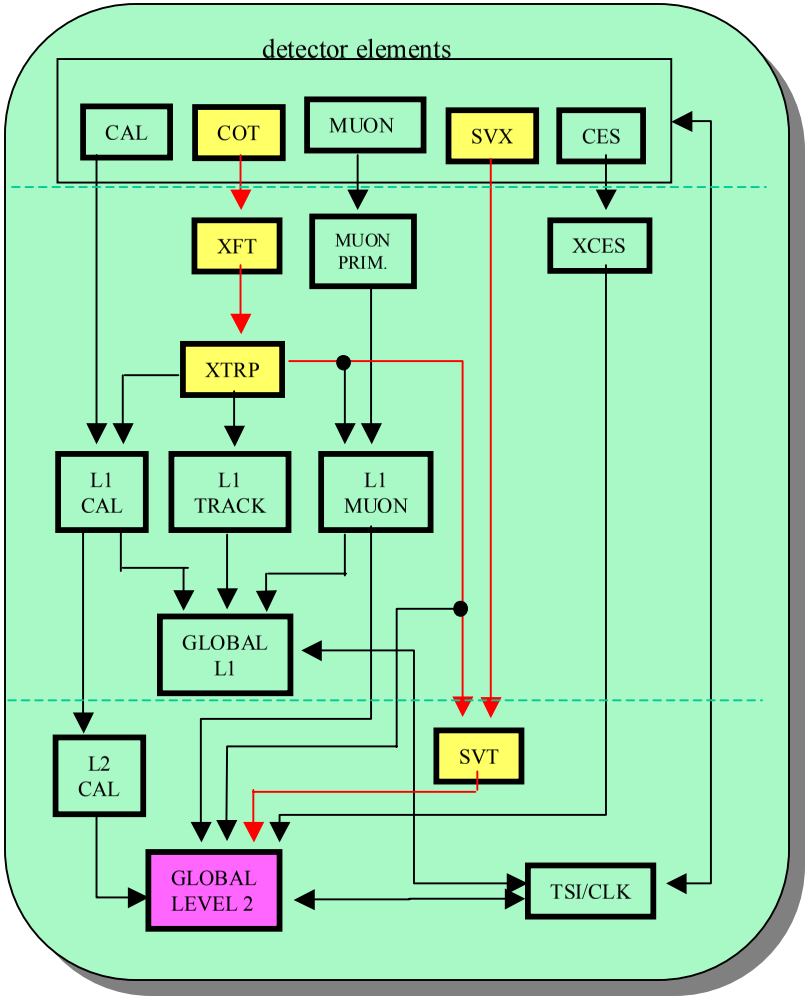


Central Tracker (Pt,ϕ)
EM + HAD/EM + Track
EM+HAD (Jet)
Muon + Track
Missing E_T, ΣE_T

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

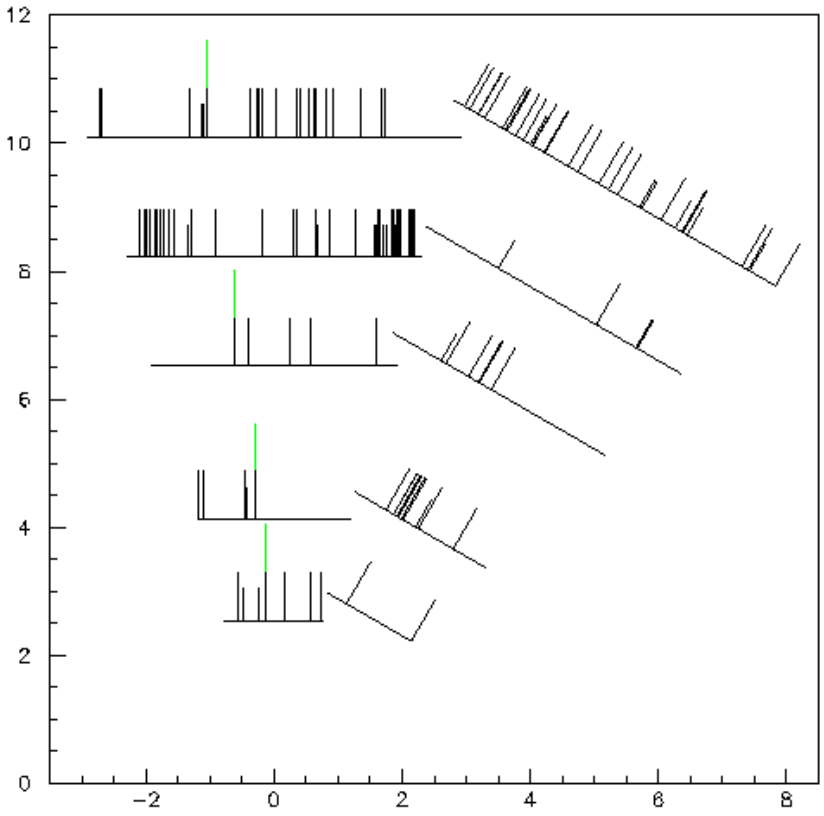
CDF Run II trigger architecture

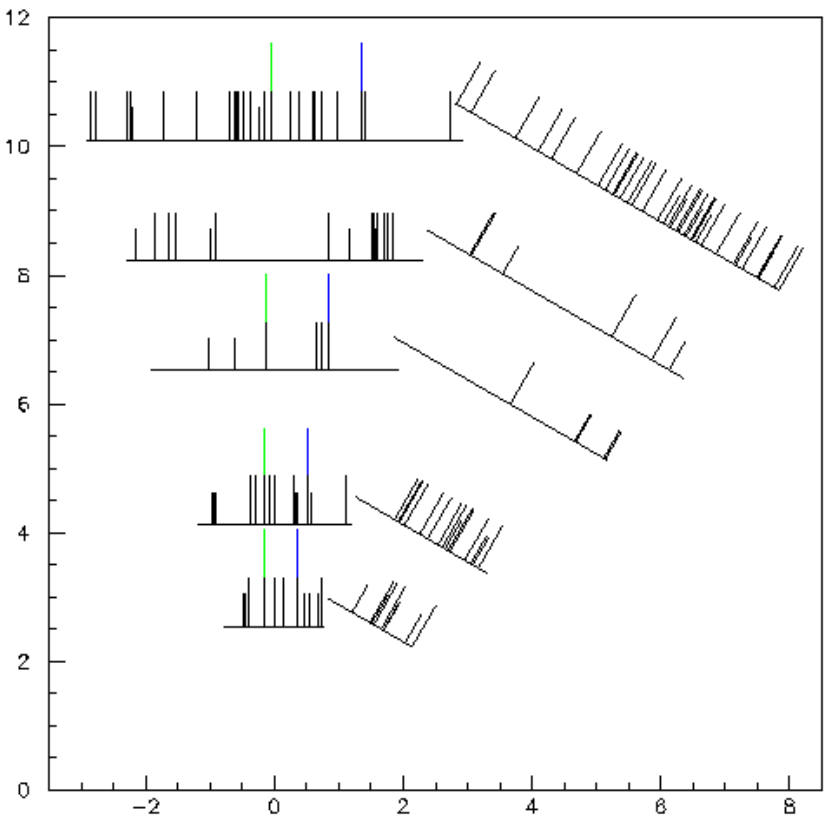


- Tracking system
  - central outer tracking (COT)
  - silicon tracking (SVX II & ISL)
- three-level trigger
  - L1: 5.5 μs pipeline
    - XFT: L1 2D COT track
  - L2: ~20 μs processing time
    - two stages of 10 μs
- SVT at stage 1 of L2
  - SVX II readout
  - hit cluster finding
  - pattern recognition
  - track fitting

Finding tracks in the silicon

SVT



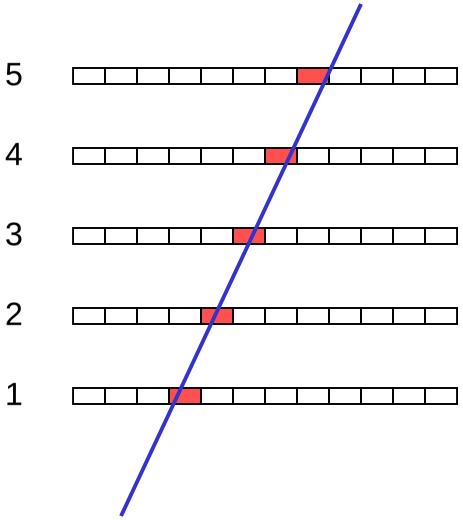


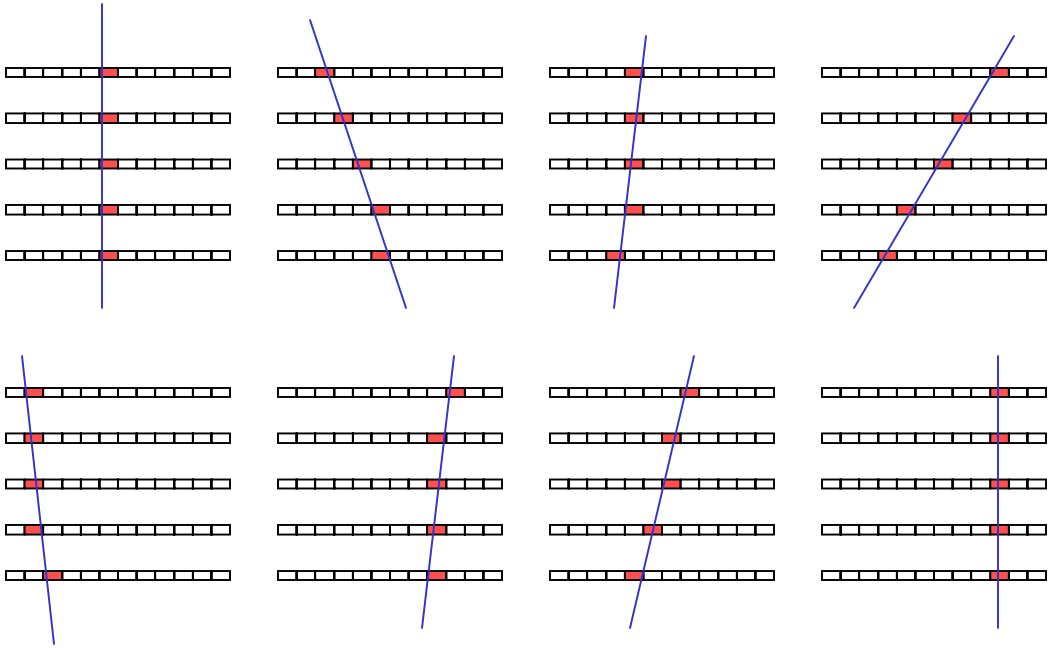
Building the "Pattern Bank"

SVT

$f(x1,x2,x3,\ldots) = 0$

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

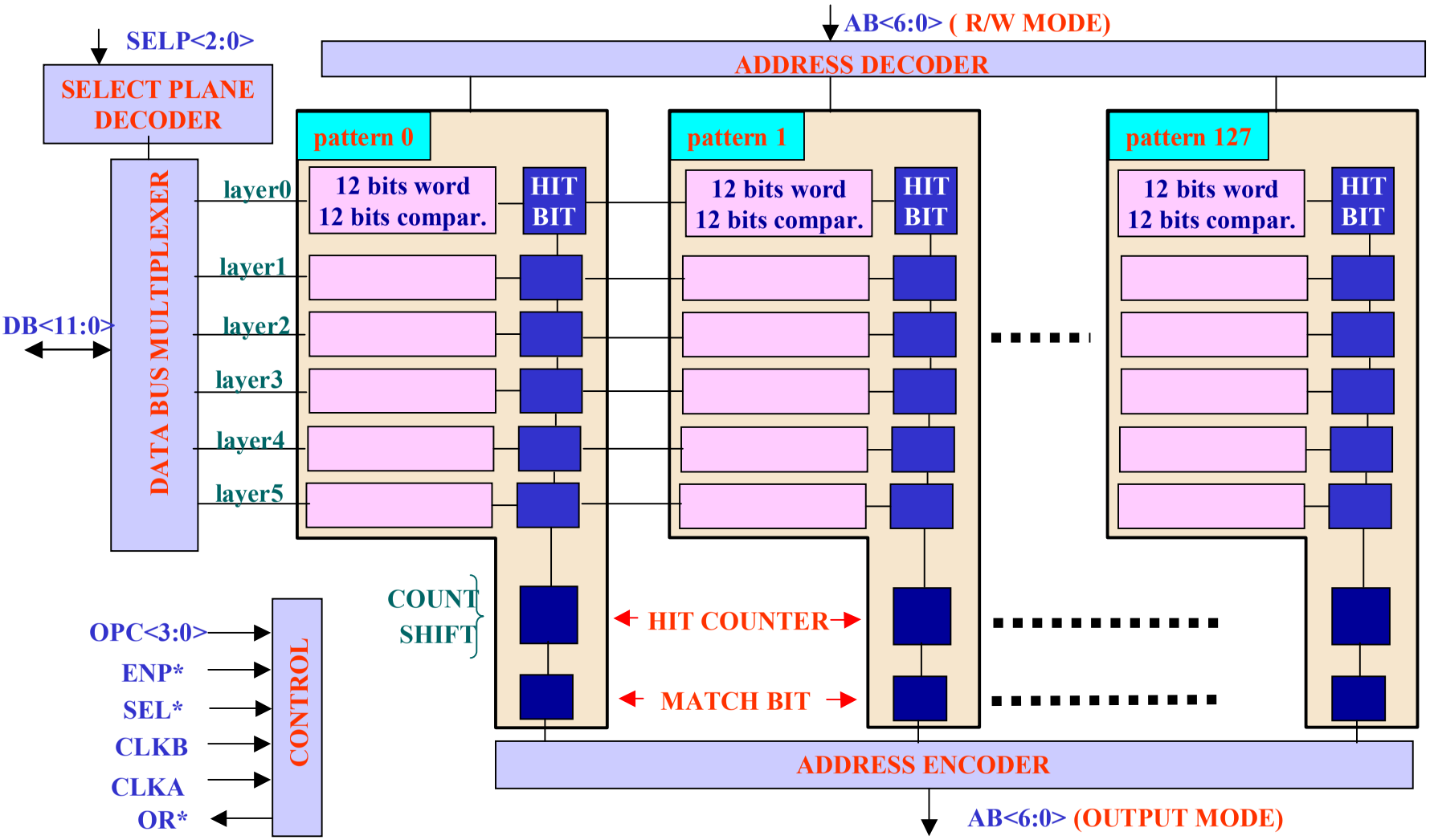




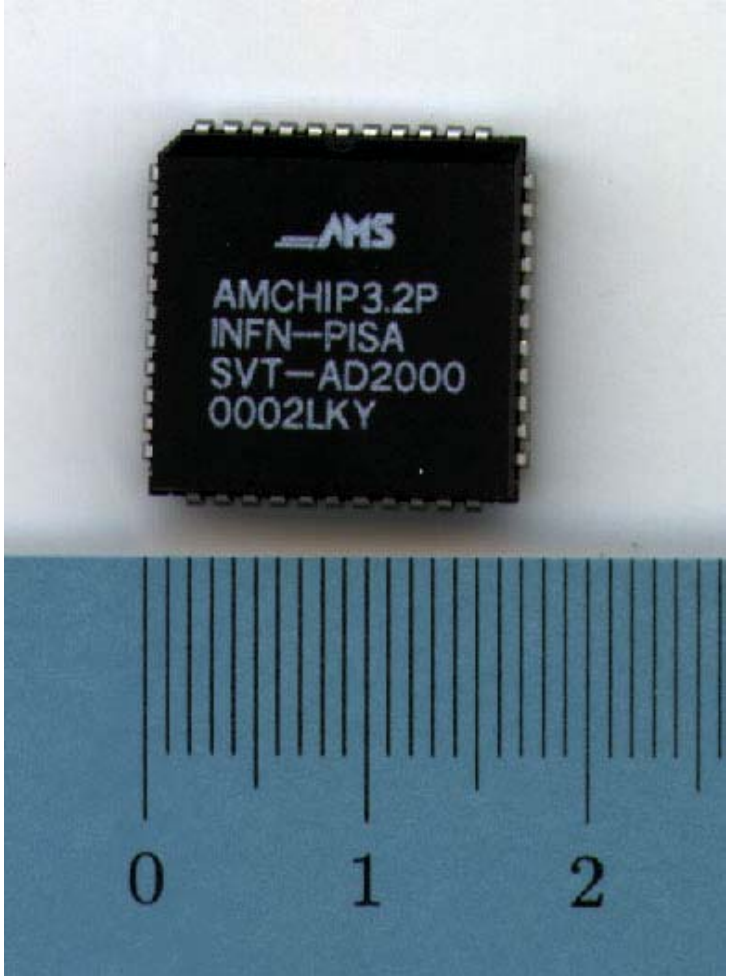
In this example:
Straight lines, 5 layers, 12 bins/layer

⇨ Total number of patterns ~ $(12)^2*(5-1) = 576$

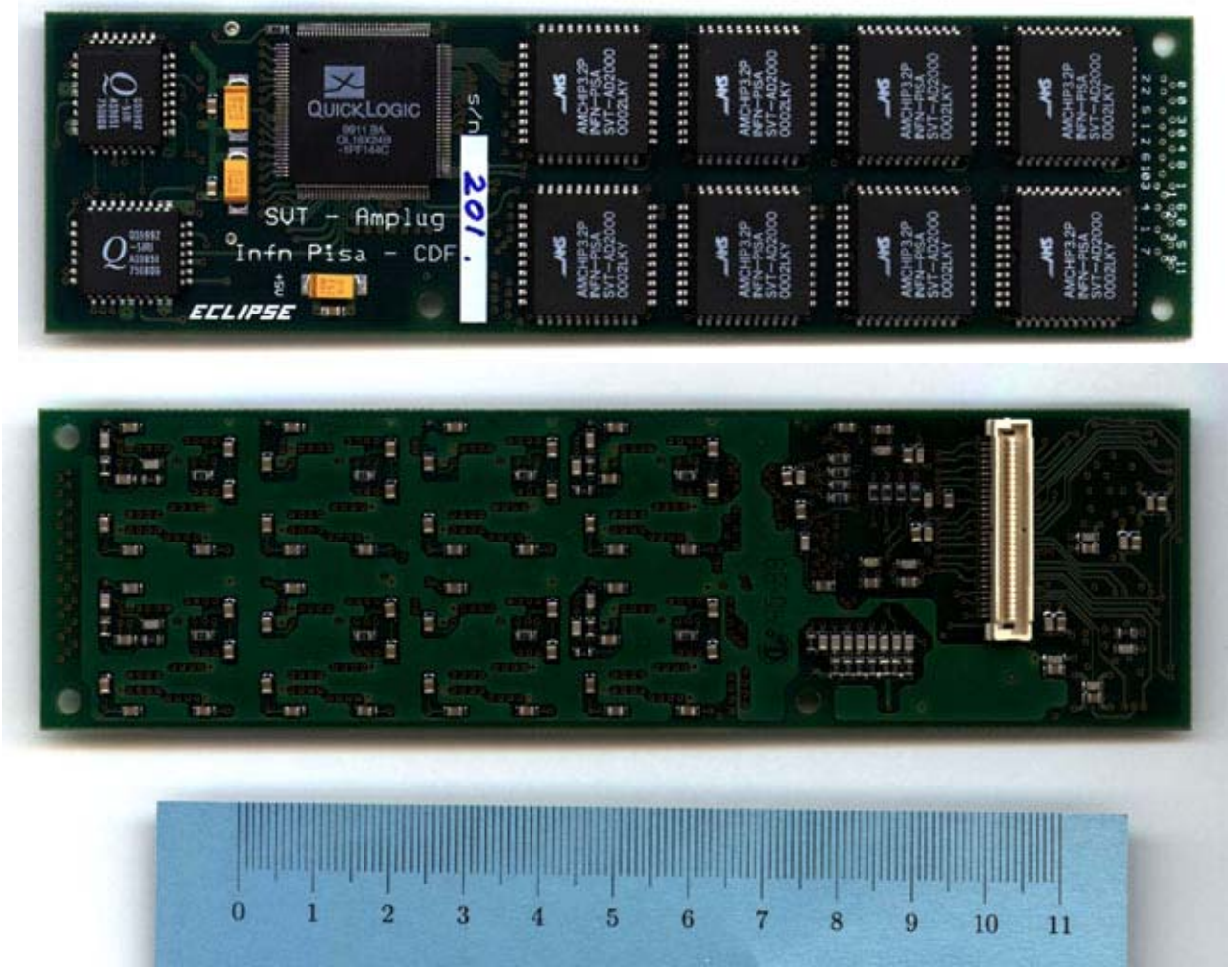
AM chip internal structure



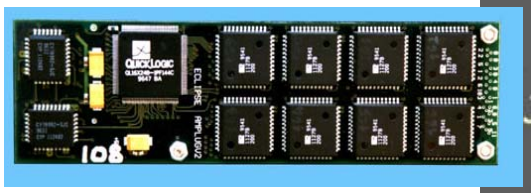
AMchip

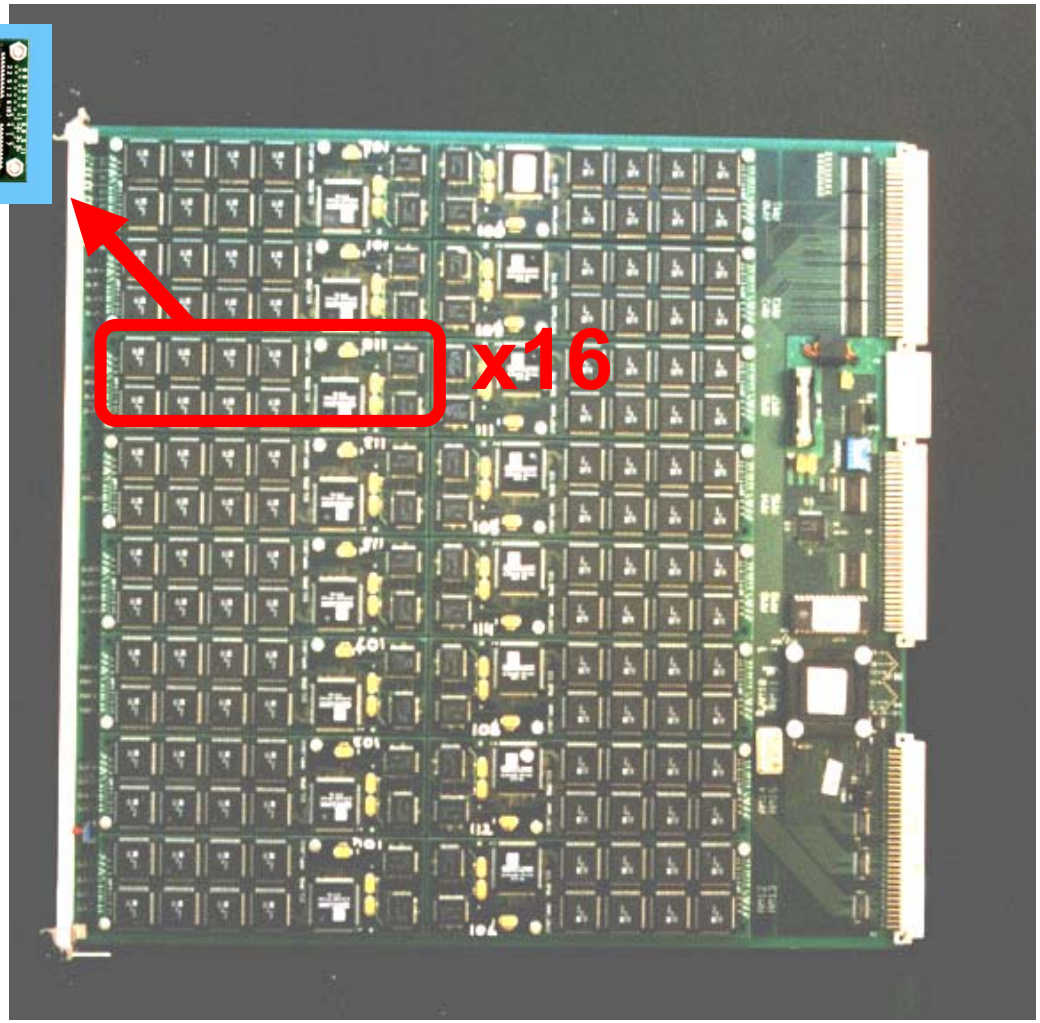


Amplug: mezzanine board



AM Board





128 Amchips

x 128 patterns each

= 16K pattern board

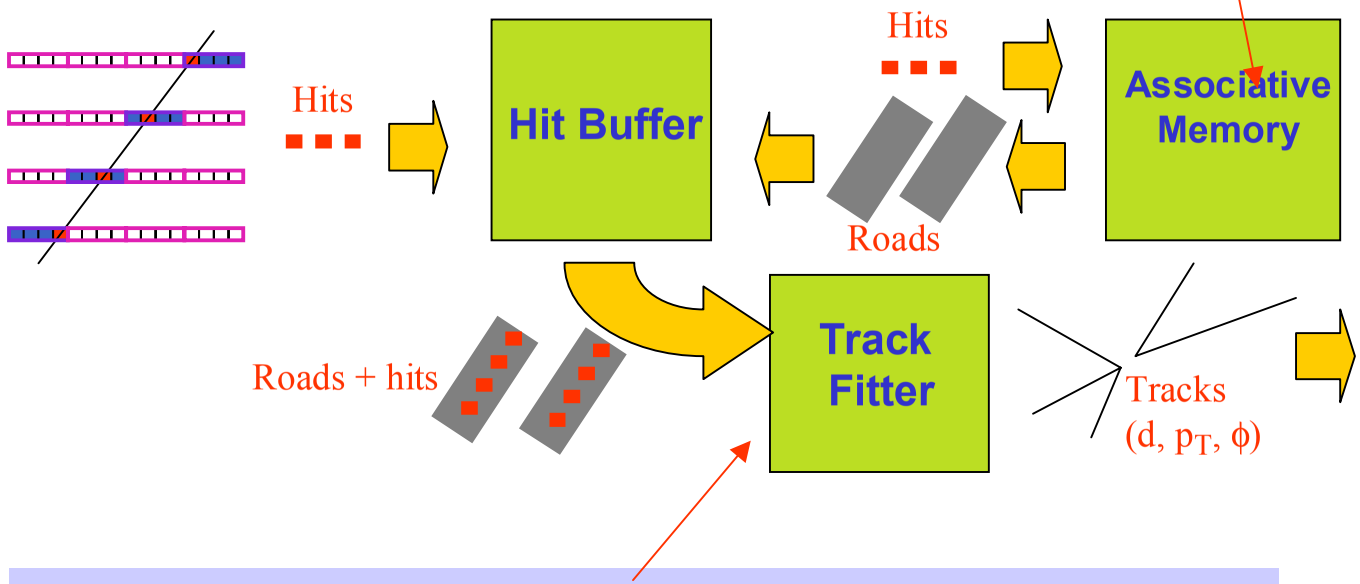
VME

AMbus

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



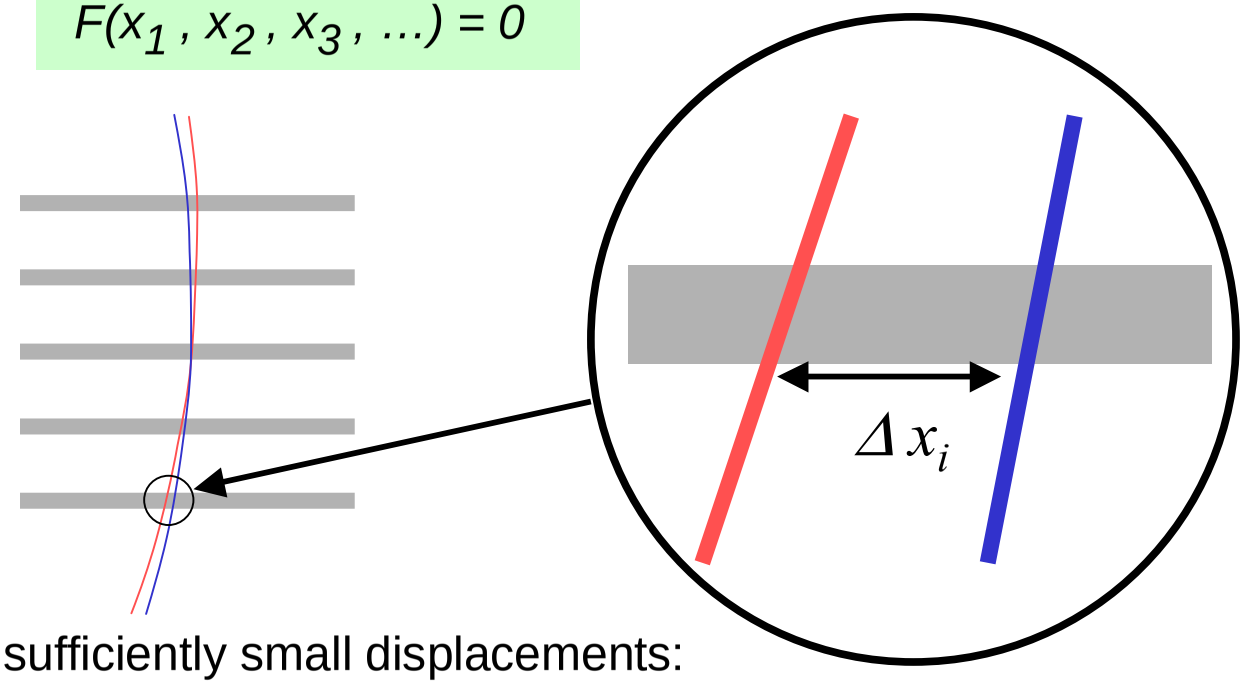
Fast track fitting with linear approximation
using full resolution of the silicon vertex detector

From non-linear to linear constraints

SVT

Non-linear geometrical constraint for a circle:

$$F(x_1, x_2, x_3, \ldots) = 0$$



But for sufficiently small displacements:

$$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$$

with constant $_i$ (first order expansion of)

Constraint surface

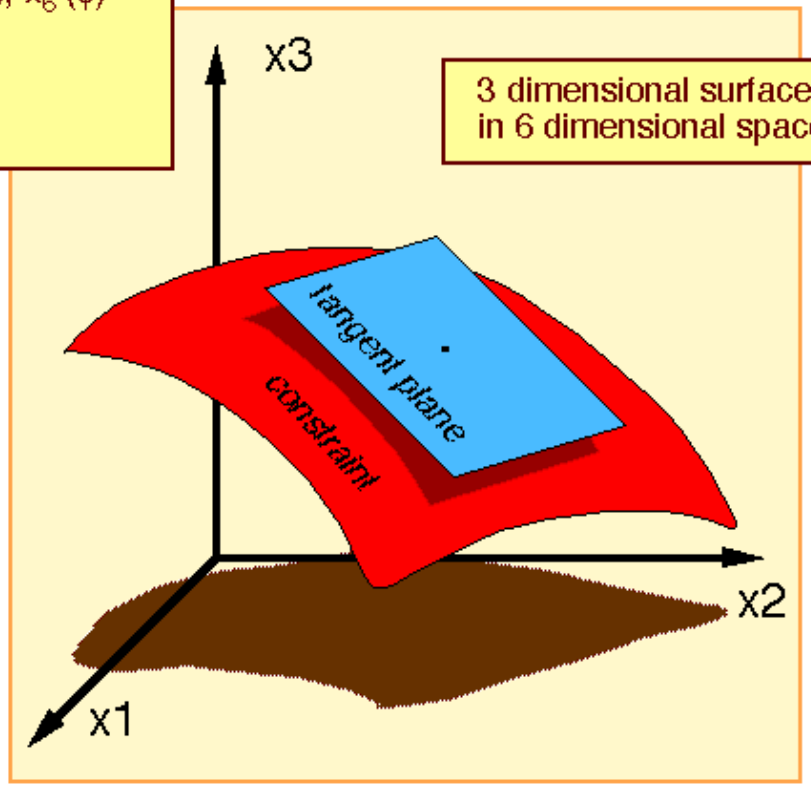
SVT

6 coordinates: x_1, x_2, x_3, x_4, x_5 (P_T), x_6 (ϕ)

3 parameters to fit: P_T , ϕ , d

3 constraints

3 dimensional surface in 6 dimensional space



tangent plane:

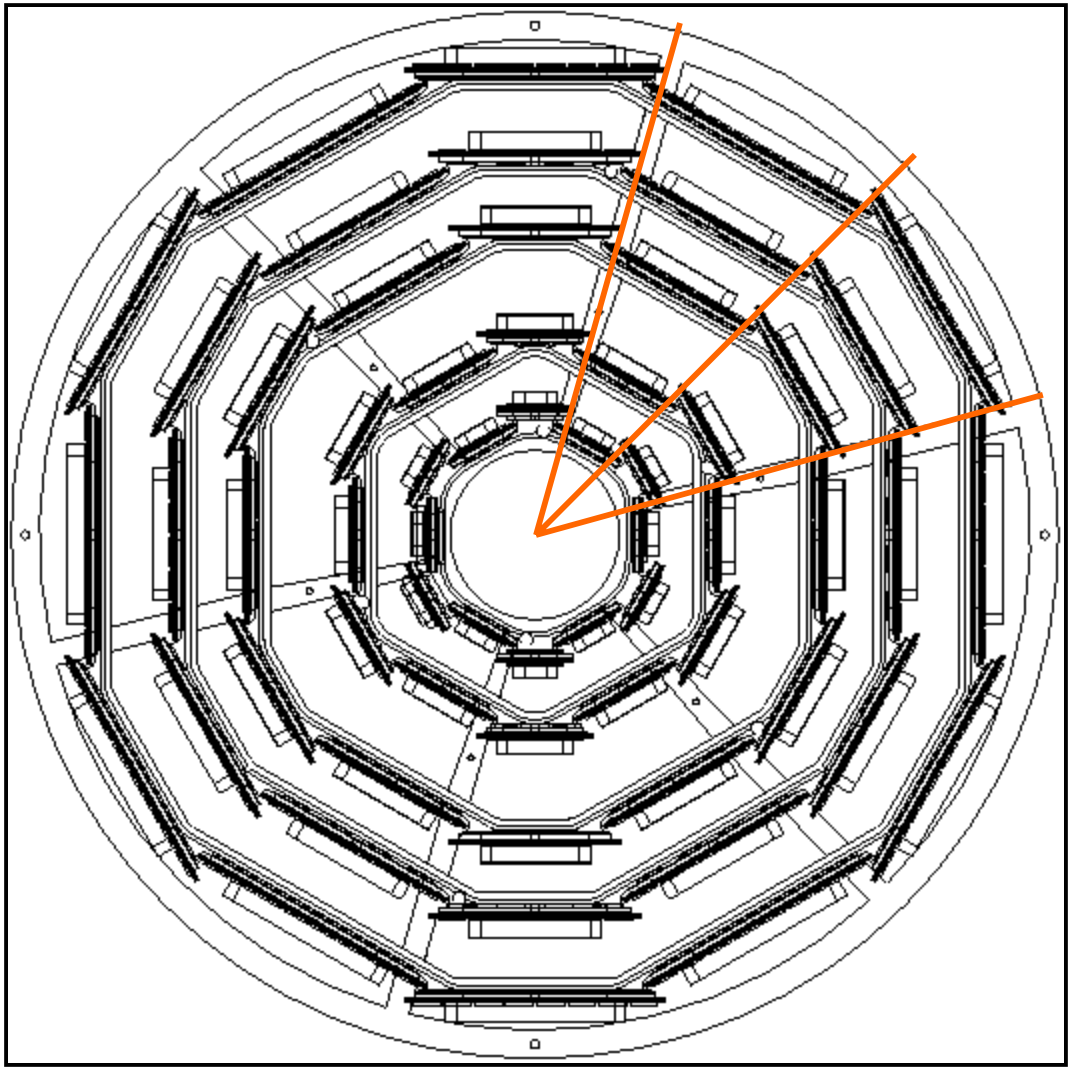
$$\sum_{1}^{6} a_i x_i = b$$

track parameters:

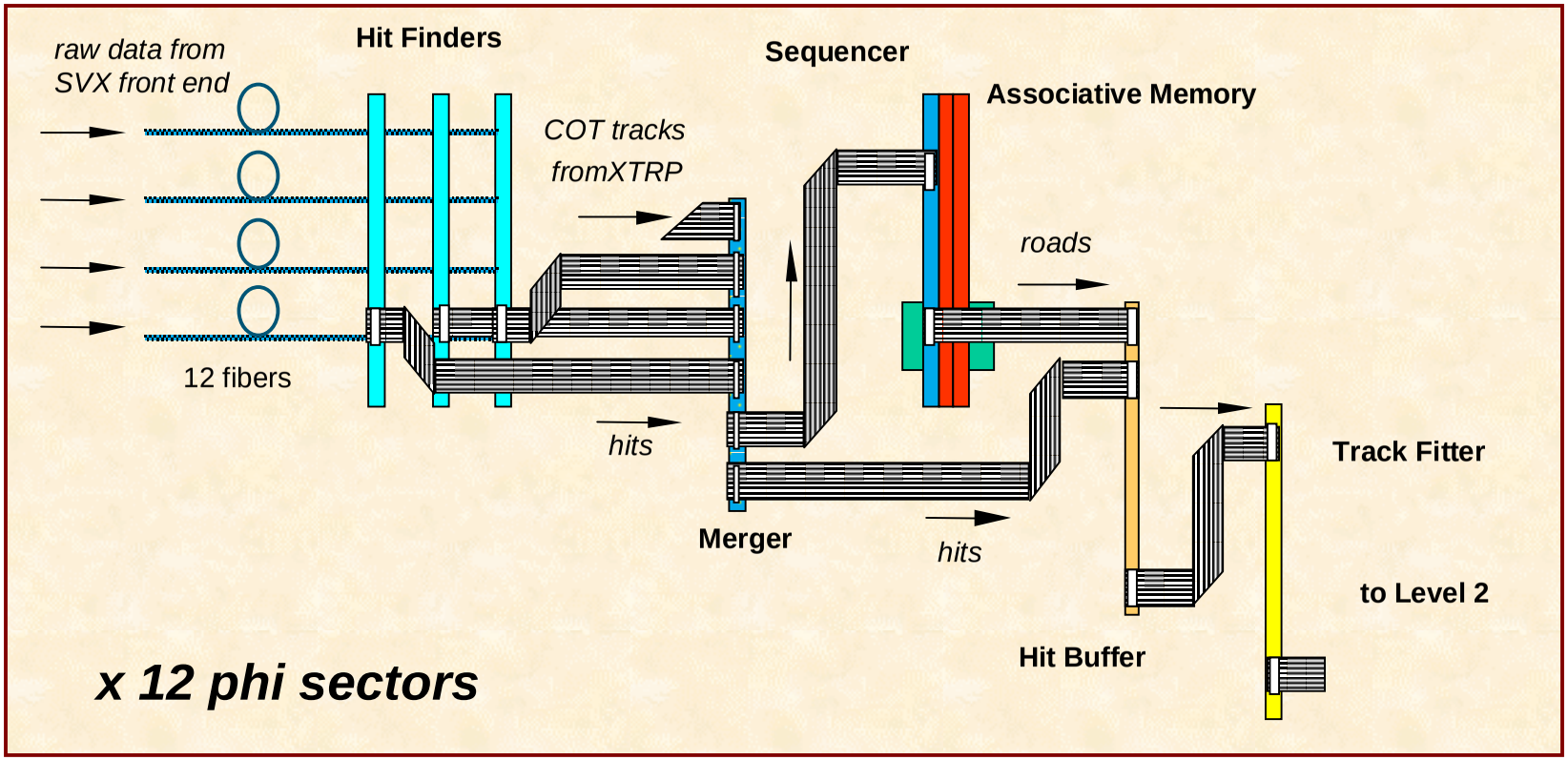
$$d \approx c_0 + \sum_{1}^{6} c_i x_i$$

Linear approximation is so good that a single set of constants is sufficient for a whole detector wedge (30° in ϕ)

SVT Wedges



SVT system architecture



SVT: board count

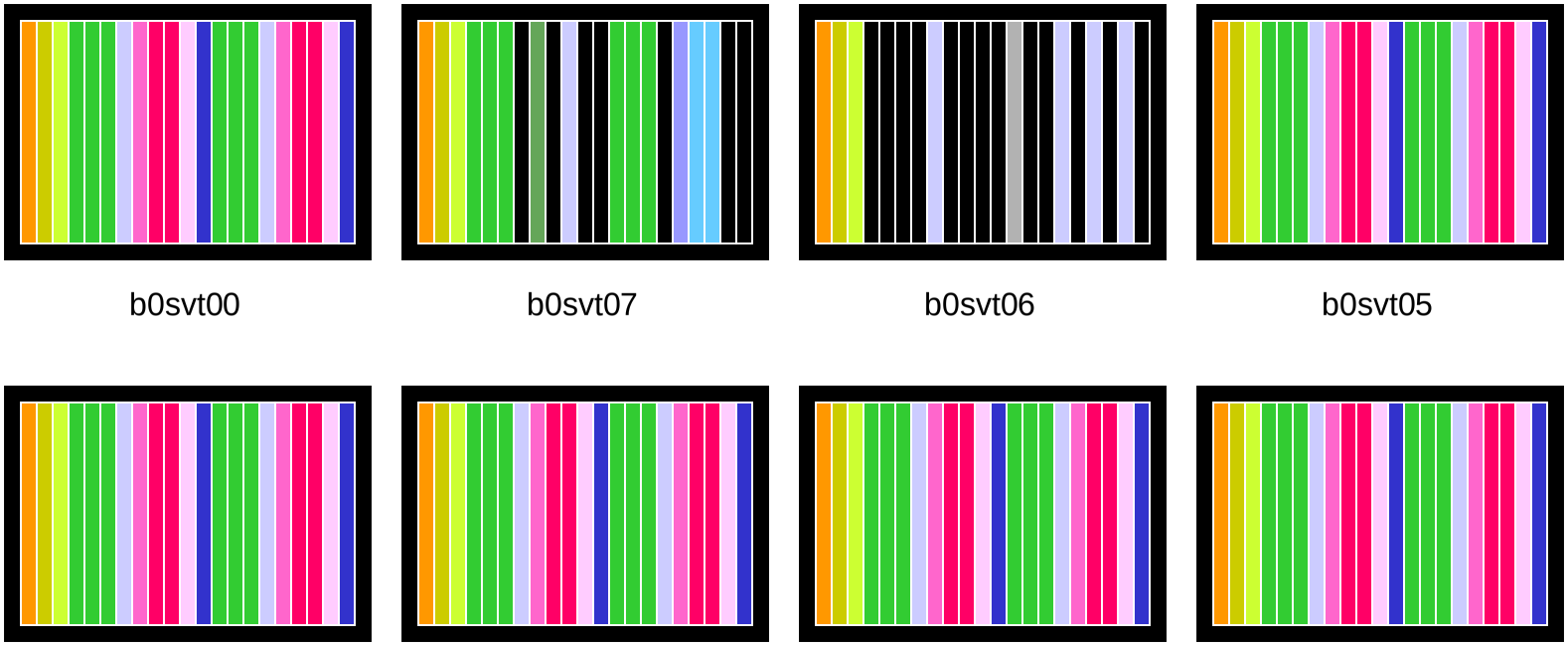
Hit Finders	42
Mergers	16
Sequencers	12
AMboards	24
Hit Buffers	12
Track Fitters	12
Spy Controls	8
XTFA	1
XTFB	2
XTFC	6
Ghostbuster	1
TOTAL	136

+ spares

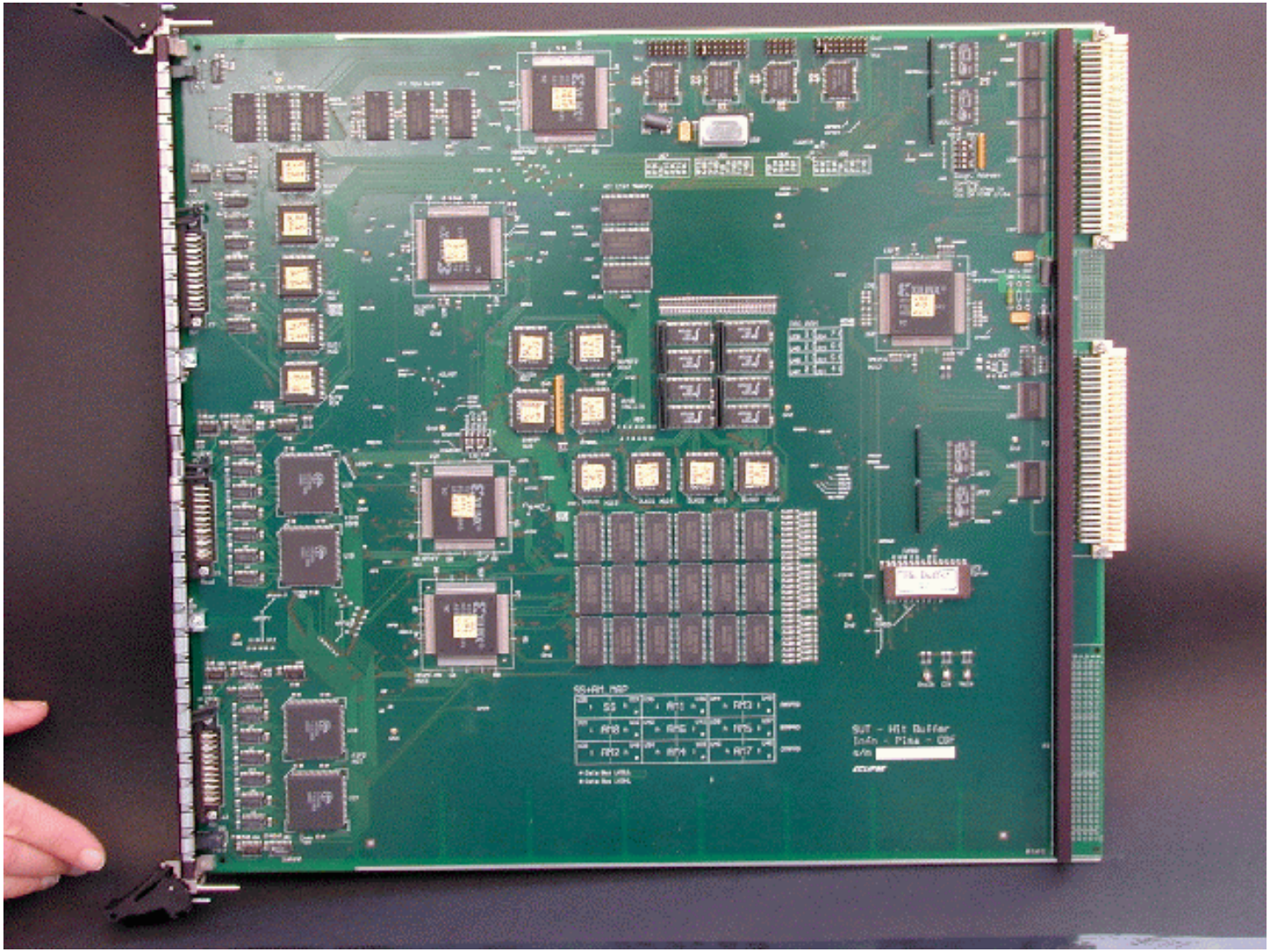
- INFN
- INFN & Geneva
- University of Chicago

SVT: board and crate layout

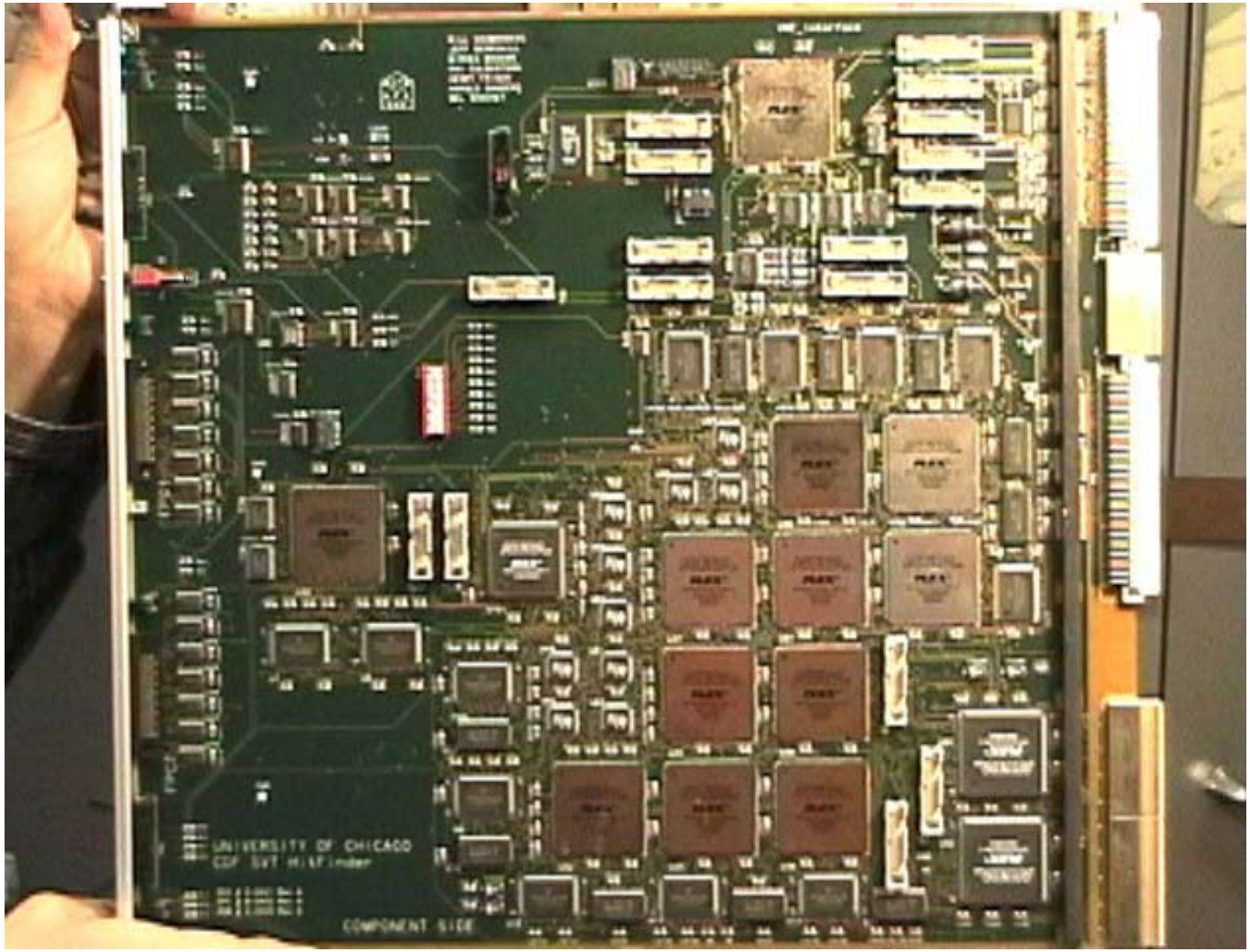
CPU	Hit Finder	Merger	XTFA
Tracer	Sequencer	Hit Buffer	XTFB
Spy Control	Associative Memory	Track Fitter	XTFC



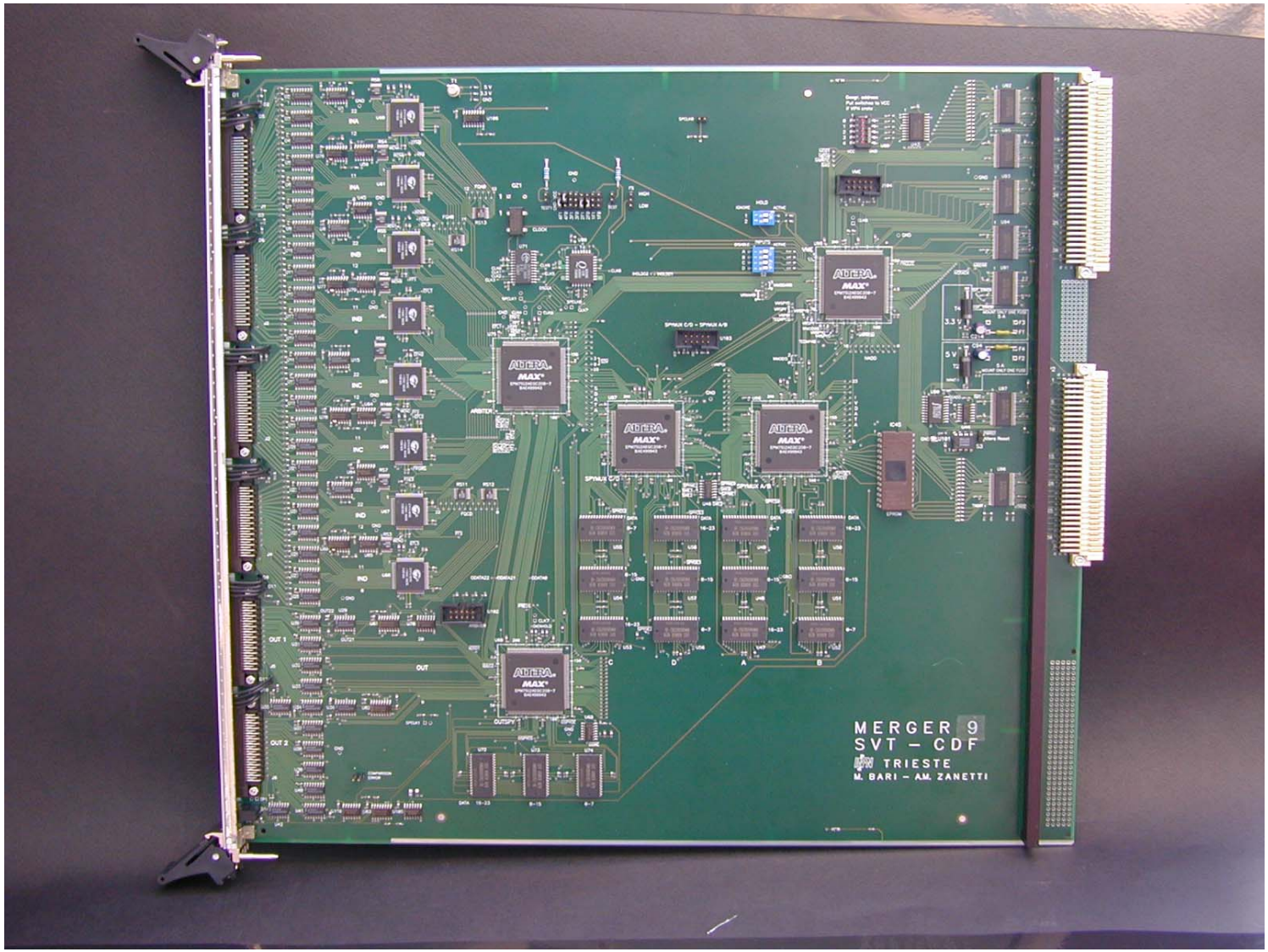
Hit Buffer board



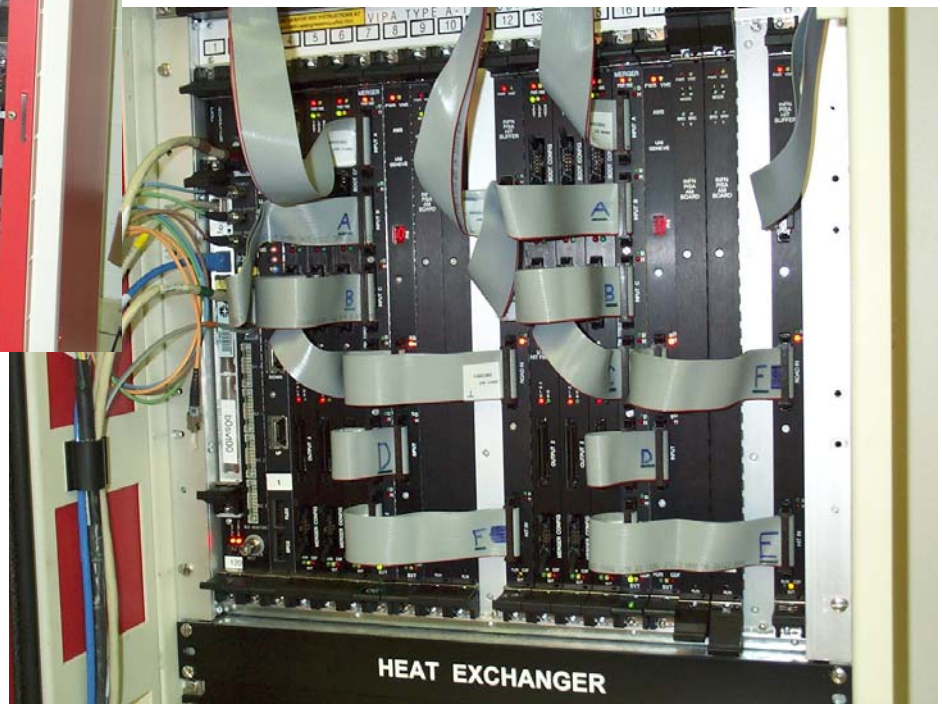
Hit Finder board



Merger board



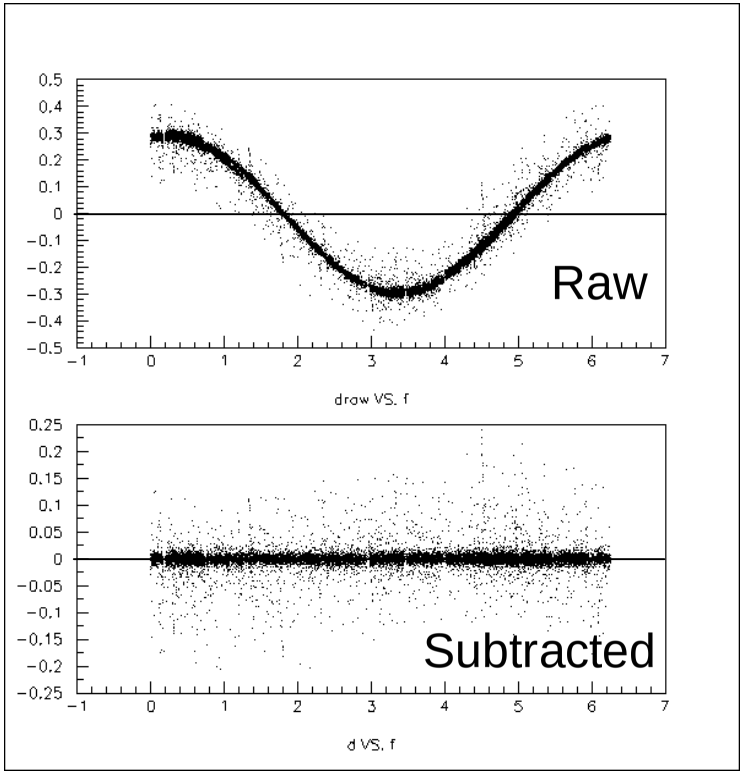
SVT crates in CDF counting room



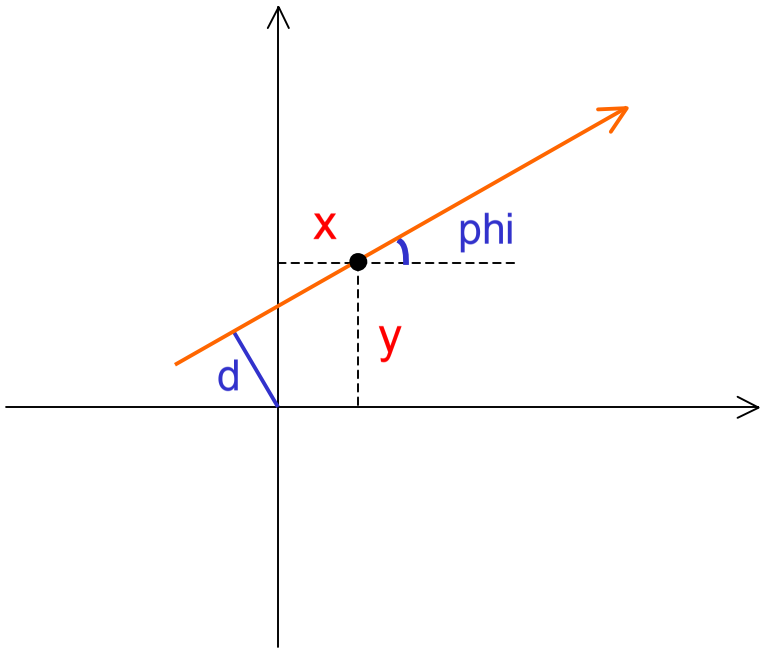
Impact parameter vs. phi

d

d



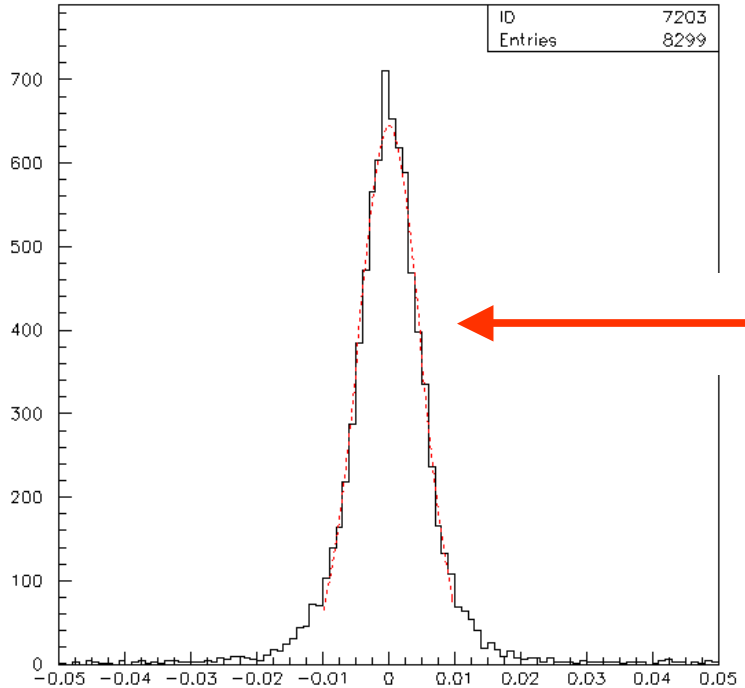
phi



$$d = y \cos(phi) - x \sin(phi)$$

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 ~ 50 um ~ 43 um ⊕ 25 um

SVT resolution beam spot size

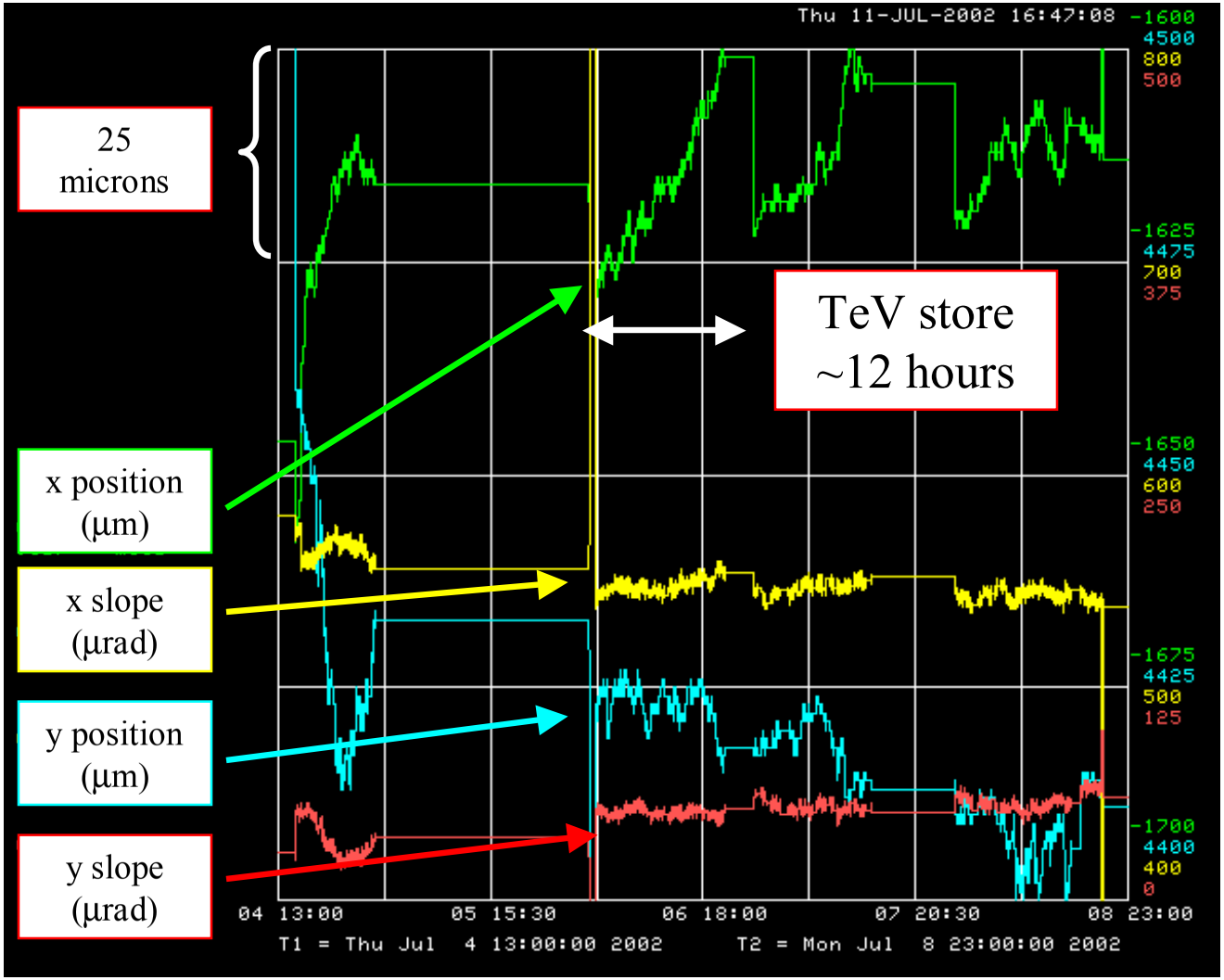
Tevatron Beam Moves!

SVT

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)



Hadronic B decays with SVT

Two paths

@ 3×10^{31} cm^{-2} s^{-1}

~ 3 KHz

- **L1:**
  - Two XFT tracks
  - $P_t > 2.5$ GeV; $P_{t1} + P_{t2} > 6.5$ GeV
  - $\Delta\phi < 135°$
- **L2:**
  - $d_0 > 100$ μm for both tracks
  - Validation of L1 cuts with $\Delta\phi > 20°$
  - Lxy > 200 μm
  - $d_0(B) < 140$ μm

Two body decays

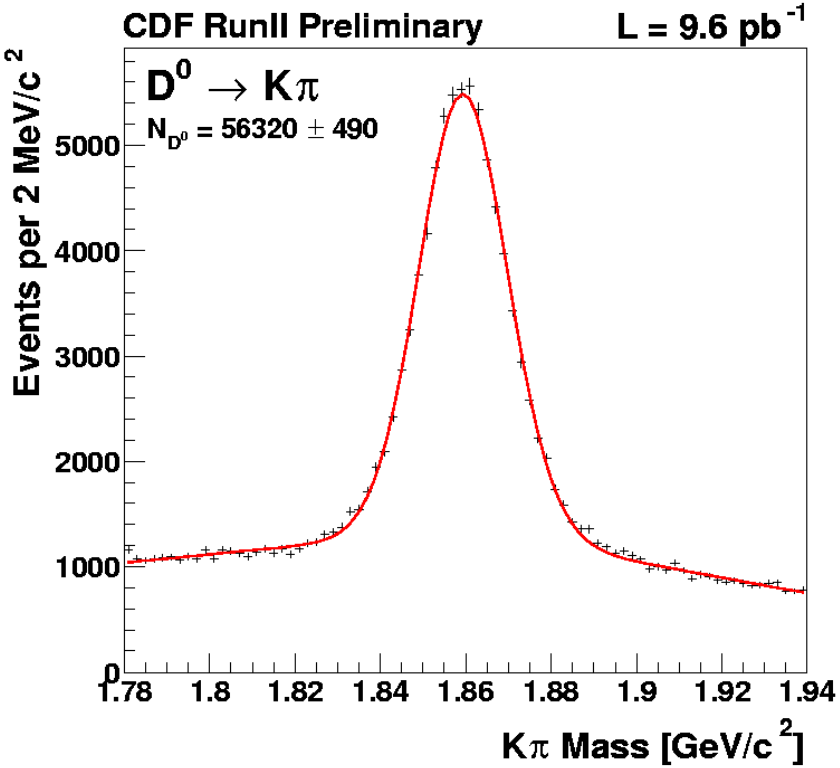
- **L1:**
  - Two XFT tracks
  - $P_t > 2.5$ GeV; $P_{t1} + P_{t2} > 6.5$ GeV
  - $\Delta\phi < 135°$
- **L2:**
  - $d_0 > 120$ μm for both tracks
  - Validation of L1 cuts with $\Delta\phi > 2°$
  - Lxy > 200 μm
  - ~~$d_0(B) < 140$ μm~~

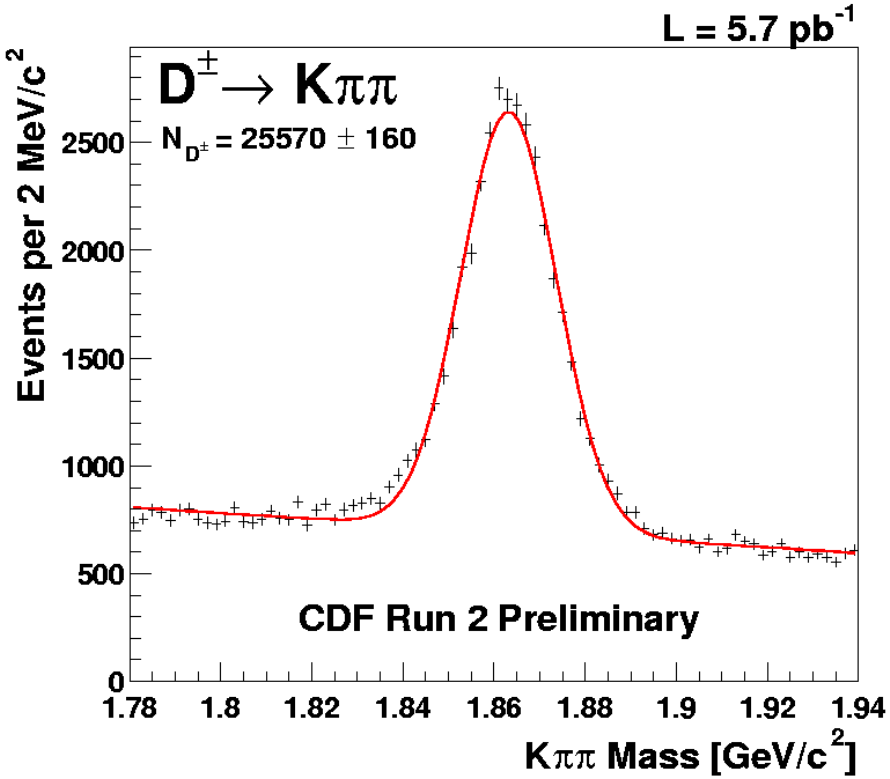
Many body decays

~ 5 Hz

CDF as a Charm factory?

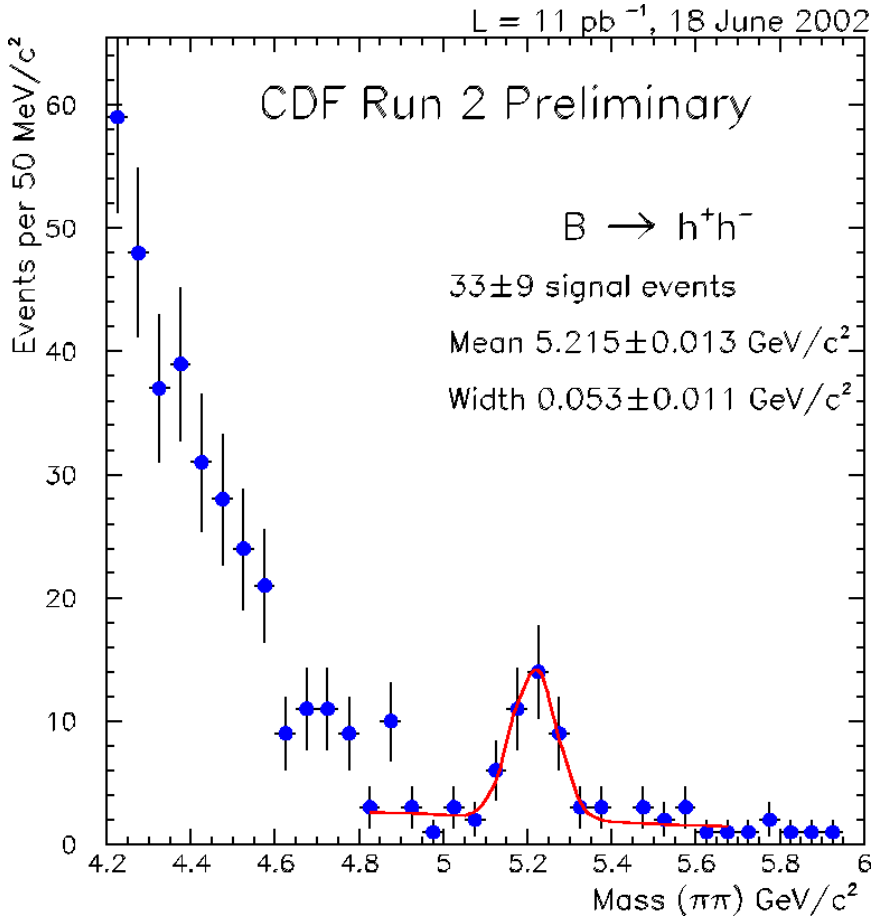
SVT

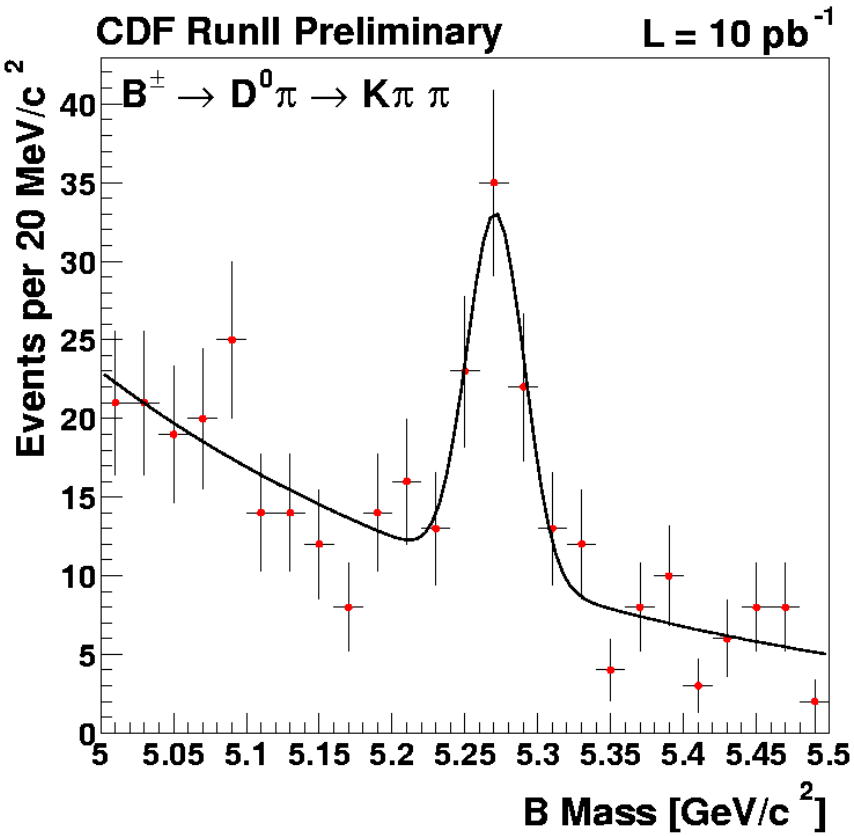




Fully Hadronic B decays

SVT





SUMMARY

- 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