The CDF Silicon Vertex Trigger

ANL – May 8, 2002

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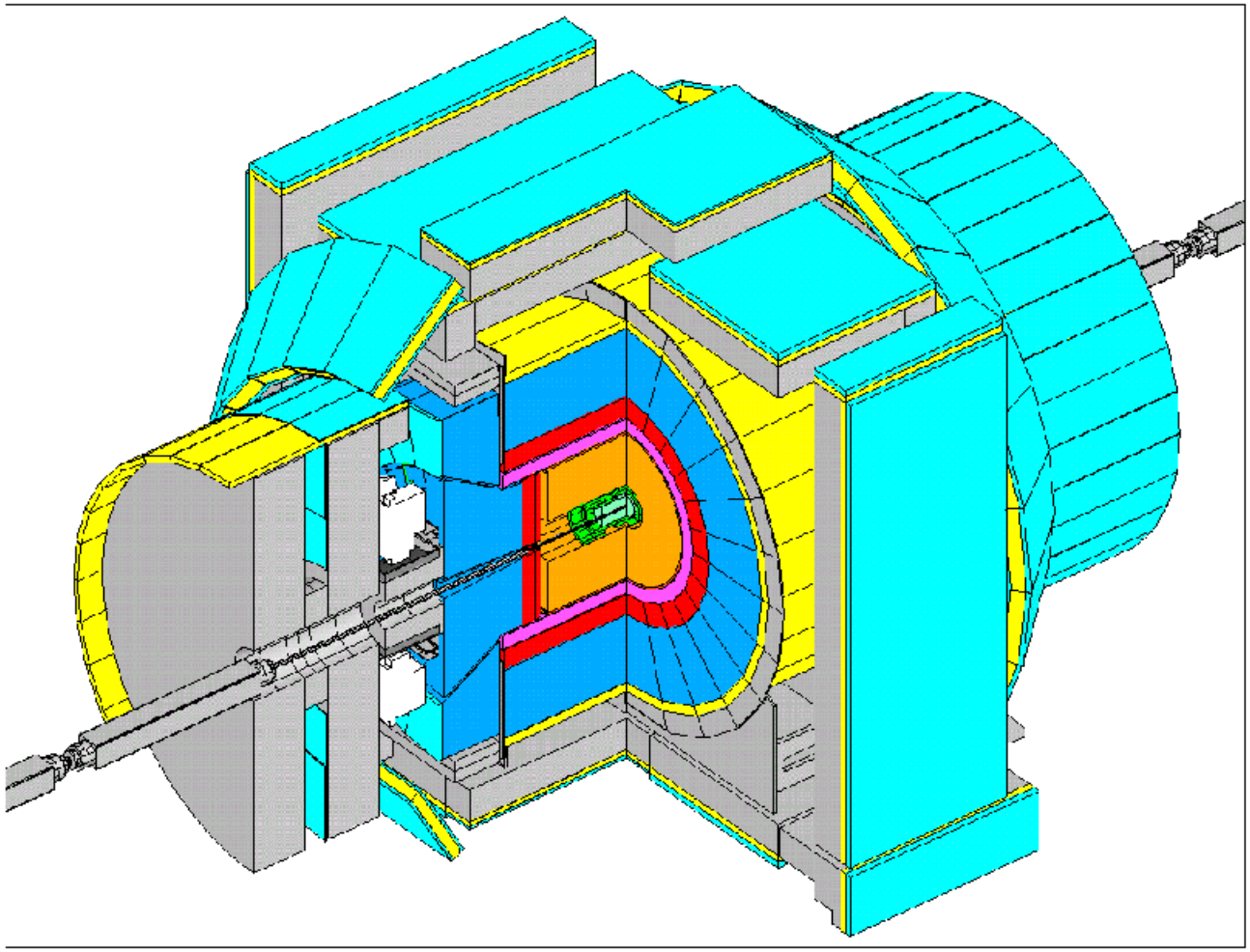
Istituto Nazionale di Fisica Nucleare
Pisa – Italy

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

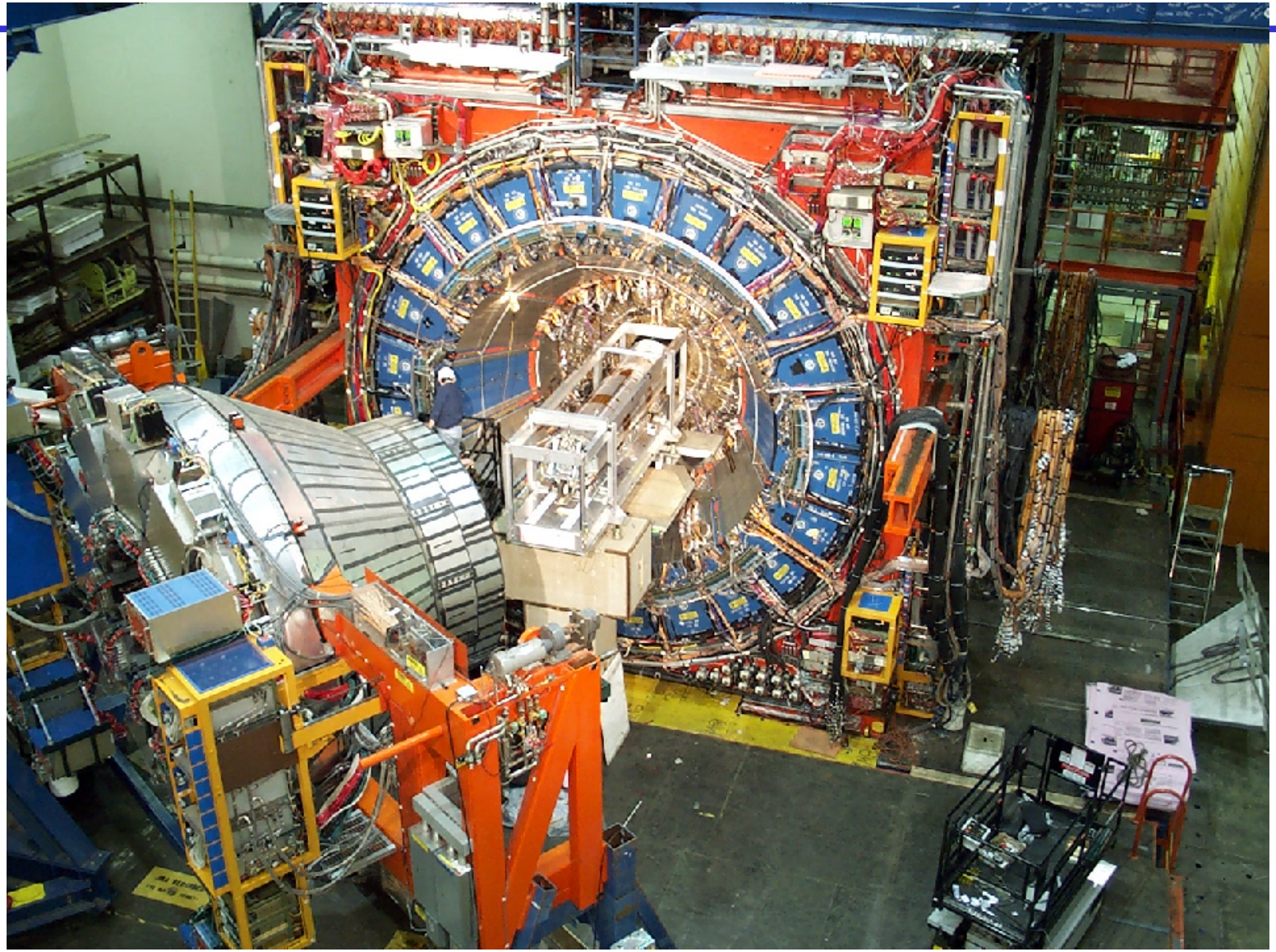
- INFN – Pisa
- INFN – Trieste
- University of Chicago
- Université de Genève

CDF DETECTOR

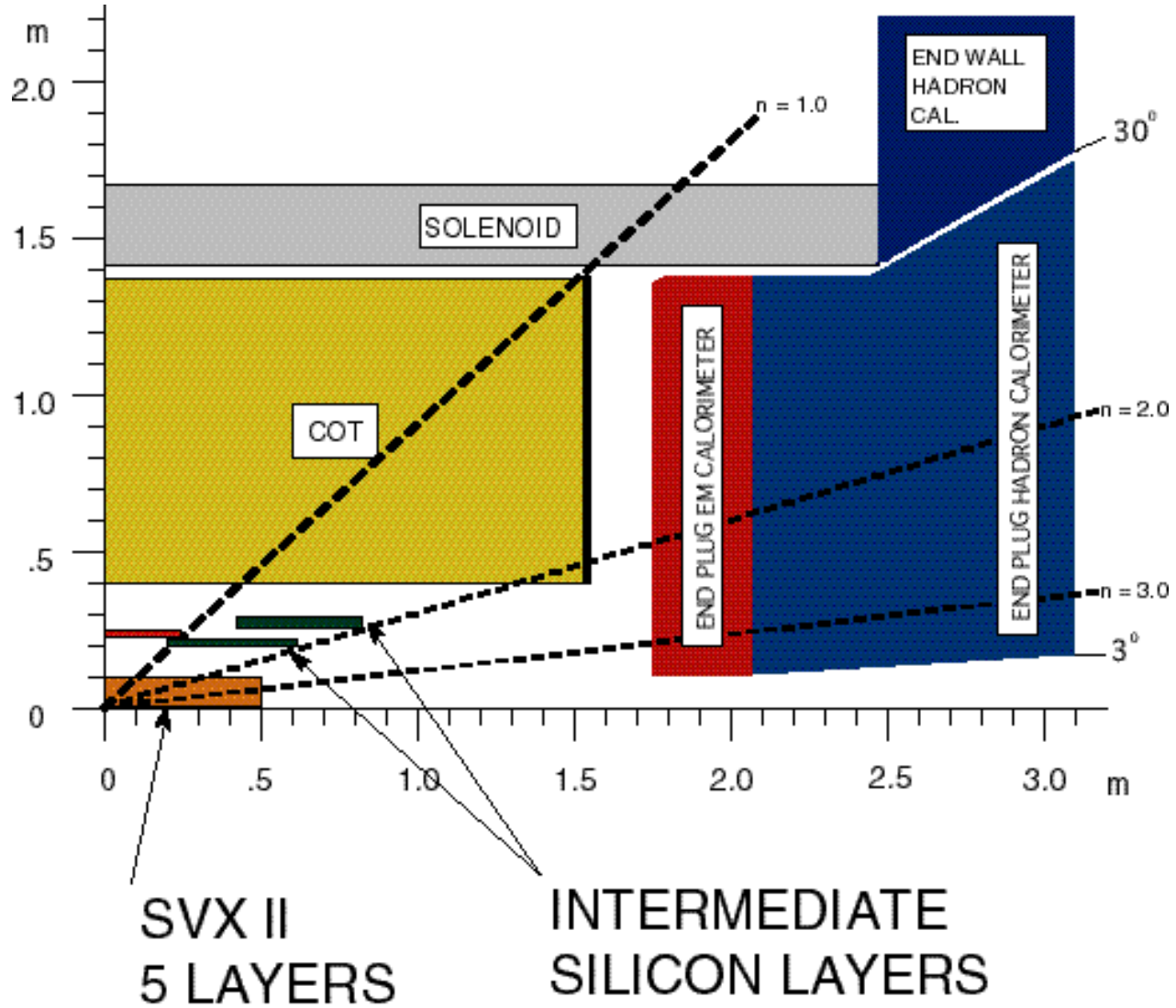
SVT



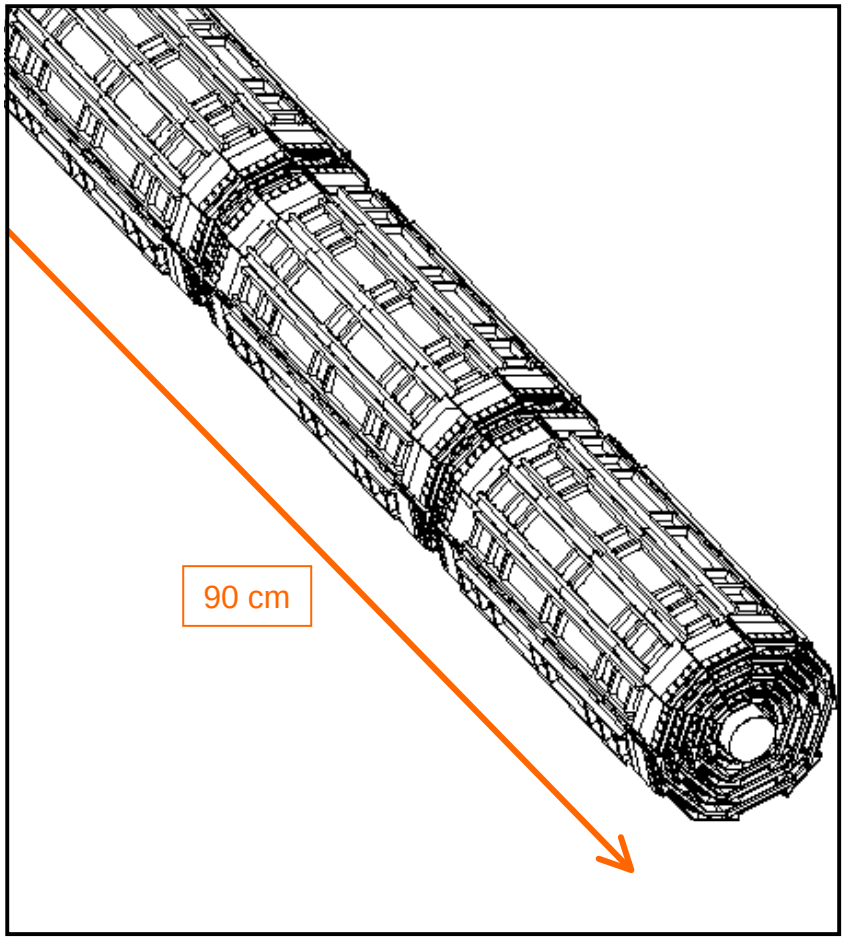
SVT

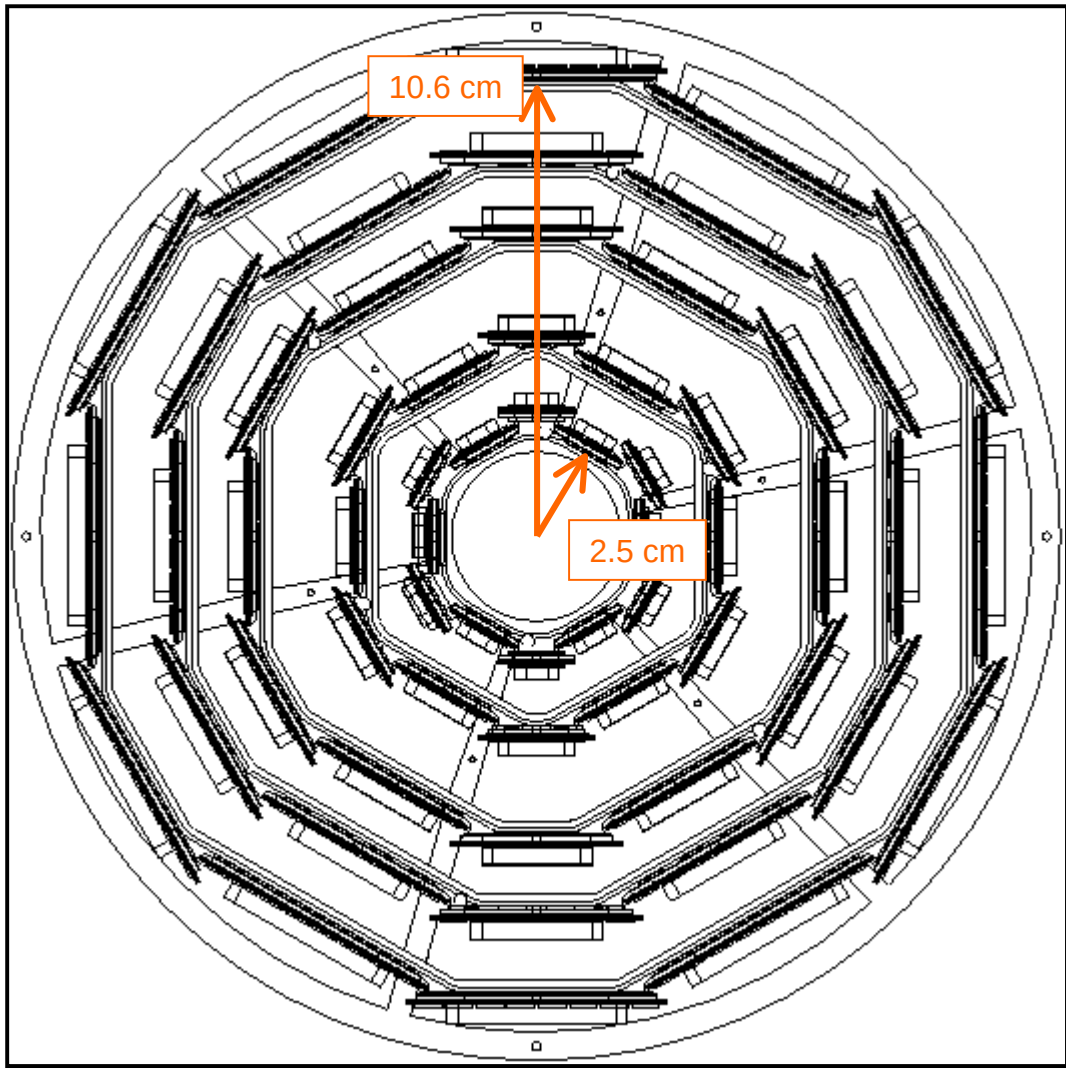


CDF r-z view

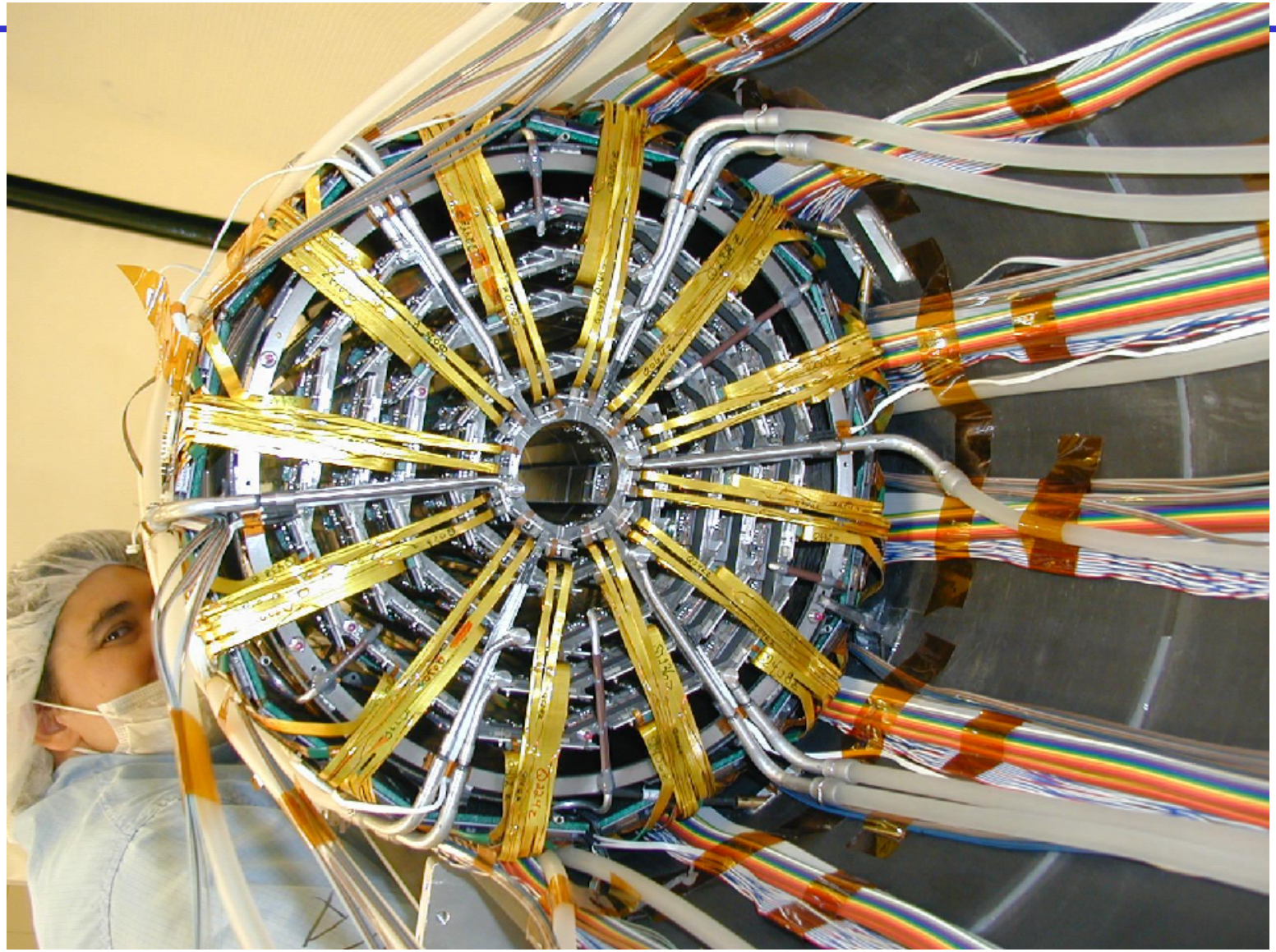

m
2.0
1.5
1.0
.5
0
0
.5
1.0
1.5
2.0
2.5
3.0
m
SOLENOID
COT
END WALL
HADRON
CAL.
END PLUG EM CALORIMETER
END PLUG HADRON CALORIMETER
n = 1.0
n = 2.0
n = 3.0
30°
3°
SVX II
5 LAYERS
INTERMEDIATE
SILICON LAYERS

SVX II





SVT

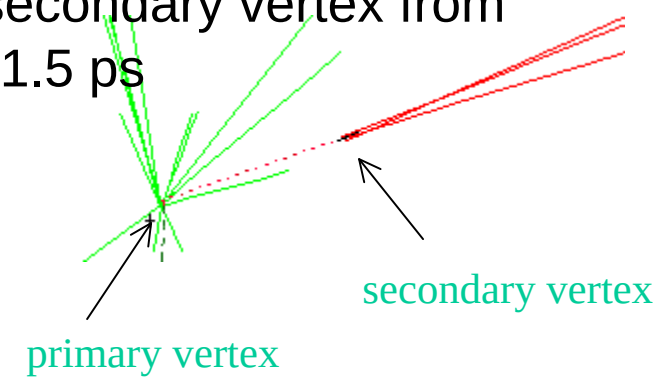


Why and how?

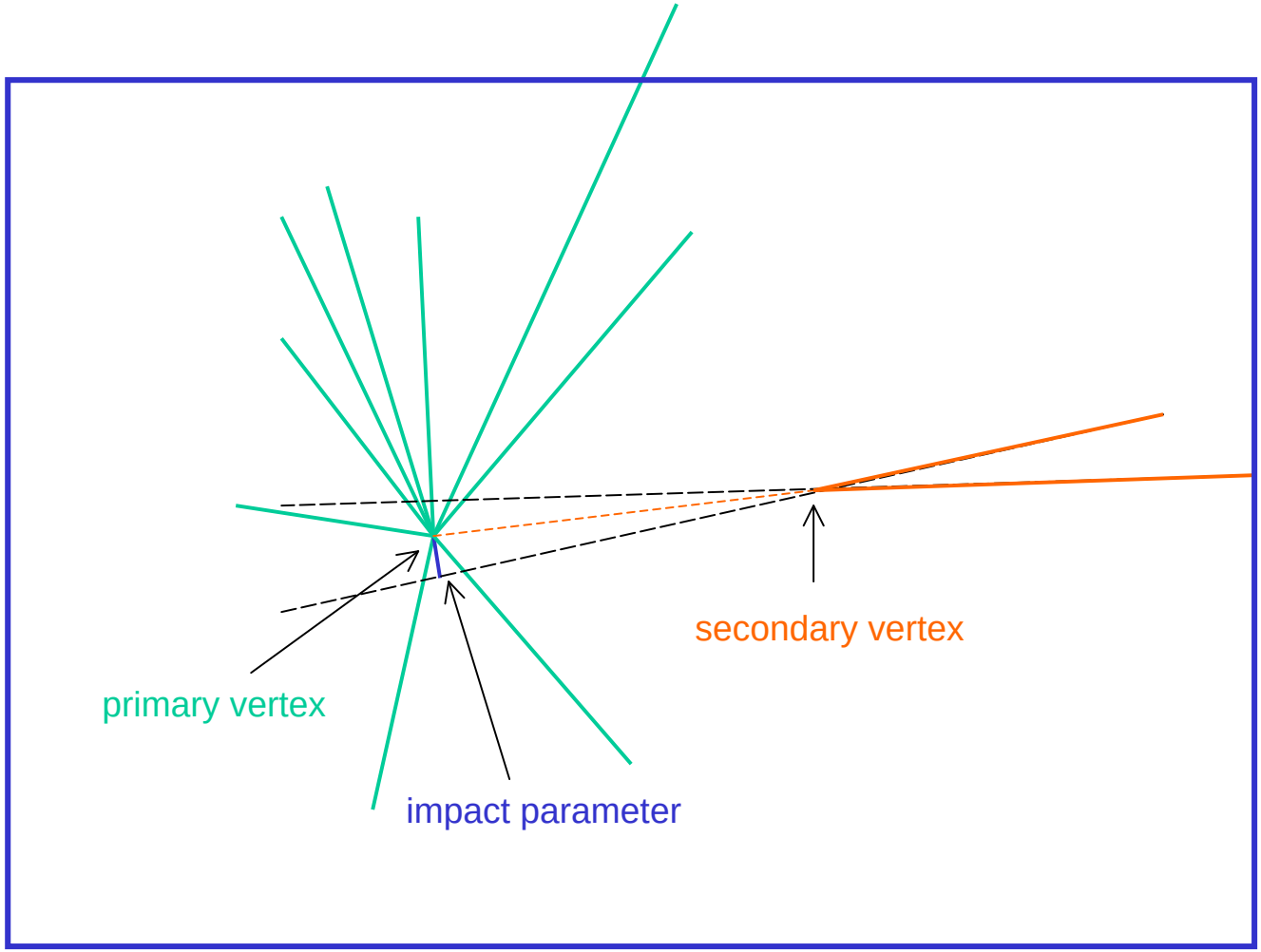
- Trigger on B hadronic decays
  - B physics studies, eg. CP violation in B decays, Bs mixing
  - new particle searches, eg. Higgs, Supersymmetry
- A b-trigger is particularly important at hadron colliders
  - large B production cross section for B physics
  - high energy available to produce new particles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

- Detect large impact parameter tracks or secondary vertex from B hadron decays using the fact that $\tau(B) \approx 1.5$ ps

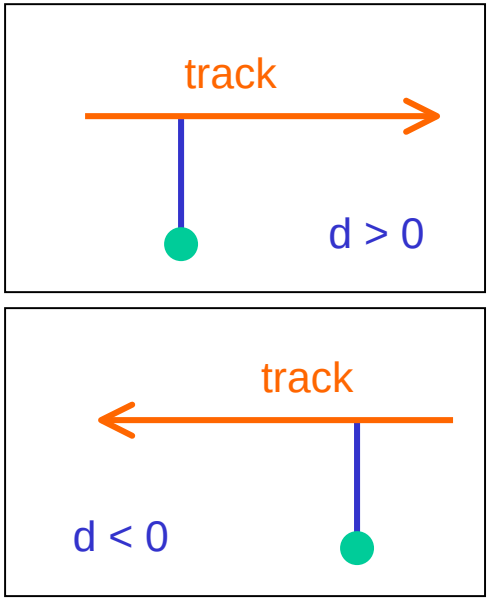
Technical challenge!



Impact parameter



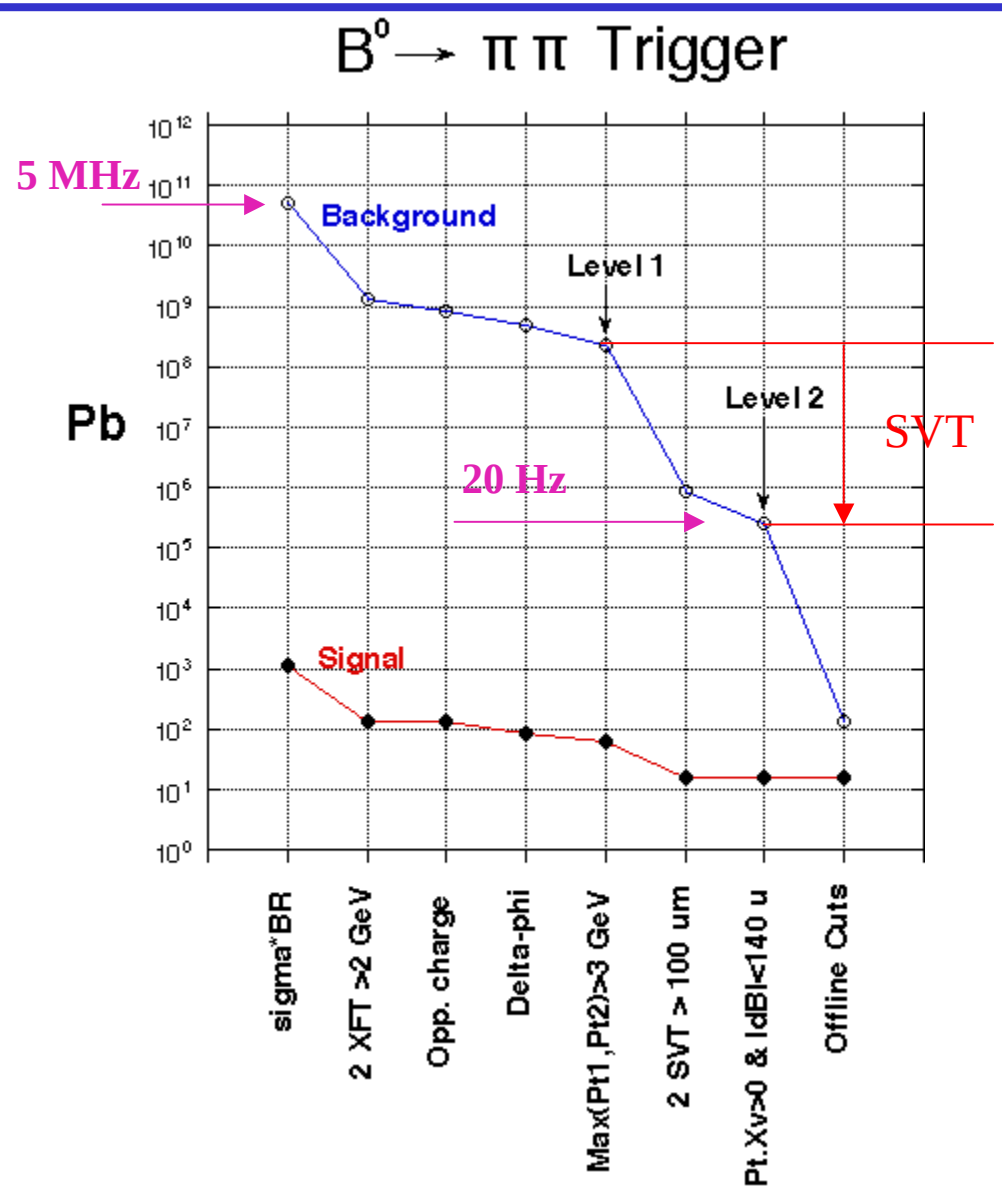
as seen from positive z axis



SVT for $B^0 \rightarrow \pi^+\pi^-$

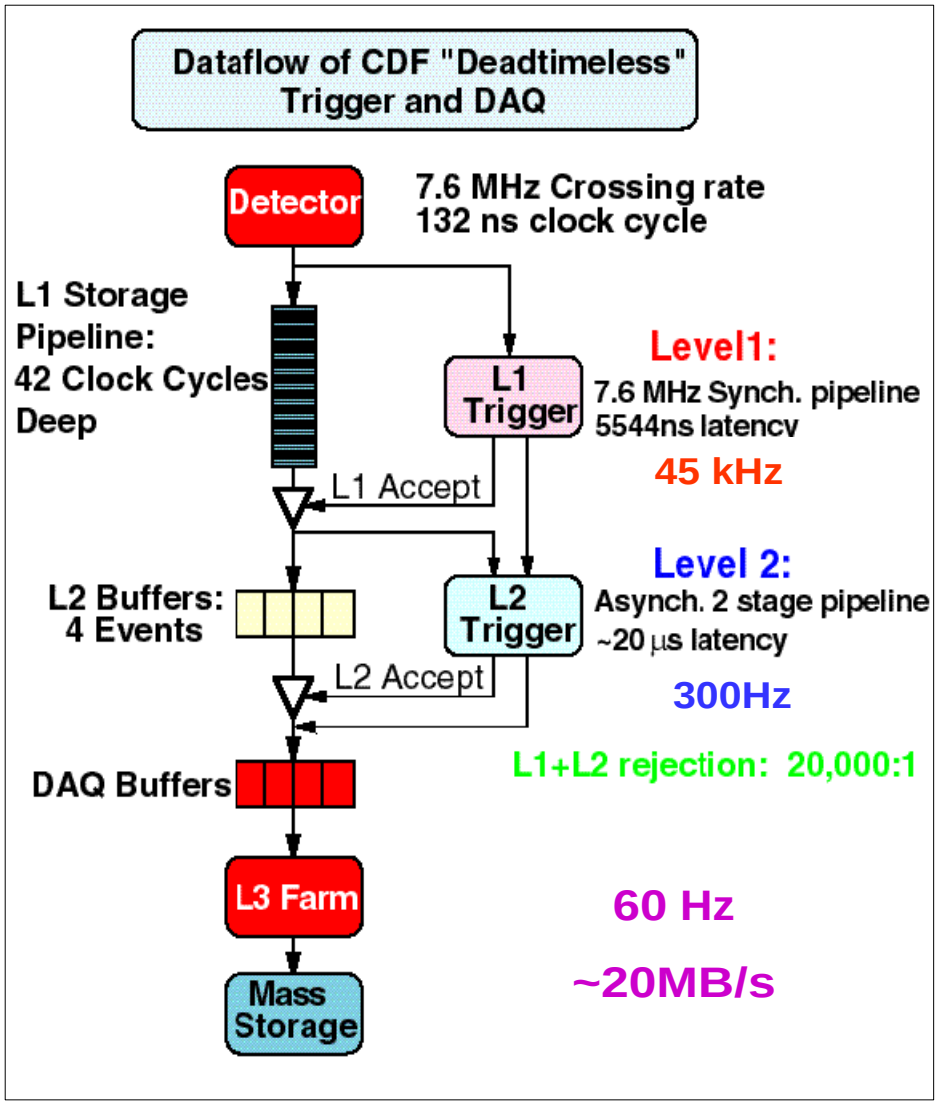
- SVT reduces the background rate by a factor of 1000
  - data recording possible by DAQ

- CDF II (2 fb^{-1})
  - $\Delta(\sin 2\beta) \approx 0.08$ (~10,000 $B^0 \rightarrow J/\Psi\ K_S^0$)
  - $\Delta(\sin 2\alpha) \approx 0.1$ (~10,000 $B^0 \rightarrow \pi^+\pi^-$)
  - B_s^0 mixing up to $X_s \sim 60$ (~10,000 $B_s^0 \rightarrow D_s\ \pi$)



Triggering in Run 2

SVT

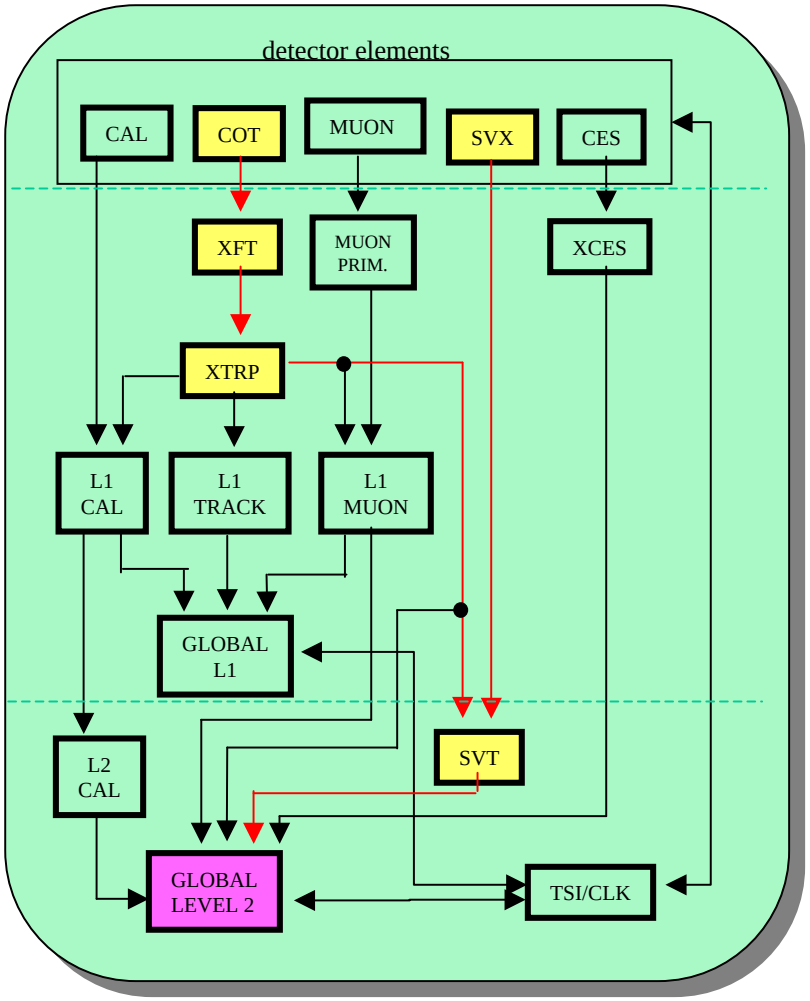


Central Tracker (Pt,ϕ)
EM + HAD/EM + Track
EM+HAD (Jet)
Muon + Track
Missing E_T, ΣE_T

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

  } 15 μs

Once upon a time…

CDF/DOC/TRIGGER/PUBLIC/1421

SVT
THE SILICON VERTEX TRACKER

Luciano Ristori

May 1, 1991

INTRODUCTION

This note describes the architecture of a device we believe we can build to reconstruct tracks in the Silicon Vertex Detector (SVX) with enough speed and accuracy to be used at trigger level 2 to select events containing secondary vertices originated by B decay. We name such a device *Silicon Vertex Tracker* (SVT).
The use of SVT as part of the CDF trigger would allow us to collect a large sample of B's (> 10^7 events) in a 100 pb^{-1} run.
B production at 2 TeV in the c.m. is abundant: Isajet predicts that, in the central region, 6.5% of two-jet events with Pt>20 GeV/c contain a B pair. Thus we need a trigger with a relatively modest rejection factor (10 ÷ 20) not necessarily requiring the presence of very high P_T tracks.
It turns out that the simple requirement of a single track with an impact parameter greater than a given threshold might do the job.
The possibility to use the output of SVT to actually reconstruct secondary vertices is left open and it's not discussed here.
In Section 1 we report the results of some simple simulations we have done to show the efficacy of the impact parameter cut, in Section 2 we overview the overall architecture of SVT, in Section 3 we describe the different parts SVT is made of and how they relate to the different stages the track finding process goes through.

1. SIMULATION RESULTS

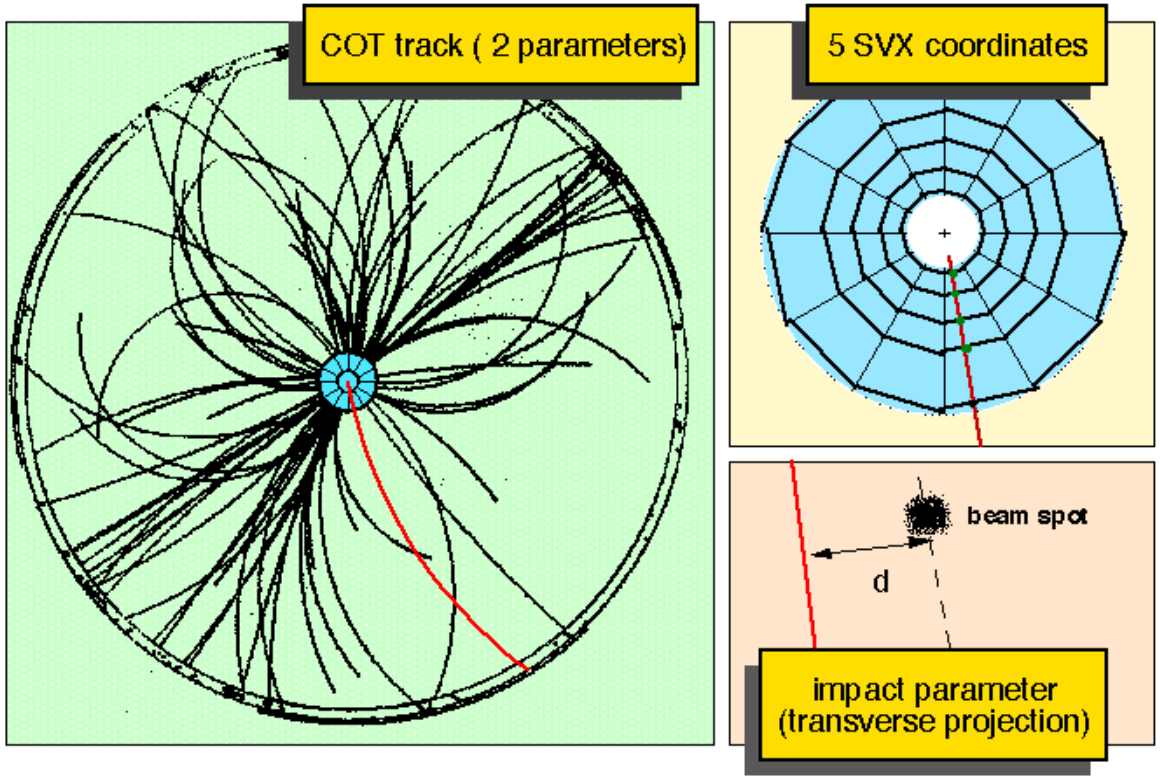
1.1 Impact Parameter Cut

The impact parameter x of each track is defined as the minimum

CDF Note 1421

May 1st, 1991

SVT: Silicon Vertex Trigger



Inputs:

- L1 tracks from XFT (ϕ, p_T)
- digitized pulse heights from SVX II

Functionalities:

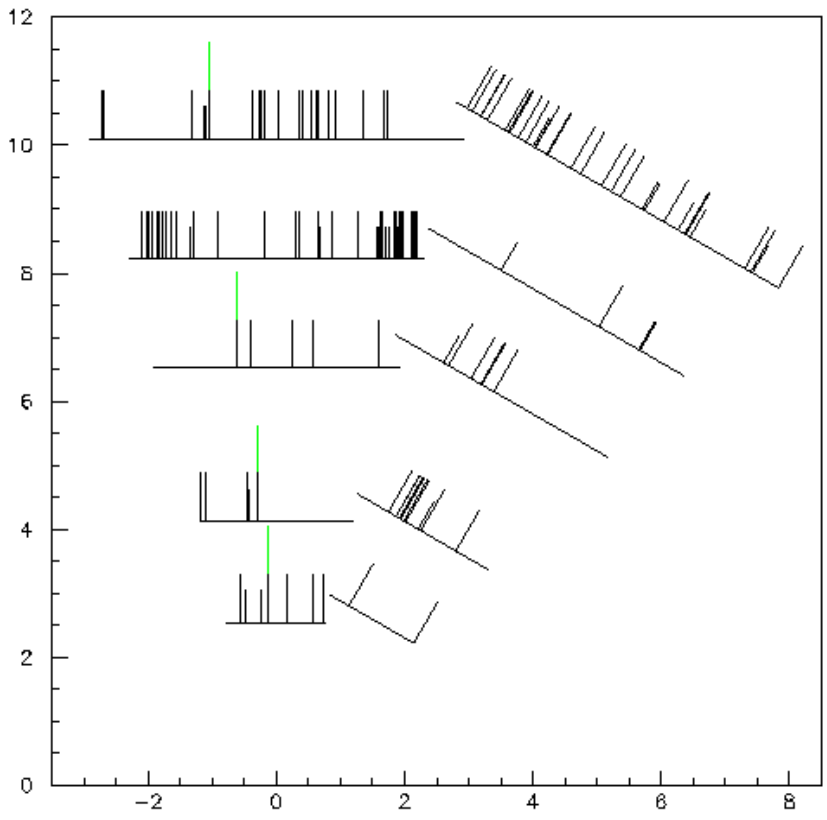
- hit cluster finding
- pattern recognition
- track fitting

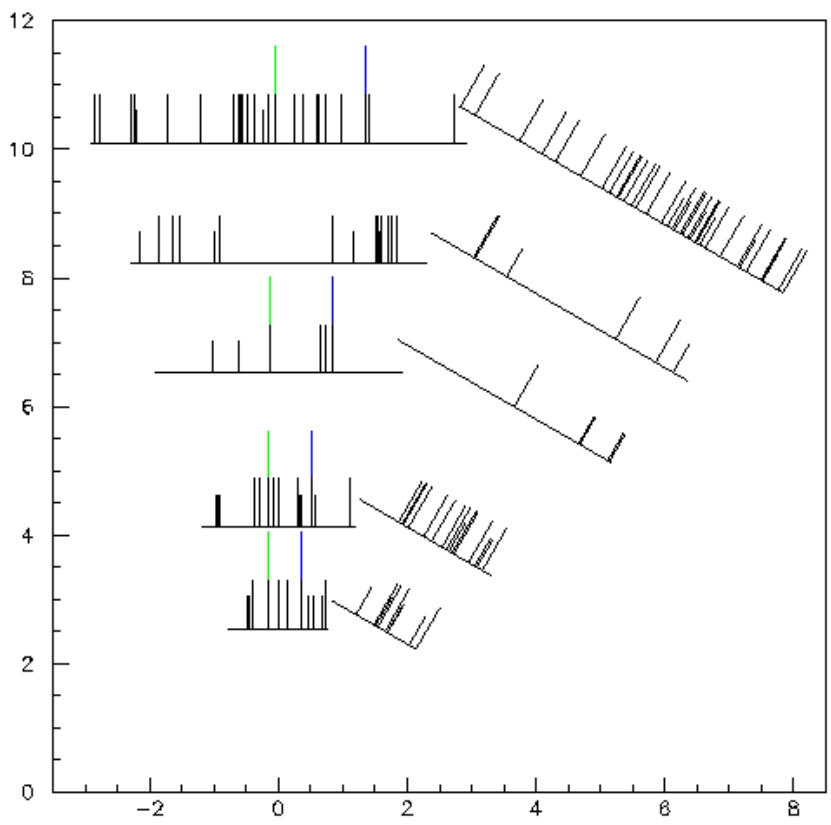
Outputs:

- reconstructed tracks (d, ϕ, p_T)

Finding tracks in the silicon

SVT

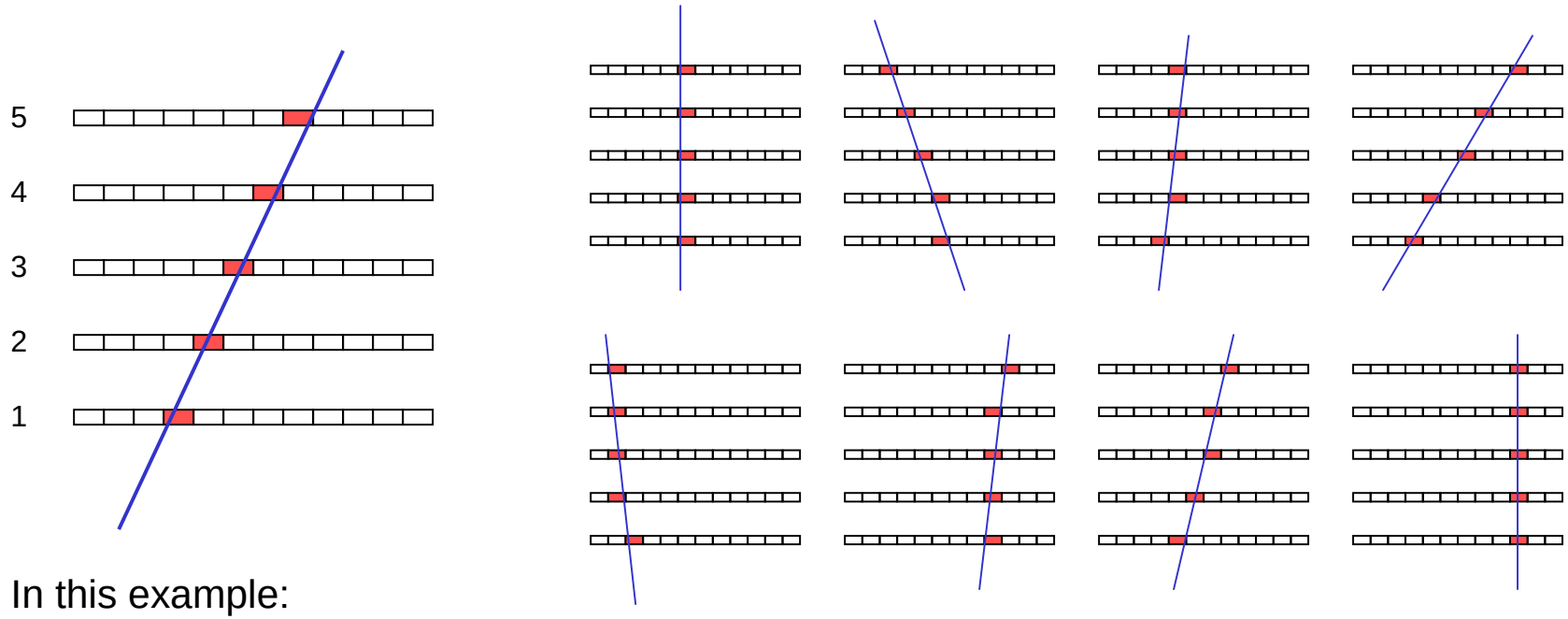




Building the “Pattern Bank”

Instead of looking for hit combinations such that *f(x1,x2,x3,…) = 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



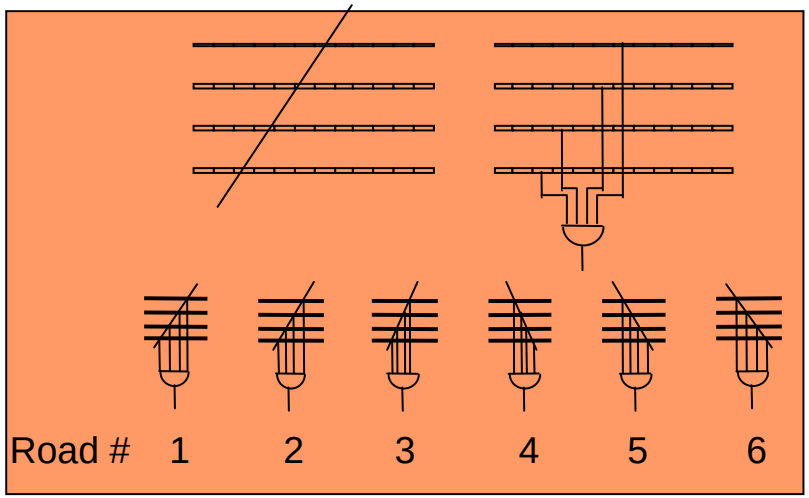
In this example:
Straight lines, 5 layers, 12 bins/layer

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

Associative Memory working principle

SVT

A set of patterns is stored in the Associative Memory. Each pattern (ROAD) contains the coordinates of hit at each detector layer of a possible track.

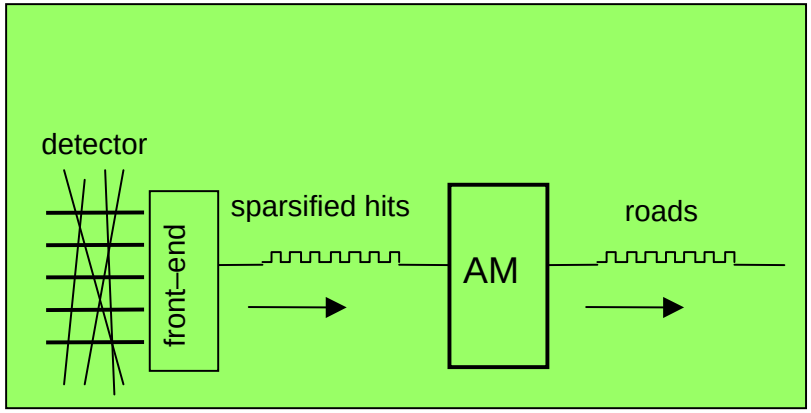


Hit coordinates are read out sequentially into the AM.

In the AM, each coordinate is compared to all the patterns in parallel.

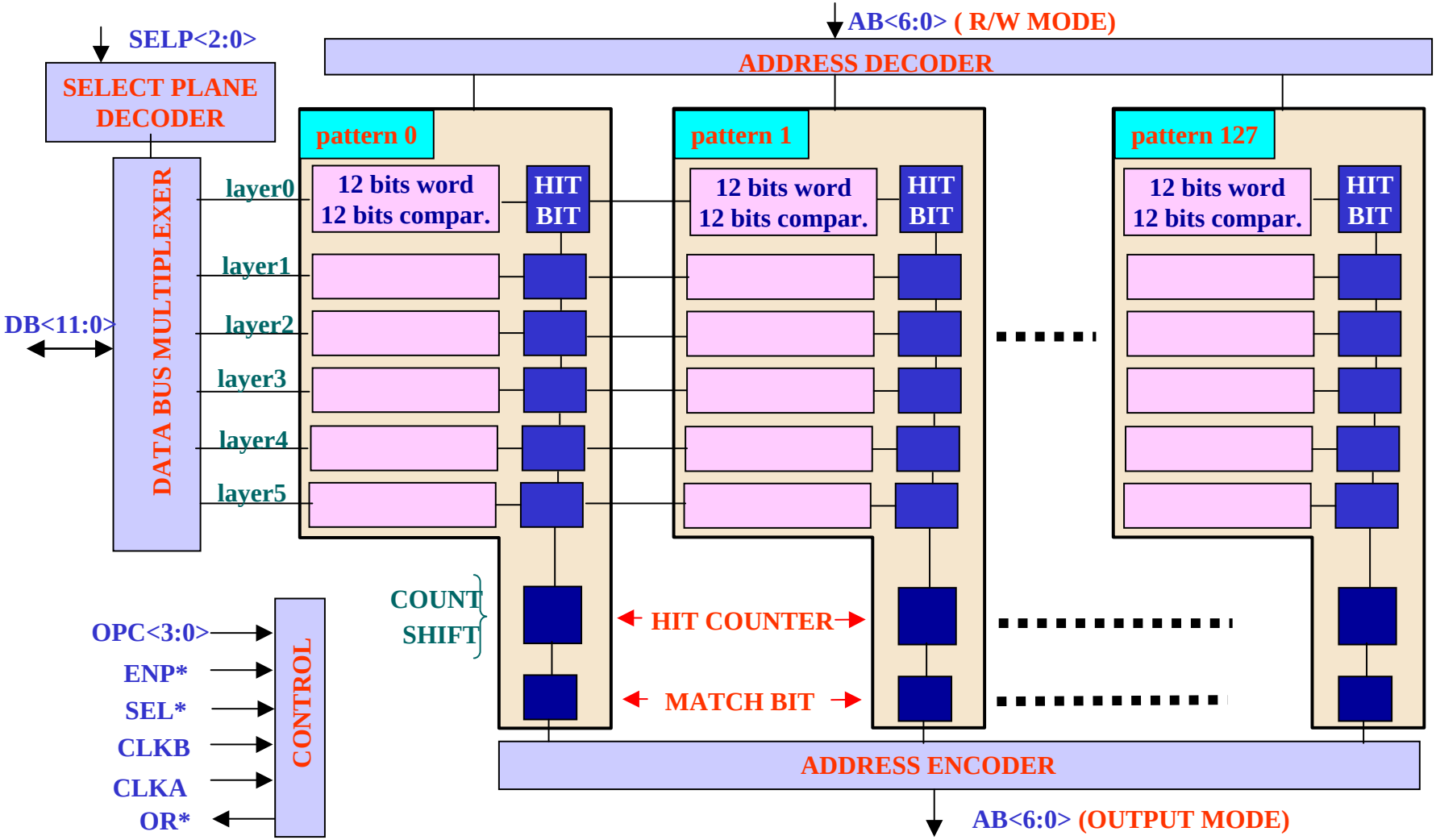
Pattern recognition is complete as soon as the last hit is read.

Roads found by the AM are output sequentially.

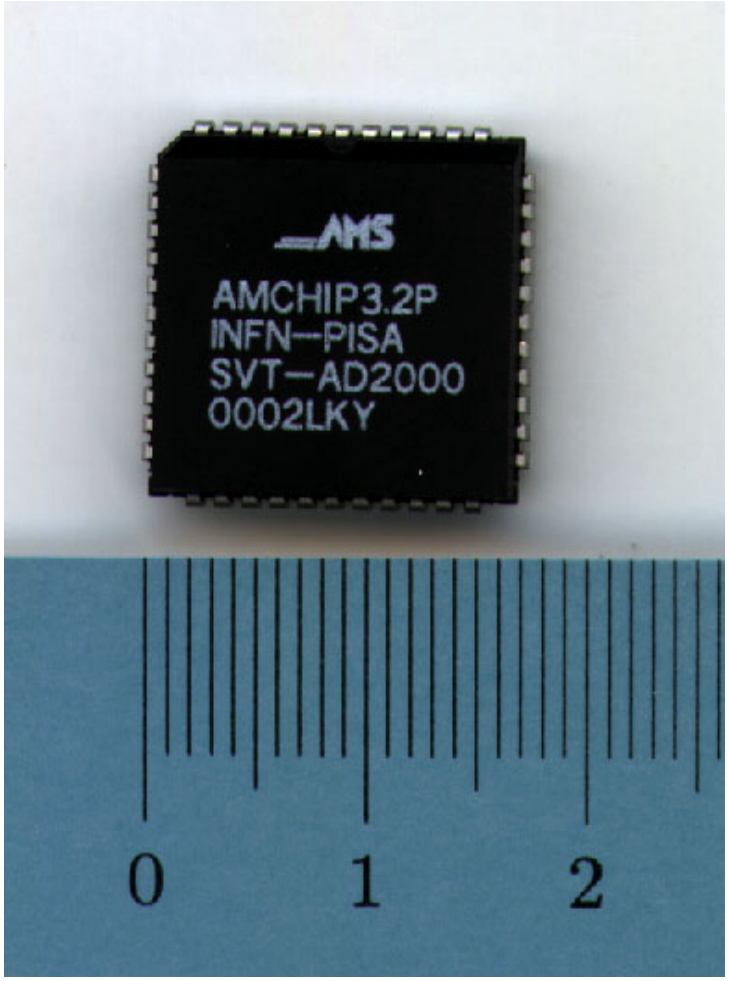


AM chip internal structure

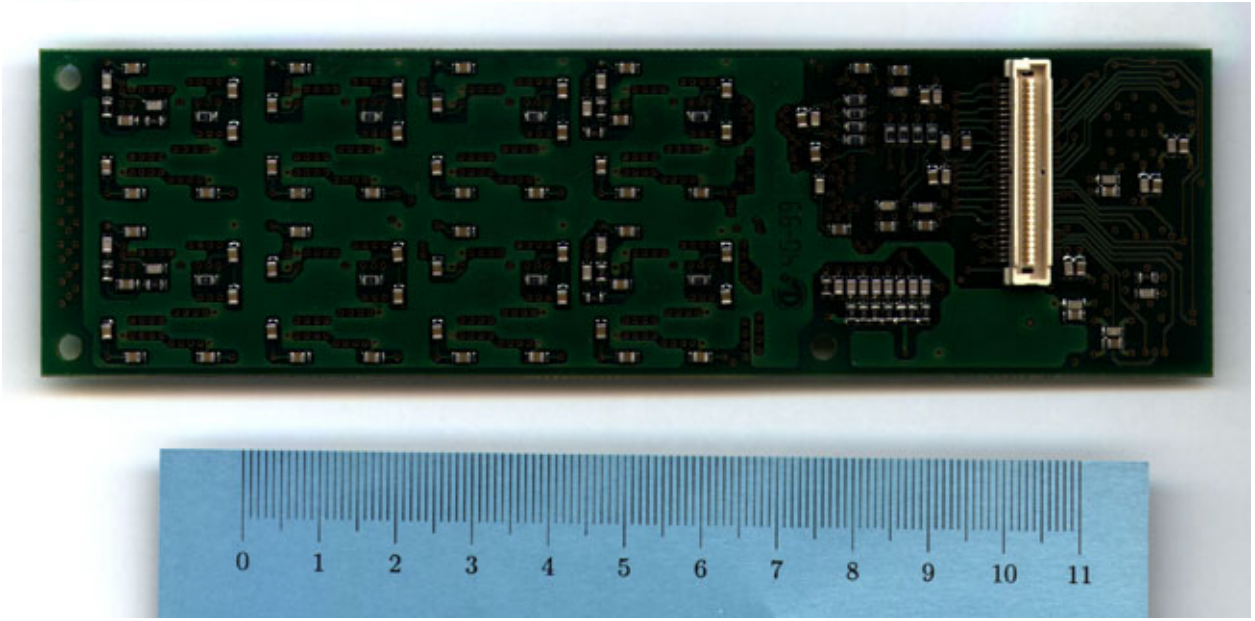
SVT



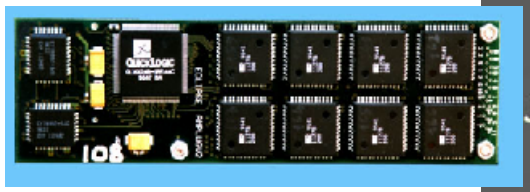
AMchip

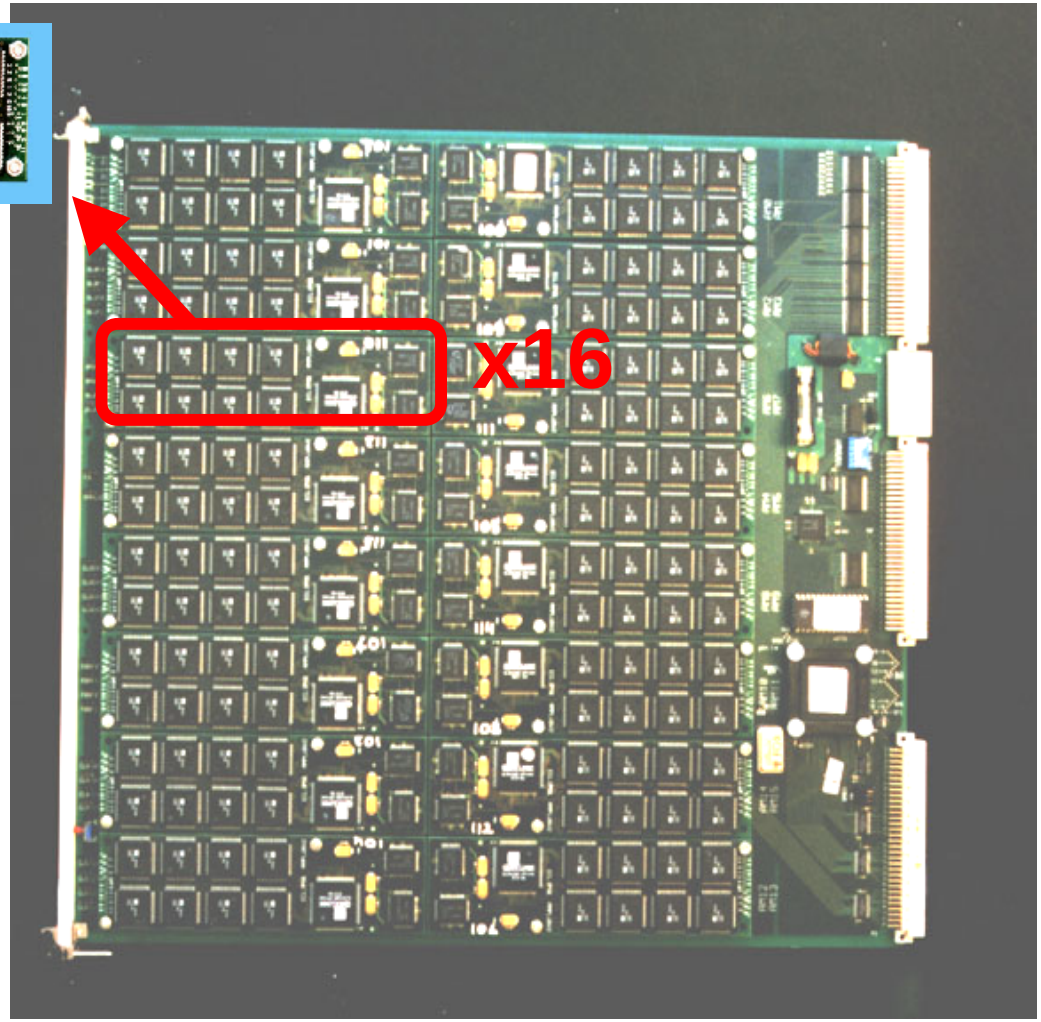


Amplug: mezzanine board



AM Board





128 Amchips

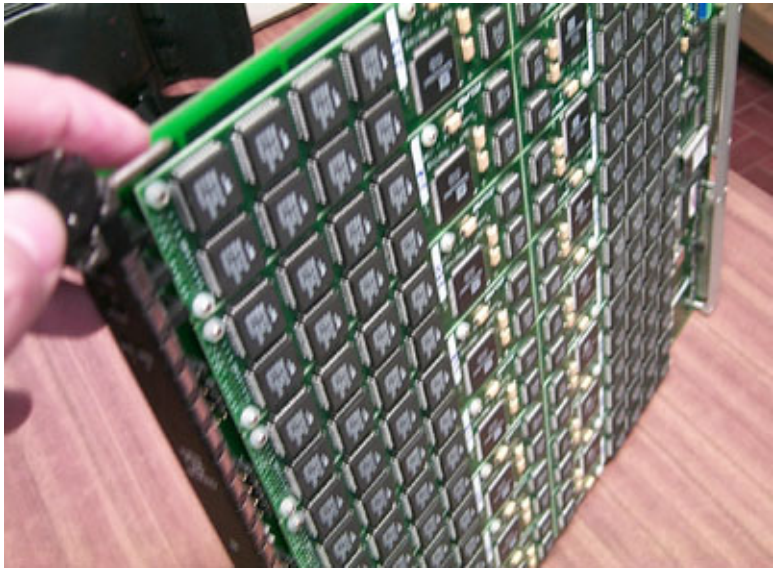
x 128 patterns each

= 16K pattern board

VME

AMbus

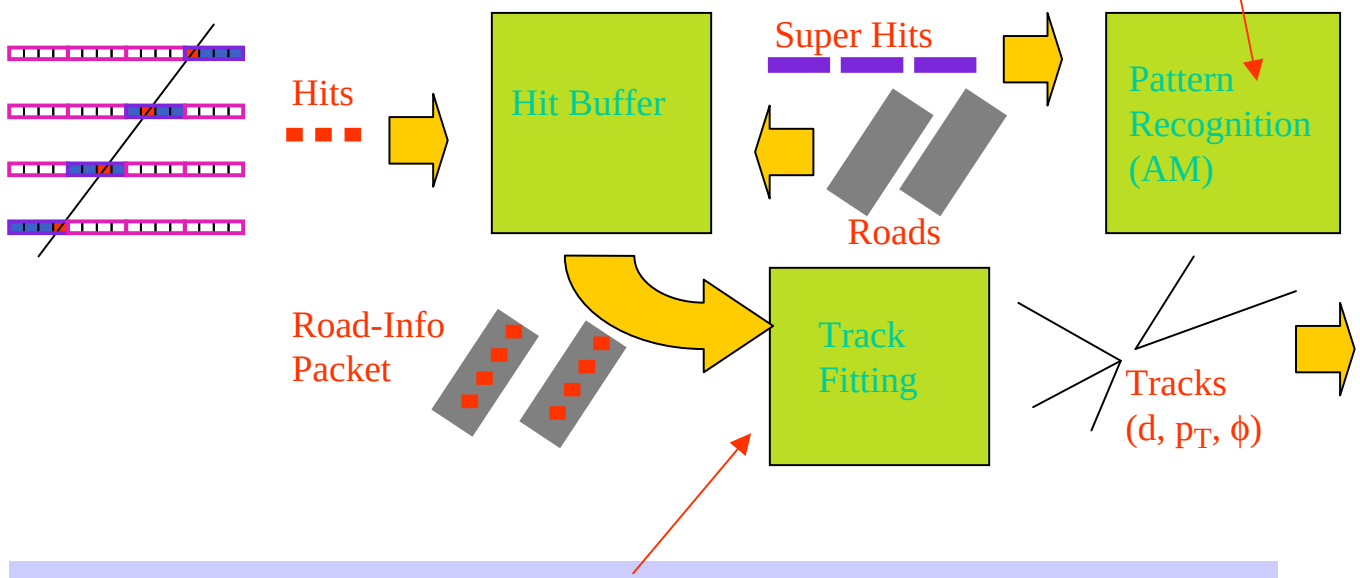
AMboard



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

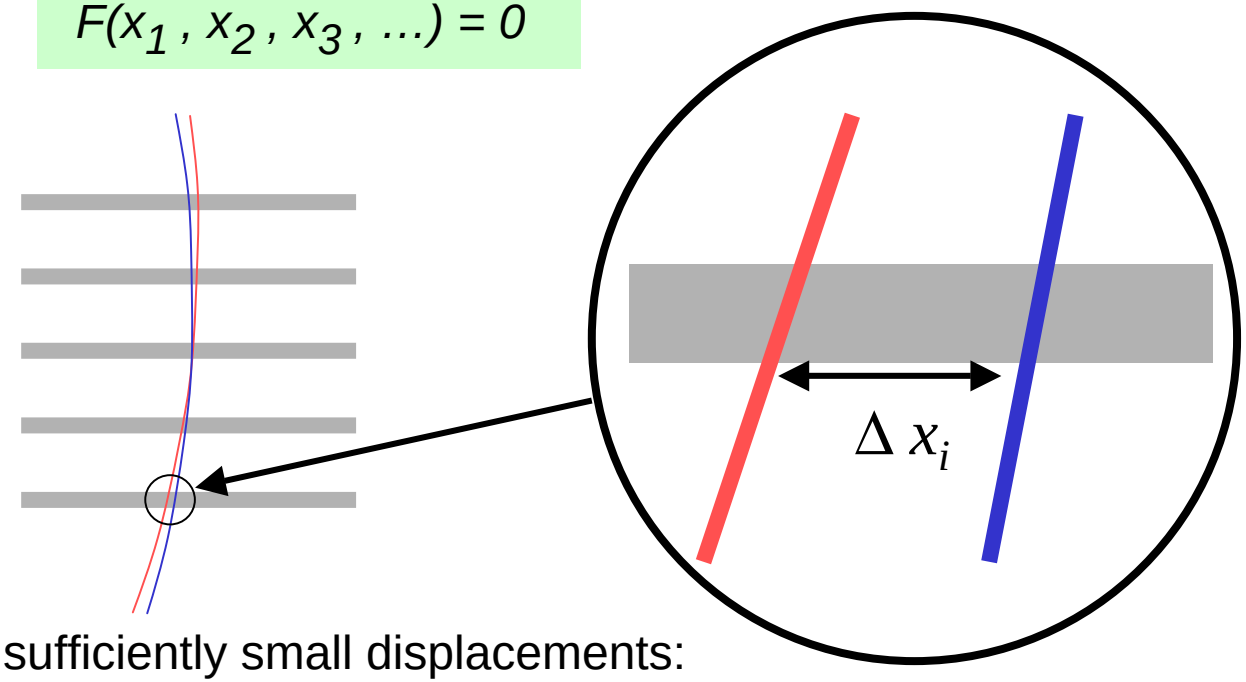


Fast track fitting with linear approximation
using full resolution of the silicon vertex detector

From non-linear to linear constraints

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 a_i (first order expansion of F)

Constraint surface

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

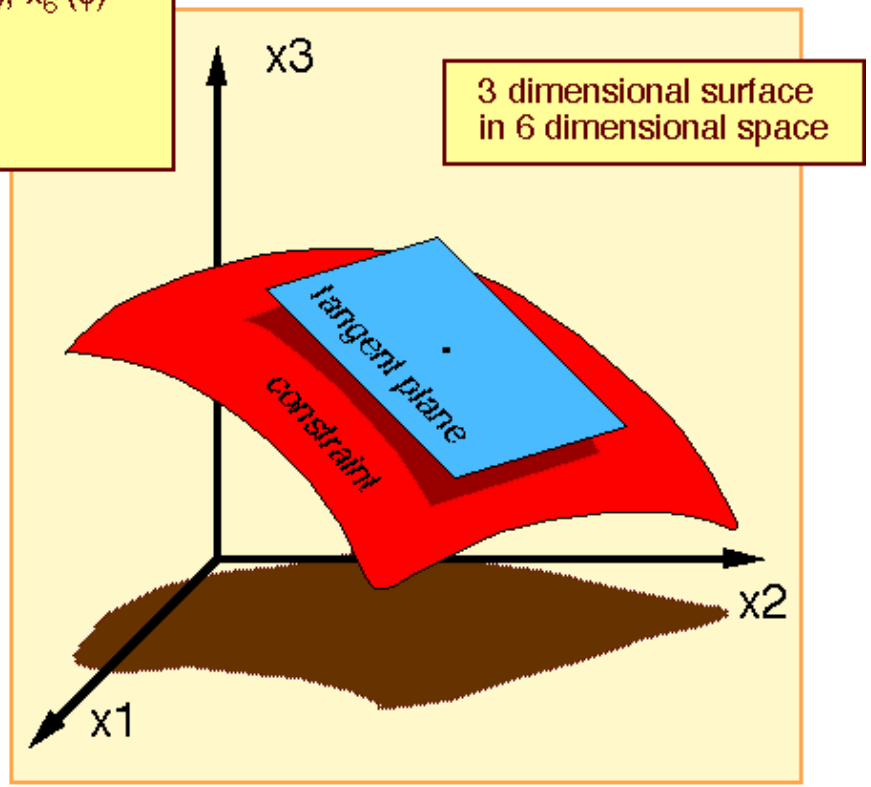
3 constraints

tangent plane:

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

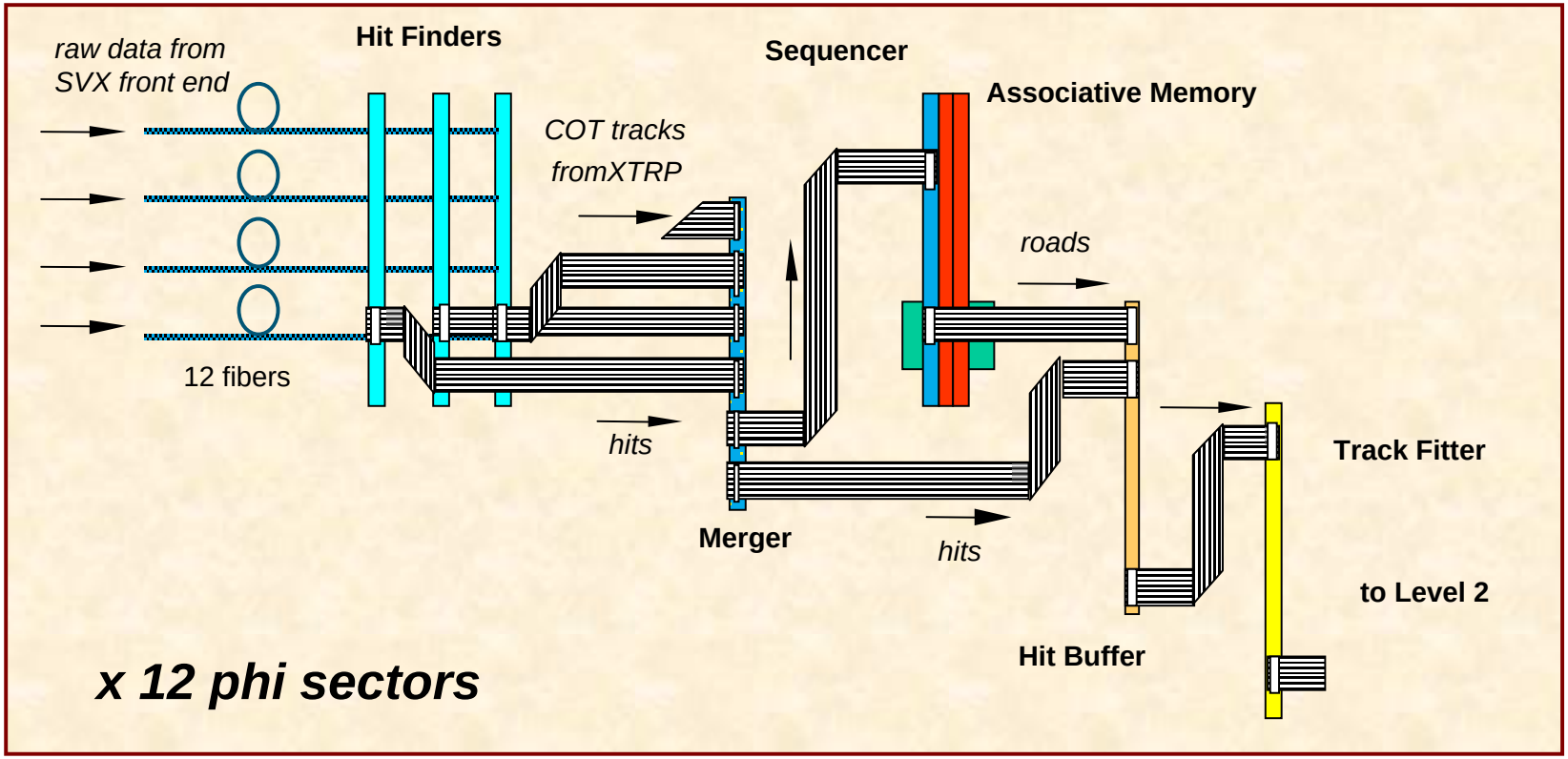
track parameters:

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

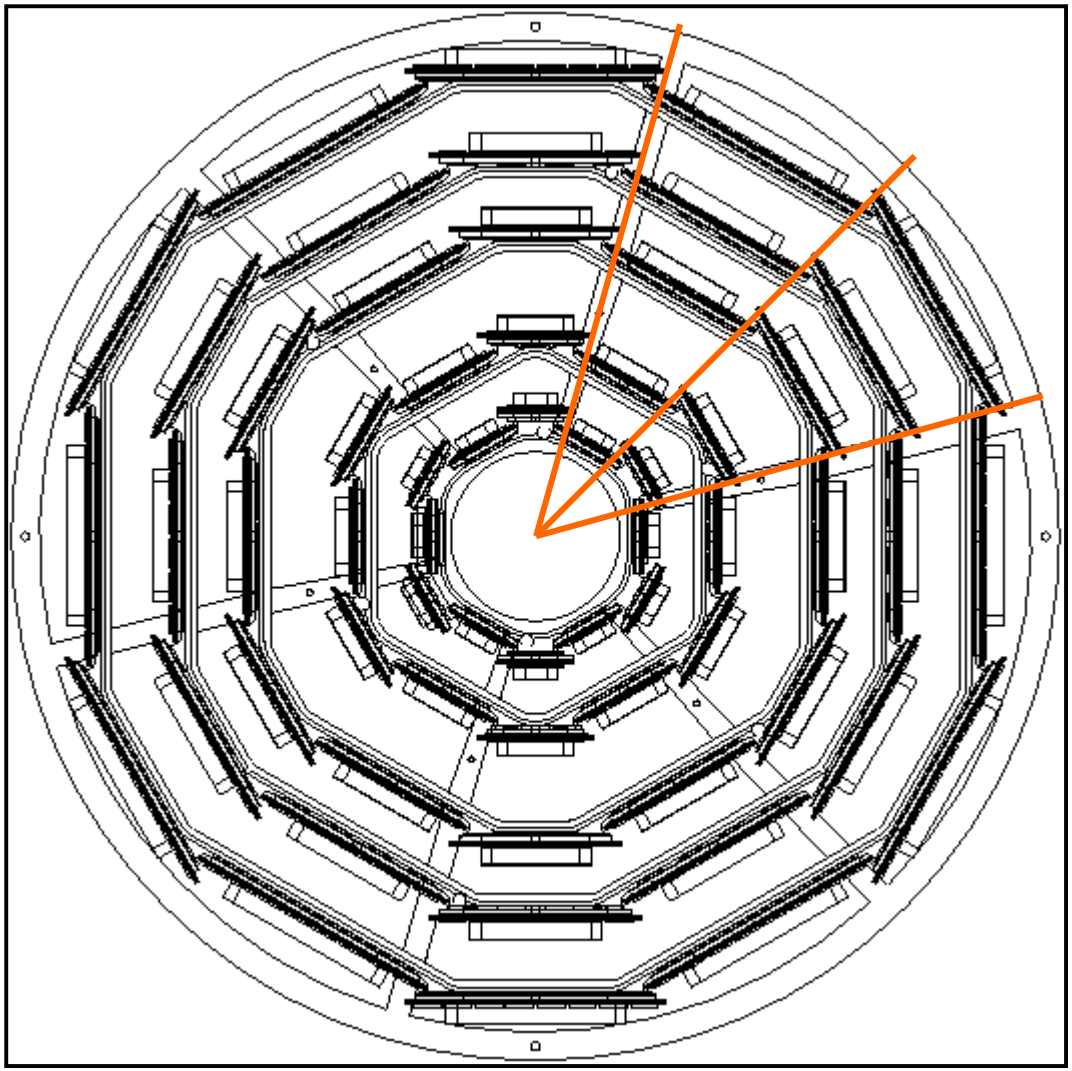


Linear approximation is so good that a single set of constants is sufficient for a whole detector wedge (30° in ϕ)

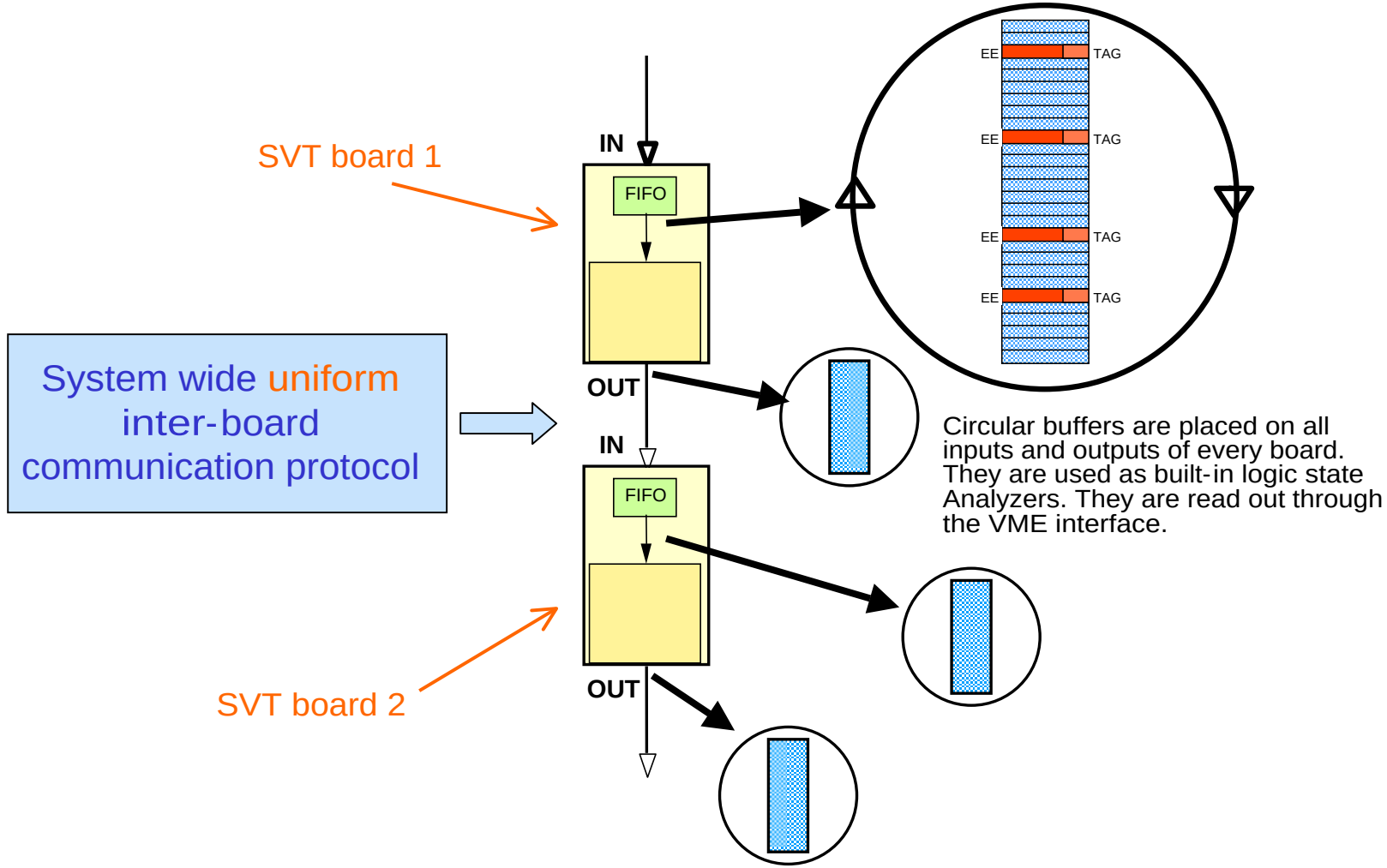
SVT system architecture



SVT Wedges

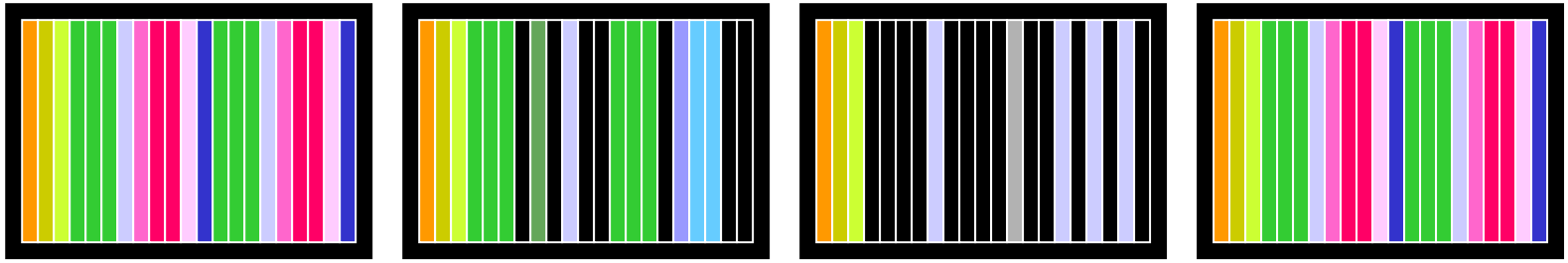


Spy Buffers

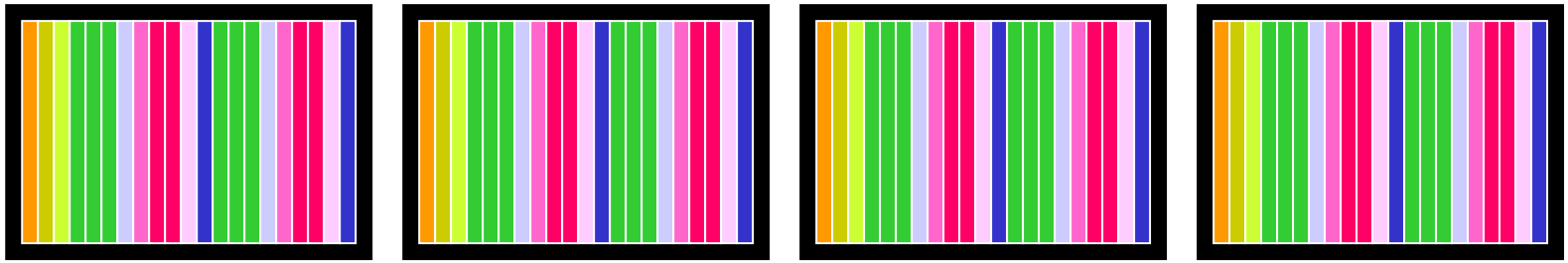

SVT board 1
IN
FIFO
OUT
IN
FIFO
OUT
SVT board 2
System wide uniform inter-board communication protocol
EE
TAG
EE
TAG
EE
TAG
EE
TAG
Circular buffers are placed on all inputs and outputs of every board. They are used as built-in logic state Analyzers. They are read out through the VME interface.

SVT: board and crate layout

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



b0svt00 b0svt07 b0svt06 b0svt05



b0svt01 b0svt02 b0svt03 b0svt04

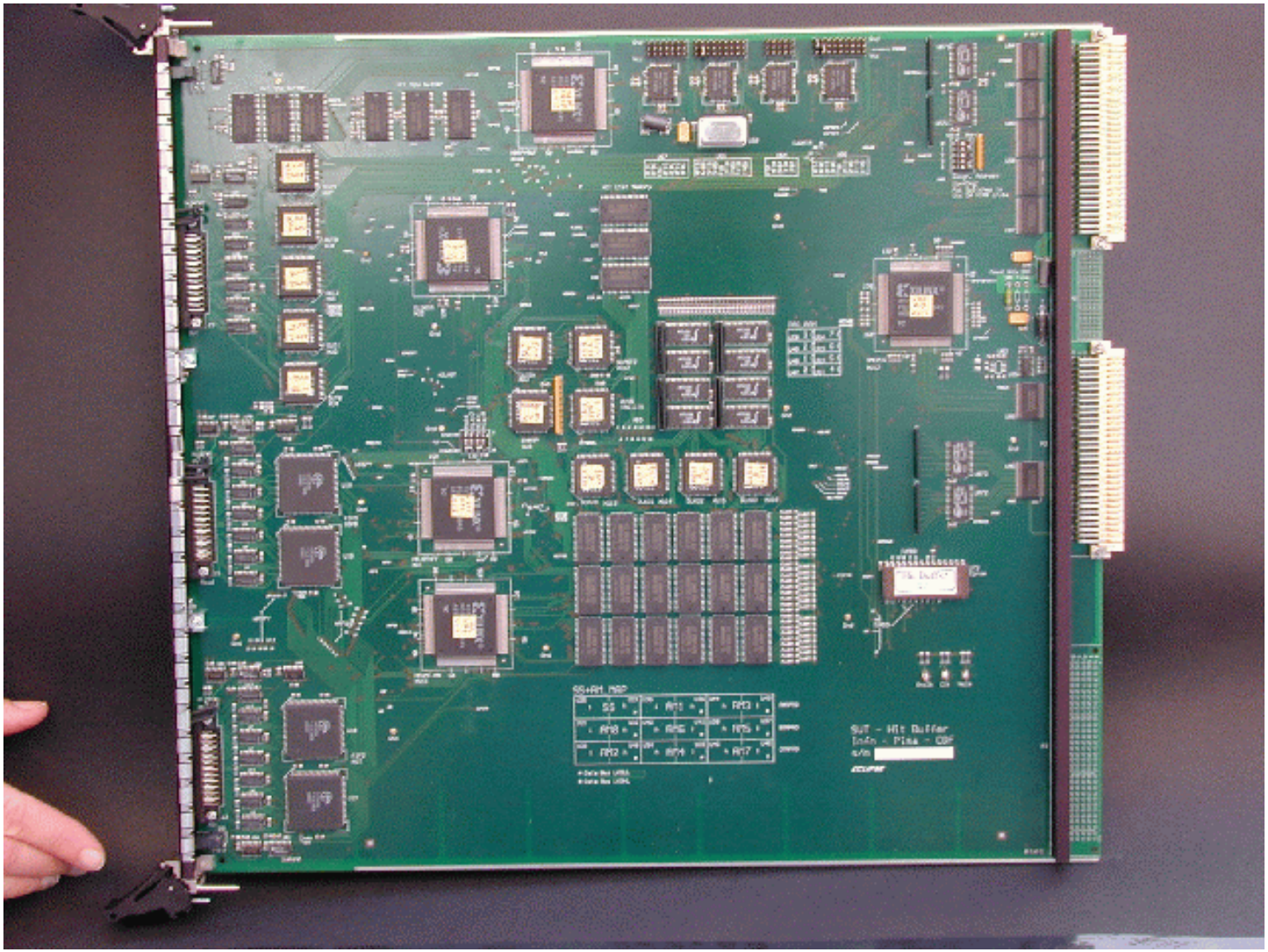
SVT: board count

Hit Finders	42
Mergers	16
Sequencers	12
AMboards	24
Hit Buffers	12
Track Fitters	12
Spy Controls	8
XTFA	1
XTFB	2
XTFC	6
TOTAL	135

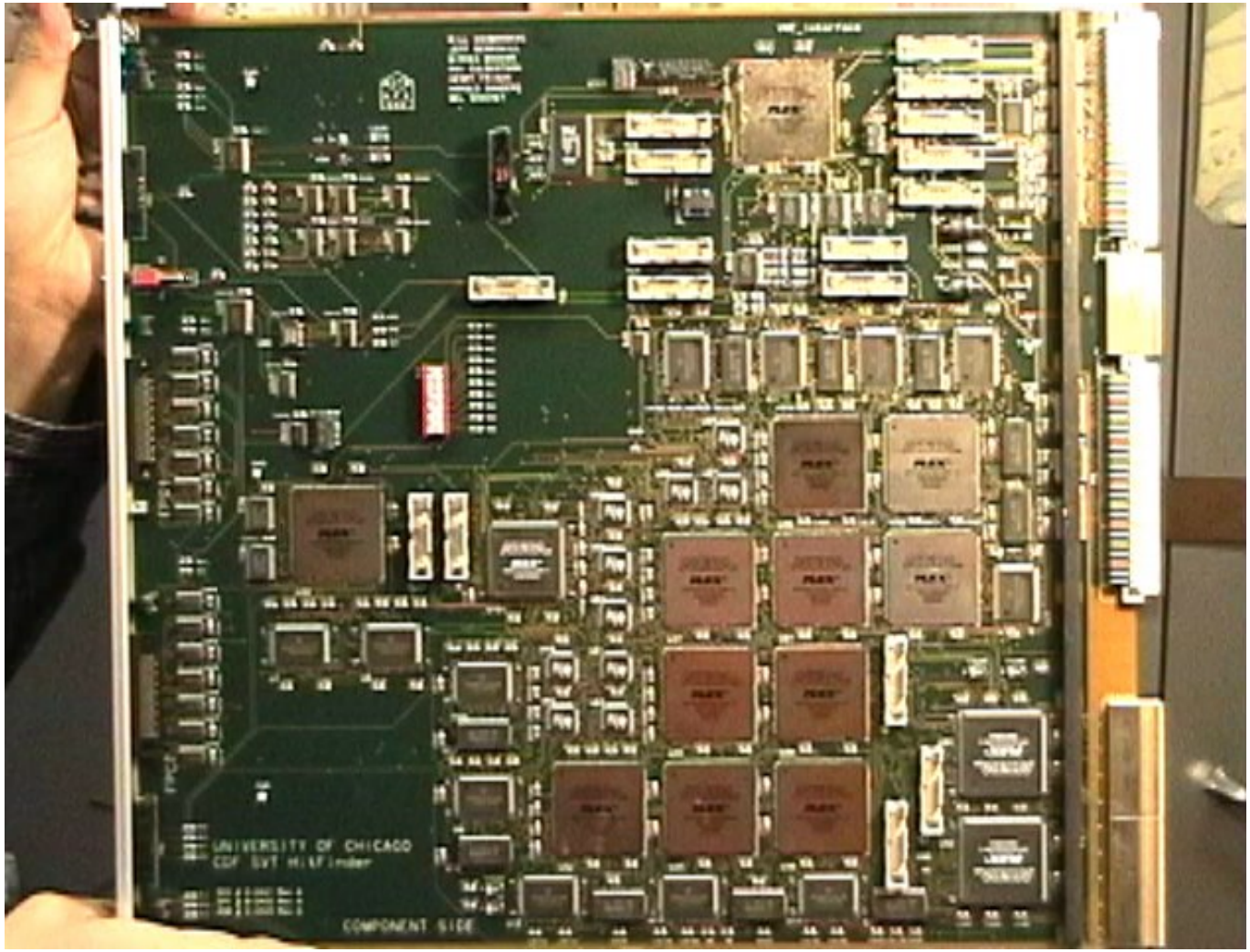
+ spares

- INFN
- INFN & Geneva
- University of Chicago

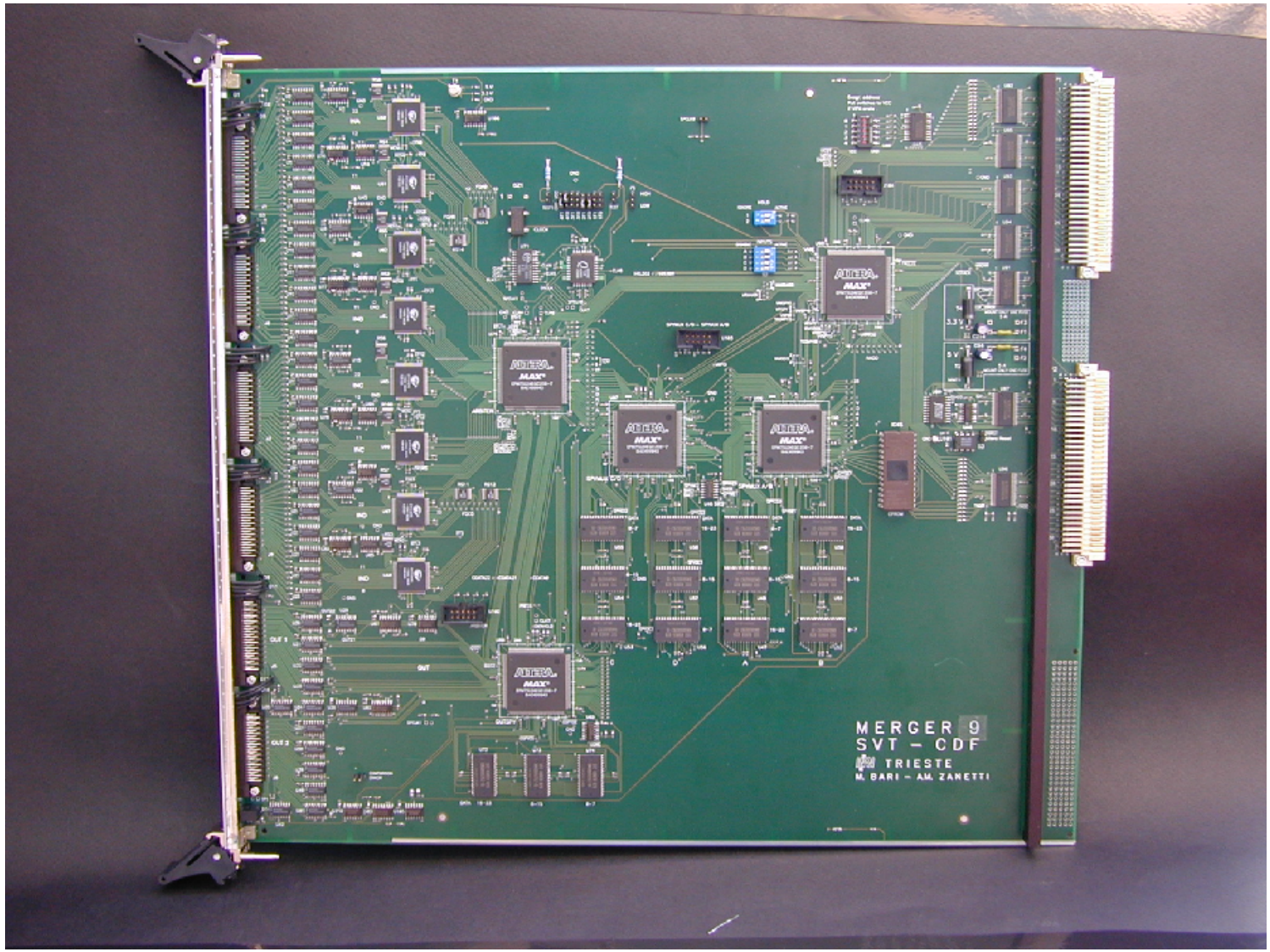
Hit Buffer board



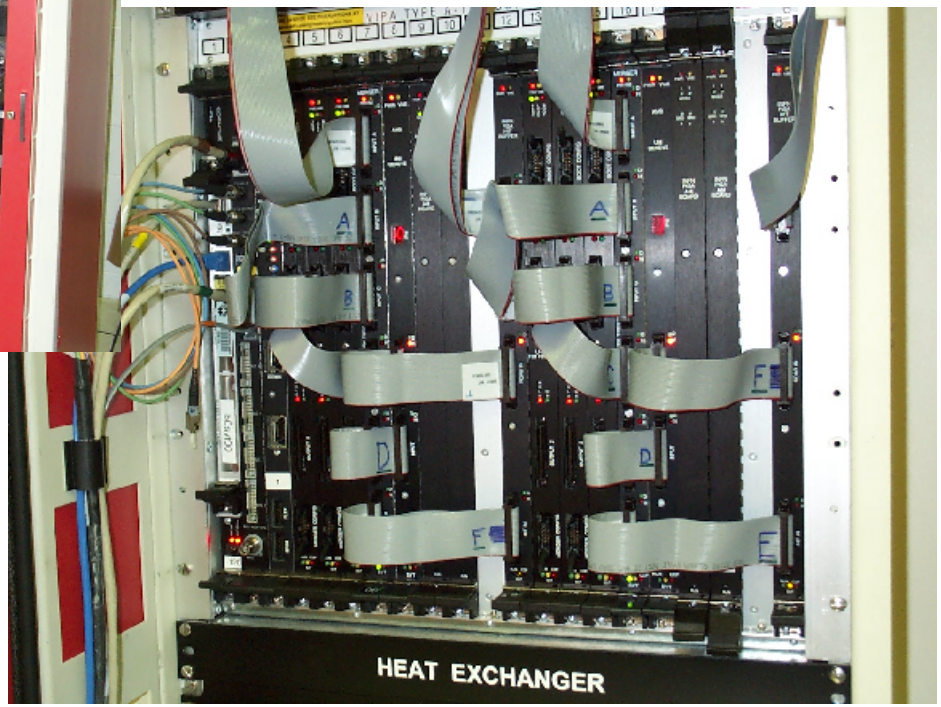
Hit Finder board



Merger board

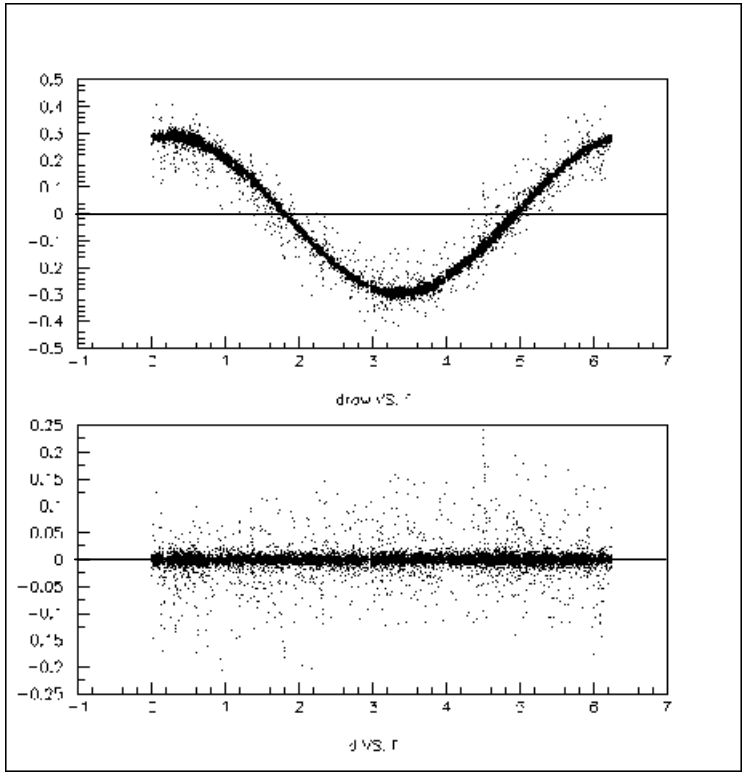


SVT crates in CDF counting room



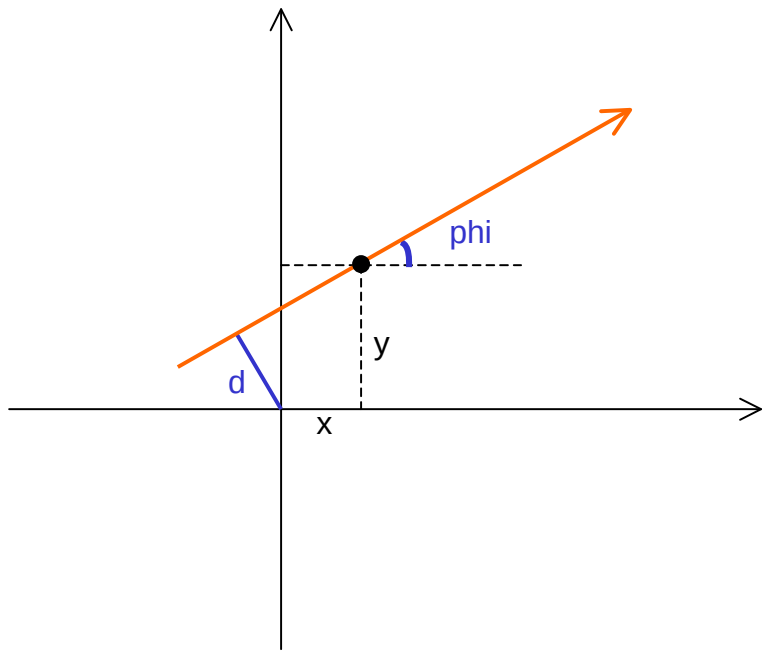
Impact parameter vs. phi

SVT



Raw

Subtracted

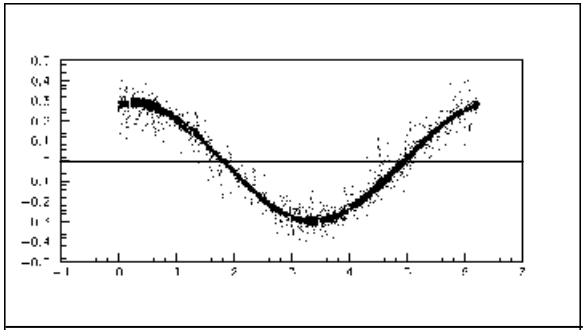


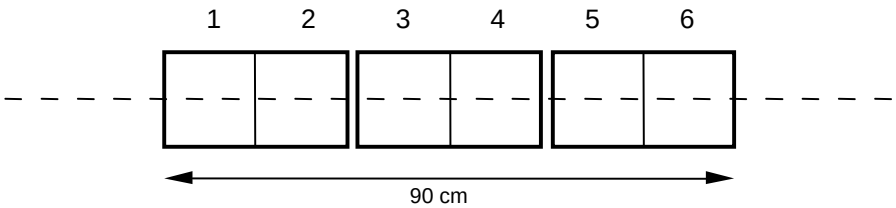
d = y cos(phi) – x sin(phi)

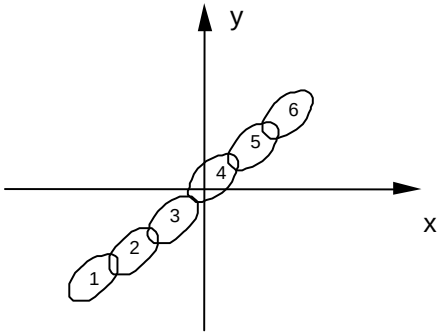
Online 3D beam position

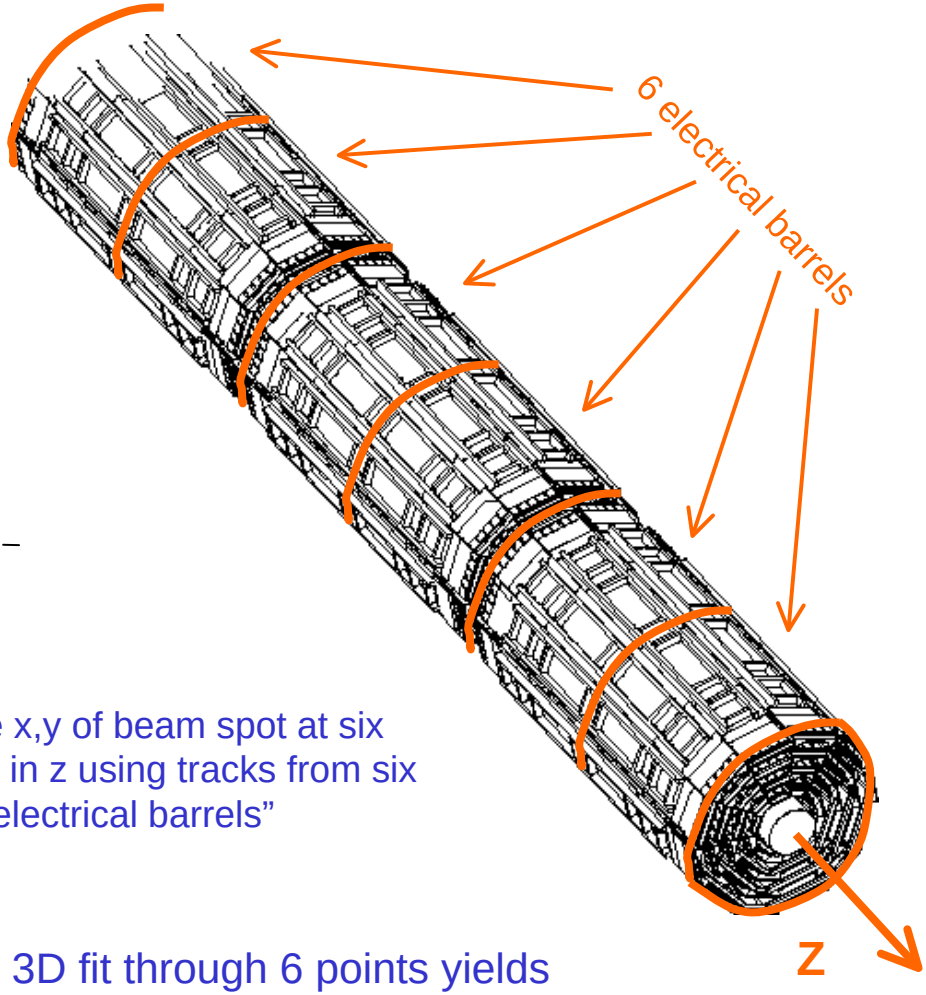
SVT

In each barrel







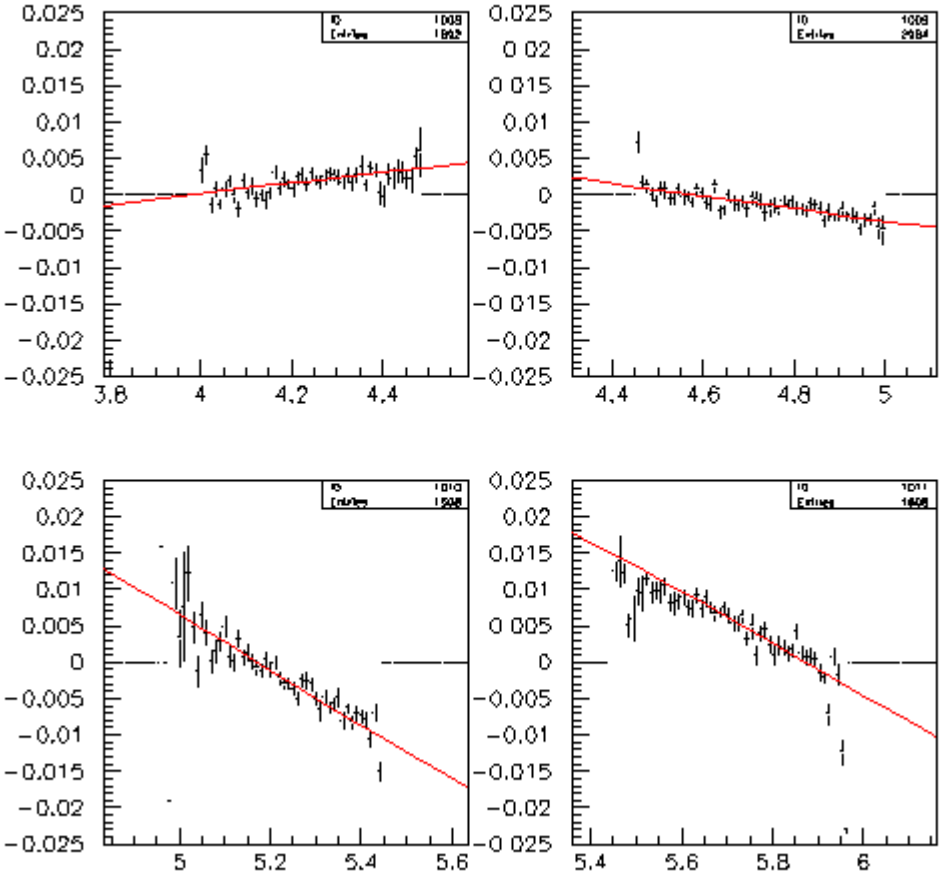


Compute x,y of beam spot at six positions in z using tracks from six distinct “electrical barrels”

3D fit through 6 points yields

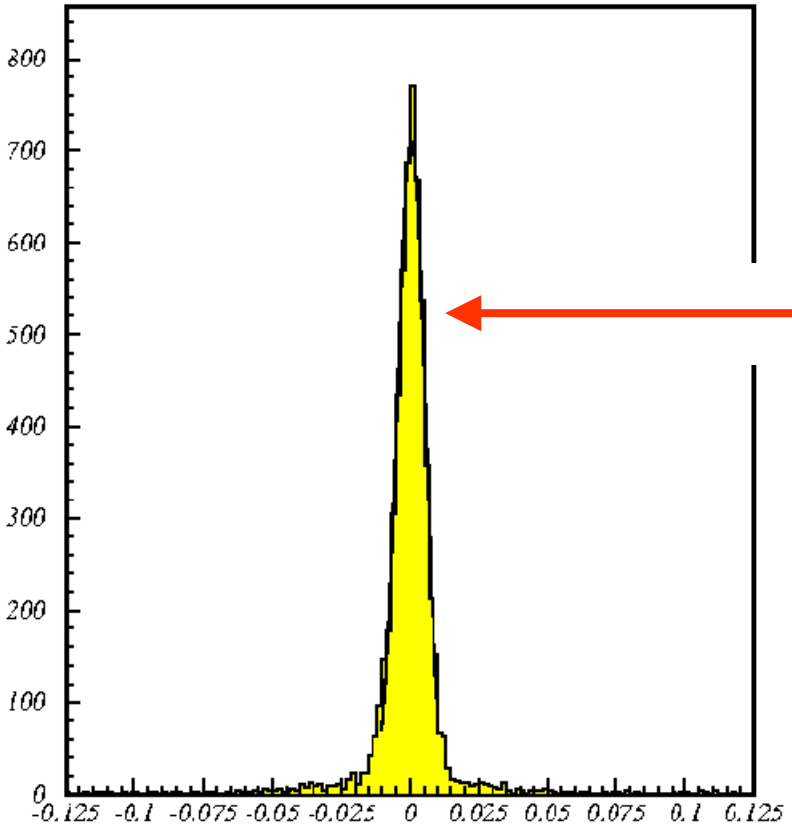
x_0, y_0, dx/dz, dy/dz

Wedge to wedge alignment



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 ~ 48 um ~ 42 um ⊕ 23 um

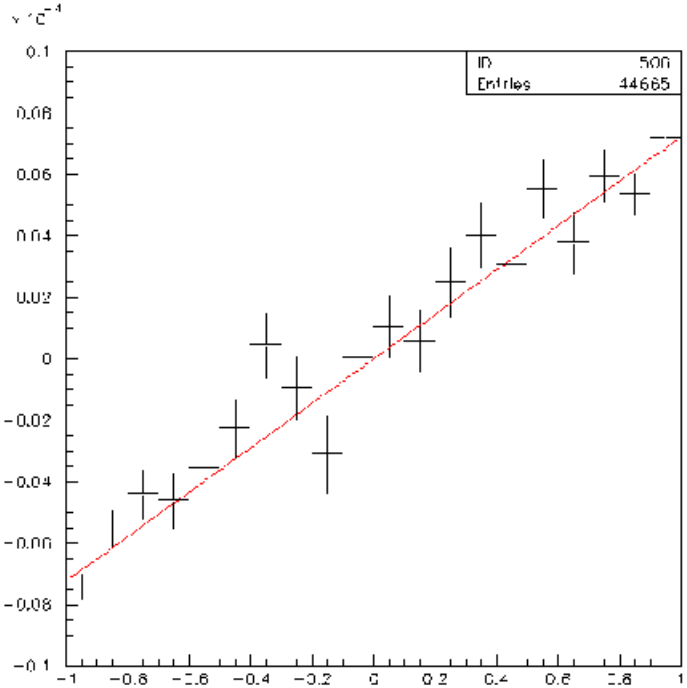
SVT resolution beam spot size

	beam	*SVT*	*Total*
sigma	23	42	48
rms	23	51	56

Two track d correlation

SVT

See CDF note 4189



Cos(phi)

$$\langle d_1 * d_2 \rangle - \langle d_1 \rangle \langle d_2 \rangle = s^2 \cos(phi)$$

Intrinsic beam width

CDF/MEMO/TRACKING/CDFR/4189

Measuring beam width and SVX impact parameter resolution

S. Donati, L. Ristori

Introduction

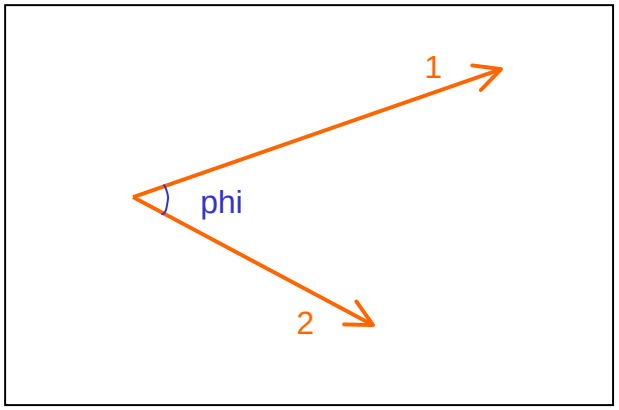
The observed impact parameter distribution of SVX tracks is the convolution of the primary vertex distribution with the impact parameter resolution and its width ($\sigma_d \sim 46\ \mu m$) is given by:

$$\sigma_d^2 = \sigma_\mu^2 + \sigma_r^2 \qquad (1)$$

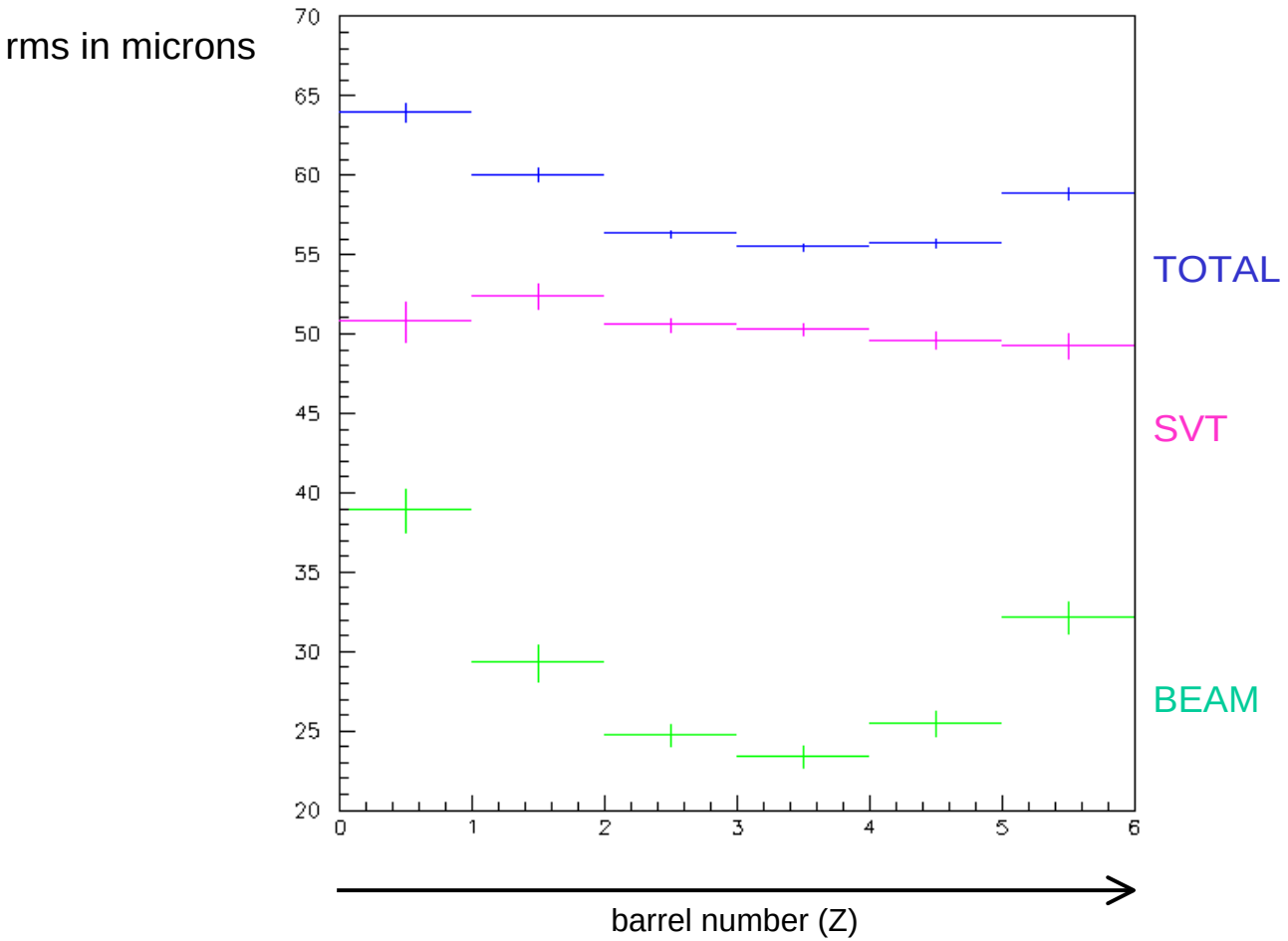
where σ_μ is the actual beam width and σ_r is the impact parameter resolution. We propose a method to measure σ_μ and σ_r separately from data.

The idea is to extract σ_μ from the measurement of the correlation between impact parameters of track pairs exiting from the same primary vertex. Since σ_d is easily measured, impact parameter resolution (σ_r) is then determined by subtraction (Eq. (1)).

This method can also be used to determine σ_μ and σ_r dependence on z and p_t.

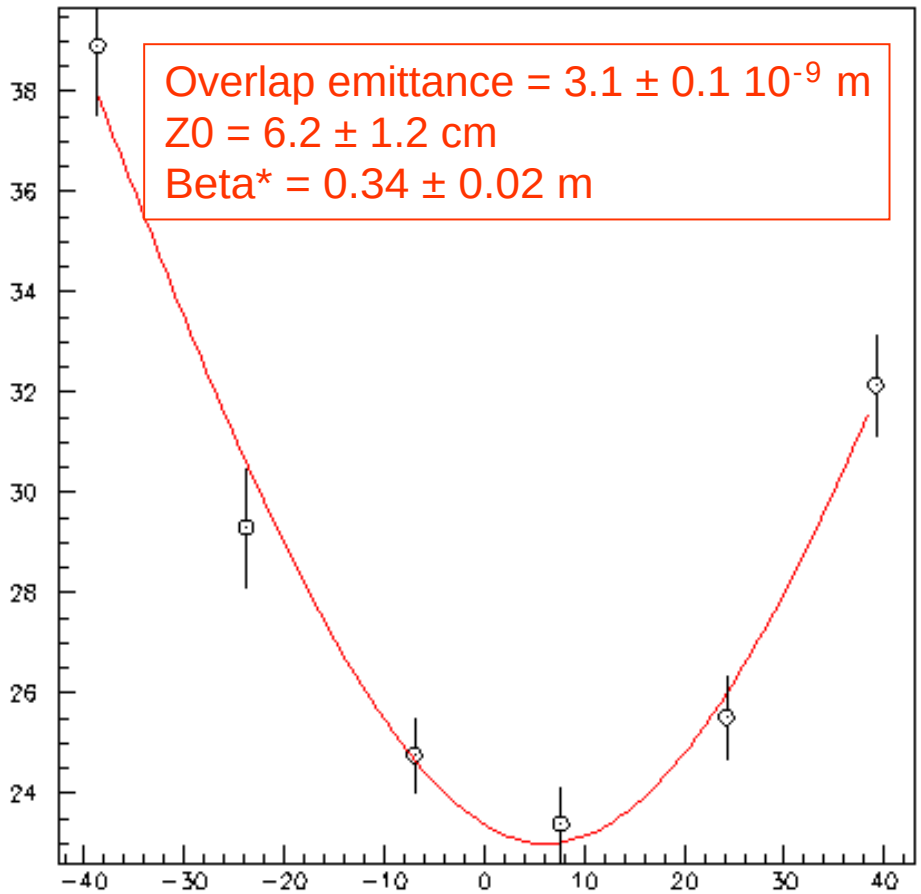


SVT + BEAM = TOTAL



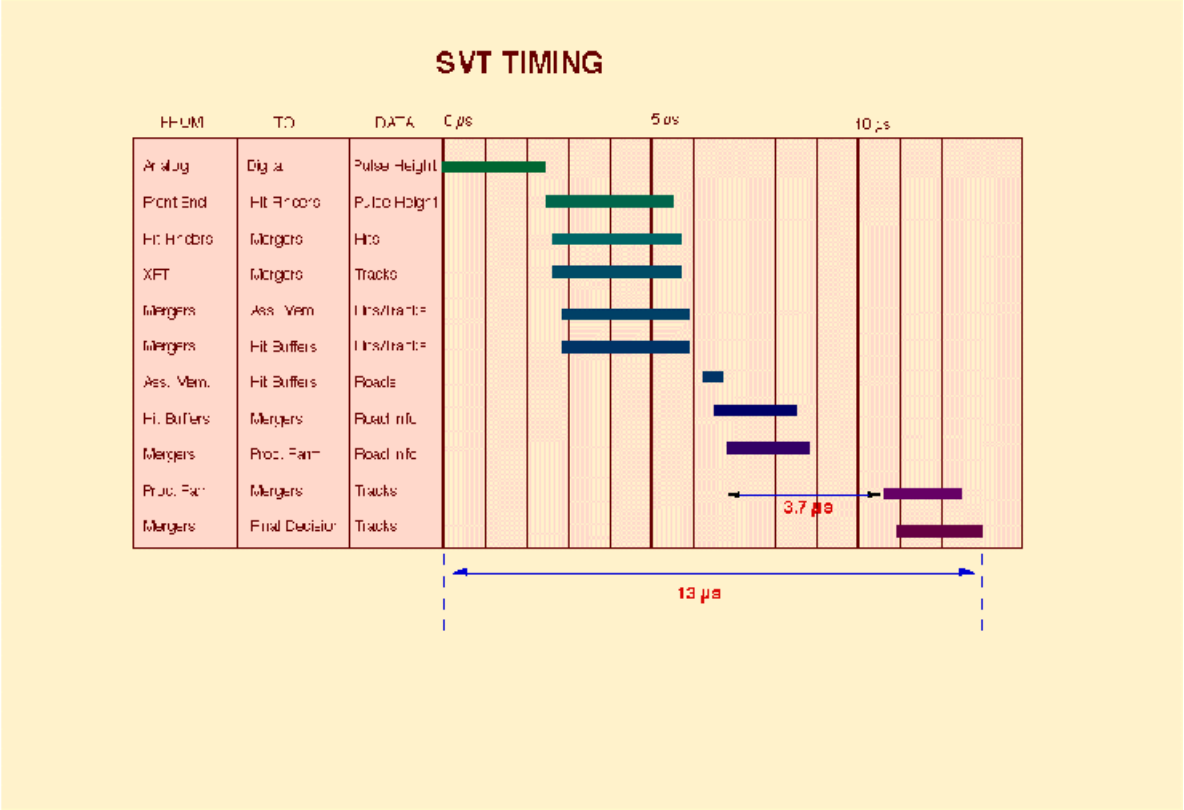
Intrinsic beam width

rms (microns)



Z (cm)

Timing

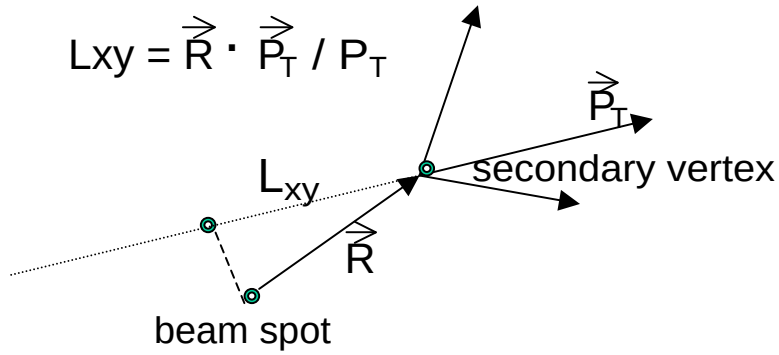


Prediction of SVT execution time from design document CDF3108 – Nov 1994

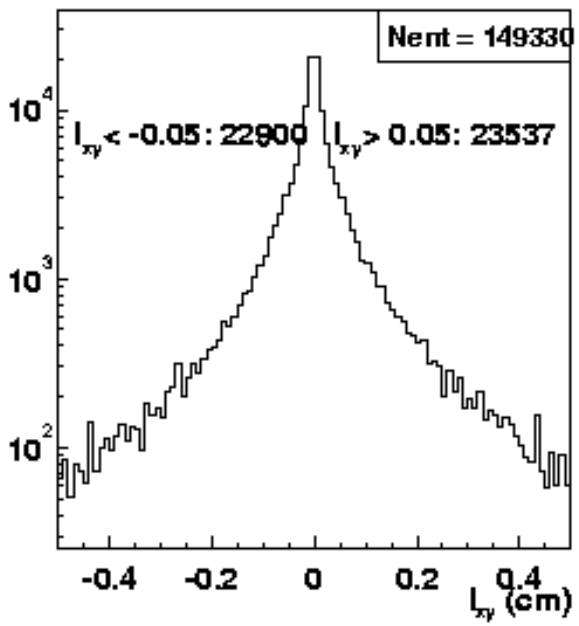
SVX readout	SVT proc.	Total (us)	
2.5	10.5	13	predicted
9	13	22	actual

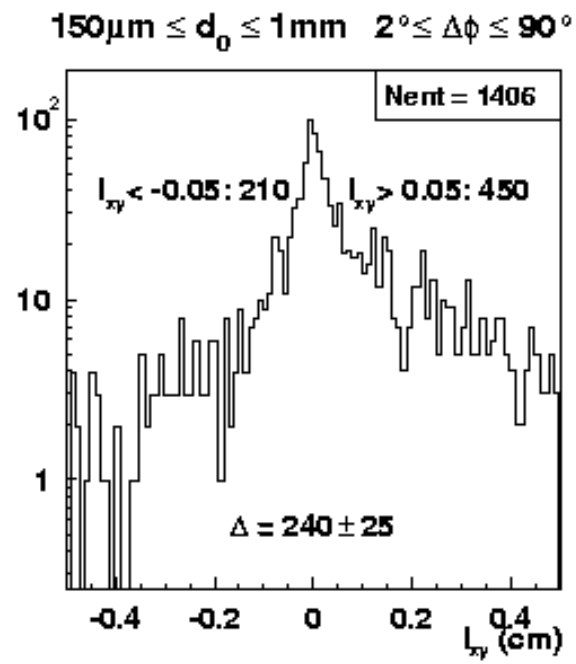
CDF Silicon Trigger Results

$$Lxy = \vec{R} \cdot \vec{P}_T / P_T$$



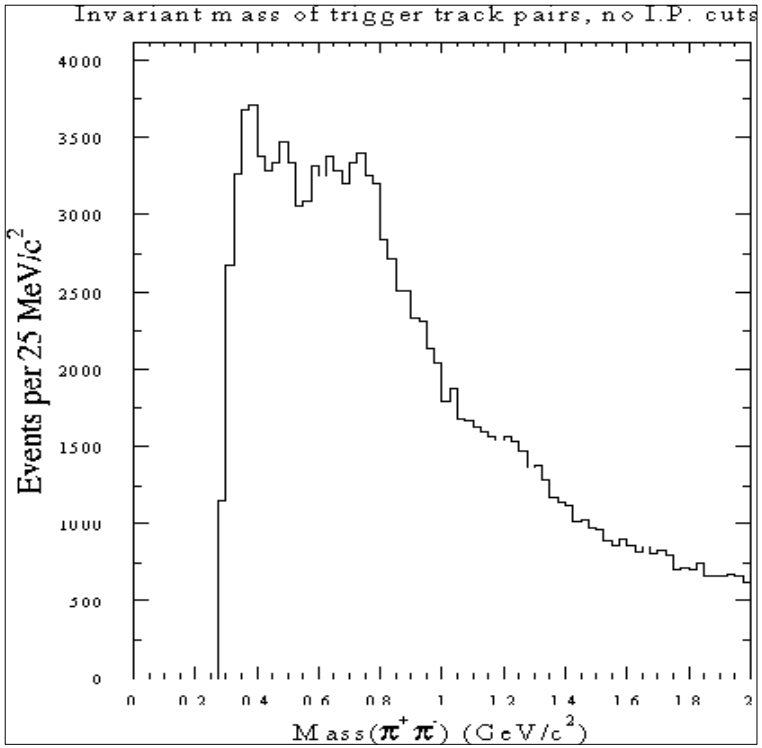
L_{xy} before and after L2 Trigger Cuts

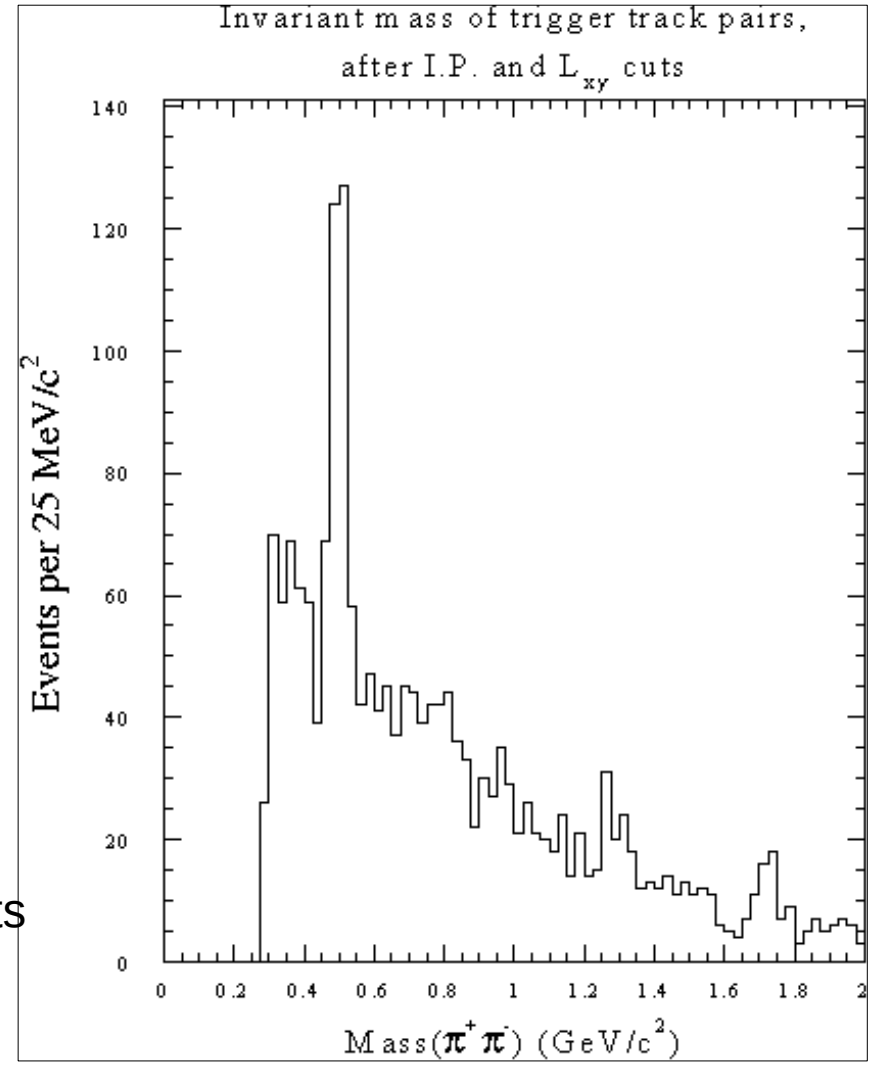




K^0 in SVT Data!

SVT

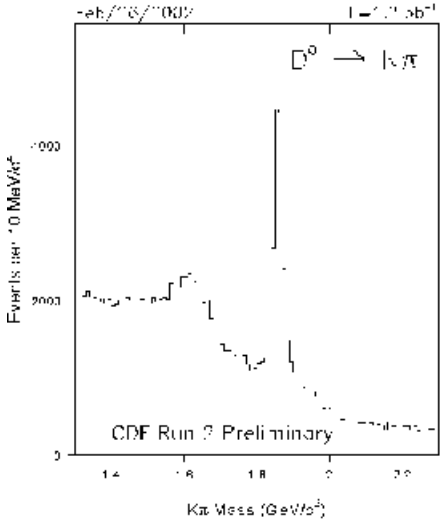


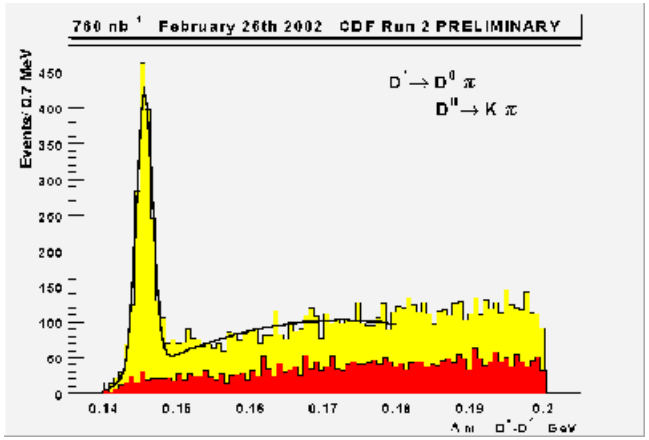


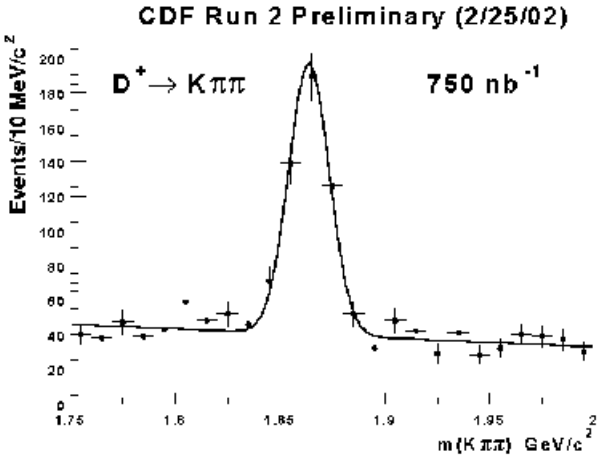
Mass before and after d_0 and L_{xy} cuts

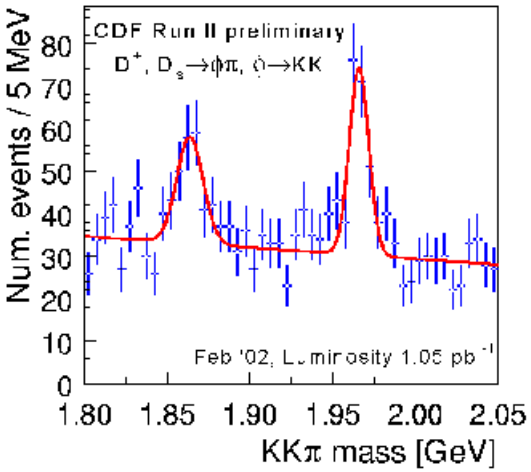
Hadronic Charm decays!

SVT









Hadronic B decays with SVT

Two paths

- L1:
  - Two XFT tracks
  - P_{t1}>2 GeV $P_{t1}+P_{t2}$>5.5 GeV
  - $\Delta\phi$<135°
- L2:
  - d_0>100 μm for both tracks
  - Validation of L1 cuts with $\Delta\phi$>20°
  - $P_t \cdot X_v > 0$
  - $d_0(B)$<140 μm

High Mass

Two body decays

- L1:
  - Two XFT tracks
  - P_{t1}>2 GeV $P_{t1}+P_{t2}$>5.5 GeV
  - $\Delta\phi$<135°
- L2:
  - d_0>120 μm for both tracks
  - Validation of L1 cuts with $\Delta\phi$>2°
  - $P_t \cdot X_v > 0$
  - ~~$d_0(B)$<140 μm~~

Low Mass

Many body decays

SVT Trigger Rates

- Two SVT L2 triggers are defined in CDF4718
  - B_pipi: 360 nb
    - 2x (d > 100 um), Delta-phi > 20^0, Lxy > 0, dB < 140 um
  - B_charm: 394 nb (200 nb overlap)
    - 2x (d > 120 um), 2^0 < Delta-phi < 90^0, Lxy > 0
- Simple requirement of two tracks with d > 100 um is currently used at L2
  - L2_TWO_TRK2_D100: 3200 nb
- L2 cuts are simulated offline on data from a L3 auto-accept prescaled path

	All	simulate	x $(72/56)^2$	Expected
B_pipi	3200 nb	287 nb	474 nb	360 nb
B_charm	3200 nb	391 nb	646 nb	394 nb

SUMMARY

- The design and construction of SVT was a significant step forward in the technology of fast track finding
- We used a massively parallel/pipelined architecture combined with some innovative techniques such as the associative memory and linearized track fitting
- Commissioning of SVT is well on track 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 despite the slow start of Run II

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