# The Silicon Vertex Trigger of CDF

Luciano Ristori
Istituto Nazionale di Fisica Nucleare
Pisa - Italy

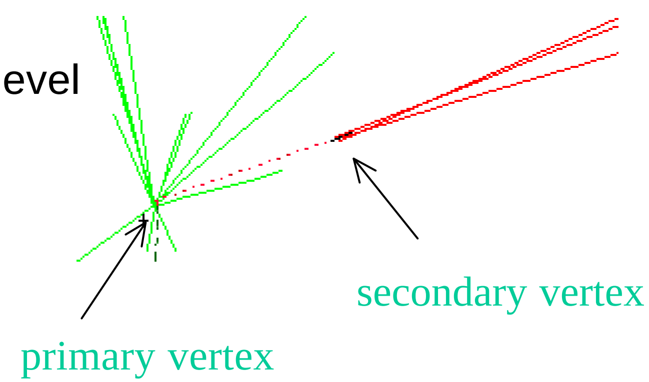
- **What is it ?**
- **How does it work ?**

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

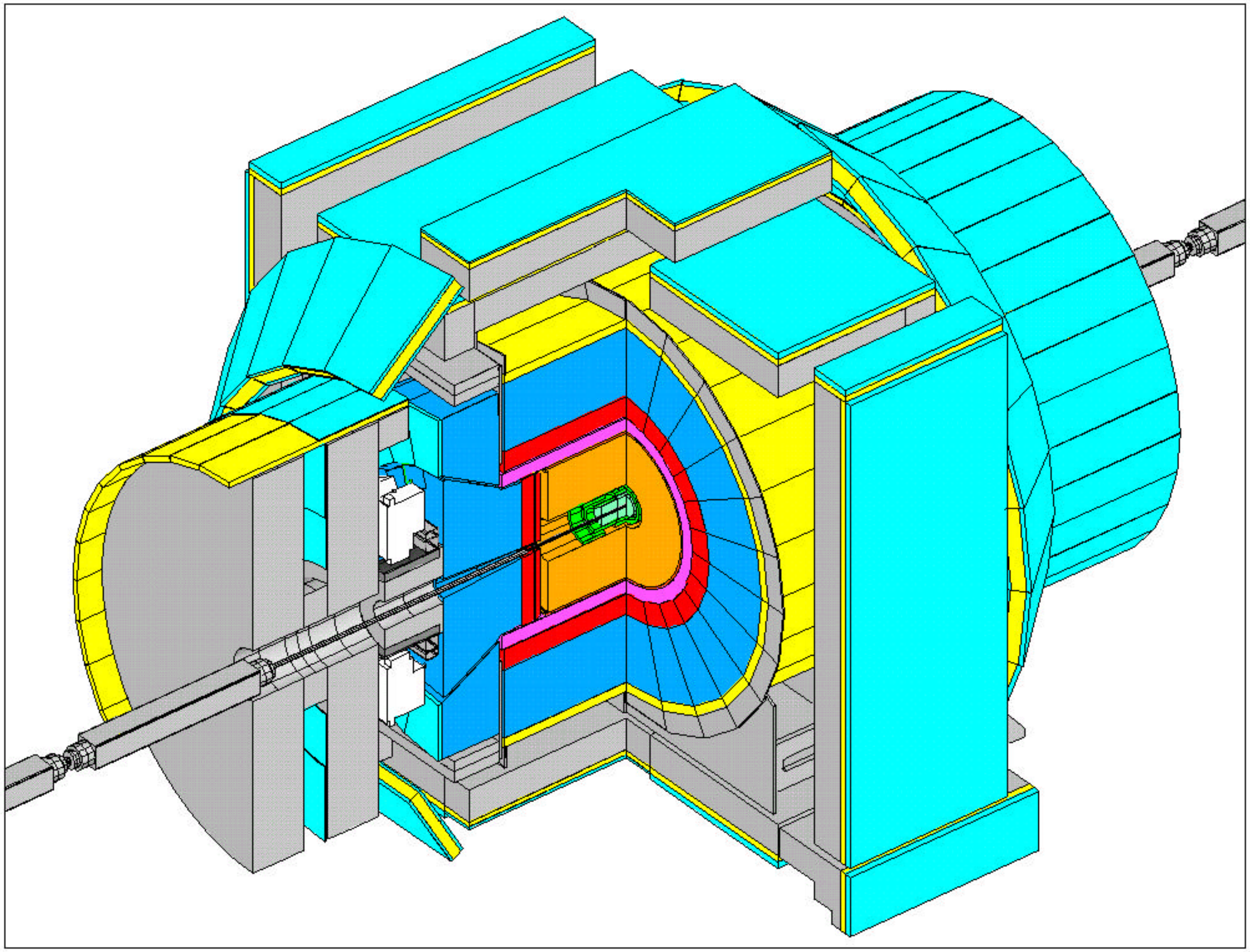
# Physics Motivation

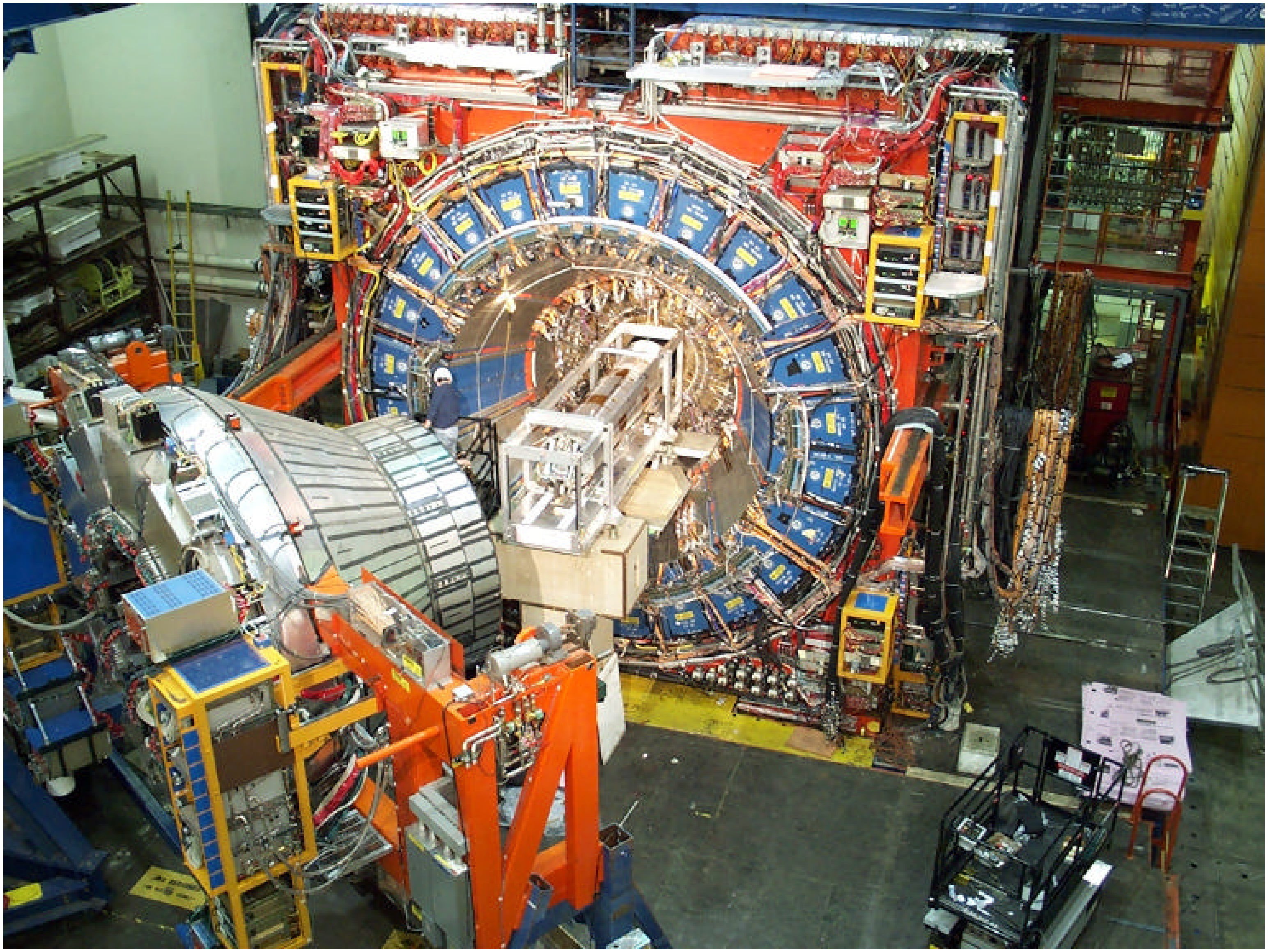
- With the great success of Silicon micro-strip detectors at high energy physics, its applications in triggering has been one of the major goals in instrumentation development
- An important application is to trigger on B hadrons inclusively, for
  - B physics studies, eg. CP violation in B decays, $B_s$ mixing
  - new particle searches, eg. Higgs, Supersymmetry
- principle: detect large impact parameter tracks or secondary vertex from B hadron decays using the fact that $\tau(B) \approx 1.5$ ps
- 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
    - necessary to suppress background at trigger level

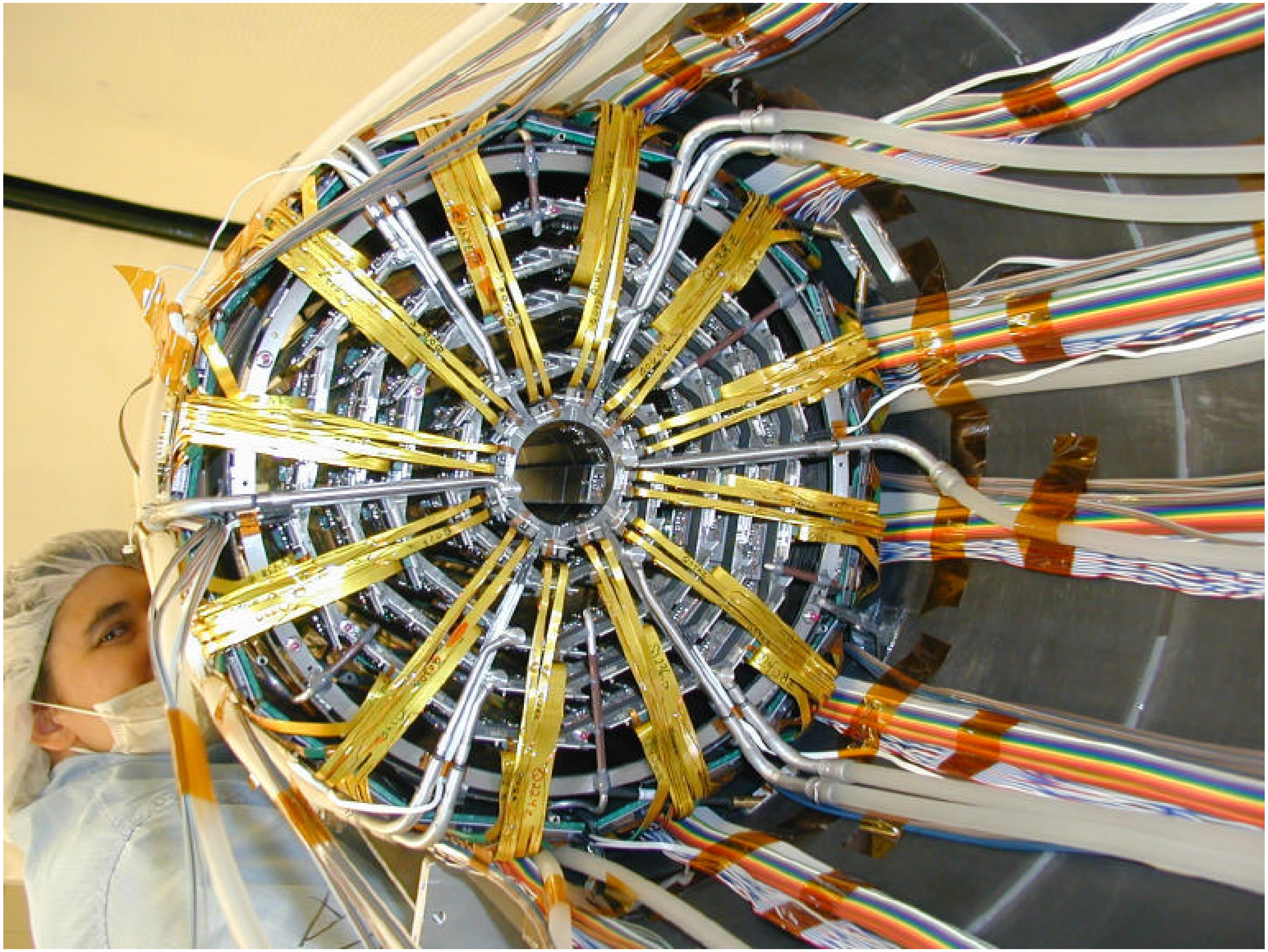



**Big technical challenge!**

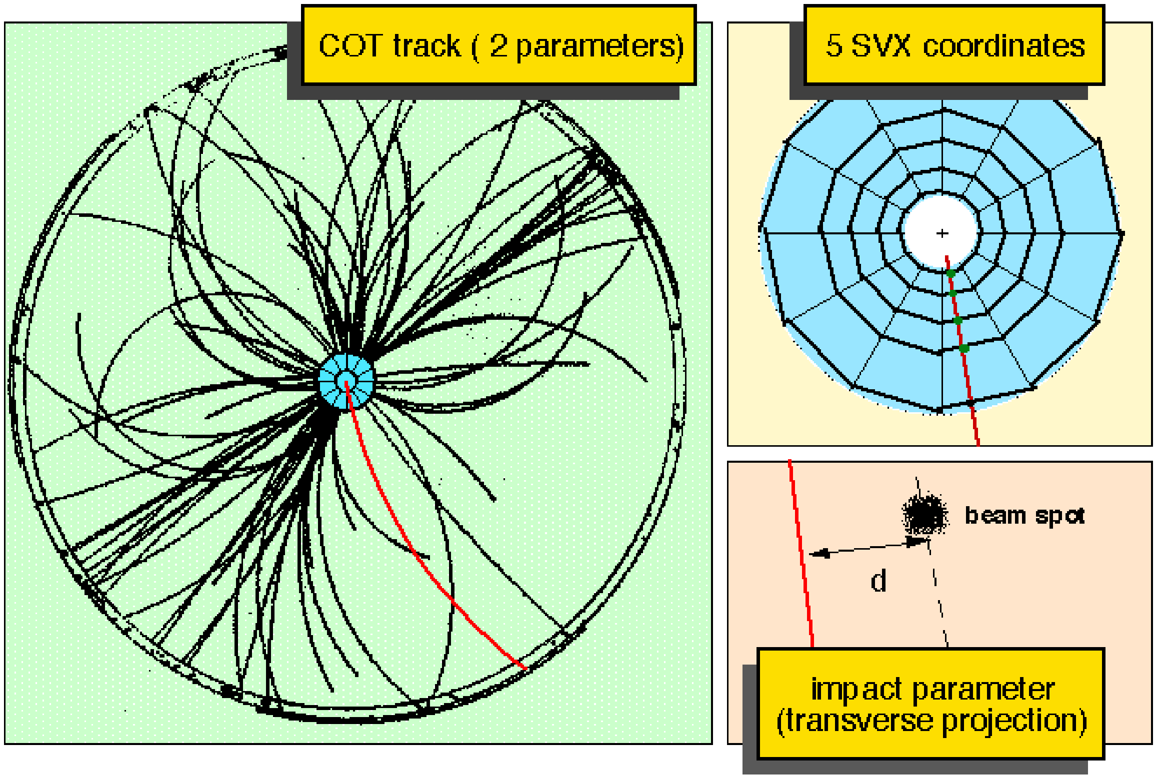
# CDF DETECTOR







# SVT: Silicon Vertex Trigger




**Inputs:**

- **L1 tracks from XFT $(f, p_T)$**
- **digitized pulse heights from SVX II**

**Functionalities:**

- **hit cluster finding**
- **pattern recognition**
- **track fitting**

**Outputs:**

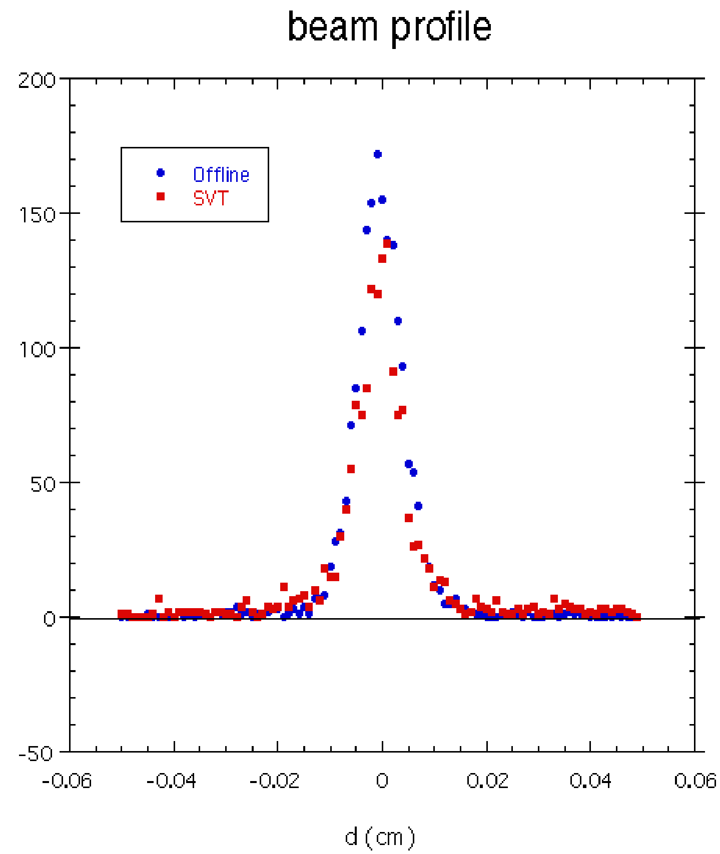
- **reconstructed tracks $(d, f, p_T)$**

# SVT performance

Tracking performance tested on CDF data using bit-level SVT simulation

$\sigma_d$ = 35 μm (at $p_T$ = 2 GeV/c)
$\sigma_\phi$ = 1 mrad
$\sigma_{pT}$ = 0.003$p_T$ ($p_T$ in GeV/c)
ε ~ 97 % (for 4 hits tracks)

almost offline quality!

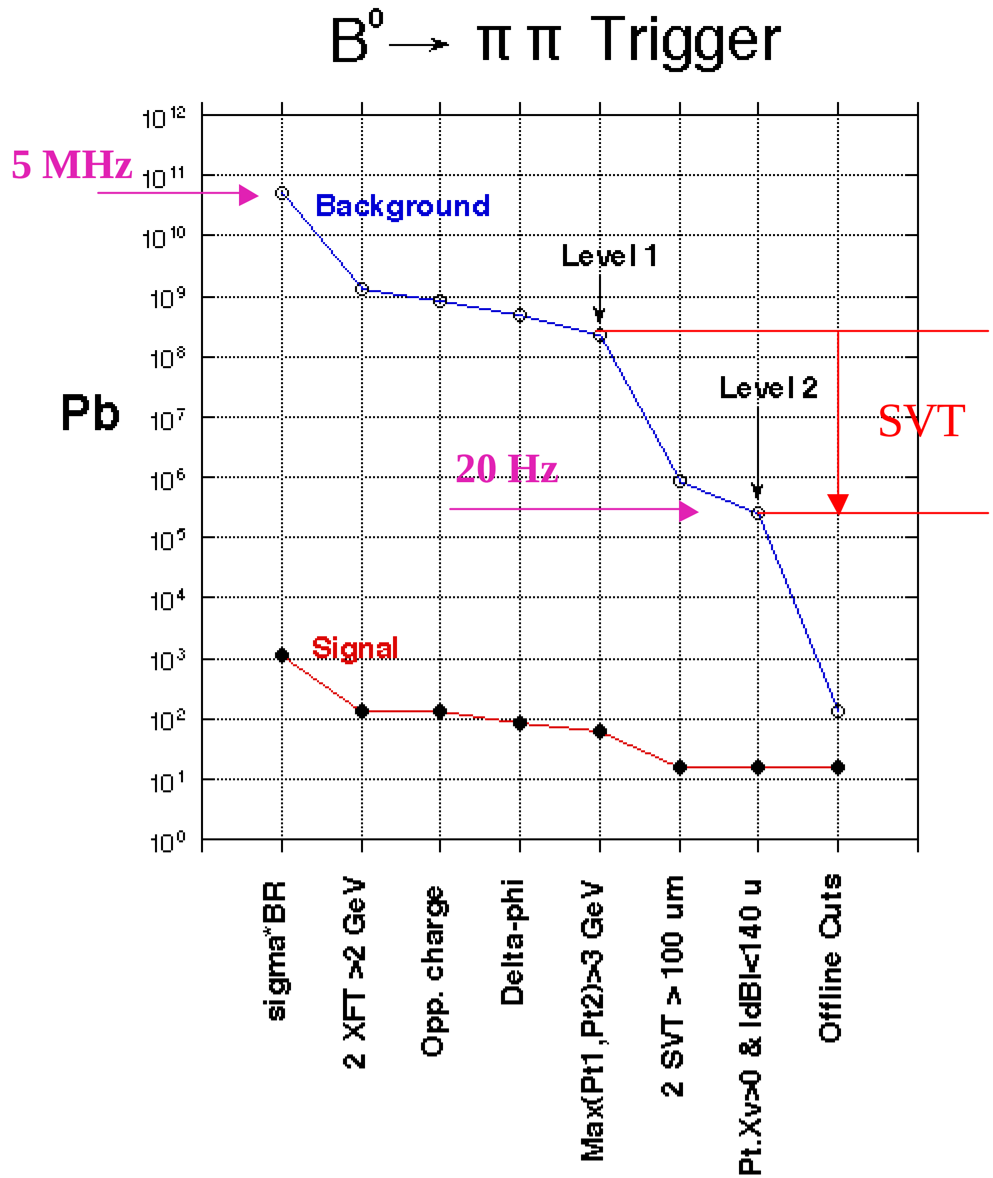



Execution time ~ 10 μs / event

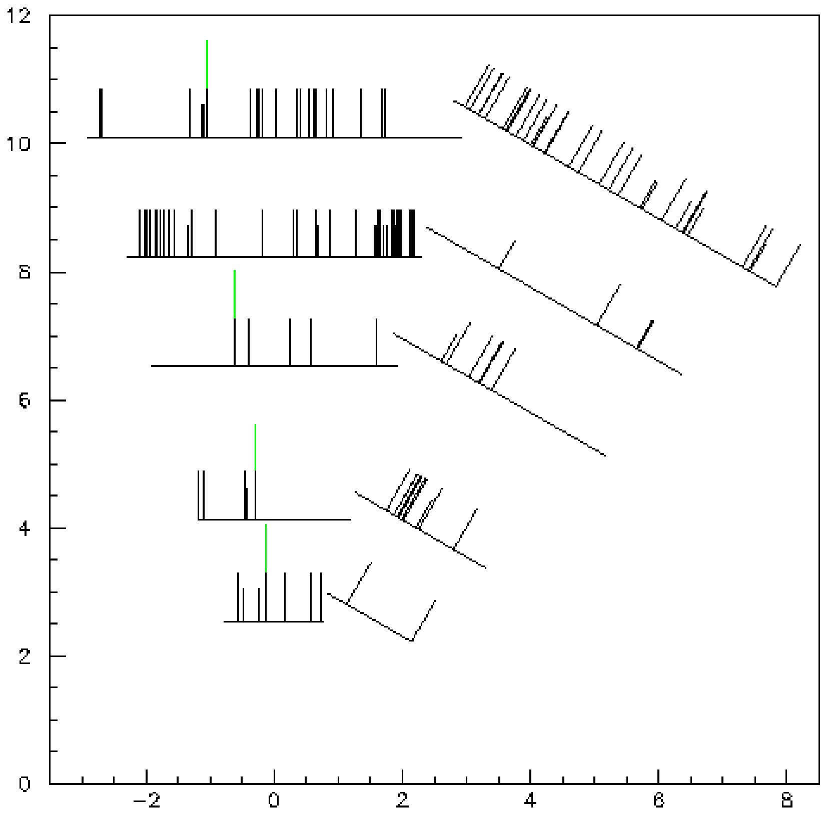
# SVT for B$^0$ ® p$^+$p$^-$

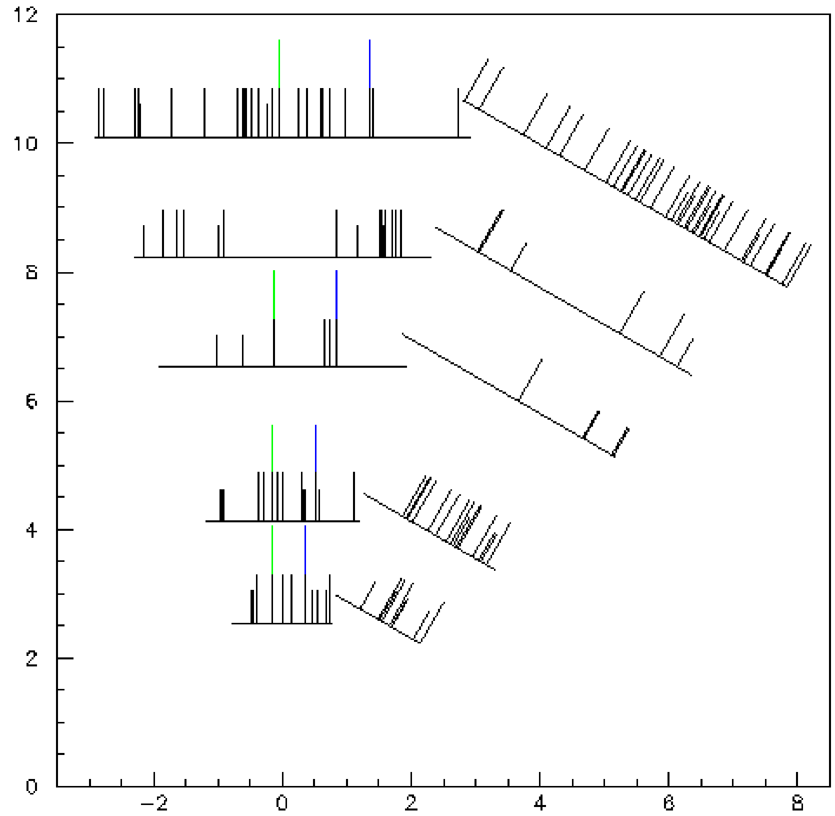
- SVT reduces the background rate by a factor of 1000
  - data recording possible by DAQ

- CDF II (2 fb$^{-1}$, 2001-2003)
  - $\Delta(\sin 2\beta) \approx 0.08$ ( ~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 $X_s$ ~ 60 ( ~10,000 $B_s^0 \rightarrow D_s\ \pi$ )



# FINDING TRACKS IN THE SILICON

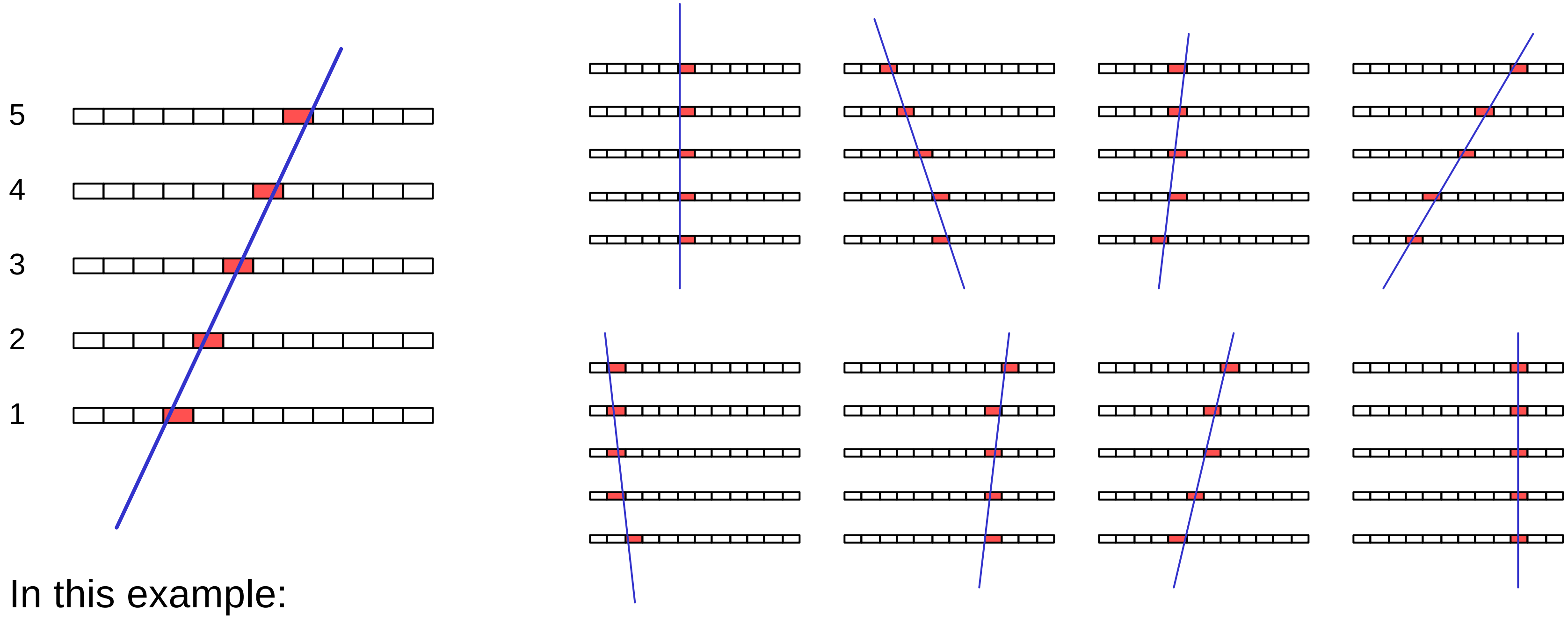


# Building the "Pattern Bank"

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

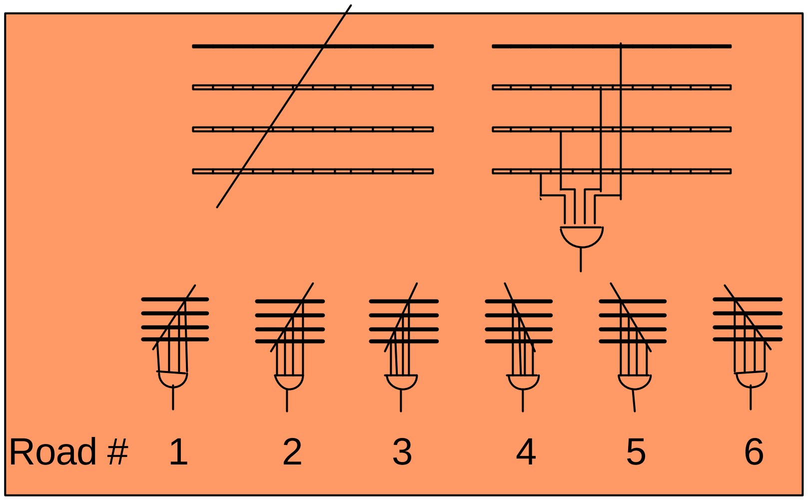



In this example:
Straight lines, 5 layers, 12 bins/layer

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

# Associative Memory working principle

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.

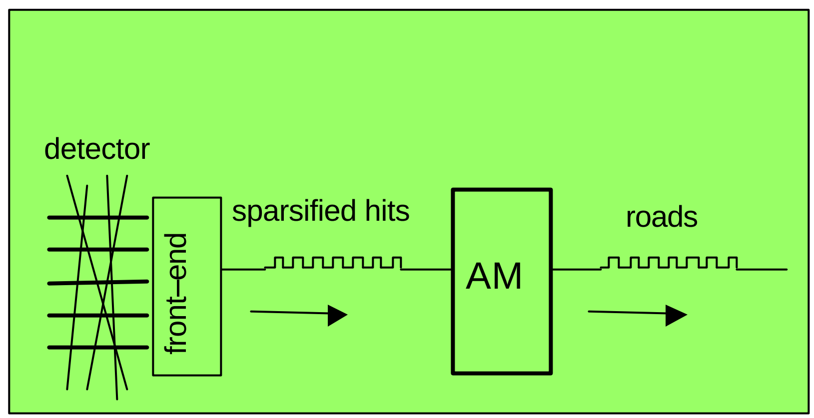



Hit coordinates are read into the AM sequentially.

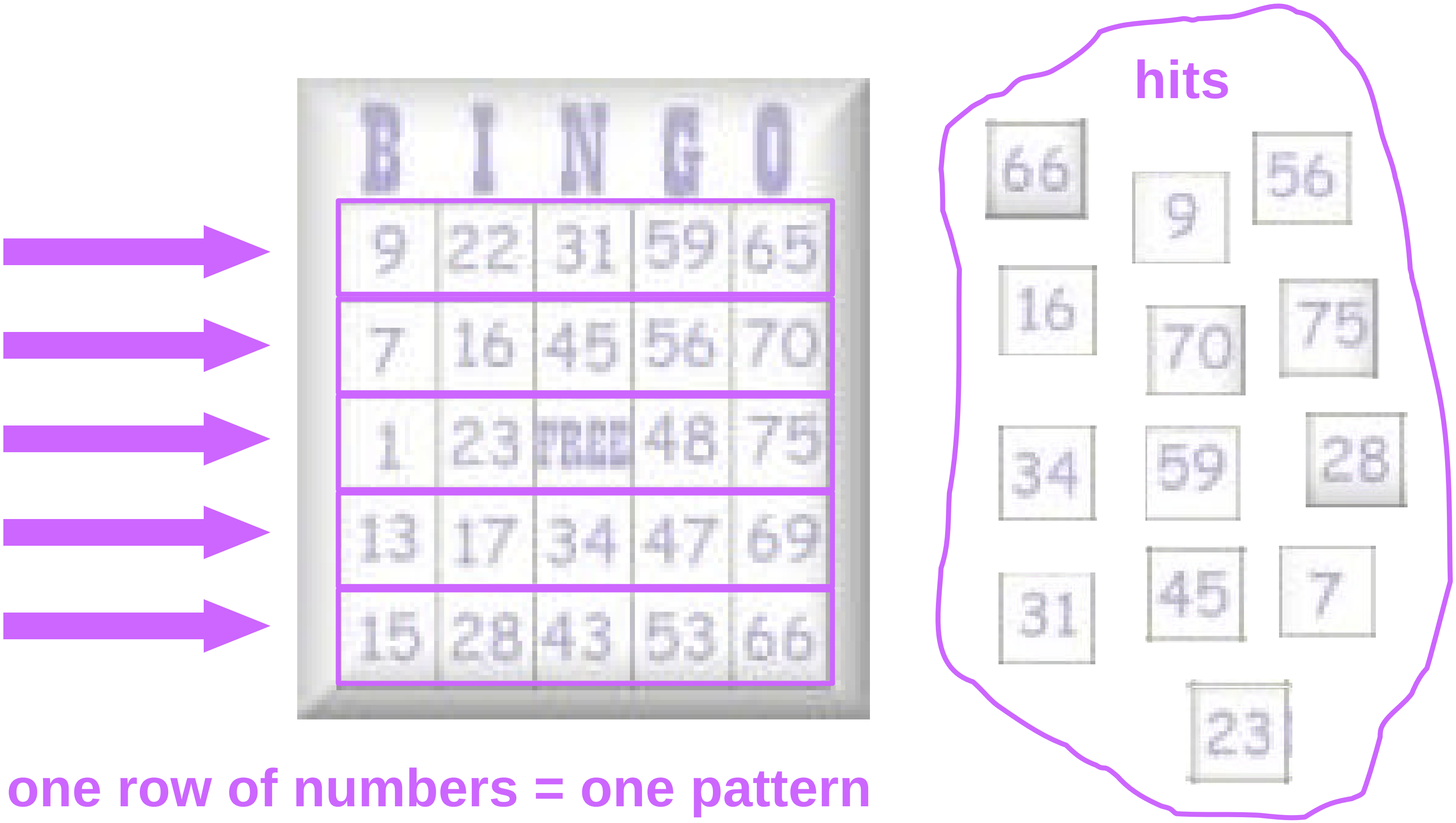
Each coordinate is compared with all the patterns in parallel.

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

Roads found by the AM are output sequentially.

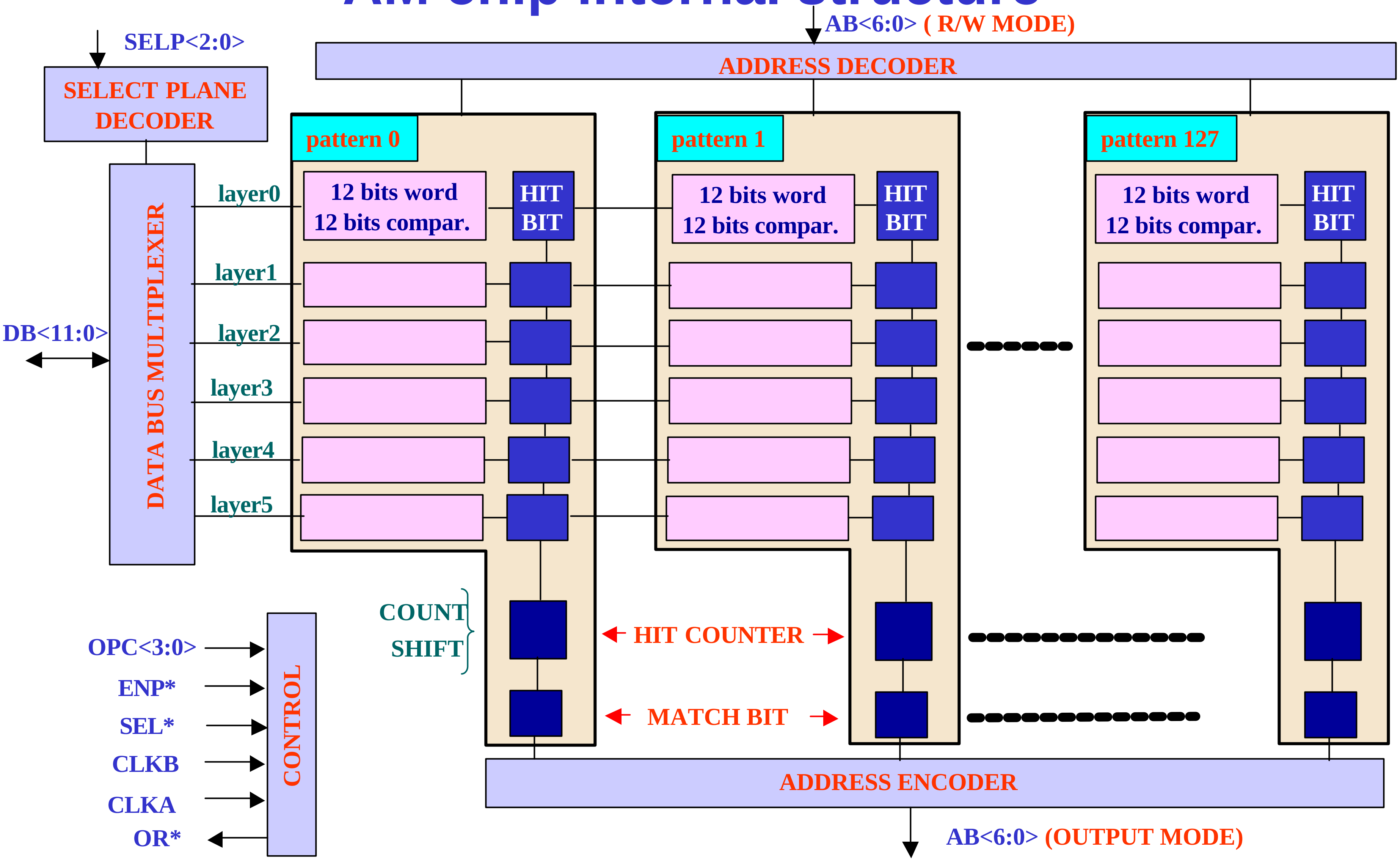


# Let’s play Bingo!

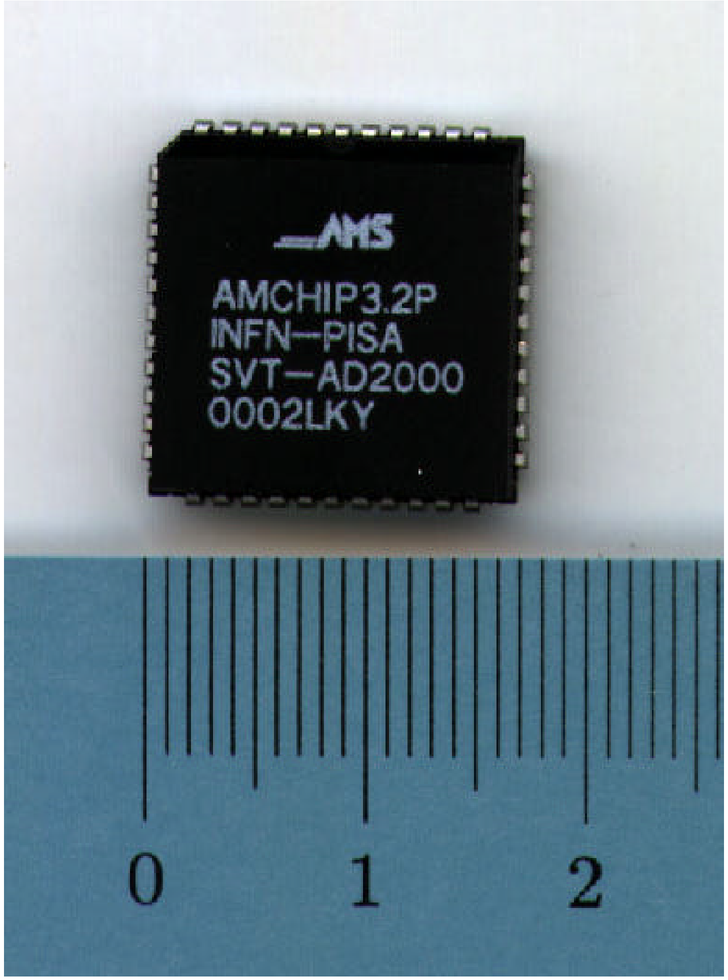



**one row of numbers = one pattern**

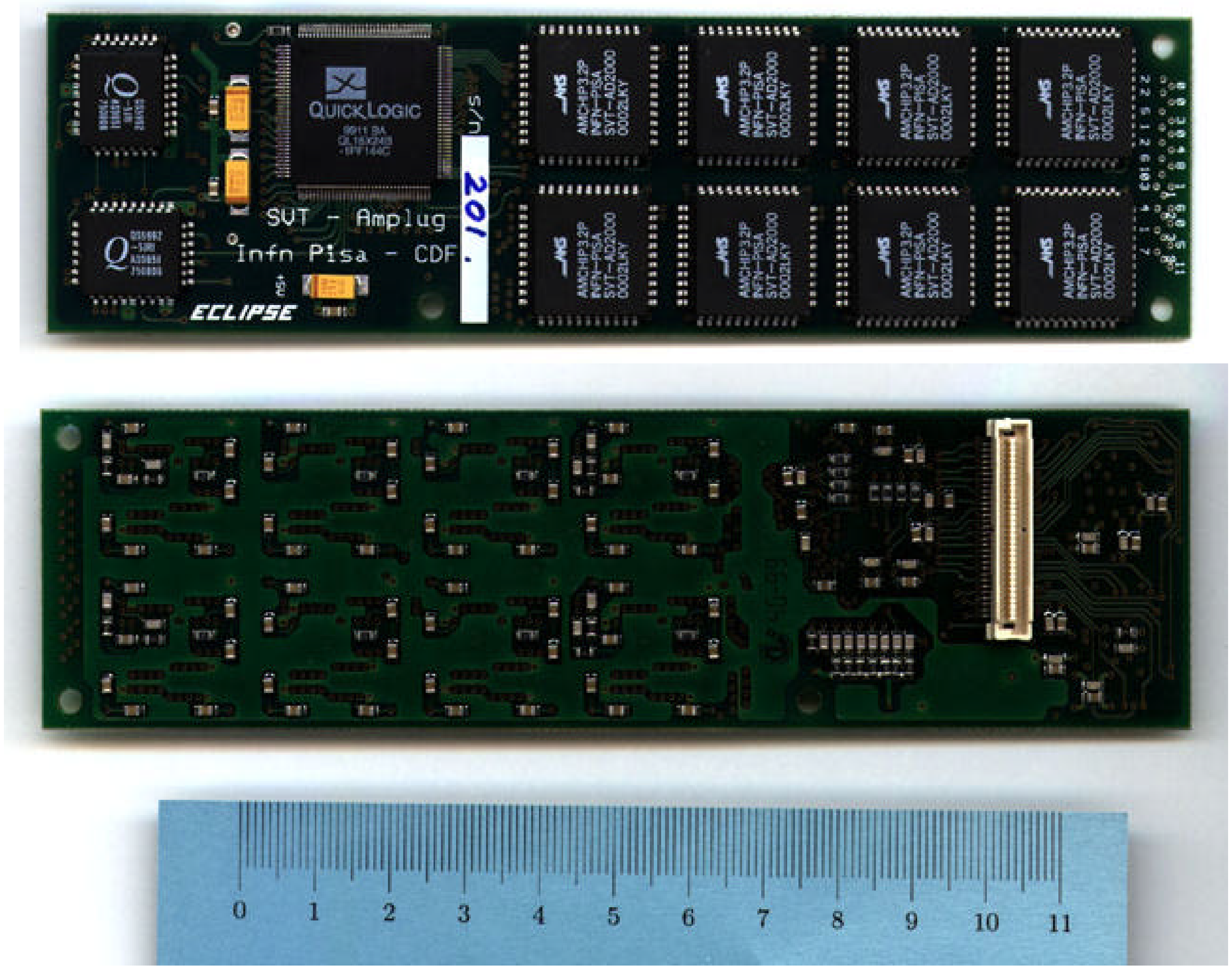
# AM chip internal structure



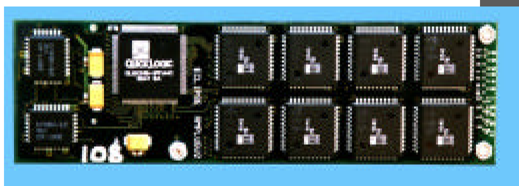
# AMchip



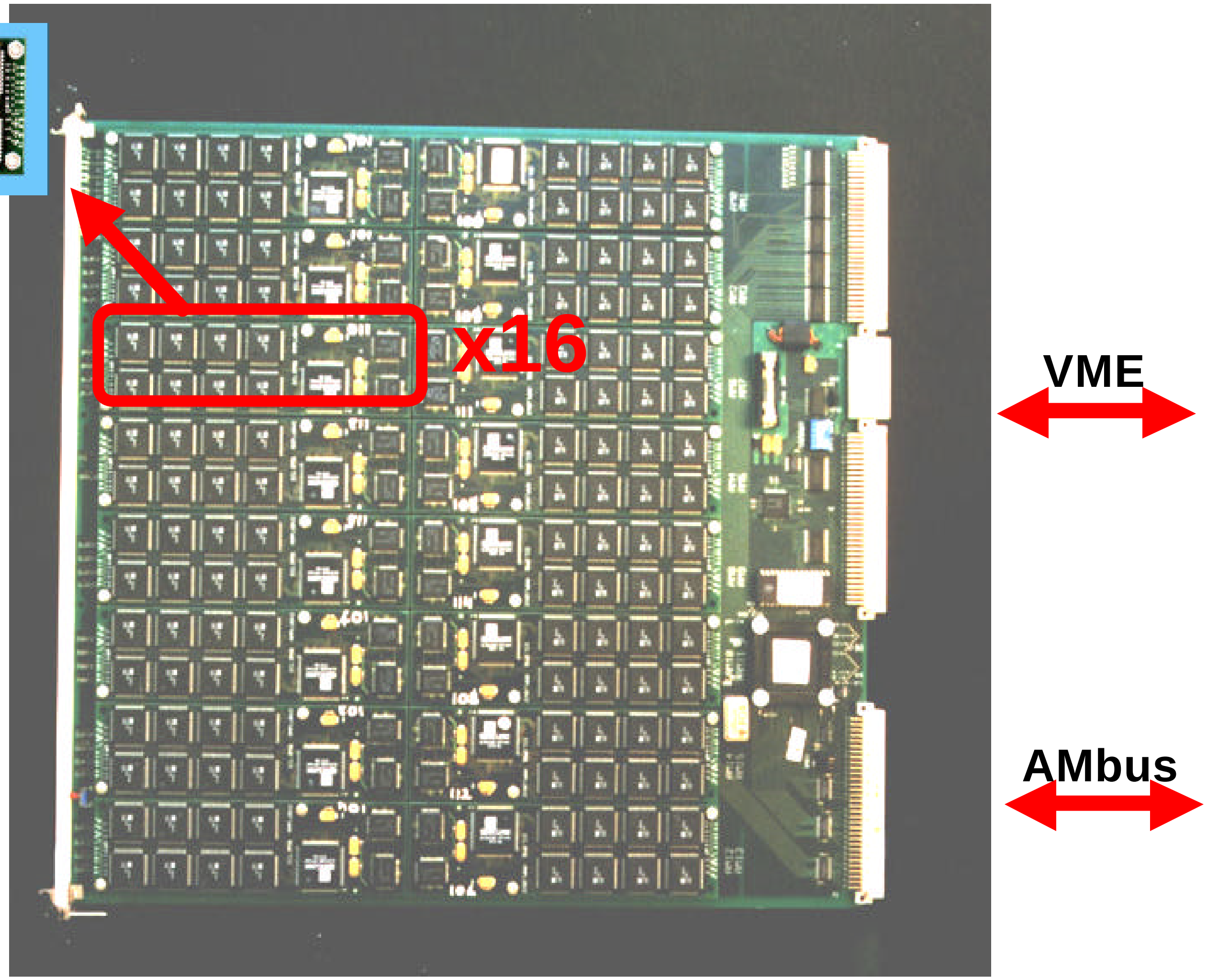
# Amplug: mezzanine board



# AM Board



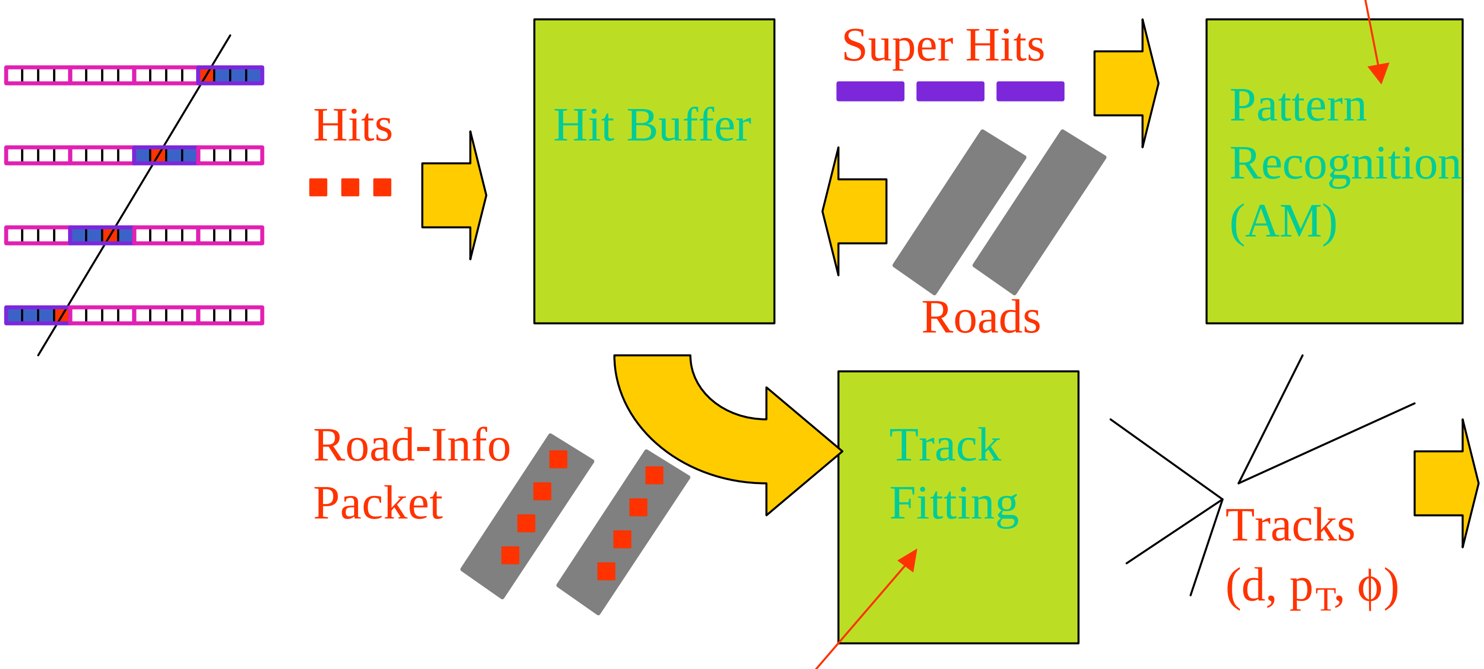
128 Amchips
x 128 patterns each
= 16K pattern board



# 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

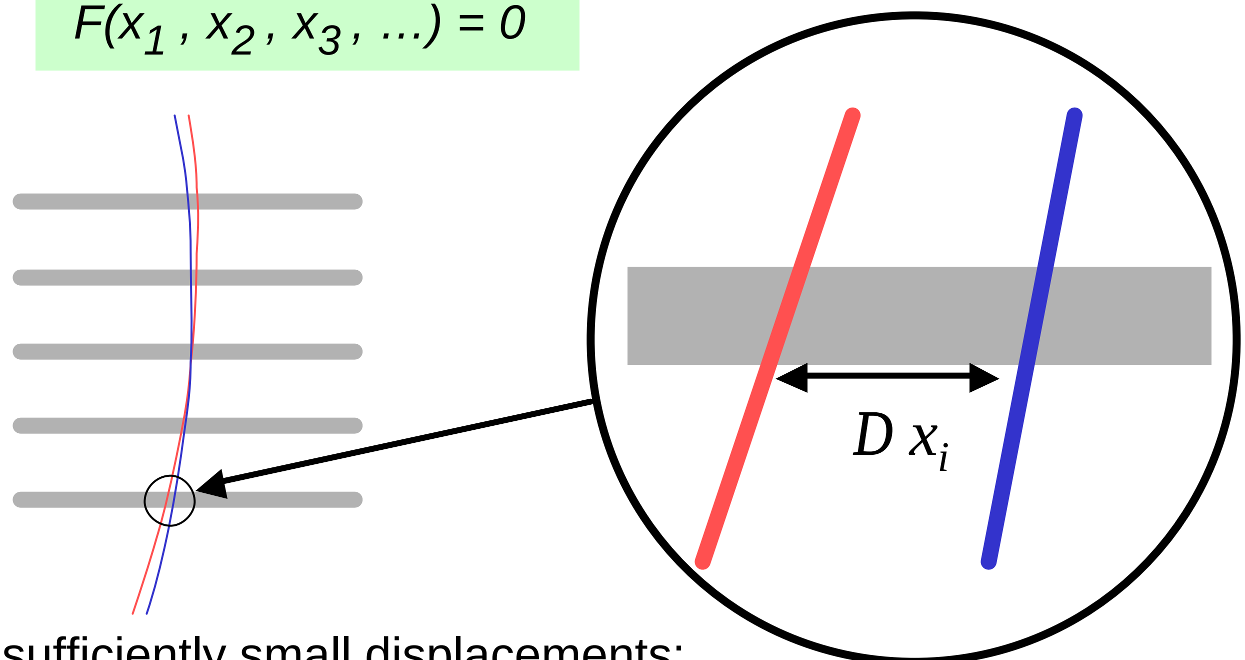



Fast track fitting with linear approximation
using full resolution of the silicon vertex detector

# 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:

$$F(x_1 , x_2 , x_3 , \ldots) \sim a_0 + a_1 Dx_1 + a_2 Dx_2 + a_3 Dx_3 + \ldots = 0$$

with constant $a_i$ (first order expansion of $F$)

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

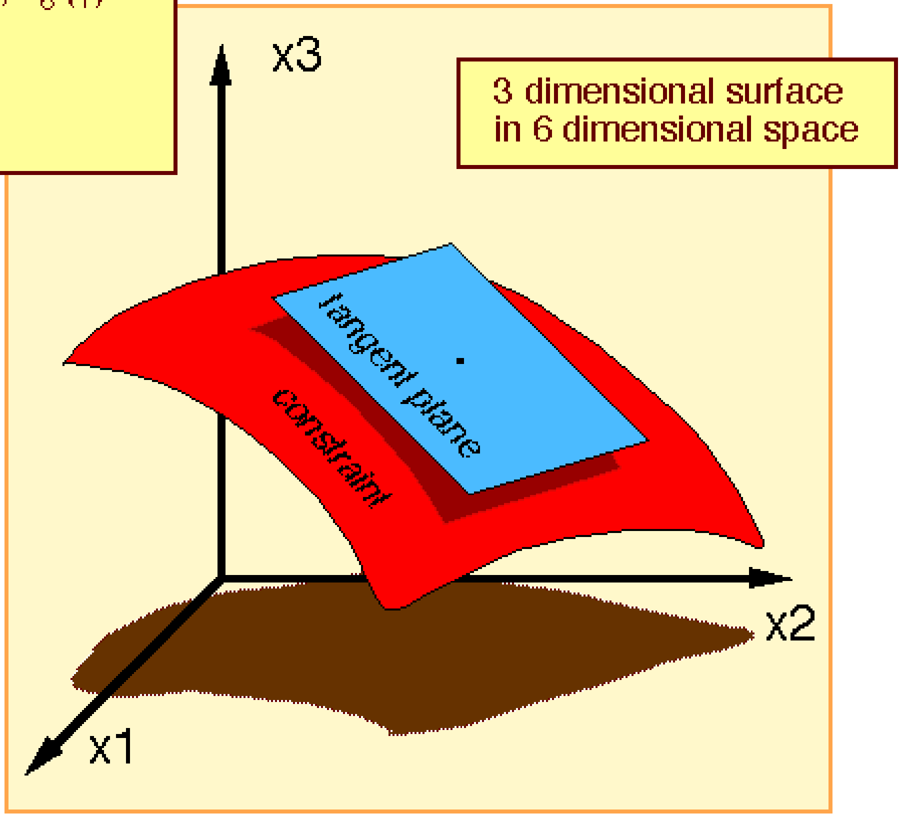
3 constraints

tangent plane:

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

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 $\phi$ )

# Constraints vs ChiSquare

Constraints: $F_k(x_1, x_2, x_3, \ldots) = 0$

K = 1…N

N = (number of points) – (number of parameters)

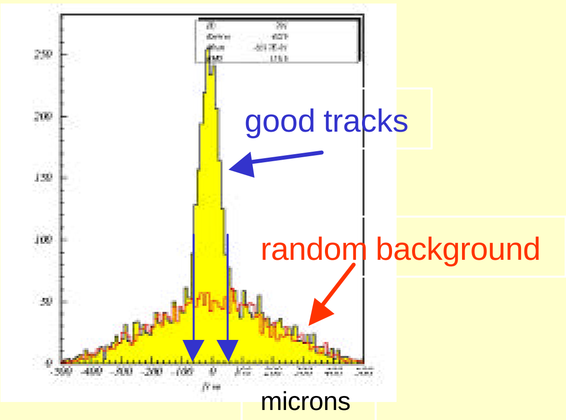
*="number of degrees of freedom of fit"*

$$\chi^2 = \sum F_k^2$$

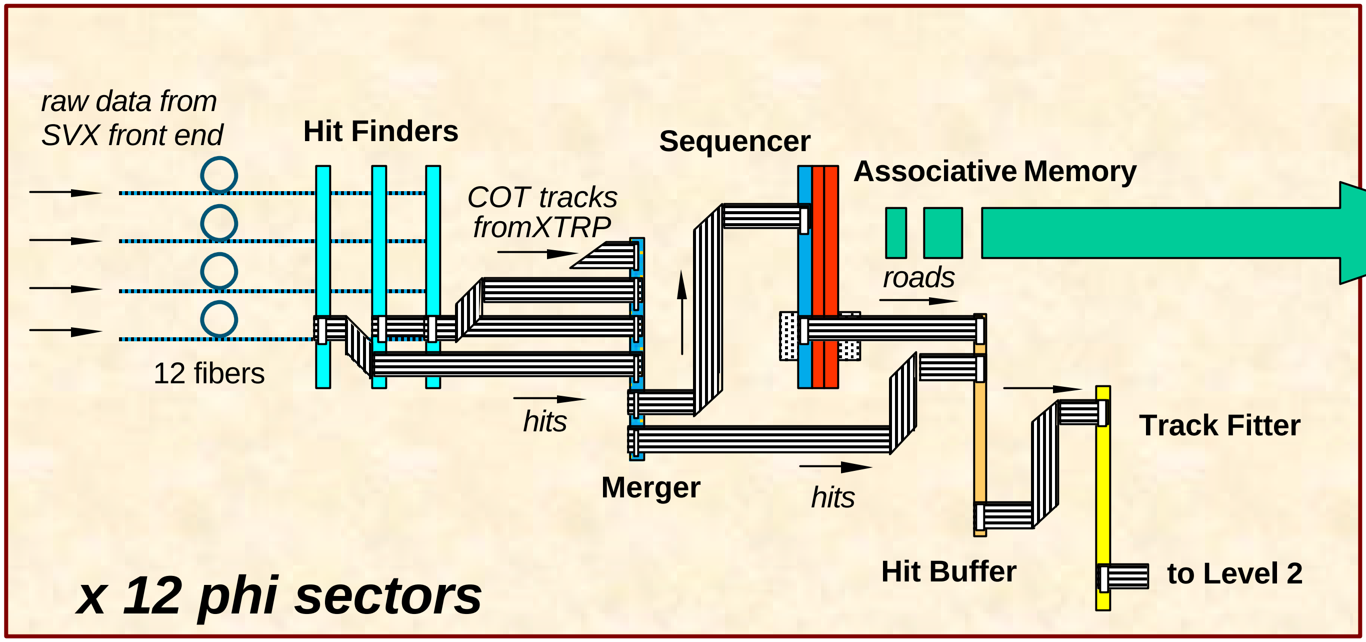
provided the $F_k$ are normalized correctly

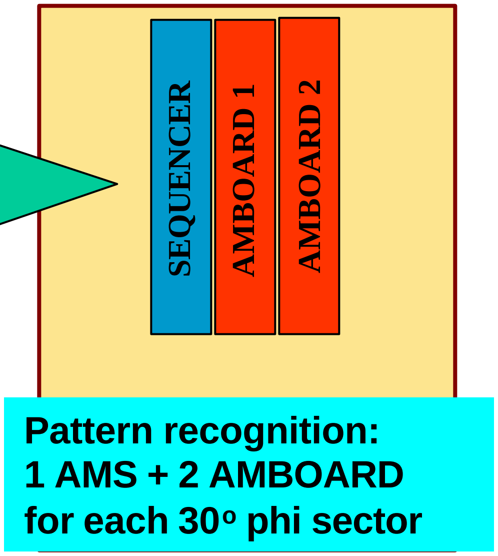
Why use $F_k$ instead of $\chi^2$ ? ? ?

Since $F_k$ are linear functions of coordinates (at least to first order) a small detector misalignment will just cause a *shift* of the peak with no appreciable increase of the *width*.



# SVT system architecture




**Hit Finder:** finding silicon hit clusters

**Merger:** merging data at various stages

**AM Sequencer**: managing AM operation, gateway to AM chips

**AM Board:** housing AM chips for road finding

**Hit Buffer:** associating hits to roads found by AM

**Track fitter:** fitting full resolution tracks

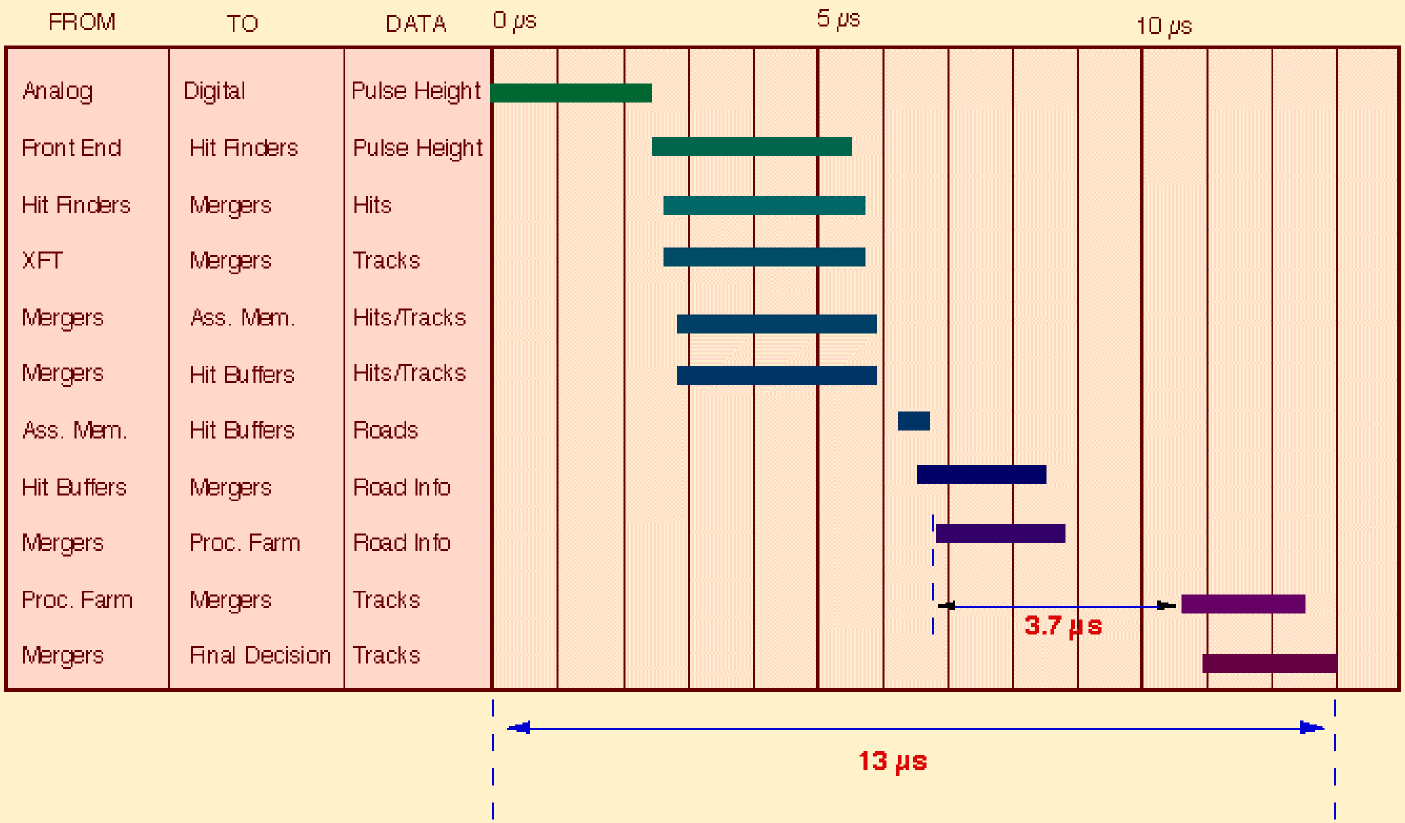
**Spy Control**: managing spy buffers and error handling

**All 9U VME boards**

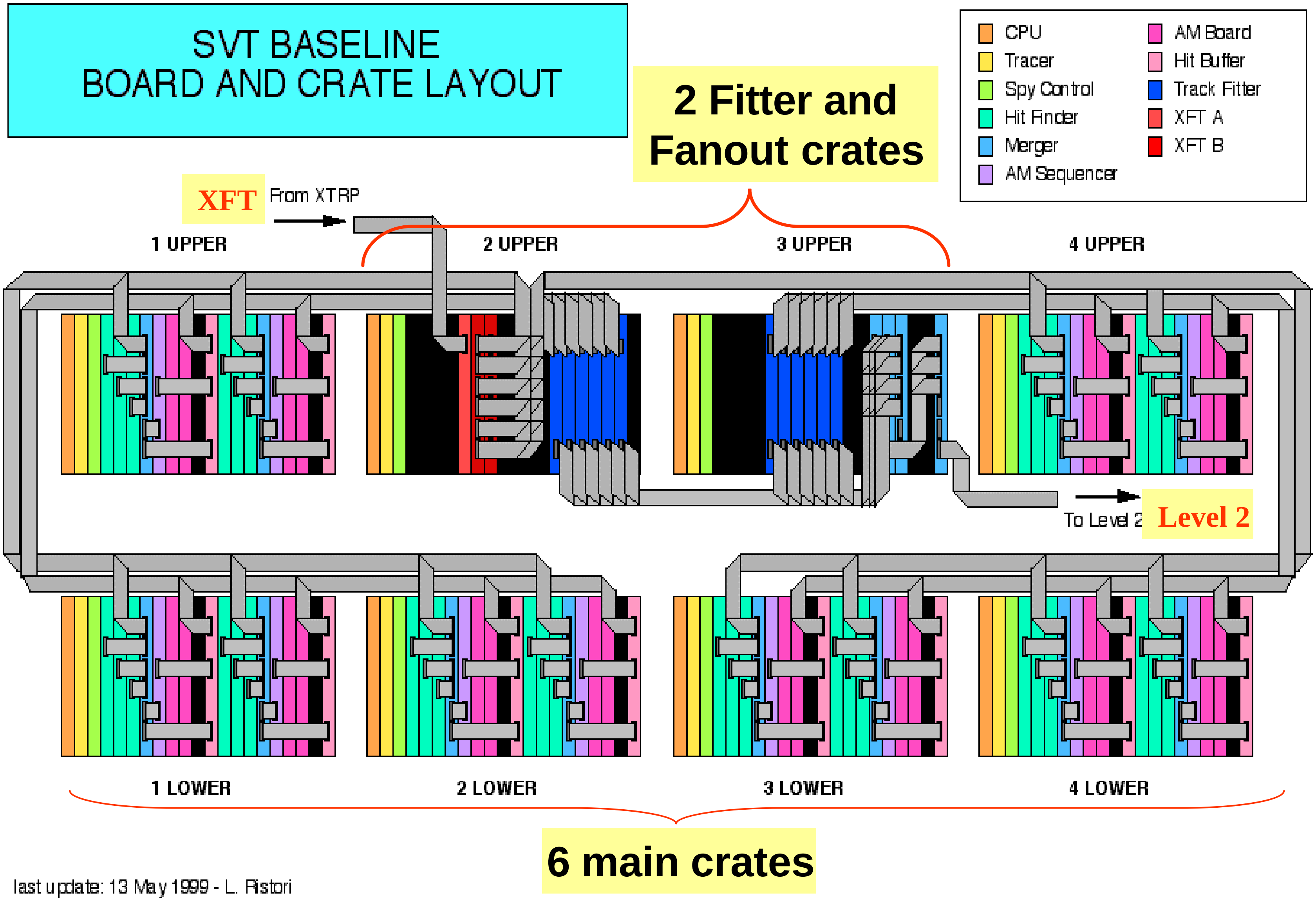
**All data driven (except AMS Û AMB)**

**All with spy buffers (except AMB)**

# SVT TIMING

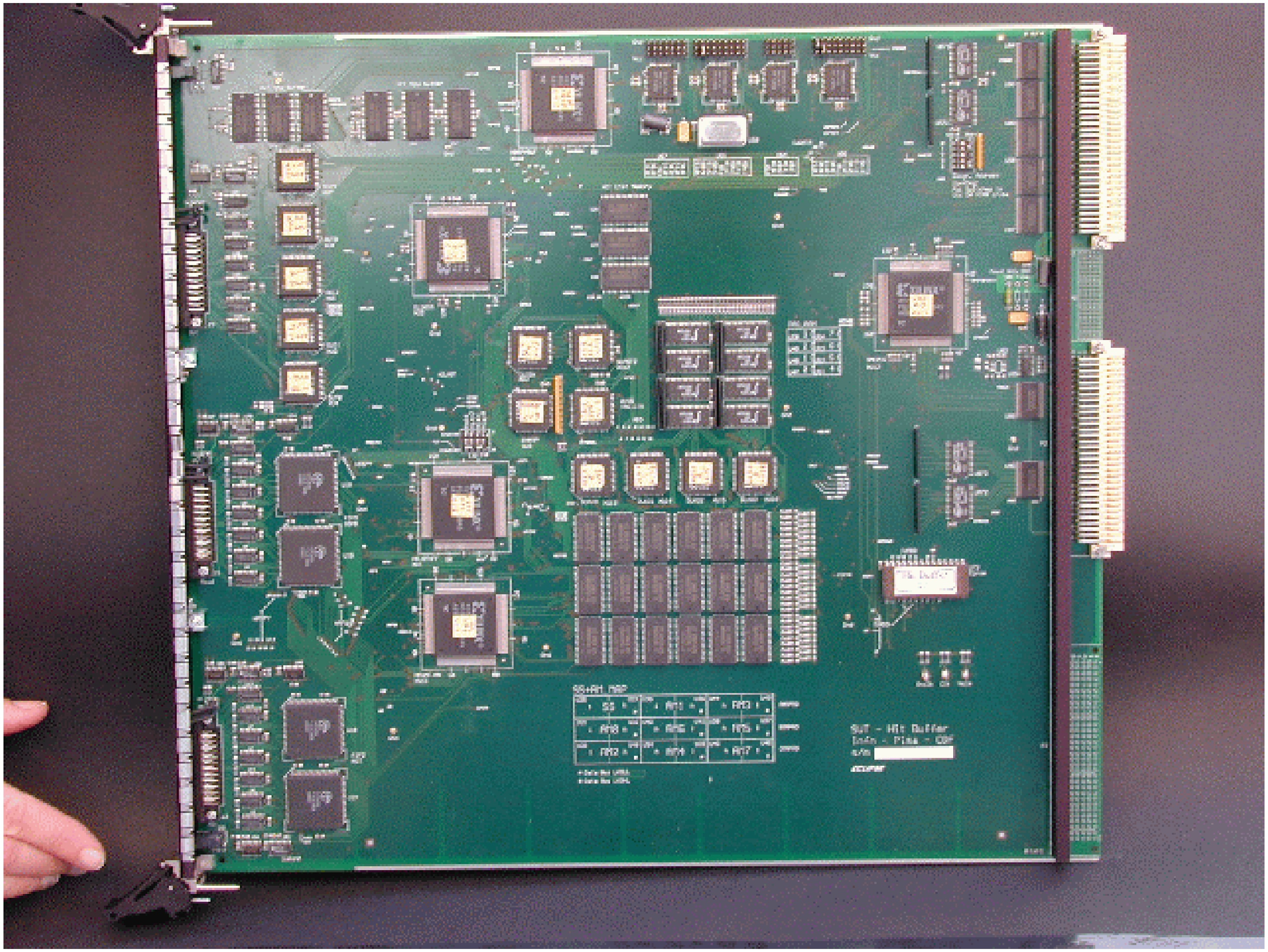

FROM
TO
DATA
0 μs
5 μs
10 μs
Analog
Digital
Pulse Height
Front End
Hit Finders
Pulse Height
Hit Finders
Mergers
Hits
XFT
Mergers
Tracks
Mergers
Ass. Mem.
Hits/Tracks
Mergers
Hit Buffers
Hits/Tracks
Ass. Mem.
Hit Buffers
Roads
Hit Buffers
Mergers
Road Info
Mergers
Proc. Farm
Road Info
Proc. Farm
Mergers
Tracks
Mergers
Final Decision
Tracks
3.7 μs
13 μs

# SVT Crate Layout

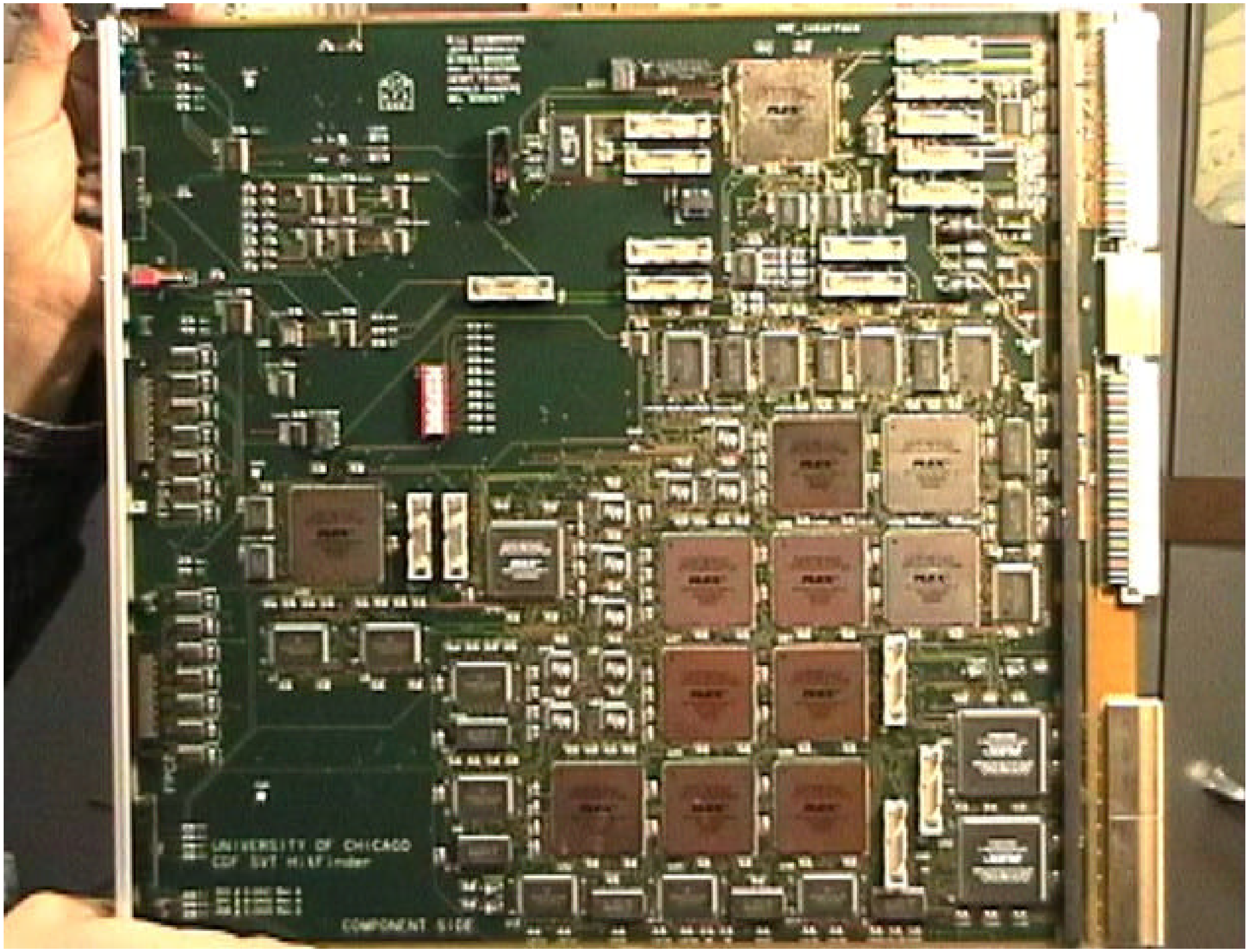



last update: 13 May 1999 - L. Ristori

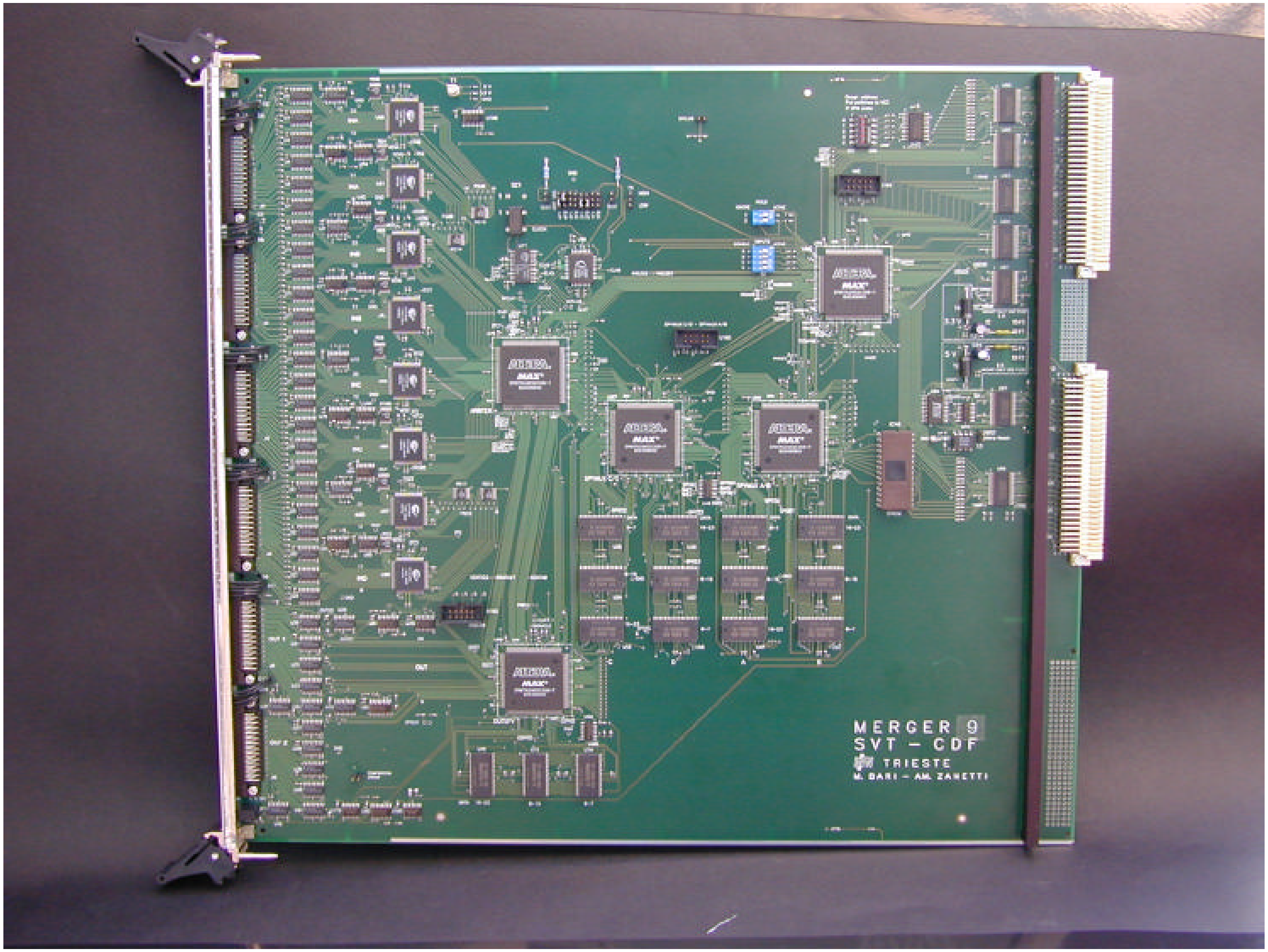
# HIT BUFFER BOARD



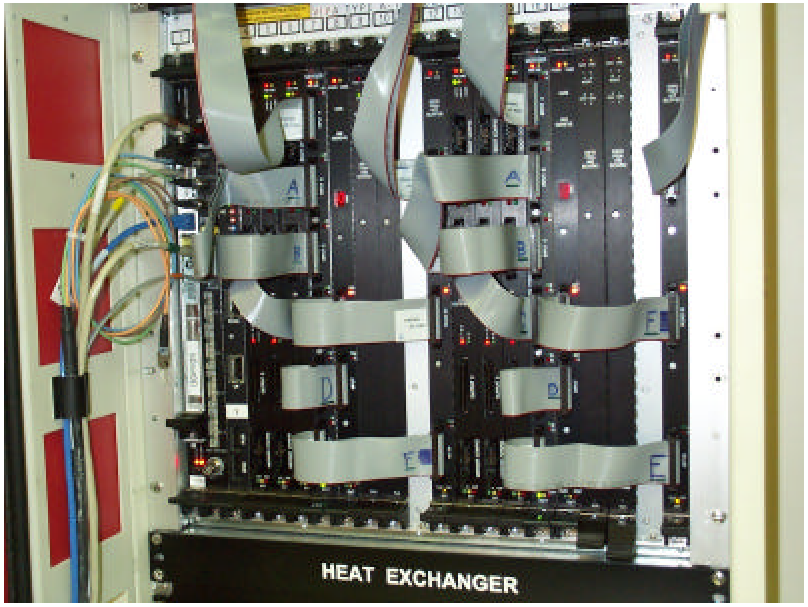
# HIT FINDER BOARD



# MERGER BOARD

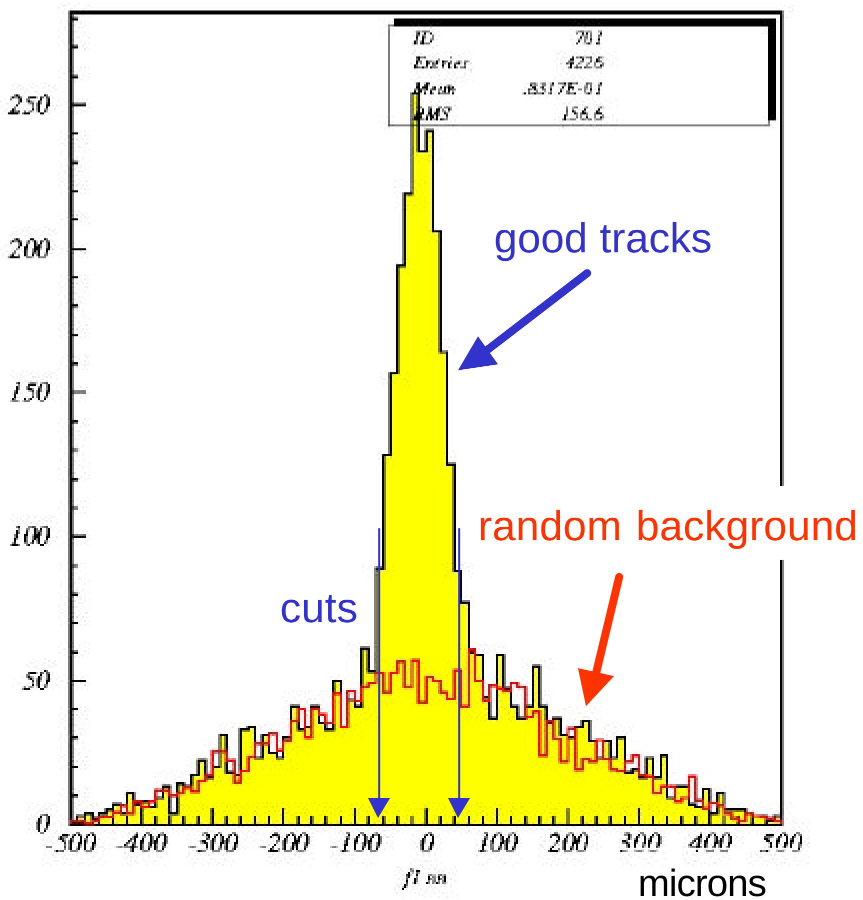


# SVT crates installed in CDF counting room

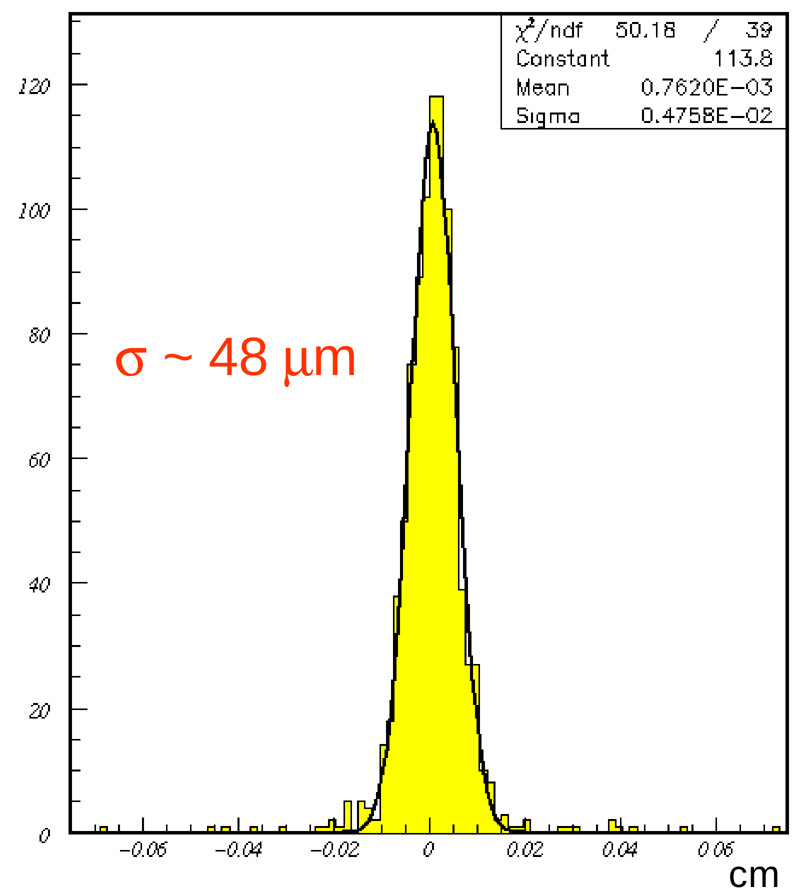


# Preliminary results from CDF "commissioning run" Oct-Nov 2000

**geometrical constraint**




**impact parameter distribution**



# SUMMARY

- The SVT project implied a significant step forward in the quality of fast track finding
- A massively parallel/pipelined architecture was used combined with some innovative techniques such as the associative memory and linearized track fitting
- Commissioning of SVT is well on track to allow CDF to start triggering on impact parameter soon after RunII of the Collider begins