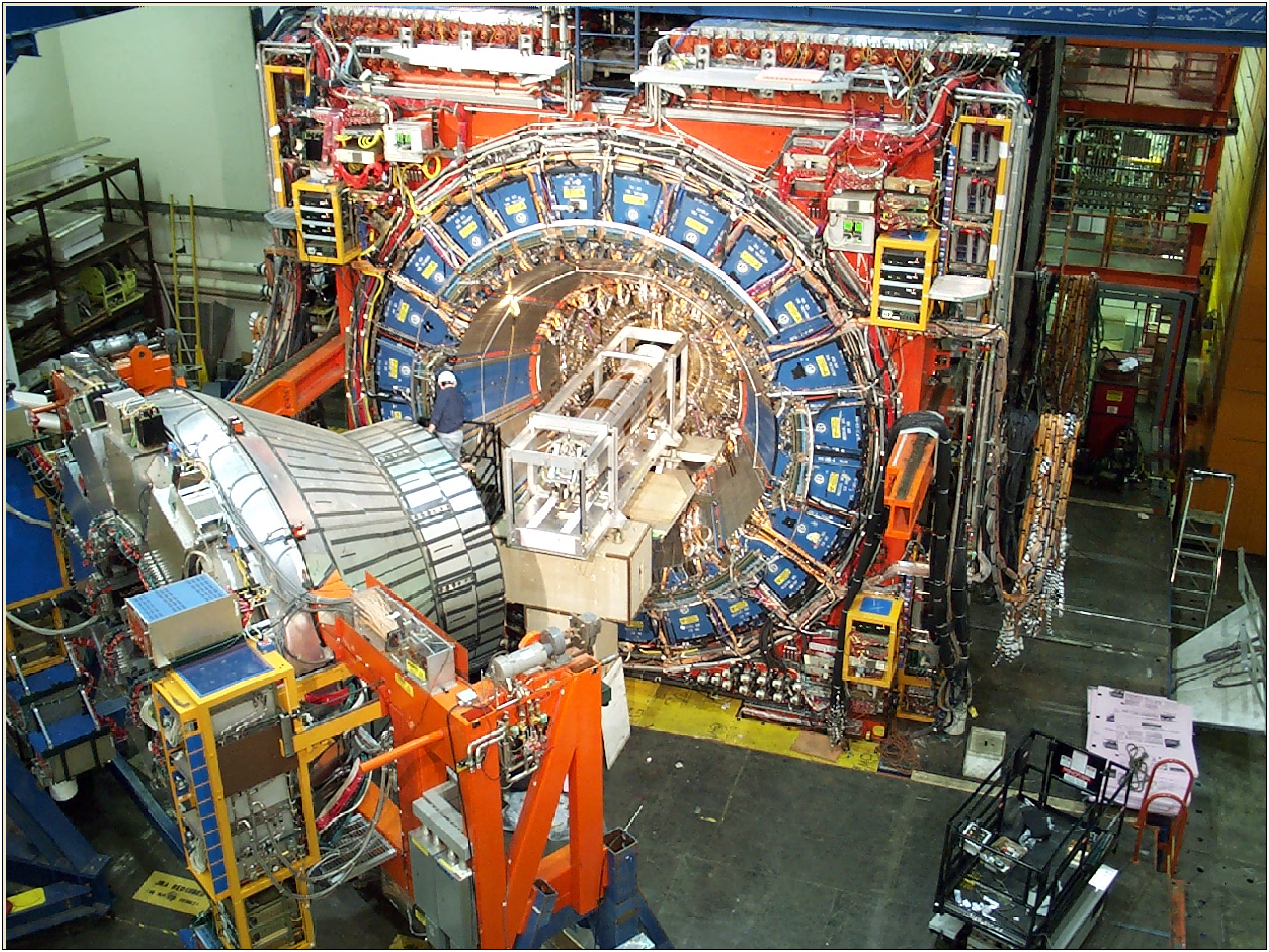
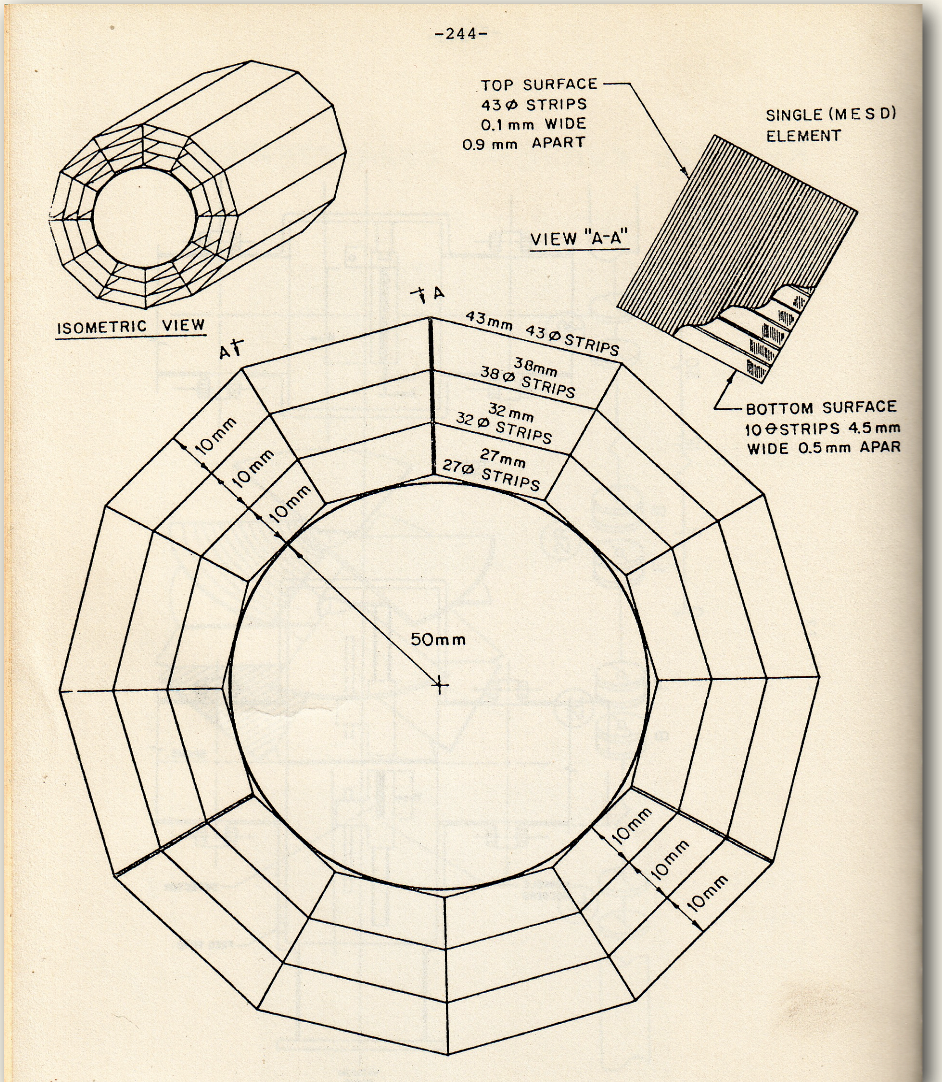
the CDF Silicon Vertex Detector and SVT

Luciano Ristori

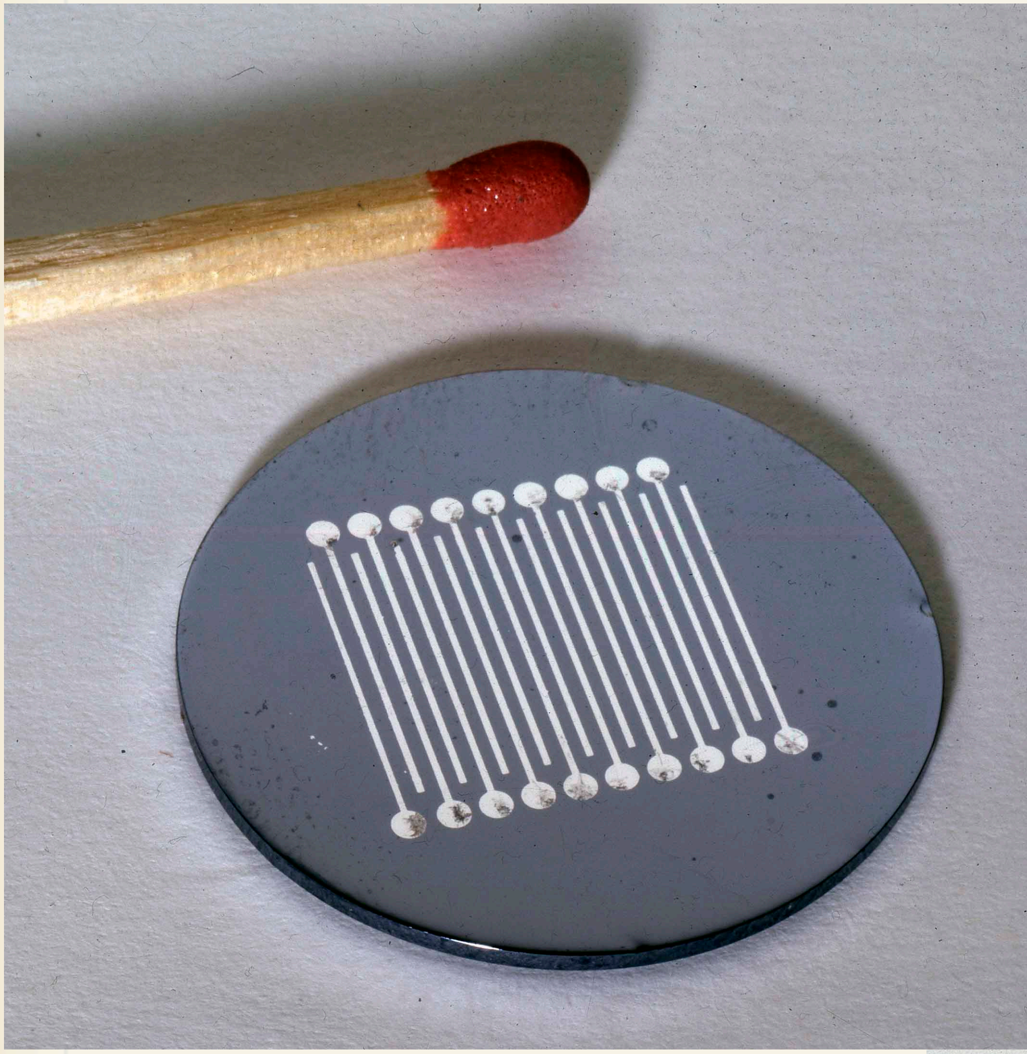
December 17, 2010



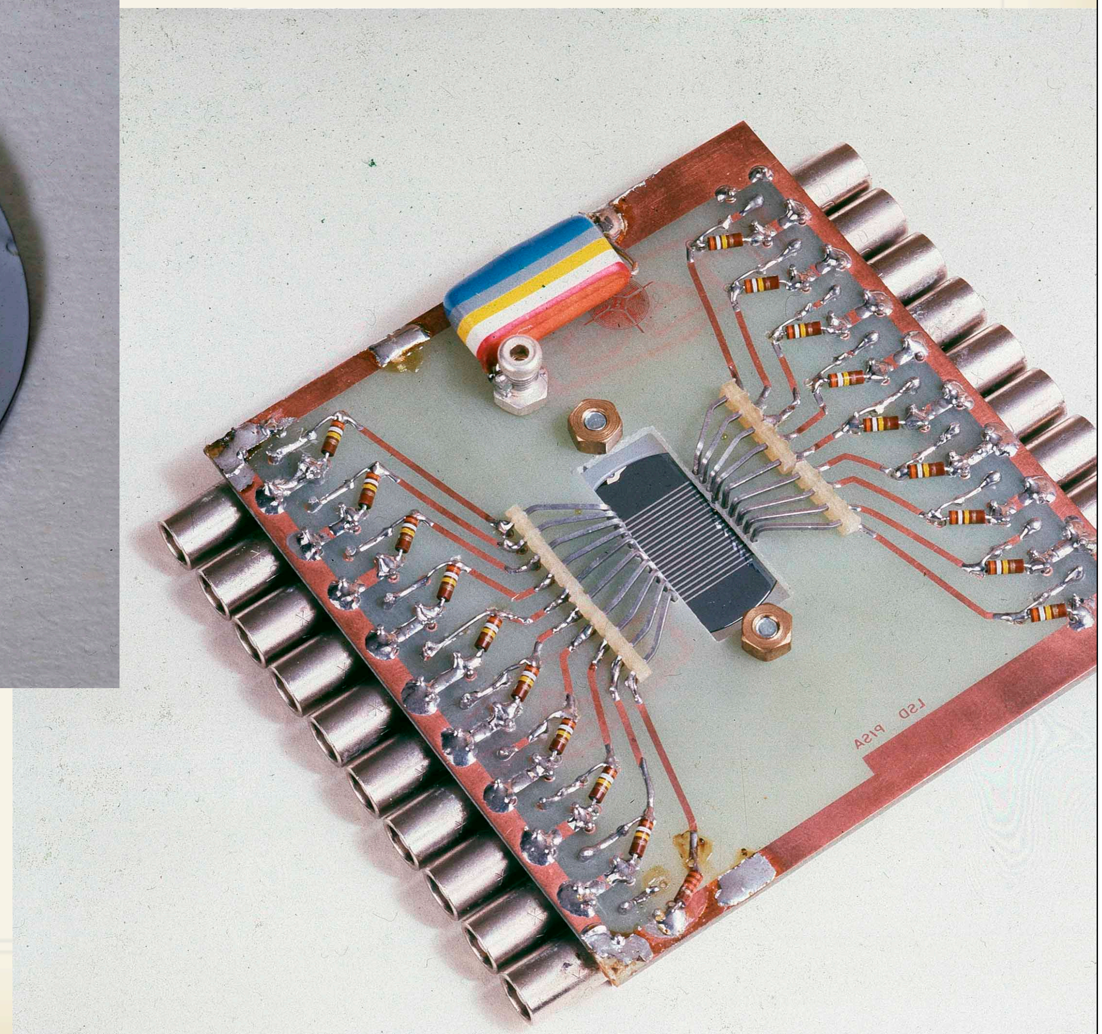


from the
"CDF Technical Design Report"
1981

1981: Aldo Menzione comes forward with the first conceptual design of a *silicon vertex detector* for a collider experiment

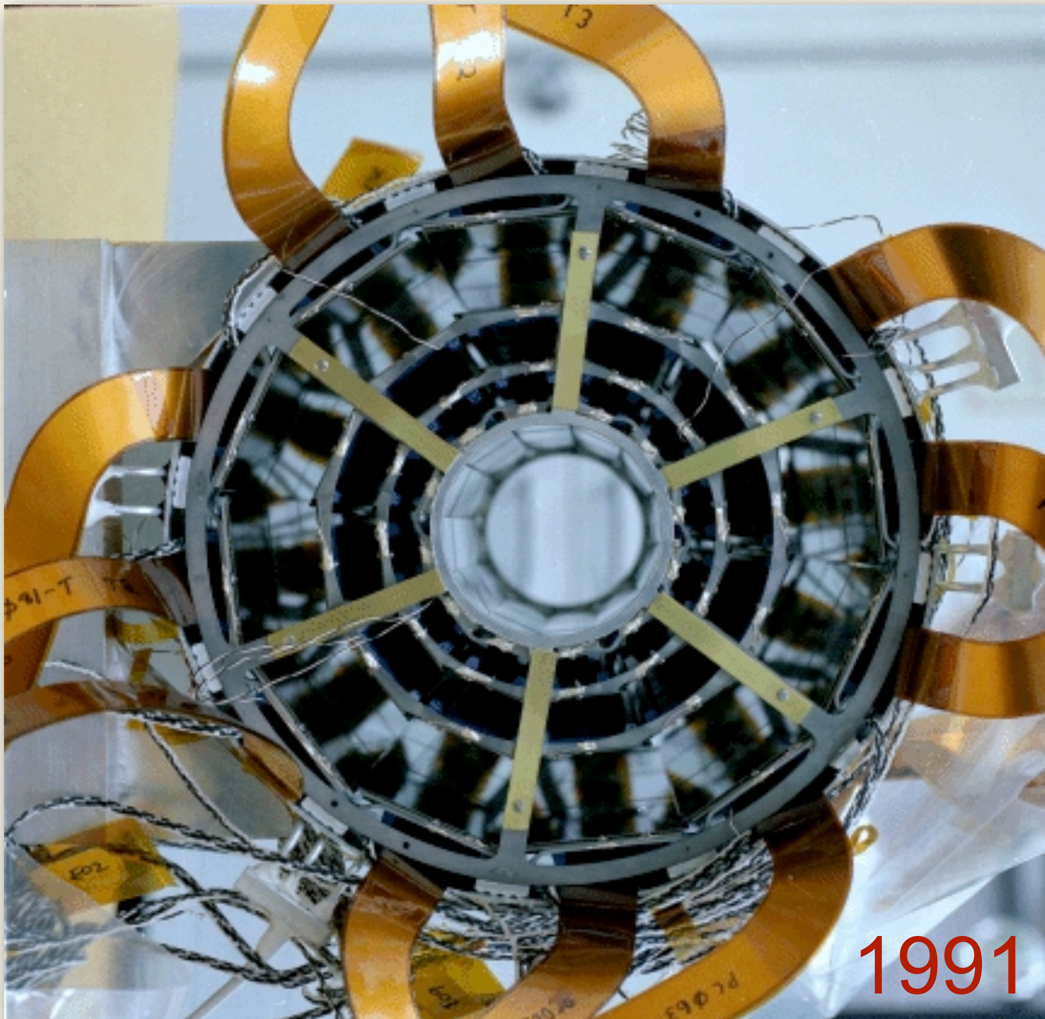


some early prototypes of
microstrip silicon detectors

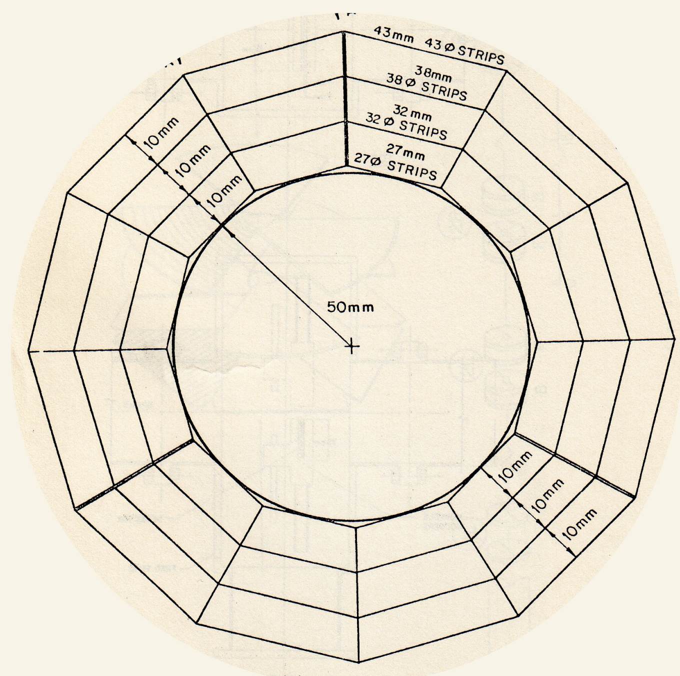


SVX: the first CDF micro vertex detector

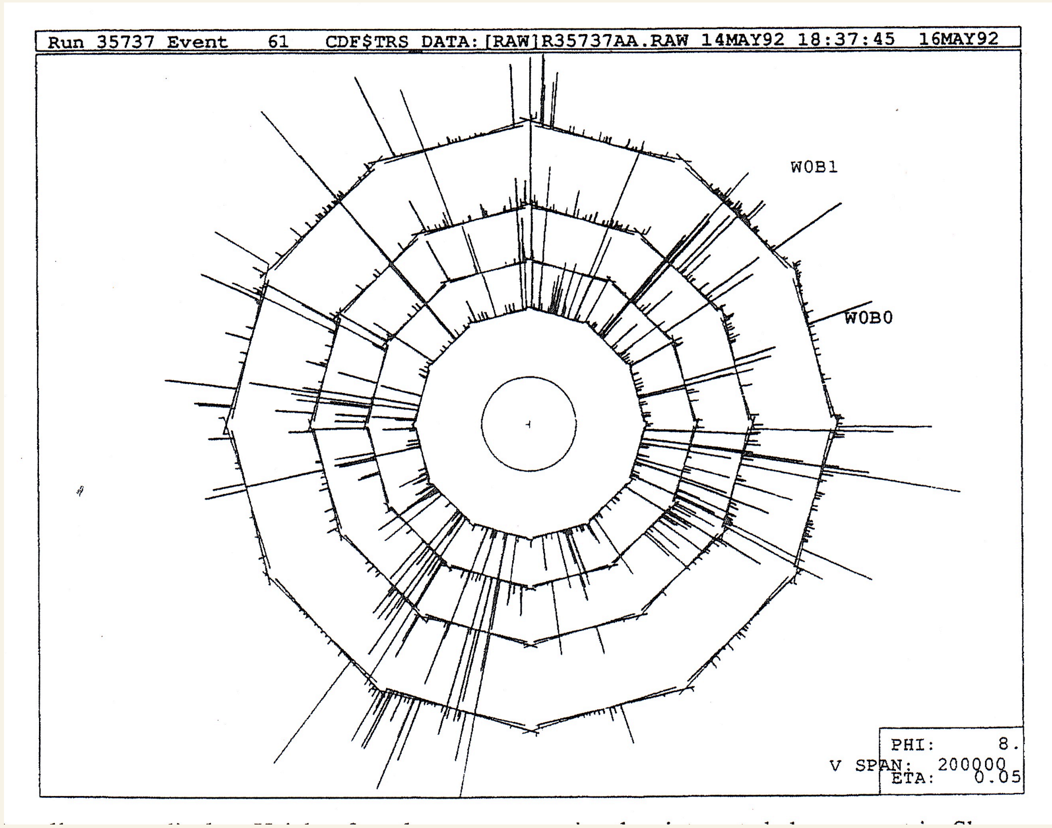
finished in 1991



1981



1992: particles from collisions are recorded by SVX

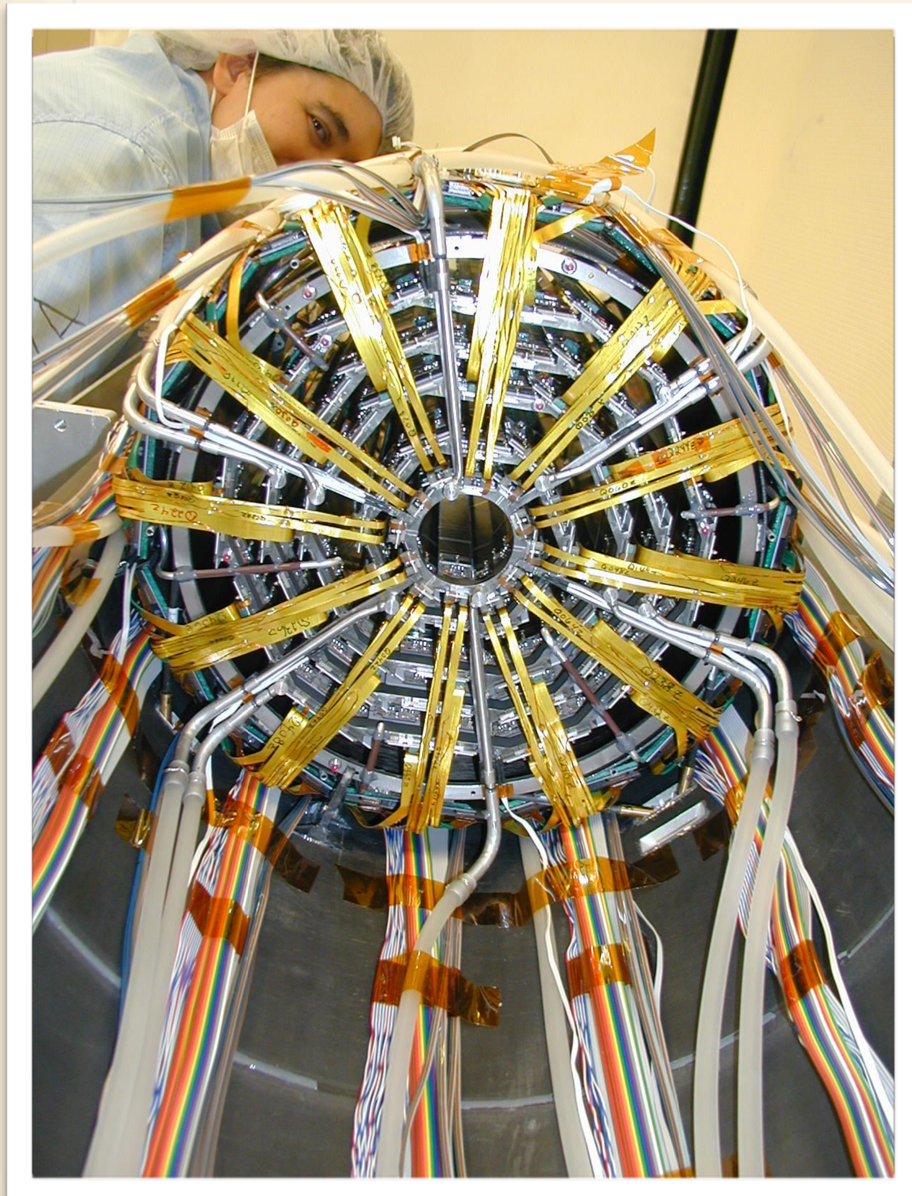


will be of crucial importance for the discovery of the Top quark in 1995

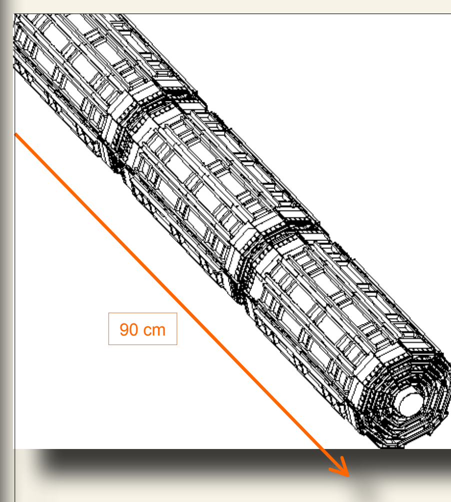
SVX and the Smithsonian

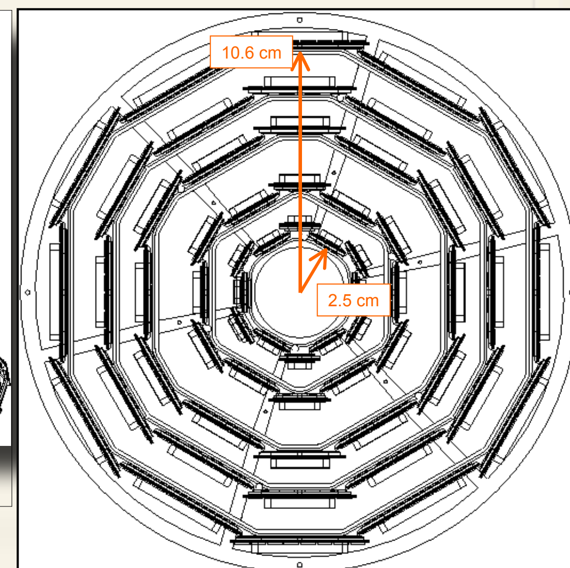
photo courtesy of Brenna Flaugher

SVX II: the latest CDF micro vertex detector



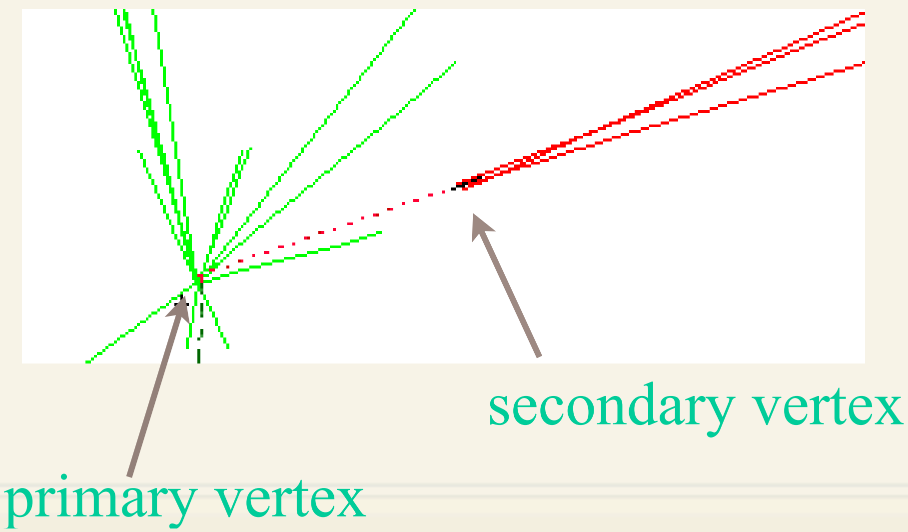
commissioned in 2001





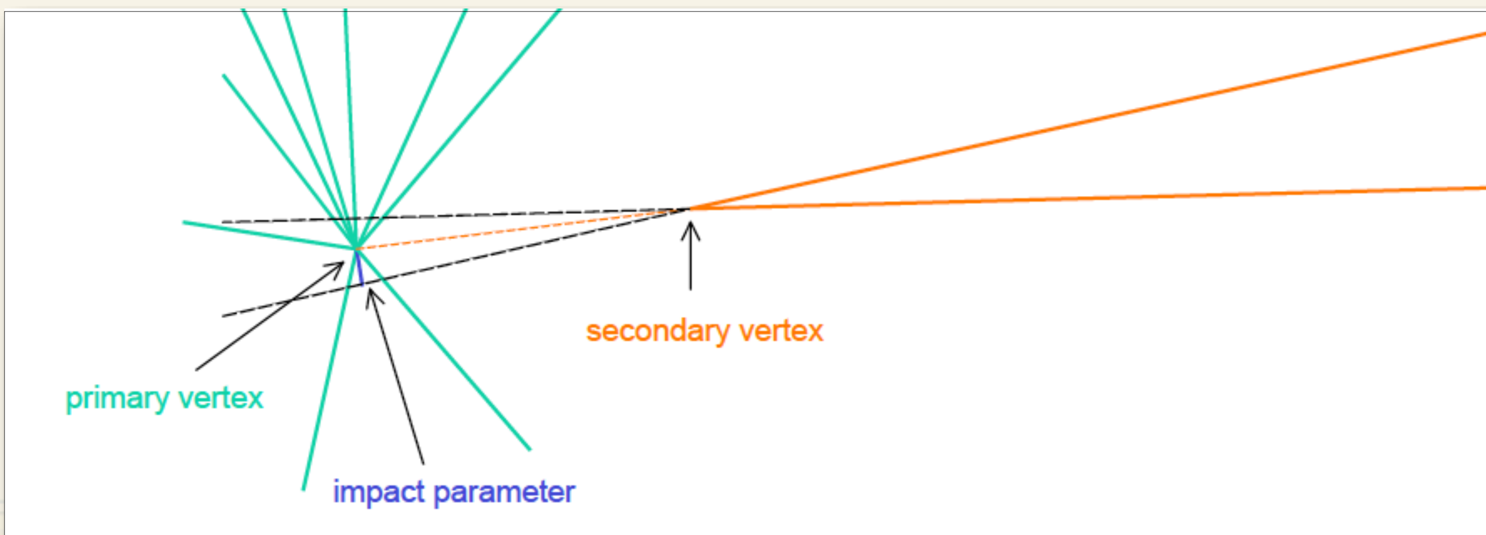
Heavy Flavor Physics

- at the start of CDF, at the end of the '80s, the first priority was the search for the *Top* quark but...
- quarks with *Charm* and *Beauty* are produced abundantly at the Tevatron and turn out to be extremely interesting too, but they are hard to identify being produced mostly at relatively low transverse momentums
- their main characteristics is a relatively long lifetime which creates *secondary vertices* at distances of the order of millimeters from the collision point



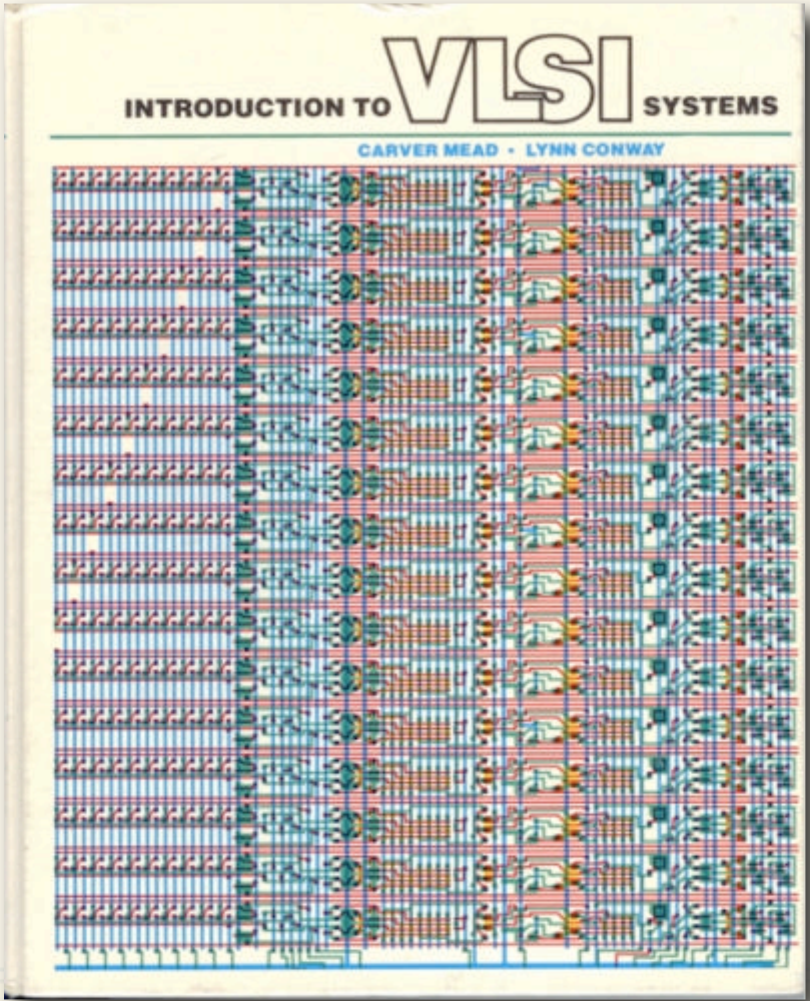
to trigger on secondary vertices you need to

- perform pattern recognition and sort hits into tracks
- fit all tracks to extract relevant parameters (P_T, phi, d)
- do all this with
  - sufficient speed to be used at trigger level (~20μs)
  - sufficient impact parameter precision (~40μm)

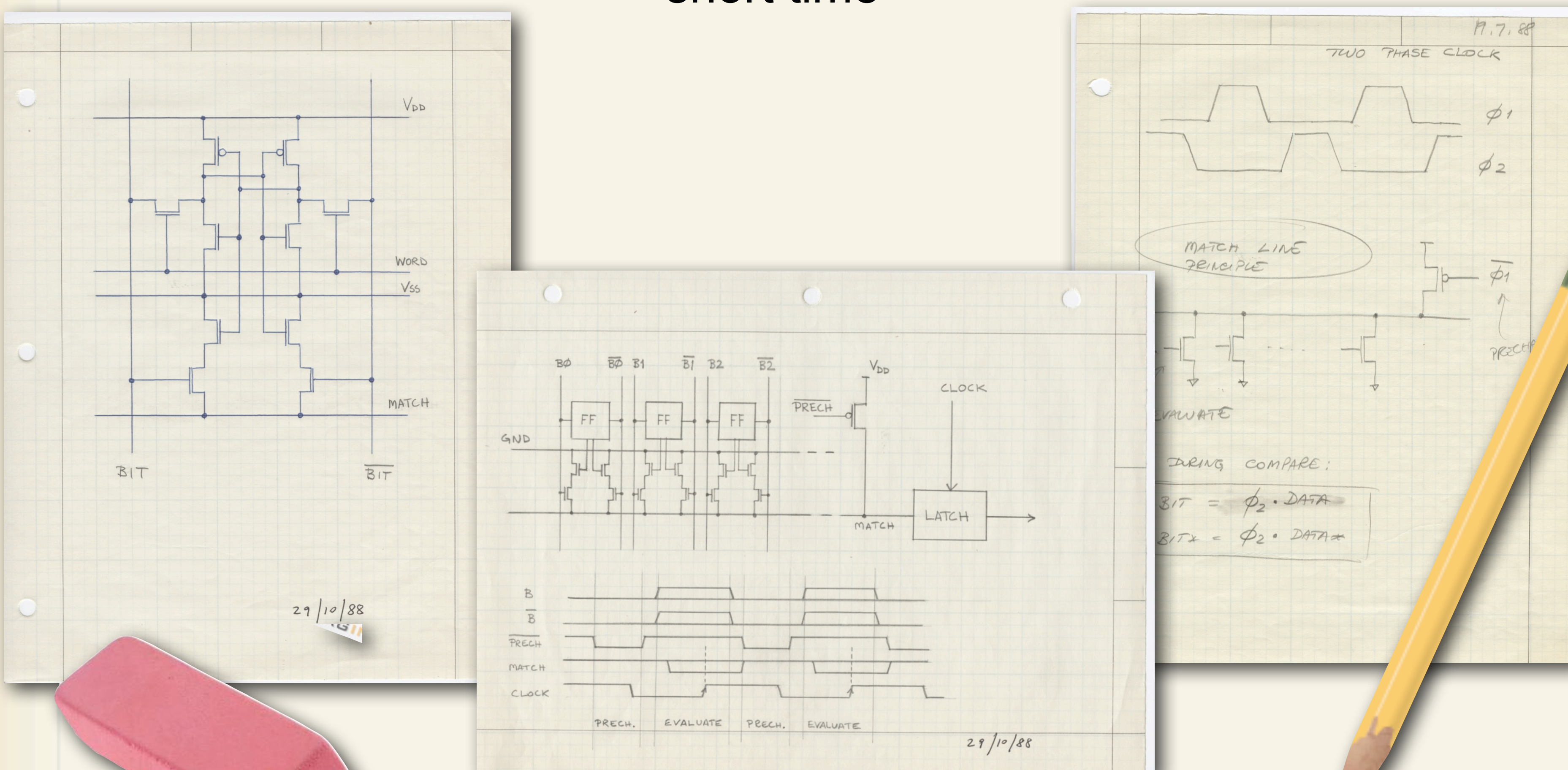


Very Large Scale Integration
the revolution

Carver Mead & Lynn Conway



in the '80s the technology of VLSI design becomes available to the universities and to small research projects it is at this point in time that we came up with the idea to use VLSI technology to solve the pattern recognition problem and reconstruct tracks in the detector in a very short time



October 1988: paper, pencil, eraser....

436

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North-Holland, Amsterdam

October 24, 1988

VLSI STRUCTURES FOR TRACK FINDING

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Received 24 October 1988

We discuss the architecture of a device based on the concept of *associative memory* designed to solve the track finding problem, typical of high energy physics experiments, in a time span of a few microseconds even for very high multiplicity events. This "machine" is implemented as a large array of custom VLSI chips. All the chips are equal and each of them stores a number of "patterns". All the patterns in all the chips are compared in parallel to the data coming from the detector while the detector is being read out.

1. Introduction

The quality of results from present and future high energy physics experiments depends to some extent on the implementation of fast and efficient track finding algorithms. The detection of *heavy flavor* production, for example, depends on the reconstruction of secondary vertices generated by the decay of long lived particles, which in turn requires the reconstruction of the majority of the tracks in every event.

Particularly appealing is the possibility of having detailed tracking information available at trigger level even for high multiplicity events. This information could be used to select events based on impact parameter or secondary vertices. If we could do this in a sufficiently short time we would significantly enrich the sample of events containing heavy flavors.

Typical events feature up to several tens of tracks each of them traversing a few position sensitive detector layers. Each layer detects many hits and we must correctly correlate hits belonging to the same track on different layers before we can compute the parameters

2. The detector

In this discussion we will assume that our detector consists of a number of layers, each layer being segmented into a number of *bins*. When charged particles cross the detector they *hit* one bin per layer. No particular assumption is made on the shape of trajectories: they could be straight or curved. Also the detector layers need not be parallel nor flat. This abstraction is meant to represent a whole class of real detectors (drift chambers, silicon microstrip detectors etc.). In the real world the coordinate of each hit will actually be the result of some computation performed on "raw" data: it could be the center of gravity of a cluster or a charge division interpolation or a drift-time to space conversion depending on the particular class of detector we are considering. We assume that all these operations are performed upstream and that the resulting coordinates are "binned" in some way before being transmitted to our device.

3. The pattern bank

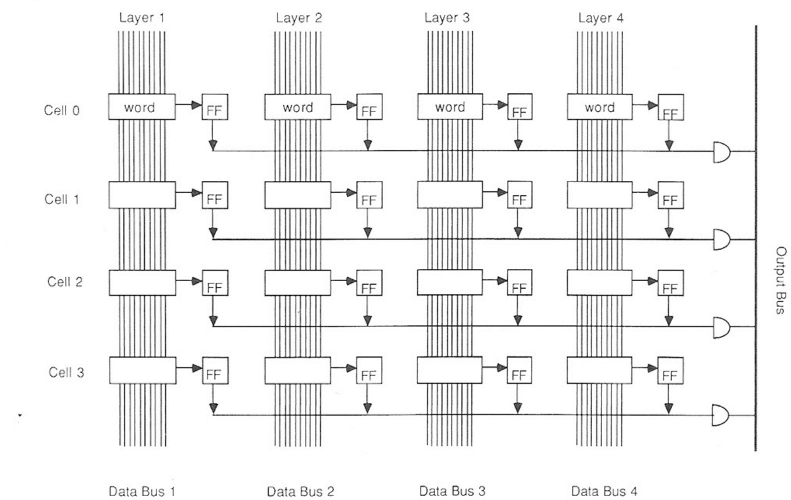


Fig. 3. Associative memory architecture.

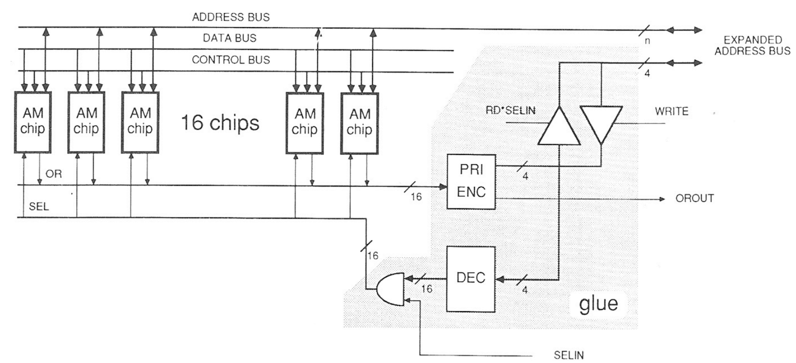


Fig. 5. 16 AM chips tied by the "glue".

We discuss the architecture of a device based on the concept of *associative memory* designed to solve the track finding problem, typical of high energy physics experiments, in a time span of a few microseconds even for very high multiplicity events. This "machine" is implemented as a large array of custom VLSI chips. All the chips are equal and each of them stores a number of "patterns". All the patterns in all the chips are compared in parallel to the data coming from the detector while the detector is being read out.

Linearized Fit

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

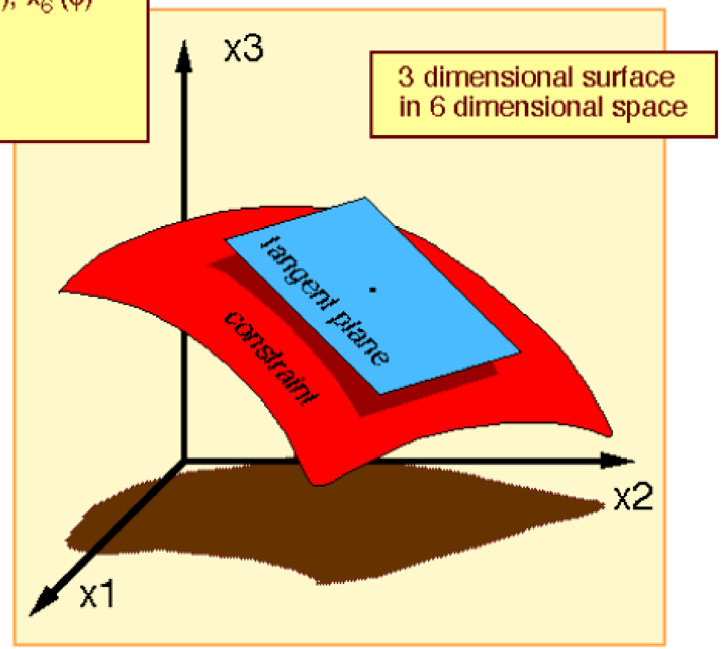
3 constraints

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)

linear transformation

hit coordinates → track parameters

single AM pattern = small volume in phase space

CDF/DOC/TRIGGER/PUBLIC/1421

SVT
THE SILICON VERTEX TRACKER

Luciano Ristori

May 1, 1991

INTRODUCTION

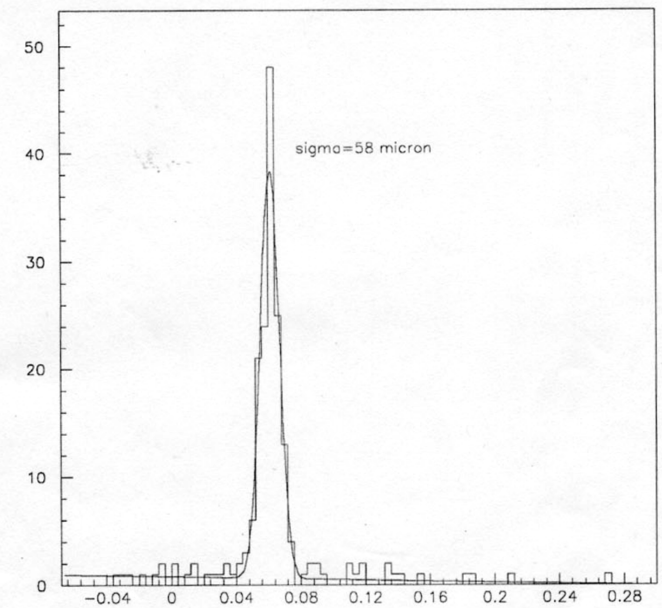
This note describes the architecture of a device we believe we can build to reconstruct tracks in the Silicon Vertex Detector (SVX) with enough speed and accuracy to be used at trigger level 2 to select events containing secondary vertices originated by B decay. We name such a device *Silicon Vertex 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 *s* of each track is defined as the minimum

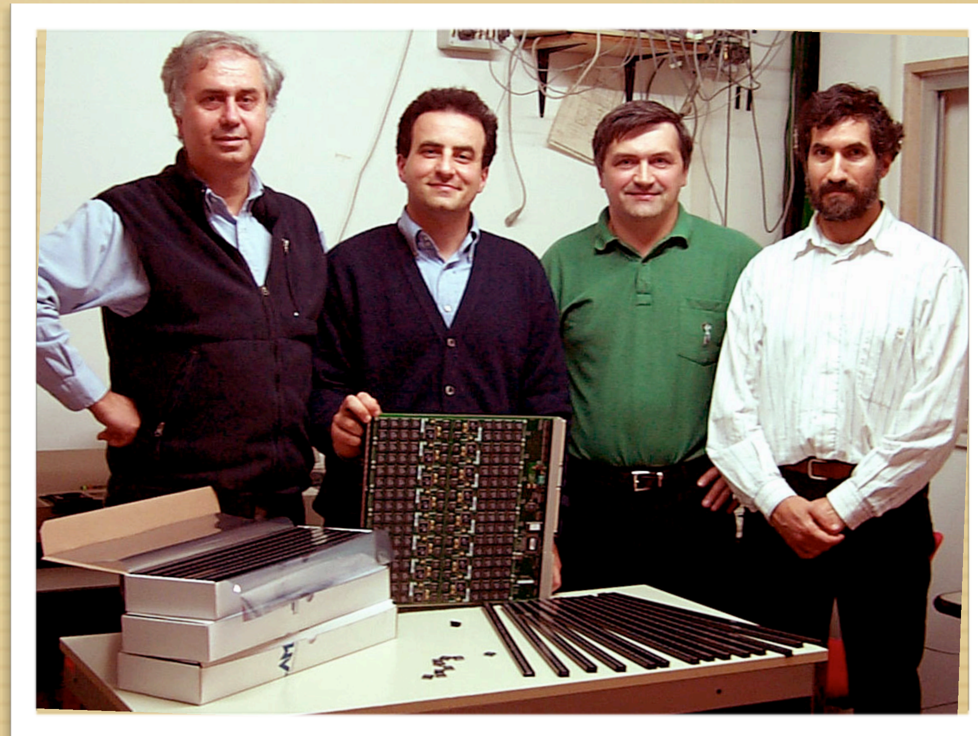
real data + SVT simulation



Transverse profile of the Tevatron luminous region obtained feeding real data from SVX into the simulation of SVT. The sigma of this curve (58 μm) is the result of the folding of spot size with impact parameter resolution.

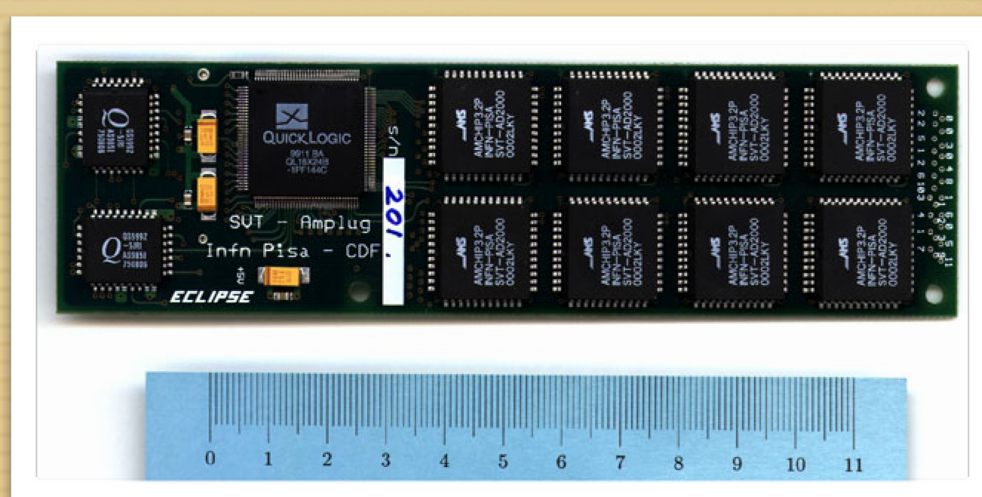
Nov 17, 1992

Luciano Giovanni Alexei Fabio



Fabio Morsani

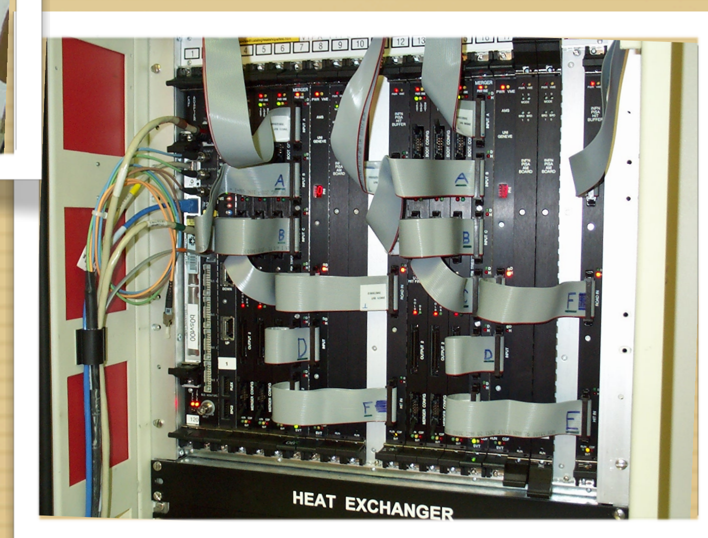
Associative Memory chip



Associative Memory plug

August 31, 2000

All SVT boards
installed at Fermilab




SVT was born on Halloween night 2000

From: Giovanni Punzi <giovanni.punzi@tiscalinet.it>
Subject: **Tracks in SVT !!!**
Date: November 1, 2000 6:16:39 AM CST
To: World SVT <svt@fnal.gov>
Reply-To: giovanni.punzi@tiscalinet.it

Show in M

Hello SVTers,
we have got clear tracks in SVT from run 102831 !!!! This is in spite of the lack of XFT information !
I thought the easiest way to show you this was to simply display the whole of my Mathematica session with all plots and comments:

first tracks in SVT

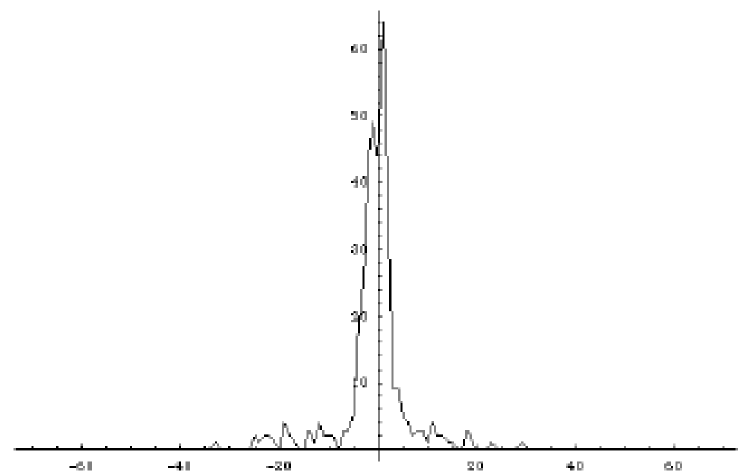
Enjoy !

Giovanni

dieci anni di ricerca
nel profondo della foresta
oggi grandi risate
sulla riva del lago

Soen

SVT_first_.nb 11/02/200



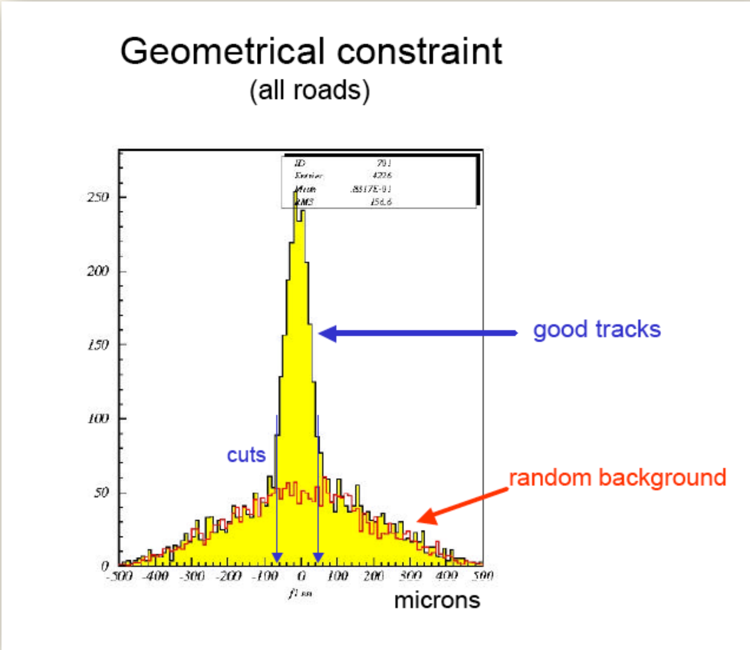
Out[255]= - Graphics -

This is VERY CLEAN now !!! The beam constraint cleans up the sample a lot !!!
Note that Kernel and d are basically uncorrelated, as they should:

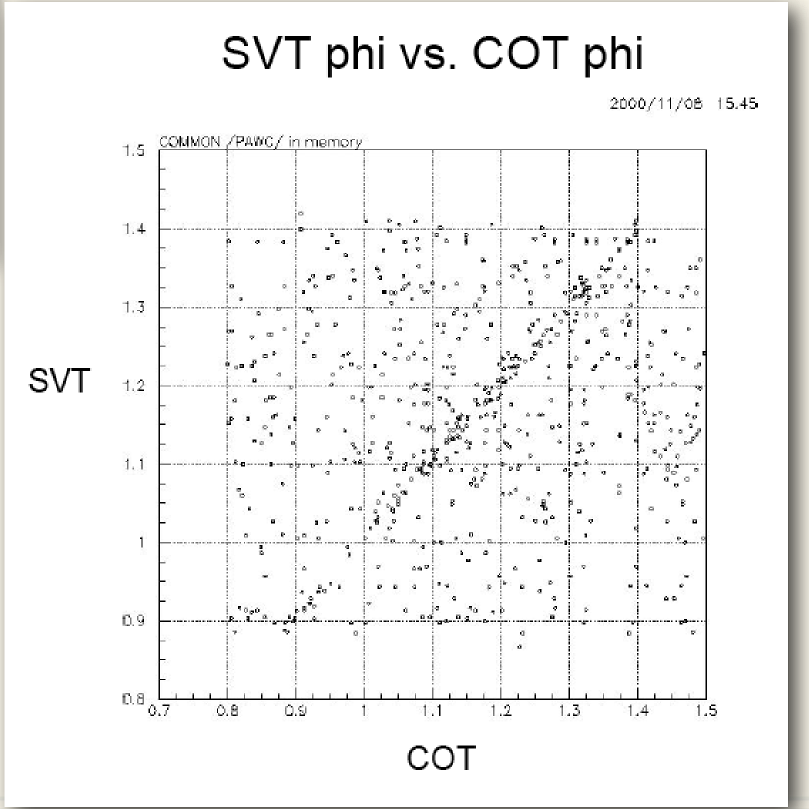
In[256]:= K.Dsub / Sqrt[K.K*Dsub.Dsub]

Out[256]= -0.0529577

...so there is no trick,the correlation between the two variables is given by physics!!!



we prove that the tracks seen by SVT are real

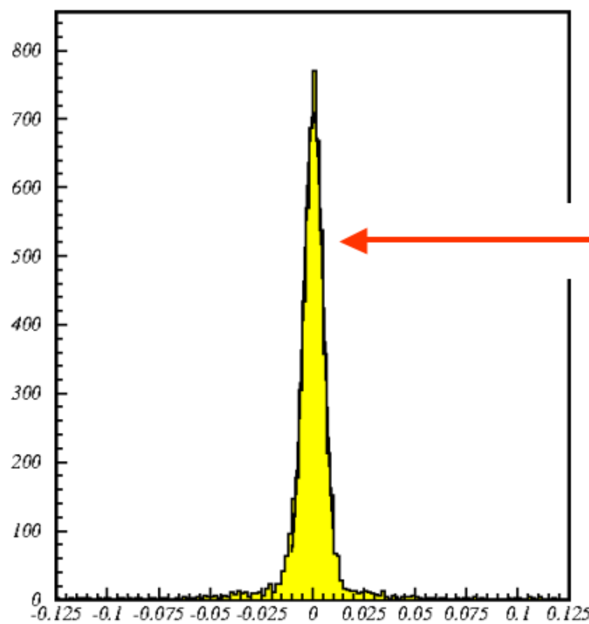


the precision of the measurement of the impact parameter is as expected

SVT: beam profile

SVT

Impact parameter distribution



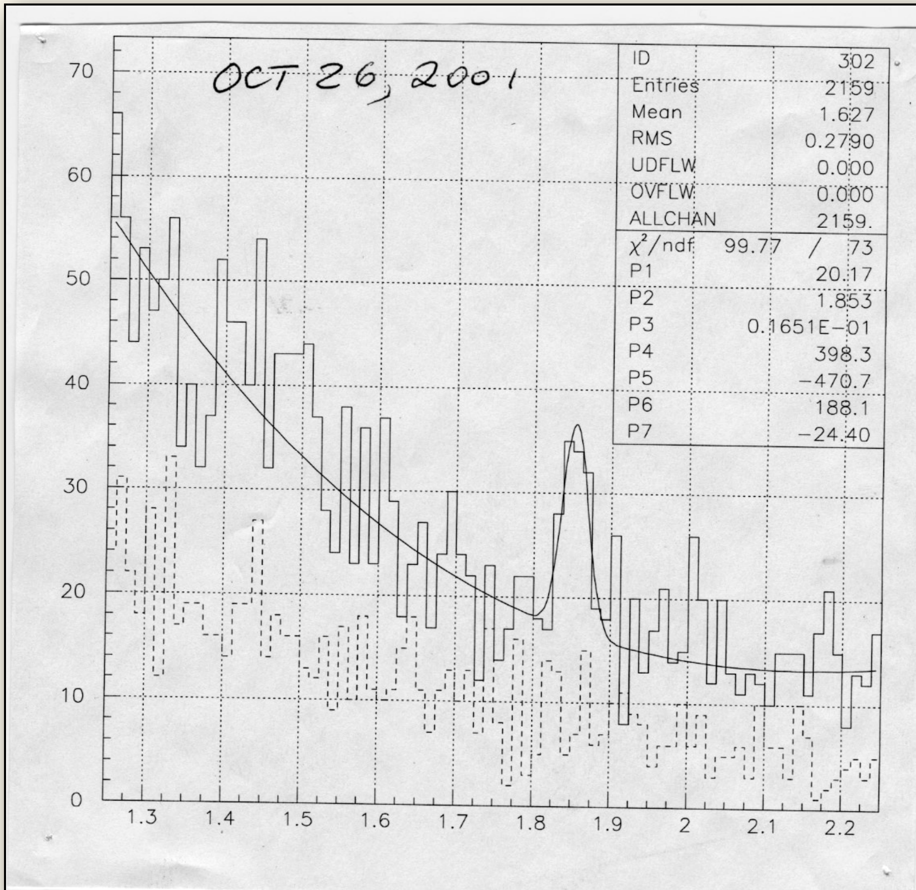
This distribution is interpreted as the convolution of the actual transverse size of the beam spot with the impact parameter resolution of the SVT

sigma ~ 48 um ~ 42 um ⊕ 23 um

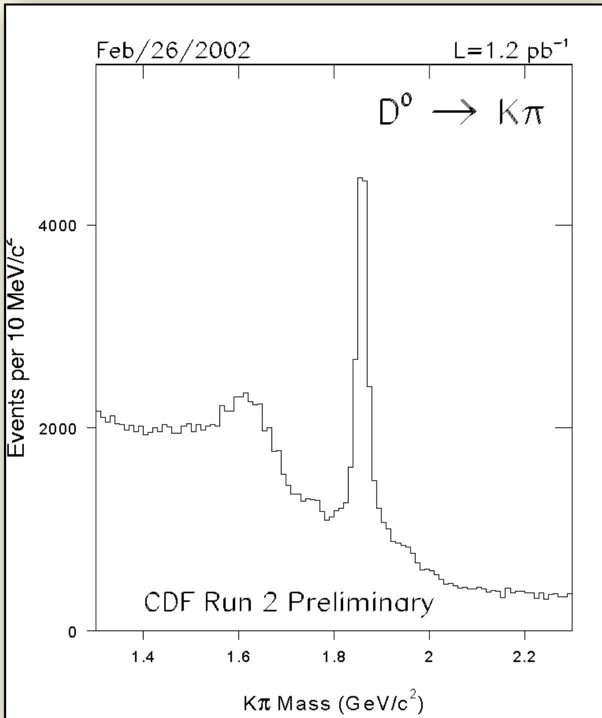
SVT resolution   beam spot size

	beam	SVT	Total
sigma	23	42	48
rms	23	51	56

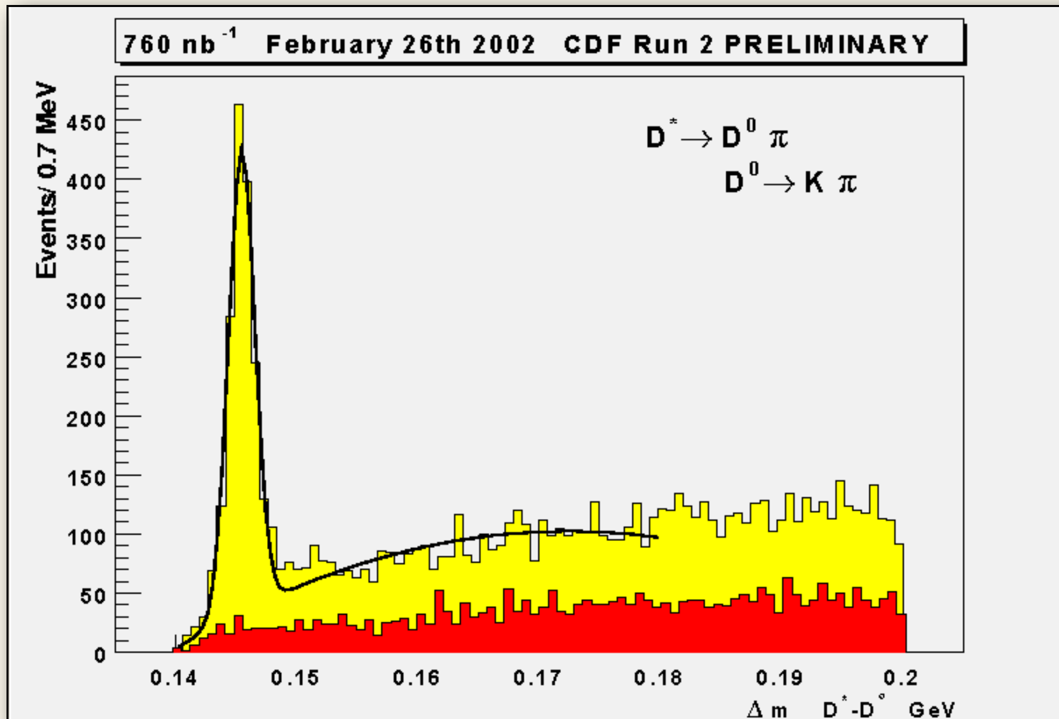
October 2001: the next important milestone

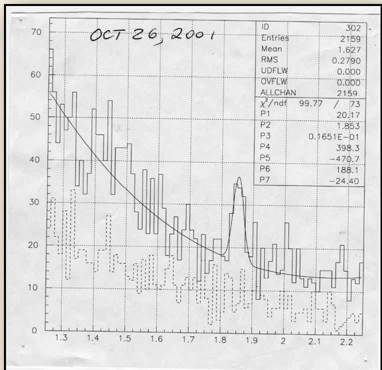


D^0 signal in the events selected by SVT

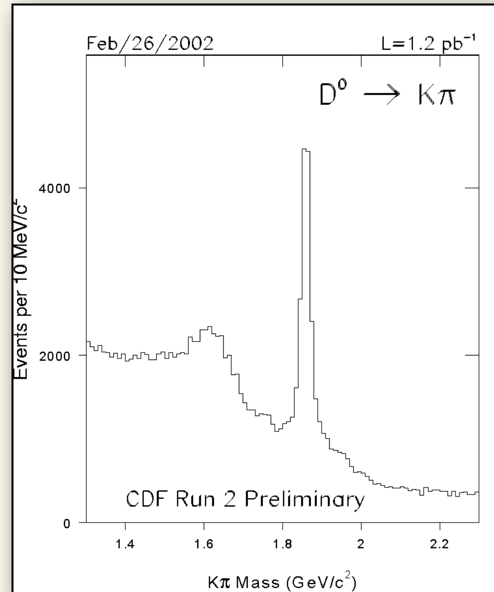


February 2002: we have many D^0 and D^*

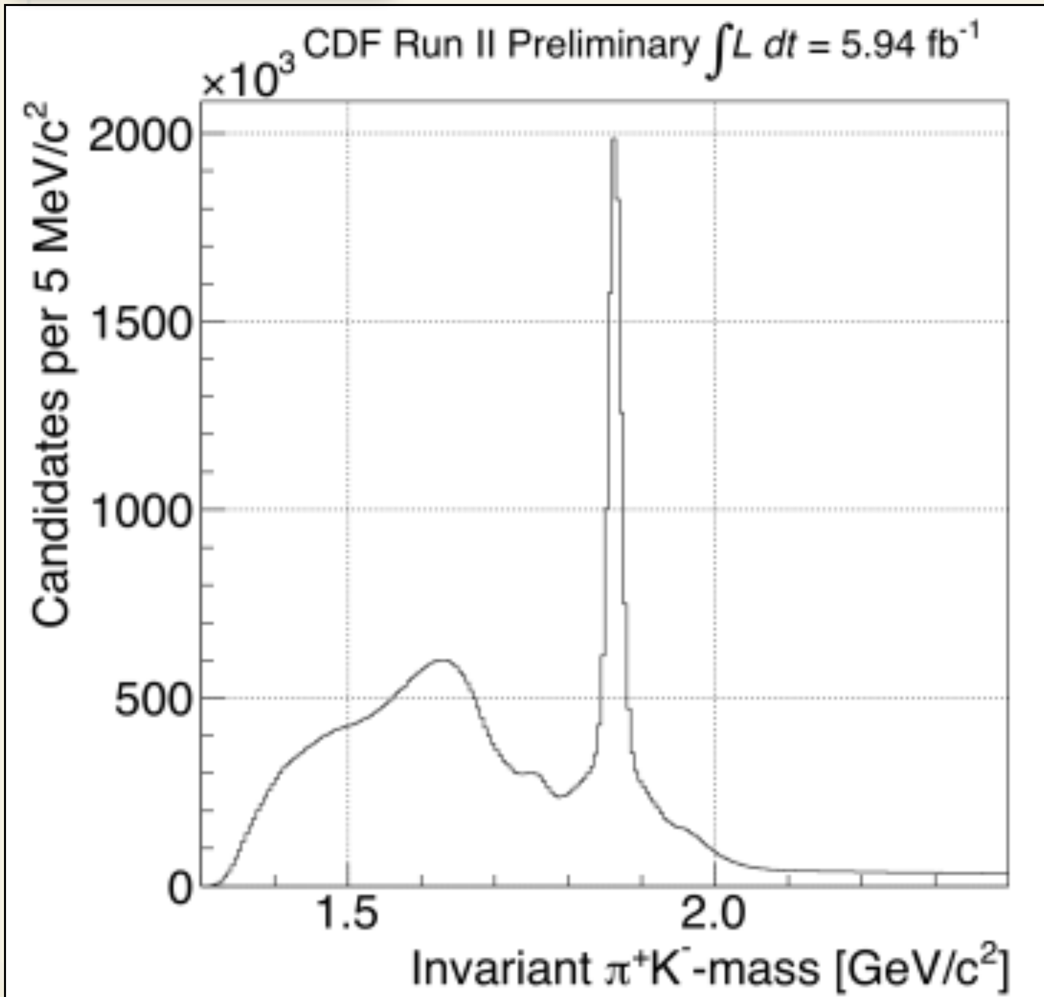




Oct 2001: ~50 $D^0 \rightarrow K\pi$

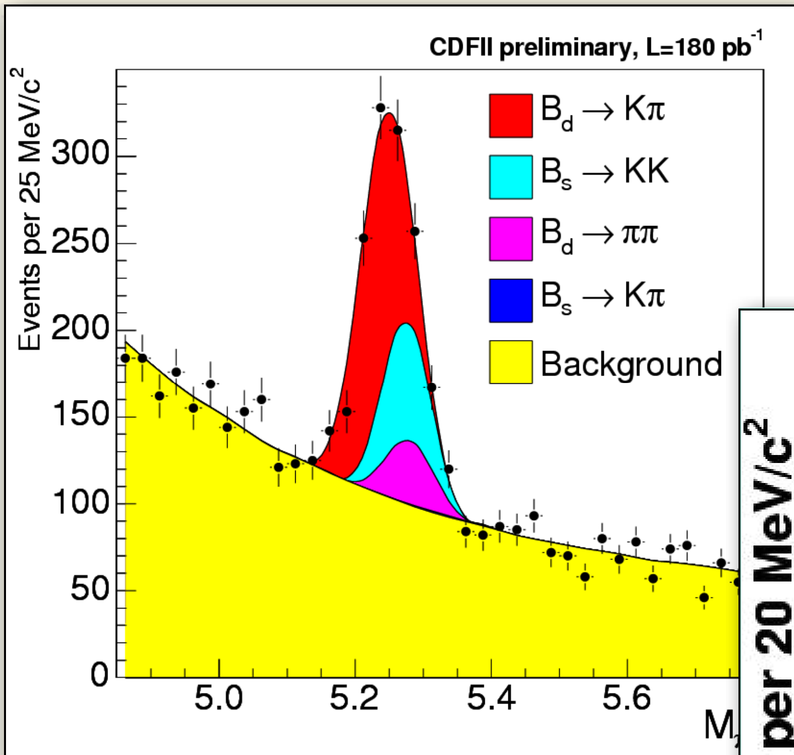


Feb 2002: ~5000 $D^0 \rightarrow K\pi$



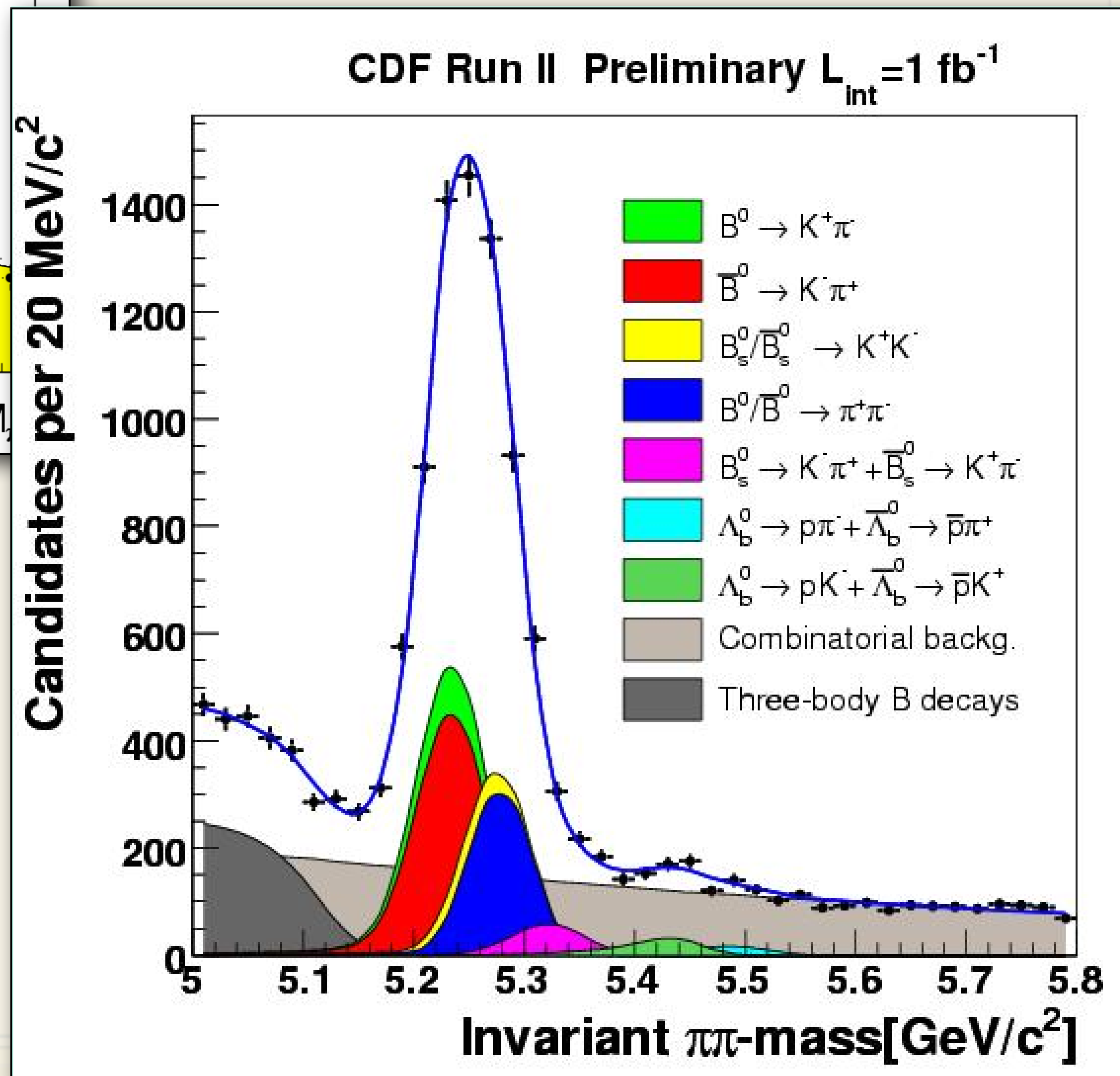
today:
~30 million $D^0 \rightarrow K\pi$

and in the end...
the mass peak of $B \to h^+h^-$



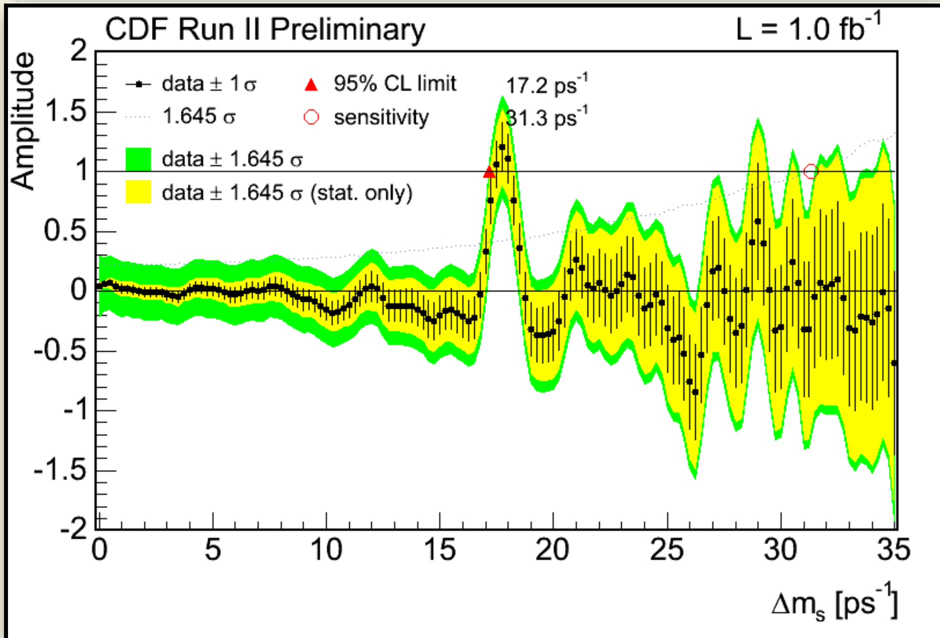
Summer 2003

it is cleaner than our most optimistic expectations

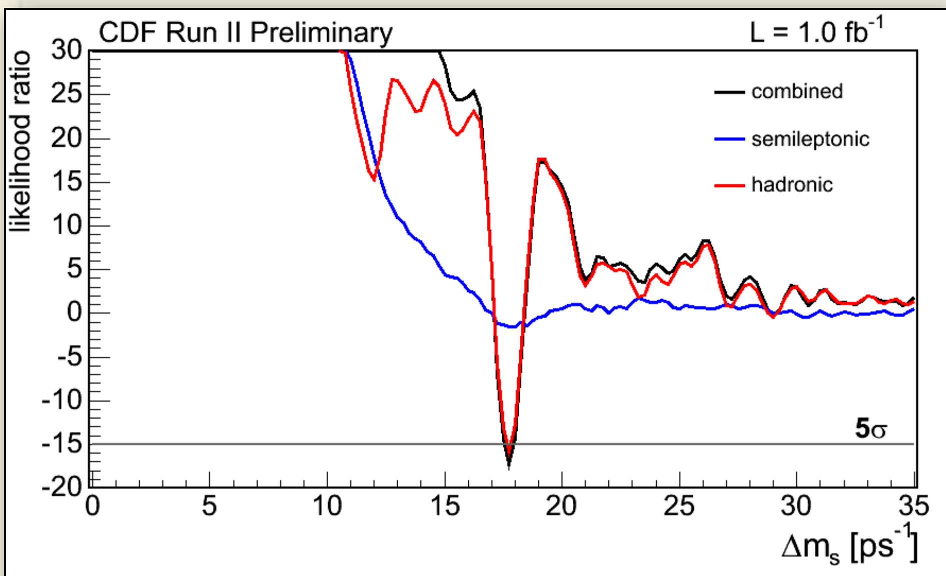


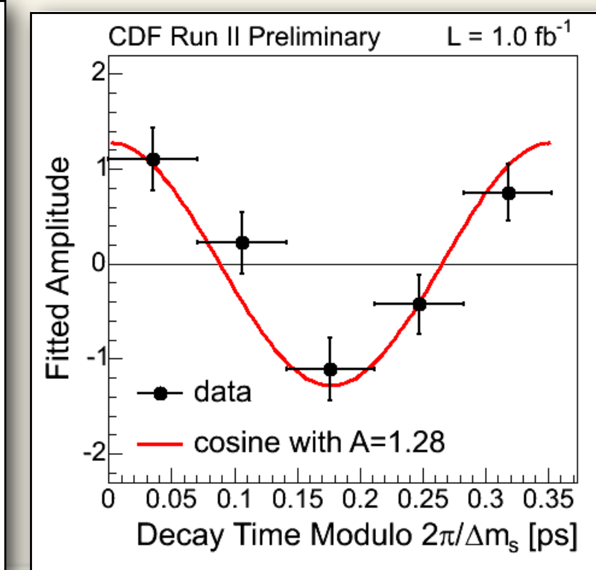
Summer 2006

Observation of B_s^0-$\bar{B}_s^0$ Oscillations



the quality of this measurement is essentially determined by the hadronic decays selected by the SVT trigger





in summary...

- SVX was crucial for the discovery of the Top quark
- SVXII is now crucial for the search for the Higgs
- The addition of SVT has allowed CDF to be competitive with the B factories in terms of yield of Charm and Beauty
- Also it opened up the sector of hadronic decays of heavy flavored mesons and barions not accessible to the B factories (B_s, B_c, Λ_b,...)