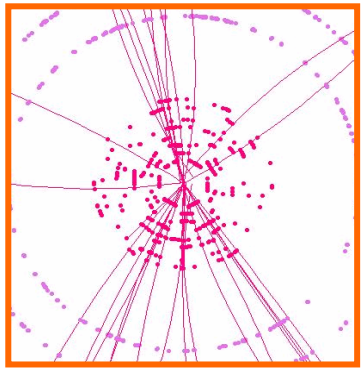
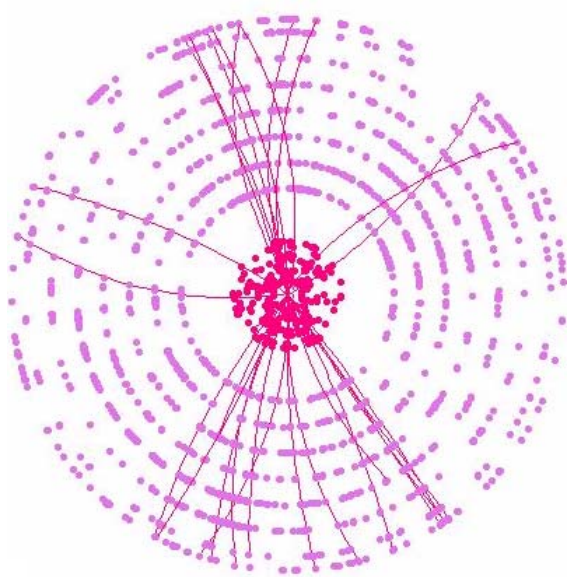


Connecting the dots…
(Tracking at D0)

Shabnam Jabeen
Kansas University

Introduction
Tracking part of D0 Detector
Tracking Algorithms
Use of Tracking Algorithms
Performance



The Question is..

Where did all this come from?

What is all this made of?

What was universe like in the beginning?

How many fundamental particles

and forces there are?

why particles have charge?

why particles have mass?

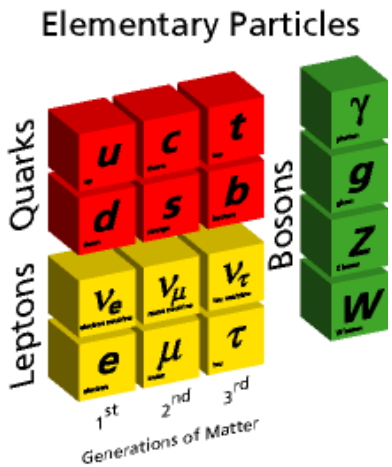
Why ------ -- -- -- ?

How …….?

…. .. ..

STANDRAD MODEL

One of the most beautiful, rich in predictions and experimentally verified models given ever



No Higgs yet !

Remarkable agreement between theory and experiment up to energies of ~ 100 GeV

But ……

We are still far from

Theory of **EVERYTHING**

Large number of theories out there but ….

"Where would a brave knight be without his noble steed ?"*

A theory is just a beautiful thought until it is proven experimentally

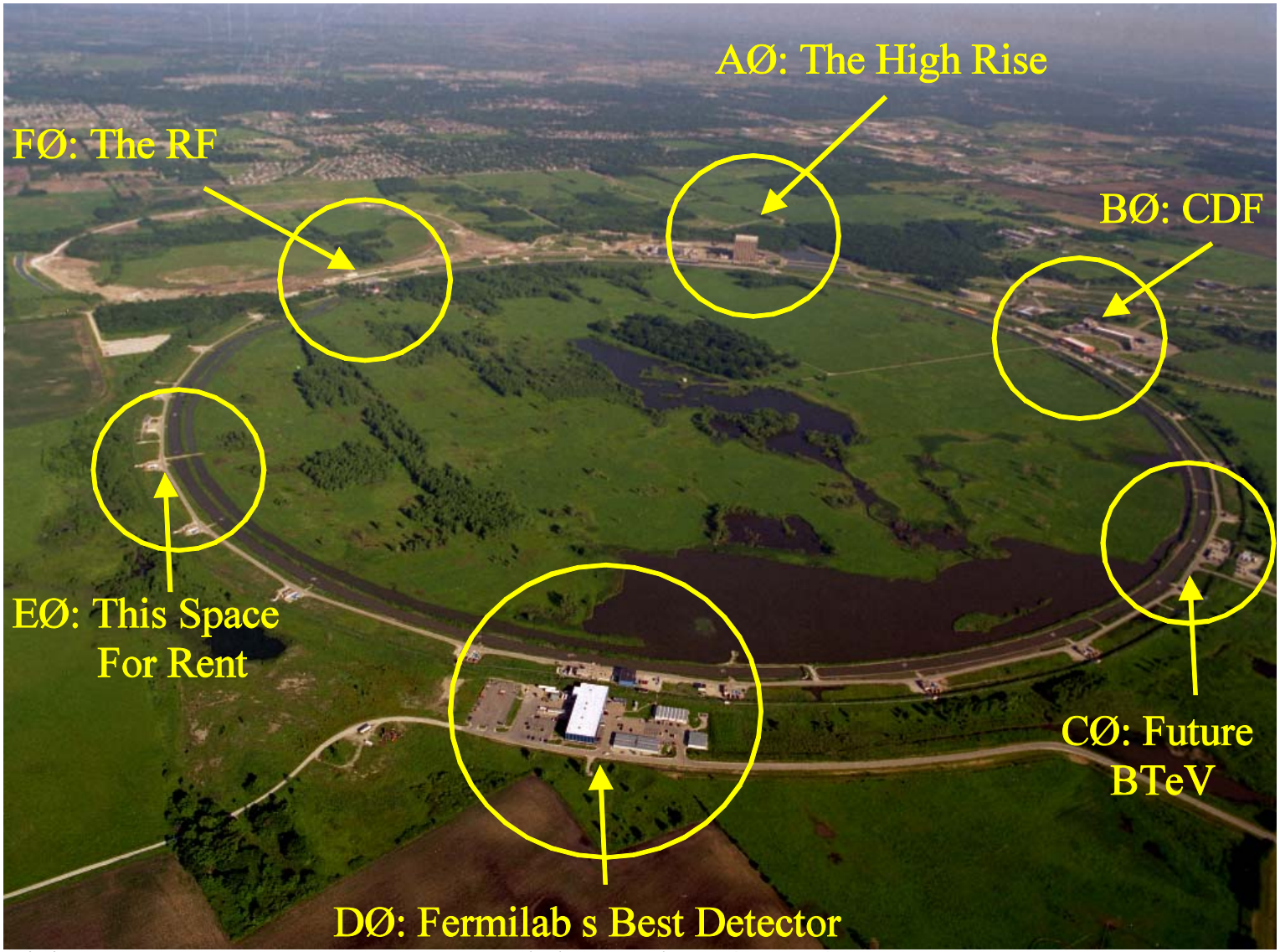
* It does not mean that a theorist is an Ogar and an experimentalist is a donkey , or vice versa

Experimental tools

- **Accelerators, detectors, computers**
- **Theoretical and simulation tools**
- **Analysis techniques**

High Energy Research is mainly carried out with large high energy colliders and complex particle detectors in few international laboratories

Tevatron – Highest energy accelerator at present

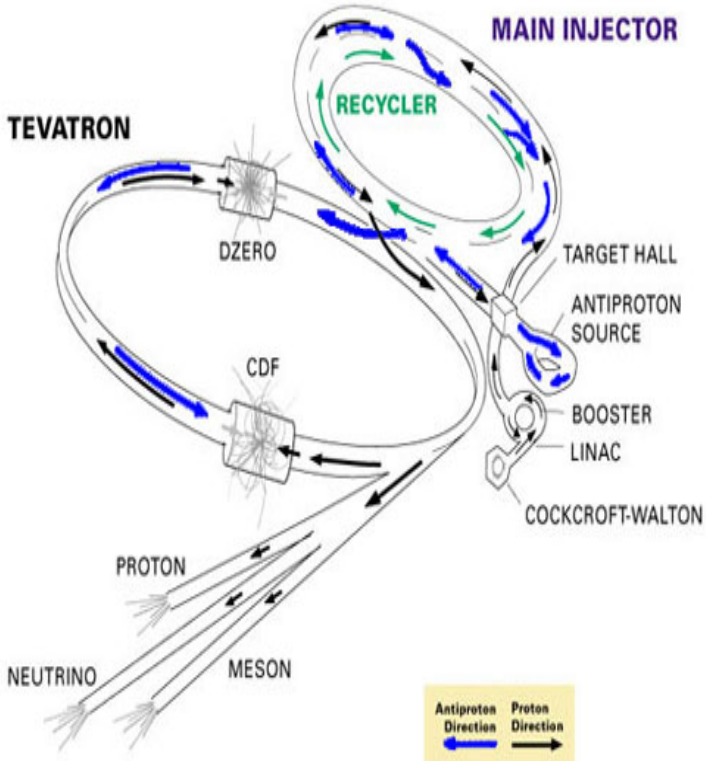


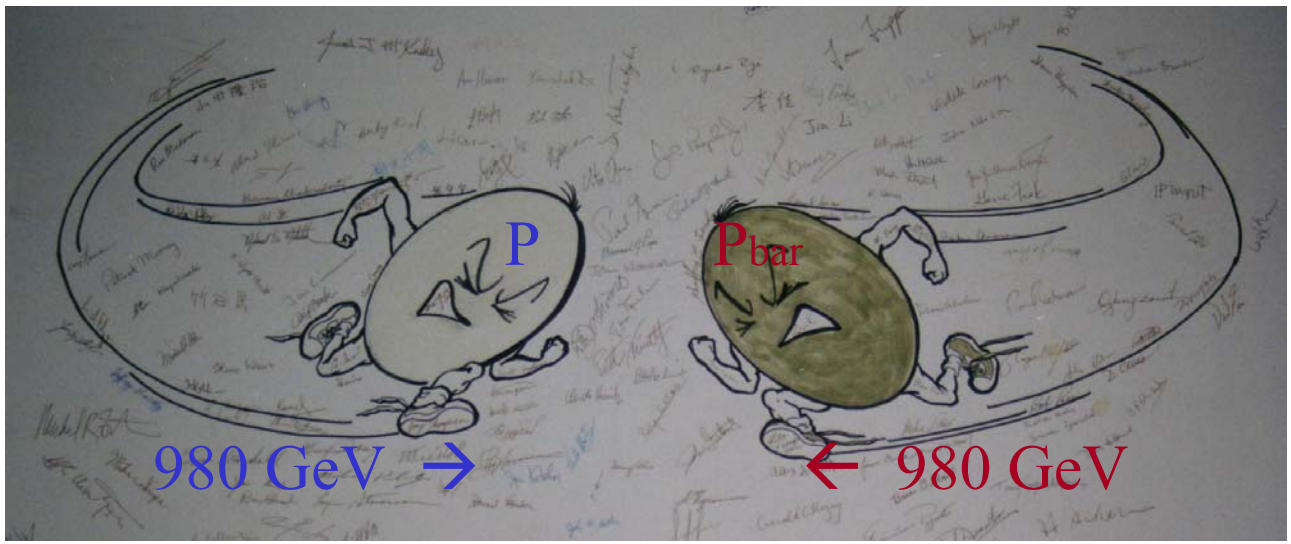
Tevatron

Higher energy collisions: 980 GeV

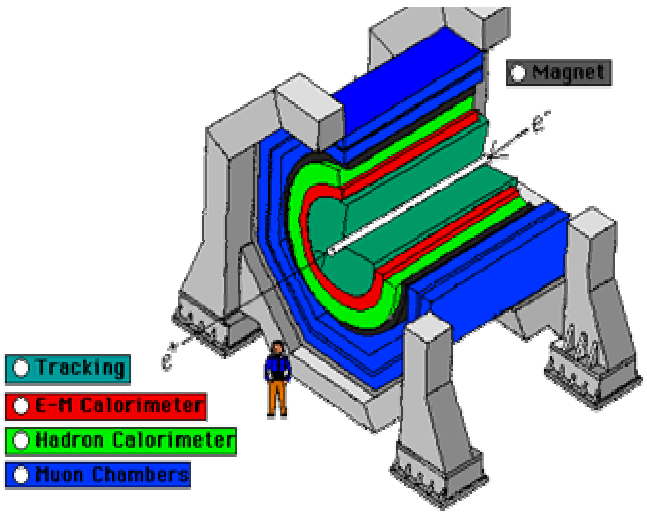
Number of p and pbar bunches: 36
(396 ns beam crossing time)

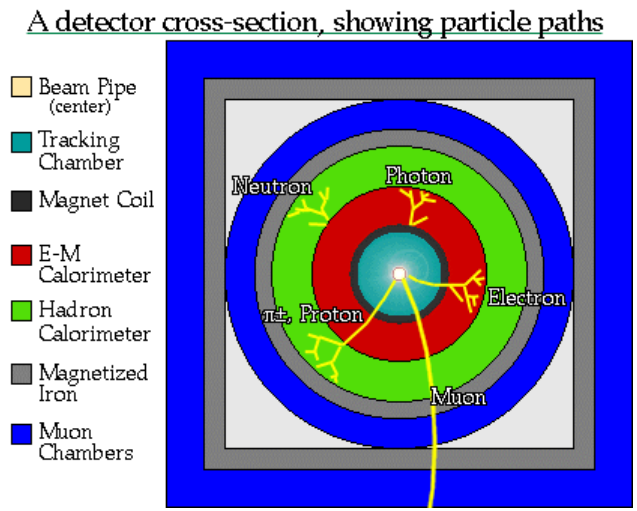
Luminosity: Run 2 goal 2-4 x 10^{32} cm^{-2} s^{-1}

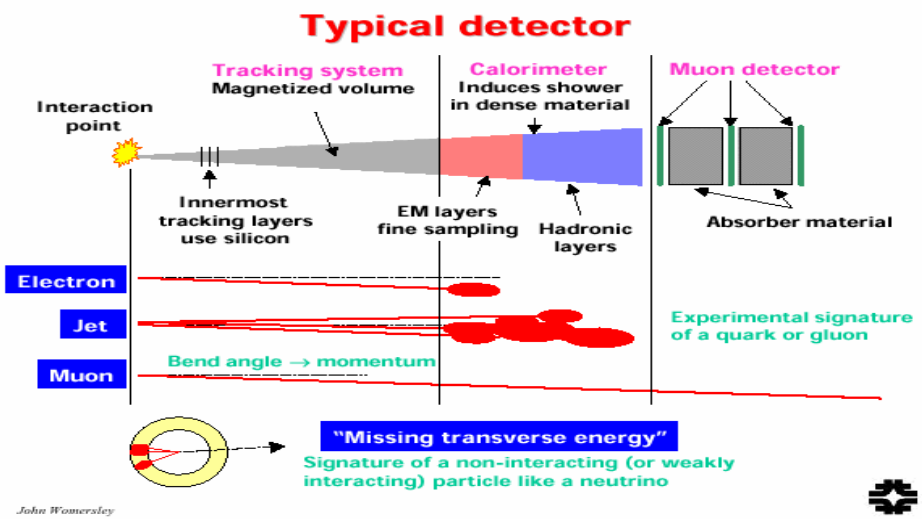



P
Pbar
980 GeV →
← 980 GeV

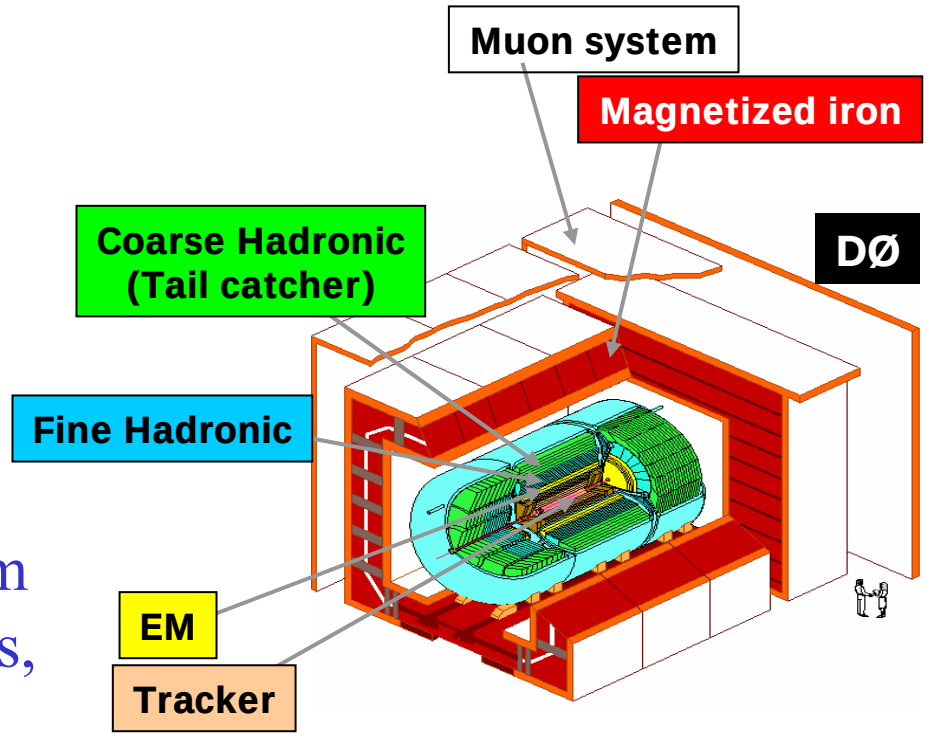
Modern Detector



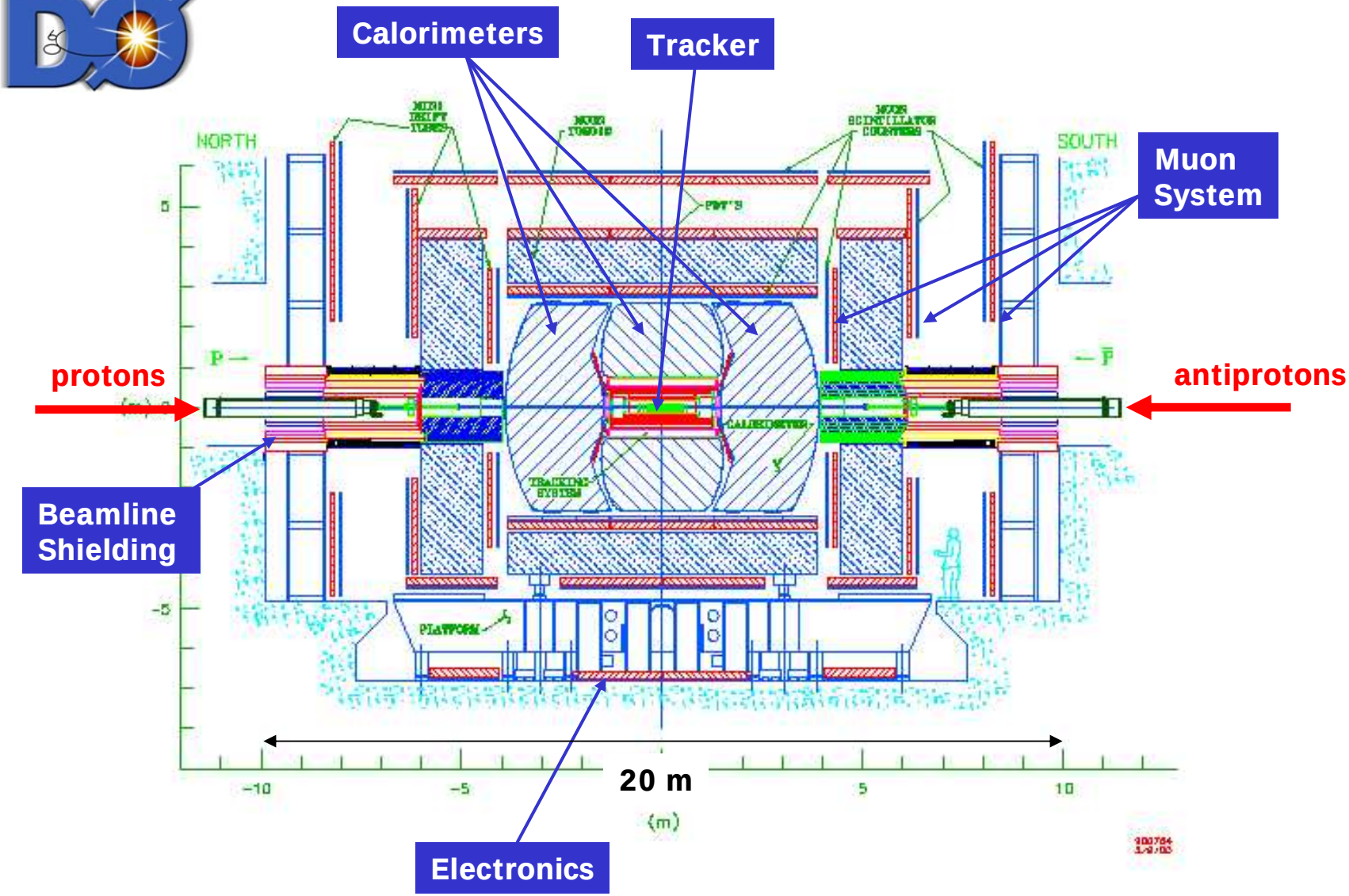




DZERO Detector



5000 tons of iron, uranium
Liquid argon, coils, cables, wires, …


Calorimeters
Tracker
Muon System
protons
antiprotons
Beamline Shielding
Electronics
NORTH
SOUTH
20 m
(m)

DØ Tracking System

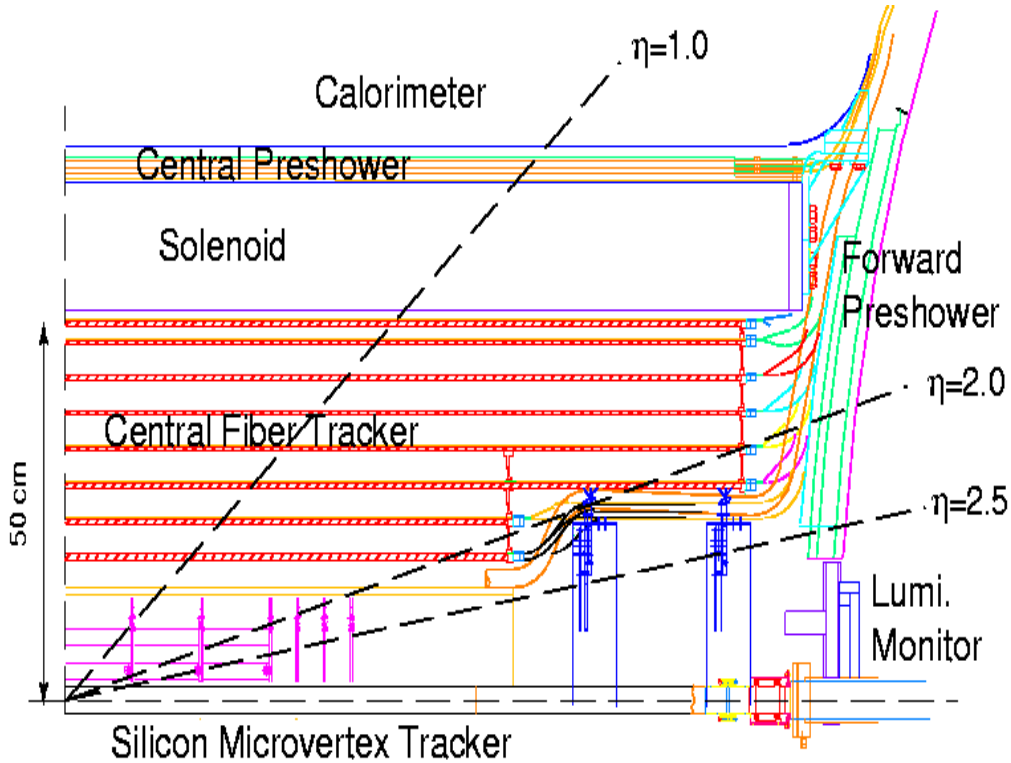
Silicon Tracker
793,000 channels

Fiber Tracker
77,000 fibers

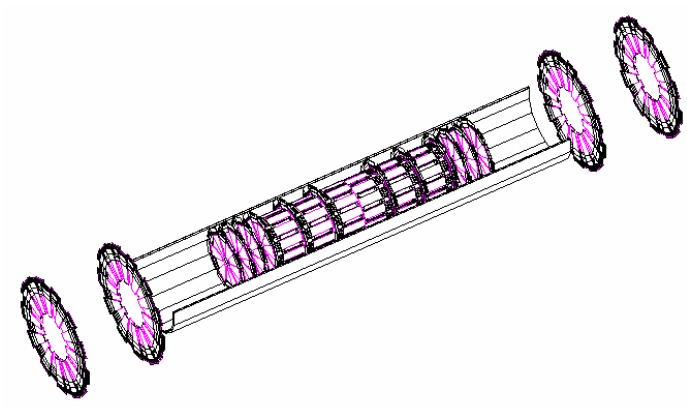
Solenoid
2T superconducting

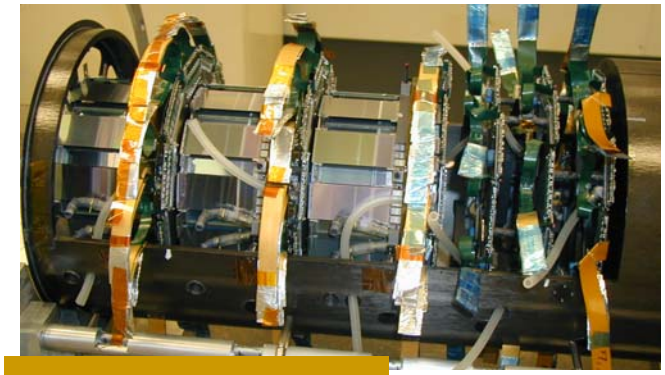
Central Preshower
6000 channels

Forward Preshower
16,000 channels

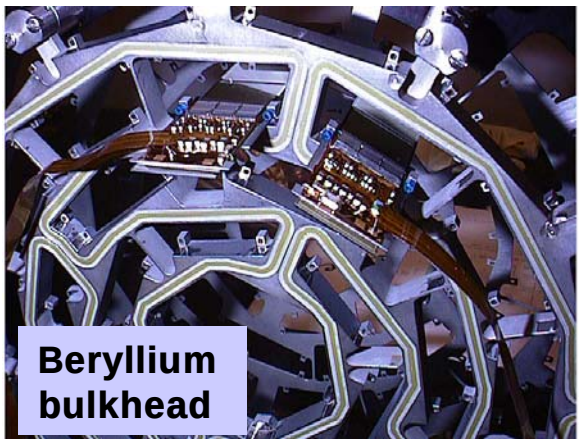


Silicon Microstrip Tracker





SMT half cylinder



Beryllium bulkhead

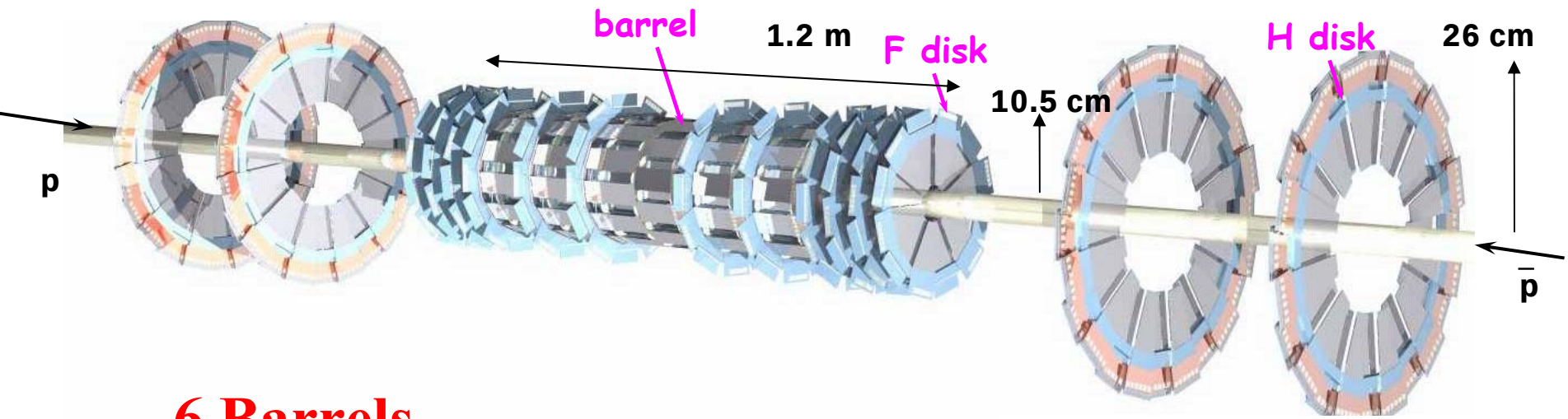
Charged particle momentum and secondary vertices

Provide tracking out to $|\eta| \sim 3$

Radiation hard > 1 Mrad

Maximum silicon temperature < 15 C

Silicon Microstrip Tracker



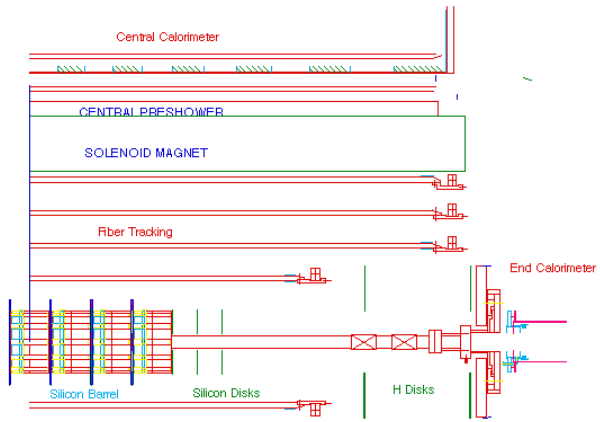
6 Barrels

12 Central F-disks

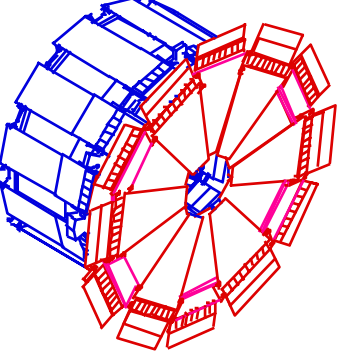
4 Forward H-disks

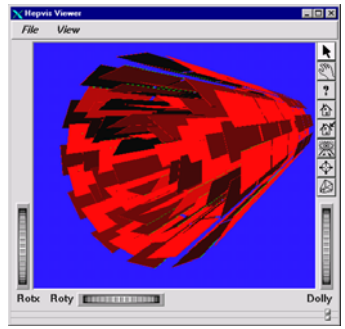
3m^2 silicon, 793k channels

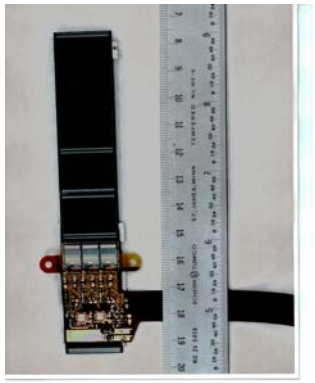
SVX chip readout



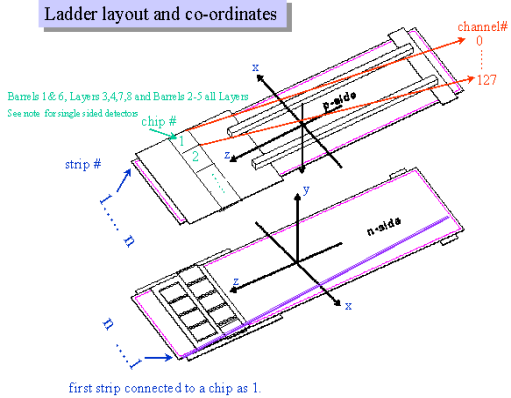
Barrels and Disks

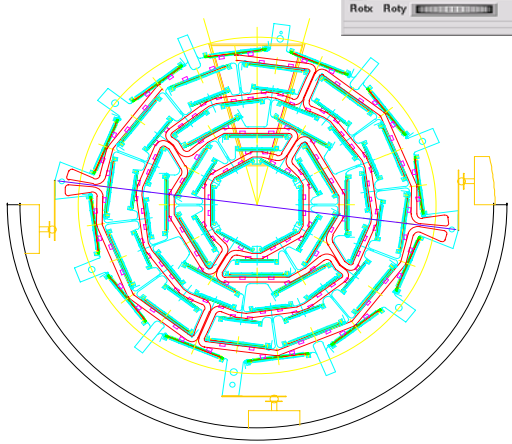


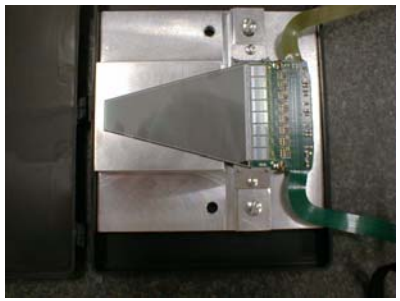




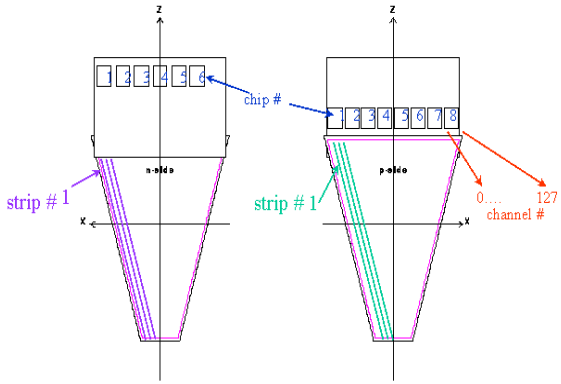
Ladder layout and co-ordinates



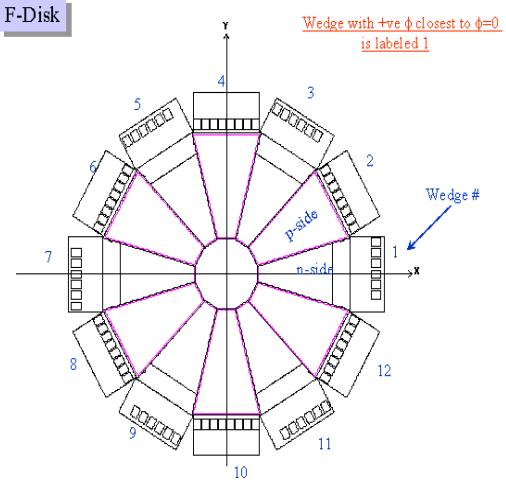




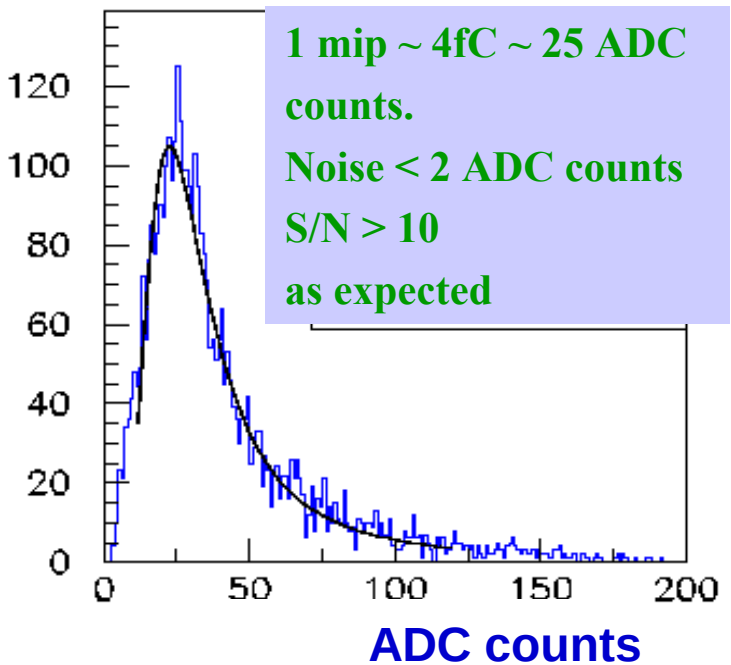
F-Disk Wedges

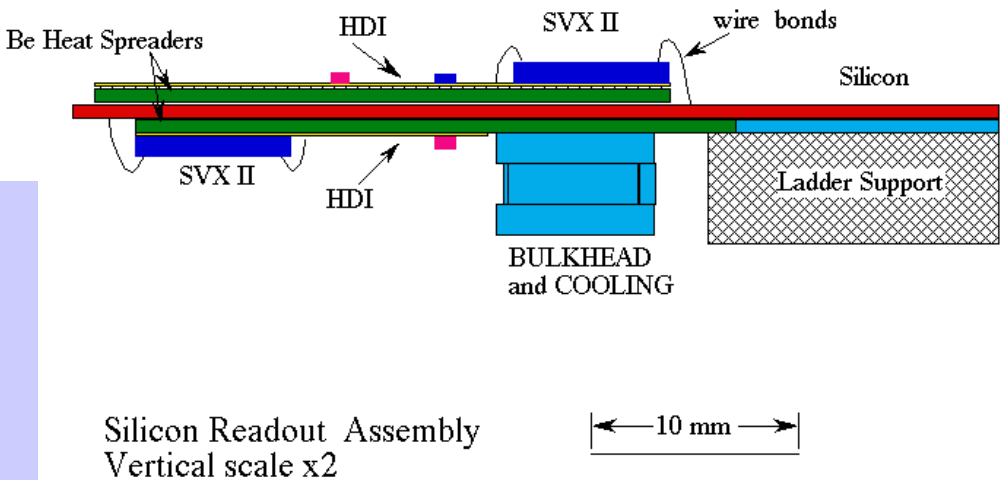


F-Disk



SMT Readout System



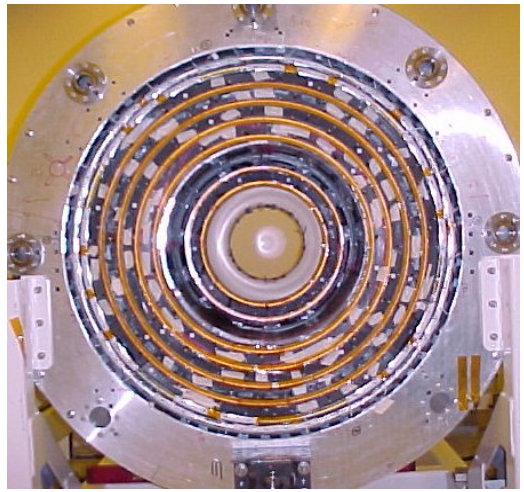


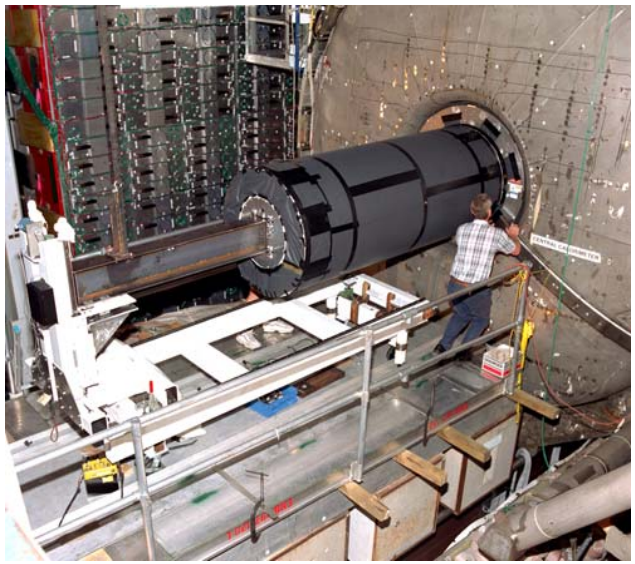
SVX IIe Chip

- 128 channel,
- Radiation hard
- Analog pipeline (32 cells)to store signals
  While L1 trigger is formed

Scintillating Fiber Tracker

Eight cylinders covered with scintillating fiber are read out with a novel light detector (VLPCs).





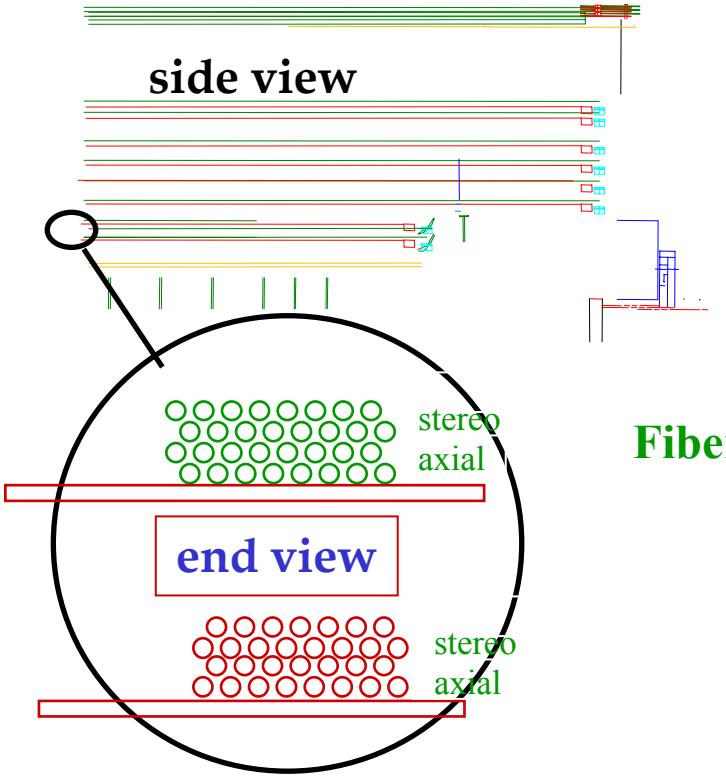
Two main functions

1. Track reconstruction and momentum measurement with silicon system
2. Fast Level 1 Triggering

$|\eta| \sim 1.7$

Hit resolution about 100μm

Fiber Tracker



Barrels

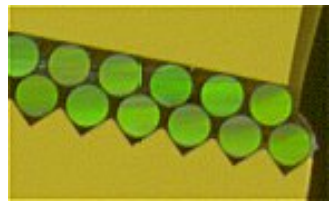
- 8 carbon fiber barrels
- 20<r<50cm

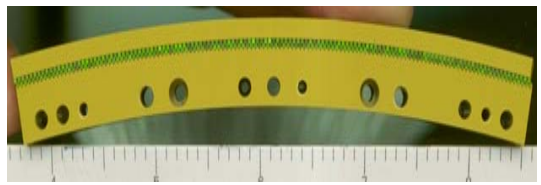
Scint Fibers

- 830μm diameter,
- 2.6m length

Fiber Ribbons

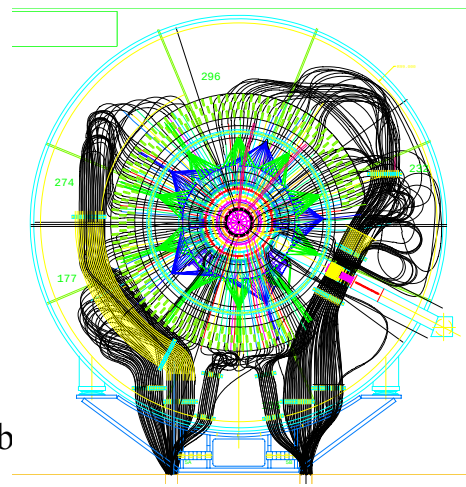
- 256 fibers
- 8 axial doublets
- 8 stereo doublets
- (2° pitch)





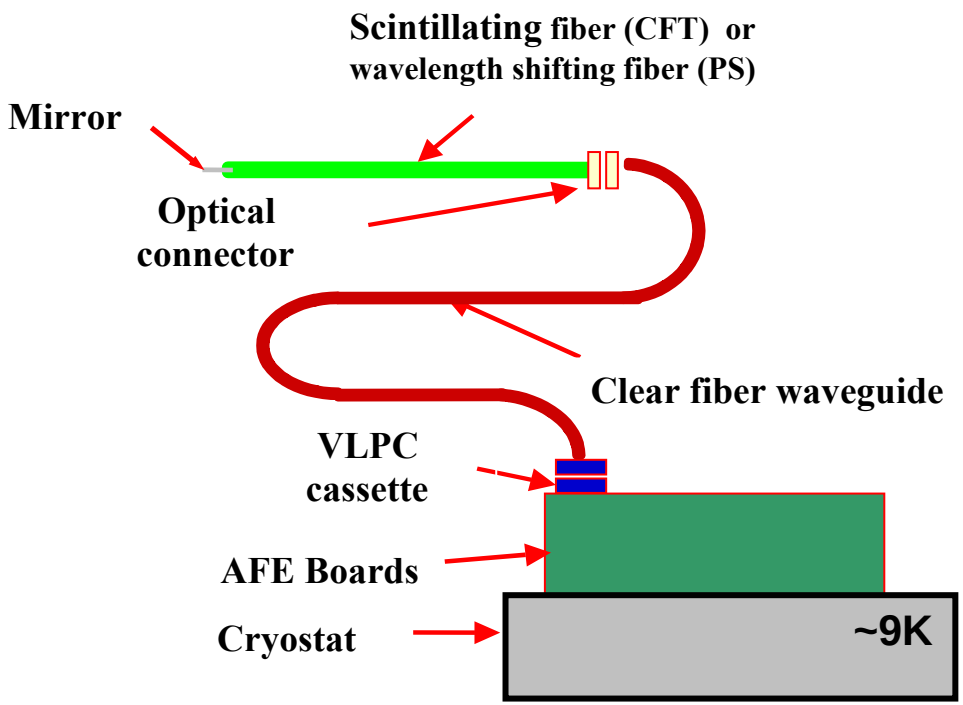
Clear waveguides

8-11m clear waveguide to photodetector



Fiber Tracker

- Scintillating fibers (or strips)
- Light detector (visible light photon counters VLPC)
  - Necessitate Cryogenics
- Readout electronics
- Trigger



Central and Forward Preshowers

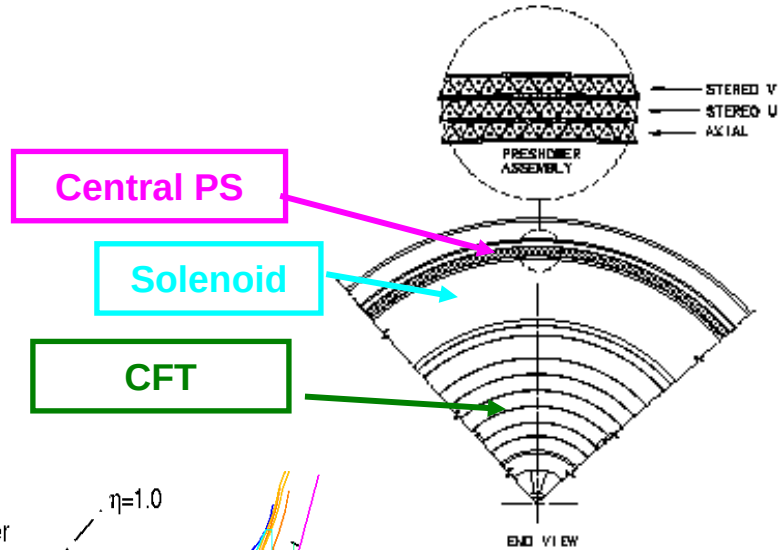
Central mounted on solenoid ($|\eta| < 1.2$)

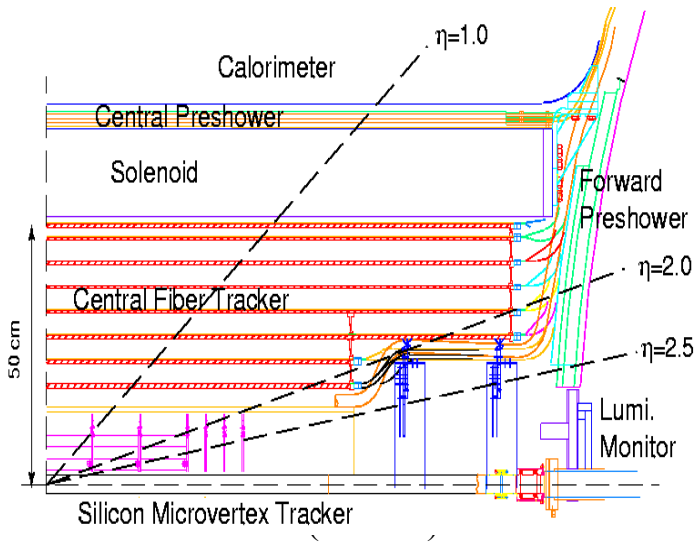
CPS: 7,680

Forward on calorimeter endcaps

($1.4 < |\eta| < 2.5$)

FPS: 14,000 channels





VLPCs for DØ

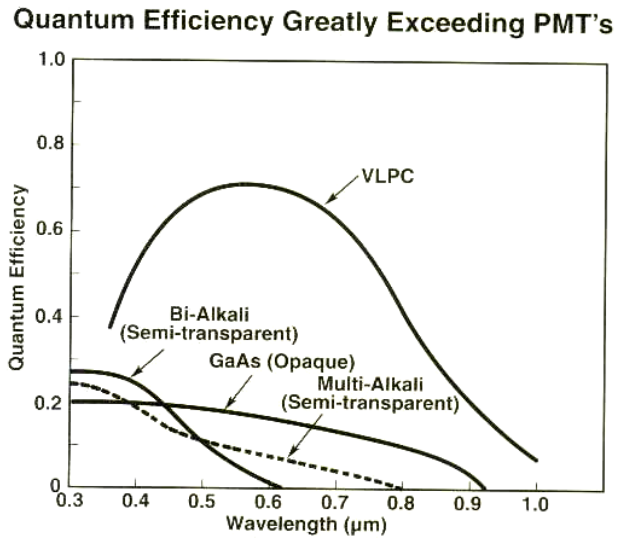
The DØ detector uses VLPC readout for the following subsystems:

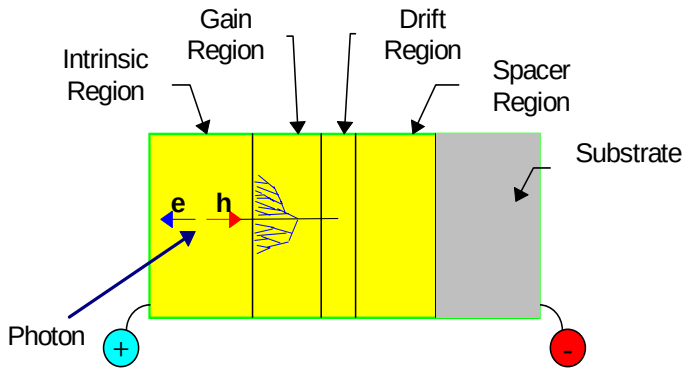
- The scintillating fiber tracker
- The central and forward preshower

VLPC: Visible Light Photon Counter

- Solid state photon detectors
- Detects single photons
- Can work in a high rate environment
- Quantum efficiency ~80%
- High gain ~40 000 electrons per converted photon
- Low gain dispersion
- operate at :

$$8\ K < T < 10\ K,\ \ 6\ V < V_{bias} < 7.5\ V$$

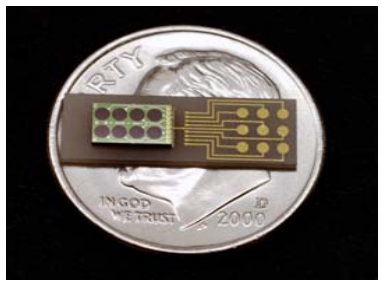


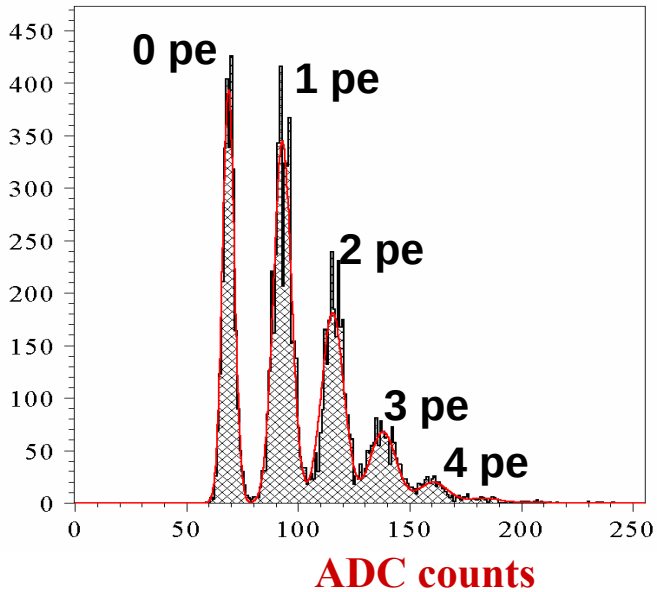


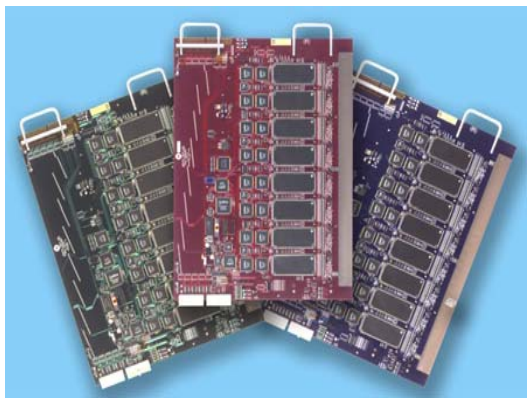
VLPC Readout Electronics

1 pe ~ 7 fC ~ 15 ADC counts
Expected signal for MIP ~ 8 pe in CFT

Excellent signal/noise performance







- AFE boards provide
  - Bias voltage + Temperature control for VLPC
  - Fast discriminator digital trigger information for L1CTT
  - Analog pulse information (SVXII chip)
  - 512 channels per board
    - 8 MCM each with 4 SVX + 1 SIFT chip
- SEQ + VRB readout as SMT

Solenoid

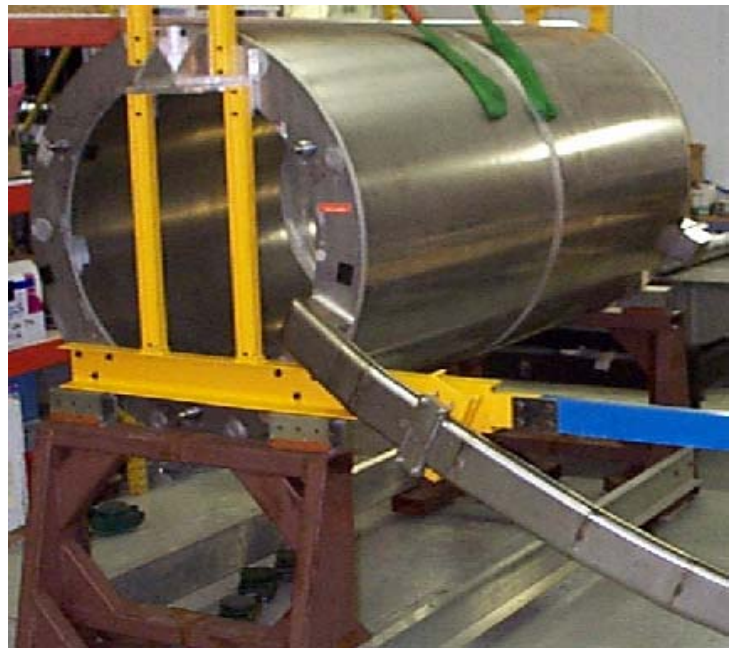
2 Tesla, ±4820 Amps

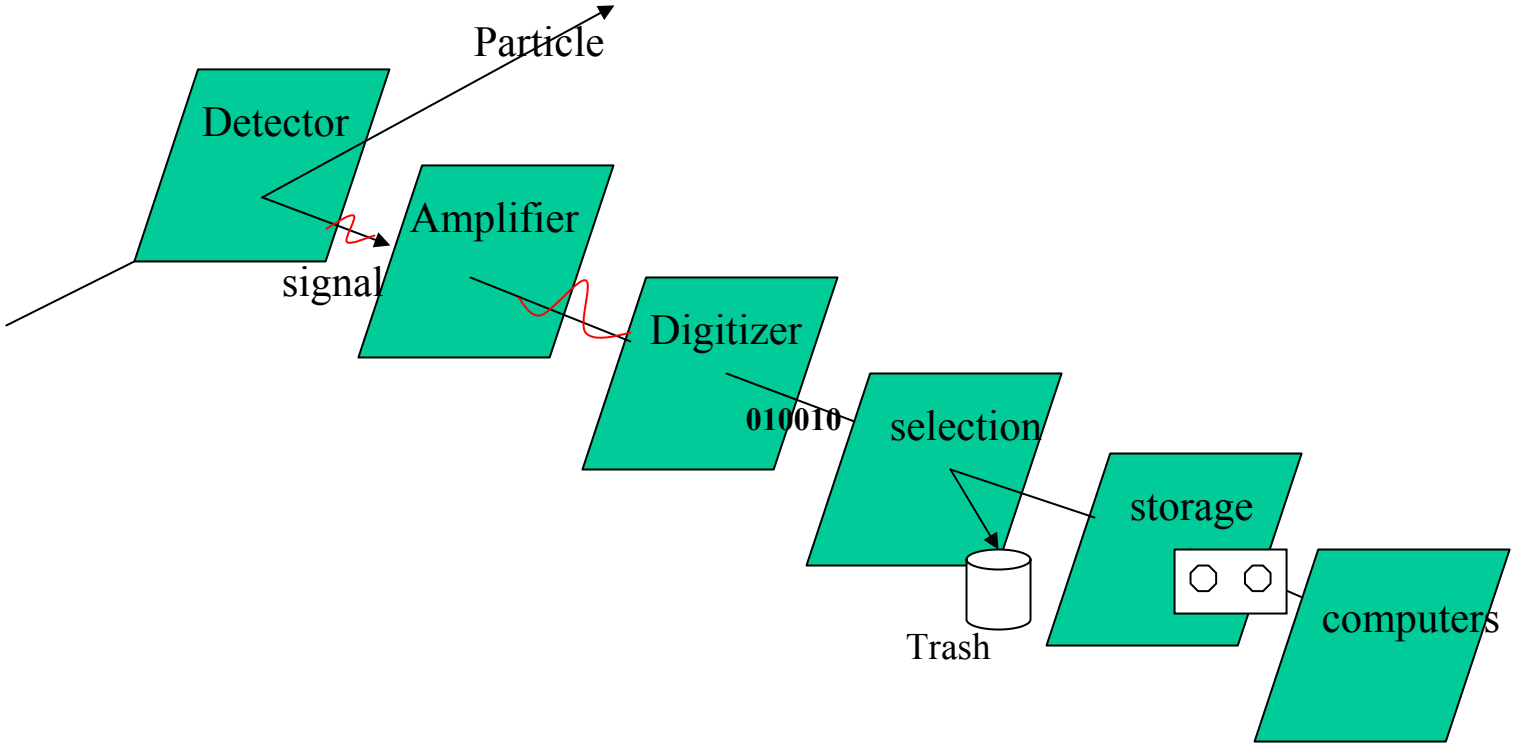
5.6 MJoules stored energy

4.5K cooling

2.7 m length

Field uniformity better than 0.5%

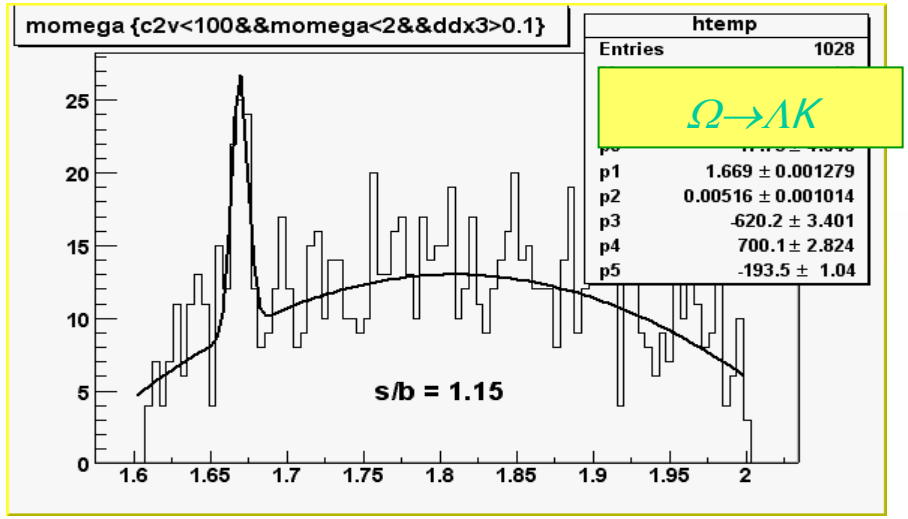


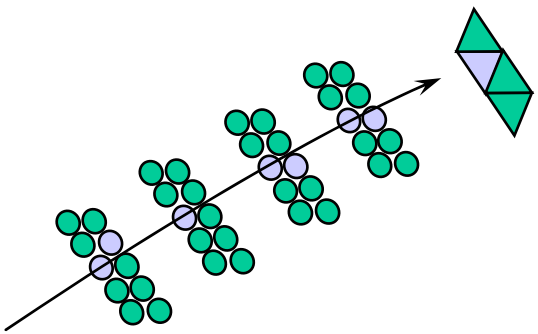

Particle
Detector
Amplifier
signal
Digitizer
010010
selection
storage
Trash
computers

Tracking

Find association between hits (detector measurements)

Construct tracks (particle trajectories) using hits





Tracking Algorithms

Global tracking or Road approach: Uses specific paths (roads) during track finding
Author: GTR group

HTF (Histogramming Track Finder): Divides D0 detector into slices in (ρ, φ)
Can use either CFT, SMT hits or their combinations to construct tracks
Author: S. Khanov
Elastic Reco(Elastic Template Algorithm): Can use existing tracks as initial seeds
, existing vertices or run in stand alone mode
Author: A. Haas

AA (Alternative Algorithm): Starts from 3 hits in different superlayers (SMT or CFT).
Track candidates are extended towards CFT
Author: G. Borrisov

Variety of Tracking Algorithms allow cross-check the tracking performance

Select the best one

Tracking Algorithms

Object Oriented approach (C++)

Variety of Tracking Algorithms allows cross-check the tracking performance

May be run simultaneously/separately to achieve best performance for different physics tasks

All of them use one final track refitting step

One common user interface

Global Tracking

Surfaces: **Build a model of the tracking detectors using abstract surfaces. Cylinders for fiber fiber tracker, x, y and z planes for silicon detectors**

Paths: **An ordered list of the surfaces that a particle coming from a ppbar collision would cross. First few surfaces are used to build a seed track.**

Propagators: **Are used to extrapolate the seed tracks between the remaining surfaces. It solves the equation of motion for a track, including the effects of magnetic field, multiple scattering and energy lost in the material**

Fitters: **Once the track reaches a new surface, fitter attempts to add a new cluster to the track**

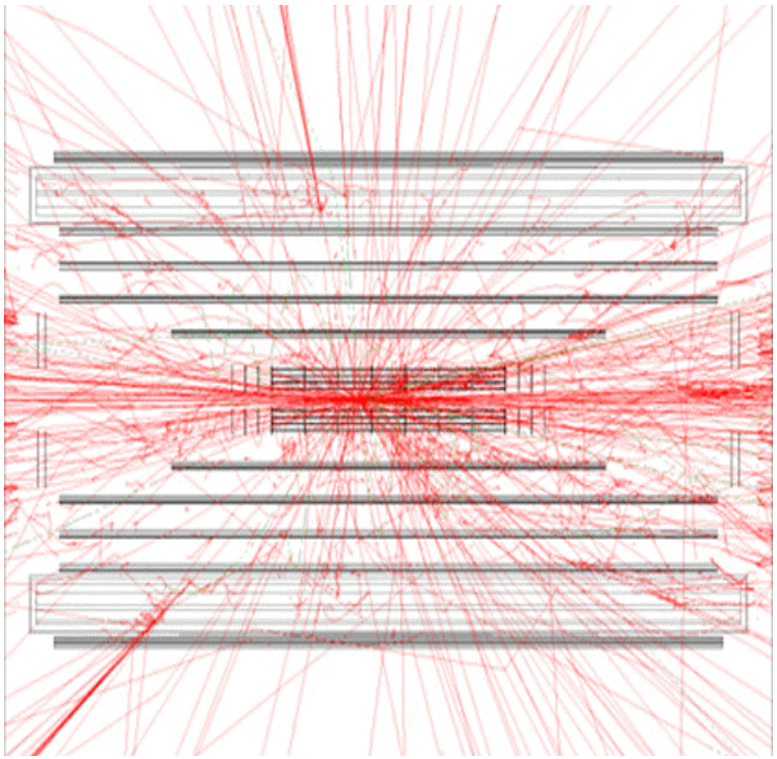
Filters: **After moving through all surfaces in a particular path, a number of filters are applied to clean the list of candidate tracks**

Global Tracking

The final output of each GTR path is a list of tracks

Tracks themselves store a list of surfaces used and the track parameters at each surface

So we **have** connected the dots!



7.5M p-pbar crossings every second

2 TB/sec data volume

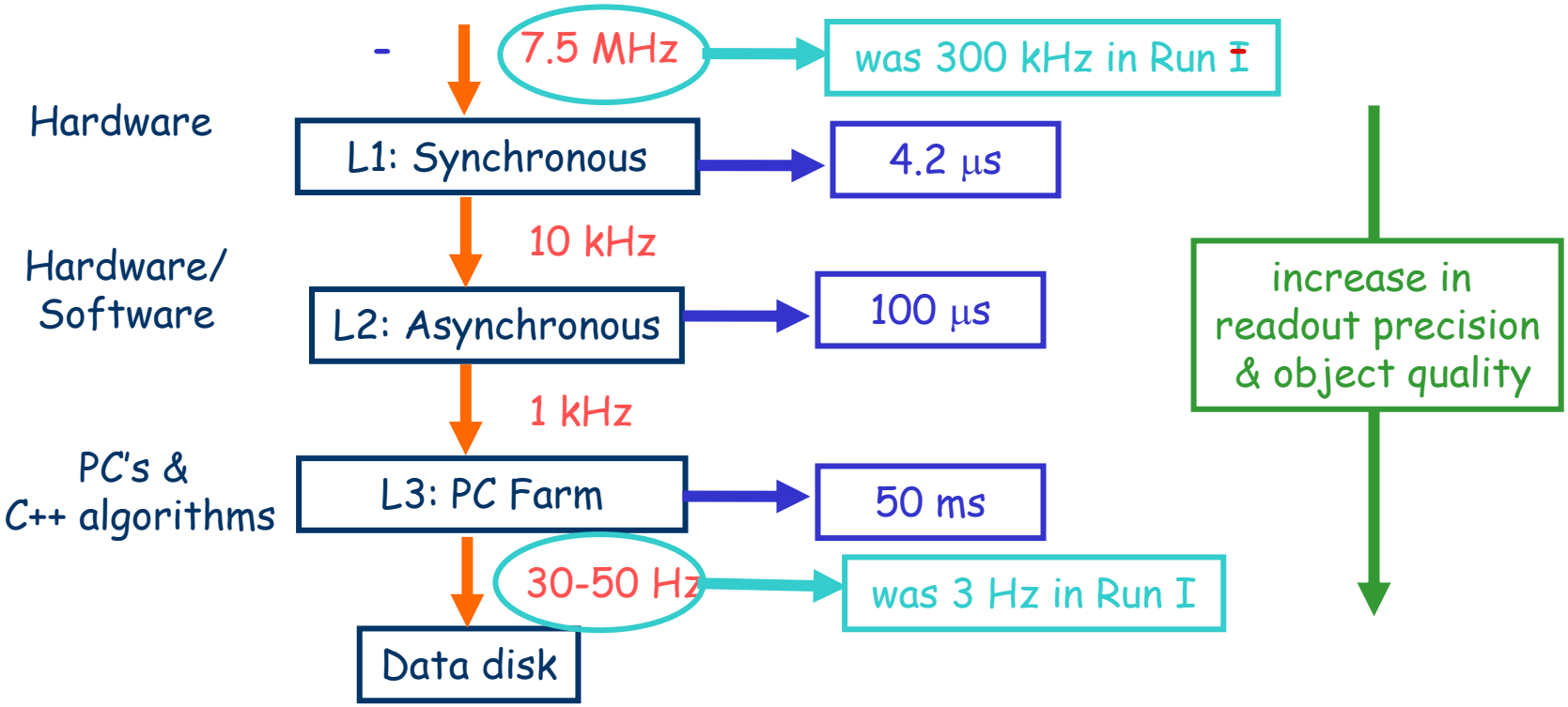
Hadron collisions:

Very messy

Hundreds of objects after collision

Need to simplify the measurement

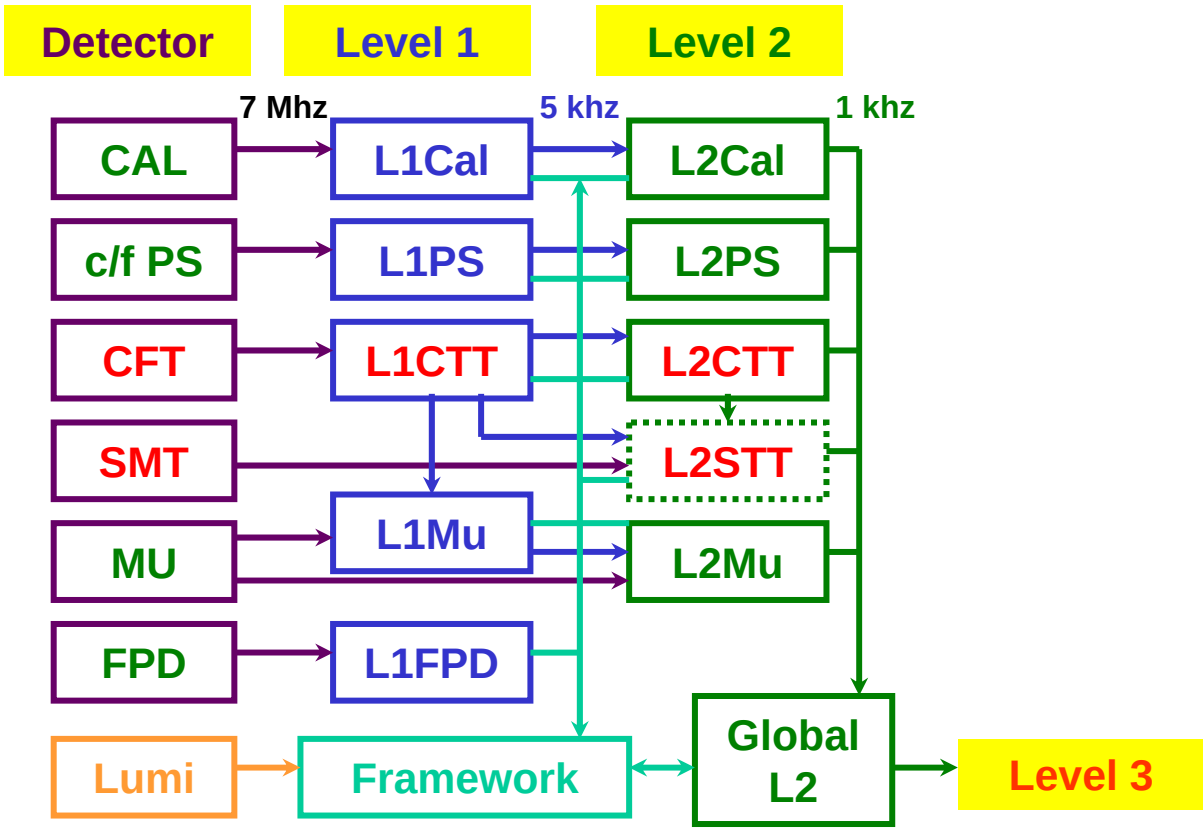
DØ Trigger Overview



250 kBytes/event

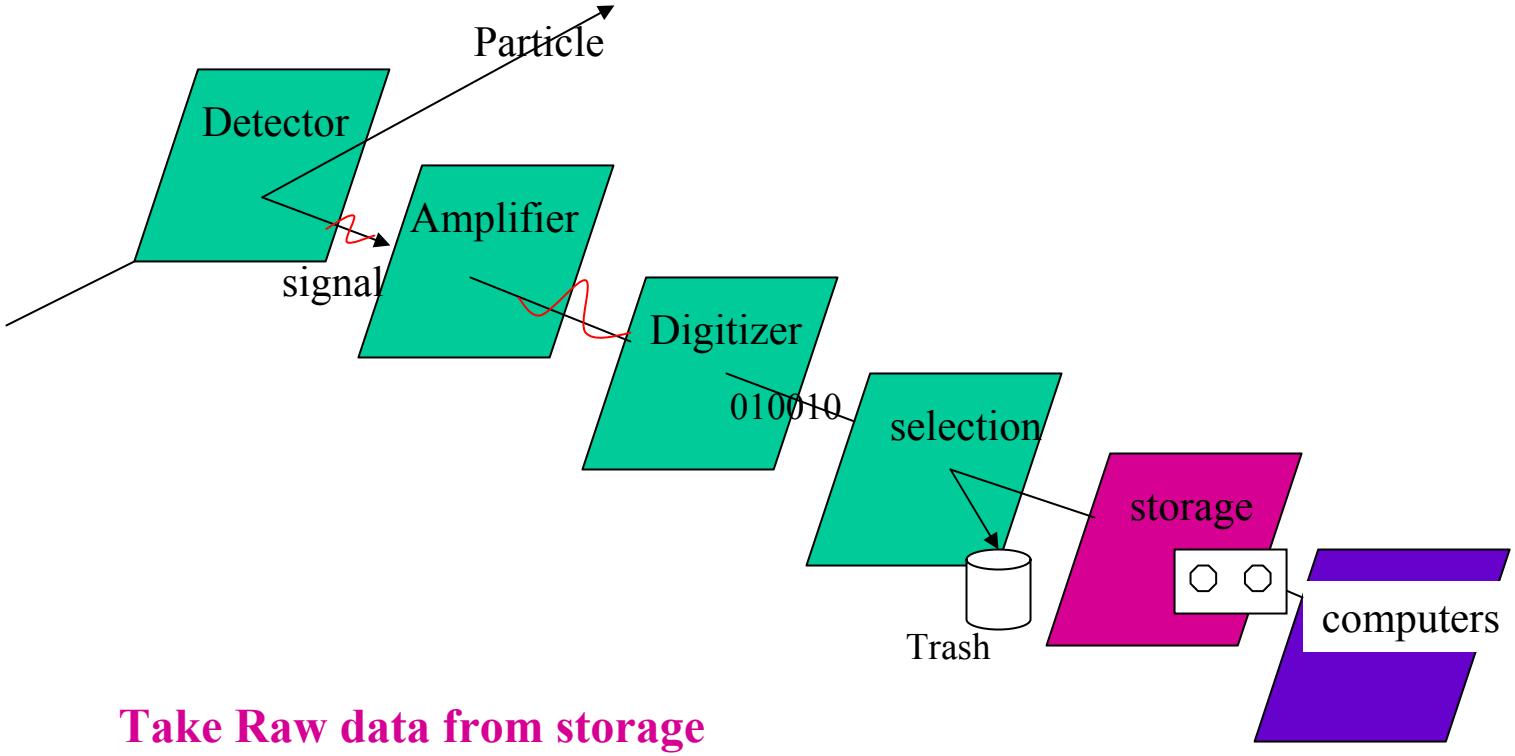
DØ L1 & L2 Triggers

Central tracking system plays an important role in L1, L2 trigger



Use of Tracking Algorithms

Example: Hit finding efficiency for CFT for raw data



Take Raw data from storage

Reconstruct the Tracks using GTR

Use these tracks and associated information to find CFT Efficiency

Use of Tracking Algorithms

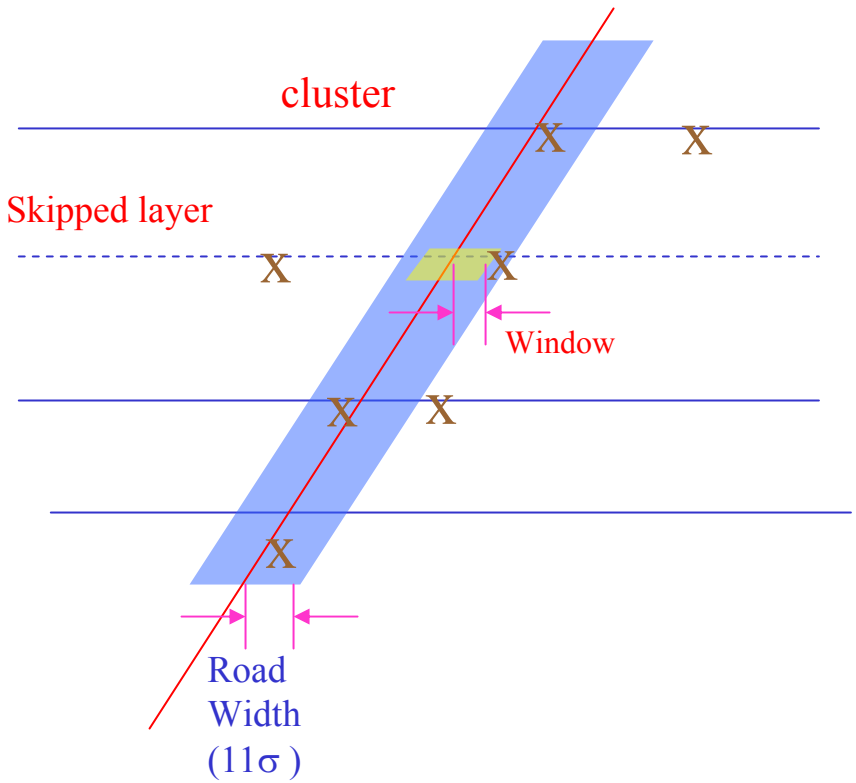
Example: Hit finding efficiency for CFT for raw data

Track selection

- Number of CFT hits =15
- Pt > 1 GeV
- No more than 1 hit within 11 σ (Tracking)
- Window = 3 σ (Resolution)

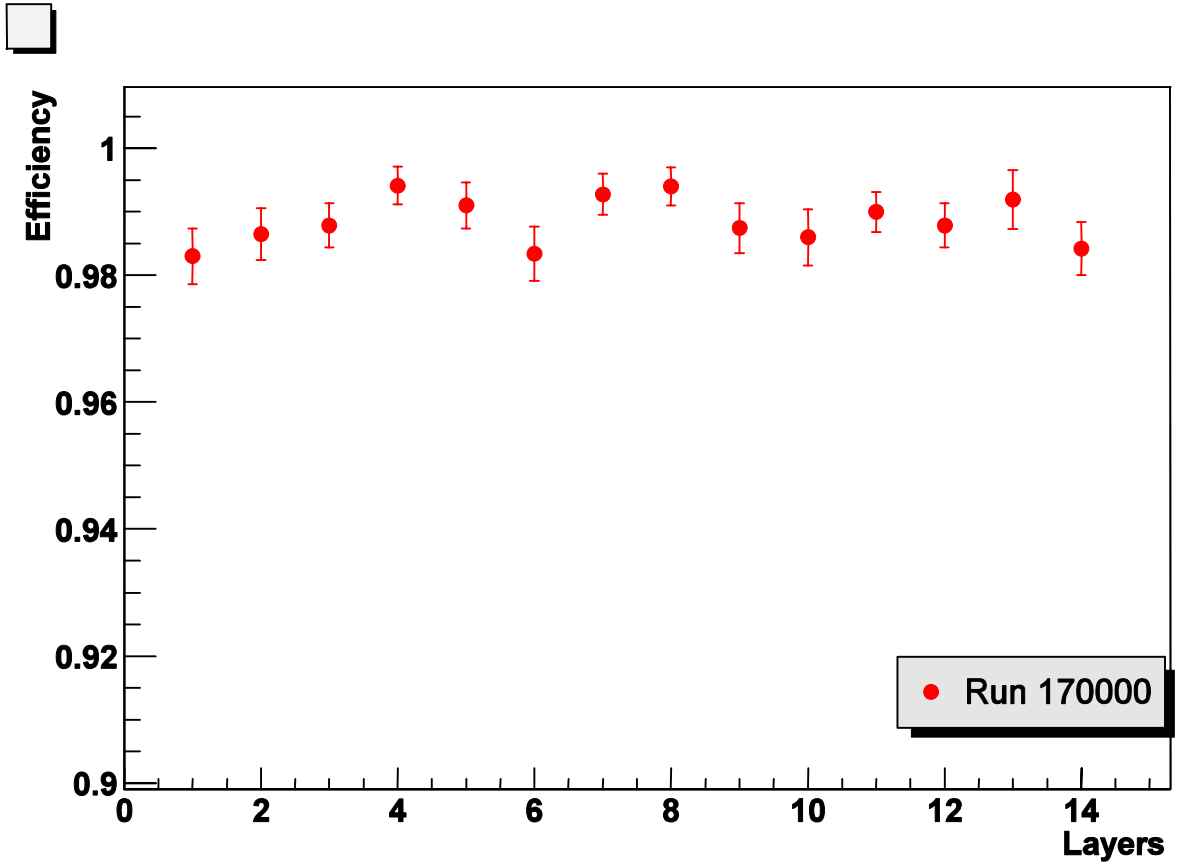
σ(Tracking) ~ 100 μ

σ (Resolution) ~ 0.013 cm



Use of Tracking Algorithms

Hit finding efficiency for CFT using raw data

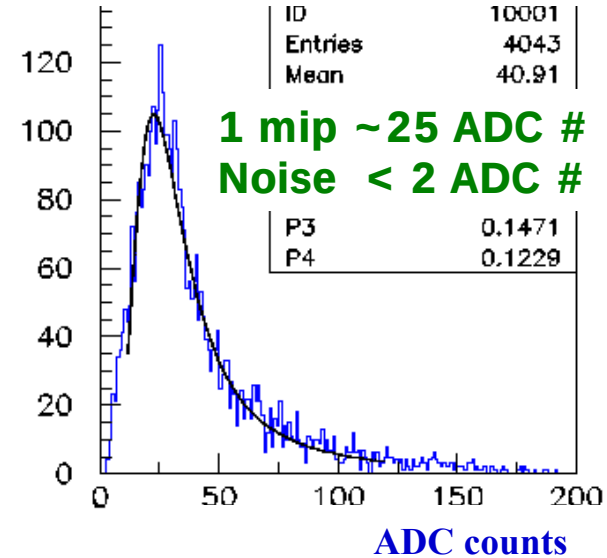


Detector Performance: Tracking

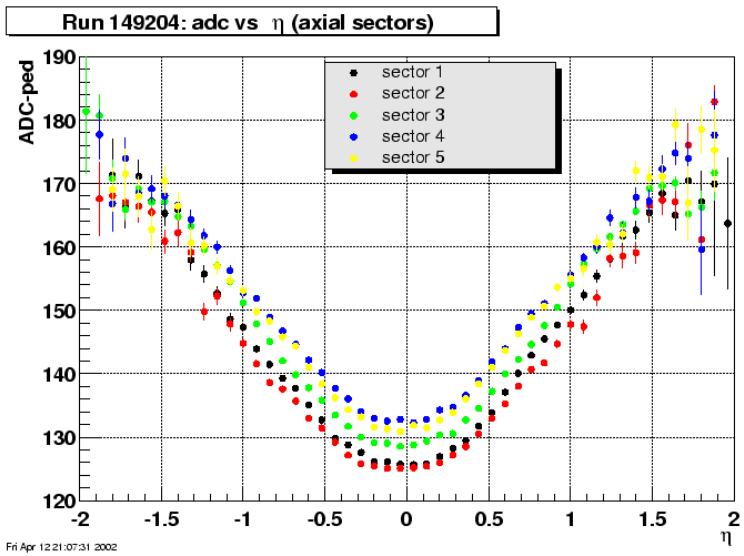
Scintillating Fiber Tracker (CFT)
<u>first time in a collider detector</u>

- **performs as expected**
- **ε > 98%** *(including dead channels)*

Silicon cluster charge



fiber light yield



track pseudorapidity

Silicon (SMT)

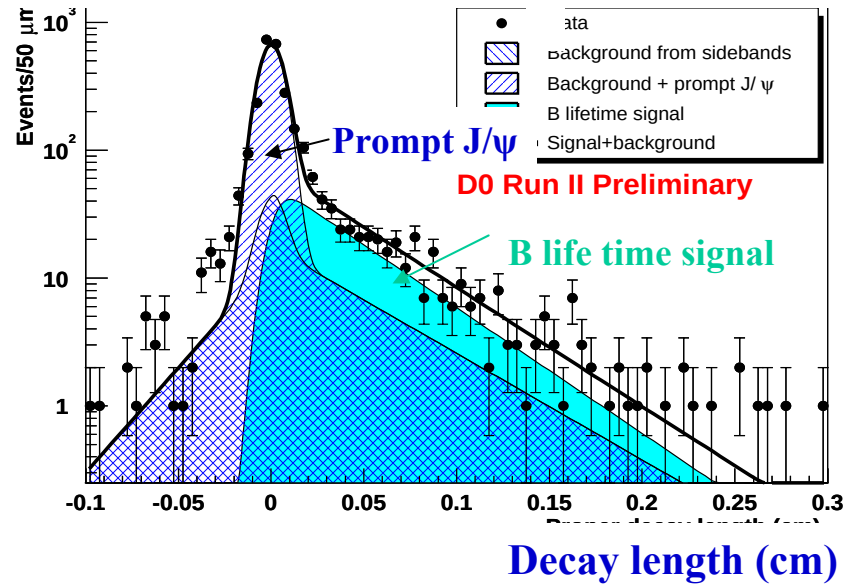
- **good S/N**
- **ε>97%**

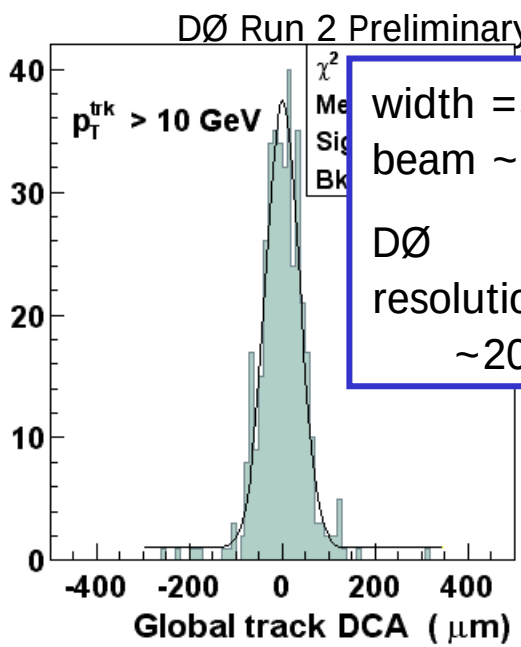
(incl. dead chnnels)

Detector Performance: Tracking

Almost on target with
- **no CFT alignment**
- **1st pass SMT alignment**

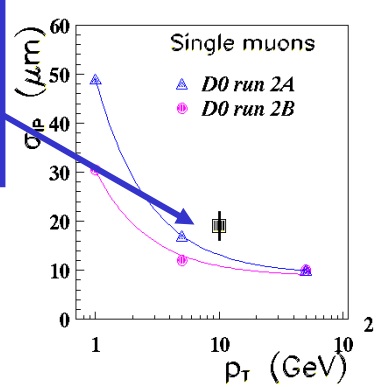
Proper B decay length (B → J/ψ + X)



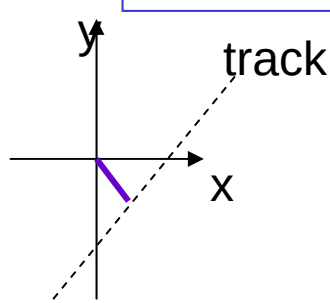


width =36μ
beam ~30μ

DØ resolution: ~20μ

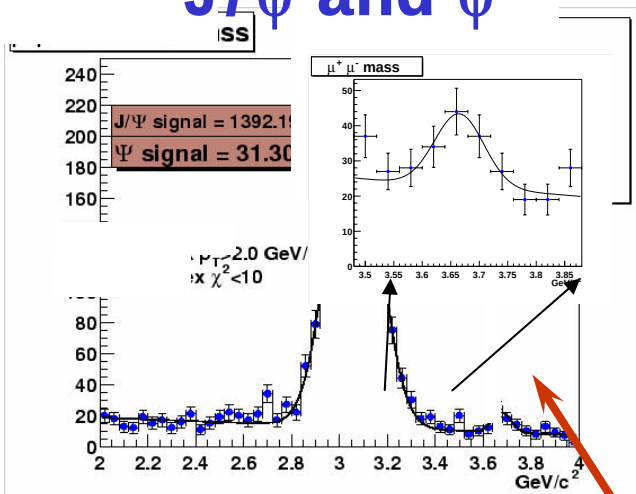


Impact Parameter

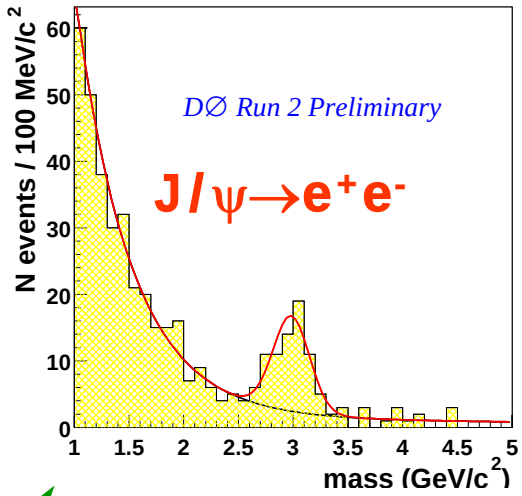


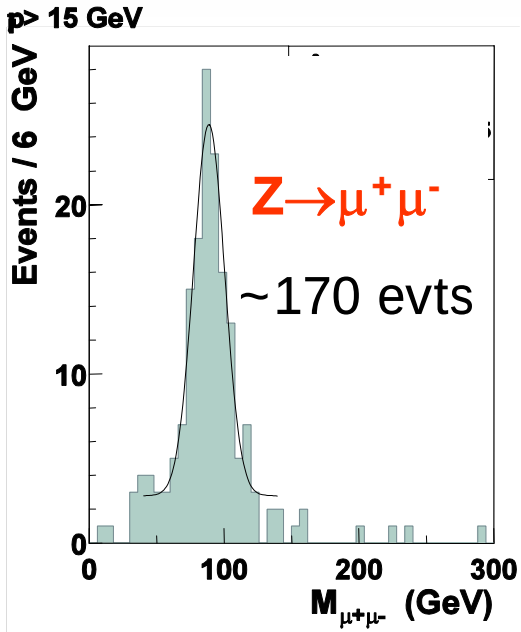
Detector Performance

J/ψ and ψ'



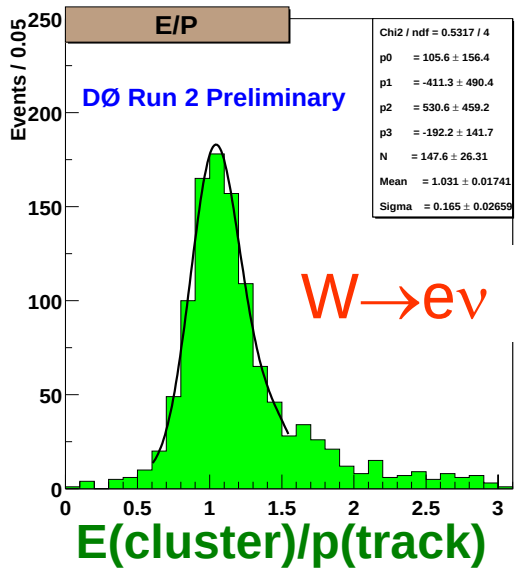
Combine tracking with other systems





Muon System

Calorimeter



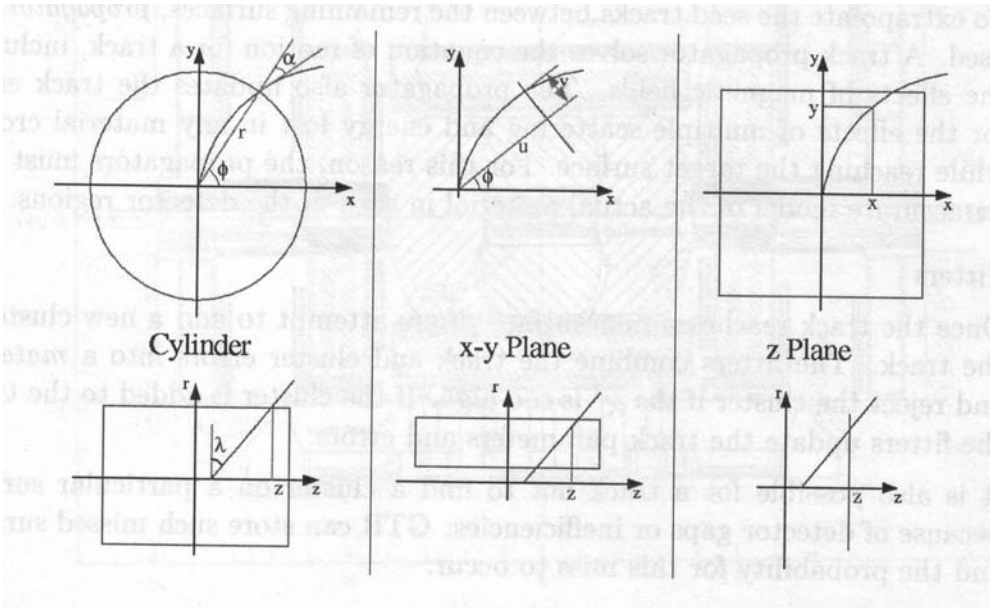
What are we going to find?

I don’t know?

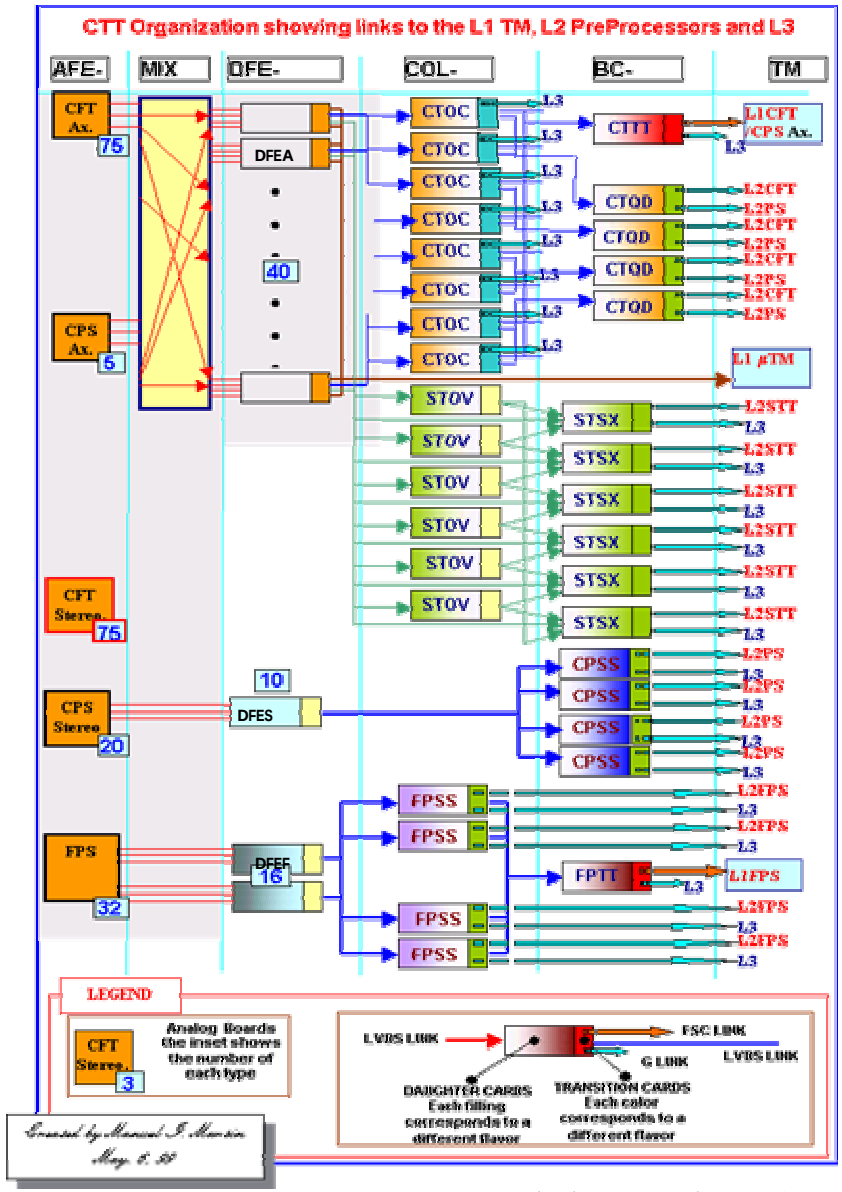
But whatever it is, we are not going to miss it!

Track Parameters

Surface	Cylinder	x-y plane	z plane
Fixed Parameters	radius, r	u, ϕ	z
Position Parameters	ϕ, z	v, z	x, y
Direction Parameters	α, $\tan\lambda$	$\mathrm{d}v/\mathrm{d}u$, $\mathrm{d}z/\mathrm{d}u$	$\mathrm{d}x/\mathrm{d}z$, $\mathrm{d}y/\mathrm{d}z$
Curvature	q/p_{T}	q/p	q/p



Central Track Trigger



Silicon Track Trigger

L1CTT finds tracks in CFT

Fiber Road Card

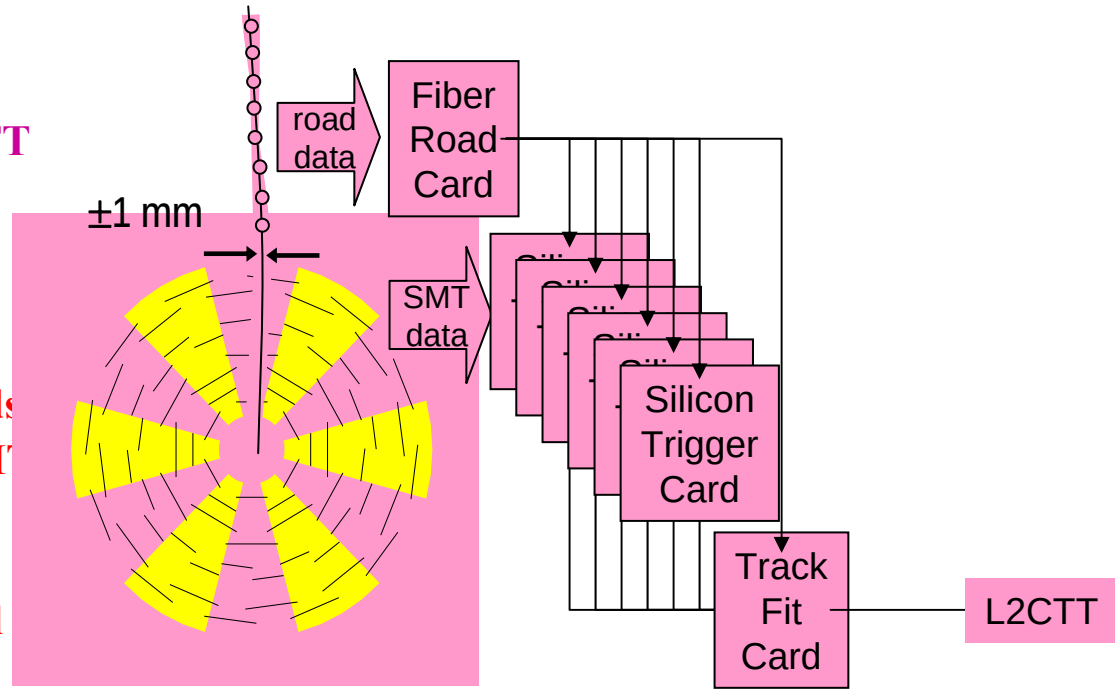
- **Receives tracks from L1CTT and trigger info**
- **transmits trigger road info to STC+TFC**

Silicon Trigger Card

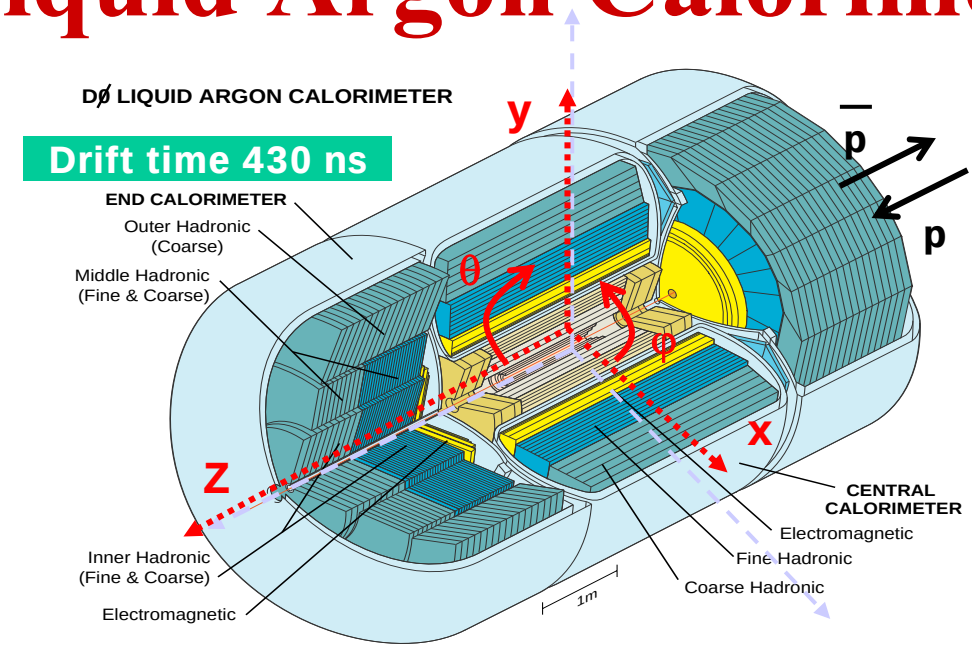
- **Select SMT clusters in roads**
- **Receives raw data from SMT**
- **Finds clusters in axial and stereo strips**
- **Associates tracks with axial**

Track Fit Card

- **Take FRC roads and STC clusters and fit track trajectory**
- **Output Track list to L2**



Liquid Argon Calorimeter



Liquid argon sampling

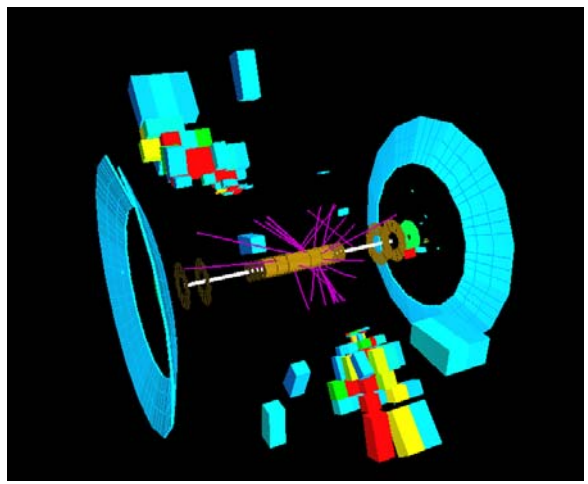
- Stable, uniform response, rad. hard
- LAr purity important (< 0.7 ppm O_2 equivalent)

Uranium absorber (Cu/Fe for coarse hadronic)

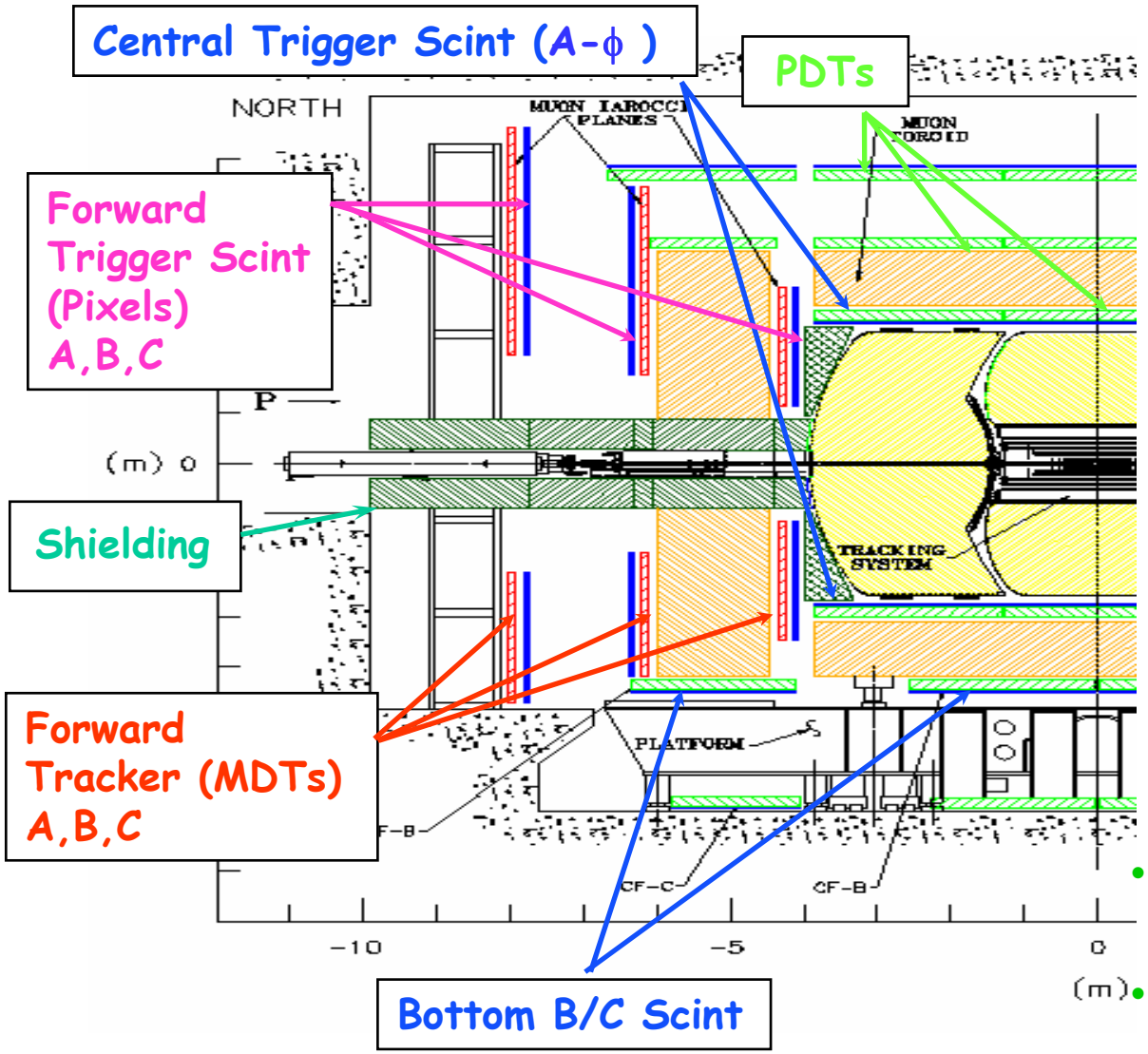
- dense absorber hence can be compact
- Nearly compensated EM and hadronic response
- Linear response

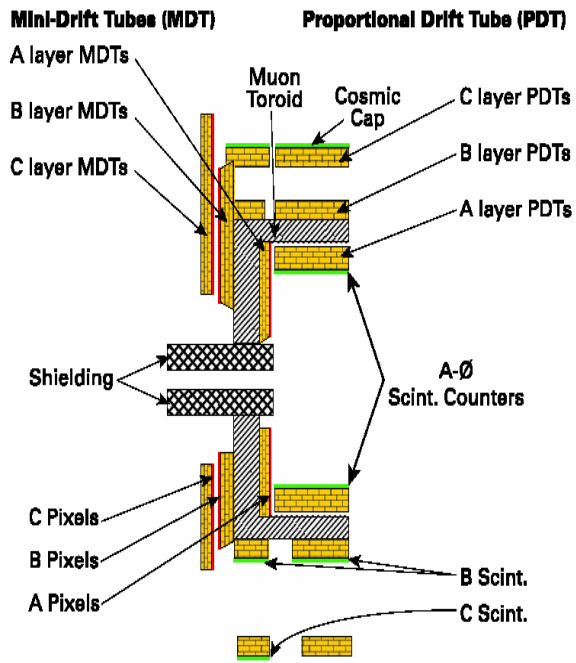
Hermetic with full coverage

- $|\eta| < 4.2$ ($\theta \approx 2^o$)
- $\lambda_{int} > 7.2$ (total)

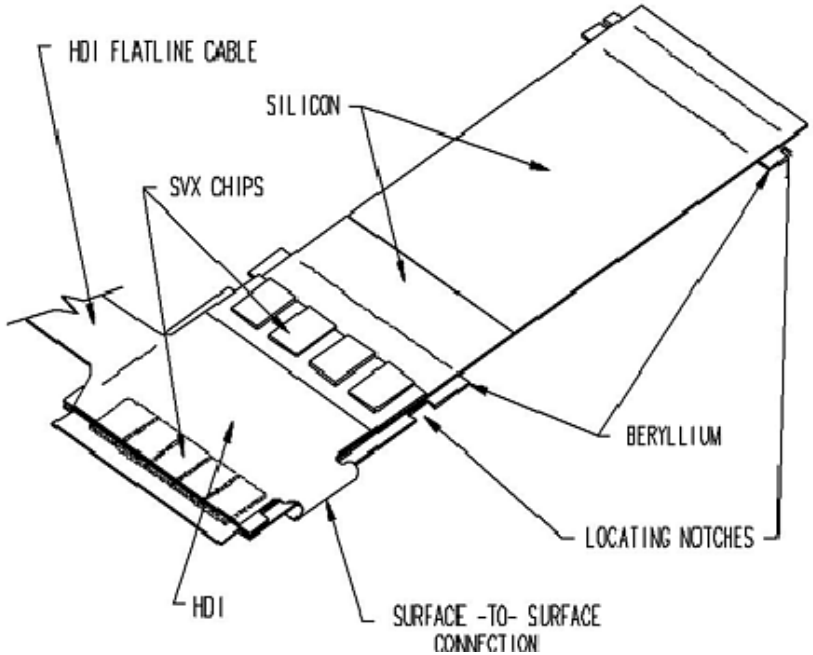


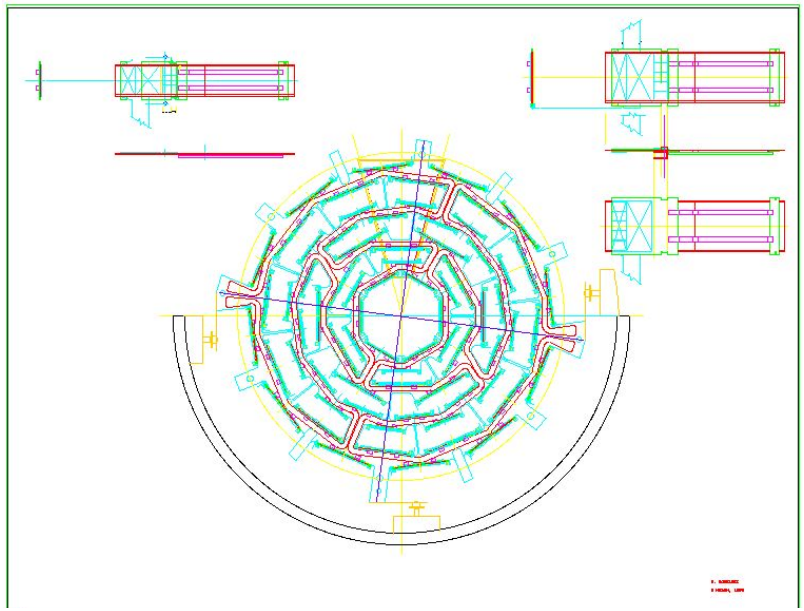
Muon Detector

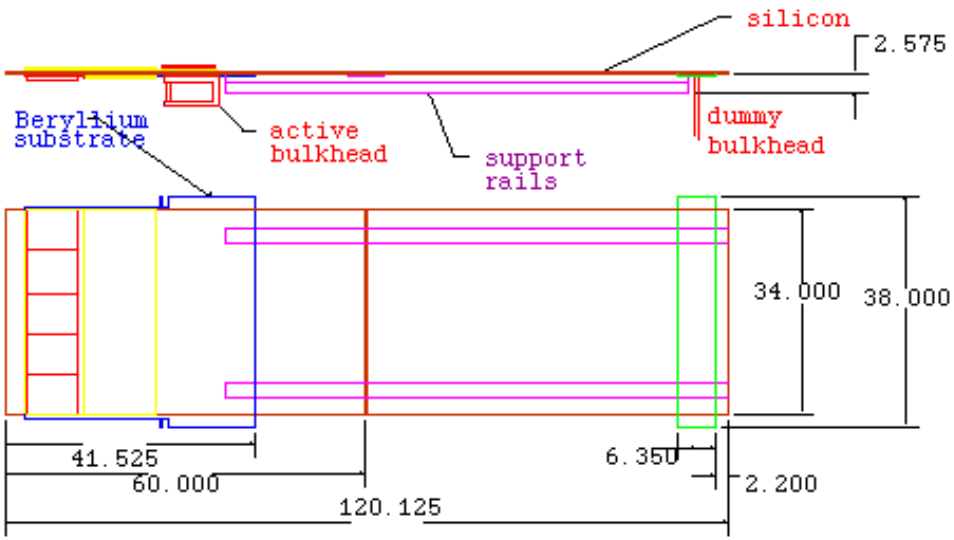


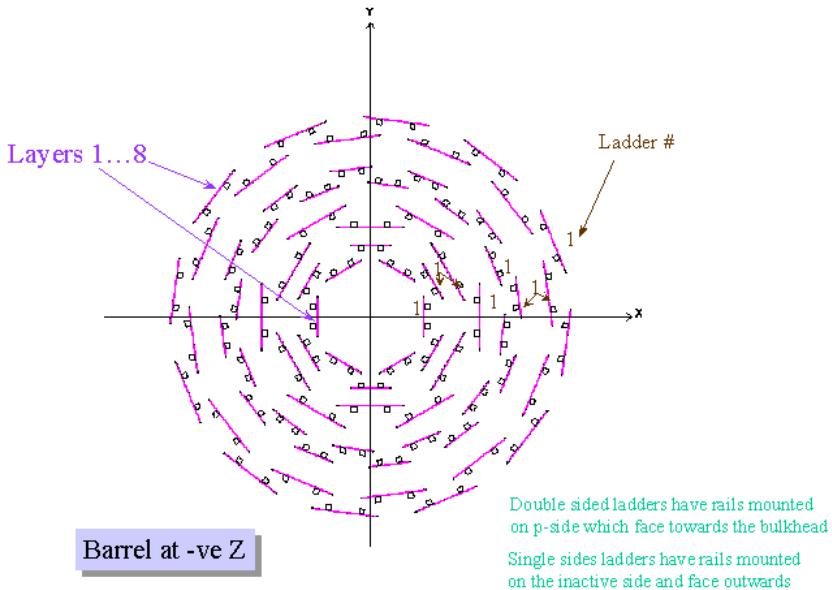


- Muon rapidity coverage to eta of 2.0
- Shielding reduces backgrounds by 50-100x

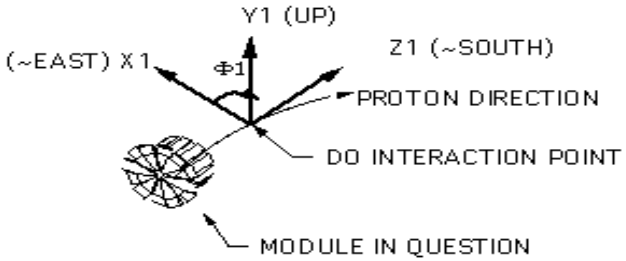

HDI FLATLINE CABLE
SILICON
SVX CHIPS
BERYLLIUM
LOCATING NOTCHES
HDI
SURFACE -TO- SURFACE
CONNECTION

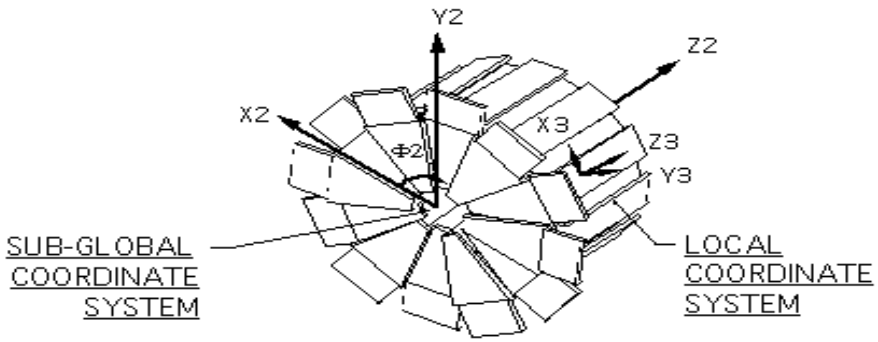



silicon
2.575
Beryllium substrate
active bulkhead
support rails
dummy bulkhead
34.000
38.000
41.525
60.000
6.350
2.200
120.125

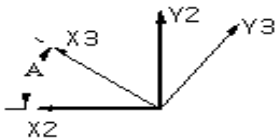

Layers 1…8
Ladder #
Barrel at -ve Z
Double sided ladders have rails mounted on p-side which face towards the bulkhead
Single sides ladders have rails mounted on the inactive side and face outwards

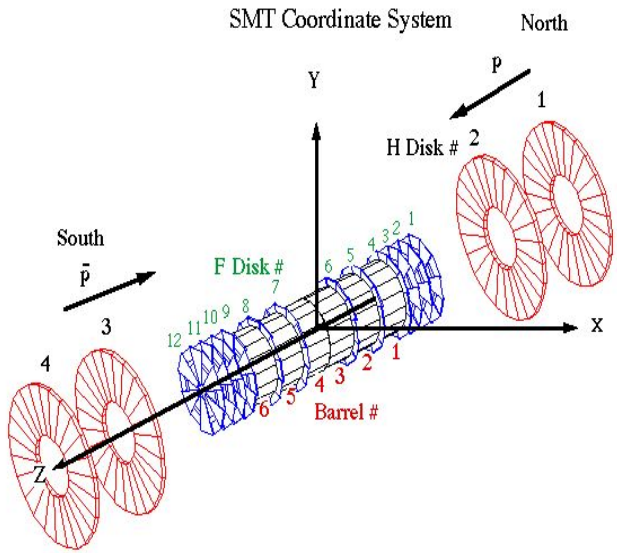
GLOBAL COORDINATE SYSTEM





NOTE: LOCAL COORDINATE SYSTEM (X3,Y3,Z3) IS ROTATED FROM THE SUB-GLOBAL SYSTEM (X2,Y2,Z2) ABOUT THE Z2 AXIS BY ALPHA.

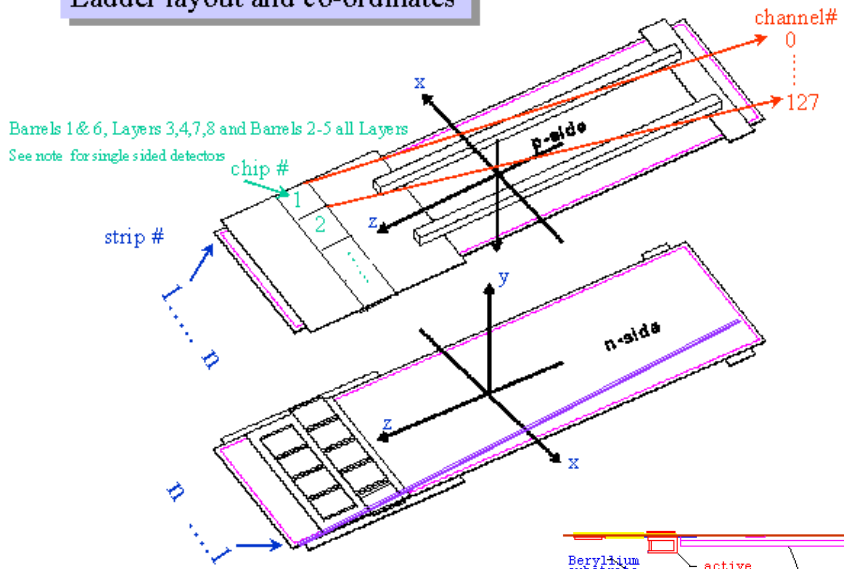




MASS CALCULATION COORDINATE SYSTEMS

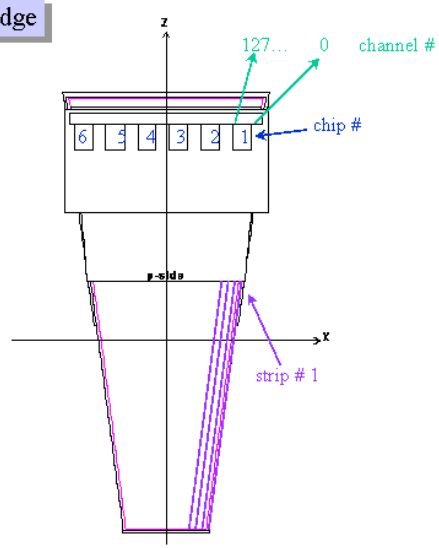
John Pawlak
4/12/94

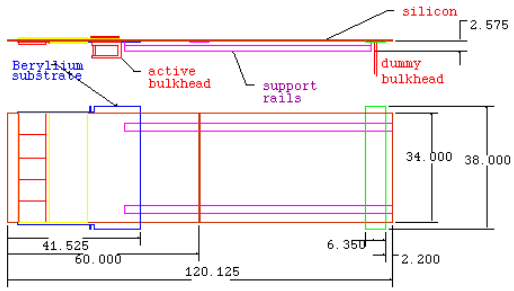
Ladder layout and co-ordinates



first strip connected to a chip as 1.

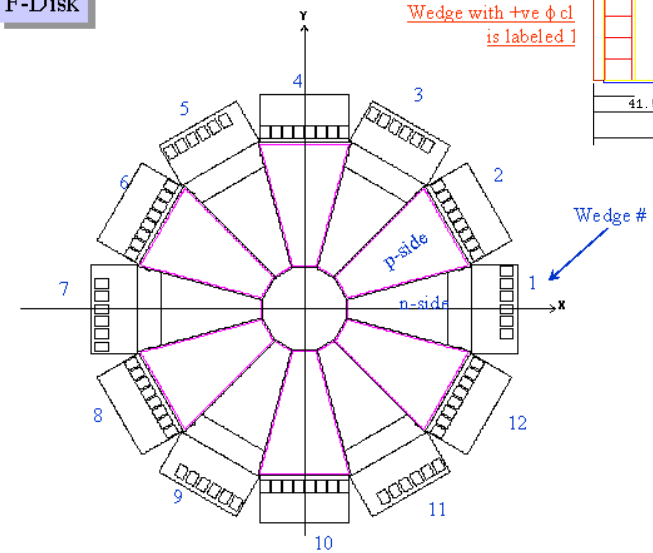
Hdisk Wedge





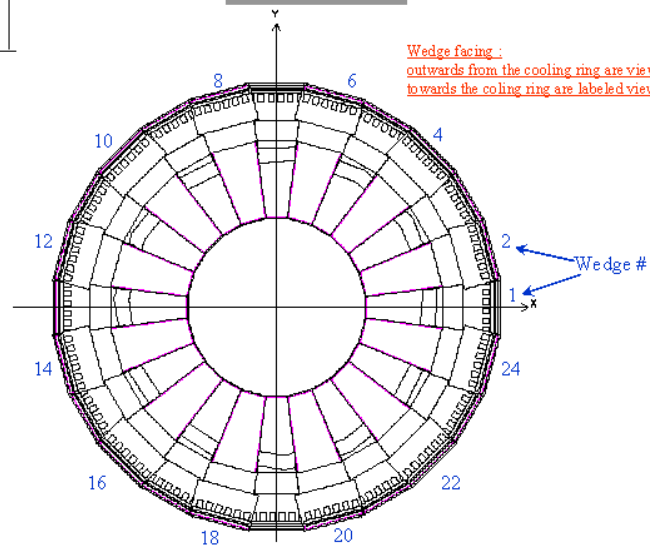
F-Disk

Wedge with +ve ϕ cl is labeled 1

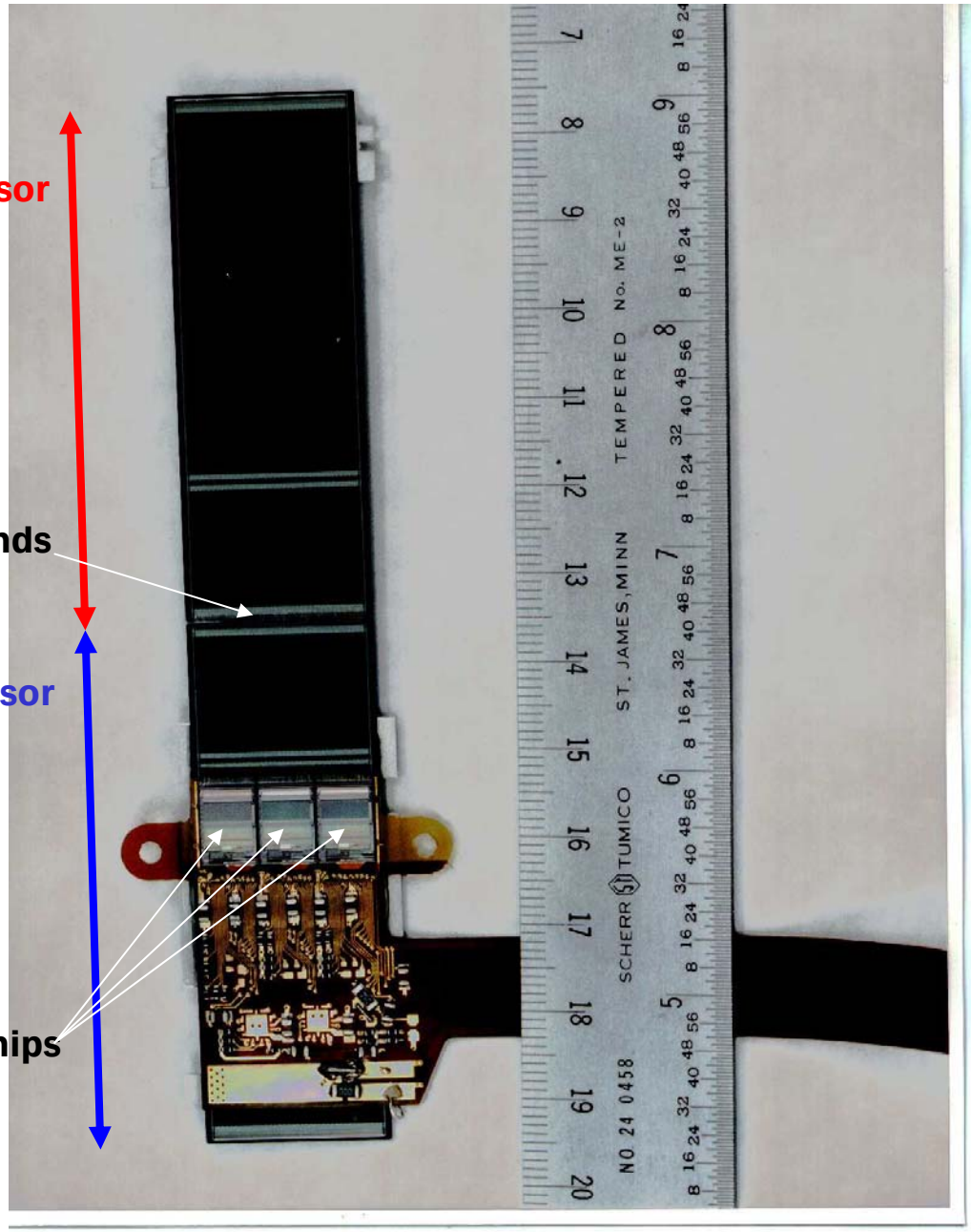


H-Disk doublet

Wedge facing :
outwards from the cooling ring are view 1
towards the coling ring are labeled view 2



ı Jabeen (Kansa



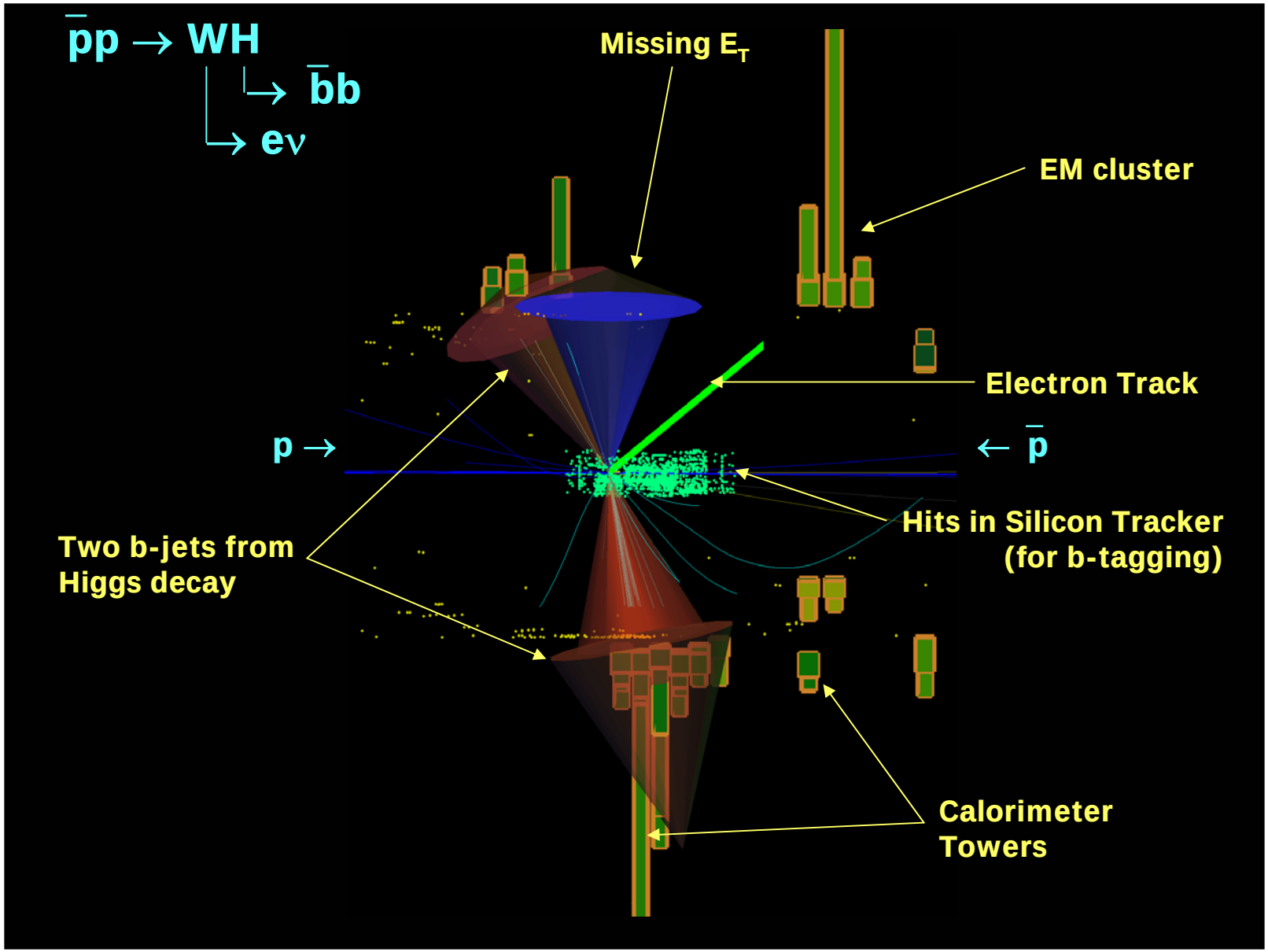
“passive” sensor

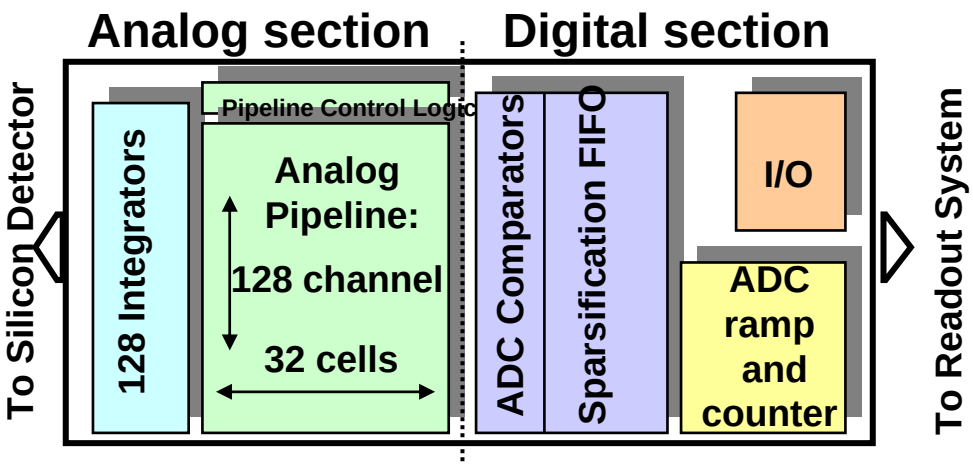
Wire bonds

“active” sensor

SVX2e readout chips

HDI (flex circuit readout)


$\bar{p}p \rightarrow WH$
$\rightarrow \bar{b}b$
$\rightarrow e\nu$
Missing E_T
EM cluster
Electron Track
$p \rightarrow$
$\leftarrow \bar{p}$
Hits in Silicon Tracker
(for b-tagging)
Two b-jets from
Higgs decay
Calorimeter
Towers


Analog section
Digital section
To Silicon Detector
128 Integrators
Pipeline Control Logic
Analog Pipeline:
128 channel
32 cells
ADC Comparators
Sparsification FIFO
I/O
ADC ramp and counter
To Readout System

Tracking

Complications: low momentum tracks, scattering, noise, high track density in jets, etc., etc., etc.

Need: Balance between
CPU, reconstruction time and efficiency Vs. scattering, noise, pT threshold

Different Tracking Algorithms