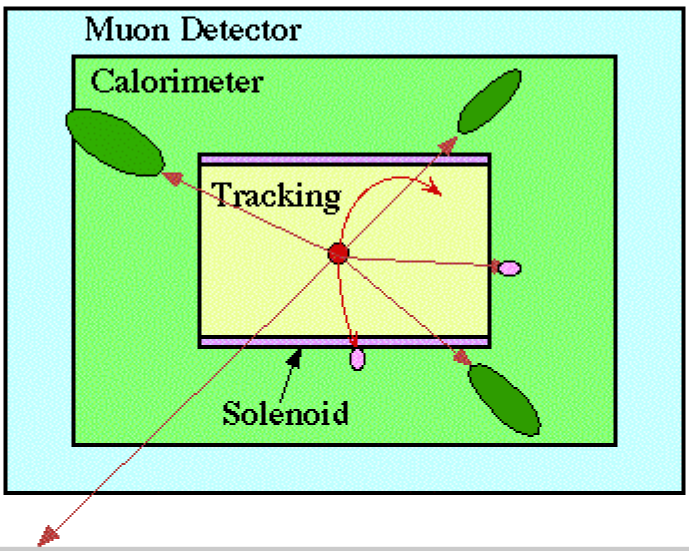
Subatomic Physics Detectors

Measure for every particle produced in an interaction.

position	(x, y, z)
momentum or energy	**P** or (E,θ,ϕ)
mass	m
electric charge	Q



Tracking detectors measure the positions of charged particles.

A solenoid provides a magnetic field so the momentum of charged particles can be determined from their radius of curvature.

Calorimeters measure the energy of hadrons, photons, and electrons.

Muon detectors identify muons because muons and neutrinos are the only particles which can pass through the the calorimeters, but muons ionize and neutrinos don't.

Some Detector Requirements

Typical high energy physics example

$$\text{proton-antiproton} \longrightarrow Z^0 + X$$
$$Z^0 \longrightarrow e^+e^-$$

To observe Z^0, need to measure e^+e^- and reconstruct mass:

$$M^2(e^+e^-) = E^2 - p^2 = 2(m_e^2 + E_{e+}E_{e-} - \mathbf{P}_{e+}\cdot\mathbf{P}_{e-})$$
$$= 4E_{e+}E_{e-}\sin^2\theta/2 \quad (\text{for } E_{e+},E_{e-} >> m_e)$$

where θ is the angle between the e^+ and the e^-. For high energy symmetric decays,

$$M \sim E\cdot\theta \quad (\text{for } E_{e+},E_{e-} >> m_e)$$

("E" is now the typical electron/positron energy) and

$$(\sigma_M/M)^2 \sim (\sigma_E/E)^2 + (\sigma_\theta/\theta)^2$$

We'd like the experimental uncertainty to be less than the natural width:

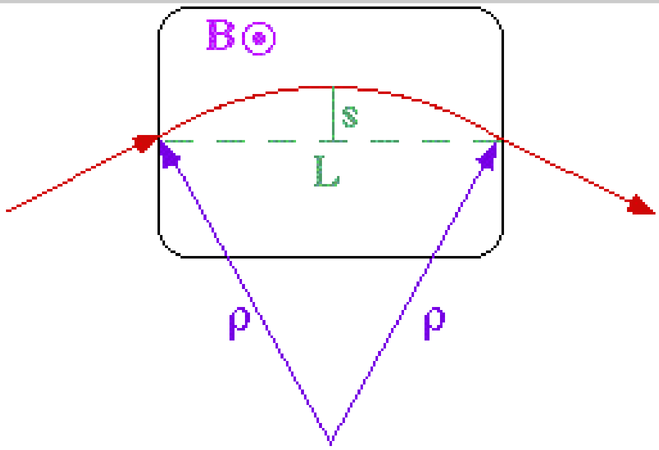
$$\Gamma_{FWHM}(Z^0) = 2.7\text{ GeV} \quad \Rightarrow \quad \sigma_Z/M_Z \sim 1\%$$

Typically E~M, and the tracking detector radius is about 1m, so $\theta \sim 1$ and

$$\sigma_\theta/\theta < 1\% \quad \Rightarrow \quad \sigma_x < 1\text{cm}$$

The best collider calorimeter in the world (ZEUS: http://www-zeus.desy.de/) has systematic uncertainties of 1-2%. If the electron energy is determined by tracking detectors, then we need $\sigma_P/P \sim 1\%$.

Measuring momentum



By simple geometry, the radius of curvature is

$$\rho = L^2/(8s) + s/2$$

So for a high energy (s<<L) unit charge (q=e) particle

$$P = 0.3\ B\ L^2/(8s)$$

(Units: GeV, m, T)

If B & L are well known, then

$$\therefore\ \sigma_P/P = \sigma_s/s = 8\ \sigma_s\ P/(0.3\ B\ L^2)$$

Typical high energy experiments (CDF http://www-cdf.fnal.gov/cdf.html & ZEUS) have B~1.5T and tracking detector radius of about $1^1/_2$m, so

$$\therefore\ \sigma_P/P \sim 1\%\ \text{at}\ P\sim10^2\ \text{GeV} \quad \Rightarrow \quad \sigma_s/s \sim 0.01\text{mm!}$$

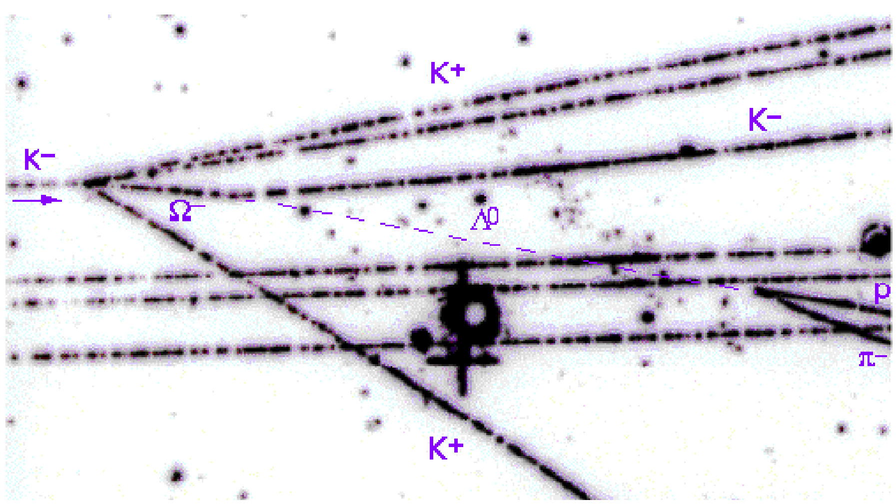
For N~10^2 measurements still need at least $\sigma_s/s \sim 0.1$mm.

Tracking Chambers

It is not for nothing that 4 Nobel prizes have been given for tracking chambers:

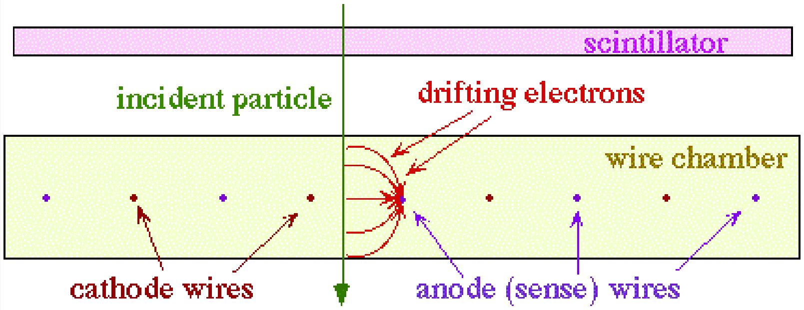
- Wilson - cloud chamber (http://www.nobel.se/physics/laureates/1927/)
- Powell - photographic emulsion method (http://www.th.physik.uni-frankfurt.de/~jr/gif/phys/powell.jpg)
- Glaser - bubble chamber (http://www.nobel.se/physics/laureates/1960/)
- Charpak - wire chamber (http://hum.amu.edu.pl/~zbzw/ph/sci/gc.htm)

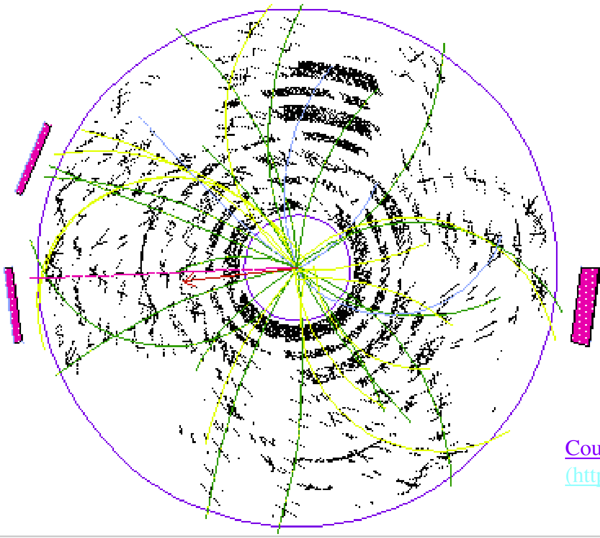
Production of an Ω^- baryon in the CERN 2m bubble chamber.
http://preprints.cern.ch/cgi-bin/setlink?base=PHO&categ=photo-ex&id=41769



(Bubble chamber pictures are studied in the High Energy Physics experiment in the undergraduate labs.)

Drift Chambers



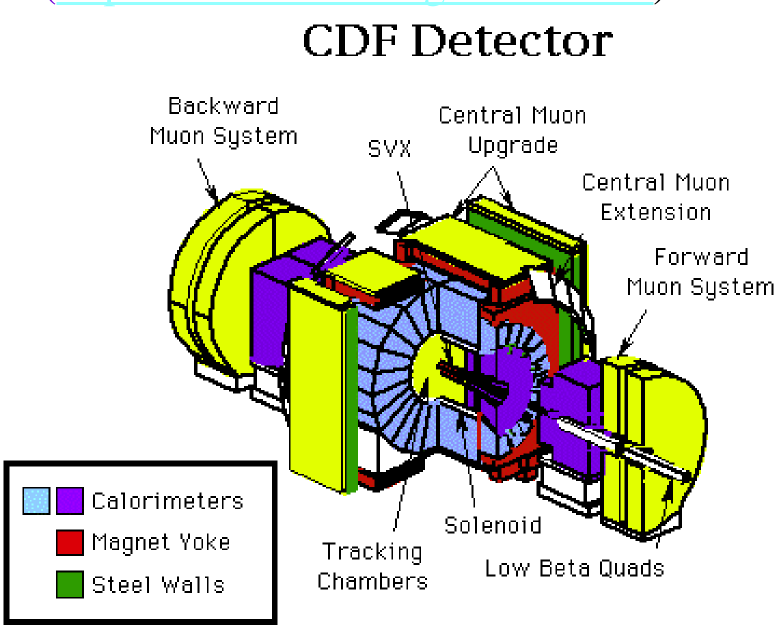


The time of arrival of the ionization electrons (relative to a start from a scintillator) is measured and the drift distance determined from the drift velocity. Drift chambers have thousands of wires, e.g. CDF or ZEUS.

Courtesy of CDF Collaboration
(http://www-cdf.fnal.gov/experiment/events/eegam_ctc_541x433.gif)

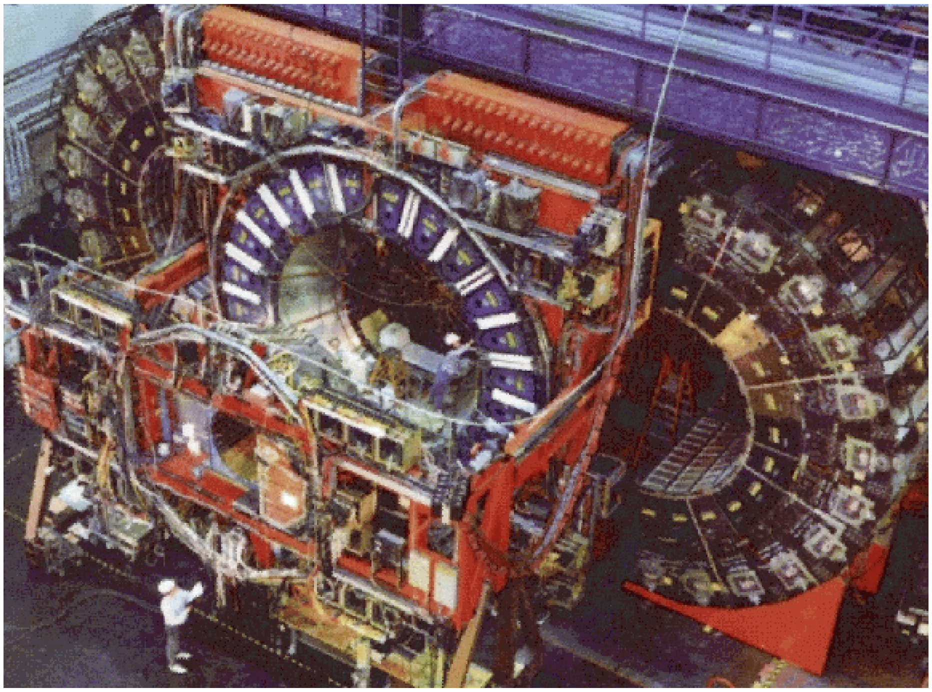
CDF experiment

Antiproton-proton collisions at a c.m. energy of 1.8 TeV
(http://www-cdf.fnal.gov/cdf.html)



Courtesy of CDF Collaboration
(http://www-cdf.fnal.gov/experiment/drawings/detector_drawings.html)

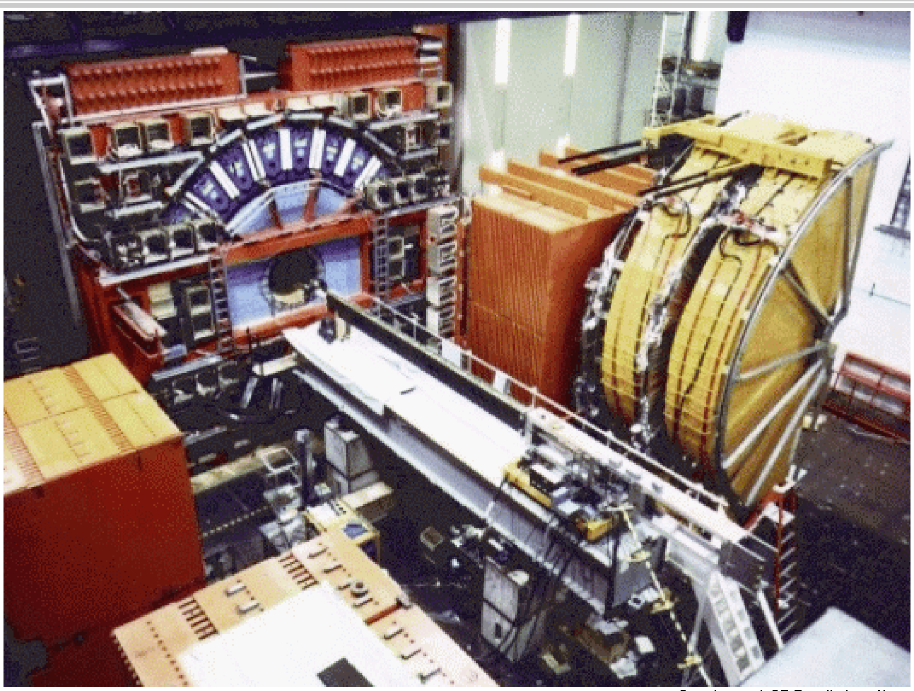
CDF Central Detector



Courtesy of CDF collaboration

The hadronic calorimeters detect hadrons by causing them to collide many times with iron plates. In these collisions, other particles are produced. These particles cross sheets of scintillating plastic where they give off small flashes of light. A measurement of the total amount of light measures the energy of the hadron.

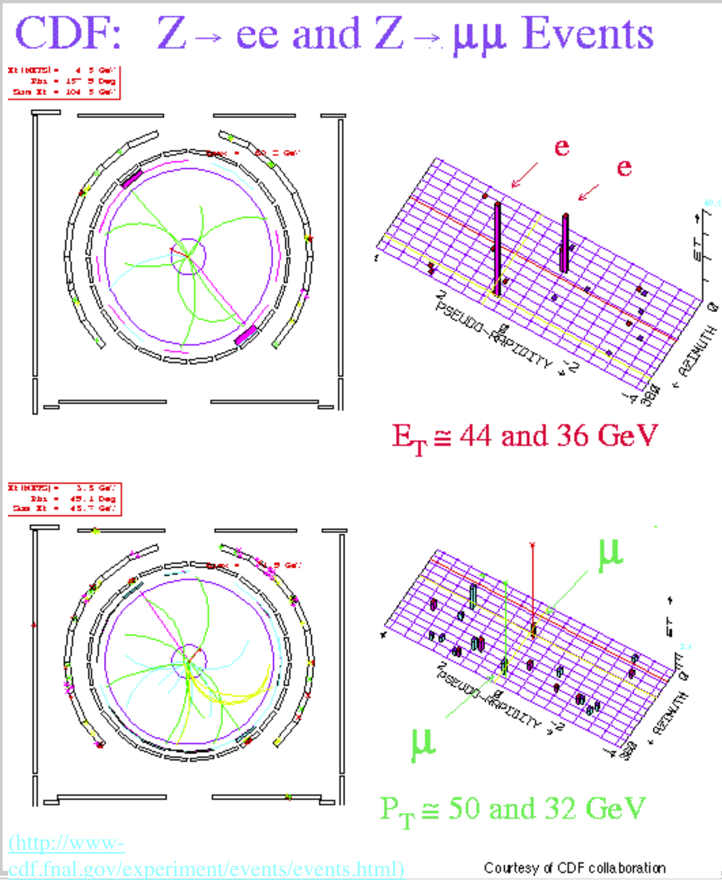
CDF Forward Detectors



Courtesy of CDF collaboration

There are also two forward detectors; so named because they are arranged along the main accelerator beam in front of and in back of the central detector. In the linked photograph, one can see these detectors in the assembly hall area outside the main machine before they were installed.

CDF experiment

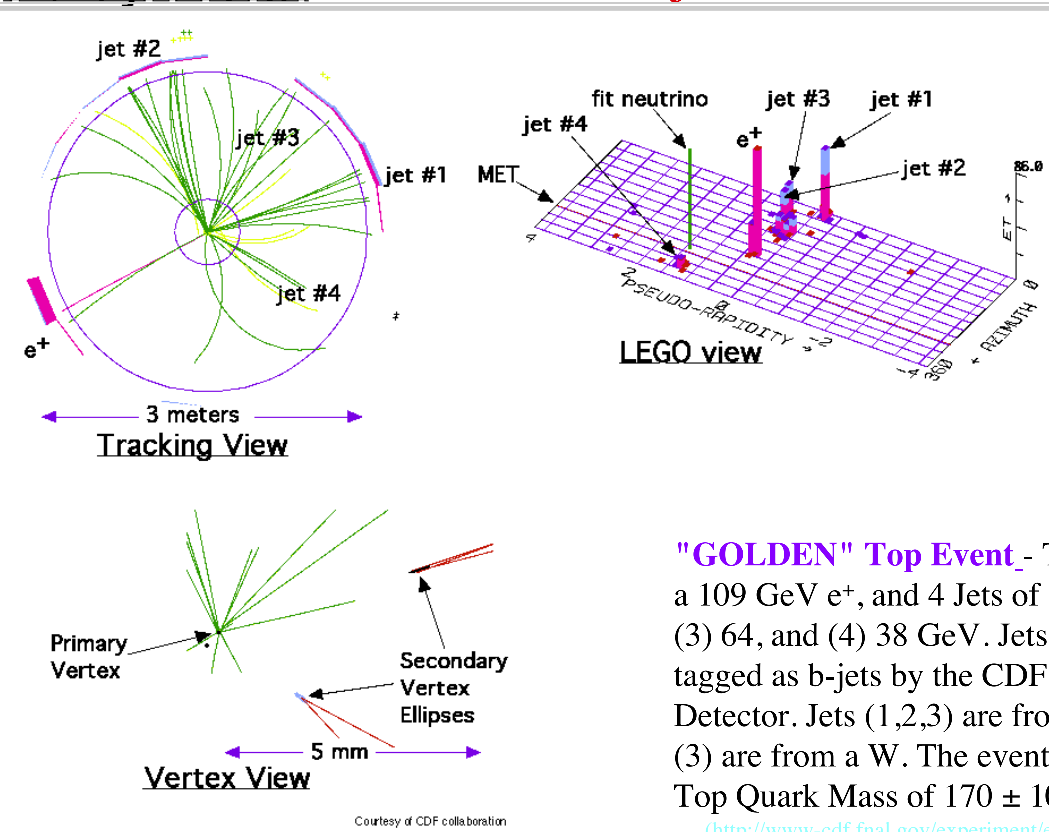


(http://www-cdf.fnal.gov/experiment/events/events.html)

Example Z events: Two events are shown, one Z --> two electrons and one Z --> two muons. Each event has a tracking view showing the charged tracks in the bend plane (we call this the r-phi view for radius-azimuth) of the the 1.4 Tesla CDF solenoid magnet. The diameter of the circle is about 3 meters. The "lego" plot is also shown for each event -- with "stacks" of electromagnetic (red) and hadronic (blue) energy seen in the calorimeter towers. Think of this "lego" plot as the surface of a cylinder around the solenoid unwrapped into a plane. Note in the Z--> two muon event the calorimeter energy scale is very small since the muons penetrate the calorimeter and leave only "minimum ionizing" pulse height. So we identify the muons from their charged tracks and hits in the Muon Chambers represented by the square box drawn outside of the 3 meter tracking circle. This box is not drawn to scale -- in the experiment the box is about 10 meters by 10 meters. Look closely to see the "hits", drawn as x's in line with nearly straight (therefore high momentum) tracks in the circle. In the lego plot we have drawn vertical lines to represent the energy of the muon tracks. Note the difference in the Z --> e^+e^- event where there are straight tracks pointing at clumps of red (electromagnetic) energy and no hits in the muon chambers.

e + 4 jet event

Electron + 4 jet event



"GOLDEN" Top Event - This event has a 109 GeV e^+, and 4 Jets of (1) 90, (2) 77, (3) 64, and (4) 38 GeV. Jets (1) & (4)are tagged as b-jets by the CDF Silicon Vertex Detector. Jets (1,2,3) are from top; (2) & (3) are from a W. The event fit gives a Top Quark Mass of 170 ± 10 GeV.

(http://www-cdf.fnal.gov/experiment/events/events.html)