Particle Physics Experiments: Principles and Techniques

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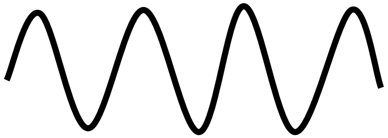
Outline

- Introduction and historical perspective
- The Tevatron complex and the DØ Experiment
- Tracking
- Calorimetry
- Particle Identification
- Experimental chain

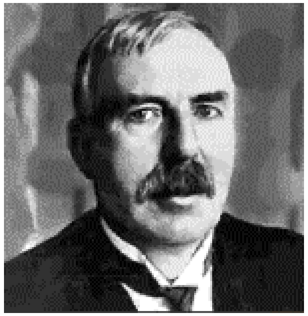
History 1: Rutherford

- The wavelength of visible light is too large to examine atomic structure



$$\lambda = \frac{hc}{pc}$$

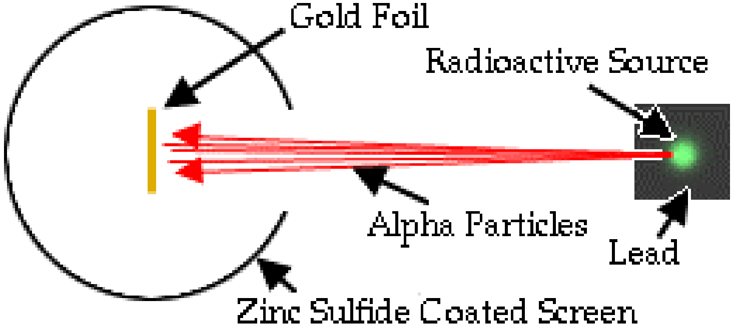
$$hc \approx 1.2\mathrm{GeV} \cdot \mathrm{fm}$$

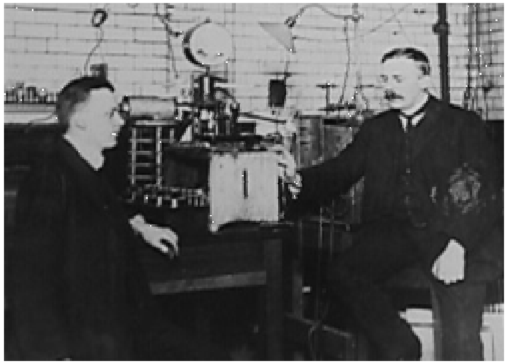


- 1911: Rutherford used alpha particles to examine the inner structure of gold atoms:

History 1: Rutherford

- **Beam:** alpha particles from ^{214}Po, momenta ~MeV/c
- **Target:** gold foil
- **Detector:** Zinc Sulfide coated screen



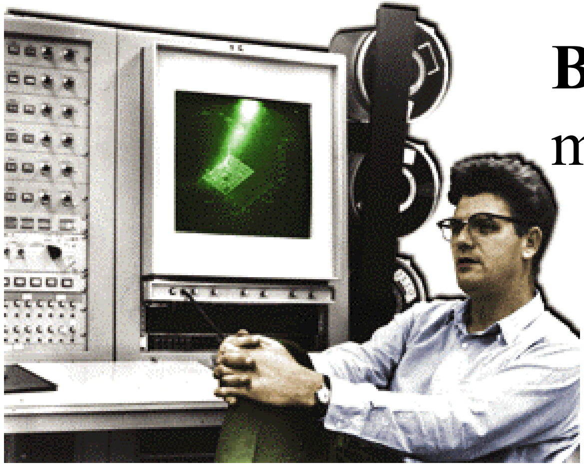


Geiger & Rutherford

- **Before:** atom was thought of as a blob of positive and negative charge.
- **After:** saw that charge was concentrated in the center

History 2: SLAC 1968

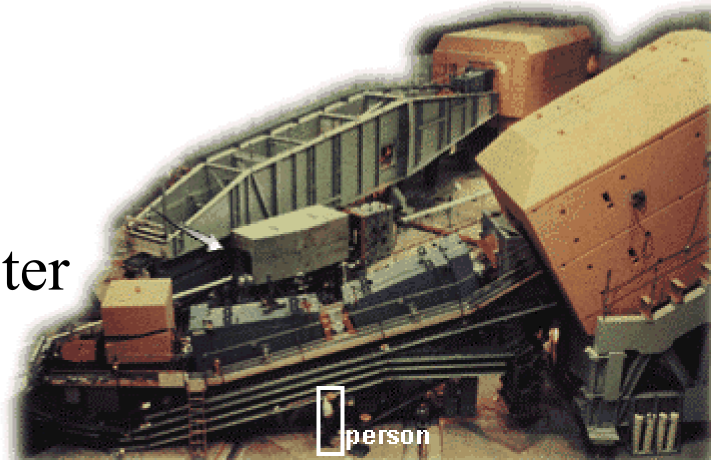
- Friedman, Kendall & Taylor



Beam: electrons from 2-mile linear accelerator: momentum ~10 GeV/c

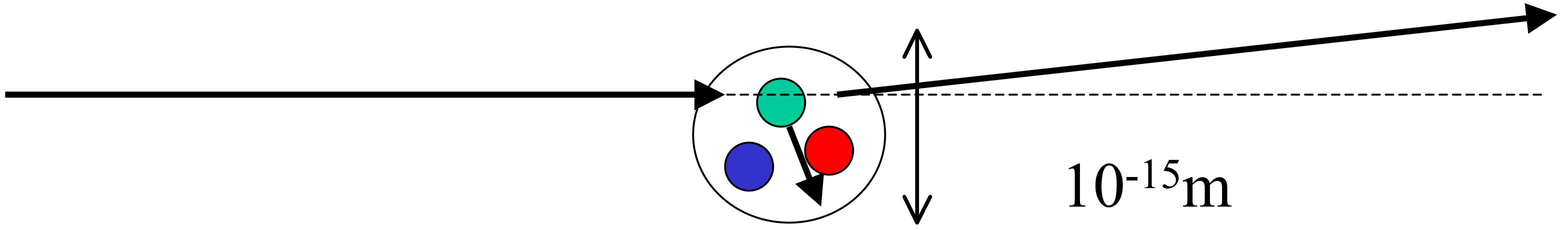
Target: protons

Detector: End Station A Spectrometer

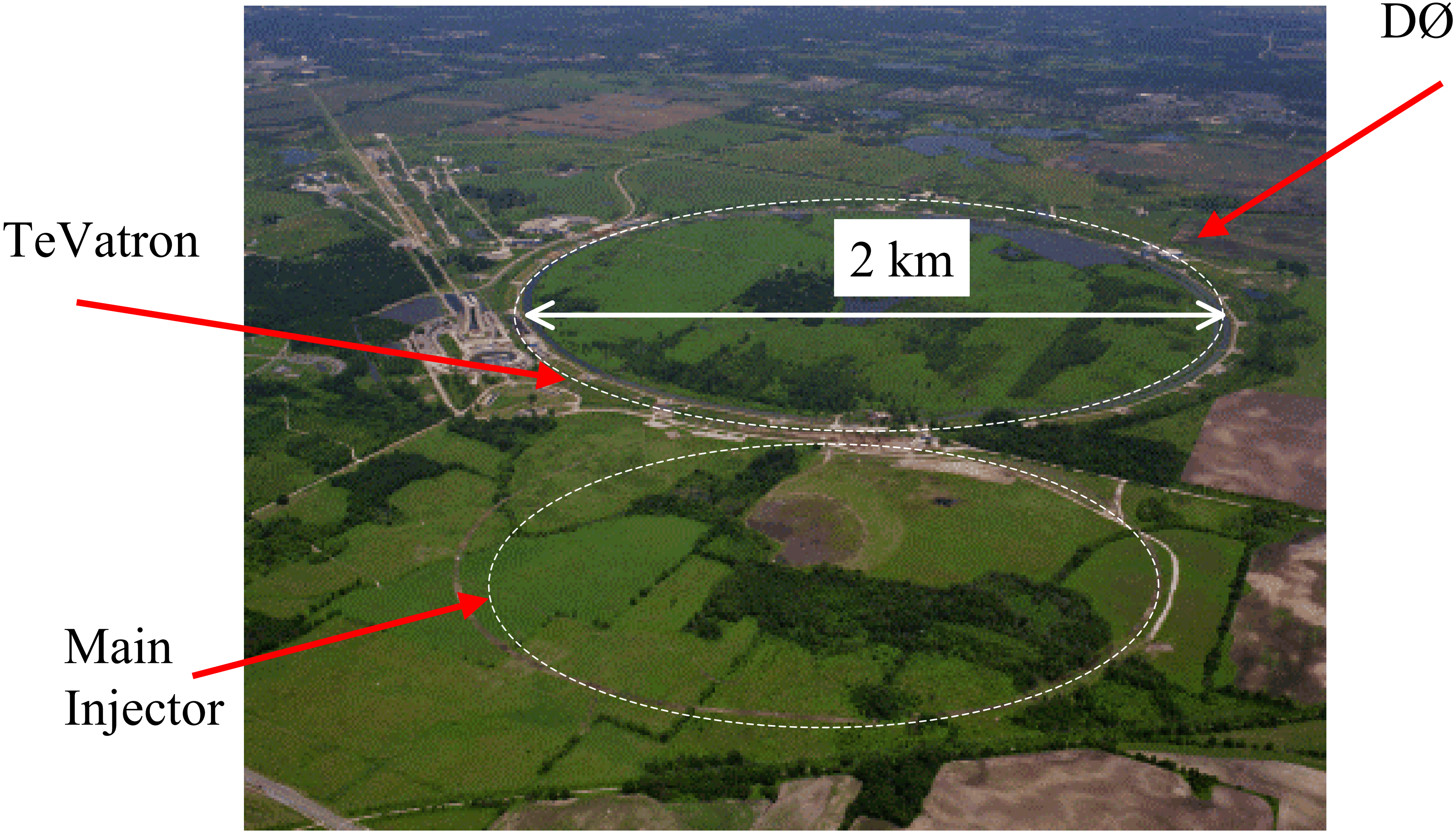


History 2: SLAC 1968

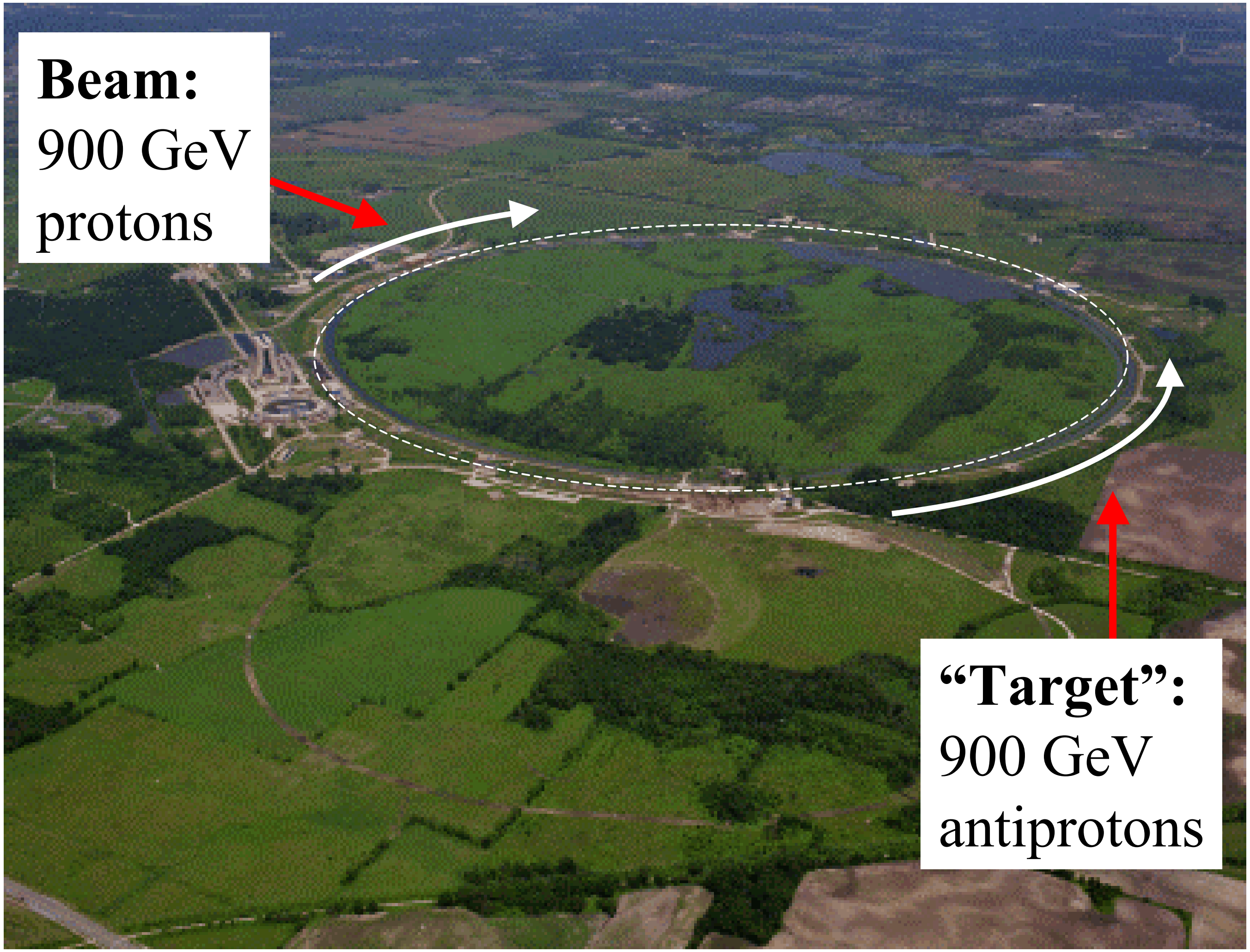
- The momentum of the electron beams gave a wavelength small enough to begin to see the structure inside a proton, and quarks became an accepted reality:



Today’s highest energy beams: Fermilab



Tevatron Collider



Beam:
900 GeV
protons

“Target”:
900 GeV
antiprotons

Collision energy = 1.8 TeV

Antiproton Accumulator

Antiprotons are created in collisions of the proton beam with a target, then collected, cooled, and stored.

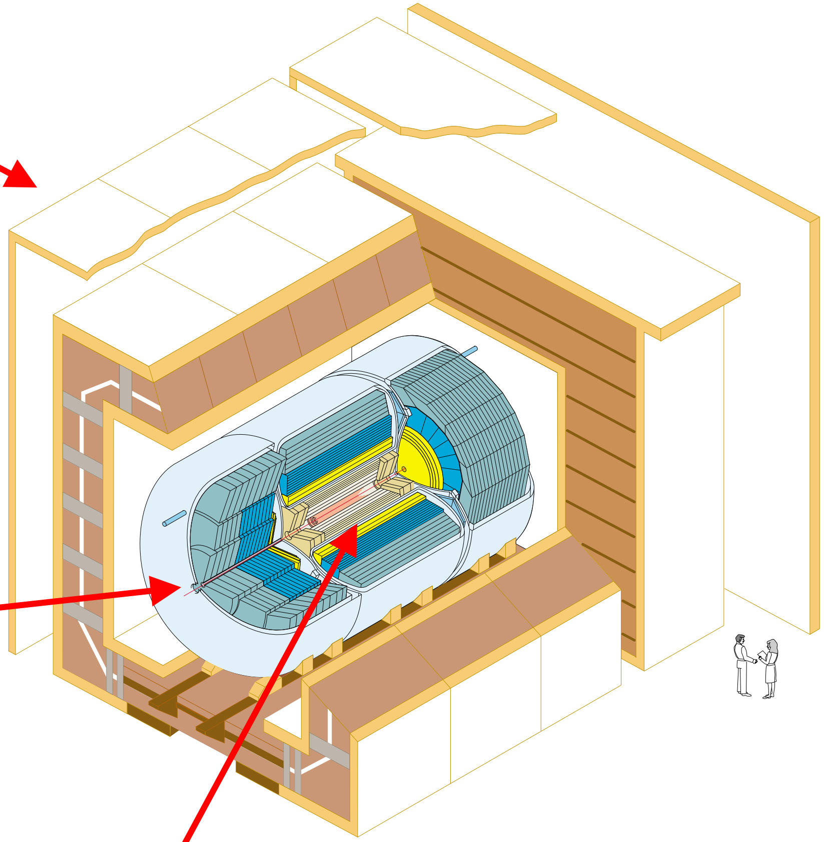
Largest accumulation of antimatter in the local universe

The DØ Detector

5000 tons of
iron,
uranium,
liquid argon,
coils, cables,
wires, ...

Accumulated data in “Run 1”, 1992-96, and (after extensive upgrade) “Run 2”, 2001-

DØ detector



Muon Spectrometer

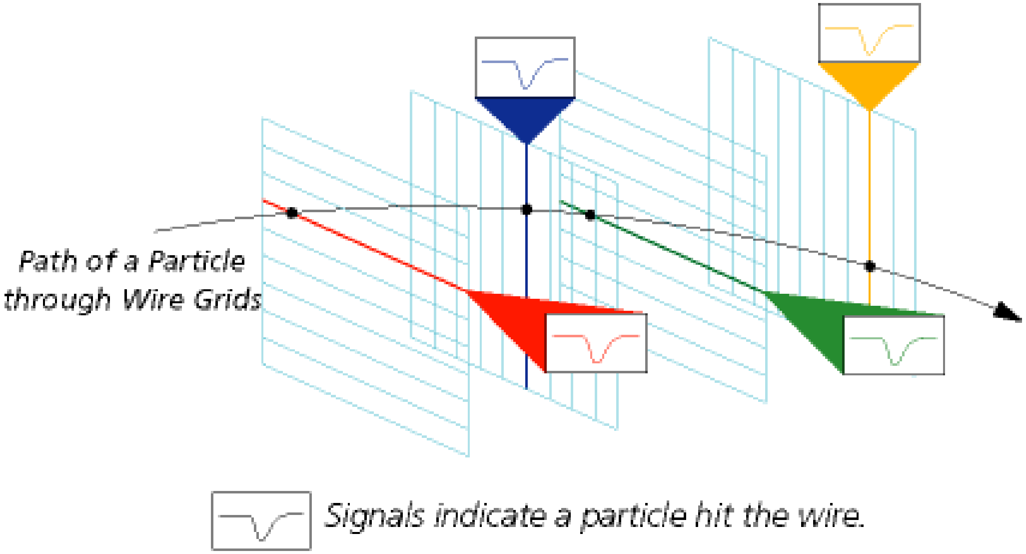
Uranium/Liquid Argon Calorimeter

Charged particle tracking

DØ Detector

Tracking

Charged particle detectors (not necessarily "wire grids") sensitive to ionization from passing charge particle.



Examples:

- Wire chambers (similar to Gieger counters)
- Scintillation fibers (produce light when charged particle passes through)
- Silicon detectors (produce electron-hole pairs when charge particle passes through)

Tracking (continued)

Radius of curvature in magnetic field = R

$$p = 0.3BzR$$

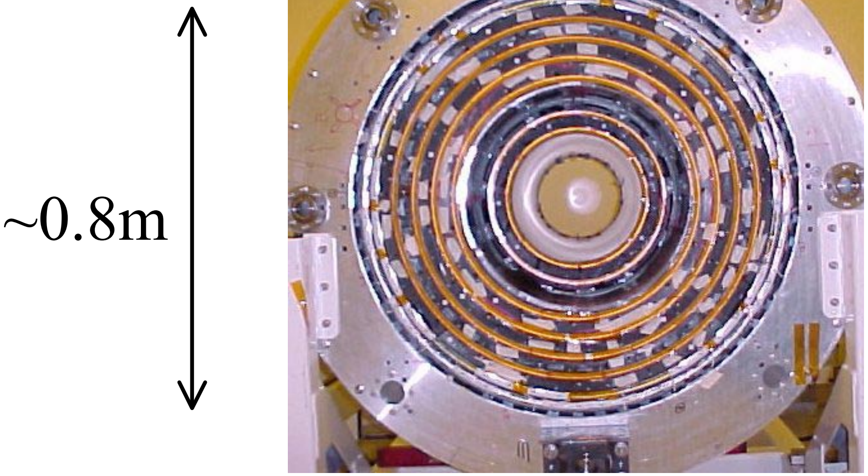
p in GeV/c

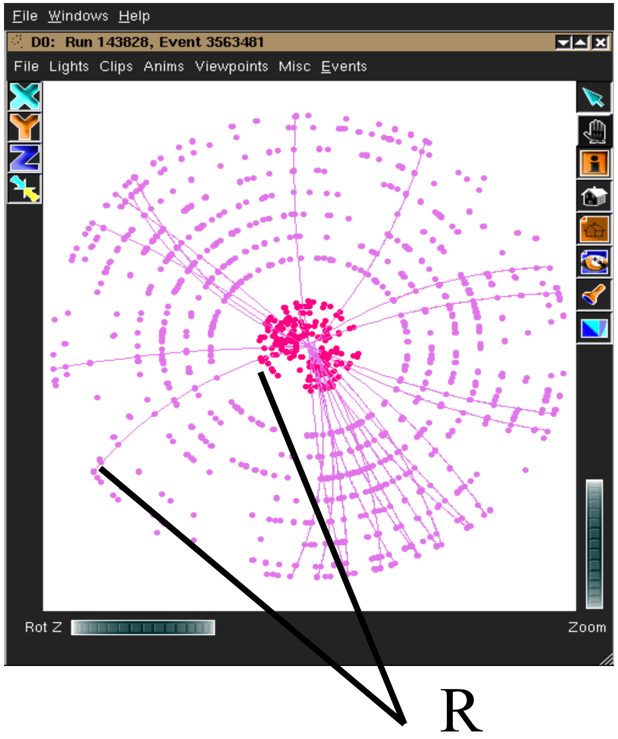
B in Tesla

ze = particle charge

ρ in m

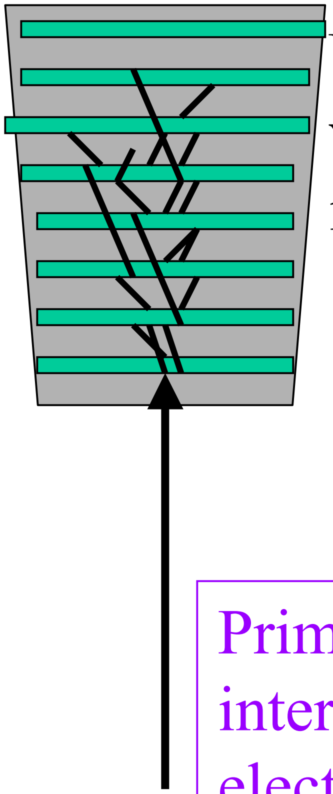
Example: DØ scintillating fiber tracker:
B = 2.0 T





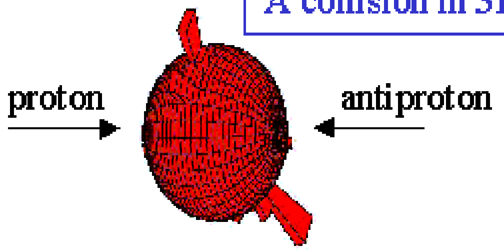
Calorimeters: total energy measurement

A single
calorimeter cell

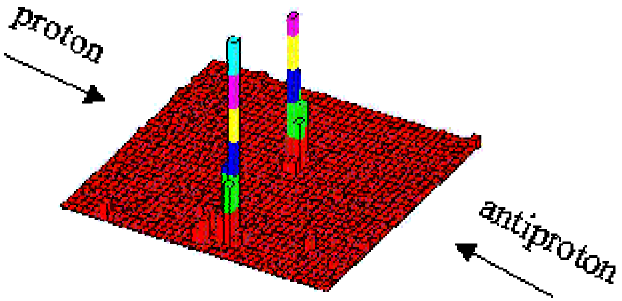


Uranium plates,
with liquid Argon
in the gaps

A collision in 3D



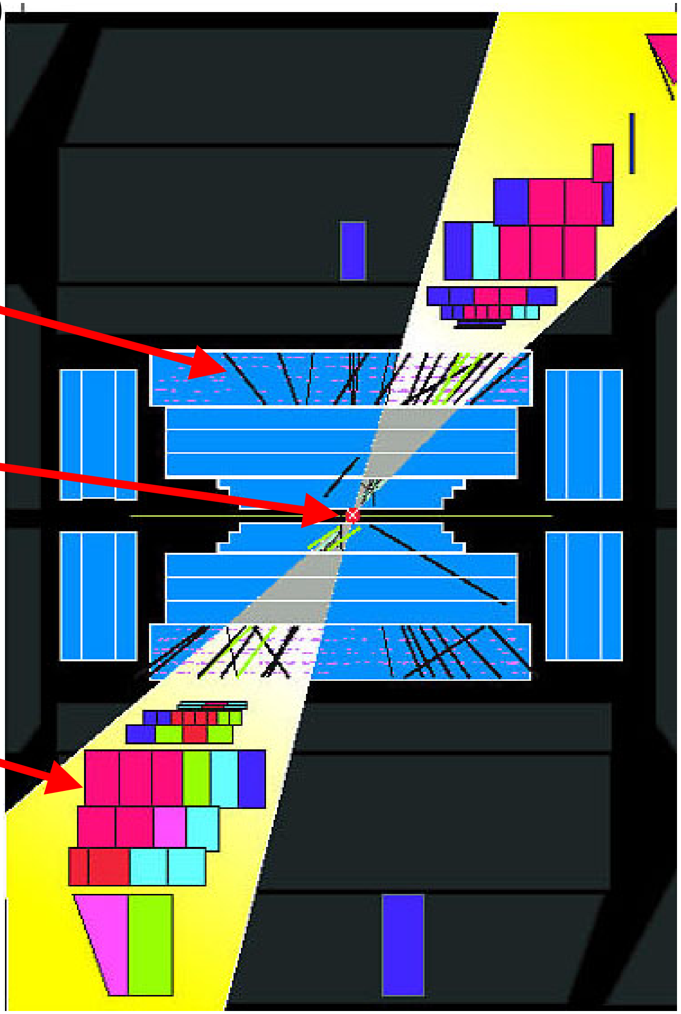
The same collision in 2D



Primary particle can be anything with significant interactions in matter (charged or neutral): pion, electron, photon, neutron, …

An event observed in the detector:

(2-dimensional slice)



Charged tracks

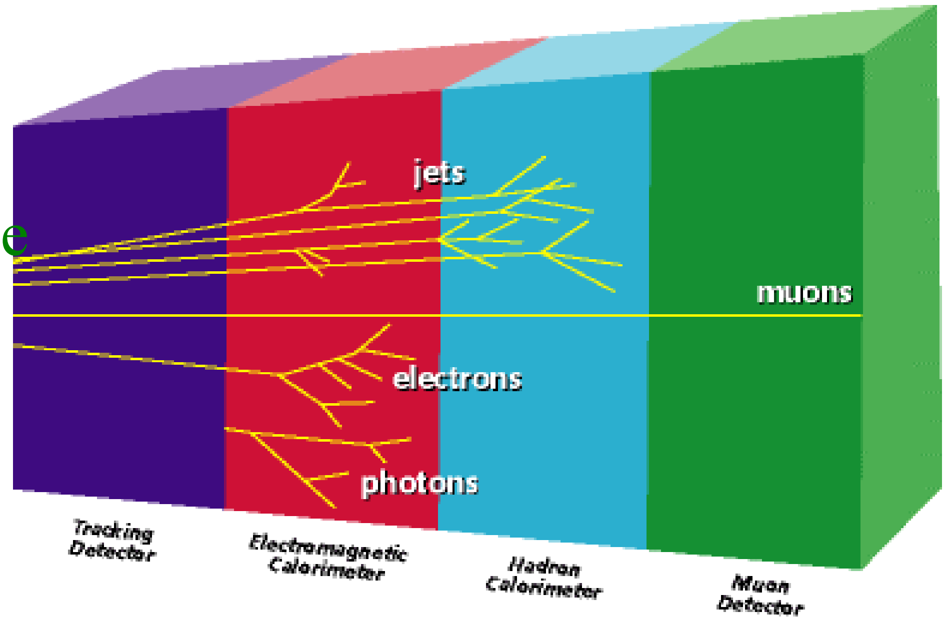
Point of collision

Colors correspond to energy deposited in a "cell" of the calorimeter

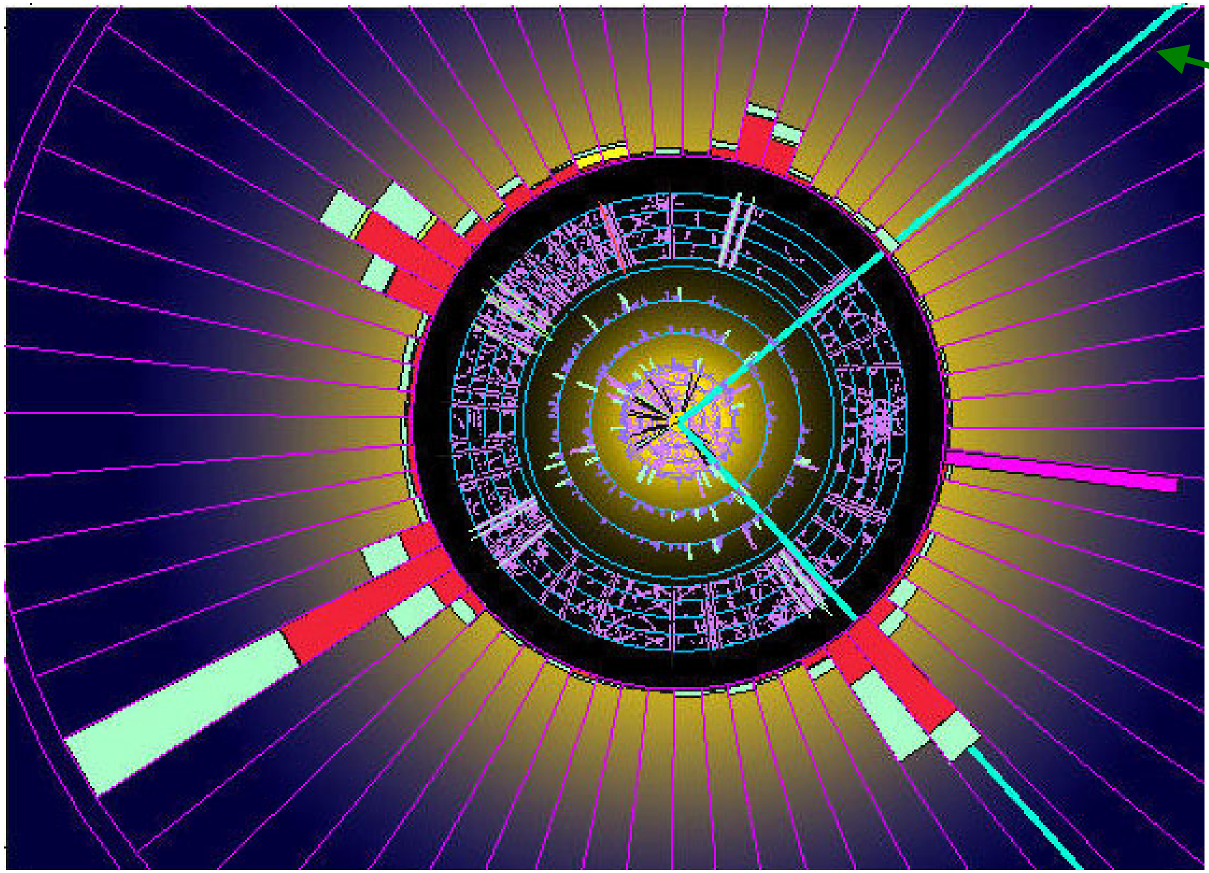
Note that energy is concentrated in two narrow cones, or "jets".

Identifying particles

- Quarks & gluons: produce jets of hadrons, which deposit energy throughout the calorimeter
- Muons: leave a track in the tracker, but penetrate the calorimeter
- Electrons: leave a track in the tracker, and deposit all energy in the first part of the calorimter
- Photons: act like electrons, but leave no track in tracker
- Neutrinos: no interaction at all (missing momentum)



A real event: what is it?



Green: tracks penetrating the calorimeter

Pink: missing momentum

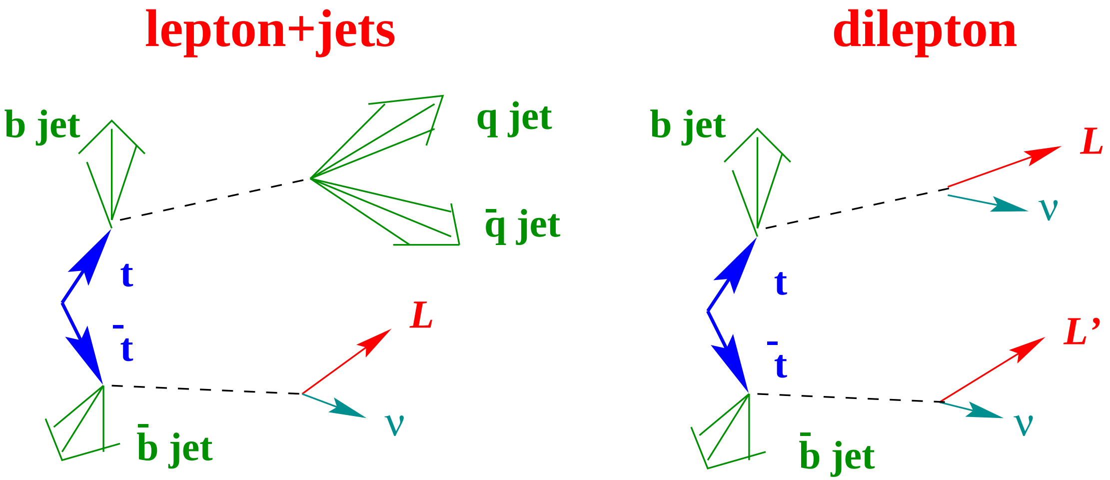
Light blue: had calorimeter

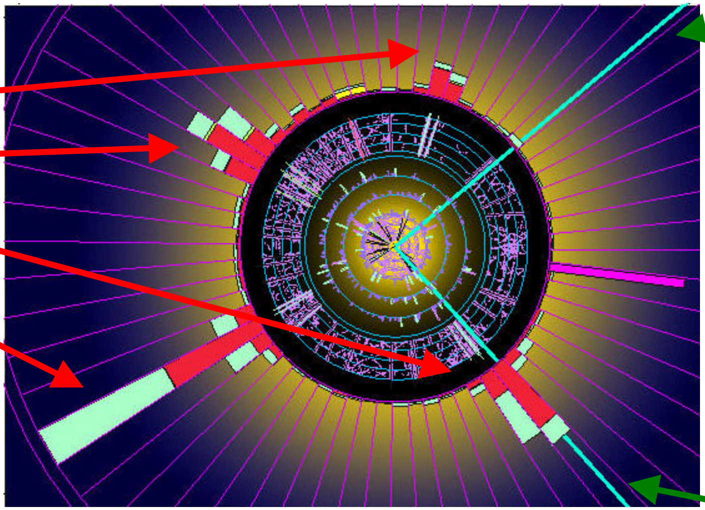
Red: EM calorimeter

Top quark

Much more complicated decays

Uses all parts of the detector





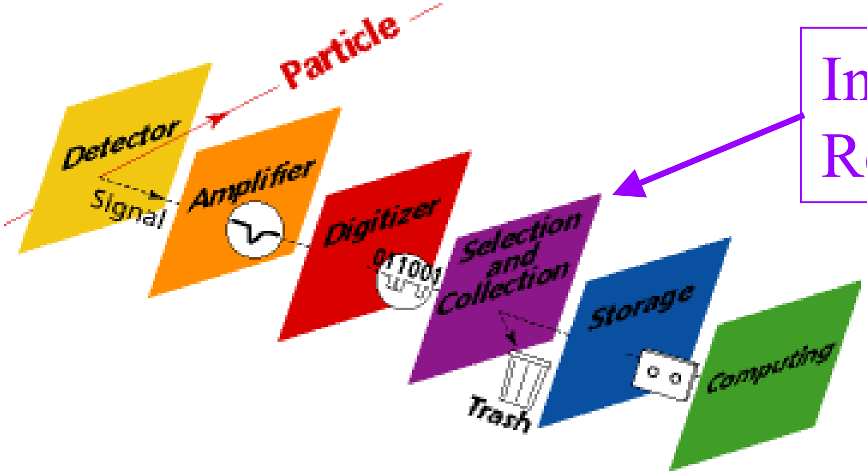
jets

Muon from W decay

Missing momentum from neutrinos

Muon from b-quark decay

Particle detection/analysis chain



Interaction rate: ~4M events/s
Recording rate: ~50 events/s

Event “reconstruction” on “farms” consisting of dozens of PC’s working in parallel

People

- About 500 people / experiment at the Tevatron (>1000 at LHC)
- Grad students, post-docs, professors, staff scientists, engineers, computing professionals
- Main activities: Designing and building detectors, operating the experiment, analyzing the data
- Outputs: >100 published papers/expt, Ph.D.'s, spinoffs