Experimental Particle Physics
PHYS6011

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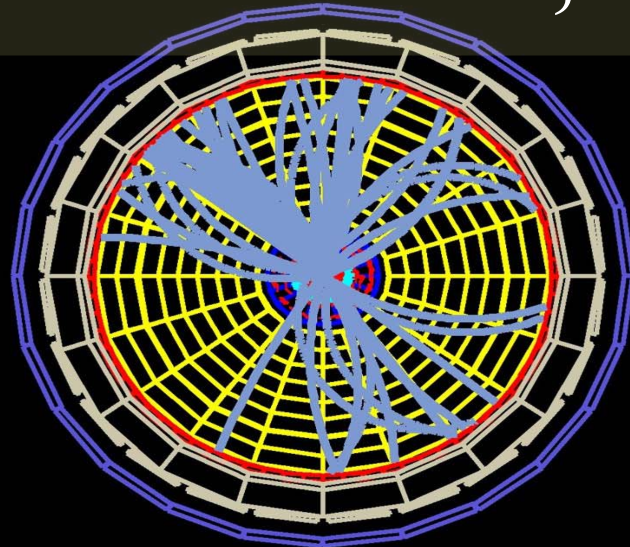


1. Introduction & Accelerators
2. <u>Particle Interactions and Detectors (2/2)</u>
3. Collider Experiments
4. Data Analysis

Interactions and Detectors

Last week:

Ionisation losses and detection

This week:

1. **Radiation Losses**
2. **Photon Absorption**
3. **Electromagnetic Showers**
4. **Hadronic Showers**
5. **Multiple Scattering**
6. **Detector Categories**

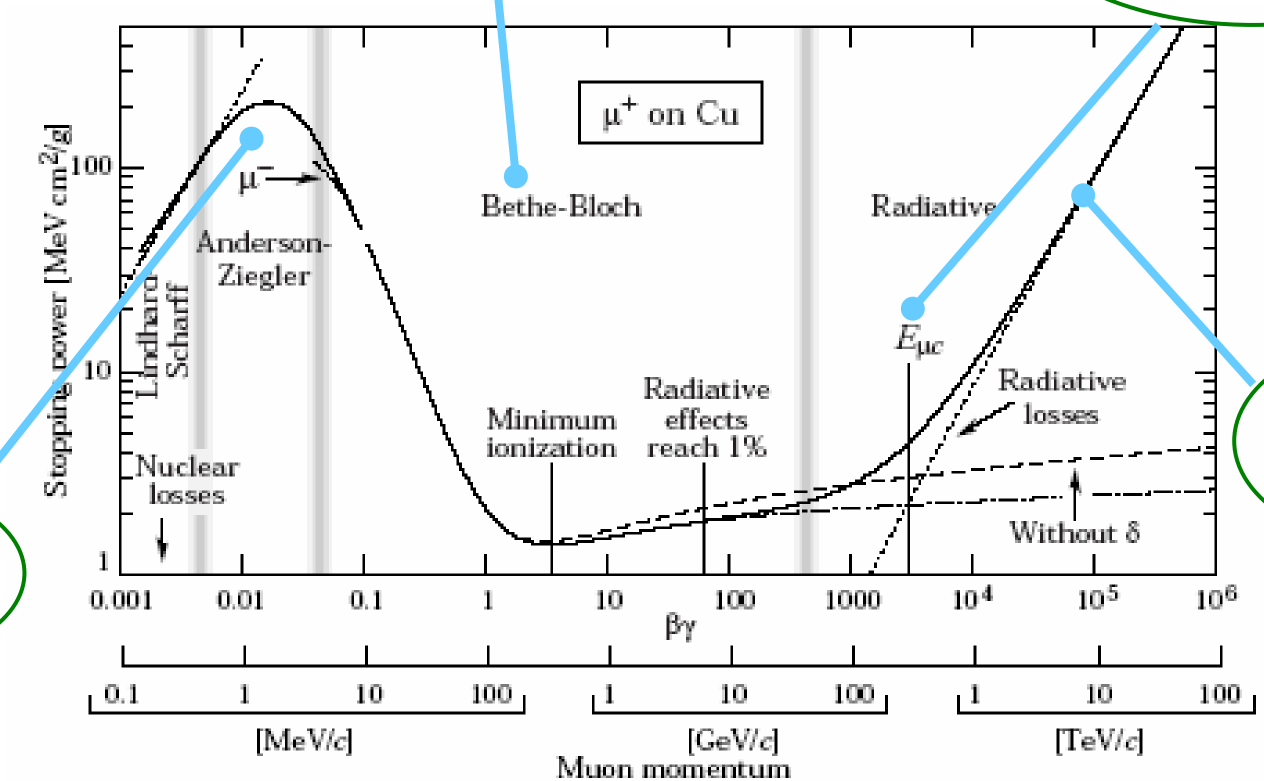
Muon Energy Loss

Ionisation/Bethe-Bloch

$$-\frac{dE}{dx} \approx Kq^2 \frac{Z}{A\beta^2}\left[\ln\frac{2m_e c^2\beta^2\gamma^2}{I^2} - \beta^2\right]$$

Critical Energy

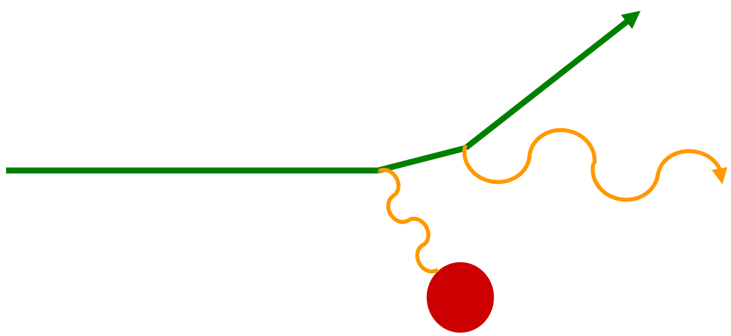
≈ 800 MeV/(Z+1.2) for electrons



Low energy region

Radiation dominated

Radiation Losses



- Bremsstrahlung
- Charged particle in nuclear electric field
- Photon can be very energetic

Energy loss for electrons:

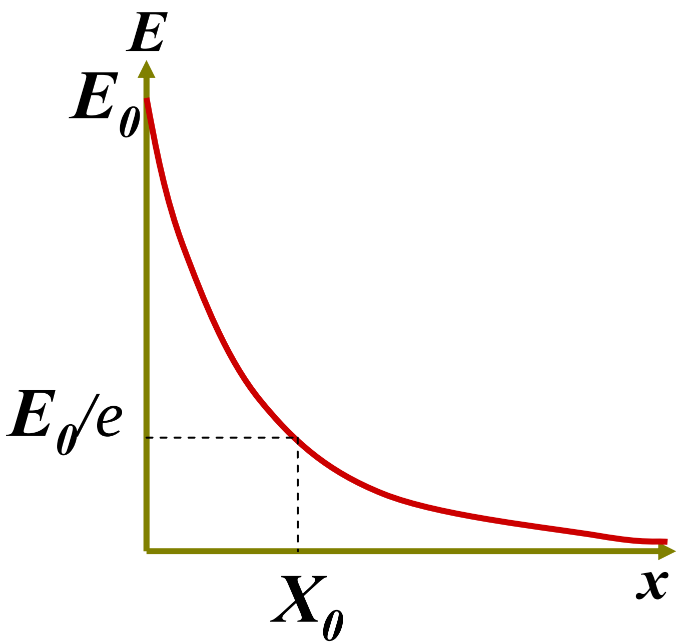
$$-\frac{dE}{dx} = \frac{E}{X_0}$$

Radiation Length

$$\Leftrightarrow E = E_0 e^{-x/X_0}$$

Radiation Length

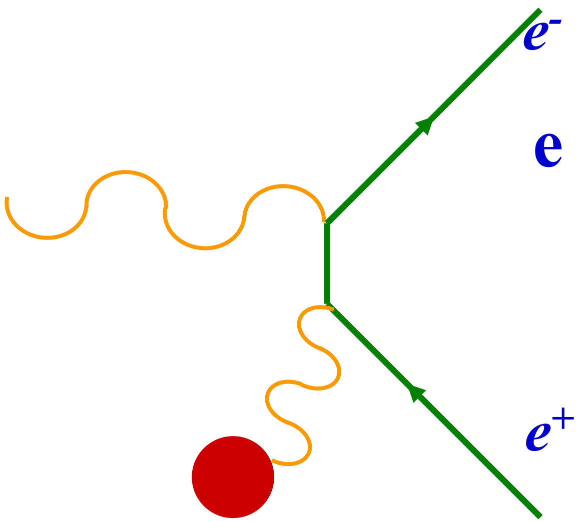
- **Exponential drop in electron energy**



$$X_0 = \frac{716.4\,\mathrm{g.cm^{-2}}\,A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

	X_0 (g cm^{-2})	X_0 (cm)
Air	**37**	**30,000**
Silicon	**22**	**9.4**
Lead	**6.4**	**0.56**

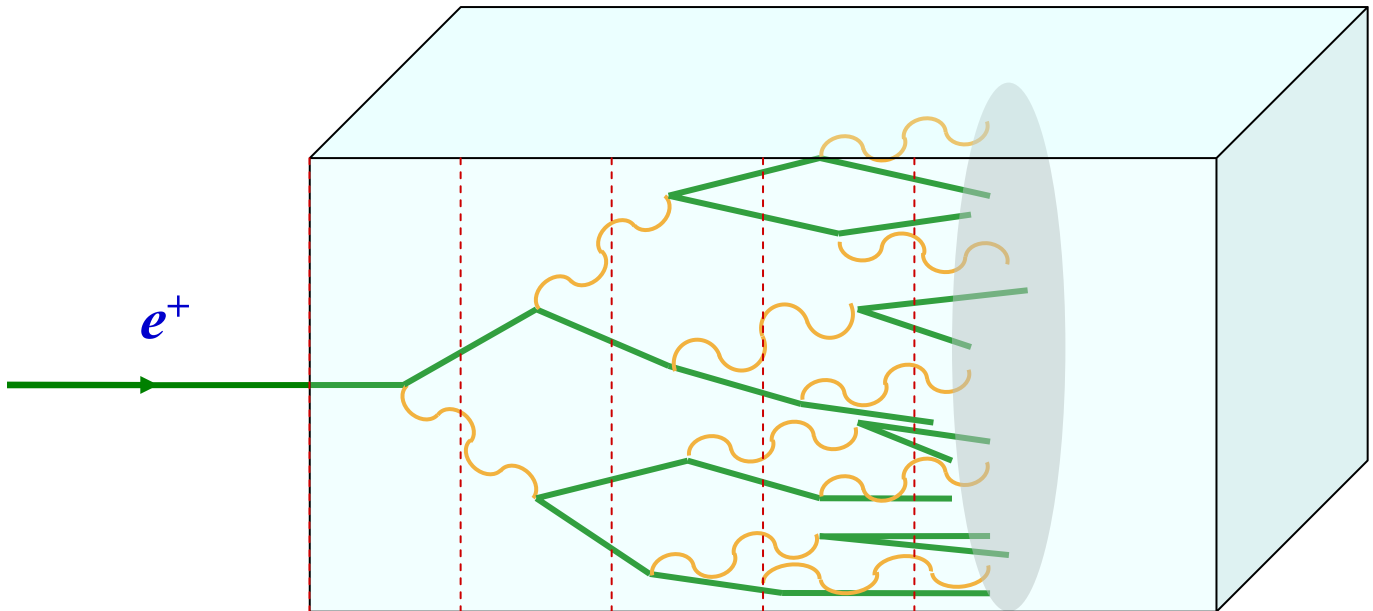
Photon Absorption



- **Electron-positron pair production**
- **Exponential absorption**
- **Length scale $9/7 \times X_0$**

$$-\frac{dn}{dx} = \frac{7n}{9X_0}$$

Simple Electromagnetic Shower

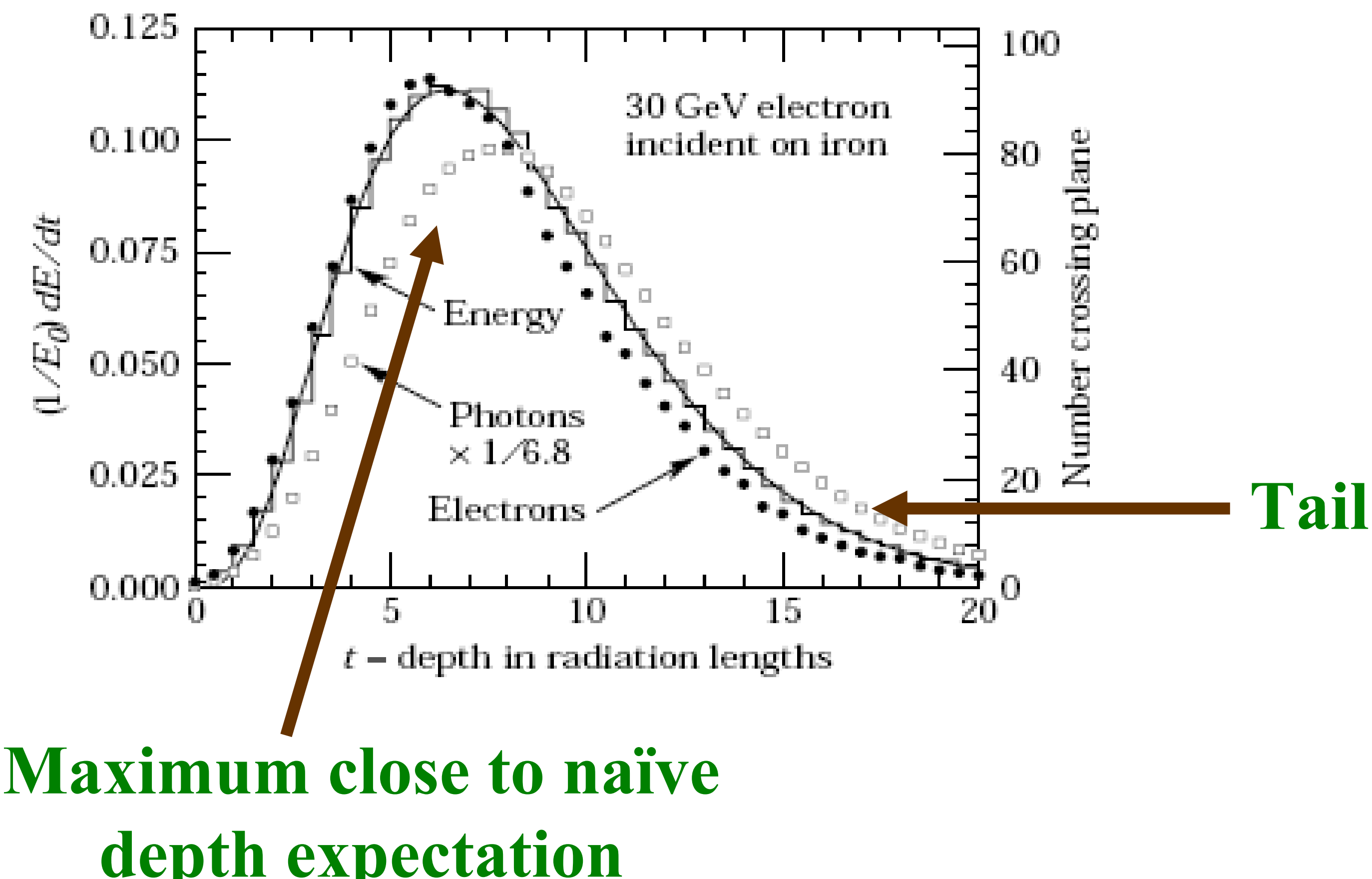


x	0	X_0	$2X_0$	$3X_0$	$4X_0$	
N	1	2	4	8	16	0
$<E>$	E_0	$E_0/2$	$E_0/4$	$E_0/8$	$E_0/16$	$<E_c$

- **Start with electron or photon**
- **Depth ~ $\ln(E_0)$**
- **Most energy deposited as ionisation**

Real EM Shower

- Shape dominated by fluctuations



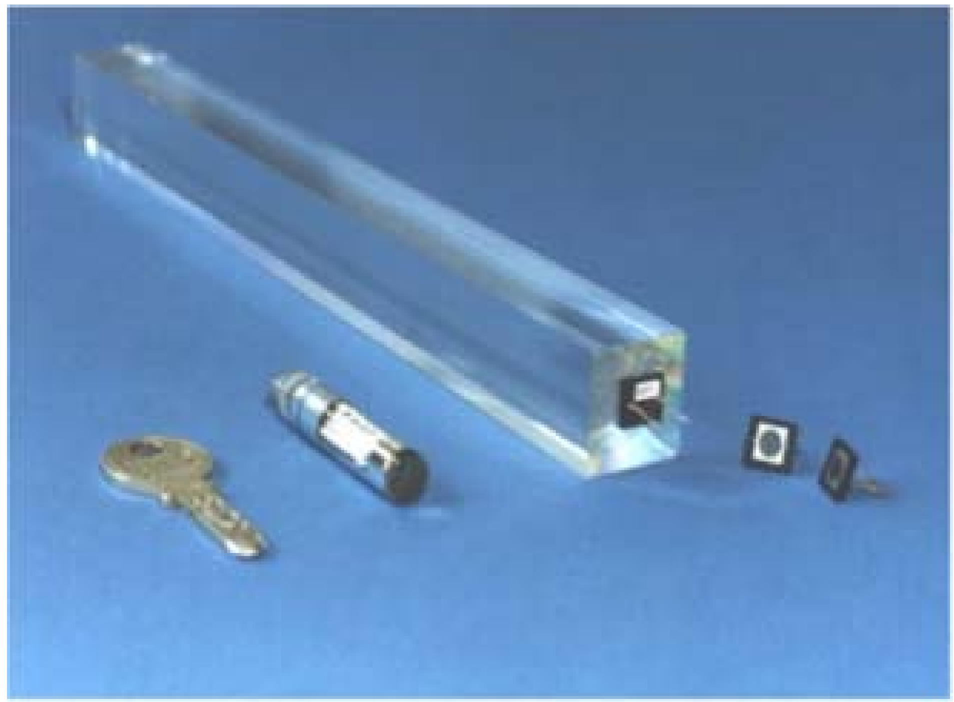
EM Calorimetry 1

Use shower to measure the energy of an electron or photon:

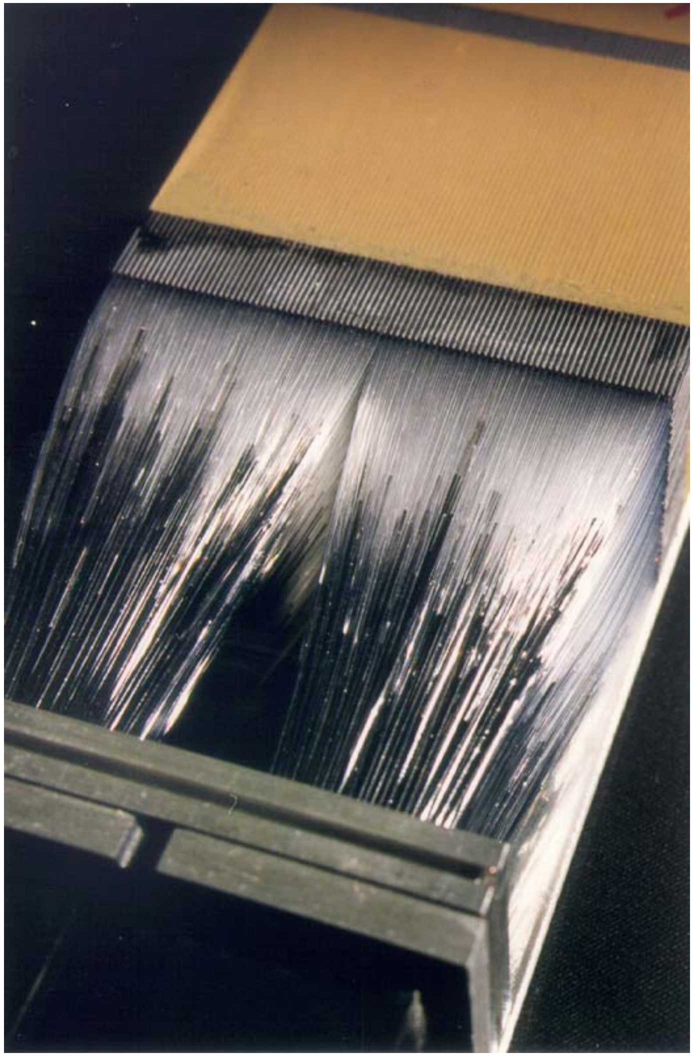
1. Contain shower within a homogeneous calorimeter

- **Crystal, glass, liquid**
- **Acts as absorber and scintillator**
- **Light detected by photodetector**
- **E.g. $PbWO_4$**

  ($X_0 \approx 0.9$ cm)



EM Calorimetry 2



2. *Sampling Calorimeter*

- **Insert detectors into larger absorber:**
- **Absorber normally dense metal:**
  - ***lead, tungsten etc***
- **Detectors can be scintillator, MWPC...**

- *Cheaper but less accurate*

Hadronic Showers

- **Nuclear interaction length >> radiation length**

$$\lambda \approx 35\text{g.cm}^{-2} A^{1/3}$$

e.g. Lead: $X_0 = 0.56$ cm, $\lambda = 17$ cm

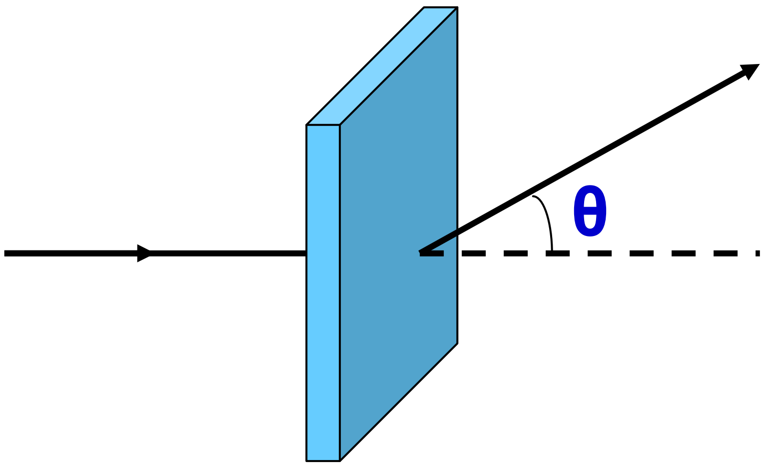
- **Hadron showers wider, deeper, less well understood**
- **Need much larger calorimeter to contain hadron shower**
  - **Always sampling**
  - **Dense metals still good as absorbers**
  - **Mechanical/economic considerations often important**
  - **Uranium, steel, brass…**

Hadronic Calorimeter

Alternating layers of steel and streamer chambers

Multiple Scattering

- Elastic scattering from nuclei causes angular deviations:



$$\theta_{RMS} \approx \frac{13.6\text{MeV}}{\beta cp} q\sqrt{x / X_0}$$

- Approximately Gaussian
- Can disrupt measurements in subsequent detectors

A Brief Pause

So far...

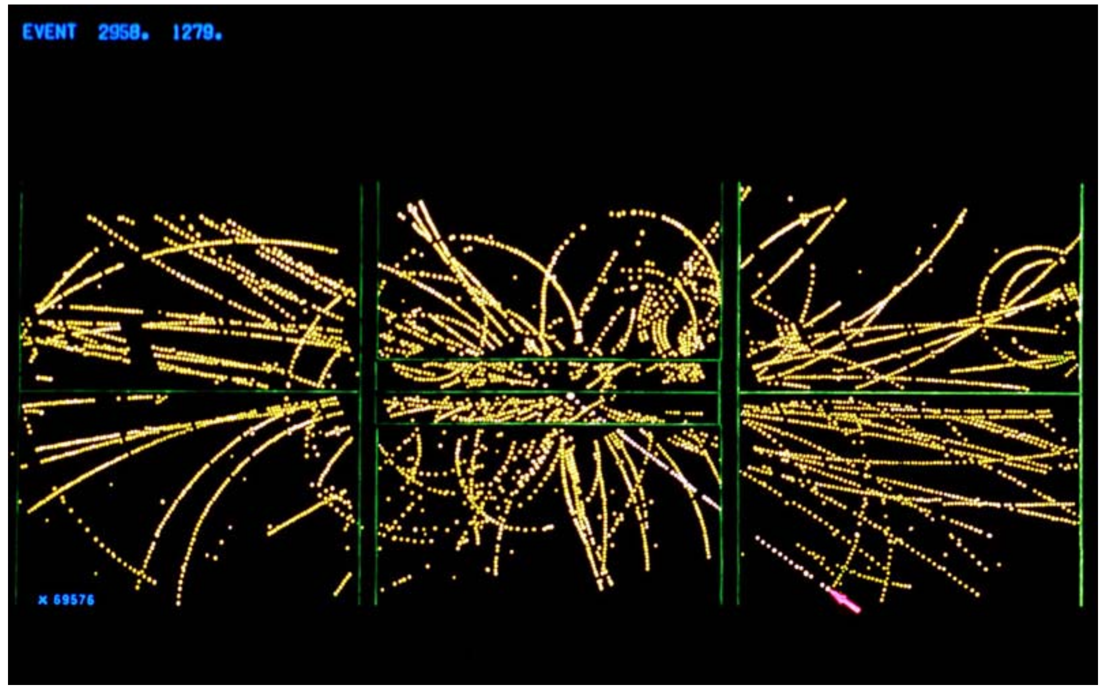
- **Particle interactions:**
  - Ionisation losses
  - Cerenkov radiation
  - Transition radiation
  - EM showers
  - Hadronic showers
  - Multiple scattering
- **Electronic detectors**

Let's put order into chaos!

Tracking Detectors

Measure trajectories of charged particles

- Low mass
  - Reduce multiple scattering
  - Reduce shower formation
- High precision
- Multiple 2D or 3D points
- *Drift chamber, TPC, silicon...*
- Can measure momentum in magnetic field ($p = 0.3qBR$)



Vertex Detectors

Ultra-high precision trackers close to interaction point

- **Spatial resolution a few microns**
- **Low mass**
- ***A few layers of silicon***

EM Calorimeter

Identify and measure energy of electrons and photons

- **Need ~ 10 X_0**
  - **10 cm of lead**
- **Will see some energy from muons and hadrons**
- **Homogenous**
  - ***Crystal***
  - ***Doped glass***
- **Sampling**
  - ***Absorber + scintillator/MWPC/…***

Hadron Calorimeter

Identify and measure energy of all hadrons

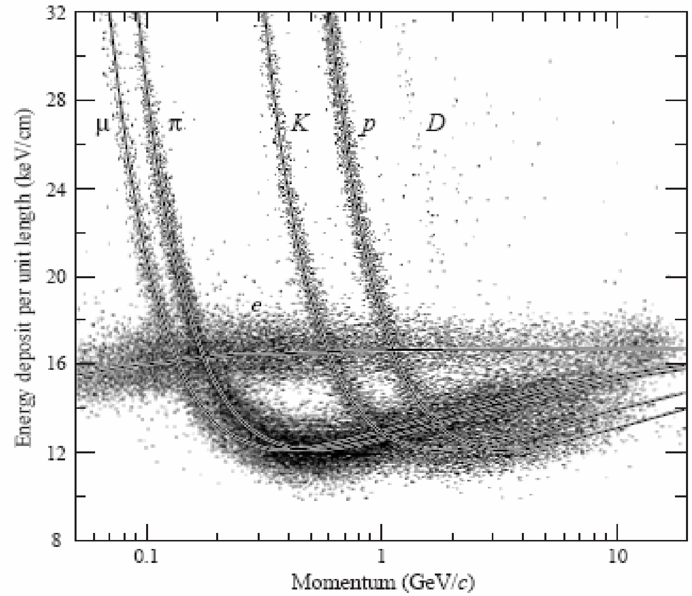
- **Need ~ 10 λ**
  - **2 m of lead**
- **Both charged and neutral**
- **Will see some energy from muons**
- **Sampling**
  - ***Heavy, structural metal absorber***
  - ***Scintillator, MWPC detector***

Particle ID

Distinguish different charged "stable" particles

- Muon, pion, kaon, proton
- Measured momentum and energy: $m^2 = E^2 - p^2$
  - Difficult at high energy $E \sim p$
- Different dE/dx in tracking detectors
  - Only for low energy $1/\beta^2$ region, no good for MIPs

- Measure time-of-flight $\rightarrow \beta$
  - *Fast scintillator*
- Measure β directly
  - *Cerenkov radiation*
- Measure γ directly
  - *Transition radiation*

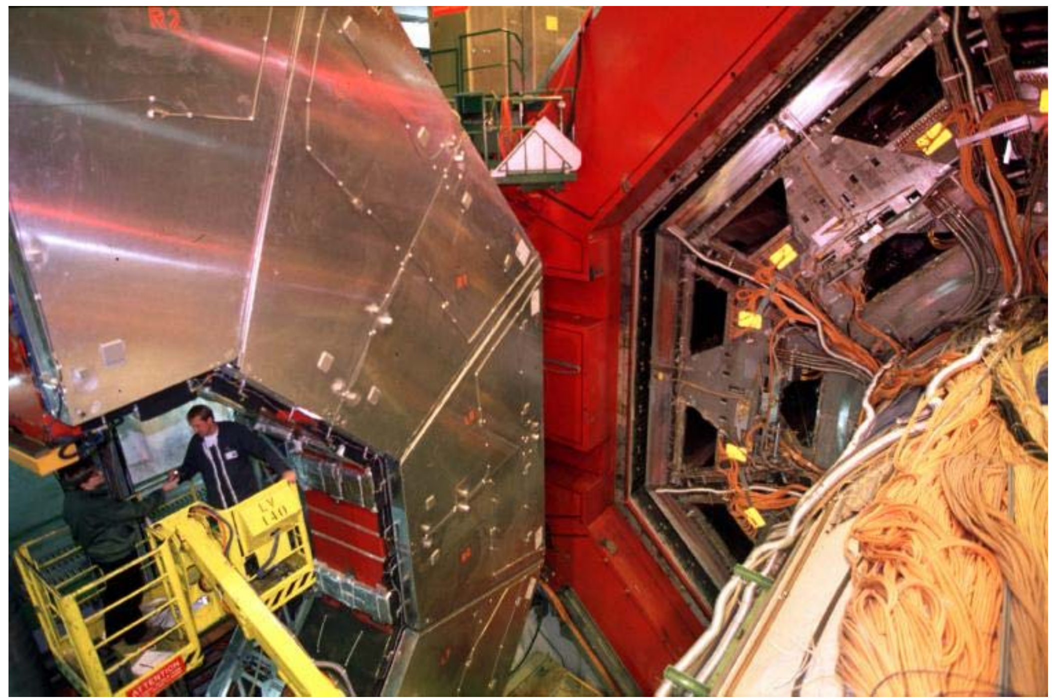


Muon Detectors

Identify muons

- **Muons go where other particles cannot reach:**
  - **No nuclear interactions**
  - **Critical energies >> 100 GeV**
    - ***Always a MIP***
  - **Stable (τ = 2.2 μs)**

- **A shielded detector can identify muons**
  - **"shielding" often calorimeters**
  - ***Scintillator, MWPC, drift chambers…***



Next Time...

Putting it all together

- building a particle physics experiment