Particle Identification

Many types of particle

- not just kinematics ($\vec{p}$, E) important to measure

- need their identity
  - leptons: e, μ, τ
  - neutrals: γ, π^0, η ...
  - charged hadrons: $\pi^\pm$, K, p ...
  - weakly interacting: ν, χ^0 ...

Each particle specie has a unique combination of

- charge Z
- mass m
- form of interaction (EM, strong, weak)

If know $\vec{p}$ or E, then a measure of β provides mass constraint

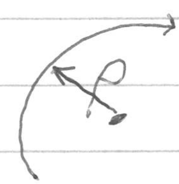
Ionization or Scintillation yields Z measure

Shower properties $\Rightarrow$ μ vs. $e^\pm/\gamma$ vs. hadrons

Some Measurements (example)

Radius of curvature, ρ, of charged particle track in B-field

$$\rho \propto \frac{|p|}{z} = \gamma \frac{m\beta c}{z}$$



Measuring time of travel (time-of-flight)

$$\tau \propto \frac{1}{\beta} \quad \text{or} \quad \theta_{rad.} = 1/\gamma$$
$$\text{or} \quad \theta_{cer} = 1/\beta$$

A measure of kinetic energy

$$E_k = (\gamma - 1)mc^2$$

This gives 3 relations in 3 unknowns

$$m,\ z,\ (\beta, \gamma)$$

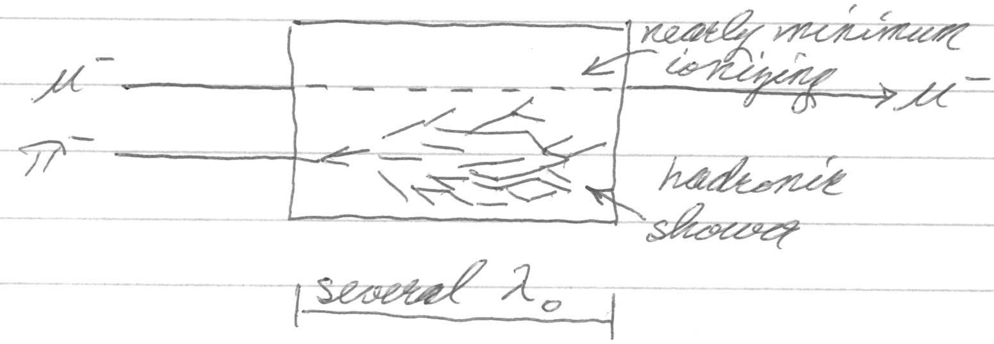
- can identify mass and charge

Types of Interactions

Requires material sensitive to distinction want to make:

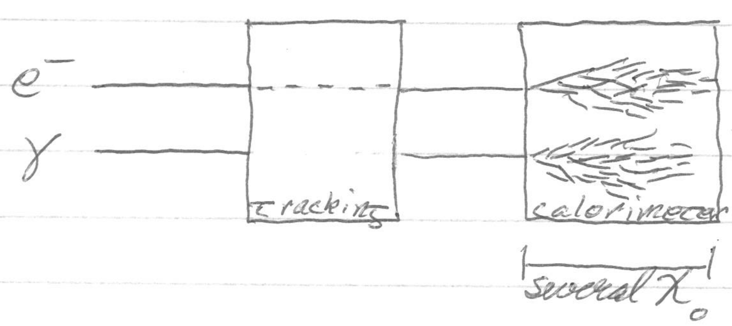
$$m_{\mu^-} \sim m_{\pi^-} \quad \text{AND} \quad q_{\mu^-} = q_{\pi^-}$$

But when incident on a large mass



Very different behavior allows discrimination

Consider a photon and an electron



- similar showers
- difference in dE/dx

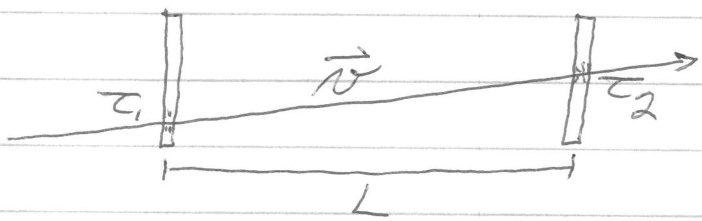
Timing Applications - Scintillators

Nanosecond (or better) timing resolution an important capability

Time-of-flight (TOF)

- use for low momentum particles
- can use to identify particle mass

Measure time of traversal between two points



$$\tau = \tau_1 - \tau_2 = L\left(\frac{1}{v}\right) = \text{"TOF"}$$

Comparing the TOF for two ~~a~~ different particles of same momentum

$$\Delta\tau = TOF_A - TOF_B = \frac{L}{c}\left(\frac{1}{\beta_A} - \frac{1}{\beta_B}\right)$$

$$= \frac{L}{pc^2}\left(E_A - E_B\right) \quad \text{(where } pc = \beta E\text{)}$$

$$\boxed{\Delta\tau = \frac{Lc}{2p^2}\left(m_A^2 - m_B^2\right)} \quad \text{where } pc \gg mc^2 \text{ and expand } E = \sqrt{p^2c^2 + m^2c^4}$$

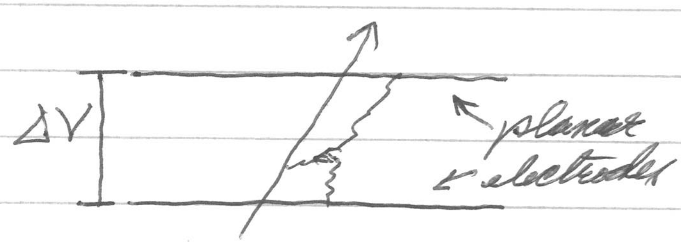
$$\propto \frac{1}{p^2} \quad \text{(small for large momenta)}$$

Scintillator device

- can obtain time resolution of 10-100ps
- for a 1m (=L) detector + 0.1ns resolution:
  - π-K seperation up to 1 GeV/c
- for a 10m detector: $\Delta t \sim 4\,ns$
  - → can now go to several GeV

Spark Chambers

ΔV > breakdown voltage

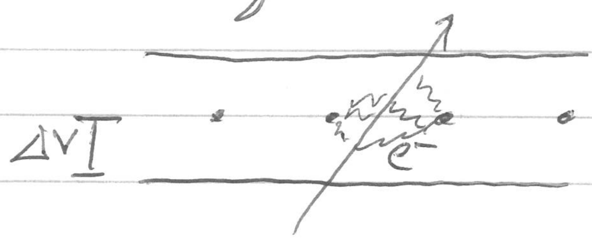


Operate detector so ionization leads to avalanche, and then
- then conducting plasma channel between electrodes
- sudden rise in current ⇒ $\frac{dV}{dt}$ large
  - can trigger on this signal

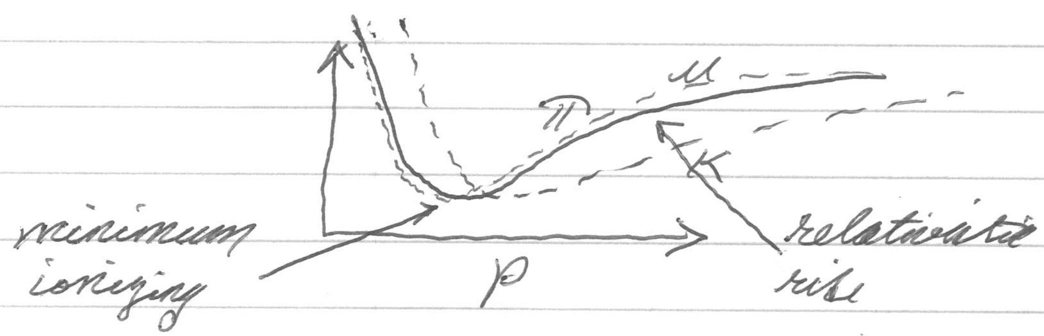
→ Resistive Plate Chambers (RPC's)
- similar: reduce gas pressure
  - ∴ operate in avalanche mode
- trigger in same way (abrupt $\frac{dV}{dt}$)

Ionization Measurements

Consider a drift chamber set-up



- gives momentum-dependent ionization measurement



- for some gases, $\frac{dE}{dx}$ rises by 50%-60% for momenta from 0.1 to 100 GeV/c (Ar-methane)

Want to maximize difference (D) in dE/dx in region of relativistic rise between 2 species
- gaseous detectors have smaller density (larger δ)
- Very difficult to separate π + μ at same momentum $\Rightarrow$ (Δm + D too small)

Resolving power = $D/\sigma_{dE/dx}$

Fluctuations in Energy Loss

large Landau fluctuations
- can be bigger than total size of relativistic rise: 30% - 100%
- means large overlaps in $\frac{dE}{dx}$ distributions
  - inefficient discrimination

Potential remedies
- (higher density reduces rise size)
- increase gas sample thickness
- sample ionization many times

Example: several planes of drift regions

Reduces resolution, but still have large tail from δ rays

- Omit highest energy loss measurements → "truncated mean"

- Many measurements can get $\sigma \doteq 5\%$
  → roughly $\propto 1/\sqrt{N}$ (N = # measurements)

Pure hydrocarbons better than noble gas mixture (95% Ar, 5% CH_4)
- but smaller relativistic rise

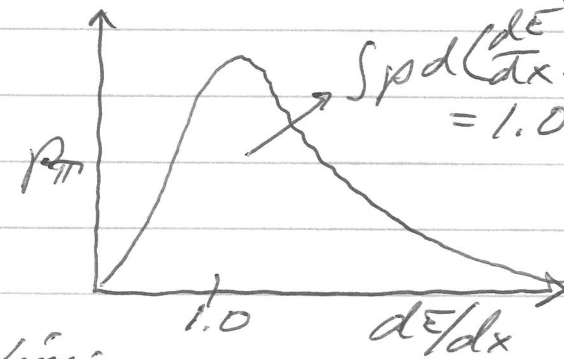
Likelihood Calculation

When be omit high energy loss measurements

- loose information: dE/dx in some layers
- bias overall measurement

One way around: use all information more carefully

Consider histogram of dE/dx for a $\pi^\pm$



$p_\pi\left(\frac{dE}{dx}\right)$ is probability to be in bin $\frac{dE}{dx}$ to $\frac{dE}{dx}$ + binsize

- "probability density function"

For some particle "x": calculate overall probability, from N measurements, to be a π

$$P_\pi = \prod_{i=1}^{N} p_\pi(A_i)$$

A_i are N measurements of dE/dx

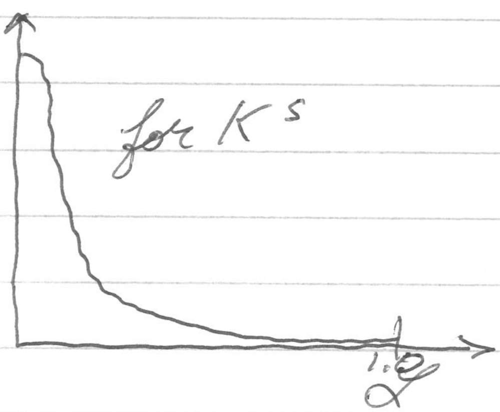
Similarly

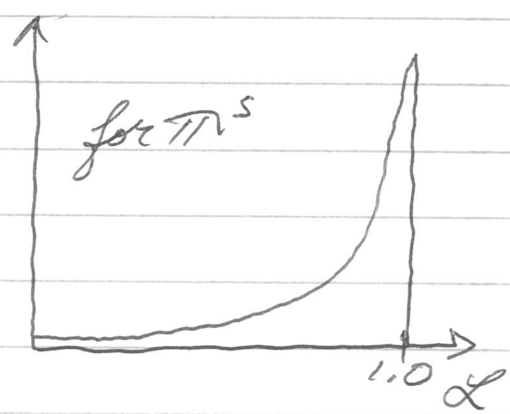
$$P_K = \prod_{i=1}^{N} p_K(A_i)$$

We then calculate the overall relative "likelihood" to be a π as

$$\boxed{\mathcal{L} = \frac{P_\pi}{P_\pi + P_K}}$$

This distribution will have values from 0...1

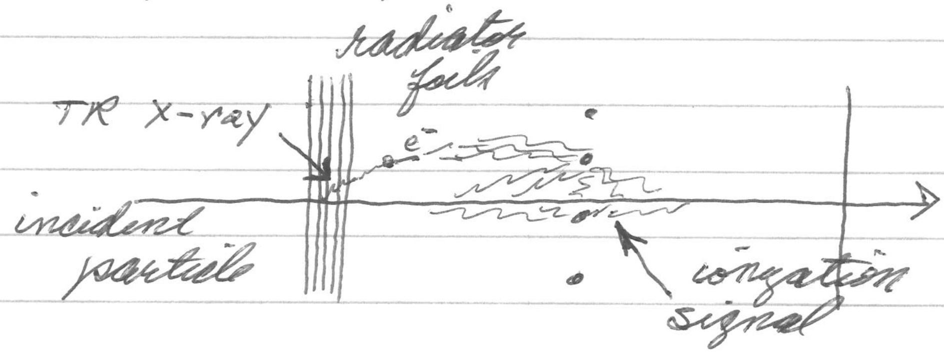




Transition Radiation Detectors

General structure

- many foils of high dielectric
- a gas ionization detector



For extremely high γ particles ($e^{\pm}$)

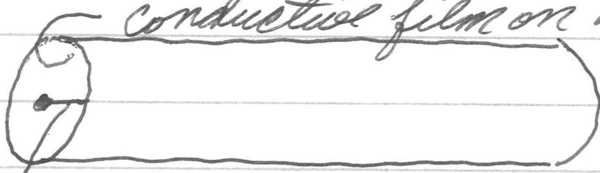
→ see charge from transition radiation (TR) and from ionization

For more massive particles (μ, hadrons)

- just observe dE/dx

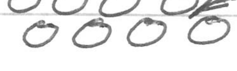
Example: ATLAS Transition Radiation Tracker (TRT)

370k kapton straw tubes



conductive film on kapton wall
∴ cathode

anode: 30μm gold-plated tungsten wire



polypropylene foils as radiator

Gas: 70:27:3 as $X_e : CO_2 : O_2$

→ high X-ray absorption cross section

As a tracker: uses drift time to obtain coordinate $\perp$ anode $\sigma \sim 130\,\mu m$

Particle Identification:

- based on measured energy deposited

  TR ~ 8-10 keV

  MIP ~ 2 keV

- may define a threshold such that

  $\pi^{\pm}$ fail

  $e^{\pm}$ pass

@ 90% $\epsilon(e)$ → 1.2% $\epsilon(\pi)$

ϵ → efficiency