Particle Identification for Calorimeters

A calorimeter has several important uses in identifying particles:

- Seperation of e and γ from hadrons
- Seperation of e and μ from each other
- indirect measure of ν's
- direct detection of ν's

For the typical materials of a calorimeter

- high Z absorber

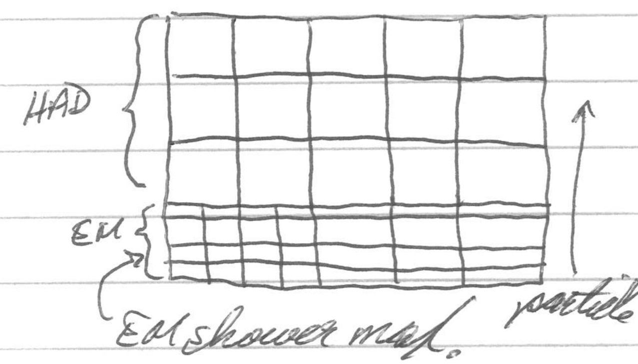
  $\therefore \underline{X_0 \ll \lambda_0}$

- typical calorimeter will either
  - be deep enough to contain e and hadron showers
  - have EM and hadronic calorimeters sequentially in longitudinal direction

Take advantage of knowledge of showers

- e => less depth, narrow in transverse
- hadron => deep and wide

One can build one detector with longitudinal variation in structure (eg. DØ)



for e/γ → measurement

- initial compartment
  - finely grained
  - longitudinally to sample shower development
  - transverse for good position measurement
  - boundary at seven X_0 to contain > 95% of showers

- next compartment
  - more coarsely grained
  - thicker absorber
  - for $\pi^\pm$ mostly, but also subsequent π^0 production

Could also build two seperate detectors

- eg. a LAr EM calorimeter, plus a scintillating hadronic calorimeter (ATLAS)

- can focus on good quality EM calorimeter
  → good e/γ measurements
- less capability (perhaps) for hadronic measurements

Parameters of Merit

- Fraction of energy in EM compartment
- Transverse width, eg.

$$w = \frac{\sum |r_i| E_i}{\sum E_i}$$

- could use likelihood technique
  → or "h-matrix"

EM cascades in Fe: 95% in $\Delta r \leq 3.5$ cm

hadronic " " : 5x wider!

Longitudinal depth of shower maximum

- or longitudinal center-of-gravity of shower

Can obtain misidentification rate for $\pi \to$ "e"

$\sim 10^{-3}$ for high electron efficiency in calorimeter

Goodness of Fit

We want to compare observations to expectations

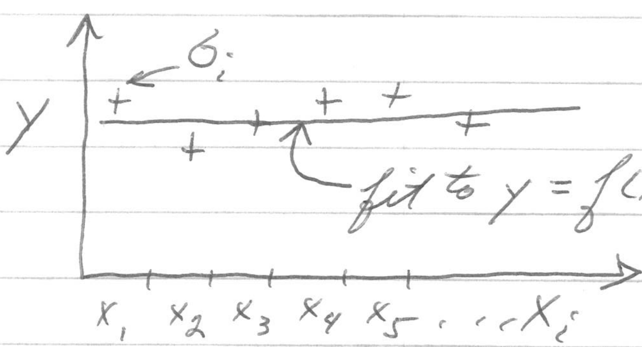
- Can do a χ^2 test

$$\boxed{\chi^2 = \sum_i \frac{(y_i - y_i')^2}{\sigma_i^2}}$$

where

y_i = measurement

y_i' = some ideal value to compare to y_i. It may be
- average of all measurements for the ith parameter
- result of a fit to many points
  ie. $y_i' = f(x_i)$



σ_i = error on ith measurement

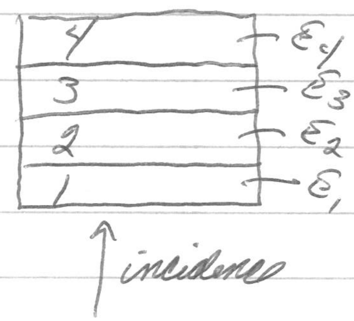
For set of N ~~independent~~ unconstrained measurements

- typical χ^2 should increase $\approx N$
  - we call N the # of degrees-of-freedom

- this could be ~~the~~ # bins in a histogram
- might be # parameters in a multiparameter χ^2

For instance, you might have four layers in a calorimeter:

- you observe an energy fraction of total energy in each layer for a candidate e^-, ε_i



- so the ε_i can be compared to typical ε_i' from, say, test beam electrons

$$\chi^2 = \sum_i \frac{(\varepsilon_i - \varepsilon_i')^2}{\sigma_i^2}$$

Linear Least Squares + Matrices

Consider several parameters x_i that are not necessarily independent

- e.g. previous example, if $\varepsilon_3 = 90\%$, then ε_4 can be no more than 10%

- need a covariance matrix to describe this

$$\sum_i \sum_j [y_i - f(x_i)] V_{ij}^{-1} [y_j - f(x_j)]$$

Example, DØ h-Matrix for electron identification

$$\chi^2 = \sum_i \sum_j (x_i - \langle x_i \rangle) H_{ij}^{-1} (x_j - \langle x_j \rangle)$$

where $H_{ij}^{-1} = \langle (x_i - \langle x_i \rangle)(x_j - \langle x_j \rangle) \rangle$

If the x_i were uncorrelated, then

$$H_{ij}^{-1} = \frac{1}{\sigma_i^2} \delta_{ij} \quad \text{(it's diagonal)}$$

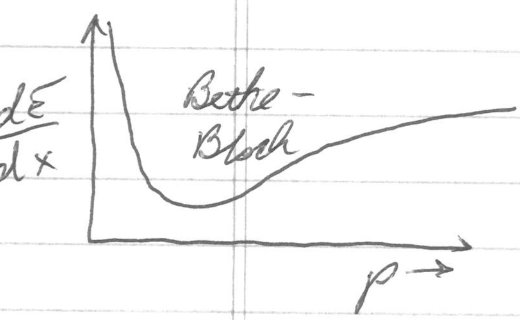
Seperation of e + μ:

Muons
- massive
- bremsstrahlung losses very rare
  - small μ/e confusion can result here

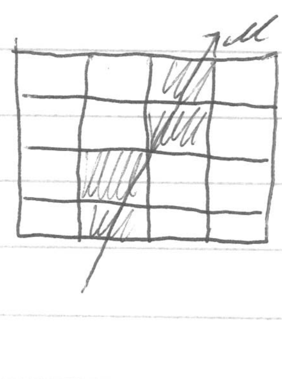
Track of μ plus cluster of γ
→ "looks like "e"

$\mu \to \mu + \gamma$

- do not interact with nucleus via nuclear interaction
- energy loss minimal vs. depth
  - near minimum ionizing level



∴ a μ is not stopped by a calorimeter
- perhaps only 2 GeV in whole device
- long narrow "MIP" trail



Electrons: shower is evident

Indirect Measurement of Neutrinos

As we said, ν's can traverse 10^5 m of material and the rate of interaction $R \sim 10^{-10}$

$\therefore$ in many situations, R effectively zero

How can we infer?

Consider pp collisions (symmetric)

$$\xrightarrow[p_1]{} \quad \xleftarrow[p_2]{}$$

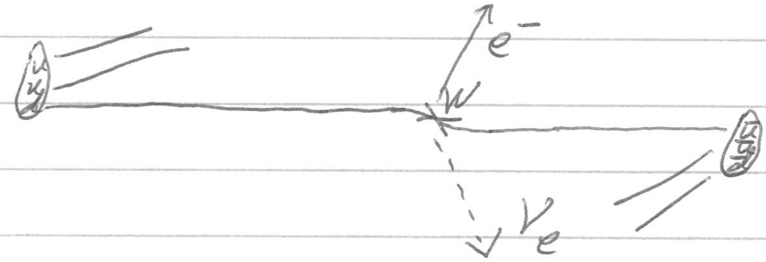
$$\vec{p}_{p_1} = -\vec{p}_{p_2} \qquad p_x = p_y = 0$$

→ however, proton is composite: partons involved in collision
- unknown fraction of energy

$$\vec{p}_{g\xi_1} \neq -\vec{p}_{g\xi_2} \qquad p_x \sim p_y \sim \frac{1}{3} m_p$$

The intrinsic p_T from the initial partons can give $\lesssim 1$ GeV to an event

Consider a $W \to e\nu$ event ($p\bar{p}$ collision)



If observe $p_T^e \sim 40$ GeV, & nothing else,
- implies there was a 40 GeV ν to balance it

Basic method of calculation:

$$``\not{E}_x" = -\sum_i^{\text{cells}} \vec{E}_{x,i}$$

($\vec{E}_{x,i}$ can be < 0 depending on direction to cell)

$$``\not{E}_y" = -\sum_i^{\text{cells}} \vec{E}_{y,i}$$

Calculate the "missing E_T" as

$$\boxed{\not{E}_T = \sqrt{\not{E}_x^{\,2} + \not{E}_y^{\,2}}}$$

Direct Detection & Identification of Neutrinos

Important to observe flavor oscillations between neutrinos

→ search for $\nu_\mu \rightarrow \nu_e$ oscillations (NOvA)

- involves a measure of θ_{13} in mixing matrix

- also depends on CP-violating phase angle
- need a lot of mass to increase R

To identify neutrinos - need to be sensitive to their decay products

- need to <u>track</u> products
  - measure energies ← calorimetry
  - directions
  - particle identification properties ← calorimetry <u>also</u>
    → longitudinal and transverse shower profiles

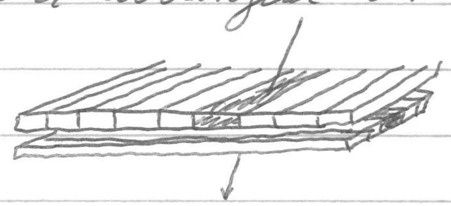
You don't know where ν will interact

∴ need simultaneous tracking and calorimetry

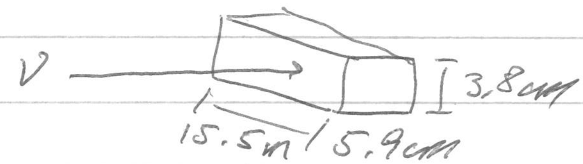
Tracking Calorimeter

→ can be sampling calorimeter
- but want to have active material dominate

- potential construction
  - long tubes of scintillator arranged in a plane

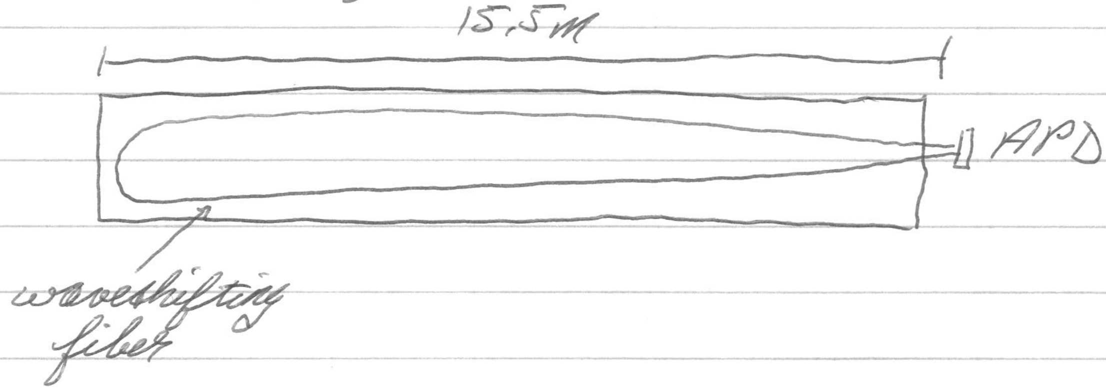


Example: NOvA
- rectangular plastic PVC cells
- 385,000
- alternating vertical and horizontal orientation



- each cell is hollow
  - filled with mineral oil + a scintillator (pseudocumene)
  - $\lambda_{scint} \sim 360-390nm$
    ↳ shifted to 400-450nm range

Wavelength-Shifting Fiber



Each cell a loop of fiber
- capture scintillation light
- bring to photodetector (APD) 85% QE
- shift to longer λ for APD: 520nm-550nm

→ fiber is 700μm polystyrene