Fall 2001

Physics 129 : Problem Set #2

1. a) $p^e_\mu = (30, -30, 0, 0)$ GeV $\quad \overset{p}{\Rightarrow} \overset{e}{\Leftarrow}$

$p^p_\mu = (820, 820, 0, 0)$ GeV

(where I have ignored the masses of e + p relative to their momenta)

$m^2 = (p^e_\mu + p^p_\mu)^2 = (820+30)^2 - (820-30)^2$ GeV^2

$m = \boxed{313 \text{ GeV}}$

b) if e^- hit a stationary proton

$p^e_\mu = (p^e, p^e, 0, 0) \qquad p^p_\mu = (m_p, 0, 0, 0)$

$m^2 = (p^e + m_p)^2 - p^{e\,2} = 2 m_p p^e + m_p^2 \sim 2 m_p p^e$

$\therefore \; p^e = E_{cm}^2 / 2m_p = (313)^2 / 2(.938)$

$= \boxed{5.24 \times 10^4 \text{ GeV}}$

2. a) $\mathcal{L} = 2 \times 10^{32}$ cm^{-2}s^{-1} $\qquad \sigma = 75 \times 10^{-3}$ b

rate $= (2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1})(75 \times 10^{-31} \text{ m}^2 \times 10^4 \frac{\text{cm}^2}{\text{m}^2})$

$= 1.5 \times 10^4$ int/sec

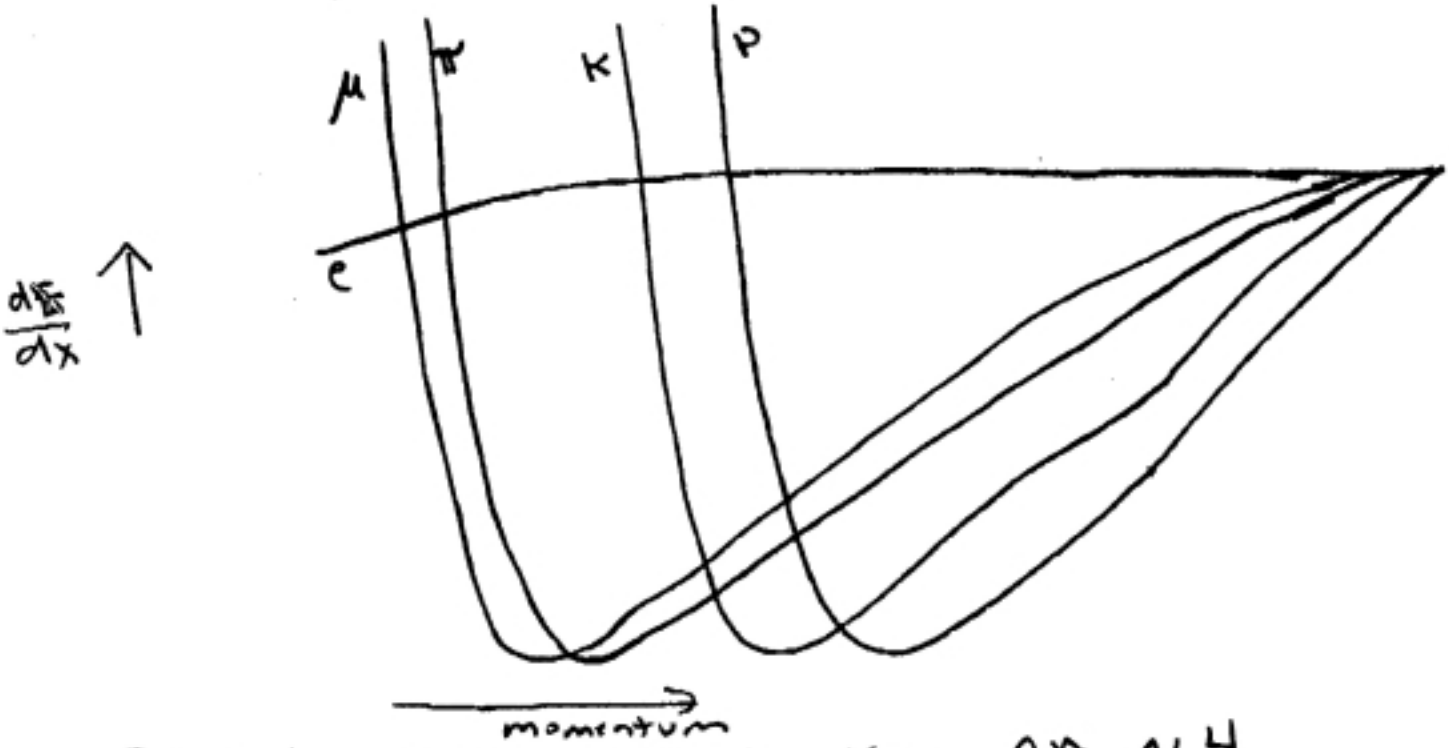
b) $\mathcal{L} = 3 \times 10^{33}$ cm^{-2}s^{-1} $\qquad \sigma = 10^{-9}$ b

rate $= 3 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \times 10^{-9}\text{b} \times 10^{-28} \frac{\text{m}^2}{\text{b}} \times 10^4 \frac{\text{cm}^2}{\text{m}^2}$

$= 3$ int/sec

Note: the difference in rate above reflects the fact that $p\bar{p}$ annihilation occurs via strong interactions but e^+e^- annihilation occurs via electromagnetic.

3a We can take curve 11.6 and relabel the x axis to be a function of $\beta\gamma$ rather than momentum of the muon. Then, since Eq 11.7 depends on β and γ <u>not</u> m, all particles would follow the curve as a fn of $\beta\gamma$. Changing mass changes p for a given $\beta\gamma$ by an amount proportional to mass, so it slides the whole curve right (for heavier masses) or left (for lighter masses). Note: by 100 MeV, the left side of the plot, electrons have already reached the plateau



For each species minimum is a $\beta\gamma \sim 4$

b At low $\beta\gamma$ ("$1/\beta^2$ region") if we know momentum of particle, it is easy to tell its species by measuring dE/dx since the curves are

3b) cont

at very different heights along y axis. But in relativistic region, curves are close together so it becomes more difficult. Once the curves plateau, we can no longer tell species apart.

Note: It is always hard to separate π + μ since their masses are similar (105 vs 138) Also, there are "cross-over points" where two species have same dE/dx for same p, so cannot tell species apart.

4. a) HyperCP (see picture on pg 5)

i. HyperCP is looking for a possible difference in the behavior of matter and antimatter called "CP violation" by studying the decays of Λ and Ξ baryons. We will learn more about CP violation in Perkins ch 3 and ch 7

ii The detector is about 50 m long and 5 m wide (here long means dimension in beam direction and width means dimension $\perp$ to beam)

iii The detectors that makeup HyperCP are:

i) Wire chambers: (C1 through C8) these multiwire proportional chambers have a total of ~18,700 wires. Each chamber consists of 4 layers. two of the

layers measure in the direction ⊥ to the beamline ("in the bend-view") the other two layers are stereo: one at + 26.0° and one at -26.0° from the bend view. These give information in the 3rd direction (into and out of the page on the picture) The chambers measure the trajectory of charged tracks

2) optical trigger and hodoscopes:
these are used to "trigger" what events will be written to magnetic tape for later analysis. A hodoscope is a highly segmented scintillation counter

3) Calorimeter - this is used to measure the energy of particles hitting the detector. It is a sampling calorimeter consisting of layers of scintillator sandwiched between layers of iron. Hadronic showers occur in the iron and are measured in the scintillator

4) Muon detector - Muons are identified by knowing that any particles that are charged and make it out the back end of the calorimeter are likely to be muons (since muons don't shower in the iron of the calorimeter - they don't feel the strong interactions)

5) HyperCP collected data at a rate of 80 KHz. I collected a total of 2.6 billion events.

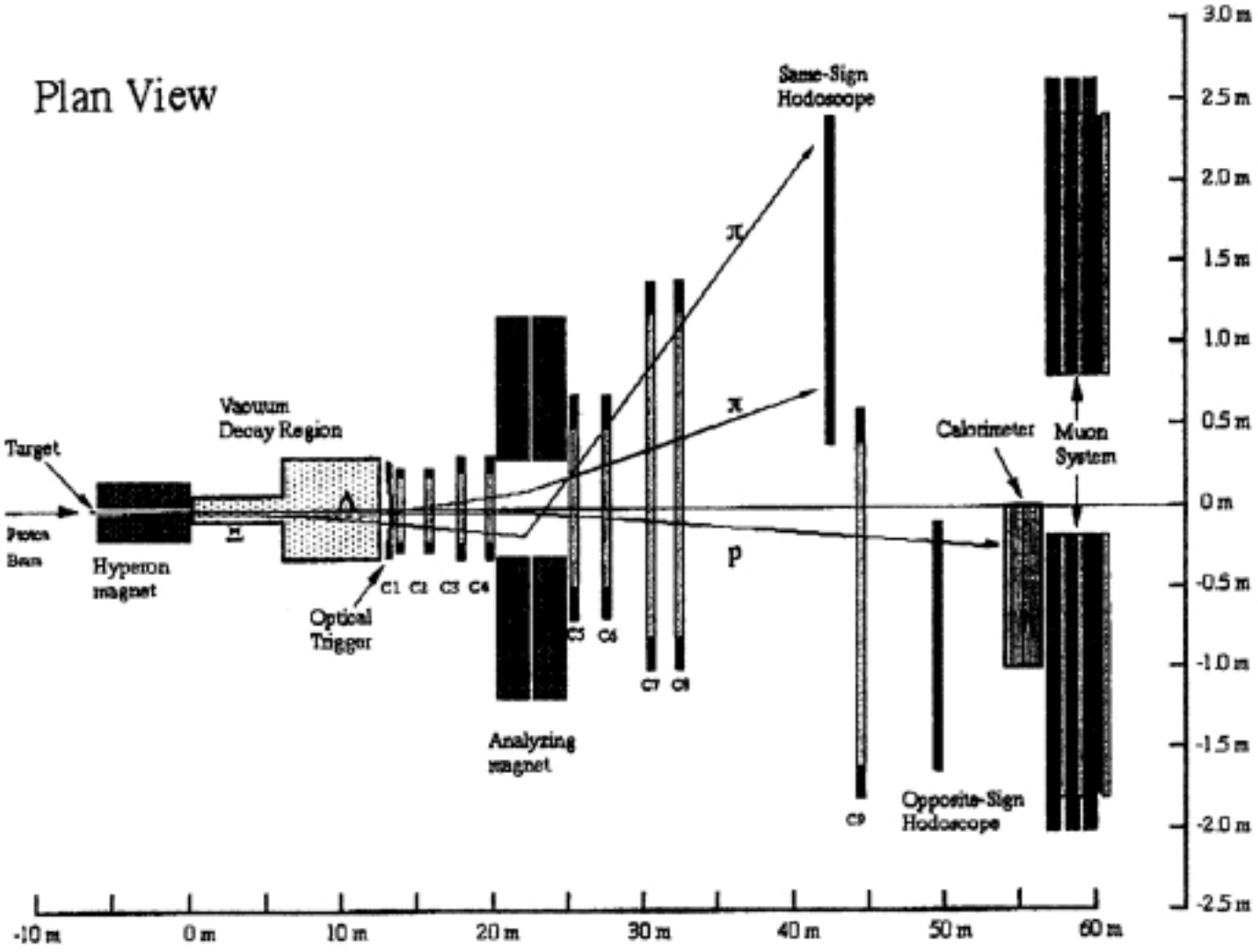
Note: Prof Luk is a member of the HyperCP experiment, if you want to learn more

The HyperCP Spectrometer

The HyperCP spectrometer is the highest-rate particle physics detector in the world, with an ability to record 80,000 events per spill second to tape, or about 15 MB/s. Its salient features, beside high rate, are good charged particle momentum resolution, and good acceptance for Xi -> Lambda + piminus decays.

Elevation View

Click on image to see photos of detector elements



A target assembly consiting of four different targets immediately followed by a collimator with a 4.88 microsr solid angle acceptance embedded in a 6 m long dipole magnet defines a charged secondary beam of 167 GeV/c average momentum, bent up at a 19.5 mrad angle to horizontal. Following a vacuum decay region is a magnetic spectrometer employing nine high-rate, narrow-pitch wire chambers. The switch from Xi to anti-Xi running is done by periodically flipping the polarity of both the hyperon and spectrometer magnets.

b) CDF (Collider Detector at Fermilab)

1. CDF will study $p\bar{p}$ interactions at a center-of-mass energy of 2 TeV. Many different final states are produced in these interactions, so CDF has a broad physics program. Some of its physics goals are:

- study properties of the top quark (eg mass, production cross section, decay rates): the top was first discovered in 1995 by CDF and concurrently by DØ (papers from the 2 experiments appeared in the same issue of the Journal Physical Review Letters). Each experiment has only seen <100 top events so far. In run II, CDF (and DØ) will see thousands of tops
- measure precisely the W mass
  The W boson causes β decay and other weak decays. In the Standard Model, its mass is predicted as a function of the top mass, a parameter called the weak angle and the mass of a still undiscovered particle called the Higgs. A precise measurement of the W mass therefore helps constrain the possible mass of the Higgs
- Study B decays - CDF will see many thousands of B decays. While the Babar experiment is also studying B mesons, CDF can produce some kinds of B species that are

too heavy to make at Babar. In particular, the B_s.

(A) CDF is roughly 20 m long (along beam direction) 12 m high

(AA) Detector Components

a) Silicon detectors - Used to measure charged particle trajectories, with an emphasis on good position resolution so the lifetime of short-lived particles can be measured. There are 3 subsystems:

"layer 00" very close to beampipe
"SVX-II" 3 barrels with 5 layers of silicon
"ISL" 3 layers at larger radius

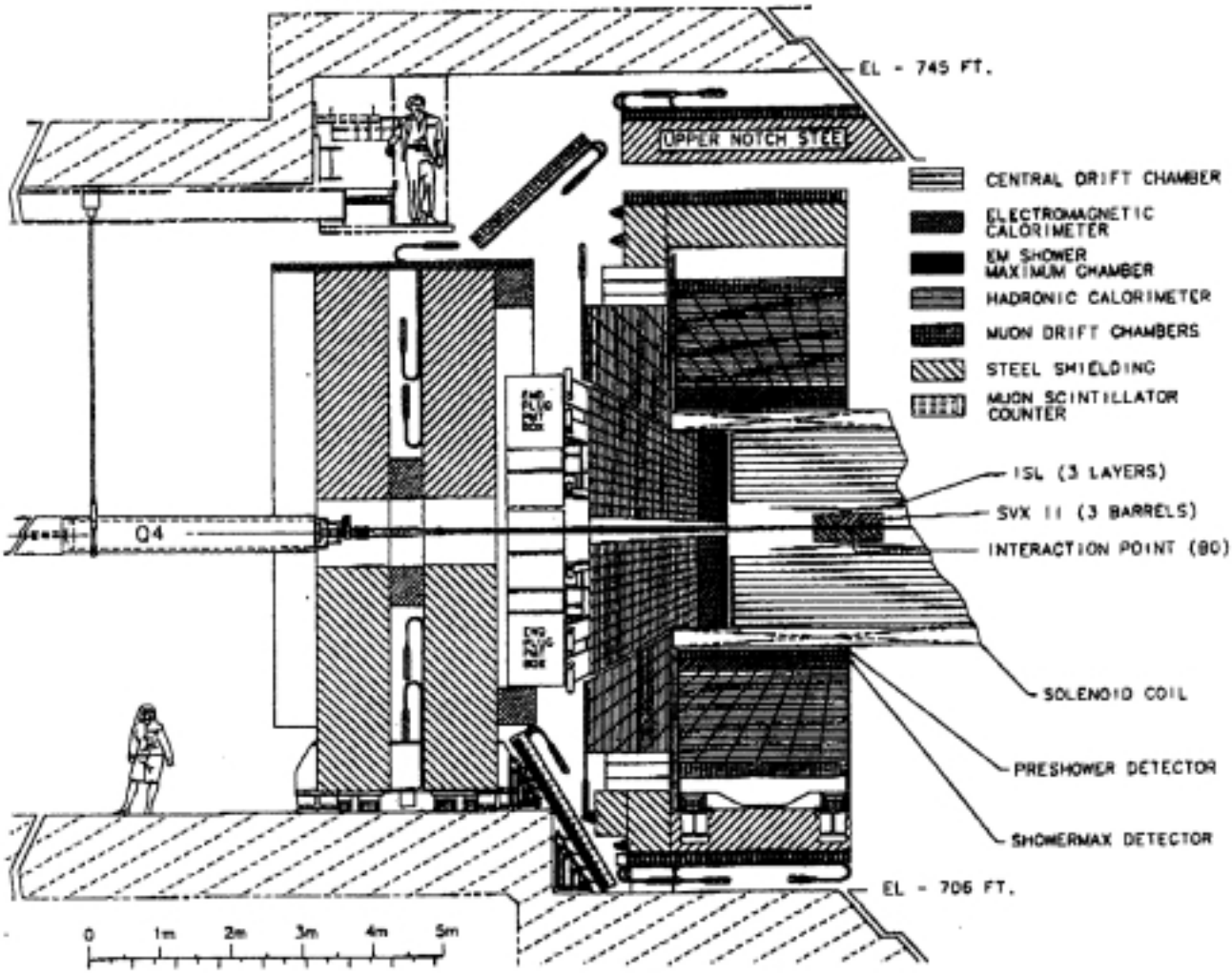
b) COT - this is a large cylindrical drift chamber used to measure the trajectory of charged particles. Each charged particle that makes it to the outer radius of the COT passes 96 drift wires.

The COT and Silicon detectors are inside a 1.4 T magnetic field (solenoid), so it is possible to measure charged particle momenta

c) Calorimeters - The electromagnetic calorimeters measure the energy of photons, π^0's and electrons. The hadron calorimeters measure the energy of π, K, P, n, There are

Calorimeters surrounding the tracking detectors (outside the magnet) for most of the solid angle

d) Muon detectors - particles that make it out the back of the calorimeter are likely to be muons CDF has a variety of muon detectors

iv) CDF will collect an integrated luminosity of about 2 fb^{-1} (this is $\int \mathcal{L}\, dt$ where t is the time the detector is collecting data)

The total number of events collected in a 2 year run is about 10^9