Lecture 23

Q: What is the flux factor at the LHC ?

Flux Factor also called L "instantaneous luminosity" or just "luminosity"

$$L = n_A n_B A l |v_A - v_B| = \frac{N_A N_B |v_A - v_B|}{\underbrace{Vol}_{\text{Vol. of bunch} = A_B \times l}}$$

Now σ is fixed, so to maximize number of events collected, need to maximize L

- $N_A = N_B = N = 10^{11}$ (fixed)
- $|v_A - v_B| = 2c$ can get much higher!
- Vol $\sim A_B \cdot l$

At the LHC, acceleration is done with radio-frequency EM feild that fixes l (Protons ride in the troughs of this feild) The wavelength of this feild sets $l \sim \frac{c}{2\times 400 \text{ MHz}} \sim \frac{3}{4} m$ The one handle we have is A_B, focusing magnets (quadruples) act like a lens near the collision points to squeeze the beam. So far focusing magnets have achieved squeezing down to the radii of 10 μm! Width of a human hair.

$$A_B \sim 10^{-10} \, m^2$$

$\Rightarrow$

$$L = 2c \frac{N^2}{lA} \sim 10^{-36} cm^{-2} s^{-1}$$

Talk a bit about Accelerators

Particles moving in a circle are accelerating.

Accelerating charged partilces ratiate. (synchrotron radiation)

Turns out, power lost to synchrotron radiation given by:

$$P \sim 0.3 \left(\frac{1 \text{ km}}{R}\right)^2 \left(\frac{E}{m}\right)^4 \frac{\text{eV}}{s}$$

For LHC:

- $\frac{E}{m} \sim 7000$
- $R_{LHC} \sim \frac{27\text{km}}{2\pi}$

$$P \sim 10^5 \frac{\text{GeV}}{\text{s}}$$

This is a major drawback of a circular collider.

To keep protins in circle need thosands of superconducting bending magnets.

$$|\vec{B}| = \frac{|\vec{p}|}{eR_{curv}} \sim 3\frac{E(\text{TeV})}{R(\text{km})}\text{Tesla}$$

$\Rightarrow$

$$E(\text{TeV}) \sim \frac{1}{3} B(T) R(km)$$

Most restrictive constraint on increasing the energy at the LHC.

Modern superconducting magnets have max strength of ~ 20 T.

With current technologies need larger ring to go to significantly higher energy.

Efforts now underway for ~ 100 TeV collider (100 km in Geneva)

China also planning something similar.

Bunches

Lets try to build some intuition around the bunches.

Say earlier that they have the diminsions of a long strand of human hair.

- $l \sim 0.40$ m
- $A_B \sim (10^{-3}\text{ m})^2$
- $\text{vol}_{\text{bunch}} \sim 10^{-6}\text{ m}^3$
- $\text{vol}_{\text{protons}} \sim 10^{11} r_p^3 \sim 10^{-34}\text{ m}^3$
- $\frac{vol_{proton}}{vol_{bunch}} \sim 10^{-28}$

Proton beams are mostly empty

$\Rightarrow$ Hard to get them to collide.

Focusing Magnets squeeze beam size

$A_B \sim (10^{-5}\text{ m})^2 \Rightarrow v_{bunch} \sim 10^{-10}\text{m}^3$

Decrease in Vol_{bunch} by 10^4 critical for physics program at LHC.

Detectors

Once bunches are accelerated they are made to collide (Every 25ns at LHC)

When protons collide and exchange large amount of momentum, create shower of partilces from collision point.

$$\underbrace{|p_1 p_2\rangle_I}_{t=-\infty} \rightarrow \underbrace{|\{p_f^i \dots p_f^n\}\rangle}_{t=+\infty}$$

Dynamics of the collision is imprinted on the final state particles.

eg:

- Energy Conservation
- Momentum Conservation
- Charge Conservation

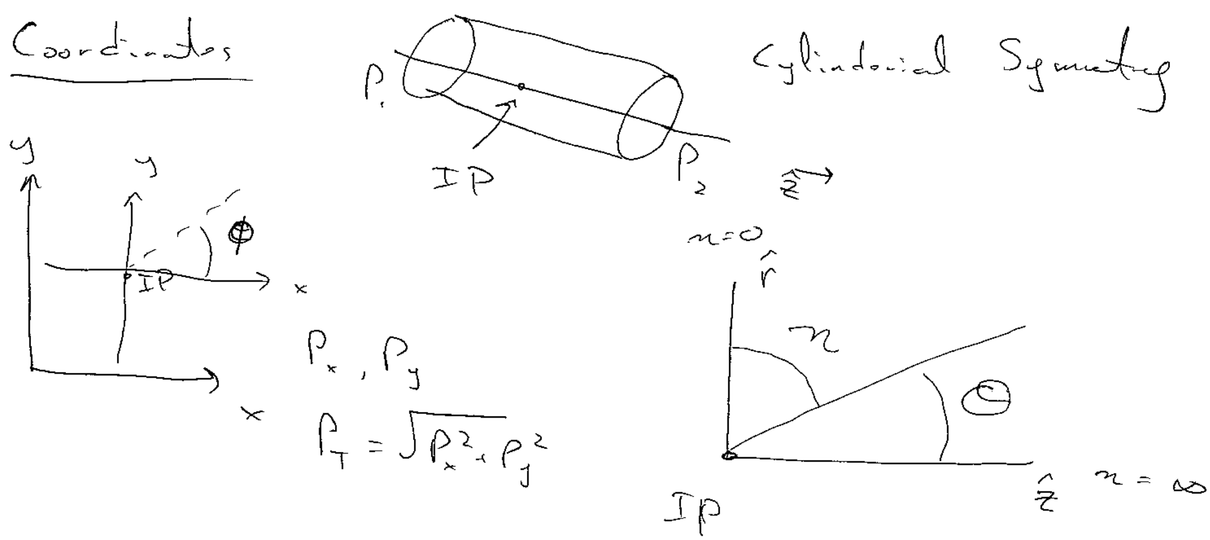
- etc

We want to measure as many particles and properties as possible.

"Easy" to measure	E and $\vec{p}$ ($\Rightarrow m = \sqrt{E^2 - p^2}$) charge of leptons and hadrons
"Hard" to measure	Angular $\vec{p}$ or Spin Charge of quarks

Detectors not built to be sensitive to spins.

<u>Coordinates</u>



"pseudo-rapidity" (Explore this in HW)

$$\eta = -\ln \tan \frac{\theta}{2}$$

"rapidity"

$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$

$\eta = y$ for massless particles.

We know $p_T^I = 0$, we dont know p_Z^I, so we are often interested in variables (like p_T) that are independent of Boosts along z.

Massless particle: $p^\mu = p_T(\cosh\eta, \cos\phi, \sin\phi, \sinh\eta)$

Massive particle: $p^\mu = (m_T \cosh y, p_T \cos\phi, p_T sin\phi, m_T \sinh y)$
where $m_T = \sqrt{p_T^2 + m^2}$ is called the "transverse mass", invariant to boosts along z

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In order to be detected, a partilce must undergo an interaction with detector material. (Again this is an enormous subject, we will only scratch surface)

Typically talk abou thow partilces loose energy to the detectors.

Three key mechanisms:

- Ionisation Energy loss
- Radiation Energy loss
- Nuclear Interactions