Teilchenphysik II (Higgs-Physik) (SS 2016)

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Exercises Sheet 08

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Exercise 27: (Pseudo-)Rapidity (homework)

In the lecture you have seen the definition of the rapidity

$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

and the pseudorapidity

$$\eta = -\ln\left(\tan(\vartheta/2)\right)$$

of a particle with energy momentum vector (E, p_x, p_y, p_z), where ϑ is the angle of the particle relative to the z-axis in the laboratory frame.

a) Show that the rapidity is a form invariant quantiy under *Lorentz* transformations along the z-axis, i.e. under such tranformations y is shifted by a constant offset that only depends on the transformation itself and not on y. Hint: a reminder of the *Lorentz* transformation along the z-axis:

$$E' = \gamma(E - \beta p_z)$$
$$p'_z = \gamma(p_z - \beta E)\,.$$

where $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ and $\beta = v_z/c$ is the velocity of the particle along the z-direction divided by the speed of light, c. What is the rapidity of a particle with $\beta = 0, 0.1, 0.5, 0.9, 0.99$ in direction of the z-axis in the laboratory frame?

b) Show that for $E \gg m$ the rapidity turns into the pseudorapidity. Hint the following trigonometric relations will be useful for this calculation:

$$\cos\alpha^2 + \sin\alpha^2 = 1 \qquad \cos\alpha\cos\beta - \sin\alpha\sin\beta = \cos(\alpha+\beta)$$

The big advantage of the pseudorapidity is that it only requires to measure an angle in the detector and no energies.

Exercise 28: Event Yields and Luminosities (homework)

The instantaneous luminosity ($\mathcal{L}$) of the LHC can be calculated from its beam parameters

$$\mathcal{L} = \frac{fN^2}{4\pi\sigma^2}F(\theta)$$

with the following parameters:

- f, the bunch crossing frequency ($\rightarrow$ 40 MHz);
- N, the number of protons per bunch ($\rightarrow 10^{11}$);

- σ, the mean diameter of the beam ($\rightarrow 17\,\mu$m);
- $F(\theta)$, a reduction function, which depends e.g. on the crossing angle of the two beams ($\rightarrow 0.85$).

All values are given for nominal running in design configuration at 14 TeV. For particle physics the quantity of interest is the integrated luminosity

$$\mathcal{L}_{int} = \int \mathcal{L}\mathrm{d}t\,.$$

a) Calculate the nominal luminosity of the LHC at a center of mass energy of 14 TeV. Note: cross sections in particle physics are calculated in "barn". One barn corresponds to $1b = 10^{-24}$ cm^2. Give the value of the instantaneous luminosity in cm^{-2}s^{-1} and in μb^{-1}s^{-1}. How much stable beam time does it require to collect 300fb^{-1} of integrated luminosity?

b) the total inelastic pp cross section at 14 TeV is $\sigma_{inel}(pp) \approx 85$ mb. Calculate the number of inelastic pp reactions per second under these running conditions. How many inelastic pp reactions does this correspond to per bunch crosing?

c) In the following the cross section for a few more exclusive scattering processes are given:

- $\sigma(pp \rightarrow Z + X, Z \rightarrow \ell\ell) = 3380$ pb (cross section per lepton flavor);
- $\sigma(pp \rightarrow W + X, W \rightarrow \ell\nu) = 21872$ pb (cross section per lepton flavor);
- $\sigma(pp \rightarrow t\bar{t}) = 880$ pb (inclusive);
- $\sigma(pp \rightarrow H + X) = 53$ pb (gluon fusion only, for a SM Higgs boson with $m_H = 125$ GeV).

A typical beam lifetime during physics data taking is 15 hours. Calculate how many of the corresponding particles are produced during one beam cycle in the collision point at CMS.

d) Assume that you have simulated 100'000 events of type $pp \rightarrow H + X$ (gluon fusion only, for a SM Higgs boson with $m_H = 125$ GeV) and 100'000 events of type $pp \rightarrow Z + X, Z \rightarrow \ell\ell$ with a MC event generator. To what integrated luminosity do these numbers of generated events correspond to? What normalization factors would you have to apply to normalize them to the same integrated luminosity of 300 fb^{-1}? How many events would you have to simulate to arrive at an event weight of ≈ 1?