Drell–Yan process at Large Hadron Collider

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Abstract. Drell–Yan process at LHC, $q\bar{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$, is one of the benchmarks for confirmation of Standard Model at TeV energy scale. Since the theoretical prediction for the rate is precise and the final state is clean as well as relatively easy to measure, the process can be studied at the LHC even at relatively low luminosity. Importantly, the Drell–Yan process is an irreducible background to several searches of beyond Standard Model physics and hence the rates at LHC energies need to be measured accurately. In the present study, the methods for measurement of the Drell–Yan mass spectrum and the estimation of the cross-section have been developed for LHC operation at the centre-of-mass energy of 10 TeV and an integrated luminosity of 100 pb$^{-1}$ in the context of CMS experiment.

Keywords. Drell–Yan; Linear Hadron Collider; compact moun solenoid.

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1. Introduction

The production of opposite sign charged lepton pairs in hadron–hadron collision is called the Drell–Yan process [1] first studied with muon final states. In Standard Model (SM) it is described by $s$-channel exchange of a photon ($\gamma$) or a $Z$-boson: $q\bar{q} \rightarrow Z/\gamma \rightarrow \ell^+\ell^-$. In SM, the invariant mass spectrum of the leptons is a continuously falling spectrum with a resonance peak at $Z$-mass value. Around the $Z$ peak, the heavy boson exchange process is dominating and the interference term is vanishing. At higher and lower energies, both the photon and $Z$ exchanges contribute resulting in a large amount of forward–backward asymmetry. As the theoretical prediction for the rate is precise and the final state is clean as well as relatively easy to measure, the process can be studied from the start-up phase of the Large Hadron Collider (LHC) with relatively low luminosity. Surely with increasingly accumulated luminosity, the mass reach will be higher and more interesting.

The fermion-pair production above the $Z$ pole is a rich search field for new phenomena at the present and the future high energy colliders (see e.g. [2] and references therein).

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Hence the Drell–Yan (DY) process is an irreducible background to several searches beyond SM physics, like, production of additional, heavier, neutral gauge boson $Z'$ whose decay branching to charged lepton pair varies according to the model specifications.

The total cross-section takes into account the s-channel contributions by $\gamma$, $Z$ and any other possible New-Physics candidate, like, $Z'$, as mentioned earlier. The angular differential cross-section in the centre-of-mass system has the form

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s}[A_0(1 + \cos^2 \theta) + A_1 \cos \theta],$$

where $\sigma = \frac{4\pi\alpha^2}{3s}A_0$ and $A_{FB} = \frac{3}{8}A_1A_0$ gives the total cross-section and the forward–backward asymmetry, respectively. The terms $A_0$ and $A_1$ are fully determined in SM by the electroweak couplings of the initial- and final-state fermions. Thus the total cross-section and the forward–backward asymmetry as functions of the invariant mass and the rapidity of the final-state lepton pair are good observables to search for New Physics which can be measured well experimentally at the LHC in leptonic final states.

In proton–proton collisions the antiquark in the initial state is from the sea and the quark can have valence or sea origin. At a hadron collider operating at a centre-of-mass energy of $\sqrt{s}$, the momentum fractions carried by the initial-state partons, $x_1$ and $x_2$.