Measuring Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ Production in the LHC with the ATLAS Experiment

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Abstract.

Work is ongoing to measure the cross section of the exclusive production of opposite charge muon pairs in 4.6 fb^{-1} of ATLAS data collected at a centre of mass energy of 7 TeV in 2011. The results are compared to a similar analysis done by the CMS collaboration[1] on 40 pb^{-1} of data collected in 2010. The higher instantaneous luminosities of the 2011 run presents an interesting challenge in this analysis which is sensitive to pile-up. The preliminary results are seen to be generally consistent with the results found by CMS.

1. Introduction and Theory

Exclusive interactions in this context occur when two charged hadrons interact via photon exchange and escape the interaction intact while at the same time creating particle/antiparticle pair. In this case the production of di-muon pairs in proton-proton collisions in the Large Hadron Collider are considered.

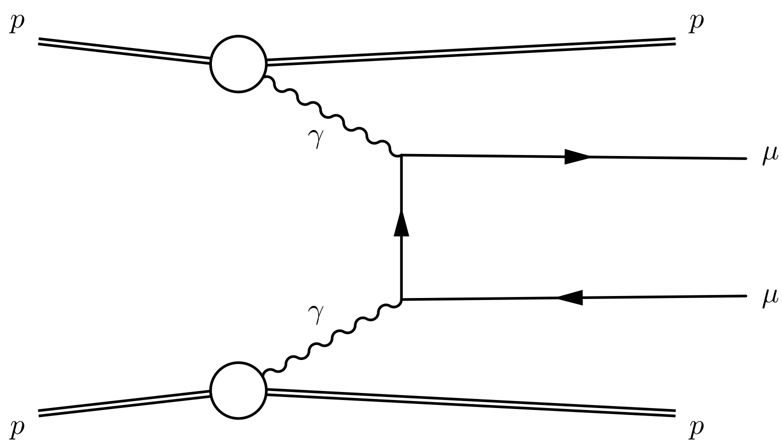

Figure 1: Feynman Diagram of the Exclusive Process

Exclusive production is a process well described by Quantum Electrodynamics and as such measuring the cross-section allows for a precise test of the Standard Model. The process is best described by the Equivalent Photon Approximation (EPA)[2] in which the Coulomb field of a fast moving charged particle can be approximately treated as a packet of free electromagnetic waves.

Di-muon production is being considered due to the accuracy with which muons can be tracked by the ATLAS detector.

Figure 1 shows the Feynman diagram of the signal process. As can be seen, there are two protons and two muons in the final state. Although there are four particles in the final state, the protons are only deflected by a small angle and are not seen by the detector. As such the only information about the process comes from the two muons. Thus in an ideal case our final state signal is one with two opposite sign muons coming from a vertex, with no other tracks associated with that vertex.

In addition to our signal process there are several processes which produce final states which (to the detector at least) look very similar. The first case is the Single Dissociative case, so called because one of the protons dissociates (i.e. breaks apart) in the process.

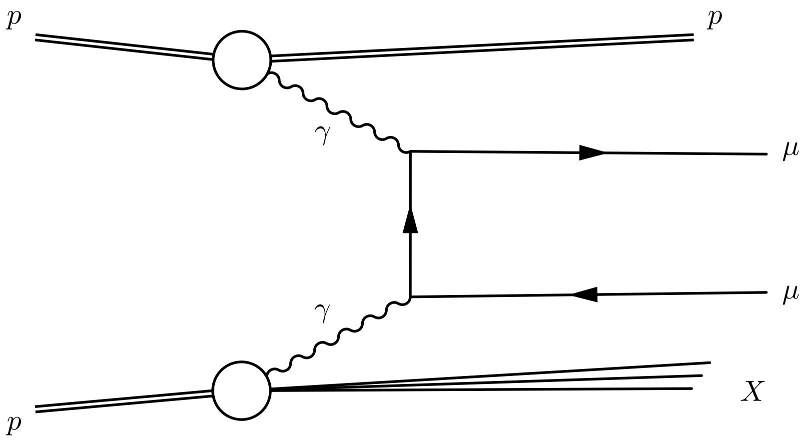

Figure 2: Feynman Diagram of the Single Dissociative Process

Although the final state does not contain two intact protons the small angle at which the hadronized constituents of the proton are deflected by means that these products are most likely invisible to the detector, making it hard to discriminate a single dissociative process from a purely exclusive one.

The case is similar for the Double Dissociative case, as seen in figure 3, in which both protons break apart. Again, due to the small angle of deflection it is quite possible that the detector only sees two muons in the final state.

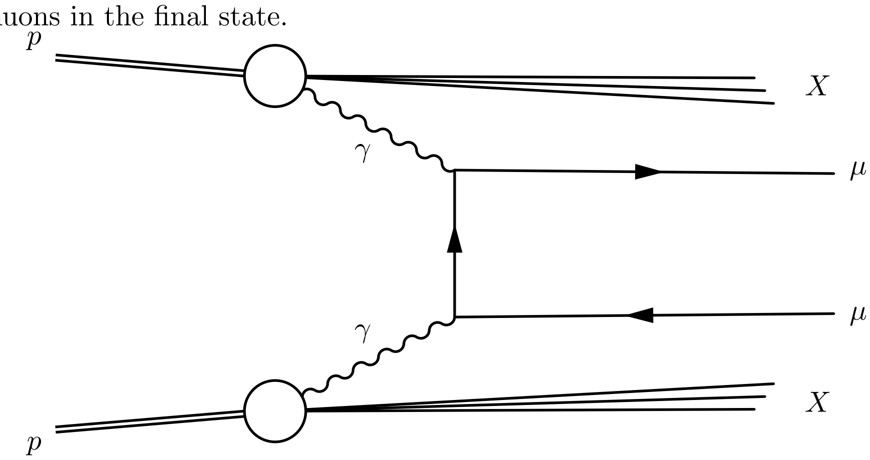

Figure 3: Feynman Diagram of the Double Dissociative Process

The final case which contributes to the signal-like processes is due to Drell-Yan processes, shown if figure 4

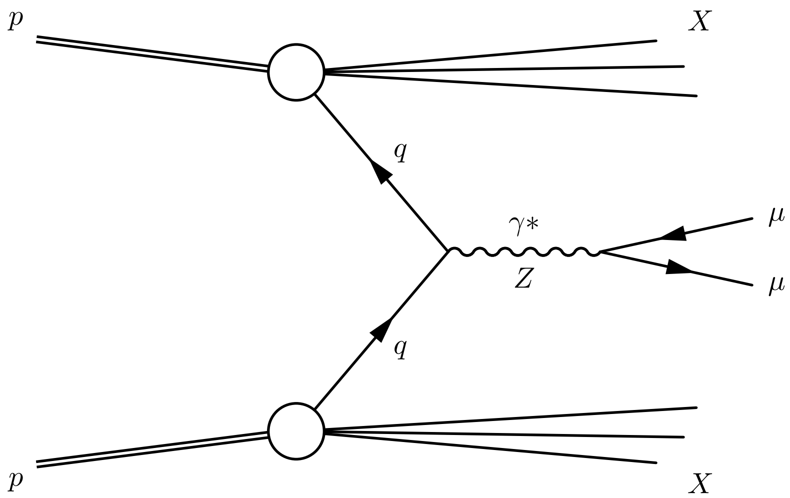

Figure 4: Feynman Diagram of the Drell-Yan Process

In a Drell-Yan process, a quark in one proton annihilates with an anti-quark in the other proton, resulting (in this case) in two opposite sign muons. Again, the protons break apart and hadronize, sometimes resulting in extra tracks seen by the detector. Although the Drell-Yan process is significantly different from the Exclusive process and has different kinematic characteristics, the much higher cross-section of the Drell-Yan process means that at least some of the events will have a similar profile to the exclusive case.

There are thus many non-exclusive processes which fulfil our criteria of having two muons originating from the same vertex. In order to improve signal efficiency selection criteria based on the kinematics of the Exclusive process are applied to the data.

For the Exclusive process we expect the energy of the photons to be very similar, thus resulting in a central state which is not boosted in the transverse plane. The criteria we can thus apply is by checking for muons with very similar p_T, thus with a low Δp_T. Also as there is no transverse boost, we expect the muons to be "back-to-back", i.e. have a low acoplanarity, where acoplanarity is defined as: $1 - |\Delta\phi/\pi|$. Additionally a cut is applied to the 3-dimensional opening angle to prevent contamination from cosmic rays.

Table 1 shows the basic selection criteria.

Table 1: Signal Selection Criteria

Parameter	Accepted Values
$\mid \eta \mid$	< 2.4
p_T	> 10 GeV
tracks per vertex	$= 2$
vertex exclusivity	$= 3$mm
$M_{\mu\mu}$	20-60 GeV
Δp_T	< 1.5 GeV
Acoplanarity	< 0.008
θ_{3D}	$< 0.95\pi$

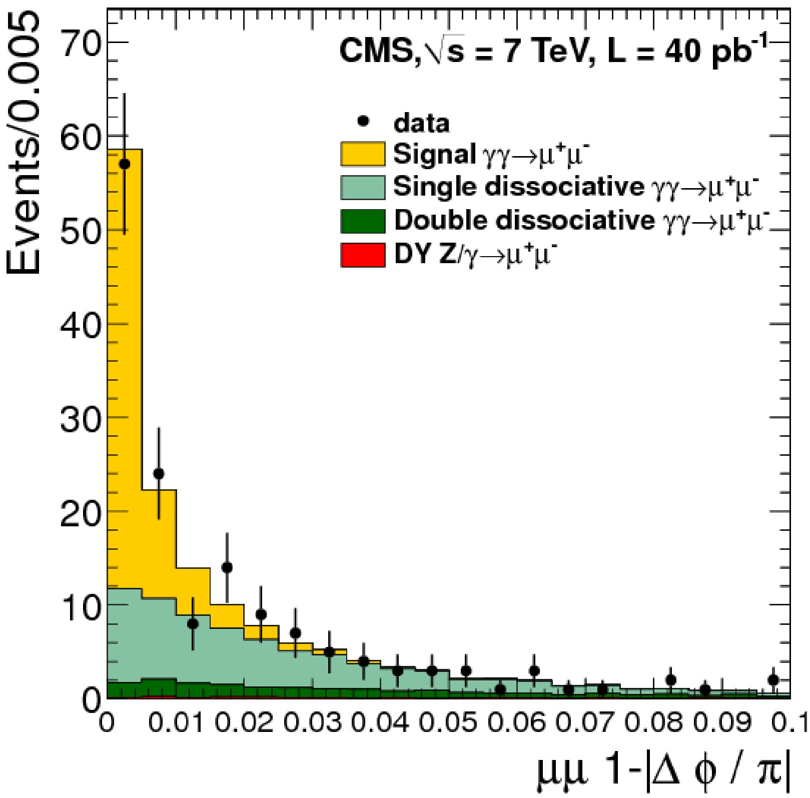

Figure 5: Acoplanity of Muon Pair
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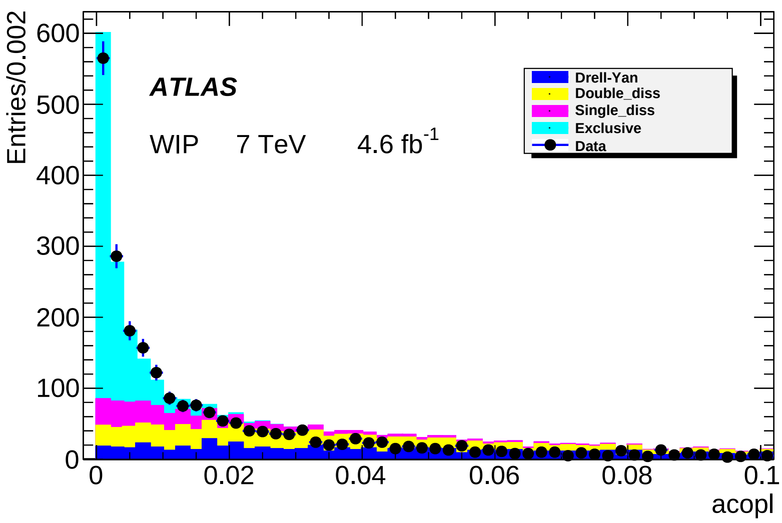

Figure 6: Acoplanity of Muon Pair

2. Results

The results are compared to that of an analysis by CMS [1]. One of the main differences between the analyses is that in the case of the CMS analysis, an additional criteria was applied that selected only collision events in which a singe vertex was present. This has the advantage that all tracks in the event must be due to the single vertex, thus misreconstructed tracks are not a problem. This becomes significantly less favourable at higher luminosities where the probability of a single vertex event becomes rare. The cut on vertex exclusivity used in this analysis (i.e. the requirement that there cannot be another vertex or track within 3 mm of the candidate vertex) removes most of the background contamination, but some events still make it through. As can be seen in figure 6 when compared to 5, the contamination due to Drell-Yan processes is more significant, but the results are still generally consistent with the measurements made by CMS.

In conclusion it can be seen that despite the higher pile-up environment an analysis such as this one seems feasible due to the accuracy of the ATLAS detector. It remains to be seen if this will hold true for Run 2, but it does not seem impossible.

References

[1] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1201** (2012) 052

[2] V. M. Budnev, I. F. Ginzburg, G. V. Meledin and V. G. Serbo, Phys. Rept. **15** (1975) 181.