Study of $W^{\pm}$ boson in the ALICE muon spectrometer: considerations and analysis using the HLT tool

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Abstract
$W^{\pm}$ bosons produced in proton-proton collisions can be observed in the ALICE muon spectrometer via their decay into single muons at a transverse momentum, $p_t \sim M_w/2 \cong 40$ GeV/c. However the identification of these single muons is complicated by a large amount of muonic background, especially in the low p_t region. Therefore, it is necessary to apply precise p_t cuts below the region of interest. This can be done by means of the High Level Trigger (HLT). In this paper we present the performance of detecting high p_t muons at the HLT level. In order to improve the momentum resolution of the L0 trigger, fast clusterization of the tracking chambers together with L0 trigger matching and fast tracking reconstruction is applied. This will reduce the background in the high p_t muon analysis.

1 Introduction

In this paper we discuss the study of W bosons produced in proton-proton collisions up to the maximum Large Hadron Collider (LHC) energy of $\sqrt{s} = 14$ TeV. In particular, we focus our discussion on the role played by the High Level Trigger (HLT) [1, 5] in the analysis of the reconstructed single muons produced directly by the decay of W bosons ($W \rightarrow \mu\upsilon$) in the ALICE muon spectrometer. While a detailed description of the spectrometer is given elsewhere [1, 2], only a summarized description is given here.

The ALICE muon spectrometer is designed to accommodate 10 tracking planes consisting of several hundreds of high resolution cathode pad chambers, a large warm dipole magnet, front absorbers, muon filter and two sets of fast trigger planes consisting of around 80 resistive plate chambers, with moderate space resolution. It covers a polar acceptance angle of $2° < \theta < 9°$. The main aim of the spectrometer is to measure the production of heavy-quark resonances *via* their decay into pairs of muons to an accuracy of 1% - 2% on their mass resolution [1, 6]. As demonstrated in the previous study [3-4], the acceptance of the spectrometer will make it possible to probe parton distribution functions (PDF) at small Bjorken ranges, $x \in (10^{-4} - 10^{-3})$ and, since W bosons are produced in primary hard collisions they will allow binary scaling cross checks in nucleus-nucleus, proton-nucleus or nucleus-proton collisions. They can also be used as references to observe Quark Gluon Plasma (QGP) induced effects on other probes, e.g. suppression of high p_t muons from heavy quarks. In the spectrometer single muons can be reconstructed up to momenta of about 1 TeV and efficiencies of ~ 96% and ~ 94% can be obtained for single muons with p_t between 5 GeV/c and 60 GeV/c in proton-proton and lead-lead collisions, respectively [4]. Although muons from the decay of W resonances are produced with a relatively high $p_t \sim M_w/2 \cong 40$ GeV/c identifying these muons is not simple because of muonic contributions due to open charm and beauty, with their p_t spread over a wide region and dominating at low p_t region. Thus, it is crucial to apply precise p_t cuts below our region of interest, i.e. $p_t < 30$ GeV/c. This can be accomplished by means of the muon HLT [5]. Due to the limited spatial resolution of trigger chambers a p_t cut higher than few GeV with the L0 trigger is not possible. In ALICE the trigger signals are issued based on the series of levels varying from levels 0 (L0) up to the HLT level [1, 4]. The role of the muon spectrometer trigger is to select events containing muon tracks, with p_t above a given threshold. While the L0 signal of the muon spectrometer is issued at about 700 - 800 ns the HLT is delivered at about 1ms.

In this paper we present the performance of the high p_t muon trigger at the HLT level in order to improve the momentum resolution of the L0 trigger level. This is achievable by means of a fast clusterization of the tracking chambers, L0 trigger matching and fast tracking reconstruction. Such a trigger will reduce background for a high p_t muon analysis in proton-proton collisions at 14 TeV.

2 Generation of W in proton-proton collisions

The simulations for the production of W boson in proton-proton collisions at LHC energy, $\sqrt{s}$ = 14 TeV, were performed using the event generator PYTHIA 6.2 [7] in AliRoot [8] framework. This was accomplished by considering the 2→1 processes ($f\bar{f} \to W$), with initial and final state radiation turned on. The muon spectra were then generated by forcing W to decay either directly into single muons ($W \to \mu\upsilon$) or via charmed decay ($W \to cX$, $W \to c\bar{s}$) and in all cases the parton distribution function, CTEQ4L PDF [9], was taken into account. The differential cross sections were extracted according to the formulism of Frixione and Mangano [11] making use of the PYTHIA calculated cross section (which takes into account the branching ratio of the decay channel) of 17.23 nb, which was re-normalized according to the NLO theoretical cross section, NLO = 20.9 nb [10-11].

Fig. 1 (a) and (b) represent differential production cross sections as a function of transverse momentum in full phase space (4π) for $W^{\pm}$ and single muons ($\mu^{\pm}$), respectively. In Fig. 1 (a), as expected, W^+ has a higher production cross section than W^- because for proton-proton collisions at LHC energies the production of W^+ is dominated by the coupling of the $u\bar{d}$ quarks while W^- is dominated by $d\bar{u}$ quarks [12] and in proton-proton collisions there are more up (*u*) than down (*d*) quarks, i.e. $N_u \sim 2N_d$. Accordingly, as shown in Fig. 1(b) μ^+ has a higher production cross section than μ^-. Also, $W^{\pm}$ are peaked at low p_t (< 10 GeV/c) because most of their momenta are carried forward by quarks while in Fig.1 (b), $\mu^{\pm}$ are peaked at $p_t = M_w/2 = 30 \sim 42$ GeV/c, because they are emitted when $W^{\pm}$ decay at rest.

Fig.2 (a) shows the reconstructed single muon differential cross sections as a function of p_t in the ALICE Muon Spectrometer while Fig.2 (b) gives the corresponding μ^+ / μ^- ratio. For the reconstruction we took into account the following parameter settings: $171° < \theta < 178°$, $-4.0 < \eta < -2.4$, $p_t > 1.0$ GeV/c and $p > 4.0$ GeV/c, where θ is the opening angle of the spectrometer and η is the pseudo-rapidity. In Fig 2 (a) both μ^+ and μ^- are peaked at high $p_t = 30 \sim 42$ GeV/c, as per expectation, and only 14 % of the reconstructed W single muon events are accepted in the spectrometer. The comparison of Fig.2 (a) and Fig.1 (b) shows that reconstruction through the spectrometer has a significant effect on the shape of $\mu^{\pm}$ pt distributions. The low p_t tail (< 20 GeV/c) shown in Fig.1 (b) which indicates contributions from unwanted background is significantly reduced in Fig.2 (a). This is indicated by the high p_t muon charge asymmetry which is exhibited in Fig. 2 (b) where the μ^+/μ^- ratio deviates from unity as p_t increases. This high p_t region can be used to study the W charge asymmetry.

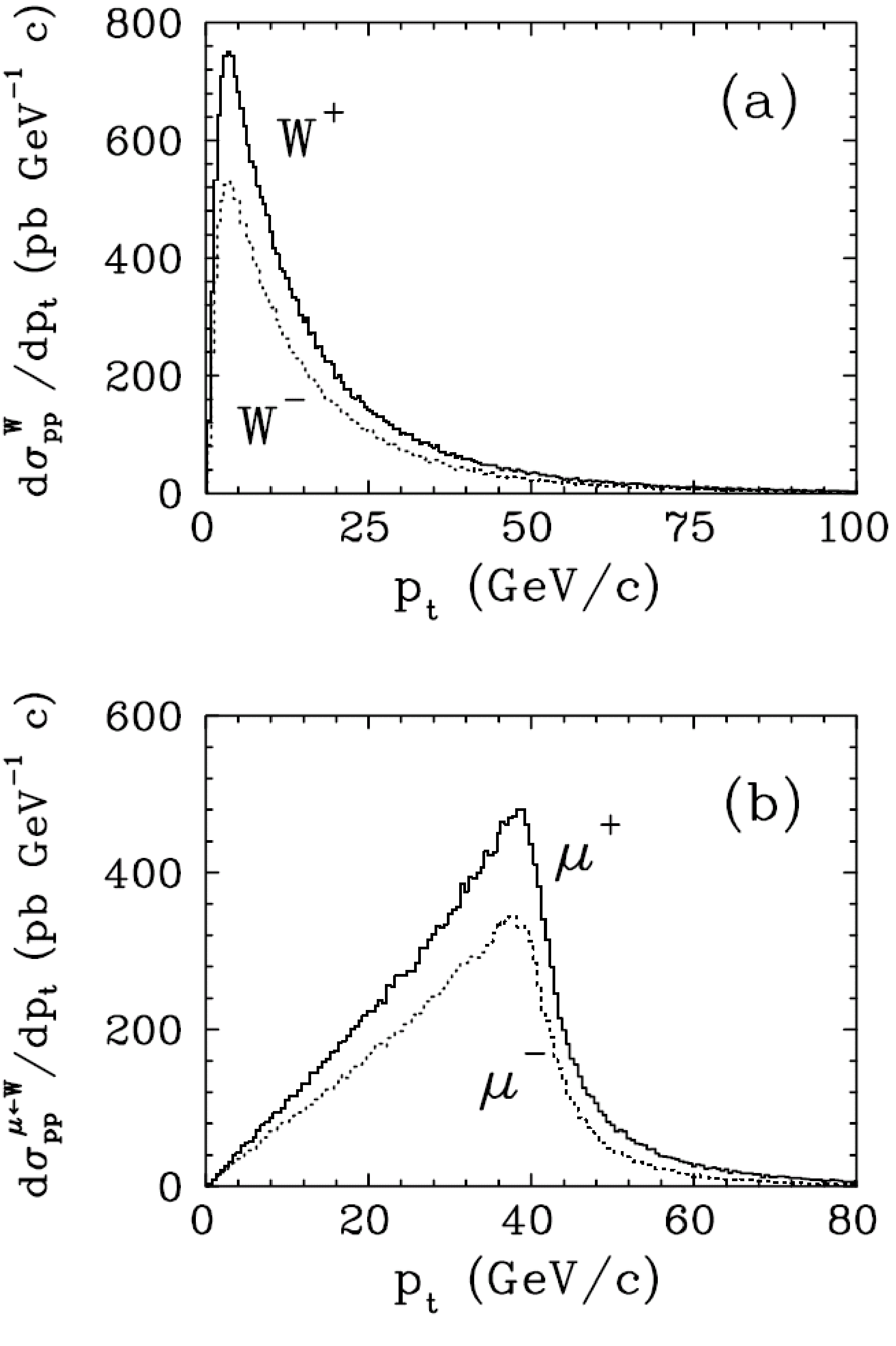

Fig. 1: Differential production cross sections over 4π for (a) $W^{\pm}$ bosons and (b) single muons as a function of transverse momentum (p_t) for proton-proton collisions at $\sqrt{s}$ = 14 TeV.

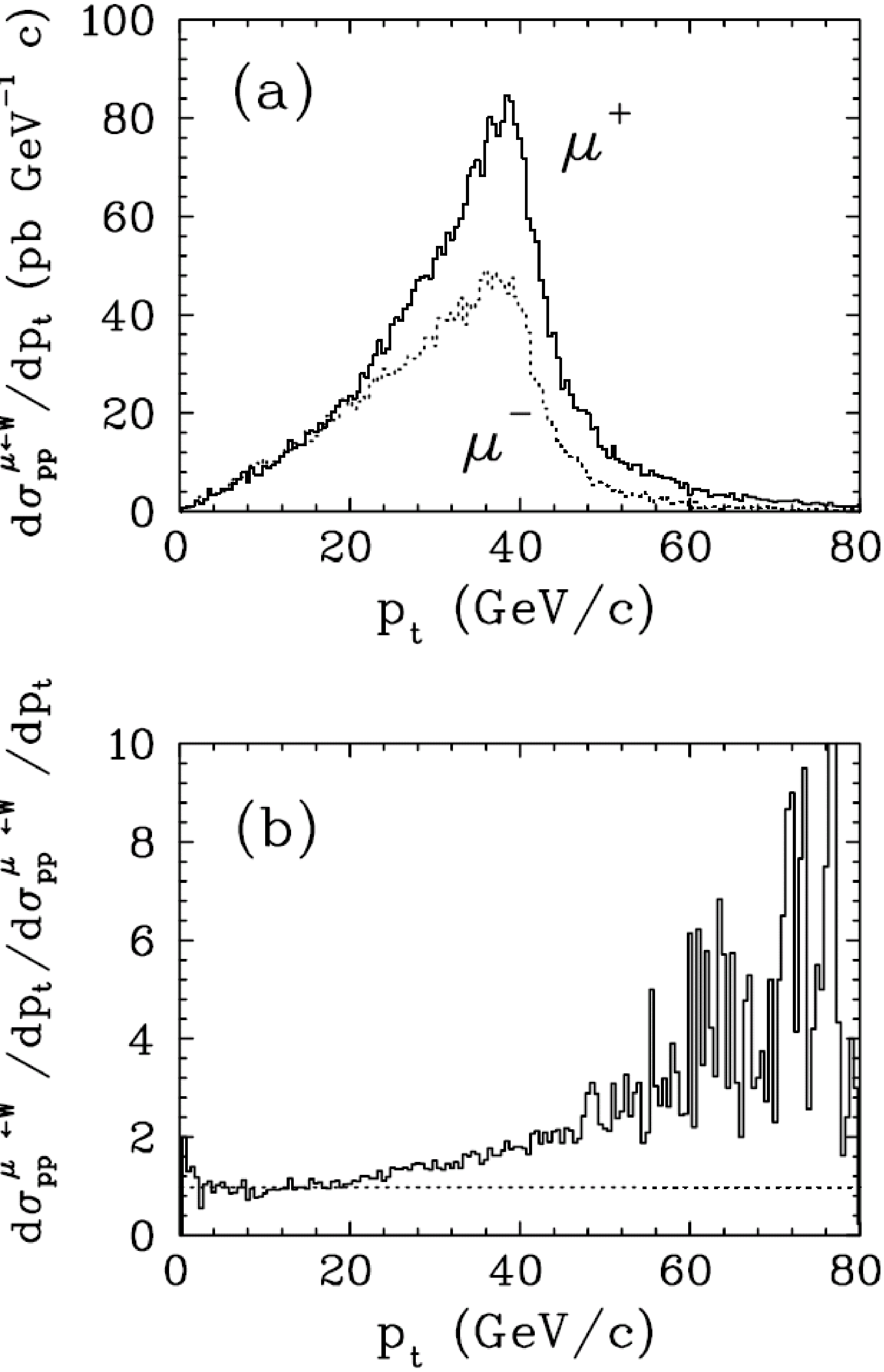

Fig. 2: Differential production cross sections for single muons from $W^{\pm}$ decay as a function of transverse momentum (p_t) in the ALICE muon spectrometer for proton-proton collisions at $\sqrt{s}$ = 14 TeV.

3 Sources of single muons in the ALICE Muon Spectrometer

For proton-proton collisions at LHC energies single muons are due to decays of light mesons, open charm and beauty and W and Z boson [3-4]. Single muons from the decay of light mesons populate the low pt region ($p_t \sim 2$ GeV/c) while open charm and beauty decays are spread over a wide p_t region. However, muons from light meson decay are not expected to contribute in the ALICE muon spectrometer because they will be significantly reduced by the front absorber and / or the muon filter wall. In addition, although the muons from open charm and beauty decays have widely spread p_t distributions however, as shown in Fig.3, they are mostly dominant in the low p_t region, with the cross-over region between them and W muonic decay at 20 GeV/c $\leq p_t \leq$ 28 GeV/c. This is the p_t region where the cross section for the $W \rightarrow \mu$ start to increase and ultimately becomes dominant at p_t = 30 ~ 42 GeV/c. Therefore, it is absolutely crucial to apply p_t cuts below 30 GeV/c since this is the p_t region where unwanted muonic background due to the decay of open charm and beauty dominate. As a consequence, this would also allow the increase of the statistics in the W muon yield. The purpose of this study is to demonstrate how this is achievable by means of the HLT analysis tool.

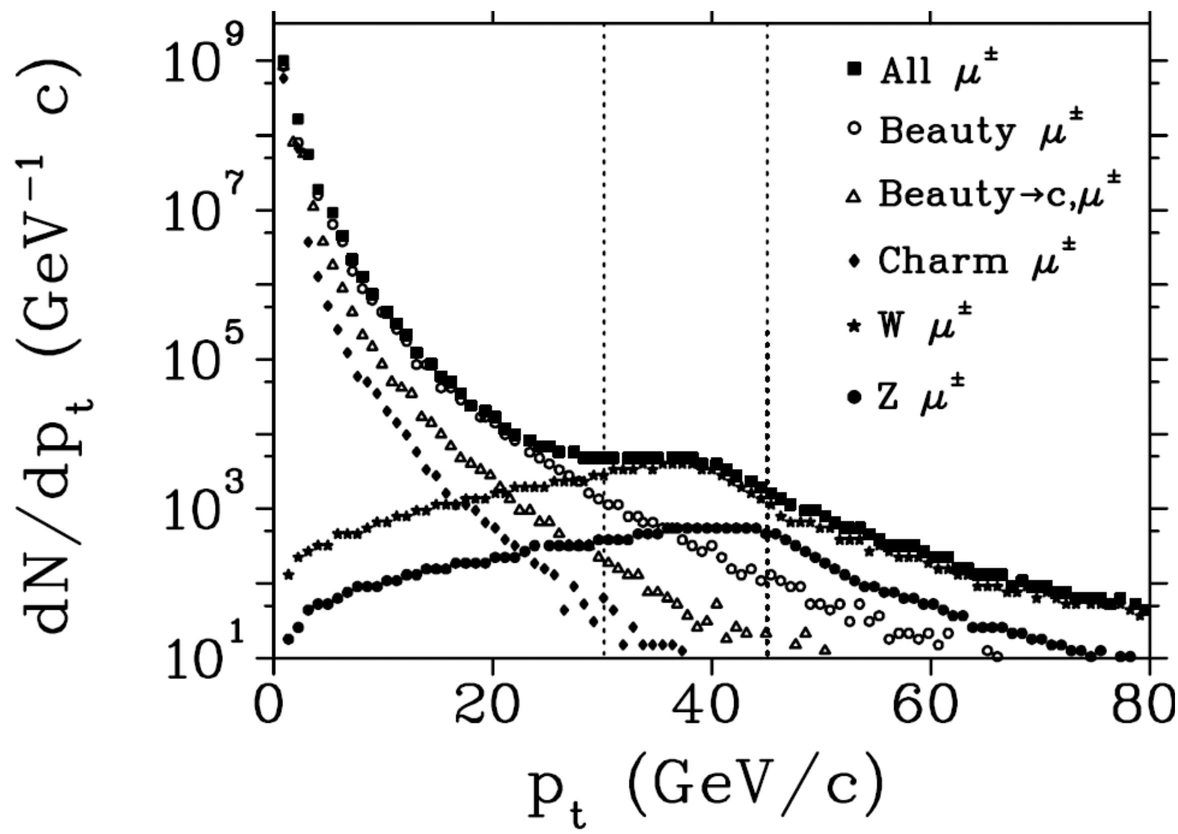

Fig. 3: Comparison of transverse momentum distributions for reconstructed single muons produced in the decay of W bosons, open charm and beauty, Z bosons and summed contributions of all single muons in proton-proton collisions at 14 TeV reported by Z. Conesa del Valle *et al.* [3, 4].

4 Analysis using the muon HLT tool

The objective of the muon HLT tool is to perform online reconstruction of the ALICE muon spectrometer data in order to improve the measured p_t resolution [1, 5]. This will enable us to attain better separation between signal and background, which could eventually lead to lower trigger rates [6]. In addition, the HLT is designed to improve the background-to-signal ratio in the raw data transferred to storage. This tool uses a track-finding algorithm where the selected region of interest is used to search for the hit on the next chamber that forms part of a muon track in the spectrometer. In this study the HLT single muon track-finding algorithm was implemented in order to reduce low p_t muon background in the reconstructed W muon data in the spectrometer for proton-proton collisions at 14 TeV. For this purpose, the optimized spectrometer parameters used in this study are given in Table 1. The HLT was set to trigger only on single muons produced from the direct decay of W by applying high p_t precision cuts to reject events below the given cut.

Table 1: Optimized ALICE muon spectrometer parameters used in the HLT analysis of the W muonic data

Parameter	Definition	Value
ZMIDDLE	z coordinated for the middle of the magnetic field	-975 cm
BFIELD	Magnetic field integral	-3 T.m
DCCUT	Direct current cut	50
ROI7A	Parameter A for the region of interest in chamber 7	0.02 cm
ROI7B	Parameter B for the region of interest in chamber 7	2.2 cm
ROI8A	Parameter A for the region of interest in chamber 8	0.023 cm
ROI8B	Parameter B for the region of interest in chamber 8	2.3 cm
ROI9A	Parameter A for the region of interest in chamber 9	0.049 cm
ROI9B	Parameter B for the region of interest in chmaber9	4.8 cm
ROI10A	Parameter A for the region of interest in chamber 10	0.045 cm
ROI10B	Parameter B for the region of interest in chamber 10	4.2 cm
CHZ7	Chamber 7 z coordinate position	1276.5 cm
CHZ8	Chamber 8 Z coordinate position	1307.5 cm
CHZ9	Chamber 9 z coordinate position	1406.6 cm
CHZ10	Chamber 10 z coordinate position	1437.6 cm
CHZ11	Chamber 11 z coordinate position	1603.5 cm
CHZ13	Chamber 13 z coordinate position	-1703.5cm

Several test runs were performed where about ten thousand events (2% of W statistics expected per one year of data taking) were simulated. The HLT cuts were set at p_t = 10 GeV/c, 15 GeV/c and 20 GeV/c, respectively. Preliminary results obtained from these test runs are given in Fig. 4 (a) to (c), where the HLT triggered W muon events are compared with those obtained from the L0 trigger. While all cases show satisfactory rejection of events below the applied cuts Fig. 4 (b) however, clearly presents the best possible scenario for an optimal cut since the cut is sharper compared to Fig. 4 (a) and (c). As shown in Fig. 4 the ratio between L0 and HLT triggered muon tracks is consistently around unity.

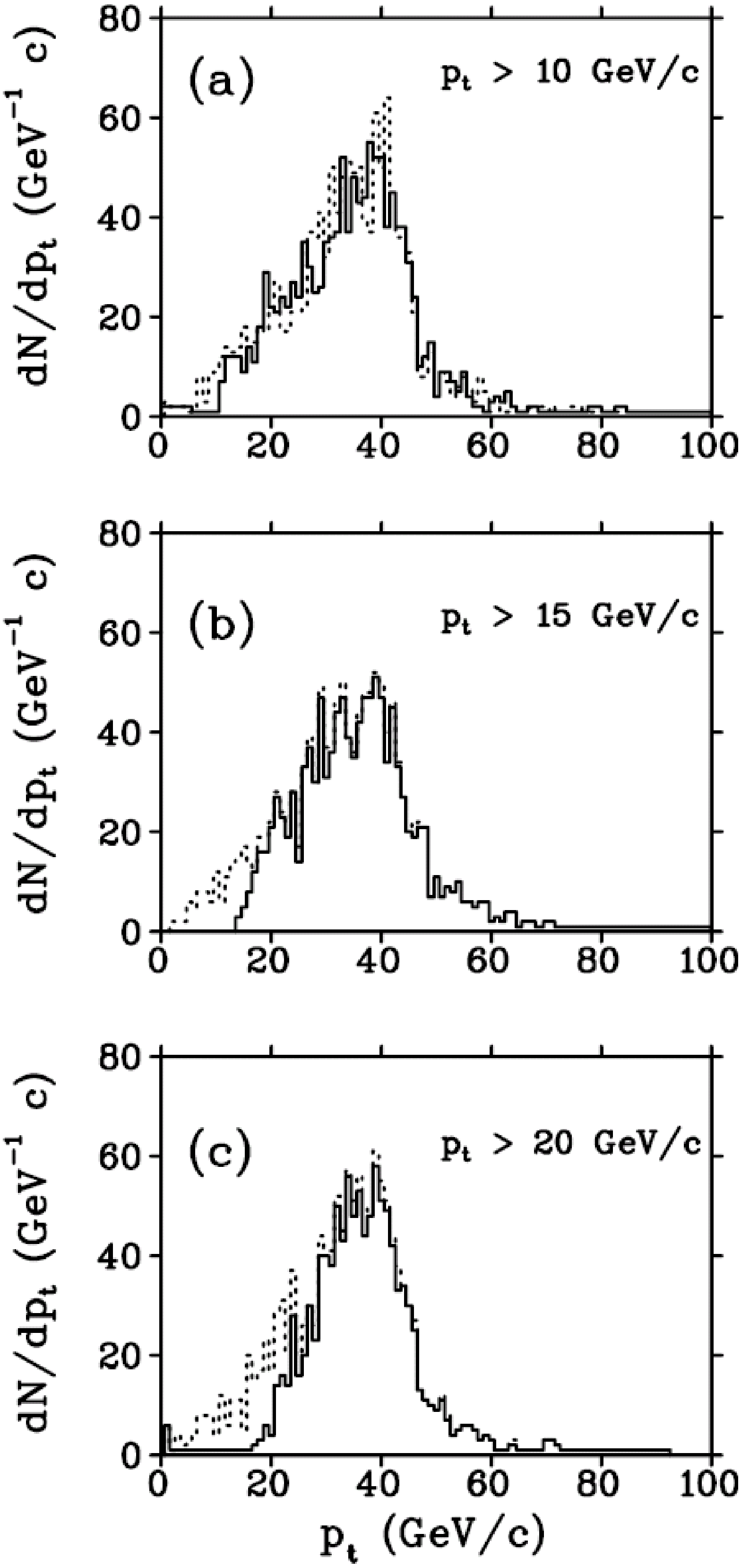

Fig. 4: Production cross section for reconstructed W muon tracks analysed using the HLT tool (solid line) compared with single muons obtained from L0 trigger (dotted line) for high p_t cuts = 10 GeV/c, 15 GeV/c and 20 GeV/c, respectively.

5 Remarks and Conclusion

The preliminary results presented here demonstrate how the ALICE muon spectrometer can be used to study the production of W bosons via the direct decay into high p_t single muons and, in particular, to investigate the W charge asymmetry, which is expected to be more pronounced in nucleus-nucleus and proton-nucleus or nucleus-proton collisions where the proton to neutron ratio is much higher.

Furthermore, we have demonstrated how the muon HLT tool can be used to reject unwanted muon events in a p_t region below 20 GeV/c, above which W muonic decay dominates in proton-proton collisions at LHC energies. Further investigations on the performance of the HLT are ongoing. This includes an increase in statistics (approximately 50 times more) so that the HLT results can be compared with the existing runs. This would allow better optimization of the HLT p_t cut between 10 GeV/c and 20 GeV/c.

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