DØ Muon System at TEV33

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ABSTRACT

Muon system is an important part of any general purpose collider experiment in the past, present and future. DØ detector at Fermilab Tevatron has muon system with large rapidity coverage, small backgrounds and good trigger capabilities. Currently this system undergo major modifications for the next Tevatron run at luminosity of $2{\cdot}10^{32}cm^{-2}s^{-1}$. In this paper we will analyze limits of the muon system operation with increase in Tevatron luminosity as well as describe modifications which are necessary in order to run at luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$ which is the goal of the TEV33 program.

I. INTRODUCTION

Due to their unique properties muons play an important role in most of recent high energy physics discoveries: c and b quarks, W and Z bosons and t quark. Muon decay modes of heavy objects typically have low backgrounds and can be selected using simple trigger algorithms. Property of muon to penetrate large amount of materials without large energy losses can be successfully used to tag heavy quark jets (b-jets, for example).

Objects with large mass are typically produced almost in rest in the center of mass system. So, detection of their decay products, such as muons, is proportional to the detector solid angle coverage. This is why hermetic muon system with large rapidity coverage is an advantage in search for new objects. Calculations show that system with pseudorapidity of $|\eta|<2$ will have 90% acceptance for heavy objects decay [1]. This is why DØ Collaboration goal is to have muon system pseudorapidity coverage to $|\eta|<2.0$.

Another important feature of the DØ muon system is its thickness. From 14 (central) to 18 (forward) interaction lengths of material. This drastically reduces punchthrough and other backgrounds in the muon detection. Relatively small decay volume before calorimeter provides low π/K decay backgrounds. The magnetized toroids provide independent to central tracker momentum measurement which helps with muon triggering and identification.

Below we will describe DØ muon system design for the first run during Main Injector era in 1999 with luminosity of $2{\cdot}10^{32}cm^{-2}s^{-1}$. We will then define limits of normal operation of the muon system with increase in Tevatron luminosity and describe modifications which are necessary in order to run at luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$ which is goal of the TEV33 program.

II. DØ MUON SYSTEM FOR YEAR 1999 TEVATRON RUN

The layout of the DØ muon system for its 1999 Tevatron run is presented in Figure 1. It consists of central and two forward toroids with average magnetic field of 1.8T. In the central region $|\eta|<1.0$ two layers of scintillation trigger counters are used to trigger on muons and reduce cosmic ray backgrounds in the muon samples. In order to reconstruct muon tracks Proportional Drift Tubes (PDT) are used. They have drift cell with cross section of 5cm$\times$10cm and length up to 5m. Three PDT layers in the muon system are called A, B and C starting from the closest to the interaction region.

In the forward region $1.0<|\eta|<2.0$ there are three layers of scintillation counters with projective tower geometry 0.1 in ϕ and 0.1 in η. These counters are used for muon triggering and ϕ track determination. For muon track reconstruction 3 layers of Mini Drift Tubes (MDT) are used with total number of detector planes equal to 10 (4A+3B+3C). They have drift cell with 1cm$\times$1cm cross section and up to 6m in length.

In order to reduce backgrounds from beam-jets interaction with accelerator elements special shielding (see Figure 1) will be installed around beam pipe. It consists of soft steel, poly and lead and reduces background fluxes on forward muon detectors up to 50 times in comparison with no shield layout.

Due to considerable reduction in beam crossing time from 3.5μs to 132ns all muon electronics will be rebuilt with deadtimeless pipeline design. Three levels of triggering will be implemented. At Level 1 trigger raw information about hits in muon detectors is used. At Level 2 trigger spec-processors runs to purify events sample using detailed information about hits in different muon detectors. Finally Level 3 trigger based on "offline" type computer farm with high level algorithms and links between different detector subsystems selects events to be written to tape.

The muon detector acceptance below η of 2.0 is around 80%. The losses are mainly due to "no detector" zones under calorimeter (supports) and between chambers. The muon system stand alone momentum resolution is around 20% and limited by multiple scattering in the iron toroids. Although it is poorer than central tracker resolution it is very useful for muon identification especially inside jets. Most of the elements are the same as they were during first DØ run started in 1992 (see [2]) such as magnets and central PDT. New detectors will be added during 1996-1999 shutdown. The details of the upgrade for the 1999 run are presented in [1].

III. DETECTION OF MUONS BY DØ AT TEV33 LUMINOSITY

In the following paragraph we will summarize operation of the DØ muon system when luminosity will reach $1{\cdot}10^{33}cm^{-2}s^{-1}$ and determine elements which will start to fail.

Inclusive single muon rate for $|\eta|<2.0$ is 1kHz at luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$. Most of them are from b-quark decays. So,

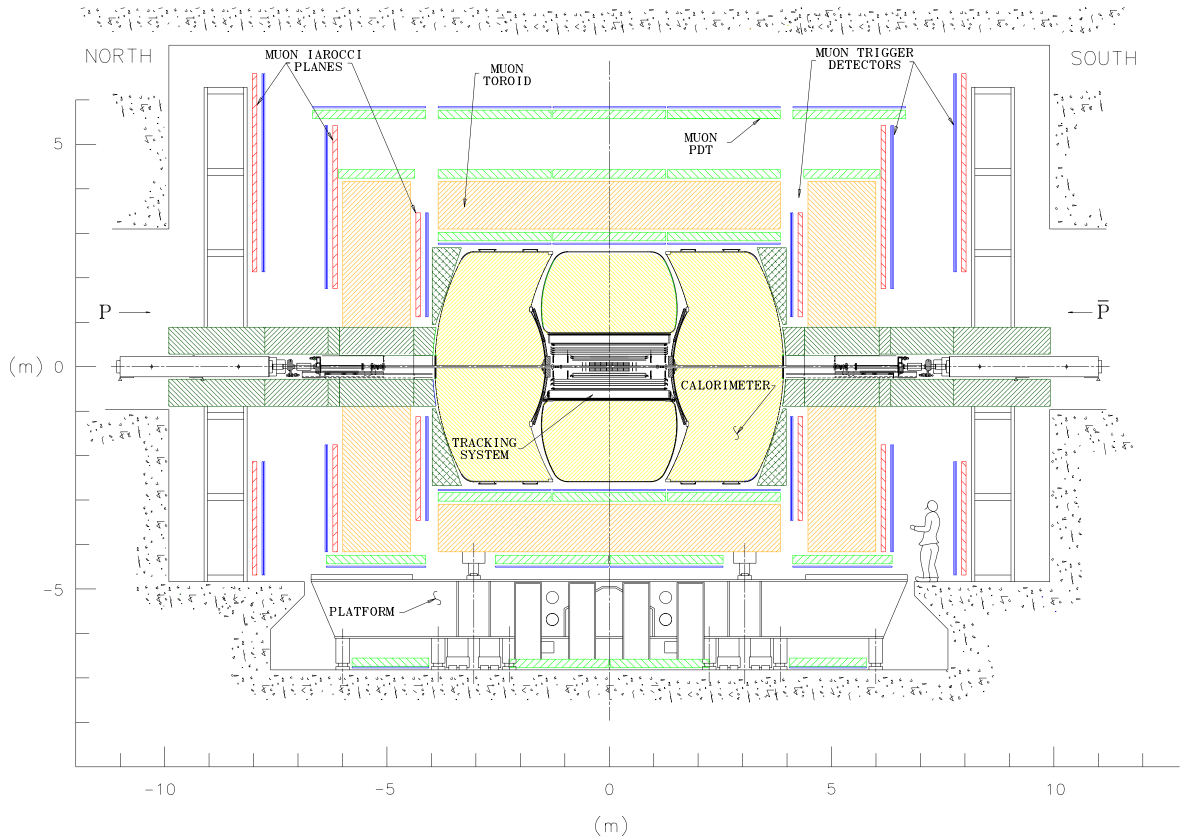

Figure 1: Layout of the DØ detector for year 1999 run.

hits in muon detectors from real muons are still on negligible level in comparison with other sources. The most serious source of hits in muon detectors is remnants of high energy showers leaking through natural holes (for cables, beam pipe, etc.) in the detector. In addition low energy neutrons will create "neutron gas" inside the collision hall which via interaction with nuclei will produce gamma rays which via photo-effect and Compton scattering produce hits in the muon detectors. We have done detailed studies of backgrounds in the DØ detector by Monte Carlo simulation (GEANT, GCALOR, MARS) and using results obtained in 1992-1996 Tevatron run. Typical flux of charged particles in the central region will be around $2{\cdot}10^5$ particles/m^2s at luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$ (here and below all numbers correspond to Tevatron luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$). Based on known particle fluxes ([1]) we can estimate occupancy of different muon detectors. The occupancy is defined as probability to find hit in an event in a single detector cell. For central system PDT occupancy will be around 15%. For MDT occupancy will be 0.3% and for scintillation trigger counters occupancy will be around 0.5%. The drastic difference in PDT and MDT occupancy is due to different cell sizes and maximum electron drift times.

Another serious problem is aging of different detectors under irradiation. The central muon PDT can handle only around 1mC/cm of anode charge [3]. Although methods of cleaning anode wires have been developed [4] they require long shutdown in order to clean all wires. Using results of 1992-1996 DØ run we can predict useful lifetime of PDT around 1fb^{-1} much less than 30fb^{-1} planned for TEV33 project. For the MDT anode charge more than 1C/cm (see Figure 2) can be accumulated which corresponds to integrated luminosity of 100fb^{-1} even in the most forward region of the detector (where particle fluxes are the highest).

For the scintillation counters aging of scintillator and wavelength shifter is not a problem up to 100krad doses and they will get up to 1krad at 30fb^{-1}. The phototubes gain will decrease by approximetly 10-20% in average due to dinodes aging at 30fb^{-1}. This degradation can simply be corrected by 40V increase in cathode voltage.

So, all muon detectors, except PDT, will be able to run at luminosity of $1{\cdot}10^{33}cm^{-2}s^{-1}$. High PDT occupancies and fast aging require their replacement for TEV33 project. We propose to replace them with chambers made of MDT. The MDT can be produced of any preselected length in large quantities and relatively inexpensive. The chambers made of MDT can be done of almost the same mechanical sizes as current PDT chambers. So, they simply fit into existing detector. The typical structure of one MDT layer is shown in Figure 3. Total number of MDT channels needed to replace central PDT is 72k (in the forward muon system 48k MDT cells will be used). Based on detailed cost estimate made for 1999 Tevatron run the cost of PDT replacement is around $5M (including electronics). This is the largest part of the DØ muon system upgrade for TEV33. The rest of the system can be used without modifications.

IV. ELECTRONICS, TRIGGER AND RECONSTRUCTION

All muon front-end electronics and trigger system is designed to run at beam crossing time of 132ns or larger. This is why we propose not to decrease beam crossing time below 132ns for the TEV33 project. In another case major electronics upgrade which will take a lot of time (years) and costly will be needed. The MDT electronics for the central PDT replacement will be done exactly as forward region electronics saving a lot on designing and commissioning. With ”luminosity leveling” (constant luminosity during the store) and filling two out of three abort gaps the average number of interactions per crossing will remain close to the value planned for 1999 run at luminosity of $2{\cdot}10^{32} cm^{-2} s^{-1}$. All our studies show that muon trigger rates is a function of the average number of interactions per crossing (not luminosity directly) until detectors resolution time is better than beam crossing interval. In this case trigger rates estimate performed for 1999 run (see Reference [1]) will be valid. Taking into account increase in combinatoric rates due to neutron gas density increase (see above) we can estimate Level 1 single muon trigger rate at 1-2 kHz. Level 2 and Level 3 triggers will be used to select practically clean sample of events with muons. Taking into account that real muon rate with P_t above 3GeV/c will be around $1{\cdot}10^2$Hz and can’t be written to tape without prescale. Higher P_t threshold will be used (real muon rate is approximetly 1Hz for P_t above 10GeV/c) or more complex triggers (muon+jet(s), muon+electron, dimuon, etc.) will be used to select interesting events. Reconstruction of muon events with typical detector occupancy below 0.5% is not a problem. In 1992-1996 Tevatron run DØ forward muon system had occupancy of 5% in average and algorithms to reconstruct muon tracks have been developed. We anticipate high efficiency of muon track reconstruction (above 90%) and possibility to use existing software with minor modifications.

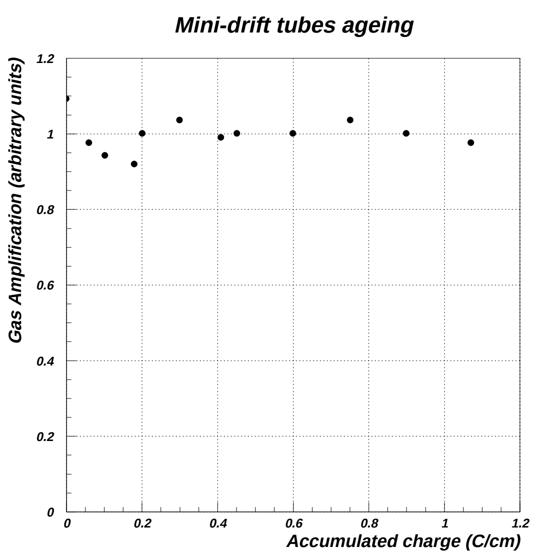

Figure 2: Relative gas gain of MDT vs accumulated anode charge. Gas mixture of $CF_4(90\%)$+$CH_4(10\%)$ was used.

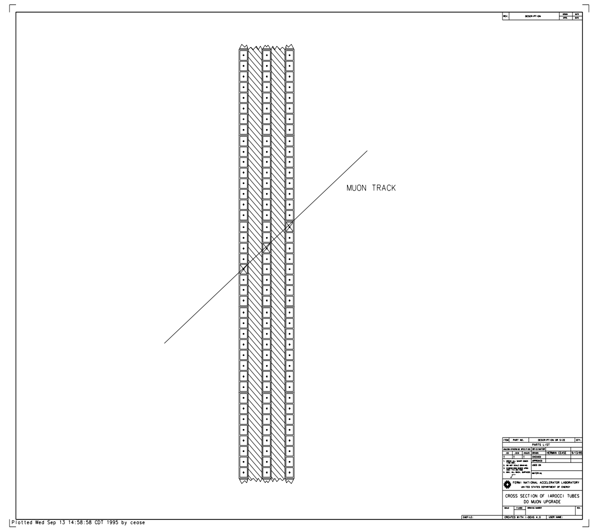

Figure 3: Design of 3-plane MDT chamber.

V. SUMMARY

Large part of the DØ muon system designed for 1999 Tevatron run will be able to run at luminosity of $1{\cdot}10^{33} cm^{-2} s^{-1}$ without modifications. DØ has to replace central system tracking detectors with mini-drift tubes to be used in the forward region for year 1999 run. Early decision on TEV33 scenario and approval of detectors upgrade will help with almost continuous use of production facilities for mini-drift tubes and front-end electronics. This replacement will cost around $5M (in FY96 dollars) including detectors and electronics. The rest of the muon system will be capable of handling luminosity of $1{\cdot}10^{33} cm^{-2} s^{-1}$ and integrated luminosity of 30fb^{-1}.

VI. REFERENCES

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