Design of the FCC-hh Muon Detector and Trigger System

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Abstract

The design of a muon detector and first-level muon trigger system for the FCC-hh baseline experiment is presented. The baseline FCC-hh detector configuration with a solenoid magnet system providing a field integral of 18 Tm over a wide pseudorapidity interval and a muon system around the solenoid and the calorimeter system is assumed. In order to identify muons with high momentum resolution one needs to measure the muon incidence angle at the entry point of the muon system with an angular resolution better than $100 \mu\text{rad}$. This precision can be achieved with chambers with two quadrupole layers which are separated by a 1.5 m thick spacer structure and contain 15 mm diameter aluminium drift tubes filled with Ar:CO(93:7) at 3 bars absolute pressure. Each drift-tube chamber is combined with a double layer of thin-gap RPC chambers which provide bunch crossing identification with better than 1 ns time resolution, muon trigger seeds, and coordinate measurement along the tubes.

Keywords: muon system, FCC, drift-tube chambers, sMDT, thin-gap RPCs

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1. A muon system for a detector at the FCC-hh

The FCC-hh [1] is the name for a proposed future circular proton-proton collider with a centre-of-mass energy of 100 TeV and a peak luminosity of $3 \cdot 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ designed to deliver in its lifetime an integrated luminosity of 20 ab^{-1} . The present conceptual design of a detector at the FCC-hh has the structure depicted in Figure 1. The inner detector and the calorimeters will be operated in a 4 T magnetic field created by a solenoid. A muon system will surround the solenoid. It will consist of four parts:

- $|\eta| < 1.0$: barrel muon system;
- $1.0 \leq |\eta| < 1.5$: outer end-cap muon system;
- $1.5 \leq |\eta| < 2.2$: inner end-cap muon system;
- $2.2 \leq |\eta| < 3.0$: forward muon system.

The muon system will have to provide a muon trigger. The angle between the straight-line interconnection of the entry point in the muon system with the proton-proton interaction point and the direction of flight at the entry point can be used as a stand-alone measurement of the muon momentum. As shown below an angular resolution better than $100 \mu\text{rad}$ is needed for a high momentum resolution up to $p_T = 1 \text{ TeV}$.

Figure 1: Schematic drawing of a quadrant of the baseline detector design for the FCC-hh [2].

2. Proposal for the instrumentation of the muon system

Such an angular resolution can be achieved with small diameter drift-tube chambers, so-called "sMDT chambers" [3]. These chambers use drift tubes which have a diameter of 15 mm and 0.4 mm thick aluminium walls and are filled with Ar:CO₂(93:7) at 3 bar absolute pressure.

The muon chambers will be exposed to a large background of neutrons and γ rays, which will lead to counting rates of up to 500 Hz cm^{-2} in the barrel and the outer end-cap muon system and up to 10 kHz cm^{-2} in the inner end-cap and forward

muon system [4]. sMDT chambers can be operated at counting rates of up to 30 kHz cm^{-2} and background occupancies of up to 30%. If one uses 2.8 m long tubes in the barrel and the outer end-cap muon system, the chambers will have a background occupancy below 4%. In the inner end-cap and the forward regions chambers with 40 cm long tubes have to be used to keep the occupancy below 10%. A full GEANT-4 [5] simulation of sMDT chambers has been performed to determine the achievable angular resolution under the expected background conditions. Figure 2 shows the dependence of the angular resolution of an sMDT with 2.8 m long tubes on the distance of the quadruple layers (defined as the distance of the 4th and 5th tube layer), Figure 3 the corresponding results for 40 cm long tubes. An angular resolution better than $80 \mu\text{rad}$ can be obtained with a multilayer distance of 1.5 m for the expected maximum rates. At 2.5 times higher rate than nominal in the inner end-cap and forward regions a resolution of $110 \mu\text{rad}$ is achieved.

A muon system consisting of a single monolithic layer as illustrated in Figure 4 for the barrel muon system can therefore be used at the FCC. The sMDT chambers will have to be combined with a double layer of thin-gap RPC chambers which provide bunch crossing identification with better than 1 ns time resolution, muon trigger seeds, and coordinate measurement along the tubes.

Figure 2: Dependence of the angular resolution of an sMDT chamber on the distance of its quadruple layers for the maximum expected background rate in the barrel and outer end-cap regions and 2.5 times higher rates.

Figure 3: Dependence of the angular resolution of an sMDT chamber on the distance of its quadruple layers for the maximum expected background rate in the inner end-cap and the forward regions and 2.5 times higher rates.

Figure 4: Conceptual design of the barrel muon system equipped with a single monolithic layer of sMDT chambers.

3. Simulation of the stand-alone muon momentum resolution

The stand-alone muon momentum resolution which can be obtained with the proposed muon system was studied with a GEANT-4 based simulation. In this programme the calorimeters and solenoids were simulated as homogeneous blocks with the correct average radiation and nuclear interaction lengths. The simulation was carried out with the latest FCC magnetic field map. The expected stand-alone muon momentum resolution for the nominal background rates is summarized in Figure 5 as a function of the muon transverse momentum. Up to $p_T \approx 1 \text{ TeV}$ the momentum resolution is constant and dominated by multiple scattering: 5% resolution is achieved in the barrel region, about 10% in the end-caps and about 20% in the forward region. 20-40% resolution is reached at 10 TeV.

Figure 5: Expected stand-alone muon momentum resolution for different regions of the muon system.

References

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