Muon Scintillator R&D Letter of Intent

The CEPC program spans a wide range of center-of-mass energies and beam luminosities to achieve the highest yields of Higgs, W, and Z bosons produced in the exceptionally clean environment of an e^+e^- collider [1]. The CEPC is designed to operate at 240 GeV with $\mathcal{L} = 3\times10^{34}\ cm^{-2}s^{-1}$ as a Higgs factory ($e^+e^- \to ZH$), at around 160 GeV of the WW production threshold with $\mathcal{L} = 10\times10^{34}\ cm^{-2}s^{-1}$, and at around 91.2 GeV as a Z factory with $\mathcal{L} = 32\times10^{34}\ cm^{-2}s^{-1}$ [2,3]. The high energies and high luminosities require excellent performances of detectors, which requires a new designed muon detector system. There will be vast amount of bottom quarks, charm quarks, J/ψ signals and τ-leptons produced in collisions, which bring in a lot of muon tracks. An outermost muon detector system is envisioned to provide redundancy, aid muon identification in busy environments and reduce backgrounds. Embedded in the solenoid flux return yoke, the detector is designed to identify muons with high standalone efficiency ($\geq 95\%$) and purity for muon p_T down to ~ 3 GeV over the largest possible solid angle. The muon detector should provide standalone measurements of the muon momenta and trigger signals. Moreover, the detector can compensate for leaking energetic showers and late showering pions from the calorimeters, which could help to improve the jet energy resolutions. It can also aid in searches for long-lived particles that decay far from the IP, but still inside the detector.

A baseline design of the CEPC muon detector is divided into one barrel and two endcaps, consisting of azimuthal segmented dodecagon modules [2]. The baseline design consists of 8 sensitive layers alternating with iron absorber layers. The total iron thickness is 6.7 interaction lengths, and the total sensitive area amounts to $8600\ m^2$. With an improvements on plastic scintillator and Silicon PhotoMultiplier (SiPM), the excellent performance of a muon detector can be achieved with the technology based on 'scintillator-strip + Wave-length-shift (WLS) fibre + SiPM'. Plastic scintillator has a decay time about $2\ ns$, which is short for the detector to run in a high rate condition. SiPM could achieve a time resolution better than $100\ ps$ [4]. A WLS fibre is used to collect the photons from the scintillator and guide them to SiPM. The technology has been using in Belle II detector recently [5]. CEPC project will bring in oppotunity to improve such technology. Beside the regular requirement on serving as a muon detector, a well improved performance may allow to search for new Physics with a large size detector running in a Higgs factory, such as searching for long-lived particles with the tracks in the muon detector.

Questions

To maximize the performance of a muon detector based on scintillator, optimizations of the detector design and a set of critical R&D tasks has been identified.

Some of the key challenges to be address in the near future are:

Detector Simulation To optimize the performance of the detector, simulation based on Geant4 should be studied.

Parameters of Scintillator The light yield, the decay time, and the length of attenuation of the scintillator produced by extrusion technique should be optimized with the impact from cost, which is critical for a large size detector. The geometry of a scintillator strip should be optimized too.

Paremeters of SiPM and WLS Fibre Various categories of SiPM [4] and WLS fibre should be studied to have the best combination of a detector channel.

Couplings The couplings among scintillator strip, WLF fibre and SiPM should be studied well. Good couplings are much helpful for the light collection and homogeneity of detector channels/modules.

Spatial Resolution The minimum position resolutions of $\sigma_{r\phi} = 2.0\ cm$ and $\sigma_z = 1.5\ cm$ are required. The position measurements should provide several space point measurements, and information on muon momenta which can be used independently or combined with the measurements in the tracking system.

Time Resolution Such technology has shown a time resolution better than $1\ ns$ from a single detector channel, while there is still space to improve the time resolution. If the time resolution can achieve $\sim 200\ ps$, the performance of the detector can be improved much by taking the advantage of the excellent time resolution. It can be used to measure the time-of-flight of some tracks, which is much helpful for searching for long-lived particles.

Readout System Preamplifier is typically required for the small signals from SiPMs. Besides the amplification, the dynamic range should be considered during the design of preamplifier. Low noise level, number of channels, and especially the time resolution are the requirements of the readout system.

Calibration System To achieve the good performance and reject backgrounds, a calibration system should be considered. This can be based on a laser system, and algorithms should be developed too.

Trigger System The muon detector can supply trigger signals according to the muon tracks from the collisions.

Radiation Hardness The radiation hardness should be tested for the scintillator, the WLS fibre, the SiPM and the FE readout.

Detector Construction The construction should be done in an optimized way to keep the good performance of the detector.

Contacts

The contact people from the scintillator-based muon detector studies for CEPC to the Snowmass 2021 study groups are as follows:

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References

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