Muon4Future 2025

Monday, 26 May 2025 - Friday, 30 May 2025

Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti

Book of Abstracts

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Pulling out all the Stops: Measuring the normalisation of signal events in the Mu2e experiment

Author: George Sweetmore[1]

[1] *The University of Manchester*

The Mu2e experiment at Fermilab will investigate charged lepton flavour violation (CLFV) through the direct observation of coherent, neutrinoless conversion of muons into electrons in the proximity of an aluminium nucleus. It aims to achieve a sensitivity to the ratio of the conversion rate to the muon nuclear capture rate on the order of 10^{-17}, a factor of 10^{4} better than the current limit. In order to achieve this limit, a Stopping Target Monitor (STM) system must be put in place to measure the rate of muons stopped in the target to a precision of 10%. The STM is pivotal in achieving the primary physics goals of the Mu2e experiment by determining the number of muons captured in the aluminium target. This presentation will detail the design, status and performance of the STM system and the plans for the first Mu2e physics run.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

none

New Physics opportunities with low and high energy muon beams:

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Probing charged lepton flavor violation and quantum entanglement in muon on-target experiments

Authors: Leyun Gao[1]; et al.[None]

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Firstly, we'd like to share a novel and cost-effective experiment proposal to probe the charged lepton flavor violation (CLFV) process mediated by an extra massive neutral gauge boson Z' beyond the Standard Model, as a part of the Peking University Muon (PKMuon) Experiment. The considered process can be uniquely sensitive to specific CLFV parameter combinations, such as the coupling coefficient product $\lambda_{e\mu}\lambda_{\mu\mu}$. Additionally, we will present a realistic proposal and a comprehensive study of quantum entanglement in a state composed of different-flavor fermions in muon-electron scattering. Entanglement in the resulting muon-electron qubit system and the violation of the Bell inequality can be observed with a high event rate. This paves the way for performing quantum tomography with muons.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

none

New Physics opportunities with low and high energy muon beams:

none

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

none

New Physics oppportunities with low and high energy muon beams / 50

Searches for heavy neutrinos at multi-TeV muon collider: a resonant leptogenesis perspective

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In this work, the Standard Model (SM) is extended with two right-handed (RH) neutrinos and two singlet neutral fermions to yield active neutrino masses via (2,2) inverse see-saw mechanism. We first validate the multi-dimensional model parameter space with neutrino oscillation data, obeying the experimental bounds coming from the lepton flavor violating (LFV) decays: $\mu \to e\gamma$, $\tau \to e\gamma$, $\tau \to$

μγ. Besides we also search for the portion of the parameter space which yield the observed baryon asymmetry of the universe via resonant leptogenesis. Further, we pick up a few benchmark points from the aforementioned parameter space with TeV scale heavy neutrinos and perform an exhaustive collider analysis of the final states: 2l +ET / and 1 l +2 j +/ ET in multi-TeV muon collider.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

none

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Higgs self coupling at a 10 TeV Muon Collider

Authors: Alessio Gianelle[1]; Carlo Giraldin[2]; Davide Zuliani[1]; Donatella Lucchesi[1]; Leonardo Palombini[1]; Lorenzo Sestini[1]; Massimo Casarsa[1]

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The 2025 ESPPU highlights the extended characterization of the Higgs potential as a priority for future experiments, as it allows the determination of the Standard Model vacuum stability and the test of various Beyond Standard Model hypotheses, paving the way for the study of the electroweak phase transition in the early Universe. A 10 TeV Muon Collider is predicted to produce O(10^4) double Higgs events in 5 Snowmass-years of operation. This and its relatively clean collision environment would allow a Muon Collider to measure the Higgs self-coupling down to the percent level. Also, a 10 Snowmass-years run could enable the determination of the Higgs'quartic coupling, with an uncertainty of about 50%. This contribution discusses the expected accuracy of the double Higgs cross-section at a 10 TeV Muon Collider using detailed detector simulations, including physics and machine backgrounds.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

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Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

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Prospects for true muonium observation at existing beamlines and colliders

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True muonium (TM), the bound state of a muon and an antimuon, remains unobserved due to its short lifetime and production cross-sections, together with its extremely high ($13Z^2$) dissociation cross-section in matter. Recent theoretical and experimental studies have, however, identified feasible pathways to its discovery at current high-energy physics facilities.

At the LHCb experiment, the production of the vector 1S TM state via $\eta \to \gamma TM$ with subsequent $TM \to e^+e^-$ decay has been proposed in 2019. Preliminary studies suggested that a displaced e^+e^- vertex search could achieve a significance exceeding five standard deviations thanks to the large LHC-Run3 statistics.

In 2024 a resonant search for true muonium via $e^+e^- \to TM \to e^+e^-$ interactions has been proposed, using a 43.7 GeV positron beam at the CERN Super Proton Synchrotron (SPS) North-Area H4A beam facility. Simulations indicate that the spin-1 TM state could be observed with high significance with about 10^{12} positrons impinging on an assembly of multiple thin lithium targets by searching for displaced e^+e^- vertices, thanks to its large decay-in-flight distance of about 11 cm.

Another method to observe true muonium using e^+e^- interactions, proposed in early 2025, employs photon-photon fusion into the spin-0 TM state (para-TM), decaying into two photons. Thanks to its high integrated luminosity and to the presence of triggers dedicated to photons, the Belle-II experiment, featuring a 10.58 GeV center-of-mass energy, is a very good candidate for this measurement. Monte Carlo simulations incorporating trigger, detector efficiencies and resolutions and background processes suggest that para-TM production via photon-photon fusion is feasible. Applying machine learning techniques, such as extremely randomized trees, to simulated events indicates that the TM signal can be distinguished from background, with projected statistical significances reaching discovery level, using the current dataset of about 400 fb-1 already collected at Belle-II.

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Scintillating fibre-based muon beam monitor for the FAMU experiment

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The FAMU experiment aims at measuring the Zemach radius of the proton with an accuracy better than 1% through accurate spectroscopy of the ground state hyperfine splitting of muonic hydrogen atoms. This measurement plays a crucial role in validating high-precision QED calculations, and testing the proton-muon interaction. Muonic hydrogen atoms are produced by injecting a pulsed low-momentum (55 MeV/c) negative muon beam in a pressurised 1-litre 8 bar gaseous target. The exotic atoms are let thermalise for a few hundreds of ns and then hit with a tunable mid-infrared laser to excite the transition. The experimental data need to be normalised as a function of the muon beam intensity in order to take into account of the number of muonic atoms in the chamber when the laser is injected. This normalisation is made possible thanks to a beam monitor composed of two layers of 1 mm pitch squared fibres, read-out at alternate ends by SiPM's. This system, initially designed as a position-sensitive hodoscope, proved to be a linear and sensitive flux monitor by taking into account of the total integrated charge collected by the SiPM circuit during beam pulses. This observable has been thoroughly studied in order to check for its linearity and determine its value for single muon interactions. Thanks to dedicated low flux measurements and accurate simulations, the detector has eventually been used as a flux-meter, with a measured resolution below 2%. In addition, the detector played a crucial role in observing beam fluctuations and beamline faults, which can now be promptly corrected as they occur. In conclusion, the FAMU experiment has been provided with a beam monitor capable of beam shape analysis, flux measurement and extraction of time information, which has been playing a crucial role in the data acquisition and data analysis of the experiment. Similar detectors can be applied in other experiments to fully characterise low-momentum muon beams; some specific applications at ISIS are currently under development.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

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Advancements in Muon-based Facilities and Broader Applications:

none

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Optimising an ECAL barrel for a Muon Collider: the Crilin design

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Among future collider concepts, the Muon Collider presents a groundbreaking opportunity to push the energy frontier. However, its realization comes with a major challenge: Beam-Induced Background (BIB), a byproduct of muon decay along the beam pipe, which significantly complicates detector design and event reconstruction. Despite the implementation of tungsten conical absorbers (nozzles) in the forward regions, a persistent component of BIB still reaches the detector, consisting of low-momentum particles with delayed arrival times relative to the primary collisions. This background is particularly severe for the electromagnetic calorimeter, where the barrel's inner face experiences an intense particle flux of approximately 300 particles per cm^2, a total ionizing dose of ~1 kGy/year, and a neutron fluence of 10^{14} n/cm^2 per year.

To fully exploit the potential of a Muon Collider, a calorimeter capable of mitigating BIB while maintaining excellent energy resolution is crucial. One promising solution is CRILIN (CRystal calorImeter with Longitudinal INformation), a semi-homogeneous electromagnetic calorimeter utilizing Lead Fluoride (PbF_2) crystals read by UV-extended Silicon Photomultipliers. Engineered for high granularity, longitudinal segmentation, and exceptional timing performance, CRILIN is designed to suppress BIB-induced effects while delivering high energy resolution ($<10\%/\sqrt{E}$). This talk will present simulation studies assessing CRILIN's capabilities, along with recent experimental results from prototype testing, demonstrating its viability in the demanding Muon Collider environment.

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Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

none

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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A Large Muon EDM from Dark Matter

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We explore a model of dark matter (DM) that can explain the reported discrepancy in the muon anomalous magnetic moment and predict a large electric dipole moment (EDM) of the muon. The

model contains a DM fermion and new scalars whose exclusive interactions with the muon radiatively generate the observed muon mass. Constraints from DM direct and indirect detection experiments as well as collider searches are safely evaded. The model parameter space that gives the observed DM abundance and explains the muon $g-2$ anomaly leads to the muon EDM of $d_\mu \simeq (4-5)\times 10^{-22}\, e\,\mathrm{cm}$ that can be probed by the projected PSI muEDM experiment. Another viable parameter space even achieves $d_\mu = \mathcal{O}(10^{-21})\, e\,\mathrm{cm}$ reachable by the ongoing Fermilab Muon $g-2$ experiment and the future J-PARC Muon $g-2$/EDM experiment.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

none

New Physics opportunities with low and high energy muon beams:

none

Neutrino physics with muon beams: theory, experiments and future perspectives:

none

Muons beams technologies: production, cooling and acceleration at different energy:

none

Advancements in Muon-based Facilities and Broader Applications:

none

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

none

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Search for light Dark Sectors with the HIAF Muon Beam: HFRS-PKMu experiment proposal

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Sub-GeV light dark matter usually requires the existence of new light mediators, such as the dark Z boson in the $L_\mu - L_\tau$ gauge theory. Here we study the search potential for such a Z' boson based on a muon on-target experiment proposal, through $\mu e^- \to \mu e^- X$, with X decays invisibly. The experimental signature would be scattered muon and electron from the target, at large angles compared to backgrounds. Apart from these, activities will be low in the subdetectors located downstream from the interaction point. Here we focus on the usage of the 1-10 GeV muon beam from the HIAF-HFRS facility which is expected to start operation in 2025-2026. Compared with existing experiments or proposals using the CERN 160 GeV muon beam, we find high sensitivity on 10 MeV Z' range.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

none

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Fundamental symmetry violations in charged-lepton flavor-changing processes

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In this talk, I describe how worldwide experimental searches for charged-lepton flavor-changing processes also provide new opportunities for discovering violations of Lorentz and CPT invariance. Model-independent effective interactions describing perturbative Lorentz and CPT violation have been investigated in electromagnetic muon and tau decays, and coherent muon-to-electron conversion in nuclei. Results from the MEG, BaBar, and SINDRUM II experiments have enabled hundreds of first constraints on coefficients parametrizing time-independent signals of Lorentz and CPT violation. Future experiments, including MEG II, COMET, and Mu2e, are projected to increase these constraints by up to two orders of magnitude. I also outline how time-dependent modulations of transition rates, which remain completely unexplored and are uniquely characteristic of Lorentz and CPT violation, can be probed.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

none

New Physics opportunities with low and high energy muon beams:

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Next generation muon facility: laser wakefield acceleration for muon production at ELI Beamlines

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Co-authors: Anna Cimmino [1]; Bedrich Rus [1]; Brendan Reagan [2]; Gabriele Maria Grittani [1]; Jackson Williams [3]; Sergei Bulanov [1]

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New-generation PW class lasers can be used to accelerate electrons up to tens of GeVs. The accelerated electrons can in turn produce muons when interacting with a high-Z target.
The European laboratory ELI Beamlines has already established itself as a leader in laser-driven electron acceleration. Multi-GeV electron beams have been already produced and provided to international academic users. Continuous work is being done to further increase electron energy. The first user experiment aiming at detecting muon produced from electrons accelerated with the already available 1 PW laser, is scheduled for spring 2025.
The laboratory is currently commissioning its 10 PW laser which could accelerate electrons up to several tens of GeV. Given the increased interest in the laser community and the potential multidisciplinary applications, from high energy physics to muon imaging techniques, ELI Beamlines is considering to build in the near future a dedicated muon experimental station for 100 GeV scale muons.
This contribution will shortly present the status of the laser acceleration of high energy electron acceleration, the potential and the limitation of the technique, including the current status of the research on laser based muon production. Then, the focus will be on the preliminary work performed at ELI Beamlines laboratory on this subject and the plans being considered for future developments.

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

Charged lepton flavor violation: theory, experiment and future perspectives:

New Physics opportunities with low and high energy muon beams:

Neutrino physics with muon beams: theory, experiments and future perspectives:

Muons beams technologies: production, cooling and acceleration at different energy:

Advancements in Muon-based Facilities and Broader Applications:

none

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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A versatile and efficient cosmic muon generator for secondary cosmic-ray muon applications

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Co-authors: Davide Pagano [2]; Germano Bonomi [3]

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In the last years, muon radiography (aka muography, based on the flux attenuation) and muon tomography (based on the scattering angle) have made important progress in a wide field of applications, reaching impressive results. And besides these imaging techniques, secondary cosmic ray muons are also used for detector testing and alignment practically in every Nuclear Physics or Particle Physics experiment.
From the simulation point of view, a fair number of cosmic-ray muon generators are already available, based on different software frameworks and on various models of the angular/momentum distribution of the cosmic muons flux. As a matter of fact, the implementation of a realistic flux can make the generator time-consuming, which is a strong limit when high statistics is needed.
Recently, we have developed a new Monte Carlo generator for cosmic-ray muons, named Efficient COsmic MUon Generator (EcoMug), conceived with a particular emphasis on the efficiency (> 10^5 muons generated per second on a standard machine) and on the flexibility (it is supplied with a standard muon angular/momentum distribution implemented by default, but it is expected to be easily reconfigured by the user implementing its own angular/momentum distribution).
Differently from other similar tools, EcoMug is able to generate muons from different kind of surfaces (plane, cylinder and half-sphere), while keeping the correct angular/momentum distribution of generated tracks inside a fiducial volume. This allows to optimise the generation surface according to the system under study, and makes it possible a further improvement of the overall simulation efficiency.
Moreover, this generator is written as a header-only C++11 library, ready to be integrated into whatever C++ code, in particular C++ code based on Geant4 simulation tool.
In this contribution we will briefly present the main features of EcoMug.
References
D. Pagano, G. Bonomi, A. Donzella, A. Zenoni, G. Zumerle and N. Zurlo EcoMug: An Efficient COsmic MUon Generator for cosmic-ray muon applications Nucl.Instrum.Meth. A 1014 (2021) 165732

Muon dipole moments (magnetic and electric): theory, experiments and future perspectives:

none

Charged lepton flavor violation: theory, experiment and future perspectives:

none

New Physics opportunities with low and high energy muon beams:

none

Neutrino physics with muon beams: theory, experiments and future perspectives:

none

Muons beams technologies: production, cooling and acceleration at different energy:

none

Advancements in Muon-based Facilities and Broader Applications:

none

Muons in other fields: muography, muon spin spectroscopy, muon-catalyzed fusion:

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Muon cooling at PSI

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At the Paul Scherrer Institute, the muCool collaboration is developing a technique to cool positive muon beams for high precision experiments that require low energy and small transverse phase space. Applications include muon-spin resonance studies, cold muonium beam production, and muon EDM searches.

The technology employs fast phase-space compression in a cryogenic helium gas target using electric and magnetic fields. After compression, the muon beam must be extracted into vacuum and re-accelerated.

This talk presents recent advancements in the muCool experiment, with a focus on the extraction stage and a novel scheme first tested in 2024.

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Muon-decay parameters at COHERENT

Author: Sergio de la Cruz Alzaga[1]

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We study the most general Lagrangian for muon decay at low energies, including light Dirac right-handed neutrinos (νWEFT), in the COHERENT experiment at the Spallation Neutron Source at Oak Ridge National Laboratory. Using the COHERENT data, we derive the first direct constraint on the Michel parameters governing the $\bar{\nu}_\mu$ energy distribution. We also discuss future sensitivities and assess the implications for the Lorentz structure of the interactions mediating muon decay.
We thus demonstrate that Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) measurements at spallation sources are valuable probes of muon decay physics.

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Charged lepton flavor violation: theory, experiment and future perspectives:

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Neutrino physics with muon beams: theory, experiments and future perspectives:

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The RadioMonteCarLow 2 community effort

Corresponding Author: adrian.signer@psi.ch

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Physics perspectives at the ion-muon collider

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Muon catalysed fusion

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Advanced 2D/3D Muon Spin Rotation Tomography with Si-Pixel Detectors

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High - Intensity Muon Beams (HIMB) project

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Currently PSI delivers the most intense continuous muon beam in the world with up to a few 10^8 μ+/s and aims at upgrading its beamlines within the HIMB project to reach intensities of 10^10 μ+/s, with a huge impact for low-energy, high-precision muon experiments. The use of hyperparameter search algorithms in the simulation of the new HIMB beamline layouts has shown that not only the stringent rate requirements can be met, but that higher phase space quality can be achieved.

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