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MODELLING OF A STRAW TRACKER IN THE NA64 EXPERIMENT ON THE M2 SPS MUON BEAM IN THE GEANT4 SOFTWARE ENVIRONMENT

The NA64 experiment is aimed at searching for mediator particles that carry out the interaction between standard matter and dark matter. The main goal of the experiment is to detect Light Dark Matter (LDM) particles with masses below 1 GeV. The missing energy/momentum technique is used in the experiment, e.g. in the muon run energy of muons in the final state is expected to be 80 GeV. The NA64 experiment has a fairly extensive detector system, including several types of detectors. Straw trackers are used in both muon and electron modes of the experiment. One of the essential components of the detection system along the beamline is the straw tube detector. Straw trackers allow one to reconstruct the tracks of primary and secondary particles and subsequently estimate their momentum based on the curvature of the track. This paper presents a straw tracker model built using the Geant4 software package. Secondary radiation particles were also included in straw tube responses. The main goal of this work is to construct and analyze a straw tracker model using the GEANT4 toolkit. The research methodology is based on the use of the Monte Carlo method, which underlies the work of GEANT4. The results of the study have practical significance, consisting in the use of models for optimizing the technical and design parameters of straw trackers.
Keywords: dark matter, NA64 experiment, straw tracker, Monte-Carlo method.

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GEANT4 бағдарламалық ортасында M2 SPS мюон шоғырындағы NA64 экспериментінде строу трекерді модельдеу

NA64 эксперименті 160 Гэв энергетикалық мюон сәулесін және 100 Гэв энергетикалық электронды сәулені жүзеге асыратын қараңғы секторларды табуға бағытталған. Эксперименттің негізгі мақсаты — массасы 1 Гэв-тан төмен Жеңіл Қараңғы Материяның (ЖҚМ) бөлшектерін анықтау. Жетіспейтін энергия/импульс техникасы экспериментте қолданылады, мысалы, мюондарда соңғы күйдегі мюондардың энергиясы 80 Гэв болады деп күтілуде. NA64 экспериментінде детекторлардың бірнеше түрін қамтитын жеткілікті кең детекторлық жүйе бар. Строу трекерлері эксперименттің муондық және электронды режимдерінде қолданылады. Сәуле сызығының бойындағы тректерді тіркеу жүйесінің маңызды компоненттерінің бірі — строу-трекер. Строу трекерлері бастапқы және қосалқы бөлшектердің іздерін қайта құруға және кейін жолдың қисаюына негізделген олардың импульсін бағалауға мүмкіндік береді. Бұл құжат GEANT4 бағдарламалық пакетін пайдаланып жасалған строу трекер үлгісін ұсынады. Екінші реттік сәулелену бөлшектері строу түтіктерінің реакцияларына да енгізілді. Бұл жұмыстың негізгі мақсаты-GEANT4 құралдар жинағын қолдана отырып, строу трекерінің моделін құру және талдау. Зерттеу әдістемесі GEANT4 жұмысының негізінде Жатқан Монте-Карло әдісін қолдануға негізделген. Зерттеу нәтижелері строу трекерлердің техникалық және құрылыстық параметрлерін оңтайландыру мақсатында тұратын практикалық маңыздары бар.

Түйін сөздер: қараңғы материя, NA64 эксперименті, строу трекері, Монте-Карло әдісі.

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Моделирование строу трекера в эксперименте NA64 на мюонном пучке M2 SPS в программной среде GEANT4

Эксперимент NA64 направлен на поиск темных секторов, реализующих мюонный пучок с энергией 160 ГэВ и электронный пучок с энергией 100 ГэВ. Основная цель эксперимента — обнаружение частиц Легкой Темной Материи (ЛТМ) с массами менее 1 ГэВ. В эксперименте используется метод недостающей энергии/импульса, например, для мюонного режима энергия мюонов в конечном состоянии, как ожидается, составит 80 ГэВ. Эксперимент NA64 имеет довольно обширную систему детекторов, включающую несколько типов детекторов. Строу трекеры используются как в мюонном, так и в электронном режимах эксперимента. Одним из важнейших компонентов системы регистрации треков вдоль линии пучка является строу трекер. Строу трекеры позволяют реконструировать треки первичных и вторичных частиц и впоследствии оценить их импульс на основе кривизны трека. В данной статье представлена модель строу трекера, созданная с использованием программного пакета GEANT4. Вторичные частицы также были включены в отклики строу трубок. Основная цель этой работы — построить и проанализировать модель строу трекера с использованием инструментария GEANT4. Методология исследования основана на использовании метода Монте-Карло, лежащего в основе работы GEANT4. Результаты исследования имеют практическое значение, заключающееся в использовании моделей для оптимизации технических и конструктивных параметров строу.

Ключевые слова: темная материя, эксперимент NA64, строу трекеры, метод Монте Карло.

Introduction

One of the main candidates for the role of the "theory of everything" is the Standard Model (SM). It provides some description of the Universe, has good evidential grounds, and most scientists are inclined to use it. However, despite its obvious popularity, the Standard Model has a number of shortcomings, including the lack of a description of gravitational interaction, CP invariance violation, neutrino oscillations, baryon asymmetry, anomalous magnetic moment of the muon, etc. The available cosmological data [1-3] allow us to assume the existence of a new type of matter - dark matter (DM). In most models, dark matter particles interact with SM particles either gravitationally or through special mediator particles. Today, the hypothesis that DM is a thermal relic that existed in thermodynamic equilibrium with ordinary matter at the initial stages of the origin of the world has become popular. This formulation allows for the existence of the so-called dark sector (DS) - an analogue of ordinary matter, light in the same lower hierarchy of particles. Then the interaction of the particles of the DS and baryonic matter will have a non-gravitational character, consistent with weak interactions [4], and the particles are called WIMPs (Weakly Interacting Massive Particles).

Launched in 2016 at CERN, the NA64 experiment is dedicated to searching for the so-called dark photon, as well as the Z'-boson associated with L_μ-L_τ model, the particles that mediate the interaction of DM and SM. The experiment is based on the idea of the production of a dark photon A' during the interaction of high-energy electrons or muons with an active target, similar to the formation of bremsstrahlung. Initially, the experiment was carried out on the electron beam of the H4 channel at the SPS, but later it was modified to search for DS particles that weakly interact with second-generation leptons, using the muon beam of the M2 channel. As part of the experiment, the search for the missing energy as a result of the scattering of leptons on target nuclei is carried out. Thus, the experiment on the electron beam was called NA64e, and on the muon beam - NA64μ. The muon mode of the NA64 experiment is aimed at searching for the Z’ boson, which is produced as a result of scattering of muons on target nuclei. Subsequently, Z’ decays either into a pair of neutrinos $\nu\bar{\nu}$, or into a pair of particles DS with a smaller mass $\chi\bar{\chi}$. Thus, part of the energy is carried away by the Z’-boson or its decay products, and does not reach the detector, but the detectors measure the residual energy of the scattered muon. The detector system of the experiment includes the following types of detectors: MicroMegas detectors, gas electron multipliers, scintillation hodoscopes, BMS, and straw trackers. We will consider the latter in this article. More details about the design and operating principle of the remaining detectors are described in [5-8].

Methodology for searching for Dark Matter particles in the NA64μ experiment

The experiment is located in the M2 beamline of the Super Proton Synchrotron (SPS). The launch of this modification of the NA64 experiment was motivated by the so-called anomalous magnetic moment of the muon [9], more details about the anomalous magnetic moment of the muon are described in [10, 11, 12]. The goal of the NA64μ experiment is to search for light dark matter with a mass less than 1 GeV. The experiment is based on the missing energy/momentum method, which consists of measuring the beam energy before and after the collision with the target and observing the violation of the energy conservation law. A schematic representation of the experimental setup is shown in Figure 1.

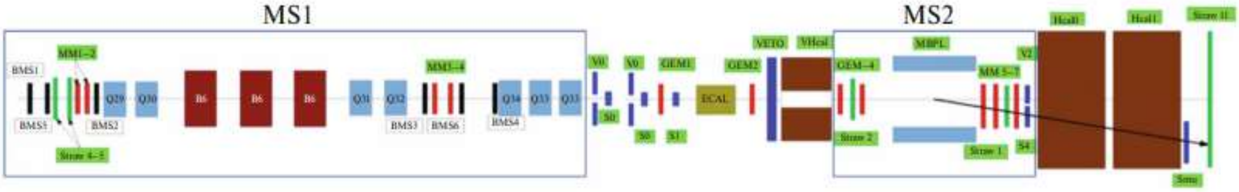

Figure 1 – Experimental setup of NA64μ. The target is ECAL.
The detector systems before and after the target are designated as MS1 and MS2.

The muon beam is obtained at SPS by accelerating protons to energies of ~450 GeV with subsequent collision with a beryllium target. The pions and kaons resulting from the collision decay, forming muons, which are sent to the so-called "sorting" by energy, the focusing-defocusing system (FODO). In this way, a muon beam with an energy of 160±3 GeV is obtained [13], and its moment is recorded. Then the beam is directed to the target, which is a shashlik-type calorimeter. It is a structure of 150 lead-scintillator layers. Inside the target, events occur according to 2 scenarios: in the standard case, as a result of scattering, muon bremsstrahlung appears

$$\mu + Z \rightarrow \mu + Z + \gamma, \qquad (1)$$

in a non-standard case, it will not be a photon that is born, but a dark boson Z’, which will subsequently decay into a pair of Standard Model particles or a pair of Dark Sector particles

$$\mu + Z \rightarrow \mu + Z + Z', Z \rightarrow \nu\bar{\nu}, \chi\bar{\chi}, \qquad (2)$$

ECAL detects the energy of muons and secondary particles, then the momentum and energy of the muons are measured in the track detectors, magnetic spectrometer and HCAL. In the standard case, the total energy of muons and secondary particles will be about 160 GeV, but in the signature case, the output will be observed to be muon energy of about 80 GeV [14] and no detection of secondary particles - this will mean that part of the initial energy $(1 - f)E_0$ is carried away by an invisible particle.

Materials and methods of research

Straw trackers

Straw trackers are used throughout the experimental setup and are an integral part of it. They are a system of thin-walled tubes glued together. Straw trackers are essentially proportional drift counters. Their peculiarity lies in the small amount of material, i.e. it is essentially invisible to the high-energy muon beam. In the context of the NA64 experiment, it is important that muons do not lose energy when passing through the tracker system. Due to their thin walls, straw trackers ensure that there is no energy loss. Straw trackers are widely used in modern high-energy experiments: ATLAS [15], Muon g-2 [16], LHCb [18], etc. As mentioned earlier, straw trackers are proportional counters, and they have a typical proportional counter design. The detector is a hollow cylinder, the length of which is much greater than the base radius. The walls of the cylinder act as a cathode, and a thin wire in the center of the cylinder serves as an anode. A potential difference arises between the electrodes, and the field is stronger near the anode. The working volume of the detector contains gas, in this case, a mixture of Ar (80%) + CO2 (20%) gases [18]. A charged particle, passing through the sensitive volume of the detector, excites and ionizes gas atoms. The resulting ions and electrons drift toward the electrodes. Separate sections fastened together form a straw tracker.

The tracks, the so-called "traces" of the particle's passage, are reconstructed by measuring the time of flight of electrons and ions from the ionization point to the electrodes. When approaching the anode, an avalanche of electrons occurs due to the action of a strong electric field, and depending on the voltage and gas composition, the number of electrons drifting to the anode can reach 104-105 [19]. The resulting signal, passing through a preamplifier, is fed to a time digital converter for subsequent processing.

The NA64μ experiment uses two types of straw trackers: small chambers consisting of two substations of 64 tubes glued together in two rows, and a large chamber. In the small trackers, the substations are rotated by 90° relative to each other and have linear dimensions of 20 × 20 cm. Large substations are rotated by ±7° relative to the beam axis and have dimensions of 120 × 60 cm [18, 20]. Each tube is made of two layers of Kapton, either glued or ultrasonically welded, with a thin layer of aluminum deposited on the outer Kapton layer. A tungsten wire with a diameter of 30 μm serves as an anode. A schematic of the straw tube is shown in Figures 2 and 3.

Using GEANT4 tools for modeling straw trackers

The main tool in this work is the GEANT4 software environment. GEANT4 (GEometry ANd Tracking) was created by the eponymous collaboration at CERN mainly to study the interaction of particles with matter. It can be used to simulate processes occurring in a wide energy range - from eV to PeV [21]. Thanks to the toolkit, it is possible to build the geometry of not only the detector, but also the entire experimental setup, as well as set the characteristics of materials, physical processes, etc. GEANT4 was written in C++, and compared to its previous generations, it is a pioneer in the use of object-oriented programming. The software environment is based on the Monte Carlo method [22], since modeling the behavior of particles often requires averaging multiple cases of interaction, a set of so-called statistics. The choice of this software package in the framework of the work was motivated by the fact that all previous simulations carried out by the NA64 experiment team were written using GEANT4.

In this study, the FTFP_BERT class was used to describe physical processes, allowing one to specify the particle type, physical models, and cross sections of the processes occurring [23].

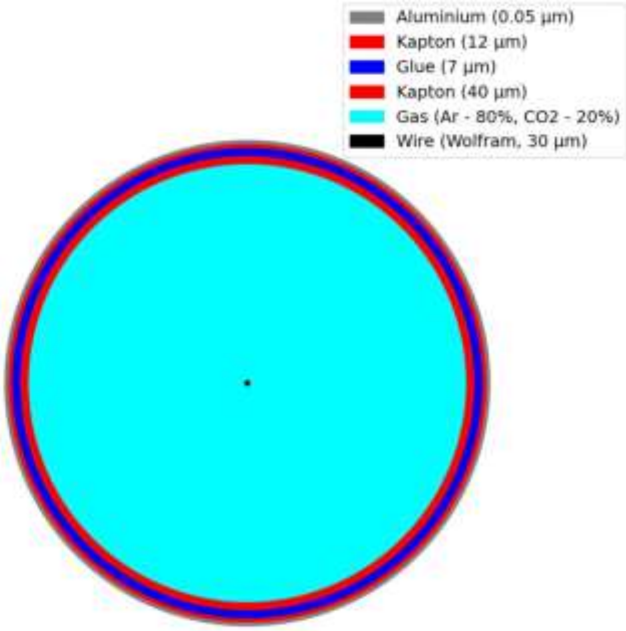

Figure 2 – Schematic representation of the cross-section of a straw tube.

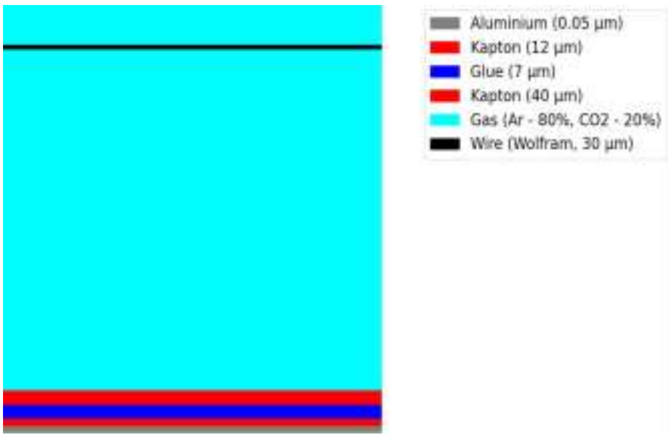

Figure 3 – Schematic representation of the longitudinal section of a straw tube.

This class was chosen because it describes well the interaction components at high energies — hadronic and electromagnetic. In this work in order to create a straw tracker model one straw tube was simulated, then its copies were created using the G4PVReplica class. A lead box simulating an electromagnetic calorimeter was also created. The simulation results were presented as one-dimensional and two-dimensional histograms using ROOT [24] and Matplotlib libraries [25].

Results and discussion

As a result, 3D models of straw trackers were obtained, shown in Figures 4 and 5. A beam of 10.000 particles was also launched and tracks of the beam and its reaction products with the calorimeter were obtained (Figure 6).

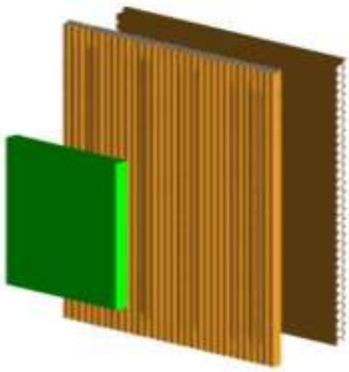

Figure 4 – Model of a small straw chamber 20×20 cm. The lead box simulating an electromagnetic calorimeter is shown in green.

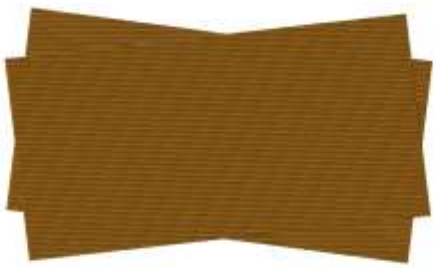

Figure 5 – Model of a large straw chamber. The planes of the substations are inclined by ±7°.

As a result of the beam-target interaction, as expected in the experiment, part of the energy was carried away by the reaction products. In this regard, an energy spectrum was obtained (Figure 7), in which two peaks corresponding to muons and the electromagnetic component of the particles formed are clearly visible. The spectrum and tracks show that the energy is carried away mainly by gamma rays and electrons.

The experiment assumes a deviation of the beam trajectory due to the scattering of muons on target nuclei. To assess this effect, beam profiles were obtained from the trackers before interaction with the target and from large trackers located at some distance from the small ones (Figures 8 and 9).

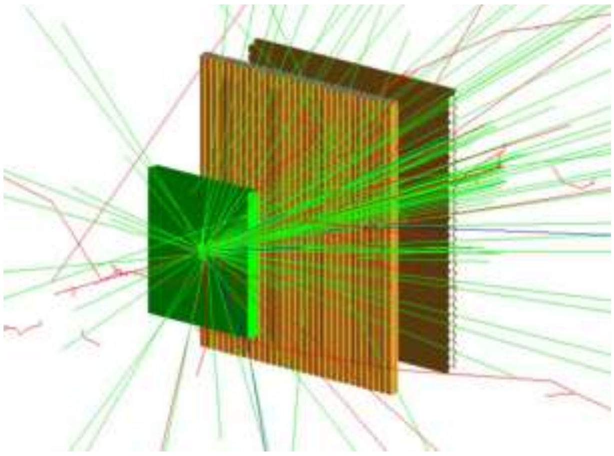

Figure 6 – Beam and secondary particle tracks. Negatively charged particles are shown in red, positively charged particles in blue, and gamma rays in green.

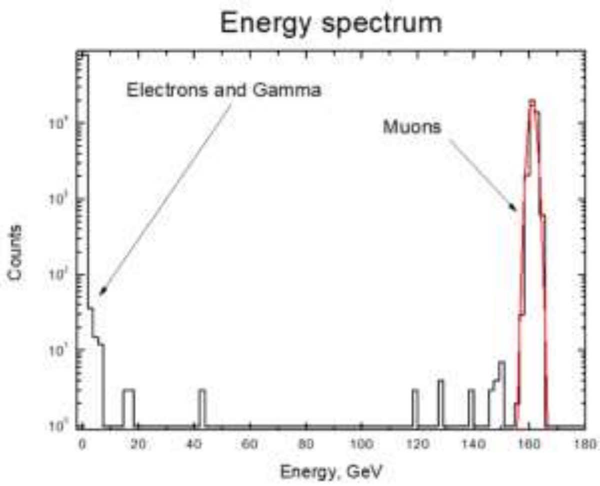

Figure 7 – Energy spectrum of the beam and secondary particles.

The halo around the beam is due to the absence of trigger system which includes scintillation detectors and veto-counters.

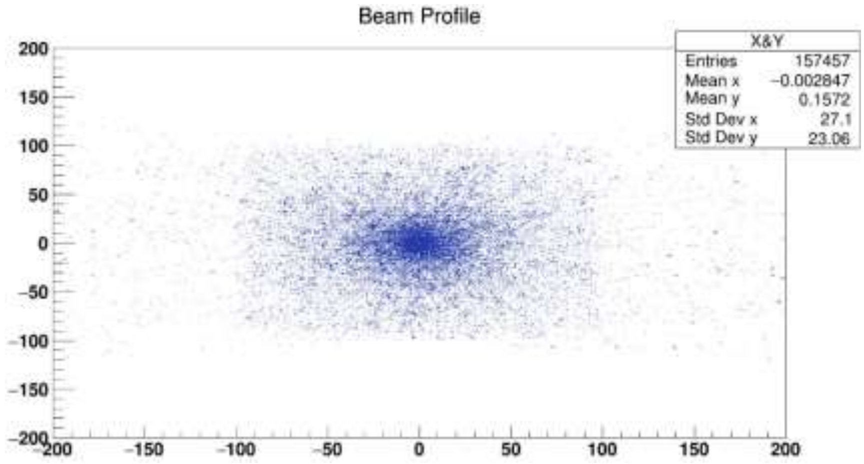

Figure 8 – Beam profile on a small straw chamber, labeled XY.

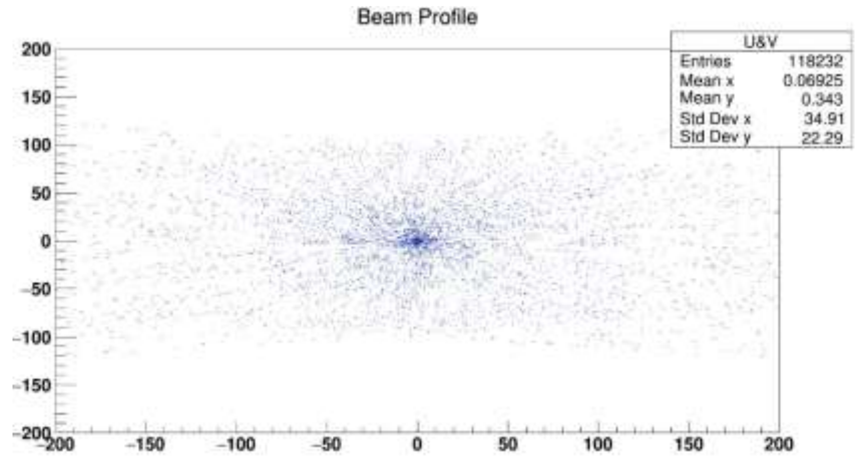

Figure 9 – Scattered beam profile from a large straw chamber labeled UV.

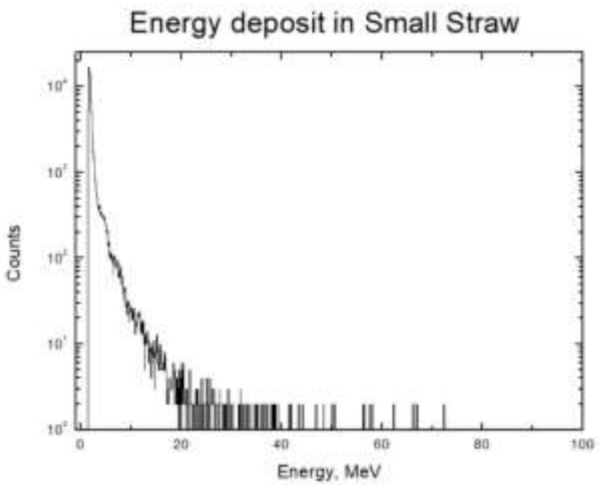

Figure 10 – Energy deposit distribution in small straw.

The energy loss distribution in the detector was obtained, shown in Figure 10. This behavior of the distribution is typical for the case of interaction of high-energy muons with matter. It is also evident from the distribution that the beam does not experience any abnormal energy losses. This means that the models are in fairly good agreement with each other and with theoretical expectations.

The distribution shows that 160 GeV muons lose ~1.65 MeV of energy when passing through the detector. This agrees well with the theoretical value of 1.79 MeV, calculated using the Bethe-Bloch formula.

The track length distribution in one of the straw chambers was also obtained and is shown in Figure 11. A large peak at 11.75 mm is clearly visible, which corresponds to high-energy muons that hit the straw perpendicularly. And longer tracks correspond to scattered muons and electrons that hit at some angle.

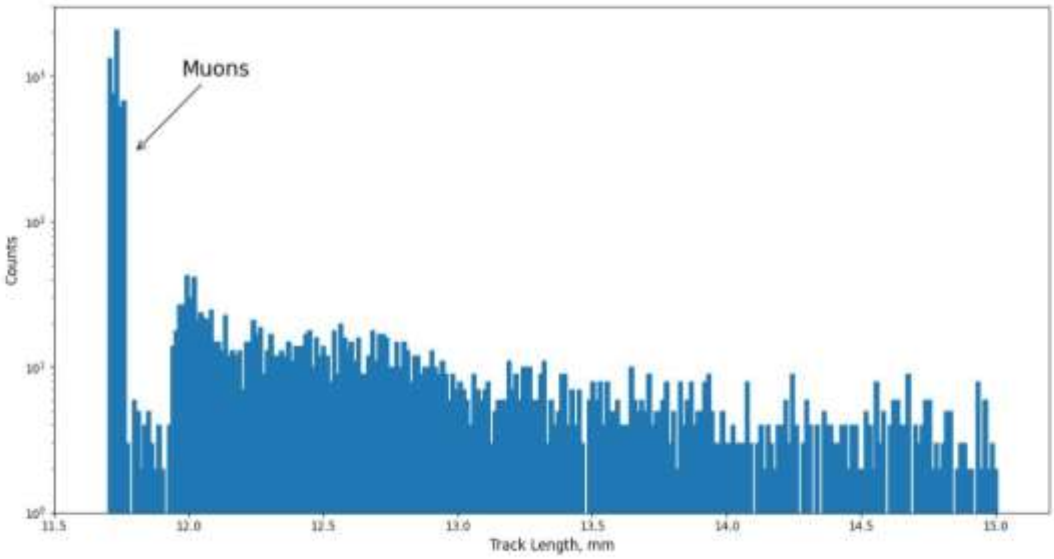

Figure 11 – Track length distribution.

Conclusion

In this study, three-dimensional models of small and large straw trackers were constructed, and particle tracks, their energy spectrum, beam profiles from two stations were obtained. Despite the halo of secondary particles, the obtained beam profiles show its good centralization. The energy spectrum demonstrates the absence of anomalous energy losses, which is consistent with the classical scenario of interaction of muons with matter. An energy loss assessment was performed and found to be consistent with the theoretical value obtained using the Bethe-Bloch formula for the given gas mixture. Using the GEANT4 and ROOT instruments, a distribution of track lengths in the range of 10-15 mm was obtained. The obtained data can be useful for analyzing background processes in the experiment. The results of the study will help in the further development of modifications and improvements to straw trackers, which are widely used in particle physics and high-energy physics.

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References

1 F. Zwicky, On the Masses of Nebulae and of Clusters of Nebulae In A Source Book in Astronomy and Astrophysics, 1900–1975, (Harvard University Press, 1979), pp. 729-737. https://doi.org/10.4159/harvard.9780674366688.c115

2 M. Persic, P. Salucci, and Stel F., The universal rotation curve of spiral galaxies—I. The dark matter connection, Monthly Notices of the Royal Astronomical Society **281**(1), 27-47 (1996). https://doi.org/10.1093/mnras/278.1.27

3 D. Clowe, M. Bradač, A.H. Gonzalez, M. Markevitch, S.W. Randall, C. Jones, and D. Zaritsky, A direct empirical proof of the existence of dark matter, The Astrophysical Journal **648**(2), L109 (2006). https://doi.org/10.1086/508162

4 S.N. Gninenko, N.V. Krasnikov, and V.A. Matveev, Search for light dark matter in the NA64 experiment, Physics-Uspekhi **64**(12), 1286 (2021). https://doi.org/10.3367/UFNe.2021.09.039066

5 D. Banerjee, Resistive multiplexed micromegas detectors to search for dark sector physics and test the weak equivalence principle for anti-matter at CERN, Doctoral dissertation, ETH Zurich (2017). https://doi.org/10.3929/ethz-b-000231250

6 F. Sauli, The gas electron multiplier (GEM): Operating principles and applications, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **805**, 2-24 (2016). https://doi.org/10.1016/j.nima.2015.07.060

7 O.C. Allkofer, J.J. Aubert, G. Bassompierre, K.H. Becks, Y. Bertsch, C. Besson (European Muon Collaboration), A large magnetic spectrometer system for high-energy muon physics, Nuclear Instruments and Methods **179**(3), 445-466 (1981). https://doi.org/10.1016/0029-554X(81)90169-5

8 P. Abbon, et al. The COMPASS experiment at CERN, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **577**(3), 455-518 (2007). https://doi.org/10.1016/j.nima.2007.03.026

9 S. Gninenko, Proposal for an experiment to search for dark sector particles weakly coupled to muon at the SPS. – 2019. – №. CERN-SPSC-2019-002. (2019). https://doi.org/10.17181/CERN.LEK5.O4J3

10 A. Keshavarzi, K.S. Khaw, T., and Yoshioka, Muon g− 2: A review, Nuclear Physics B **975**, 115675 (2022). https://doi.org/10.1016/j.nuclphysb.2022.115675

11 M. Takeuchi, S. Iguro, T. Kitahara, and M.S. Lang, Current status of the muon g-2 interpretations within two-Higgs-doublet models, Physical Review D **108**(11), 115012 (2023). https://doi.org/10.1103/PhysRevD.108.115012

12 G. Arcadi, L. Calibbi, M. Fedele, F. and Mescia, Muon g-2 and B Anomalies from Dark Matter, Physical review letters **127**(6), 061802 (2021). https://doi.org/10.1103/PhysRevLett.127.061802

13 Y.M. Andreev, D. Banerjee, B.B. Oberhauser, J. Bernhard, P. Bisio, N. Charitonidis (NA64 Collaboration), Shedding light on dark sectors with high-energy muons at the NA64 experiment at the CERN SPS, Physical Review D **110**(11), 112015 (2024). https://doi.org/10.1103/PhysRevD.110.112015

14 Y.M. Andreev, et al. Exploration of the Muon g-2 and Light Dark Matter explanations in NA64 with the CERN SPS high energy muon beam, arXiv preprint arXiv:2401.01708 (2024). https://doi.org/10.48550/arXiv.2401.01708

15 A. Vogel, and ATLAS Collaboration, ATLAS Transition Radiation Tracker (TRT): Straw tube gaseous detectors at high rates, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **732**, 277-280 (2013). https://doi.org/10.1016/j.nima.2013.07.020

16 B.T. King, et al. The straw tracking detector for the Fermilab Muon g-2 Experiment, Journal of Instrumentation **17**(02), P02035 (2022). https://doi.org/10.1088/1748-0221/17/02/P02035

17 S. Bachmann, and LHCb OT collaboration. Performance of the LHCb outer tracker in run-I and run-II of the LHC, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **1069**, 169746 (2024). https://doi.org/10.1016/j.nima.2024.169746

18 V.Y. Volkov, et al. Straw chambers for the NA64 experiment, Physics of Particles and Nuclei Letters, 16, 847-858 (2019). https://doi.org/10.1134/S1547477119060554

19 W. Erni, et al. Technical design report for the P ANDA (Anti Proton ANnihilations at DArmstadt) Straw Tube Tracker: Strong interaction studies with antiprotons, The European Physical Journal A **49**, 1-104 (2013). https://doi.org/10.1140/epja/i2013-13025-8

20 S. Gertsenberger, Simulation of the Straw Detector in the NA64 Experiment for the Muon Run, Physics of Particles and Nuclei Letters **20**(6), 1492-1495 (2023). https://doi.org/10.1134/S1547477123060158

21 S. Agostinelli, et al. GEANT4—a simulation toolkit, Nuclear instruments and methods in physics research section A: Accelerators, Spectrometers, Detectors and Associated Equipment **506**(3), 250-303 (2003). https://doi.org/10.1016/S0168-9002(03)01368-8

22 T. Basaglia, et al. Geant4: A game changer in high energy physics and related applicative fields, Future Generation Computer Systems **159**, 411-422 (2024). https://doi.org/10.1016/j.future.2024.05.042

23 J. Allison, et al. Recent developments in Geant4, Nuclear instruments and methods in physics research section A: Accelerators, Spectrometers, Detectors and Associated Equipment **835**, 186-225 (2016). https://doi.org/10.1016/j.nima.2016.06.125

24 I. Antcheva, et al. ROOT—A C++ framework for petabyte data storage, statistical analysis and visualization, Computer Physics Communications **180**(12), 2499-2512 (2009). https://doi.org/10.1016/j.cpc.2009.08.005

25 A.H. Sial, S.Y.S. Rashdi, and A.H. Khan, Comparative analysis of data visualization libraries Matplotlib and Seaborn in Python, International Journal **10**(1), 277-281 (2021). https://doi.org/10.30534/ijatcse/2021/391012021

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