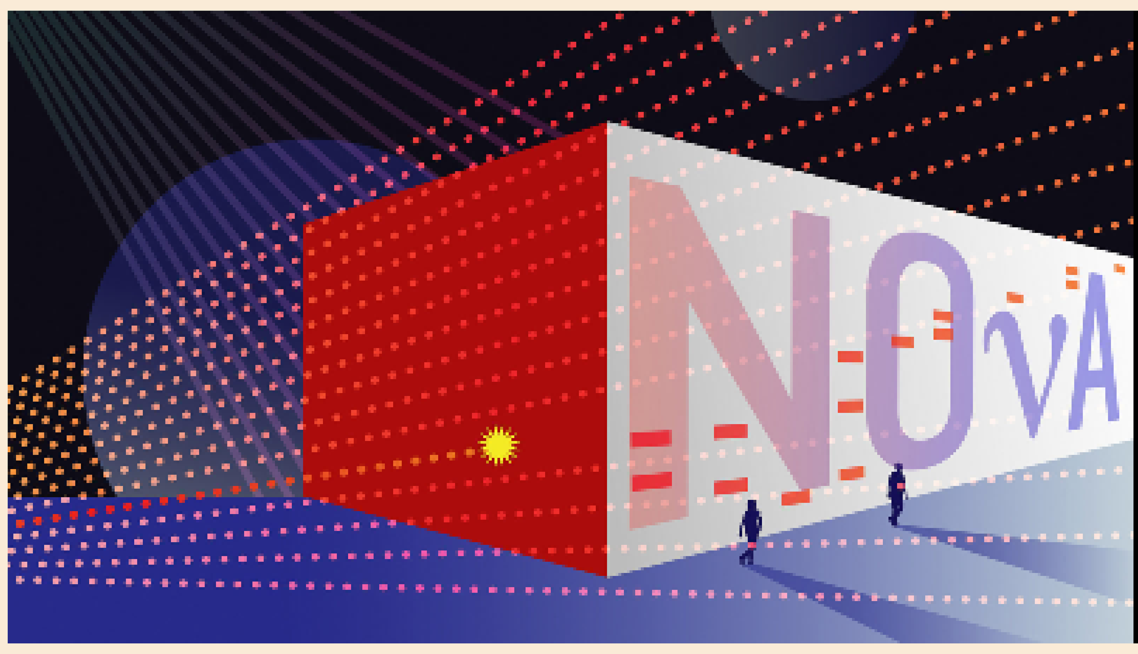

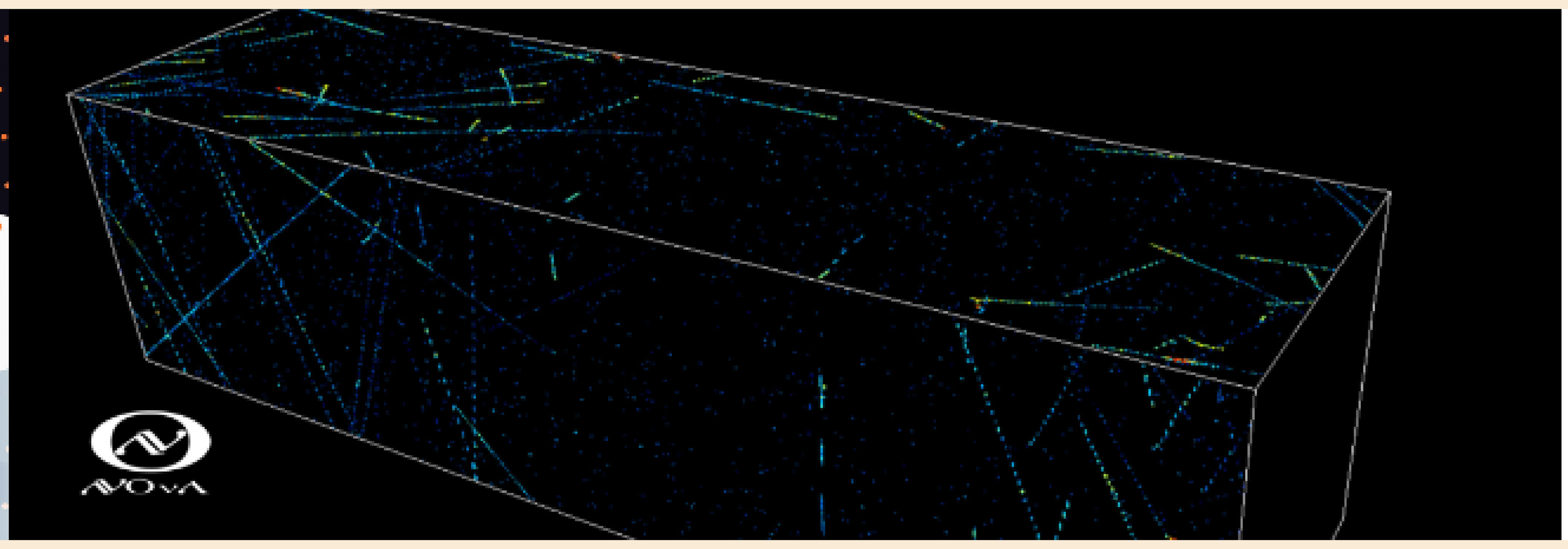

Search for weakly interacting particles with non-standard energy deposition in the NOvA experiment

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Introduction

LIPs in NOvA experiments and their role in non-standart models:

The quantization of electric charge remains an unresolved issue within the Standard Model of the electroweak and strong interactions. Decades of searches for long-lived fractionally charged particles (FCPs) have been conducted in various cosmic ray experiments. Previous cosmic ray FCPs searches have relied on underground experiments such as MACRO [1], Kamiokande-II [2], and LSD [3], as well as on space experiments including the Space Shuttle-launched AMS-01 [4], the BESS upper-atmosphere balloon [5], and the Dark Matter Experiment (DAMPE) [6]. Unlike the underground experiments, which require FCPs energies of the order of hundreds of GeV, the orbital searches started with energies of only a few GeV. The advantage of searching for LIPs (Lightly ionizing particles) in the far detector in the NOvA experiment is that the search for these particles is carried out under conditions on the earth's surface. Despite significant efforts by underground and in-space experiments, no evidence for such particles has been found. However, these searches have established strong flux limits, summarized in Table 1 below:

	Experiment	Charge (e)	Upper limit (90 %-)
Underground	MACRO (2004)	1/4 - 2/3	$6.1 \cdot 10^{-16}$
	Kamiokande II (1991)	1/3	$2.1 \cdot 10^{-15}$
		2/3	$2.3 \cdot 10^{-15}$
	LSD (1993)	1/3	$2.3 \cdot 10^{-13}$
		2/3	$2.7 \cdot 10^{-13}$
In-space	AMS-01 (2003)	2/3	$3.0 \cdot 10^{-7}$
	BESS (2008)	2/3	$4.5 \cdot 10^{-7}$
	DAMPE (2023)	2/3	$6.2 \cdot 10^{-10}$

We start with a particle such as a muon to specify the existence of a lightly ionizing particle with a fractional charge. A muon is a particle with minimal ionization. Particles with fractional charge in the Bethe-Bloch theory lose energy much slower. The formula of the theory is as follows:

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]. \tag{1}$$

LIPs and Muons

We simulate a fractionally charged particle with charge of $-\frac{1}{3}$ and energy of 3 GeV with properties are similar in properties to a muon. We just duplicate a muon by bhanging only its charge. So, the simulation is going on with muon particle with charge of 1 and energy of 3GeV, and with LIP with charge of $-\frac{1}{3}$ and energy of 3GeV. The properties of the muon are given according to the standard model.

Aim

One of the goal to construct energy distributions for muons and LIPs and to show that the distributions are shifted from each other due to the peculiarity of energy deposition for each particle in the detector.

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NOvA detector

NOvA consists of two detectors, one at Fermilab (the near detector), and one in northern Minnesota (the far detector). Neutrinos from NuMI pass through 810 km of Earth to reach the far detector. The far detector weighs 14,000 tons and measures 15x15x60 m. The near detector weighs 300 tons and measures 4x4 x15 m. The design of both detectors is the same: they consist of polyvinyl chloride cells filled with liquid scintillator, and the light pulses from them are collected by a special optical fiber. The near detector is located underground at a depth of 100 m, and the far detector is on the surface. NOvA's main goal is to observe the oscillation of muon neutrinos to electron neutrinos. In this analysis far detecor is using. Next steps described later in the poster.

Muon's simulation. Event diplay view

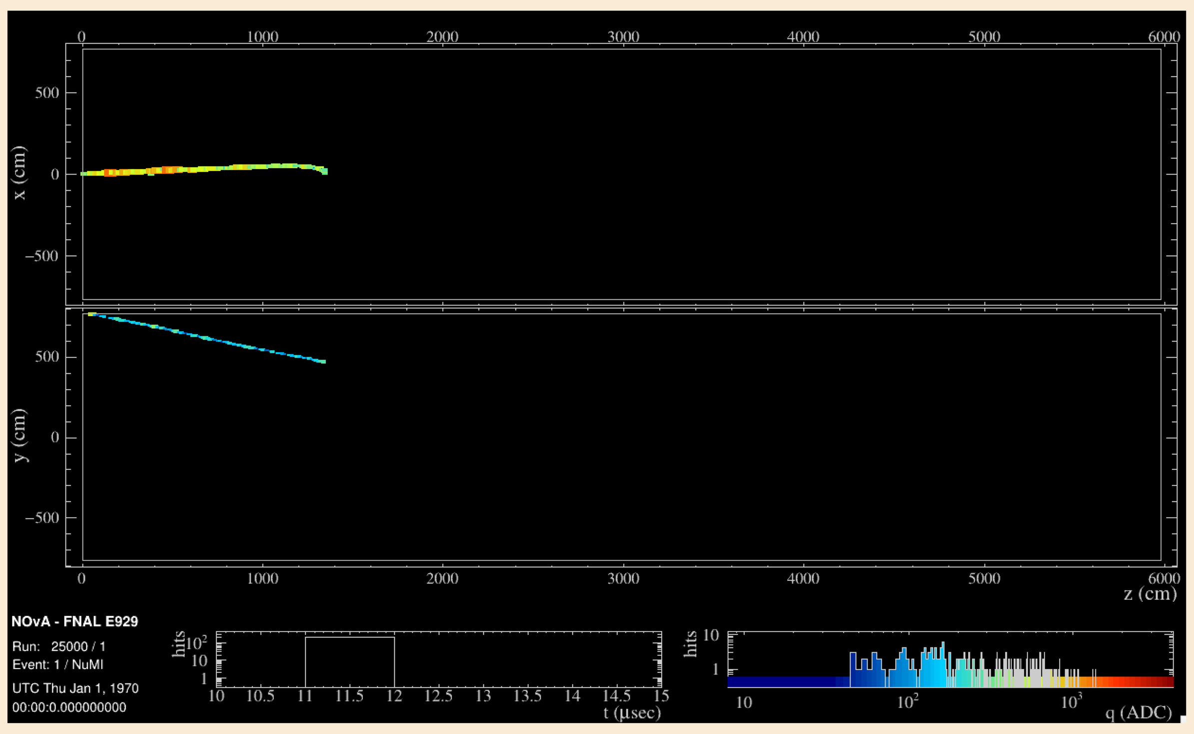

Figure 1: The reconstructed event of muon simulation with the energy of 3GeV and charge of -1e

LIP's simulation. Event diplay view

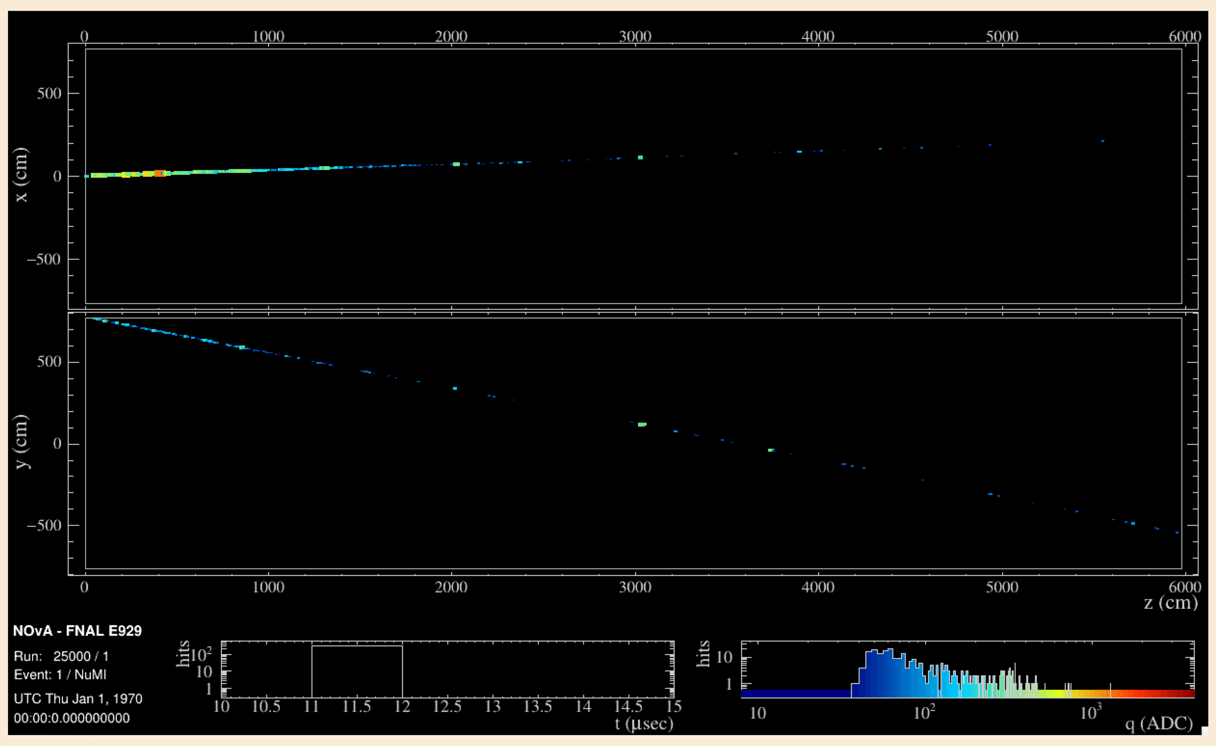

Figure 2: The reconstructed event of LIP simulation with the energy of 3GeV and charge of $-\frac{1}{3}$e

Distribution of energy deposition $\frac{dE}{dX}$ for muons and LIPs

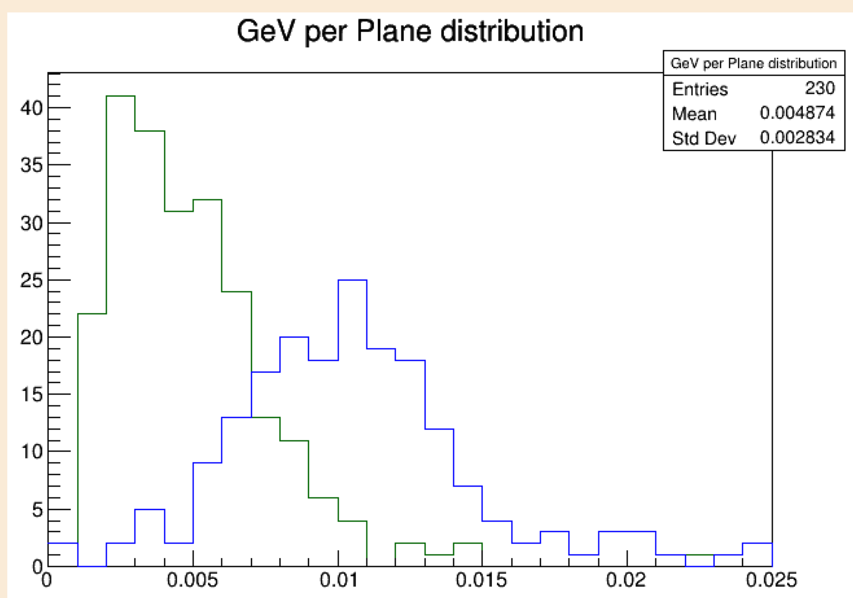

Figure 3: The result of the simulation of both events (1 event muon, and 1 event LIP). The energy distribution is constructed from the ADC for every cell in the detector.

Conclusion

- Simulated events for muon and lightly ionizing particle in the far detector in NOvA experiment;
- The measured ADC values for each cells of the muon's and LIP's tracks were recalibrated to dE/dx values;
- To make further analysis MPV in muon/LIP simulated samples will be used as score output for evaluation of the separation muon's track from hipotetical LIPs under current study.

Acknowledgement

In conclusion I am grateful to A. Antoshkin for his contribution to this work. Also I am grateful to O. B. Samoylov. His efforts to this analysis work is highly appreciated.