Sensitivity potential to a light flavor-changing scalar boson with DUNE and NA64μ

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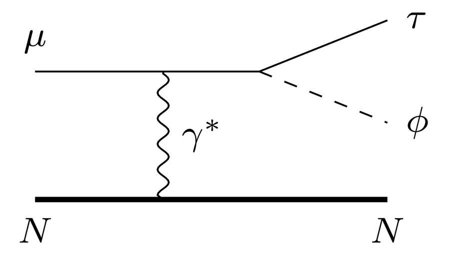
Introduction

Observations in cosmology and astrophysics imply the existence of a Dark Sector with new particles that could weakly couple to Standard Model (SM) particles. In this work [1], we study the sensitivity potential of **μ-on-target experiments** to new physics using a **charged lepton flavor violation (CLFV)** benchmark model, which uses a light, scalar boson associated with $\mu - \tau$ conversion. A class of new theories [2] proposes the search for CLFV, which is heavily suppressed in the SM.



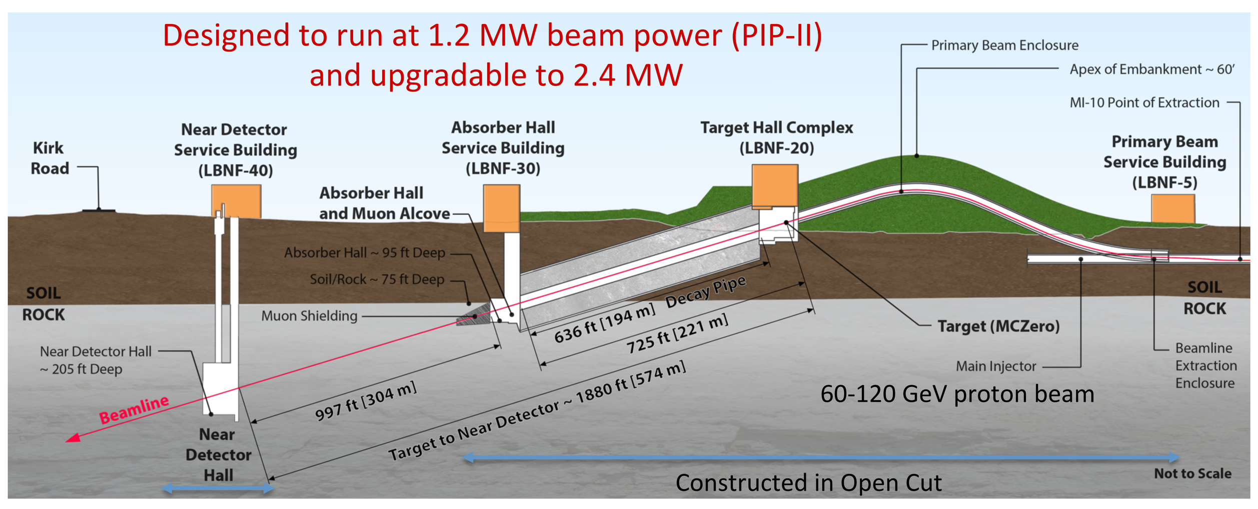
$$\mathcal{L}_{\mathcal{I}} = \phi\bar{\mu}(g_V + g_A\gamma^5)l + \phi^*\bar{l}(g_V^* - g_A^*\gamma^5)\mu$$

Two different approaches exploited:

- The proton beam at Fermilab, which is used to produce the neutrino beam for the **Deep Underground Neutrino Experiment (DUNE)** will produce a high-intensity **muon beam** dumped in an absorber. The system could be used to search for scalar boson particles at the Near Detector.
- The **NA64μ** experiment at CERN uses a 160-GeV energy muon beam with an active target to search for excess events with missing energy and momentum as a probe of new physics.

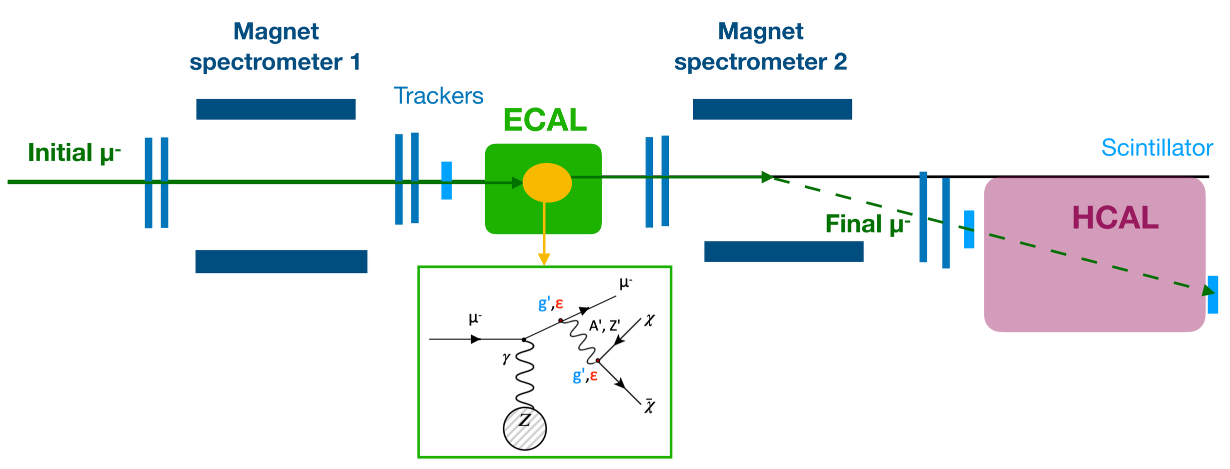
DUNE as a muon-on-target experiment

- The **DUNE neutrino beam** is produced by a 60-120 GeV proton beam hitting a graphite target [3], after which hadrons decay to leptons and neutrinos in a $\sim$ 220-m-long decay pipe.
- At the end of the pipe a dedicated $\sim$ 30-m-long stainless-steel structure acts as a beam-dump to stop all muons 300 m upstream from the Near Detector (see simulated muon energy spectrum on the right.)
- New particles produced in the beam-dump could be detected at the Near Detector.



The NA64μ experiment

- NA64μ [4] is a fixed-target experiment at CERN looking for new particles of Dark Matter and portal interactions produced in electromagnetic showers.
- The experiment uses the 160-GeV muon beam from the CERN SPS.
- Beam scintillators, veto counters, low material-budget trackers and dipole magnets allow to precisely constrain the momentum of the incoming 160-GeV muons impinging on an active target.
- Missing energy/momentum carried away by the produced hypothetical, long-lived ϕ boson, leaves a scattered muon as experimental signature.



Expected signal rates

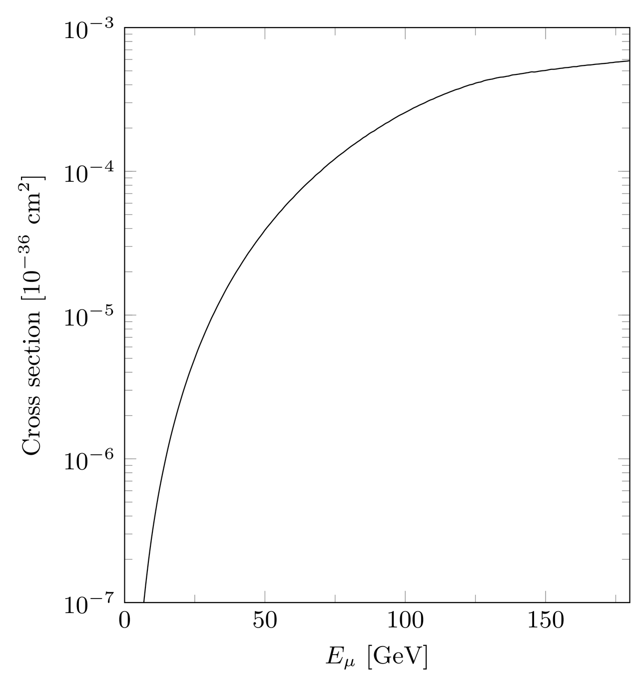
- ϕ bosons are generated by the μ-on-target process, and a fraction of them decay and can be detected. The number of such signal events is

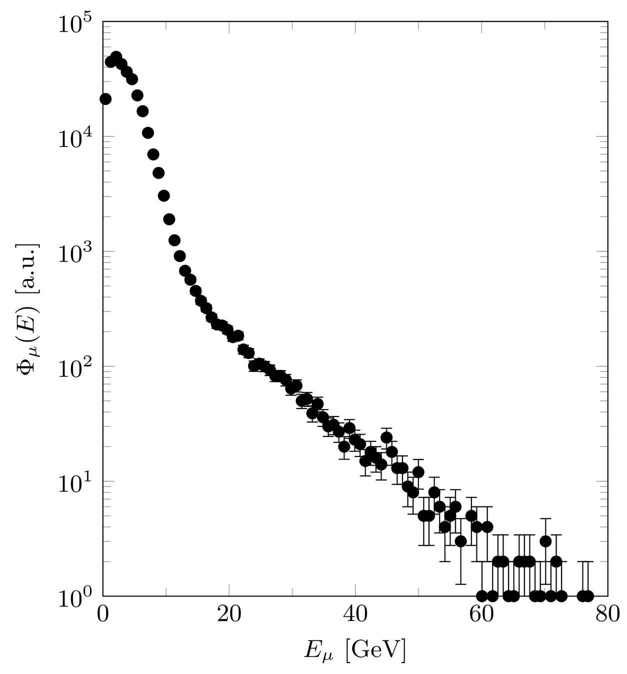
$$N_\phi = \int dE_\phi \Phi_\phi(E_\phi) \times \frac{l_{\text{det}}}{\gamma\beta c\tau_\phi},$$

where $l_{\text{det}}/\gamma\beta c\tau_\phi$ is the fraction of bosons decaying in flight to produce a signal in the detector, and $\Phi_\phi(E_\phi)$ is the flux of ϕ bosons

$$\Phi_\phi(E_\phi) = \int dE\Phi_\mu(E) \times \int_{E_{\text{min}}}^{E} dE_l \frac{n_A}{-dE/dl} \int_0^{\theta_{\text{det}}} d\theta_\phi \sin\theta_\phi \frac{d^2\sigma(E_l, E_\phi)}{dE_\phi d\cos\theta_\phi}.$$

- $\Phi_\mu(E)$ is the flux of the muon beam as a function of energy, n_A is the number of target atoms per volume, E_l is the muon energy after traveling a length l in the target and losing energy according to the stopping power $-dE/dl$, E_{min} is the energy of the muon at the end of the target, and θ_{det} is the angular acceptance of the detector.

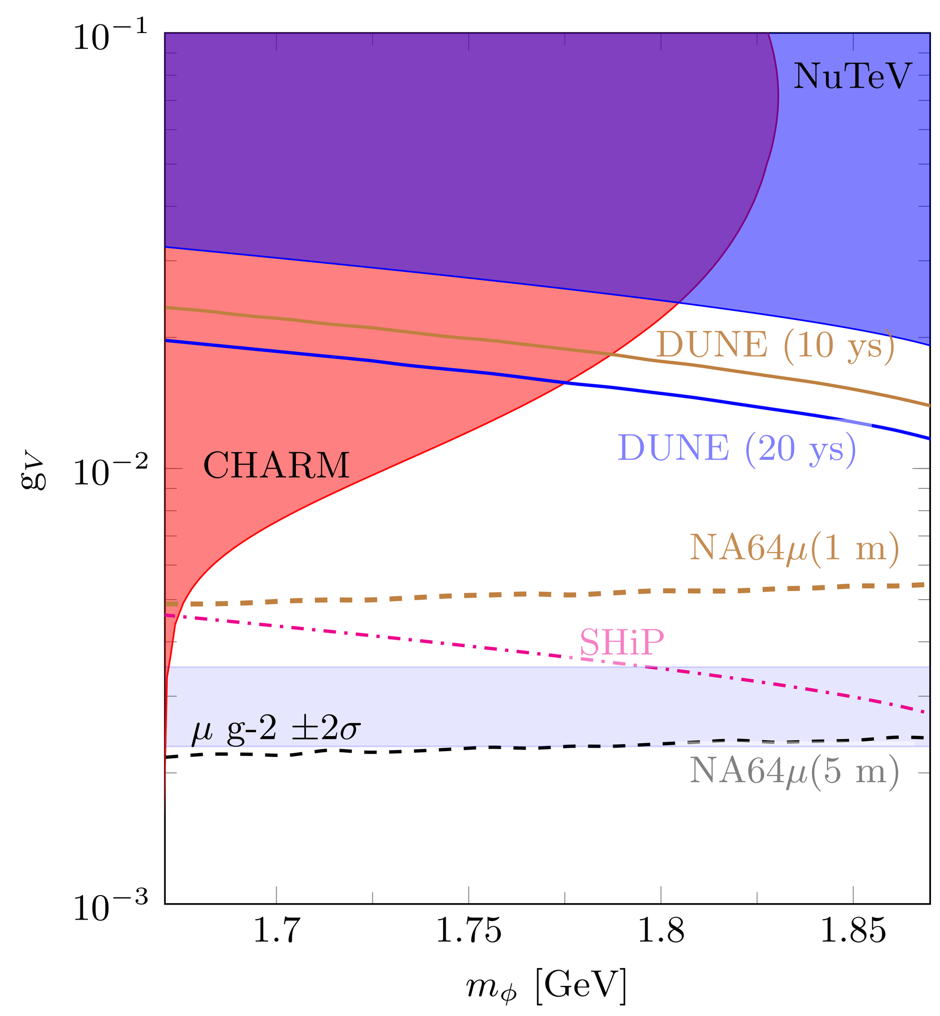




- The production cross-section for the ϕ boson [5] as a function of the incoming lepton energy is shown above. Assuming $m_\phi \simeq m_\tau$, the threshold for the production is given by $E_\mu > [(2m_\tau + m_N)^2 - m_\mu^2 - m_N^2]/2m_N \simeq 3.8$ GeV for Pb.

Sensitivity potential of DUNE and NA64μ

We find [1] that NA64μ and DUNE have complementary potential to cover a significant portion of the benchmark model parameter space, (m_ϕ, g_V). NA64μ with an optimized setup could probe the coupling parameter down to $g_V \simeq 3 \times 10^{-3}$, completely covering the muon $g_\mu - 2$ preferred region and thus providing a similar projected reach as SHiP. DUNE will also be able to cover unexplored parts of the parameter space, potentially improving on the obtained constraints from NuTeV.



References and acknowledgments

References

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