Probing neutrinophillic scalars with high-energy muon beams

Jyotismita Adhikary
National Centre for Nuclear Research(NCBJ)
Warsaw, Poland

Together with Kevin Kelly, Felix Kling and Sebastian Trojanowski

Based on e-Print: 10.1103/PhysRevD.111.075019

NARODOWE CENTRUM NAUKI
2021/42/E/ST2/00031

Scalars2025: Higgs bosons and cosmology

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

Outline

1. The model: Neutrino-phillic scalars
2. Dark matter models coupled to neutrino-phillic scalars
3. Signature of neutrinophillic scalars
4. The muon collider
5. Possible backgrounds and mitigation

Neutrino-phillic scalar mediator

ϕ ← Complex scalar carrying lepton number -2

- The particle ϕ couples to Standard Model (SM) neutrinos through a portal that involves a dimension-6 operator.

Lepton doublets

Higgs doublet

$$\mathcal{L}_{\text{portal}} = \frac{(L_\alpha H)(L_\beta H)}{\Lambda^2_{\alpha\beta}}\phi$$

After electroweak symmetry breaking

$$\mathcal{L} \supset \frac{1}{2}\lambda_{\alpha\beta}\nu_\alpha\nu_\beta\phi + \text{h.c.},$$

K. Kelly, Y. Zhang
arXiv: 1901.01259

DM candidates

$$\mathcal{L}_{\rm DF} \supset \frac{1}{2} y \bar{\chi}^c \chi \phi + \text{h.c.},$$

- Dirac fermion DM with lepton number +1.
- Undergoes freeze out.

$$\mathcal{L}_{\rm CS} \supset \frac{1}{6} y \chi^3 \phi + \text{h.c.}.$$

- Complex scalar with lepton number +⅔.
- Undergoes freeze out.

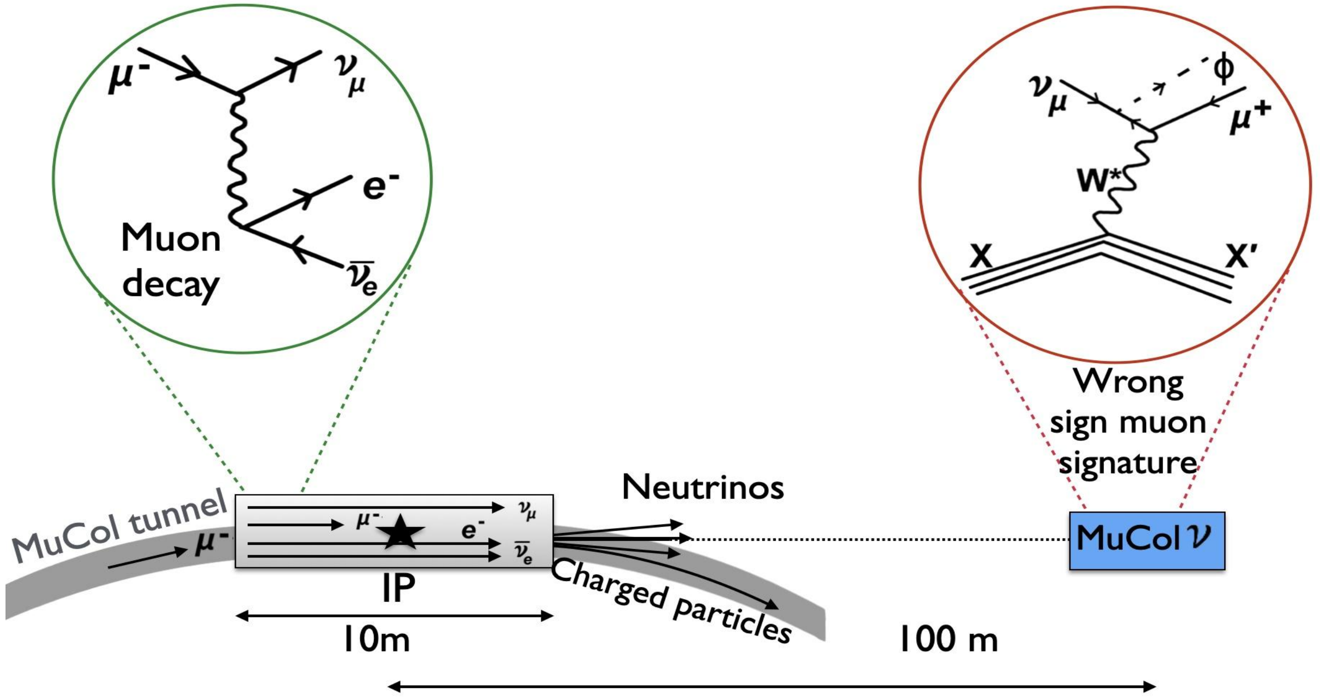
Kevin J. Kelly, and Yue Zhang
1901.01259

$$\nu_4 = \nu_s \cos\theta + \nu_a \sin\theta$$

- Sterile neutrino couples to SM neutrinos via ϕ
- Freezes in via Dodelson- Widrow mechanism.

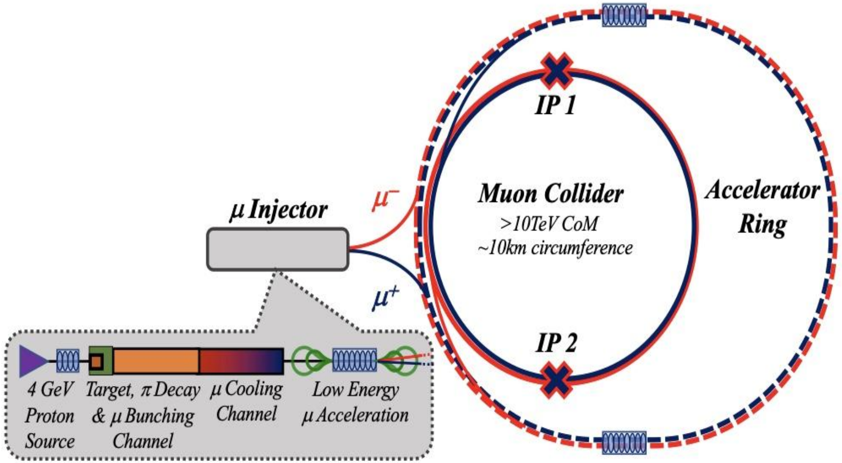
Scott Dodelson, Lawrence M. Widrow
9303287,
Gouvêa et. al. 1910.04901

The wrong-sign muon signature



Note: One beam is enough to probe the signature

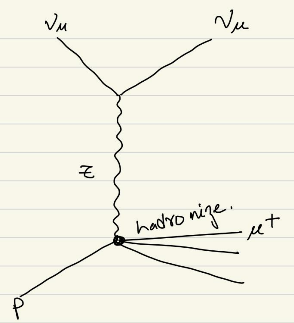
Muon collider

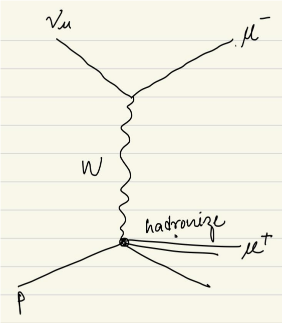


- This design envisions a 4.5 km long storage ring into which about 10^{13} muons will be injected each second.
- While these muons can decay anywhere in the ring, the largest flux of neutrinos originates from decays in the straight sections around the IPs.
- We conservatively assume that the straight section have a length of 10 m, resulting in about 10^{10} neutrinos per second.

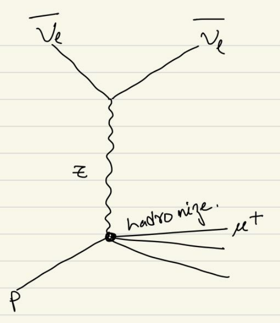
Neutrino induced backgrounds

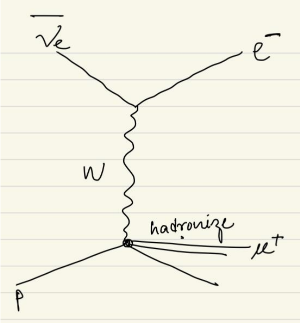
Neutral and charged current ν_μ events



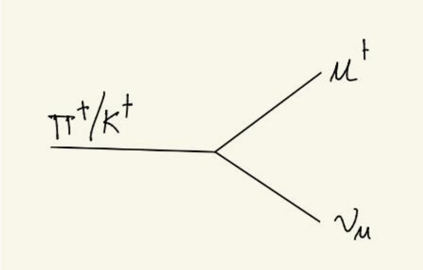


Neutral and charged current ν_e events





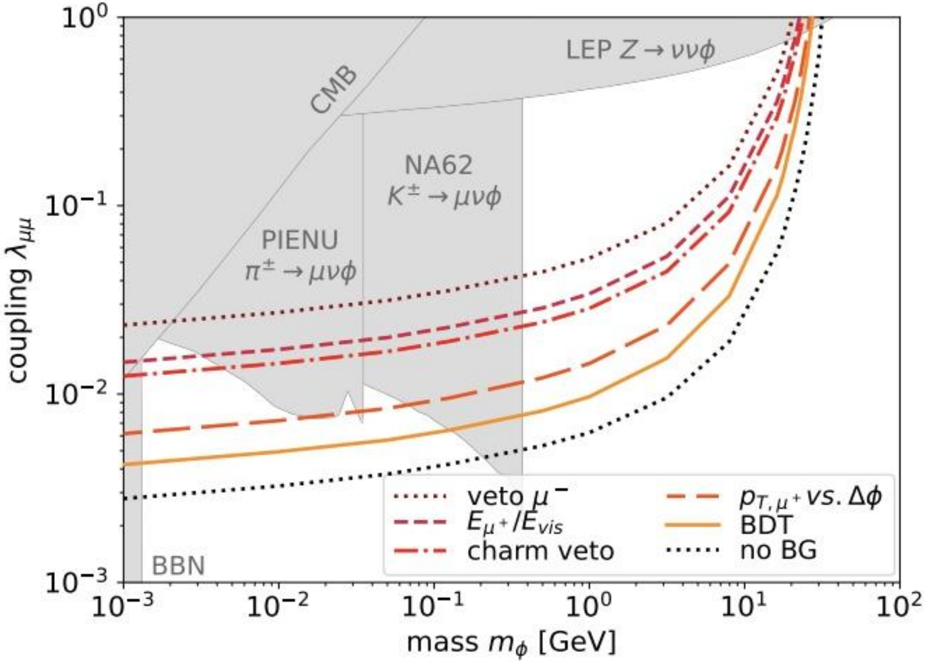
Pion/Kaon decay in flight



Background mitigation

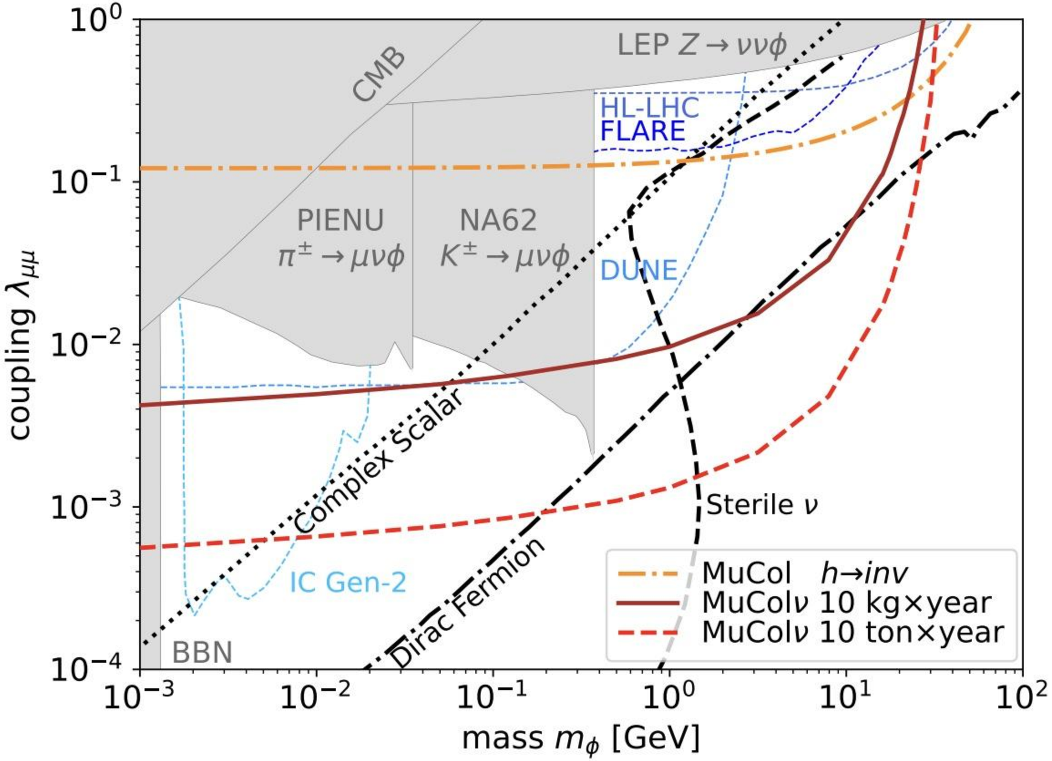
Cut	Background Rates					Signal Efficiency for m_ϕ	
	CC prompt	CC displaced	NC prompt	NC displaced	All	1 GeV	20 GeV
All Events	$1.89 \cdot 10^7$		$6.24 \cdot 10^6$		$2.52 \cdot 10^7$	1.00	1.00
$E_{\mu^+} > 100$ GeV	$3.23 \cdot 10^4$	$4.59 \cdot 10^3$	$2.45 \cdot 10^3$	$1.29 \cdot 10^3$	$4.06 \cdot 10^4$	0.783	0.661
$E_{\mu^-} < 30$ GeV	$2.43 \cdot 10^3$	$9.11 \cdot 10^2$	$2.30 \cdot 10^3$	$1.29 \cdot 10^3$	$6.93 \cdot 10^3$	0.78	0.661
$E_{\mu^+} > 0.5E_{visible}$	$2.40 \cdot 10^2$	33.77	$2.09 \cdot 10^2$	$1.79 \cdot 10^2$	$6.61 \cdot 10^2$	0.576	0.412
charm veto	48.47	30.85	43.87	$1.78 \cdot 10^2$	$3.01 \cdot 10^2$	0.555	0.411
p_{T,μ^+} vs. $\Delta\phi$	1.68	0.767	2.86	4.56	9.88	0.386	0.233
BDT	0.155	0.646	0.081	1.35	2.23	0.416	0.214

Background mitigation

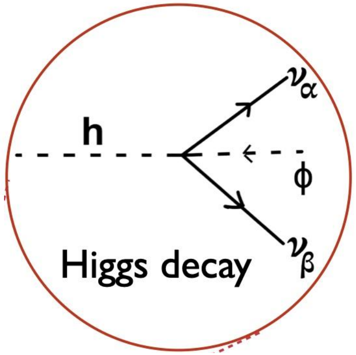


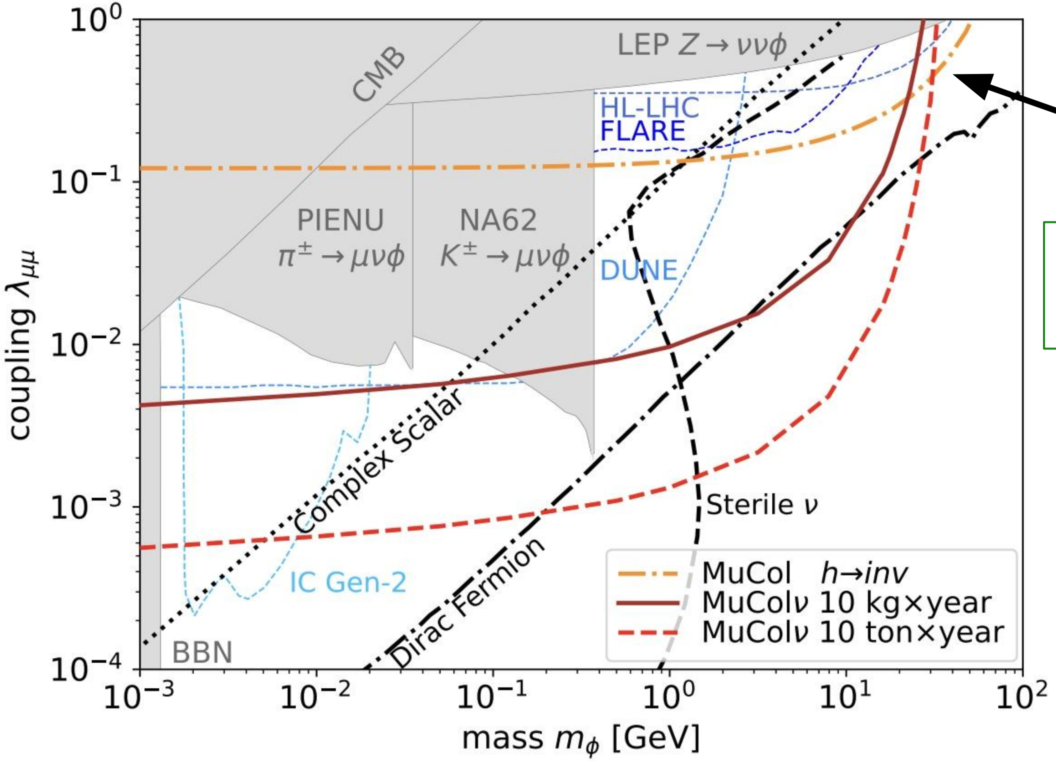
Sensitivity after each cut

Sensitivity reach



Sensitivity reach





$$\mathcal{L} \supset (\lambda_{\alpha\beta}/v)\,\nu_\alpha\nu_\beta\phi h,$$

Surpass the sensitivity of LHC measurements

Conclusions

- With this work we have tried to probe neutrinophillic mediator with high energy muon beams.
- The MuColν detector would be especially capable of searching for a neutrinophilic mediator ϕ through the mono-neutrino scattering process $\nu\mu N \rightarrow \mu + \phi X$, exceeding searches from other terrestrial approaches for $m\phi$ in the ~few MeV – ten GeV range
- The search for mediator will also open windows to probe dark matter models that couple via the mediator to the Standard model particles.
- Neutrinos have always been a loose string in the standard model and there are plans to study neutrino physics in muon collider along with BSM physics.