

New physics at the next neutrino facilities

Pedro Machado XIX International Workshop on Neutrino Telescopes February 25th, 2021

Fermilab U.S. DEPARTMENT OF Office of Science





The nature of neutrinos





Matter-antimatter asymmetry





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Why neutrinos?

Proton decay



Portal to new physics?





Why neutrinos?



Why neutrinos now????





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MINOS event

 $\nu_e CC$



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NOvA event





MINOS event

0.6

0.4

osition (m)

Transverse

-0.4

-0.6

-0.2

0

0.2

0.4

Depth (m)

0.6

0

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https://cdcvs.fnal.gov/redmine/projects/novaart/wiki/Running_the_EventDisplay



NOvA event





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SK/T2K event



http://www-sk.icrr.u-tokyo.ac.jp/sk/sk/t2k-e.html



NOvA event







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SK/T2K event



IceCube event



https://icecube.wisc.edu/science







NOvA event





MiniBooNE event



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SK/T2K event



IceCube event









NOvA event





MiniBooNE event

Liquid scintillator event (e.g. Daya Bay, JUNO, RENO, ...)

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SK/T2K event

IceCube event



Jinping

Event time Run Event TRG Type(s) TotalPE: MaxPE:	:MC :0 :No Trigger 600.0 5.0
MaxPE: NumHits:	5.0 480



1602.01733







NOvA event





MiniBooNE event



Liquid scintillator event (e.g. Daya Bay, JUNO, RENO, ...)



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SK/T2K event



IceCube event



LArTPCs









400



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JUNO (20 kton)



DUNE (40 kton)



Hyper-Kamiokande (260 kton)



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Beyond statistical limitations

IceCube-Gen2 (~ 10 km³)

(sorry IceCube collaboration, your experiment is too big to fit my slide...)







JUNO (20 kton)





DUNE (40 kton)



Add the most intense neutrino sources ever to this picture!

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Beyond statistical limitations

IceCube-Gen2 (~ 10 km³)

(sorry IceCube collaboration, your experiment is too big to fit my slide...)







Topics to be discussed

Joachim Kopp sterile neutrinos and the SBL anomaly, non-standard interactions. acronyms for neutrino experiments

Pilar Coloma sterile neutrinos broadly

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Challenge 4: "New v Physics"











Dark neutrinos









Dark neutrinos

couples more strongly to RH neutrinos





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Similar to transition magnetic moments





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inos



see e.g. Gninenko 0902.3802



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		_
		- 1

Double bang signatures at IceCube/DeepCore



Coloma M Martinez-Soler Shoemaker PRL 1707.08573 Coloma EPJC 1906.02106

Neutrino-electron scattering like events in Minerva (and others)



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Dark neutrinos

New signatures in LArTPCs







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- All electric charges, in the SM, are multiples of the down quark charge Q(down quarks) = -1/3 Q(up quarks) = +2/3 Q(e, μ , τ) = -1
 - Are there particles with tiny charges?
 - "Dark electromagnetism" typically leads to millicharged particles



ArgoNeuT demonstrated the LAr capability to detect sub-MeV depositions (blips)



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No particle identification, no track, just a blip

What can be done with it?



0.24 tons active volume

LAr TPC 47×40×90 cm³, 2 readout planes, 480 wires, 4 mm spacing, no light detection system





Millicharged particles

R. Harnik, Zhen Liu, and O. Palamara, arXiv:1902.03246



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Millicharged particles

R. Harnik, Zhen Liu, and O. Palamara, arXiv:1902.03246







s at the next neutrino facilities

PHYSICAL REVIEW LETTERS 124, 131801 (2020)

Improved Limits on Millicharged Particles Using the ArgoNeuT Experiment at Fermilab

R. Acciarri,¹ C. Adams,² J. Asaadi,³ B. Baller,¹ T. Bolton,⁴ C. Bromberg,⁵ F. Cavanna,¹ D. Edmunds,⁵ R. S. Fitzpatrick,⁶ B. Fleming,⁷ R. Harnik,¹ C. James,¹ I. Lepetic,^{8,*} B. R. Littlejohn,⁸ Z. Liu,⁹ X. Luo,¹⁰ O. Palamara,^{1,†} G. Scanavini,⁷ M. Soderberg,¹¹ J. Spitz,⁶ A. M. Szelc,¹² W. Wu,¹ and T. Yang¹

(ArgoNeuT Collaboration)





Millicharged particles









14 orders of magnitude!!!

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 $(L \sim km)$

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Dynamical distorted neutrino oscillations:

L-dependent matter effect







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Krnjaic M Necib 2017

Br Capozzi Shoemaker Vec Liao Marfatia Ge №

> Choi C Dev M Martine



se	e also
dar et al	2017
chi 2017,	2018
aran Ruiz	2019
Whisnant	2018
Ge Parke	2018
1urayama	2019
, Cline	2019
Chun Kim	2020
ez-Mirave	2020





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Based on Kelly Kumar Liu 2011.05995 see also Brdar et al 2011.07054









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Based on Kelly Kumar Liu 2011.05995 see also Brdar et al 2011.07054









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Based on Kelly Kumar Liu 2011.05995 see also Brdar et al 2011.07054







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Based on Kelly Kumar Liu 2011.05995 see also Brdar et al 2011.07054

Dark matter in neutrino experiments

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Dark matter in neutrino experiments

MiniBooNE PRD 1807.06137

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Other experiments can also do similar searches, including JSNS², DUNE, SHiP, FASER, ...

Dark matter in neutrino experiments

Fixed-Target Searches for New Physics with $\mathcal{O}(1 \text{ GeV})$ Proton Beams at Fermi National Accelerator Laboratory

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Toups et al SNOWMASS21-RF6_RF0-NF2_NF3-AF2_AF5-099

- PIP-II beamline upgrade at FNAL
- 100-ton LAr detector with 50 keV recoil threshold for CEvNS
- 5 years of data taking

Neutrino physics is at its most exciting time

Diversity in EXPs

Sizes technologies signatures energies thresholds sources

. . .

What else can we do?

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