

IceDUNE

JUNE 16-18, 2021



New Particles

Working Group 4

List of topics discussed throughout the workshop

1. HNL searches:
 - a. Double bangs
 - b. Exclusive final states
 - c. Electric/Magnetic dipole moments

→ **Extensions to the neutrino sector**

2. Long-lived charged particles (e.g., $S\tau$)
 - a. One of two charged tracks in the DUNE FD
3. Milli-charged particles
 - a. Not competitive with the beam
4. Micro black holes (bonus! Yuber.)

→ **Other exotica**

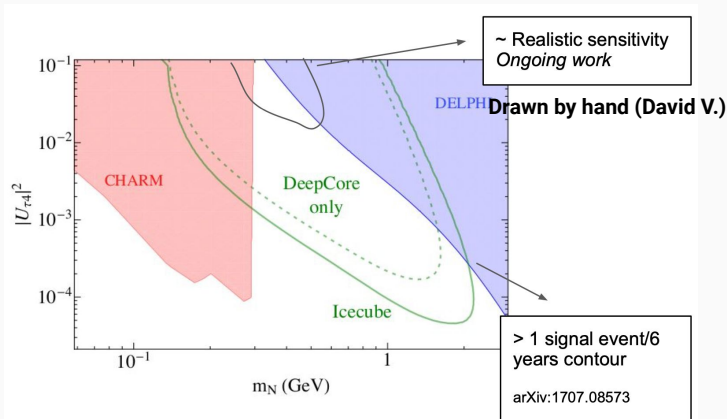
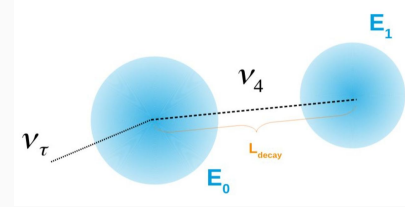
5. Dark Matter searches:
 - a. Direct annihilation to neutrinos
 - b. Boosted DM

→ **Dark matter searches**

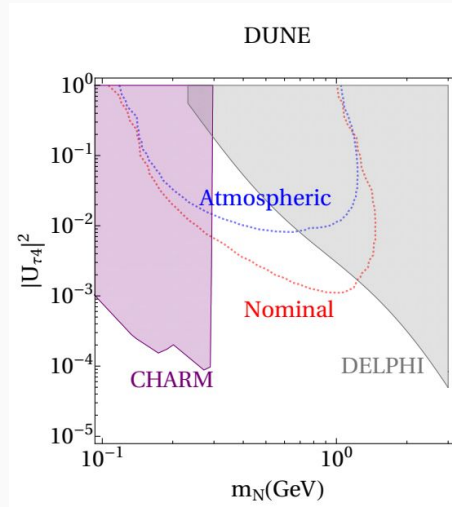
Heavy neutral leptons

Double bangs:

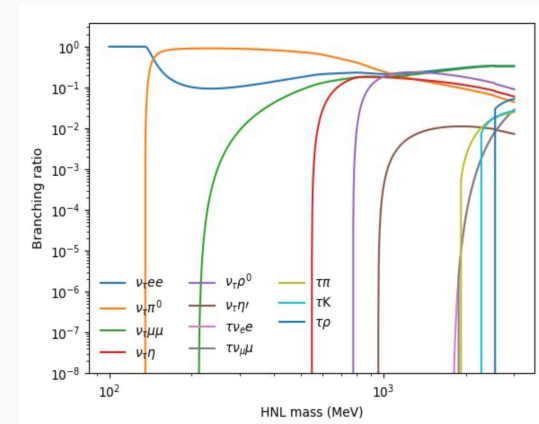
- IceCube search — challenging backgrounds due to misID (Goliath)
- DUNE -- better PID (David)
 - may also be interesting to look for exclusive channel: ($\mu+\mu^-$, π^0 , $\rho^0 \rightarrow \pi+\pi^-$).
 - A more inclusive search would, however, cover more models:
 - transition mag. Moments
 - HNL+A' scenarios.



P. Coloma et al, PRL 119, 201804 (2017)



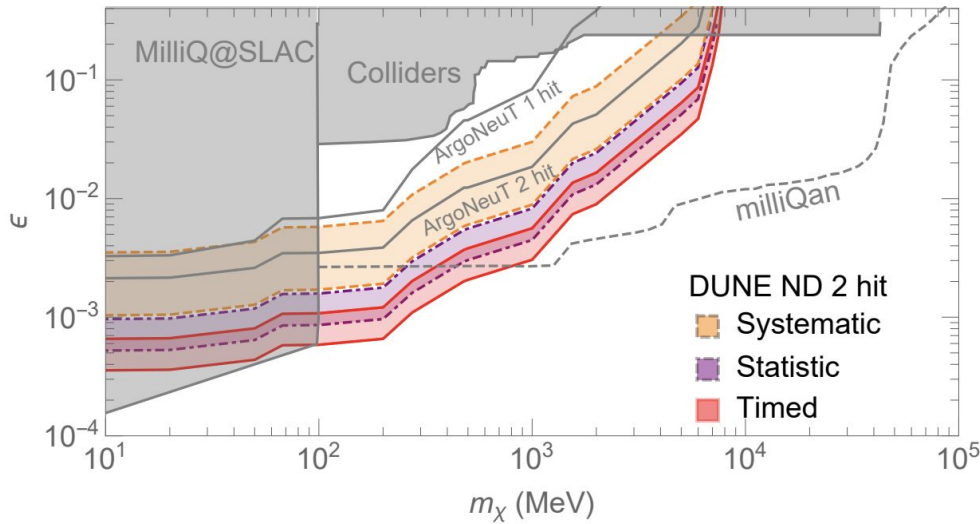
M. Atkinson et al, arXiv:2105.09357



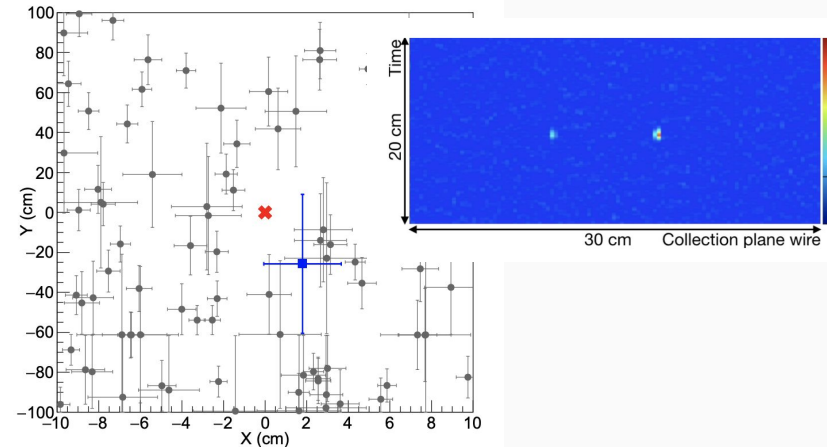
By David V.

Millicharges (“dim” tracks)

Harnik, R., Liu, Z. & Palamara, O., *JHEP*. 2019, 170 (2019).



ArgoNeuT coll., *Phys. Rev. Lett.* 124, 131801 (2020)



Millicharges:

Ionisation: DUNE beam much more powerful than atmospheric production due to the ability of pointing.

Hard scattering: possible, but much suppressed rate (IR-dominated propagator), so cannot compete with beams.

Atmospheric production is relevant for low threshold exps: SK, JUNO, DD exps.

Arguelles, Kelly, Munoz, 2104.13924

- Side note on HNL EDM

Similarly to mCP, it is possible that neutral fermions with **large electric Dipole Moments (eDM)** would leave “faint” tracks.

$$d N_L \sigma^{\mu\nu} \gamma^5 N_R F_{\mu\nu}$$

- CP violating dim-5 operator.
- $d \sim 1e-15$ e.cm possible (1 TeV scale new physics, 100's GeV N)

Very poorly explored literature so far, though studies exist for milliQan at the LHC.

- EDMs of $d \sim 8.0e-17$ e.cm behave very similarly to a mCP with $Q/e \sim 3e-3$ at milliQan.

M. Sher, J. Stevens, PLB 2017.12.022

Challenge for UV completions when N is a light fermion, but we could not convincingly discard the possibility. May also be interesting to consider transition eDM (very similar to mag. moment story)

Perhaps warrants some model-building studies at low energies, and assessment of constraints at neutrino/beam-dump experiments.

Long-lived charged particles (STaus)

Long-lived STaus: long-lived charged tracks

- Drell-Yan production at the very beginning of atmospheric showers to draw as much energy as possible -- direct coupling to SM, so the mass is the only interesting free param.
- Studied at IceCube, but DUNE could be more sensitive to double track events
 - Tridents in the rock? Complementarity with HNL searches?
- Ionization losses dominate until much higher energies for the massive particle.

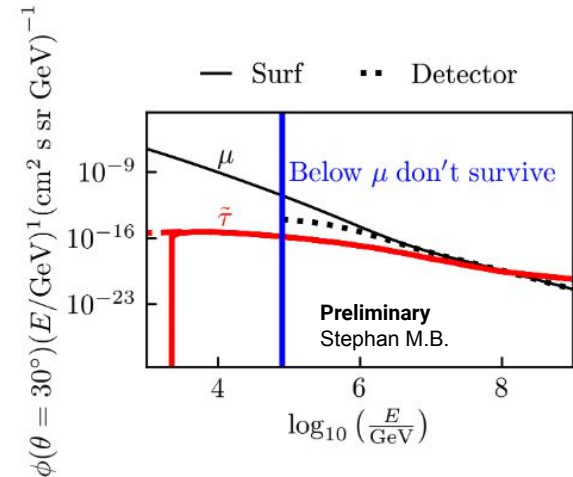
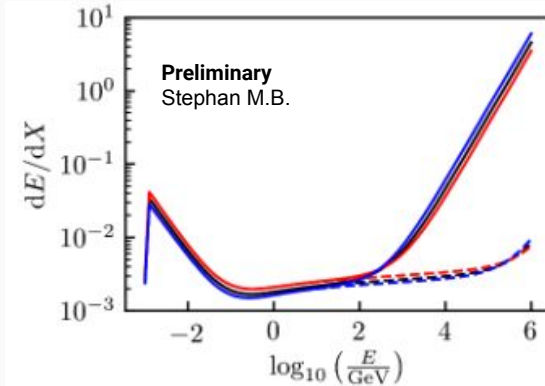
Zenith angles:

- (85 - 90) degrees for IC,
- but (0 - 90) degrees for DUNE (rock = 3 x the density of ice)

Lower bound on STaus mass using public IC data

- **> 320 GeV** → competitive w/ CMS/ATLAS.

S. Meighen-Berger *et al*, PLB 811 (2020) 135929



Long-lived charged particles (STaus)

Long-lived STaus: long-lived charged tracks

- Drell-Yan energy as po

- Studie

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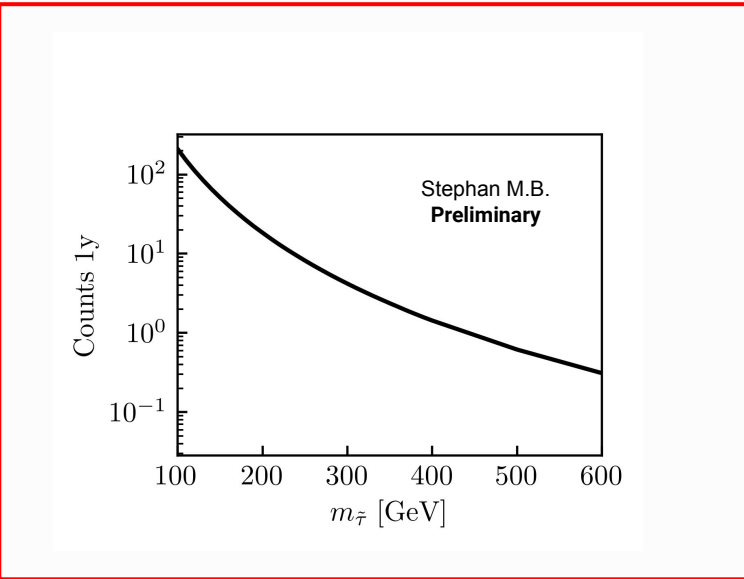
- Ionizat

Zenith angle

- (85 - 9
- but (0

Lower bound

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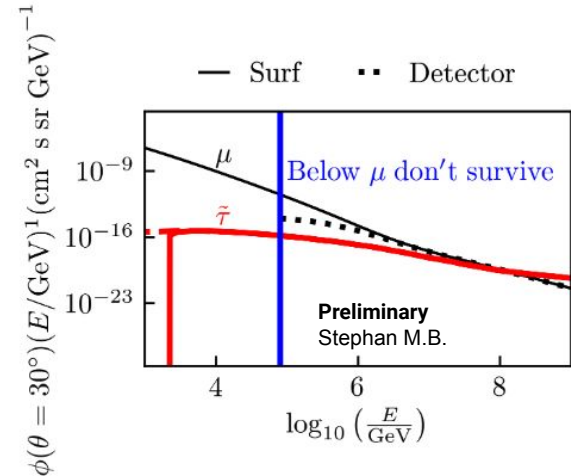
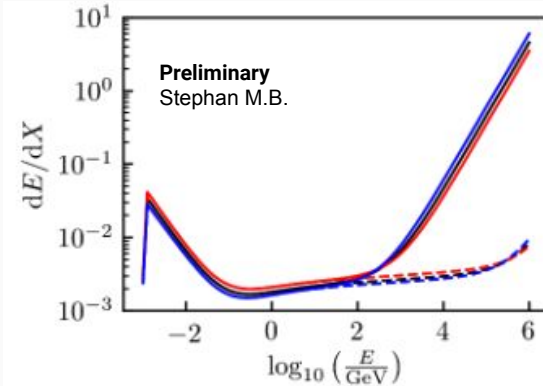
owers to draw as much interesting free param.

ouble track events ches?

e massive particle.

Early sensitivity estimate without backgrounds at DUNE FD:

- one DUNE module (50 m²) could set a lower bound of $> 350 \text{ GeV}$



Dark matter annihilations to neutrinos

Monochromatic source of neutrinos. Electron channel very promising (in most detectors)

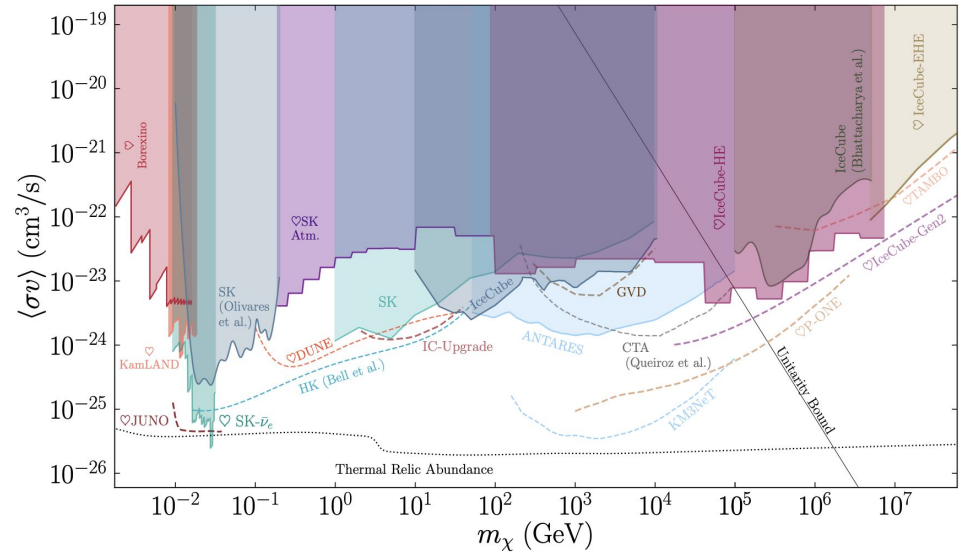
Realistic models for DM annihilation at the low masses only (\ll TeV), otherwise problems with unitarity.

Detailed study at DUNE very much welcome.

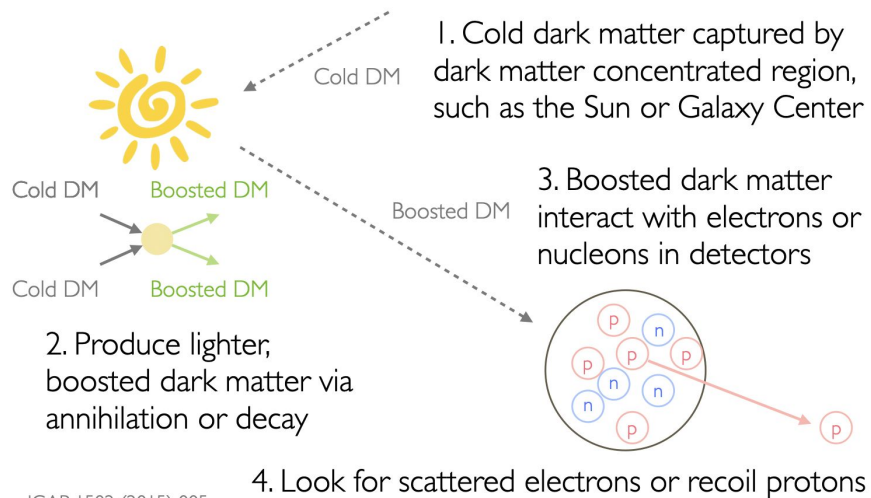
Detailed assessment of backgrounds and efficiencies.

- Is a flavour blind analysis possible with NC events? Much worse reconstruction of E_{nu} in that case, but no study so far.

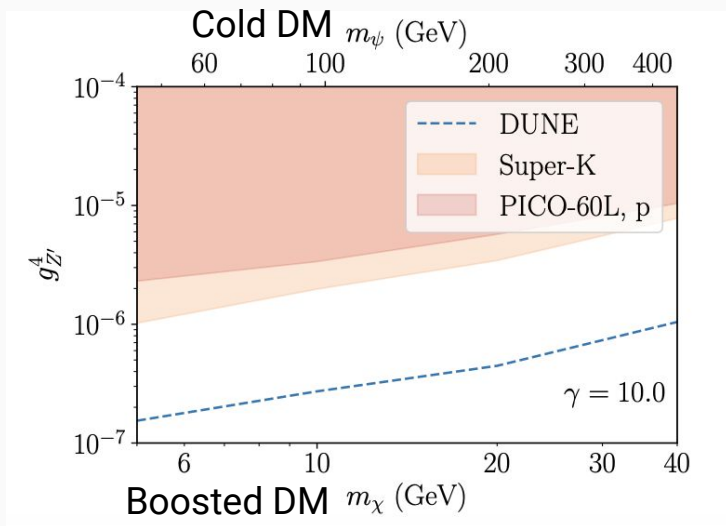
C. Argüelles et al, arXiv:1912.09486



Boosted Dark Matter



JCAP 1502 (2015) 005



J. Berger et al, Phys. Rev. D 103, 095012 (2021)

Hadronic channels are most promising at DUNE.

Similar to light DM and (hard scatt of) mCP, energy of Boosted DM reconstructs Cold DM mass.