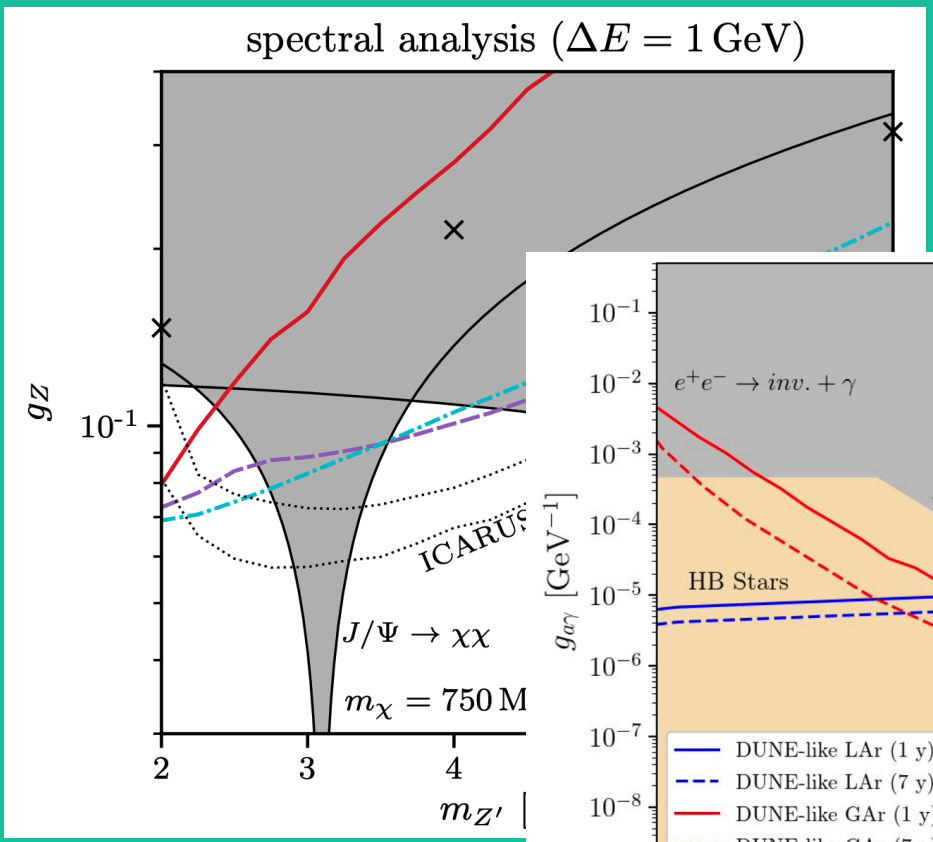

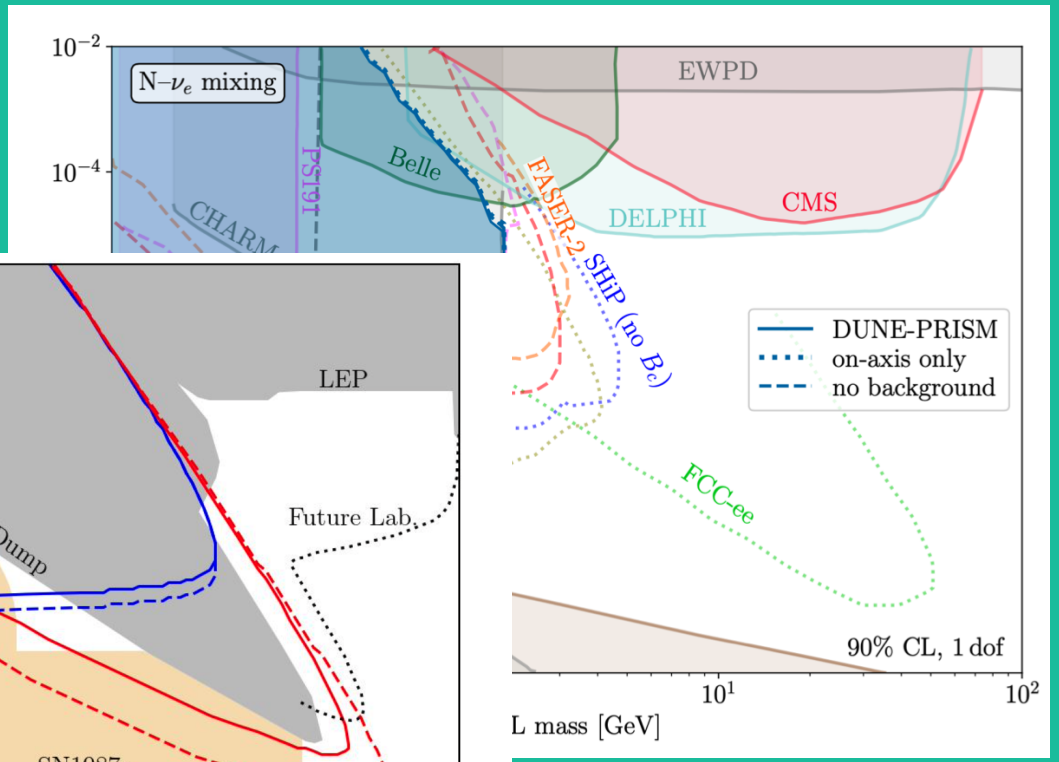

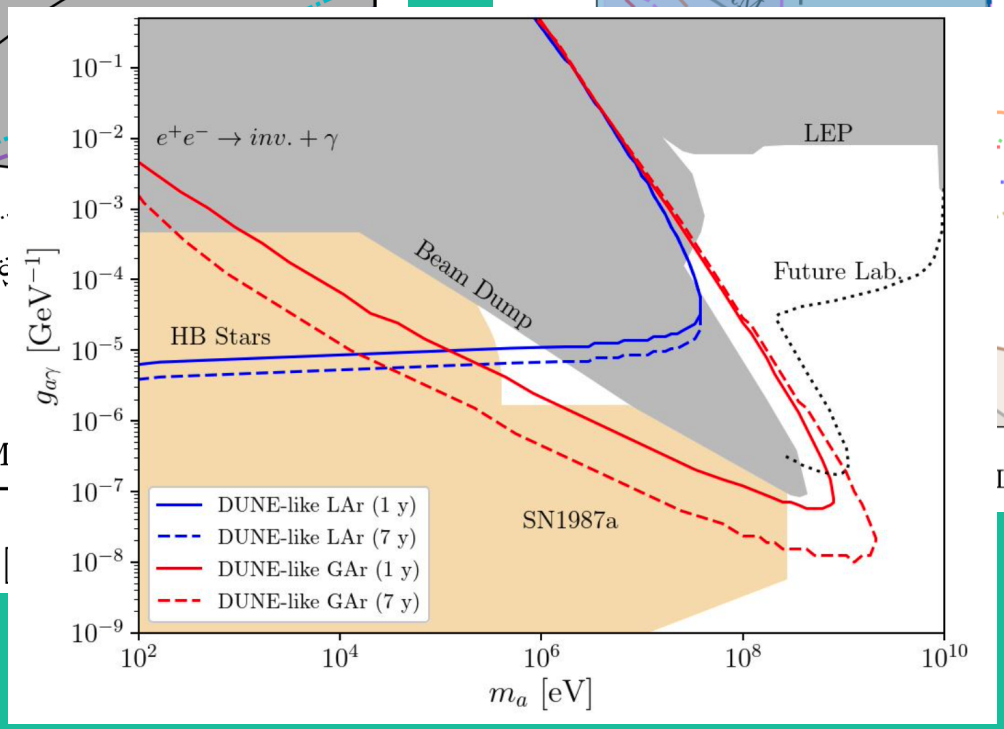

BSM opportunities with ND-GAr

Tanaz A. Mohayai

ND-GAr: HPgTPC+ECAL Weekly Meeting

July 25, 2023

Phase II Effort

- A new **Phase II** organization has recently emerged, led by M. Sorel & S. Söldner-Rembold, focusing on two top-level topics, **Phase II** ND and FD
  - ★ One of the group's notable events was the successful organization of the **Phase II ND Workshop** at Imperial

The list of community-contributed BSM topics at the Phase II ND Workshop

Physics: Physics II

Convener: Morgan Wascko (Imperial College London)

2:00 PM **BSM opportunities at DUNE Phase II**

Speaker: Silvia Pascoli (University of Durham)

DUNE_ND_ICL23.pdf

2:30 PM **Probing the nature of Heavy Neutral Leptons in DUNE**

Speaker: Frank Deppisch (University College London)

frank-deppisch-DU...

3:00 PM **Dark Matter / Dark Sector searches with the DUNE Near Detector**

Speakers: Kevin Kelly, Kevin Kelly

KJK_DUNE_PhaseII...

3:30 PM **Search for sub-millicharged particles (SUBMET)**

Speaker: Jaehyeok Yoo (Korea University)

20230621_Jae_sub...

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Highlighted HNLs and key characteristics in DUNE ND Phase II that can enhance the search

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Explored the sensitivity to HNLs in $0\nu\beta\beta$ and direct searches such as DUNE

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Focused on the complementary nature & emphasized on ND-GAr's power in reducing the irreducible background to dark sector searches

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20230621_Jae_sub...

A fixed-target experiment at JPARC looking for sub-millicharged particles

Main Outcomes of Phase II ND Workshop

- The collaboration and community agree that a magnetized gaseous argon TPC is the right approach for Phase II near detector upgrade
- A new working group is also formed, led by conveners A. Marino & P. Dunne, along with the BSM Liaison TM
  - ★ Tasked with preparing the **Phase II** report & strengthening ties to physics groups including the BSM group
- High-level goal: a physics-requirements driven approach to produce a full technical design for ND-GAr

The ND-GAr Snowmass white paper, a recent report on ND-GAr's BSM capabilities, was a crucial input to the community!

A Gaseous Argon-Based Near Detector to Enhance the Physics Capabilities of DUNE

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

D. Physics Beyond the Standard Model

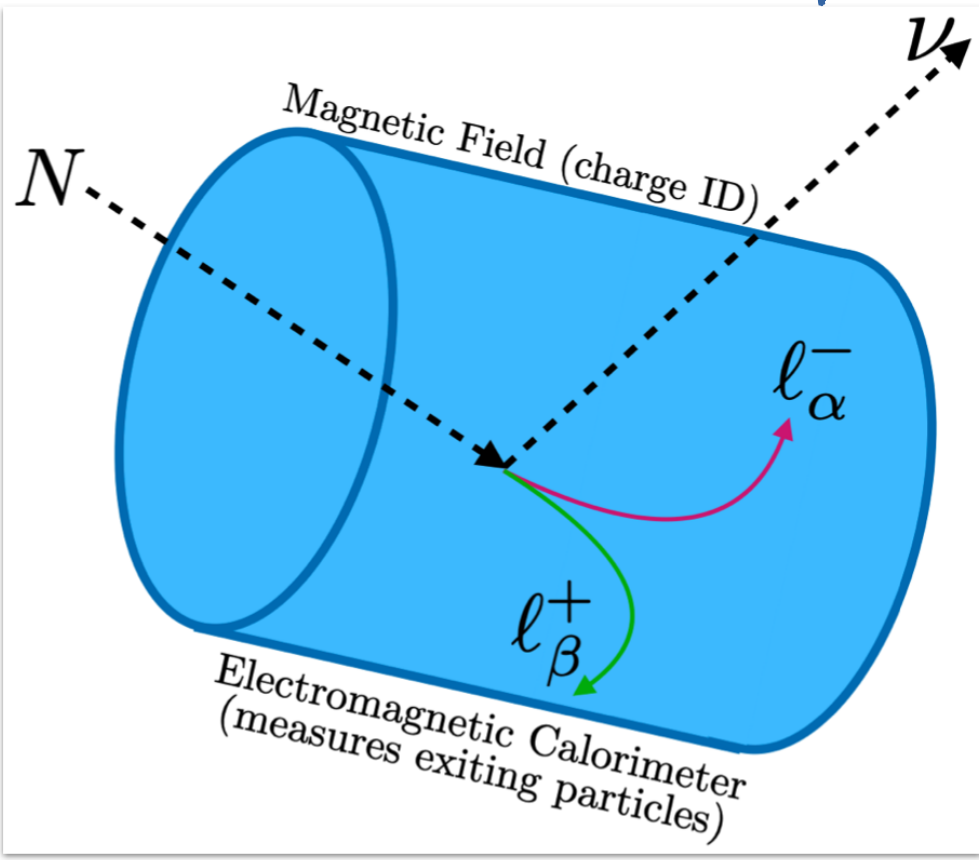
LBNF's high-intensity proton beam will provide a large neutrino flux that will be sampled by ND-GAr. This will enable DUNE to discover new particles and unveil new interactions and symmetries beyond those predicted in the Standard Model (beyond the standard model, or BSM). In particular, ND-GAr can search for neutrino tridents, heavy neutral leptons (HNL), light dark matter, heavy axions, and anomalous tau neutrinos that come from short-baseline mixing with sterile neutrinos [26].

In general, the background contributions in searches for rare events tend to scale directly with the detector mass (which is larger for ND-LAr), while signal events often scale with detector volume (which is similar for ND-LAr and ND-GAr). As a result, the ND-LAr suffers more significantly from backgrounds than ND-GAr. ND-GAr's relatively large volume will be beneficial in the search for the rare decay events. Independent ND-GAr analyses that complement those in ND-LAr will serve to constrain backgrounds and achieve a stronger BSM physics reach with the near detector complex than could be achieved with either detector alone [27].

ND-GAr Enhances DUNE BSM Searches

- Overview of key ND-GAr capabilities for BSM searches at the ND complex:
  - ★ **Large volume** – favorable for rare decay searches
  - ★ **Low mass/density** – effective at rejecting the ν scattering background
  - ★ **Low threshold** – ability to see hadronic activity near the vertex for rejecting ν scattering background
  - ★ **PID, energy resolution, & B-field** – effective at μ/π separation & selecting new physics in events with oppositely charged particles

From Kevin Kelly's talk at the recent Phase II ND Workshop



Decay Signal ∝ Volume

Neutrino Scattering Backgrounds ∝ Mass

ND-GAr Enhances DUNE BSM Searches

From Kevin Kelly's talk at the recent Phase II ND Workshop

- Overview of key ND-GAr capabilities for BSM searches at the ND complex:
  - **Large volume** – favorable for rare decay searches

  new physics in events with oppositely charged particles

We have expected performance metrics based on the ND-GAr reference design. Our goal is to define the physics requirements to either reaffirm these numbers or redefine them and develop the design of ND-GAr

Decay Signal ∝ Volume

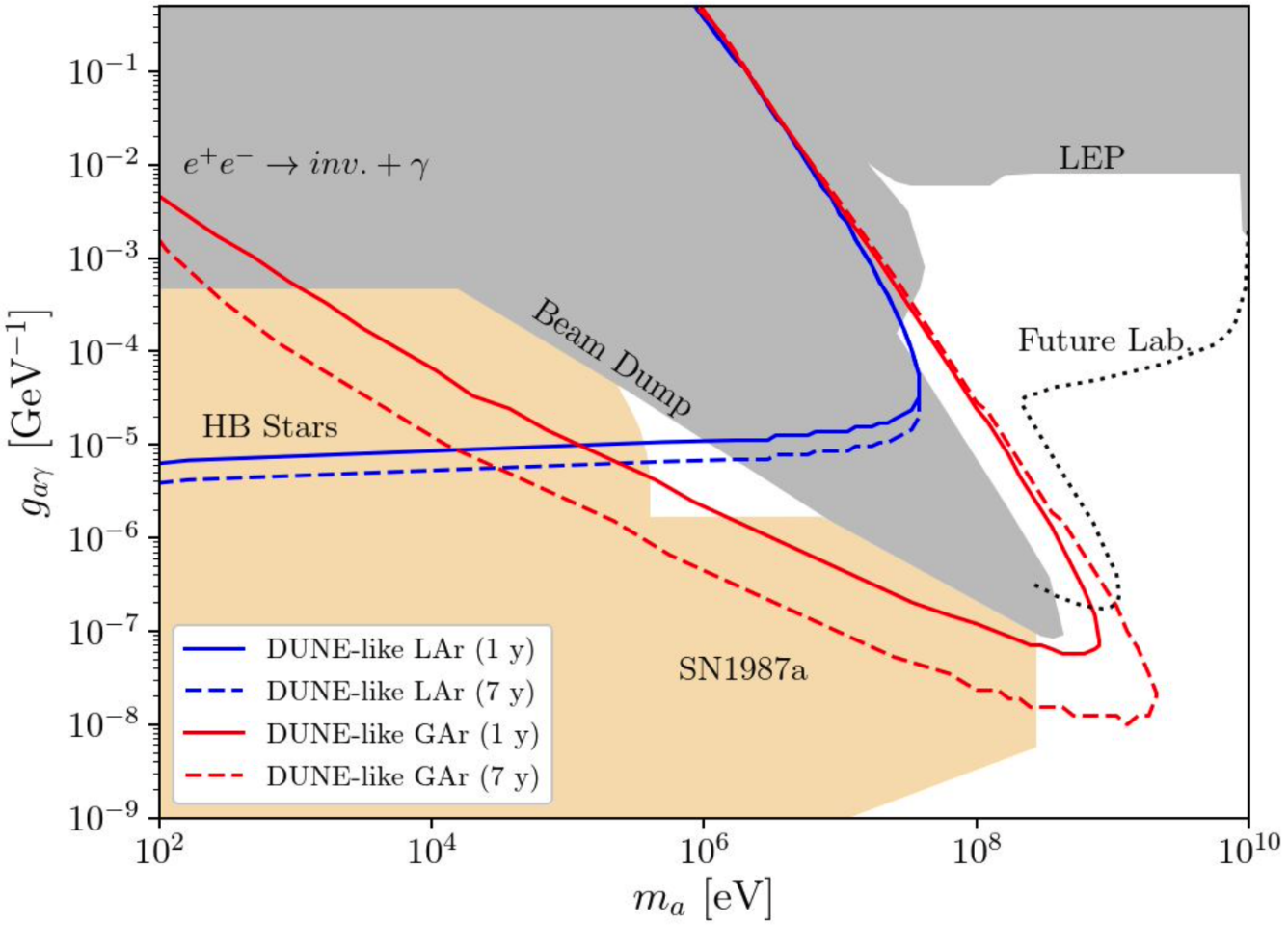
Neutrino Scattering Backgrounds ∝ Mass

BSM Searches with ND-GAr

- In this talk, showcasing a subset of BSM work that highlights ND-GAr's strengths:
  - Axion-like Particles (ALP)
  - Low mass Dark Matter (LDM)
  - Heavy Neutral Leptons (HNL)
  - Anomalous ν_τ Interactions
  - Neutrino Tridents

Axion-like Particles (ALP)

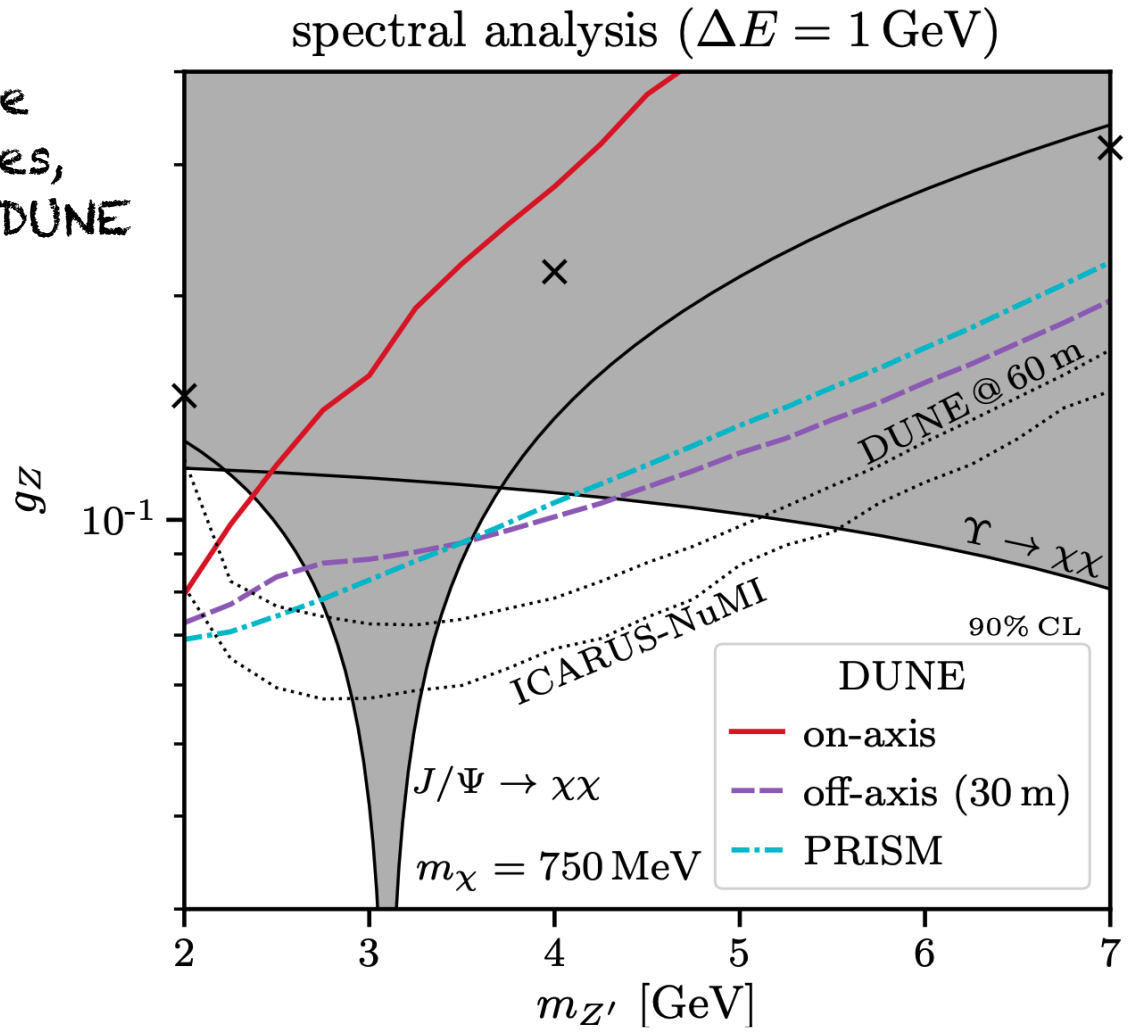
- The decays of the ALP to two γs
  - ★ ND-GAr efficiently rejects the NC π^0 background thanks to its unrivaled sensitivity to low energy hadrons at the ν interaction vertex
- Brdar et al. demonstrate ND-GAr's ability to access an extensive HNL parameter space, enhancing DUNE's discovery potential



Low Mass Dark Matter (LDM)

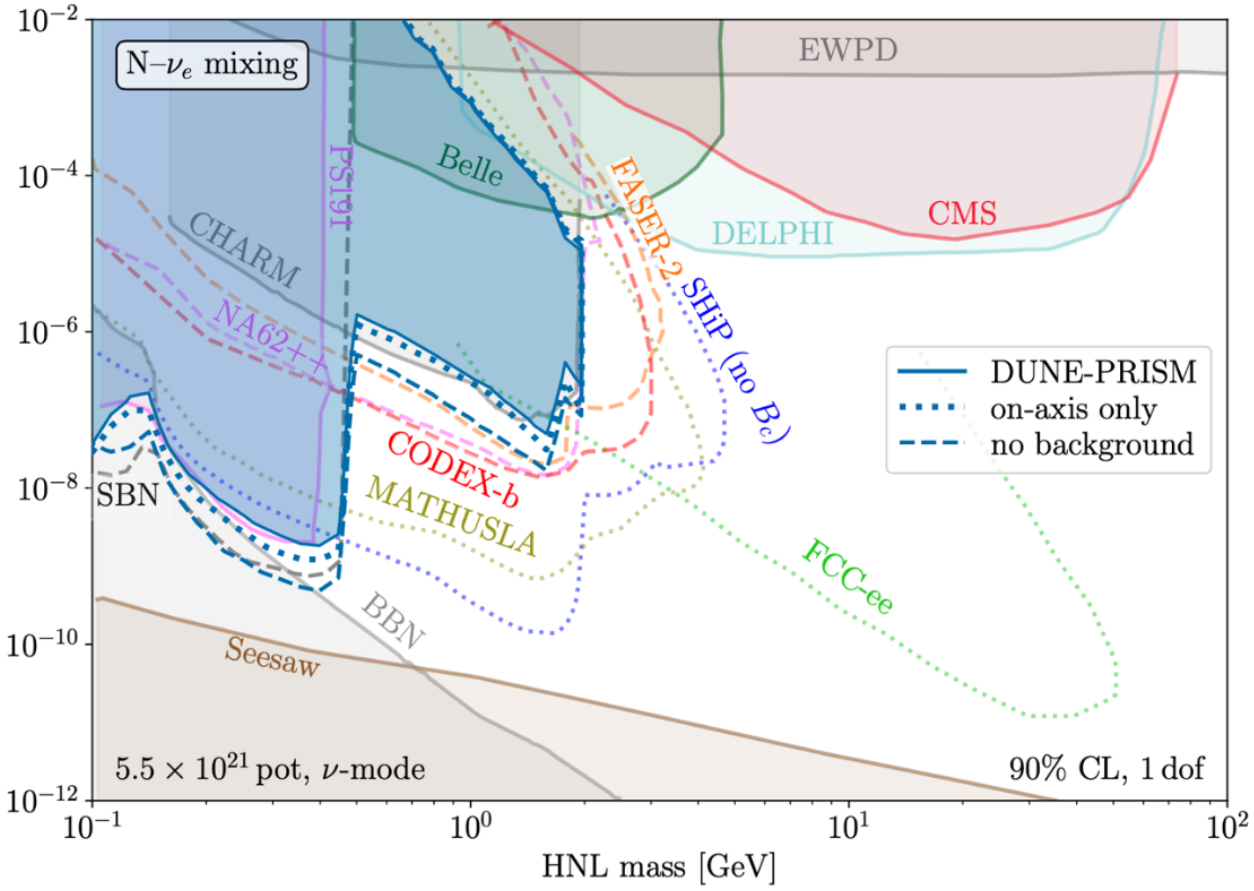
- Interacts or decays in the detector resulting in a single-electron final state
  - ND-GAr's unrivaled sensitivity to low-energy hadrons proves critical in rejecting the ν_e CC background
  - Low mass/density of ND-GAr helps with limiting the ν-e scattering bkg

Parameter space coverage from J. Kopp et al. studies, includes the ND-GAr in DUNE Phase II ND complex



Heavy Neutral Leptons (HNL)

- The final state can include e^+e^-, $e^+\mu^+$, $e^+\pi^-$, $\mu^+\pi^-$
  - Make use of ND-GAr's unrivaled sensitivity to low-energy hadrons and sign tagging in B-field to reject the ν_μ CC background that have charged π/s in the final states
  - From J. Kopp et. al, a parameter space comparable to an ideal experiment can be reached!



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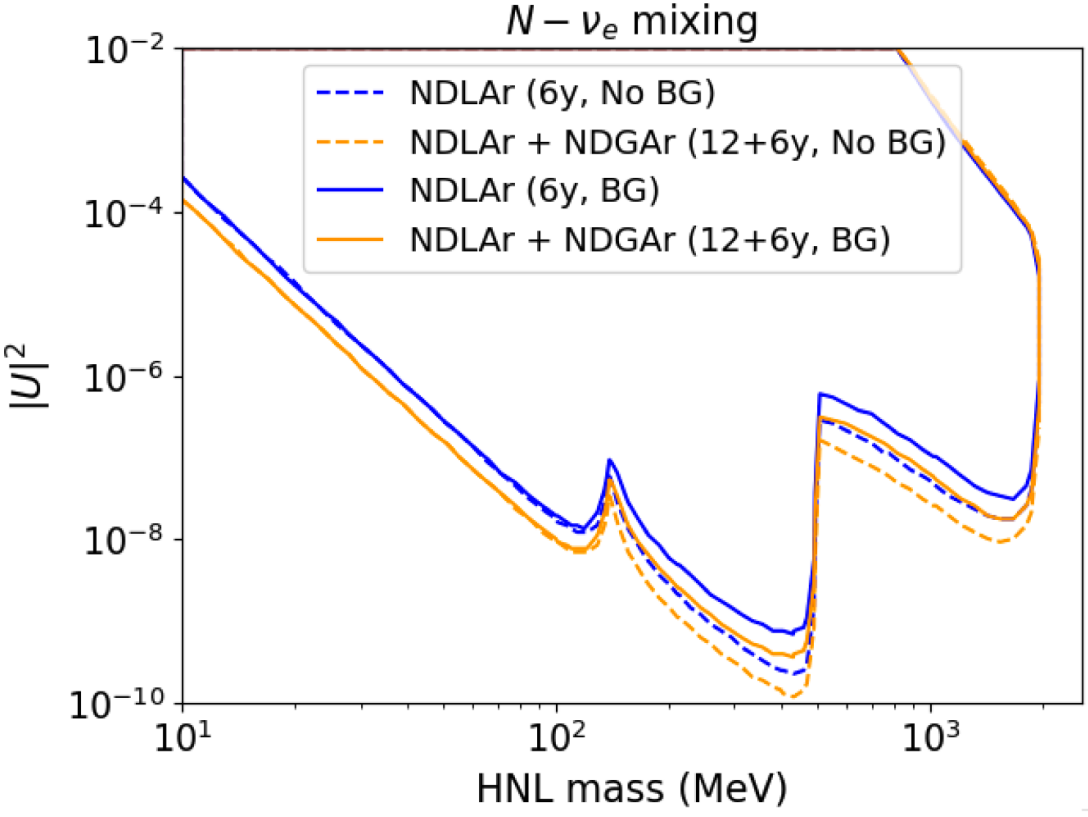
  - From J. Kopp et. al, a parameter space comparable to an ideal experiment can be reached!
  - Updated study by P. Barham Alzás illustrates that a relatively large parameter space comparable to an ideal experiment can be reached



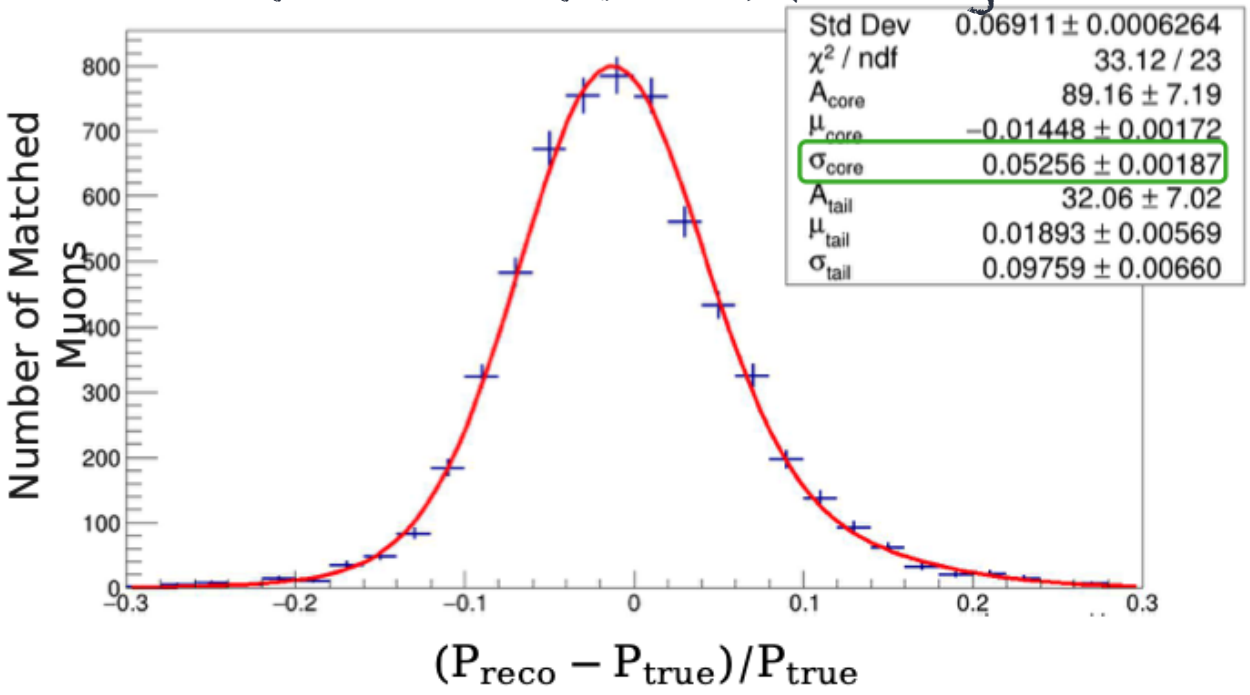
Anomalous ν_τ

- The final state of τ decay can include hadrons, electrons or μs
- In case of $\tau \rightarrow \mu$ channel, ND-GAr is the only ND that can select energetic μs, thanks to its B-field & containment abilities
  - ★ e.g. TMS is limited to measuring μs up to 6 GeV/c
- H. Razafinime's studies has provided initial insights into the momentum resolution for these high-energy ms using GArSoft

8 to 14 GeV

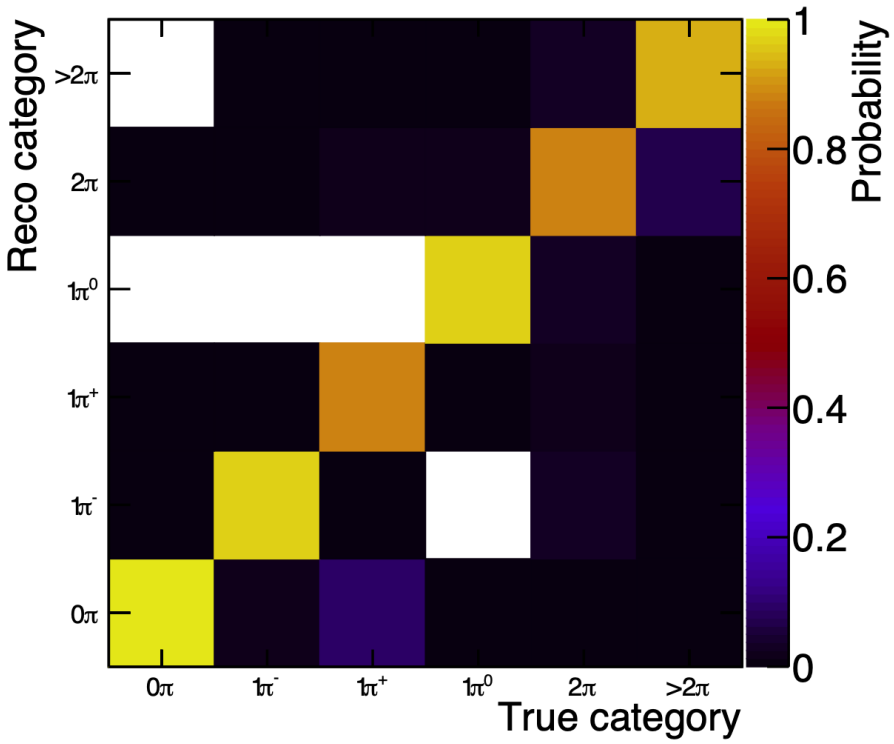
$\sigma_{core} = 0.052$

H. Razafinime, from the Seattle Snowmass Summer Meeting



Neutrino Tridents

- Scattering of a ν on a heavy nucleus producing oppositely charged leptons
  - ★ e.g. for A’ → μ+μ- signal, can make use of ND-GAr's unrivaled sensitivity to low-energy hadrons and its excellent capability to distinguish between μs and πs to reject the ν_μ CC 1π background
- K. Kelly et al. discuss these background rejection capabilities in detail in . *High Energ. Phys. 2020, 174 (2020)*
  - ★ We can also consider the selection efficiency of ν_μ CC interactions with multi-pions from the TDR era



Key points to take away

- ND-GAr amplifies DUNE's BSM reach thanks to its unique design features:
  - ★ **Large volume**
  - ★ **Low mass/density**
  - ★ **Low threshold**
  - ★ **PID, energy resolution, & B-field**

- We aim to strengthen the ties between the ND-GAr group & the BSM group to take a physics-requirement driven approach to develop the ND-GAr design:
  - ★ Showcase the work by BSM group using ND-GAr in the ND Phase II report and any documents thereafter
  - ★ On the ND-GAr side, invite talks from the BSM group
  - ★ More ideas from ND-GAr group are welcome!