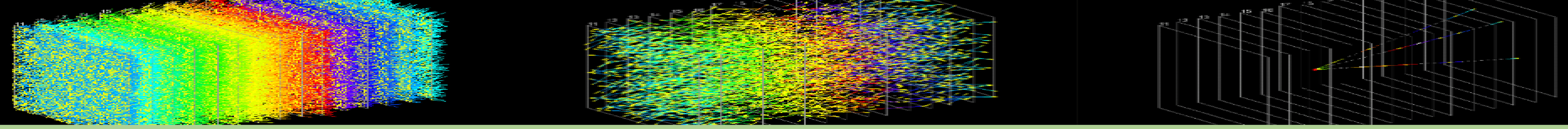

Probing the unseen

Prospects for sterile neutrino searches using the NINJA detector

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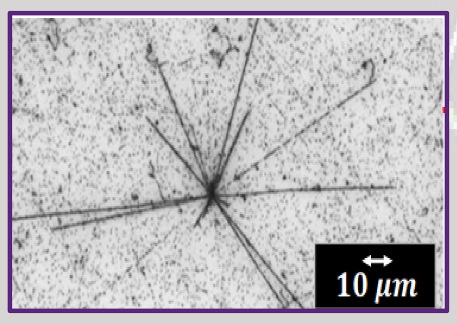
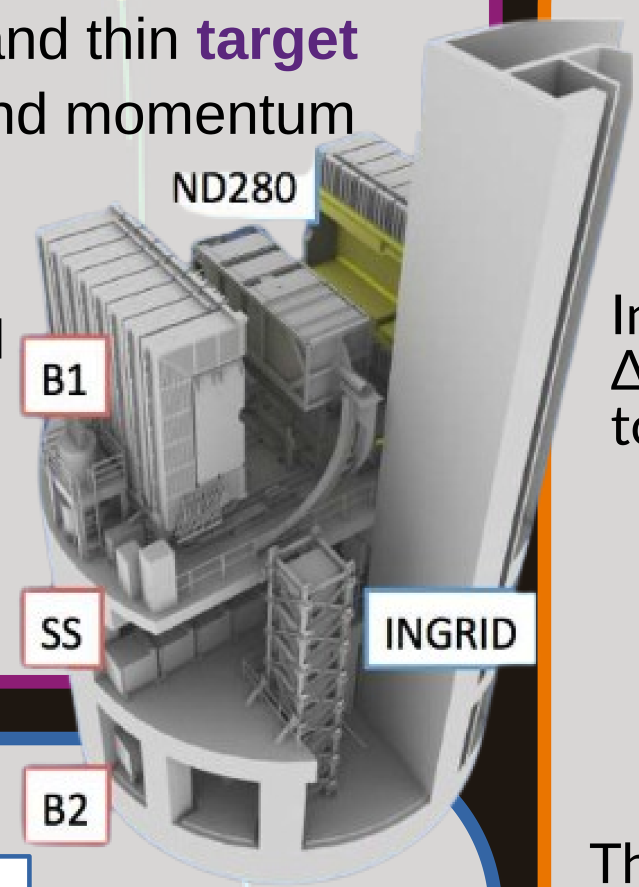
on behalf of the **NINJA** colaboration

THE NINJA EXPERIMENT

Designed to precisely measure neutrino–nucleus interaction cross sections using an Emulsion Cloud Chamber **(ECC)** detector. By using an alternating structure of **emulsion films** and thin **target layers**, we can achieve high-resolution tracking and momentum measurement of neutrino-induced particles.



Currently located at the B2 floor (1.5° off-axis) of the J-PARC NM building, future runs may also explore on-axis (SS) and more off-axis (GROUND, 6°) configurations.



FLUX & PROBABILITY

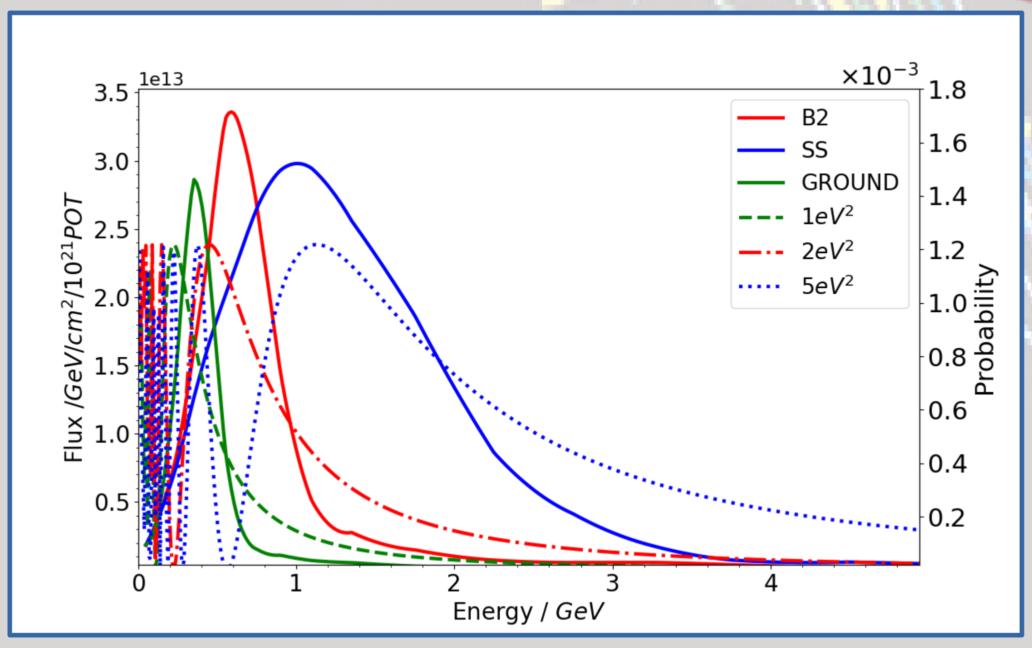


Fig. 1: Probability (right), presented with dashed lines, and flux (left), presented with solid lines, relevant for NINJA.

- Three detector locations with **L = 280 m** with **10^{21} POT/year**
- Pb target assumed

3+1 NEUTRINO OSCILLATIONS

The 3+1 model extends the Standard Model by introducing one additional neutrino state that is **not gauged under weak interactions**. This adds a new mass eigenstate, ν_4, with a corresponding large mass-squared difference $\Delta m^2_{41} \sim O(1\ \mathrm{eV}^2)$, and extends the PMNS mixing matrix to 4 × 4 form:

$$V = U_{34}(\theta_{34},\delta_{34})U_{24}(\theta_{24},\delta_{24})U_{14}(\theta_{14},0)U_{3\nu}$$

In the short-baseline (SBL) approximation, where standard splittings Δm^2_{21} and Δm^2_{31} are negligible, the **oscillation probabilities** simplify to:

$$P(\nu_e \rightarrow \nu_e) \approx 1 - \sin^2(2\theta_{ee})\sin^2\frac{\Delta m^2_{41} L}{4E_\nu}$$

$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2(2\theta_{ee})\sin^2\frac{\Delta m^2_{41} L}{4E_\nu}$$

disappearance channel

$$P(\nu_\mu \rightarrow \nu_e) \approx 1 - \sin^2(2\theta_{\mu e})\sin^2\frac{\Delta m^2_{41} L}{4E_\nu}$$

appearance channel

The effective **mixing angles** are defined as:

$$\sin^2 2\theta_{ee} = 4|V_{e4}|^2(1-|V_{e4}|^2)$$

$$\sin^2 2\theta_{\mu\mu} = 4|V_{\mu 4}|^2(1-|V_{\mu 4}|^2)$$

$$\sin^2 2\theta_{\mu e} = 4|V_{\mu 4}|^2|V_{e4}|^2$$

Oscillation effect become significant when $\frac{\Delta m^2_{41} L}{4E_\nu} \sim O(1)$

which sets the relevant L/E$_\nu$ scale for short-baseline experiments such as NINJA.

EVENTS

		APPEARANCE CHANNEL (0.95@ $\nu_\mu \rightarrow \nu_e$)	DISAPPEARANCE CHANNEL (0.95@ $\nu_\mu \rightarrow \nu_e$)
INTRINSIC BEAM	$\nu_e \rightarrow \nu_e$	100	/
ν_μ as ν_e	$\nu_\mu \rightarrow \nu_\mu$	0.5	/
	$\nu_e \rightarrow \nu_\mu$	0.5	/
MISS ID ν_e as ν_μ	$\nu_\mu \rightarrow \nu_e$	/	0.5
	$\nu_e \rightarrow \nu_e$	/	0.5
NC active ν	$\nu_\mu \rightarrow \nu_e$	1	1
	$\nu_\mu \rightarrow \nu_\mu$	1	1
	$\nu_\mu \rightarrow \nu_\tau$	1	1
WRONG SIGN	$\bar\nu_\mu \rightarrow \bar\nu_e$	100	/
	$\bar\nu_e \rightarrow \bar\nu_e$	100	/
	$\bar\nu_\mu \rightarrow \bar\nu_\mu$	/	100
	$\bar\nu_e \rightarrow \bar\nu_\mu$	/	100

Table 1: Detector efficiencies used in the analysis.

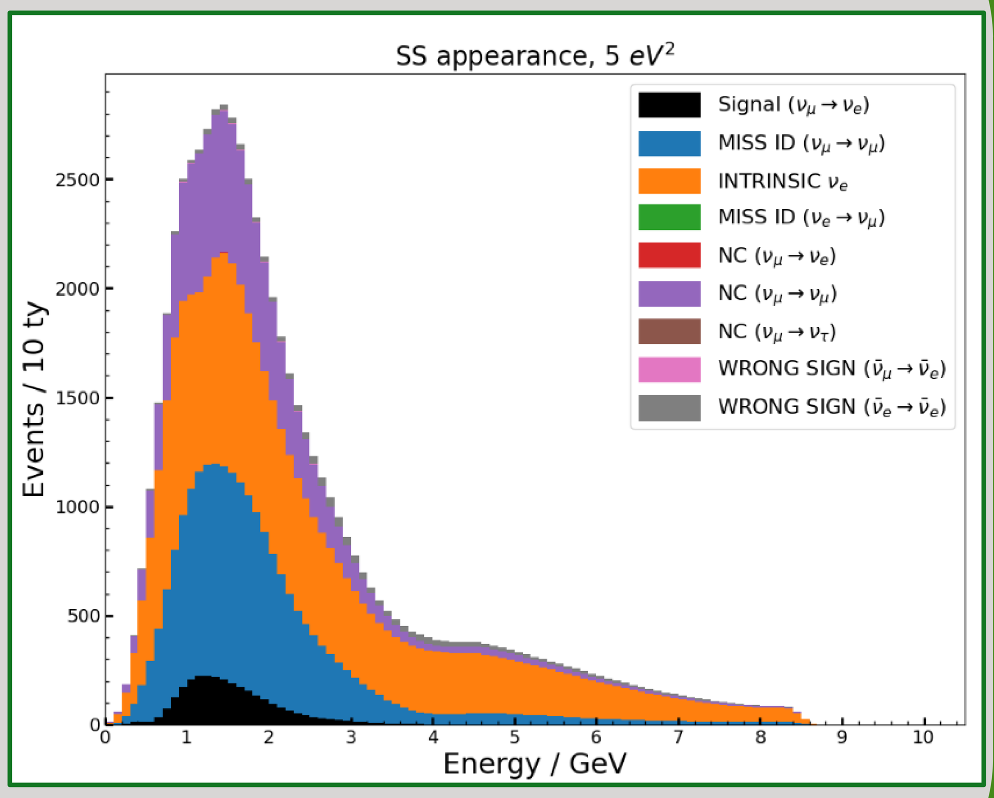


Fig. 2: Event spectra for signal and background for the SS floor.

SENSITIVITY

- Gaussian **energy resolution** with a width of 10%.
- **Systematic uncertainty** → an overall normalization error of 5% for the signal and 10% for the background.

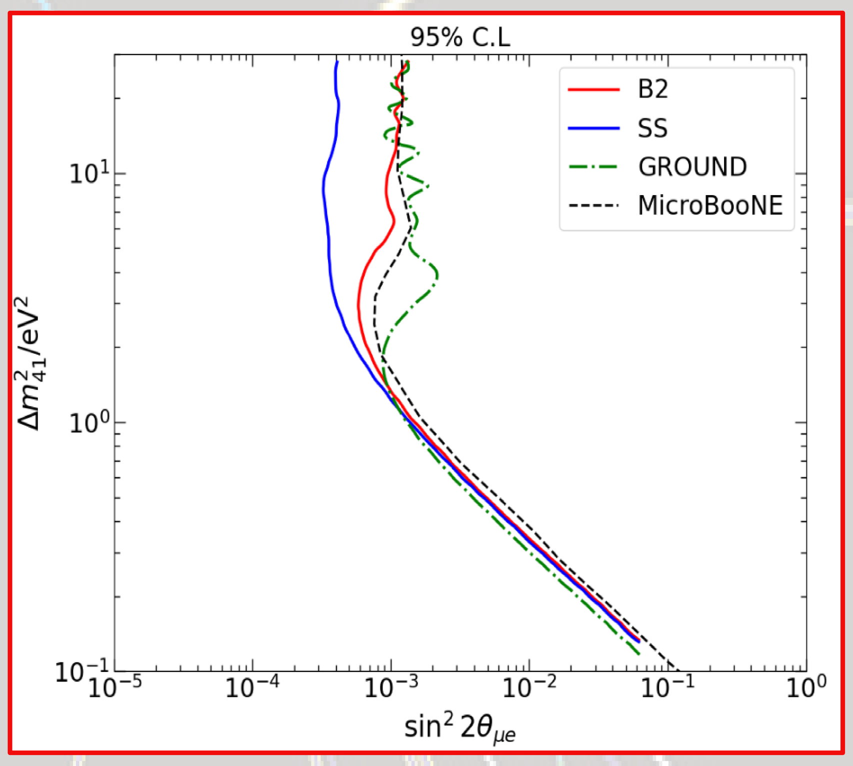


Fig. 3: Bounds on sterile parameters for three detector locations with 10 ty exposure.

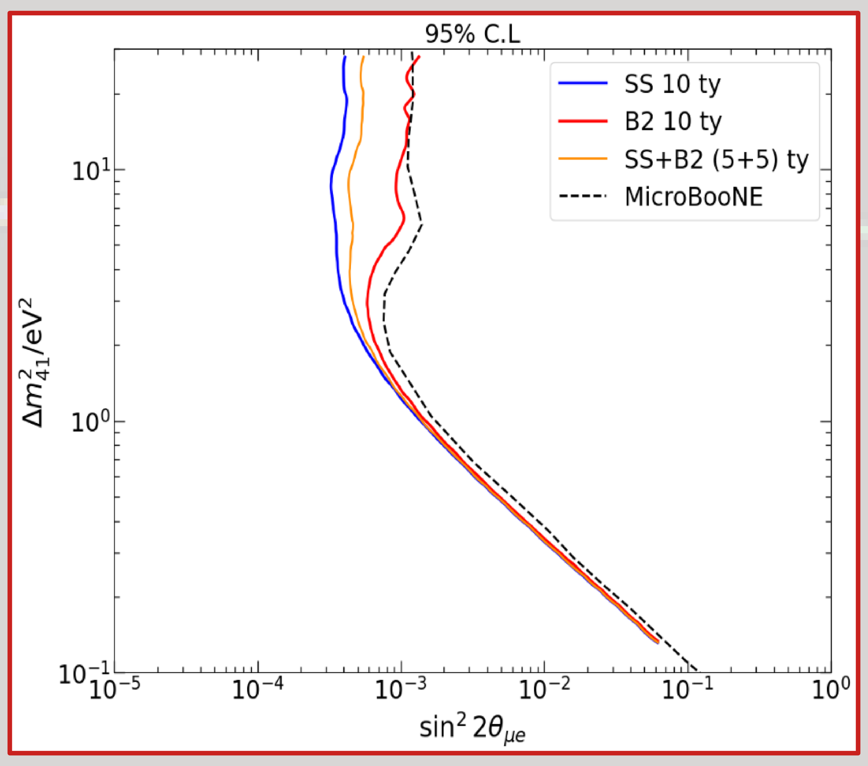


Fig. 4: Bounds on the sterile neutrino mixing parameters for B2, SS floor and a combined analysis with 5ty exposure at each location (SS+B2).

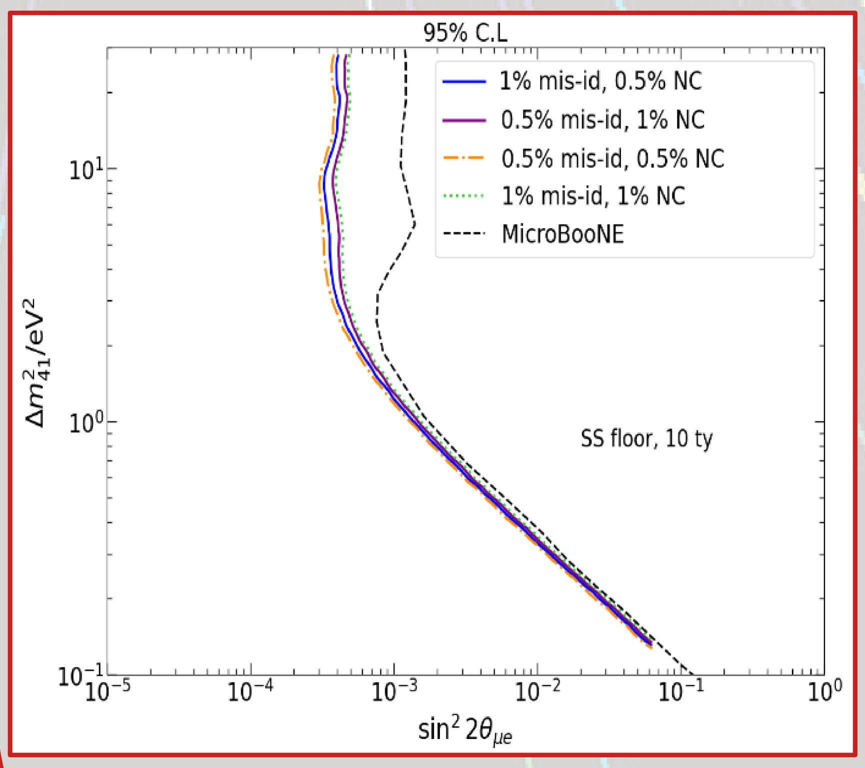


Fig. 5: Comparison of the impact of varying neutral current (NC) rejection and misidentification (mis-ID) rates.

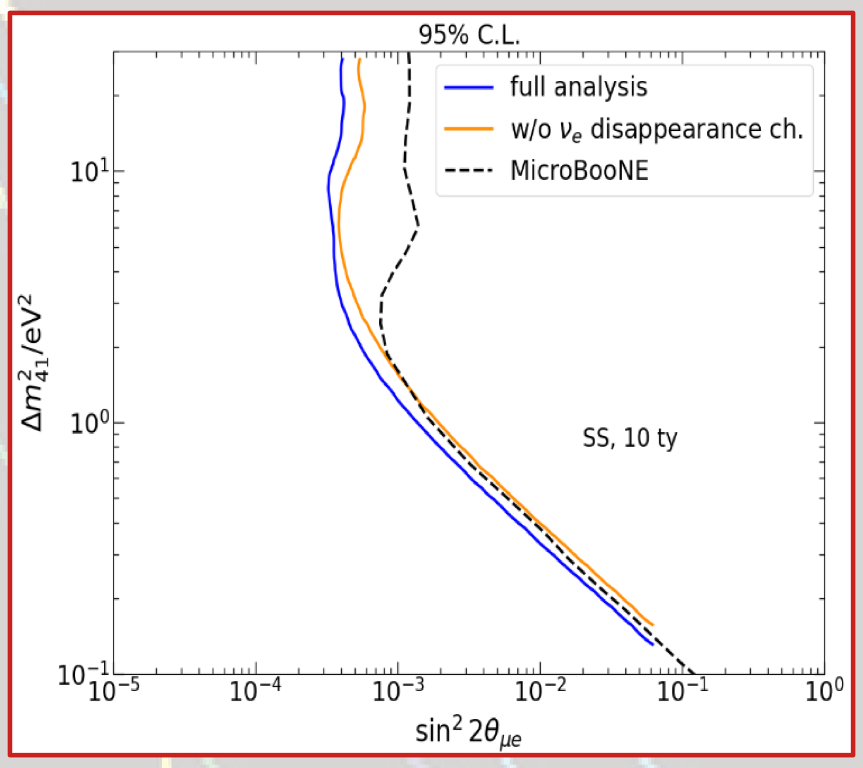


Fig. 6: Comparison of exclusion limits at the SS floor for 10 ty exposure with (blue) and without (orange) the ν_e disappearance channel.

SUMMARY

- With a 10 ty exposure, the SS-floor flux yields a more stringent limit on 3+1 sterile-neutrino parameters than the current MicroBooNE bound.
- Muon misidentification has a notable impact on sensitivity, while neutral current events exhibit only a modest change.
- We have demonstrated the importance of combining both appearance and disappearance channels in the sensitivity analysis, resulting in strengthened bounds on sterile-neutrino parameters.
- Utilizing both off-axis (B2) and on-axis (SS) fluxes, NINJA gains sensitivity across a broader range of mass-squared differences and can yield a stronger bound than the current one.