Probing Long-Lived Particle Production in Muon Decays

at the SNS with a Highly Capable Hydrocarbon Detector

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Based on

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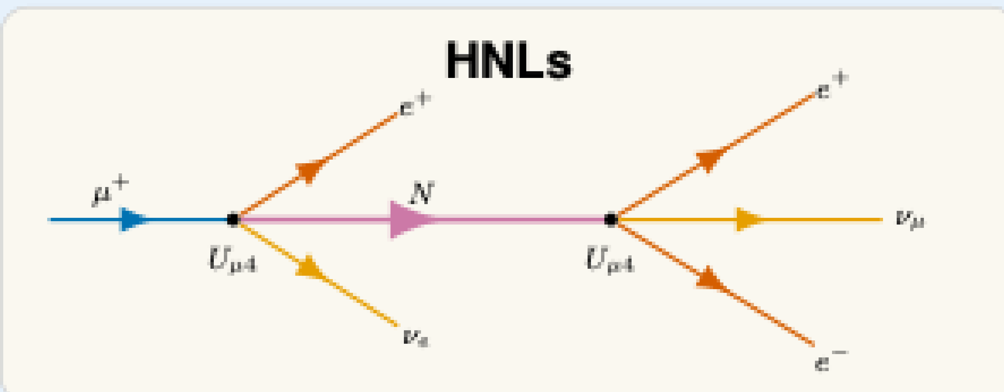
PROSPECT

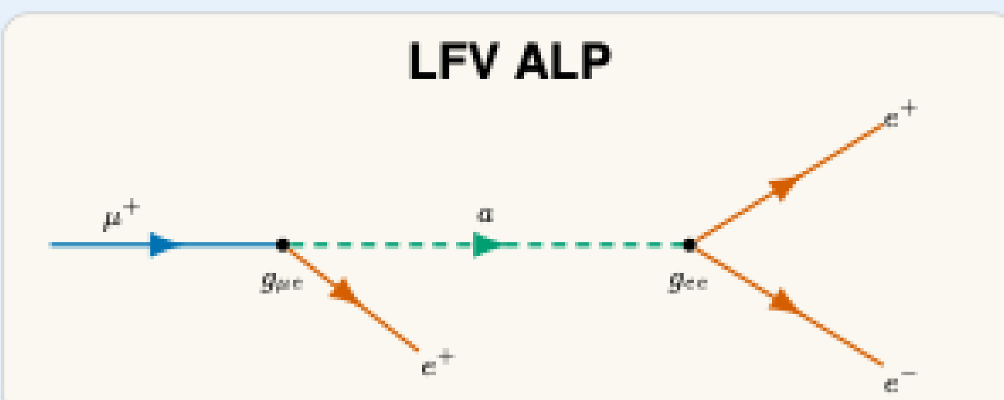
A tons-scale HC² detector at SNS can beat world-leading HNL and ALP limits by >10×

1) Why μ^+ DAR

Two BSM benchmarks from μ^+ decay



HNL (3-body): motivated by seesaw ν-mass

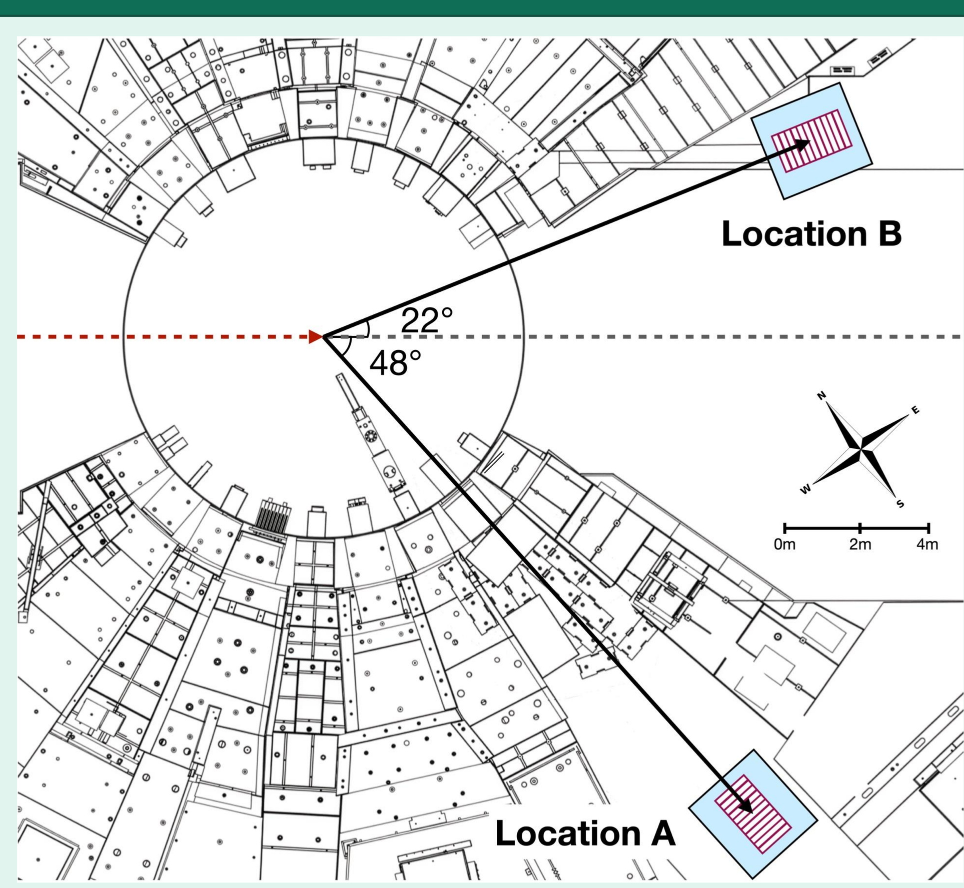


ALP (2-body): motivated by the smallness of CP-term

SNS as a prolific muon source

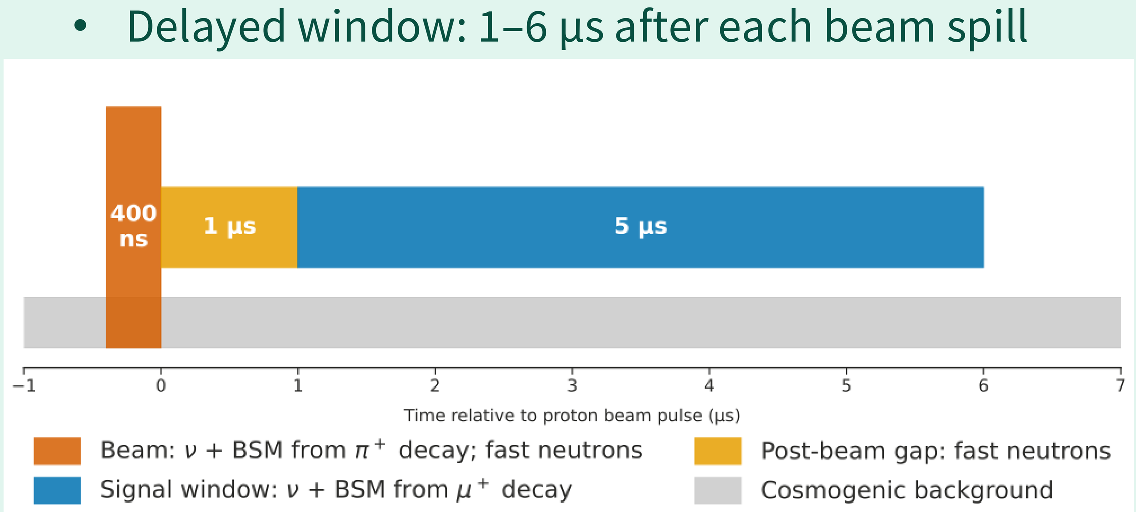
- The Spallation Neutron Source at ORNL delivers a 2 MW, 1.3 GeV proton beam into a liquid mercury target
- Each proton produces ~0.11 stopped π^+
- High-intensity, isotropic source of μ^+ at rest

2) The HC² concept



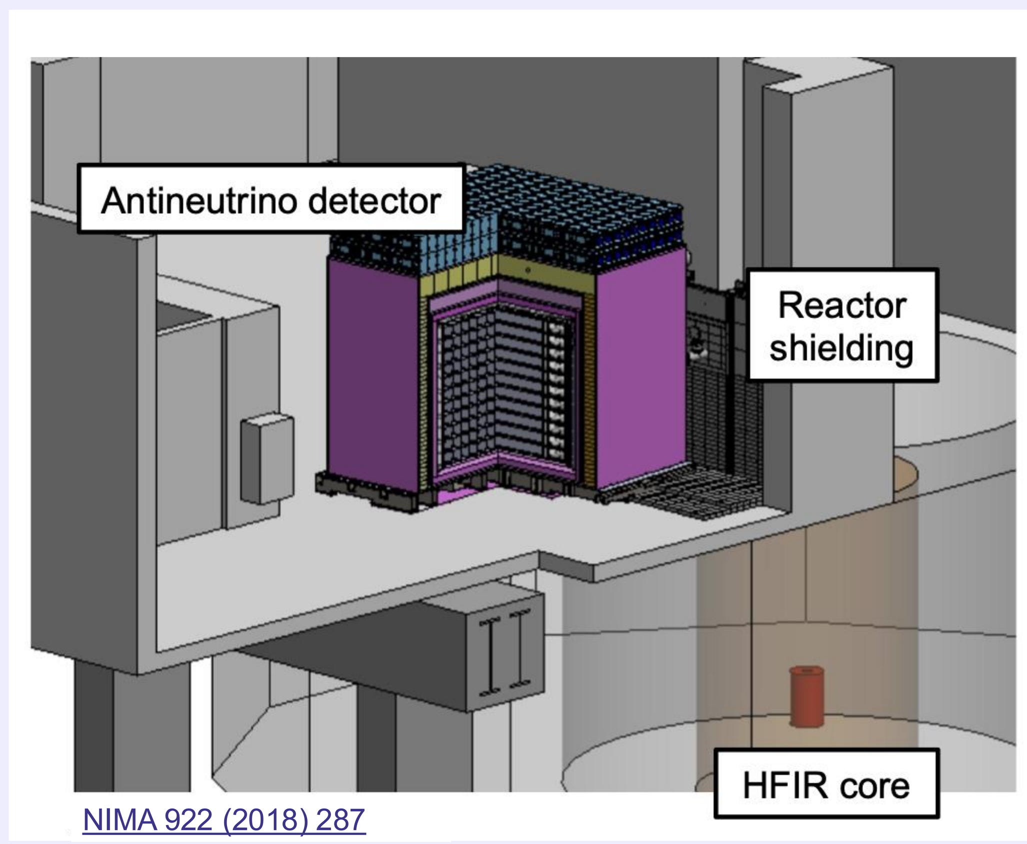
- Tons-scale segmented hydrocarbon scintillator
- Proposed deployment at ~20 m from SNS target

- Delayed window: 1–6 μs after each beam spill

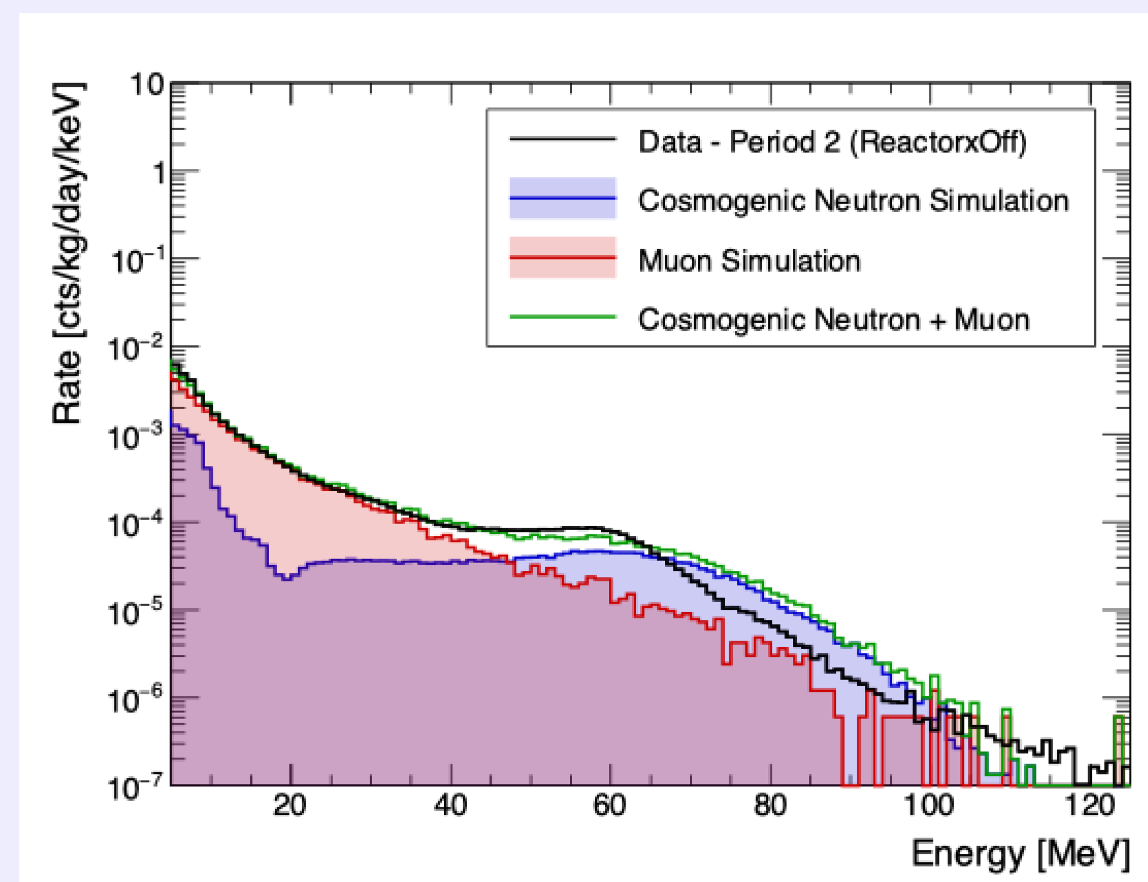


3) Validation with PROSPECT

Layout of the PROSPECT detector



PROSPECT data vs cosmic MC



Why this detector?

- PROSPECT was an on-surface, segmented ^{6}Li-LS detector at HFIR at ORNL
- Its reactor-off data lets us benchmark cosmic backgrounds **on real on-surface data**, not just MC

Can you spot the signal?
Pick up a card
✓ Accept or ✗ Reject

- **~90–95% agreement** between data and MC across 20–100 MeV
- Cosmic μ dominates below 50 MeV; cosmic n above

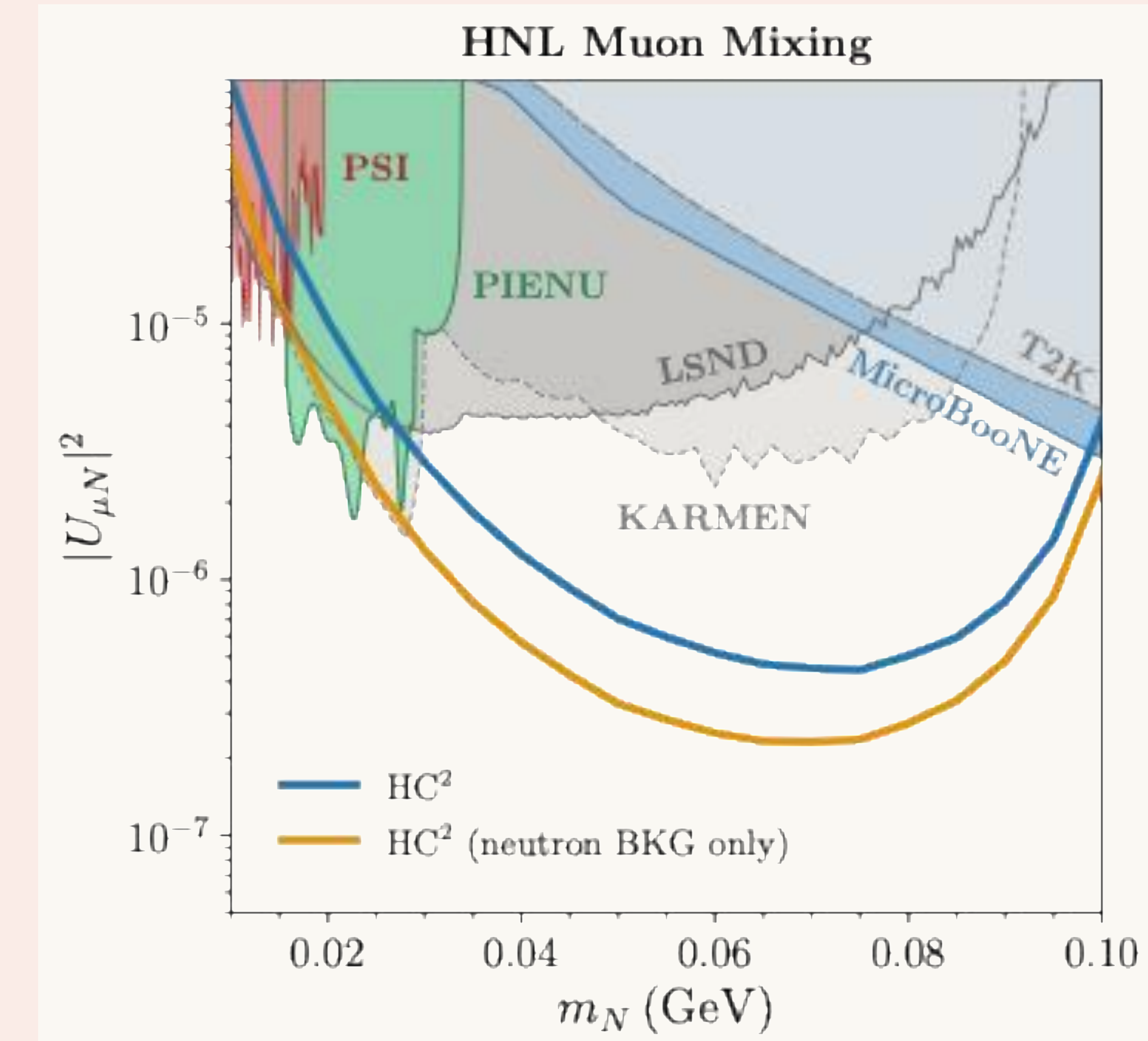
SG4 reliably predicts cosmic backgrounds. The same machinery applied to HC² at the SNS gives a reliable projection.

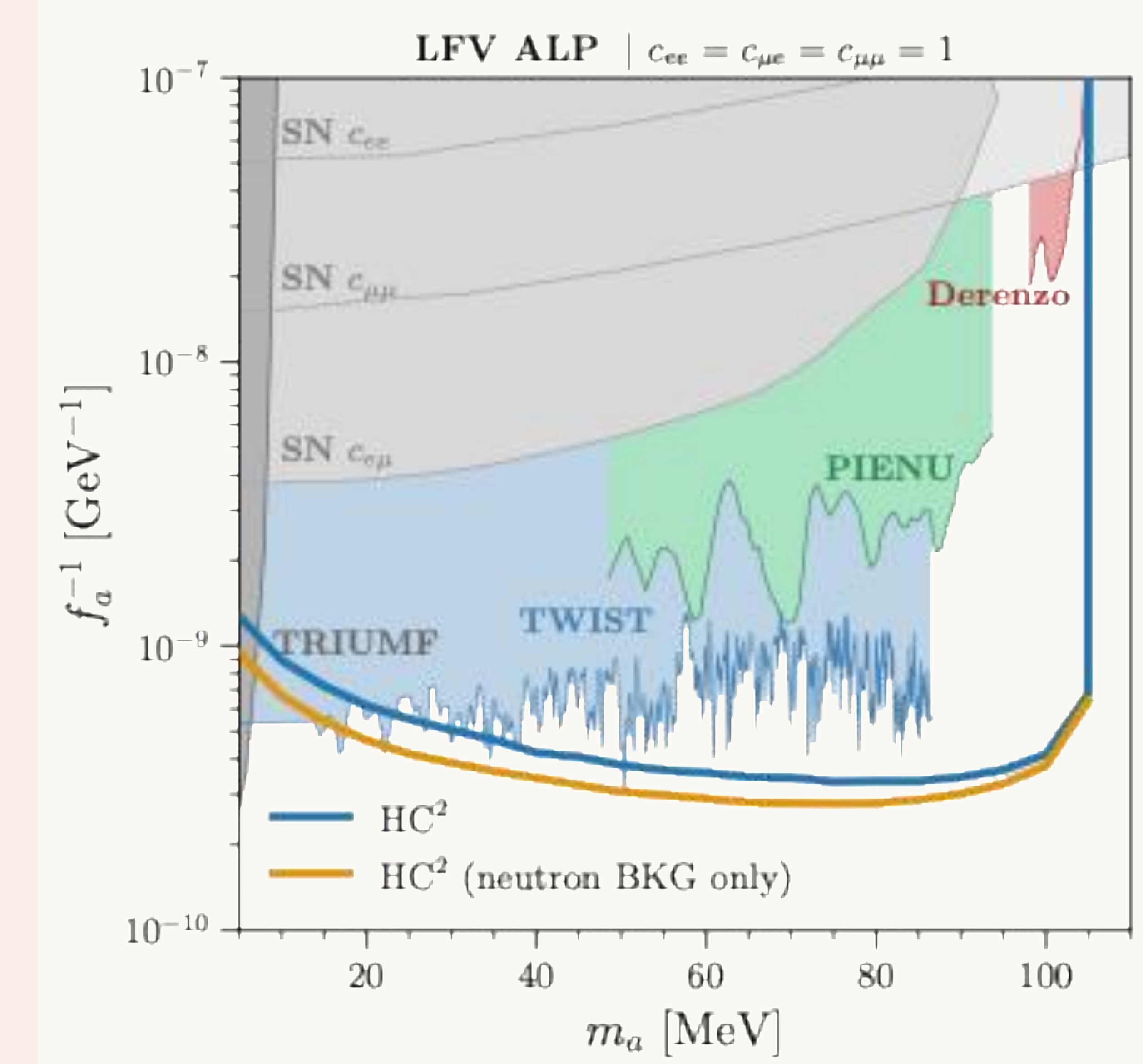
4) Projected HC² sensitivity

HC² backgrounds at the SNS

- **Few hundred cosmic counts** expected over 3 years
  - An external muon veto could push counts to ~100
- **PSD + segmentation** are the critical capabilities , ^{6}Li doping is **not essential**

Sensitivity plots





Hierarchy $c_{\mu e} \ll c_{ee}$ makes HC² even more powerful (see paper).

5) Comments on ^{12}C CC interactions

- Reaction: $\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$, leptons up to 40 MeV
- Two channels: ground state and excited state
- Scaling from JSNS²: HC² expects **hundreds of events in each channel**
- Could match **LSND/KARMEN precision (~10-15%)**
- Useful input for **JUNO**

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