Searches for New Physics through Coherent Scattering with π−Decay-At-Rest Neutrino Sources

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New Directions in Neutrino Physics
Aspen Winter Workshop, Feb. 3-9, 2013

+ “… ~~New~~ Directions in Neutrino Physics”
Current

COHERENT SCATTERING

↑

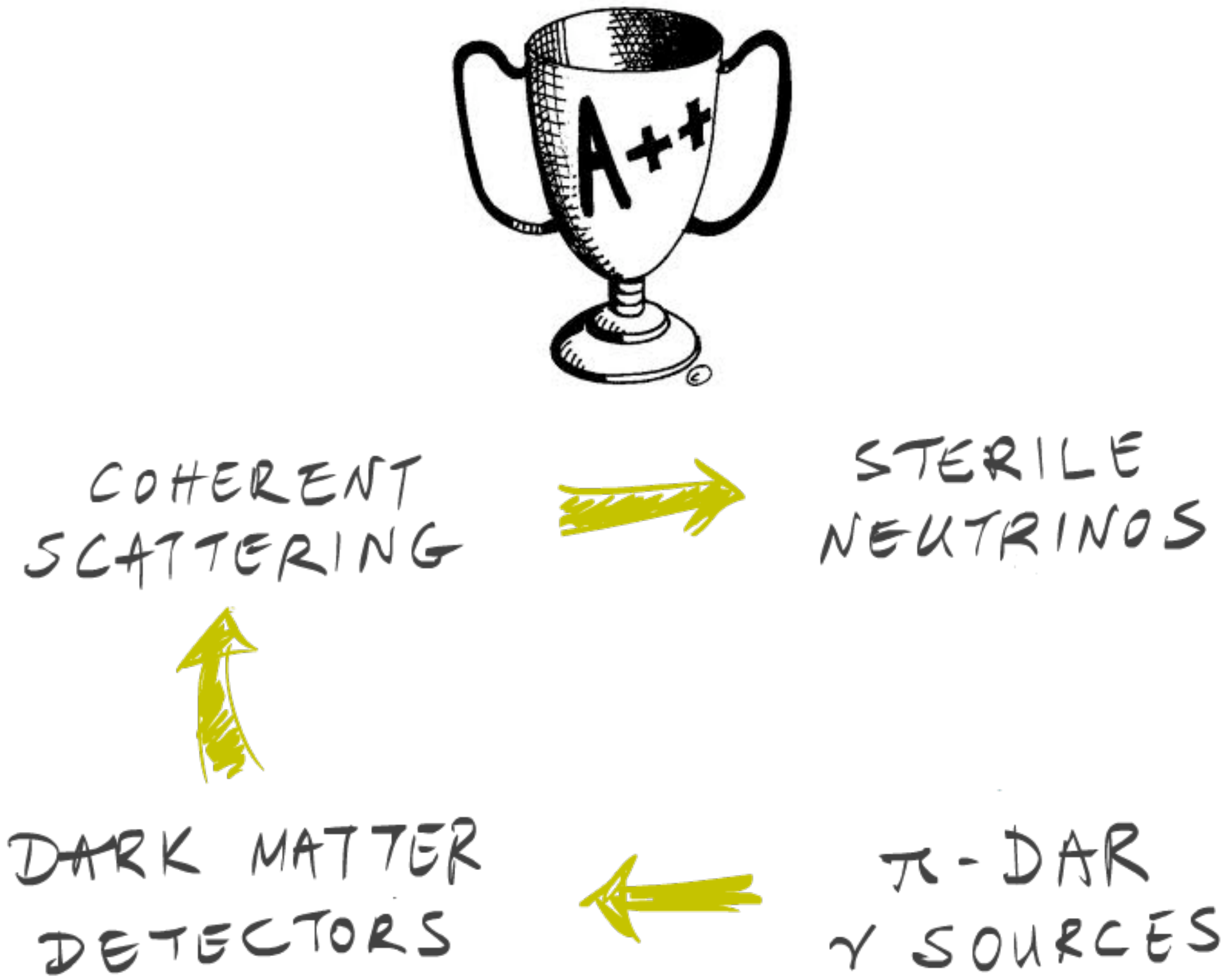
DARK MATTER DETECTORS

STERILE NEUTRINOS

↑

π - DAR
ν SOURCES

+ "… New Directions in Neutrino Physics"



Based on work performed in collaboration
with

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J. Spitz

PRD 86, 013004 (2012)

+ "… New Directions in Neutrino Physics"

Outline

- Why neutrino-nucleus coherent scattering?
- Why sterile neutrinos?
- How we can get to both with
  - $\pi \rightarrow \mu$ Decay-At-Rest (DAR) source +
  - Dark-matter-style detectors
- Sterile neutrino oscillation sensitivities

+ Neutrino-Nucleus Coherent Elastic Scattering

(see talk by J. Collar Fri. p.m.)

Why should we measure this?

- Precisely predicted standard model process (~5% theor. uncertainty),

  and has never been observed

- Probe of beyond-Standard-Model physics:
  - Sterile neutrinos
  - Non-standard interactions (NSI)
  - $\sin^2\theta_W$
- Neutrino-flavor blind process
- Dominant interaction cross section (x10-100) for $E_\nu < 50$ MeV
- Relevant to SuperNova dynamics
- Applications in:
  - SuperNova neutrino detection
  - Geoneutrino detection
  - Solar neutrino physics
  - Nuclear physics (see talk by K. Patton this a.m.)

Sterile Neutrino Oscillations

(see talk by P. Langacker Fri. a.m.)

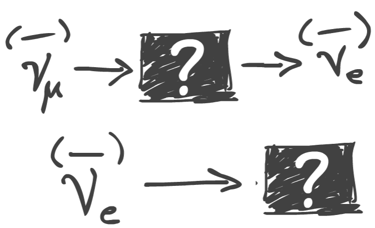
Why should we look for them?

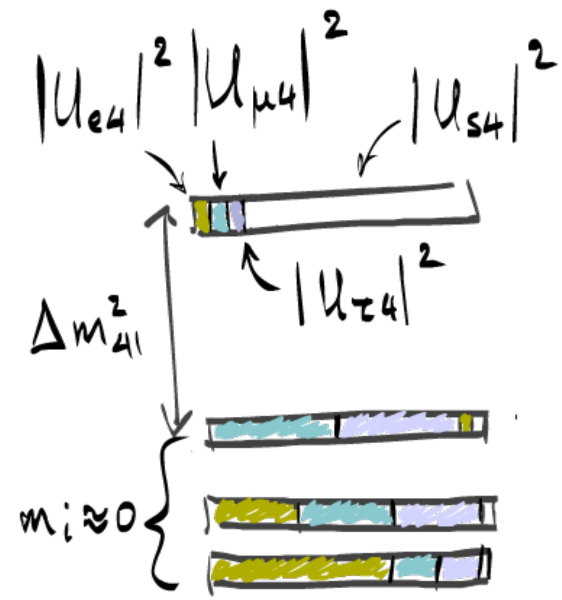
- Increasing number of experimental hints (independently) consistent with sterile neutrino oscillations over the past 3 years
  - "Short-baseline anomalies":
    LSND, MiniBooNE, Reactor Anomaly, Gallex/SAGE calibration source experiments
    ν_e appearance and disappearance
- Absence of any observed effects in ν_μ disappearance channels makes physics interpretation challenging…
  - $\nu_\mu \rightarrow \nu_e$ implies $\nu_e \rightarrow \nu_{\text{not } e}$ AND $\nu_\mu \rightarrow \nu_{\text{not } \mu}$
- "Non-standard" oscillations?
- Need definitive and complementary searches

Sterile Neutrino Oscillations

Why should we look for them?

- Need unambiguous signatures to address whether the fundamental source of short-baseline anomalies is sterile neutrinos:
  - All hints so far show up in charged-current-based searches (indirect probes)
    - $P(\nu_\alpha \rightarrow \nu_{\beta\neq\alpha}) = 4|U_{\alpha 4}|^2|U_{\beta 4}|^2 \sin^2(1.27\Delta m^2 L/E)$
    - $P(\nu_\alpha \rightarrow \nu_\alpha) = 1 - 4|U_{\alpha 4}|^2(1-|U_{\alpha 4}|^2)\sin^2(1.27\Delta m^2 L/E)$, $\alpha,\beta=e,\mu,\tau$





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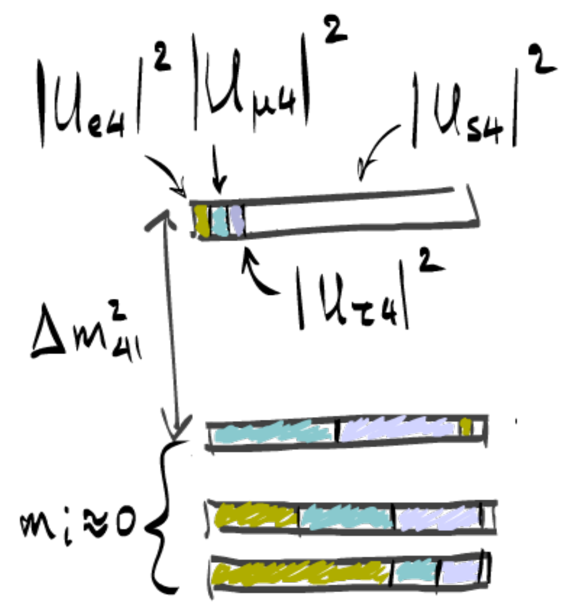
- Neutral-current-based searches!
  - Effective "disappearance" of all types of active neutrinos in a beam: ν_e, ν_μ, $(\nu_\tau) \rightarrow \nu_s$
  - Any "missing flavor" attributed to sterile "flavor":
    - $P(\nu_\alpha \rightarrow \nu_s) = 4|U_{\alpha 4}|^2|U_{s4}|^2 \sin^2(1.27\Delta m^2 L/E)$
  - Relatively unexplored at short baselines

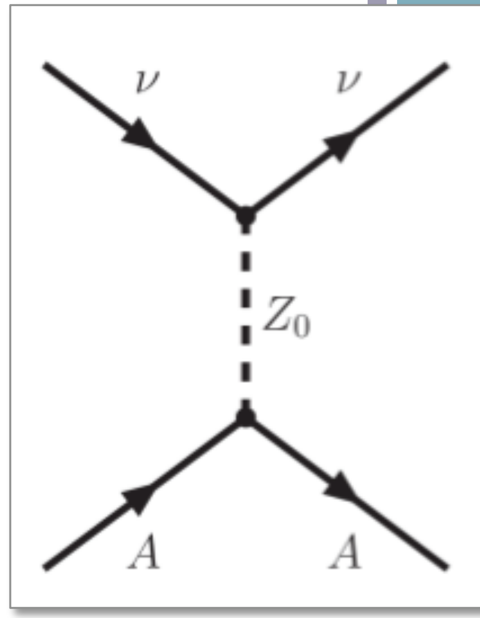


Neutrino-Nucleus Coherent Elastic Scattering

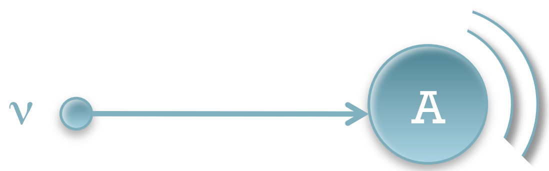
How do we detect it?

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2$$

nuclear recoil energy



- Cross section favors low recoil energies, T, ~5-50 keV

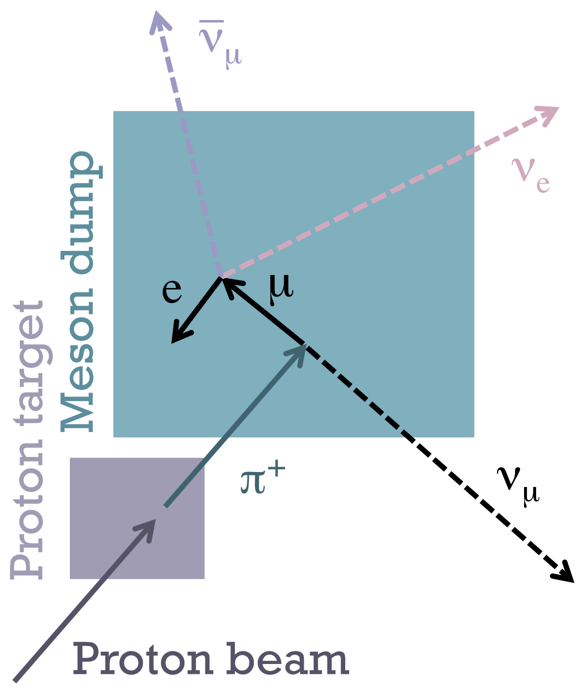


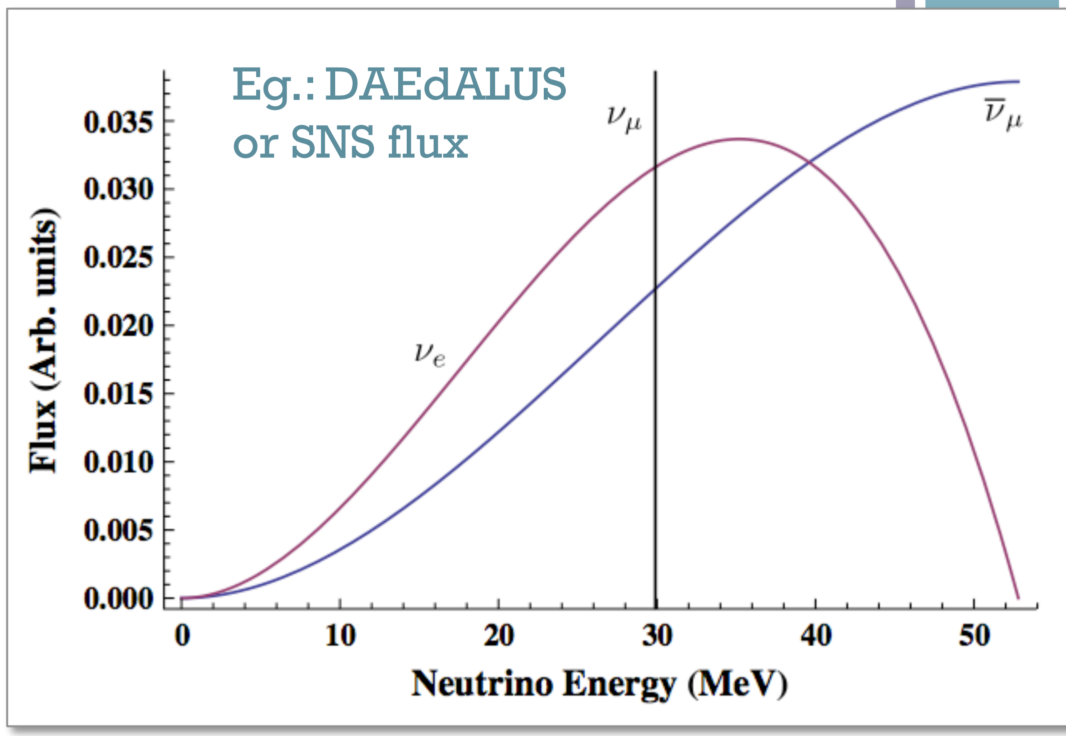
Very low energy (WIMP-like) recoils

- Within reach of current dark matter detector technology!
- Need sufficient detector mass, high-intensity neutrino flux…

$\pi \rightarrow \mu$ DAR Sources

Well-understood, high-intensity neutrino flux with $E_\nu < 52.8$ MeV





$\bar{\nu}_e$ content from π^- at $<10^{-3}$

- Flux normalization uncertainty at ~10%;
  ~1.5% thru $\nu_e e \rightarrow \nu_e e$ scattering in DAEdALUS detector
- Coherent scattering cross section dominates by ~x10

+ More "New Directions in Neutrino Physics"

Also considered:
Electron Capture and Reactor neutrino sources

- Detector threshold requirements quite different.
  Even lower recoil energy thresholds required!
  - DAR: 10 keV thresh
  - Reactor: 100 eV thresh
  - EC source: 10 eV thresh

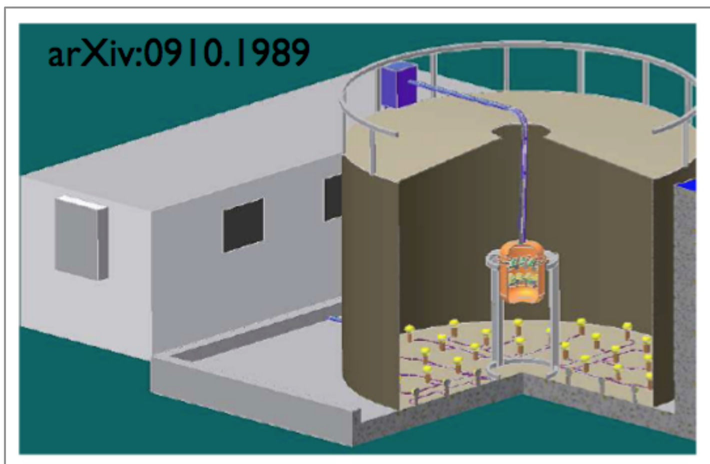
(not yet proven)

- See Phys.Rev. D85 (2012) 013009
  + Work in preparation by Figueroa-Feliciano et al.

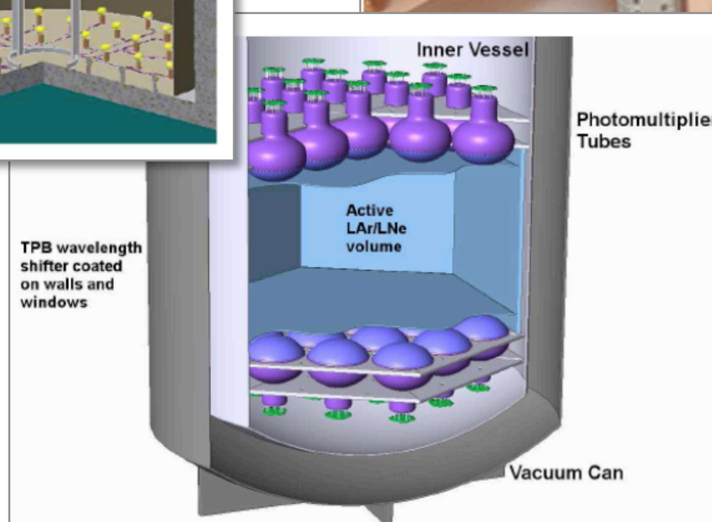
"Ideal" detectors

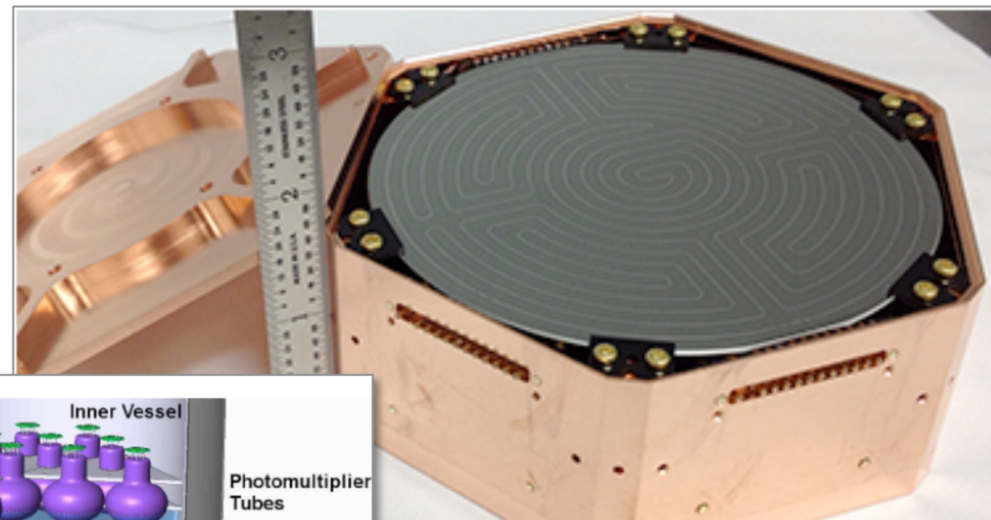
Tonnage + low background + low energy threshold

- Two detector options (dark matter technology):
  Germanium-based, inspired by SuperCDMS
  Liquid argon-based, inspired by CLEAR



CLEAR





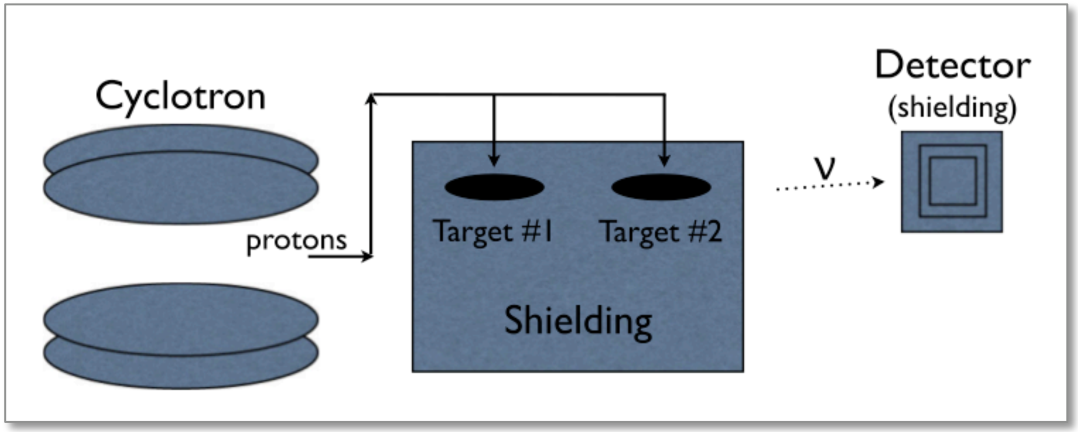
SuperCDMS

Sensitive to keV-scale nuclear recoils

Example Configuration

DAEdALUS cyclotron + multiple proton targets (L) + single detector

(see talk by M. Toups Sat. a.m.)



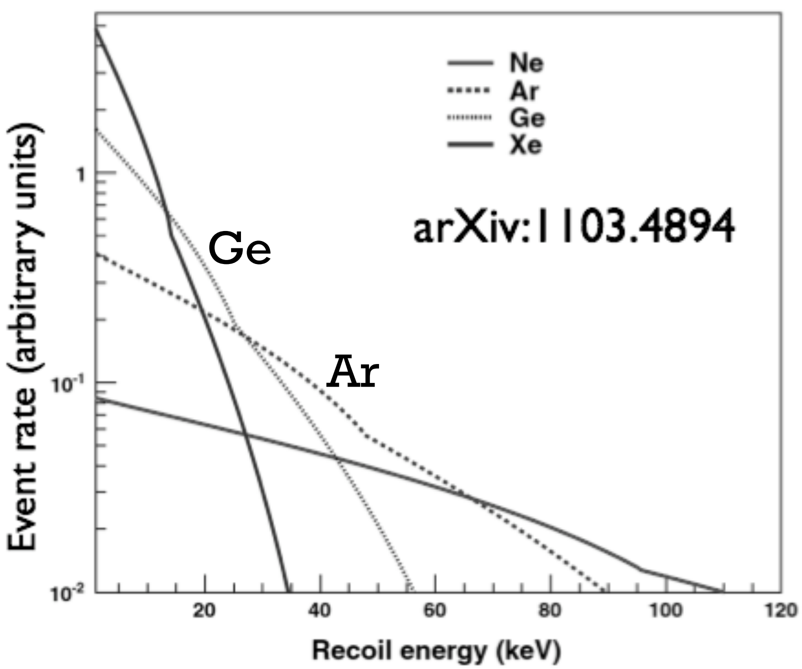
ν source	4×10^{22} ν/flavor/year
Duty factor	13%
Baseline correlation	0.99
ν flux norm. uncertainty	1.5%
Uncorr. sys. uncertainty	0.5%
Distances from ν source	20 m, 40 m
Exposure	5 years: 1 near, 4 far
Depth	300 ft

+ Example Configuration

Detector

- Option 1: Germanium
  Option 2: Liquid argon

Relative distributions of E_{recoil} from a π-DAR source



Detector parameters for sterile neutrino search:

	^{76}Ge	^{40}Ar
Active mass	100 kg	456 kg
Efficiency	0.67 (flat)	0.50 (flat)
Threshold	10 keV	30 keV
$\frac{\Delta E}{E}$ at threshold	3%	18%
Radiogenic background	2/year	See text*
Cosmogenic background	$0.1/(10\ \mathrm{kg} \cdot \mathrm{day})$	$0.1/(10\ \mathrm{kg} \cdot \mathrm{day})$
Beam-related background	0/year	0/year

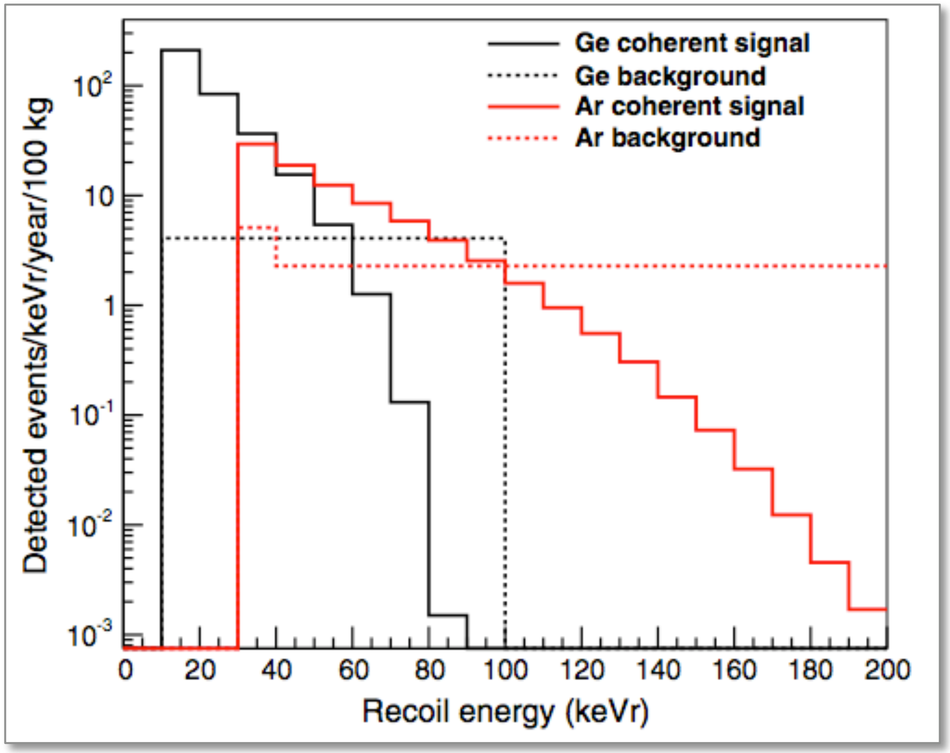
*includes surface (100/yr) and ^{39}Ar backgrounds

+ Example Configuration

Signal & backgrounds:

- Expected rates in the absence of oscillations: (20m source)
- Fits restricted to E_{recoil}<100/200 keV (Ge/Ar); rate is dominated by low E_{recoil}
- Note:
  $E_{thr,Ge} = 10$ keV
  $E_{thr,Ar} = 30$ keV

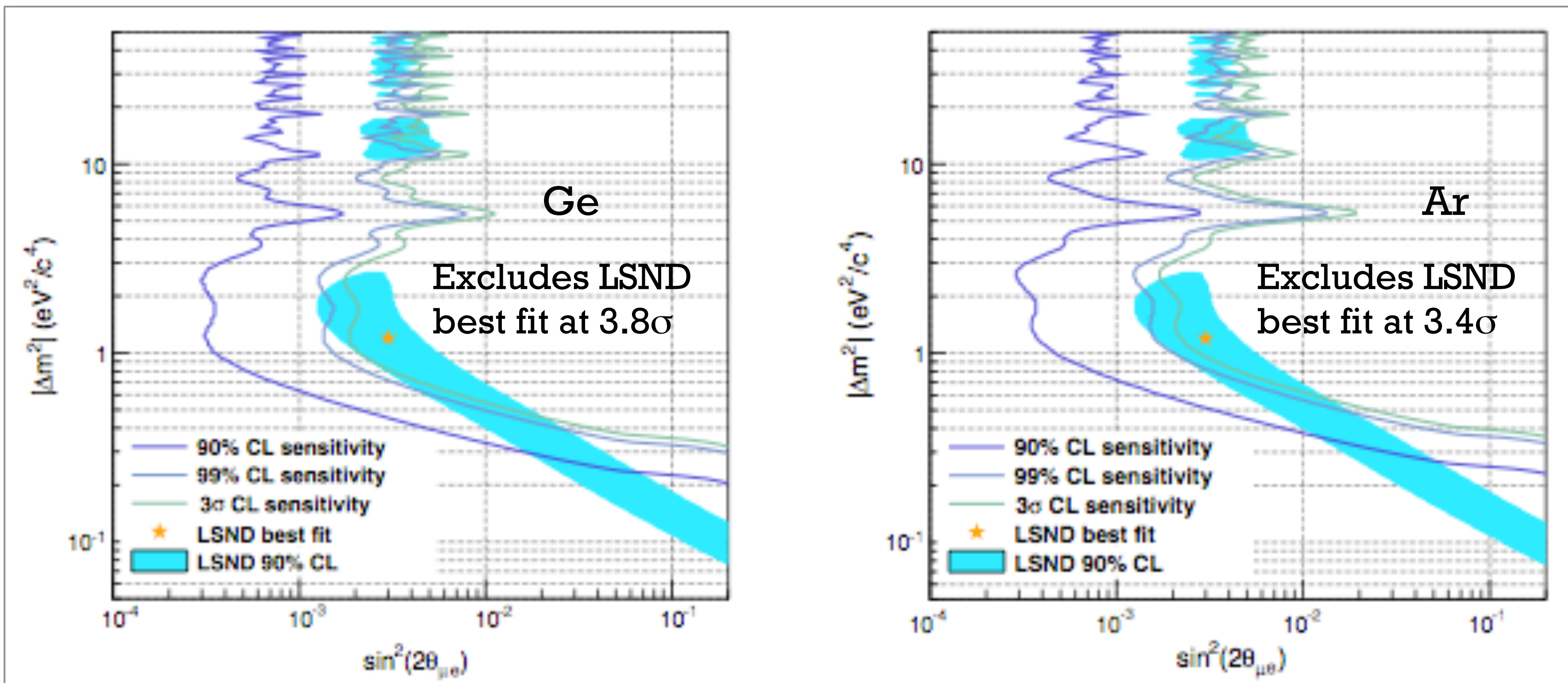
  This will affect oscillation sensitivity



Sensitivity Reach

L-dependence!

- Energy of neutrino cannot be reconstructed, rely in precisely known L
- Fit flavor-summed E_{recoil} spectra from two baselines simultaneously, accounting for systematic correlations between the two baselines



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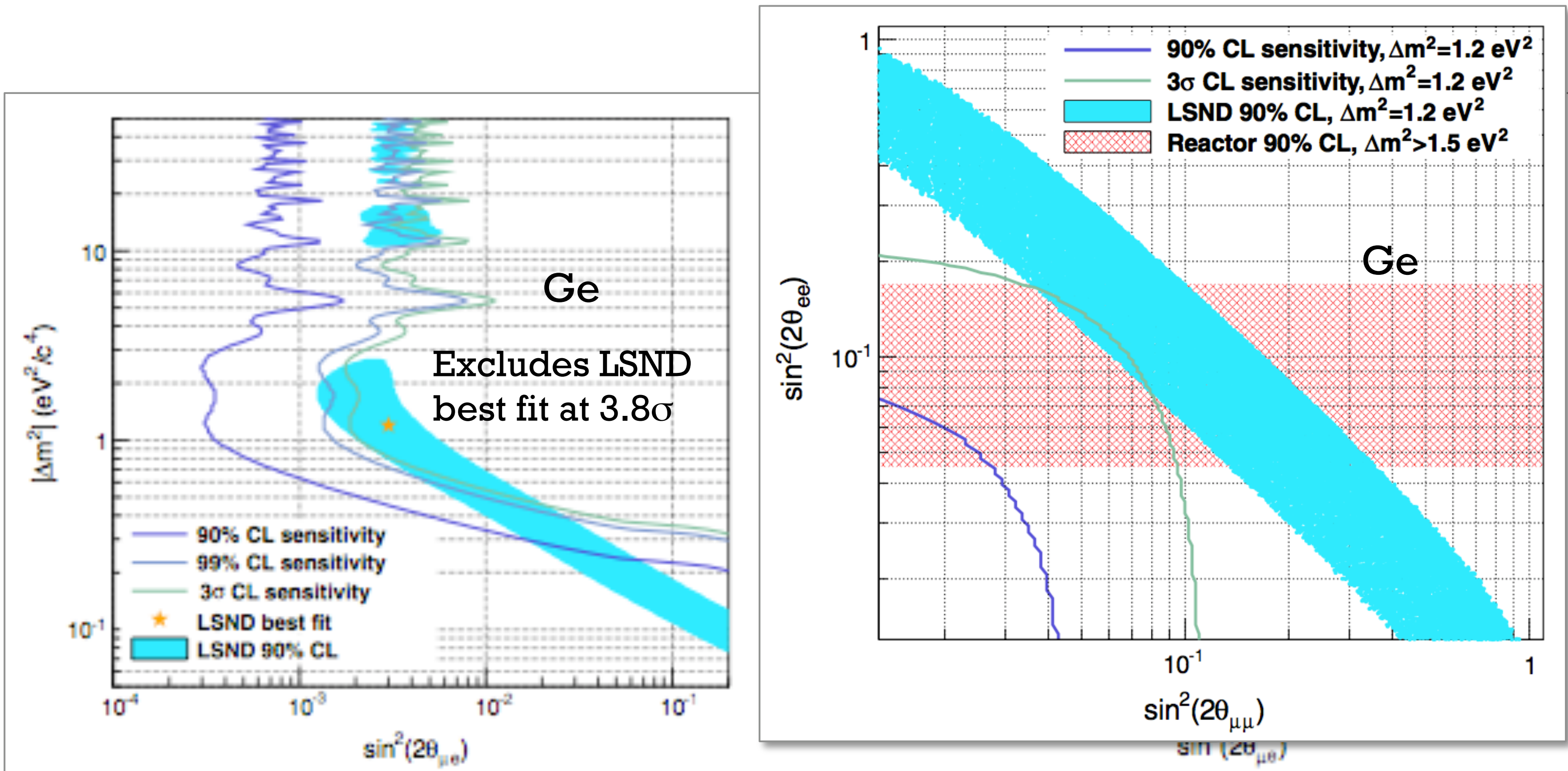
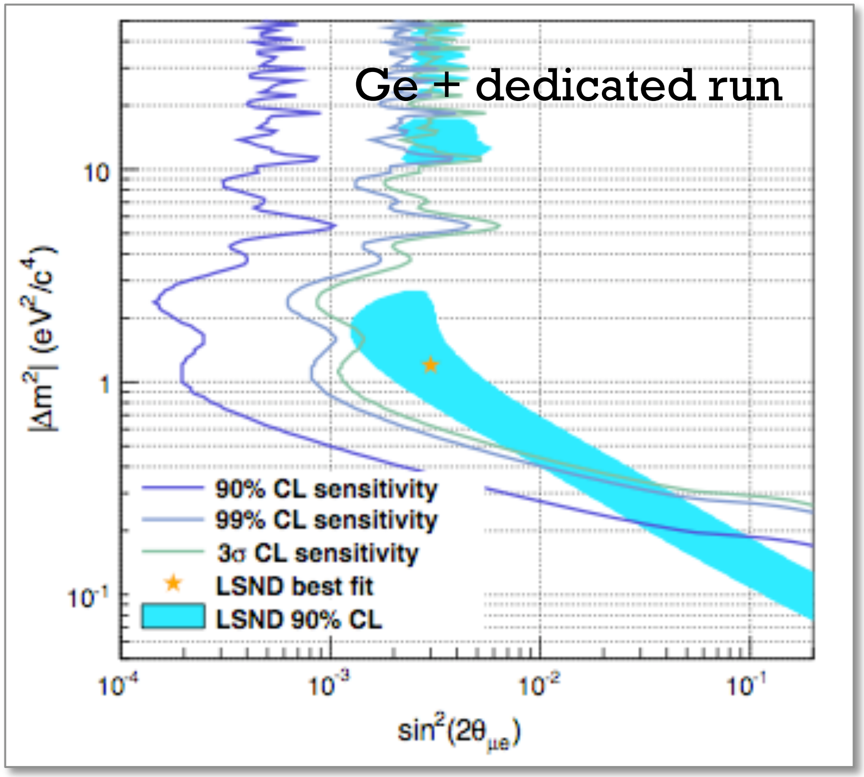


Sensitivity Reach

"Dedicated" physics run with a Ge detector

- Duty factor raised from 13%→50%, same instantaneous power, for 5 years (staged approach to DAEdALUS)



Excludes LSND best fit at 4.8σ

Summary

- Discovery of neutrino-nucleus coherent elastic scattering is possible with existing or proposed technology
- A high-intensity π-DAR source such as one provided by one of the DAEdALUS accelerators can be used to study coherent scattering in a SuperCDMS-style or CLEAR-style detector with high precision
- Offers possibilities for a powerful test of sterile neutrino oscillation hypothesis
  - L dependence is key (very little energy information), along with controlled normalization systematics
- Also offers possibilities for other low-E neutrino physics searches (SuperNova, NSI, …) and has applications in low-E neutrino measurements