New Physics Opportunities in Neutrino Experiments

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CCAPP

NSF

Neutrinos Are Special; Now is Special

Laboratory Nu:

Goal:
Particle nature of neutrinos

Superpower:
Window to BSM

Why now?
DUNE, FNAL, world program

Kryptonite:
Requires precision tests

Cosmology Nu:

Goal:
Constituents of universe

Superpower:
Only known part of DM

Why now?
Galaxy surveys, CMB, 21cm

Kryptonite:
Only measure bulk effects

Astrophysics Nu:

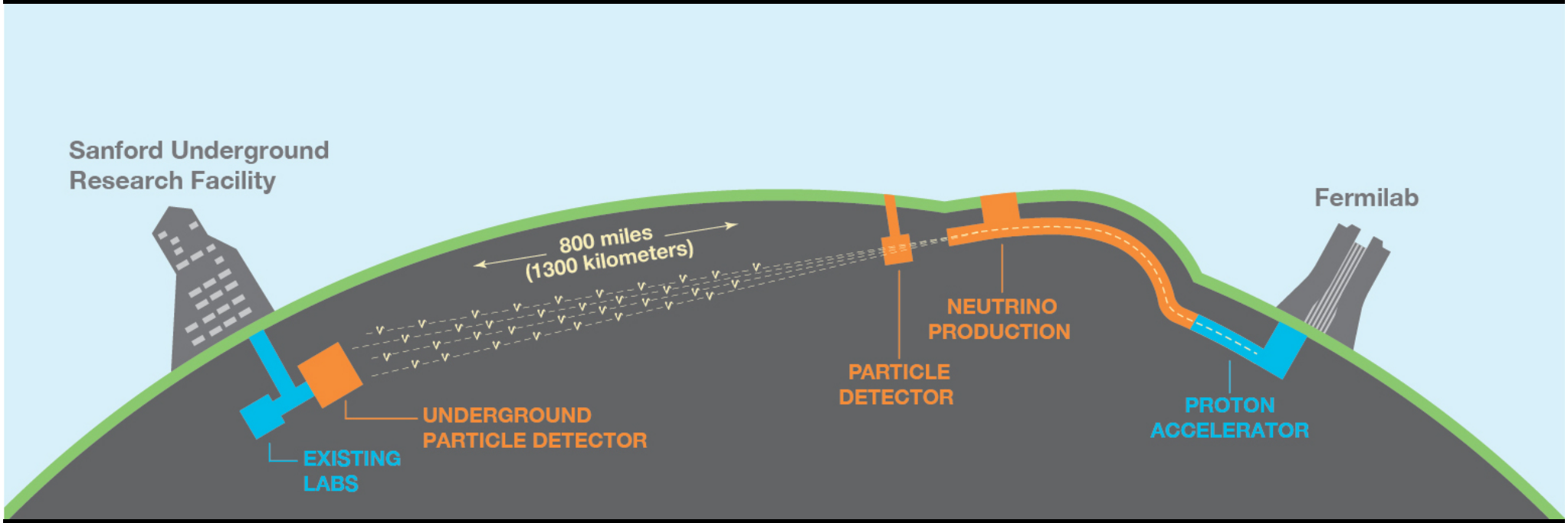
Goal:
Mechanisms of sources

Superpower:
Reveals deep interiors

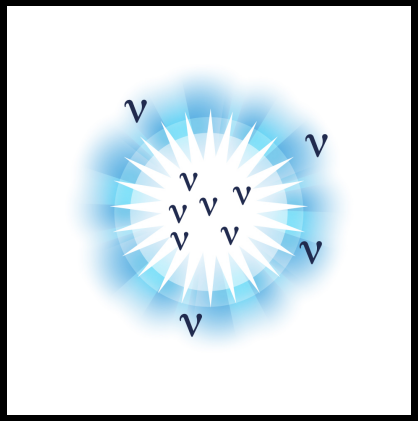
Why now?
IceCube, SK-Gd, GZK, etc.

Kryptonite:
Need neutrino properties

Why I'm Excited: Behold DUNE

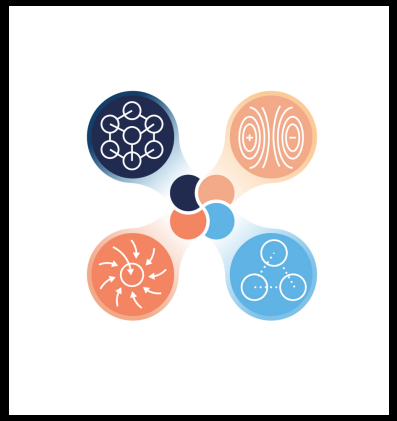


Origin of Matter



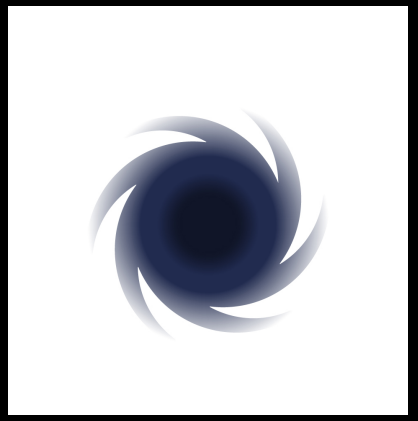
(Nu vs. Nu-bar)

Unification of Forces



(Proton Decay)

Black Hole Formation



(Supernova Neutrinos)

Why I'm Excited: Rest of the FNAL Program

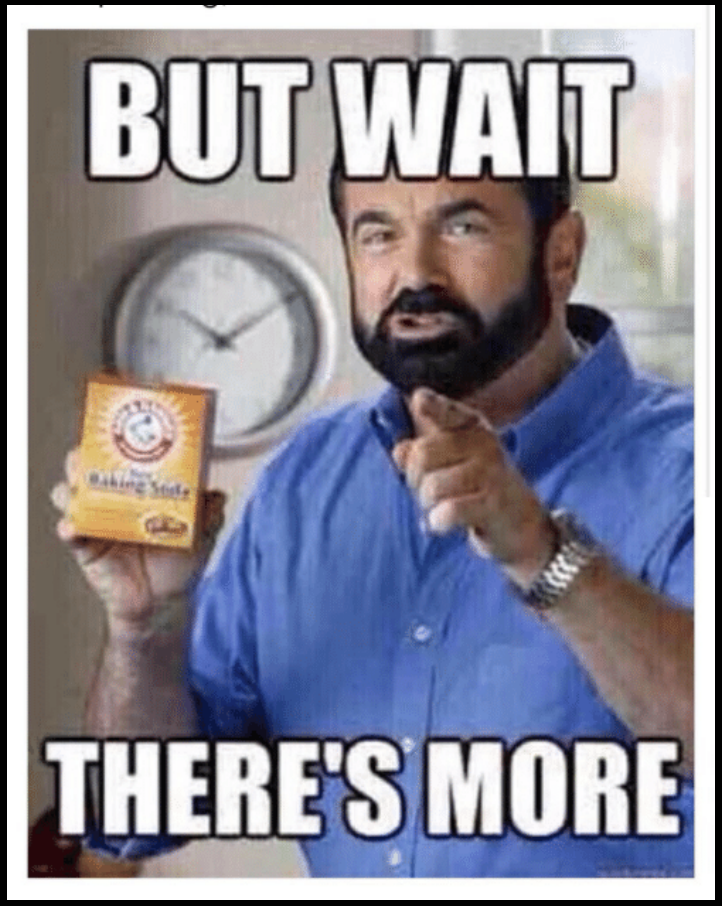
Examples:

- Is MiniBooNE seeing sterile neutrinos?
- What are the neutrino cross sections?
- How do neutrinos break nuclei?
- What is the full power of PID in LAr?
- Can we find dark-sector particles?
- Can we make new tests of cosmic rays?

Why I'm Excited: Rest of the World Program

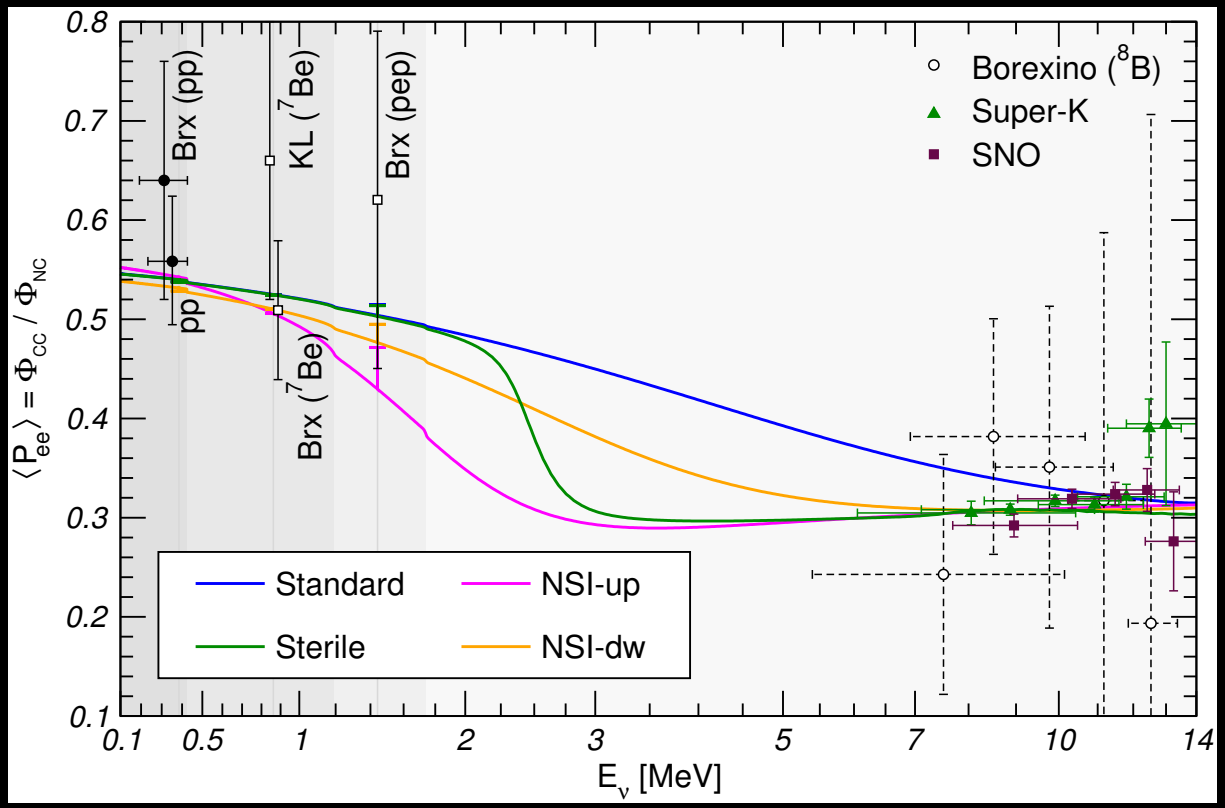
Examples:

- Tests of absolute neutrino mass (KATRIN, etc.)
- Tests of Majorana/Dirac in double beta decay
- Tests of hierarchy at accelerators and reactors
- Tests of sterile neutrinos at reactors
- Tests of coherent scattering


BUT WAIT
THERE'S MORE

Solar Neutrinos in DUNE

Discovery Potential: Particle Physics



Maltoni and Smirnov (2016)

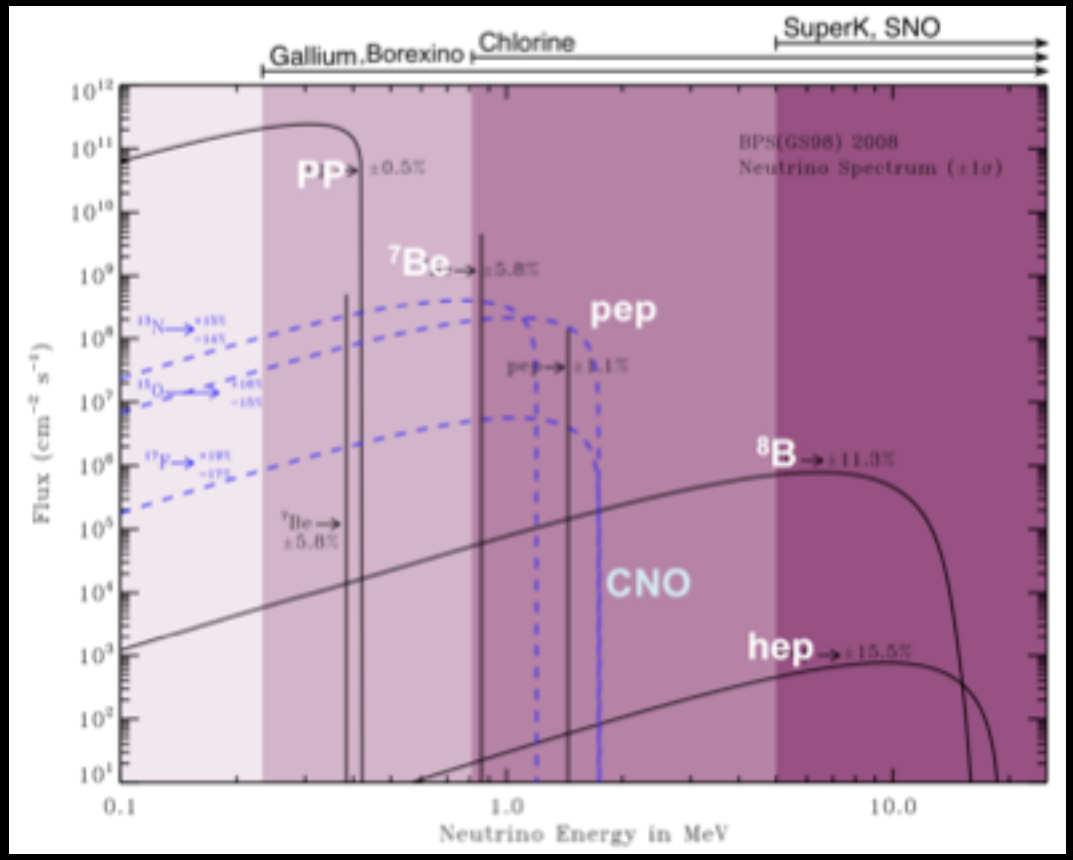
Directly measure energy dependence of MSW effect

Test solar-reactor dm^2 discrepancy

Many ways to search for new physics

Needs precise astrophysics to maximize potential

Discovery Potential: Astrophysics



Precisely measure 8B flux and hence core temperature

Discover *hep* flux and hence probe density profile

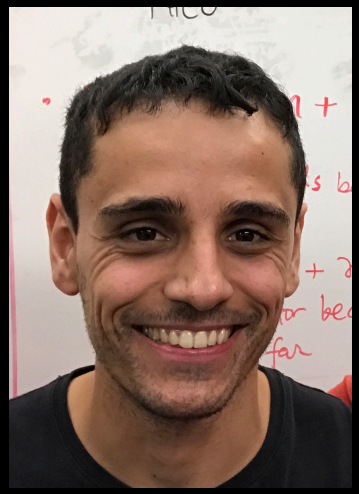
Discover CNO flux and hence probe metallicity puzzle

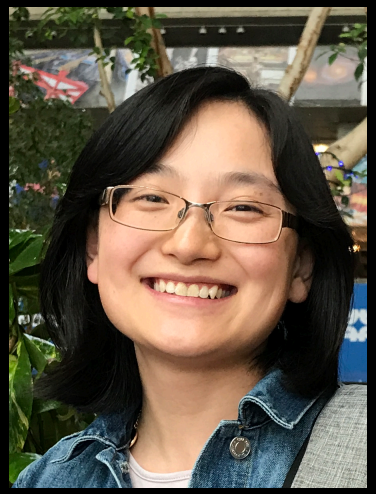
Needs precise particle physics to maximize potential

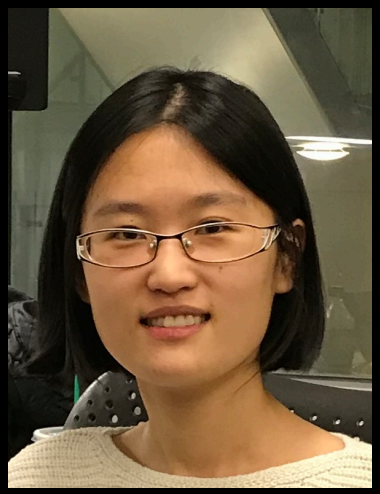
Our Proposal for "DUNE-Solar"

DUNE as the Next-Generation Solar Neutrino Experiment

Francesco Capozzi,[1, 2, 3] Shirley Weishi Li,[2, 4] Guanying Zhu,[2] and John F. Beacom[1, 2, 5]





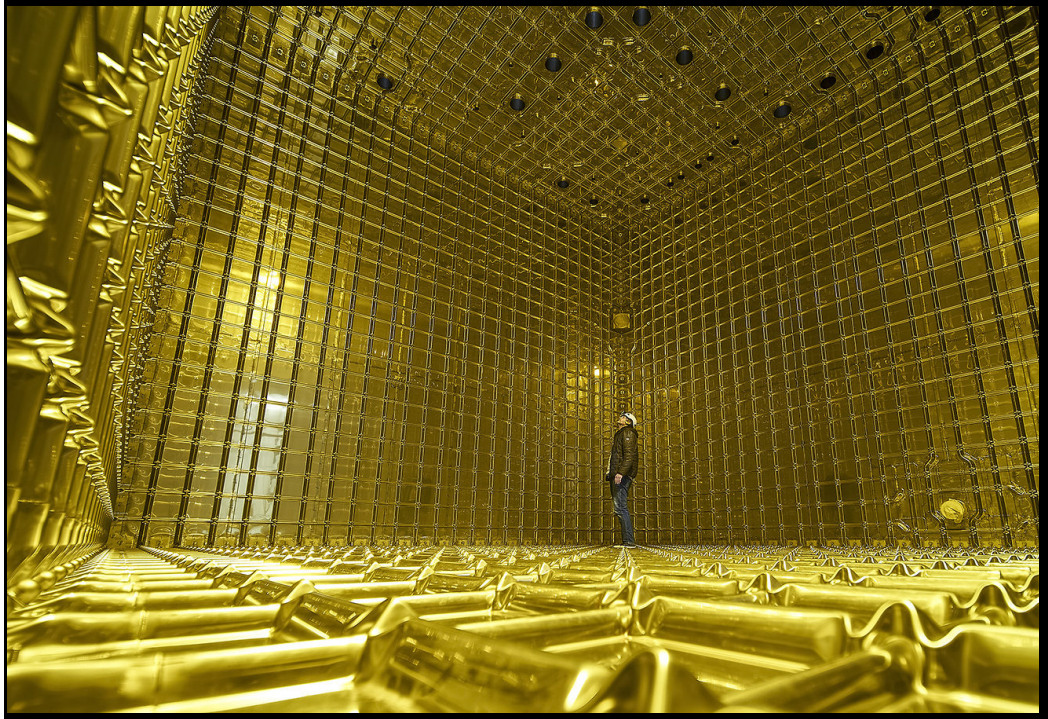


Author Disclaimers:

We speak for ourselves as theorists, not on behalf of the DUNE Collaboration

This work is based on our ideas, our calculations, and publicly available information

DUNE Detector and Properties



Four modules, each 10 kton

Assume 100 kton-year
Triggering, processing, etc.
Read out as TPCs (charge)
Energy threshold 5 MeV
Energy resolution 7%
Angular resolution ~ 25 deg

We define physics goals and find the technical requirements
We find that they are challenging but feasible

Our Goals for DUNE-Solar

Particle Physics:

Best precision on sin^2
Best precision on dm^2
Powerful tests of new physics in comparison to JUNO reactor data

Astrophysics:

Best precision on 8B flux
Best precision on hep flux
Powerful tests of new astrophysics in comparison to other solar data

Must break essential degeneracies between the two

Our Strategy, Part 1

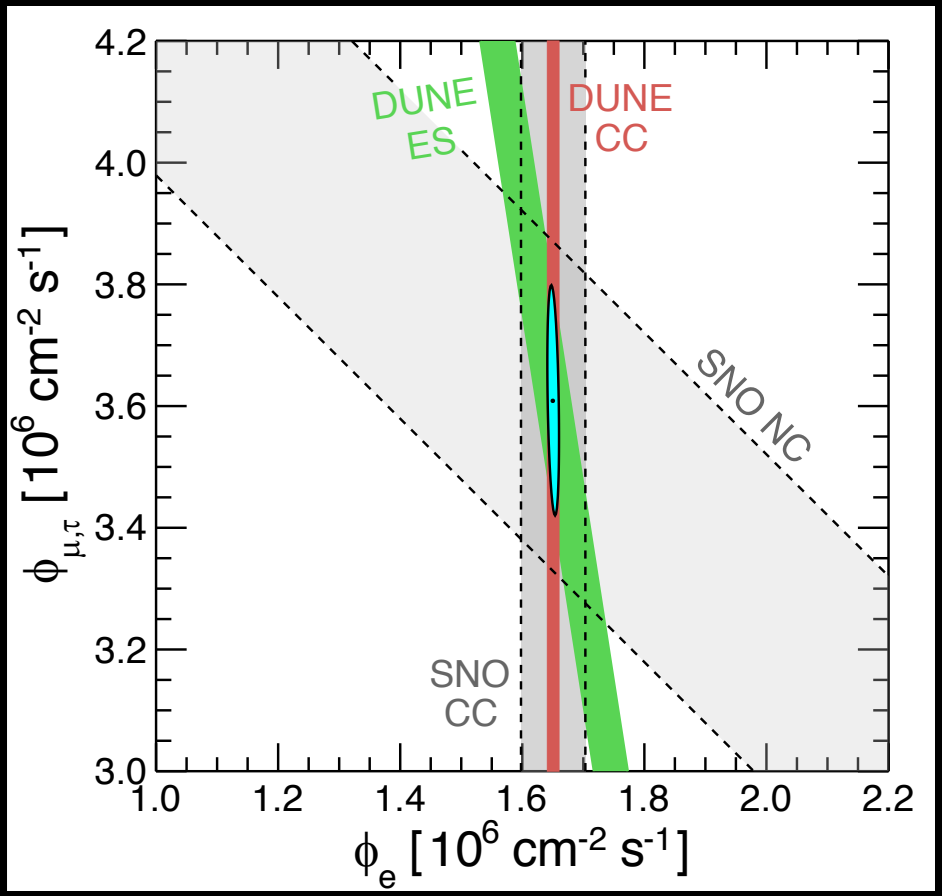
- The degeneracy between $\sin^2\theta_{12}$ and $\phi(^8\mathrm{B})$ can be broken by separately measuring two detection channels:

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^* \,, \qquad (1)$$

for which the rate scales as $R_{\mathrm{Ar}} \propto \phi(^8\mathrm{B}) \times \sin^2\theta_{12}$, and

$$\nu_{e,\mu,\tau} + e^- \rightarrow \nu_{e,\mu,\tau} + e^- \,, \qquad (2)$$

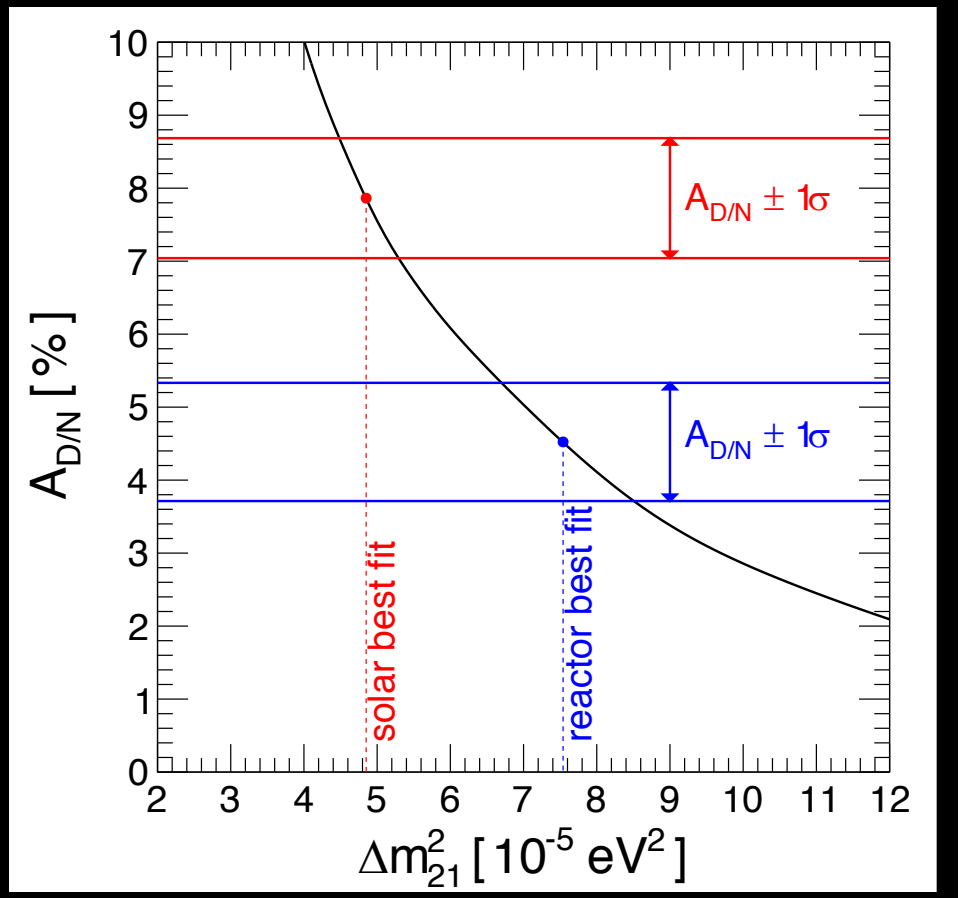
which scales as $R_e \propto \phi(^8\mathrm{B}) \times \left(\sin^2\theta_{12} + \frac{1}{6}\cos^2\theta_{12}\right)$.



Isolate sin^2, 8B flux with crossing (and huge statistics)

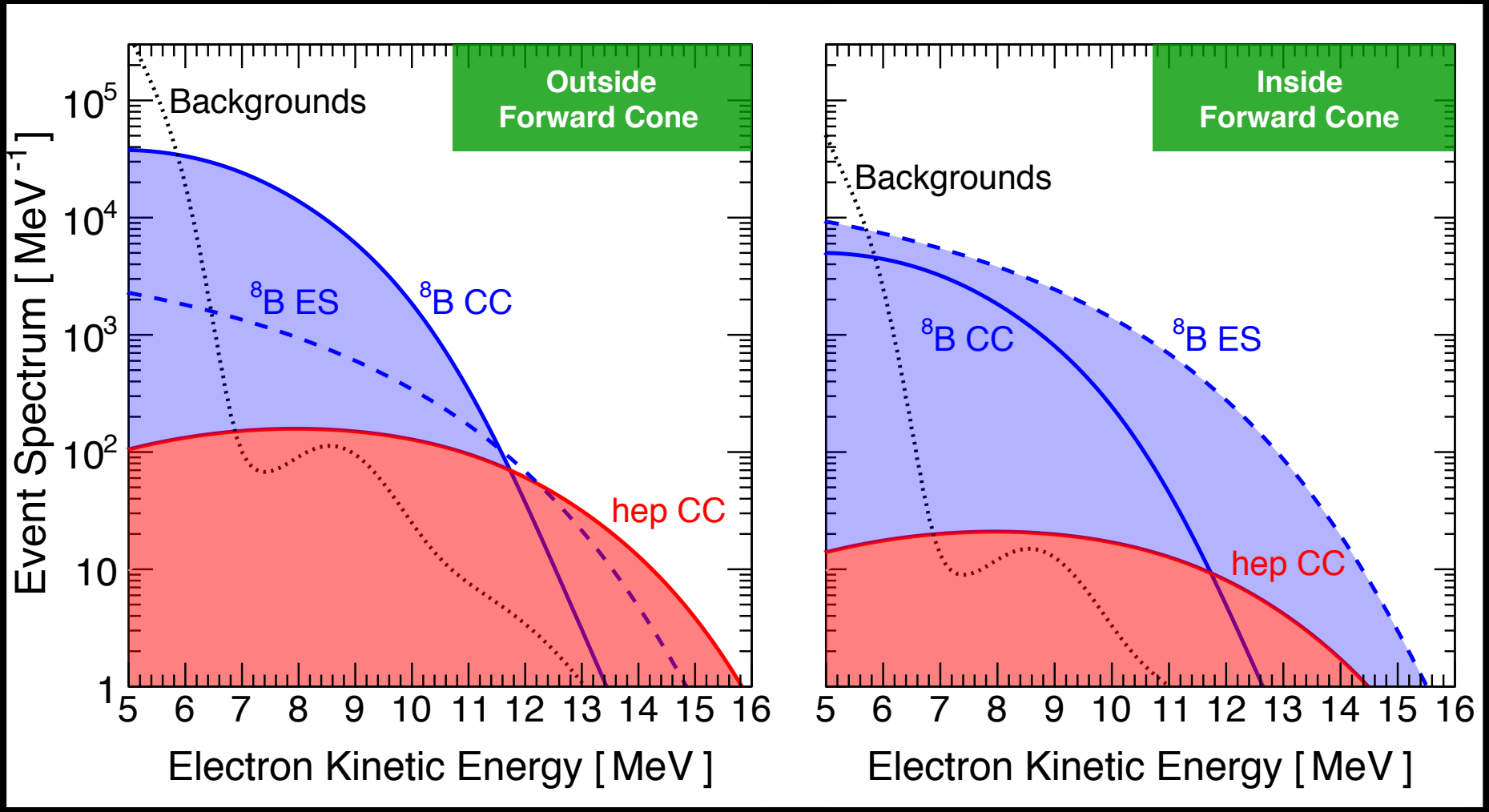
Our Strategy, Part 2

- Δm^2_{21} can be isolated through the day-night flux asymmetry, $A_{D/N} = (D - N)/\frac{1}{2}(D + N)$, which scales as $\propto 1/\Delta m^2_{21}$. For the solar Δm^2_{21}, an exposure of 100 kton-year, and using only events above 6 MeV and outside the forward cone, we expect $D = 3.04 \times 10^4$ and $N = 3.29 \times 10^4$ signal events, along with 0.83×10^4 background events in total. Considering only statistical uncertainties, $A_{D/N} \simeq -(7.9 \pm 0.8)\%$ ($\sim 10\sigma$). Though



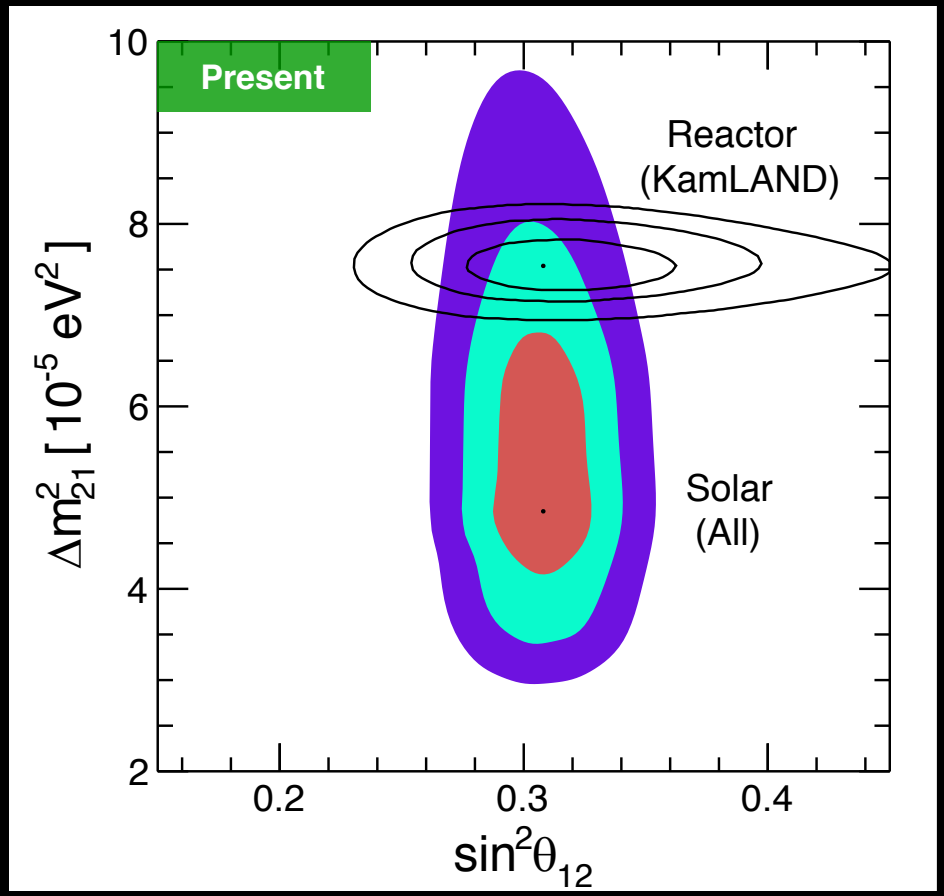
Isolate dm^2 with day-night effect (and huge statistics)

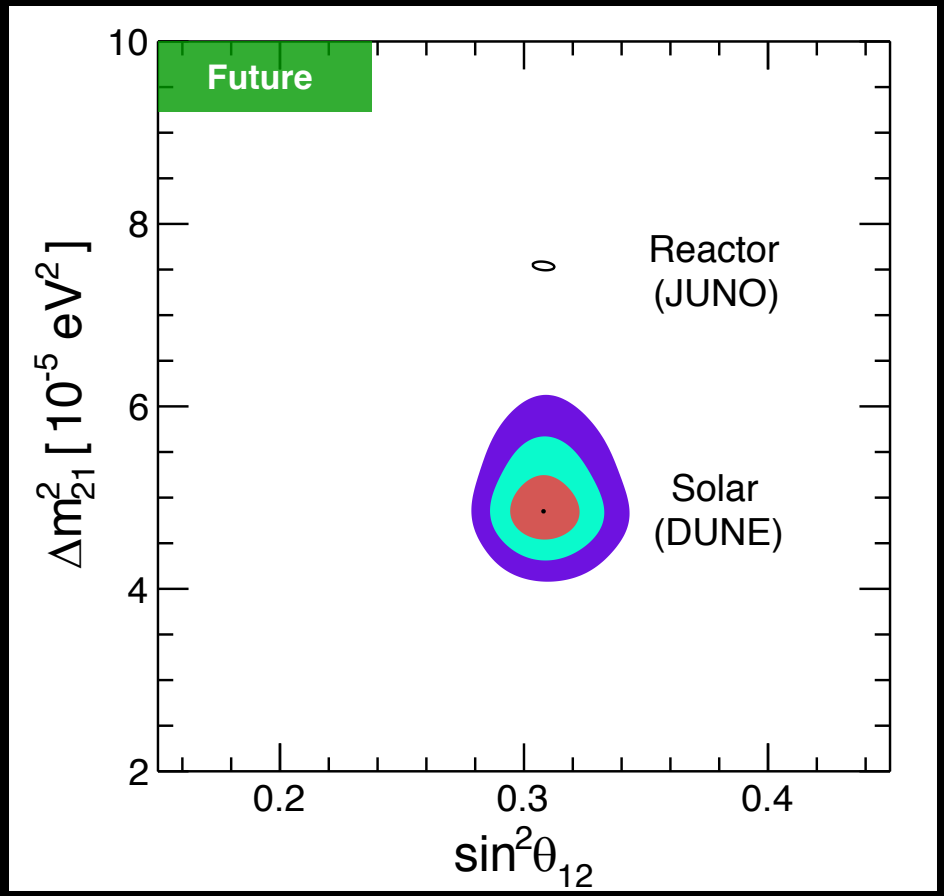
Calculated Spectra



In each panel, we assume only statistical separation

Calculated Sensitivity





In addition, 8B flux measured to ~ 2.5%, hep flux to ~ 11%

Prospects for Solar Neutrinos

- Solar neutrinos: great open questions, need new experiments
- This is the first study to consider the solar-neutrino prospects in DUNE in a comprehensive, detailed, realistic way
- DUNE would open substantial discovery space in particle physics and astrophysics that cannot be fully matched

This could greatly expand the return of DUNE


BUT WAIT
THERE'S MORE
BUT WAIT
THERE'S MORE

Back to the Bigger Picture

Is MiniBooNE Seeing Sterile Neutrinos?

Laboratory
Could have large dm^2, large sin^2 sterile neutrino mixing
This would reveal new particle physics

BUT

Cosmology
This would violate neutrino number, neutrino mass
Evading would require new early universe physics

BUT

Astrophysics
But this could change supernova neutrino signals
This could provide new probes of astrophysics

These are not separable problems

Other Key Problems

Do sterile neutrinos exist at other dm^2 and sin^2?

What are the absolute neutrino masses?

Do neutrinos have non-standard interactions?

Will neutrinos surprise us?

These are not separable problems either

How to Advance our Goals?

We’re going to need a bigger boat

The Time for Neutrino Science is Now

Neutrino Science

Laboratory ν	Cosmology ν	Astronomy ν
Efforts: Fermilab and more	Efforts: CMB and more	Efforts: IceCube and more
Context: Precision Physics, BSM reach	Context: Precision Cosmology, BSM reach	Context: Transient Astronomy, Multi-messenger

Neutrinos are multi-frontier science

Overall Conclusions