Neutrinos and Cosmic Rays at Snowmass

BNL Snowmass Retreat

December 17, 2021

Peter B. Denton

Lots of BNL Letters of Interest on Neutrinos and Astroparticle Physics

- Neutrino Non-Standard Interactions, PBD (ed.), J. Gehrlein, +many
- Direct Probes of the Matter Effect in Neutrino Oscillations, PBD (ed.), S. Parke
- Ultra-High-Energy Neutrinos, M. Bustamante (ed.), PBD (ed.), S. Wissel (ed.), +many
- Computing Neutrino Oscillations in Matter Efficiently, PBD (ed.), +many
- Cosmic Neutrino Probes of Fundamental Physics, PBD, +many
- Opportunities and signatures of non-minimal HNLs, PBD, J. Gehrlein, +many
- Neutrino Opportunities at the ORNL Second Target Station, PBD, +many
- CEvNS: Theoretical and experimental impact, PBD, J. Gehrlein, +many
- Supernova neutrinos and particle-physics opportunities, PBD, +many
- Synergy of astro-particle physics and collider physics, PBD, +many
- Studies of the Muon Excess in Cosmic Ray Air Showers, PBD, +many
- Forward Physics Facility, PBD, +many
- + others!

Whitepaper involvement

- Tau Neutrino Whitepaper (see Mary's talk next)

  Significant BNL contribution

- Forward Physics Facility Whitepaper (see Milind's talk later)
- Beyond the Standard Model effects on Neutrino Flavor

  Neutrino decay contribution

- Neutrino Self Interactions
- High-Energy and Ultra-High-Energy Neutrinos
- Ultra-High-Energy Cosmic Rays

  GRAND contribution

- + others!

Reach out if interested in contributing or signing!

Neutrino Decay

Since neutrinos have different masses, they decay

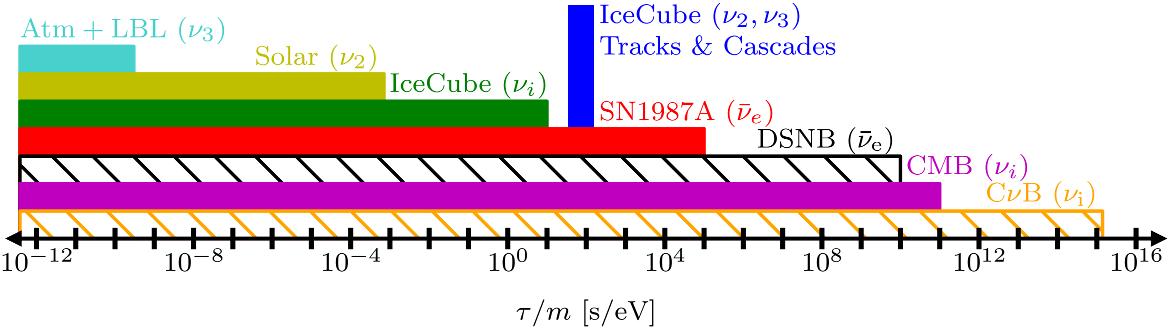
- Loop suppressed
- Long lifetime: $\tau \gtrsim 10^{35}$ years

Test this!

Typical Lagrangian for $\nu_i \to \nu_j + \phi$ with $m_i > m_j$

$$\mathcal{L} \supset \frac{g_{ij}}{2}\bar{\nu}_j\nu_i\phi + \frac{g'_{ij}}{2}\bar{\nu}_j i\gamma_5\nu_i\phi$$

Invisible ν Decay Constraints and Evidence



M. Gonzalez-Garcia and M. Maltoni 0802.3699

J. Berryman, A. de Gouvea, D. Hernandez 1411.0308

G. Pagliaroli, et al. 1506.02624

PBD, I. Tamborra 1805.05950

Kamiokande-II, PRL 58 1490 (1987)

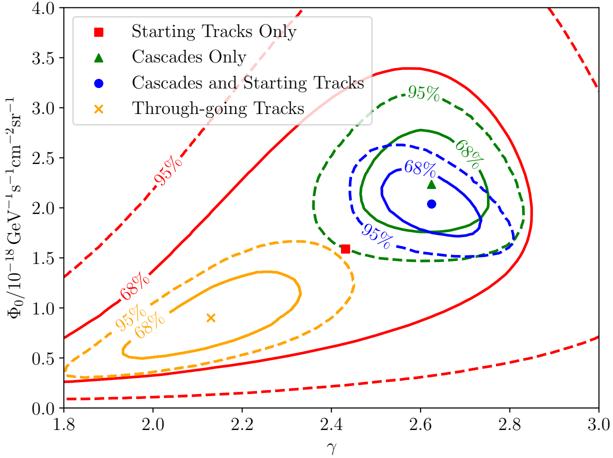
S. Ando hep-ph/0307169

S. Hannestad, G. Raffelt hep-ph/0509278

A. Long, C. Lunardini, E. Sabancila 1405.7654

Tension

$$\Phi(E) = \Phi_0 E^{-\gamma}$$



$$\boxed{\Delta\gamma = +0.54}$$

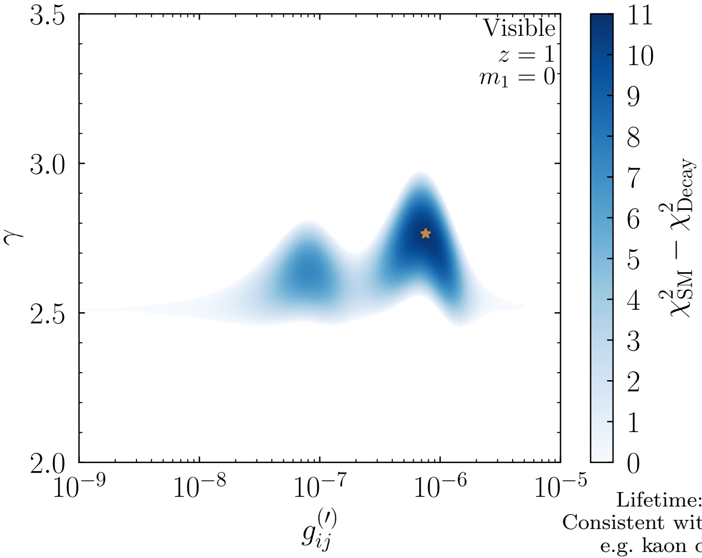
"The p-value for obtaining the combined fit result and the result reported here from an unbroken powerlaw flux is 3.3σ, and is therefore in significant **tension**."

IC 1607.08006

"This [cascade] fit [is] in **tension** with previous results based on through-going muons"

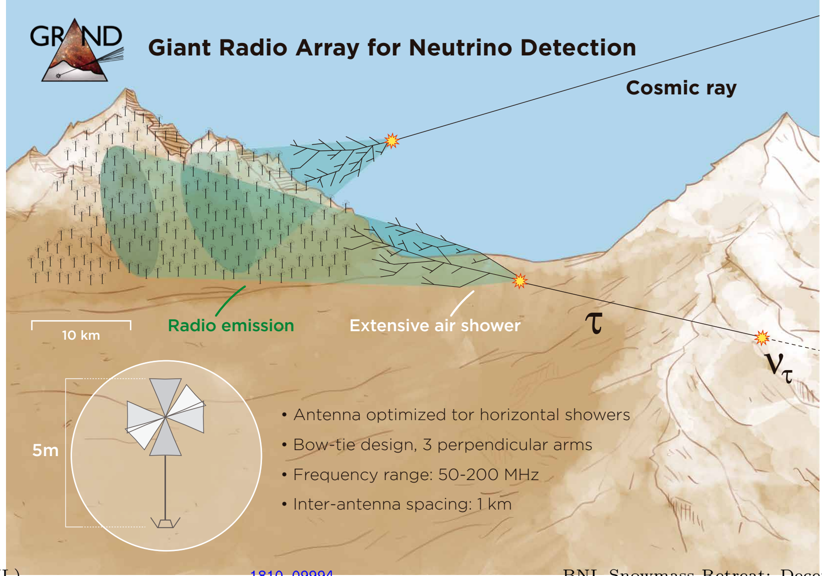
IC 1808.07629

Preferred Region: Visible



Lifetime: $\tau/m \sim 100$ s/eV
Consistent with lab constraints,
e.g. kaon decay at $g \sim 10^{-3}$

Giant Radio Array for Neutrino Detection (GRAND)



Ultra-High Energy Cosmic Rays (UHECRs)

- UHECRs with $E > 5 \times 10^{10}$ GeV detected for several decades

$\sqrt{s} > 300$ TeV

- Should be coming from nearby within ~ 50 Mpc

Greisen, Zatsepin, Kuzmin 1966

- Sources haven't been identified
- Magnetic fields are hard
- Composition is hard

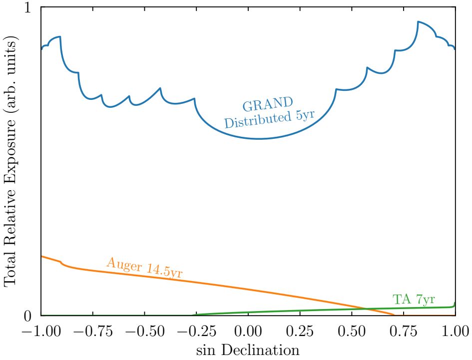
Protons are bent less, iron is bent more

Disagreement on both flux and composition
between Auger (Argentina) and Telescope Array (Utah)

GRAND will be a state-of-the-art UHECR experiment

- Fantastic exposure
- Good enough pointing
- Good enough composition measurements
- Full-sky coverage

Essential for understanding Auger-TA discrepancies



Preliminary arrays under construction

Self-triggering technique has already been validated!

Conclusions

- Lots of Snowmass participation in neutrino and astroparticle theory at BNL
- Neutrino decay is a rich BSM scenario with a possible hint at IceCube
- Upcoming high energy neutrino experiments can also do cosmic ray physics

Need more UHECR studies!

Backups

Why IceCube for Neutrino Decay

- DSNB and CνB are still some time off
- The next galactic supernova could come tomorrow, or in fifty years
- If ν_1 is stable SN1987A isn't too relevant (25 events + theory uncertainties)
  - Mass ordering looks to be normal at $\sim 3 - 3.5\ \sigma$

    Less now: PBD, J. Gehrlein, R. Pestes 2008.01110
  - Texture in the $\nu - \phi$ mixing matrix
- Early universe constraints mostly constrain the typical decay diagram

  G. Dvali and L. Funcke 1602.03191

  M. Escudero and M. Fairbairn 1907.05425
- IceCube measures **all three flavors** over > 1 decade in energy
- Astrophysical uncertainties seem like a problem, aren't really

Uncertainties

or "How to muck it all up with astrophysics"

What doesn't work:

- Multiple classes of sources with different spectra
- pp vs. $p\gamma$ sources
- Different redshift evolution $\Rightarrow$ shift the g_{ij}
- Neutron decay sources
- Varying the oscillation parameters
- IceCube track or cascade normalization

What could work: (other than neutrino decay)

- Muon damped $\Rightarrow \Delta\gamma \sim +0.2$
- Track and cascade spectra are fit over slightly different energy ranges $\Rightarrow$ broken power law can help
- Energy misreconstruction (tracks could be susceptible to this)
- Dark matter?