Distinguishing flavors of astrophysical neutrinos

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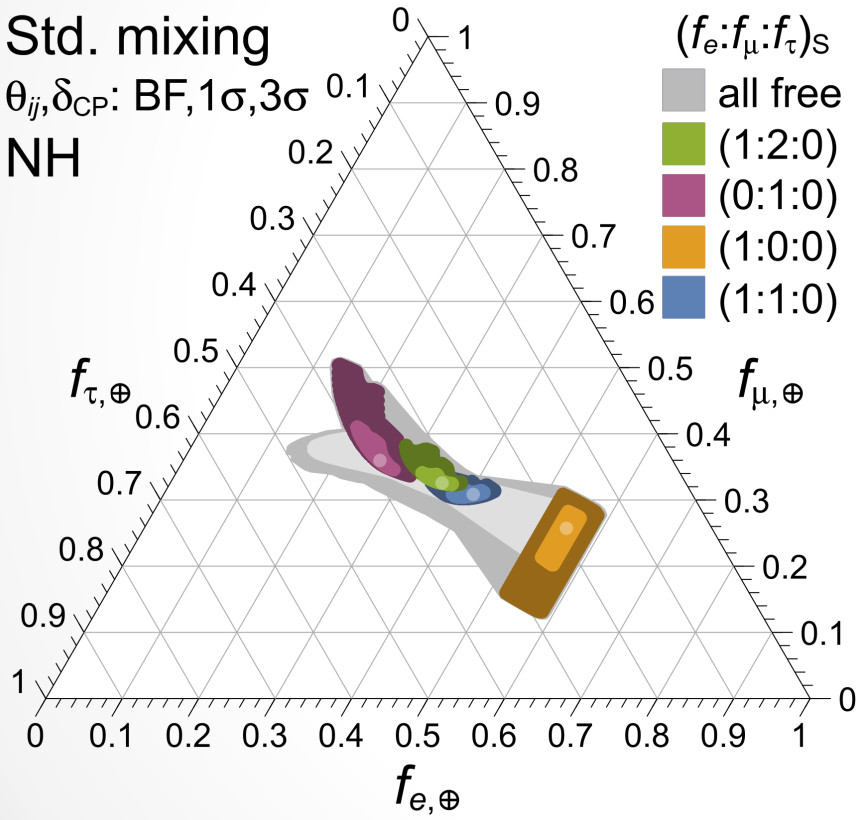
IPA 2017, Madison

Observable – flavor composition

What can we learn from flavor composition?

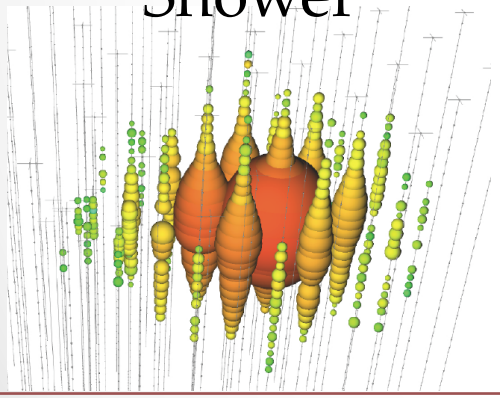
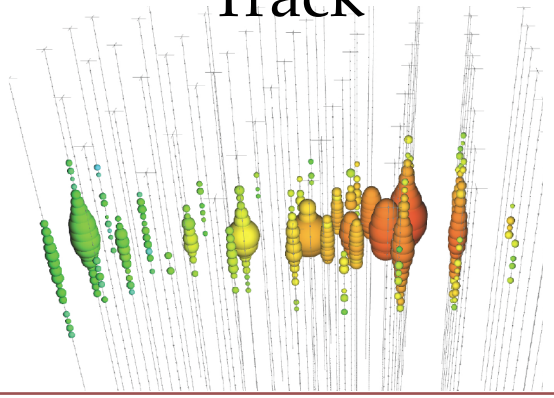
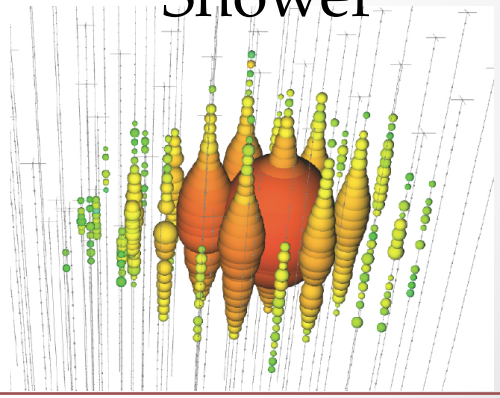


Bustamante *et al.*, PRL 2015

- $(f_e : f_\mu : f_\tau) =$ $(\phi_e : \phi_\mu : \phi_\tau) \,/\, \phi_{\text{total}}$
- Region with standard mixing is small
- Outside → new physics

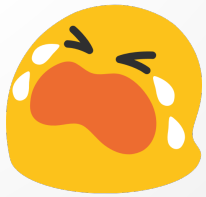
We can learn quite a bit!

How do we measure flavors?

ν_e	ν_μ	ν_τ
$\nu_e + N \rightarrow e^- + \text{hadrons}$	$\nu_\mu + N \rightarrow \mu^- + \text{hadrons}$	$\nu_\tau + N \rightarrow \tau^- + \text{hadrons}$ $\tau \rightarrow \begin{cases} e^- + \nu + \nu \ (18\%) \\ \mu^- + \nu + \nu \ (17\%) \\ \text{hadrons} \ (65\%) \end{cases}$
Shower 	Track 	Shower 

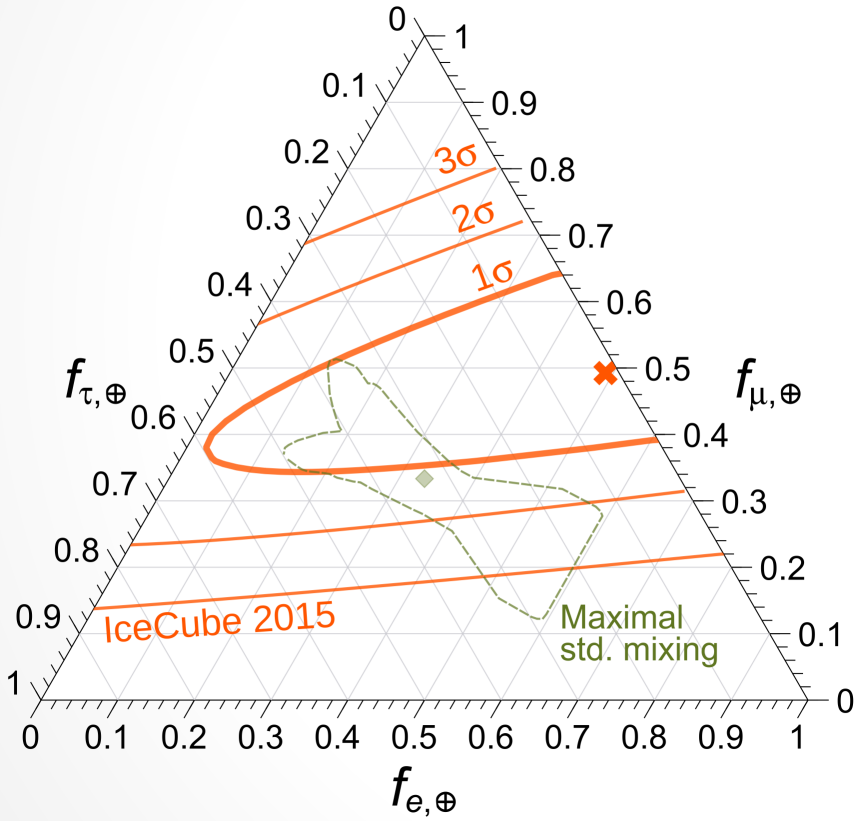
icecube.wisc.edu

ν_e and ν_τ look the same



How well does it work?

Current IceCube sensitivity



- Vertical size: statistics
- Horizontal size: ν_e and ν_τ separation

Bustamante *et al.*, PRL 2015
IceCube, ApJ 2015

We need to break this $\nu_e - \nu_\tau$ degeneracy

The crucial difference

ν_e CC showers are more electromagnetic

ν_τ CC showers are more hadronic

Charged-current:

$$\nu_e + N \rightarrow e^- + \text{hadrons}$$

$$\nu_\tau + N \rightarrow \tau^- + \text{hadrons}, \ \tau \rightarrow \begin{cases} e^- + \bar{\nu}_e + \nu_\tau \ \text{(BR 18\%)} \\ \text{hadrons} \ \text{(BR 65\%)} \end{cases}$$

Neutral-current:

$$\nu_l + N \rightarrow \nu_l + \text{hadrons}$$

It's all about E.M. vs. hadronic showers

New shower observables

Collective light from thousands of interactions

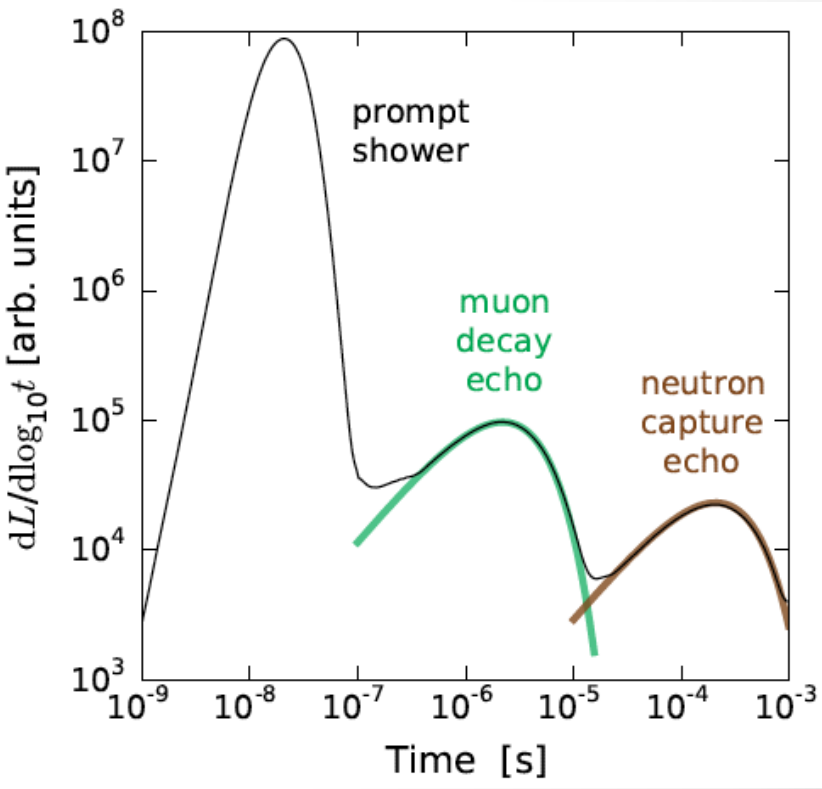
Muon echo:

π^+ at rest $\xrightarrow{\text{decay}}$ μ^+ $\xrightarrow{\text{decay}}$ e^+

Neutron echo:

n at rest $\xrightarrow{\text{capture on H}}$ 2.2 MeV γ

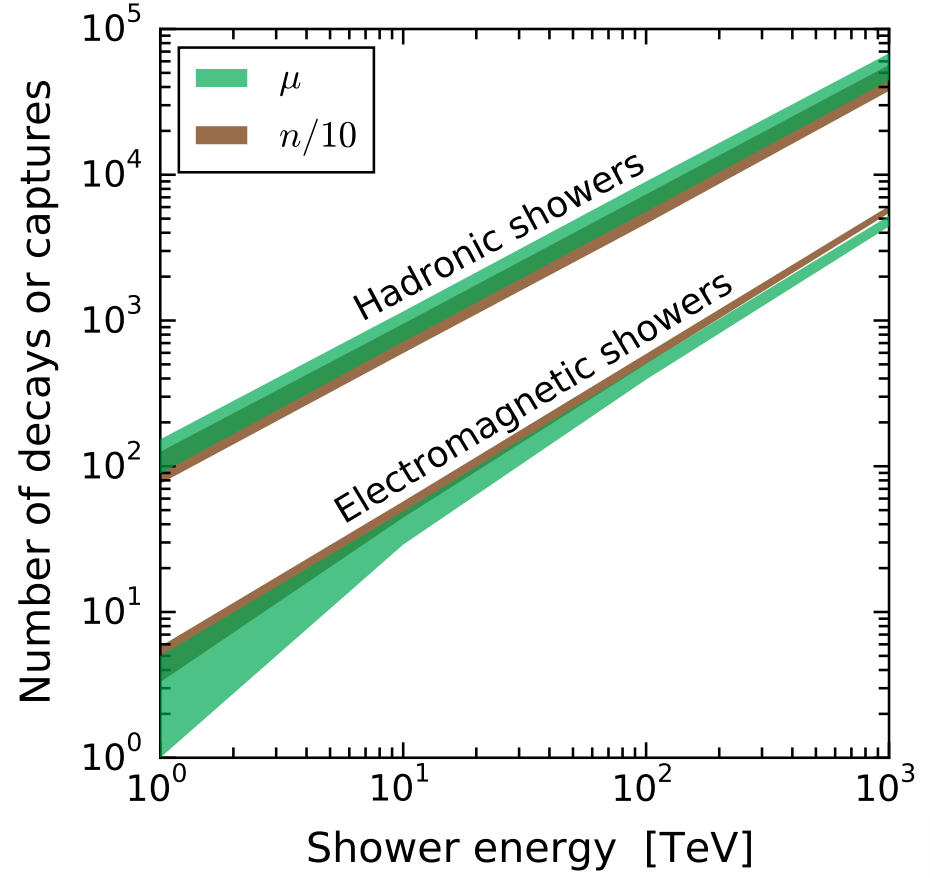
100 TeV shower



Li, Bustamante, and Beacom, 2016
Submitted to PRL

E.M. v.s. hadronic showers

Echo intensities in E.M. and hadronic showers

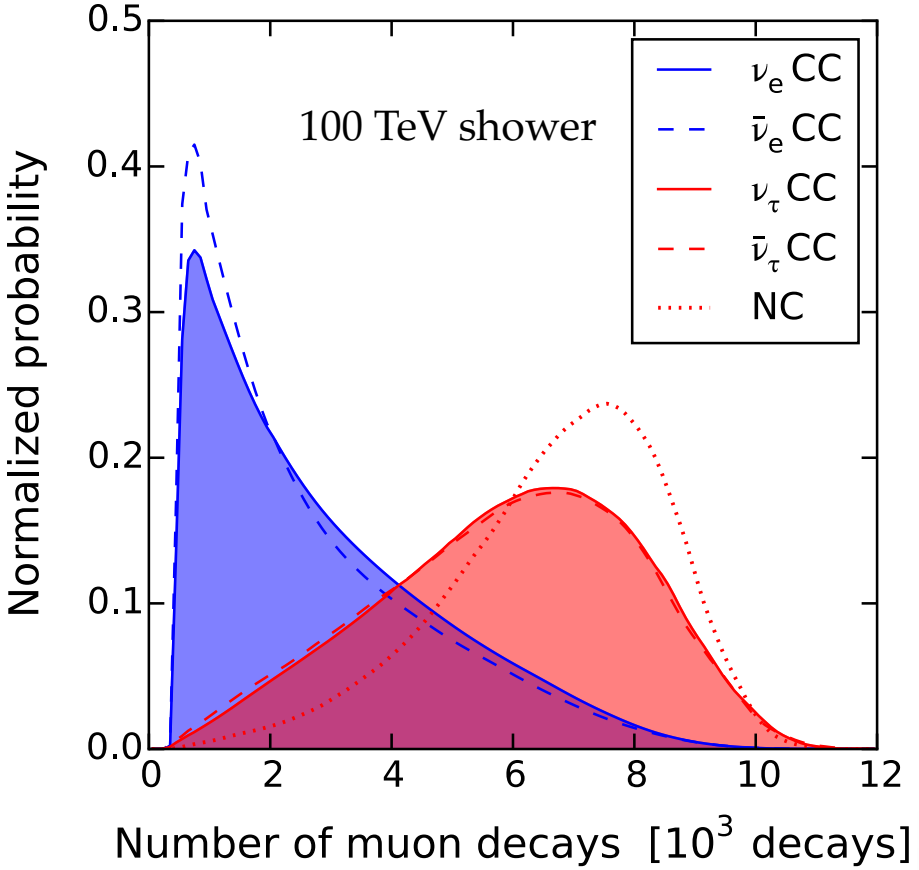


Li, Bustamante, and Beacom, 2016

Echoes are stronger in hadronic showers

Discriminating ν_e and ν_τ

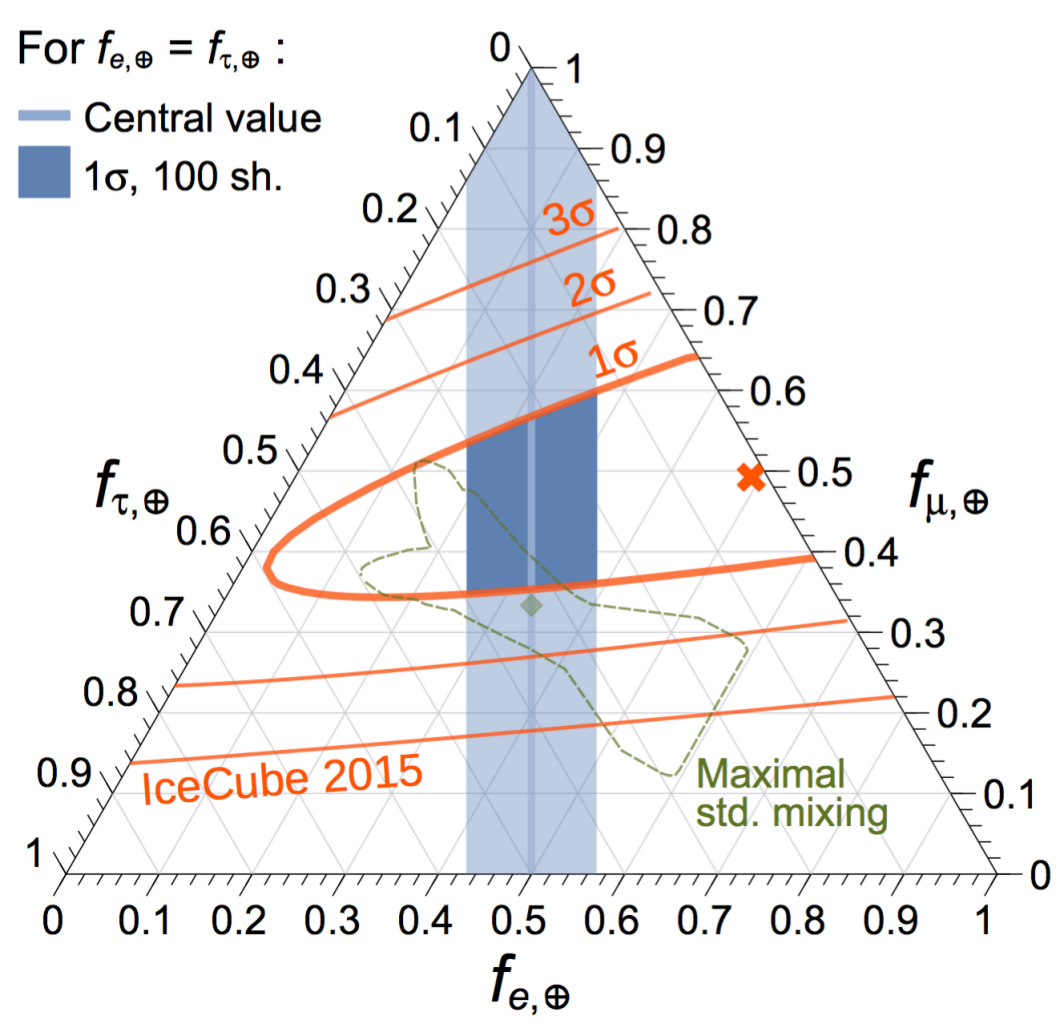
Echo intensities in neutrino-induced showers



Li, Bustamante, and Beacom, 2016

Echoes are stronger in ν_τ showers

Predicted sensitivity



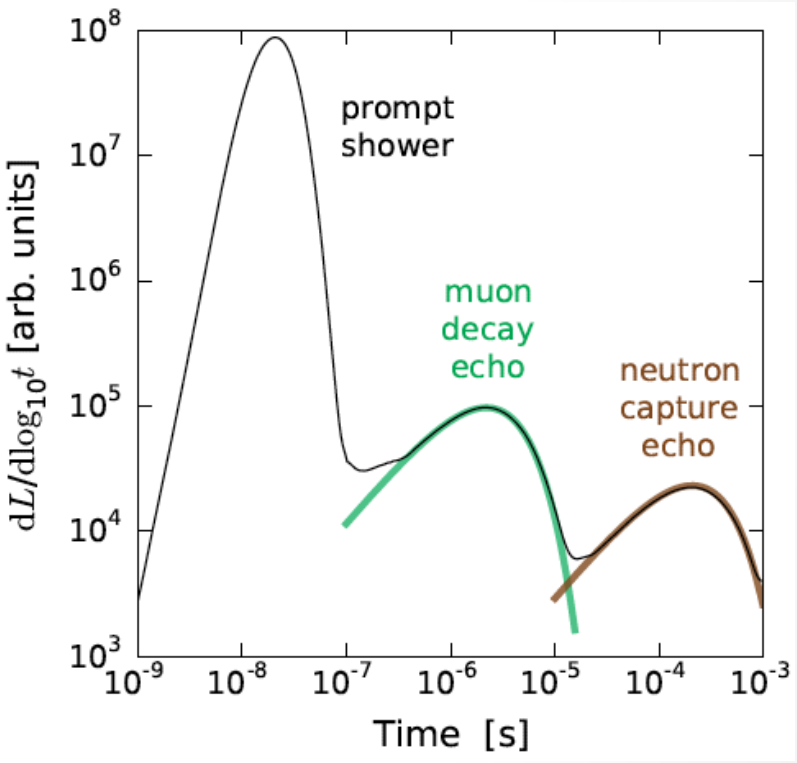
Li, Bustamante, and Beacom, 2016

Caveat – detectability

Potential concerns

- Trigger threshold
- Afterpulse
- Light scattering

Li, Bustamante,
and Beacom, 2016



It looks promising, but work is needed

IceCube is implementing it!

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Li, Bustamante,
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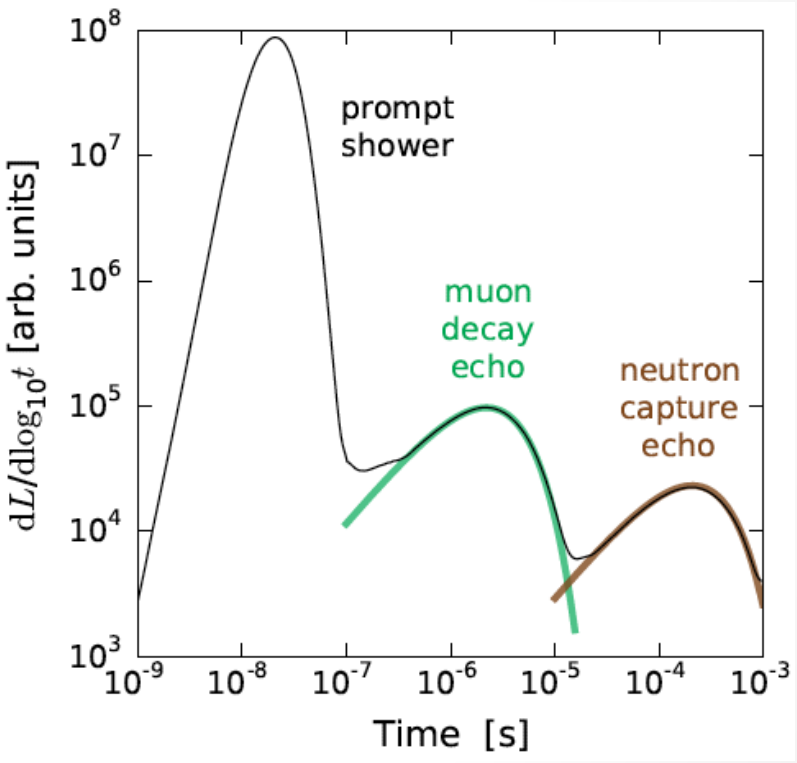

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Conclusions

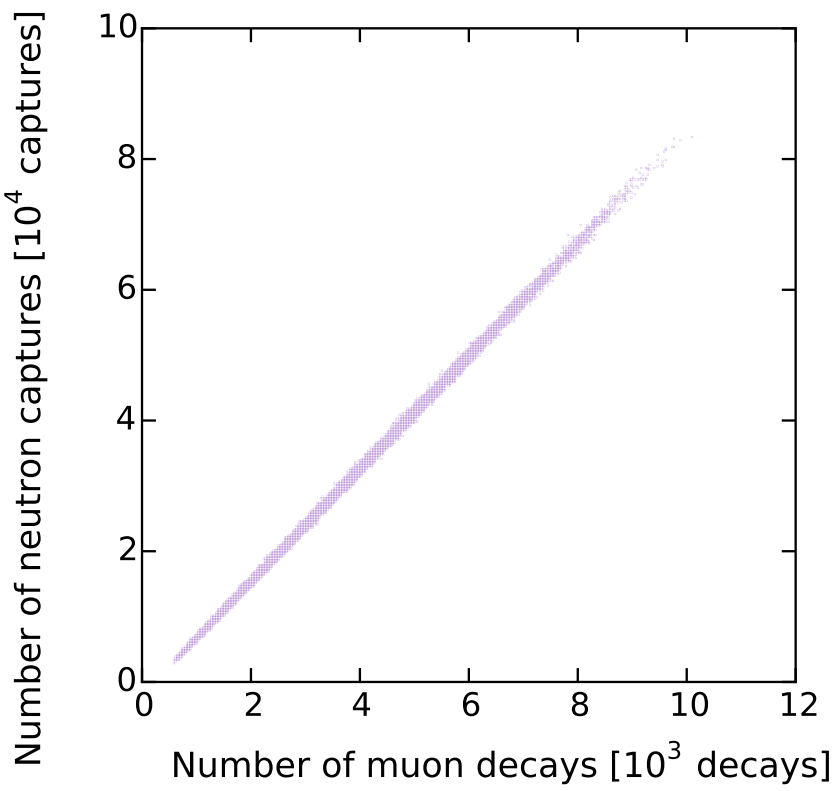
- The flavor composition of astrophysical neutrinos is a rich observable
- The light, or *echo*, from muon decays and neutron captures can distinguish between electromagnetic and hadronic showers
- They are stronger in ν_τ-initiated showers than ν_e-initiated showers
- Great physics potential worth going after

Thank you!

Back up

Correlation between echoes

Muon and neutron echo intensity correlation



Extremely tight correlation on an event-by-event basis

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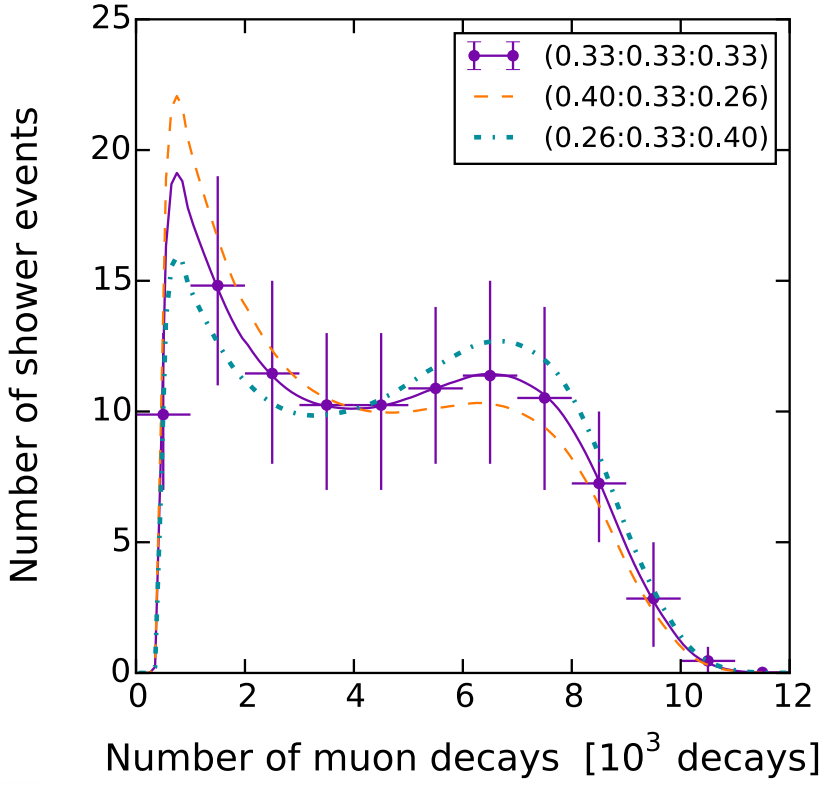
repetitive information

Li, Bustamante, and Beacom, 2016

We only need to detect one of the echoes

Investigating sensitivity

The muon decay distribution for all flavors



Li, Bustamante, and Beacom, 2016

Equal ratio makes the distribution flat