



# Distinguishing neutrino flavors in high-energy showers



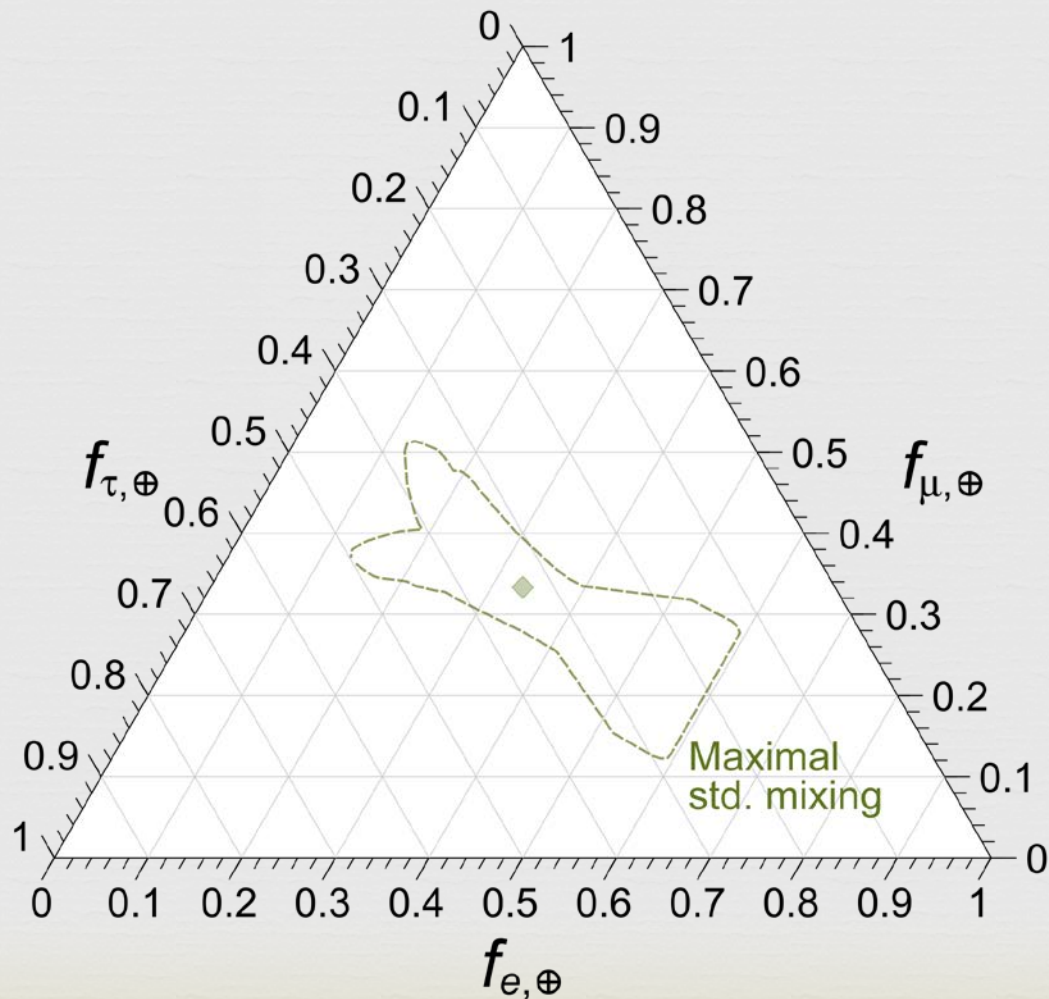
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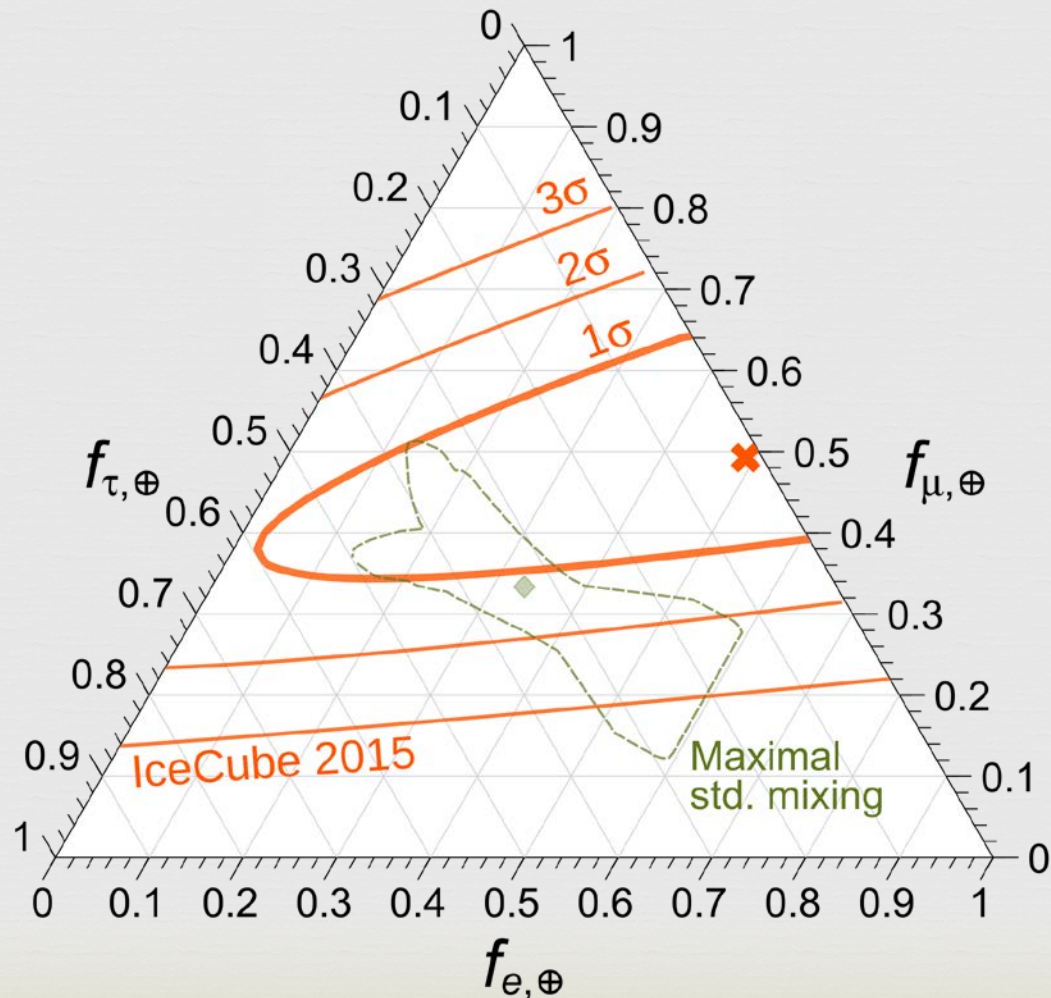
# Flavor composition: a rich observable



Bustamante *et al.* 2015



# Flavor composition: not enough sensitivity



Bustamante *et al.* 2015  
Aartsen *et al.* 2015

# Track and showers



$\nu_e$

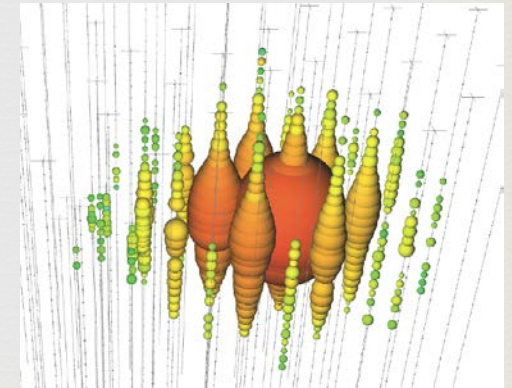
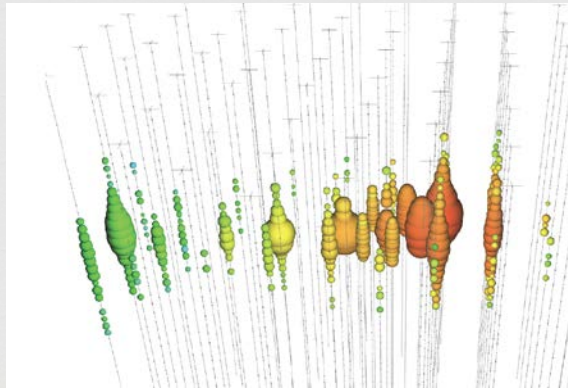
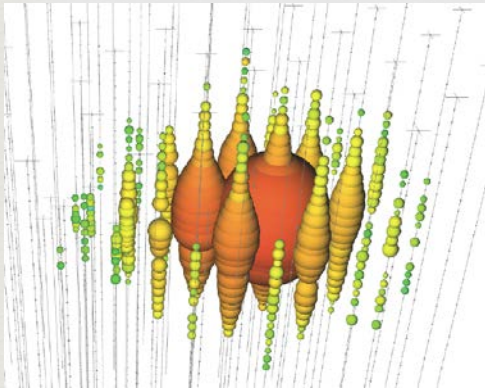
$\nu_\mu$

$\nu_\tau$

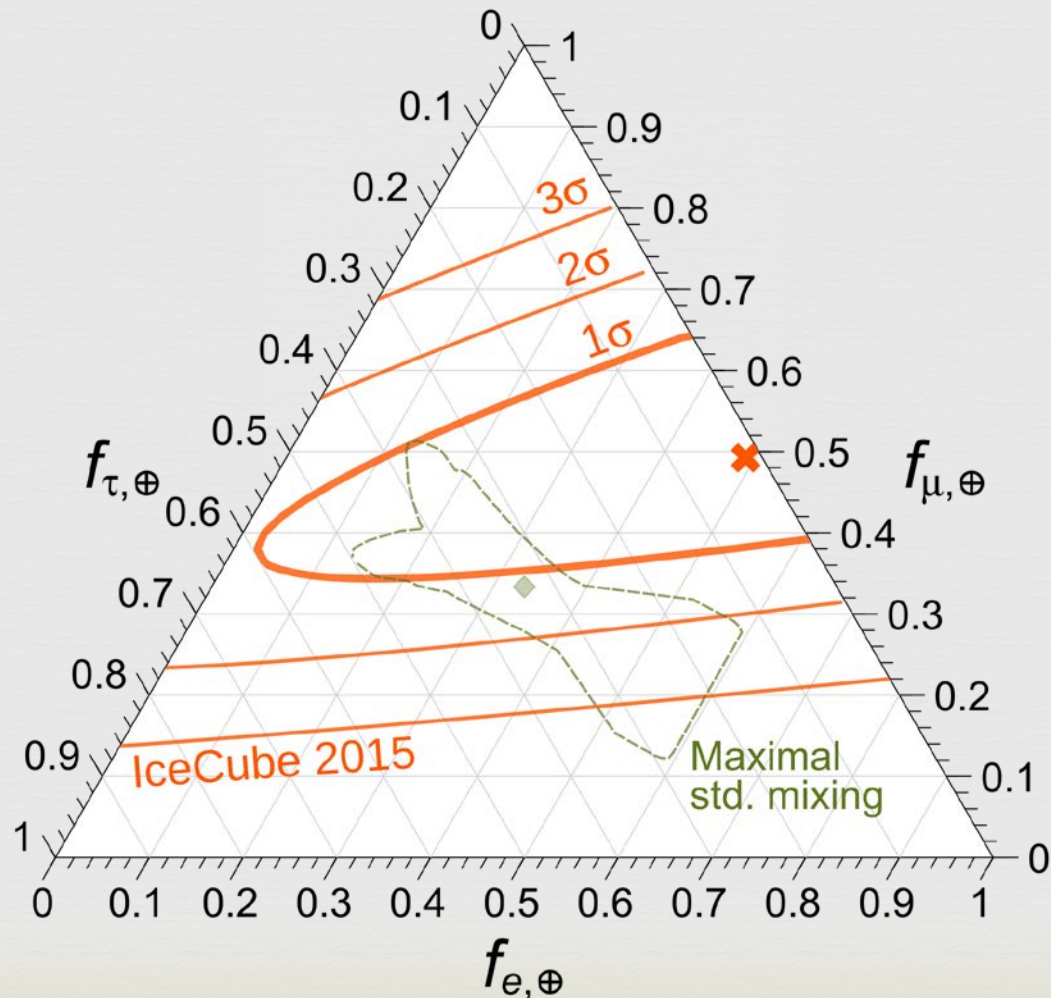
$$\nu_e + N \rightarrow e^- + \text{hadrons}$$

$$\nu_\mu + N \rightarrow \mu^- + \text{hadrons}$$

$$\nu_\tau + N \rightarrow \tau^- + \text{hadrons}$$
$$\tau \rightarrow \begin{cases} e^- + \nu + \nu & (18\%) \\ \mu^- + \nu + \nu & (17\%) \\ \text{hadrons} & (65\%) \end{cases}$$



# The problem: $\nu_e$ and $\nu_\tau$ look the same!



Bustamante *et al.* 2015  
Aartsen *et al.* 2015

# There is a crucial difference between the two channels



$\nu_e$  CC showers are more electromagnetic

$\nu_\tau$  CC showers are more hadronic

Charged-current:

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

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

Neutral-current:

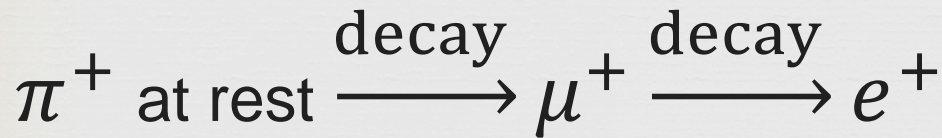
$$\nu_l + N \rightarrow \nu_l + \text{hadrons}$$



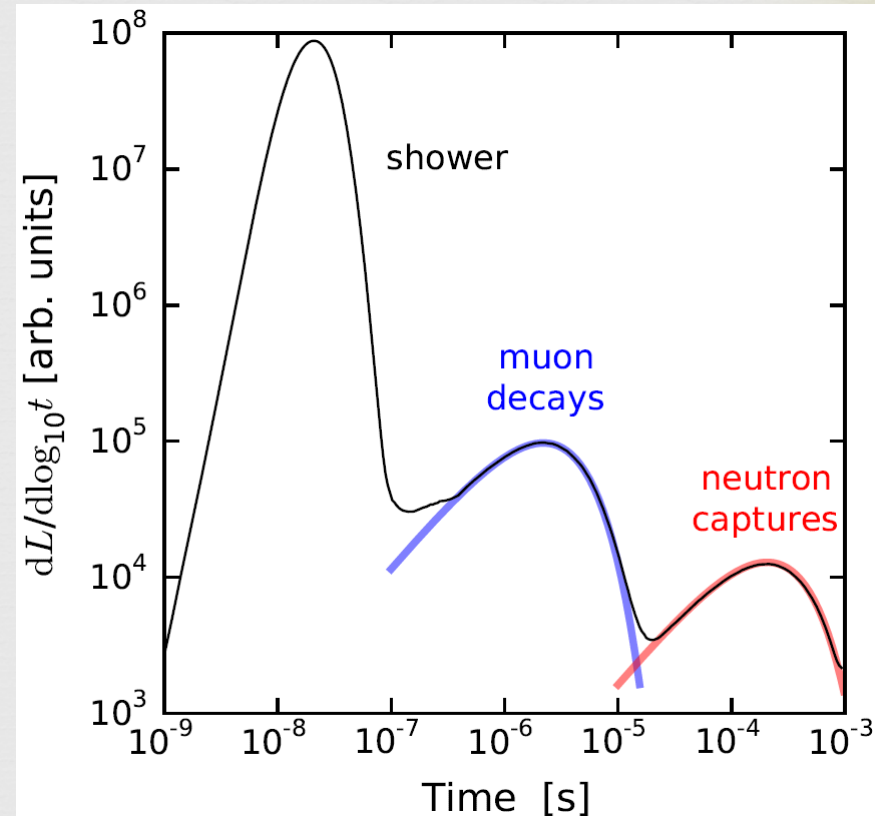
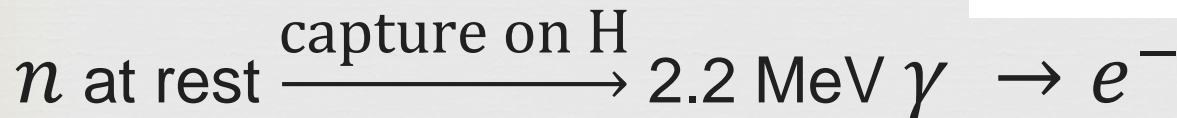
# New shower observables



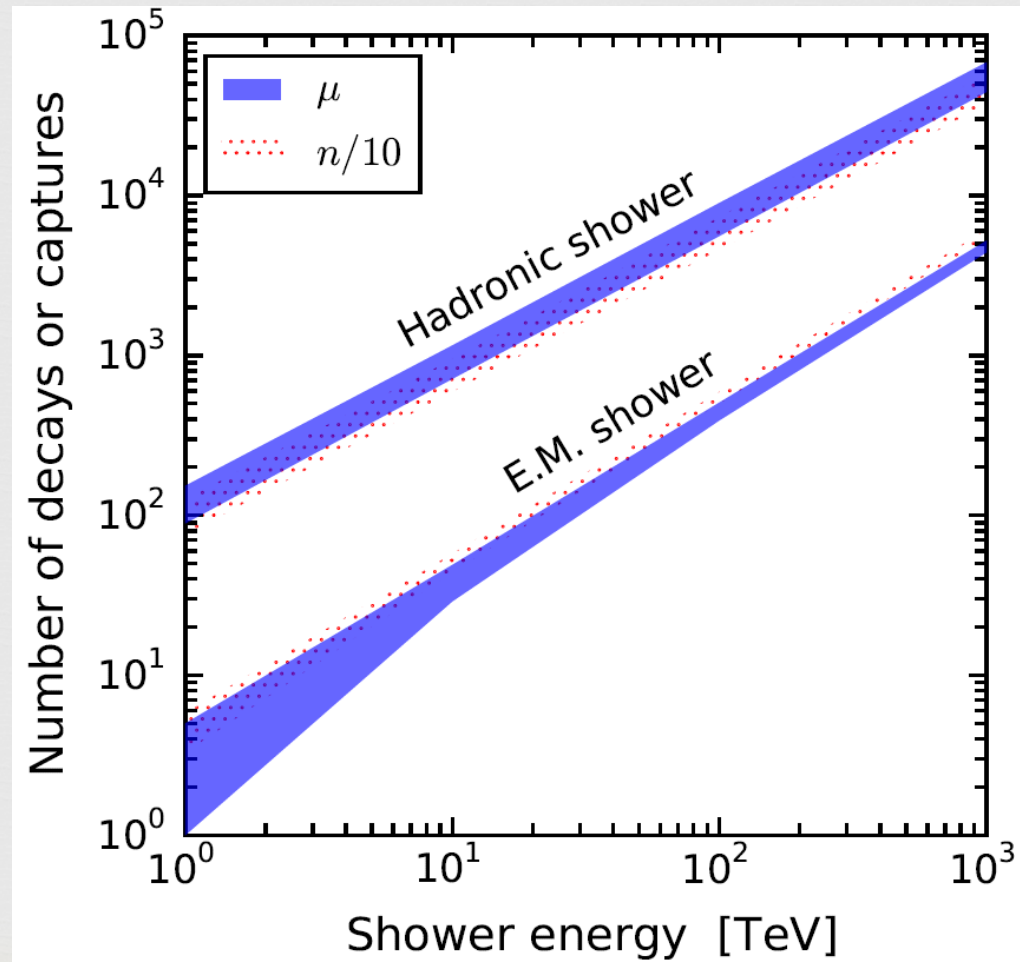
Muon echo:



Neutron echo:



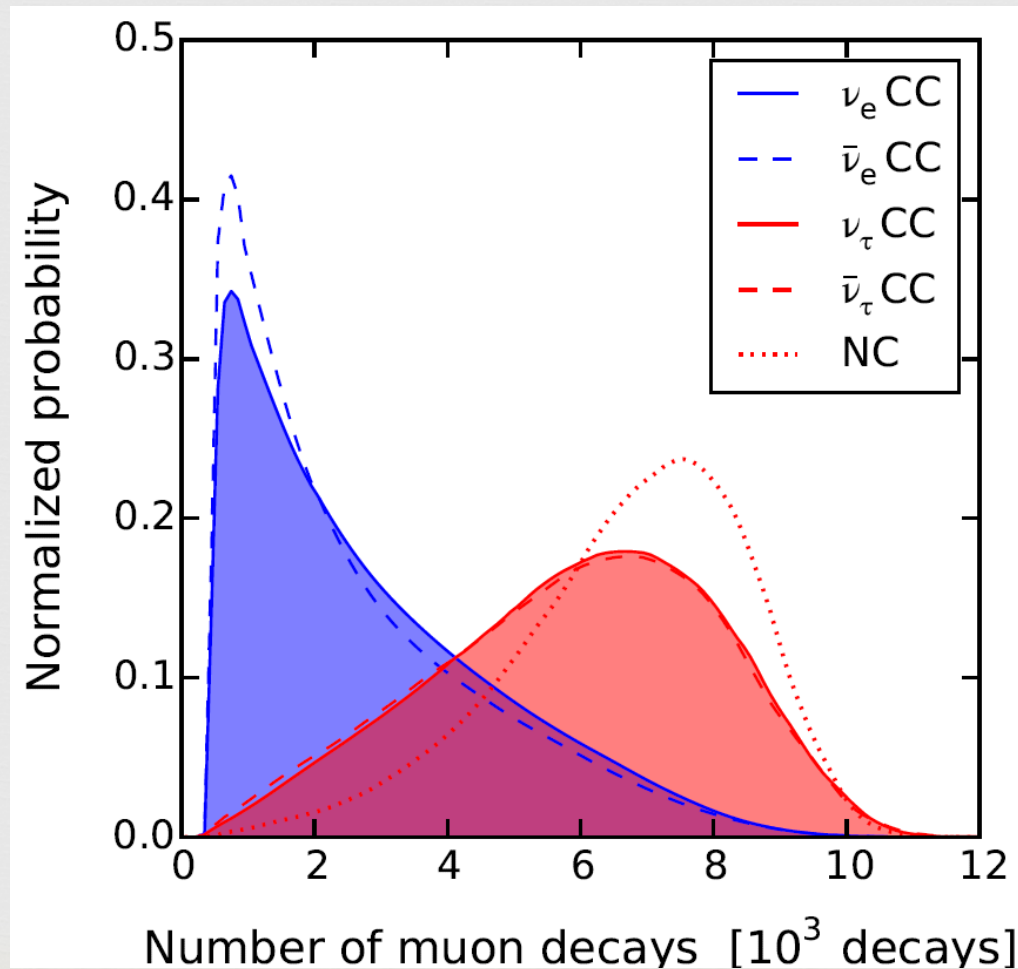
# Echoes are stronger in hadronic showers



Li, Bustamante, and Beacom, In prep



# Echoes are stronger in $\nu_\tau$ showers

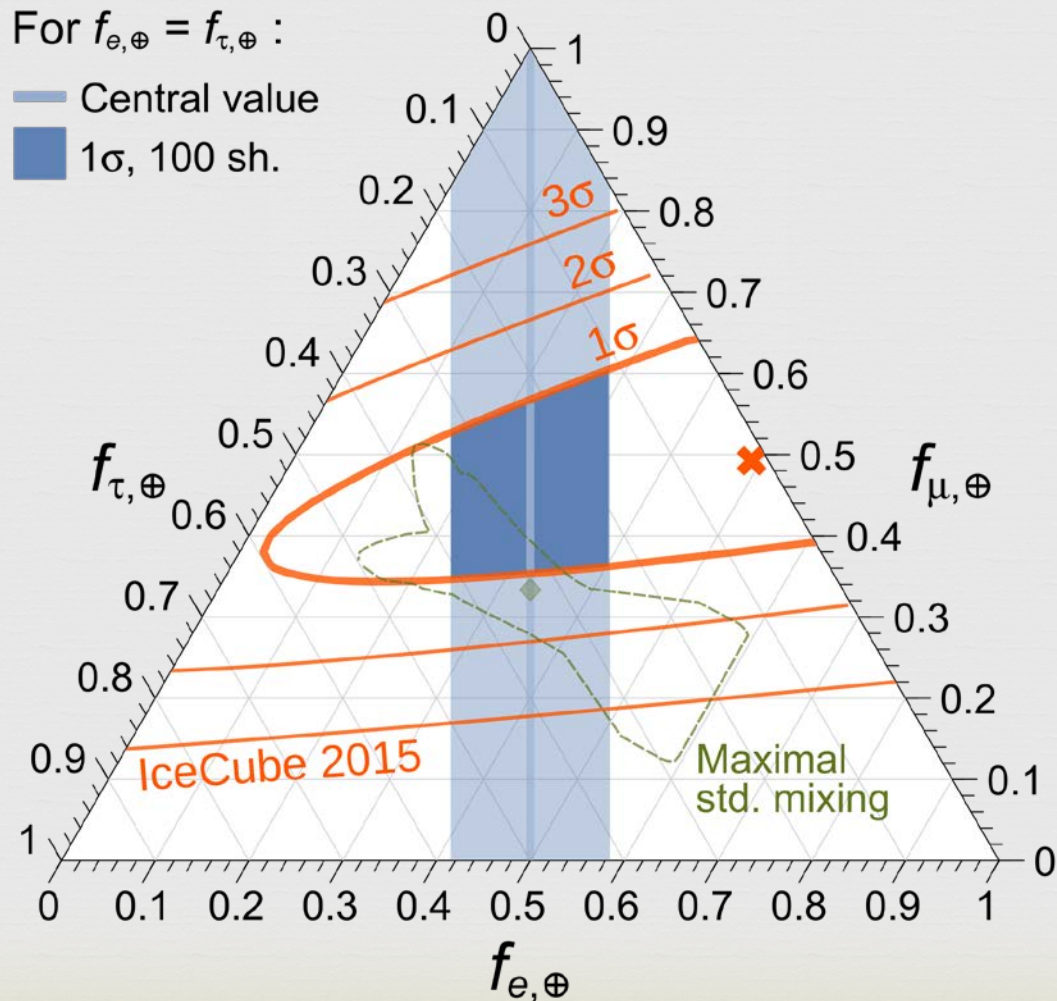


Li, Bustamante, and  
Beacom, In prep

IF

we can detect the echoes with  
100% efficiency...

# Predicted sensitivity



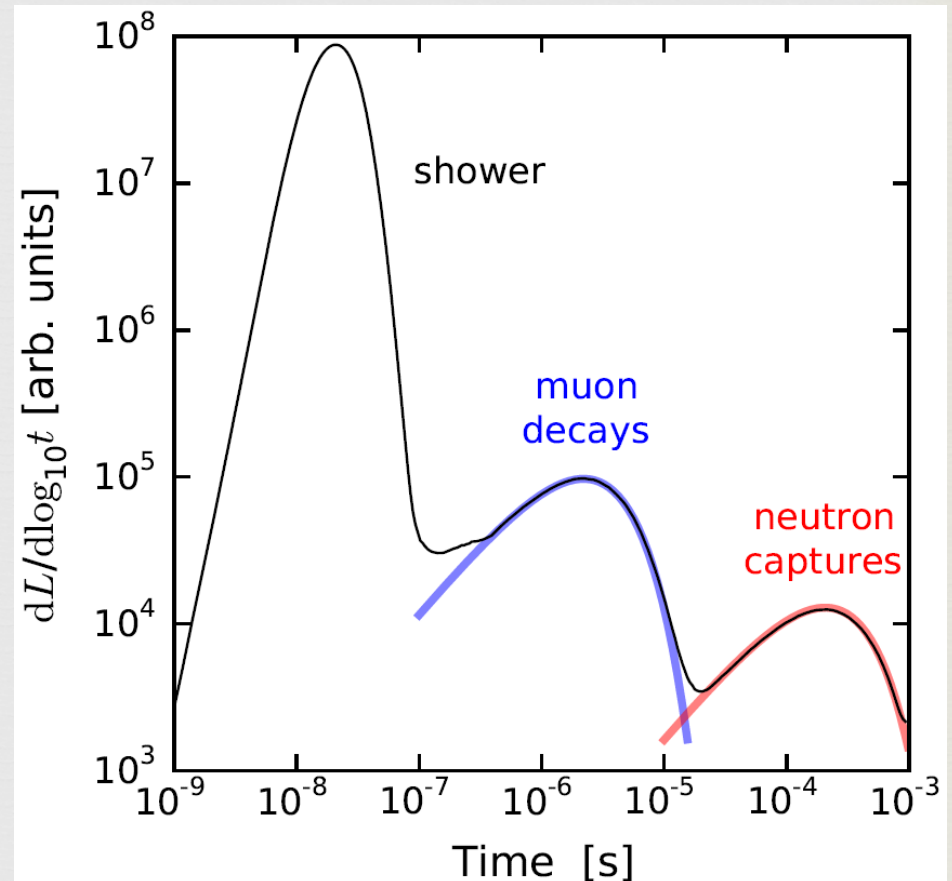
Li, Bustamante, and Beacom, In prep



# Caveats - detectability



- Trigger threshold
- Afterpulsing
- Light scattering



# Conclusions



- The light, or *echo*, from muon decays and neutron captures can distinguish between electromagnetic and hadronic showers
- They are stronger in  $\nu_\tau$ -initiated showers than  $\nu_e$ -initiated
- Great physics potential worth going after