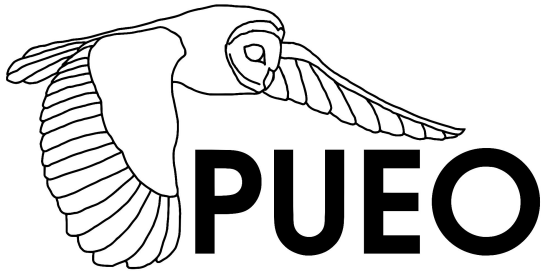
Prospects for UHE Neutrino Flavor Measurements with PUEO

Christoph Welling, Austin Cummings & Rachel Scrandis
for the PUEO Collaboration



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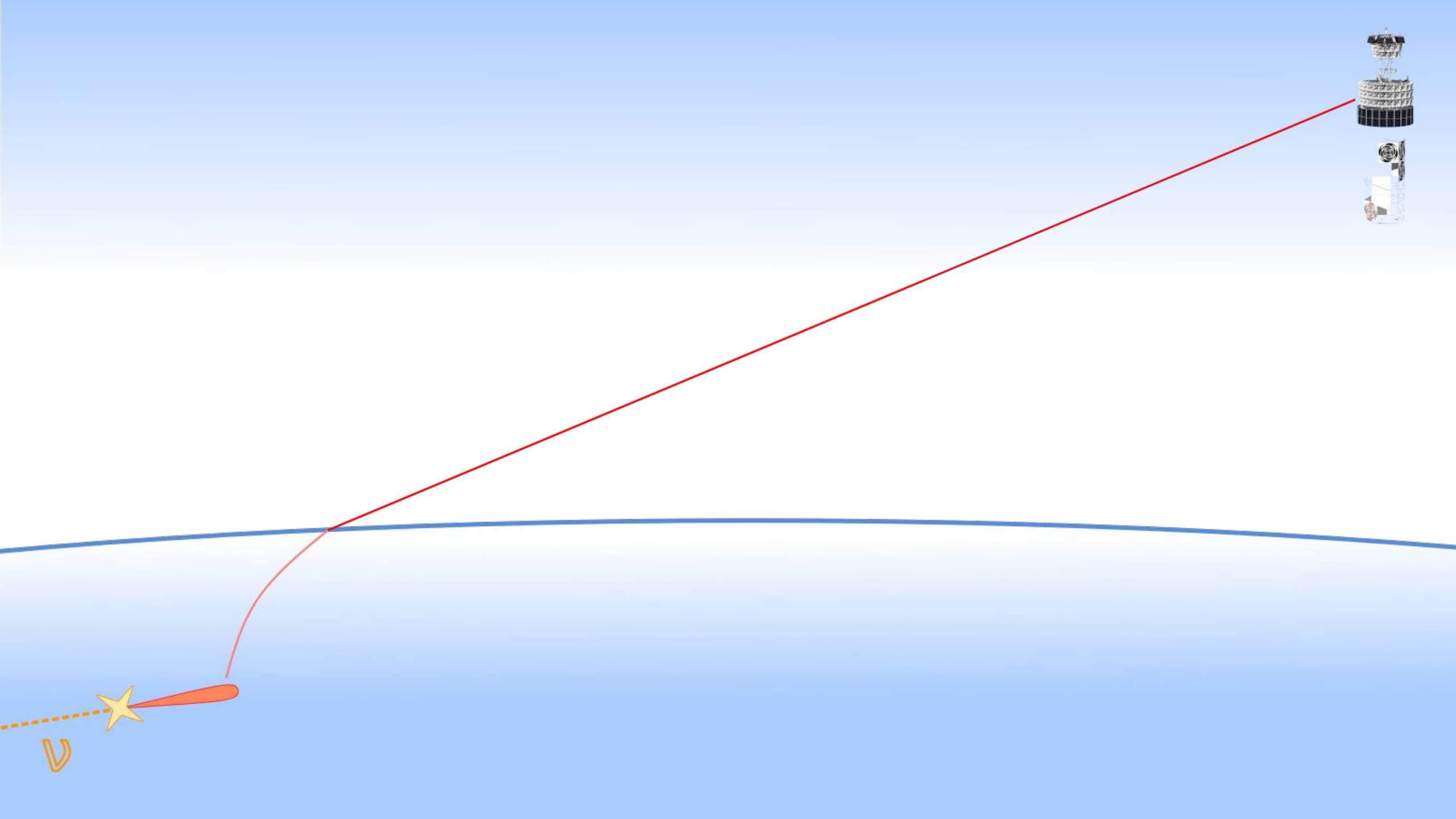
Payload for Ultrahigh Energy Observations

- Search for RF signals from Askaryan effect
- Targeting neutrinos above ~1EeV
- NASA long duration balloon
- Launching from McMurdo
- On track to launch in ~1 month!


V

Building on ANITA

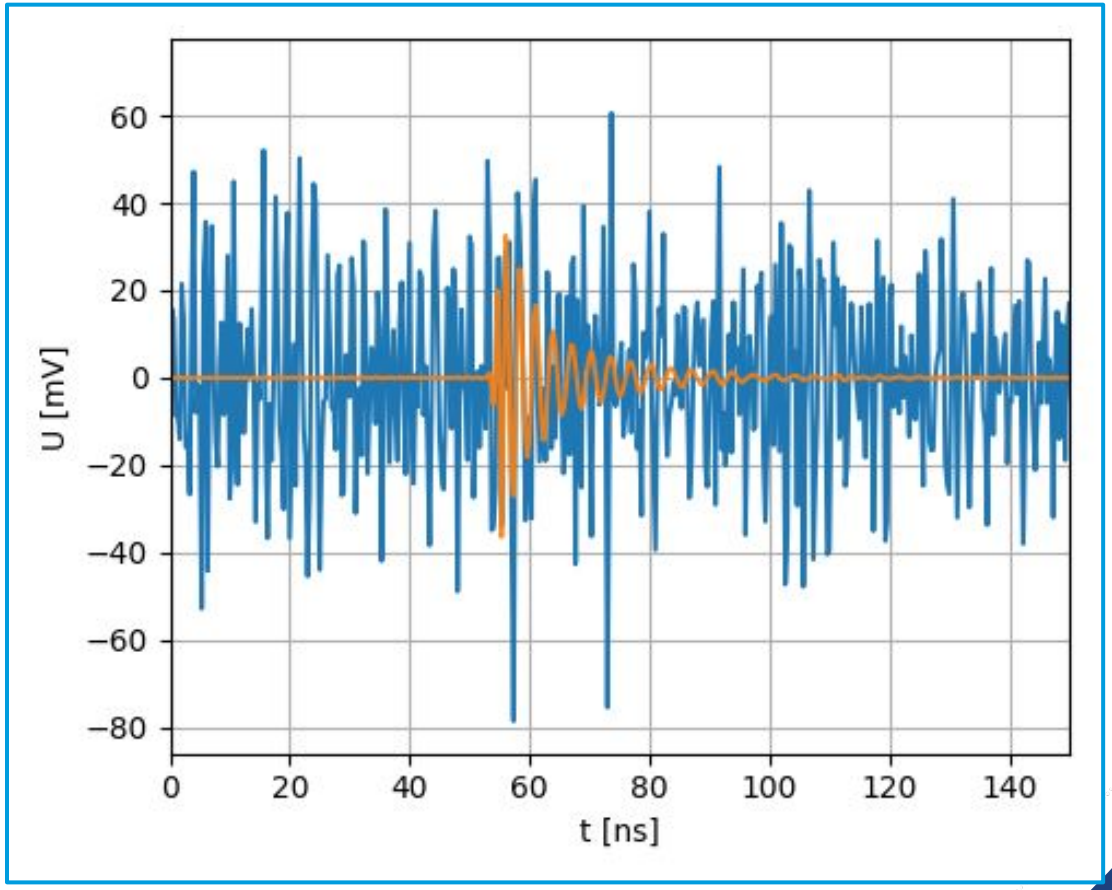
- Higher frequency band (300-1400MHz)
- Doubled antenna count to 96
- Drop-down low-frequency instrument
- Radio-frequency system on chip (RFSoC)
- Interferometric trigger

PUEO

ANITA IV

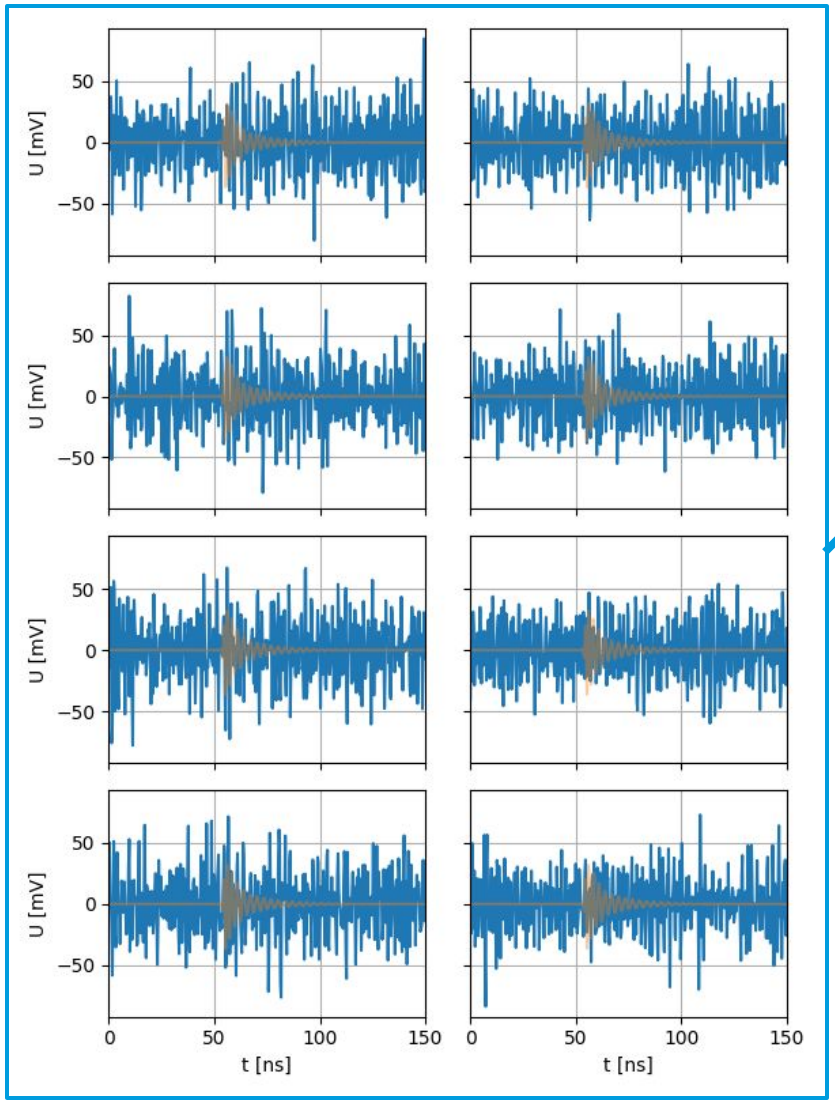
Interferometric Trigger

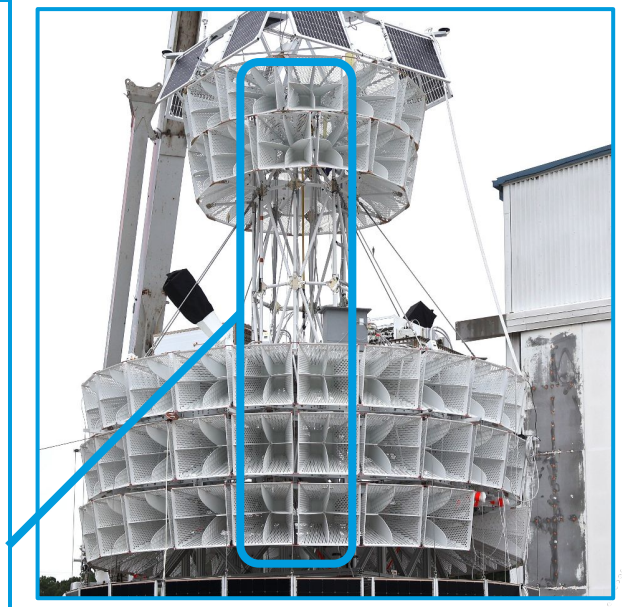
- Looking for very faint signals



Interferometric Trigger

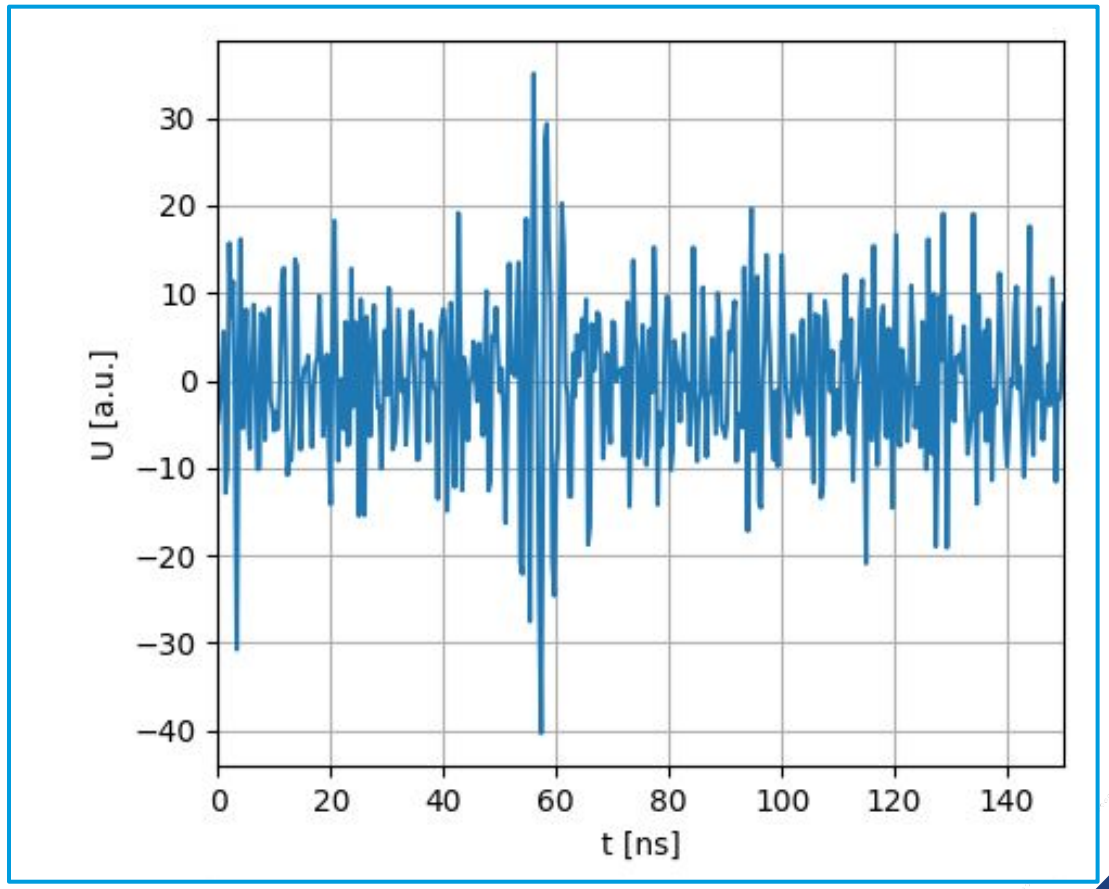
- Looking for very faint signals
- Beamforming signals from 8 antennas





Interferometric Trigger

- Looking for very faint signals
- Beamforming signals from 8 antennas
- Coherent sum improves SNR by sqrt(N)≈ 2.8



Interferometric Trigger

- Looking for very faint signals
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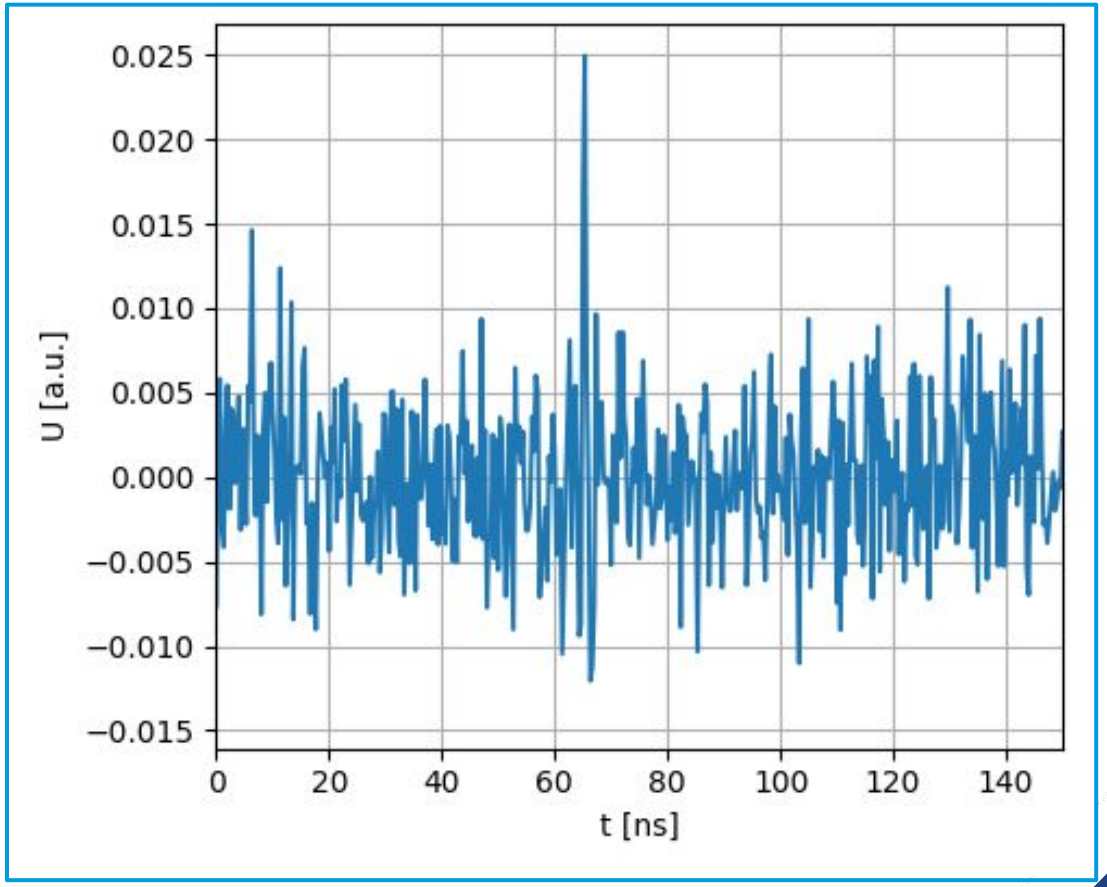
- Coherent sum improves SNR by sqrt(N)≈ 2.8
- Dedispersion



Interferometric Trigger

- Looking for very faint signals
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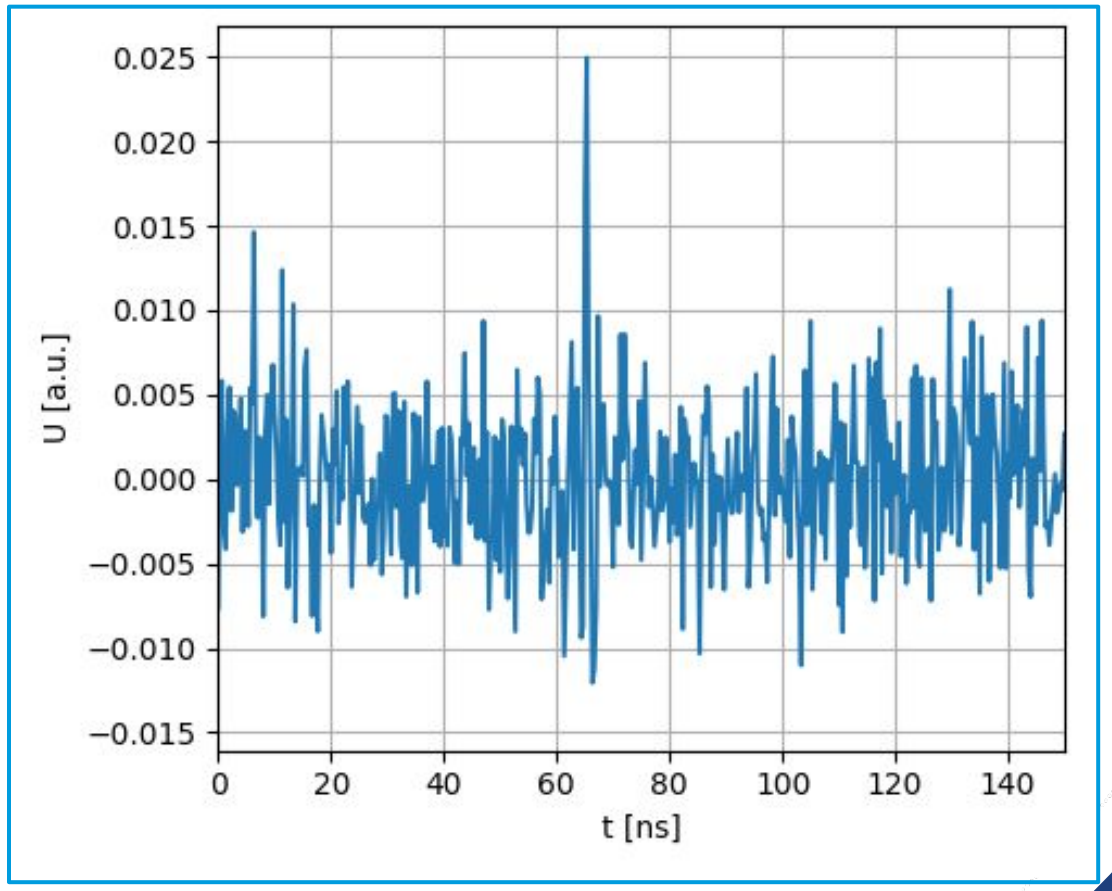
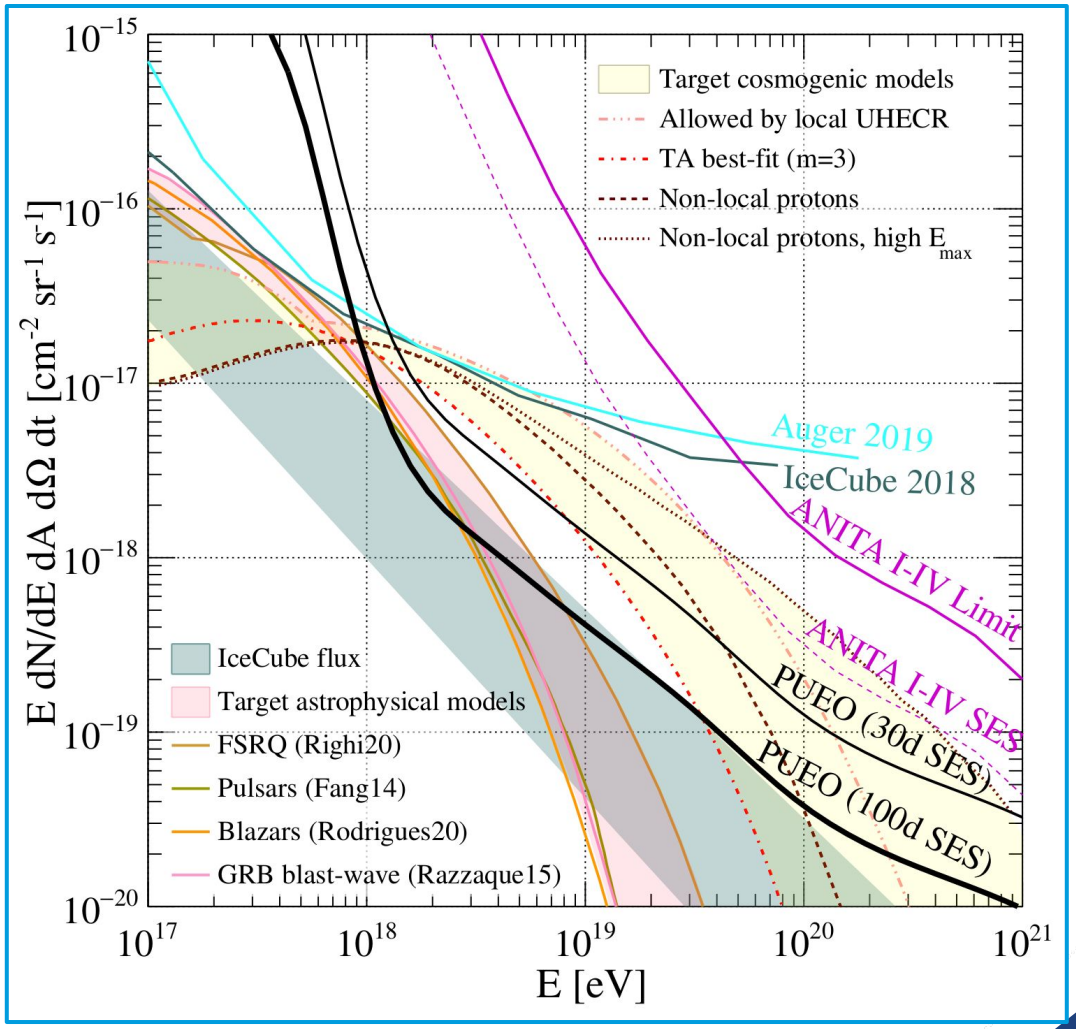
- Dedispersion
- Coincidence between neighboring antenna sets



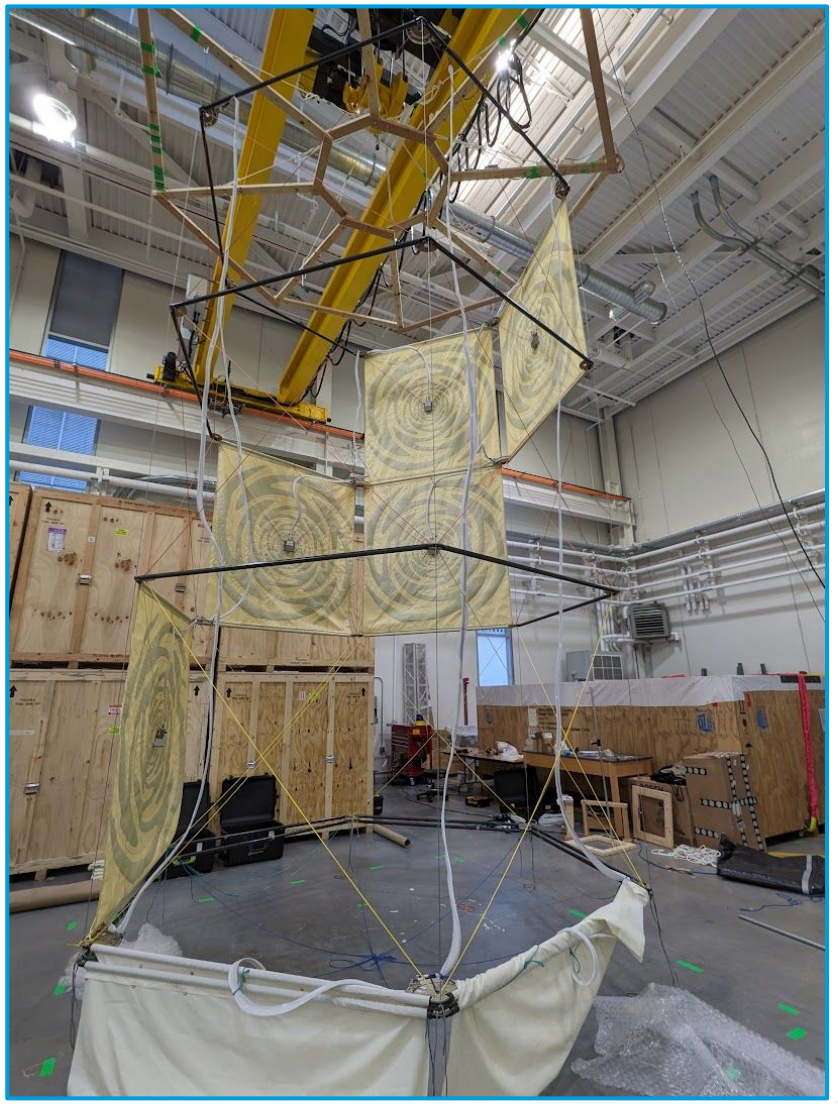
Interferometric Trigger

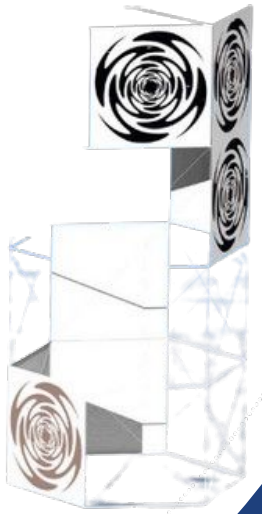
- Looking for very faint signals
- Beamforming signals from 8 antennas
- Coherent sum improves SNR by sqrt(N)≈ 2.8
- Dedispersion
- Coincidence between neighboring antenna sets
- Large improvement in sensitivity and energy threshold over ANITA



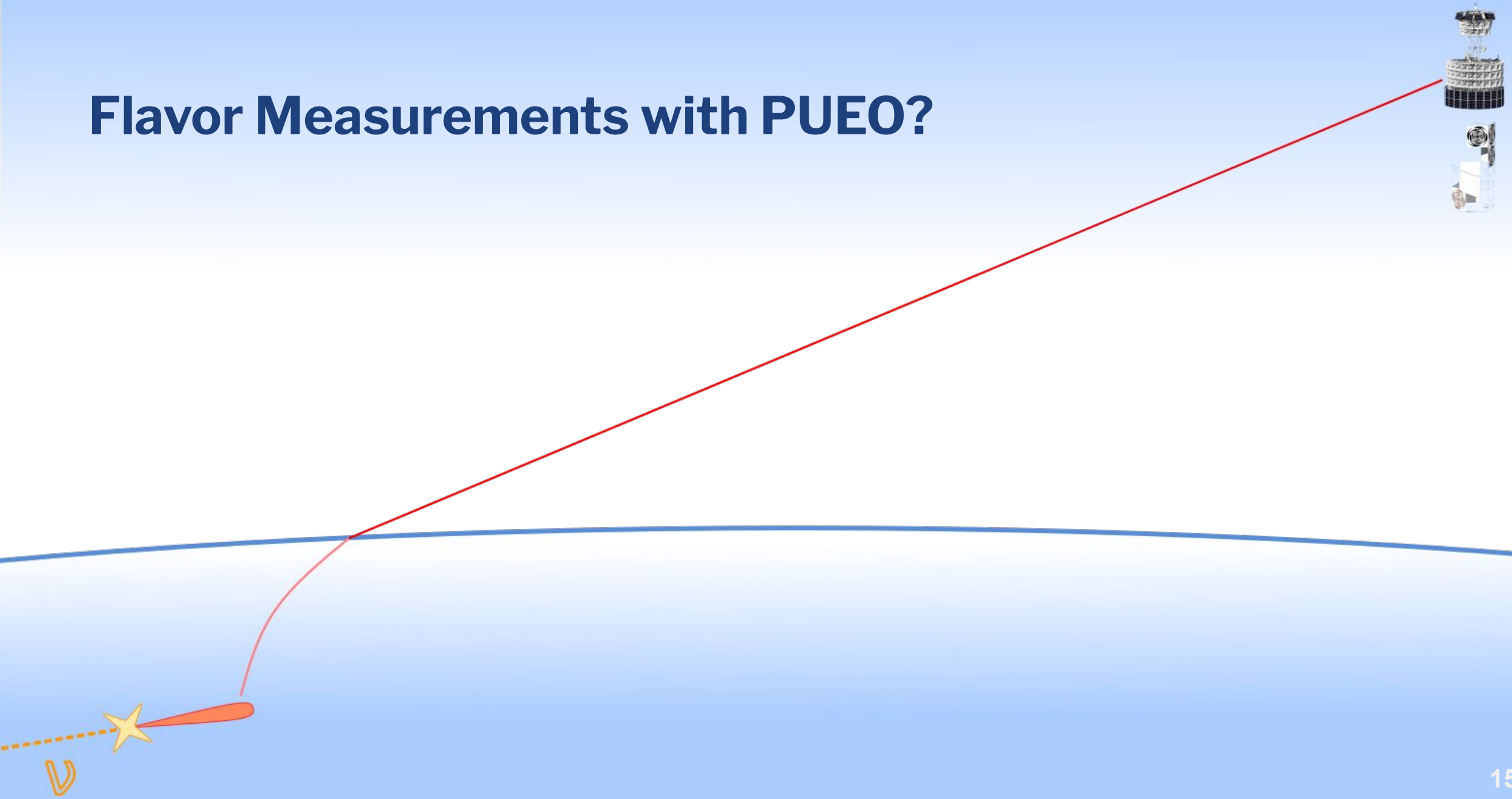
The Low Frequency Instrument

- 50-500MHz band
- Sinuous antennas printed on fabric
- Folded up during launch
- Enhances sensitivity to air showers:
  - Cosmic rays
  - Earth-skimming τ
  - ANITA “mystery events”





Flavor Measurements with PUEO?



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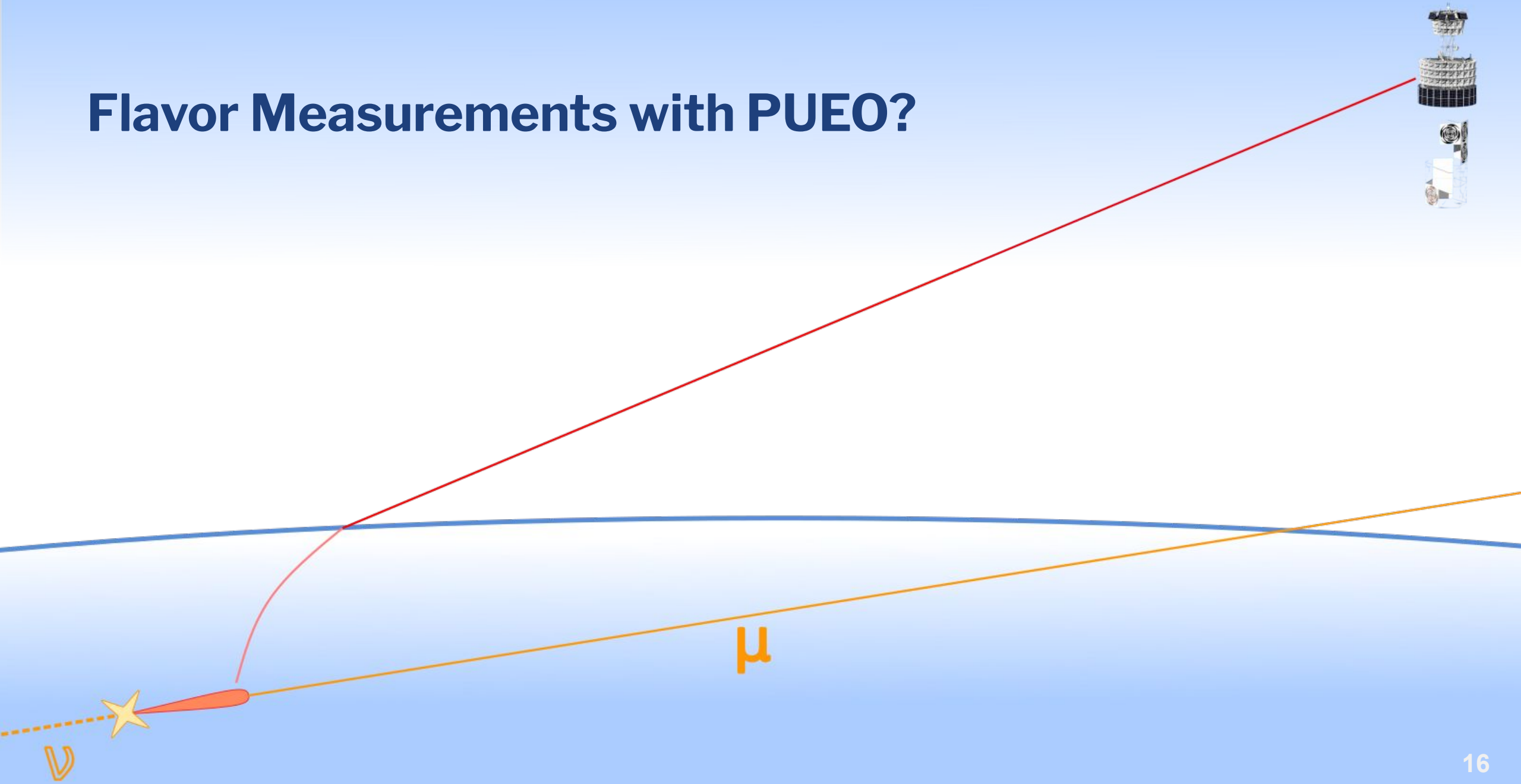

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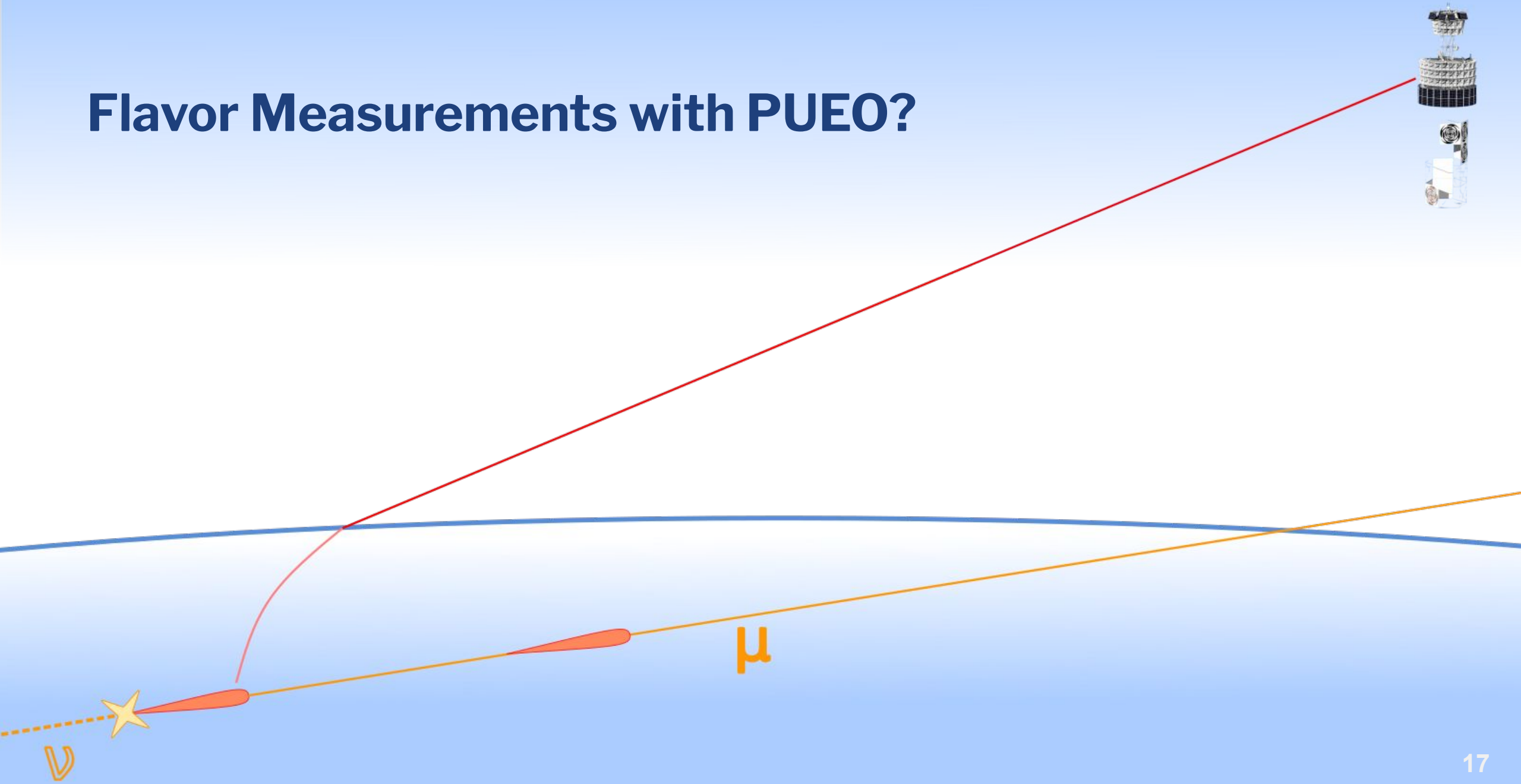
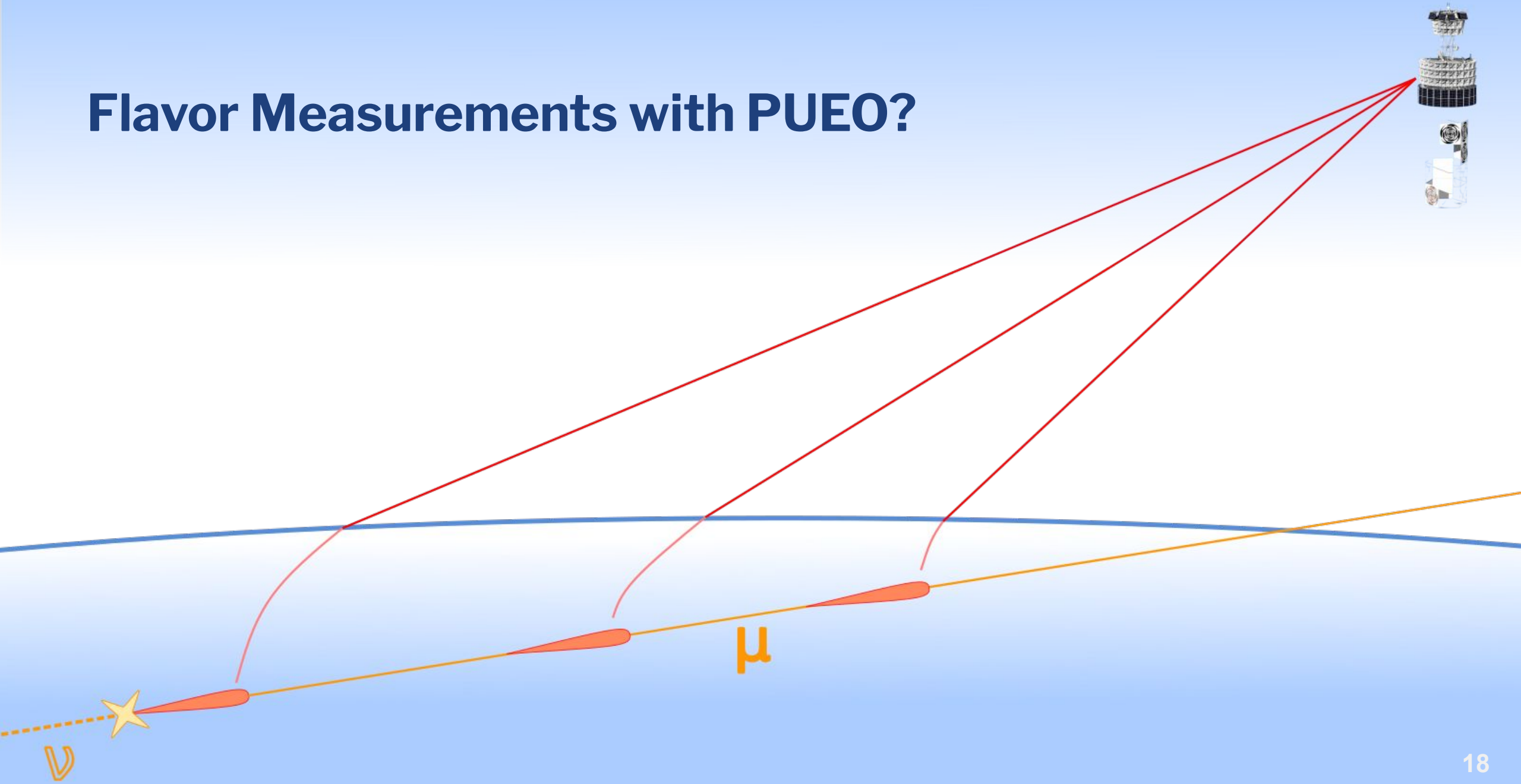


Flavor Measurements with PUEO?

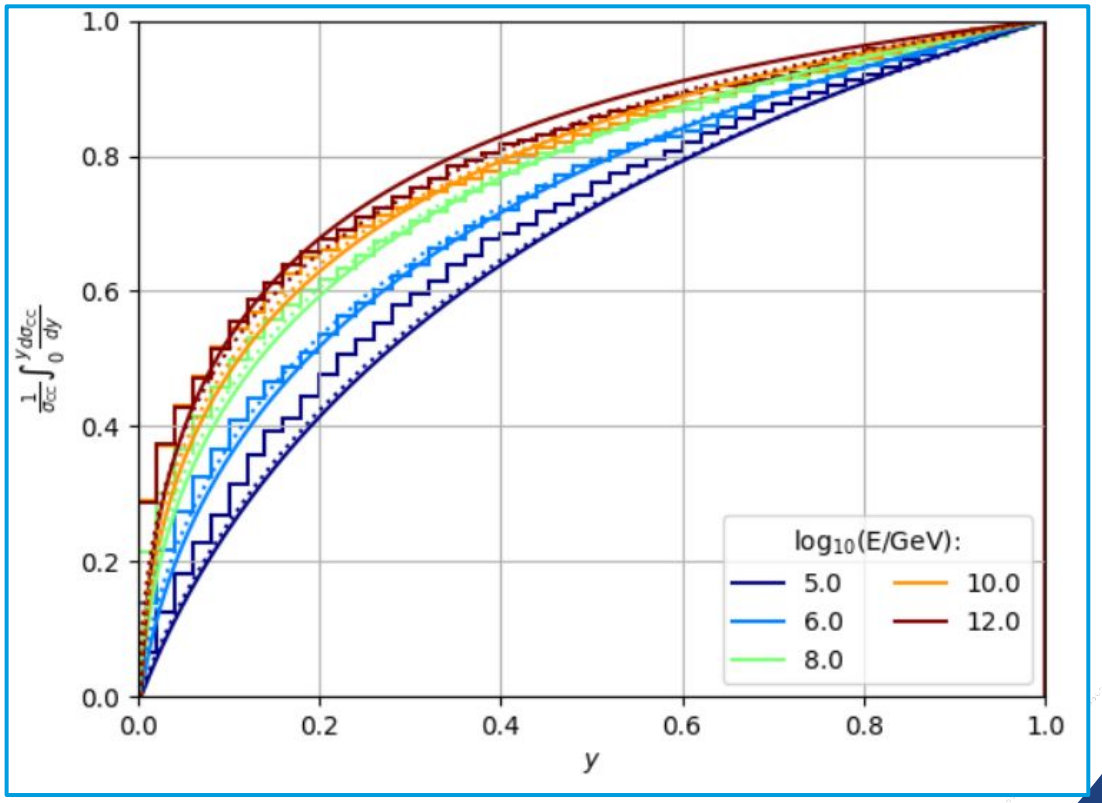


Can we actually detect this?

- At first, looks very unlikely
- But there are actually a few things helping:
  - Neutrino & lepton interactions at UHE
  - Event geometry
  - Signal timing
  - Easier statistics

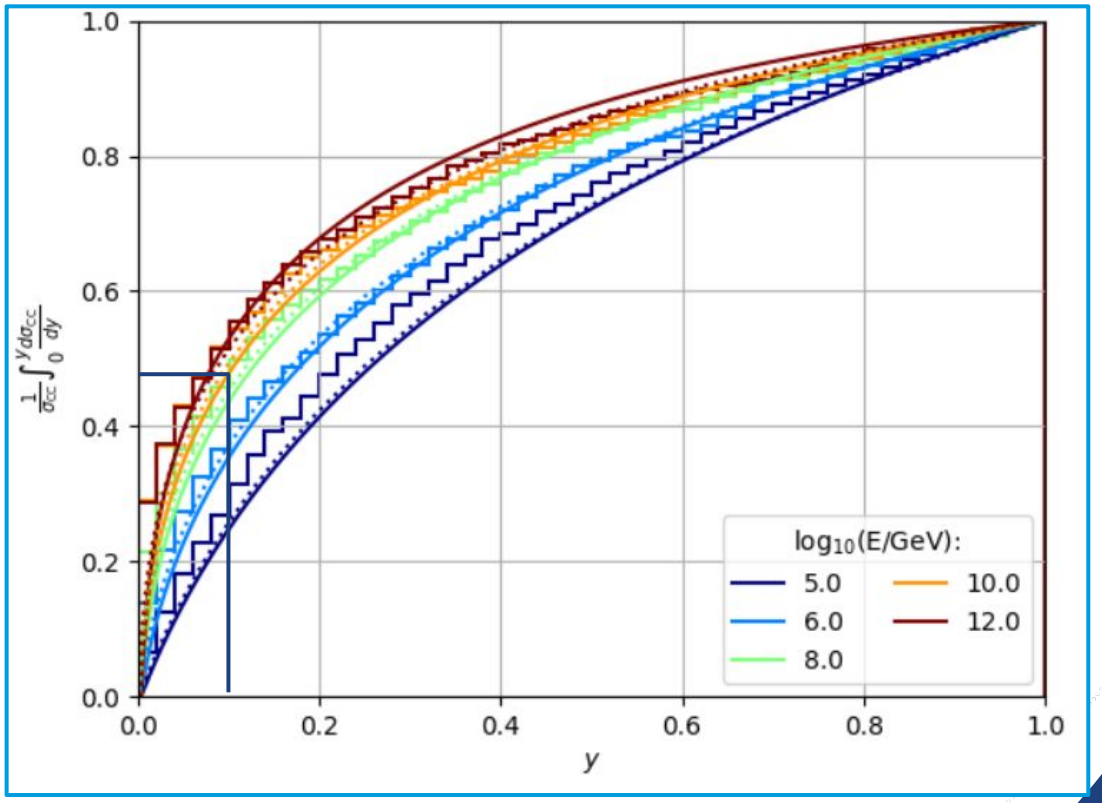
UHE Lepton Interactions

- Lepton keeps most of its energy



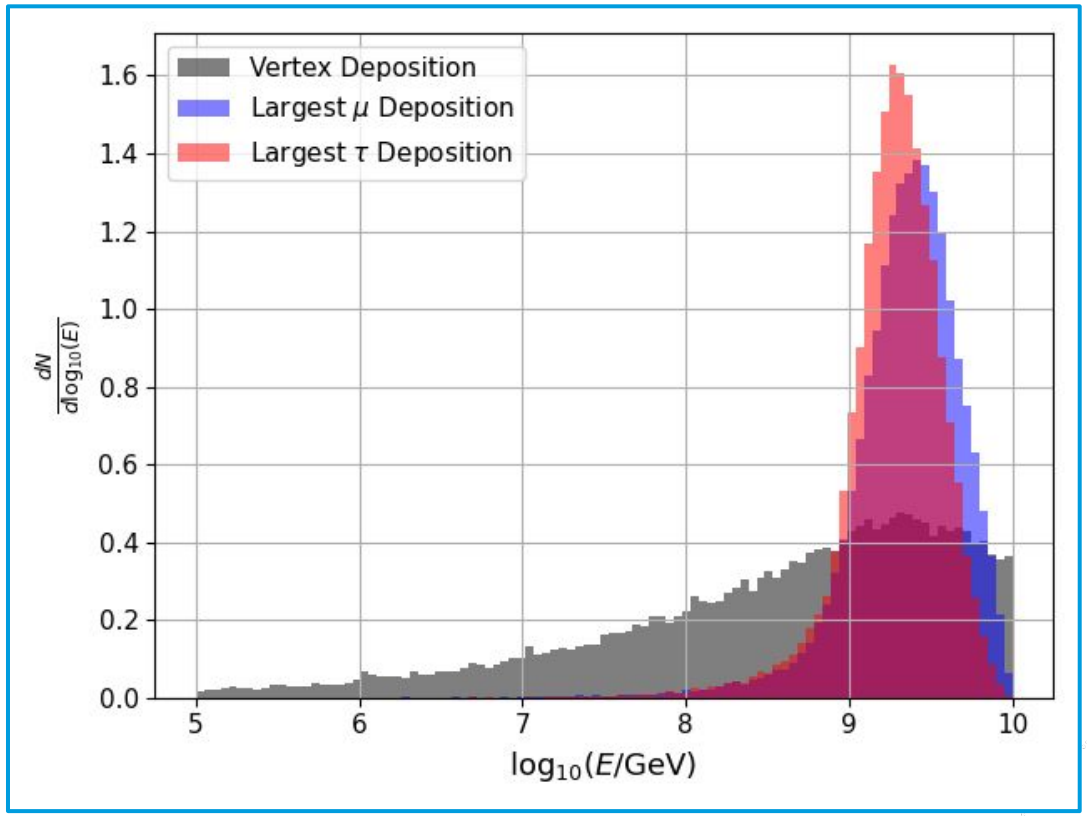
UHE Lepton Interactions

- Lepton keeps most of its energy
- At 10EeV: ~50% of events have >90% of energy in lepton



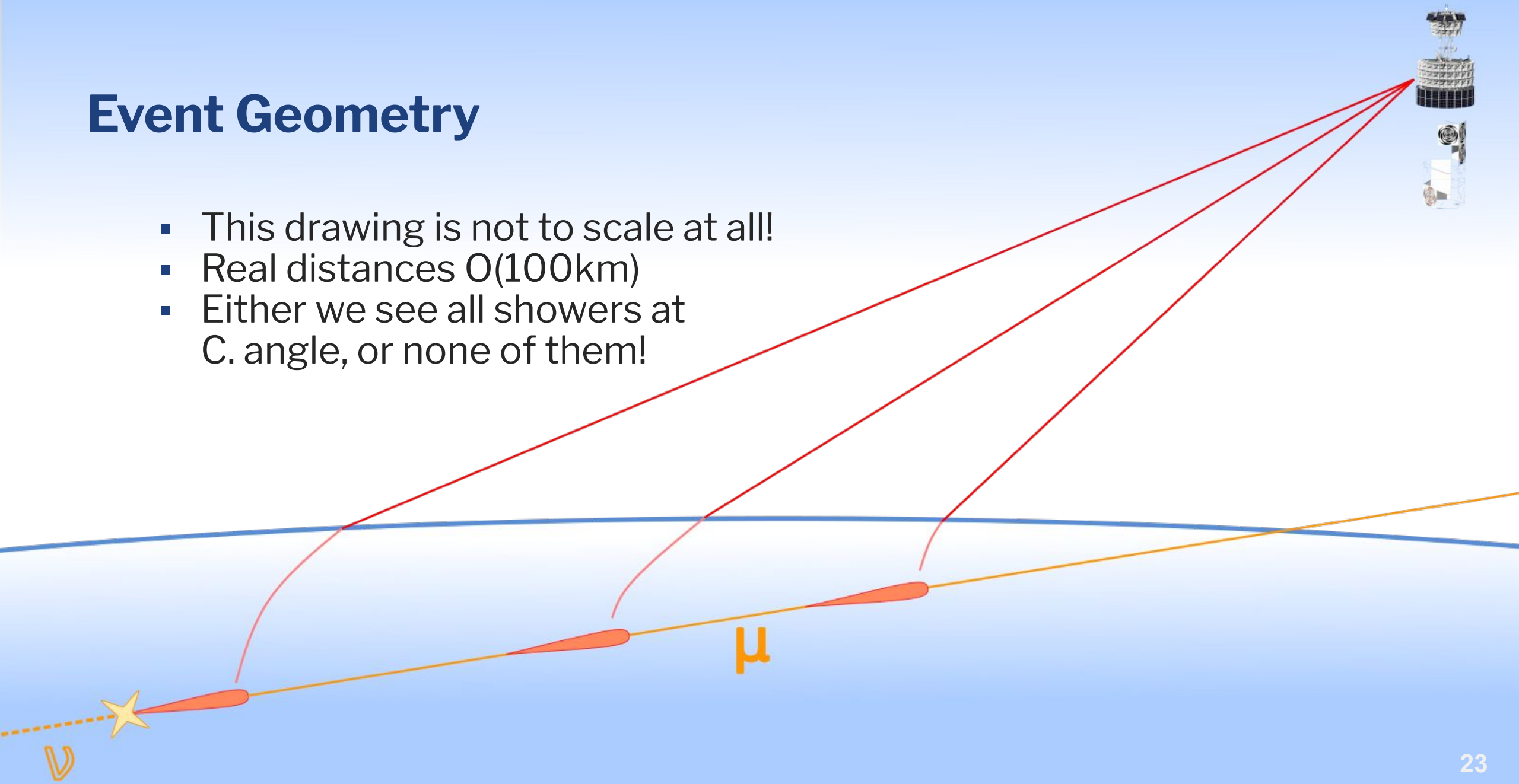
UHE Lepton Interactions

- Lepton actually produces higher-energy showers



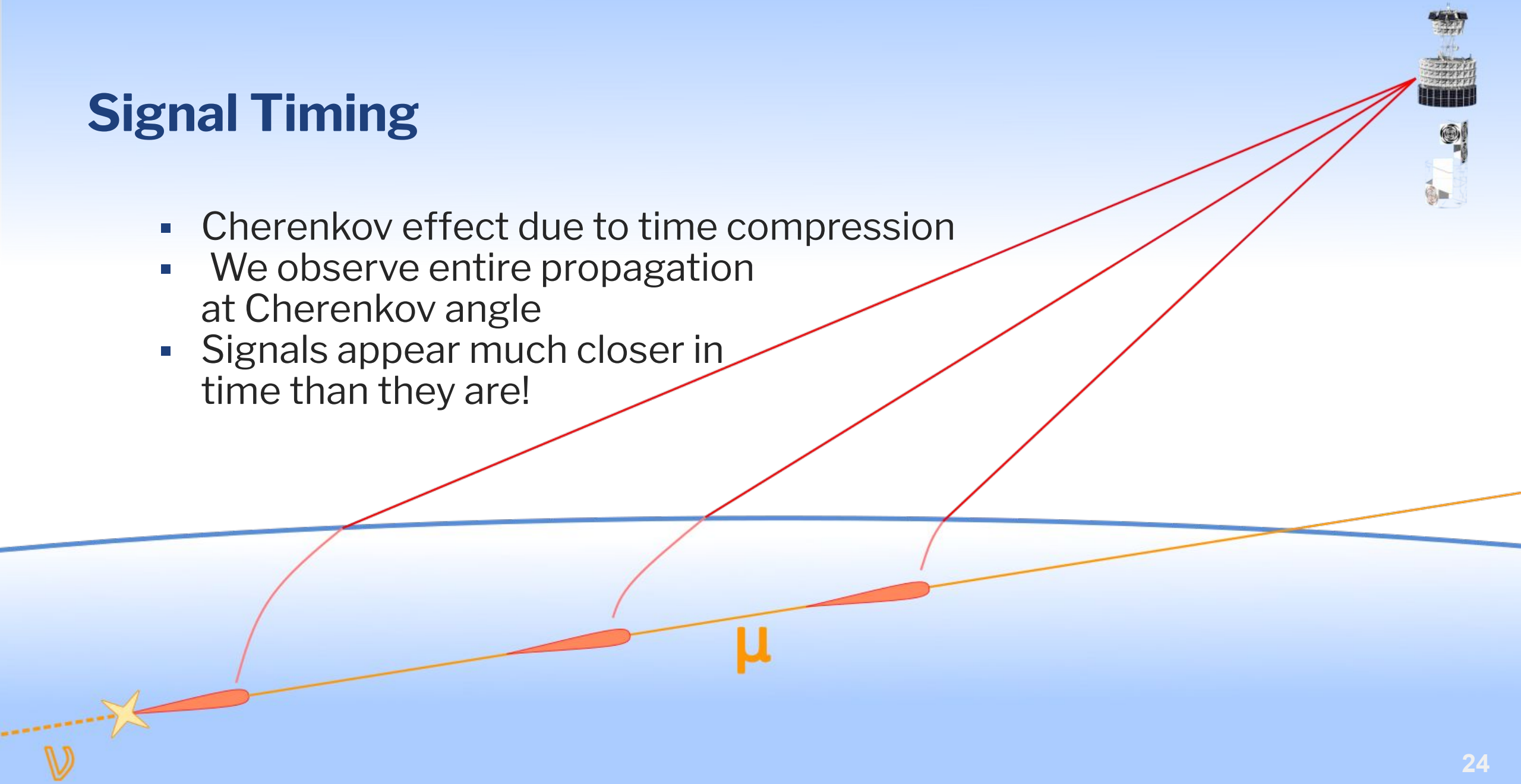
Event Geometry

- This drawing is not to scale at all!
- Real distances O(100km)
- Either we see all showers at C. angle, or none of them!



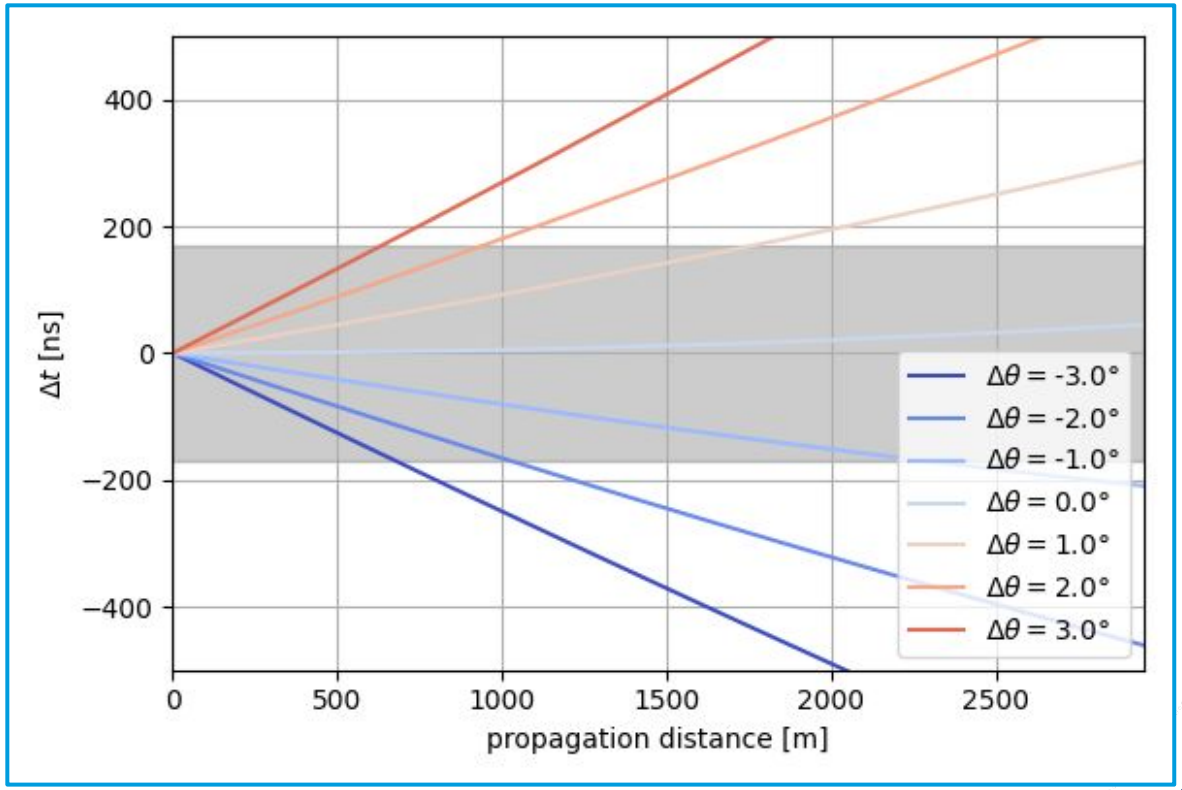
Signal Timing

- Cherenkov effect due to time compression
- We observe entire propagation at Cherenkov angle
- Signals appear much closer in time than they are!

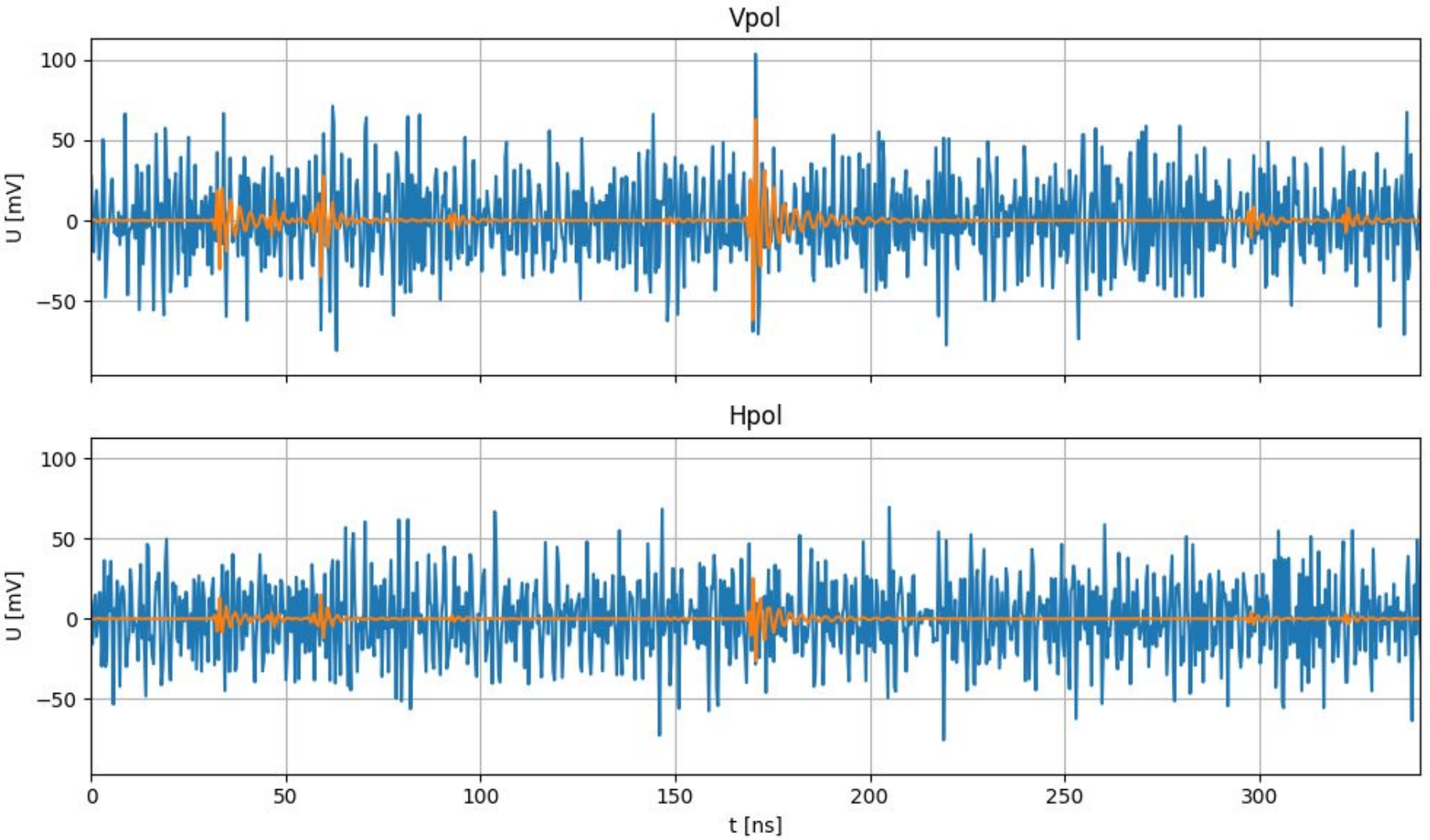


Signal Timing

- Time between signals smaller than recorded waveform
- Will “accidentally” record secondary showers
- Search for sub-threshold signals

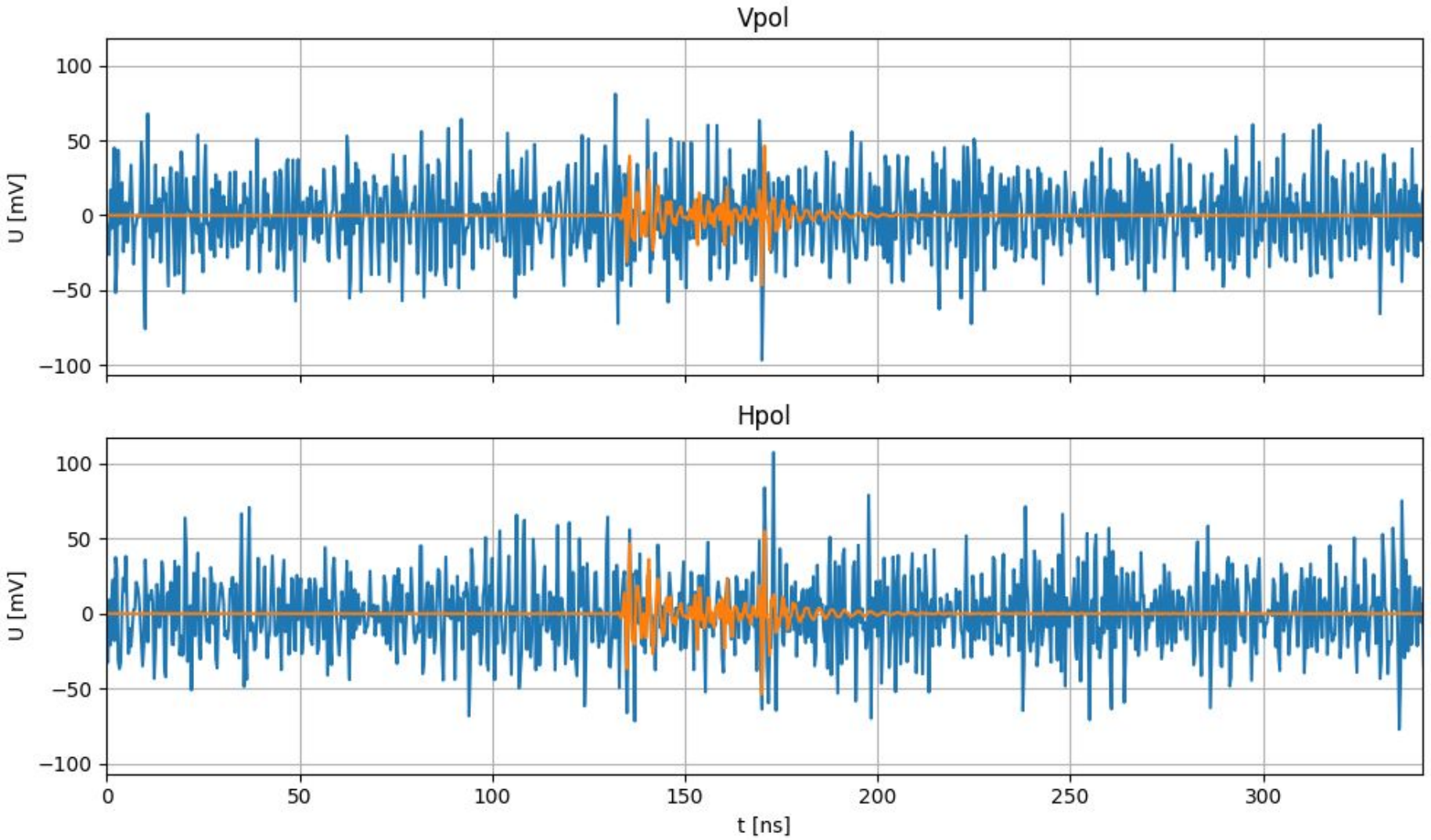


Example Waveforms



ν_μ
E_ν=100 EeV

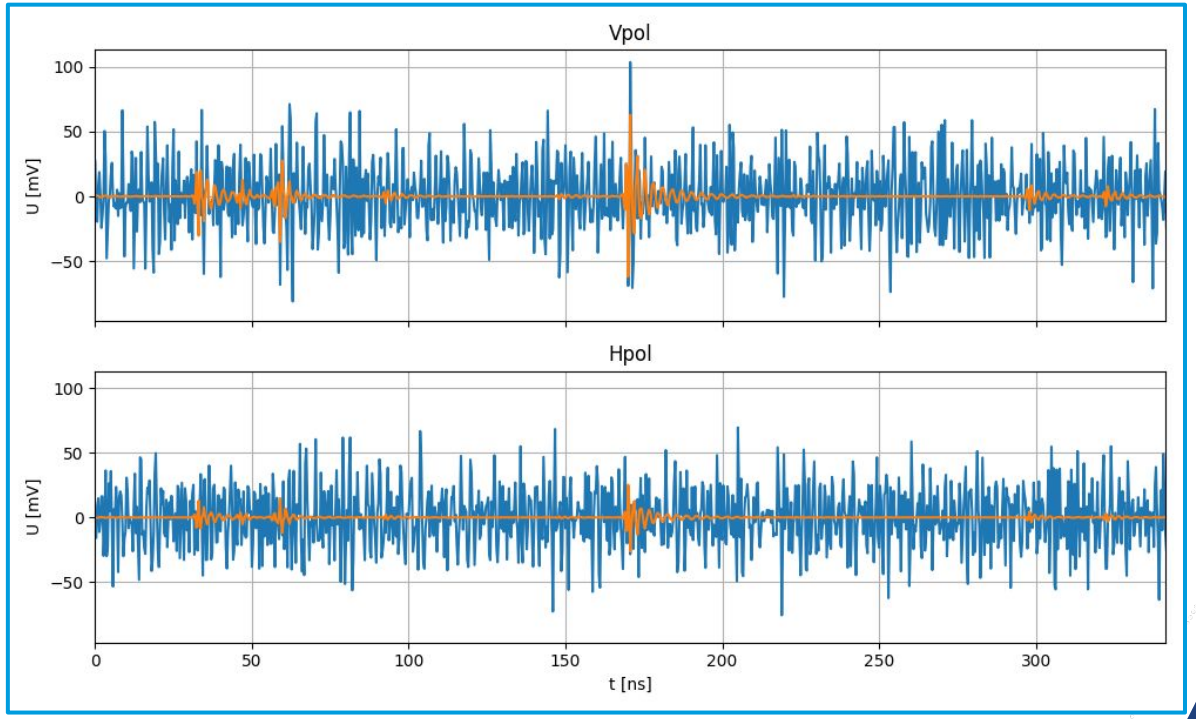
Example Waveforms



ν_μ
E_ν=1000 EeV

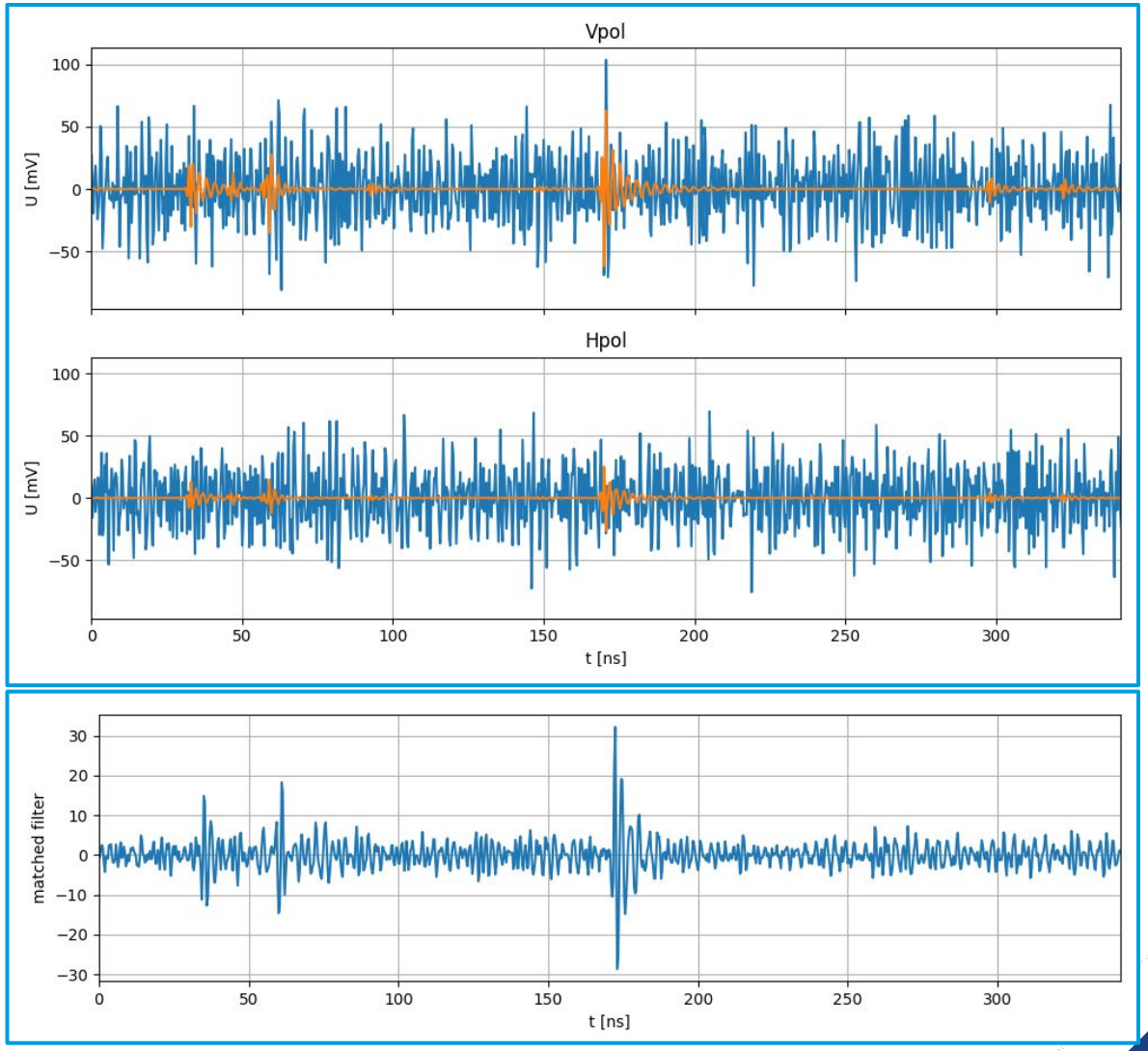
Can we actually find these signals?

- Let's say we find a neutrino…
  - We are sure it's a neutrino signal
  - We can reconstruct the event geometry
- Can we tell if there is a 2nd pulse in the waveform?



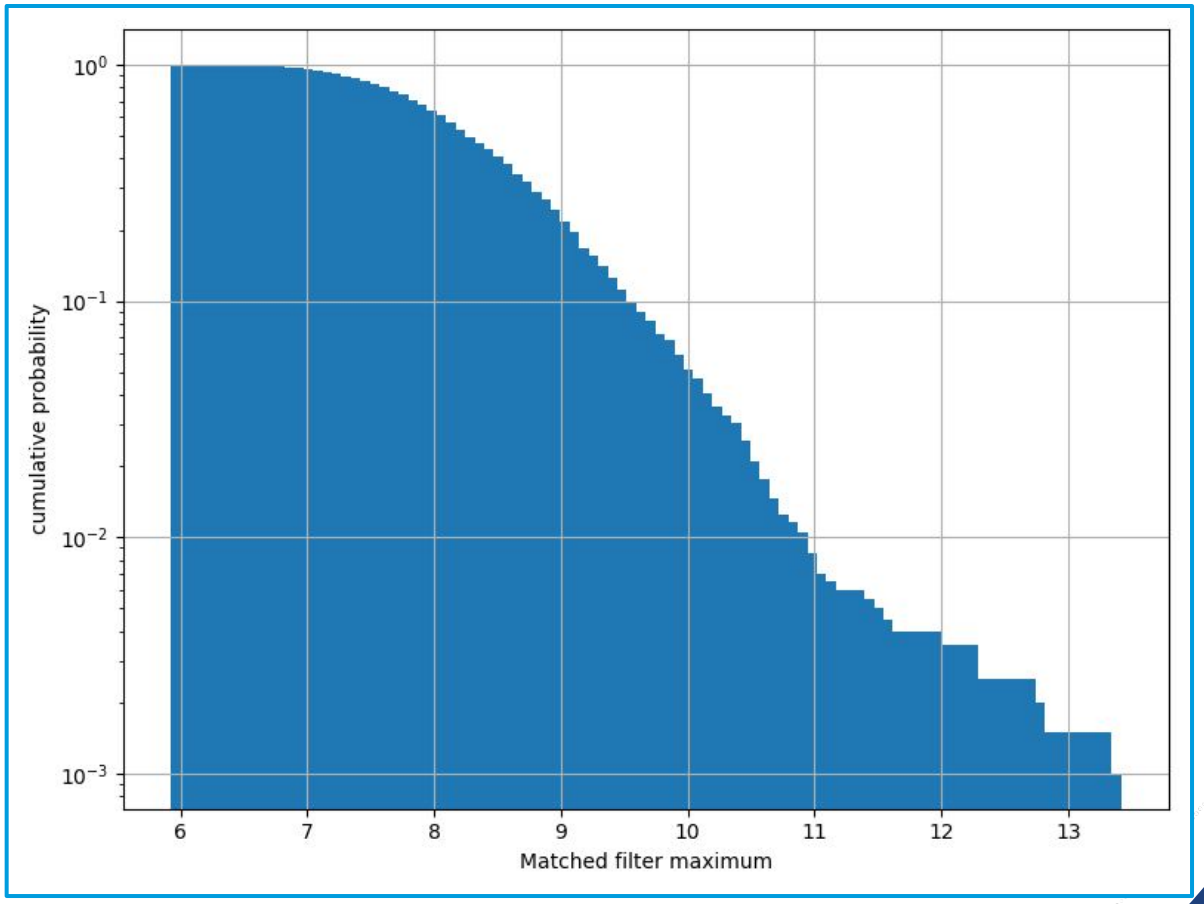
Matched Filter Search

- Template generation based on primary pulse
- Individual template for each channel
- Calculate matched filter response using channels within 50° azimuth



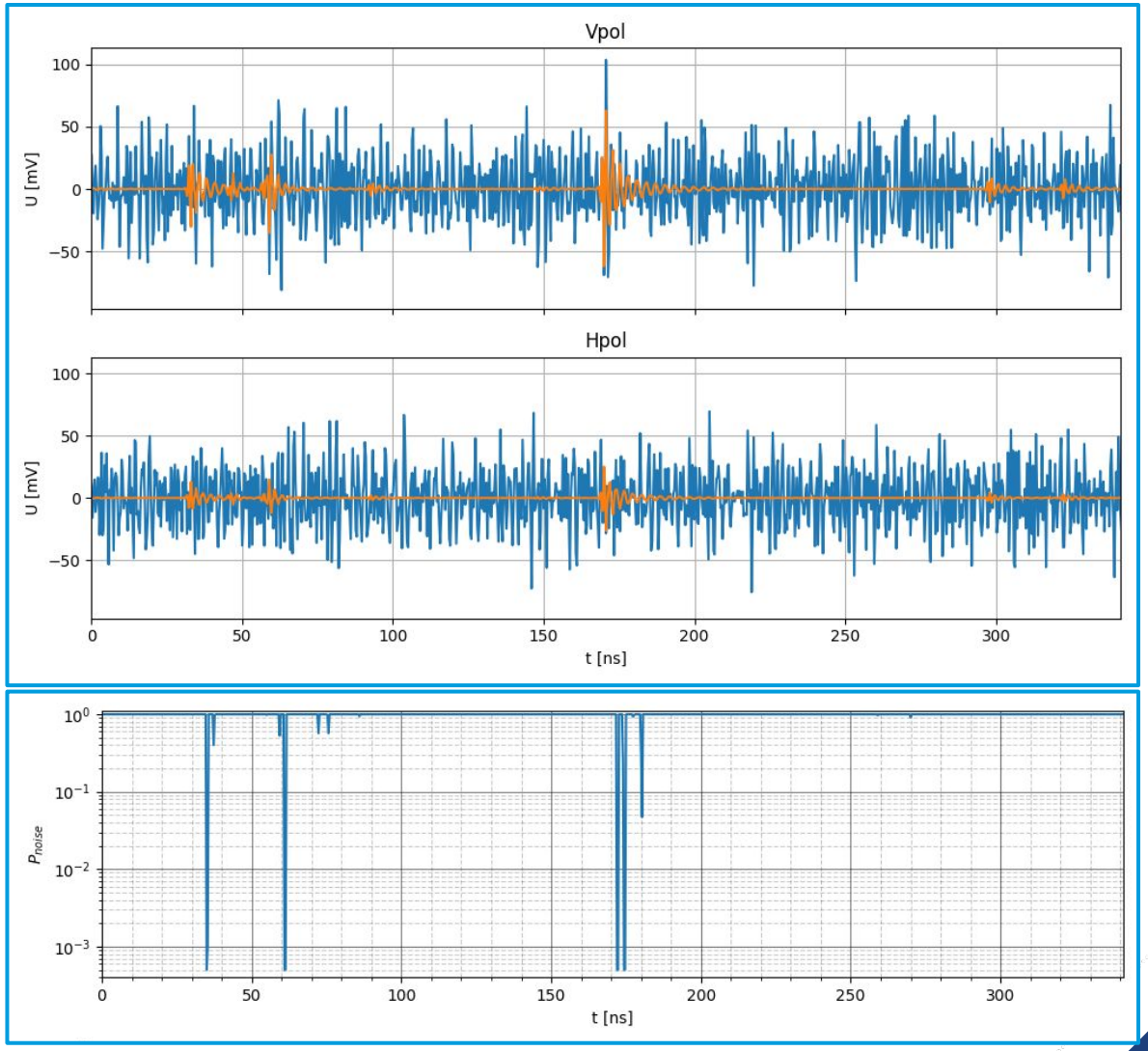
False Positive Rate

- Neutrino signals are independent of background
- Therefore, can estimate false positive rate from background sample
- Forced triggers taken during flight
- For now, simulate thermal noise

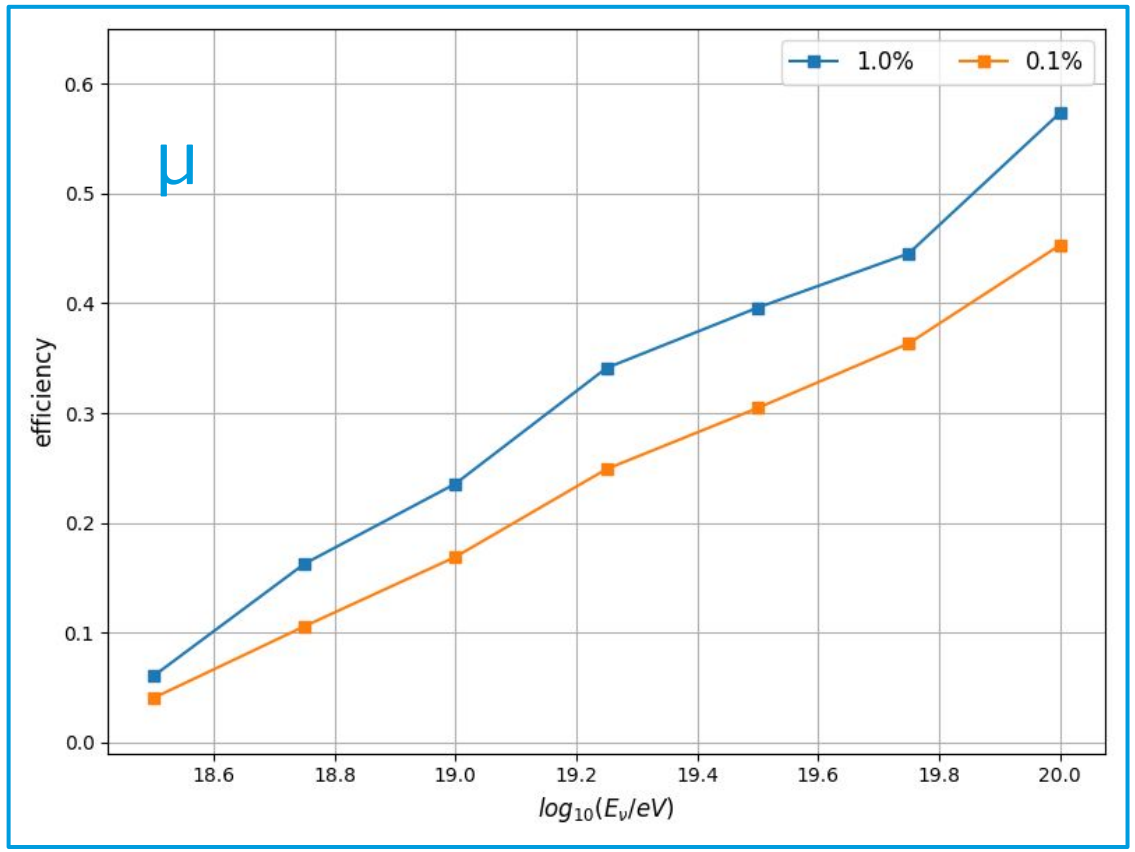


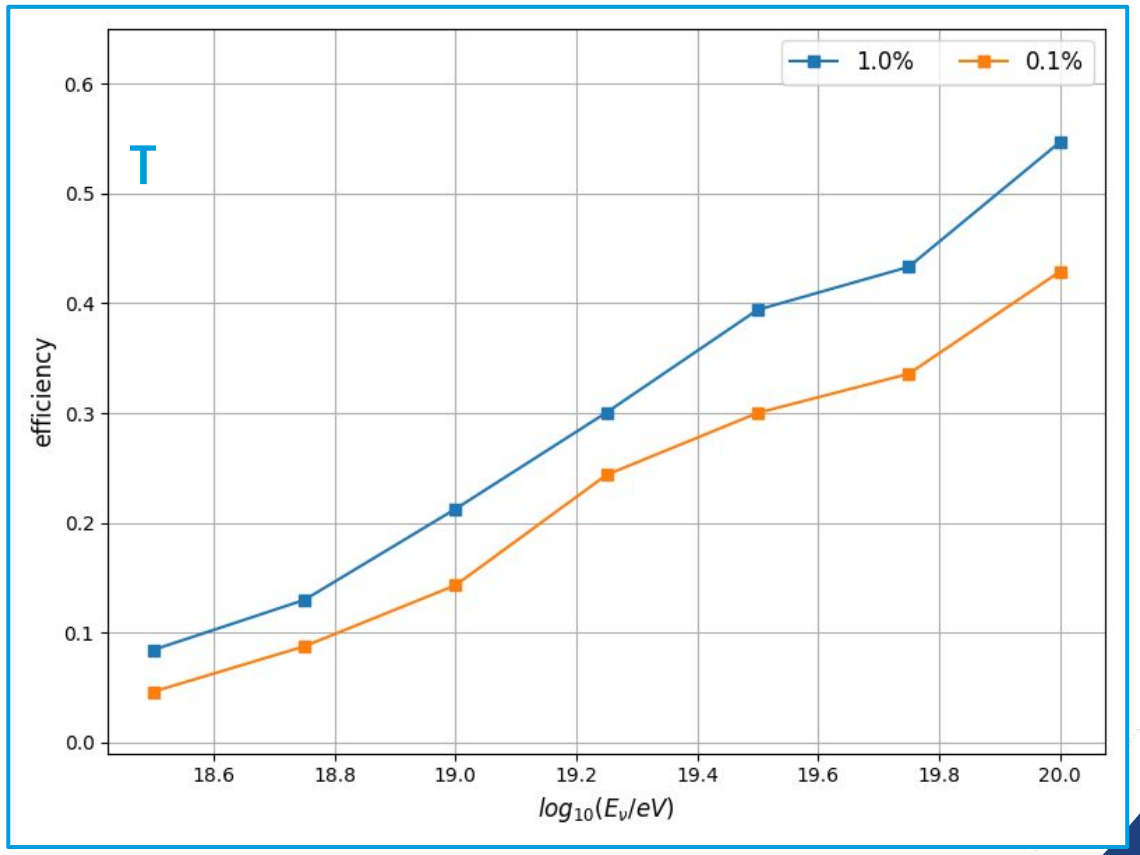
False Positive Rate

- Map correlation to false positive rate
- Classify event as μ/τ if probability below threshold



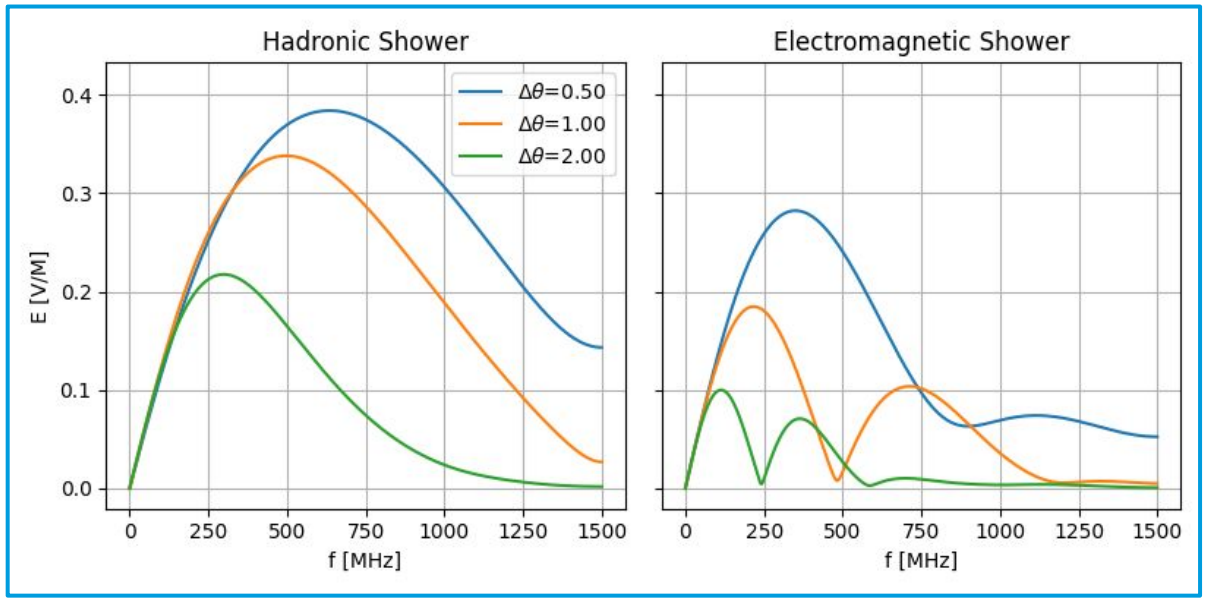
Results


μ
1.0%
0.1%
efficiency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18.6
18.8
19.0
19.2
19.4
19.6
19.8
20.0
$log_{10}(E_\nu/eV)$


τ
1.0%
0.1%
efficiency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18.6
18.8
19.0
19.2
19.4
19.6
19.8
20.0
$log_{10}(E_\nu/eV)$

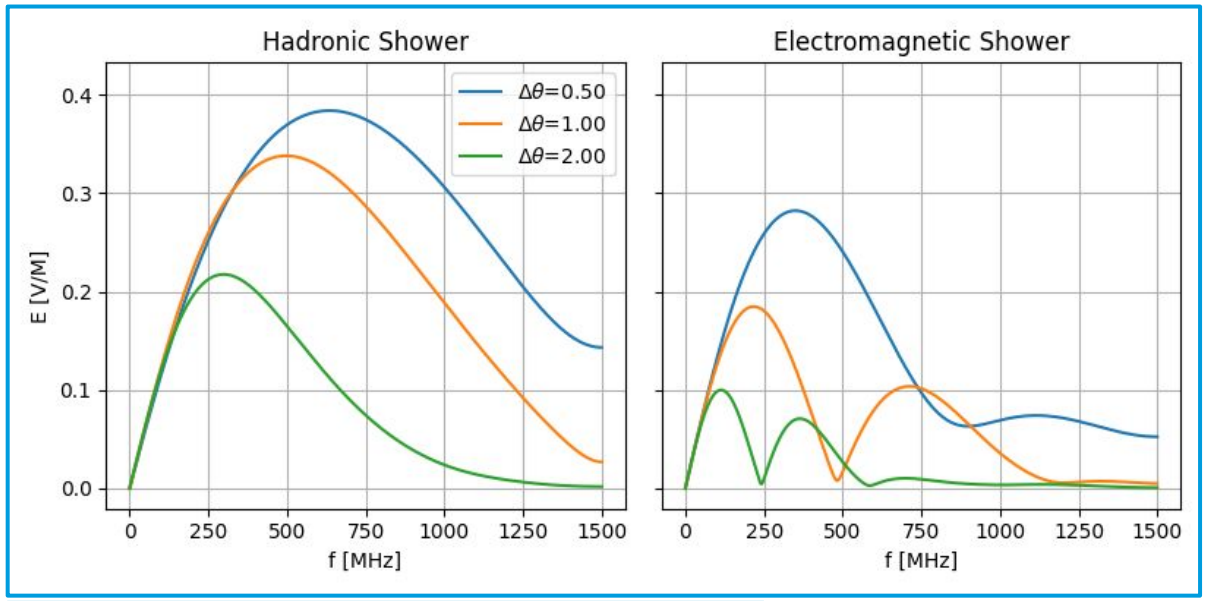
Outlook: Other Flavors

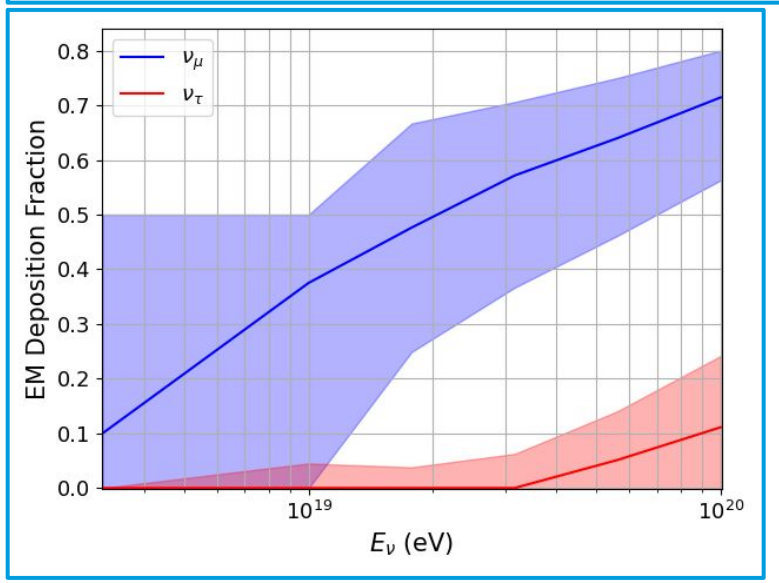
- EM showers are longer than hadronic showers
- LPM effect
- Distinct features in spectrum
  - Already demonstrated for in-ice detectors (Coleman et al 2024)



Outlook: Other Flavors

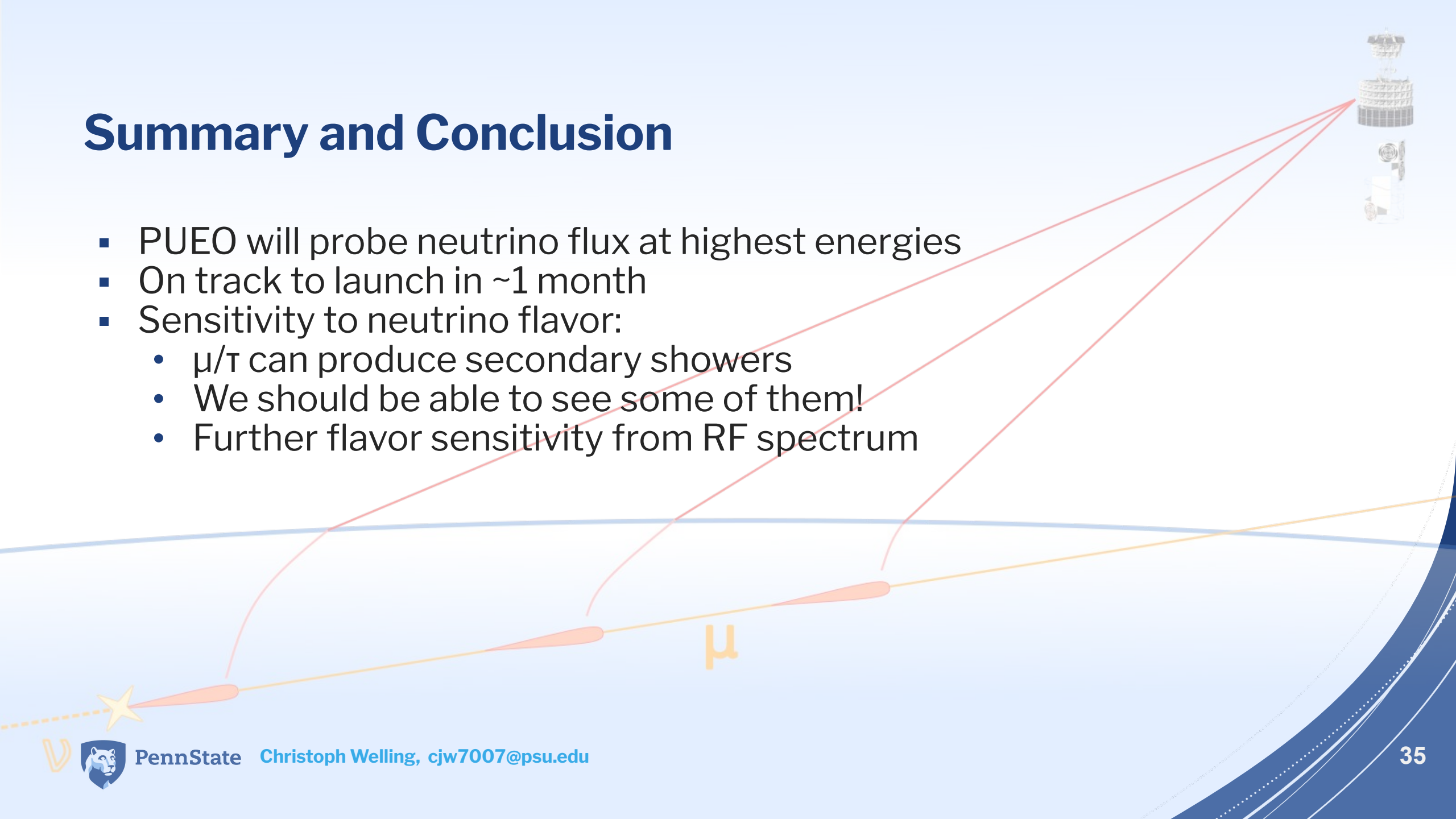
- EM showers are longer than hadronic showers
- LPM effect
- Distinct features in spectrum
  - Already demonstrated for in-ice detectors (Coleman et al 2024)
- **But**: Muons also produce EM showers





Summary and Conclusion

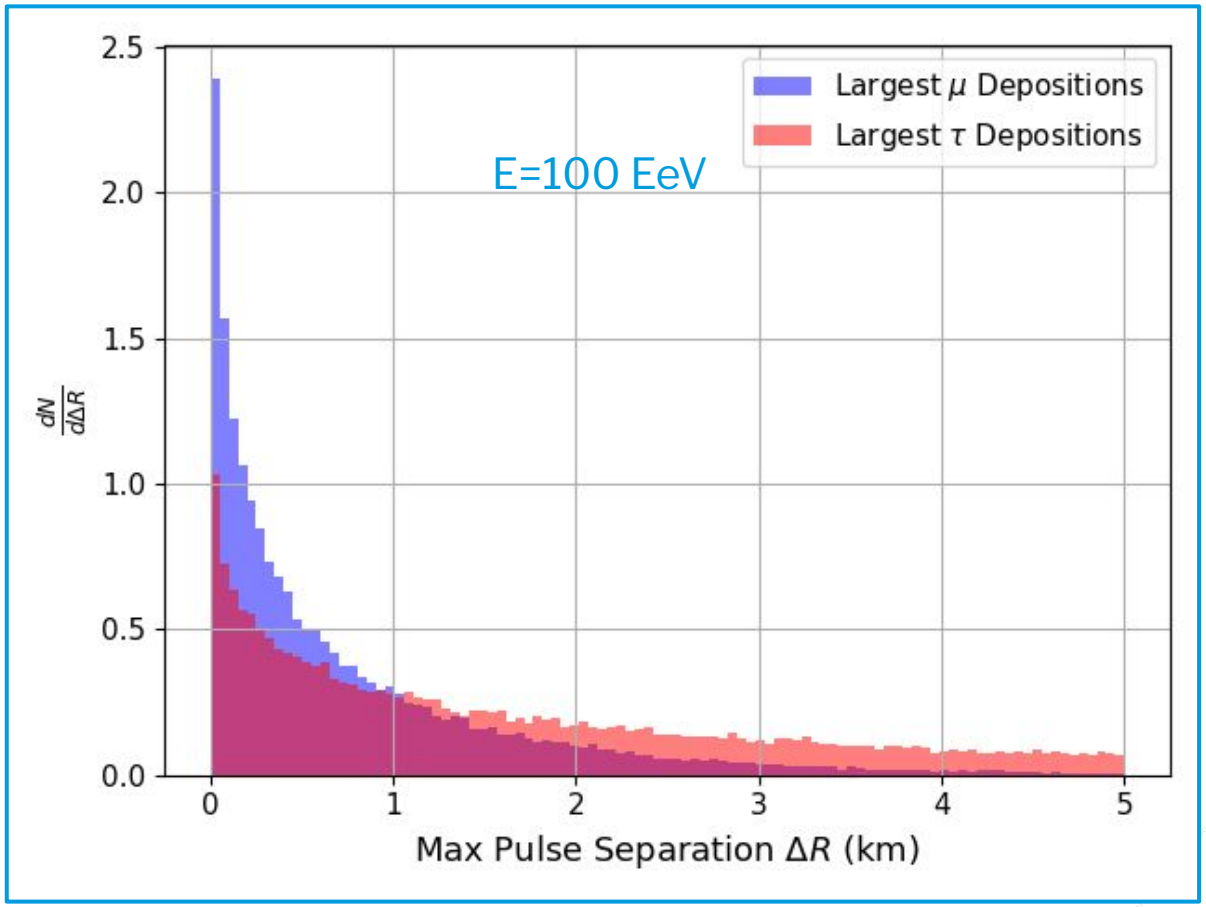
- PUEO will probe neutrino flux at highest energies
- On track to launch in ~1 month
- Sensitivity to neutrino flavor:
  - μ/τ can produce secondary showers
  - We should be able to see some of them!
  - Further flavor sensitivity from RF spectrum



Backup

Signal Timing

- Time between signals smaller than recorded waveform
- Will “accidentally” record secondary showers
- Search for sub-threshold signals



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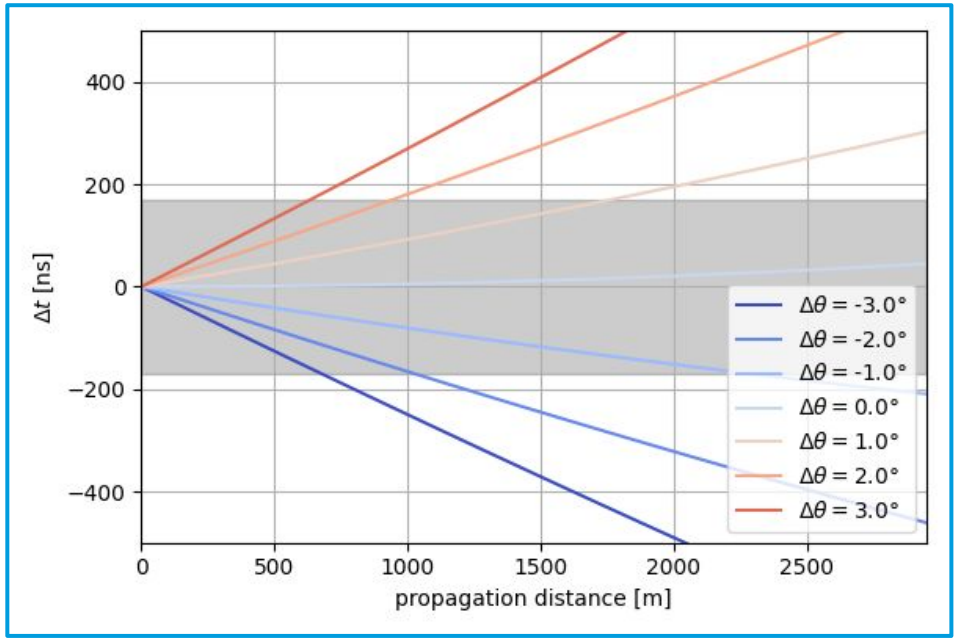

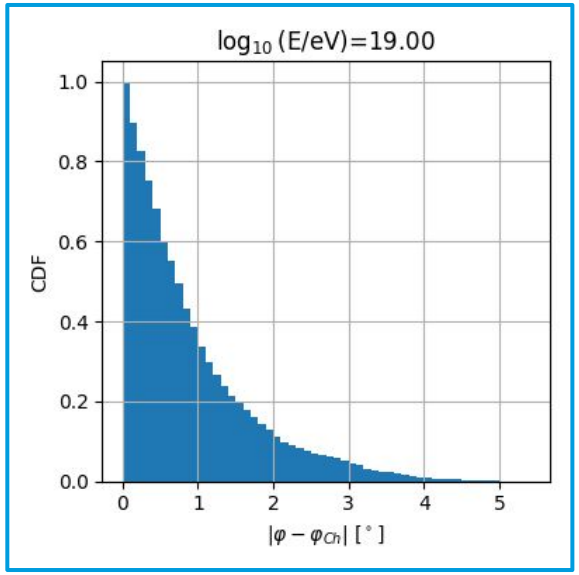

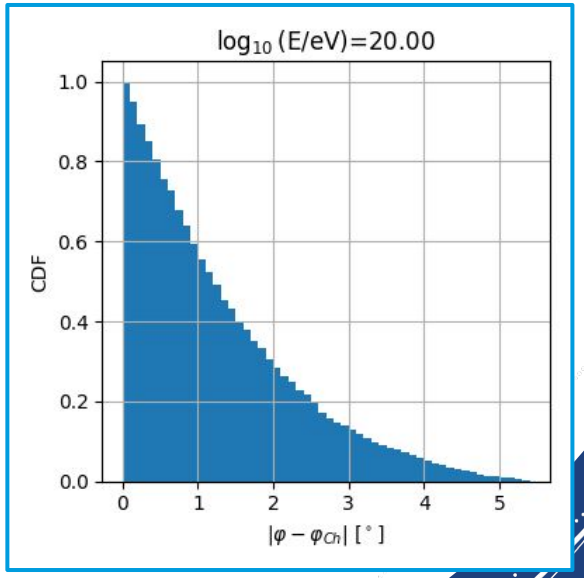

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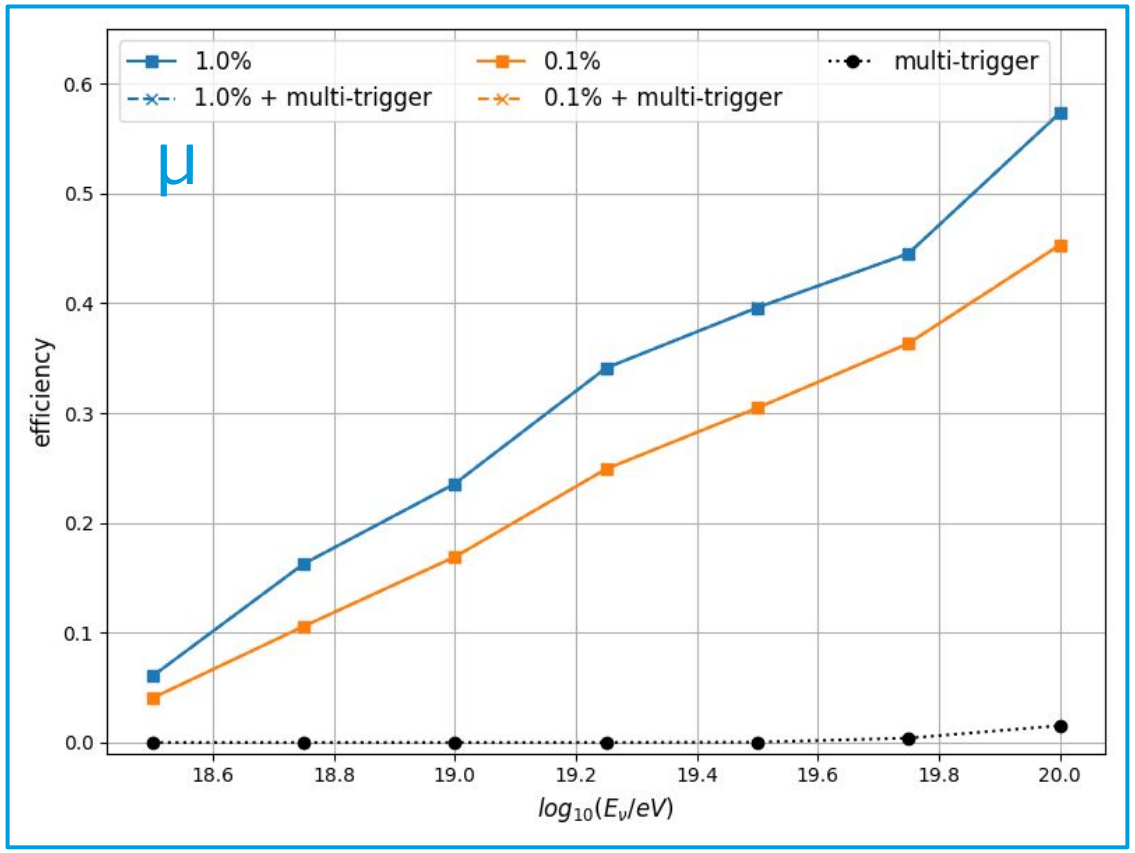
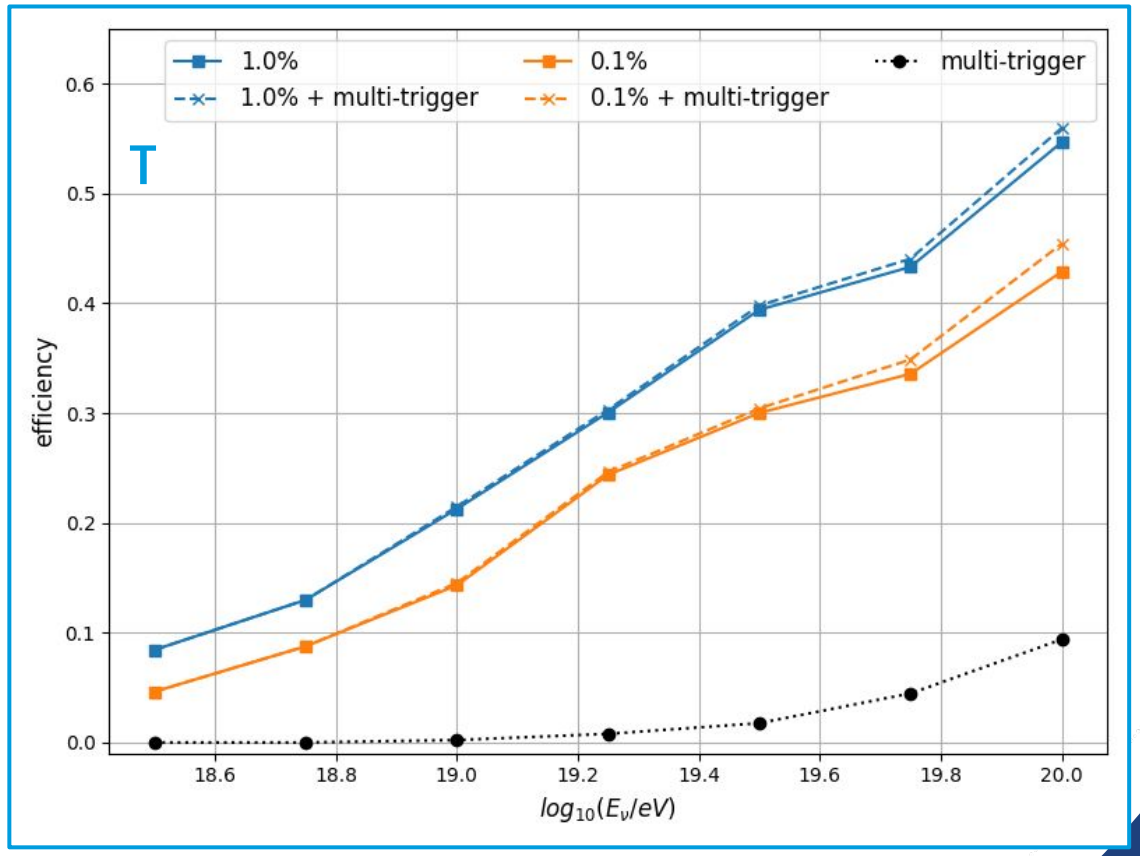
Results


1.0%
0.1%
multi-trigger
1.0% + multi-trigger
0.1% + multi-trigger
μ
efficiency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18.6
18.8
19.0
19.2
19.4
19.6
19.8
20.0
log10(Eν/eV)


1.0%
0.1%
multi-trigger
1.0% + multi-trigger
0.1% + multi-trigger
τ
efficiency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18.6
18.8
19.0
19.2
19.4
19.6
19.8
20.0
log10(Eν/eV)