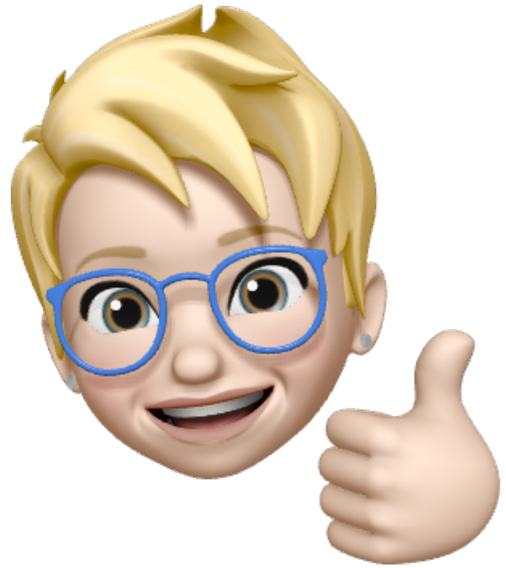
Guess who’s back?

A story of neutrinos, matter-antimatter asymmetry, and hopefully no parallel universes

Dr Linda Cremonesi, 2020 July 9th



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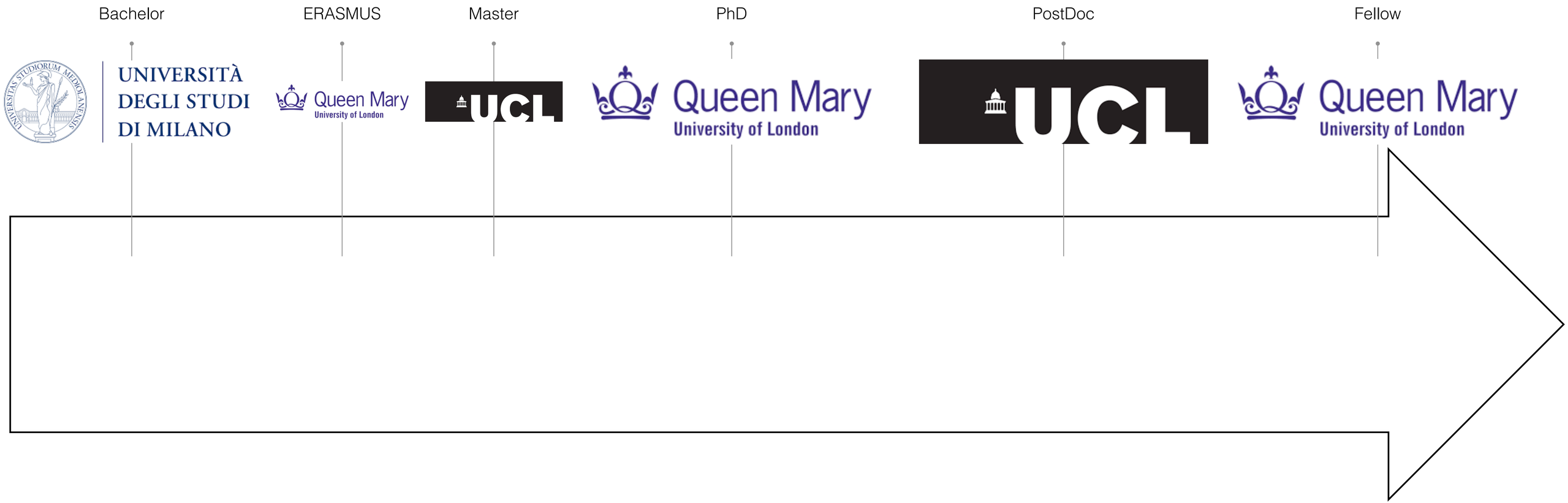
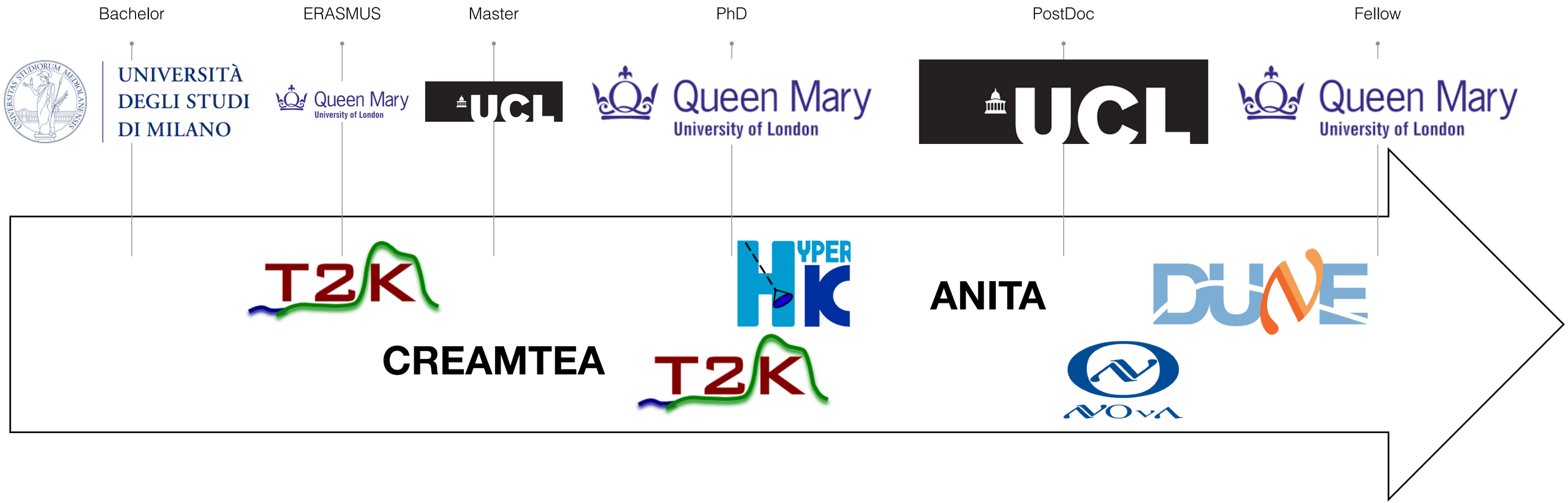
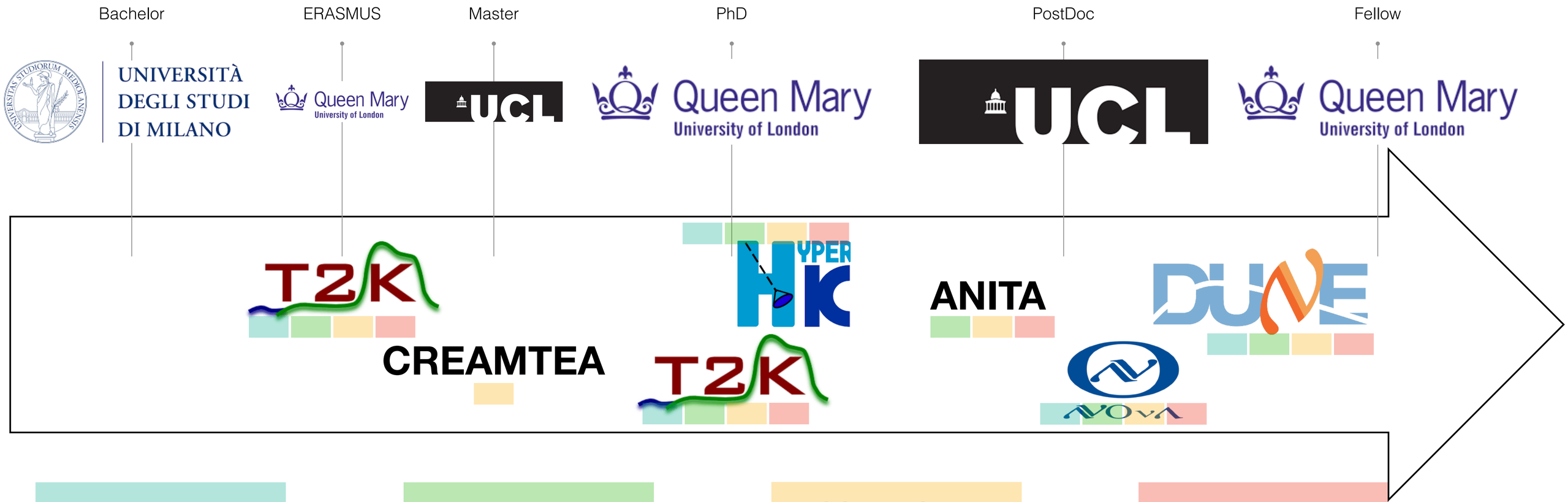
Third time’s the charm



Third time's the charm



Third time's the charm



Neutrino Oscillations

Neutrino Interactions

Neutrino Detector Technology

Neutrino Astronomy

The plan for today

(Overview of my research interests)

Neutrino Astronomy

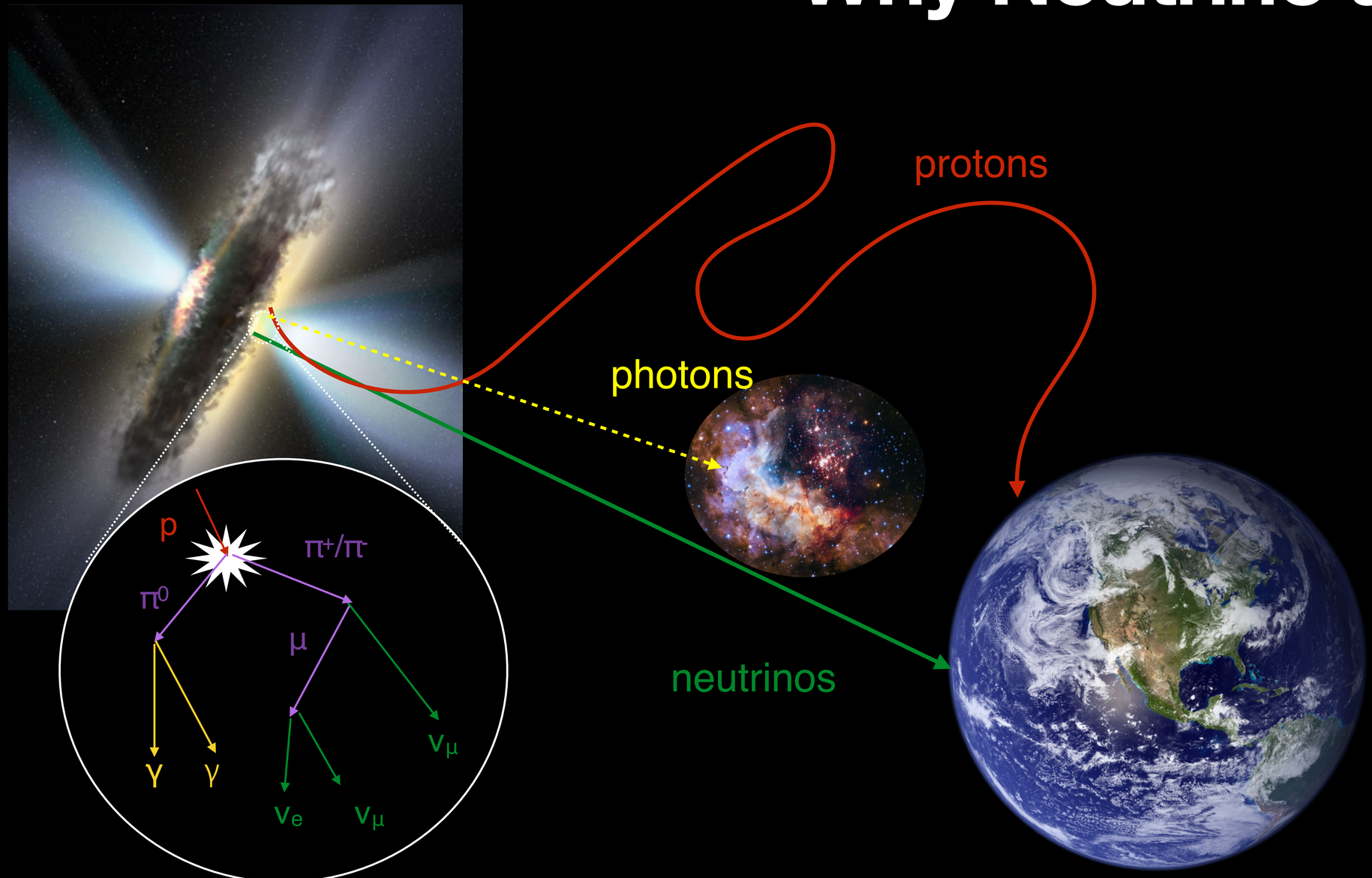
Neutrino Interactions

Neutrino Oscillations

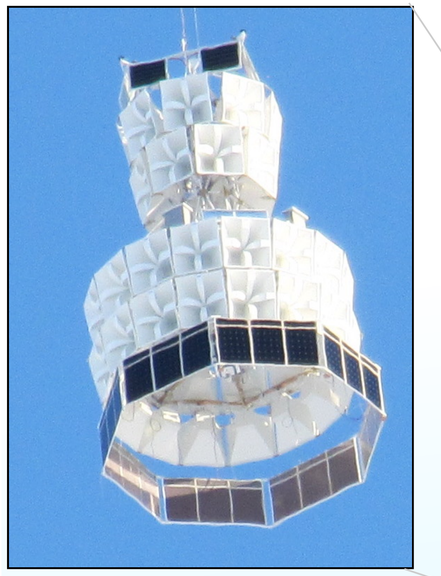
Check out the latest nus news at Neutrino 2020
https://indico.fnal.gov/event/43209/timetable/#20200622.detailed

Neutrino Astronomy

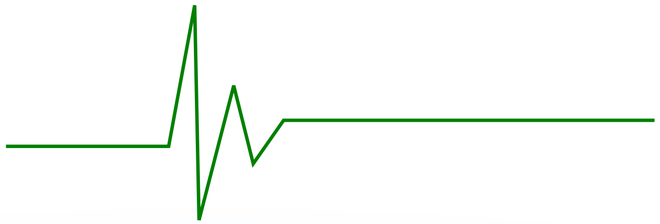
Why Neutrino astronomy?



ANtarctic **I**mpulsive **T**ransient **A**ntenna



Not to scale, angles don't reflect reality



NEUTRINOS = VPOL

balloon

40km altitude

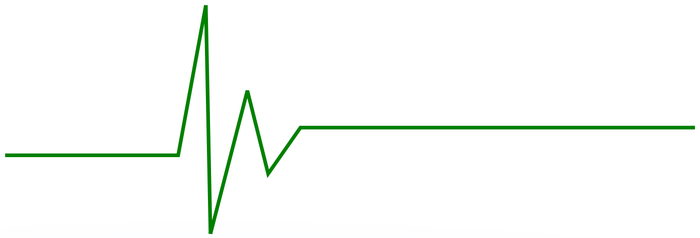
Ice

Askaryan emission

~EeV neutrino

ANtarctic **I**mpulsive **T**ransient **A**ntenna

Not to scale, angles don't reflect reality



NEUTRINOS = VPOL

COSMIC RAYS = HPOL

balloon

direct UHECR

geomagnetic + Askaryan emission

reflected UHECR

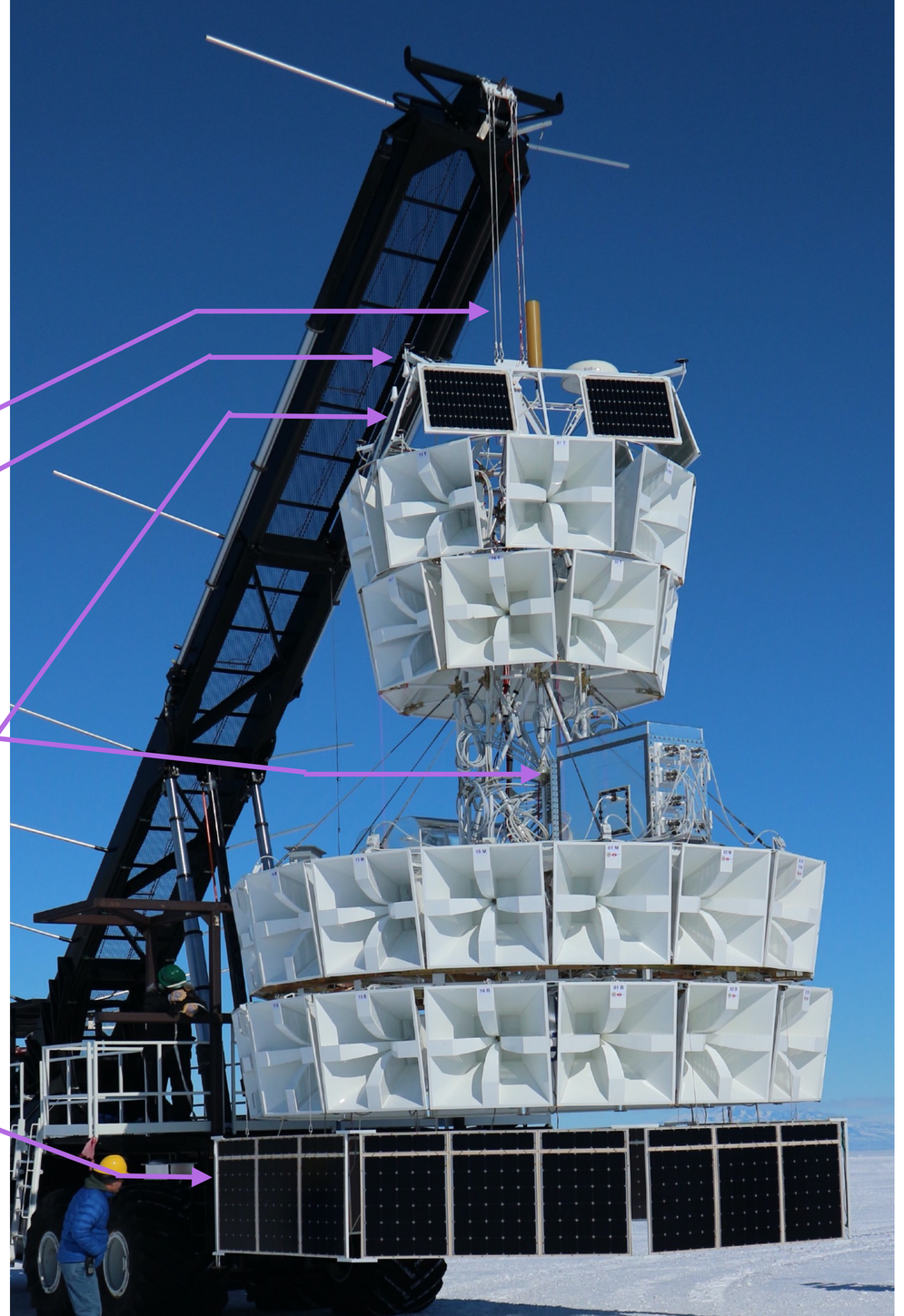
geomagnetic + Askaryan emission

Ice

Askaryan emission

~EeV ν

ANITA instrument

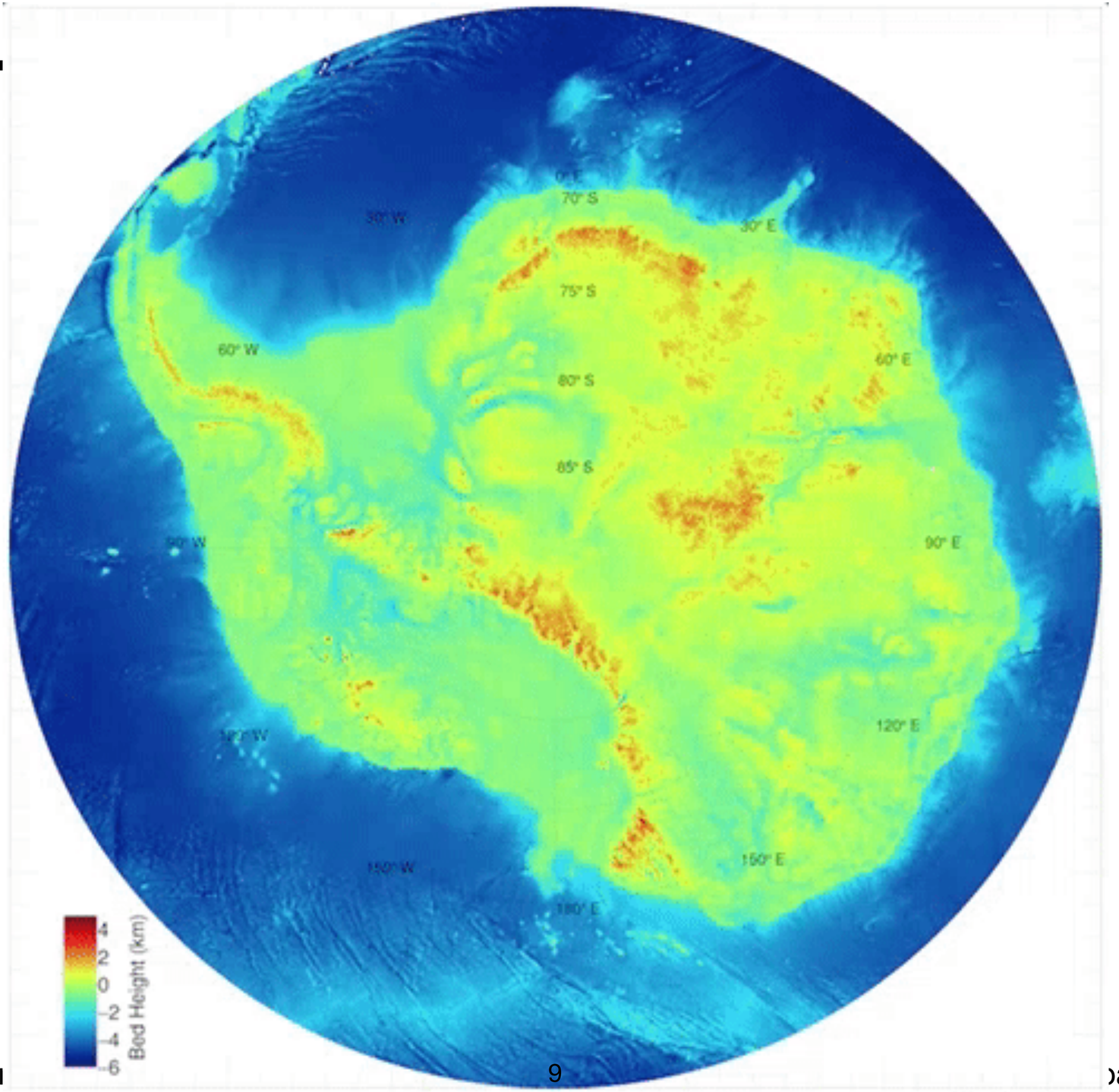


ANITA-4

Take off

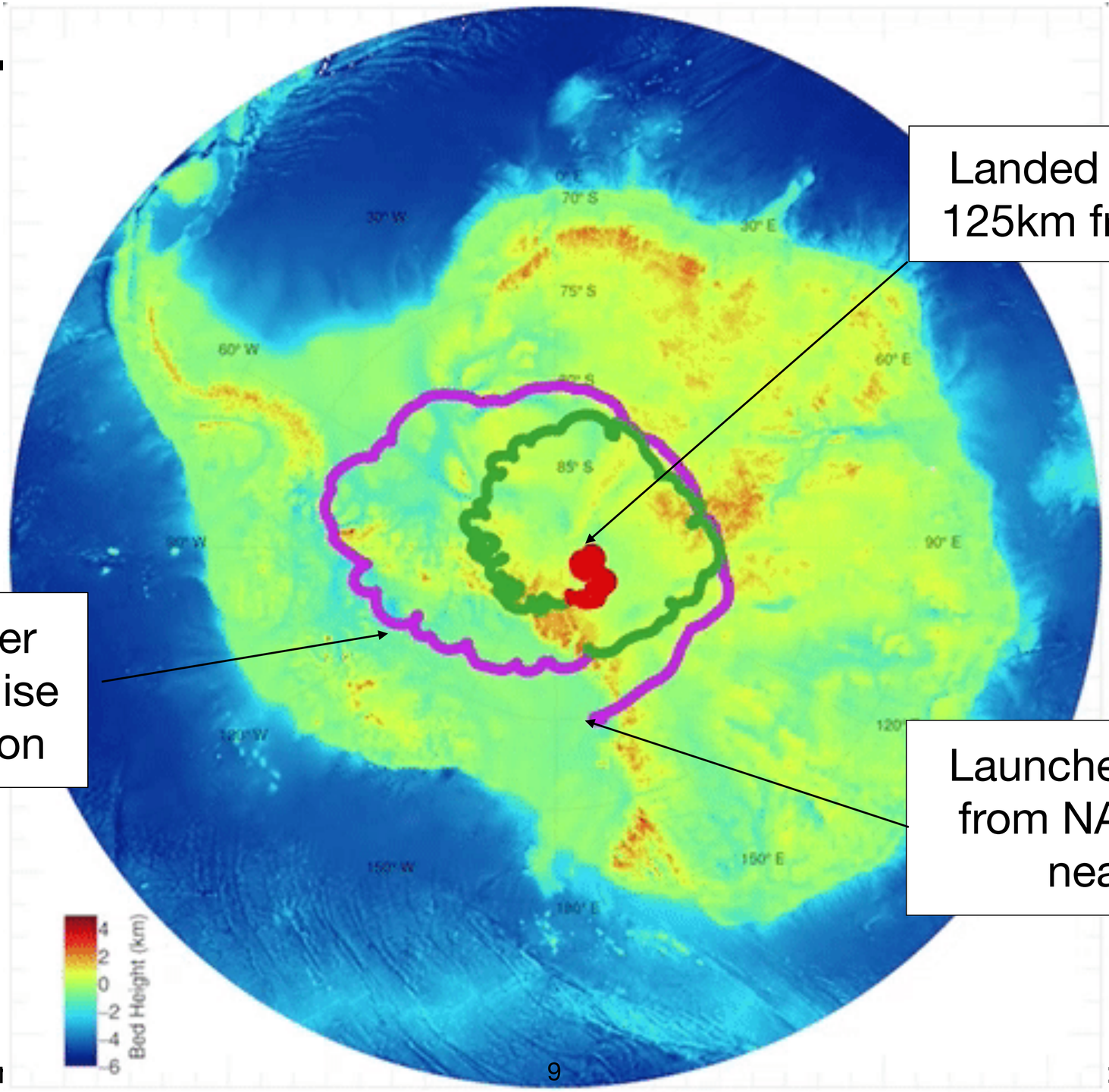
ANITA-4

Flight Path



ANITA-4

Flight Path



Landed Dec 30th 2016
125km from South Pole

Calibration pulser
at WAIS to optimise
pointing resolution

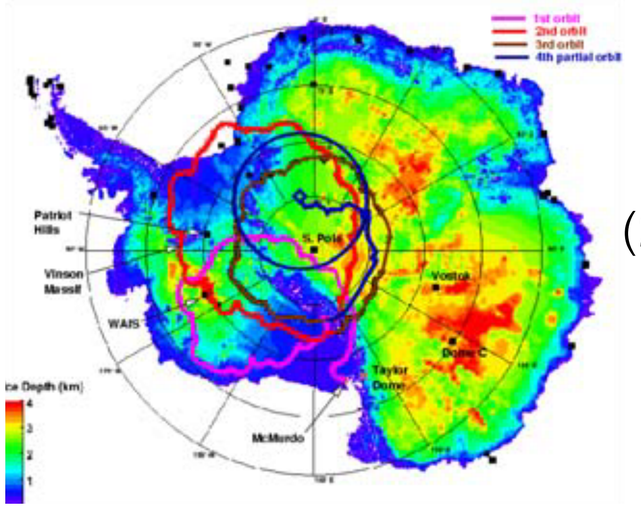
Launched Dec 2nd 2016
from NASA LDB facility,
near McMurdo

ANITA-4
Recovery

- Partial recovery done on Jan 10th 2017
- Full recovery done in December 2017

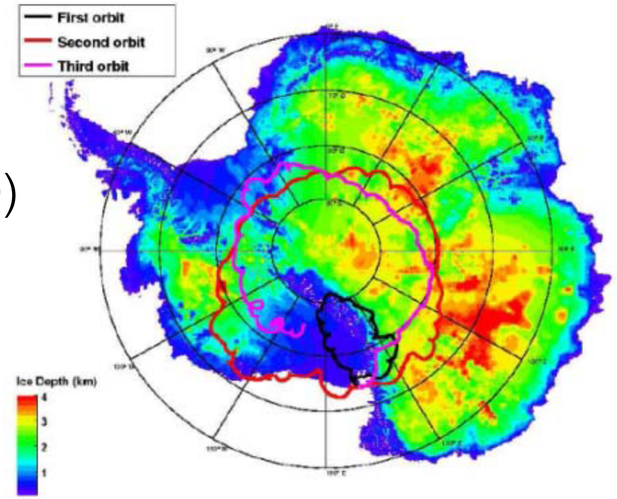
ANITA

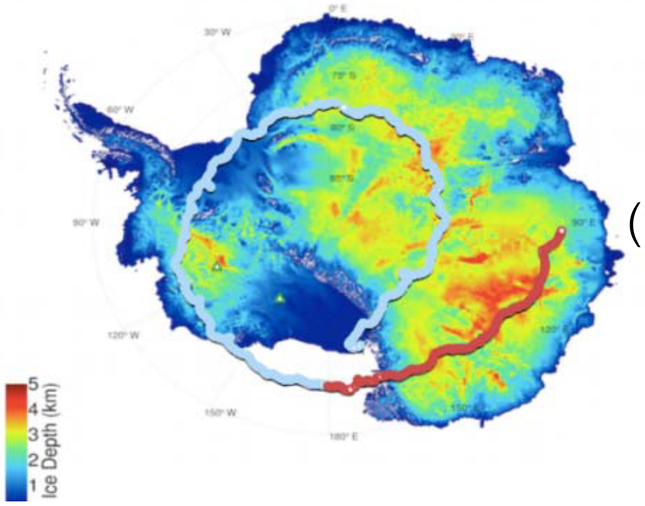
Flights



ANITA-1
(2006-2007)
35 days

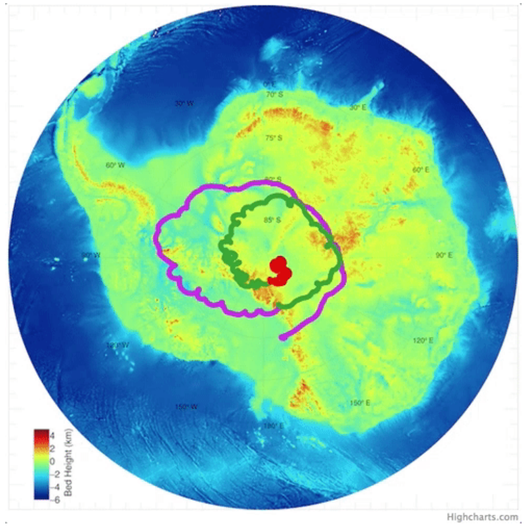
ANITA-2
(2008-2009)
30 days





ANITA-3
(2014-2015)
22 days

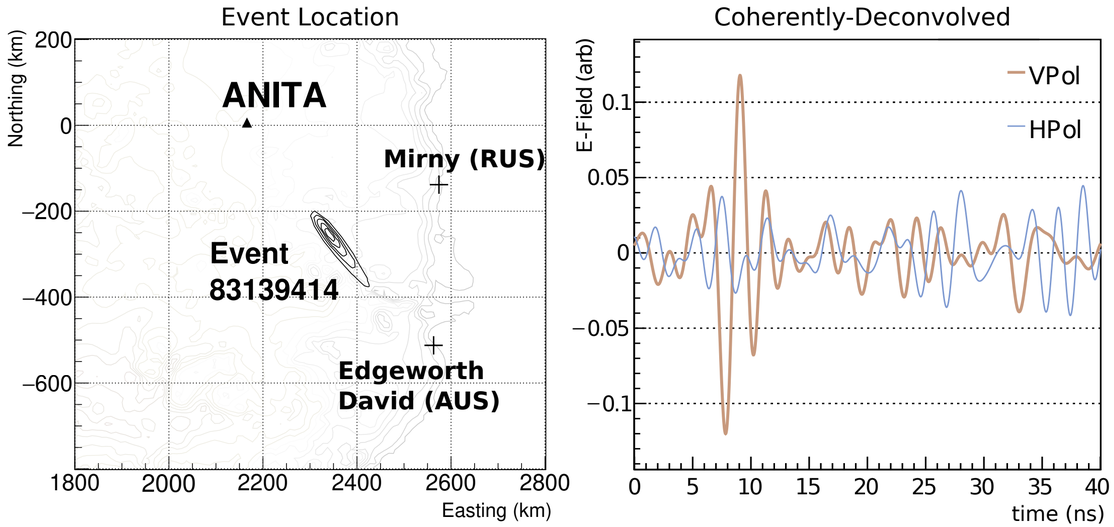
ANITA-4
(2016)
30 days

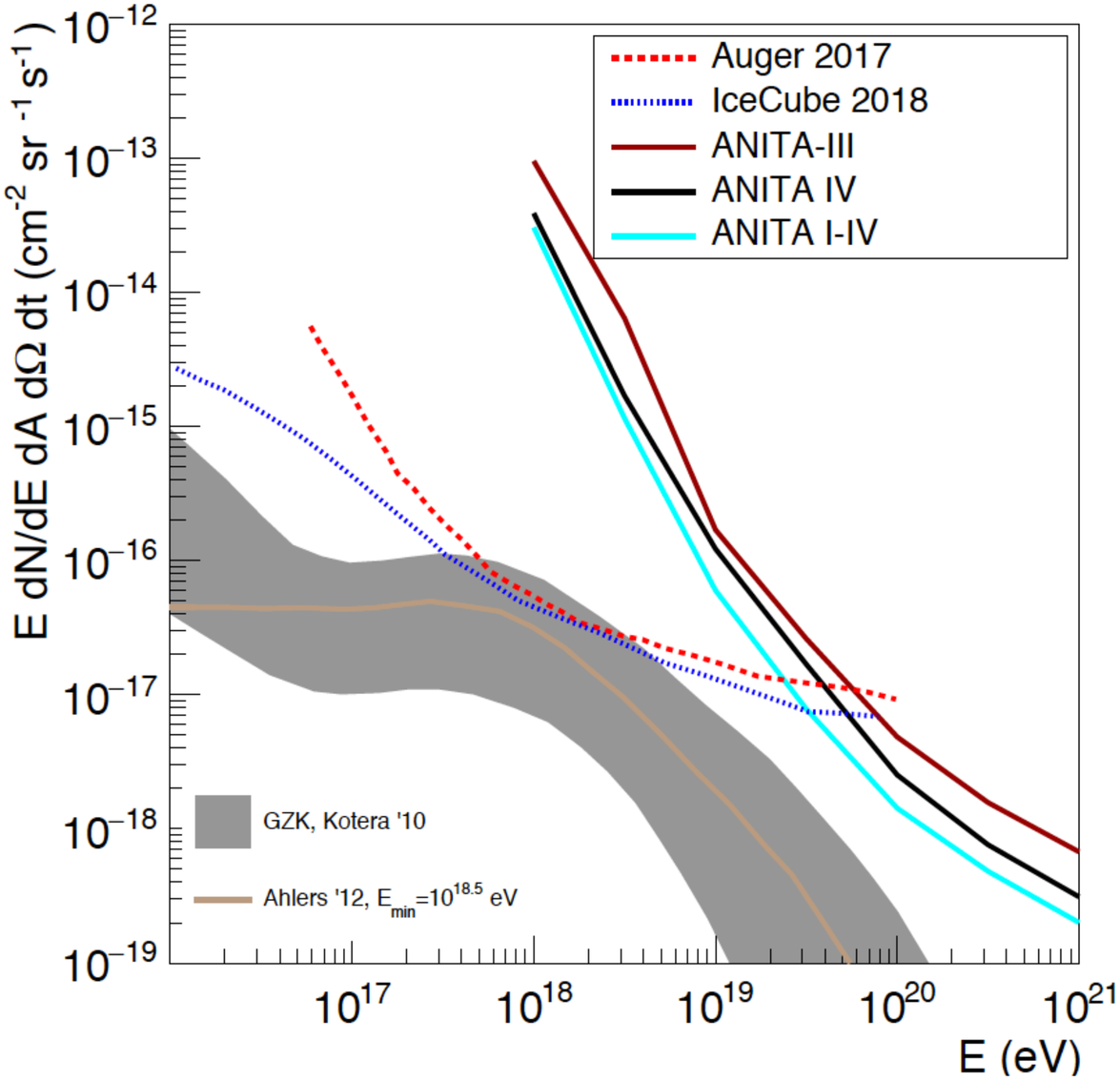


ANITA Neutrino Search

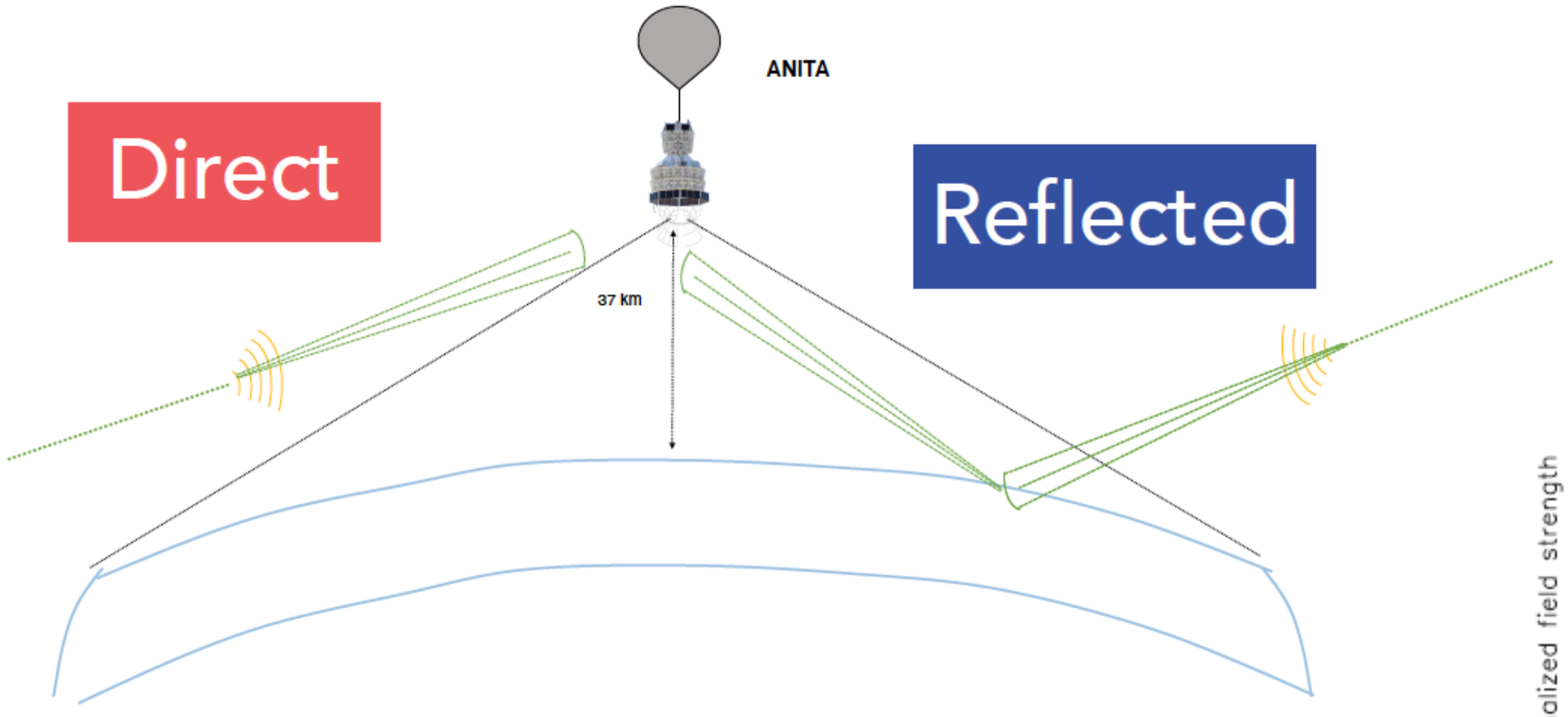
JINST 14.08 (2019), P08011
Phys. Rev. D 99, 122001
Phys. Rev. D 98, 022001

- ANITA-3 and ANITA-4 found 2 events consistent with background estimation
- Most stringent limits at the end of the spectrum

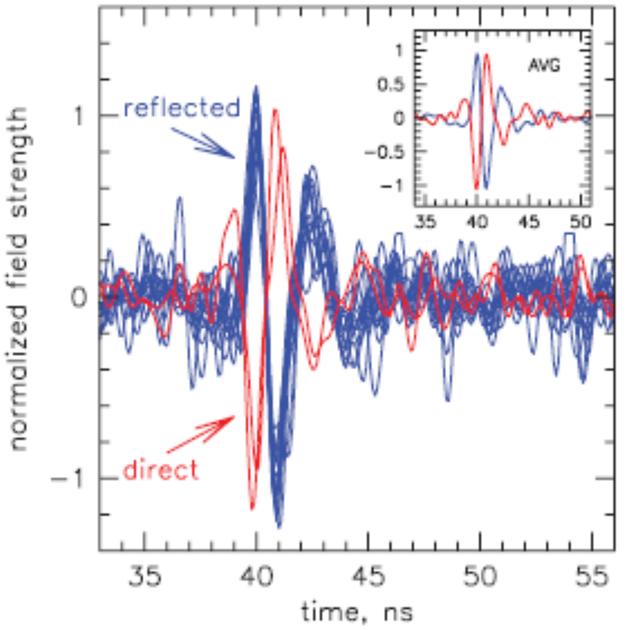




ANITA Cosmic Ray Search

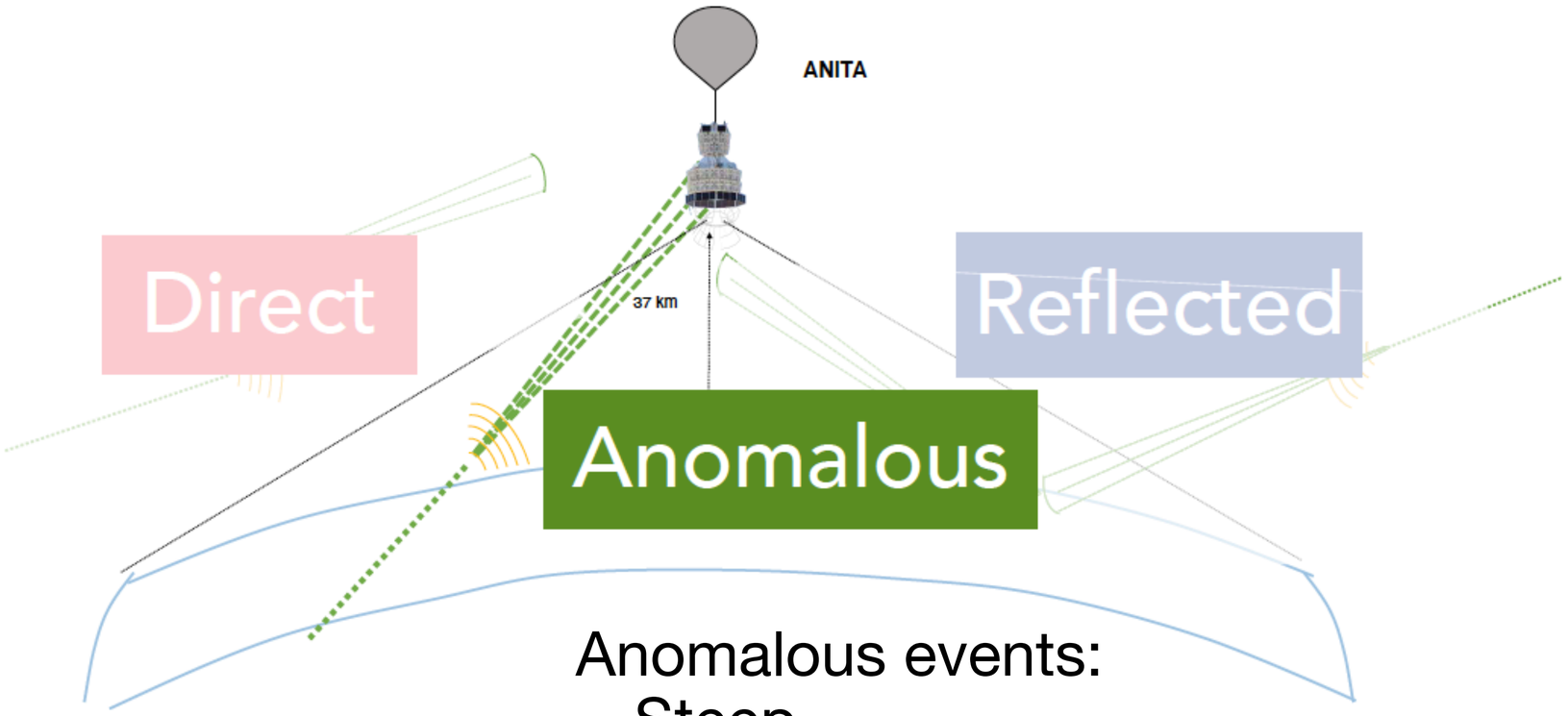


	CR
ANITA-1	16
ANITA-2	2
ANITA-3	28
ANITA-4	29



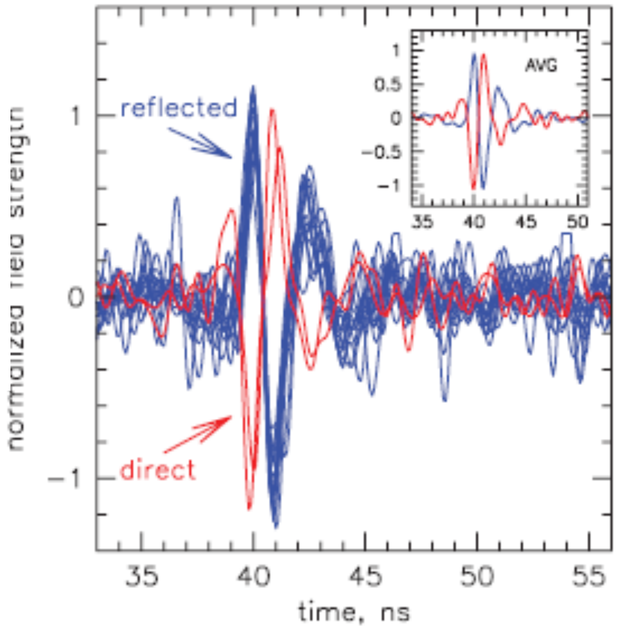
ANITA Anomalous Events

Phys. Rev. Lett. 121, 161102



	Anomalous
ANITA-1	1
ANITA-2	0
ANITA-3	1
ANITA-4	*answer in 2 slides

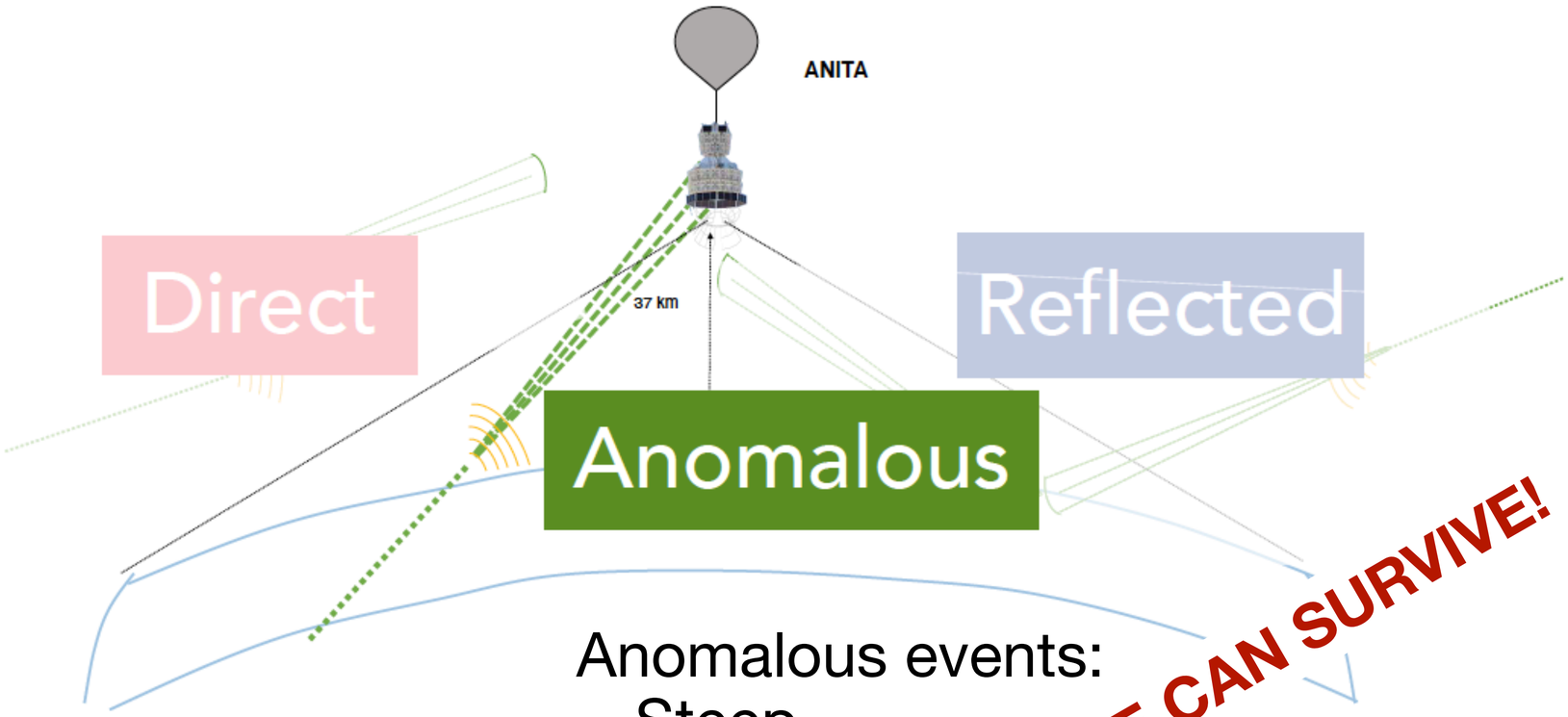
Anomalous events:
- Steep
- Direct



Chord length: 5500-7000 km (20-30,000km water equivalent)
1600km SM interaction length @ 1 EeV

ANITA Anomalous Events

Phys. Rev. Lett. 121, 161102

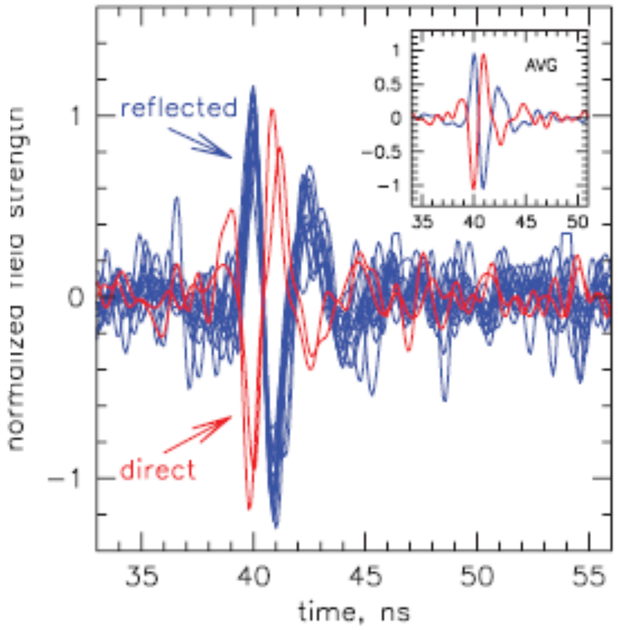


	Anomalous
ANITA-1	1
ANITA-2	0
ANITA-3	1
ANITA-4	*answer in 2 slides

Anomalous events:
- Steep
- Direct

NO SM PARTICLE CAN SURVIVE!

Chord length: 5500-7000 km (20[illegible]00km water equivalent)
1600km SM interaction leng[illegible] EeV



All news is good news?

IFLSCIENCE!

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Scientists Confirm The Electron Is Truly Round, And It's A Big Deal.

PHYSICS
Dandelion Seeds Reveal A New Form Of Aerodynamics

PHYSICS
These Are Stephen Hawking's Last Messages To Humanity

PHYSICS
Stephen Hawking's Final Paper Tackles A Crucial Black Hole Mystery

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NEWS

NASA scientists detect evidence of parallel universe where time runs backward

By Yaron Steinbuch May 19, 2020 | 10:47am | Updated

LIVESCIEN

An Astonishing Discovery Might Have Just Brok Particle Physics

Live Science > Space

Bizarre Particles Keep Flying Out of Antarctica's Ice, and They Might Shatter Modern Physics

By Rafi Letzter, Staff Writer | September 26, 2018 08:16pm ET

News > Weird News > Space

NASA scientists detect parallel universe 'next to ours' where time runs backwards

An experiment in the frozen wastes of Antarctica has revealed evidence of a universe born in the same Big Bang as ours – but with rules of physics that are completely the opposite

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DAILY NEWS 28 September 2018

Weird signals in Antarctica could be hints of a new realm of physics

Moveable Hacking Environment Space Gaming Health Tech Science

COSMIC MYSTERIES | By Daniel Oberhaus | Sep 28 2018, 6:40pm

Mysterious Cosmic Rays Shooting from the Ground in Antarctica Could Break Physics

NASA went searching for micro black holes in Antarctica. Instead, it detected cosmic rays shooting from the ground and some physicists think it could be evidence of a supersymmetric particle.

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BY AMANDA B. KEENER OCTOBER 22, 2018

NEWS PARTICLE PHYSICS

Hints of weird particles from space may defy physicists' standard model

Mail

Is there a mirror universe? Researchers in Antarctica observe mysterious particles that some argue is evidence of a parallel world formed at the Big Bang where time runs backward

- Scientists traveled to Antarctica looking for high energy particles from space
- Instead, they were surprised to find them coming from Earth
- The team believed the unexpected behavior suggested a new kind of particle
- Some explain the particle's strange behavior by suggesting it came from a mirror universe created at the same time as the Big Bang, where time flows backward

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One in three Britons has cor

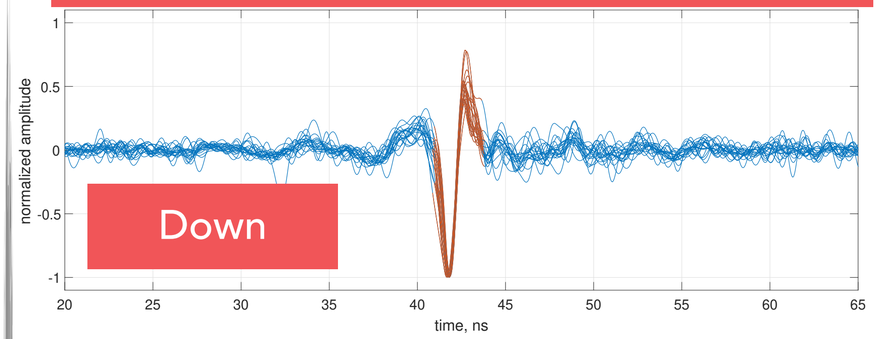
Slide from S. Wissel (Neutrino 2020, talk and video)

ANITA-4 CR WAVEFORMS

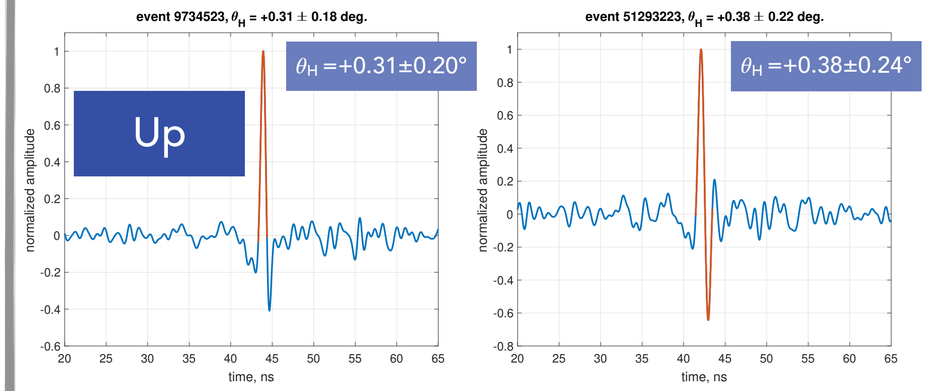
- Events classified by **1st Dominant Pole***
  - **Reflected:** Down or Down first
  - **Direct:** Up or Up first

*Polarity reconstruction via 4 deconvolution methods using Stokes amplitude to find the peak lobe(s)

21 Reflected Events, Below Horizon



2 Direct Events, Near & Above Horizon



Slide from S. Wissel (Neutrino 2020, talk and video)

ANITA-4 CR WAVEFORMS

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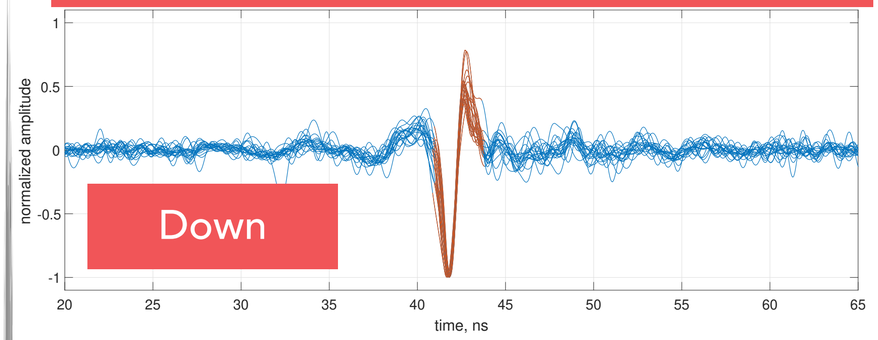
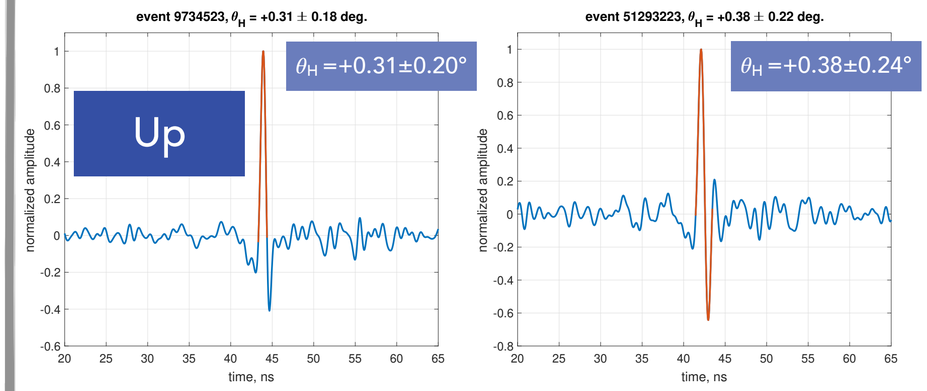


2 Direct Events, Near & Above Horizon



4 additional events
near the horizon, but *below* it

Expect the same polarity as the reflected events: **Down**

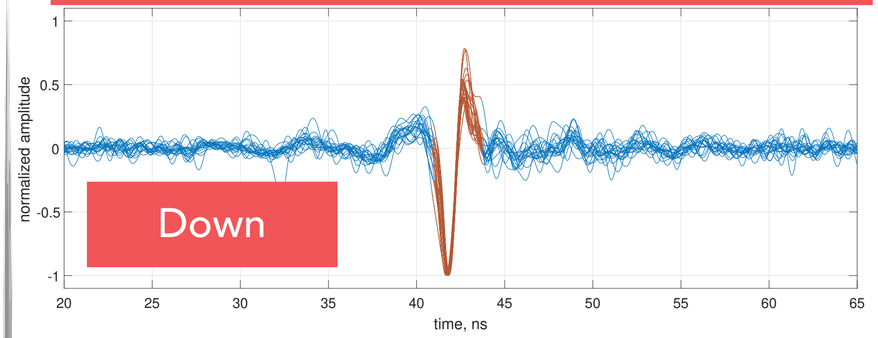
Slide from S. Wissel (Neutrino 2020, talk and video)

ANITA-4 CR WAVEFORMS

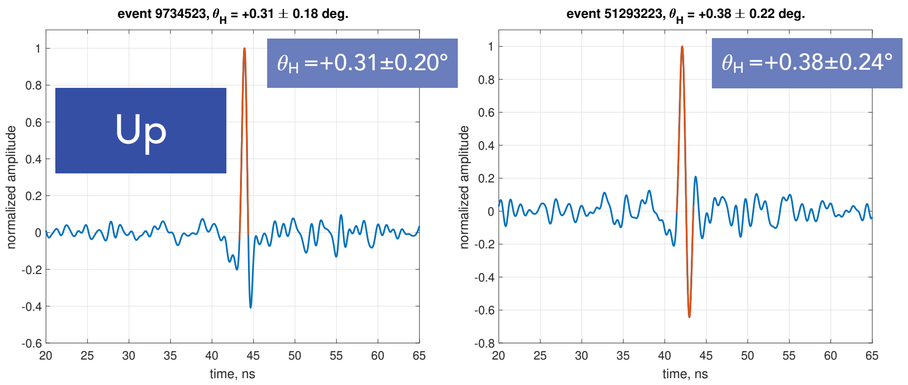
- Events classified by **1st Dominant Pole*** Preliminary
  - **Reflected:** Down or Down first
  - **Direct:** Up or Up first

*Polarity reconstruction via 4 deconvolution methods using Stokes amplitude to find the peak lobe(s)

21 Reflected Events, Below Horizon

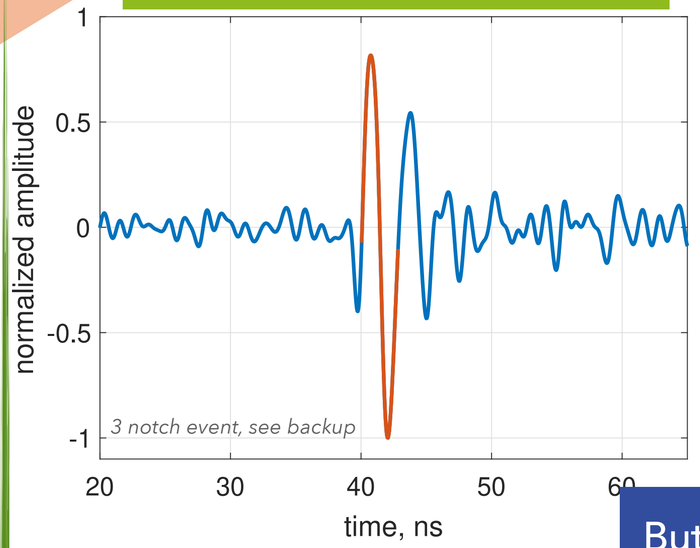


2 Direct Events, Near & Above Horizon

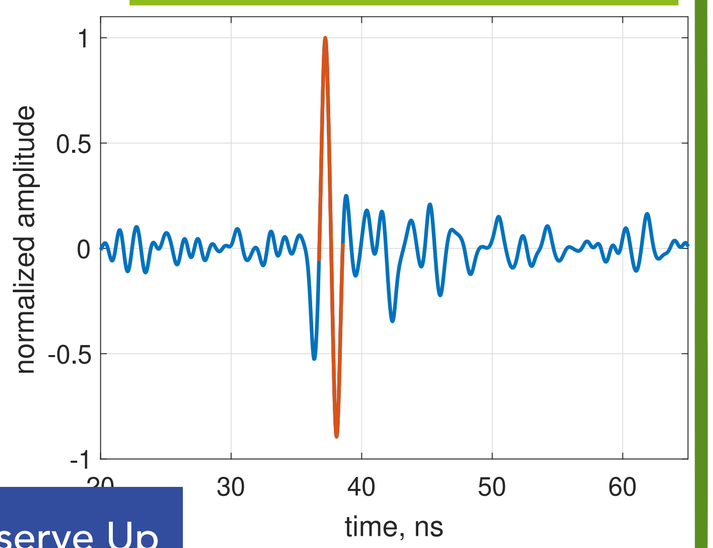


4 Direct Events, Near & Above Horizon

4098827, θ_H = -0.25±0.21°

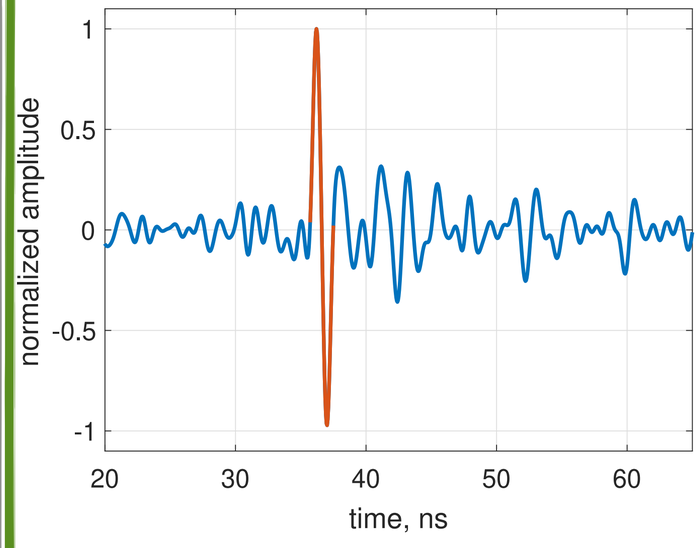


19848917, θ_H=-0.65±0.20°

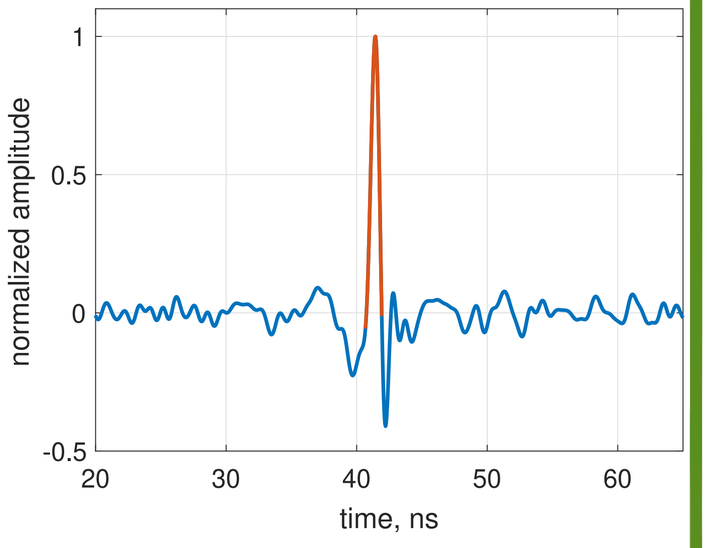


But observe Up

50549772, θ_H = -0.81±0.20°



72164985, θ_H = -0.19±0.10°



ANITA-4 Air Shower Results

Slide from S. Wissel (Neutrino 2020, talk and video)

- **29 on background of $0.37^{+0.27}_{-0.17}$** events result from blinded search for Hpol, impulsive, isolated events. Remained blind to polarity*
- **4 / 27 near horizon events** with inconsistent polarity with significance **~3σ** Preliminary
- Systematics in significance estimate include :
  - anthropogenic background per polarity ($0.19^{+0.14}_{-0.09}$ events)
  - polarity mis-reconstruction (10^{-2} for 1 event; 10^{-4} others)
  - pointing error ($\delta\theta$ = 0.1°, bias ±0.1°)
  - radio propagation effects (refraction, ice surface, ray defocusing)
- **No new steep events** with inconsistent polarity like in ANITA-1 & ANITA-3

Preliminary

Results from targeted CR search		
Angle wrt horizon	**Steep** > 1°	**Near Horizon** < 1°
Total Events	23	6
Consistent with Geometry		
Reflected (Down)	21	0
Direct (Up)	0	2
Inconsistent with Geometry		
Direct (Up)	**0**	**4**
Indeterminate Polarity		
	2	0
Total	**29**	

See posters #552 (ANITA-4) and #486 (PUEO)

What's next?

- ANITA-4 Cosmic ray and tau papers will come out soon
- Dedicated source searches is underway
- PUEO (Payload for Ultra-high Energy Observations) planning flight in 2023
- I will keep a small involvement in ANITA/ PUEO

Constrain the end of the neutrino spectrum by 4-10x

High effective area for transients

Lower threshold by phasing 2x antennas at trigger level

"Guess who's back?"

Interlude: Neutrino oscillations and neutrino interactions

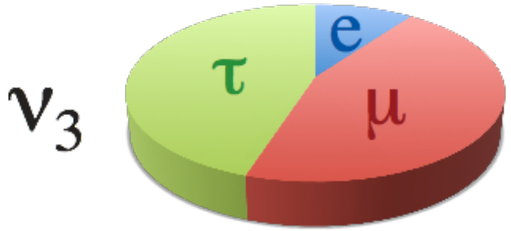
Sandbox Studio, Chicago

“Guess who’s back?”

Why neutrino oscillations?

New symmetry?

How much do neutrinos mix?



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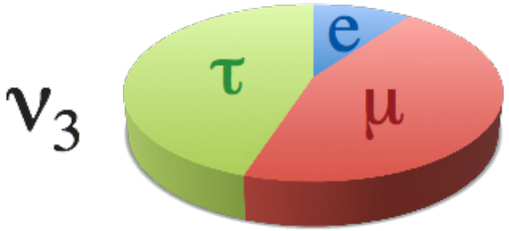
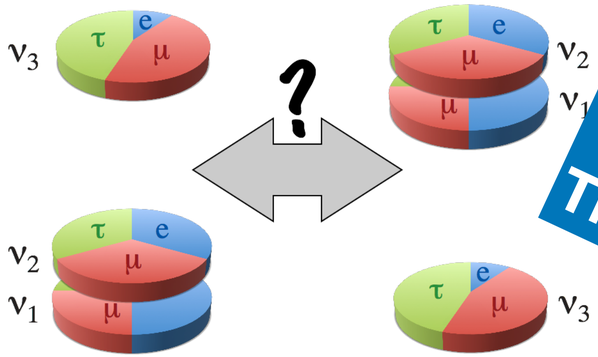


Majorana?

Which is the lightest neutrino?



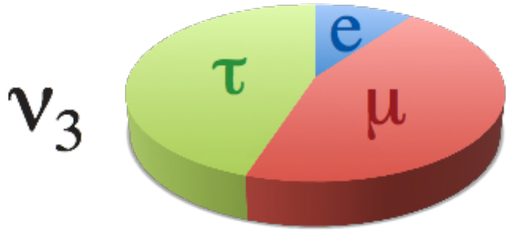
Grand Unified Theories

Normal Ordering Inverted Ordering

Why neutrino oscillations?

New symmetry?

How much do neutrinos mix?



Majorana?

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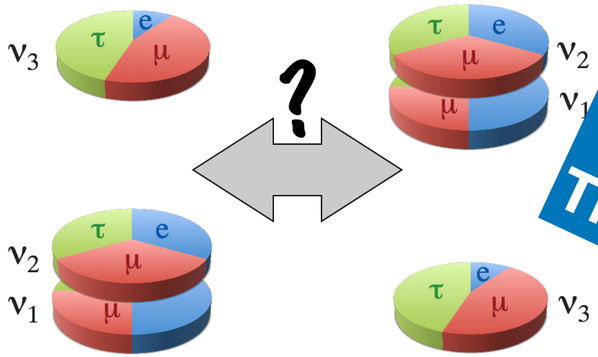


Grand Unified Theories

Normal Ordering Inverted Ordering

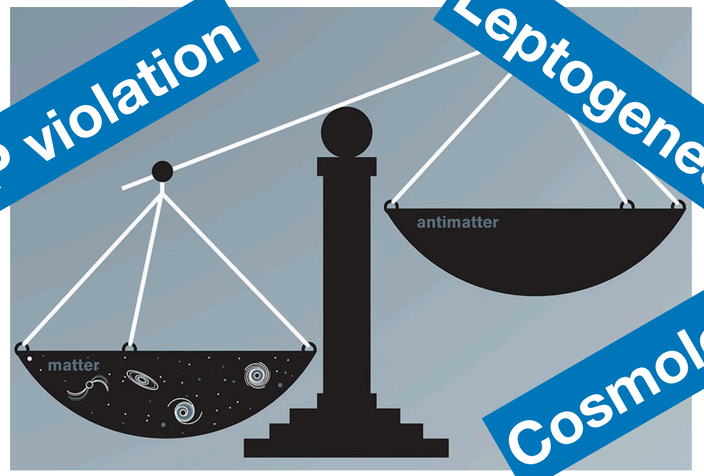
Do neutrinos and antineutrinos oscillate in the same way?

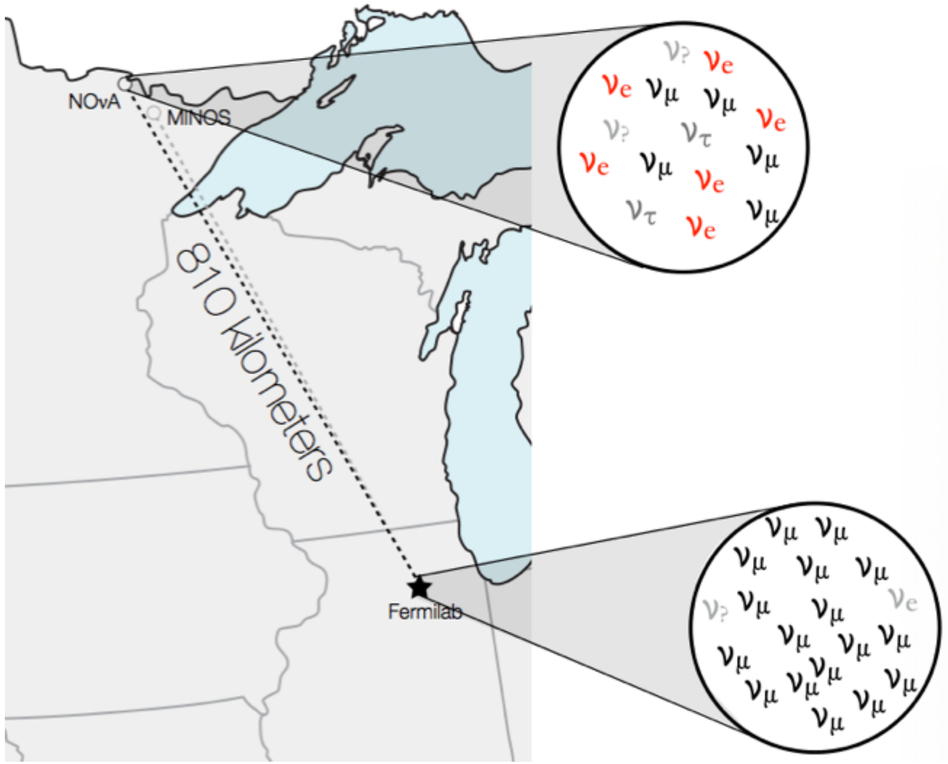
?

CP violation

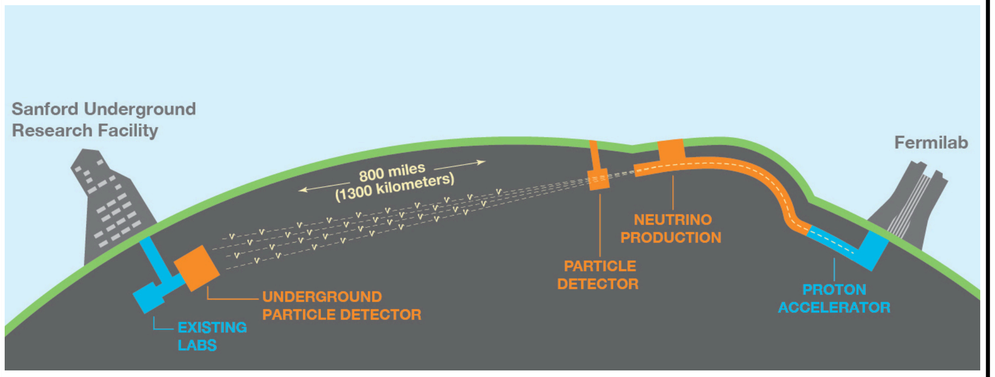
Leptogenesis

Cosmology





Set to discover neutrino mass ordering

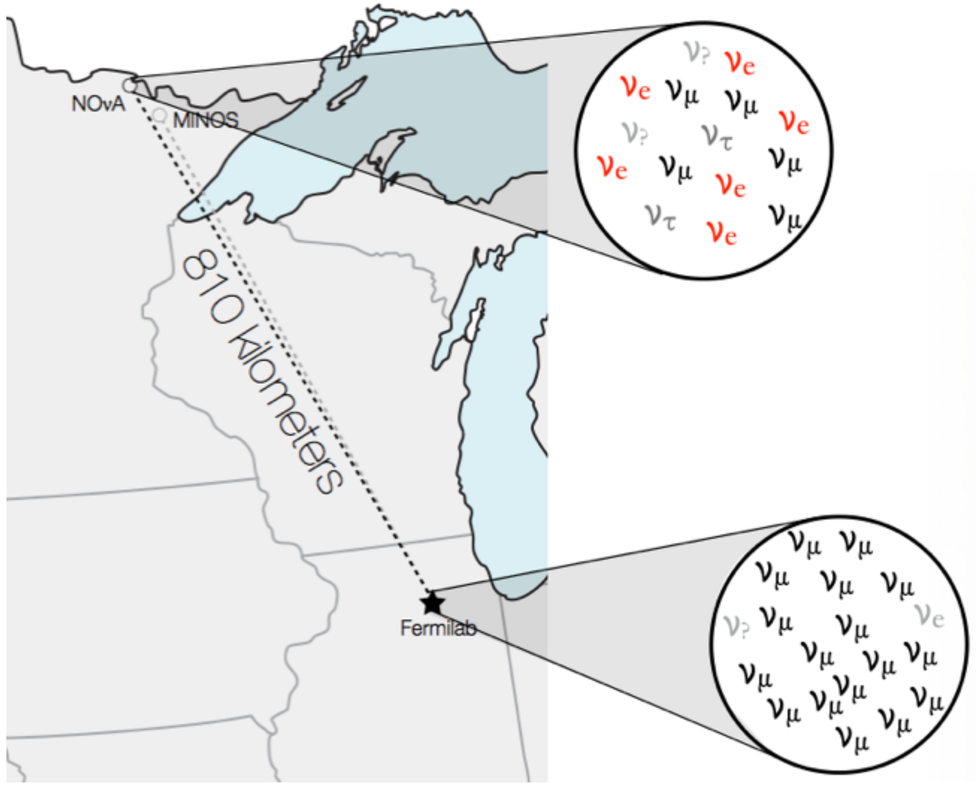


Under construction

Set to measure matter/antimatter asymmetry in the universe

The NOvA experiment

- NOvA is a long-baseline neutrino experiment:
  - 2 detectors, 14 mrad off-axis, 809 km apart.
  - Designed to measure for $\nu_\mu \rightarrow \nu_e$ oscillations: detectors provide excellent imaging of both ν_μ and ν_e CC events.
- NOvA can run in neutrino-mode or antineutrino-mode.



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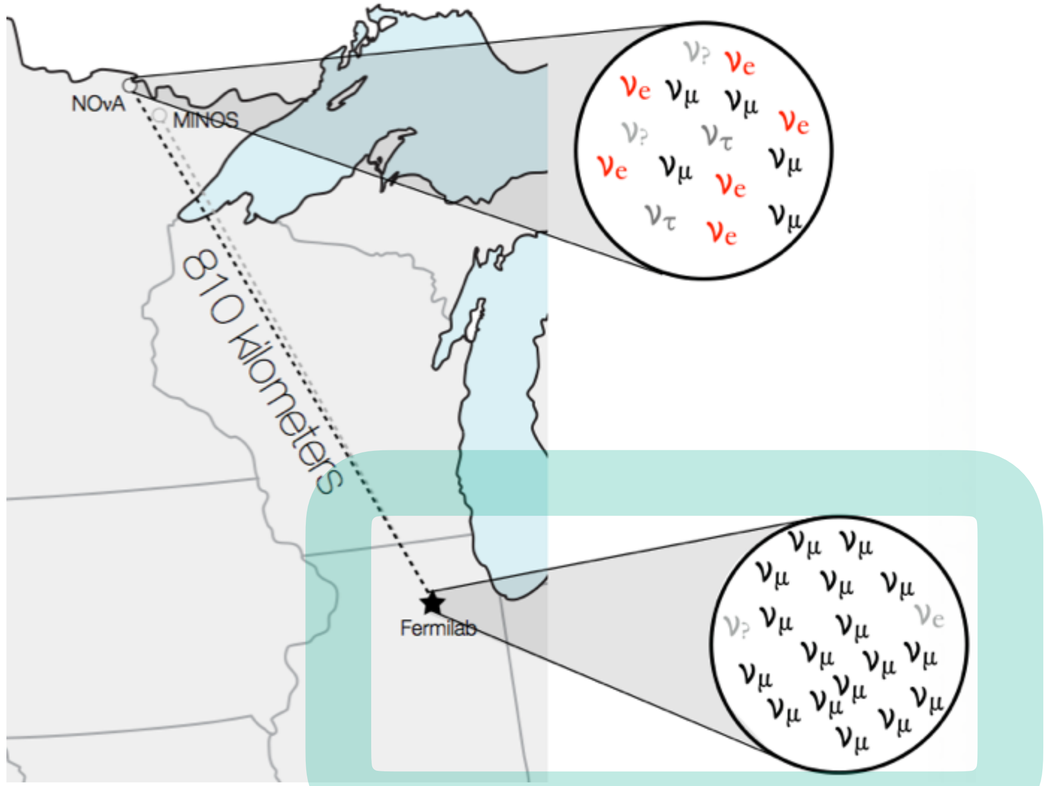
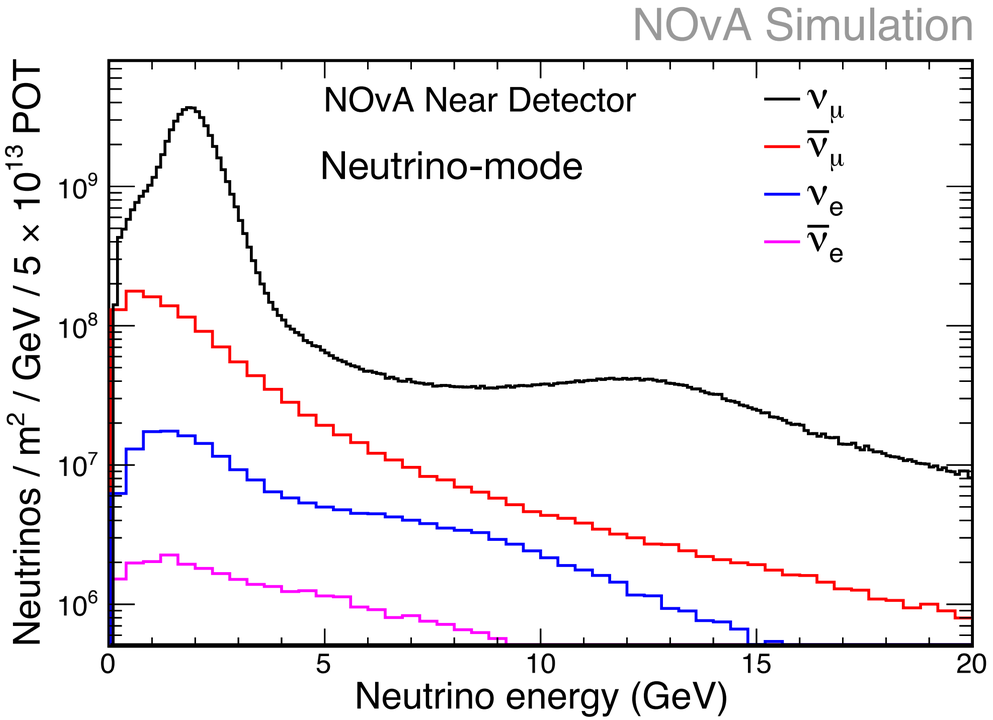


- High neutrino flux at Near Detector:
  - used as control for the oscillation analyses,
  - provides a rich data set for measuring cross sections.
- ND located 1km from the NuMI beam target.
- 96% pure ν_μ beam, 1% ν_e and $\overline{\nu}_e$



"Guess who's back?"

Measuring neutrino oscillations

$$N \approx \Phi(E_\nu) \otimes \sigma(k, k') \otimes \epsilon \otimes P(\nu_\alpha \rightarrow \nu_\beta)$$

Events at FD $\approx$

Measuring neutrino oscillations

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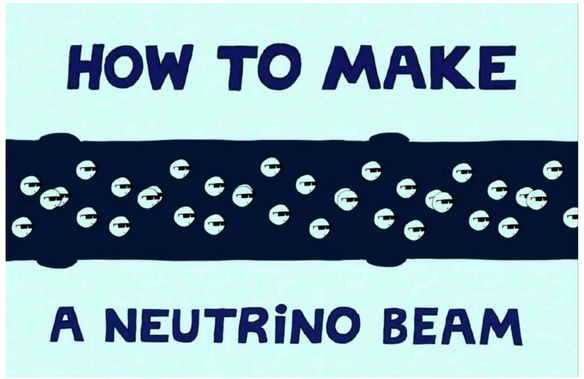
Events at FD $\approx$ Neutrino flux



https://youtu.be/U_xWDWKq1CM

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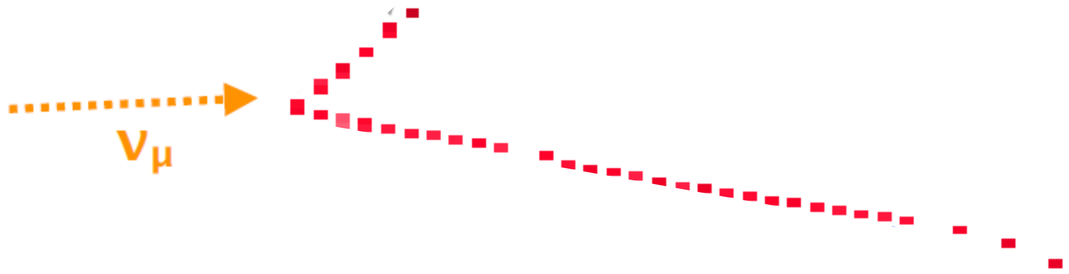
Events at FD $\approx$ Neutrino flux $\otimes$ Neutrino interactions

https://youtu.be/U_xWDWKq1CM



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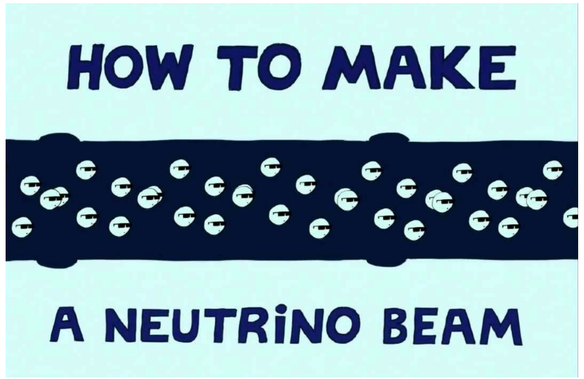

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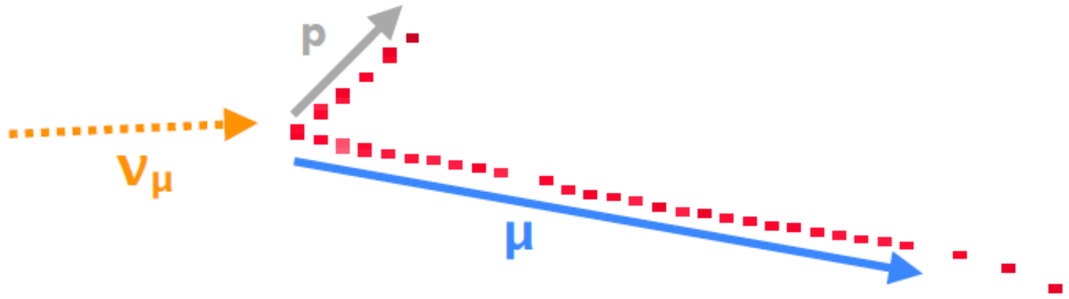

Measuring neutrino oscillations

$$N \approx \Phi(E_\nu) \otimes \sigma(k, k') \otimes \epsilon \otimes P(\nu_\alpha \to \nu_\beta)$$

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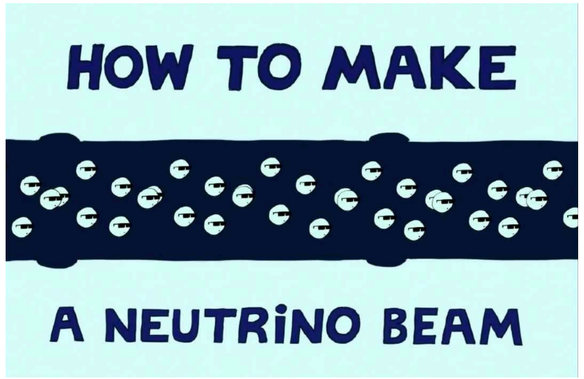

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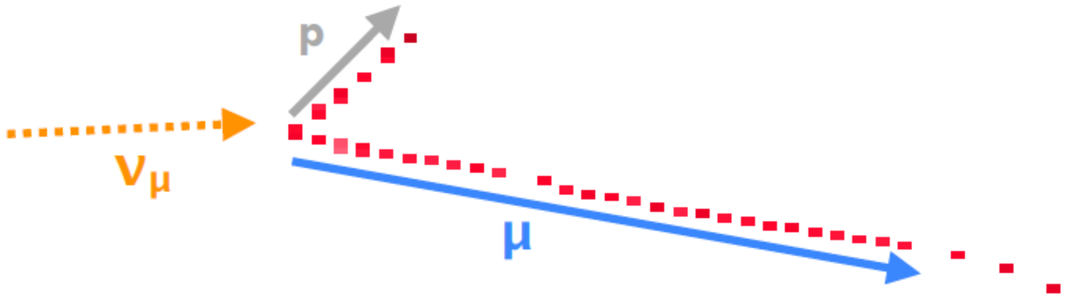
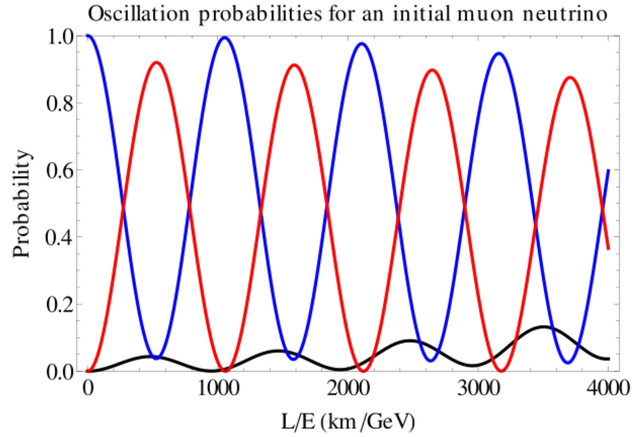
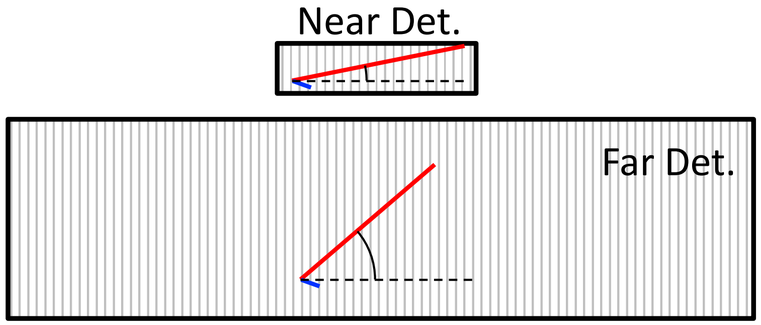
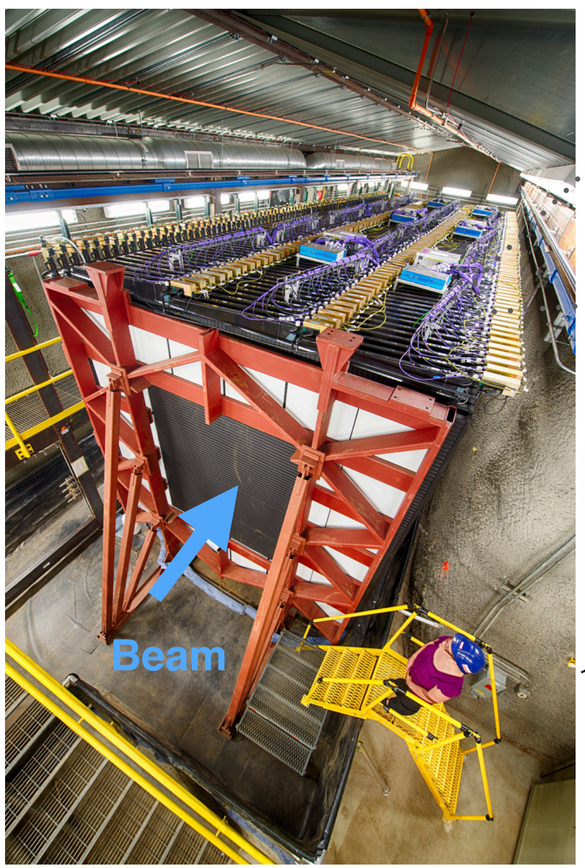
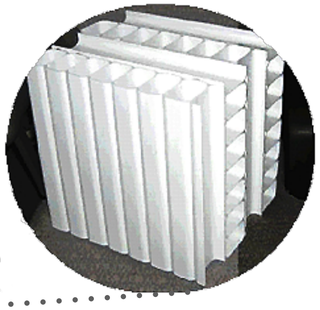


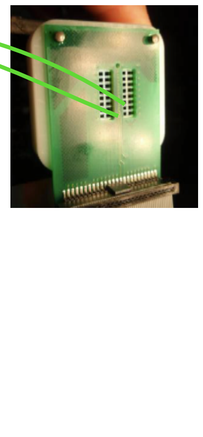


NOvA detectors

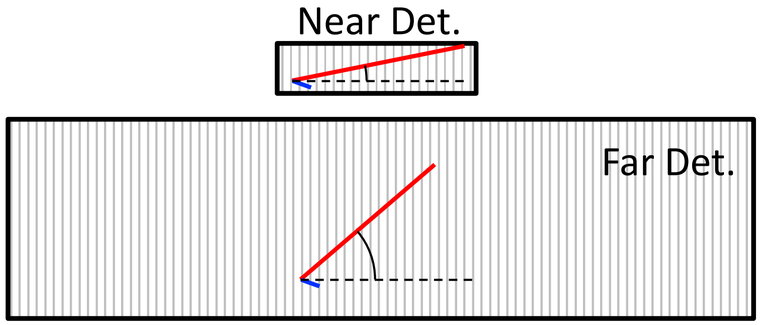


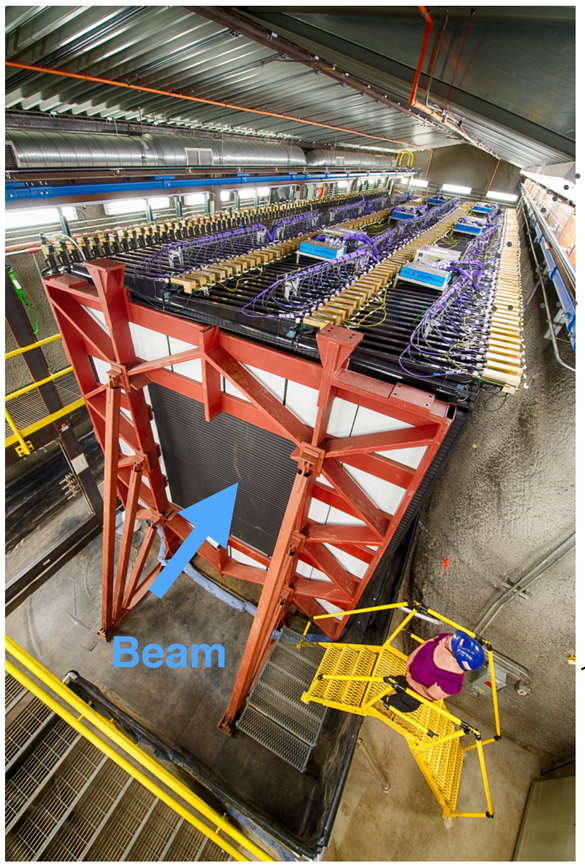


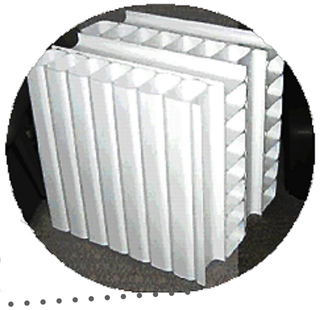


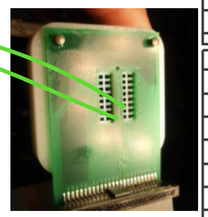


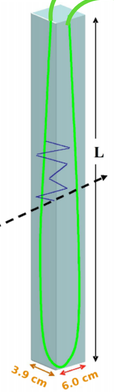
NOvA detectors

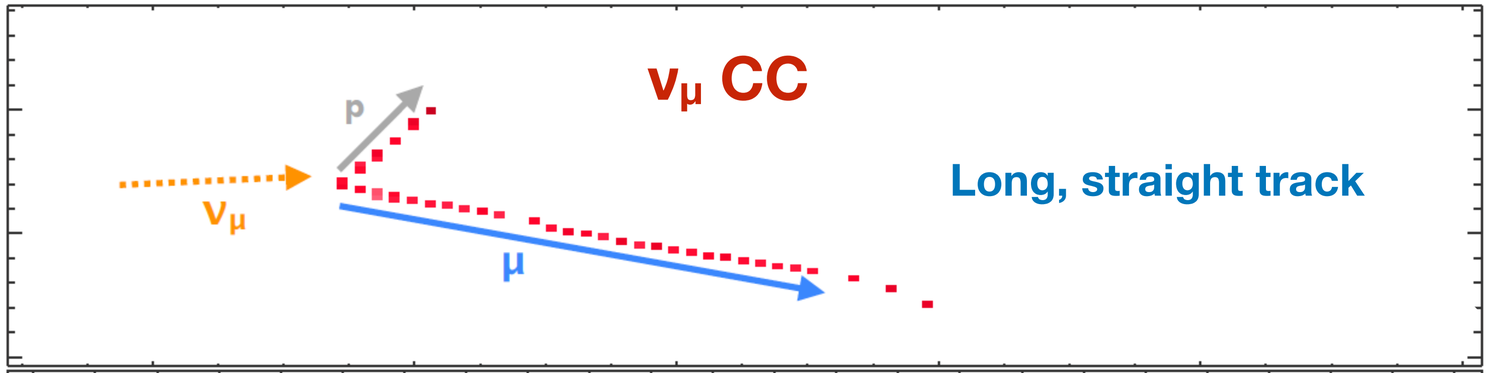


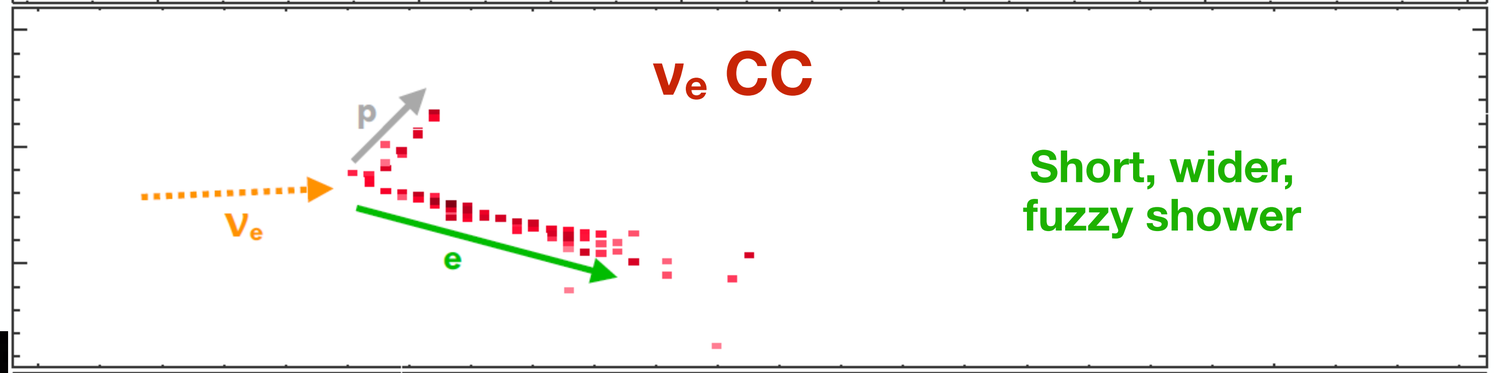


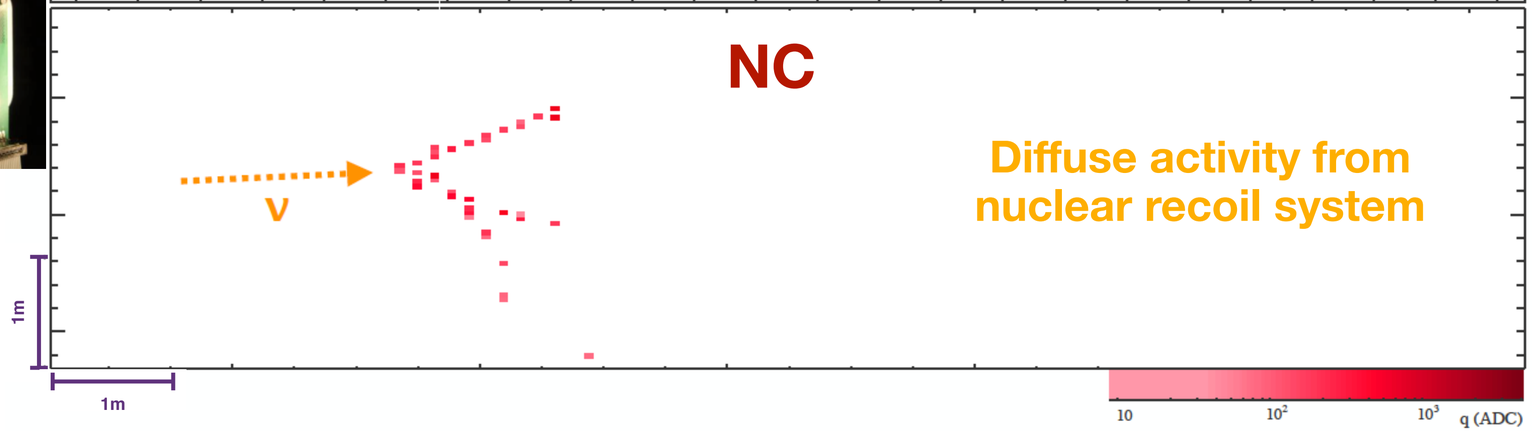






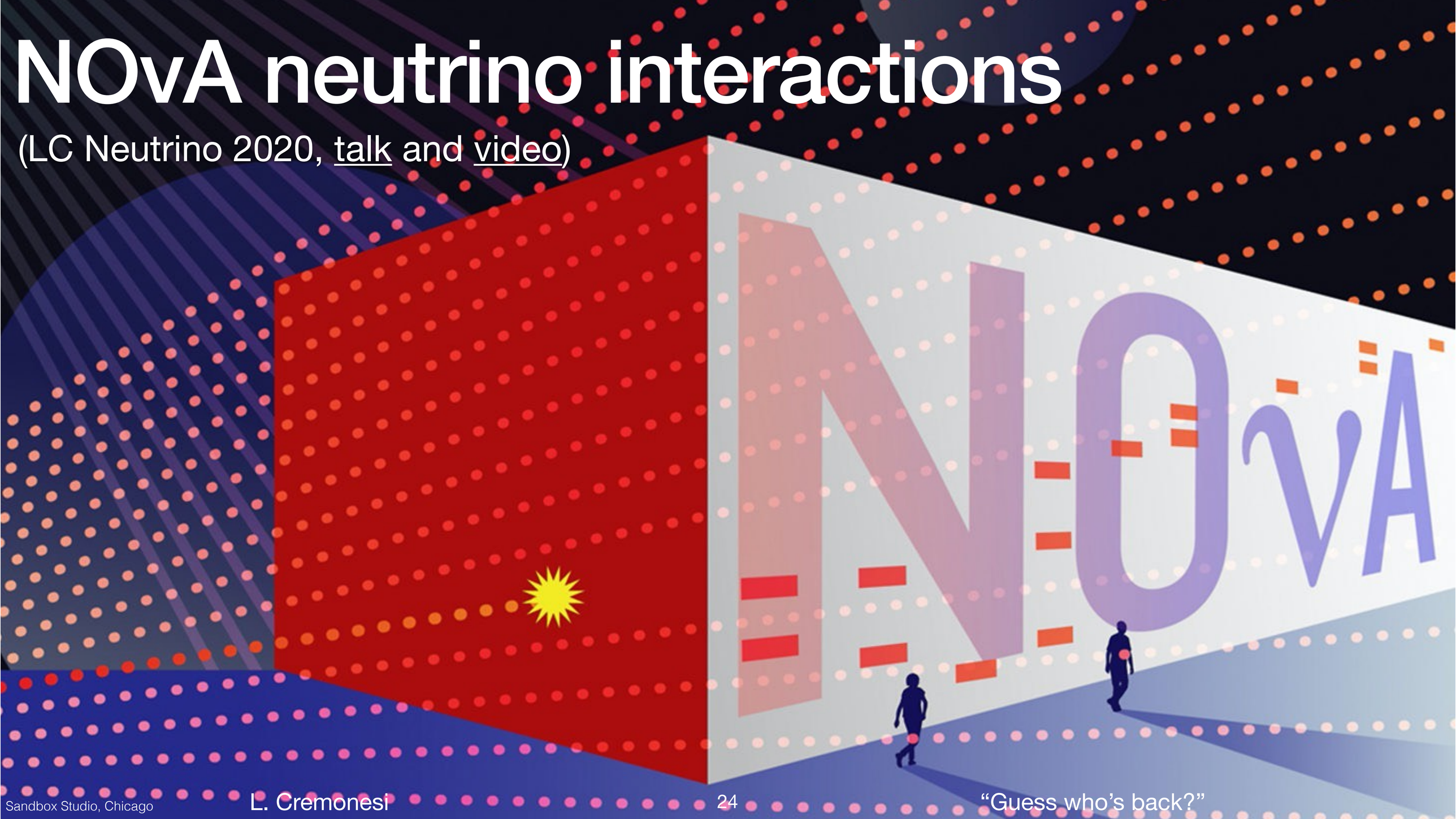




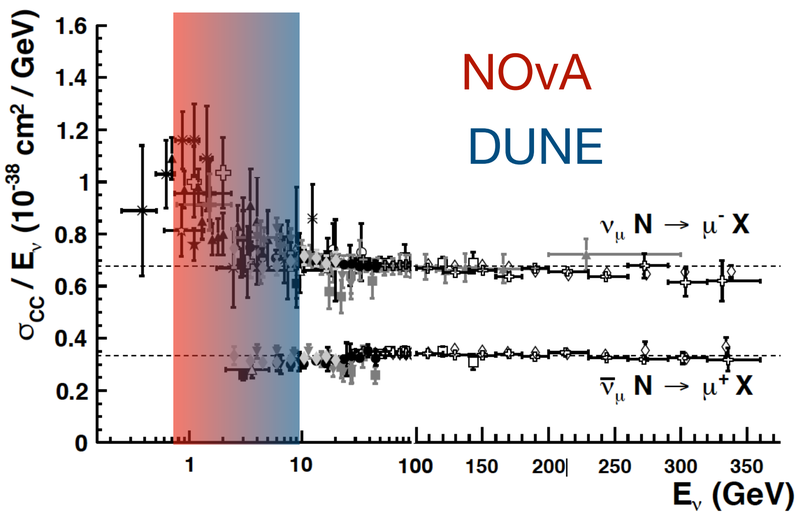


NOvA neutrino interactions

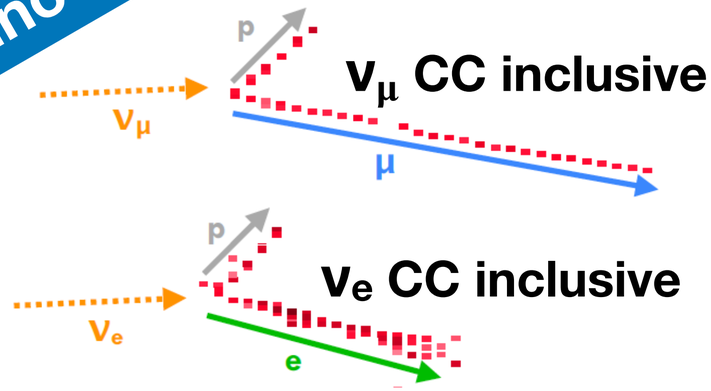
(LC Neutrino 2020, talk and video)

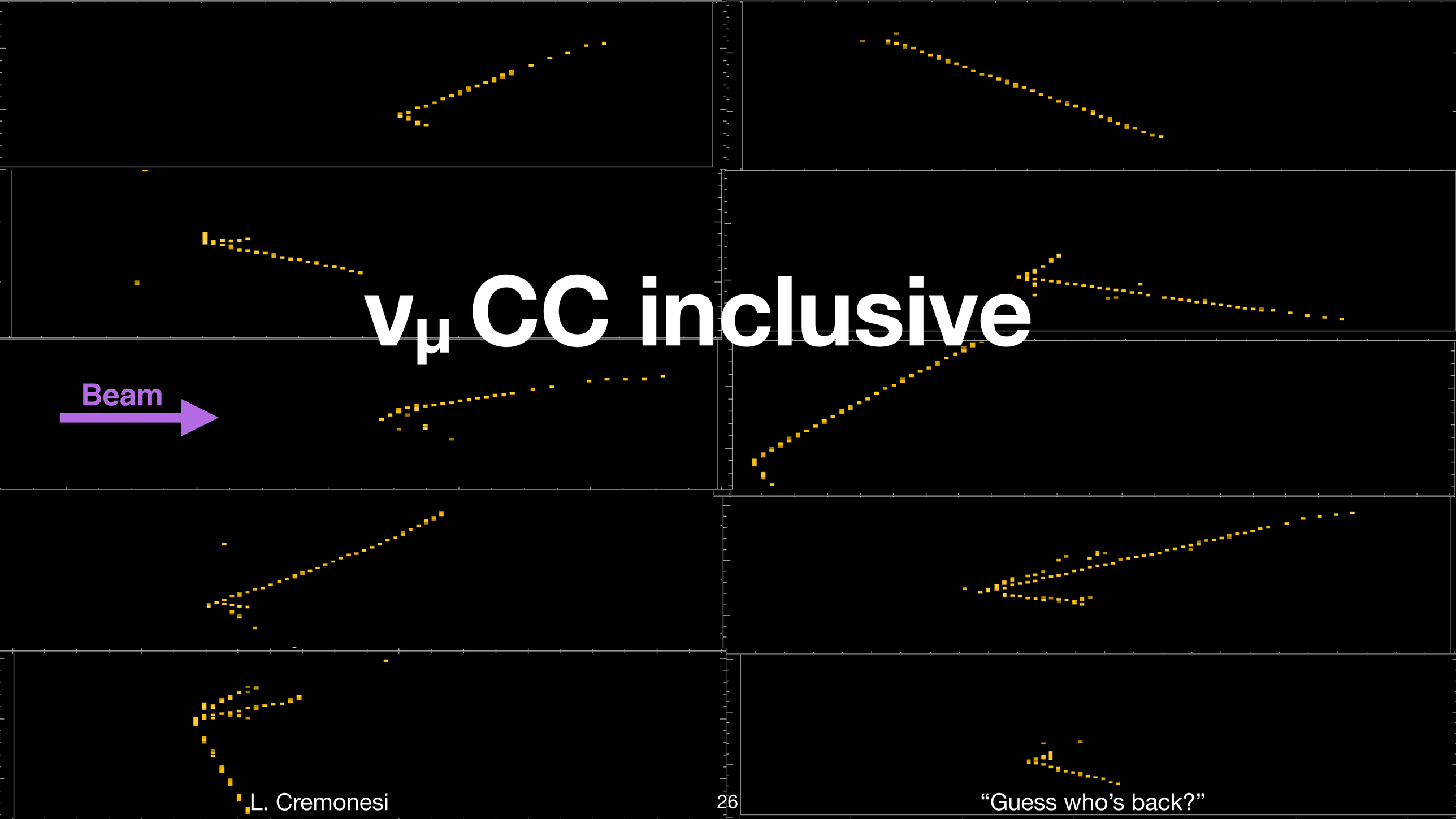


NOvA cross section programme



Neutrino 2020

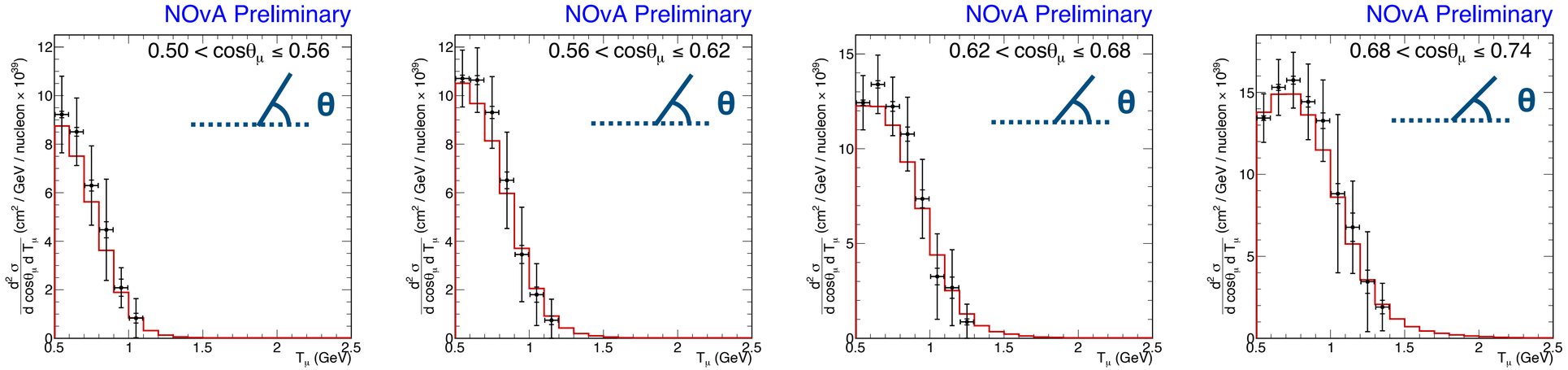


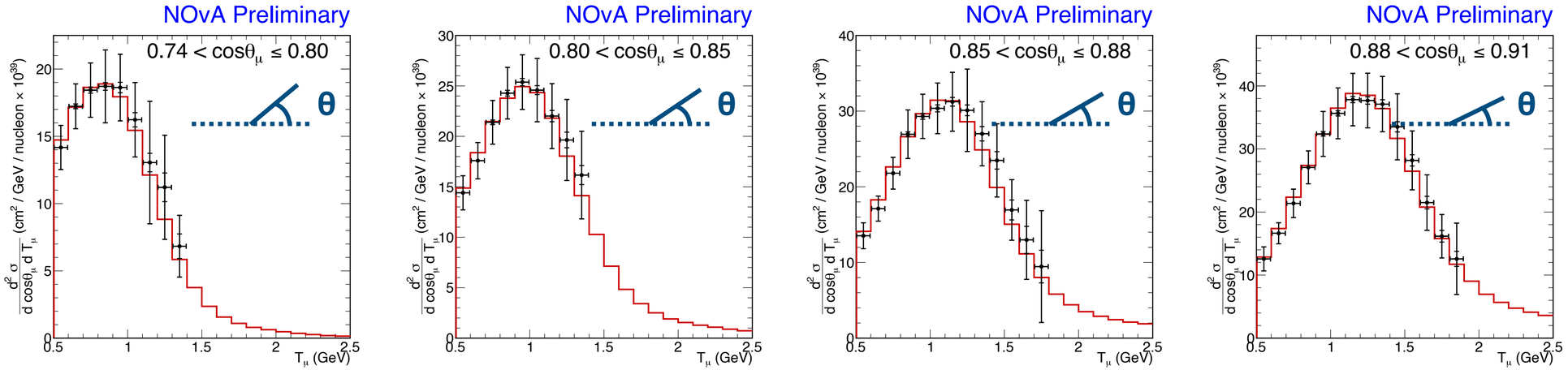


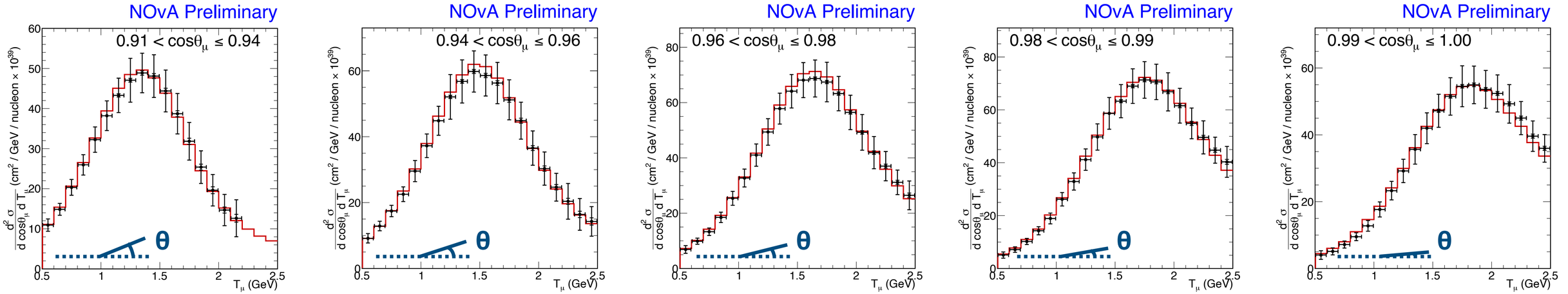
ν_μ CC inclusive

ν_μ CC inclusive

More than 1M ν_μ CC events in our selection





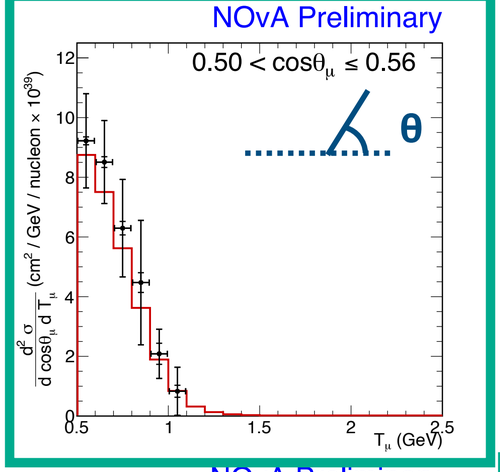


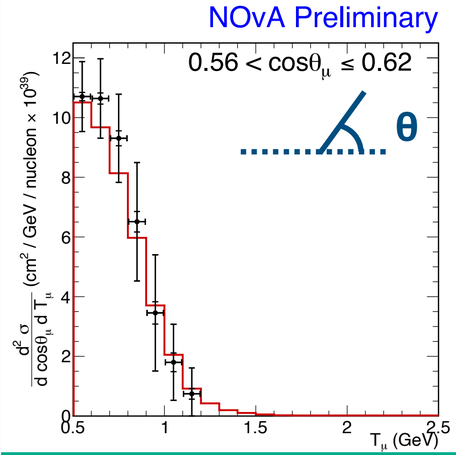
Results in 1-page

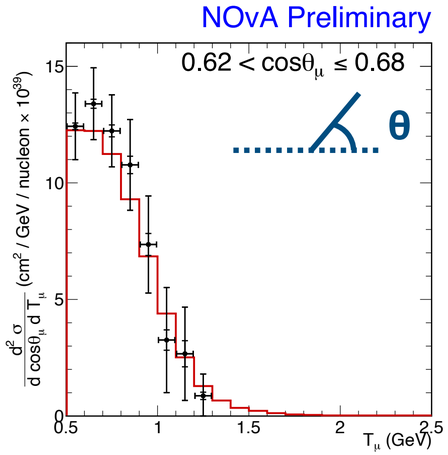
ν_μ CC inclusive

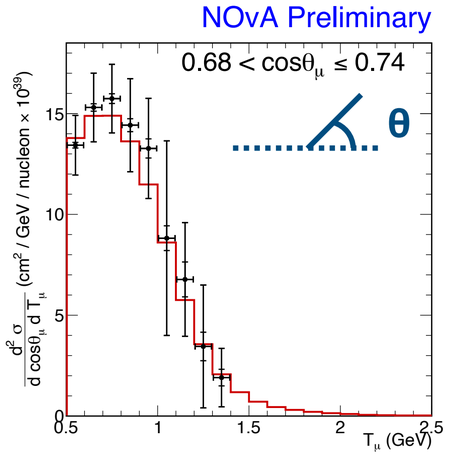
Data (Stat. + Syst.)

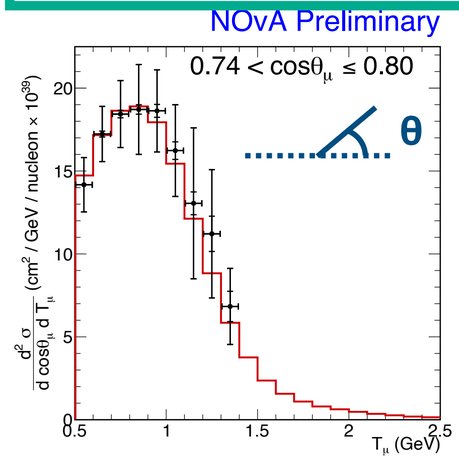
GENIE 2.12.2 - NOvA Tune

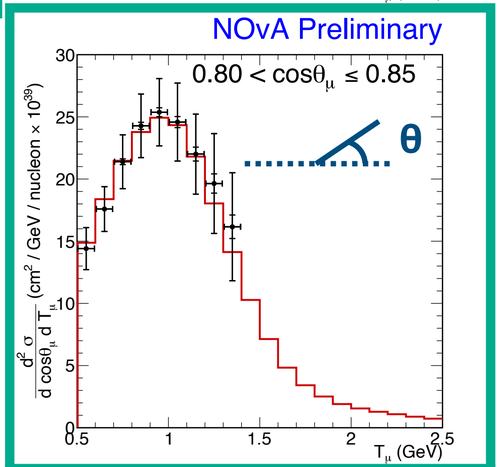


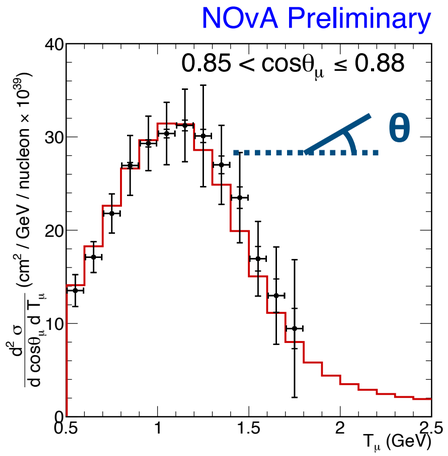


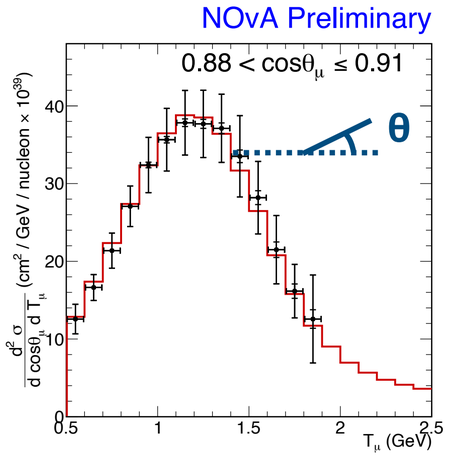


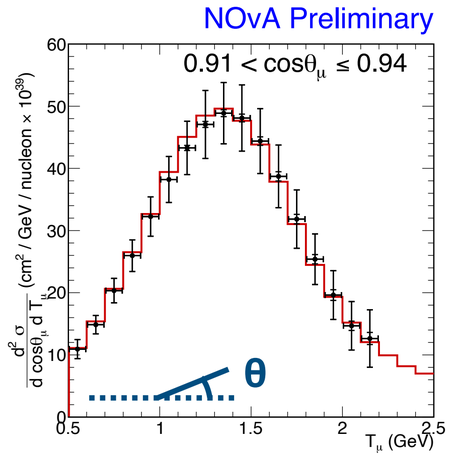


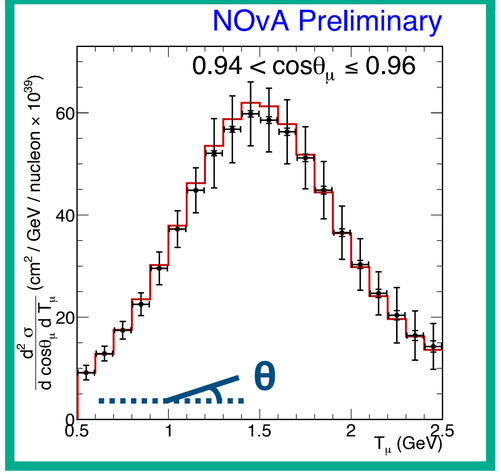


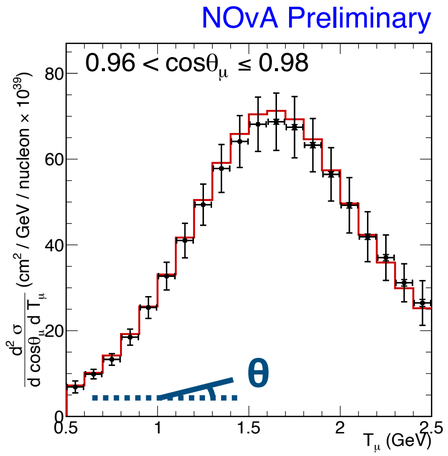


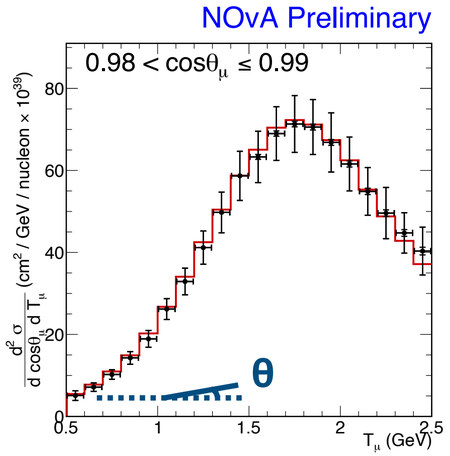


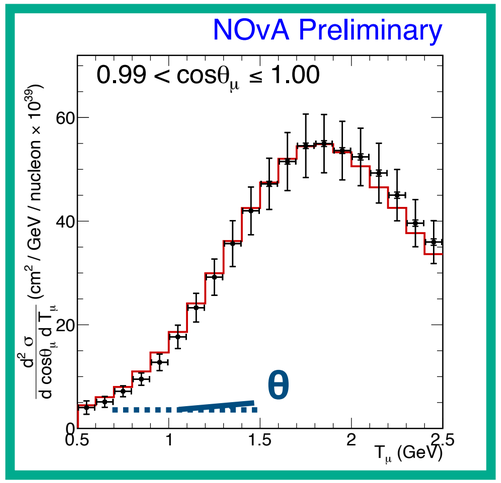










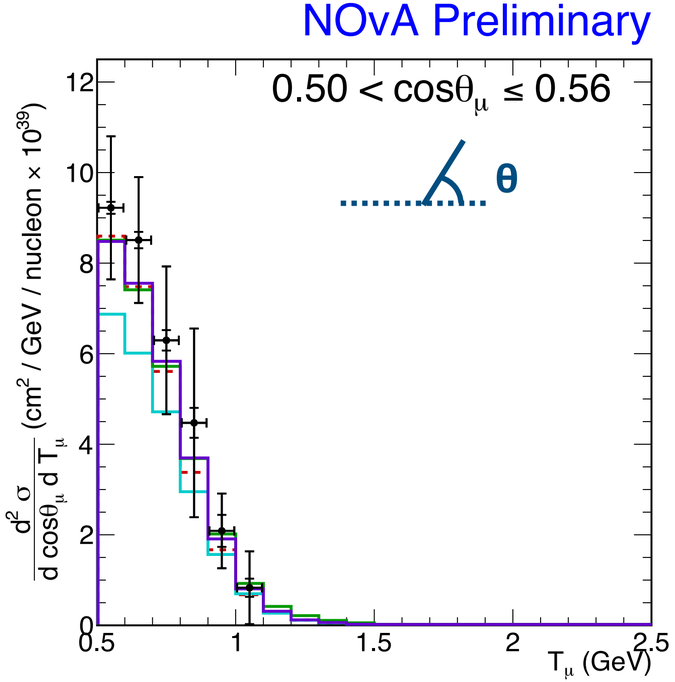


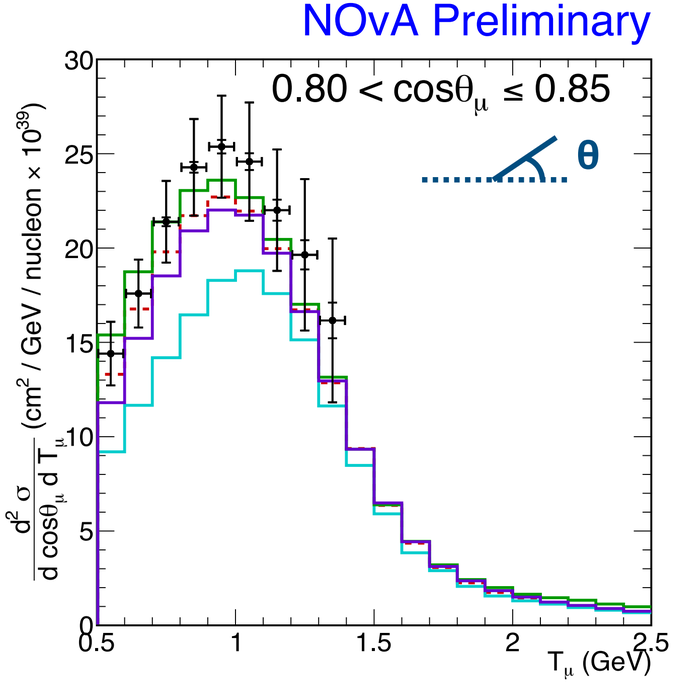
Results in 1-page

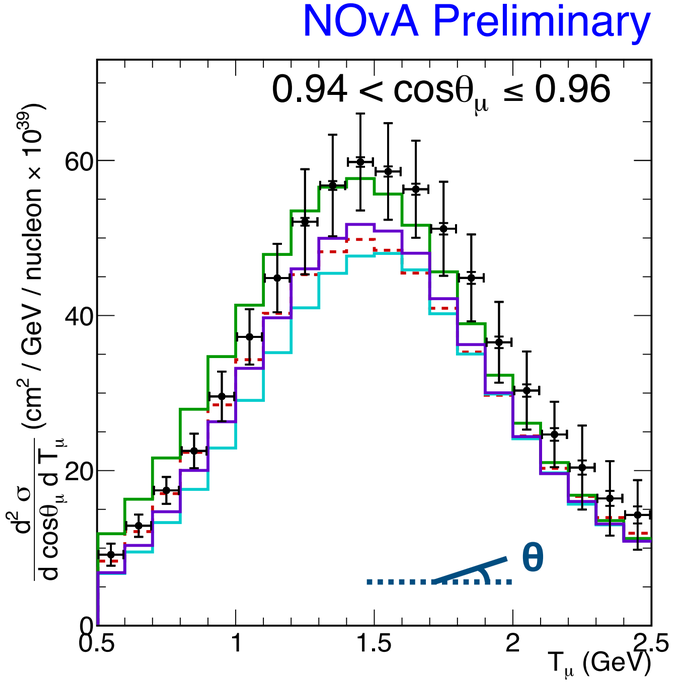
ν_μ CC inclusive

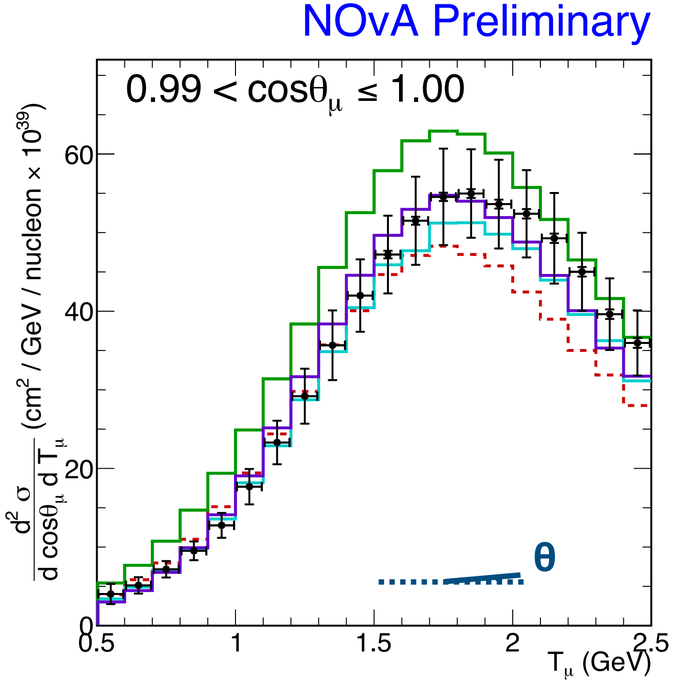
Data (Stat. + Syst.)

GENIE 2.12.2 - NOvA Tune









Example 4 cosine slices

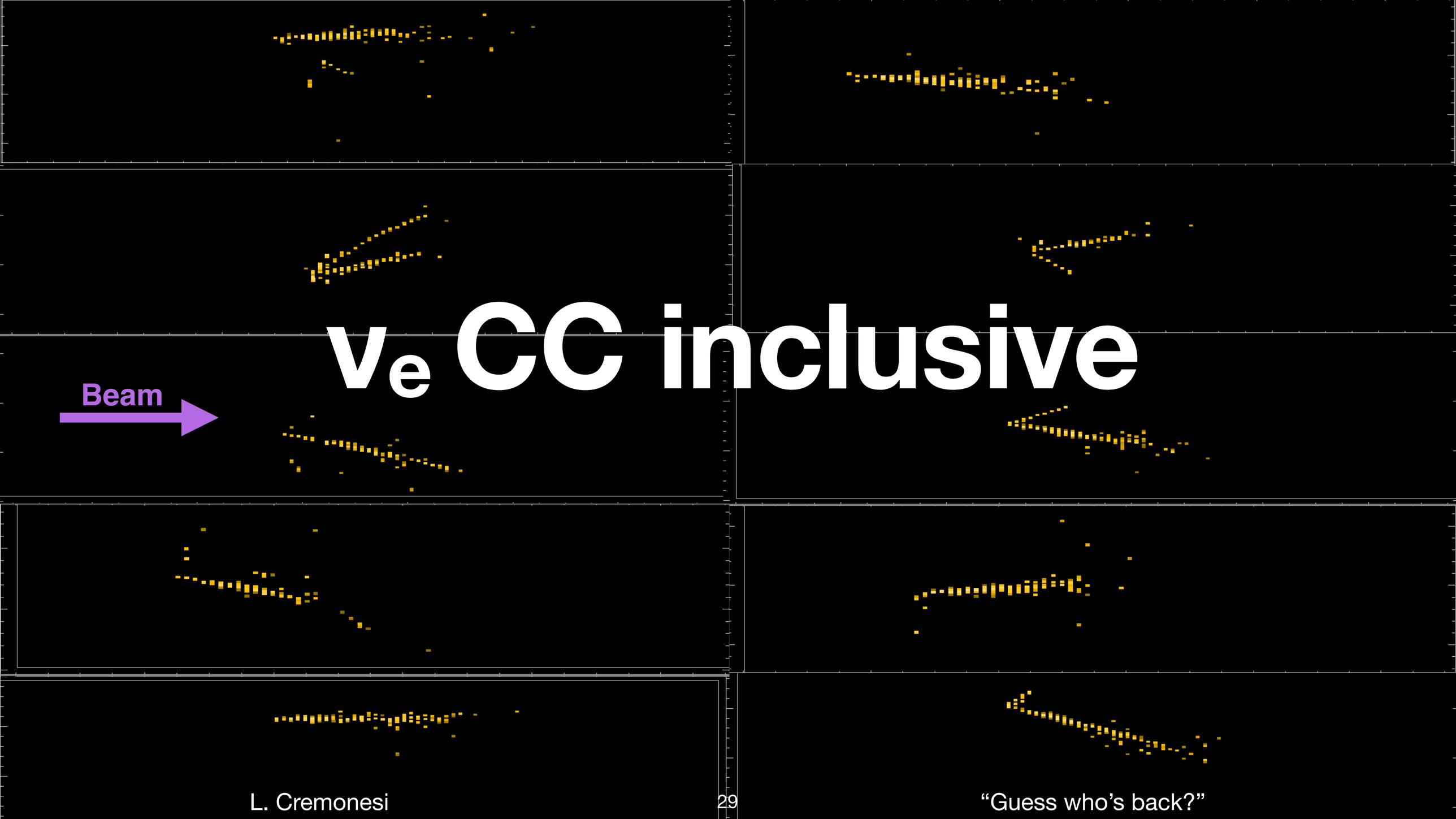
ν_μ CC inclusive

- **Data (Stat. + Syst.)**
- **GENIE 3.00.06***
- **GiBUU 2019**
- **NEUT 5.4.0**
- **NuWro 2019**

- Out of the box generator comparisons.
- All generators reproduce well the shape of our data.
- We notice an overall normalisation difference in GiBUU.

***N18_10j_02_11a: combination of G18_10j_00_000 and G18_10b_02_11a**

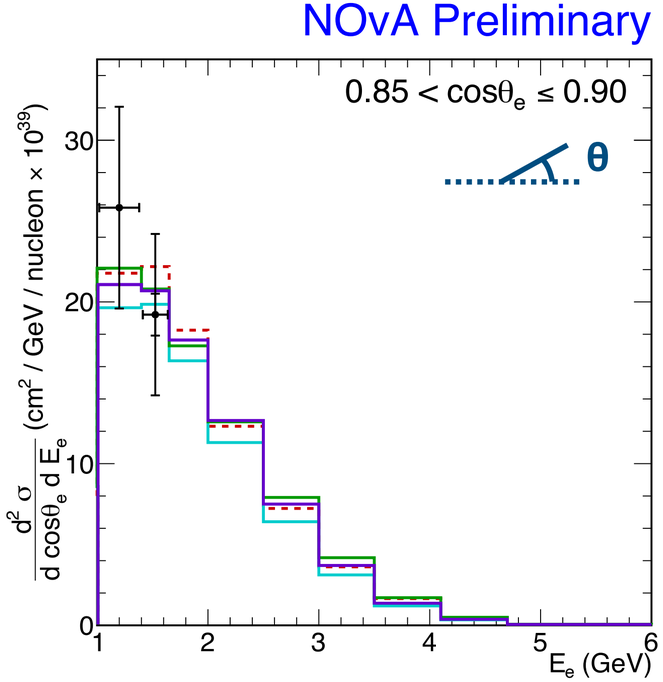
"Guess who's back?"

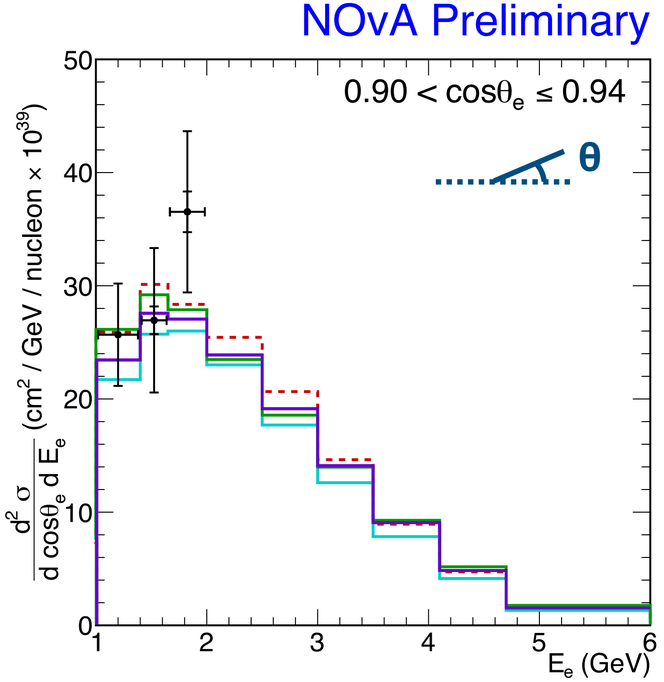


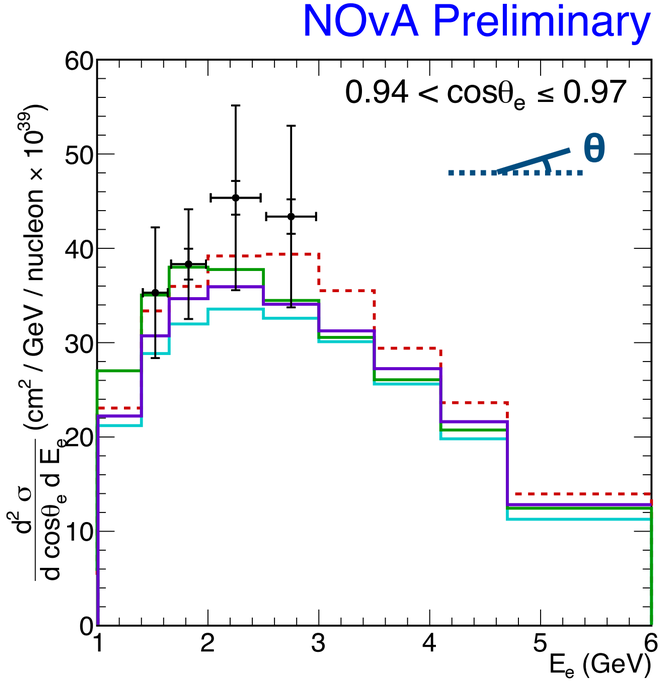
ν_e CC inclusive

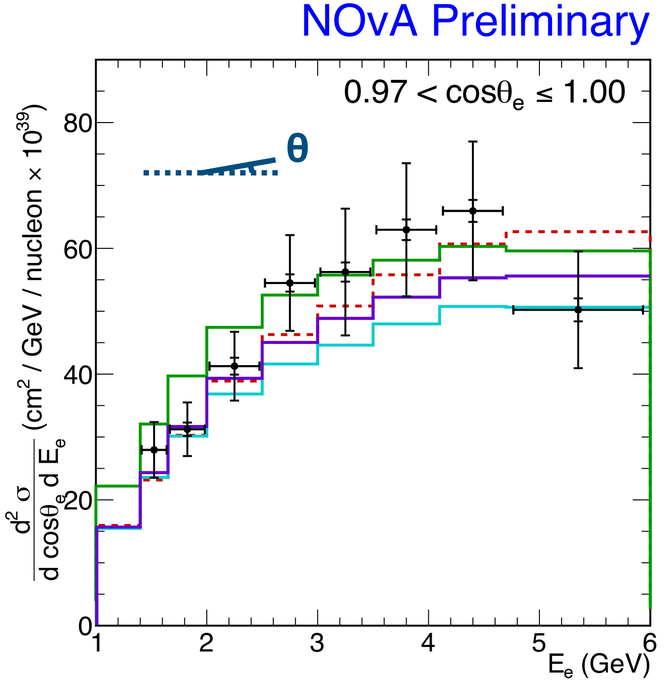
ν_e CC inclusive

1% of our event rates, but still around 10k ν_e CC events in our selection









ν_e CC inclusive

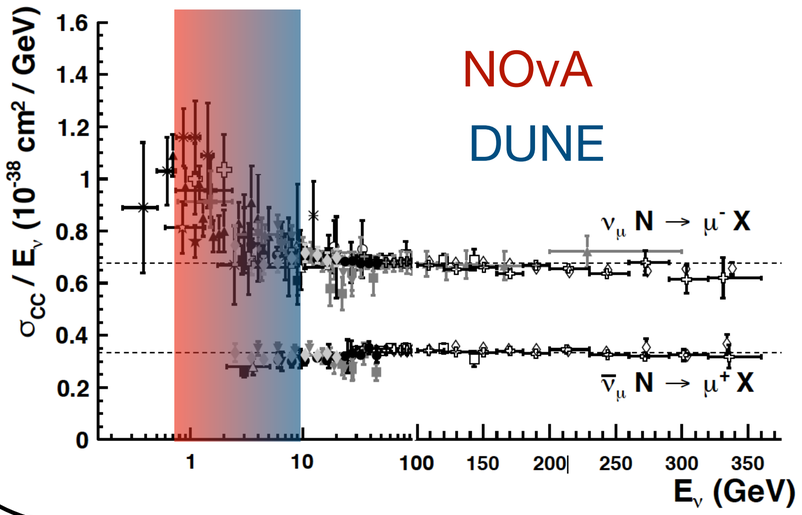
- **Data (Stat. + Syst.)**
- **GENIE 3.00.06***
- **GiBUU 2019**
- **NEUT 5.4.0**
- **NuWro 2019**

- **First double differential measurement.**
- Around 10k events.
- Uncertainties ~ 15-20% in each bin.
- Good agreement with generators.

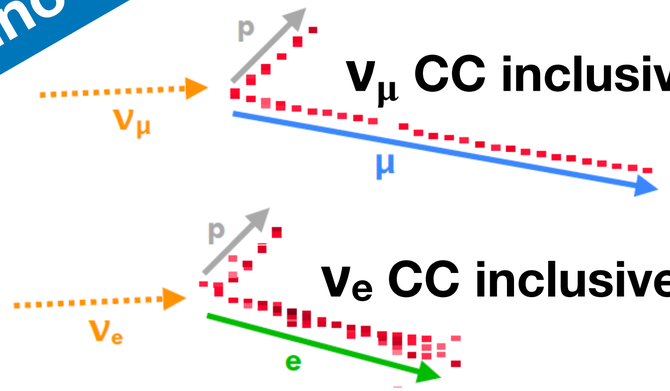
***N18_10j_02_11a: combination of G18_10j_00_000 and G18_10b_02_11a**

"Guess who's back?"

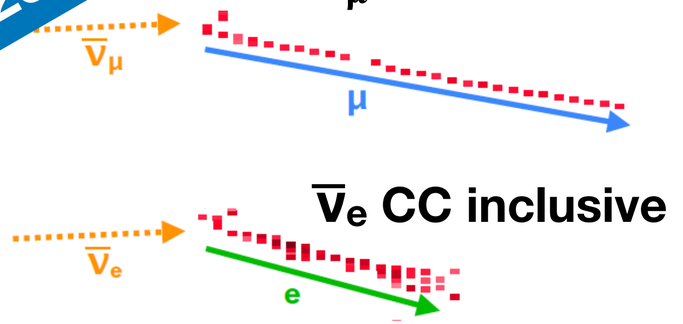
NOvA cross section programme



Neutrino 2020

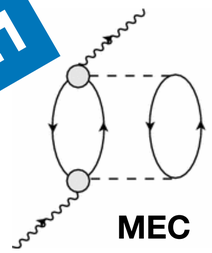


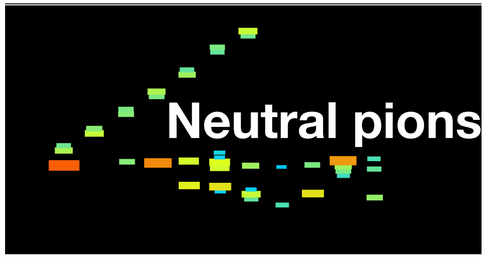
Late 2020

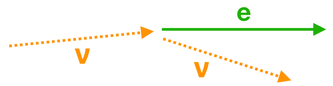


+ ratios

2021







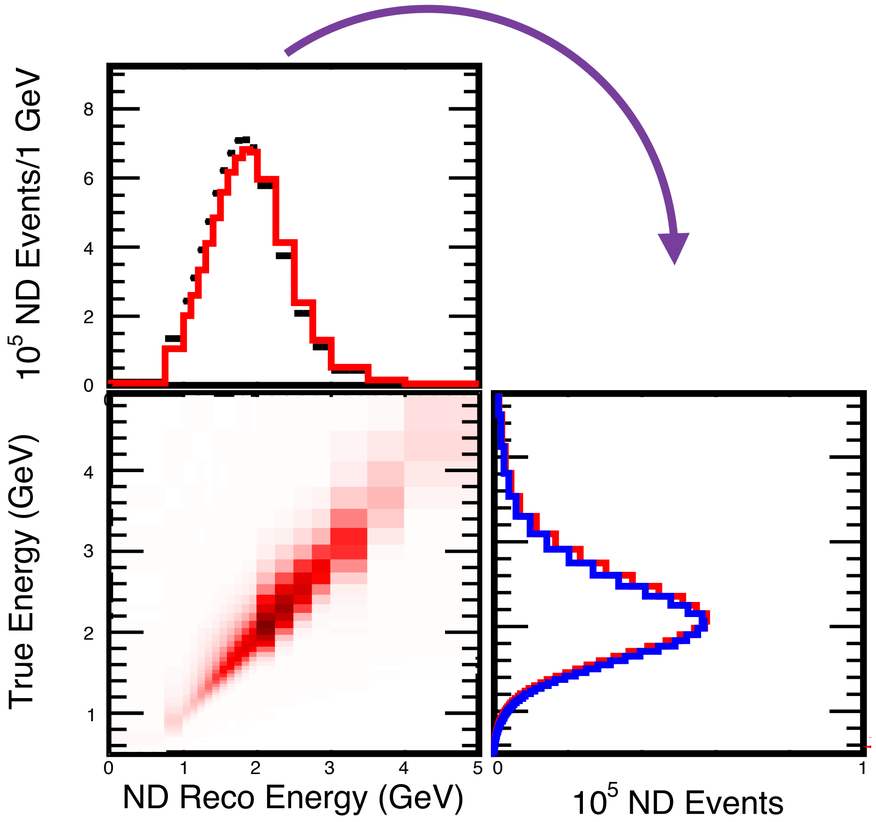
ν on e

+ NC,
charged pions,
...

NOvA Oscillations results and plan

From the Near to the Far Detector

Translate ND data/MC observation to true energy



ND data

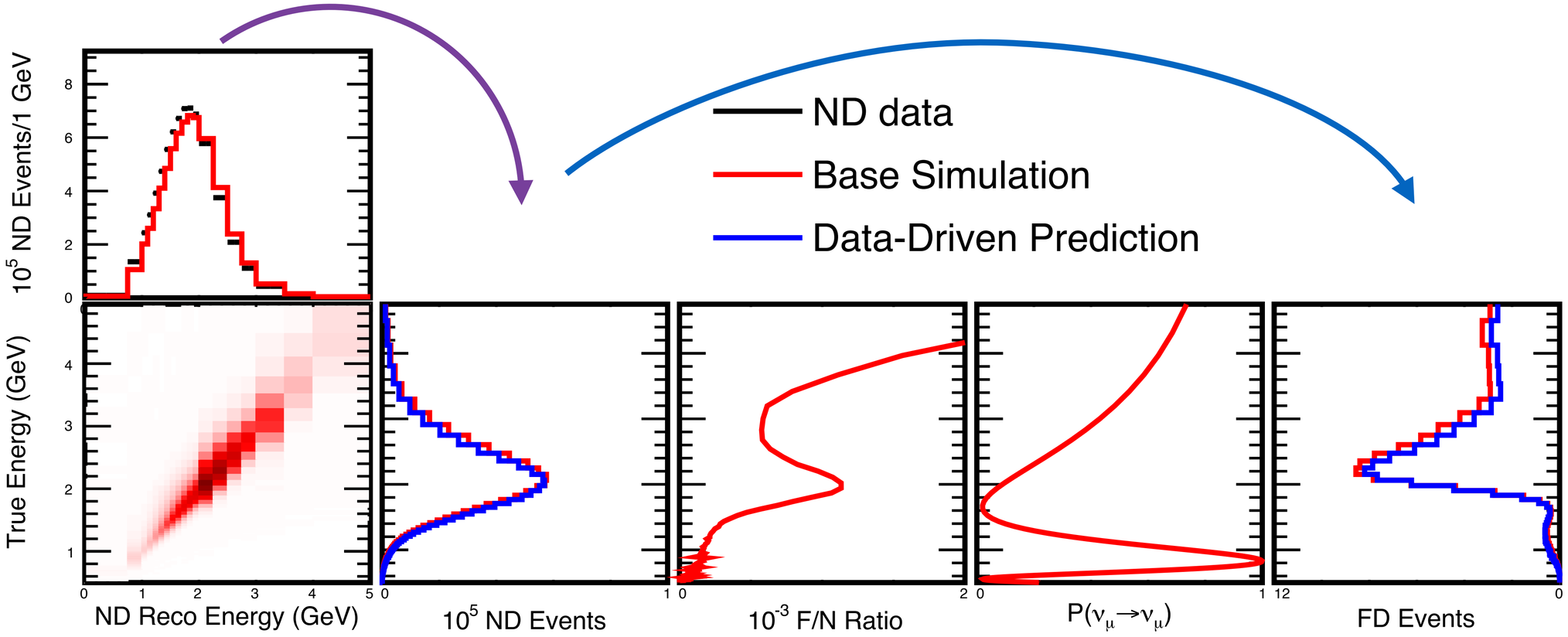
Base Simulation

Data-Driven Prediction

From the Near to the Far Detector

Translate ND data/MC observation to true energy

Oscillate ratio to the FD

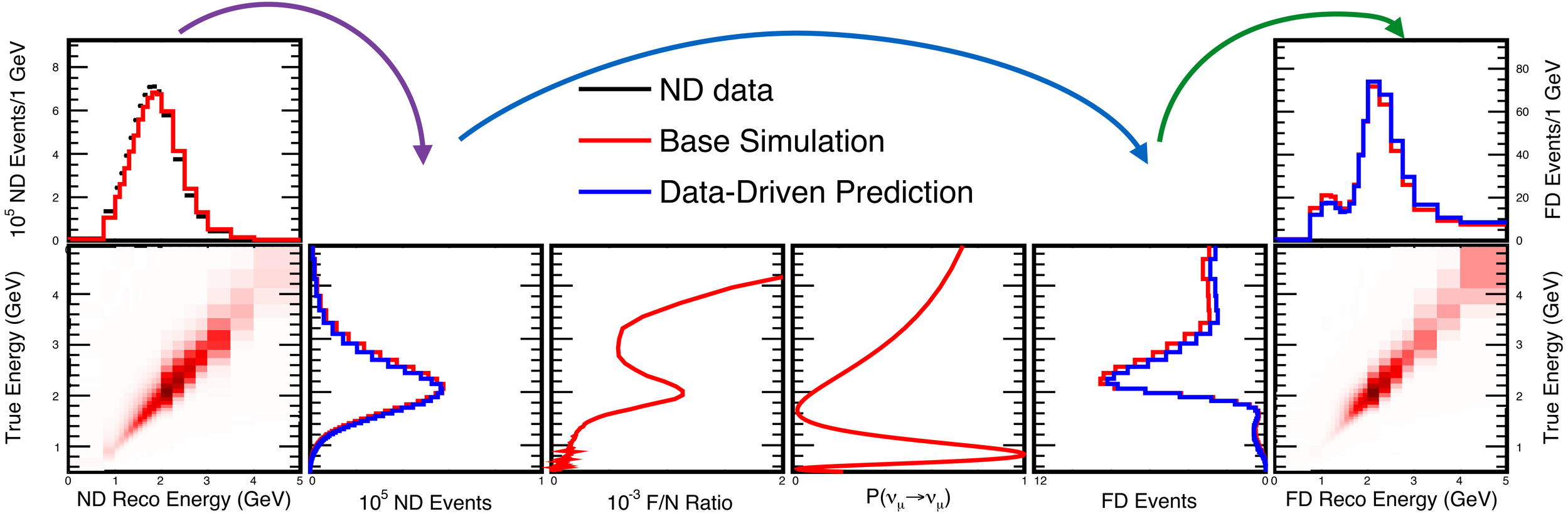


From the Near to the Far Detector

Translate ND data/MC observation to true energy

Oscillate ratio to the FD

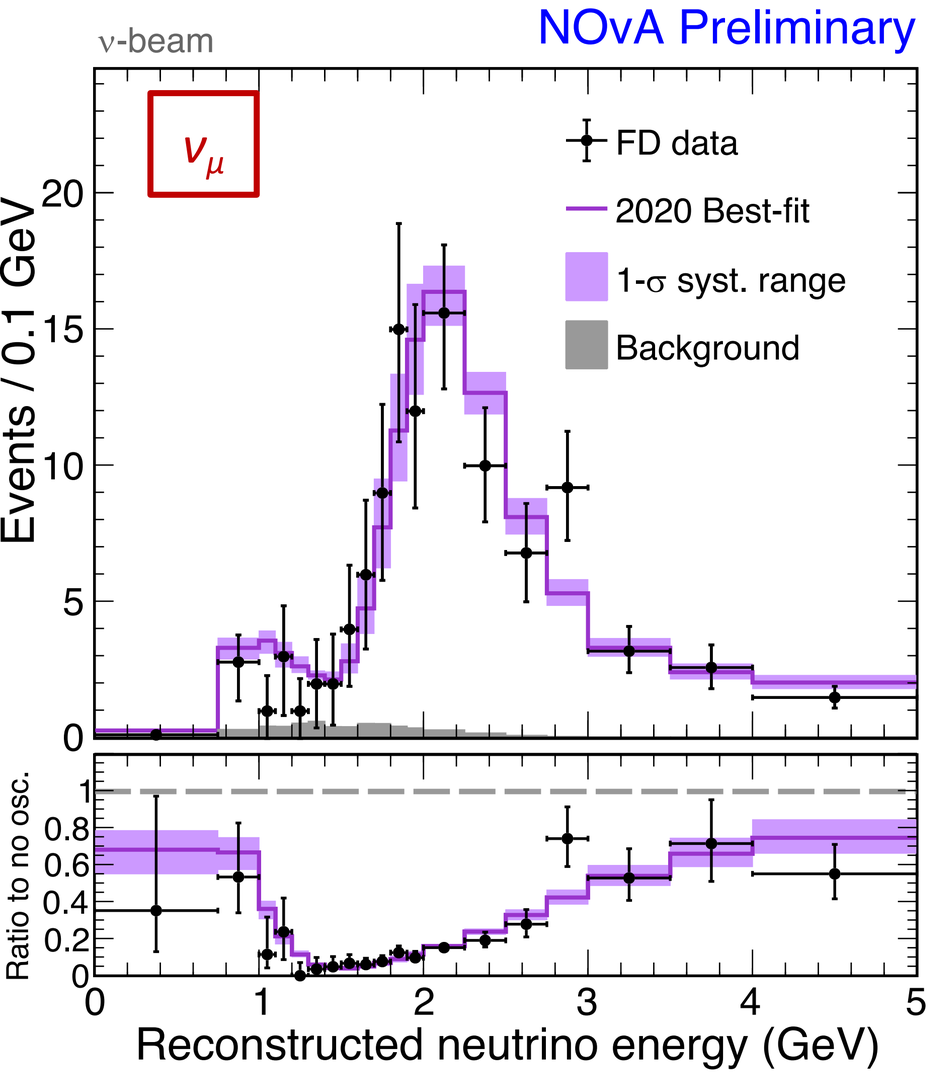
Smear back into reconstructed energy

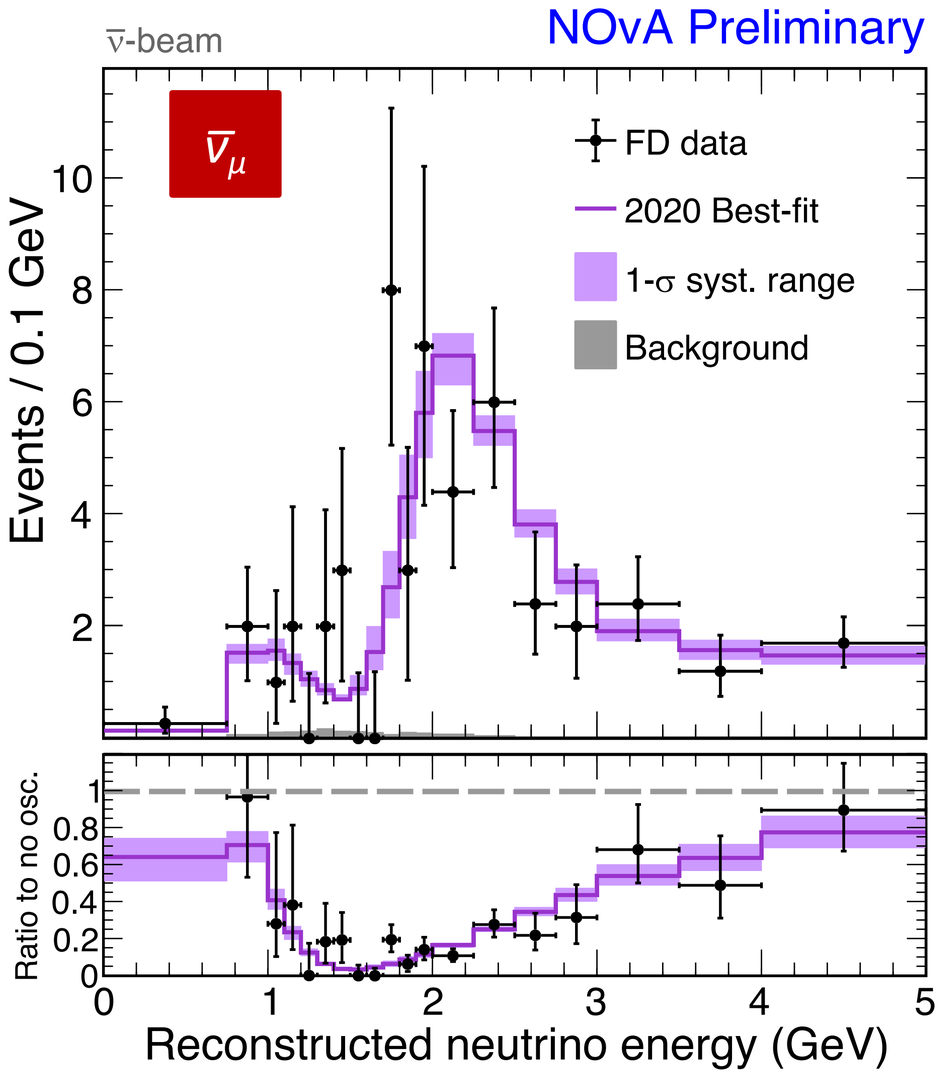


- Since NOvA has functionally similar Near and Far Detectors the flux combined with the cross sections uncertainties largely cancel.

ν_μ and $\bar{\nu}_\mu$ Data at the Far Detector

Slide from A. Himmel Neutrino 2020 (talk and video)





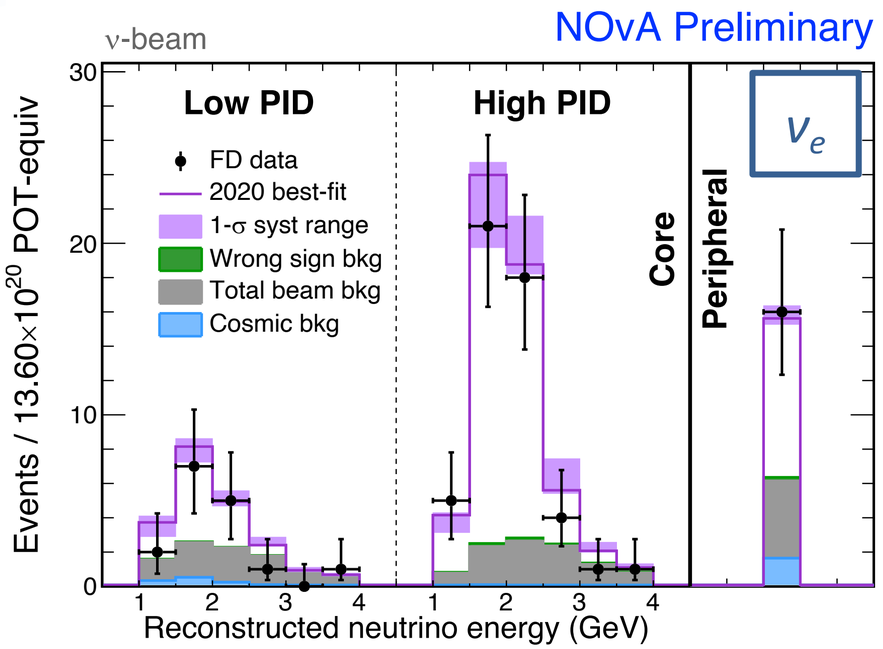
211 events, 8.2 background

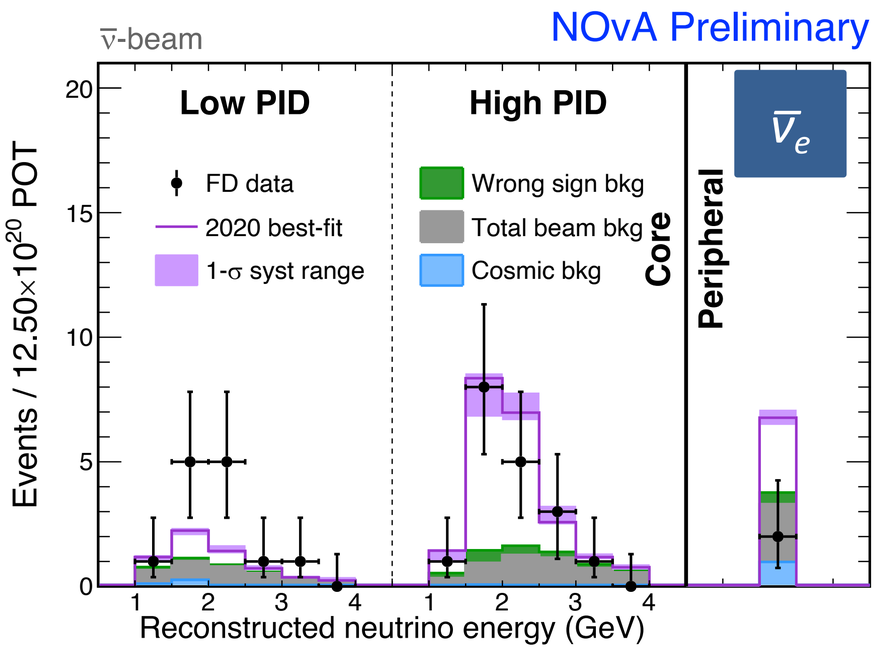
105 events, 2.1 background

no's back?"

ν_e and $\bar{\nu}_e$ Data at the Far Detector

Slide from A. Himmel
Neutrino 2020
(talk and video)





Total Observed	82	Range
Total Prediction	85.8	52-110
Wrong-sign	1.0	0.6-1.7
Beam Bkgd.	22.7	
Cosmic Bkgd.	3.1	
Total Bkgd.	26.8	26-28

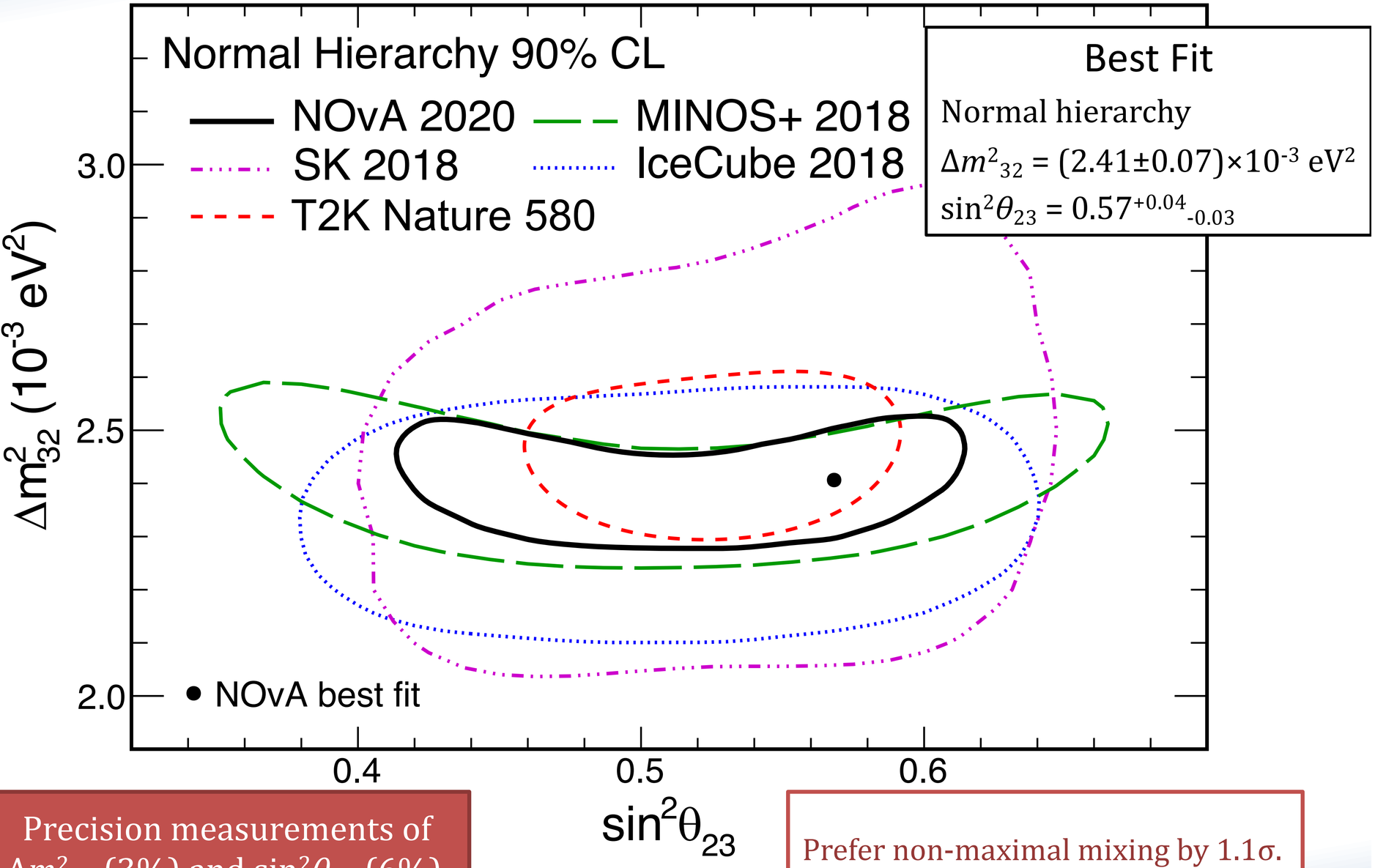
Total Observed	33	Range
Total Prediction	33.2	25-45
Wrong-sign	2.3	1.0-3.2
Beam Bkgd.	10.2	
Cosmic Bkgd.	1.6	
Total Bkgd.	14.0	13-15

>4σ evidence of $\bar{\nu}_e$ appearance

…o's back?"

Slide from A. Himmel
Neutrino 2020
(talk and video)

NOvA Preliminary



Best Fit

Normal hierarchy

$\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}$ eV^2

$\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$

Precision measurements of Δm^2_{32} (3%) and $\sin^2\theta_{23}$ (6%).

Prefer non-maximal mixing by 1.1σ.

o's back?"

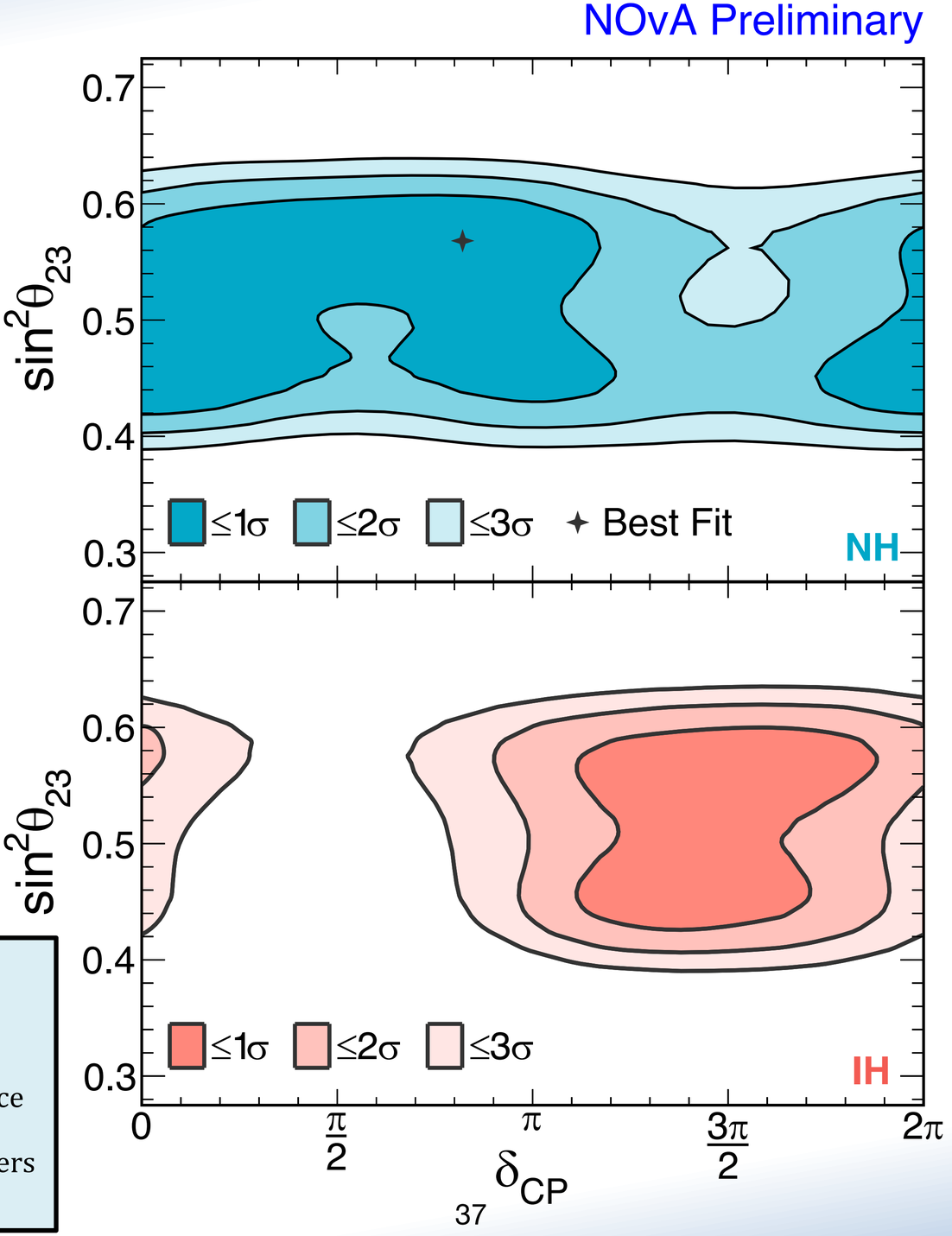
Best Fit

Normal hierarchy

$\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}$ eV^2

$\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$

$\delta = 0.82\pi$



Slide from A. Himmel
Neutrino 2020
(talk and video)

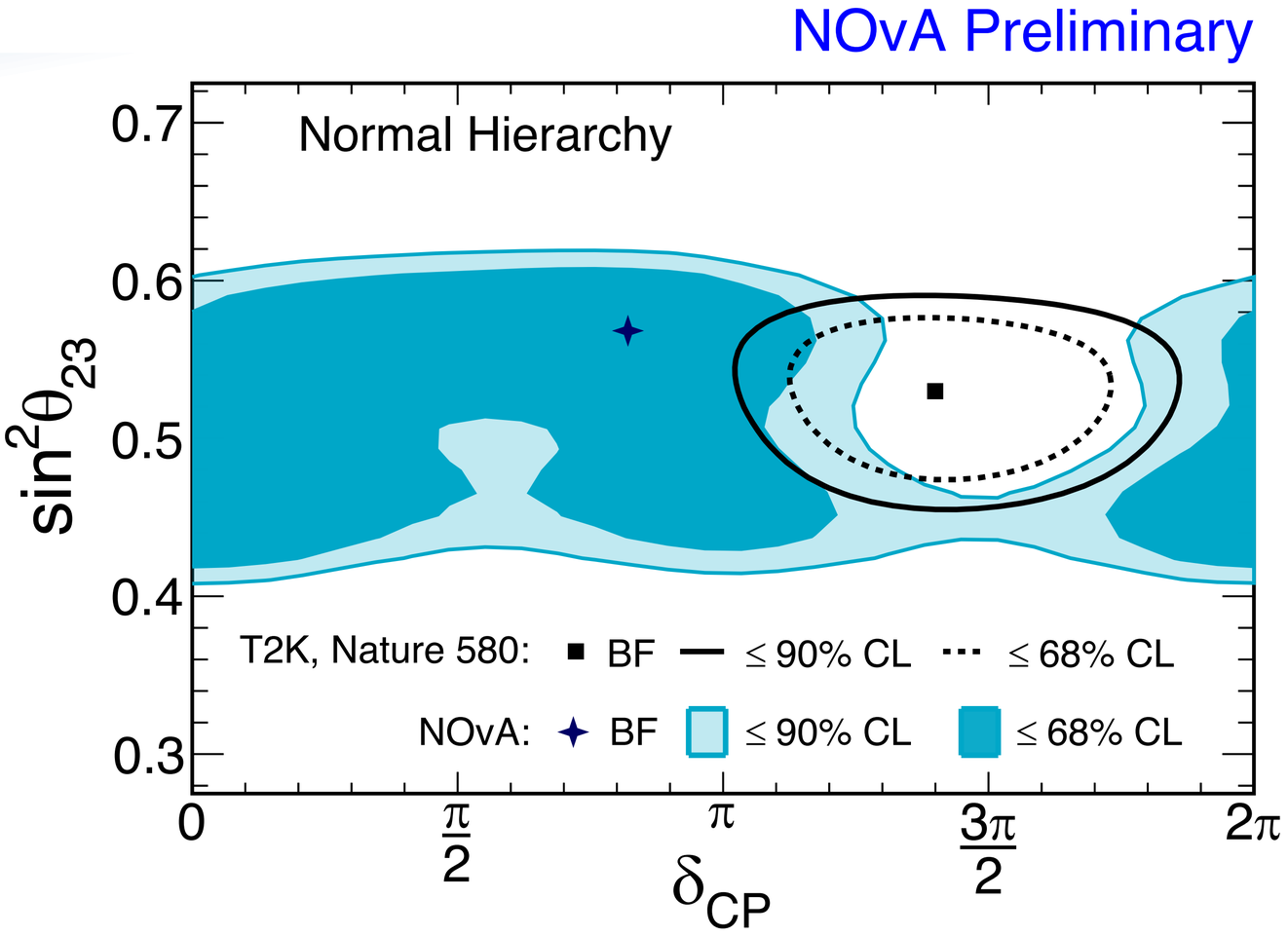
Posters

83. Long-baseline neutrino oscillation results from NOvA
   - Liudmila Kolupaeva & Karl Warburton

262. Accelerating Calculation of Confidence Intervals for NOvA's Neutrino Oscillation Parameter Estimation with Supercomputers
   - Steven Calvez, Tarak Thakore

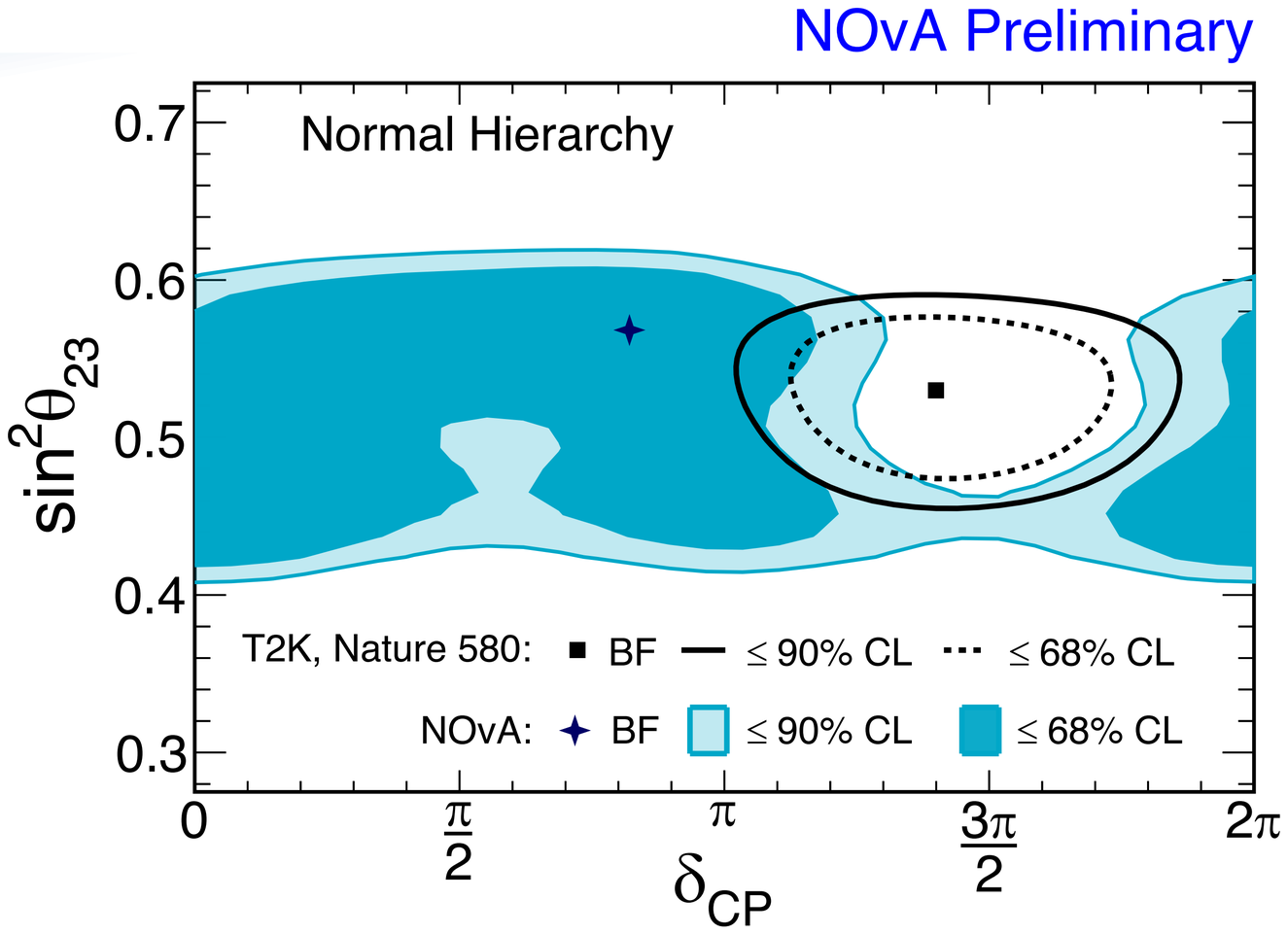
…o's back?"

Twitter controversies



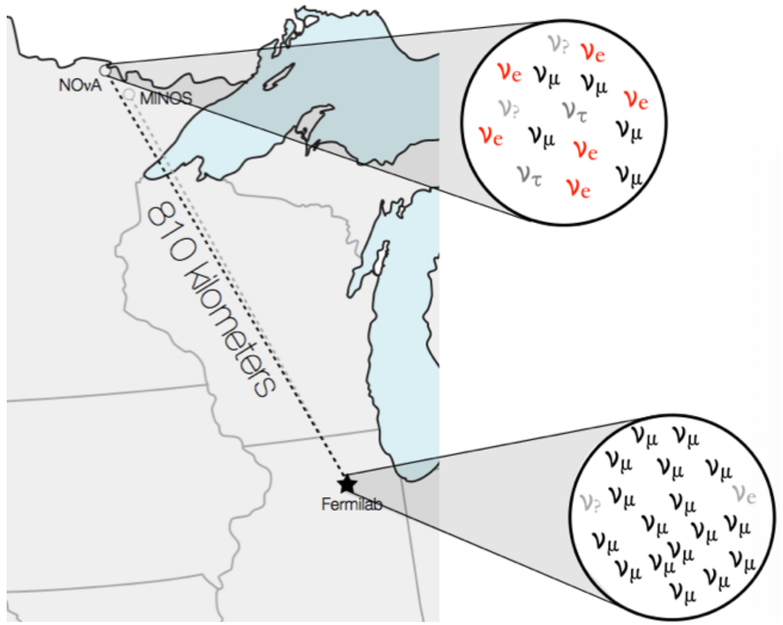
Caveat 1: old T2K contour, new one is larger
Caveat 2: quantifying consistency requires a joint fit

Twitter controversies

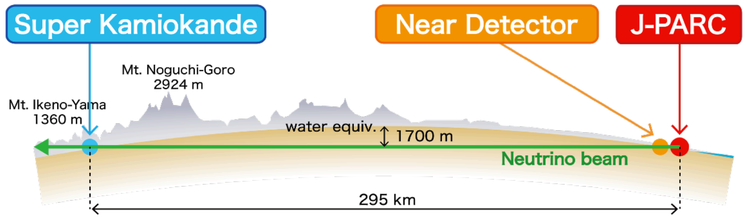


Caveat 1: old T2K contour, new one is larger
Caveat 2: quantifying consistency requires a joint fit

Joint oscillation analysis



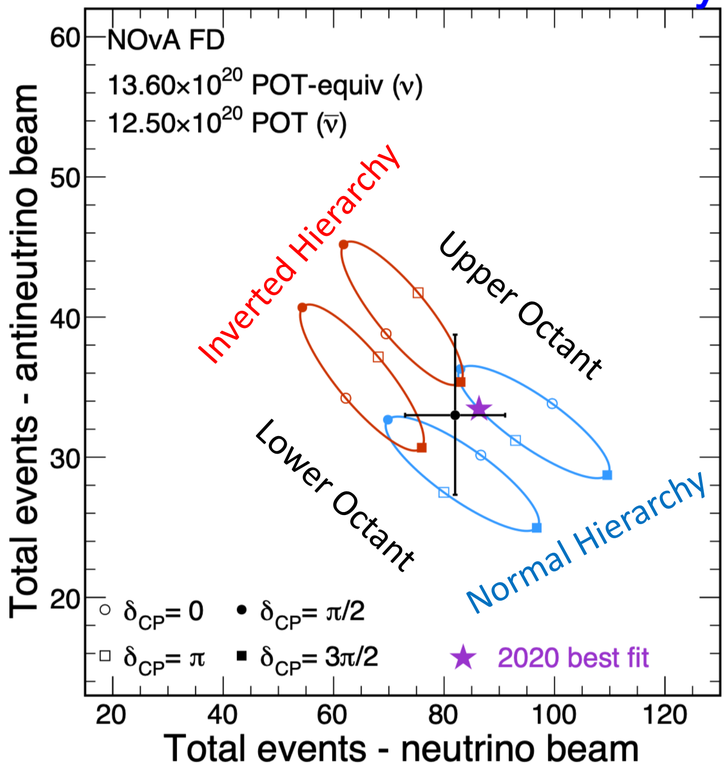
Baseline: 810km
Energy: ~2GeV



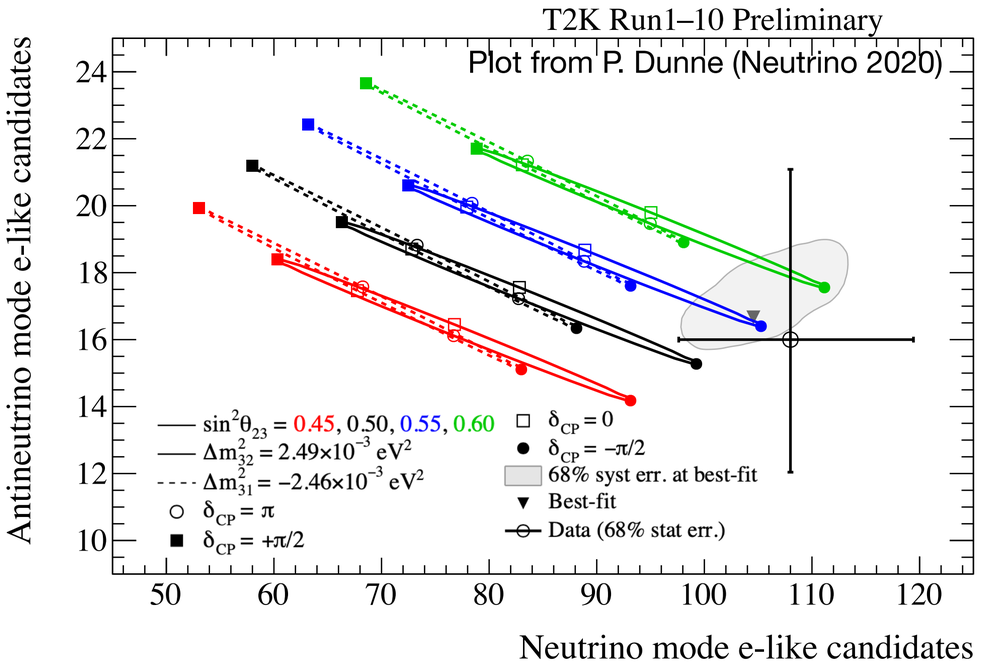
Baseline: 295km
Energy: ~0.6GeV

Joint oscillation analysis

NOvA Preliminary



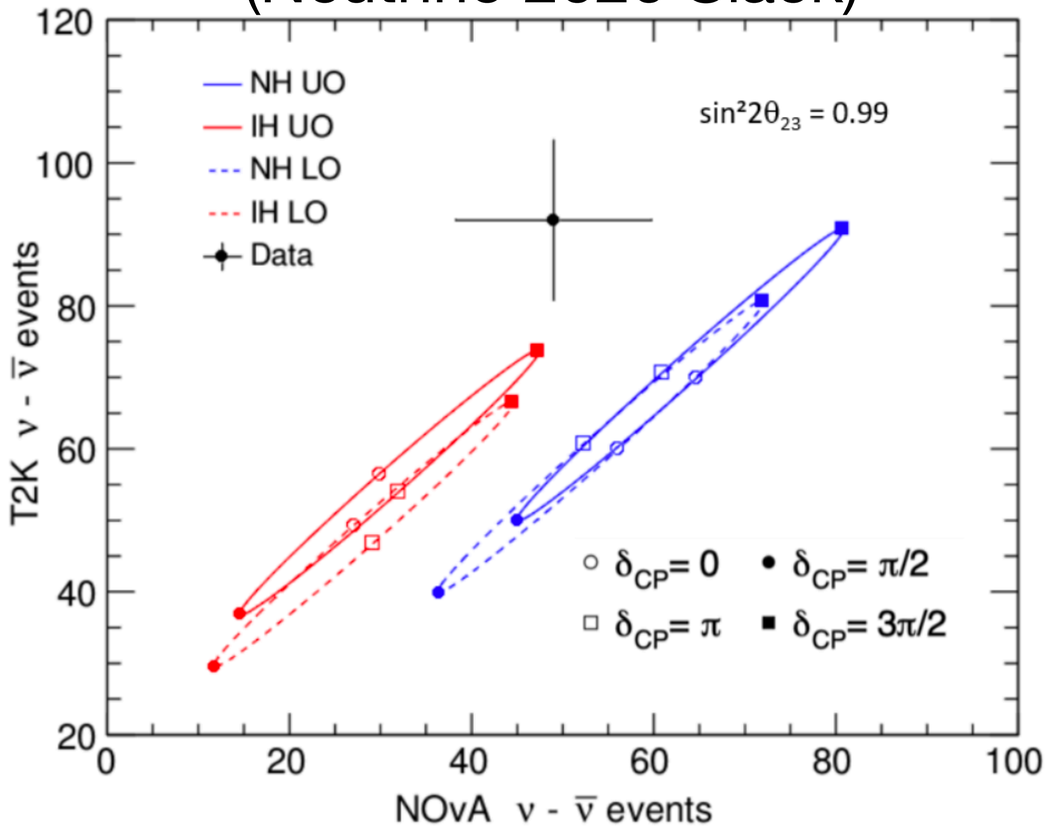
Baseline: 810km
Energy: ~2GeV



Baseline: 295km
Energy: ~0.6GeV

Quick pheno reaction from Neutrino 2020

Plot from Joao Coelho
(Neutrino 2020 Slack)



Quick pheno reaction from Neutrino 2020

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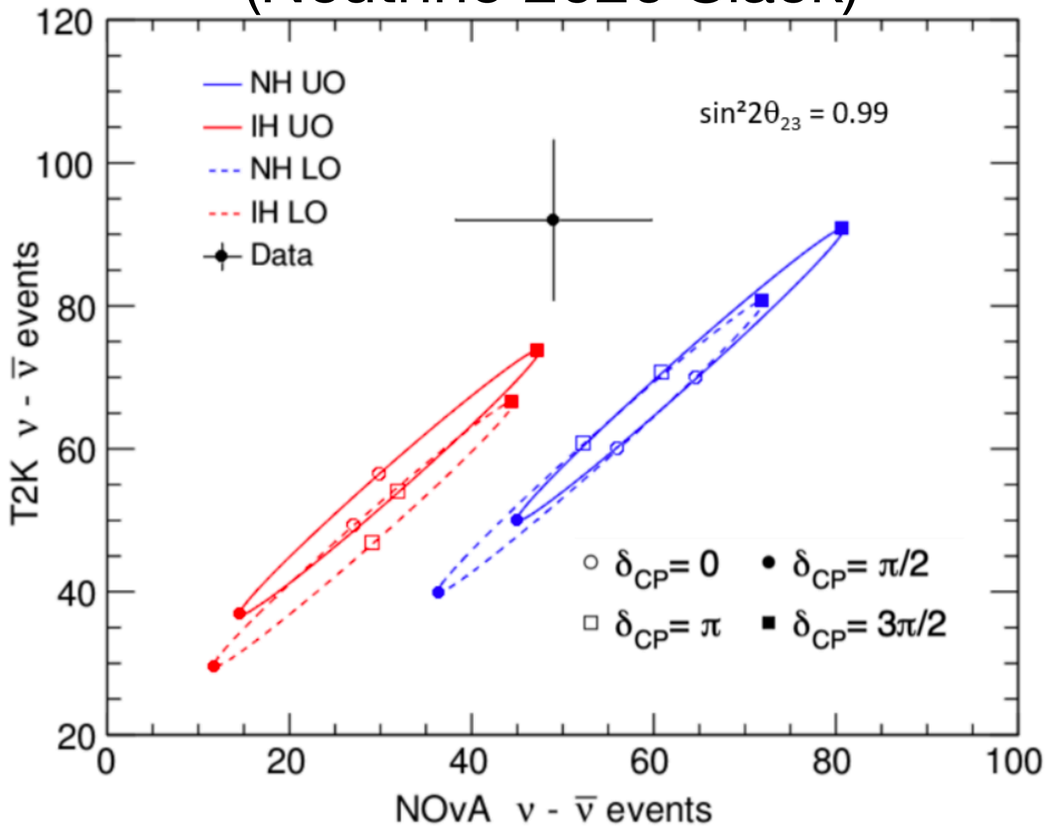
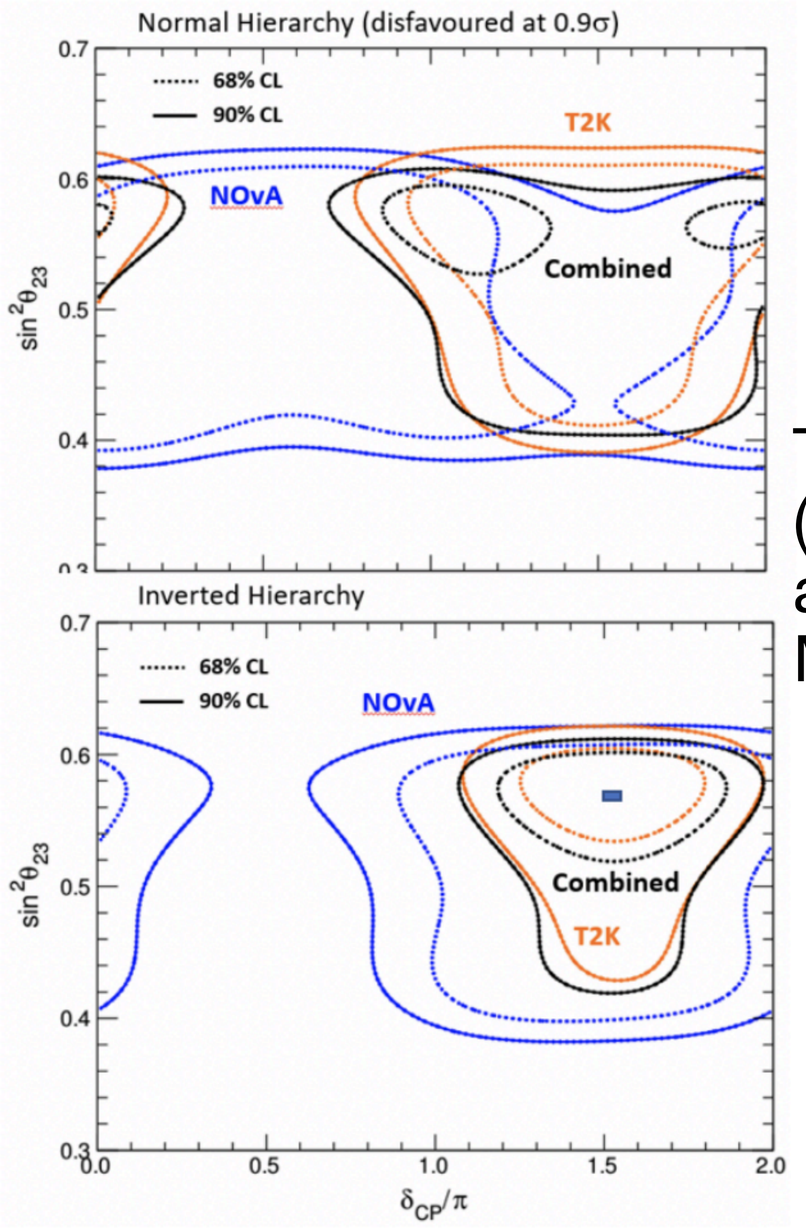
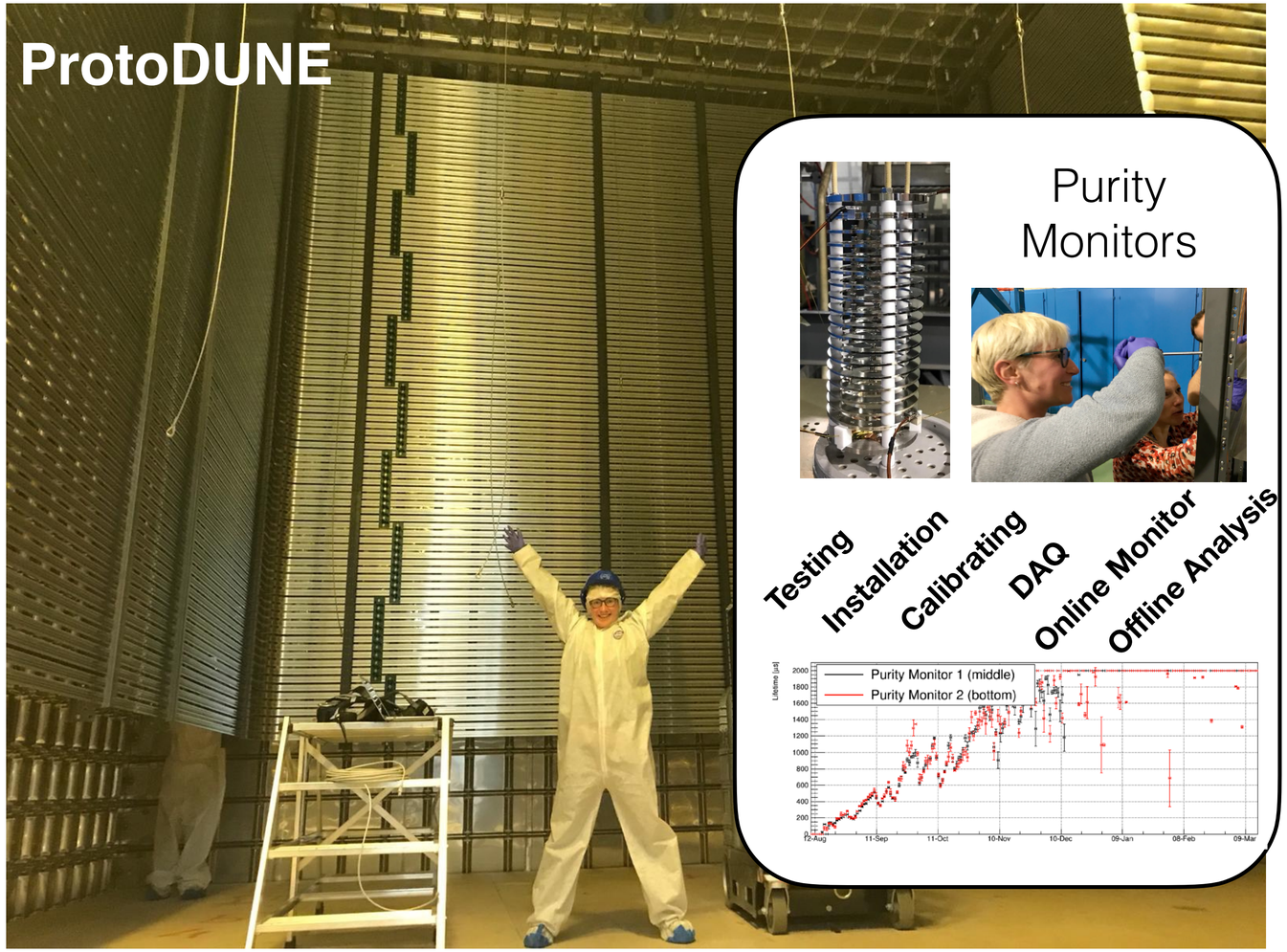


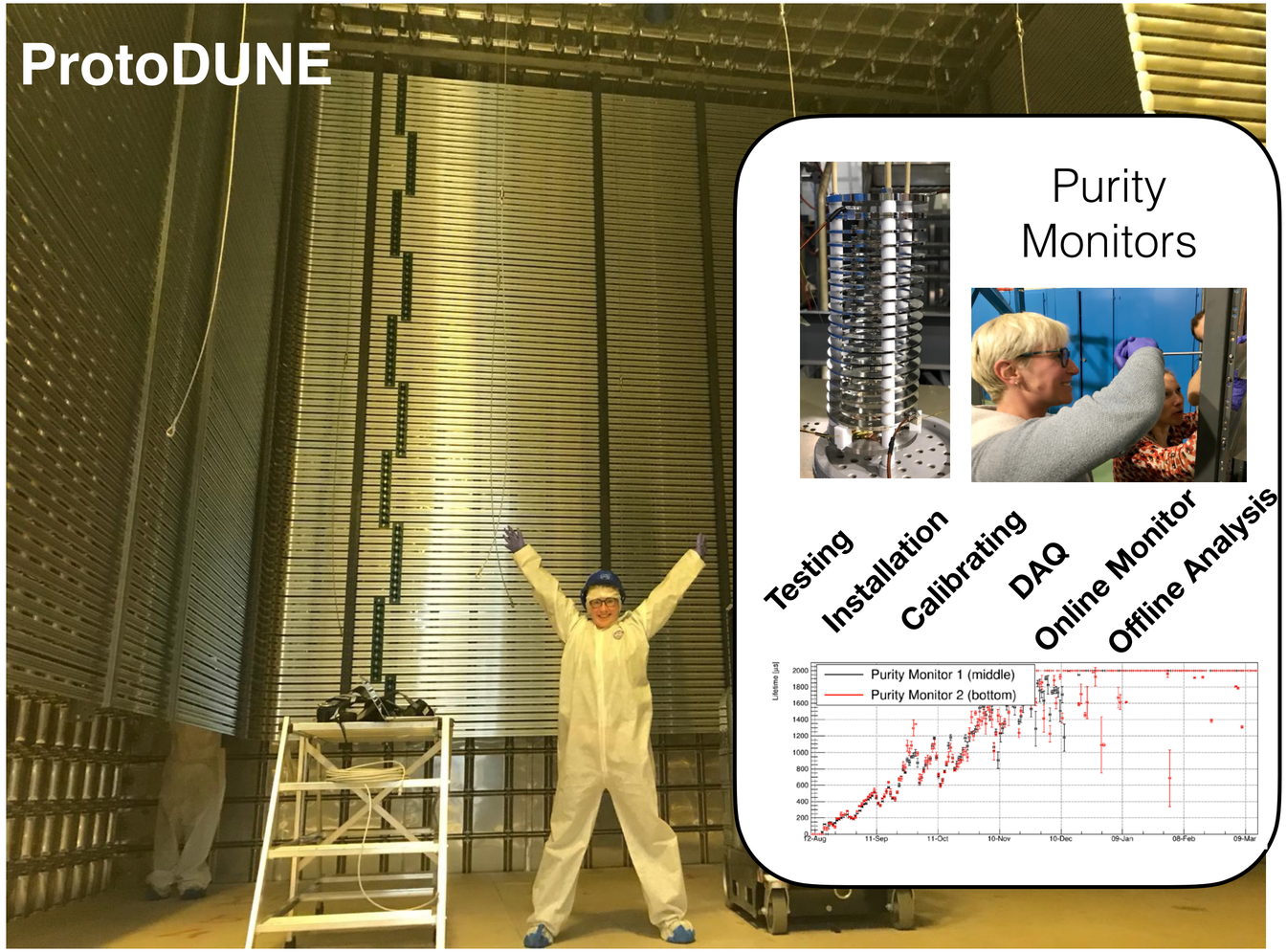


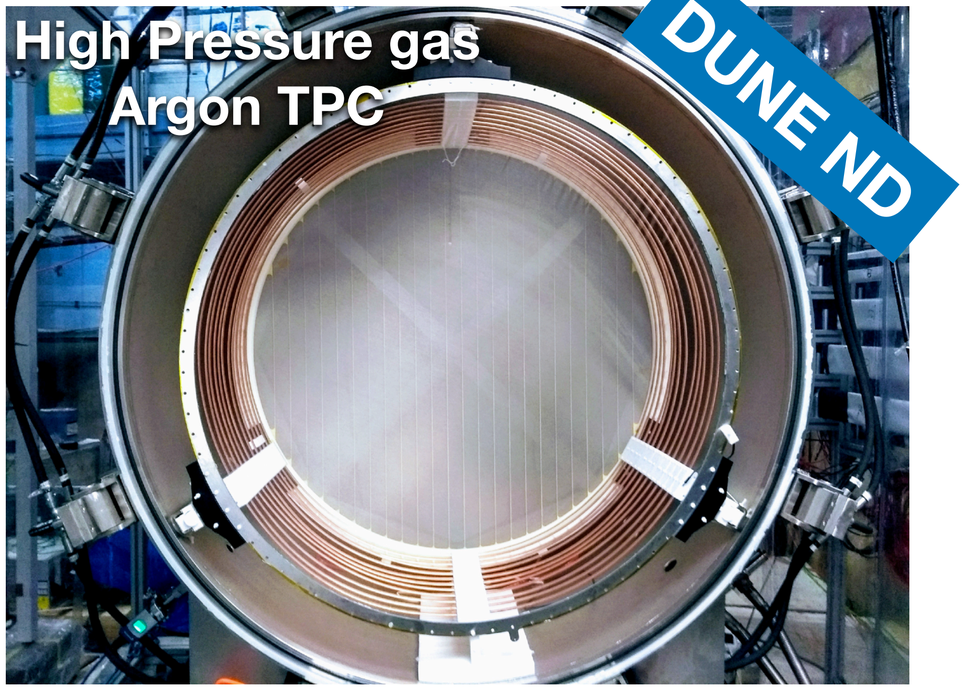
Toy MC
(J. Coelho
and A.
Mahnn)

What about DUNE?

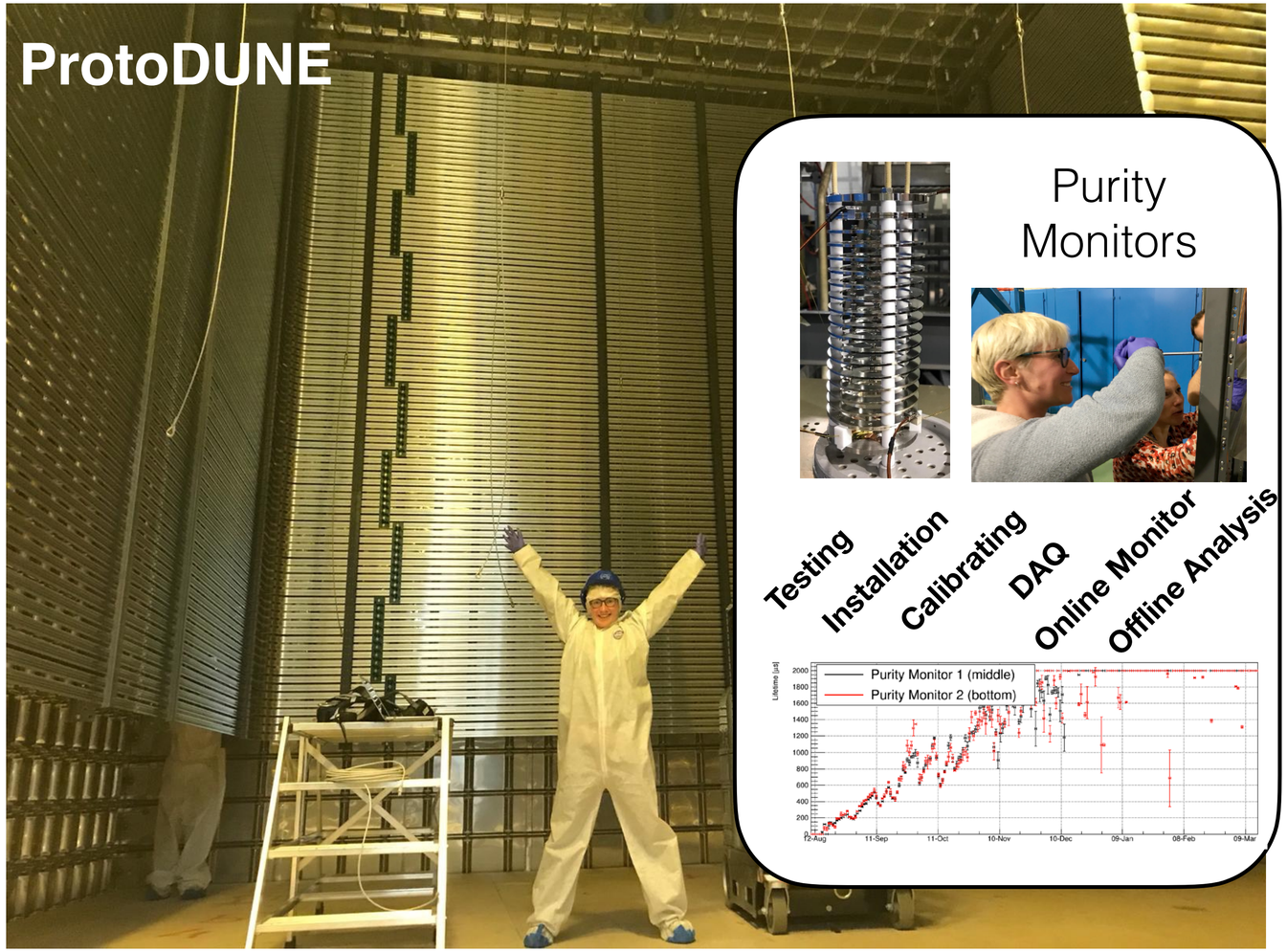


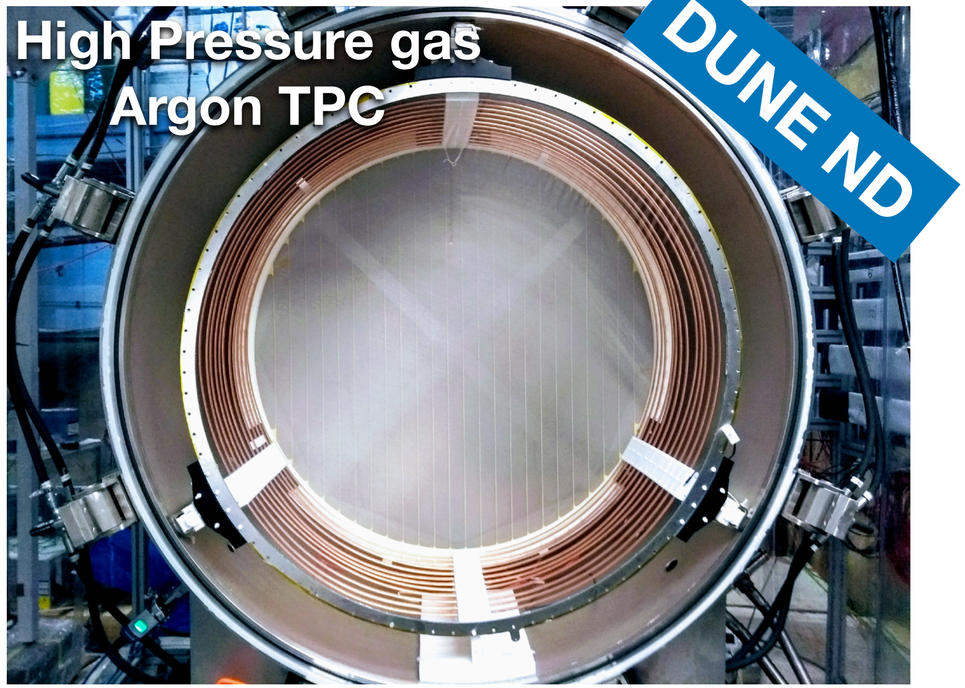
What about DUNE?

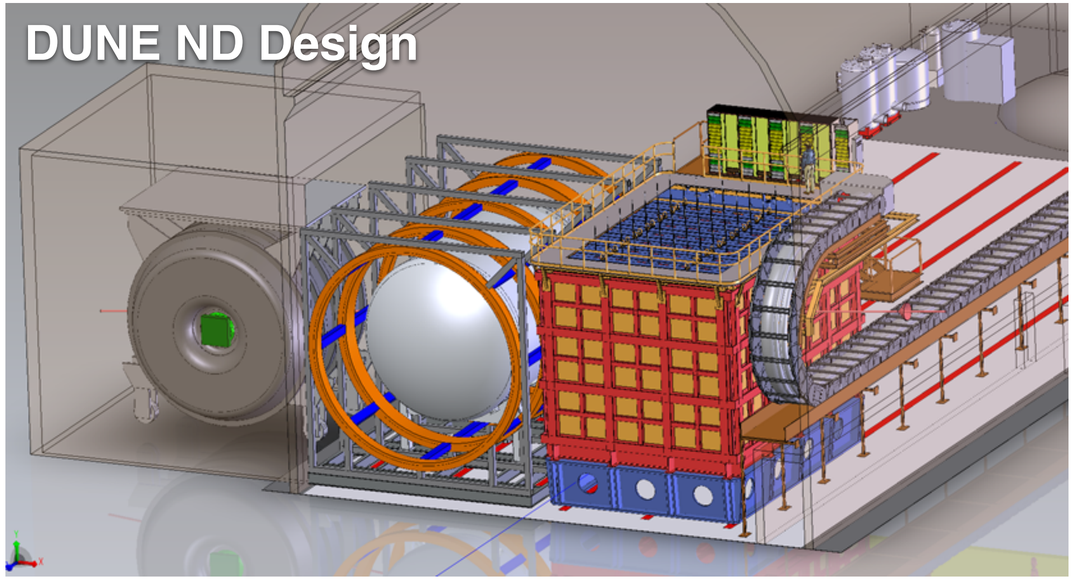




What about DUNE?







What kept me sane during the lockdown?

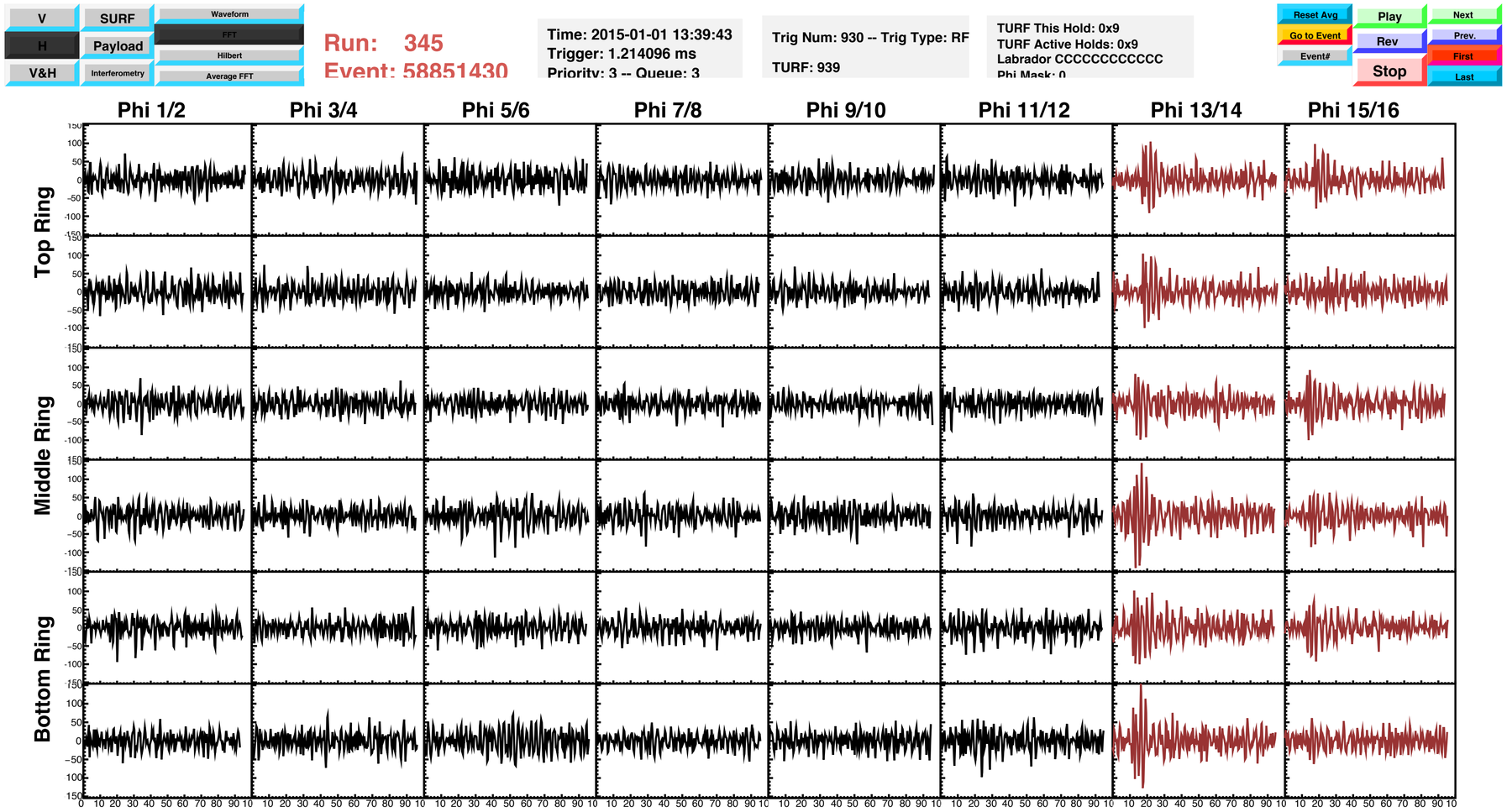
What kept me sane during the lockdown?

What kept me sane during the lockdown?

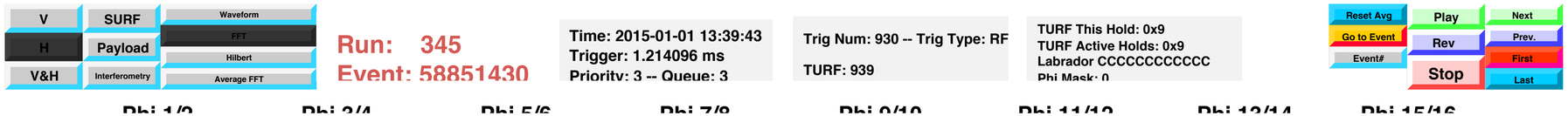

Thank you!

Back up slides

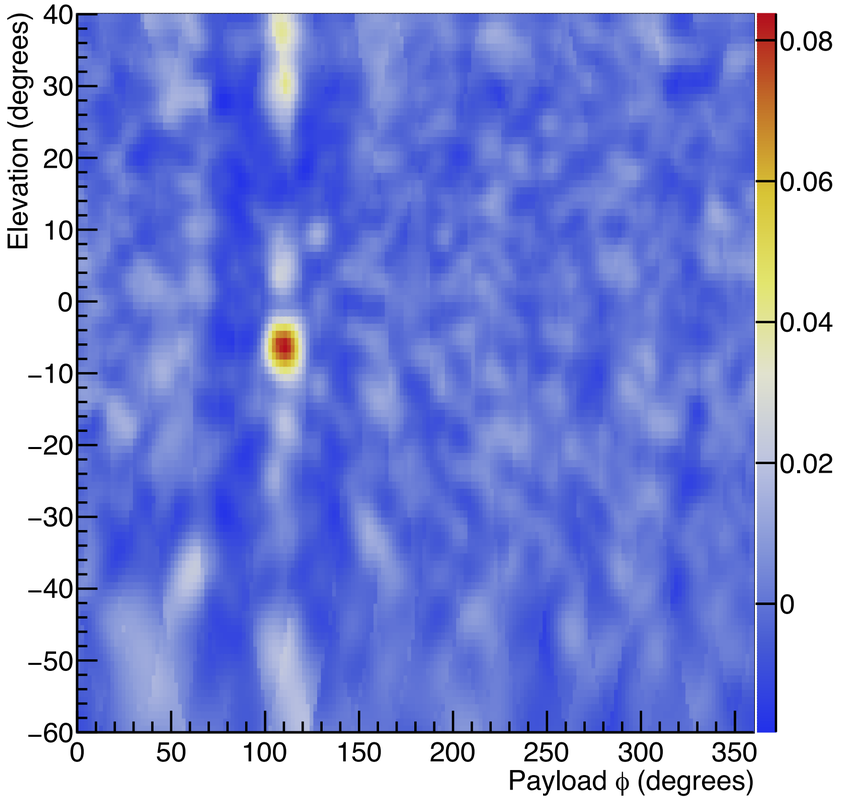
How ANITA sees the world



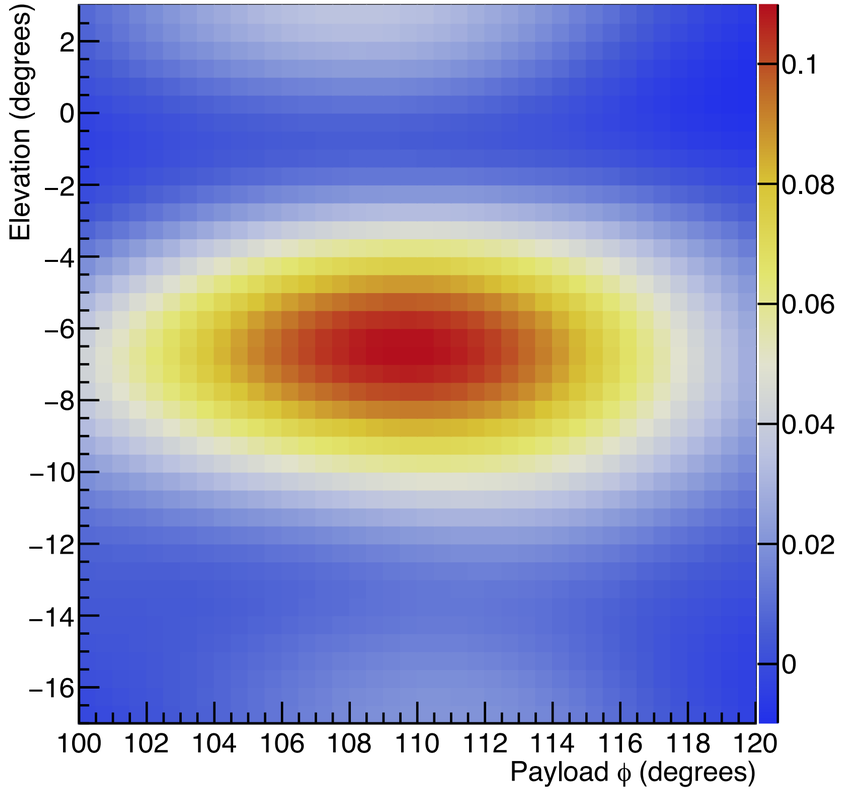
How ANITA sees the world



Interferometric Map

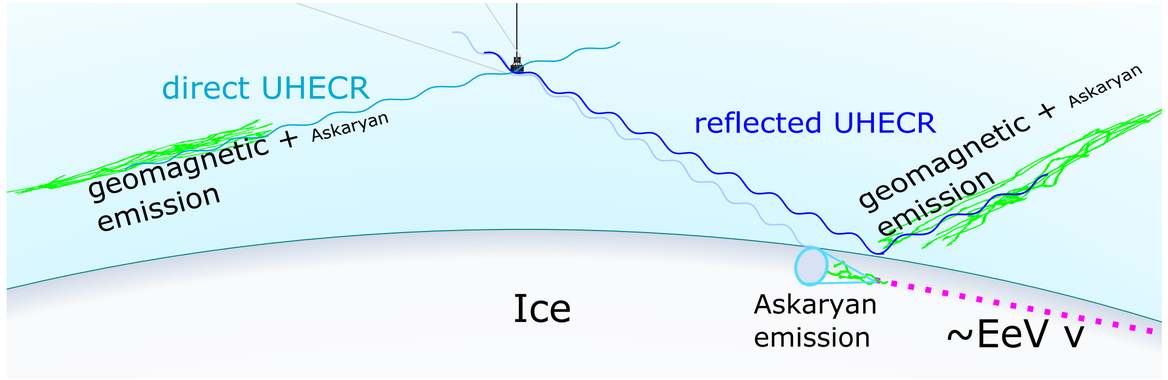


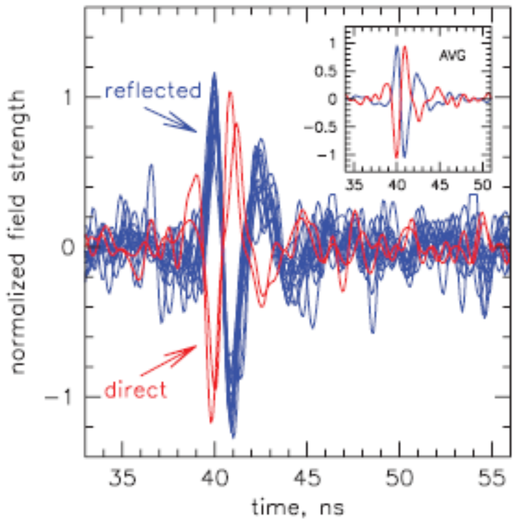
Zoomed Map



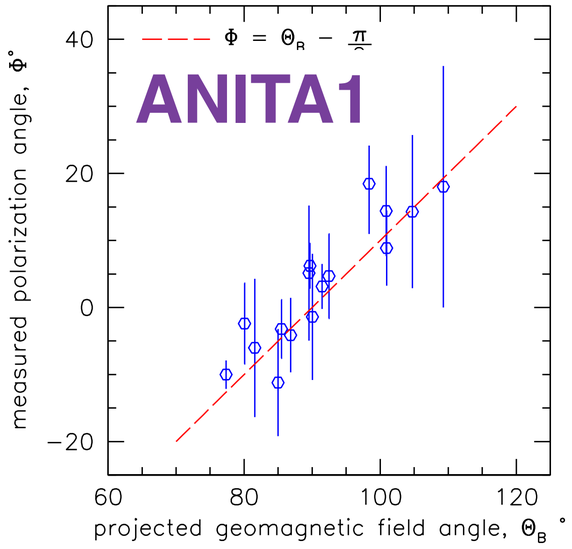
UHECR

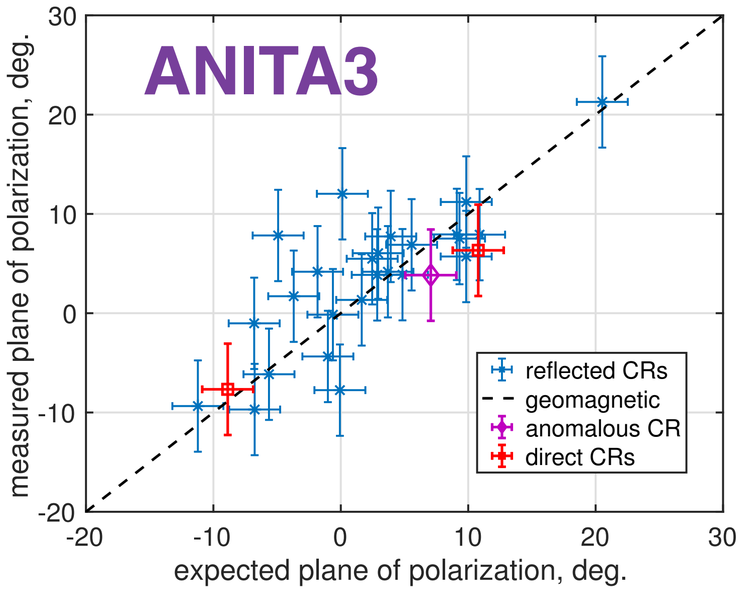
ANITA1: 16 UHECR
 14 reflected + 2 direct
ANITA-2: 2 UHECR
 H-pol trigger was off
ANITA-3: 25 UHECR
ANITA-4: analysis in progress





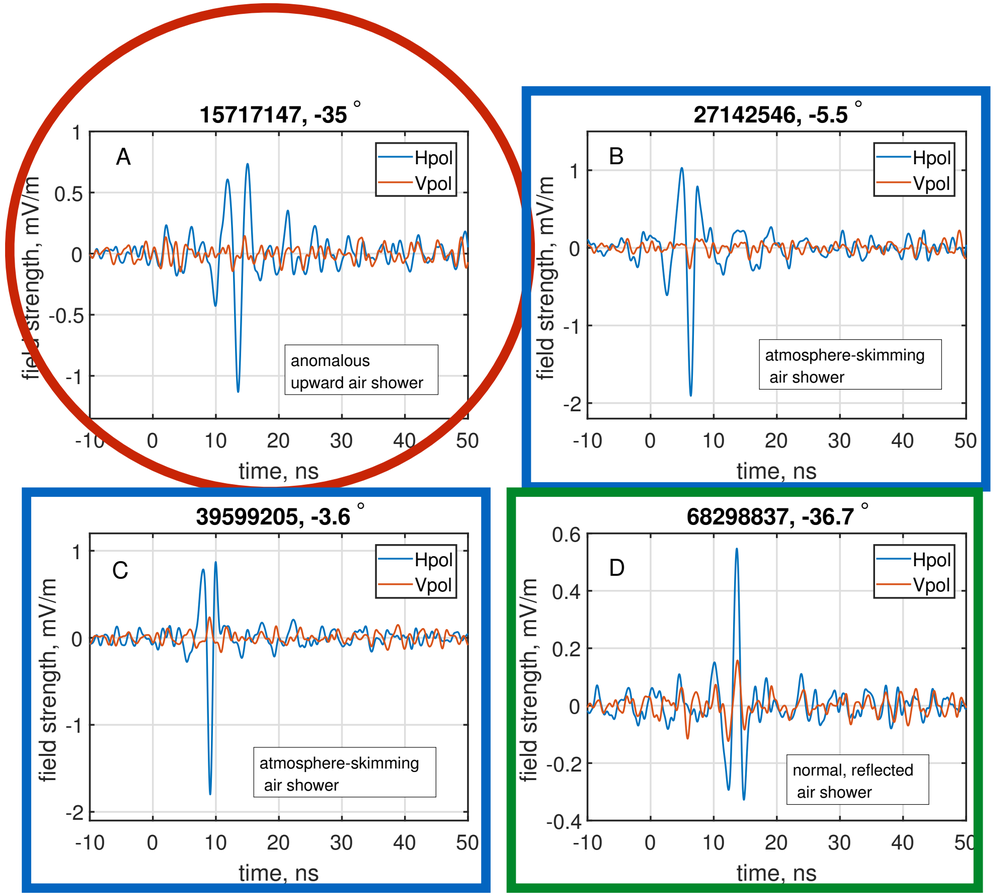
PRL 105, 151101 (2010)

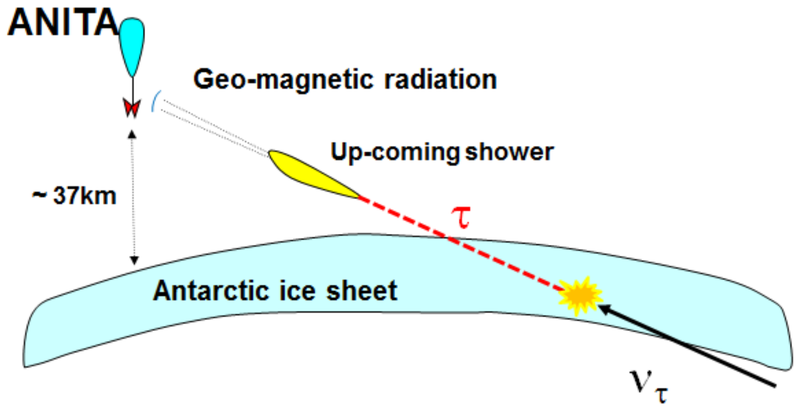




arXiv:1803.05088 [astro-ph.HE]

2 mystery events





Direct Cosmic Rays

Reflected Cosmic Rays

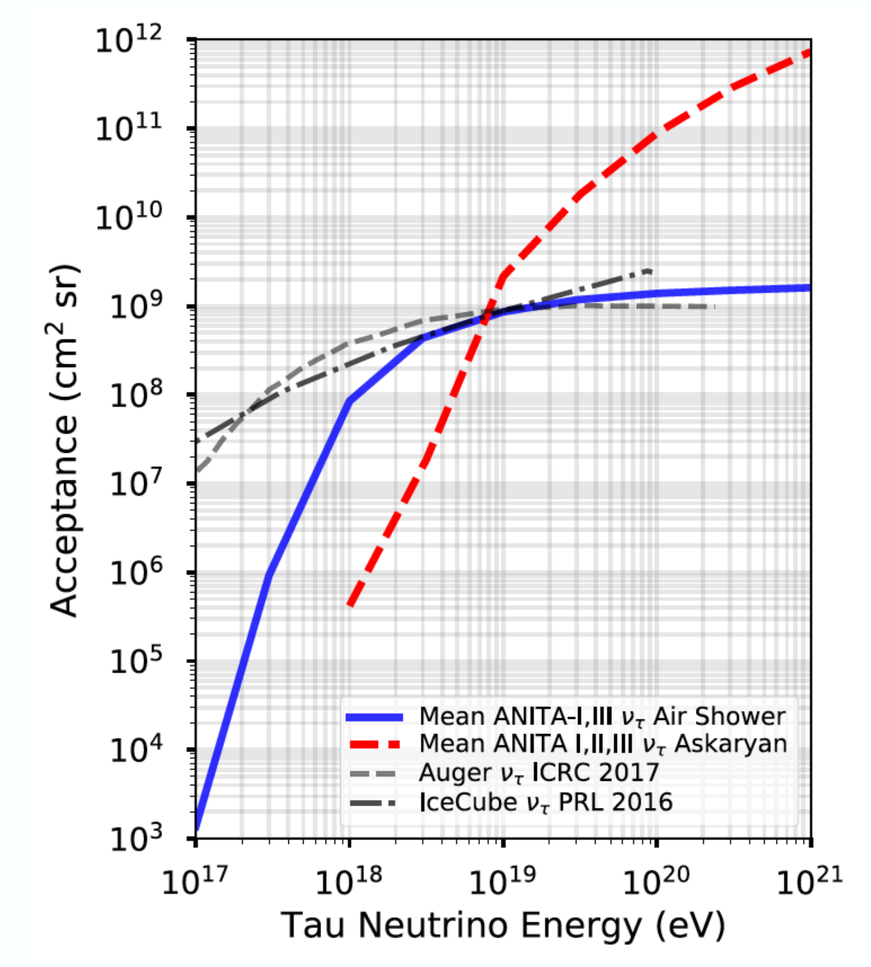
NEW PHYSICS ?

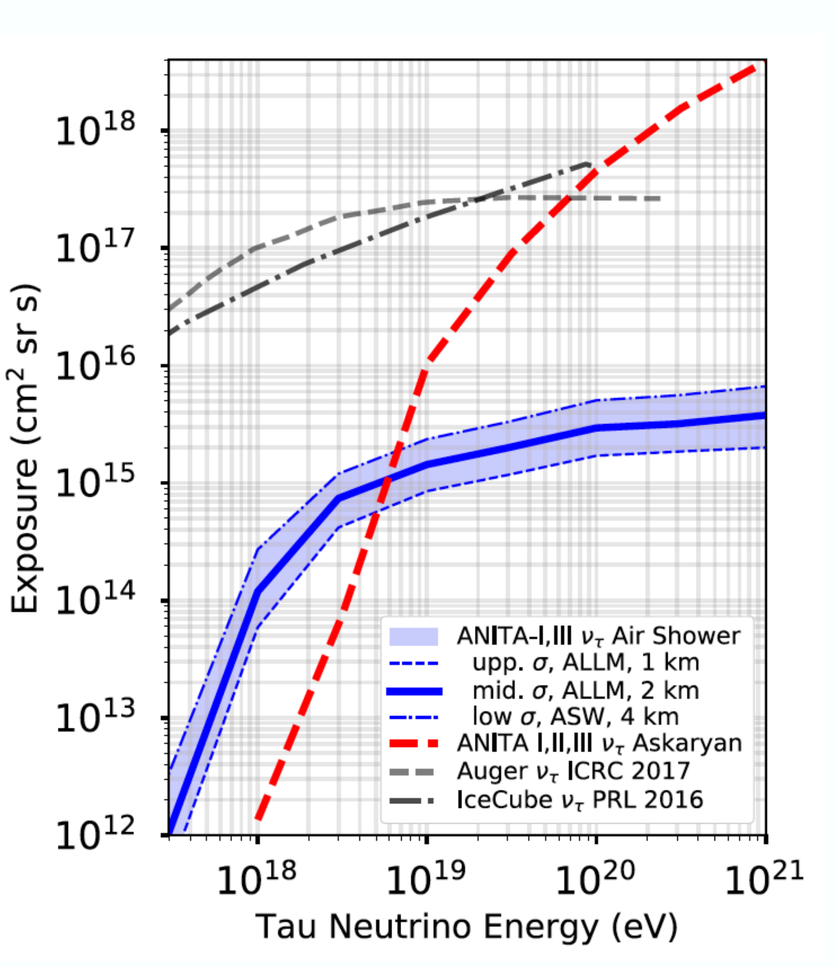
Chord length: 5500-7000 km (20-30,000km water equivalent)
1600km SM interaction length @ 1 EeV

Background estimate < 10^{-2}

Diffuse neutrinos: problem 1

- If these are tau neutrinos why hasn't IceCube seen them?

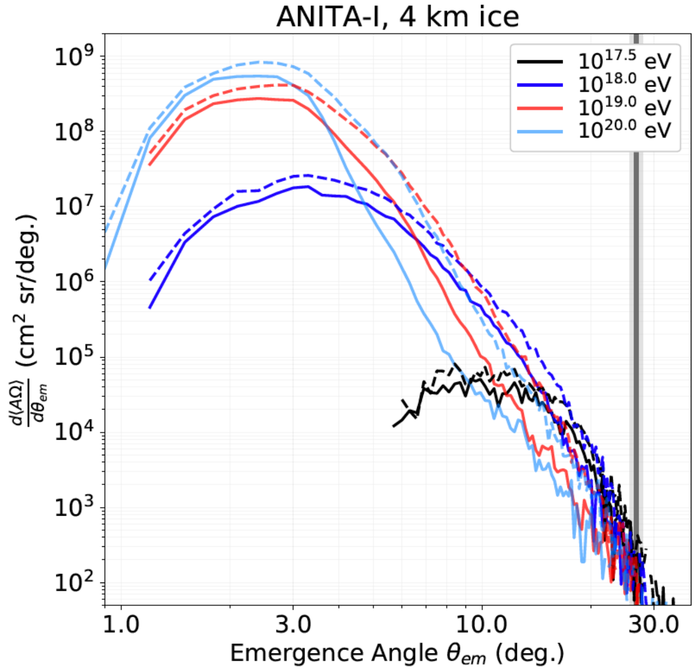


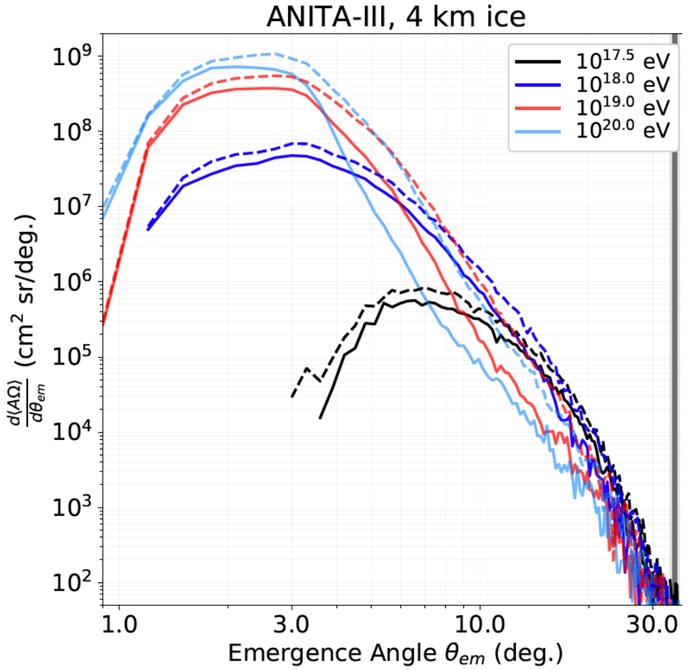


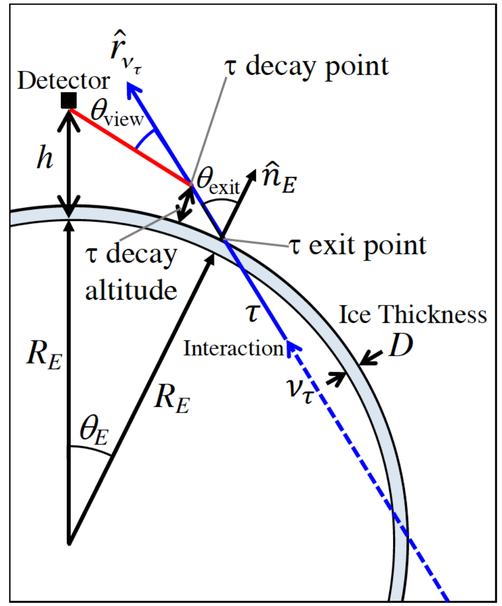
arXiv: 1811.07261

Diffuse neutrinos: problem 2

- Both ANITA-1 and ANITA-3 events were relatively close to the balloon
- There is much more acceptance close to the horizon
- Where are those tau candidate events?





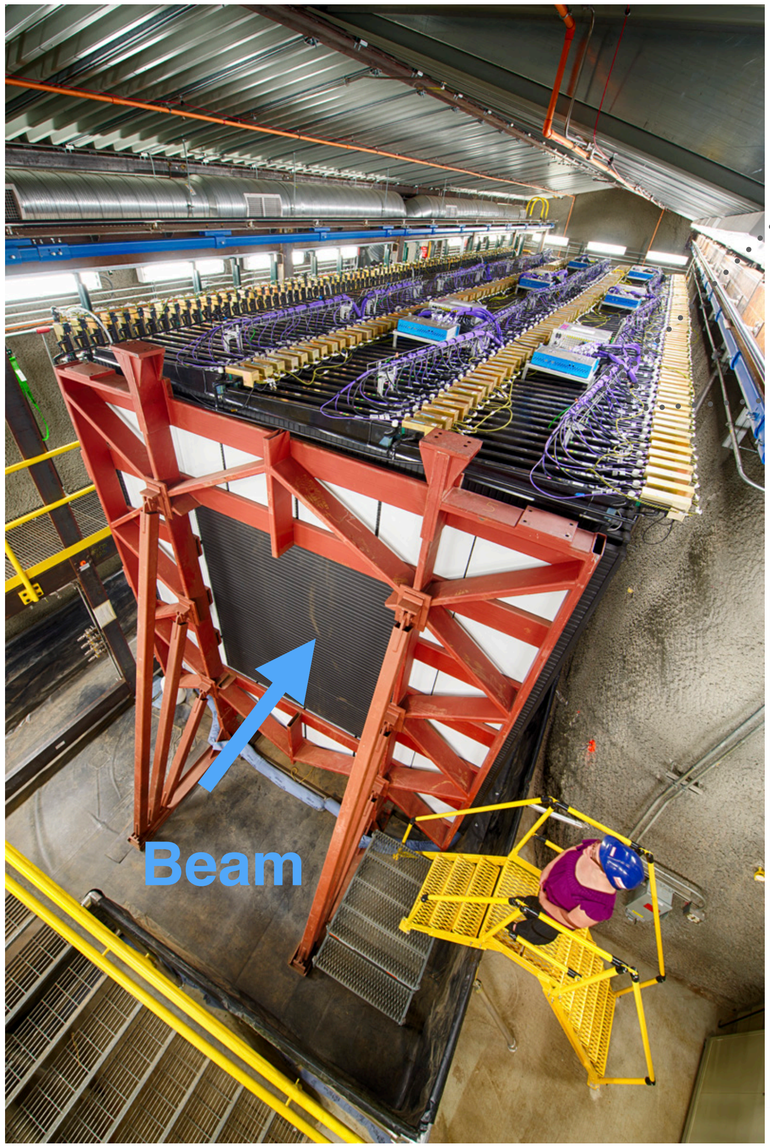


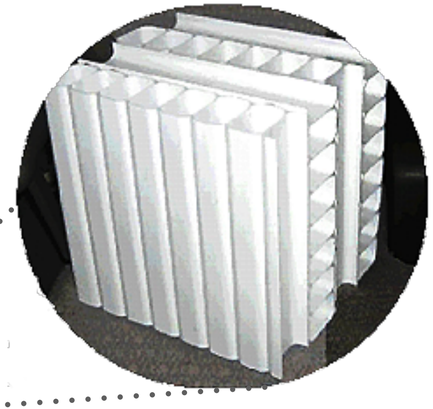
arXiv: 1811.07261

Some other interpretations..

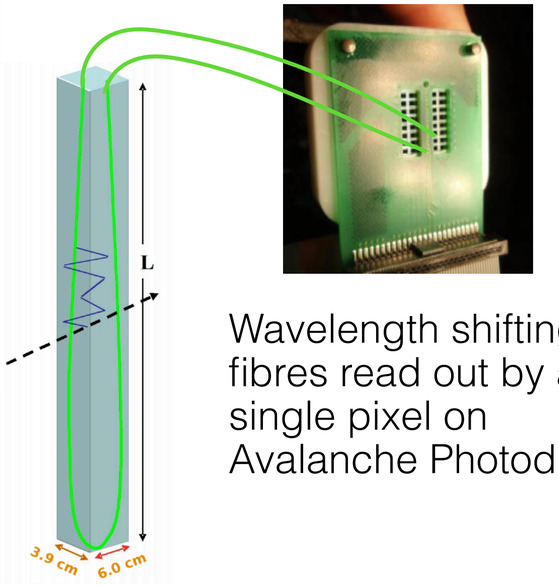
- Sterile neutrinos explanation ($\sigma_{vs} \sim \theta^2 \sigma_v$), would need powerful transient source to avoid IceCube's constraints (arXiv:1802.01611)
- Decay of massive dark matter candidate (>E18 eV) into two right handed neutrinos (arXiv: 1902.04584)
- Intermediary BSM particle produced in UHECR interactions with low cross-section and and low EM energy losses (stau) (arXiv:1809.09615)
- Powerful transient source search with 1.5 degree error:
  - No concurrent GRBs
  - SN2014dz, type Ia SN at z=0.017, 5 hours after initial discovery (a posteriori chance association 2.7σ)
  - IceCube point-source analysis excluded the possibility of them coming from a transient source (arXiv: 2001.01737)

NOvA Near Detector

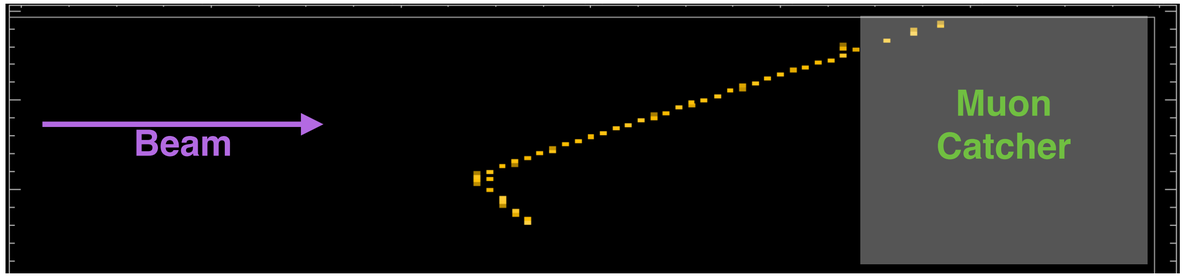




Alternating planes allow for 3D reconstruction

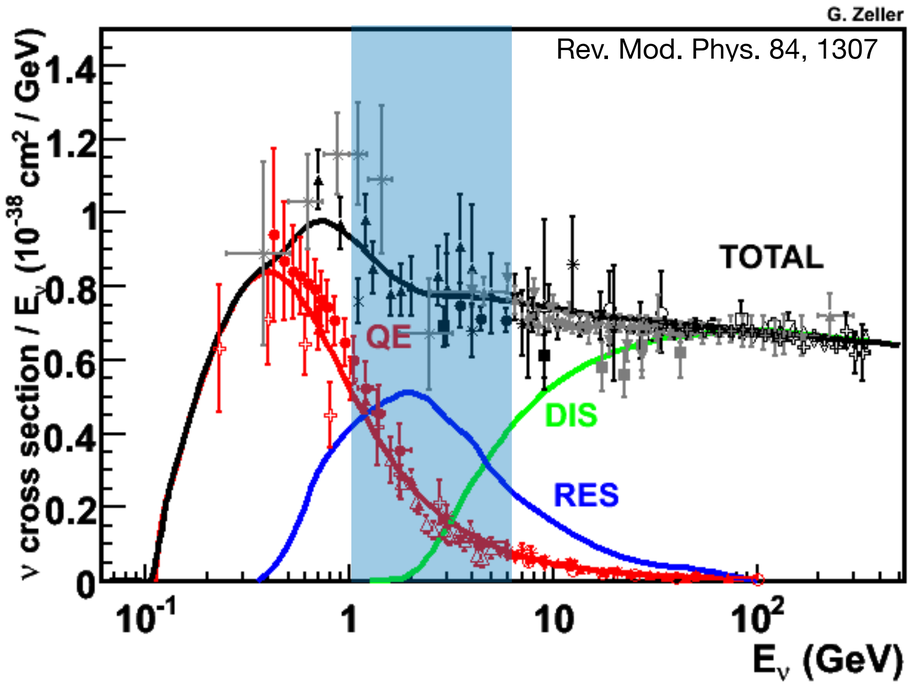


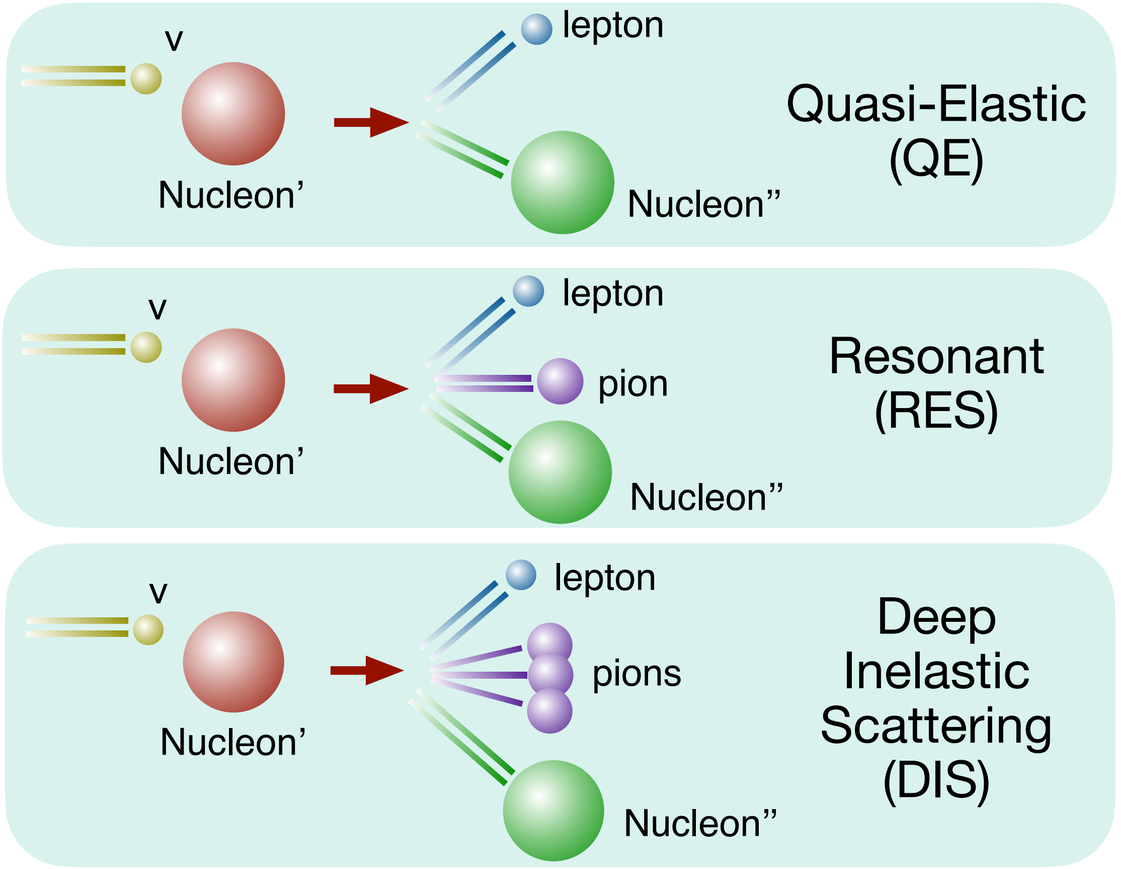
Wavelength shifting fibres read out by a single pixel on Avalanche Photodiode



- 300t tracking calorimeter
- Extruded plastic cells, filled with liquid scintillator
- 0.17 X_0 per layer
- 77% hydrocarbon, 16% chlorine, 6% TiO_2 by mass
- Muon catcher (steel + NOvA cells) at downstream end to range out ~2GeV muons.

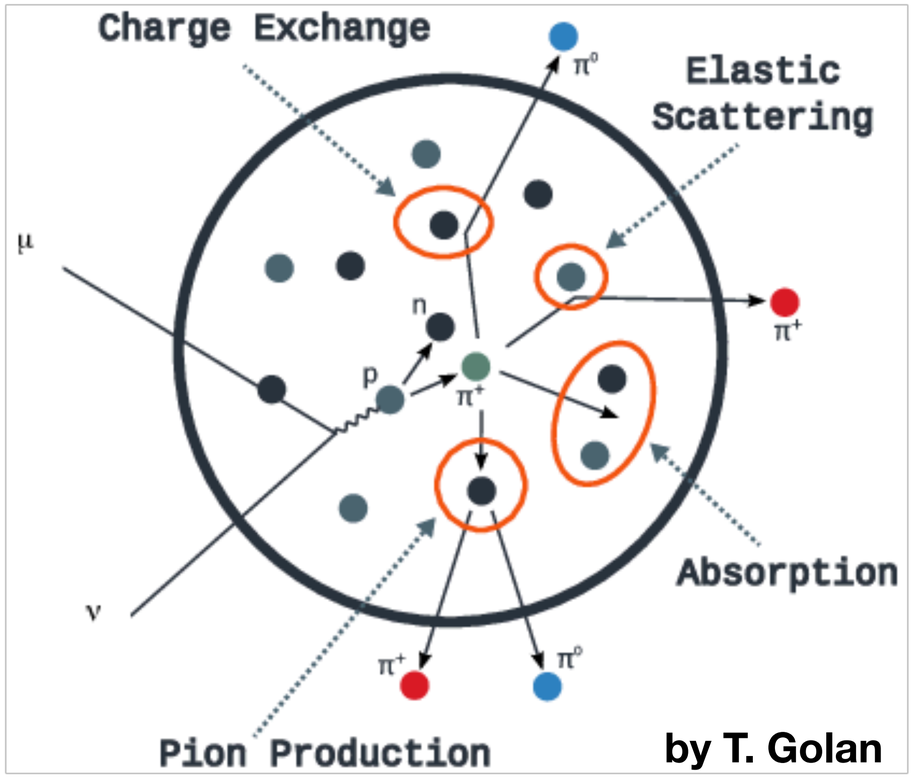
Neutrino CC interactions at NOvA

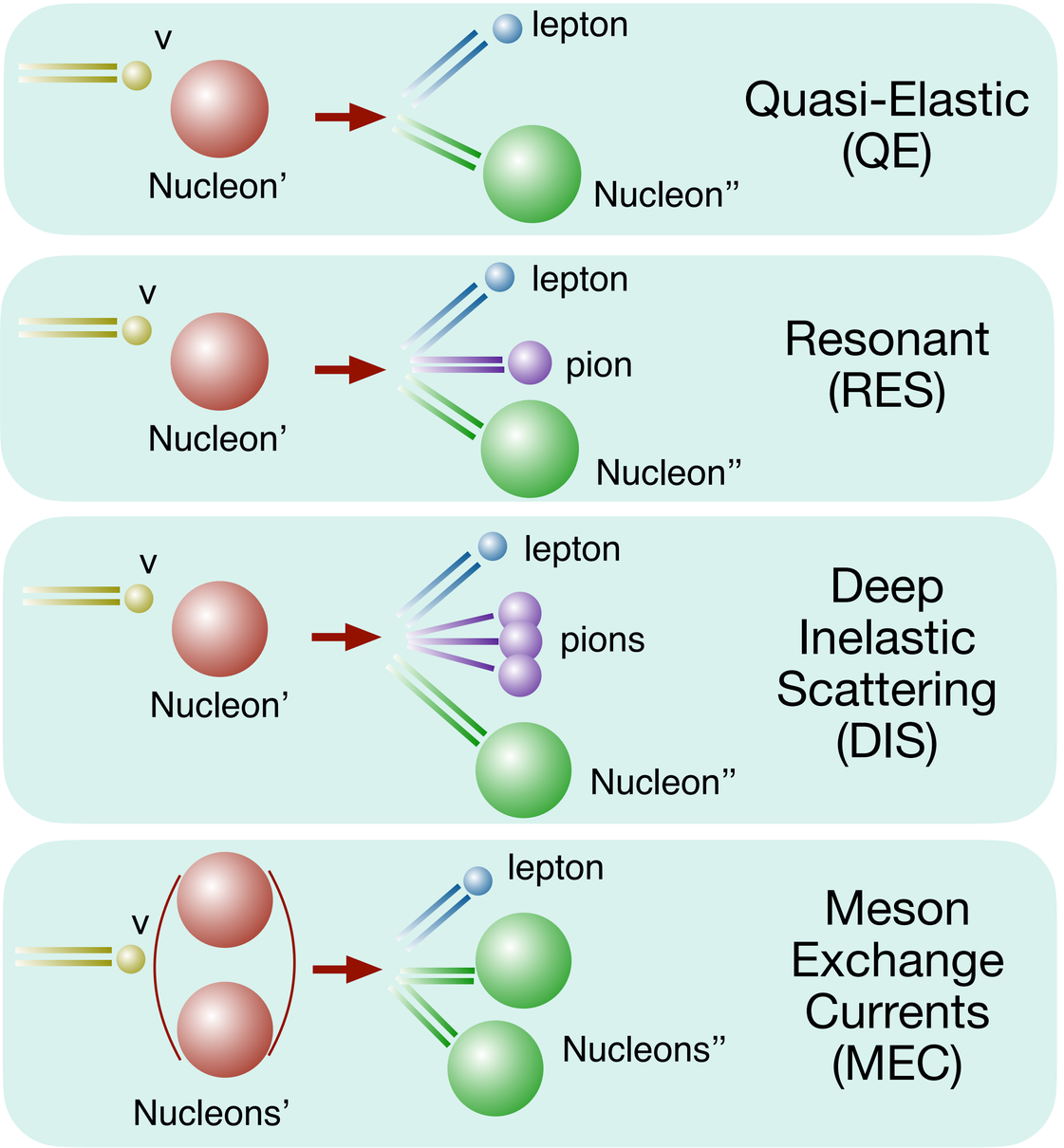




- NOvA flux peaks between 1 and 5 GeV: it sits in the transition region between different neutrino interaction processes.

Neutrino CC interactions at NOvA





- These neutrino interactions happen inside the nuclear media.

Cross section measurements

$$\sigma = \frac{N^{\text{events}} P}{N_t \Phi \epsilon}$$

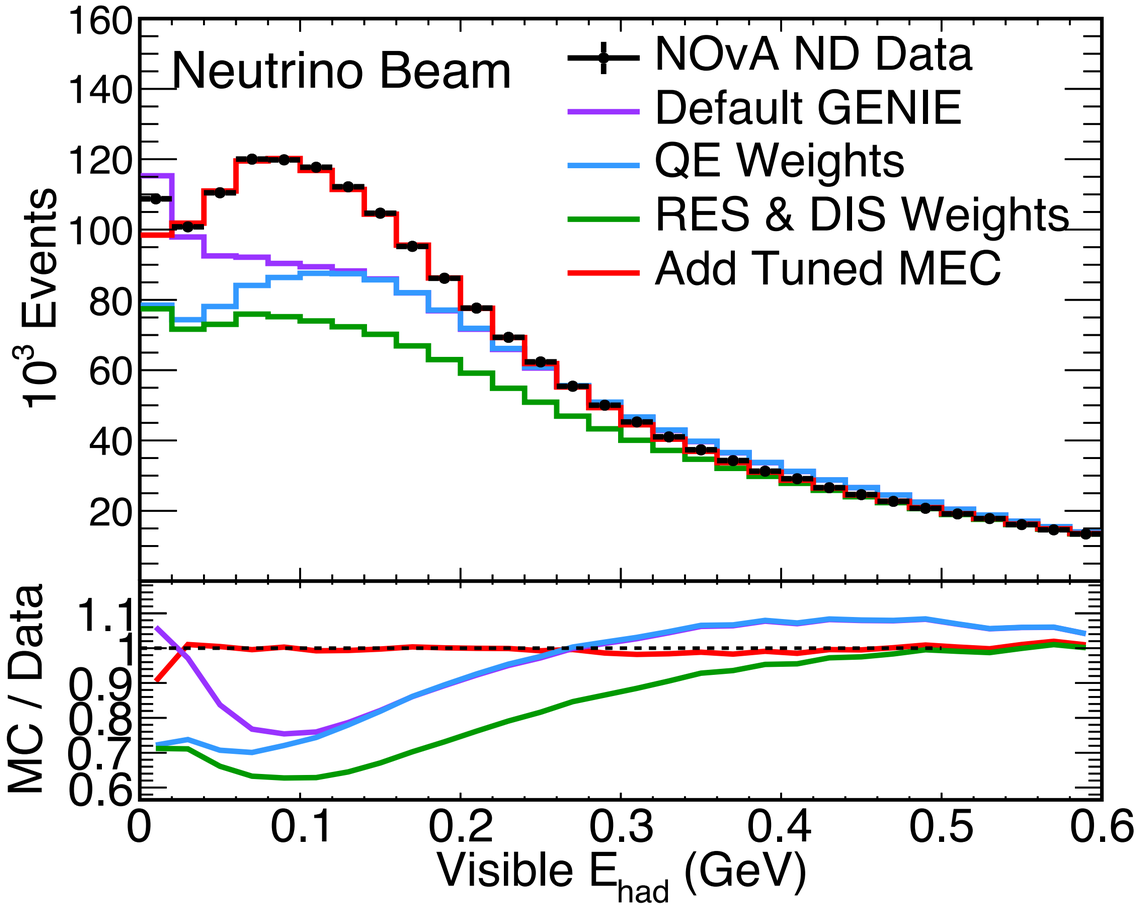
Cross Section	Events	Purity	Targets	Flux	Efficiency

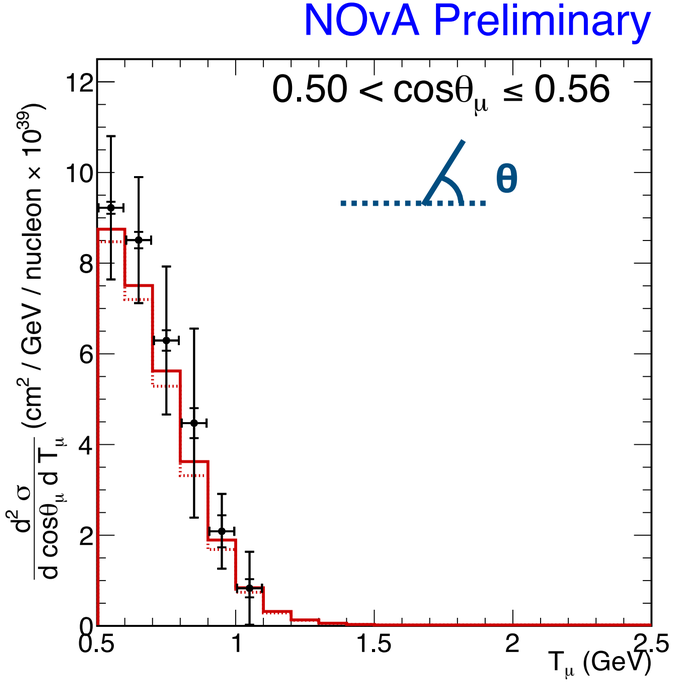
- Measurements of neutrino cross sections depend on the **efficiency** and **purity** which are estimated from our simulation.

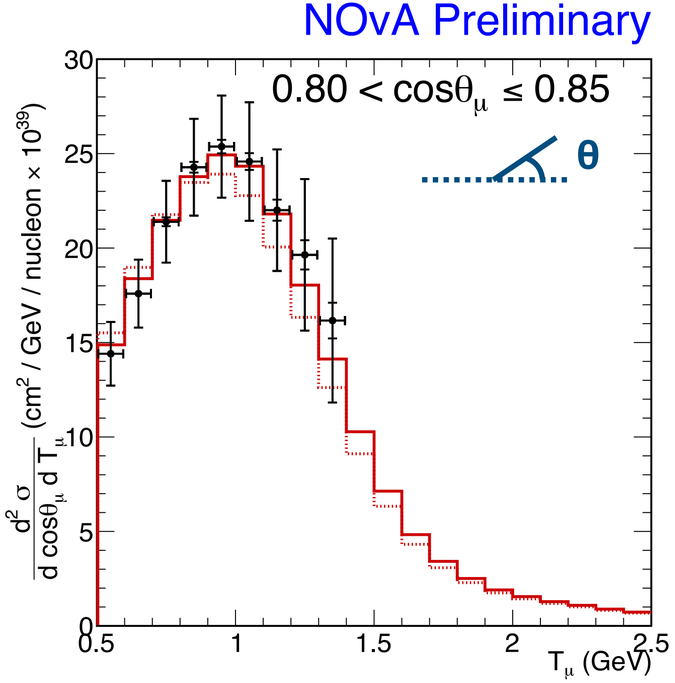
- We use NOvA and external data to tune interaction model (GENIE 2.12.2):

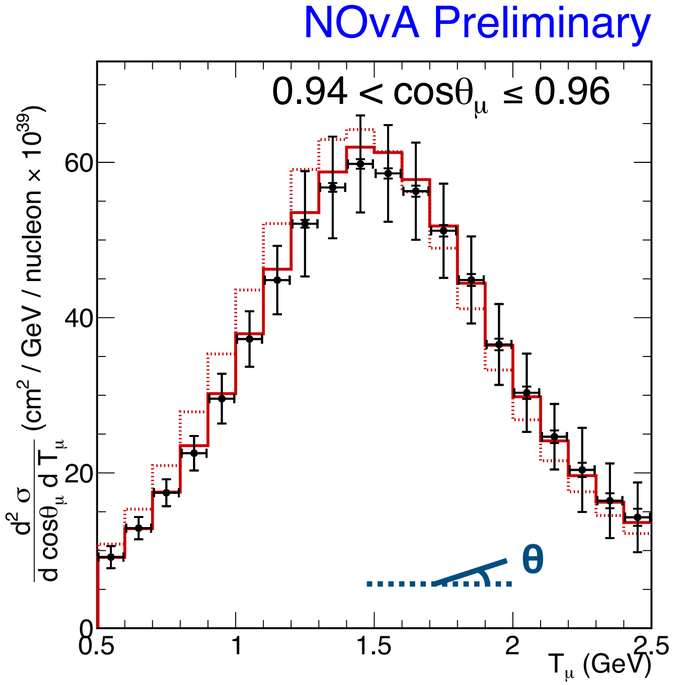
  - Suppress QE and RES,
  - Increase DIS,
  - Add MEC.

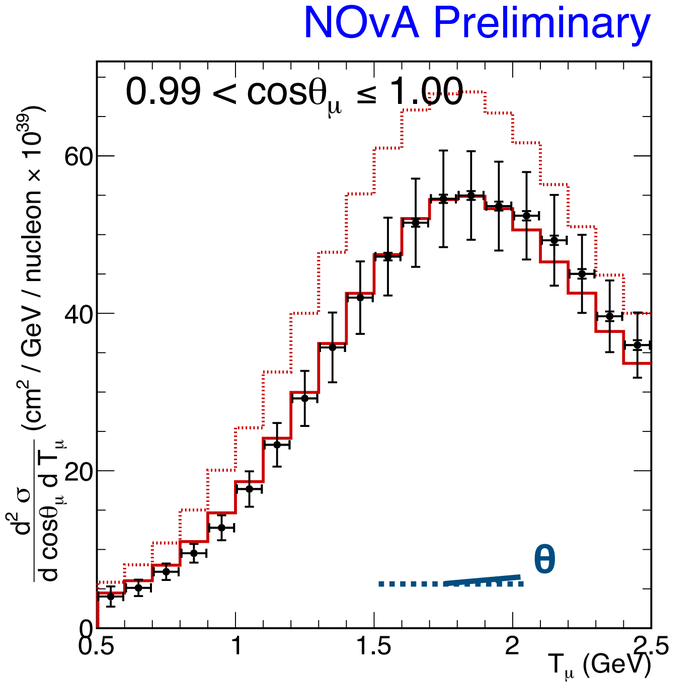
- Same tune that was used in the NOvA 2018 analysis:
  Ref to NOvA 2018 Analysis: Phys.Rev.Lett. 123 (2019) 15, 151803
  Ref to Tune: arXiv:2006.08727.









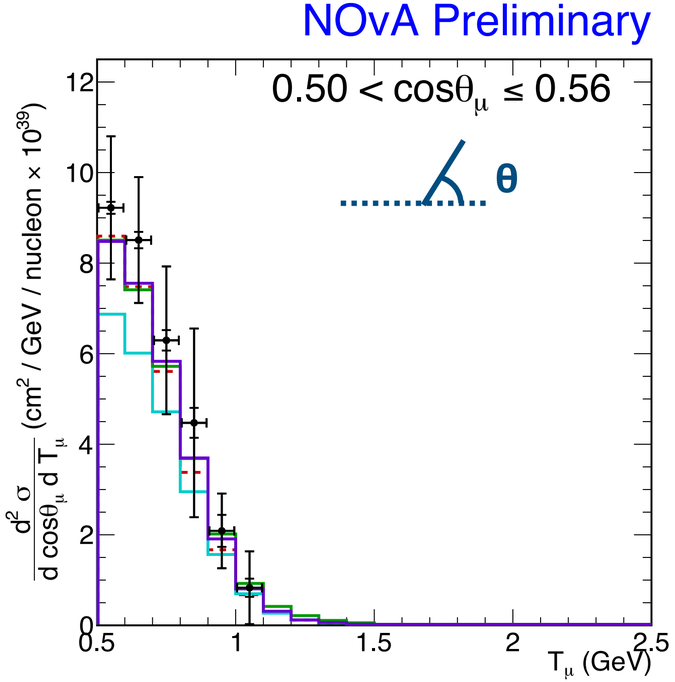


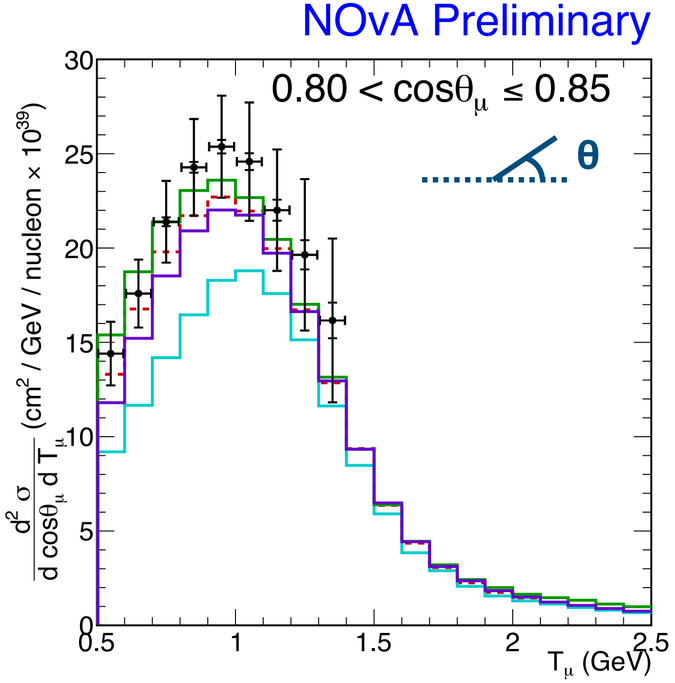
Example 4 cosine slices

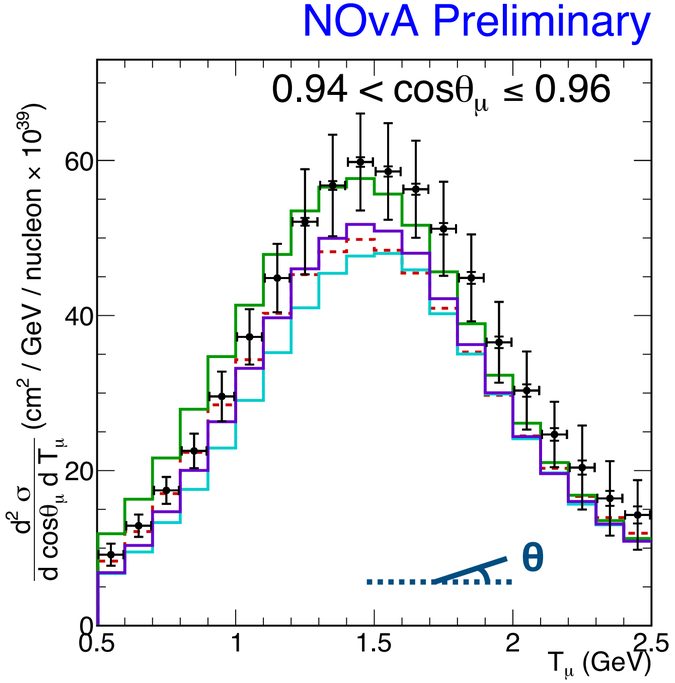
ν_μ CC inclusive

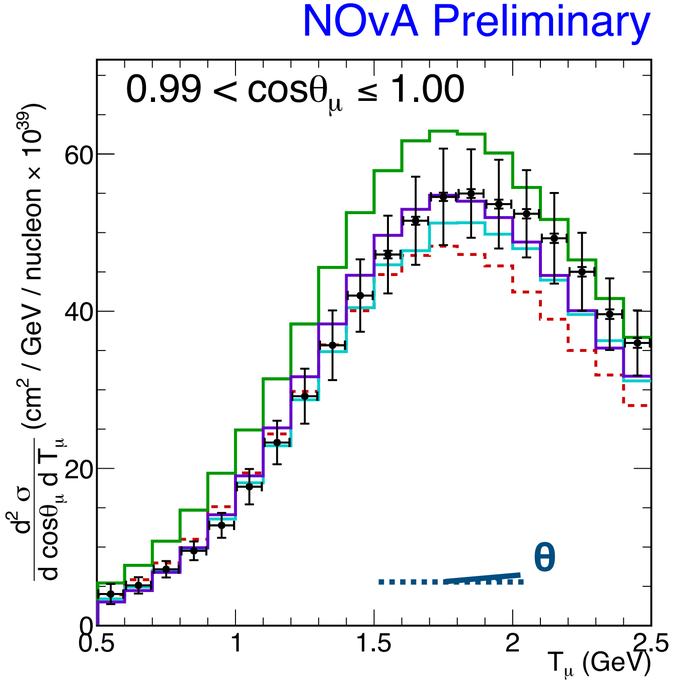
Data (Stat. + Syst.)
GENIE 2.12.2 - NOvA Tune
GENIE 2.12.2 - Untuned

- Good agreement between tuned/untuned GENIE versions in high angle slices.
- At forward angle, where QE and MEC events dominate, the untuned GENIE 2 overshoots data.









Example 4 cosine slices

ν_μ CC inclusive

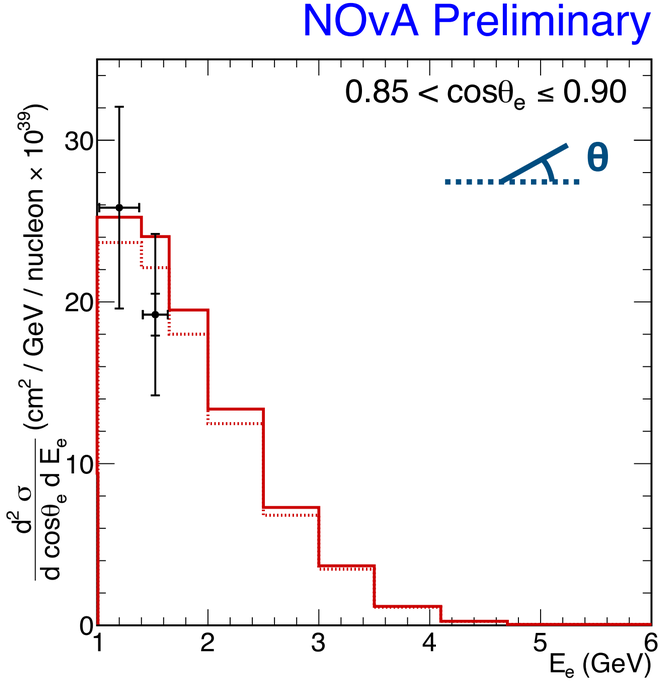
- Data (Stat. + Syst.)
- GENIE 3.00.06*
- GiBUU 2019
- NEUT 5.4.0
- NuWro 2019

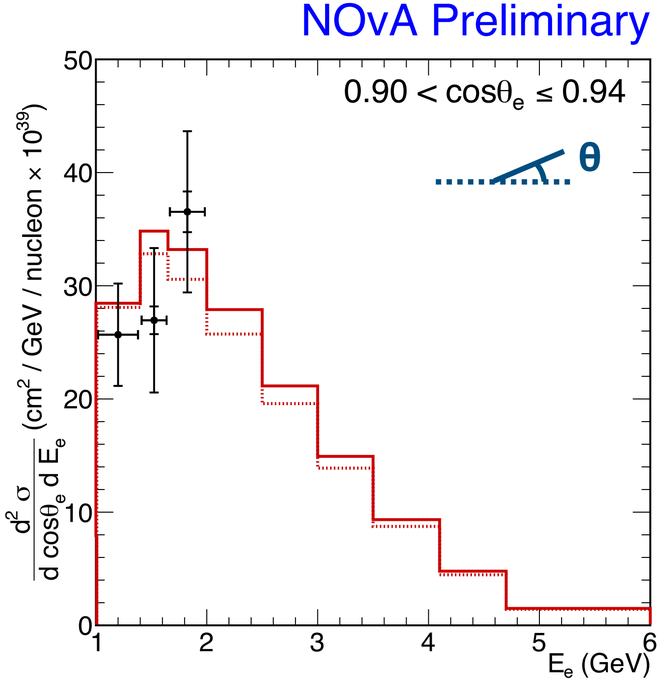
We used the total covariance matrix to calculate p-values.

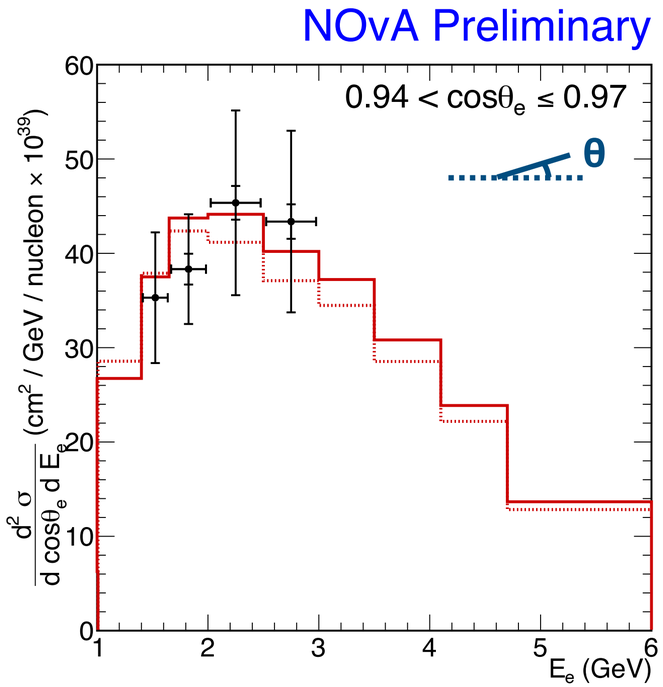
Generator	p-value
GENIE 2.12.2 - Tuned	0.93
GENIE 2.12.2 - Untuned	0.24
GENIE 3.00.06*	0.26
GiBUU 2019	0.03
NEUT 5.4.0	0.52
NuWro 2019	0.22

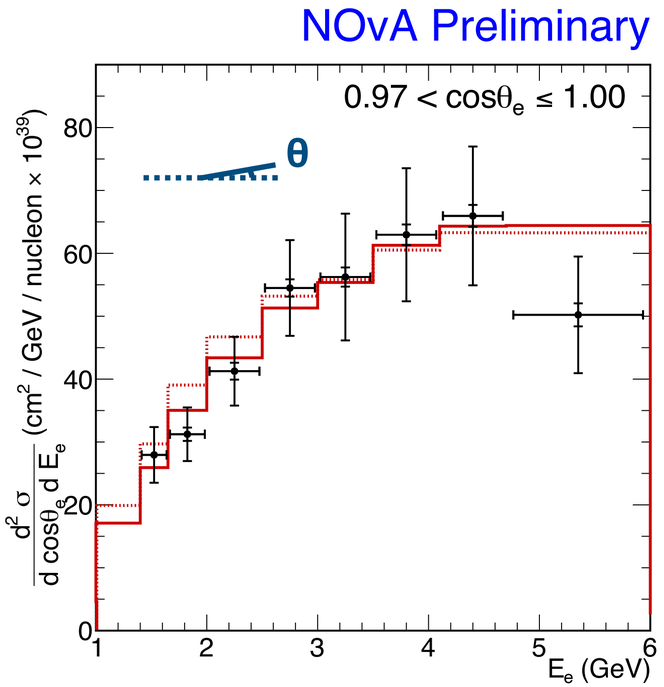
***N18_10j_02_11a: combination of G18_10j_00_000 and G18_10b_02_11a**

"Guess who's back?"









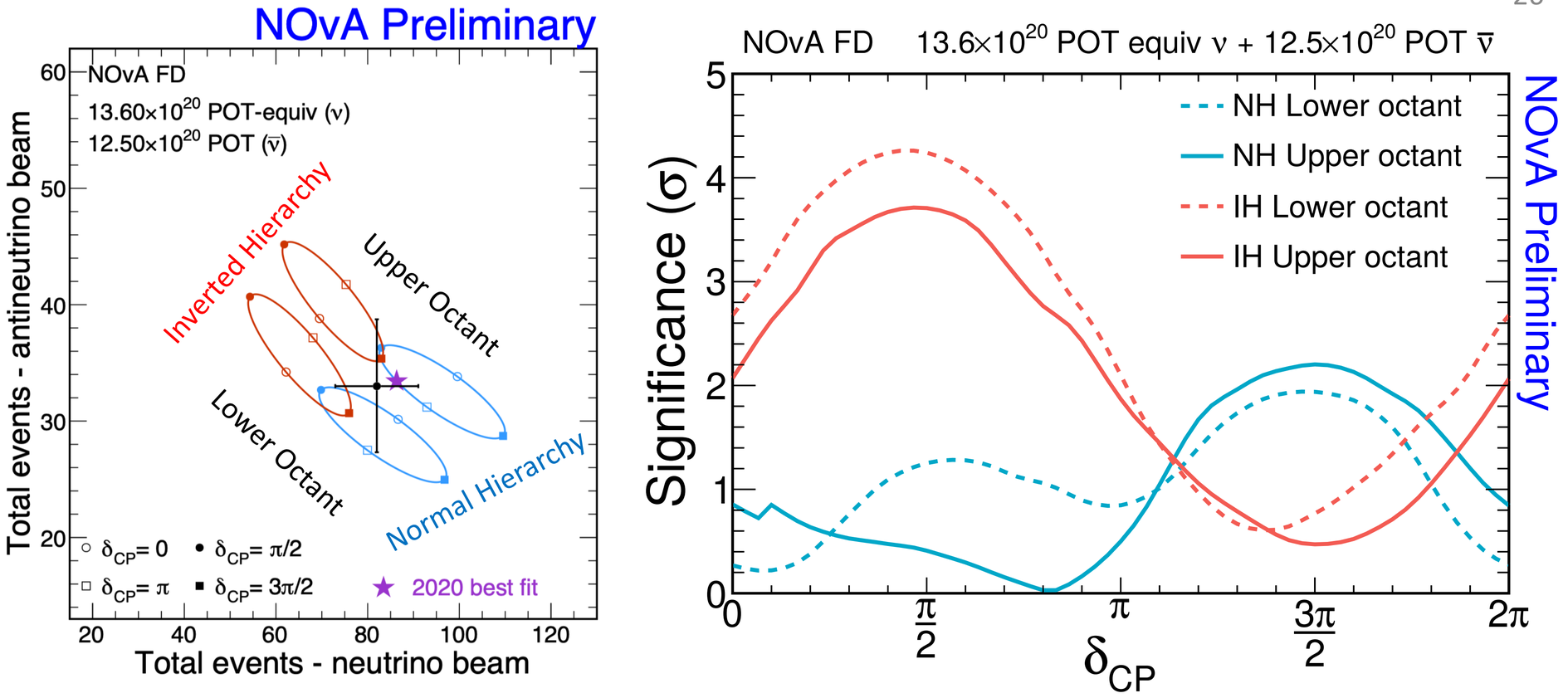
ν_e CC inclusive

Data (Stat. + Syst.)

GENIE 2.12.2 - NOvA Tune

GENIE 2.12.2 - Untuned

- Good agreement between tuned/untuned GENIE versions in all angle slices.



- We see no strong asymmetry in the rates of appearance of ν_e and $\bar{\nu}_e$