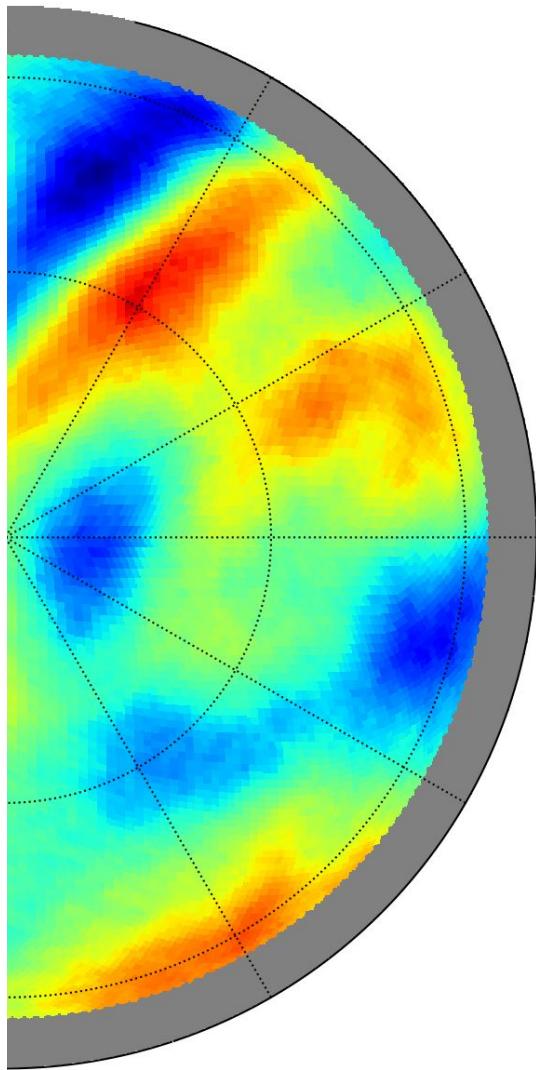


# Cosmic-Ray Anisotropy at PeV Energies with IceTop

Rasha Abbasi  
Paolo Desiati  
Juan Carlos Díaz-Vélez &  
**Frank McNally**  
for the IceCube Collaboration



# History

2010 First observation

[Abbasi et al. \(2010\)](#)

2011 Small-scale structure

[Abbasi et al. \(2011\)](#)

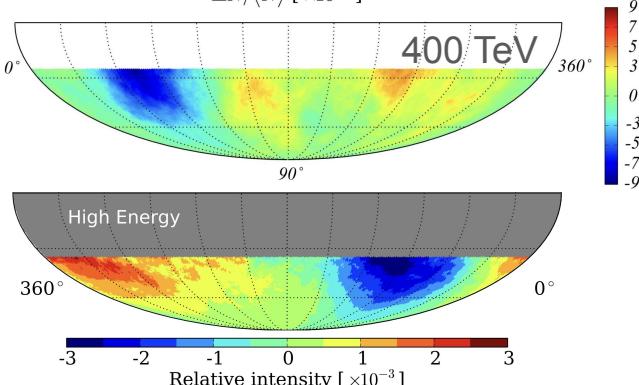
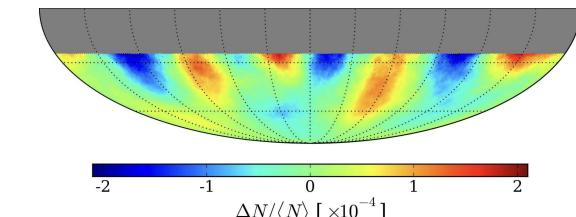
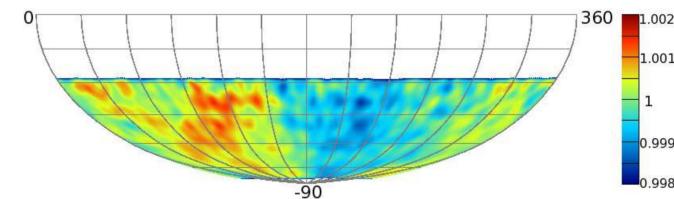
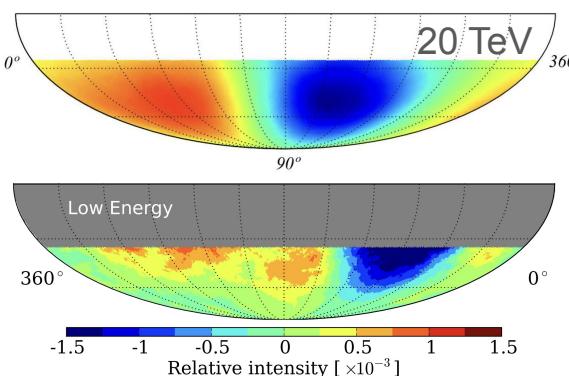
2012 Energy dependence

[Abbasi et al. \(2012\)](#)

2013 IceTop

[Abbasi et al. \(2013\)](#)

# Anisotropy in IceCube

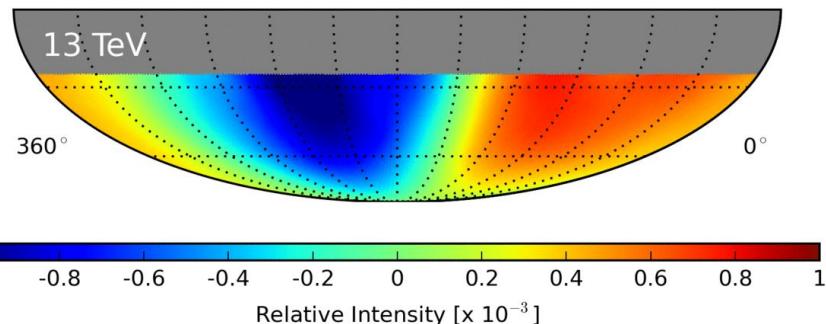


# History

# Anisotropy in IceCube

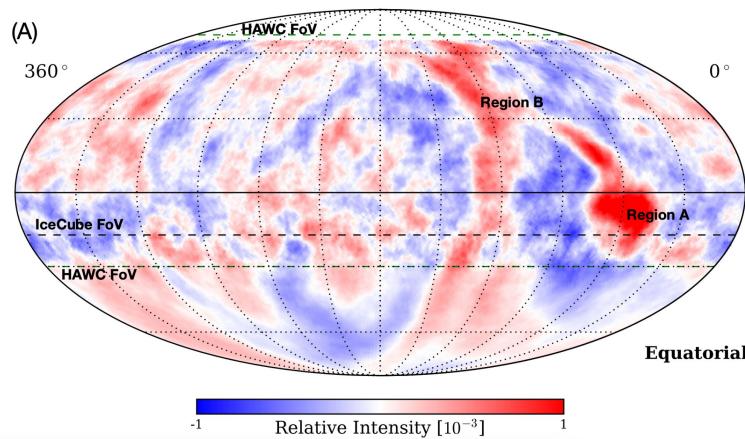
2016 Six-Year Update

[Aartsen et al. \(2016\)](#)



2019 Full-Sky with HAWC

[Abeysekara et al. \(2019\)](#)

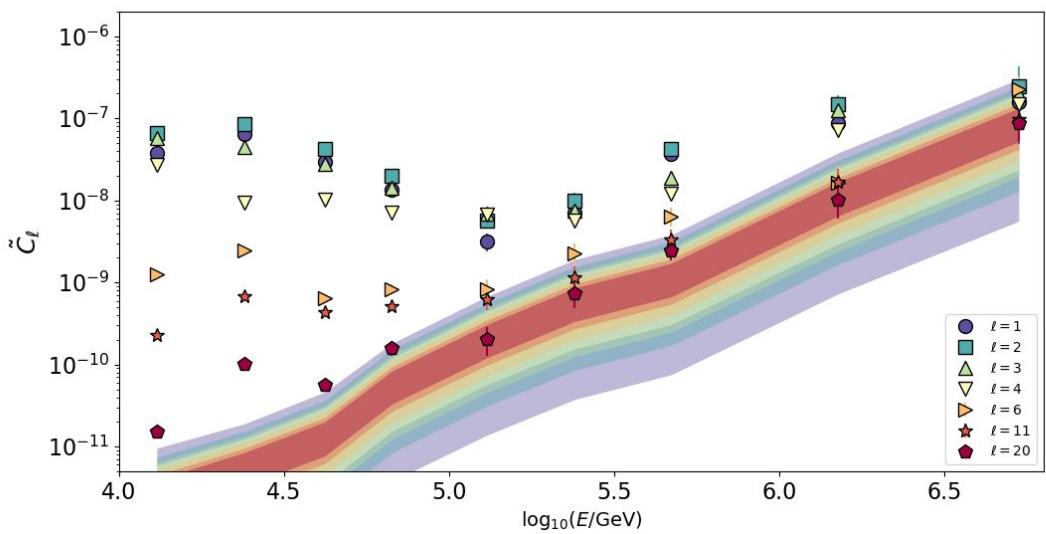


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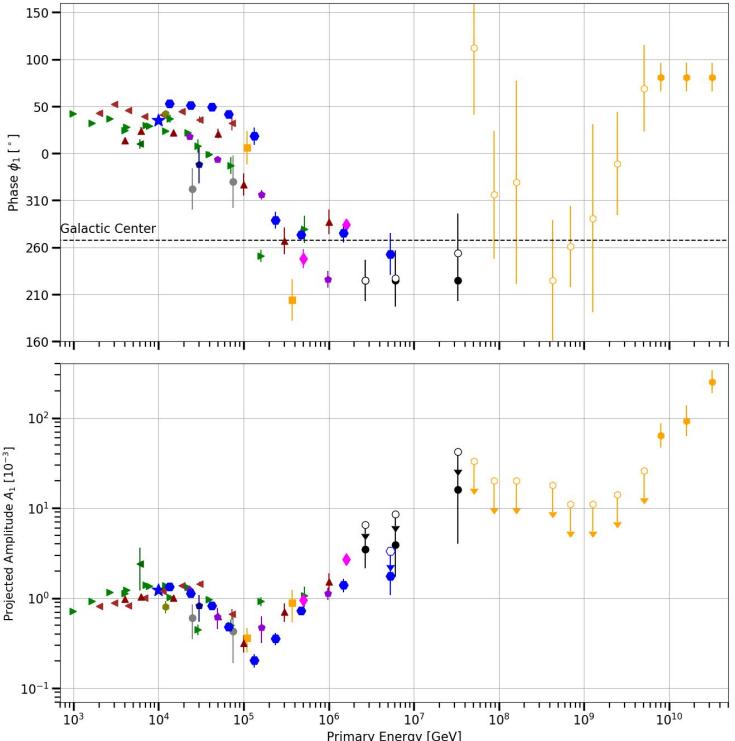
2025

## Twelve-Year Update

[Abbasi et al. \(2025\)](#)



# Anisotropy in IceCube



# Present Day

# IceTop Update

**Objective:** Revisit recent in-ice analysis with IceTop surface array

Improved statistics

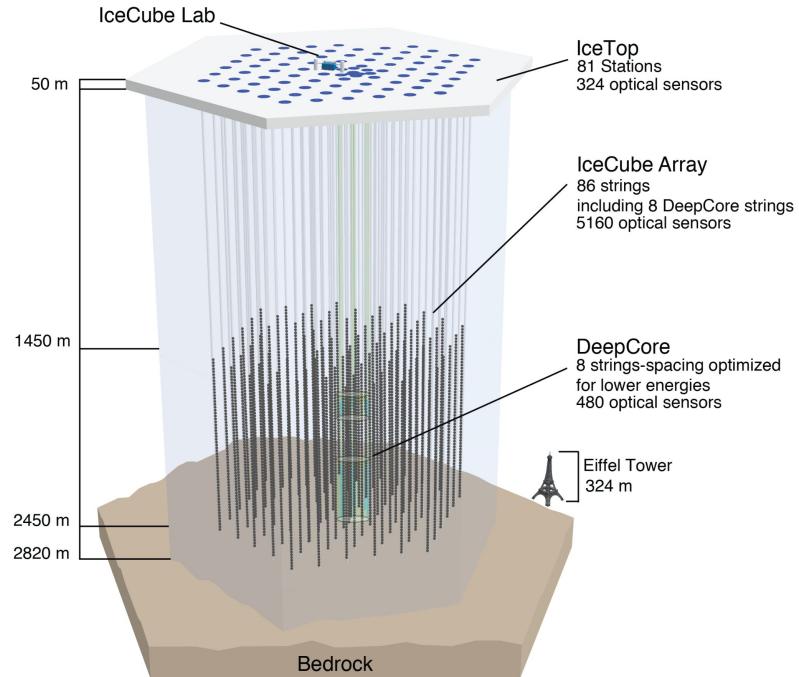
Eleven years of data  
(~1 billion events)

Same location and methods...

Systematic test for  
previous observations

...different detector

Electromagnetic (IceTop) vs  
muonic (in-ice) sensitivity



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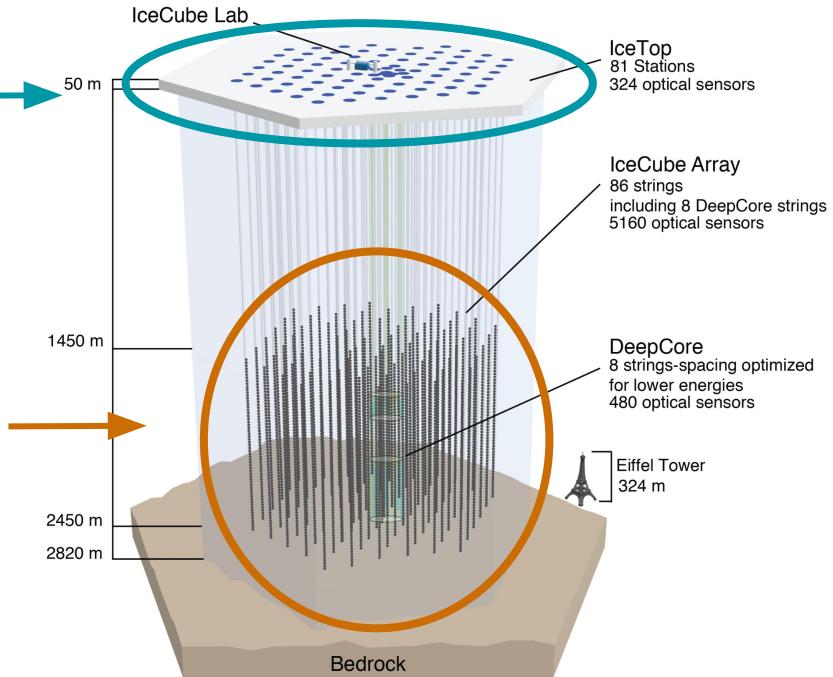
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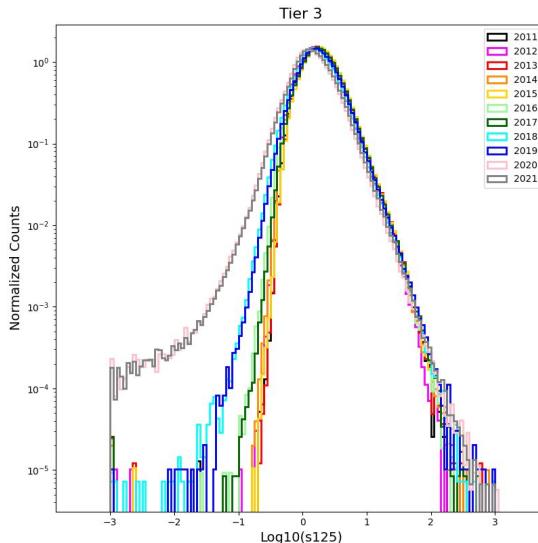
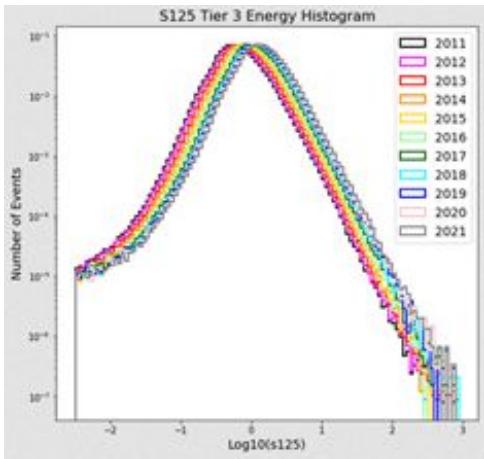
*ICETOP*

*IN-ICE*



# Methodology

- Snow accumulation over time diminishes detector response
- Data driven approach: adjust cuts on number of stations hit ( $N_{\text{Stations}}$ ) so energy proxy ( $S_{125}$ ) distribution remains roughly constant

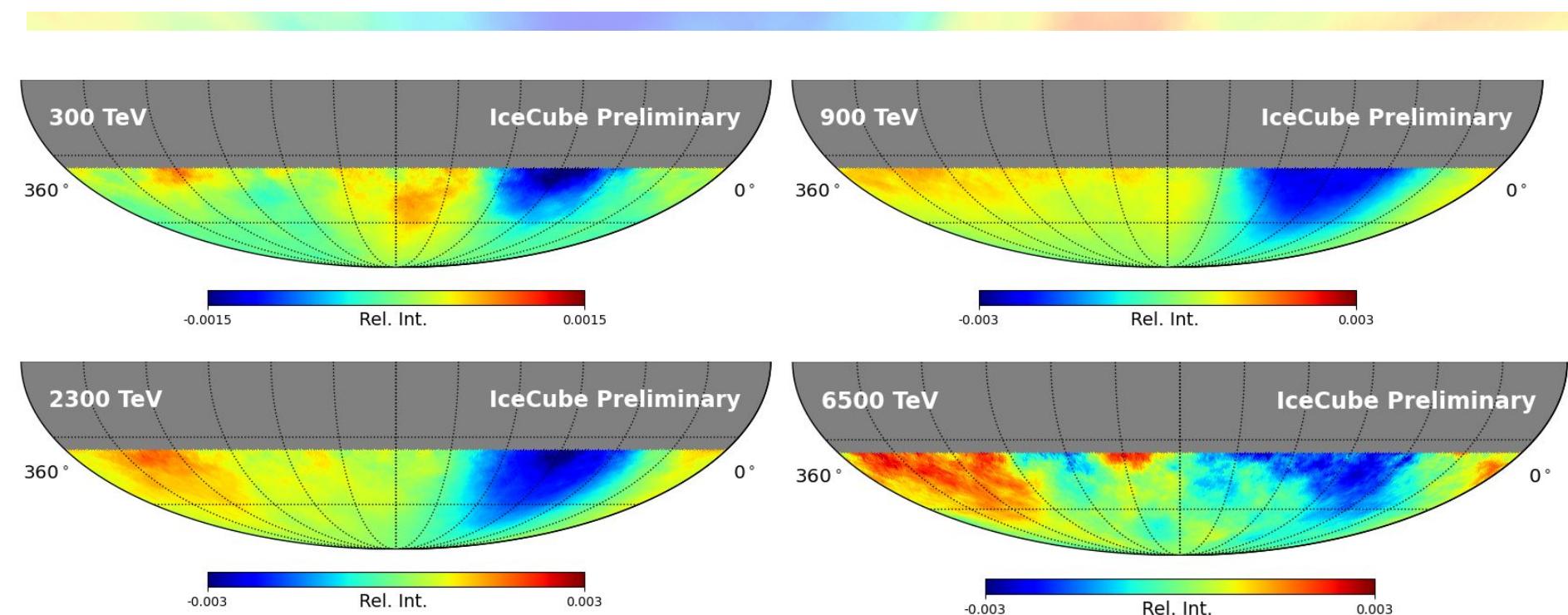


# Energy Binning

	Tier 1	Tier 2	Tier 3	Tier 4
<b>2011</b>	3 - 4	5 - 9	10 - 16	$\geq 17$
<b>2012-13</b>	3 - 4	5 - 8	9 - 15	$\geq 16$
<b>2014</b>	3 - 4	5 - 7	8 - 14	$\geq 15$
<b>2015</b>			8 - 14	$\geq 15$
<b>2016-17</b>			7 - 13	$\geq 14$
<b>2018-19</b>			6 - 12	$\geq 13$
<b>2020-21</b>			5 - 11	$\geq 12$

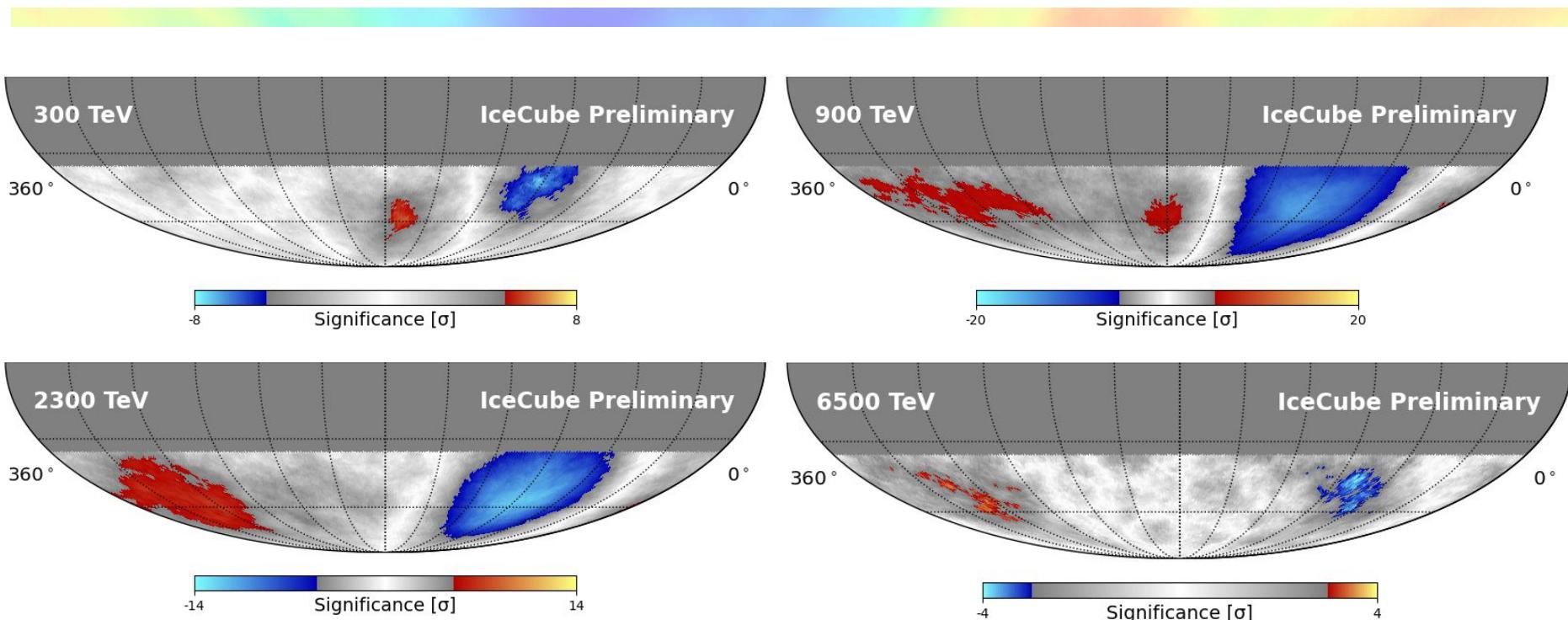
# Results

## Energy Dependence



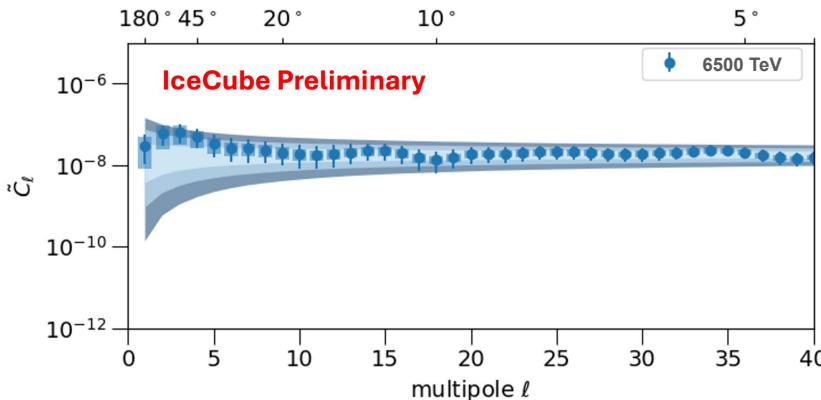
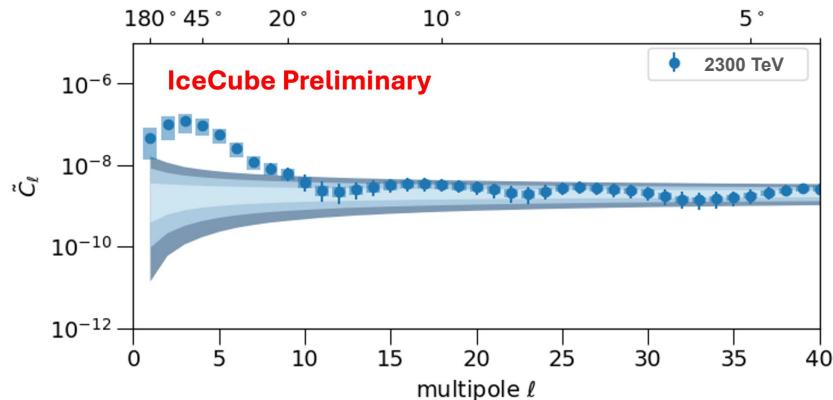
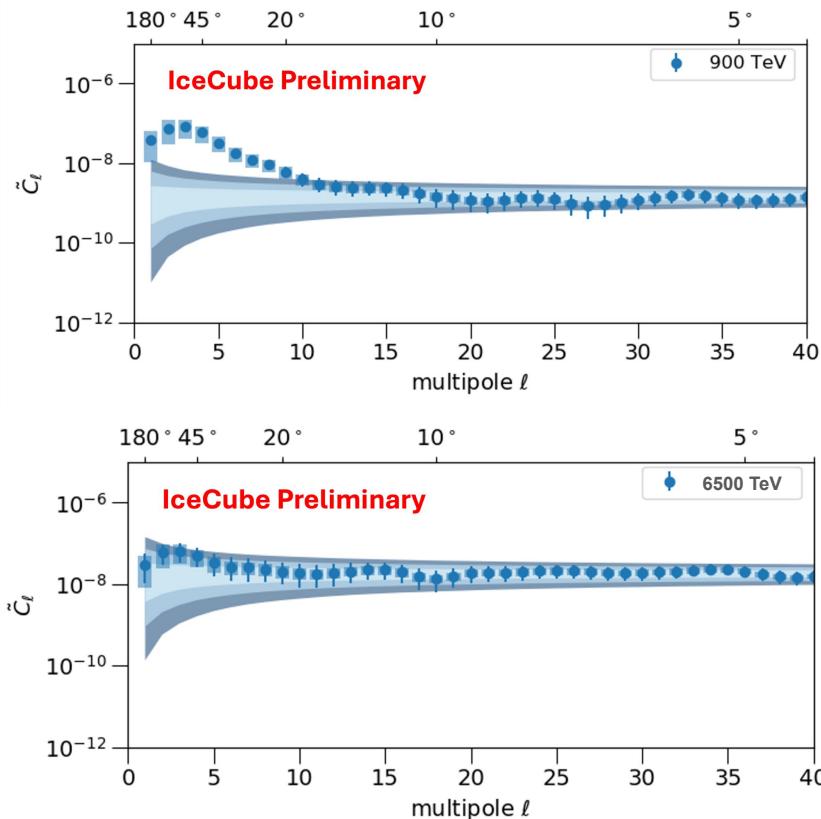
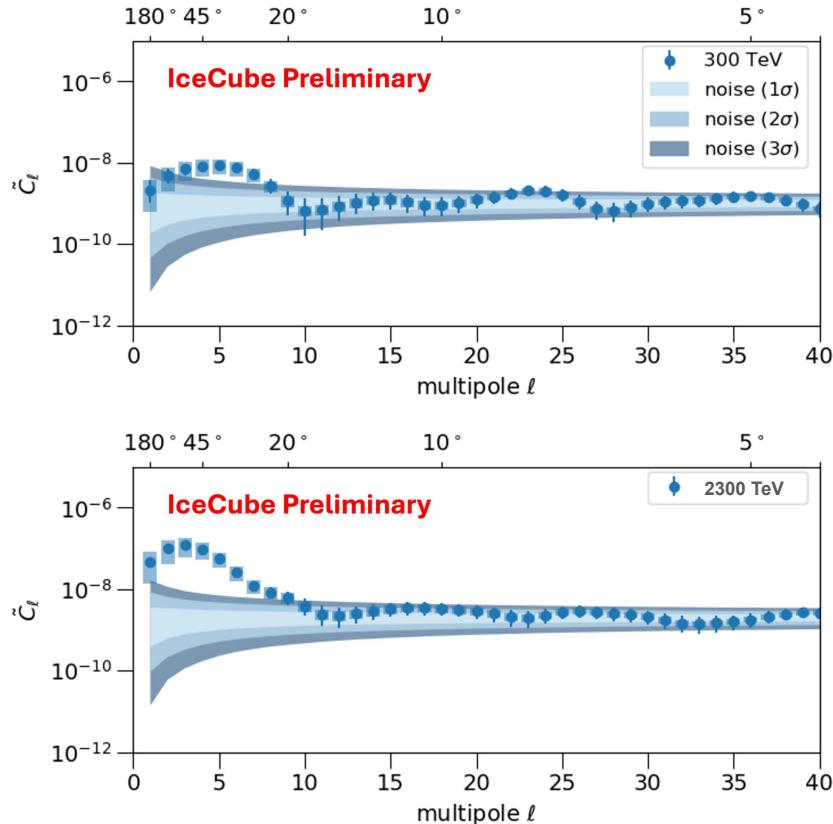
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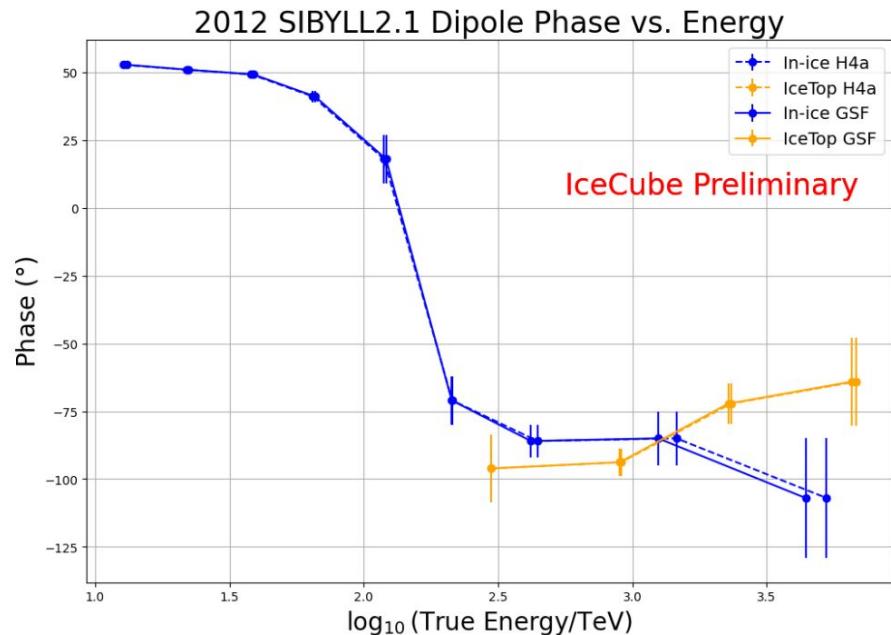
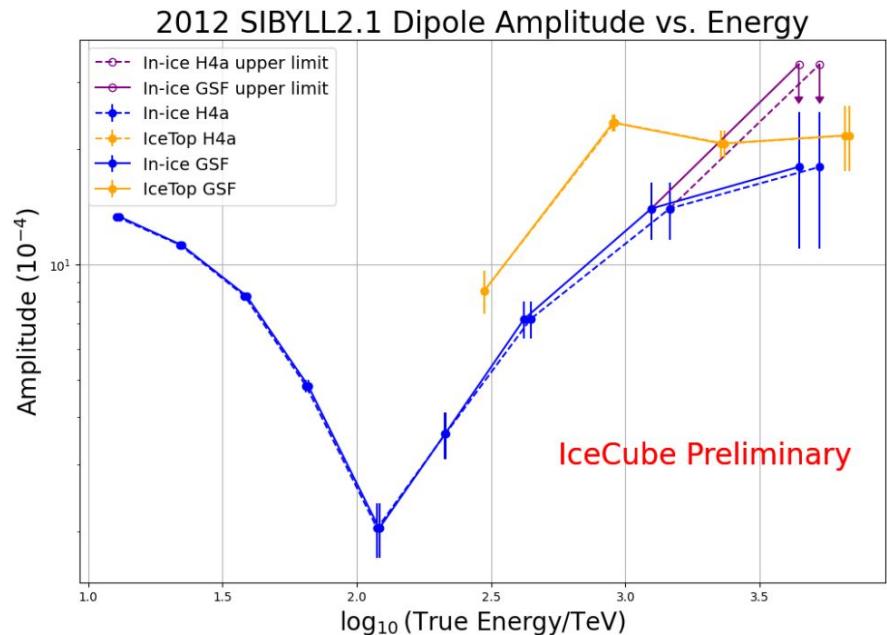
# Results

# Angular Power Spectra



# Results

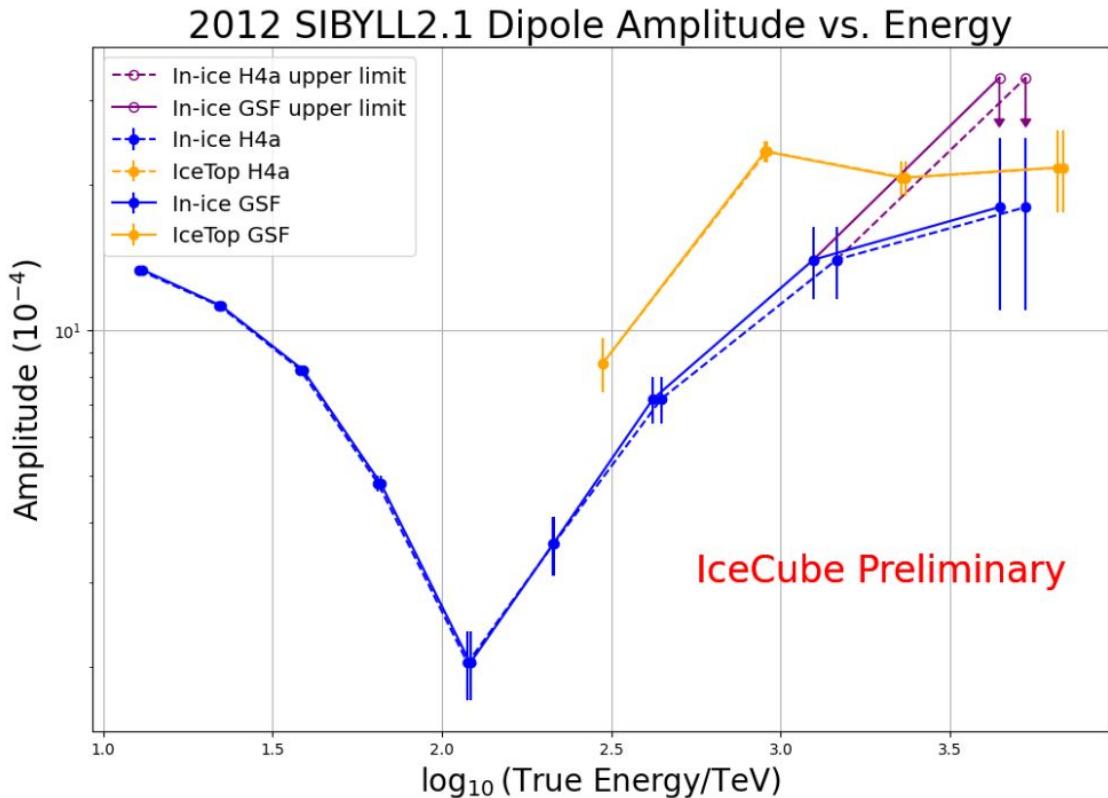
## Dipole Phase & Amplitude



# Methodology

# Dipole Phase & Amplitude

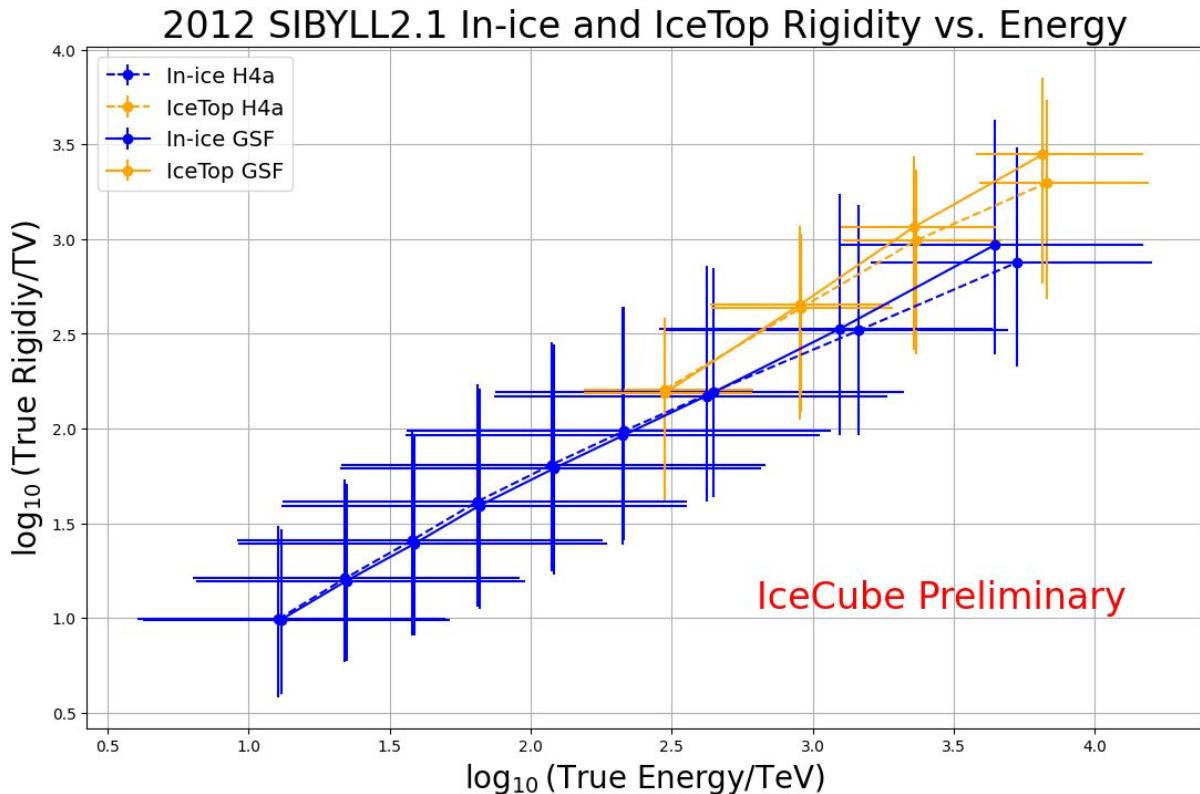
- Data put into energy bins based on measurables
  - IceTop: NStations
  - In-Ice: number of hits and reconstructed zenith
- Plot displays median Monte Carlo energy for each energy bin
- What if we displayed the median Monte Carlo **rigidity** instead?



# Methodology

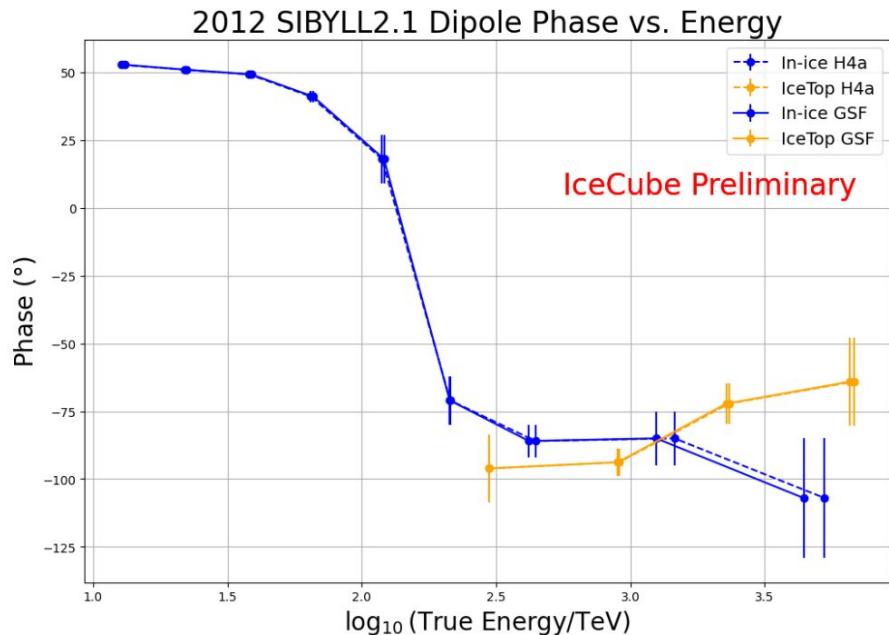
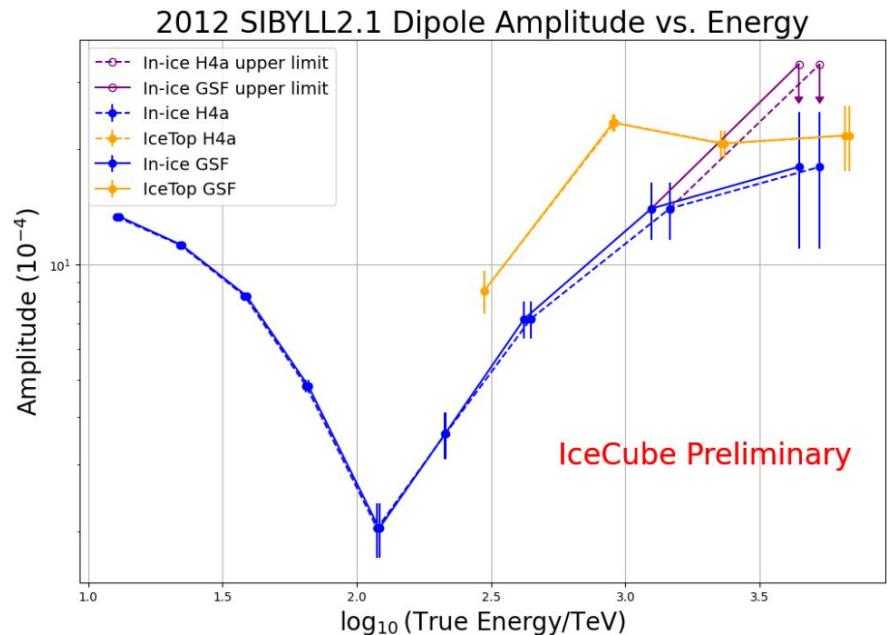
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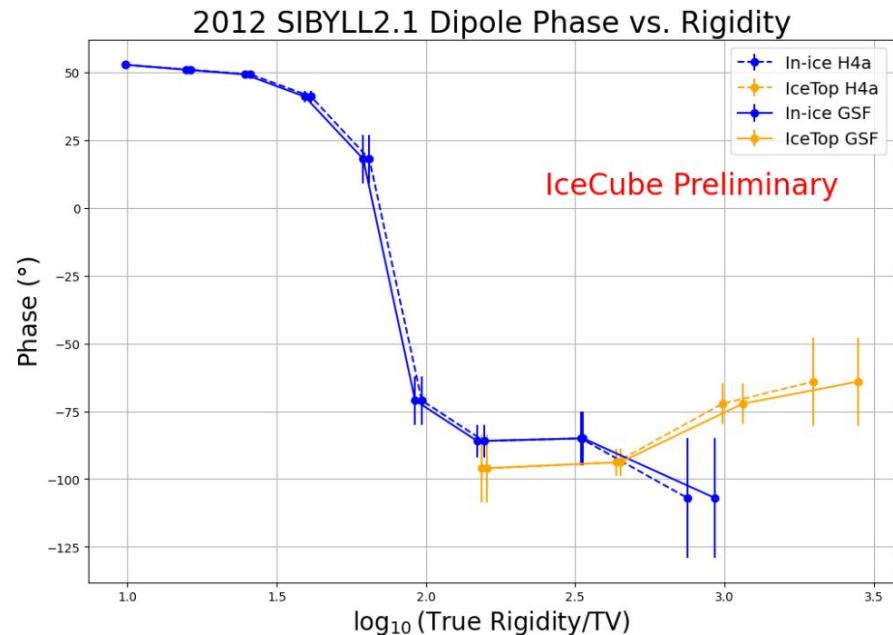
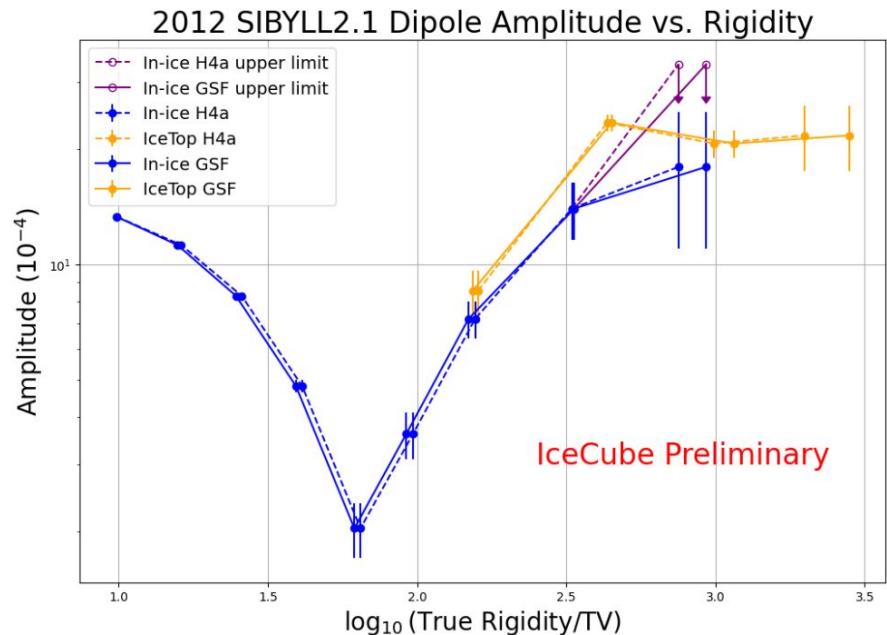
# Results

## Dipole Phase & Amplitude



# Results

## Dipole Phase & Amplitude



# Summary



## Results

- New IceTop **skymaps** and **angular power spectra** provide additional detail for studying cosmic-ray anisotropy in the PeV energy region
- Dipole phase and amplitude more consistent with in-ice measurements when considered as a function of **rigidity**

## Upcoming Work

- Time modulation, anti- and extended sidereal frames
- Compton-Getting analysis
- Joint IceTop / TALE analysis
- Joint in-ice / HAWC analysis
- Spectral anisotropy

# Contributors

# Undergraduate Personnel

## Mercer

**Rajwol Chapagain**

Simulation study of energy distributions over time

**Robert Futrell**

Rigidity analysis

**Aidan Hayes**

Simulation study of energy distributions over time

**Aiden Hinners**

Angular power spectrum, rigidity analysis

**Charles Joiner**

Systematic checks of detector stability

## Loyola

**Gunwati Agrawal**

Simulation study, snow accumulation study, IceTop data processing/analysis

**Elizabeth Bastow**

IceTop Data processing/analysis, data stability

**Grace Bratrud**

IceTop data processing/analysis

**Katherine “Jo” Gruchot**

Anisotropy time dependence

**Will Hayes**

Events livetime/rates

**Savannah Lehrman**

Simulation study, snow accumulation study, IceTop data processing/analysis

**Alexandra McClure**

IceTop Data processing/analysis, rigidity analysis

**Andrew Moy**

Anisotropy time/energy dependence

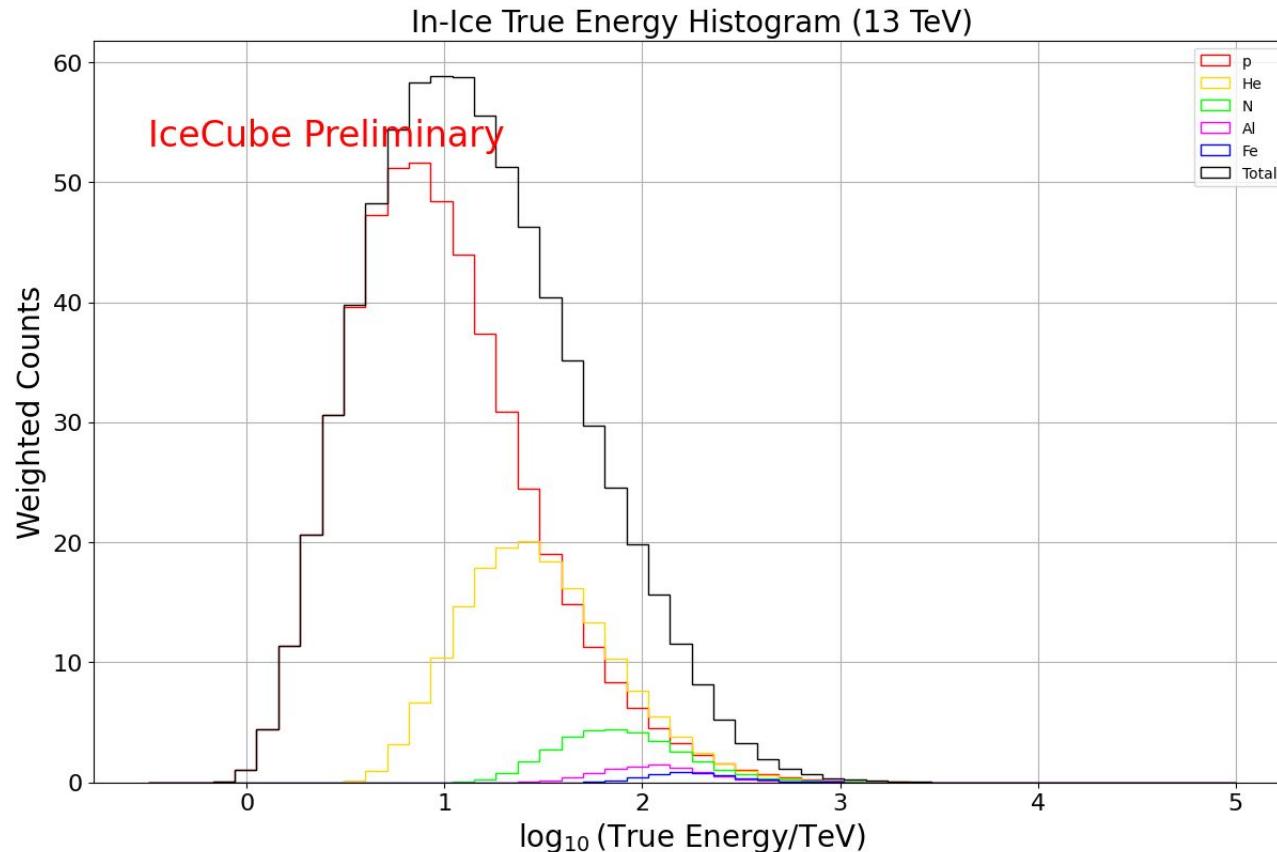
**Joe Summers**

IceTop simulation/data comparison

# Backup Slides

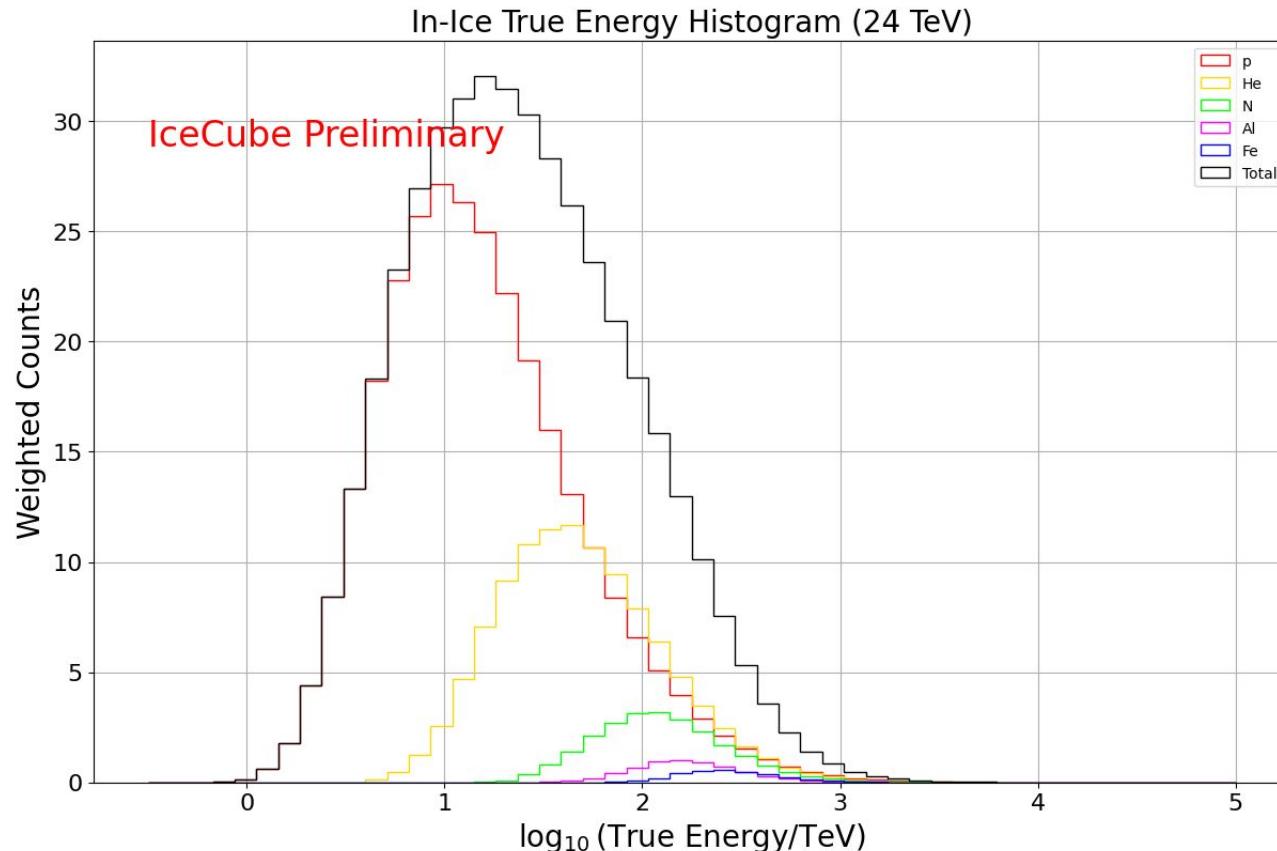
# Methodology

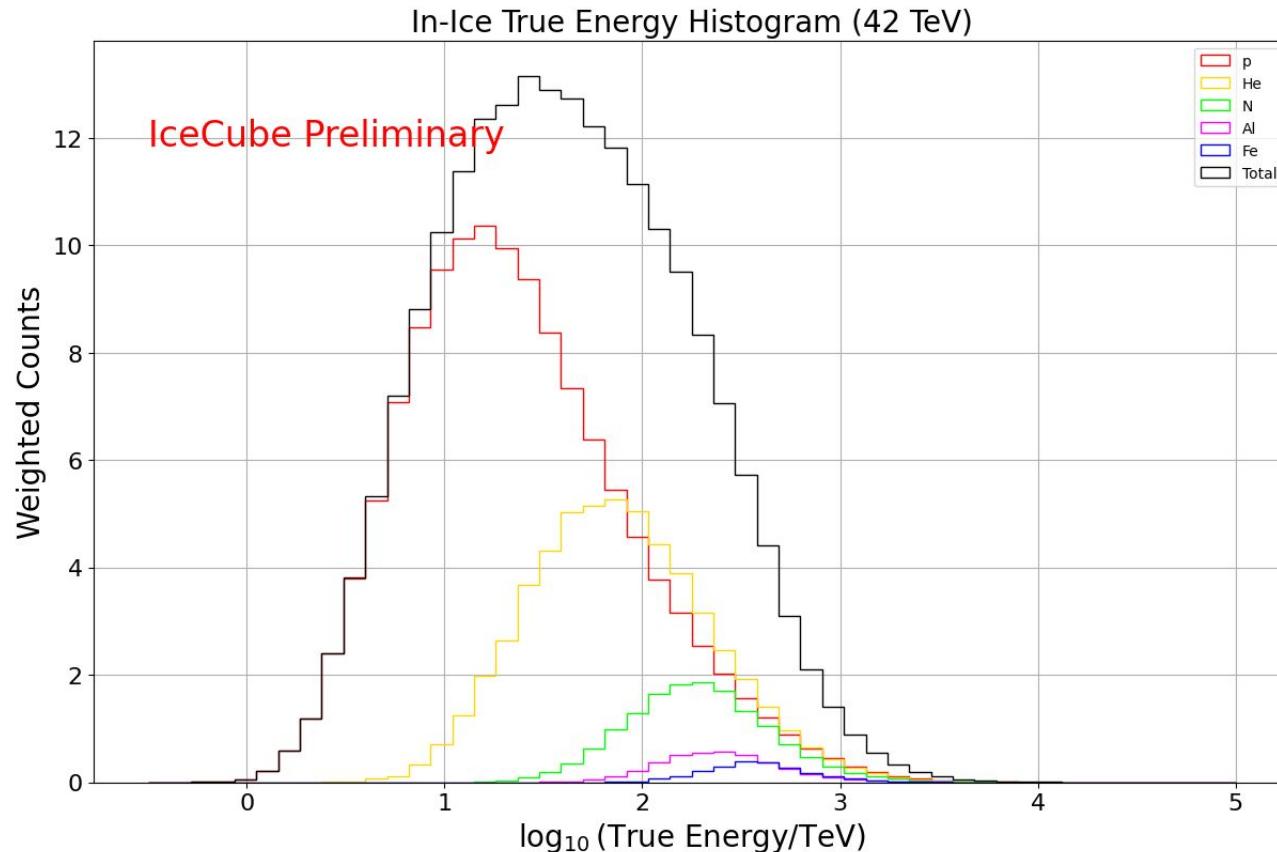
# In-Ice Rigidity Study



# Methodology

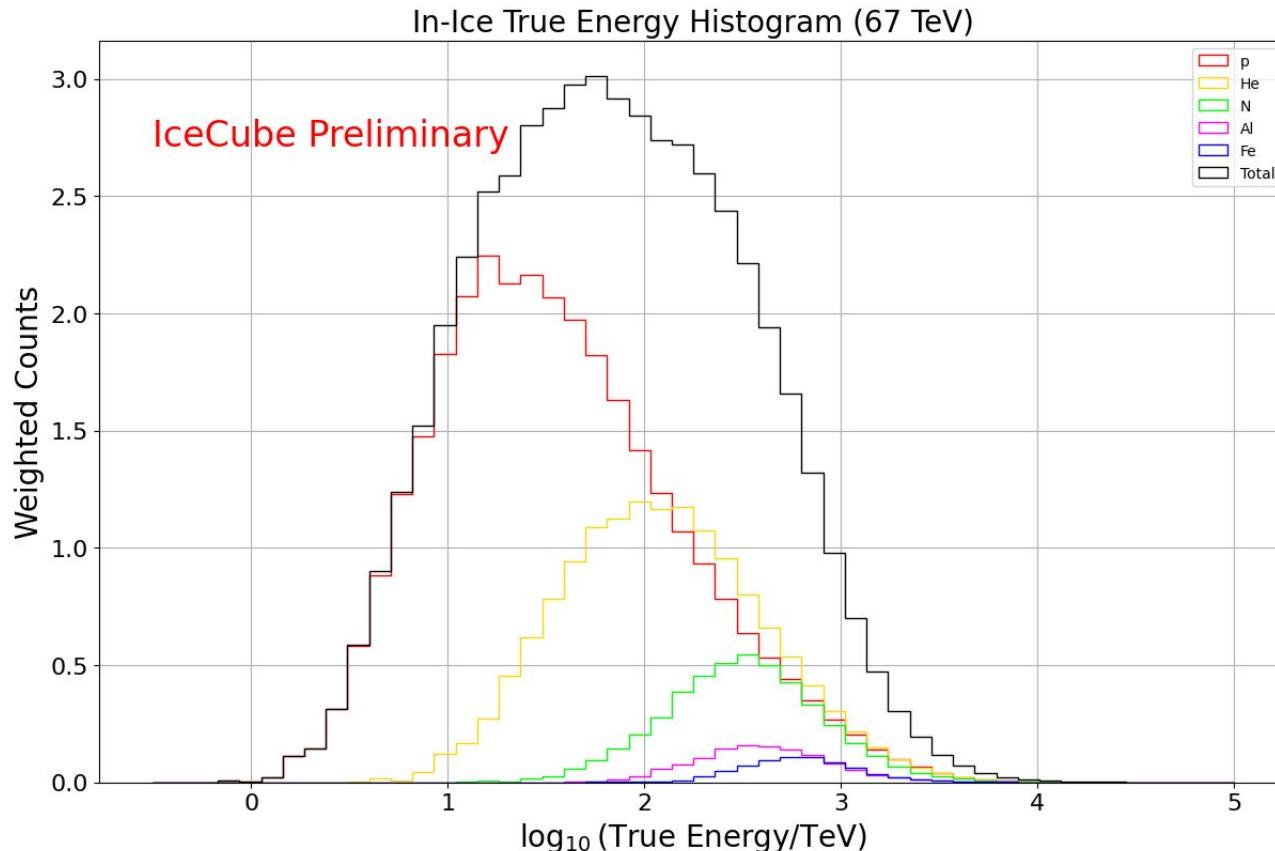
# In-Ice Rigidity Study





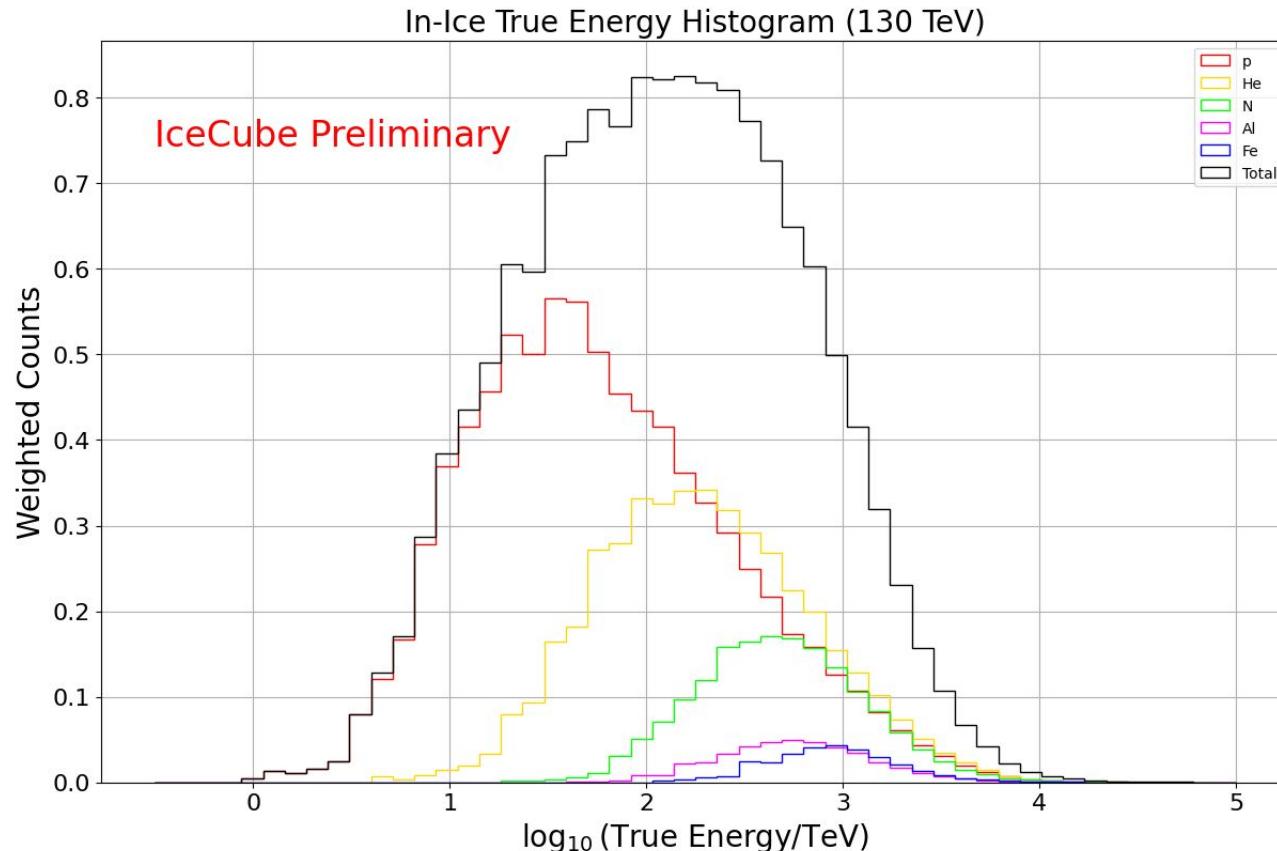
# Methodology

# In-Ice Rigidity Study



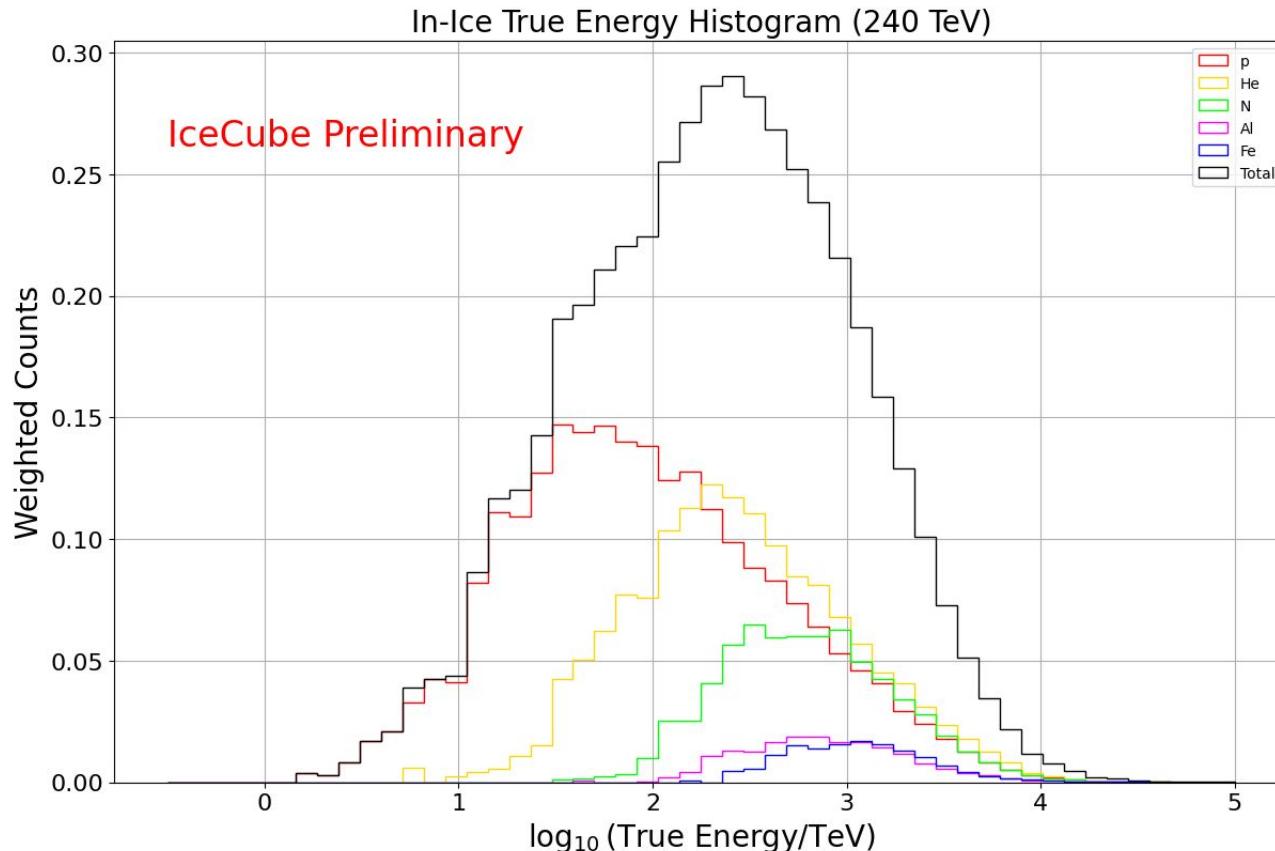
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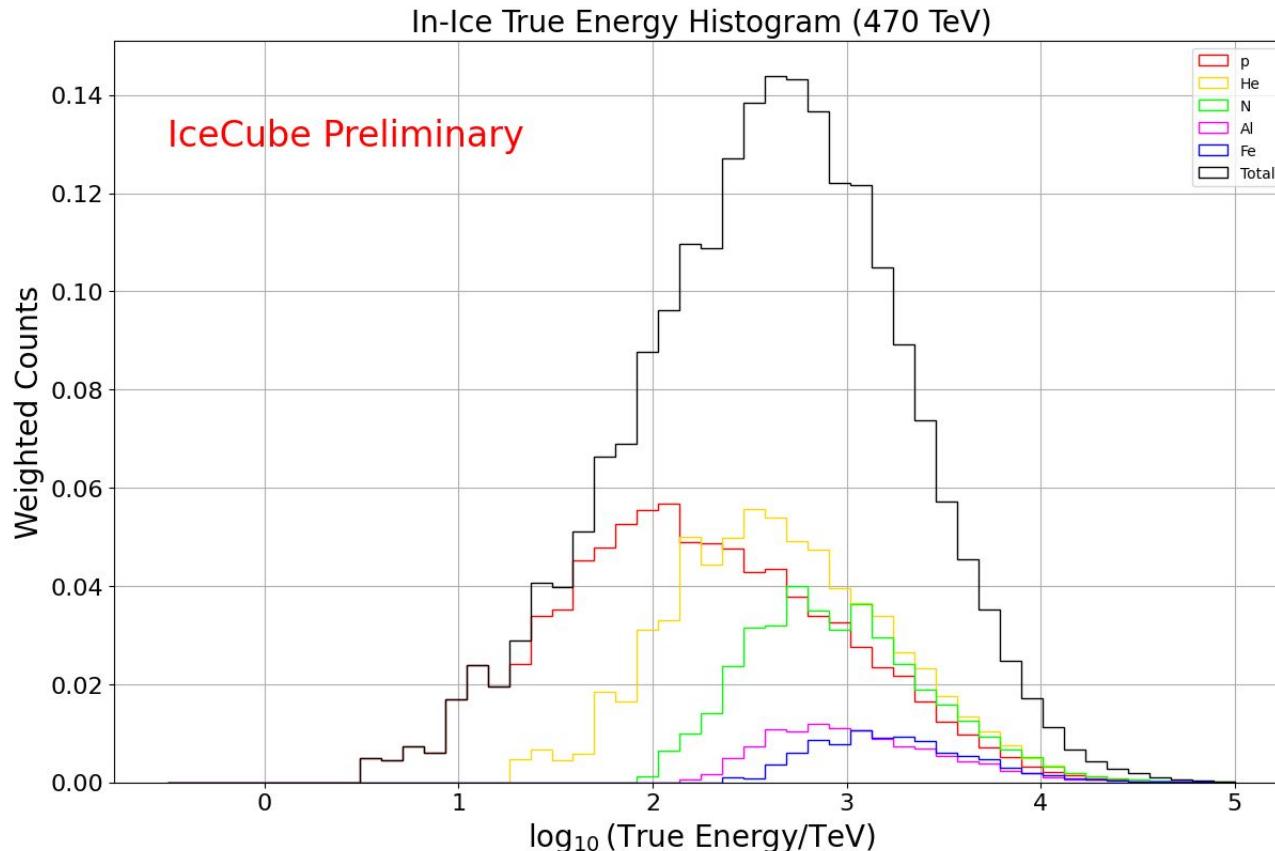
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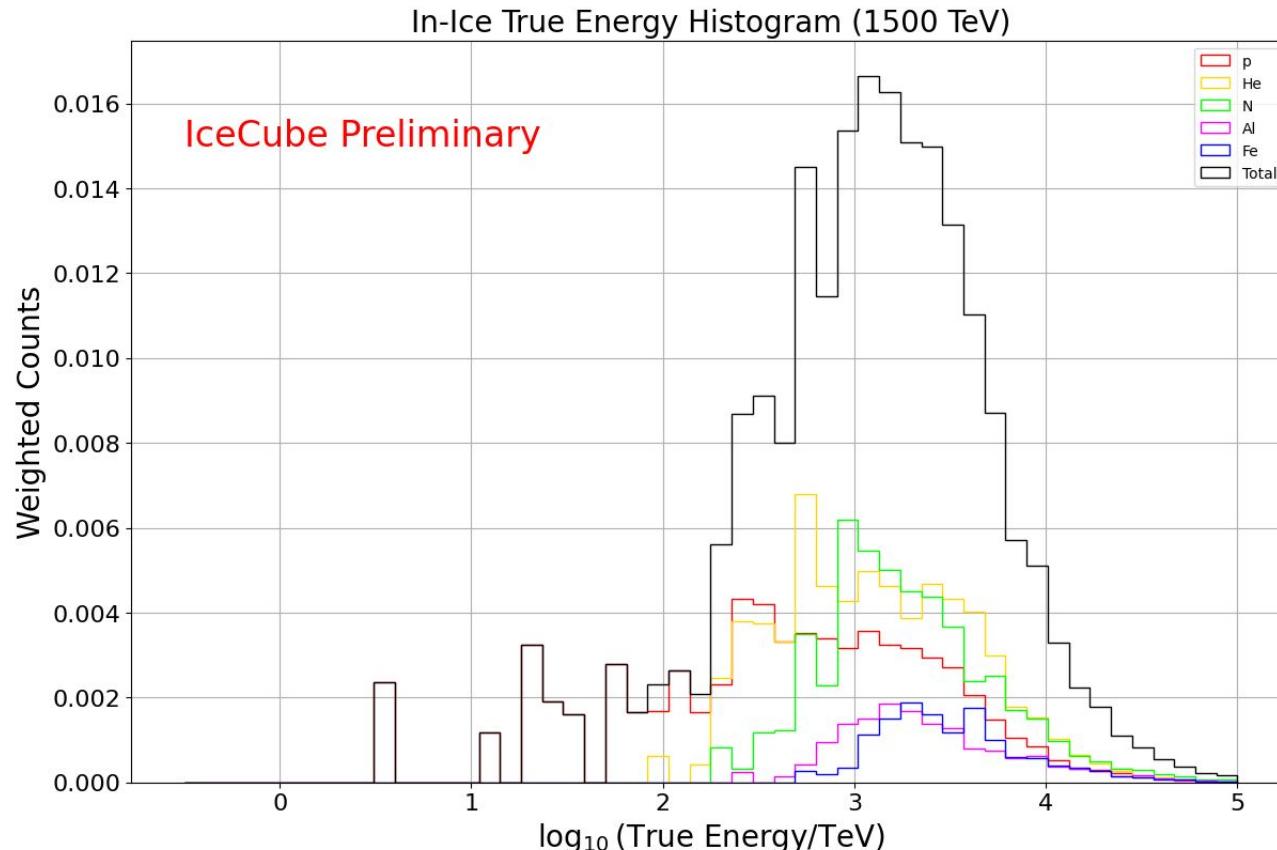
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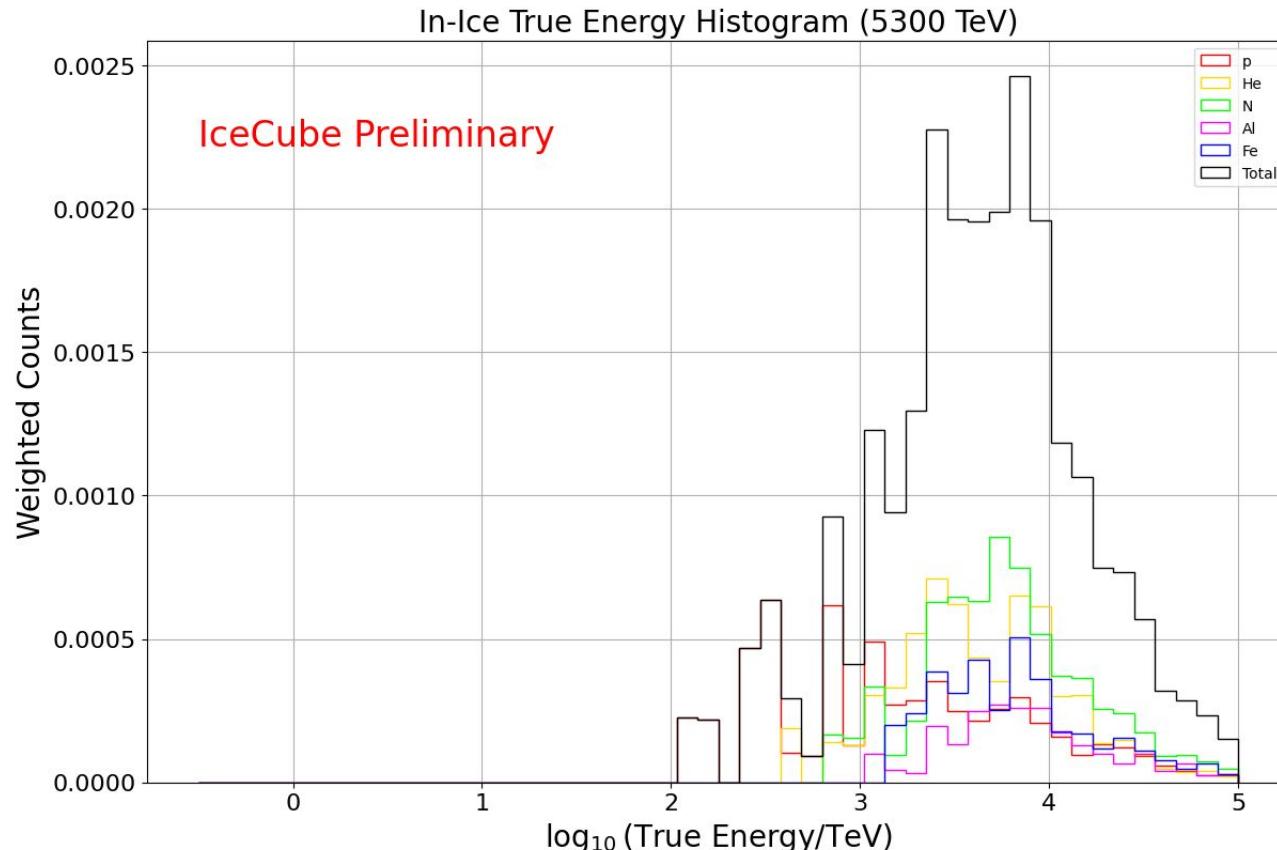
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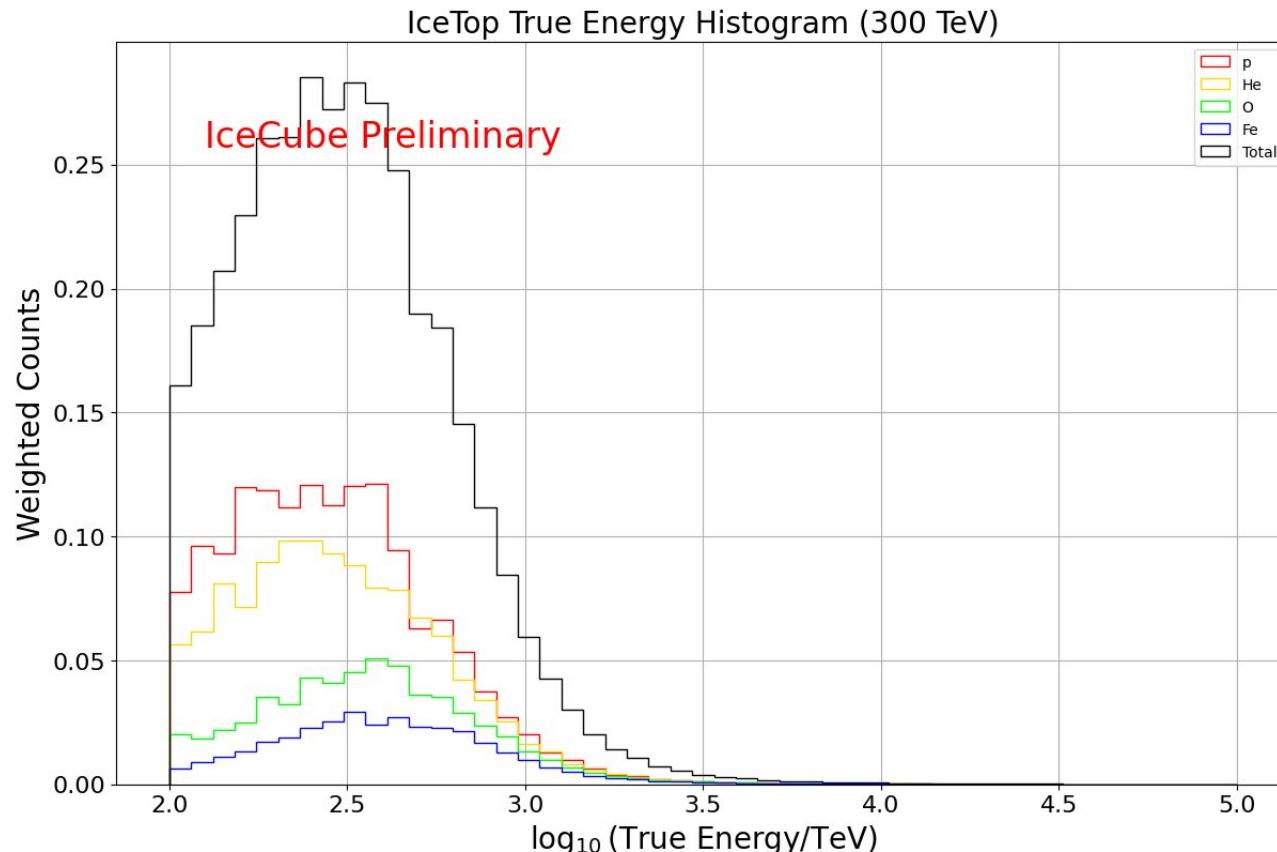
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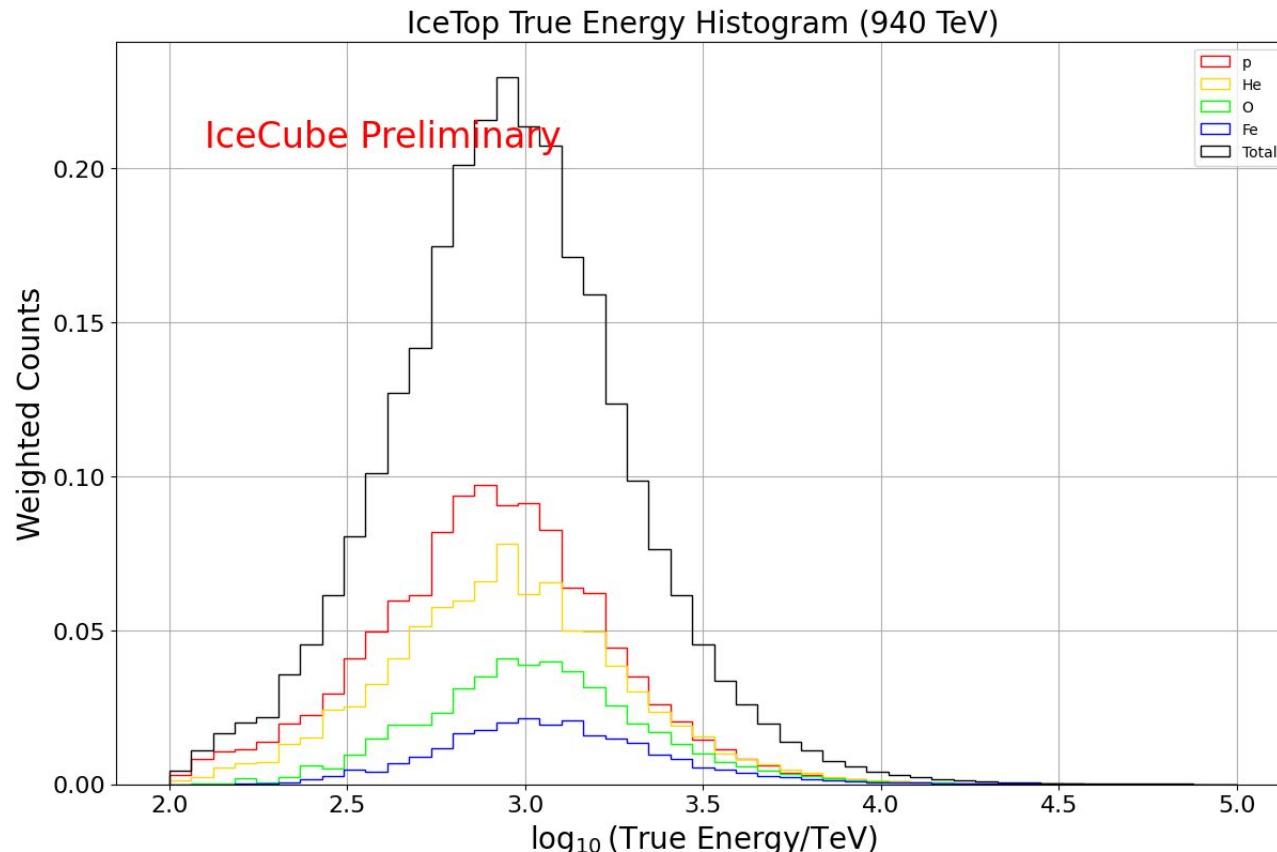
# Methodology

# IceTop Rigidity Study



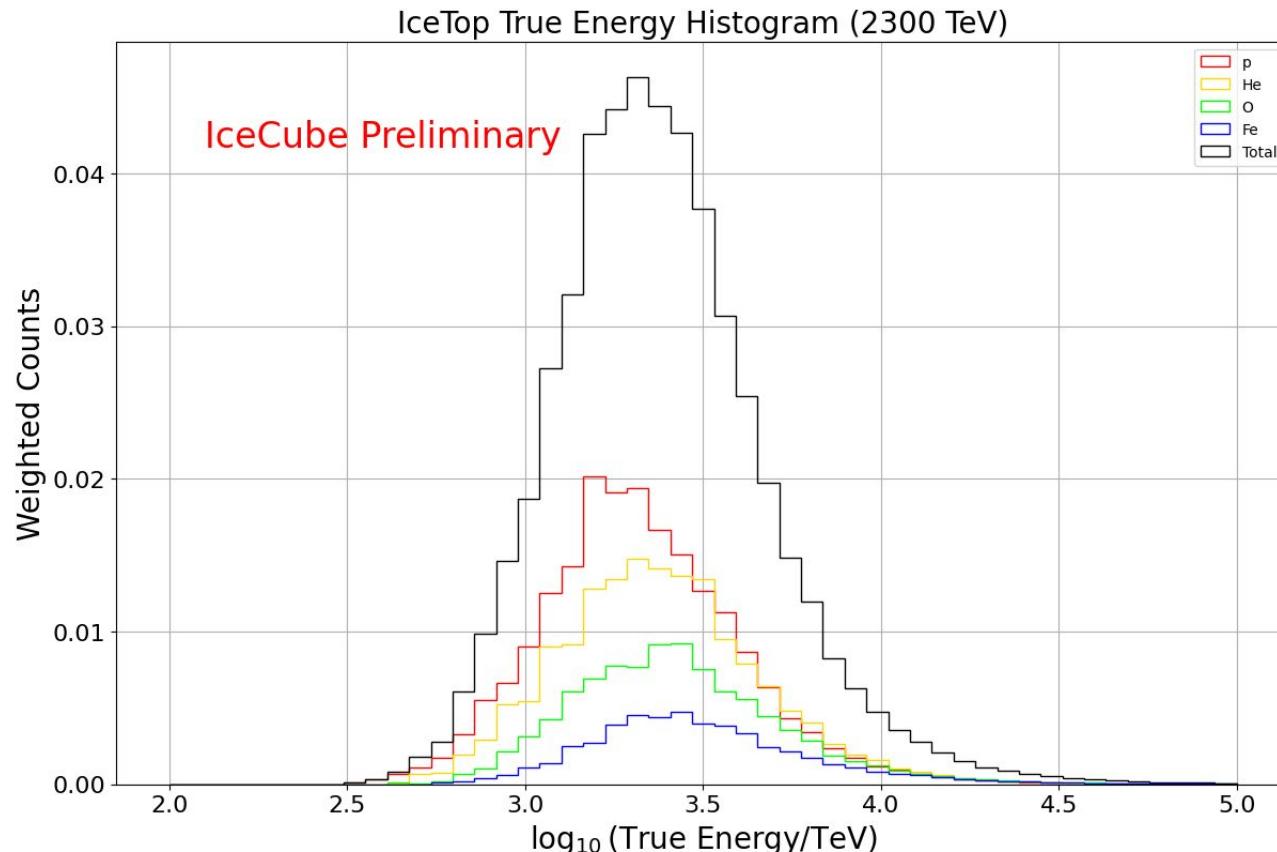
# Methodology

# IceTop Rigidity Study



# Methodology

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# Methodology

# IceTop Rigidity Study

