Cosmic Watch:

Investigating Cosmic Muons With Planes

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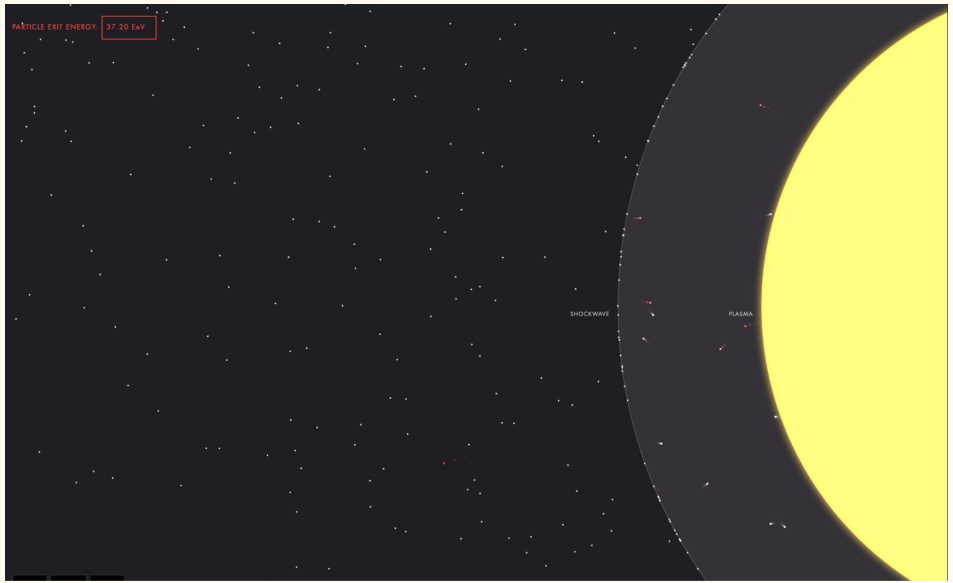
The Oh-My-God Particle

- Ultra-high-energy cosmic ray particles
- Fly's Eye Cosmic Ray Detector
- 0.99999999999999999999951c
- 40 million times faster than LHC
- $3.2 \pm 0.9 \times 10^{20}$ eV (Most are 10^6 eV to 10^9 eV)

https://www.quantamagazine.org/20150514-the-particle-that-broke-a-cosmic-speed-limit/

What? Who? Why?

- Where do they come from?
  - Research today
  - Our galaxy
    - Sun
  - Neighboring galaxies
    - Pulsars
    - Supernovas



https://www.quantamagazine.org/ultrahigh-energy-cosmic-rays-traced-to-hotspot-20150514/


PARTICLE EXIT ENERGY: 37.20 EeV
SHOCKWAVE
PLASMA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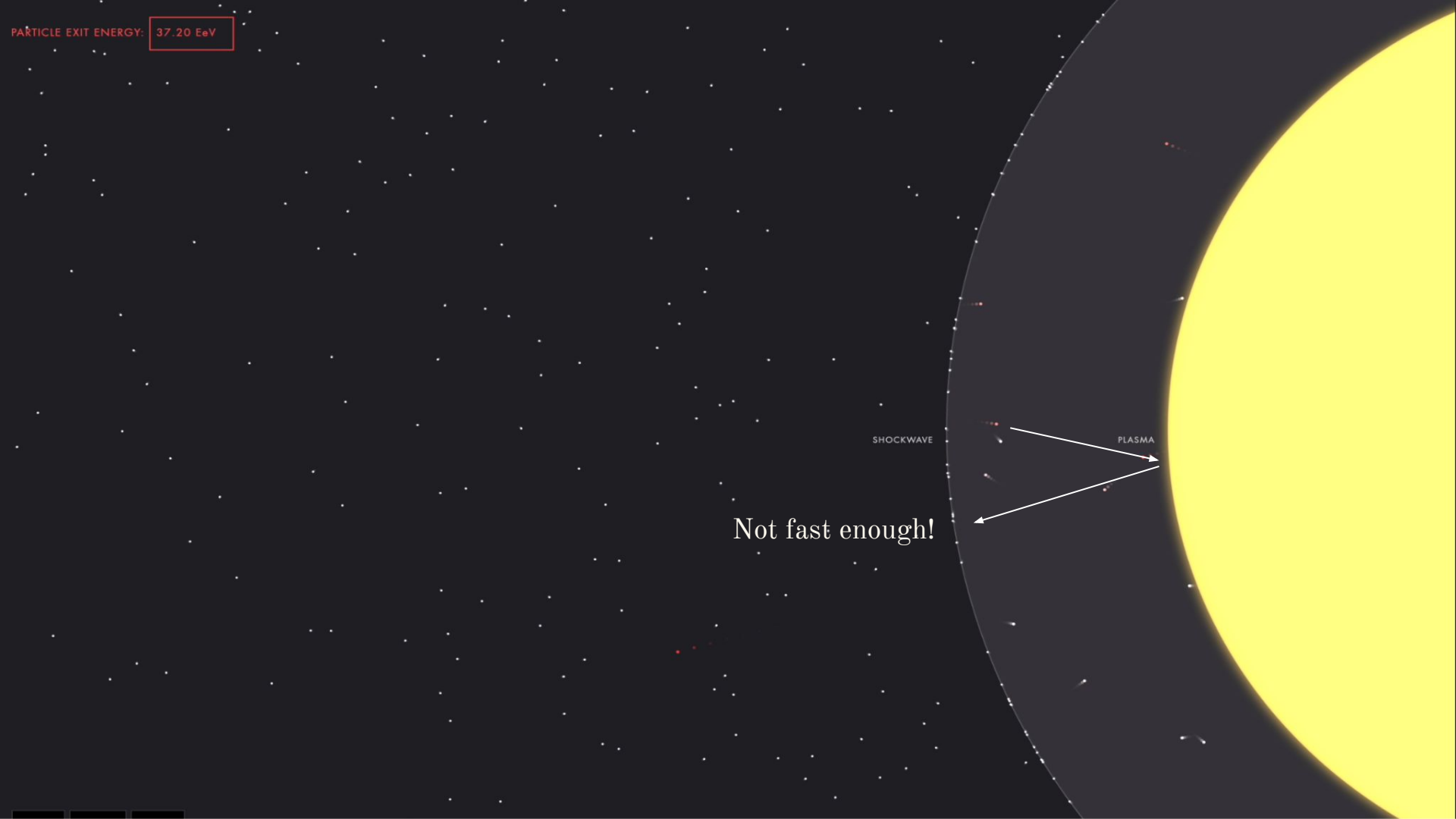
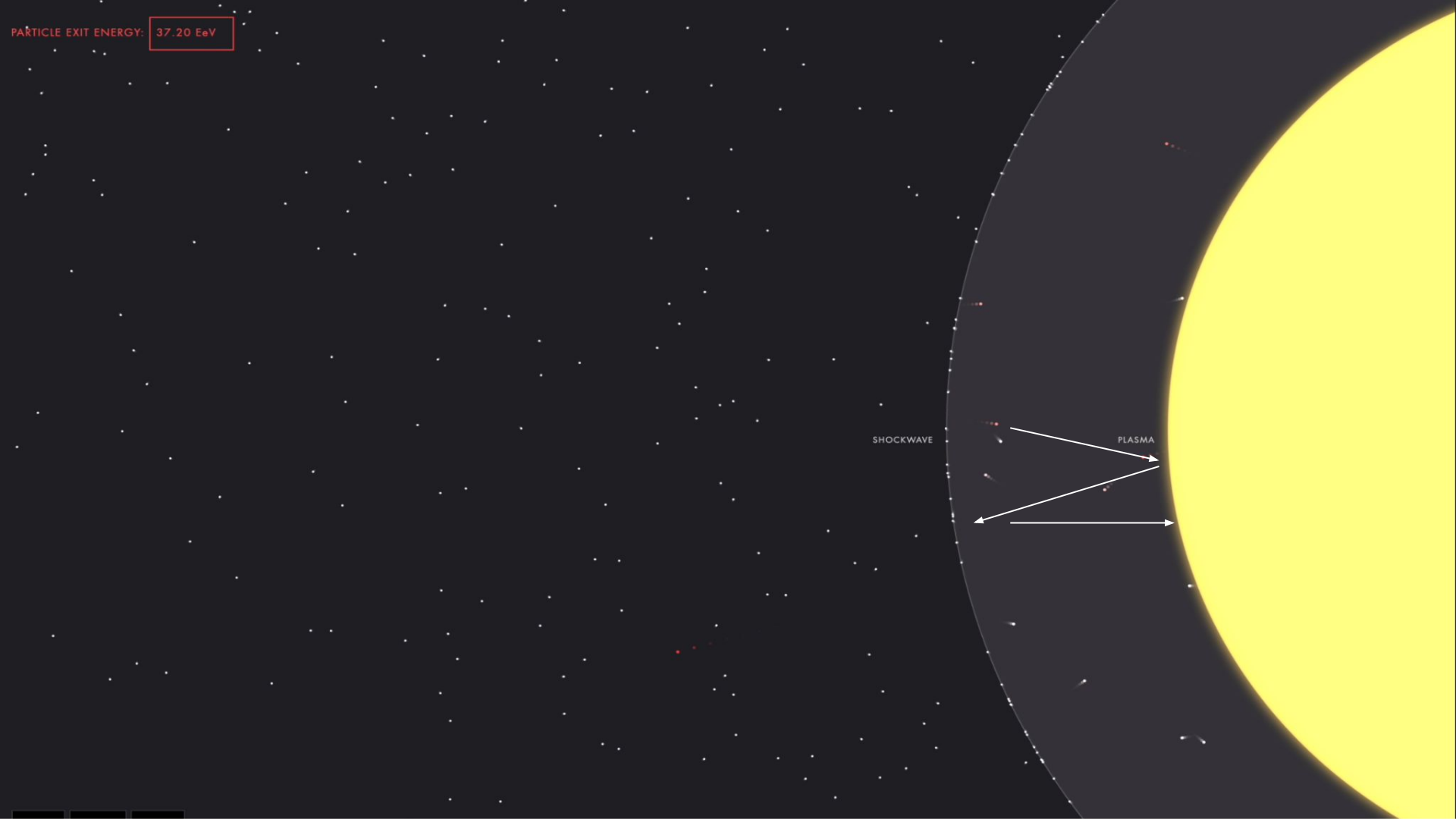
SHOCKWAVE
PLASMA


PARTICLE EXIT ENERGY: 37.20 EeV
SHOCKWAVE
PLASMA
Not fast enough!


PARTICLE EXIT ENERGY: 37.20 EeV
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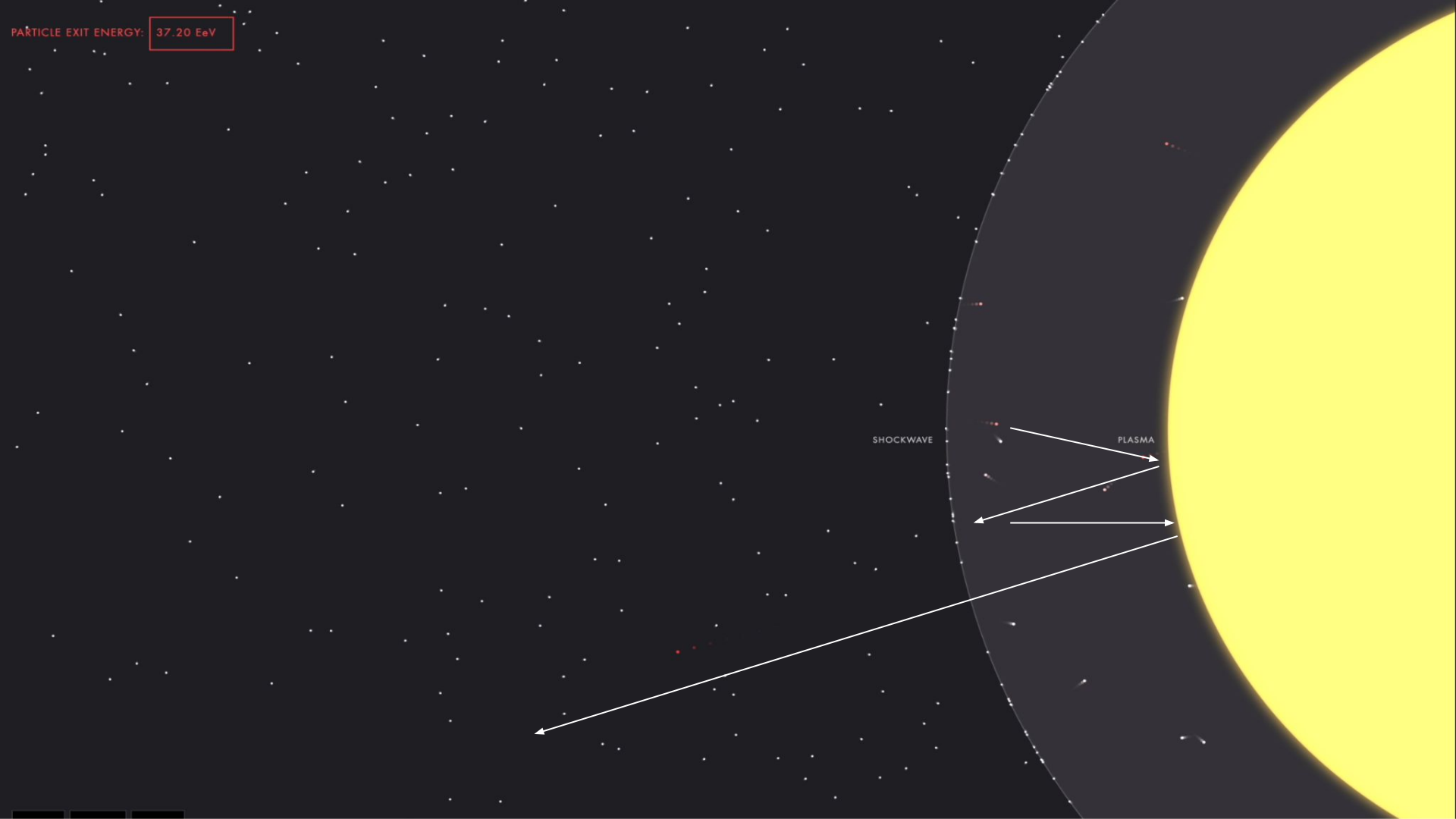
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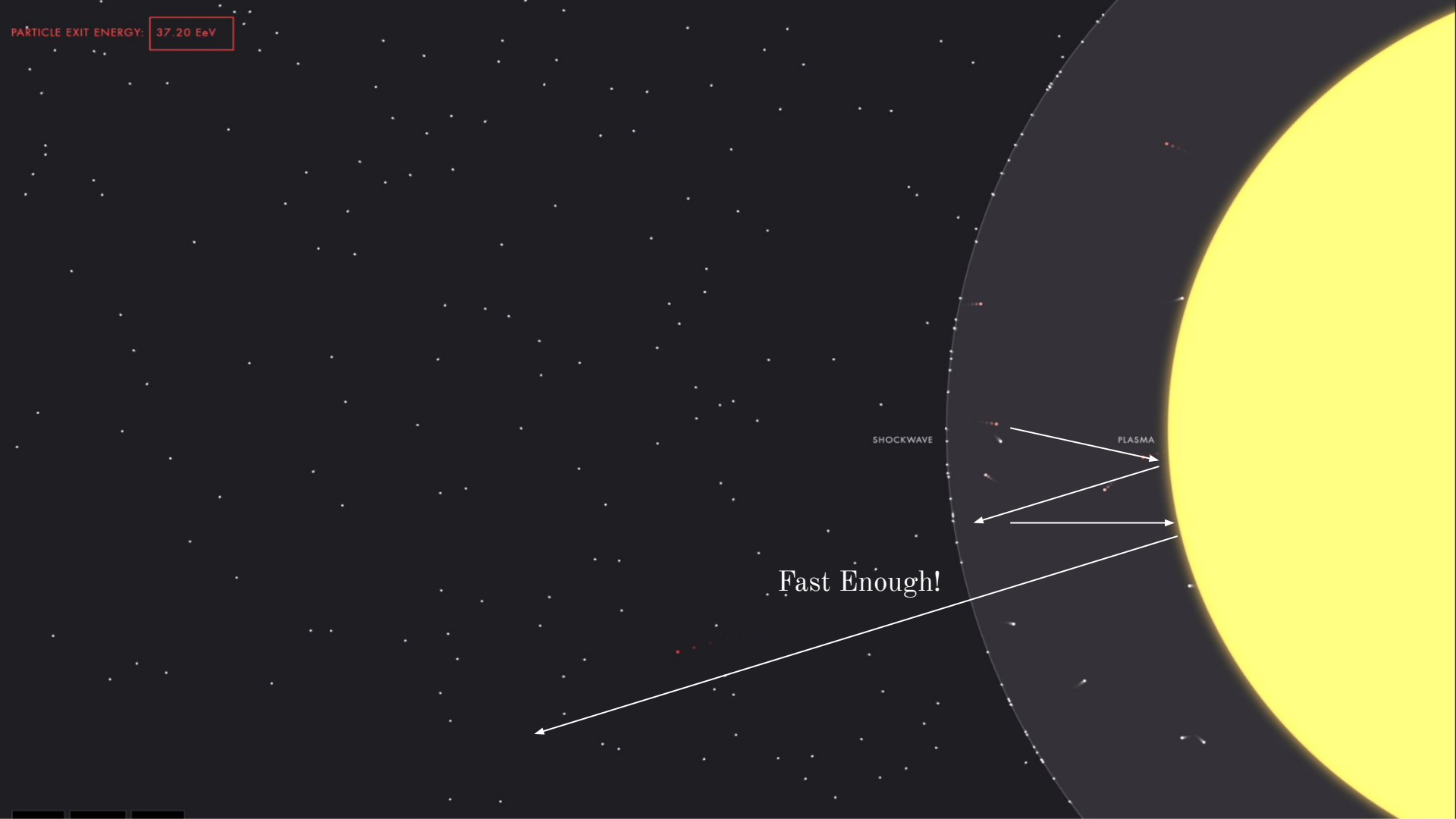

PARTICLE EXIT ENERGY: 37.20 EeV
SHOCKWAVE
PLASMA
Fast Enough!

What? Who? Why?

- 74% ionized hydrogen

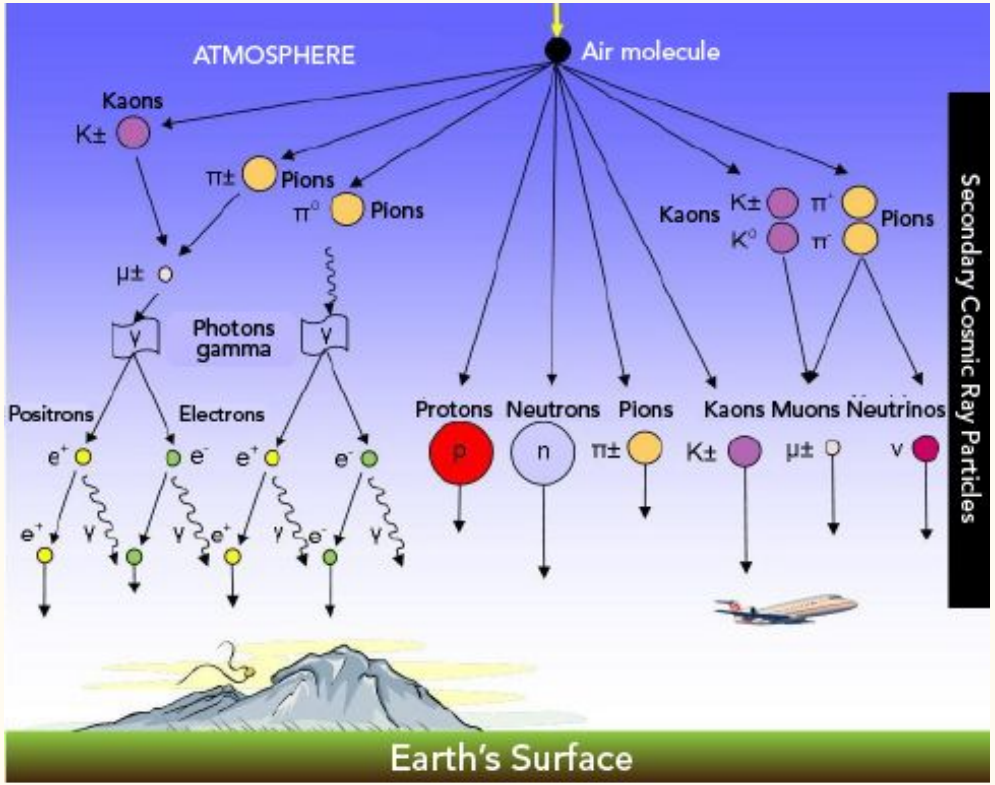
  (free protons)

- 18% from helium nuclei

  (two protons and two neutrons)

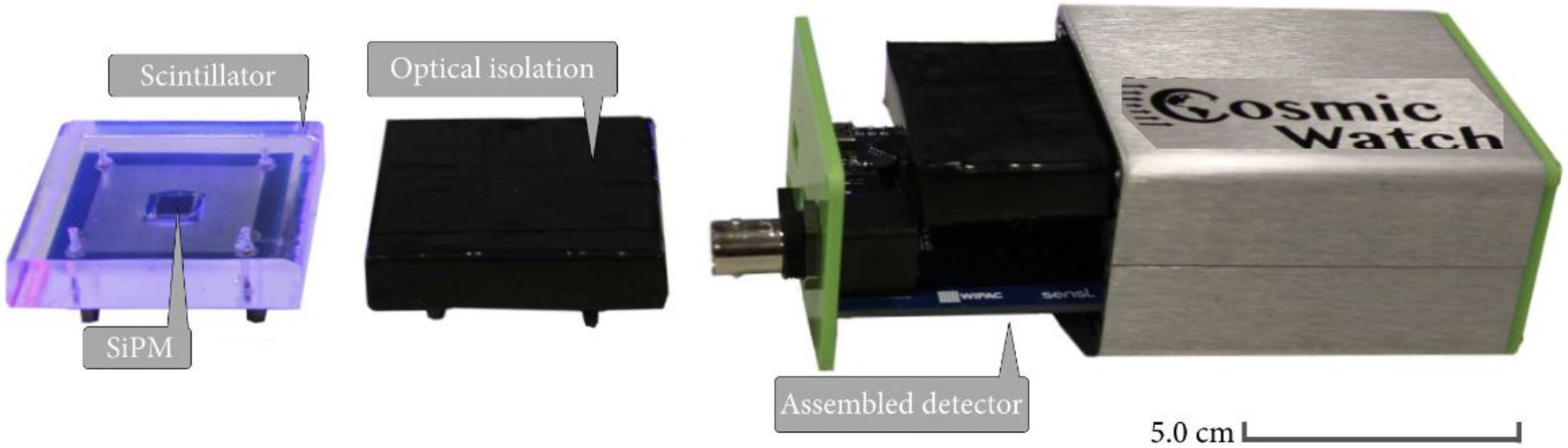
- 8% trace amounts of heavier

  elements



https://letstalkscience.ca/educational-resources/backgrounders/what-are-cosmic-rays

The Cosmic Watch

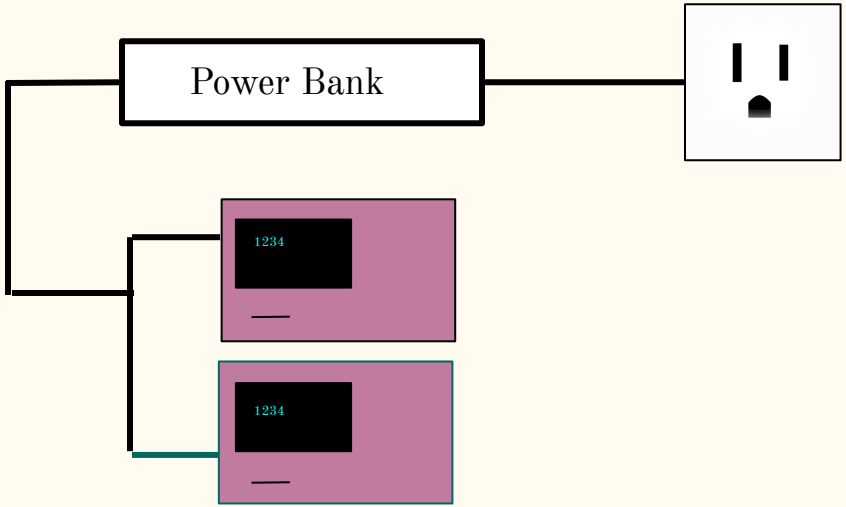


Goal

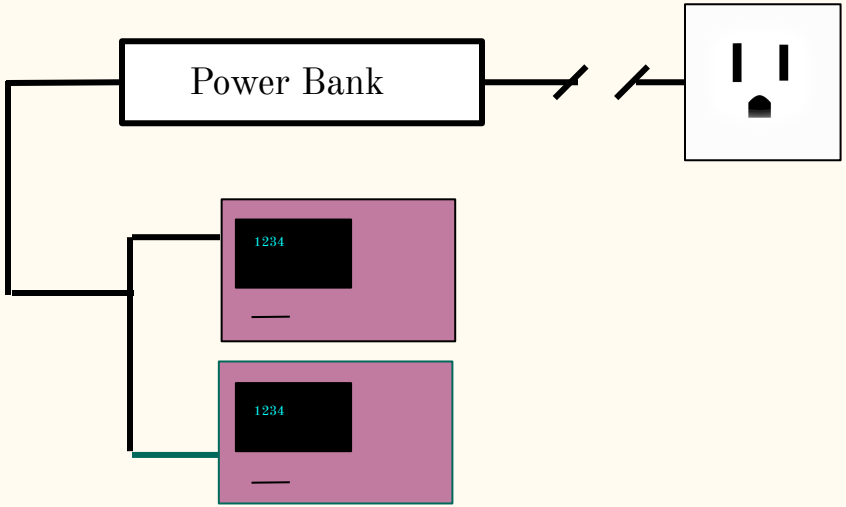
Investigate the relationship between count rate of cosmic muons as a function of altitude

1. Determine the function between altitude and counts
2. See how well the function describes the experimental data
3. Determine how energies vary across flights

Experimental Setup



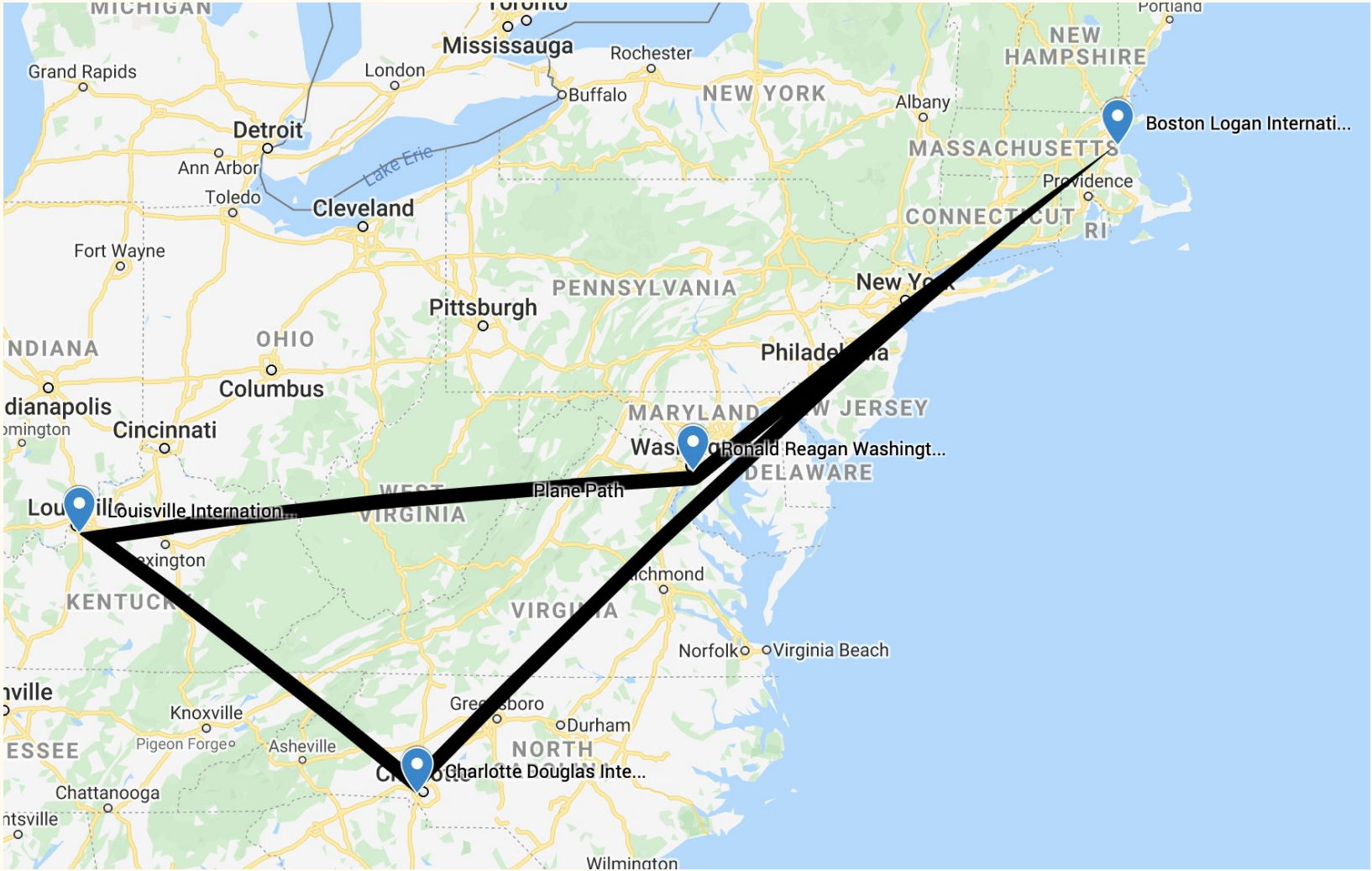
Experimental Setup



American Airlines Flights

Flight Number, Date and Time	Max Altitude (km)	Duration (s)
653 11/18 9:45 am	10.97 ±0.88	7250±580
5326 11/18 1:21 pm	7.92±0.63	3438±275
4917 11/21 6:21 am	10.67±0.85	3668±293
2152 11/21 9:00 am	9.46±0.76	3995±319

Flight data is extracted from FlightAware.com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Charlotte Douglas Inte...
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Wilmington
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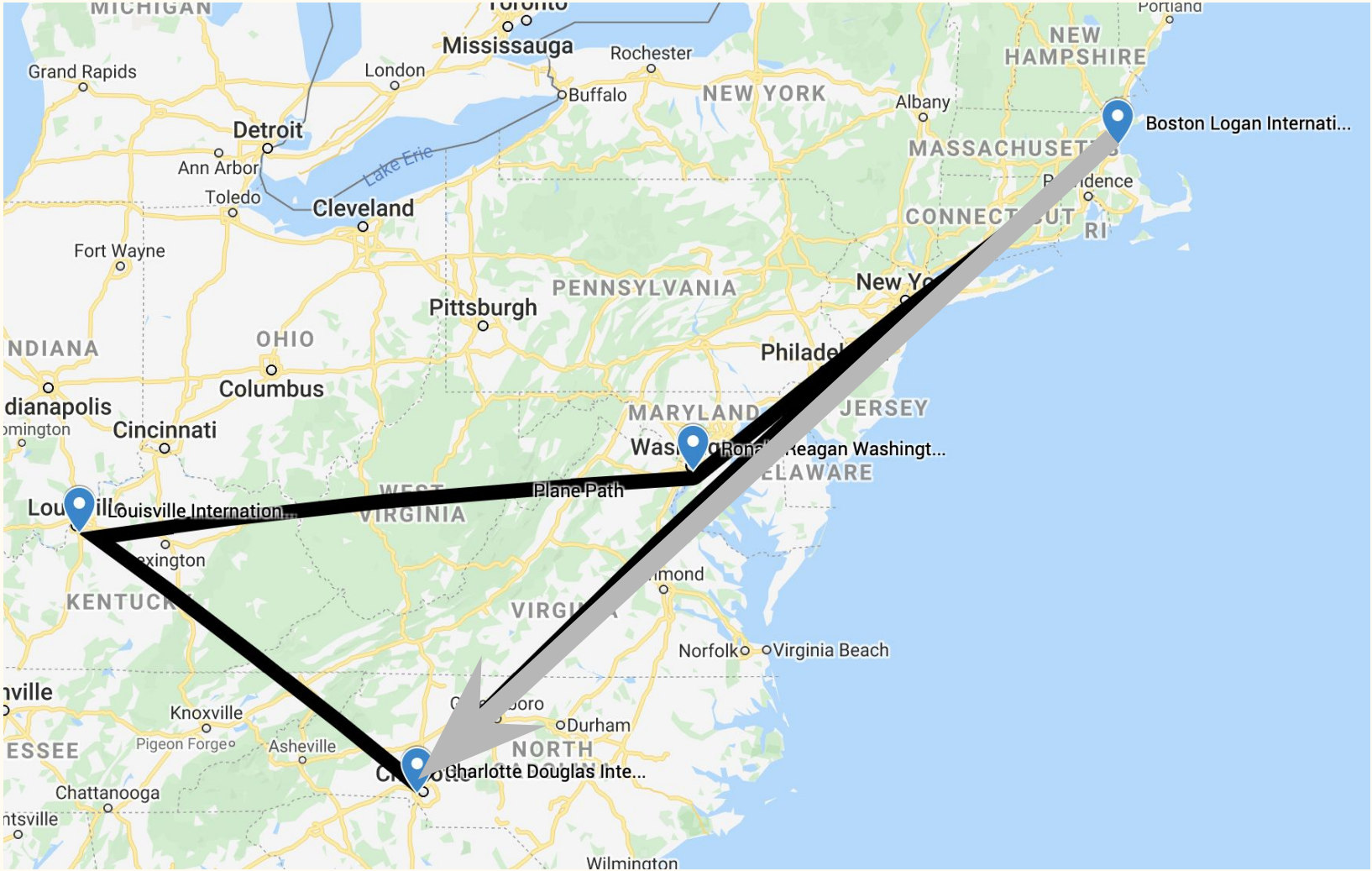
VIRGINIA
NORTH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Louisville International
Plane Path
WEST VIRGINIA
Lexington
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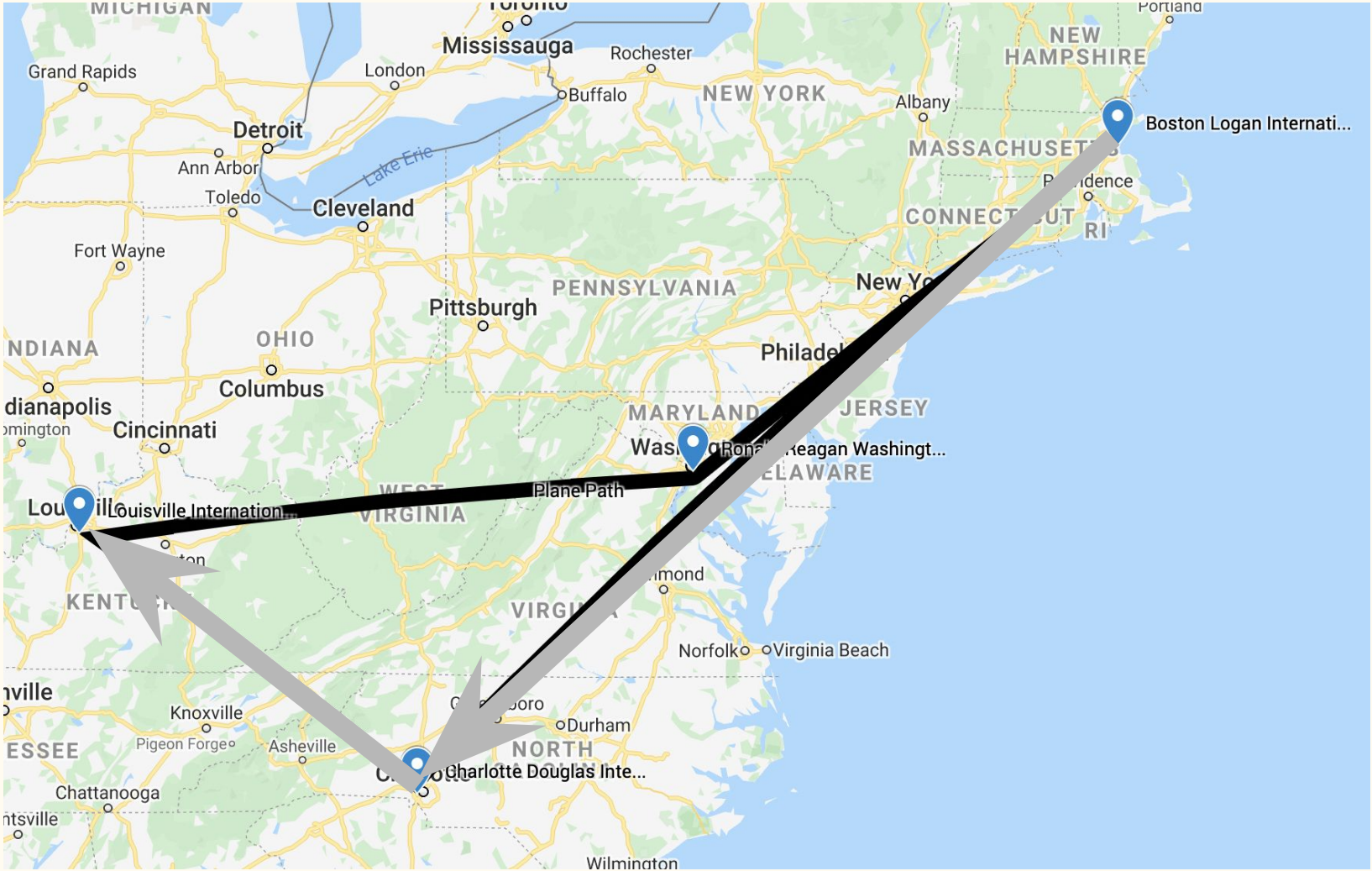
Wilmington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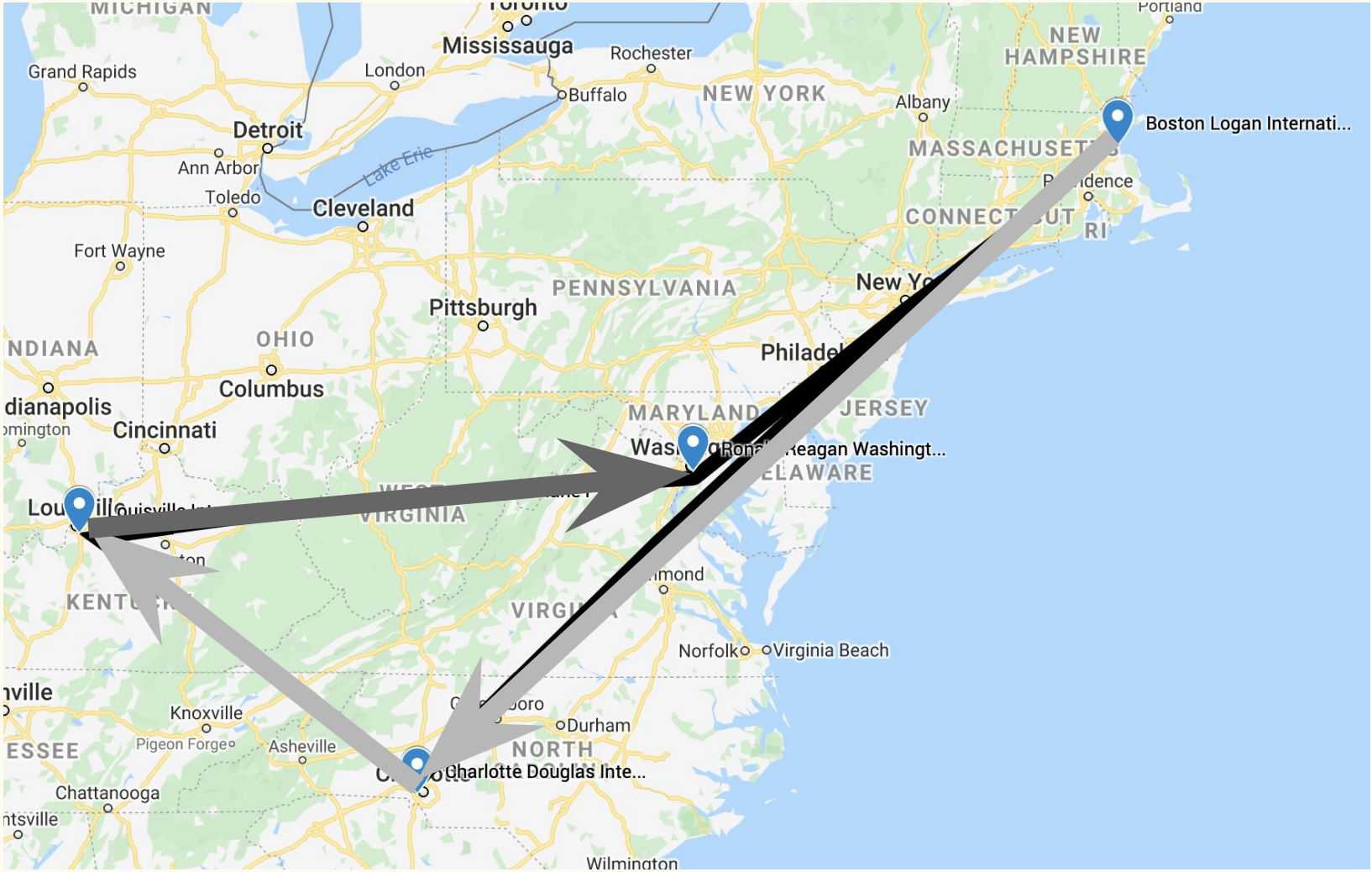
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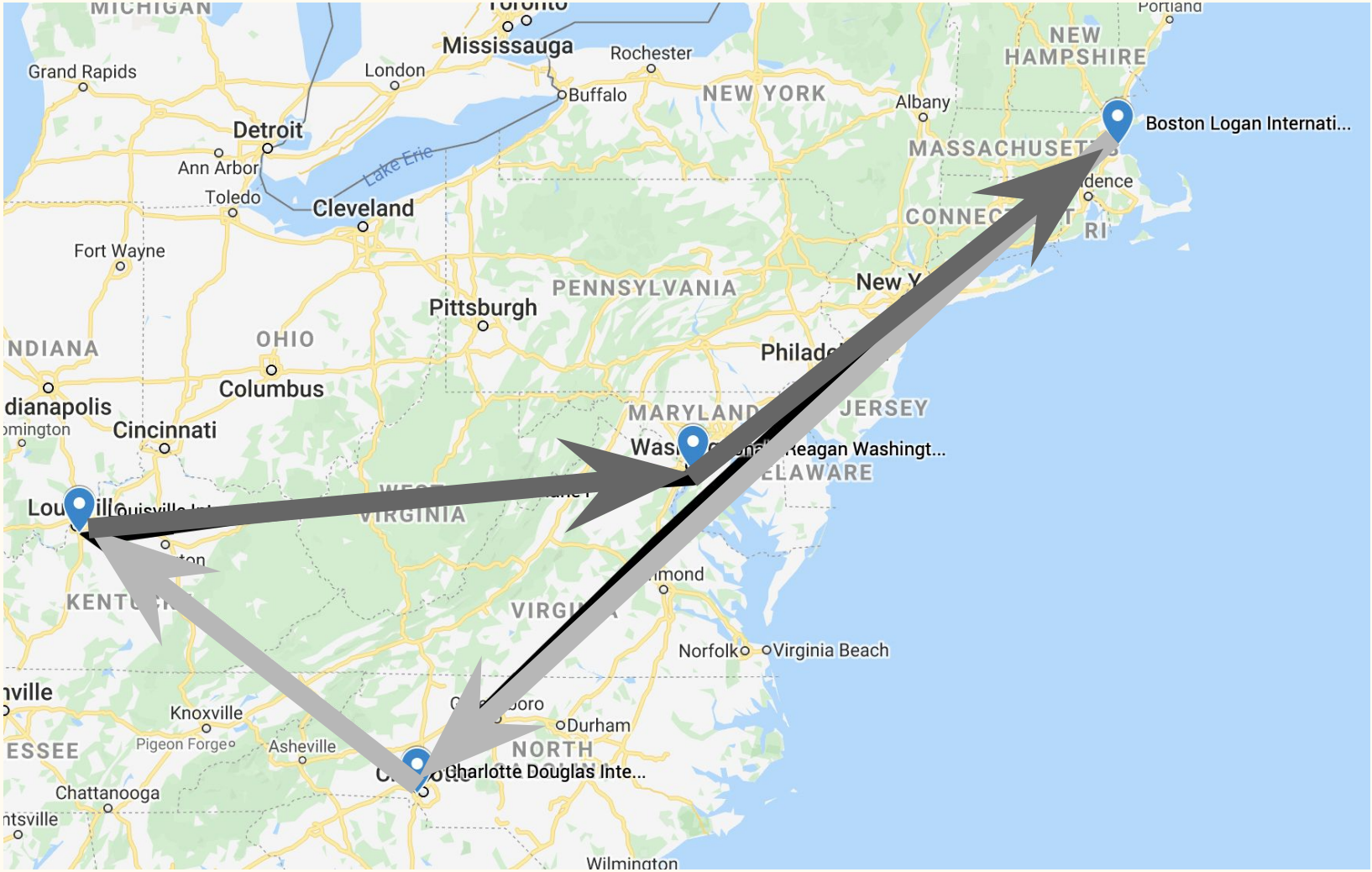
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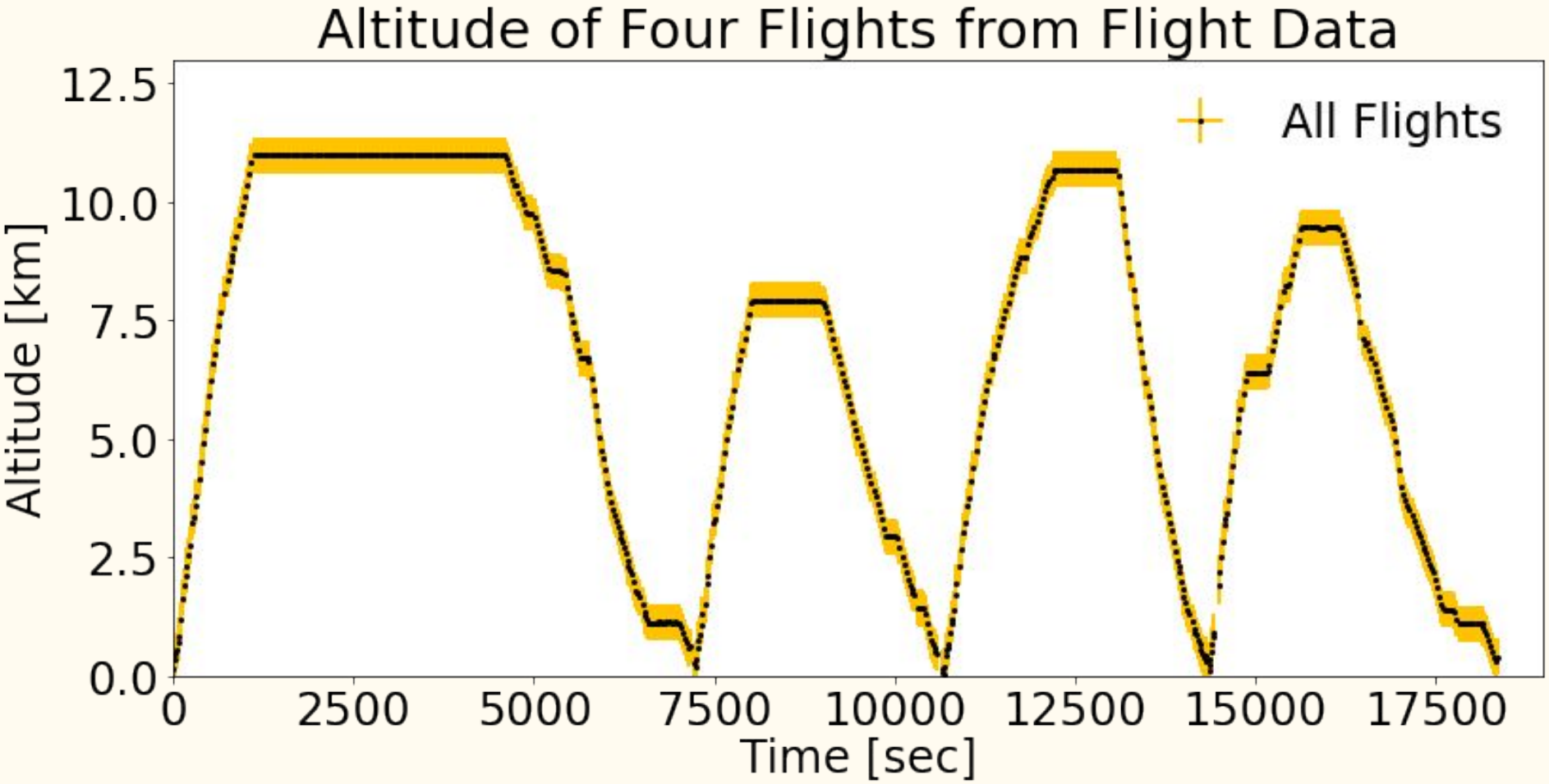
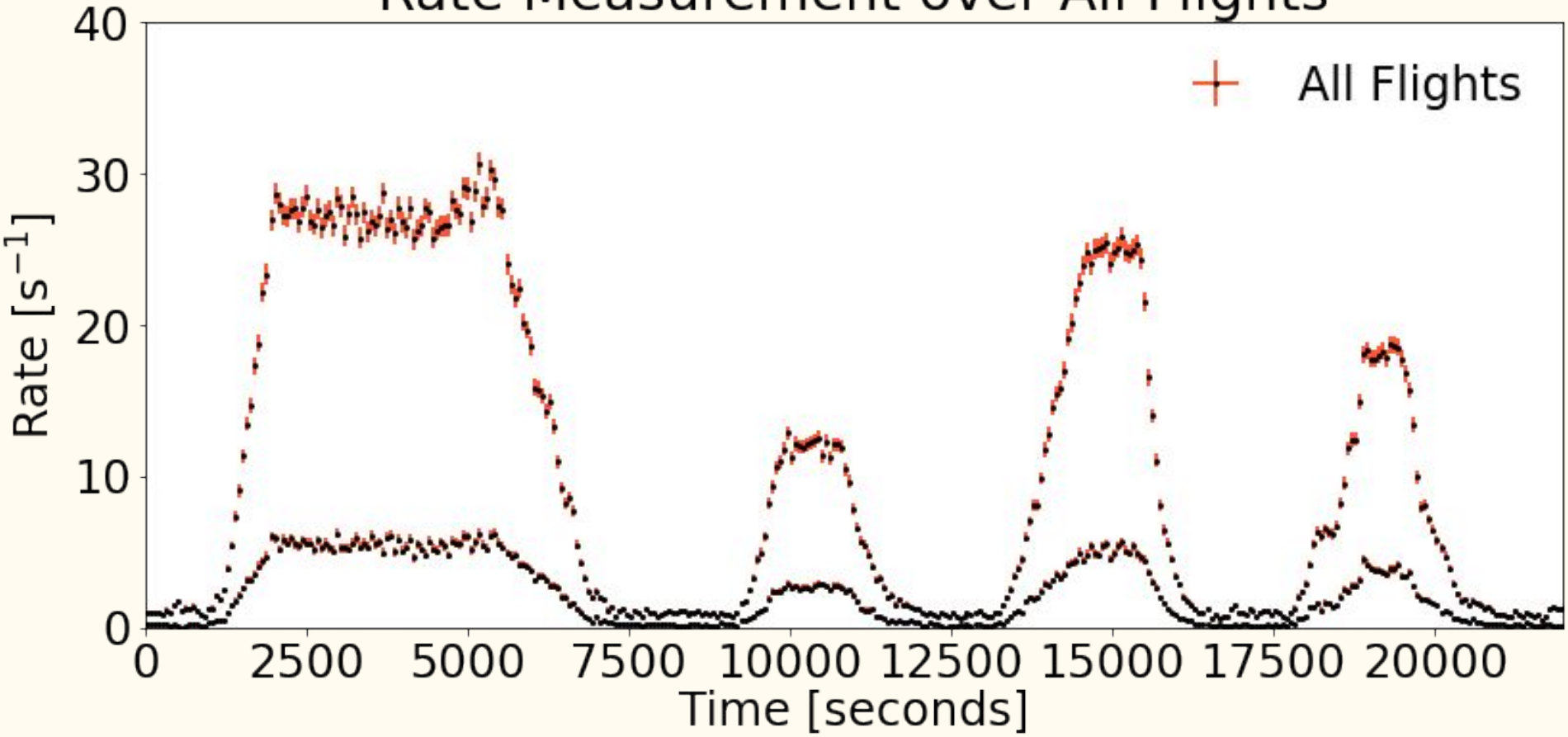
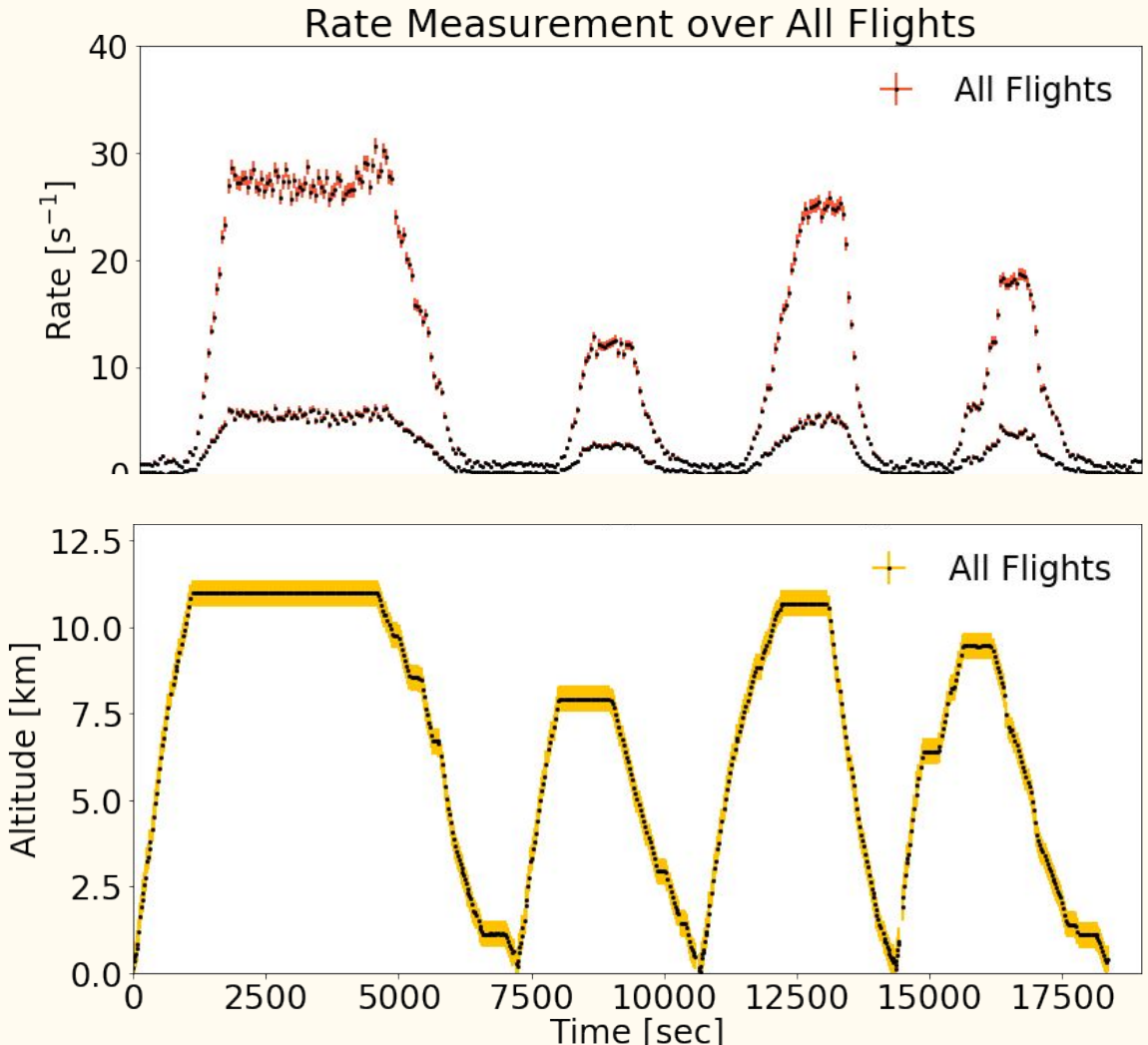
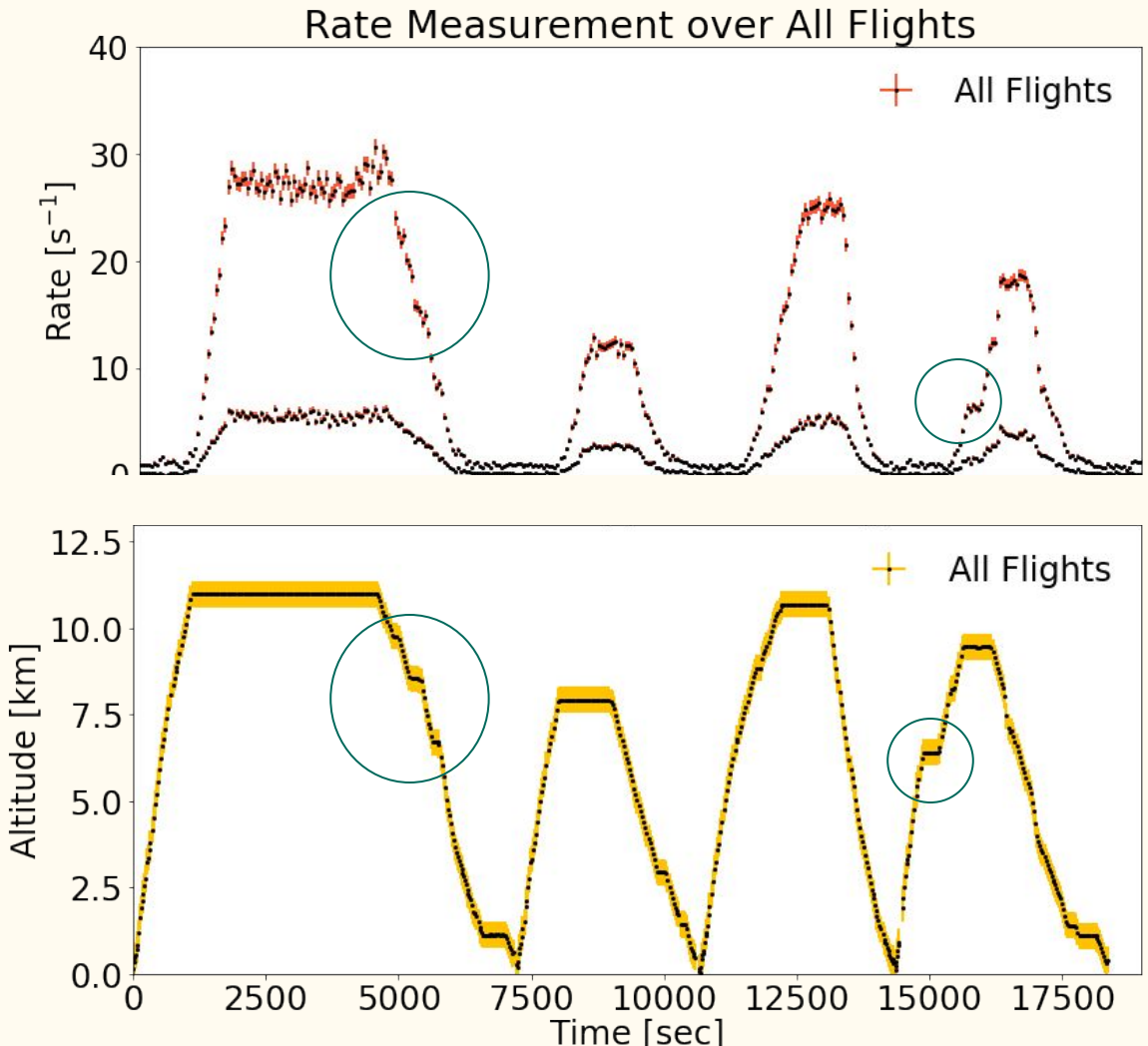

Altitude of Four Flights from Flight Data
All Flights
Altitude [km]
12.5
10.0
7.5
5.0
2.5
0.0
0
2500
5000
7500
10000
12500
15000
17500
Time [sec]



Total Count rate: 15.0772 +/- 0.044Hz	4.8833 +/- 0.0347Hz	9.8344 +/- 0.0487Hz	5.7157 +/- 0.0351Hz	
Coincident Count rate: 3.0732 +/- 0.0199Hz	1.1214 +/- 0.0166Hz	2.0905 +/- 0.0224Hz	1.2579 +/- 0.0165Hz	



- Background radiation
- Decay altitude
- Similarities



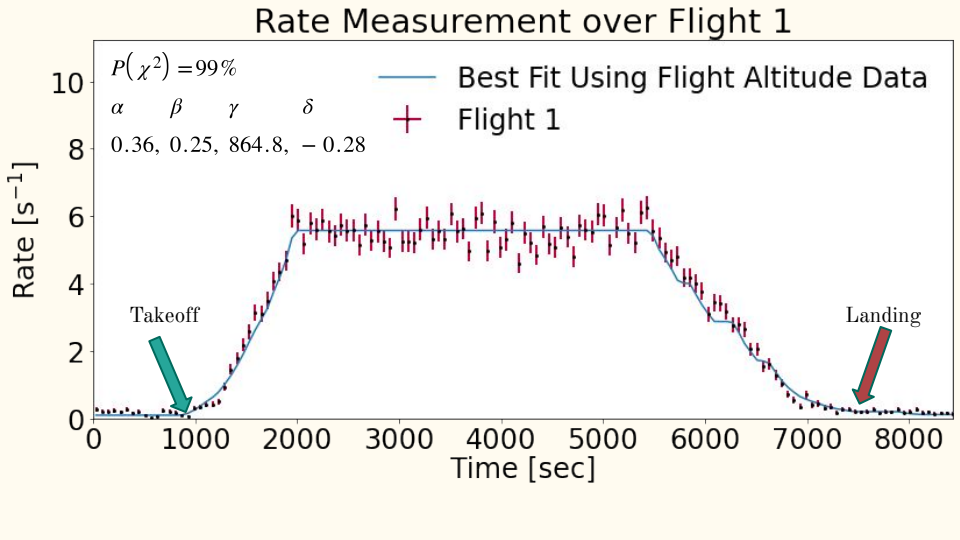
- Background radiation
- Decay altitude
- Similarities

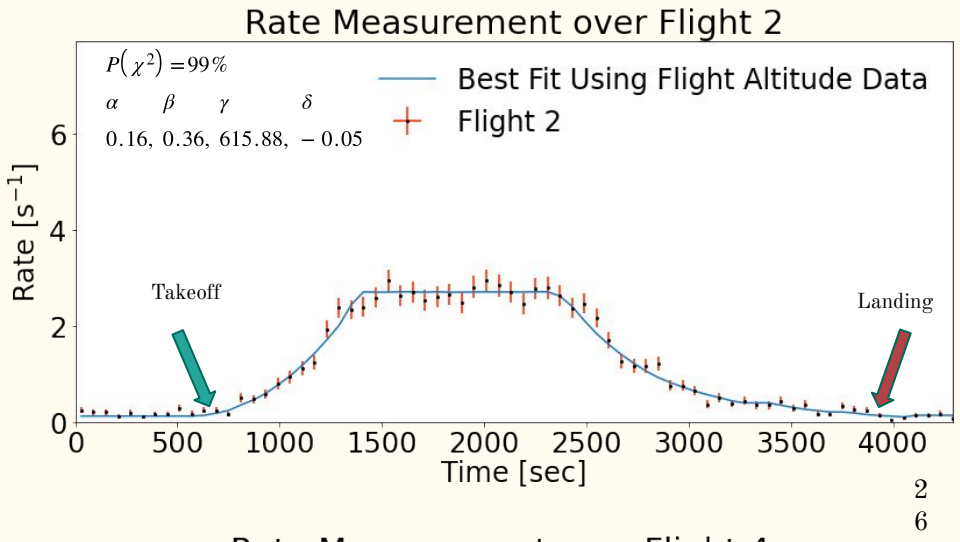
Connecting Altitude and Rate

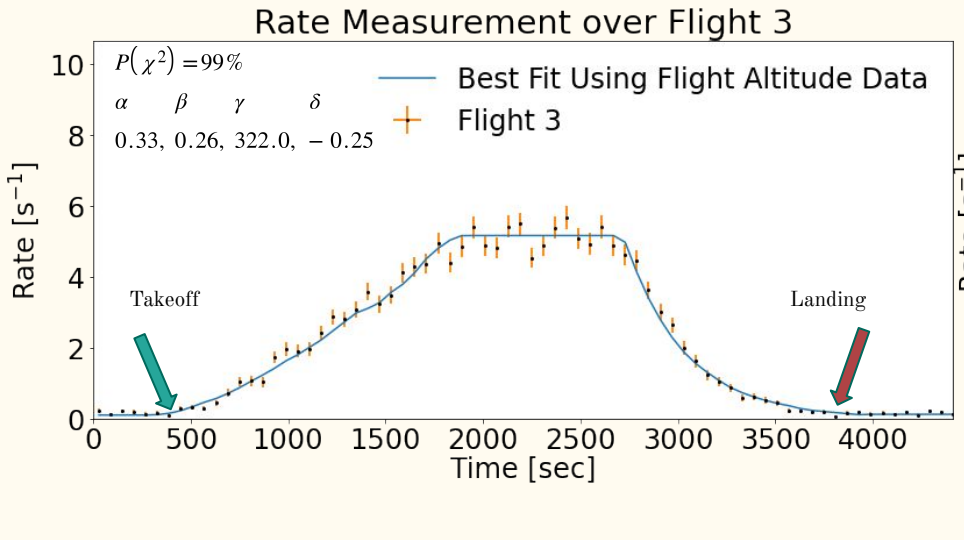
$$Rate\ [Hz] = \alpha\ e^{\beta \cdot Altitude[t-\gamma]} + \delta$$

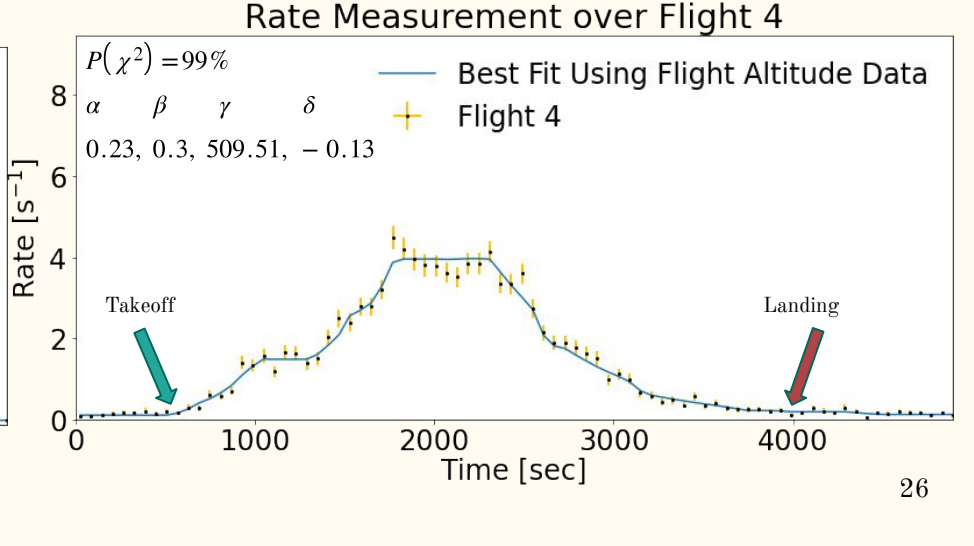
Altitude[t-γ] : Flight data taken from flightaware.com, taken at 30 second intervals, interpolated with cubic spline

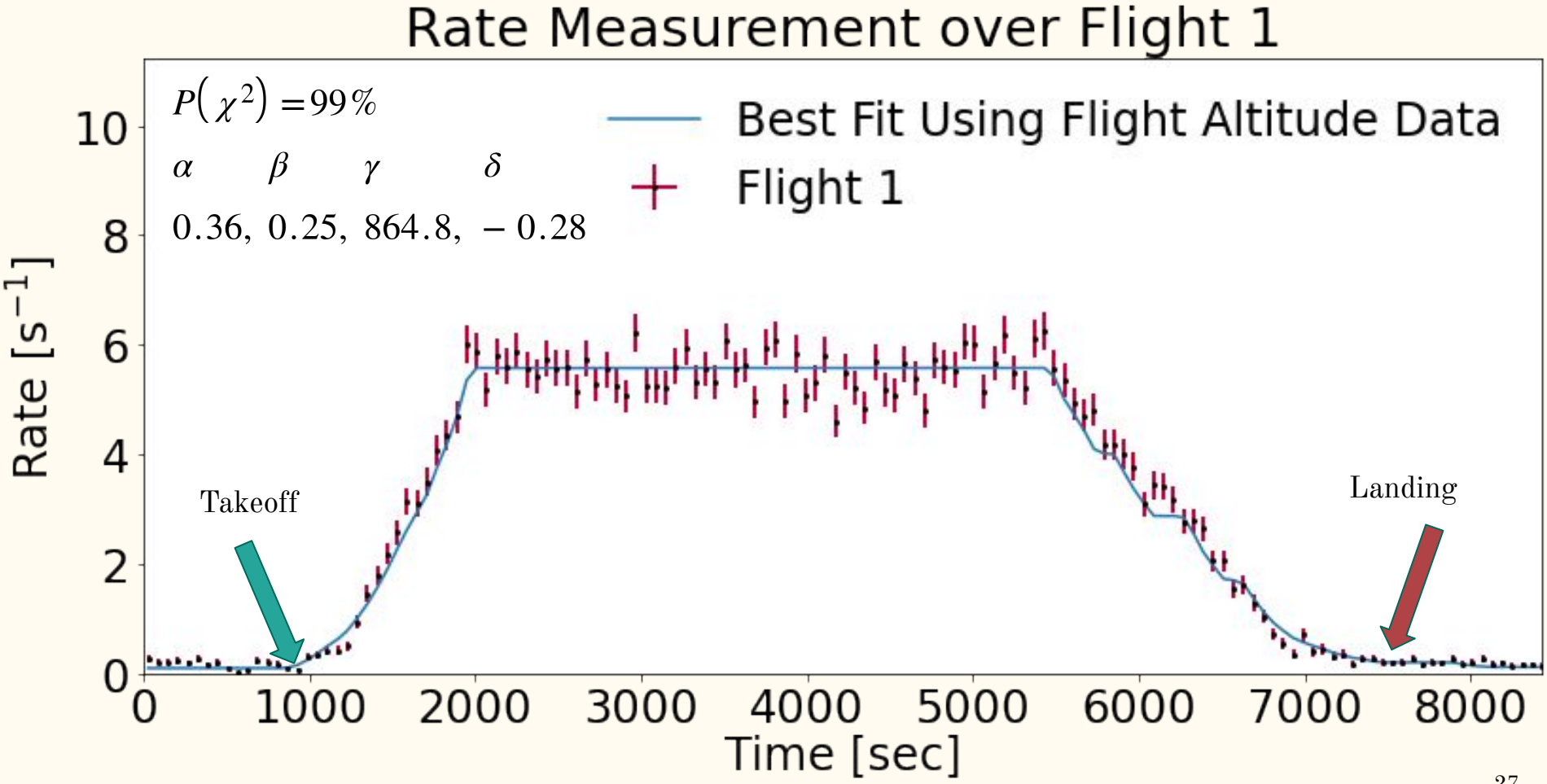
γ factor to allow for fit to match up takeoff and landing time


Rate Measurement over Flight 1
$P(\chi^2) = 99\%$
α β γ δ
0.36, 0.25, 864.8, − 0.28
Best Fit Using Flight Altitude Data
Flight 1
Takeoff
Landing
Rate [s^{-1}]
Time [sec]

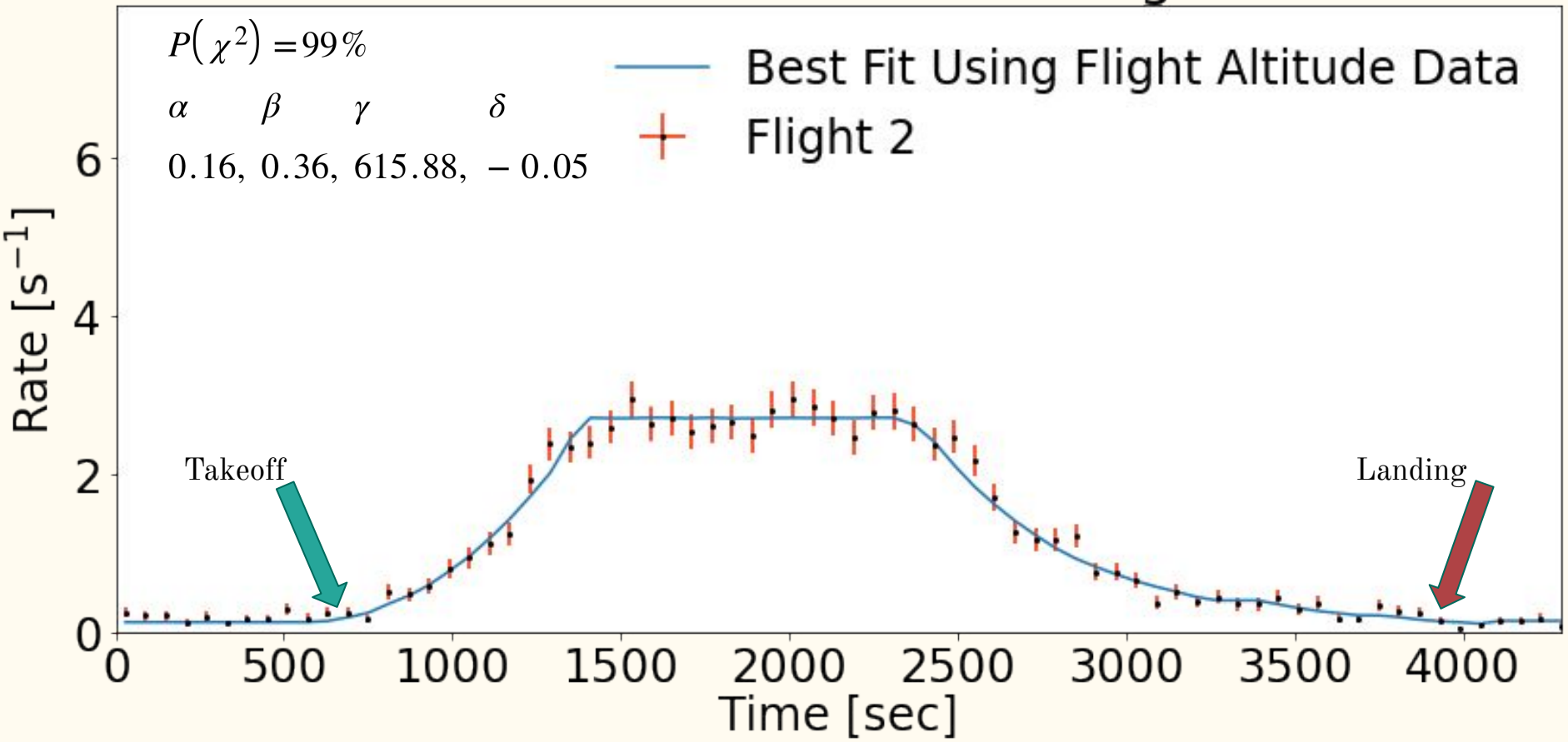

Rate Measurement over Flight 2
$P(\chi^2) = 99\%$
α β γ δ
0.16, 0.36, 615.88, − 0.05
Best Fit Using Flight Altitude Data
Flight 2
Takeoff
Landing
Rate [s^{-1}]
Time [sec]


Rate Measurement over Flight 3
$P(\chi^2) = 99\%$
α β γ δ
0.33, 0.26, 322.0, − 0.25
Best Fit Using Flight Altitude Data
Flight 3
Takeoff
Landing
Rate [s^{-1}]
Time [sec]

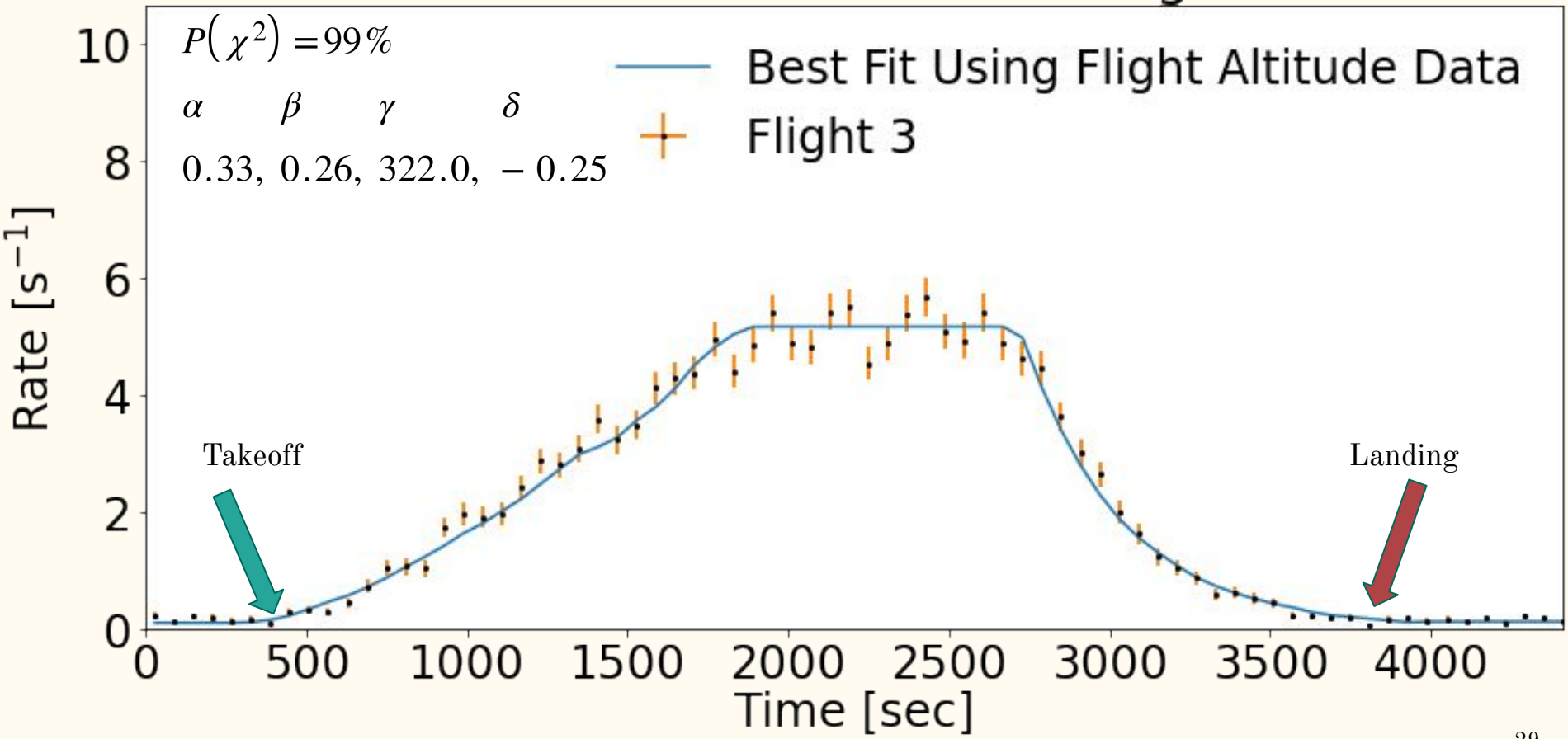

Rate Measurement over Flight 4
$P(\chi^2) = 99\%$
α β γ δ
0.23, 0.3, 509.51, − 0.13
Best Fit Using Flight Altitude Data
Flight 4
Takeoff
Landing
Rate [s^{-1}]
Time [sec]

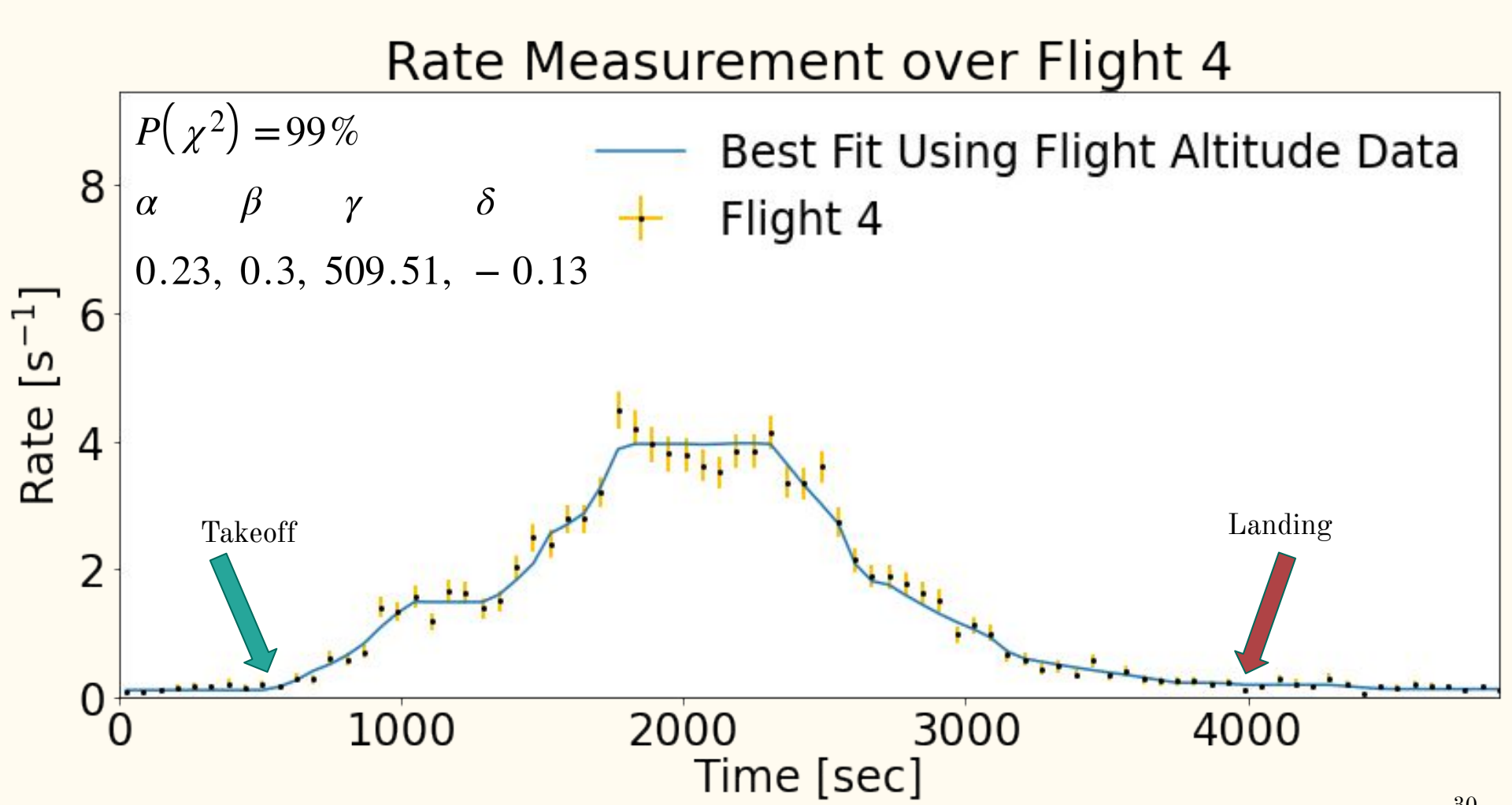

Rate Measurement over Flight 1
$P(\chi^2) = 99\%$
α β γ δ
0.36, 0.25, 864.8, −0.28
Best Fit Using Flight Altitude Data
Flight 1
Takeoff
Landing
Rate [s^{-1}]
Time [sec]
0
2
4
6
8
10
0
1000
2000
3000
4000
5000
6000
7000
8000

Rate Measurement over Flight 2



Rate Measurement over Flight 3

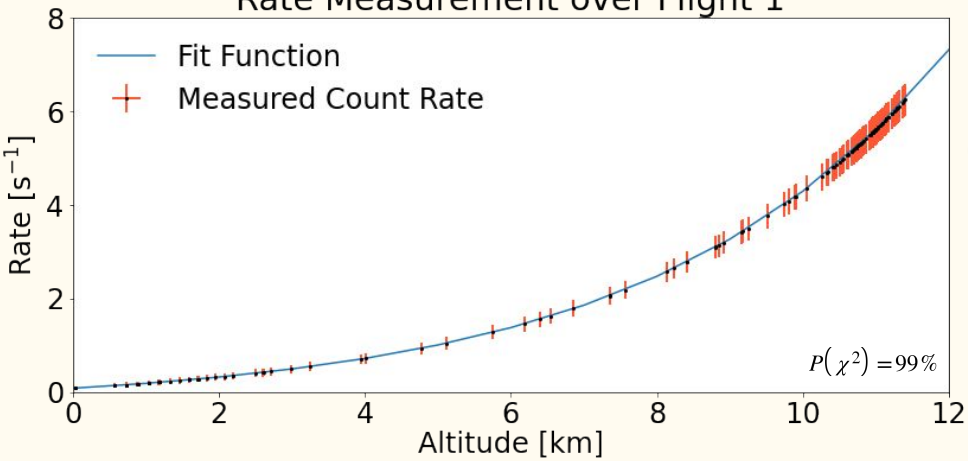


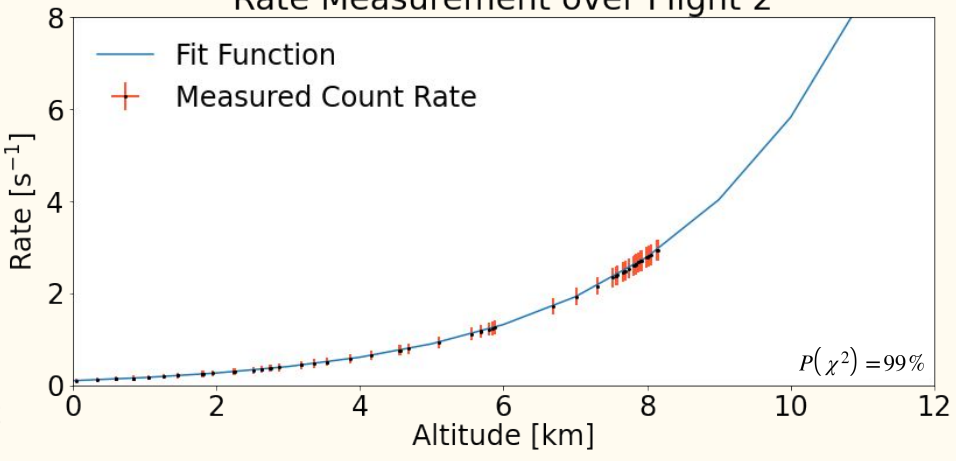

Rate Measurement over Flight 4
$P(\chi^2) = 99\%$
$\alpha \quad \beta \quad \gamma \quad \delta$
$0.23,\ 0.3,\ 509.51,\ -0.13$
Best Fit Using Flight Altitude Data
Flight 4
Takeoff
Landing
Rate [s^{-1}]
Time [sec]
0
2
4
6
8
0
1000
2000
3000
4000

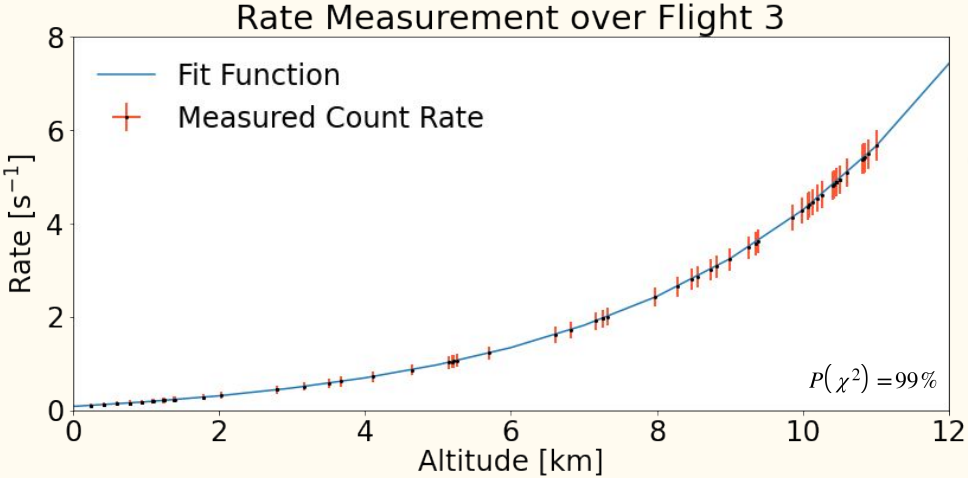
How well does the fit describe the data?

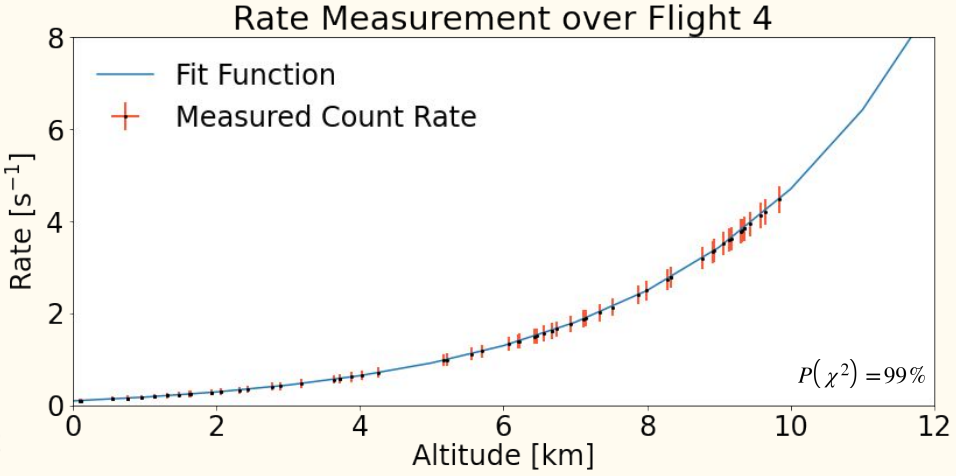
$$Rate\ [Hz] = \alpha\ e^{\beta \cdot Altitude}\left[t - \gamma\right]_{+}\ \delta$$

- We have found **α β γ δ** for each flight
- Use our Cosmic Watch data to go from rate to altitude
- Discover the exponential relationship!

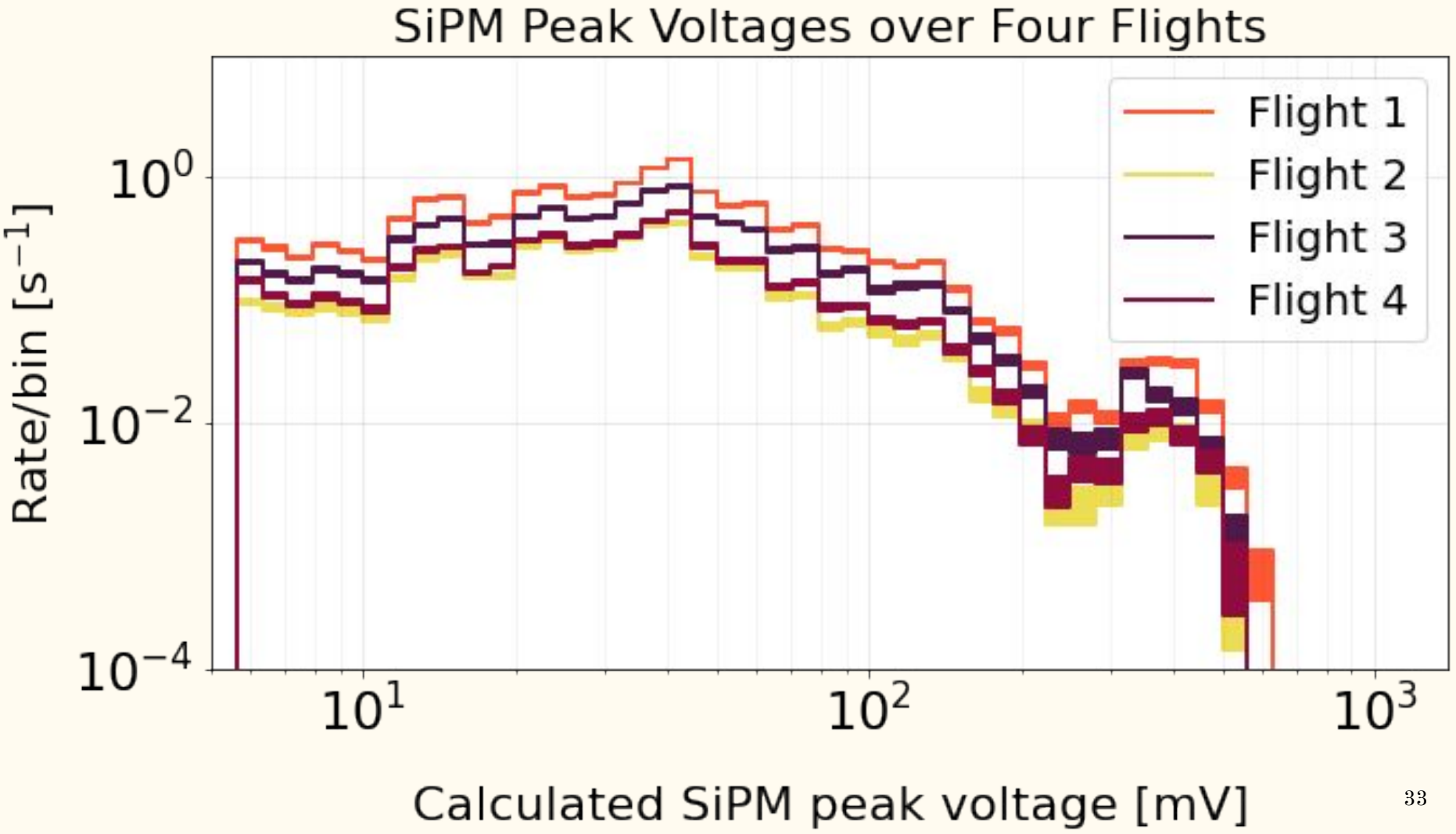








The count rate uncertainties from square root of the sum all the events measured at a given altitude


SiPM Peak Voltages over Four Flights
Flight 1
Flight 2
Flight 3
Flight 4
10^0
10^{-2}
10^{-4}
Rate/bin [s^{-1}]
10^1
10^2
10^3
Calculated SiPM peak voltage [mV]

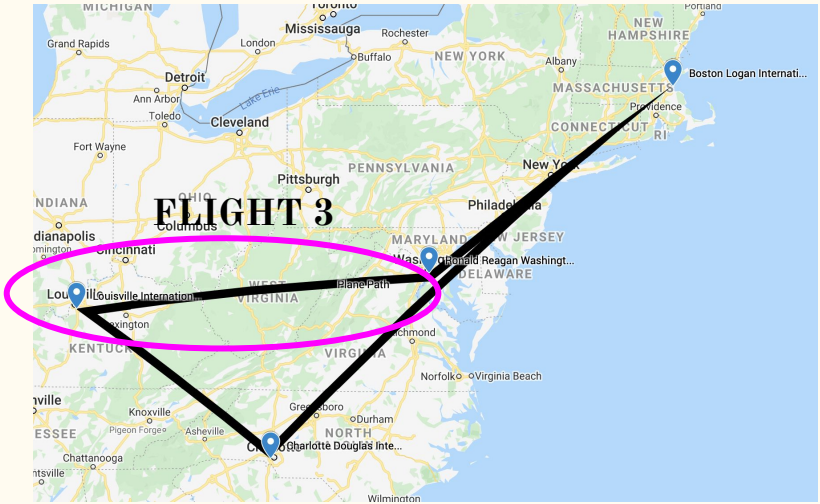
Uncertainties

The Latitude Effect

Uncertainties

The Latitude Effect

- Magnetic field behaves like dipole magnet
- Uniform across latitudes



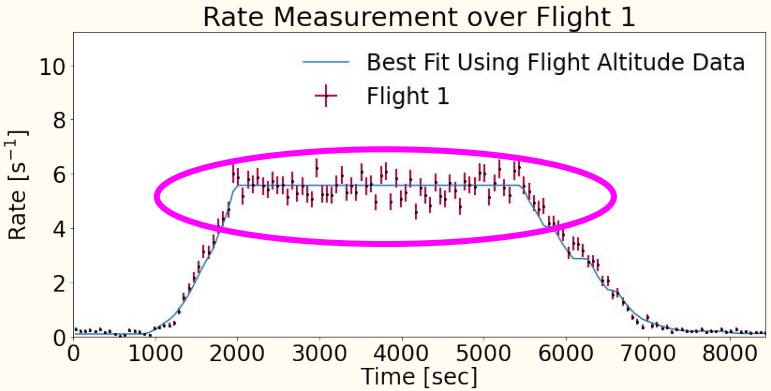
Uncertainties

The Latitude Effect

- Magnetic field behaves like dipole magnet
- Uniform across latitudes

Uncertainty Value: 5%

- Deviation of counts at constant altitude



Uncertainties

Weather

- Varies based on flight number, flight location, and flight altitude
- Pressure, temperature, etc.
- Alters the presence of background radiation

Uncertainties

Weather

- Varies based on flight number, flight location, and flight altitude
- Pressure, temperature, etc.
- Alters the presence of background radiation

Uncertainty Value: 6%

- Largest deviations in pressure along flight path

Conclusion

- Experimentally confirms that at higher altitudes we find more cosmic rays

(Flight 3) $$Rate\ [Hz] = \alpha\ e^{\beta \cdot Altitude}\left[t - \gamma\right] + \delta$$

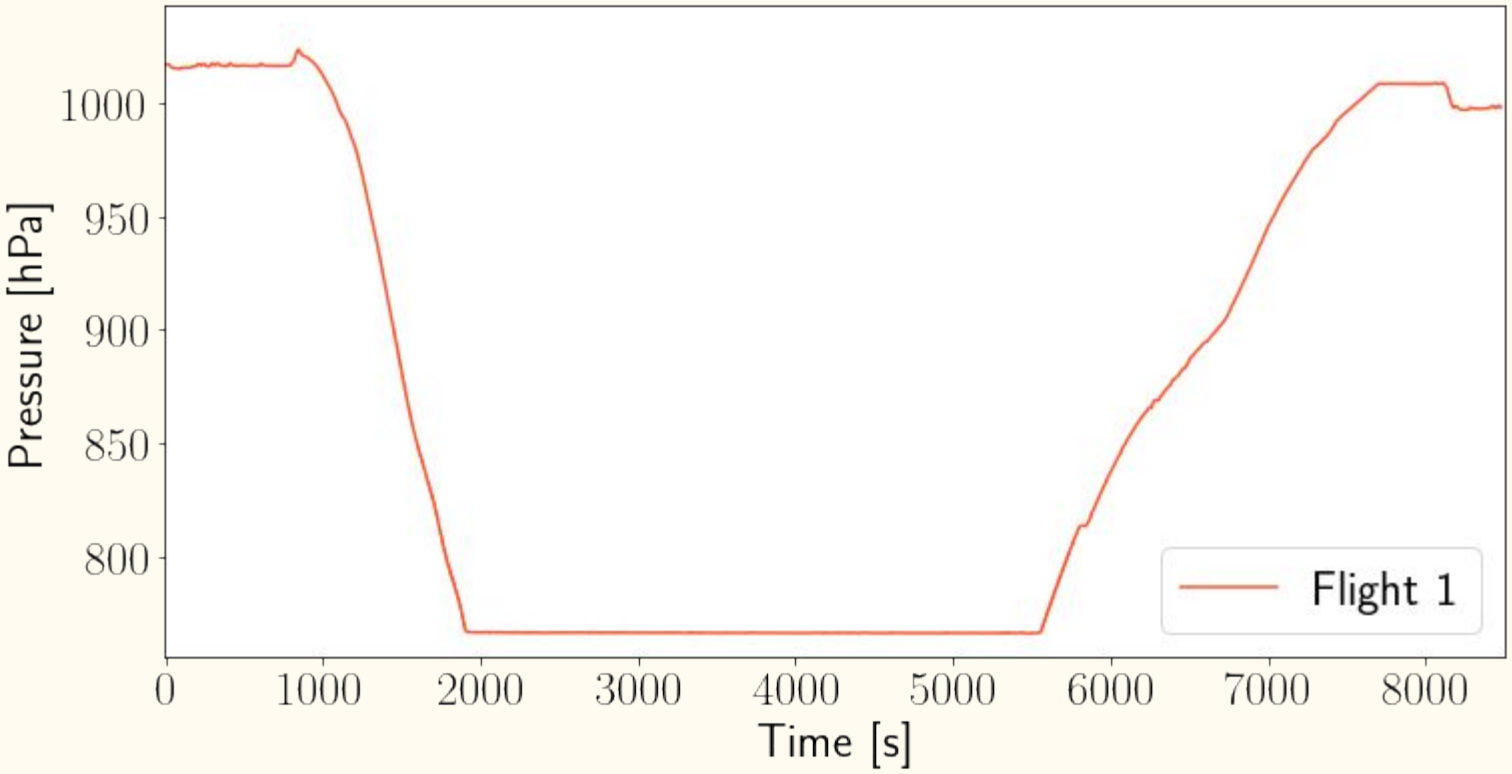
$$\alpha = 0.33 \pm 0.04 \quad \beta = 0.26 \pm 0.03 \quad \gamma = 322 \pm 41 \quad \delta = -0.25 \pm 0.03$$

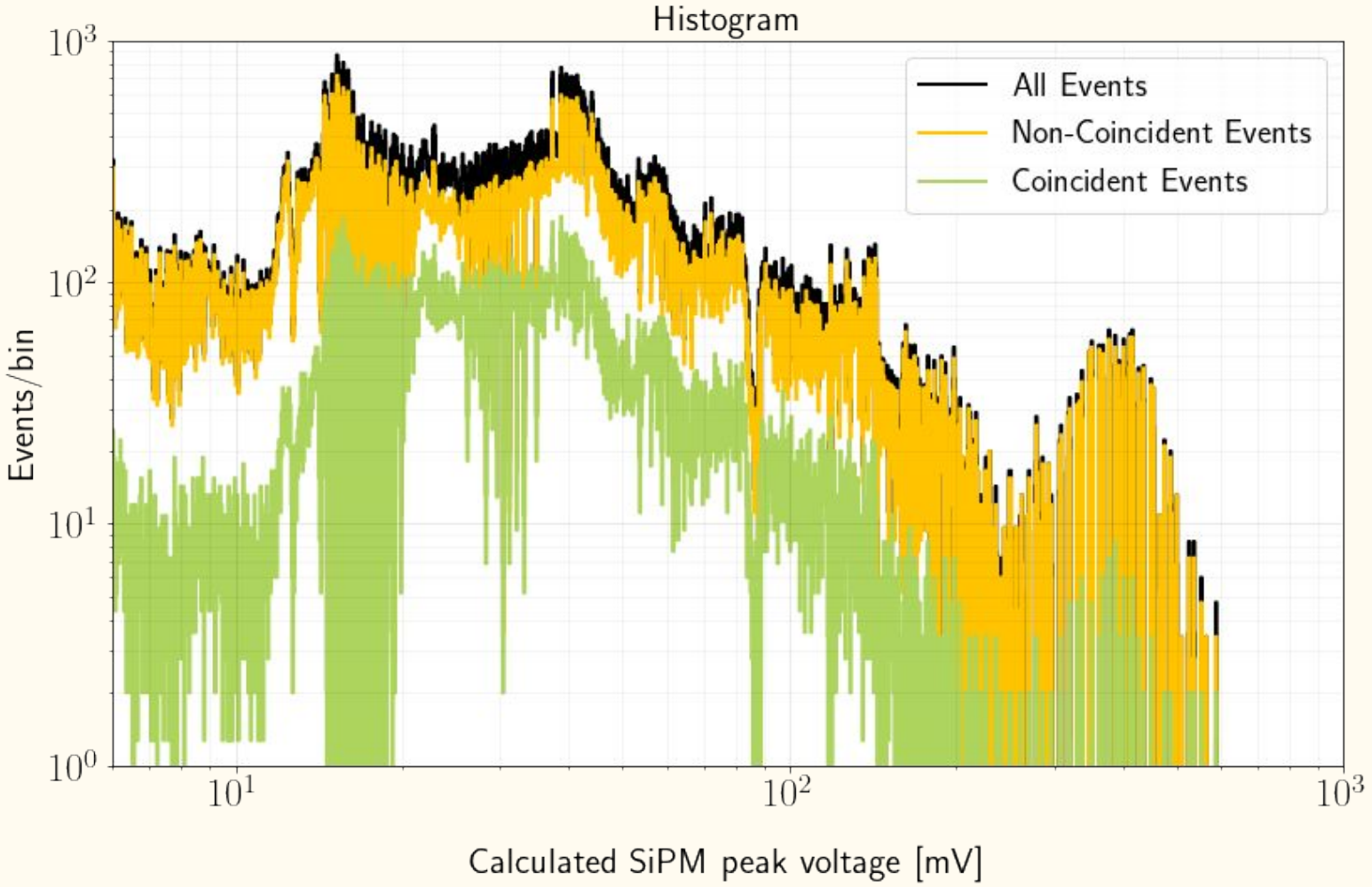
- Four flights, two detectors, two days
- Relationship between counts, energy, and altitude

Future experiments:

- Investigate flight paths through repeat flights
- Use Cosmic Watch data to uncover magnetic anomalies

Thank You


Pressure [hPa]
1000
950
900
850
800
0
1000
2000
3000
4000
5000
6000
7000
8000
Time [s]
Flight 1


Histogram
All Events
Non-Coincident Events
Coincident Events
Events/bin
10^0
10^1
10^2
10^3
10^1
10^2
10^3
Calculated SiPM peak voltage [mV]