Searches for Point Sources of Astrophysical Neutrinos in IceCube

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Contents

- Anatomy of an IceCube analysis
  - Overview of obtaining a final event sample
- Results of recent analyses
- Analysis method for time-independent sources
- Code exercise

Anatomy of an IceCube Analysis

- Goal: **Observe Something**

Usually called "signal"

•Examples:
  - Neutrinos originating from a single point in the sky
  - Any astrophysical neutrinos
  - GZK neutrinos
  - Neutrinos associated with Dark Matter

- Method:
  - Reduce data to keep signal and remove background
  - Do some sort of statistical test to decide whether you observe signal

Anatomy of an IceCube Analysis

- Goal: **Observe Something**
- Steps:

Detector takes data

- PMT, DOM, DAQ, Trigger

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Separate signal from background

- Apply algorithms to get particle's identity, energy, position direction
- Throw away particles that don't look like signal

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Apply statistical test to test if you observe signal

Anatomy of an IceCube Analysis

- Goal: **Observe Something**

Physics! Talks by Stefan, Markus, etc.

- Steps:

Detector takes data

- PMT, DOM, DAQ, Trigger

Low-level! Talks by John, Mark, etc.

Separate signal from background

- Apply algorithms to get particle's identity, energy, position direction
- Throw away particles that don't look like signal

Jake's talk later today! Also, analysis talks

Apply statistical test to test if you observe signal

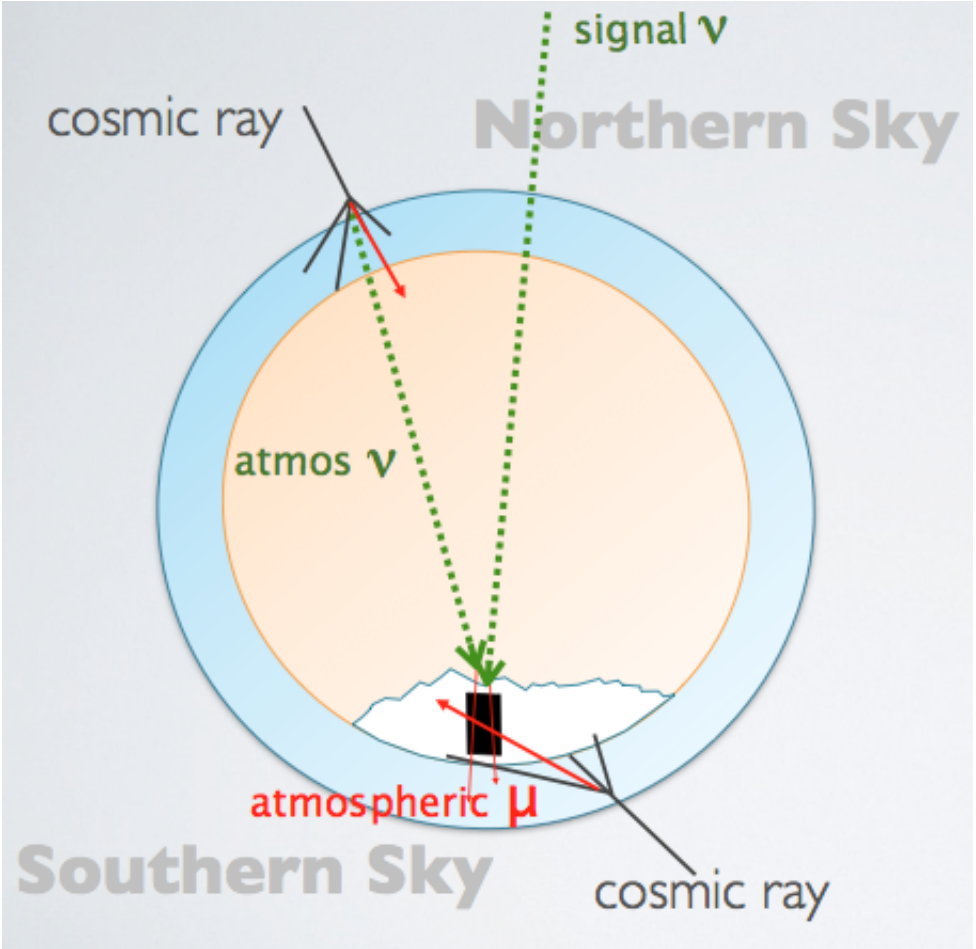
Statistics talk and analysis talks! Gary, Jake, Chris Marcos, etc.

Point Source Searches: The Goal

- Observe neutrinos originating from a single point in the sky
  - Time-independent: Add up data from multiple years
  - Time-dependent: Look for neutrinos coincident in time, or coincident with known gamma-ray flares
  - Extended: Look for neutrinos originating from regions (Galactic plane, Fermi bubbles, any object a few degrees across)

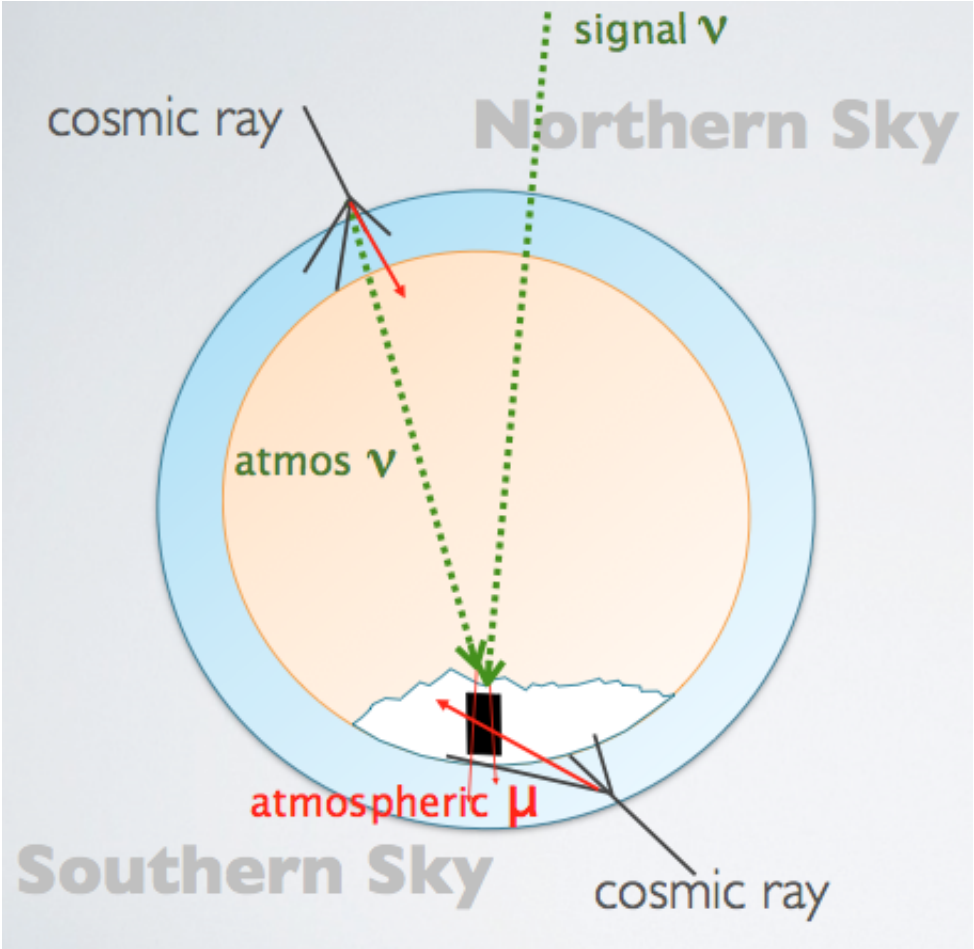
Obtaining a final sample

- Reducible backgrounds:
  - Mis-reconstructed cosmic-ray muons
  - Muon filter has~20 Hz of upgoing events
  - Atmospheric neutrinos ~ mHz
- Downgoing cosmic-ray muons that trick our reconstructions to appear upgoing dominate the filter-level data

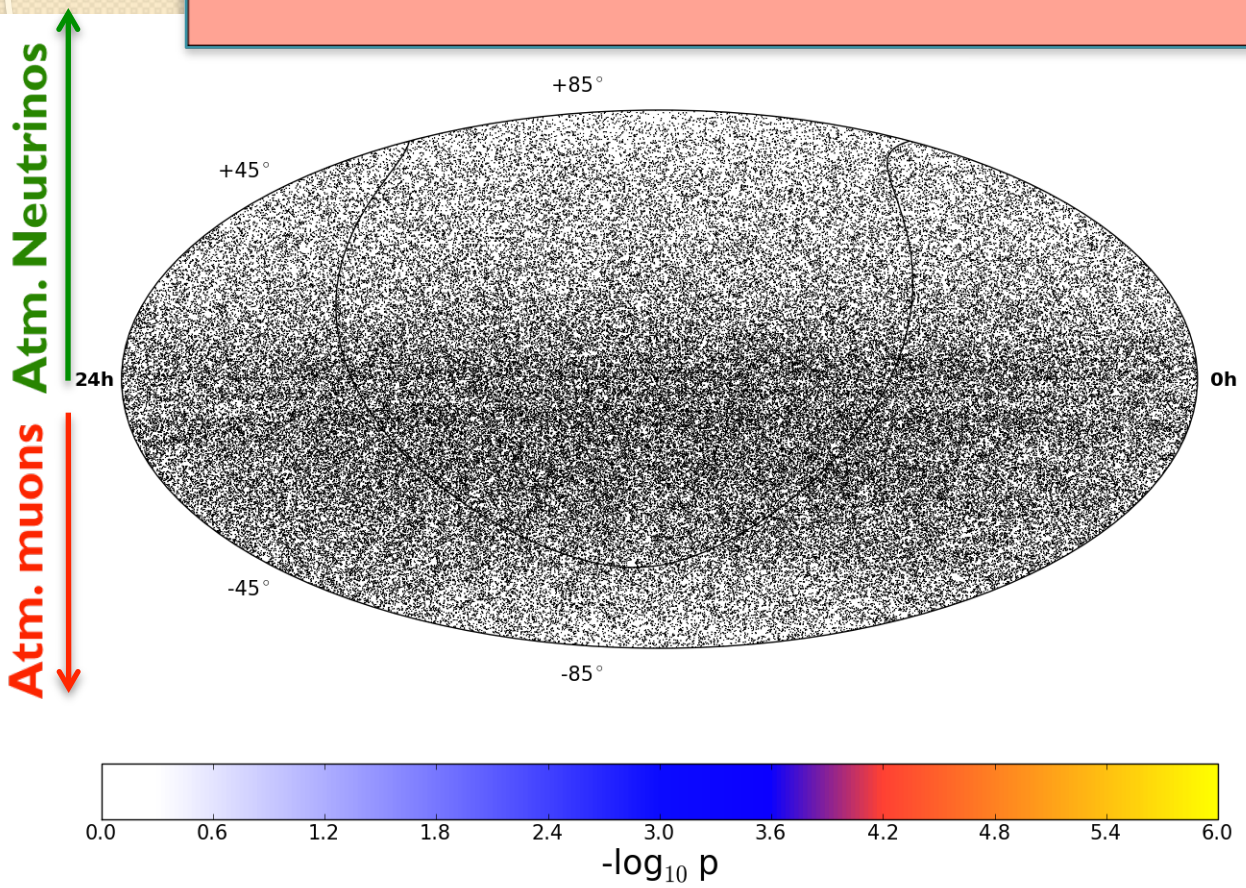


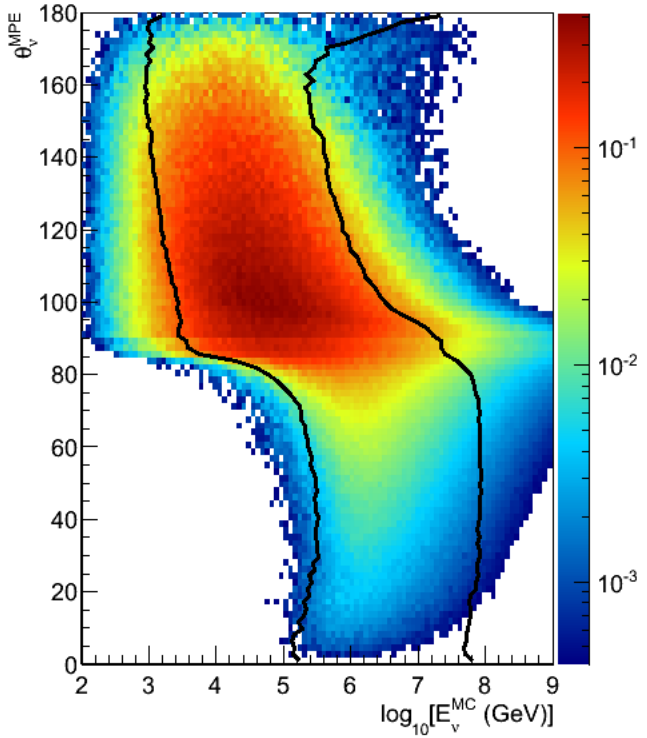
Obtaining a final sample

- Reducible backgrounds:
  - Mis-reconstructed cosmic-ray muons
- Muon Filter → L2 → L3 → Boosted Decision Tree → Final Sample
- Irreducible backgrounds:
  - Atmospheric neutrinos in the upgoing region
  - High-energy cosmic ray muons in the downgoing region



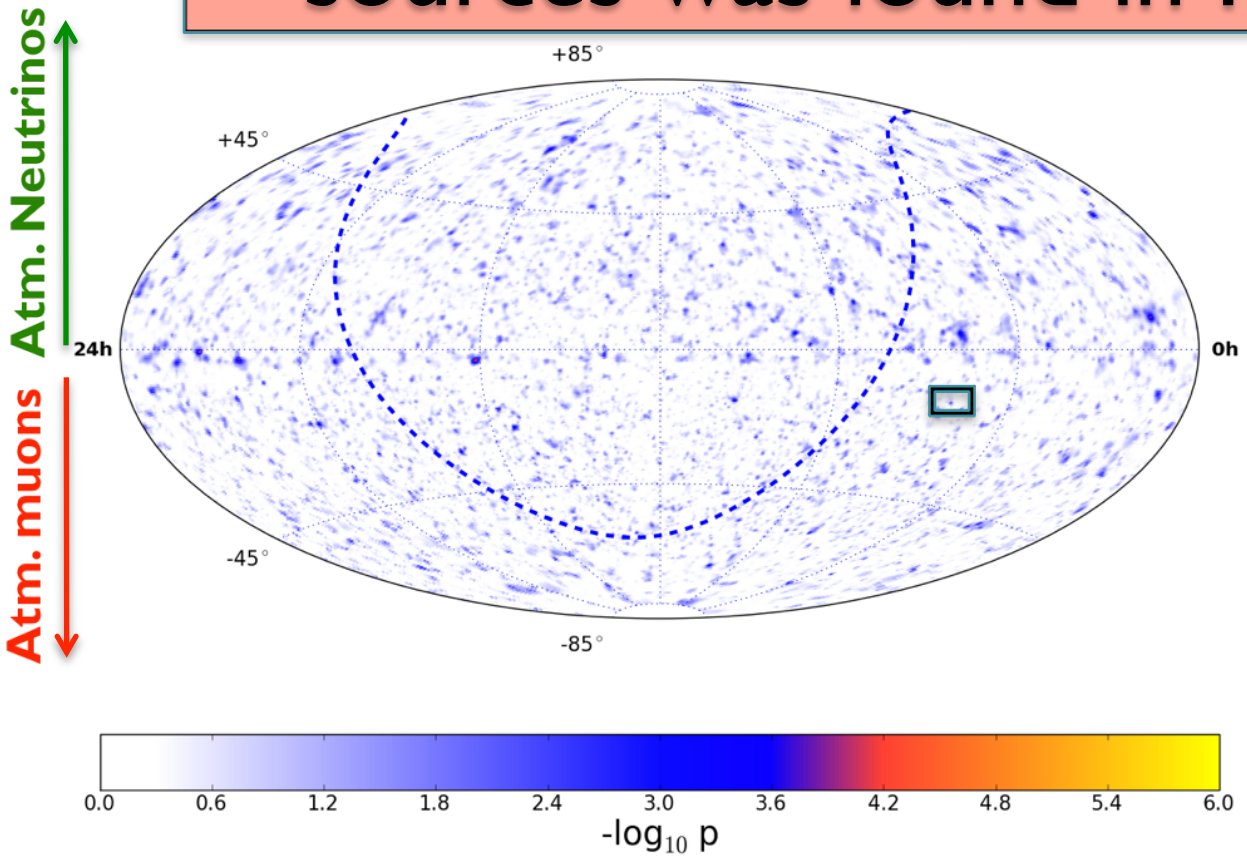
The IC59+40 Final Sample

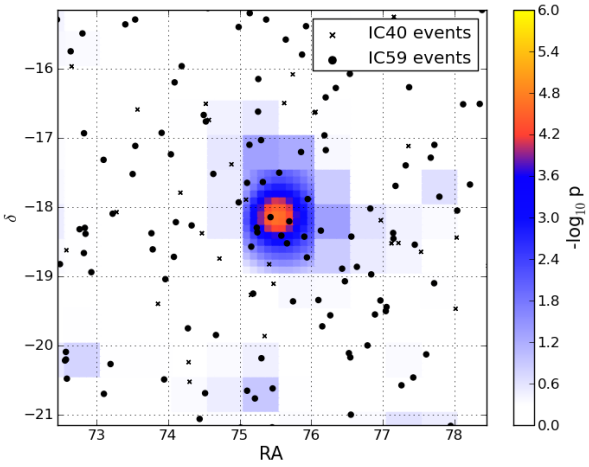


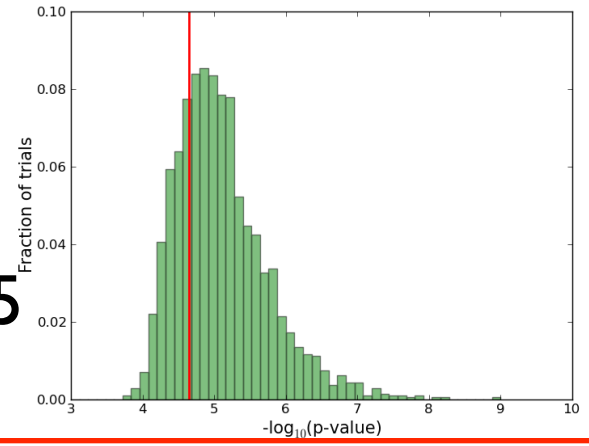


- Total events: 43339 (upgoing) + 64230 (downgoing)
- Livetime: 348 days (IC59) + 375 days (IC40)

No evidence of time-independent sources was found in IC59+40







- Hottest spot: RA: 75.45, Dec: - 18.15
  - -log10(p-value) = 4.65
  - $nSrc_{best}$ = 18.3
  - γ_{best} = 3.9

Post-trials p-value = 0.742

The goals of the next 45 minutes

- Understand what the skymap on the previous slide means
  - How significances were calculated
  - How to interpret them
- Understand why the analysis is done the way it is
- Use a toy MonteCarlo to understand the point source sensitivity and discovery potential

To the board!

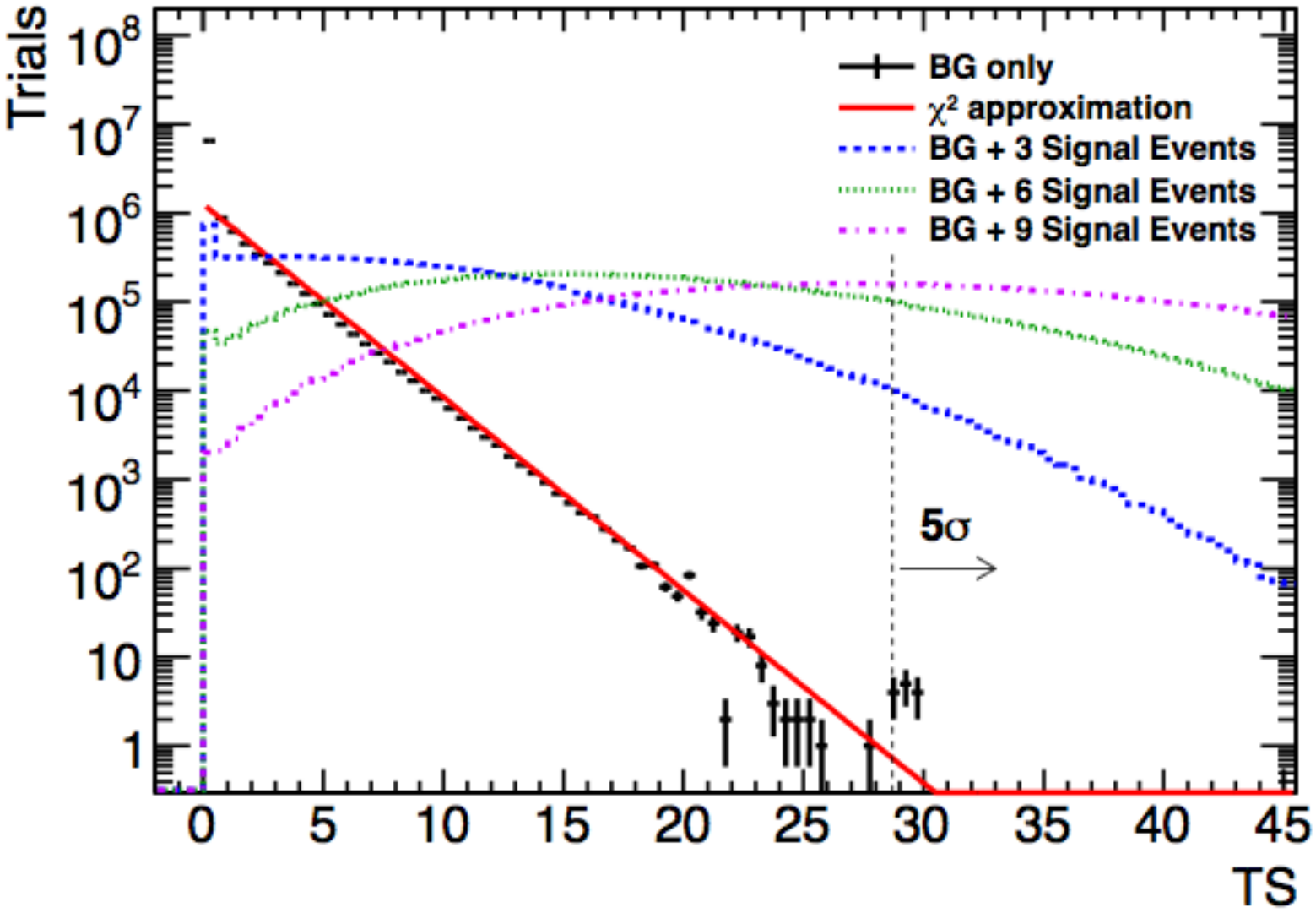
Code

- http://code.icecube.wisc.edu/svn/sandbox/jfeintzeig/Bootcamp/
  - Toy MC of event generation and point source analysis, written in python and using numpy, scipy, and matplotlib

Some take home points

- Statistics is crucial for high-energy physics and astronomy
- You gain statistical power by using more information about the data
  - s/sqrt(b) → binned poissonian llh → unbinned spatial llh → unbinned spatial and energy llh
- The method of maximum likelihood is used everywhere
  - Directional and energy reconstructions, point source analysis, diffuse analysis, dark matter fits from the analysis phone call yesterday…

Test statistic distributions



Sensitivity and Discovery Potential Curves