
Constraining the neutrino flux from cosmic population of Gamma-ray Bursts

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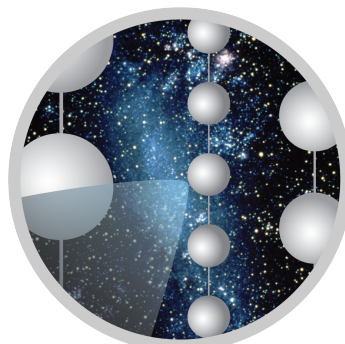
23rd November 2021

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Stockholm
University



ICECUBE



Oskar Klein
centre

Cosmic rays and neutrino connection

Cosmic rays can lead to production of neutrinos via the following channels:

- $p\gamma$ interactions
- pp interactions (less efficient)
- Decay of pions and muons

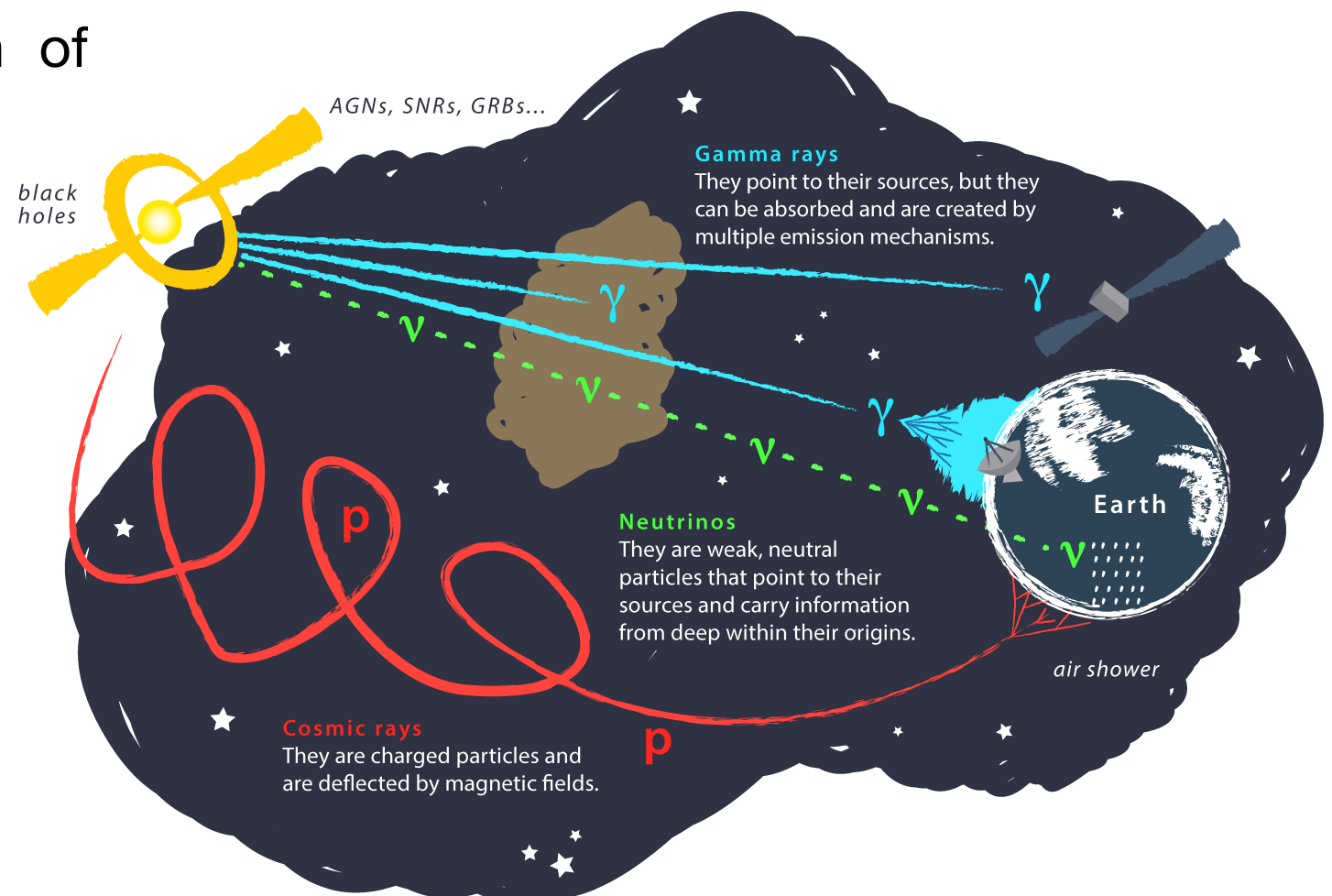
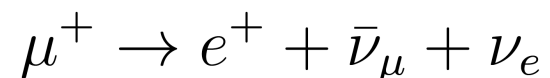
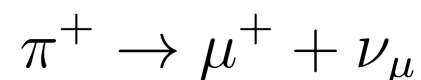
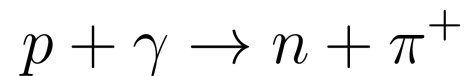


Image Credits: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

Neutrinos are undeflected by magnetic fields, and they interact only weakly so they can escape from dense environments. This makes them possible to be used as messengers.

Gamma Ray Bursts as sources of high-energy neutrinos

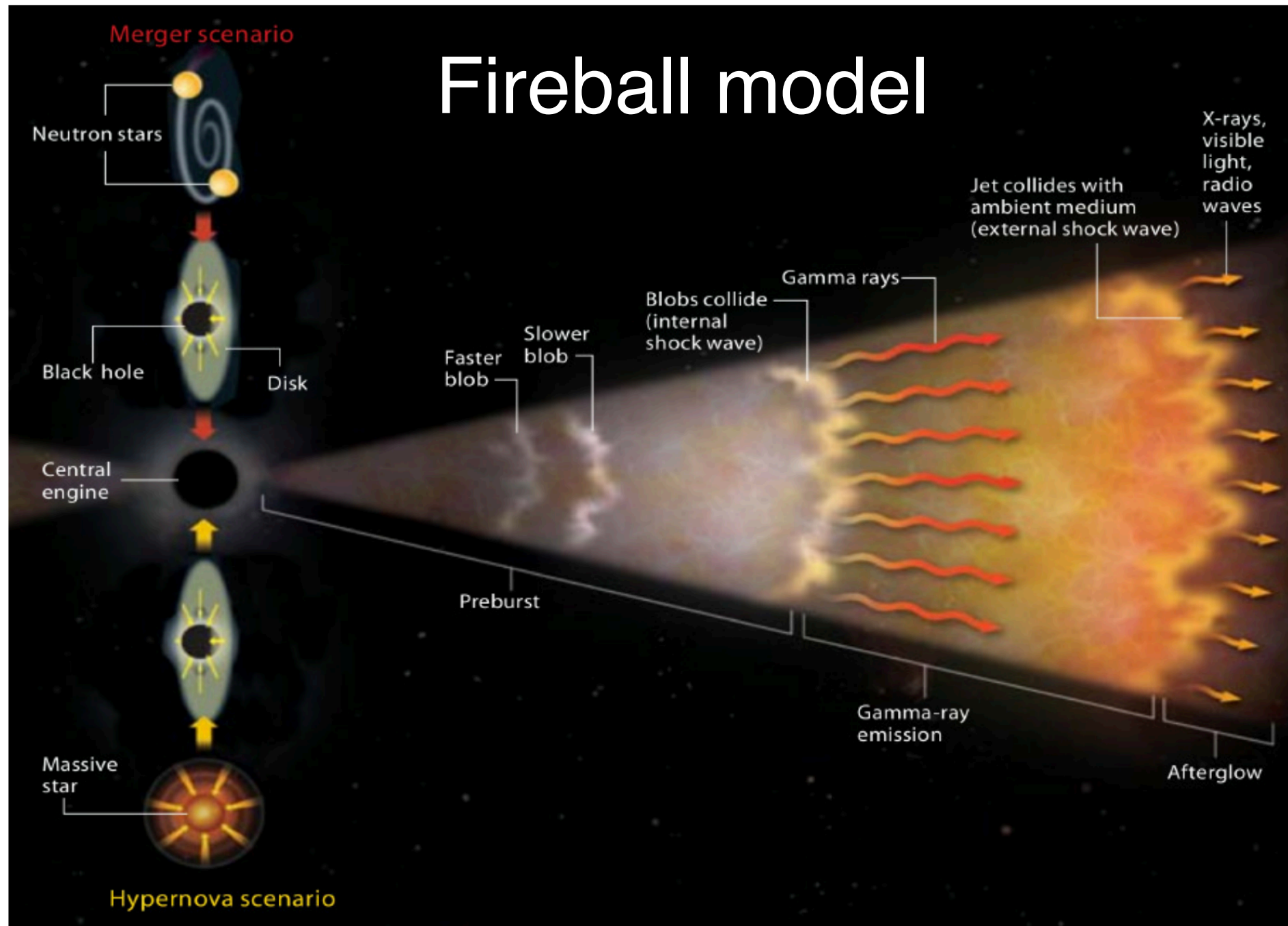
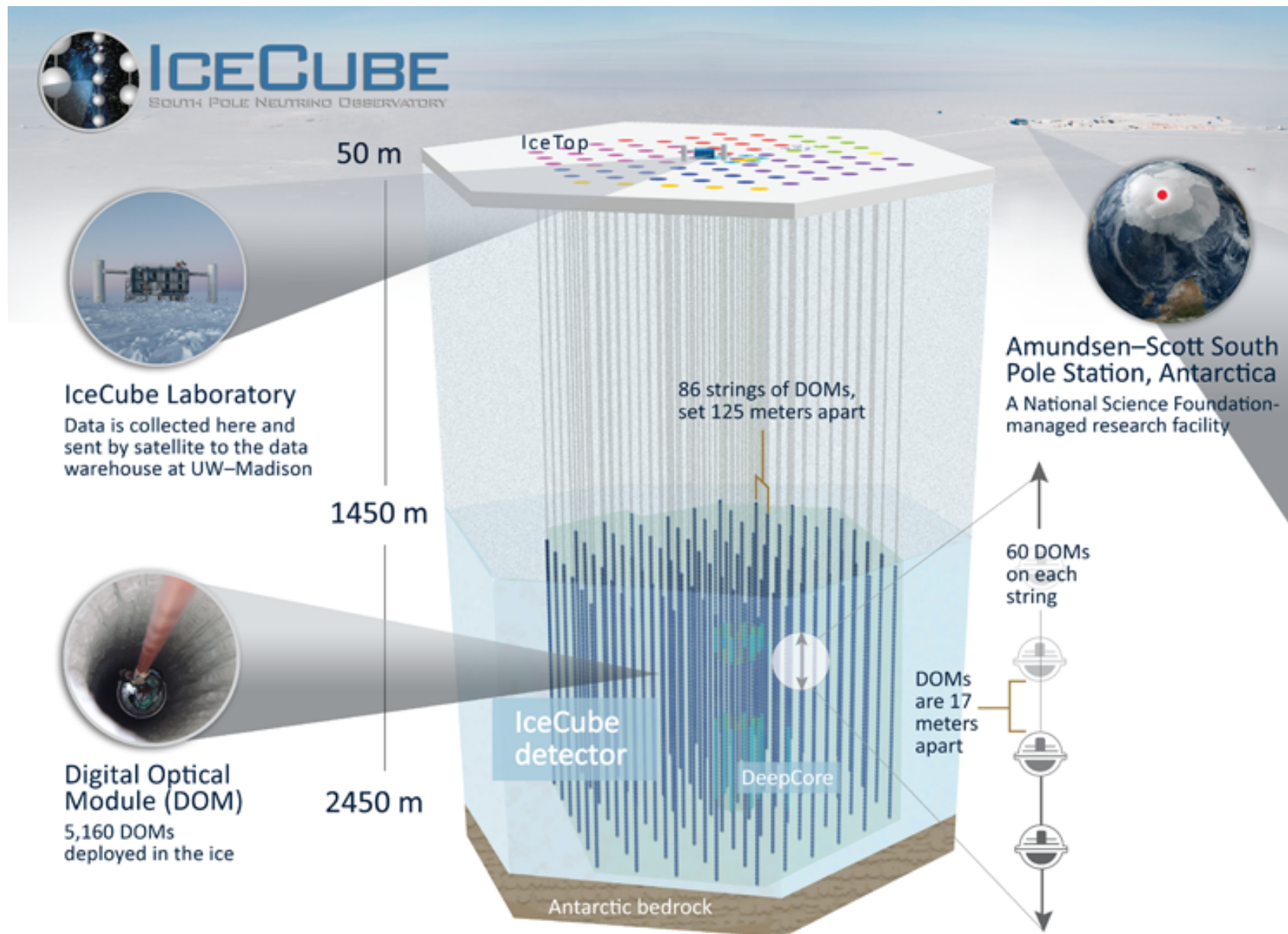


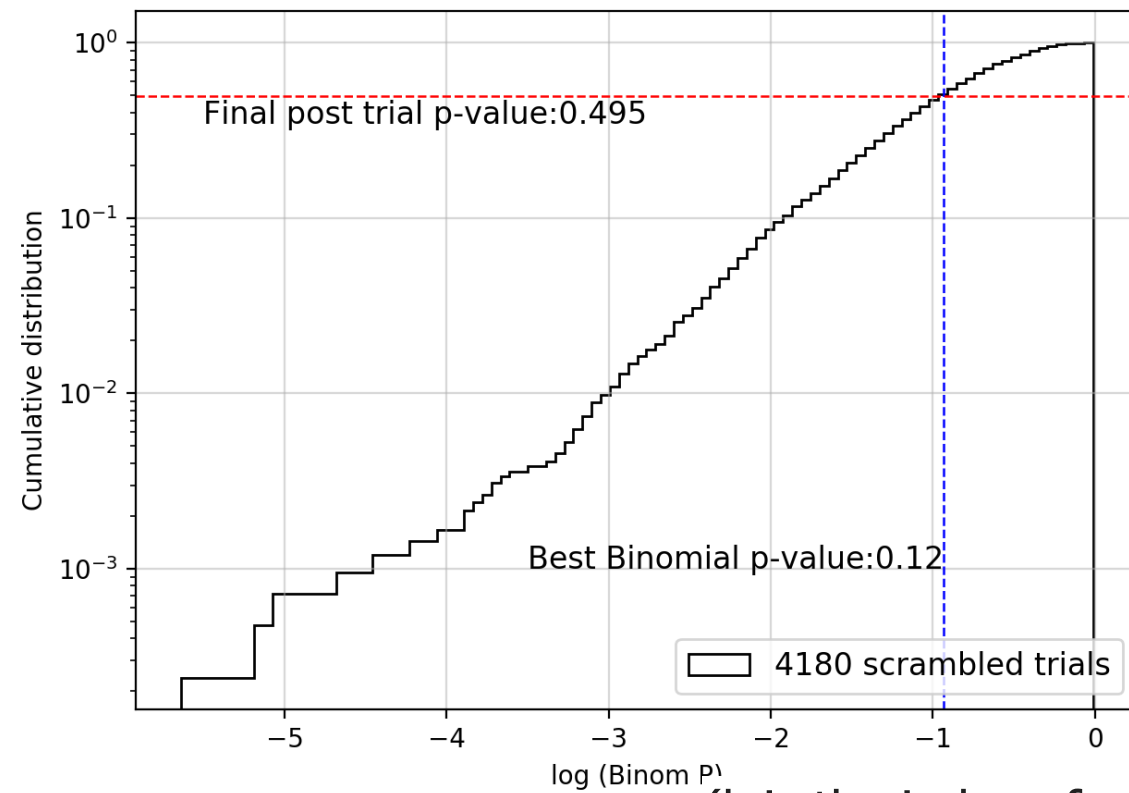
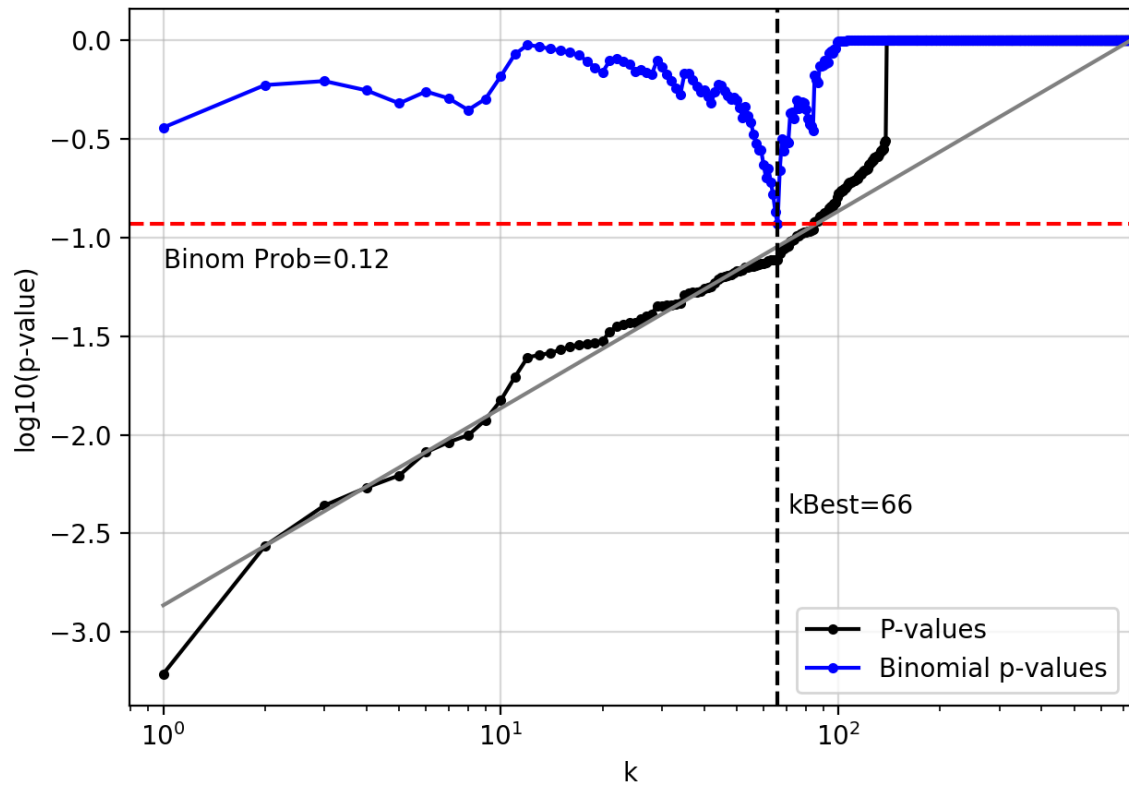
Image Credits: NASA

IceCube Neutrino Observatory

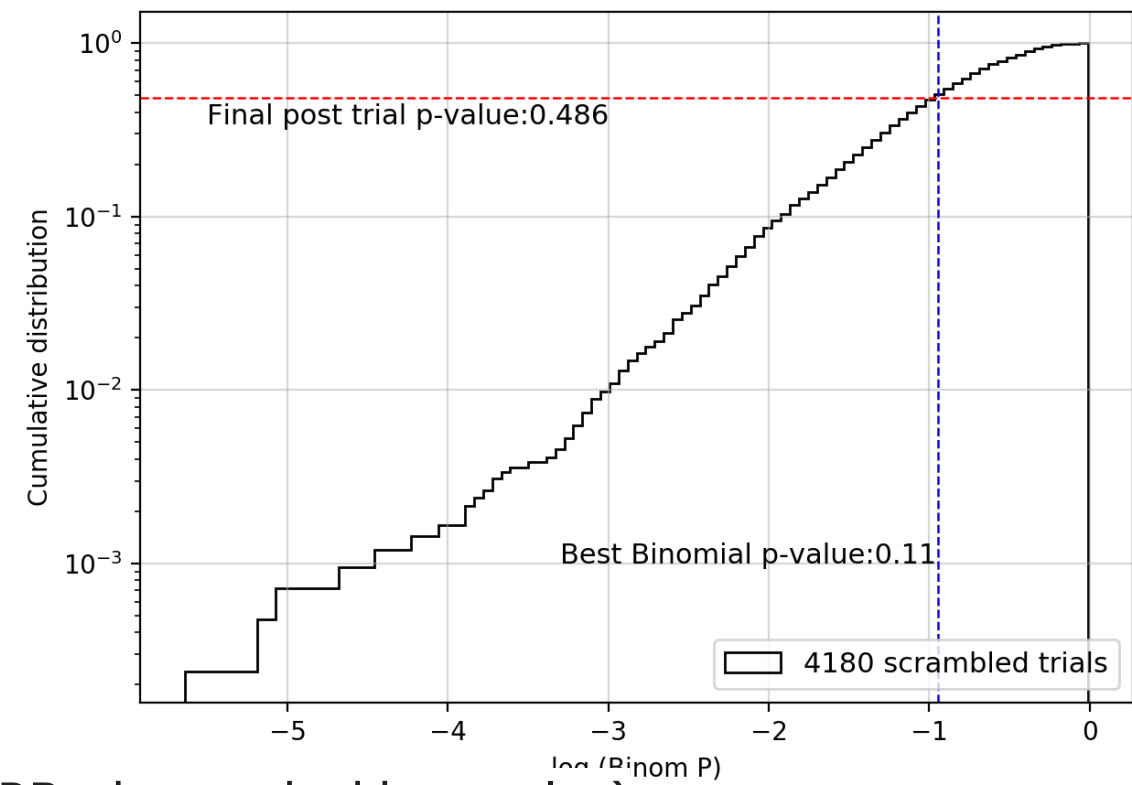
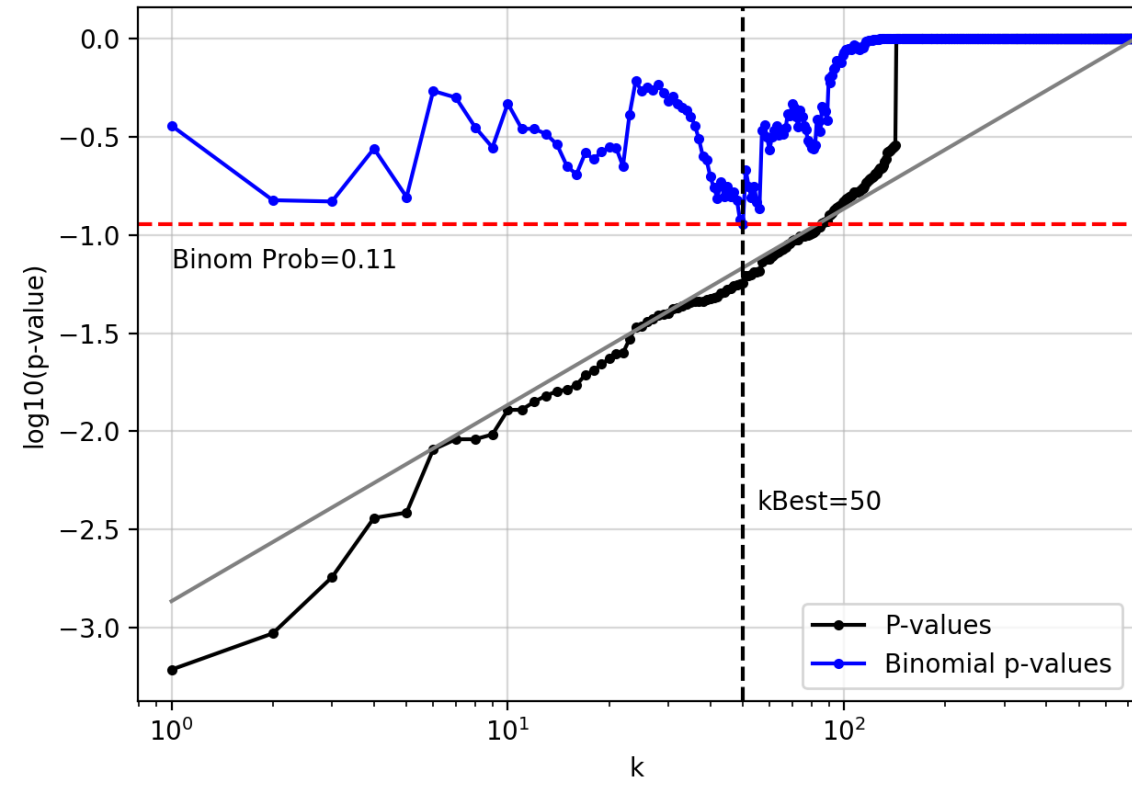


- A water Cherenkov detector at the South Pole making use of Antarctic ice as the medium.
- Total instrumented volume: 1 km³.
- Total 5160 Digital Optical Modules deployed over 86 strings.

Precursor search results



Prompt+Afterglow results



(k is the index of each GRB when ranked by p-value)

Constraining GRB contribution to Diffuse Neutrino Flux

- The GRBs analysed were a subset of the total (cosmic) population of GRBs.
- The diffuse neutrino flux is the total high energy (>10 TeV) astrophysical neutrino flux observed by IceCube.
- We want to set a limit on the contribution of the total GRB source population to the diffuse flux (not just limit on the observed GRBs' contribution to the flux).

Setting population limits:

- For my analysis, I made selection of 733 GRBs from GRBWeb* which had good localisation ($< 0.2^\circ$) and within the GFU data period.
- During this time period, Swift observed 546 long GRBs. All 546 of these GRBs are in my selection of 733 GRBs.
- We will use the Swift catalog for implementing a GRB population model.

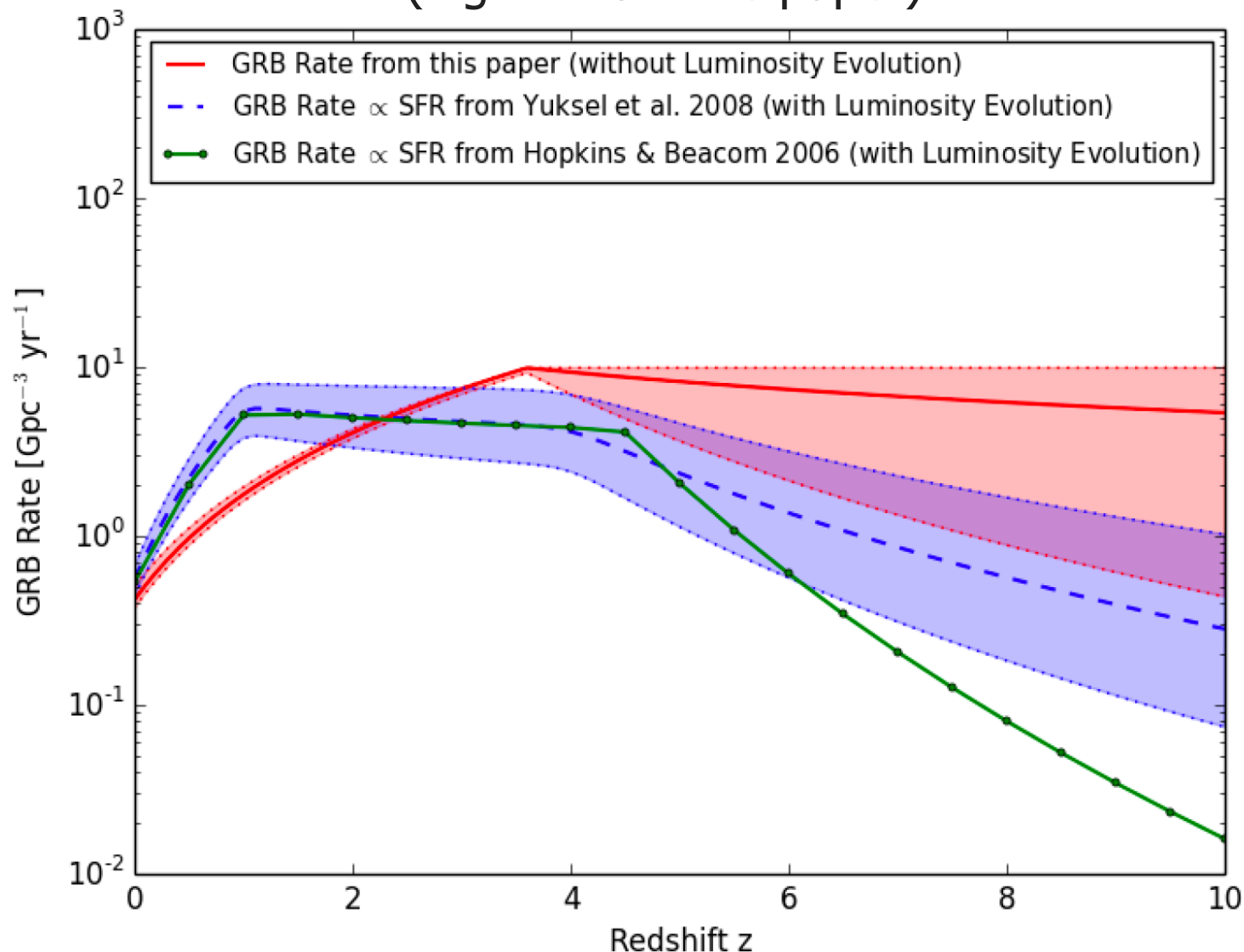
*(https://user-web.icecube.wisc.edu/~grbweb_public/)

- **Implementing a GRB model**

- **'Probing the Cosmic Gamma-Ray Burst Rate with Trigger Simulations of the Swift Burst Alert Telescope'** Amy Lien, Takanori Sakamoto, Neil Gehrels et.al. predicts ~4.5k GRBs/year.
- The above mentioned paper contains:
 - a cosmic population model
 - the detector selection effects which I can use to downsample from the total GRB population to the GRBs in my sample.

This paper allowed us to extrapolate the swift observation to a cosmic population of GRBs

The Lien et. al. model of GRB rate vs redshift (Fig.17 from the paper)



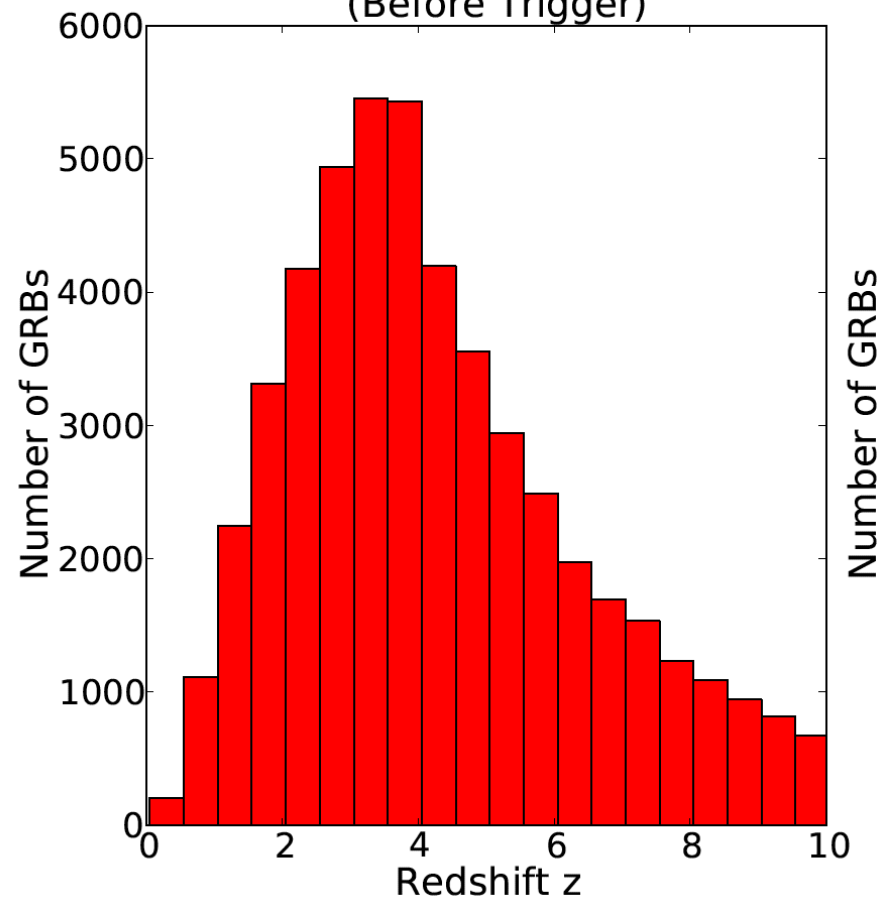
- If GRB rate follows SFR (blue curve), then the authors find that the GRB properties (luminosity distribution) needs to evolve with redshift.
- On the other hand, if GRB properties remain the same (don't evolve), the authors fit the GRB population rate with the red curve.

We will use the model produced by the authors, with no luminosity evolution (red curve). For making population limits, we will assume the GRBs are standard candle neutrino sources.

Implementing Lien et al. GRB population model

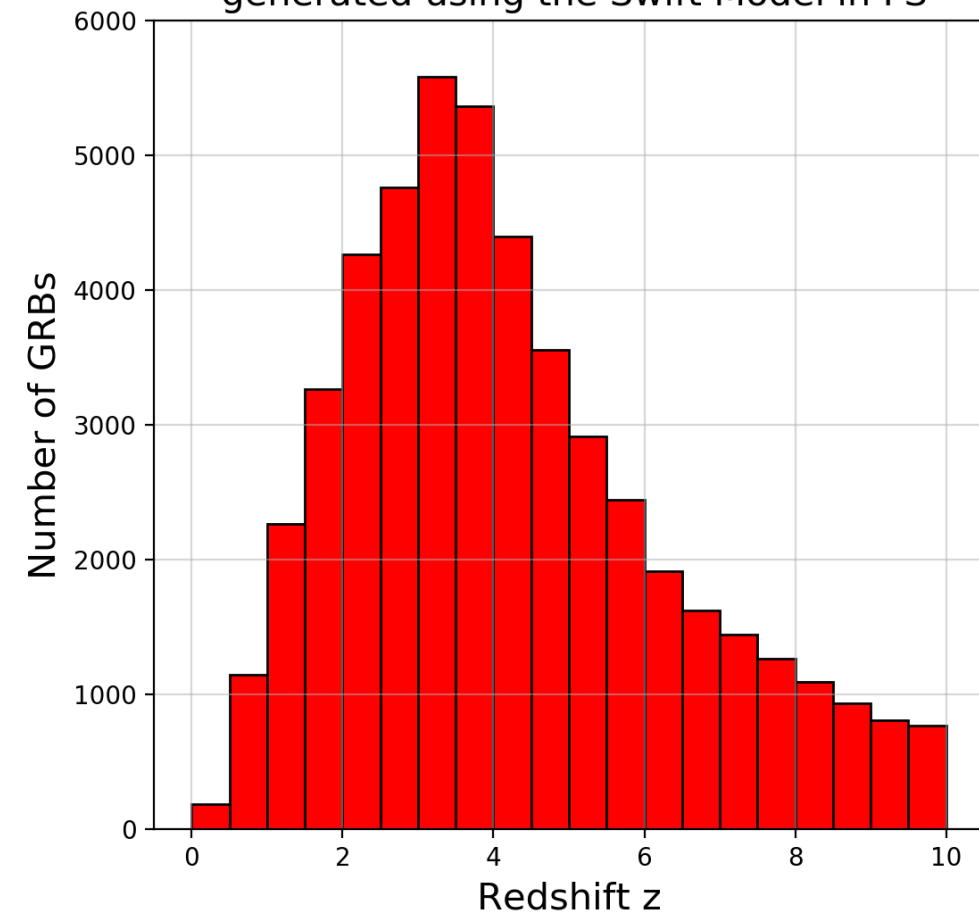
From Lien et al.

Input redshift Distribution
(Fig.9 a from the paper)
(Before Trigger)



From my simulations (using FIRESONG software)

Input redshift Distribution for 50k GRBs
generated using the Swift Model in FS



- The plots above are for the same arbitrary number of simulated sources (50k) for comparison.
- For the rest of the calculations I will be using the actual estimated rate normalization by Lien et. al. so that it matches the total cosmological number of GRBs during the ~7.5-year analysis period.

Total population \rightarrow (simulated) Swift-detected sample

From Eq. 9 Lien et al. :

$$R_{Swift} = \mathcal{R}_{GRB;dz} \times f_{detect} \times FOV \times t_{survey},$$

**Swift observed
GRBs
(what we want)**

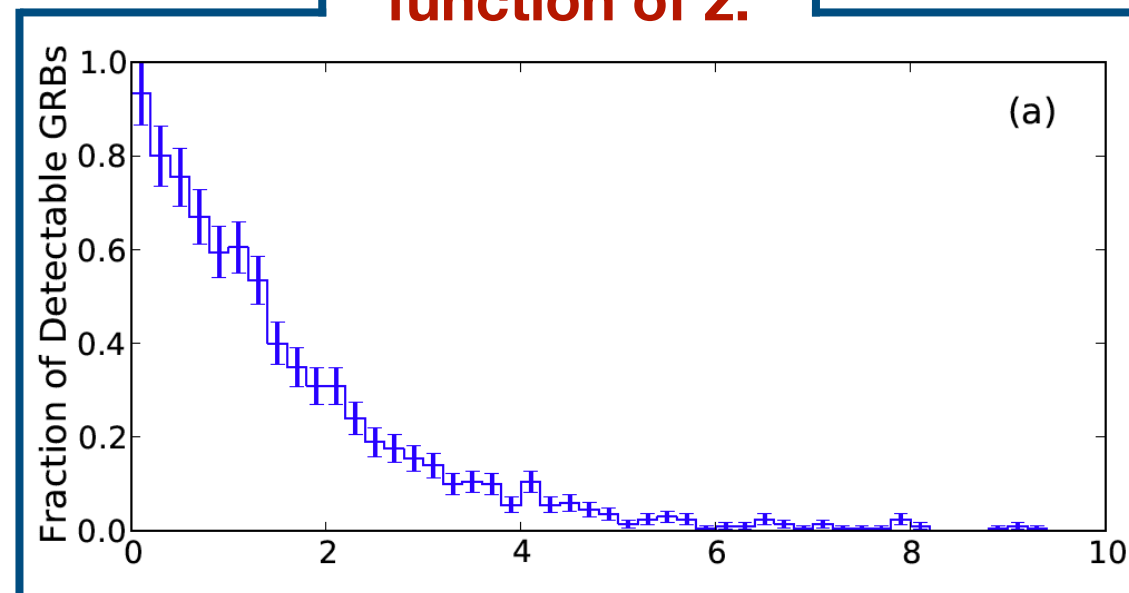
**Actual redshift
distribution
(previous plot)**

**Swift detection
efficiency as a
function of z:**

**Fractional field-of-
view of BAT
(2 sr/4pi sr)**

**fraction of the time
that BAT spends on
searching for GRBs
(~90%)**

Figure 16 (a) from the paper:



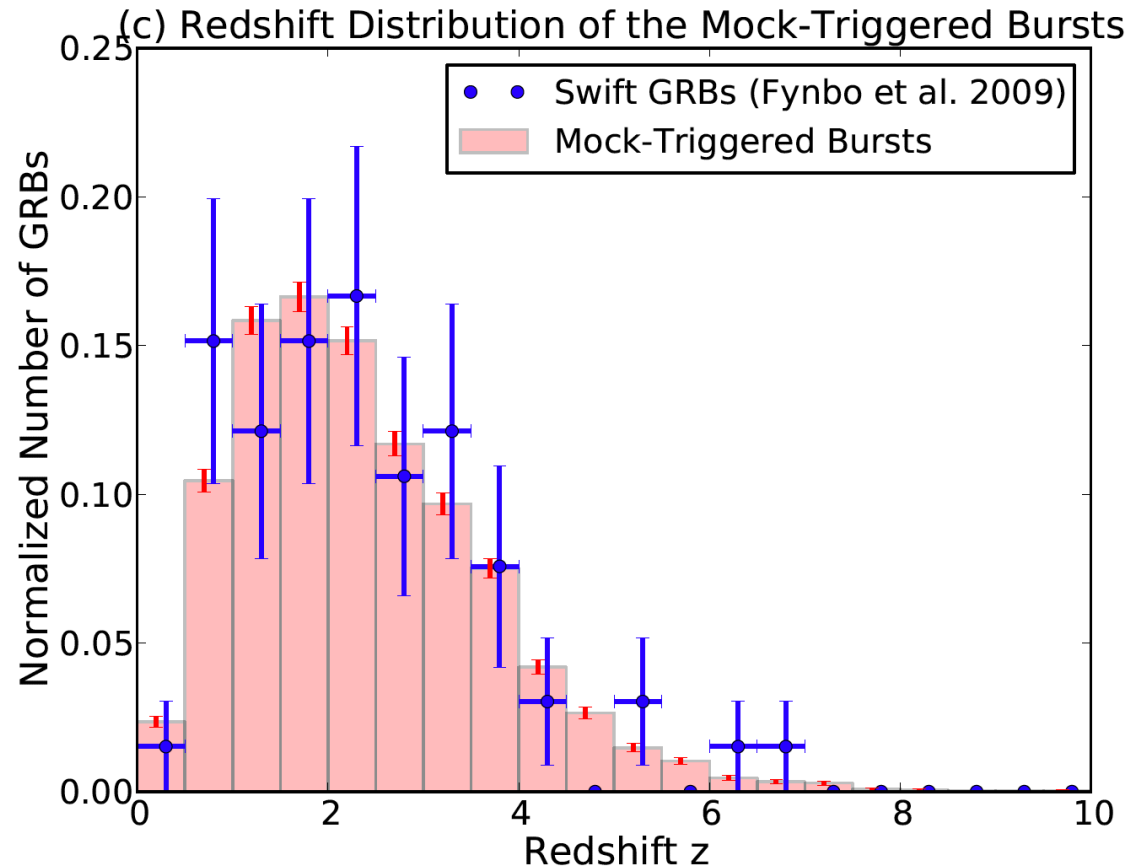
Implementing downselection

1. Take Firesong total GRB population, randomly keep GRBs according to the detection efficiency.
2. Downsample according to fraction of field of view that Swift has for the whole sky.

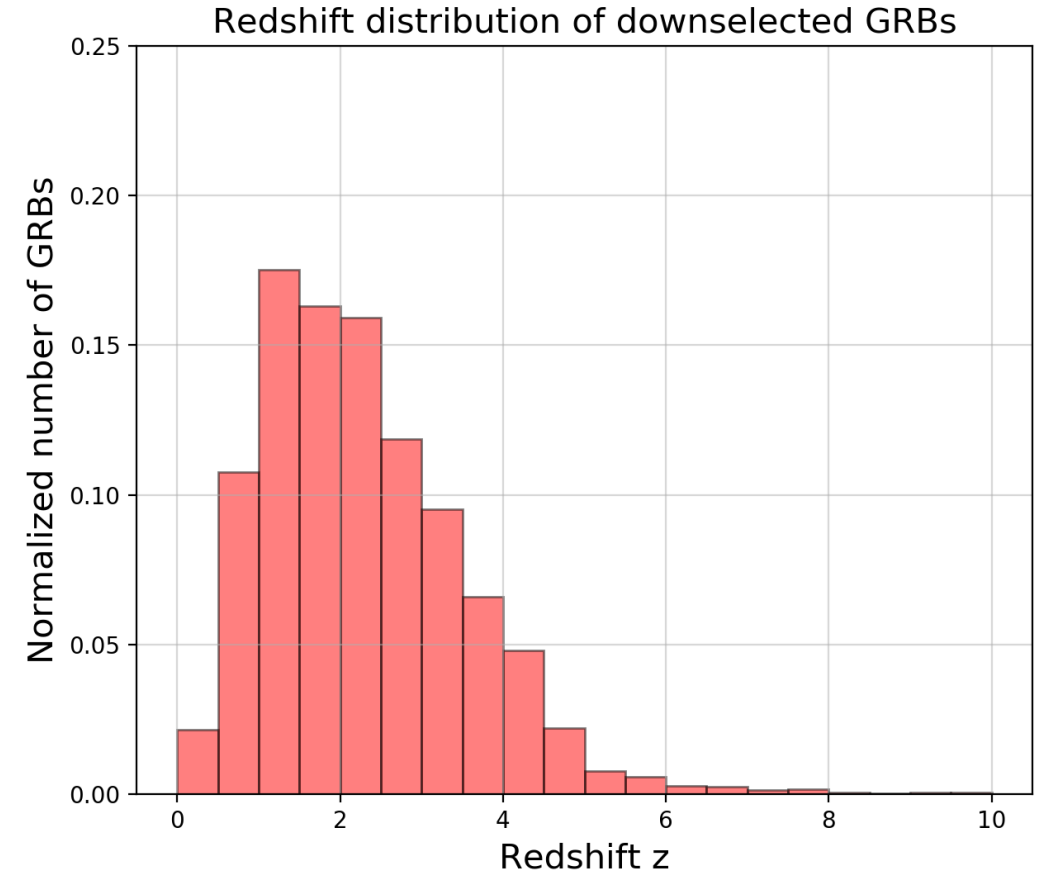
Final GRB sample:

From Lien et al.

Figure 9(c) from the paper:



From my simulations



- **Key takeaways**

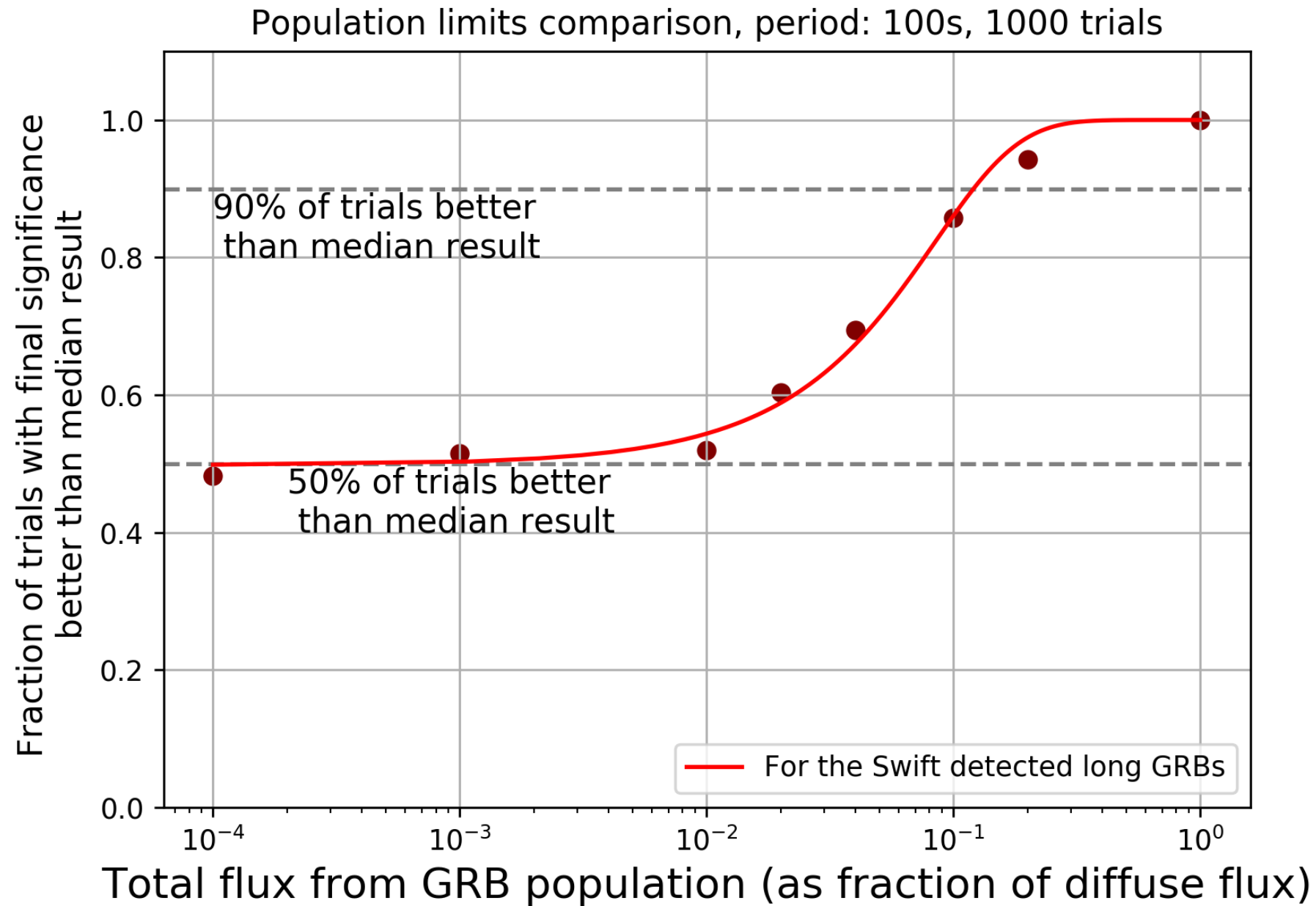
- We can simulate a cosmic GRB sample, and can down-select to a sample of 546 GRBs with a redshift distribution that matches the Swift-detected GRBs.

- **Next step**

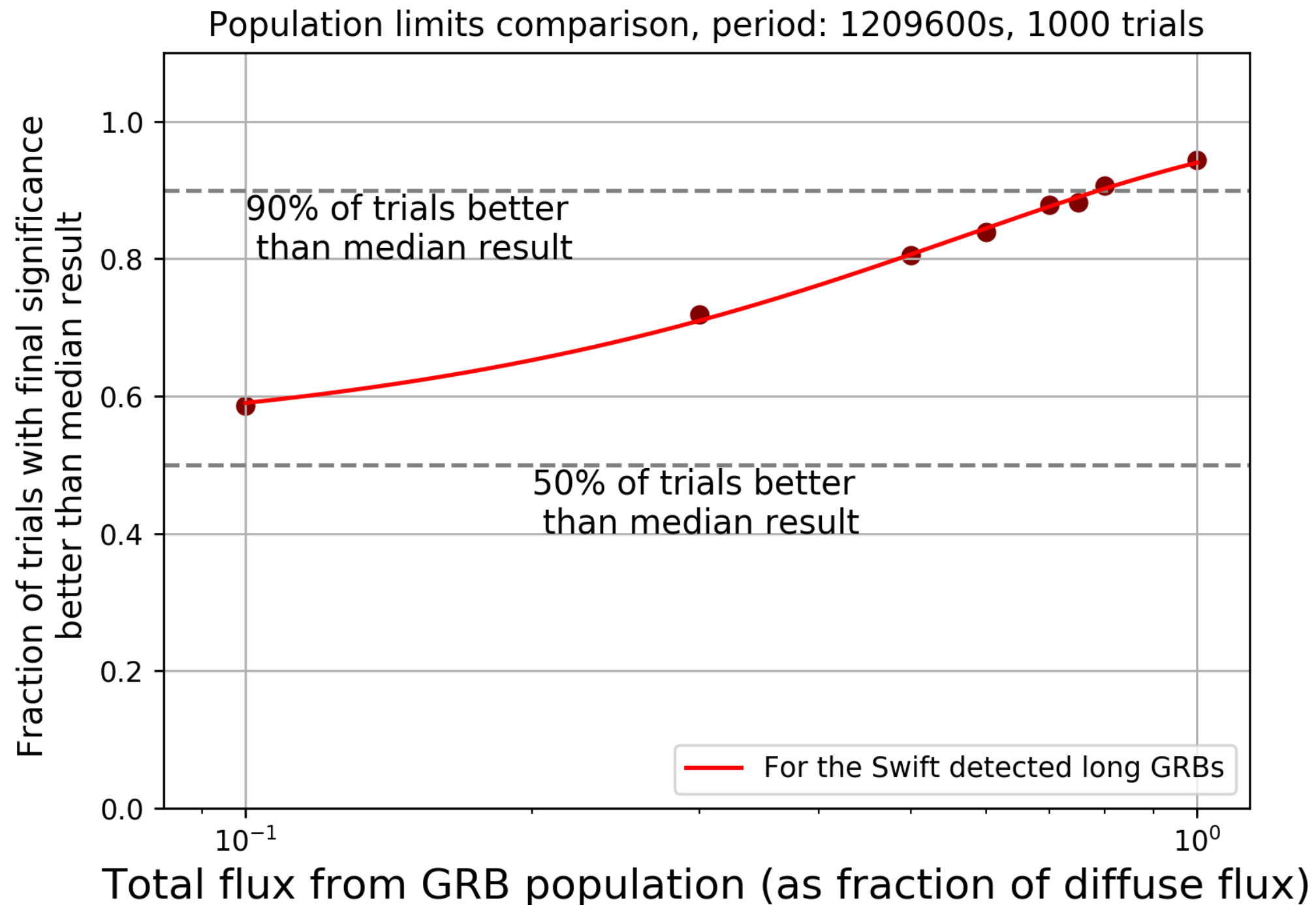
- Use Firesong to scale the total neutrino flux from all GRBs (cosmic sample, not down-selected sample)
- Where the diffuse flux is simulated as a power law:

$$\frac{dN_{diffuse}}{dE} = 1.44 \times 10^{-8} (E/100 \text{ TeV})^{-2.28} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$$

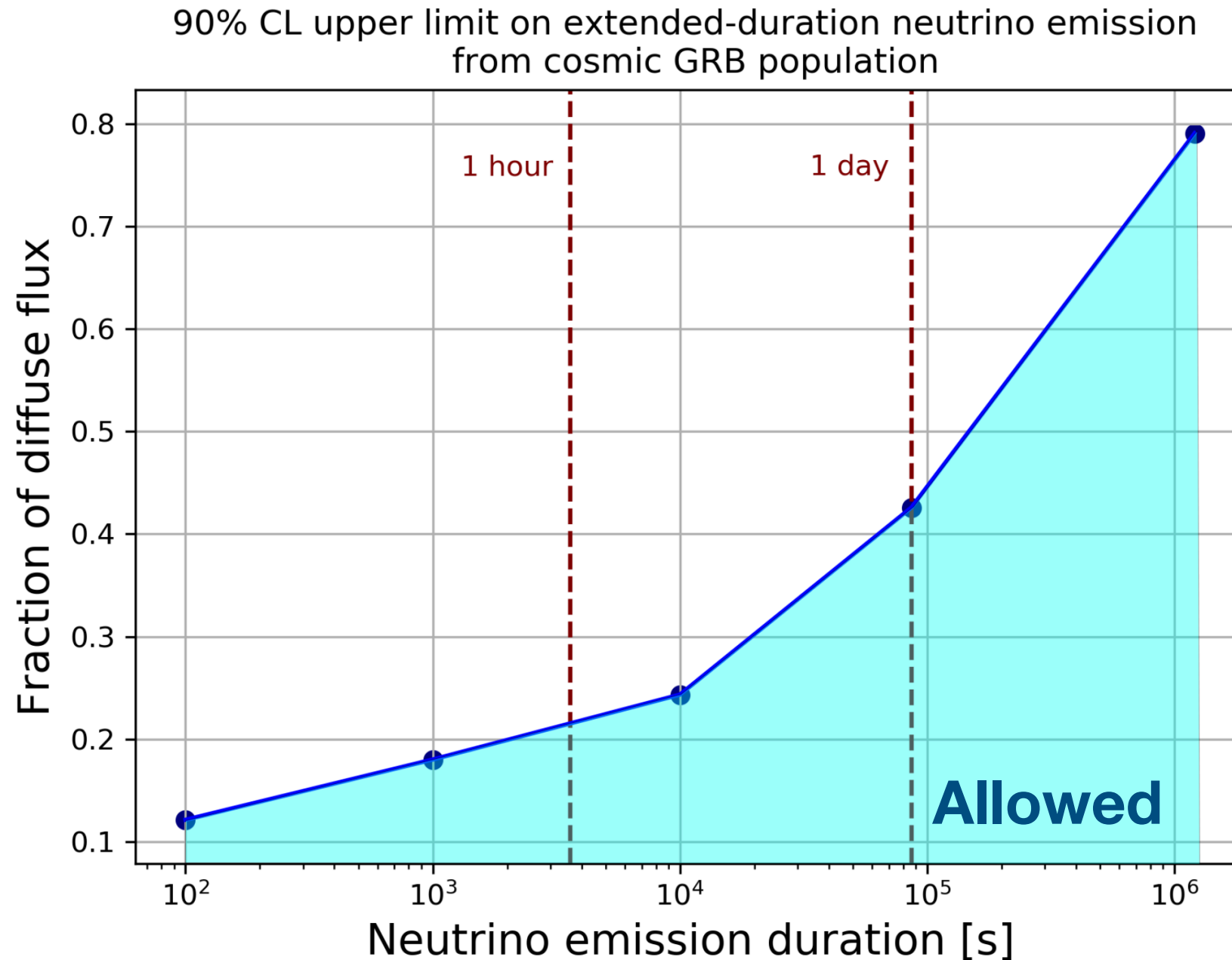
For simulations with Lien et al. GRB population model, neutrino emission duration: 100s



For simulations with Lien et al. GRB population model, neutrino emission duration: 2 weeks



Limits on neutrino emission from cosmic GRB population



Since I have $p \sim 50\%$ for both precursor and afterglow results, the upper limits are the same for both the precursor and afterglow analysis.

Summary of results

- GRBs have long been considered as candidates for CR acceleration and neutrino production. Previous IceCube analyses did not find any evidence for emission from the prompt phase.
- After recent observations of gamma-ray emission up to hours after the prompt phase, we expand the search to include longer time windows.
- The analysis results are consistent with background expectation.
- For the first time, we constrain on extended timescales the contribution of the total long GRB population to the astrophysical neutrino flux. For emission on prompt timescales and up to a few hours after, the constraint is 10-25% of the total diffuse flux.
- The unblinded results were presented at the 37th International Cosmic Ray Conference 2021 ([PoS\(ICRC2021\)1118](#)).
- We are working on a paper to summarise the results together with a data release.

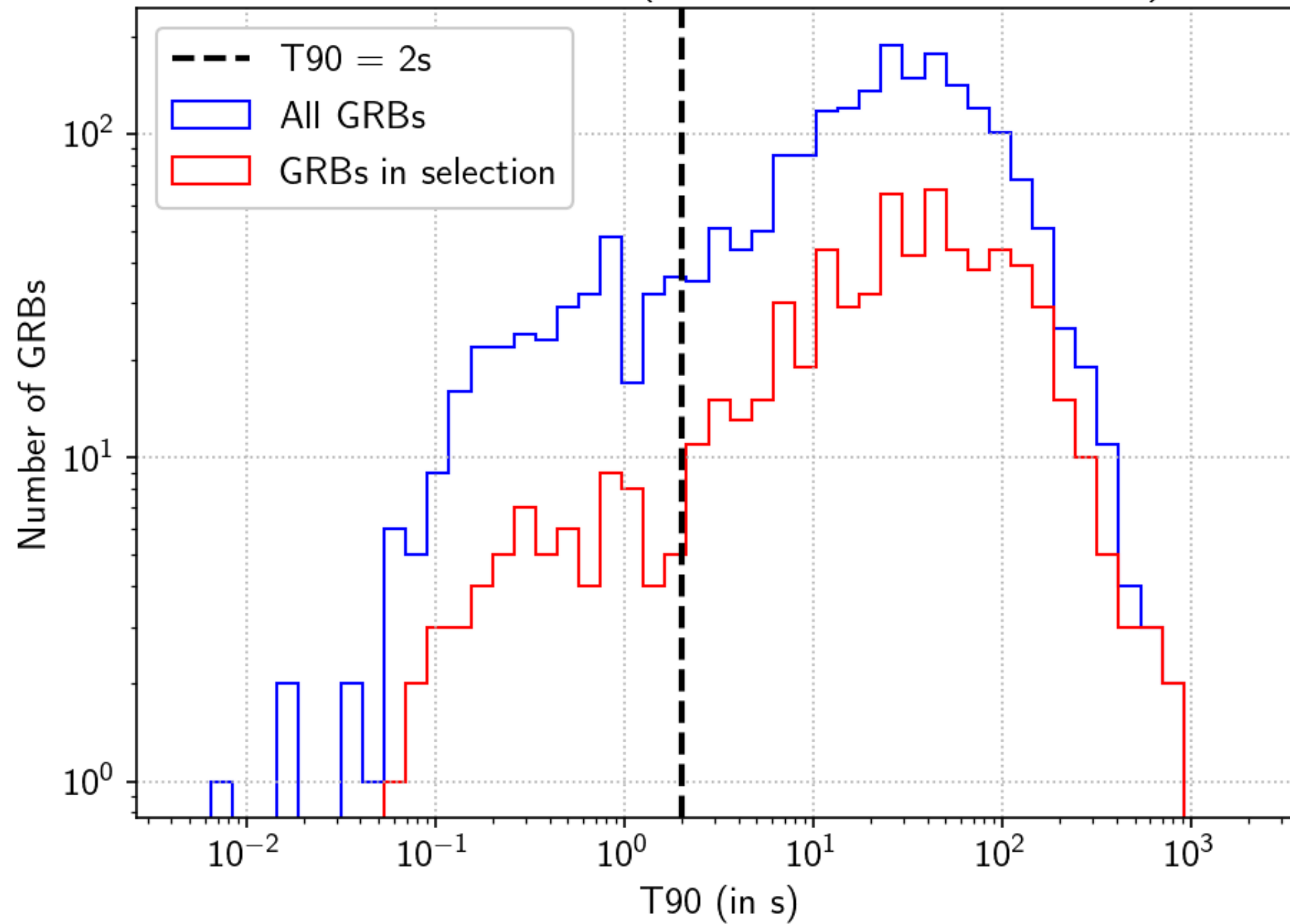
Thank you!

Backup slides

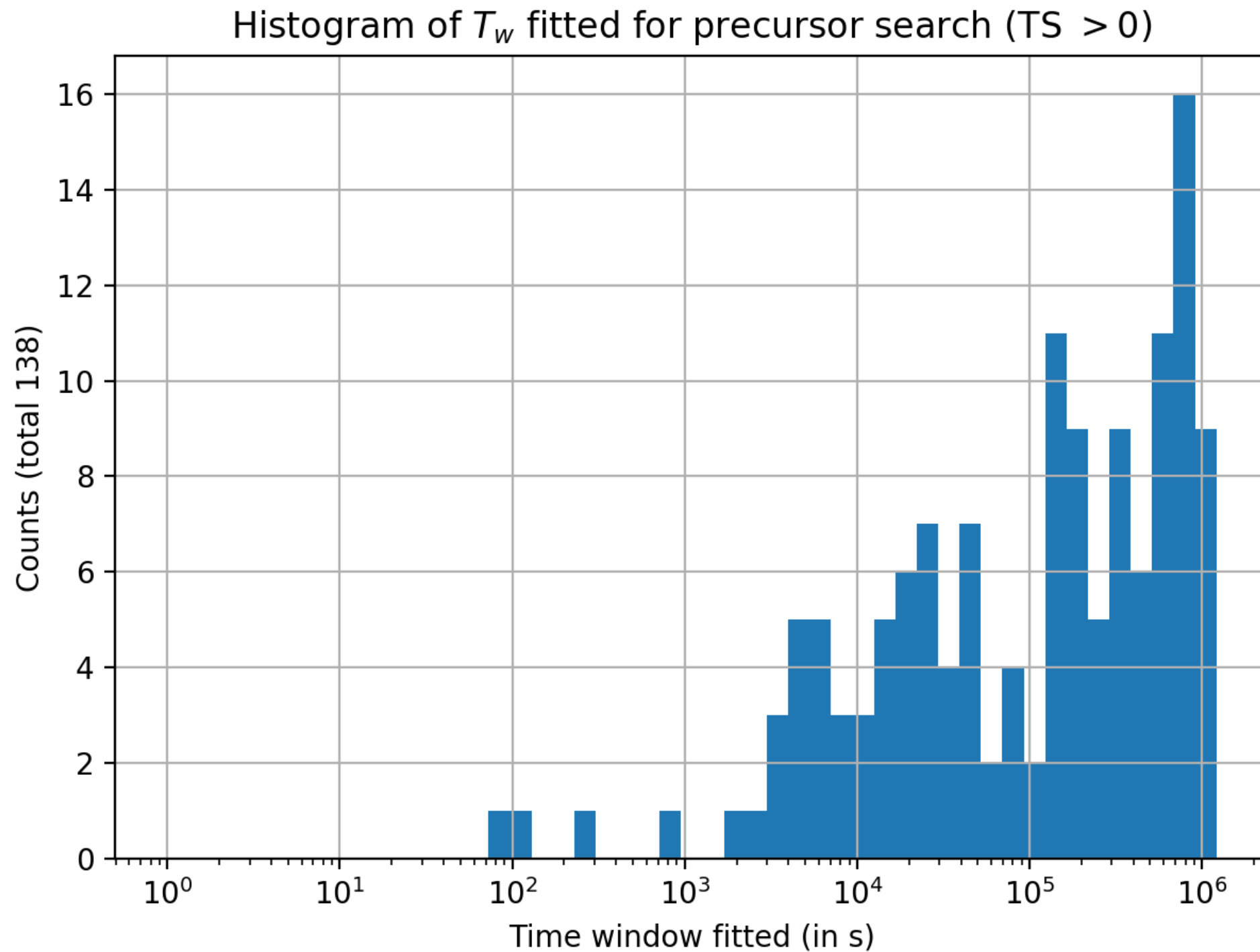
Total GRBs in selection: 733

	Known fluence	Known T90	Short GRBs	Long GRBs
GRBs in selection	690	680	66	614
Swift	614	620	64	556
Fermi GBM	289	289	32	257
Fermi GBM only	60	60	2	58
Swift+Fermi GBM	229	229	30	199

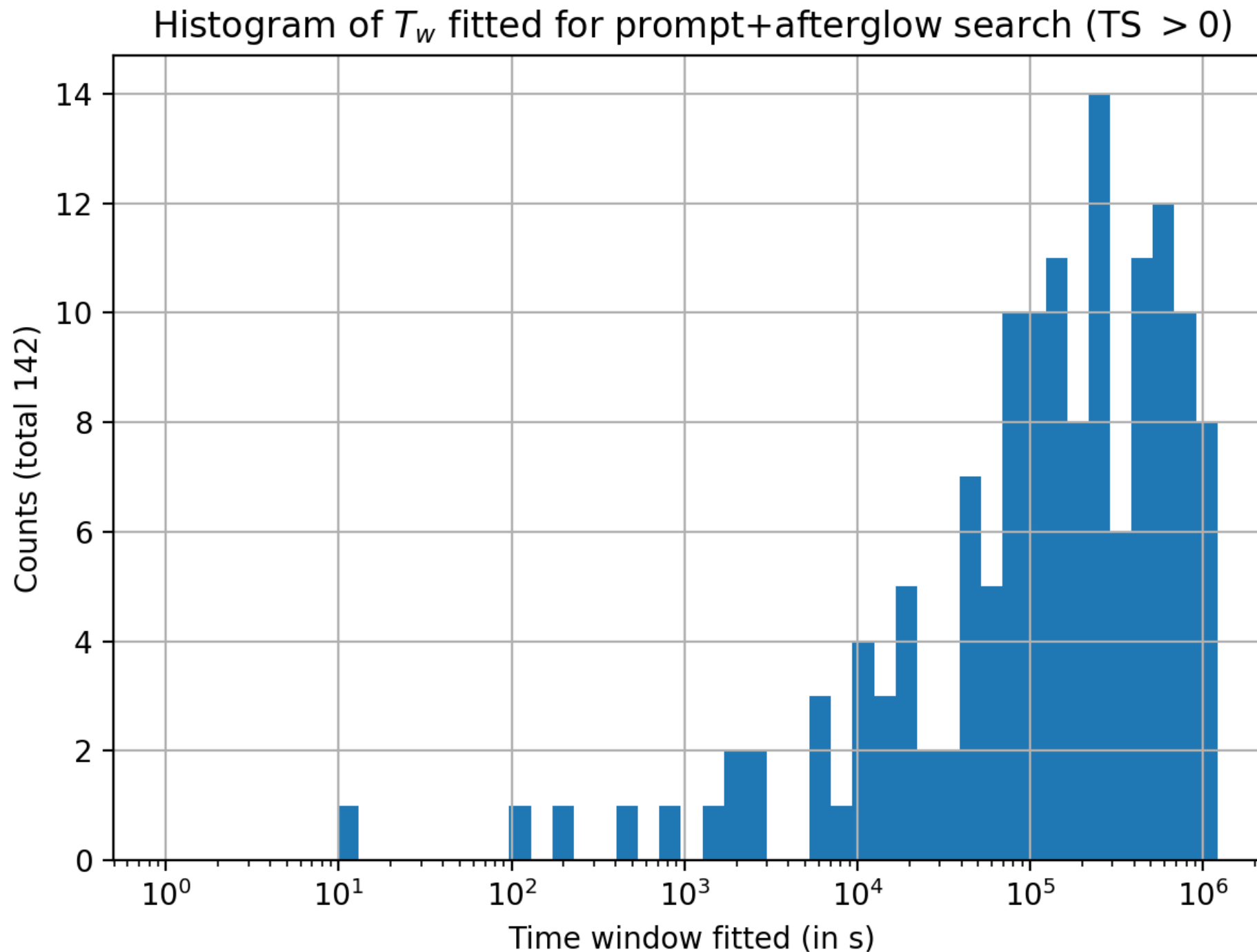
Histograms of T90 (cases where T90 is known)



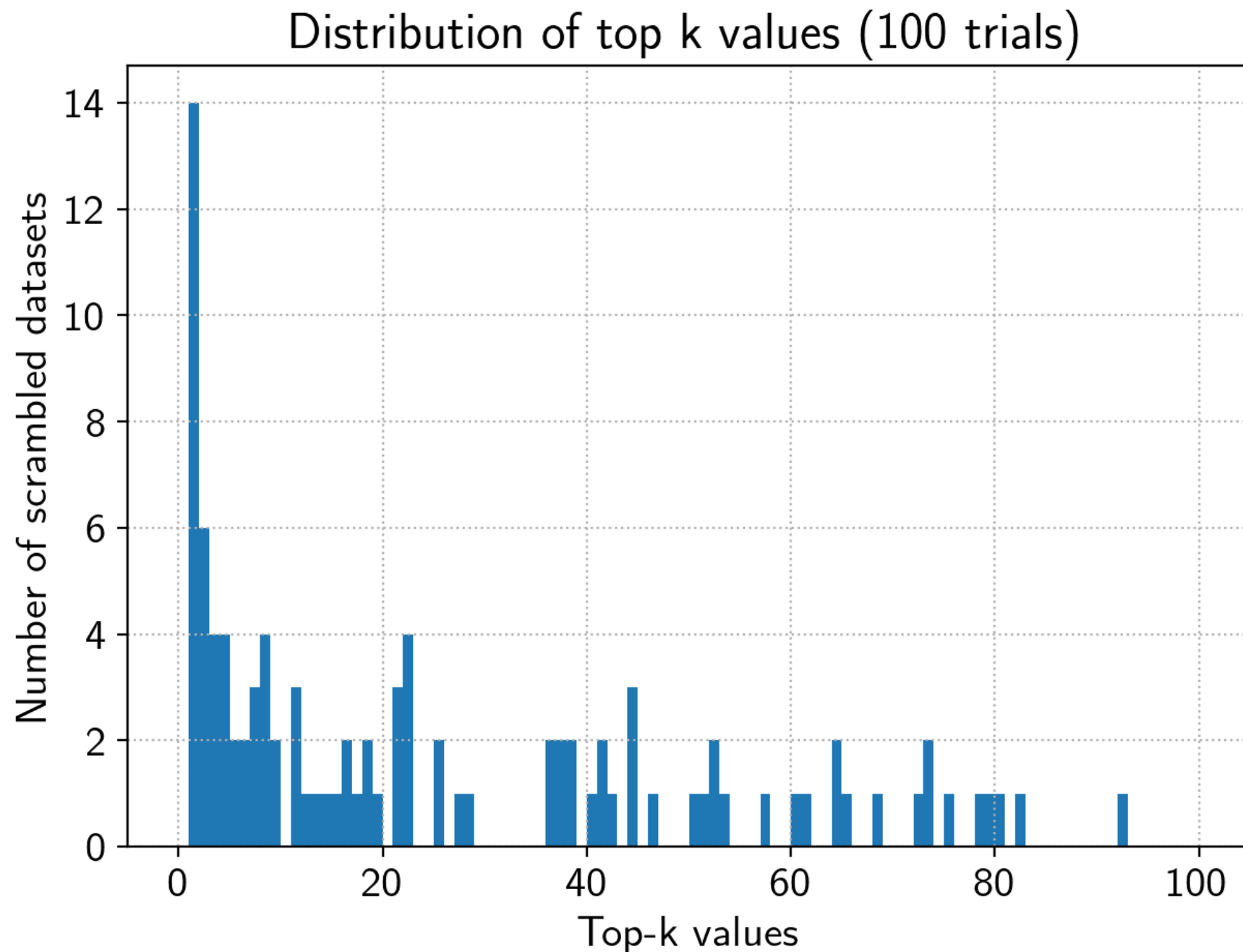
Distribution of T_w fitted for the Precursor result



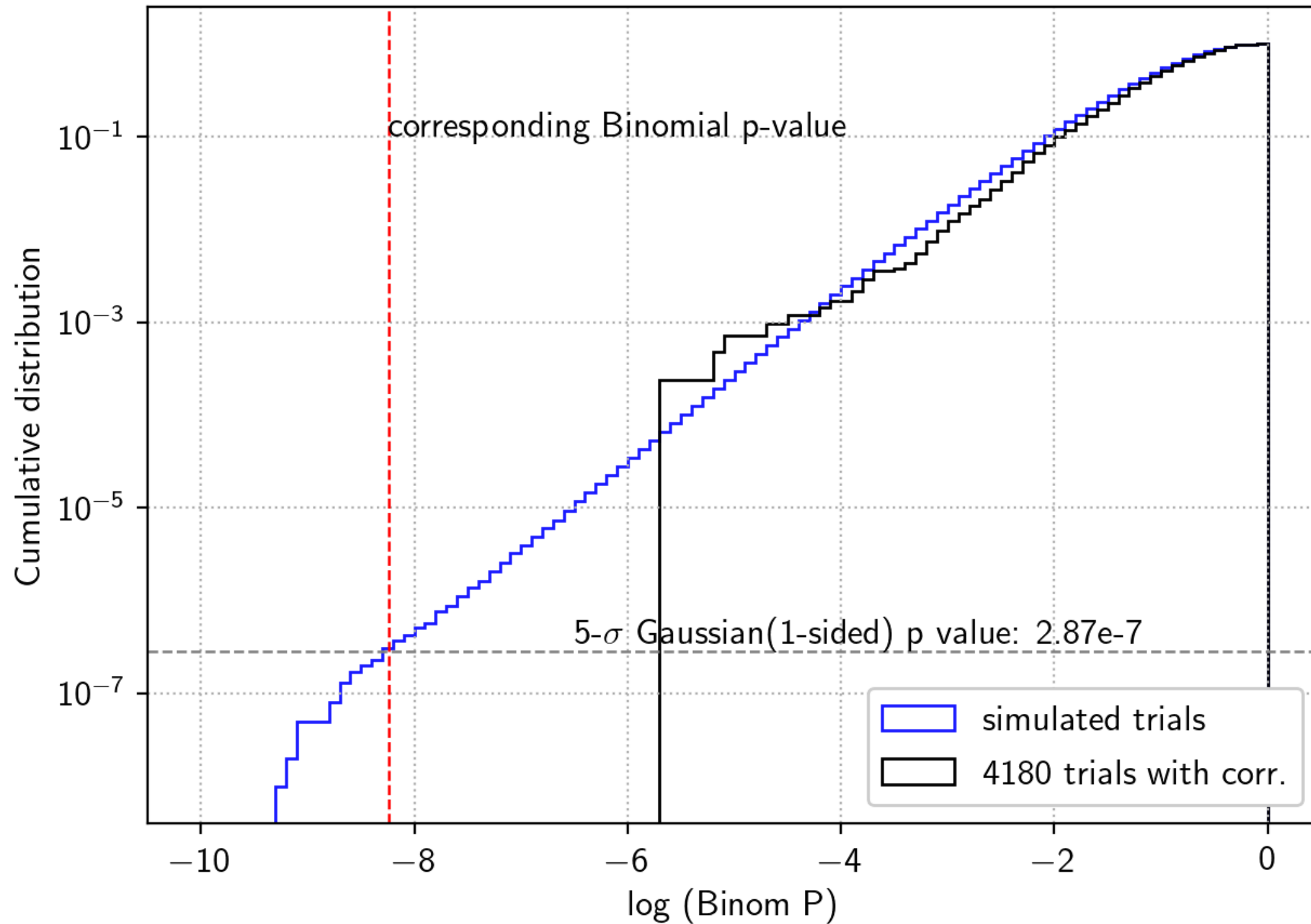
Distribution of T_w fitted for the Prompt+Afterglow result



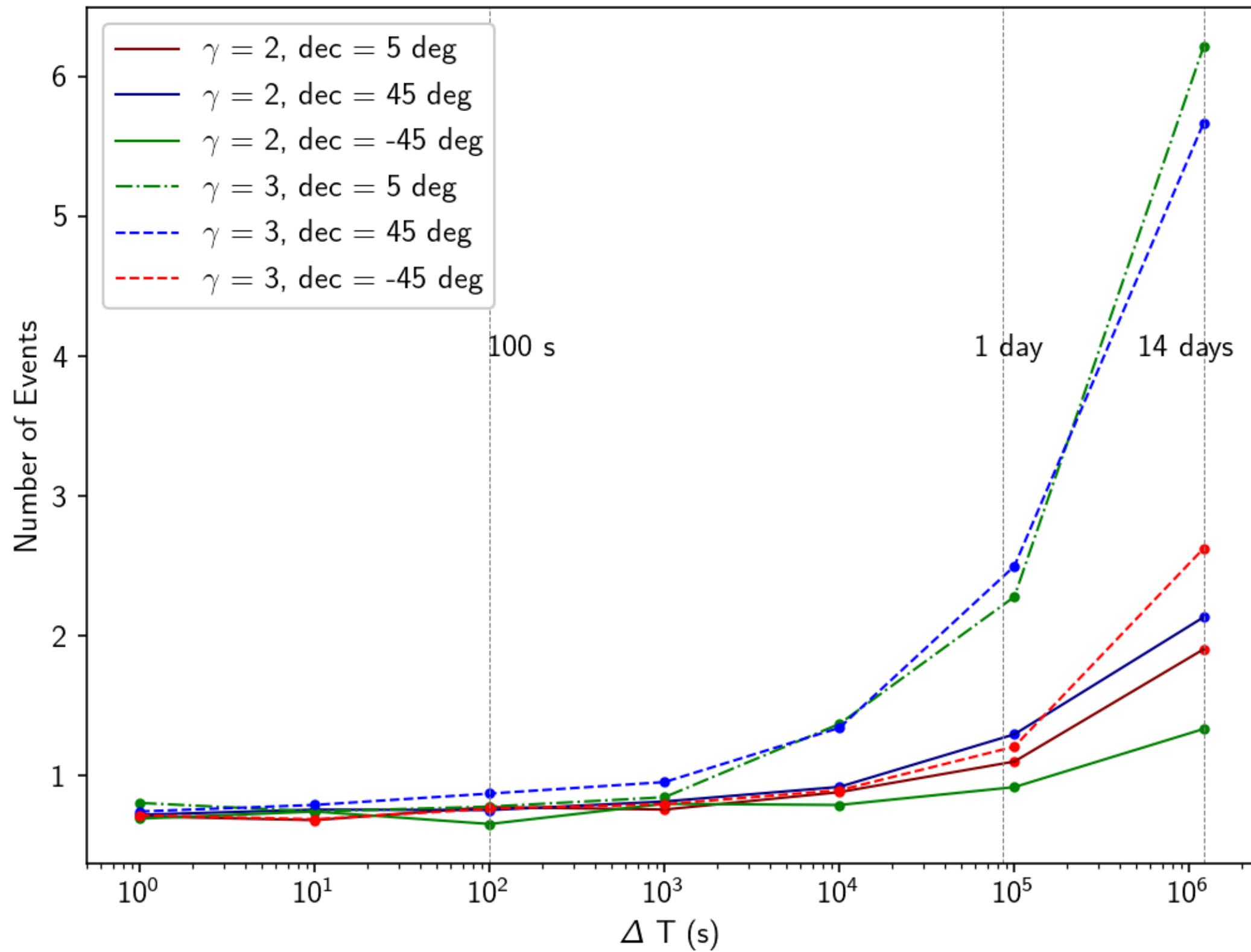
Distribution of top k values obtained from 100 scrambled datasets

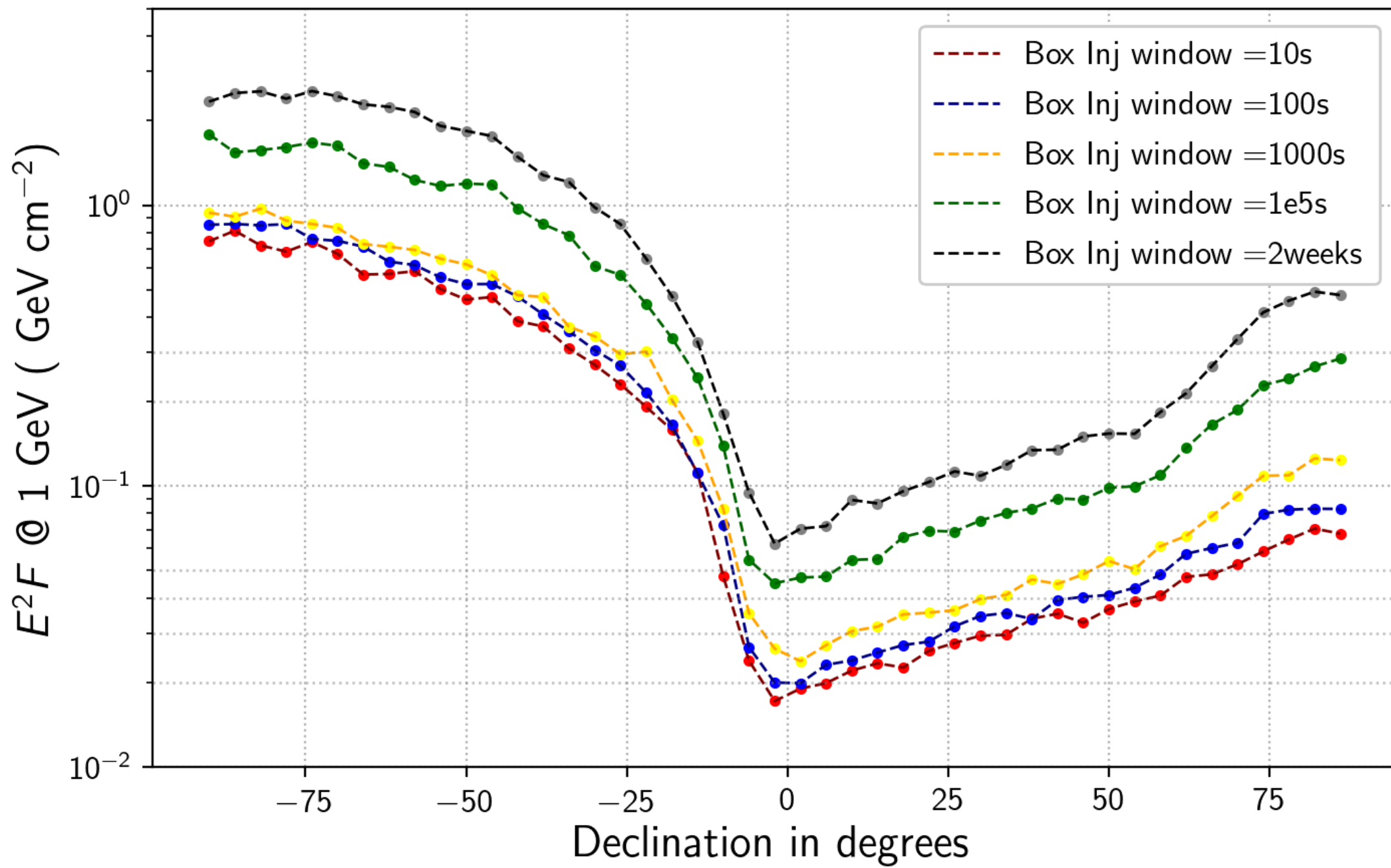


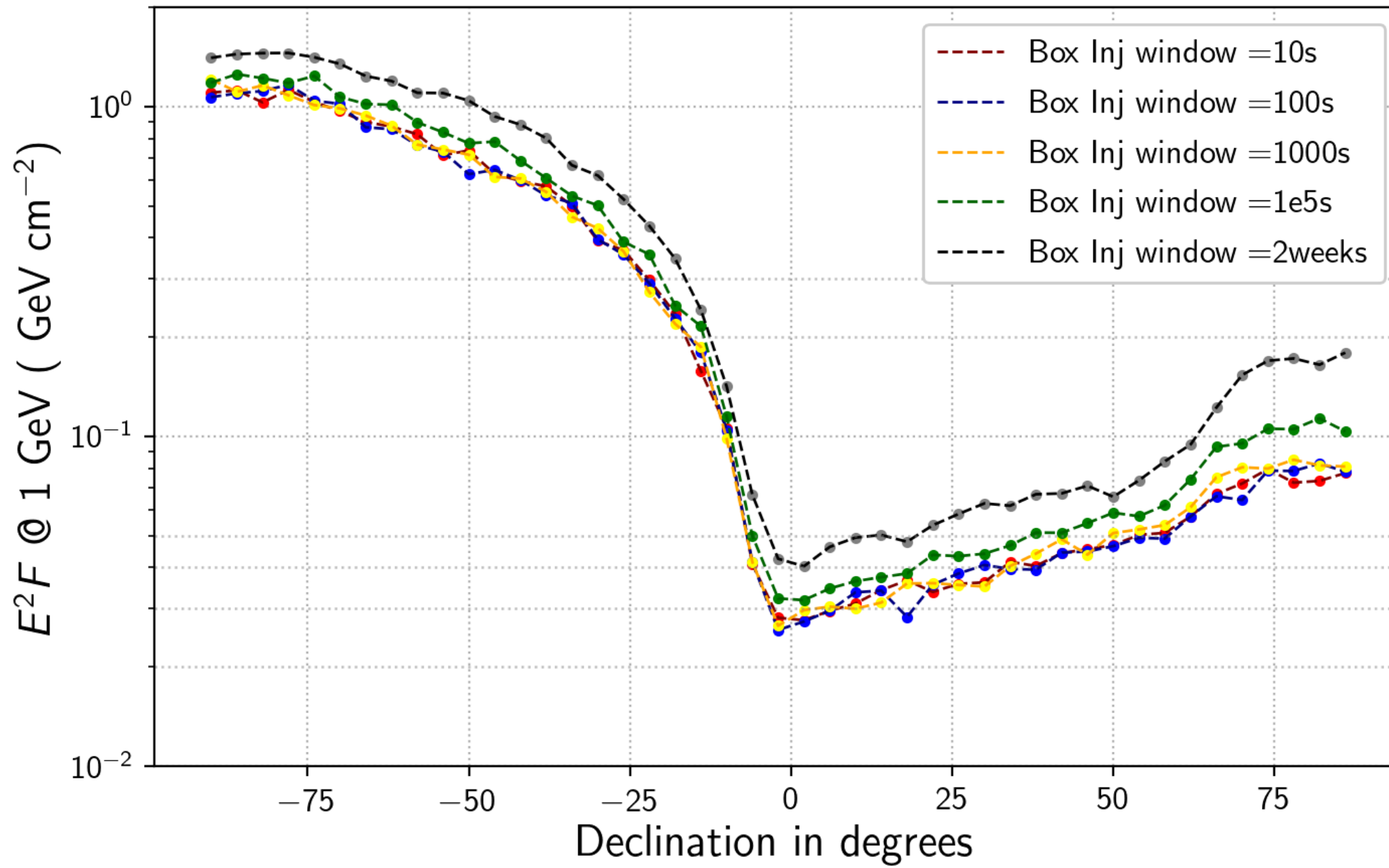
Simulated trials to estimate 5- σ cutoff

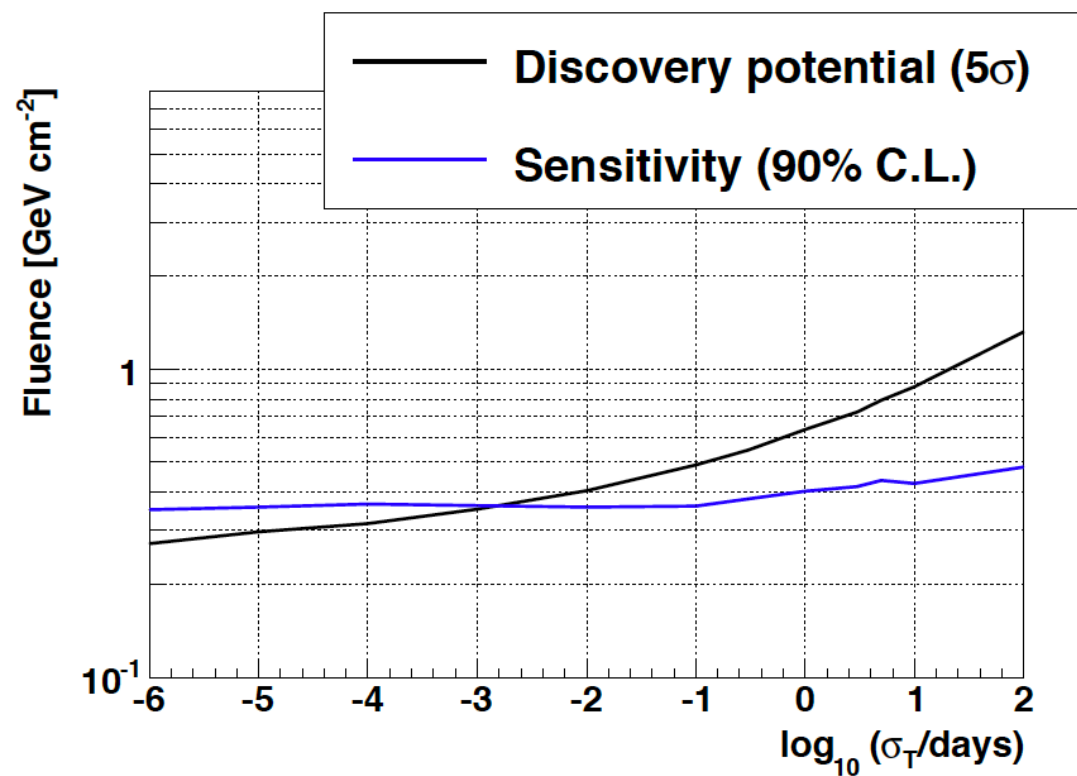


Discovery potential for 2- σ , GFU data

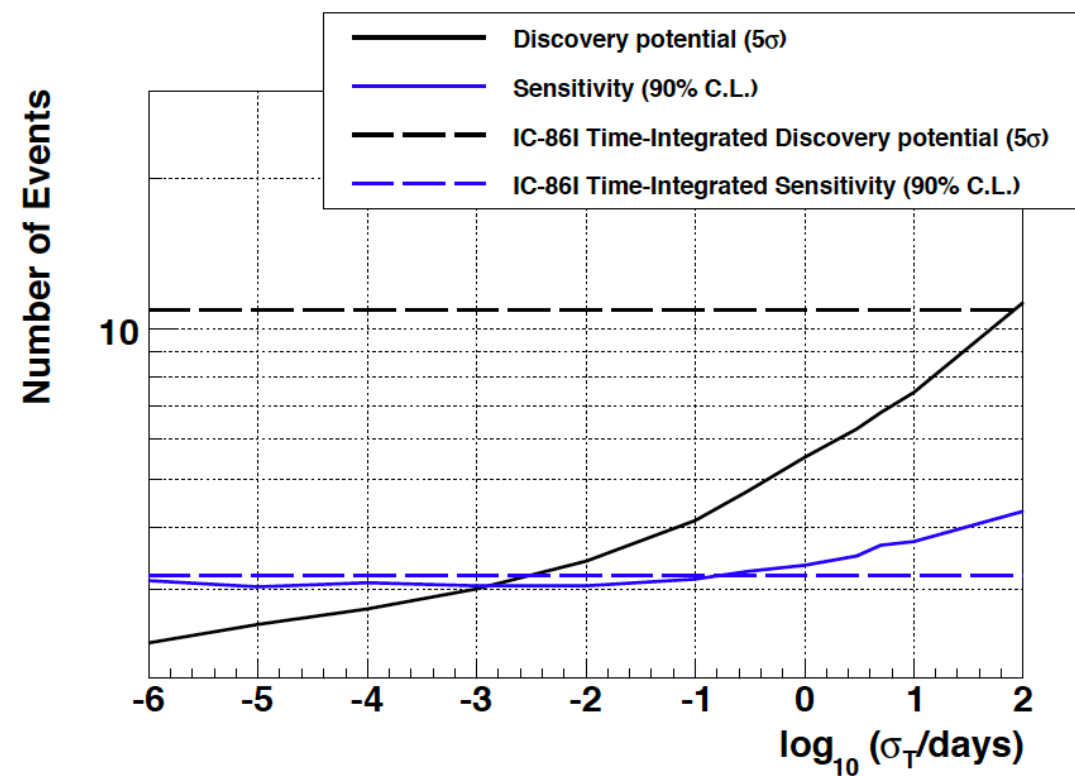








(a)

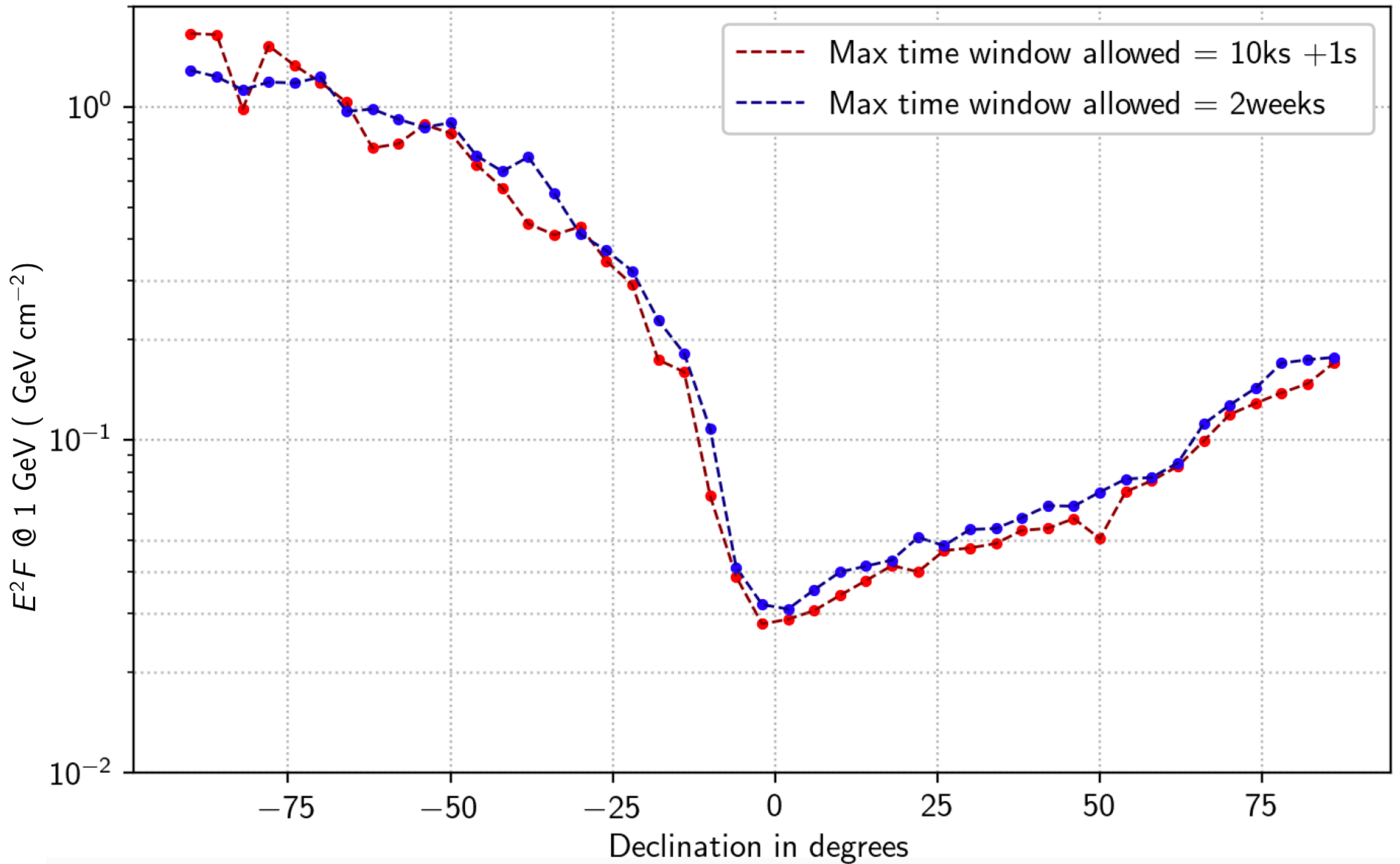


(b)

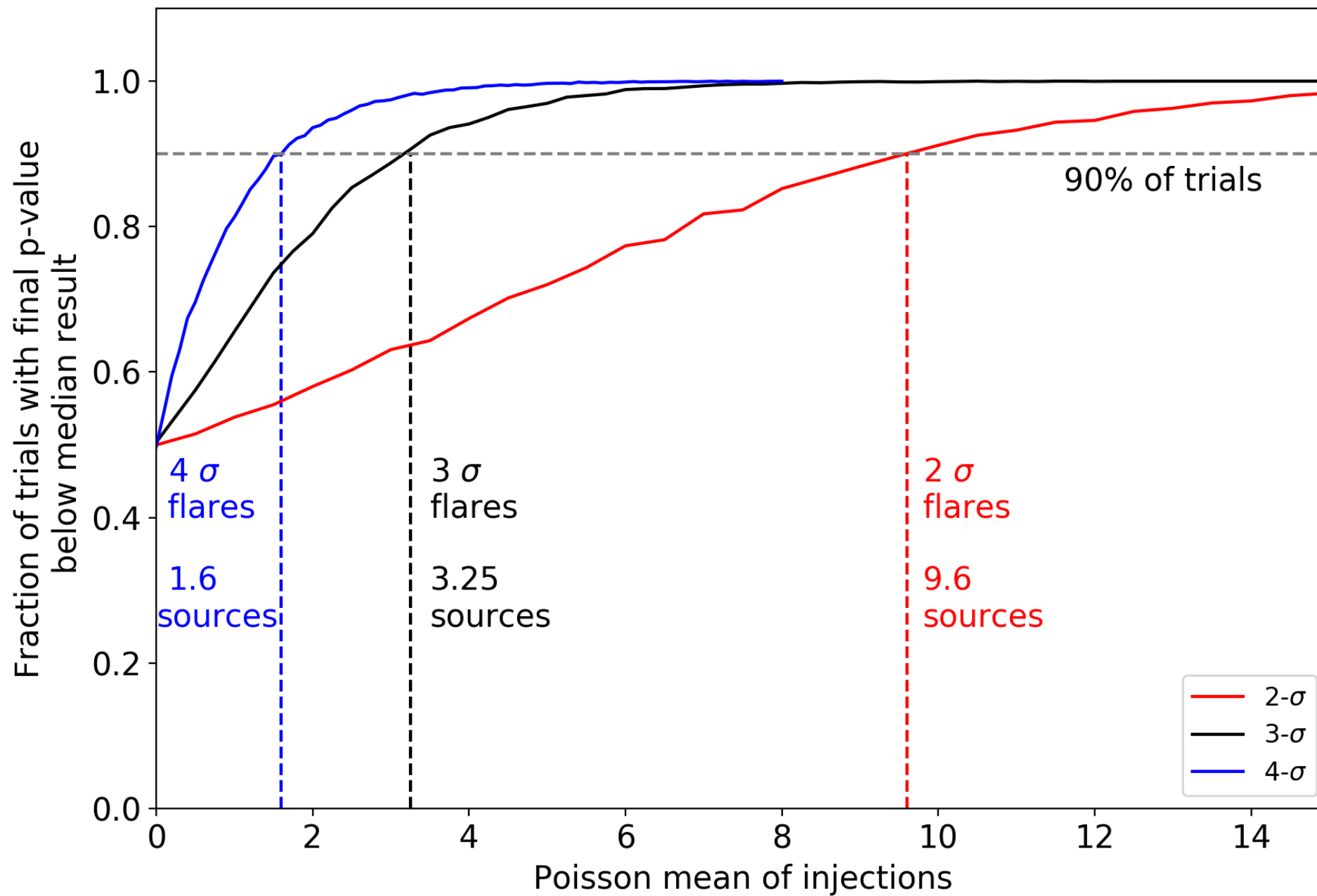
Figure 1: The 5σ discovery potential (signal required for 5σ detection in 50% of trials) and the sensitivity (90% CL median upper limit) for IC-86I shown in terms of the fluence (a) and the mean number of signal events (b) for a fixed source at $+16^\circ$ declination (solid lines) with an E^{-2} spectrum. The corresponding lines for the time integrated search are also shown. The time dependent search improves over the time integrated for flaring sources when solid lines become lower than dashed ones.

Ref: arXiv:1503.00598v2

5- σ Discovery Potential for all sky, $\gamma = 2$, GFU, Box Inj window = 10ks



Sensitivity



- Since my p-values are ~50%, this is approximately my upper limit as well.