Where There's a Wave, Bayestar leads the way
Rapid Sky Localization of Gravitational Wave

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Abstracts

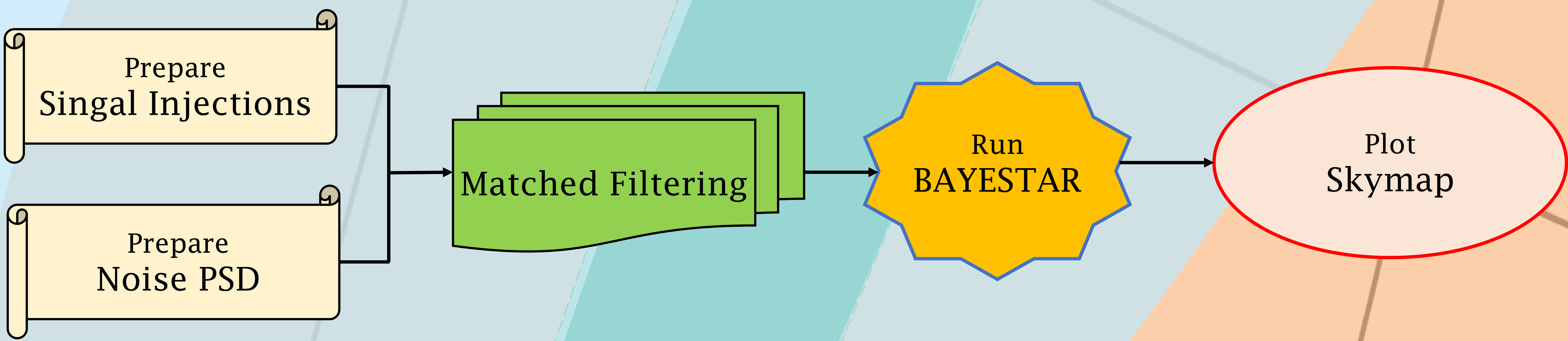
Low-latency searches are crucial for Multi-Messenger Astronomy (MMA), where gravitational waves help us to quickly locate where events happened and promptly inform other telescopes to conduct follow-up observations. Gravitational waves, like ripples in space and time, are generated by the mergers of massive compact binaries such as binary black holes, binary neutron stars, and neutron star-black hole binaries. These waves propagate outwards from the events. They could be detected by the observatories (Ligo, Virgo, and KAGRA) when they reach Earth. This study uses the rapid Bayesian sky localization tool **Bayestar** to analyze gravitational wave events originating from **Binary Neutron Star (BNS) events, GW170817.** We aim to investigate the impact of using data from **different gravitational wave detector network configurations** on the precision of sky localization.

Introduction

GW170817, observed on August 17, 2017, by the LIGO (hereafter L) and Virgo (hereafter V) observatories, was the first detected gravitational wave event originating from a binary neutron star (BNS) merger. A short gamma-ray burst (GRB 170817A) was detected just 1.7 seconds after the gravitational wave signal. This simultaneous detection provided compelling evidence that binary neutron star mergers produce short gamma-ray bursts in the same case.

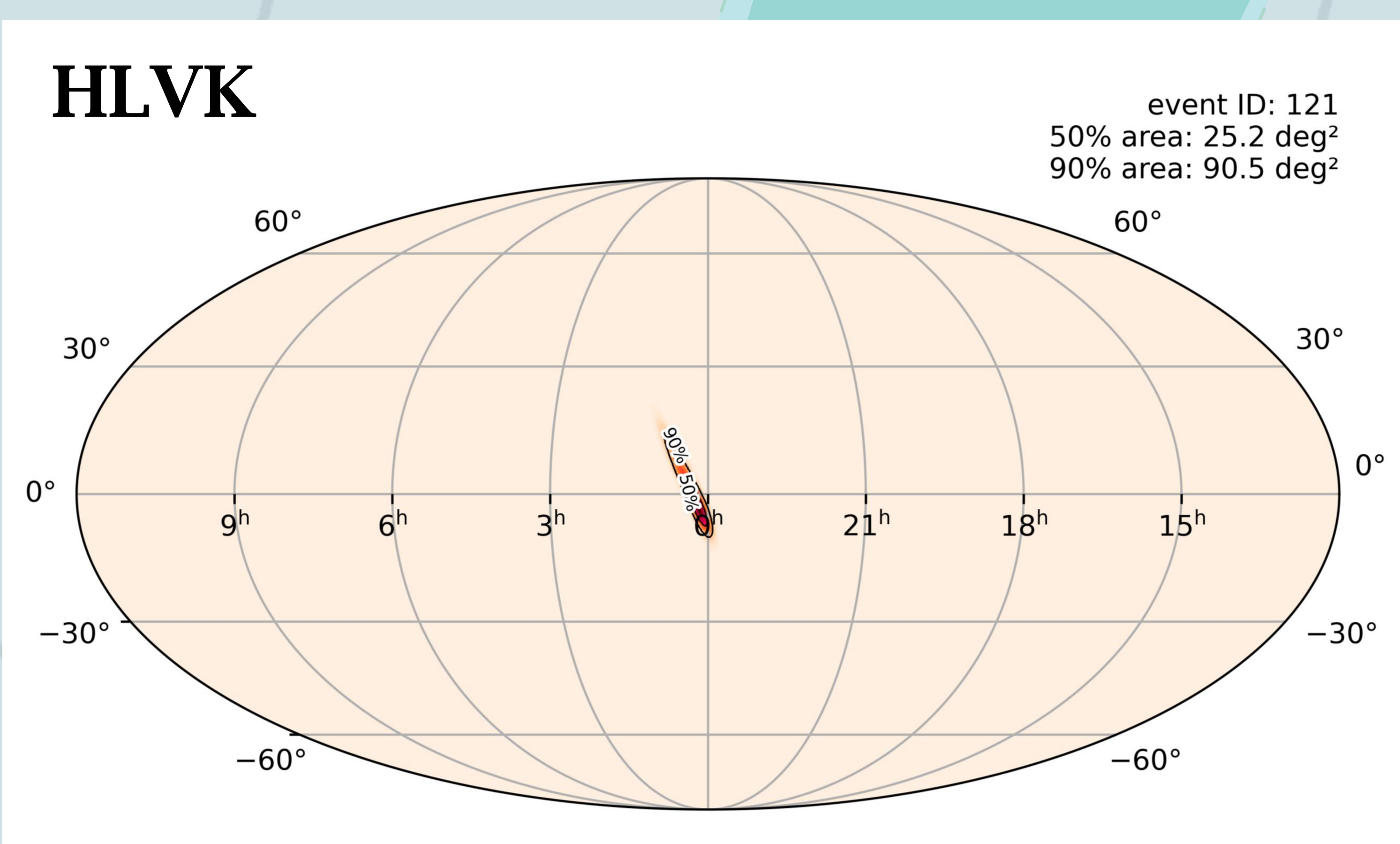
As Japan's KAGRA observatory (hereafter K) began operations only in 2020, it was not part of the GW170817 observation network. This naturally leads to the question: **How precise is the sky localization if we include KAGRA data for GW170817?** To investigate this, this study compares the sky localization precisely for the actual HLV network configuration with an HLVK network by generating sky maps of GW170817 using Bayestar. Bayestar is a rapid sky localization tool based on Bayesian inference, known for its low latency and non-Markov chain Monte Carlo approach.

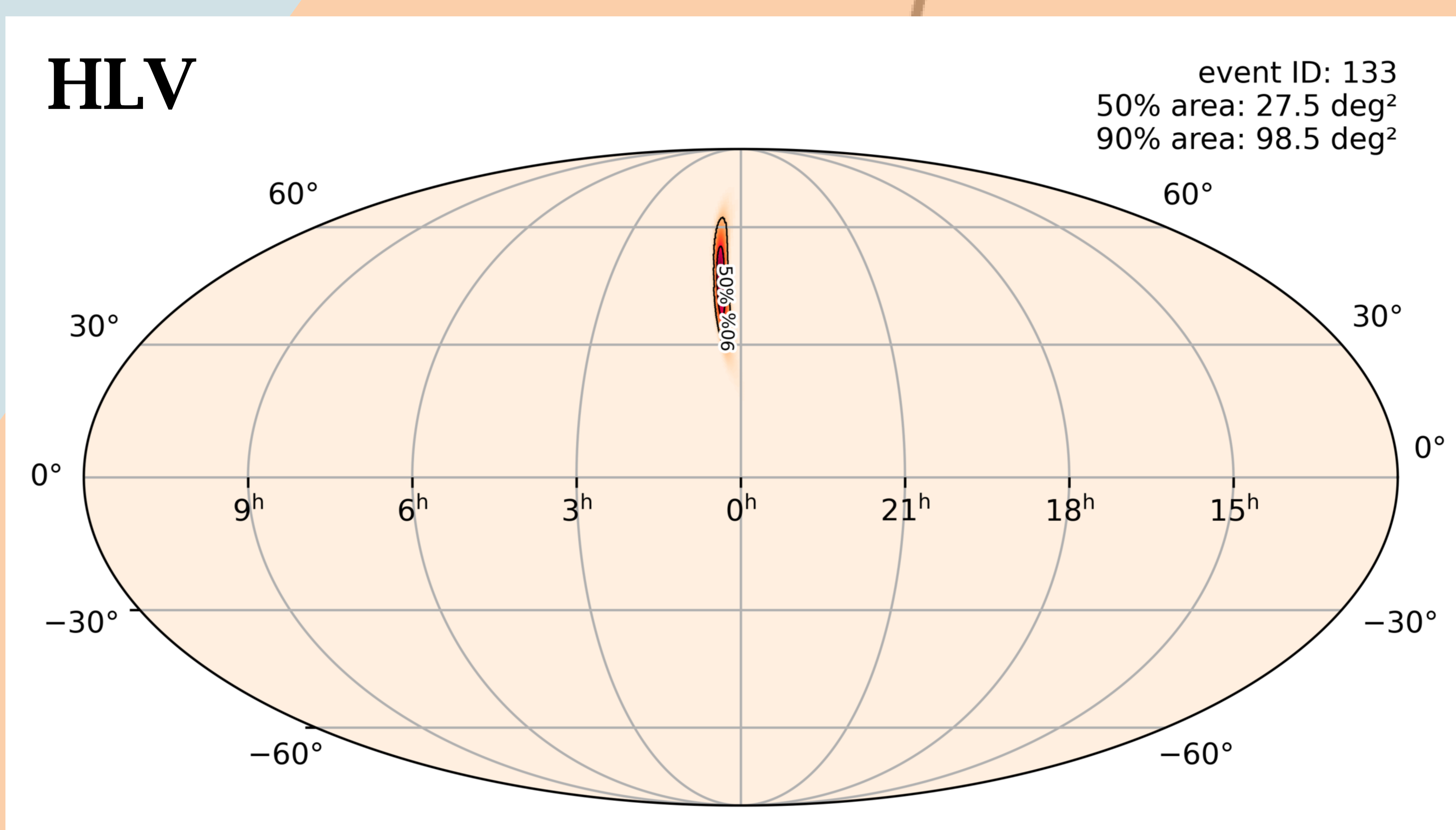
Method



The parameters for the signal injections were set to be consistent GW170817 event. For the noise PSD, the HLV detectors used the GPS time segment corresponding to the GW170817 event. The KAGRA detector used a segment from O3GK (GPS time from 1271415721 to 1271431257) to generate its noise PSD. Following matched filtering, used bayestar-localize-coincs tool to generate FITS files suitable for plotting and data analysis.

Result





Discussion

- We performed 200 events for each network (HLVK and HLV). 139 (HLVK) and 140 (HLV) of them passed the SNR threshold.
- ✓ For HLVK: Average 90% credible areas = 102.37 deg^2 , Average 50% credible area = 24.20 deg^2 (HLV). (HLV).
- ✓ For HLV: Average 90% credible areas = 111.30 deg^2, Average 50% credible area = 26.41 deg^2
- Example sky maps were selected from events with credible areas near these averages.

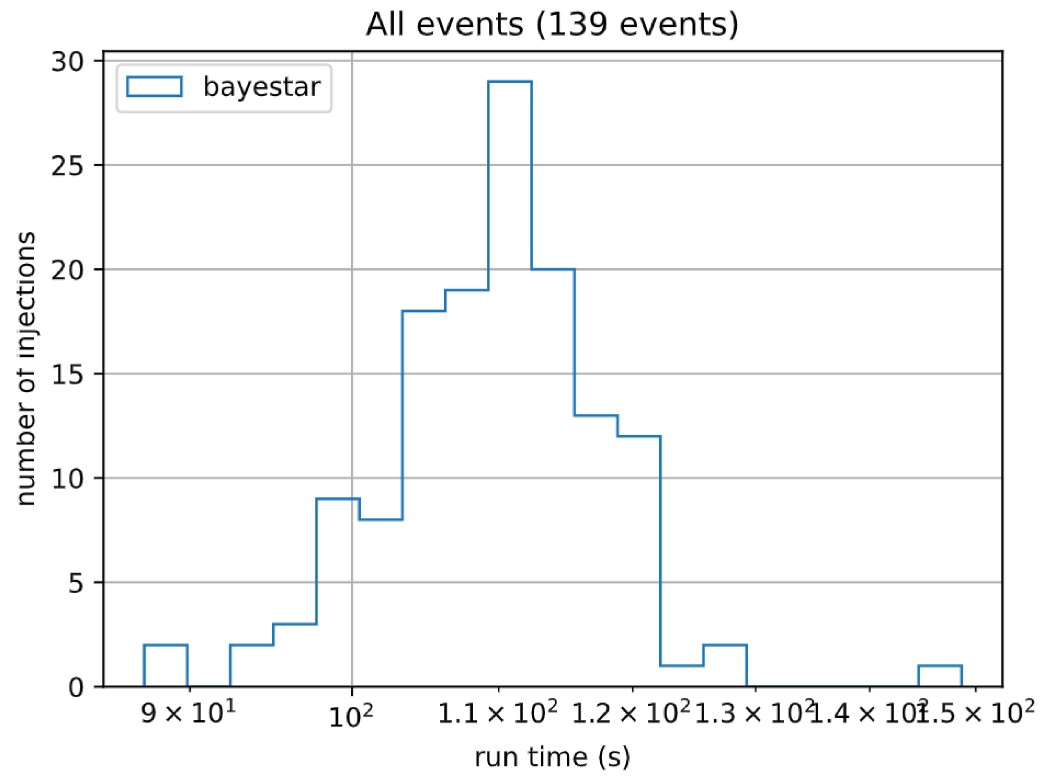
Conclusion

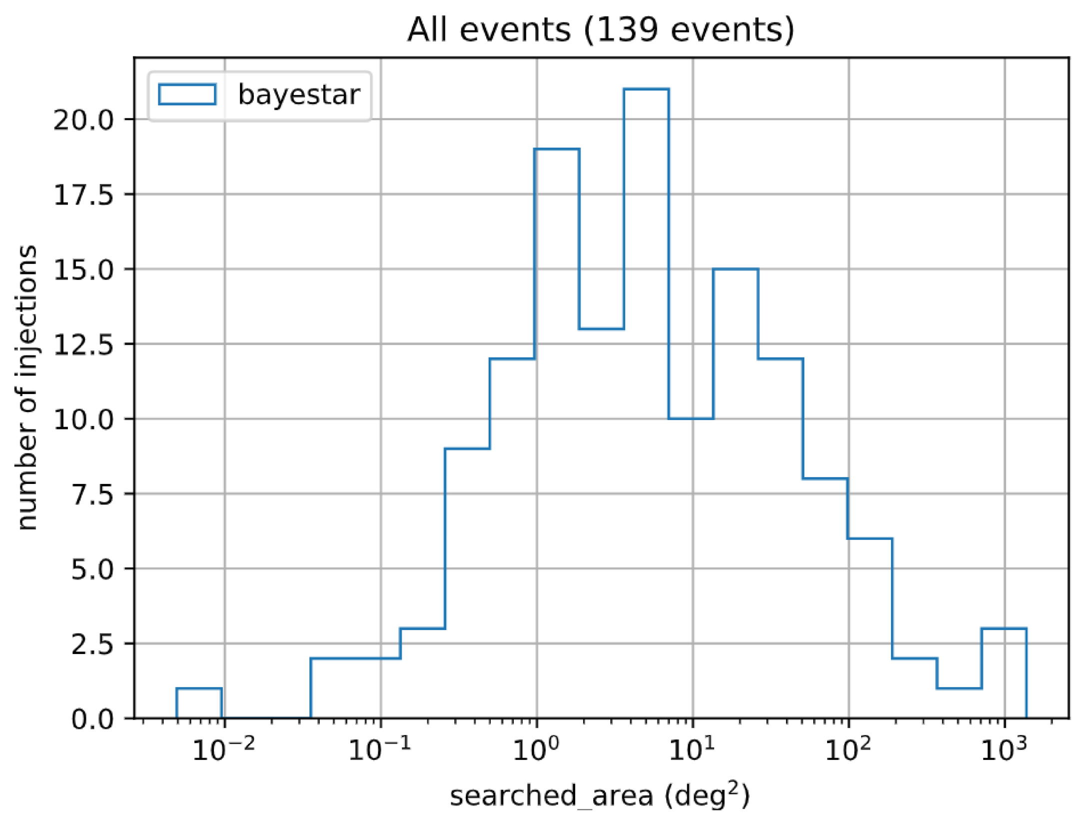
While HLVK showed slightly better performance in credible areas, the limited number of tested events (200) means the estimated accuracy and efficiency in this study are still not ideal. Testing more data may improve results.

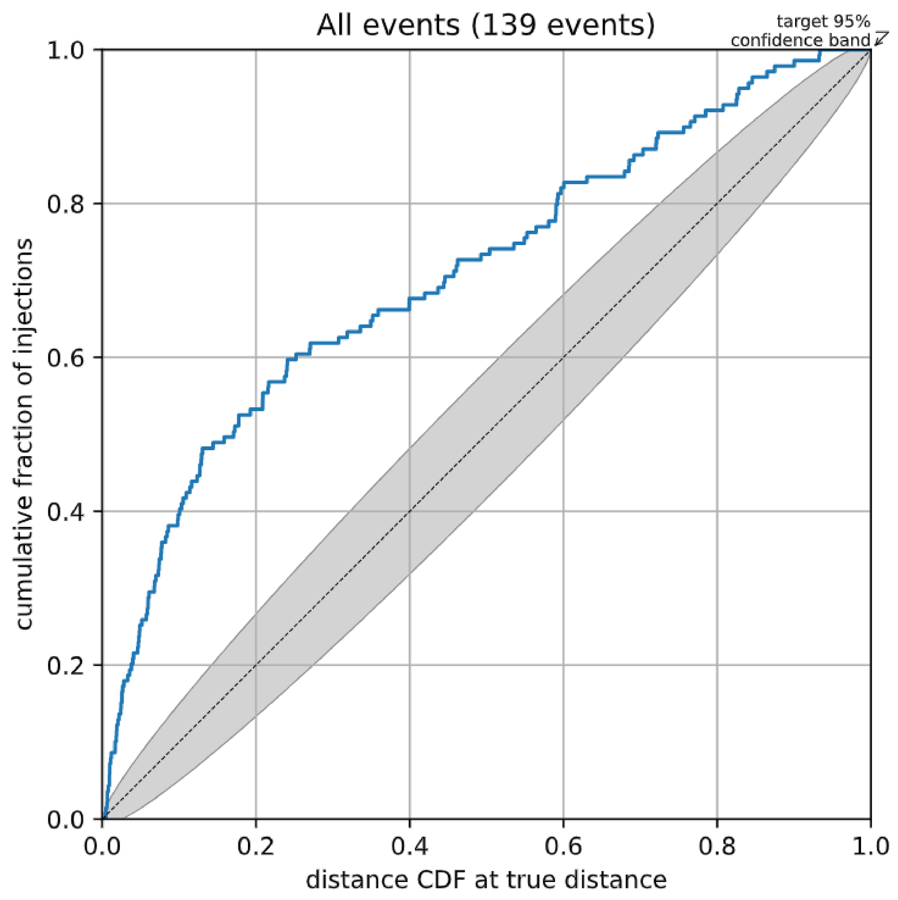
Reference

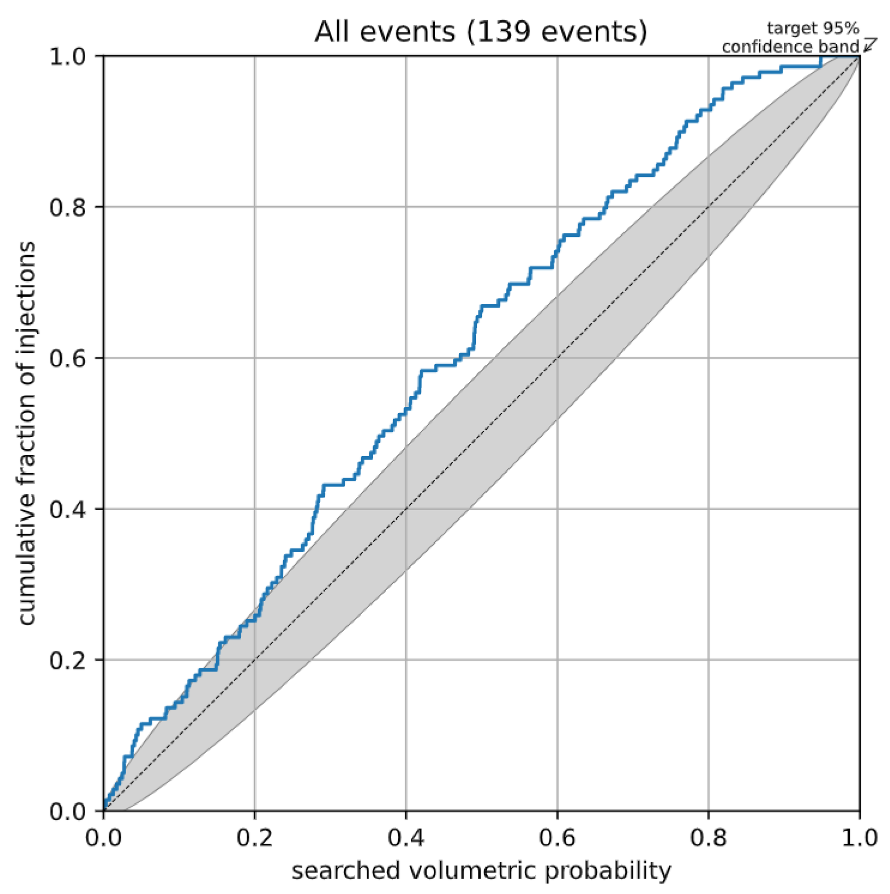
1. Abbott, B. P., Abbott, R., Abbott, T., Acernese, F., Ackley, K., Adams, C., ... & Cahillane, C. (2017). GW170817: observation of gravitational waves from a binary neutron star inspiral. Physical review letters, 119(16), 161101.
   LIGO-Virgo Open Data - ligo.skymap Documentation, https://lscsoft.docs.ligo.org/ligo.skymap/index.html,2025
2. GW170817 Event Page, Gravitational-Wave Open Science Center (GWOSC), https://gwosc.org/events/GW170817/,2025
3. GW170817 Fact Sheet, LIGO/Virgo Collaboration, 2025

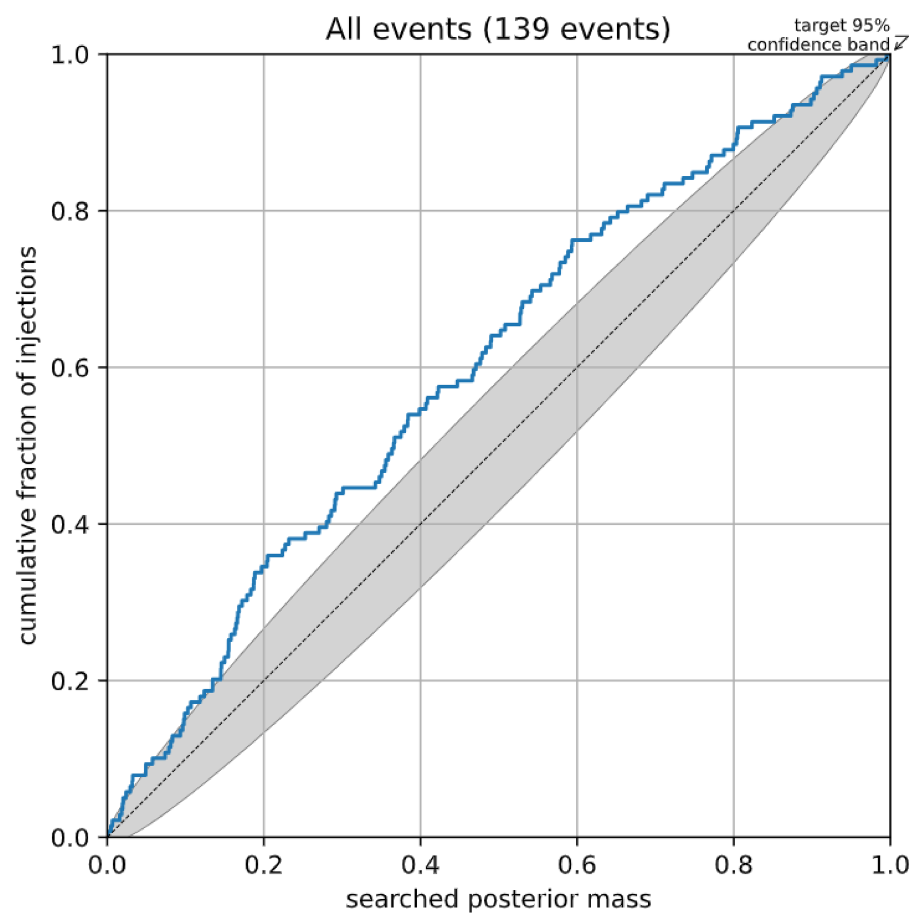
HLVK

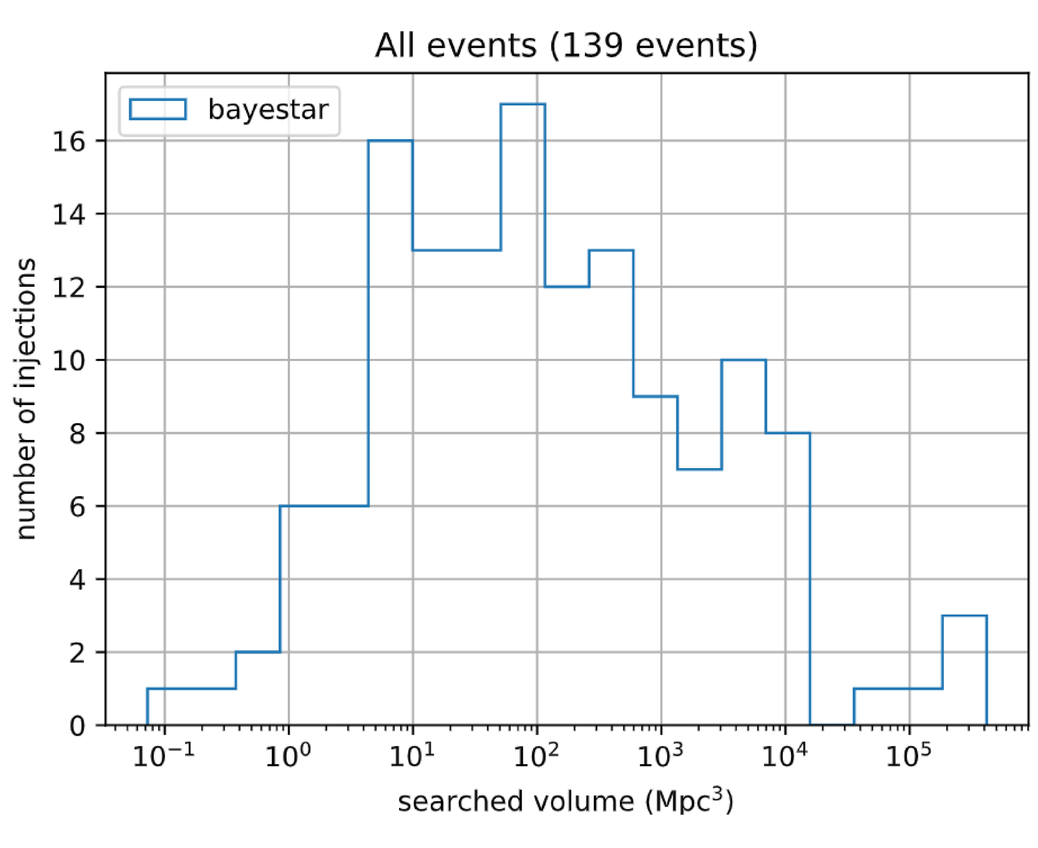

All events (139 events)
bayestar
number of injections
run time (s)


All events (139 events)
bayestar
number of injections
searched_area (deg^2)

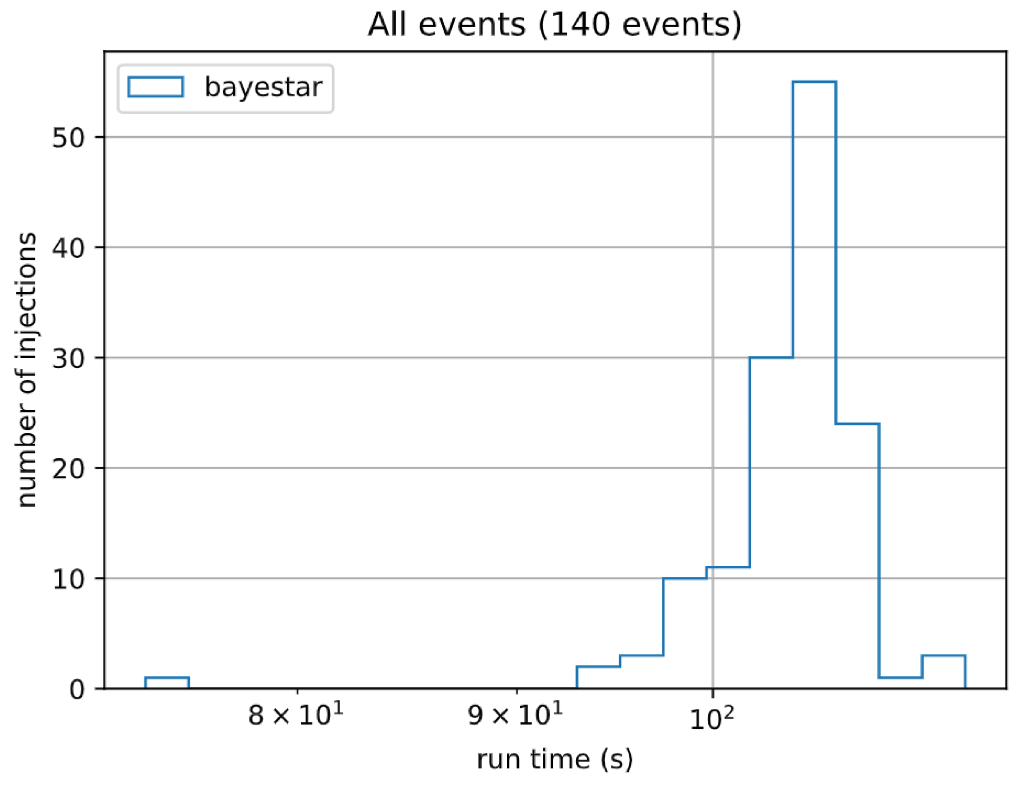

All events (139 events)
target 95% confidence band
cumulative fraction of injections
distance CDF at true distance

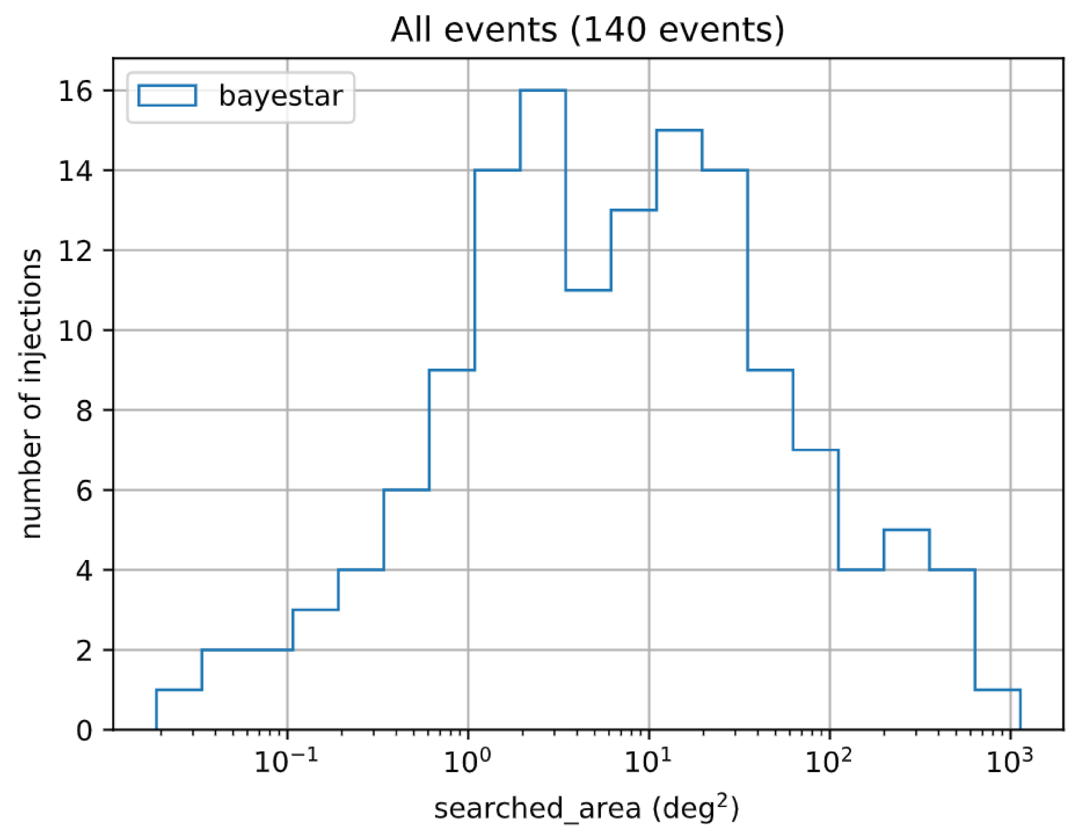

All events (139 events)
target 95% confidence band
cumulative fraction of injections
searched volumetric probability

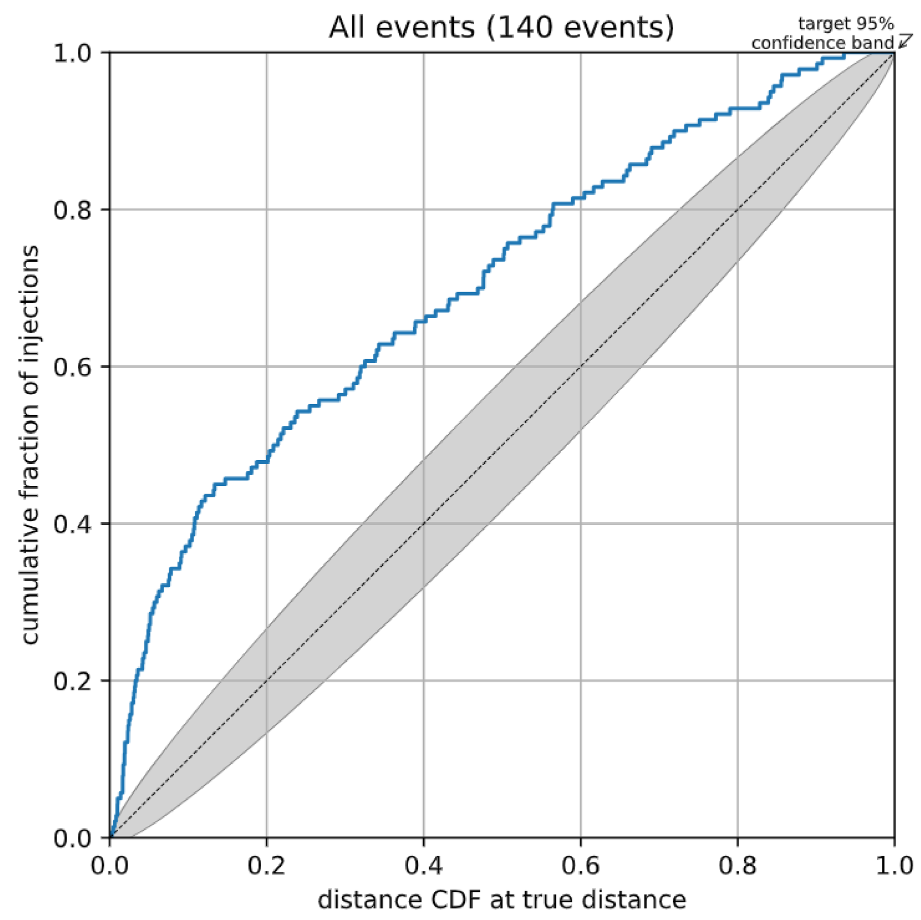

All events (139 events)
target 95% confidence band
cumulative fraction of injections
searched posterior mass


All events (139 events)
bayestar
number of injections
searched volume (Mpc^3)

HLV


All events (140 events)
bayestar
number of injections
run time (s)


All events (140 events)
bayestar
number of injections
searched_area (deg^2)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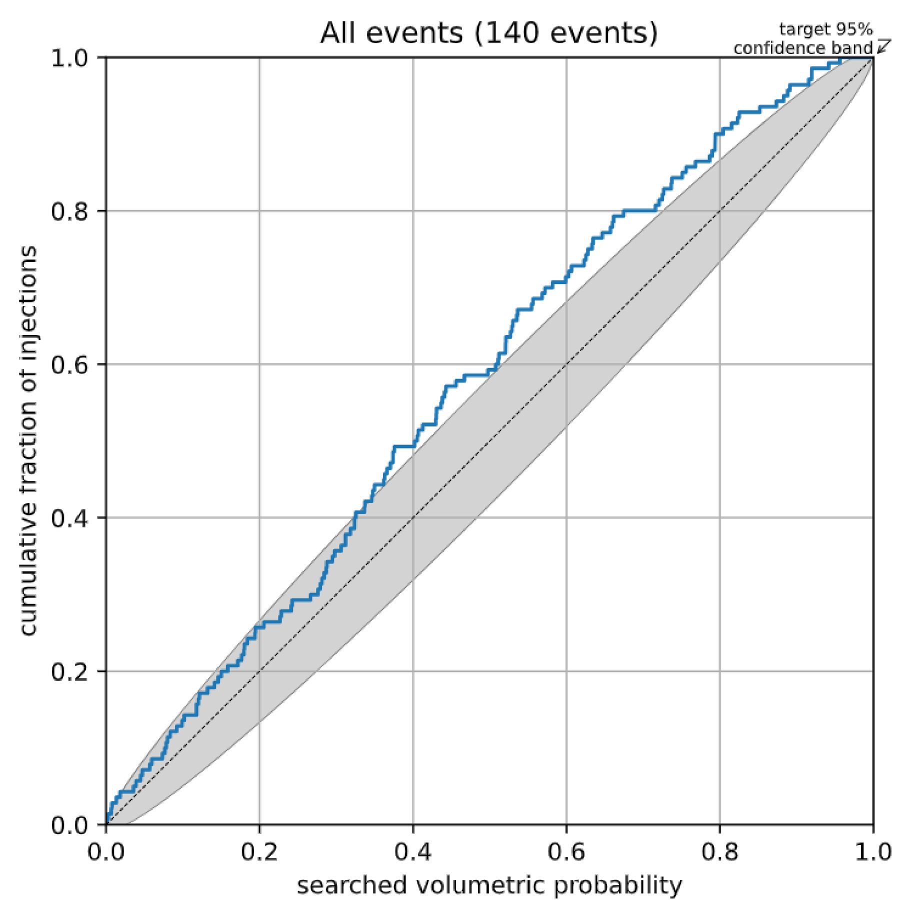
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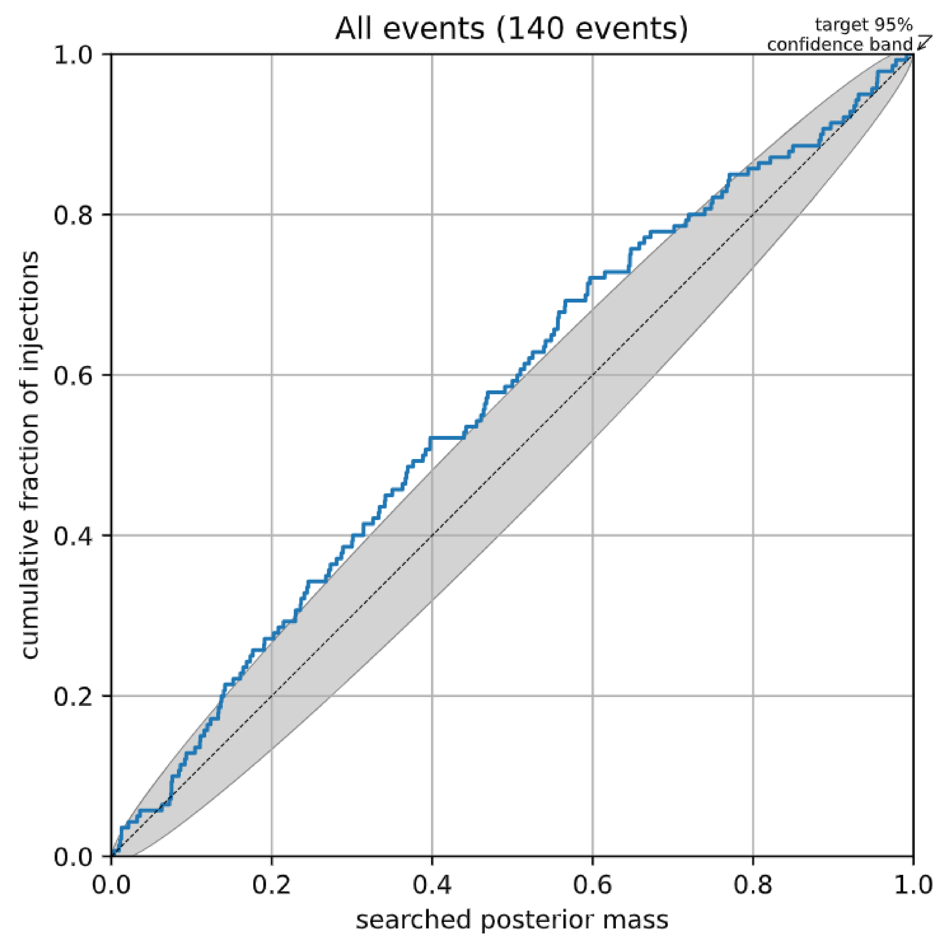
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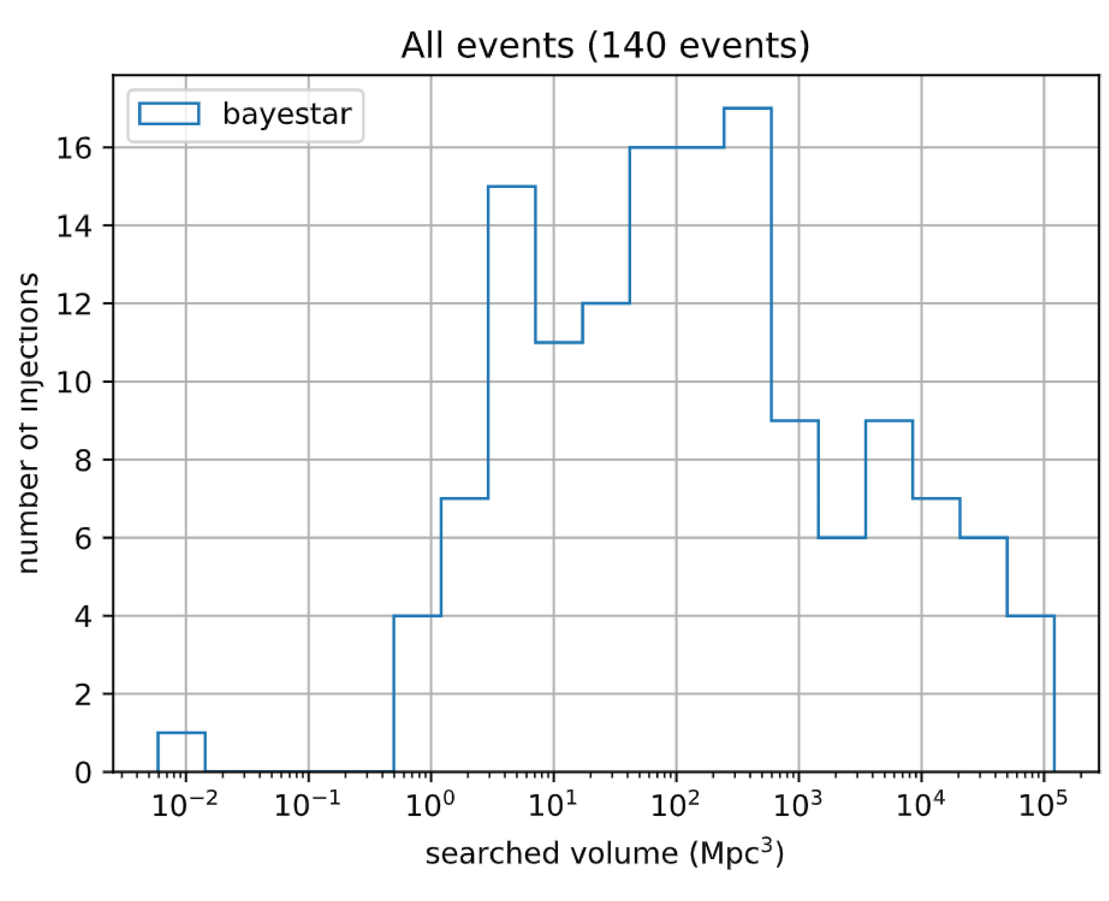
All events (140 events)
bayestar
number of injections
searched volume (Mpc^3)