Development of Non-Gaussian Noise Modeling System

DetChar Seminar

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Motivation

The presence of Non-Gaussian noise is known

from TAMA and LIGO experience

- Detector sensitivity may be limit by non-Gaussian noise
- Noise event at tail of distribution see like GW event

Quantitative modeling of gaussianity of detector noise

- Specifying time and frequency in bad gaussianity
- Narrow down the candidate of noise sources
- Make a list of non-Gaussian noise sources

developing monitor tool

These things will be progress in real time

during KAGRA Commisioning and Observation

Motivation

Understanding state of detector and surrounding environment

Use obtain information to detector and data analysis

For detector：Narrow down of noise sources

Early achievement to the target sensitivity

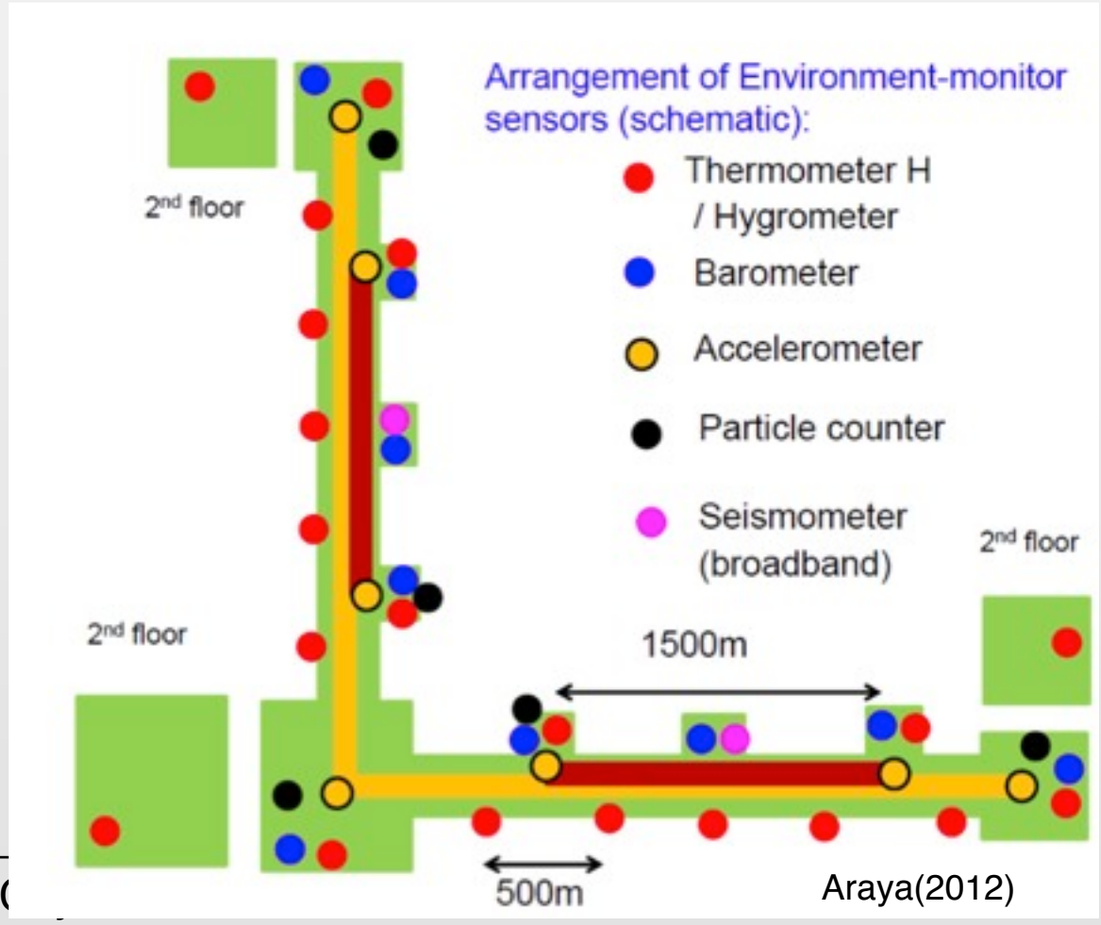
Contribution for stable operation

for analysis：Evaluating data quality

Usable／Un-usable

Stationary／Non-Stationary

Gaussian／Non-Gaussian



Araya(2012)

Example of Non-Stationarity Monitor

Result of Omega piplene

There are features of each nosise source in TF-plane

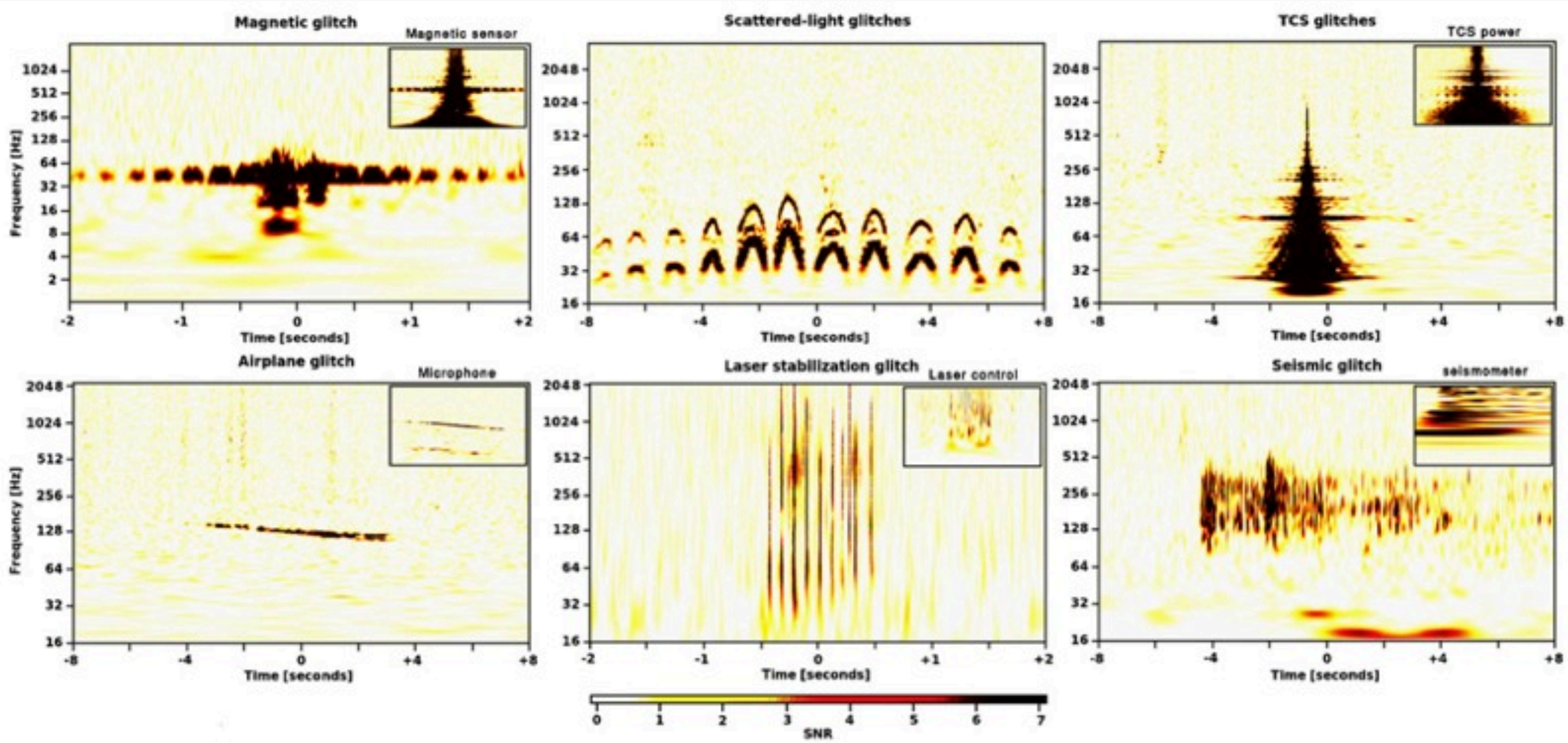
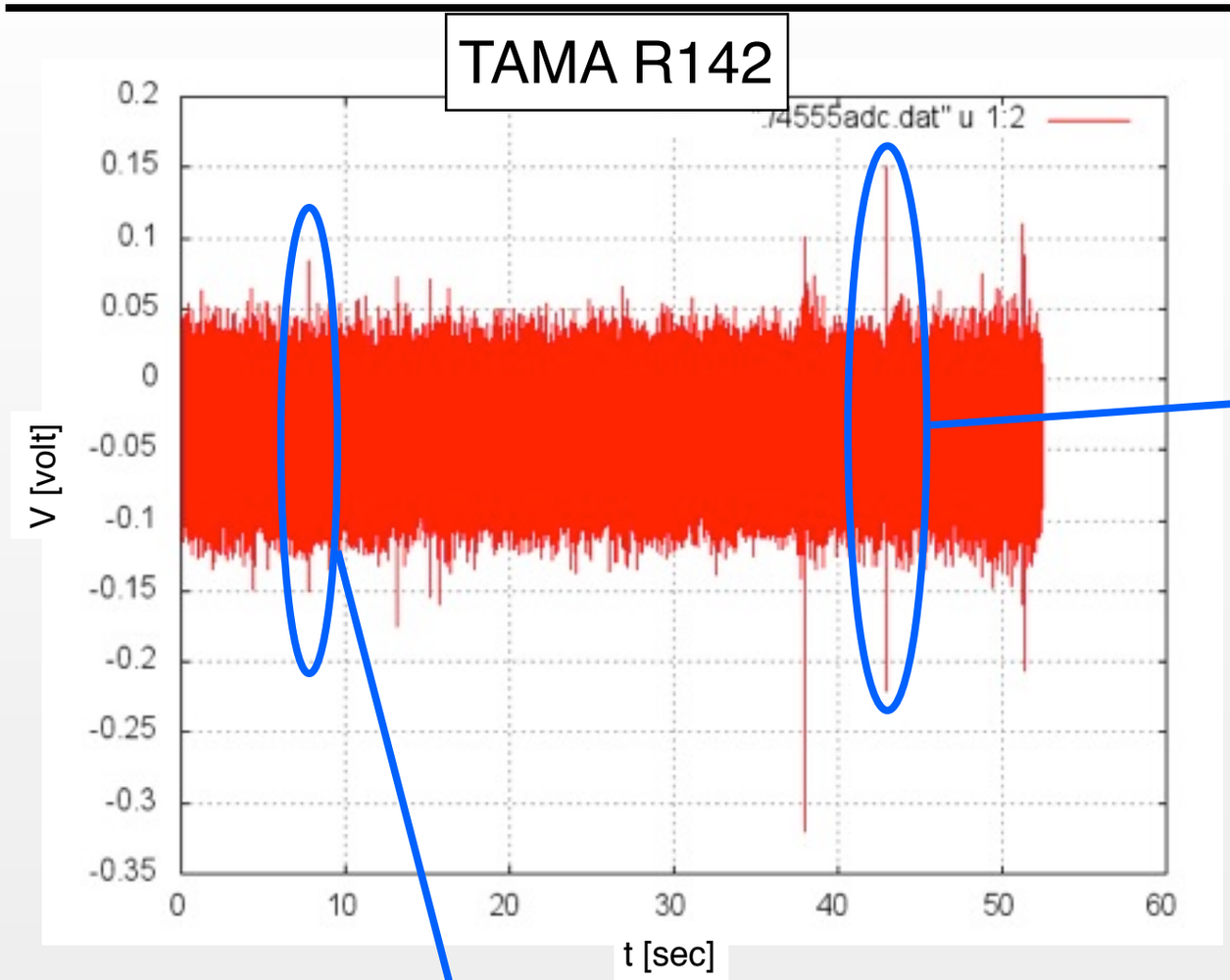
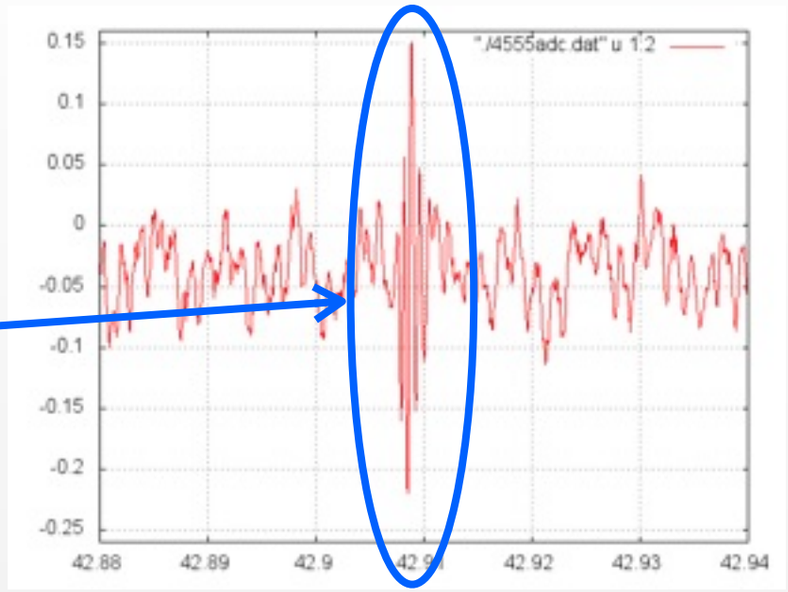


Figure 3. Omega time–frequency maps of six examples of glitches seen in the DF channel. Glitch families are identifiable by their unique time–frequency morphology. When identified, the glitch in the auxiliary channel is shown in the inset plot. The first plot shows a 50 Hz power-line glitch also detected by the magnetometers. The second map shows a series of glitches caused by scattered light induced by seismic activity. The third glitch is caused by a TCS instability. The fourth plot presents an airplane event with a clear Doppler effect. The fifth event is due to a glitch in the laser stabilization loop. The last glitch with an undefined shape is due to a seismic event up-converted to higher frequencies.

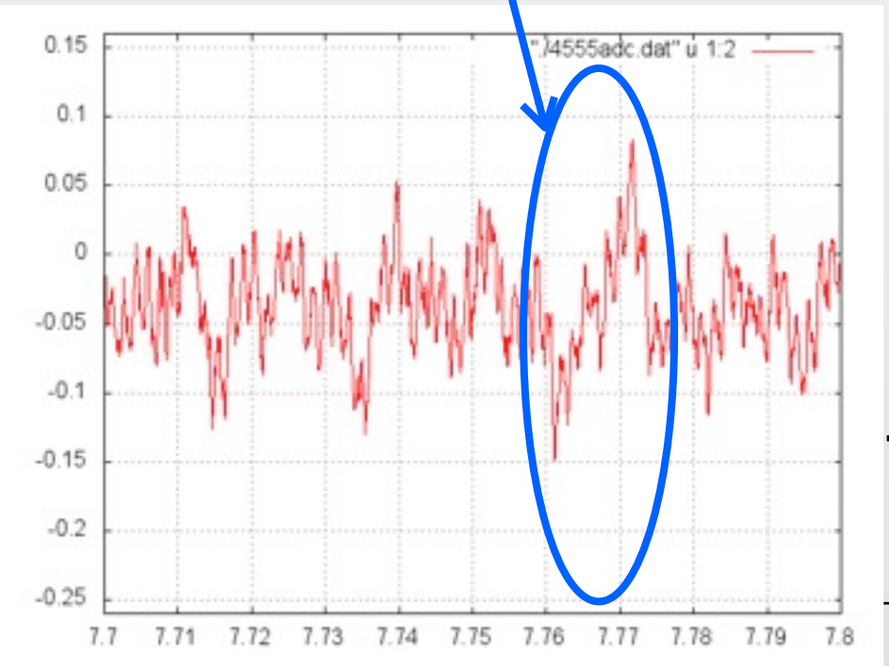
J. Aasi, et. al., Calss, Quantum Grav 29 (2012)

Classification of Noise





Looks like non-stationarity

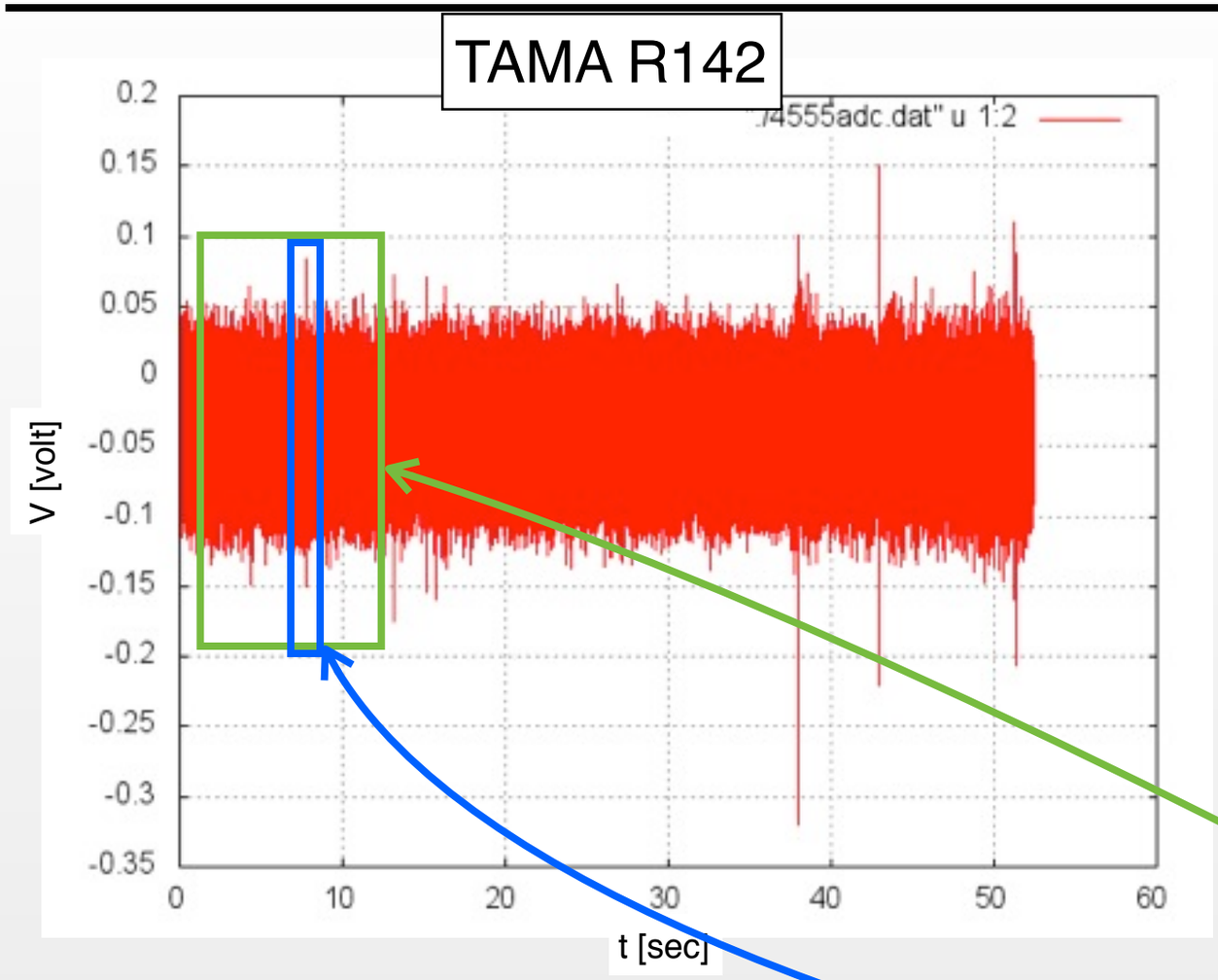


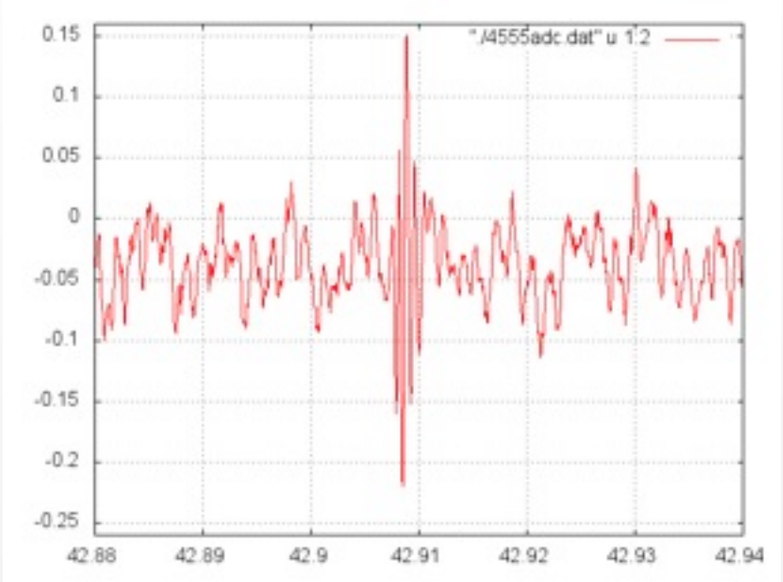
Non-stationary ?

or

Tail of distribution ?

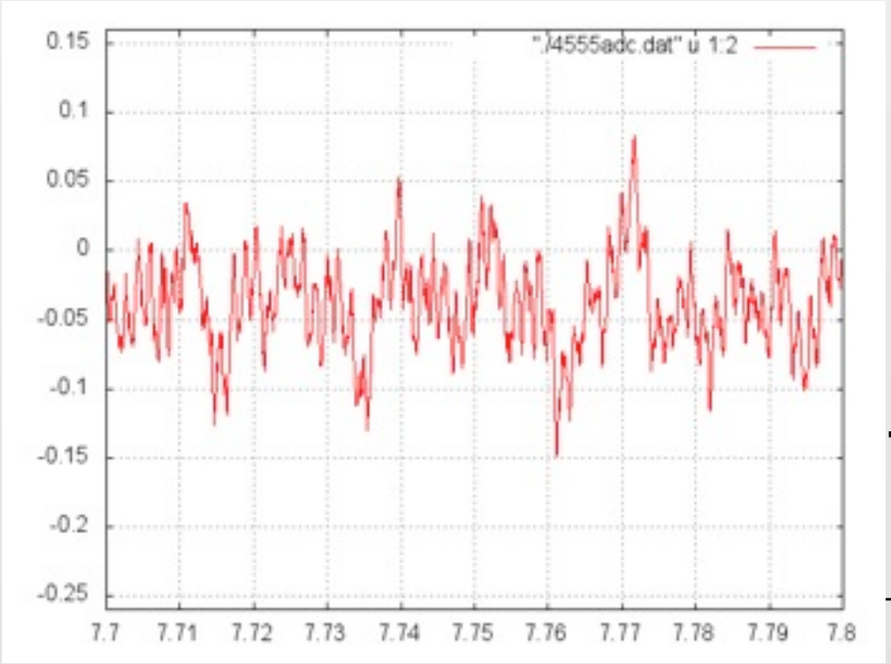
Classification of Noise





Looks like non-stationarity

Changing appearance by time window



Non-stationary ?

or

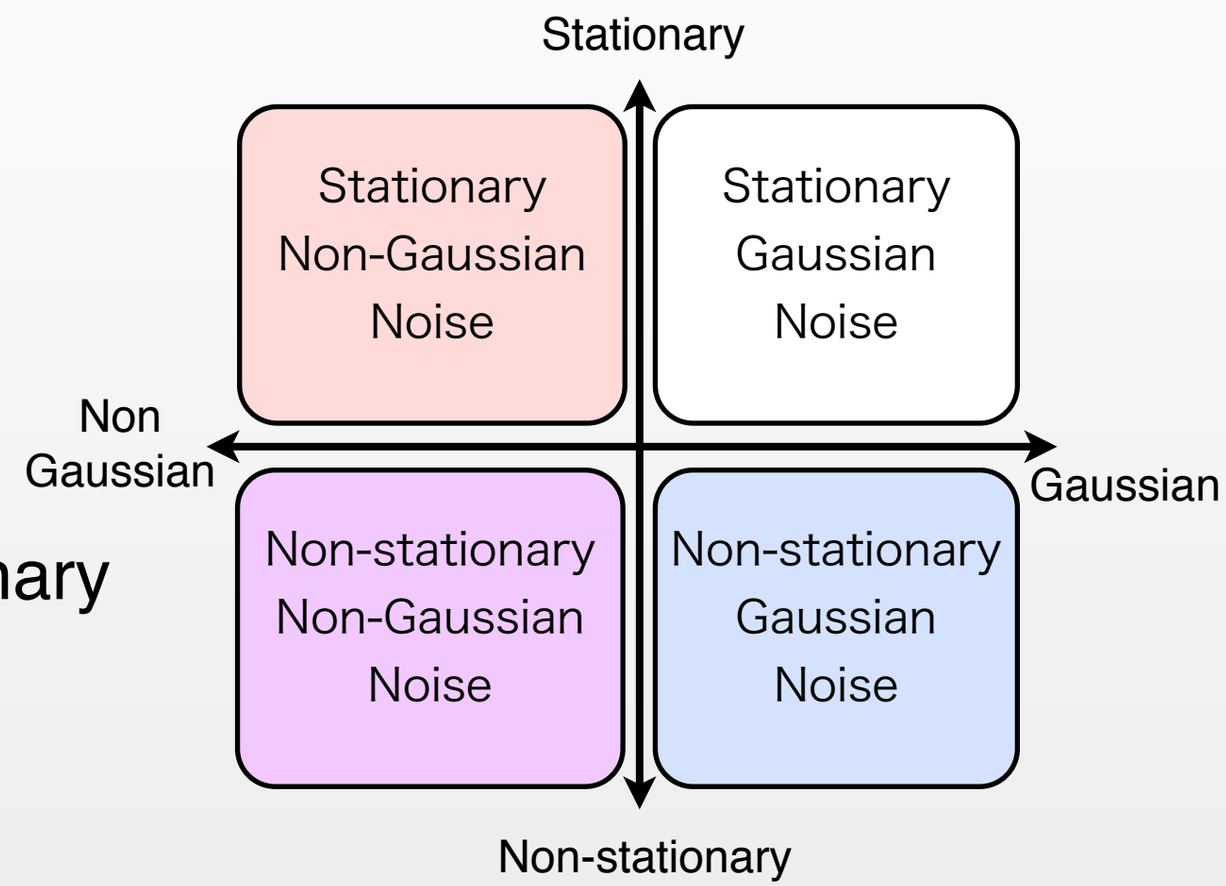
Tail of distribution ?

Classification of Noise

The gap from gaussian noise

- Stationary-Gaussian + Non-stationary
- Stationary-Non-Gaussian
- Stationary-Non-Gaussian + Non-stationary

etc...



Non-stationarity monitor tools：KleineWelle, Omega (LAL)...

LAL: LIGO/LSC Algorithm Library

Non-gausianity monitor tools：We implemented new tool

for real time monitoring

Non-Gaussian Noise Model

Gauss Noise Model

Re[n(f)] and Im[n(f)] follow Gaussian distribution

and |n(f)| follows Rayleigh distribution

$$f(x) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

Non-Gaussian Noise Model：Using Student-t Noise Model

Re[n(f)] and Im[n(f)] follow Student-t distribution

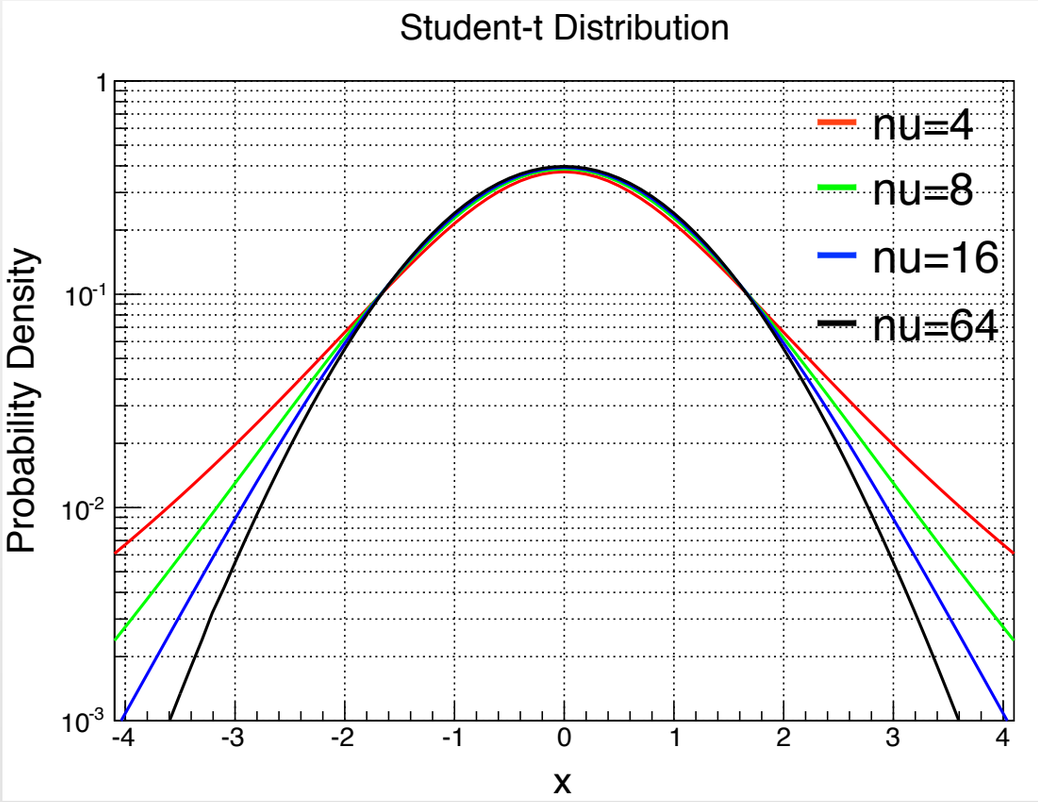
This distribution has heavier tail

and is characrized only 1 parameter (ν)

$$f(t) = \frac{\Gamma((\nu+1)/2)}{\sqrt{\nu\pi}\,\Gamma(\nu/2)}(1+t^2/\nu)^{-(\nu+1)/2}$$

When v = ∞, Student-t is equal Gaussian

Modeling noise event at tail of distribution using a clear indicator



Non-Gaussian Noise Model

In Student-t noise model,

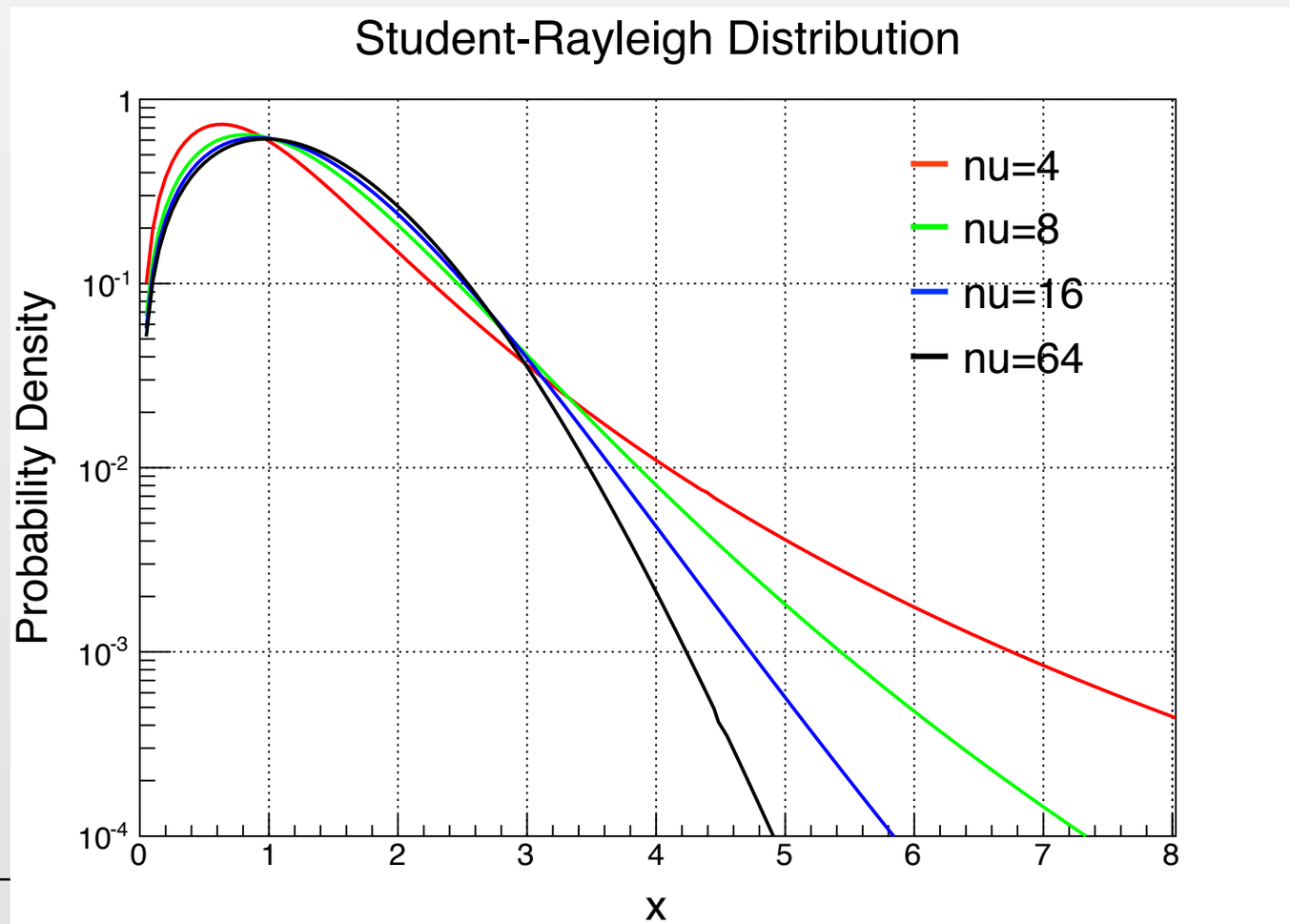
|n(f)| follows Student-Rayleigh distribution

$$f_{\mathrm{SR}}(x|\sigma,\nu) = \frac{x}{\sigma^2} f_{F(2,\nu)}\left(\frac{x^2}{2\sigma^2}\right), \qquad \text{(A18)}$$

$f_F(x)$: F-distribution fucntion

C. Röver (2011) http://arxiv.org/abs/1109.0442

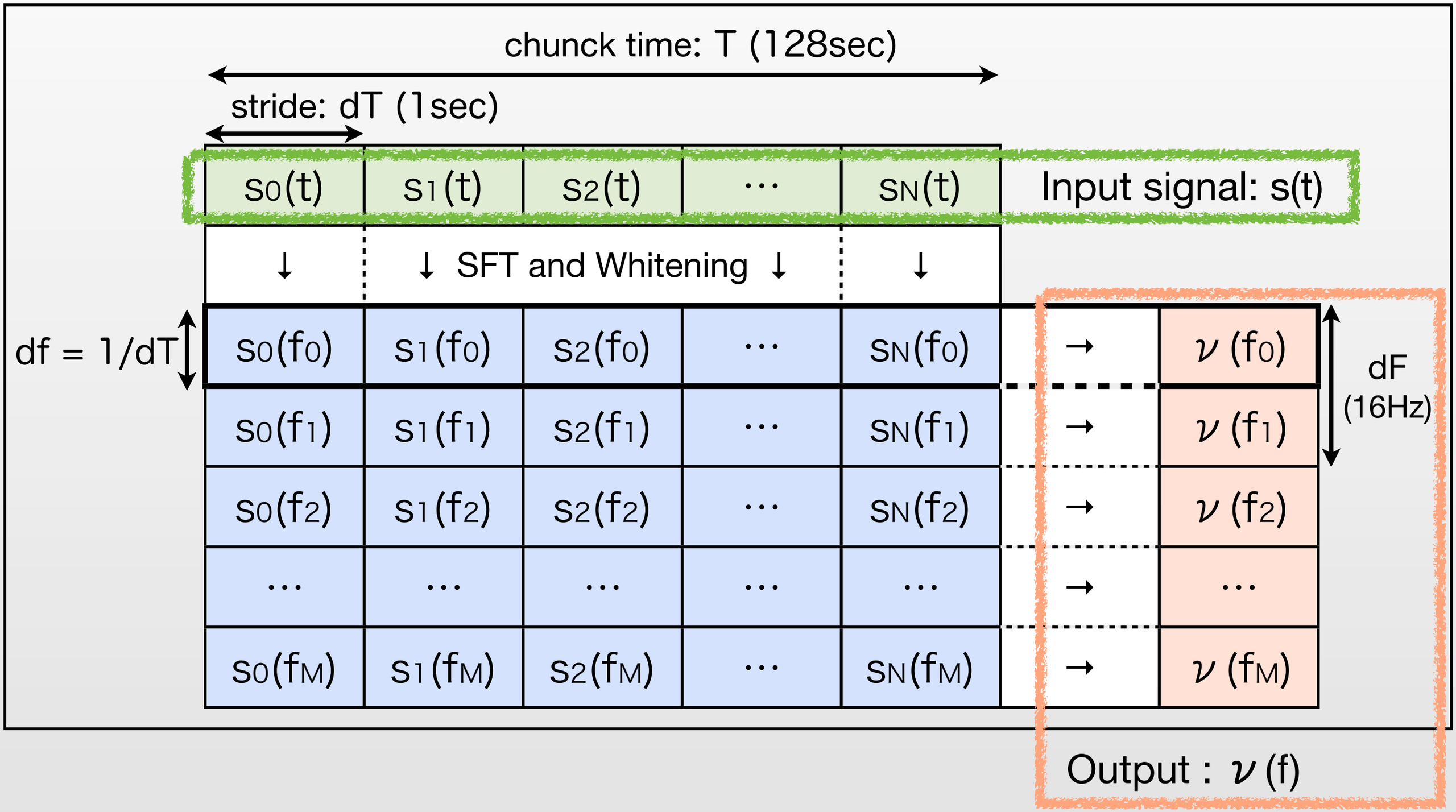
When $\nu = \infty$, Student-Rayleigh distribution is equal Rayleigh distribution



Non-Gaussianity Monitor

[1] Calculating spectrogram of detector signal (Short Fourier Transform)

[2] Estimating ν using Student-Rayleigh distribution each frequency bin



ν Estimation

$s_0(f_{j=x})$	$s_1(f_{j=x})$	$s_2(f_{j=x})$	$\cdots$	$s_M(f_{j=x})$	$\rightarrow$	$\nu\,(f_{j=x})$

How do we estimate $\nu\,(f_{j=x})$ from samples $s_i(f_{j=x})$?

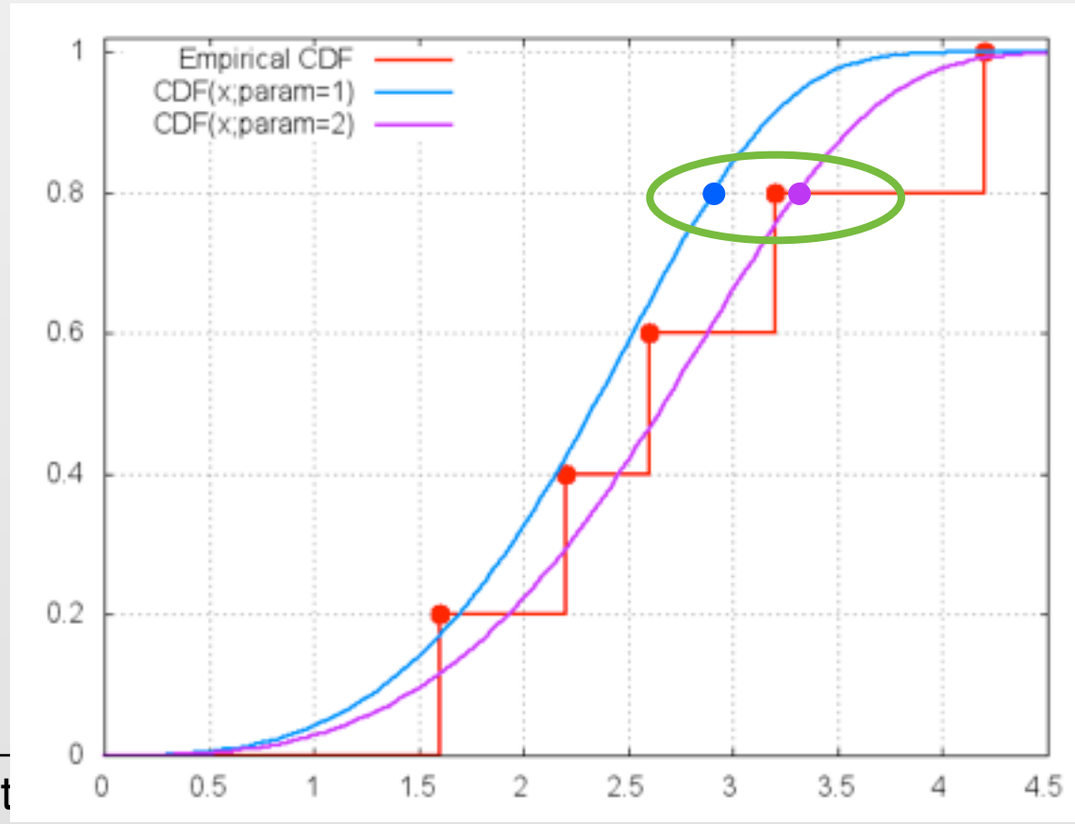
[1] Decide base quantile α (=0.99)

[2] Sorting $s_i(f_{j=x})$

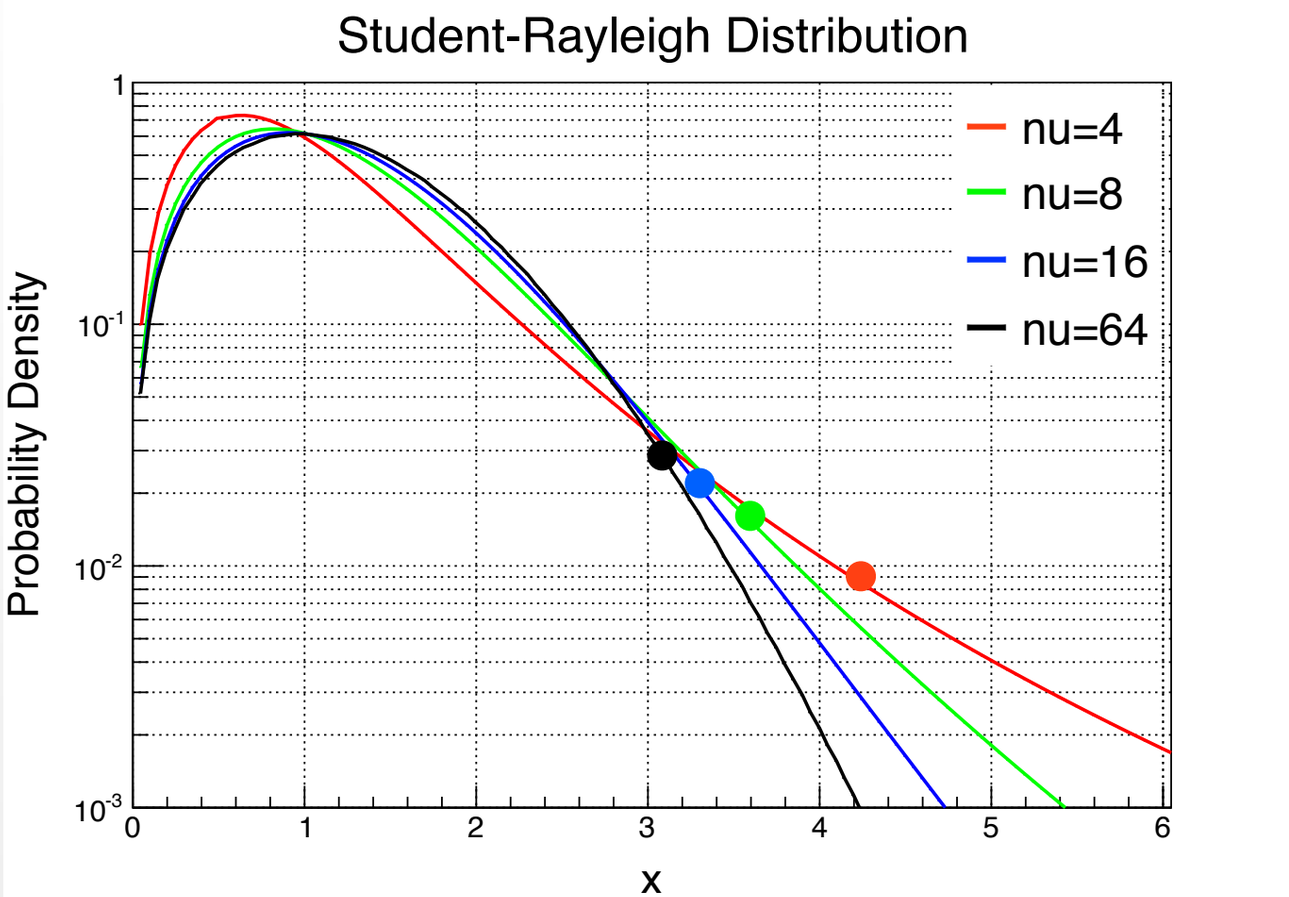
[3] Pickup quantile data $s_{i=\alpha M}(f_{j=x})$ from sorted $s_i(f_{j=x})$

[4] Calculating theoretical quantile value of Student-Rayleigh distribuiont $s_{theory}(\alpha;\nu)$ varing ν

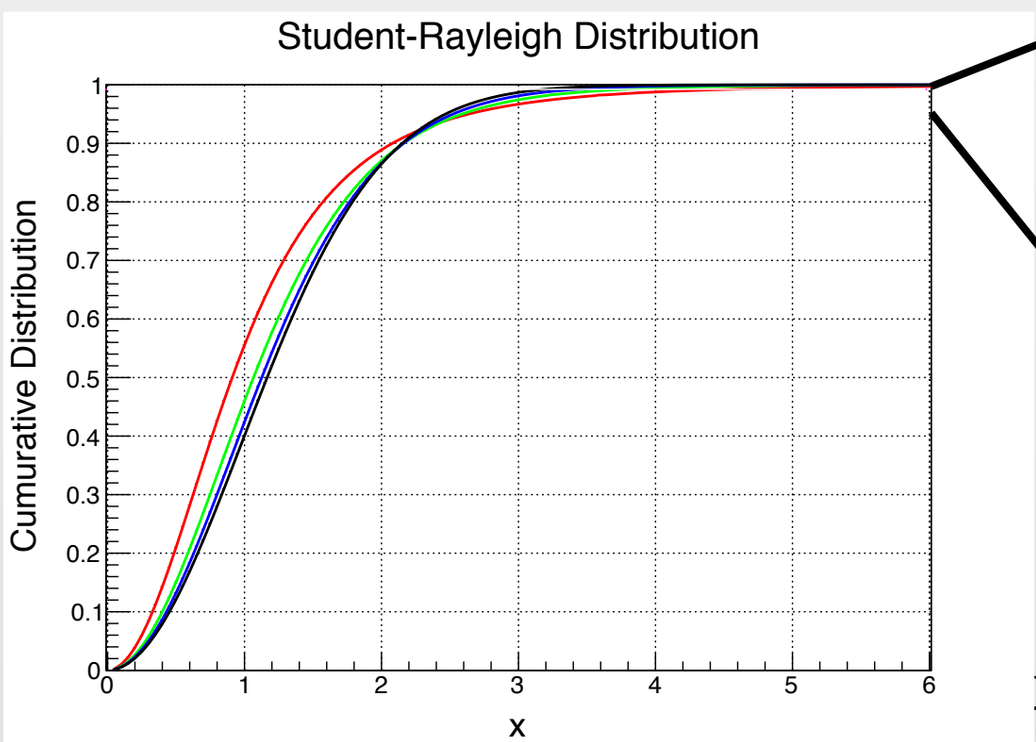
[5] Employing empirical ν as $\nu\,(f_{j=x})$ where $\nu\,(f_{j=x})$ give $s_{theory}(\alpha;\nu)$ which is the most closest to $s_{i=\alpha M}(f_{j=x})$

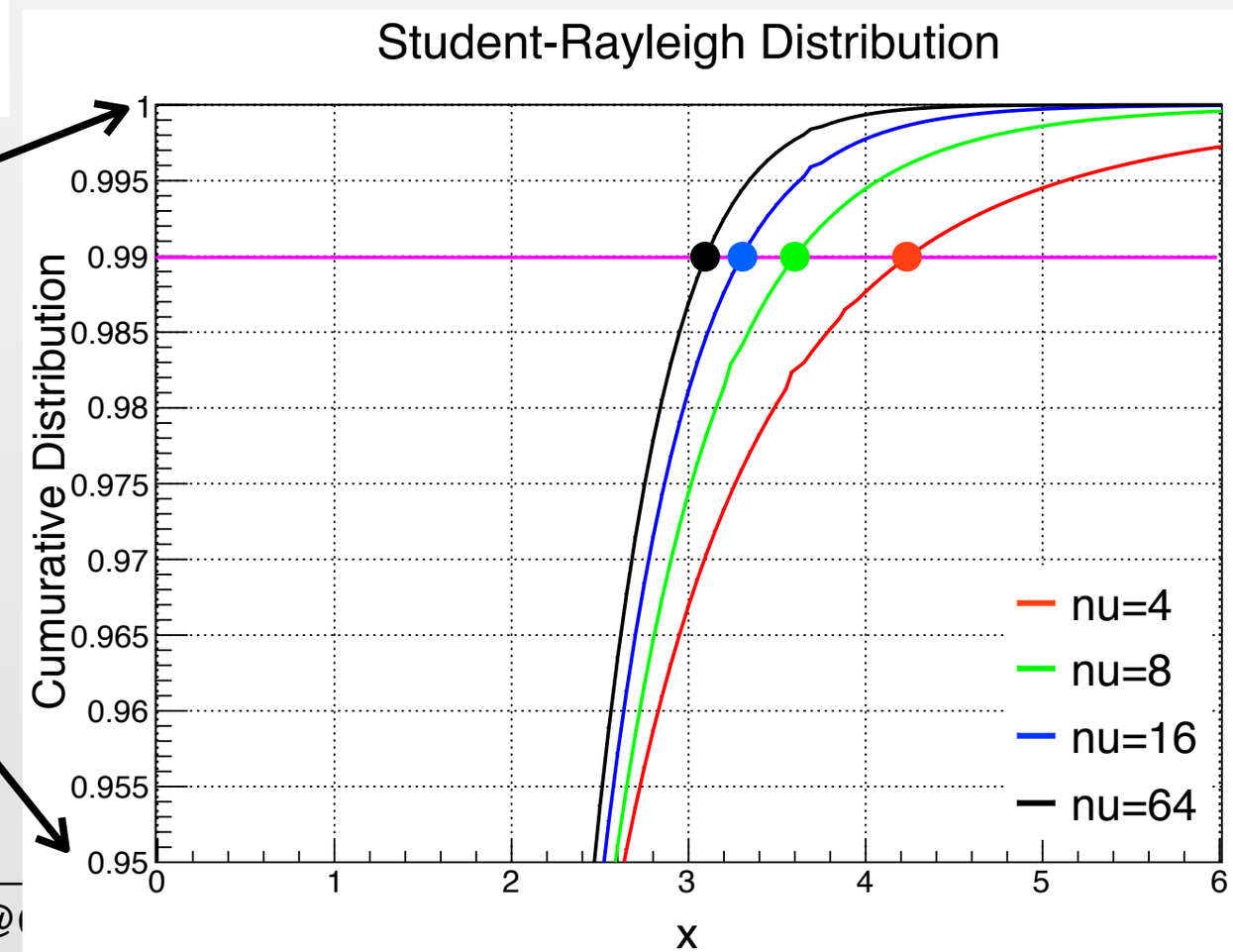


Quantile of Student-Rayleigh Distribution



The position of 99% Quantile
on the probability density function(right)
and
cumulative distribution function(below)
of Strudent-Rayleigh distribution





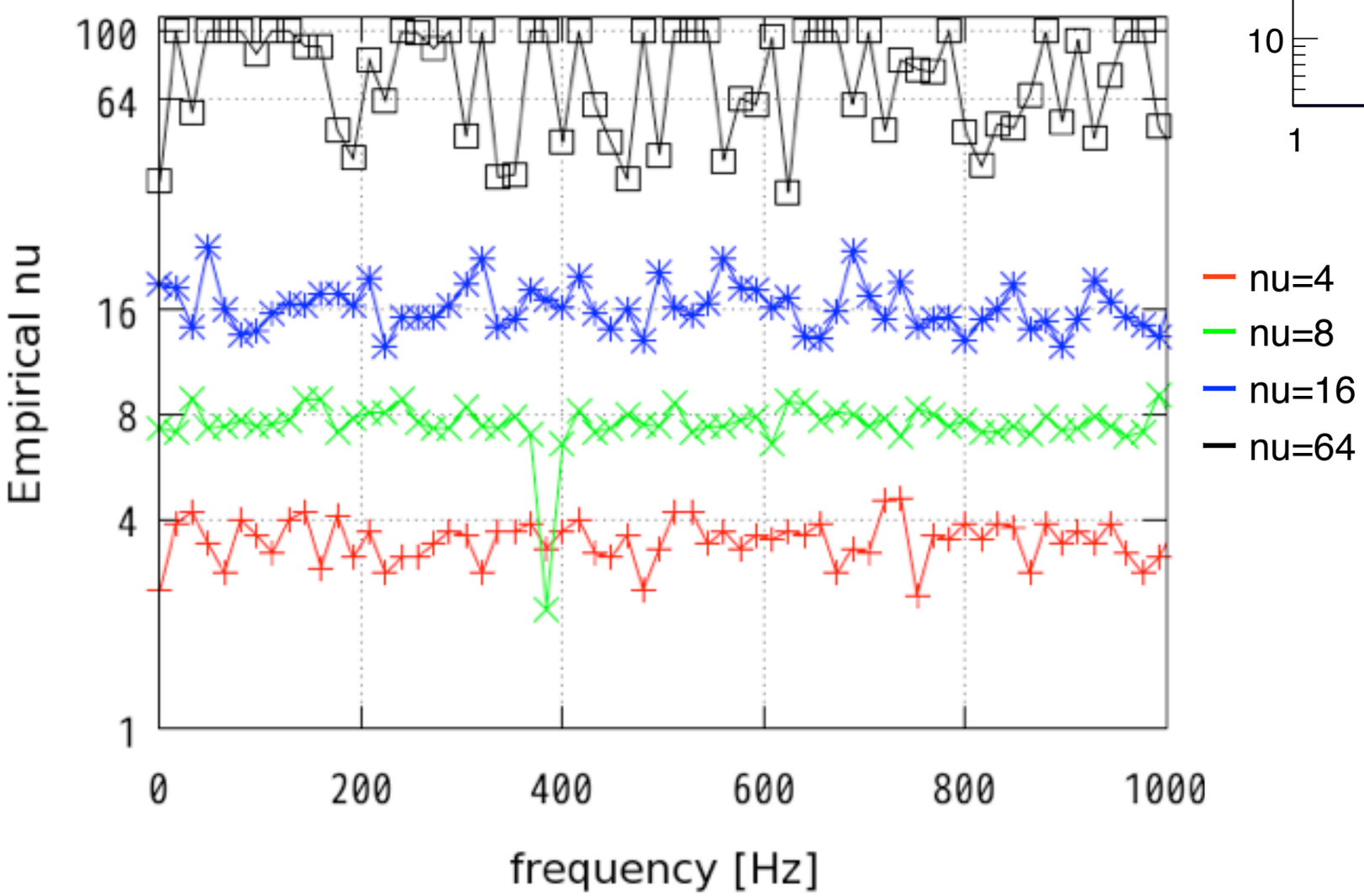
Non-Gaussianity Monitor ～ Simulation Test

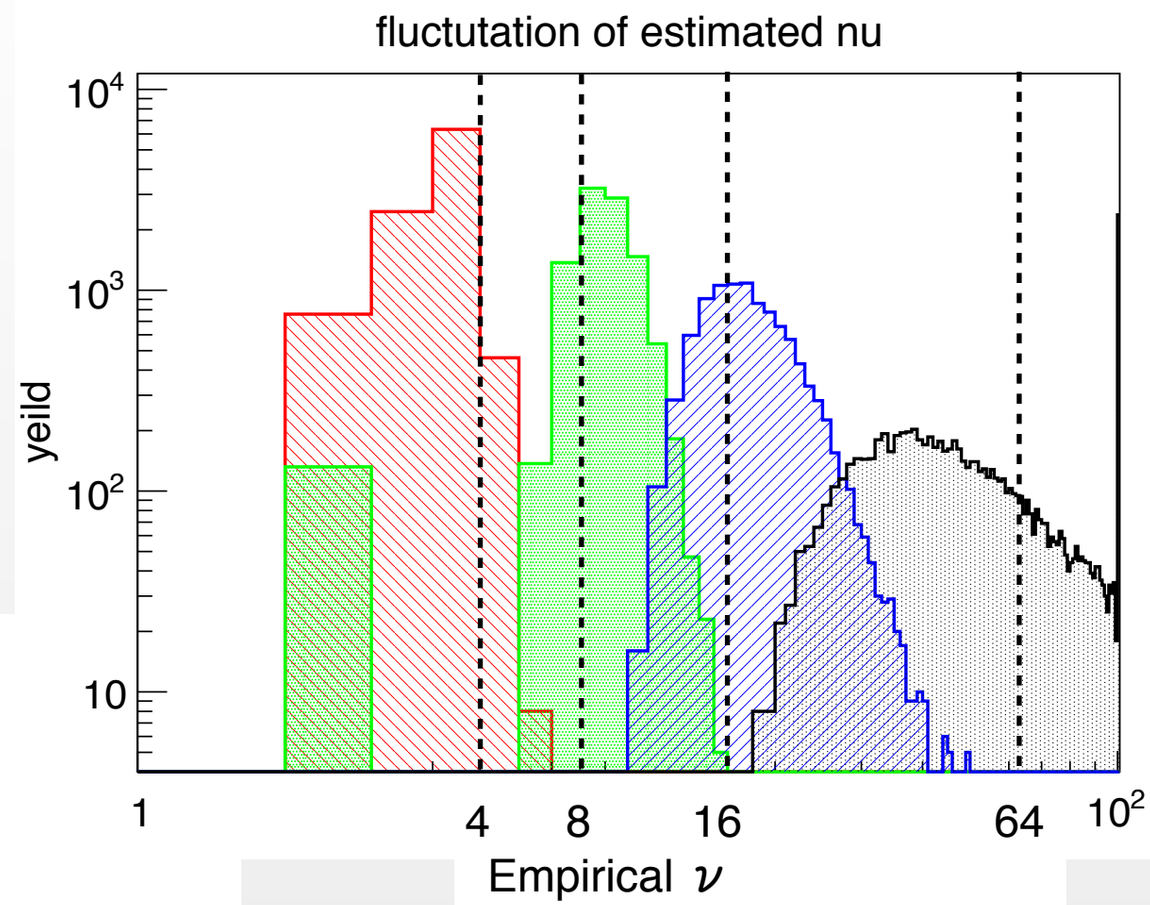
Performance test with known ν

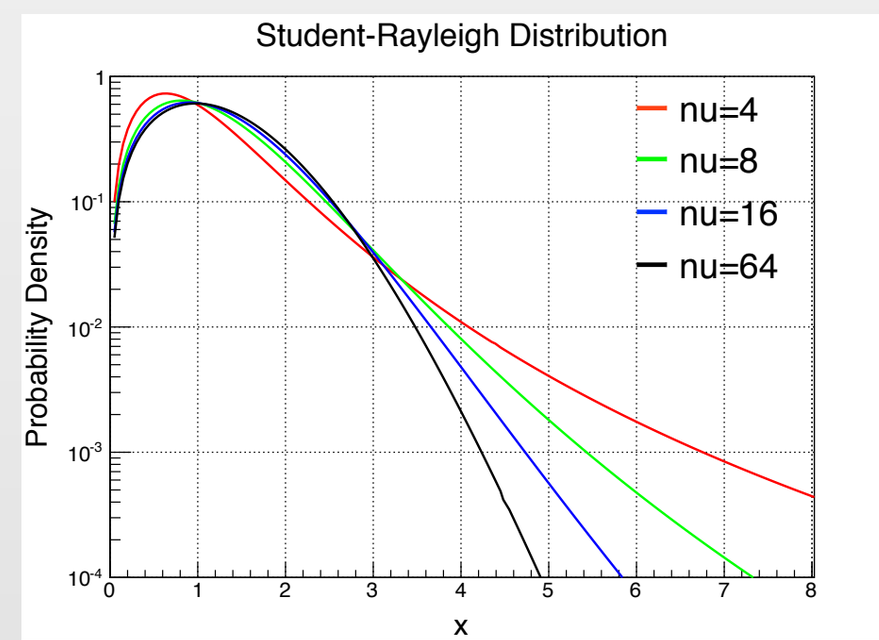
- Generating simulation signal

  with ν =4, 8, 16, 64

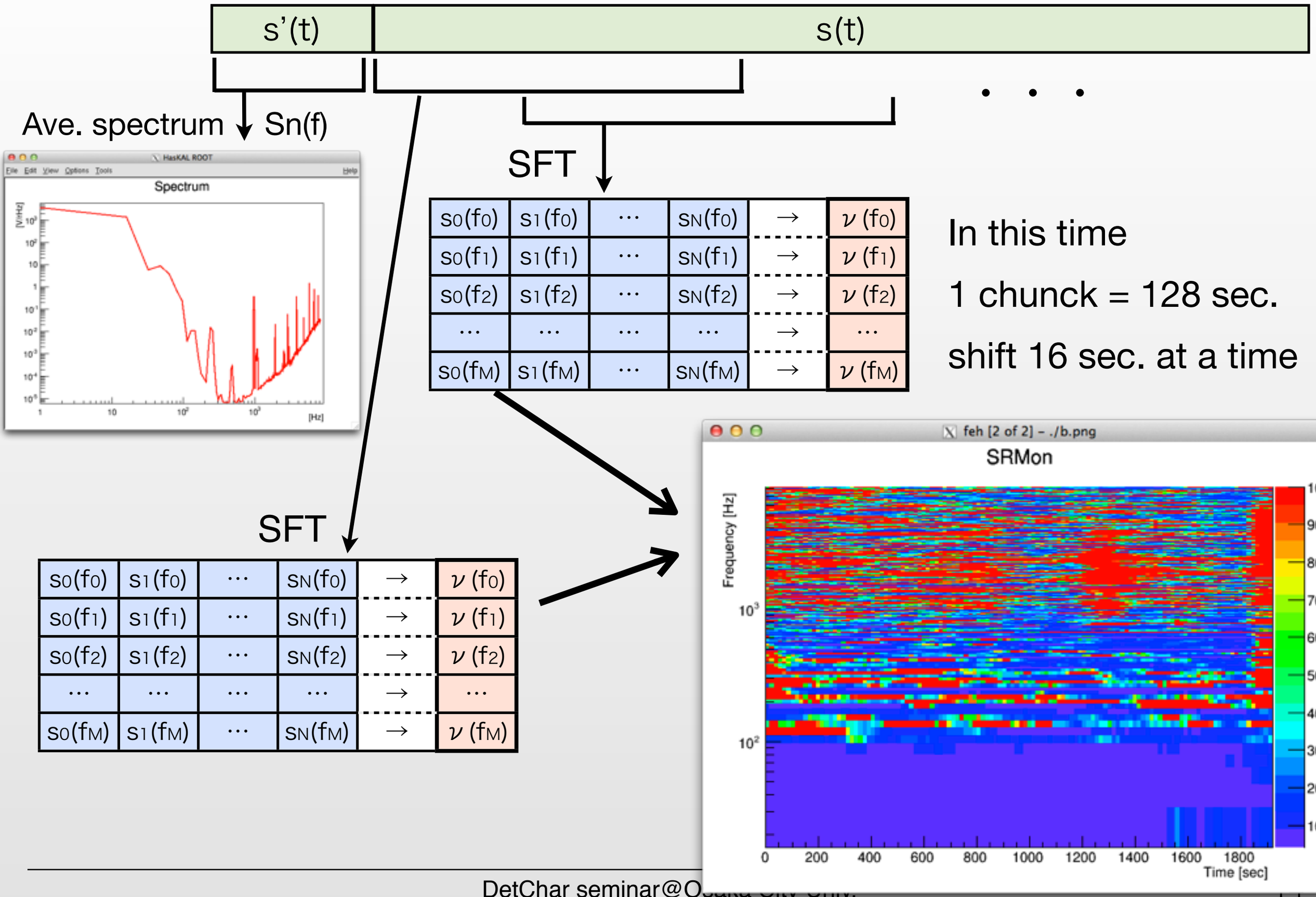
- Confirmed detectability of difference of ν







Non-Gaussianity Monitor ～ Long Time Run



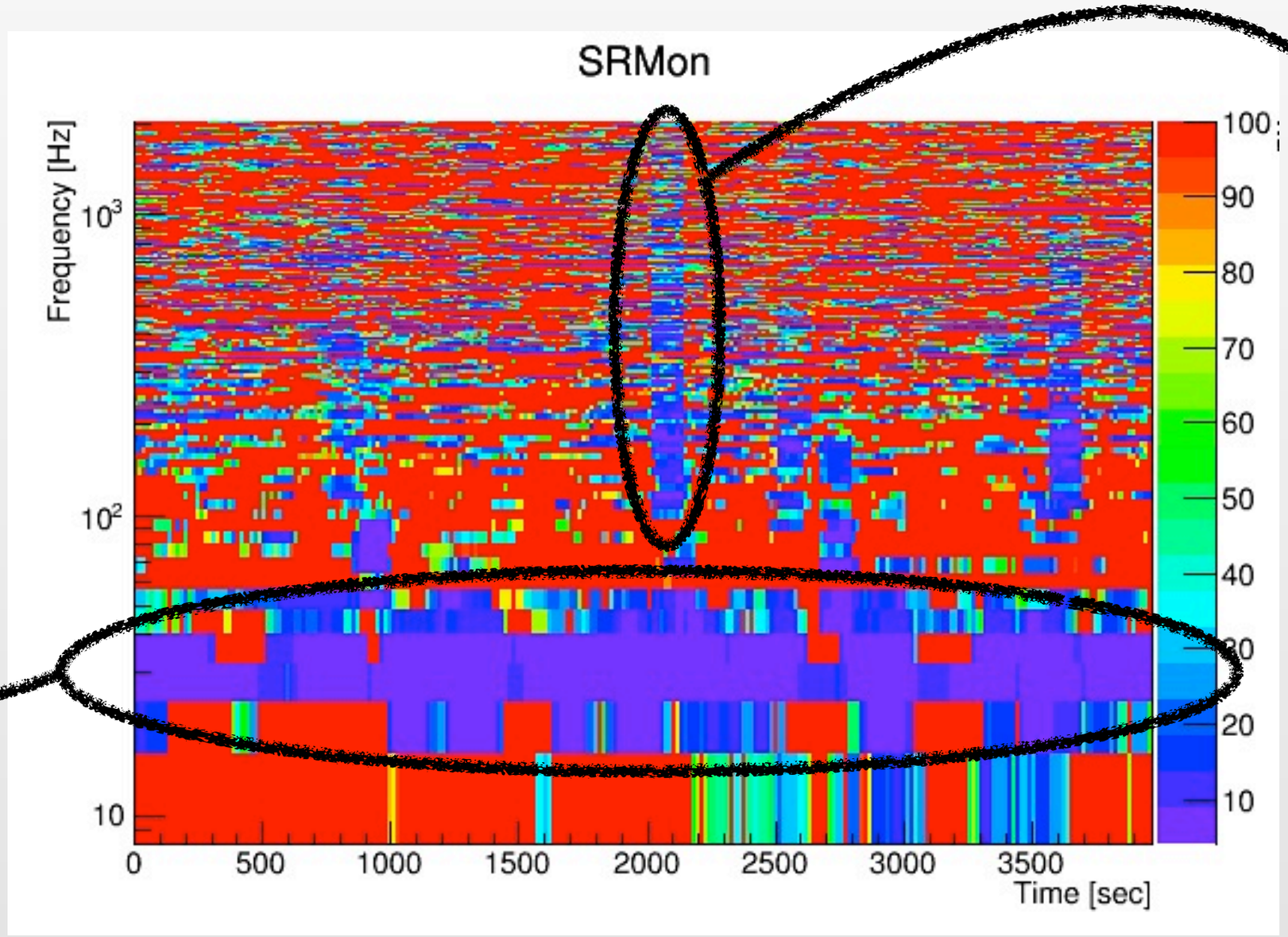
Non-Gaussian Monitor ～ using LIGO S5 Data

Using LIGO S5 data(https://losc.ligo.org/start/)

GPS Time：842747904

dt = 16 [sec], df = 16 Hz

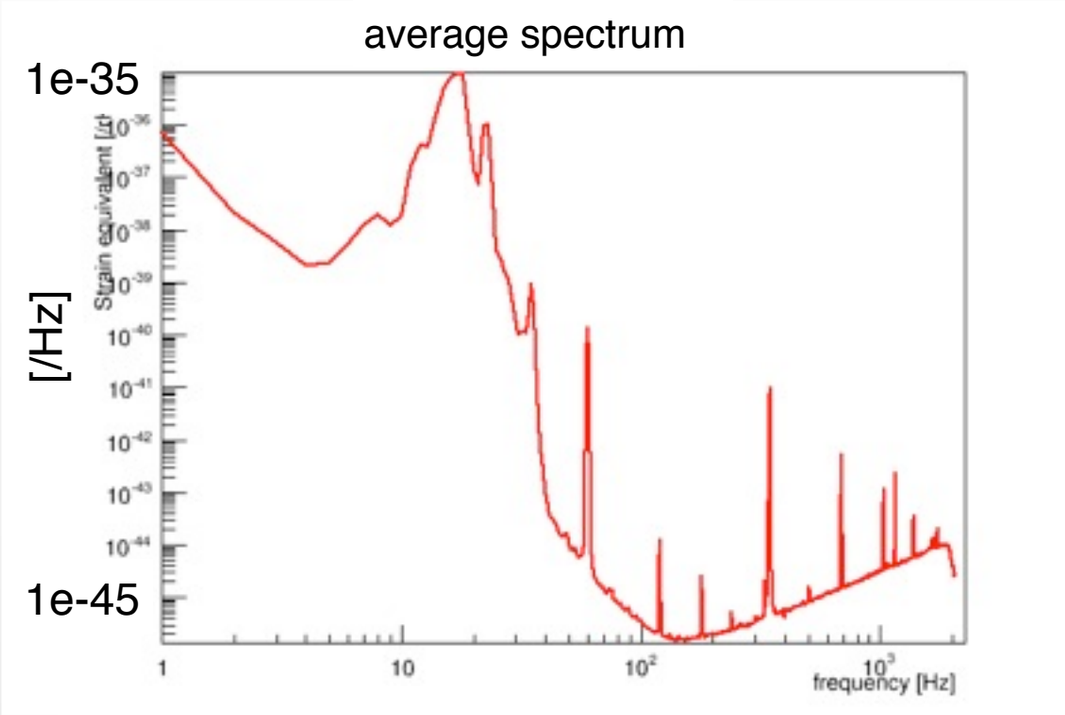
Gaussianity is constantly bad

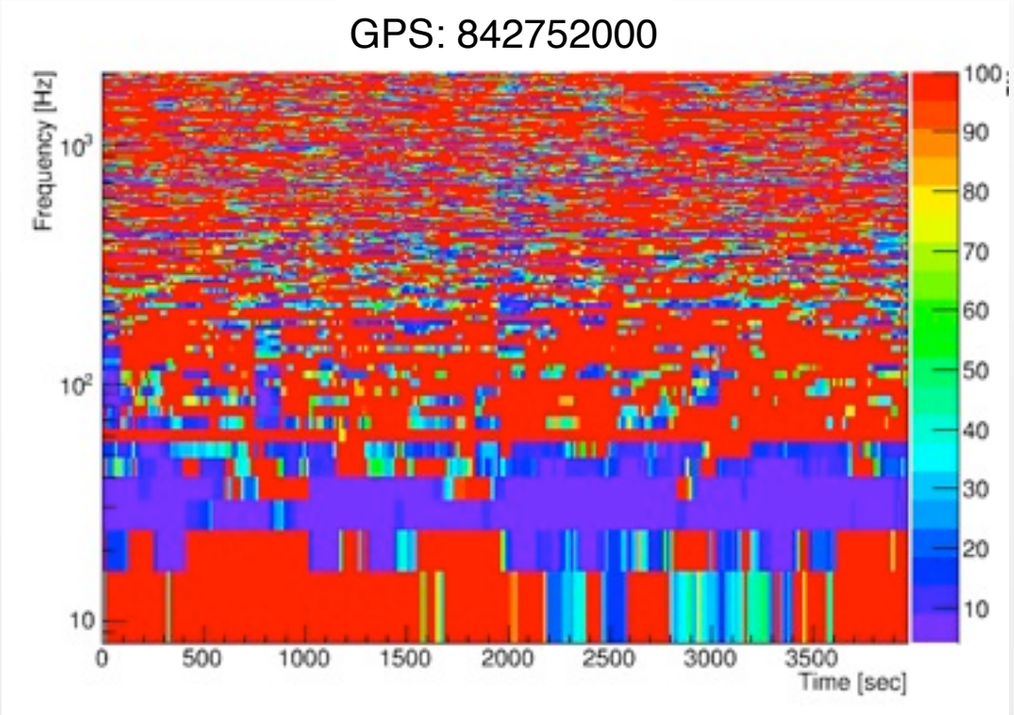


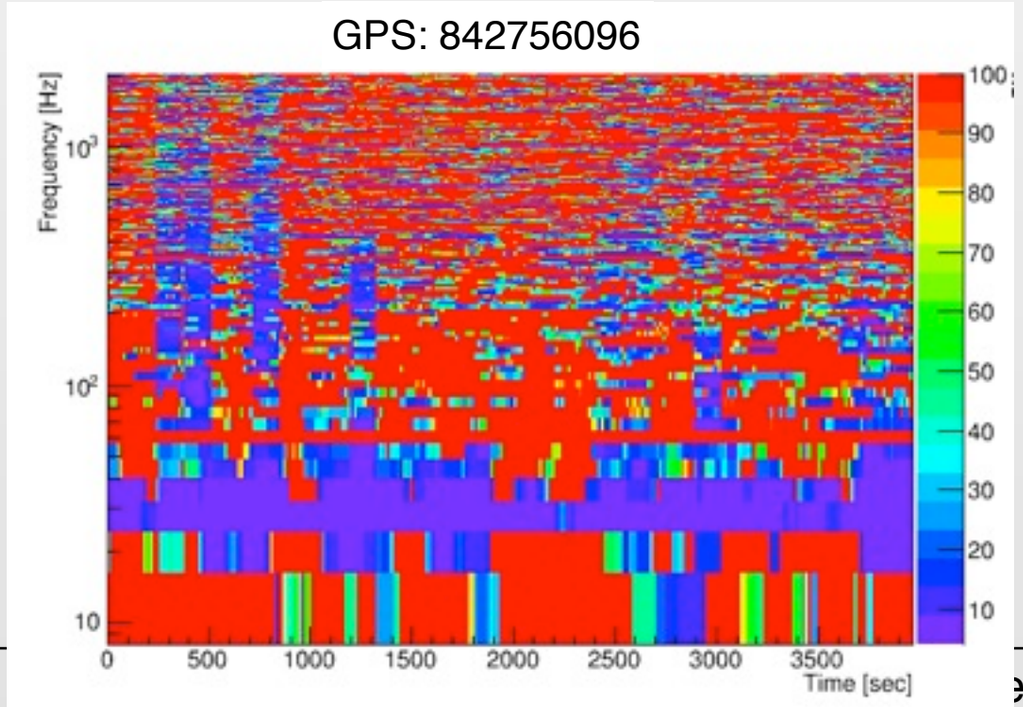
Gaussianity is suddenly bad

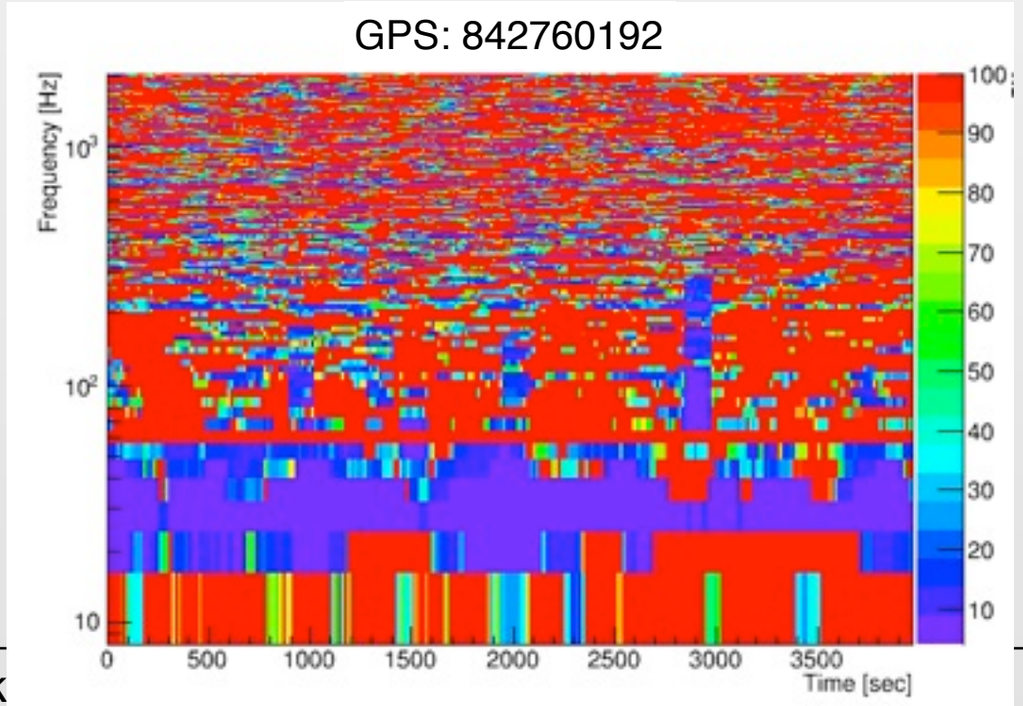
Non-Gaussian Monitor ～ using LIGO S5 Data

Applied monitor tool to continuous data(about 5 hrs.)







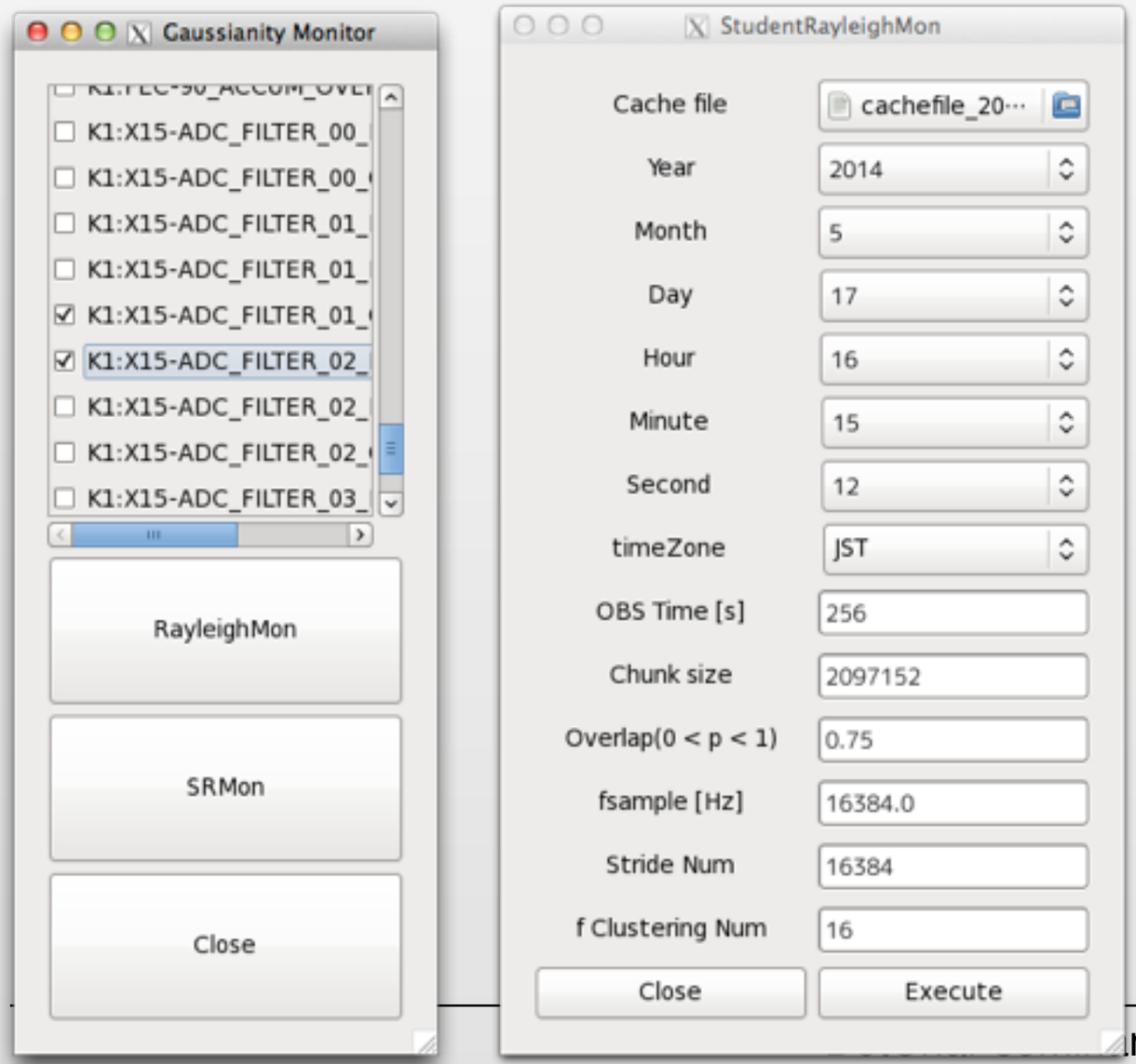


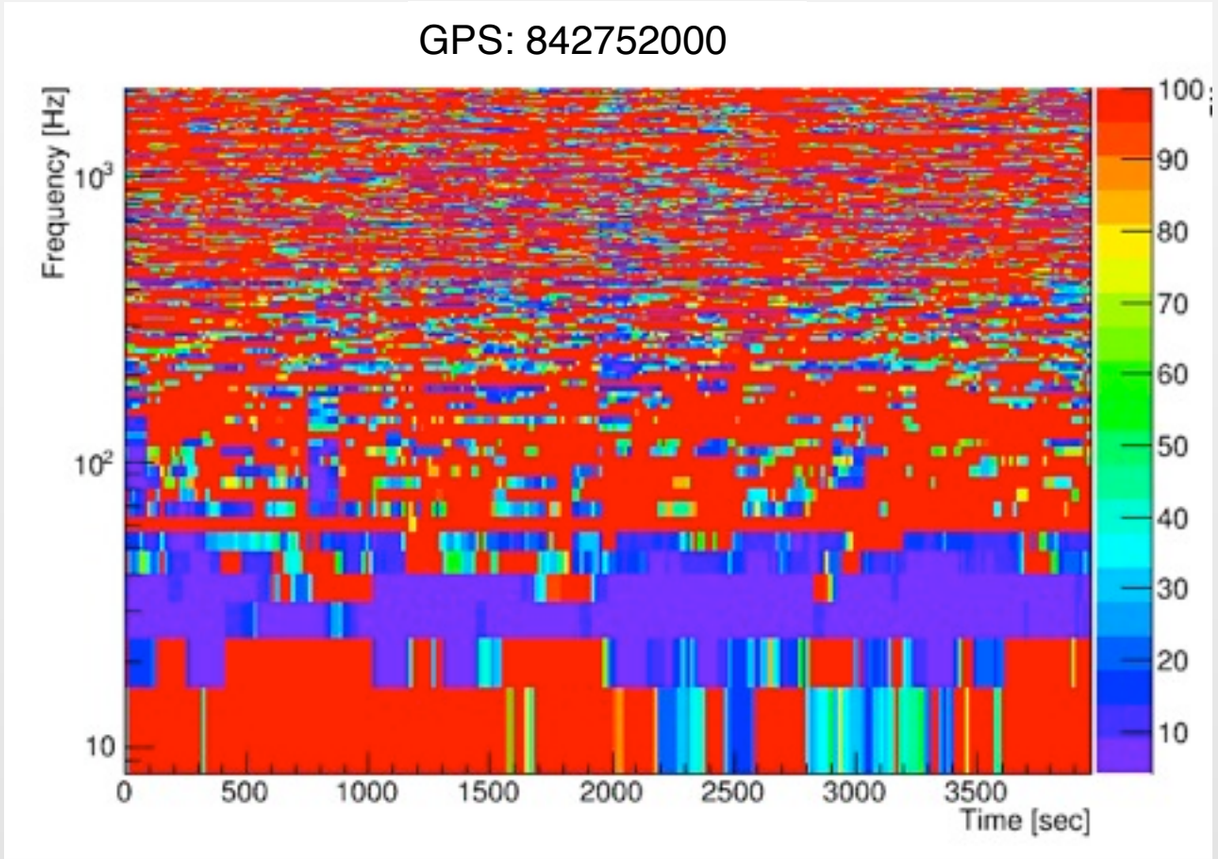
Development of Detector Characterization Tool

Toward to commissioning phase,
we are developing DetChar tool named HasKAL

HasKAL is Haskell base library
to run various monitor tools on CUI or GUI

https://github.com/gw-analysis/detector-characterization





Summary

Developed a monitor tool to evaluate non-Gausianity of signal

- Confirmed detectability of differen of ν using simulation noise
- Applied monitor tool to continuous data (about 5 hrs.)

Future Work

- Searching correlation of non-Gaussianity during multi-channels
- Classification of non-Gaussian and non-Stationary noise using Gaussianity and stationarity monitor