Noise Identification in Gravitational wave search using Artificial Neural Networks

Young-Min Kim (Pusan Nat'l Univ. & NIMS)

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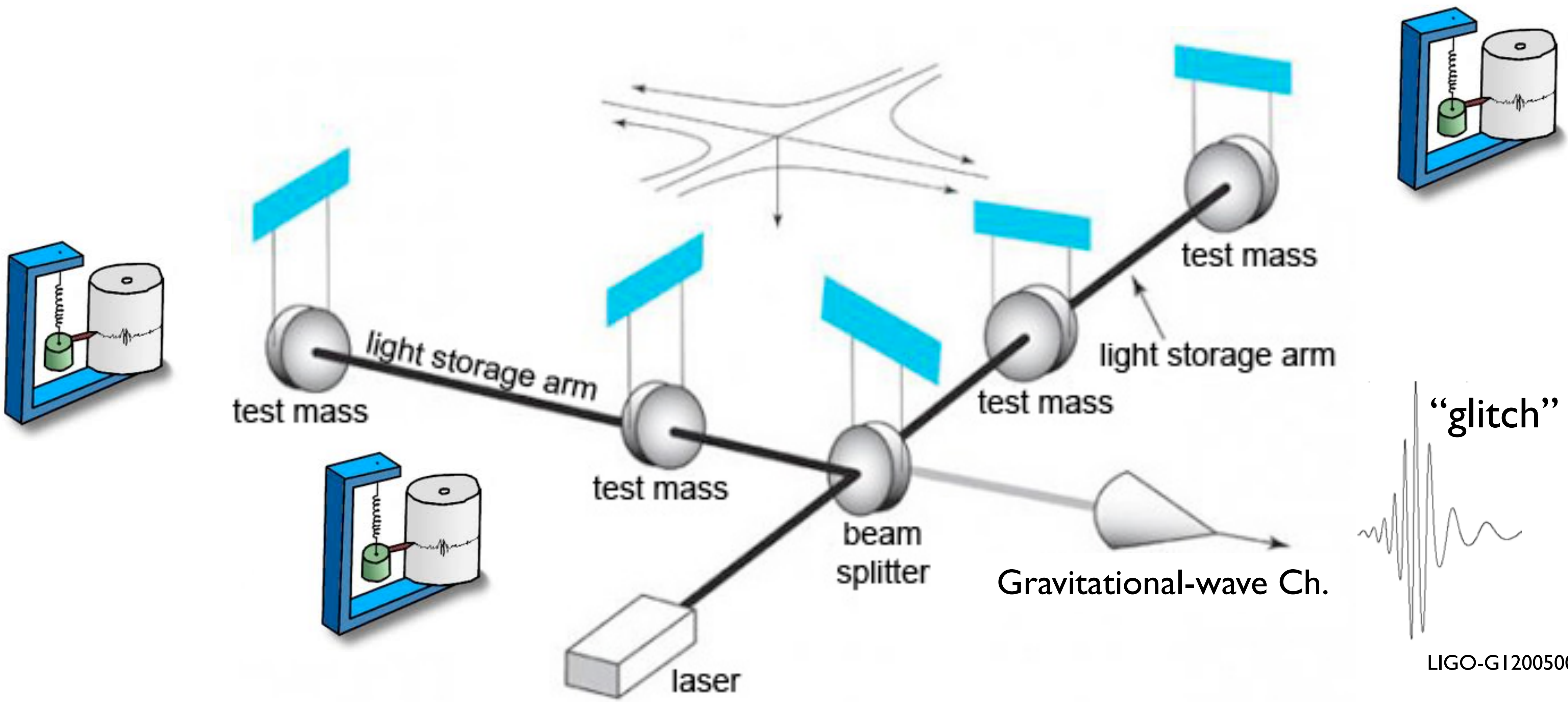
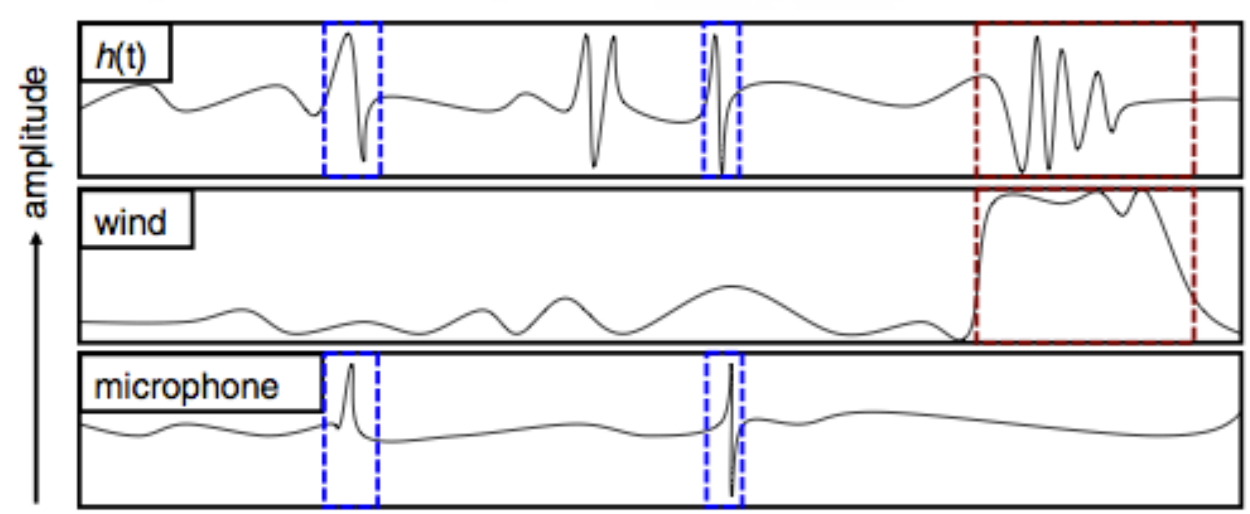
K. Hayama (Osaka City Univ.)

4th K-J workshop on KAGRA @ Osaka Univ.

Laser Interferometer for GW Observation



LIGO-G1200500



Univ.

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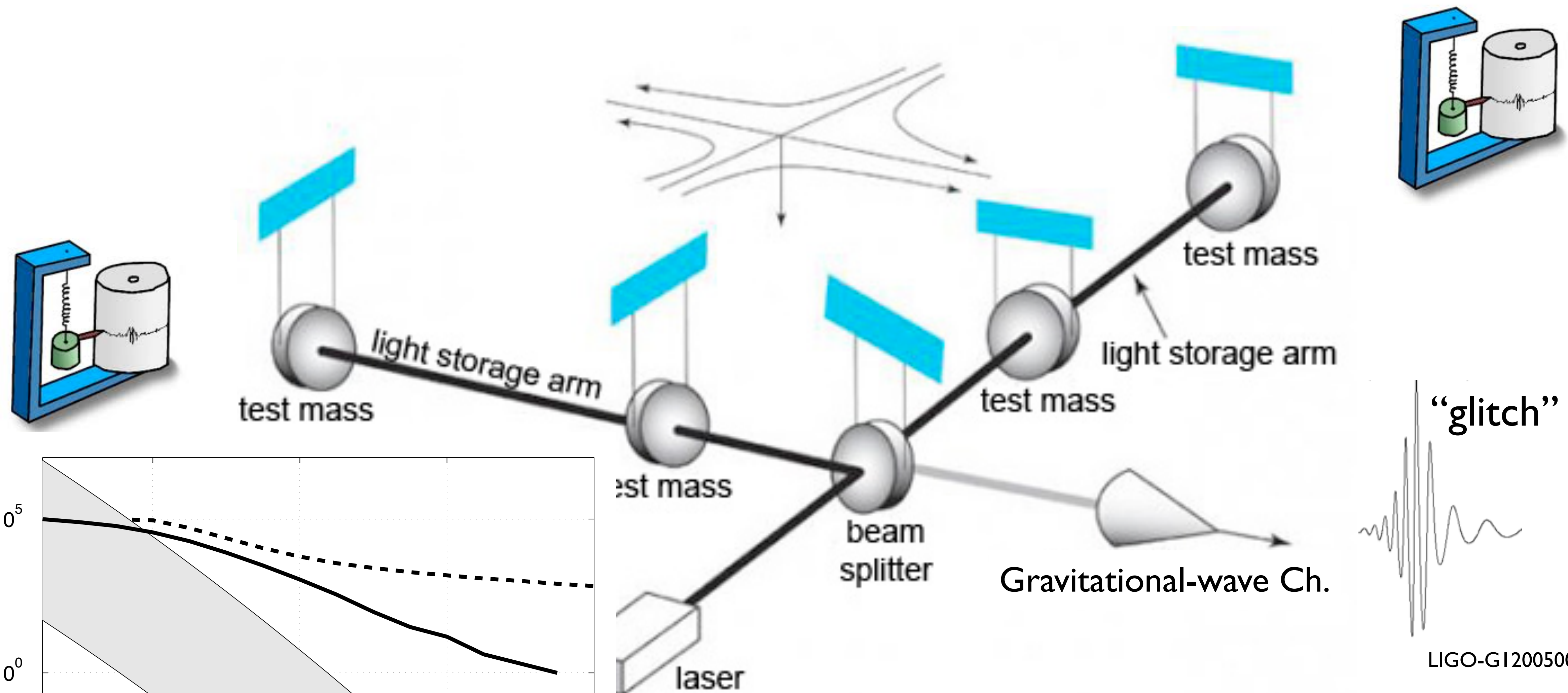

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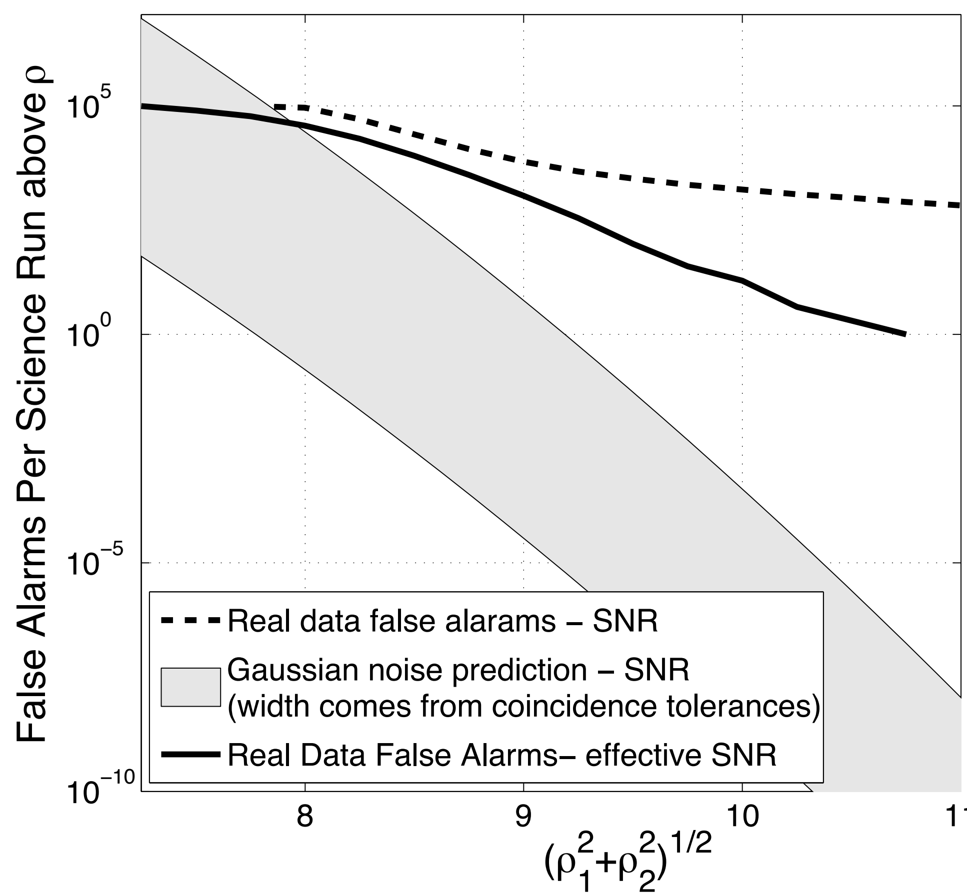

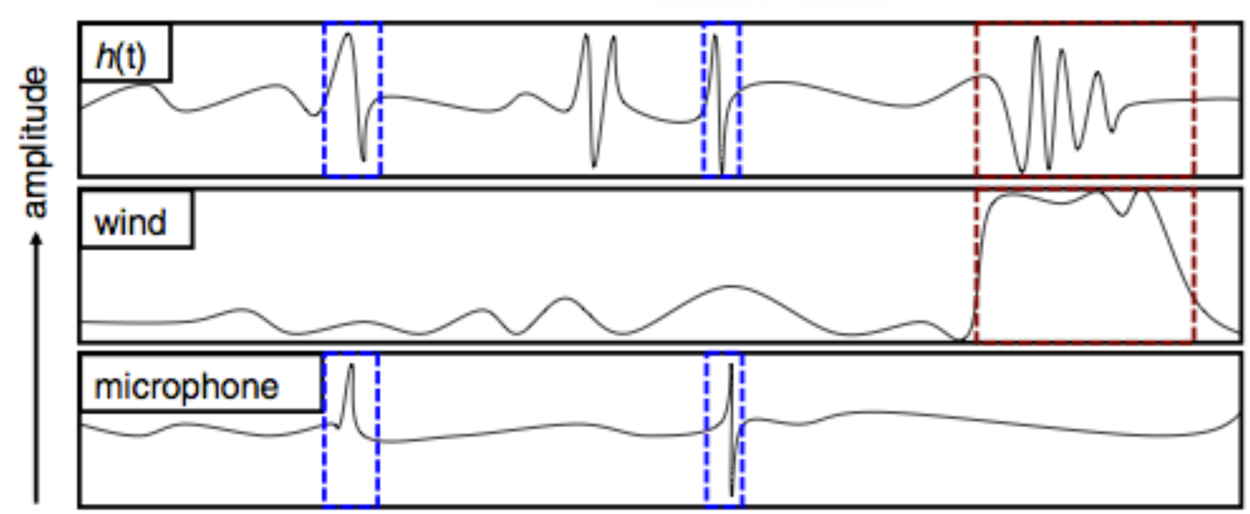

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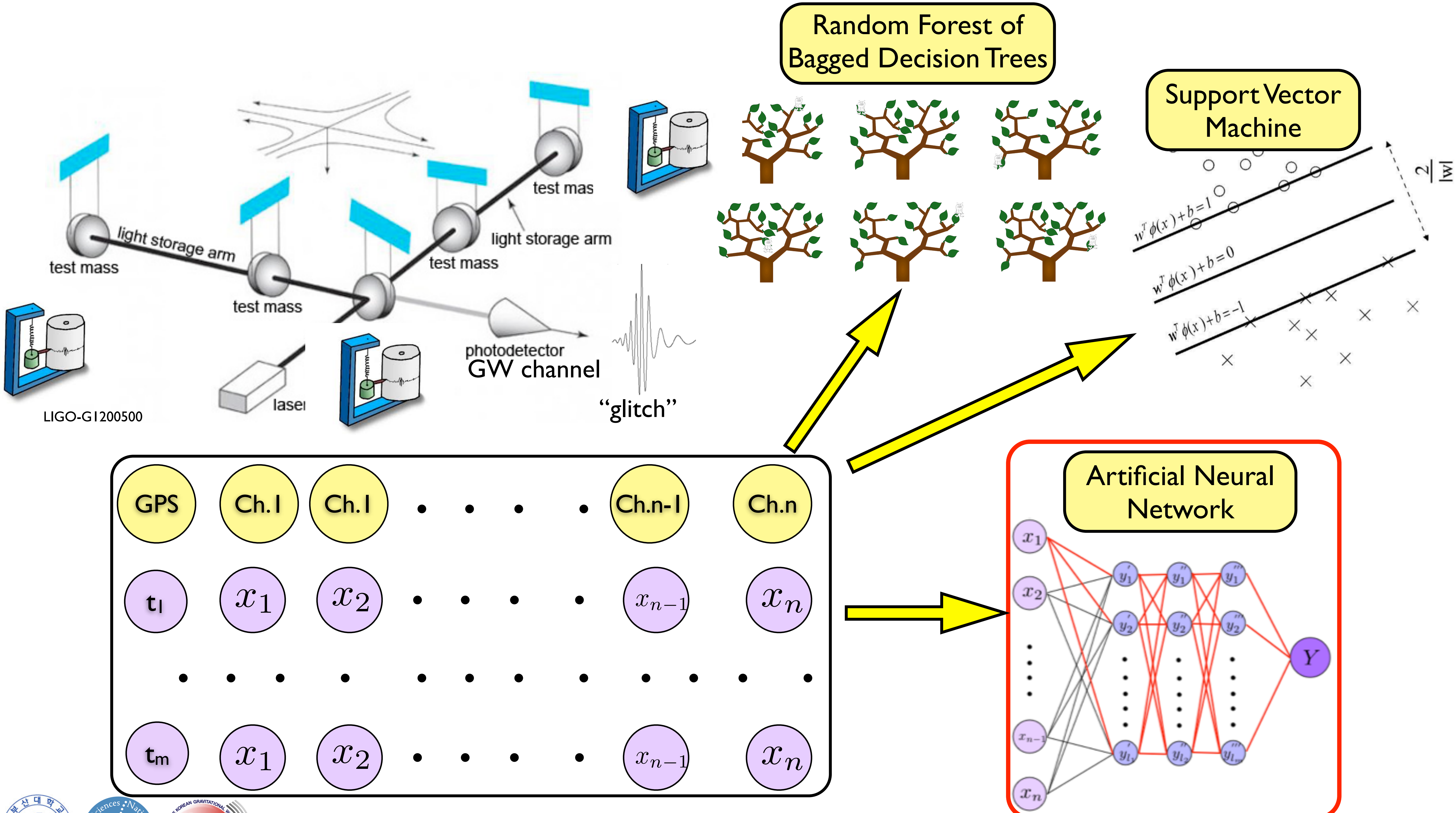
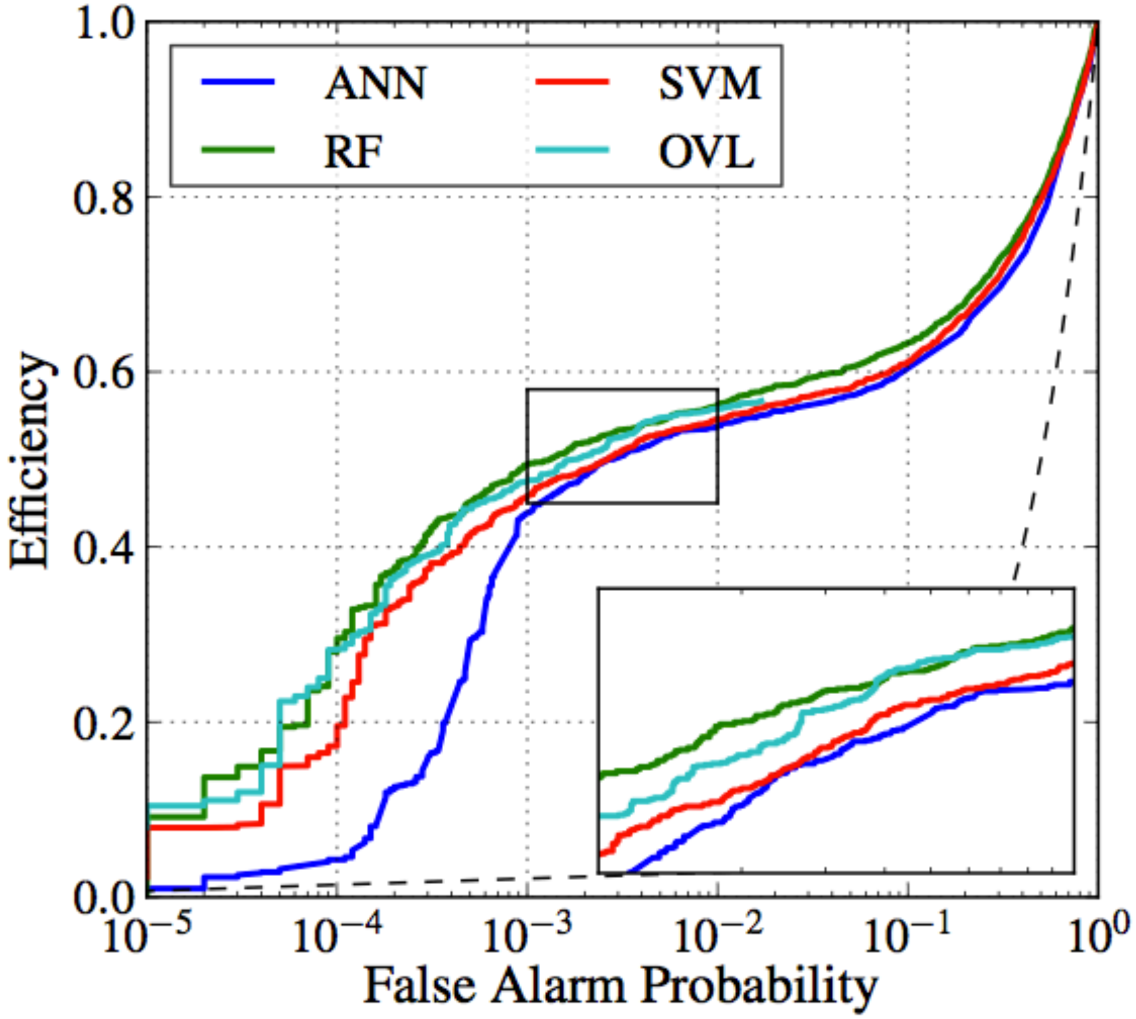
Goal

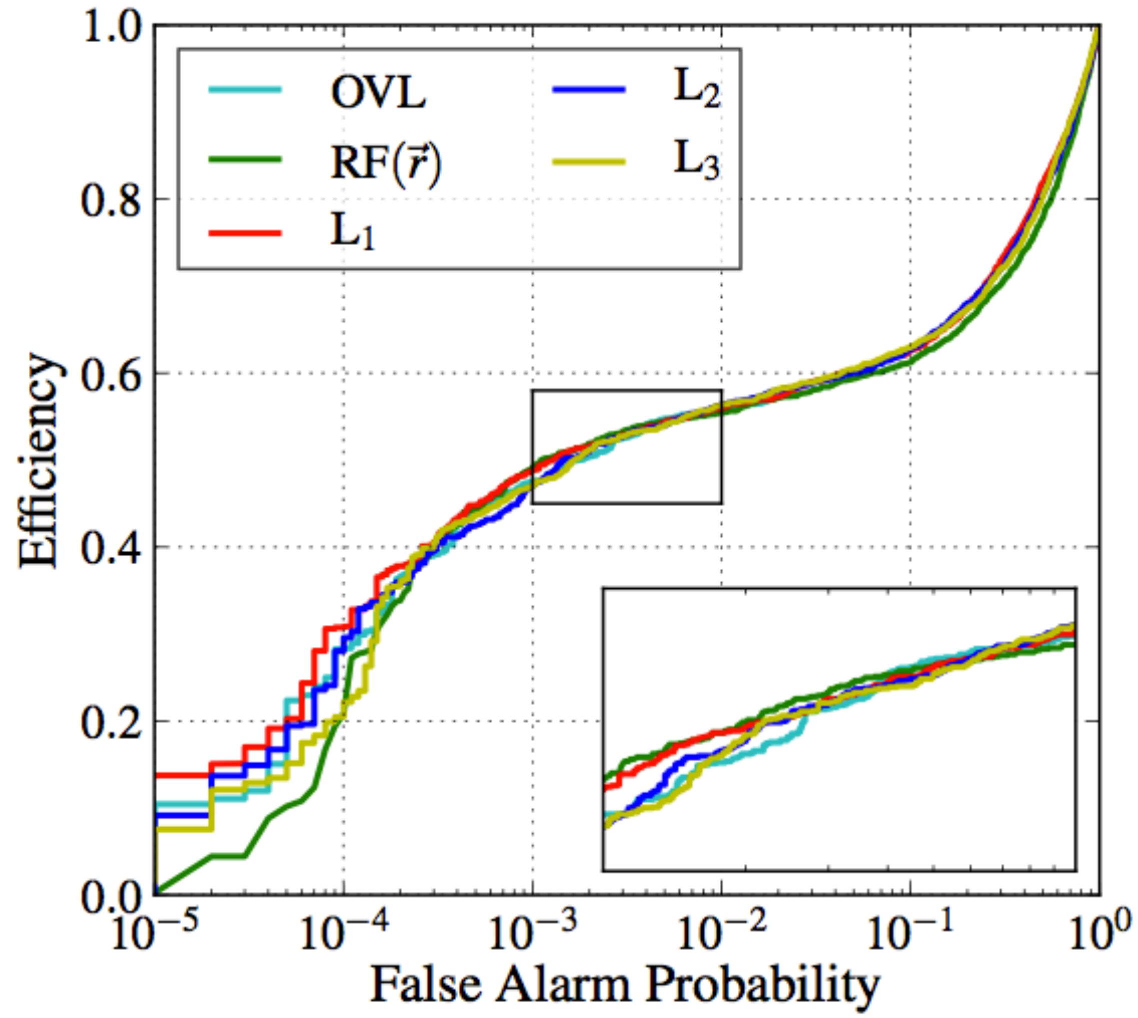
- Automate process of Glitch (non-gaussian noise transient) Identification in data preparation stage
  - Cleaning the data, monitoring, and feedback for commissioning or tuning

Multi-Variate Classifiers



AuxMVC - first draft



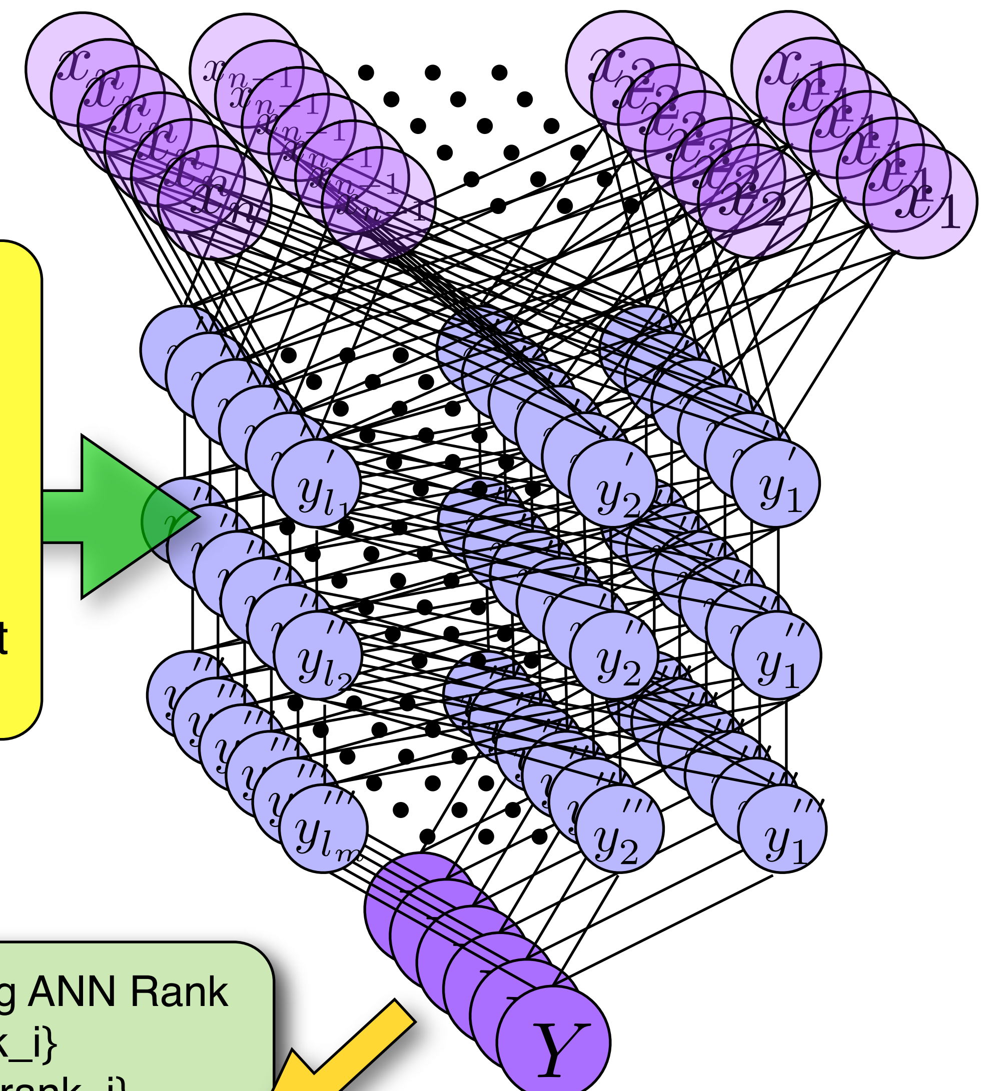


arxiv:1303.6984

Artificial Neural Networks Ensemble

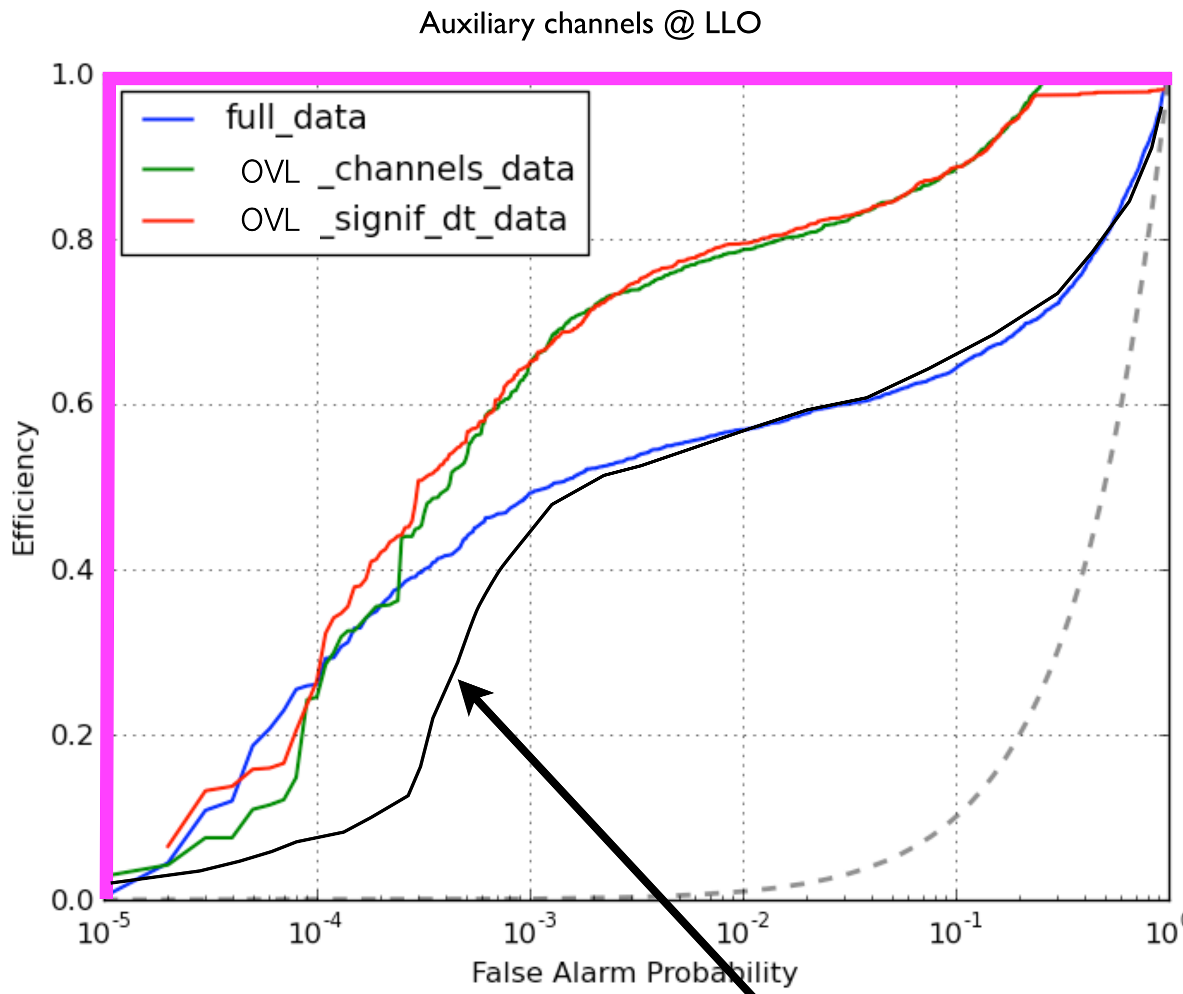
- Training Algorithm : GA (Montana & Davis, 2001), iRPROP(Igel & Hüsken, 2000)
- Evaluation : Direct application to trained network
  - ➡ tuning training parameters by hand, low complexity due to restricted network
  - ➡ over-trained ??
  - ➡ topological degeneracy from full connection
  - ➡ partial connections but random generation

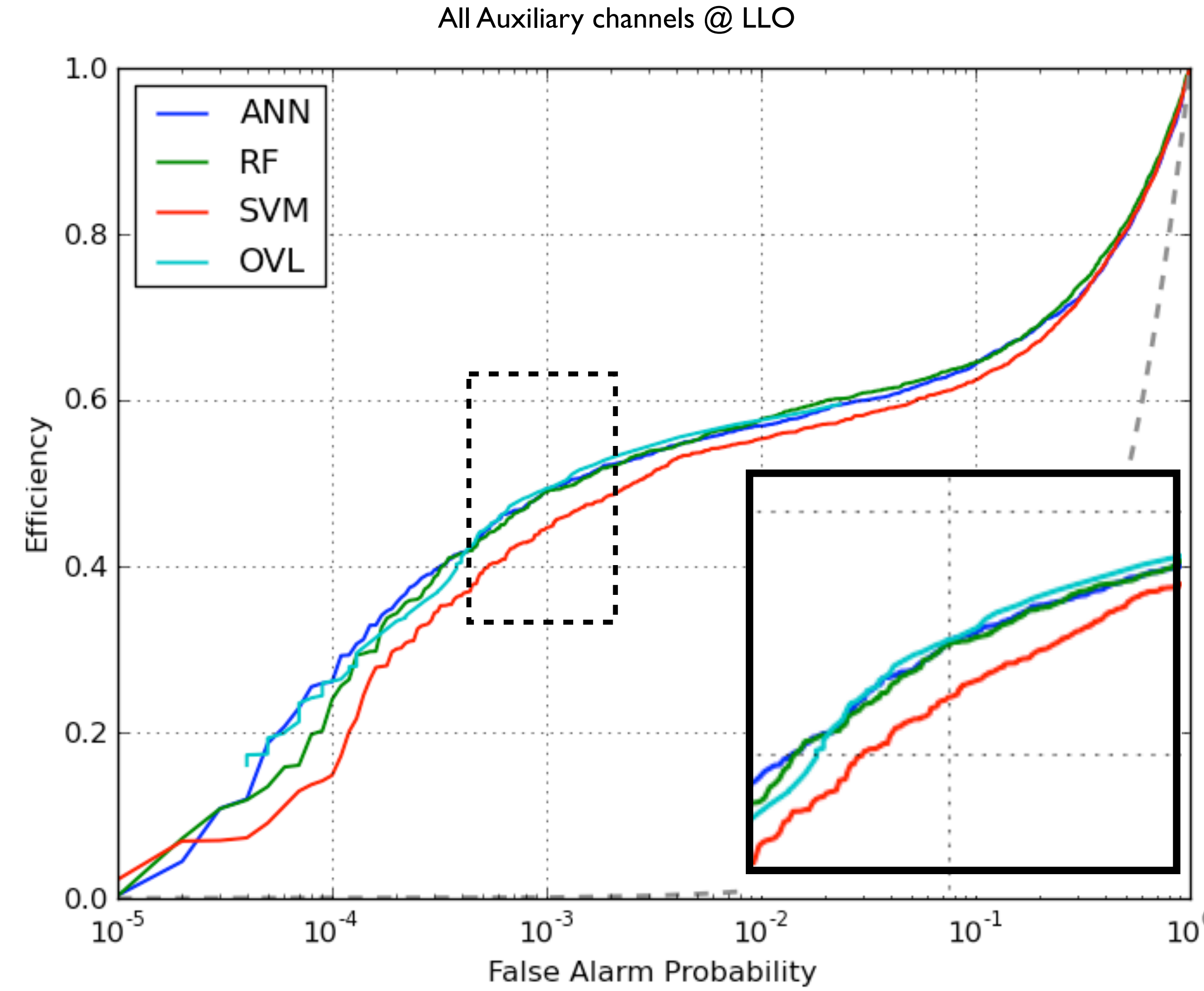
Use lots of trained neural networks for evaluation : Benchmarking Random Forest



Combining ANN Rank
- max{rank_i}
- average{rank_i}
- max{eff_i/fap_i}
- likelihood ratio
- something new ?

Application Results

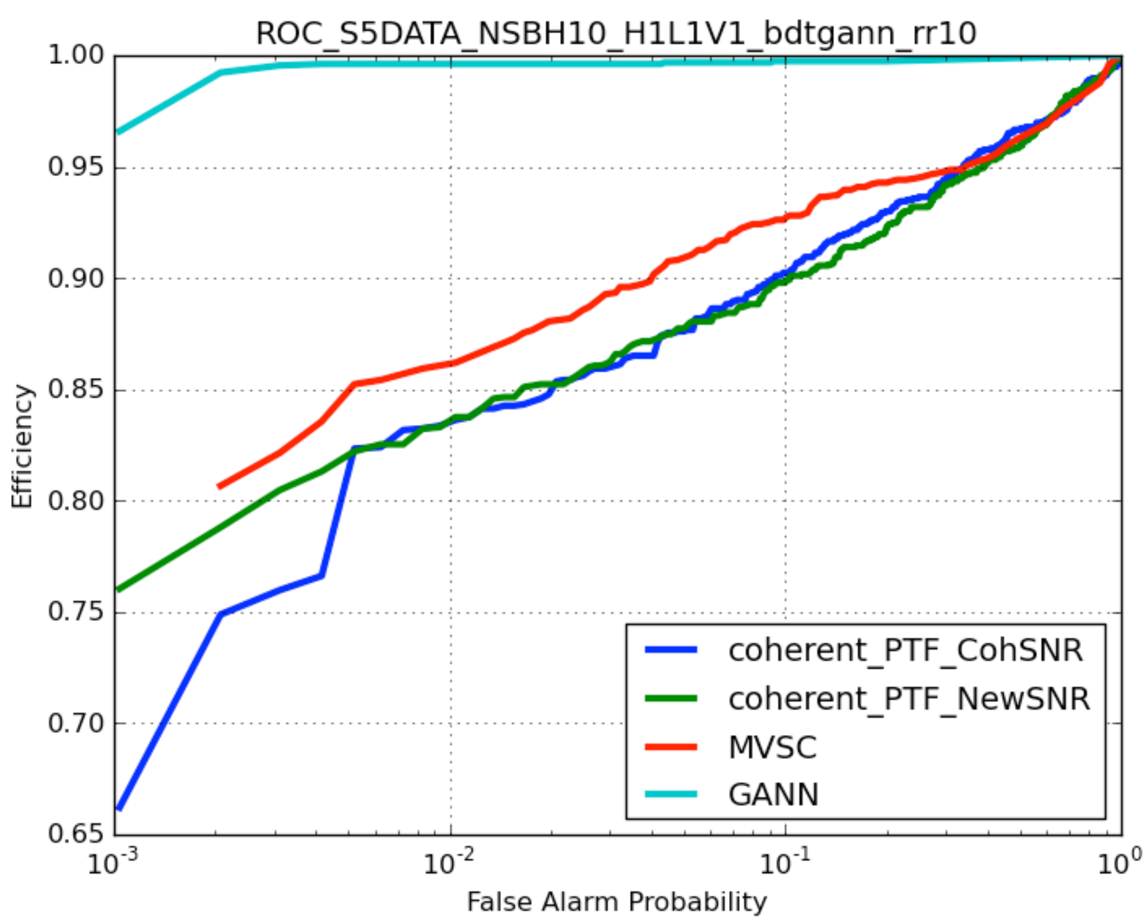




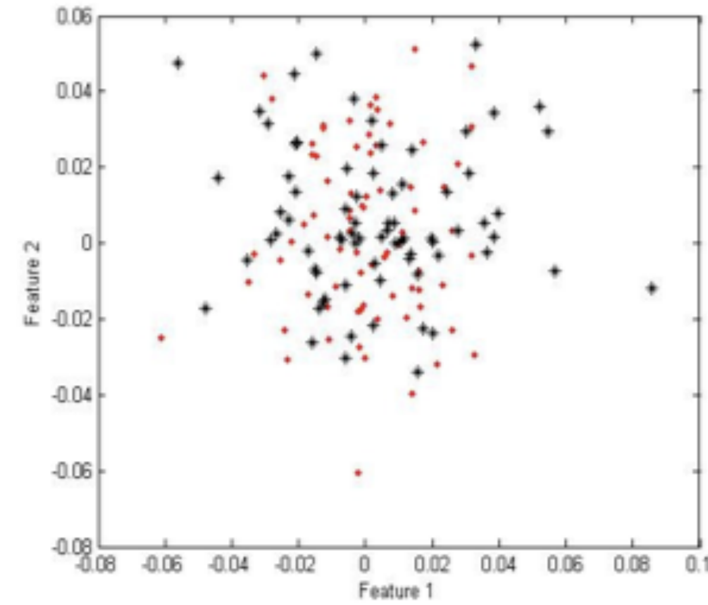
single network with full connection of limited number of neurons

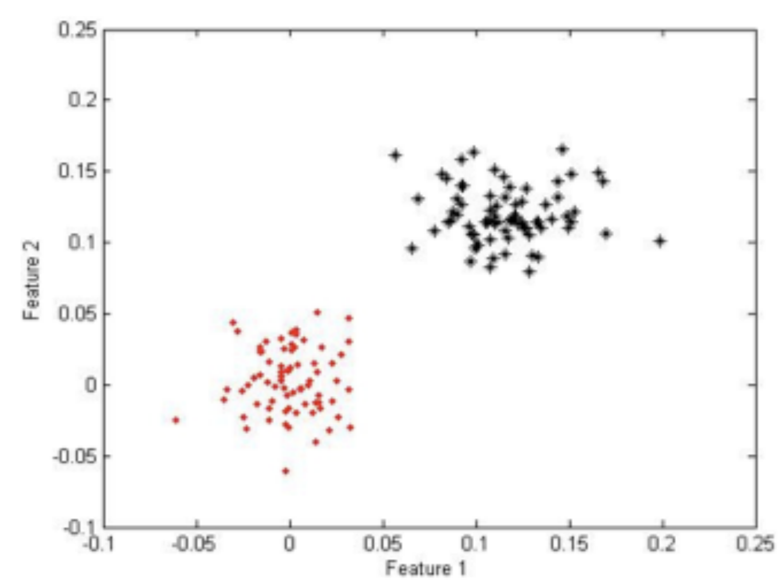
LIGO-G1201110

Q: Why AuxChannel Data So Different with GRB Data in the viewpoint of Multivariate Classifiers?



from Kyungmin Kim's presentation





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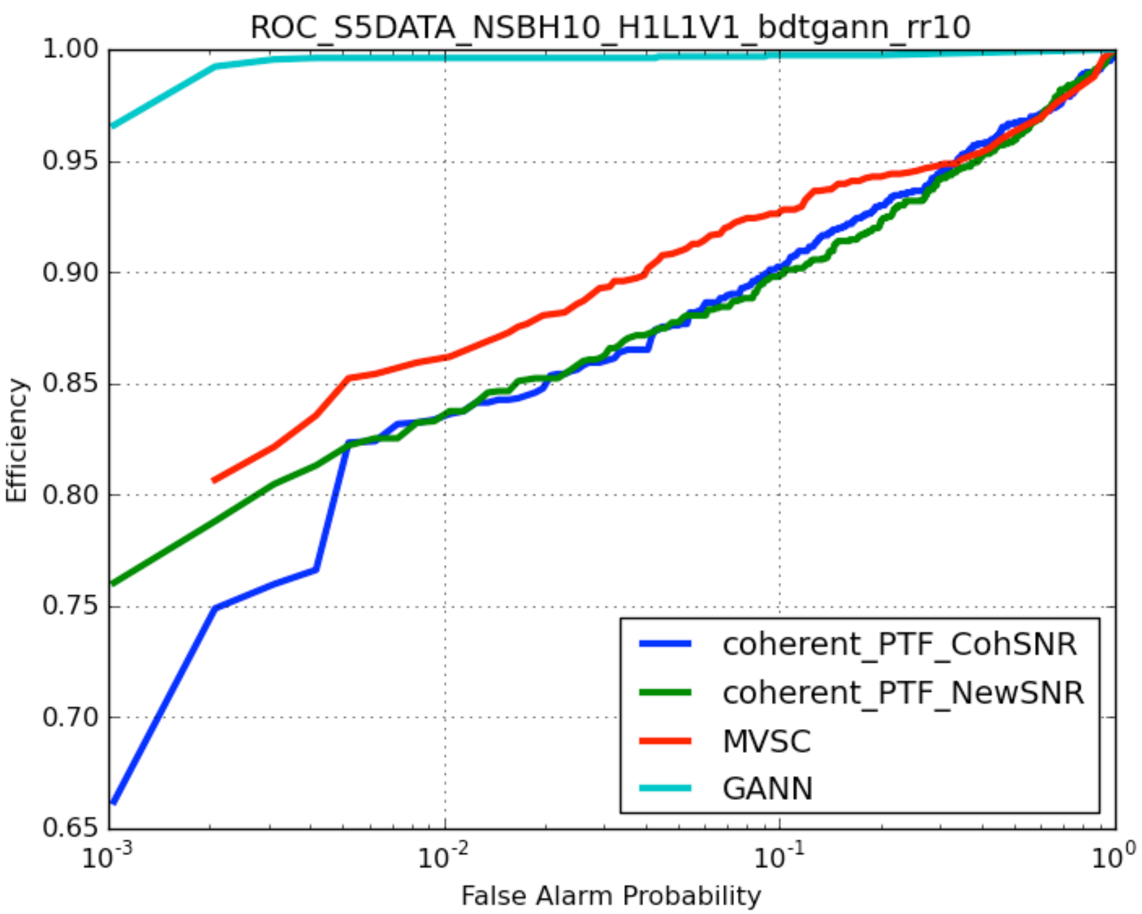

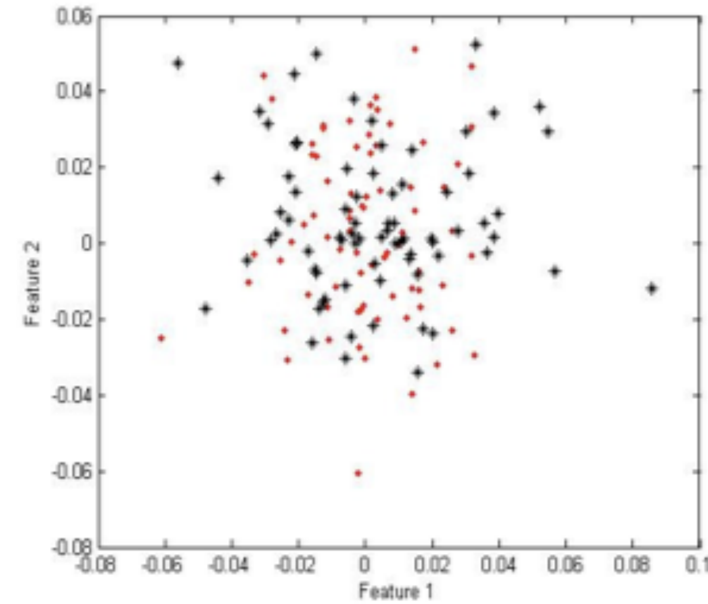

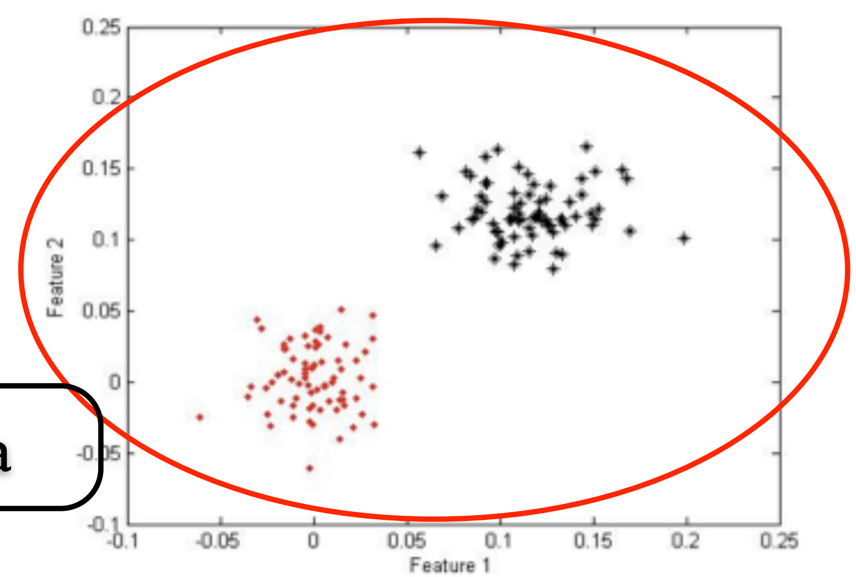

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CBC-GRB data

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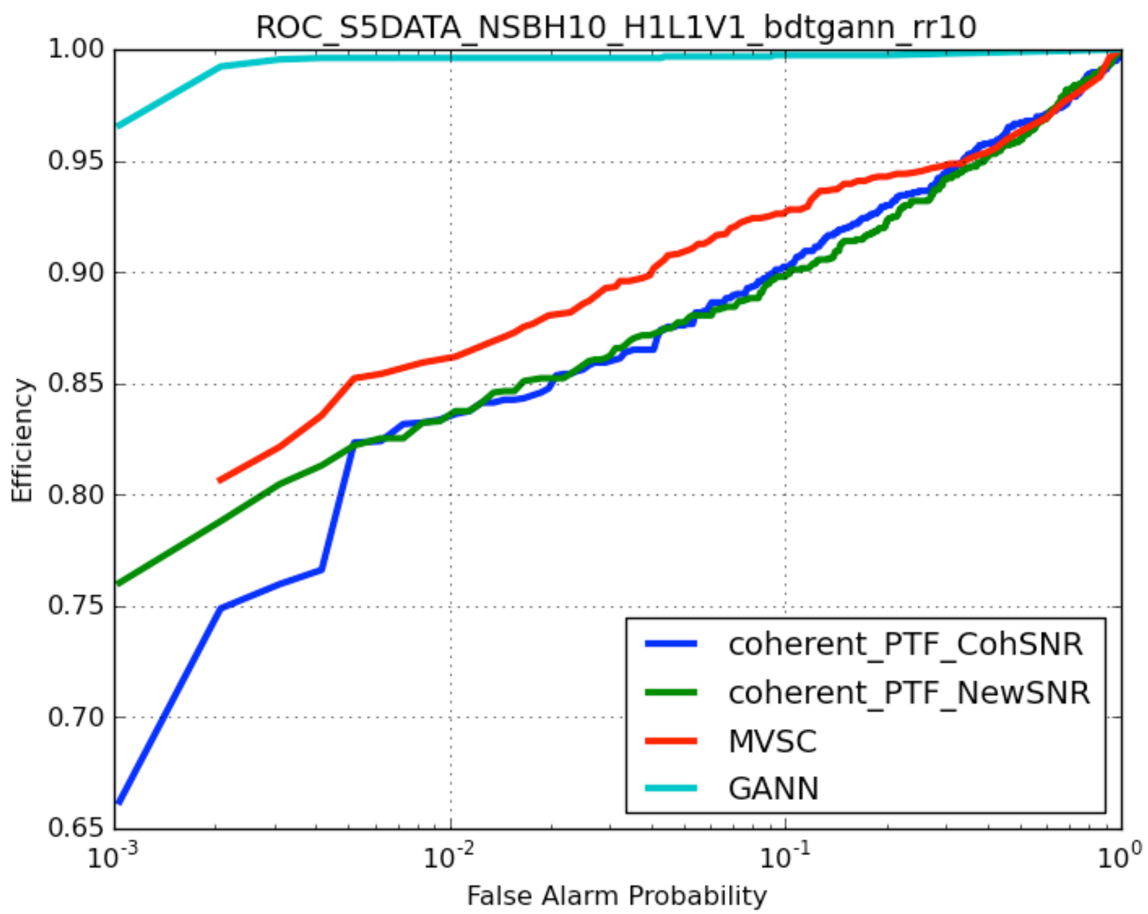
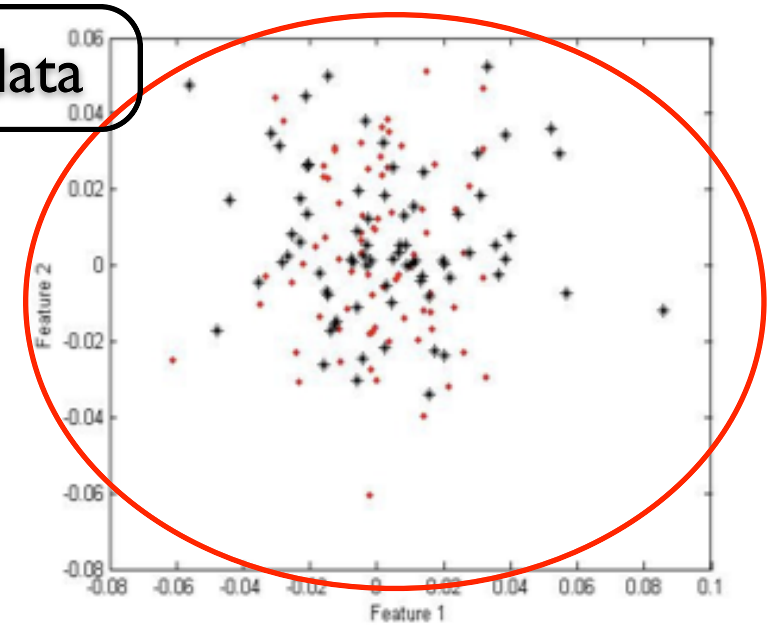


Auxiliary Ch. data



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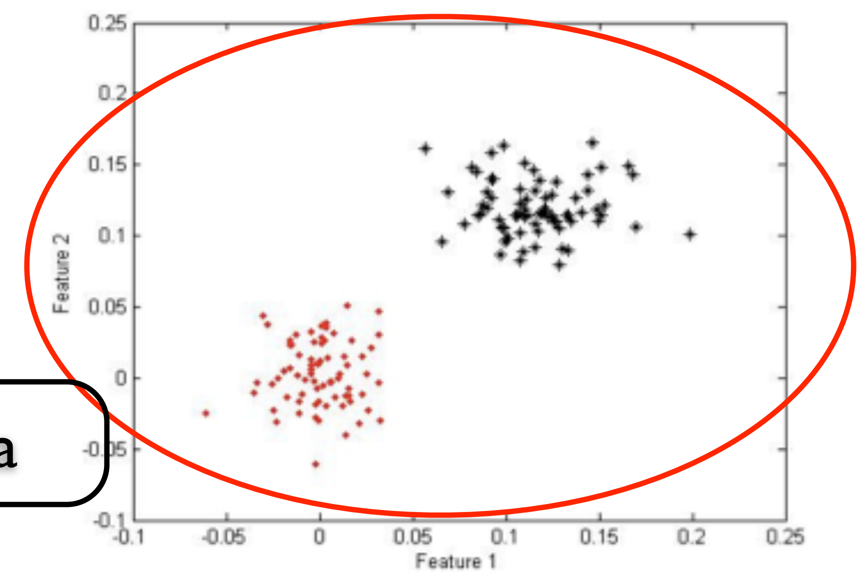
CBC-GRB data



Feature Selection : t - statistic

1. one-sample t-test

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}}$$

$$\begin{aligned} \bar{x} &= \text{sample mean} \\ s &= \text{sample standard deviation} \\ n &= \text{sample size} \\ \mu_0 &= \text{specific value} \end{aligned}$$

2. two-sample t-test

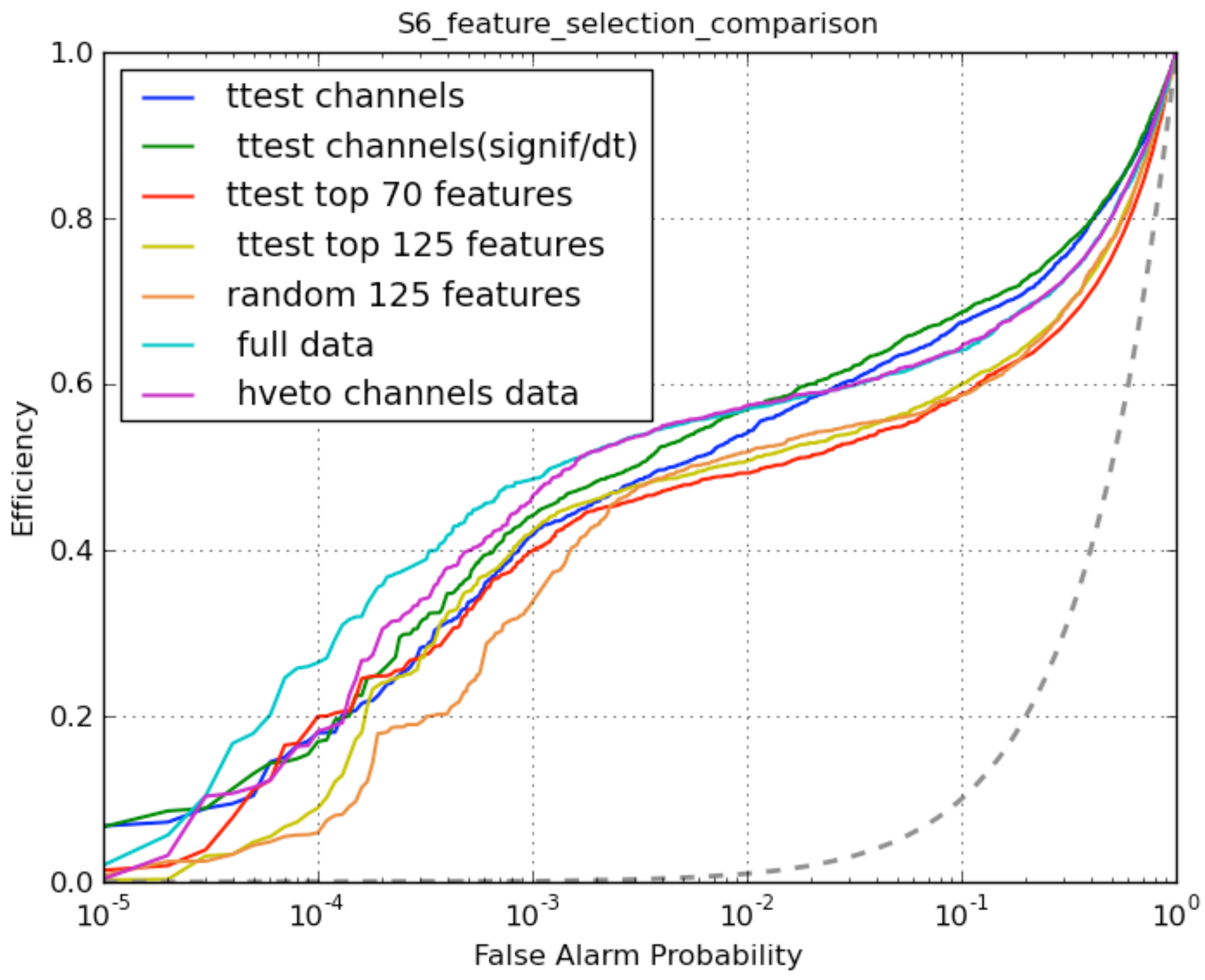
$$t = \frac{\overline{X}_1 - \overline{X}_2}{s_{\overline{X}_1 - \overline{X}_2}}$$

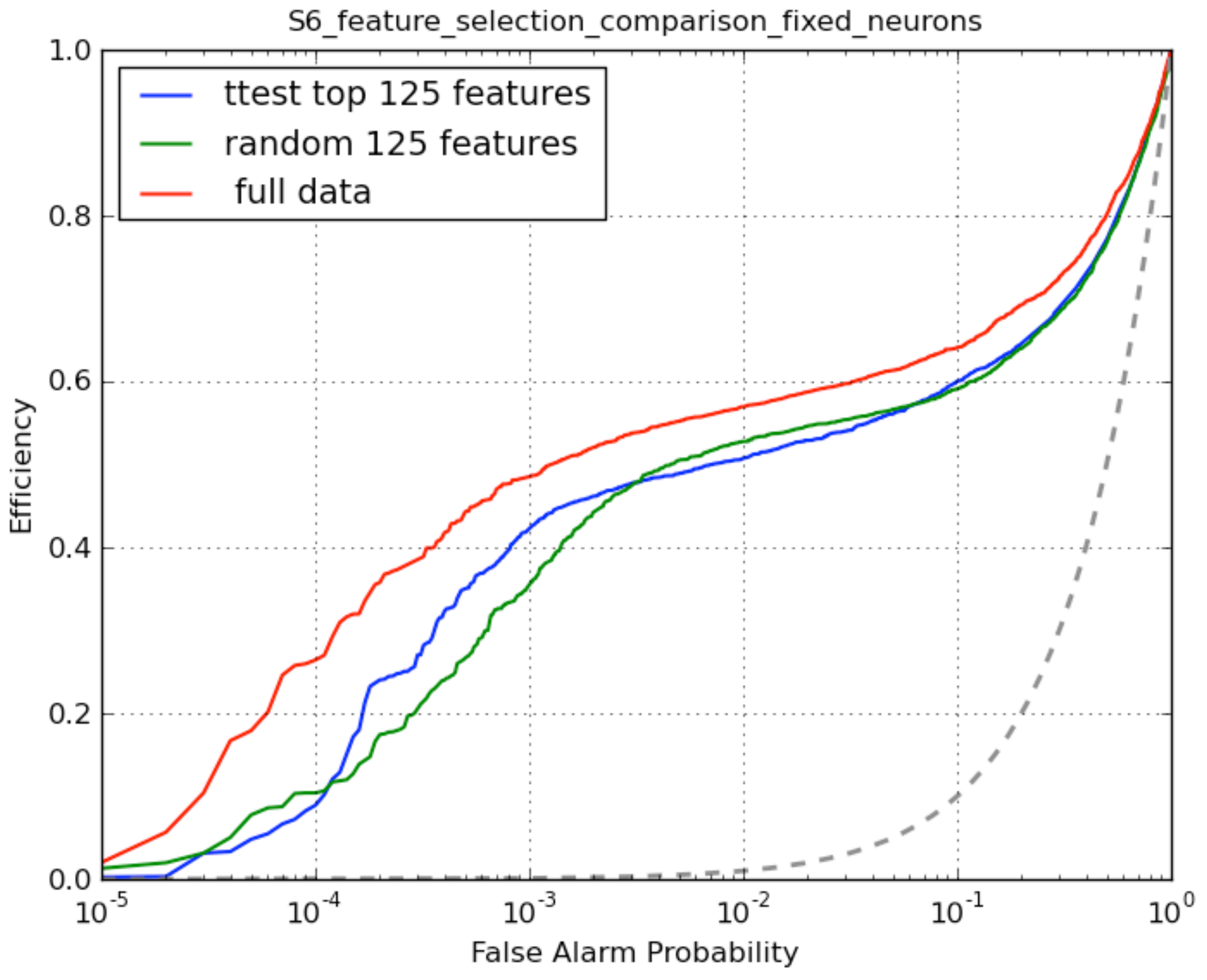
$$s_{\overline{X}_1 - \overline{X}_2} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}.$$

$$\begin{aligned} \bar{X}_i &= \text{sample mean of class i} \\ s_i &= \text{sample standard deviation of class i} \\ n_i &= \text{sample size of class i} \end{aligned}$$

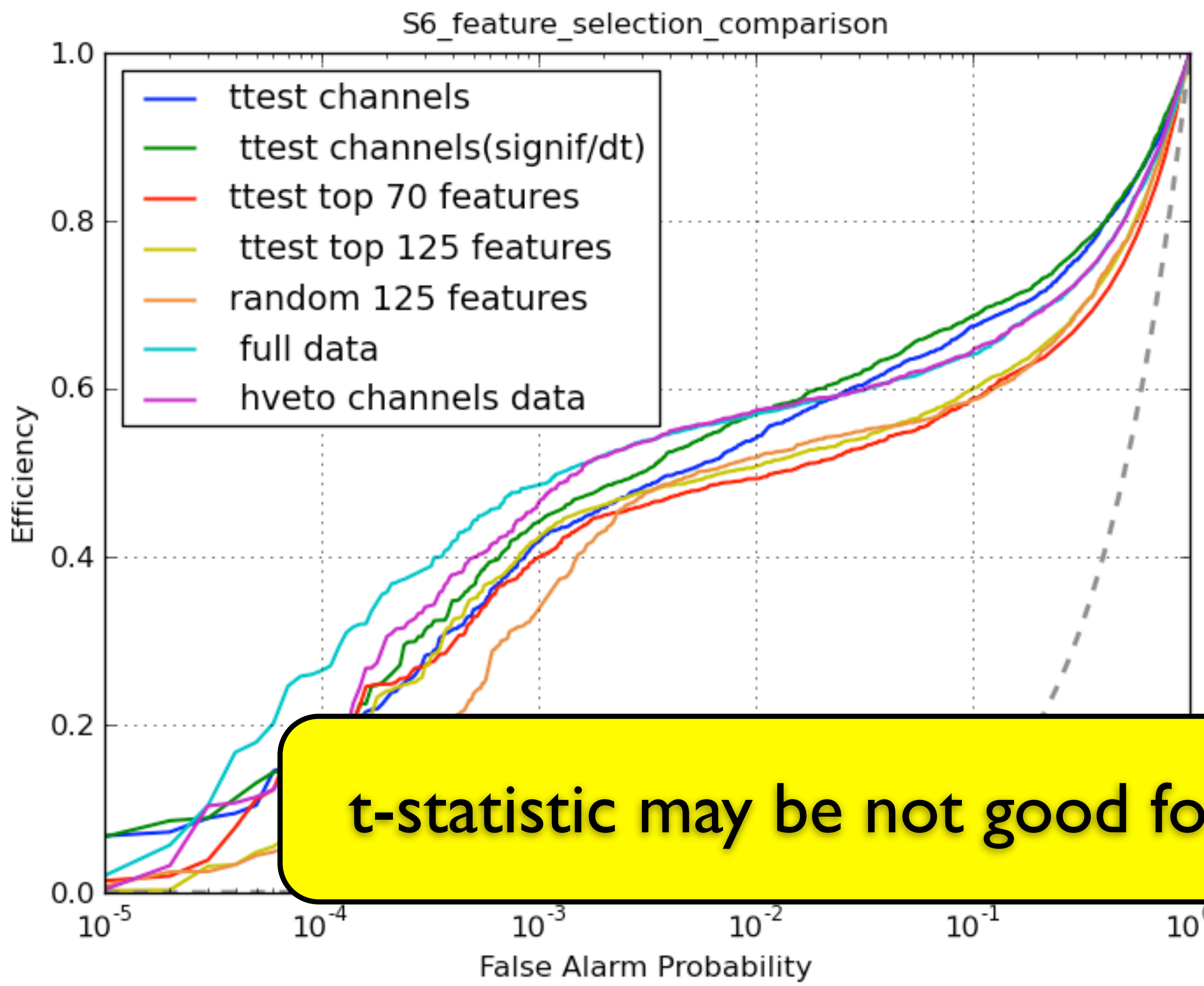
test on each auxiliary channel

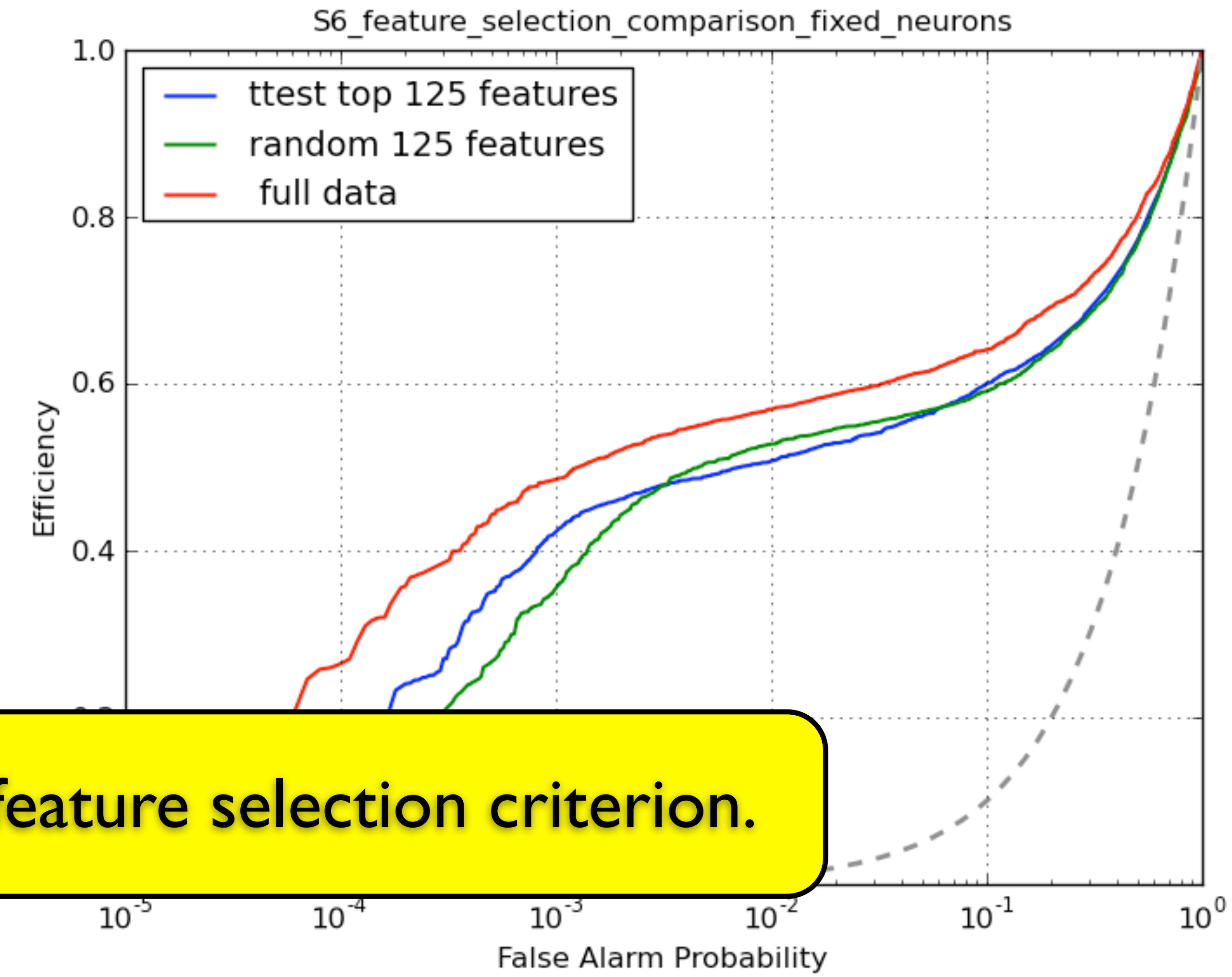
ROC performances of t-test features





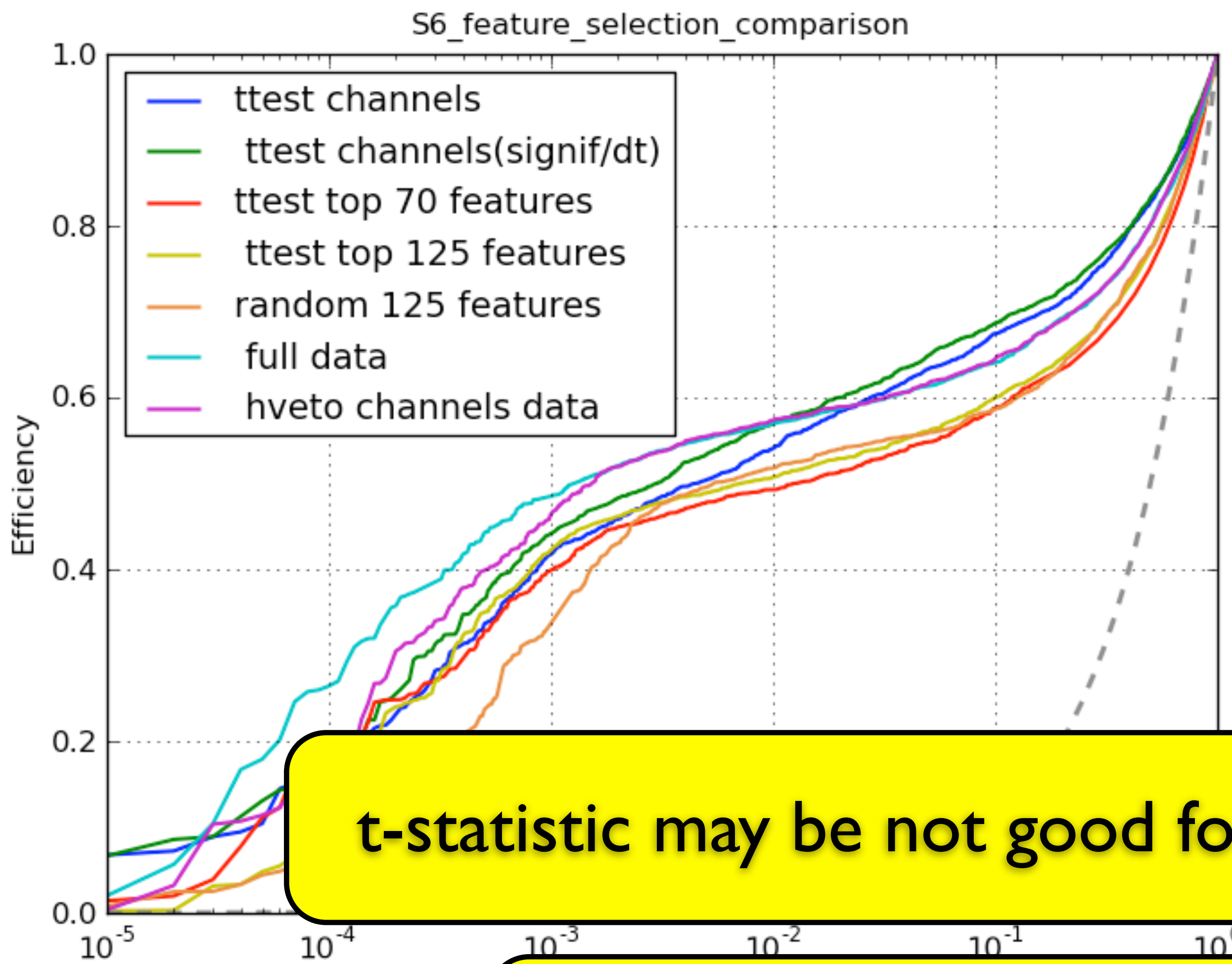
ROC performances of t-test features

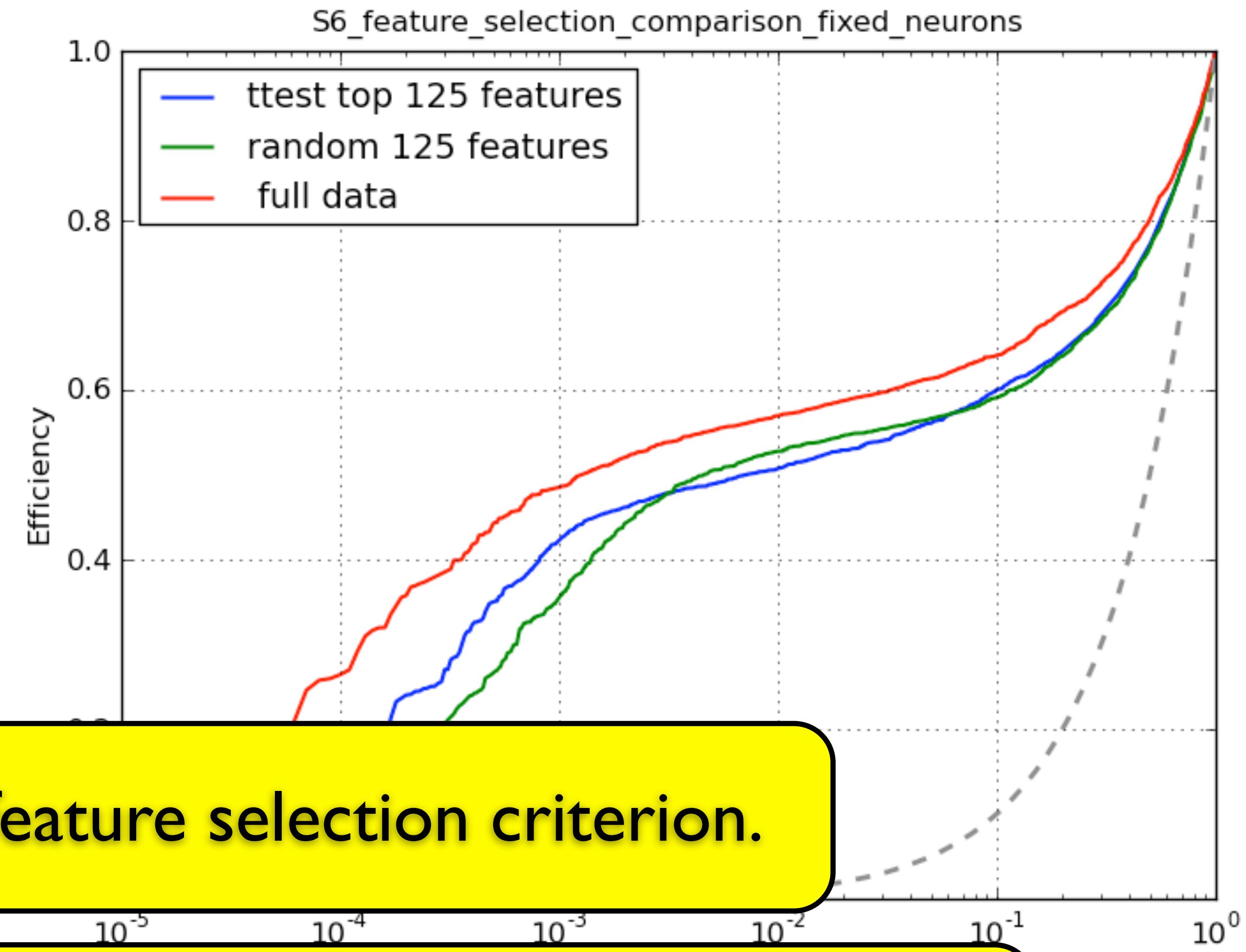




t-statistic may be not good for feature selection criterion.

ROC performances of t-test features

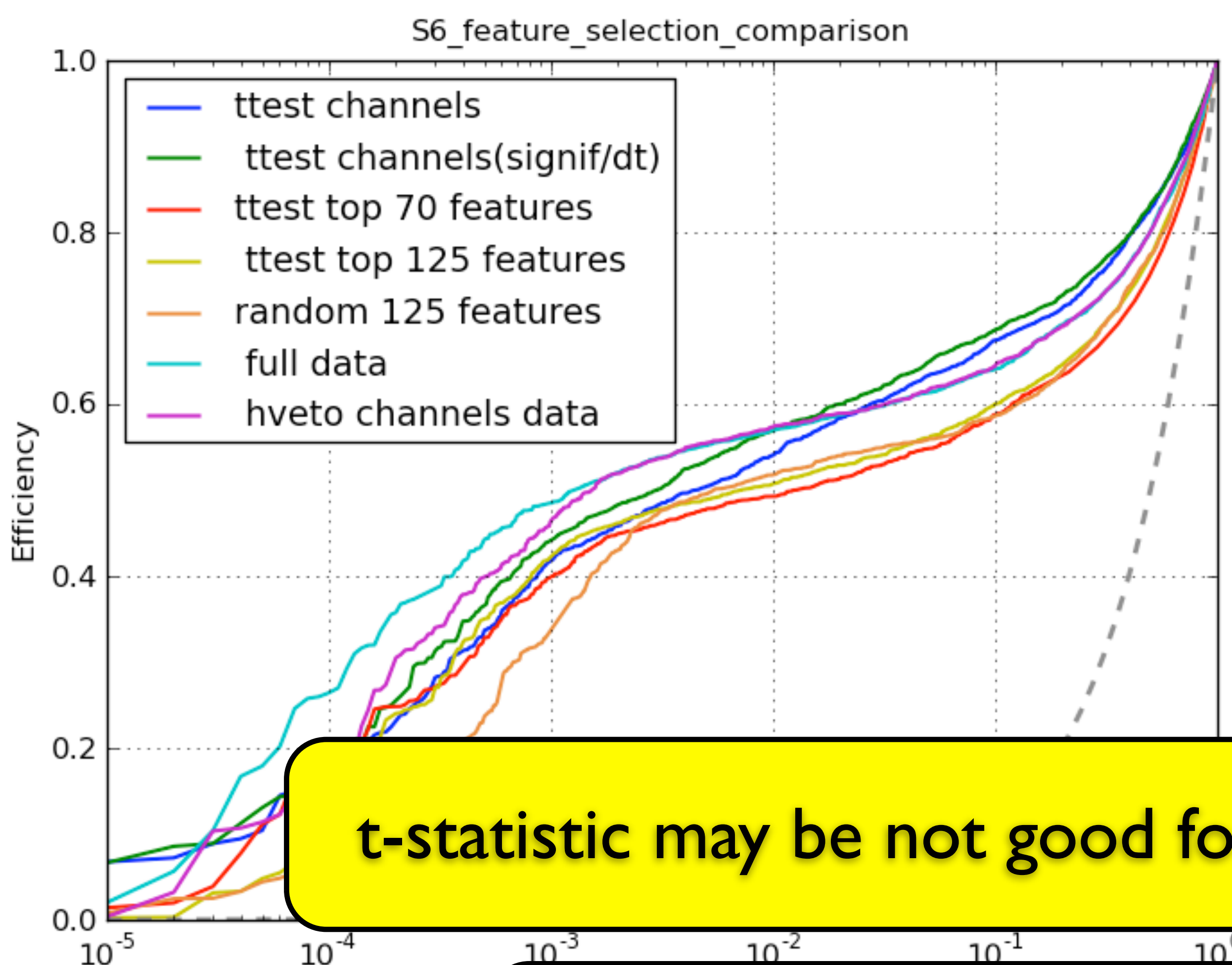


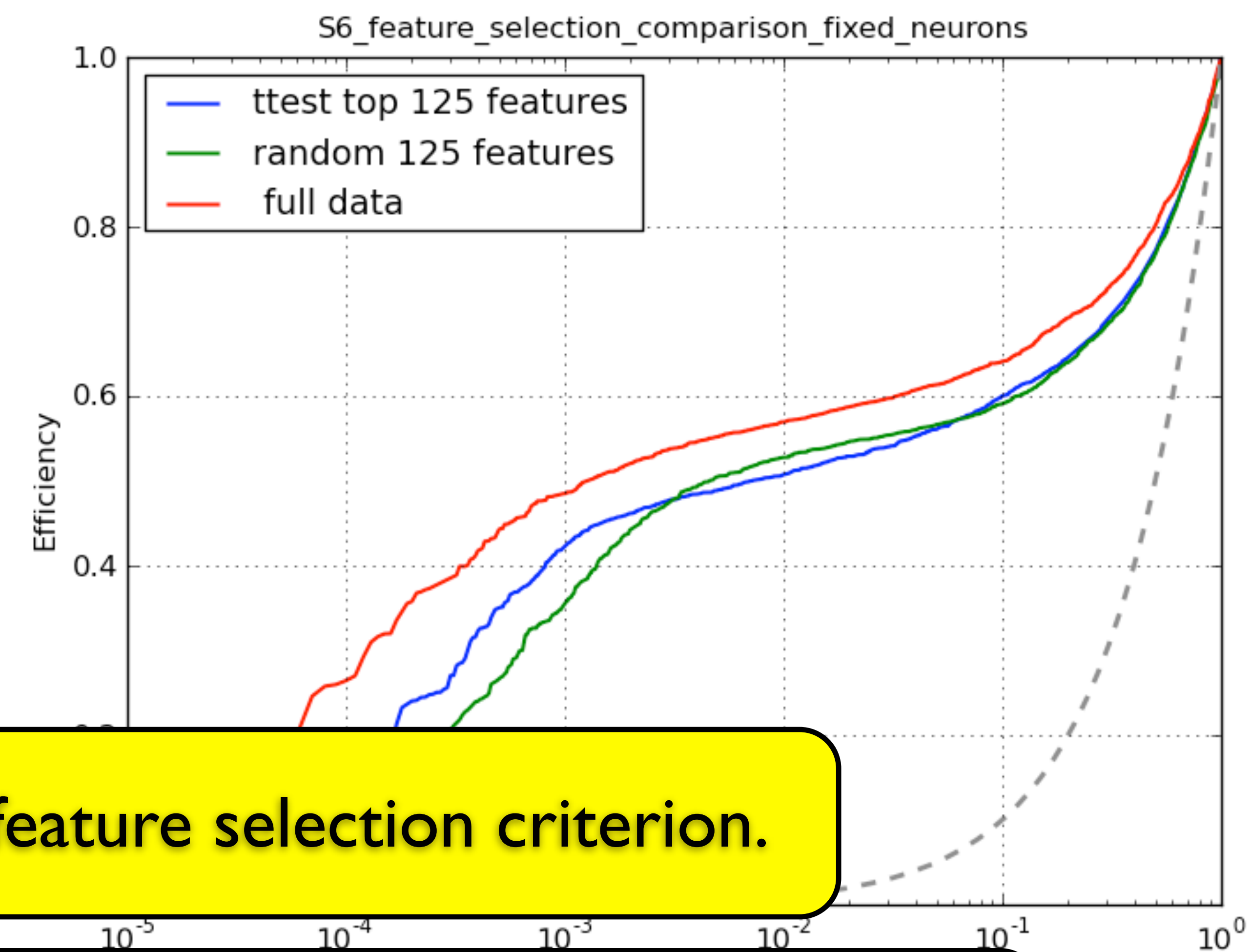


t-statistic may be not good for feature selection criterion.

Feature selection is still needed for better performance.

ROC performances of t-test features





t-statistic may be not good for feature selection criterion.

Feature selection is still needed for better performance.

Deferent input information is needed.

Goal

- Automate process of Glitch (non-gaussian noise transient) Identification in data preparation stage
  - Cleaning the data, monitoring, and feedback for commissioning or tuning
- Inclusion of different information which current input data (KW triggers) may not contain.
  - consideration of different trigger generation algorithm

Trigger Generation methods

1. KleineWelle algorithm (Current trigger generation)
2. Omega pipeline (Q-transformation)
3. Excess Power
4. Omicron pipeline
5. GSTLAL pipeline
6. Or Something NEW ???

The Hilbert-Huang Transformation

- Hilbert Transformation + Empirical Mode Decomposition
  - Decomposition of complicated data into a collection of Intrinsic Mode Function (IMF)
- It works well for non-stationary and non-linear data.
- Preliminary study of HHT on GW data analysis.
  - J. B. Camp et al, "Application of the Hilbert-Huang transformation to the search for gravitational waves" PRD 75, 061101 (2007)
  - A. Stroeer et al, "Methods for detection and characterization of signals in noisy data with the Hilbert-Huang transformation", PRD 79, 124022 (2009)

Hilbert transform

[wikipedia.org]

- In mathematics and in signal processing, the Hilbert transform is a linear operator which takes a function, u(t), and produces a function, H[u](t), with the same domain.

$$\mathcal{H}[u](t) = \frac{1}{\pi}\mathcal{P}\int_{-\infty}^{\infty} \frac{u(\tau)}{t-\tau} d\tau$$

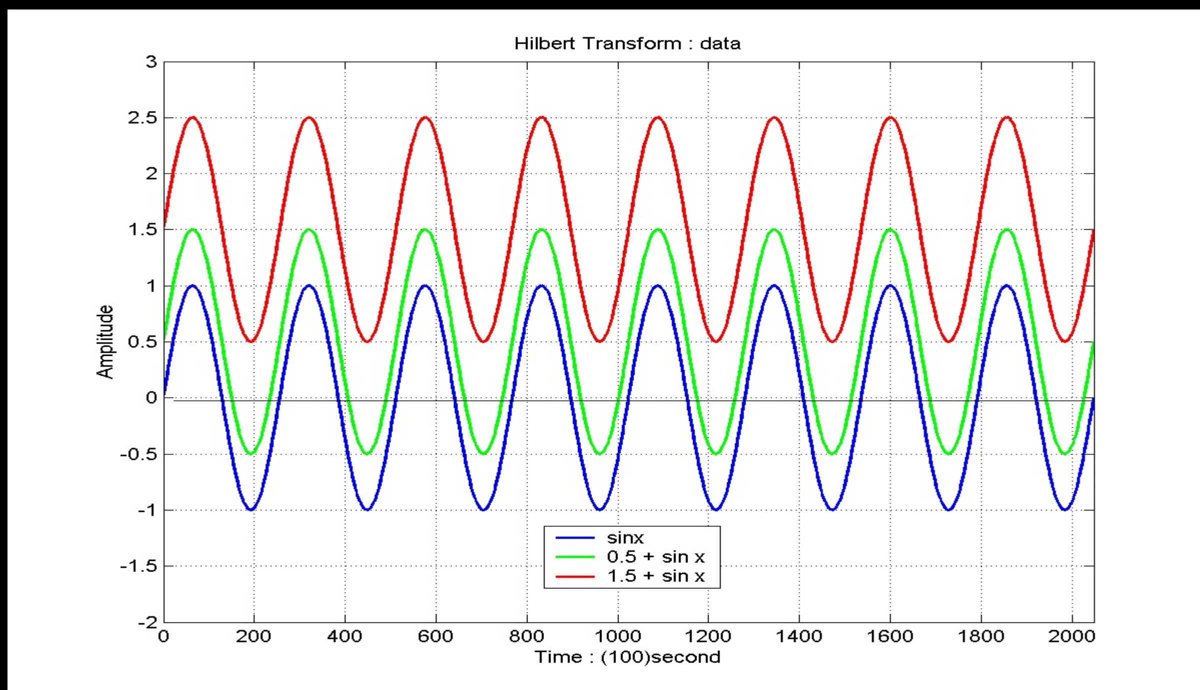
- Complexify:

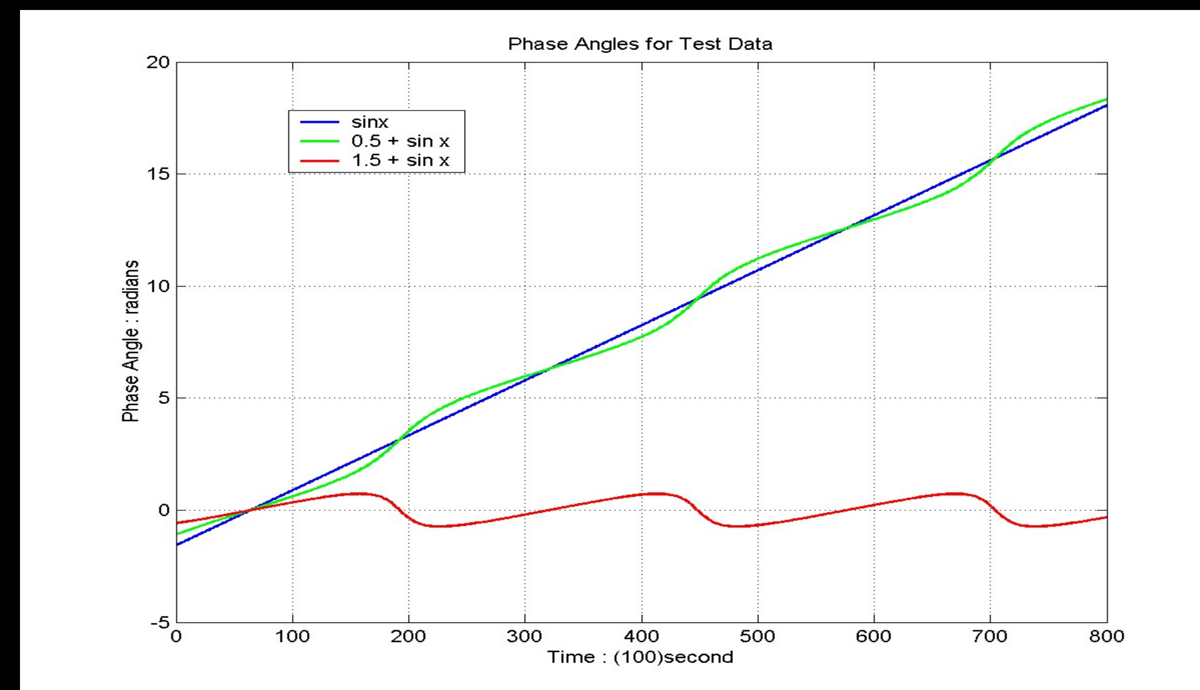
$$z(t) = u(t) + i\ \mathcal{H}[u](t) = a(t)e^{i\theta(t)}$$

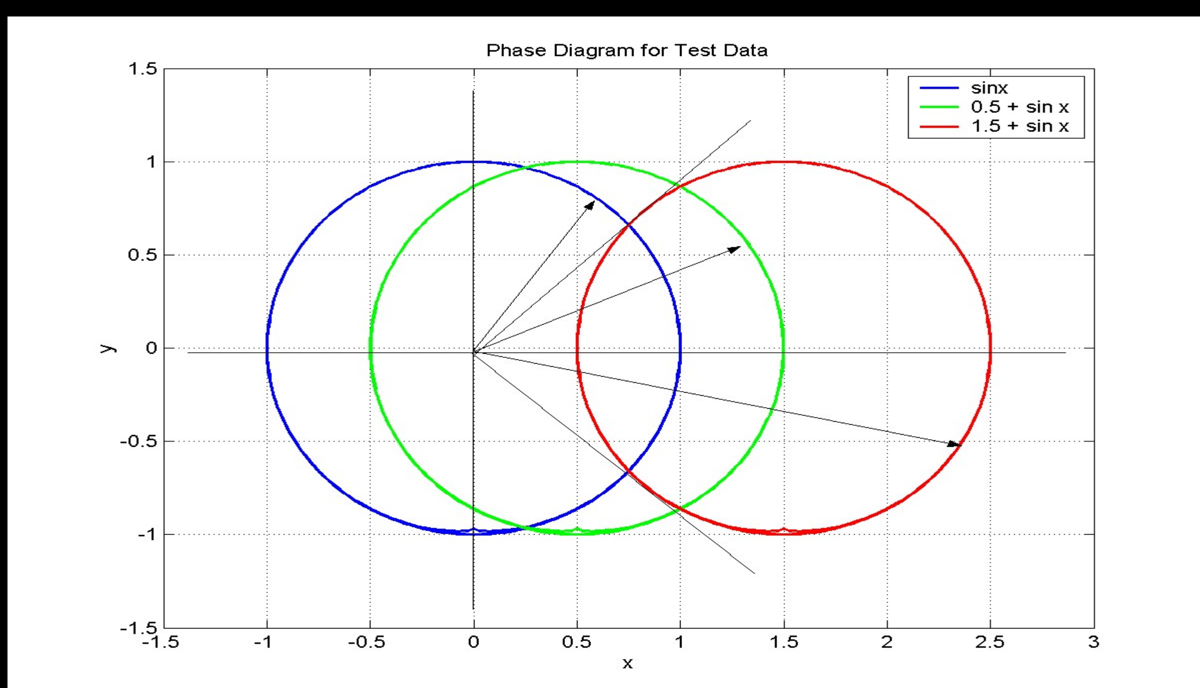
- Relationship with the Fourier transform:

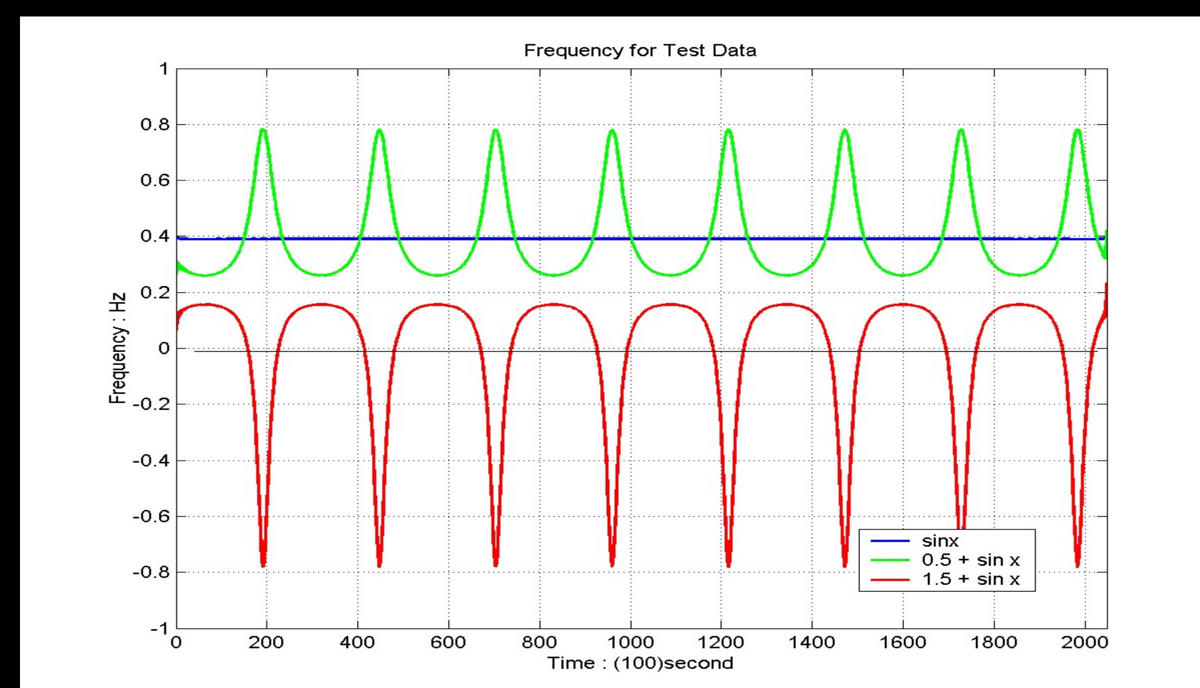
$$\mathcal{F}\left[\mathcal{H}[u]\right](\omega) = -i\ \mathrm{sgn}(\omega)\mathcal{F}[u](\omega)$$

A problem of traditional Hilbert transform



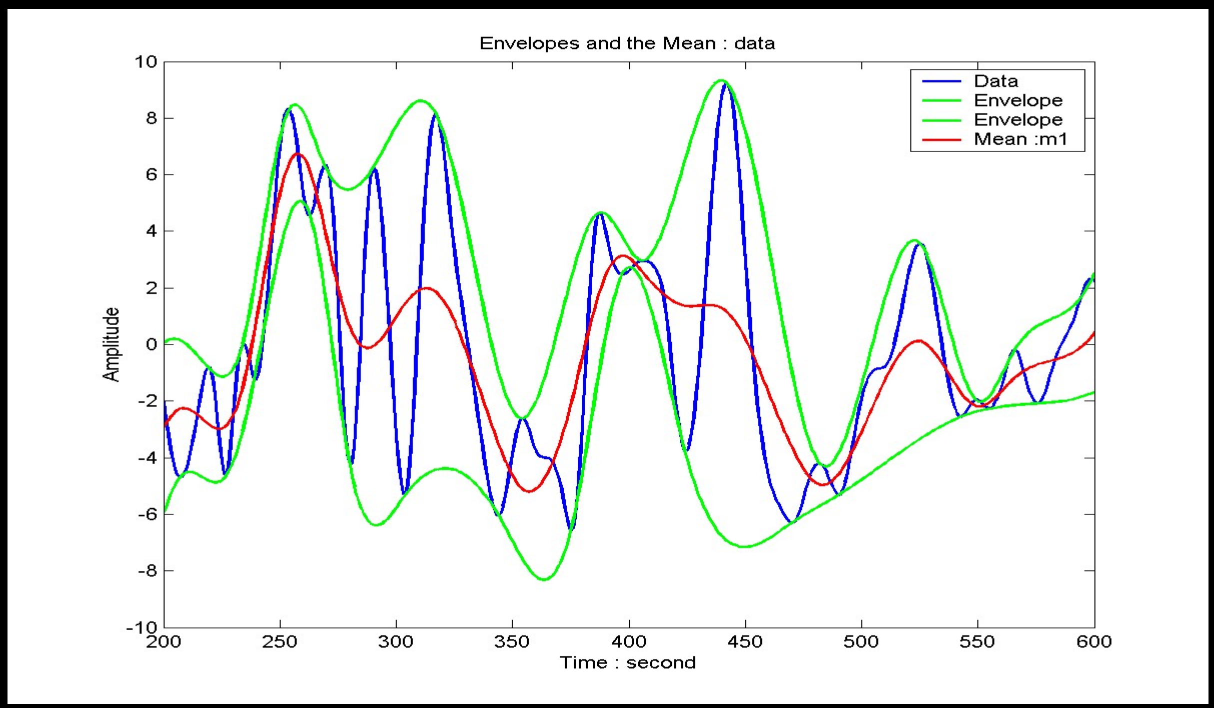


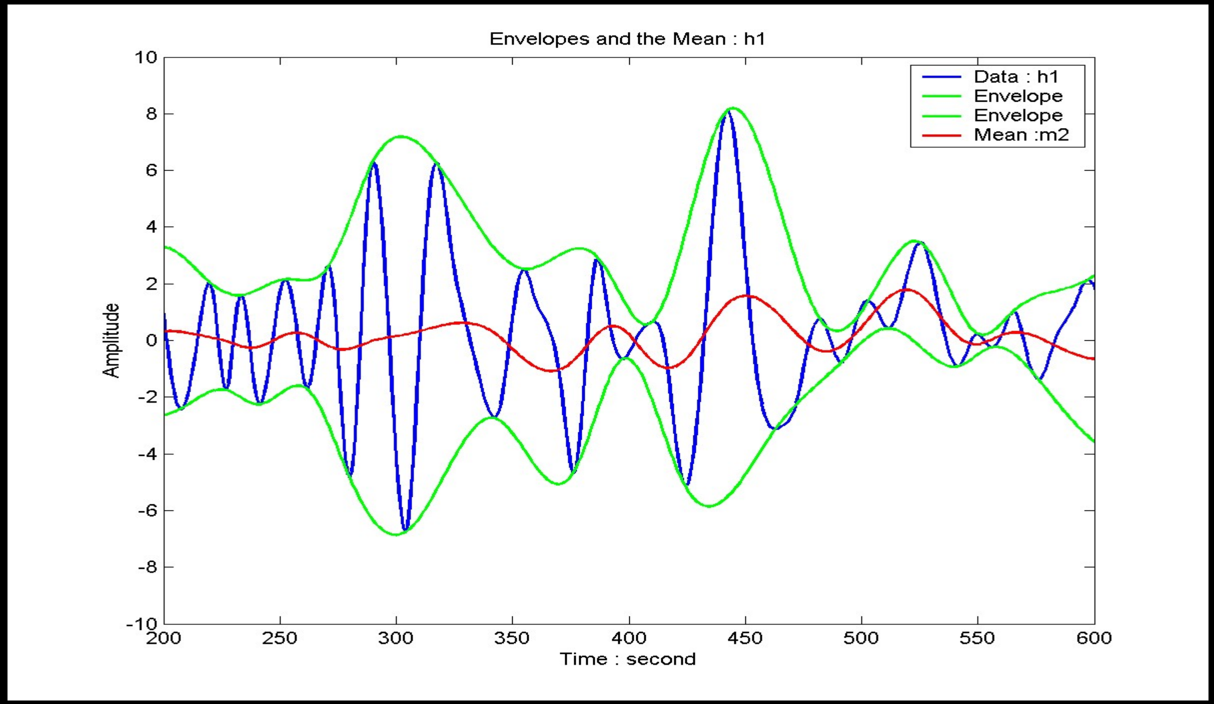




[Courtesy: Norden E. Huang]

Empirical Mode Decomposition (EMD)





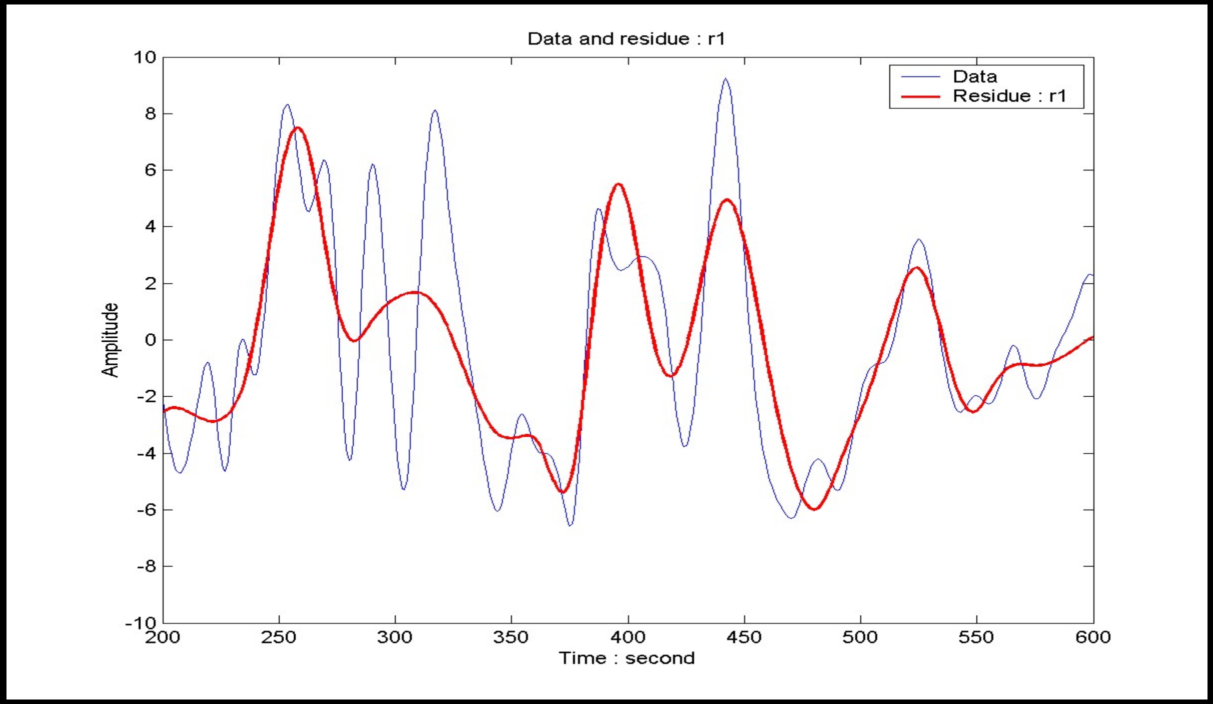
"Sifting"

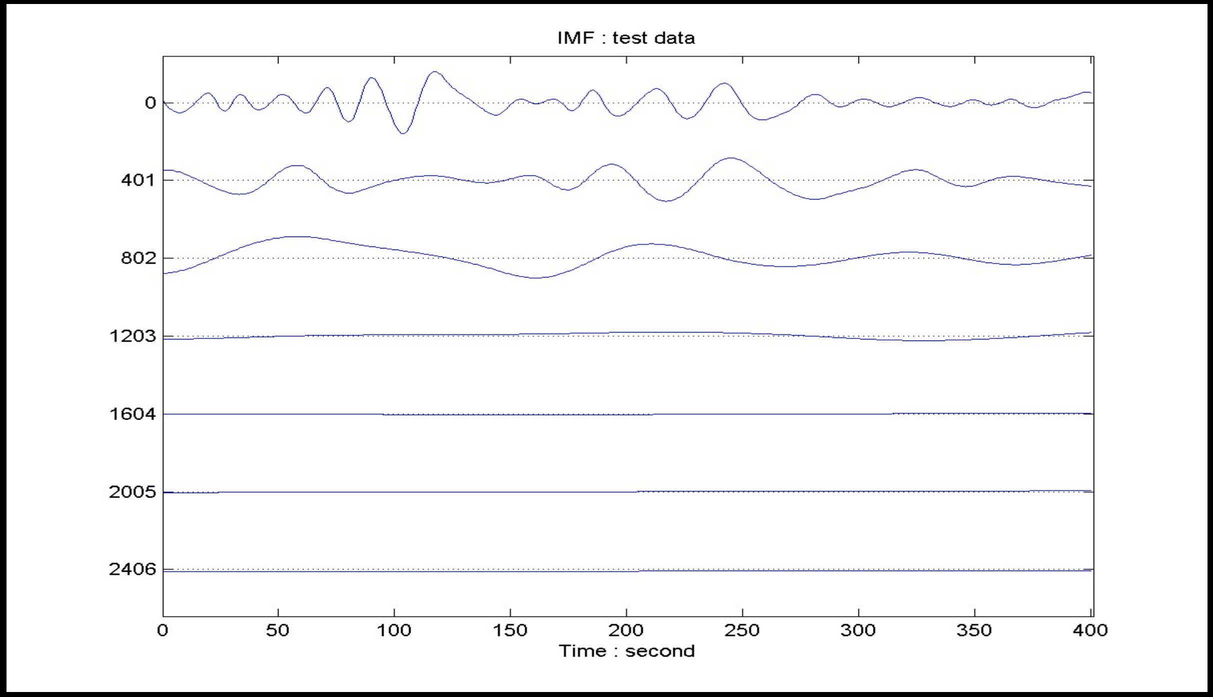
$$u(t) - m_1 = h_1,$$
$$h_1 - m_2 = h_2,$$
$$\vdots$$
$$h_{k-1} - m_k = h_k \equiv c_1$$
$$\Rightarrow u(t) - c_1 \equiv r_1 = \sum_i m_i$$

$$SD = \frac{\sum_t |h_{k-1}(t) - h_k(t)|^2}{\sum_t h_{k-1}^2(t)}$$

[Courtesy: Norden E. Huang]

Intrinsic Mode Function (IMF)





$$u(t) - c_1 = r_1,$$
$$r_1 - c_2 = r_2,$$
$$\vdots$$
$$r_{n-1} - c_n = r_n$$
$$\Rightarrow u(t) - \sum_j c_j = r_n$$

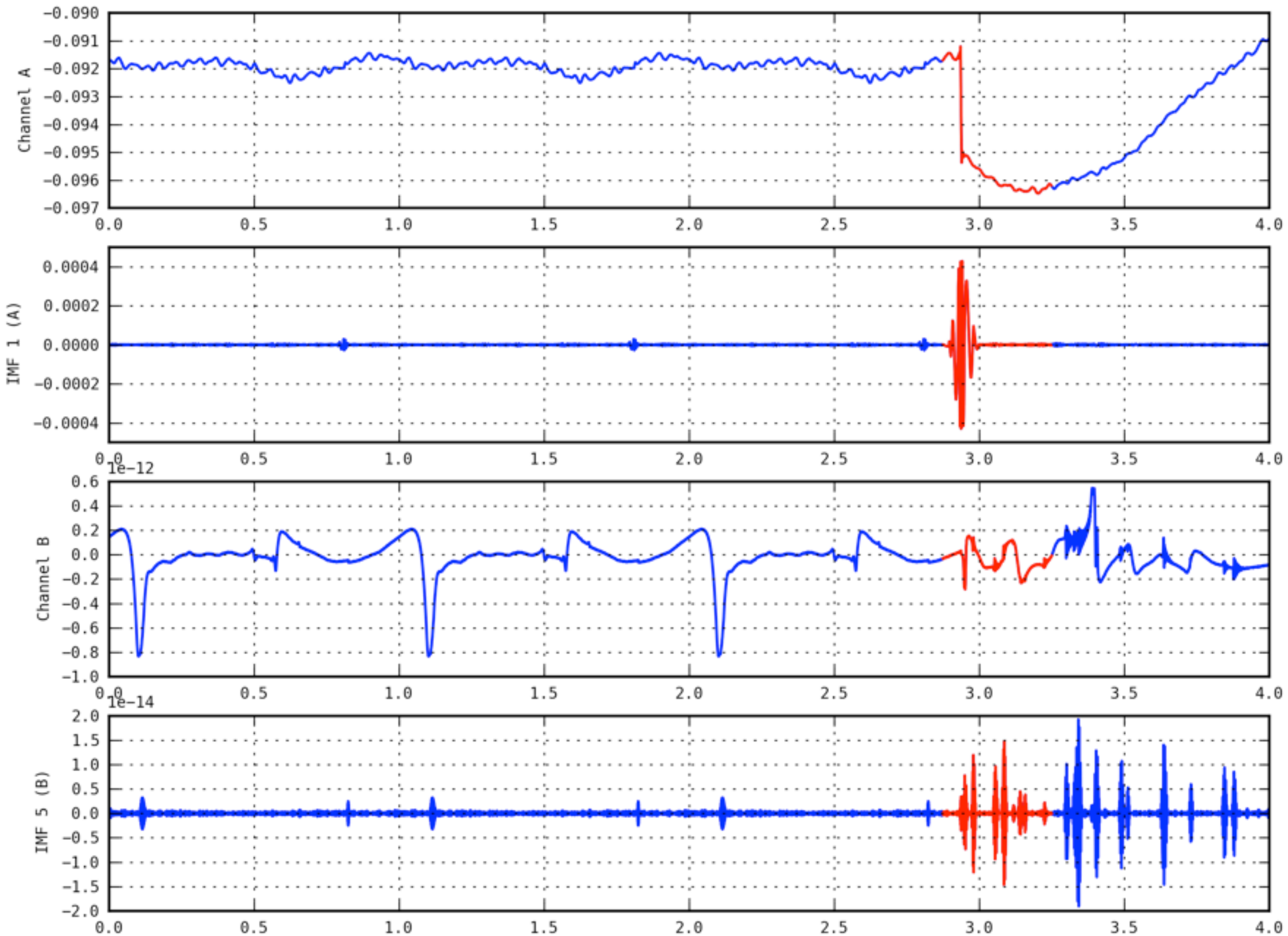
$$c_j(t) + i\ \mathcal{H}[c_j](t) = a_j(t)e^{i\theta_j(t)}$$

[Courtesy: Norden E. Huang]

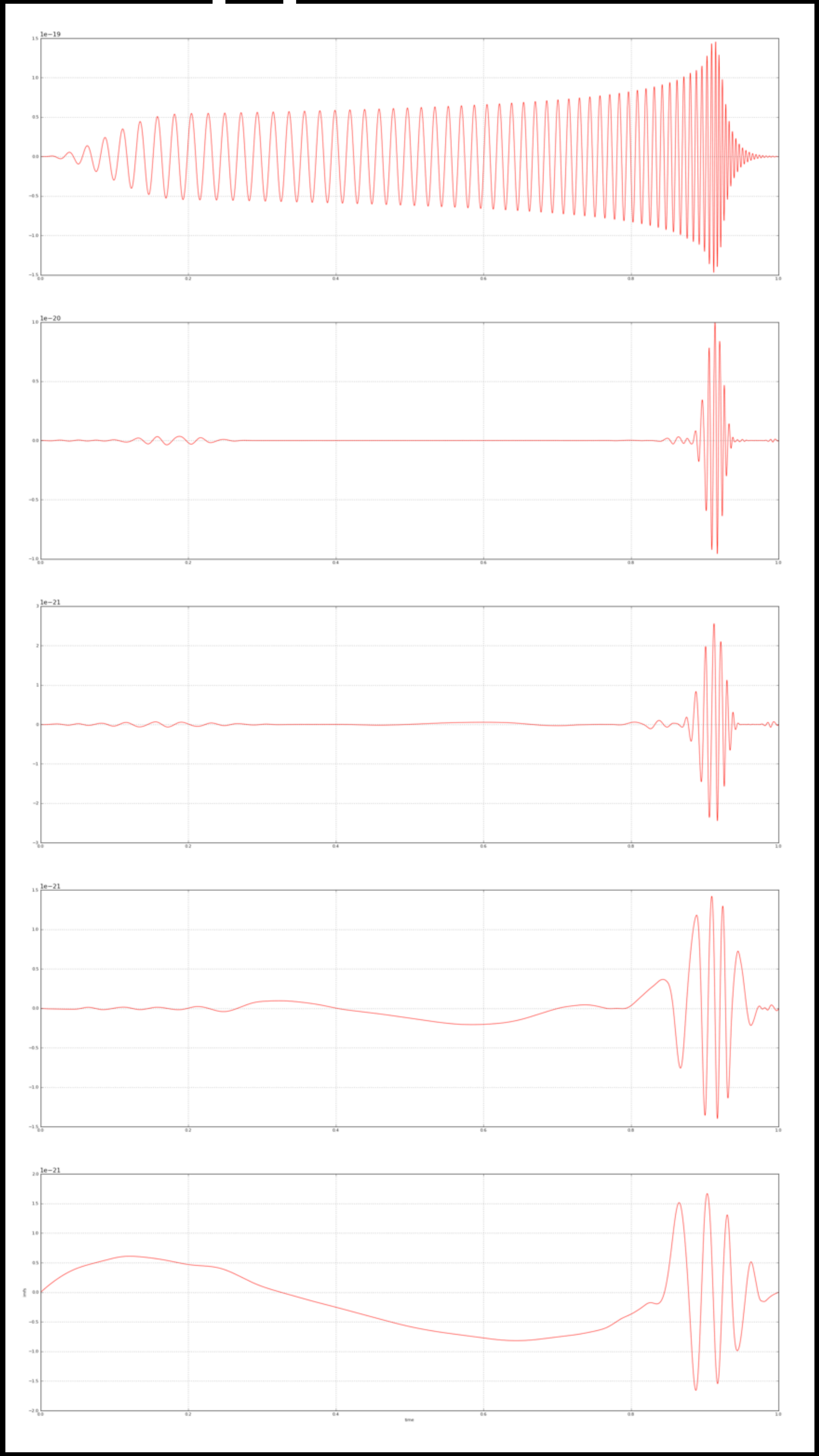
	Fourier	**Wavelet**	**Hilbert**
Basis	**a priori**	**a priori**	**Adaptive**
Frequency	Integral transform: Global	Integral transform: Regional	Differentiation: Local
Presentation	Energy-frequency	Energy-time-frequency	Energy-time-frequency
Nonlinear	**no**	**no**	**yes**
Non-stationary	**no**	**yes**	**yes**
Uncertainty	yes	yes	no
Harmonics	yes	yes	no

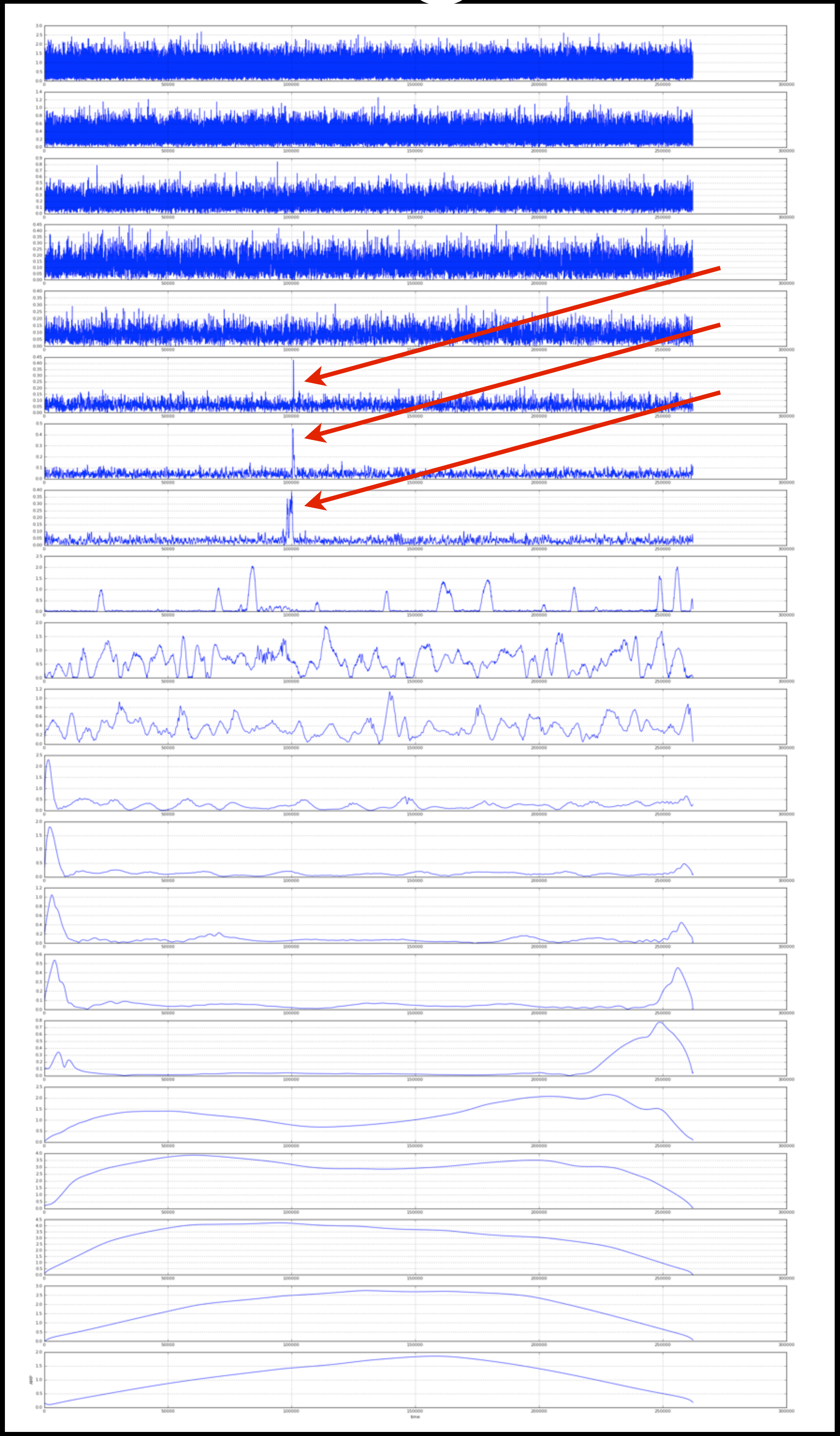
[Courtesy: Norden E. Huang]

Application to Aux. Ch.



Application to CBC signals



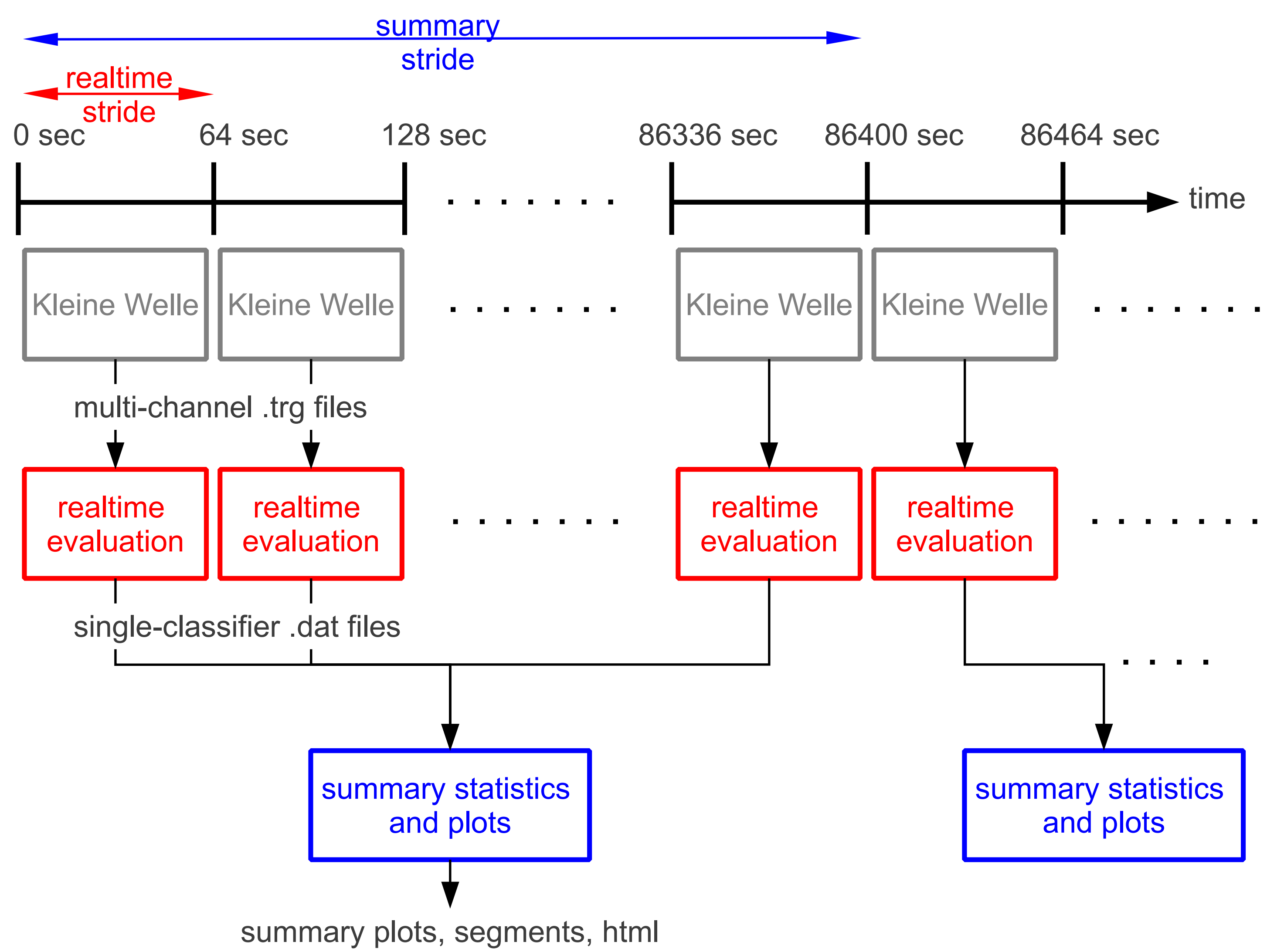


Goal

- Automate process of Glitch (non-gaussian noise transient) Identification in data preparation stage
  - Cleaning the data, monitoring, and feedback for commissioning or tuning
- Inclusion of different information which KW algorithm may not extract from raw data.
  - consideration of different trigger generation algorithm
- Real time (or low latency) analysis on Glitch Identification

Low latency Glitch Identification

- On-going project : iDQ pipeline
  - real-time (low latency) glitch identification and data quality (DQ) analysis using Machine Learning Algorithm

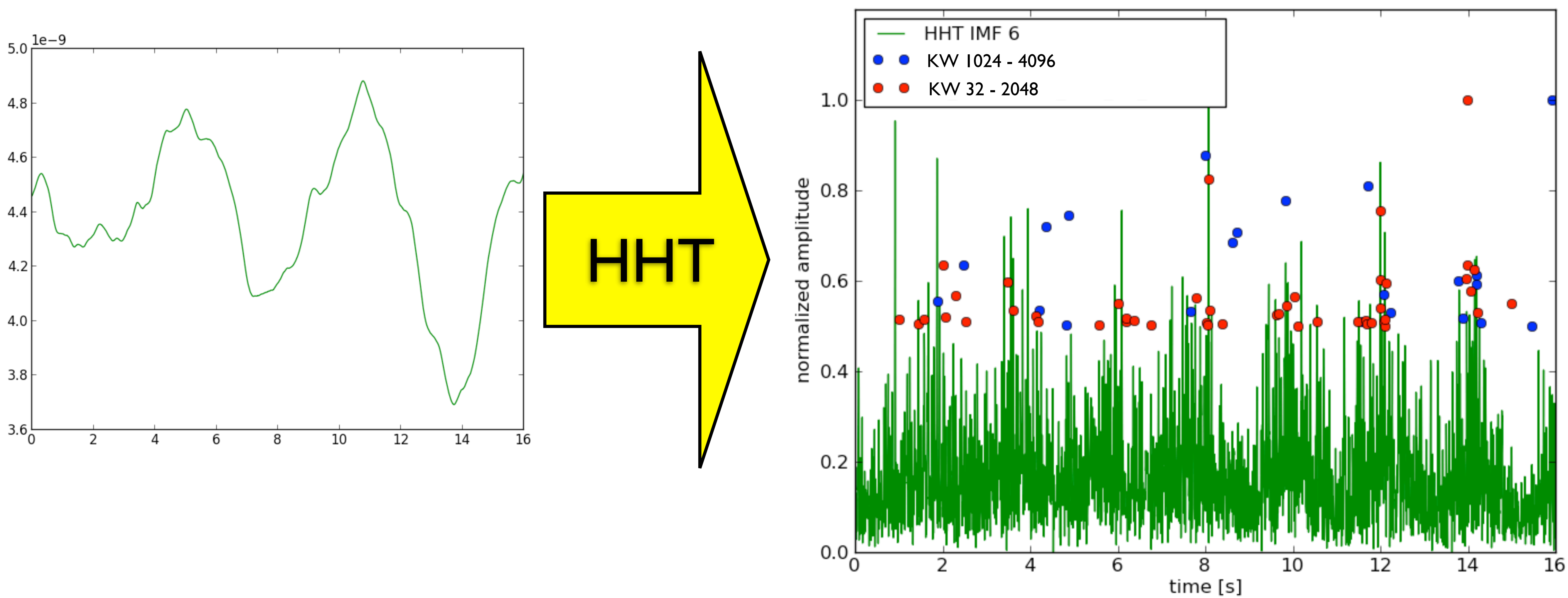


Collaboration with KAGRA

- Hayama's visit to NIMS (Feb. 2013)
  - Discussion on Research subjects for publication
  - Application of current methods to CLIO data. (if not, LIGO data as plan B.)
  - Multi-class MVC development
  - Develop a measure that measures channel's responsibility for glitches
  - Application of SOM to LIGO data
- Application of HHT to CLIO data

HHT on CLIO h(t) data

- HHT on CLIO h(t) --> 12 IMF



Summary

- Application of Machine Learning Algorithm (MLA) to Auxiliary channels data for glitch identification
  - auxmvc paper was submitted (arxiv:1303.6984)
- Artificial Neural Networks Ensemble was developed and applied to auxiliary channel data
  - At FAP 0.1%, efficiency is more than 50% for LIGO Livingston data.
  - Feature selection using t-statistic was studied. More investigation is needed.
- Trigger generation methods became more important.
  - We are studying HHT, KW algorithm, and other trigger methods.
- HHT application to CLIO data

Future works

- Genetic algorithm aided ANN (GANN) module optimization.
  - Network Topology Optimization
  - Investigation on a quantitative indicator or auxiliary channels to ANN rank
  - Implementation of GANN on computing accelerators (GPU, FPGA, etc.)
- Development of low latency analysis pipeline : iDQ pipeline, etc.
  - Implementation of GANN into iDQ
  - Access to online segments
  - Runs for Engineering Runs
- Application of MLA/GANN to different Trigger Generation Algorithm
  - Trigger generation scheme development for HHT
  - Application to Omega and/or GSTLAL triggers
- Application of HHT and MLA/GANN to CLIO data