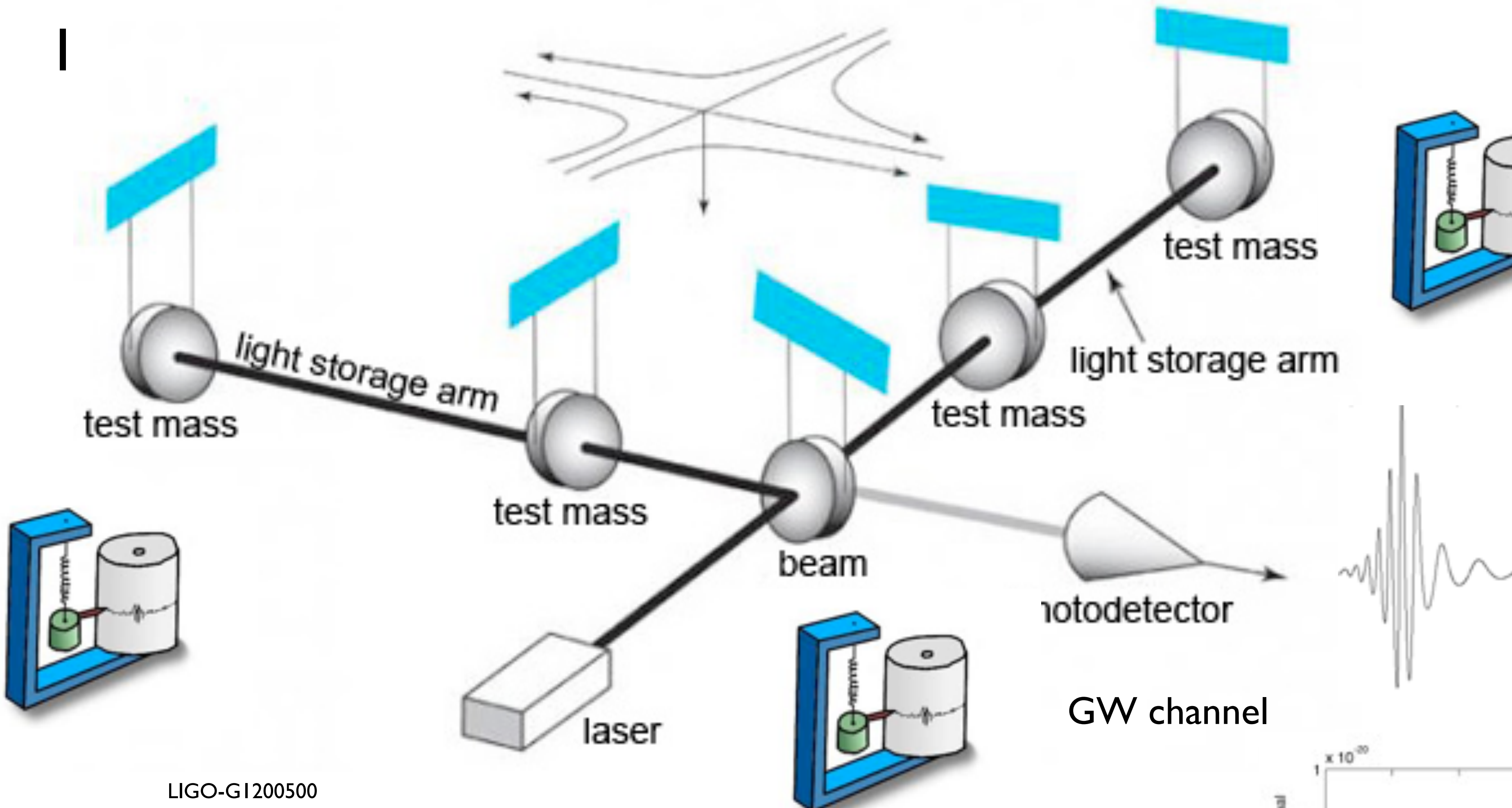
Detector Characterization on KISTI/GSDC for KAGRA

Kim, Young-Min (UNIST)

on behalf of KGWG-DetChar

Laser Interferometer

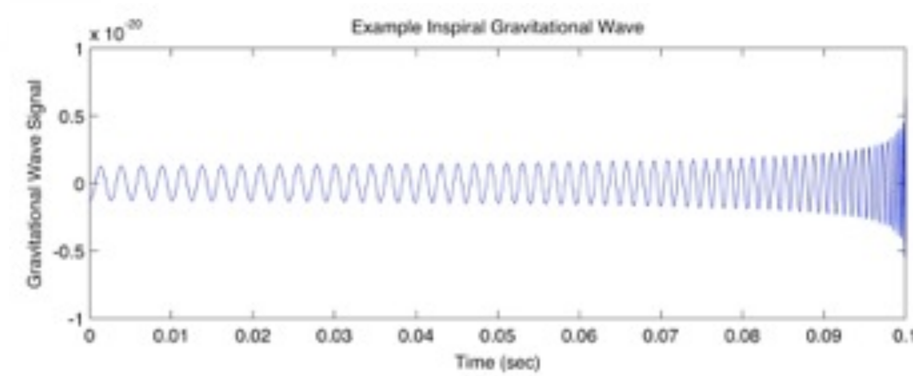
I



GW channel

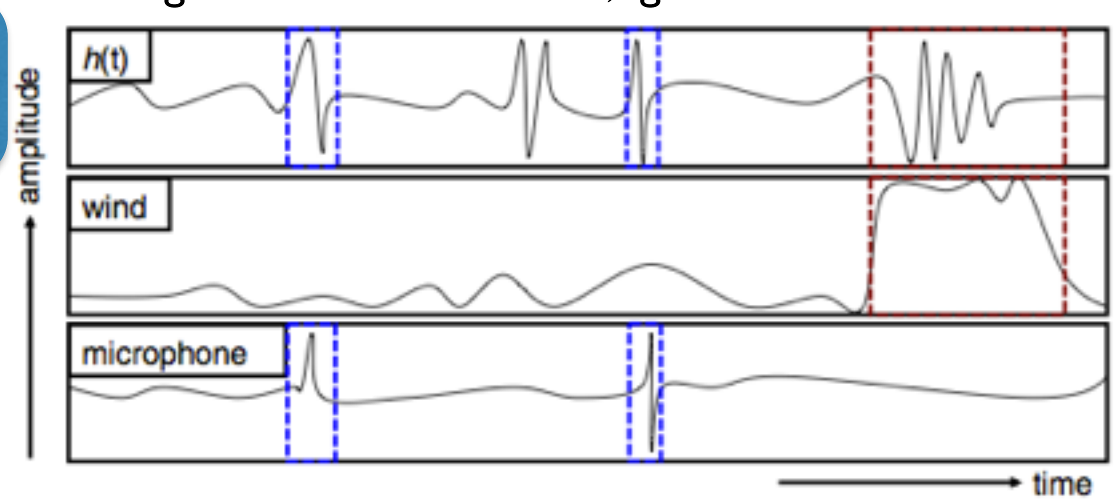
LIGO-G1200500

Signal Search



Detector Characterization

non-gaussian noise artifacts, "glitch"



Role of Detector Characterization

Interferometer is so complex!

Detector Characterization

What GPS time segment to analyze?

When was the ifo operating?

How is the data quality? :
Is this data segment noisy or not? Glitchy or not? Line noise?

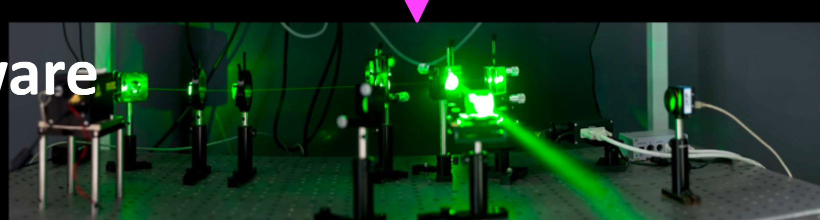
If noisy or glitchy, what's the source?
How is it coupled to h(t)?

What channel to see to know the status?

If noisy or glitchy, what's the source?
How is it coupled to h(t)?

If noisy or glitchy, what's the source?
How is it coupled to h(t)?

Hardware



Data Analysis

taken from Kokeyama's slides

Main task of the PEM subsystem

After finishing the installation tasks, We will start the commissioning phase

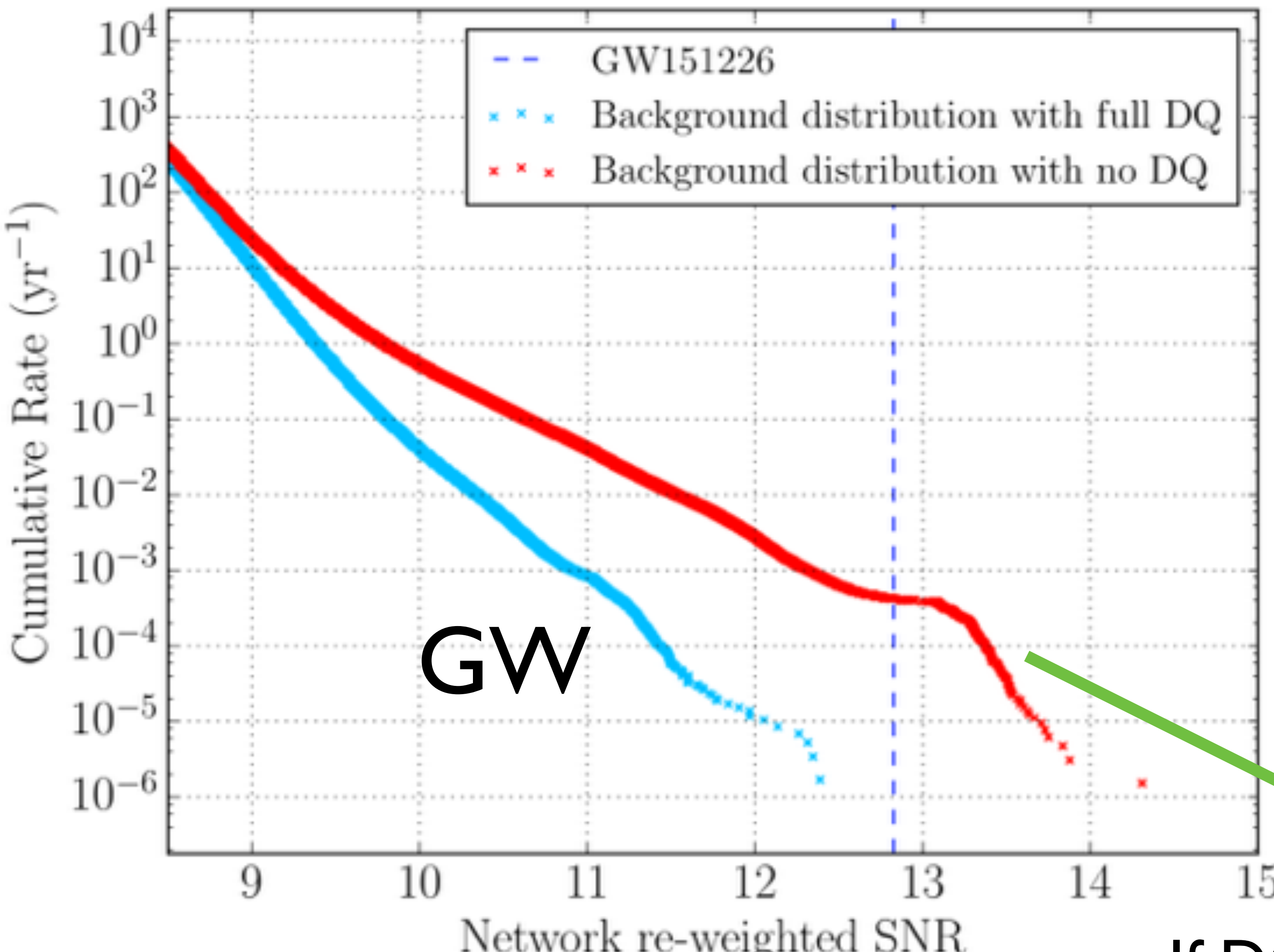
One of the important task is

Possible upgrade of VT

- V : Volume, try to achieve the good sensitivity
  - Search the origin of noise which makes the noise floor dirty and makes the glitch
  - Line noise characterization, time variance of noise floor, glitch noisy period search, veto, …
- T : Time, try to achieve the stable operation
  - Reducing the origin of unlock, quick recovery
  - Safety interferometer control syste

taken from Yokozawa's slides

The impact of Data Quality Vetoes



The false alarm rate of GW151226 **improves by a factor of 567**, from 1 in 320 years to 1 in 183000 years, **with interferometer data quality information!**

If DQ vetoes are not applied, GW151226 is no longer louder than the entire background distribution.

LIGO-Virgo Collaboration, Class. Quantum Grav. **35** (2018) 065010

What we need for the joint Observation

1. On-line Data Quality
   - Online DQ flags
   - online DQ pipeline (e.g. iDQ) - glitch identification and responsible channels
2. Off-line Data Quality
   - deep investigation on glitches, spectral lines, noise sources, etc.
   - improve search background with full DQ
3. Channel Information
   - find out ‘unsafe’ channels
   - ‘safe’ channels to be used for online / offline analysis and vetoes

KGWG DetChar Activities

1. Off-site work
   - glitch investigation with LIGO-Virgo DQ tools
   - Machine learning application to glitch identification
   - (off-line) iDQ operation
2. On-site work
   - short-/mid-term visits to the KAGRA site
   - installation of DQ tools, or development of new tools
   - DQ shifts for the operation
3. channel safety study
   - find ‘unsafe’ / ‘safe’ channels

Works in KISTI/GSDC

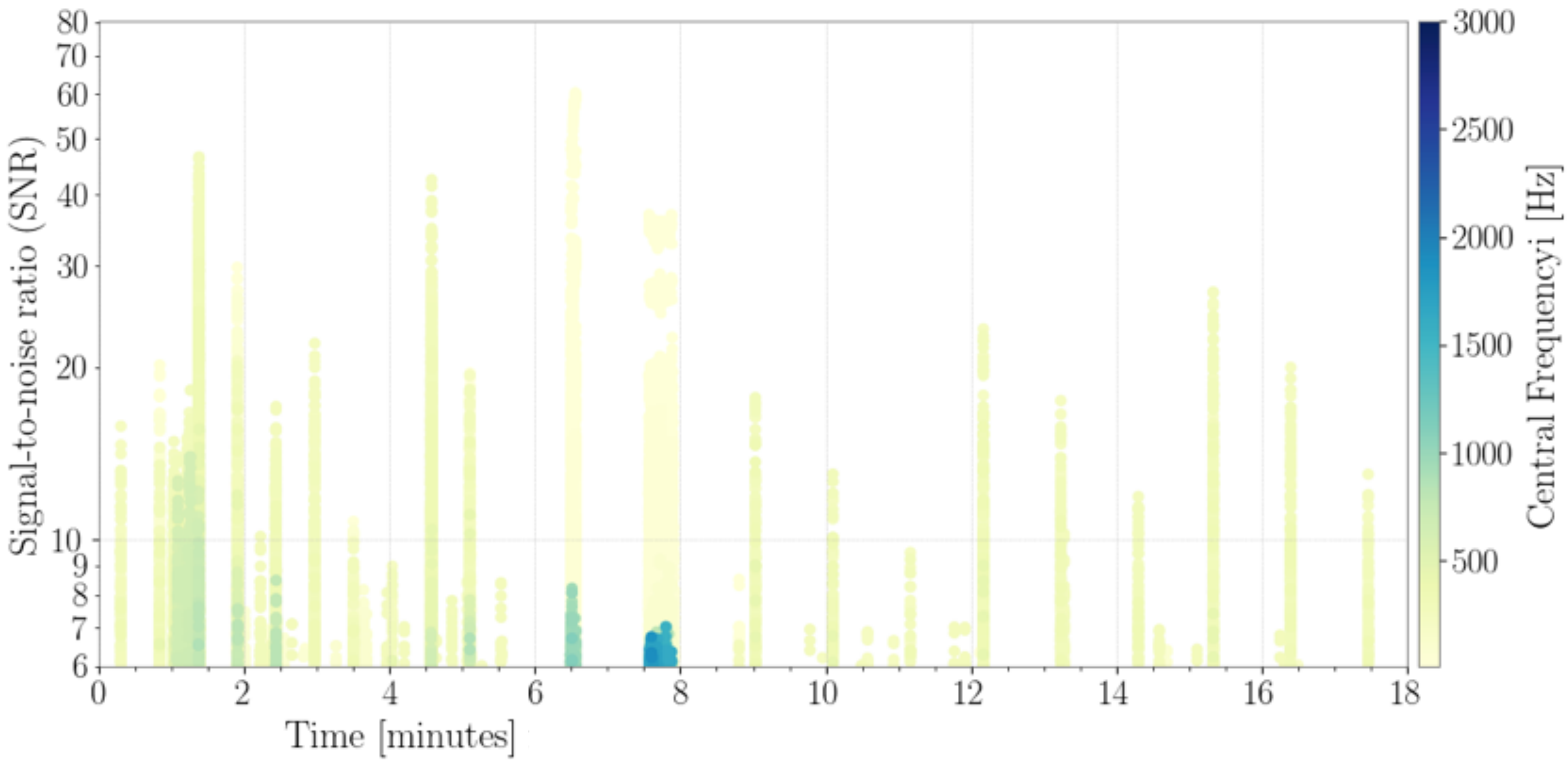
1. Off-site work
   - LIGO/Virgo tools (gwpy, omicron,hveto,bruco), CAGMon, etaGen, etc.
2. Channel Safety Study
   - using Hardware Injections : Photon Calibrator (PCal) Injection
   - Figure out which channels respond to the injections
3. Correlation study
   - CAGMon, …
4. New Event Trigger Generation method : etaGen
5. Machine Learning Application to Glitch Identification

DQ tools in KISTI/GSDC

1. Transient Signal Identification
   - Omicron
   - etaGen
2. veto algorithms
   - hveto
   - iDQ : No low-latent operation for KAGRA due to data transfer issue
3. Correlation and Coherence tools
   - CAGMon
   - BruCo
4. GWPy: a python package for GWDA

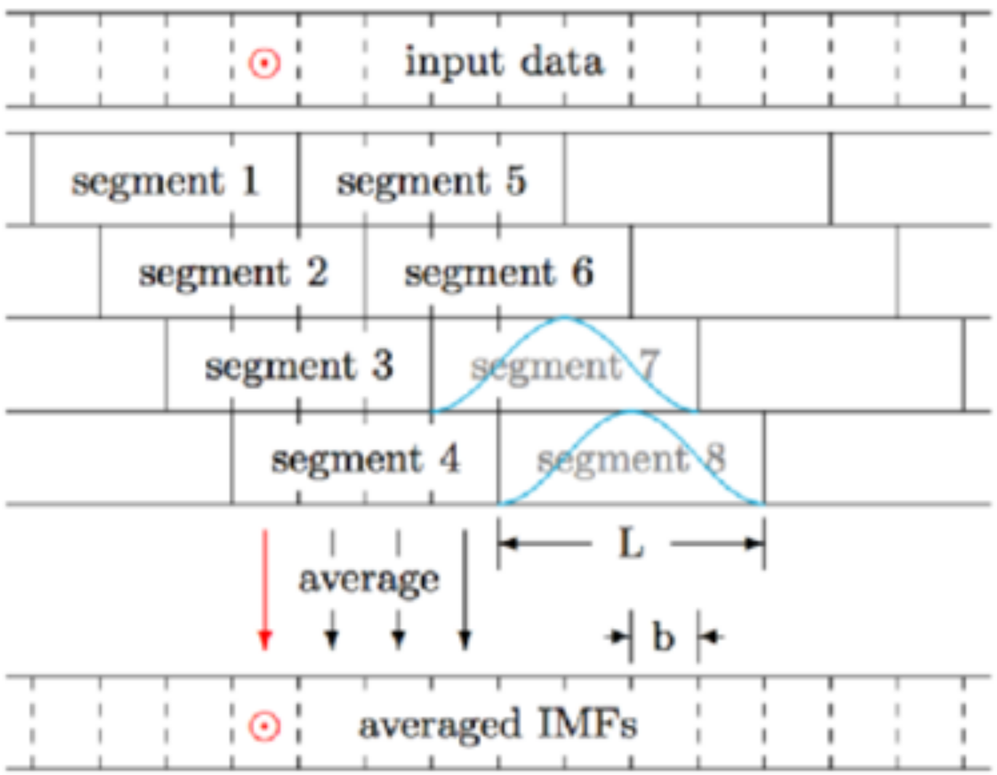
Omicron Trigger

1. Omicron algorithm (http://virgo.in2p3.fr/GWOLLUM/v2r1/index.html?Friends/omicron.html)
   - Burst-type search based on Q-transform (CQG 21, S1809 (2004))
2. Installation on KISTI/GSDC cluster



etaGen

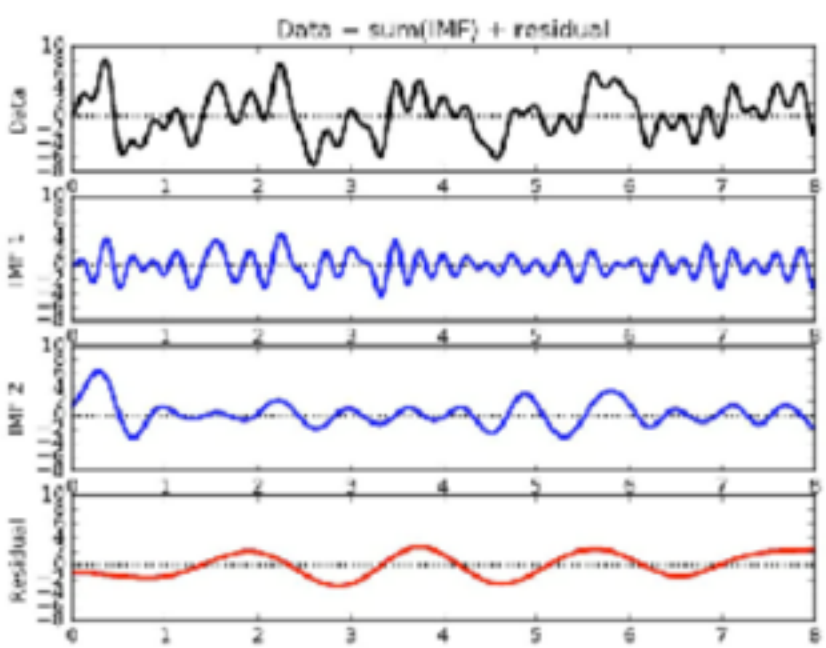
- EtaGen is an event trigger generator based on Hilbert-Huang Transform (HHT)
- HHT = Empirical Mode Decomposition (EMD) + Hilbert Spectral Analysis (HSA) (for a review, see Huang et al., Rev. Geophys. 2008)
- To reduce computing cost, we are using weighted sliding EMD (wSEMD) instead of Ensemble EMD (EEMD)

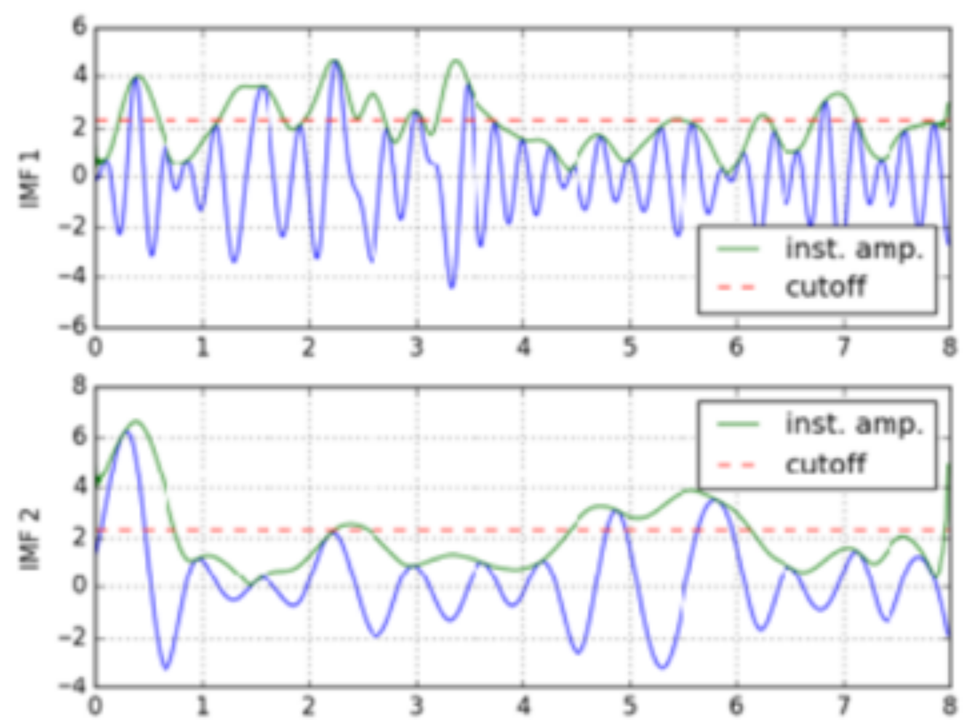


wSEMD Concept Image

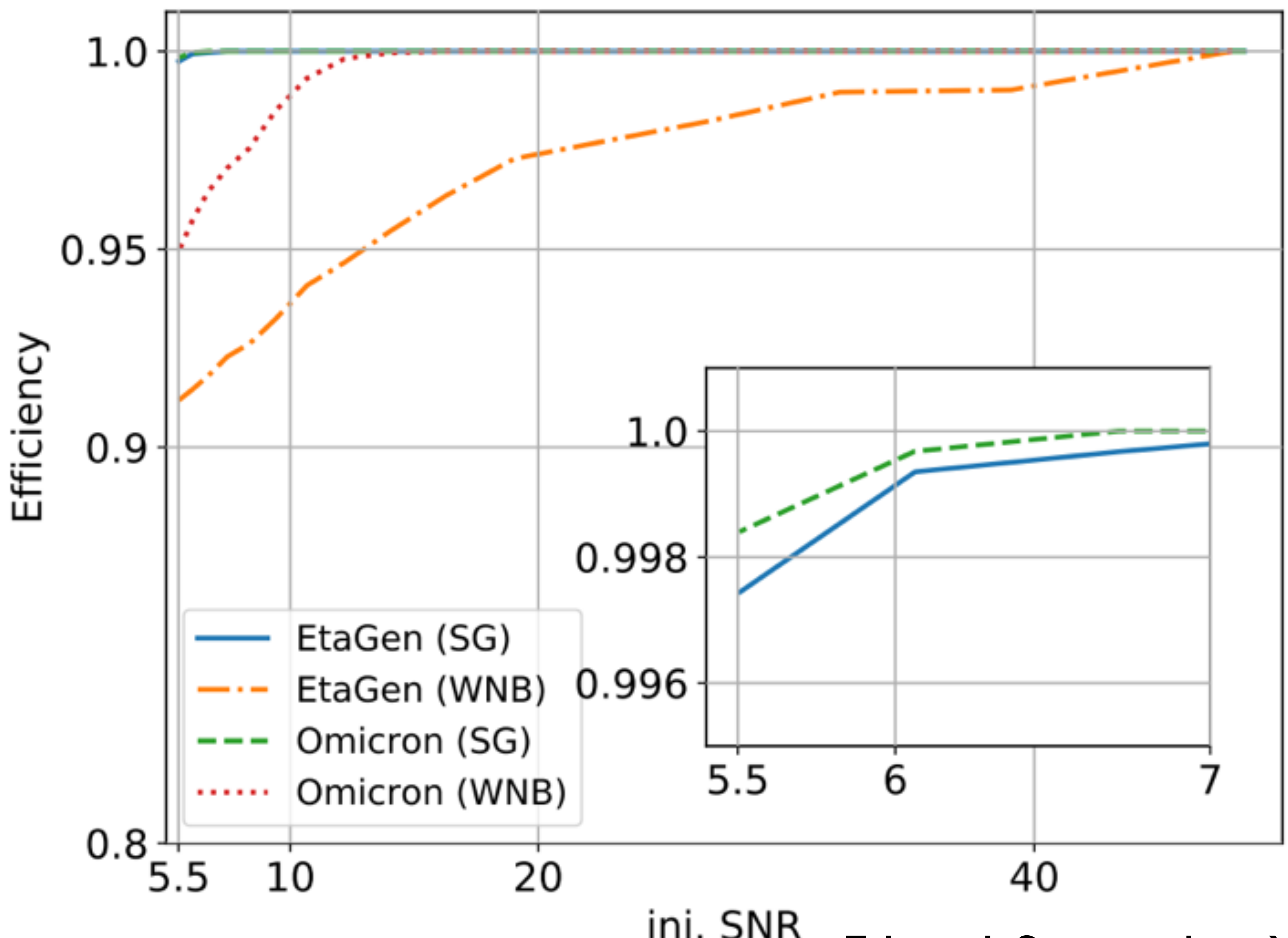
Edwin J. Son et al., arXiv.1810.07555

etaGen : how it works





etaGen : Performance test



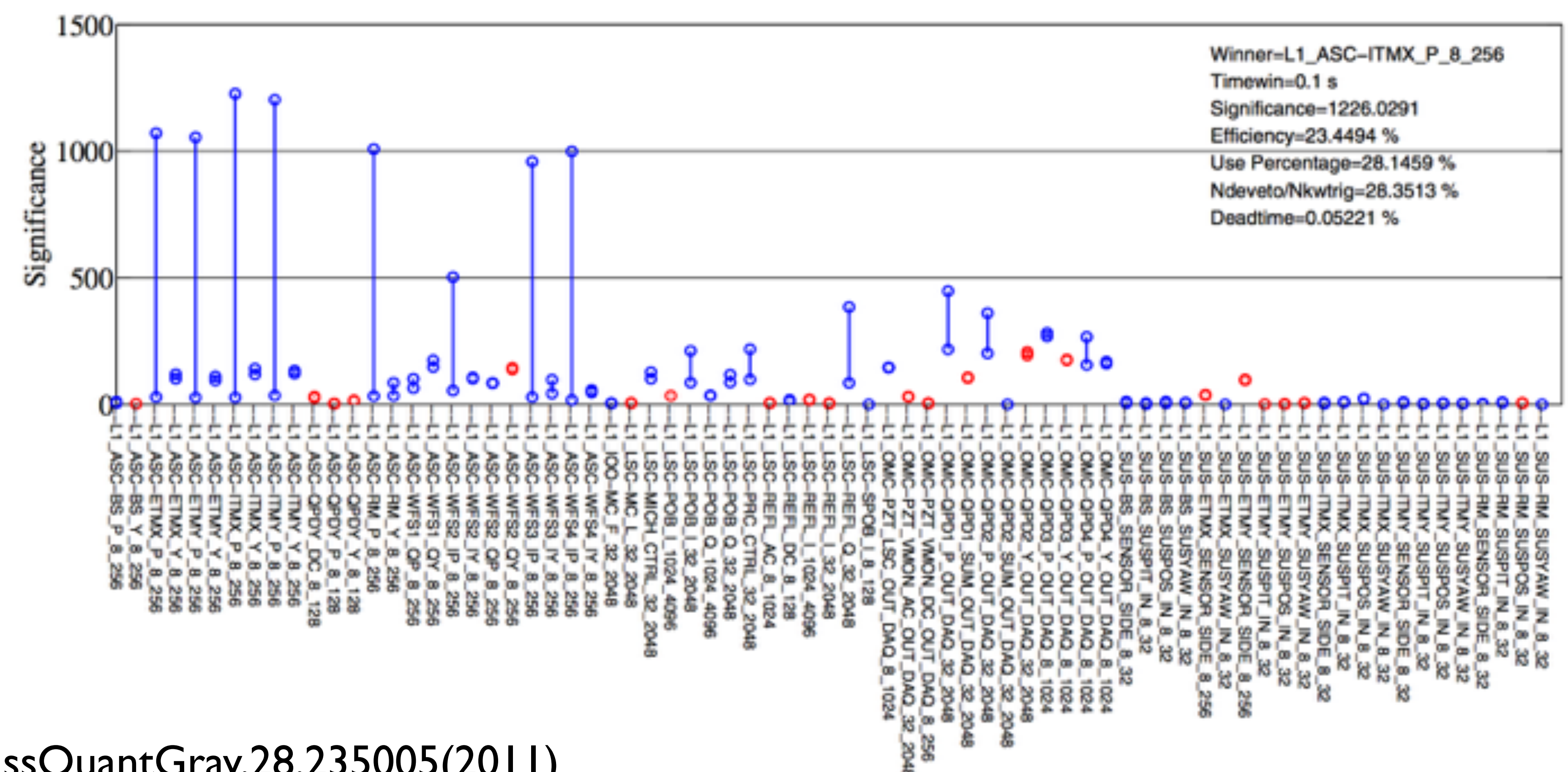
Edwin J. Son et al., arXiv.1810.07555

hVeto

$$S = -\log_{10}\Sigma_{k=n}^{\infty}[\frac{\mu^k e^{-\mu}}{k!}])$$

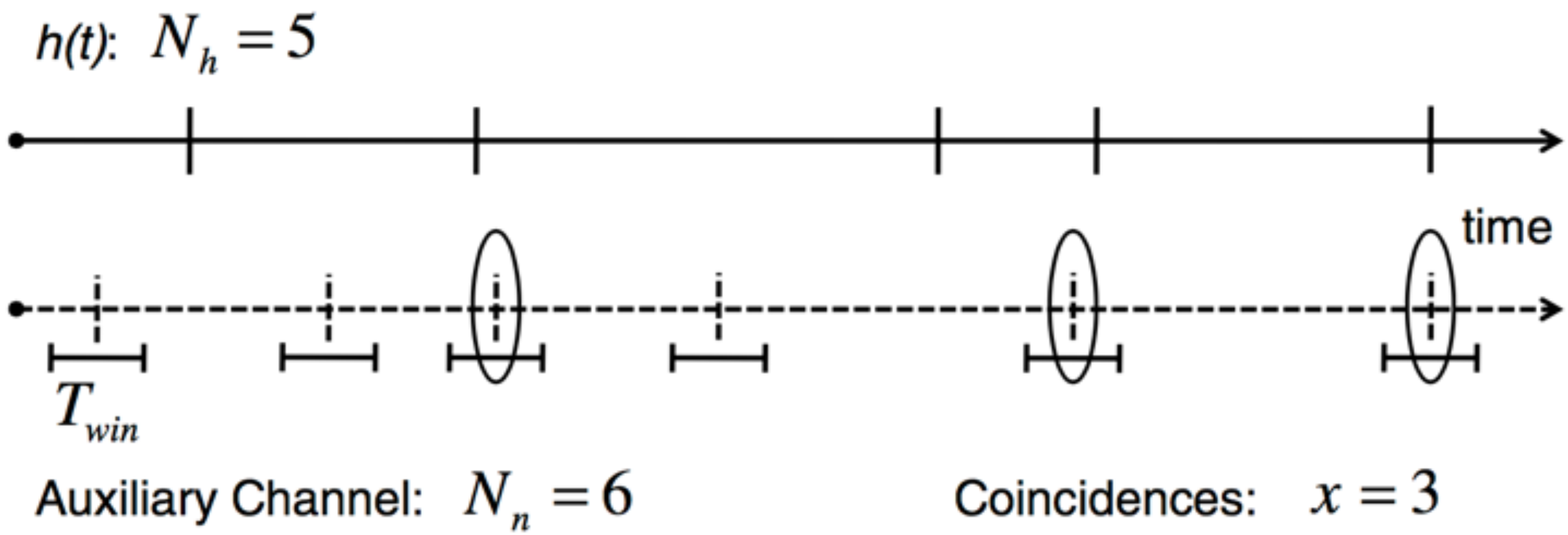
$$\mu = \frac{N_{main\_tot}N_{aux\_tot}T_{win}}{T_{tot}}$$

n : the number of coincidences
T_win : full width of coincidence time window
T_tot : a given total analysis time



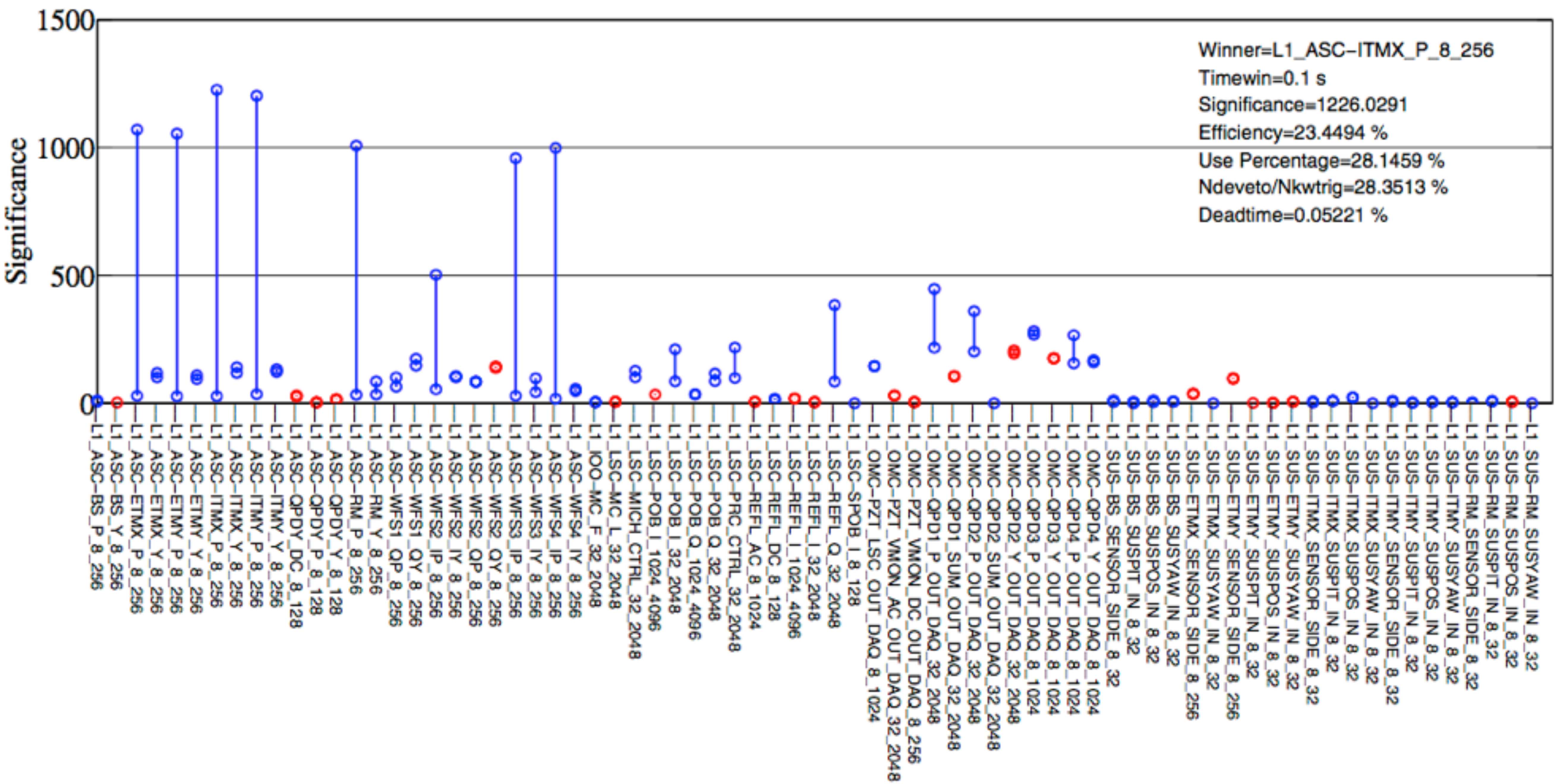
ClassQuantGrav.28.235005(2011)

Counting Experiment



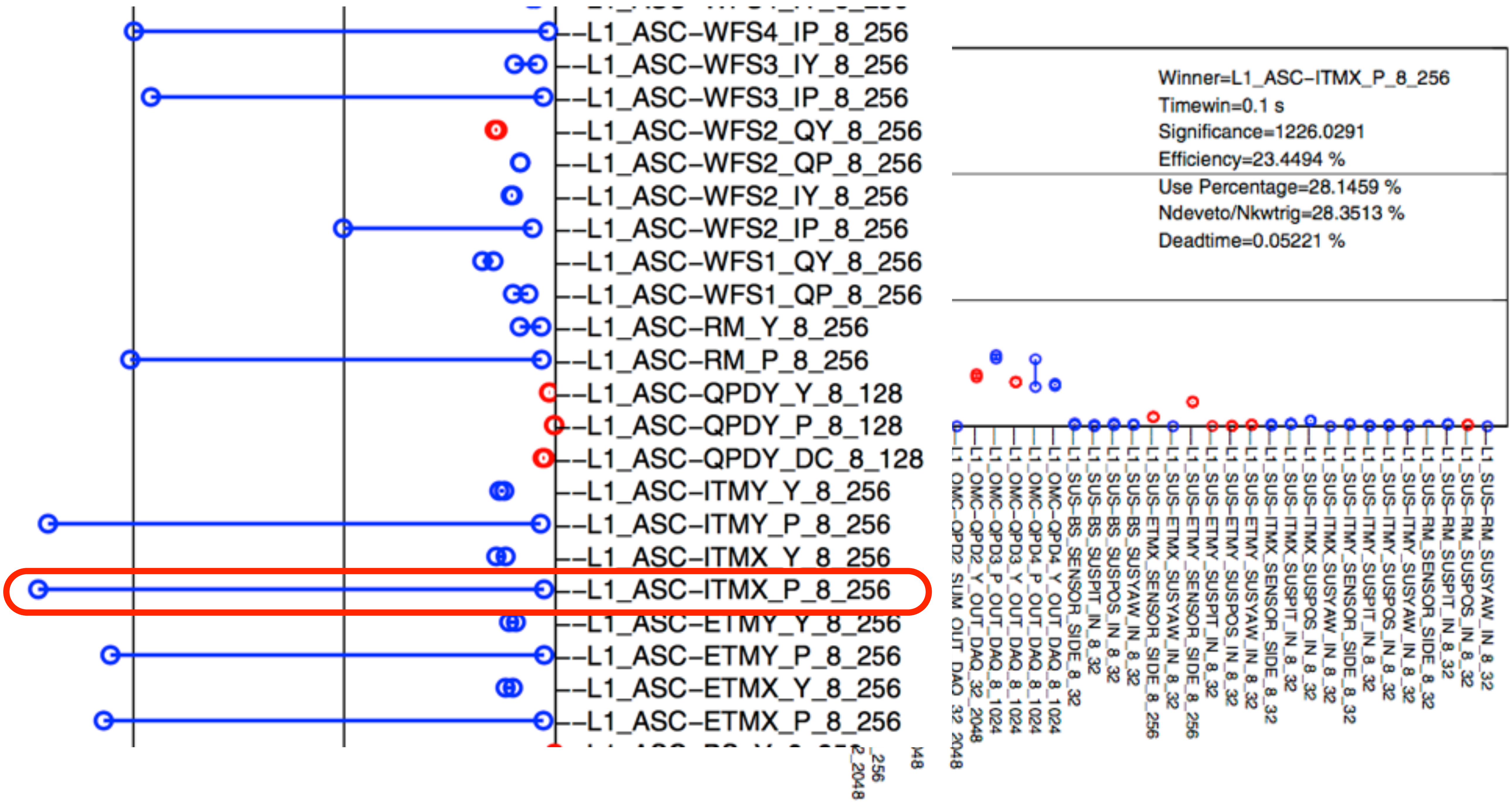
Poisson Statistics

Example: ITMX pitch



ClassQuantGrav.28.235005(2011)

Example: ITMX pitch



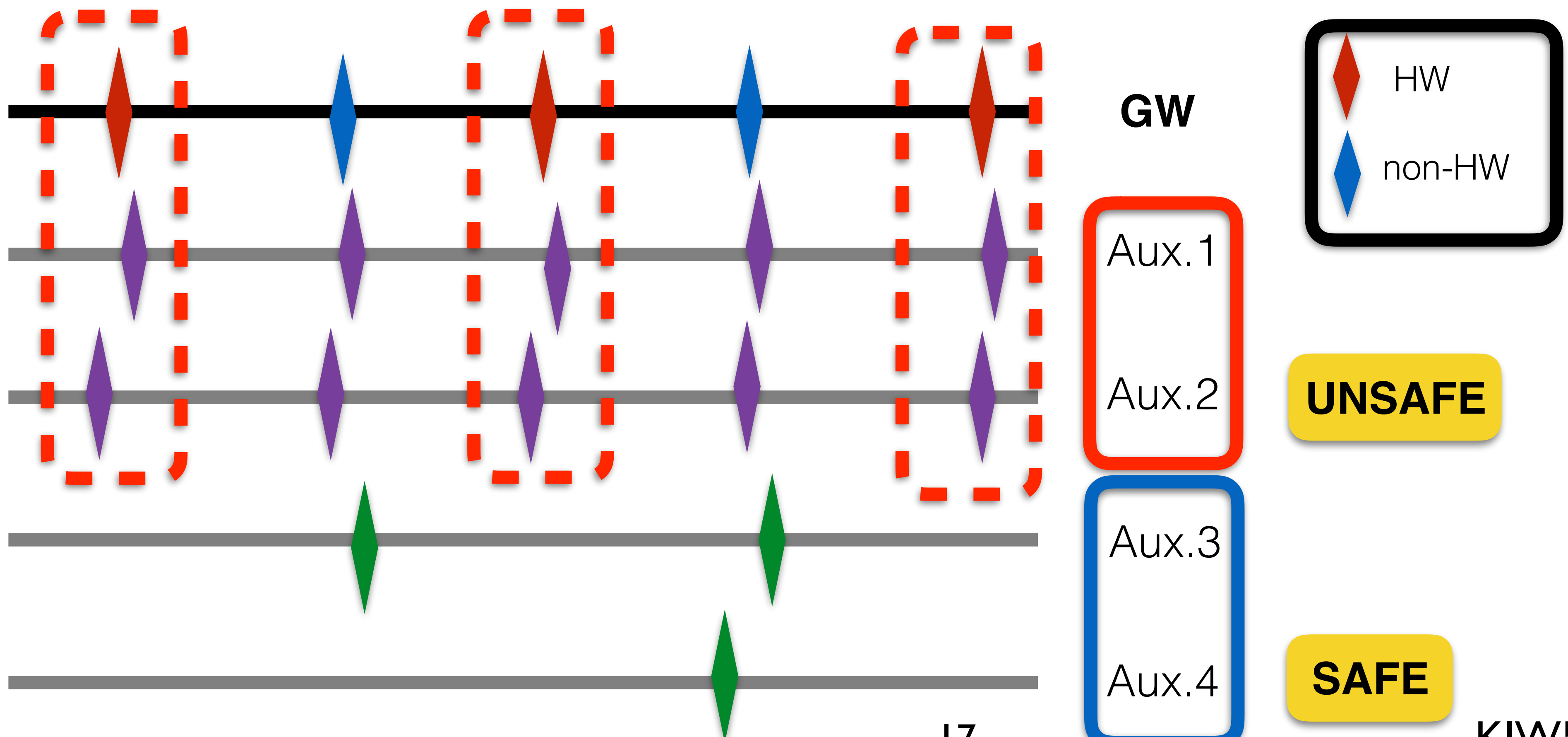
ClassQuantGrav.28.235005(2011)

Channel Safety Study with HW injections

1. The safety of a veto is important for veto criteria not to remove accidentally a true gravitational wave signal.

   - ***unsafe*** channels : Auxiliary channels with non-negligible couplings from GW channel. A corresponding response to HW injections is greater than expected by chance.

   - ***safe*** channels : it can be used as a veto or to study glitches in h(t).



How to find unsafe channels ?

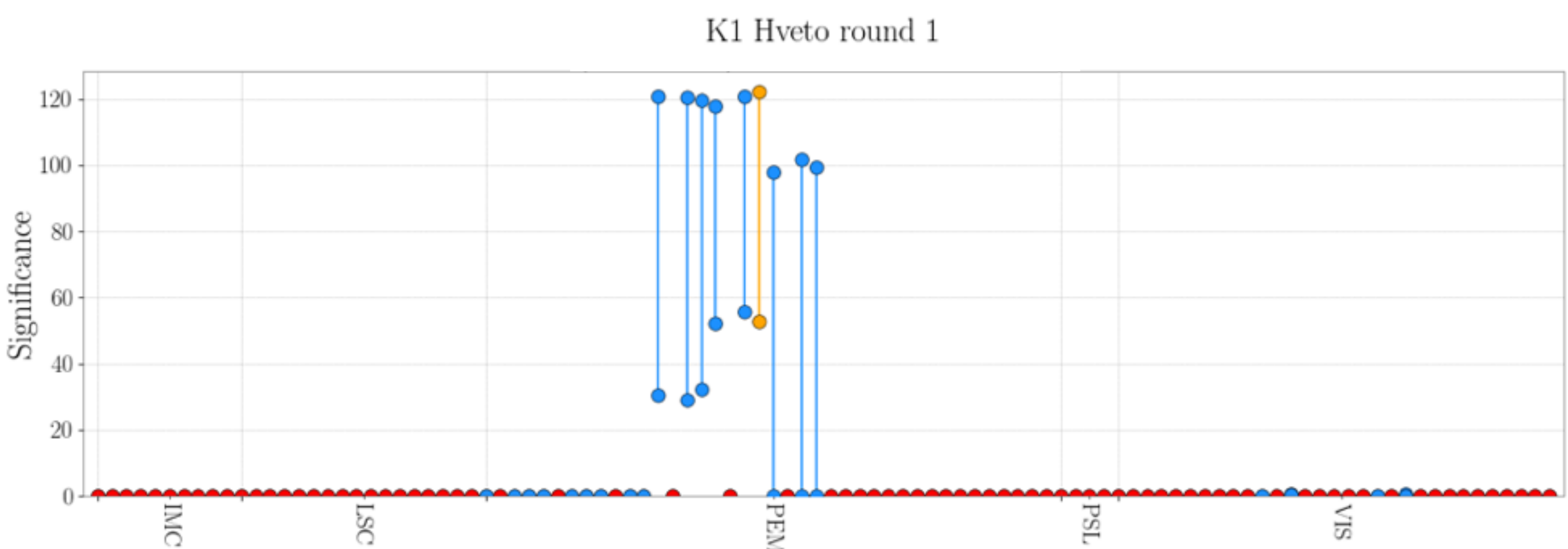
1. Heuristic Methods
   - Understanding detector itself.
2. Statistical Methods
   - hVeto, UPV, OVL, iDQ, etc…
3. Correlation methods
   - Peason’s correlaiton, MIC, CAGMon, etc
   - Coherence (BruCo)

Safety check with HW inj.

1. A response of a auxiliary channel to HW injections can be analyzed by using Omicron triggers.
    - Trigger generation rate is larger than KW triggers.
    - Efficiency / dead-time of a safe channel can be estimated.
    - We don't exactly know auxiliary channels' responses to h(t) so that we will have to check coincidences of triggers channel by channel.
2. Omicron Scans
    - a time-frequency map
    - It will be used to compare the morphologies between GW channel and an auxiliary channel which is suspicious as unsafe.

Preliminary study of CSS

1. Conducted by Pil-Jong Jung (KGWG —> ICRR)
2. http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/Subgroups/DET/CSS
3. http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/Subgroups/DET/CSS/hvetoslide



iDQ - online DQ pipeline

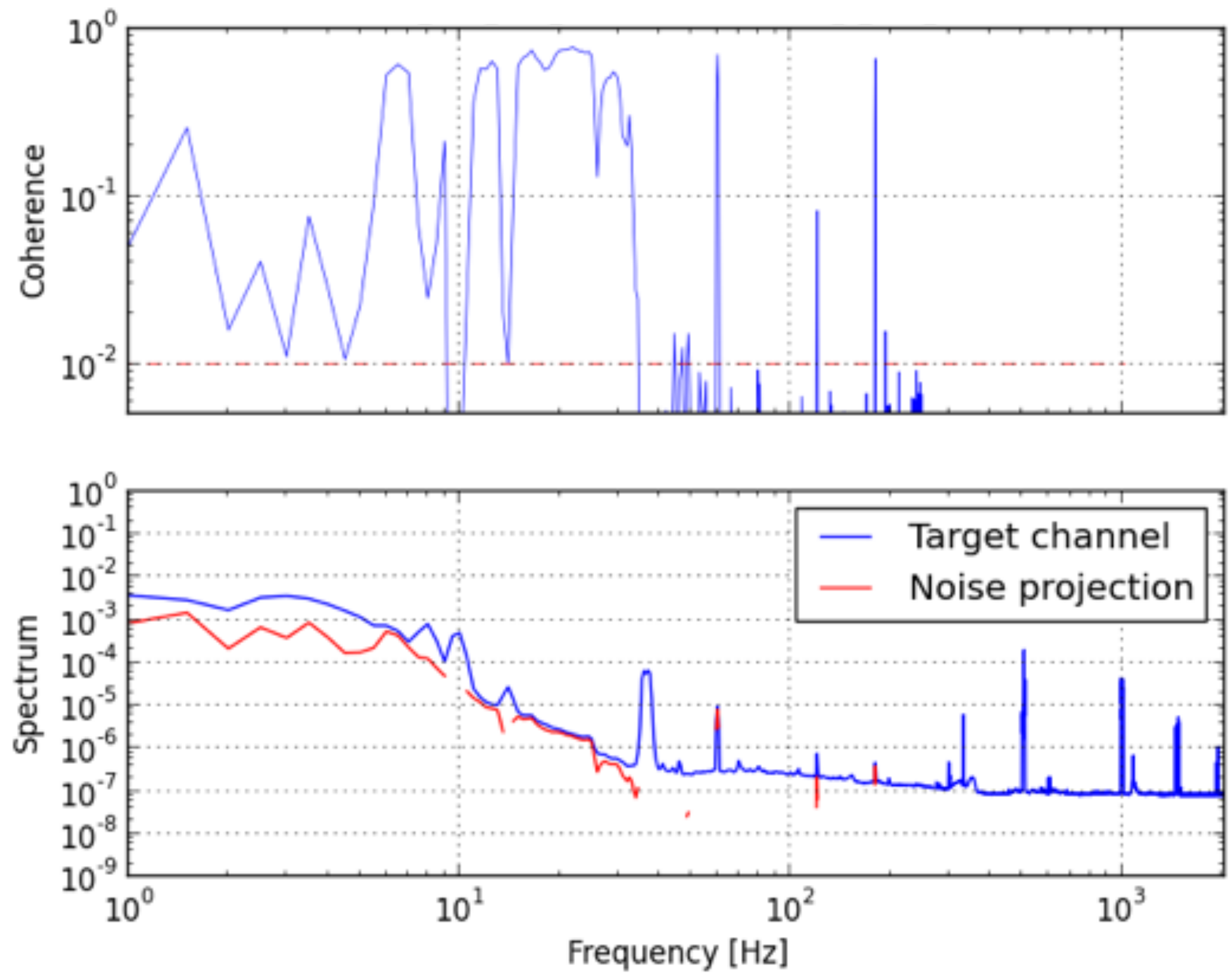
1. Developed by Reed Essick and his colleagues
   - https://docs.ligo.org/reed.essick/iDQ/index.html
2. A (near) real-time statistical data quality pipeline for glitch detection
3. Output: a probability that there is a glitch in h(t) as a function of time
4. 2-class classification
   - 1 for glitch, 0 for clean
   - train : make mapping
   - realtime : evaluate a rank (0~1)
   - calibration : conditioned probability distribution
5. responsible channels to the identified glitch

issue on running iDQ

1. Computing resource
   - Number of Channels : ~ 1000
   - train: ~1.78 GB/day (37 MB per 1800s) => 454 GB/yr (duty cycle 70%)
   - realtime: ~2.33 GB/day (2.7 GB per 10^5s) => 596 GB/yr
   - KAGRA
     1. number of channels : O(10^2)
2. Latency of Data transfer
   - off-line iDQ is currently available.

BruCo (Brute-force Coherence)

10.00	OMC_B_NSUM _OUT_DQ (0.99)	OMC_A_NSUM _OUT_DQ (0.99)	ASC-AS_C_NSUM _OUT_DQ (0.97)	_NOISEMON _LF_OUT_DQ (0.94)	_NOISEMON _RT_OUT_DQ (0.93)	_MASTER_OUT _RT_DQ (0.92)	_NOISEMON _RT_OUT_DQ (0.92)	_MASTER_OUT _RT_DQ (0.92)	_NOISEMON _RT_OUT_DQ (0.92)	_NOISEMON _LF_OUT_D (0.92)
10.50	ASC-OMC_B_NSUM _OUT_DQ (0.90)	ASC-OMC_A_NSUM _OUT_DQ (0.89)	ASC-AS_C_NSUM _OUT_DQ (0.77)	LSC-POP_A_RF45 _Q_ERR _256_DQ (0.69)	LSC-POP_A_RF45 _Q_ERR _DQ (0.69)	LSC-MICH_CTRL _256_DQ (0.68)	LSC-MICH_OUT _DQ (0.68)	SUS-BS_M3_ISCINF _L_IN1 _DQ (0.68)	SUS-PR2_M3 _ISCINF_L_IN1 _DQ (0.68)	CAL-CS_MIC _CTRL_DQ (0.68)
11.00	ASC-CHARD_P _OUT_DQ (0.37)	ASC-CHARD_P _SM_DQ (0.37)	ASC-OMC_B_NSUM _OUT_DQ (0.33)	ASC-CHARD_P _IN1_DQ (0.29)	ASC-CSOFT_P _OUT_DQ	ASC-CSOFT_P _SM_DQ	ASC-DC1_P_OUT _DQ	SUS-RM2_M1 _OSEMINF_UR	SUS-ITMY_L3 _ISCINF_P	ASC-DC1_P_ _DQ
11.50	ASC-CHARD_P _OUT_DQ (0.58)	ASC-CHARD_P _SM_DQ (0.58)	ASC-CHARD_P _IN1_DQ (0.49)	SUS-ITMY _ISCINF_P _IN1_DQ (0.37)						
12.00	ASC-CHARD_P _SM_DQ (0.57)	ASC-CHARD_P _OUT_DQ (0.57)	ASC-CHARD_P _IN1_DQ (0.47)	SUS-ITMY _ISCINF_P _IN1_DQ (0.42)						
12.50	ASC-CHARD_P _SM_DQ (0.64)	ASC-CHARD_P _OUT_DQ (0.64)	ASC-CHARD_P _IN1_DQ (0.57)	SUS-ITMY _ISCINF_P _IN1_DQ (0.56)						
13.00	SUS-ETMX_L2 _NOISEMON _UL_OUT_DQ (0.59)	SUS-ITMY_L2 _MASTER_OUT _LR_DQ (0.59)	SUS-ITMY_L2 _NOISEMON _LR_OUT_DQ (0.58)	ASC-CHAR _OUT_DQ (0.58)						
13.50	ASC-OMC_B_NSUM _OUT_DQ (0.27)	ASC-OMC_A_NSUM _OUT_DQ (0.24)	SUS-ITMY_L2 _MASTER_OUT _LR_DQ (0.12)	SUS-ITMY _NOISEMO _LR_OUT (0.12)						
14.00	ASC-OMC_B_NSUM _OUT_DQ (0.43)	ASC-OMC_A_NSUM _OUT_DQ (0.40)	ASC-AS_C_NSUM _OUT_DQ (0.14)	OMC-ASC _A_PIT_OU _DQ (0.06)						
14.50	SUS-ITMY_L2 _MASTER_OUT _LR_DQ (0.15)	SUS-ITMY_L2 _NOISEMON _LR_OUT_DQ (0.15)	SUS-ITMY_L2 _MASTER_OUT _UL_DQ (0.14)	SUS-ITMY _NOISEMO _UL_OUT (0.14)						
	SUS-ITMY_L2	SUS-ITMY_L2	SUS-ITMY_L3	SUS-ITMY						



BruCo Comparisons

1. run “filter4_bruco.py”

Top 40 coherences at 0.0 =< f =< 4096.0 Hz : coh.=(0.00996898170809,1.0]

Frequency [Hz]	Top channels										
0.00	SUS-ETMY_M0_DAMP_V_IN1_DQ (0.12) ref.	OMC-LSC_SERVO_OUT_DQ (0.12) ref.	SUS-OMC_M1_MASTER_OUT_RT_DQ (0.11) ref.	ISI-BS_ST1_BLND_Y_CPS_CUR_IN1_DQ (0.11) ref.	SUS-ETMY_M0_OSEMINF_RT_OUT_DQ (0.10) ref.	ISI-BS_ST2_GS13INF_H1_IN1_DQ (0.10) ref.	SUS-OMC_M1_FASTIMON_RT_OUT_DQ (0.10) ref.	ISI-HAM6_CDMON_H2_I_IN1_DQ (0.09) ref.	IMC-L_IN1_DQ (0.09) ref.	IMC-F_IN1_DQ (0.09) ref.	ISI-HAM6_CD_H2_V_IN1_DQ (0.09) ref.
0.25	LSC-POPAIR_B_RF18_Q_ERR_DQ (0.15) ref.	LSC-POPAIR_B_RF18_Q_ERR_256_DQ (0.15) ref.	PSL-ISS_THIRDLOOP_SERVO_OUT_DQ (0.15) ref.	PSL-ISS_SECONDLOOP_ERR1_DQ (0.15) ref.	PSL-ISS_SECONDLOOP_OUTPUT_DQ (0.14) ref.	SUS-ITMY_M0_MASTER_OUT_F3_DQ (0.14) ref.	ALS-C_COMM_A_LF_OUT_DQ (0.14) ref.	SUS-BS_M3_OPLEV_PIT_OUT_DQ (0.13) ref.	PSL-ISS_SECONDLOOP_RIN_OUTER_OUT_DQ (0.13) ref.	ASC-REFL_A_RF9_Q_SUM_OUT_DQ (0.13) ref.	PSL-ISS_SECO_RIN_INNER_OUT_DQ (0.13) ref.
0.50	IMC-IM4_TRANS_SUM_IN1_DQ (0.22) ref.	IMC-IM4_TRANS_SUM_OUT_DQ (0.22) ref.	PSL-ISS_SECONDLOOP_PD4_OUT_DQ (0.22) ref.	PSL-ISS_SECONDLOOP_PD7_OUT_DQ (0.22) ref.	PSL-ISS_SECONDLOOP_PD1_OUT_DQ (0.22) ref.	SUS-ETMY_L2_FASTIMON_UL_OUT_DQ (0.21) ref.	PSL-ISS_SECONDLOOP_RIN_CTRL_OUT_DQ (0.21) ref.	IMC-PWR_EOM_OUT_DQ (0.21) ref.	IMC-PWR_IN_OUT_DQ (0.21) ref.	SUS-ETMY_R0_FASTIMON_F2_OUT_DQ (0.20) ref.	ASC-OMC_B_I_OUT_DQ (0.19) ref.
0.75	ASC-Y_TR_B_PIT_OUT_DQ (0.09) ref.	SUS-ETMX_L2_FASTIMON_UL_OUT_DQ (0.09) ref.	SUS-ETMX_L2_FASTIMON_LR_OUT_DQ (0.09) ref.	ASC-DSOFT_Y_OUT_DQ (0.08) ref.	ASC-DSOFT_Y_SM_DQ (0.08) ref.	SUS-OMC_M1_FASTIMON_LF_OUT_DQ (0.08) ref.	SUS-OMC_M1_MASTER_OUT_LF_DQ (0.08) ref.	OMC-PZT2_MON_AC_OUT_DQ (0.08) ref.	SUS-ITMY_L3_ISCINF_Y_IN1_DQ (0.08) ref.	ASC-REFL_B_RF45_I_PIT_OUT_DQ (0.07) ref.	SUS-ETMX_R0_OSEMINF_F1_OUT_DQ (0.07) ref.
1.00	ASC-CHARD_P_OUT_DQ (0.21) ref.	ASC-CHARD_P_SM_DQ (0.21) ref.	SUS-ITMY_L2_FASTIMON_LL_OUT_DQ (0.21) ref.	LSC-SRCL_CTRL_256_DQ (0.21) ref.	SUS-SRM_M3_ISCINF_L_IN1_DQ (0.21) ref.	LSC-SRCL_OUT_DQ (0.21) ref.	CAL-CS_SRCL_DQ (0.20) ref.	SUS-ITMY_L2_MASTER_OUT_LL_DQ (0.20) ref.	ASC-CHARD_P_IN1_DQ (0.20) ref.	SUS-ETMX_L2_FASTIMON_LR_OUT_DQ (0.19) ref.	SUS-ITMY_L2_FASTIMON_LR_OUT_DQ (0.19) ref.
1.25	SUS-BS_M2_OSEMINF_UL_OUT_DQ (0.28) ref.	SUS-ITMY_L2_FASTIMON_LL_OUT_DQ (0.21) ref.	SUS-ITMY_L2_MASTER_OUT_LL_DQ (0.21) ref.	SUS-ITMX_M0_OSEMINF_F1_OUT_DQ (0.21) ref.	SUS-ETMY_M0_FASTIMON_F2_OUT_DQ (0.20) ref.	SUS-SRM_M1_MASTER_OUT_LF_DQ (0.20) ref.	SUS-SRM_M2_WIT_P_DQ (0.19) ref.				
1.50	SUS-ETMY_L2_WIT_Y_DQ (0.34) ref.	SUS-ITMY_L2_FASTIMON_UL_OUT_DQ (0.31) ref.	ASC-MICH_Y_SM_DQ (0.31) ref.	ASC-MICH_Y_OUT_DQ (0.31) ref.	SUS-BS_M3_ISCINF_Y_IN1_DQ (0.31) ref.	SUS-ITMY_L2_NOISEMON_UL_OUT_DQ (0.31) ref.	SUS-BS_M2_WIT_L_DQ (0.31) ref.	SUS-BS_M2_FASTIMON_UL_OUT_DQ (0.31) ref.	SUS-BS_M2_MASTER_OUT_LL_DQ (0.30) ref.	PEM-CS_RADIO_LVEA_NARROWBAND_2_DQ (0.30) ref.	
1.75	PEM-CS_RADIO_LVEA_NARROWBAND_2_DQ (0.73) ref.	SUS-OM2_M1_VOLTMON_LR_DQ (0.73) ref.	SUS-SRM_M3_NOISEMON_LL_OUT_DQ (0.73) ref.								
2.00	SUS-ETMY_L2_FASTIMON_LR_OUT_DQ (0.42) ref.	SUS-OM3_M1_OSEMINF_UL_OUT_DQ (0.41) ref.	SUS-ETMY_L1_OSEMINF_LR_OUT_DQ (0.41) ref.	SUS-BS_M2_MASTER_OUT_UL_DQ (0.40) ref.	PEM-CS_RADIO_LVEA_NARROWBAND_2_DQ (0.40) ref.	SUS-ETMY_L1_OSEMINF_LL_OUT_DQ (0.40) ref.	ASC-SRC1_Y_SM_DQ (0.39) ref.	ASC-SRC1_Y_OUT_DQ (0.39) ref.			
	SUS-ITMX_L2	SUS-ITMX_L3	[illegible]	[illegible]	SUS-ITMY_L2	SUS-ITMY_L3	SUS-ITMY_L2	SUS-ITMY_L1	SUS-ITMY_M0	SUS-ETMX_L2	SUS-ITMY_M0

Correlations between Auxiliary Channels

- ▶ To find a systematic way of the correlation between various auxiliary channels in GW detector
  - Helps us to fix the correlated channels that produces abnormal glitches
  - Important to monitor the dynamical variation of the detector for removing glitches
- ▶ Pearson's correlation coefficient (PCC):

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

  - a measure of linear correlation between two random variables

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- ▶ To find a systematic way of computing the correlation between various auxiliary channels in GW detector
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  - Important to monitor the dynamical variation of the detector for removing glitches
- ▶ Mutual Information Coefficient (MIC):

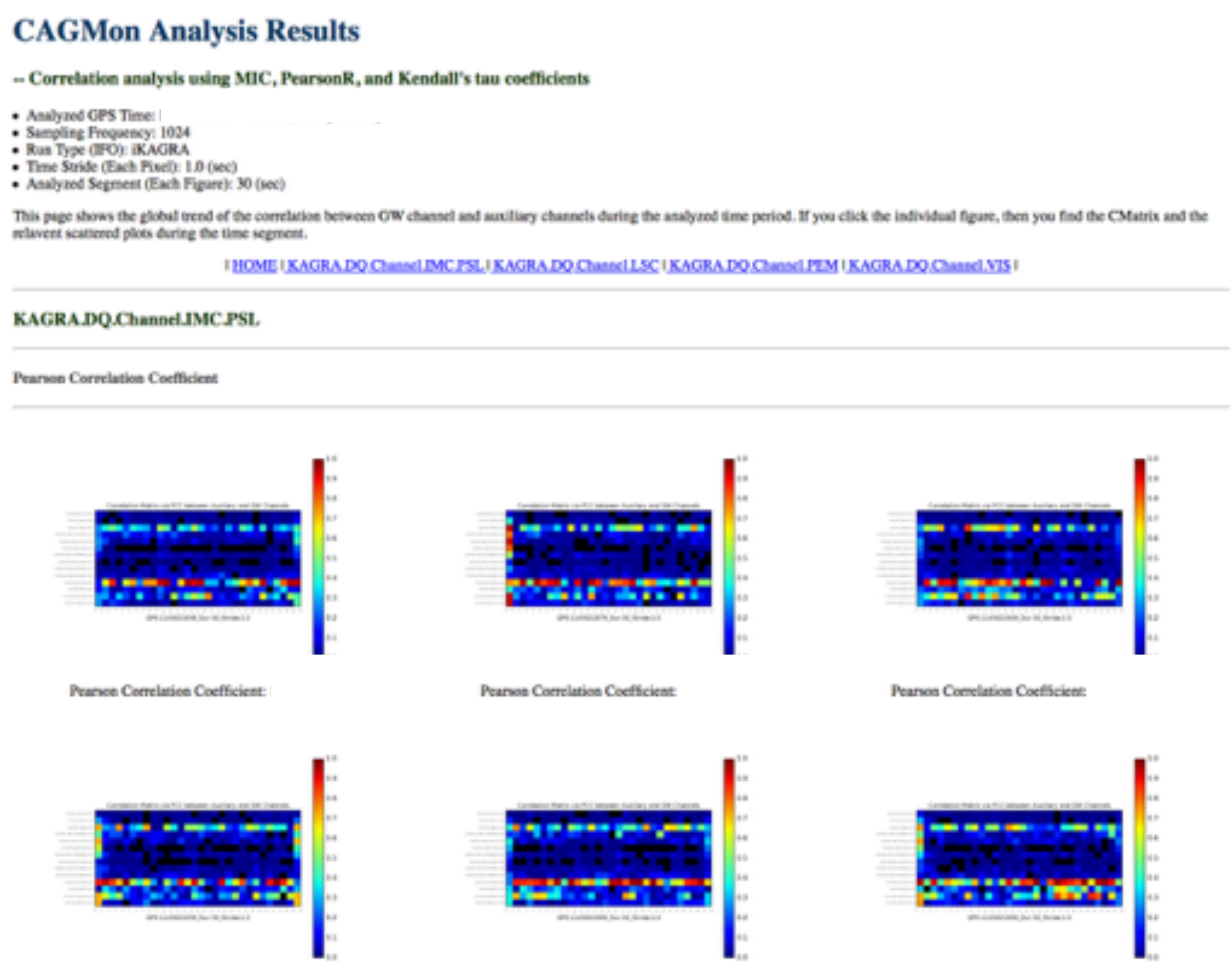
$$I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log \left(\frac{p(x,y)}{p(x)p(y)} \right)$$

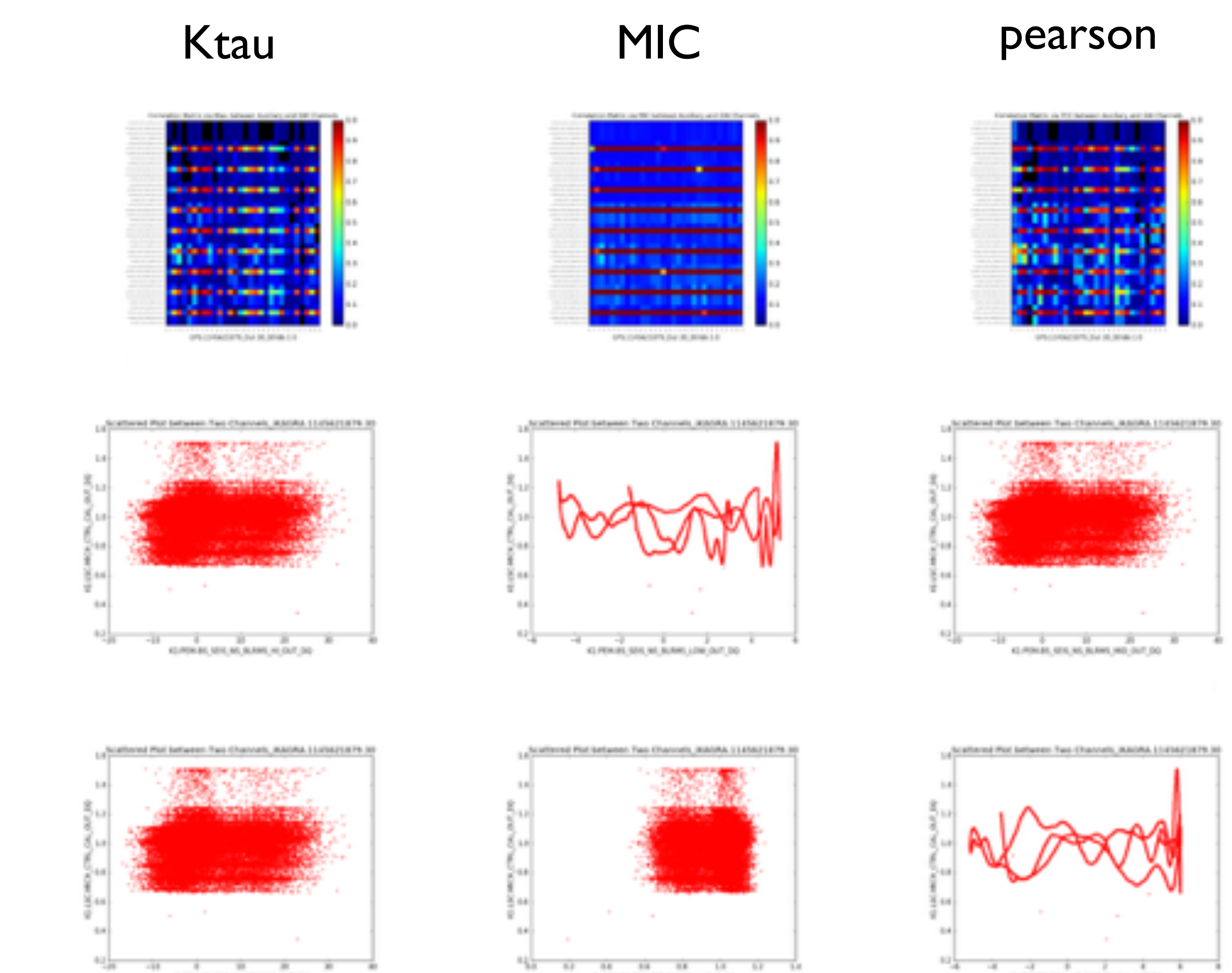
  - a measure of non-linear correlation between two random variables

CAGMon

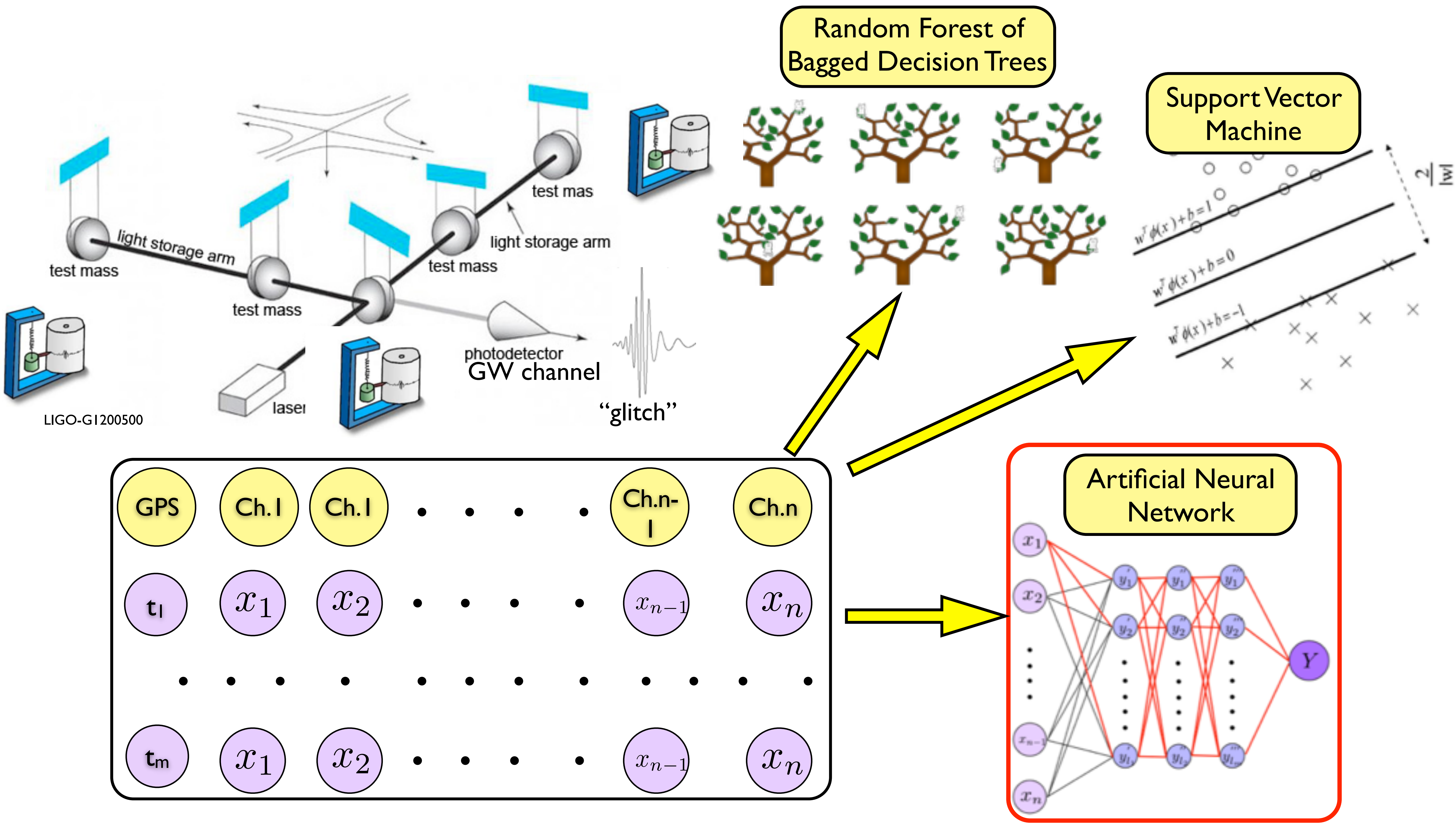
1. Developed by John J. Oh (NIMS)

   - https://git.ligo.org/john.oh/CAGMon





MLAs for Glitch Identification



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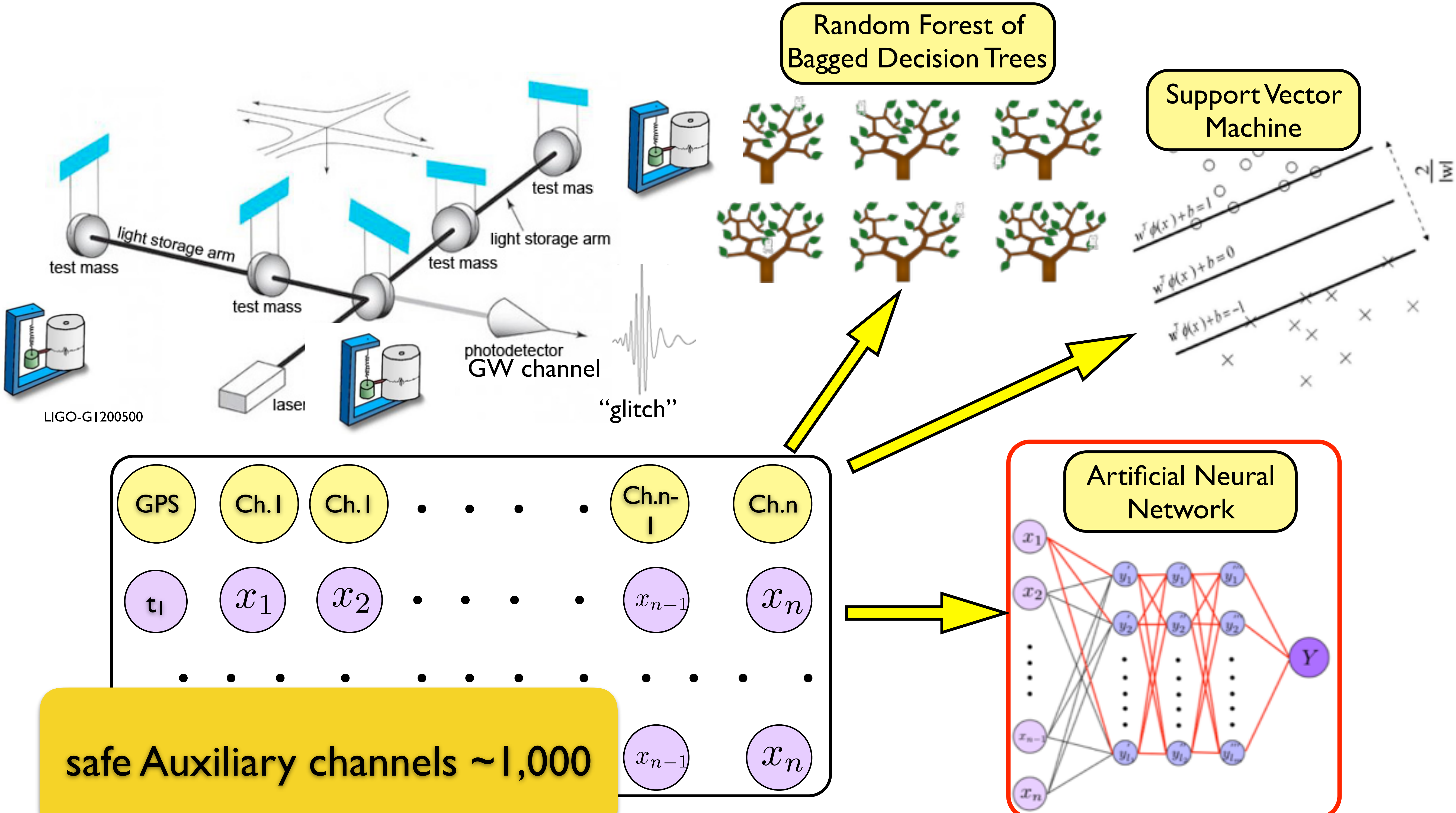

safe Auxiliary channels ~1,000

MLA application to DetChar

1. Ordered Veto List (OVL) + 3 Machine Learning Algorithms

   - application to hundreds of channels among 200,000 auxiliary channels

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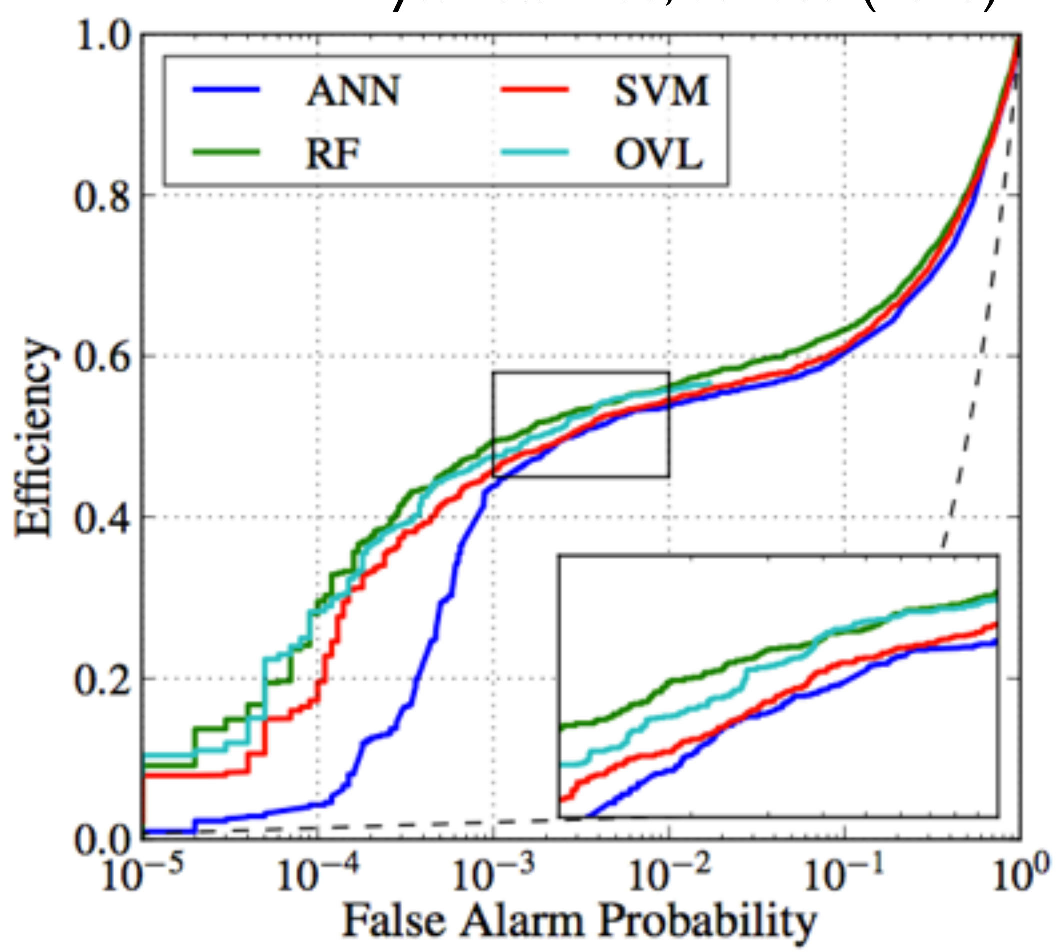

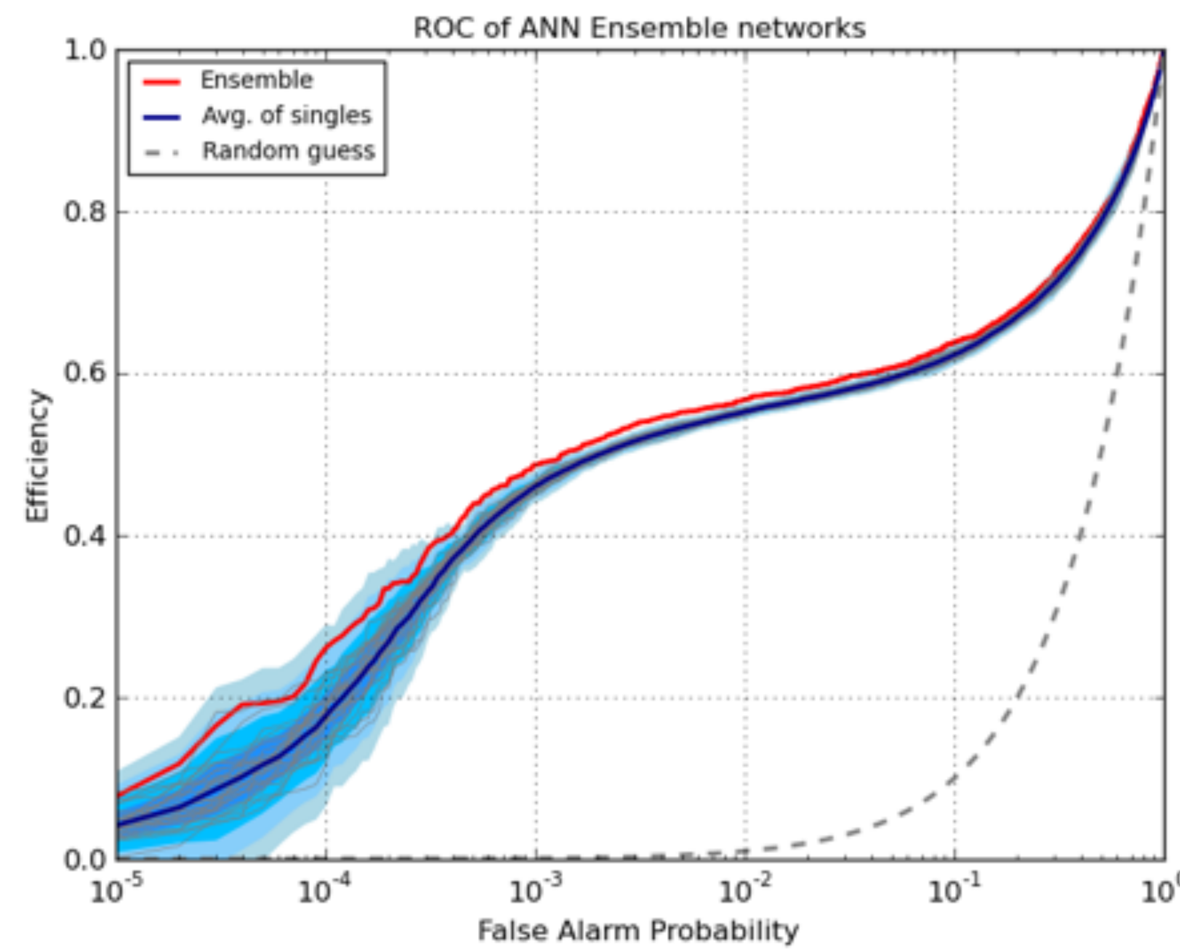

==> iDQ + MLAs

Summary and Future plans

1. LV DQ tools are adopted for KAGRA DQ investingation
   - etaGen, CAGMon were devolved by KGWG
2. Channel Safety Study was partly done and continues
3. For the joint observation with LIGO and Virgo
   - visit to the site
   - online investigation on KAGRA DQ
     - study on recent lock segments of KAGRA commissioning run
   - running off-line iDQ and optimization for KAGRA
   - spectral line tools
   - deep investigation on KAGRA DQ