Analysis of MBTA Single Detector Triggers

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- ❖ Gravitational waves
  - ➢ sources, detection
- ❖ My work
  - ➢ selection of single detector triggers
  - ➢ computation of a False Alarm Rate

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Searching for gravitational waves sources

To this day all measured GW originated from compact binary systems coalescences (CBC):

- Binary Neutron Star (BNS)
- Binary Black Hole (BBH)
- Neutron Star + Black Hole (NSBH)

MBTA: low latency analysis chain looking for CBC

Other searches: continuous waves (pulsars), bursts (unexpected sources)...

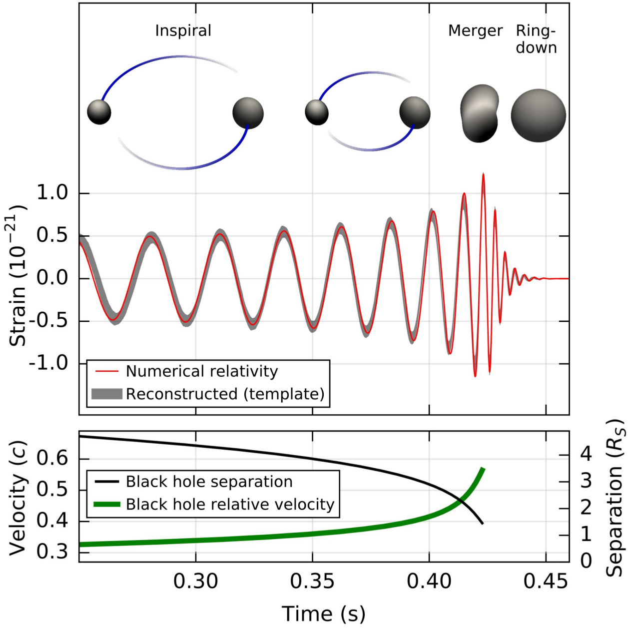
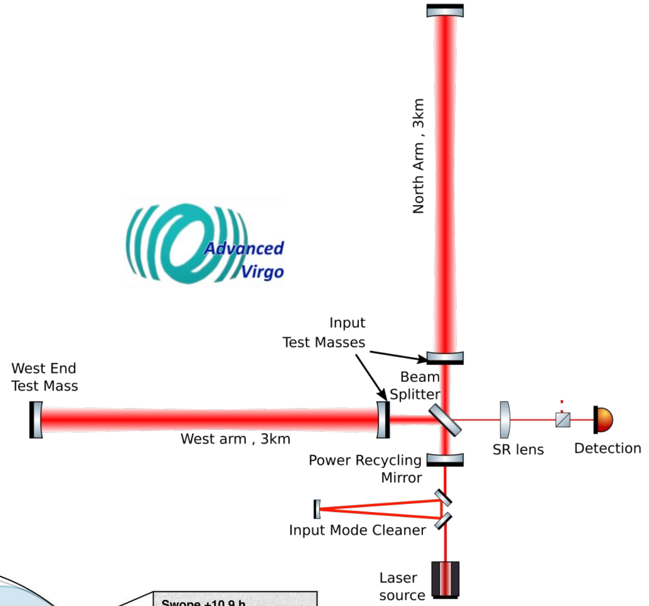
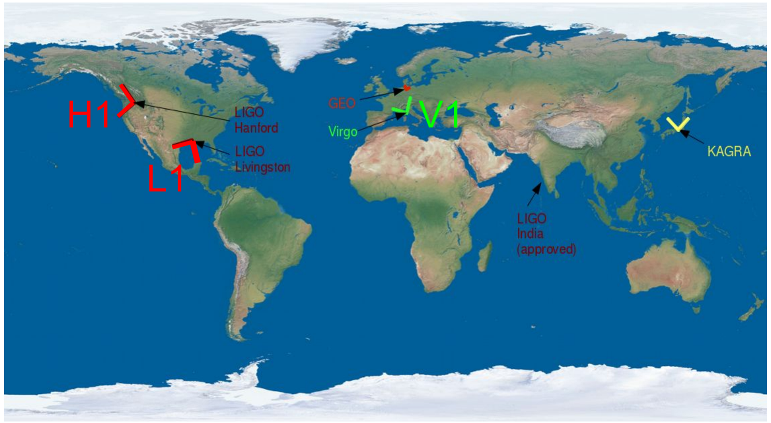


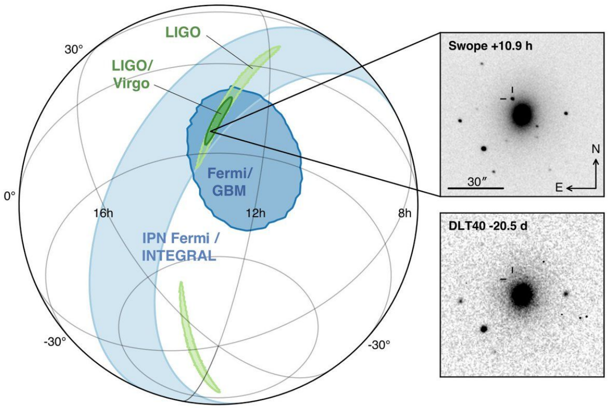
figure from B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 116, 061102

GW detection: LIGO-Virgo

- Detectors based on michelson interferometer: GW modifies the distance between the mirrors ($\sim 10^{-19}$ m)
- Network of detector on earth:
  - confident detections
  - triangulate sky position: LIGO in Hanford + Livingston (USA), Virgo in Cascina (Italy)
- Send alerts to observatories for follow-up







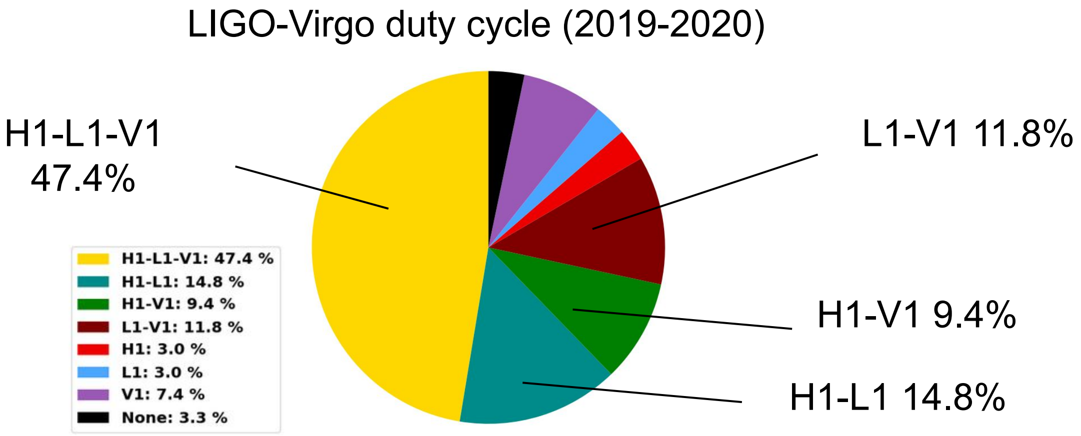
Galaxy NGC 4993 and location of the transient

GW170817 sky location PDF in right ascension and declination

My work and goals

- Initially: require events to be seen in at least 2 detectors to be candidates
- Now GW well established + more sensitive detector + better pipelines
  - → more confidence in events
- My work: use single detector triggers (events seen in only 1 detector)
  - Select good single detector triggers using several quantities
  - compute a False Alarm Rate to quantify their significance

Goal: have more detections

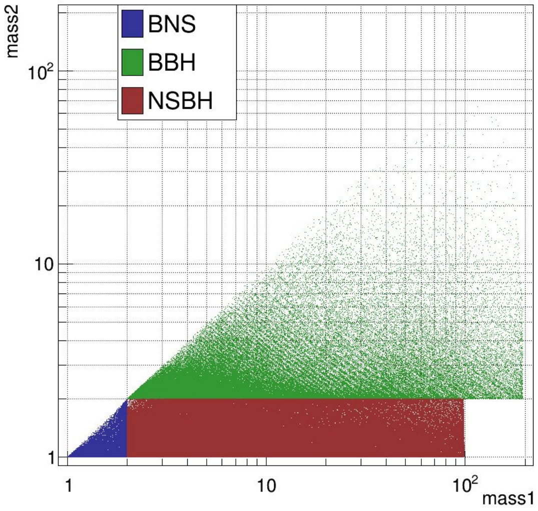


Computation of a False Alarm Rate (FAR)

Searching for known signal: matched filtering

Signal shape is known (general relativity):

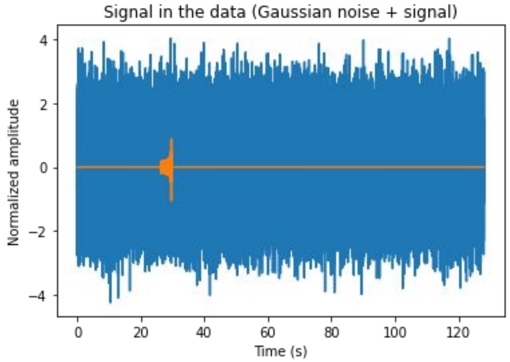
- try different set of parameters : use a template “bank” (~ 728 000 templates)
- compare data to a template (waveform): matched filtering

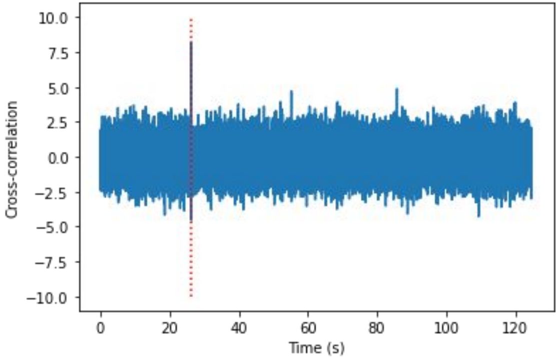


Comparison = cross-correlation of the detector output with a template

→ Matched Filtering Output (MFO) time series

Signal-to-Noise Ratio (SNR) = maximum of the amplitude of MFO





MBTA analysis pipeline

One of the pipeline analyzing LIGO and Virgo data

MBTA stands for Multi-Band Template Analysis

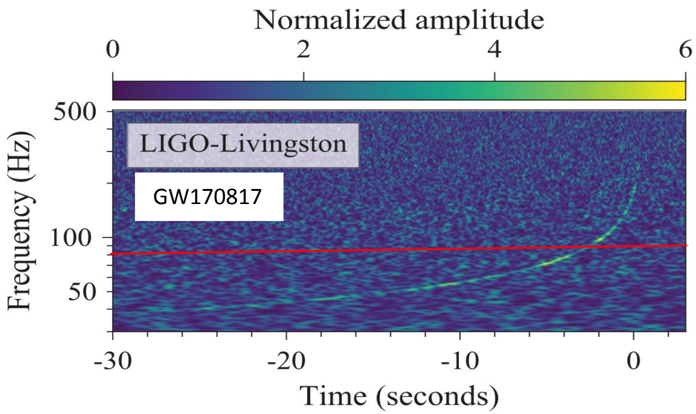
Performs matched filtering on 2 frequency bands

- A Low Frequency (LF) band from 25 to 80Hz
- A High Frequency (HF) band from 80 to 2048 Hz

Combine Matched Filtering Outputs (MFO)

For an astrophysical signal: combination is coherent

Benefit: lower computational cost



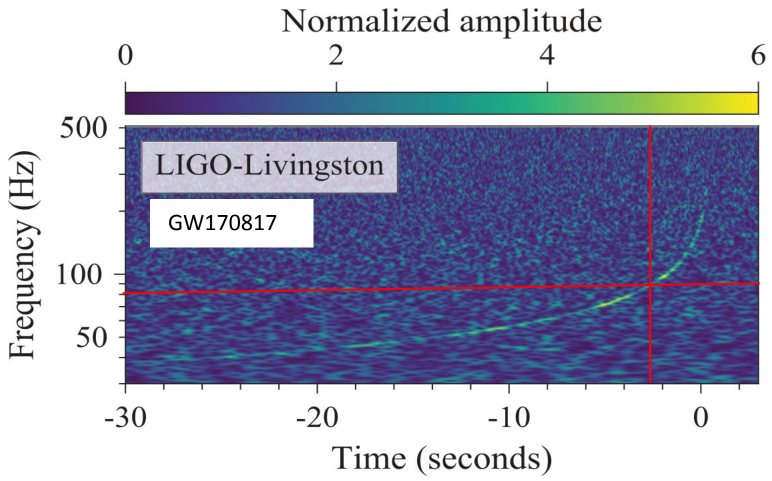
Plot from B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 119, 161101

Estimate the background: Computation of a FAR

- **Goal** : assign a False Alarm Rate (FAR) to single detector triggers

  → estimate the background

- **Method**:
  - Make random coincidences between frequency bands to build a background SNR distribution
  - Use this distribution to compute the FAR as the number of background triggers expected above a given SNR

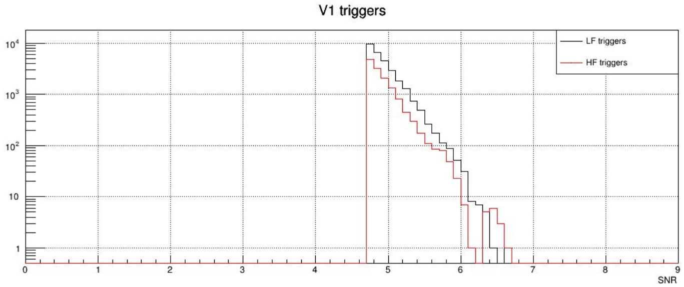


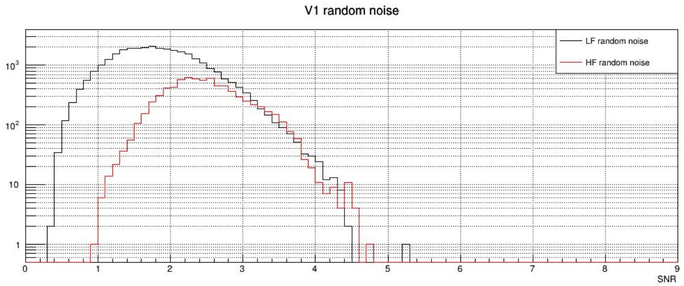
Plot from B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 119, 161101

- **Here**: Coincidences between detectors → coincidences between frequency bands at different times

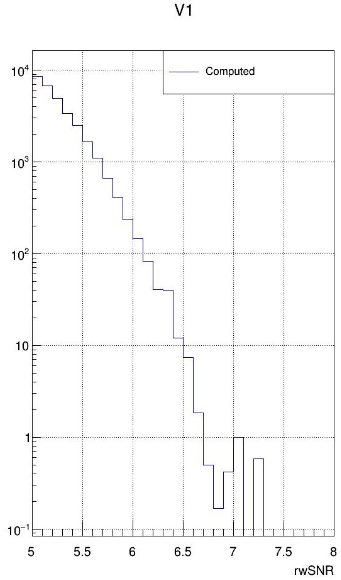
Single band triggers combination

- In one frequency band: save the triggers → upper plot
- In the other frequency band: save the data (random noise) at the same time → lower plot
- Random coincidences done with 1 trigger and 1 random noise each time





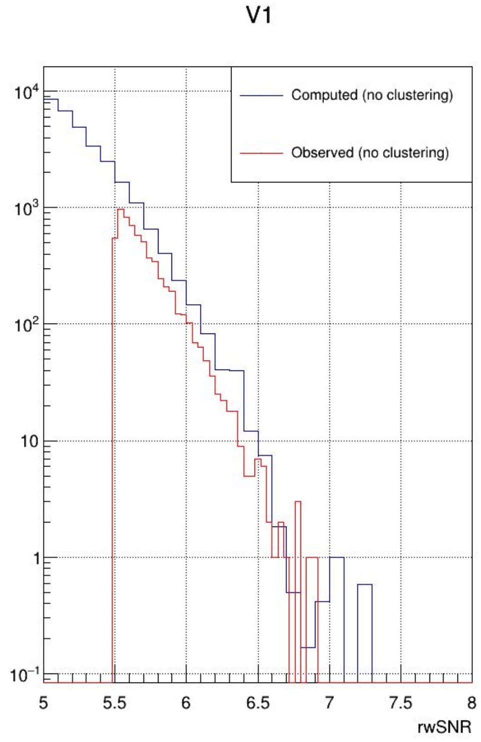
combination →



Comparing observed and computed background

- We make more coincidences per trigger than would happen in a standard analysis
  → distribution is scaled afterwards
- Results for 2000s look promising

  → plan to do on a larger scale



Single detector triggers selection

Single detector triggers selection: motivations

Detector output is not gaussian nor stationary → glitch

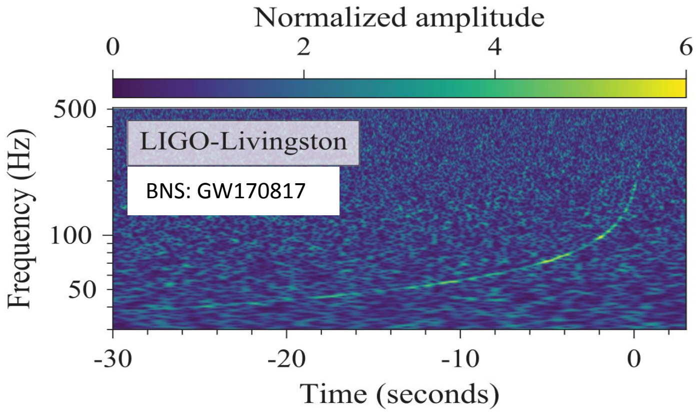
Glitches are short and pollute a large frequency range

We want to focus on signals that we can properly identify and those that are the most interesting

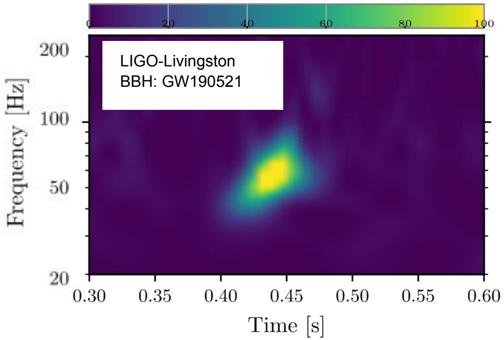
The higher the masses, the shorter the signal

- BBH signals can be very short
- BNS signals are long

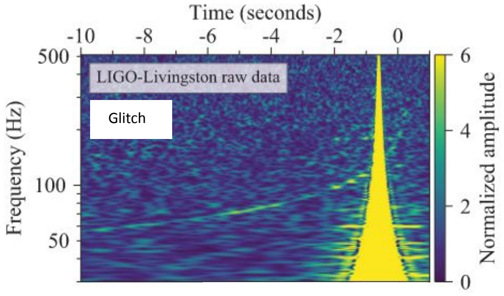
Longer signals are hardly mistaken for glitches



Plot from B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 119, 161101



plot from R. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 125, 101102



Plot from B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 119, 161101

EM bright population

Longer signal = lower mass

→ more likely to contain a neutron star

→ higher chance of emitting electromagnetic radiations

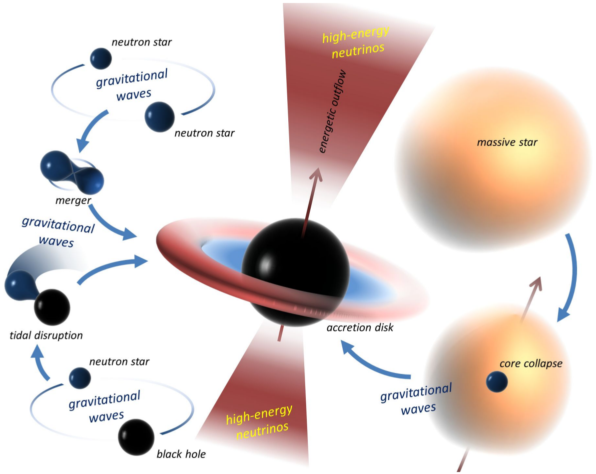
→ EM-bright candidates

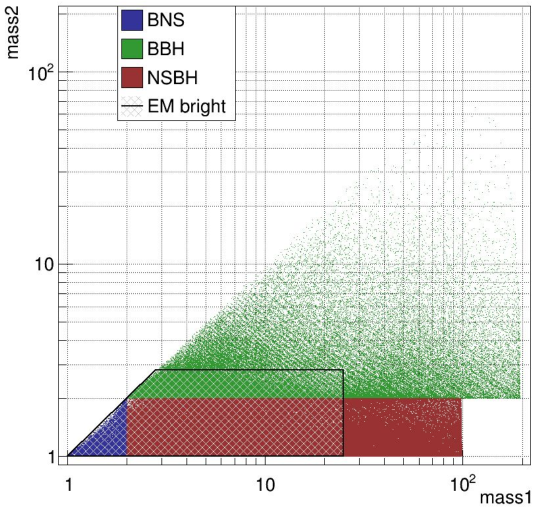
→ Interesting for online alerts

Expected constraints on an EM bright binary:

- At least 1 neutron star → 1 object with 1 M☉ ≤ mass ≤ 2.8 M☉
- not too massive black hole if any (so that matter/radiations can escape) → 1 object with 1 M☉ ≤ mass < 25 M☉

This definition follows "Search for Gravitational Waves Associated with Gamma-Ray Bursts..."





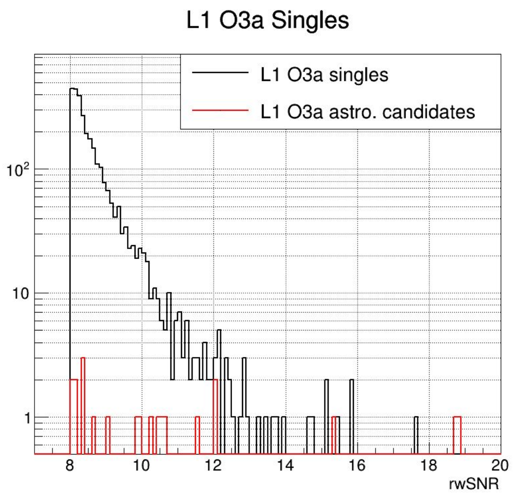
Comparing background: EM bright vs all

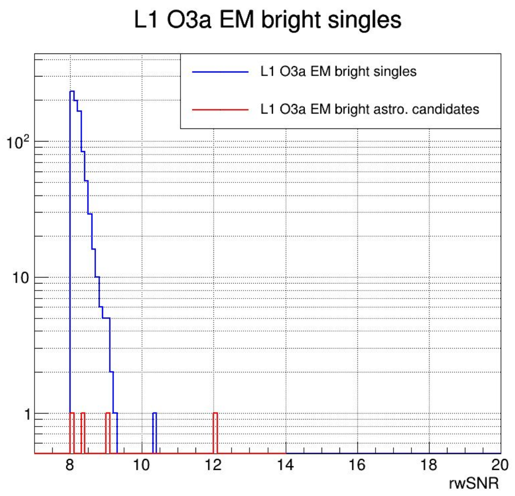
Many non-EM bright events have a high SNR

Most astrophysical candidates are indistinguishable

EM bright background is cleaner

→ Could we do even better ?





EM bright single detector triggers selection

One quantity that proved to be effective in selecting singles for the EM bright region is the “excess rate”

excess rate = ratio of trigger rate before and after quality checks

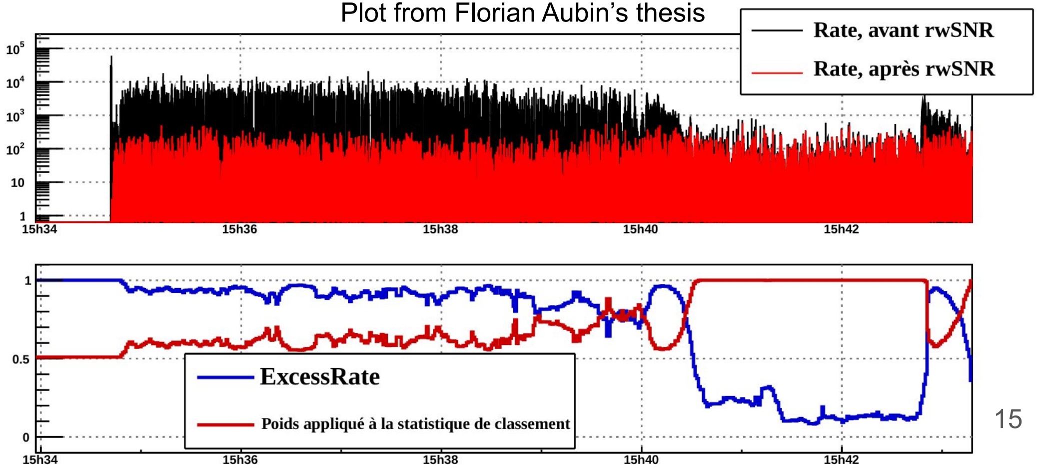
For astrophysical signal: excess of triggers during a few seconds

For noise: excess of triggers for a longer time

→ compute an excess rate weight

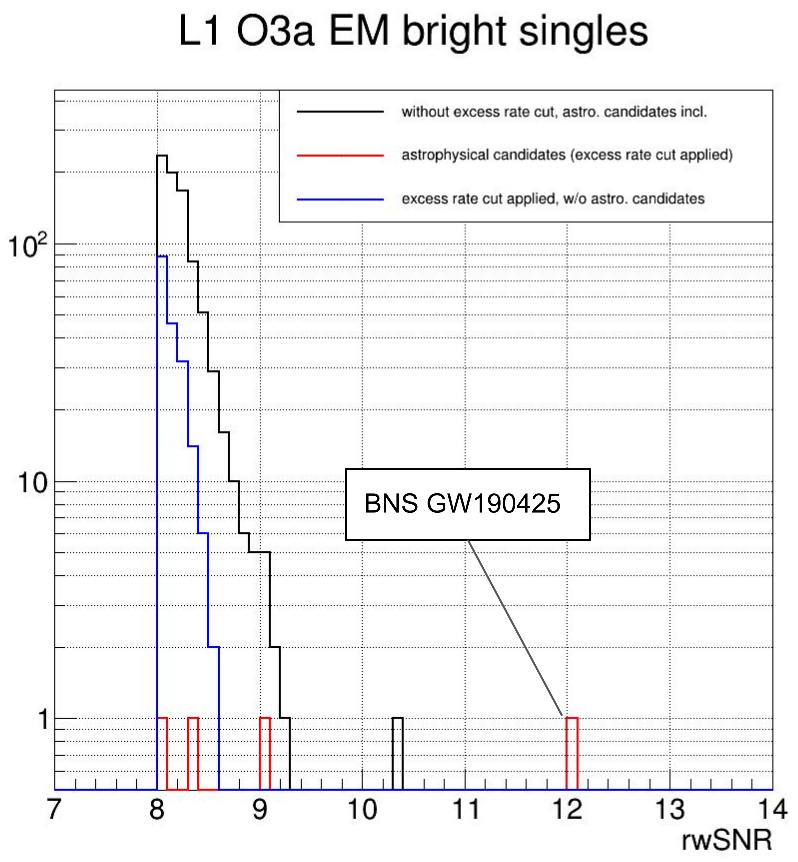
→ apply a penalty to the SNR if the trigger came at a noisy time

Plot from Florian Aubin’s thesis



EM bright singles : rejecting events with ER > 0.3

lose only ~4-5% duty cycle



Summary

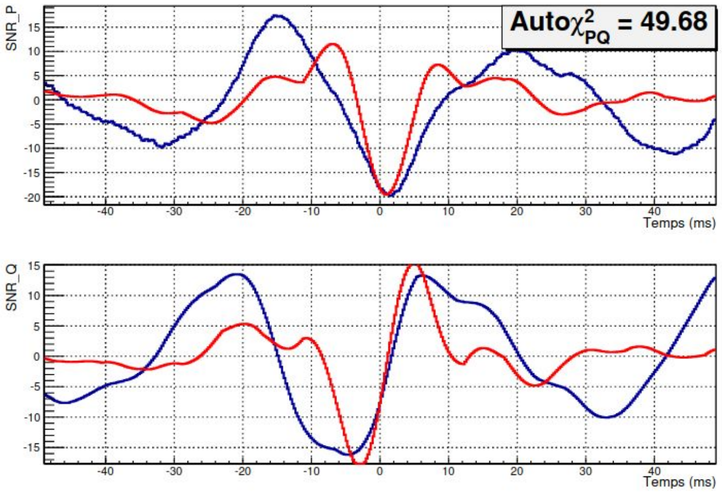
- To increase the number of detections we want to include single detector triggers in our analysis
- For an EM bright candidate population the excess rate allows for a nice selection of the single detector triggers
- Taking advantage of MBTA multi-band structure we can proceed to random coincidences to generate a background SNR distribution for single detector triggers and compute a FAR
- Final goal: use it for O4 (4th observing run of LIGO Virgo)

Additional slides

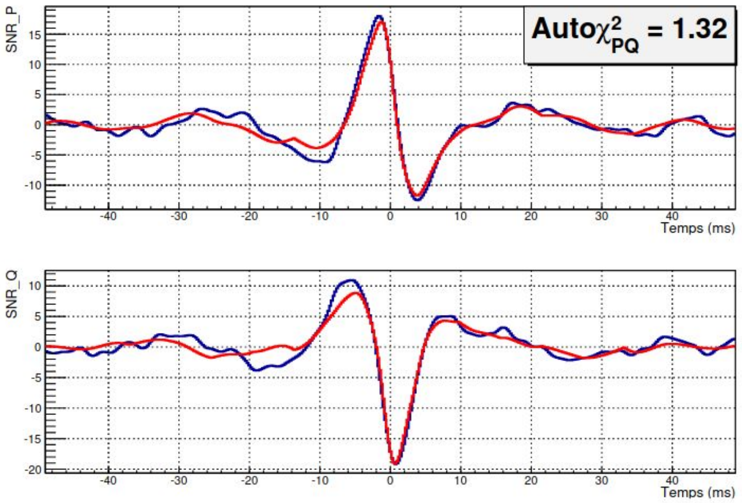
Autoχ² : definition

Autoχ² = comparison of the measured MFOs with the expected MFO (autocorrelation of the template)

Is used to reweight the SNR (a penalty is applied if the Autoχ² is too high)



Loud glitch



BBH injection

Red : expected MFOs
Blue : measured MFOs

Plots from Florian AUBIN thesis