First results from the likelihood pipeline

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- **network WaveBurst pipeline**
- **LIGO-Virgo project 1b results**
- **Coherent energy, x-correlation**
- **S4 results**
- **Summary&Plans**

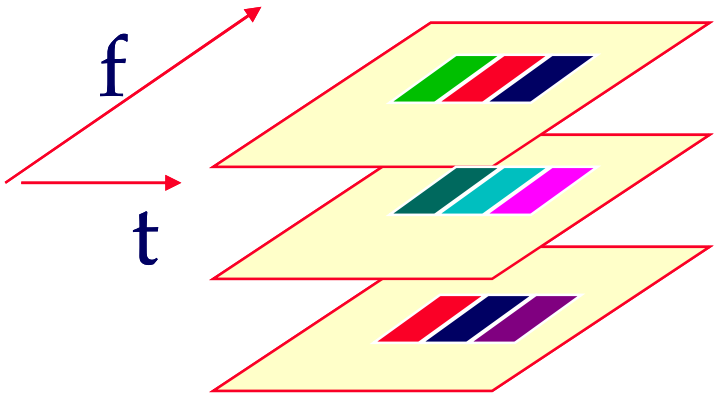
Why one more method for burst detection?

- **The network WaveBurst pipeline is based on likelihood method (PRD 72, 122002, 2005)**
  - **a coherent method for burst detection**
  - **allows reconstruction of GW waveforms and source coordinates**
  - **works for arbitrary alignment of detectors**

Search algorithm

- works in time-frequency domain
- likelihood formalism independent for each TF sample

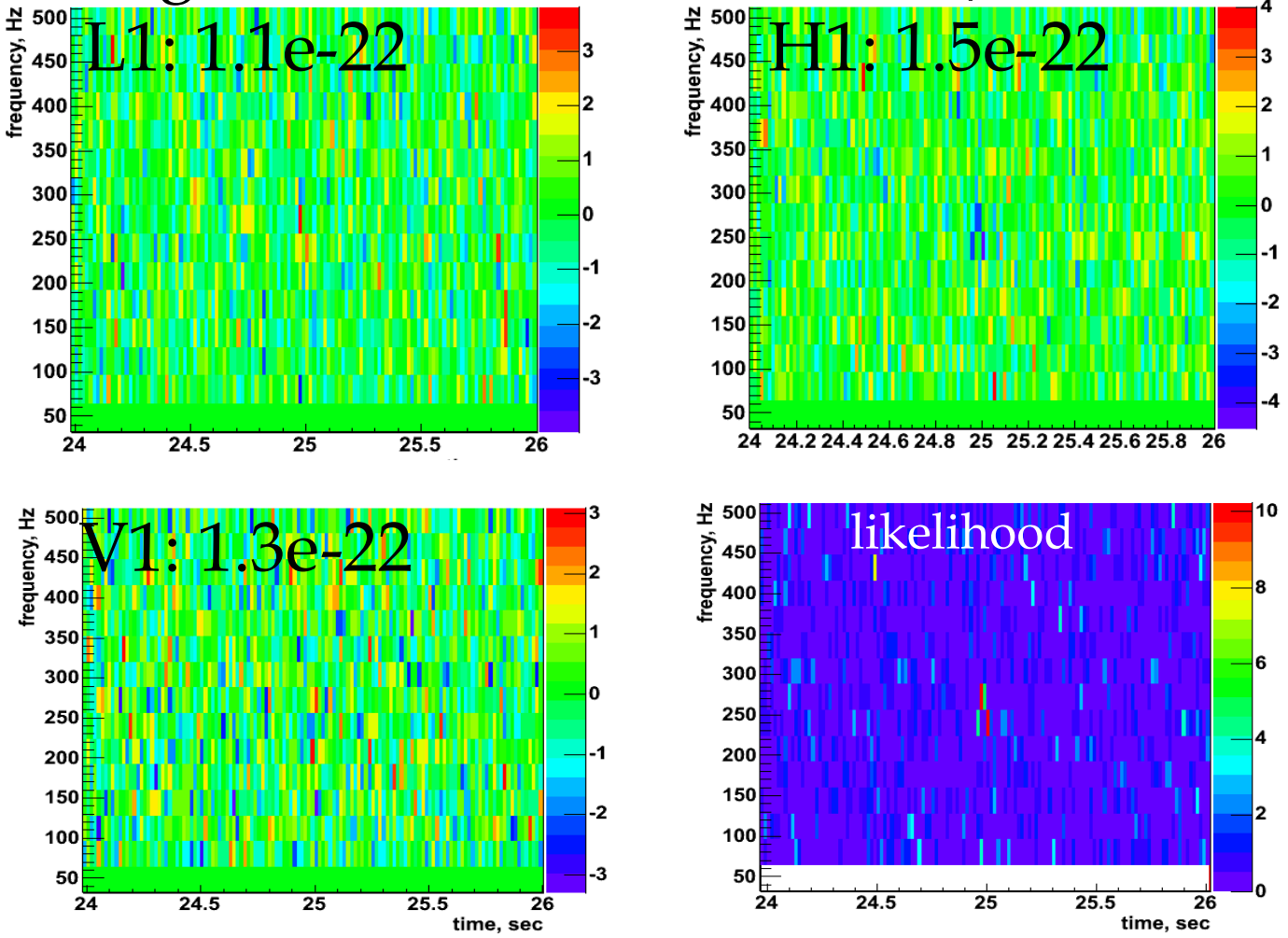
  greatly simplifies calculation of network response
- likelihood time-frequency maps
- time shifts → use 2D TF time delay filter



pick any pixel with fixed (f,t)
and calculate pixel amplitudes
a2(t,f,δ) and a3(t,f,δ) time-shifting
planes 2 & 3 by delay δ
The amplitudes a1, a2(t,f,δ) and
a3(t,f,δ) are used to calculate
pixel likelihood L(t,f,δ)

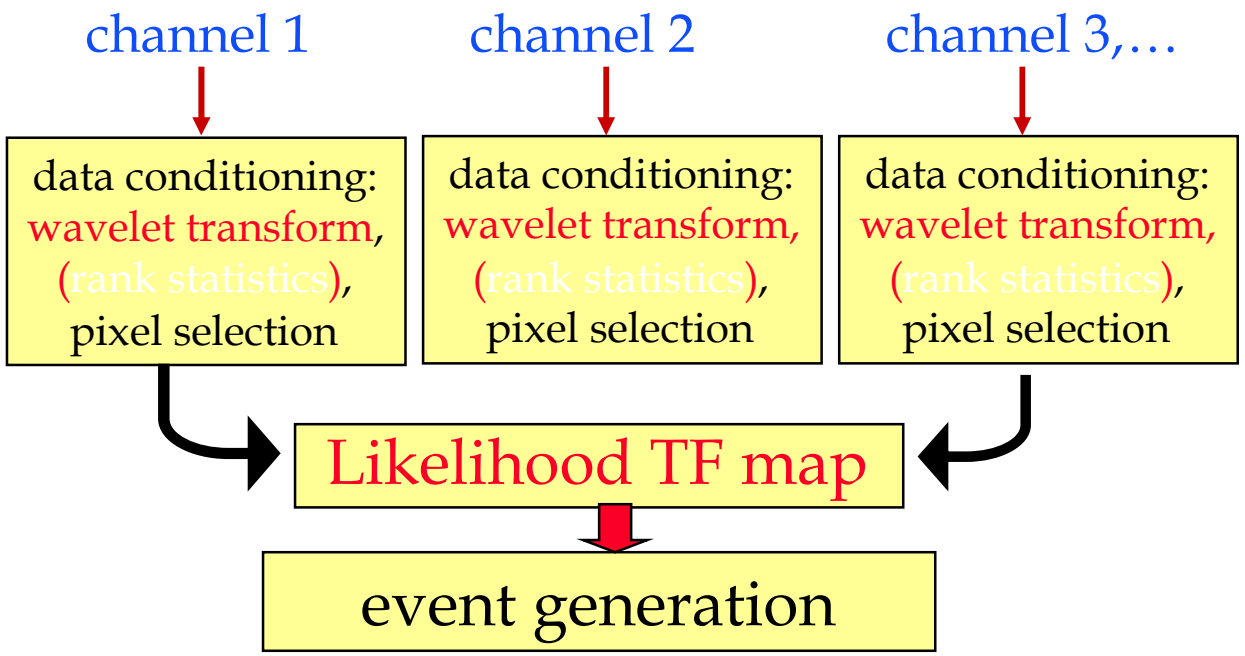
Time-frequency maps

sg250Hz, τ=0.02sec, θ=20, ϕ=150



apply threshold on likelihood and reconstruct clusters

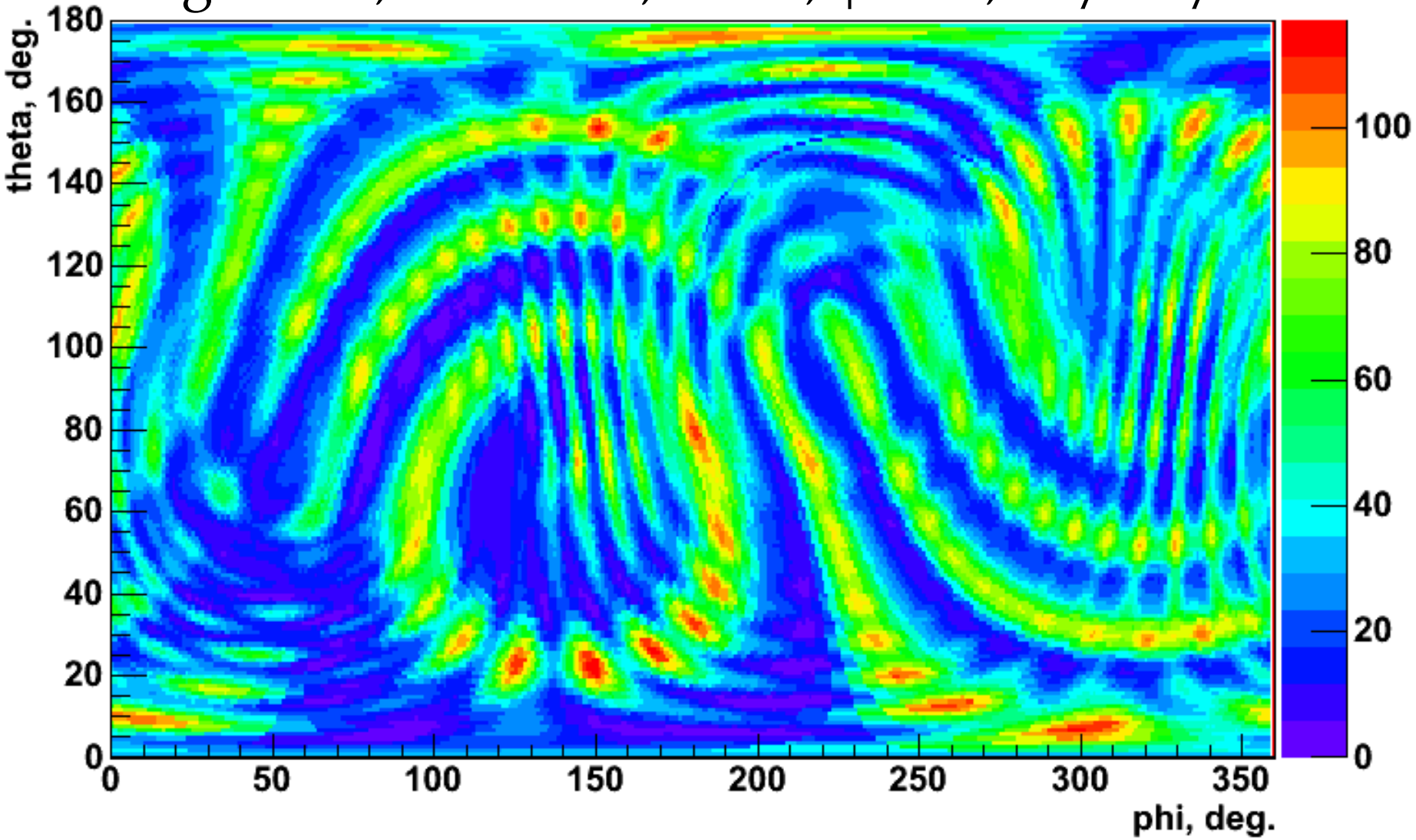
Coherent WaveBurst



- **Similar approach as for incoherent WaveBurst**
- **Uses most of existing WaveBurst functionality**

Likelihood sky maps

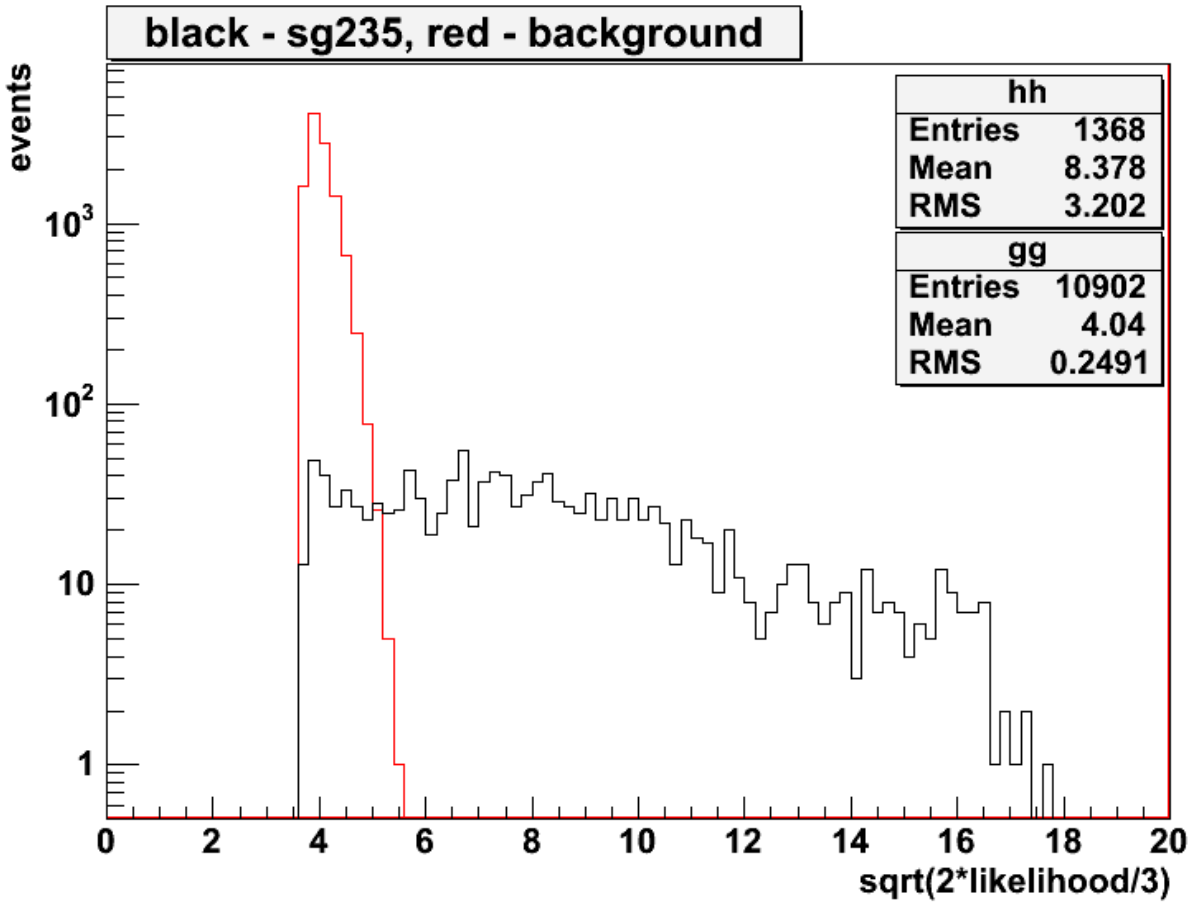
sg250Hz, τ=0.02sec, θ=20, ϕ=150, L1/H1/V1



LIGO-Virgo simulated noise

- Likelihood of triggers on the output of nWB
  - different types of injections (SG,GAUSS,SN)
  - background -- 101 time shifts (T=8726400sec)

2L is the total detected energy



Periodic table of burst algorithms

3pl – triple coincidence
or2 – OR of detector pairs

false alarm rate 1-3 μHz

Fraction (%) of detected events

	A1B2G1 or2 / 3pl	A2B4G1 or2 / 3pl	gauss1 or2 /3pl	gauss4 or2 / 3pl	sg235 or2 / 3pl	sg820 or2 / 3pl
PF	33 / 9	39 / 10	60 / 17	19 / 7	19 / 3	34 / 13
KW	26 / 6	36 / 9	52 / 13	14 / 4	38 / 6	11 / 2
PC	56 / 14	67 / 19	76 / 30	55 / 23	--	--
EGC	52 / 16	43 / 12	66 / 23	32 / 13	60 / 19	32 / 13
MF	28 / 8	43 / 13	55 / 17	17 / 8	20 / 3	1 / 0
ALF	33 / 9	47 / 14	60 / 20	28 / 12	25 / 3	6 / 2
QT	45 / 20	59 / 23	76 / 35	46 / 18	77 / 39	62 / 32
WBN	41	63	--	62	82	73

maximum likelihood statistic

- **Likelihood for Gaussian noise with variance σ^2_k and GW waveform u: $x_k[i]$ – detector output, F_k – antenna patterns**

$$L = \sum_i \sum_k \frac{1}{2\sigma_k^2} \left[x_k^2[i] - \left(x_k[i] - \xi_k[i] \right)^2 \right]$$

detector response - $\xi_k = h_+ F_{+k} + h_x F_{xk}$

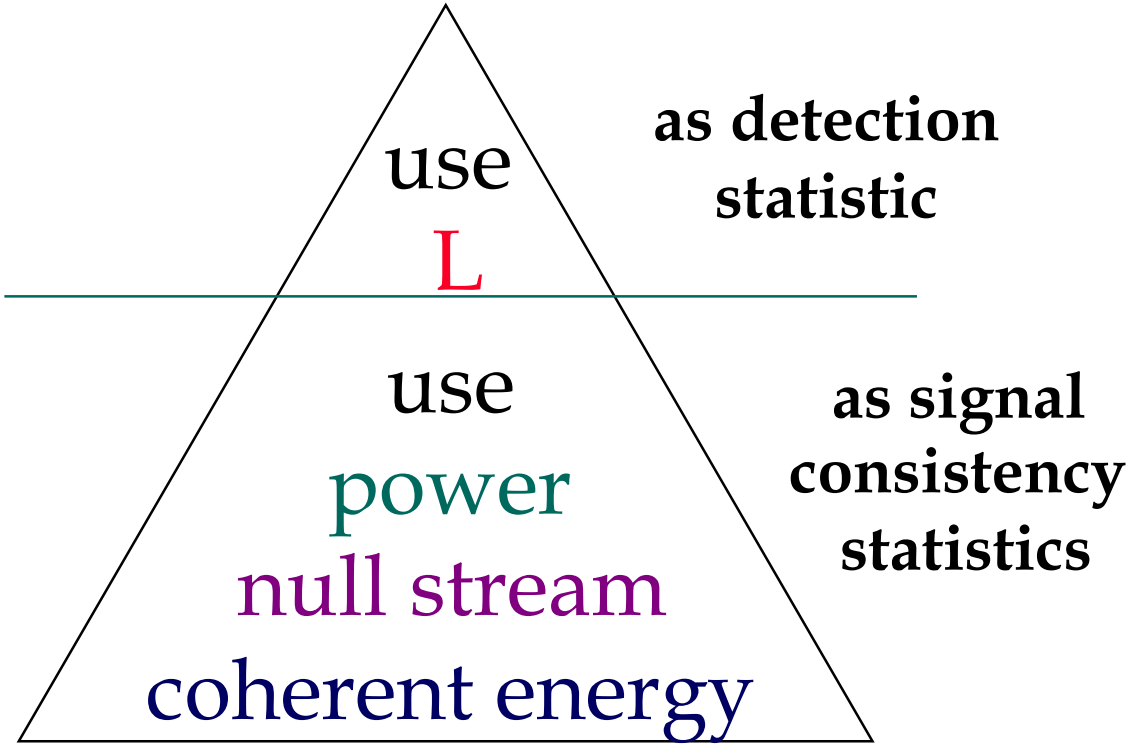
$$2L = E - N$$

detected (signal) energy — **total energy** — **noise (null) energy**

- **Events reconstructed by the pipeline are coincident in time by construction → what is definition of a coincidence?**

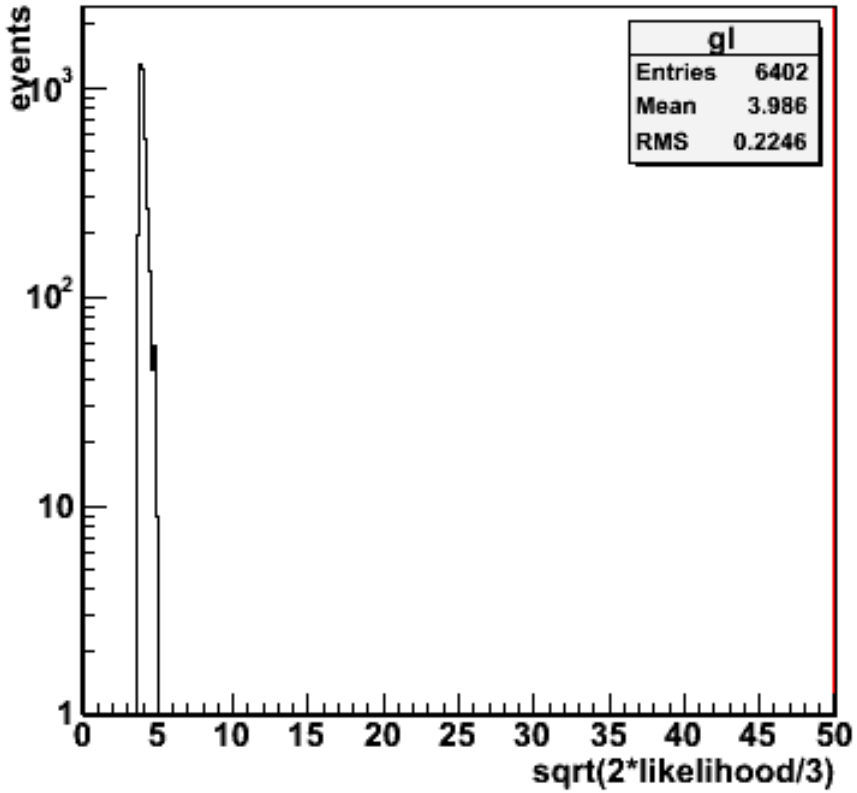
real world analysis

- In ideal world where detector noise is always Gaussian: likelihood statistic is sufficient.
- In the real world where data is always contaminated with glitches: - the signal consistency statistics are required
- Real world analysis strategy

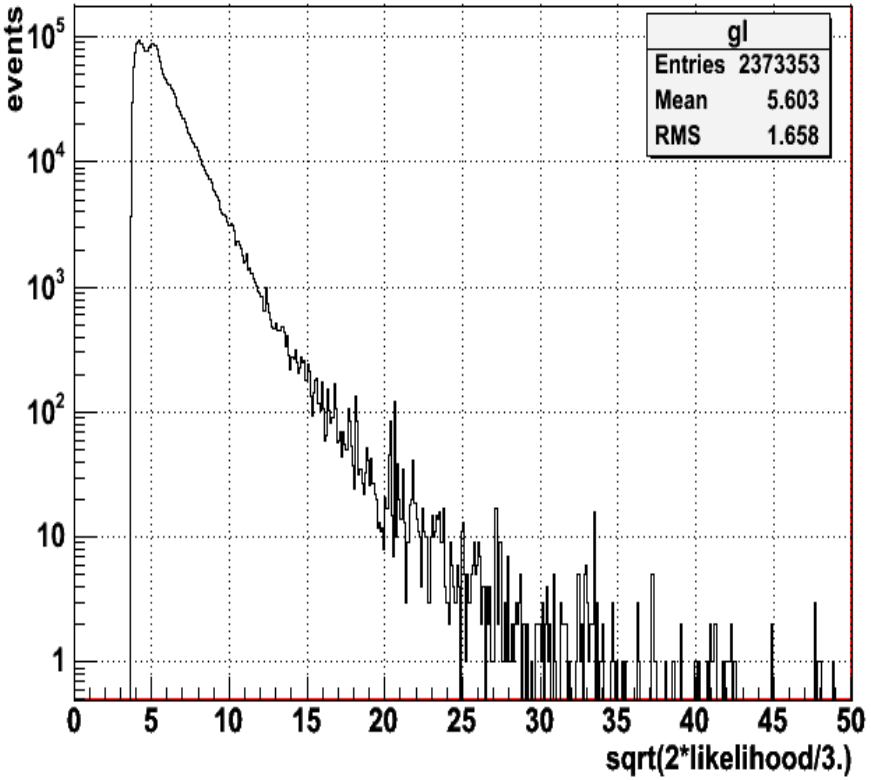


Likelihood distribution

Ligo-Virgo noise



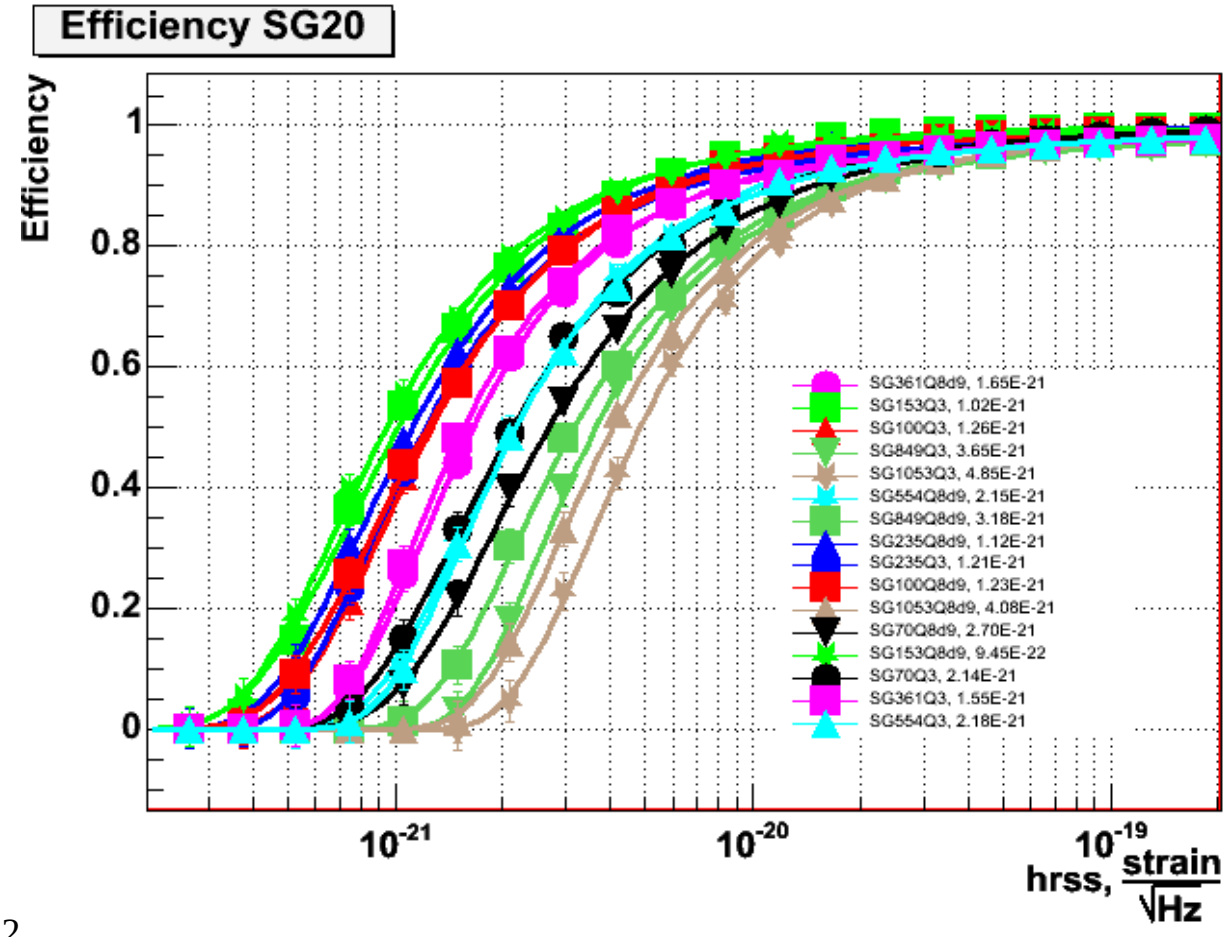
S4 data



Detection performance as ETG

sgQ9	70	100	153	235	361	553	849	1053
WB	4.60	1.32	1.13	1.29	2.04	2.49	3.71	5.00
nWB	2.70	1.23	0.94	1.12	1.65	2.15	3.18	4.01

tuned to FA rate 20μHz by setting threshold on power in each detector



Coherent energy

- **Likelihood is a quadratic form:**

$$2L = \sum_{i,j} \left\langle x_i x_j \right\rangle C_{ij} = E_{i=j} + E_{i\neq j}$$

incoherent **coherent**

- x_i **– whitened data streams**
- C_{ij} **depend on antenna patterns and detector sensitivity. For constraint likelihood:**

$$C_{ii} = \frac{1}{2g}\left(\frac{F_{+i}^2}{\sigma_i^2} + \frac{F_{\times i}^2}{\sigma_i^2}\right), \qquad C_{i\neq j} = \frac{1}{2g}\left(\frac{F_{+i}F_{+j}}{\sigma_i\sigma_j} - \frac{F_{\times i}F_{\times j}}{\sigma_i\sigma_j}\right)$$

g – network sensitivity

X-correlation for misaligned detectors

- **S-statistic**

$$r = \frac{E_{ij}}{\sqrt{E_{ii}E_{jj}}} \rightarrow \frac{\langle x_i x_j \rangle}{\sqrt{\langle x_i^2 \rangle \langle x_j^2 \rangle}}$$

arbitrary detectors — **aligned detectors**

- **Cauchy-statistic**

$$c = \frac{E_{ij}}{E - E_{ii} - E_{jj}} \rightarrow \frac{2\langle x_i x_j \rangle}{\langle x_i^2 \rangle + \langle x_j^2 \rangle}$$

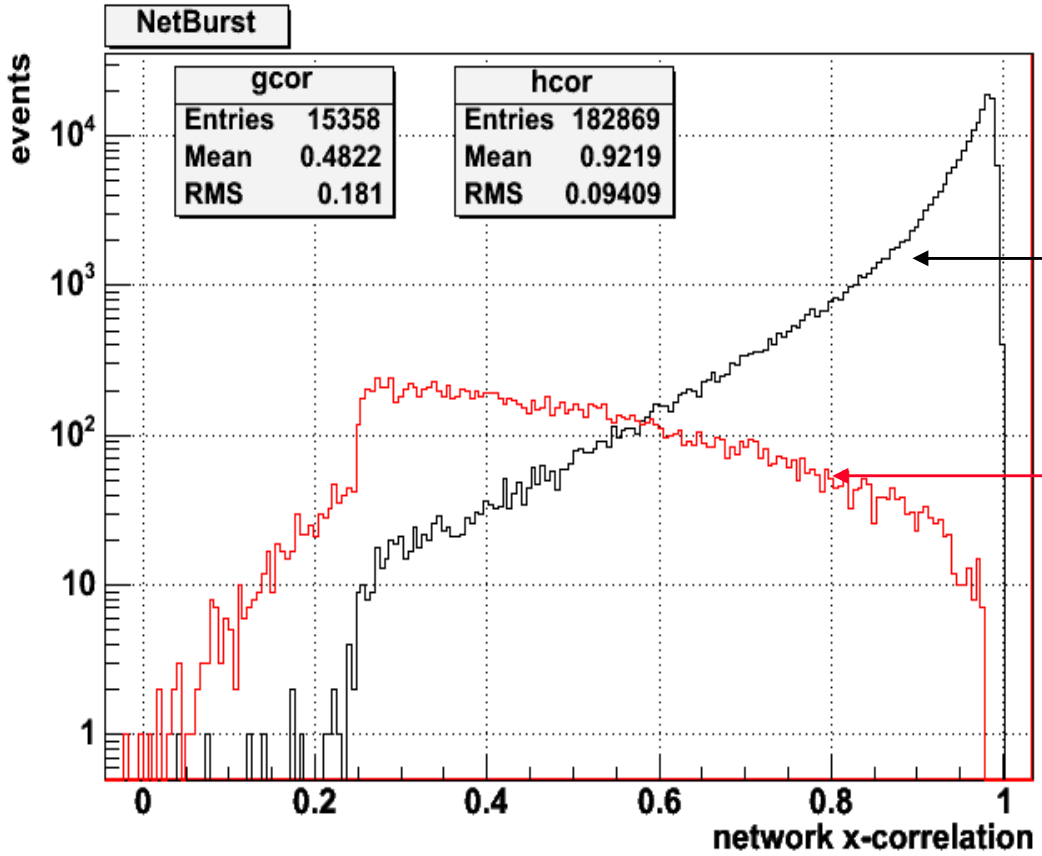
  - **network global x-correlation coefficient**

$$C_{net} = \frac{\sum_{i \neq j} E_{ij}}{E - \sum E_{ii}} = \frac{E_{coherent}}{N_{ull} + E_{coherent}}$$

- **Similar to r-statistic the KS test can be applied**

Network x-correlation

- **powerful signal consistency test different from the NULL stream**



SG injections

S4 background triggers

End-to-End pipeline

- In addition to excess power cuts apply selection cuts based on the likelihood x-correlation terms
  - works for arbitrary detector alignment

sgQ9	70	100	153	235	361	553	849	1053
WB+R	4.7	1.4	1.2	1.3	2.1	2.6	3.9	5.4
WBN	3.5	1.5	1.2	1.5	2.2	2.9	4.6	6.1

- False alarm (100 time lags) 0.2 mkHz
- Results are very preliminary
  - no DQ flags were applied
  - post-processing election cuts are not tuned

Pipeline performance

- **Search over the entire sky with good angular resolution can be computationally very intensive**

- **nWB pipeline performance for all sky search with 1^o resolution (65000 sky locations) and 101 time lags**
  - **cit 2.2GHz 64 bit obteron – 1. 0 sec/sec**
  - **Llo 3.4GHz 32 bit Xeon - 1.6 sec/sec**

- **nWB performance is comparable to the incoherent WaveBurst pipeline**
  - **typical run time on LLO cluster for S4 data is 1 day**

Summary

- **network WaveBurst pipeline (nWB) based on likelihood analysis is operational.**
  - **LIGO-Virgo project 1b data: nWB looks good in "ideal world"**
  - **S4 data: results consistent with the standard WB+R pipeline**
  - **Excellent computational performance**
- **x-correlation coefficients can be defined for arbitrary networks which offers a waveform consistency test complementary to Null stream**

Plans

- **Finalize tuning of selection cuts & S4 data analysis**
- **study coordinate and waveform reconstruction**
- **try algorithm on LIGO-GEO and LIGO-Virgo data**
- **run online coherent search on S5 data**
- **Produce likelihood statistic for triggered population search (with S.Mohanty)**
- **perform BH-BH merger search**