Waveburst sensitivity study and event property reconstruction on S2 playground data and MDC frames

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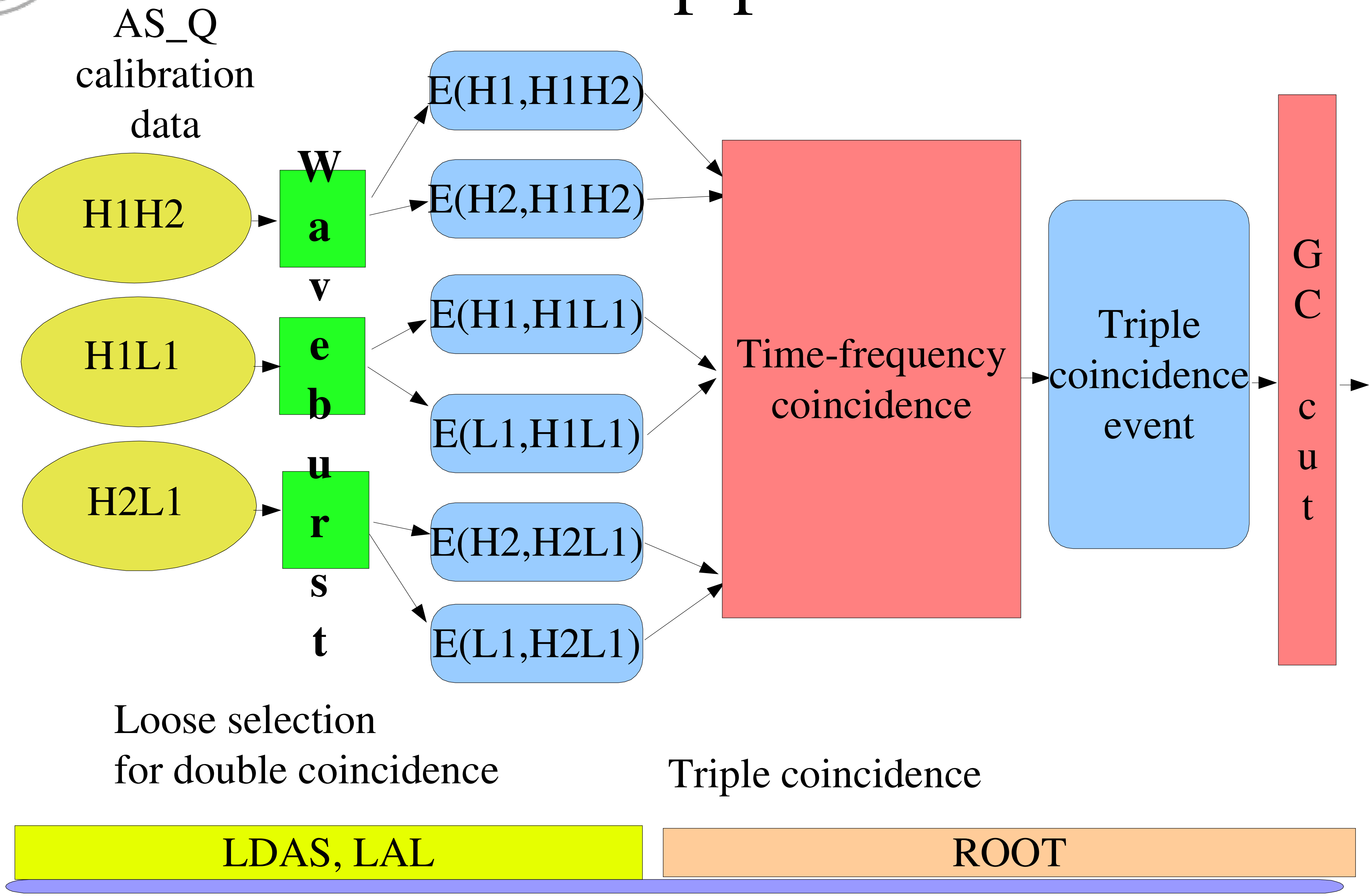
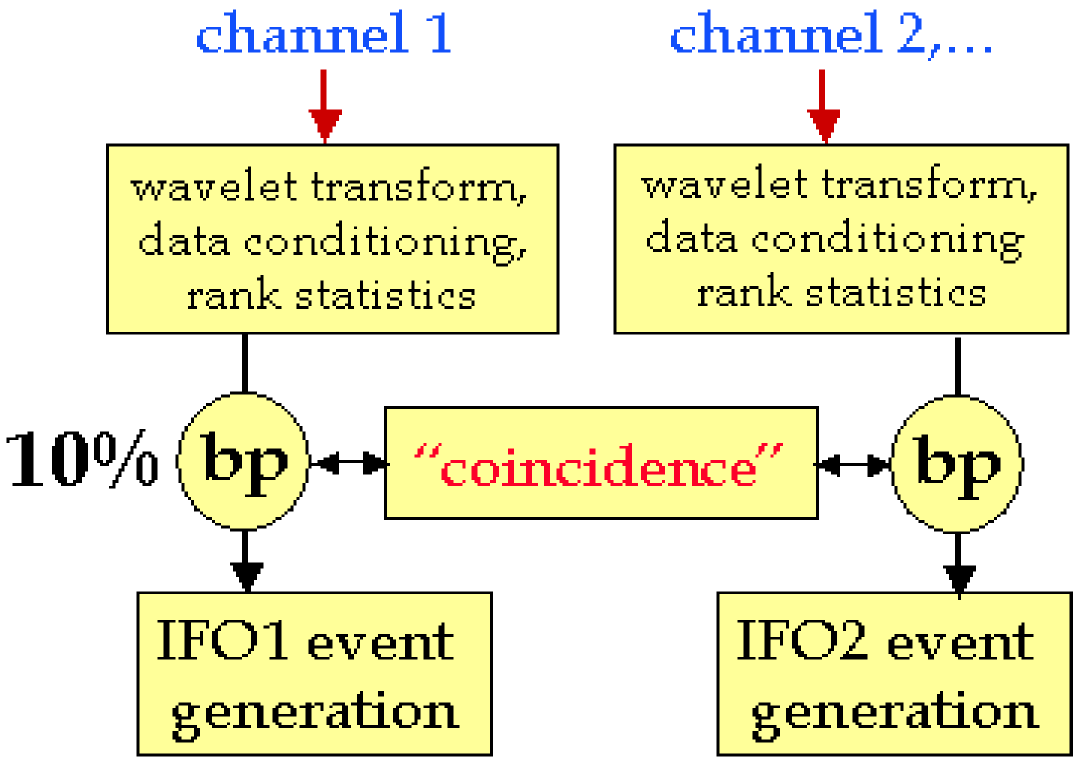
Outline

- Waveburst data pipeline and algorithm
- Triple coincidence
- Combined confidence threshold
  - Definition of geometric confidence
  - Detection efficiency vs geometric confidence threshold
- Efficiency for sine-gaussian, gaussian, bh-bh merger MDC frames
- Central time, frequency and strain reconstruction
- Future plans

Waveburst pipeline



Waveburst ETG



Settings:

time stride	**– 120 sec**
F resolution	**– 64 Hz**
T resolution	**– 1/128 sec**
band	**<4096 Hz**

NO data conditioning before wavelet transformation
tested: no effect from LPF

The output of a single waveburst job are two independently reconstructed clusters that overlap in time and frequency.

Time window

- (X,Y) average time $$T_{XY} = \frac{T_{XY}^{X} + T_{XY}^{Y}}{2}$$

- Time coincidence:

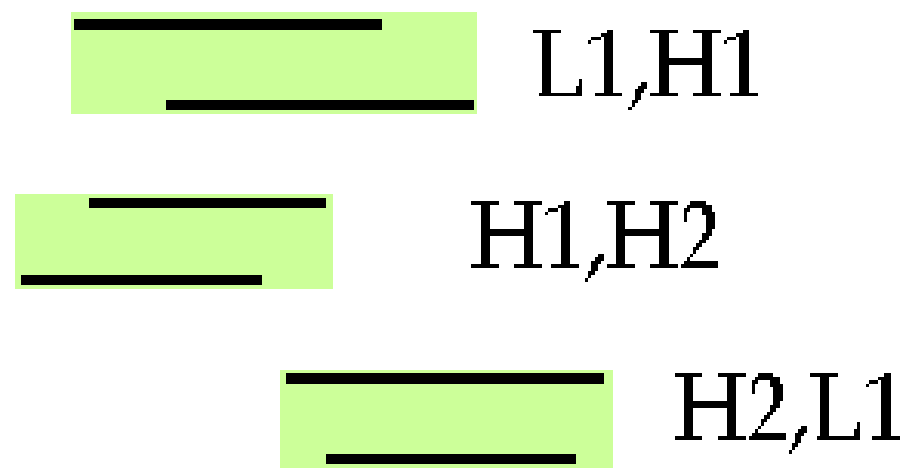
$$|T_{L_1H_1} - T_{H_1H_2}| \leq T_w$$

$$|T_{L_1H_1} - T_{H_2L_1}| \leq T_w$$

$$|T_{H_2L_1} - T_{H_1H_2}| \leq T_w$$

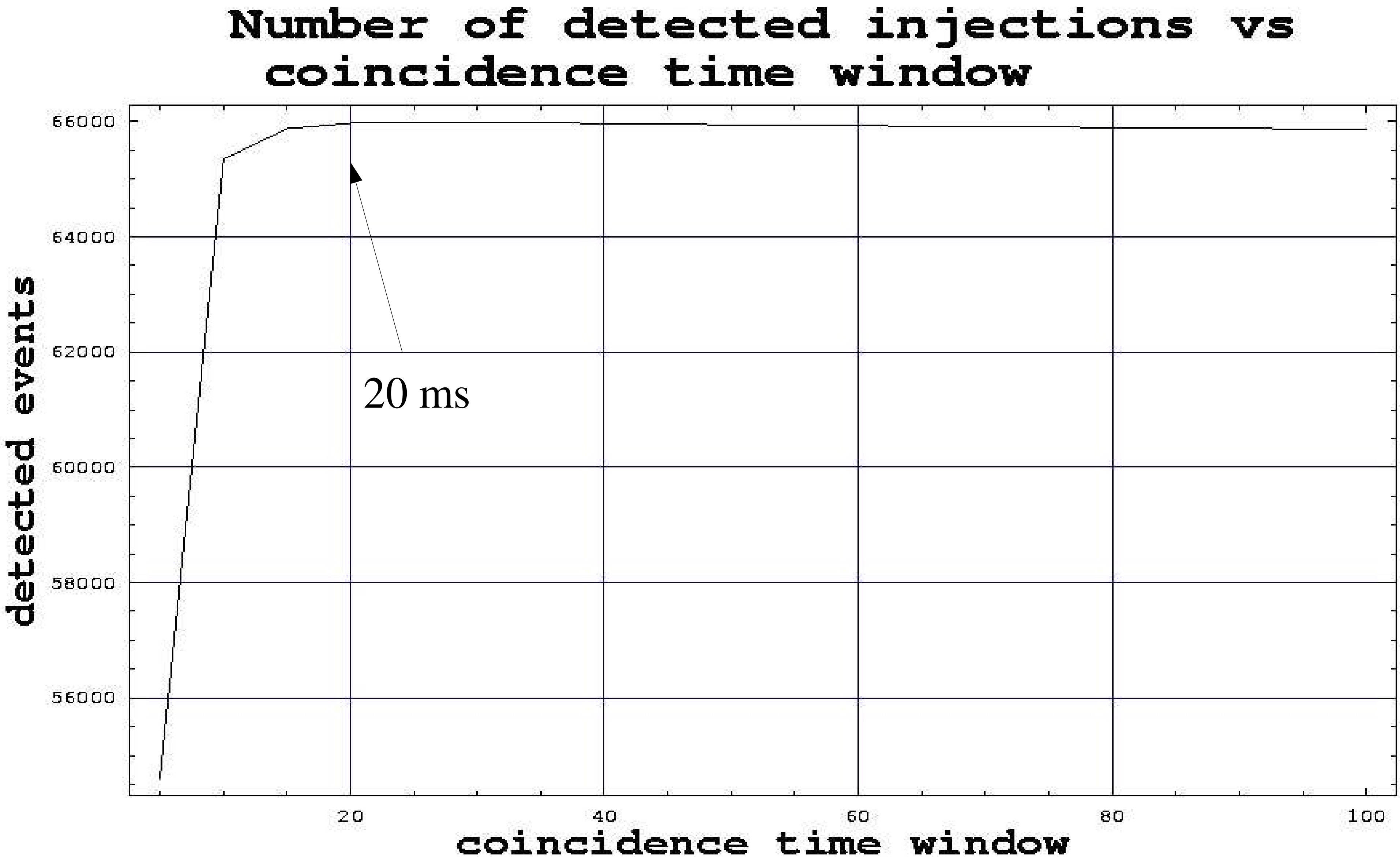
$T_w = 20ms$

- Frequency coincidence:



zero tolerance overlap

Time window


Number of detected injections vs coincidence time window
66000
64000
62000
60000
58000
56000
detected events
20 ms
20
40
60
80
100
coincidence time window

Pixel and cluster significance

- After 10% of the strongest pixels is selected on each frequency layer, the strength of the remaining pixels are characterized as follows:
  - Sort pixels according to the absolute value of their wavelet amplitudes on each frequency layer, if a pixel's rank in this list is R and there are nP nonzero pixels on the frequency layer, define non-parametric significance of this pixel as

$$Y = -\ln\left(\frac{R}{nP}\right)$$

Non parametric significance of a cluster

$$Y(cluster, k) = \sum_{i=0}^{k} Y_i$$

Cluster confidence

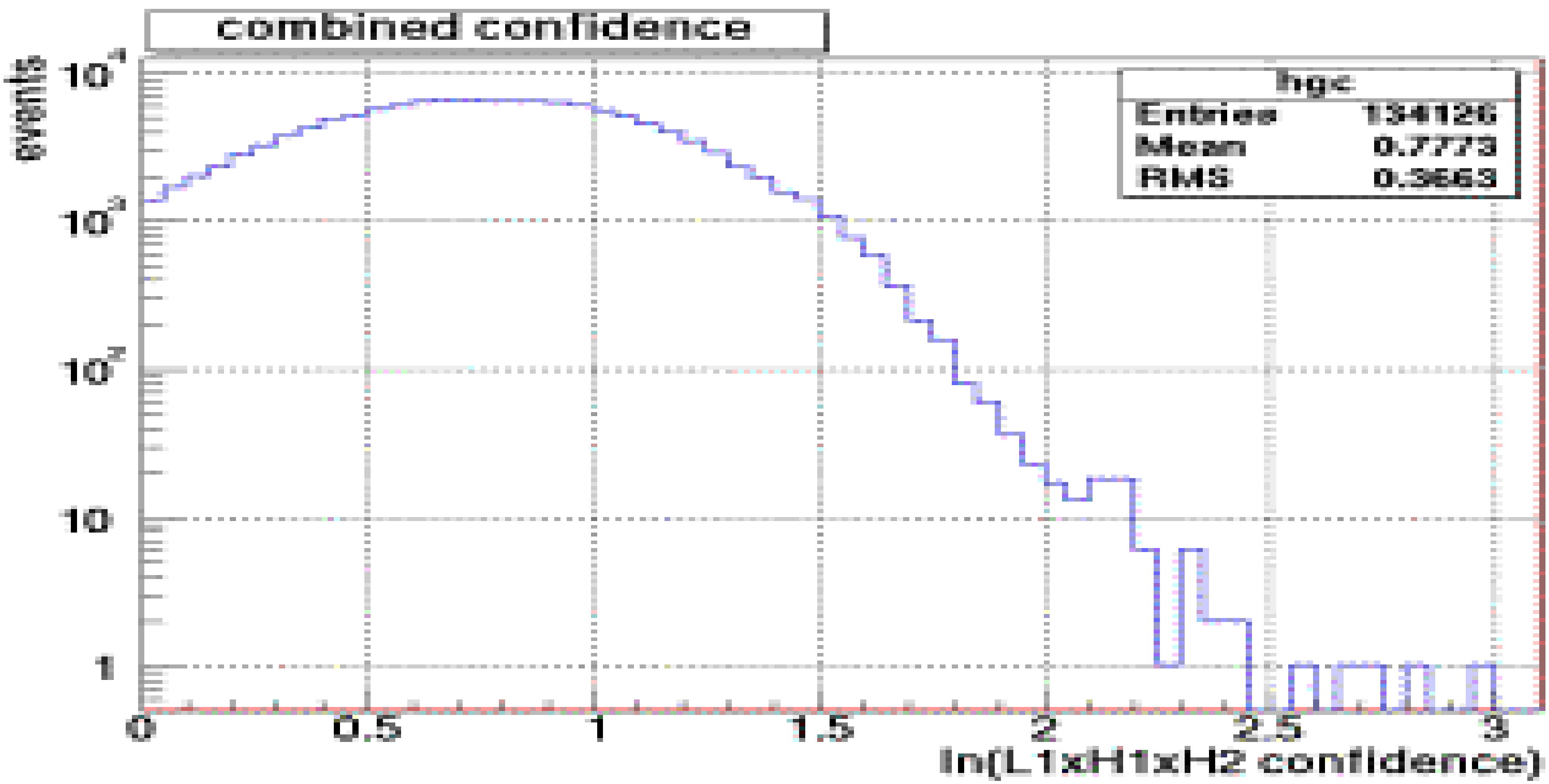
- Since pixel's significance is distributed exponentially, significance of a cluster of size k has gamma distribution.
- Cluster confidence is defined by its significance Y and size k and is a measure of how unlikely would it be for statistically independent pixels to form a given cluster:

$$C(Y,k) = -\ln\left(\frac{1}{\Gamma(k)}\int_Y^{\infty} x^{k-1} e^{-x}\, dx\right)$$

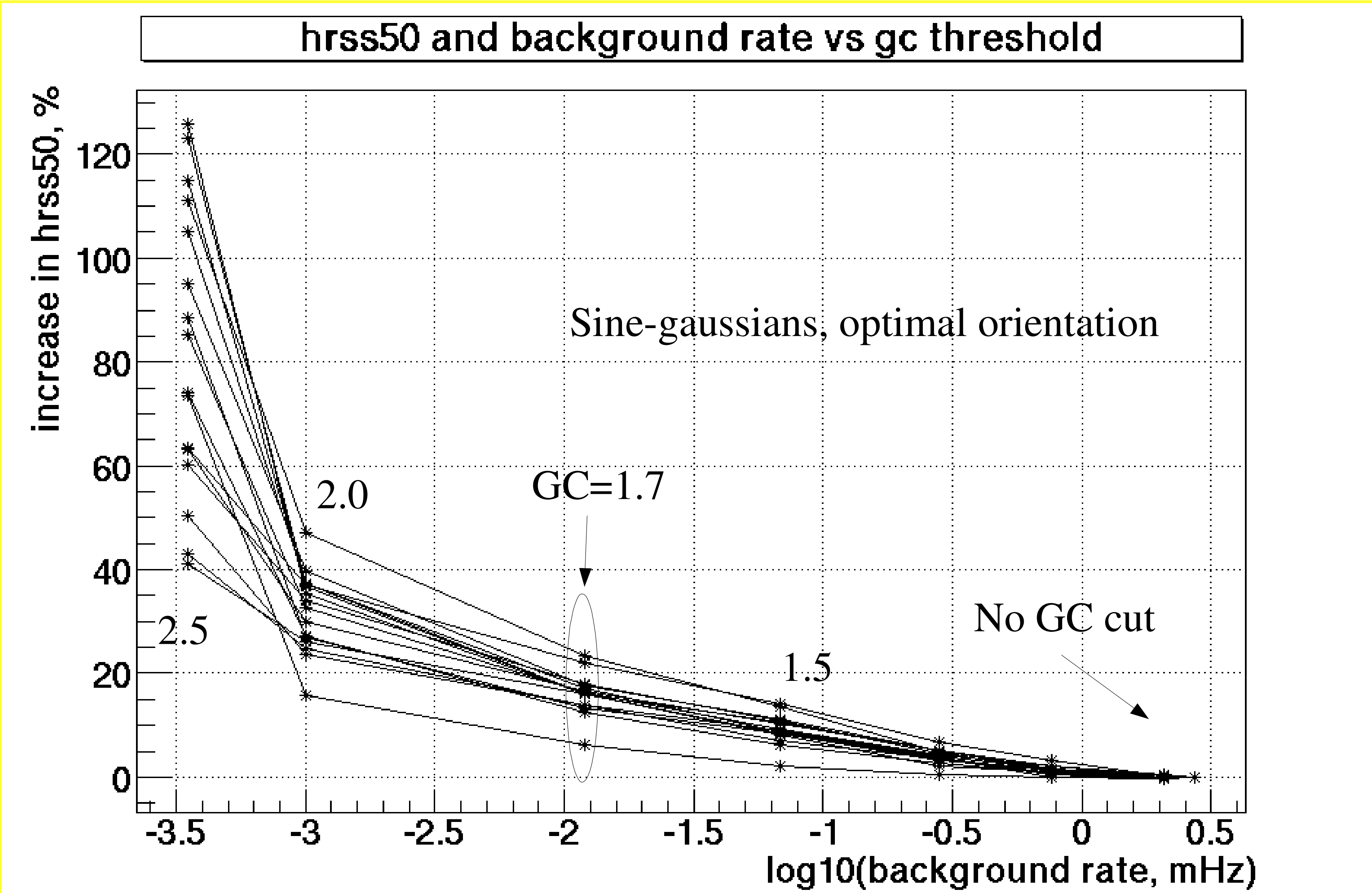
Geometric confidence

- After time window is applied we get 6 clusters for each event. We define its combined geometric confidence:

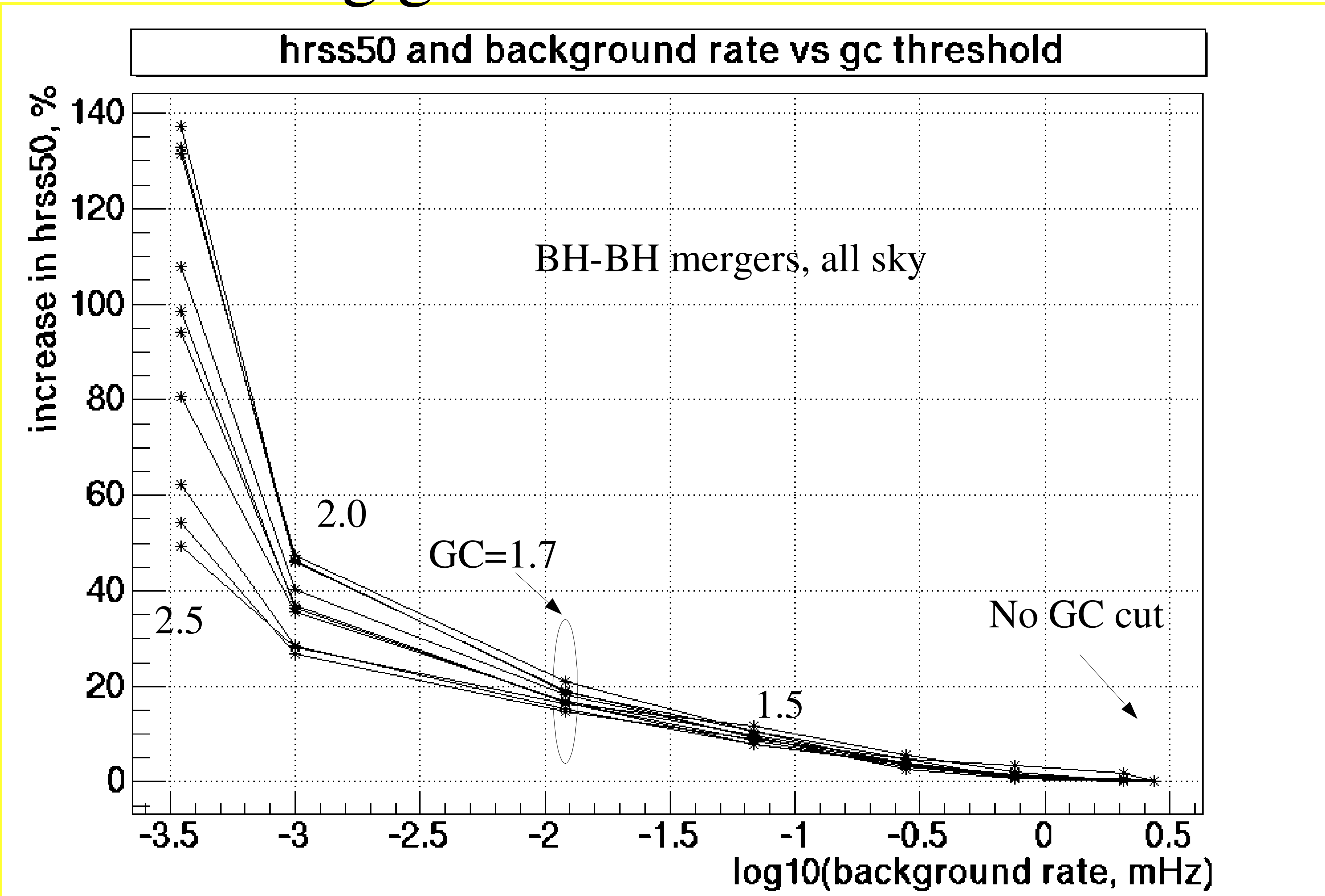
$$C_G = \sqrt[6]{C_{H1L1}^{L1} C_{H1L1}^{H1} C_{H1H2}^{H1} C_{H1H2}^{H2} C_{H2L1}^{H2} C_{H2L1}^{L1}}$$



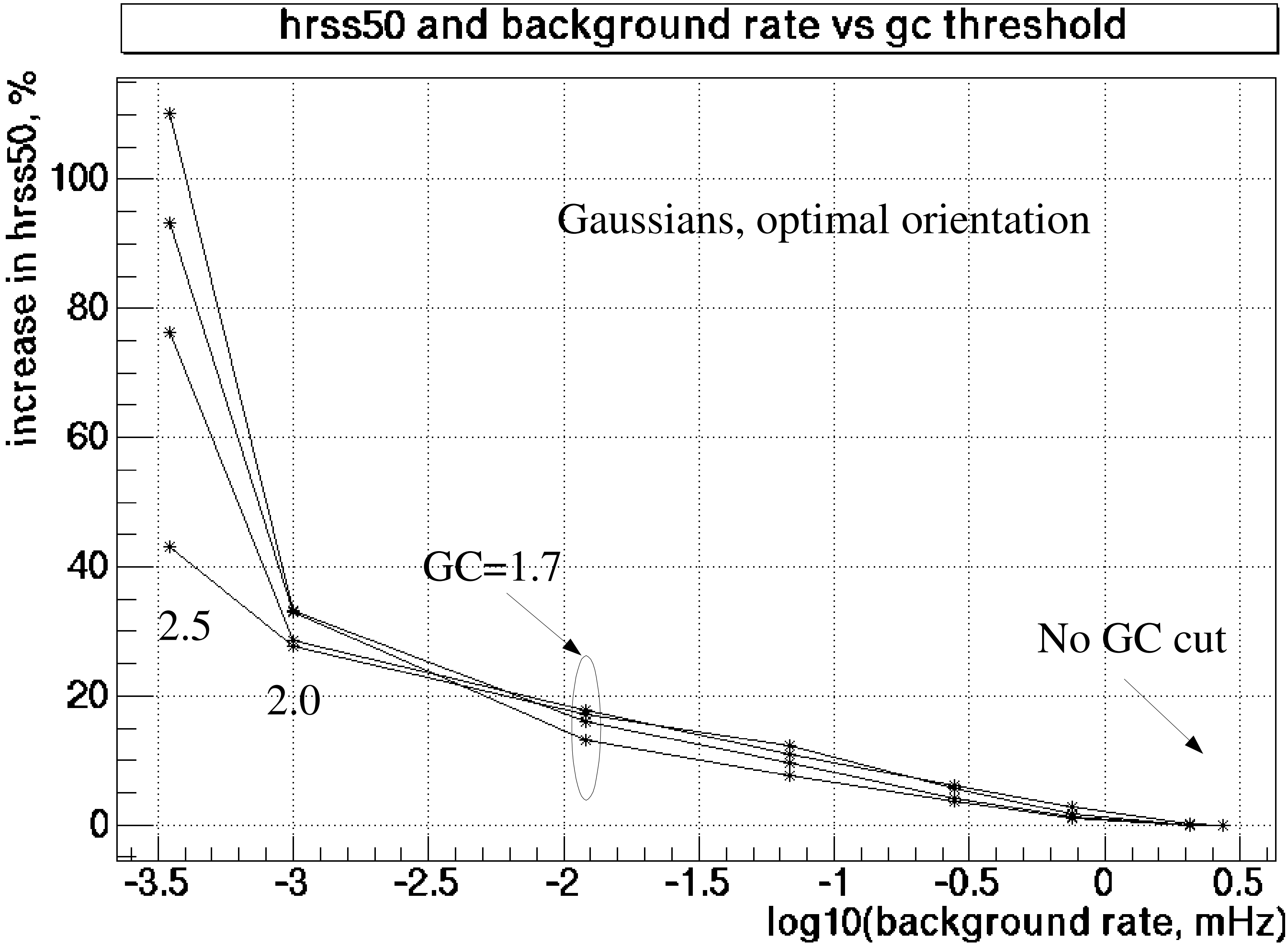
Choosing geometric confidence threshold



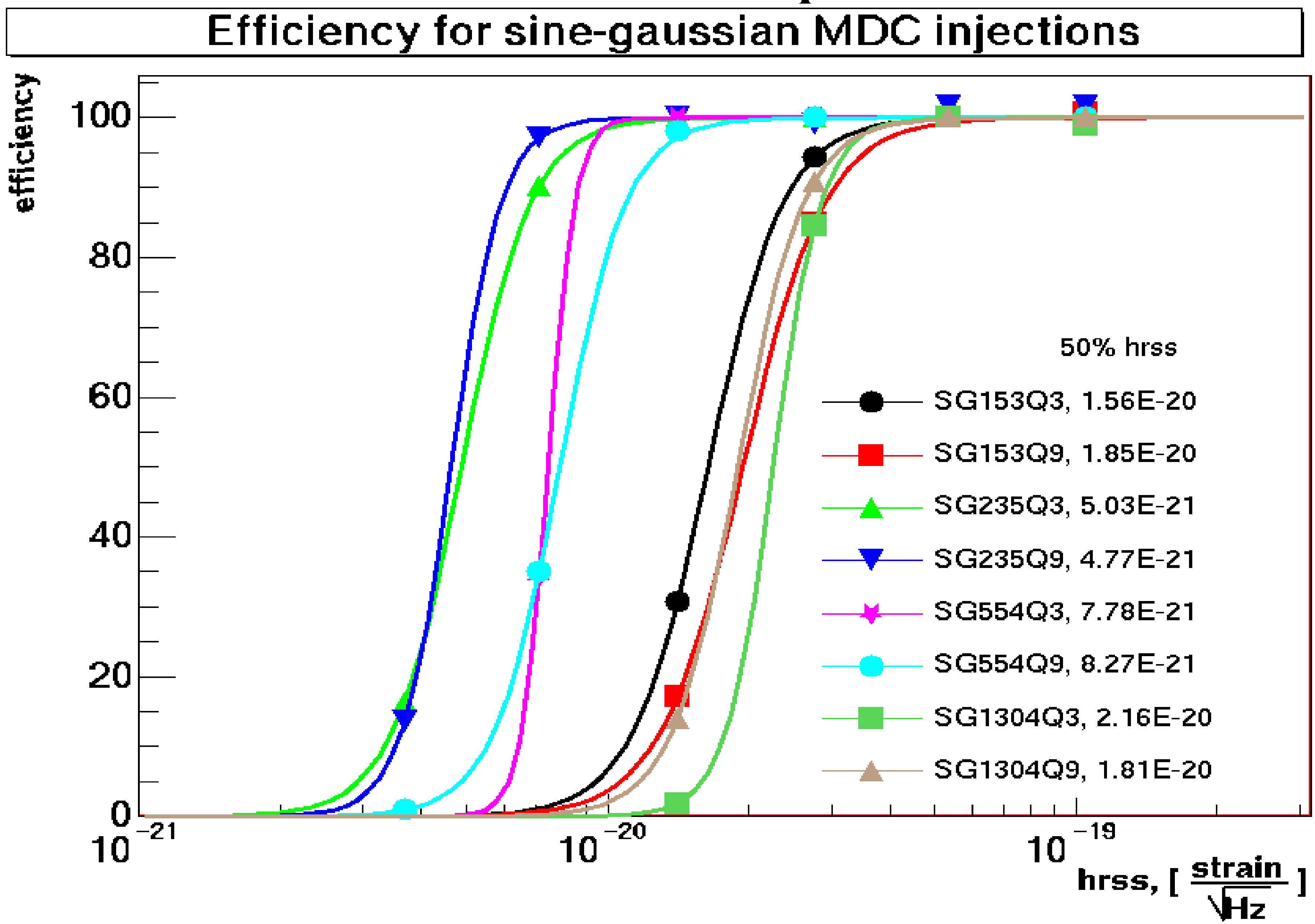
Choosing geometric confidence threshold



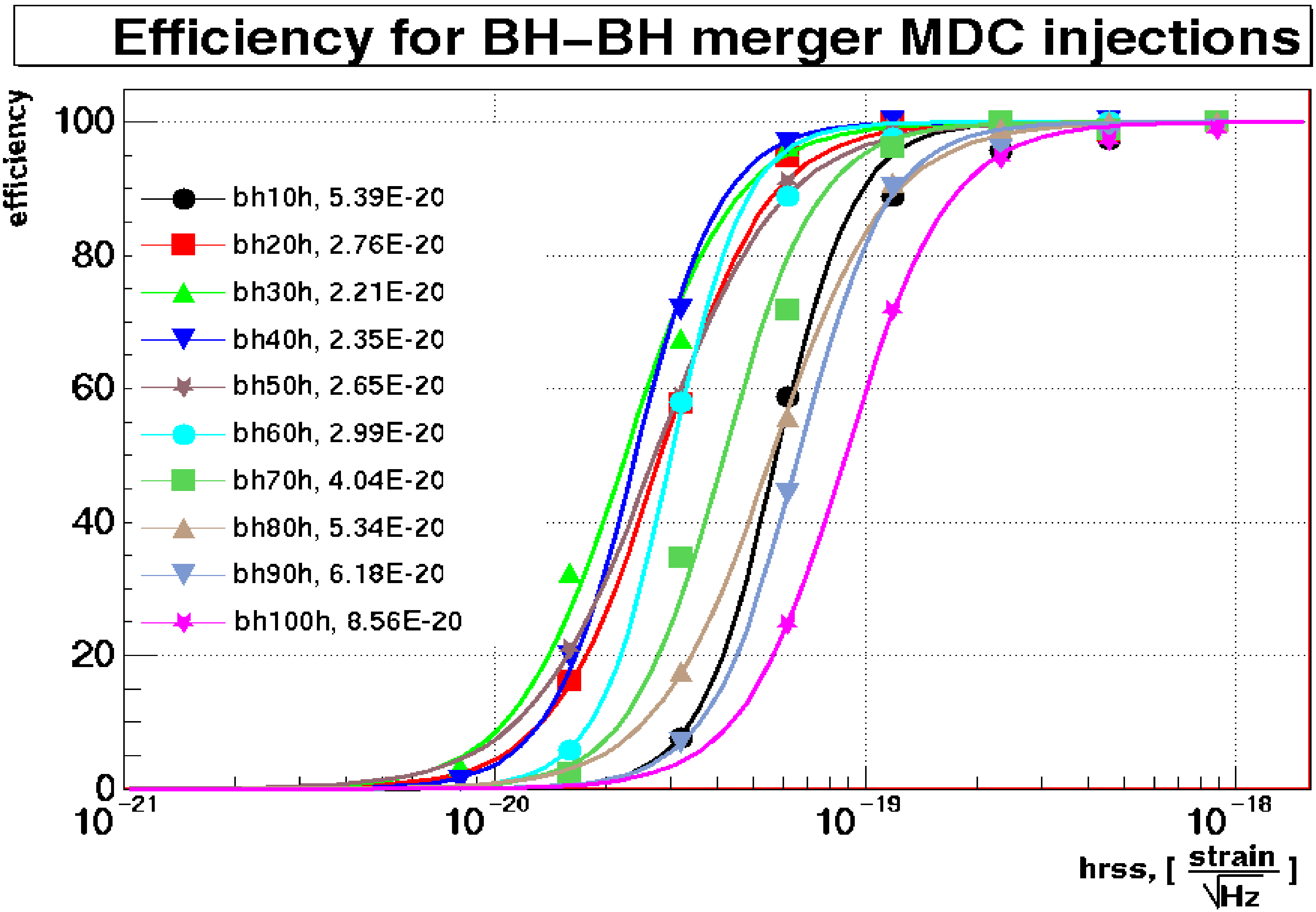
Choosing geometric confidence threshold



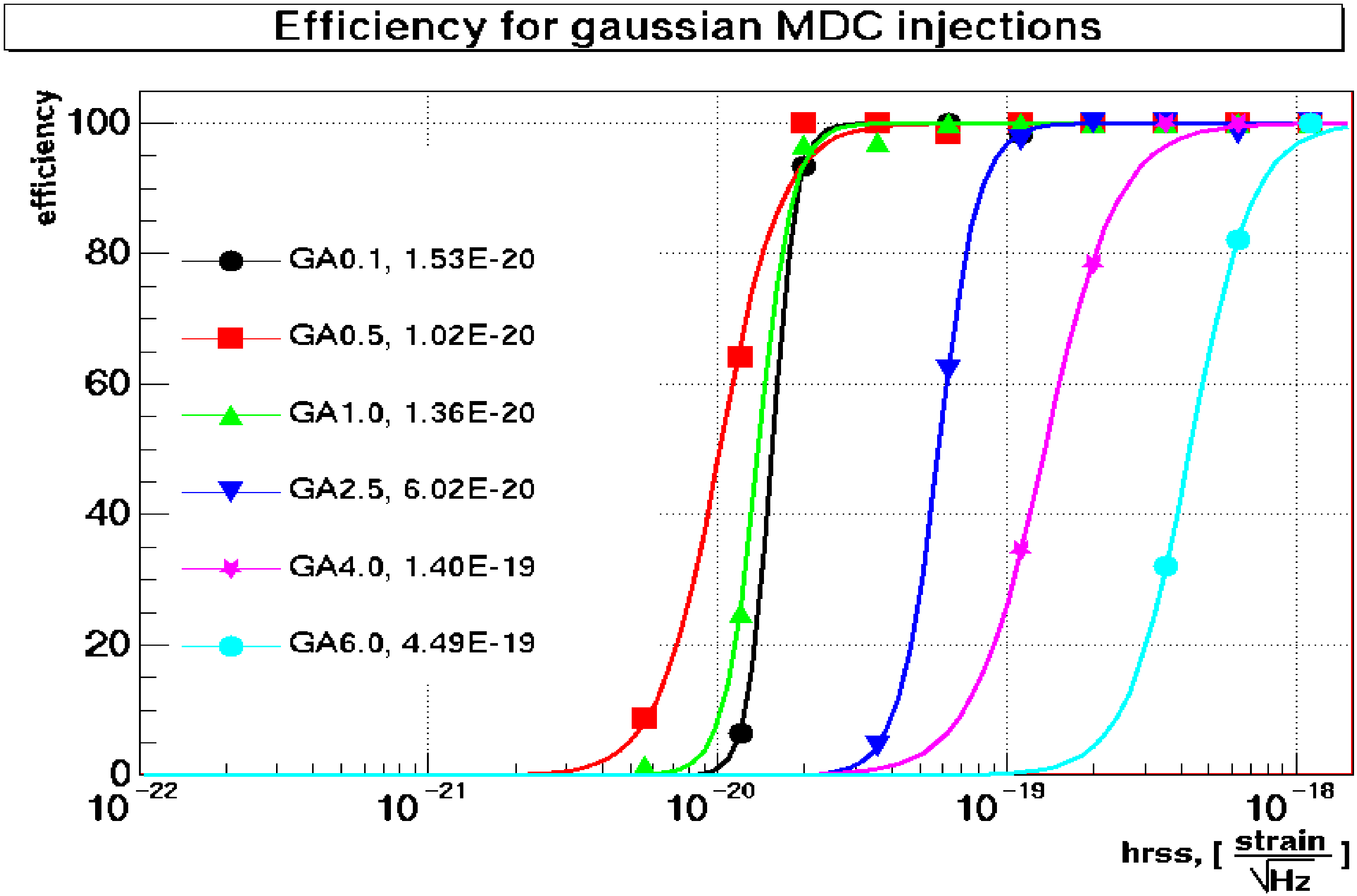
Sensitivity: sine-gaussian, optimal orientation, one polarization



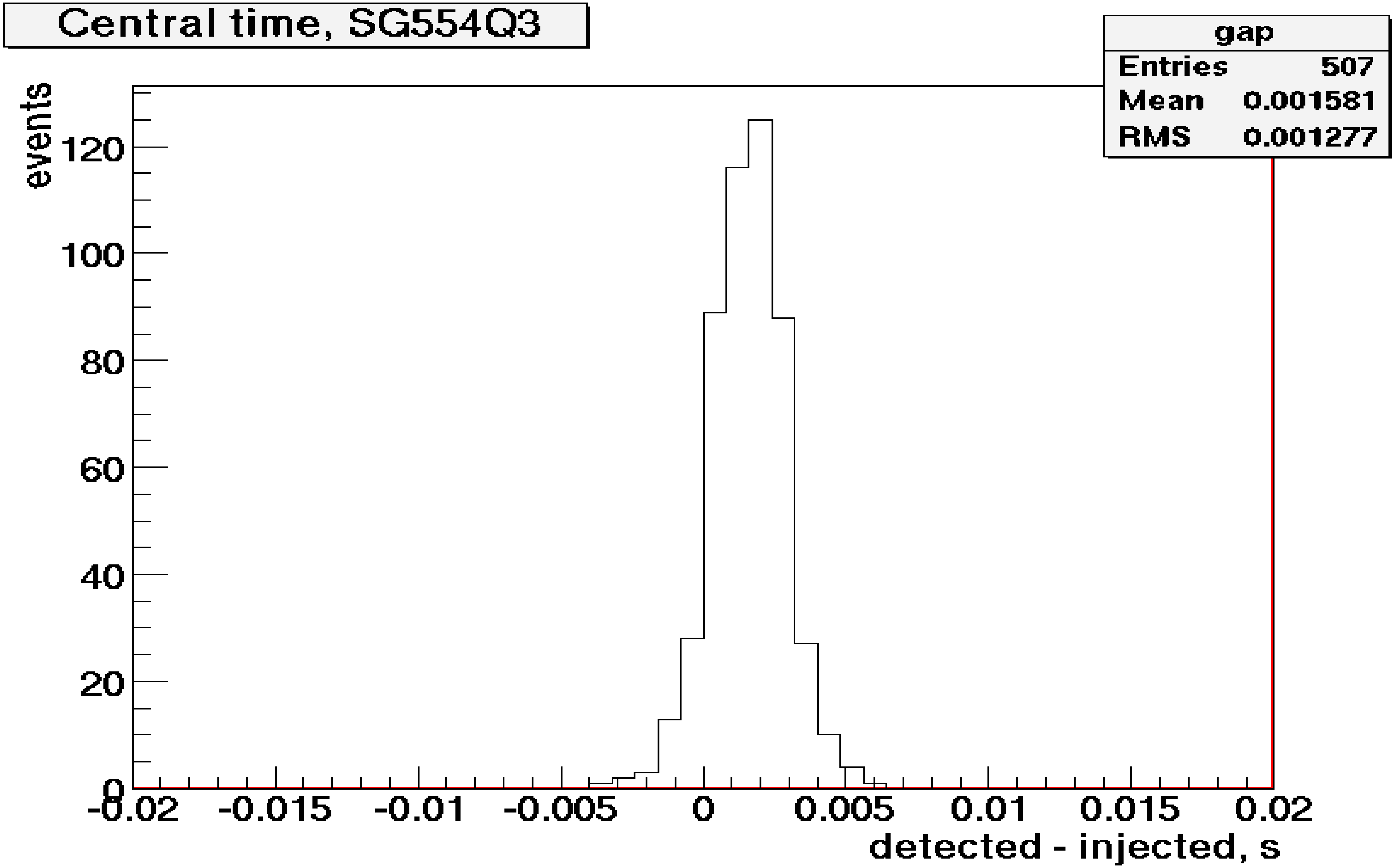
Sensitivity: BH-BH merger, all sky, two polarizations



Sensitivity: gaussian, optimal orientation, one polarization



Central time reconstruction



Central time reconstruction

Detected-injected central time, ms, mean(std)

Sine-gaussian

Q\F	**153**	**235**	**554**	**1304**
3	0.01(2.3)	3.1(1.4)	1.6(1.3)	-0.3(1.6)
9	-0.7(2.4)	3.4(1.3)	2.6(1.6)	-0.5(1.5)

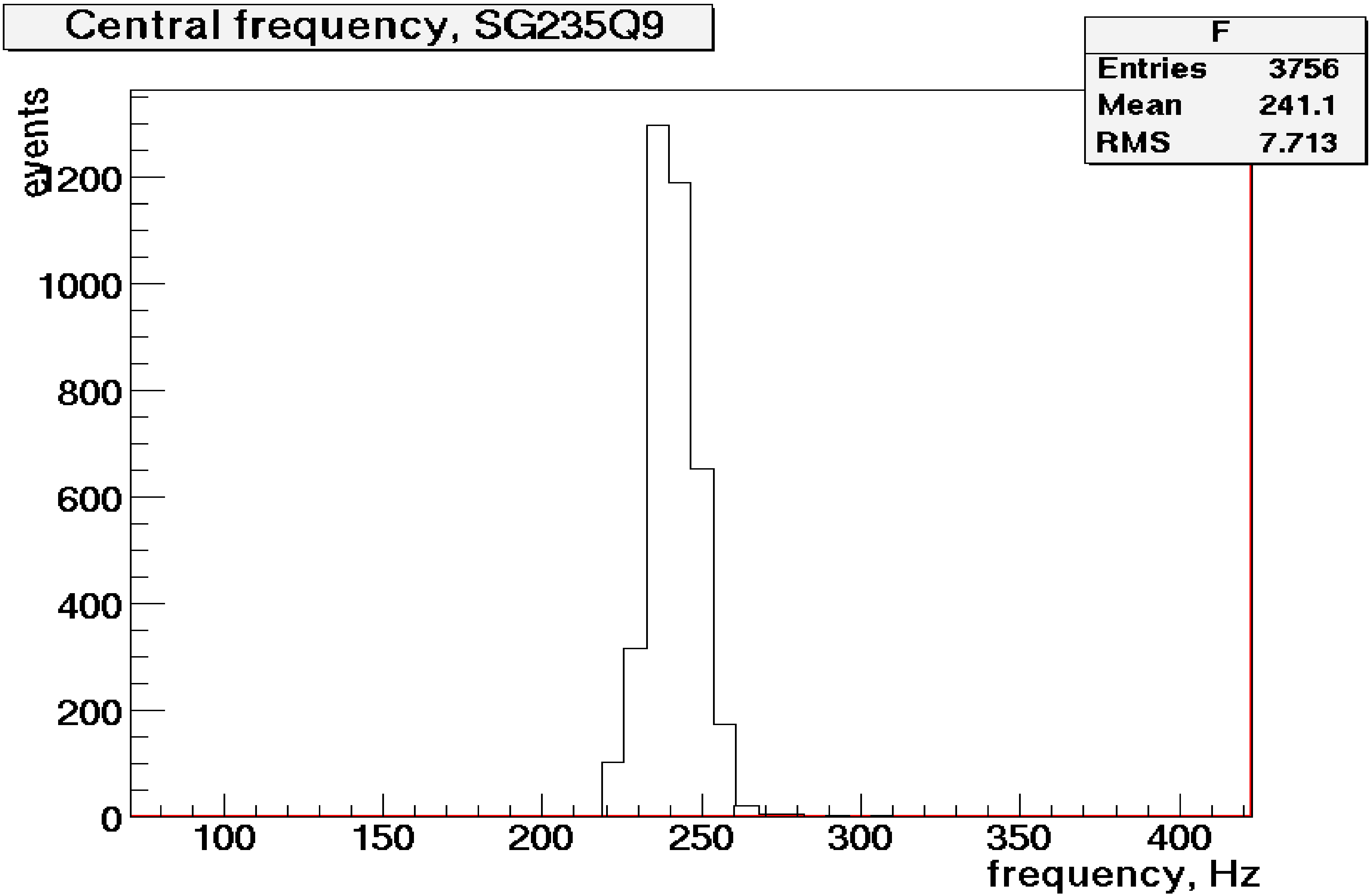
BH-BH merger

M	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
	0.2(0.8)	0.1(0.9)	1.0(1.4)	1.0(1.6)	2.7(1.5)	4.1(1.5)	4.9(1.6)	4.2(2.4)	3.6(2.4)	3.6(2.3)

Gaussian

Tau, ms	**0.1**	**0.5**	**1**	**2.5**	**4**	6
	1.1(1.1)	1.5(1.3)	2.0(1.3)	2.3(1.9)	3.6(2.3)	4.1(3.3)

Central frequency reconstruction



Central frequency reconstruction

Detected central frequency, Hz, mean(std)

Sine-gaussians

Q\F	153	235	554	1304
3	166(8)	246(16)	538(22)	1245(43)
9	159(3)	241(8)	541(9)	1297(17)

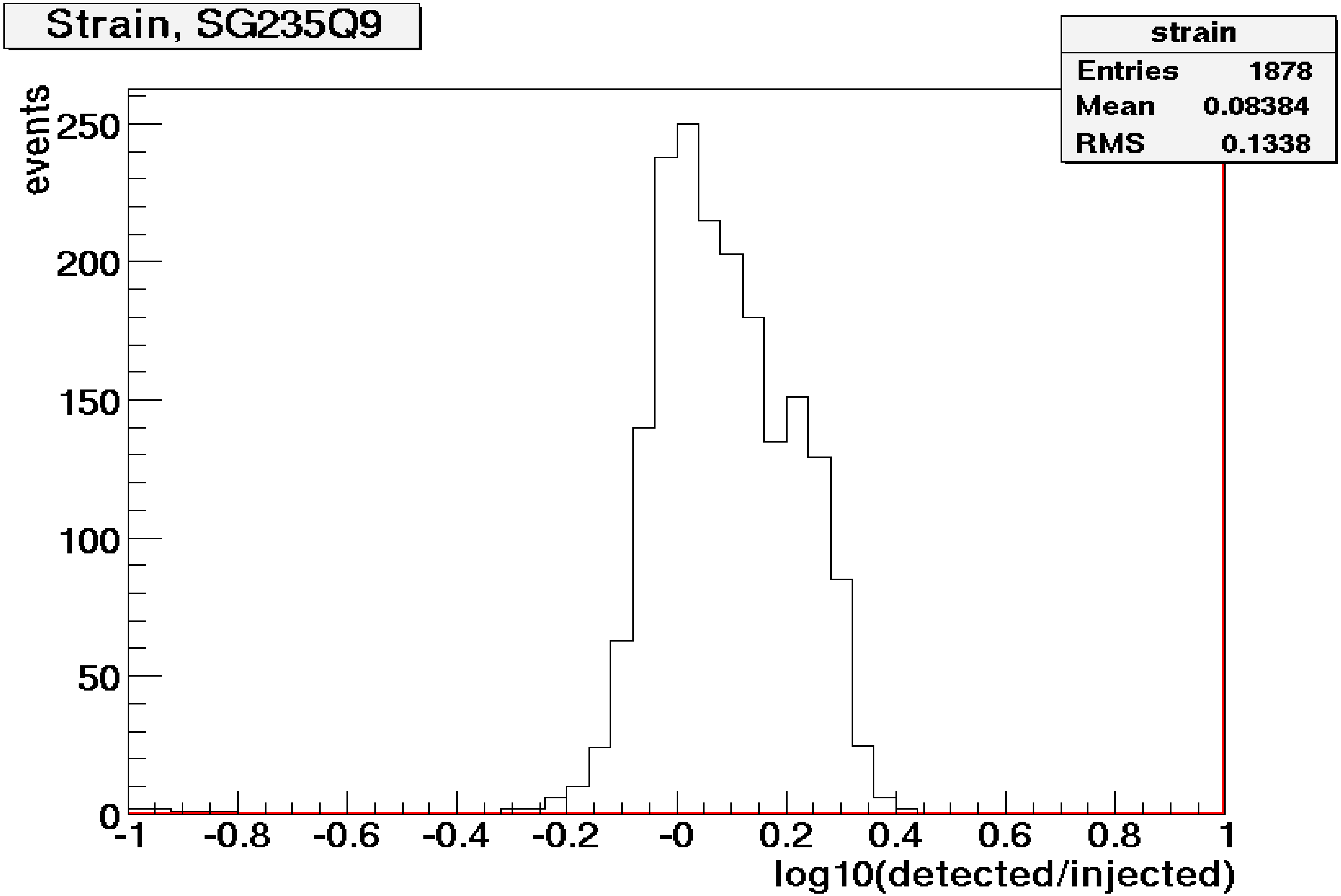
BH-BH mergers

M	10	20	30	40	50	60	70	80	90	100
Detected	856(199)	517(62)	383(37)	310(26)	267(23)	237(22)	220(18)	195(20)	176(24)	163(23)
Injected, x	1132(247)	569(123)	381(82)	286(61)	229(49)	192(41)	165(35)	144(30)	128(27)	134(24)
Injected,+	1330(237)	667(119)	446(79)	334(59)	268(48)	223(40)	192(34)	168(30)	149(26)	115(24)

Gaussians

Tau, ms	0.1	0.5	1	2.5	4	6
Detected	505(197)	318(40)	250(25)	135(24)	93(8)	103(2)
Injected	899(678)	180(136)	90(68)	36(27)	23(17)	16(11)

Strain reconstruction



Strain reconstruction

log10((detected strain)/(injected strain)), mean(std)

Sine-gaussians

Q\F	153	235	554	1304
3	-0.1(0.2)	0.1(0.1)	0.03(0.09)	-0.1(0.1)
9	-0.02(0.19)	0.08(0.1)	0.03(0.08)	-0.07(0.08)

BH-BH mergers

M	10	20	30	40	50	60	70	80	90	100
	-0.5(0.2)	-0.4(0.2)	-0.3(0.2)	-0.3(0.2)	-0.3(0.2)	-0.3(0.2)	-0.4(0.2)	-0.5(0.2)	-0.5(0.2)	-0.6(0.2)

Gaussians

Tau, ms	0.1	0.5	1	2.5	4	6
	-0.12(0.12)	0.006(0.1)	-0.11(0.12)	-0.57(0.18)	-0.66(0.16)	-1.13(0.16)

Future plans

- S2 analysis:
  - Complete simulations on the whole S2;
  - Prepare set of tests for waveburst software validation;
  - “Low threshold” analysis.
- S3 analysis.
- Add multiresolution wavelet transform to waveburst to optimize it for black hole merger search.
- Make a grid version of waveburst.
- Explore combination of DMT and Condor as a possible future framework for waveburst.
- Work out waveform reconstruction of the detected events.

References

1. T040040-00-Z. WaveBurst. S. Klimenko, I.Yakushin, G. Mitselmakher
2. Burst MDC page http://www.ligo-la.caltech.edu/~igor/MDC
3. WaveBurst S2 simulation page http://www.ligo-la.caltech.edu/~igor/SIMULATION
4. WaveBurst page http://www.phys.ufl.edu/LIGO/bursts/S2