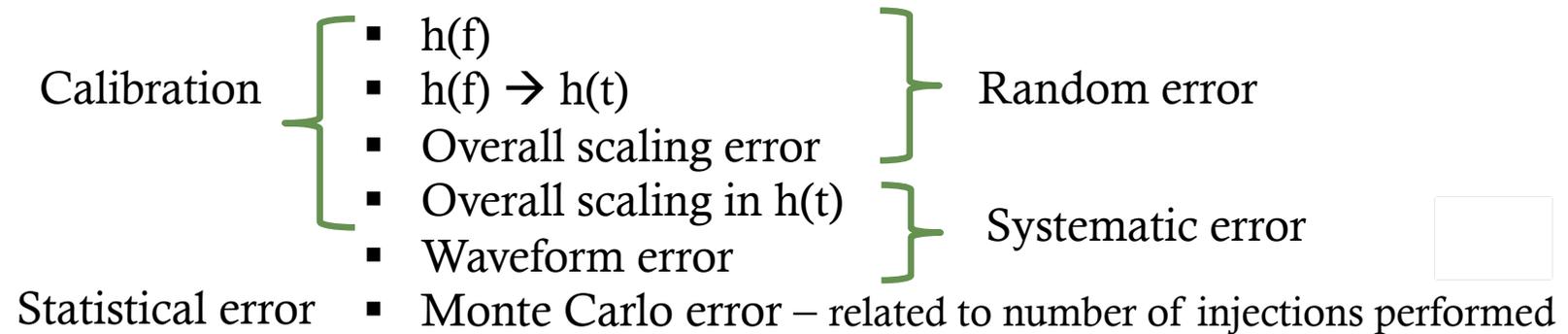


# Ringdown UL Errors Proposal

CBC F2F June 27, 2013  
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# Sources of Error



Errors propagate to UL through measured volume (i.e., though distance).

# Propagation of Error

## 1. Random Error (“Calibration Error”)

$$D = \frac{K}{\sqrt{\rho_1^2 + \rho_2^2 + \rho_3^2}}.$$

Standard random error propagation.

$$\frac{\delta D}{D} = \sqrt{\left(\frac{\rho_1}{\rho_1^2 + \rho_2^2 + \rho_3^2} \times \delta\rho_1\right)^2 + \left(\frac{\rho_2}{\rho_1^2 + \rho_2^2 + \rho_3^2} \times \delta\rho_2\right)^2 + \left(\frac{\rho_3}{\rho_1^2 + \rho_2^2 + \rho_3^2} \times \delta\rho_3\right)^2}.$$

## 2. Systematic Error (“Waveform Error”)– If an injection was made at $D$ , then the effective distance was

$$D_{\text{eff}} = \frac{K}{\sqrt{(\alpha_1\rho_1)^2 + (\alpha_2\rho_2)^2 + (\alpha_3\rho_3)^2}}.$$

$$\frac{D - D_{\text{eff}}}{D} = 1 - \sqrt{\frac{1}{\left(\alpha_1^2 \frac{\rho_1^2}{\rho_1^2 + \rho_2^2 + \rho_3^2} + \alpha_2^2 \frac{\rho_2^2}{\rho_1^2 + \rho_2^2 + \rho_3^2} + \alpha_3^2 \frac{\rho_3^2}{\rho_1^2 + \rho_2^2 + \rho_3^2}\right)}}.$$

For more info, see Dipongkar’s and Greg’s notes:

[https://www.lsc-group.phys.uwm.edu/ligovirgo/cbcnote/RingdownReview2012#Calibration\\_And\\_Waveform\\_Errors](https://www.lsc-group.phys.uwm.edu/ligovirgo/cbcnote/RingdownReview2012#Calibration_And_Waveform_Errors)

# S6 Random Error

-	H1	L1	V1
Overall scaling error	0.025	0.13	-
$ h(f) $	0.16	0.18	0.06
$ h(f)  \rightarrow  h(t) $	0.03	0.07	-

Add all sources of error in quadrature for each IFO:

$$H1 : \sqrt{0.025^2 + 0.16^2 + 0.03^2} = 16\%$$

$$L1 : \sqrt{0.13^2 + 0.18^2 + 0.07^2} = 23\%$$

Use error propagation for distance uncertainty:

$$\frac{\delta D}{D} = \sqrt{\left(\frac{1}{2} \times 0.16\right)^2 + \left(\frac{1}{2} \times 0.23\right)^2} = 14\%$$

S6 High Mass	S6 IMBH
14% in distance	TBD
42% in volume	TBD

# S5 Random Error

-	H1	H2	L1
Overall scaling error	-	-	-
h(t) mag errors <sup>1</sup>	0.104	0.101	0.144
h(t) mag errors <sup>2</sup>	0.102	0.105	0.134

The following method was used in S5 highmass:

$$\frac{\delta D}{D} = \sqrt{0.104^2 + 0.101^2 + 0.144^2} = 20\%$$

If we apply error propagation as it was applied in S6, we find:

$$\frac{\delta D}{D} = \sqrt{\left(\frac{1}{2} \times 0.102\right)^2 + \left(\frac{1}{2} \times 0.134\right)^2} = 8\%$$

S5 High Mass	S5 IMBH
20% in distance	11.1% in distance
60% in volume	33.3% in volume

<sup>1</sup> <https://dcc.ligo.org/public/0006/P0900120/017/S5paper-NIMA.pdf> <sup>2</sup>LIGO-T1000227-v1-D

# S6 Systematic Error

-	H1	L1
S6 overall scaling	0.014	0.02
Waveform error	< 0.15	< 0.15

In addition to the waveform error (varies for different masses), we must again account for the scaling error in S6 by adding these two systematic factors:

$$\text{H1} : 1 + [0.014 + 0 \text{ (or 0.15)}] = 1.014 \text{ (1.164)}$$

$$\text{L1} : 1 + [0.02 + 0 \text{ (or 0.15)}] = 1.02 \text{ (1.17)}$$

and applying the systematic correction factor so that the effective distance is reduced by:

$$\frac{D - D_{\text{eff}}}{D} = 1 - \frac{1}{\sqrt{\frac{1}{2} \times 1.014^2 + \frac{1}{2} \times 1.02^2}} = 2\%$$

$$\frac{D - D_{\text{eff}}}{D} = 1 - \frac{1}{\sqrt{\frac{1}{2} \times 1.164^2 + \frac{1}{2} \times 1.17^2}} = 14\%$$

**S6 High Mass**

0% systematic

**S6 IMBH**

TBD

# S5 Systematic Error

-	H1	L1
S5 overall scaling	-	-
Waveform error	< 0.15	< 0.15

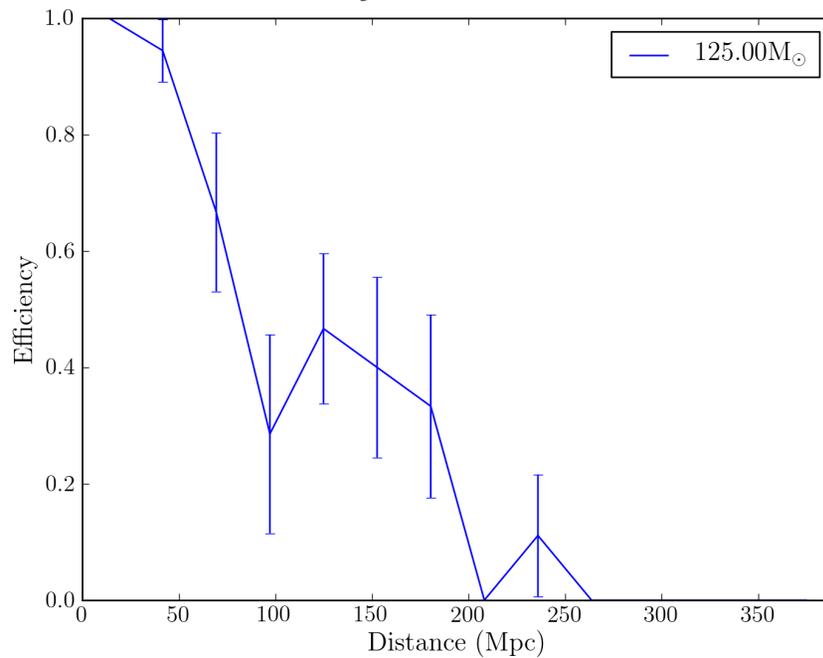
In S5, there was no overall scaling factor so we compute the systematic correction factor as:

$$\frac{D - D_{\text{eff}}}{D} = 1 - \frac{1}{\sqrt{\frac{1}{2} \times 1.15^2 + \frac{1}{2} \times 1.15^2}} = 13\%$$

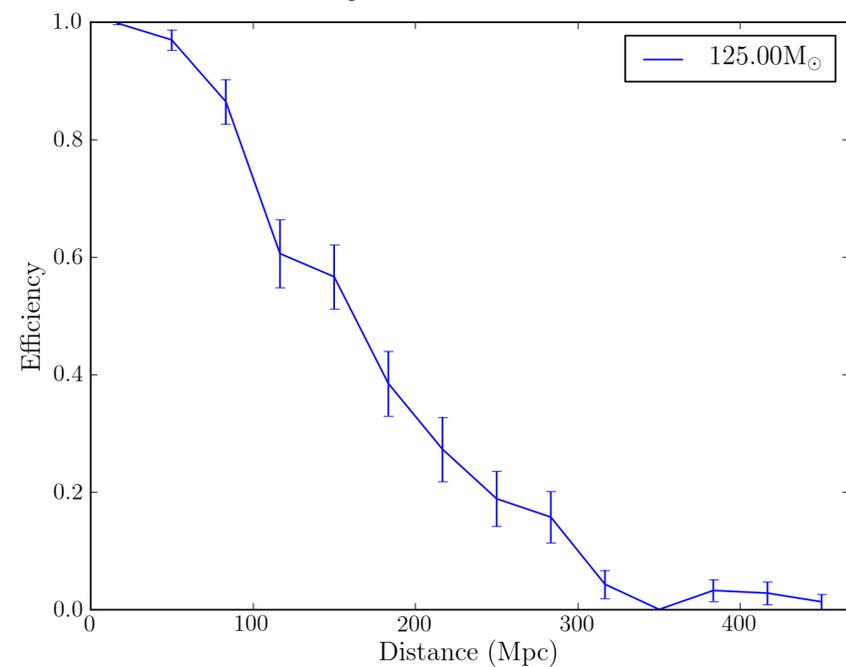
S5 High Mass	S5 IMBH
0% systematic	15% “waveform”
N/A	45% in volume?

# Statistical Errors

Before full injection runs



After full injection runs



- Efficiency curves for the 100-150  $M_{\odot}$  bin for one S6 analysis chunk.
- Statistical errors  $\sim 10\%$  or less.

# S5 Injection Run Status

## S5

		Status	Status	Status	Status	Status	Status
Months	runner	EOBNRv2 q=1 Run1	EOBNRv2 q=1 Run2	EOBNRv2 q=4 Run1	EOBNRv2 q=4 Run2	Ringdown Run1	Pipedown
1-2	Paul	complete (UWM)					
3-4	Sarah	complete (Atlas1)	complete (Atlas1)	complete (Atlas1)	complete (Atlas1)		
5-6	Dipongkar	complete (ATLAS)	complete (ATLAS)	complete (ATLAS)			
7-8	Paul	complete (CIT)					
9-10	Sarah	complete (Atlas1)	running (Atlas)				
11-12	Dipongkar	complete (ATLAS)	complete (ATLAS)	complete (Atlas1)			
13-14	Paul	complete (CIT)	complete (CIT)	complete (CIT)	running (CIT)		
15-16	Sarah	complete (CIT:pcdev2)	complete (CIT:pcdev2)	complete (CIT:pcdev2)	complete (CIT:pcdev2)	running (CIT:pcdev2)	
17-18	Dipongkar	complete (ATLAS)	complete (ATLAS)	running (ATLAS, Atlas1)			
19-20	Paul	complete (UWM by Sarah)					
21-22	Sarah	complete (CIT:pcdev2)	complete (CIT:pcdev2)	complete (CIT:pcdev2)	complete (CIT:pcdev2)		
23-24	Dipongkar	complete (ATLAS)	complete (ATLAS)	complete (ATLAS)			

# S6 Injection Run Status

## S6

		Status	Status	Status	Status	Status	Status
Period	runner	EOBNRv2 q=1 Run1	EOBNRv2 q=1 Run2	EOBNRv2 q=4 Run1	EOBNRv2 q=4 Run2	Ringdown Run1	Pipedown
S6A	Paul	complete (LHO)	complete (LHO)	complete (LHO)	complete (LHO)	complete (LHO)	
S6B pre-HEPI	Dipongkar	complete (ATLAS)	complete (ATLAS)	complete (ATLAS)	complete (ATLAS)	complete (ATLAS)	complete (ATLAS, titan1)
S6B post-HEPI	Dipongkar	complete (CIT)	complete (CIT)	complete (CIT)	-	-	-
S6B post-HEPI rerun	Dipongkar	complete (UWM)	complete (UWM)	complete (UWM)	complete (UWM)	complete (UWM)	complete (UWM)
S6C chunk 1	Dipongkar	complete (CIT)	complete (CIT)	complete (LHO)	complete (LHO)	complete (LHO)	complete (CIT)
S6C chunk 2	Sarah	complete (LHO,pcdev1)	complete (LHO,pcdev1)	complete (LHO,pcdev1)	complete (LHO, pcdev1)	complete (LHO,pcdev1)	complete (LHO, pcdev1)
S6D chunk 1	Sarah	complete (LHO,pcdev1)	complete (LHO,pcdev1)	complete (LHO,pcdev1)	complete (LHO, pcdev1)	complete (LHO,pcdev1)	complete (LHO, pcdev1)
S6D chunk 2	Paul	complete (LHO)	complete (LHO)	complete (LHO)	complete (LHO)	running (LHO)	
S6D chunk 3	Dipongkar	complete (CIT)	complete (CIT)	complete (CIT)	complete (CIT)	complete(CIT)	running (CIT, pcdev1)

# Reviewer Recommendations

- For paper
  - S5
    - 8% (24% in volume) random error
    - Account for no systematic error and suggest rescaling ULs by
$$\frac{1}{(1 - \text{systematic error})^3}$$
  - S6
    - 14% (42% in volume) random error
    - Account for no systematic error and suggest rescaling as above.
- For review
  - Compute upper limit using both previously used numbers and those above for comparison