Reconstruction of Gravitational Wave Bursts with LIGO-Virgo network

M. Drago

S.Klimenko, G.Mitselmakher, C.Pankow, G.Prodi, V.Re, F.Salemi, G.Vedovato, I.Yakushin

http://www.virgo.lnl.infn.it/Wiki/index.php/PRC

Source Reconstruction

- Reconstruction of unmodeled bursts:
  - Bursts parameters (time, frequency, correlated energy)
  - Waveforms and Detectors Response
  - **Source Coordinates**

- Motivations:
  - Prompt localization of GW events for followup with optical/radio instruments during S6/VSR2

- Algorithm: **Coherent WaveBurst**
  (*S.Klimenko, Class. Quantum Grav.* ***25*** *(2008)*)

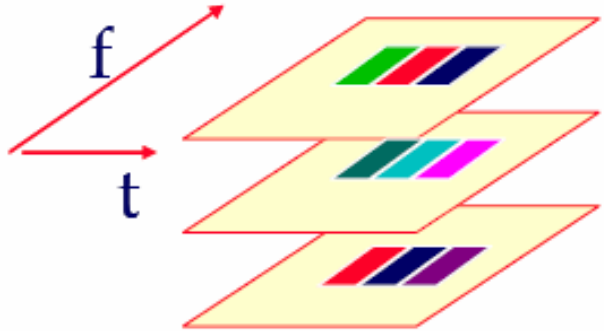
- Framework: Position Reconstruction Challenge
  (see talk by S.Klimenko)

LIGO-Virgo PRC challenge

- **Network:** V1 L1 H1
- **Data Set:** Simulated Noise (~5.7 days based on S5/VSR1 sensitivity)
- **Injections:**
  - **Waveforms:** Sine-Gaussians, and band-limited White Noise Bursts
    - SG235Q9, SG1053Q9 *linear polarization*
    - SG235Q3, SG1053Q3 *linear polarization*
    - SGC235Q9, SGC1053Q9 *circular polarization*
    - WNB_250_100_0d1, WNB_1000_1000_0d1 *random polarizations*
  - **Directions:** 46 sky positions, evenly spaced on the sky
  - **Amplitudes:** 14 levels logarithmically spaced

Coherent Waveburst (CWB)

- cWB uses wavelet time-frequency transformation at several resolutions for optimal characterization of GW signals.



- **Energetic** TF pixels are combined in clusters.

- Data from different detectors are **coherently** combined using a **Constrained Likelihood** method.
  (*S.Klimenko, Phys. Rev. D* ***72*** *(122002)*)

CWB Reconstruction

Likelihood ratio:

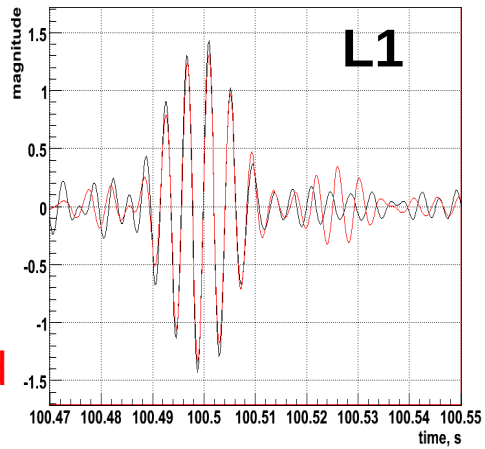
$$L = \sum_p \sum_k \frac{1}{2\sigma_k^2} \left[x_k^2[p] - \left(x_k[p] - \xi_k[p] \right)^2 \right]$$

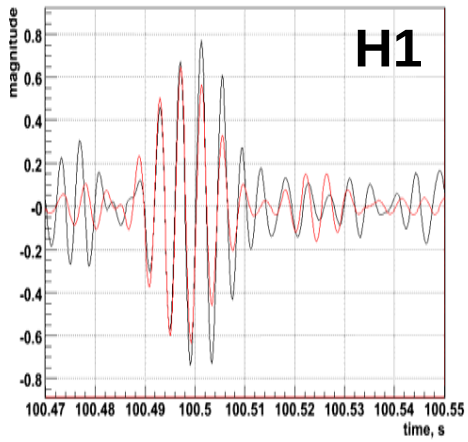
$$\xi_k = h_+ F_{+k} + h_\times F_{\times k}$$

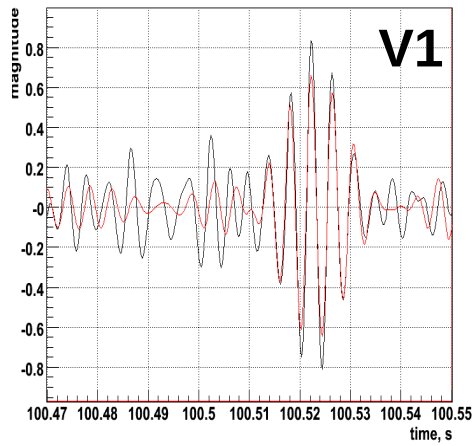
- p – Pixel index
- k – Detector index
- σ_k^2 – detector variance
- x_k – detector output
- ξ_k – reconstructed response
- $F_{+,x}$ – antenna patterns

The algorithm reconstructes the gravitational detector responses, estimates burst parameters and the source coordinates.

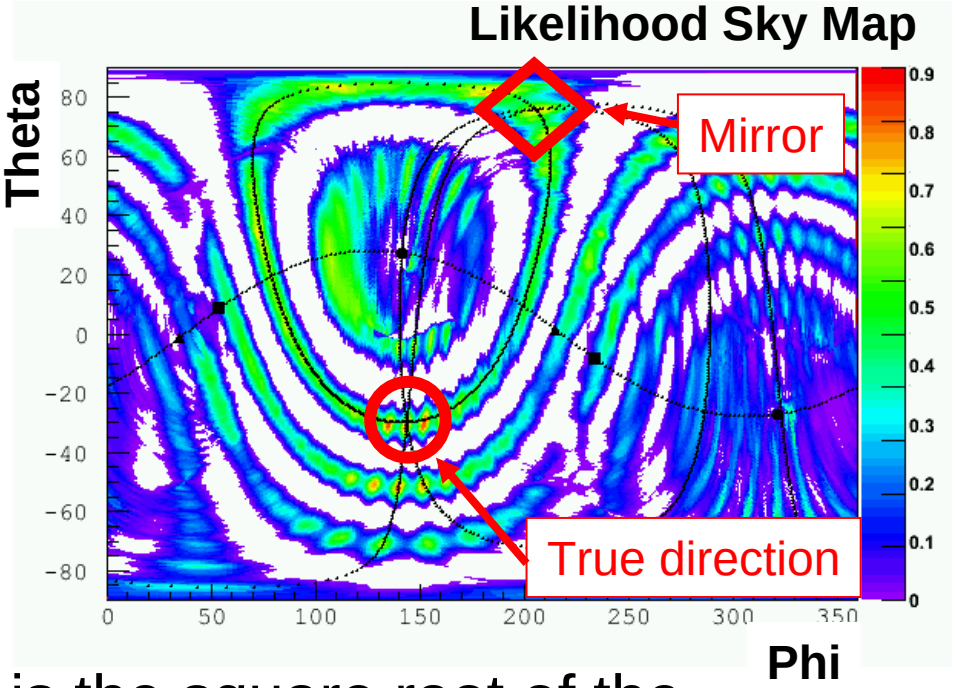
SG235Q9
(θ,φ): (-30,216)
Linear polarization
SNR: 194 (L1),
58 (H1),
54 (V1)
Red: reconstructed
Black: data stream







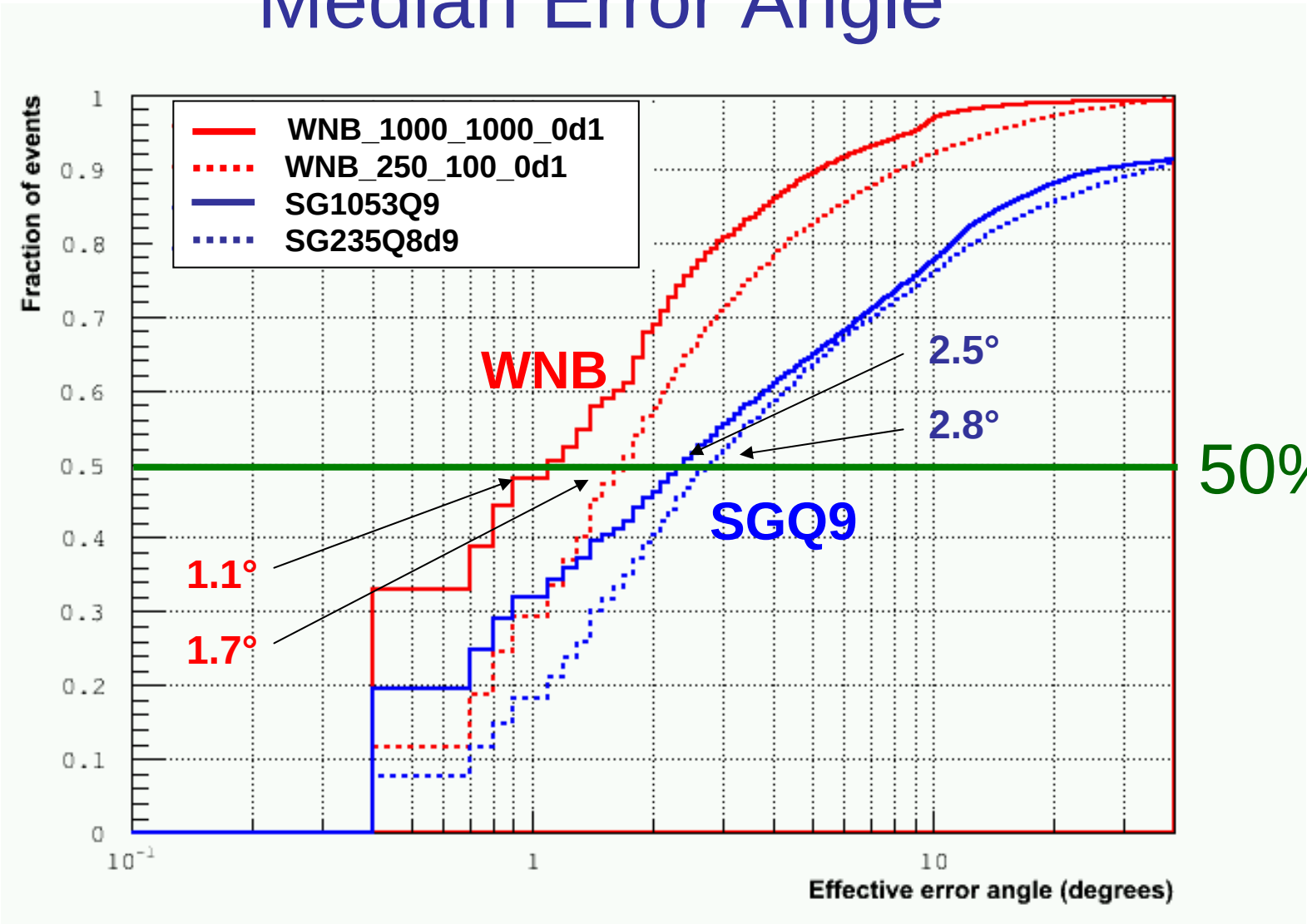
Position Reconstruction with CWB



- *Likelihood Sky Map*: for each event likelihood ratio is calculated over the sky.
- Sky Location at Maximum Likelihood: it is used as estimator of the source coordinates.

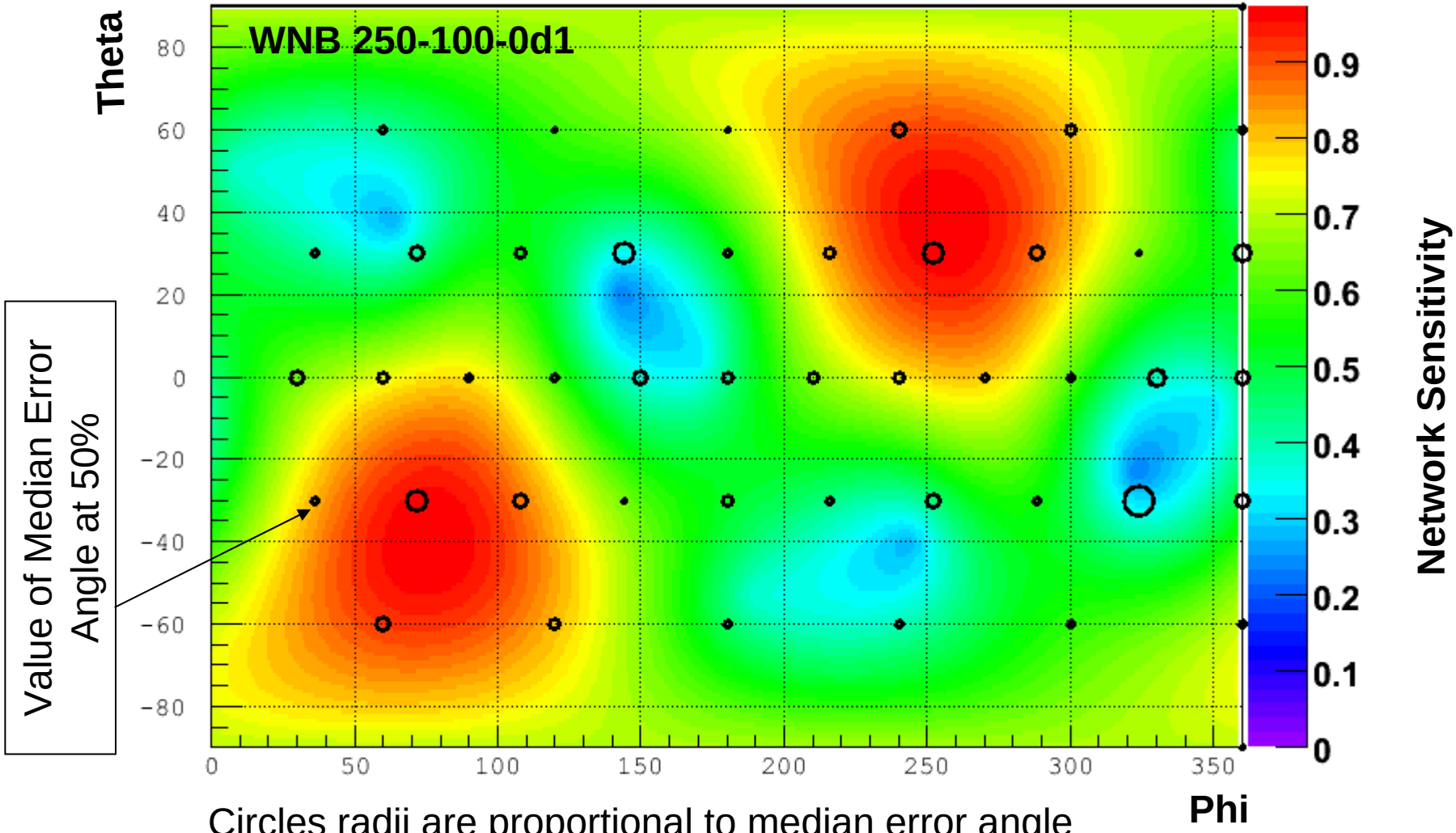
- *Median Error Angle (erA0)* : is the square root of the integrated area of the pixels with likelihood greater than computed likelihood for the injection pixel
- For each direction we compute the cumulative distribution of the meduan error angle. Its median (50% percentile) is taken as figure of merit for each direction and waveform

Cumulative Distribution Median Error Angle



Results for different sky locations

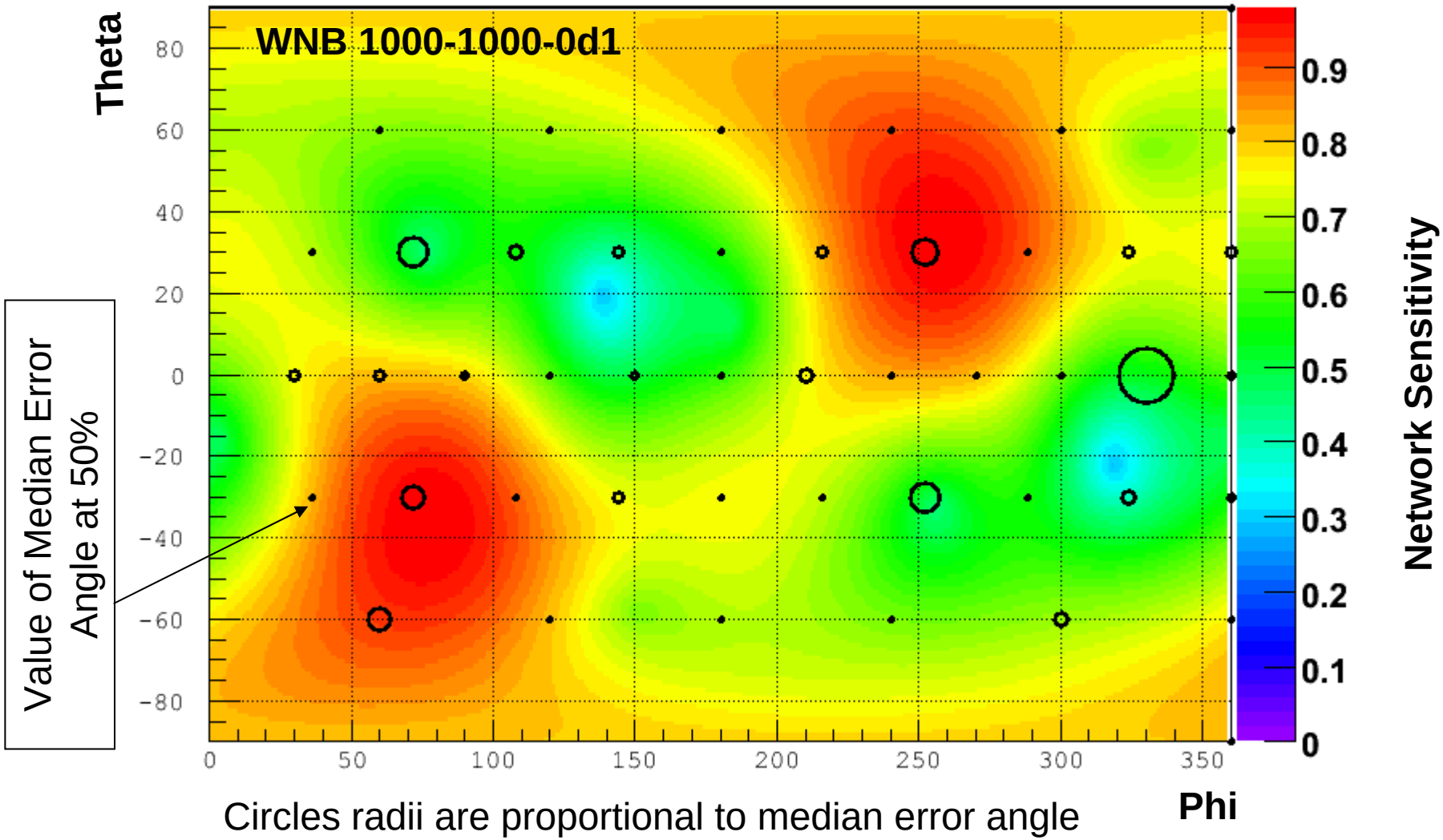
Median Error Angle @ 50%



Circles radii are proportional to median error angle

Results for different sky locations

Median Error Angle @ 50%



Circles radii are proportional to median error angle

Results summary of the MonteCarlo

Median Error Angle @ 50%

MDC		Calibrated		Mis-Calibrated	
Type	Freq (hz)	Full Set	SNR<71	TIME	AMP
WNB	**250:100:0.1**	1.7°	3.9°	2.2°	1.9°
	1000:1000:0.1	1.1°	1.9°	3.5°	1.2°
SGQ9	235	2.8°	7.0°	3.5°	2.8°
	1053	2.5°	3.5°	6.3°	2.6°
SGCQ9	235	3.5°	7.4°		
	1053	2.3°	3.2°		
SGQ3	235	2.3°	6.3°		
	1053	1.8°	2.8°		

TIME OFFSETS

V1:-60us, H1:0us, L1:60us

10° at 250Hz, 42° at 1000 Hz)

AMPLITUDE RESCALING

V1:10%, H1:0%, L1:-10%

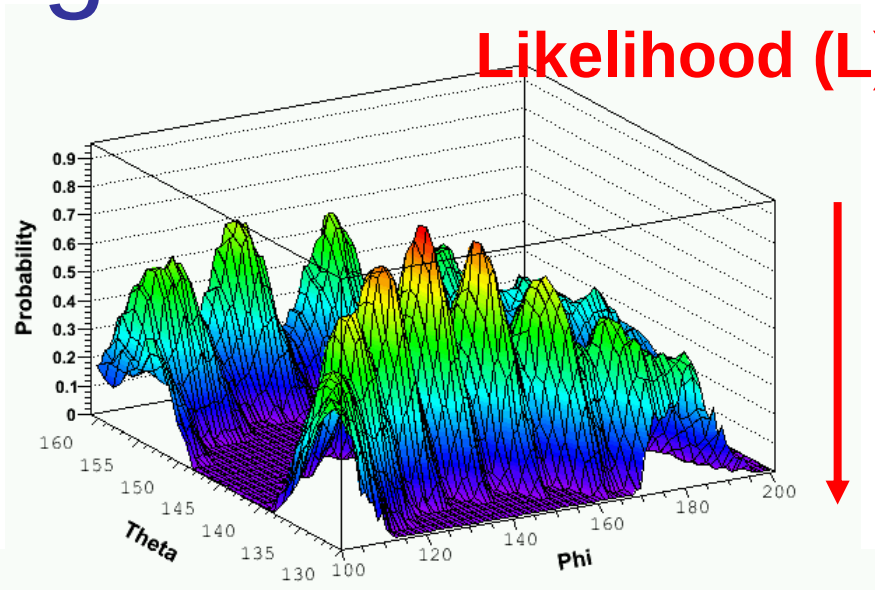
Error Regions

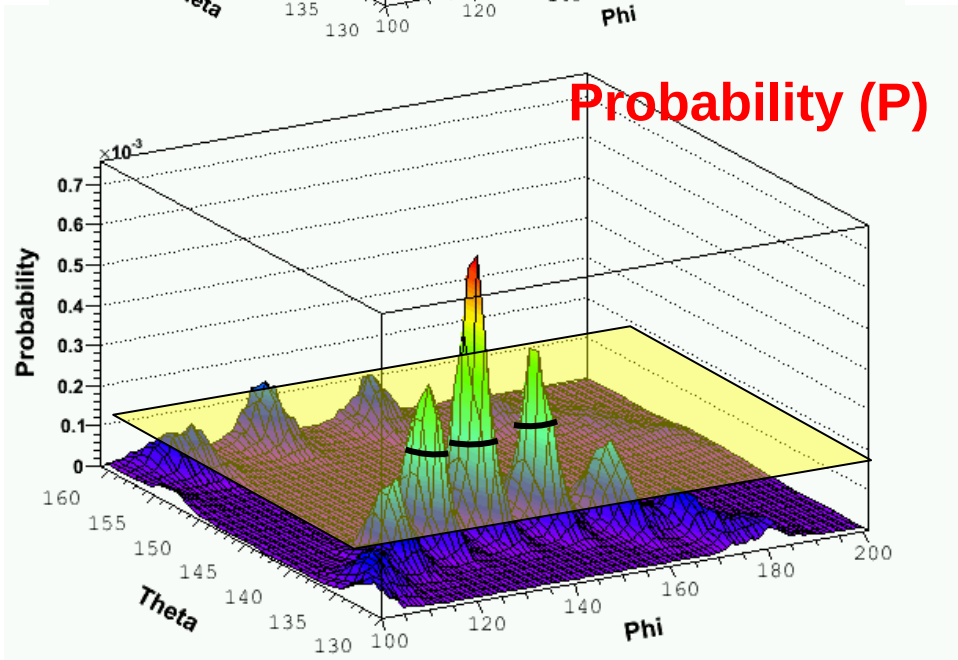
When performing observations, we must have a procedure to assign to each candidate event an error region, i.e. our estimate of the possible sky position of the source.

The error region is the area in which there is a given probability to find the source direction.

Probability Sky Map is calculated converting Likelihood Sky Map.

Coverage of error region has to be measured by MonteCarlo



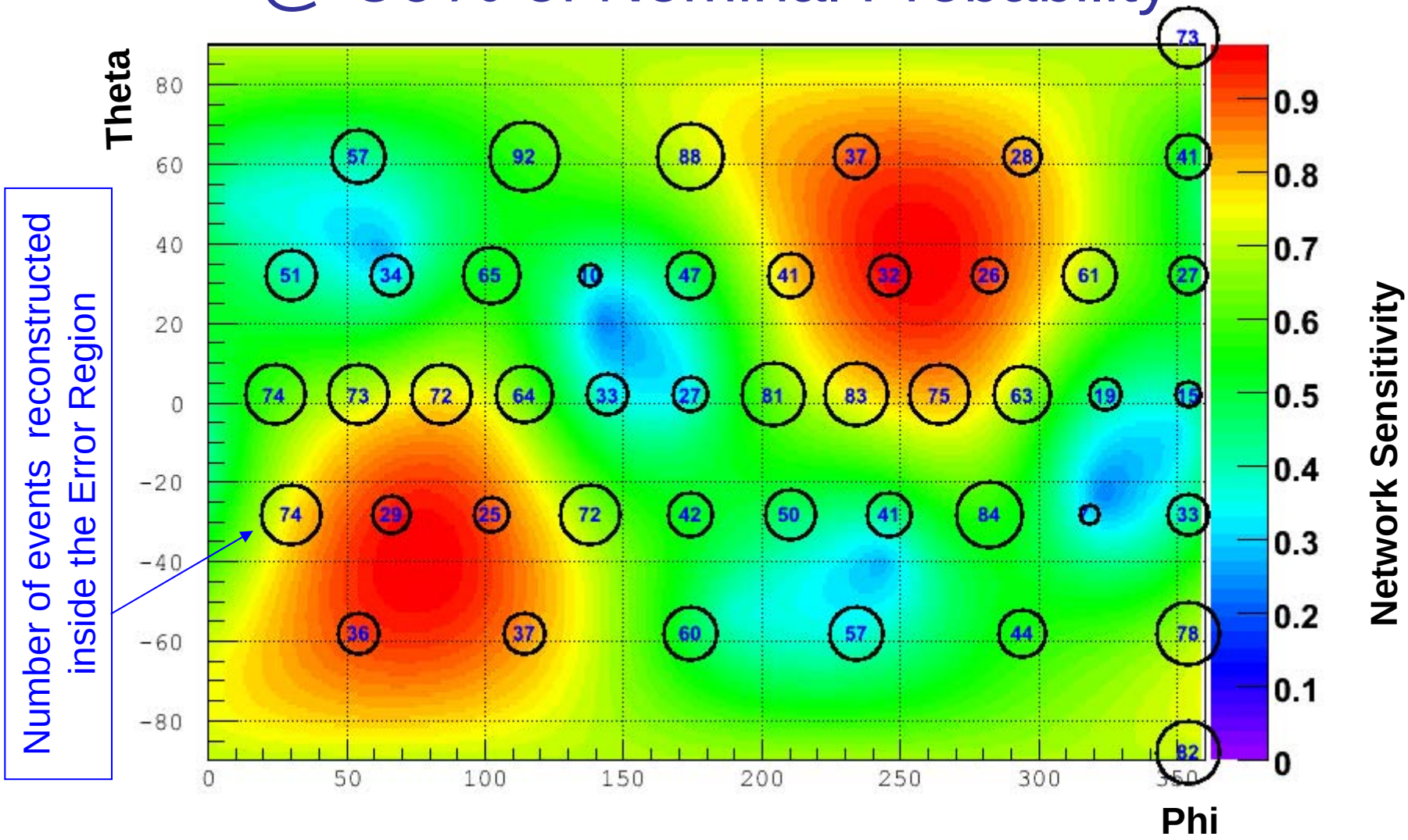


Error Region 50% (erA5)

is the area for which the integrated probability is 50%

(in general it is a not connected region)

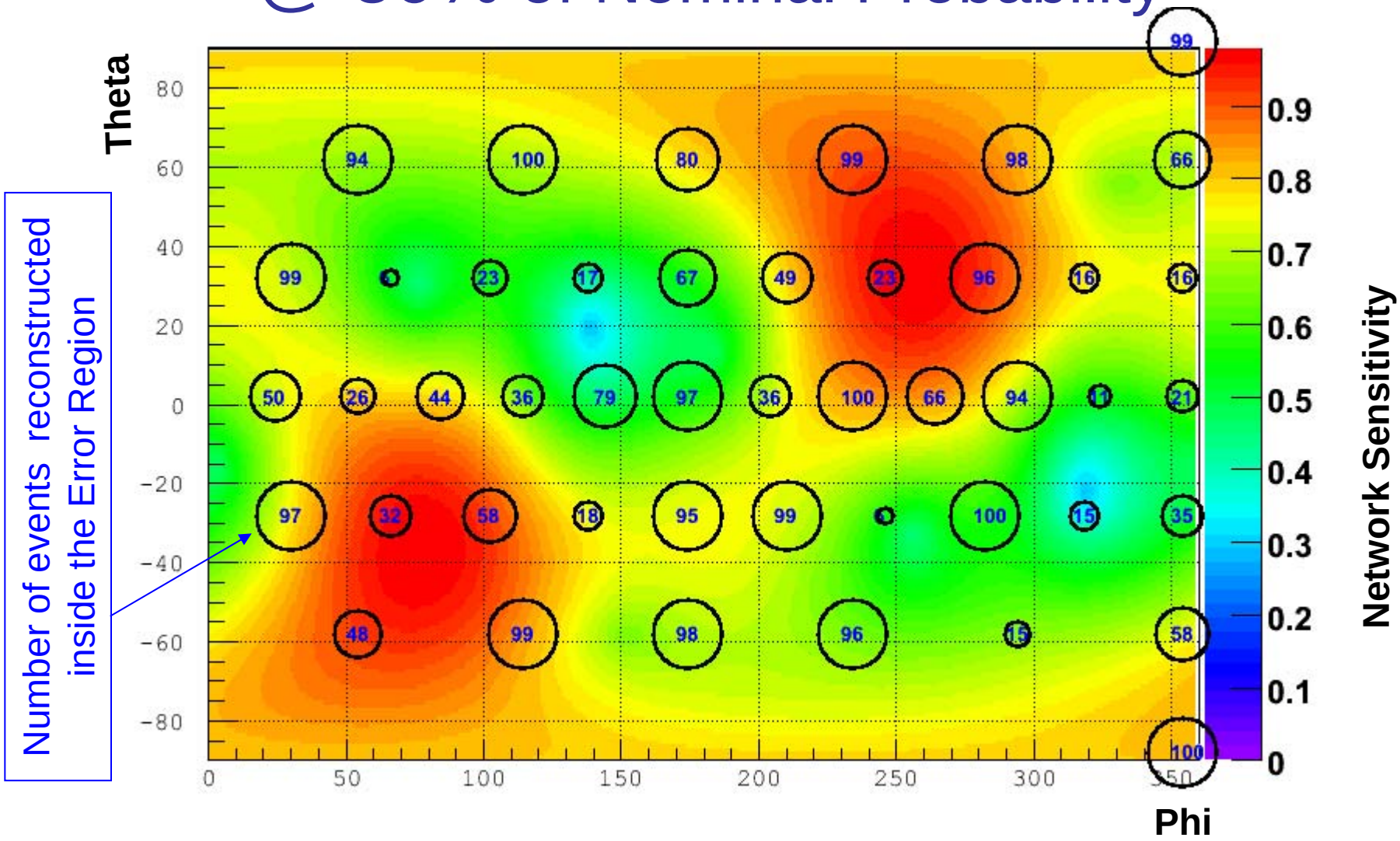
Measured coverage of Error Regions @ 50% of Nominal Probability



WNB 250-100-0d1

Measured mean coverage is 53%

Measured coverage of Error Regions @ 50% of Nominal Probability



WNB 1000-1000-0d1

Measured mean coverage is 61%

Conclusions and Plans

- Coherent WaveBurst reconstructs unmodeled GW waveforms and source locations.
- The algorithm sky localisation performances are characterised by the Median Error Angle.
- Along the source locations CWB provides Error Regions. Montecarlo simulations have been used to test this coverage.
  - For several sky locations coverage is over/under estimated.
- We plan to use CWB for localization of GW events for followup with optical/radio instruments during S6/VSR2
- We plan to improve the CWB performances:
  - Understand problems for some sky locations.
  - Improve Median Error Angle estimation.
  - Provide more uniform coverage for Error Regions over the sky.

Extra Slides

Results summary of the MonteCarlo

Percentage of detected events (Full Set)

MDC		Injected	Detected	%
Type	Freq (hz)			
WNB	**250:100:0.1**	83832	72910	86.9
	1000:1000:0.1	79842	39367	49.3
SGQ9	235	80556	71048	88.2
	1053	81676	56409	69.0
SGCQ9	235	81494	79486	97.5
	1053	82950	67257	81.1
SGQ3	235	81746	71232	87.1
	1053	82712	55973	67.6

Cumulative Distribution
Median Error Angle - Error Region 50%