LLAMA-GWHEN Significance Calculation Flowchart with Code Locations

Code locations and line numbers based on `coinc_significance.py` *commit* 1990b83

CODE LOCATION LEGEND

`CoincSignificanceIceCubeLVC._generate`	`odds_ratio`
`CoincSignificanceIceCubeLVC`	`five, five2`

SEARCH INPUTS

(different for each multi-messenger trigger)

GW

1 GW trigger

- Skymap (Ω)
- Mean distance (r_{GW})
- SNR (ρ)
- Time

line 860

```
gw_skymap =
    LVCInitialSkymapHDF5(self)
    .get_healpix()[0]
```

Neutrino

Multiple neutrino triggers

- Sky position mean (RA, Dec)
- Sky position std. dev. (σ)
- Energy
- Time

line 870

```
neutrinos =
    IceCubeNeutrinoList(self).neutrinos
```

SEARCH PARAMETERS

(constants used for many triggers)

- GW signal-noise ratio (SNR) background distribution
- Background neutrino triggers
- Effective IceCube area
- Integration bounds
- Empirical constants

lines 208-392, 794-817

```
def Aeff_skymap(skymap, enu):
...
LVC_ICECUBE_SEARCH_PARAMS =
    IceCubeLvcSearchParameters(...)
```

BACKGROUND

Adjust neutrino energy window so that it matches enough background triggers

lines 668-678

```
if (enu > maxenu): enu = maxenu
if (enu < minenu): enu = minenu
```

Find similar neutrinos in empirical background data

lines 685-705

```
while (Pempnu<5): ...
```

Calculate background (BG) rate

line 709

```
Rbg = ratebggw*ratebgnu
```

CHANCE COINCIDENCE

Real GW, BG neutrinos

$$P_{E_{GW}}\left(\frac{r_{GW}^2\rho^2}{k_0^2}\right)r_{GW}^2$$

line 722

```
p_xgw_xnu_given_hgw_c = (dist)**2*...
```

Real neutrinos, BG GW

$$\int A_{eff}\Omega_\nu d\Omega \times \int r^2 Poiss.(n, \langle n_\nu(E_\nu, r)\rangle) dr dE_\nu$$

lines 726, 741

```
fourtyeight=2.0*ratebggw*...
fourtyone=p_xgw_given_h0*integral...
```

Calculate chance coincidence likelihood

line 785

```
p_h_c = p_xgw_xnu_given_hgw_c * ...
```

SIGNAL

Calculate spatial overlap:

$$\int_{allsky} A_{eff}\Omega_\nu\Omega_{GW}d\Omega$$

lines 395-493

```
def five(...): ...
def five2(...): ...
```

Combine real GW, real neutrino probabilities with overlap integrals to get signal likelihood:

$$\int Poiss.(n, \langle n_\nu(E_\nu, r)\rangle) P(E_\nu) dE_\nu \times P_{E_{GW}}\left(\frac{r_{GW}^2\rho^2}{k_0^2}\right)r_{GW}^2 \times (t_\nu, t_{GW}\ overlap\ integral) \times (spatial\ overlap)$$

lines 780, 782

```
p_h_s1 = (five(...))*ndotgwnu/fb
p_h_s2 = fiveresult2*ndotgwnu/fb
```

ODDS RATIO *For any GW+HEN detection on this GW trigger (decomposed into partial fractions)*

$$\sum_{i=1}^{N}\frac{P(H_S|x_{GW}, x_{\nu,i})}{P(H_0|x_{GW}, x_{\nu,i}) + P(H_C|x_{GW}, x_{\nu,i})} + \sum_{i,j}\frac{P(H_S|x_{GW}, x_{\nu,i}, x_{\nu,j})}{P(H_0|x_{GW}, x_{\nu,i}, x_{\nu,j}) + P(H_C|x_{GW}, x_{\nu,i}, x_{\nu,j})} + \ldots$$

(SINGLE NEUTRINO) *(DOUBLE NEUTRINO)* *(...)*

lines 786

```
odds = (p_h_s1 + p_h_s2) / (p_h_c + p_h_0)
```