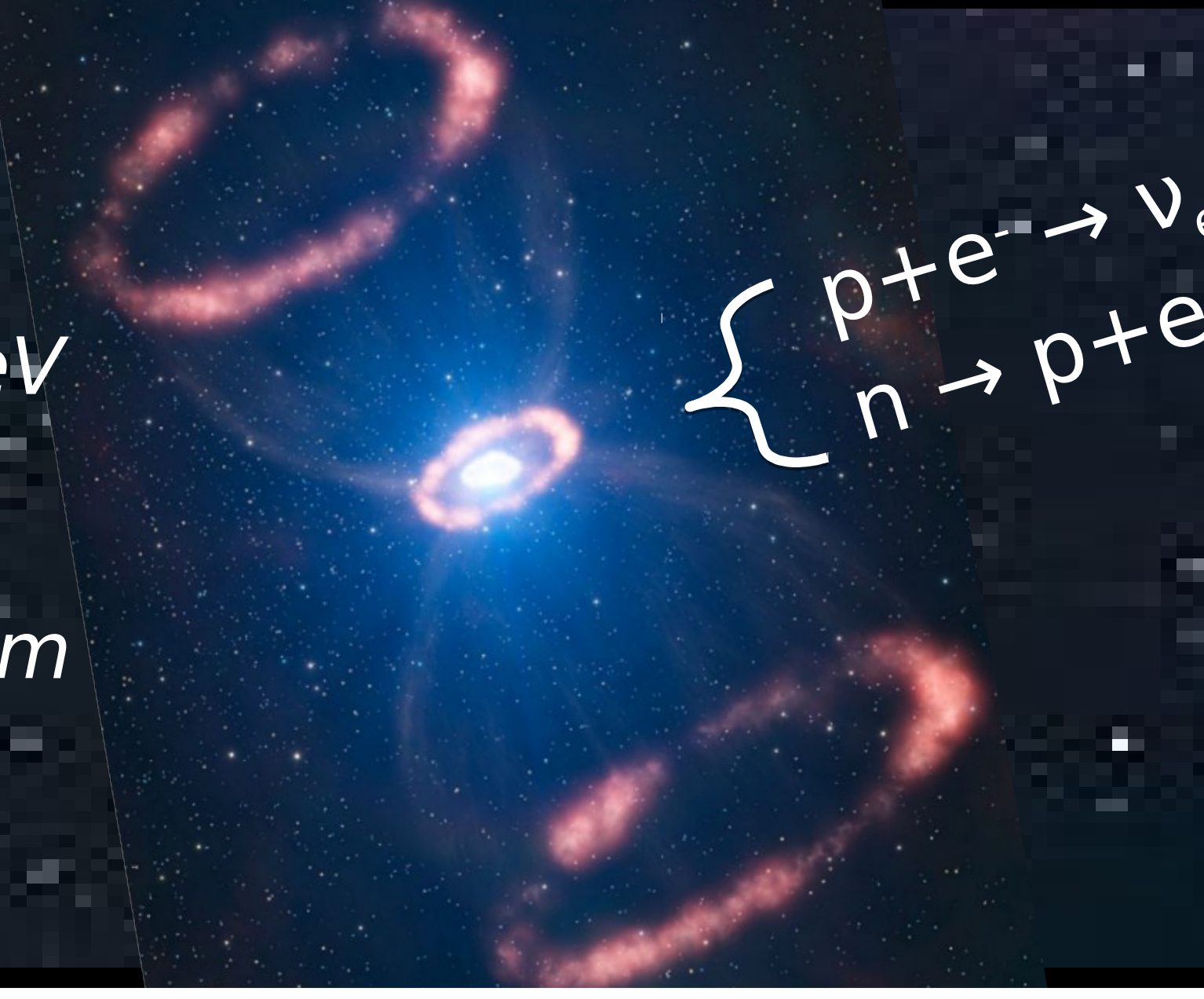

Potential MeV neutrino source detected from Supernova remanent

$$\left\{ \begin{array}{l} p + e^- \rightarrow \nu_e + n \\ n \rightarrow p + e^+ + \bar{\nu}_e \end{array} \right.$$

# Exploring the Potential of Multi-Detector Analyses for Core-Collapse Supernova Neutrino Detection

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## Motivation

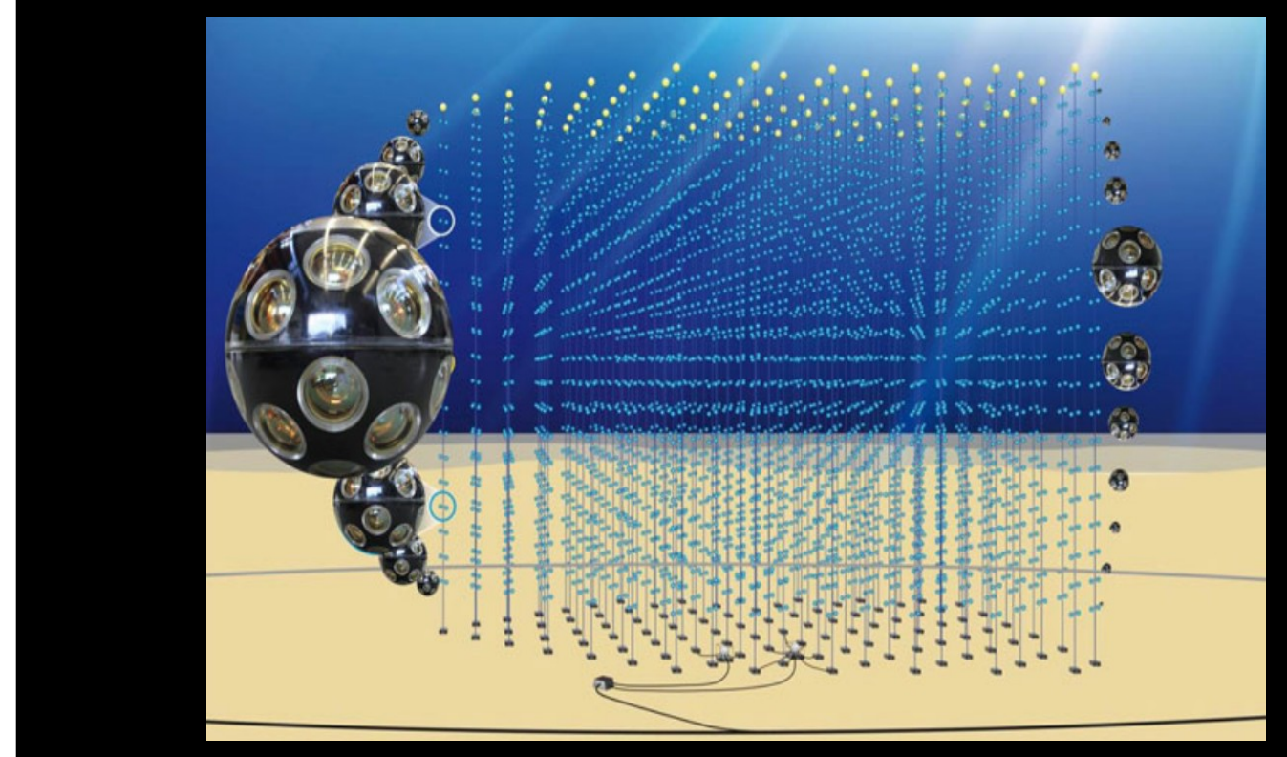
Despite hundreds of CCSNs detected in the electromagnetic spectrum since 1987, neutrino telescopes could not perform another observation due to the far distances of these events.

Neutrinos can provide unique information on the explosion mechanisms, and can be used to probe neutrino oscillation in dense environment.

In this poster, we study different techniques to enhance the potential of neutrino telescopes to low-energy astrophysical neutrinos. We present the various instruments we have used for this work. We investigate the potential of using a Bayesian approach to triangulate the position of a close-by CCSN and we explore the potential of multi-detector analyses in constraining the characteristics of the CCSN as well as neutrino oscillation parameters.

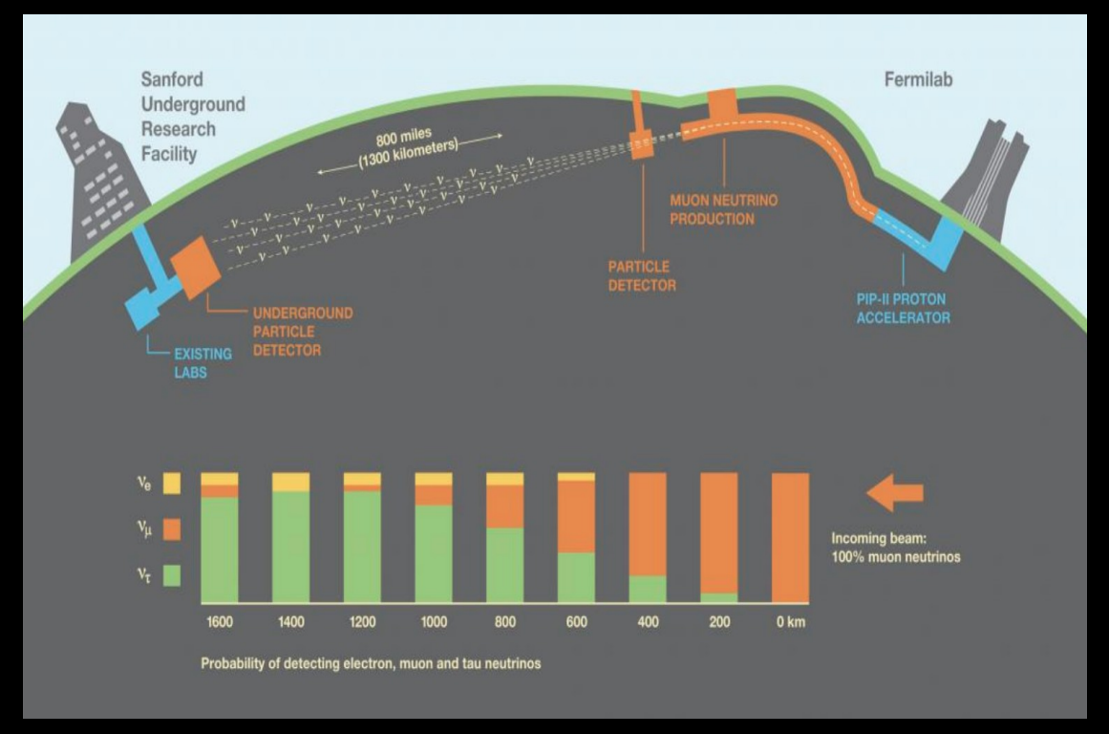
## Experiments

### KM3NeT



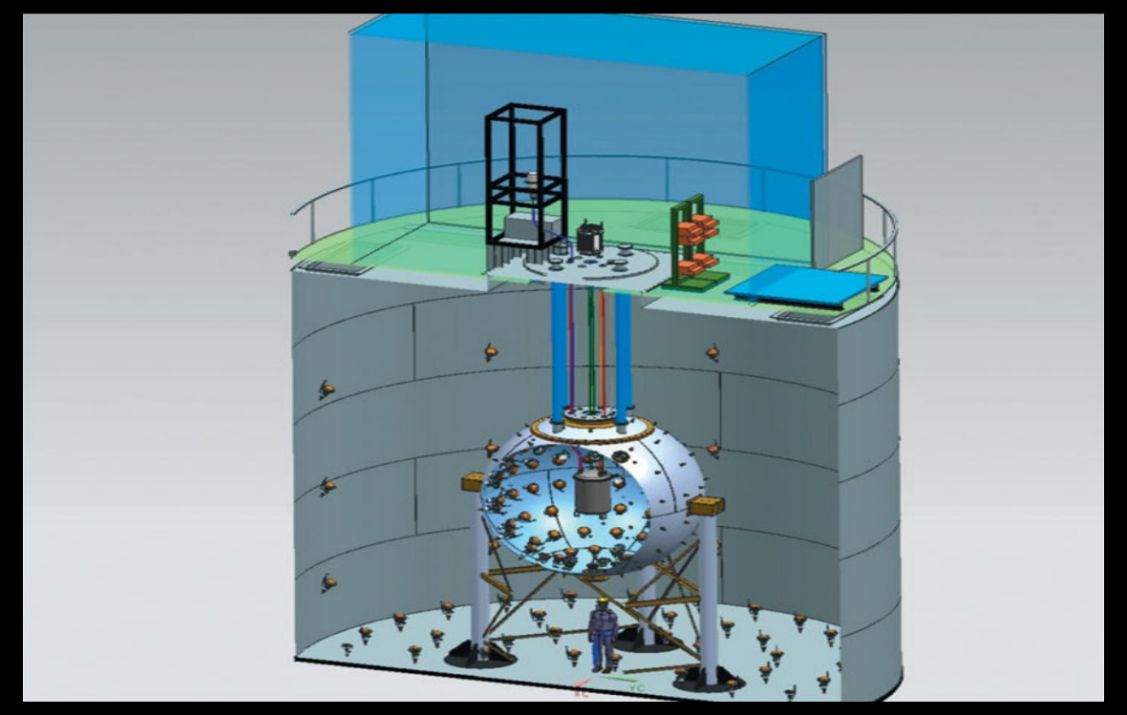
- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: ~2.5 kt [1]

### DUNE



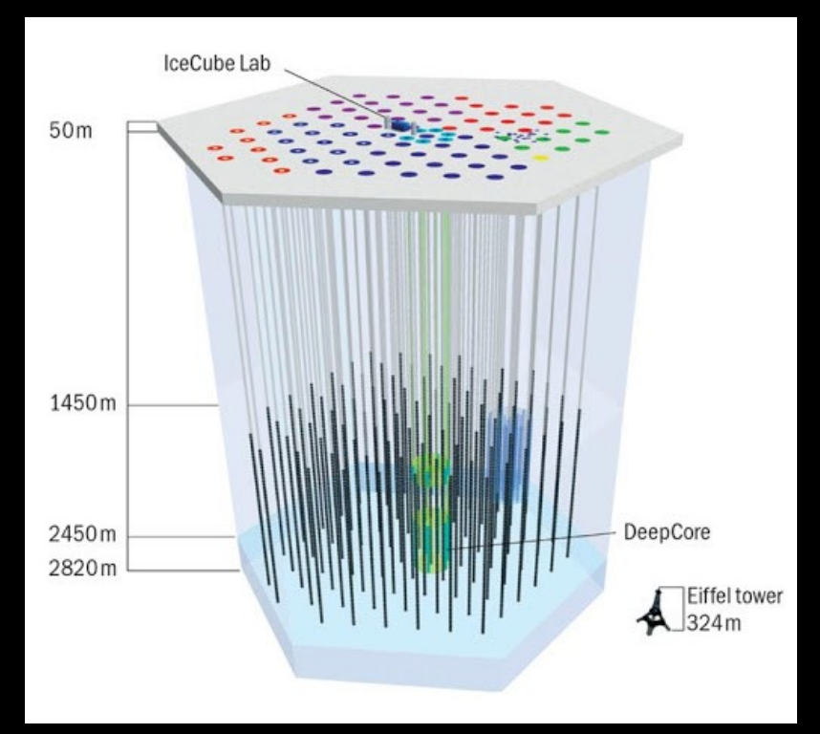
- Ar detector
- Sensitive to νe
- Effective mass: 40 kt [2]

### DarkSide-20k



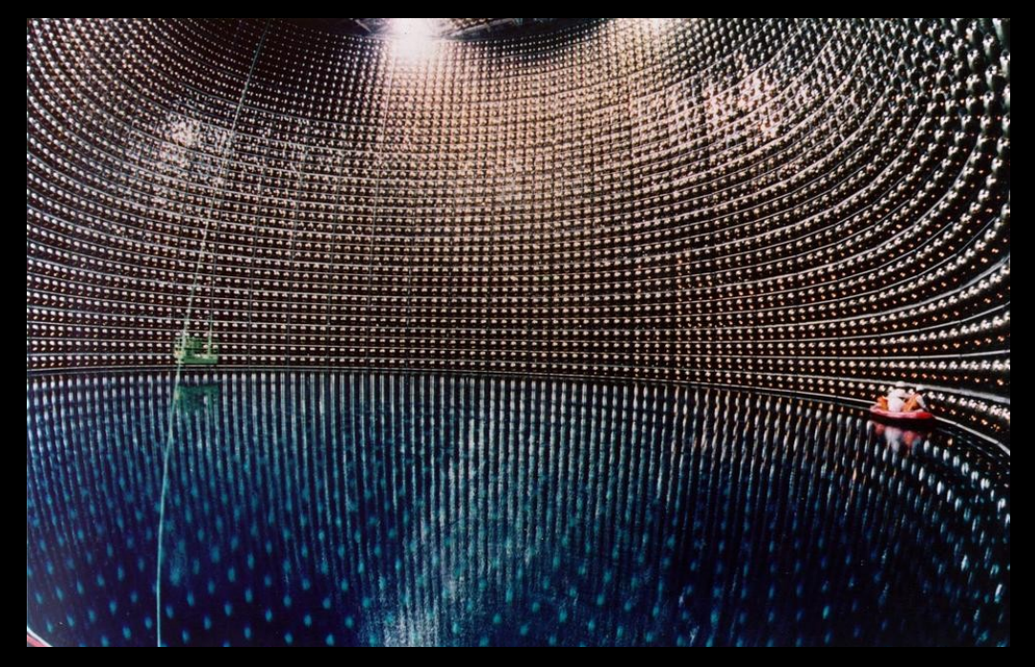
- Dark matter (Ar) detector
- Sensitive to all ν flavors
- Effective mass: 0.02 kt [3]

### IceCube



- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: 51600 kt [4]

### Super-Kamiokande



- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: 32 kt [5]

## Three phases of neutrinos emission

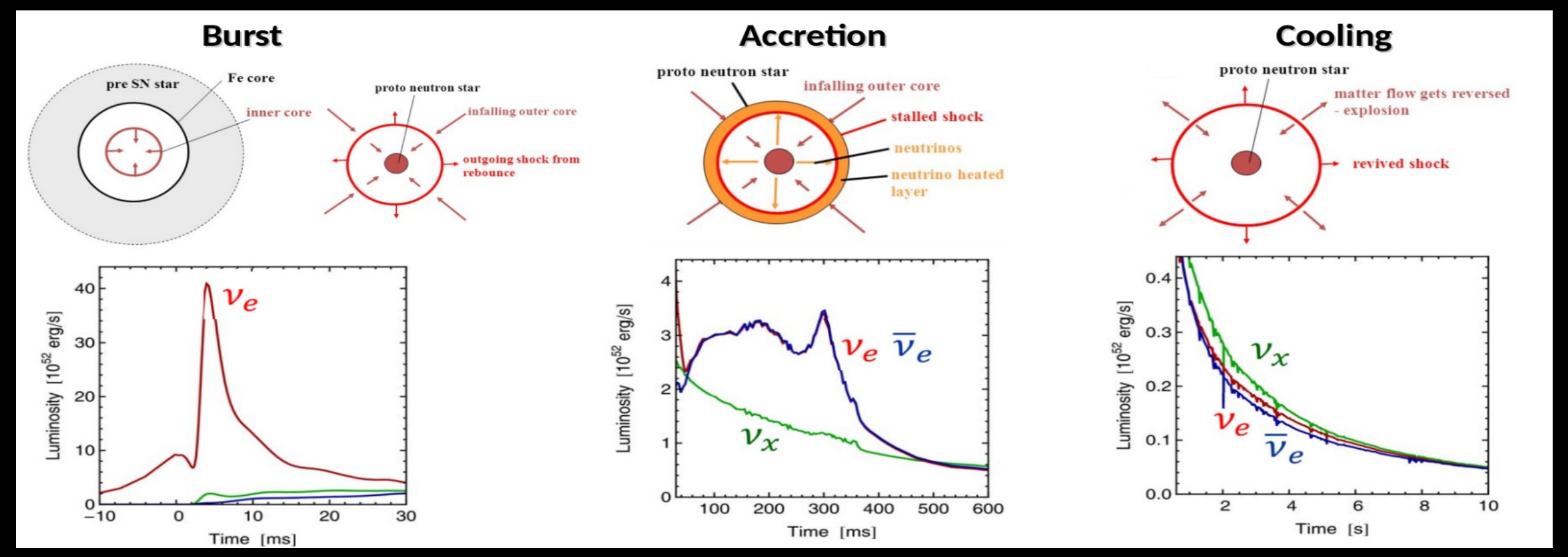


**Figure 1 :** The neutrino burst (left), the accretion phase (middle) and the cooling phase(right) of a CCSN.[6]

## Multi-detector approach for CCSN triangulation

The approach used estimate the time delay between the light curves recorded by IceCube, KM3NeT, and Super-Kamiokande detectors during a CCSN to estimate its position in the sky.

The impact of using a prior on the position of the potential CCSN through a Bayesian approach was studied.

The tested prior was a map of GAIA showing the dust distribution in the Milky Way.

**This approach allows us to reduce the 90% confidence area of the source localization by more than 55%, depending on the combination of neutrino telescopes.**

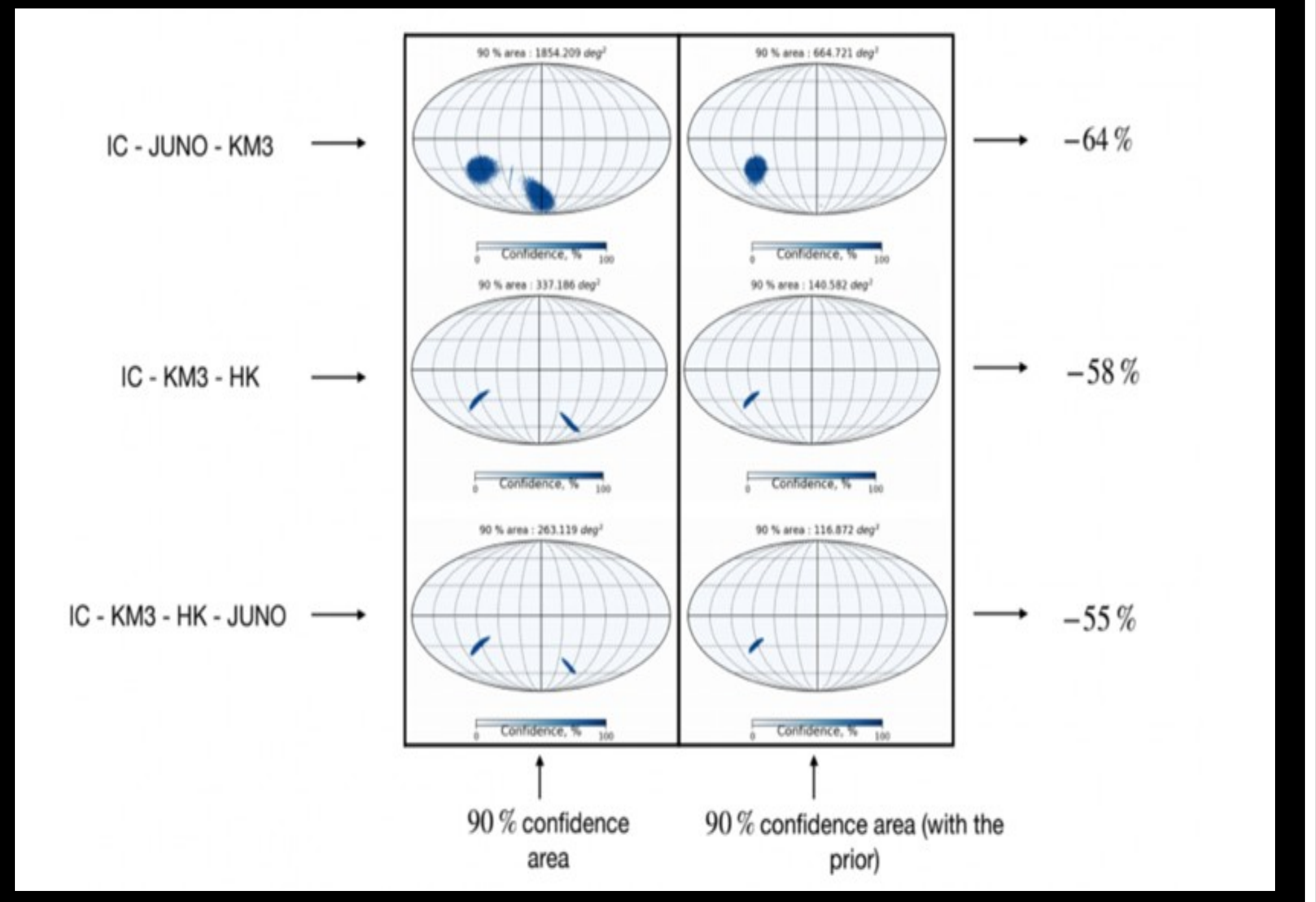


**Figure 2 :** Comparison of the confidence areas obtained by the CCSN triangulation method [7] with and without using a prior.

## Multi-detector approach for enhancing the scientific output

Two studies were followed in this analysis:
- hierarchy dependence study for 11 and 27 solar mass progenitors.
- mass dependence study for normal and inverted ordering.

### Description of the algorithm:

1. Estimation of the CCSN neutrino event rate in the detectors as the product of the differential neutrino flux, the cross section, the detection efficiency and the detector volume

$$N_{ev} = \int_{E_{min}}^{E_{max}} dE \, \frac{d\Phi}{dE_\nu} \, \sigma \, \epsilon_{det} \, V_{det}$$

2. Light curve comparison using ratios or asymmetries variables between the number of neutrinos predicted in KM3NeT, DUNE and DarkSide

**Ratio = N_det1 / N_det2**
**Asymmetry = (N_det2 - N_det1) / (N_det2 - N_det1)**

*N_det1: Number of event in detector1 ; N_det2: Number of event in detector2*

3. Statistical methods for model discrimination by computing the optimal time windows in ms to estimate the significant difference between tested hypothesis:
- Loop over time throughout the duration of the light curves with a step of 10 ms.
- Calculate the difference between two hypotheses.
- Select the time windows giving the highest differences between two hypotheses.

### Light curves

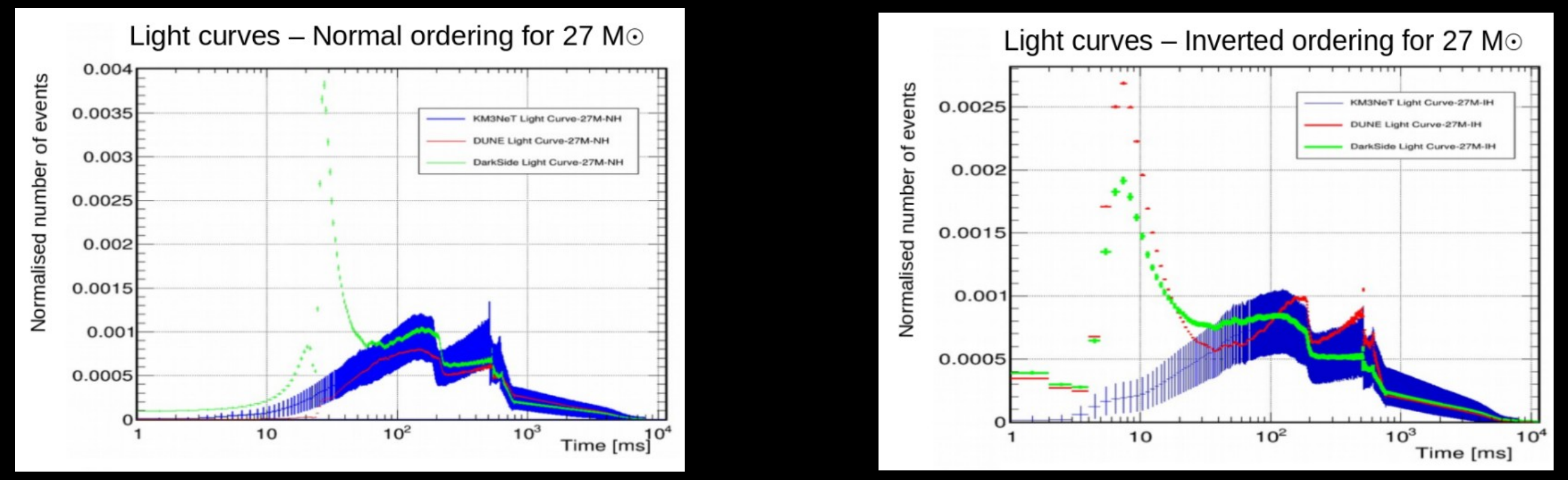


**Figure 3 :** Light curves from KM3NeT, DUNE and Darkside respectively on blue, green and red for a 27 solar mass progenitor.

### Determination of the neutrino mass ordering

### Constraints on the progenitor mass

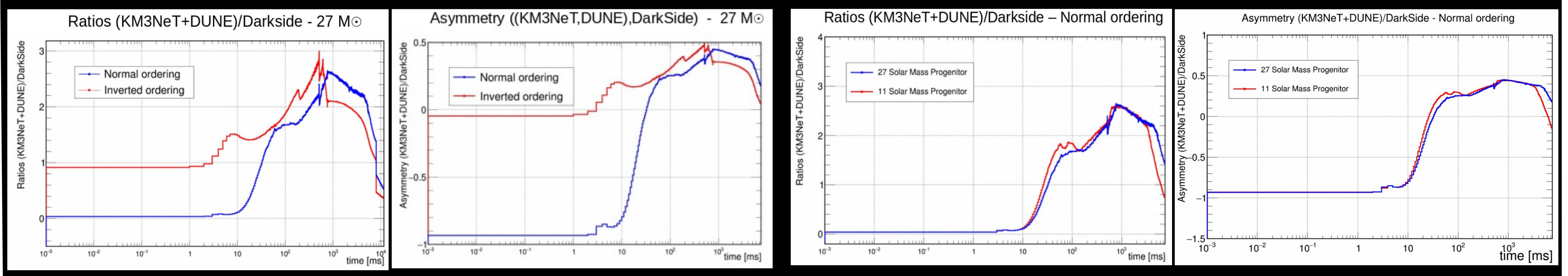


**Figure 4 :** Ratio and asymmetry for KM3NeT, DUNE and DarkSide light curves

### Summary and Prospects

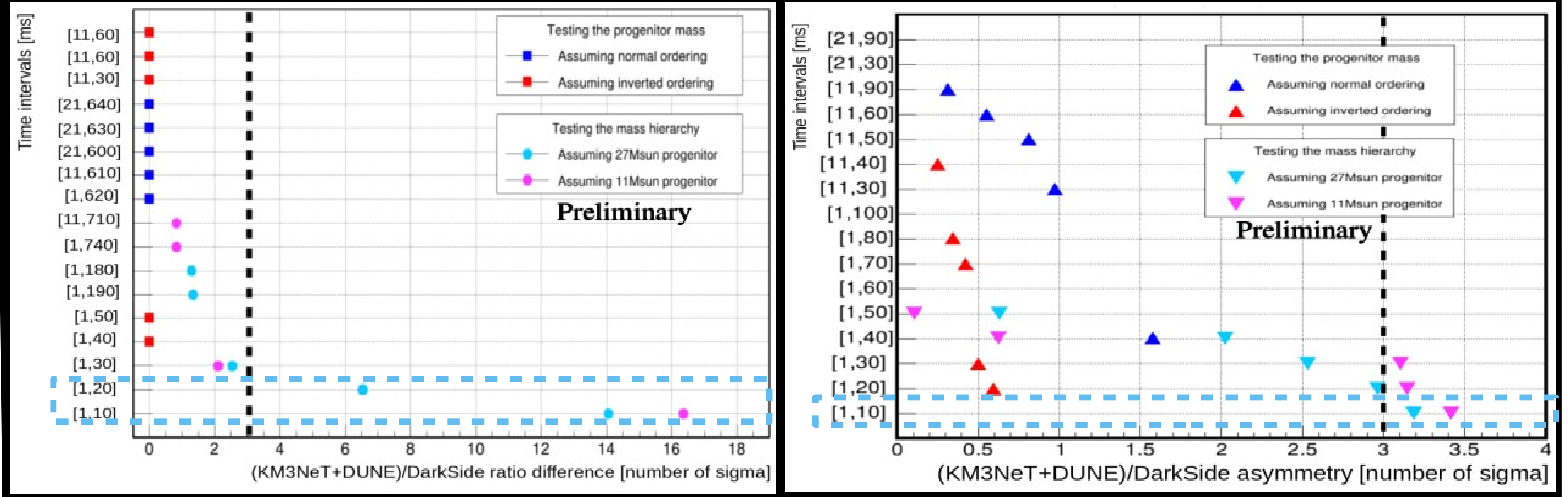


**Figure 5 :** Mass ordering and progenitor mass estimate for ratio and asymmetry variables

**Good sensitivity to mass ordering estimate**

- Significant difference estimated for mass ordering study:
- More than 14 σ for [1,10] ms and more than 6 σ for [1,20] ms for ratio variable.
- More than 3 σ is estimated for [1,10] ms for the asymmetry variable, m.

- No time window leading to a 3 σ difference could be identified for the two progenitor masses.

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