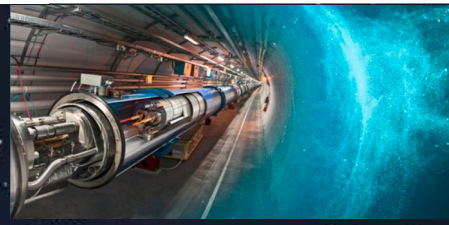
First Pan-African Astro-Particle and Collider Physics Workshop

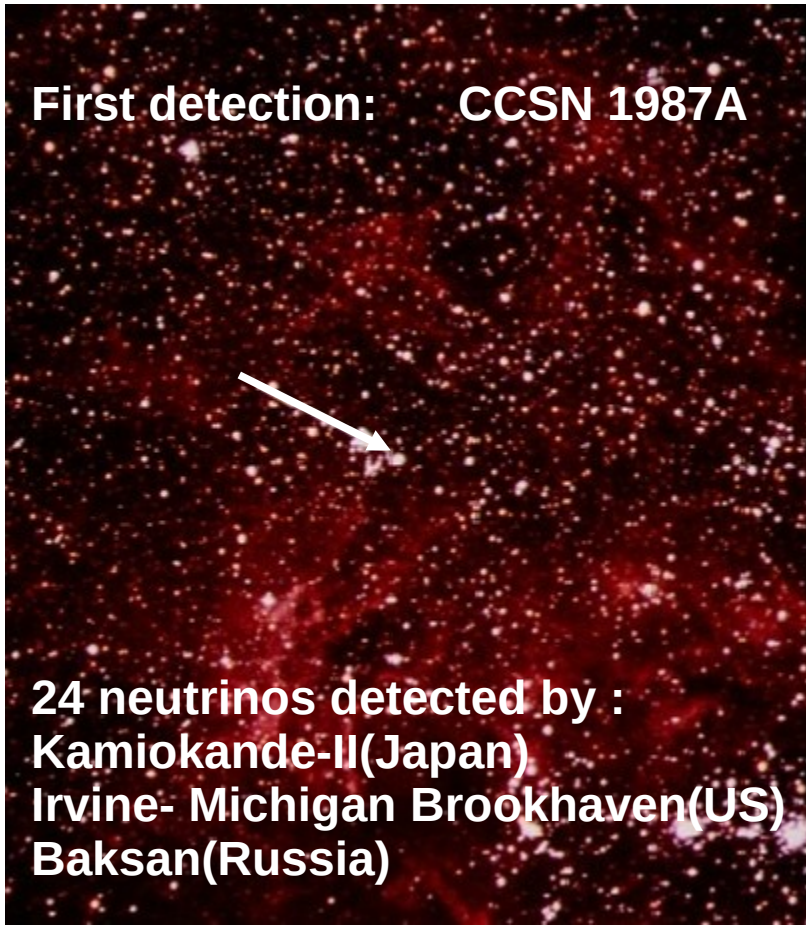


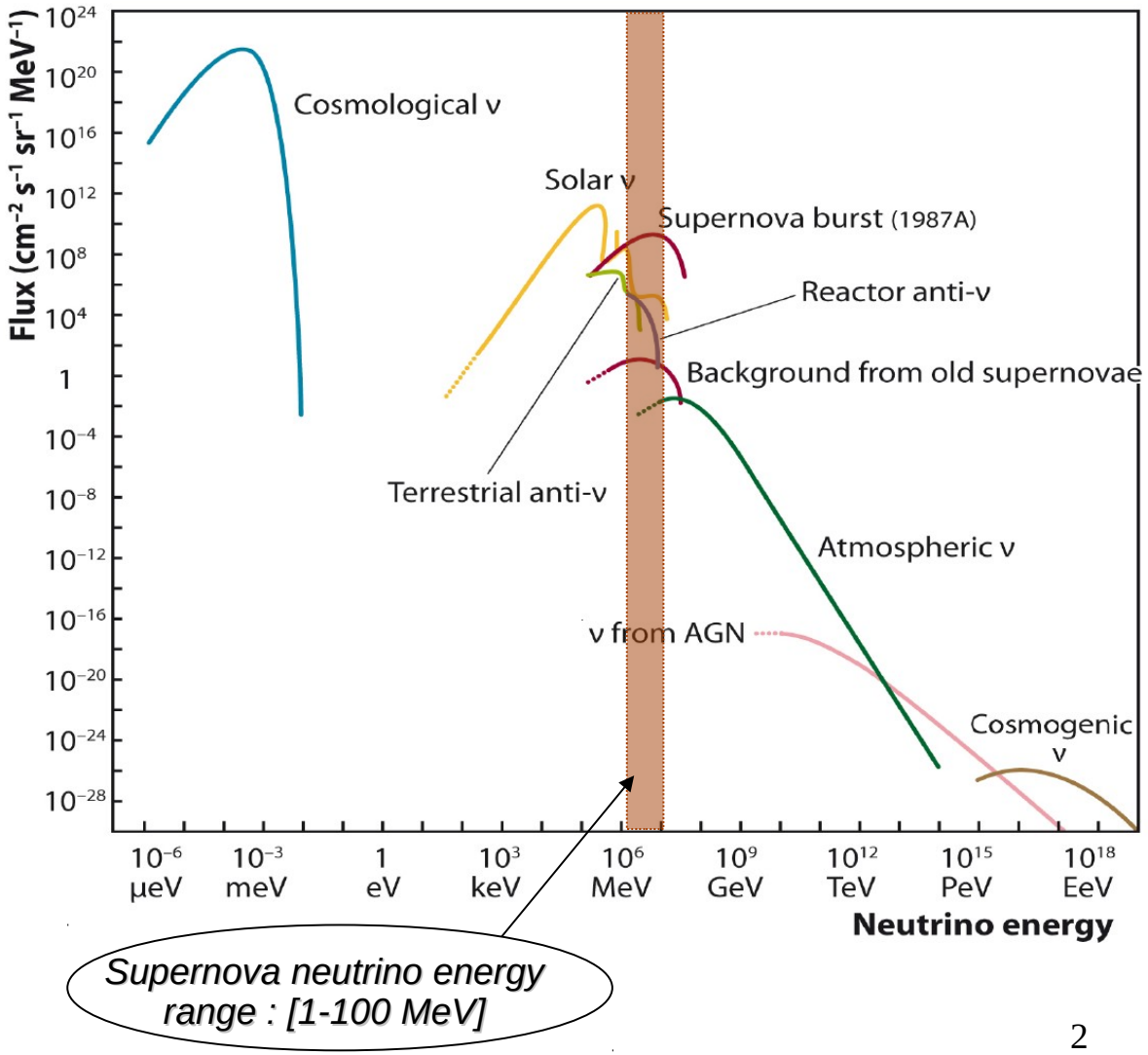
Exploring the Impact of Magnetic field on Core-Collapse Supernova Neutrino Light Curves Detection

Meriem Bendahman[1 2] , Sonia El Hedri[1] , Matteo Bugli[3] , Antoine Kouchner[1] , Yahya Tayalati[2]

1 Laboratoire Astroparticules et Cosmologie, Université Paris Cité, Paris
2 Faculty of Sciences, Mohammed V University, Rabat
3 CEA Saclay, Department of Astrophysics

Neutrinos from Core Collapse Supernovae



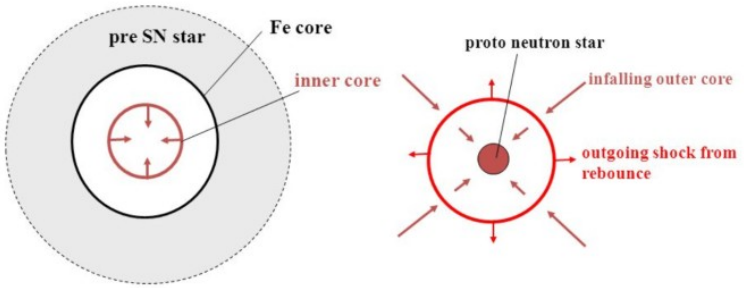


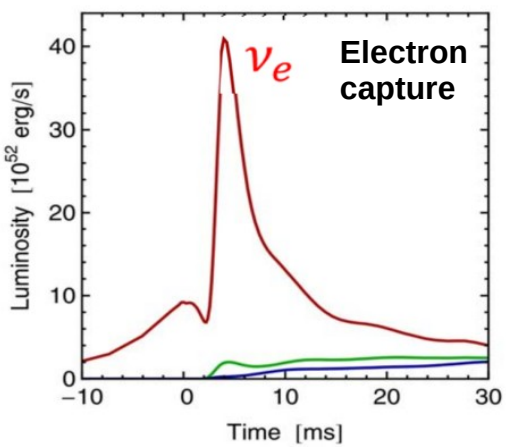
From **24 neutrino events**
→ new knowledges :

- The distance to the explosion.
- The interaction probability.

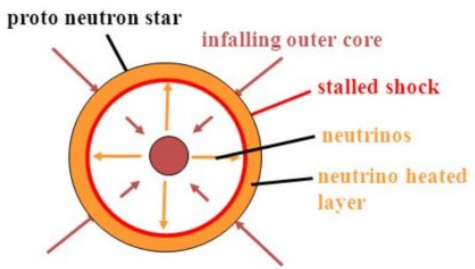
Three phases of neutrino emission

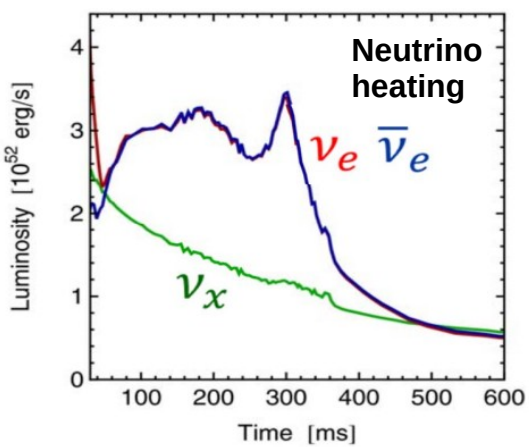
Burst



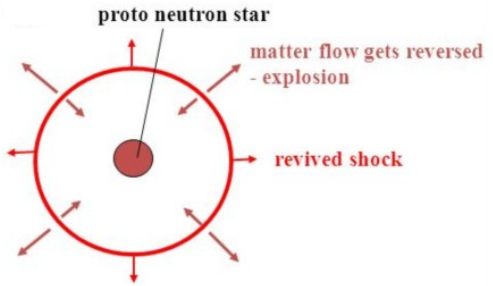


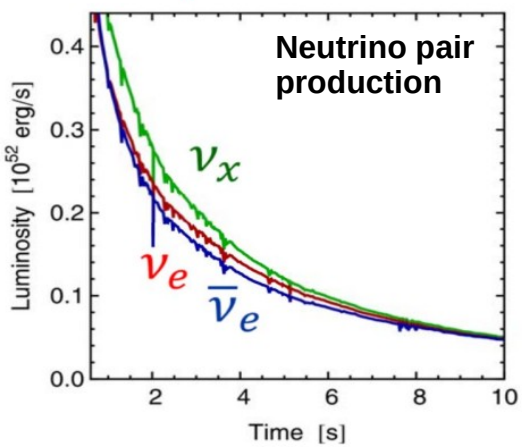
Accretion





Cooling

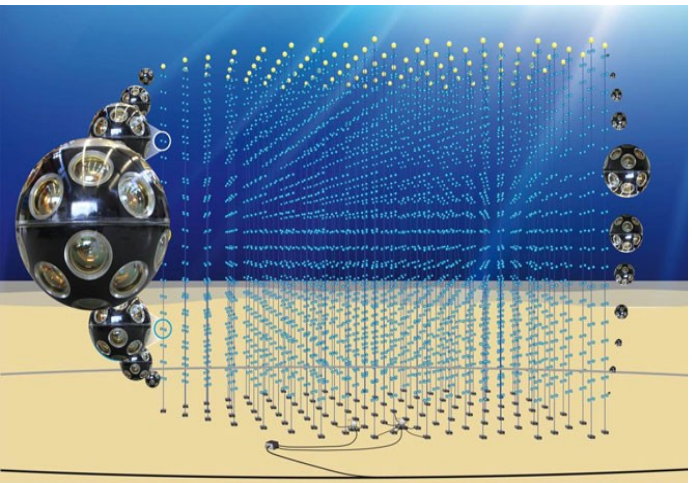




- ✓ With neutrino emission, we can identify the explosion phases of a supernova.
- ✓ In the supernova, MSW Effect lead to flavor conversion which depend on mass ordering.

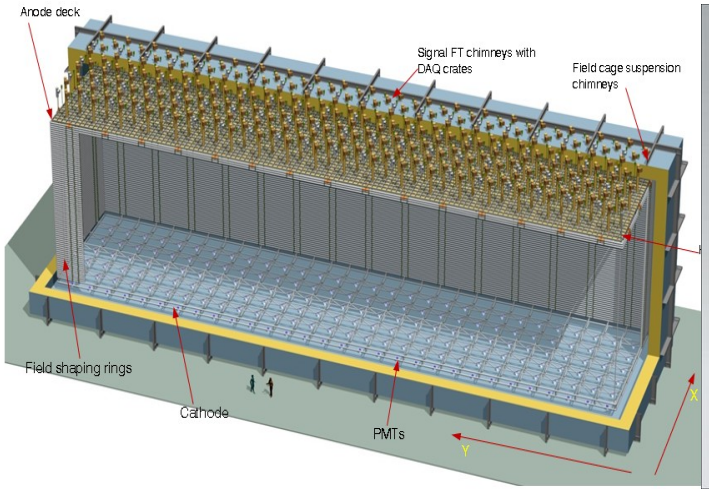
The detectors considered: KM3NeT, DUNE and DarkSide

KM3NeT



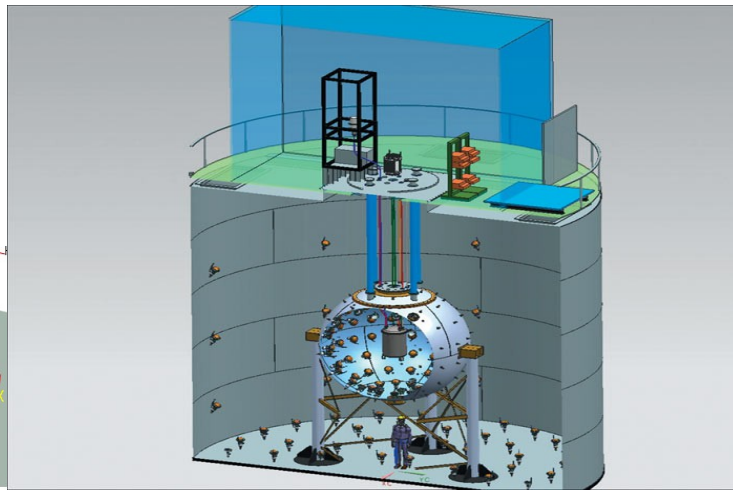
- Water Cherenkov detector
- Sensitive to anti νe
- Effective mass: ~100 kt (2 blocks)

DUNE



- Ar detector (long-baseline)
- Sensitive to νe
- Effective mass: 40 kt

DarkSide



- Dark matter (Ar) detector
- Sensitive to all ν flavors
- Effective mass: 49.7 t (DS20k)

Supernova neutrino studies

Multi-detector approach for enhancing the scientific output

Goal : Set constraints on the models and Discriminate between different supernova models

- **Determine the neutrino mass ordering and estimate the mass of the progenitor :**

2 studies at 10 kpc:

✓ Mass ordering dependence study for 11 Msun ad 27 Msun.

✓ Mass dependence study for normal and inverted ordering.

- **Compare between core-collapse supernova neutrino light curves considering different magnetic field topologies :**

28 Msun progenitor at 10 kpc.

→ Understand the impact of magnetic field on neutrino emission from CCSN.

Multi-detector approach

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

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

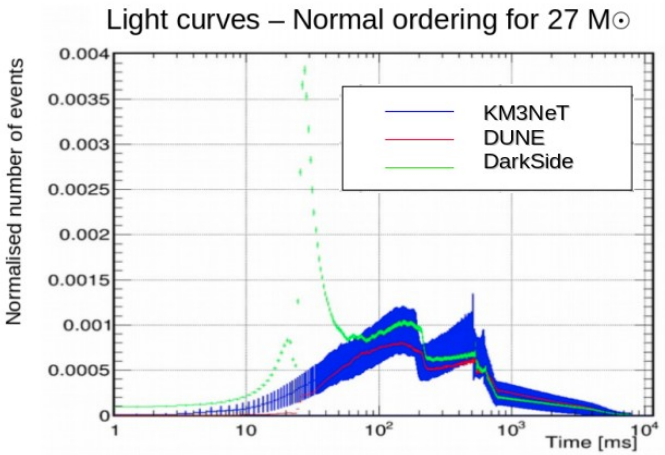
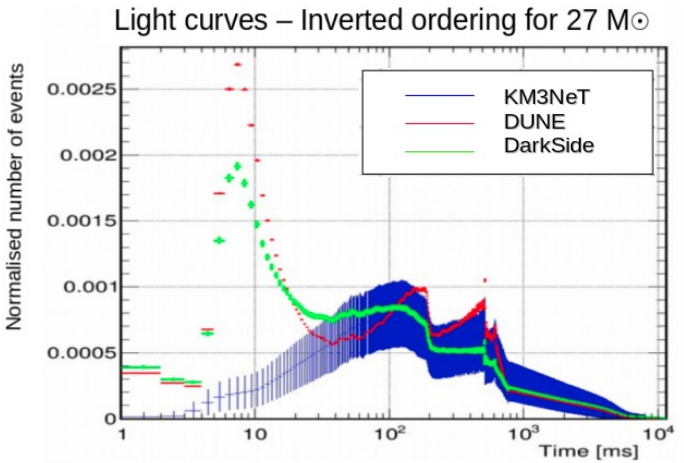
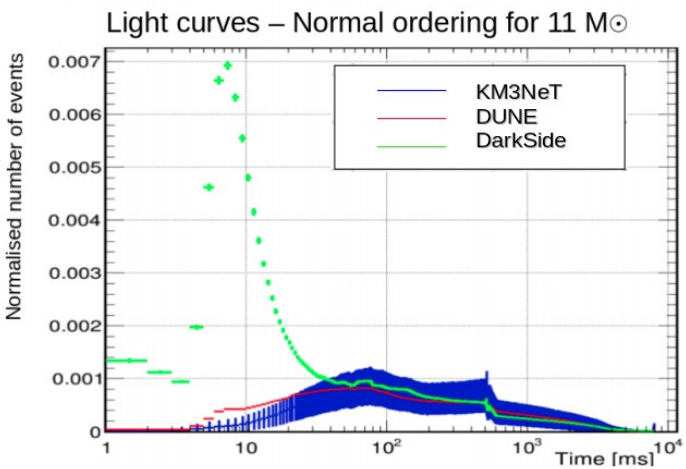
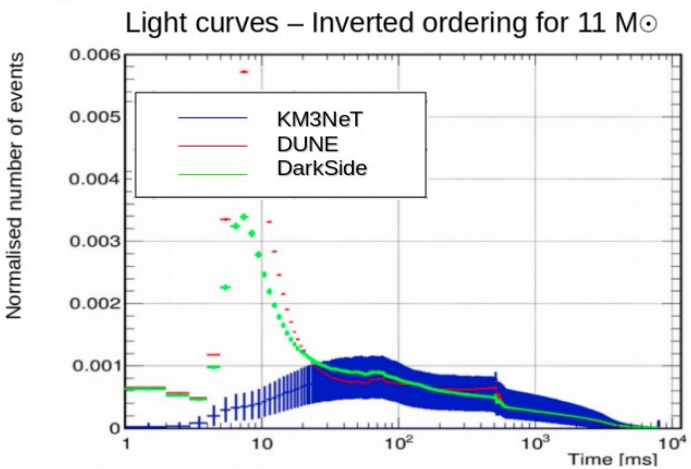
- $\mathtt{Ratio = NdetA/NdetB}$
- $\mathtt{Asymmetry = (NdetB - NdetA)/(NdetB + NdetA)}$

3. Statistical methods for model discrimination by computing the optimal time windows in milliseconds to estimate the significance of the difference between the testing hypotheses:

- Loop over time throughout the duration of the light curves.
- Calculate the difference between two hypotheses.
- Select the time window giving the highest difference between two hypotheses.

Supernova neutrino detection rates

https://pos.sissa.it/395/1090/pdf

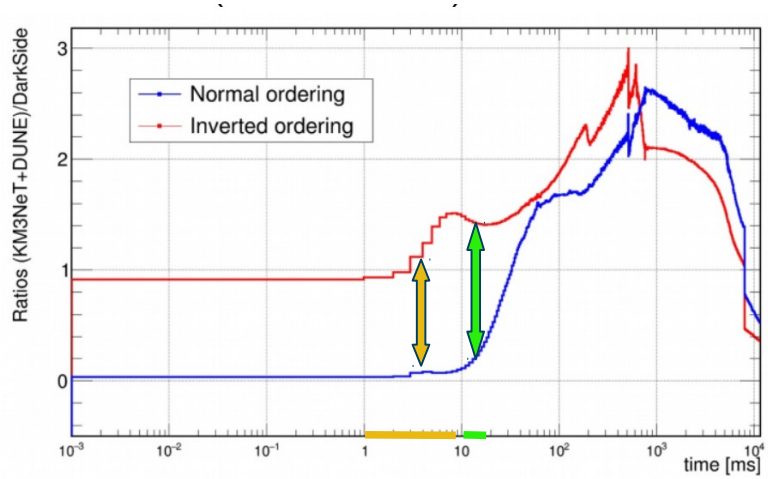
Progenitor mass \ Mass Ordering	Normal ordering	Inverted ordering
27 Msun Progenitor		
11 Msun Progenitor		

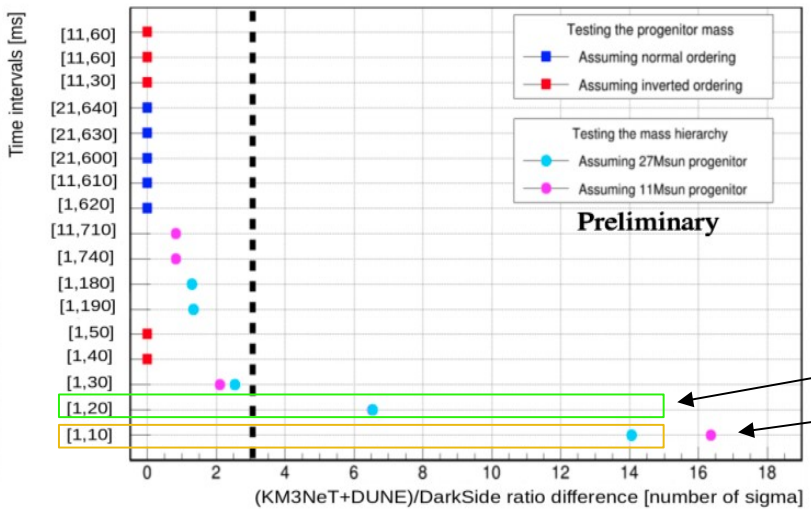
- ✓ Difference in light curve shape between 27 Msun and 11 Msun progenitors.
- ✓ Less significant difference for later times.

Mass ordering and progenitor mass estimate for ratio and asymmetry variable

Estimating Statistical significance for: Ratio = NdetA/NdetB

Ratio variable



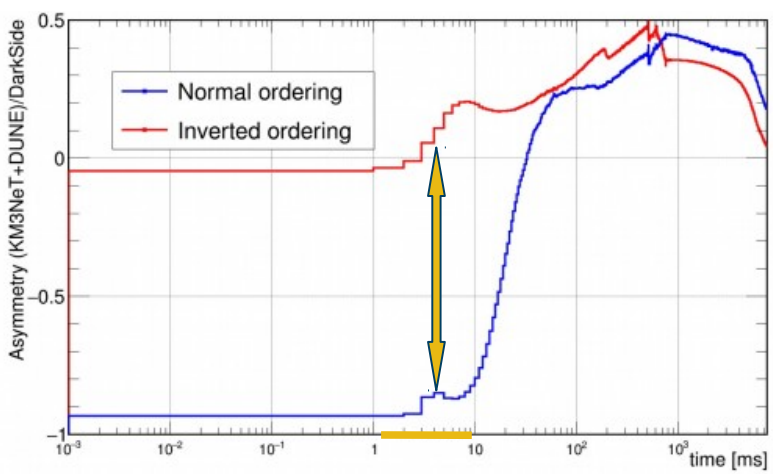


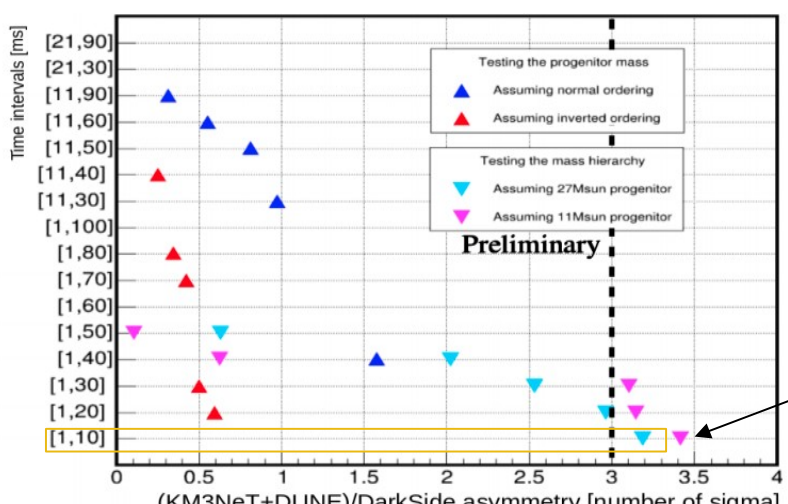
discrimination at 6 sigma

discrimination at 14 sigma

Estimating Statistical significance for: Asymmetry = (NdetB − NdetA)/(NdetB + NdetA)

Asymmetry variable



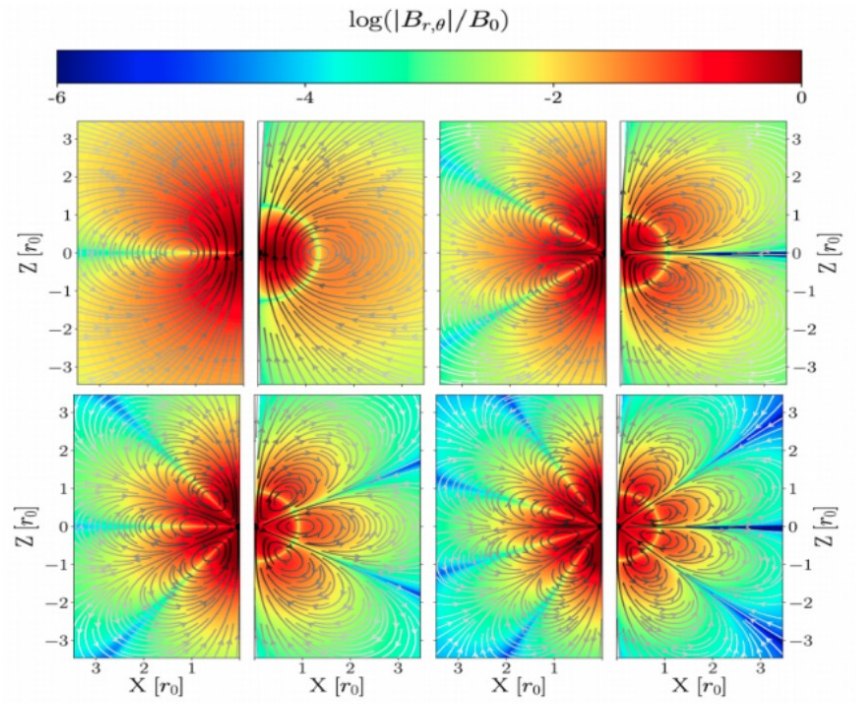


discrimination at 3 sigma

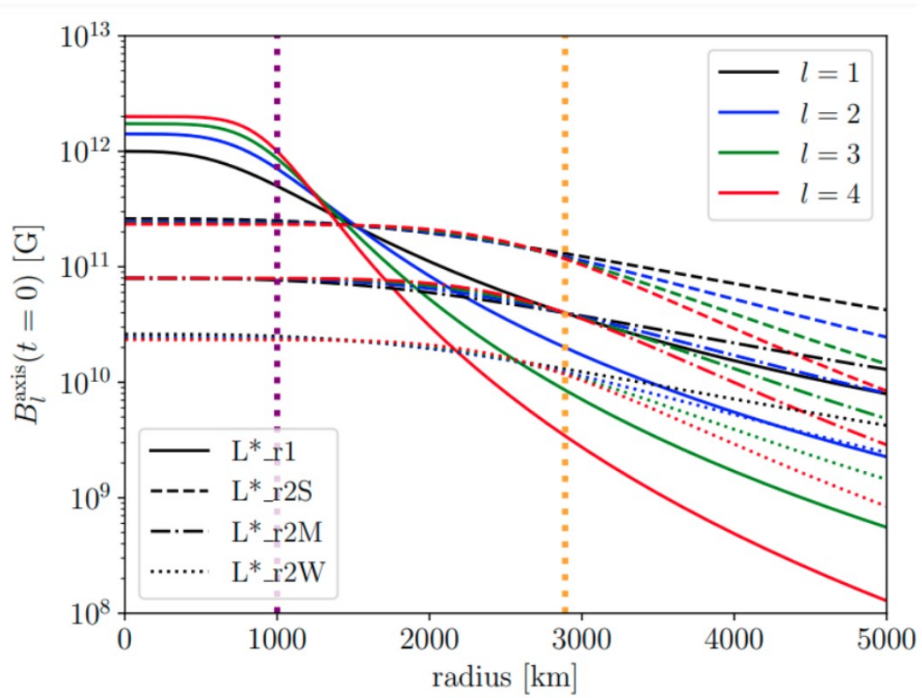
Exploring magnetic field impact on neutrino light curves

Models of magnetorotationally-driven core-collapse explosions. *Matteo Bugli* (AIM)

- Starting the simulations superimposing a magnetic field on the hydrodynamic models.
- Considering several configurations, differing by magnetic field strength (from 10^10 to 10^12 G) and topology (dipolar, quadrupolar...).



Magnitude of the radial (left side) and polar (right side) components of the magnetic field in units of B0, at t = 0. The axes are expressed in units of r0. The streamlines track the initial poloidal magnetic field employed in the simulation *(BUGLI ET AL. 2020,2021)*



Radial magnetic field along the rotational axis for all models in the present work, at t = 0. Black, blue, green and red lines refer respectively to l = 1, 2, 3, 4. The purple and orange dotted vertical lines represent the two characteristic radii considered, r0 = [1, 2.89] ×10³ km *(BUGLI ET AL. 2020,2021)*

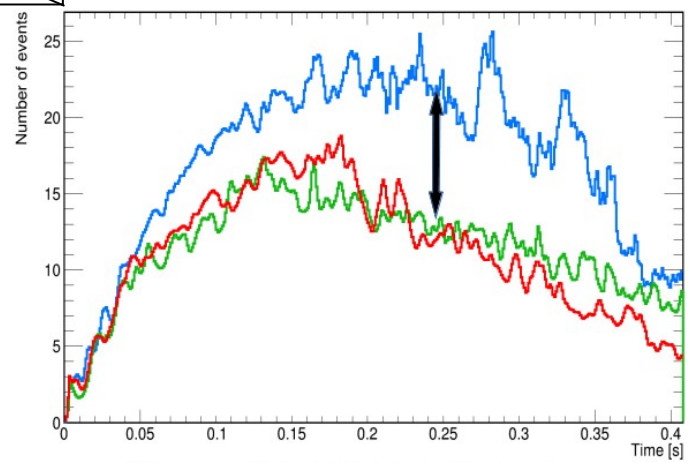
Benchmark models

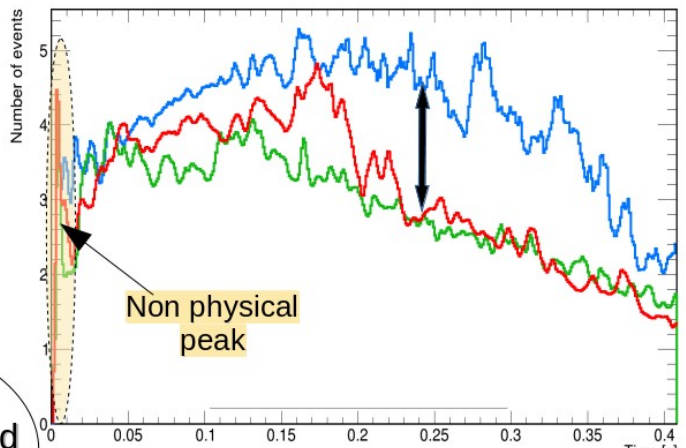
- 3D Simulation
- The progenitor mass = **28.1 Msun**
- 3 Neutrinos species: **νe, anti νe** and **νx**
- All quantities are measured at **500 Km** from the center
- Magnetic field intensity **B0=1e12 G**
- 2 topologies are considered : **Dipole** and **Quadrupole** (l=1 and l=2)
- The radius : **r0=1.00e8 cm**

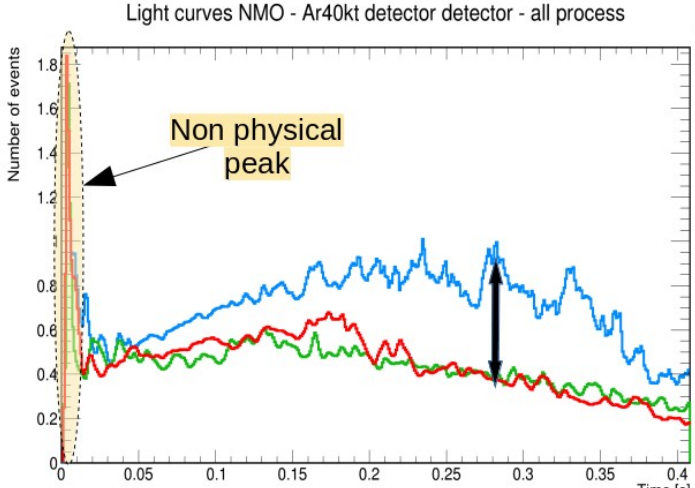
Supernova neutrino rates

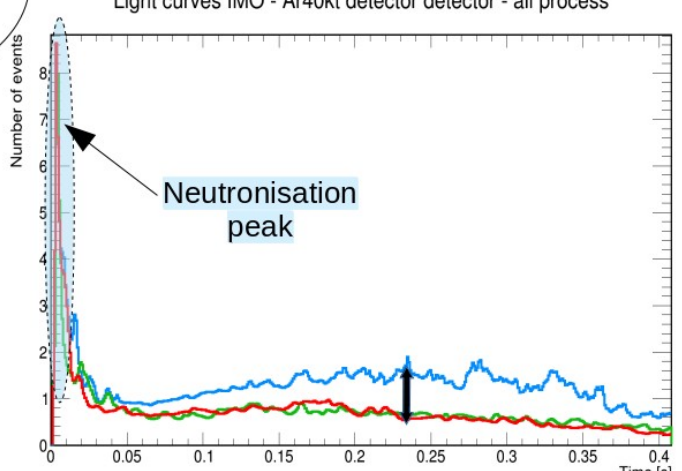
Without Magnetic field — Dipole (l=1) — Quadrupole (l=2) ; Equator line of sight

Detector \ Mass Ordering	Normal ordering	Inverted ordering
KM3NeT	Light curves NMO - 100ktwt detector - all process	Light curves IMO - 100ktwt detector - all process
DUNE	Light curves NMO - Ar40kt detector detector - all process	Light curves IMO - Ar40kt detector detector - all process









A decrease of the neutrino rate is observed in the presence of magnetic field

Conclusion and perspectives

Conclusion

- Significant differences are estimated for mass ordering study at 10 kpc.
- Discrimination at 1.5 sigma for progenitor mass study at 10kpc.
- For a galactic supernova, we can determine mass ordering.
- The impact of magnetic field on the neutrino light curves is observed to be significant.
- New working CCSN pipeline: quickly simulate a wide range of models by using SNEWPY *https://github.com/SNEWS2/snewpy.*

Perspectives

- Include detector effects.
- Understand the B field dependence of the light curves.
- Elaborate discriminating variables to estimate the impact of the magnetic field.