Simulated Detection Rates of Pre-Supernova Neutrinos using SNOwGLoBES

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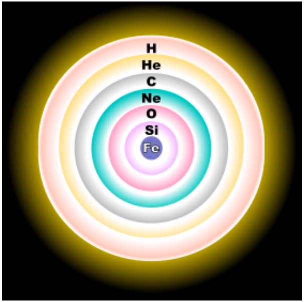
Pre-Supernova Neutrinos

- neutrinos emitted **before** the supernova
- produced during the different burning stages



[2]

Stage	Duration [1]
H $\rightarrow$ He	$7 \cdot 10^6$ years
He $\rightarrow$ C	$7 \cdot 10^5$ years
C $\rightarrow$ O	600 years
O $\rightarrow$ Si	6 month
Si $\rightarrow$ Fe	1 day
Core Collapse	1/4 second

Pre-Supernova Neutrinos

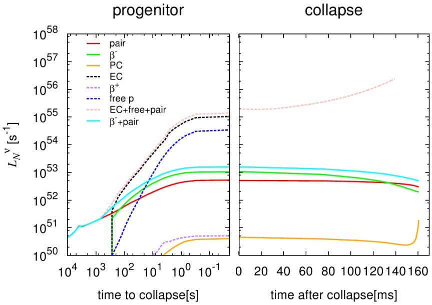


Figure 1: Time evolution of neutrino number luminosity. Supernova emission data taken from Kato et al. [4].

Considered interactions:

- thermal pair emisson
  - electron-positron annihilation
  - plasmon decay
  - bremsstrahlung
  - photo process
- neuclear weak interactions

  ν_e : electron capture, β^+ decay

  $\bar{\nu}_e$: positron capture, β^- decay

Motivation

Why do we investigate pre-supernova neutrinos?

- establish a supernova early warning system [3]
- distinguish the type of the progenitor [4]
    - iron-core collapse supernova (FeCCSN), $10M_\odot \leq M$
    - electron capture supernova (ECSN), $8M_\odot \leq M \leq 10M_\odot$
- determine progress of the burning phase [4]

Detection possible?

	FeCCSN	ECSN
$\bar{\nu}_e$	✓	×
ν_e	✓	✓

Setting and Neutrino Oscillations

- progenitor at 200 pc (betelgeuse)
- calculate event rates for DUNE, JUNO, and Hyper-K
- using the adiabatic limit for oscillations:

Survival Probabilities

	normal	inverted
ν_e	$\nu_{x,0}$	$\sin^2\theta_{12}\ \bar{\nu}_{e,0} + \cos^2\theta_{12}\ \nu_{x,0}$
$\bar{\nu}_e$	$\cos^2\theta_{12}\ \bar{\nu}_{e,0} + \sin^2\theta_{12}\ \nu_{x,0}$	$\bar{\nu}_{e,0}$

- $\cos^2\theta_{12} = 0.692$
- θ_{13} terms don't appear because $\cos^2\theta_{13} \approx 1$ and $\sin^2\theta_{13} \approx 0$

SNOwGLoBES Results for DUNE

→ approximately 191 events for normal ordering until 0.1s before the collapse.

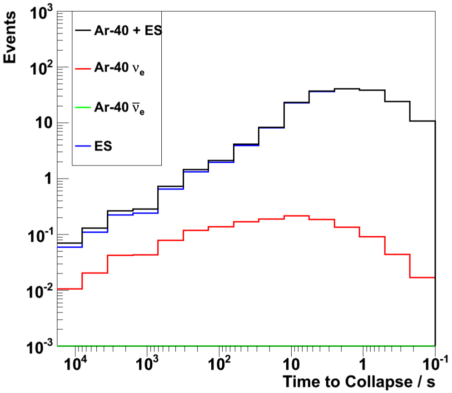


Figure 2: Estimated neutrino events in DUNE integrated over energy.

SNOwGLoBES Results for DUNE

→ approximately 879 events for inverted ordering until 0.1s before the collapse.

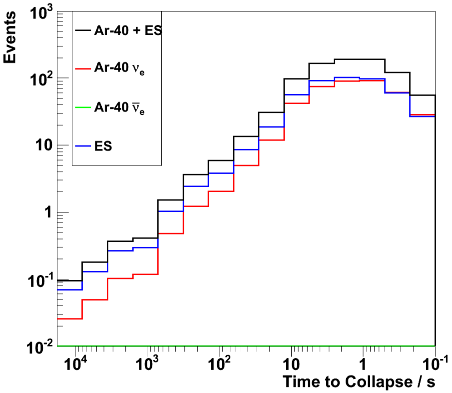


Figure 3: Estimated neutrino events in DUNE integrated over energy.

SNOwGLoBES Results for JUNO

→ approximately 486 events for normal ordering until 0.1s before the collapse.

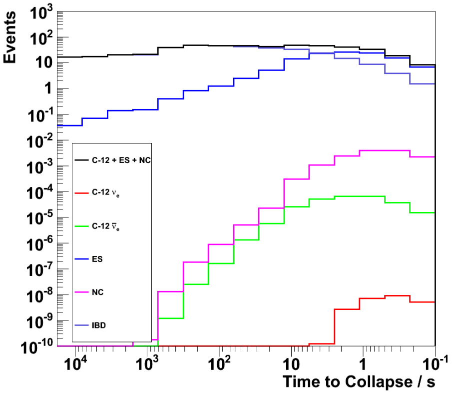


Figure 4: Estimated neutrino events in JUNO integrated over energy.

SNOwGLoBES Results for JUNO

→ approximately 355 events for inverted ordering until 0.1s before the collapse.

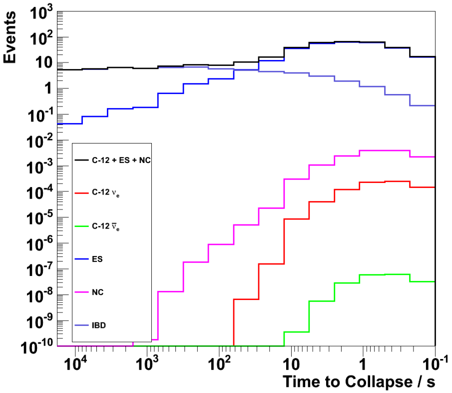


Figure 5: Estimated neutrino events in JUNO integrated over energy.

SNOwGLoBES Results for Hyper-K

→ approximately 2005 events for normal ordering until 0.1s before the collapse.

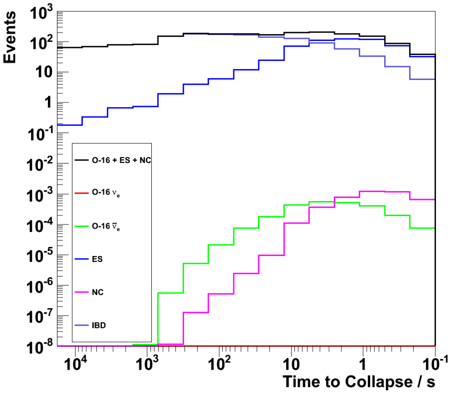


Figure 6: Estimated neutrino events in Hyper-K integrated over energy.

SNOwGLoBES Results for Hyper-K

→ approximately 1664 events for inverted ordering until 0.1s before the collapse.

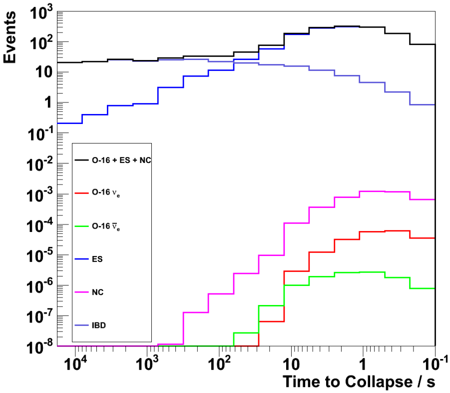


Figure 7: Estimated neutrino events in Hyper-K integrated over energy.

Adding Backgrounds

- assuming constant background rates from 1 Hz to 100 kHz
- The residual is $S = T - B$, with
  - B the background rate integrated over a time bin
  - T the sum of the background rates and the neutrino event rates integrated over a time bin
- propagation of uncertaincies: $\Delta S = \sqrt{2B + S}$
- calculating significance bin by bin: $\frac{S}{\Delta S}$
- also looked at the impact of detector sided thresholds

Backgrounds in DUNE (normal ordering, no threshold)

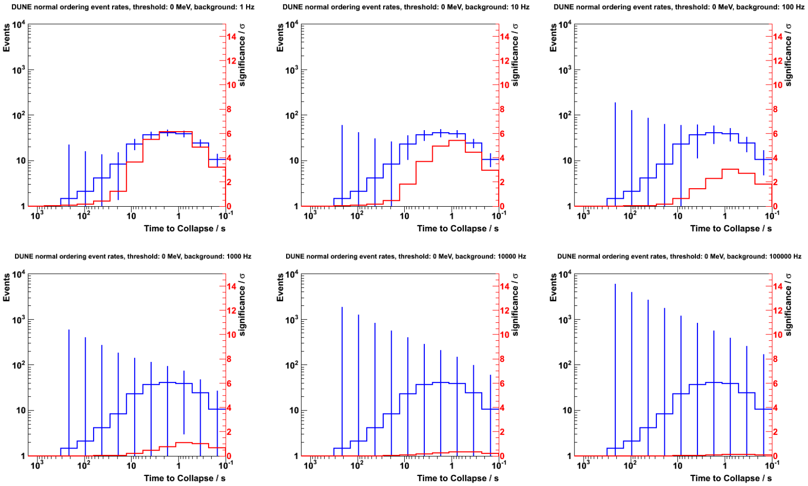


Figure 8: Events and according significance in DUNE for normal ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in DUNE (normal ordering, 4 MeV threshold)

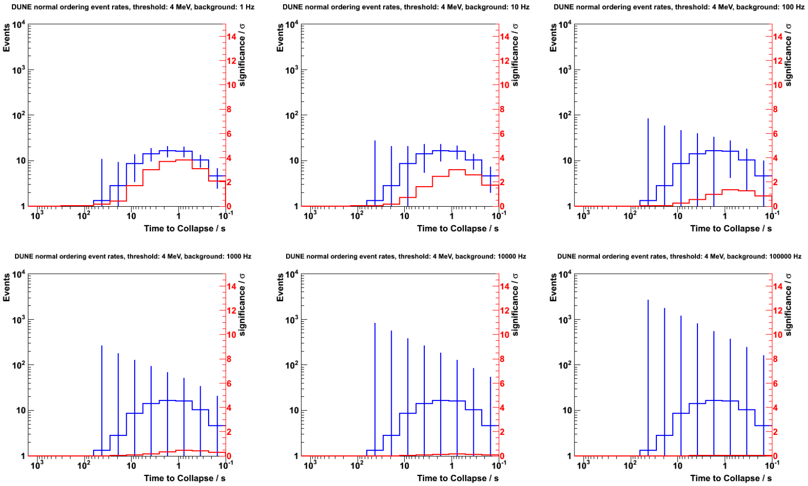


Figure 9: Events and according significance in DUNE for normal ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in DUNE (inverted ordering, no threshold)

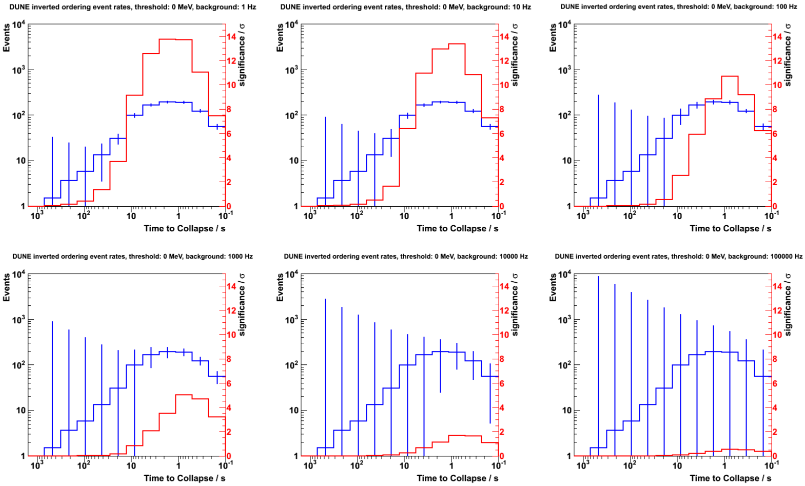


Figure 10: Events and according significance in DUNE for inverted ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in DUNE (inverted ordering, 4 MeV threshold)

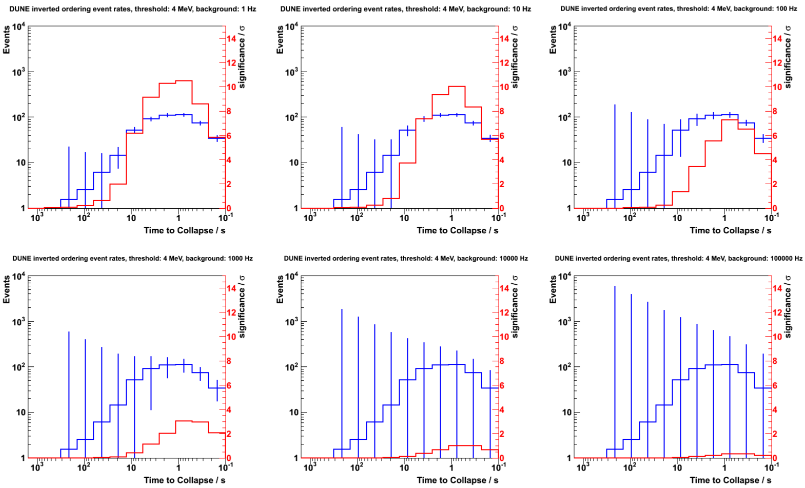


Figure 11: Events and according significance in DUNE for inverted ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in JUNO (normal ordering, no threshold)

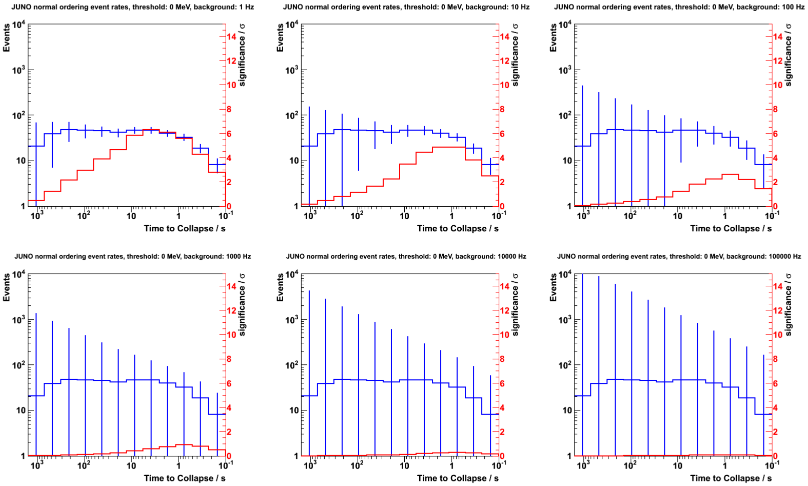


Figure 12: Events and according significance in JUNO for normal ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in JUNO (normal ordering, 4 MeV threshold)

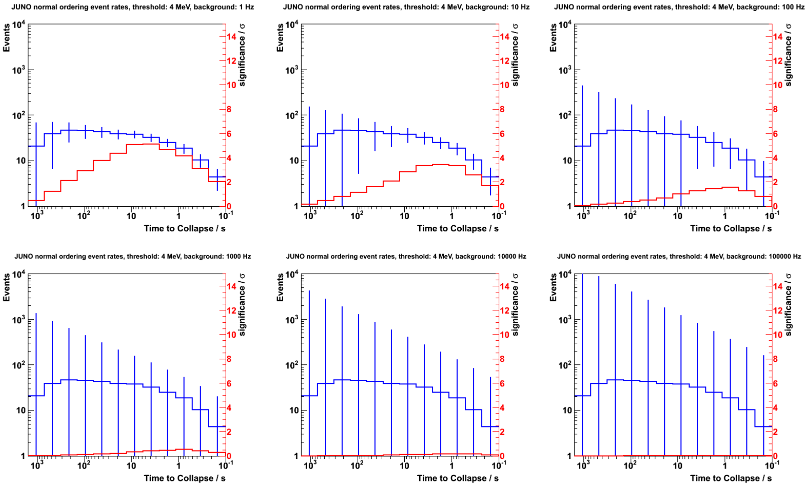


Figure 13: Events and according significance in JUNO for normal ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in JUNO (inverted ordering, no threshold)

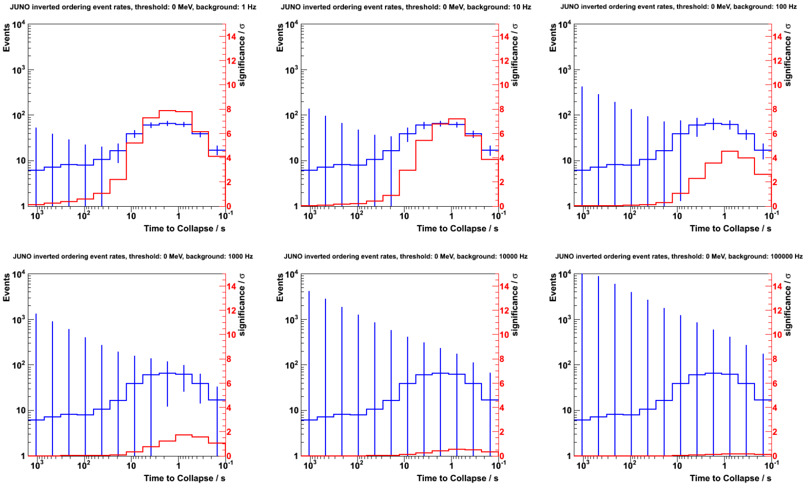


Figure 14: Events and according significance in JUNO for inverted ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in JUNO (inverted ordering, 4 MeV threshold)

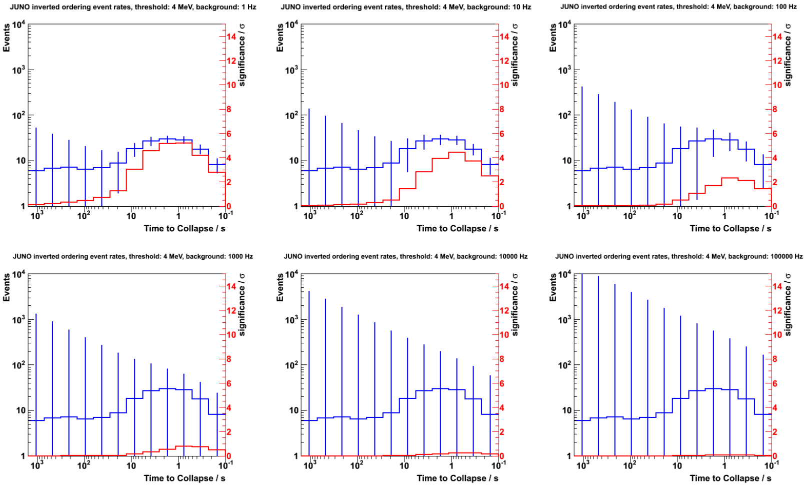


Figure 15: Events and according significance in JUNO for inverted ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in Hyper-K (normal ordering, no threshold)

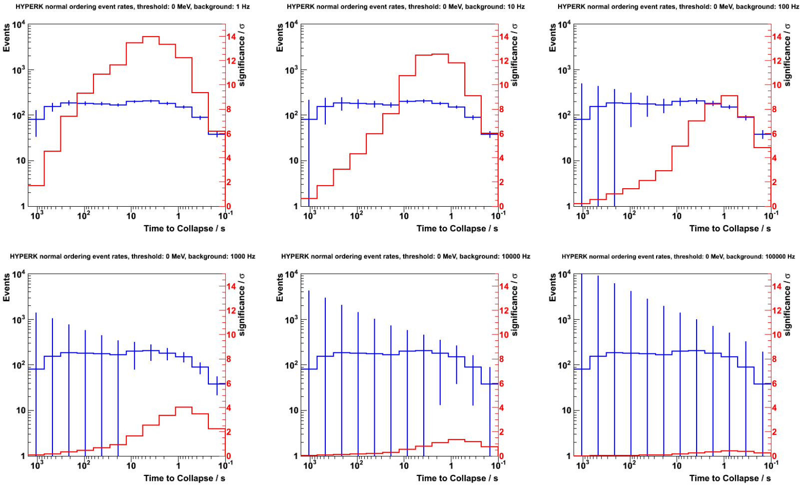


Figure 16: Events and according significance in Hyper-K for normal ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in Hyper-K (normal ordering, 4 MeV threshold)

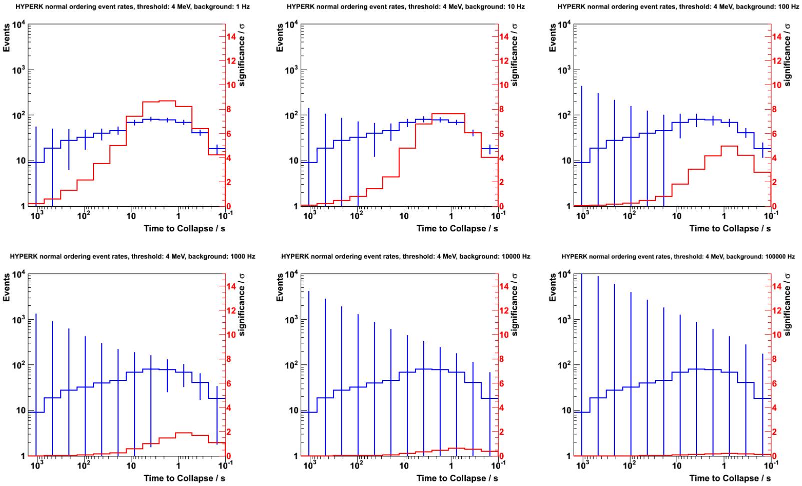


Figure 17: Events and according significance in Hyper-K for normal ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in Hyper-K (inverted ordering, no threshold)

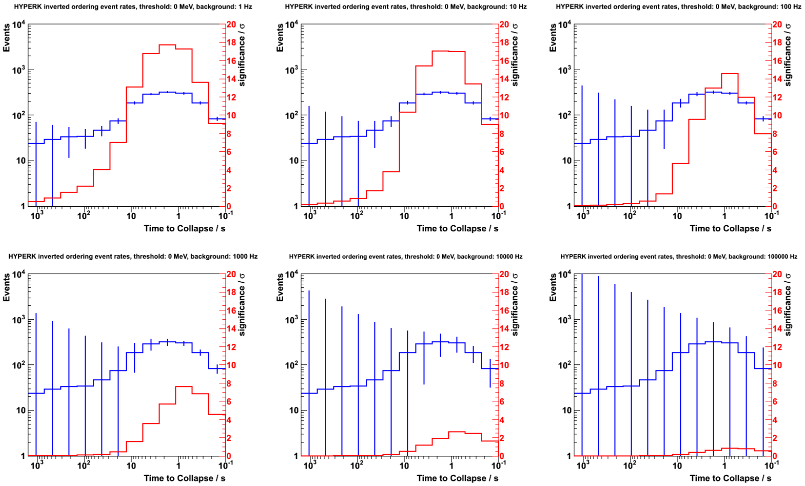


Figure 18: Events and according significance in Hyper-K for inverted ordering, no threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Backgrounds in Hyper-K (inverted ordering, 4 MeV threshold)

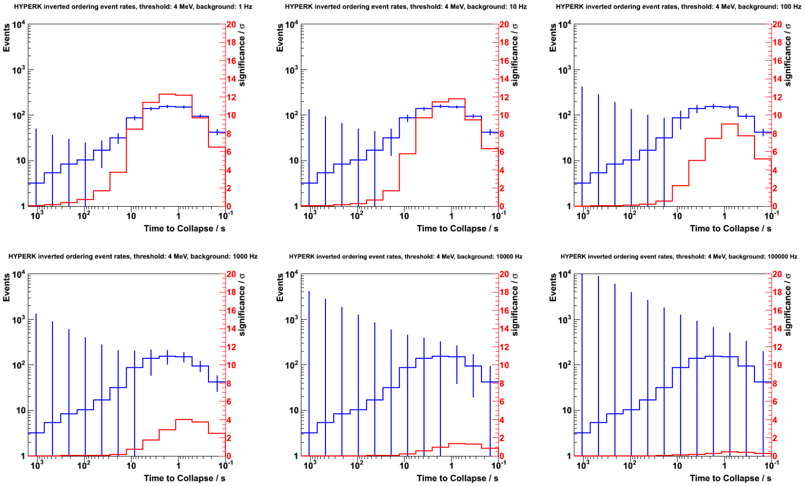


Figure 19: Events and according significance in Hyper-K for inverted ordering, 4 MeV threshold, and different backgrounds at a distance of 200 pc to the progenitor.

Results of the Background and Threshold Analysis

- time window for significant events: 1 s up to 10 s
  - $\longrightarrow$ reasonable time buffer size $\leq 10\,\mathrm{s}$
  - $\longrightarrow$ early warning system for supernova quite optimistic in this scope
  - $\longrightarrow$ distinguishing the state of the burning phase probably not possible in this scope
- thresholds don't affect the significance to much
  - $\longrightarrow$ could be a useful tool to reduce backgrounds
- prospect: using more advanced statistical methods leads to better early warning
  - $\longrightarrow$ take knowledge from simulations about increasing neutrino fluxes into account

Considering Different Distances for DUNE (normal ordering, no threshold)

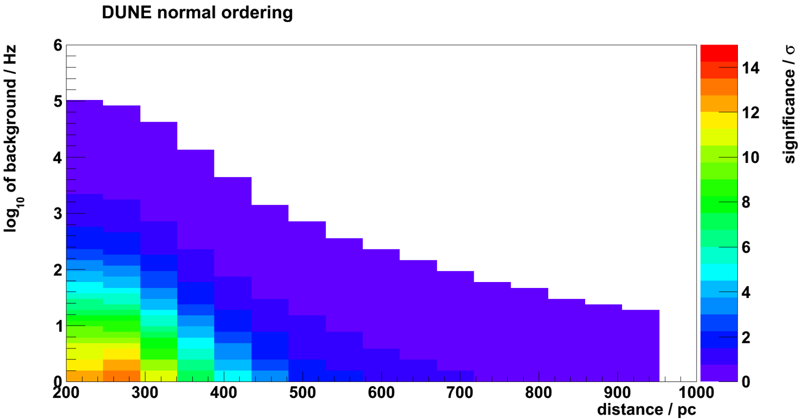


Figure 20: Significance of pre-supernova neutrino events in DUNE for normal ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Considering Different Distances for DUNE (inverted ordering, no threshold)

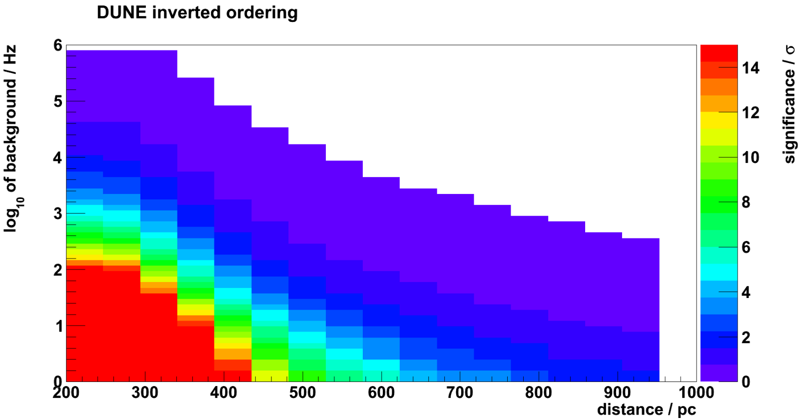


Figure 21: Significance of pre-supernova neutrino events in DUNE for inverted ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Considering Different Distances for JUNO (normal ordering, no threshold)

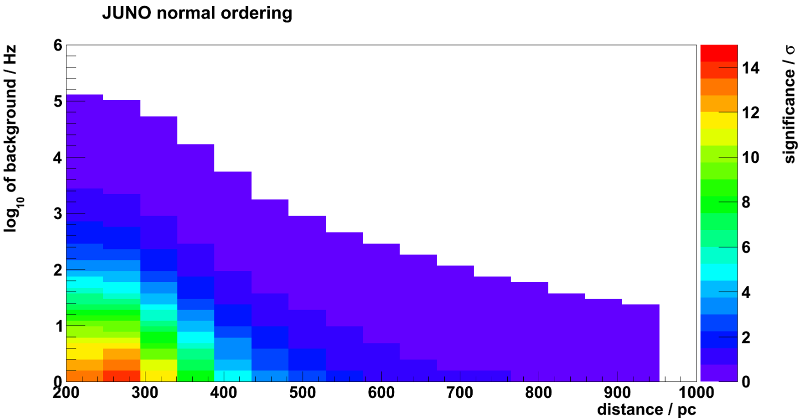


Figure 22: Significance of pre-supernova neutrino events in JUNO for normal ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Considering Different Distances for JUNO (inverted ordering, no threshold)

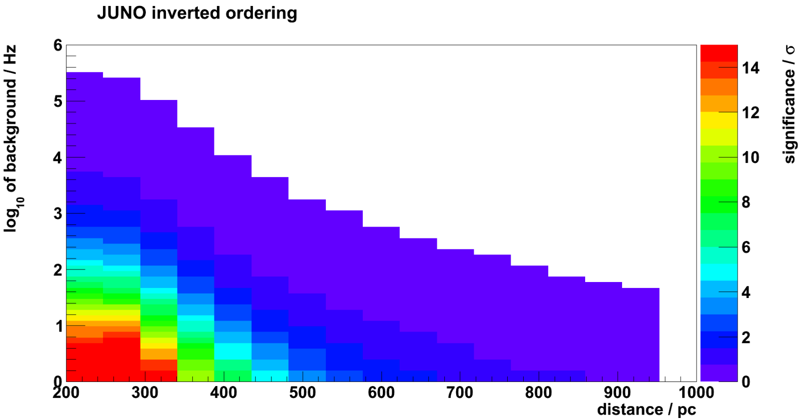


Figure 23: Significance of pre-supernova neutrino events in JUNO for inverted ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Considering Different Distances for Hyper-K (normal ordering, no threshold)

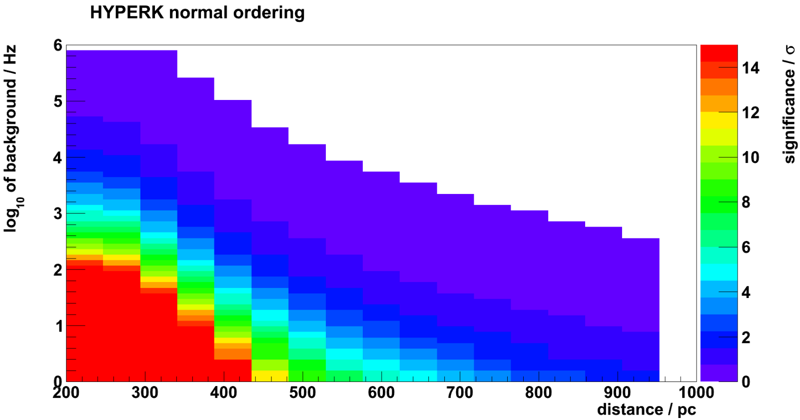


Figure 24: Significance of pre-supernova neutrino events in Hyper-K for normal ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Considering Different Distances for Hyper-K (inverted ordering, no threshold)

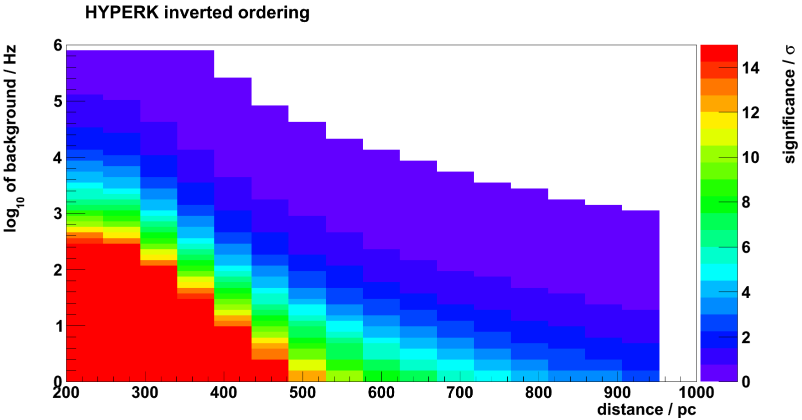


Figure 25: Significance of pre-supernova neutrino events in Hyper-K for inverted ordering and no detector-sided threshold. Event rates and backgrounds have been integrated over the last 10 s before the collapse.

Results of the Distances Analysis

- Distances $> 200\,\mathrm{pc}$ reduce the significance drastically
- Low Backgrounds need to be achieved in order to measure pre-supernova neutrinos from stars further away than Betelgeuse ($\approx 220\,\mathrm{pc}$)

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Neutrino emission in all flavors up to the pre-bounce of massive stars and the possibility of their detections.
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