Presupernova neutrinos: Shape analysis and combination

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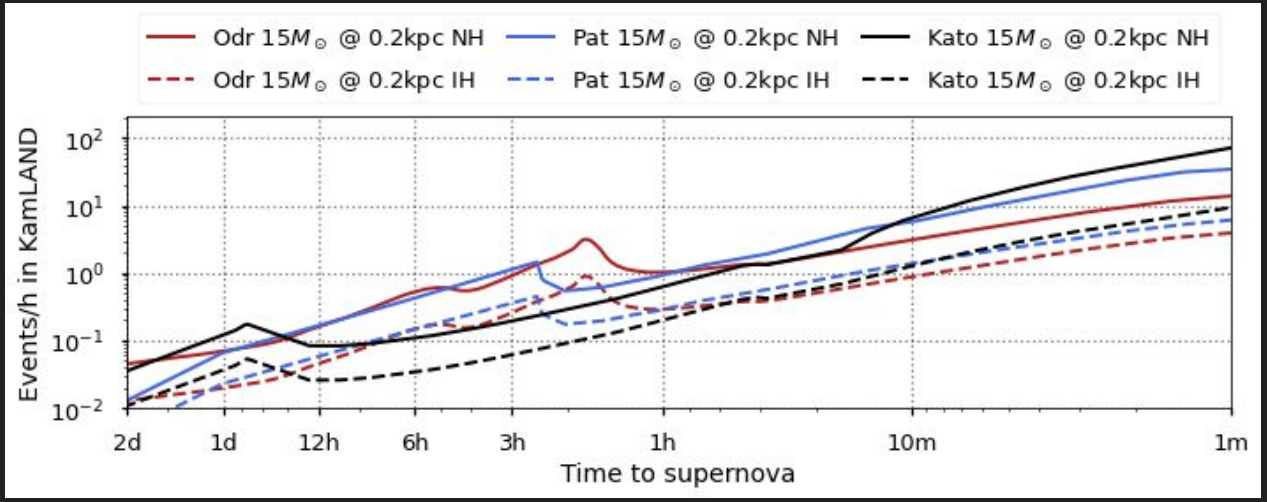
SNEWS2021 collaboration meeting
Presupernova

12 May 2021

Motivation

Presupernova signal is weak and gradually increasing vs time.



Enhancing the detection significance (i.e. difference from the background) of such signal allows :

- **Larger** SN detection distance
- **Earlier** alert time

Shape analysis: significance calculation using the knowledge of the (expected) signal shape vs. time

Combination: using information from several experiments

Input

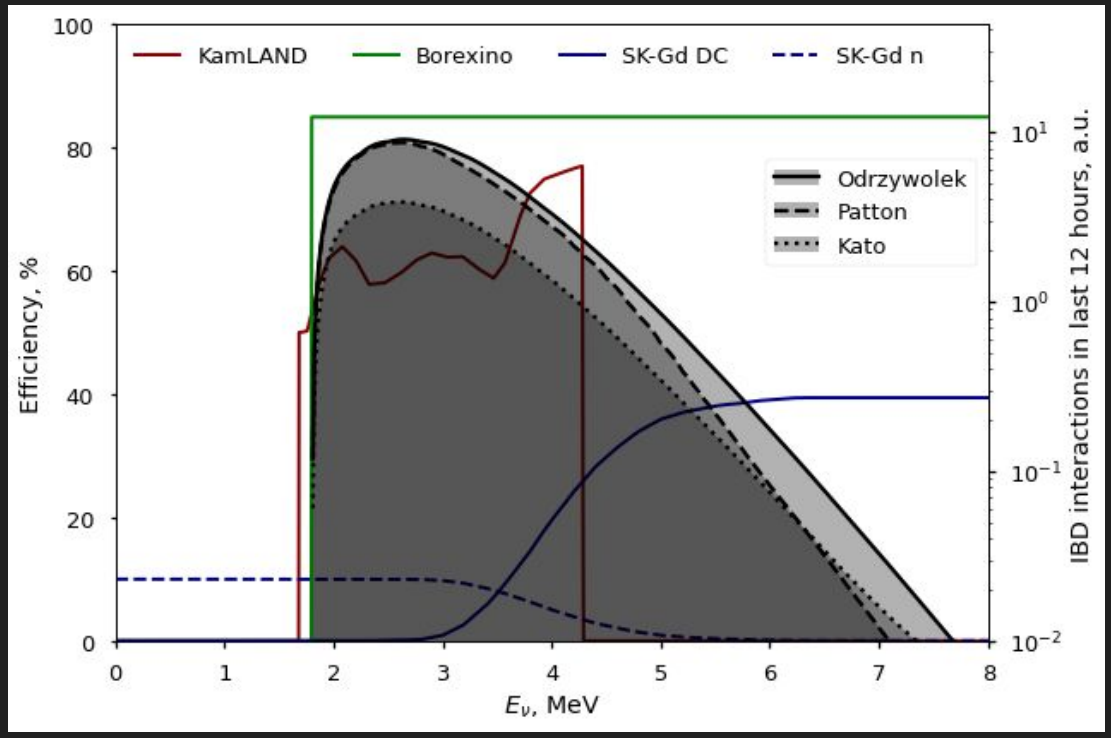
Three models for 15M_{sun} presupernova:

- Odrzywolek
- Patton et al.
- Kato et al.

Four analyses with comparable sensitivity to preSN:

- KamLAND
- Borexino
- SK-Gd positron+neutron DC
- SK-Gd neutron capture only (positron lost)

Only IBD channel (Strumia-Vissani)



Detector	N_{sg} in last hour before SN @200pc Kato15	Odr15	Pat15	N_{bg}/hour	Counting window
Borexino	3.95 (0.705)	1.15 (0.327)	2.11 (0.5)	0.0014	48 hours
KamLAND	7.13 (1.19)	2.4 (0.681)	4.39 (1.0)	0.0029	48 hours
SK-Gd DC	86.6 (17.5)	15.7 (4.45)	29.7 (8.13)	1	12 hours
SK-Gd neutron	42.5 (7.05)	14.8 (4.21)	26.8 (6.09)	5.5	12 hours

Counting analysis vs. shape analysis

Analysis: calculate the significance of observing SN on top of the expected background

Counting Analysis:

neutrino interactions in a given time window:

$$N = N_{sg} + N_{bg}$$

- Follows Poisson distribution
- Easy and fast calculation
- Model-independent
- Works bad in high background
- Time precision limited by the time window

Shape Analysis:

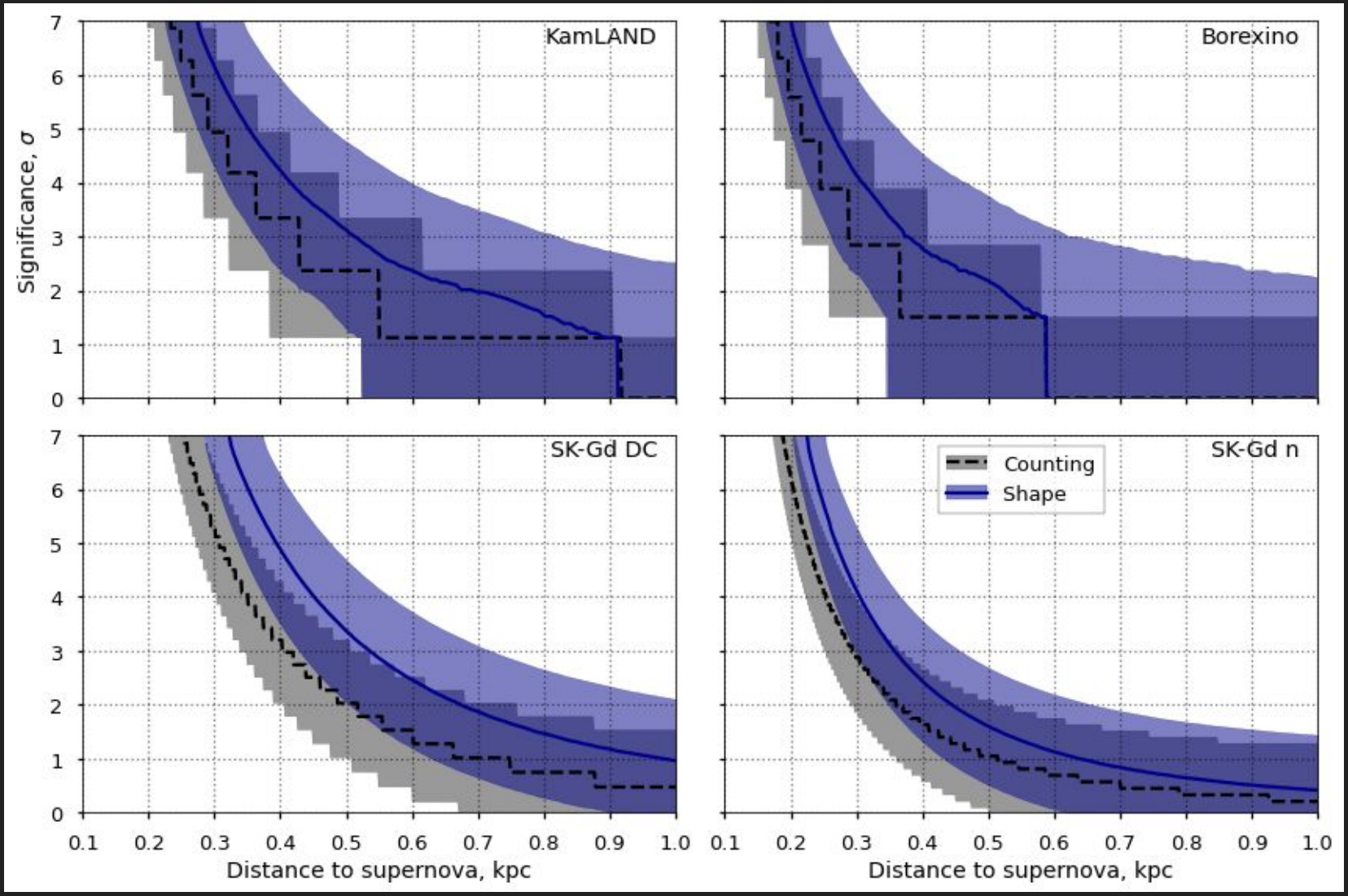
use log likelihood ratio

$$L = log(1+S(t)/B(t)),$$

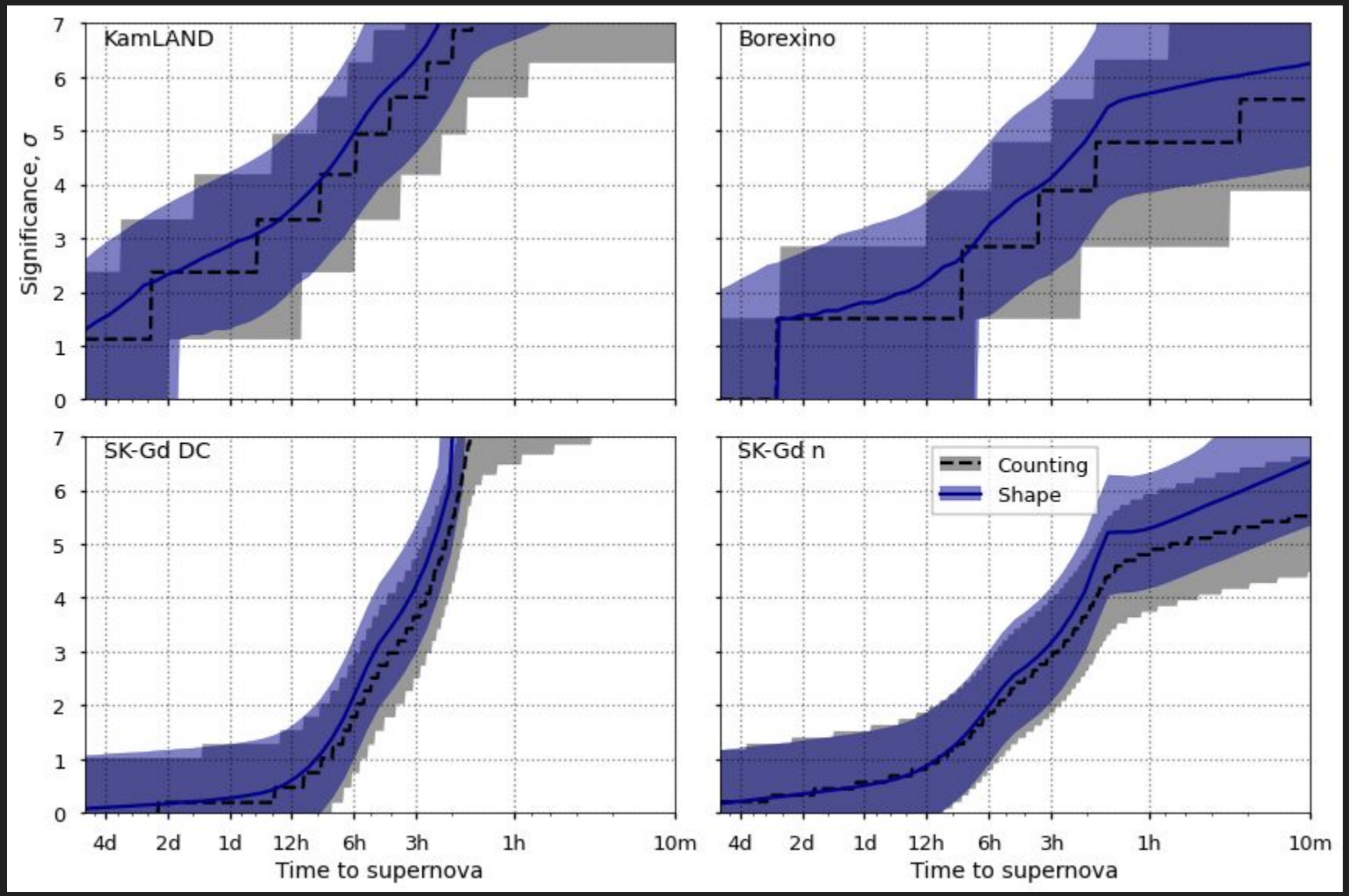
S and B - expected sg and bg rates.

- Complicated distribution calculation
- Limited precision (no analitical solution)
- Depends on the expected signal model
- Enhanced significance in high background
- Significance peak around SN start

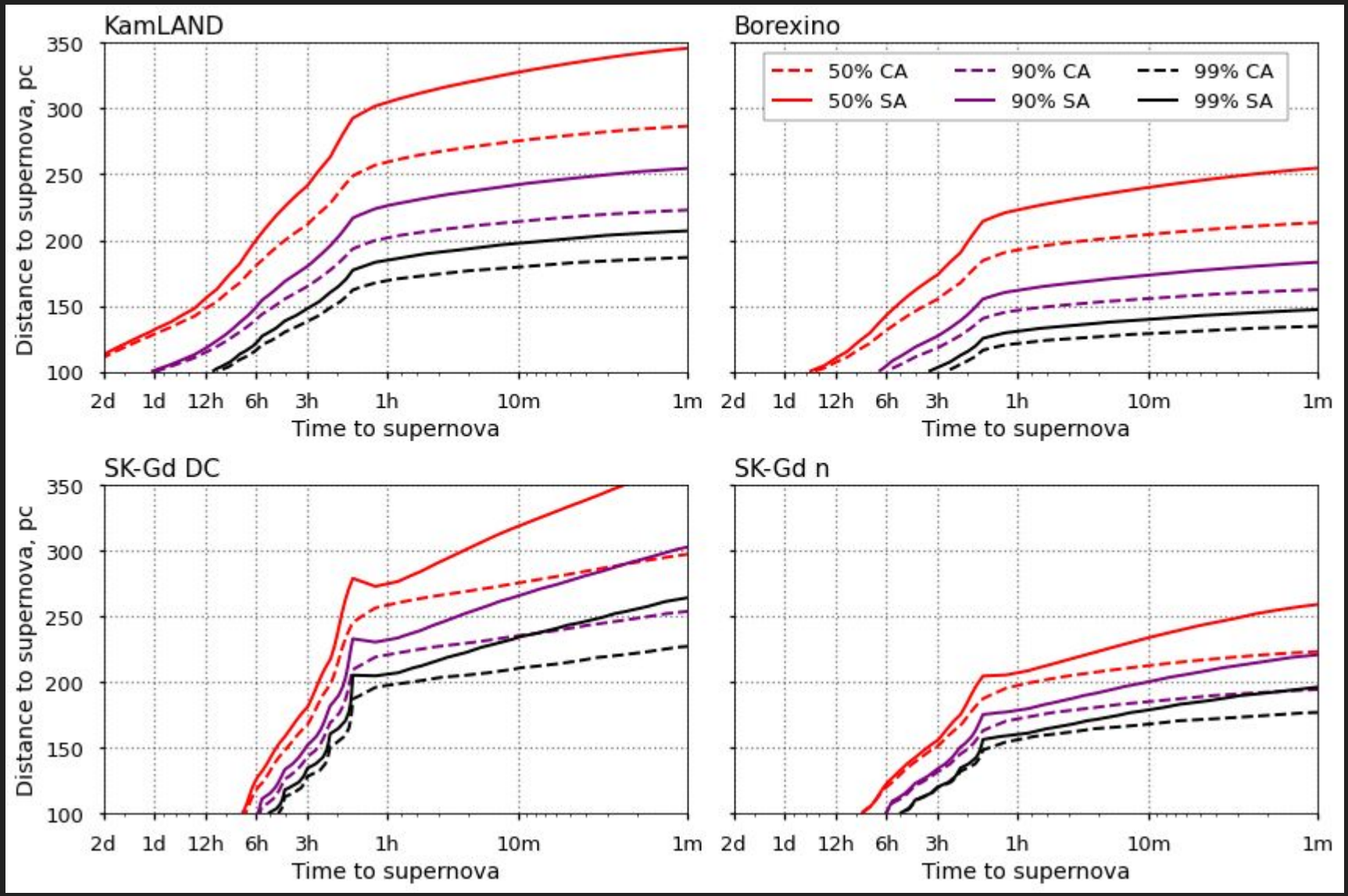
CA vs SA for Odr15 vs. distance



CA vs SA for Odr15@200pc vs time



CA vs SA for detection at z=5 sigma

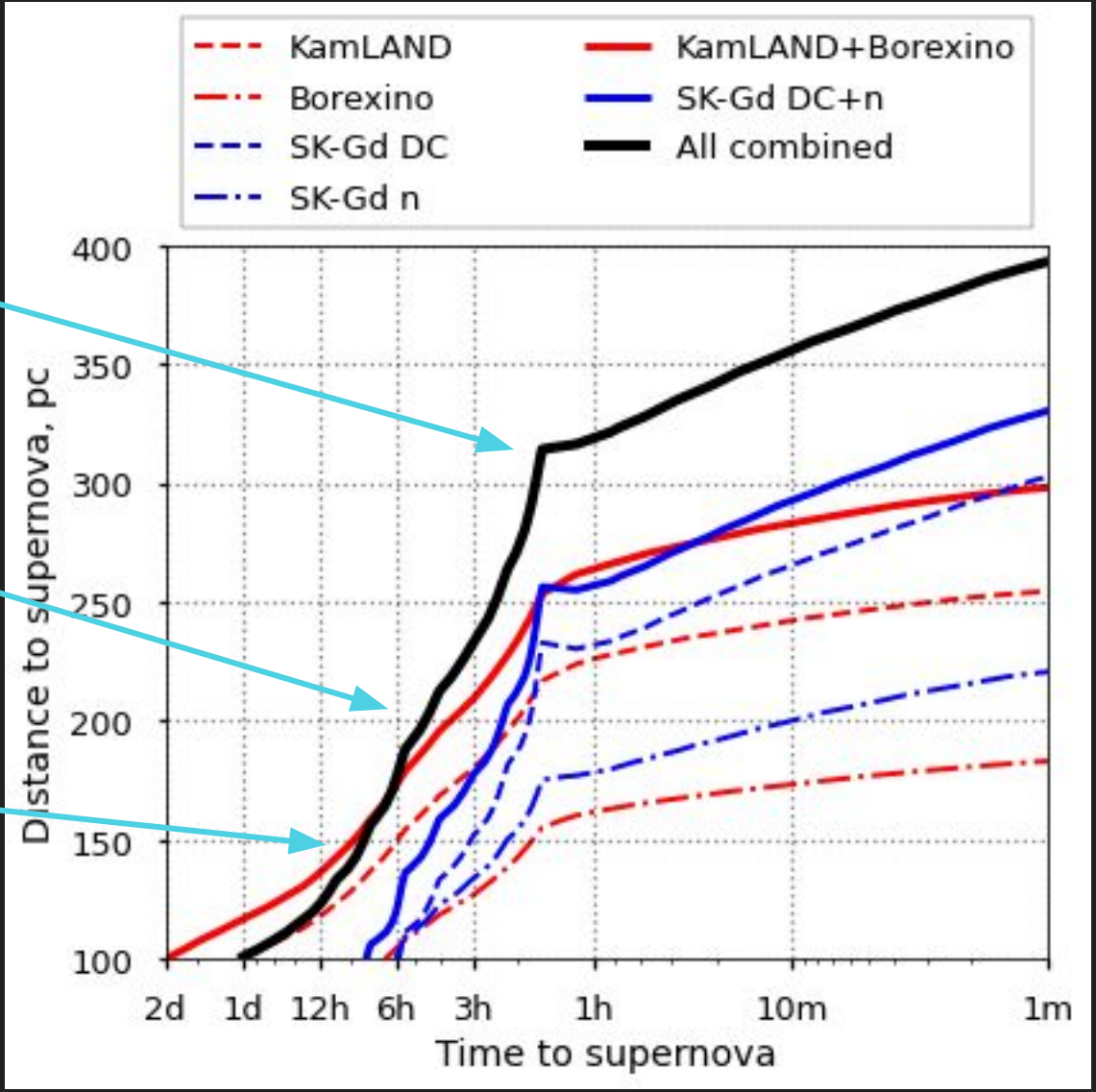


Combination (90% detection efficiency at z=5 sigma)

Dist increase @1h:
230pc (Sk-Gd DC)
270pc (SK or KL+Bx)
330pc (all)

Time increase @200pc:
2h (KamLAND) vs
4h (KamLAND+Borexino) vs
5h (all)

Less certain on early times:
tuned for full preSN signal,
and here is only starting part



Summary

- Considered methods enhance the presupernova detection significance
- Shape analysis:
  - Better enhancement over counting in case of higher background
  - Model dependent, but works fine if the signal shapes have common features
  - CA is equal to SA with expected flat signal shape vs time - even wrong model is usually better than this.
- Combination:
  - Increases detection time **2h -> 5h** @200pc
  - Increases detection reach by **~100pc**
  - Experiments with weaker sensitivity are important!
- We considered only a subset of experiments for demonstration
  - The same approach works for CCSN neutrinos.
  - And for other interaction channels
  - And for larger future experiments
  - This evaluation can be done in the future after integrating preSN models with SNEWS simulation pipeline
- SA and Combination methods are available as python package: sn_stat
  - Applicable for the real-time analysis