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COMBINED SENSITIVITY OF SK + JUNO ON BLACK HOLE FRACTION

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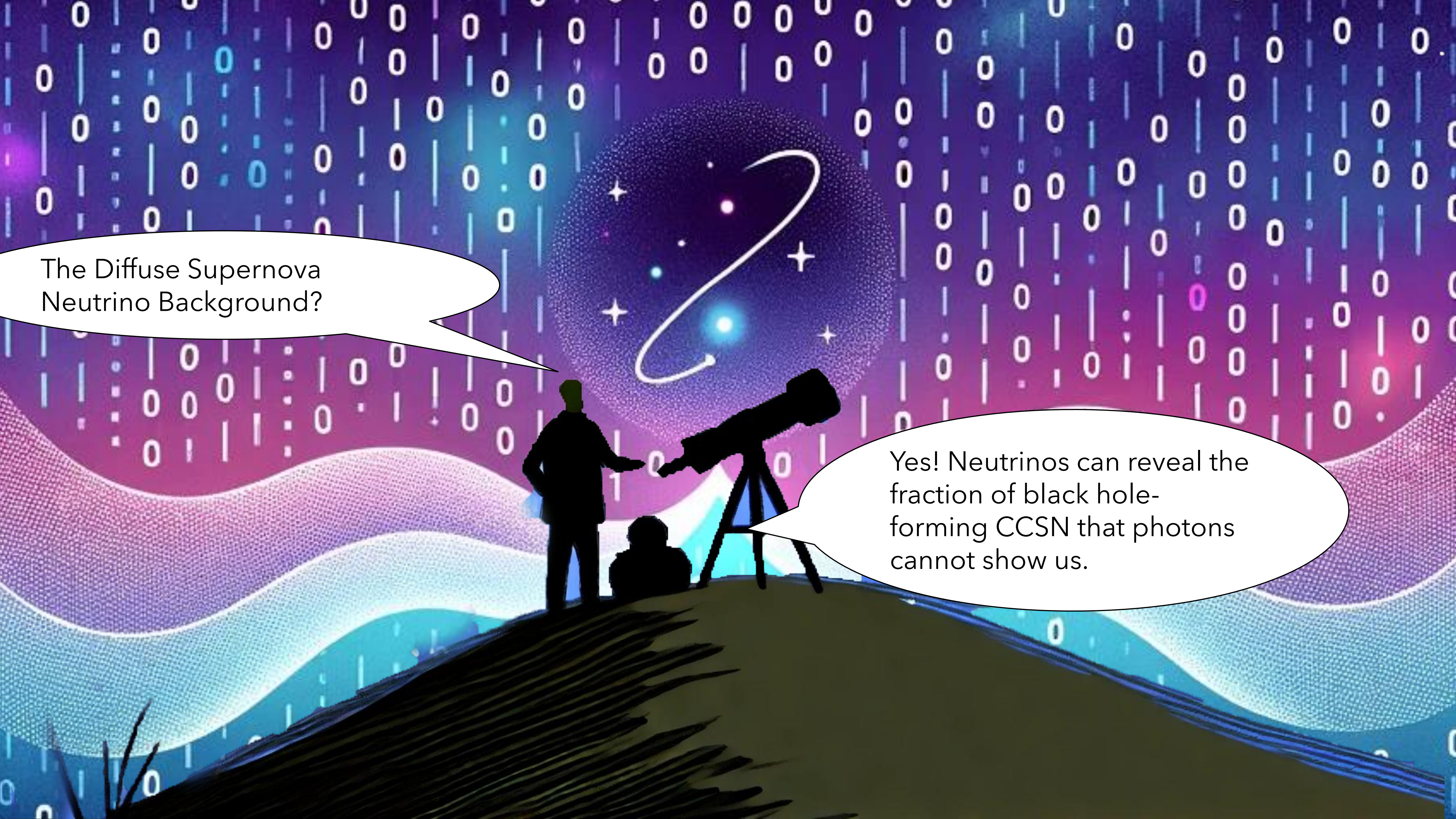
MOTIVATION

Imagine a few years into the future:

We have observed now the DSNB …


We can't detect stars that silently vanish into black holes in distant galaxies. It's like they disappear without a trace !
You mean not relying on light?
Perhaps it's time we use a different cosmic messenger?
Exactly! Let's turn to neutrinos!

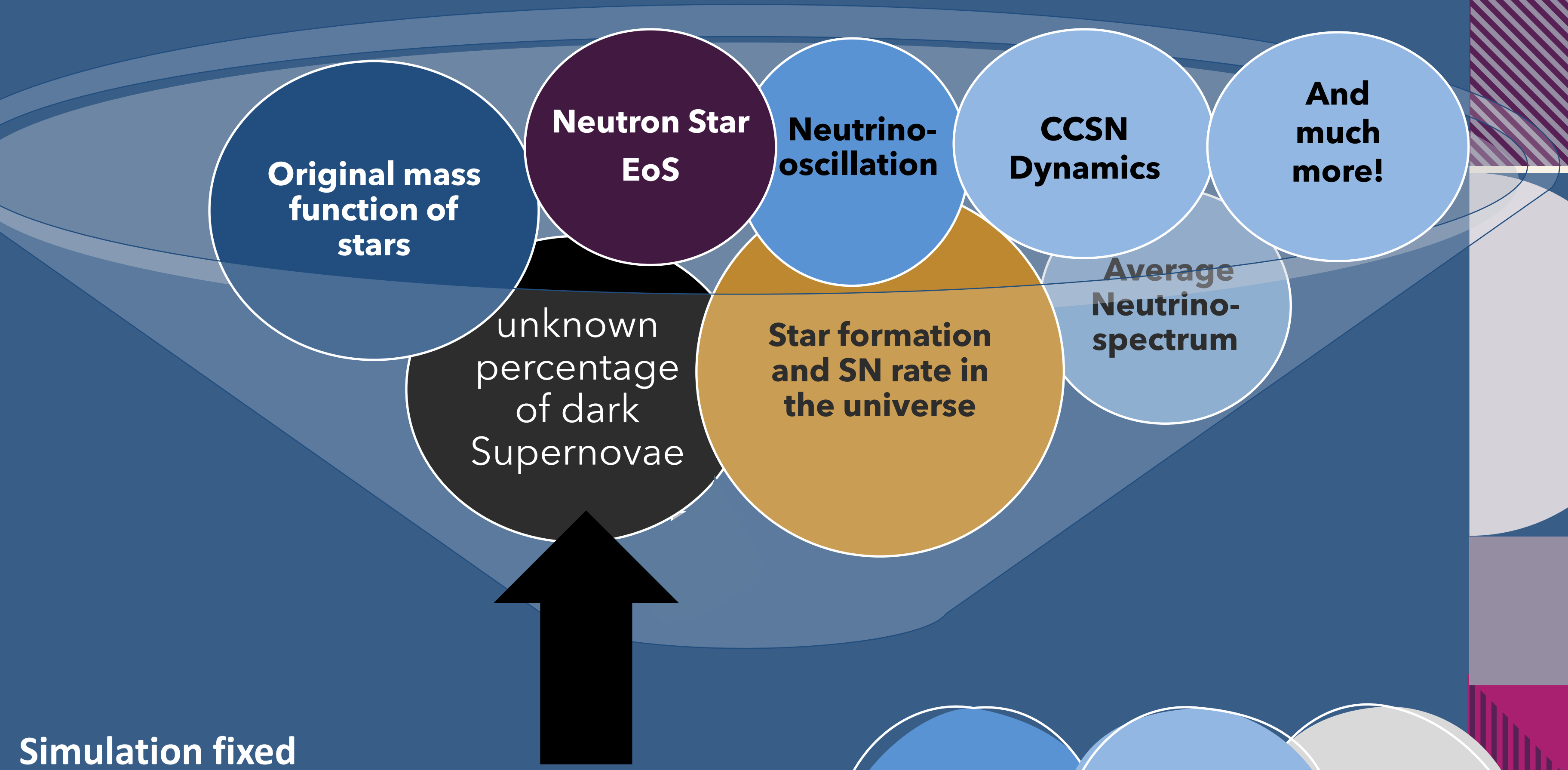

The Diffuse Supernova Neutrino Background?
Yes! Neutrinos can reveal the fraction of black hole-forming CCSN that photons cannot show us.

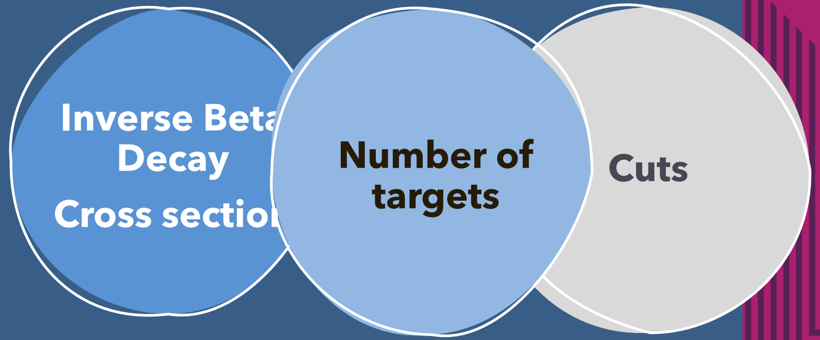

How?

THE EFFECT OF BLACK HOLES ON NEUTRINO ENERGIES

- Accretion heating before black hole formation further increases the neutrino energy.
- Shorter emission timescale means more energetic neutrinos are emitted in a brief period before the emission stops abruptly.
- Higher neutrinospheric temperatures result in higher-energy neutrinos in black hole-forming supernovae.

CALCULATION OF THE DSNB





The uncertainty range is dominated by insufficiently constrained cosmic rate of stellar core-collapse events.

LSST survey at the upcoming Vera Rubin Telescope will allow to better constrain the SN rate as a function of redshift.

GW Telescopes can better constrain the nuclear EoS and therefore the neutron star mass limit.

Simulation fixed parameters:

- Baryonic mass limit of 2.7 M_{sun}
- α_{BH}=2.0

THE INFLUENCE OF A FRACTION ON THE SPECTRA

https://arxiv.org/pdf/2010.04728

- DSNB Spectrum from 200 x1D CCSN simulations done by the Garching Group*

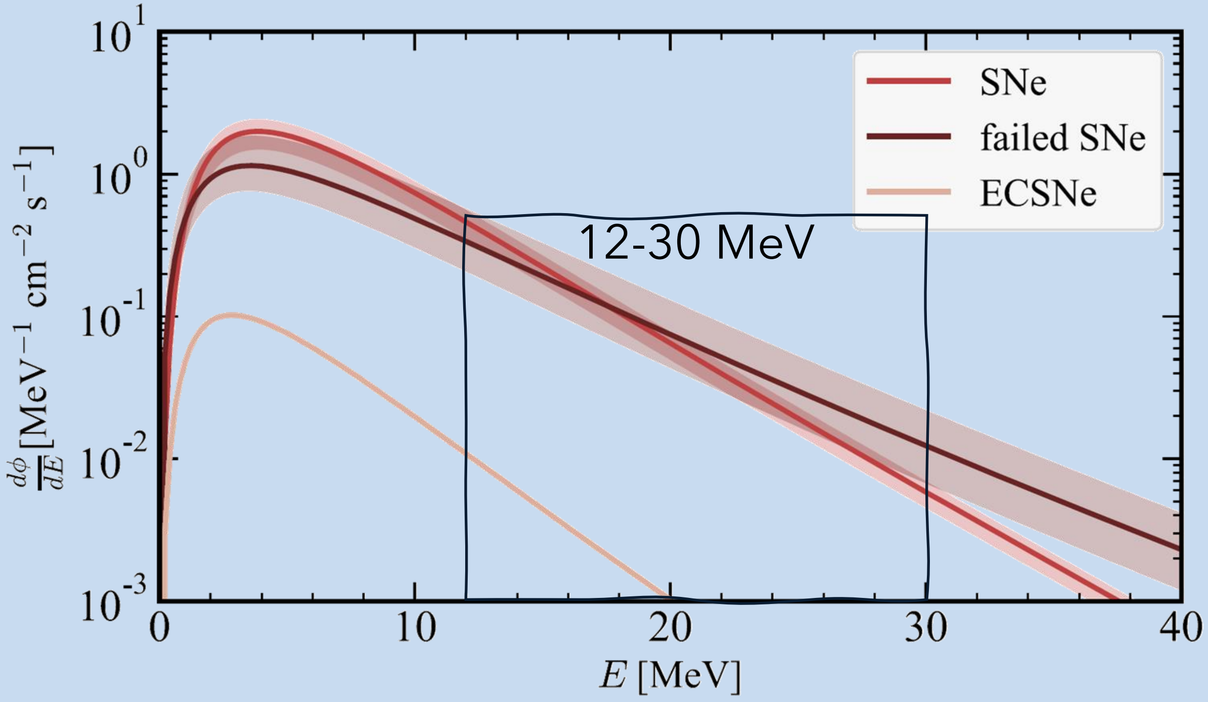
Fractions of Successful and Failed SNe

Engine Model	Successful SNe	Failed SNe
Z9.6 and S19.8	82.2%	17.8%
Z9.6 and N20	77.2%	22.8%
Z9.6 and W18	73.1%	26.9%
Z9.6 and W15	70.9%	29.1%
Z9.6 and W20	58.3%	41.7%

W20 "Upper"

W18 "Fiducial"

S19.8 "Lower"

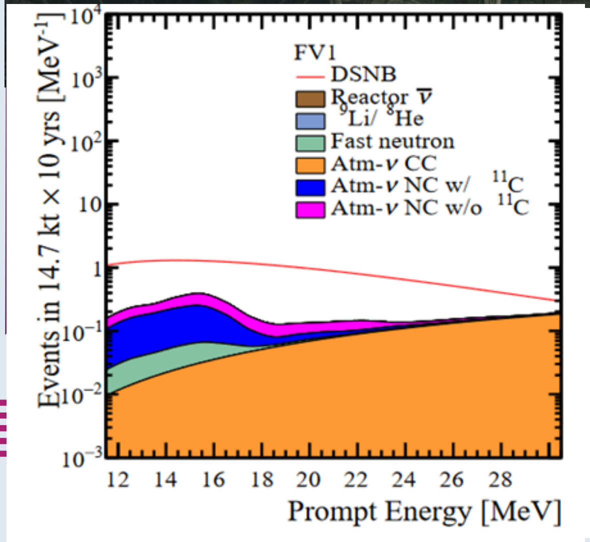


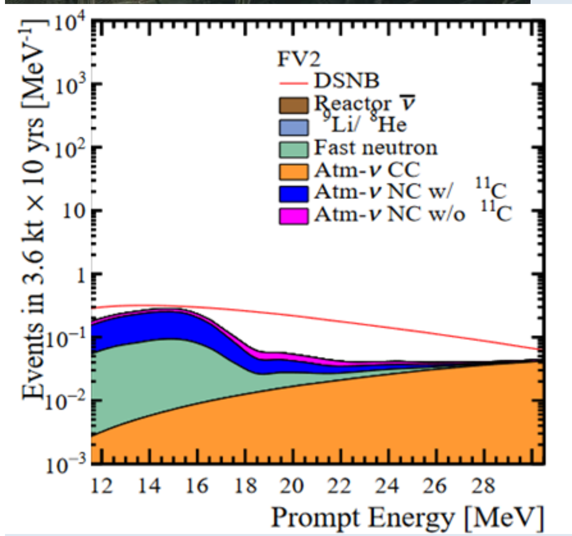
*The DSNB models are available for download upon request on the Garching Core-Collapse Supernova Archive https://wwwmpa.mpa-garching.mpg.de/ccsnarchive/archive.html.

COMBINATION OF FLUX & BACKGROUNDS

BACKGROUNDS IN JUNO AND SK

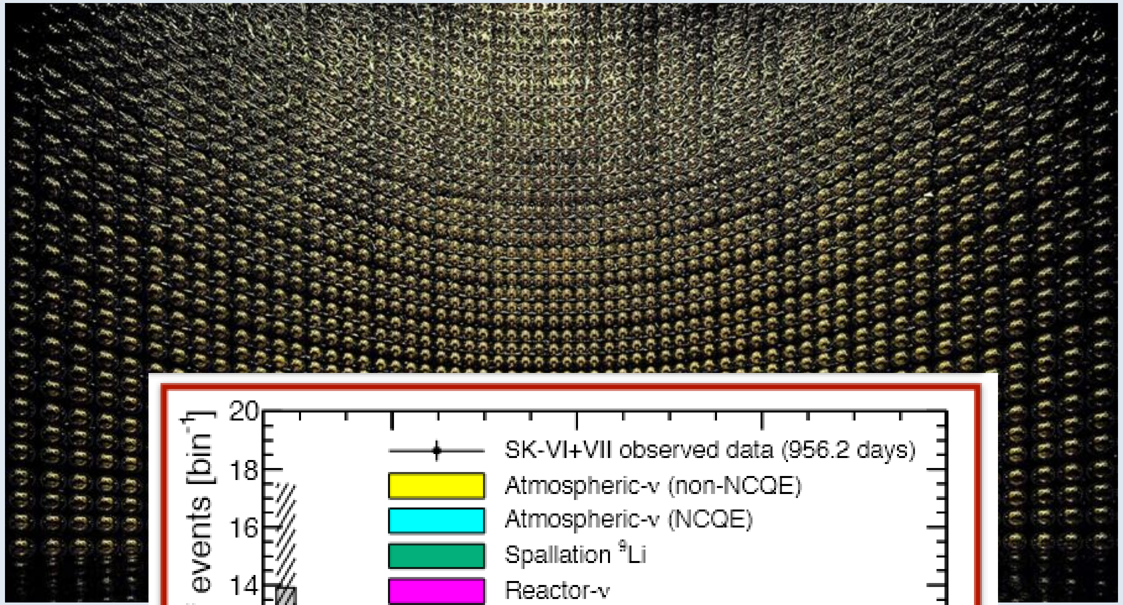
JUNO

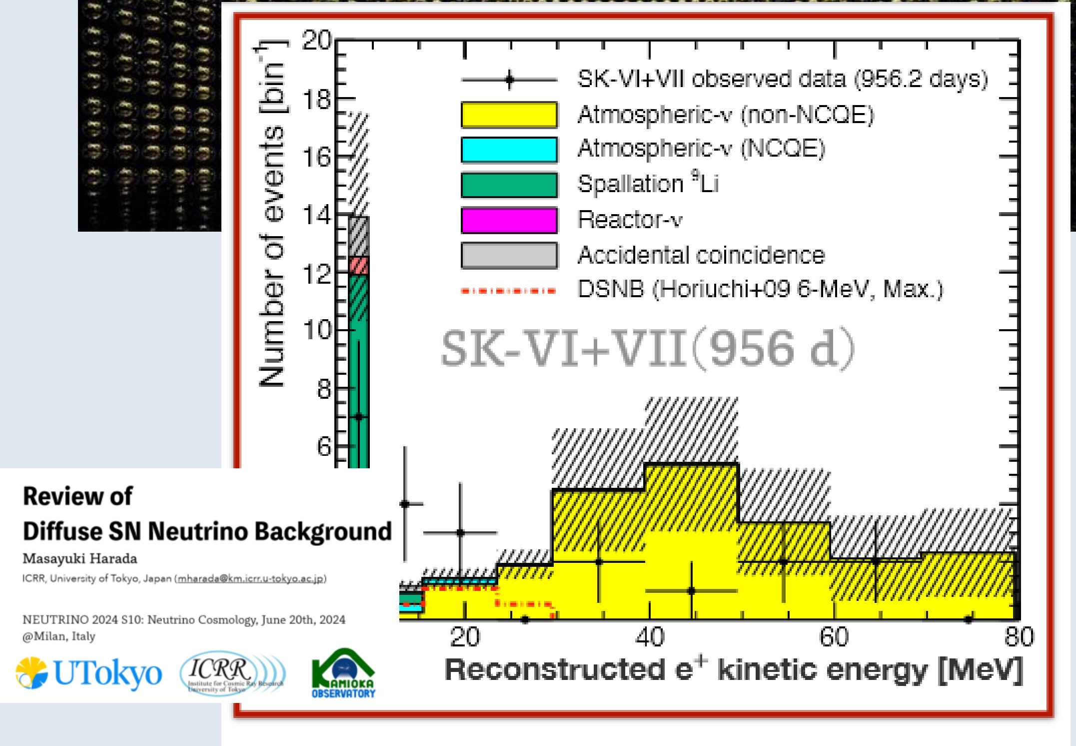




https://arxiv.org/pdf/2205.08830

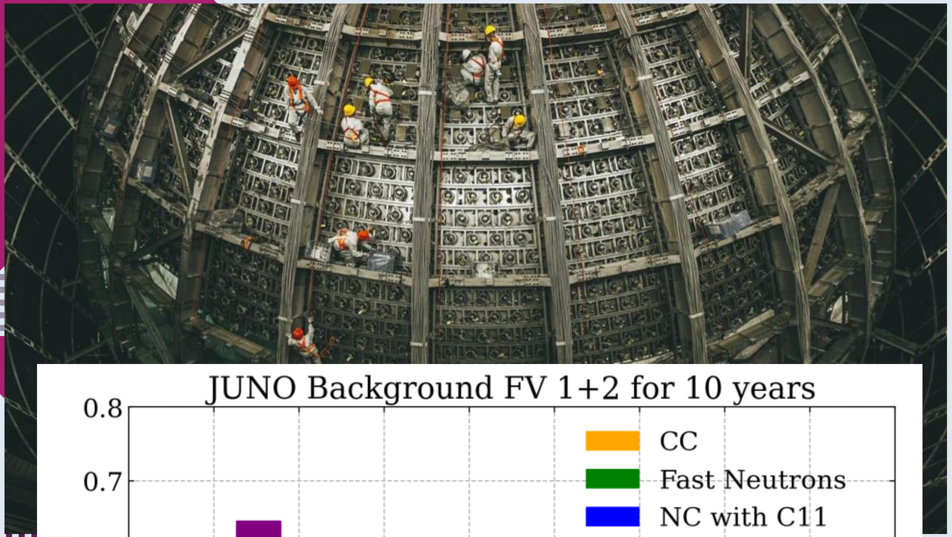
SuperK

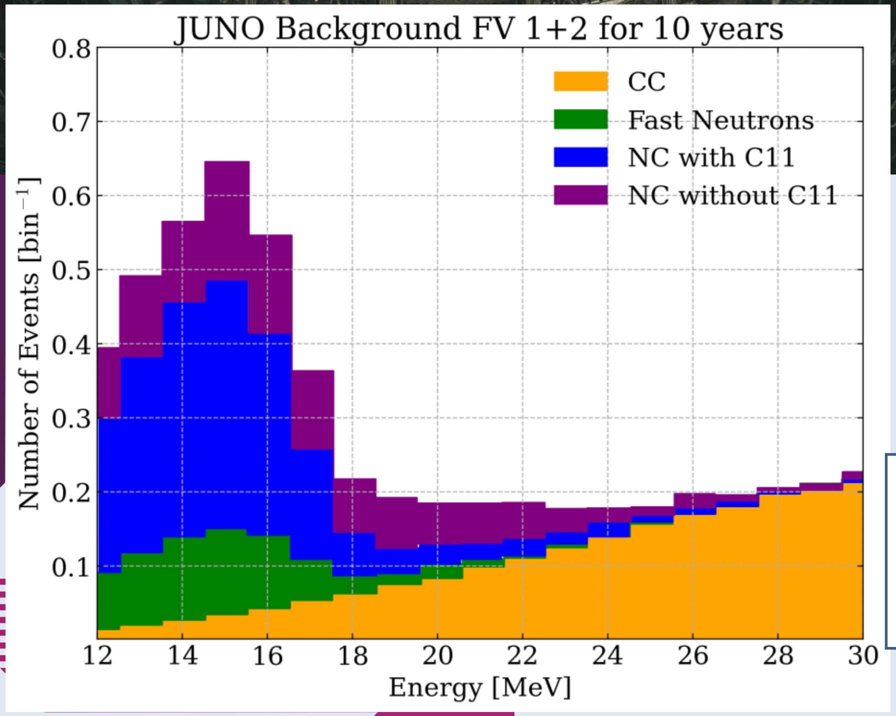




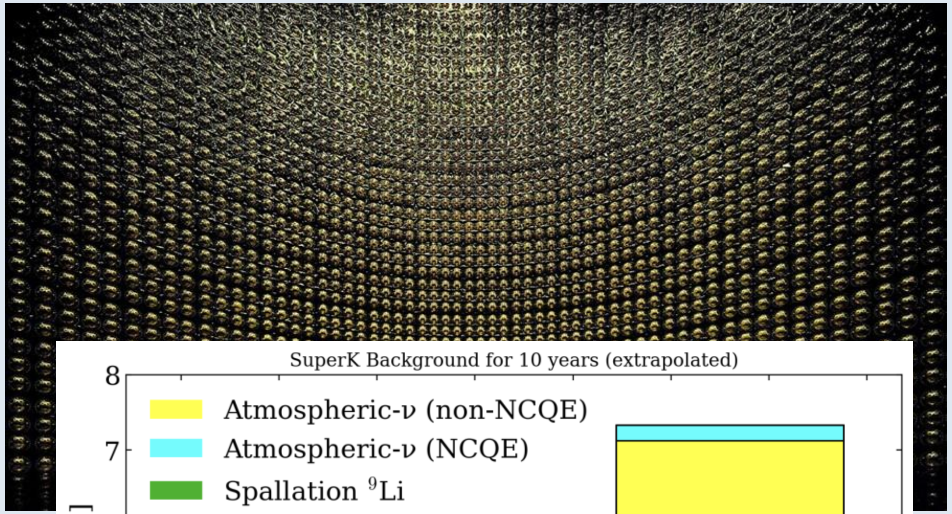
BACKGROUNDS IN JUNO AND SUPERK

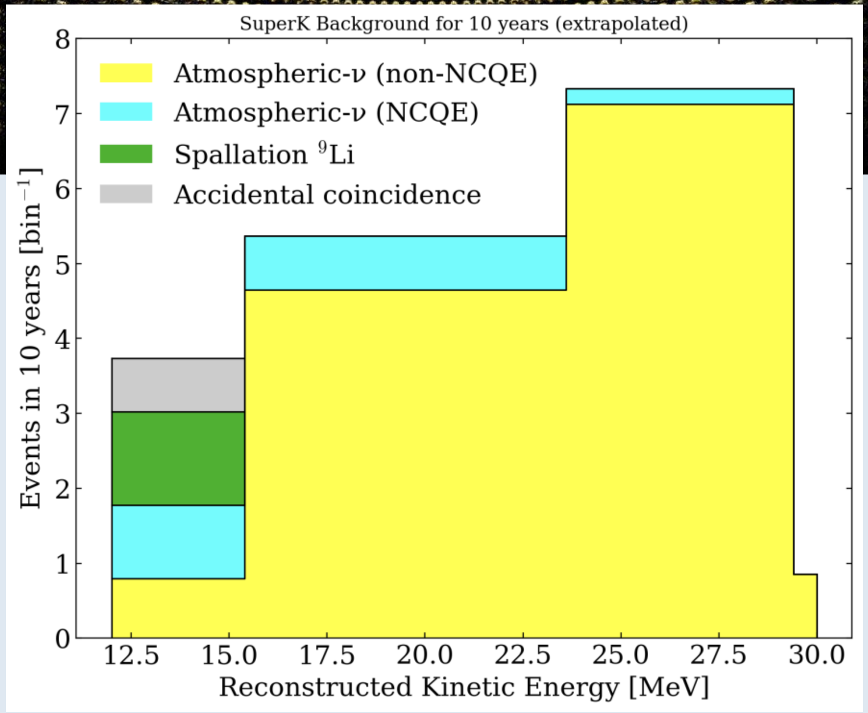
JUNO





SuperK





~5.5 residual BG events

+

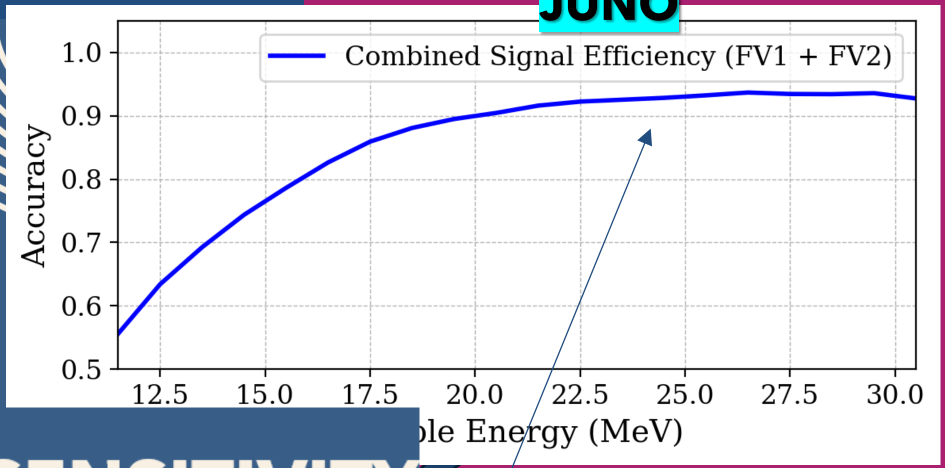
~17.3 residual BG events

DSNB Flux

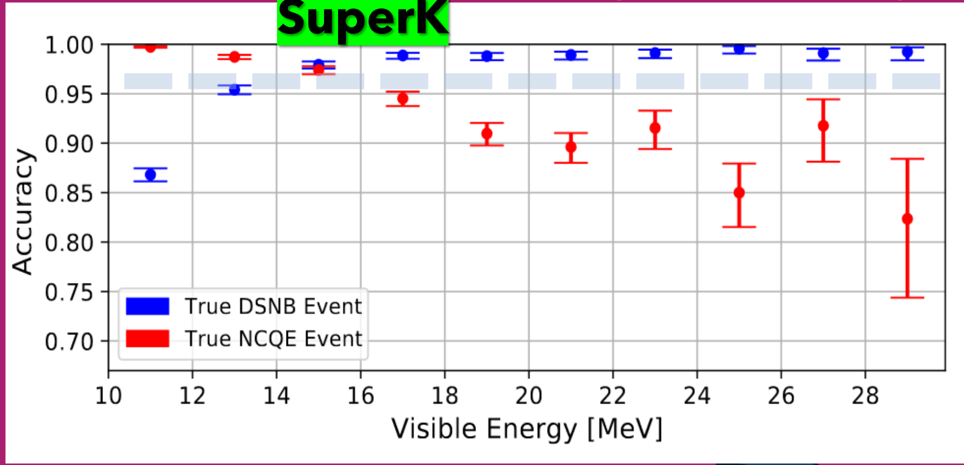
x Machine Learning Signal Efficiency

x Machine Learning Signal Efficiency

JUNO



SuperK



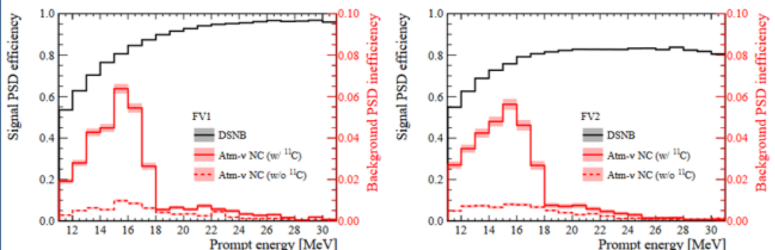
JUNO SIGNAL SENSITIVITY

https://arxiv.org/pdf/2205.08830

Sensitivity

Signal	Rate[147 kt × yr]	muon veto		PSD	TC cut	
12 MeV	16.2		15.2	12.9		12.1
15 MeV	20.8	93.6%	19.4	16.7	93.6%	15.6
18 MeV	25.2		23.6	20.4		19.1
21 MeV	29.0		27.2	23.7		22.1

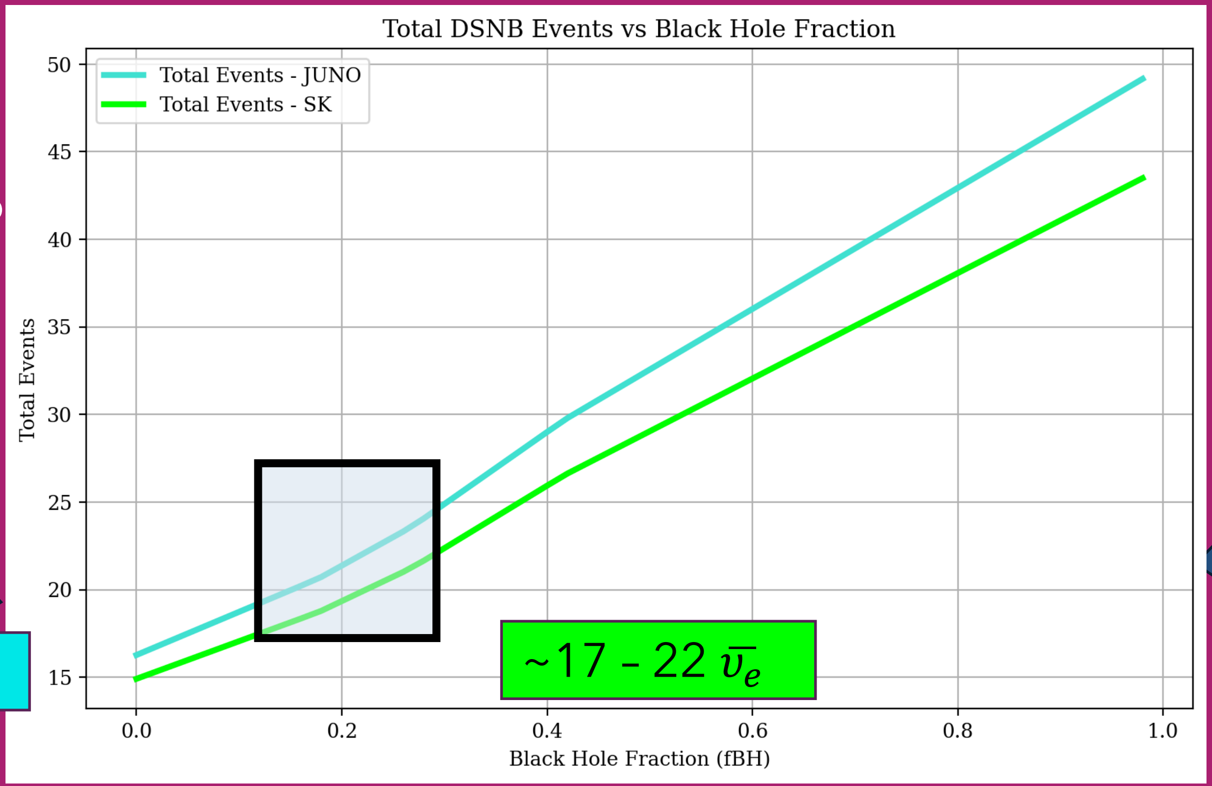
Signal	Rate[36 kt × yr]	muon veto		PSD
12 MeV	3.9		3.6	2.8
15 MeV	5.0	93.6%	4.6	3.6
18 MeV	6.0		5.6	4.4
21 MeV	6.9		6.5	5.1



.936
n veto

.936
C Cut

25 $\overline{\nu}_e$



~17 – 22 $\overline{\nu}_e$

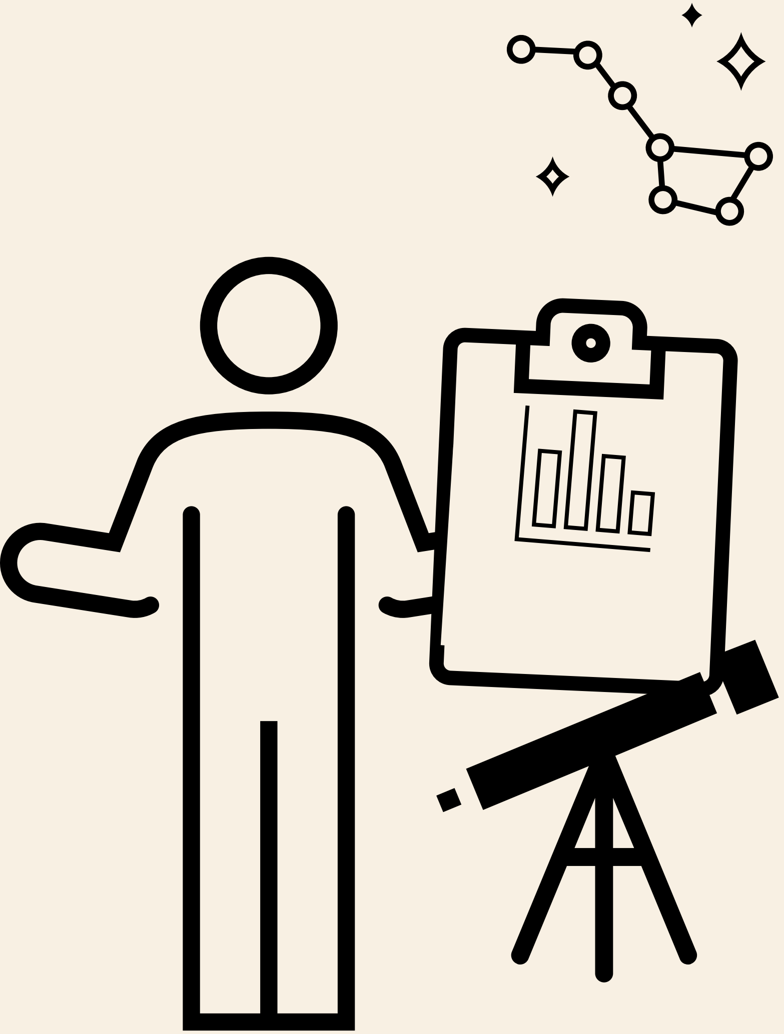
x0.67 Neutron Capture

TWO TESTS

1st Test, the <u>expected</u> events do **not** include BH events.

2nd Test, the <u>expected</u> events include BH events

FIRST TEST

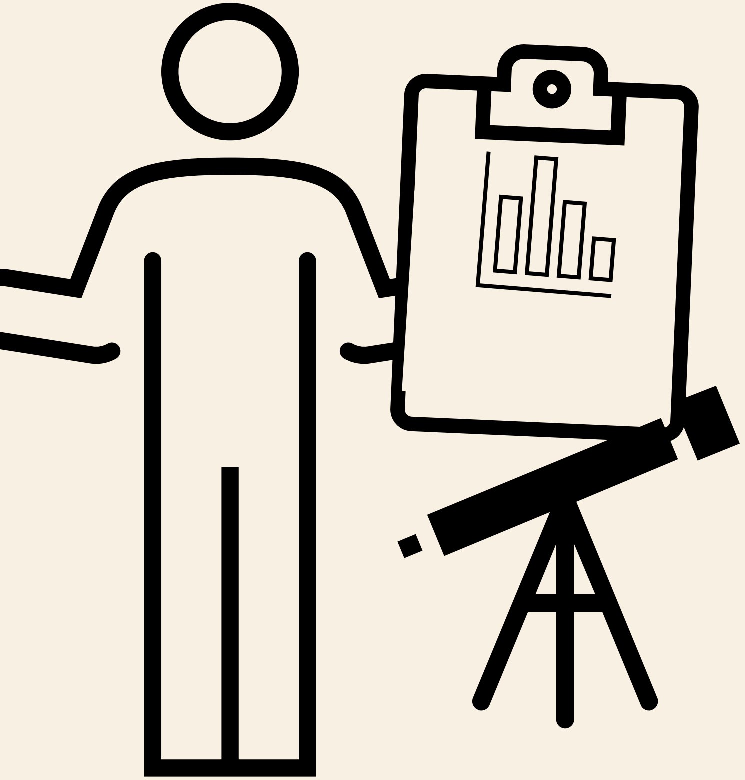


Assumption:

•**Precise Knowledge of Successful CCSN Rate:** We have an accurate measurement of the rate of successful core-collapse supernovae (CCSN) that form neutron stars, obtained through astronomical observations.

•**Testing for Failed CCSN Contribution:** This known rate allows us to investigate whether the measured Diffuse Supernova Neutrino Background (DSNB) includes an additional contribution from failed CCSN that result in black holes.

FIRST TEST METHODOLOGY:



Data/Input:

Successful Supernovae (NS)
Failed Supernovae (BH)
Background Events (BKG): Include background neutrino events relevant to the experiment (e.g., JUNO and SuperK).

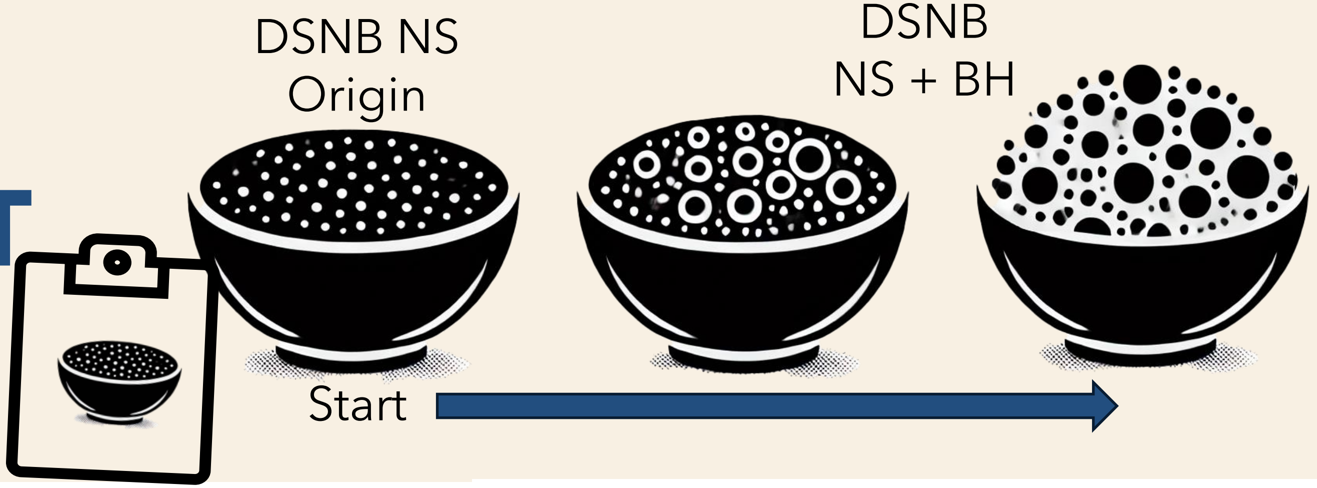
Statistical Analysis:

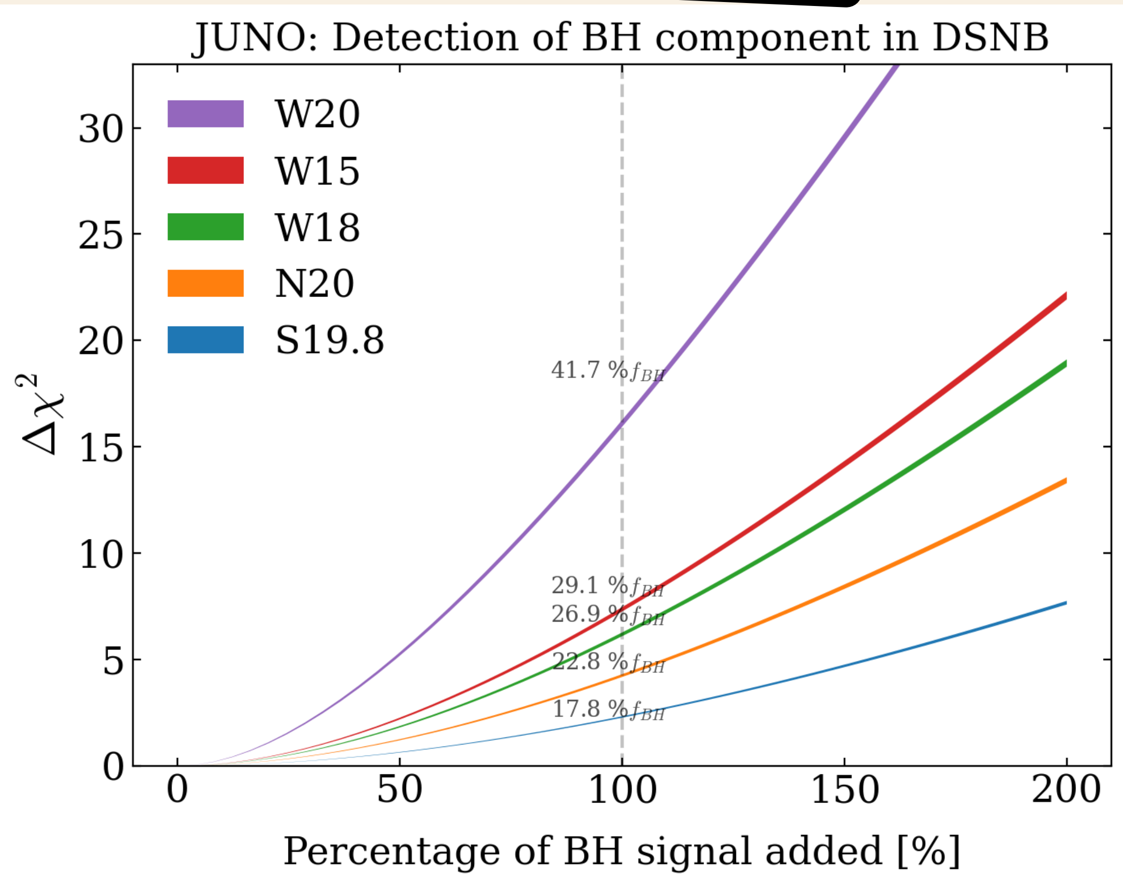
1. For each model, we add a variable fraction [0-200%] of BH events
2. For each fraction, we compare the
- **Expected events:** NS events+ background
- **Observed events:** NS events + scaled BH events + background

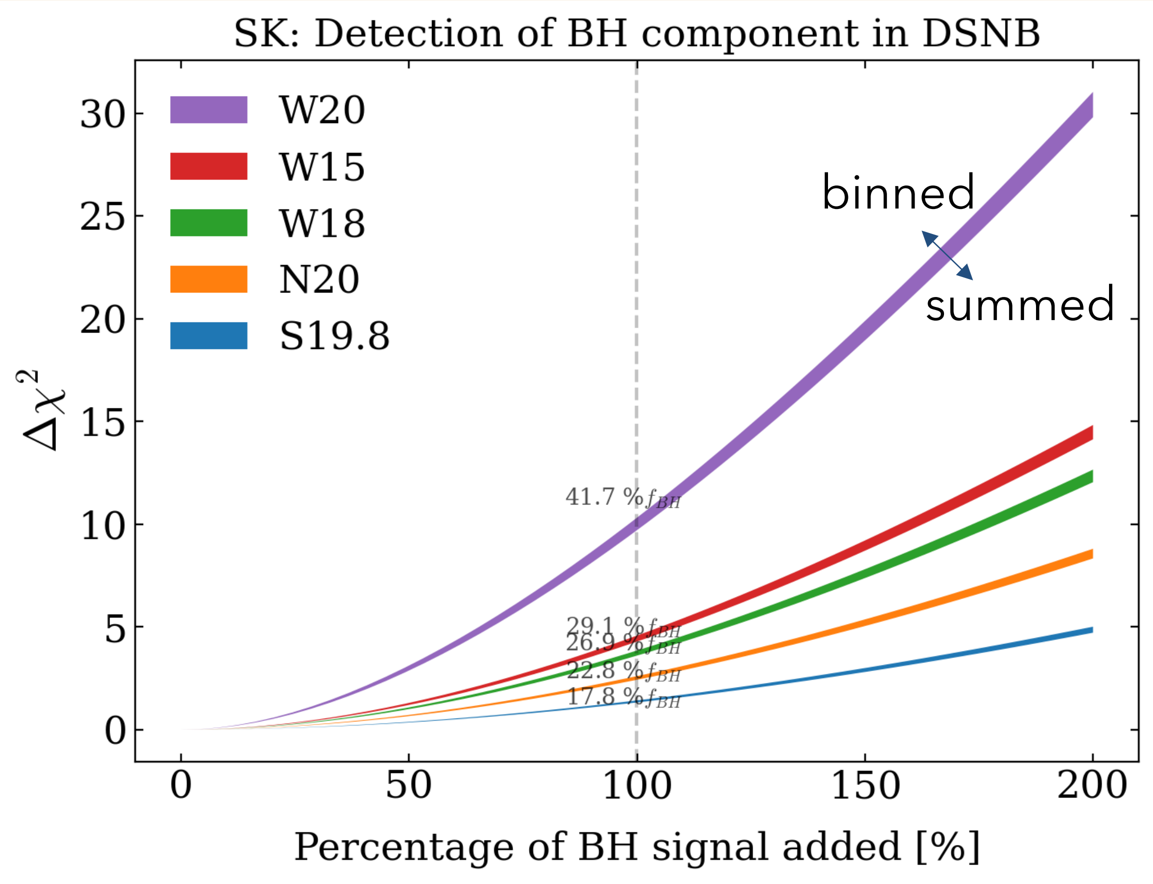
3. Likelihood Function: Utilize the Poisson likelihood function to compute the test statistic $-2\ln\lambda$.

Bin-by-Bin Sensitivities: Perform the statistical test for each energy bin given a detector resolution.
Summed Sensitivities: Sum over all bins to evaluate the overall sensitivity of the experiment to the failed CCSN contribution.

FIRST TEST PLOTS:







CONSIDERING THE FUTURE:

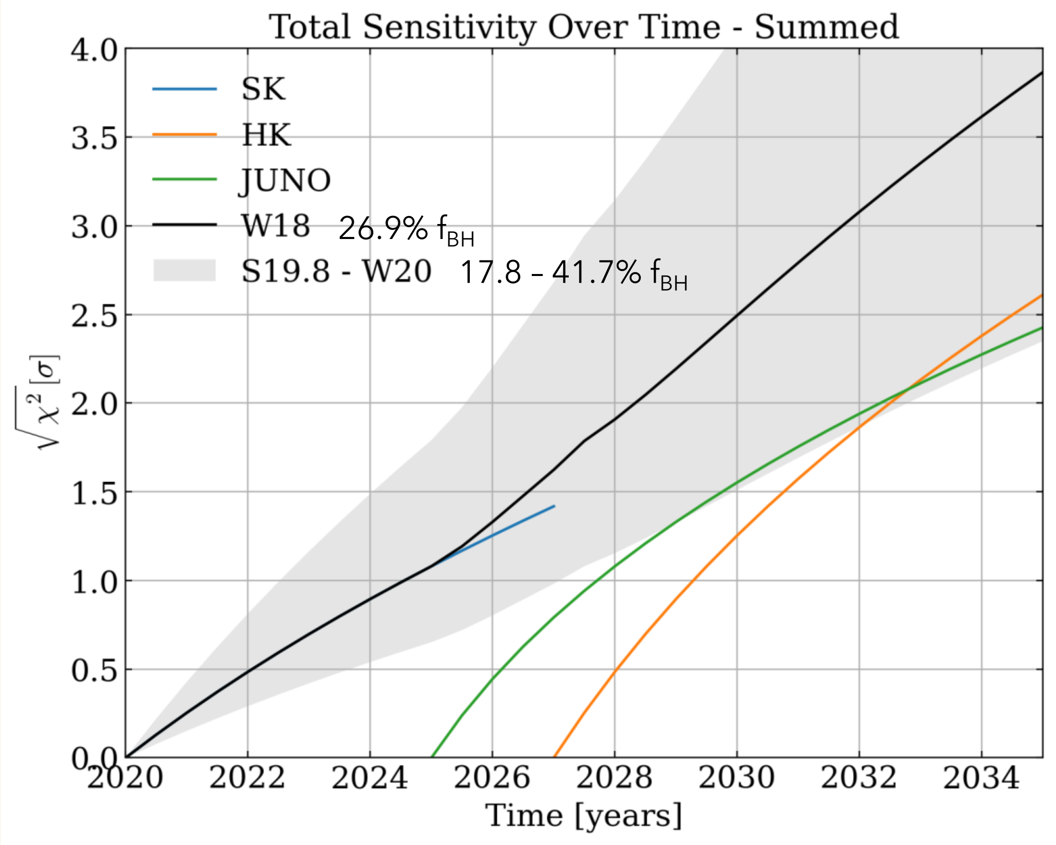
TIMELINE OF BLACK HOLE COMPONENT SENSITIVITY IN THE DSNB ACROSS EXPERIMENTS

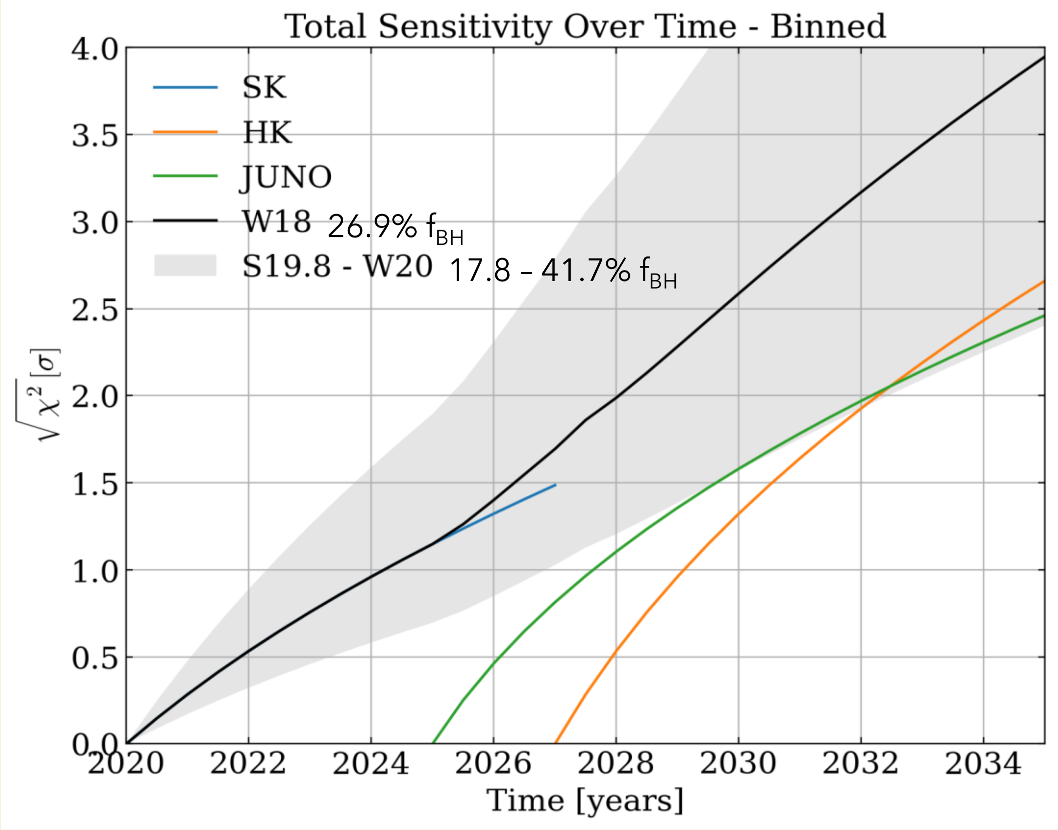
Super-Kamiokande:
- Operates from Year 0 to 7. (2020-2027)
- Assumption: SK stops data-taking when HK begins.

JUNO:
- Operates from Year 5 onwards. (2025-)
- Contribution: Increases sensitivity, particularly in specific energy ranges.

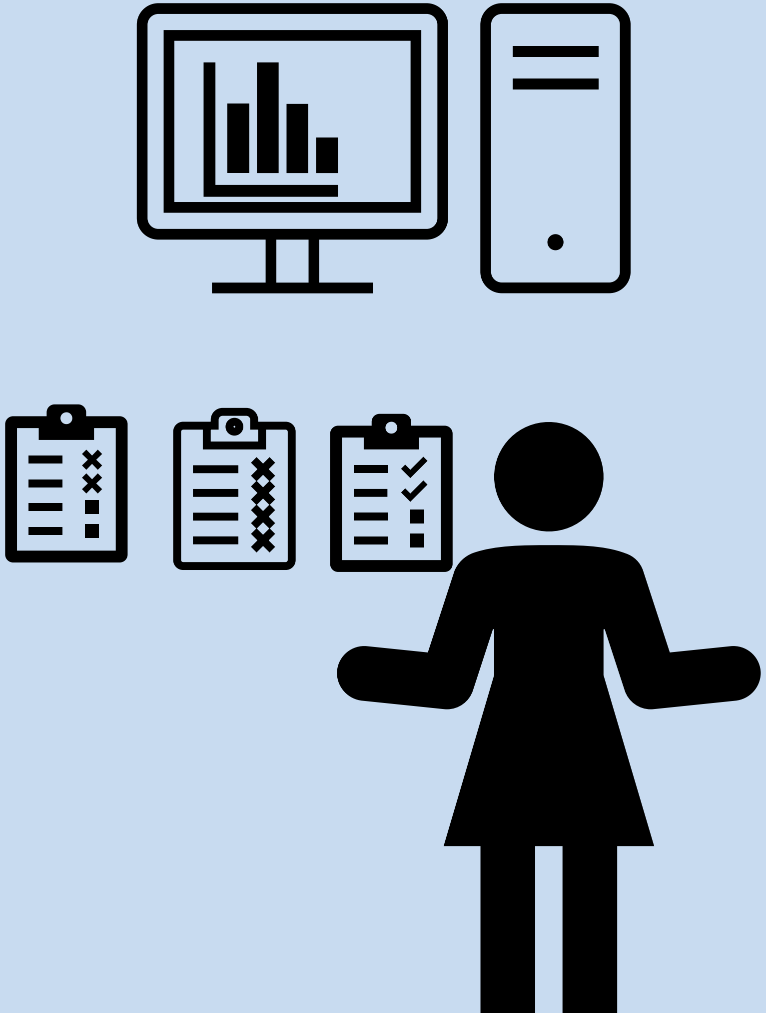
Hyper-Kamiokande:
- Operates from Year 7 onwards. (2027-)
- Assumption: Double SK (Background and Signal).

FIRST TEST
SUMMED VS BINNED
WITH BACKGROUNDS





SECOND TEST



Objective:

- **Assess Sensitivity to BH Fraction:** Determine how sensitive we are to different black hole fractions in the DSNB by comparing spectra of different mixtures.
- **Spectrum Fitting:** Evaluate how well (or poorly) a DSNB spectrum with a specific neutron star and scaled black hole mixture can be fitted with a specific model.

SECOND TEST METHODOLOGY:

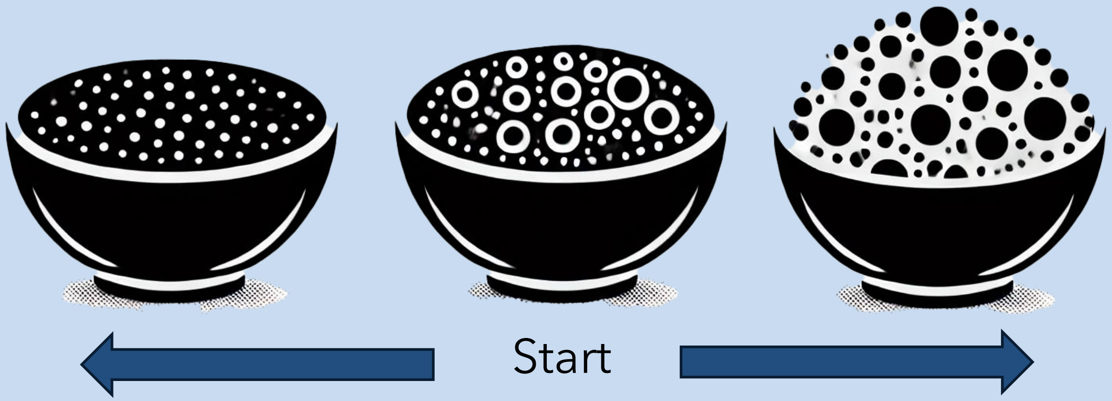
Statistical Analysis:

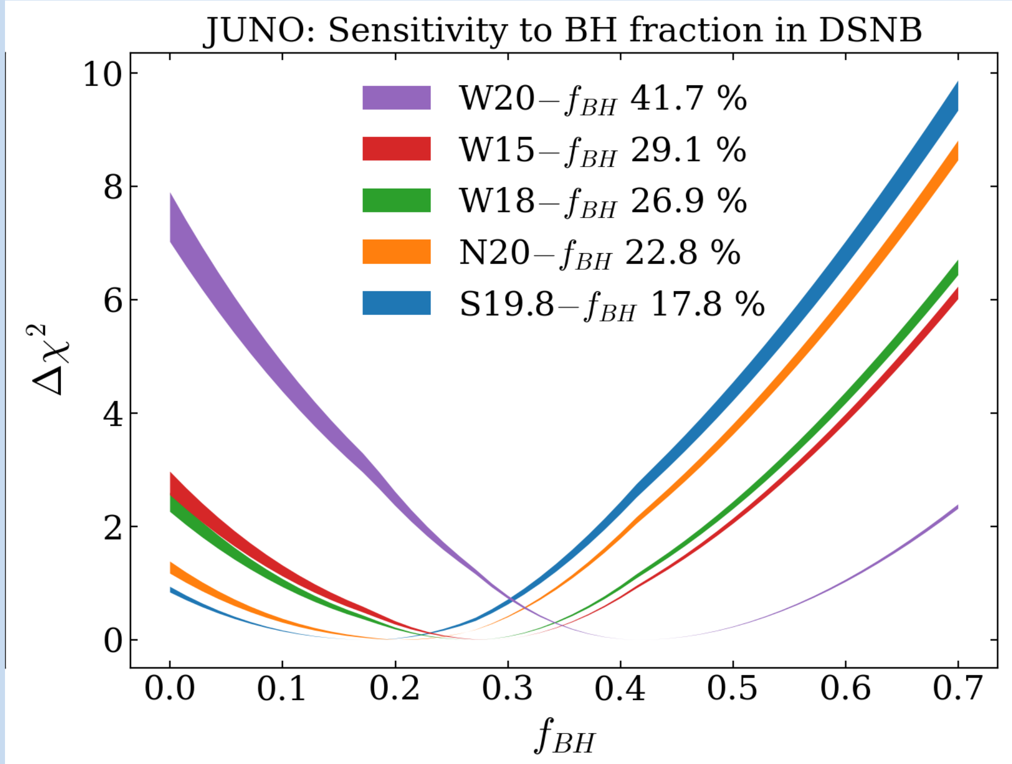
1. **Interpolated Spectra:**
For a given BH fractions (fBH), interpolate NS and BH fluxes to generate new spectra

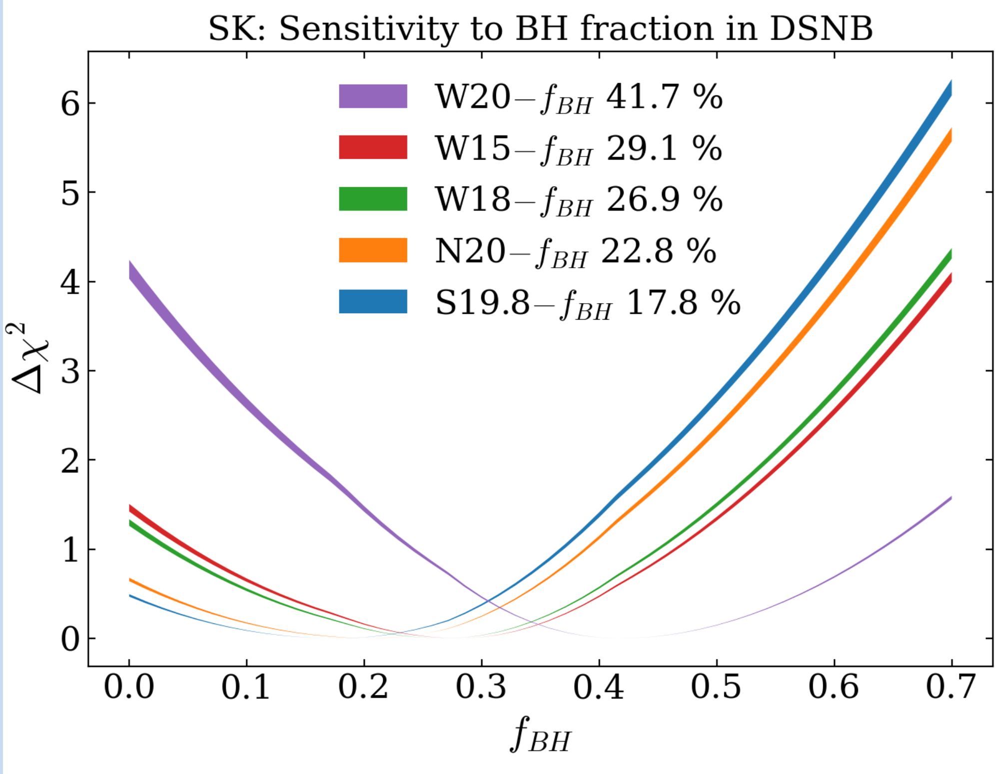
- **Expected events:** (NS + BH) events from model+ background
- **Observed events:** (NS + BH) events interpolated across models for a given fBH + background

2. Likelihood Function: Utilize the Poisson likelihood function to compute the test statistic $-2\ln\lambda$.

SECOND TEST PLOTS:

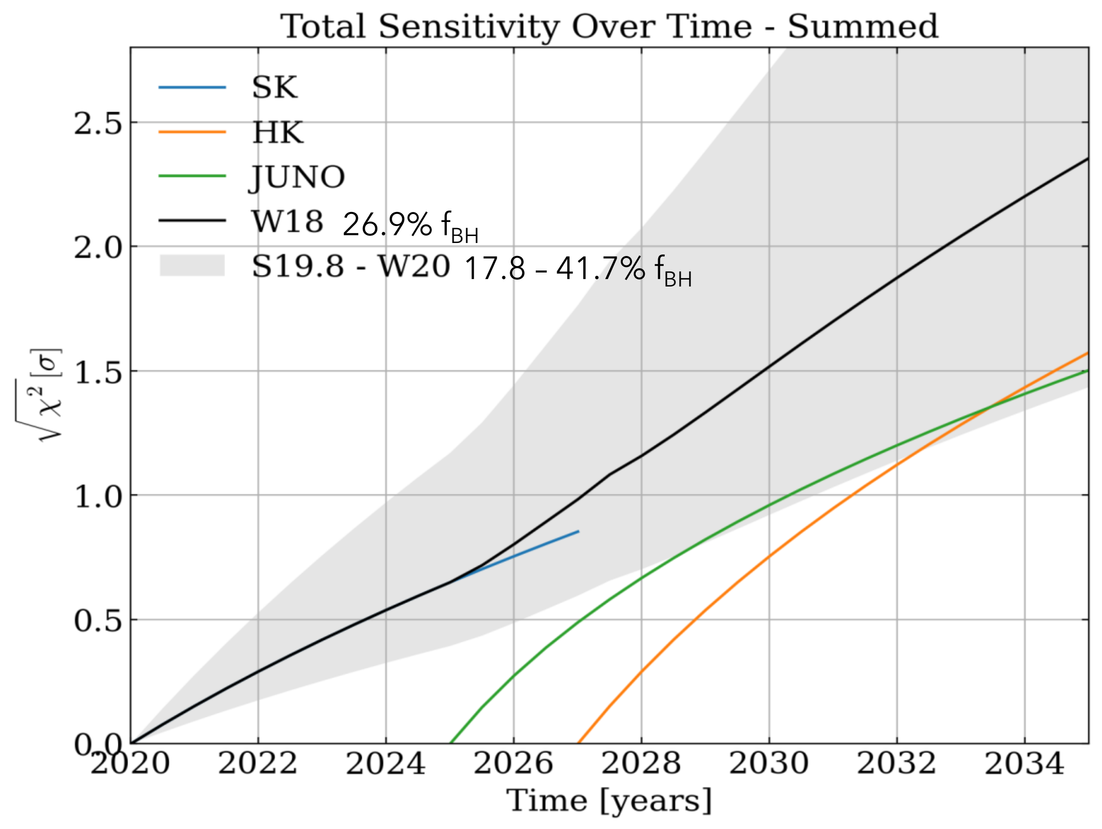


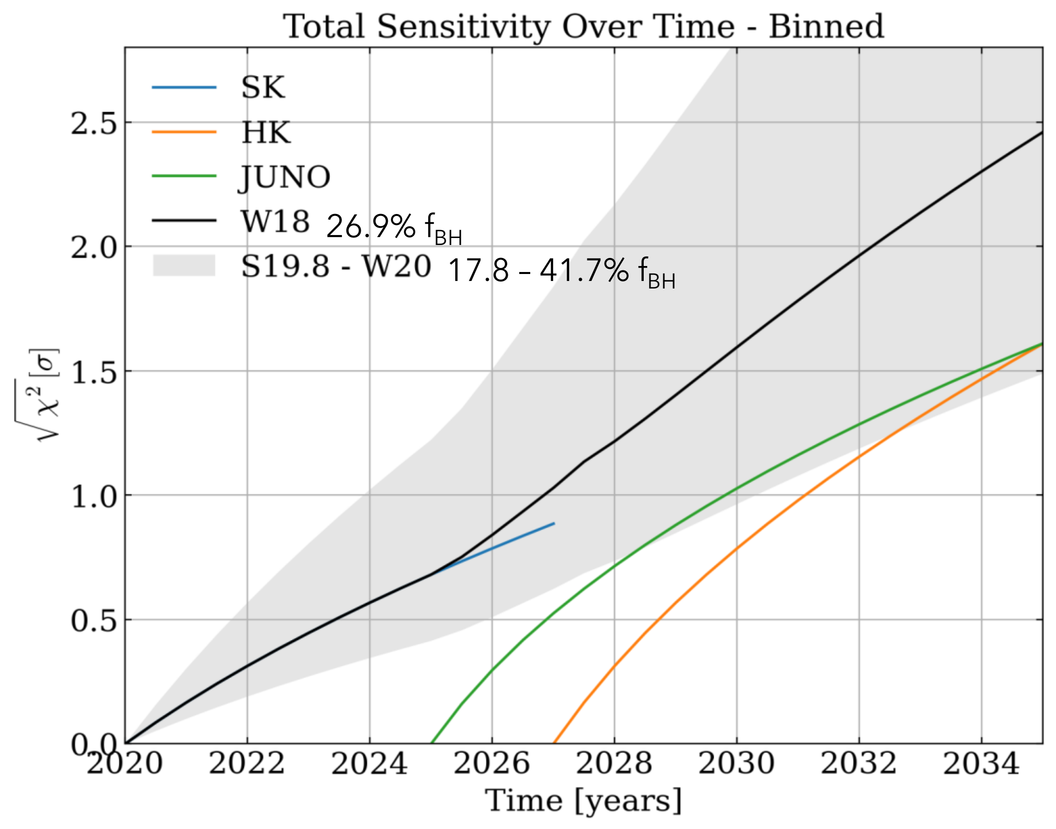




SECOND TEST

SUMMED VS BINNED WITH BACKGROUNDS





THANK YOU FOR YOUR ATTENTION

QUESTIONS?

CONTACT:
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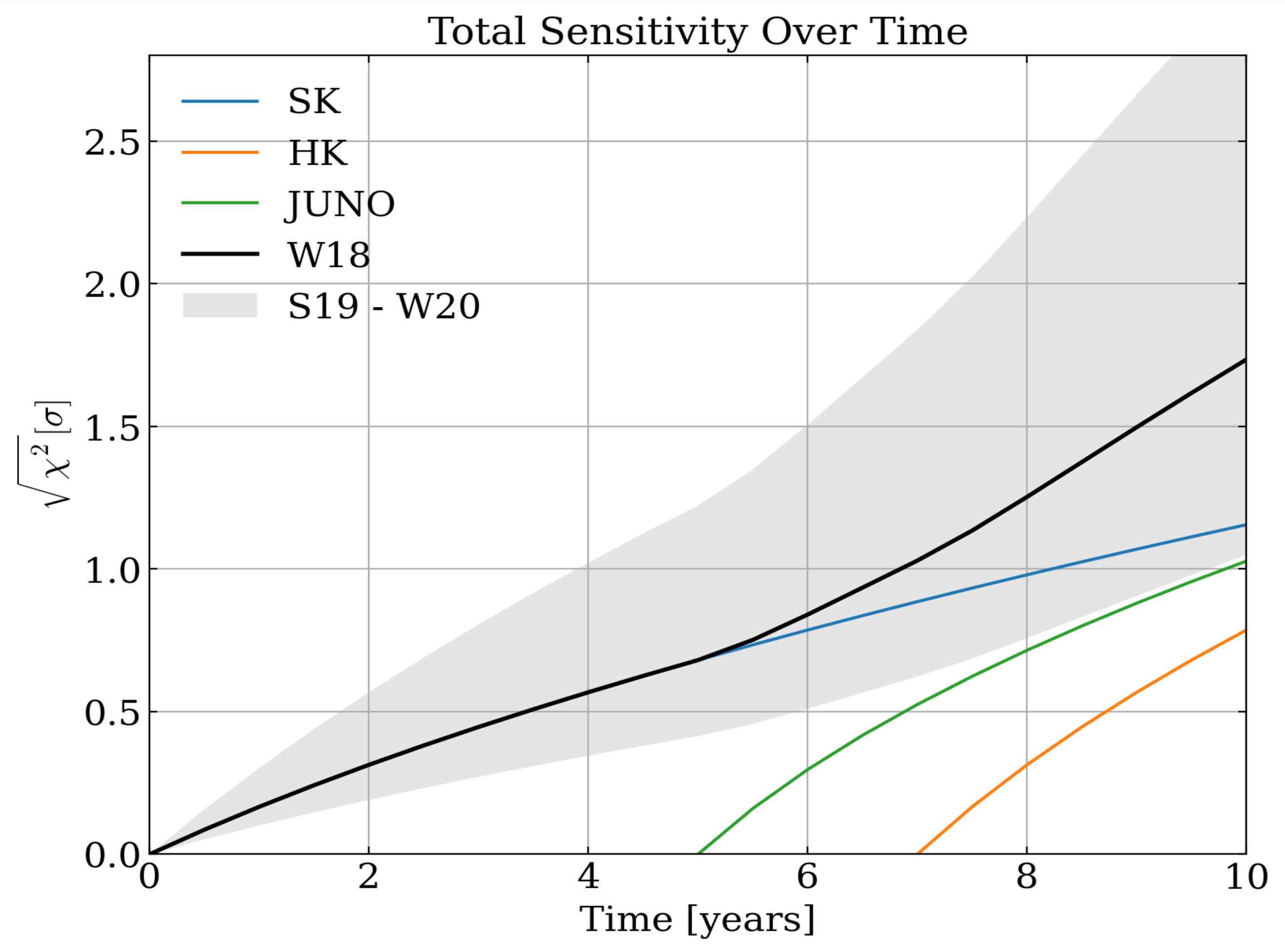
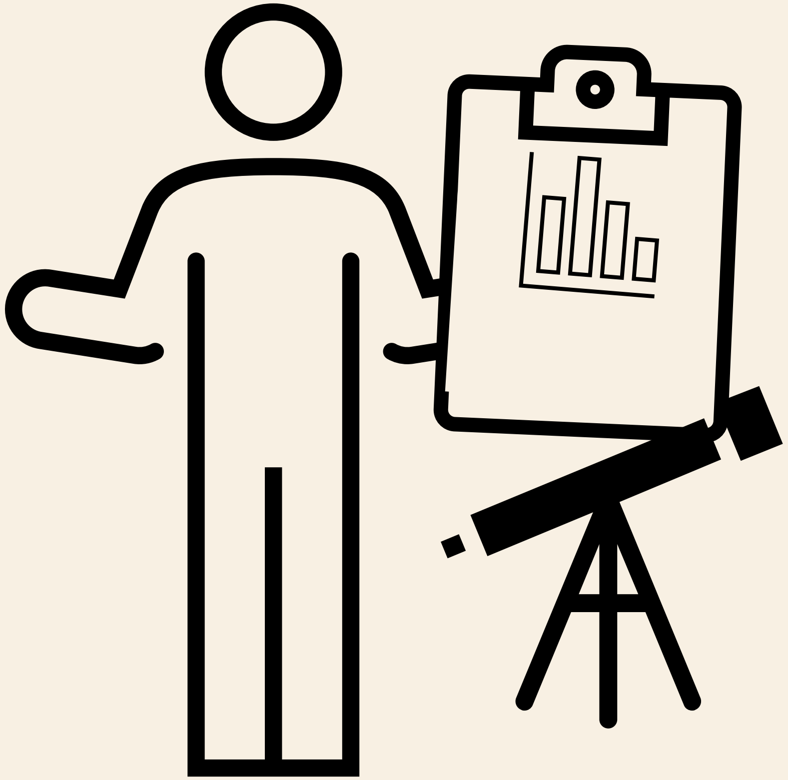
TIMELINE WITH SK NOT SHUTTING DOWN



FIRST TEST METHODOLOGY:



1. **Event Rate Calculation:**
   1. **Successful Supernovae (NS):** Calculate the expected neutrino event rates from successful CCSN.
   2. **Failed Supernovae (BH):** Consider a variable fraction of failed CCSN contributing to the event rates.
   3. **Background Events (BKG):** Include background neutrino events relevant to the experiment (e.g., JUNO and SuperK).

2. **Statistical Analysis:**
   1. **Observed vs. Expected Events:** Compare the expected events (successful CCSN + background) with the observed events, which may include a contribution from failed CCSN.
   2. **Likelihood Function:** Utilize the Poisson likelihood function to assess the probability of observing the data given the expected rates.
   3. **Test Statistic:** Compute the test statistic $-2\ln\lambda$ to quantify the difference between the observed and expected event rates.

3. **Sensitivity Evaluation:**
   1. **Bin-by-Bin Analysis:** Perform the statistical test for each energy bin to identify discrepancies.
   2. **Summed Sensitivities:** Sum over all bins to evaluate the overall sensitivity of the experiment to the failed CCSN contribution.

SECOND TEST METHODOLOGY:

1.Event Spectrum Calculation:

- **Observed Events (ex)**:
  ex=events_NS+events_BH+events_BKG

- **Interpolated Spectra (Model Predictions):**
  For varying BH fractions (fBH), interpolate NS and BH fluxes to generate new spectra.
  Expected Events (ob):
  ob=interp_NS+interp_BH+events_BKG

2.Statistical Analysis:

Likelihood Function: Use the Poisson likelihood to compare the observed events (ex) with the expected events from the model (ob).

$$-2\ln\lambda=-2\sum(ex\cdot\ln(ob)-ob-\ln(ex!))$$

Sensitivity Calculation:

1. Compute the test statistic for each BH fraction.
2. Normalize the test statistics by subtracting the minimum value to highlight relative differences.

3. Interpretation:

Best Fit Identification:

The BH fraction corresponding to the minimum test statistic indicates the best fit to the observed data.

Sensitivity Assessment:

Analyze how the test statistic varies with different BH fractions to understand the experiment's sensitivity.

JUNO SIGNAL SENSITIVITY

https://arxiv.org/pdf/2205.08830

Sensitivity

Signal	Rate[147 kt × yr]	muon veto		PSD	TC cut	
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