Contributions to SK Diffuse Supernova Neutrino Background Analysis

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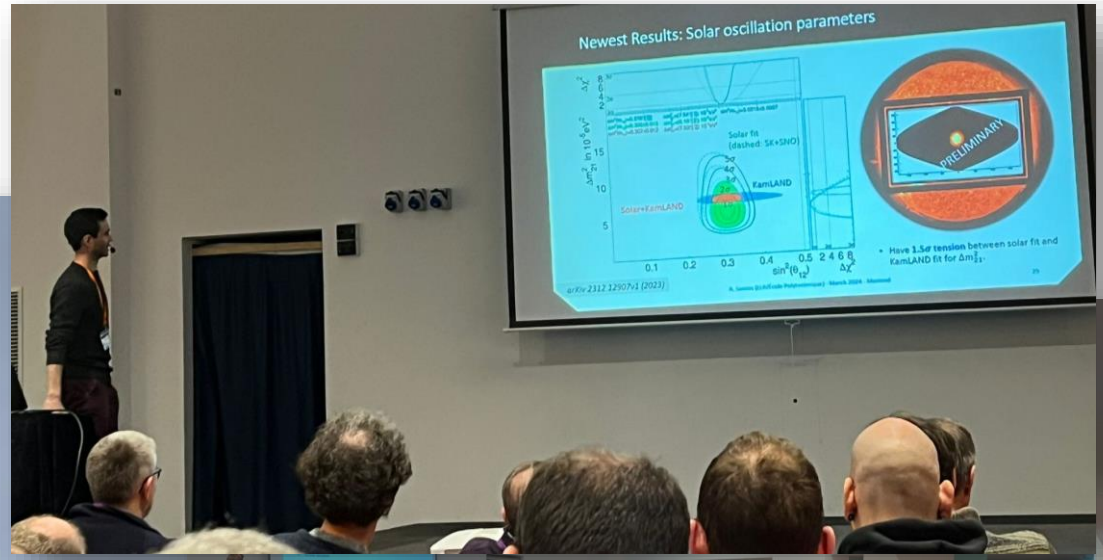
4 Apr. 2024

Neutrino Group

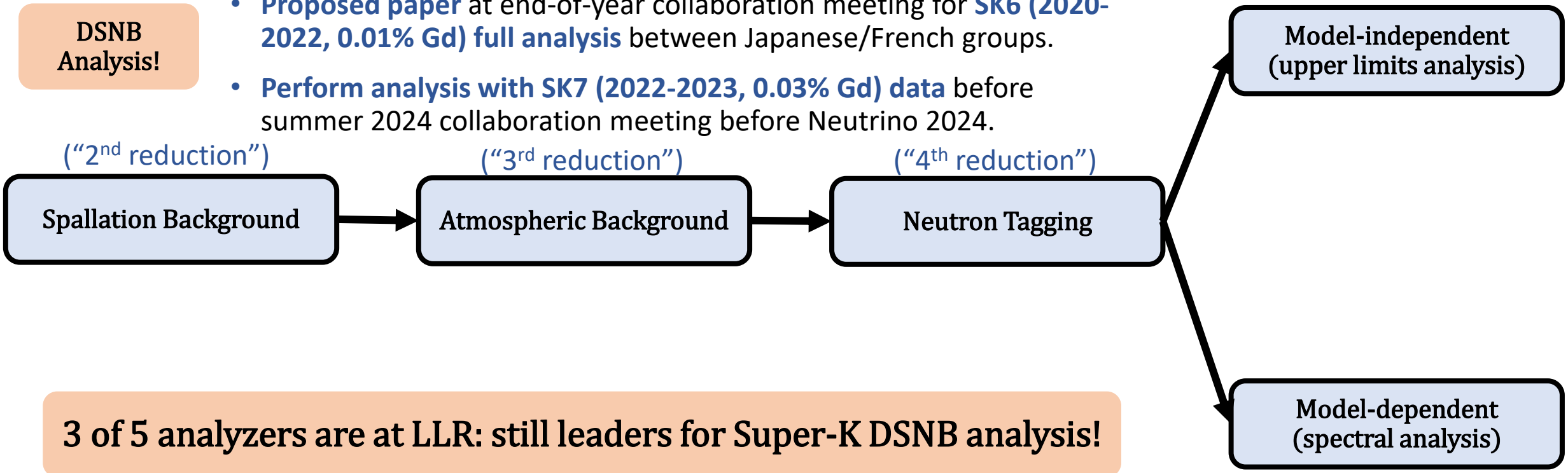
Thanks for sending me out to Moriond EW :D



Super-K Analysis for Diffuse Supernova Neutrino Background

DSNB Analysis!

- **Proposed paper** at end-of-year collaboration meeting for **SK6 (2020-2022, 0.01% Gd) full analysis** between Japanese/French groups.
- **Perform analysis with SK7 (2022-2023, 0.03% Gd) data** before summer 2024 collaboration meeting before Neutrino 2024.



3 of 5 analyzers are at LLR: still leaders for Super-K DSNB analysis!

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("2nd reduction") ("3rd reduction") ("4th reduction")

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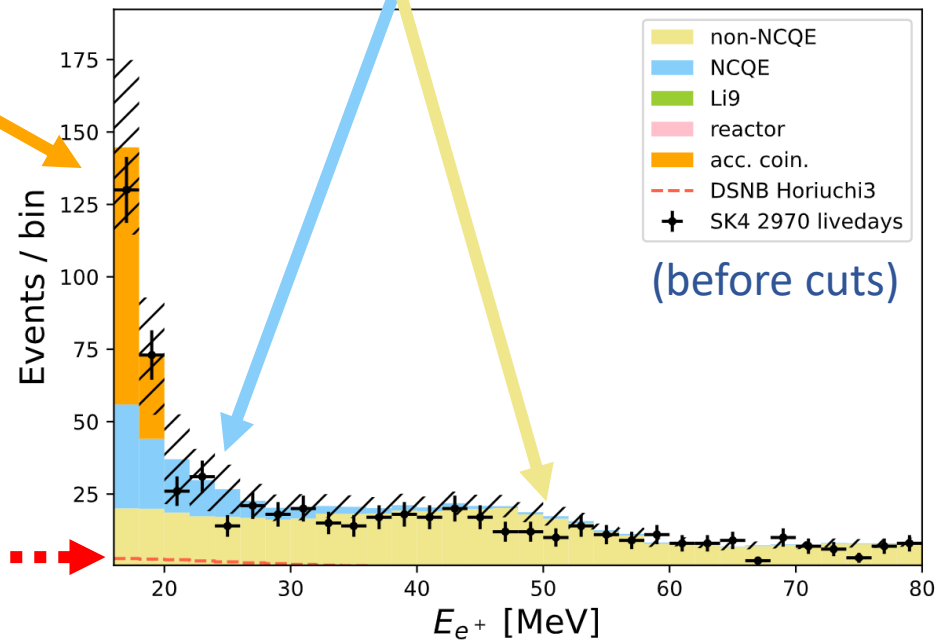

(before cuts)

(Itsy, bitsy DSNB signal)

(Two-part inverse beta decay signal!)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

(positron) + (delayed neutron capture)

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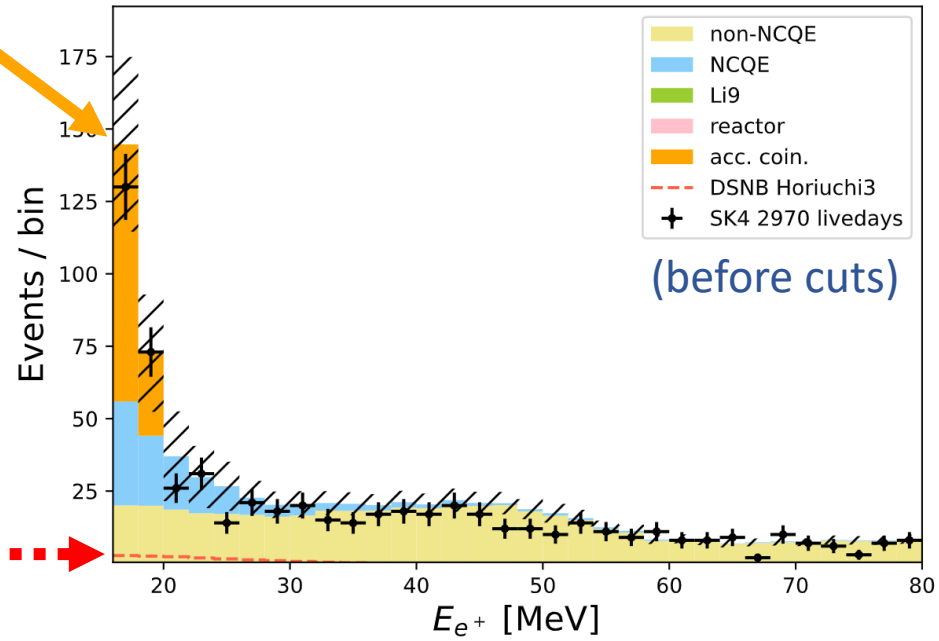

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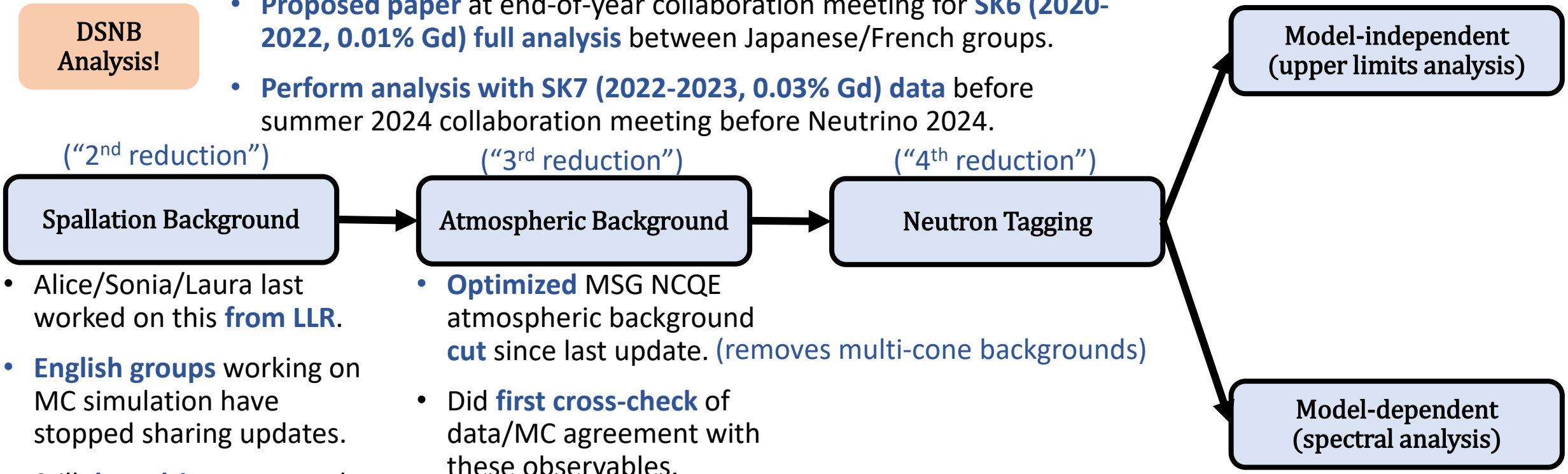

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- **Optimized** MSG NCQE atmospheric background **cut** since last update. (removes multi-cone backgrounds)
- Did **first cross-check** of data/MC agreement with these observables.
- **Found MC error** for one of them (counting electrons coming from invisible μ/π). (looking for decays after prompt peak)
- Working on a **"pre-activity" data/MC discrepancy** too. (looking for gammas before prompt peak)

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(Two-part IBD signal!)

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Neutron Tagging ("4th reduction")

- **Re-processed** updated MC/data files with BDT.
- Did **first cross-check** of data/MC agreement for important BDT inputs.
- **Found bad treatment** of separating $e^{\pm}$ of μ/π decays from neutron captures. (μ-decays/Gd-ncaptures on same timescale)
- Refining **new $e^{\pm}$/neutron capture separation**.

Model-independent (upper limits analysis)

Model-dependent (spectral analysis)

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- Introduced **CL_s approach**.
- Finishing **multi-phase upper limit combination** with correlated systematic uncertainties.
- Just need **comparison of energy scale** across phases.

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- **Comparing cut optimization** with Antoine.

Super-K Analysis for Diffuse Supernova Neutrino Background

Final steps before analysis contributions finished!

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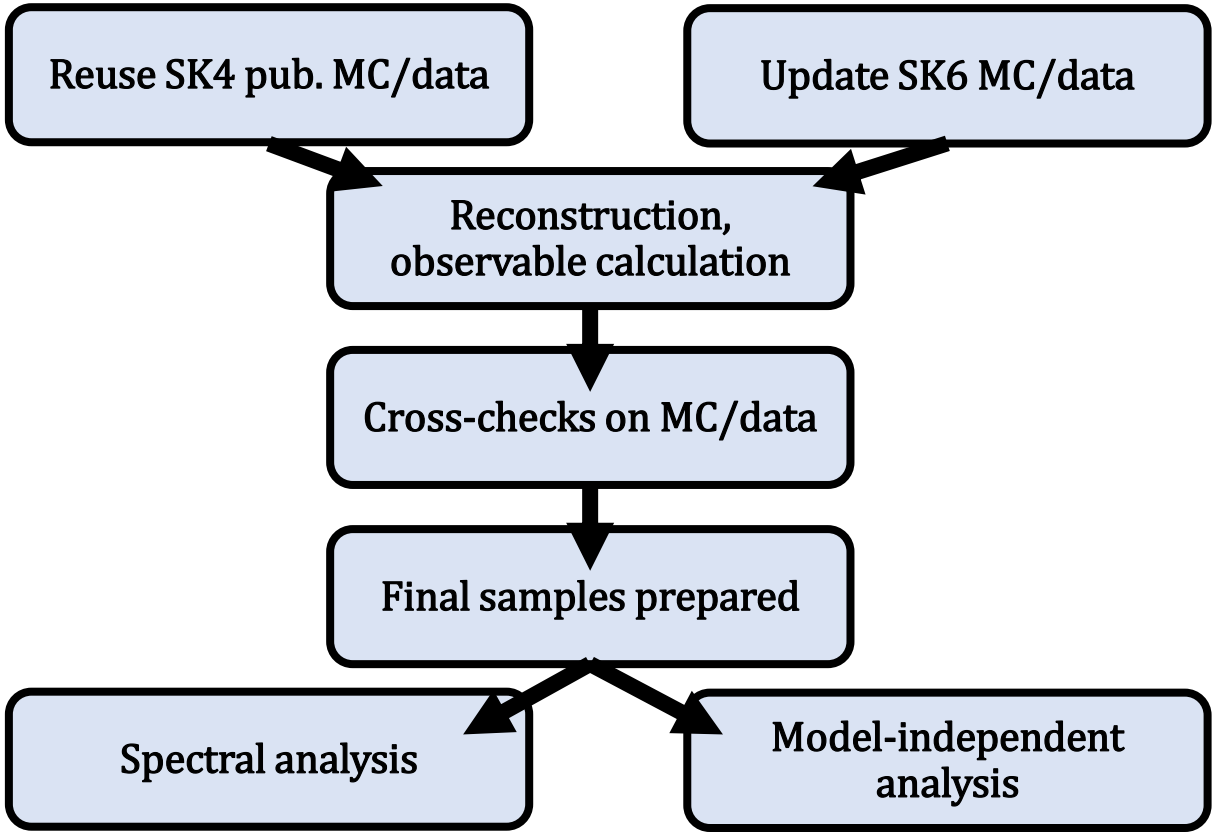
Backup

Overview of pipeline for this DSNB work



Cross-checks for DSNB SK-VI paper

$1^{st}/3^{rd}$ reduction checks

- dwall: Distance to wall
- effwall: Distance to wall along direction
- bsgood: Goodness of BONSAI fit
- θ_c: Cherenkov angle
- Lclear: ring “clearness”
- q50/n50: charge-to-hit ratio in 50ns
- nmue: Number of “decay electrons”
- maxpre: maximum pre-activity for a sample

Neutron tagging checks

- Neutron multiplicity for CC-dominated samples
- Neutron multiplicity for NC-dominated samples
- BDT discriminatory variables

Super-K Analysis for Diffuse Supernova Neutrino Background

("2nd reduction") ("3rd reduction") ("4th reduction") (final results)

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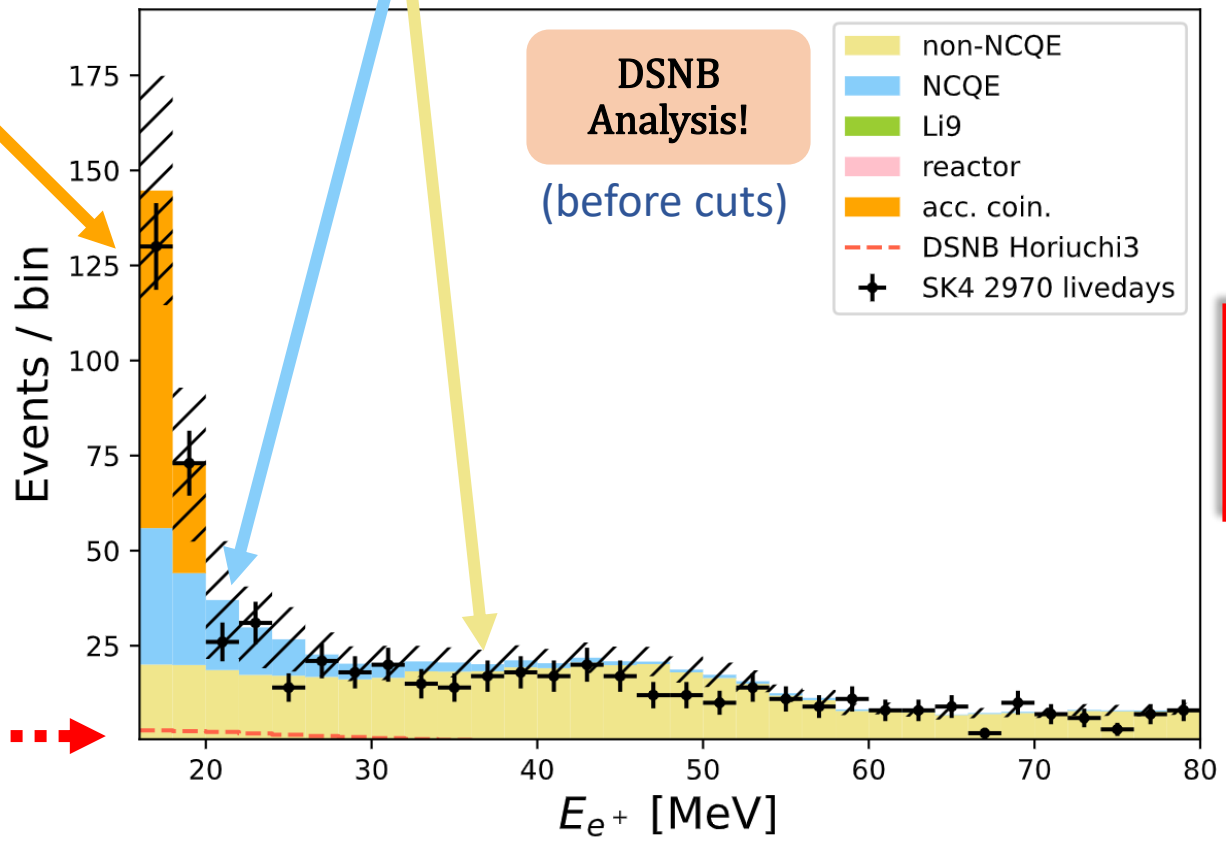


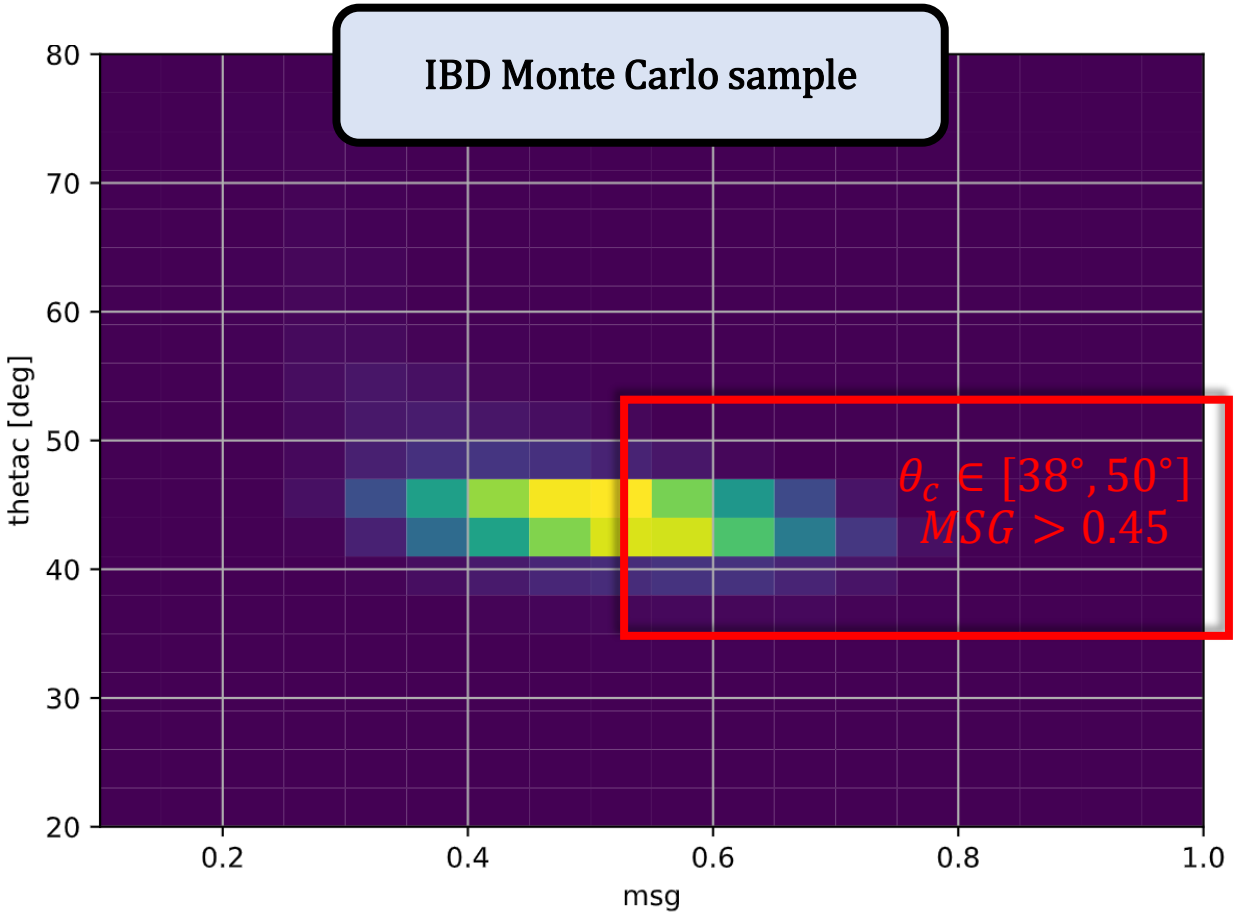
(Itsy, bitsy DSNB signal)

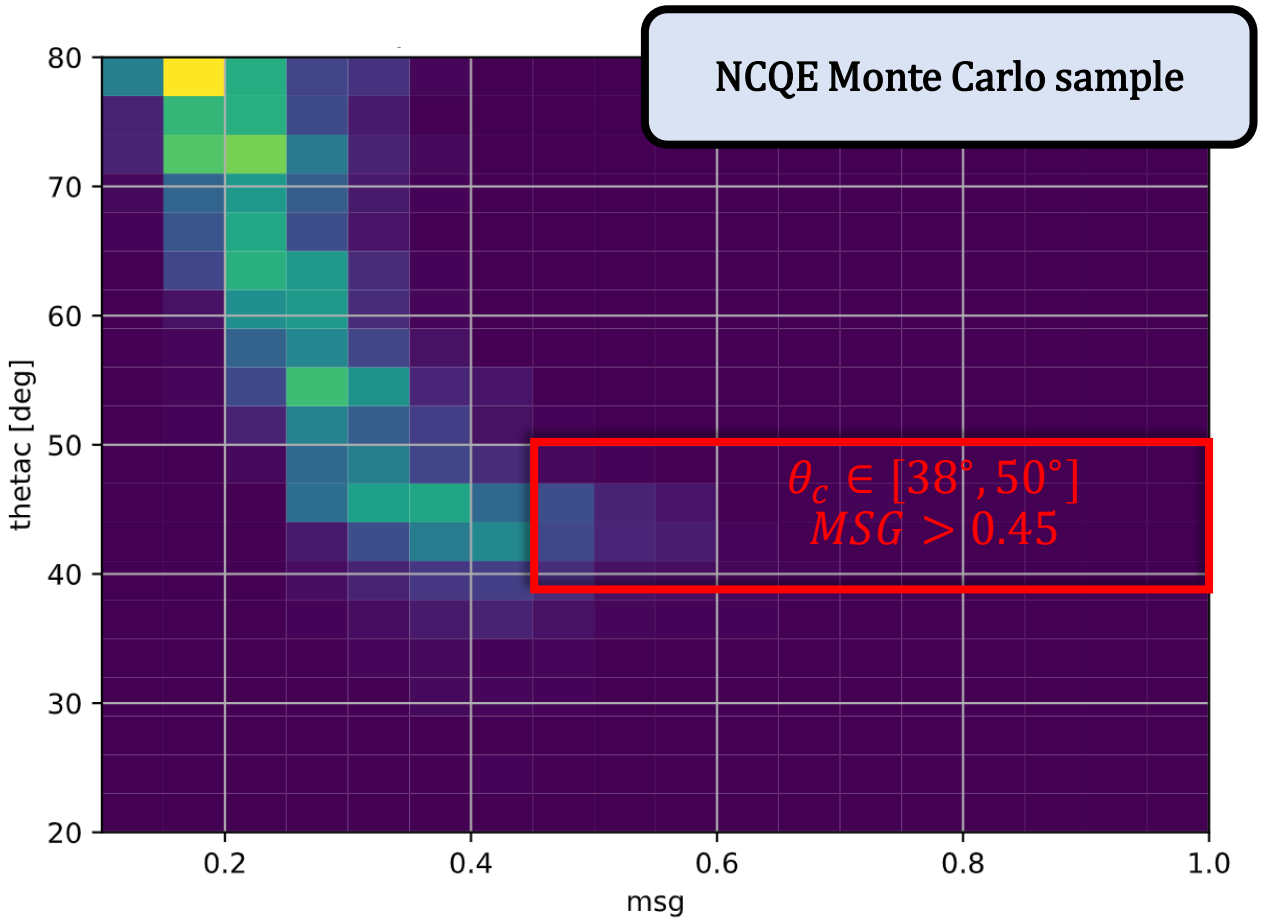
(Two-part inverse beta decay signal!)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

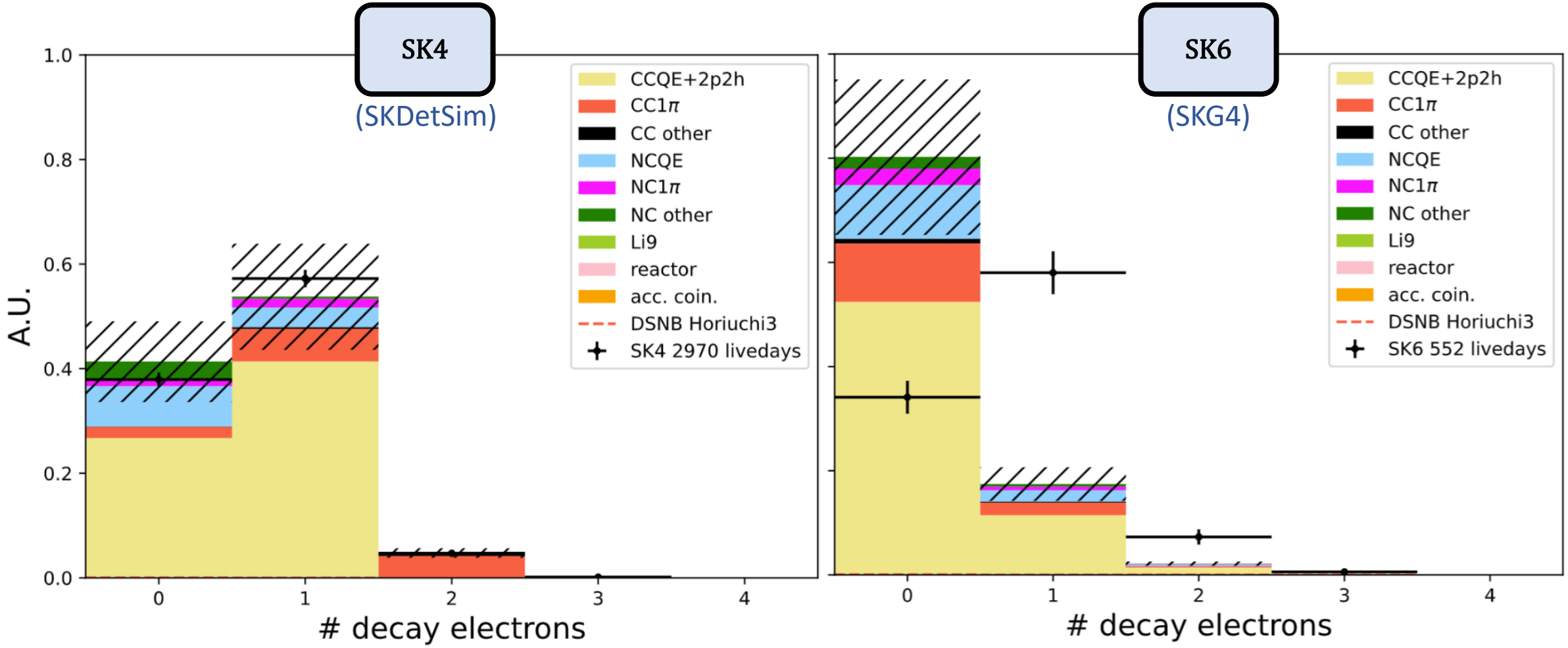
(positron) + (delayed neutron capture)

MSG cut for reducing NCQE backgrounds for DSNB analysis





SK4/SK6 cross-checks: “decay electron” ($nmue$)



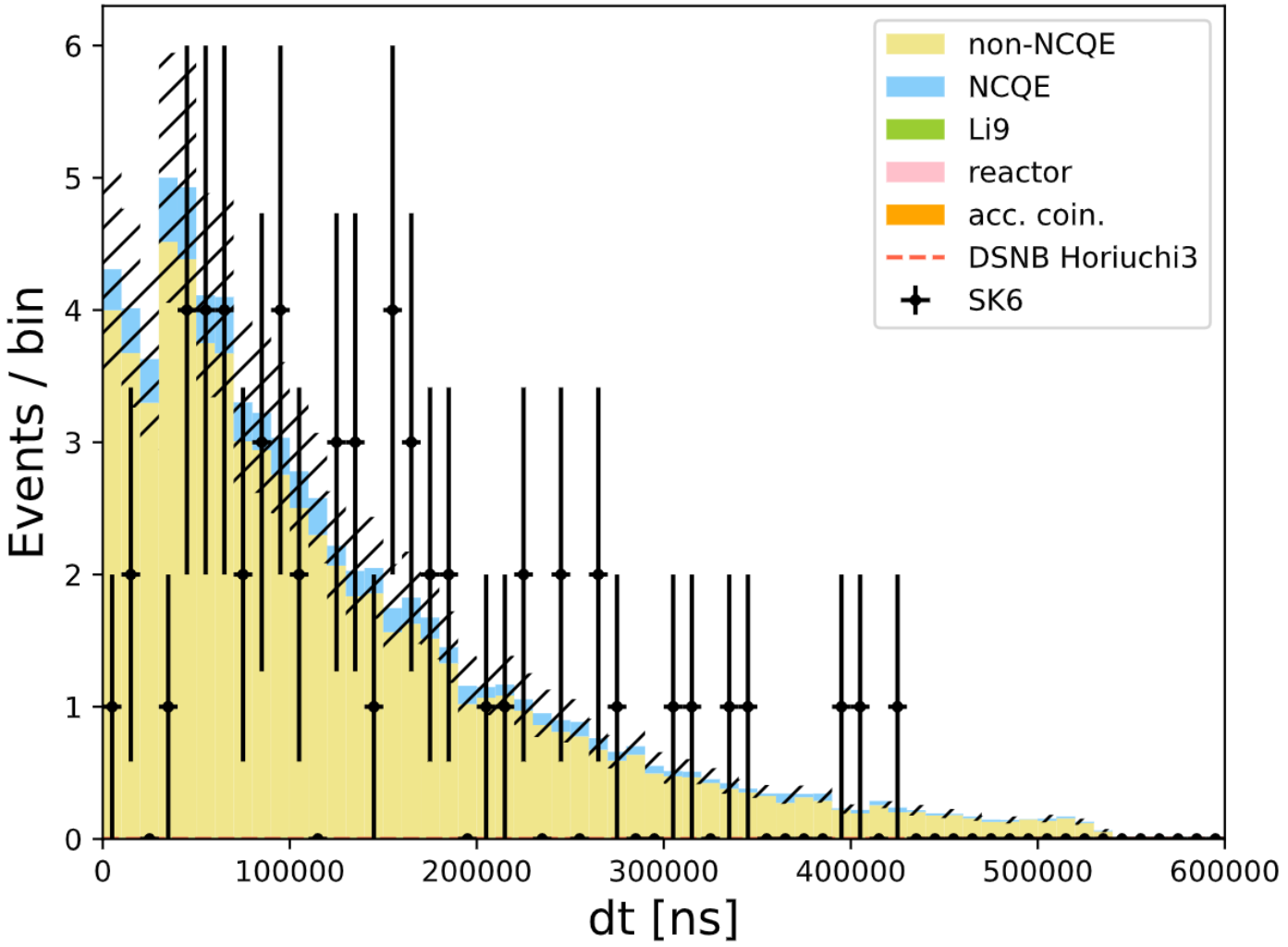
Simple selection steps (and comparison with APFit method)

Pre-selection

- $E \in [30, 80]$ MeV bsenergy
- dwall > 200cm, bsgood > 0.5
- effwall > max(300, 500-50*(E[MeV]-16)) cm
- nmue=0

APFit Method

- Candidates need **more than 50 hits in 50 ns in t**.
- You can **see early time window** scanned up until **around 30 μs** which **diminishes** total number of **ncaptures tagged** by the BDT.



Simple selection steps (and comparison with APFit method)

APFit Method

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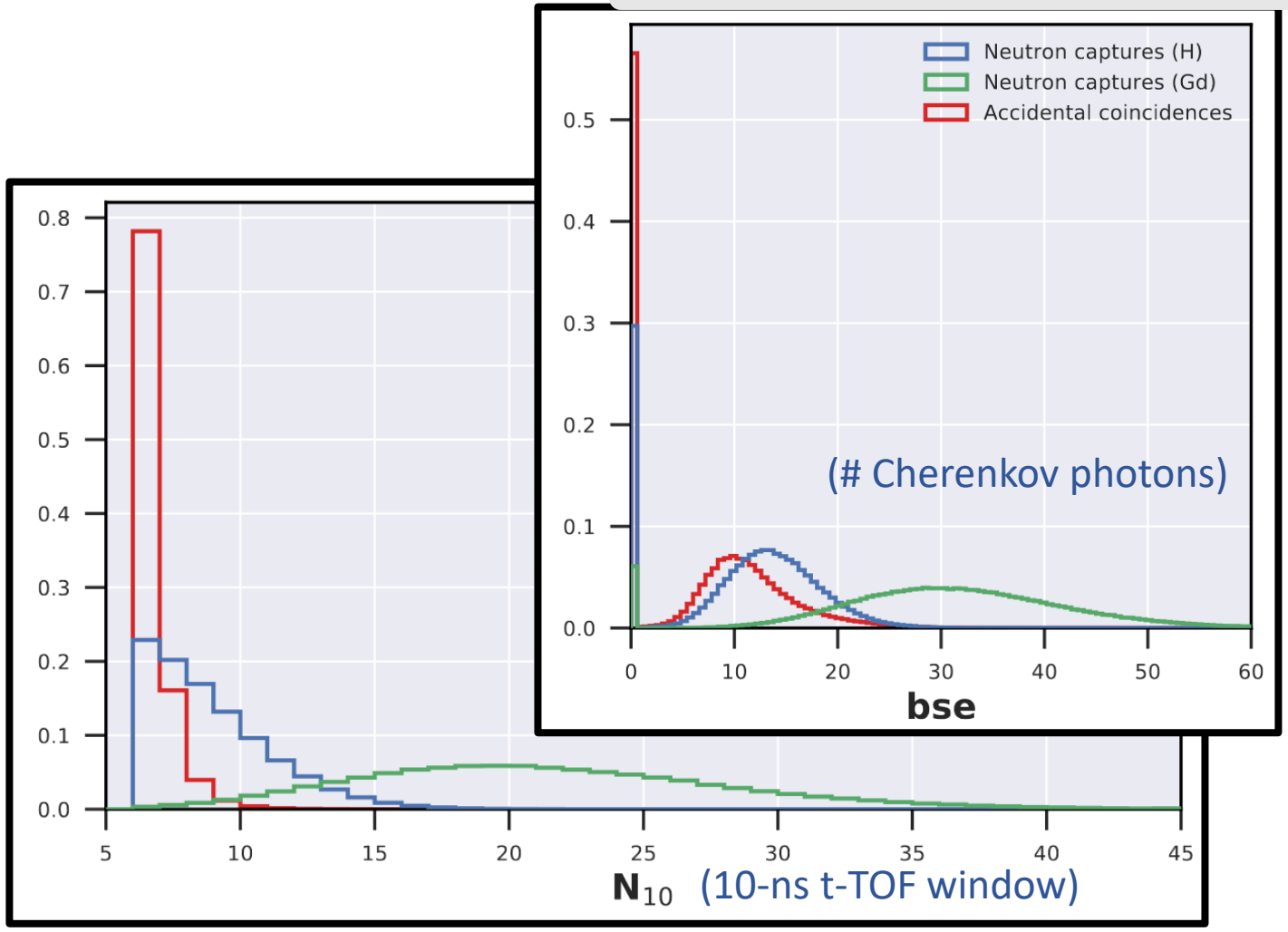
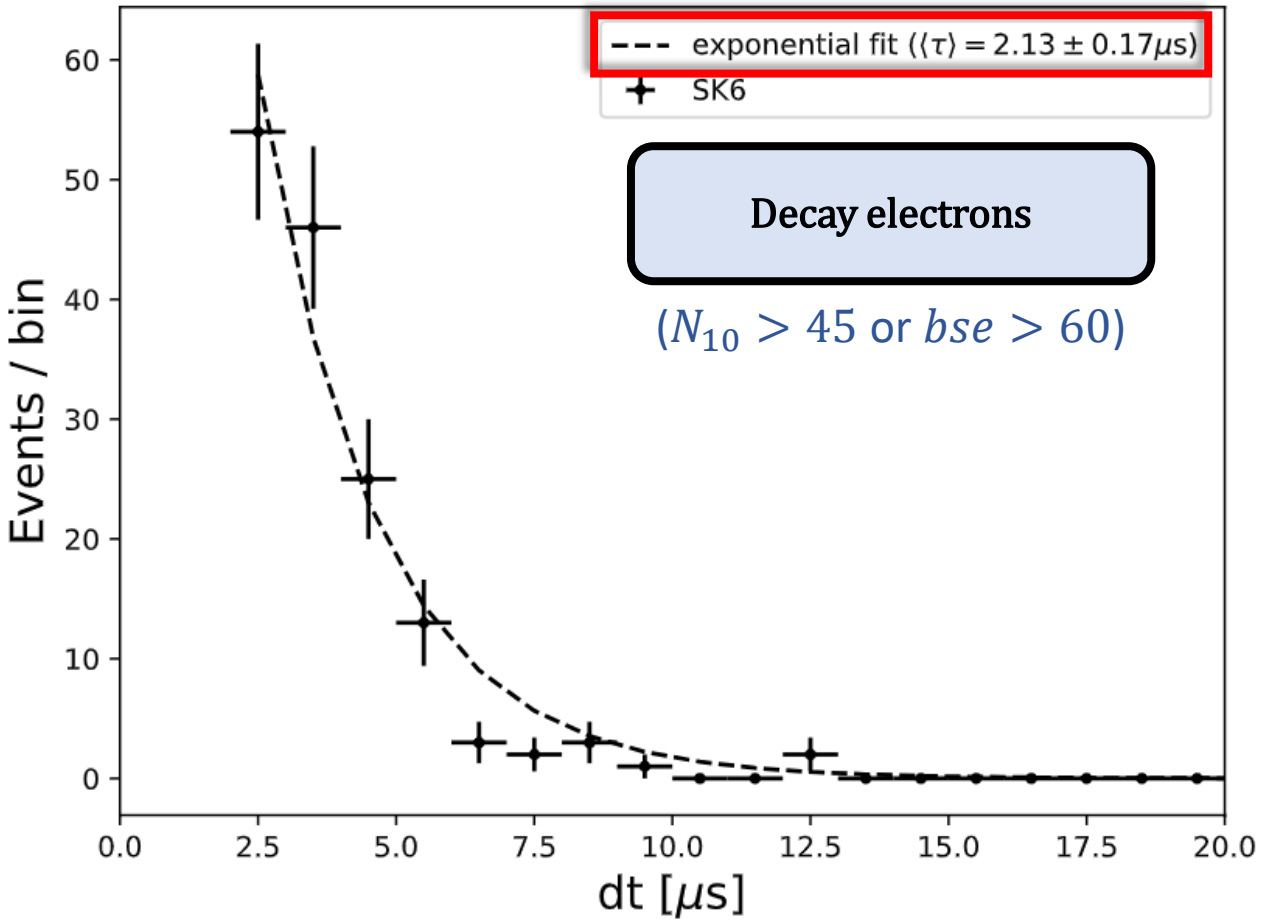
New lowE Method

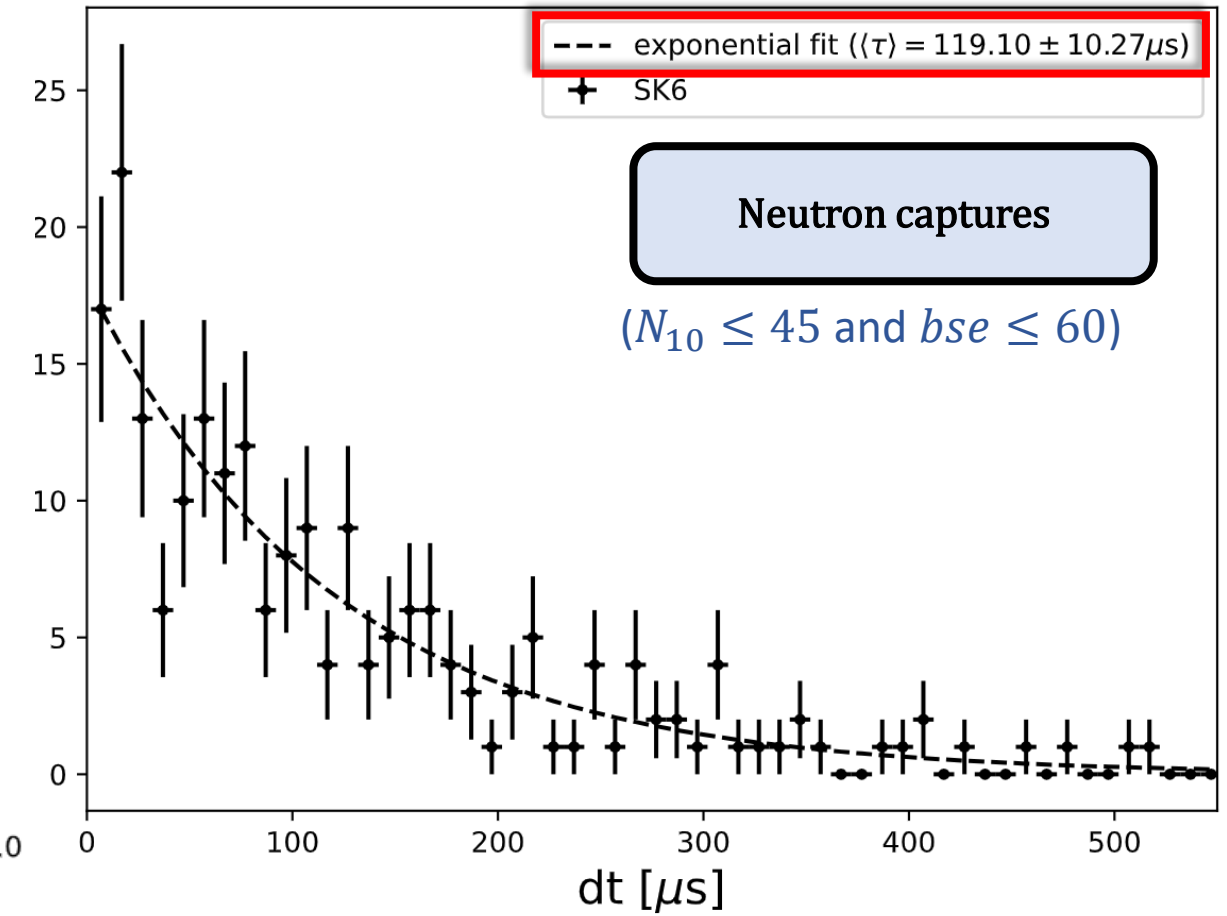
- Move to **t-TOF** since CCQE invisible muon distance from prompt before decay is comparable to neutron capture.
- BDT neutron tagging approach already calculates **22 variables** to distinguish from dark noise backgrounds.
- Select $N_{10} > 45$ or $bse > 60$ as decay-e.
- N_{10} here is lower threshold than APFit approach (since t-TOF).

A. Giampaolo, PhD Thesis (2023)



Data checks of ncapture/decaye separation in SK6





- **Decay-e sample** timing $\tau = 2.1 \pm 0.2\mu$s **consistent** with μ-decays.
- **Neutron capture sample** timing $\tau = 119.1 \pm 10.3\mu$s **consistent** with half captures on Gd, half on protons.

Old: Update given in October 2023

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("2nd reduction")

Spallation Background

- Member from **English group developing MC samples** (usually estimate using only data).
- **Japanese PhD and postdoc newly involved** in cuts and checking data in even lower energy regions.

("3rd reduction")

Atmospheric Background

- **Andrew developed new cut** capable of removing ~99% of main background with more than 75% of signal.
- **Japanese and English colleagues recreating and validating** a Convolutional Neural Network (**CNN**) to remove same background.

("4th reduction")

Neutron Tagging

- **LLR BDT** still most effective data/MC-validated tool.
- **Japanese group** developed less performant, **cut-based algorithm** used for preliminary SK6 results.
- **Japanese and English colleagues** testing a **neural network approach** but having issues with data/MC agreement.

Model-independent (upper limits analysis)

- Japanese PhD student (now postdoc in SK) **published first SK6 result**.
- Andrew acquired analysis and **completed SK6 results with new cut and Alberto's neutron tagging BDT**.

Model-dependent (spectral analysis)

- **SK6 preliminary results shown** to Super-K by Alberto in 2022.
- **Antoine took over from Alberto/Sonia's leadership** to complete SK1-4+SK6.