

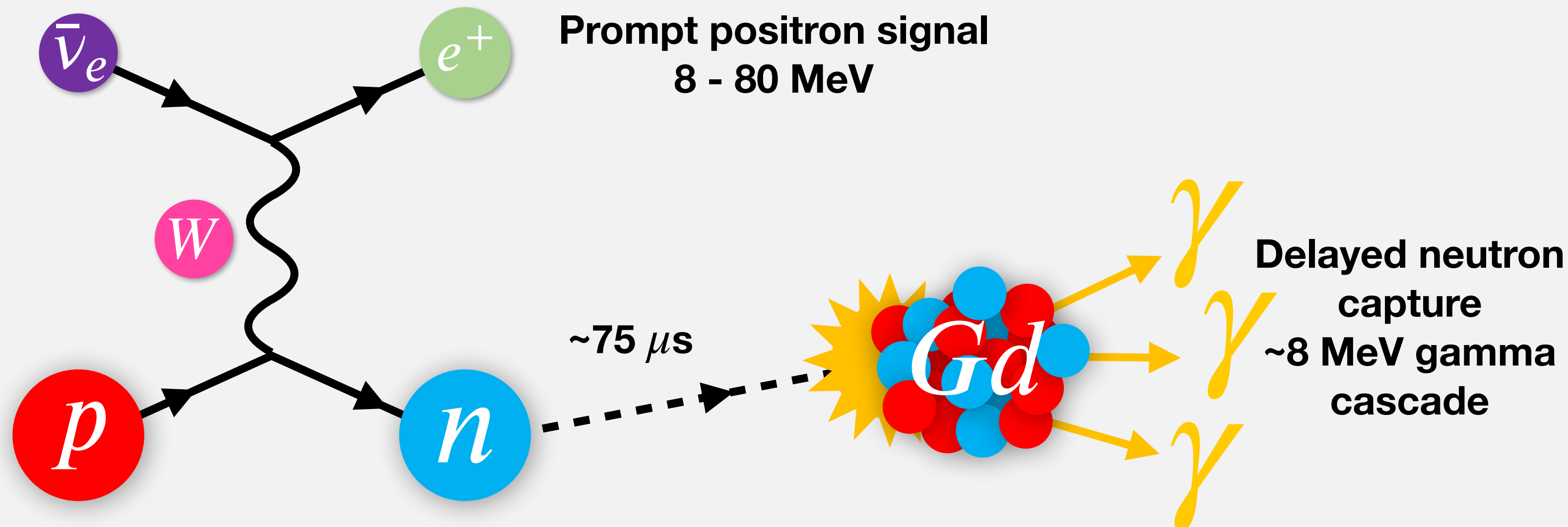
# Modelling cosmic ray muon spallation for Super & Hyper-Kamiokande DSNB

Jack Fannon

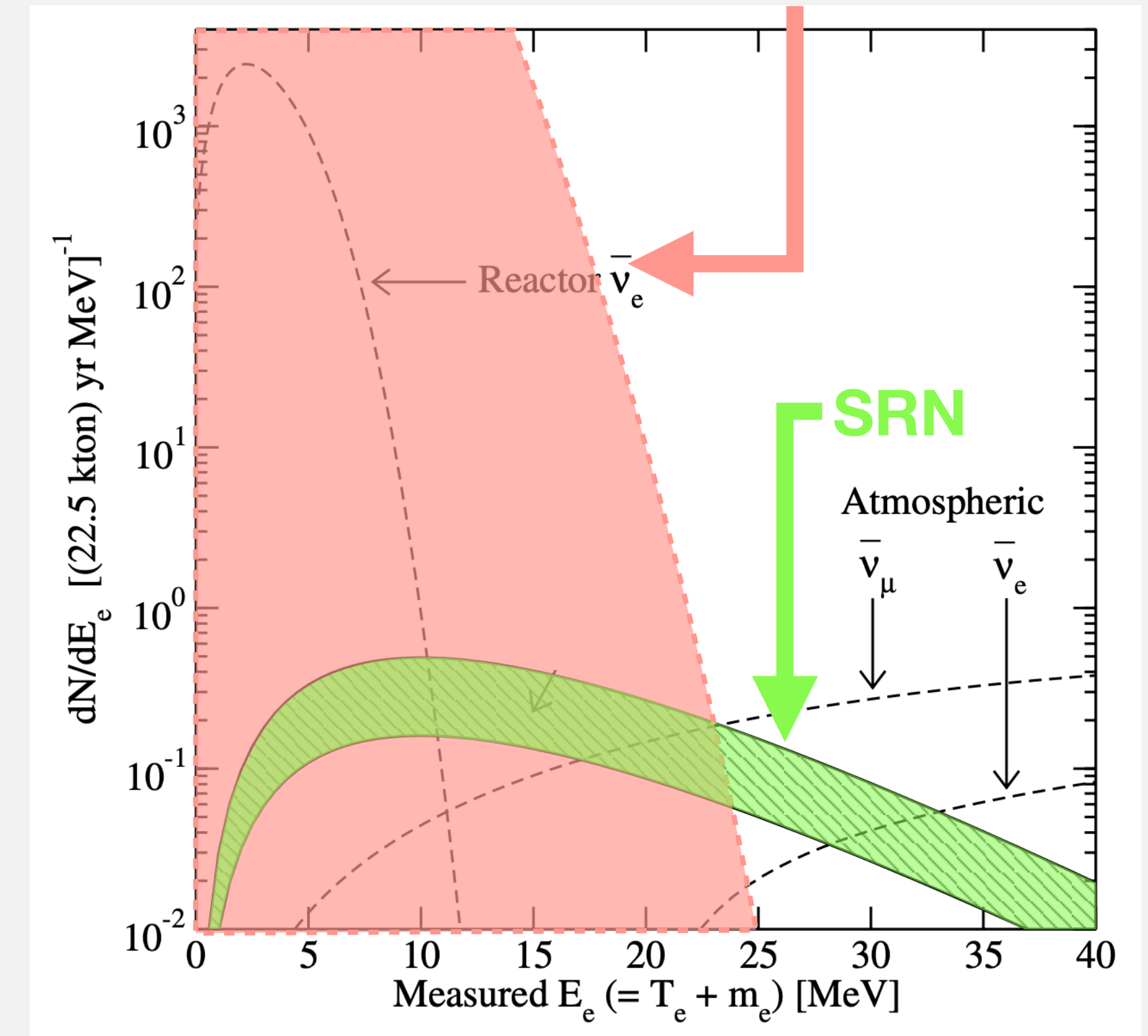


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- The **cumulative neutrinos** created by all past **core collapse supernovae** in the universe.
- Estimate **5-20 events/year** from 8-80 MeV for a 50 ktonne water Cherenkov detector.
- Can be identified through inverse beta decay interactions:



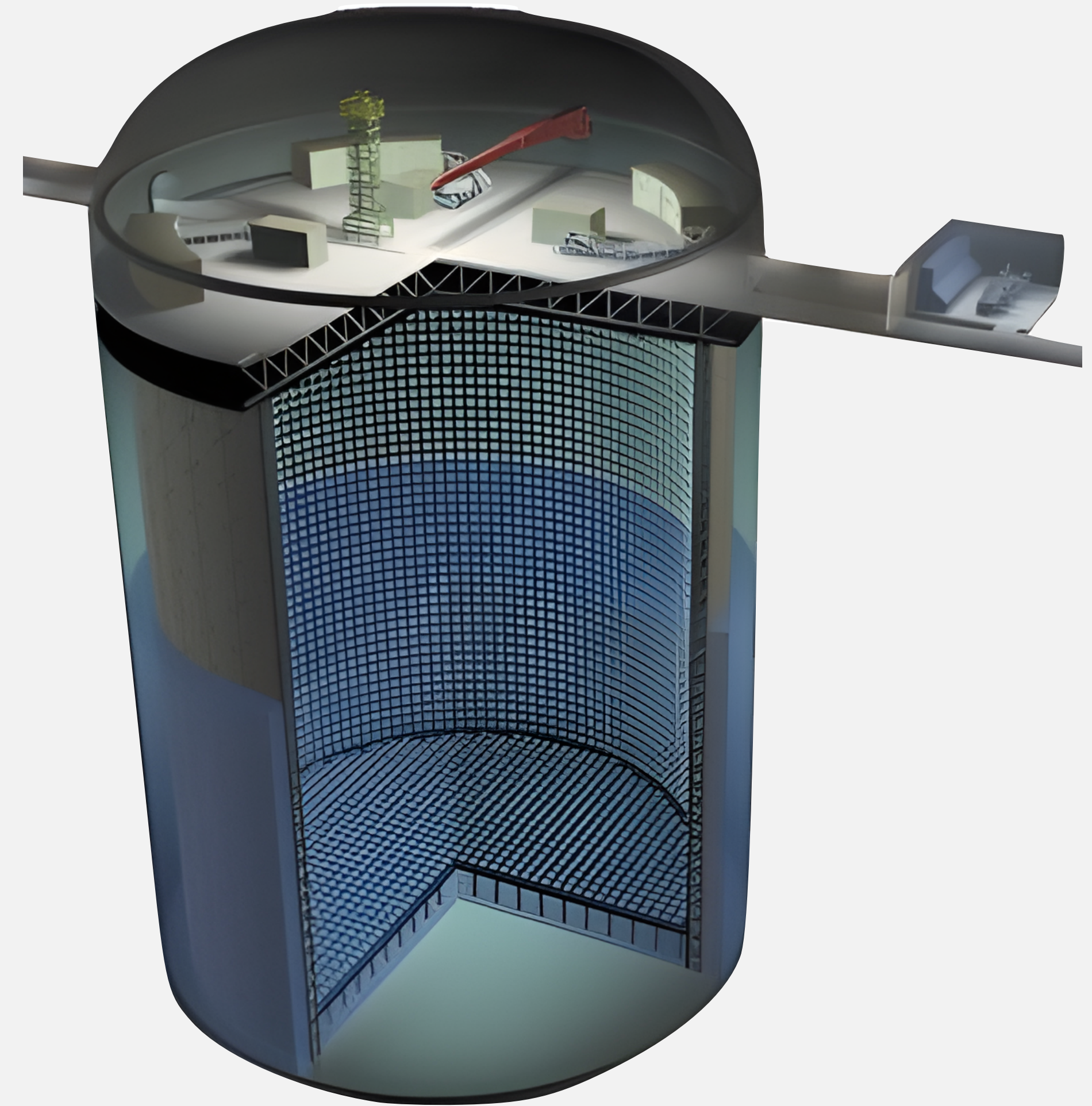
## Cosmic muon spallation



**Spallation background overlaid onto the positron kinetic energy spectra for low energy antineutrino events.**

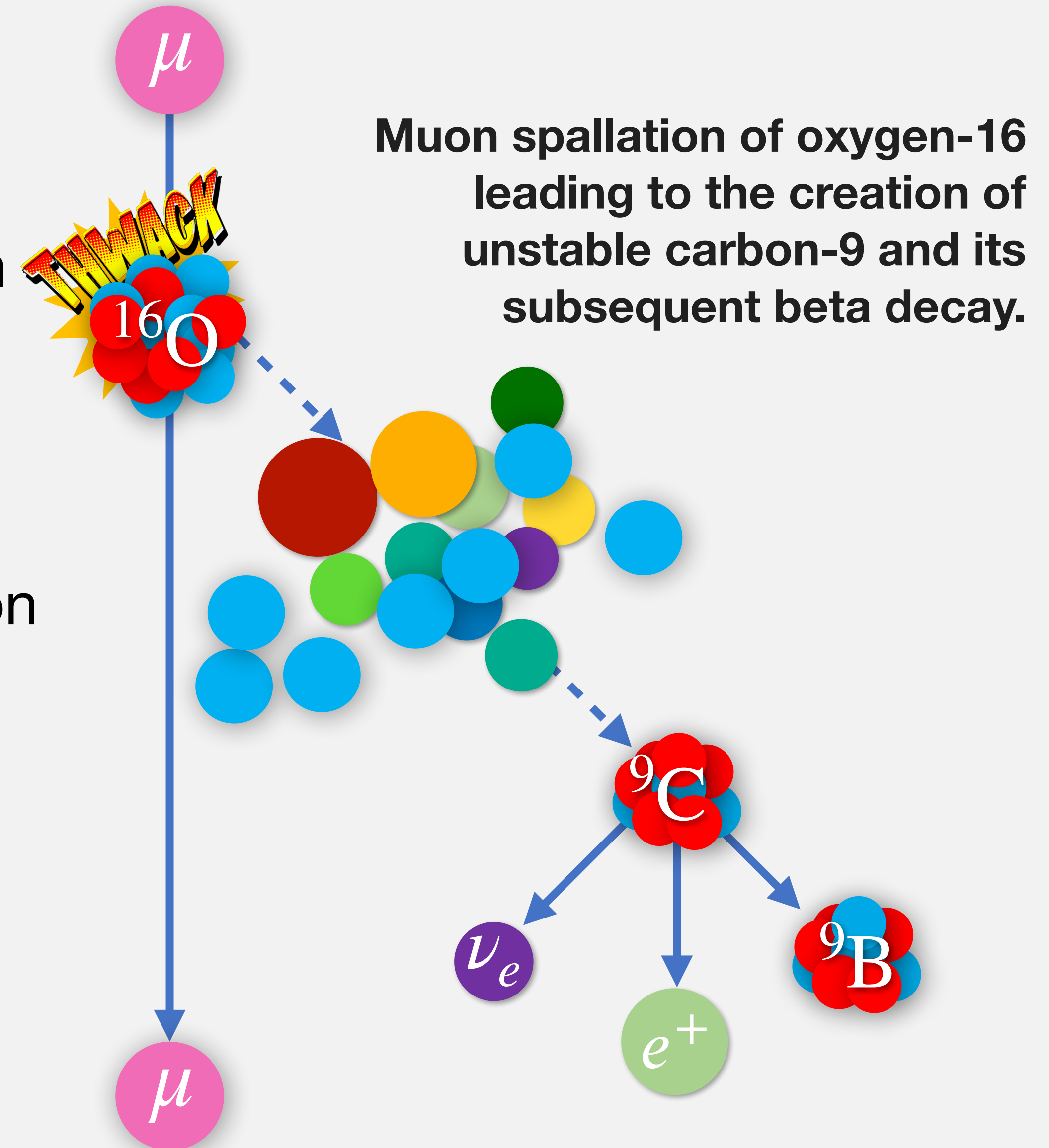
PhysRevLett.93.171101

- **Super-Kamiokande Gadolinium (SKGd)**
  - **50 ktonne Gd-water Cherenkov detector** located in western Japan.
  - Underneath 1000 m (2700 m.w.e) of rock. **Reduces muon rate to ~ 2.5 Hz.**
  - Operational since 1996 currently in phase VII with **0.03% Gd by weight.**
- **Hyper-Kamiokande** - Future 260 ktonne pure water Cherenkov detector.
  - 650 m rock overburden (1755 m.w.e) – Muon rate ~45 Hz. Spallation background will be even higher.



**Super-Kamiokande detector. The 2.5 m thick outer detector can be seen.**

- Muons produce daughter particles that initiate **electromagnetic and hadronic showers through spallation processes.**
- **Hadronic showers** are the dominant production route for **unstable isotopes.**
  - 89% vs 11% for direct interactions between muon and oxygen nuclei.
- Decay products  $e^{\pm}$ ,  $n$ ,  $\gamma$ , are **produced at low energy** –  $< 20$  MeV
- Showers can be **located by neutron captures...**



Create a **simulation-based** cut using **machine learning** to classify spallation-caused low-E events against SRN candidates.

Transport muons with MUSIC



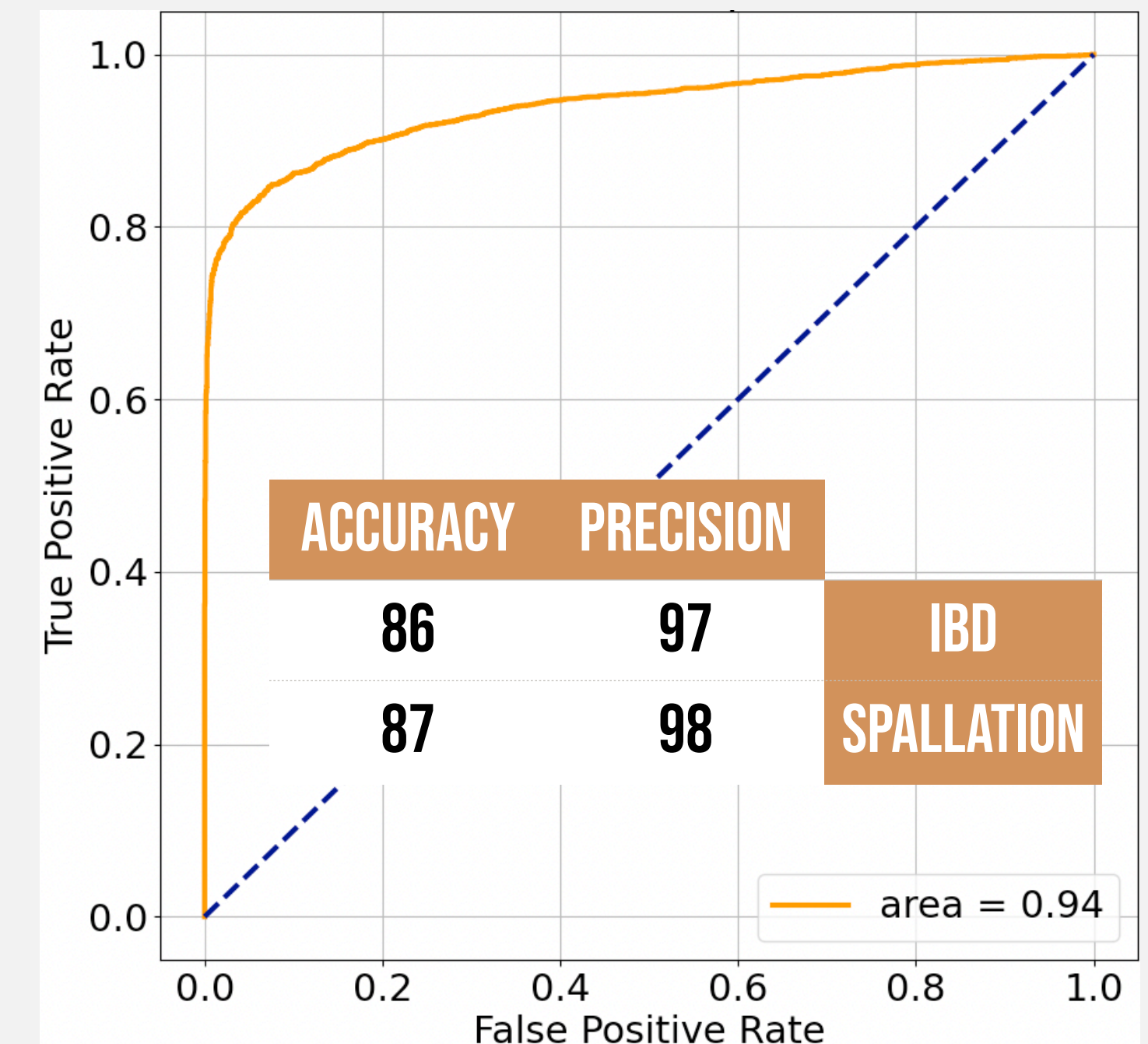
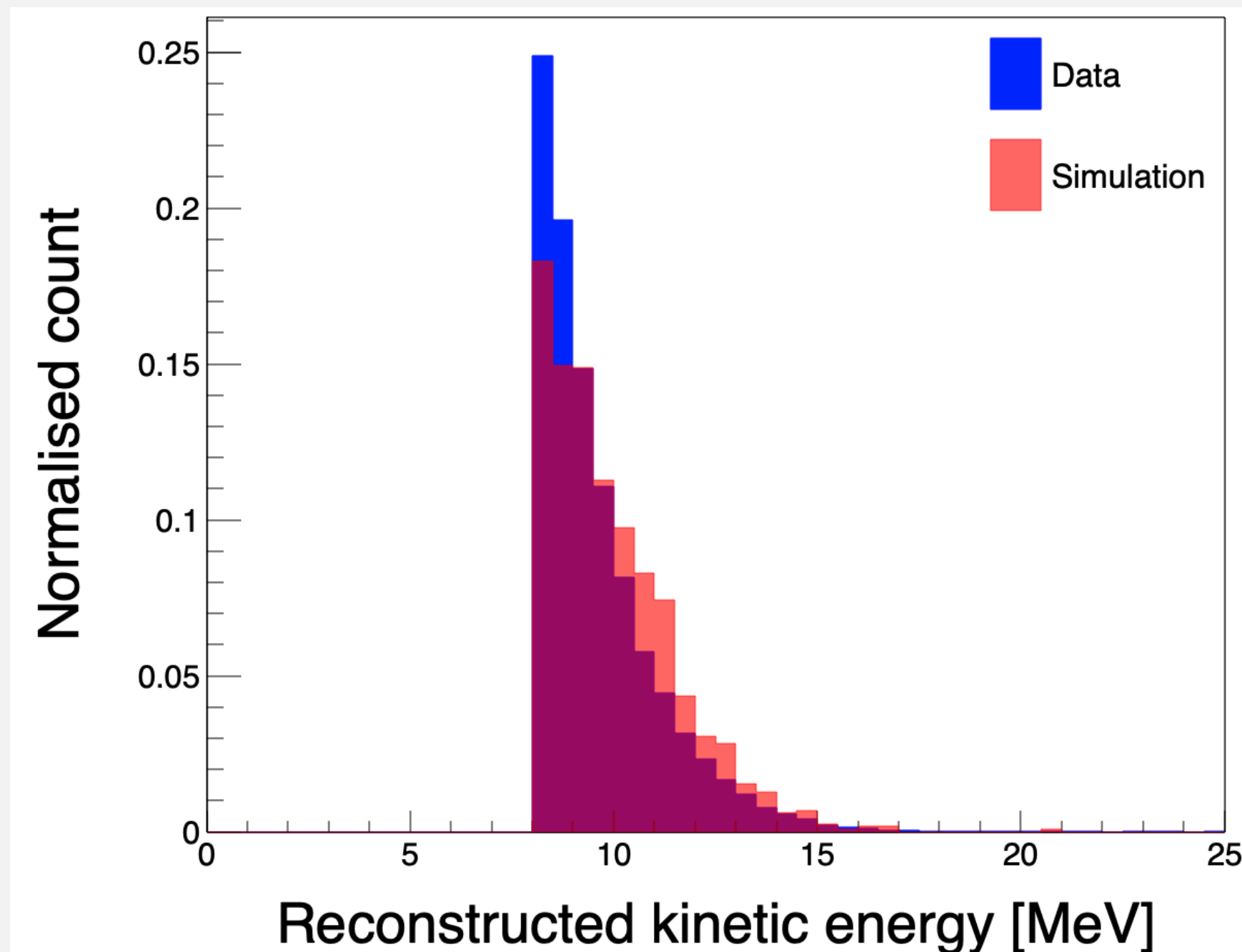
FLUKA

Detector response sim

Machine learning classification

Simulation results show a **good agreement with SK data** (left).

Preliminary machine learning classifications show **good discrimination power** between spallation-caused LowE events and IBD events (right).

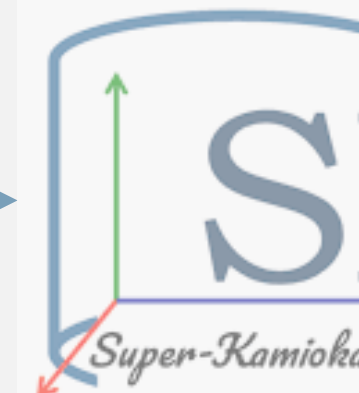


Create a simulation-based cut using machine learning to discriminate spallation-caused low-E events against IBD events

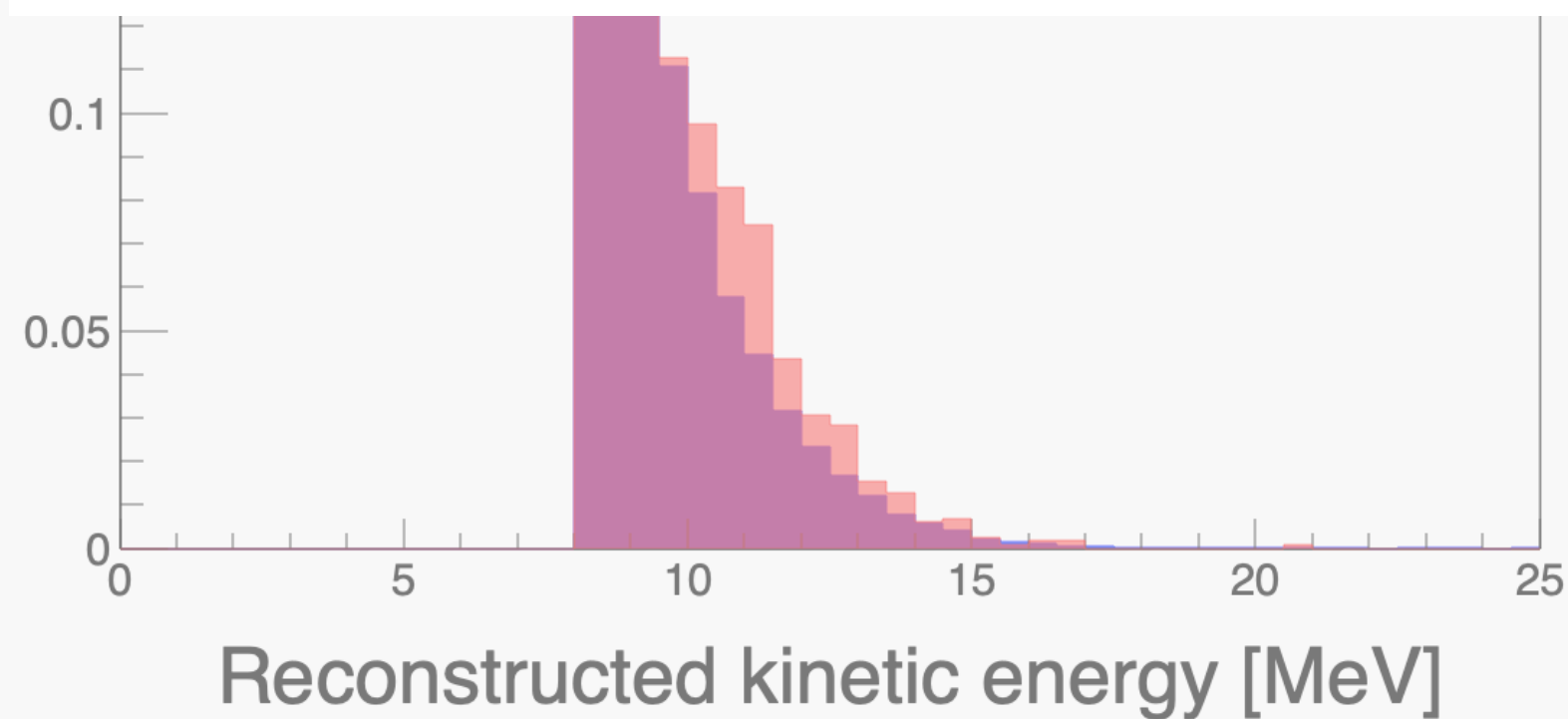
Transport muons with MUSIC



FLUKA



Please feel free to chat to me in the poster session at poster EX-15.



Simulation results show good agreement with data (left). Preliminary machine learning classifications show good discrimination power between spallation-caused LowE events and IBD events (right).

University of Sheffield | MODELLING COSMIC RAY MUON SPALLATION FOR SUPER & HYPER-KAMIOKANDE DSNB | JACK FANNON | HYPER-KAMIOKANDE

**SUPER-KAMIOKANDE**

- 50 ktonnes water Cherenkov (WATCH) detector.
- Cylinder ~40 m diameter by 40 m.
- Water is doped with Gd to 0.03%
- Higher neutron capture cross section, energy and shorter time to capture
- 2.2 MeV  $\gamma$  on H vs ~8 MeV  $\gamma$  cascade on Gd.
- 200  $\mu$ s at 0% and ~70  $\mu$ s at 0.03% Gd
- 1000 m overburden

**HYPER-KAMIOKANDE**

- Planned to turn on in 2027
- Will hold 260 ktonnes of pure water (190 ktonnes fiducial).
- Cylinder 68 m diameter 71 m tall
- Instrumented by ~20000 50 cm PMTs + 1000 mPMTs (ID) for 20% photosensor coverage.
- Outer detector used for muon-veto.
- ~600 m overburden.

THE EXPERIMENT

Diagram of the SK experiment. The inner detector, outer detector, dome, control room, and water filtration system can be seen [1].

**DIFFUSE SUPERNOVA BACKGROUND NEUTRINOS**

- Neutrinos created by all past core collapse supernovae in the universe.
- Detection would yield information about the stellar collapse/formation rate.
- Main channel for DSNB detection in WATCH is inverse beta decay (IBD):
- Prompt Cherenkov ring from positron.
- Delayed flash of light from neutron capture.
- Detection limited by statistics and overwhelming backgrounds.

**MUON SPALLATION**

- High energy muons can cause hadronic showers in water.
- Unstable radioactive isotopes can be created in the showers.
- Some isotopes decay to electron/positrons in the < 20 MeV range.
- Current Super-Kamiokande SRN spallation reductions are data-based and spallation remains a major background.
- Could a simulation based, machine learning classifier be more efficient in reducing the spallation background?

**SIMULATIONS**

- MUSIC, a muon propagation code, calculates the expected muon flux at HK and SK.
- Particle physics simulation, FLUKA, is used to simulate the muon interactions in water.
- Events creating background-causing isotopes are selected and particle primaries are written out.
- Output is piped into detector response simulations - SKG4 (SK) and WCSim (HK).

**RESULTS & NEXT STEPS**

- SKG4 simulation shows a good agreement with data events after passing through part of the data reduction.
- Preliminary training runs of machine learning classification shows good classifying power with gradient boosting classifier.
- Generate more backgrounds for a HK DSNB analysis: solar and atmospheric neutrinos.
- Generate an IBD sample (generator added to WCSim) to use as signal events for the HK analysis and run the classifier for HK.

ACCURACY	PRECISION	IBD	SPALLATION
86	87	88	89

area = 0.94

[1] Kajita, T. & Kearns, Edward & Shiozawa, Mikio. (2016). Establishing Atmospheric Neutrino Oscillations with Super-Kamiokande. Nuclear Physics B. 908. 10.1016/j.nuclphysb.2016.04.017.