Prototype Particle ID for the SABRE South Liquid Scintillator Veto

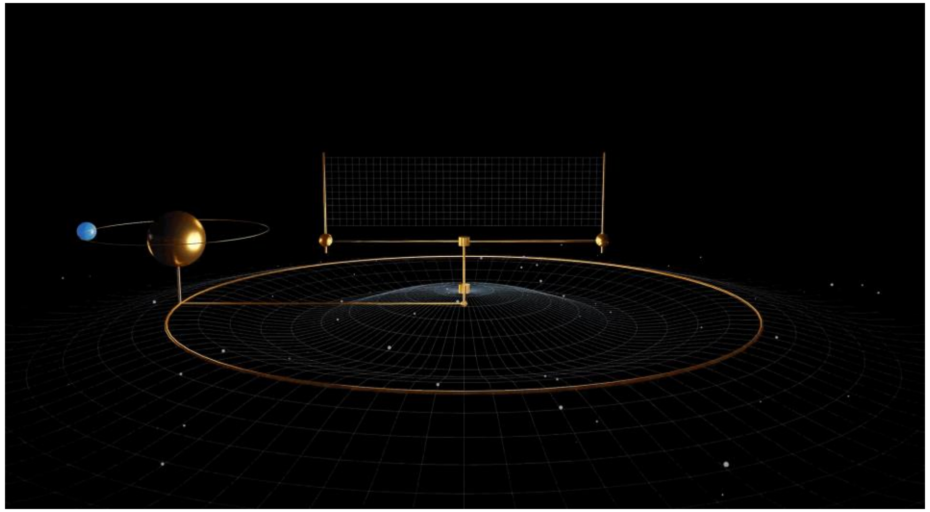
Lachlan Milligan

DAMA/LIBRA and Annual Modulation

- If the galaxy sits within a dark matter halo, it is predicted that the rate of direct detections will vary due to the motion of the Earth in the halo

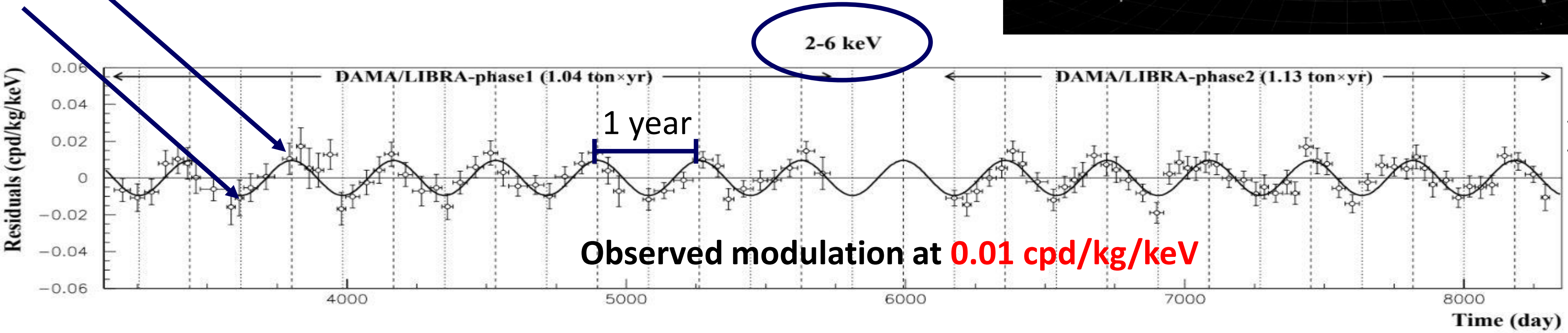
$$R(E) = R_0(E) + R_m \cos(\omega(t - t_0))$$

- DAMA measures annual modulation at 12.9σ
  - **SABRE to verify using same target material**
  - **Technology upgrade with use of active veto and muon veto**



Max in June

Min in Dec.



Observed modulation at 0.01 cpd/kg/keV

R. Bernabei et al., Nuc. Phys. Atom. En.

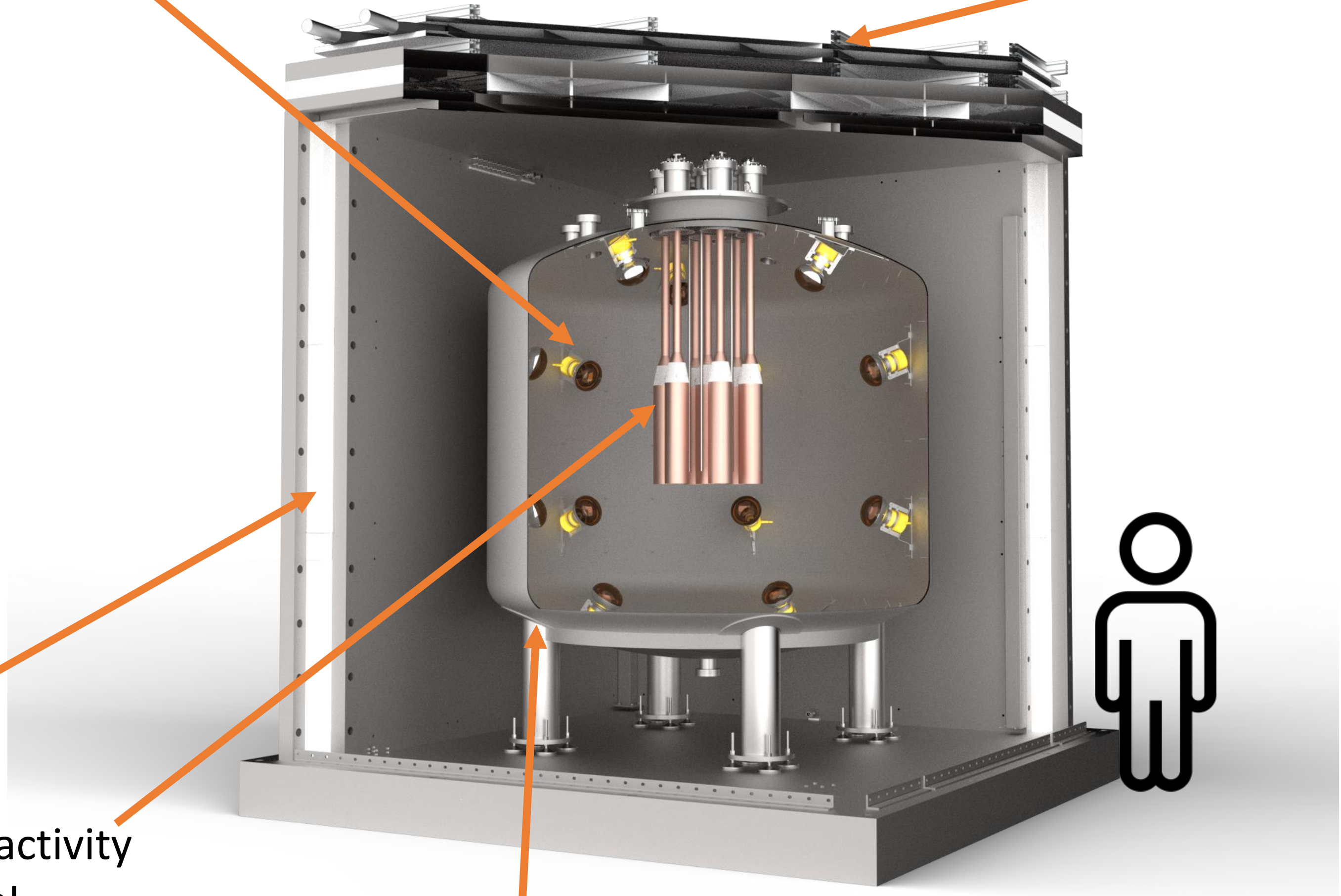
The SABRE South Experiment

Key improvements:

1. High purity NaI(Tl) crystals
2. Lower energy threshold – highly efficient PMTs directly coupled to crystals
3. Dual hemisphere data – SUPL and LNGS
4. **Active background veto**

Liquid scintillator veto:

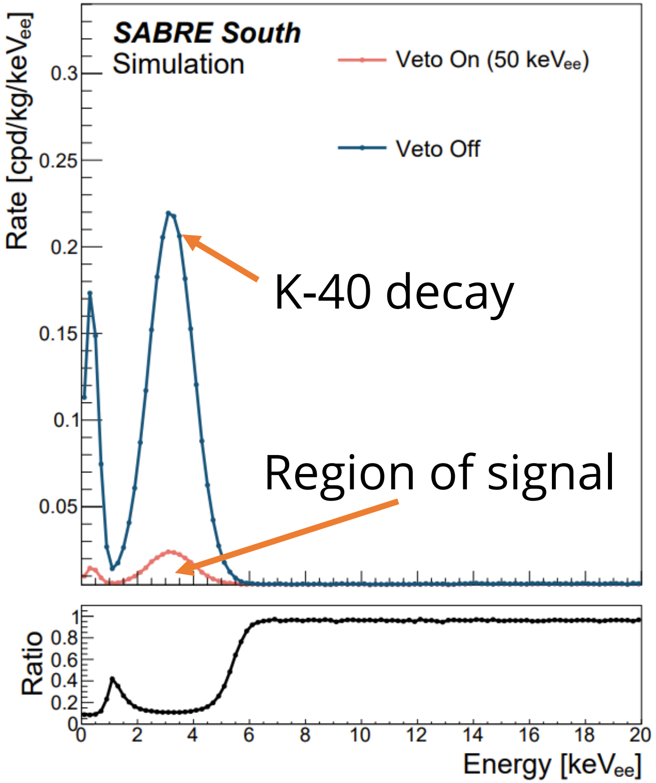
- 12 kL of Linear Alkyl-Benzene doped with PPO and bis-MSB
- 18 Hamamatsu R5912 PMTs



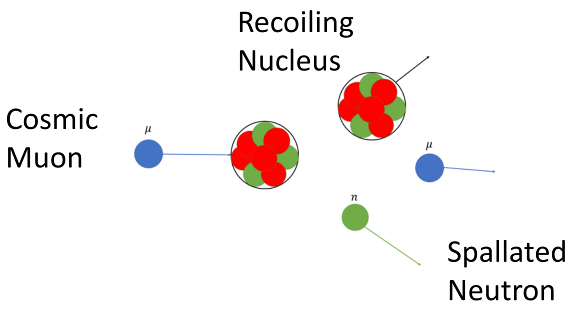
The SABRE South Active Veto

Key purpose:

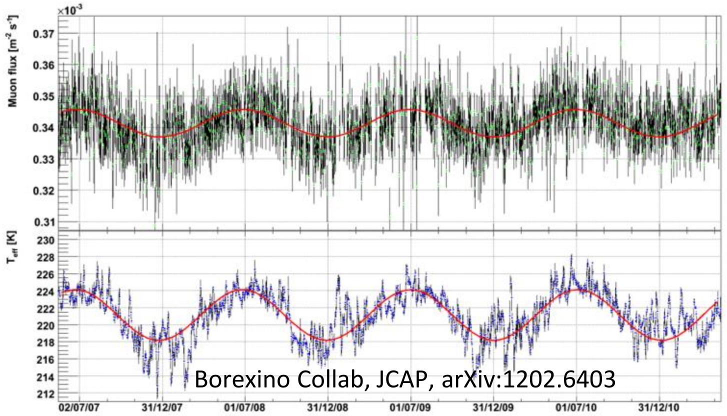
- Optimal veto of K-40 background in crystals (mimic a DM signal)
- Require >85% veto efficiency of K-40 background

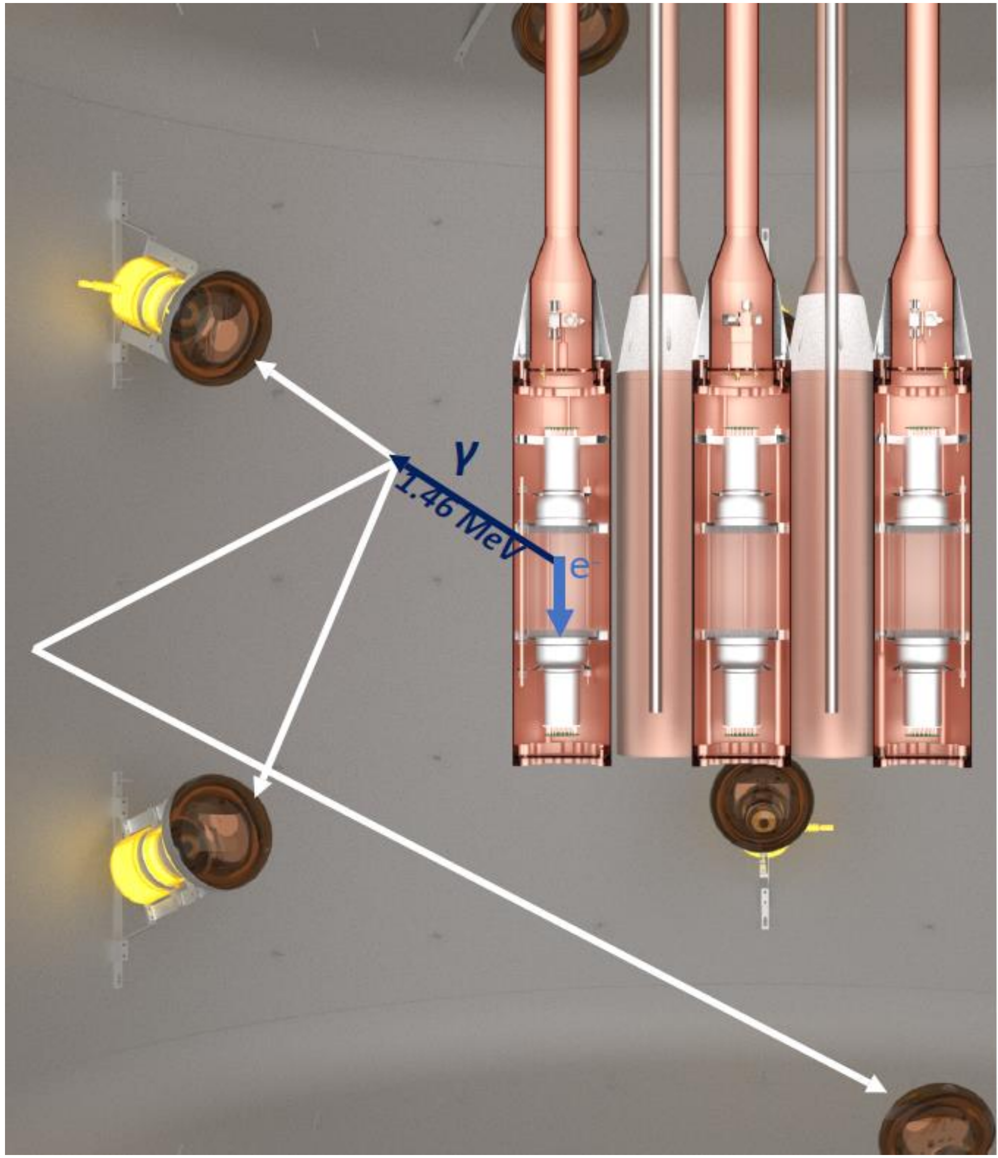


SABRE South Collaboration, arXiv:2205.13849



Borexino Muon Flux Modulation

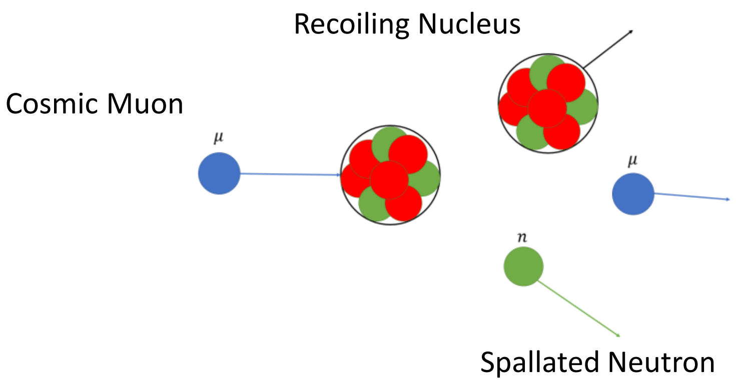




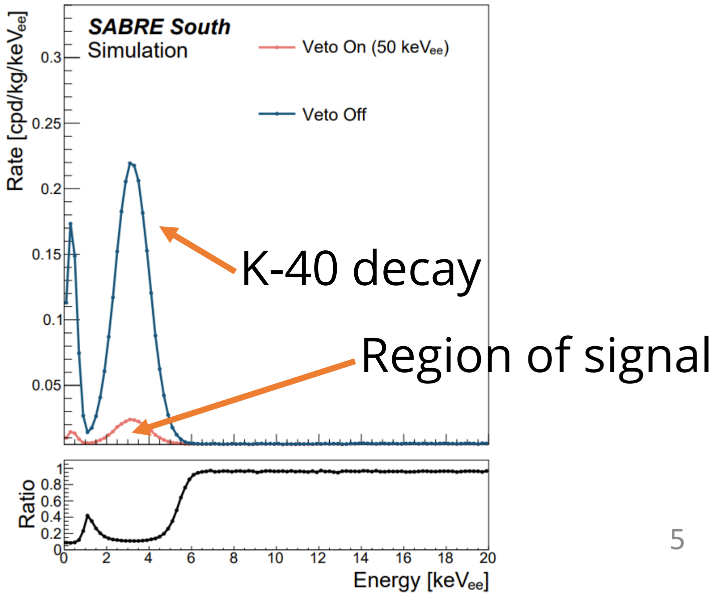
LS Veto Requirements

Can we study the backgrounds detected? → Background position reconstruction and identification

Identify neutron vs. gamma backgrounds?



vs.



Liquid Scintillator Detectors

Large scale neutrino detectors most commonly use liquid scintillator due to:

1. Ability to **separate energy deposits due to neutrons and photons via pulse shape discrimination**
2. Sensitivity to low energies (MeV/keV) i.e. high light yield 12 photons/keV

Necessary for optimal reconstruction of $\bar{\nu} + p \rightarrow n + e^{+}$

SNO+

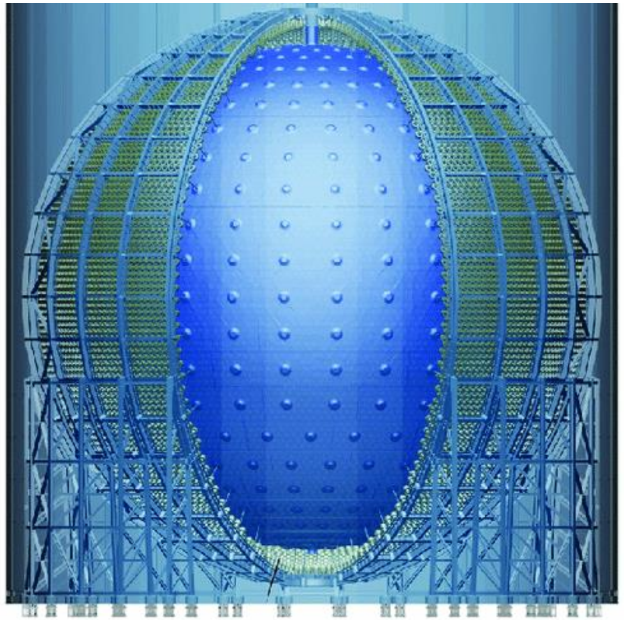
780 tonnes of LAB based LS

Dense array of 25 cm PMTs

JUNO

20 ktonnes of LAB based LS

Array of 51 cm Hamamatsu PMTs



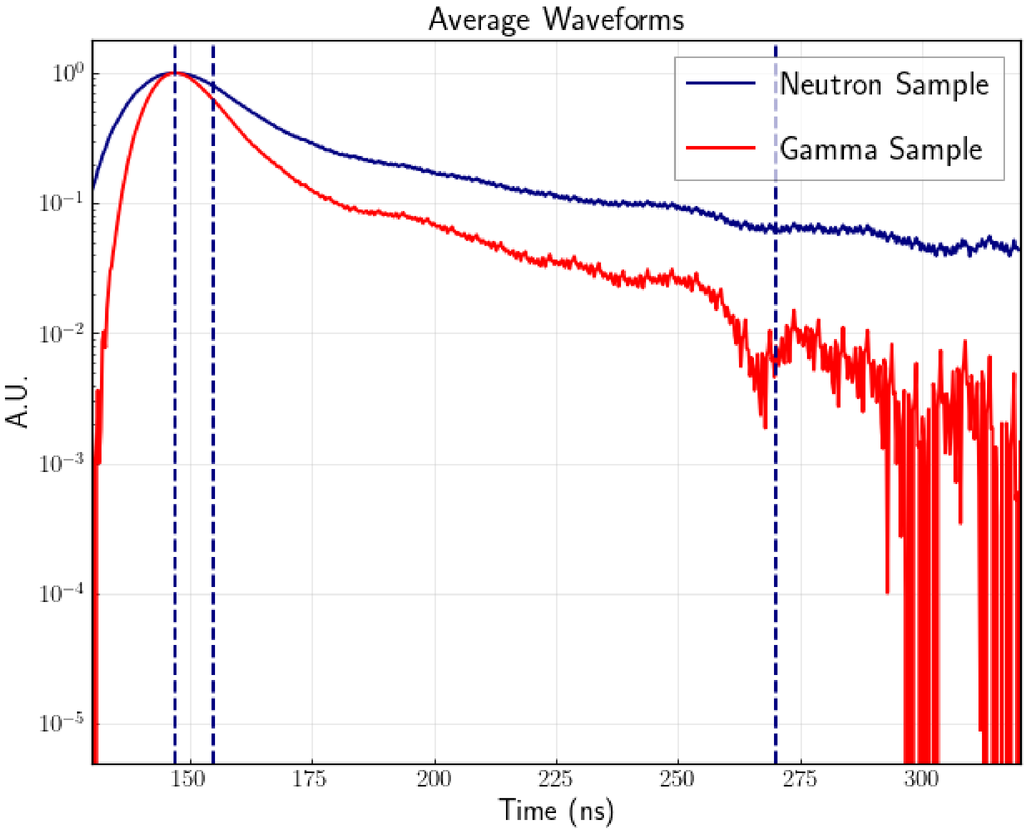
Similar/same components as SABRE South LS veto

Pulse Shape Discrimination

Differing interaction mechanisms ➜ Differing proportions of light in pulse

- Neutron vs. Gamma (nuclear vs. electronic interactions)

Pulse shape variables typically exploit different amounts of light in tail for different particles

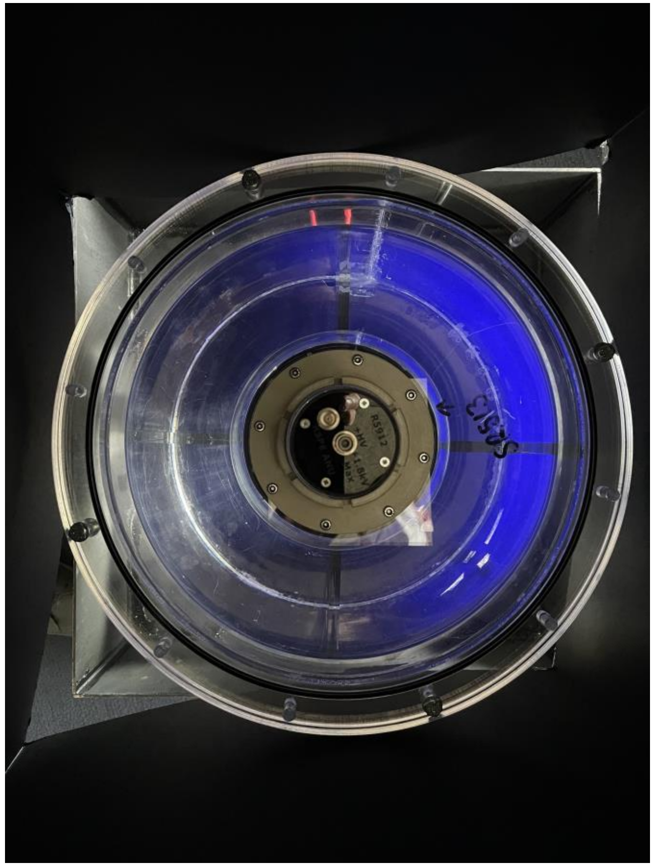


e.g. Charge ratio variables exploit higher proportion of delayed light emission in neutron interactions

$$Q_{ratio} = \frac{Q_{delayed}}{Q_{prompt}}$$

Pulse Shape Discrimination with Prototype

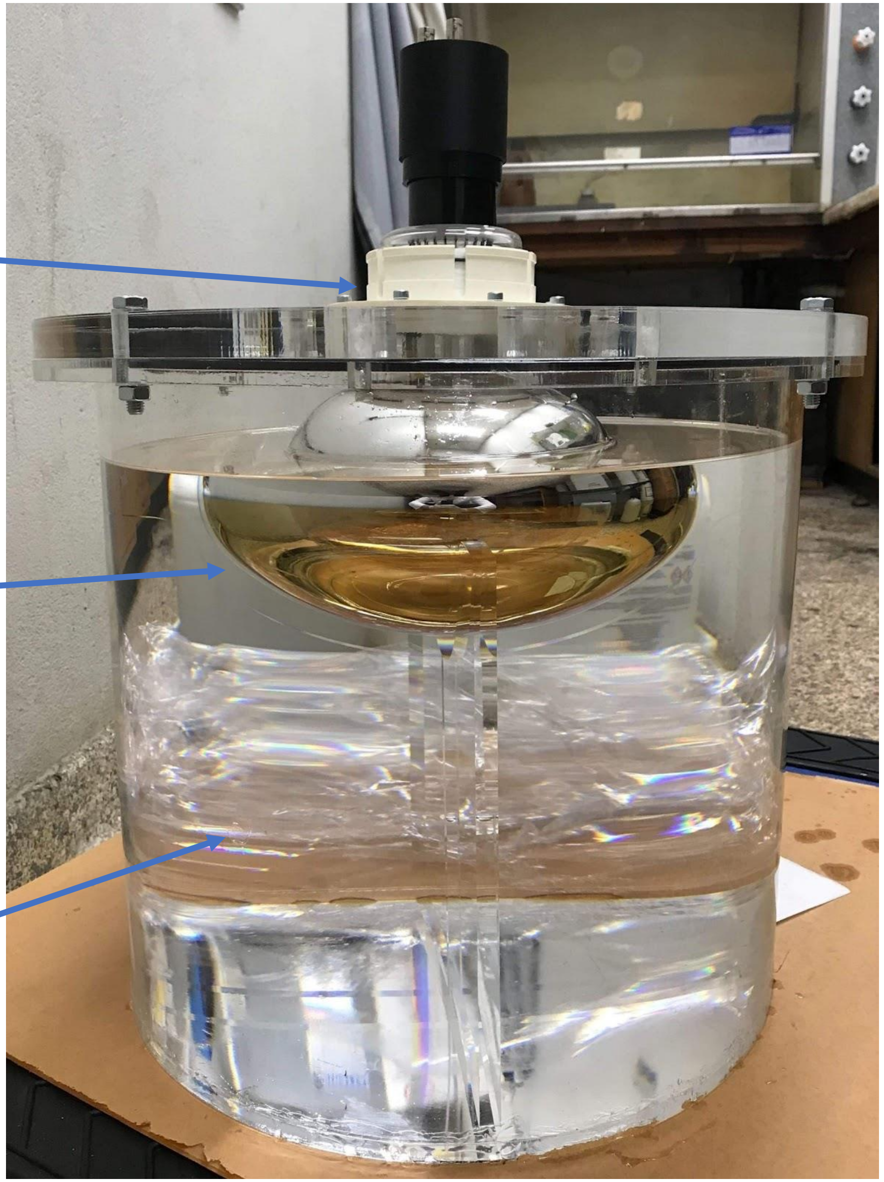
Simplified prototype of veto: SABRINA (little SABRE) – study discrimination b/w gammas/neutrons



3D printed flange holding up PMT with rubber O-ring

Directly coupled Hamamatsu R5912 PMT

LAB-based LS, with 3g/L of PPO and 15mg/L of bisMSB



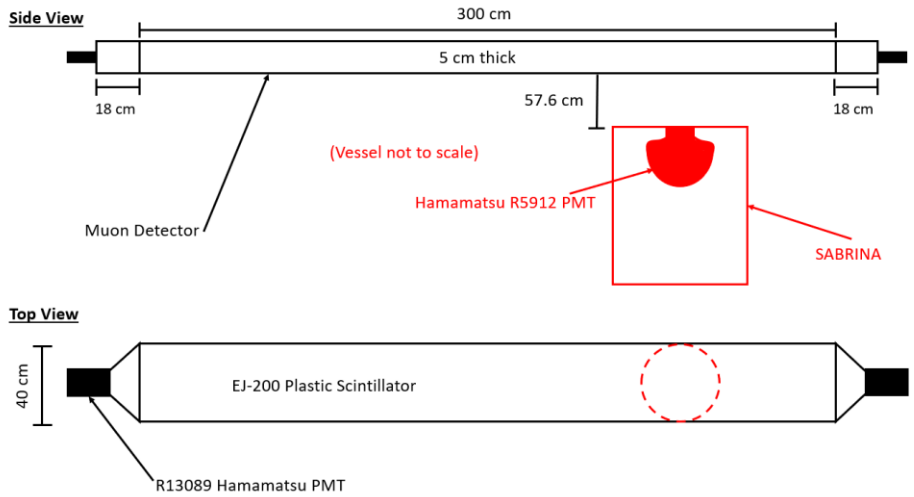
Pulse Shape Discrimination with Prototype

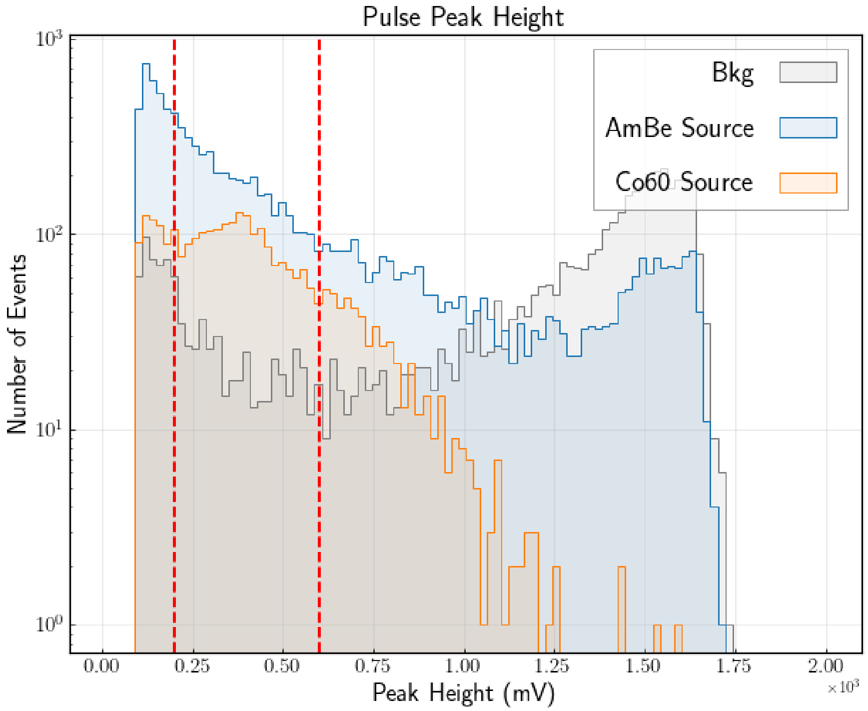
Am-Be neutron/gamma source + Co-60 gamma source

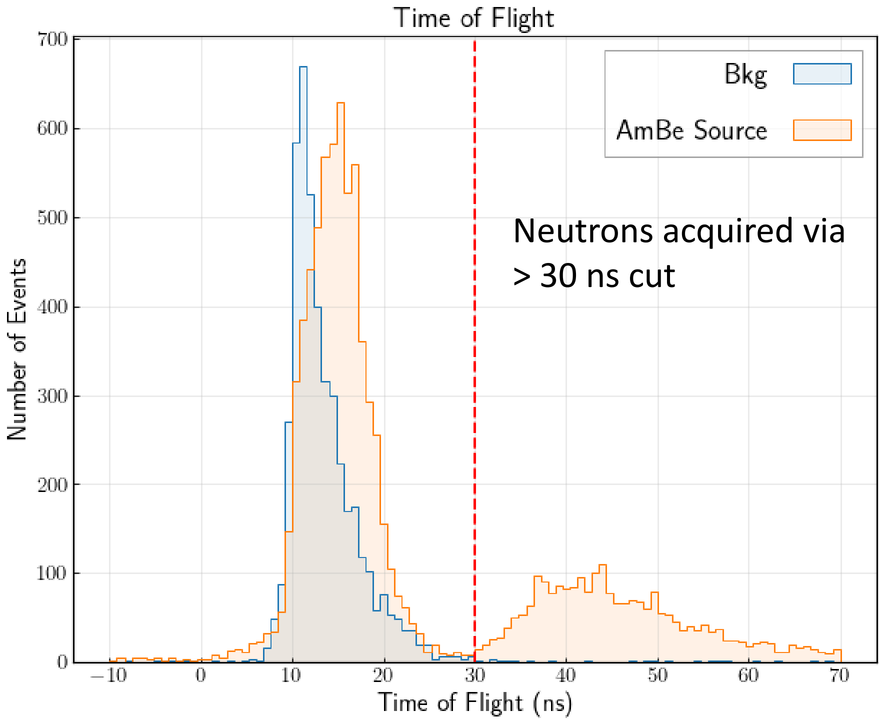
Clean neutron sample required

- Utilise time-of-flight between SABRINA and muon detector

Gamma sample from Co-60 source w/ muons excluded by requiring events to be >200mV and <600mV







Pulse Shape Discrimination with Prototype

New multivariate approach developed to combine variables

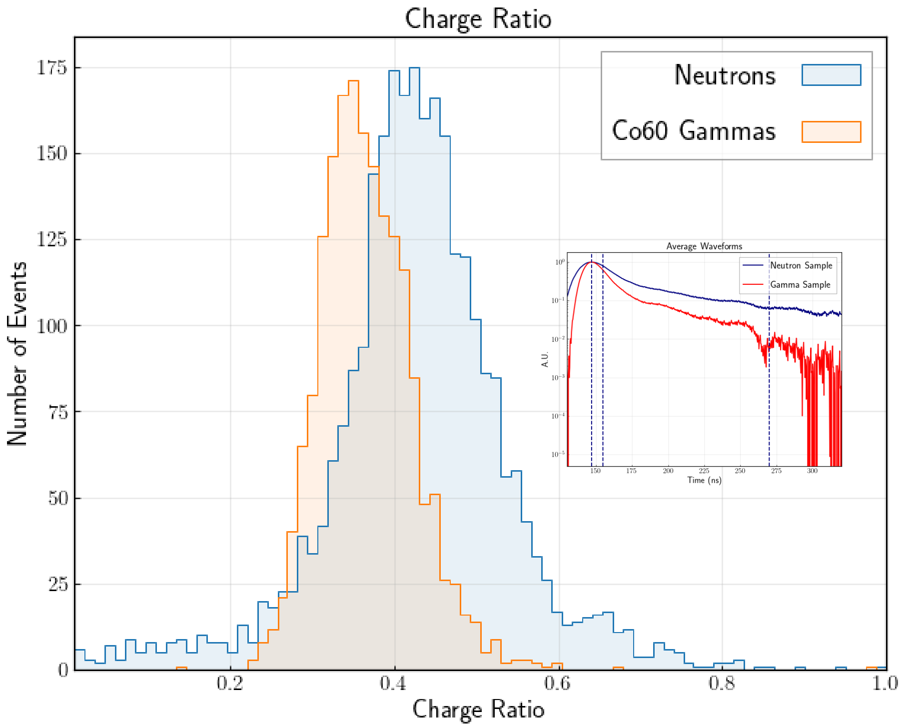
Ensemble of pulse shape variables fed into multivariate discriminator

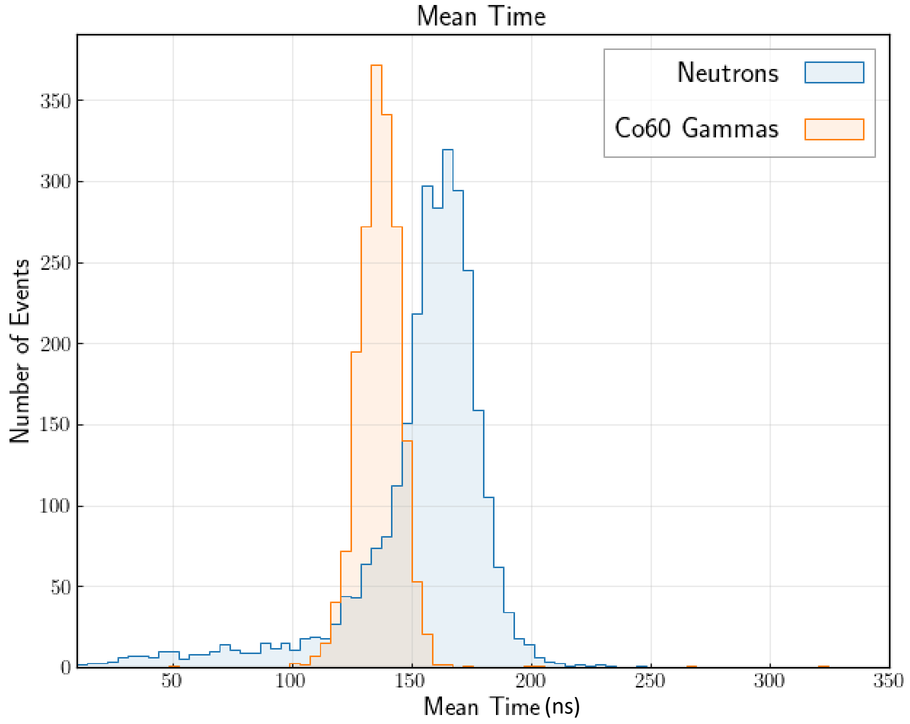
This study utilises the 4 pulse shape variable fed into a boosted decision tree (BDT)

Charge ratio $$Q_{ratio} = \frac{Q_{delayed}}{Q_{prompt}}$$

Amplitude weighted mean time: Modification to charge calculation accounting for duration of pulse

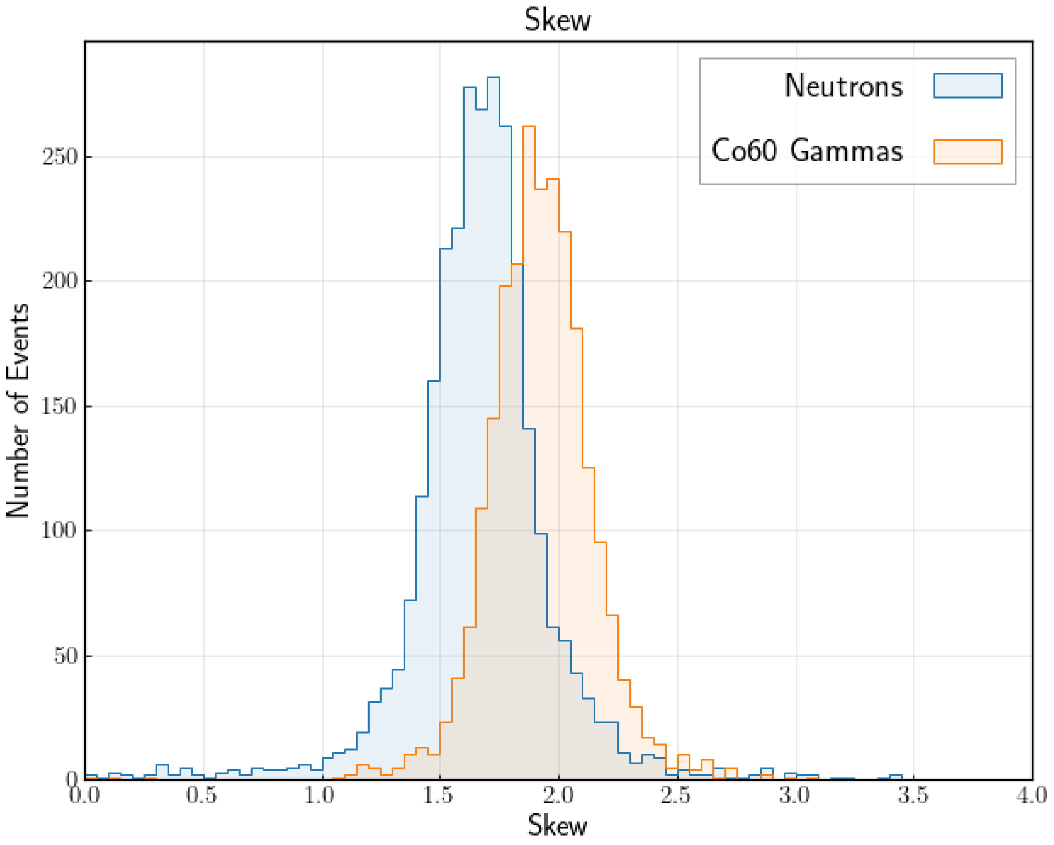
$$\langle t \rangle = \frac{\sum_i A_i t_i}{\sum_i A_i}.$$



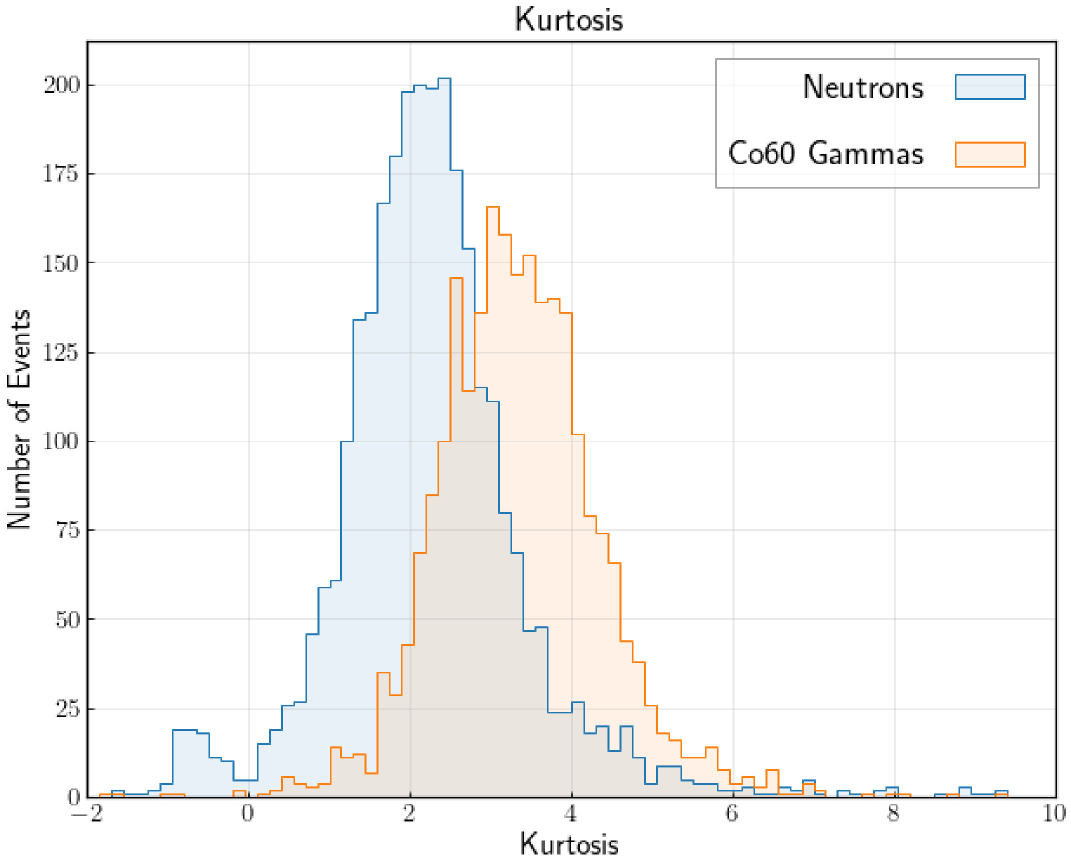


Pulse Shape Discrimination with Prototype

Skew: third statistical moment of pulse



Kurtosis: fourth statistical moment of pulse



Pulse Shape Discrimination with Prototype

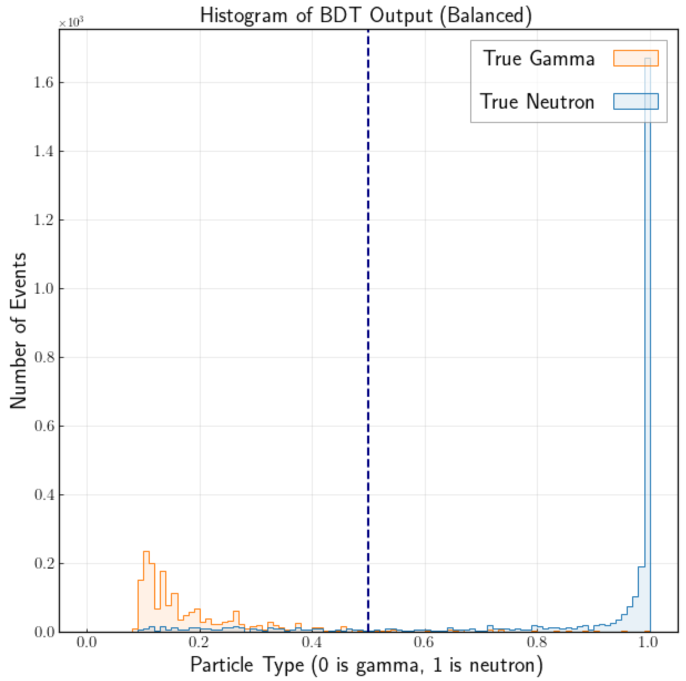
BDT utilised for multivariate discrimination

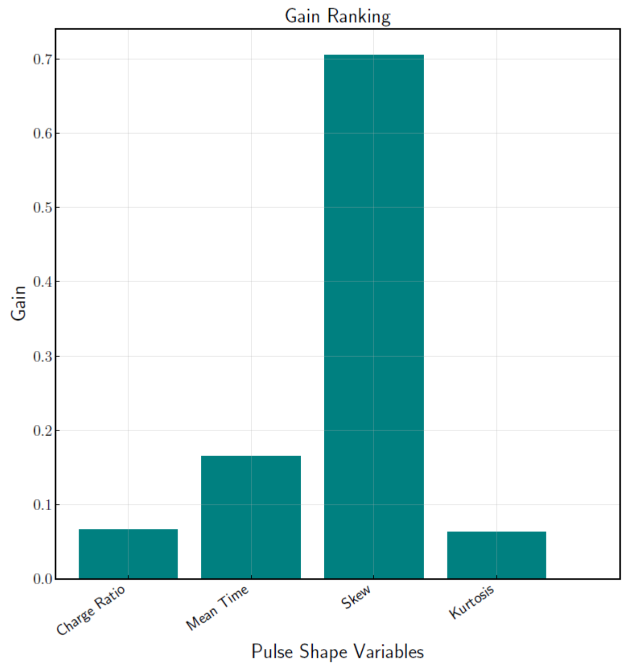
- Compare performance of single cut on commonly used variable to BDT performance
- BDT (neutron): ~90% efficiency, ~10% fake rate
- Q_{ratio} (neutron): ~60% efficiency, ~35% fake rate

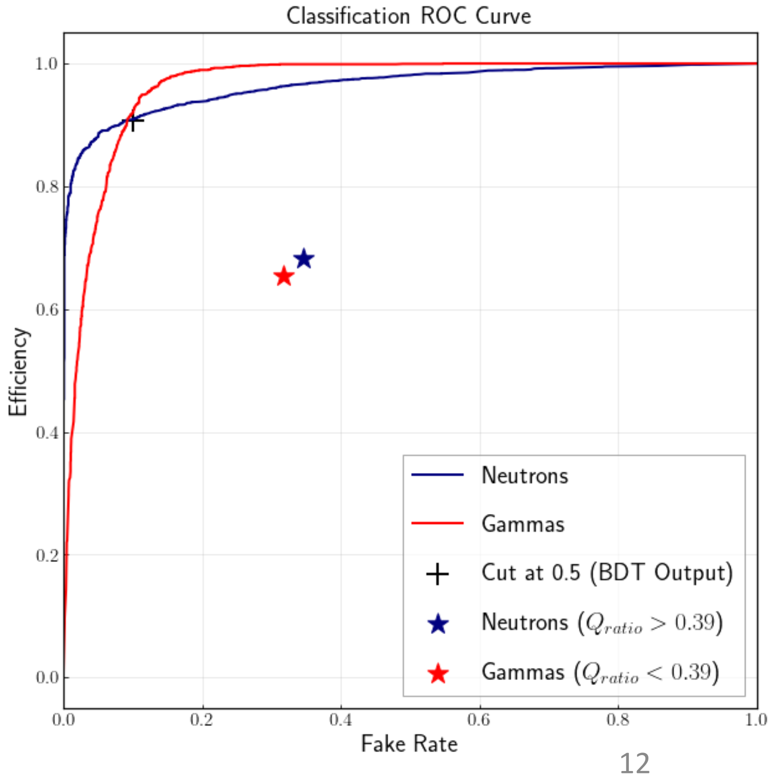
Understanding of BDT performance at over a range energies is also required

- Need to be done via simulation w/ digitisation

Also testing effect of lumirror







Summary

SABRE veto purpose built to veto key WIMP mimics

Background identification being explored via studies of particle ID with prototype detector

Discrimination between neutrons and gamma rays with variables exploiting different pulse shapes

BDT combining PSD variables showing promise with improved neutron/gamma discrimination