Carnegie Mellon University

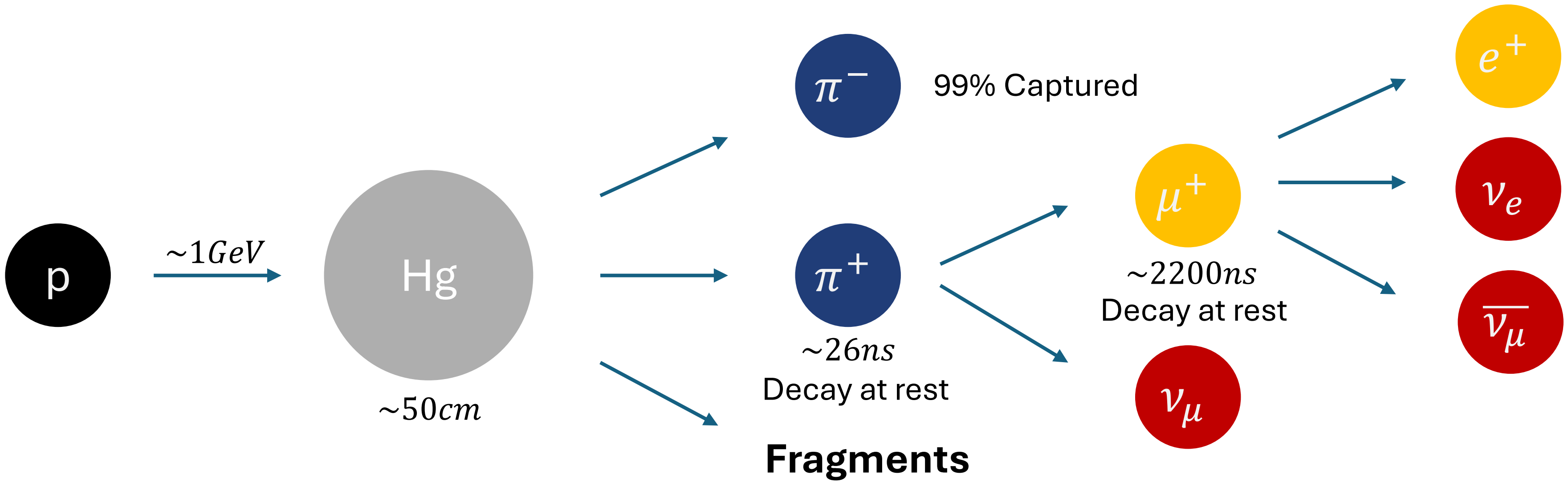
Module 2 of the COHERENT D2O Detector

Gen Li and Kirsten McMichael

Magnificent CEvNS

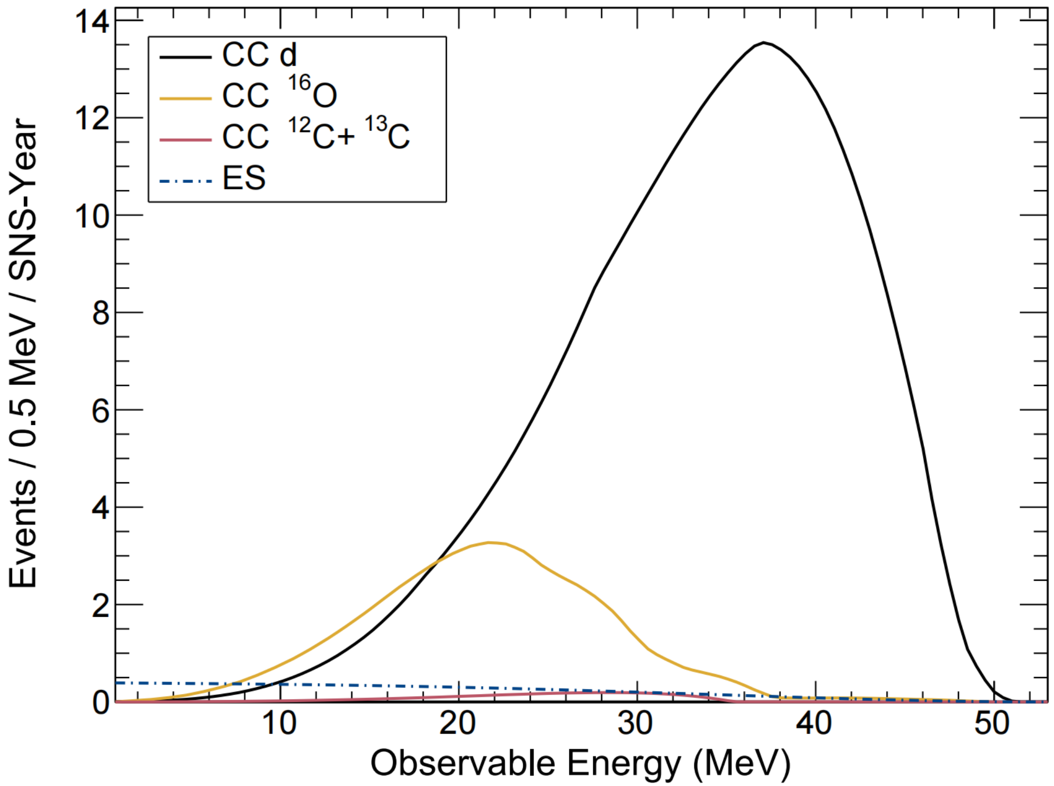
June 2024

Neutrino Flux from ORNL SNS



Motivations for D2O Detector

- ν flux is simulated at $\sim 10\%$ uncertainty.
- D2O: $\nu_e + d \to p + p + e^-$
- Cross section for CC $\nu_e + {}^{16}O$ has never been tested at this energy range → Module 2



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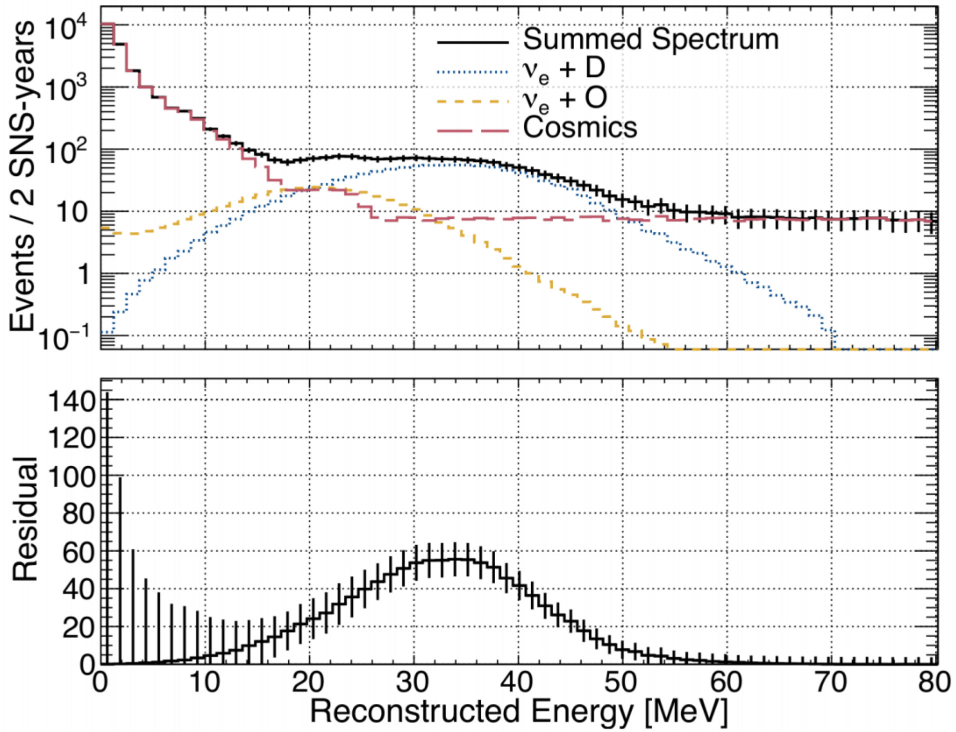
Motivations for D2O Module 2

- Module 2 has the same design as Module 1, except for containing H2O instead of D2O.
- Measure σ of $\nu_e +^{16} O \rightarrow e^- +^{16} O$ without the background from CC $\nu_e + d$.
- Interesting to large-scale water Cherenkov detectors (Super K and Hyper K) !



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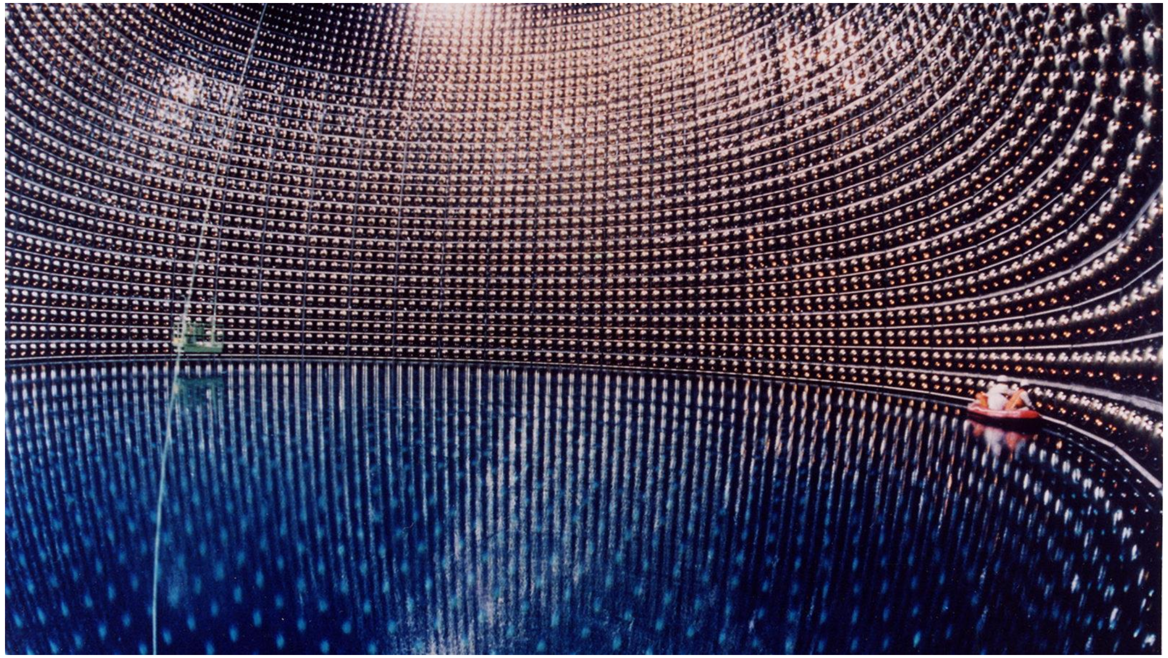
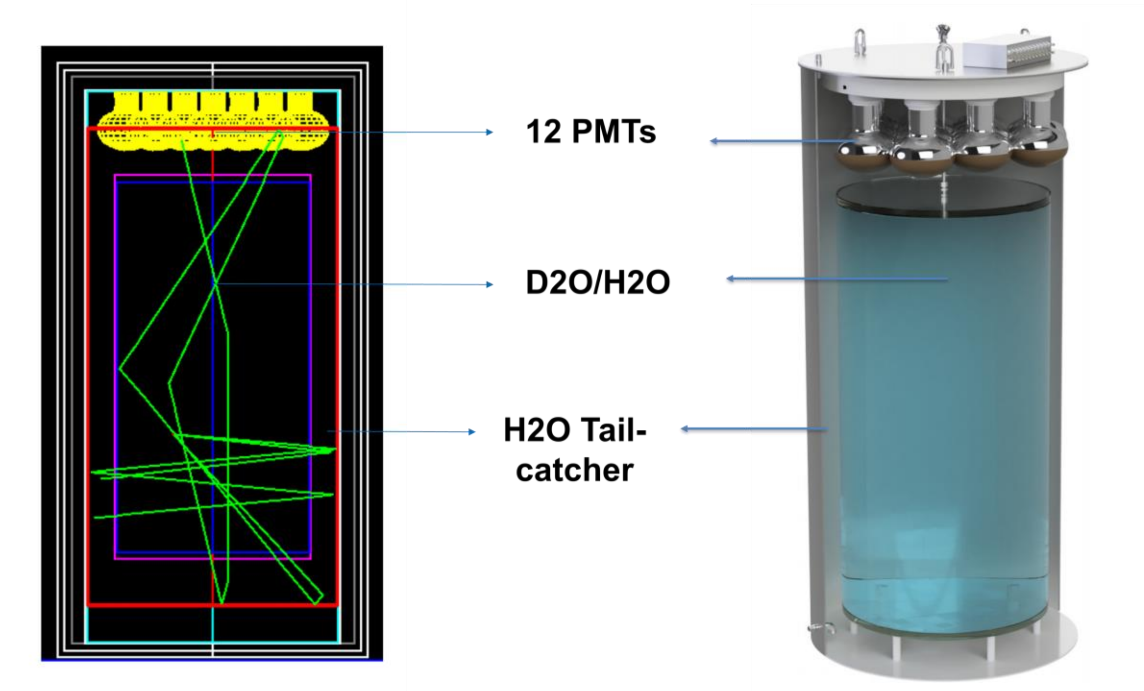


Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo

Design of D2O Detector

- Water Cherenkov Detector
- 592kg D2O in acrylic tank
- 12 PMTs for Cherenkov radiation
- Tyvek covers inner wall of steel vessel
- Outside: lead shielding + muon veto panels



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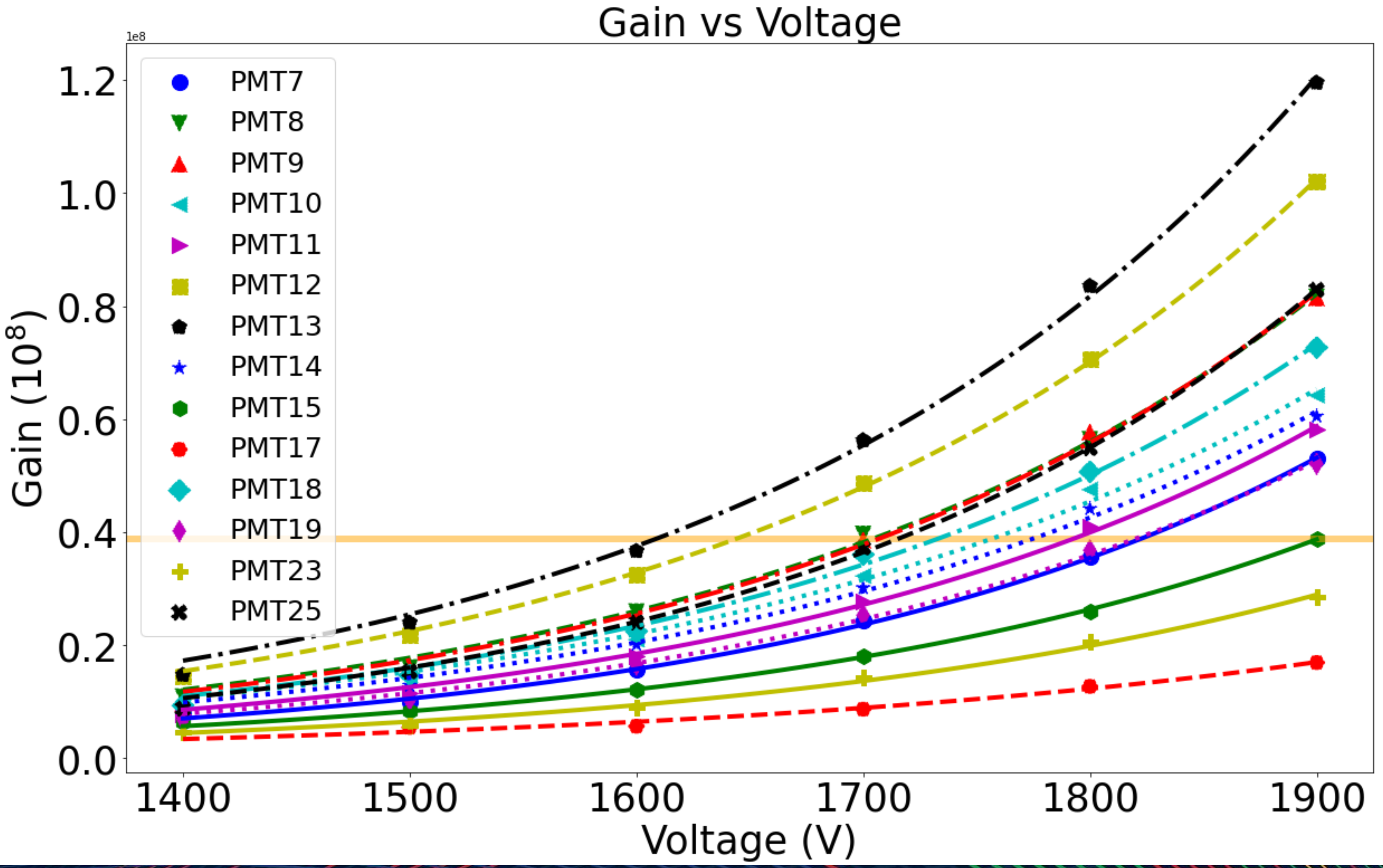
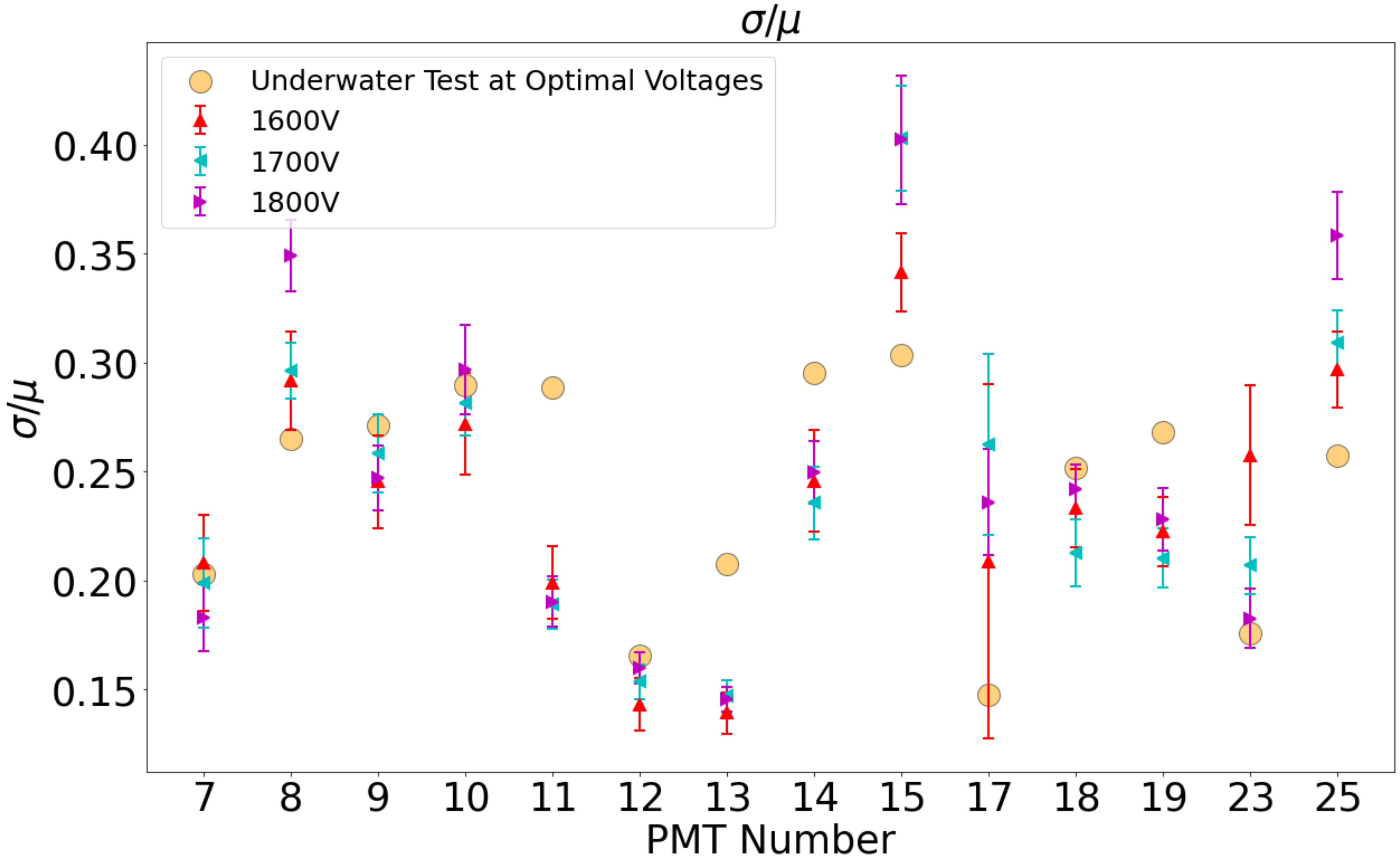
PMT Testing Results for D2O Module 2



- According to the gain of PMT15 at 1900V, we found the optimal voltage for each PMT to get the same gain.

PMT Testing Results for D2O Module 2



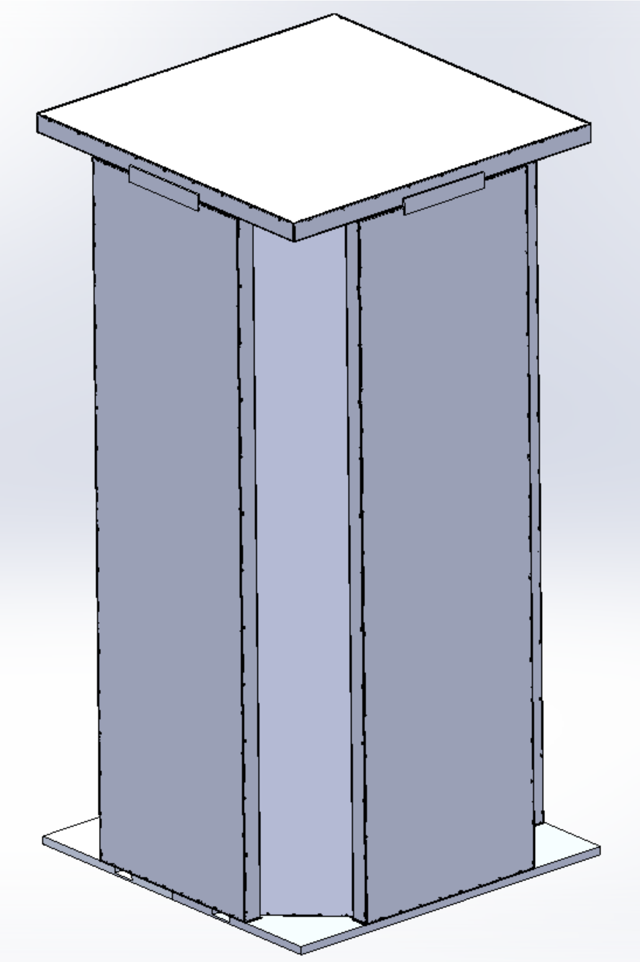
PMT Selection

PMT Number	Dark Rate (Hz)	σ/μ	V_{opt} (V)
1107	838	0.27	1820
1108	1188	0.25	1700
1109	1233	0.15	1710
1110	1448	0.21	1760
1111	1068	0.29	1790
1112	906	0.27	1640
1113	898	0.18	1610
1114	1165	0.17	1770
1115	1017	0.26	1900
1117	855	0.26	2200
1118	811	0.3	1730
1119	1483	0.29	1820
1123	806	0.2	1980
1125	1745	0.3	1720

- Ruling out two with the lowest gain and the highest dark rate.

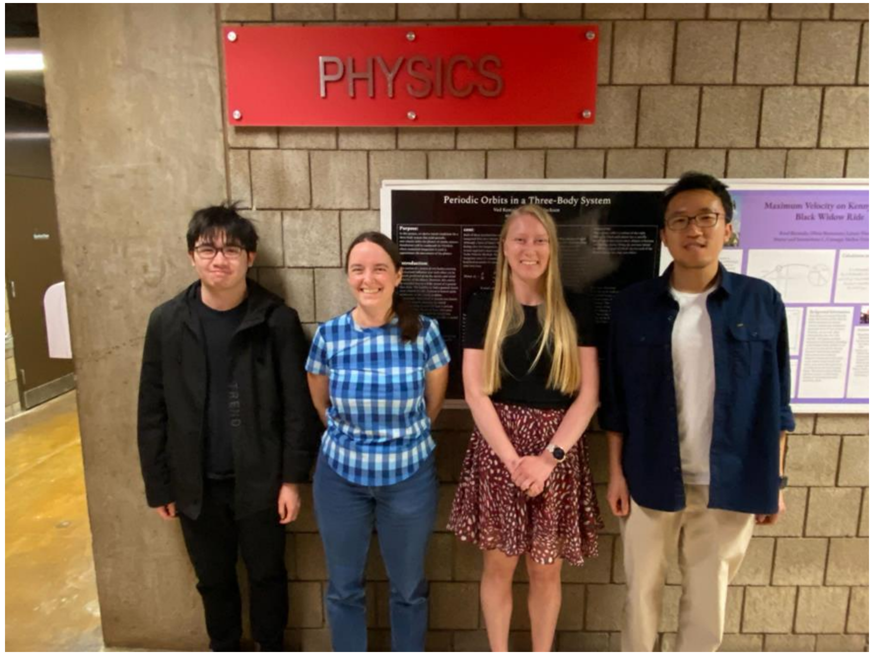
Future Work

- Muon veto panels to be completed.
- Module 2 will be commissioned in summer 2024.
- Next multi-month run with both Module 1 and Module 2 aims to start in Summer 2024.



Acknowledgement

- D2O group members: Manoj Adhikari, Igor Bernardi, Yuri V Efremenko, Karla Tellez-Giron-Flores, Gen Li, Jon Link, Kirsten McMichael, Jason Newby, Diana Parno, Daniell Shi, Joel Sander, Kate Scholberg, Tulasi Subedi, Keegan Walkup, Eli Ward.
- Thanks for listening!



DOE Award Number: DE-SC0022125

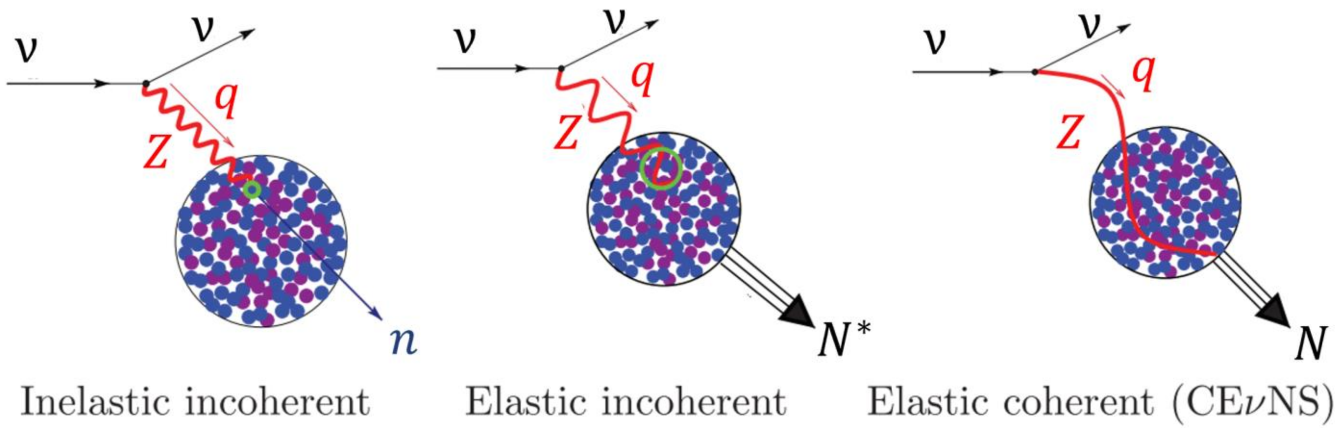
Status of Module 1

- Module 1 is built and operated in summer 2023.
- Collected 982MWh of beam-on data in 2023.
- Data is still 90%+ blinded, we are currently working on analysis and preparation for next SNS run.

From Igor Bernardi, in APS April Meeting 2024

CEvNS and COHERENT

- **C**oherent **E**lastic **Neutrino**-**N**ucleus **S**cattering
- No internal excitations or ejected particles
- Approximate condition: $QR \ll 1$
  - Q is the momentum transfer to the nucleus
  - R is the nuclear radius
- Nuclear Recoil is tiny! $E_r \cong \frac{2E_\nu^2}{M}$ $(\sim keV)$

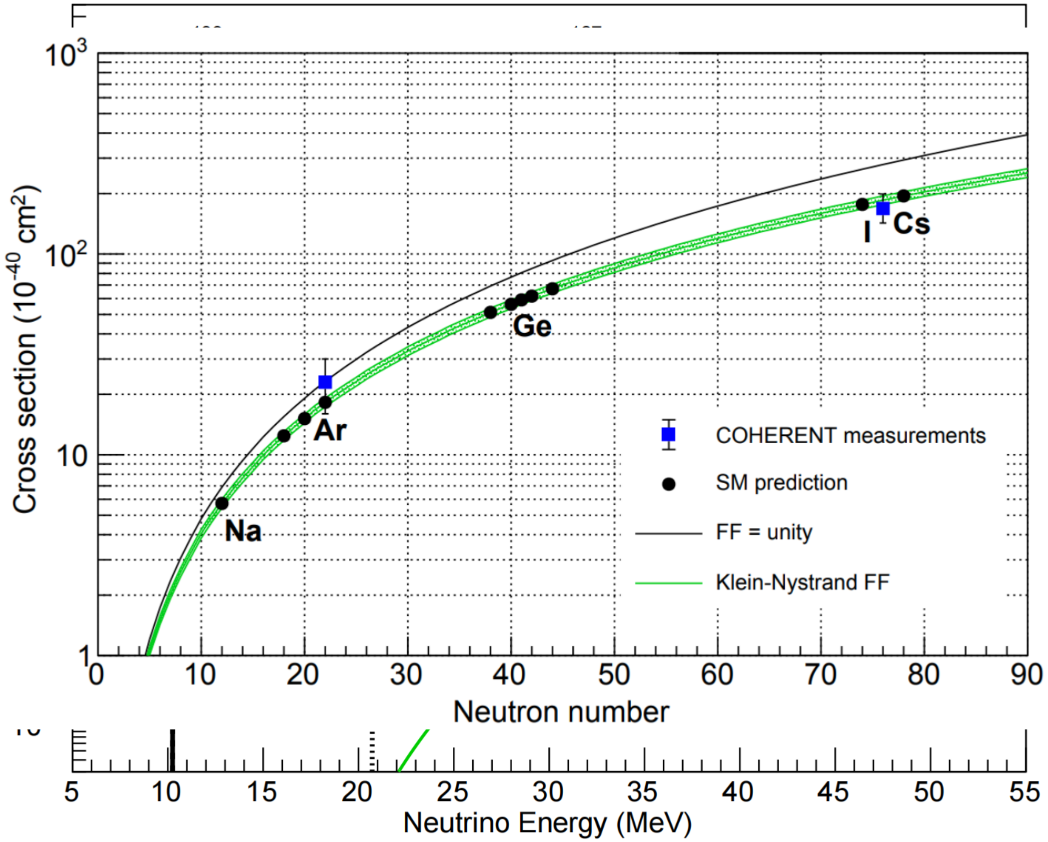


EPL, 143 (2023) 34001

CEvNS and COHERENT

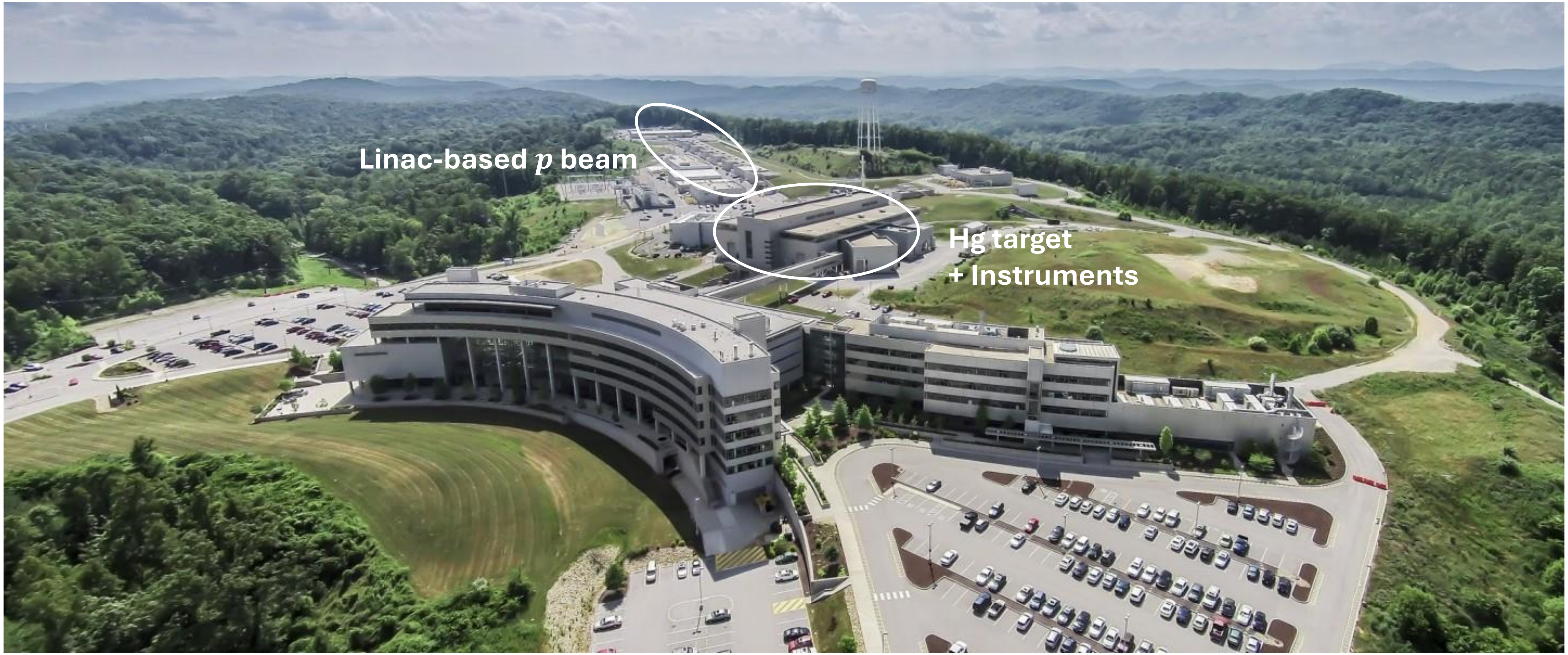
- When $T \ll E_\nu$: $\sigma \propto N^2$

- When $E_\nu < 100\ MeV$, CEvNS channel dominates.

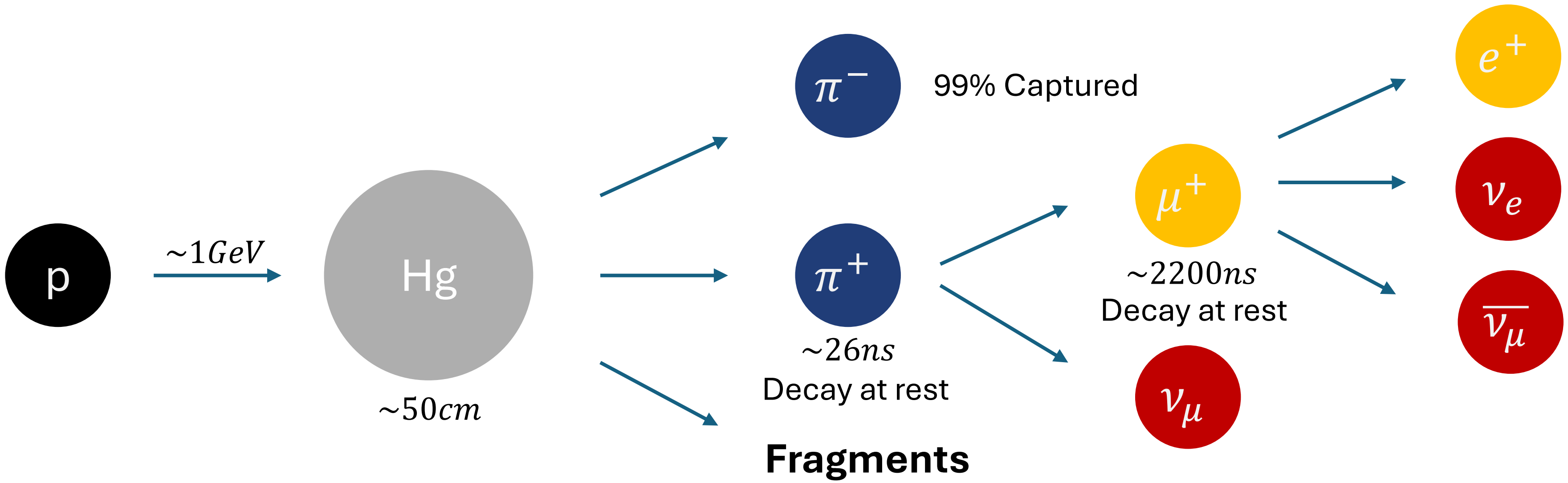


arXiv:2111.07033

Oak Ridge National Lab Spallation Neutron Source (ORNL SNS)

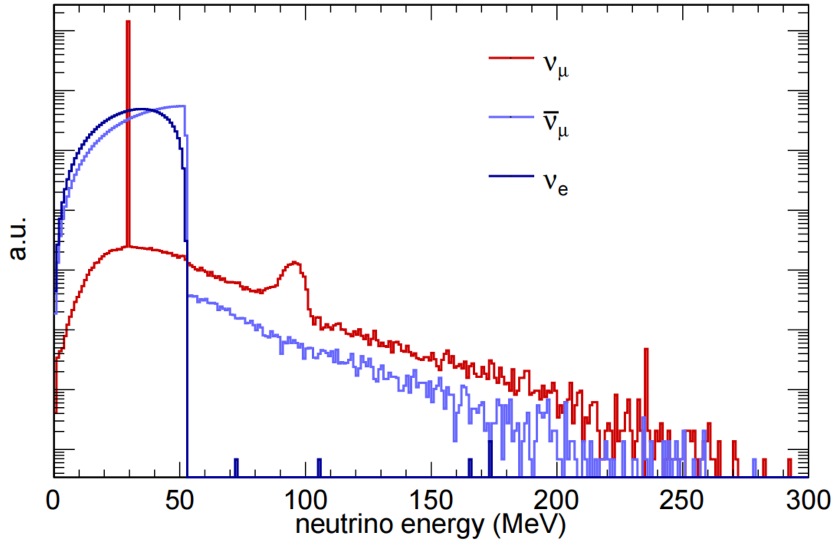


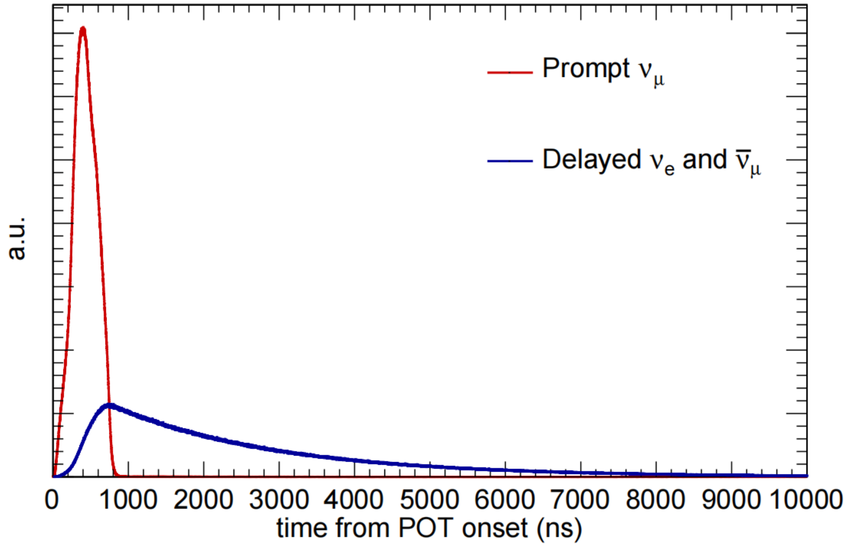
Neutrino Flux from ORNL SNS



Neutrino Flux from ORNL SNS

- $\pi^+ \rightarrow v_\mu + \mu^+; \quad \mu^+ \rightarrow \overline{v_\mu} + v_e + e^+$
- $\sim 4.3 \times 10^7 cm^{-2}s^{-1}$ at Neutrino Alley ($20m$ from Hg target).





PRD106, 032003 (2022)

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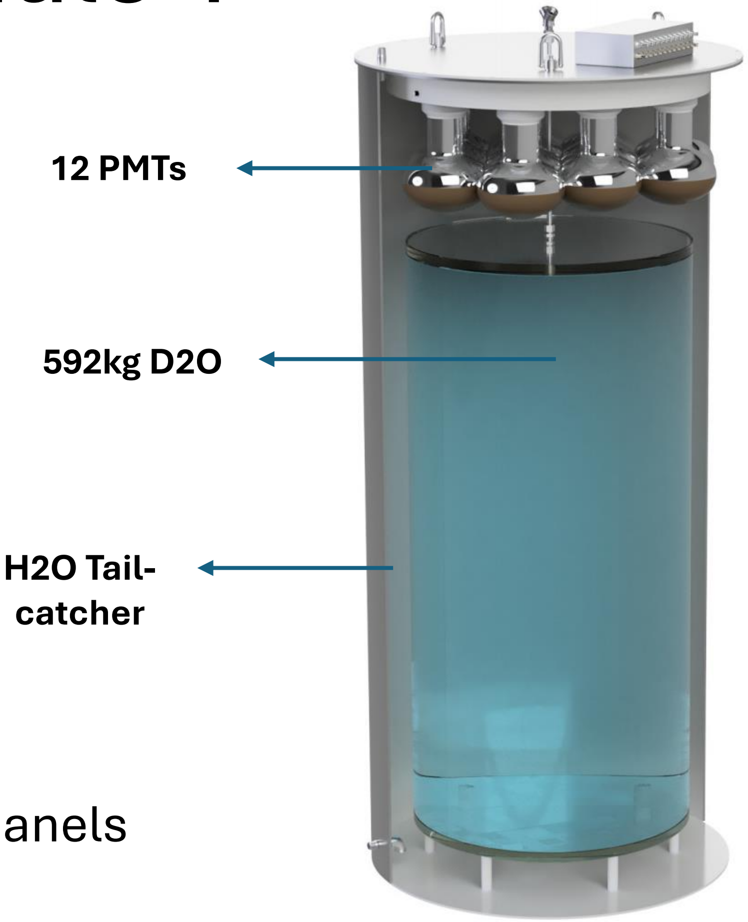

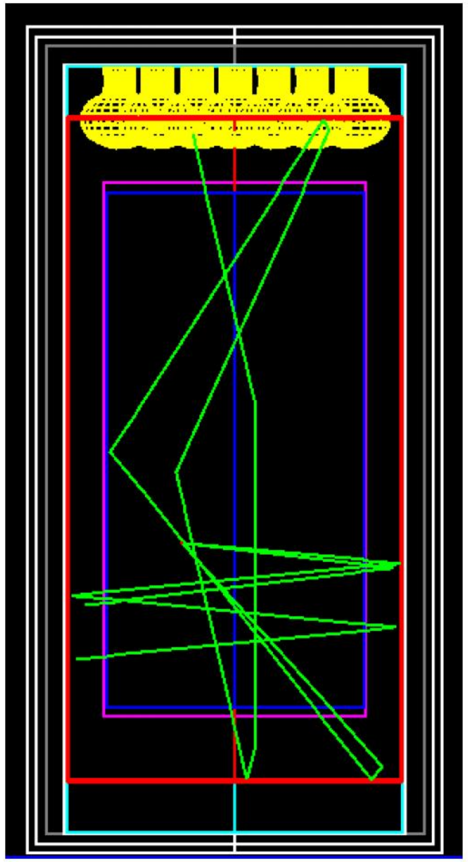

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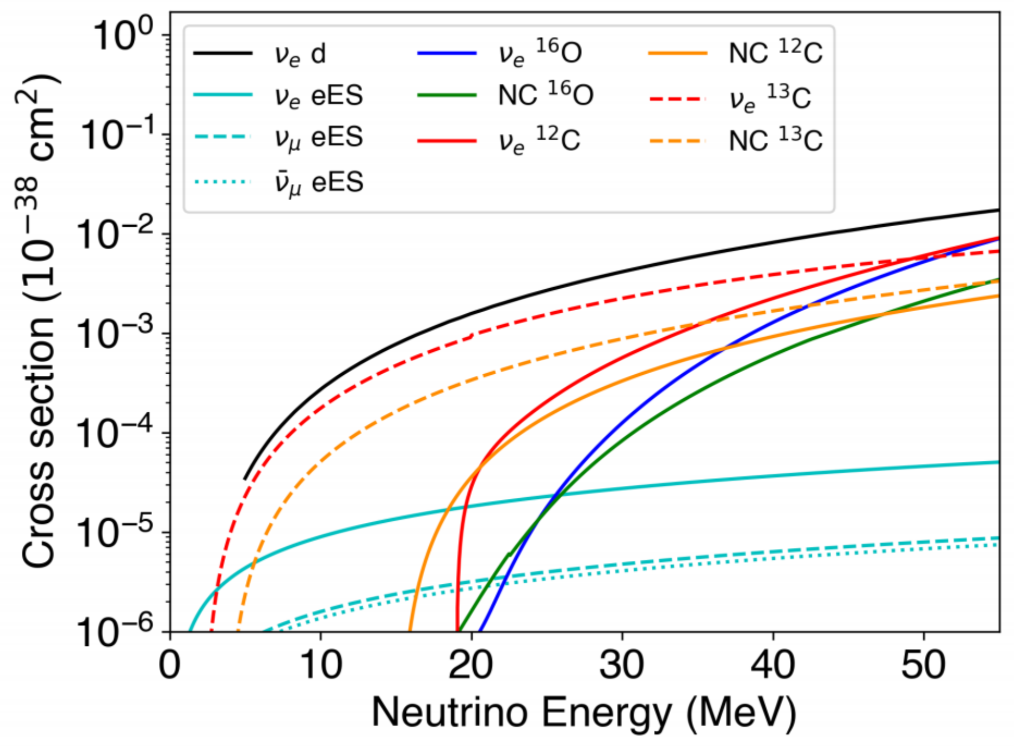

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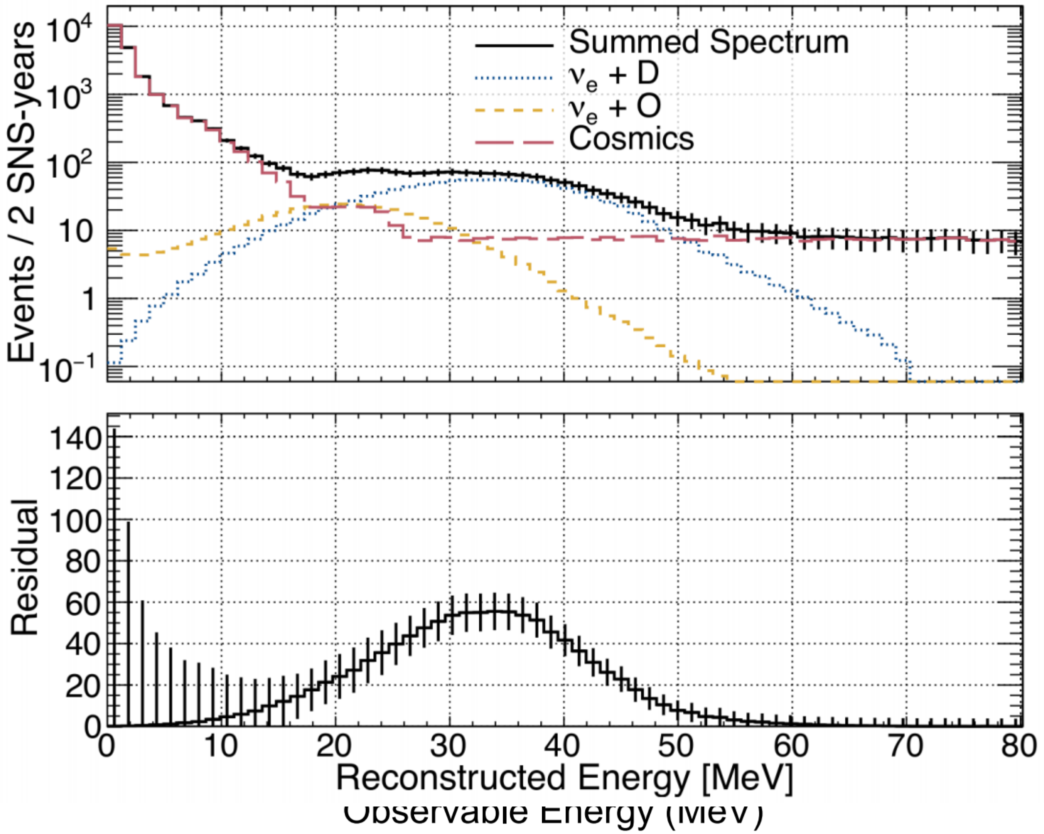
Design of D2O Module 1

- The observable electron energies are distinguishable, which makes it possible to reconstruct CC d events.

- After considering the smearing effect, we can simulate signal and background energy spectra.



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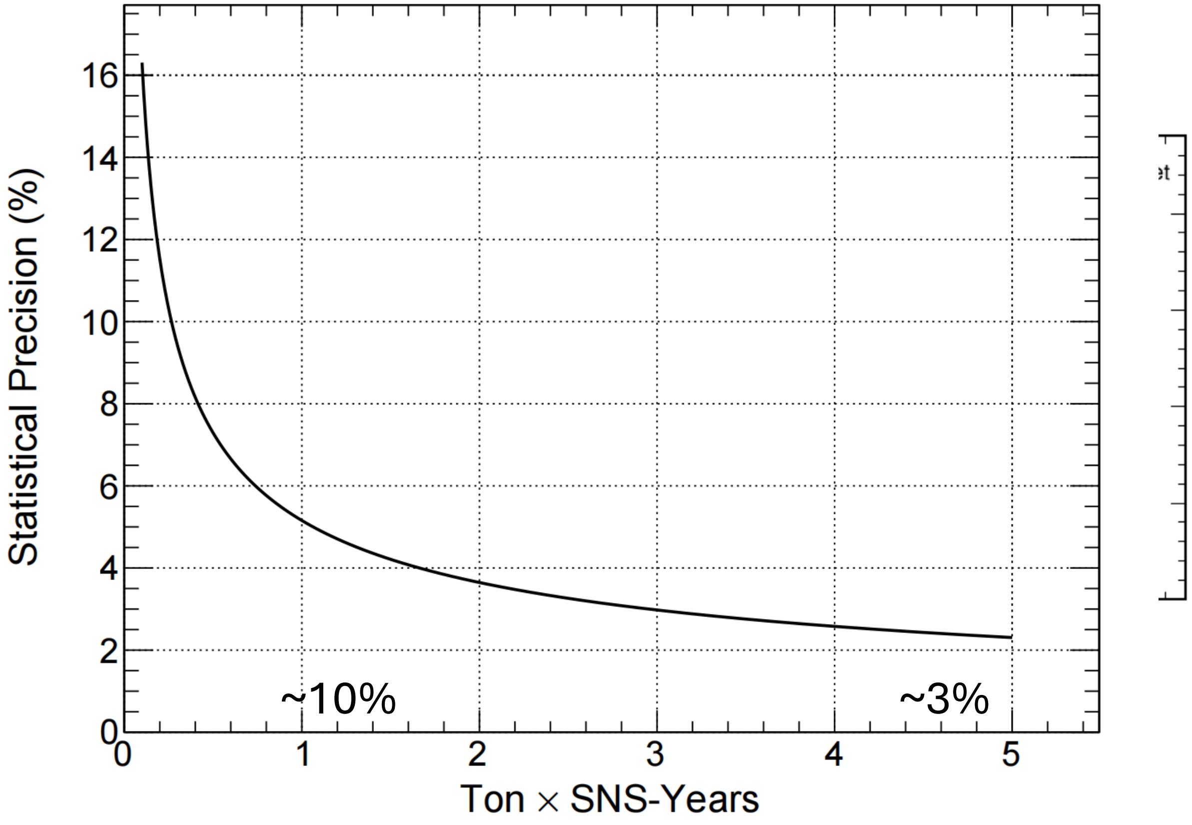
Goals and Predictions

- The statistical uncertainty will decrease significantly from 10% after several years of running.

- Better sensitivity to physics beyond the Standard Model.



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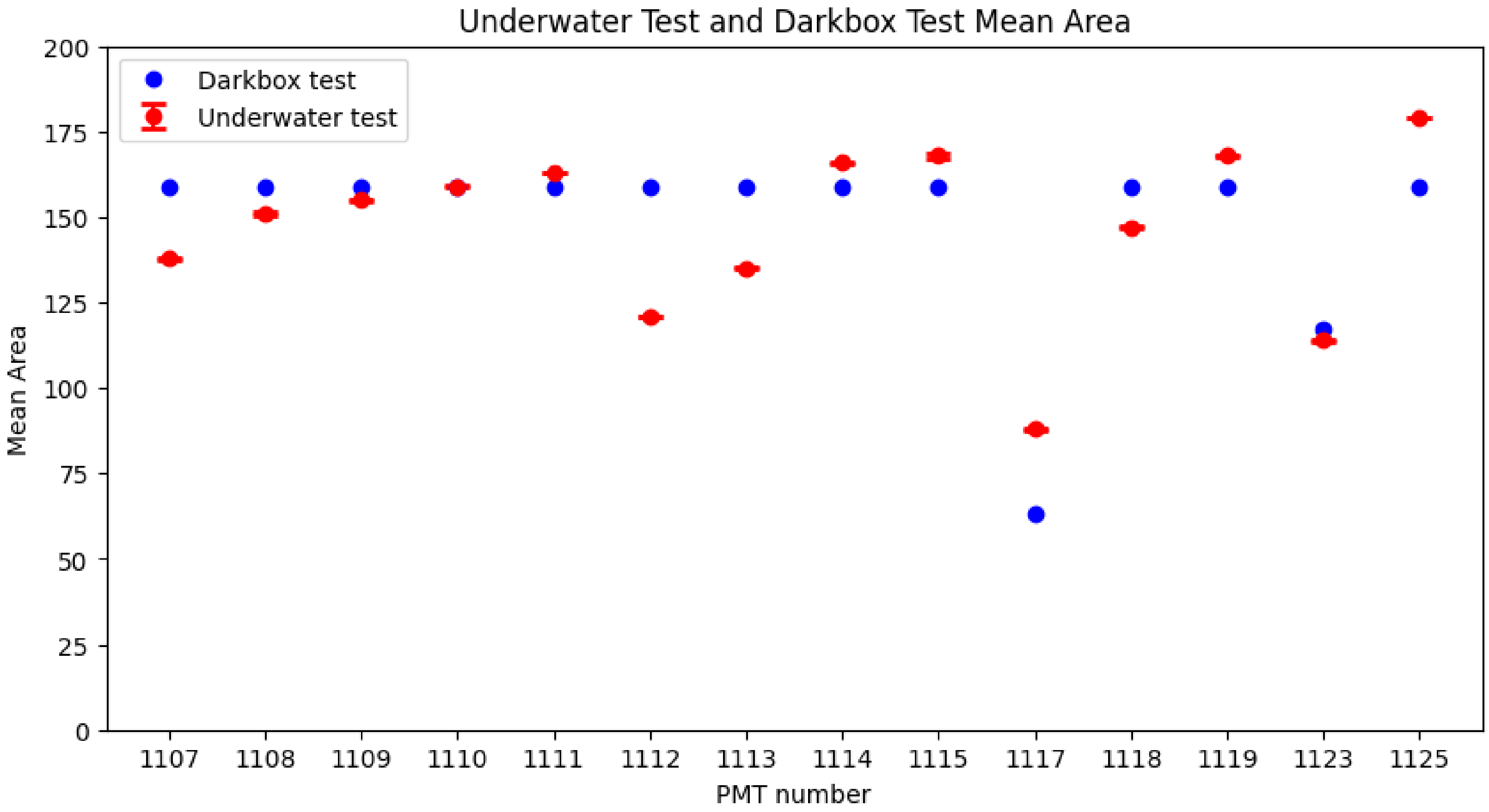
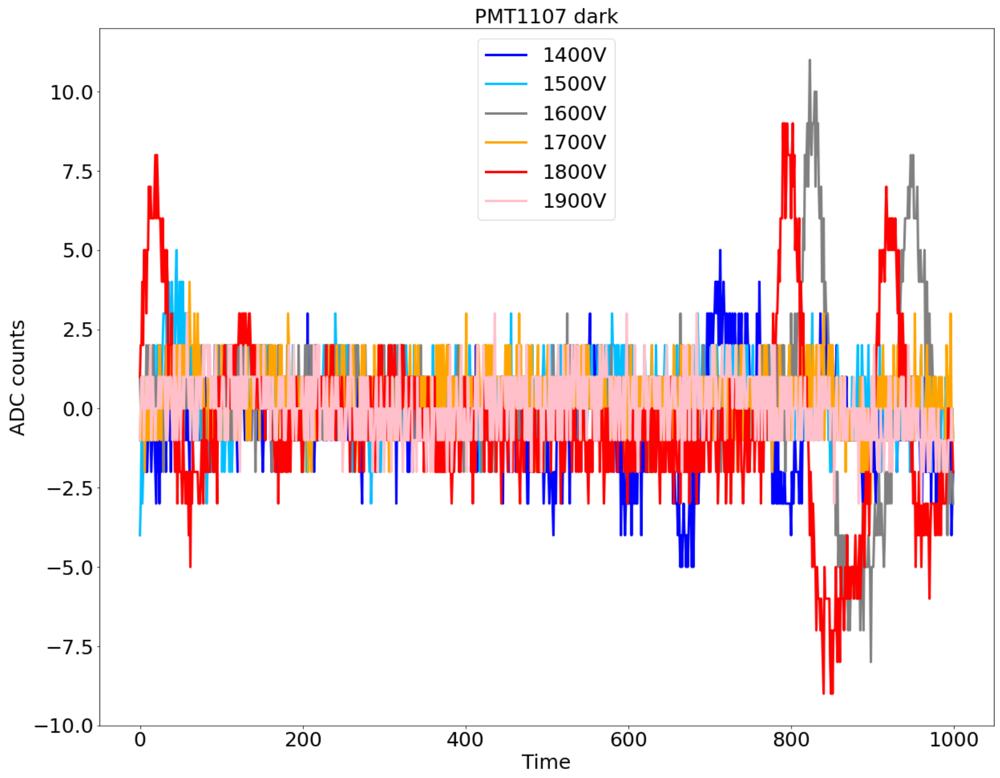
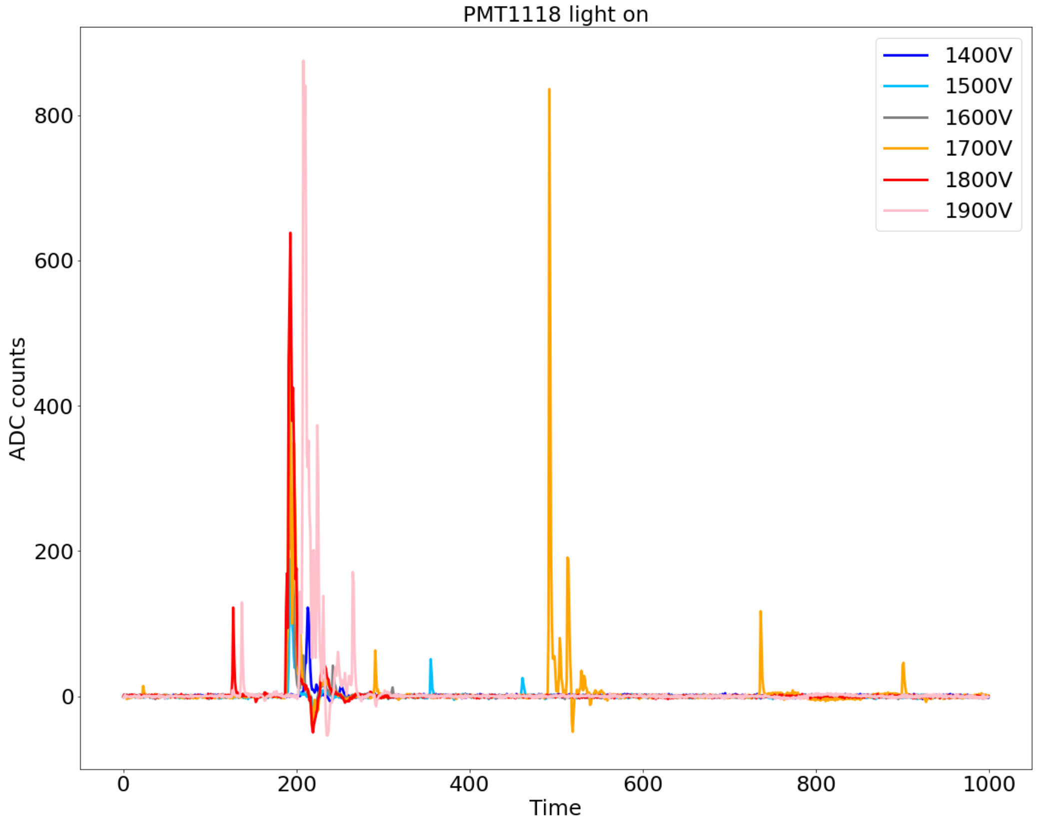
Dark box vs. Underwater



Signal


PMT1107 dark
1400V
1500V
1600V
1700V
1800V
1900V
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
ADC counts
0
200
400
600
800
1000
Time


PMT1118 light on
1400V
1500V
1600V
1700V
1800V
1900V
800
600
400
200
0
ADC counts
0
200
400
600
800
1000
Time

Gain

- The Gain is solely dependent on the dark rate test.
- $\#Photoelectron = \frac{<Area_{LED}>}{<Area_{dark}>}$
-
- $\#electron = \frac{<Area_{LED}>}{eR}$
- $Gain = \frac{\#electron}{\#Photoelectron} \propto < Area_{dark} >$