



# THE DEAP-3600 MUON VETO SYSTEM

AN OVERVIEW

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WNPPC - FEBRUARY 2018



**Carleton**  
UNIVERSITY

# OVERVIEW

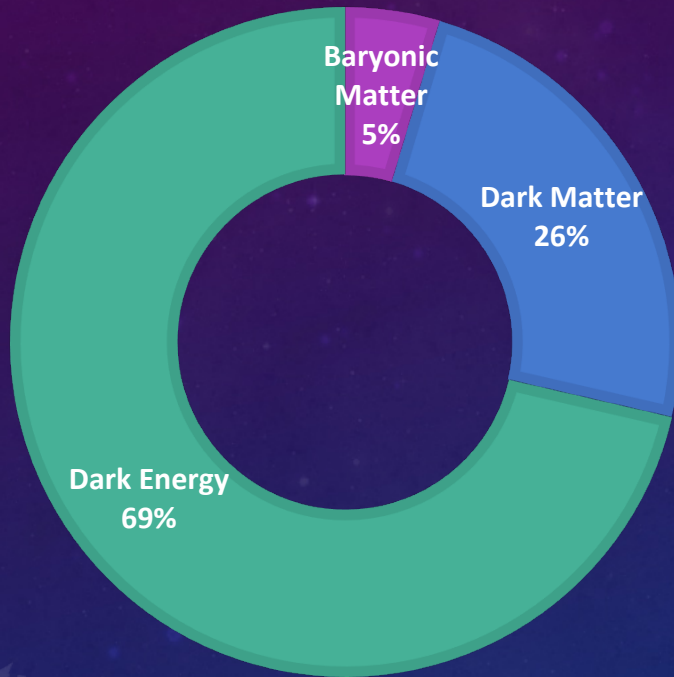
- Dark Matter
- DEAP-3600 overview
- Cosmic Rays
- Veto Hardware
- Muon Detection in DEAP-3600
- Calibration System
- Characterization Studies
- Underground Muon Rate



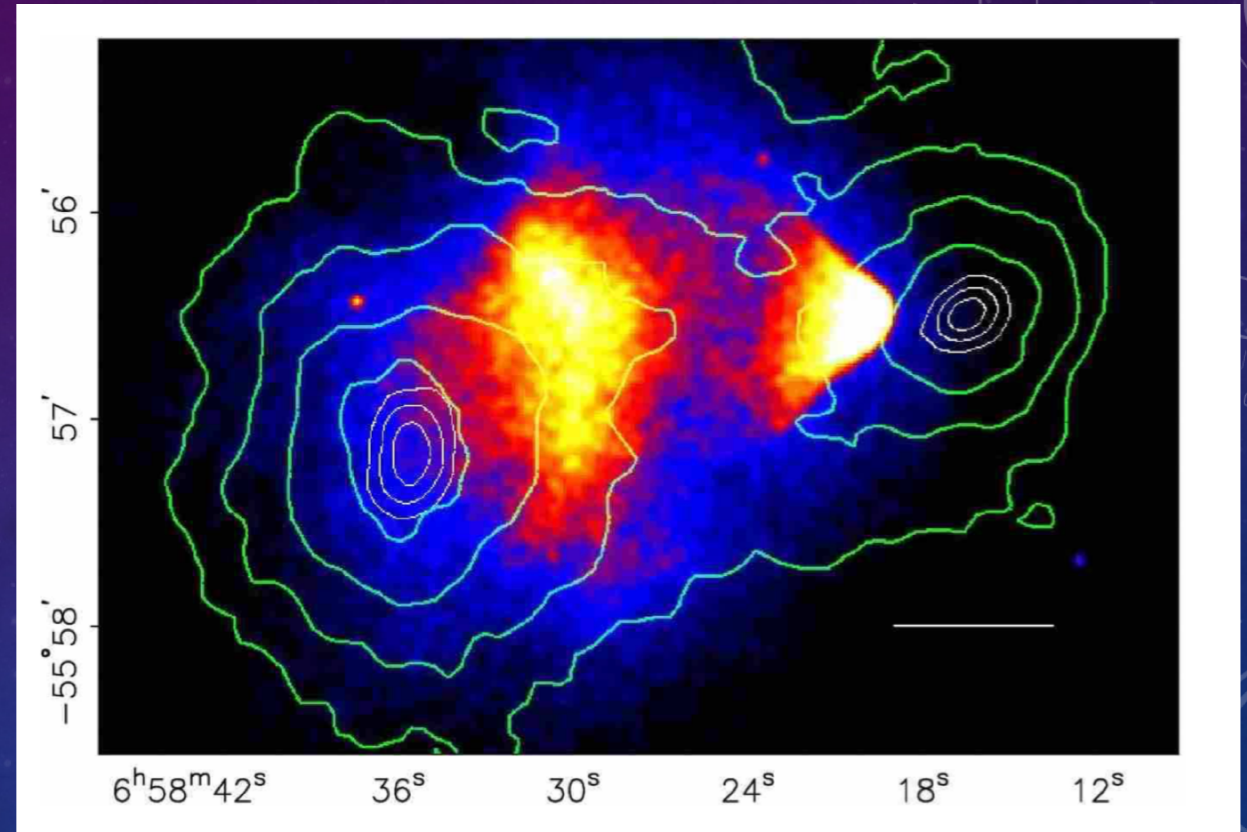


# DARK MATTER

Is it real or just fantasy?



Source: The Universe



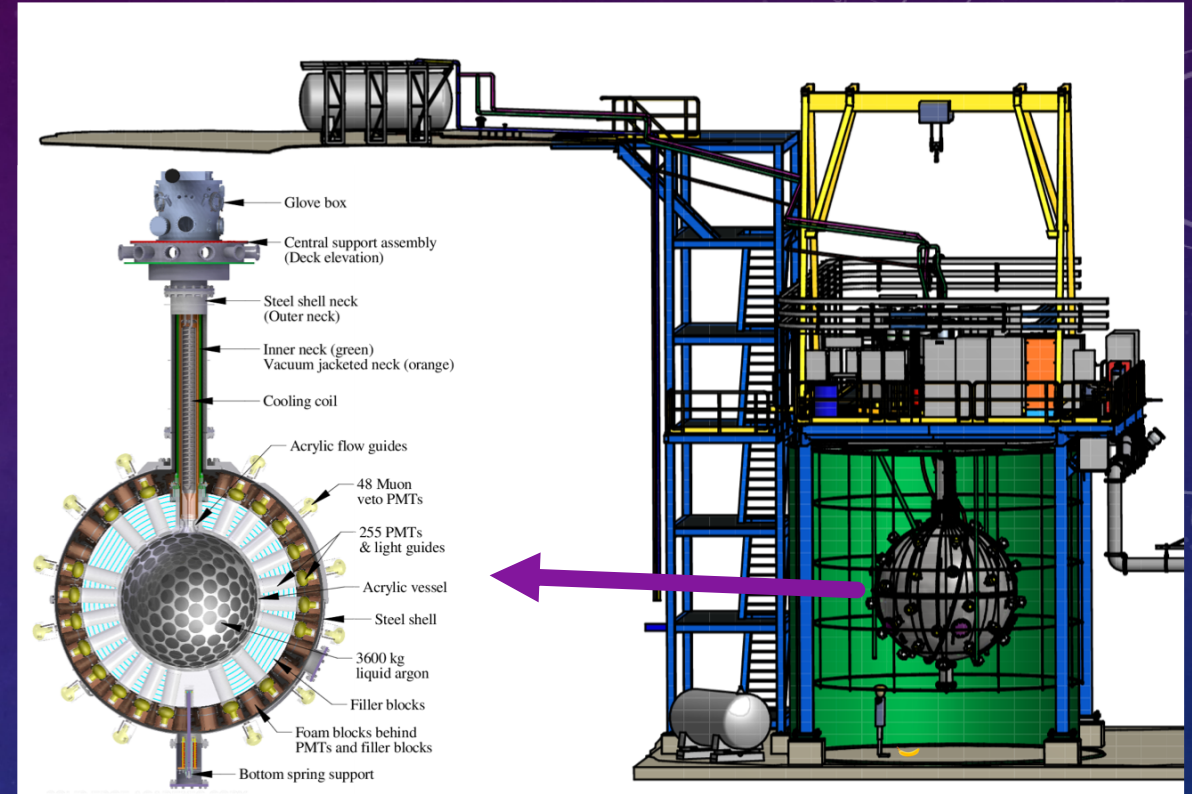
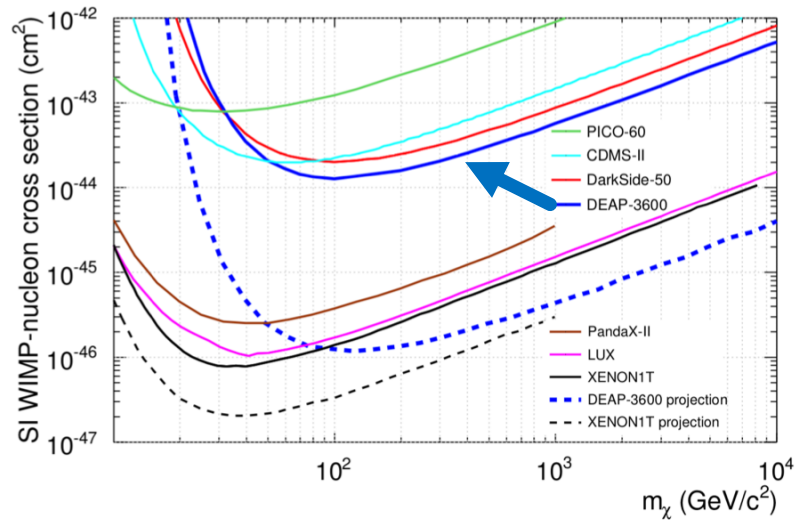
Source: [arXiv:astro-ph/0608407](https://arxiv.org/abs/astro-ph/0608407)

The bullet cluster provides strong evidence for additional mass surrounding luminous (baryonic) matter <sub>3</sub>

# DEAP-3600

- Located ~2 km underground @ SNOLAB
- Single phase liquid argon (LAr)
- ~3300 kg target volume (~1000 kg fiducial)
- 255 LAr-facing high QE PMTs
- 48 water Cherenkov veto PMTs
- 4 Neck veto PMTs

Source: arXiv:1707.08042



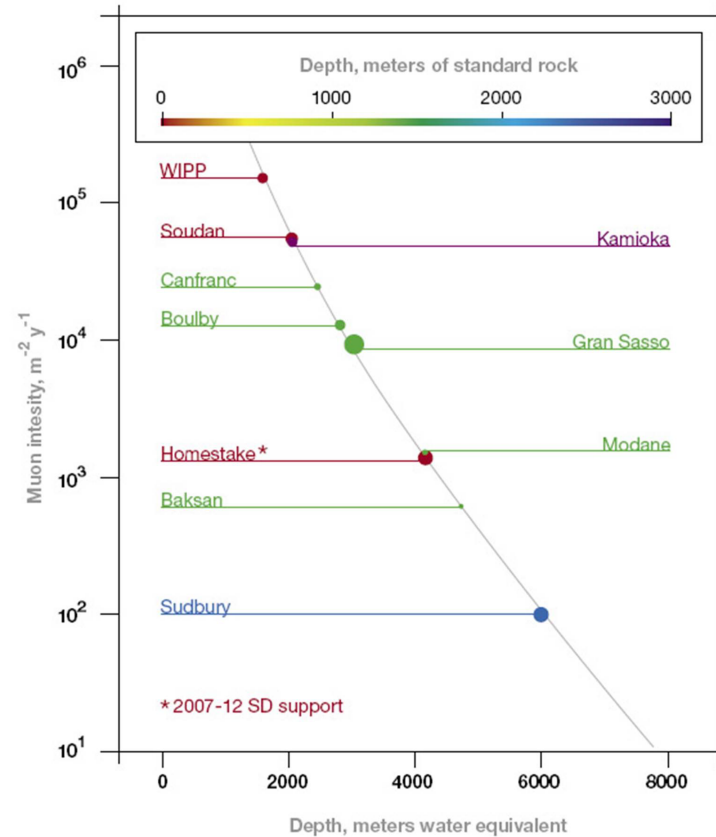
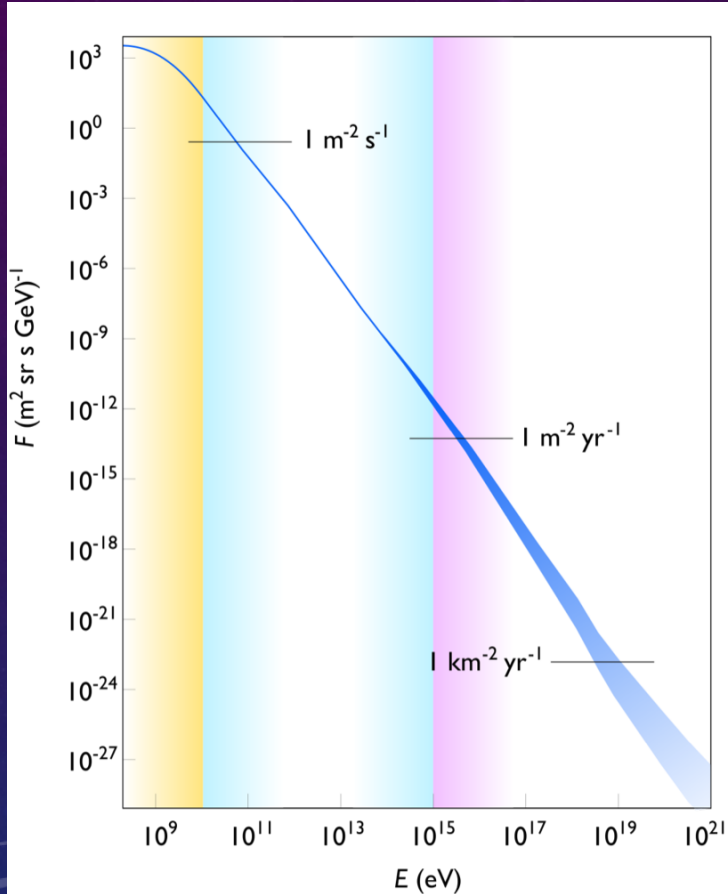
Source: arXiv:1712.01982

First results released last year which produced a leading limit for argon-based dark matter detectors. Note: 4.44 days exposure using 2200 kg fiducial mass

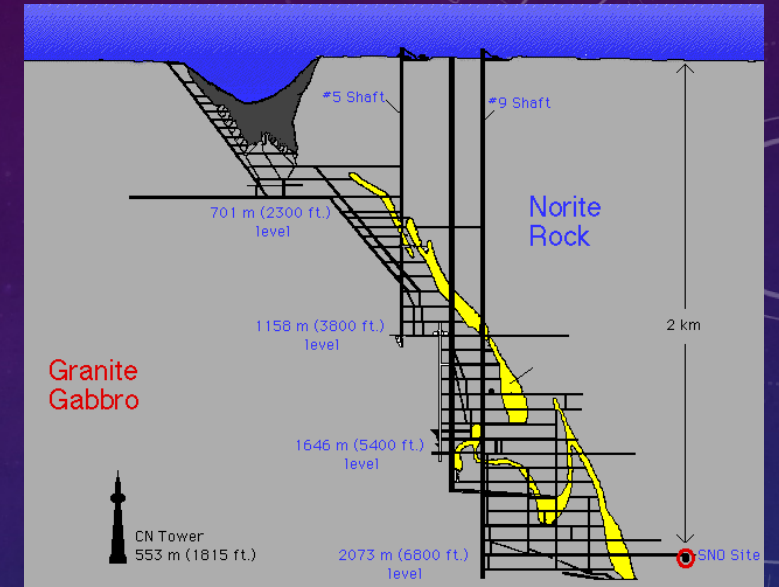


# COSMIC “RAYS”

Those things from space that rain on your dark matter parade



Source: [http://www.deepscience.org/contents/underground\\_universe.shtml](http://www.deepscience.org/contents/underground_universe.shtml)



Source: SNOLAB

We escape from the cosmic background by hiding “deap” underground at SNOLAB.

High energy muons still manage to crash our party...

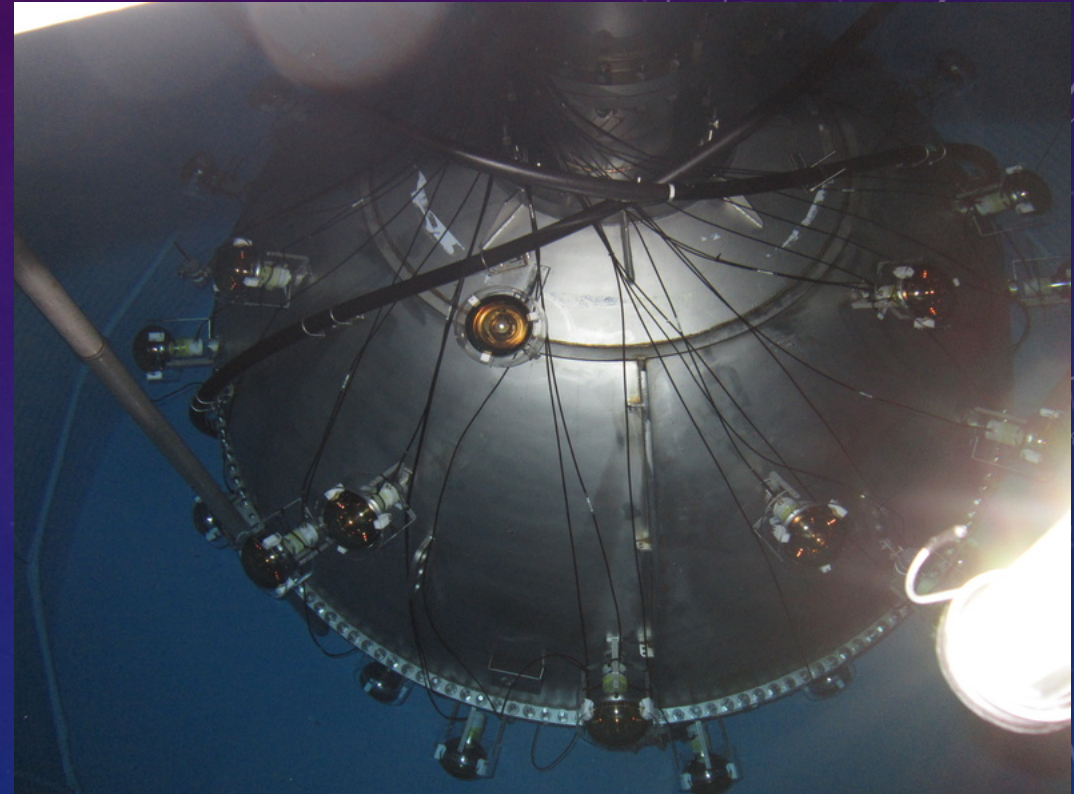


# MUON VETO HARDWARE



Left: DEAP-3600 deck and water shield tank. The inner detector (non-instrumented) shown inside water tank.

The veto tank was designed to not only tag muons but to also moderate cosmogenic neutrons and shield from external gammas

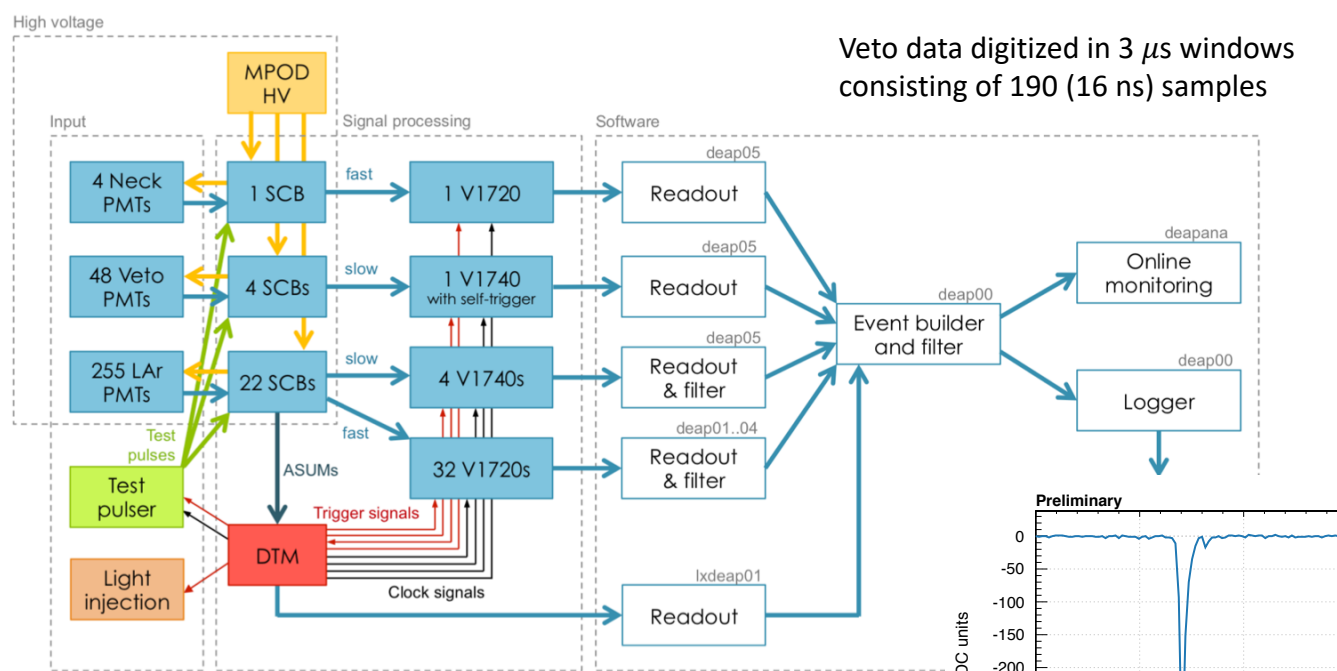


Above: (Not a submarine or depth charge!) DEAP3600 fully instrumented inside a full water shield tank

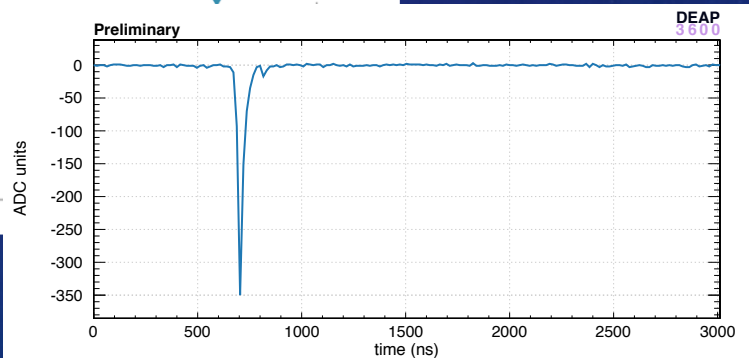


# MUON VETO HARDWARE

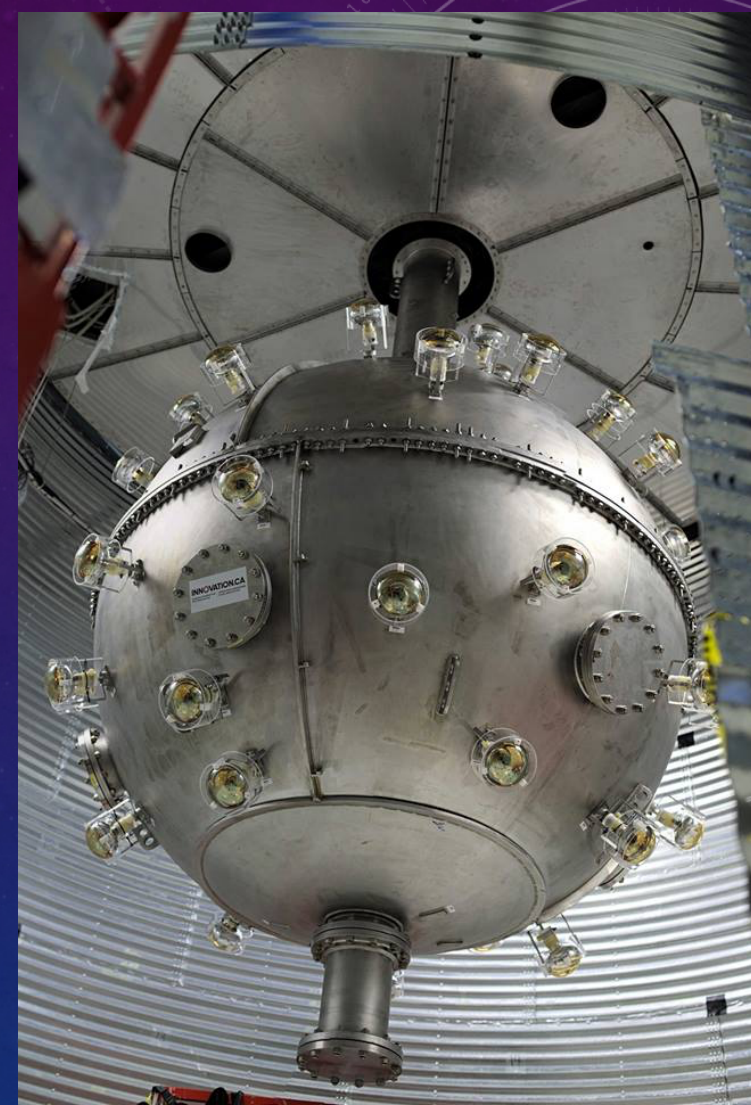
- 48 Hamamatsu R1408 8" PMTs
- Veto PMT pulses digitized by CAEN V1740 ADCs
- PMTs arranged into 8 groups of 6 around steel shell



Veto data digitized in  $3 \mu\text{s}$  windows consisting of 190 (16 ns) samples



DEAP-3600 electronics map



DEAP-3600 in an empty veto tank. The muon veto PMTs are visible on the stainless steel shell

# DETECTING MUONS

Relativistic muons will produce Cerenkov light in the water shield which is detected by the veto PMTs

Veto channel triggering:

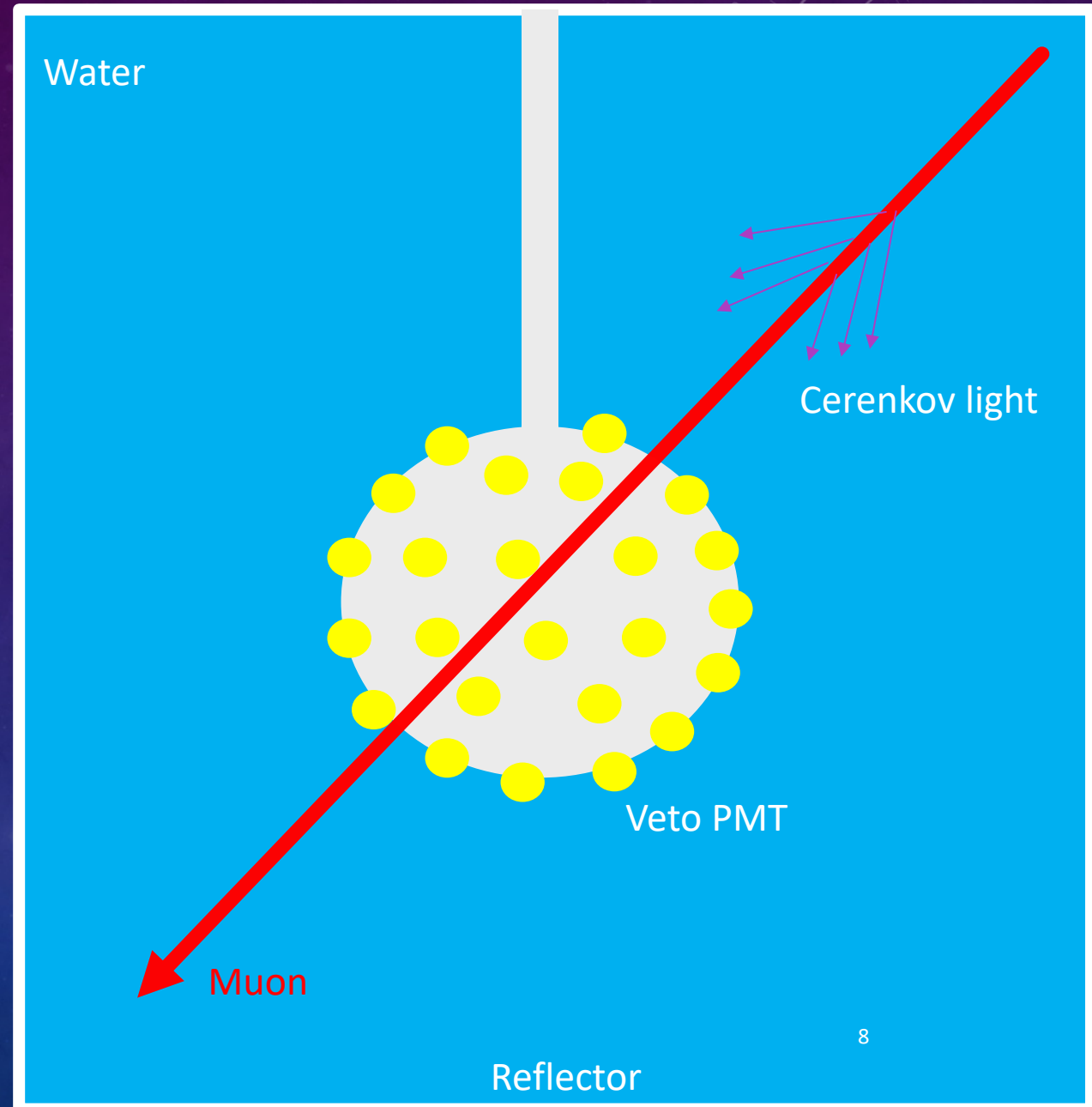
- Pulse amplitude above ADC threshold

Veto majority triggering:

- At least one PMT above threshold in any 3 different groups

Muon veto system operates in “self triggering” mode

Veto PMT data available for pulse analysis offline



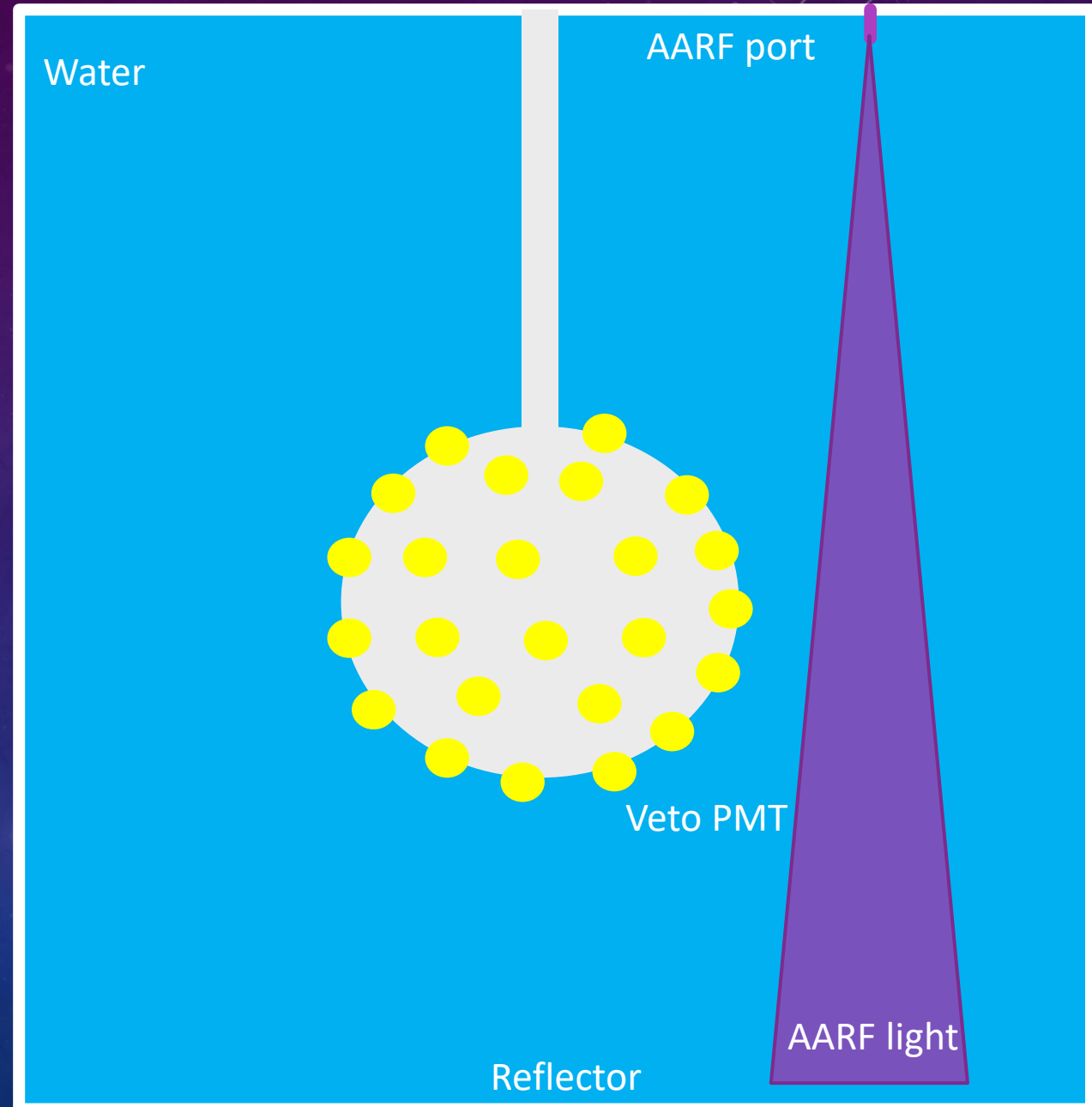


# CALIBRATION SYSTEM

## Aluminum-Acrylic Fibre System (AARF)

Laser light pulses from driver module are sent into the water from a port located at the top of the water tank

Calibration runs use AARF driver to trigger veto PMTs which allows single photoelectron calibrations of each PMT. Consequently, AARF triggering requires no channel threshold which allows for other studies (threshold optimization, dark noise, etc.)



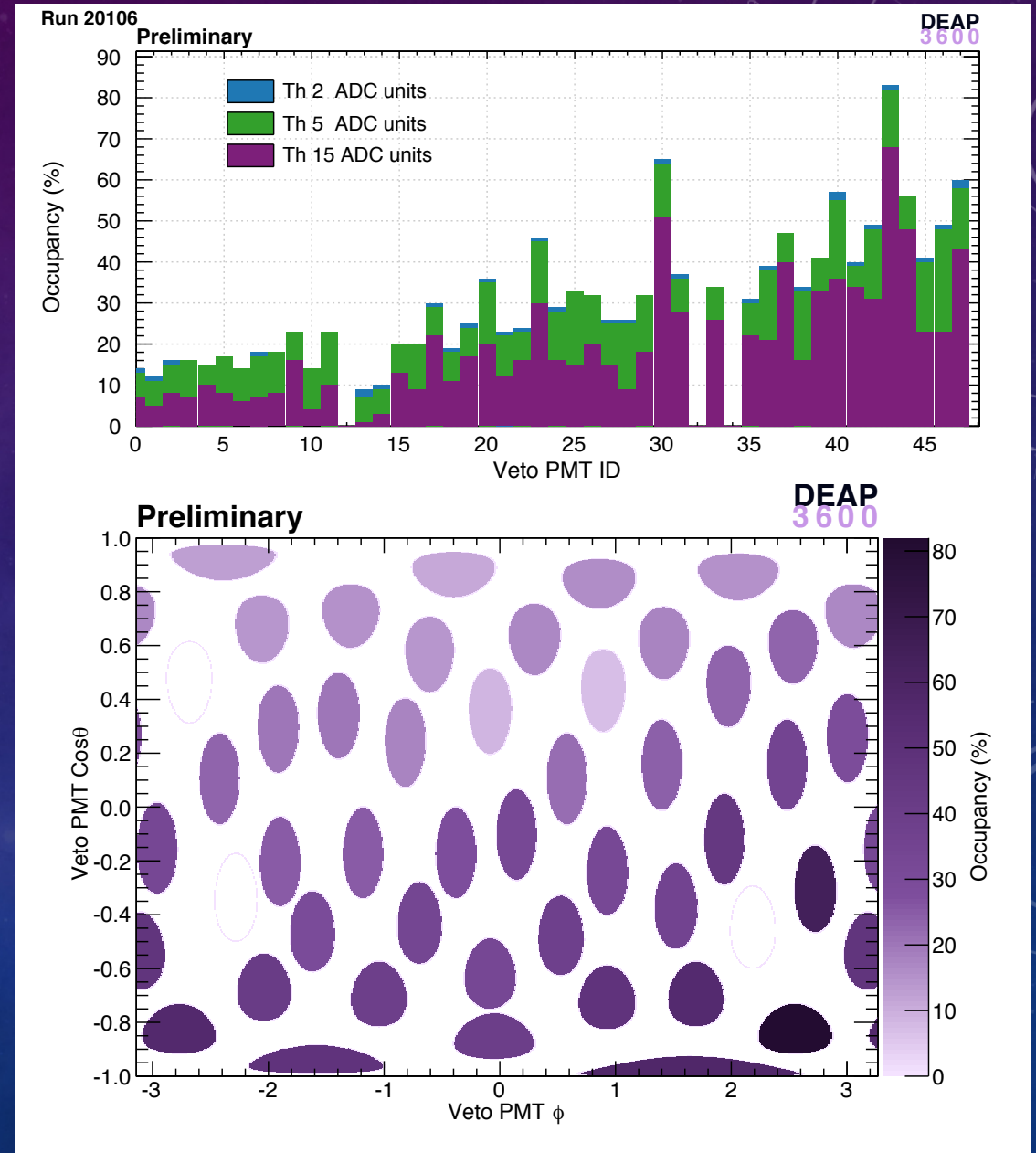
# CALIBRATION SYSTEM

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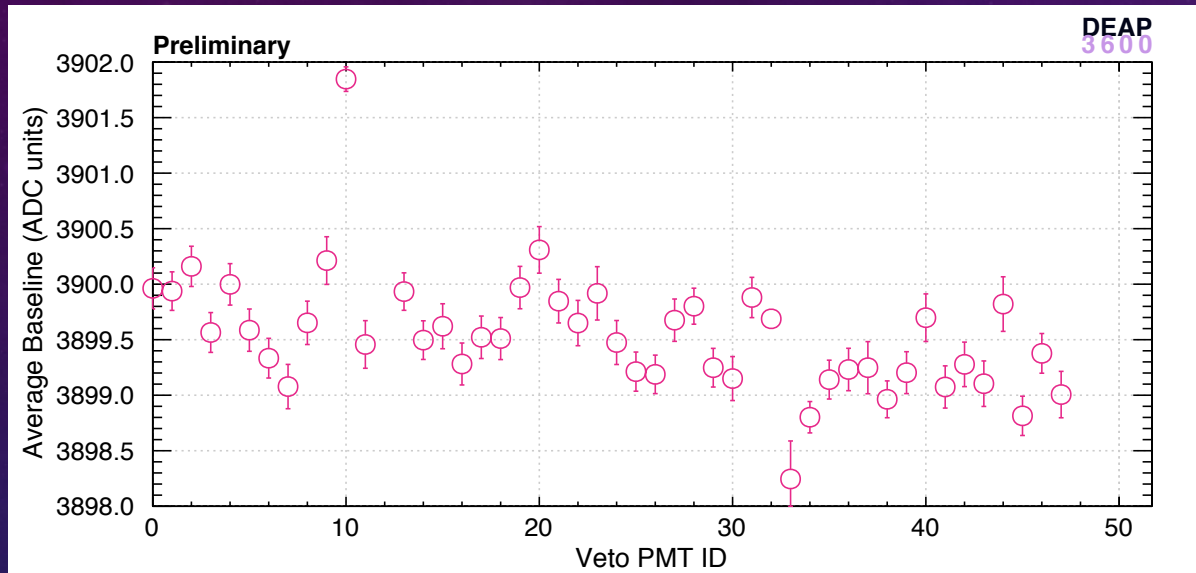
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$$Occ_{PMT} = \frac{\text{Detected Pulses}}{\text{Total AARF triggers}}$$

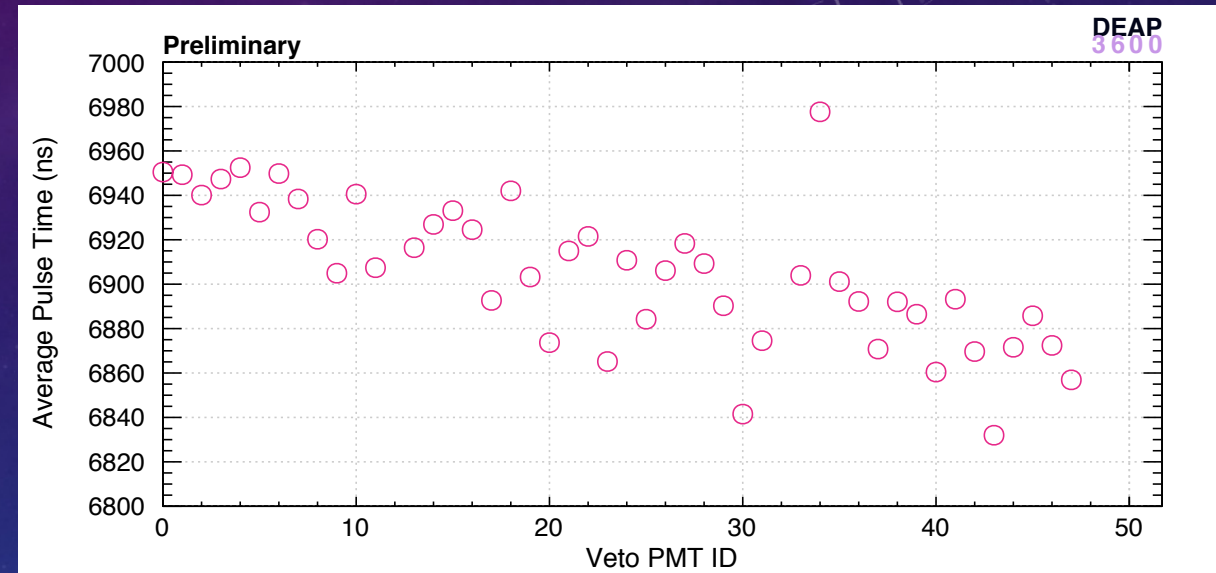




# CHARACTERIZATION STUDIES

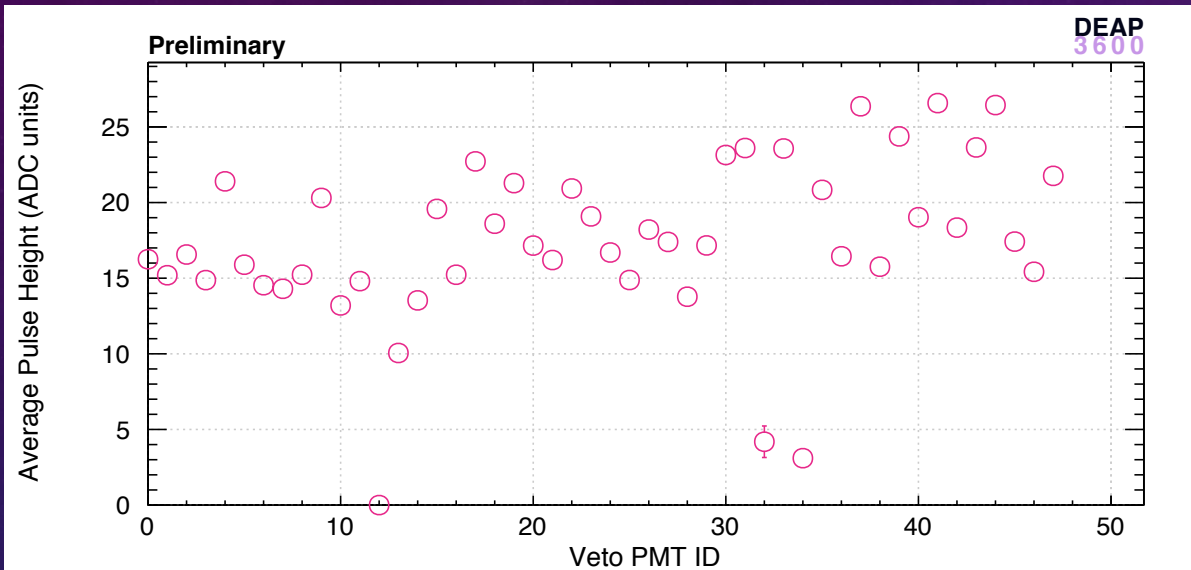


Pulse baseline very stable PMT to PMT

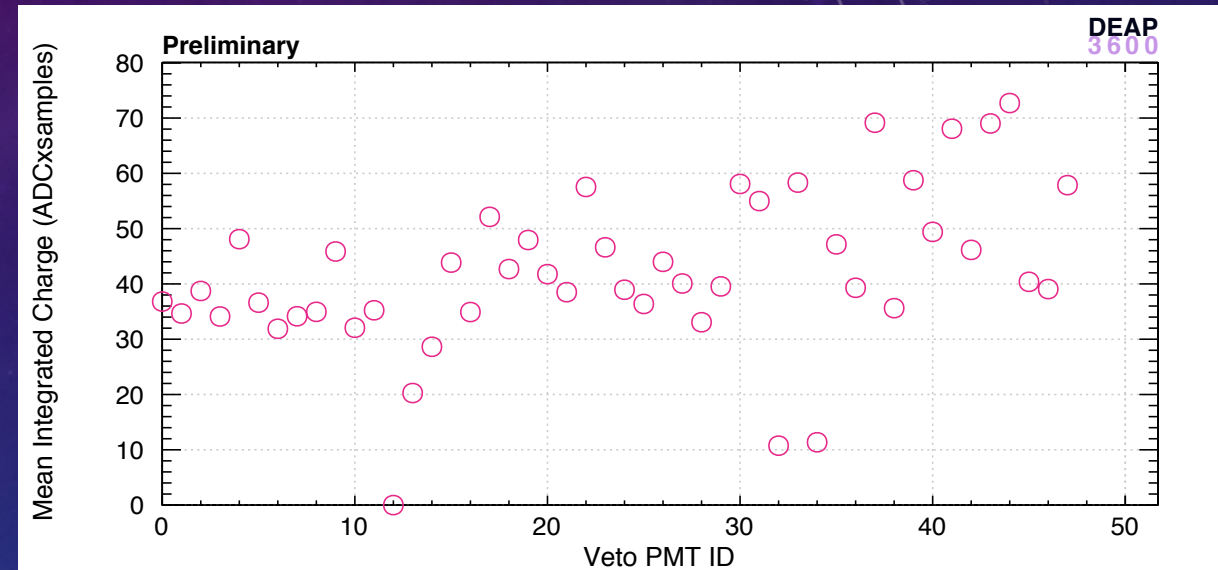


Trend in pulse times is due to PMTs at the top of the veto system only seeing indirect laser light

# CHARACTERIZATION STUDIES



Coarsely uniform average pulse height



Charge distributions more varied – Definitely necessitates a more detailed calibration



# MUON RATE

Underground muon rate/characteristics studied in detail by Mei & Hime[1] and SNO[2]. The expected rate is given by:

$$N_{\mu} = (3.31 \pm 0.01(stat) \pm 0.09 (sys)) \times 10^{-10} s^{-1} cm^{-2}$$

with a preferred direction of  $\cos\theta = 0.9008$

Expected flux through the veto tank given by:

$$N_{\mu_{expected}} = N_{\mu} \times A_{eff}$$

where  $A_{eff} = \pi r(r \cos(\theta) + 2h \sin(\theta))$

$$r = 3.90 \text{ m}$$

$$h = 7.78 \text{ m}$$

$$N_{\mu_{expected}} = 36.0 \pm 0.1 (stat) \pm 0.8 (sys) \text{ day}^{-1}$$

Next: Full characterization of veto performance and measurement of underground muon flux

Reference:

[1] Phys. Rev. D 73 053004 (2006)

[2] Phys. Rev. D 80 012001 (2009)

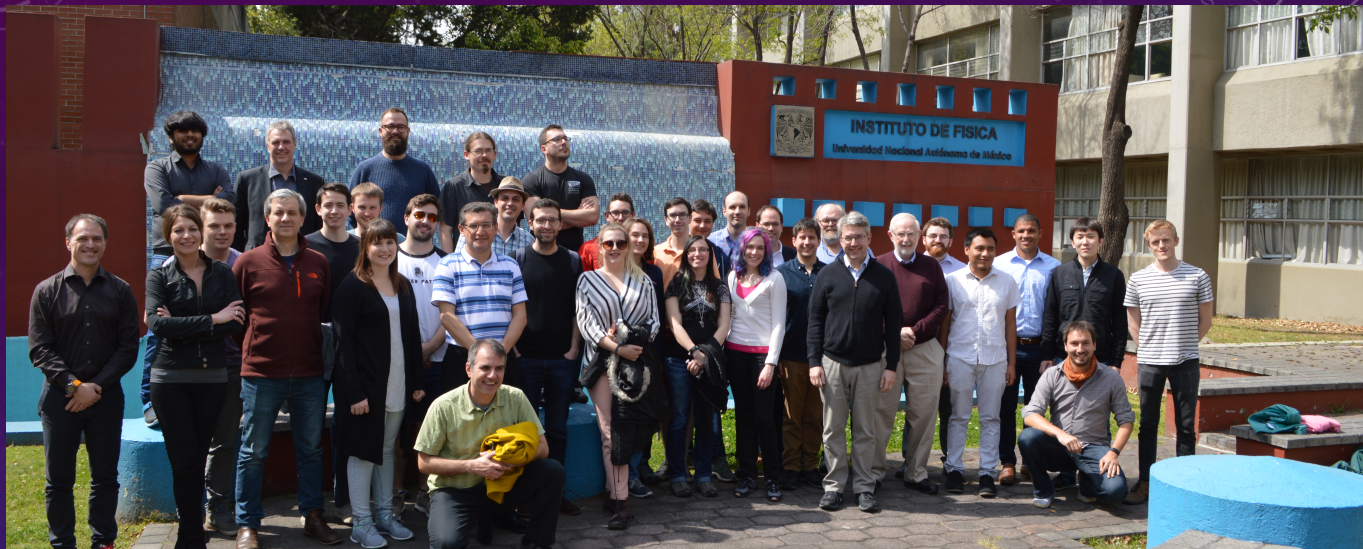
# SUMMARY

- DEAP-3600 currently taking data
- Already the most sensitive single phase argon-based dark matter detector
- New data to be published in the near future
- Detailed muon veto characterization underway
- At first glance things look good



# THANKS!

Thanks to Prof. Mark Boulay, Dr. Shawn Westerdale, and the entire DEAP-3600 collaboration



Interested in working on DEAP-3600 or DarkSide-20k? Talk to me!

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