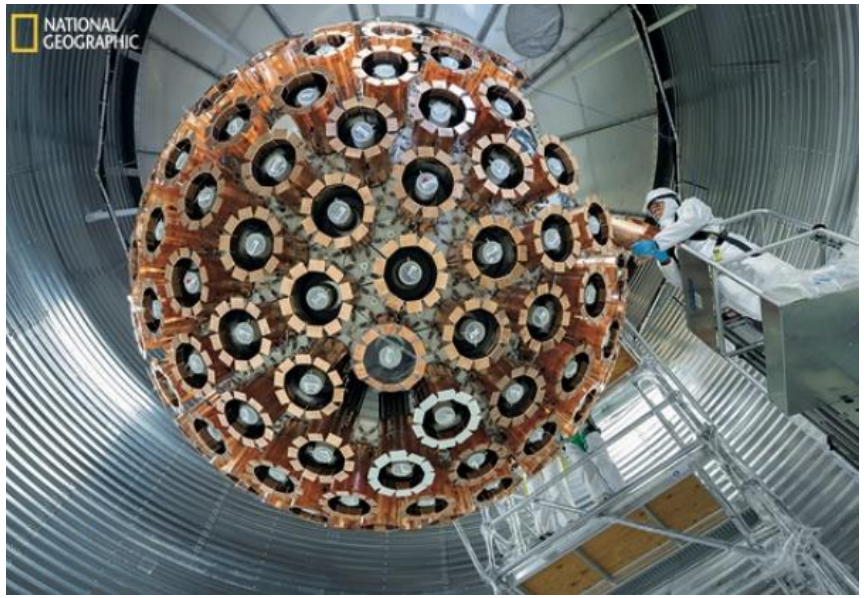
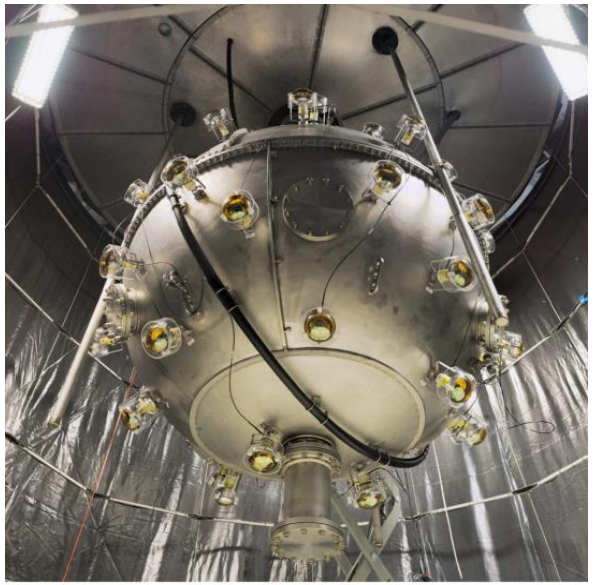
Carleton UNIVERSITY

DEAP 3600

DEAP-3600 dark matter experiment stability and ^{39}Ar decay analysis





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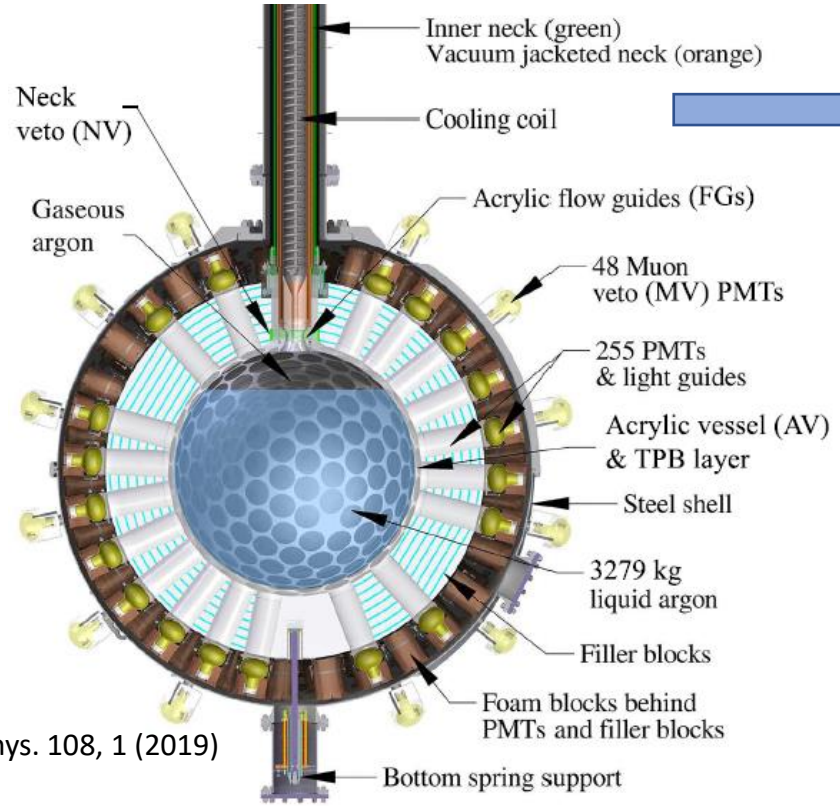
Outline

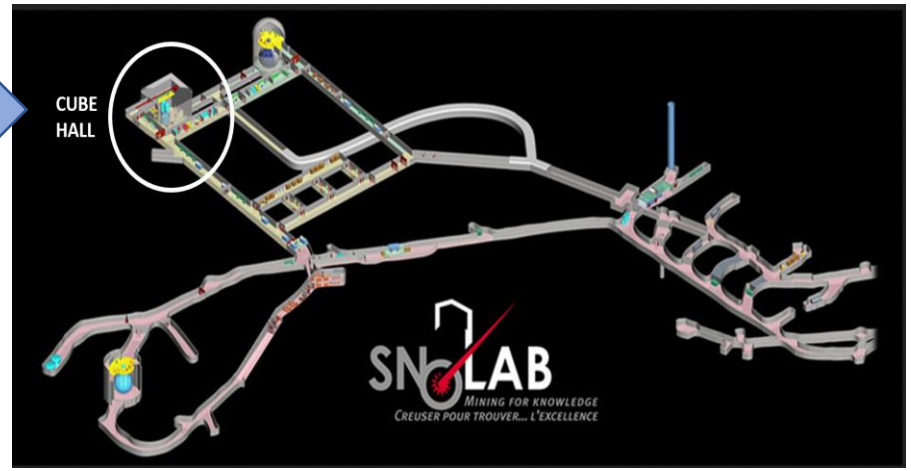
- The DEAP-3600 experiment
- Annual modulation for WIMP search
- Event rate analysis and ^{39}Ar dating
- Stability of detector
- Summary
- References

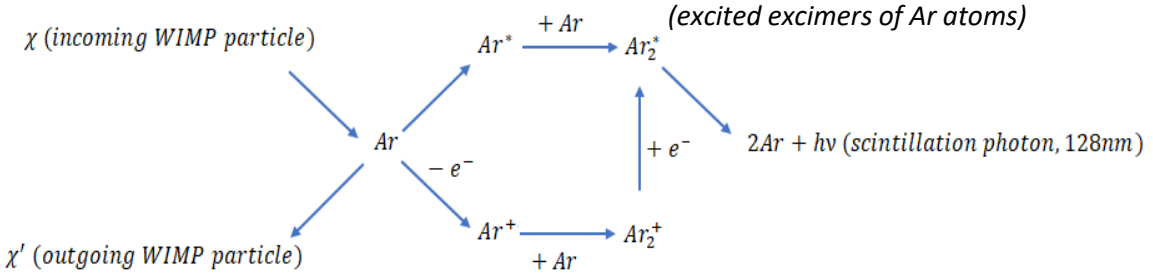
DEAP-3600 experiment

- The Dark matter Experiment using Argon Pulse-shape discrimination
- Single phase Liquid Argon (LAr) scintillation light detector



Astropart. Phys. 108, 1 (2019)

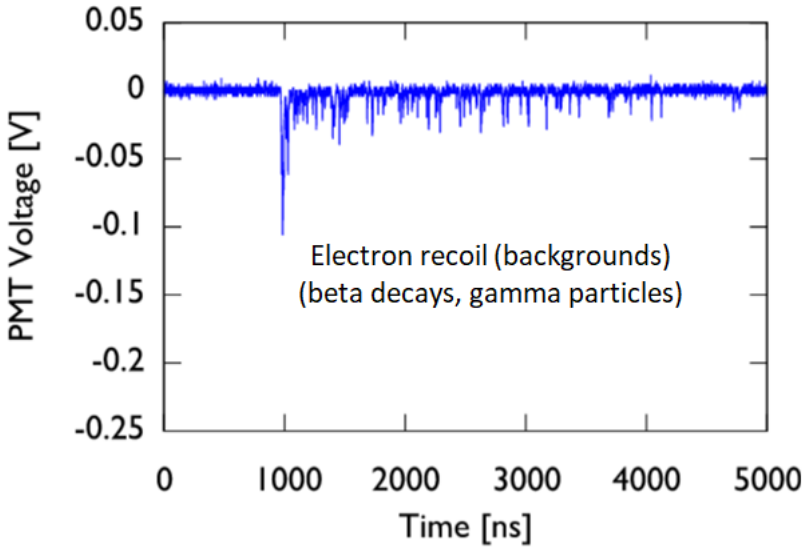


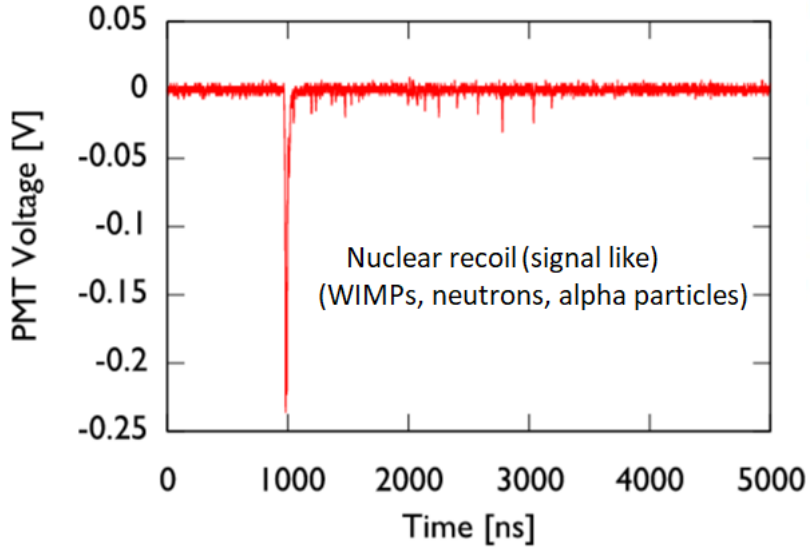


Pulse Shape Discrimination

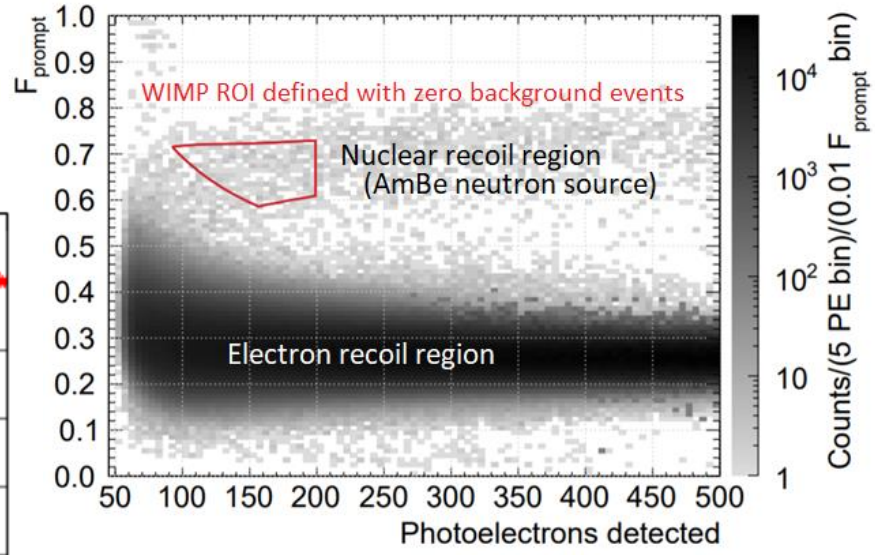
- Decay times of excimers, τ_S(singlet) = 6ns and τ_T(triplet) = 1300ns
- A prompt region is defined with equation,

$$F_{prompt} = \frac{\sum_{t=-28\,ns}^{60\,ns} PE(t)}{\sum_{t=-28\,ns}^{10\,\mu s} PE(t)}$$





Phys. Rev. D, 100, 022004 (2019)

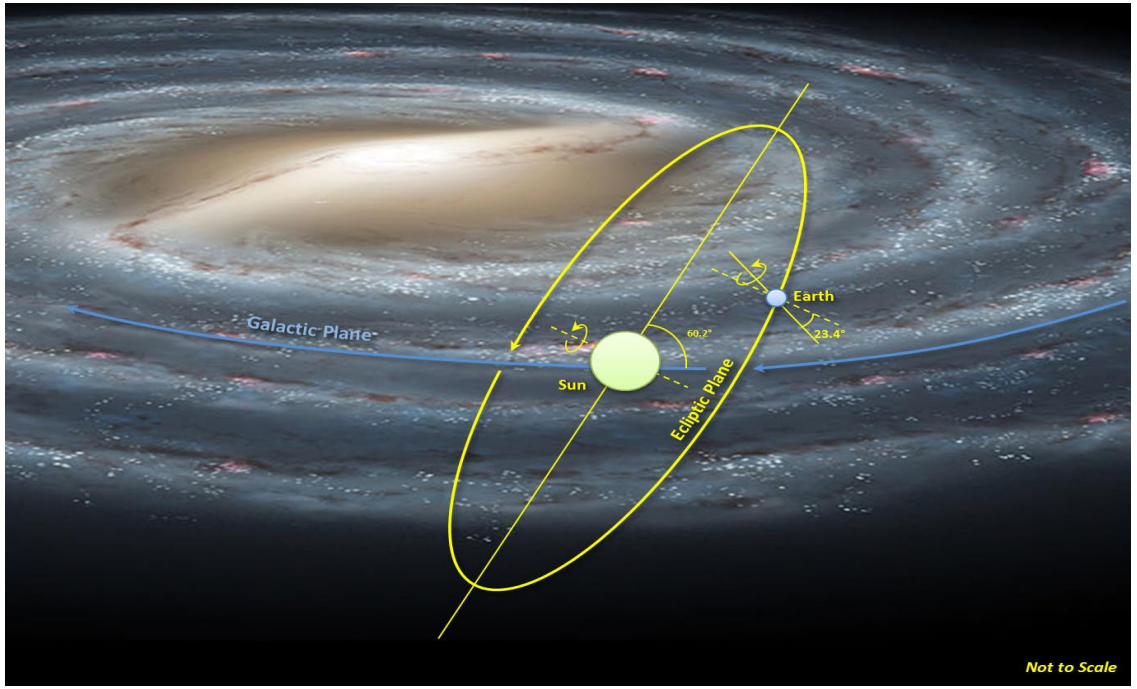


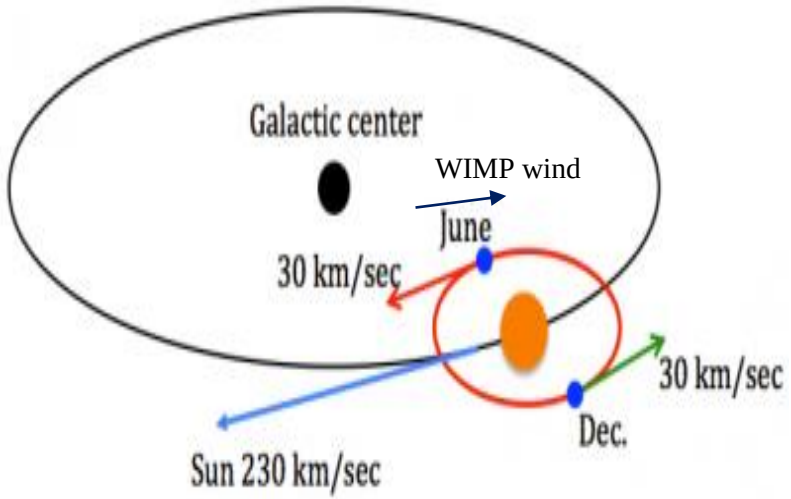
Brief history of DEAP-3600

- Initial design begins in 2006, details for the design and construction of DEAP-3600, Astropart. Phys. 108, 1 (2019), arXiv:1712.01982v2
- DEAP-3600 was taking physics data from May 2016 to March 2020, first WIMP search with 4.44 live days of data, Phys. Rev. Lett. 121, 071801 (2018), arXiv:1707.08042v2
- Second WIMP search publication with open data of 231 live days, Phys. Rev. D, 100, 022004 (2019), arXiv:1902.04048
- Other physics analysis,
  - Electromagnetic backgrounds and activity of ^{42}K in DEAP-3600, Phys. Rev. D, 100, 072009 (2019), arXiv:1905.05811
  - Constraints to the dark matter-nucleon effective couplings in presence of distinct halo substructures, Phys. Rev. D 102, 082001 (2020), arXiv:2005.14667
  - The liquid-argon scintillation pulseshape in DEAP-3600. Eur. Phys. J. C 80, 303 (2020), arXiv:2001.09855
  - Pulseshape discrimination against low-energy ^{39}Ar beta decays, Eur. Phys. J. C 81, 823 (2021), arXiv:2103.12202
  - First direct detection constraints on Planck-scale mass dark matter, Phys. Rev. Lett. 128, 011801 (2022), arXiv:2108.09405
- Hardware upgrades to improve sensitivity underway for refill in 2022

Annual modulation in nuclear recoil rate

- Annual modulation of the expected WIMP signal, not expected in most of the known backgrounds





Annual modulation in nuclear recoil rate

- The count rate of interactions of WIMPs with target nuclei,

$$\frac{dR}{dE_R}(t) = S_0(E_R) + S_m(E_R)\cos\omega(t - t_0)$$

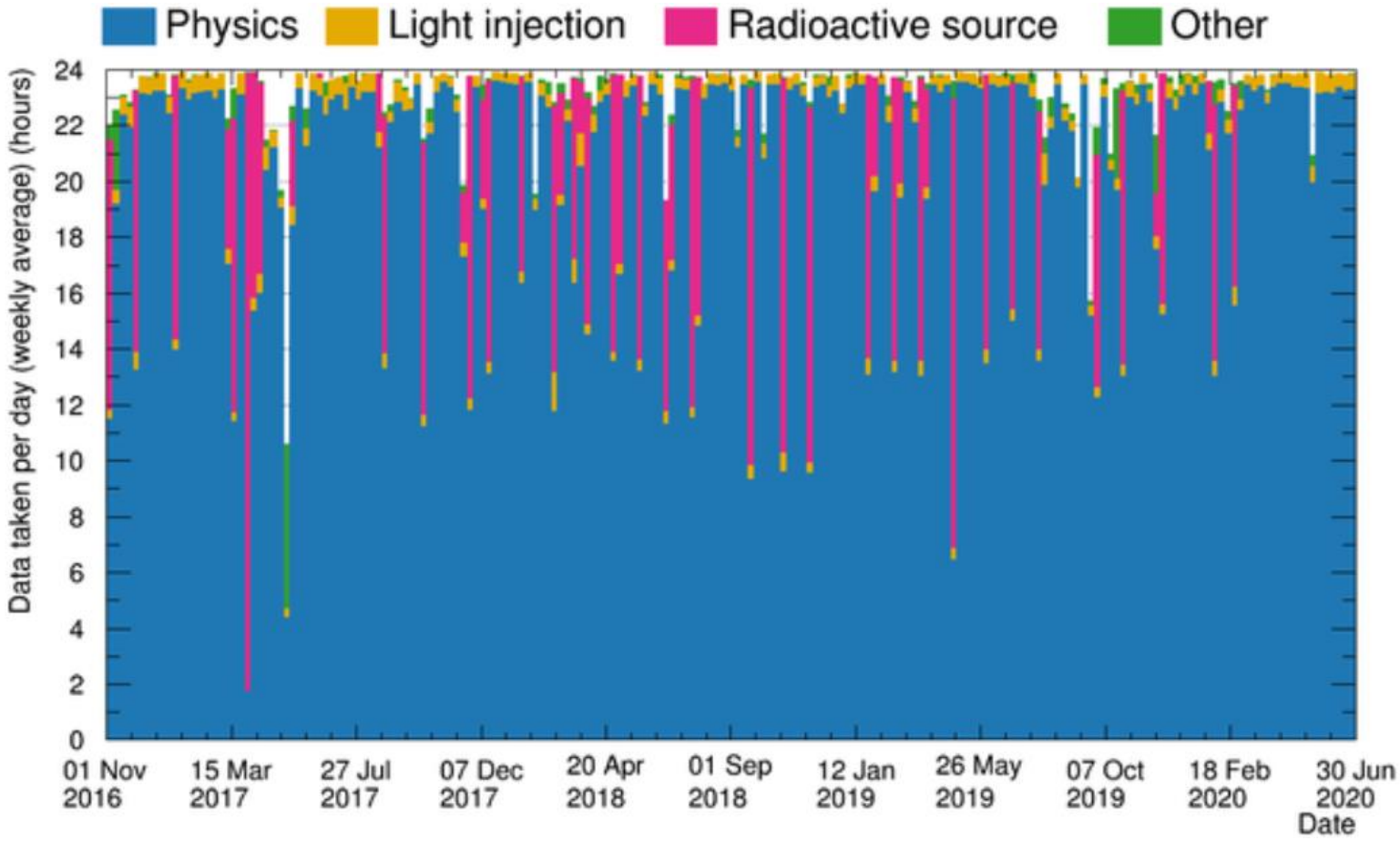
ω - angular frequency of the earth's rotation
t_0 - time at which the velocity of the earth with respect to galactic rest frame is maximum

- The amplitude of the modulation,

$$A_1(E) \approx \frac{1}{2}\left[\frac{dR}{dE}(E, \text{June } 1) - \frac{dR}{dE}(E, \text{Dec } 1)\right]$$

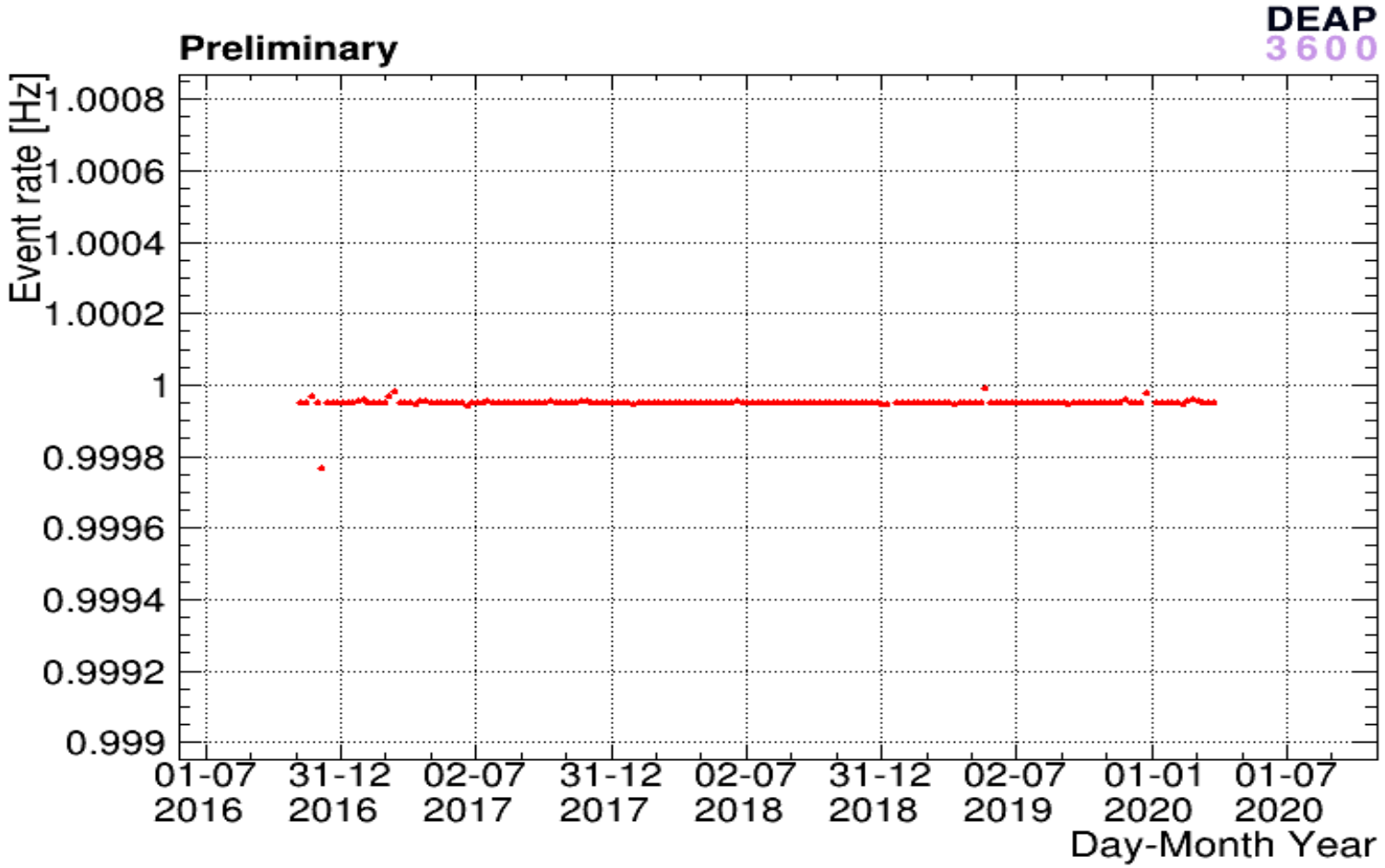
- For LAr based detectors annular modulation of WIMP signals has not been recorded yet, DEAP-3600 experiment would be first one to study this in LAr target material

DEAP-3600 second fill data-taking



- The liquid argon physics data was recorded from November 2016 to March 2020
- More than 3 years of data, appropriate to study the modulation in event rates for WIMP recoil region with time
- The time varying characteristics of long-lived elements in detector can be well understood

Event rate analysis



- Algorithm was made to plot the rates of different event types from DEAP-3600 data with respect to time information and validated with the calibration trigger events
- Periodic events are test pulses of 1Hz injected in the trigger system to monitor the time stability
- For the further validation of the algorithm, the event rates for ^{39}Ar decay can be calculated

^{39}Ar lifetime measurement

- ^{39}Ar is mainly produced by following nuclear interactions from cosmic rays,
  $^{40}_{18}Ar_{22} + n \rightarrow {}^{41}_{18}Ar_{23} \rightarrow 2n + {}^{39}_{18}Ar_{21}$, $^{40}_{18}Ar_{22} + n \rightarrow {}^{39}_{17}Cl_{22} + d$ where, $^{39}_{17}Cl_{22} \rightarrow {}^{39}_{18}Ar_{21} + e^{-} + \bar{\nu}_e$

- Nuclear decay of ^{39}Ar,
  $^{39}_{18}Ar_{21} \rightarrow {}^{39}_{19}K_{20} + e^{-} + \bar{\nu}_e$ (Half life = 269+/-3 years measured in 1965)
  (dominant contribution in the event rate, 1 Bq per kg of argon)

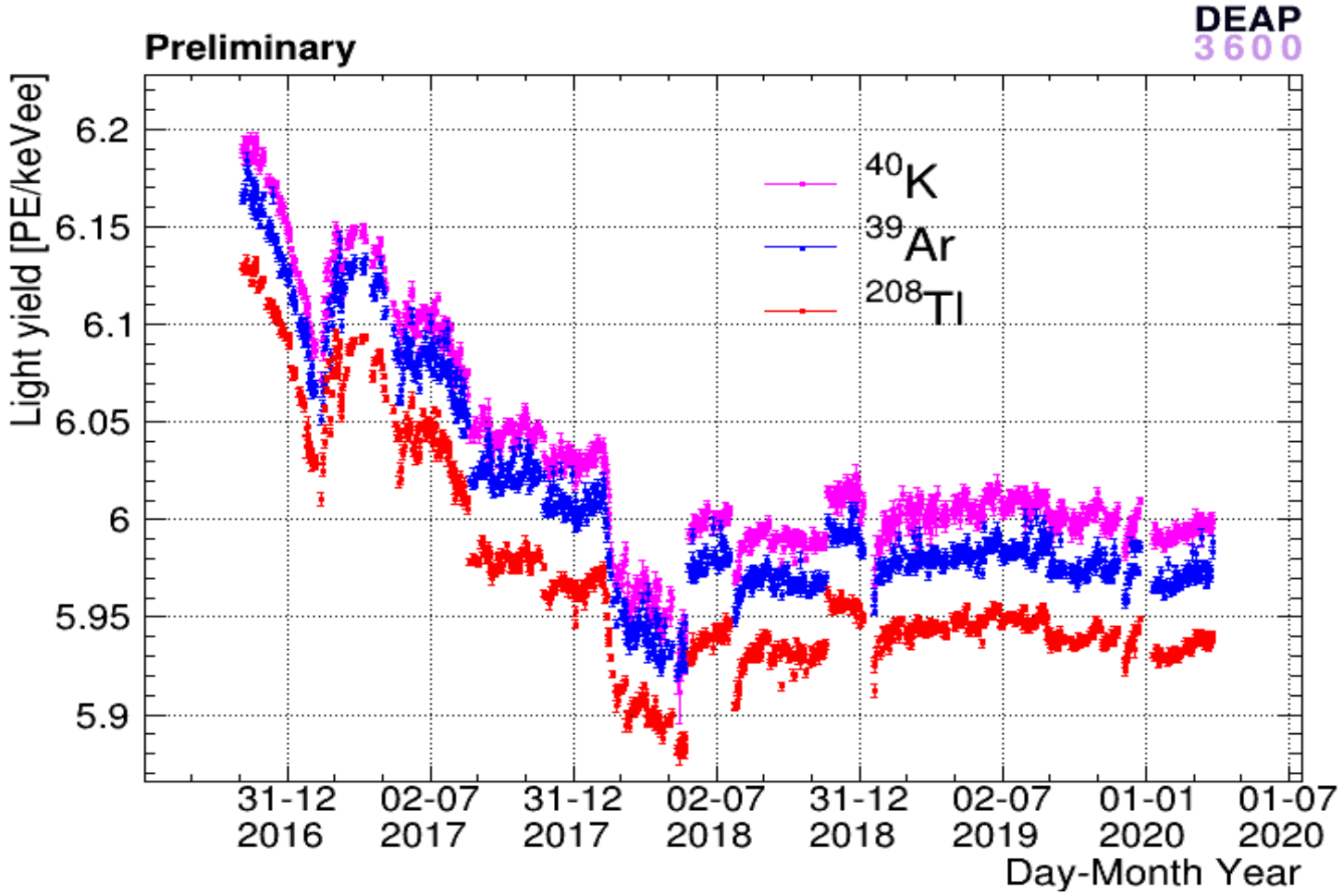
- The exponential decay fit function can be used with the event rates of ^{39}Ar decays,
  $R(t) = R_o * exp(-t/\tau)$

  where R(t) is the rate of ^{39}Ar at any time t, R_o is activity at t=0, and τ is mean lifetime

- This measurement with DEAP will be the first measurement of half life by measuring the evolution of the decay rate over time which would contribute to fields using radiological dating such as geology and geochronology

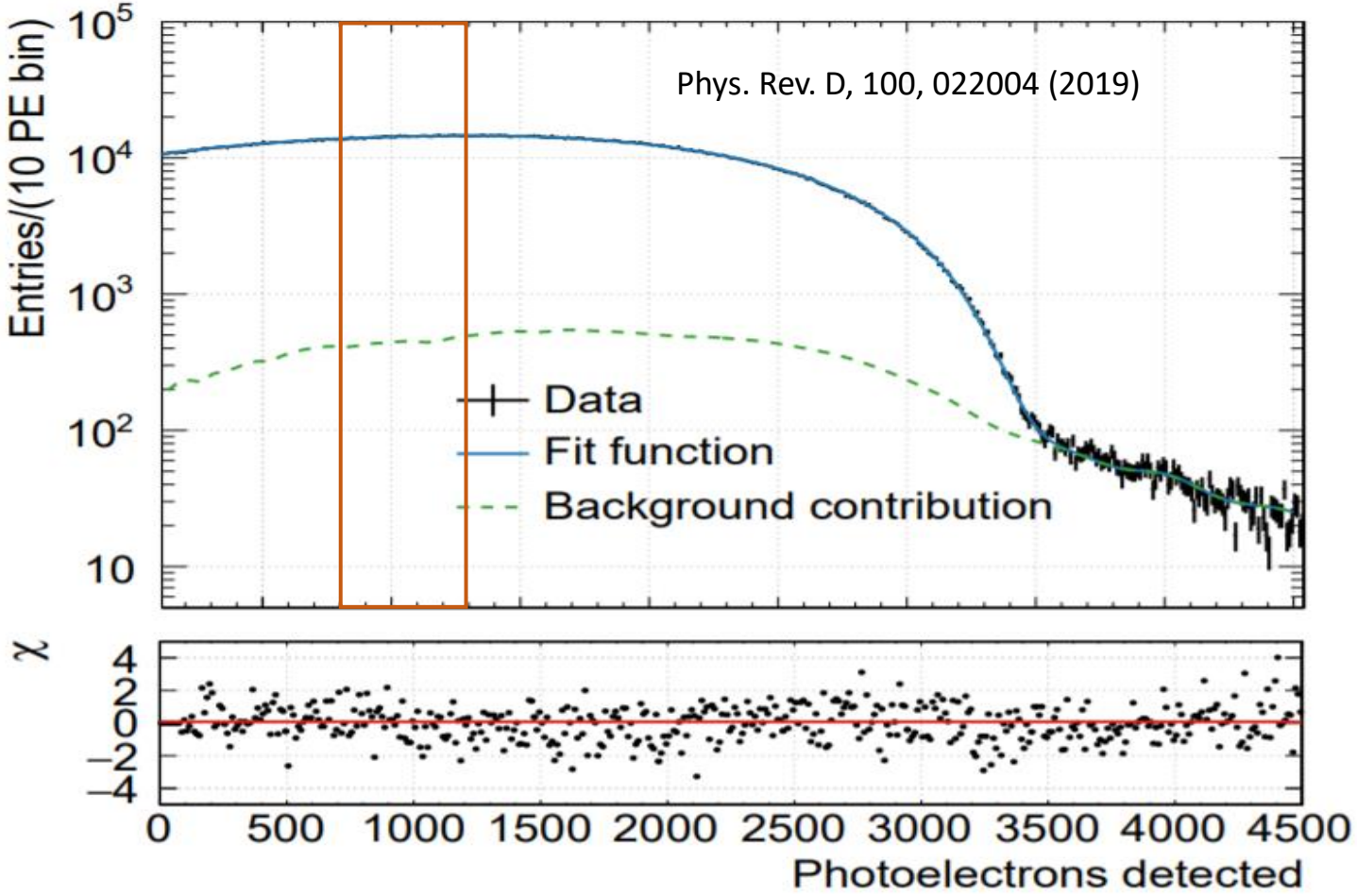
Good stability of detector and complete understanding of systematics is required!

Stability of detector



- Light yield values of detector was calibrated by fitting the ^{39}Ar, ^{208}Tl and ^{40}K peaks
- The light yield of detector was stable and has a little variation of 0.3 PE/keVee over the dataset
- Corrections are applied for the very little variations of light yield for precise measurement of ^{39}Ar decay events

^{39}Ar event rate and detector response



- To analyze the rate of ^{39}Ar beta events versus time, a stable region of interest is selected
- The systematics related to the time dependence of acceptance for different event selection cuts
- This study will give the direct measurement of the ^{39}Ar lifetime
- The evaluated differential systematics will be used in the modulation analysis in WIMP nuclear region

Summary

- The stability of DEAP-3600 detector is very good over more than three years of running period
- The event rate analysis in nuclear recoil signals over time is an alternate way to look for the interaction of WIMPs with argon
  - A good understanding of detector response and systematics is required (especially at low energies)
- The study of time dependence of different event rates includes many exciting analyses
- The background ^{39}Ar beta decay events can be used for the interesting measurements such as lifetime of these isotopes which would contribute to other fields like K-Ar and Ar-Ar dating

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Sudbury/Warsaw, September 2021

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References

- Stoenner R W, Schaeffer 0 A, and Katcoff S (1965). Half-Lives of Argon-37, Argon-39, and Argon-42. Science, 148, 1325
- Lewin J D and Smith P F (1996). Review of mathematics, numerical factors, and corrections for dark matter experiments based on elastic nuclear recoil. Astroparticle Physics, 6, 87
- Freese K, Lisanti M, and Savage C (2013). Annual Modulation of Dark Matter: A Review. Reviews of Modern Physics, 1209, 3339
- DEAP-3600 Collaboration (2018). First results from the DEAP-3600 dark matter search with argon at SNOLAB. Physical review letters, 121, 071801
- DEAP-3600 Collaboration (2019). Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB. Physical Review D, 100, 022004
- Froborg F and Duffy A R (2020). Annual modulation in direct dark matter searches. Journal of Physics G: Nuclear and Particle Physics, 47, 094002