The stability of the DEAP-3600 dark matter detector and projected sensitivities for time-varying signals

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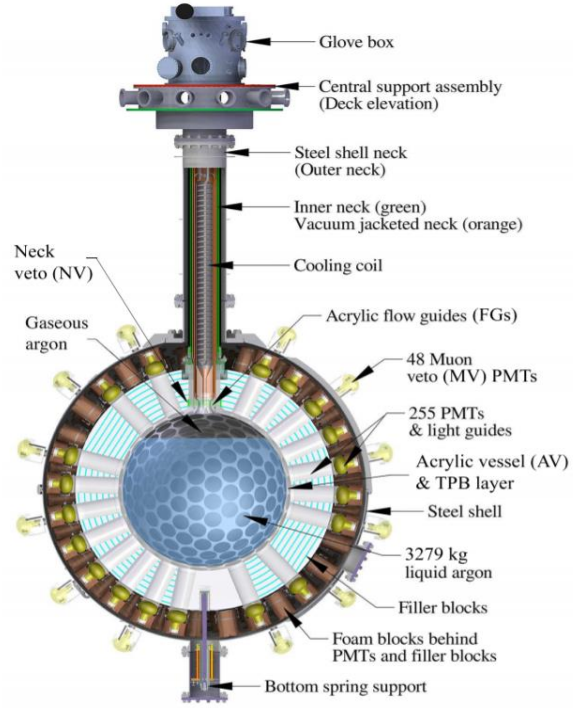
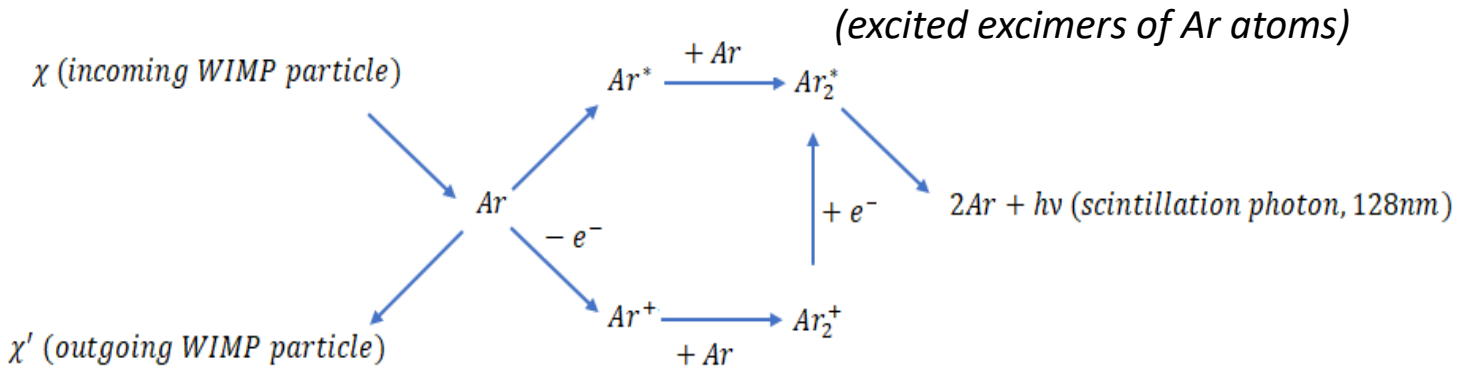
Outline

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

DEAP-3600 experiment

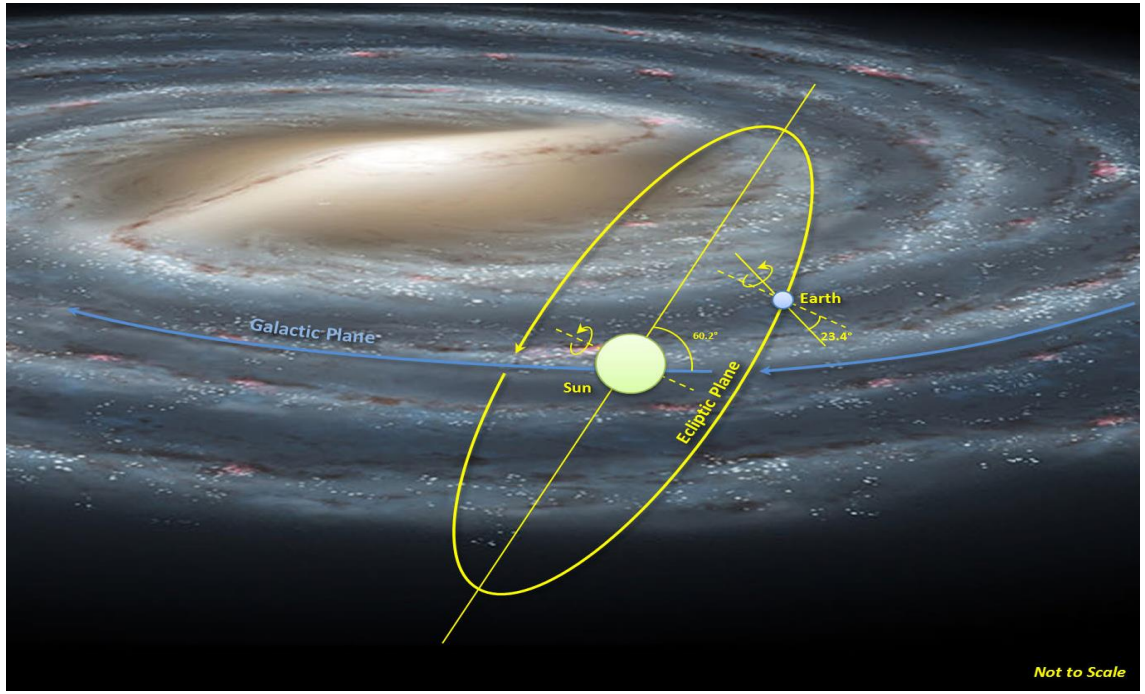
- The Dark matter Experiment using Argon Pulse-shape discrimination
- Single phase Liquid Argon (LAr) scintillation light detector
- DEAP-3600 experiment is located 2km underground at SNOLAB, Sudbury, ON

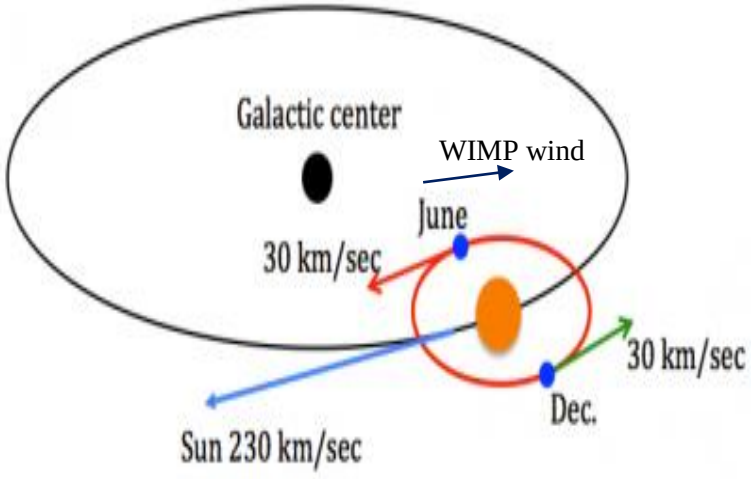




Annual modulation in nuclear recoil rate

- Earth travelling in the same direction as the wind, resulting lower nuclear recoils
- Earth traveling in the opposite direction resulting in higher nuclear recoils
- 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

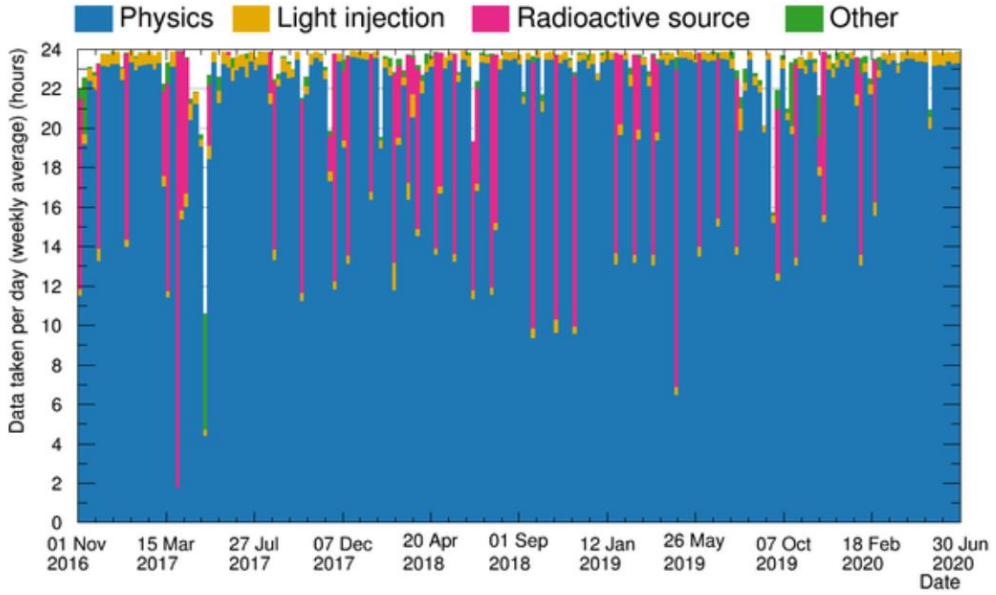
- The amplitude of the modulation,

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

- 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

Event rate analysis

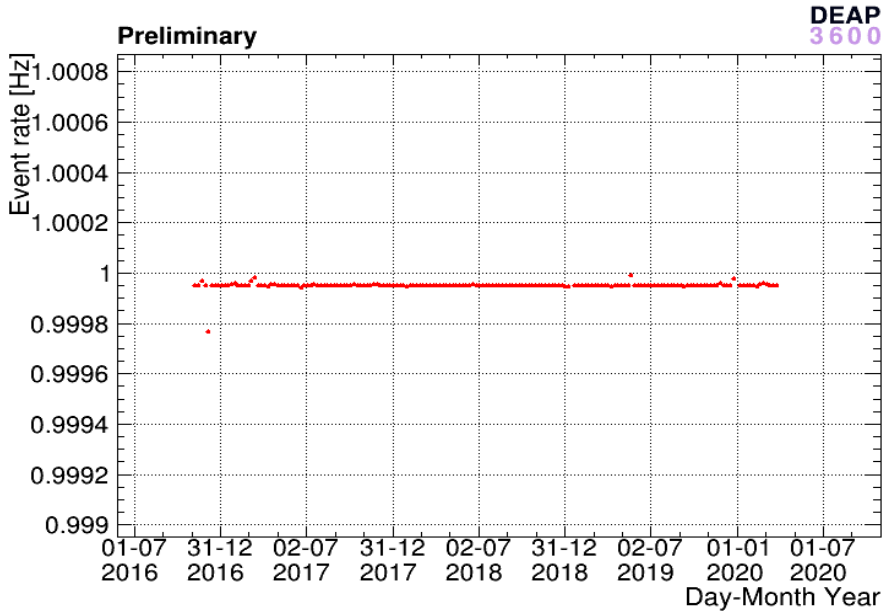
- The liquid argon physics data was recorded from November 2016 to March 2020



- 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 production and decay

- ^{39}Ar is mainly produced by following nuclear interaction,

$$^{40}_{18}Ar_{22} + n \rightarrow {}^{41}_{18}Ar_{23} \rightarrow 2n + {}^{39}_{18}Ar_{21}$$

- 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,

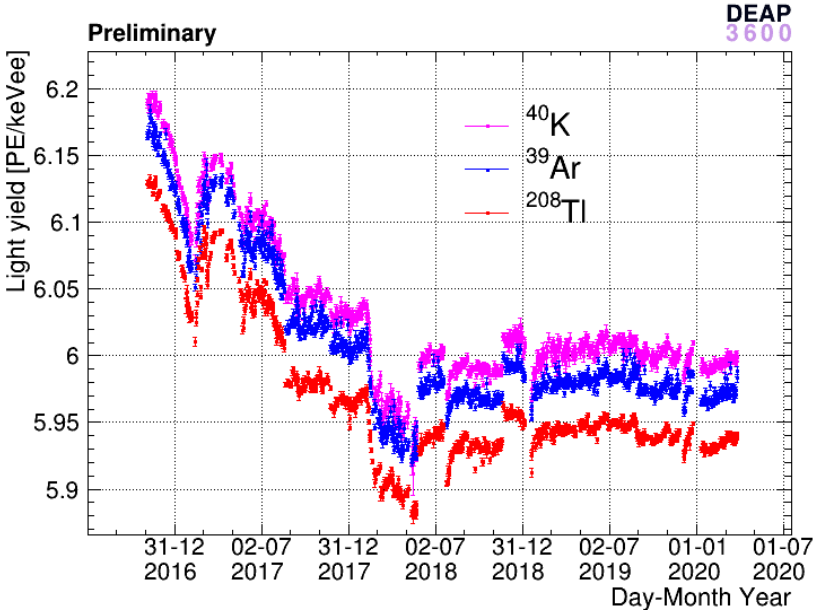
$$R(t) = R_o * exp(-t/\tau)$$

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

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

Stability of detector

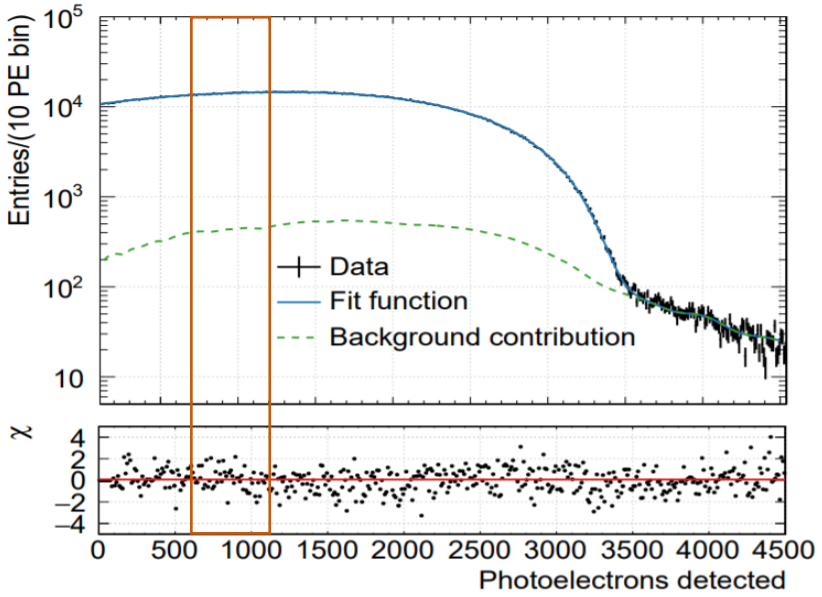
- Light yield values of detector was calibrated by fitting the ^{39}Ar, ^{208}Tl and ^{40}K peaks
- The light yield of detector was stable and has a little variation of 0.3 PE/keVee over the dataset



- 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 of the rate of ^{39}Ar beta events versus time over three-year dataset, a stable region of interest is selected (as shown)



- The systematics related to the time dependence of acceptance for different event selection cuts
- The evaluated differential systematics would 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 analysis
- 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 of like K-Ar and Ar-Ar dating

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