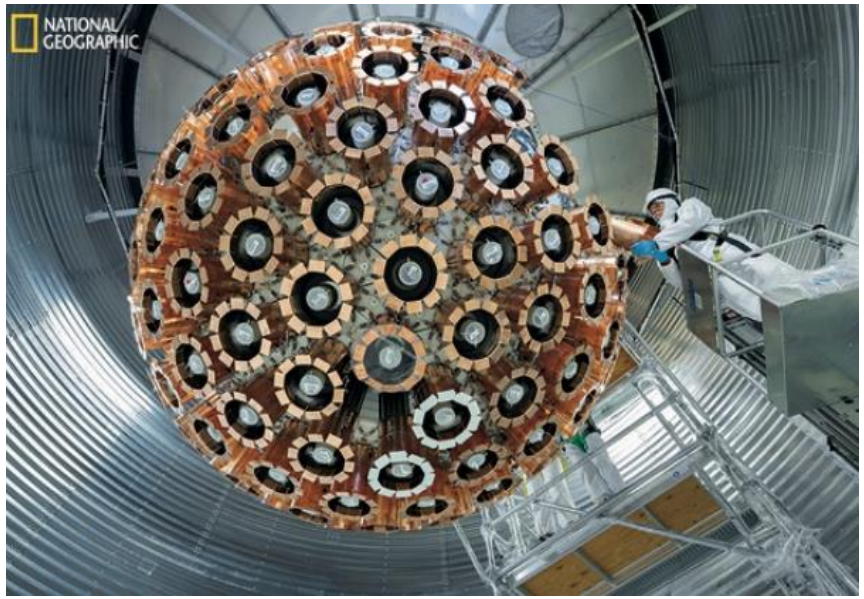
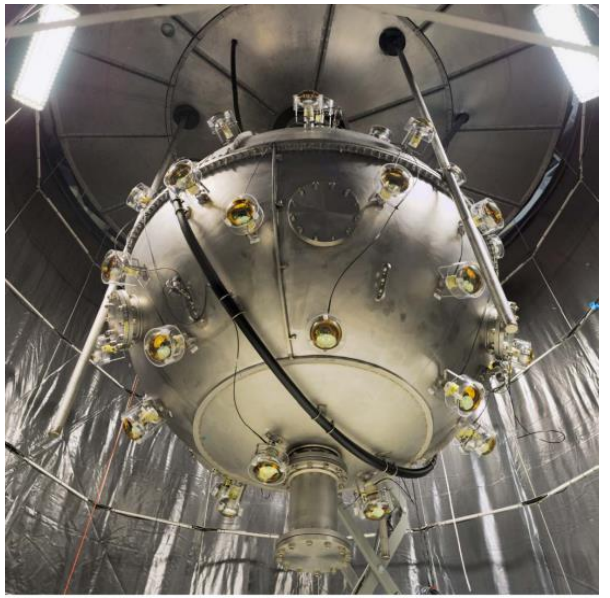
^{39}Ar decay analysis and annual modulation search with DEAP-3600





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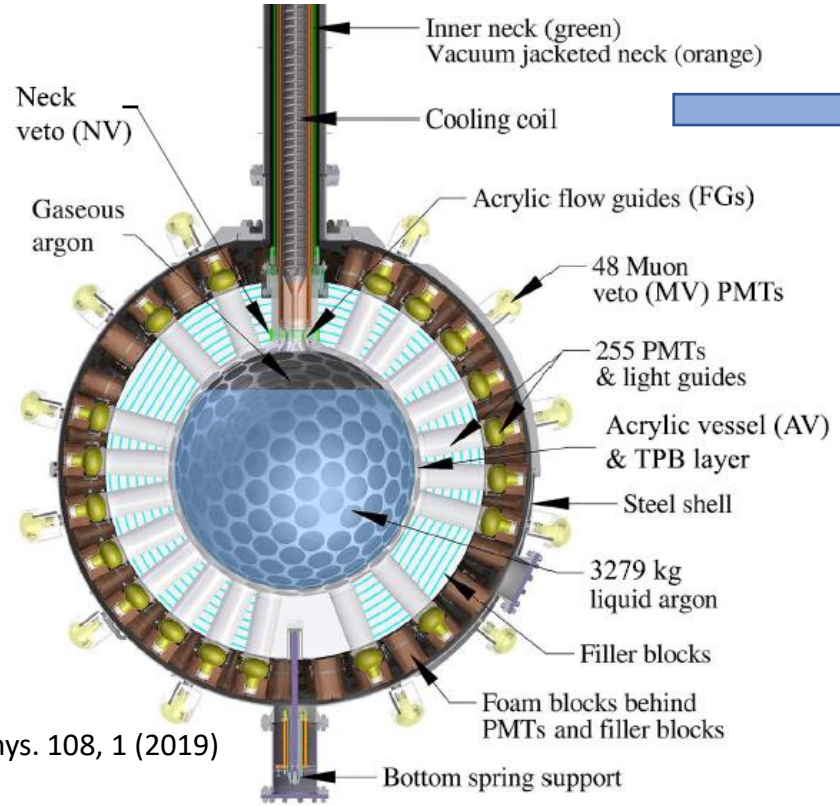
Outline

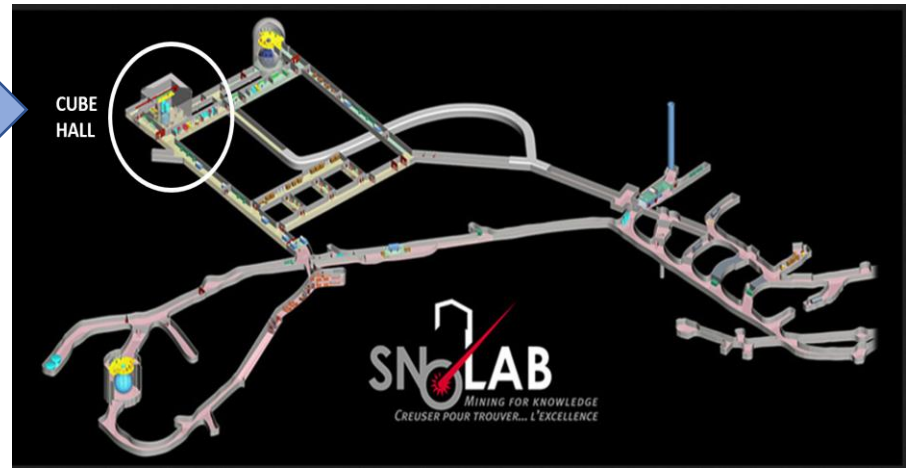
- The DEAP-3600 experiment
- Annual modulation for WIMP search
- Event rate analysis
- ^{39}Ar dating and detector systematics
- Summary
- References

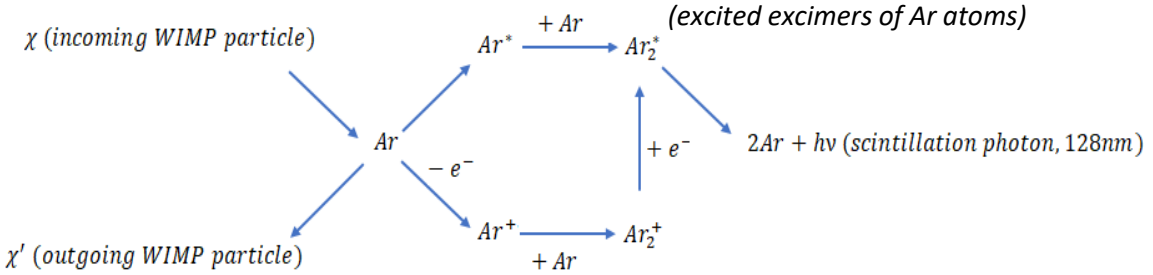
DEAP-3600 experiment

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



Astropart. Phys. 108, 1 (2019)



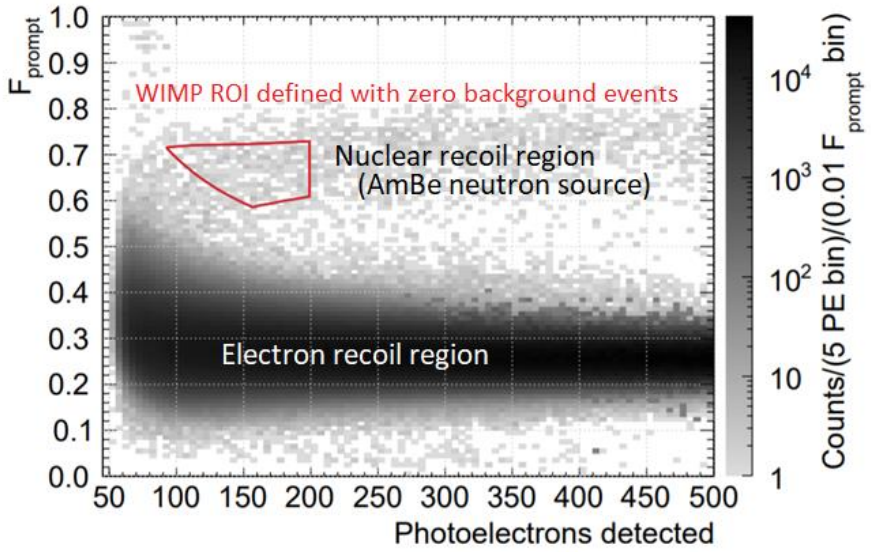


DEAP-3600 experiment

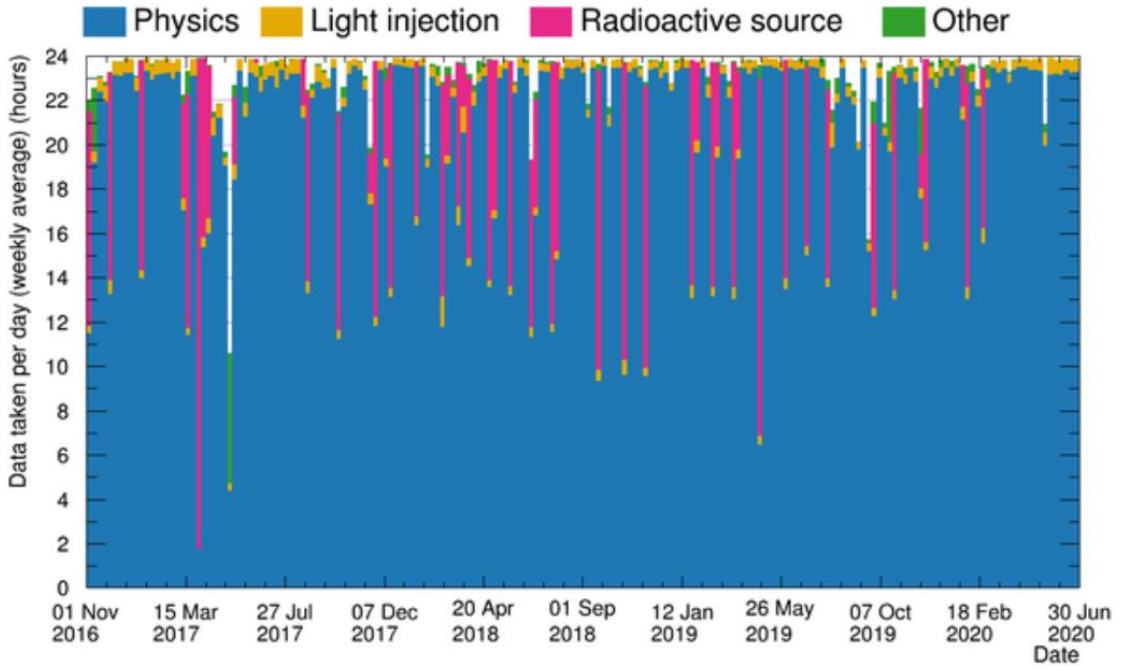
- Pulse Shape Discrimination is used with decay times of excimers, τ_S(singlet) = 6ns and τ_T(triplet) = 1300ns
- A prompt region is defined with the equation,

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

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



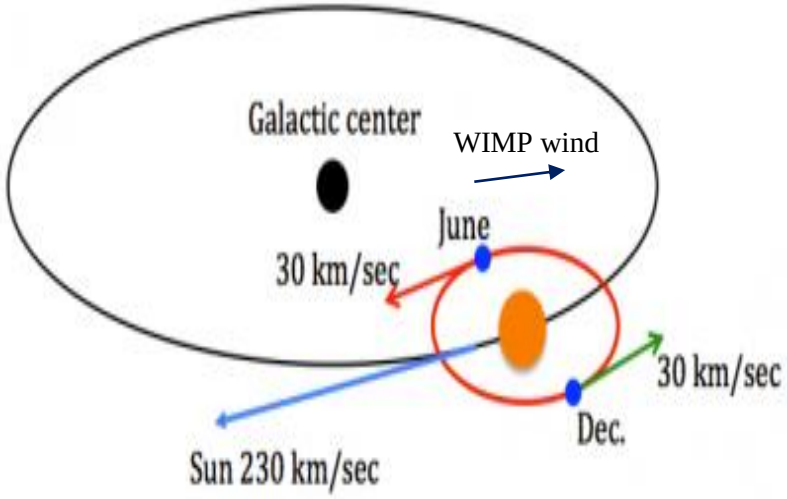
231 days of the dataset published!



More than 3 years of data to study

Annual modulation in nuclear recoil rate

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



Nuclear recoil rates,

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

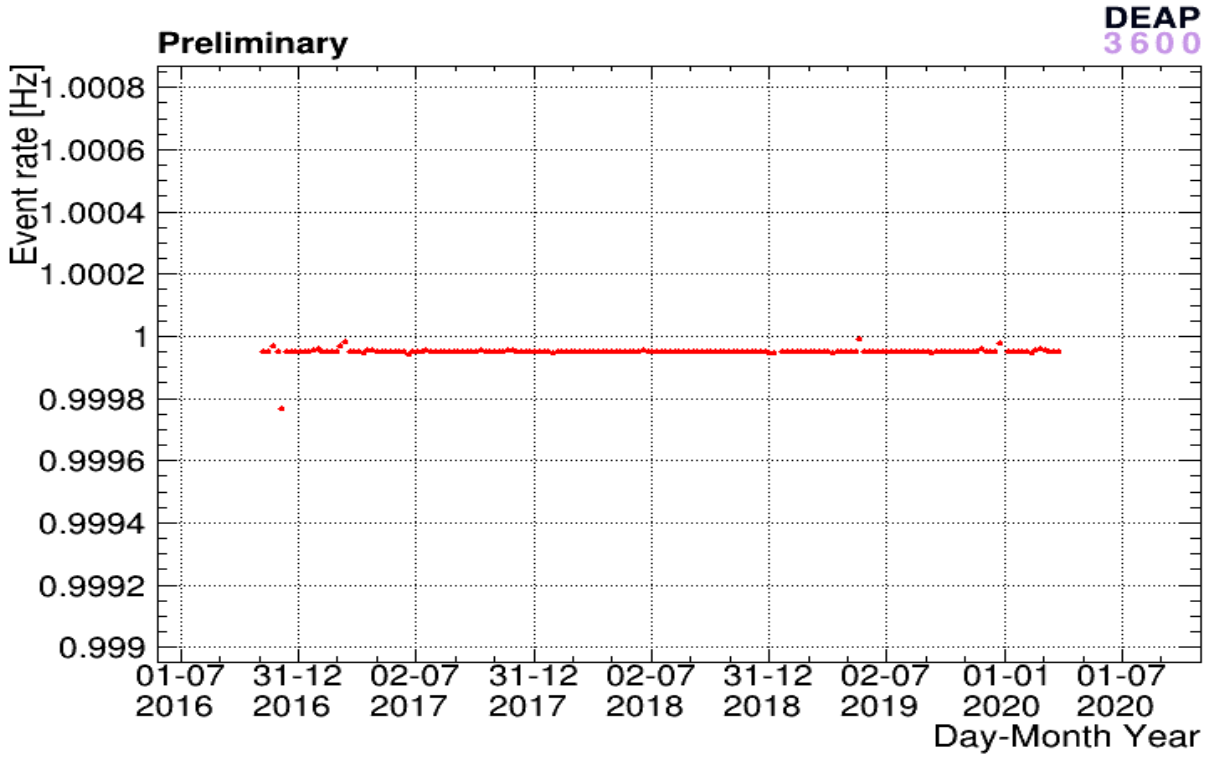
The amplitude of the modulation,

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

- DEAP-3600 will be the first liquid argon experiment to search for an annual modulation of event rates that could be due to WIMP dark matter

Event rate analysis

- Algorithm was made to plot the rates of different event types with time, which is validated with the calibration events



Event rate of periodic test pulses that are injected into the trigger system and recorded at a frequency of 1 Hz

- For the further validation of the algorithm, the event rates for ^{39}Ar decay can be calculated

^{39}Ar lifetime measurement

- ^{39}Ar is the dominant electron recoil background and is mainly produced by 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, $^{39}_{17}Cl_{22} \rightarrow {}^{39}_{18}Ar_{21} + e^{-} + \bar{\nu}_e$

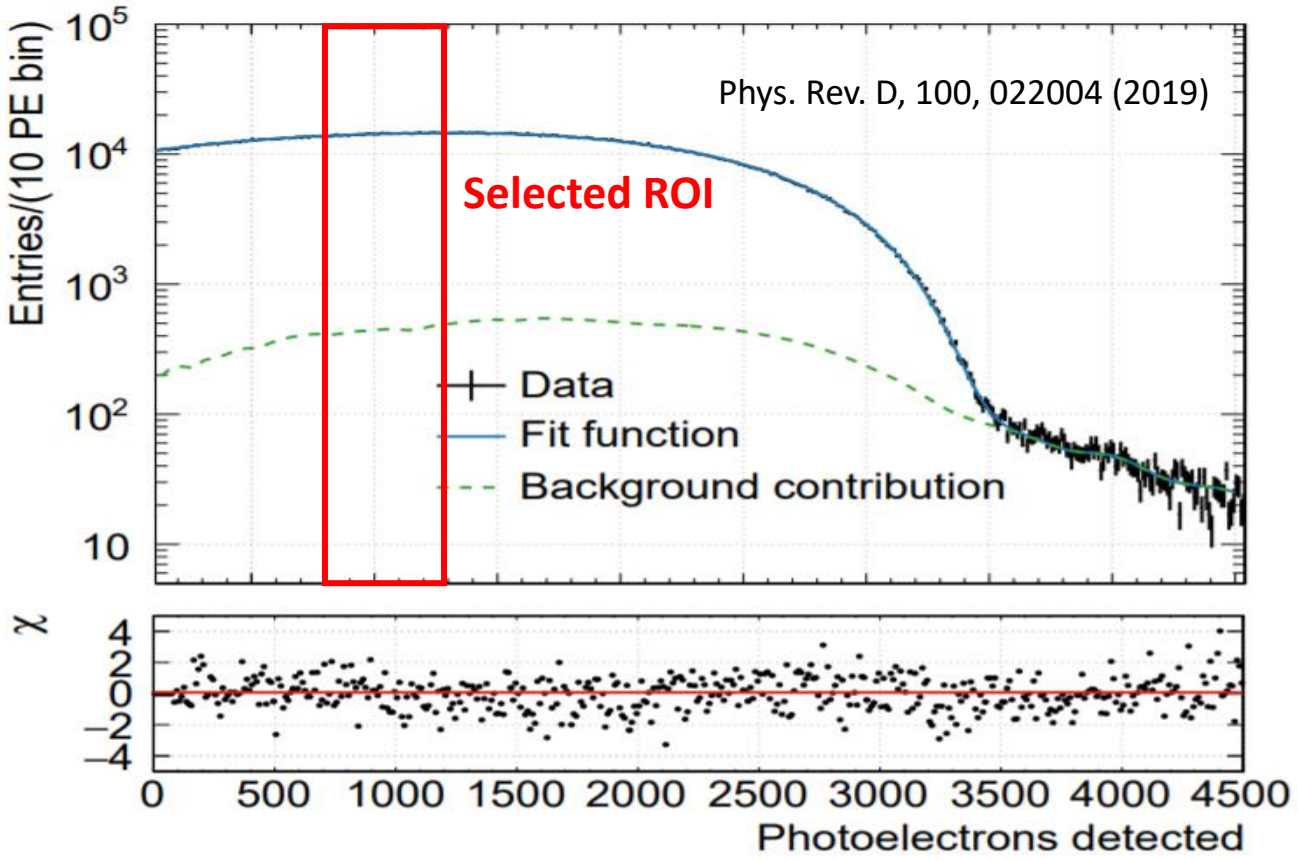
- Nuclear decay of ^{39}Ar,

$$^{39}_{18}Ar_{21} \rightarrow {}^{39}_{19}K_{20} + e^{-} + \bar{\nu}_e$$ (Half-life = 269+/-3 years measured in 1965)

- The exponential decay fit function with other background events can be used with the event rates of ^{39}Ar decays to determine the mean lifetime from this direct measurement
- DEAP is the first experiment measuring the decay rate with time for the half-life of this isotope which would contribute to the fields using radiological dating such as geology and geochronology

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

Region of interest in ^{39}Ar beta spectrum



The differential systematics are evaluated for the lifetime study and will be used in the modulation analysis in WIMP nuclear region

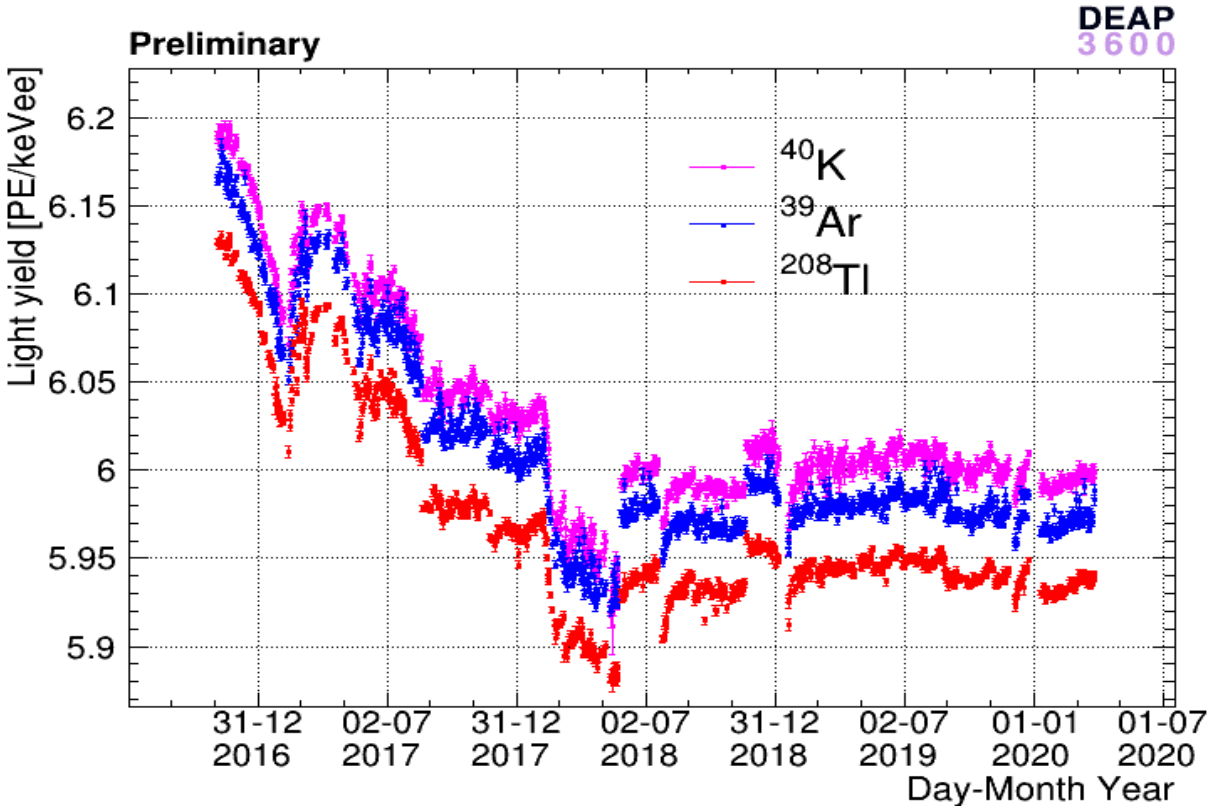
Event rate fit model for ROI

$$R(t) = R_0 * \exp(\frac{-t}{\tau}) * \prod_j \epsilon_{1,j}(t) + (\frac{f_{2^{39}ArinROI}}{f^2_{1^{39}ArinROI}}) * R_0^2 * \delta t * \exp(\frac{-2t}{\tau}) * \prod_j \epsilon_{2,j}(t) +$$
$$(\frac{f_{3^{39}ArinROI}}{2 * f^3_{1^{39}ArinROI}}) * R_0^3 * \delta t^2 * \exp(\frac{-3t}{\tau}) * \prod_j \epsilon_{3,j}(t) + (\frac{f_{^{39}Ar,CherenkovinROI}}{f_{1^{39}ArinROI}}) *$$
$$R_0 * \exp(\frac{-t}{\tau}) * R_{Cherenkov}(t) * \delta t * \prod_j \epsilon_{ArCherenkov,j} + R_{bg}$$

R(t) is the activity of total event rates in ROI at any time t, R_0 is the activity of ^{39}Ar at the beginning of the dataset, and τ is the mean lifetime of the ^{39}Ar isotope

Light Yield Stability in detector

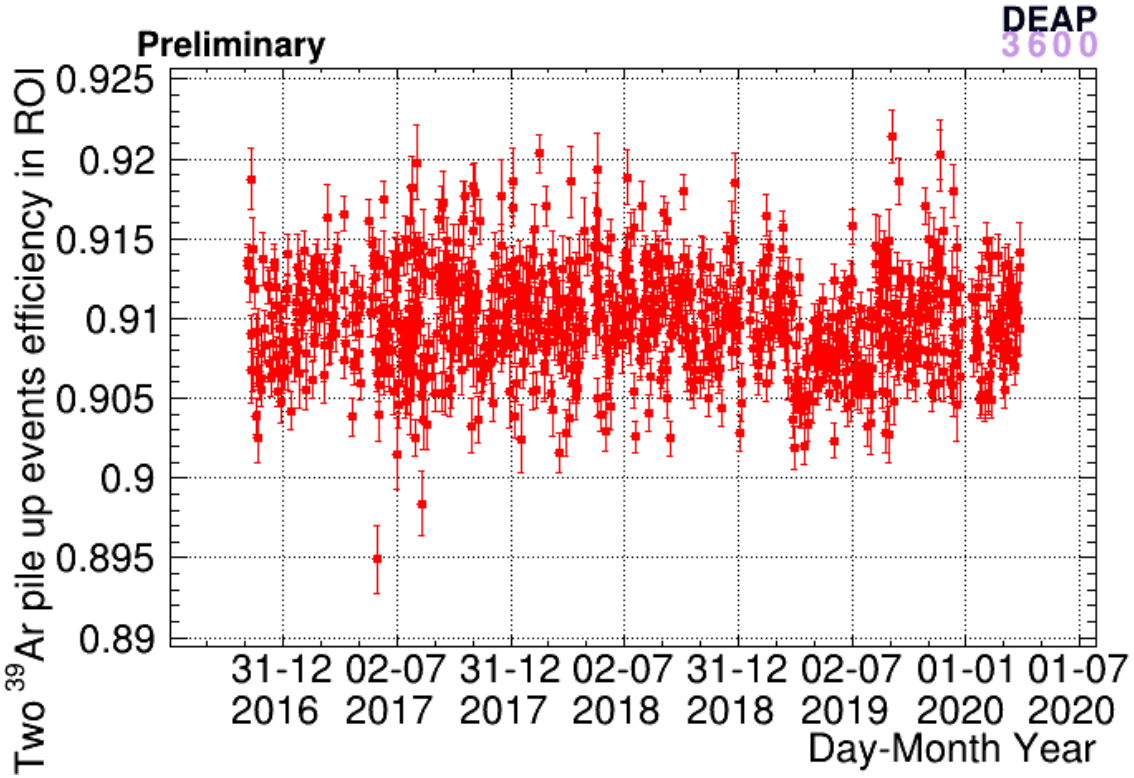
- The light yield of the detector was stable and has a little variation of 0.3 PE/keVee over the dataset

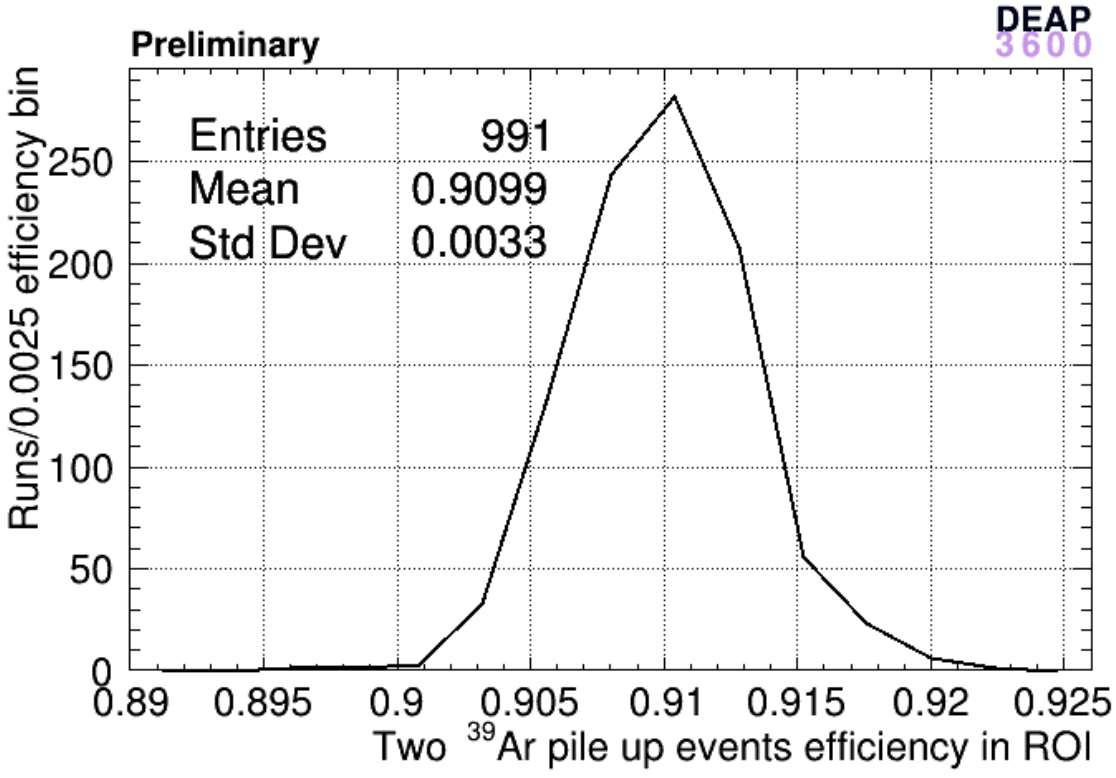


- Corrections are applied for the very little variations of light yield for precise measurement of ^{39}Ar decay events

Event selection efficiency

- Time dependence on the efficiency of selecting event types is investigated
- Selection of ^{39}Ar decay events in ROI is almost perfectly efficient





Systematic uncertainty on mean lifetime of ^{39}Ar

Preliminary

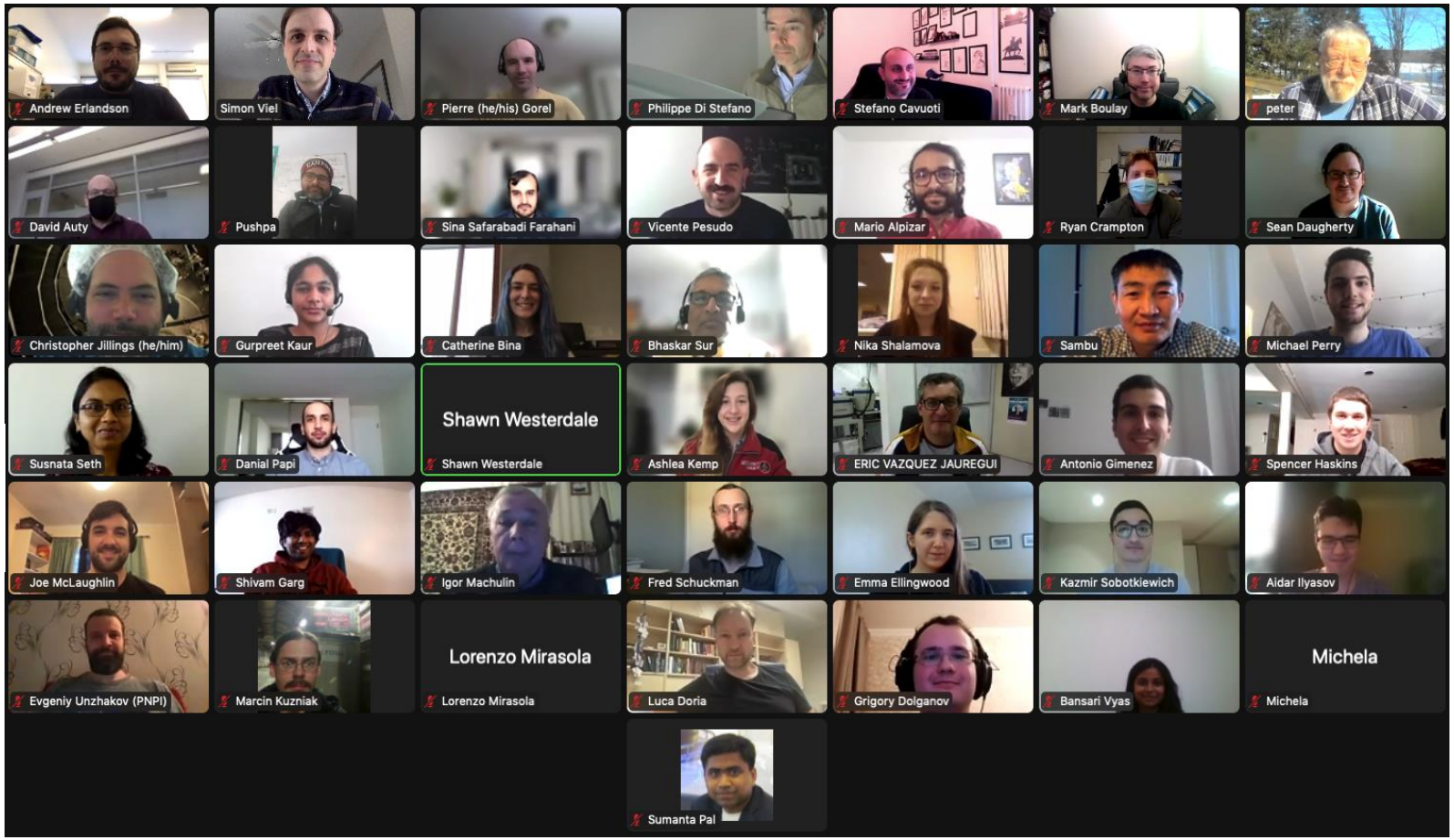
DEAP 3600

Systematic uncertainty source	Uncertainty on τ (year)
Light yield corrections to energy	11.6
Efficiency for selecting single ^{39}Ar events	0.1
Efficiency for selecting double ^{39}Ar events	2.9
Efficiency for selecting triple ^{39}Ar events	0.1

Total systematic uncertainty on τ is maximum of 12 years

Summary

- 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 stability of the DEAP-3600 detector is very good over more than three years of the running period
- The study of the 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 the lifetime of these isotopes which would contribute to other fields like K-Ar and Ar-Ar dating
- The dominant systematic affecting the event rate studies are investigated in detail and the results will be presented in the upcoming publications



DEAP-3600 Online collaboration meeting
February 2022

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