Energy response and position reconstruction in the DEAP-3600 dark matter experiment

TAUP 2017, Sudbury

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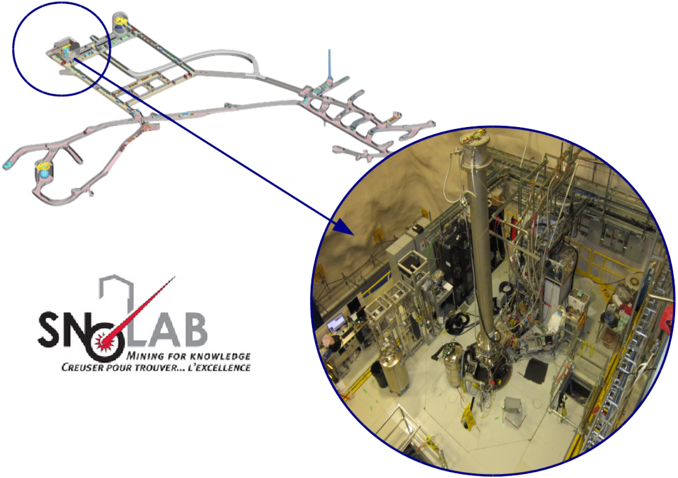
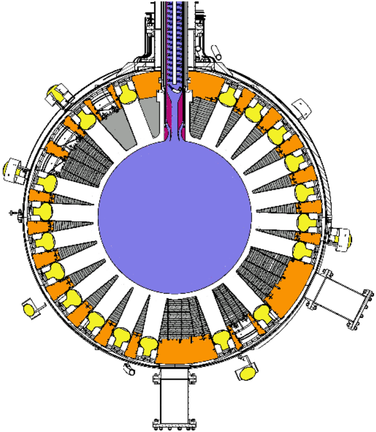
Located at SNOLAB, 2 km underground at 6000 mwe:



The experiment:

- Pixelated detector
- capable to hold 3600 kg LAr target material, currently filled to 3260 kg
- 255 PMTs to measure energy and position of events in the LAr
- AV coated with wavelength shifter TPB
- Detection of WIMPs via nuclear recoils with a target sensitivity to WIMP-nucleon cross secion 10^{-46} cm^2 at WIMP masses of 100 GeV



Running stable since November 2016

Radioactive Calibration Sources

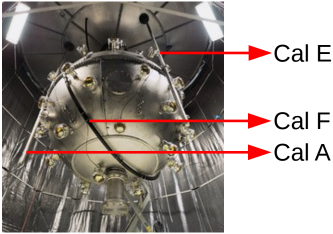
^{39}Ar

Internal source

- β^- emitter with $Q = 565\,$keV
- From cosmic ray interaction on ^{40}Ar
- Isotropically distributed in LAr

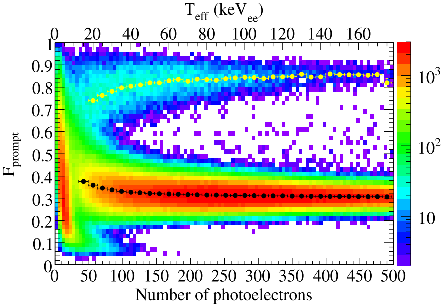
^{22}Na

External source



Discriminating the ^{39}Ar signal using PSD:

$$f_{\text{prompt}} = \frac{q_{\text{prompt}}}{q_{\text{event}}}$$

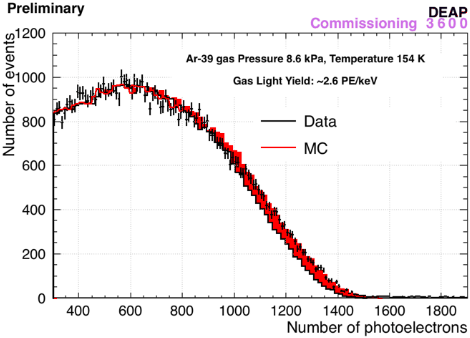


DEAP-1 calibration data
`Astroparticle Physics 85 (2016) 1-23`

- Ar Dimer states with different life times:
  - Singlet τ 6 ns -predominantly nuclear recoils
  - Triplet τ 1500 ns -predominantly electromagnetic events

$\rightarrow$ Percentage of light signal in prompt light as indication of singlet state population

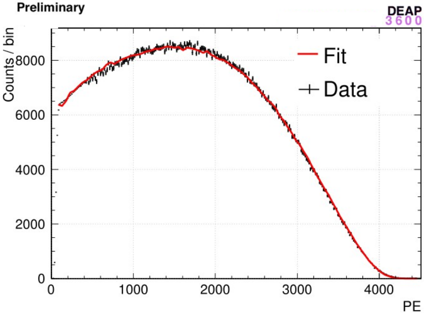
Understanding the energy response using ^{39}Ar, Gas phase calibration:



- Light yield uniformly scaled to match the simulation to data

Cool down phase, before fill

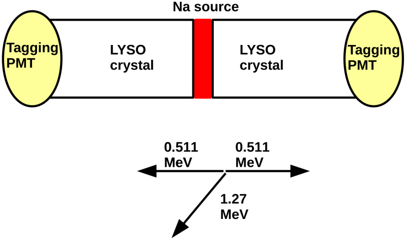
Understanding the energy response using ^{39}Ar, LAr phase calibration:

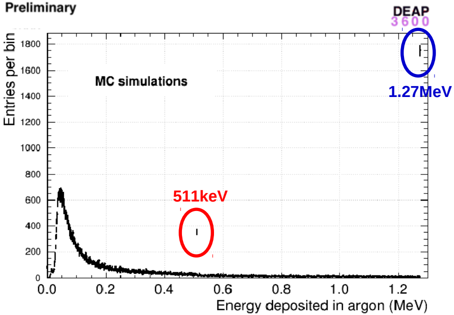


- Light yield uniformly scaled to match the simulation to data

First fill data

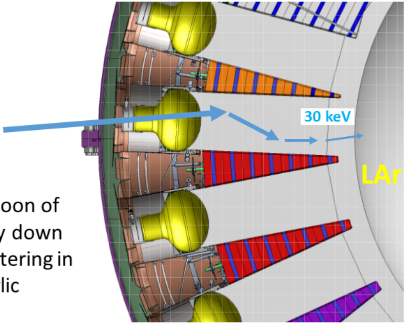
External ^{22}Na source allows tagged monoenergetic gamma rays:

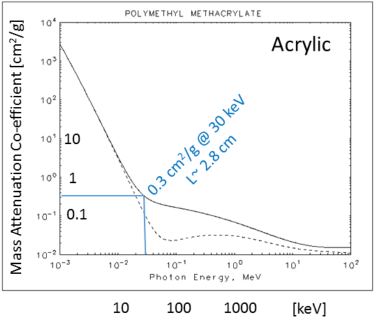




The low energy feature

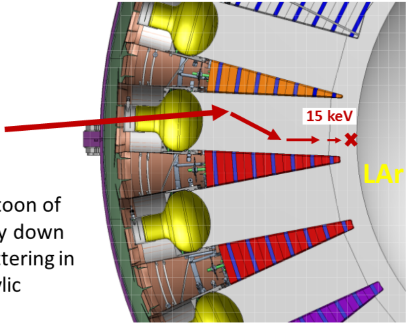
Cartoon of γ-ray down scattering in acrylic



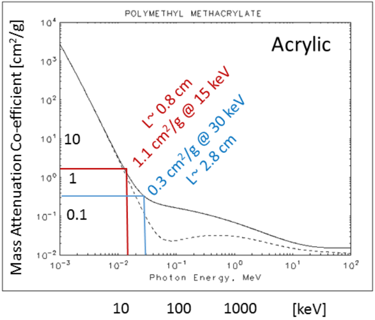


Plot and data from NIST.gov
X-ray mass attenuation coefficients

The low energy feature



Cartoon of γ-ray down scattering in acrylic



Plot and data from NIST.gov
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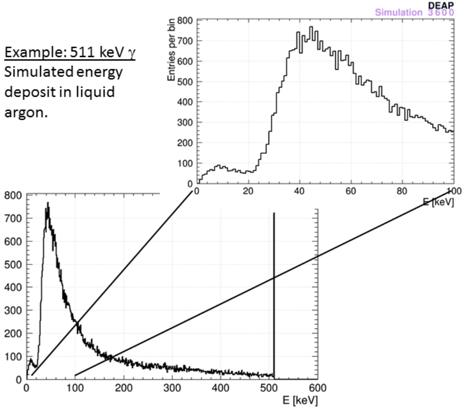
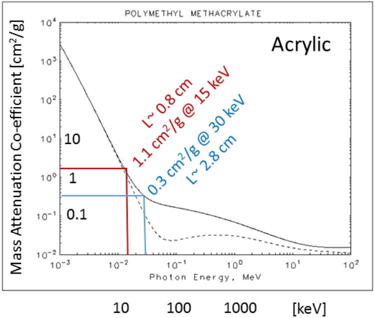
The low energy feature

Both the Rising and Falling Edge in Distribution Energy Deposit Arise from Electromagnetic Physics

Example: 511 keV γ
Simulated energy deposit in liquid argon.

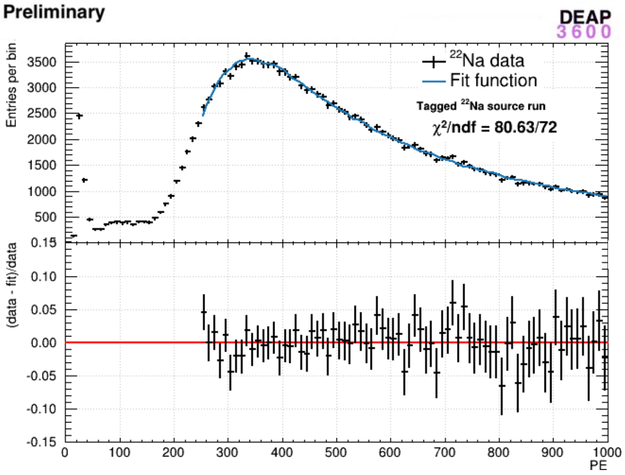




Plot and data from NIST.gov
X-ray mass attenuation coefficients

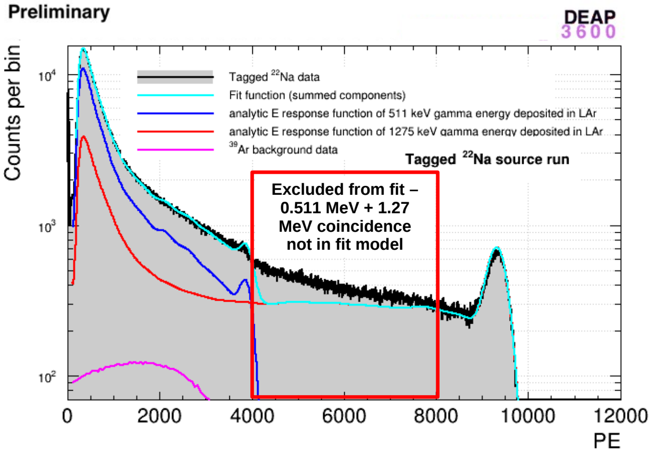
Fits on the ^{22}Na spectrum:

Fit on low energy feature

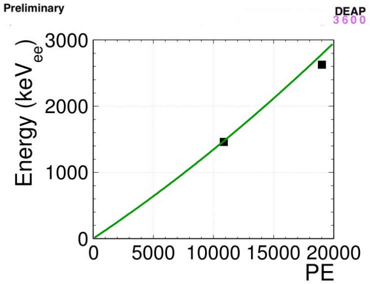


Fits on the ^{22}Na spectrum:

Fit on full spectrum: consistency check only



Combining ^{39}Ar and ^{22}Na:



Saturation effects at high energies not yet accounted for

WIMP ROI: $80 - 240$ PE

$c_0 + c_1\text{PE} + c_2\text{PE}^2$

Preliminary light yield:

$LY = 7.36^{+0.61}_{-0.52}(\text{fit syst.}) \pm 0.22(\text{SPE syst.})\text{PE/keV}_{ee}$ @80 PE

Measurement of event position:

Two main approaches possible:

- Time-based
- Charge-based

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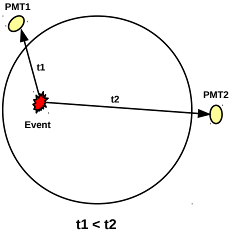
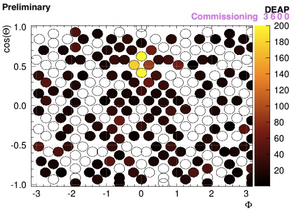


- Finite speed of light
- PMT hit time proportional to source distance from PMT
- Absolute vertex resolution uniform across volume
- Dependent on scintillator response times, PMT transit time, DAQ quality

Measurement of event position:

Two main approaches possible:

- Charge-based



- Charge patterns of the PMTs
- Point-like source: closer PMTs expected to have more photon hits and charges
- Pattern detector dependent
- Vertex resolution improved towards the edge of the detector

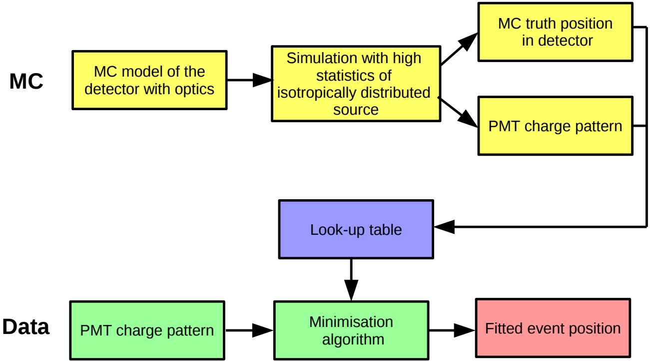
Measurement of event position:

Two main approaches possible:

- Time-based
- Charge-based

DEAP-3600 small enough for charge-based vertex reconstruction to deliver the better position resolution

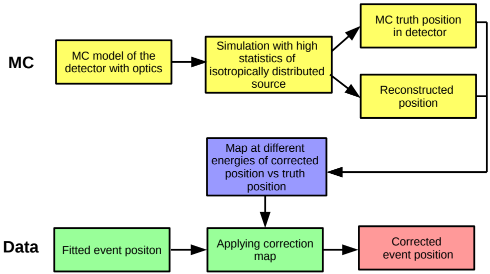
How it is done:



Work in progress!

Fiducialisation and de-biasing using ^{39}Ar:

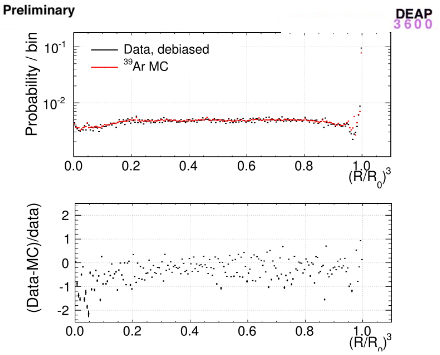
- Isotropic ^{39}Ar distribution
- Map true radius to reconstructed radius
- Account for energy dependence



Fiducialisation and de-biasing using ^{39}Ar:

- Fiducial mass from activity of de-biased ^{39}Ar decay spectrum after applying fiducial cuts

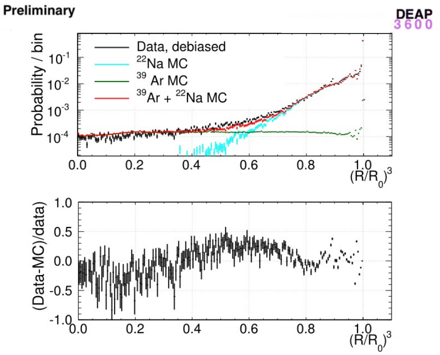
consistent with 2222 kg of LAr



Work in progress!

^{22}Na studies to understand surface backgrounds:

- ^{22}Na low energy feature at low energies near ROI helps determine fiducial cut parameter



Work in progress

The Deap-3600 collaboration:

University of Alberta
Carleton University
Laurentian University Université Laurentienne
Canadian Nuclear Laboratories

Queen's University
Royal Holloway University of London
Particle Physics Rutherford Appleton Laboratory
SNOLAB Mining for knowledge Creuser pour trouver... l'excellence
University of Sussex
TRIUMF
Instituto de Física

The speakers operational support was provided by NSERC

Back Up

DEAP-3600 calibration program:

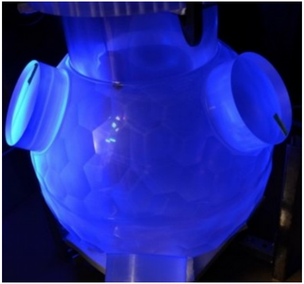
Calibration Source	Calibration goal	Notes
Laserball	Optical (PMT) calibration	vacuum runs only
LED Light Injection	Optical (PMT) calibration, monitoring	used in all run phases
^{22}Na	Energy and position reconstruction, gamma response	Argon phase
AmBe	Energy calibration, gamma and neutron response	Argon phase
^{39}Ar	Intrinsic, energy and position reconstruction	Argon phase

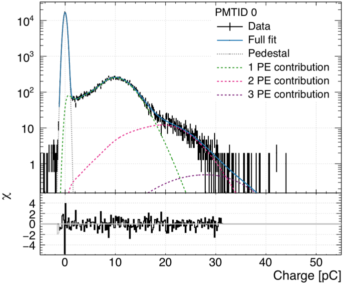
- Argon phase: gas phase (GAr), partial fill phase, liquid argon phase (LAr)
- LED Light Injection system with fibres installed on PMTs
- External calibration sources: ^{22}Na (1 MBq) and AmBe (74 MBq)
- Intrinsic calibration source: ^{39}Ar (expected 1.01 Bq/kg)

Single Photon counting:

Ideal measurement: single photon counting correcting for PMT effects

De-excitation photons ($128\,\text{nm}$) $\rightarrow$ TPB ($420\,\text{nm}$) $\rightarrow$ Photoelectron cascades in PMTs

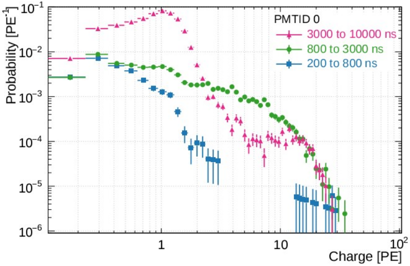




arXiv:1705.10183

- Translation of PMT pulses to number of photoelectrons observed using charge division (qPE)

Correction of different effects necessary:



Effects to correct on PE estimator:

- PMT effects:
  - After-pulse (AP): caused by back-scatter of electrons on PMT dynodes
  - Saturation of PMTs
  - Dark noise
- Other effects:
  - Pile-up of two or more events in same event window

arXiv:1705.10183