DEAP-3600

STUDY OF THE ENERGY RESPONSE AND POSITION RECONSTRUCTION WITH ^{22}Na SOURCE

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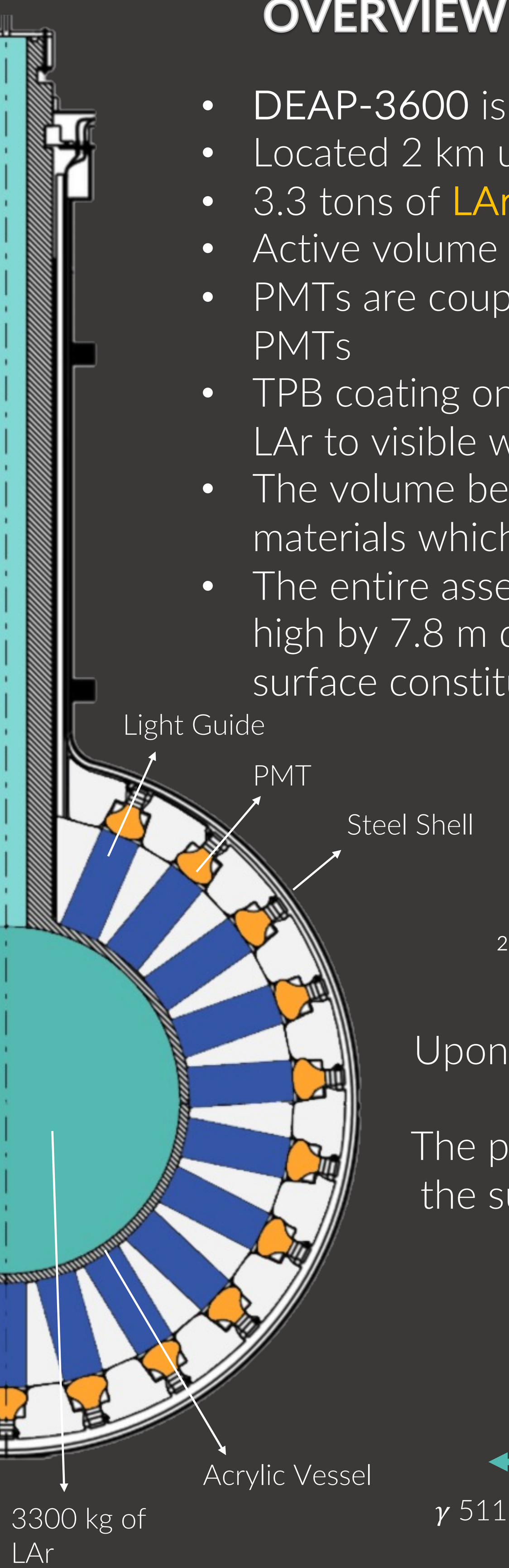
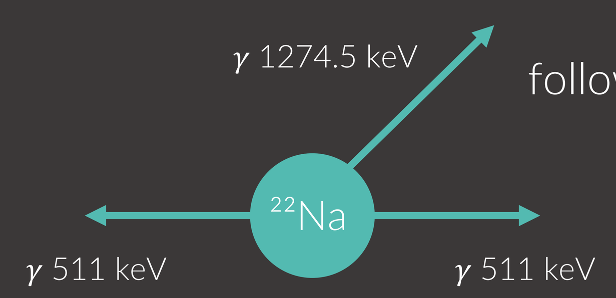
OVERVIEW OF THE DEAP-3600 EXPERIMENT

- DEAP-3600 is a single-phase liquid argon (LAr) dark matter detector
- Located 2 km underground at SNOLAB (Sudbury, Canada)
- 3.3 tons of LAr contained in a spherical acrylic vessel 851 mm in radius
- Active volume is viewed by 255 low radioactivity Photomultiplier Tubes (PMTs)
- PMTs are coupled to light guides which transport scintillation photons to the PMTs
- TPB coating on the acrylic converts the 128 nm scintillation light produced by the LAr to visible wavelengths
- The volume between the light guides is filled with alternating layers of insulating materials which provide passive shielding of neutrons and thermal insulation
- The entire assembly is contained in a stainless-steel sphere submerged in a 7.8 m high by 7.8 m diameter wide water tank with 48 PMTs mounted on its outer surface constituting a Cherenkov muon veto (MV)



^{22}Na CALIBRATION SOURCE

- ^{22}Na decays to an excited state of ^{22}Ne via a β+ decay (90.6 %) or electron capture (9.4 %)
- Upon transition to the ground state, the ^{22}Ne emits a γ with an energy of 1.275 MeV
- The positron from the ^{22}Na β+ decay annihilates with an electron from the surrounding materials, emitting two back-to-back γs with energies of 511 keV
- The emission of the three γ particles following the ^{22}Na decay is "simultaneous", providing a very suitable tagging algorithm for a ^{22}Na calibration source in DEAP-3600

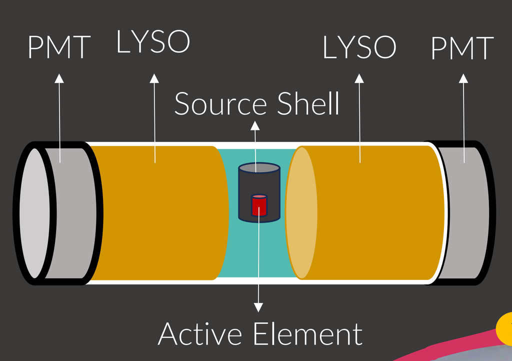


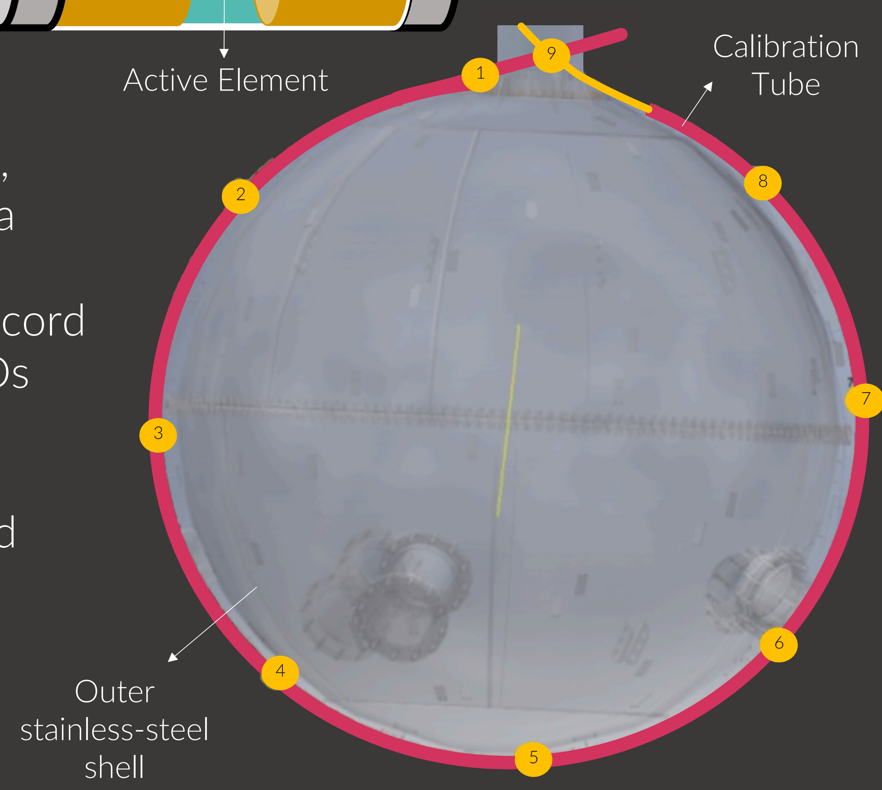
GOAL OF THIS WORK

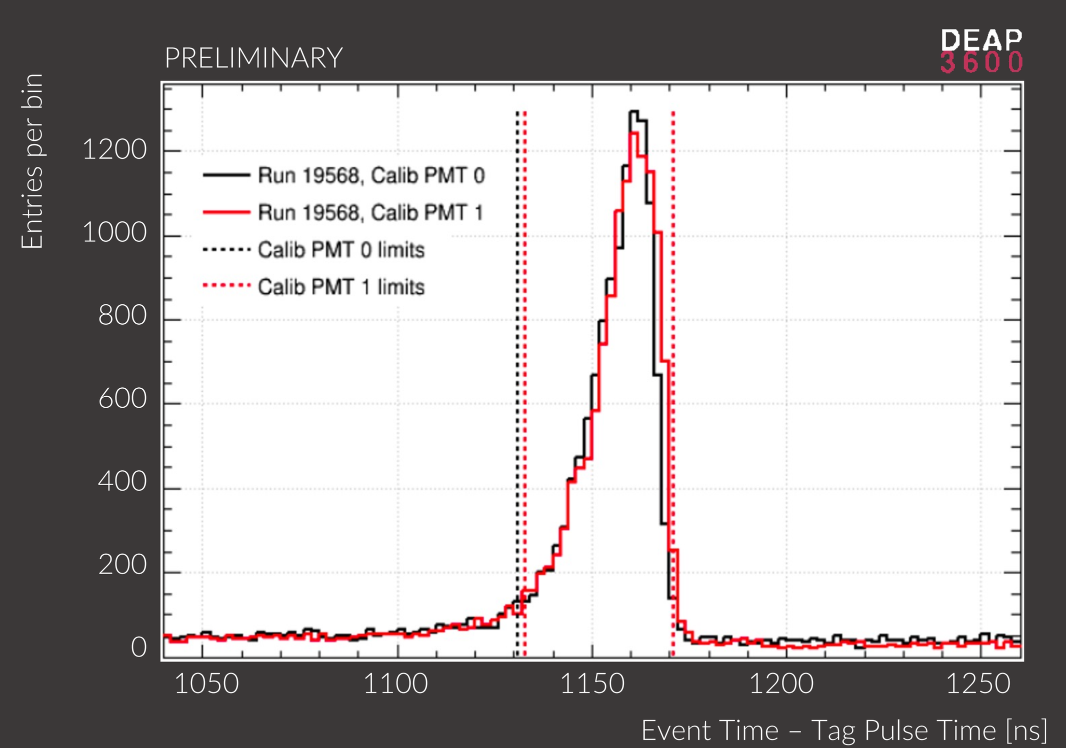
Exploit the excellent tagging properties of the ^{22}Na source to improve the event reconstruction and the overall performances of the experiment

SOURCE DESCRIPTION

- A stainless-steel cylinder contains the active element
- Source encapsulated with a copper foil and a copper closure
- On either side there are two LYSO crystals, scintillators used to tag the γs from the ^{22}Na decay
- The crystals are attached to PMTs which record the scintillation light emitted from the LYSOs
- To avoid contaminating the LAr target material, the source is only deployed around the outer steel shell in a calibration tube
- Along that cable, 9 pre-set positions were marked





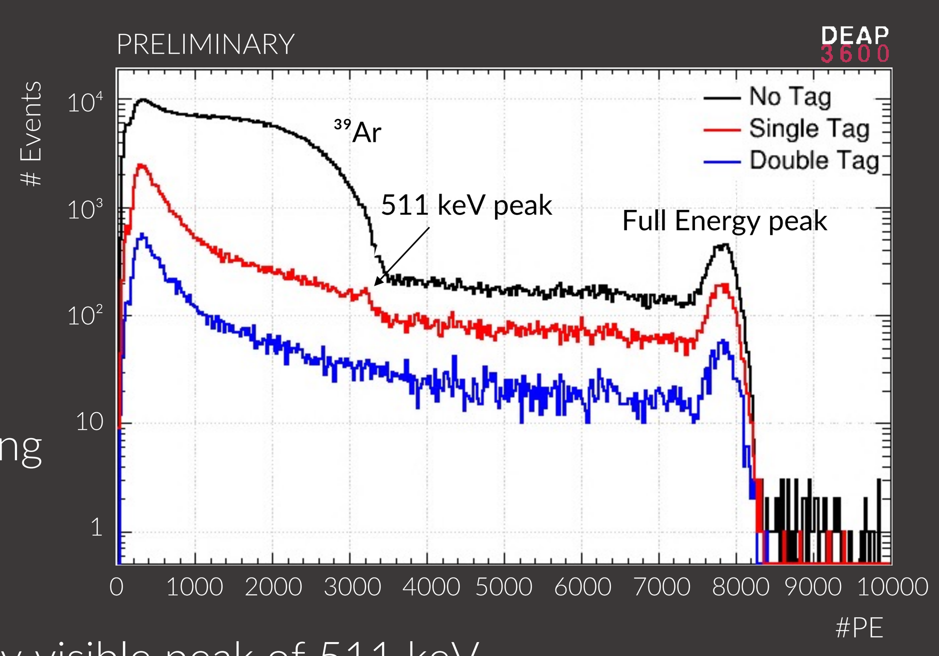


TAGGING ALGORITHM

- The tagging is based on the timing between the calibrated event time and the time the pulse was detected in the calibration PMTs
- The ^{22}Na pre-processor runs on the first 10 sub runs of a processed run
- Looking at the calibration PMT pulses, the algorithm detects and marks an appropriate tag window, used for the remaining sub runs in the run
- For runs in which the algorithm fails (due to high baseline, pile up or other factors) the processor uses default values from the tightest bound of 7 runs analysed

ENERGY RESPONSE

- Bayesian estimator of the number of photoelectrons (PE) observed from scintillation light
- The shape of the energy spectrum is dependent on the tagging by the PMTs
- 3 different tagging configurations:
  - trigger in the detector and in both tagging PMTs, that corresponds to the tightest tagging condition
  - trigger in the detector and just in one tagging PMT and this leads to the clearly visible peak of 511 keV
  - trigger only in the detector, when we are able to see the ^{39}Ar beta decay on top of the ^{22}Na spectrum



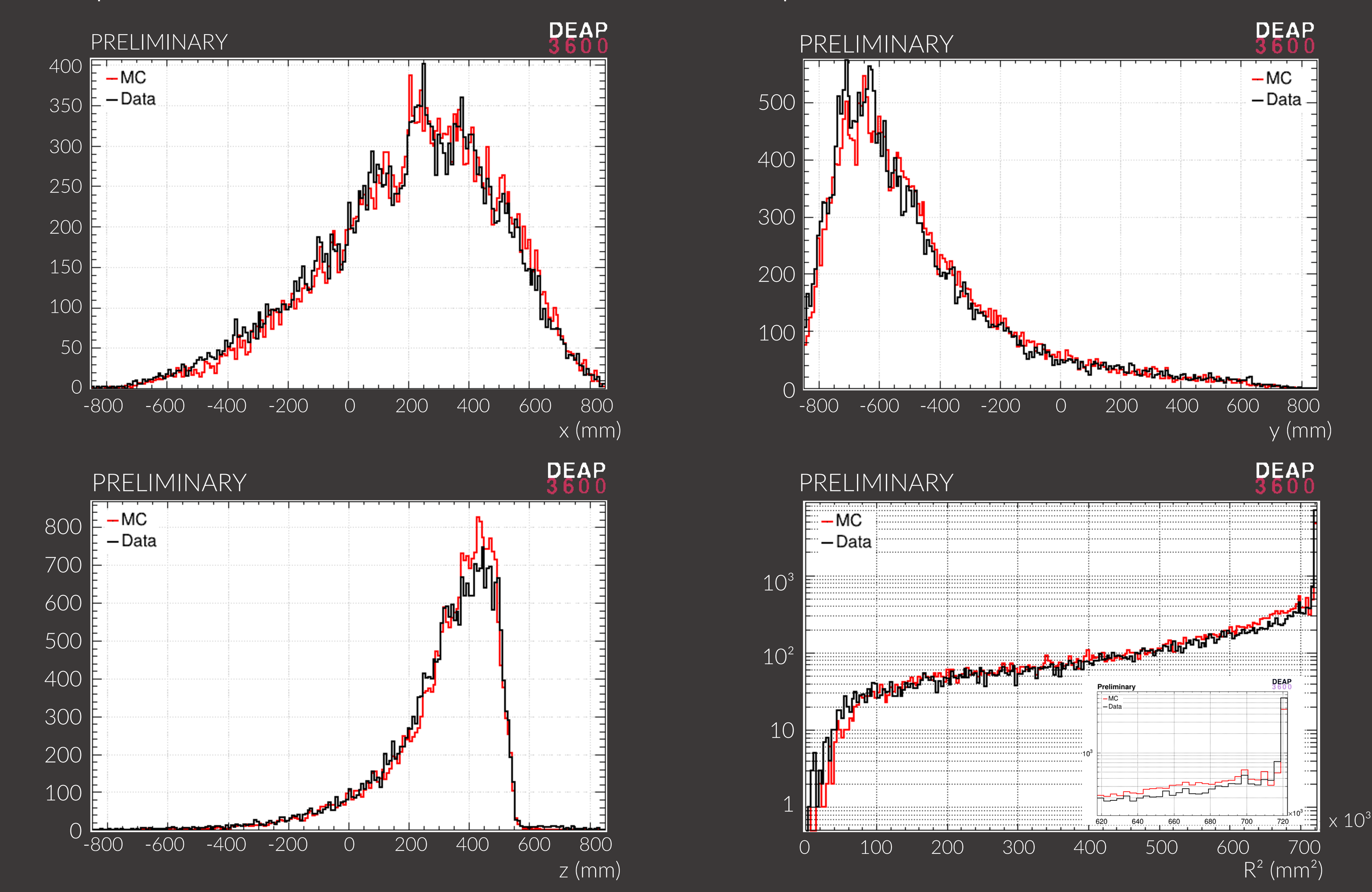
ENERGY CALIBRATION

Position	Average LY (PE/keV)	Position	Average LY (PE/keV)	Position	Average LY (PE/keV)
1	6.13 ± 0.02	4	6.16 ± 0.02	7	6.17 ± 0.02
2	6.13 ± 0.03	5	6.20 ± 0.03	8	6.11 ± 0.02
3	6.19 ± 0.02	6	6.19 ± 0.01	9	6.10 ± 0.02

- Events with one tag considered
- Gaussian fit has been applied to the 511 keV and the full energy peak to measure their energies in PEs
- Then the energy calibration has been performed dividing the results by the energies of those peaks in keV
- The measurement has been repeated for all the 9 positions around the steel shell, obtaining an average value of 6.15 ± 0.02 PE/keV

POSITION RECONSTRUCTION

- The PEs patterns of the PMTs are used as the basis for the position reconstruction
- PMTs located closer to the source should get more photon hits and detect high number of PEs: the vertex resolution gets better as you get closer to the detector's edge
- The PMT charge pattern of each event is read out and compared to a look-up database - from high statistics optical simulations - using a minimization procedure
- The best match is given back as the fitted event position by the fitter
- Position reconstruction have been applied also on MC simulations of the source
- Good agreement between data and MC
- Discrepancy for high values of R^2 due to the selection of the fiducial volume which has an impact in the detector resolution and in the position reconstruction



CONCLUSIONS

^{22}Na source has excellent tagging properties that have been exploited to study the performances of the DEAP-3600 detector:

- We can unambiguously tag events from the ^{22}Na identifying the γs from the source
- We performed an energy calibration of the detector, finding an average of 6.15(2) PE/keV
- We used the events from the ^{22}Na source to test the position reconstruction algorithm; the comparison of it with MC allows us to improve our detector
- Currently within the WIMP-search PE region, near the 630 mm radius of the fiducial volume, events are typically reconstructed within 30–45 mm

BIBLIOGRAPHY :

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- Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB, R. Ajaj *et al.* (DEAP Collaboration), Phys. Rev. D **100**, 022004 – Published 24 July 2019