Validating position reconstruction algorithm with 241Am-9Be neutron source in DEAP-3600

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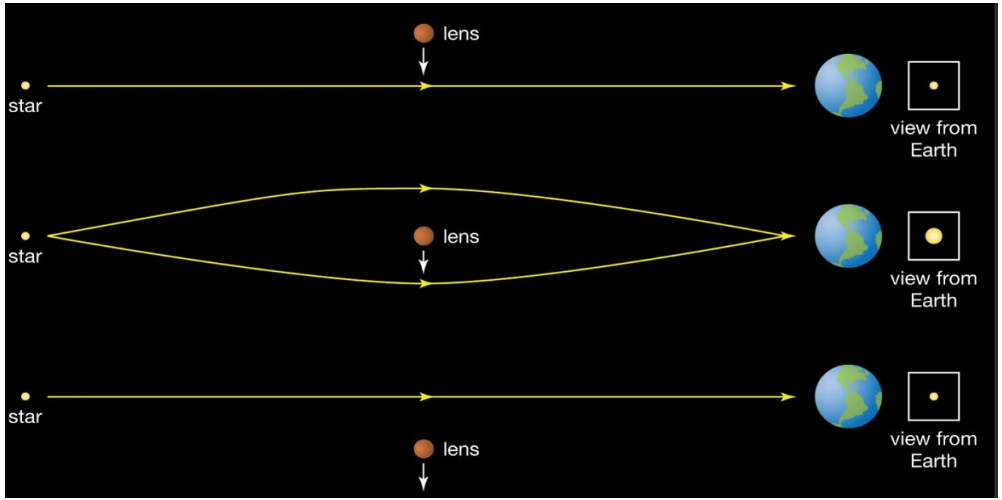
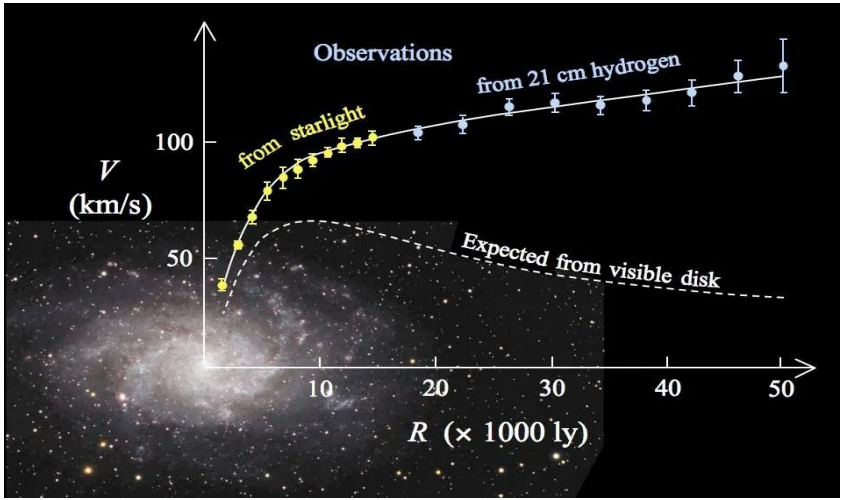
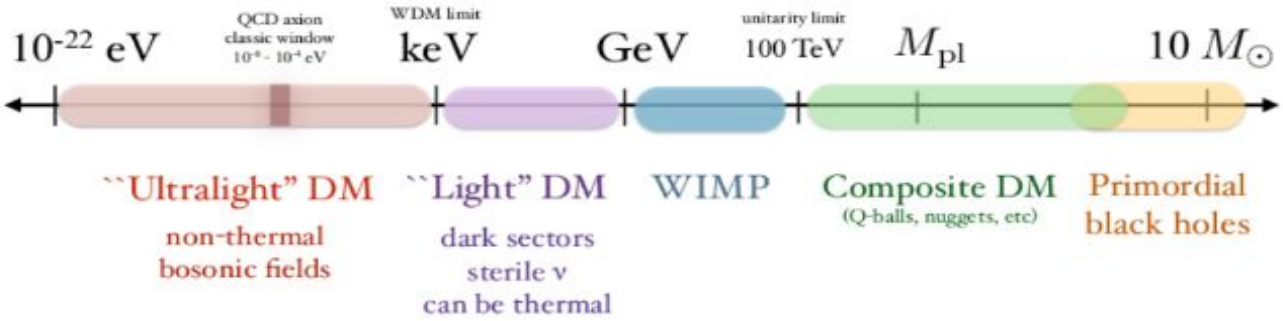
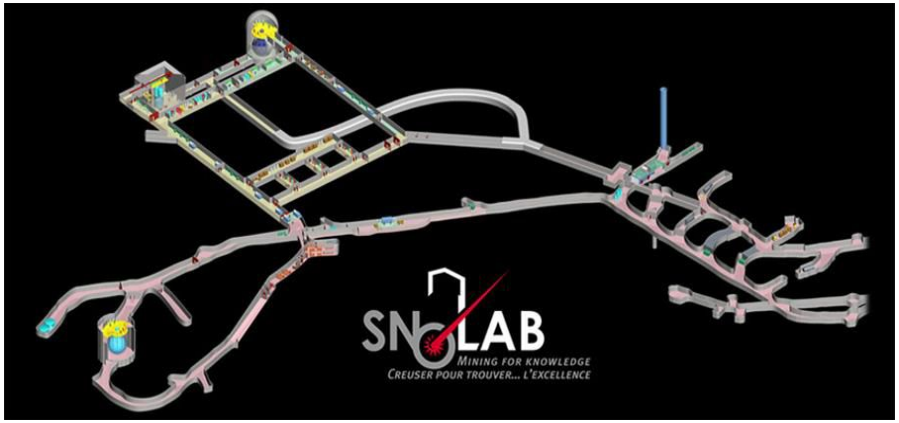
Dark matter (or hidden mass?)

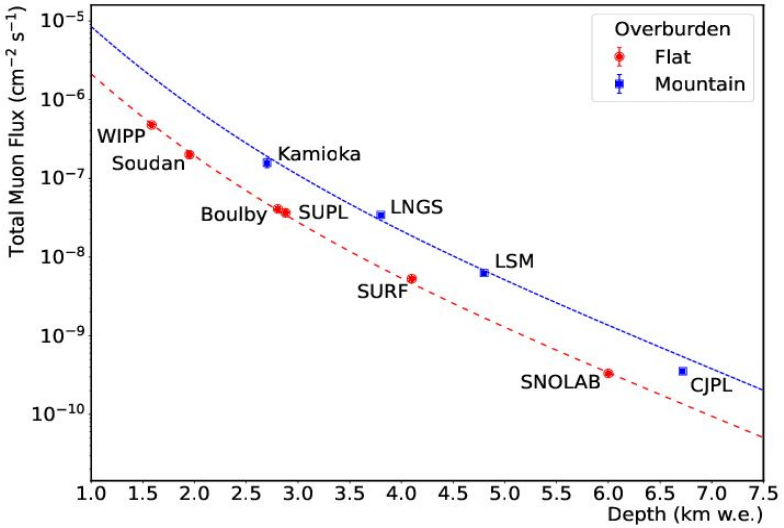


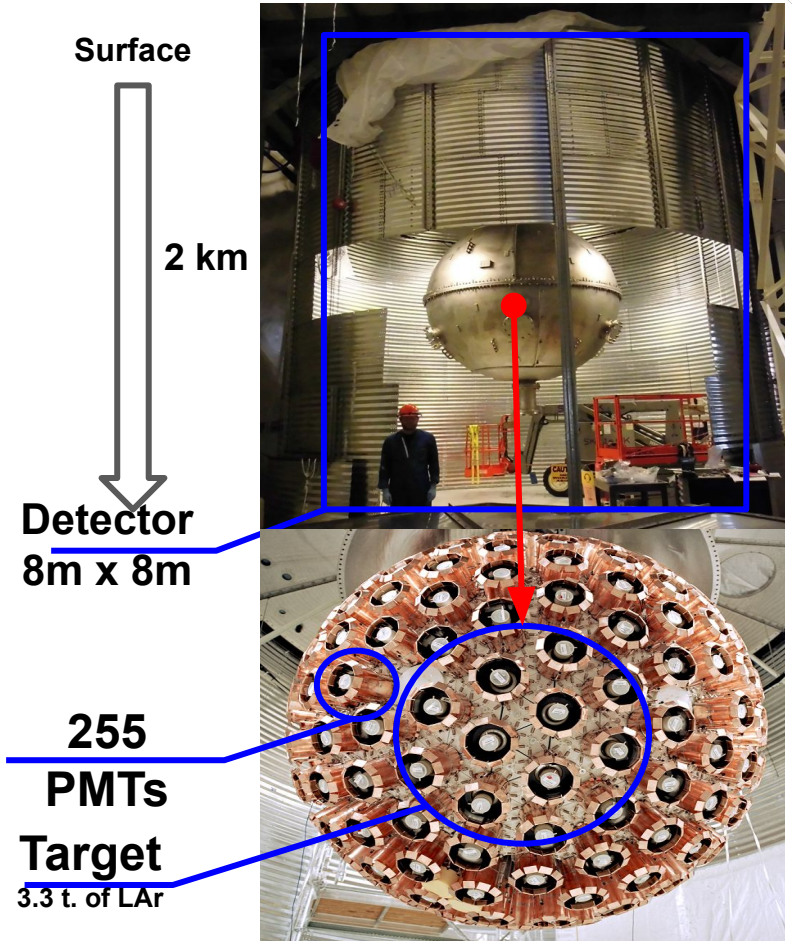




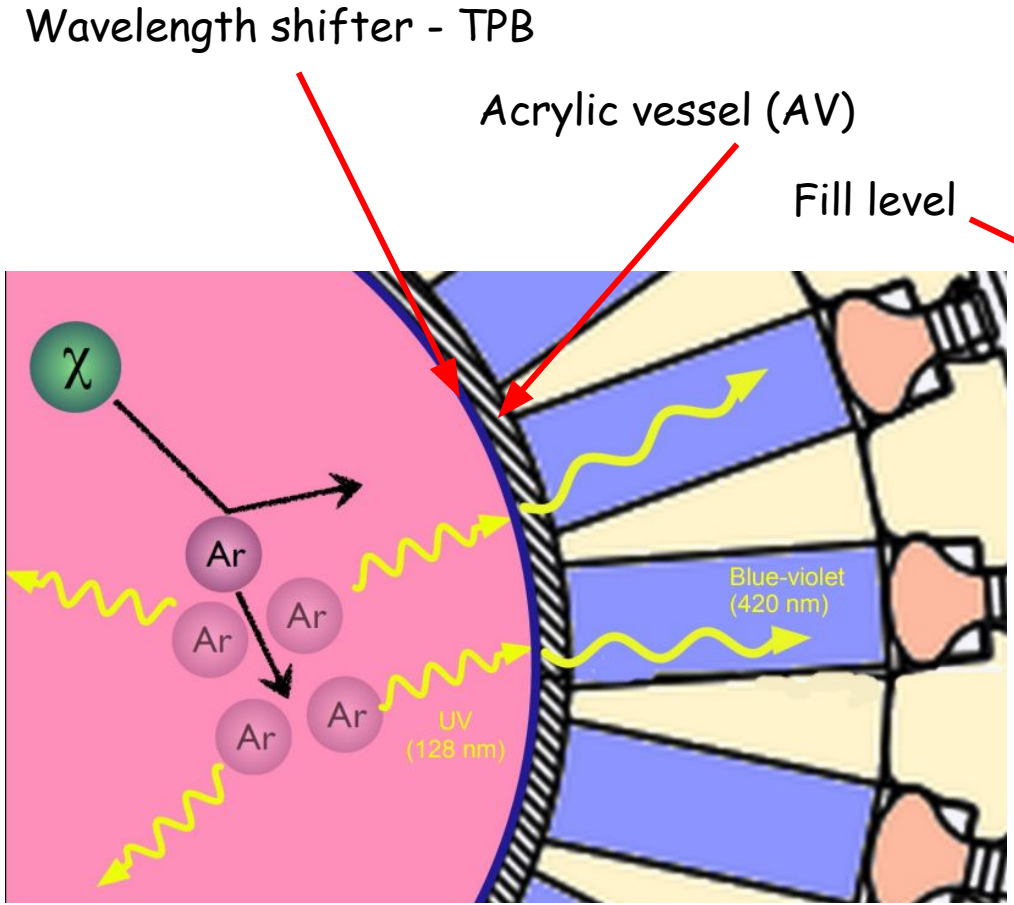
The detector

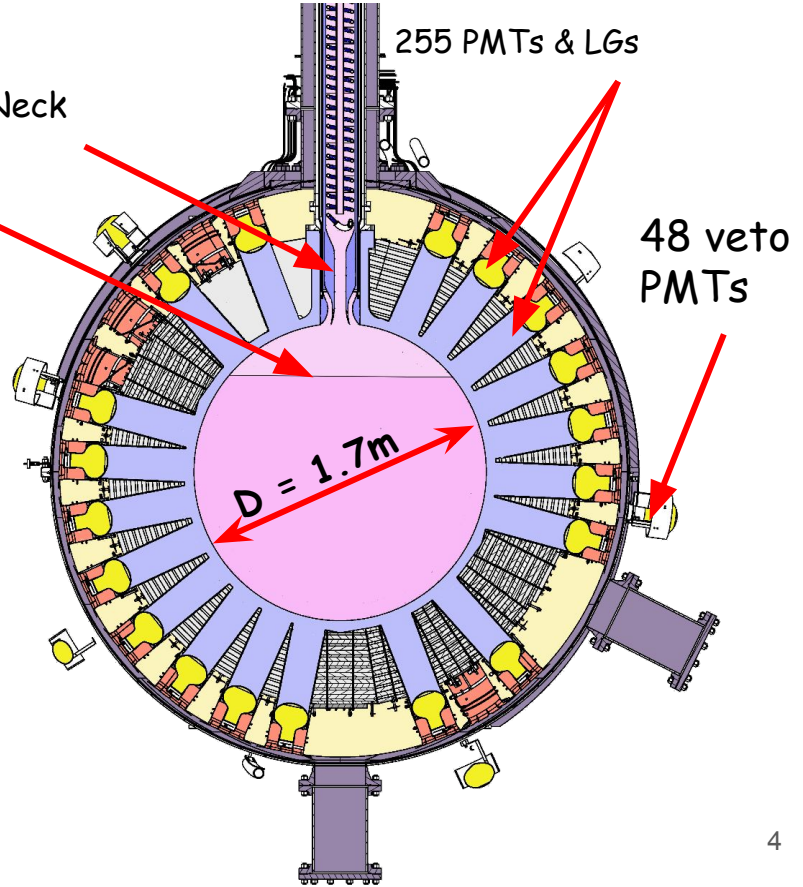






The detector



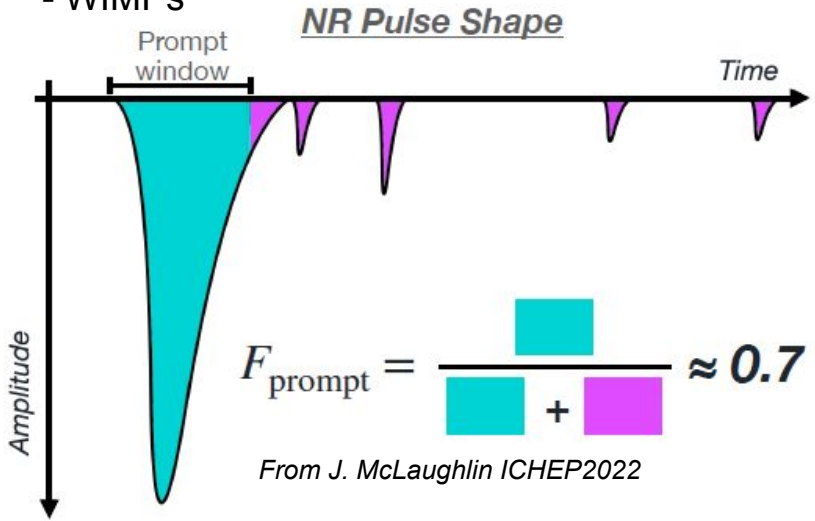


Pulse Shape Discrimination

The DEAP Collaboration, Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB, Physical Review D 100.2 (2019)

Nuclear Recoils

- Scattering directly with argon nuclei;
- Excimers mostly populate the singlet state, relax quickly. Induced by:
  - Neutrons
  - Alphas
  - WIMPs



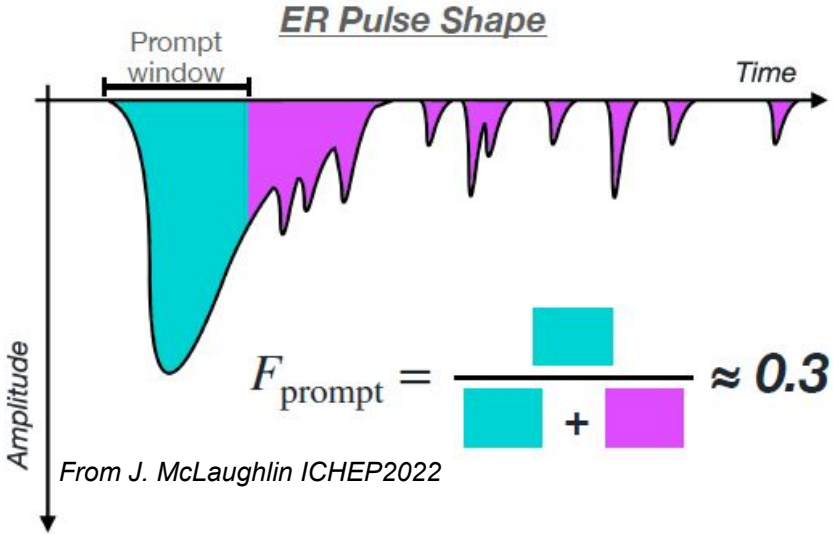
From J. McLaughlin ICHEP2022

Electronic Recoils

- Scattering with argon atomic electrons, ionizing argon;
- excimers tend to populate triplet state, relax slowly.

Induced by:

- Betas (especially 39Ar at ~3 kHz)
- Gammas



From J. McLaughlin ICHEP2022

Ideal analysis

- Incomplete coverage of the acrylic vessel surface
- Detector non-symmetry
+ 0 background events from outside
+ Perfectly pure materials
+ No electronic noise
+ No force majeure: earthquakes, power outages, magnetic storms, etc.

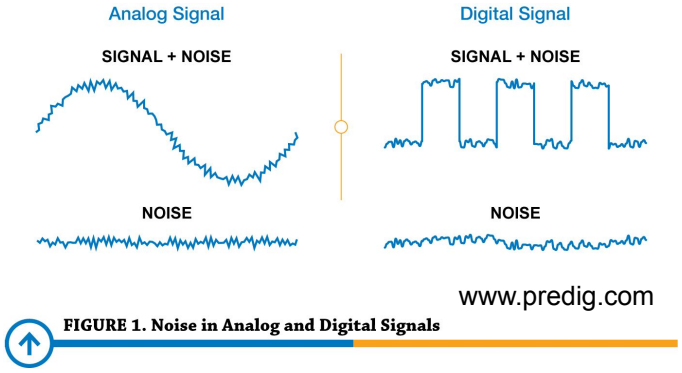
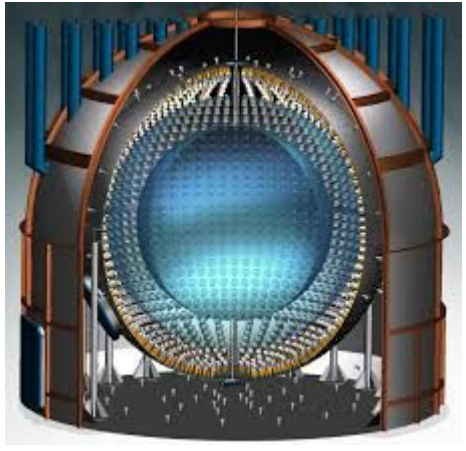
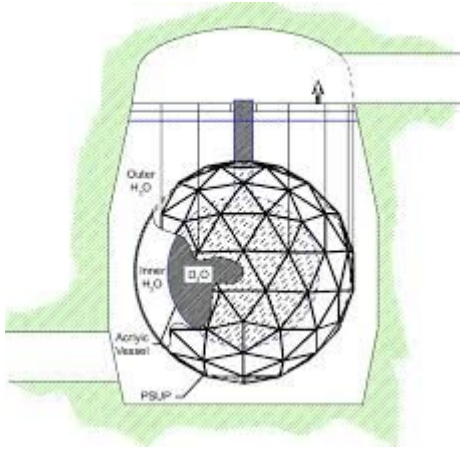
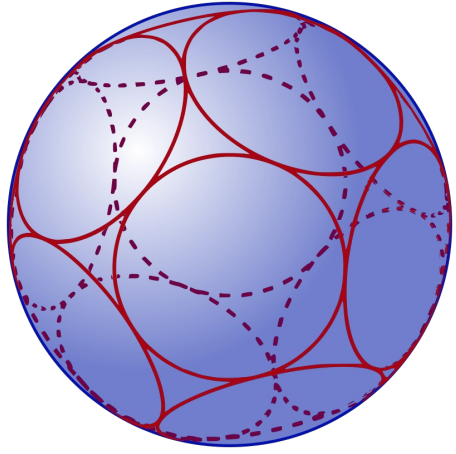


FIGURE 1. Noise in Analog and Digital Signals

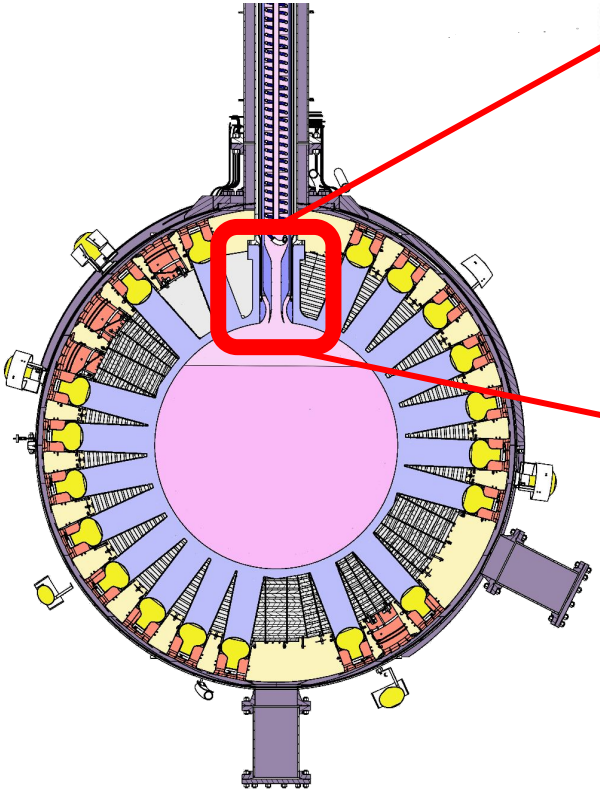


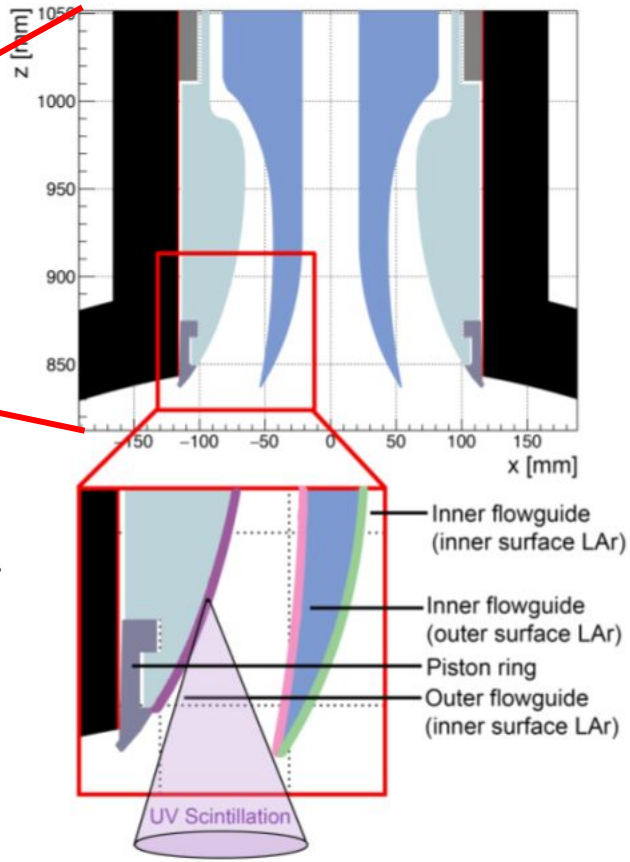


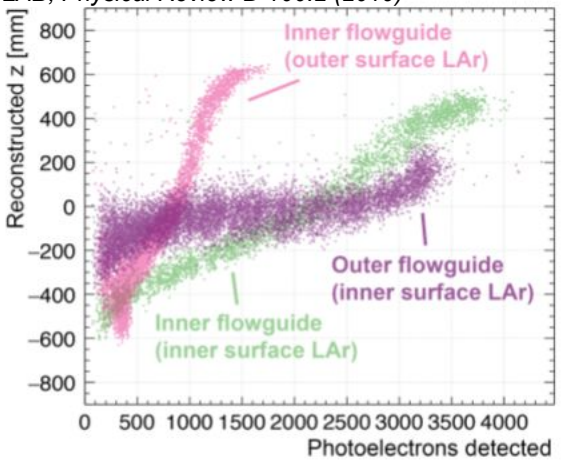


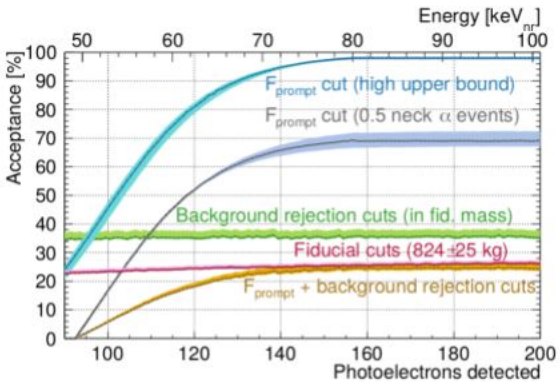
The neck

The DEAP Collaboration, Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB, Physical Review D 100.2 (2019)







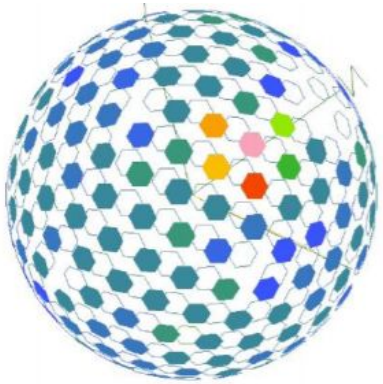


$$N_{bkg}^{ROI} = N_{ER}^{ROI} + N_{Cher}^{ROI} + N_{n,rdg}^{ROI} + N_{n,csg}^{ROI} + N_{\alpha,AV}^{ROI} + N_{\alpha,neck}^{ROI}$$

Position reconstruction

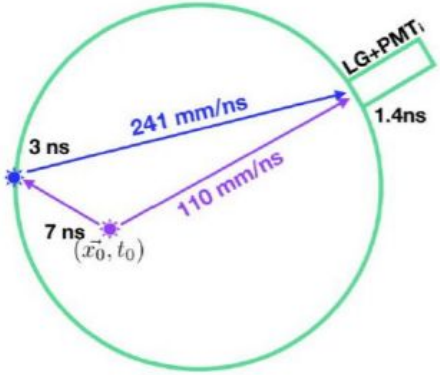
The DEAP Collaboration, Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB, Physical Review D 100.2 (2019)

MBLikelihood - MBL



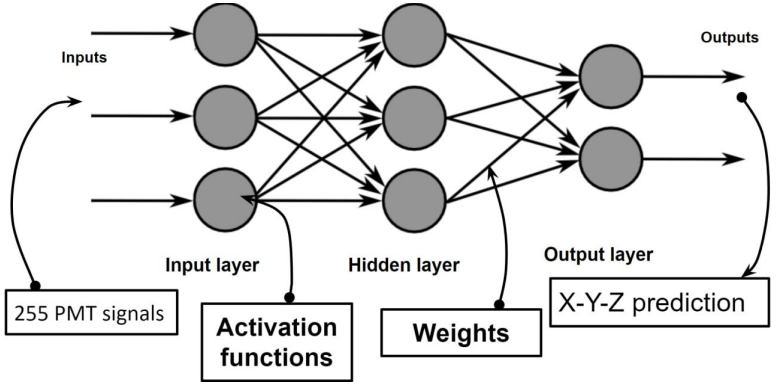
- Construct a Likelihood function
- **Uses PMT pulses from event**

TimeFit2 - TF2



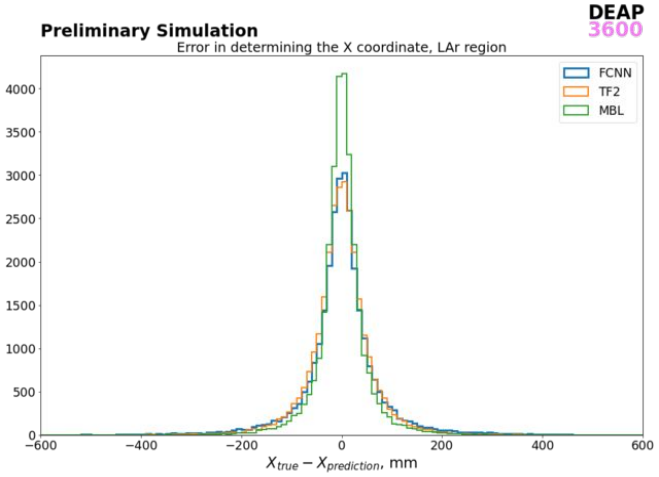
- Construct a Likelihood function
- **Uses times of arrival of prompt photons**

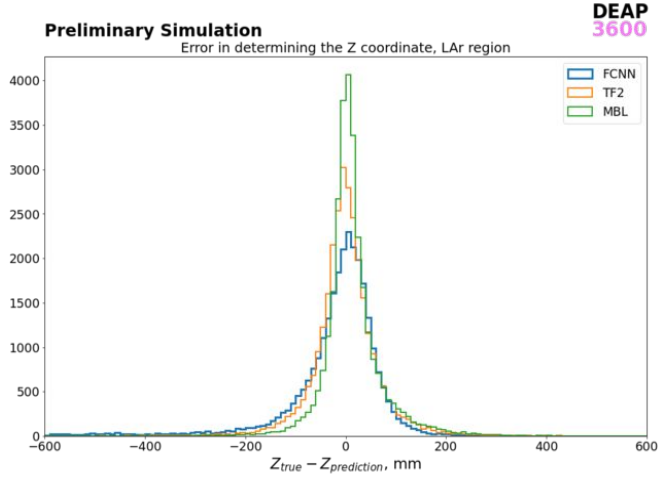
Neural network - FCNN

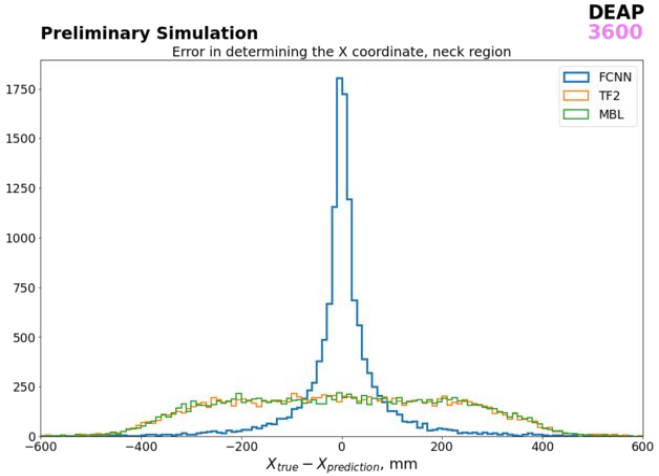


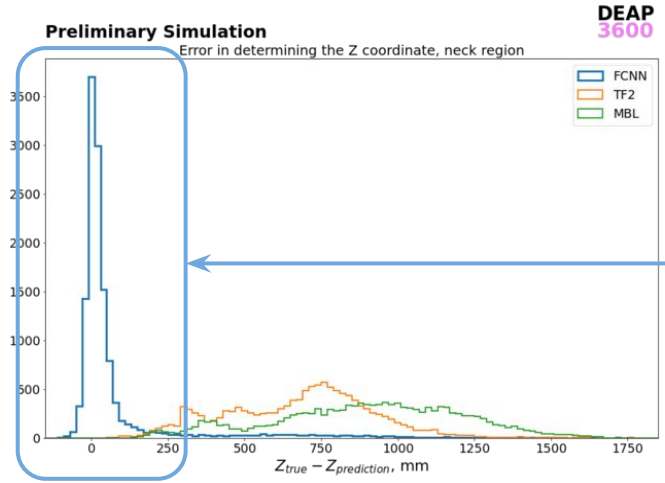
Uses PMT pulses as inputs to tune the **activation function** and **weight** values in neuron connections
(Work in progress)

Current FCNN results





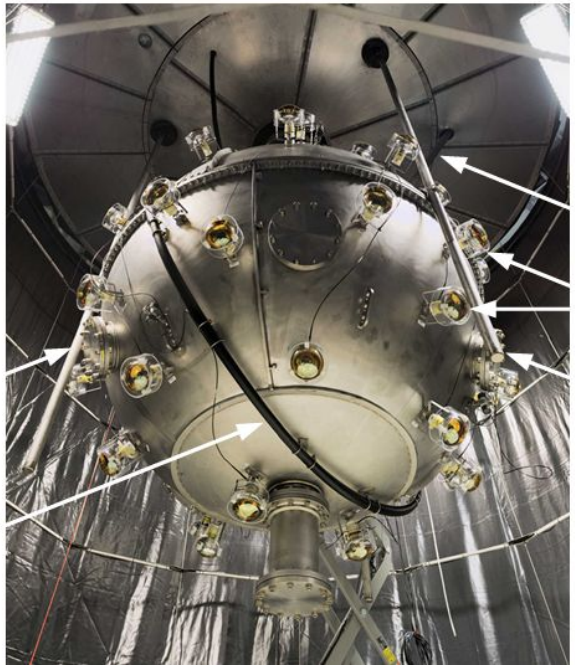


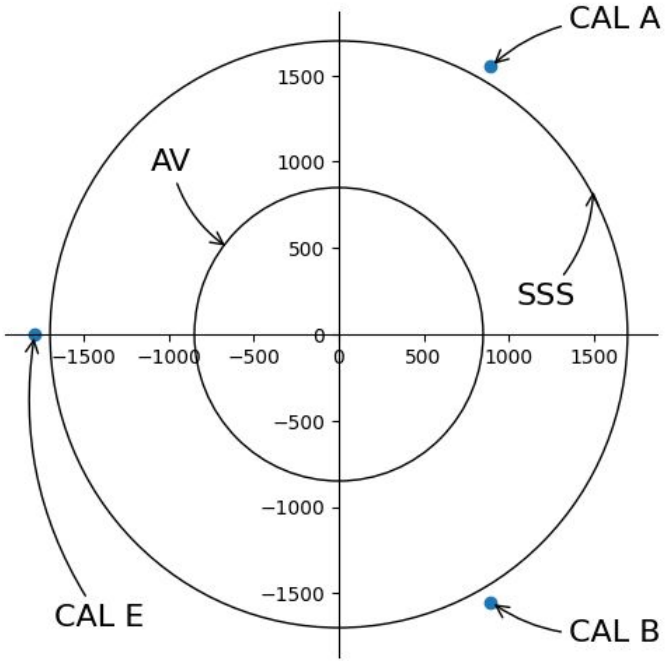


$$X_{\text{error}} = X_{\text{true}} - X_{\text{reconstructed}}$$
$$Z_{\text{error}} = Z_{\text{true}} - Z_{\text{reconstructed}}$$

Good neck discrimination!

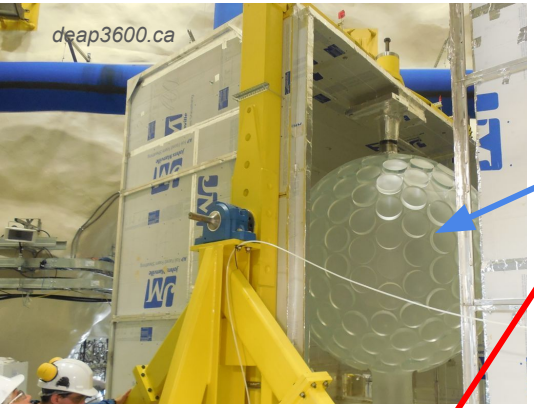
Neutron calibration source





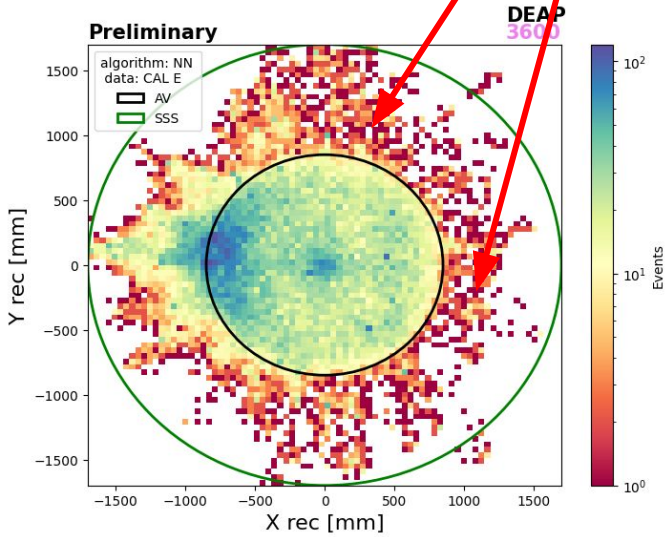
Coordinate	CAL A	CAL B	CAL E
X [mm]	895.35	895.35	-1790.7
Y[mm]	1550.7932	-1550.7932	0
Z [mm]	0	0	0
R [mm]	1790.7	1790.7	1790.7

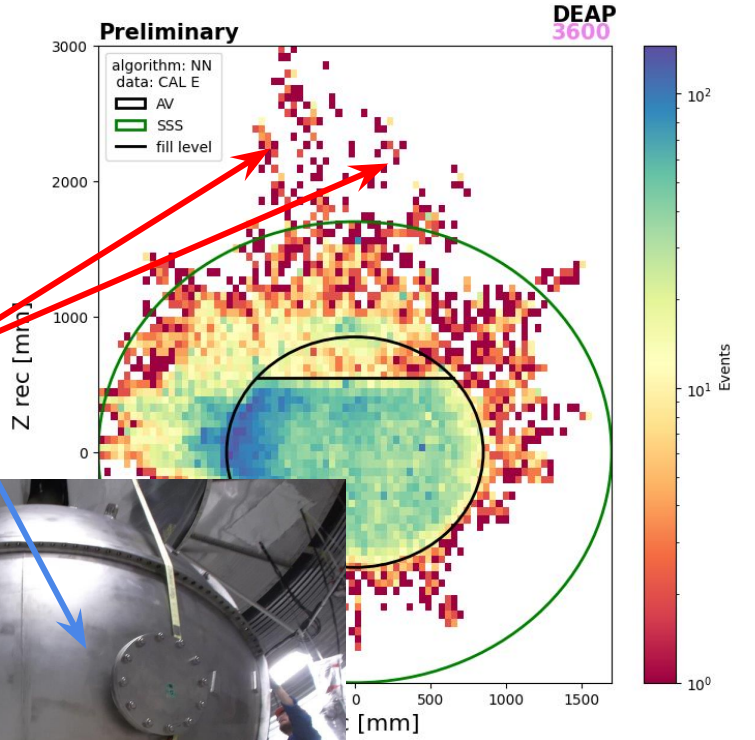
Calibration data

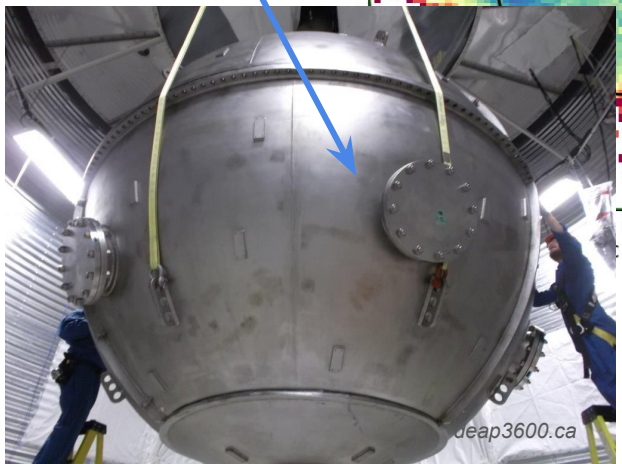


Outside acrylic vessel

Outside stainless steel shell



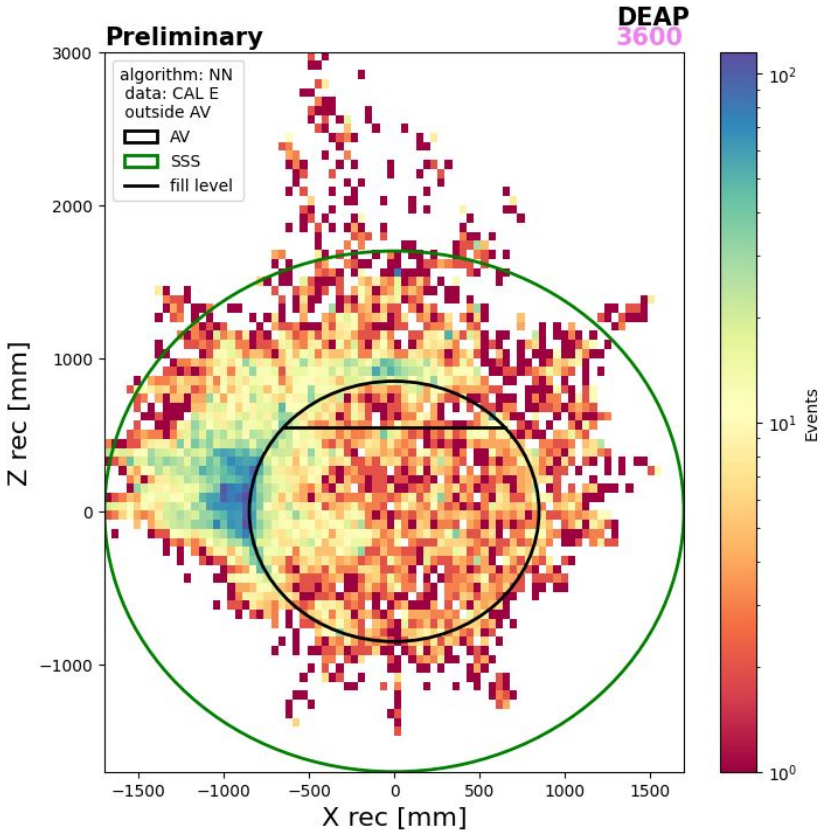




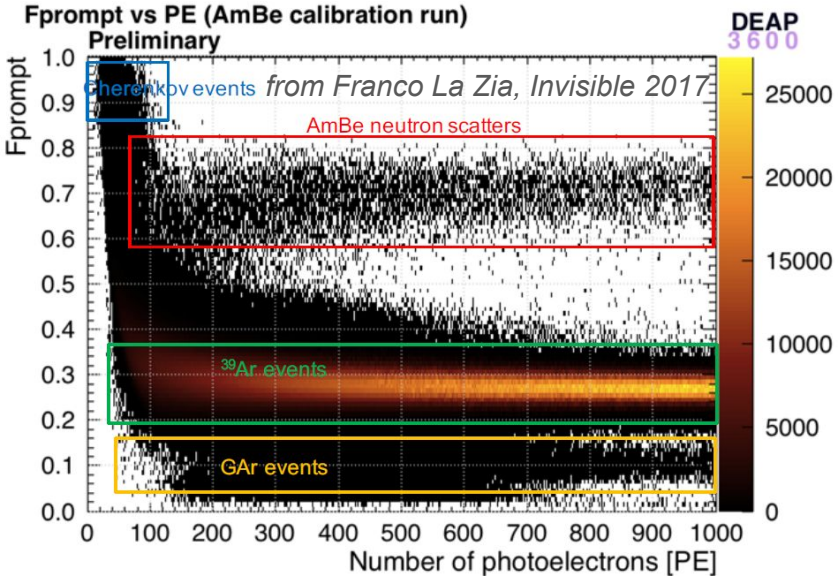
Outside events

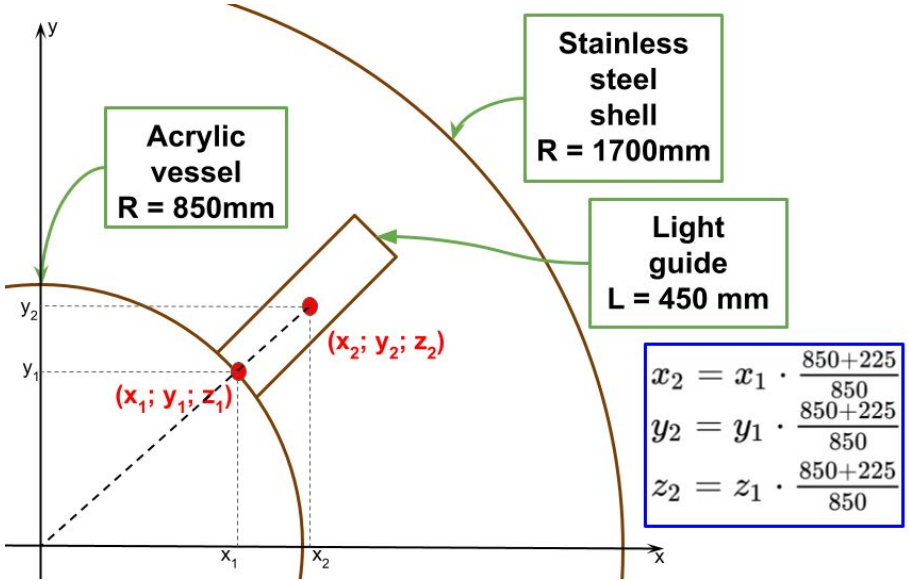
- Using the likelihood method, these events are reconstructed on the surface of the acrylic vessel (R = 850 mm)
- Almost all events have low energy and a high value of the fprompt parameter

Cherenkov events



Cherenkov dataset and “true” position





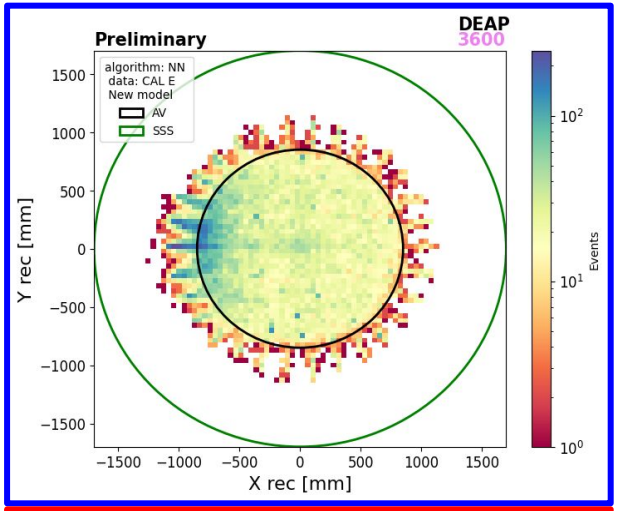
Shift it in the center of AV, 22.5 cm radially offset

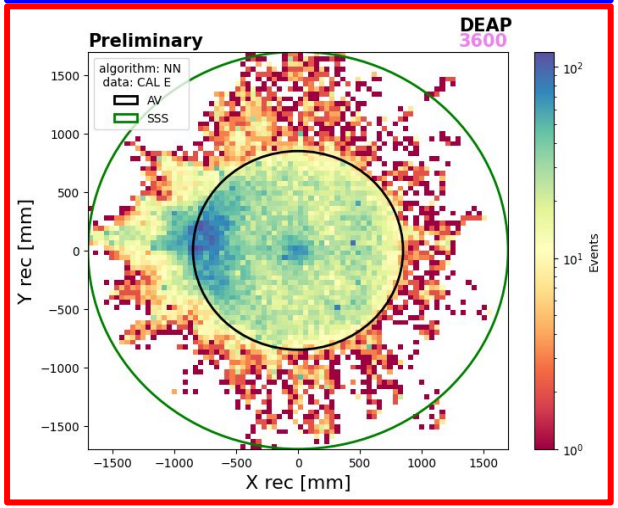
Why we do that? We need just to teach model to determine such events and do NOT reconstruct it somewhere else

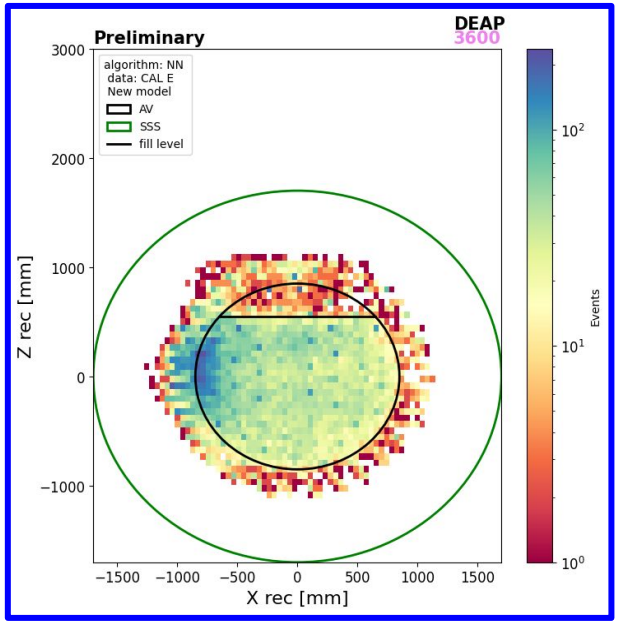
New model

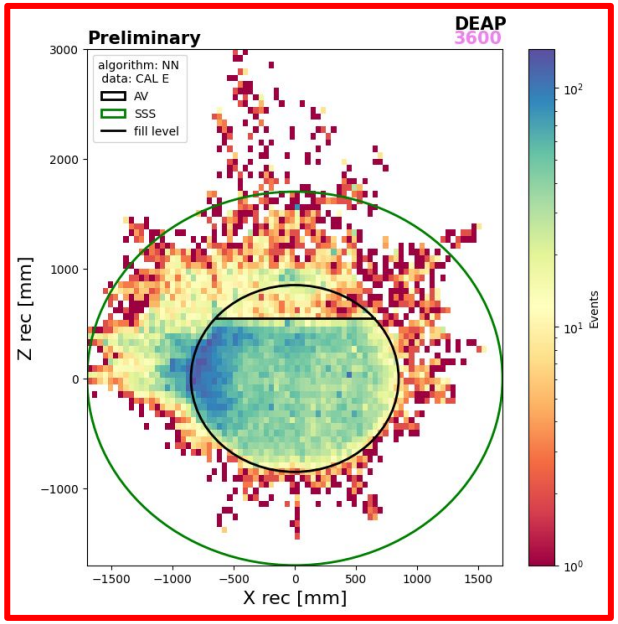
Red = Cherenkov -

Blue = Cherenkov +







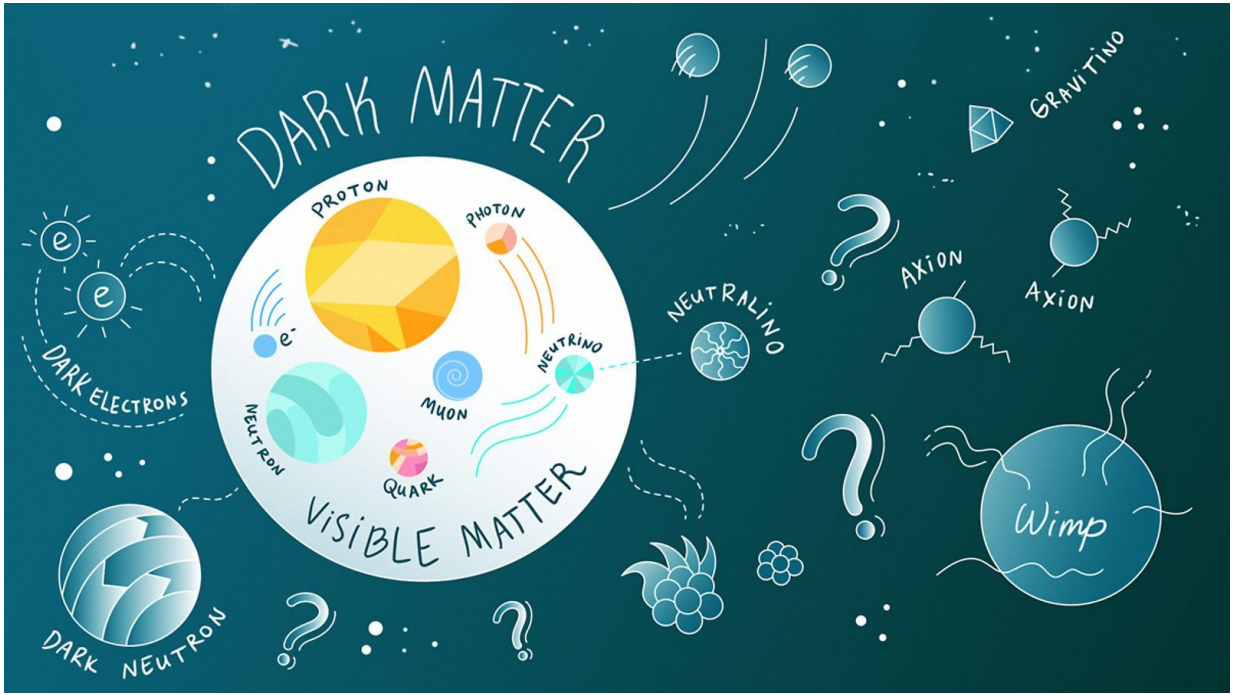


Conclusion

- There are discrepancies in the algorithms used to reconstruct the event position in the DEAP-3600 experiment. Also these algorithms do not work in the detector neck region.
- Previously, an event position reconstruction model based on neural networks has been established. Such a model proved itself well when working in the full range of detector coordinates.
- The developed algorithm was tested on data collected using the AmBe calibration source. As a result, it was decided to add Cherenkov-type events to the training data set.
- After testing the new algorithm with Cherenkov-type events in the training set, it was shown that all events are reconstructed more properly either inside the acrylic vessel or in the light guide region.

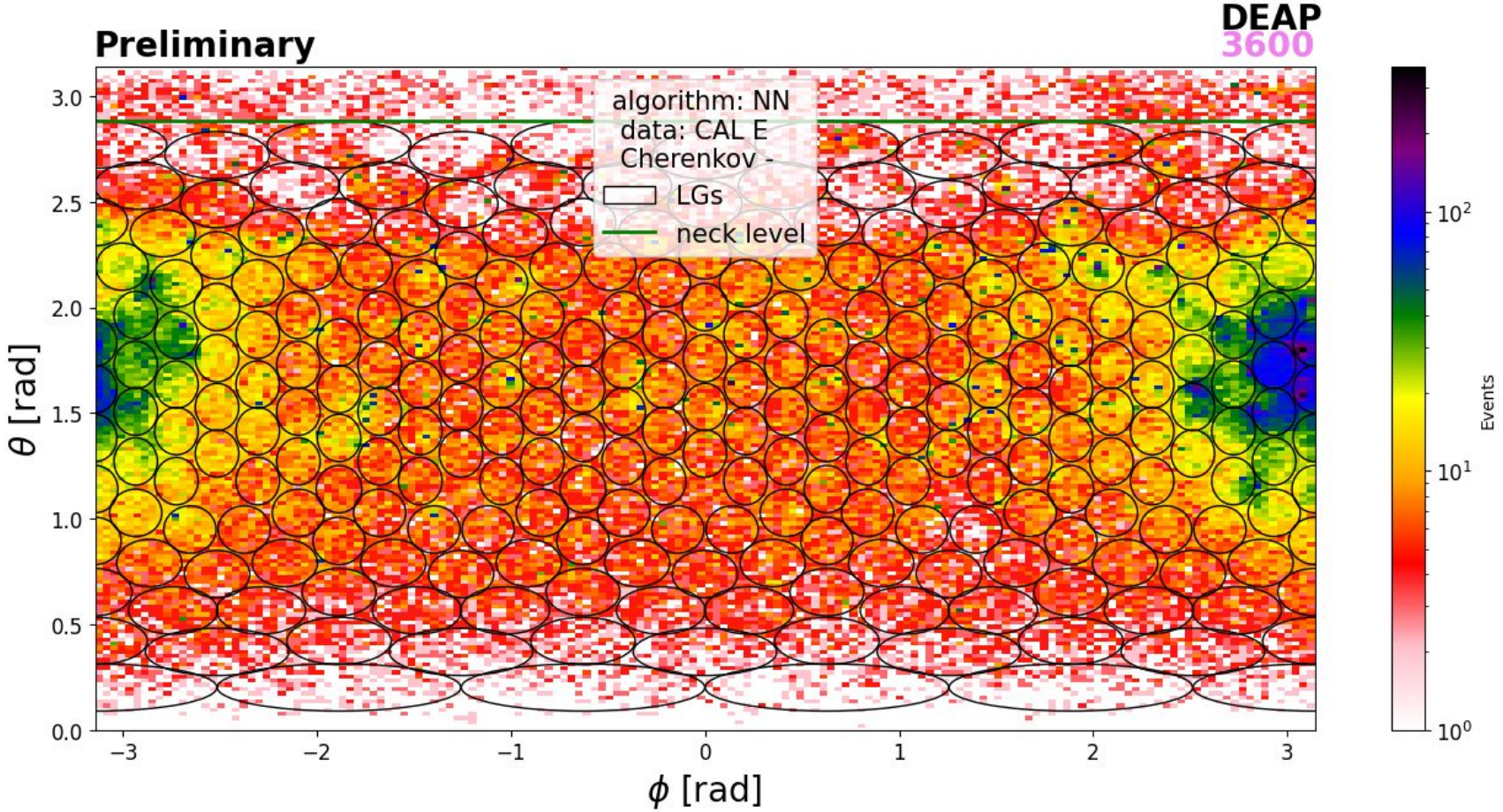
Thank you for your attention!

Questions?



Extra slides

Extra slides Heatmap without Cherenkov events



Extra slides Heatmap with Cherenkov events