Light detection in the Dark-matter Experiment using Argon Pulse Shape Discrimination

Fabrice Retière on behalf of the DEAP collaboration

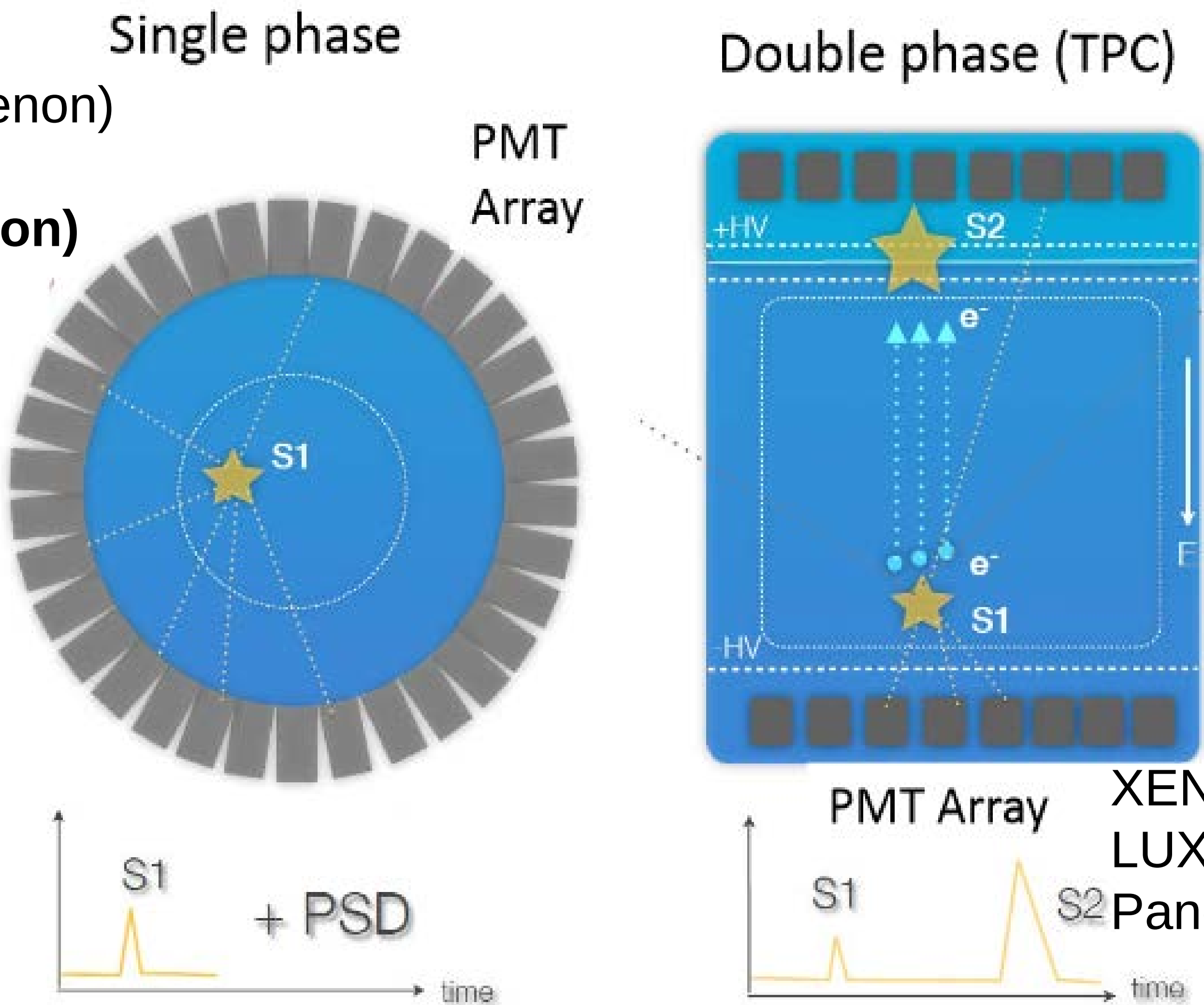
Two technologies for dark matter search with noble liquids

XMASS (Xenon)

DEAP (Argon)

XENON1T (Xenon)
LUX, LZ (Xenon)
PandaX (Xenon)

DarkSide (Argon)



Scintillation in LAr

Excitation: Ar^* (1)

$$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$$
$$Ar_2^* \rightarrow 2Ar + \gamma$$

Ionization: Ar^+ (2)

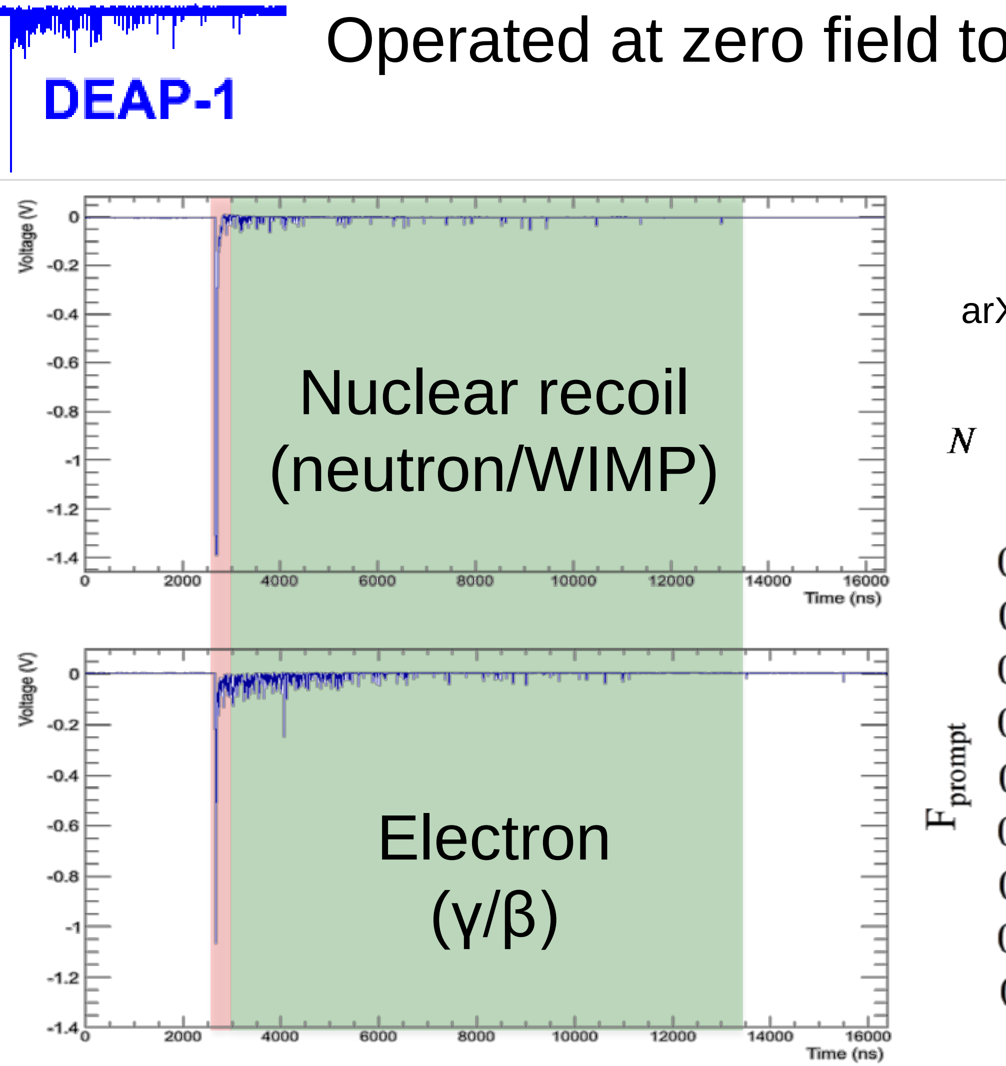
$$Ar^+ + Ar \rightarrow Ar_2^+$$
$$Ar_2^+ + e^- \rightarrow Ar^{**} + Ar$$
$$Ar^{**} \rightarrow Ar^* + heat$$
$$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$$
$$Ar_2^* \rightarrow 2Ar + \gamma$$

- **Excitation**
  - Production independent of energy density
  - Singlet ~35%, triplet ~65%
- **Ionization**
  - Production higher for high energy density
  - Singlet ~50%, triplet ~50%
- **Pulse shape discrimination**
  - $\tau_{singlet}$ ~ 6ns
  - $\tau_{triplet}$ ~ 1500ns

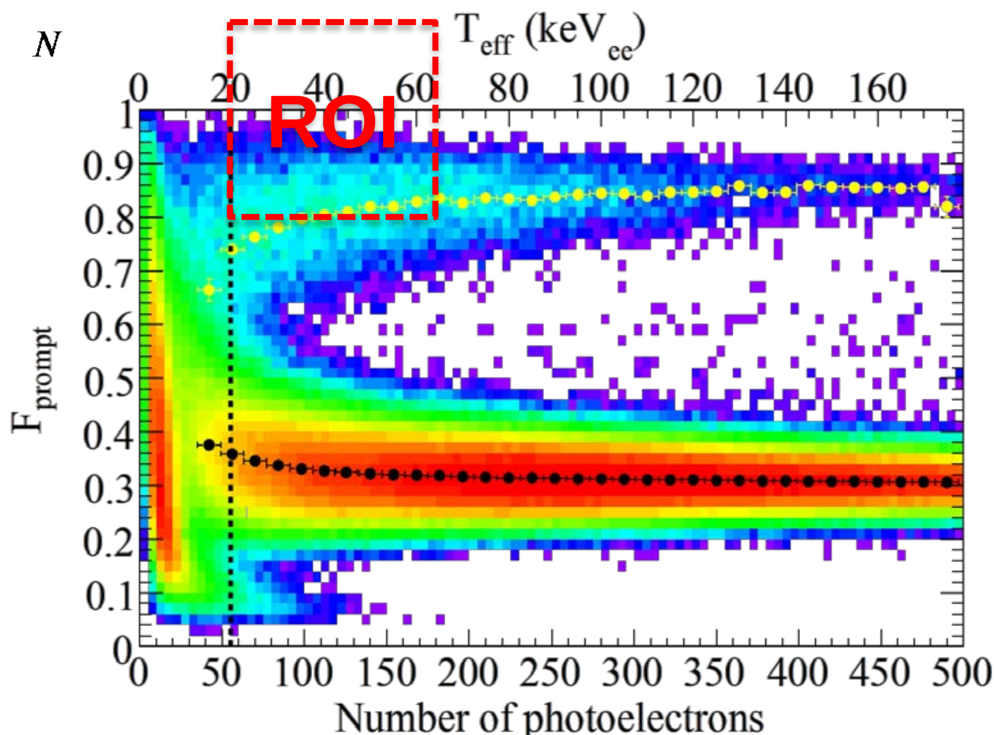
DEAP-3600 approach
Maximize pulse shape discrimination

Operated at zero field to maximize photon yield

$$\mathrm{FPrompt} = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$

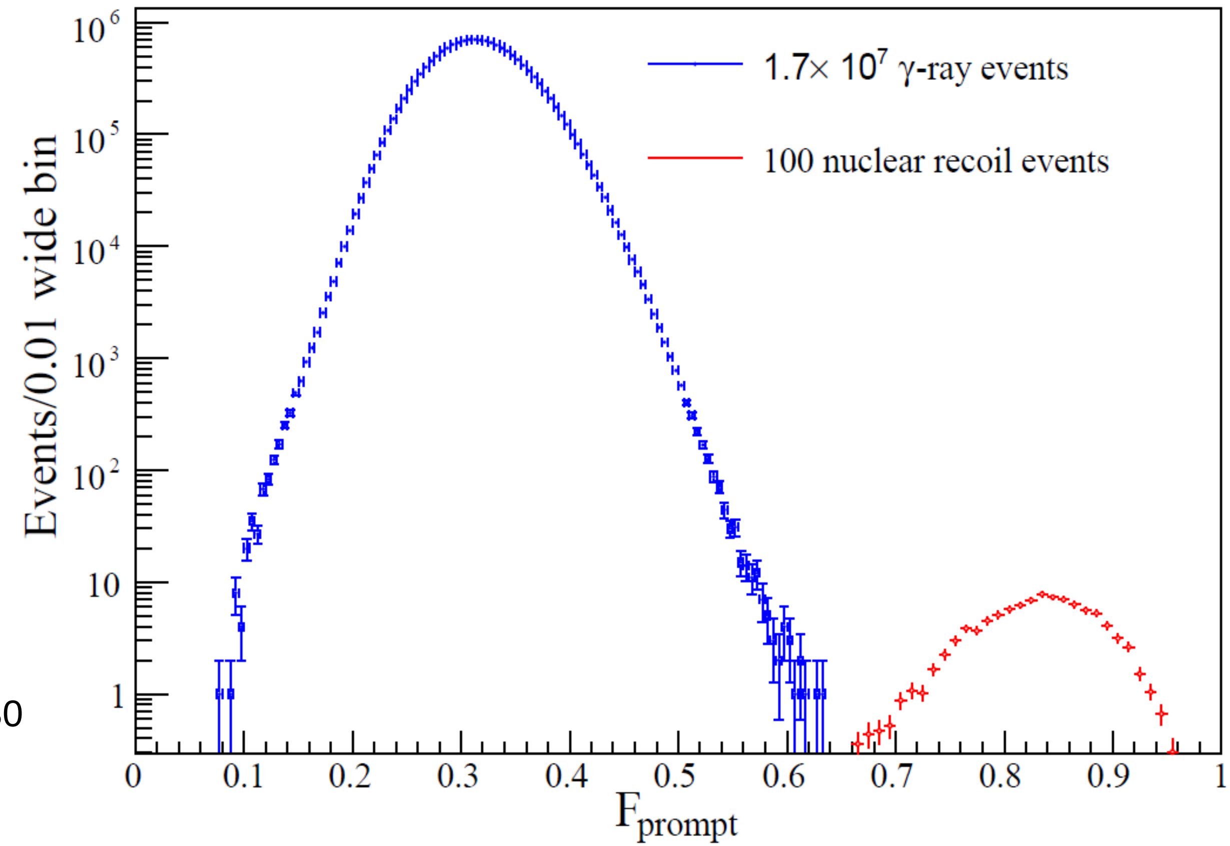


arXiv:0904.2930



Pulse shape discrimination

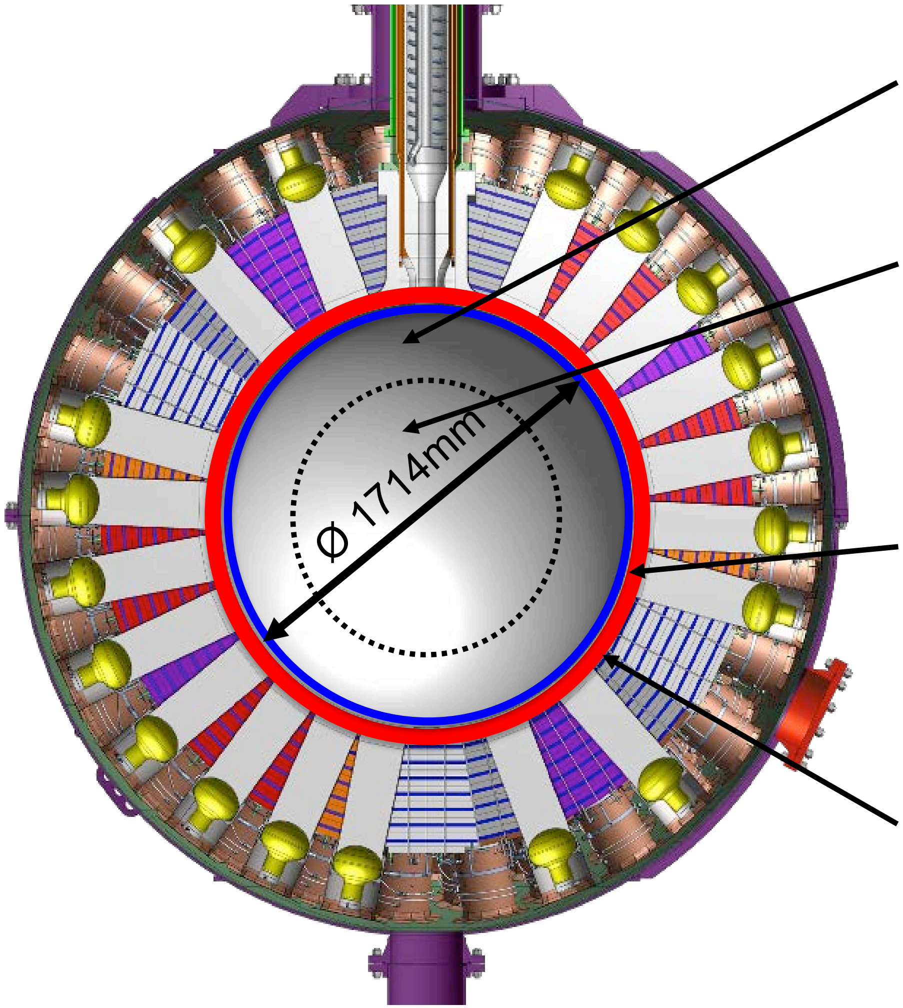
DEAP-1



arXiv:0904.2930

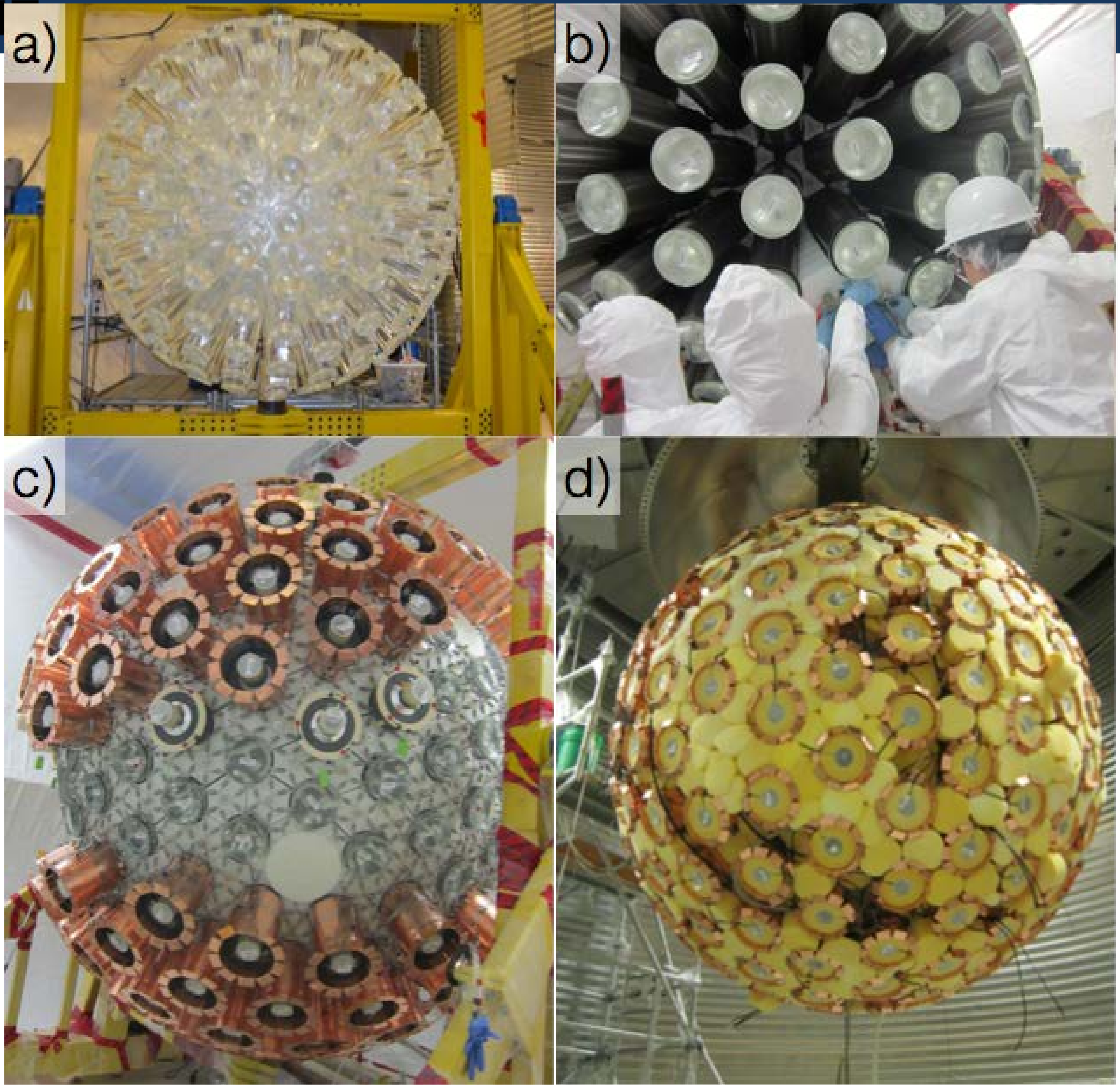
- γ suppression better than 3×10^{-8} in 43-86 keVee achieved at SNOLAB
- Simple model of photon statistics predicts 10^{-10} suppression at 15 keVee, allowing for sufficient background rejection of ^{39}Ar in DEAP-3600

Maximum PSD but worse position reconstruction

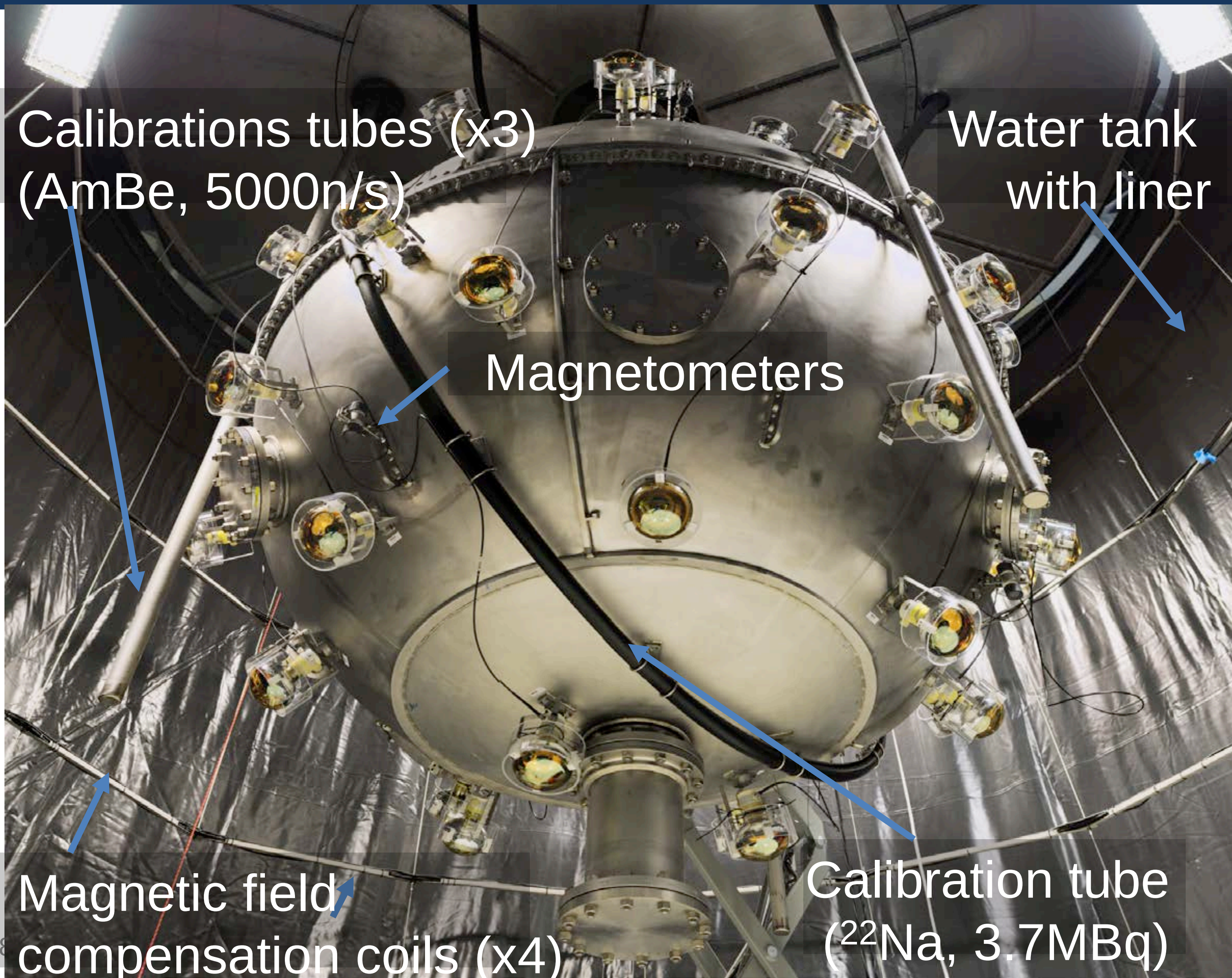


- **3600 kg of Liquid Argon**
- **1000 kg Fiducial mass**
  - Target sensitivity 10^{-46}cm2 at 100GeV WIMP mass
- **Wavelength shifter (distilled TPB)**
- **Vessel**

A photogenic detector



Now fully closed



Moving towards completion

- ❑ **Wavelength shifter deposition on-going**
- ❑ **Liquid Argon fill expected this summer**
- ❑ **First data in liquid Argon by the end of 2015**
- ❑ **Data taking with empty detector**
    - o Cerenkov in acrylic light guides

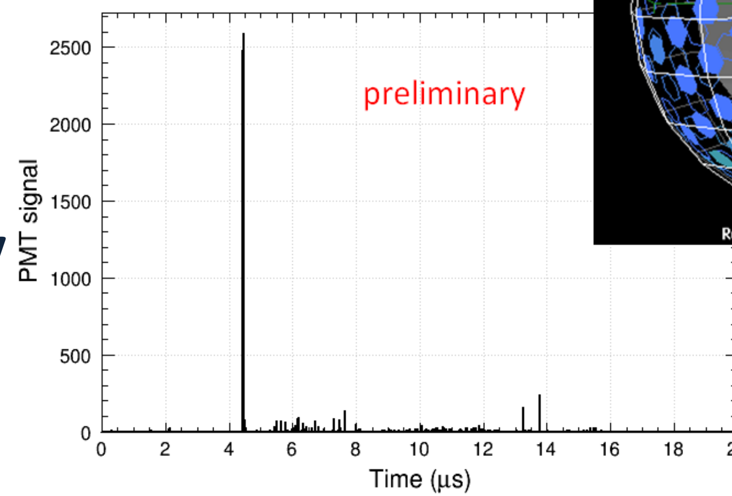
A high energy event

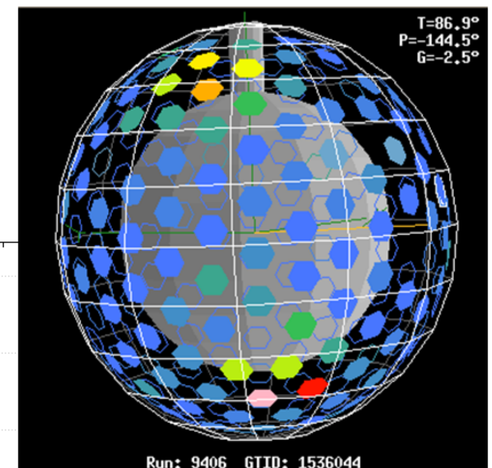
Run: 9406 Subrun: 3 Event: 300460

Total energy: 1520 PE

High event rate: ~1 event/day

Expected muon rate: 1.6 muons/day





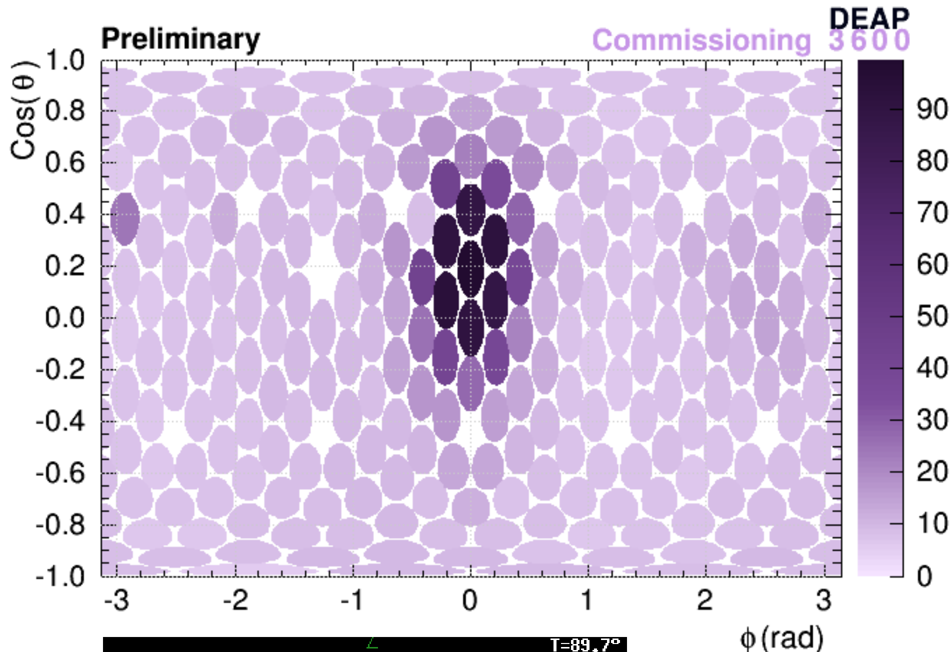
Detecting scintillation light

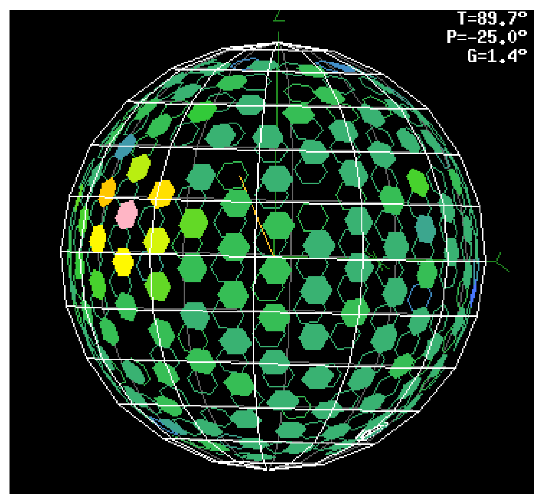
Main process	Contrib. to PSD	Contrib. to pos. reco.	Remedy
LAr scintillation	Recombination fluctuations	-	Model? Dedicated setup
LAr purity	Triplet lifetime	-	Recirculate & filter
LAr scattering	-	Worsen, non-unif. bias	External source?
TPB abs. / em.	- (fast time constant)	- (100% absorption)	
TPB scattering	- (if not too large)	Worsen, non-unif bias	Calibrate
TPB – AV interface	-	Increase scatter	Calibrate
Attenuation in light guide	Photon loss	Photon loss, non-unif bias	Calibrate
PMT efficiency	-	Bias if not uniform	Calibrate
PMT dark noise	Increase late "light"	-	Cut out, likelyhood
PMT after-pulsing	Increase late "light"	-	Cut out, likelyhood
Electronics noise	Worsen resolution	-	Pulse counting

Calibrating optics

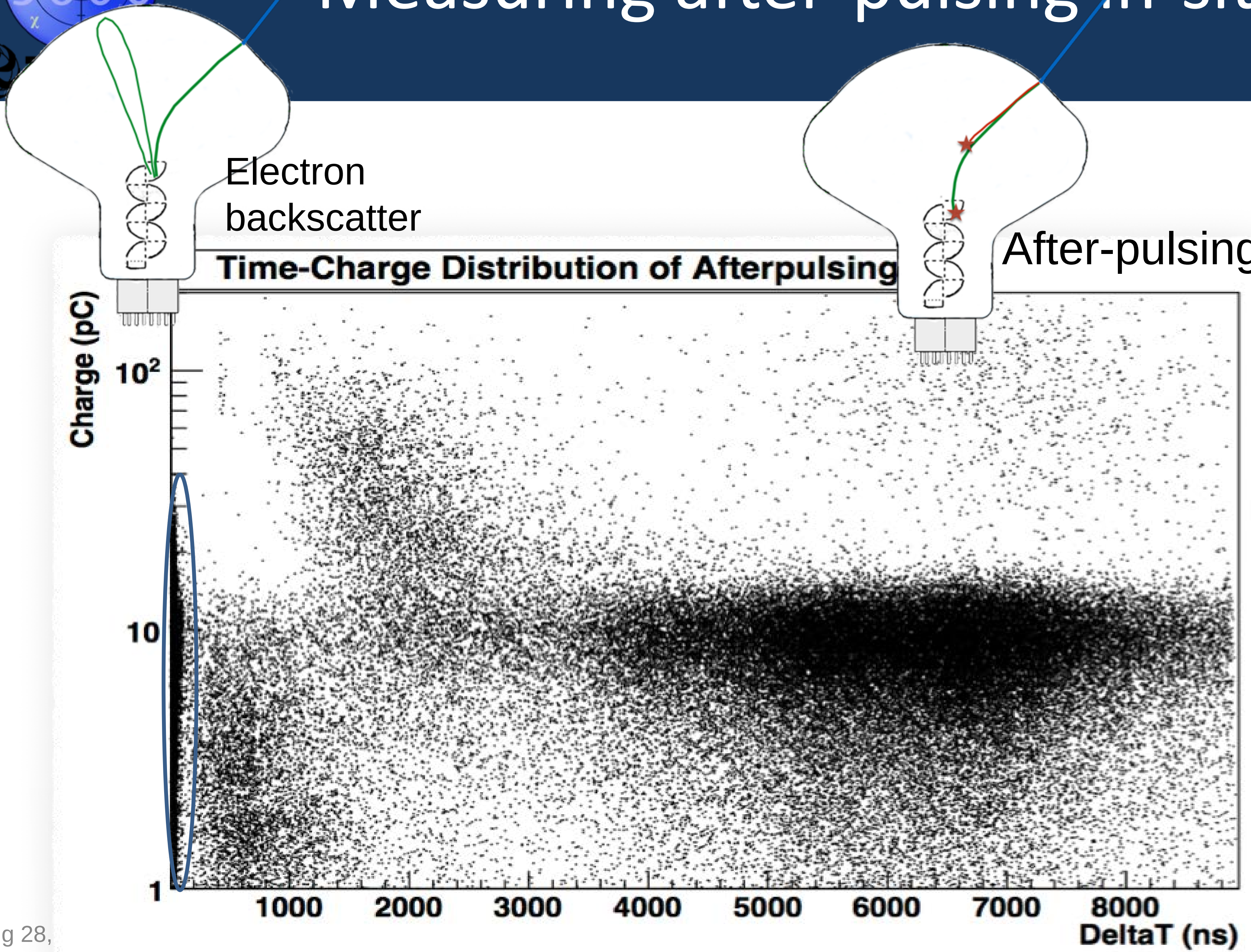
- **Inject light in light guides**
- **Laser ball**
  - 440nm and 375nm a the center of the detector
- **^{39}Ar uniformity**
  - Full and partial fill
- **Surface alphas**

Light injected in a light guide



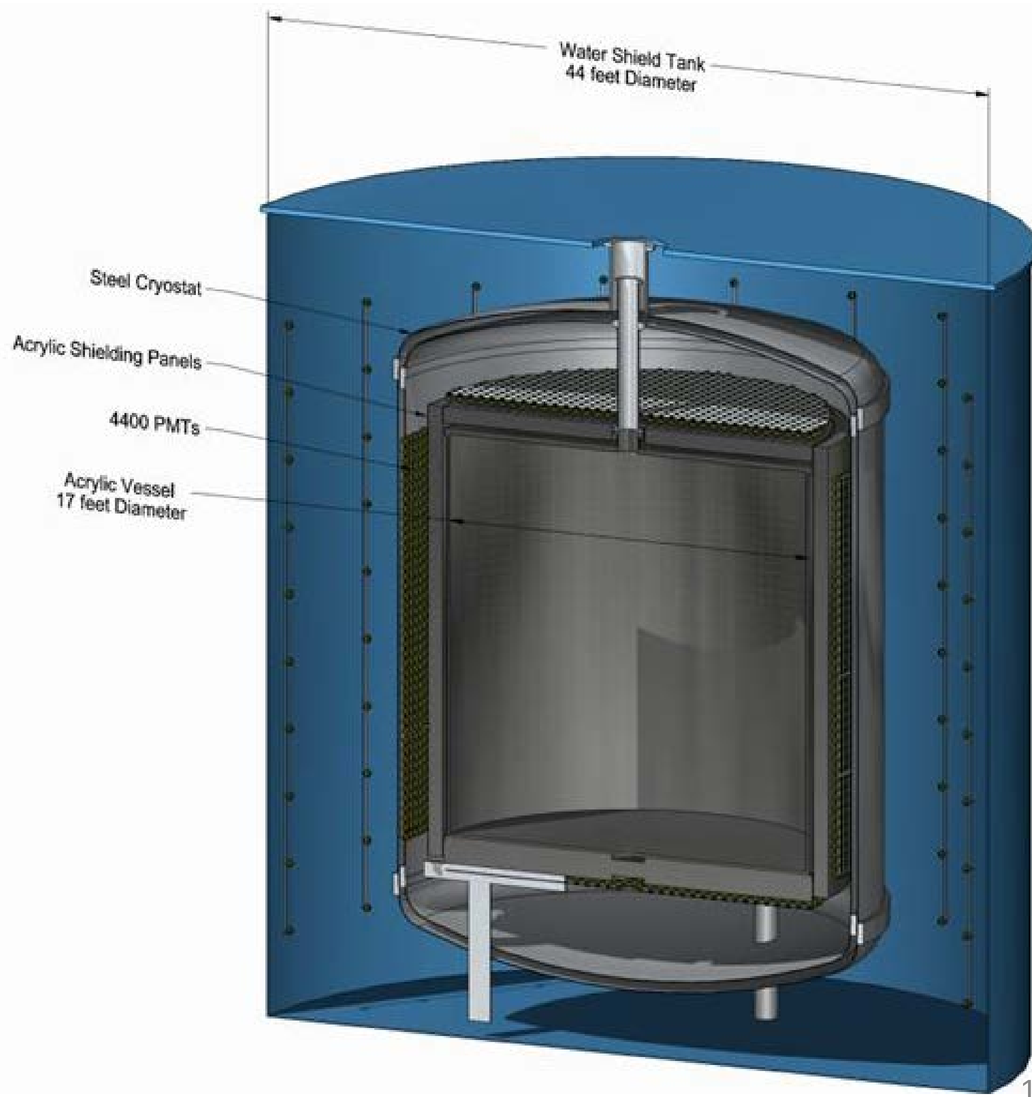


Measuring after-pulsing in-situ



Outlook

- ❑ **Filling with Liquid Argon this year**
  - First measure of PSD coming soon
    - ➢ We will know how far we can push it
  - Assess position reconstruction with ^{39}Ar
- ❑ **Dark matter limit in 2016**
- ❑ **If concept is a success consider 50t "upgrade"**
  - Depleted argon
  - New photo-detectors (100 m^2), SiPM, HPD,…



DEAP Collaboration

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Projected backgrounds

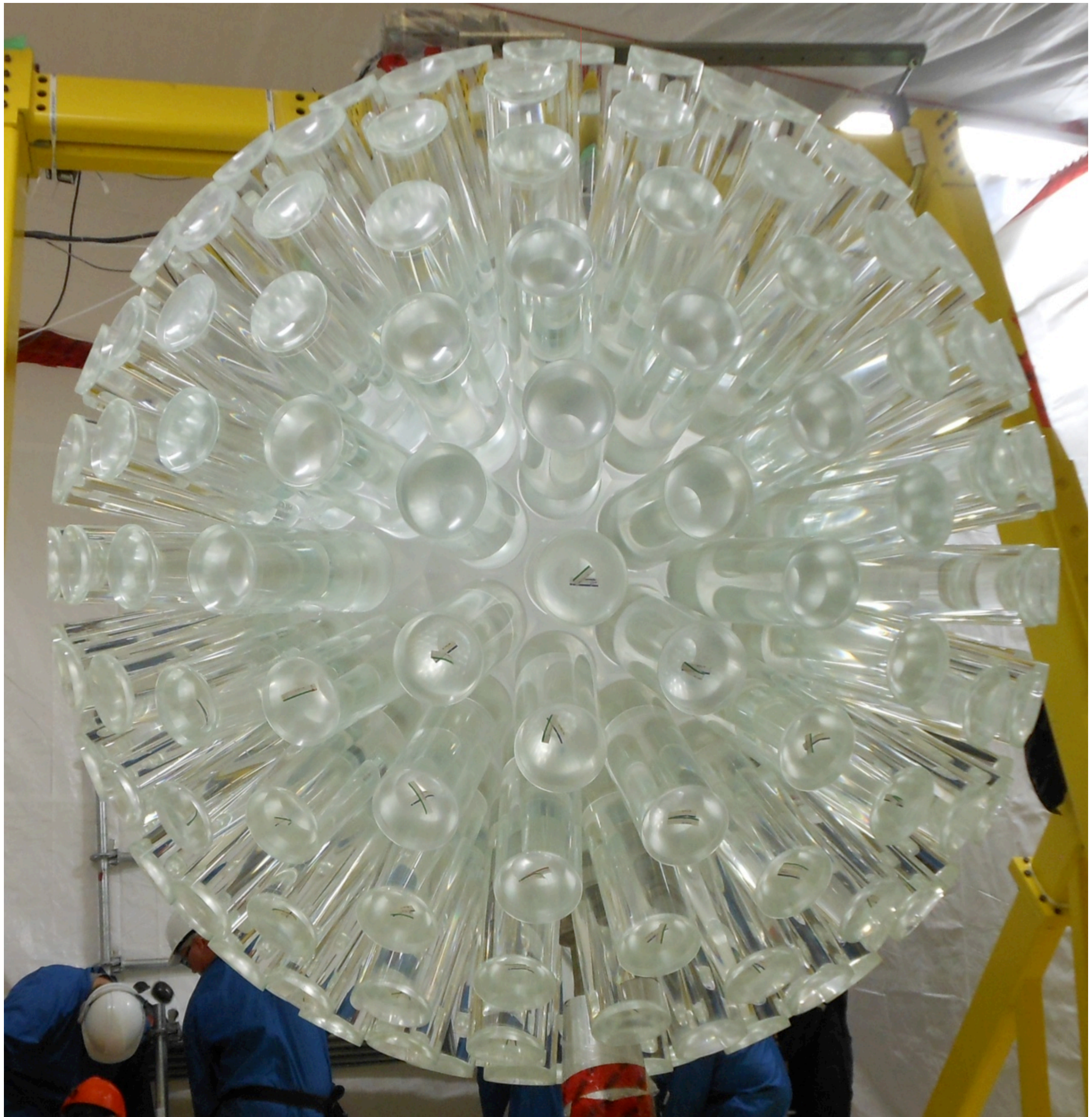
Assuming 8PE per keV

Background	Rate/count	Mitigation
Neutron In 1t LAr	< 2 pBq/kg < 0.06 count/year	Shielding: 6000 mwe (SNOLAB), Active water shield, light guides and filler blocks Material selection
β & γ In 1t LAr	< 2 pBq/kg < 0.06 count/year	Pulse shape discrimination Material selection (for γ)
Radon In 1t LAr	< 1.4 nBq/kg < 44 count/year*	Material selection, SAES getter, cold charcoal radon trap ** High energy events, not in ROI*
Surface α In 1t LAr	< 0.2 mBq/m^2 < 0.6 count/year	Material selection (acrylic), sanding of AV (1mm removal), fiducialization.

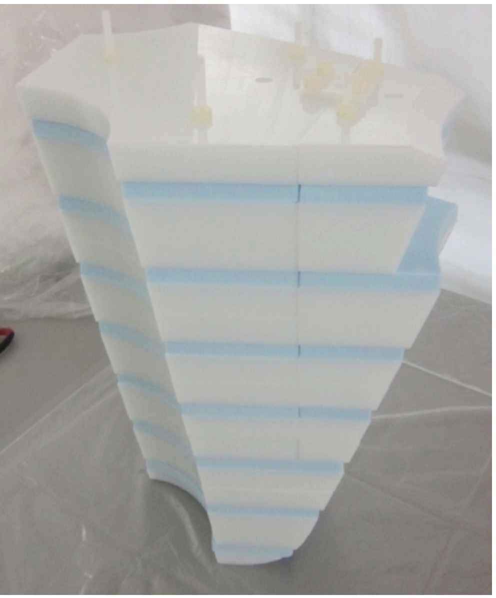
Total of <0.6 events in ROI in 3 years for a spin-independent WIMP-nucleon cross section sensitivity of 10^{-46} cm^2 at 100GeV.

“Naked” acrylic vessel

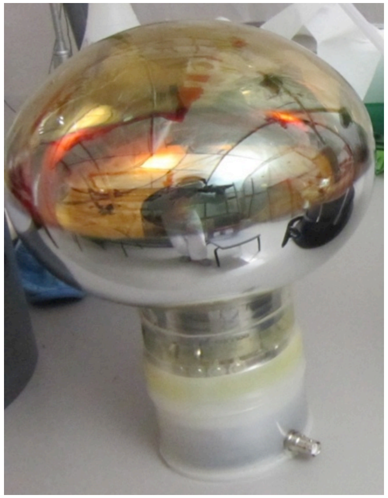
Bonded acrylic light guides

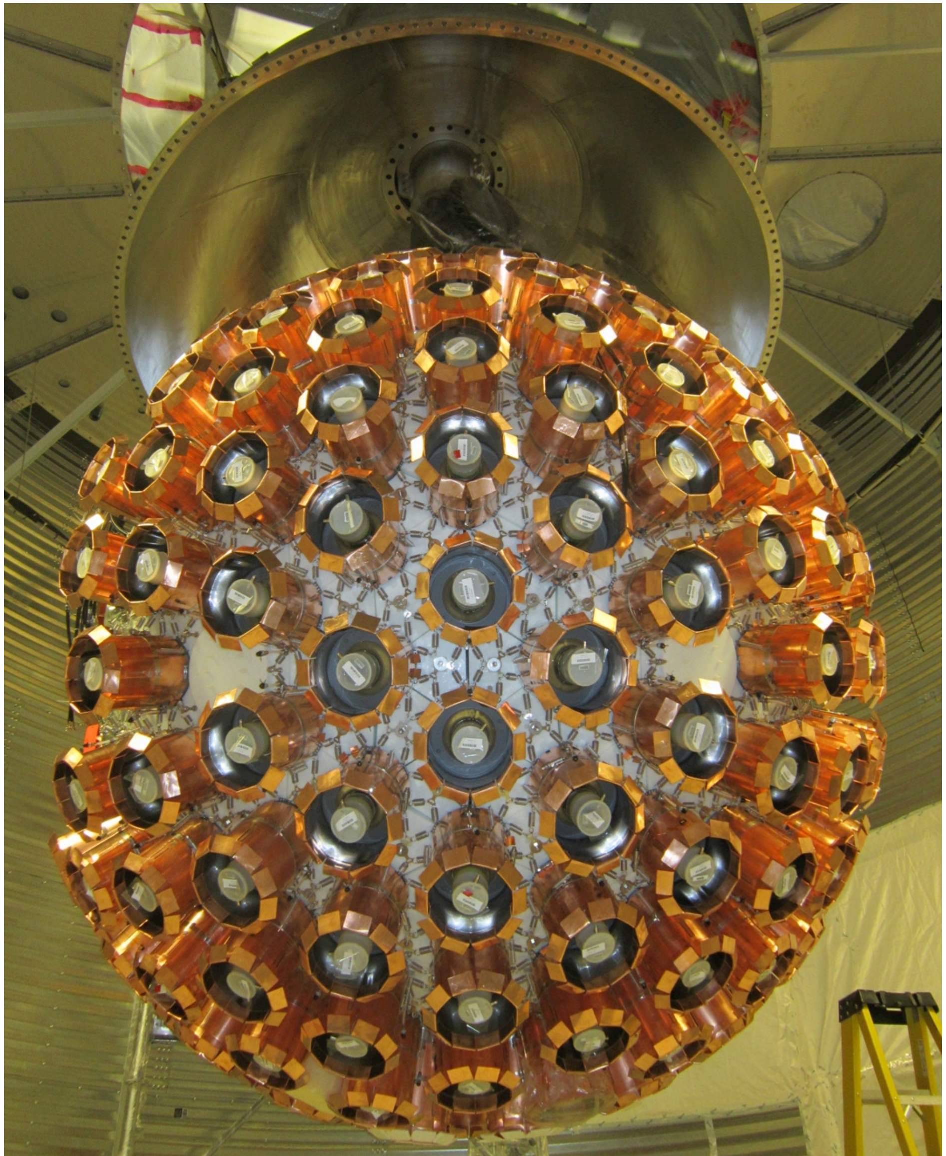


Add PMTs, reflectors and filler blocks

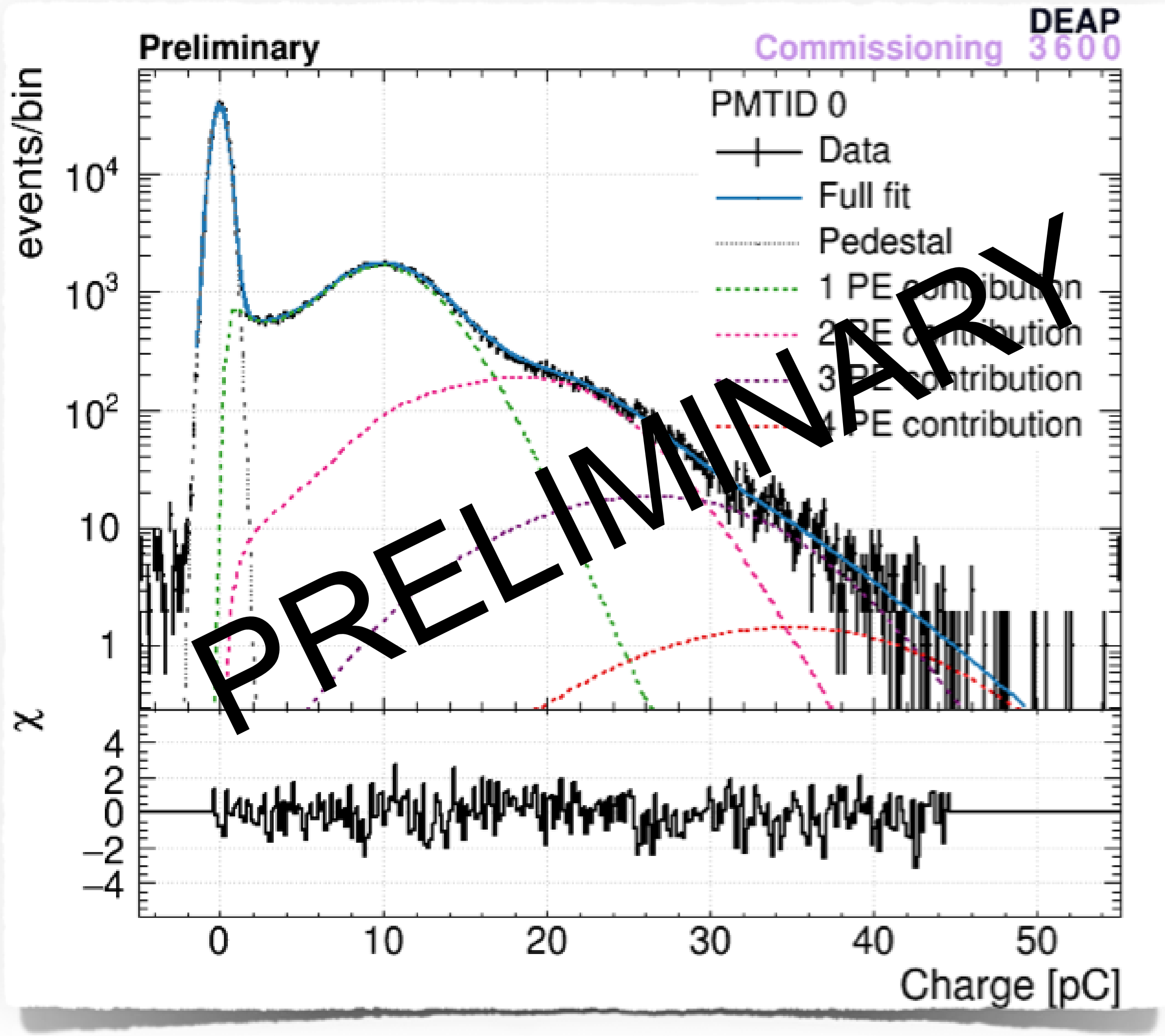


Relying on high efficiency R5912





Pulse Charge



Measured from prompt window in AARF data.