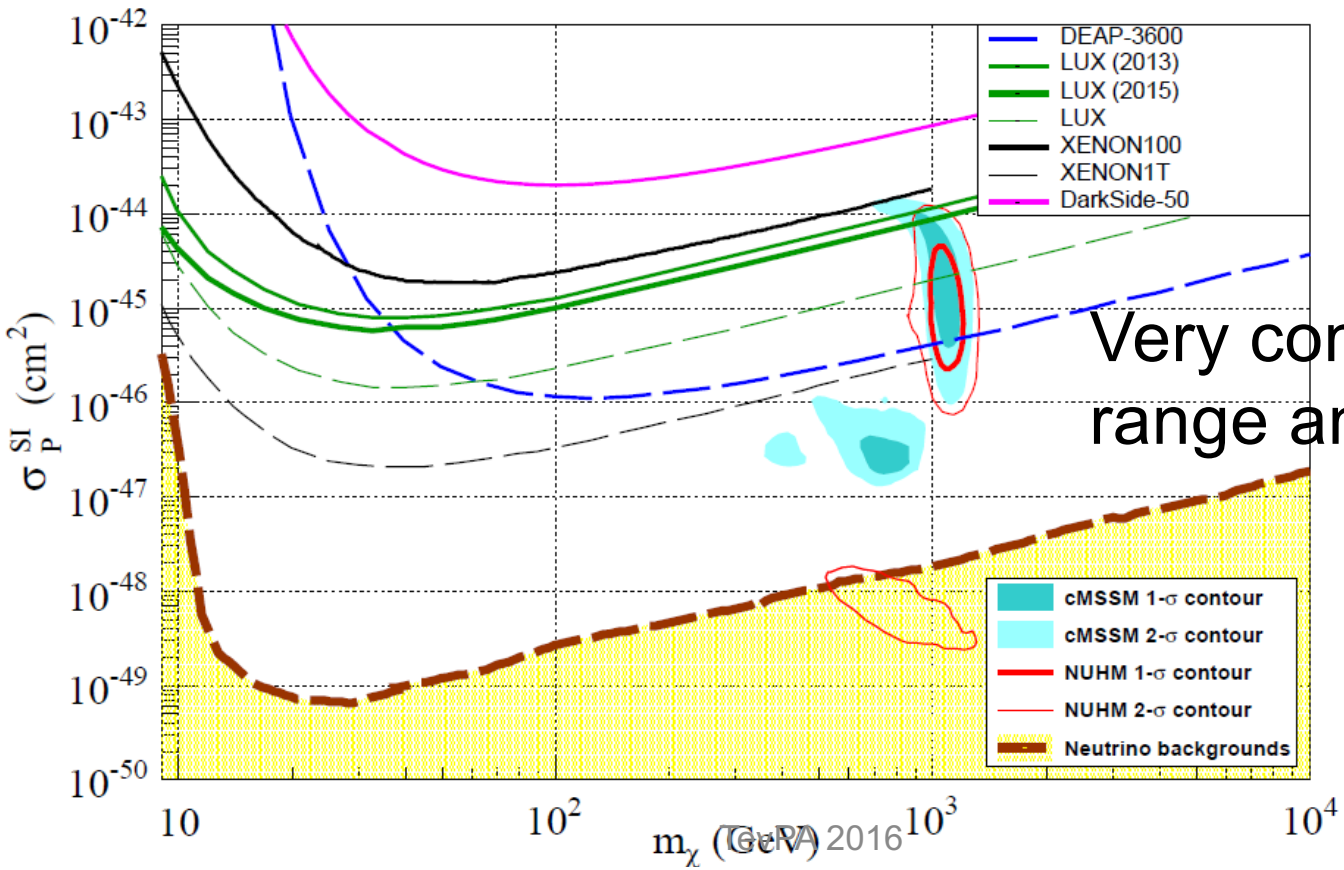
First light from DEAP-3600, a single phase liquid argon detector for dark matter search

Fabrice Retière on behalf of the DEAP collaboration

DEAP-3600 physics reach

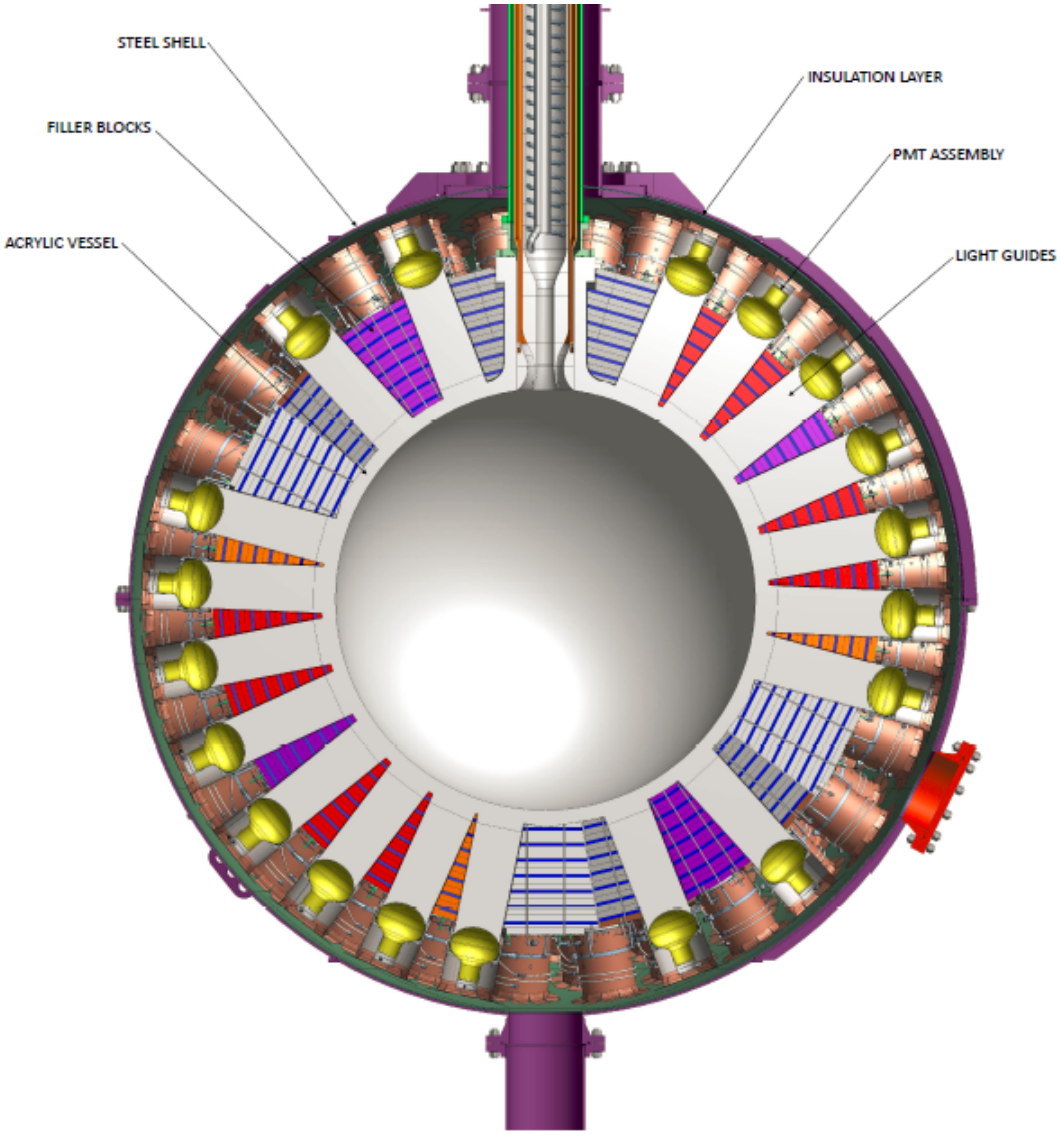
❑Target

- 1,000kg fiducial of liquid Argon
- Background < 1 count over 3 years



Very competitive in TeV range and beyond

DEAP-3600 concept



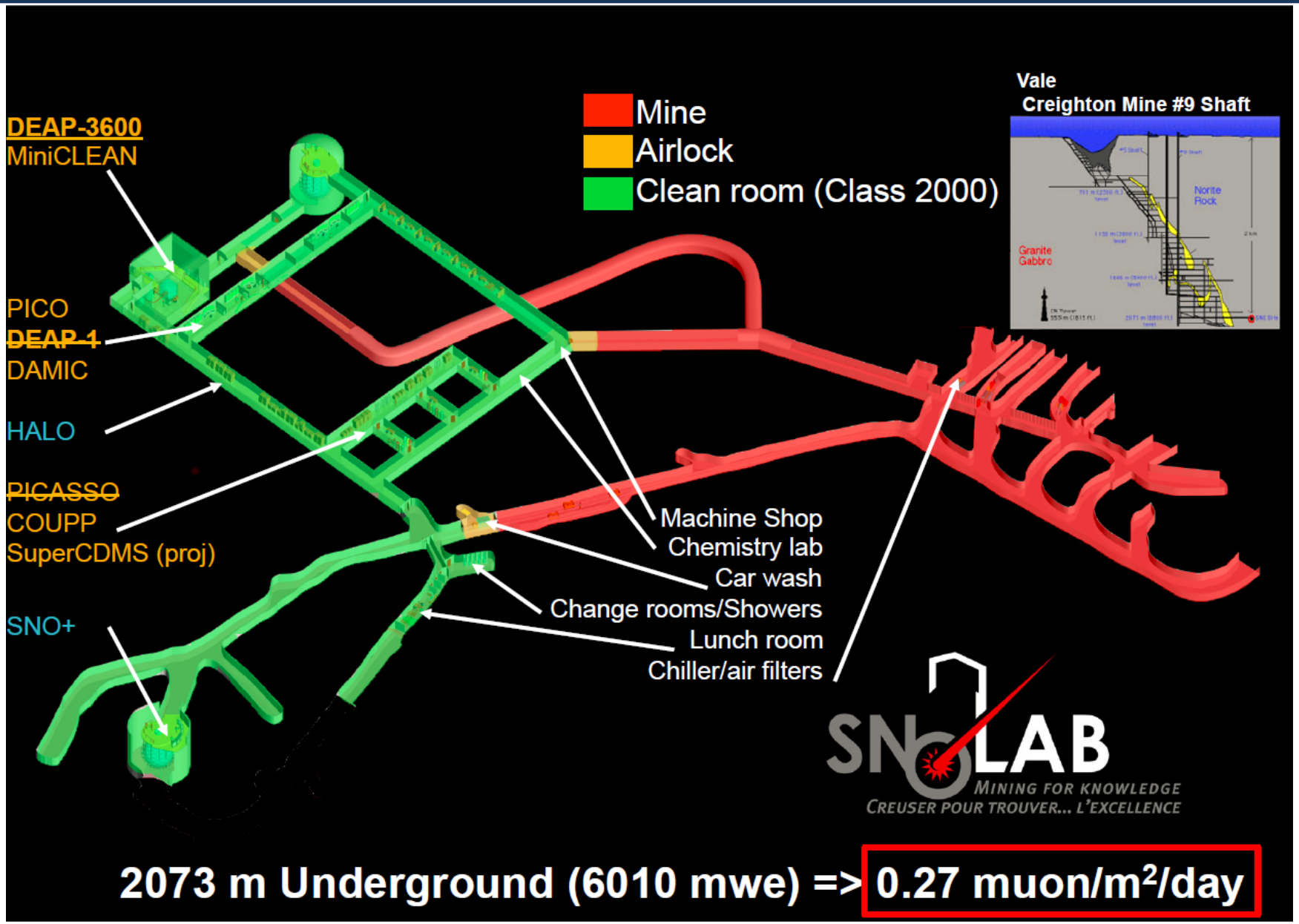
- **3,600kg of liquid Argon**
  - Enclosed in 85 cm radius acrylic ball
  - 1,000kg fiducial
- **Scintillation only**
  - Aka single phase
  - Light viewed by 255 photo-multiplier tubes
    - HQE Hamamatsu R5912

Outline

- **DEAP-3600 through its background mitigation technique**
  - Neutron background mitigation
  - γ and β rejection by pulse shape discrimination
  - Surface α background mitigation
- **Beyond DEAP-3600**
  - Reaching the coherent scattering neutrino limit

SNOLAB

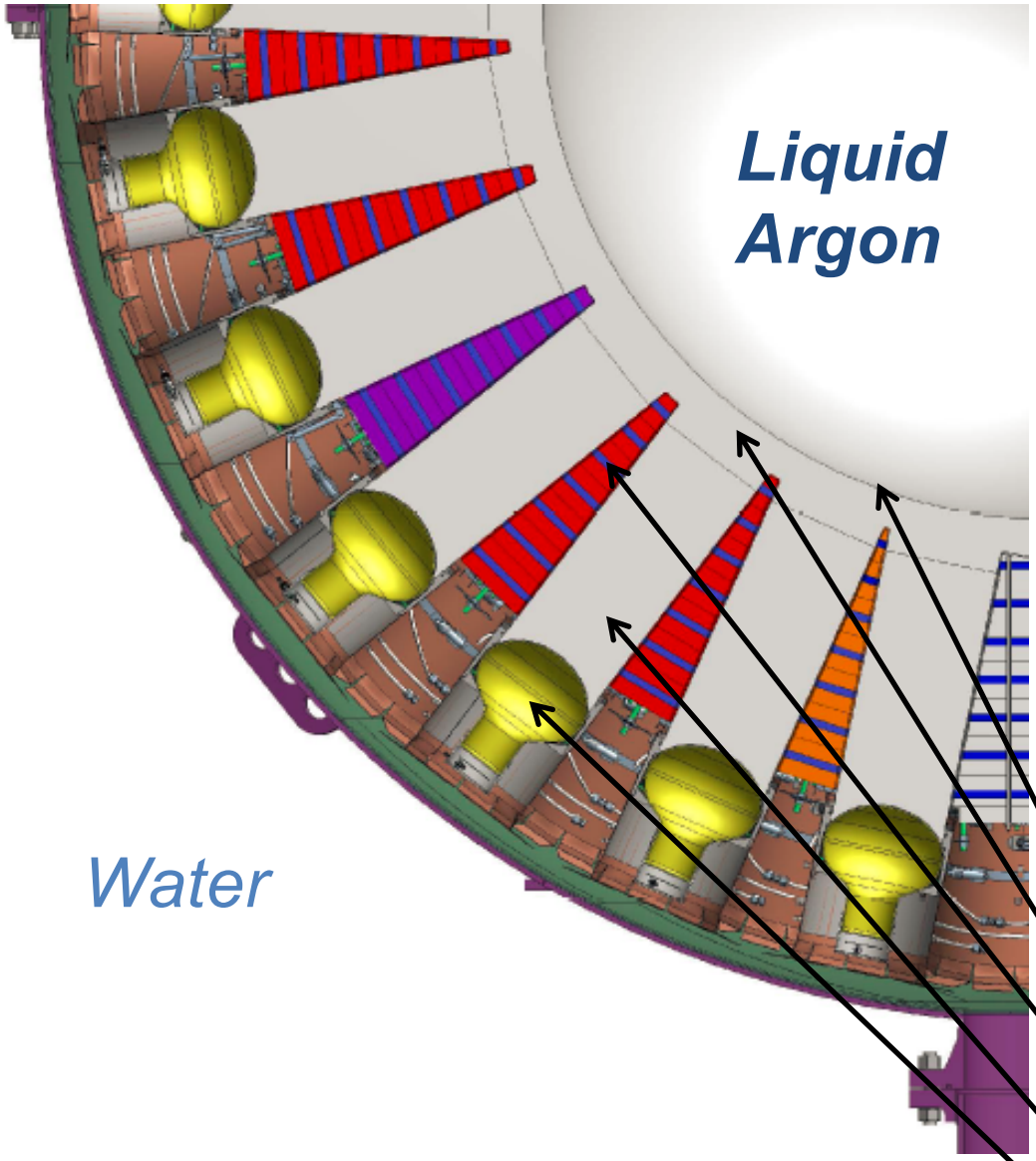
neutron mitigation



A day at SNOLAB: http://www.youtube.com/watch?v=sZPLcv-ASwc
SNOLAB Virtual Tour: https://www.snolab.ca/facility/vr-tour

Shielding with acrylic

neutron mitigation

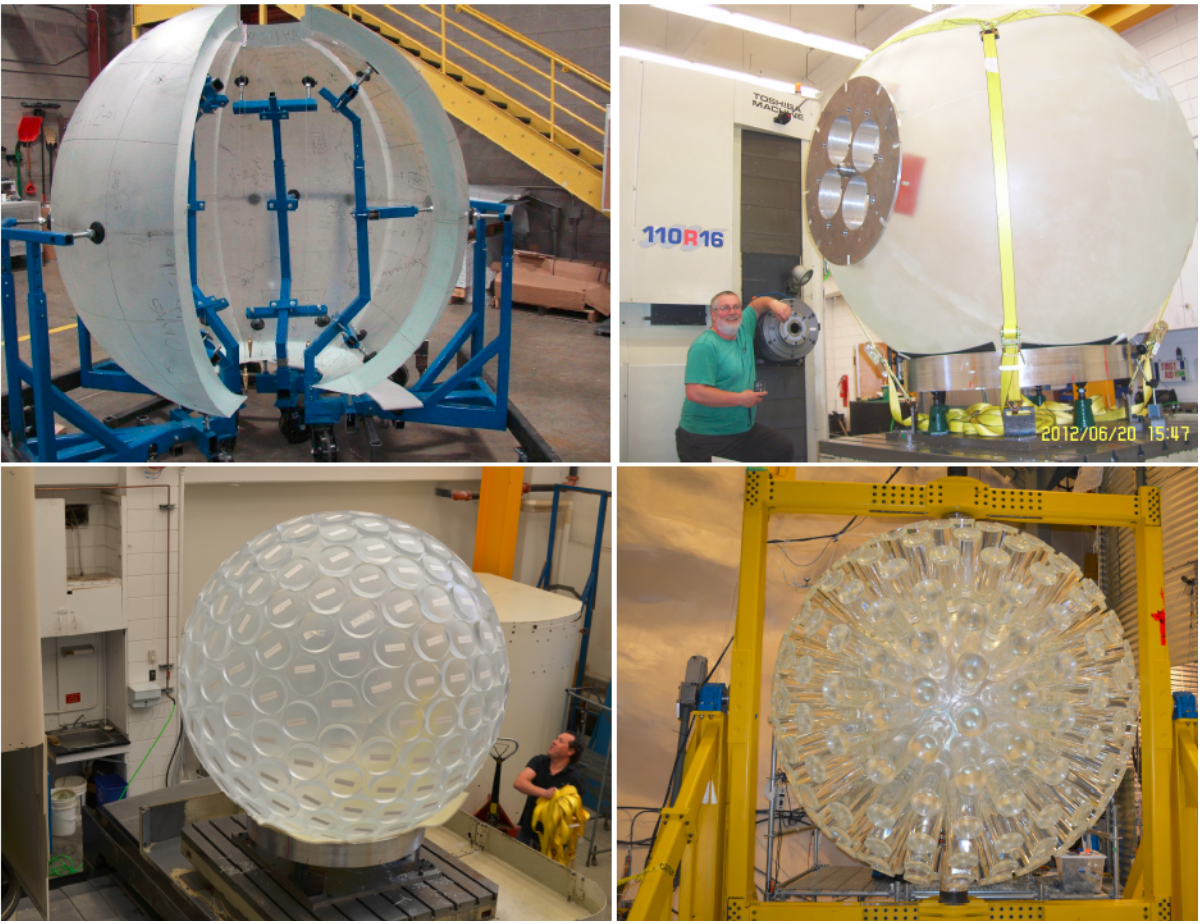


- ❑ Inside a water tank
- ❑ ~50cm of light guide acrylic and filler blocks
- ❑ Ultra-low radioactivity acrylic
- ❑ PMT dominant source of neutrons

- TPB wavelength shifter
- Acrylic vessel
- Filler block
- Acrylic light guide
- PMT

Acrylic work

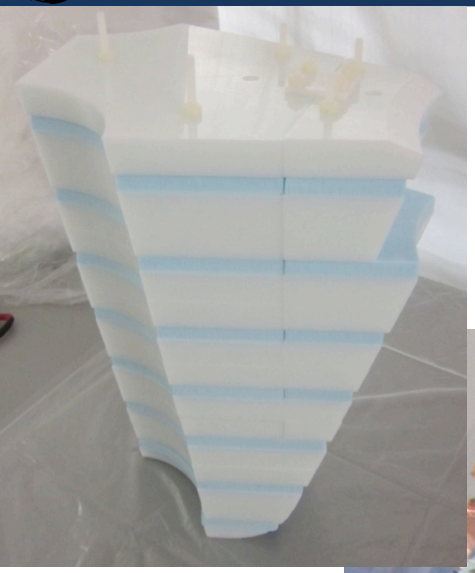
neutron mitigation

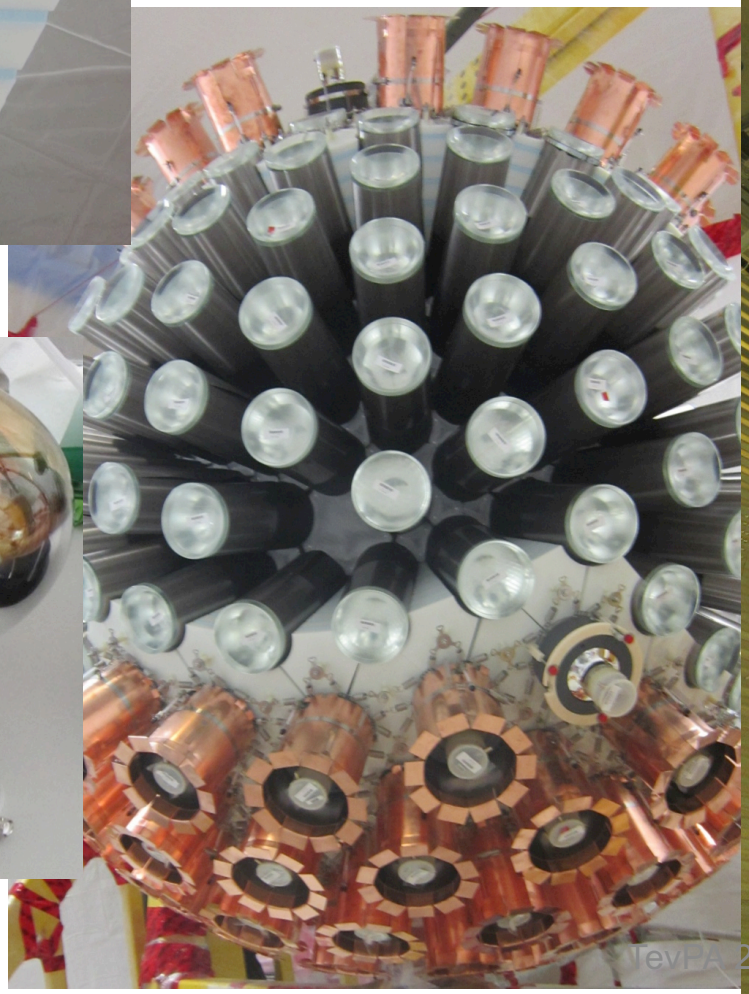


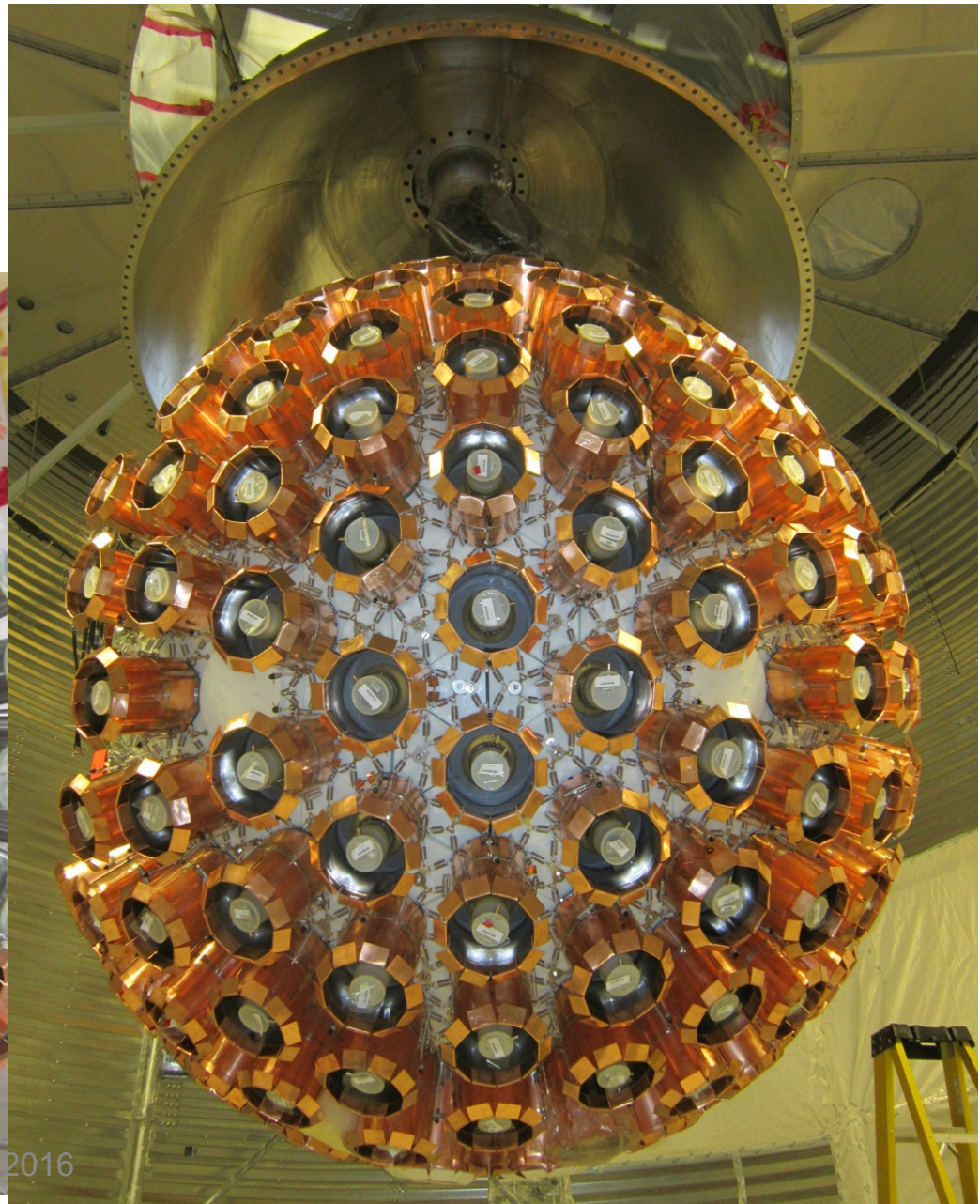
- Acrylic ball and light guide bars manufacturing by Reynolds Polymer
  - Radiopurity control at each manufacturing steps
- Stub machining at U. Alberta
- Light guide machining at TRIUMF
- Light guide bonding underground at SNOLAB

Then adding PMTs, reflectors and filler blocks

neutron mitigation

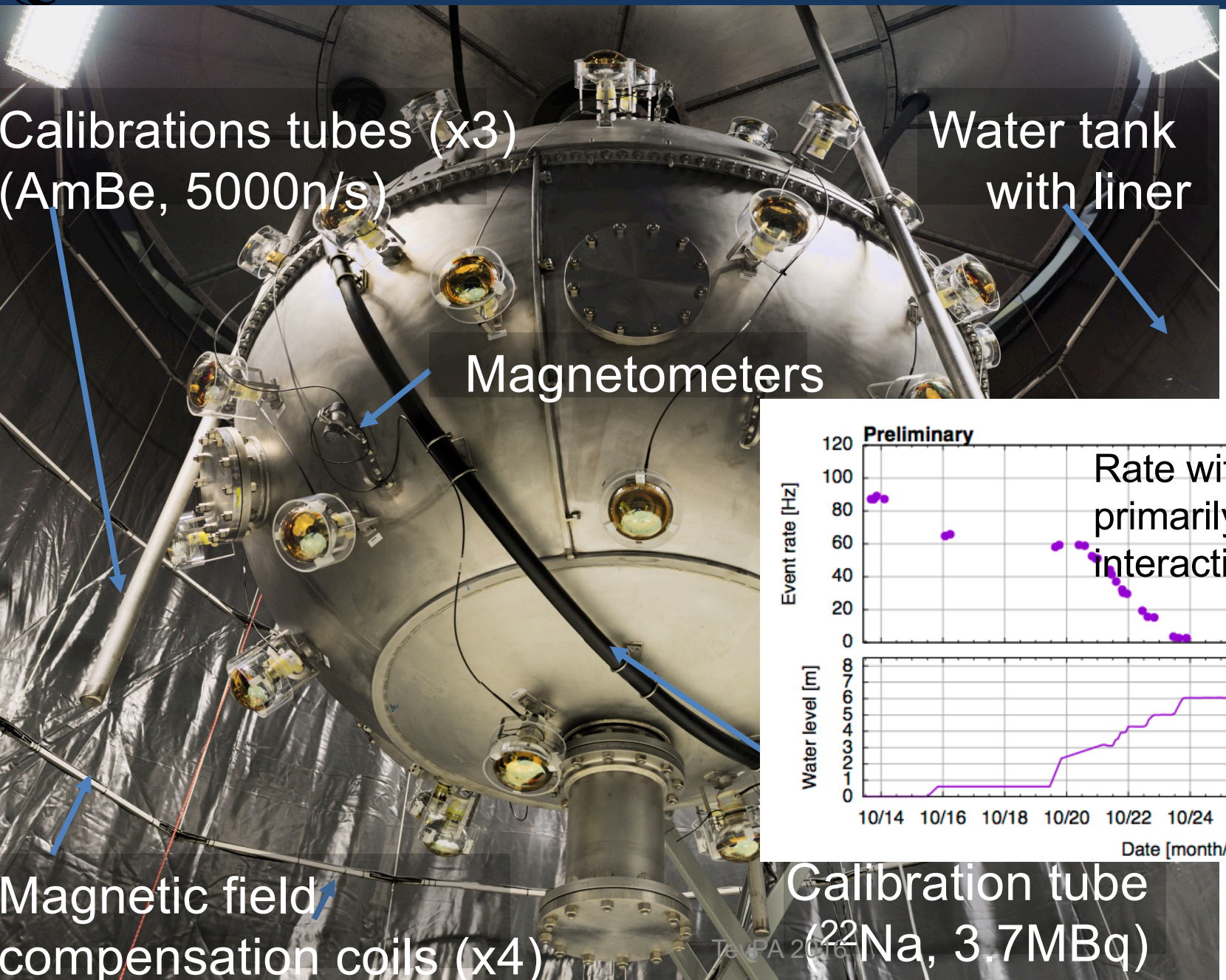


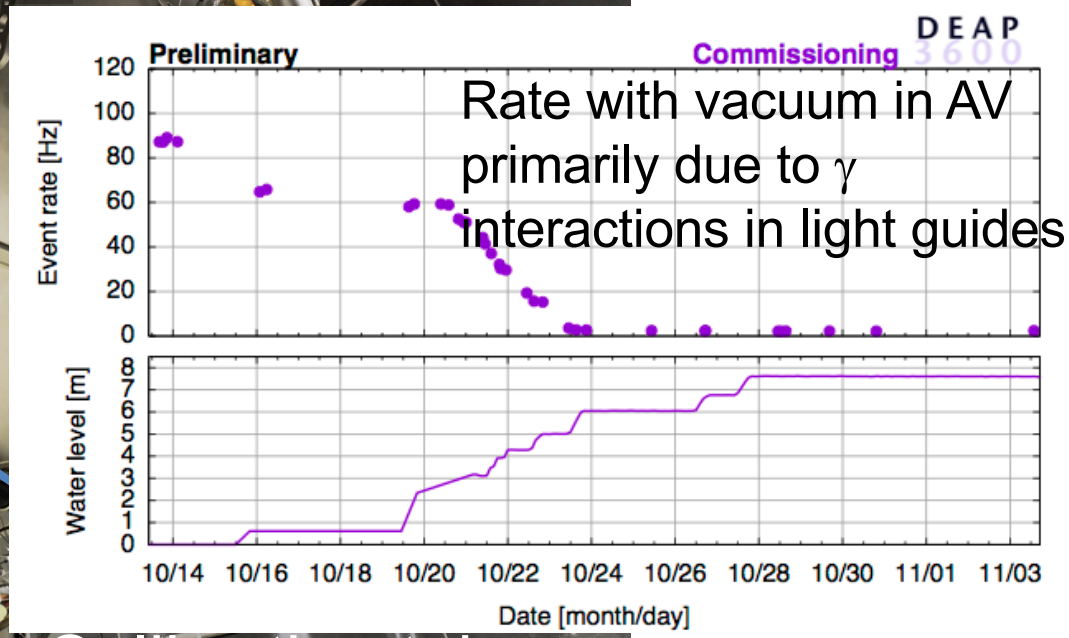


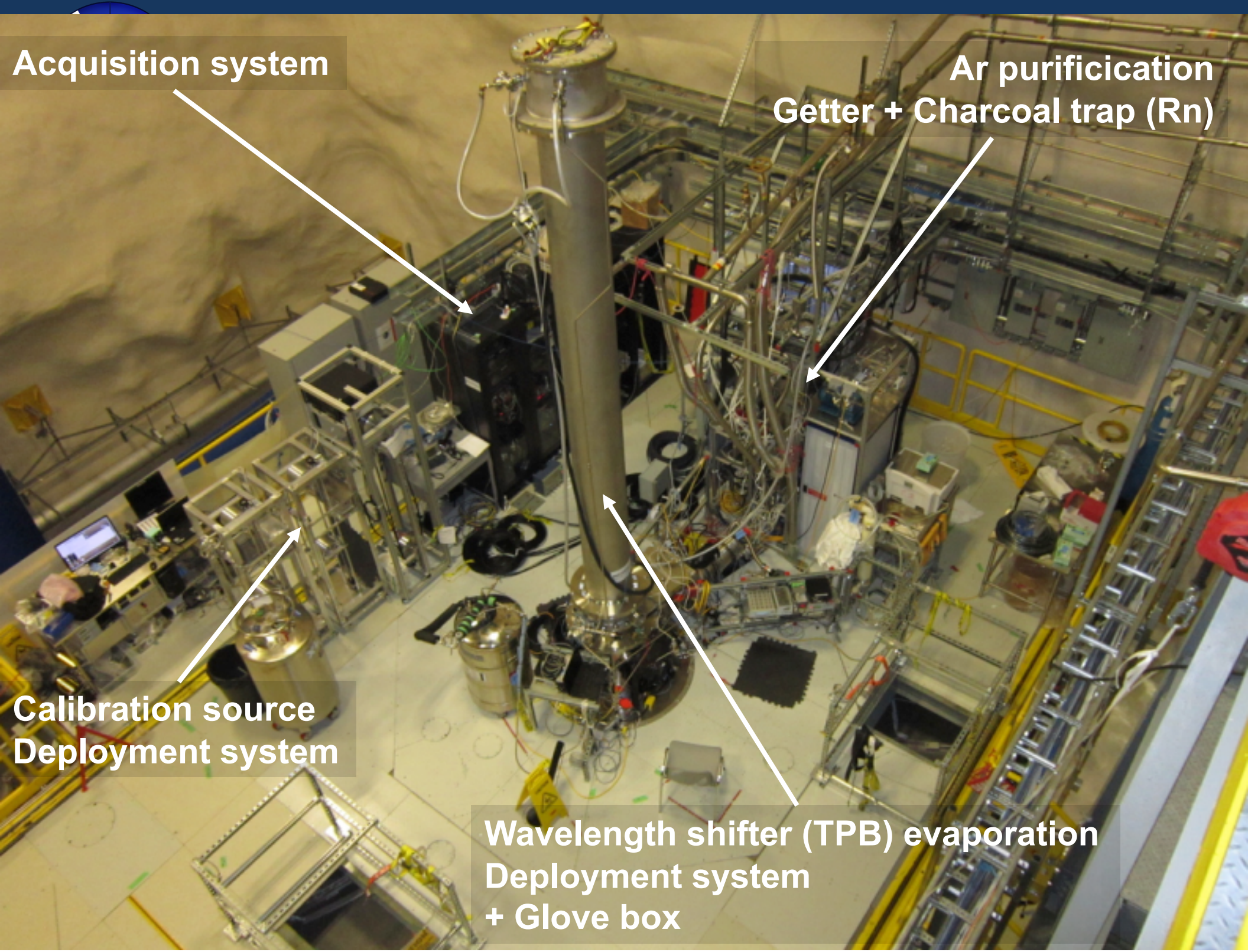


And embed the whole assembly in a water tank

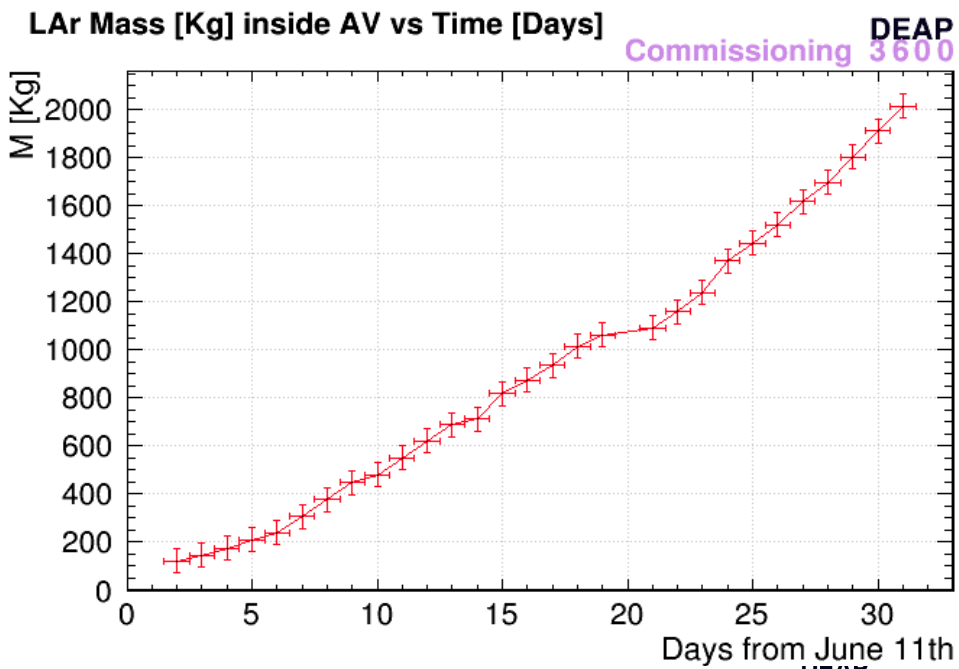
β/γ, neutron mitigation



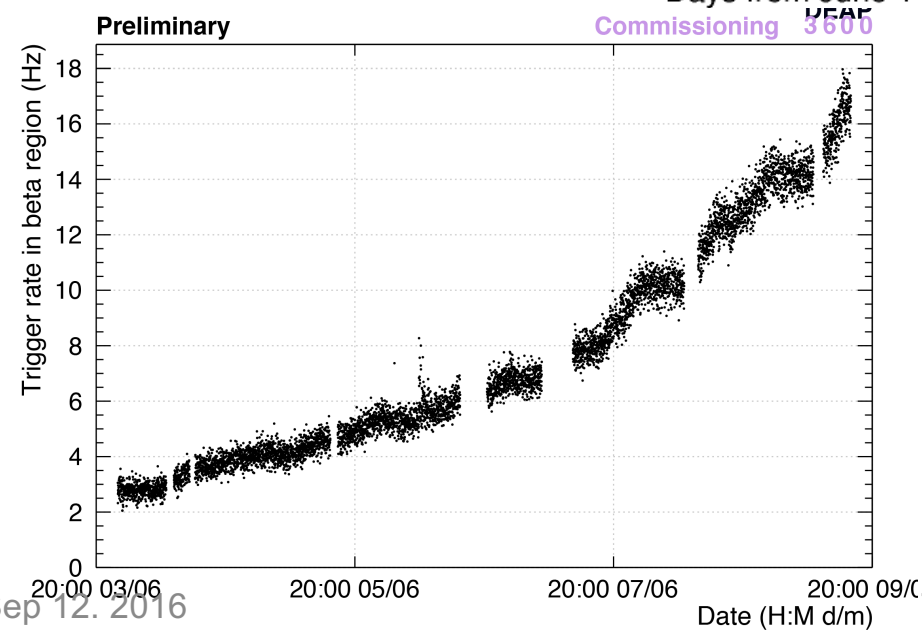


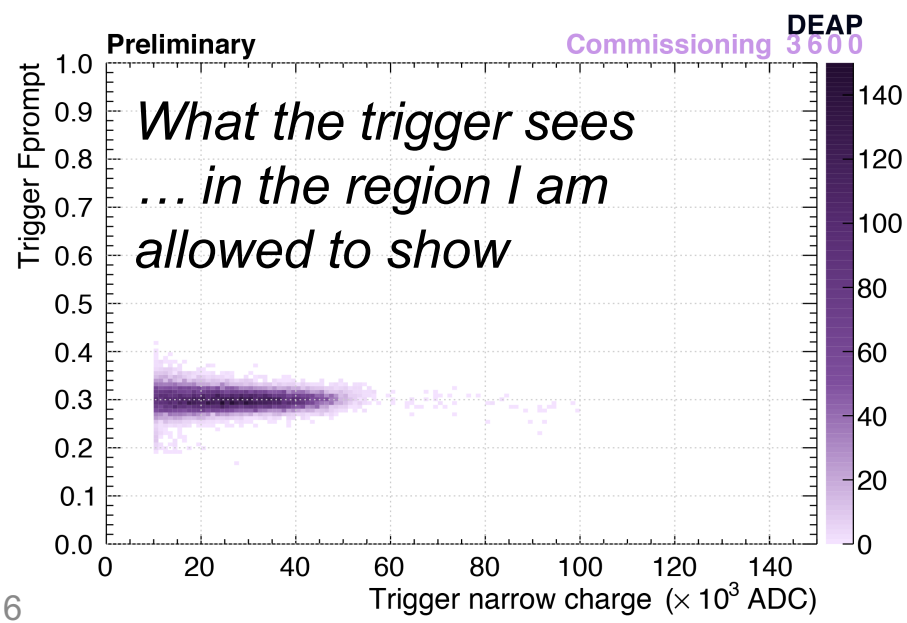

Acquisition system
Ar purificication
Getter + Charcoal trap (Rn)
Calibration source
Deployment system
Wavelength shifter (TPB) evaporation
Deployment system
+ Glove box

Starting to fill with liquid Argon early June



- **Quick increase in data rate**
  - Due to ^{39}Ar decay occurring at ~1Bq/kg
  - As seen by trigger system



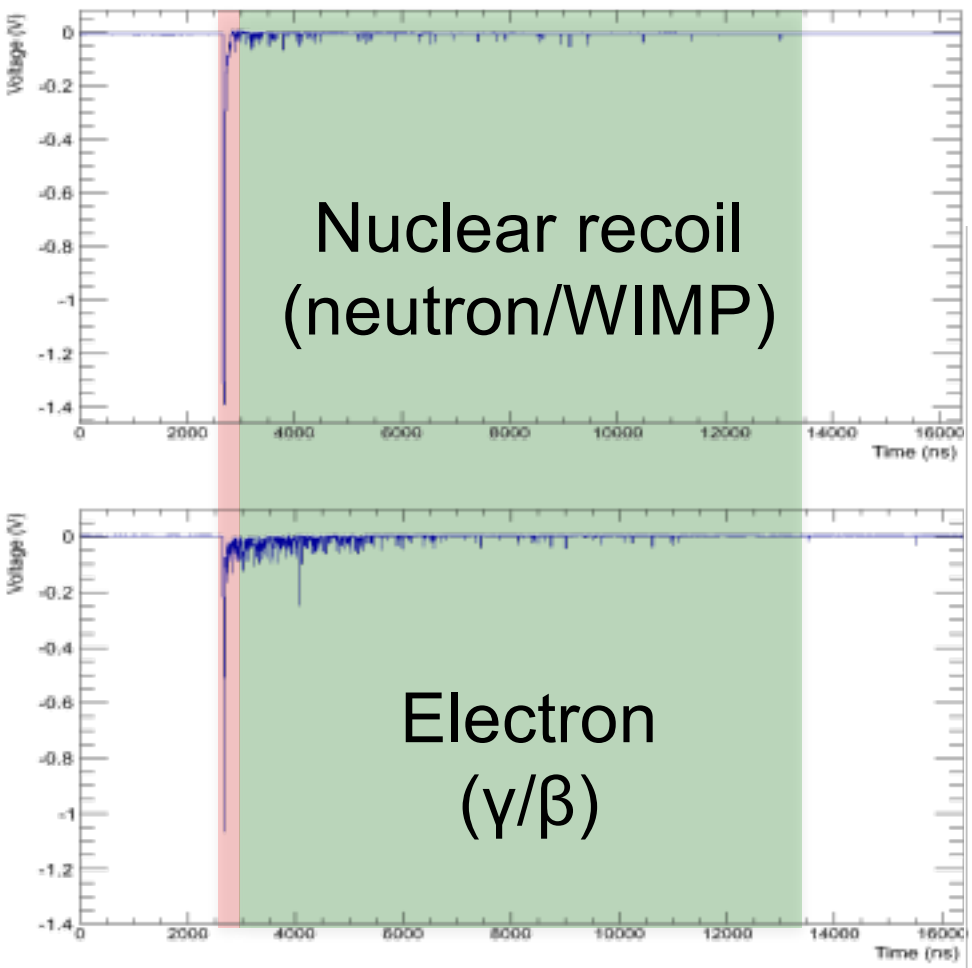


Pulse shape discrimination for eliminating e- recoil

β/γ mitigation

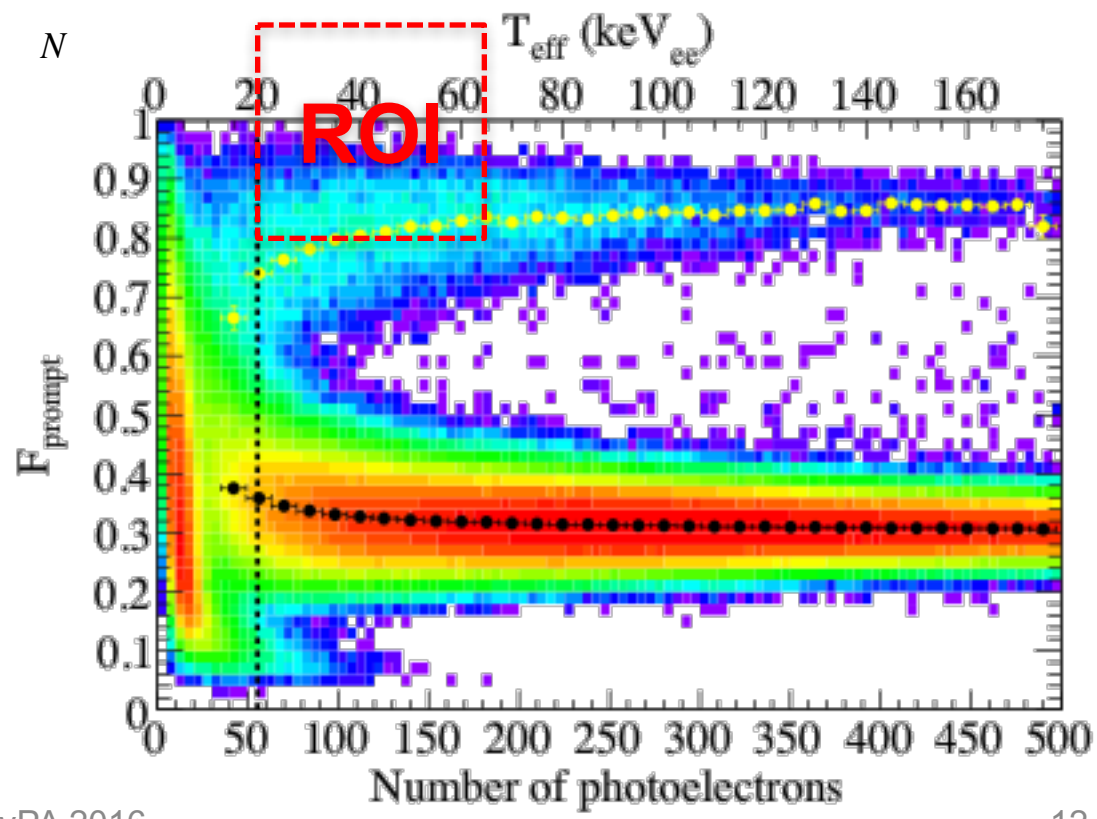
DEAP-1

Critical for rejecting huge ^{39}Ar background (~3.5kHz)



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

arXiv:0904.2930



Where does it come from? scintillation in LAr

β/γ mitigation

Excitation: Ar^* (1)

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

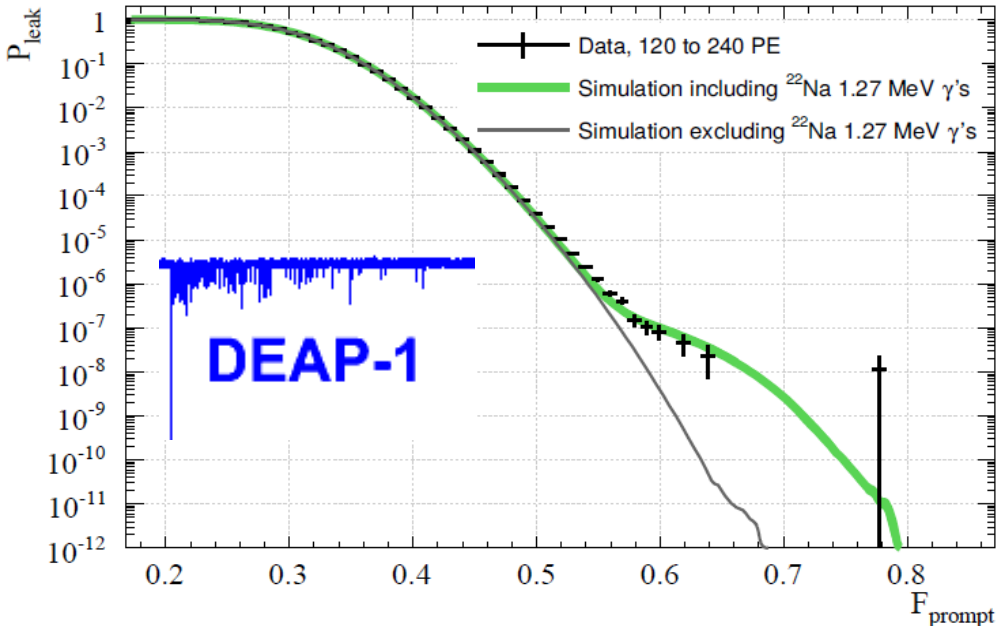
Ionization: Ar^+ (2)

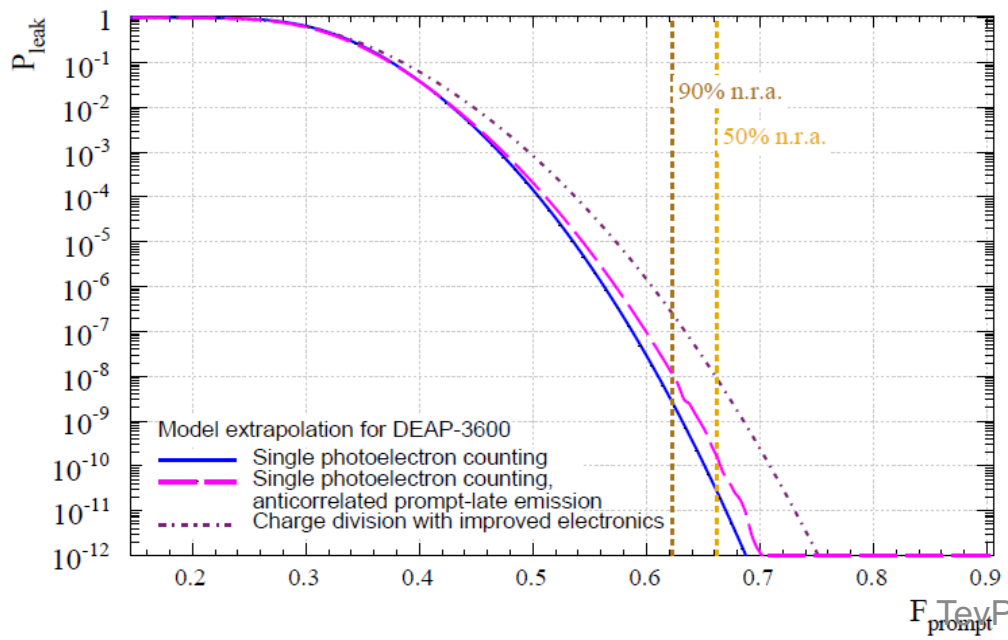
$$Ar^+ + Ar \rightarrow Ar_2^+$$
$$Ar_2^+ + e^- \rightarrow Ar^{**} + Ar$$
$$Ar^{**} \rightarrow Ar^* + heat$$
$$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$$
$$Ar_2^* \rightarrow 2Ar + \gamma$$

- **Excitation**
  - Production independent of energy density
  - Populate mainly triplet state
- **Ionization + recombination**
  - Production higher for high energy density
  - Populate mainly singlet state
- **Pulse shape discrimination**
  - $\tau_{singlet}$ ~ 6ns, $\tau_{triplet}$ ~ 1600ns
  - e- recoil, 35% singlet, 65% triplet
  - Nuclear recoil, 75% singlet, 25% triplet

The power of PSD

β/γ mitigation

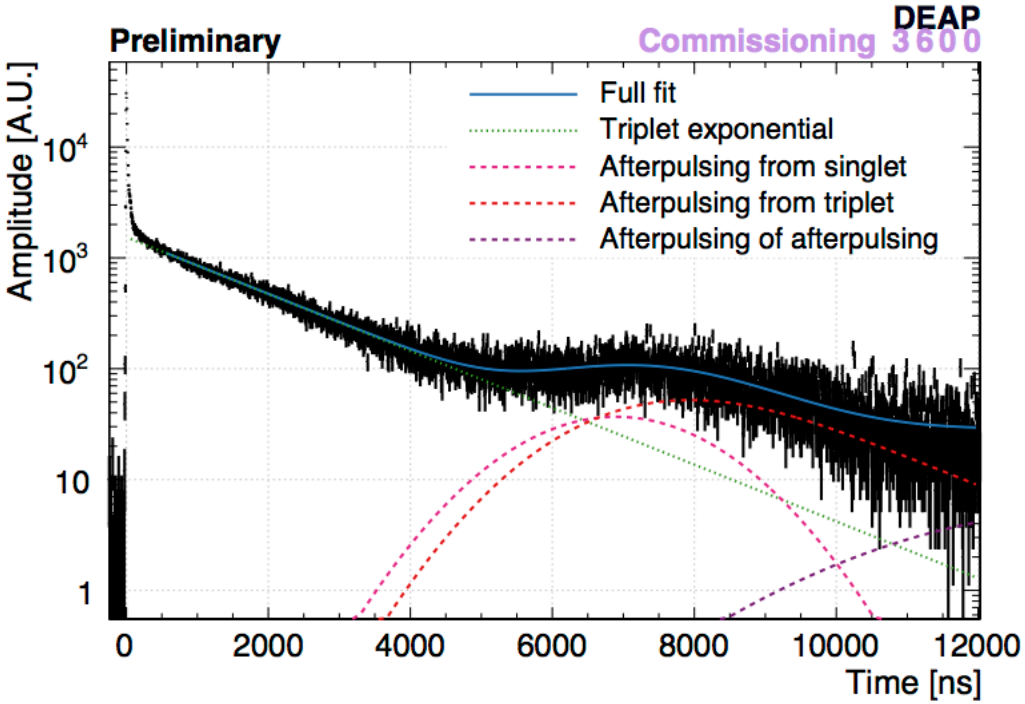


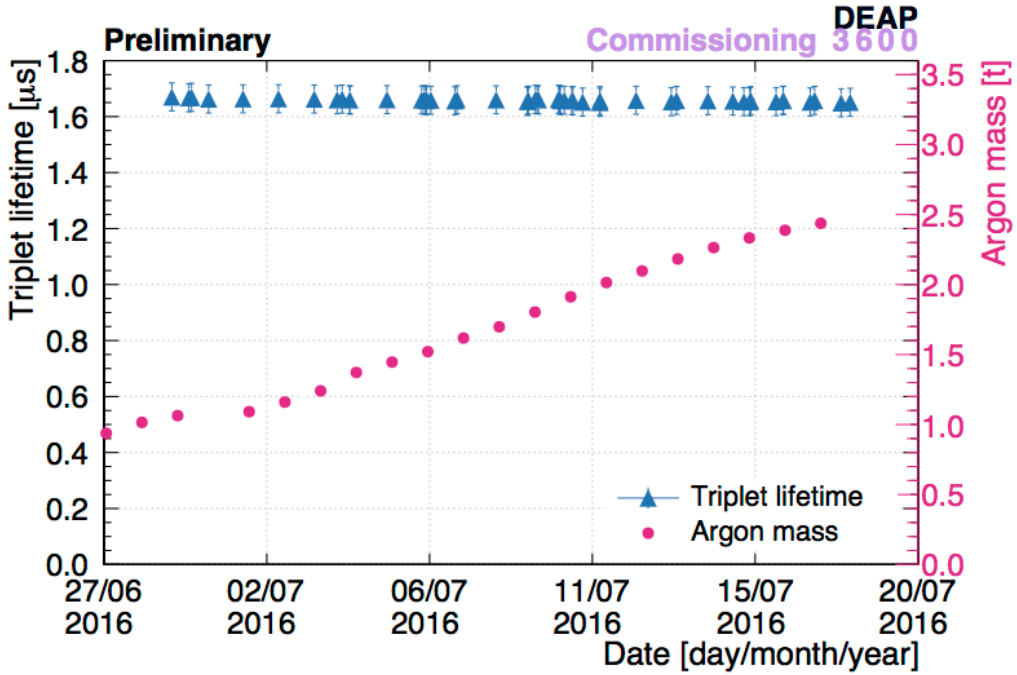


- DEAp-1 measure e-recoil suppression better than 3×10^{-8}
- Model predicts 10^{-10} suppression allowing for sufficient background rejection of ^{39}Ar in DEAP-3600

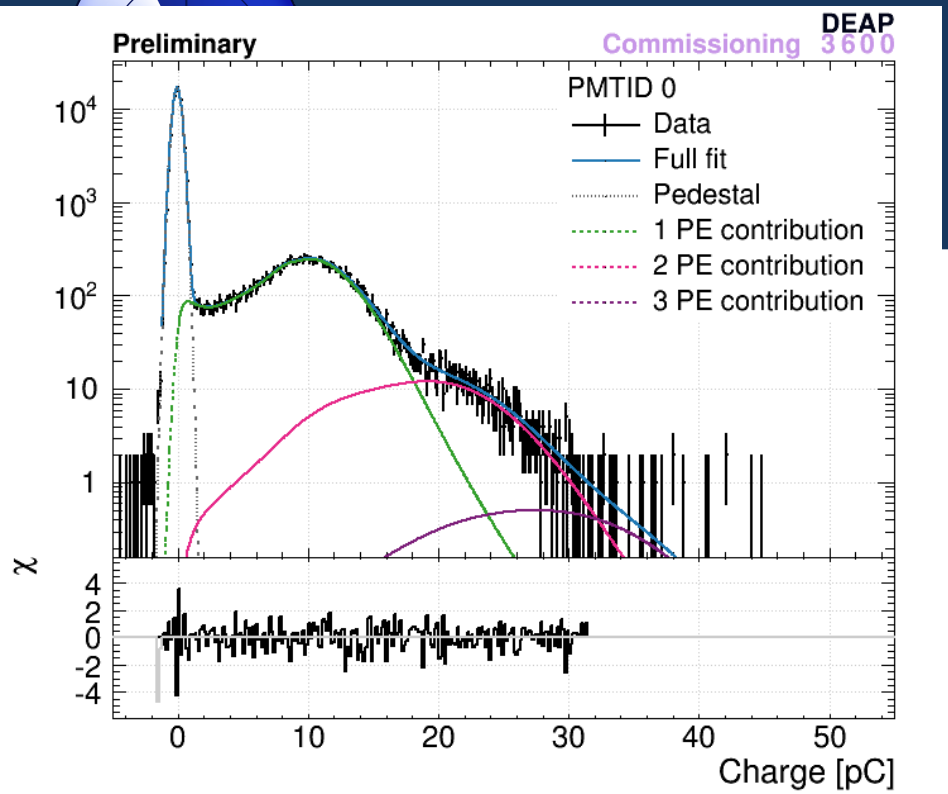
Triplet lifetime during the fill. Stable and high!

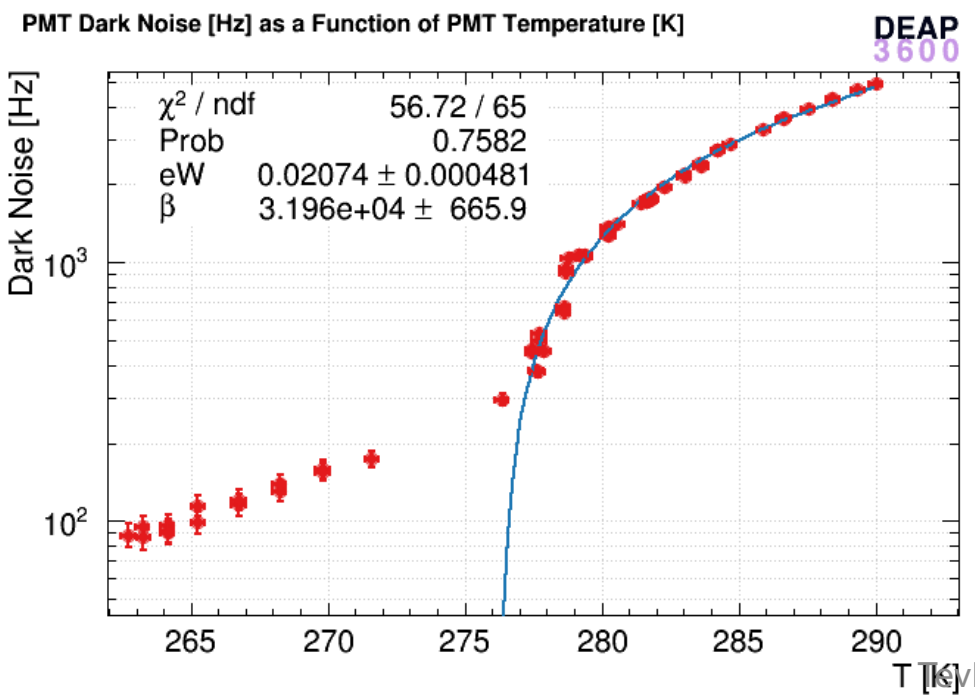
β/γ mitigation





PMT and PSD

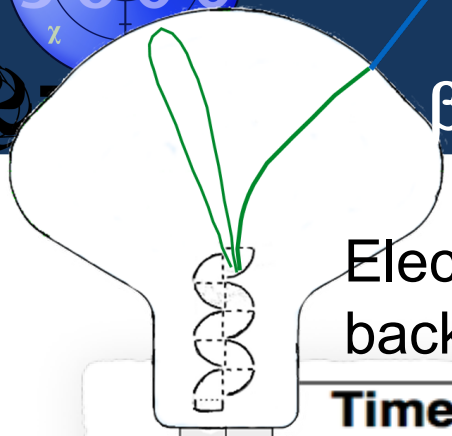


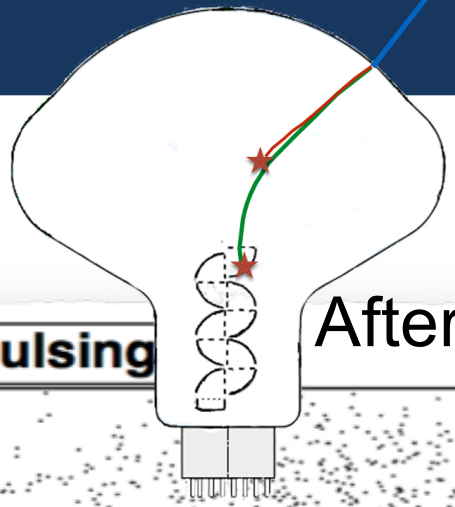


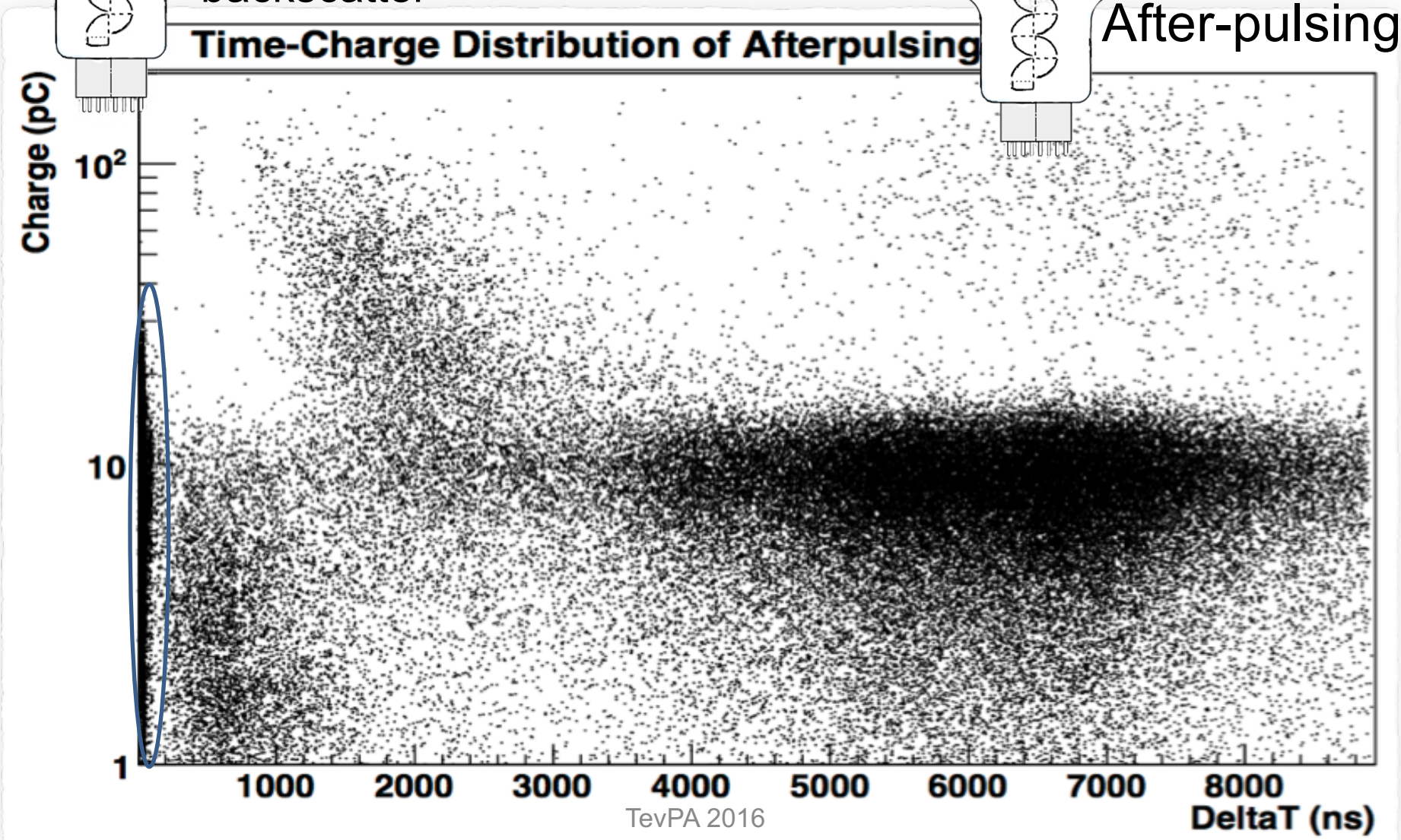
- **Dealing with PMT nuisances**
  - Gain drift and fluctuation
  - Dark noise
  - After-pulsing
    - Measured very precisely in situ

Measuring after-pulsing in-situ

β/γ mitigation

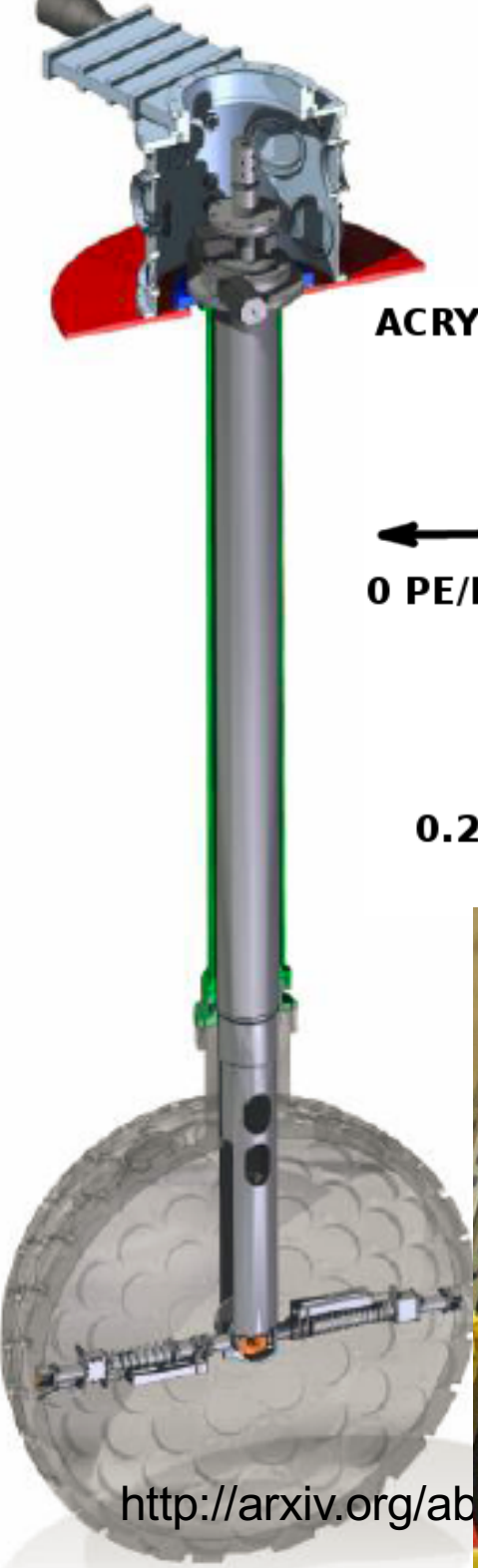


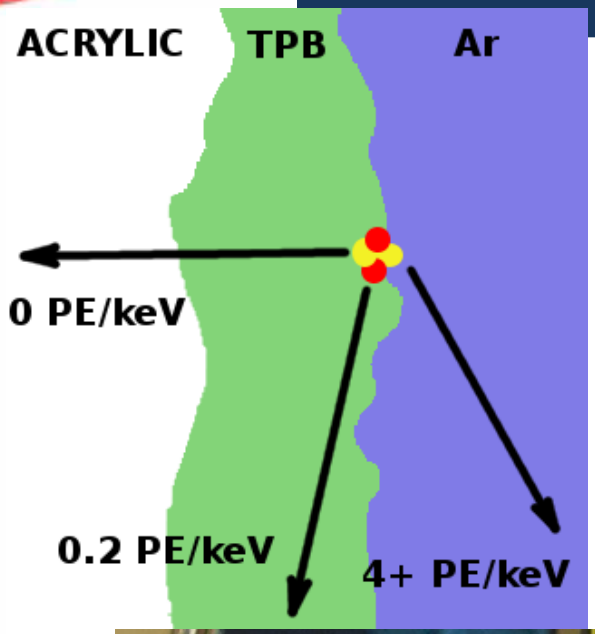




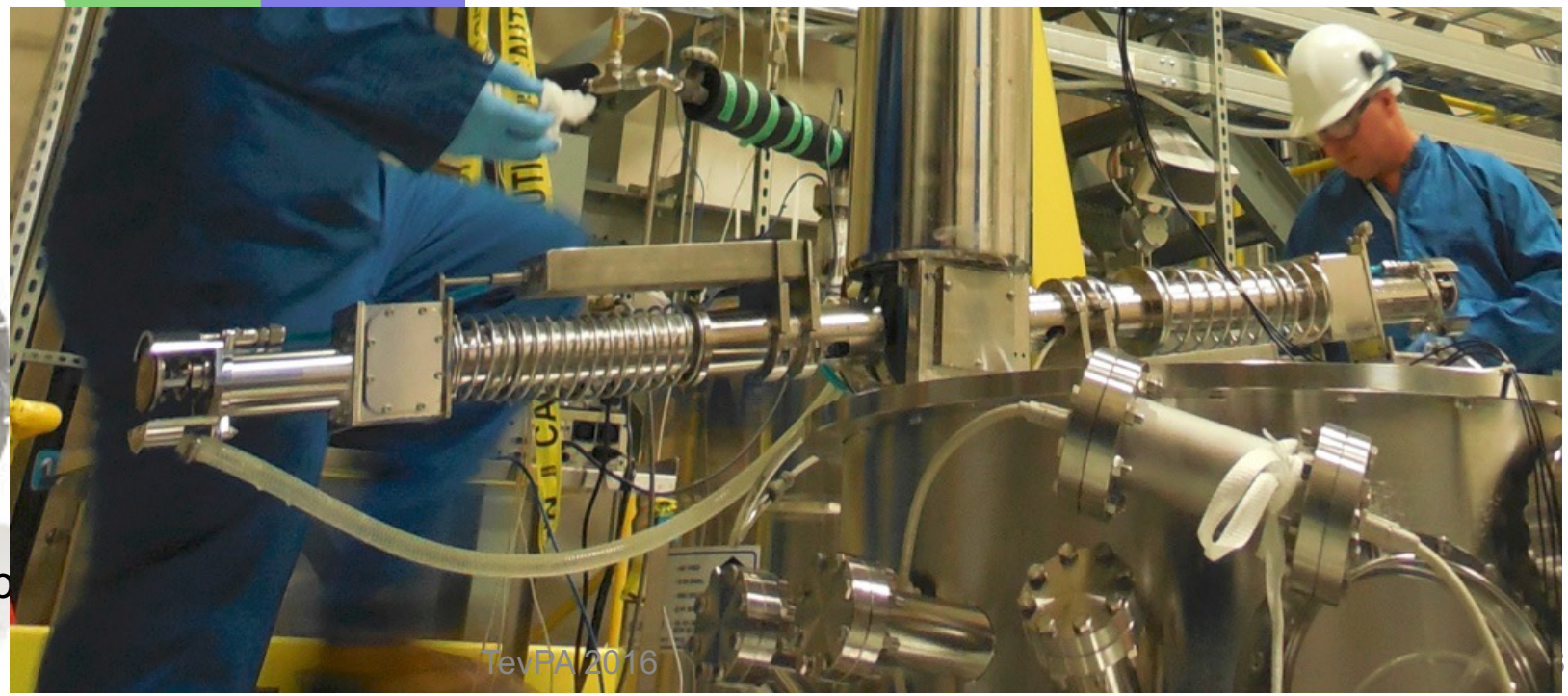
Radon and its annoying daughters

α mitigation



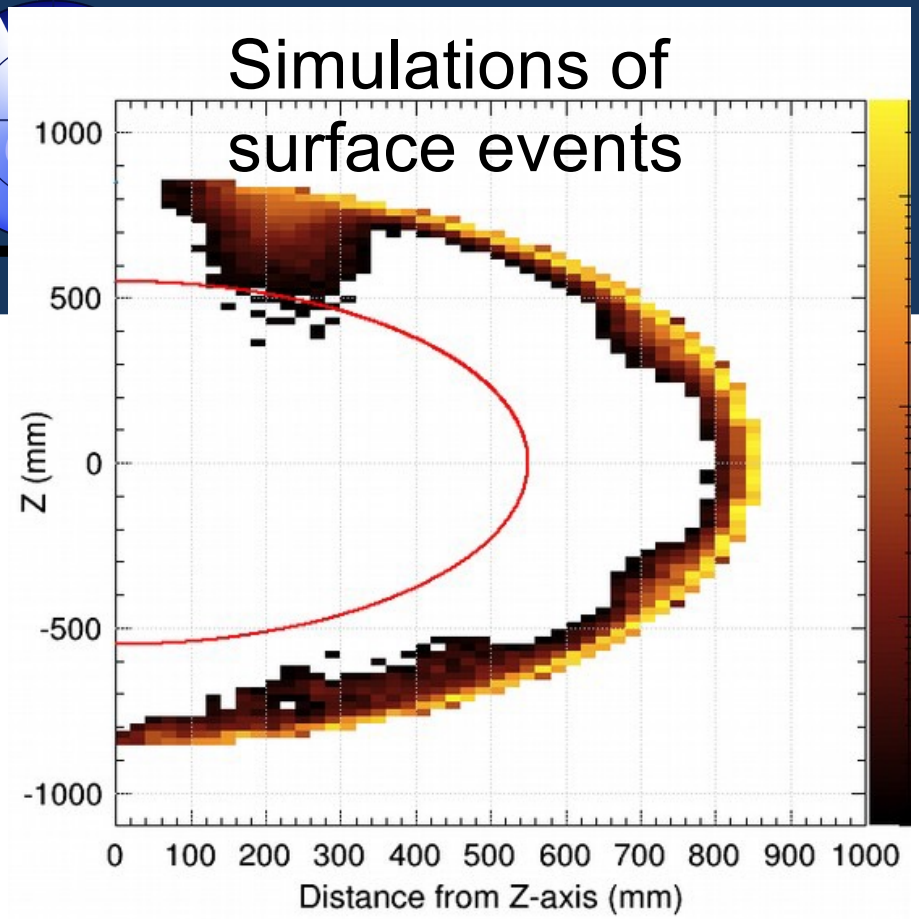


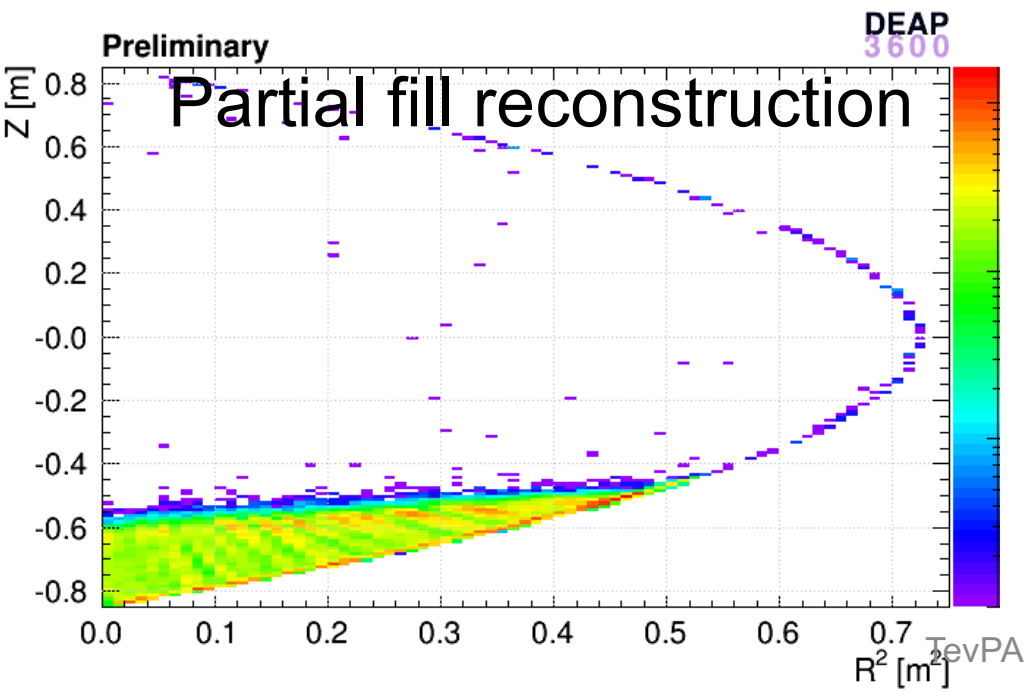
- **Rn + daughter decays in LAr not an issue**
  - Too high energy
  - Issue, decay with "missing" energy
- **Solutions:**
  - Minimize radon emanation with filters and a trap
  - AV resurfacing: shave a mm off the surface
    - Then TPB (wavelength shifter) deposition
  - Position reconstruction

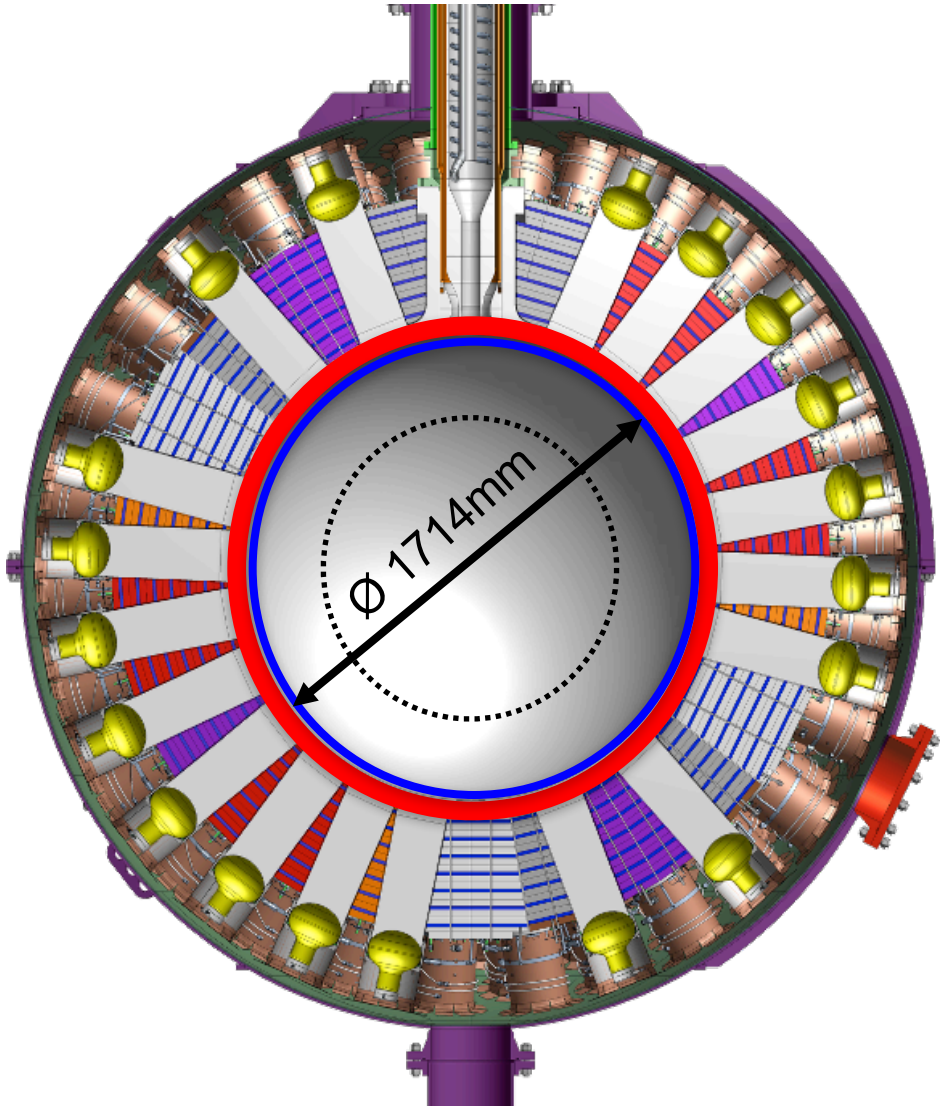


http://arxiv.org/ab

Position reconstruction







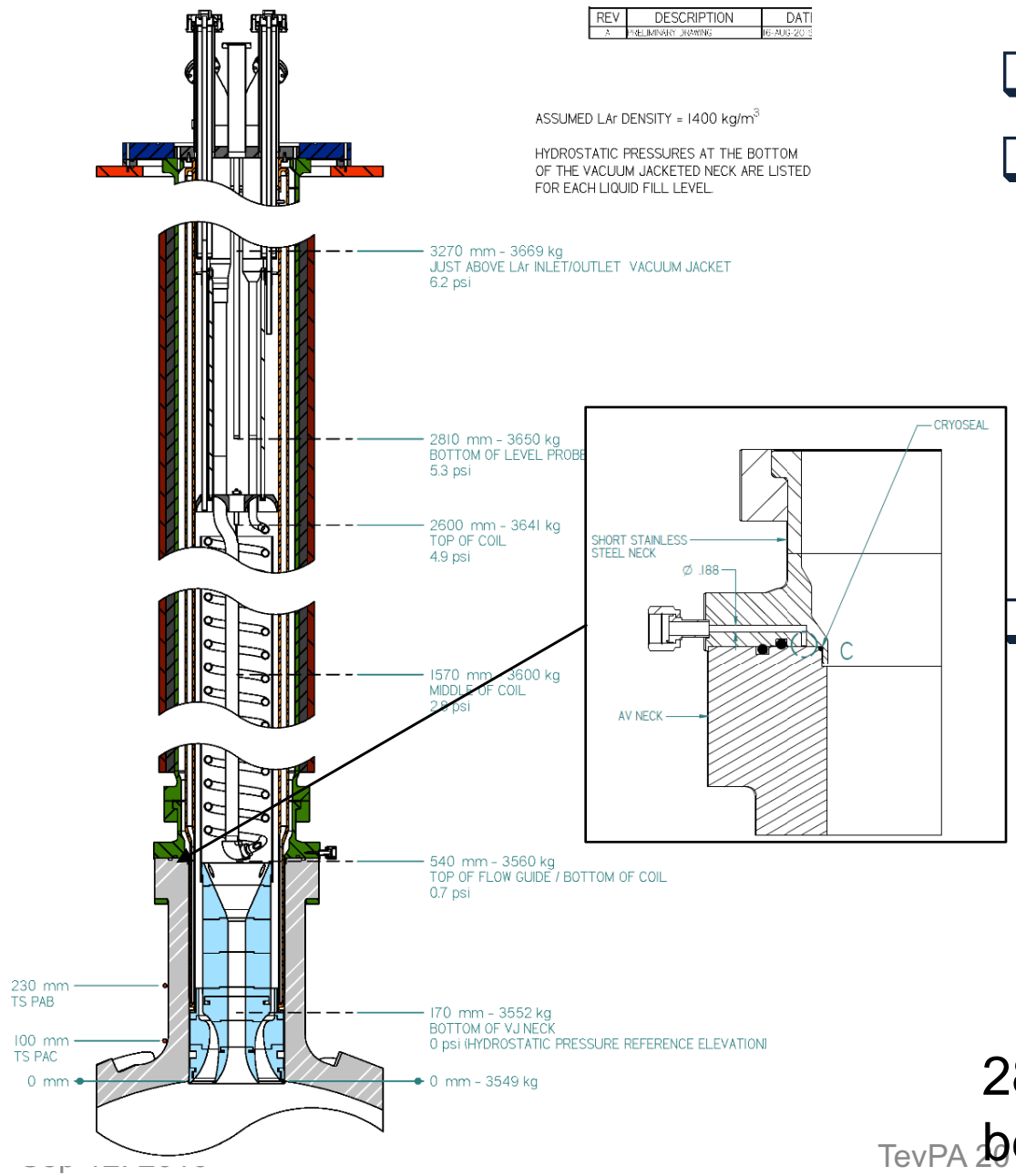
Fiducial mass ~ 1 out of 3.6 tons

Projected physics reach

Background	Target count for a 3tonne-year exposure	Mitigation
Neutron In 1t LAr	<0.2	Shielding: 6000 mwe (SNOLAB), Active water shield, light guides and filler blocks Material selection
β & γ In 1t LAr	<0.2	Pulse shape discrimination Material selection (for γ)
Radon In 1t LAr	negligible	Material selection, SAES getter, cold charcoal radon trap ** High energy events, not in ROI*
Surface α In 1t LAr	<0.2	Material selection (acrylic), sanding of AV (1mm removal), fiducialization.

So far, backgrounds appear to be close to target

Aug 17th incident

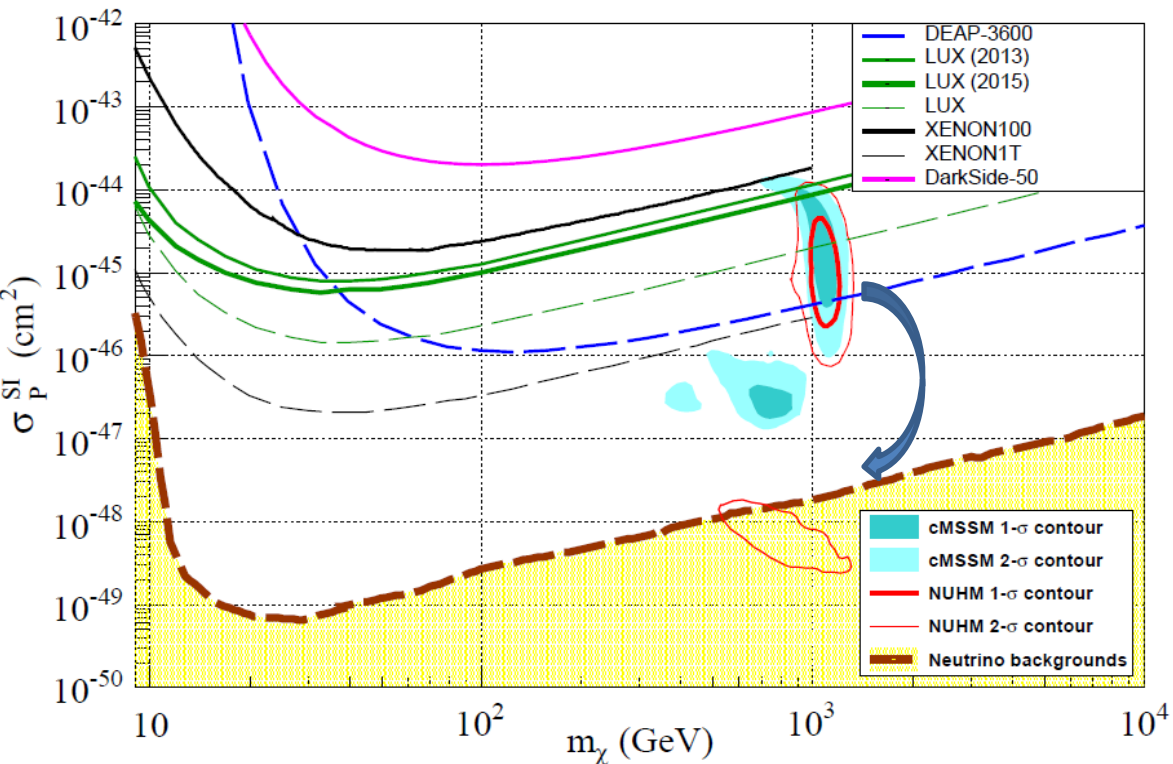


- **Liquid Argon in the neck**
- **Seal failure at the acrylic – steel interface**
  - Seals got too cold
  - Nitrogen leaked into the argon → 100ppm
    - More than the purification system can handle
- **Remedy**
  - Vent Argon
    - Completed by end of Aug.
  - Refill with fresh argon up to the edge of the neck in Sep-Oct
    - Physics data taking expected to start in Oct. 2016

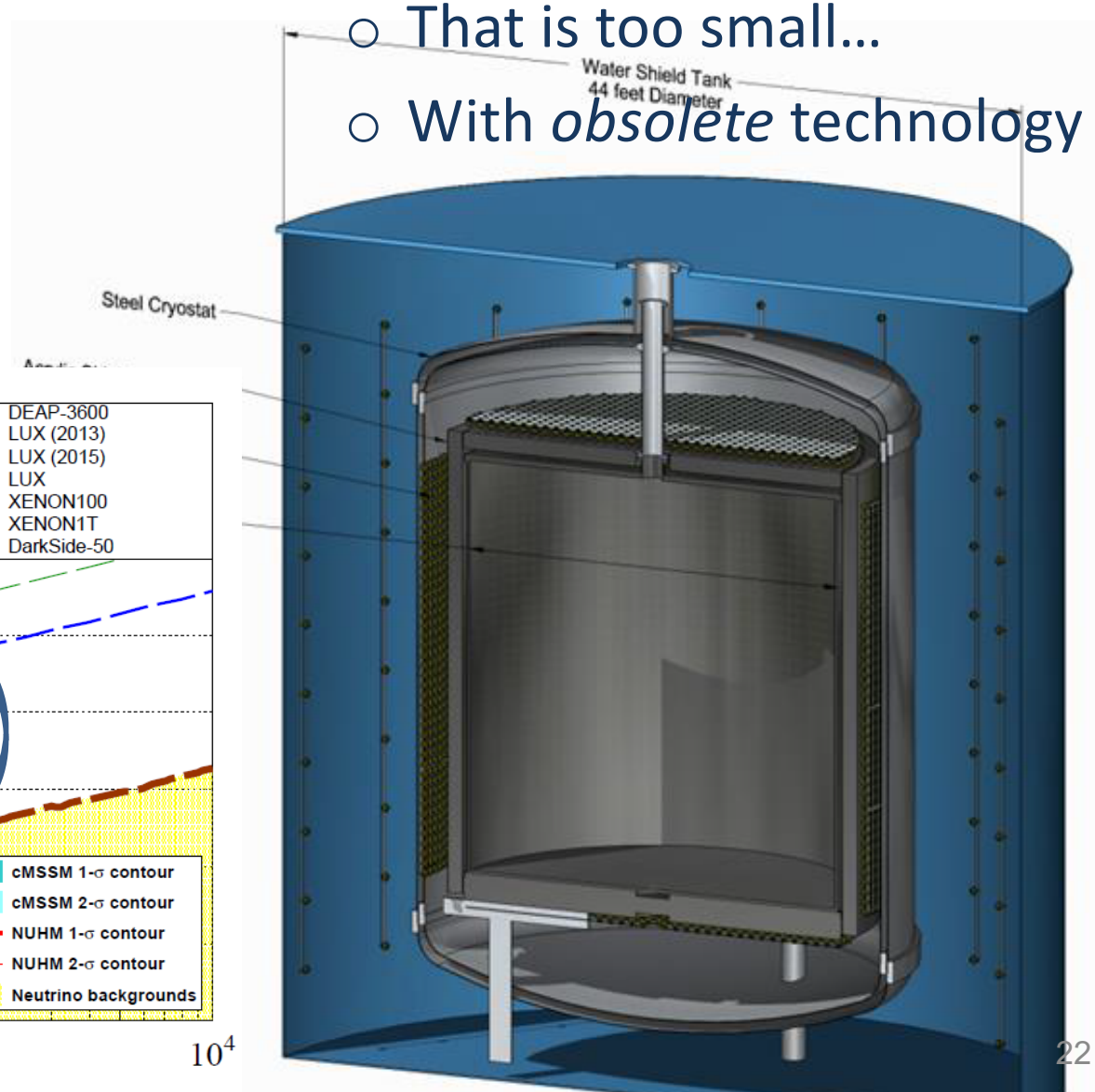
280kg-day exposure before incident before fiducialization and other cuts

Beyond DEAP-3600

- **If DEAP-3600 background manageable**
  - Upgrade to 5 tons?
  - Go all the way to n floor
    - Need at least 200 tons



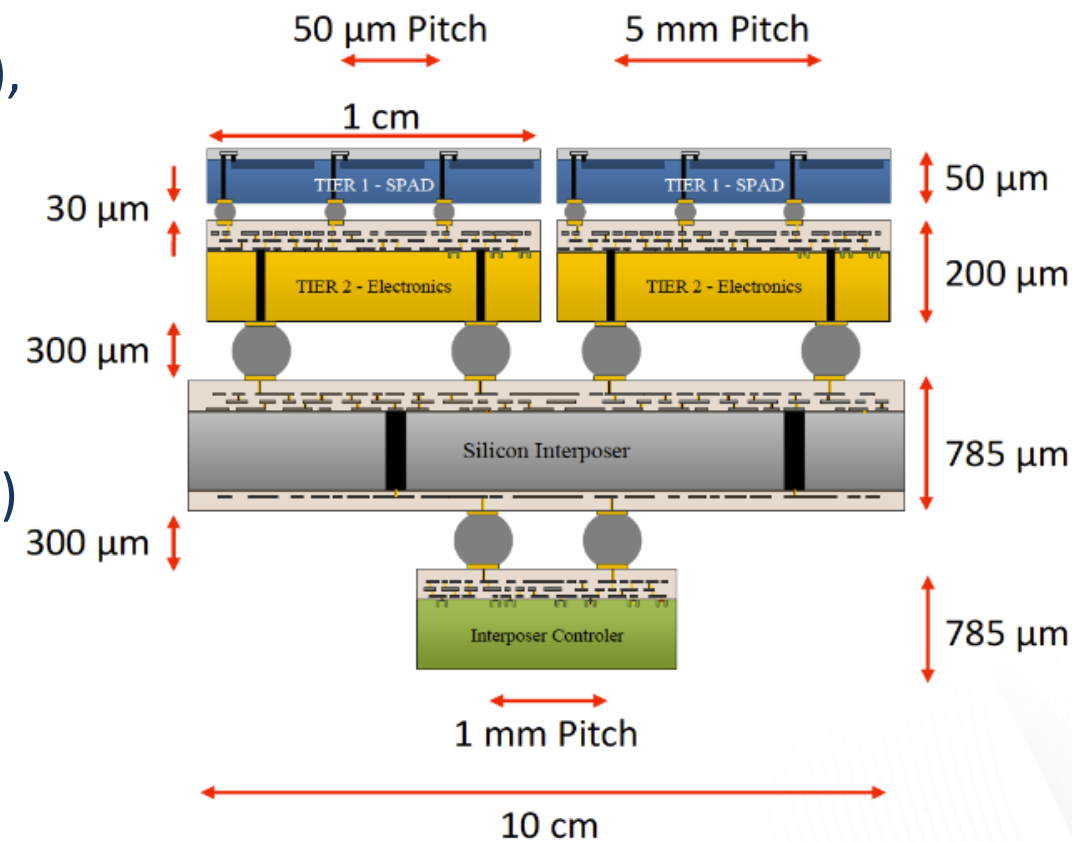
- **A 50tons concept**
  - That is too small…
  - With *obsolete* technology



Tackling the photo-detection challenge

- ~150m^2 of photo-detector required for a 200 tons single phase detector
  - DEAP-3600 ~8 m^2 (with PMT), nEXO ~ 4m^2 with SiPMs
- SiPMs compelling because
  - Low radioactivity
  - Highly tilable
  - Perform better cold
  - High efficiency (>50% in blue) and currently 10% at 125nm
  - high timing resolution
  - However many issues
    - Scaling to very large area
    - Cost?

- A compelling solution: 3DdSiPMs



U.Sherbrooke (QC, Canada) & Teledyne-DALSA

Summary

- **DEAP-3600 construction phase is over**
- **Data taking with liquid argon has started**
  - Current exposure competitive with other LAr experiment
    - First look at data look promising. Backgrounds and light yield more or less as expected
  - Set-back of a few months due to neck incident
  - Physics data taking starting in October
- **(already) thinking about the future**
  - To reach the neutrino floor
  - Need new technologies

Thank you

University of Alberta

Carleton University

Laurentian University / Université Laurentienne

Queen's University

Particle Physics, Rutherford Appleton Laboratory

SNOLAB — Mining for knowledge / Creuser pour trouver... l'excellence

University of Sussex

Royal Holloway University of London

TRIUMF

Institute de Física

Canadian Nuclear Laboratories

JUST JOINED !