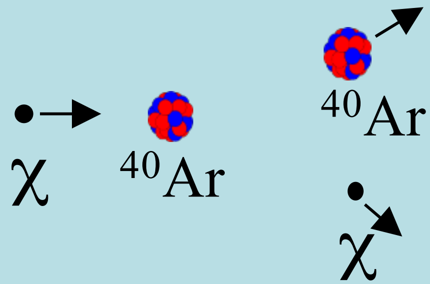
Searching for Dark Matter with DEAP

Dr Kevin Graham
Carleton University

DBD16 November 10, 2016
Osaka, Japan

DEAP-3600 Dark Matter Search

Liquid Argon for DM (Single-phase)



Scattered nucleus detected via Lar scintillation

Good Pulse-shape discrimination between β/γ and nuclear recoils with scintillation

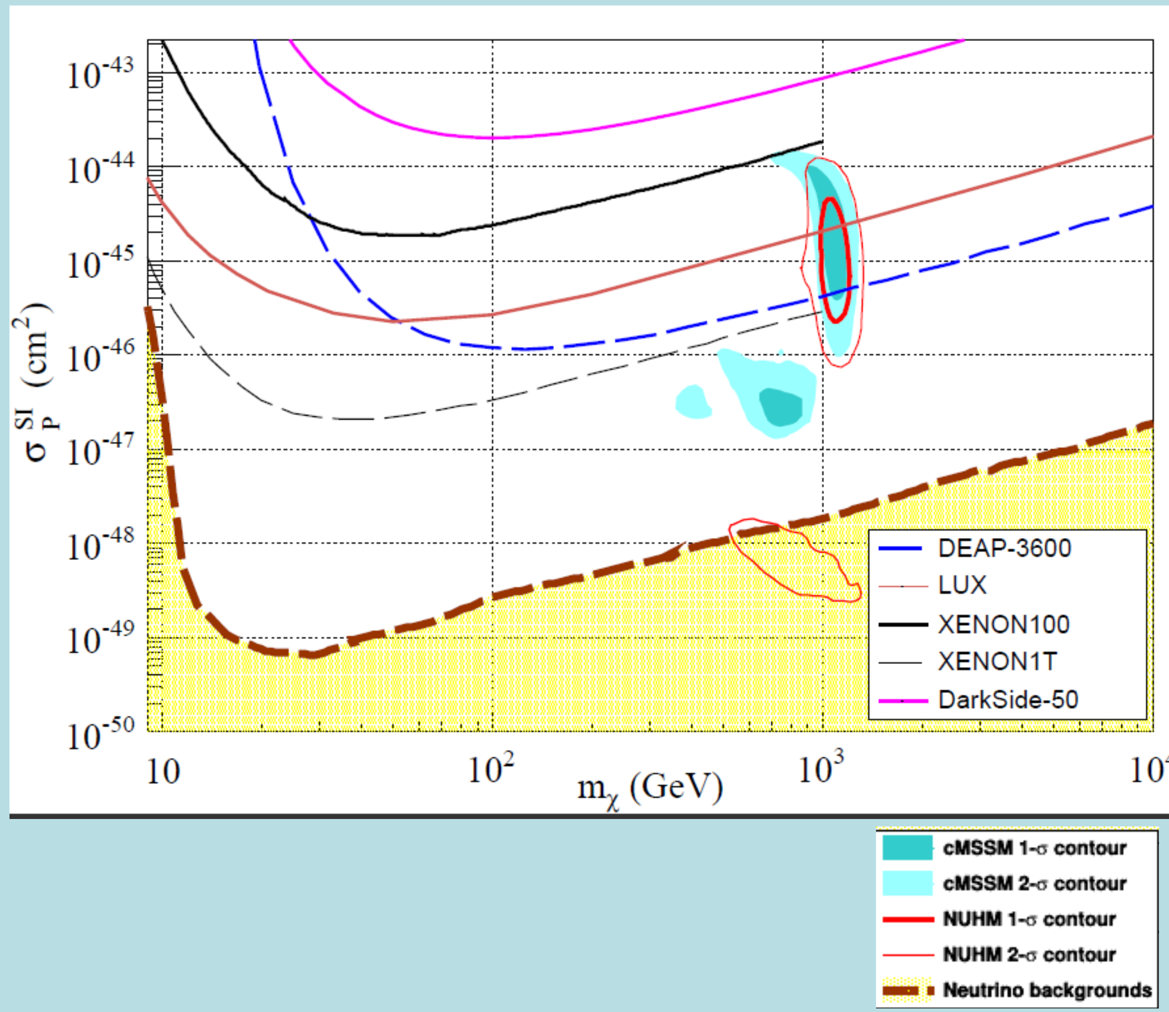
Argon is **easy to purify**

Very large target masses possible, no absorption of UV scintillation photons in argon, no pileup until beyond tonne-scale

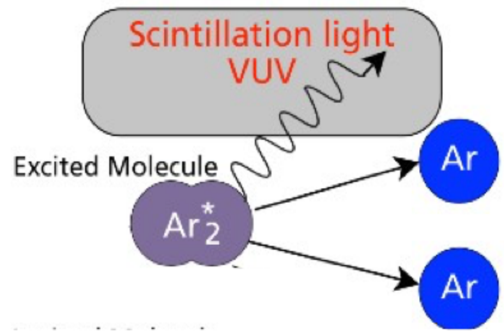
Position reconstruction allows surface background removal, based on photon detection (~5 cm resolution allows removal of radon daughter events from analysis)

DM Sensitivity

1 tonne fiducial mass (3.6 tonnes total) designed for < 0.2 background events/year with 60 keVr threshold

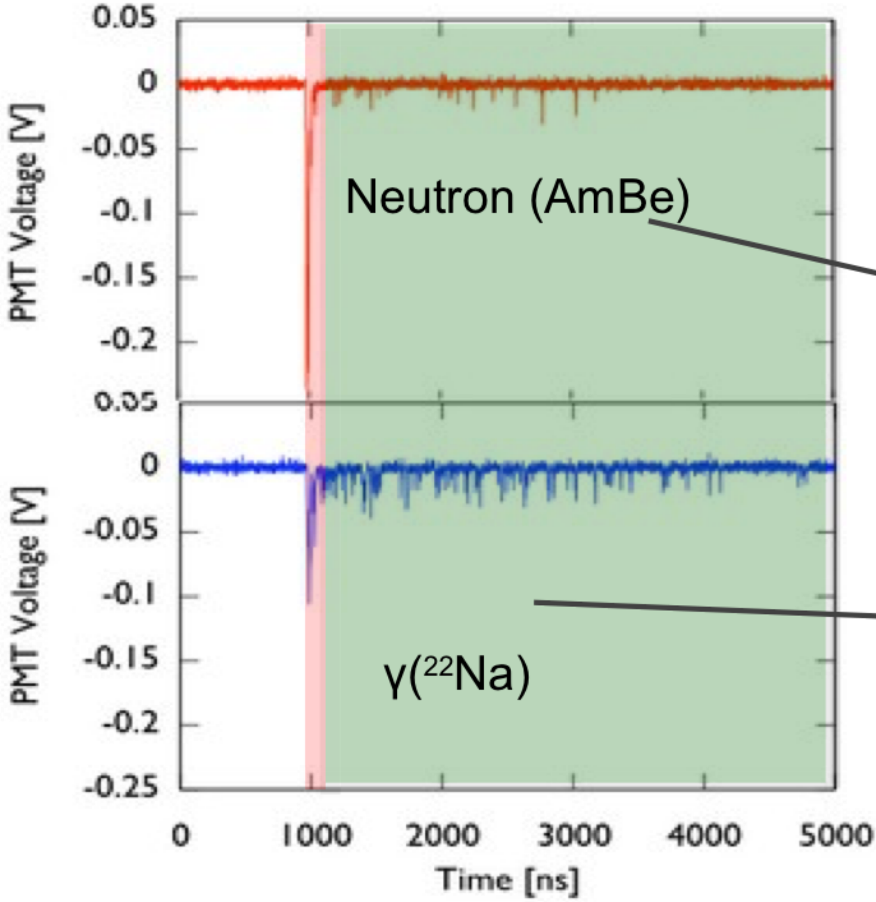


Pulse shape discrimination (PSD)

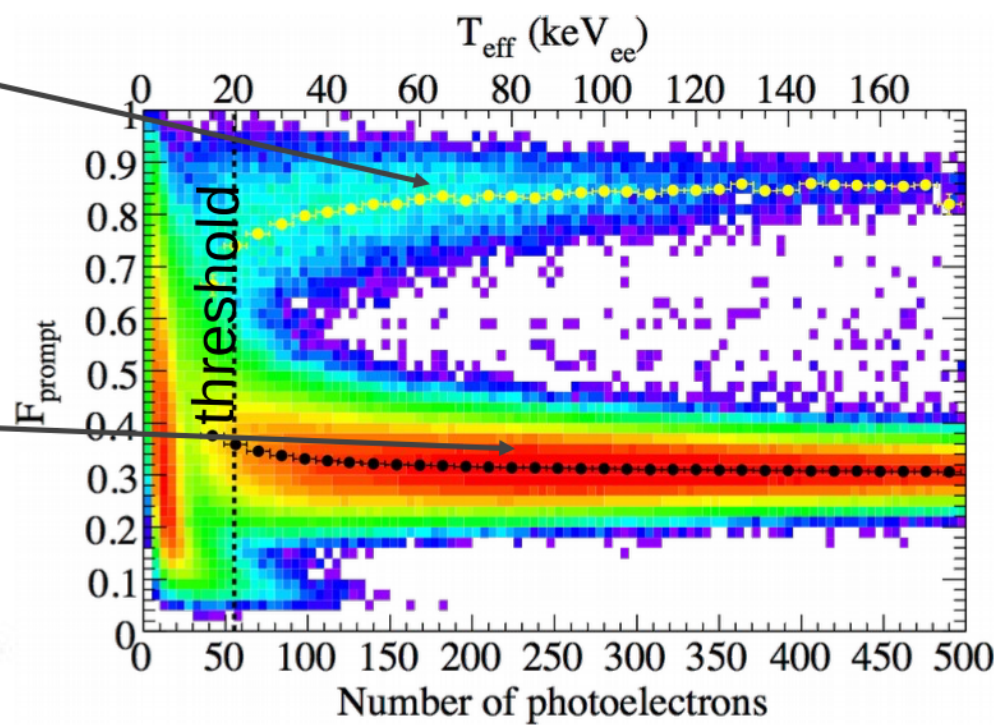


Ar singlet and triplet excited states have well separated lifetimes (7ns vs. ~1.5us)

PMT signal:



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



Prompt : 0-150ns
Late: 150ns-10μs

Single phase LAr:
scintillation channel is sufficient, no ionization channel

Background mitigation

- **β/γ events:** dominated by ^{39}Ar beta decay rate, 1 Bq/kg
  - pulse shape discrimination is **very powerful in liquid argon**

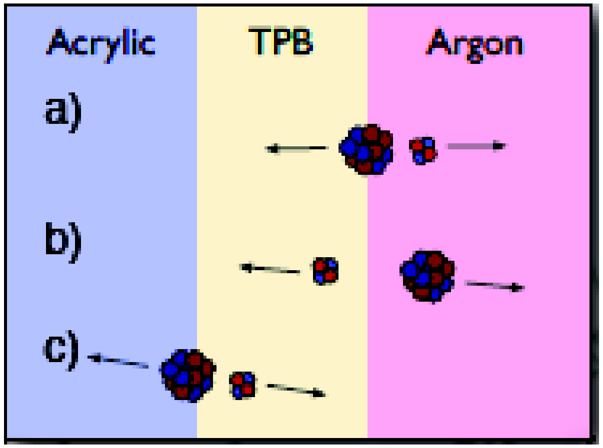
~10^{-10}

- **surface events:** Rn daughters and other surface contamination
  - procured ultrapure materials (screening, quality assurance, co-operation with suppliers)
  - surfaces sanded in-situ
  - limited exposure to radon
  - position reconstruction & fiducialization
  - other analysis techniques

<u>rejection factor:</u>

~10^{-3}

~10



- **neutron recoils:** (α,n)+fission, cosmogenic μ-induced

  NO neutrons!
  - SNOLAB depth + water Cerenkov muon veto
  - clean detector materials (material assay, quality assurance)
  - shielding

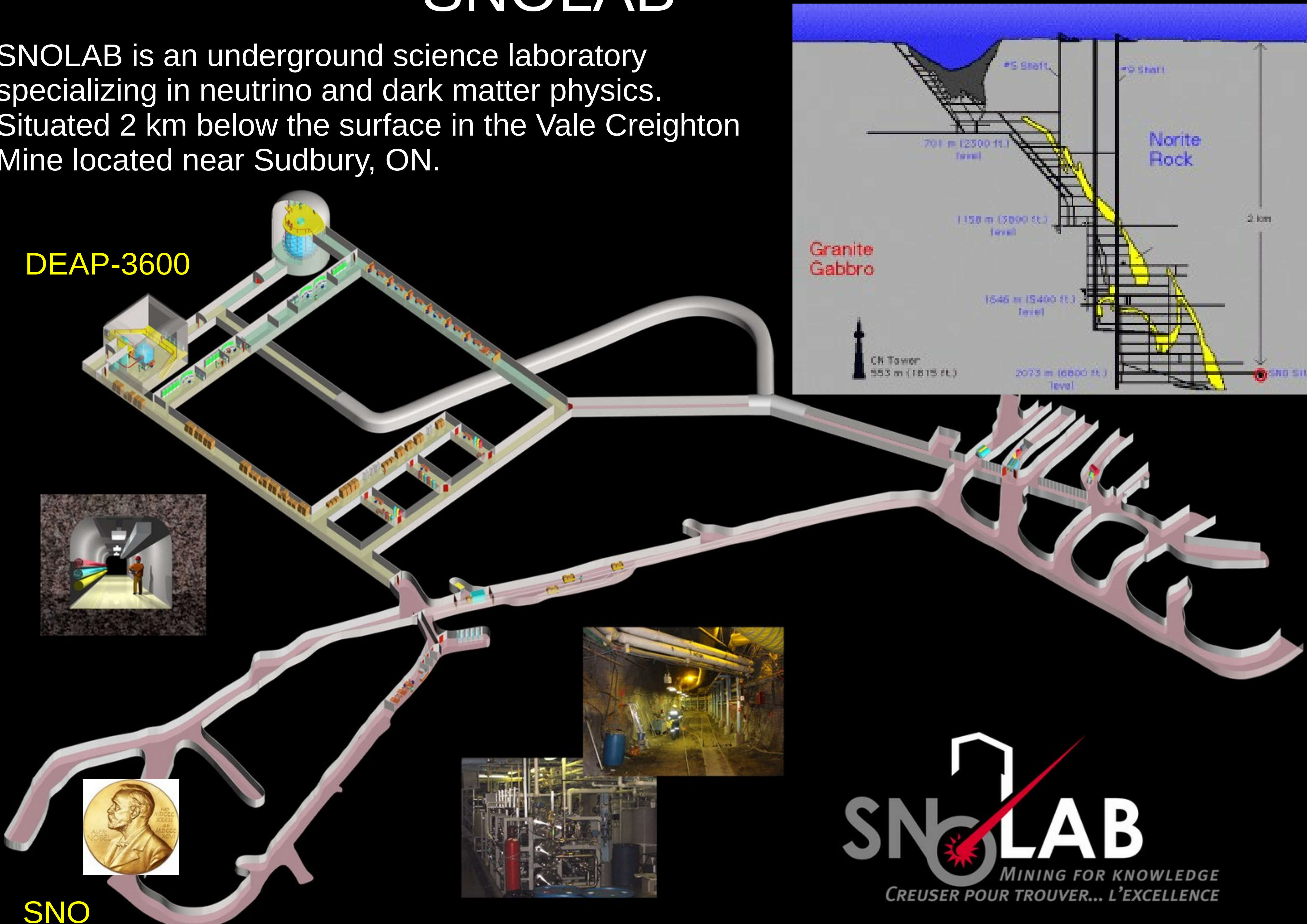
Projections for DEAP-3600 Backgrounds

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

SNOLAB

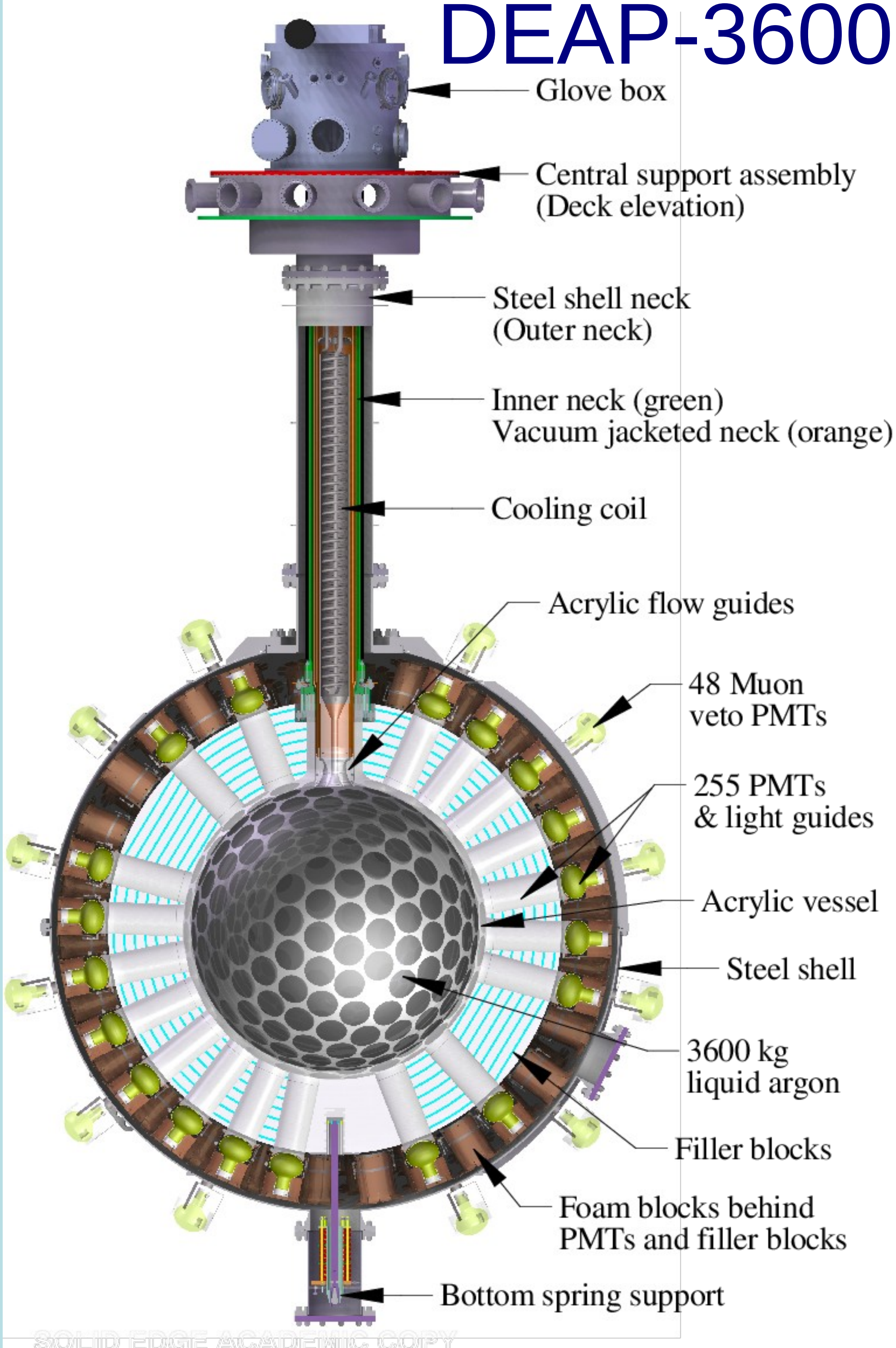
SNOLAB is an underground science laboratory specializing in neutrino and dark matter physics. Situated 2 km below the surface in the Vale Creighton Mine located near Sudbury, ON.



MINING FOR KNOWLEDGE

CREUSER POUR TROUVER... L'EXCELLENCE

DEAP-3600 Dark Matter Search



- **Single phase liquid argon** approach: simple, scalable, inexpensive
- 3600 kg target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel
- In-situ vacuum evaporated TPB wavelength shifter (~10 m^2)
- Bonded 50 cm long light guides + PE shielding provide neutron moderation
- 255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)
- Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction
- Detector immersed in 8 m water shield, instrumented with PMTs to veto muons
- Located 2 km underground at SNOLAB

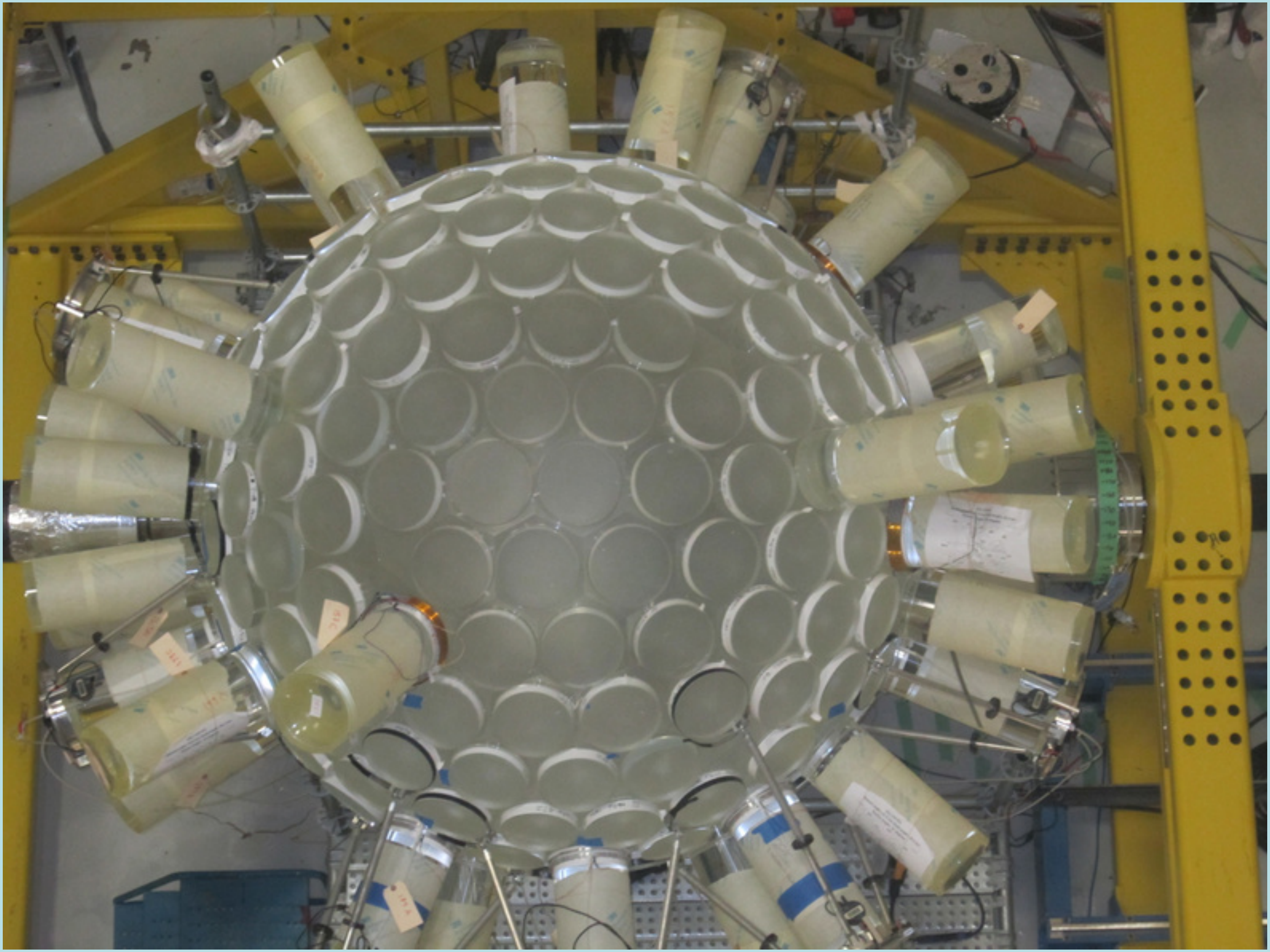
Fabrication and Assay of DEAP Acrylic

- Fabrication from pure MMA monomer at RPTAsia (Thailand), strict control of radon exposure for all steps, to < 10^{-20} g/g ^{210}Pb (RPT was fabricator of the SNO Acrylic Vessel)
- Assay of production acrylic < 2.2×10^{-19} g/g ^{210}Pb
  (Corina Nantais M.Sc. Thesis 2014, <0.2 bkg events/3 years)

Monomer cast at RPT Asia, 2010

Thermoformed Panel at RPT Colorado

Bonding light guides to the DEAP AV, underground at SNOLAB



DEAP-3600 Detector Assembly

Specular reflector + opaque wrap

Acrylic Light Guide

PE neutron shielding “blocks”

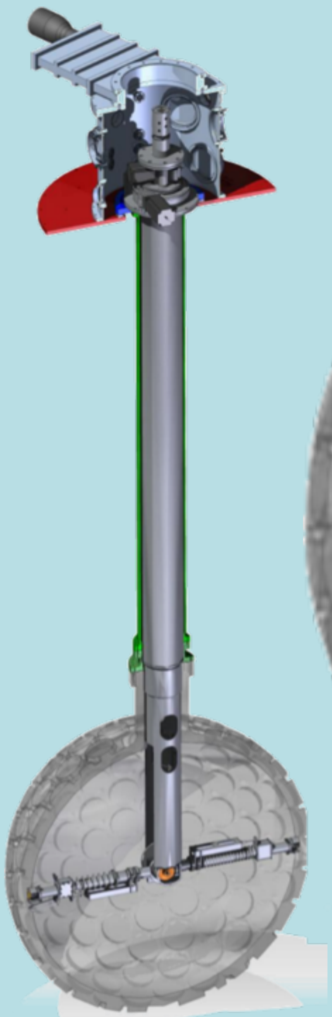
PMT with silicone oil coupling

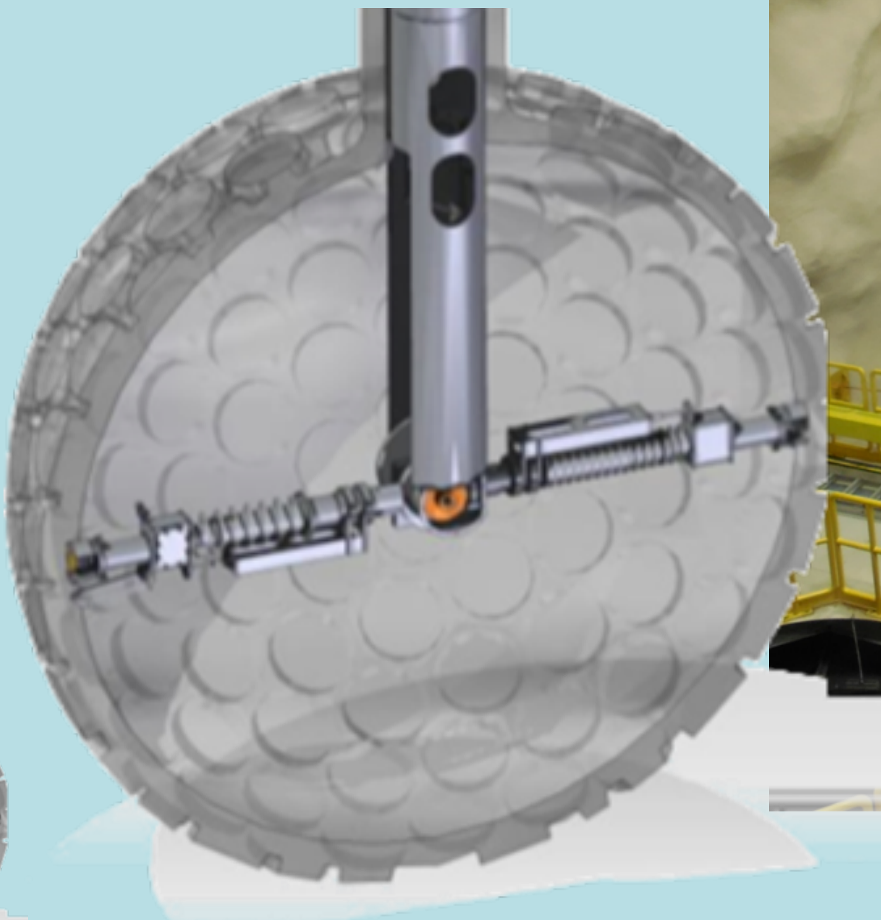
Copper sleeve over PMT

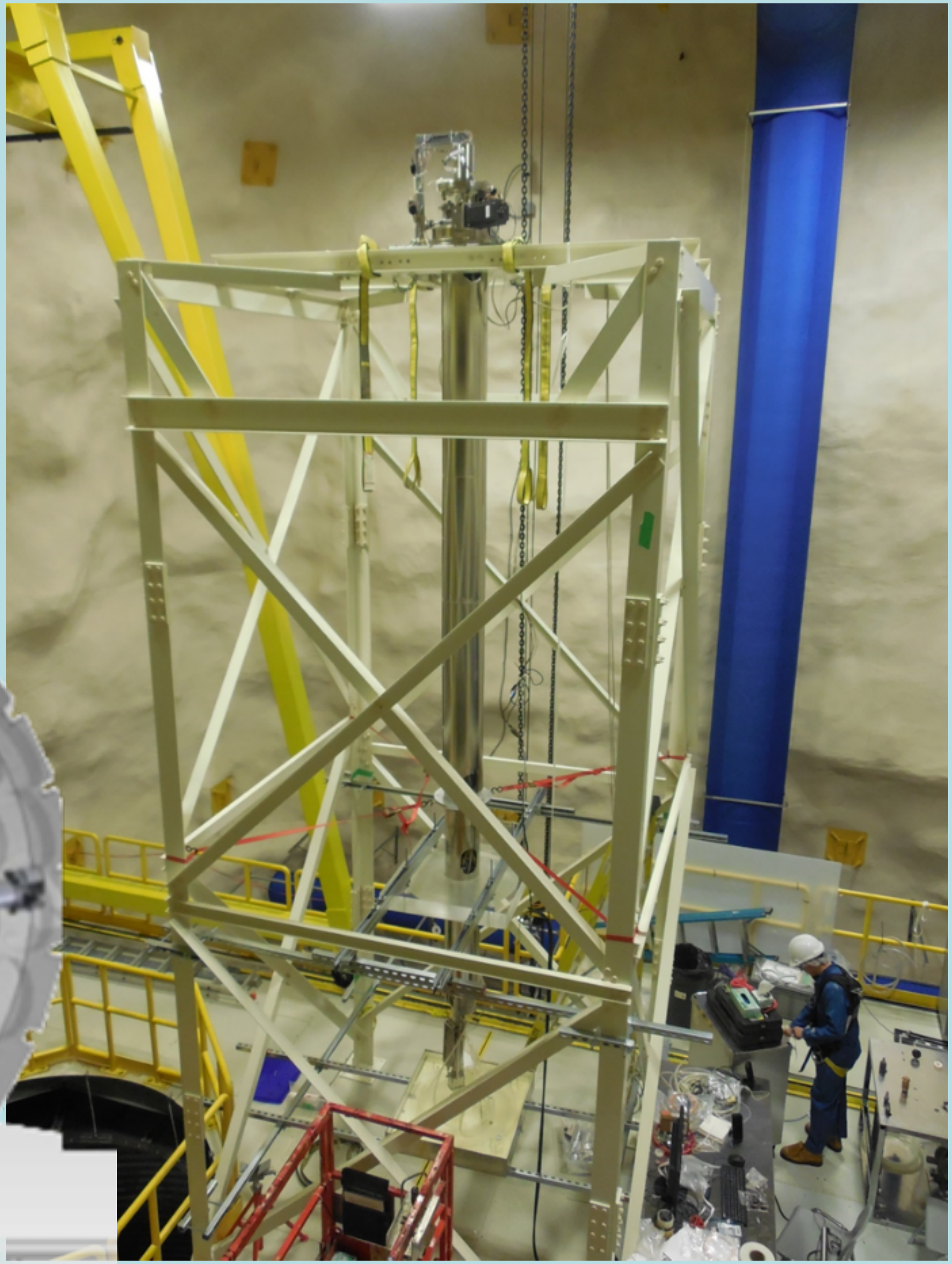
2,500 person-weeks of assembly (students, faculty, PDFs, technicians, engineers)

Acrylic Vessel Resurfacer

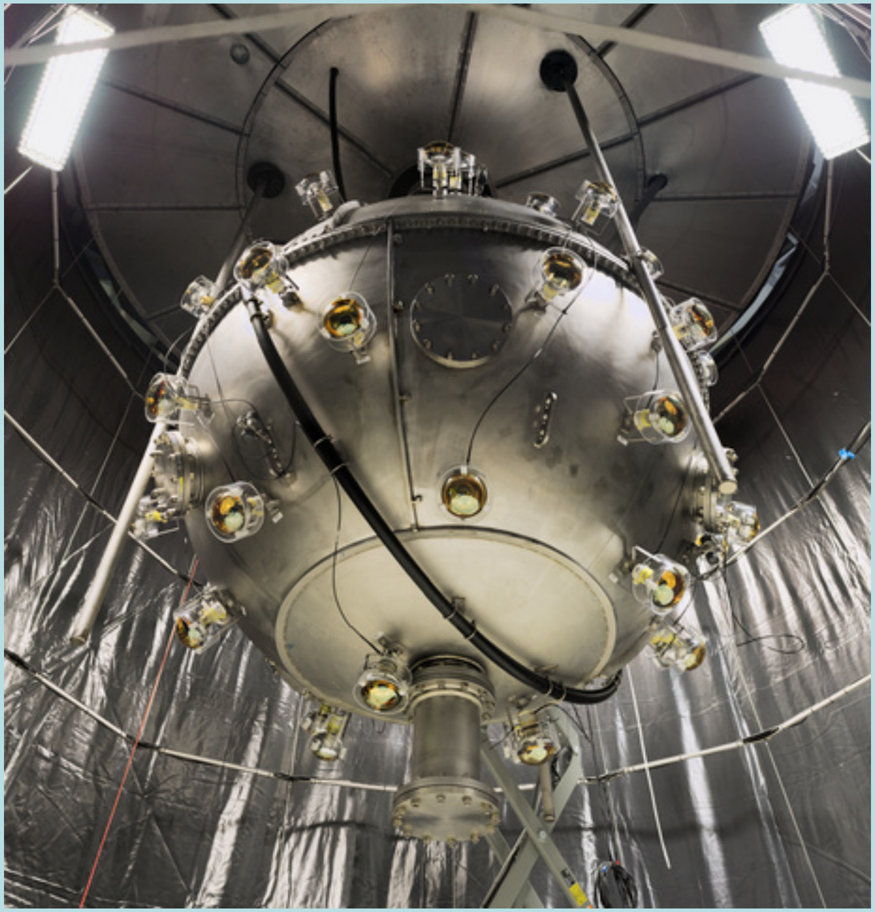
- Mechanical sander to clean inner surface
- Components selected for low radon emanation
- Remove 0.5-mm surface *in situ* with N_2 purge
- Cleans surface to bulk-level impurities
  (order 100,000 cleaner than SNO vessel)





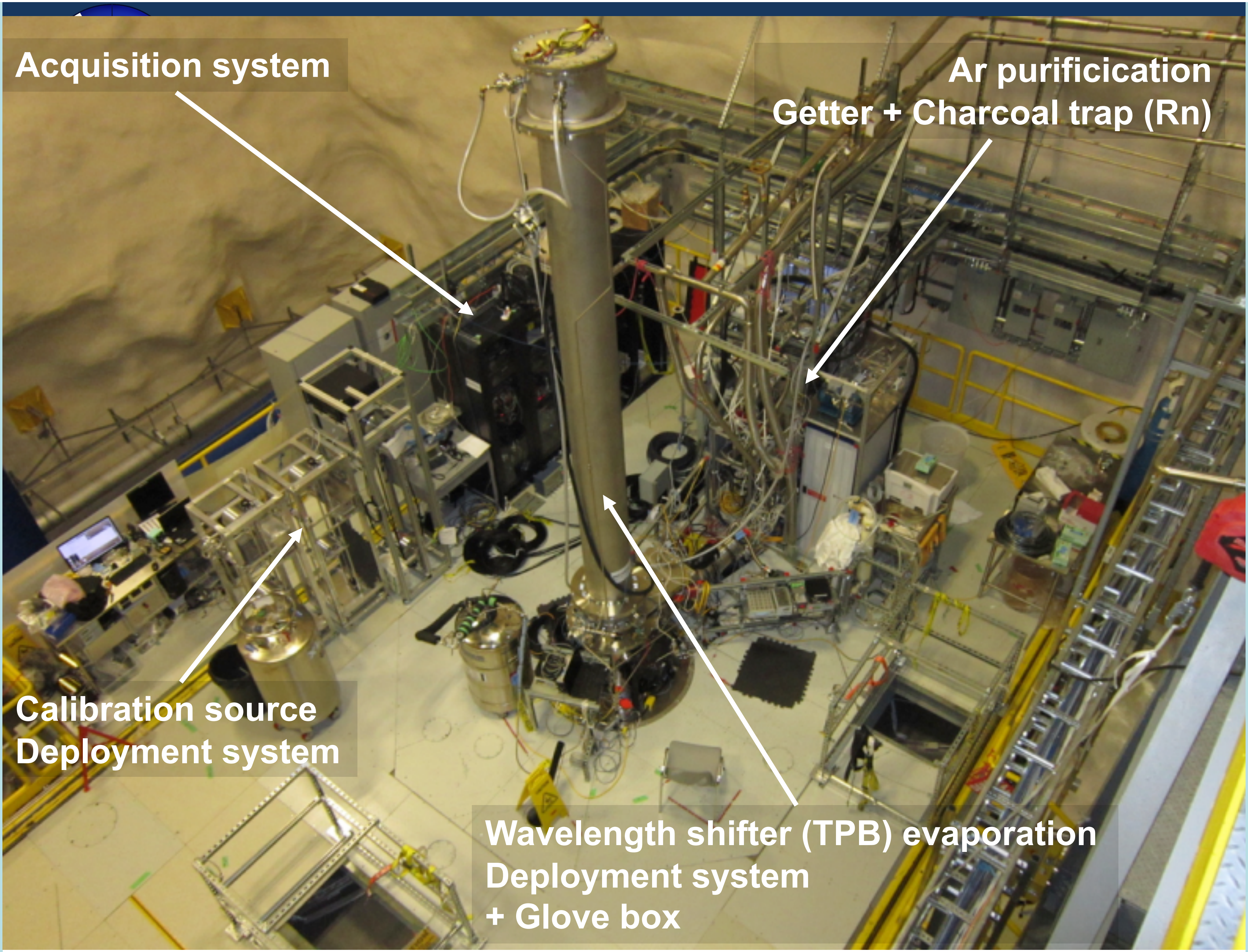


Completed Detector and Shield Tank

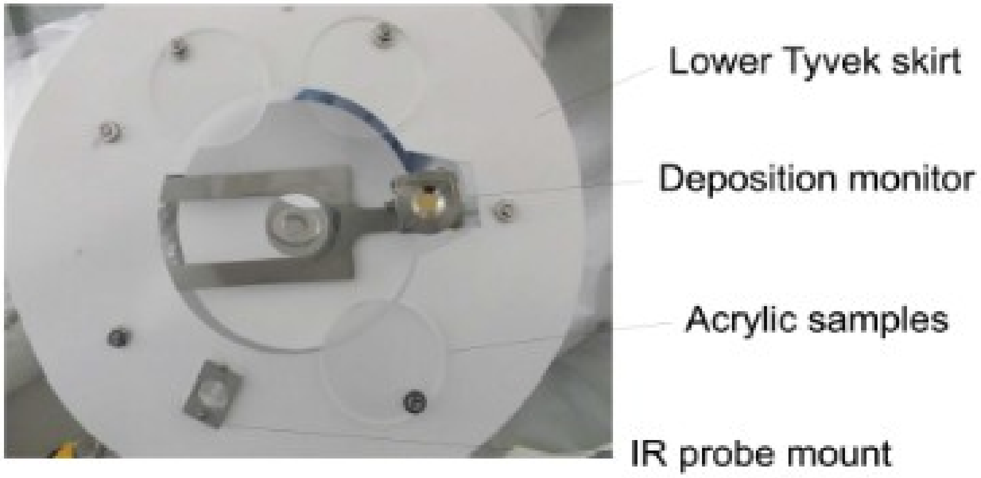


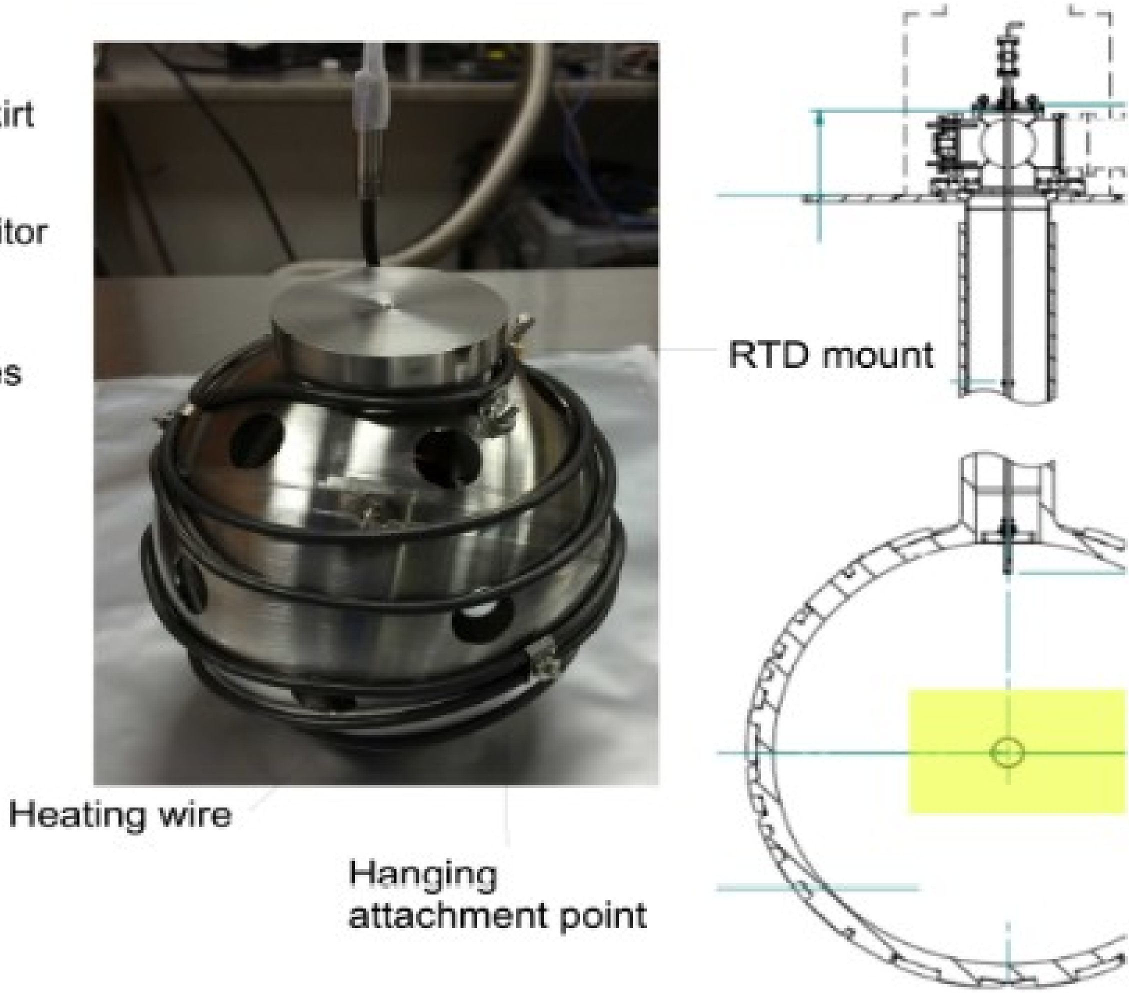
Completed Detector: Steel Shell, calibration tubes, muon veto in Shield Tank (fall 2015)

Shield Tank and emergency vent lines, tank was filled with water Oct 2015


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

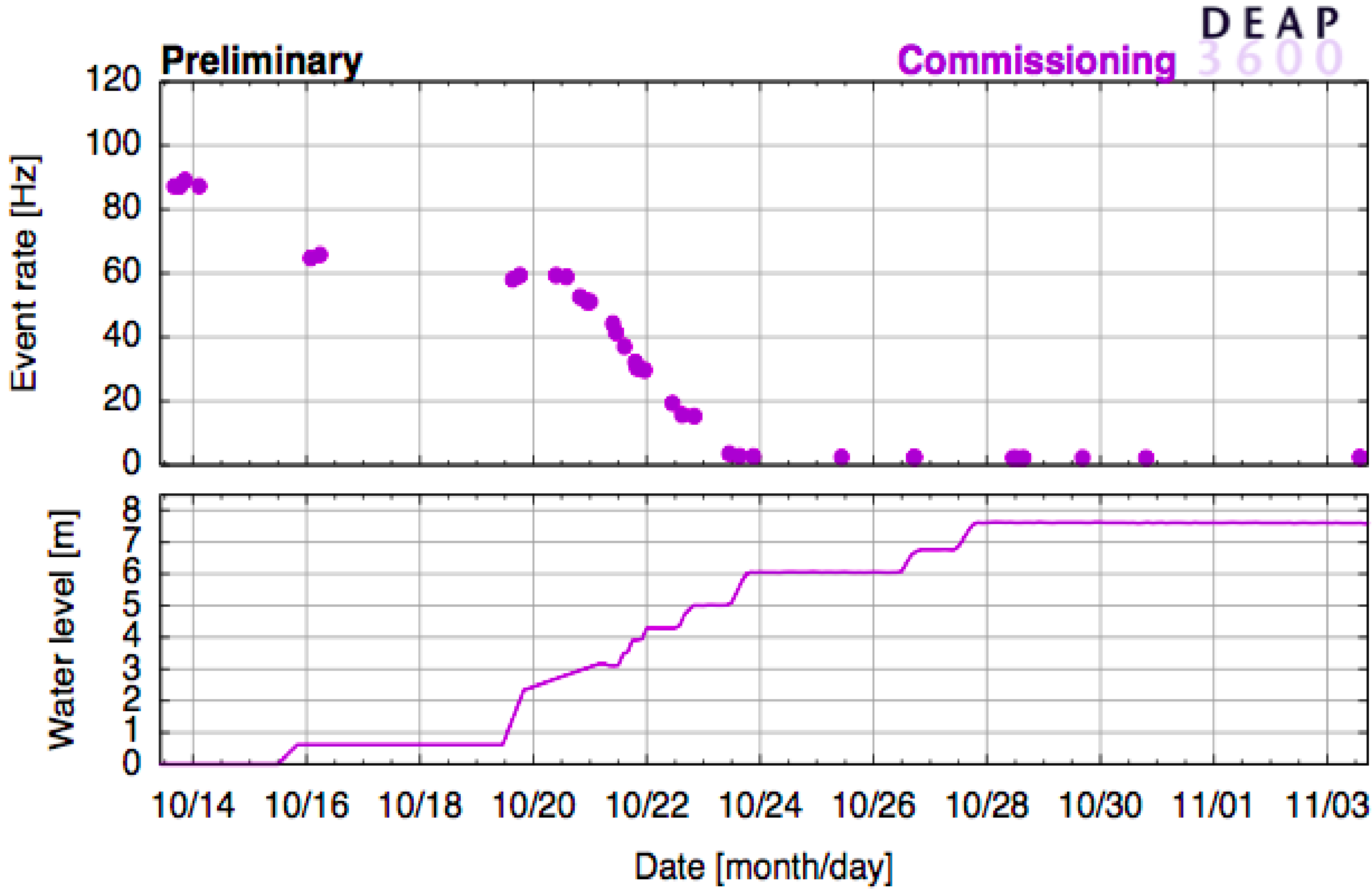
TPB source/laserball deployment system





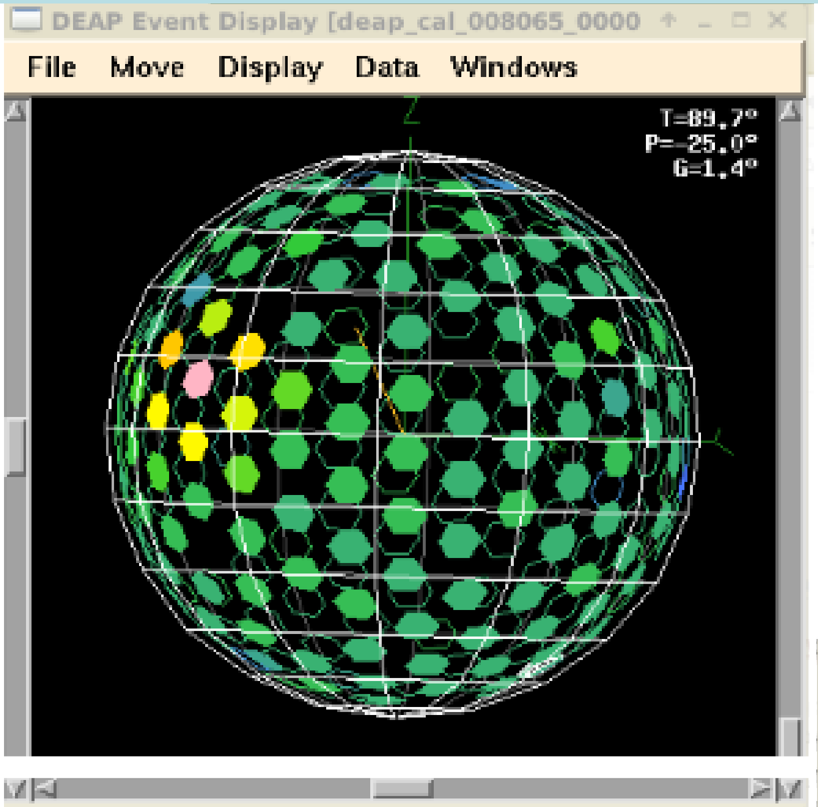
B. Broerman et al., JINST 11 (2016) C02058,
detailed technical paper in preparation

Water shield tank fill



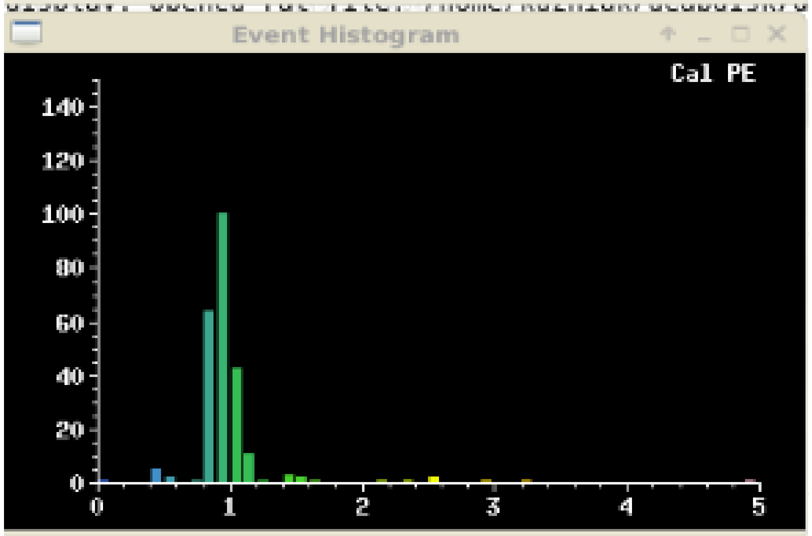
Filled October 2015

Event Display



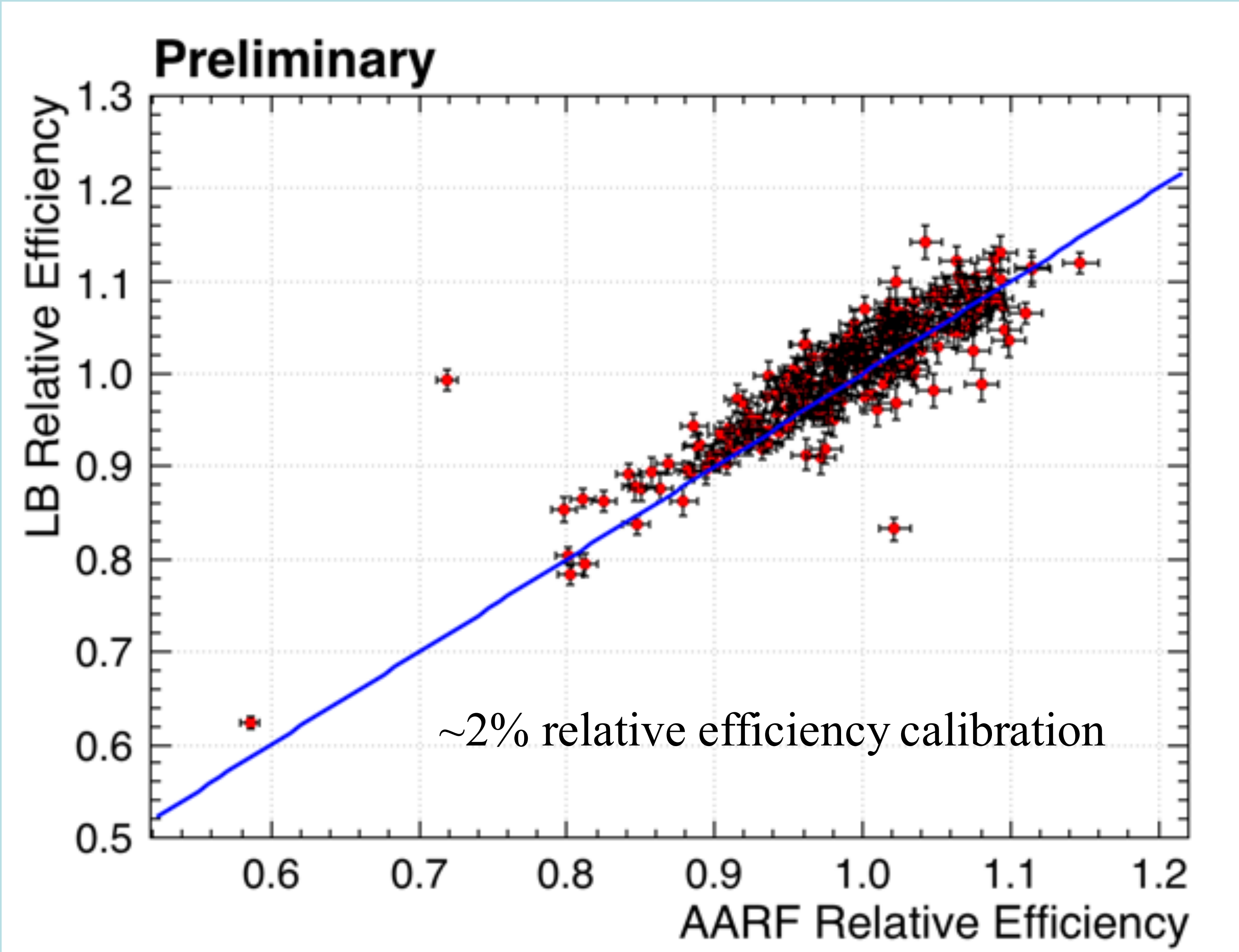
Electronics and trigger system operational for over a year (CAEN v1720s):

- Commissioning, electronics calibration
- Optical calibration with internal optical fibres and deployed diffusing Laserball source



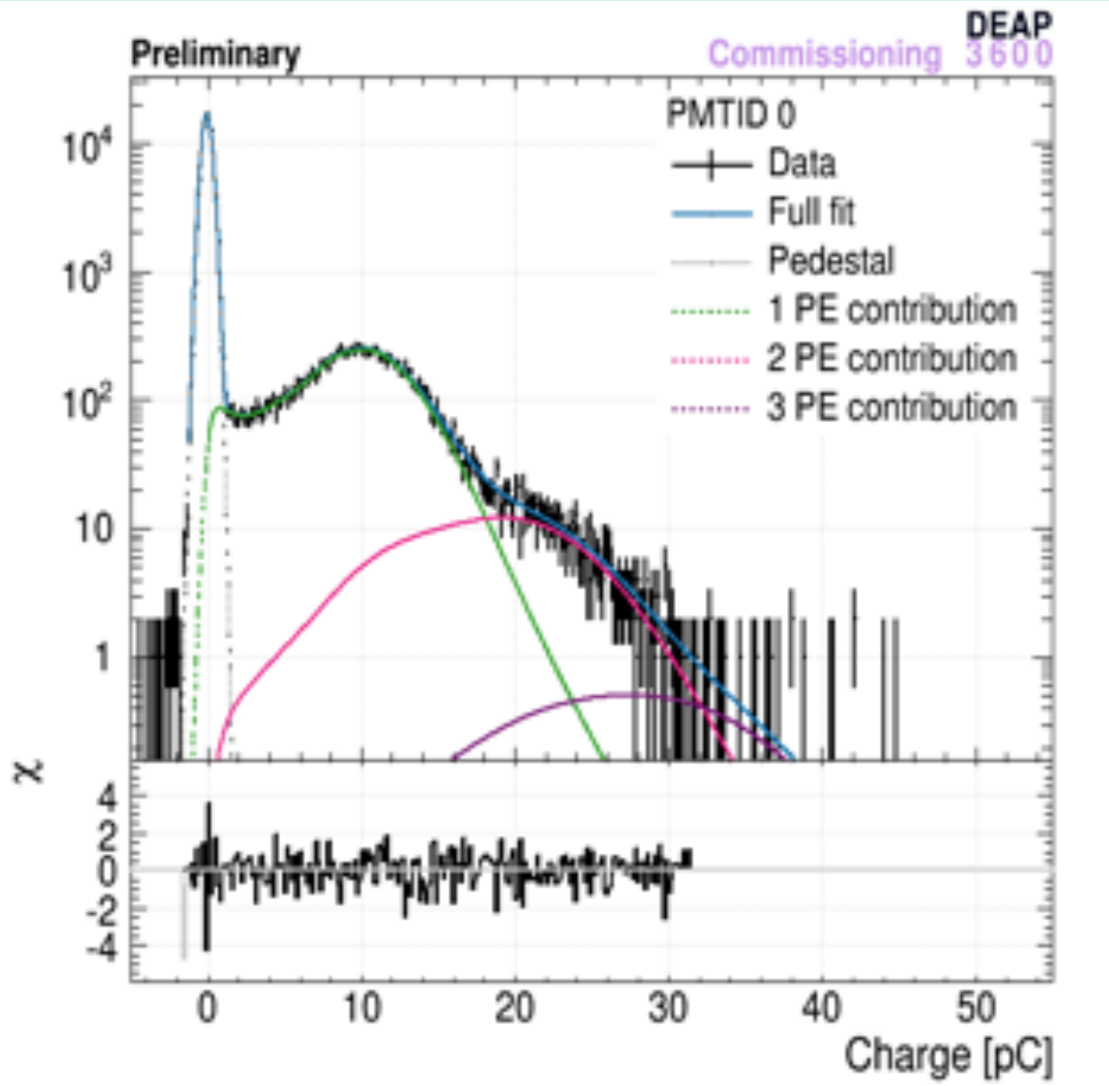
In-situ calibration of relative PMT efficiencies

(Diffusing laserball source at center)



Internal fiber system (20 fibers into light guides)

PMT Calibration



Calibrate to convert from PMT charge to number of photoelectrons (PE)

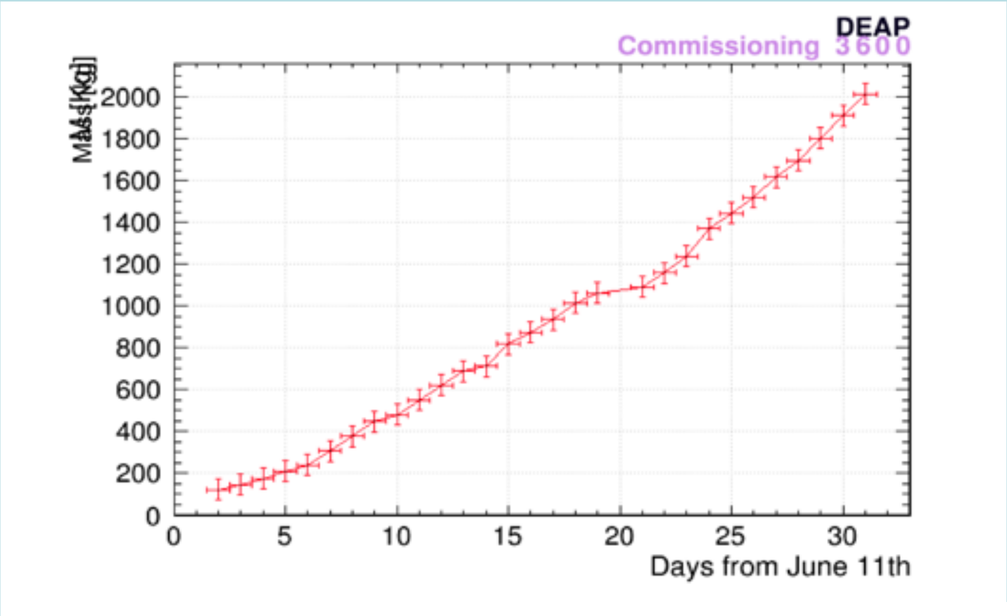
- Analysis operated routinely and automated

Provides:

- mean Single PE charge for simple charge division calibration
- functional form of the SPE distribution used by more advanced SPE counting algorithms
- input for DAQ simulation

Detailed paper in preparation

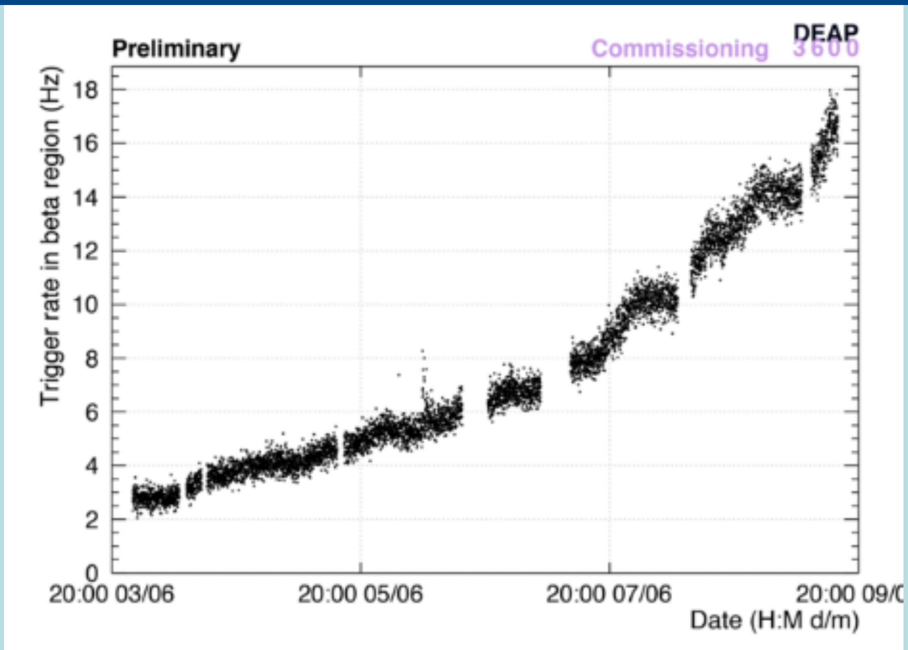
Detector Filling

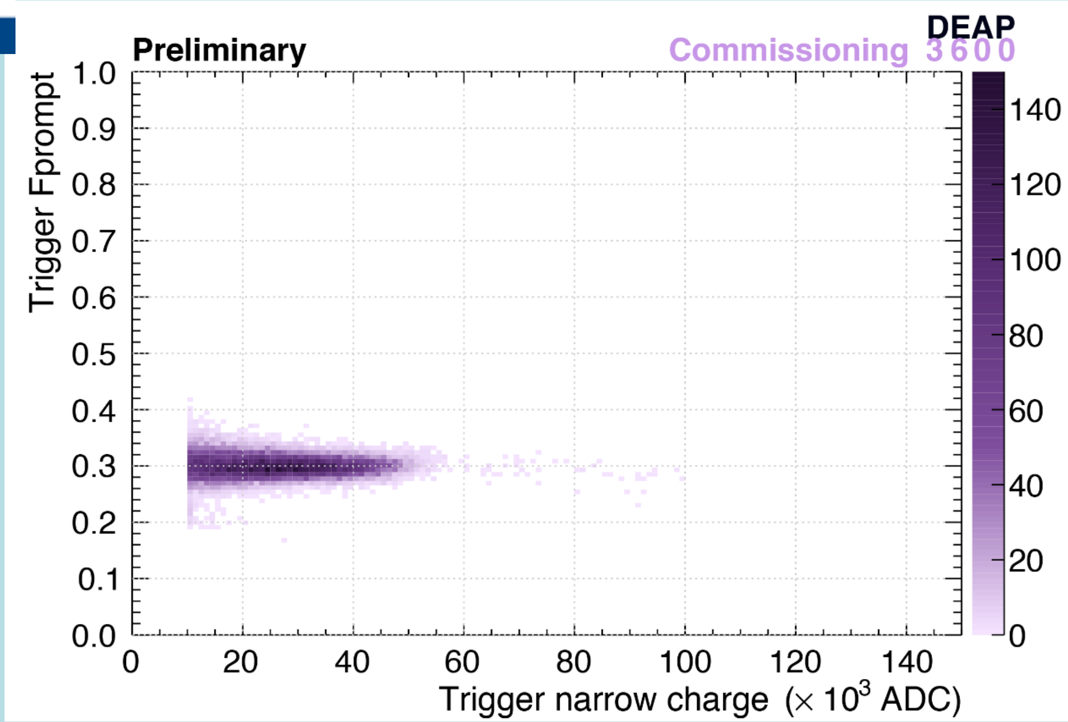


^{39}Ar beta decays at ~1 Bq/kg

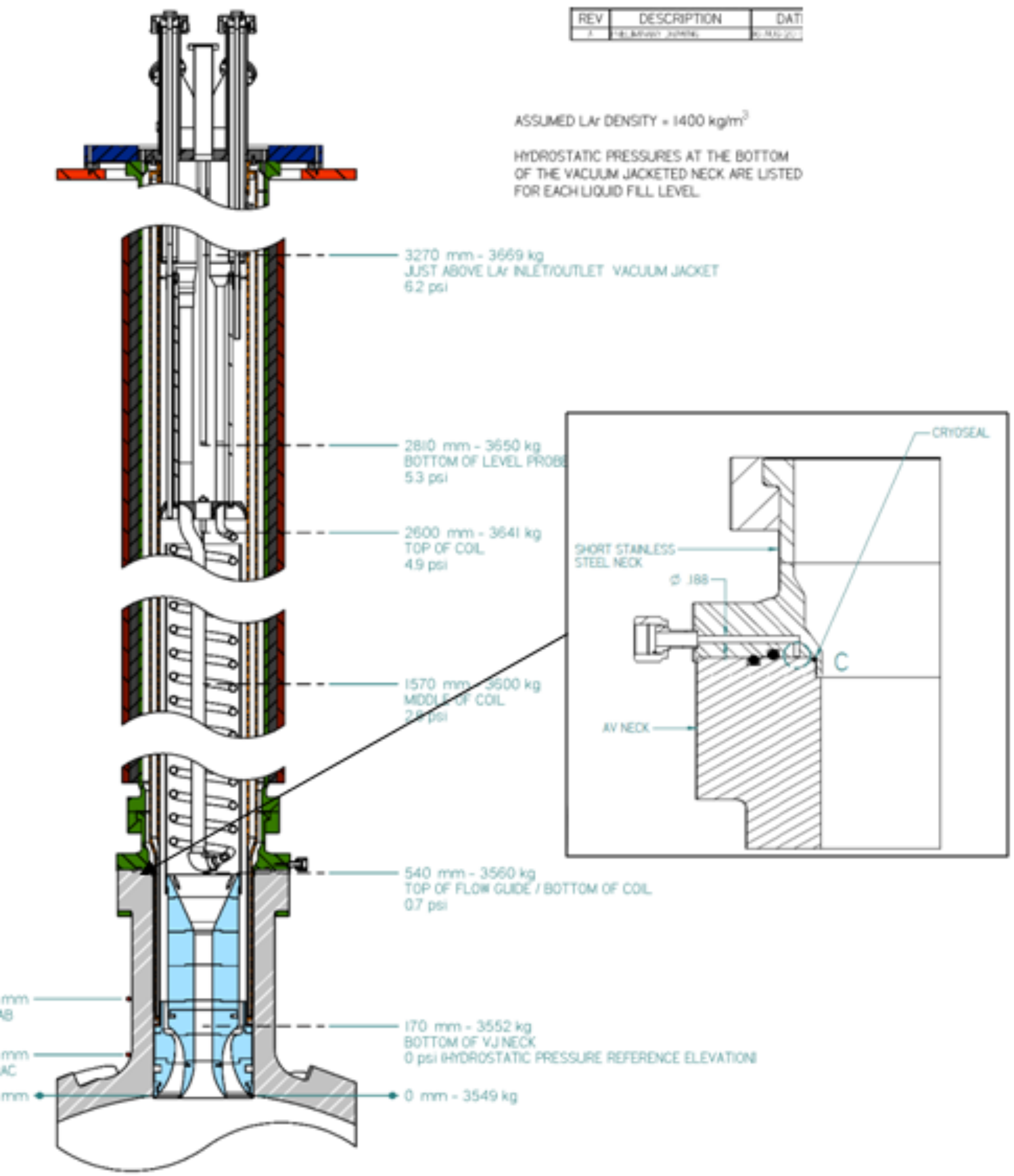
select/reject with PSD

use as tool monitor response, fill level etc





Aug 17th incident

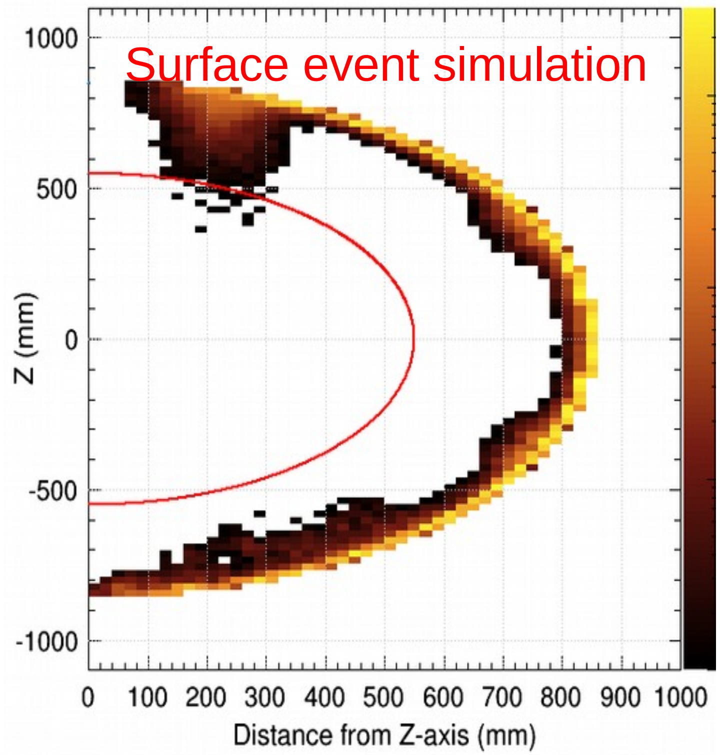


- **During 1st fill liquid Ar reached the neck level**
- **Clean Rn-scrubbed N2 leaked into LAr**
  - **Seal at the acrylic-steel interface got too cold and failed**
  - **100 ppm level contamination**
    - More than the purification system can handle
- **Remedy**
  - **Vent Argon**
    - Completed by end of Aug.
  - **Refill with fresh argon up to the edge of the neck**
    - 2nd fill expected to be completed in Oct. 2016

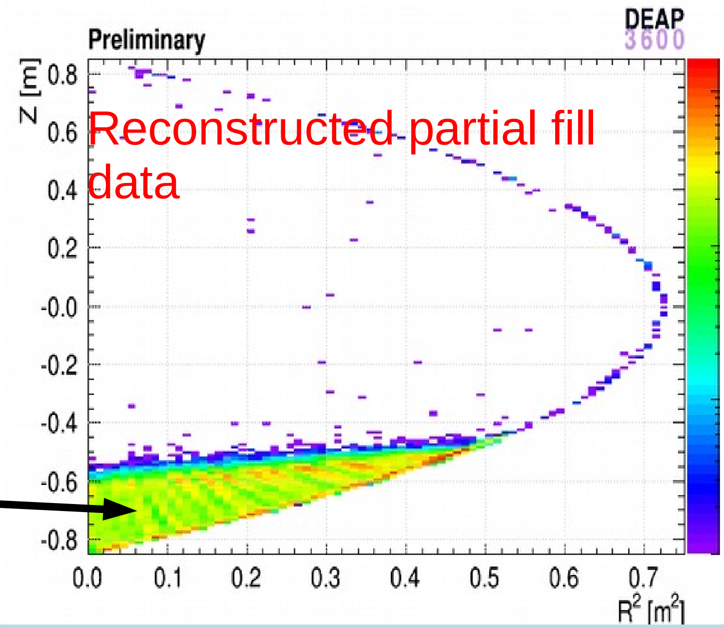
Finalizing analysis of the data collected with partially full detector :
280 kg-yr total exposure (before cuts).

Position reconstruction

- Main measure against surface backgrounds
- Two independent maximum likelihood fitters tuned to Monte Carlo
- Fiducial leakage probabilities of ~1.3e-3 (specification target) or better are achieved with current algorithms
- Spherical fiducial cut with an additional conical cut around the neck are considered



- Now benchmarking the Monte Carlo and the reconstruction algorithms against real detector events!



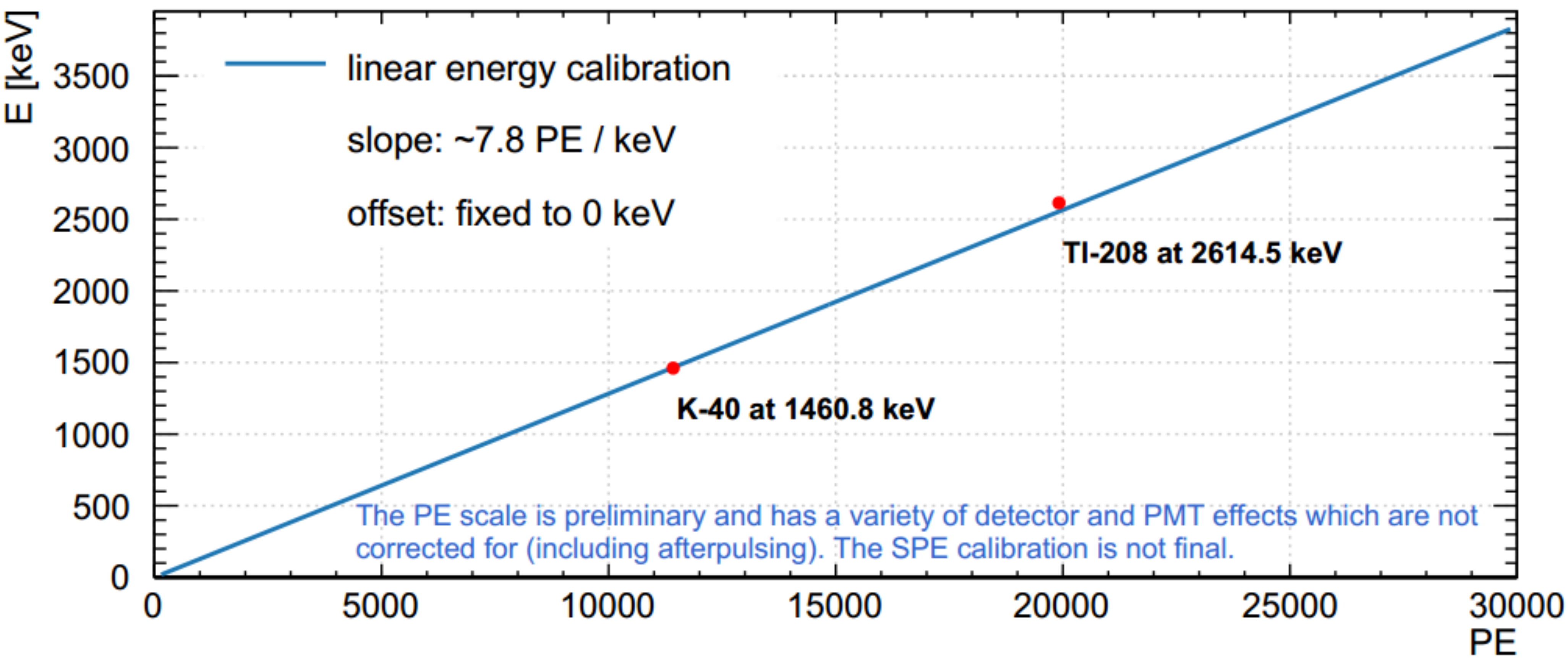
Ar39 betas in liquid argon

Energy response

- First indications of good Light Yield, linearity of the energy scale and energy resolution.

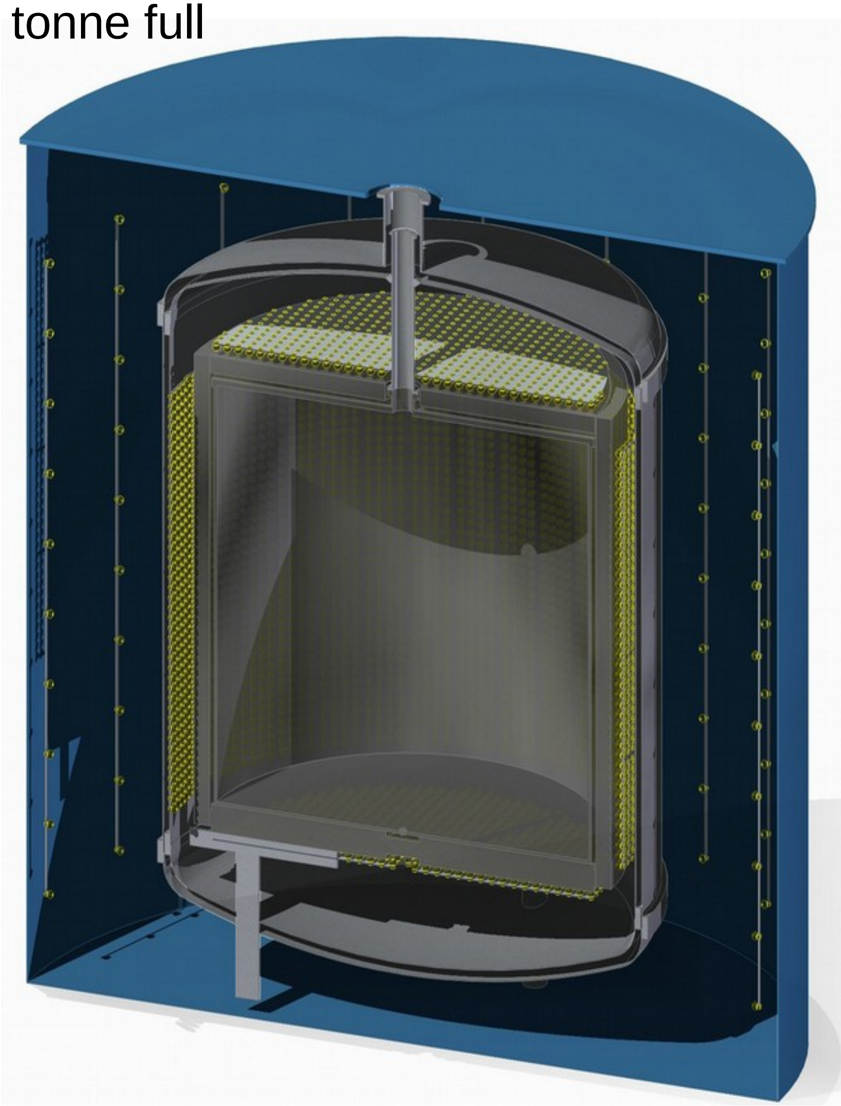
- No sophisticated corrections applied yet. PE calibration is approximate and does not correct for PMT effects (including afterpulsing).

PRELIMINARY - Detector partially filled with LAr

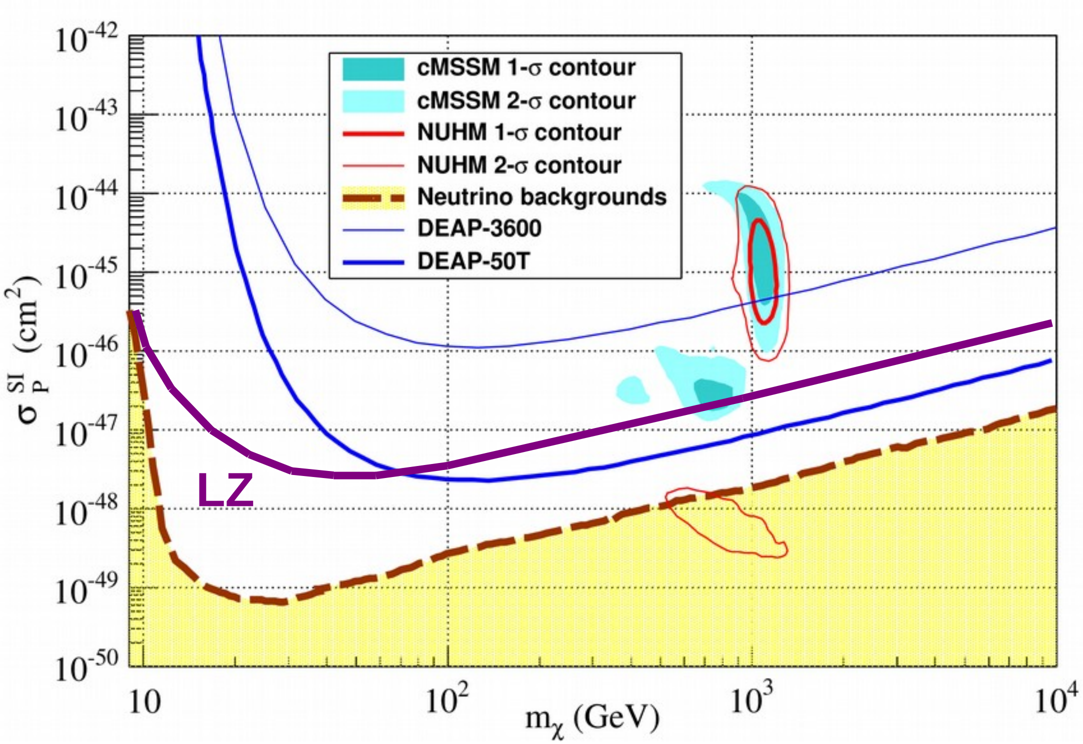


Next generation detector

50 tonne fiducial,
150 tonne full



- Can exhaust the available parameter space above the neutrino floor, probe cMSSM & NUHM
- **Not sensitive to *pp* neutrino-electron elastic scattering, which limits ~10 tonne Xe detectors**
- Complementary to LZ



Nuclear and Particle Physics Proceedings 273-275 (2016) 340-346

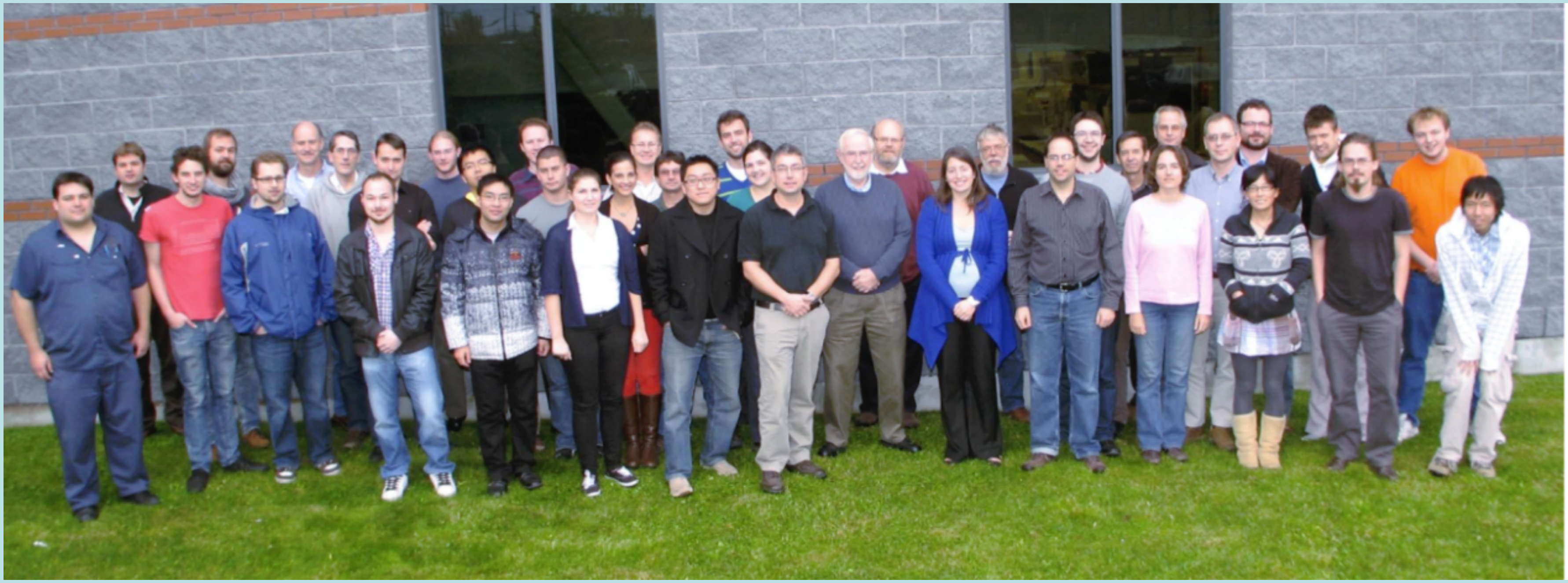
- Technology can be scaled to very large target masses, > 100 tonnes or **10^{-48} cm^2** sensitivity
- Better position reconstruction => relaxed targets on surface contamination
- Large detector will require Underground Argon

- Developing a large general purpose facility for noble liquid detector R&D at Carleton University

Summary

- DEAP-3600 has commenced operations!
  - DEAP was initially full mid-August (but seal failure)
  - have refilled and commenced ‘nominal’ data collection

  - have substantial exposure from ‘partial fill’ data set
  - calibrating and understanding detector response well underway
  - no surprises so far in terms of backgrounds
  - analyzing partial fill data potentially with aim to publish first result



DEAP Collaboration: 65 researchers in Canada, UK, and Mexico

University of Alberta

Carleton University

Laurentian University / Université Laurentienne

Queen's University

Royal Holloway University of London

Particle Physics
Rutherford Appleton Laboratory

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

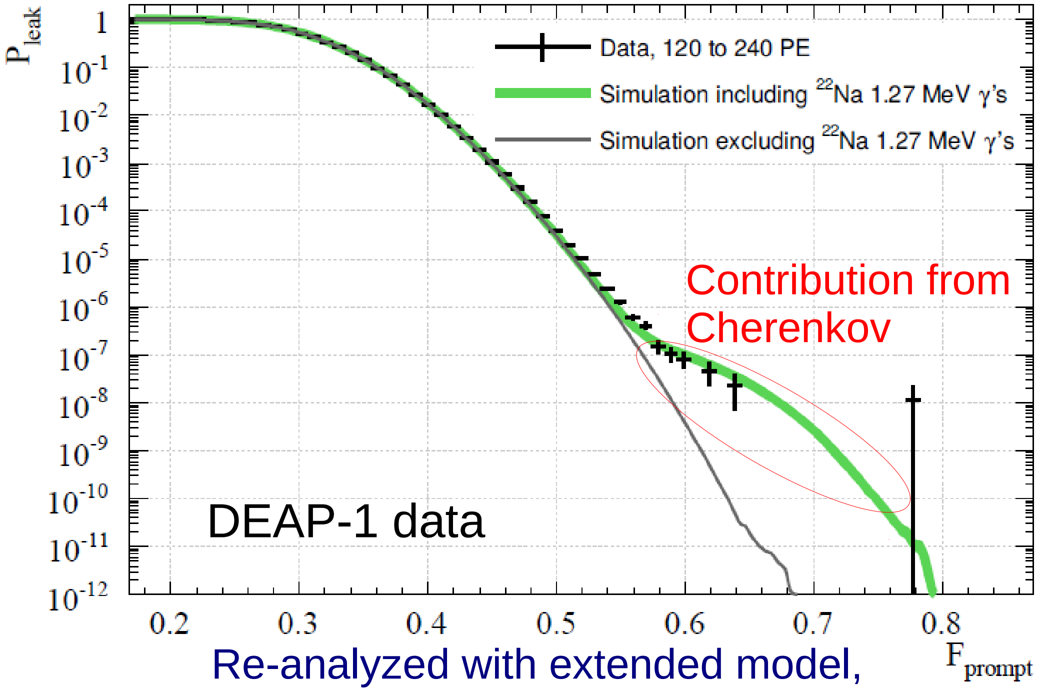
IF Instituto de Física

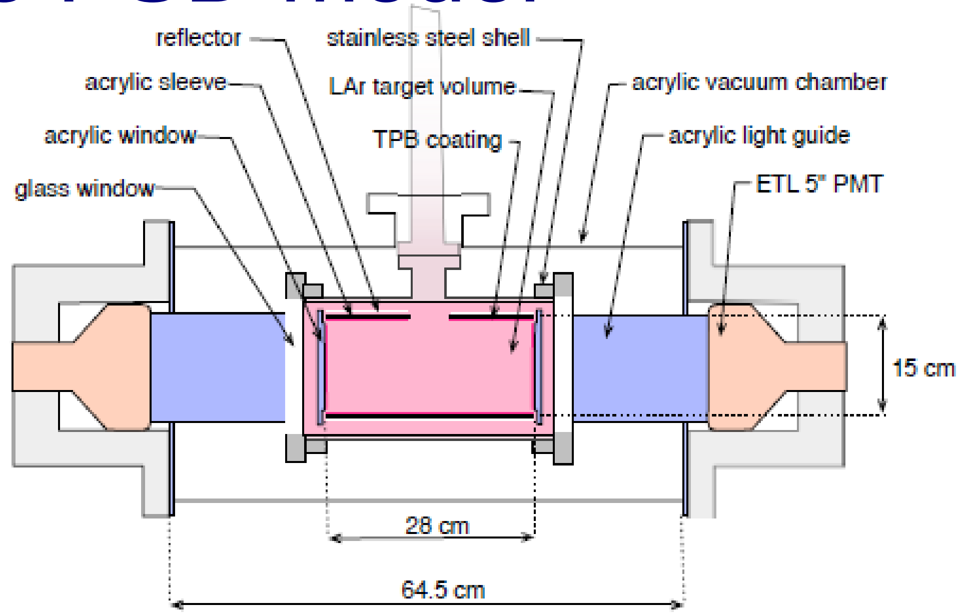
US University of Sussex

TRIUMF

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

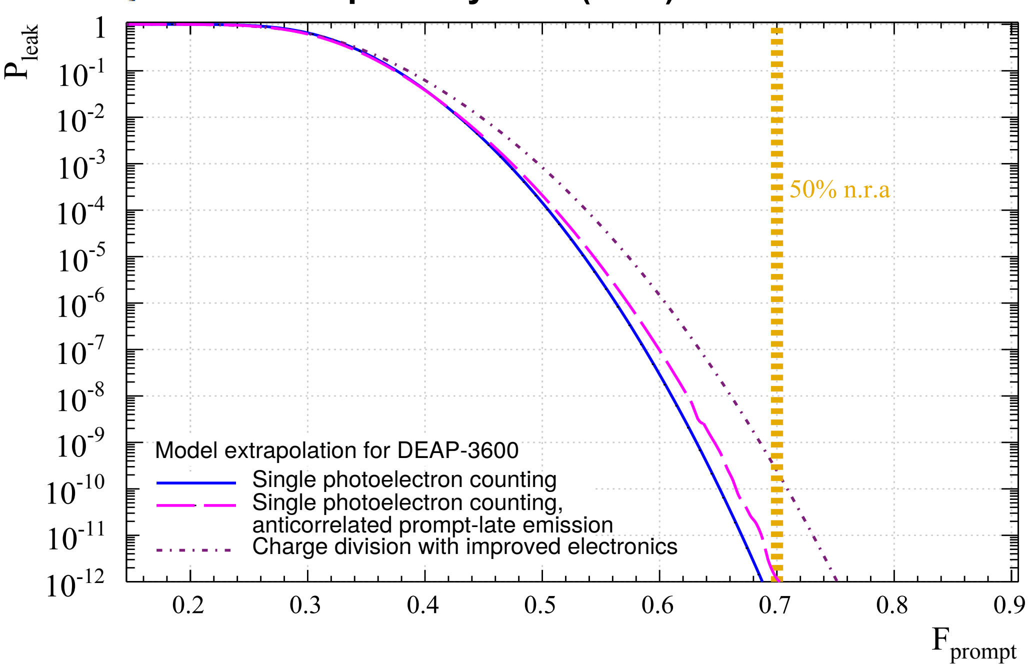
DEAP-1 and the PSD model





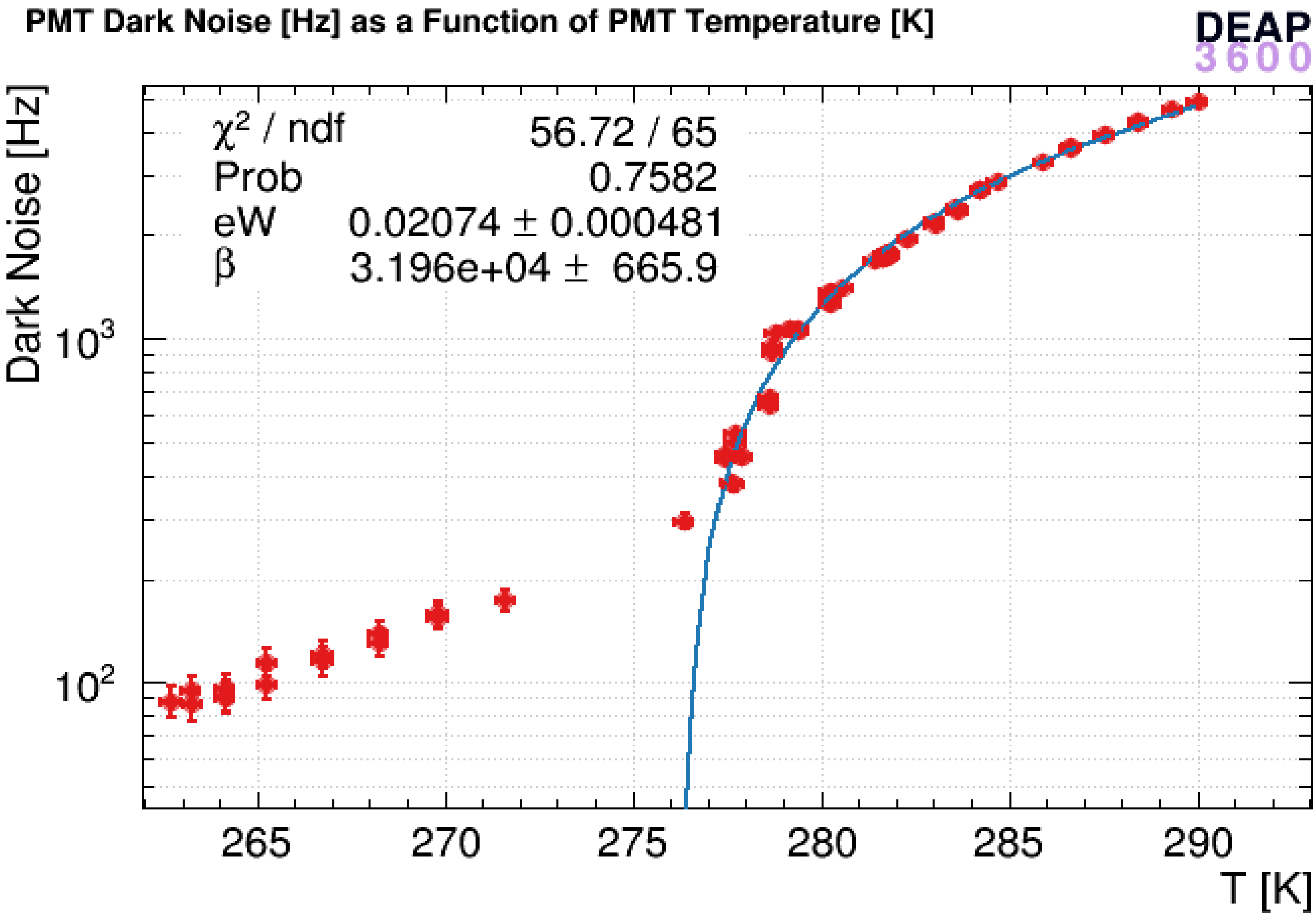
Re-analyzed with extended model,

Astropart.Phys. 85 (2016) 1-23



- PSD of ~10^{-10} required in DEAP-3600 to beat down backgrounds from ^{39}Ar (beta emitter) present at 1 Bq/kg rate.
- Measured with a tagged Na-22 gamma source using DEAP-1 at SNOLAB.
- Collected 1.23e+8 events.
  Leakage <2.7e-8 (90% C.L.)
- Data well described with analytic model and toy simulation
- Projection for DEAP-3600 indicates PSD of 10^{-10}

Key parameters monitored during the cooldown



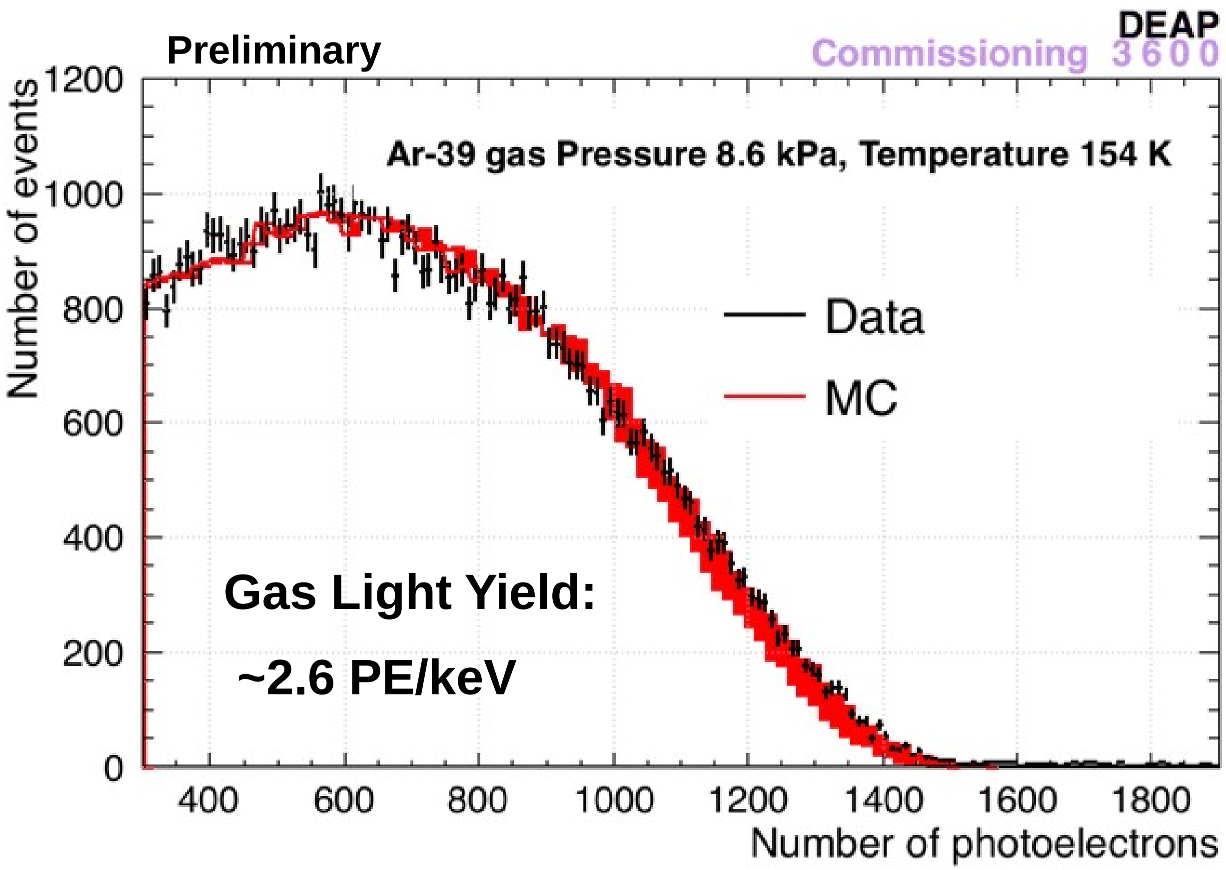
Also monitoring: mean SPE charge, afterpulsing distribution, ...

Detailed paper in preparation.

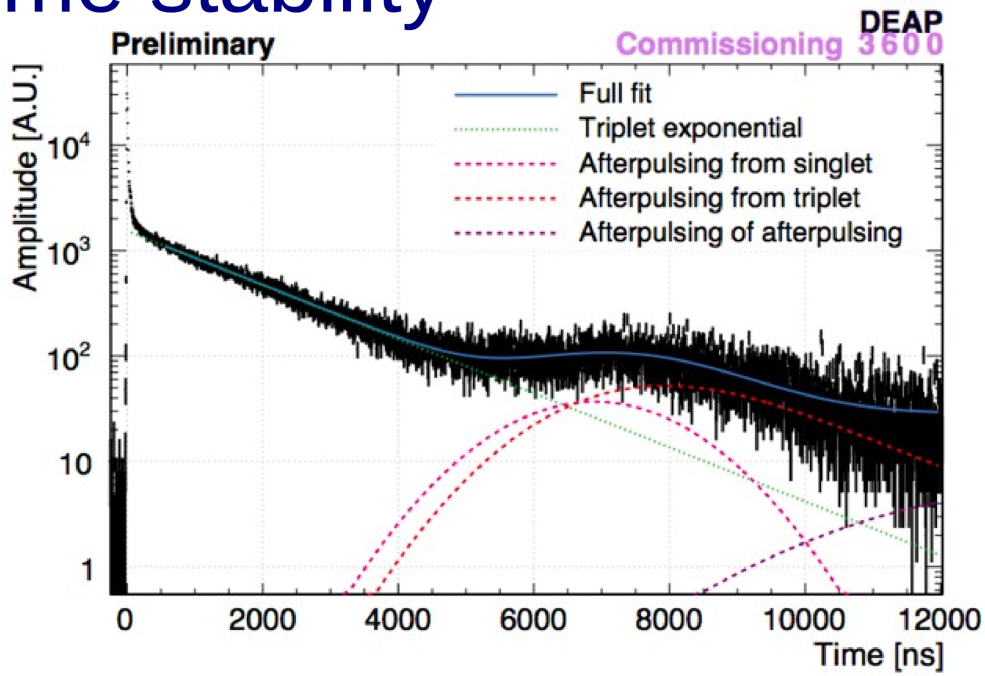
Gaseous Ar data

- After initial "vacuum" data taking phase detector filled with clean Ar gas
- Collected data in stable temperature and pressure conditions as well as during cooldown

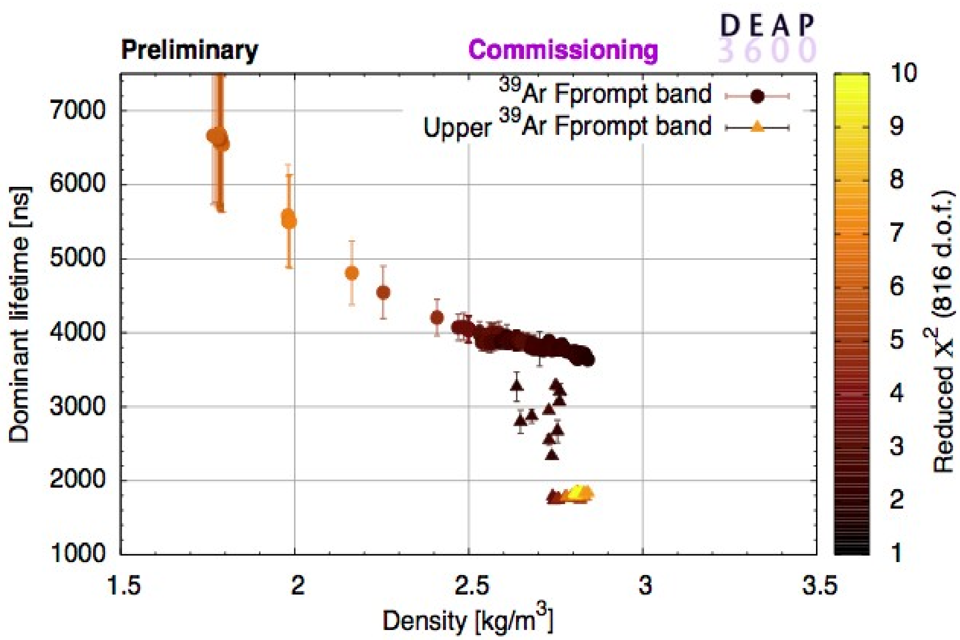
- Used Ar39 spectrum for early light yield estimates, by comparing full detector Monte Carlo with the data

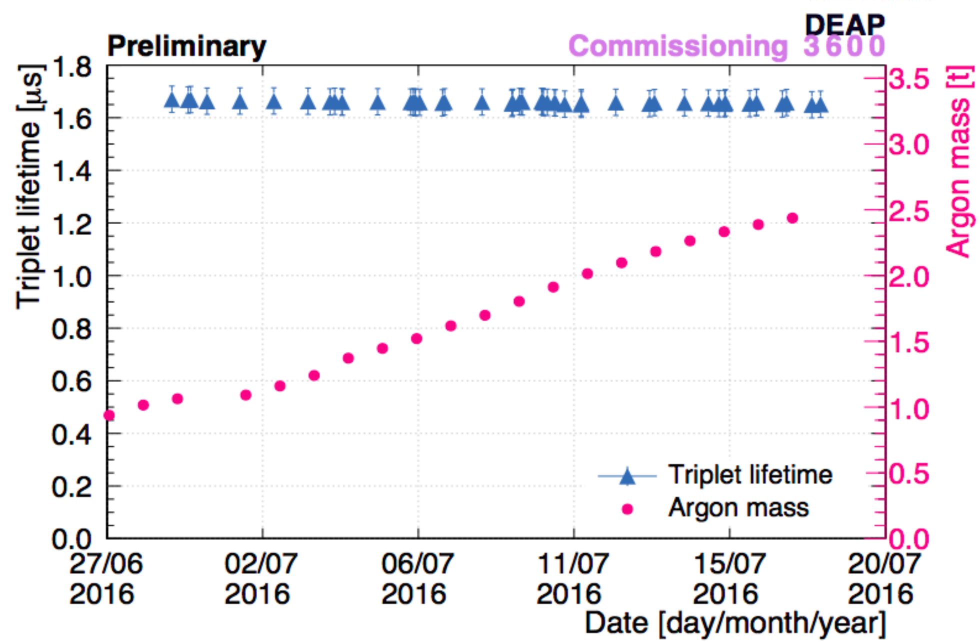


Triplet lifetime stability



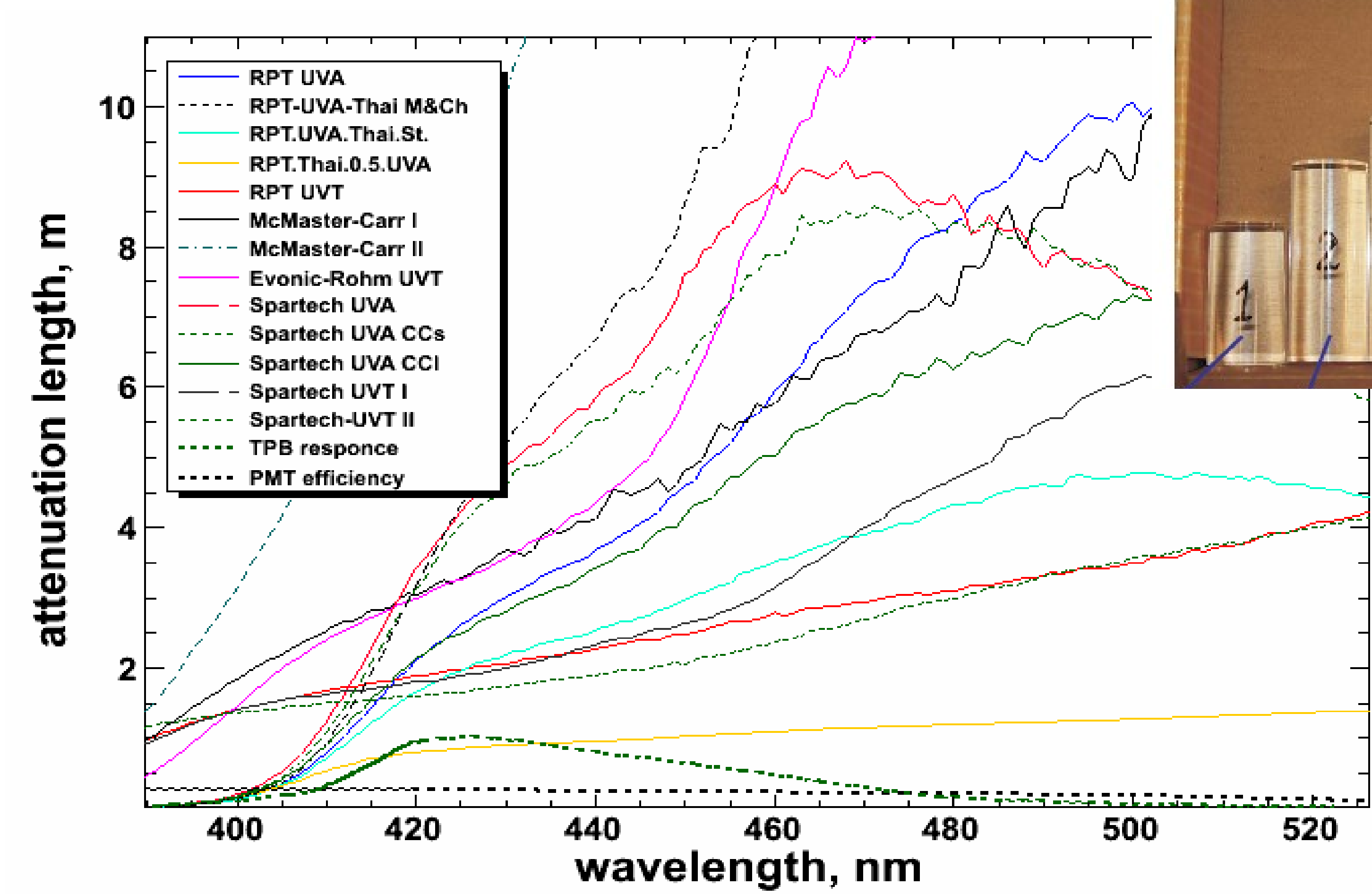
- Triplet lifetime and light yield stable over many days of operation in a closed loop, <u>without re-purification</u>
- (Process systems can be run also in re-circulation/purification mode)



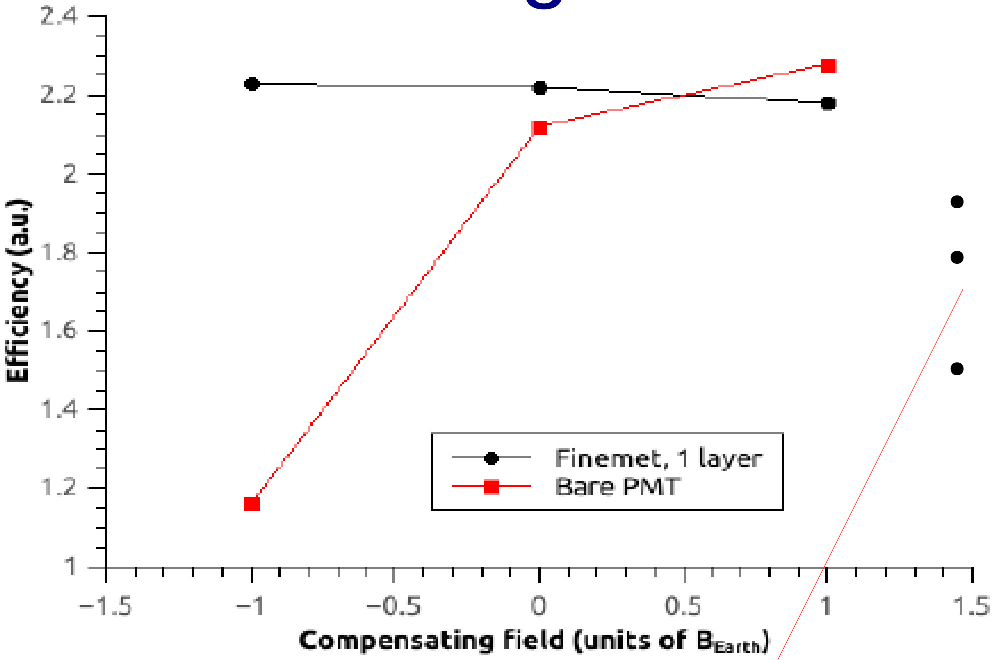


Acrylic attenuation measurements

- Proposed a method based on UV-Vis spectrometer and transmission measurements of samples of different length



Magnetic field compensation



- PMT efficiency depends on B field
- Using a combination of passive FINEMET shields
- And a simple set 4 compensation coils (to cancel the Z component)