The DEAP-3600 Dark Matter Experiment

Bei Cai

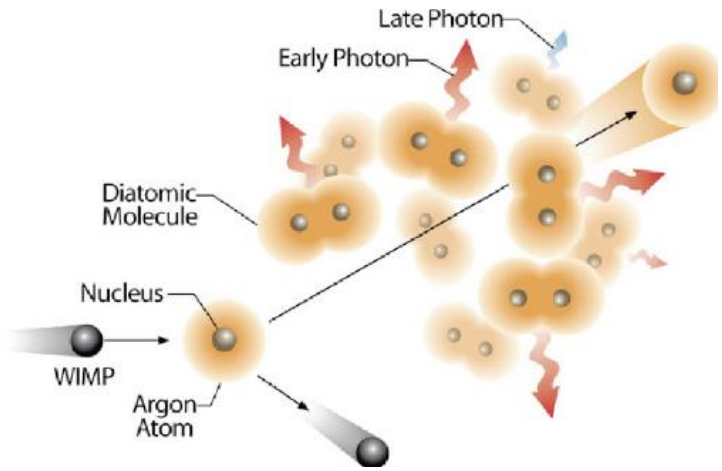
for the DEAP-3600 Collaboration

DEAP: Dark matter Experiment using Argon Pulse-shape discrimination

CAP Congress

June 15, 2015

Direct WIMP detection with liquid argon



Excellent pulse-shape discrimination (PSD) between electron recoils and nuclear recoils

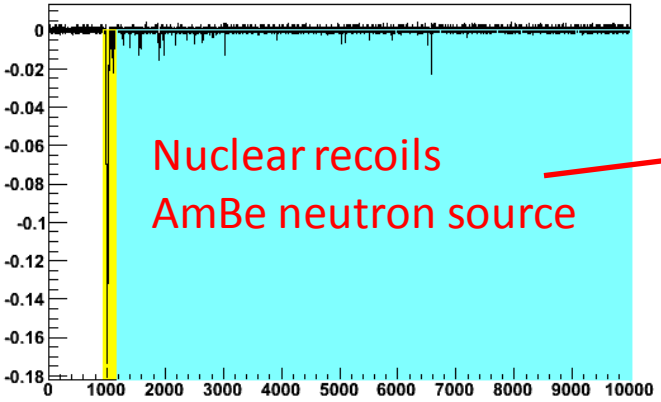
Good scintillator (40 photons/keV)

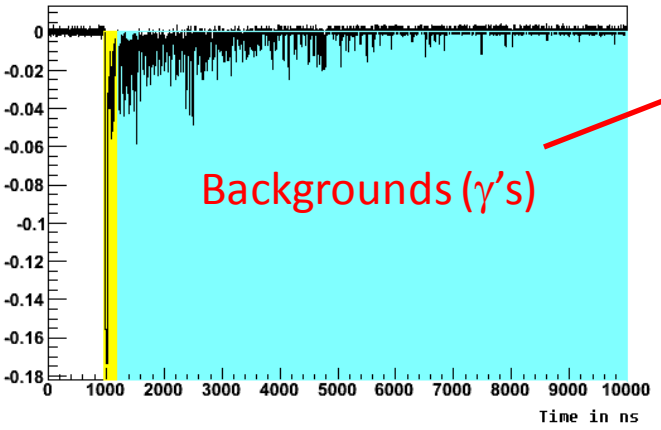
Inexpensive and easy to purify

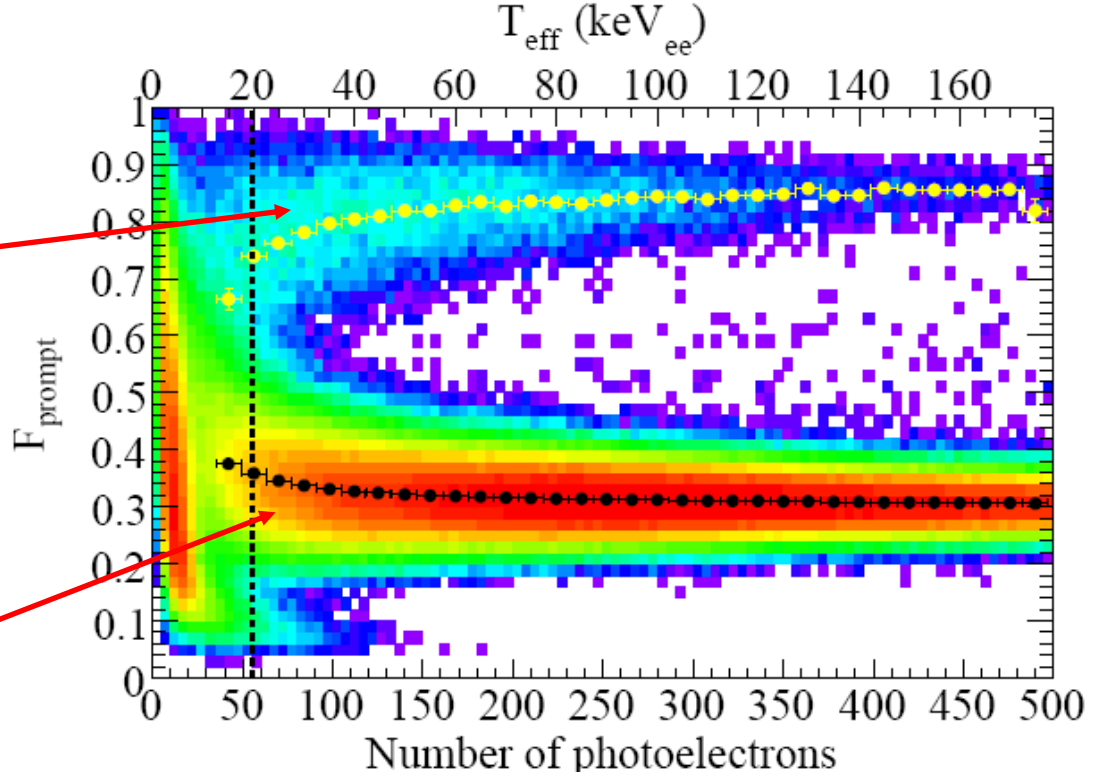
Single-phase detector, easy to scale up

- Energy transfer in liquid argon leads to formation of excited dimers
- Dimer molecules are in either singlet or triplet states, and the lifetimes are well-separated:
  - ~ 6 ns for singlet state (prompt)
  - ~ 1.5 μs for triplet state (delayed)
- Fraction of dimers in singlet or triplet states depends on the incident particle type

PSD in liquid argon with DEAP-1

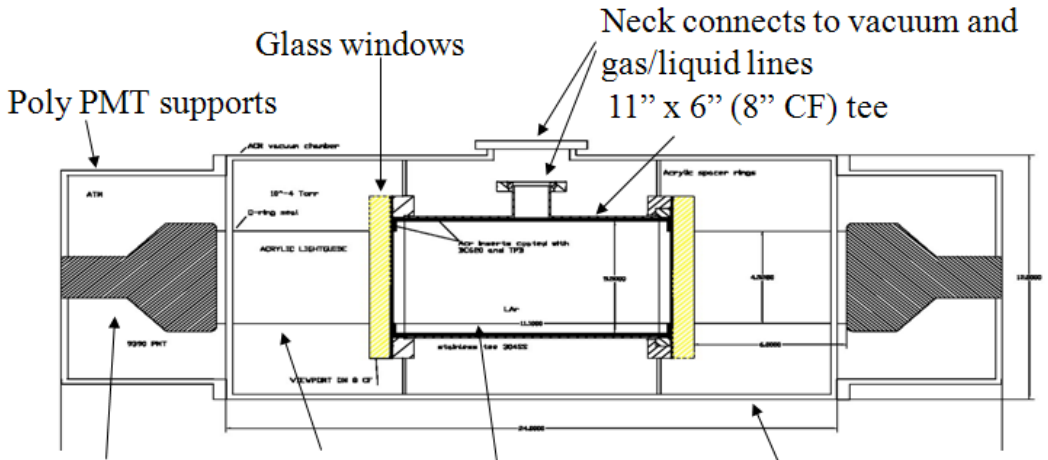




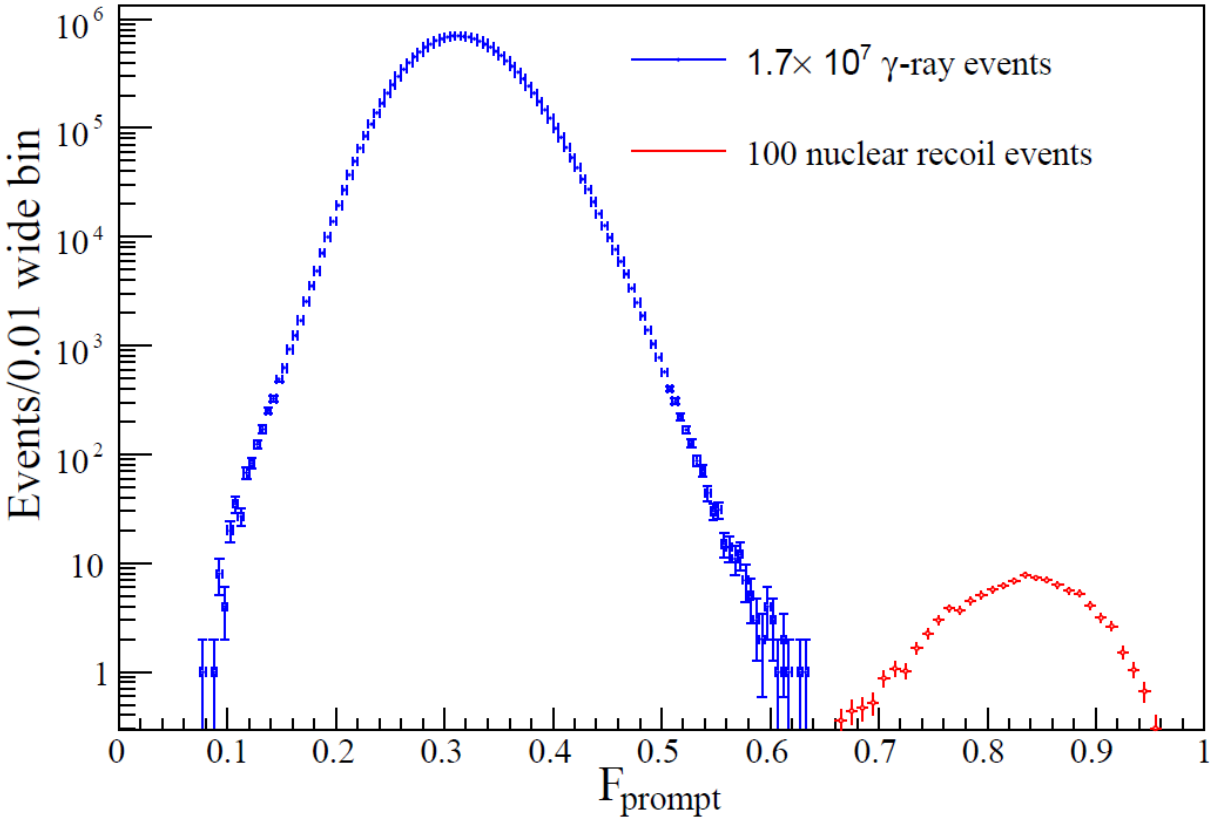


Yellow: Prompt light region
Blue: Late light region

$$F_{prompt} = \frac{PromptPE(150ns)}{TotalPE(9\mu s)}$$



β/γ background suppression in liquid argon



- 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

The DEAP-3600 Detector

Located at SNOLAB, 2 km underground in Sudbury, Ontario

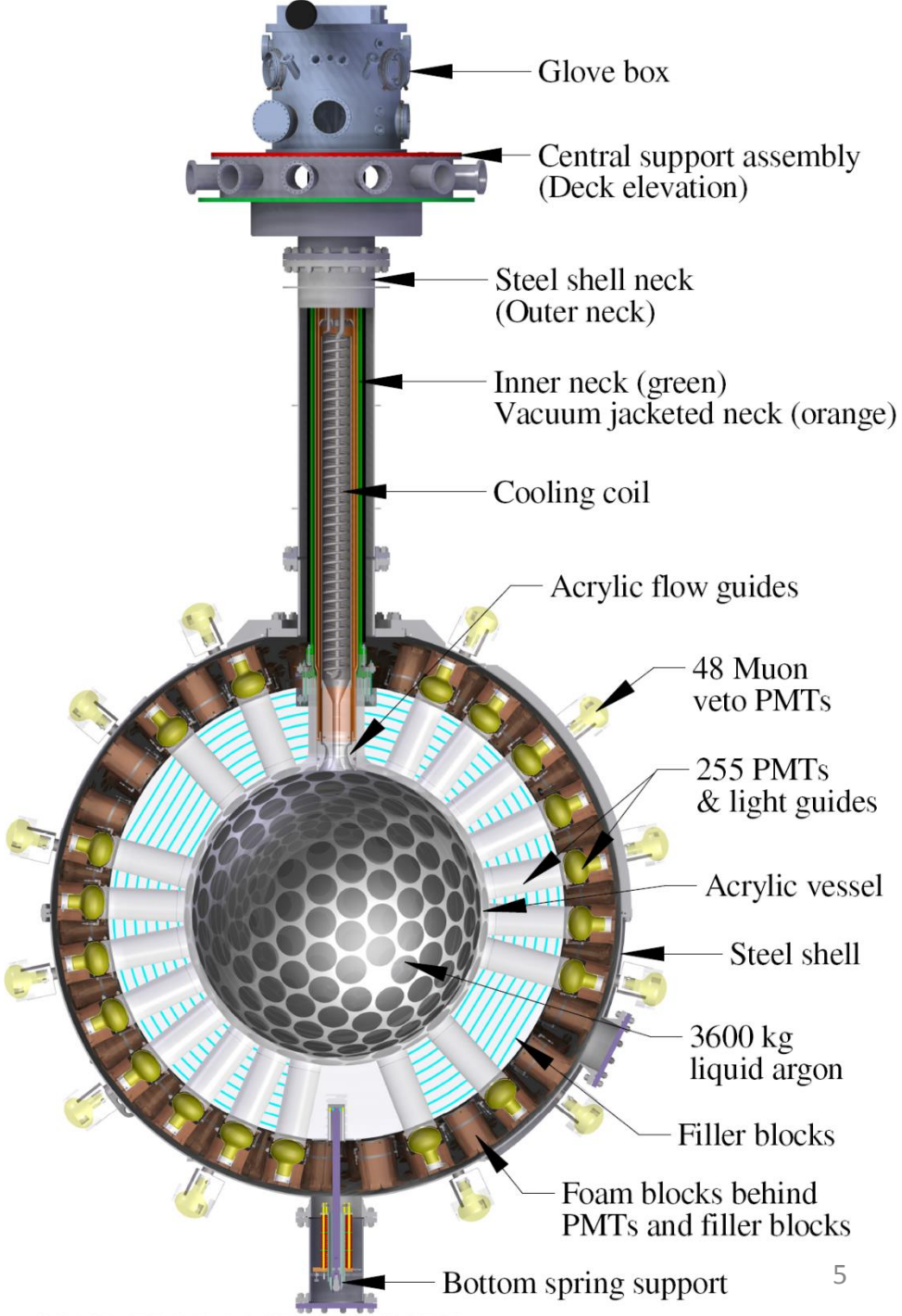
3600 kg argon target (1000 kg fiducial) in ultraclean Acrylic Vessel

Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction

255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 71% coverage)

50 cm light guides + PE shielding provide neutron moderation

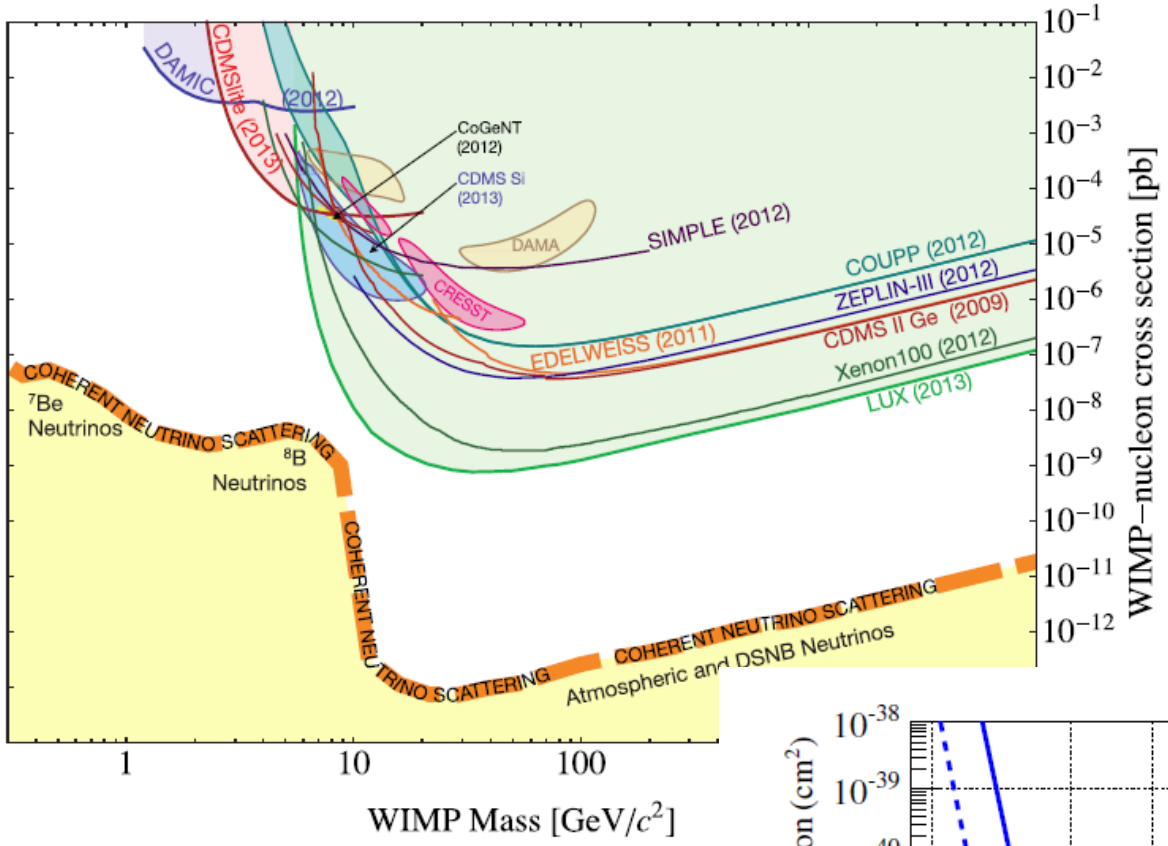
Steel Shell immersed in 8 m water shield



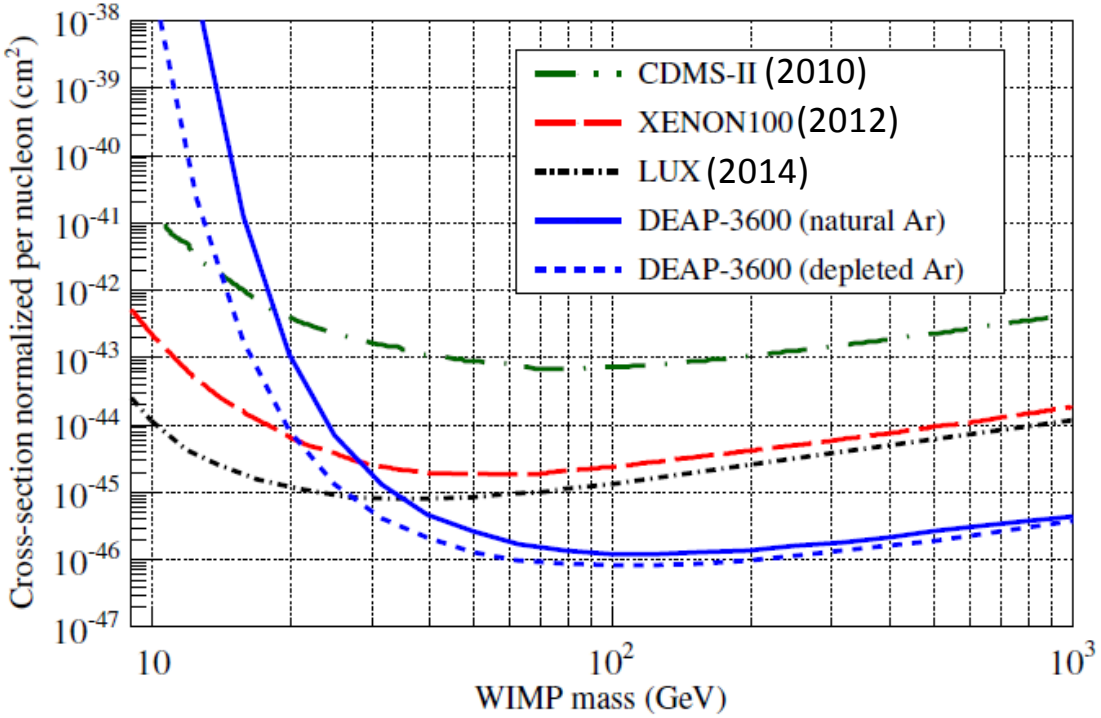
Critical elements of the design

- Ultrapure cryogenic acrylic vessel bonded underground
- Large stainless steel pressure vessel welded underground
- Argon purification system with extremely low target levels of radon emanation
- Large target of liquid argon viewed by low-radioactivity HQE PMTs near room temperature
- Custom large-scale robotic resurfacer for radon control
- Custom large-scale (10 m^2!) in-situ thin-film deposition device

Spin-independent WIMP-nucleon cross section



J. Billard et al, Phys. Rev. D 89, 023524 (2014)



arxiv.org:1410.7673

Backgrounds in DEAP-3600

- β/γ backgrounds
  - Dominated by ^{39}Ar (1 Bq/kg)
  - Pulse-shape discrimination
  - Depleted argon after natural argon run
- Neutron backgrounds
  - Clean materials and shielding
  - Muon suppression at SNOLAB
- Surface contamination
  - Clean detector surface (resurfacer device)
  - Vertex reconstruction for fiducial volume

Fabrication and assay of DEAP acrylic

- Fabrication from pure MMA monomer at RPT Asia Thailand, strict control of radon exposure for all steps
- DEAP Collaborators present during fabrication
- Control to $<2.2 \times 10^{-19}$ g/g ^{210}Pb from radon exposure
- Developed system to vaporize and assay large quantities of acrylic (10 kg samples), count residue with Ge well detector for ^{210}Pb peak, and with alpha counter for ^{210}Po (C. Nantais MSc thesis)

Monomer cast at RPT Asia 2011

Thermoformed panel at RPT Colorado 2012

AV neck machining
(U of Alberta, Jul 2012)

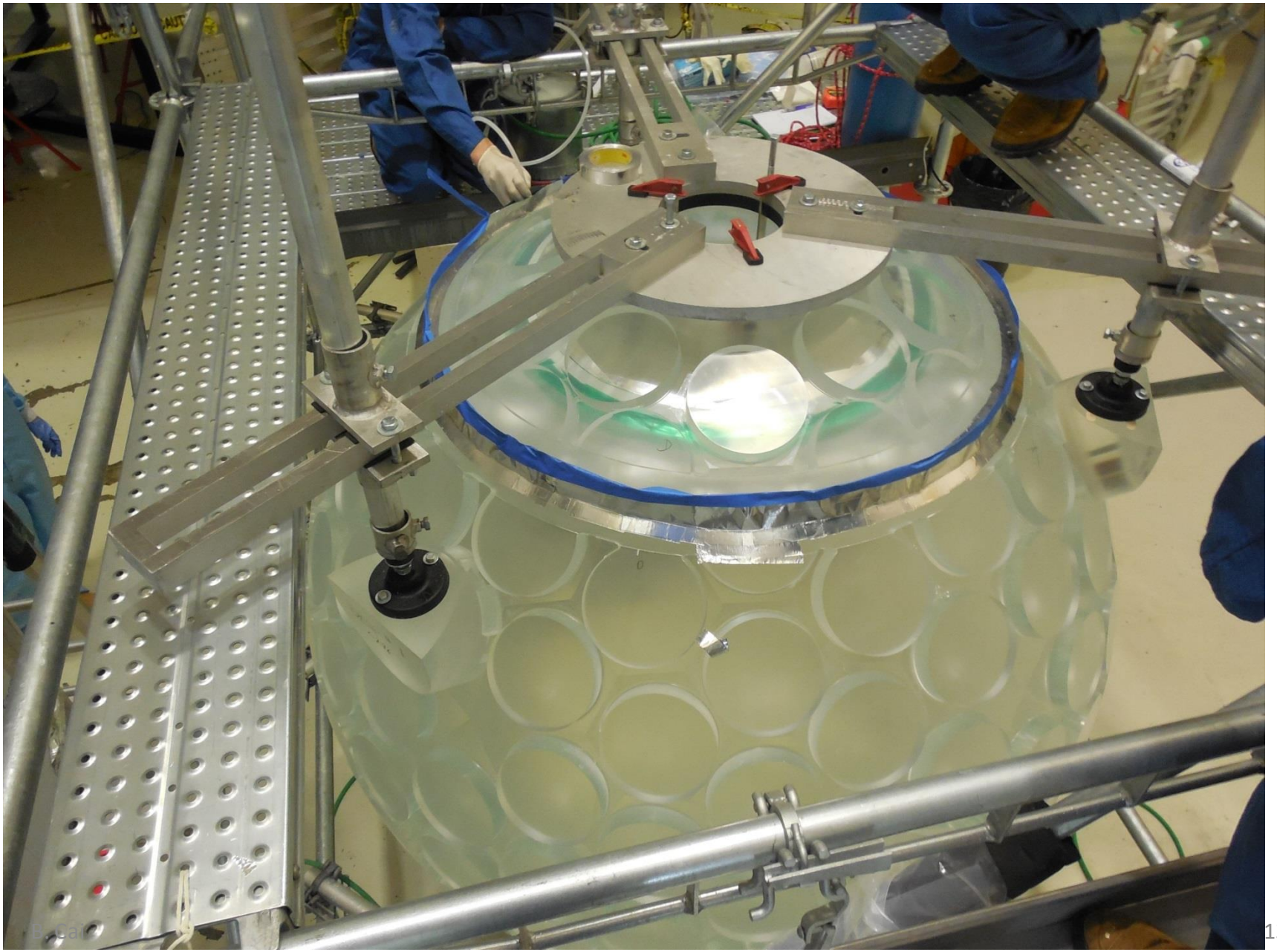
AV shoulder machining
(Sep 2012)

AV stub machining
(Fall 2012)

AV arrives at SNOLAB (Oct 2012)

AV slung down the shaft
(Dec 2012)

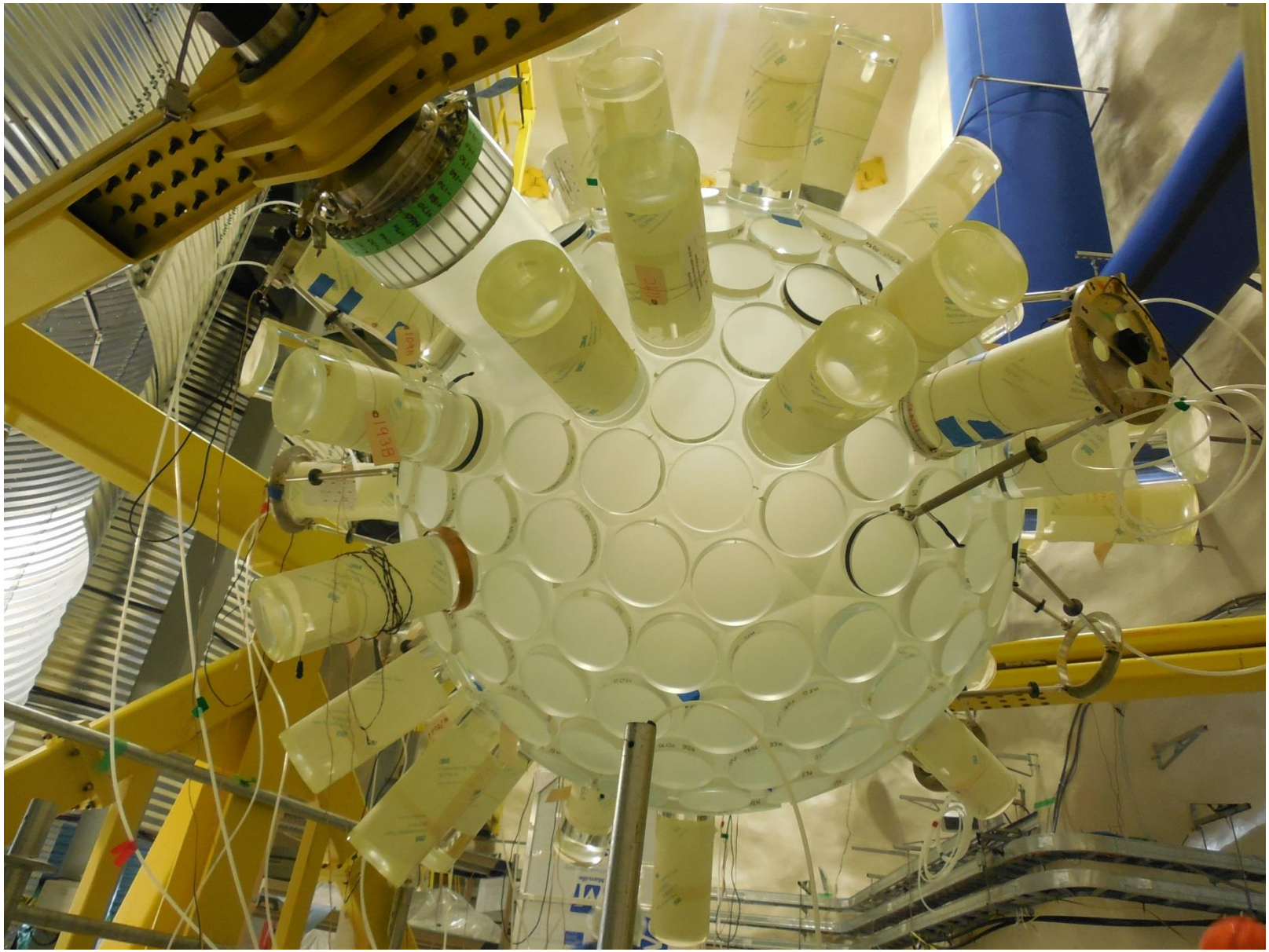
AV shoulder bond (RPT at SNOLAB Jan 2013)



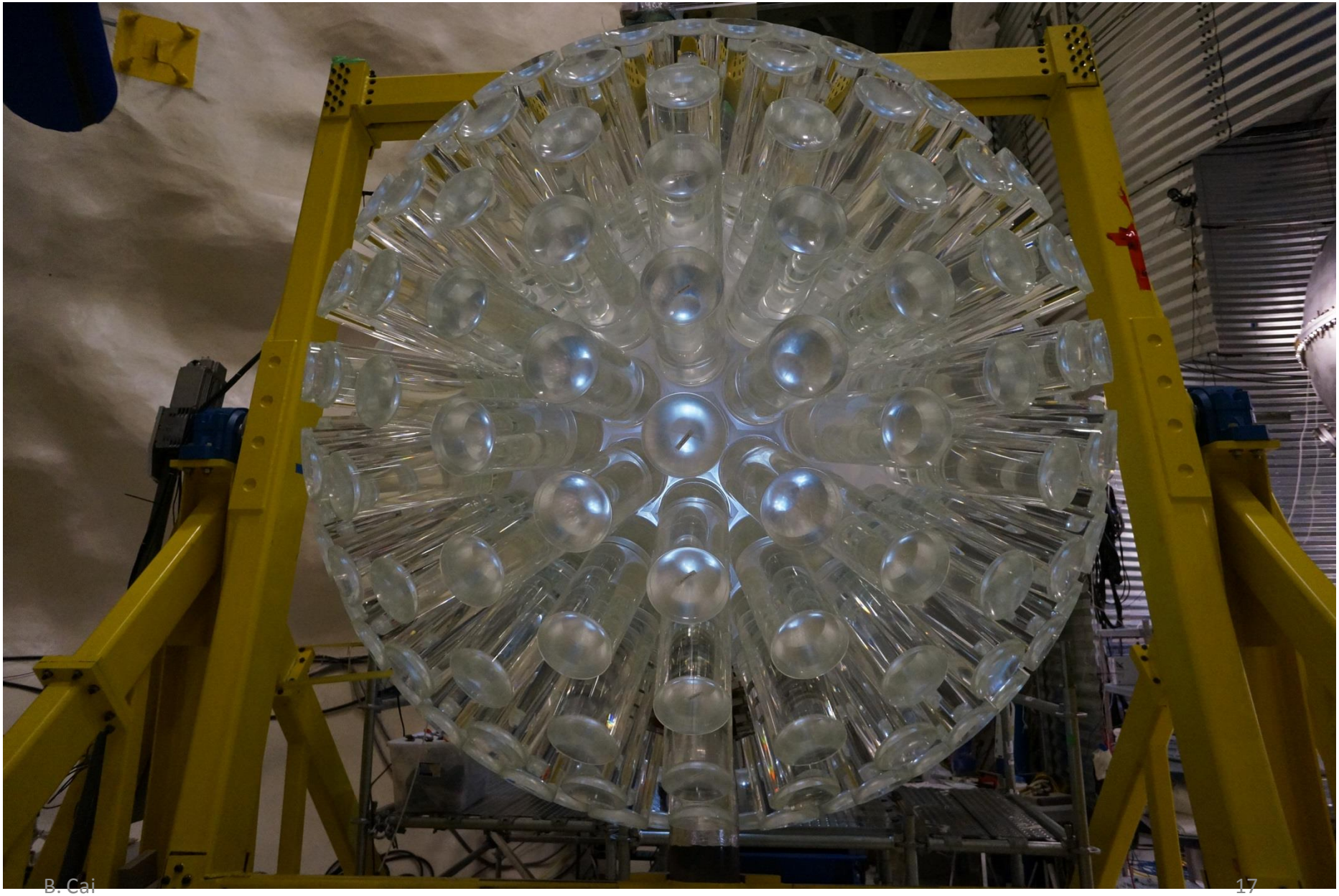
AV neck bond (RPT at SNOLAB Feb 2013)

4th anneal after underground machining (June 2013)

Vessel sealed and purged, approx. 50 LGs bonded (September 2013)

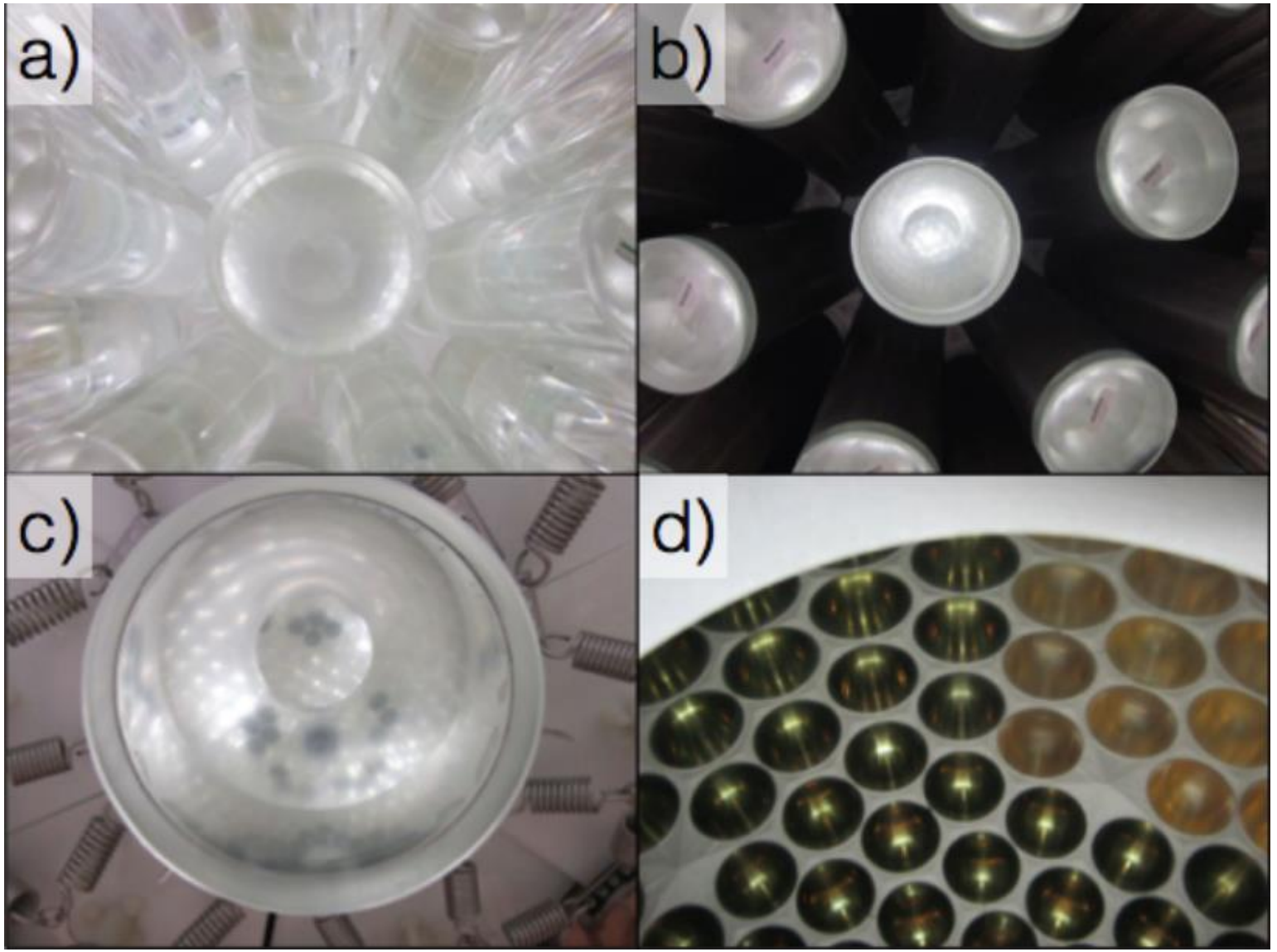


Light guide bonding completed (November 2013)



Light guides on AV

Reflectors on light guides

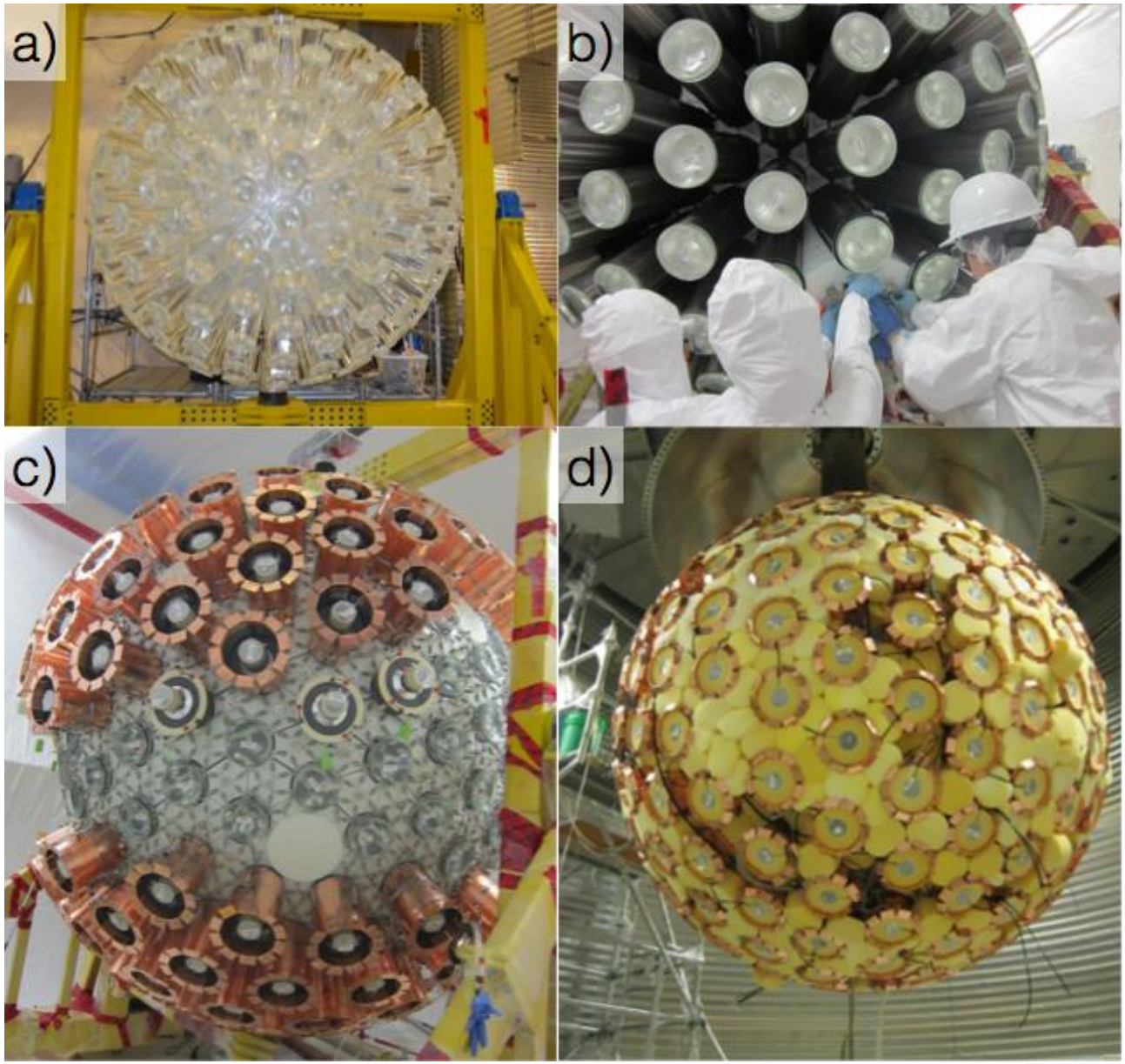


View from a light guide

View down the neck

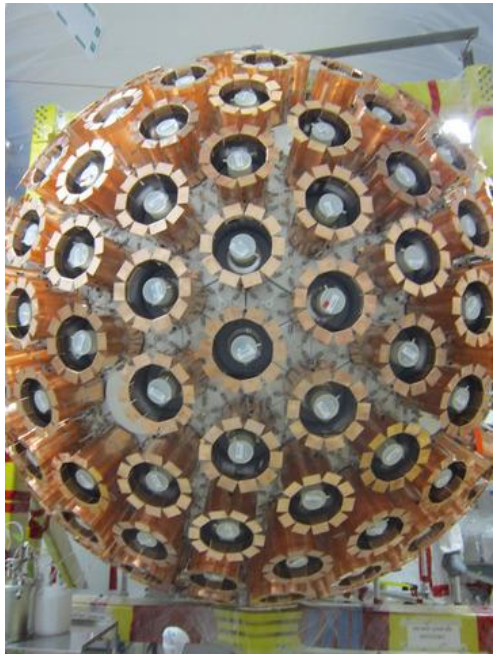
Light guides on AV

Reflectors on light guides



PMT installation Oct 2014

All PMTs installed, cabled, most foam insulation in place Dec 2014

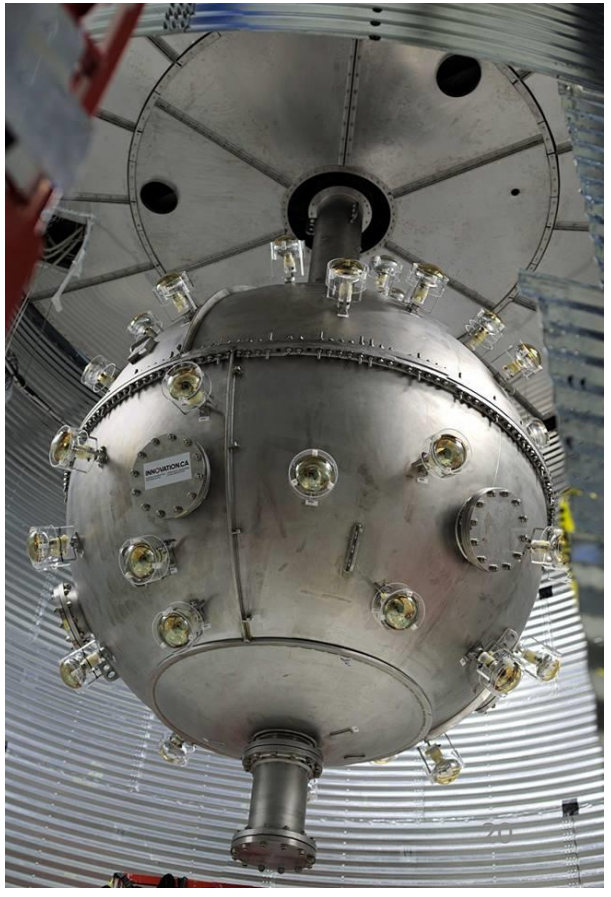


Completed inner detector

Detector ready for Final Lift onto neck

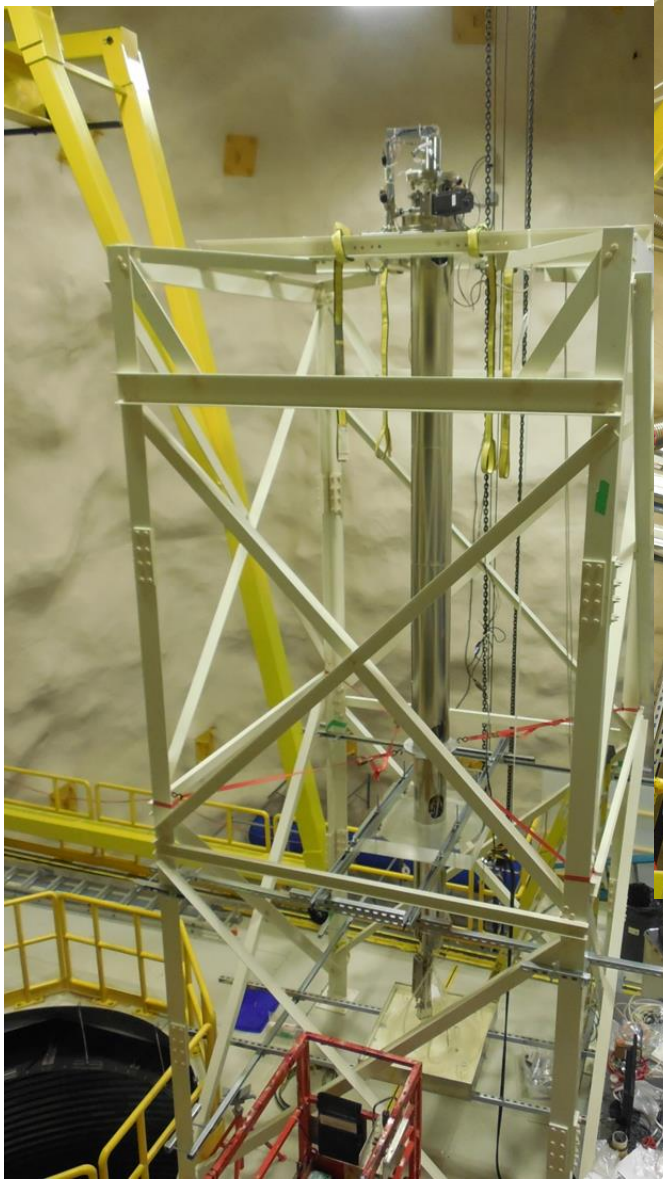
Steel Shell closing Dec 2014

Steel Shell in shield tank

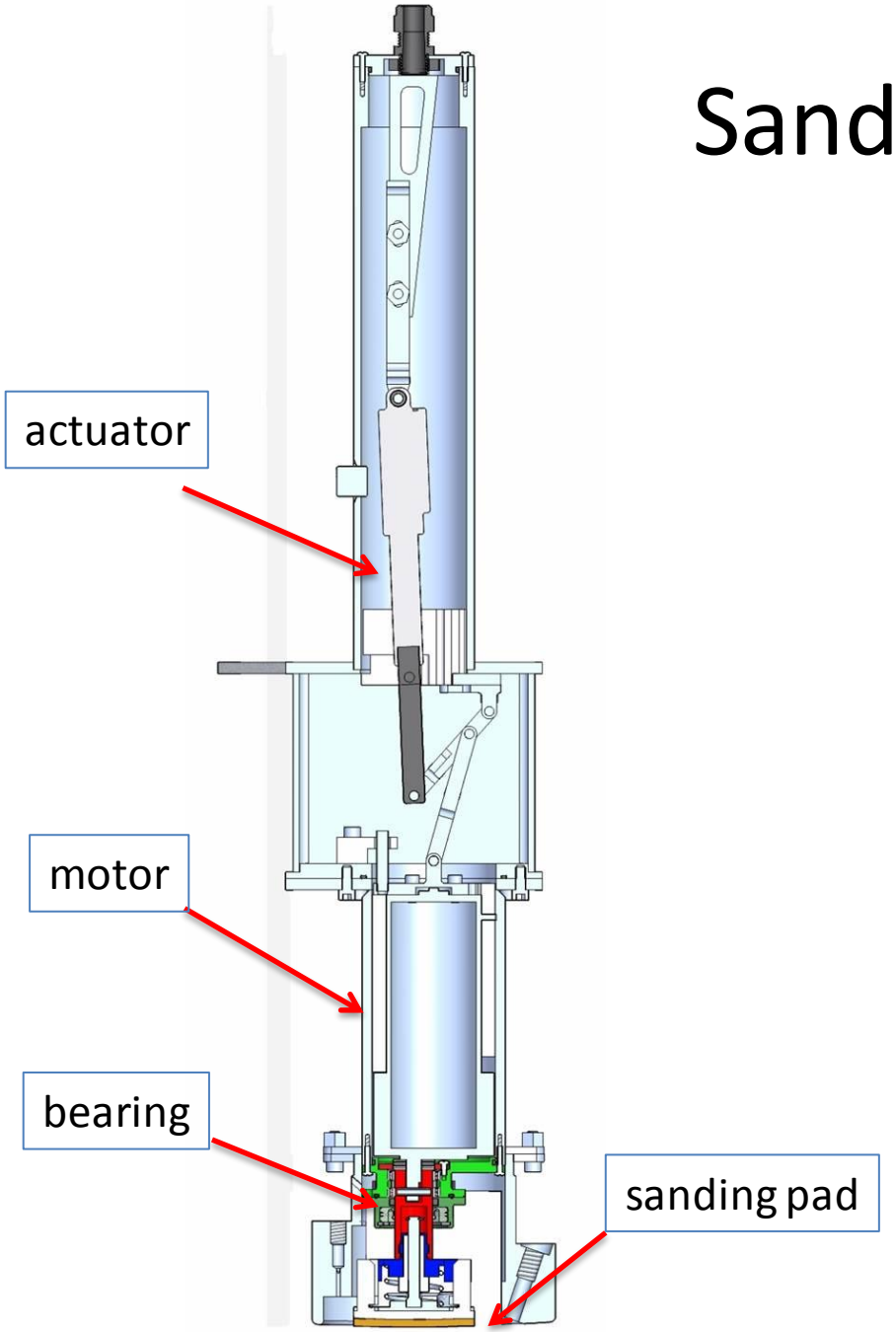


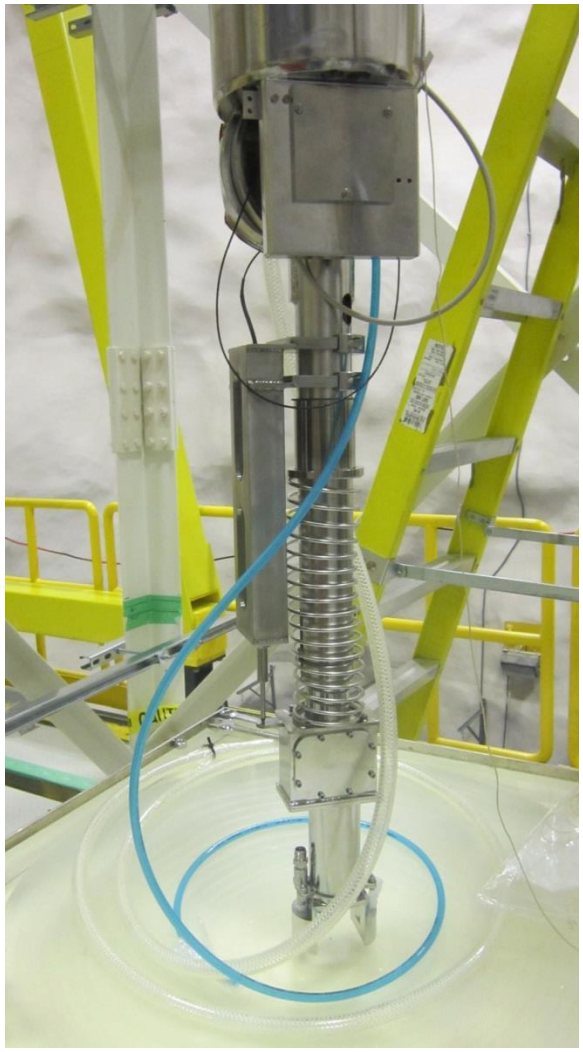
Veto PMTs installed Mar 2015

The Resurfacer



Sanding head assembly





3M 6002J M74 diamond sanding pads, 200 grit, recommended by RPT, durable and good acrylic removal rate

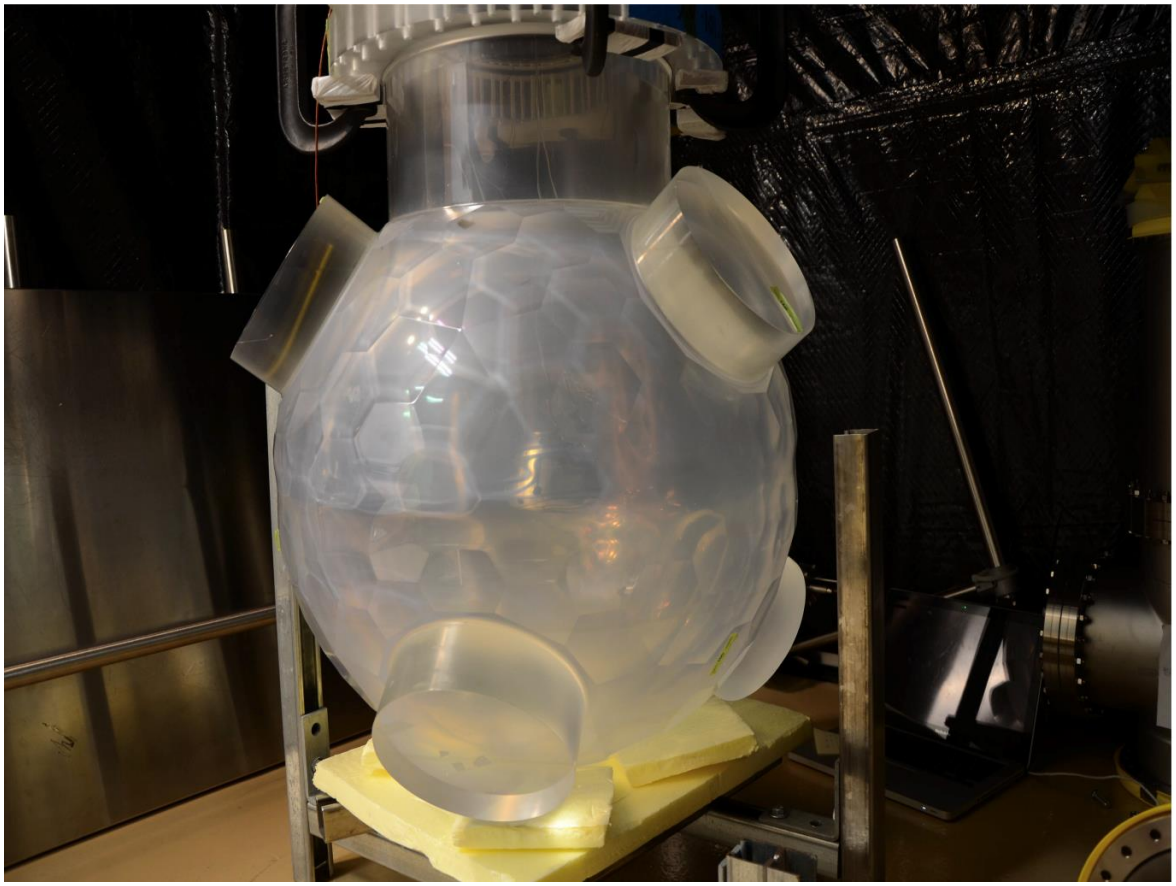
Background reduction with resurfacer

- AV radon exposure:
  - 9 months surface, 6 months mine air, 1 month radon reduced air
  - $5x10^4$ α/day/m^2 on AV surface before resurfacing
- 200 hours of resurfacing
- Removed all radon daughters deposited on surface
- Estimated order of 10 α/day/m^2 on AV surface after resurfacing

Current status of DEAP-3600

- Acrylic vessel resurfacing was completed at the end of 2014
- Detector optical calibration, PMT and electronics commissioning ongoing (winter 2014/spring 2015)
- Commissioning cryogenic system (winter 2014/spring 2015)
- Vacuum-baked acrylic vessel (spring 2015)
- Completion of shield tank components, calibration hardware, veto PMT system (late spring 2015)
- Inner wavelength shifter is being deposited on the AV
- Next steps are commissioning with argon gas followed by cool down/liquid argon fill (starting summer 2015)
- Fill the shield tank with ultrapure water (July 2015)

TPB wavelength shifter deposition



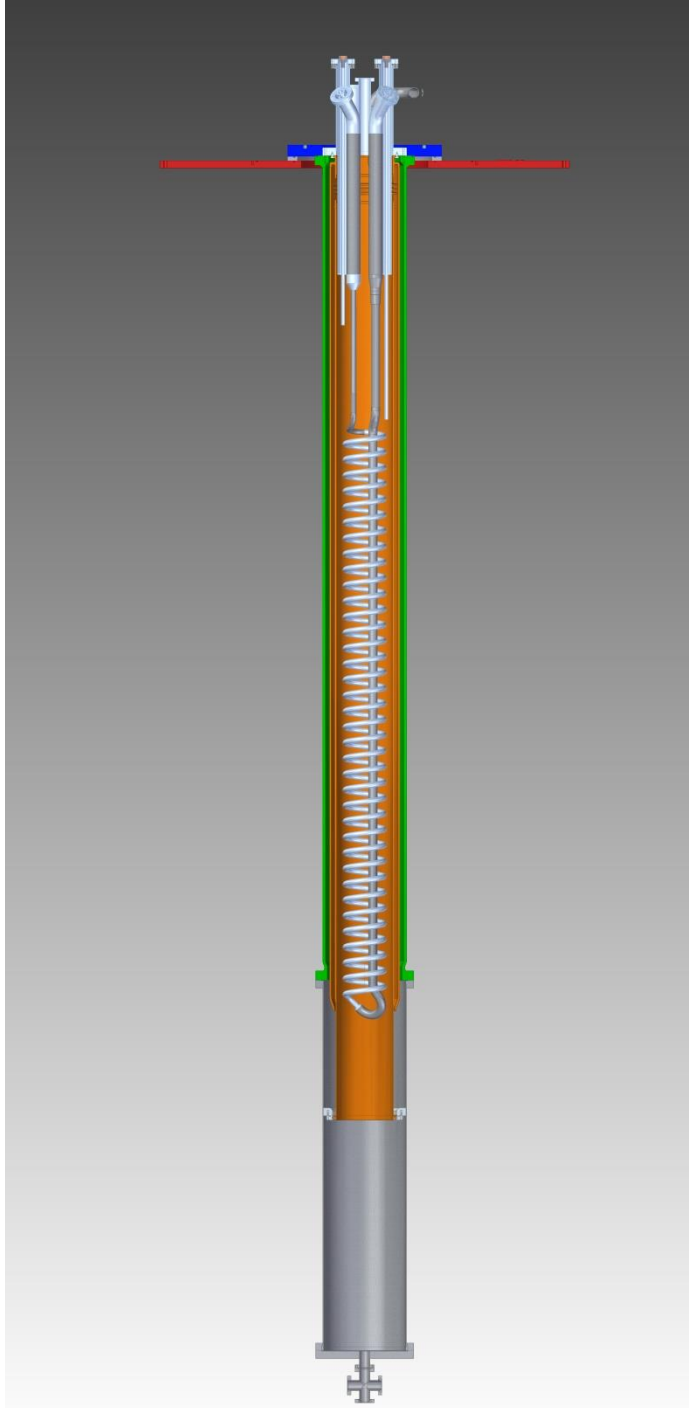
Process system

Ar purification getter and charcoal trap

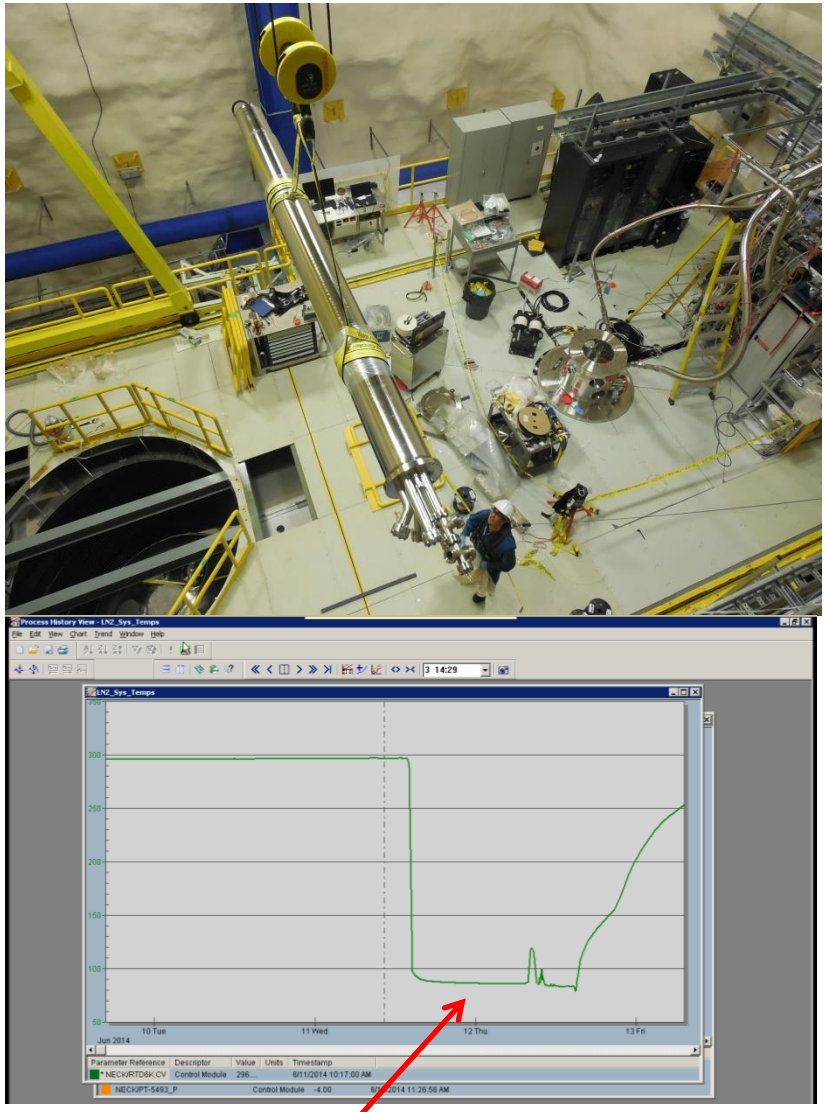

Cryocoolers and LN2 dewar


Ar dewar


Cooling coils being prepared for final acid bath



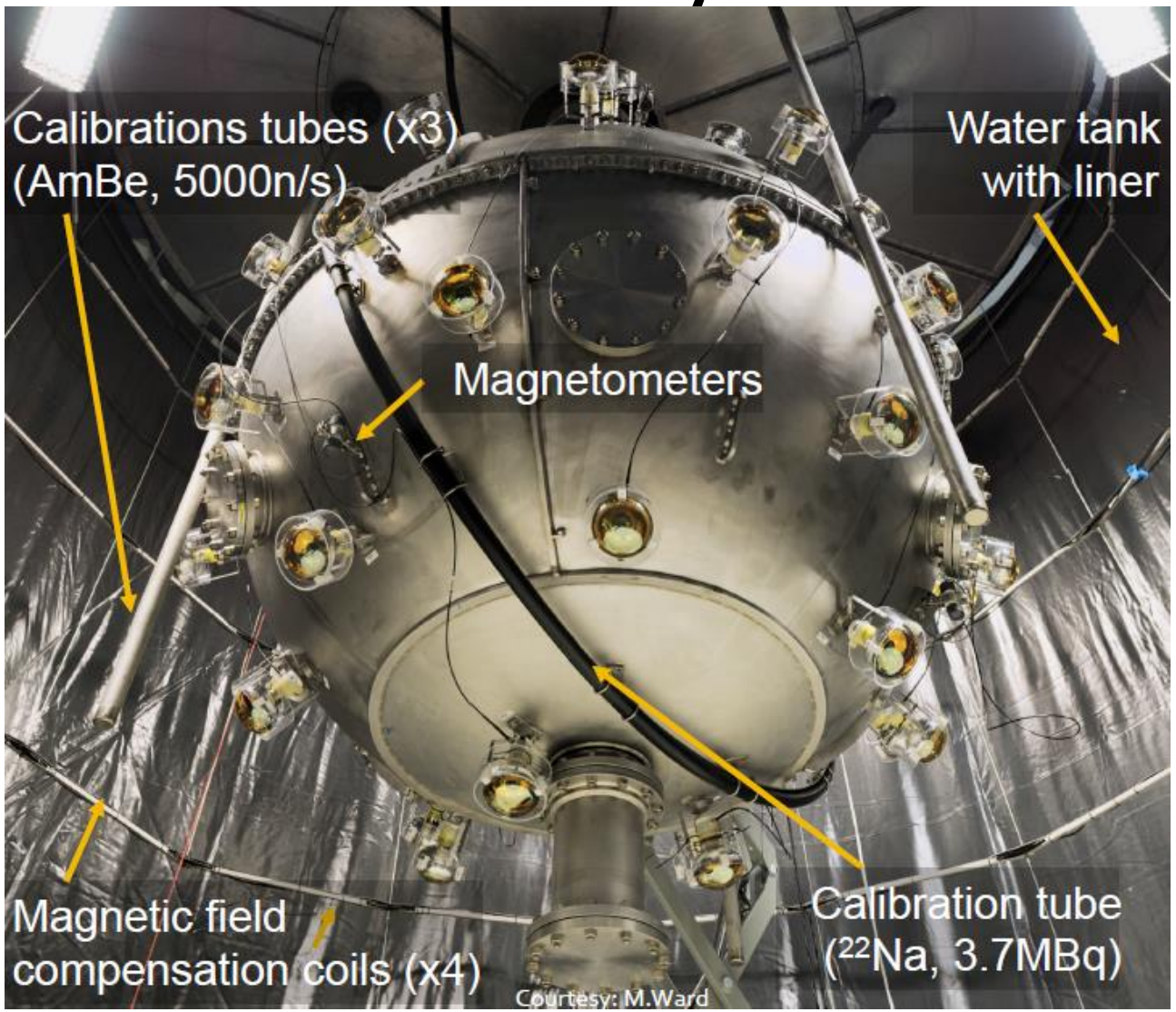
DEAP-3600 argon cooling system



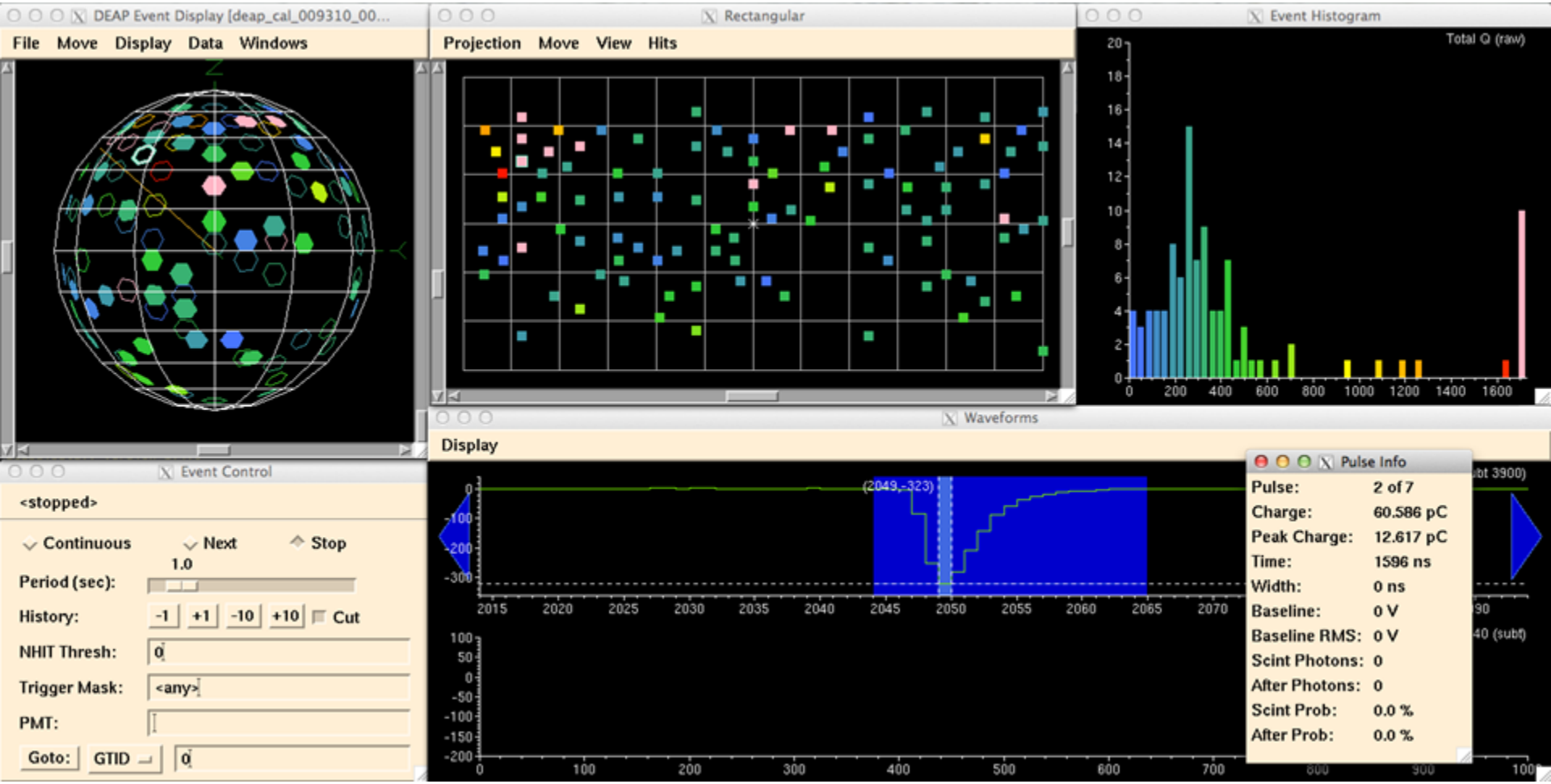
Commissioning at 86 K, June 11, 2014

Data acquisition system

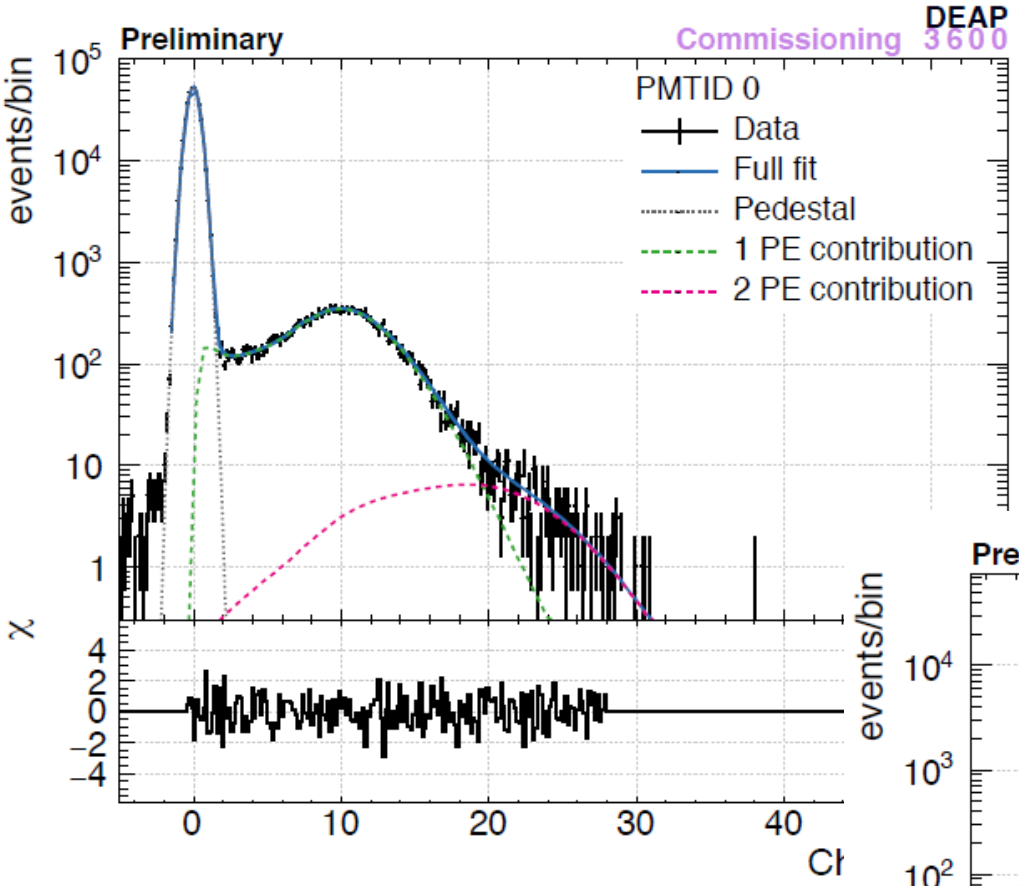
Calibration Systems



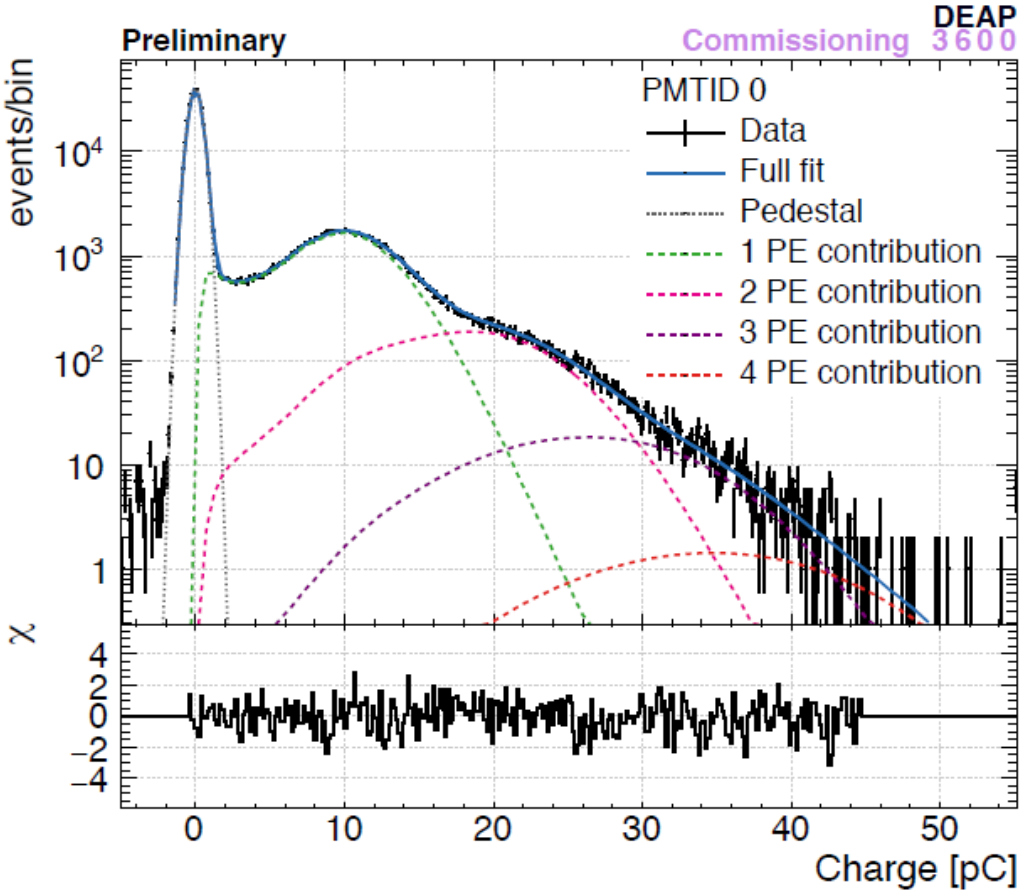
Light injection through fibers



Single photo-electron spectra



Low light intensity



High light intensity

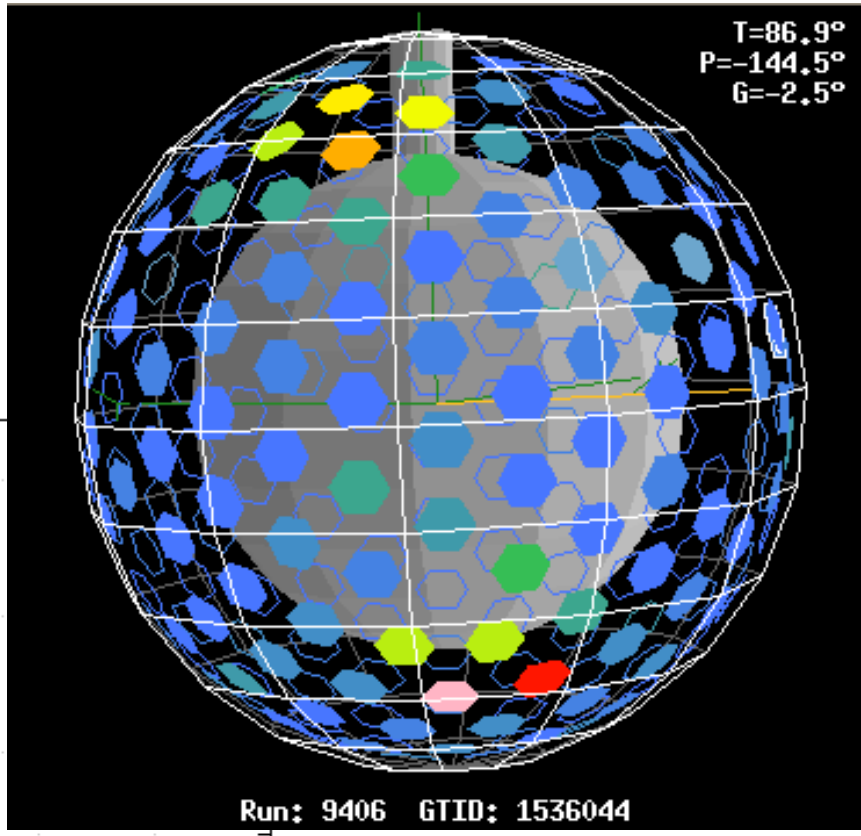
A high energy event

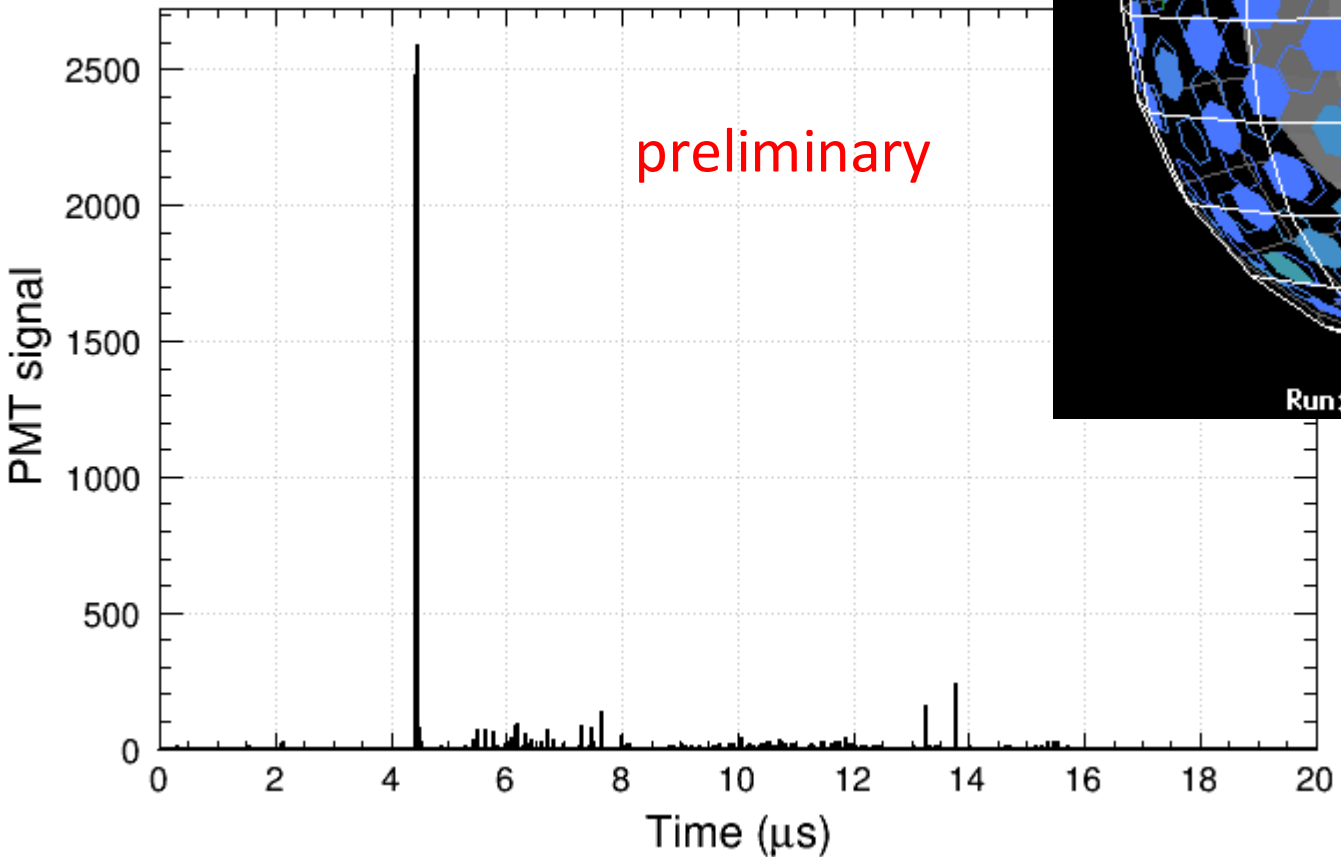
Run: 9406 Subrun: 3 Event: 300460

Total energy: 1520 PE

High event rate: ~1 event/day

Expected muon rate: 1.6 muons/day





Conclusion

- DEAP-3600 will search for dark matter interactions on argon starting summer 2015 with sensitivity to spin-independent WIMP-nucleon cross section >20 times better to current limits
- Construction is completed, currently depositing wavelength shifter and preparing for argon running
- Have been commissioning PMTs and electronics since late 2014, optical calibration ongoing
- Stay tuned

~60 collaborators in Canada, the 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

University of Sussex

TRIUMF

Instituto de Física

Thanks to CFI, NSERC, the provinces of Alberta and Ontario, and SNOLAB for funding and support

DEAP presence at CAP

- Presentations (Tuesday afternoon)
  - DEAP-3600 trigger — B. Smith
  - Optical data — B. Beltran
  - Single photo-electron counting — T. McElroy
  - Neck alpha backgrounds — J. Bueno
  - Wavelength thickness studies — D. Cranshaw
- Posters (Wednesday evening)
  - Detector design and construction — DEAP Collaboration
  - The resurfacer — P. Giampa, B. Cai
  - Single PE calibration — C. Jillings, M. Kuzniak, T. Pollmann
  - Neck alpha backgrounds — C. Mielnichuk
  - ^{39}Ar energy calibration — C. Stone, C. Jillings

Backup slides

Pulse-shape background discrimination