DarkSide

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Princeton/FNAL

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Assergi (AQ)
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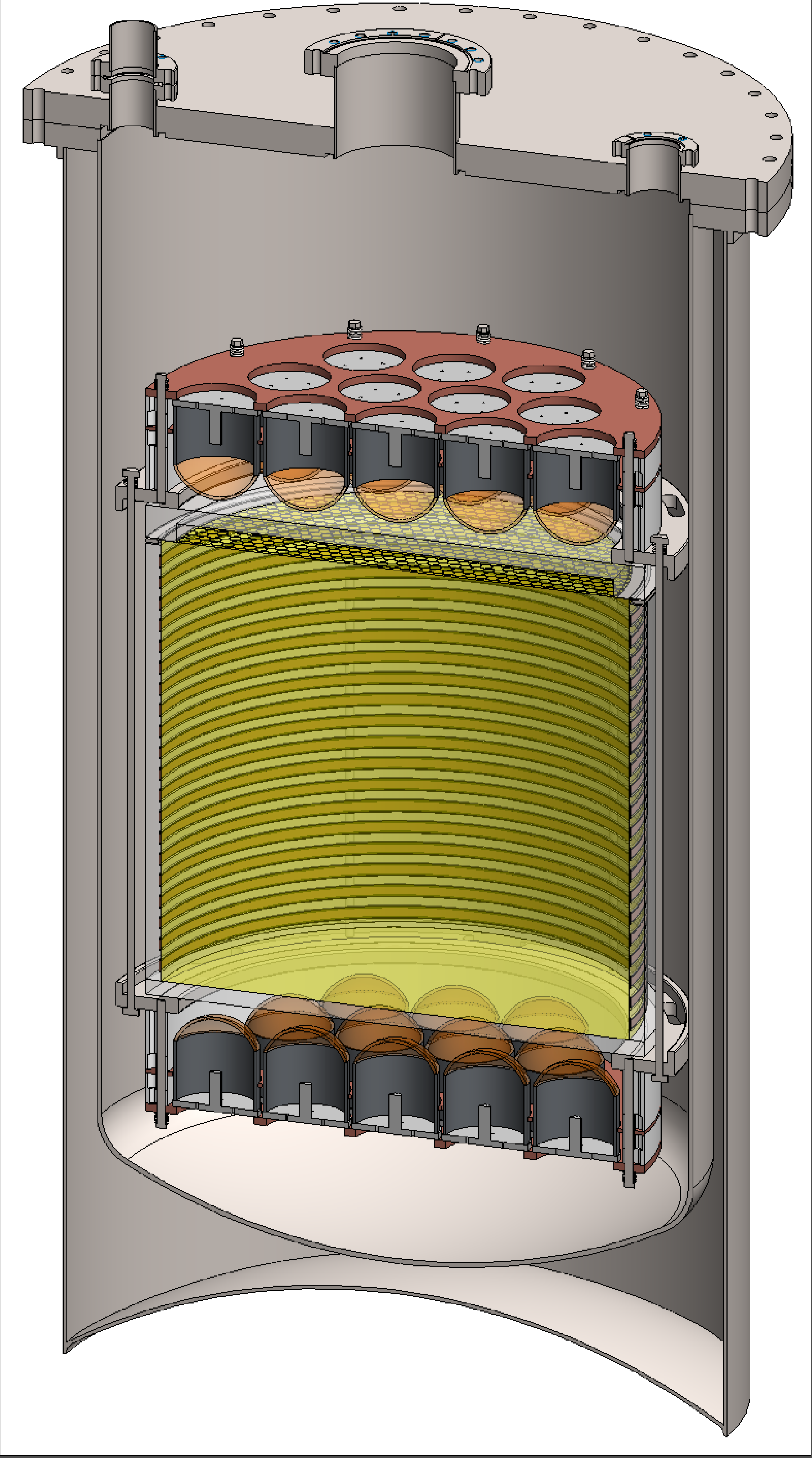
DarkSide

Program Goals

Technology



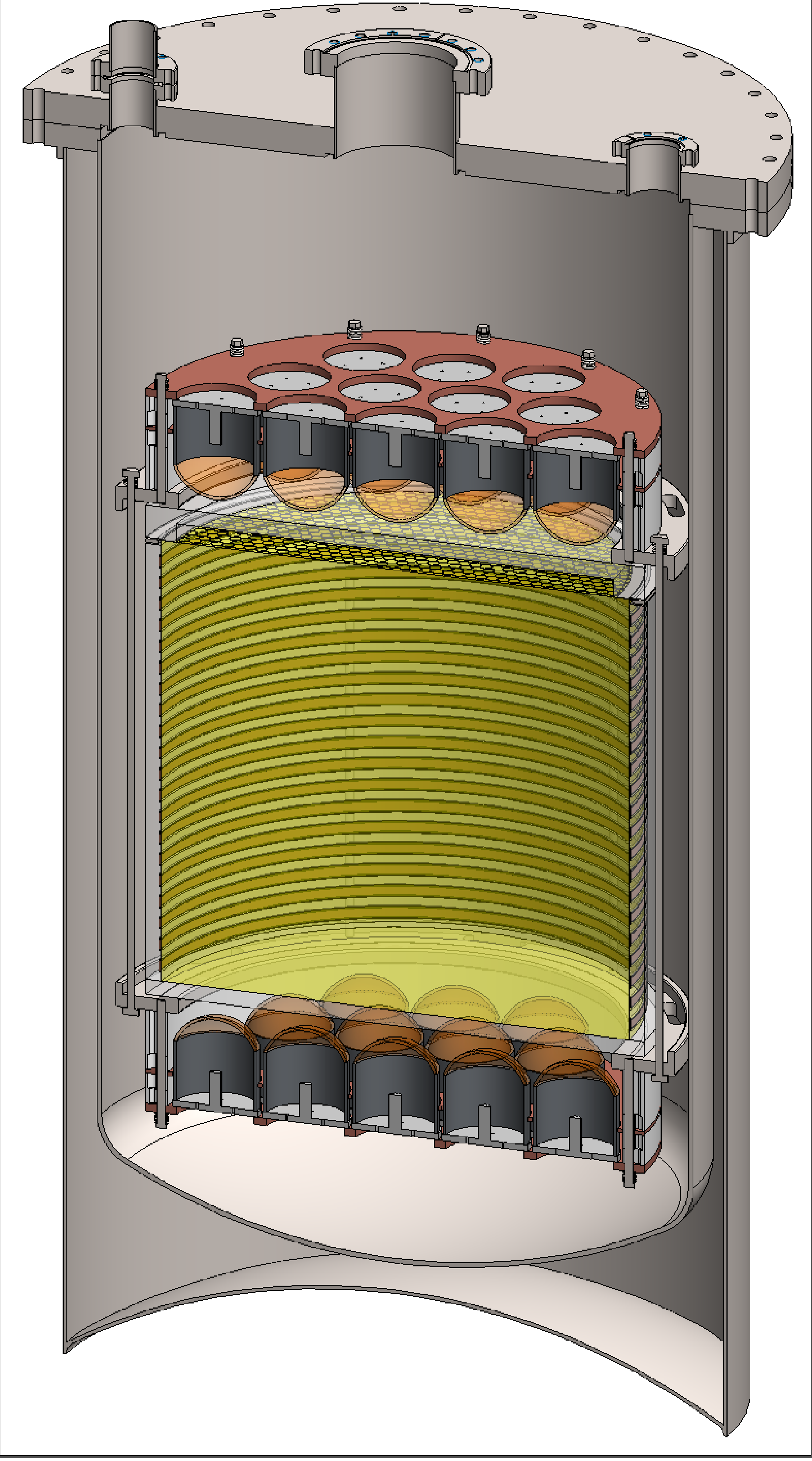
DarkSide

Program Goals

Technology

DarkSide ⊗ Borexino Counting Test Facility (CTF)

Implications for DM Searches @ LNGS



Status of DM Exploration

- Direct DM searches currently reporting ~tonne-day exposures
- Experiments in progress aiming for >= tens of tonne-day
- SUSY models suggest tonne-year exposures may be necessary

Challenges for Future DM Searches

1. Radioactivity reduction in active and passive detector parts
2. Powerful discrimination against residual radioactivity
3. Reduction of internal neutron sources (mainly photodetectors)
4. Mitigation of external neutron flux and rejection of residual external neutron events

How are these challenges met by DarkSide?

A. DarkSide's Depleted Argon (DAr) TPC and its new technology elements address the first three points with a powerful and scalable strategy

B. In addition, a re-configured CTF would allow external neutron background reduction to levels compatible with tonne-year sensitivity, even at a relatively shallow site like Gran Sasso.

Game Changing Technologies of DarkSide

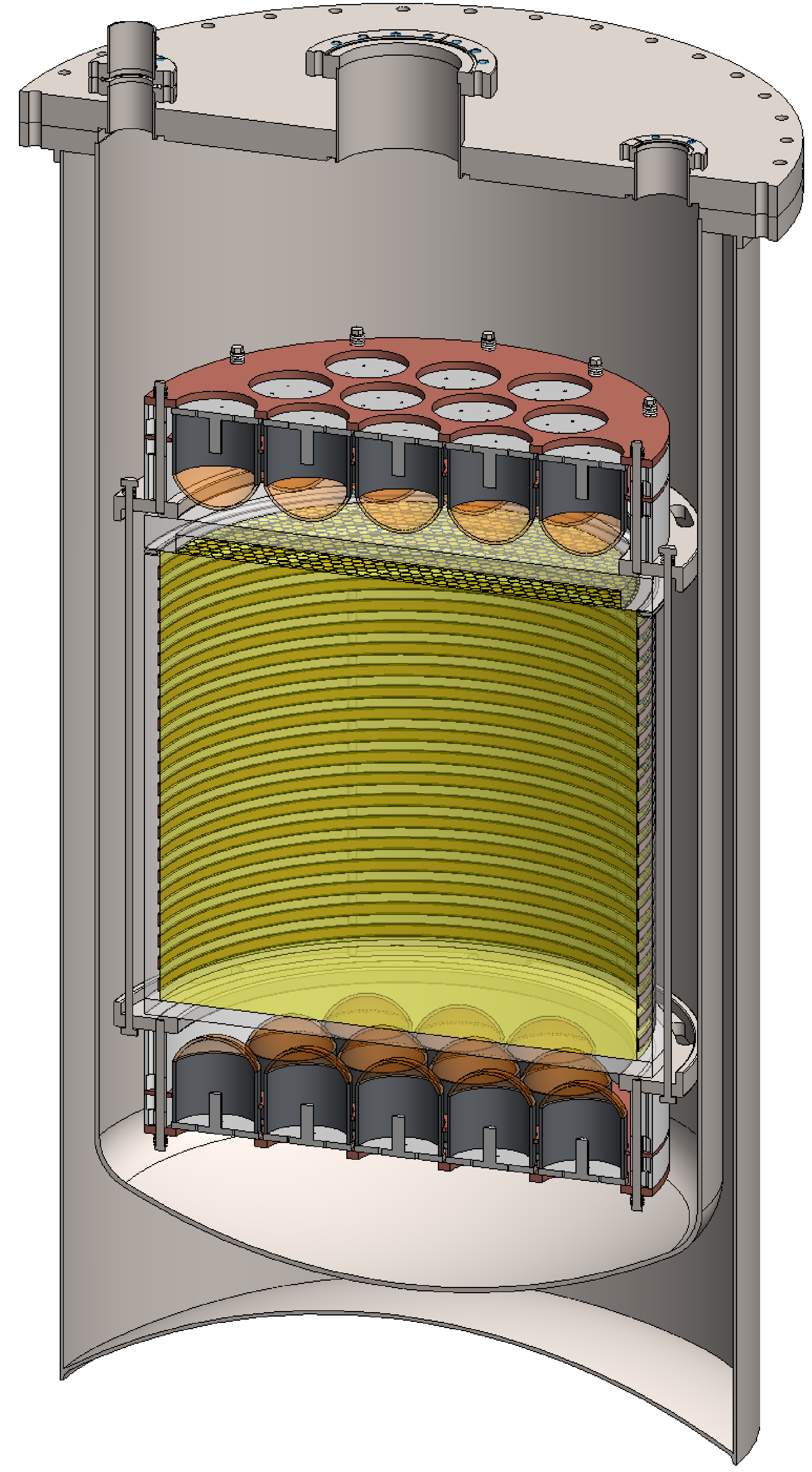
1. Depleted Argon from underground sources
2. High efficiency borated liquid scintillator neutron veto (>99.8% rejection efficiency for radiogenic neutrons)
3. QUPID photosensors
   - no background detected in best Ge
   - new photocathode with high QE at liquid argon temperature

DarkSide-50

- first implementation of the new technologies
- dual-phase TPC à la WARP
- 50 kg DAr active mass

sensitivity 10^{-45} cm^2 in 3-yrs background-free operation

demonstrate potential of the technology for multi-ton year background-free sensitivity



Discrimination in Argon

- LAr is one of the brightest scintillators known. Pulse shape of primary scintillation provides very powerful discrimination for NR vs. EM events:
  Rejection factor exceeds 10^8 for > 60 photoelectrons (Boulay & Hime 2004; Benetti et al. (WARP) 2006)

- Ionization drift is well established technology on very large scale detector. Ionization:scintillation ratio is a strong and semi-independent discrimination mechanism:
  Rejection factor ~10^2 (Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006)

- Spatial resolution from ionization drift localizes events, allowing rejection of multiple interactions, "wall events", etc.

- Two-phase LAr-TPC combines these characteristics into a powerful detection technique, as established by WARP

Why is depleted argon from underground crucial?

- Radioactive ^{39}Ar produced by cosmic rays in atmosphere
  - beta decays, $Q = 565$ keV, $t_{1/2} = 269$ years
- In atmospheric argon:
  - $^{39}Ar/Ar$ ratio 8×10^{-16}
  - specific activity 1 Bq/kg
- Consequences: atmospheric ^{39}Ar limits size of two-phase argon detectors to 500-1000 kg due to ^{39}Ar events pile-up

Why is depleted argon from underground crucial?

- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!
- Low background from ^{14}C crucial for observation of low energy neutrinos with organic liquid scintillators
  - Borexino: hydrocarbons from deep underground reservoirs results in low cosmogenic ^{14}C
- Motivated by success in Borexino, investigation of underground sources of Ar
  - ^{39}Ar production by cosmic rays strongly suppressed underground

Underground DAr: a Reality

- Princeton group demonstrated collection of underground Ar with <.04 Bq/kg ^{39}Ar in 10's-of-kg quantity of DAr from natural gas wells in USA
- Cryogenic distillation to remove N_2, He, etc., about to be commissioned at Fermi Lab
- These achievements enable construction of multi-ton DAr TPCs for direct DM searches

Underground Source

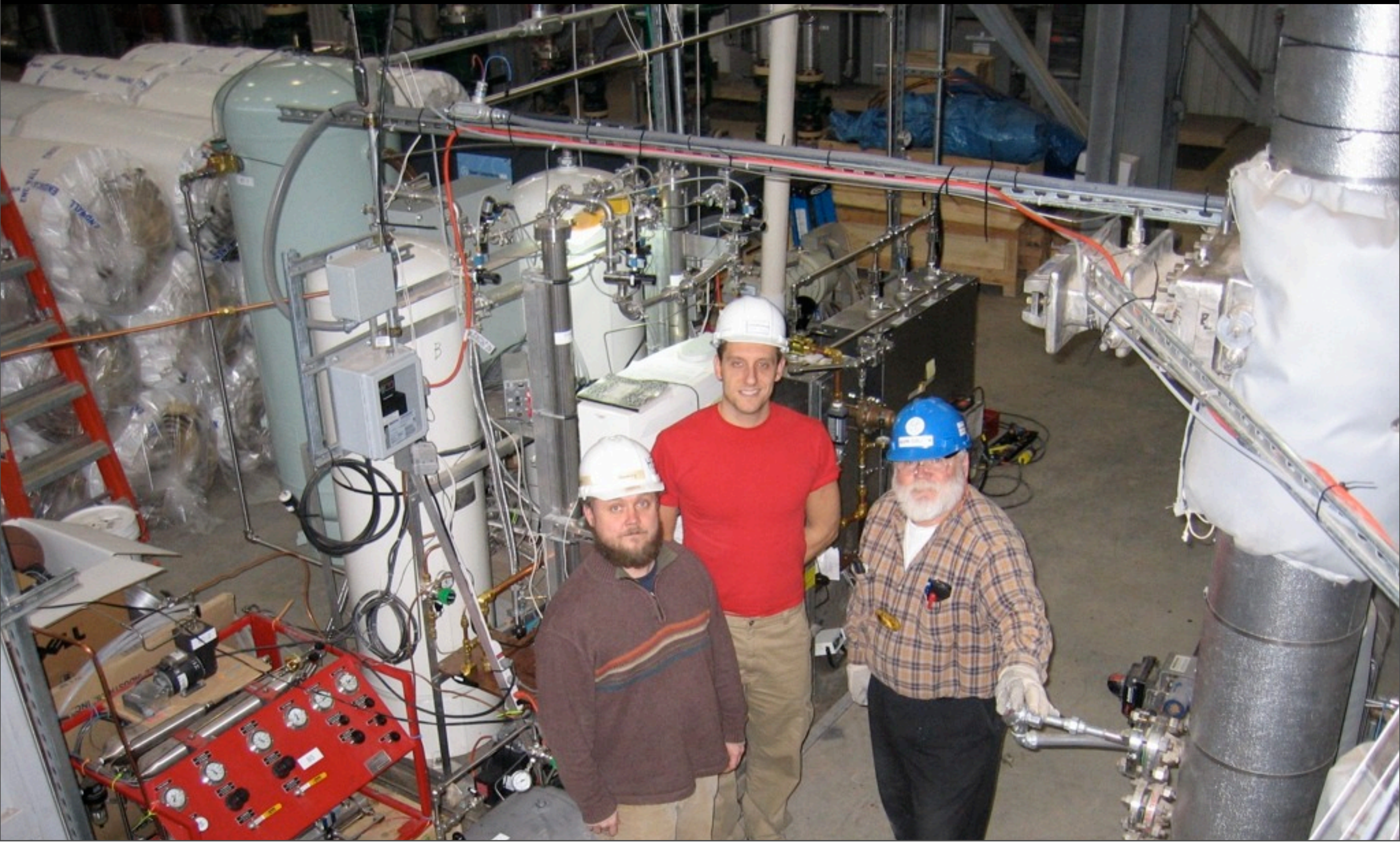
- Kinder Morgan Doe Canyon complex (Cortez, CO)
  - Ar ~400 ppm in underground gas
- ^{39}Ar level: factor 25 reduction or greater
- Total Ar production capacity: 3 tons per day

Extraction Technology

- Extraction technology for gas separation developed starting from Rn scrubber nuilt in Princeton for construction of BX Vessels (Calaprice, Pocar, Shutt)
- Extraction plant entirely designed and built by Princeton personnel
- Starting from Ar ~400 ppm in underground gas, arriving at Ar ~6% in crude Ar (balance N_2, He)
- Significant capital investment from NSF, 4 years development plan
- First continuous campaign started Feb 2010, goal 100 kg

Princeton Extraction Plant

Achieved 1.2 kg/day, Collected ~30 kg



Extraction Upgrade Plans

- Plan to expand production capacity to 20 kg per day in 2011
- Engineering of plant expansion already started
- New plant nominally capable of producing ~1 ton in two months!!!

Princeton Prototype Cryogenic Distillation Column @ FNAL PAB

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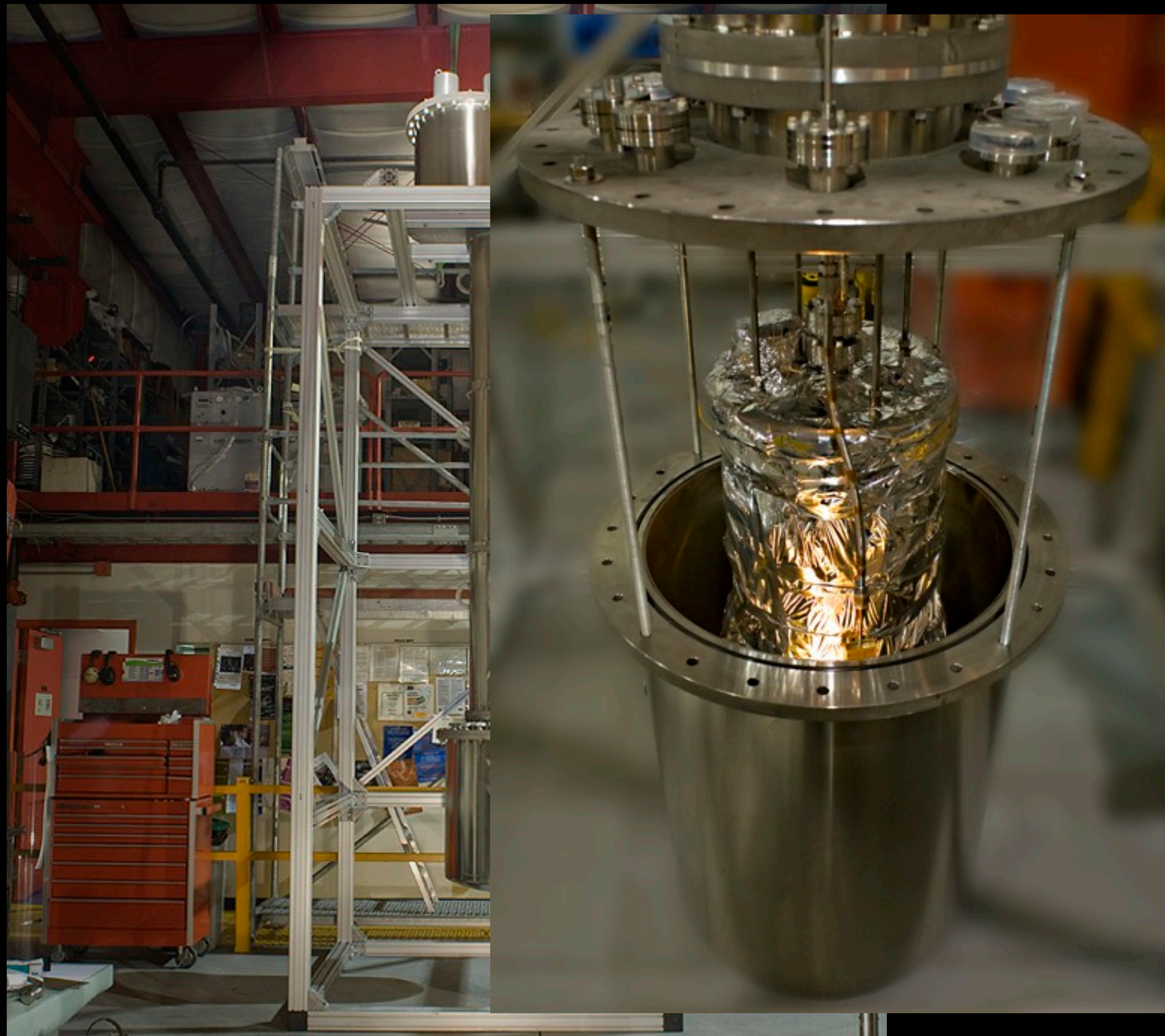
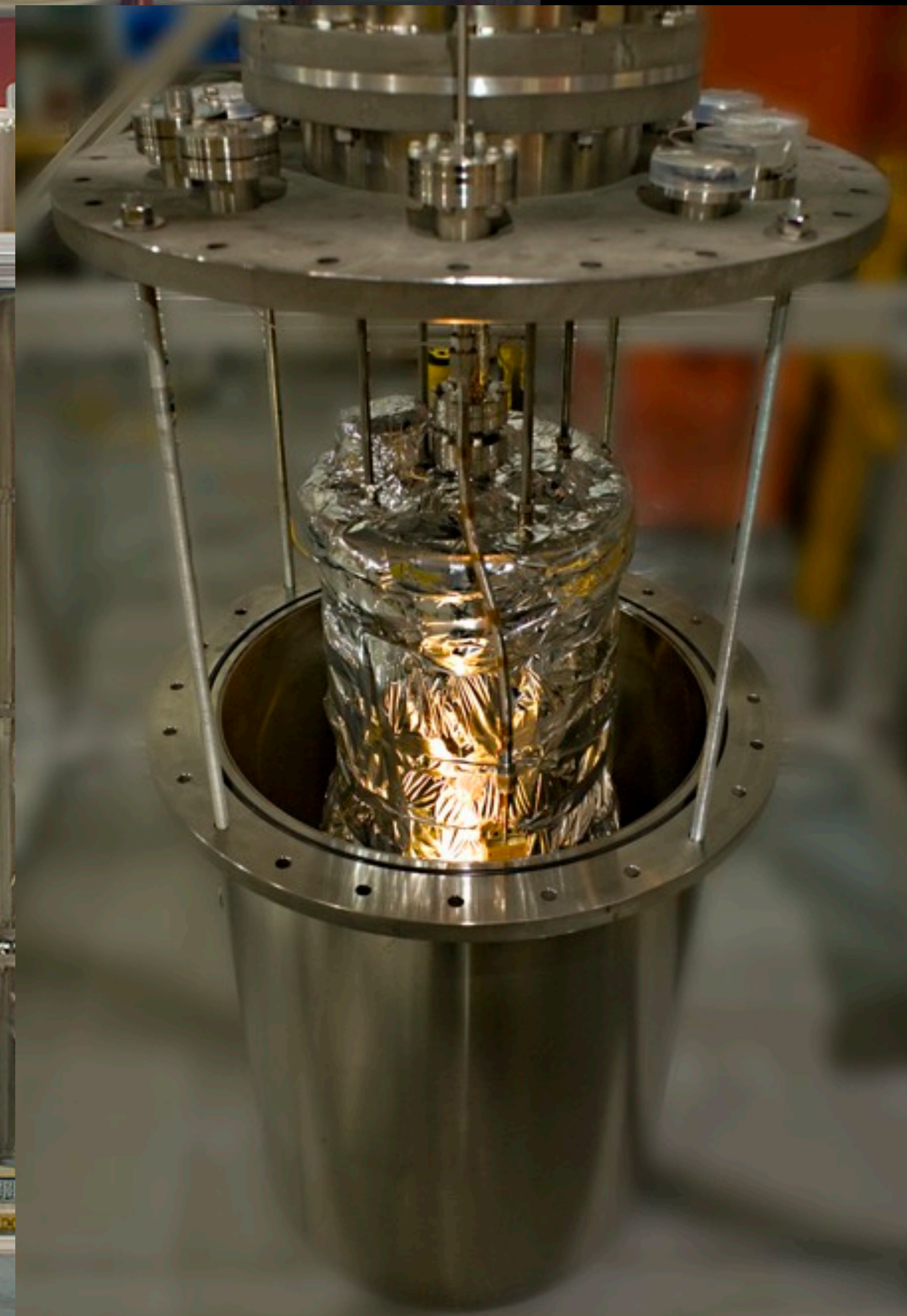
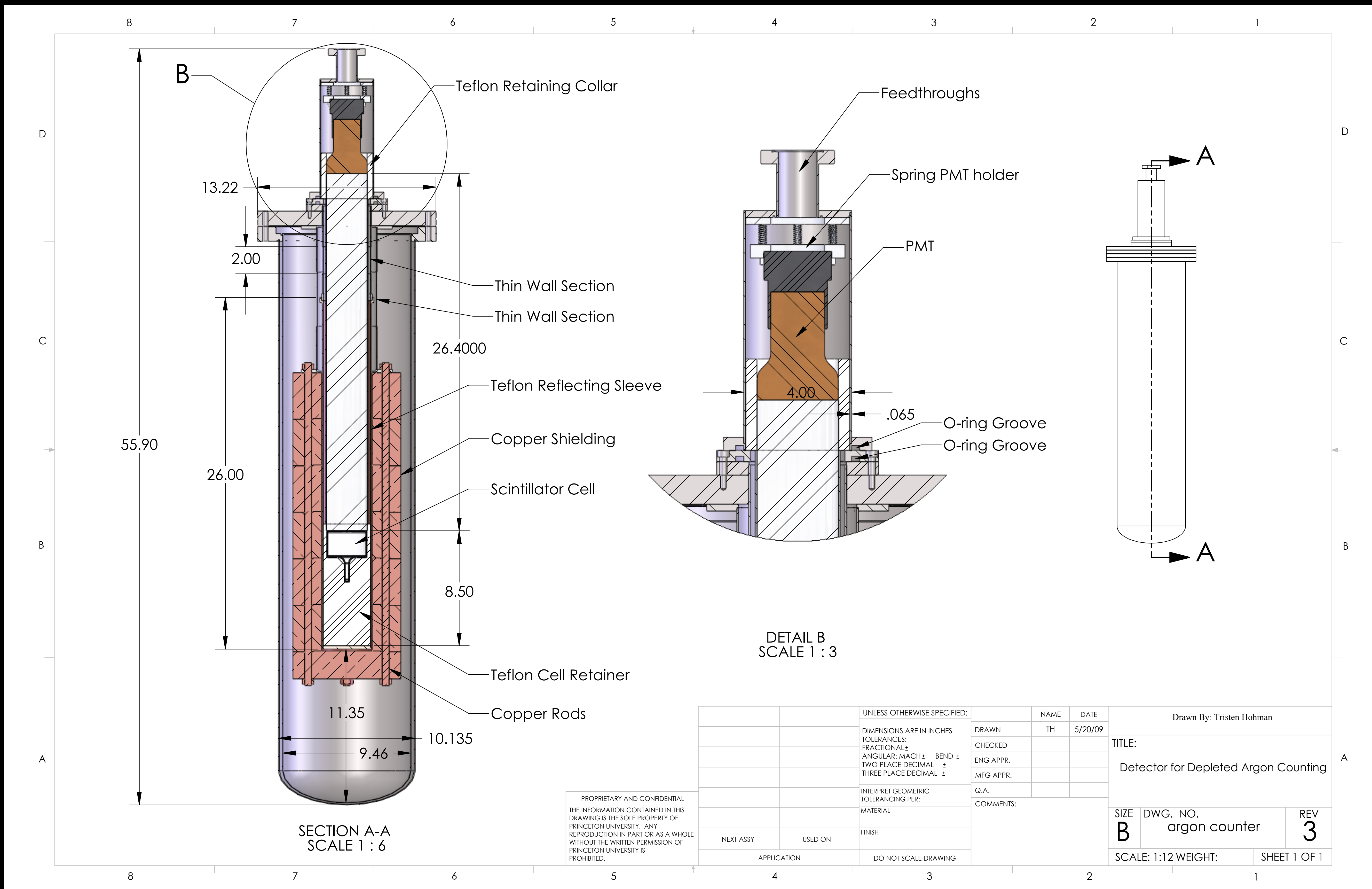


Princeton Prototype Cryogenic Distillation Column @ FNAL PAB



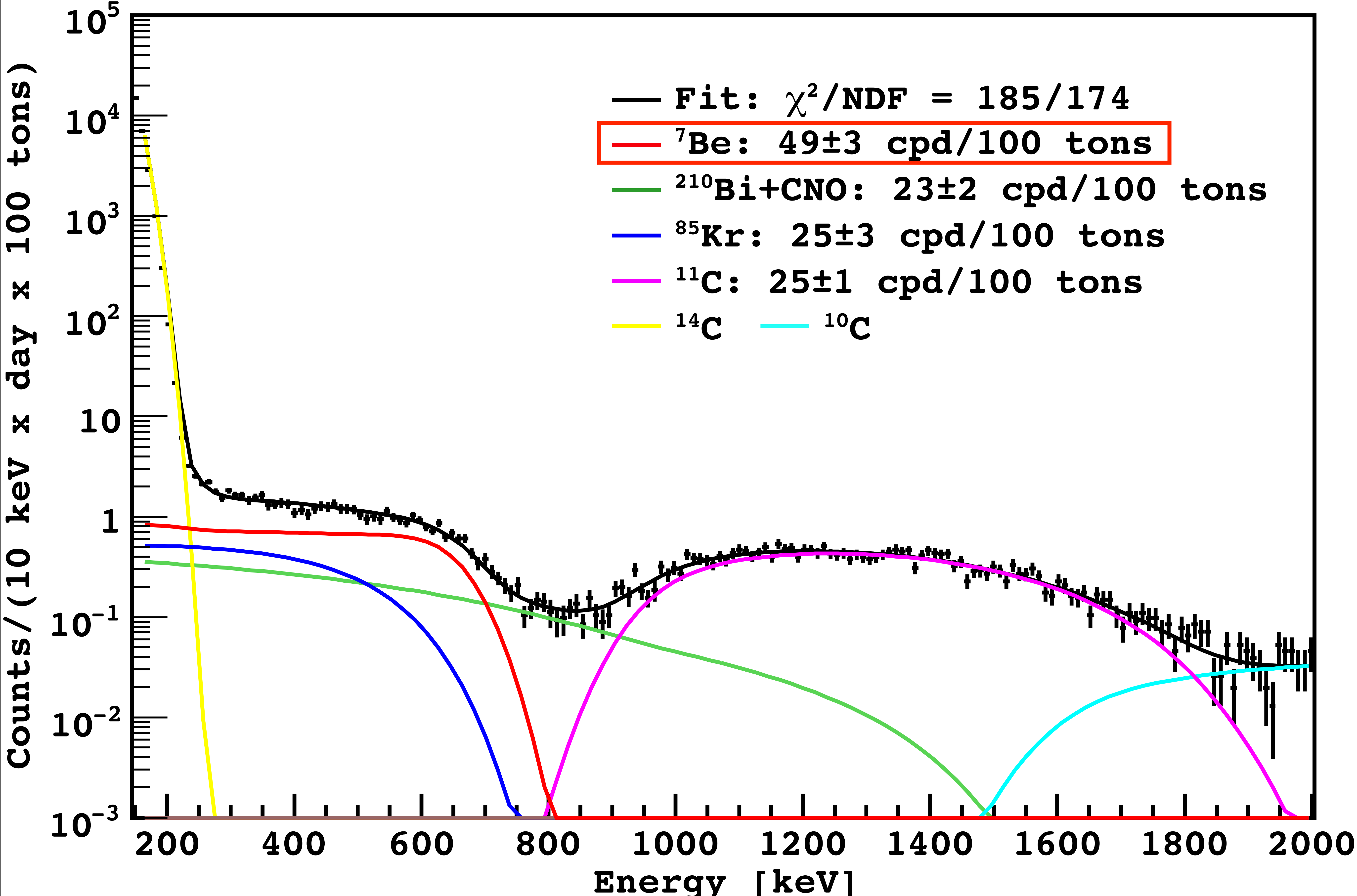
Counter for Underground DAr Measurement



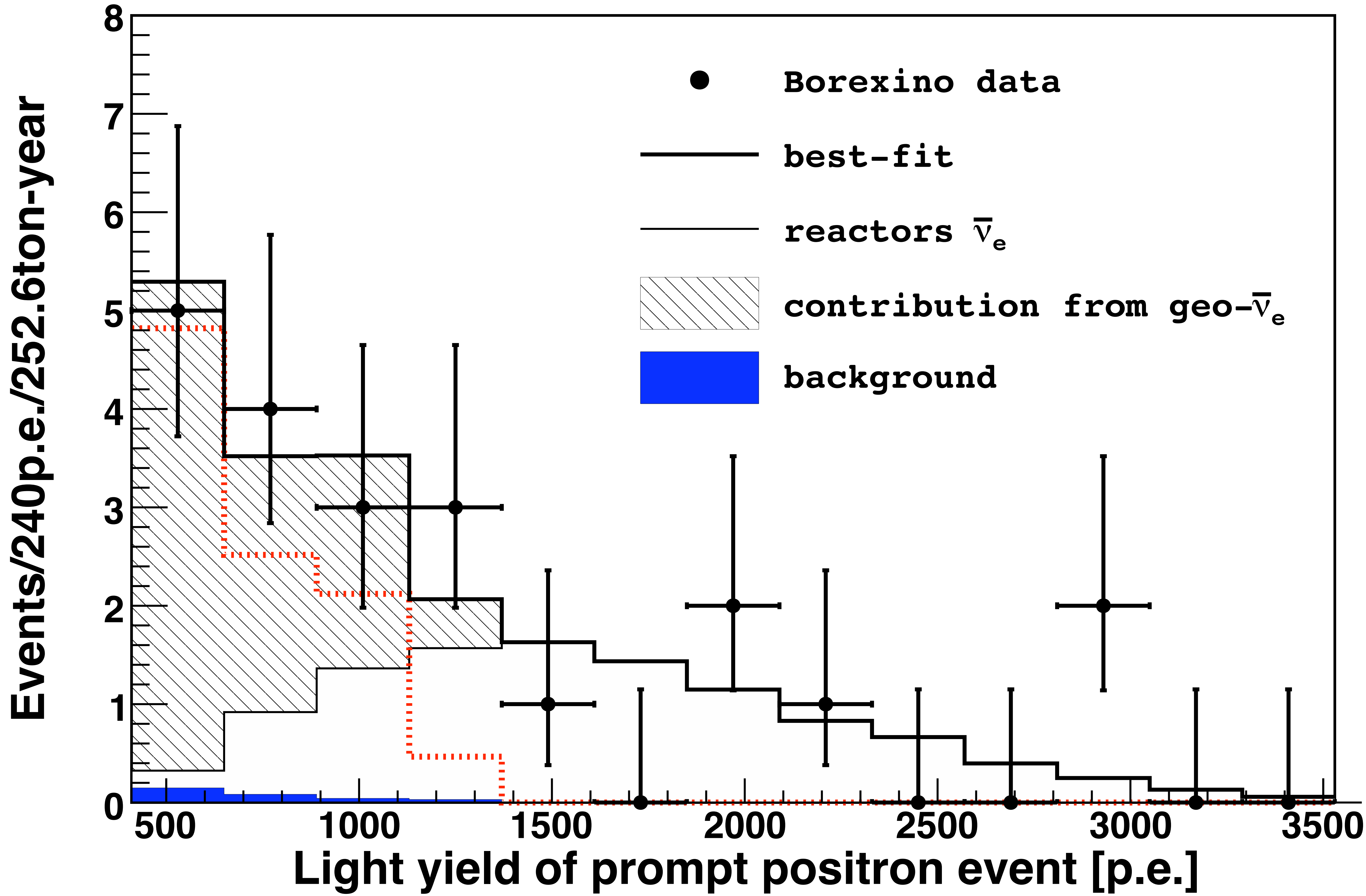
Neutron Veto

- Our approach (F. Calaprice): rely on (n,α) on ^{10}B
- Alpha particle extremely low range
- Alpha particle can be observed using borated liquid scintillator ... remember BOREX?
- 99.8% efficiency for radiogenic neutrons with ~1 m thick shield
- Many 9's of efficiency possible with thicker shields for radiogenic neutrons not captured within detector

^{7}Be Results: 192 Days



Geo-anti-ν_e

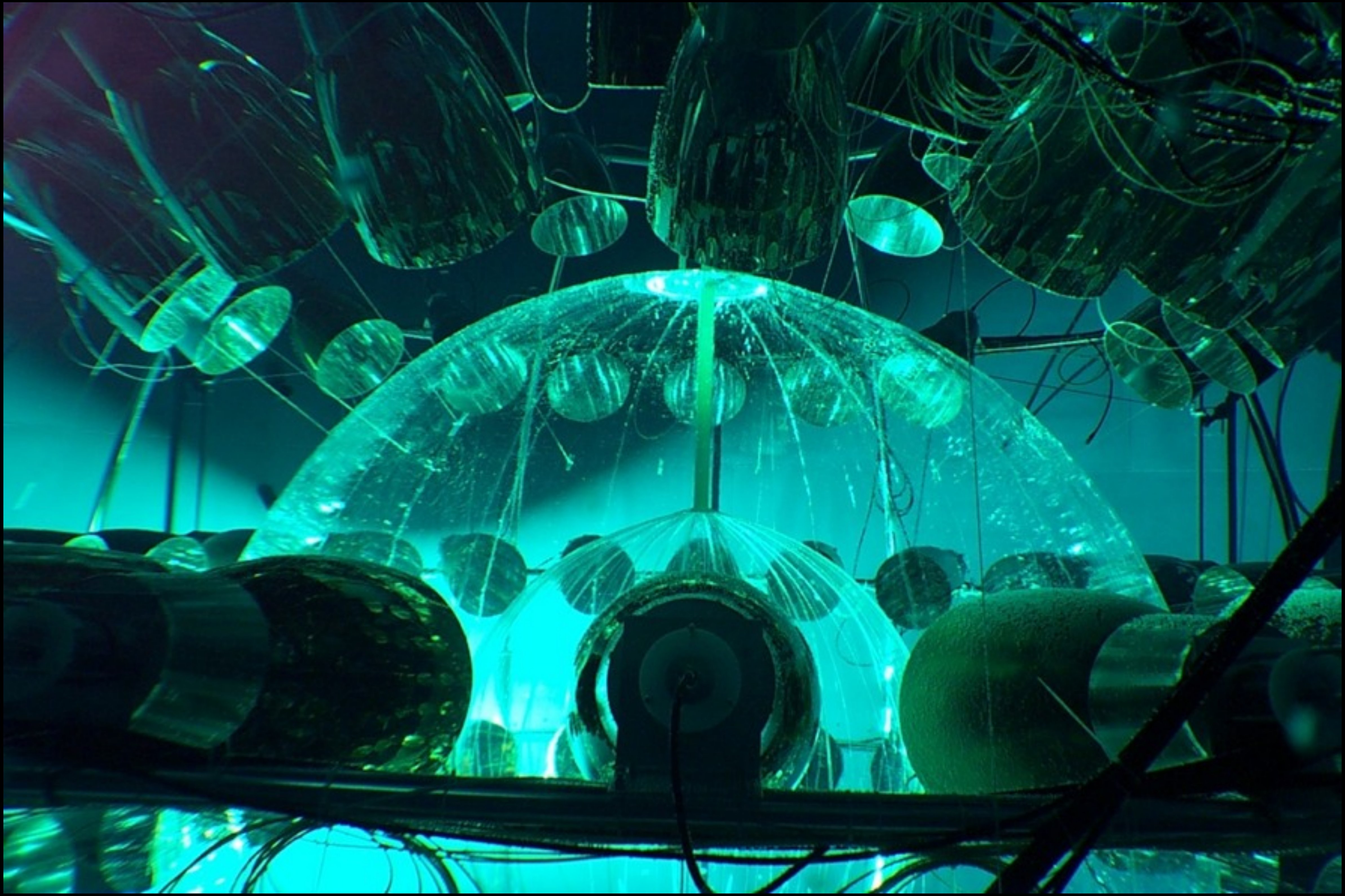


Borexino data
best-fit
reactors $\bar{\nu}_e$
contribution from geo-$\bar{\nu}_e$
background
Events/240p.e./252.6ton-year
Light yield of prompt positron event [p.e.]
0
1
2
3
4
5
6
7
8
500
1000
1500
2000
2500
3000
3500

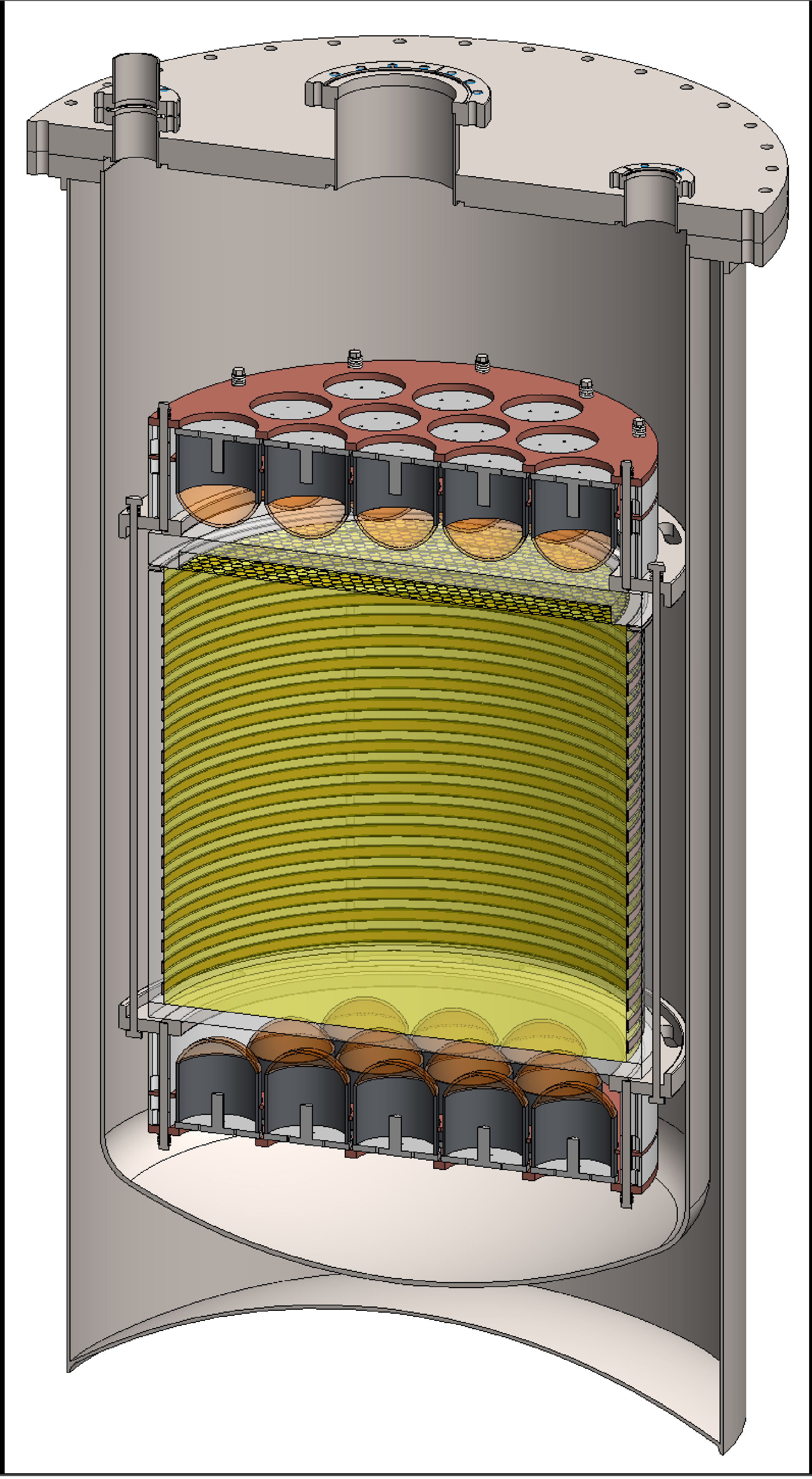
Calaprice's Talk: Summary

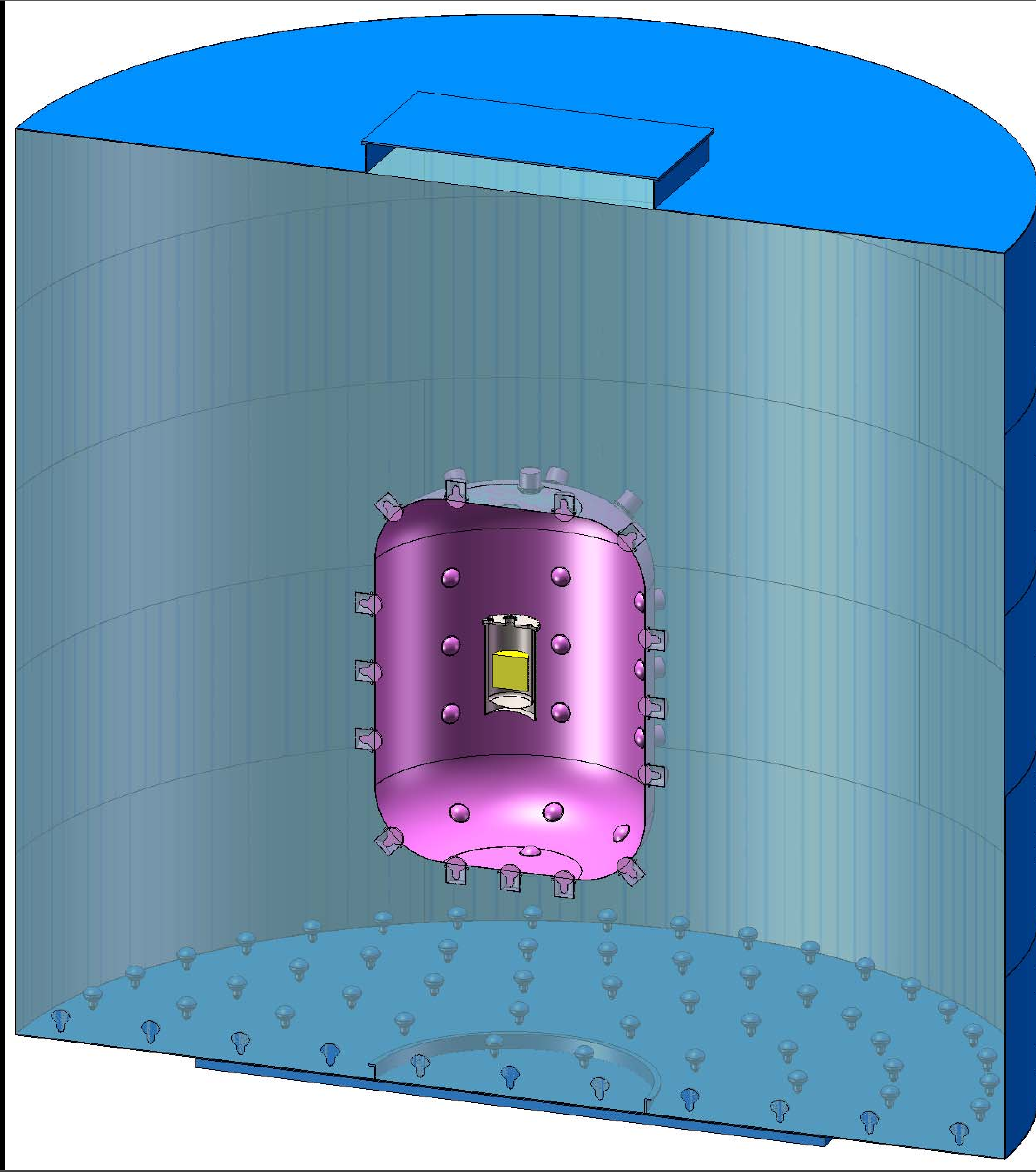
- Possibility to conduct high sensitivity DM searches at shallow depth (LNGS ~3,600 m.w.e.) questioned for long time in DM community
- Possibility of achieving a background of ~10^{-48}-10^{-49} cm^2 at shallow LNGS depth can be addressed experimentally using current Borexino data
  - Central role of technologies and facilities developed for BX
- It is possible to conduct **ultimate** DM search at LNGS!

Proposal of DarkSide to Borexino



Conduct DarkSide Development Test within CTF tank





Benefits to Borexino

- CTF used so far for testing scintillator for Borexino. CTF vessel built by Princeton group
- Upgraded sintillator screening facility required for next, extremely challenging steps in Borexino program (*pp*, *pep*, CNO neutrinos; higher precision ^{7}Be, ^{8}B, geo-anti-ν_e)
- Combine active scintillator veto for DarkSide and new screening facility for BX in CTF tank; extremely beneficial to BX program

Benefits to DarkSide

- Integration of water and scintillator purification plants (distillation column, counter-current water extraction column, stripping column)
- Availability of second purification plant under construction by Princeton University for purification of scintillator fluors
- Unique expertise of Borexino collaboration in handling of scintillators and low background techniques

Background of DarkSide/CTF

- Cosmogenic Neutrons: <0.1 events/(ton-yr)
- Radiogenic Neutrons: <0.1 events(ton-yr)

DarkSide

UMass Amherst

Arizona State University

Augustana College

Black Hills State University

Fermilab

University of Houston

University of Notre Dame

Princeton University

Temple University

UCLA

Augustana College, USA Prof. Drew Alton

Black Hills State University, USA Prof. Dan Durben, Prof. Kara Keeter, Prof. Michael Zehfus

Fermi National Accelerator Laboratory, USA Dr. Steve Brice, Dr. Aaron Chou, Dr. Jeter Hall, Dr. Hans Jostlein, Dr. Stephen Pordes, Dr. Andrew Sonnenschein

Princeton University, USA Jason Brodsky, Prof. Frank Calaprice, Huajie Cao, Alvaro Chavarria, Ernst de Haas, Prof. Cristiano Galbiati, Eng. Augusto Goretti, Eng. Andrea Ianni, Tristen Hohman, Ben Loer, Pablo Mosteiro, Prof. Peter Meyers, Eng. David Montanari, Allan Nelson, Eng. Robert Parsells, Richard Saldanha, Eng. William Sands, Dr. Alex Wright, Jingke Xu

Temple University, USA Prof. Jeff Martoff, Prof. Susan Jansen-Varnum, Christy Martin, John Tatarowicz

University of California at Los Angeles, USA Prof. Katsushi Arisaka, Prof. David Cline, Chi Wai Lam, Kevin Lung, Prof. Peter F. Smith, Artin Teymourian, Dr. Hanguo Wang

University of Houston, USA Prof. Ed Hungerford and Prof. Lawrence Pinsky

University of Massachusetts at Amherst, USA Prof. Laura Cadonati and Prof. Andrea Pocar

University of Notre Dame, USA Prof. Philippe Collon, Daniel Robertson, Christopher Schmitt

University of Virginia, USA Prof. Kevin Lehmann

Other European Groups Have Expressed Interest

INFN Laboratori Nazionali del Gran Sasso
INFN and Università degli Studi Genova
INFN and Università degli Studi Milano
INFN and Università degli Studi Napoli
Joint Institute for Nuclear Research, Dubna
RRC Kurchatov Institute, Moscow
St. Petersburg Nuclear Physics Institute
Technische Universität München

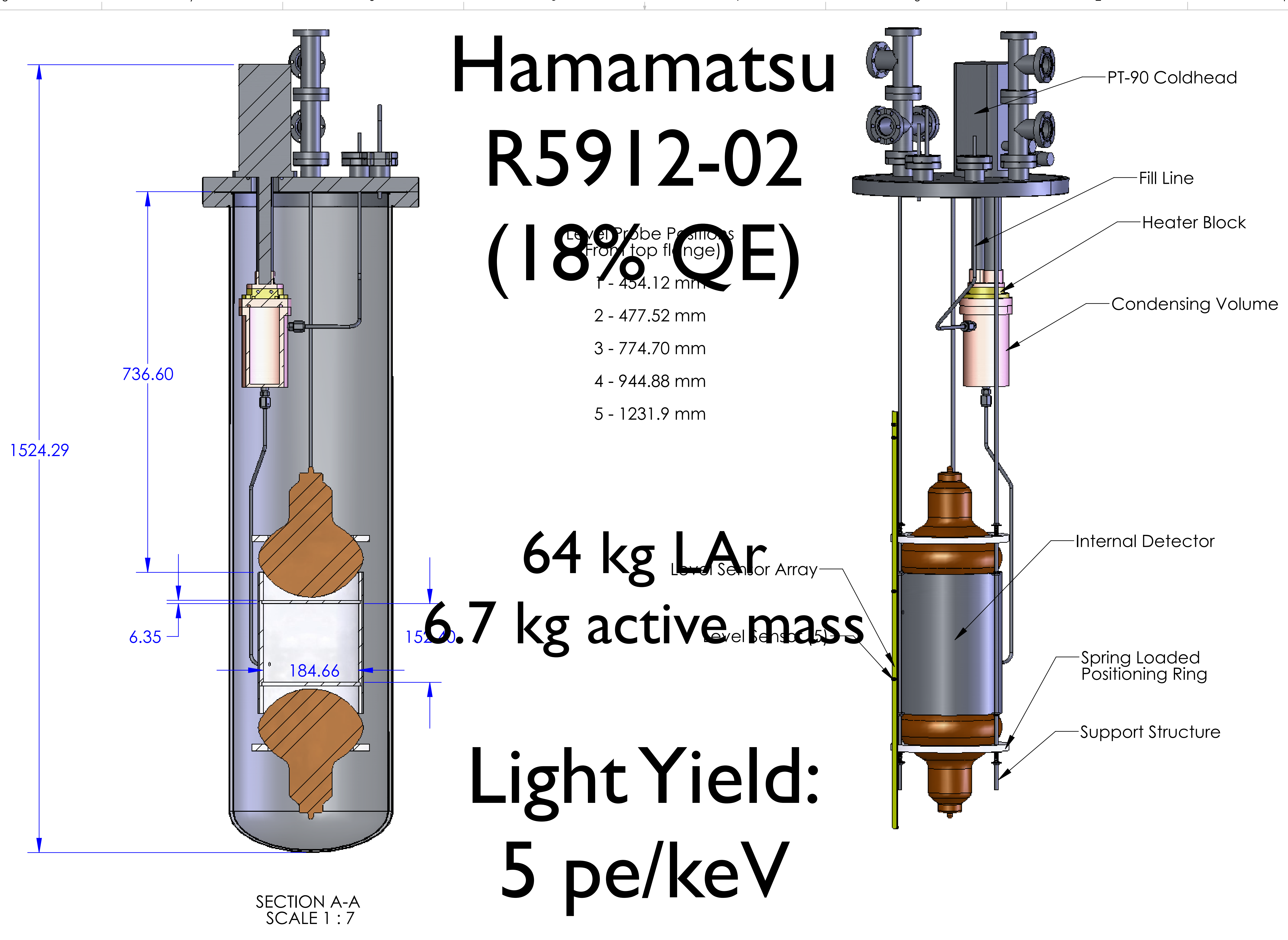
The DarkSide Quest for High Light Yield in Argon Detectors

Hamamatsu R5912-02 (18% QE)

64 kg LAr

6.7 kg active mass

Light Yield: 5 pe/keV

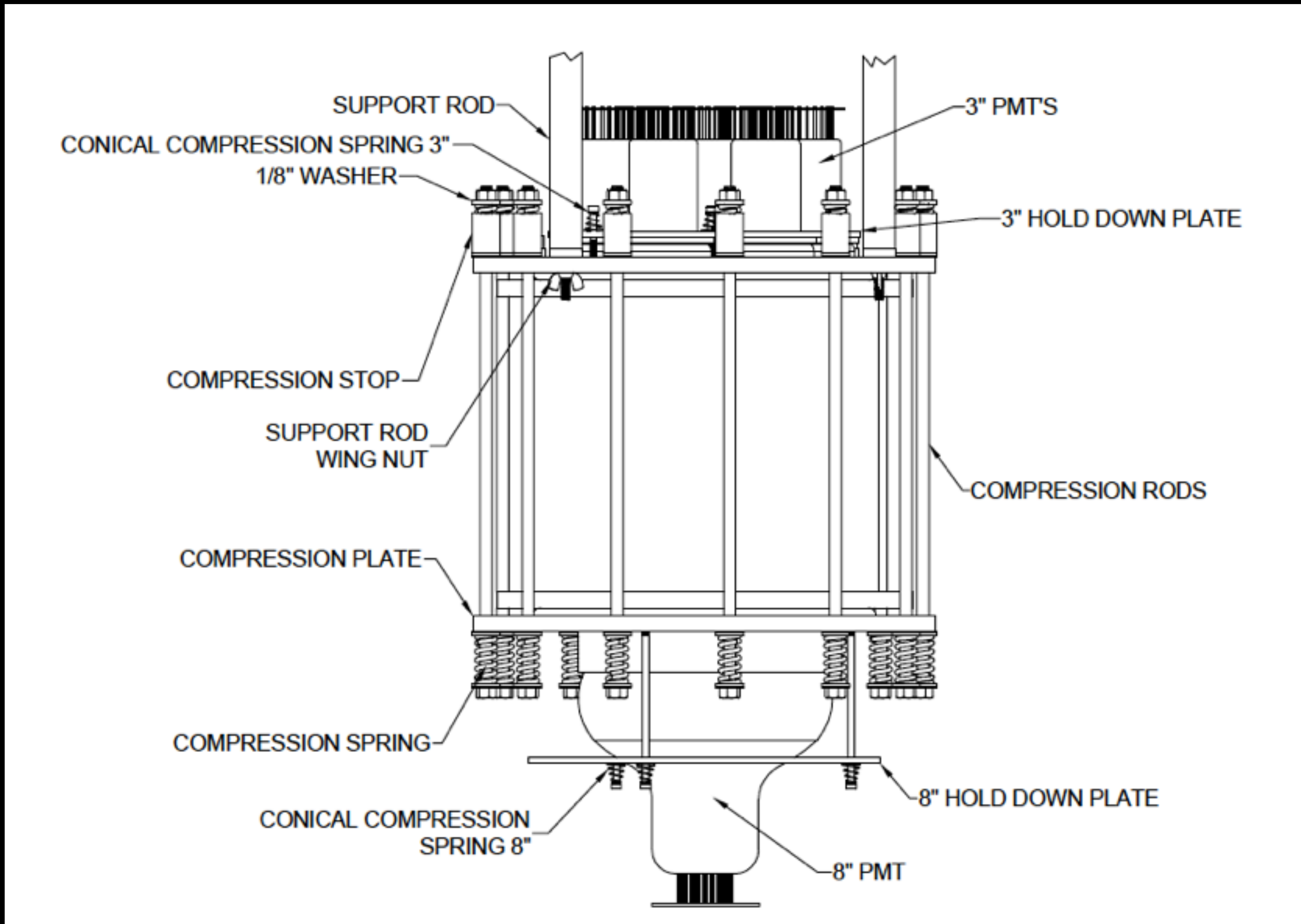


Hamamatsu R11065 (32% QE)

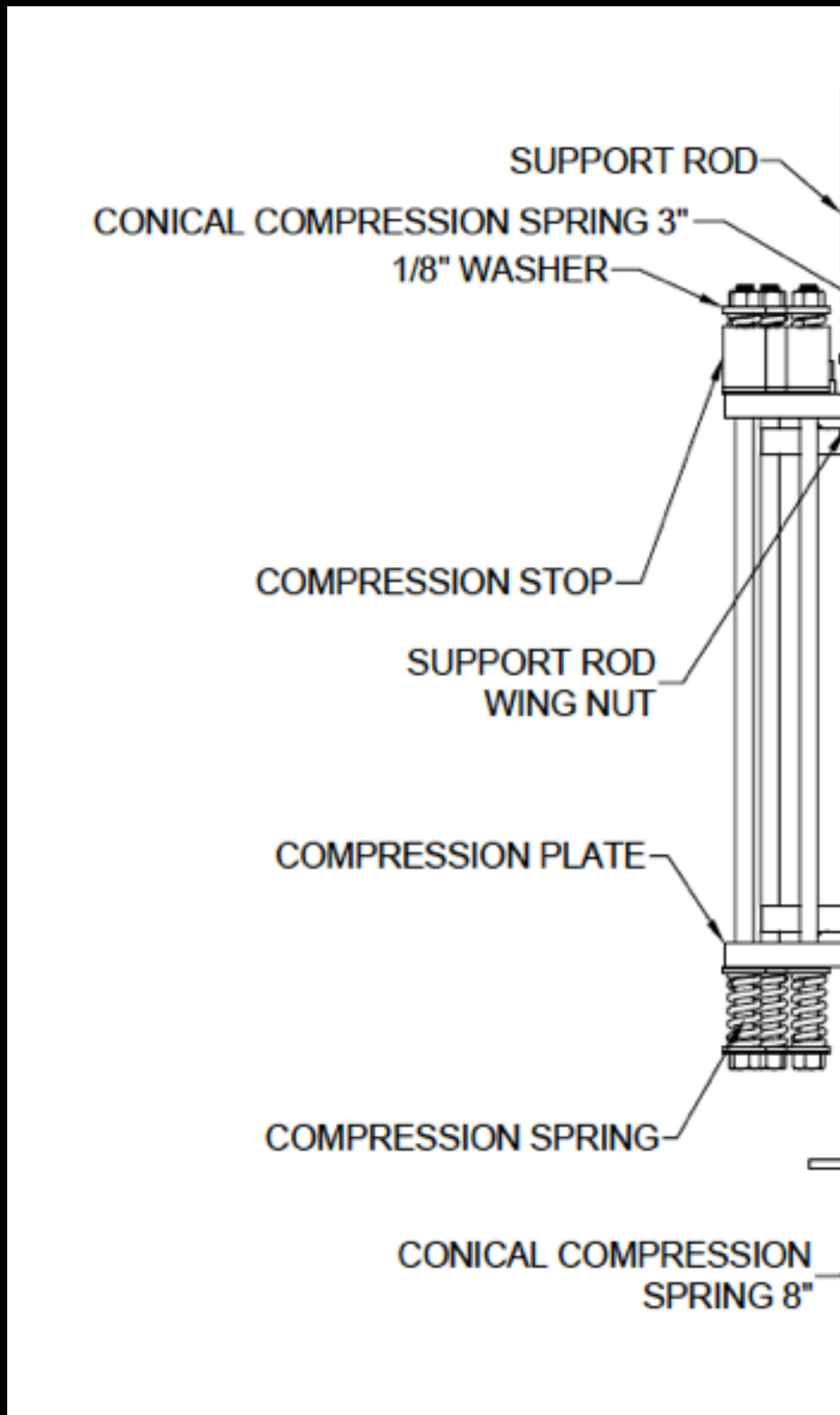
2 kg LAr
0.7 kg active mass

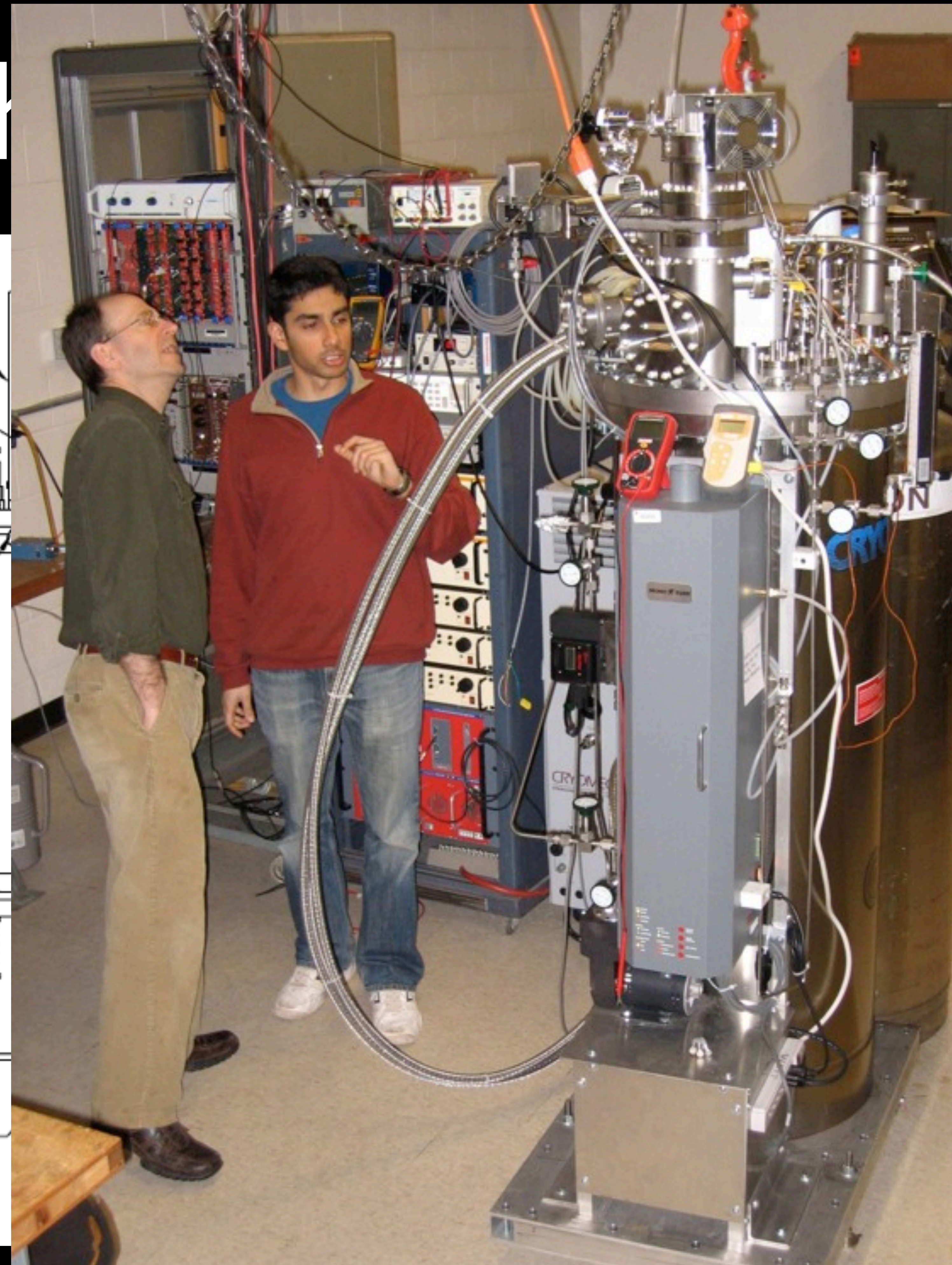
Light Yield: 7.3±0.2 p.e./keV

20-kg 2-Phase Detector



20-kg 2-Ph


SUPPORT ROD
CONICAL COMPRESSION SPRING 3"
1/8" WASHER
COMPRESSION STOP
SUPPORT ROD
WING NUT
COMPRESSION PLATE
COMPRESSION SPRING
CONICAL COMPRESSION
SPRING 8"



DarkSide Photosensors

- EM backgrounds in DarkSide are suppressed to the necessary levels for tonne-year sensitivity by ultra-pure DAr discrimination
- Internal neutron backgrounds (mostly from (α,n) in conventional PMTs) would still interfere with tonne-year sensitivity
- Zero background operation of 50 kg detector possible with metal-bulb Hamamatsu R11065
- DarkSide collaboration procured a set of Hamamatsu R11065 for first installation

DarkSide & QUPIDs

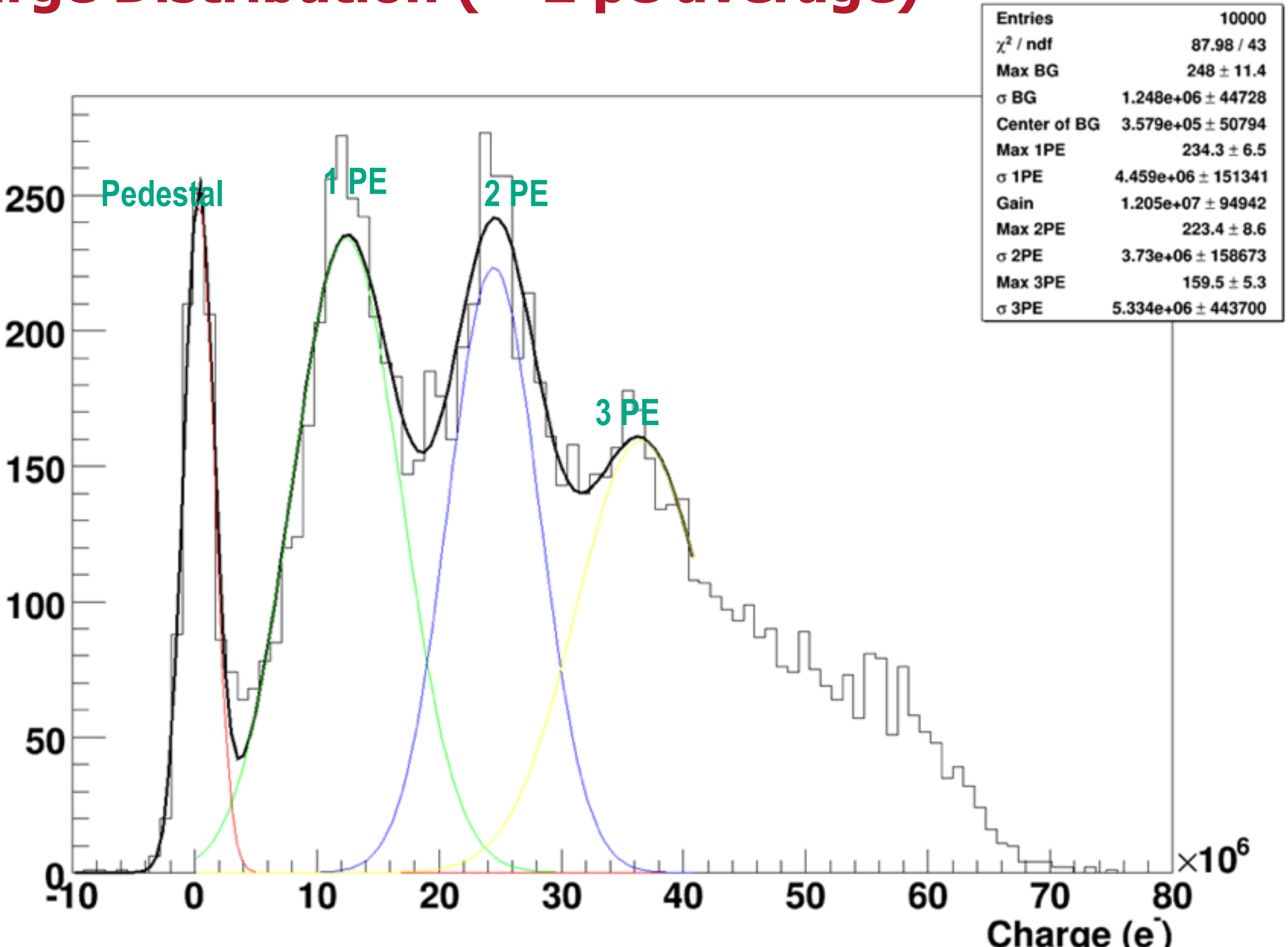
- However, UCLA group has worked with Hamamatsu to develop and bring to manufacture the QuPID photosensor
- Fused Silica envelope + APD
  - no dynodes, minimal glass-metal seals
  - no need for a "PMT base"
- Therefore no detectible radioactivity in 3 mo. GATOR exposure.

DarkSide & QUPIDs

- Excellent single (and 2-, 3-, 4-) PE response
- >30% QE at LAr temperature
- Prototypes already delivered from Hamamatsu, mass production process development completed
- Routine delivery to commence soon - first implementation reserved for DarkSide and XENON collaborations
- Use of QUPIDs removes the dominant internal neutron source in DarkSide, reducing this background below that required for tonne-year sensitivity

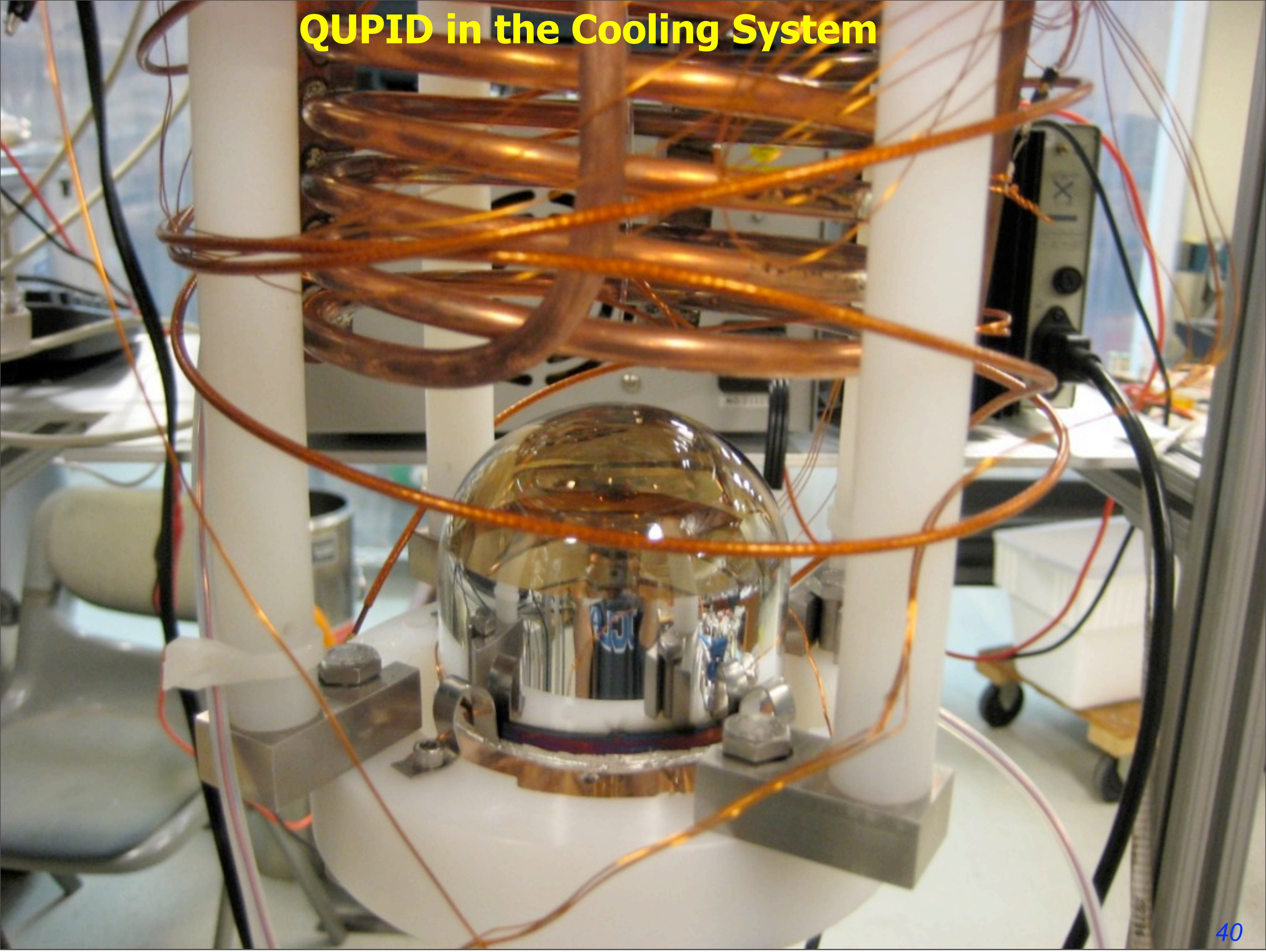
New 3" QUPID (Production Version)

Charge Distribution (~ 2 pe average)



Hamamatsu Data

QUPID in the Cooling System



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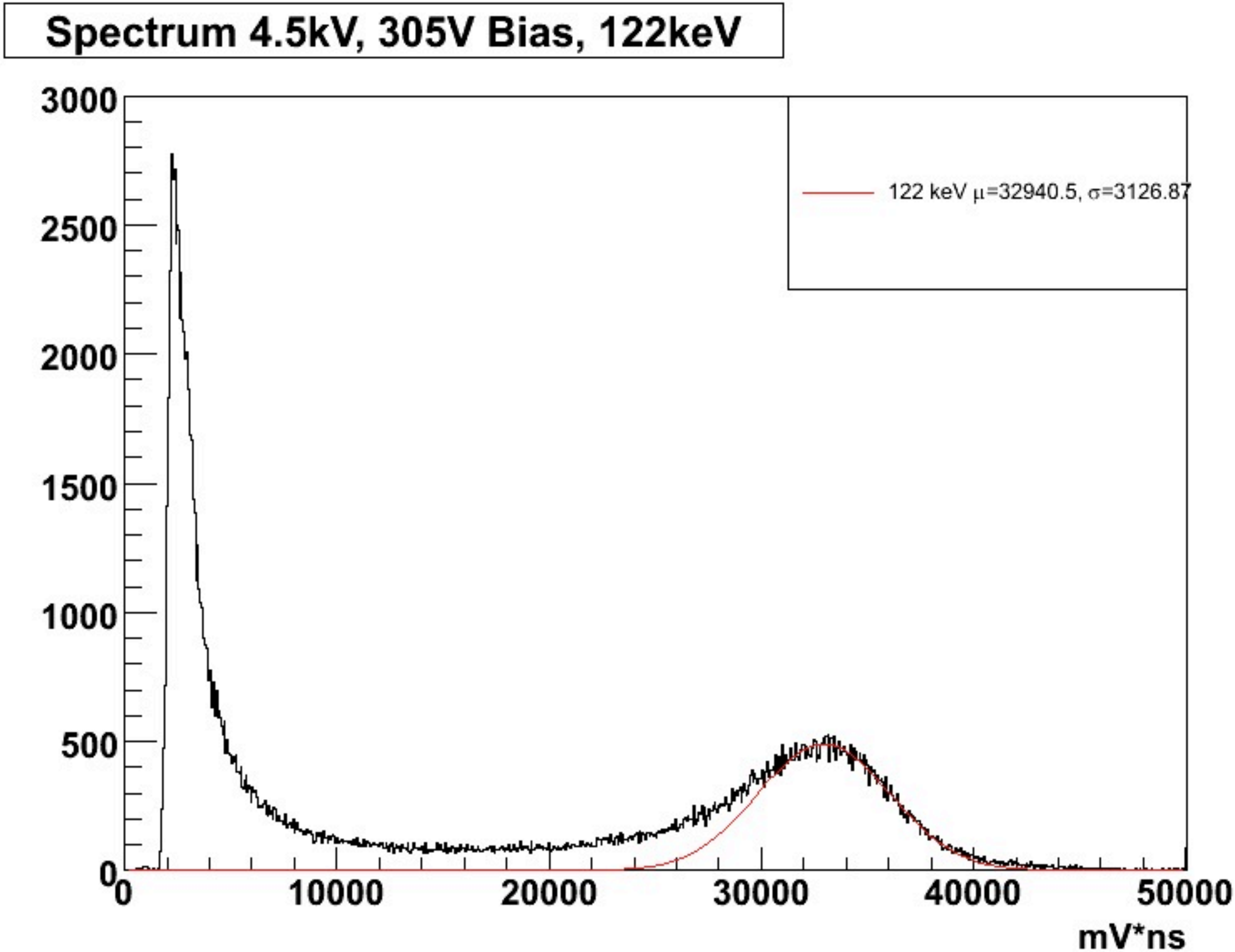
The first Scintillating lights detected by QUPID from ^{57}Co in Liquid Xenon



Recalling the Program Goal

- Bring together three innovative techniques
  1. Depleted Argon from underground sources, reduced by factor 25 or more
  2. 3” QUPID low background photosensors
  3. High efficiency borated liquid scintillator neutron veto (>99% possible!)

Perspectives and Future

- Define and establish technical basis for multi-ton detectors
- Goal is to reach zero background with very large exposure
  - Many tons fiducial target
  - Many years of background-free exposure
- Very large scale dark matter detectors can be built and operated at LNGS using two technologies already developed at LNGS (BX scintillator and two-phase depleted argon)


The End