The DarkSide Program

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Presentation

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Image Credit: Fermilab

DarkSide Collaboration

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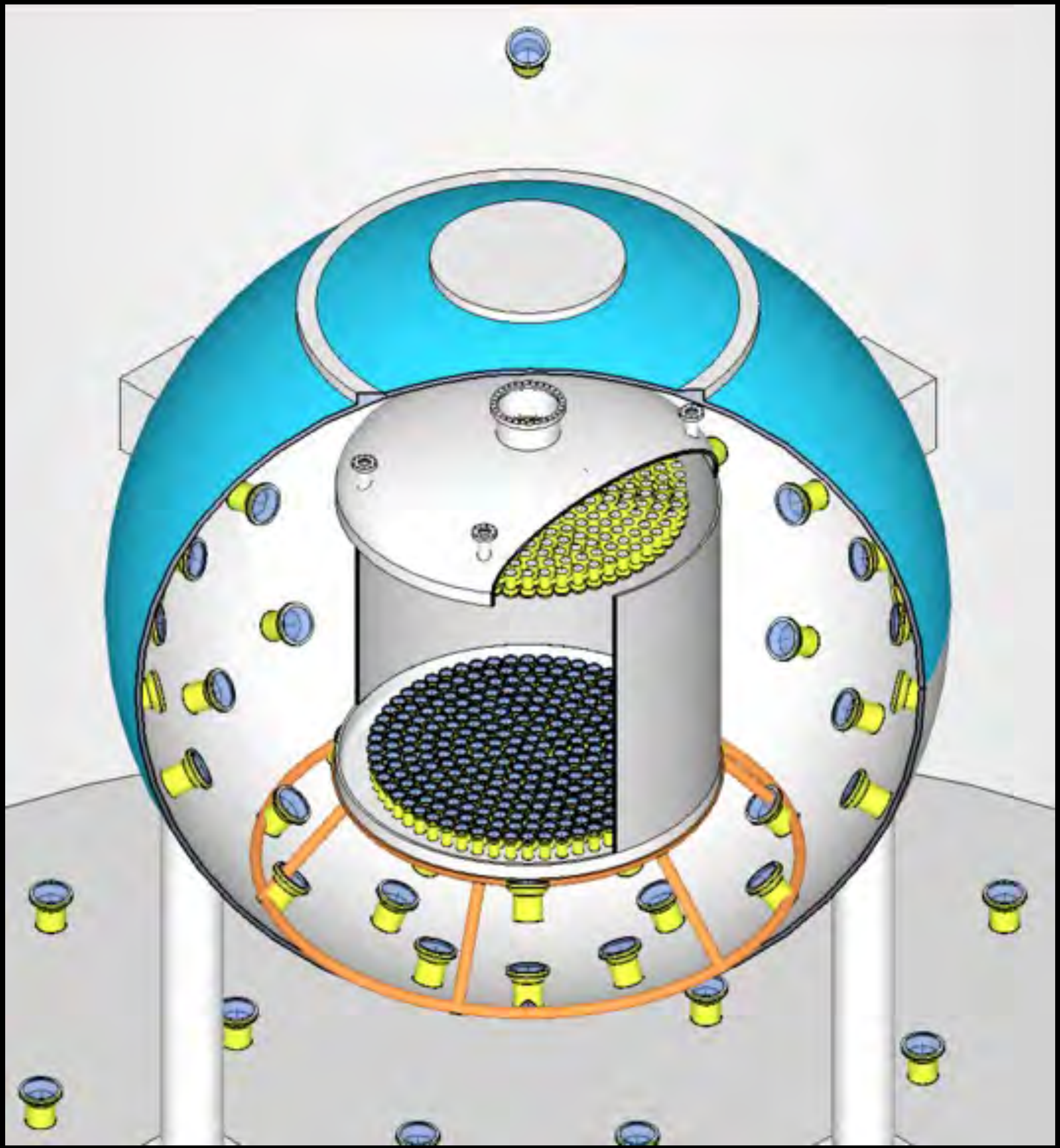
Joint Institute for Nuclear Research, Russia
Princeton University, USA
RRC Kurchatov Institute, Russia
St. Petersburg Nuclear Physics Institute, Russia
Temple University, USA
University College London, UK
University of Arkansas, USA
University of California at Los Angeles, USA
University of Chicago, USA
University of Hawaii, USA
University of Houston, USA
University of Massachusetts at Amherst, USA



DarkSide Program: Status

- Technology for DM detector: 2-phase TPC with underground argon as target
- DarkSide-50 (2×10^{-45} cm^2)
  - Funded by DOE, INFN, NSF - Online very soon
- DarkSide-G2 (10^{-47} cm^2)
  - R&D funded by NSF (NSF DCL, May 1 2012)
  - R&D requested to DOE (G2 FOA, Jul 6 2012)

DarkSide
Aim at zero-background technology

- Pulse Shape Discrimination (PSD) of Primary Scintillation, S1, (rejects e/gamma) (unique to Argon - atomic physics of Argon dimer)
- Ionization:Scintillation Ratio, S2/S1 (rejects e/gamma - not unique to Argon)
- Sub-cm Spatial Resolution (identify surface bkgs) (advantage of two-phase)
- Underground argon (avoid event pile-up from ^{39}Ar)
- Neutron Veto (identify neutrons with high efficiency in finite volume)
- Water shield (identify muons and avoid cosmogenic neutrons)
- Screen and select all detector materials for minimum radioactivity

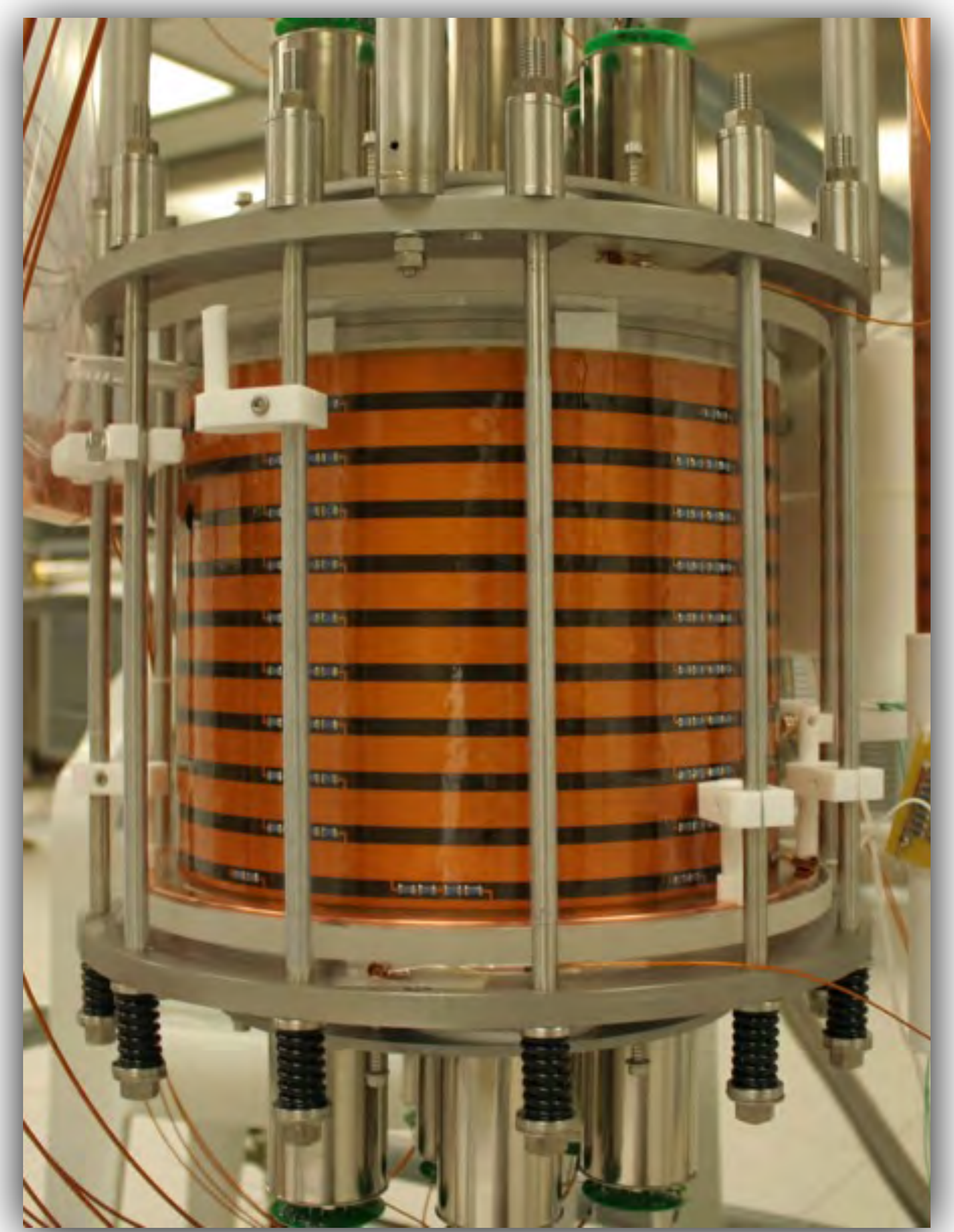
Recent Milestones

- Operated DarkSide-10 prototype for 1 year
- Constructed as part of DarkSide-50:
  - 1,000 tonnes water Cerenkov muon veto
  - 30 tonnes organic liquid scintillator neutron veto
  - two Rn-free clean rooms for final preparation of detector
  - argon recirculation, purification, and recovery systems
- All facilities built sized to house DarkSide-G2

DarkSide-10 TPC

7 (top) + 7 (bottom)
R1140 HQE
Hamamatsu PMTs

20 cm × 20 cm

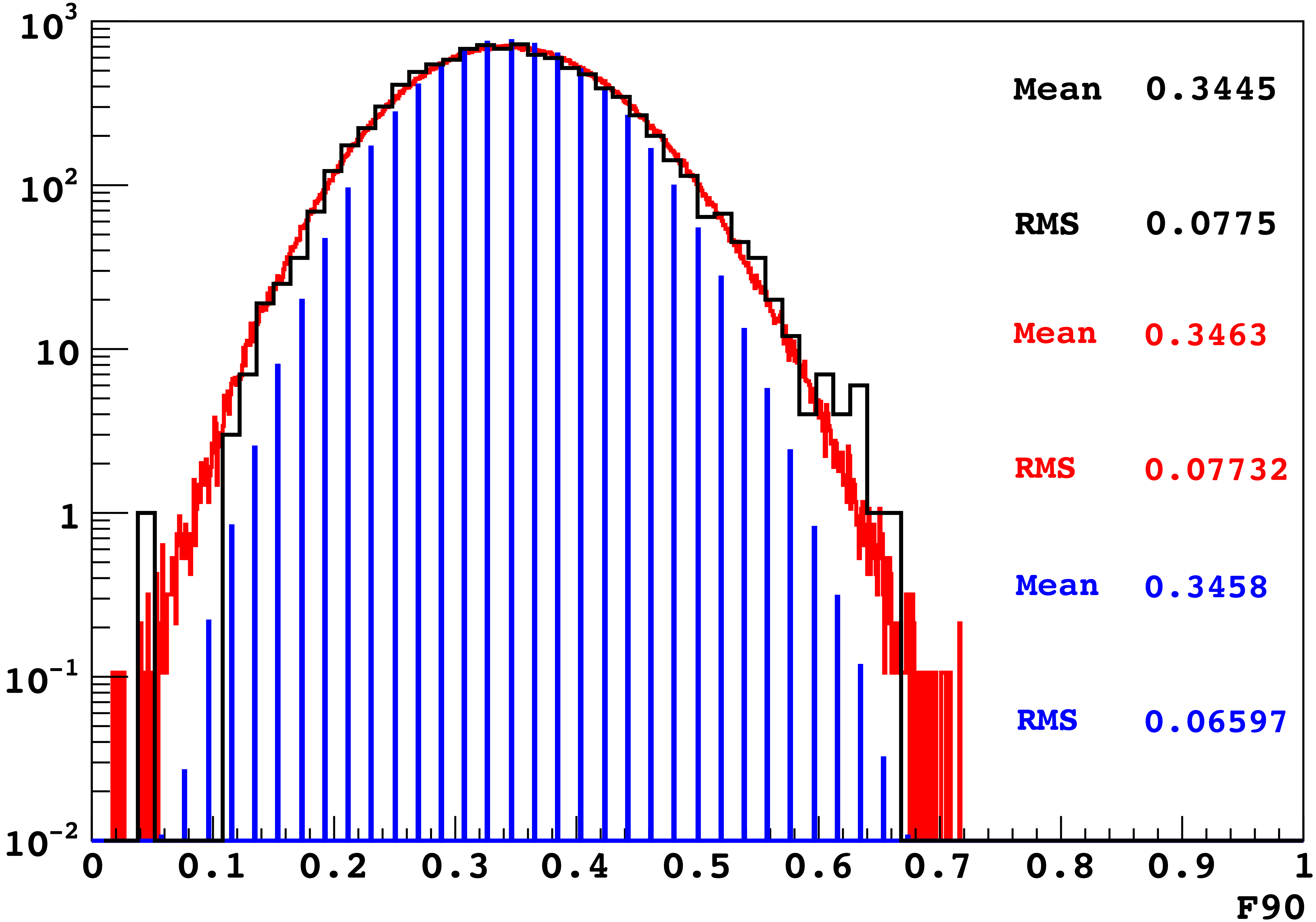


DarkSide-10 Activities and Results

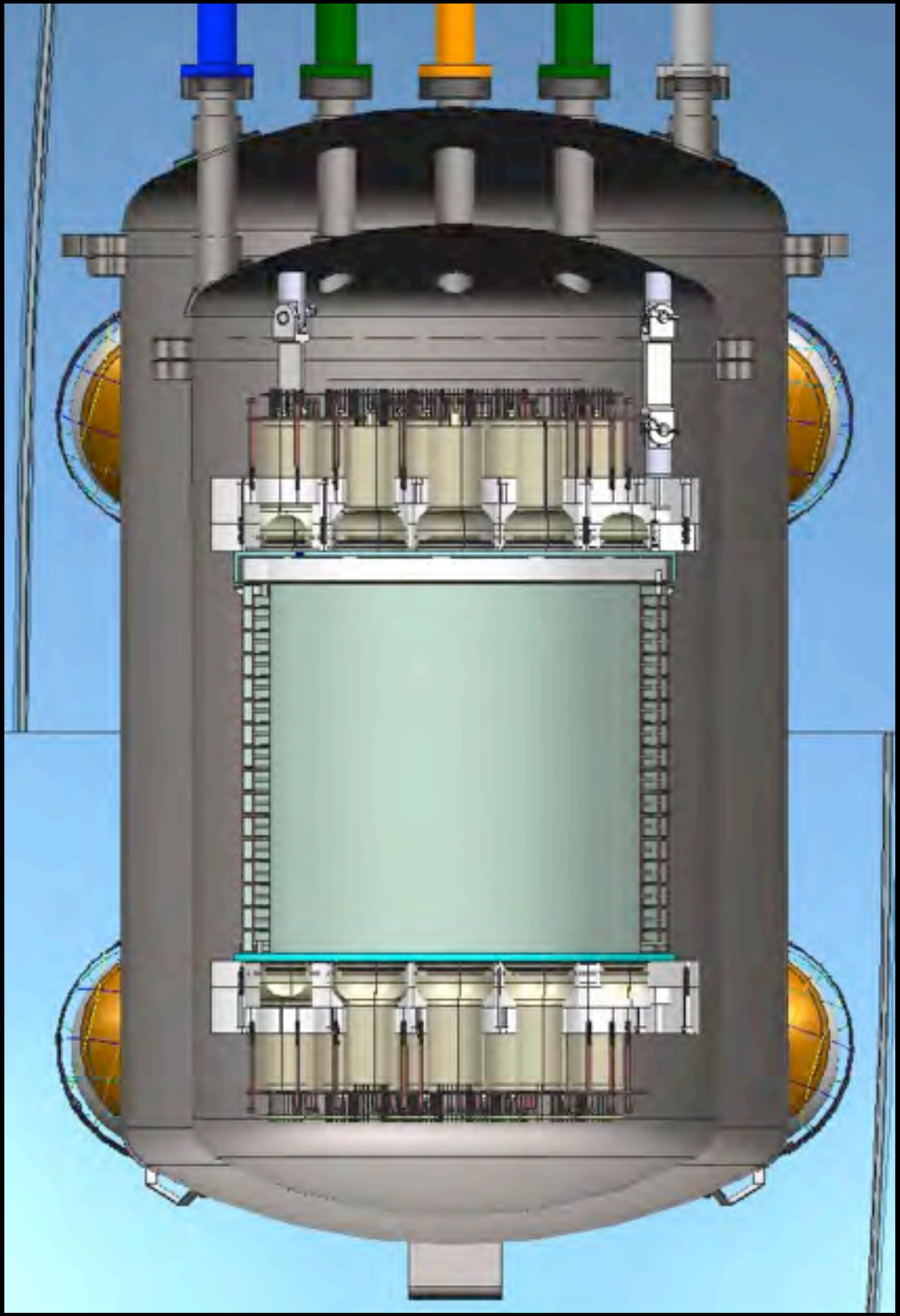
- Not physics capable (a fraction of a neutron per day due to cryostat, feedthroughs, and shield)

1. Compare performance of different reflectors for light collection
   - Obtained record light yield of 8.9 pe/keV$_{ee}$
2. Perform long-term test of HHV system
   - Stainless steel-cryofitted HDPE HHV feedthrough reached required 36 kV and operated stably for over 8 months

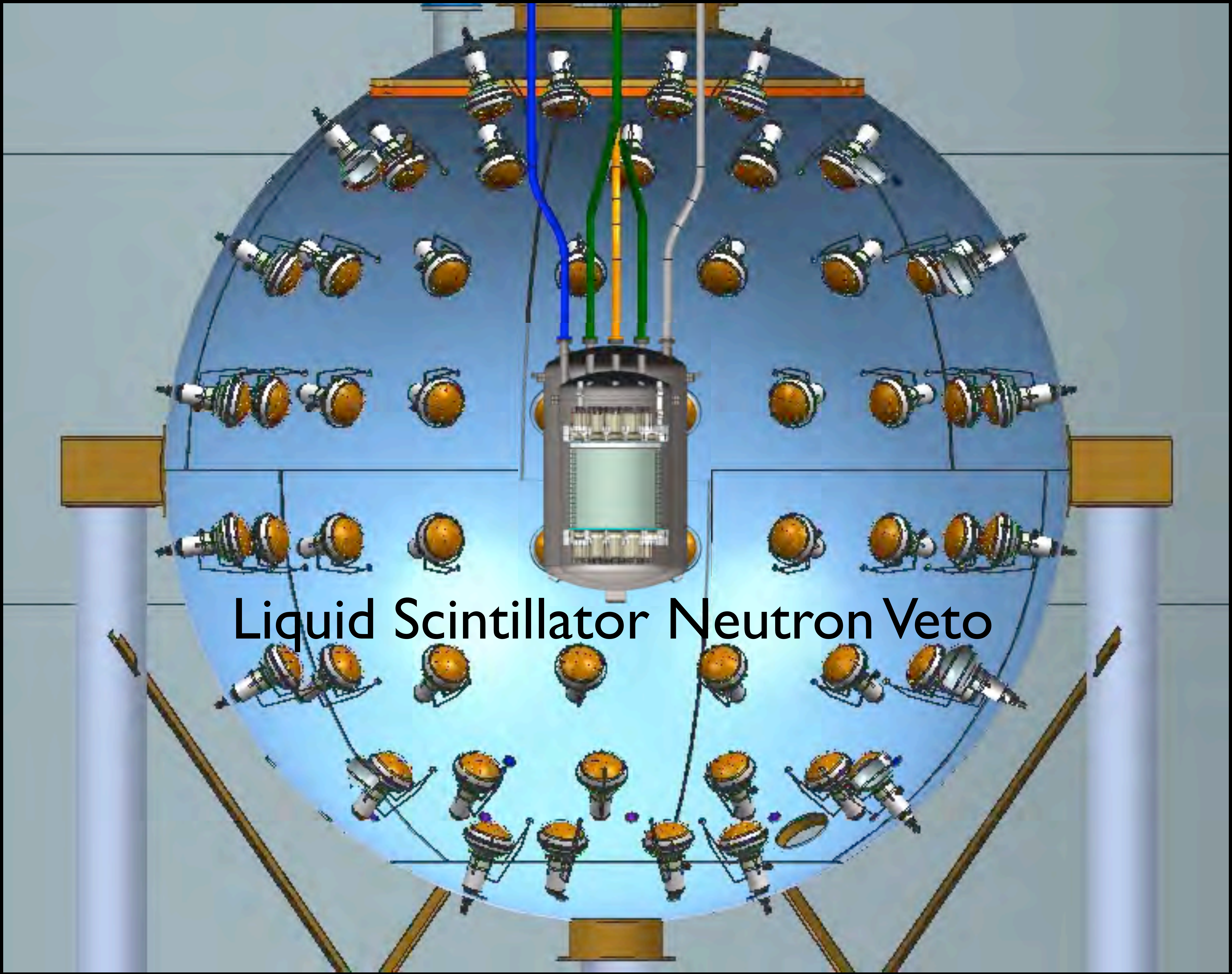
PSD with DS-10



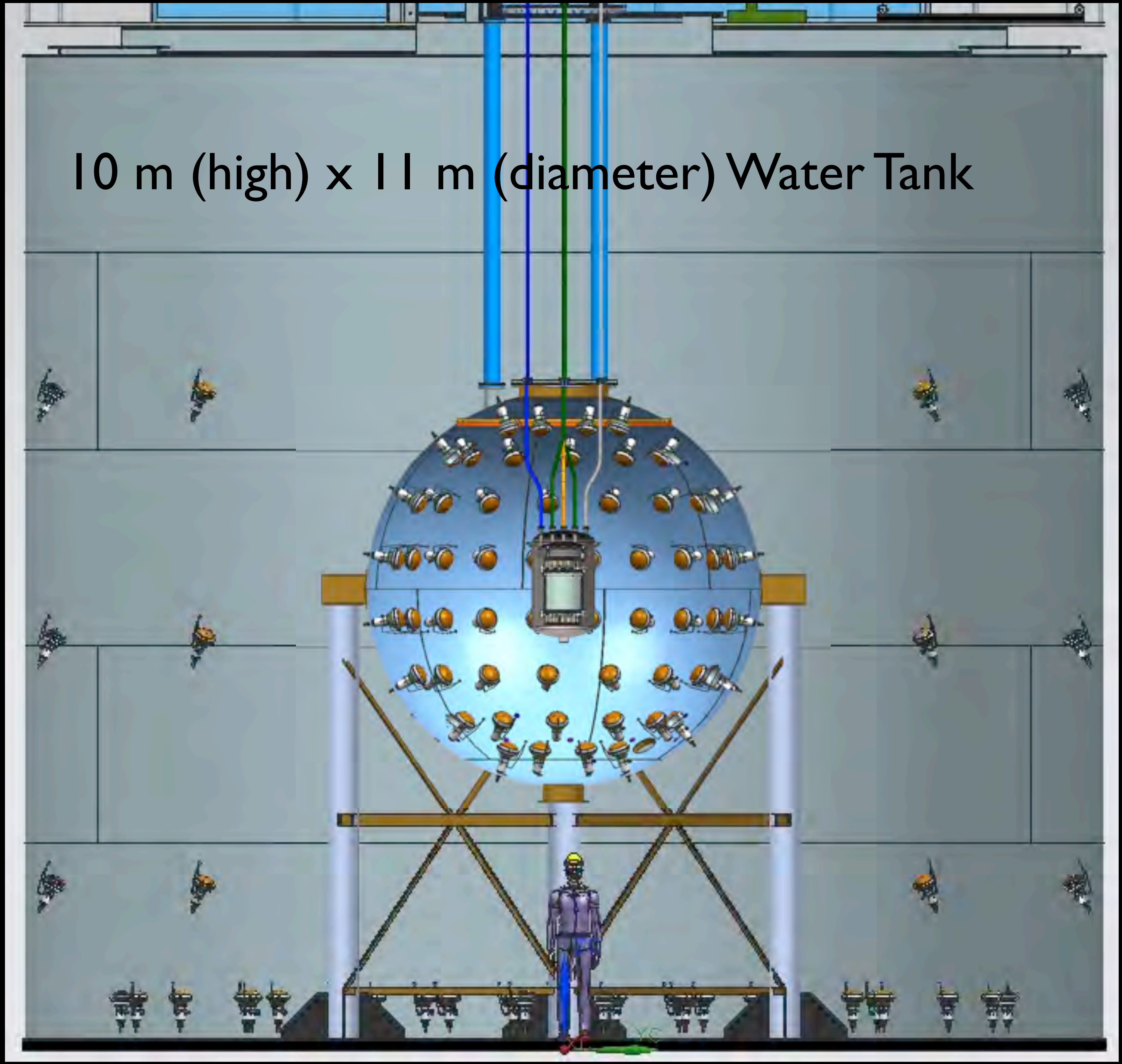
On the basis of date from DS-10, developed a detailed model to describe PSD curves for β/γ. Model applied to infer sensitivity quoted in the white paper. The model describes well the F90 broadening observed in DS-10 down to ~20 keV_{nr}.



Liquid Argon TPC
& Cryostat


Liquid Scintillator Neutron Veto

10 m (high) x 11 m (diameter) Water Tank



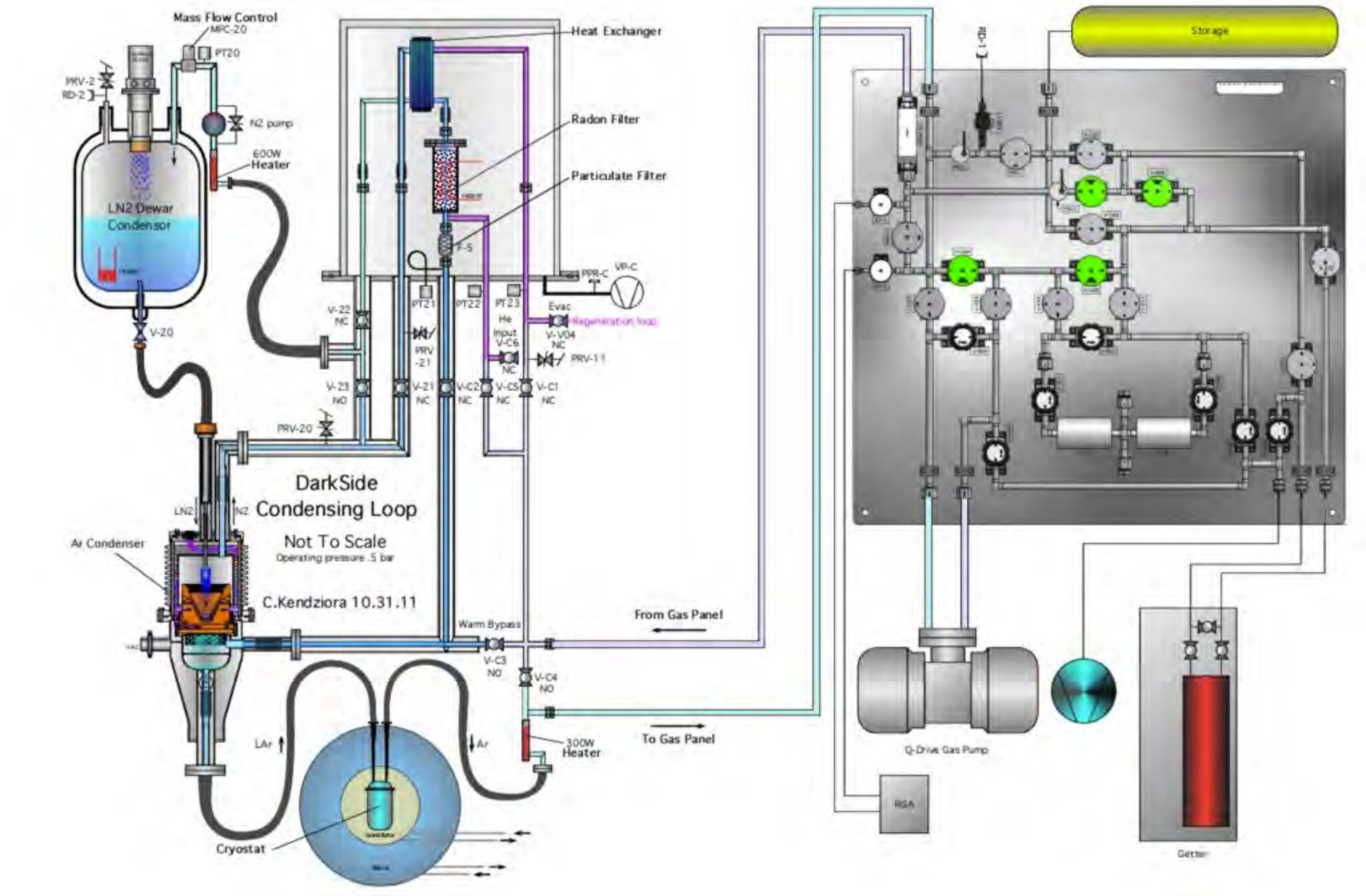
LSV

CR1

CRH

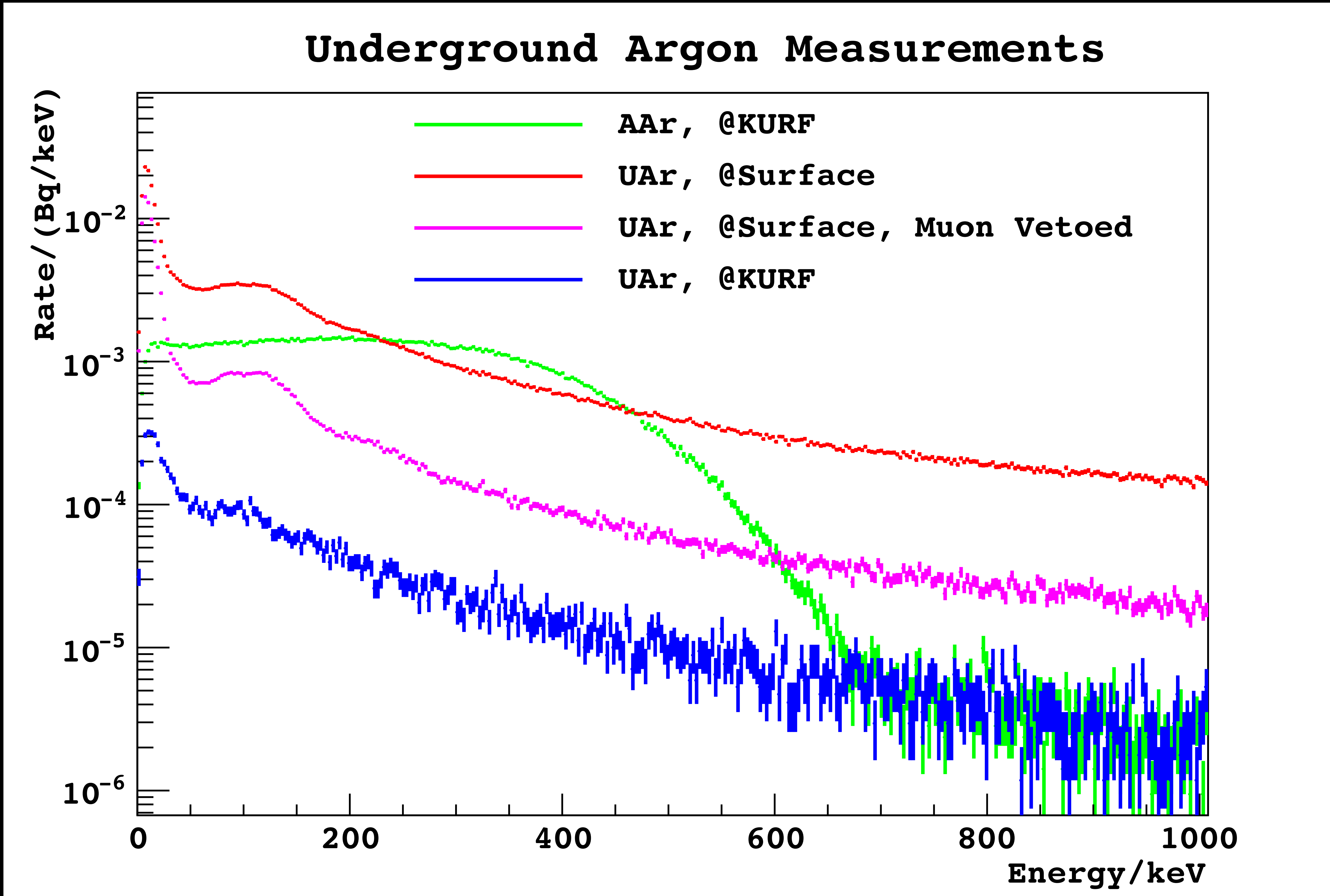
CRH

Recirculation and Purification System



Underground Argon Extraction Plant (150 of 150 kg collected)

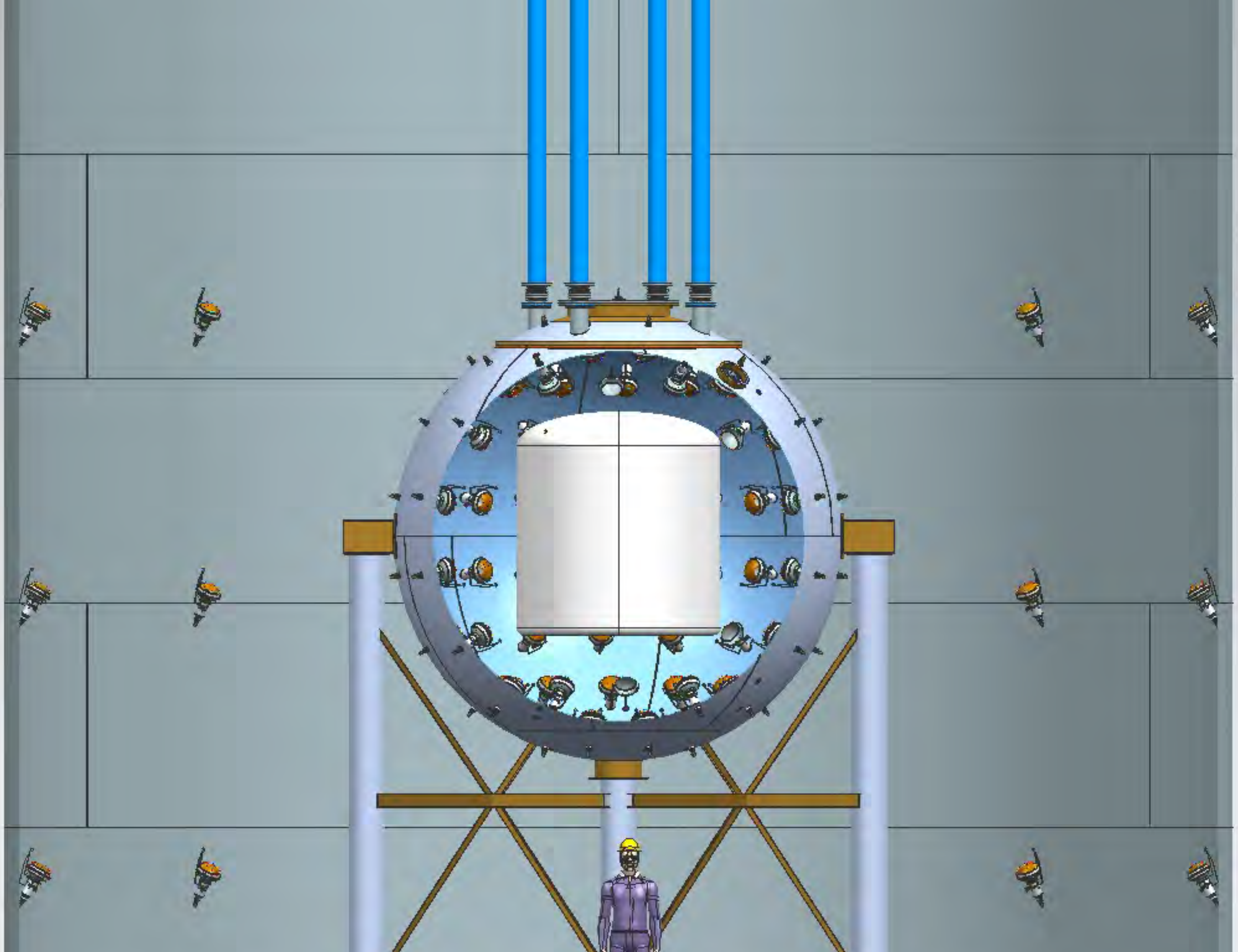
UAr: Depletion factor >100

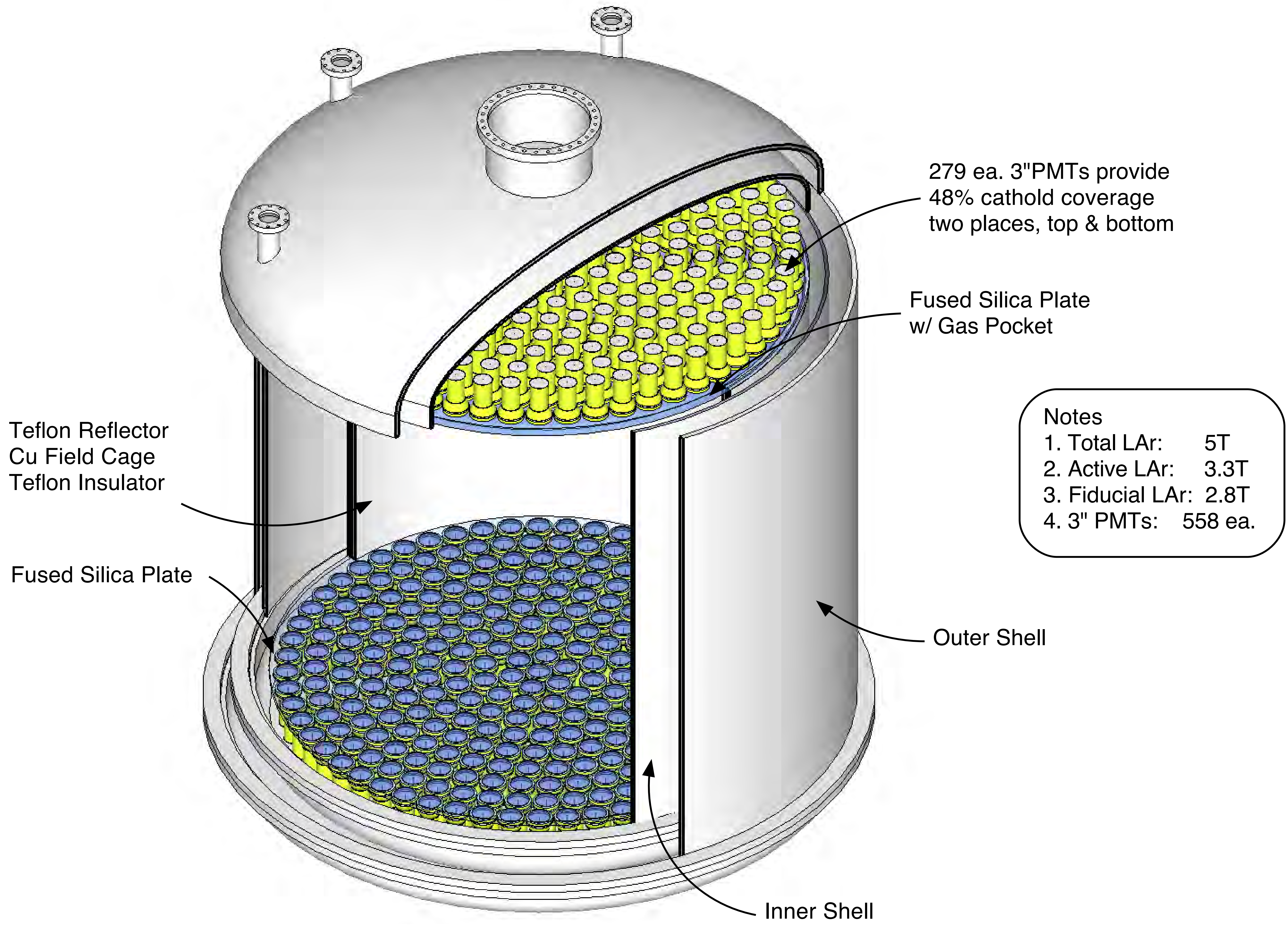


Cryogenic Distillation Column

Assembled and operated at the Fermilab PAB

Special thanks to PAB staff!




279 ea. 3"PMTs provide
48% cathold coverage
two places, top & bottom
Fused Silica Plate
w/ Gas Pocket
Teflon Reflector
Cu Field Cage
Teflon Insulator
Notes
1. Total LAr: 5T
2. Active LAr: 3.3T
3. Fiducial LAr: 2.8T
4. 3" PMTs: 558 ea.
Fused Silica Plate
Outer Shell
Inner Shell

The End

Like the jelly beans in this jar, the Universe is mostly dark: 96 percent consists of dark energy (about 70%) and dark matter (about 26%). Only about four percent (the same proportion as the lightly colored jelly beans) of the Universe - including the stars, planets and us - is made of familiar atomic matter.

The End

Image Credit: Fermilab

Snowmass 2013
Darkside Whitepaper

1. **Is your experiment currently operating and with what target mass?**
No. A technical, non physics-capable prototype, DarkSide-10 (10 kg active mass of atmospheric argon), was decommissioned in January 2013.

If not, when do you expect to operate, and with what total target mass?
The DarkSide-50 physics experiment is nearing completion. We expect begin commissioning the full detector system at the end of March 2013. The dark matter detector DarkSide-50 is a two-phase Time Projection Chamber (TPC) with a 150 kg total LAr mass, 50 kg active mass, 33 kg fiducial mass. The fill for the physics run will be done with underground argon depleted in the cosmogenic ^{39}Ar. DarkSide-50 located inside a 1,000 ton water shield/Čerenkov muon veto and a 30 ton borated-liquid scintillator neutron veto.

What total target mass do you expect to have operating 10 years from now?
DarkSide-G2 (5 ton total LAr mass, 3.3 ton active, 3.0 ton fiducial) is next after Darkside-50 with start of operations possible in 2016. A third generation experiment DarkSide-G3, with a total mass in the range 20–50 tons, may follow.

2. **Fiducial target mass: what is your current ratio of fiducial target mass to total target mass?**
In Darkside-50 the ratio of fiducial to total active mass is 33 kg/50 kg=0.67, and the ratio of fiducial to total LAr mass is 33 kg/150 kg=0.22.

How to you expect that ratio to scale in the future?
In DarkSide-G2 the fiducial to active mass ratio scales to 3.0 ton/3.3 ton=0.91, and the ratio of fiducial to total LAr mass scales to 3.0 tons/5.0 tons=0.60.

Describe briefly the basis for this scaling.
In a TPC, the fiducial/active mass ratio and the fiducial/total LAr mass ratio improve with surface to volume ratio.

3. **Backgrounds after passive and active shielding: what is the current demonstrated background level, in both your total volume and in your fiducial volume, before detector discrimination is applied for each type of background (gamma, beta, alpha, radiogenic neutrons, cosmogenic neutrons)? Please quote in units of events/keV/kg/day and specify the energy range your are using (preferably 10–100 keV). Use either keV$_{ee}$ (electron equivalent) or keV$_{\mathrm{nr}}$ (nuclear recoil) as appropriate for the type of background.**
First, note that to answer using the requested units one would have to present an energy spectrum of the background, not an integral rate in a given range.
Secondly, answering this depends on one's interpretation of the term "demonstrated background level". Since neither the Darkside-50 LAr-TPC nor the neutron and muon veto that complement it have yet been operated, we don't have demonstrated background levels.
The background levels expected from our simulations, based on assays of materials and actual performance of the DarkSide-10 prototype operated for a year in LNGS, are shown in Table I. The numbers listed are the average rates over the energy range: 20 - 200 keV$_{\mathrm{nr}}$, equivalent to 8 - 160 keV$_{ee}$.

Is your dominant background from the active target material, the experiment materials surrounding the active target, or from the environment (including cosmic rays)?

Source	Rate in Active Mass events/(keV·kg·day)	Rate in Fiducial Mass events/(keV·kg·day)
γ [keV$_{ee}$]	1.7	0.9
β [keV$_{ee}$]	1.3	1.3
α [keV$_{ee}$]	4.5×10^{-3}	$<2.6 \times 10^{-8}$
Radiogenic n [keV$_{\mathrm{nr}}$]	5.9×10^{-8}	5.4×10^{-8}
Cosmogenic n [keV$_{\mathrm{nr}}$]	6.4×10^{-9}	6.4×10^{-9}

TABLE I: Expected background levels for DarkSide-50 from simulations and radio-assay of materials.

Again, we have no demonstrated dominant background. However before discrimination (which is the subject of this section of questions) our dominant background is expected to be from ^{39}Ar, followed closely by experiment materials surrounding the active target.

By what factor do you need to reduce these backgrounds for future experiments?
The expected background levels are satisfactory for DarkSide-G2.

Describe briefly how you would achieve such reductions.
Further reductions below the present expected levels are available. The expected ^{39}Ar background level depends on the radiopurity of the underground argon supply we have developed. The numbers are still based on an upper limit for the radiopurity, the best results so far obtainable with a ∼1 kg sample counted underground at KURF. The actual level may be much lower. Work is continuing to improve the sensitivity of the ^{39}Ar measurement.
The PMTs are responsible for more than half the remaining background. We have developed with Hamamatsu a new variant of the R11065 (the R11065-20) with about 1/10 the background of the current variant available for the past two years. DarkSide-50 will be instrumented with the R11065-20 variants as they become available.

4. **Detector discrimination: what is your current demonstrated experiment discrimination factor, in both your total volume and in your fiducial volume, for each type of background (gamma, beta, alpha, radiogenic neutrons, cosmogenic neutrons)? Please quote these at 100 keV$_{\mathrm{nr}}$, and for 10 keV$_{\mathrm{nr}}$, or the lowest energy you have measured them.**
(See Table 2) Based on experience with the DarkSide-10 prototype, the DarkSide-50 β/γ discrimination cuts will be set in an energy-dependent manner so as to leave a leakage fraction which does not vary with energy. The constant leakage fraction is chosen to give an energy-integrated background of less than 0.1 events in a 0.1 ton·yr exposure.
Neutron discrimination in the liquid argon TPC is based on a multiple-interaction cut and rejecting inelastic interactions that result in electron recoils. We note that the liquid argon TPC is surrounded by an active liquid scintillator detector and an instrumented water tank that greatly enhance our neutron discrimination capabilities. Based on simulations, it is estimated that the liquid scintillator will reduce the radiogenic neutron background from within the TPC by a factor of ∼100 and the combination of water tank and liquid scintillator will reduce the cosmogenic neutrons by a factor of ≫3000. These additional reductions, not included in the summary Table II, were taken into account when estimating the backgrounds in Table I.

By what factor might these improve in the future? Describe briefly how you would achieve any improvements. Significant improvements are expected from a new, extremely low noise front-end using cold amplifier-cable drivers in the LAr, developed at LNGS. These will be tested in DarkSide-50. Combined with a change in the pulse-shape analysis from pulse integration to photon counting, this will practically eliminate the effects of electronic noise and single-photoelectron resolution on the PSD. At this time we do not have a quantitative estimate of the resulting improvement in sensitivity.

Do you have "outlier" events that cannot be described by your simulations or calibrations?
DarkSide-10 was operated with with atmospheric Argon (1 Bq/kg ^{39}Ar), without a tight neutron shield, and has large sources of radioactive backgrounds very close to the fiducial volume (cryostat and its ceramic feedthroughs). As expected, the resulting background spectra do contain neutron-like events. However we cannot prove that every event in this region is a neutron event, or if some are "outliers" leaking from the millions of ^{39}Ar beta events.

5. **Energy threshold: what are your current demonstrated energy thresholds (trigger and analysis) for electron recoils and nuclear recoils?**

Source	Leakage Fraction Total Volume	Leakage Fraction Fiducial Mass
γ [keV$_{ee}$]	1×10^{-7}	1×10^{-7}
β [keV$_{ee}$]	1×10^{-7}	1×10^{-7}
Radiogenic n [keV$_{\mathrm{nr}}$]	0.72	0.72
Cosmogenic n [keV$_{\mathrm{nr}}$]	0.72	0.72

TABLE II: DarkSide-50 expected discrimination. For both β's and γ's, the event discrimination cuts are chosen so as to leave a constant (in energy) leakage fraction that integrates to a background of less than 0.1 events in 0.1 ton·yr exposure.

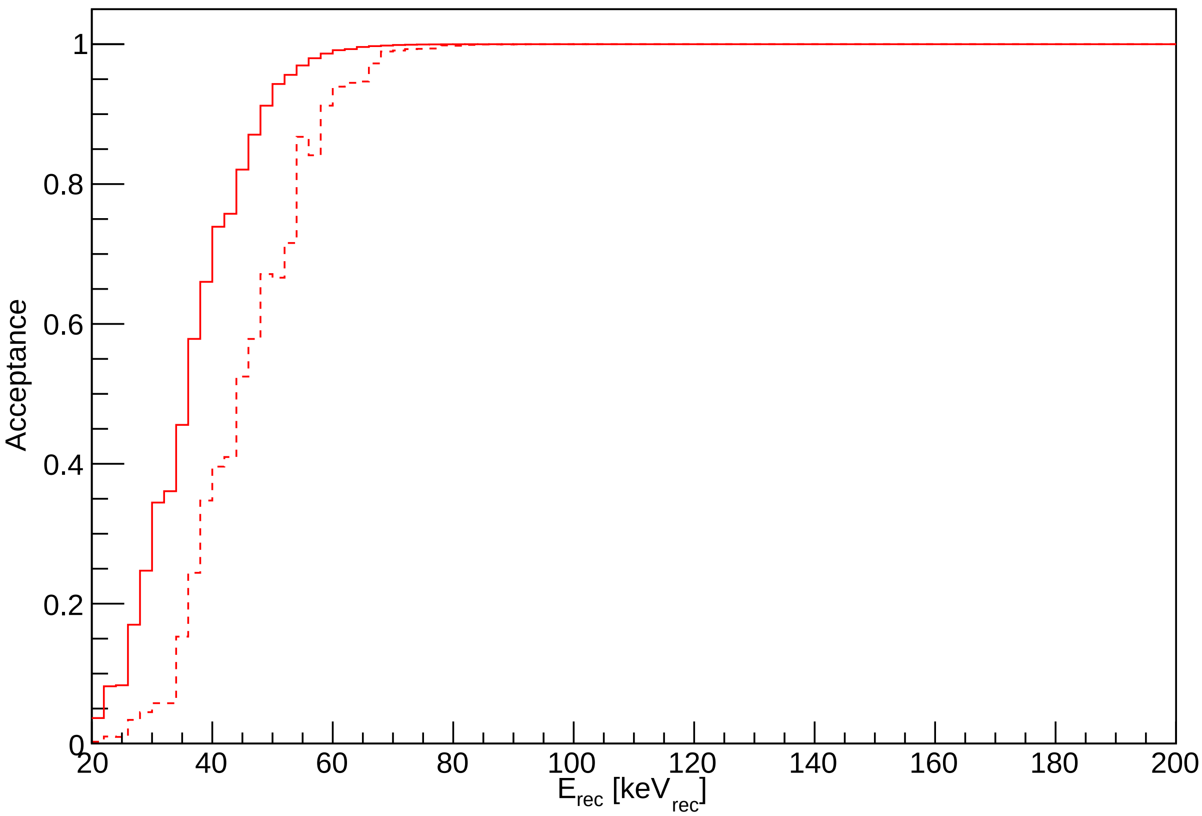


FIG. 1: Nuclear recoil acceptance as a function of energy expected for Darkside-50. Full line: both PSD and S2/S1 discrimination applied. Dashed line: only PSD discrimination. Discrimination cuts are set as required for current upper limit of ^{39}Ar activity; lower actual activity would allow cuts to be relaxed, further increasing the acceptance.

Data from the Darkside-10 prototype demonstrated thresholds of $5\,\mathrm{keV}_{ee}$, $9\,\mathrm{keV}_{\mathrm{nr}}$ for triggering, $9\,\mathrm{keV}_{ee}$, $20\,\mathrm{keV}_{\mathrm{nr}}$ for analysis.

Specify the nuclear recoil acceptance at your energy thresholds and describe briefly how you expect the thresholds and acceptance to evolve in the future.
(See Figure 1) The event discrimination cuts are chosen so as to leave an energy-independent leakage fraction that integrates to a background of less than 0.1 events in 0.1 ton·yr exposure. The corresponding nuclear recoil acceptance (excluding dead time loss due to accidental coincidences in the neutron veto) is shown in Fig. 1. The solid line shows the acceptance for both PSD and S2/S1 discrimination, while the dashed line shows the acceptance when using PSD only.
The cuts were chosen assuming an ^{39}Ar activity in our underground Argon at its current upper limit of 6.5 mBq/kg. Should it turn out to be lower, the cuts could be relaxed and our acceptance at low energy would increase. Improvements to the discrimination power (see question 4) would also improve the acceptance.

6. **Sensitivity versus WIMP mass: what are your current demonstrated SI and SD sensitivities as a function of WIMP mass, at least for 5, 10, 100, 1000 and 10000 GeV? What sensitivities do you project in the next 5, 10 and 15 years?**
^{40}Ar is spinless and has no SD sensitivity. There is no demonstrated sensitivity as the experiment is not yet running. The expected sensitivity for DarkSide-50 is shown in Figure 2. The expected sensitivity for DarkSide-G2 is shown in Figure 3.

7. **Experimental challenges: what are the main physics and engineering challenges you currently face in getting your experiment to work?**

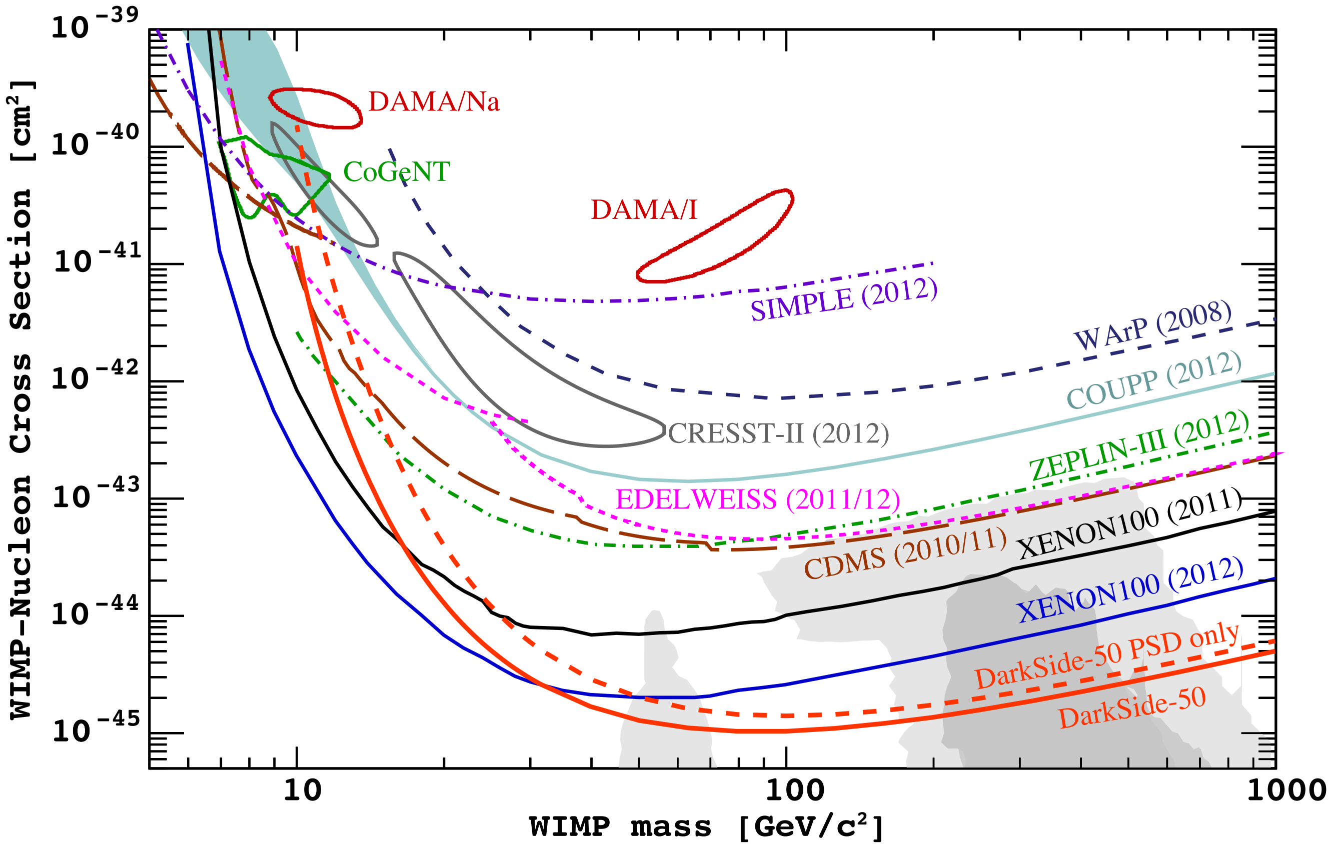


FIG. 2: DarkSide-50 Expected Sensitivity.

PMT stability at 86 K. Rate of purification of underground argon.

What physics and engineering challenges do you expect to face for improving the sensitivity of the experiment?

– Development of photosensors of larger sensitive area (possibly 5" diameter) and even lower radioactivity

– Development of a DAQ architecture capable of handling the bit-rate generated by DarkSide-G2.

– Collection and purification of underground argon at the ton scale

Is there detector R&D needed to enable a future experiment?
Yes. See the paragraph above for the areas of most pressing need.

What are the facility requirements (size, depth, ...) for your next generation experiment?
The Darkside-50 and Darkside-G2 designs assume operation at LNGS inside a powerful passive/active shield/veto system which we have already built and are about to commission in Hall C. This system consists of a 30 ton borated-liquid scintillator neutron veto detector, located inside a 1,000 ton water Čerenkov detector.

8. **Annual modulation: have you demonstrated experiment stability at the level needed to study annual modulation, and for what nuclear recoil energy energy threshold? If not, what are the main obstacles you face?**
We have not demonstrated this. PMT stability is a potential obstacle.

9. **Unique capabilities: do you have unique capabilities to identify whether a signal is due to WIMPs, aside from the standard event by event discrimination and multiple scattering?**
Yes. DarkSide-50 is the first (and to date, only) experiment under construction with the dark matter detector operated inside an active neutron veto (a 30 ton low-threshold borated-liquid scintillator detector), which is itself

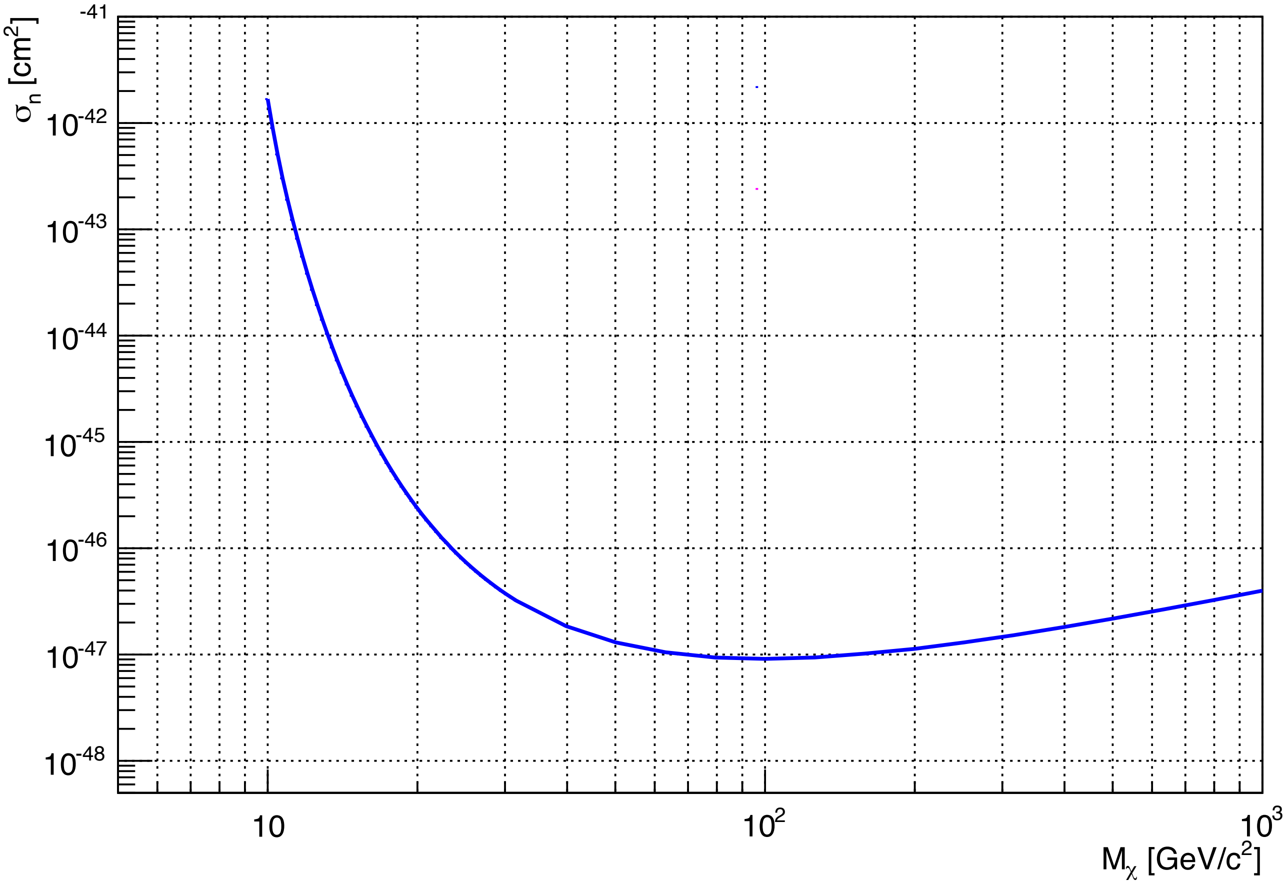


FIG. 3: DarkSide-G2 Expected Sensitivity

inside a muon veto (1,000 ton water Čerenkov detector). This system gives DarkSide-50 the unique capability of tagging and rejecting with high efficiency events from radiogenic (>99.5%) and cosmogenic (>99.9%) neutrons masquerading as WIMP scatters.

Does your technology allow different targets in the same experiment? If so, what changes are required to make use of these?
In a manner of speaking – our DUSEL-G2 design MAX was a paired LAr and LXe experiment, with separate vessels, differential light reflectors, with a wavelength shifter for LAr and without for LXe, with PMTs optimized for each noble liquid, but with otherwise nearly identical technology and shared infrastructure.

Does your experiment have sensitivity to dark matter interactions other than spin-independent or spin-dependent?
Yes in case of inelastic dark matter interactions.

10. Determining WIMP properties and astrophysical parameters: if a signal is detected, what information does your experiment provide about WIMP properties (especially WIMP mass), and about dark matter distribution in the galaxy?
The spectral shape of WIMP events contains information on WIMP mass and kinematics, as discussed in e.g. J.D. Lewin and P.F. Smith, Astroparticle Physics **6**, 87 (1990). Detailed studies are underway and we will update this section prior to finalization of the document.