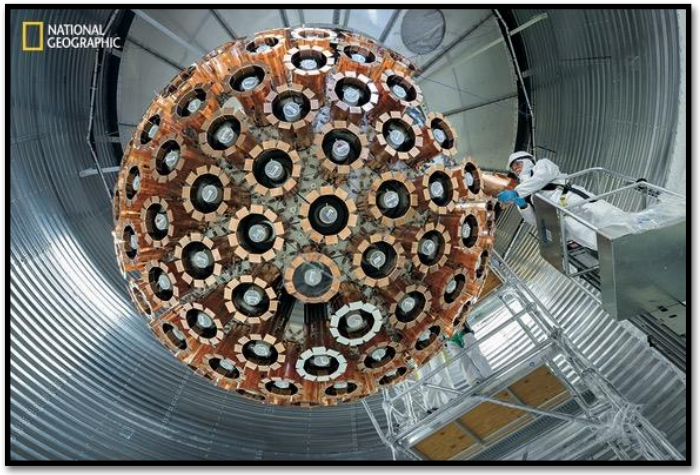
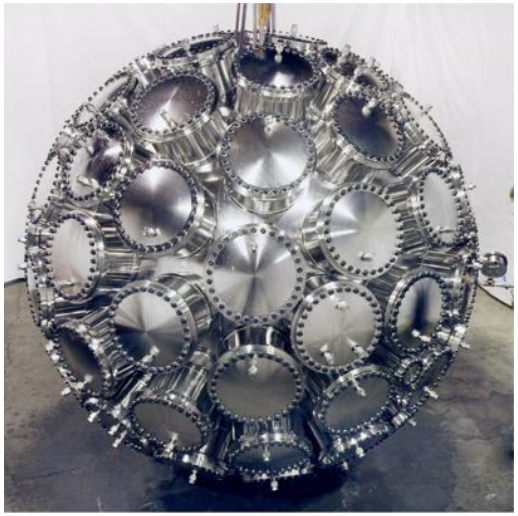
Argon Dark Matter Searches: DarkSide-20K and Beyond



DEAP-3600 detector at SNOLAB



miniCLEAN at SNOLAB

ArDM commissioning JCAP, 03, 003 (2017)

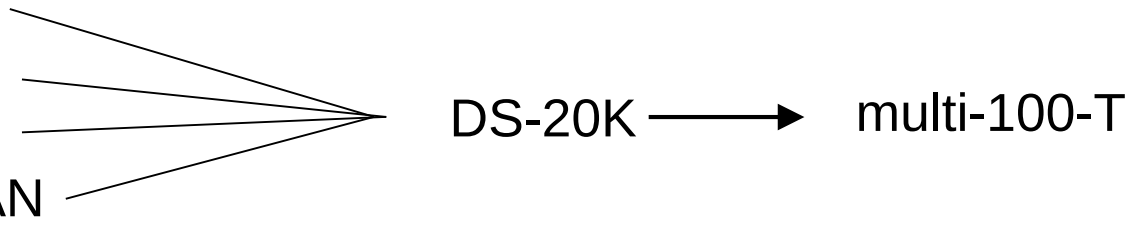
DS-50 at LNGS

Mark Boulay
Carleton University
Canada
March 23, 2017
US Cosmic Visions

(New) Argon Collaboration

Researchers from

- DarkSide
- DEAP
- ArDM
- MiniCLEAN



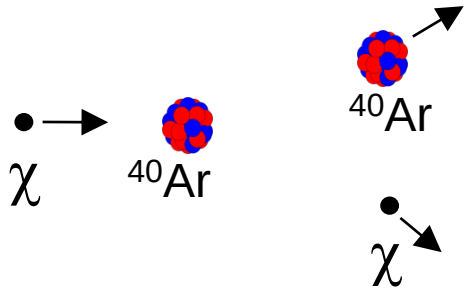
planning to collaborate on future program:

- Completion of current science and R&D programs by each collaboration (DS-50, DEAP-3600, MiniCLEAN, ArDM)
- Joint collaboration on DS-20K at LNGS, including Low Radioactivity Argon (operation starting 2021) and SiPM photodetectors
- Joint collaboration on future multi-hundred-tonne LAr detector, site TBD (mid-2020's)

Towards global argon collaboration:

DarkSide, DEAP, miniCLEAN, ArDM > 350 researchers

Argon for Dark Matter Searches – Some Basics



Scattered nucleus (with 10's of keV) is detected in liquid argon.

Argon is inexpensive and relatively "easy" to purify to levels required for DM searches - true for O_2, N_2, etc. and **also for radon**

Singlet/triplet ratio and lifetimes in argon allow extremely good scintillation PSD (β/γ vs nuclear recoil rejection of 10^{10}) – low background single phase (scintillation-only) detector possible

TPC also exploiting charge collection (S1/S2) increases background rejection (β/γ vs recoil + position reconstruction)

^{39}Ar – approx. 1 Bq of β decays per kg of argon – must be reduced or rejected in analysis

ArDM - a Ton-scale LAr TPC for DM research

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics

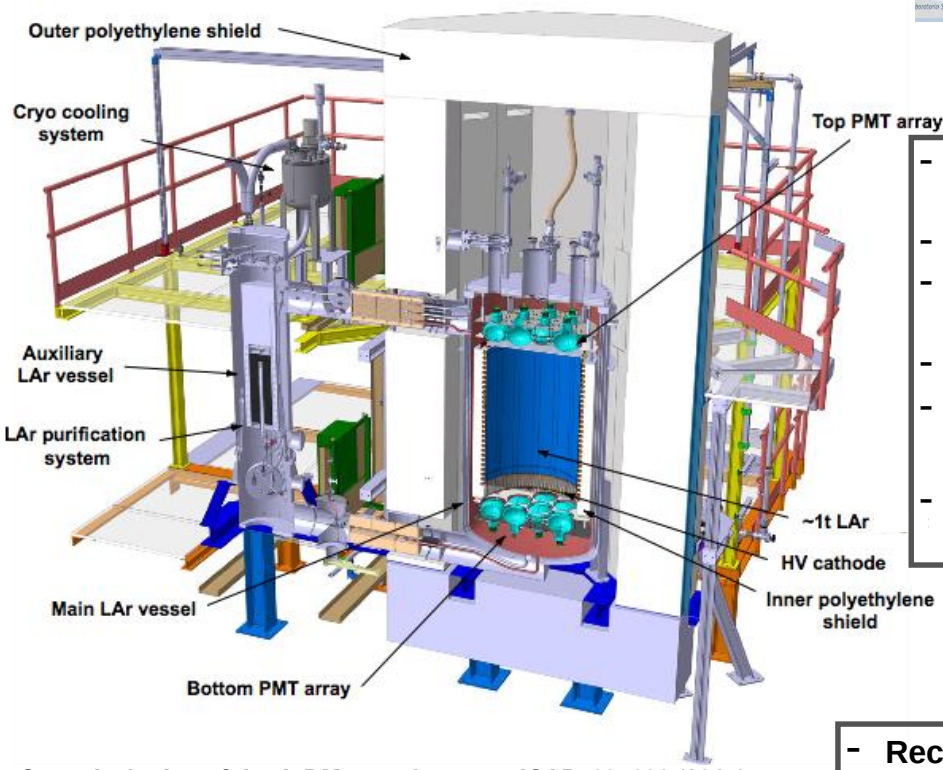
Ciemat

CERN

LSC

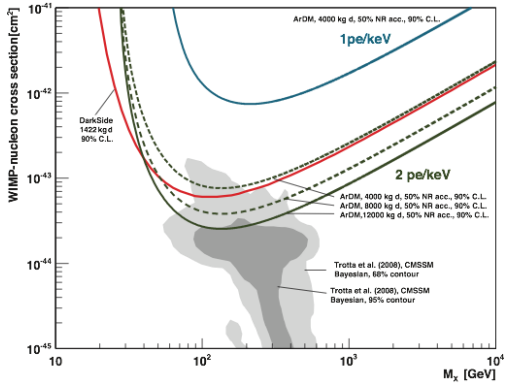
ETHZ led collaboration with CIEMAT, LSC, CERN ….

- **Contribution to searches of higher mass WIMPs!**
- **Design parameters / developments for future LAr facilities!**

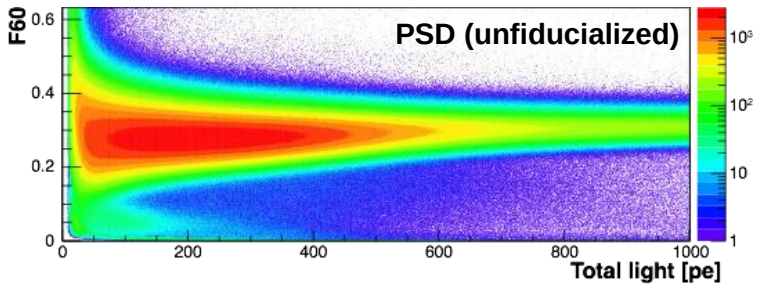


Commissioning of the ArDM experiment… JCAP, 03, 003 (2017)

- **Experiment commissioned in single phase in 2015**
- **3×10^9 triggers recorded**
- **Low background goal confirmed**
- **Detector upgraded in 2016**
- **Double phase run planned for 2017**
- **Main tasks: Verification of sensitivity and neutron IA**

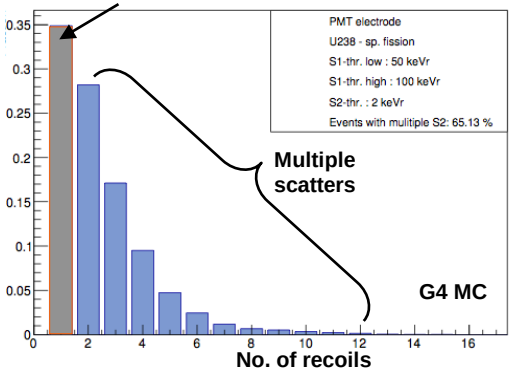


1 neutron event per ~20d expected



- **Recent integration of ArDM in the DS project**
- **Combining efforts towards future G2 and G3 facilities**

Single scatter neutrons (indistinguishable BG)



^{39}Ar depleted argon research planned for 2018 and beyond

DarkSide-50

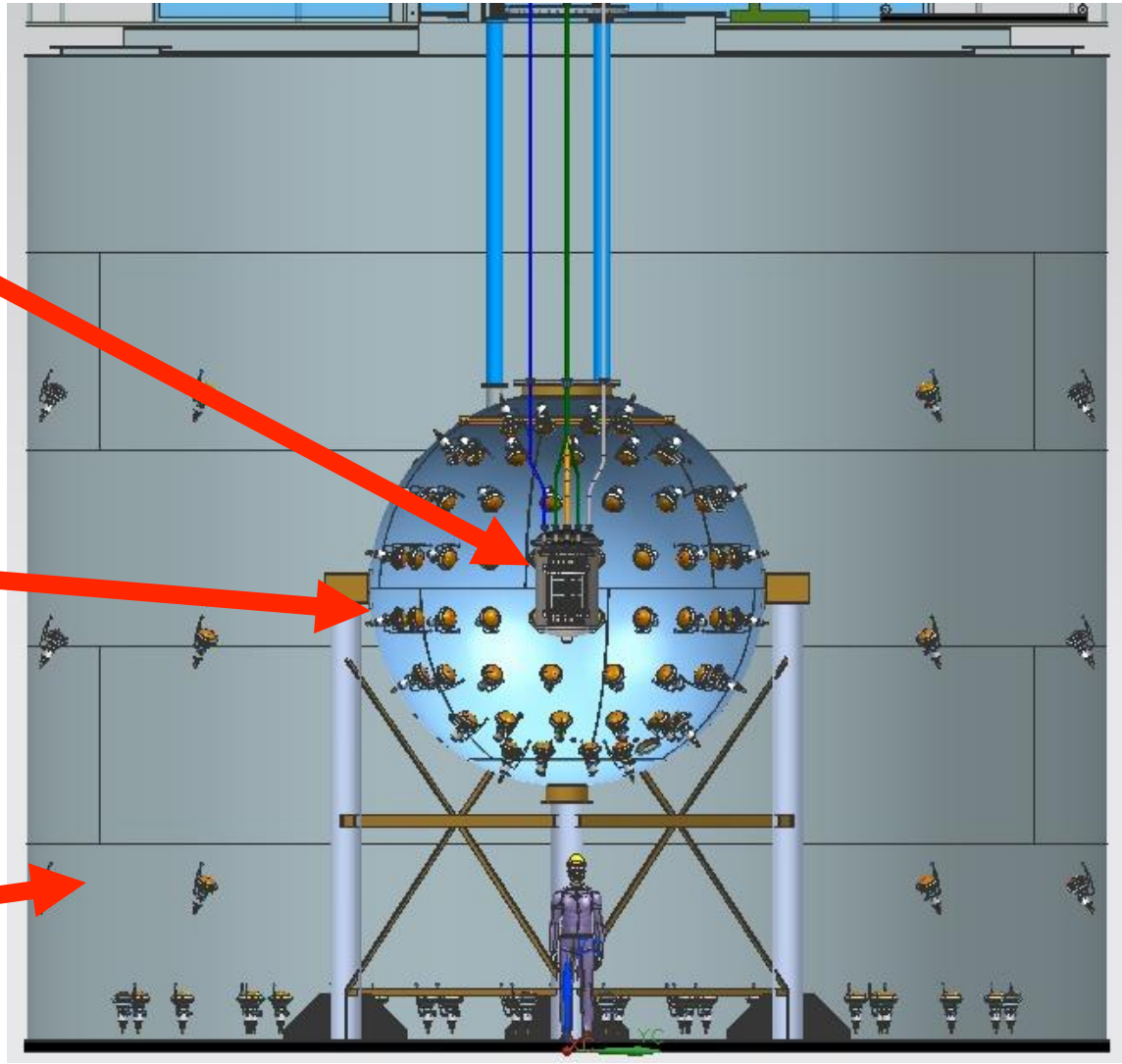
Pioneered development of Low-Radioactivity (underground) Argon (low ^{39}Ar content)

Demonstrated low-background operation with TPC, UAr < 1400 times atmospheric ^{39}Ar

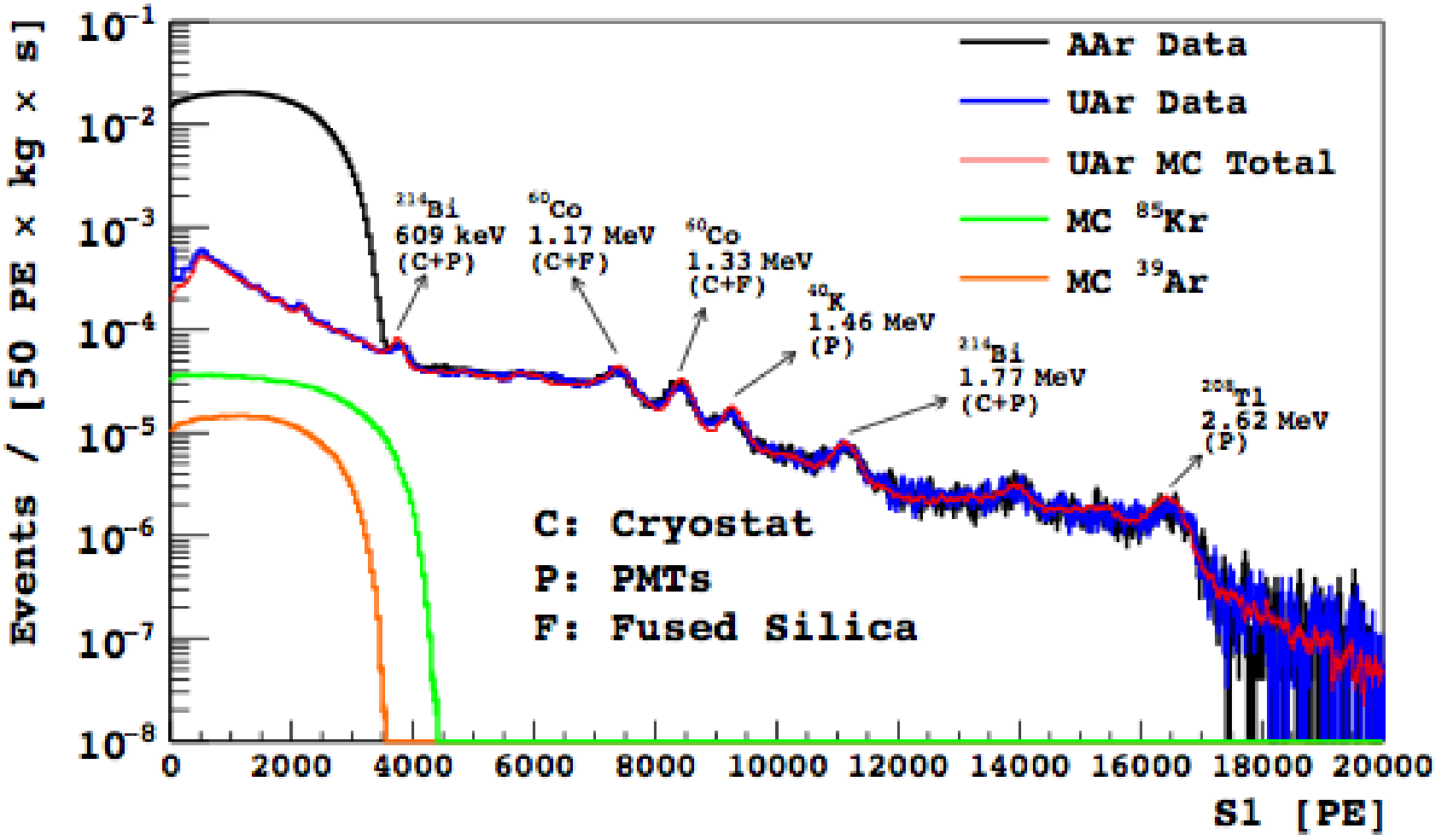
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

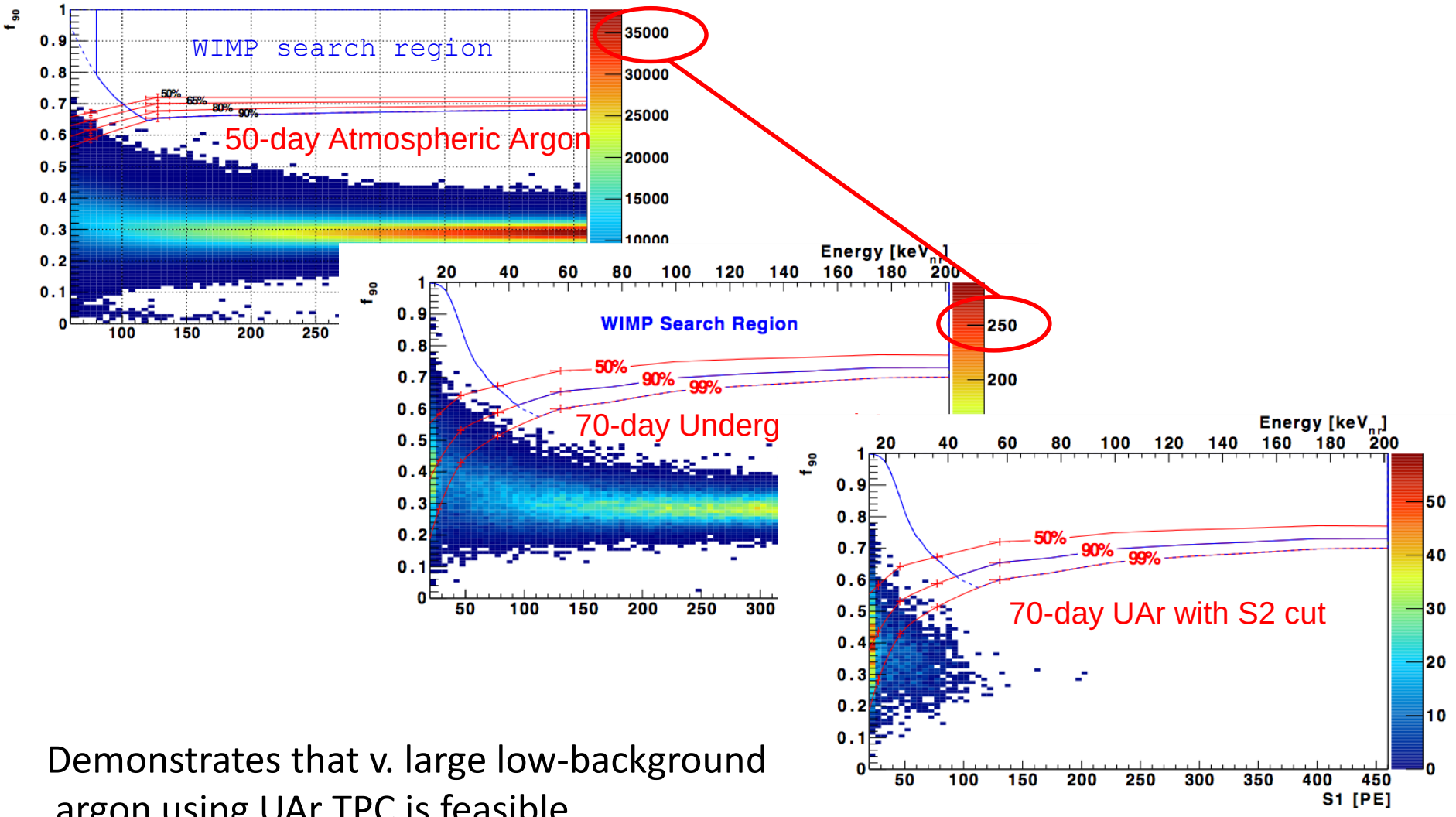
10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



Underground Argon (UAr) with DS-50

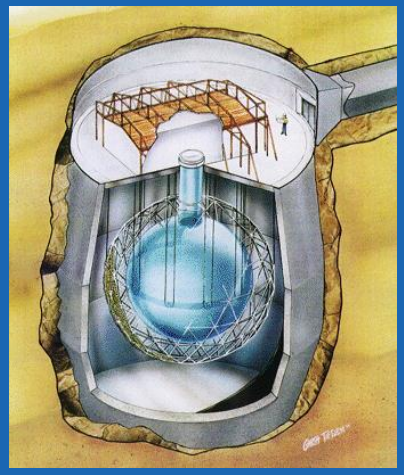


DS-50 Data with atmospheric and underground argon (UAr)



Demonstrates that v. large low-background argon using UAr TPC is feasible

SNOLAB



original SNO exp.

DEAP-3600, MiniCLEAN

Cube Hall

Cryopit

Phase III Stub

PICO-2L, DEAP-1, DAMIC

SuperCDMS, PICO-60

Cube Hall in 2009

PUPS

Ladder Labs

SNO Cavern

South Drift

Personnel facilities

2009: Low Background Counting

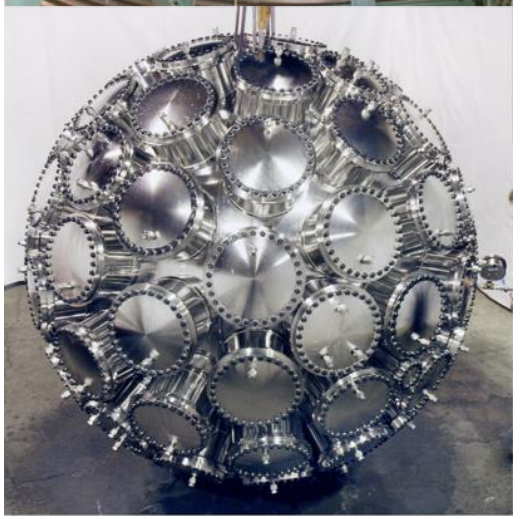
SNO+

Utility Area

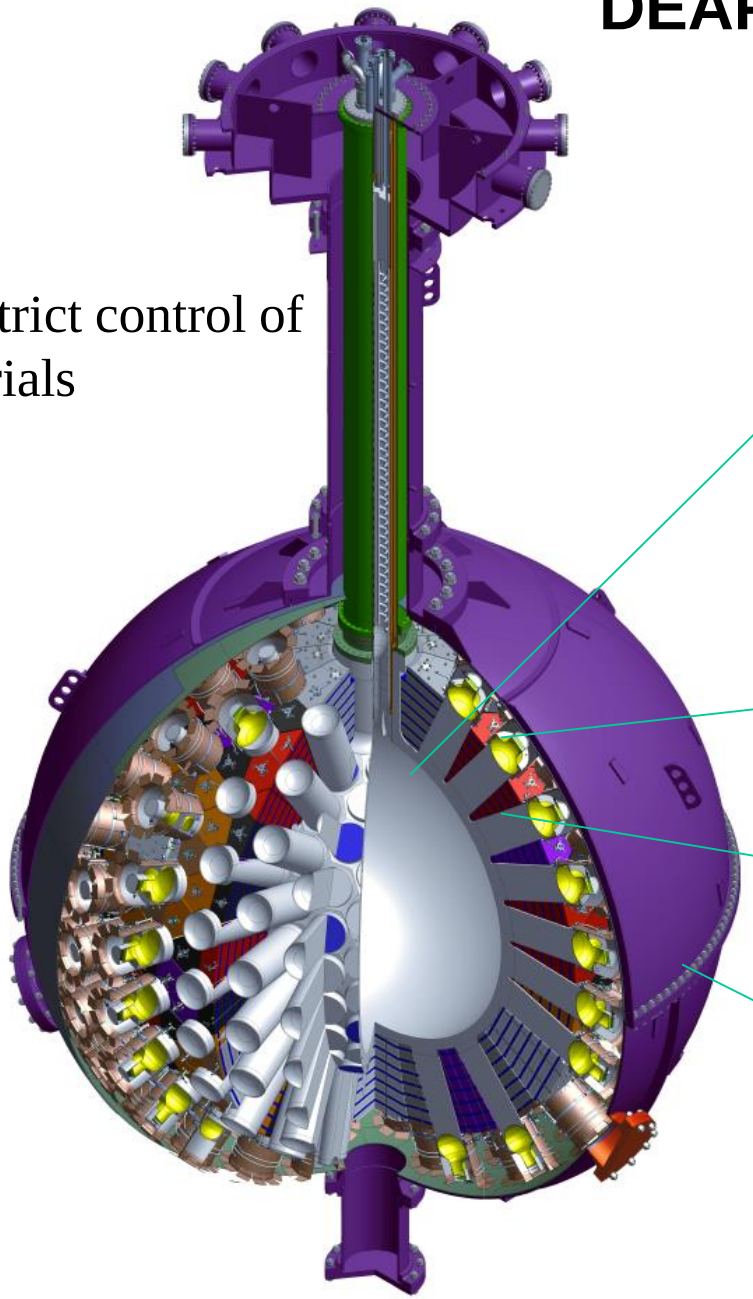
2 km underground to shield from cosmic ray backgrounds

MiniCLEAN – successful operational readiness review at SNOLAB. Now filling with Liquid Argon

- Current Project Status
  - Exceptional purity: Gas triplet time constant >3.6 μs
  - Detector atmospheric liquid argon fill underway
- Run plan (CY 2017)
  - 3 months - fill and final commissioning
  - 3 months - baseline technical demonstration
    - light yield, background levels, position reconstruction,…
  - 6 months - ^{39}Ar spiked data
    - Pulse Shape Discrimination R&D at 10^{-10} level
- Lead by Pacific Northwest National Lab since 2014
  - Completion of detector construction (2015)
  - Cool down and commissioning (2016)
  - Favorable Operations Readiness Review (2016/17)
  - Leads project management, operations, data analysis & ^{39}Ar spike program
- Informs technology choices for 100+ ton experiment



DEAP-3600 Detector (single-phase)



very strict control of materials

3.5 meters

3600 kg argon
in sealed ultraclean
Acrylic Vessel (1.7 m ID)

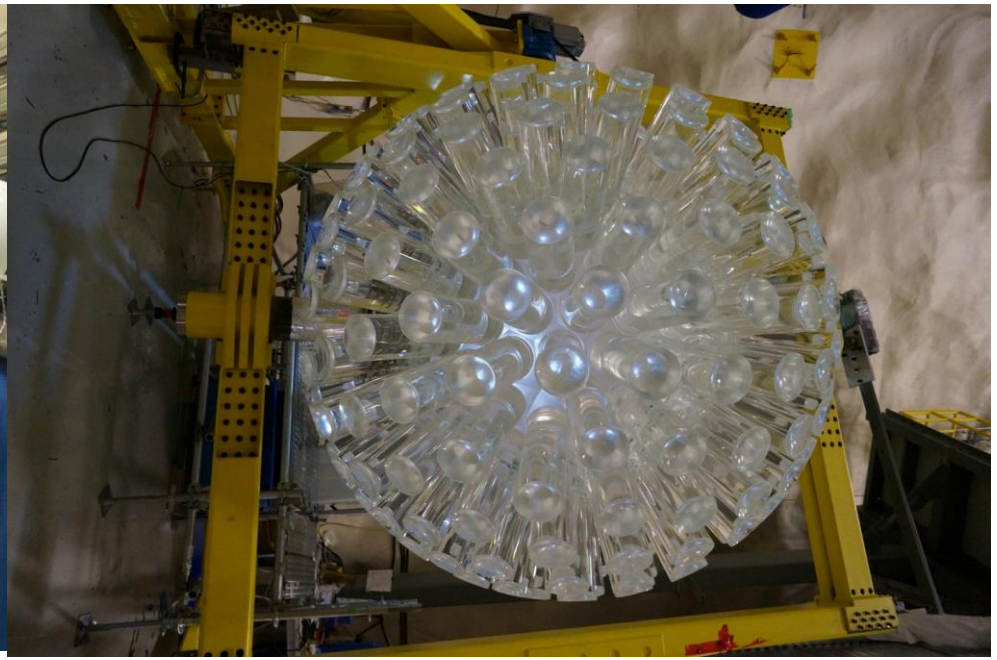
Vessel is “resurfaced”
in-situ to remove
deposited Rn daughters
after construction

255 Hamamatsu
R5912 HQE PMTs 8-inch
(Light Sensors)

50 cm light guides +
PE shielding provide
neutron moderation

Steel Shell immersed in 8 m
water shield at SNOLAB

DEAP Assembly at SNOLAB (2013-2016)



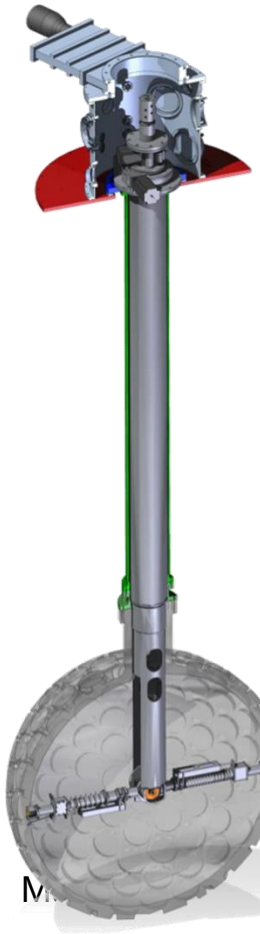
Background	Fiducial No. Events in Energy ROI – 3 live years
Neutrons	<0.2
Surface α's	<0.2
^{39}Ar β's (natural argon)	<0.2

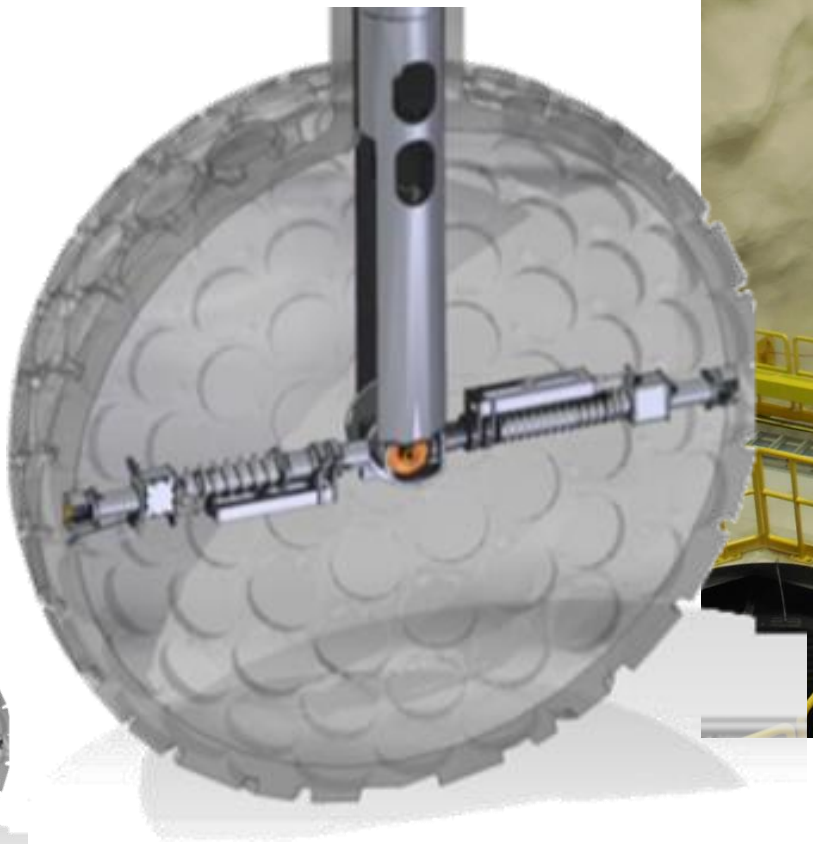
designed for
1-tonne fiducial mass
3 live years

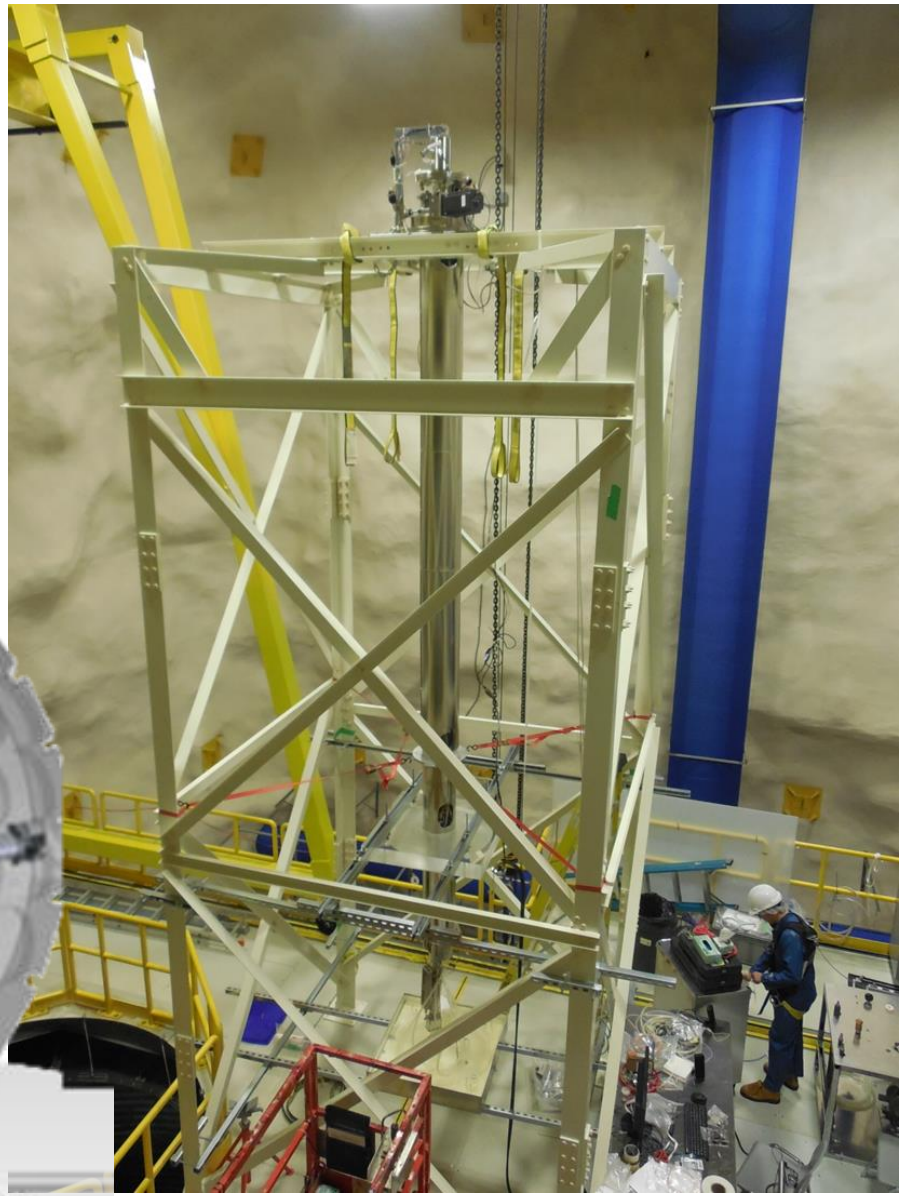
Mark Boulay

Acrylic Vessel Resurfacer

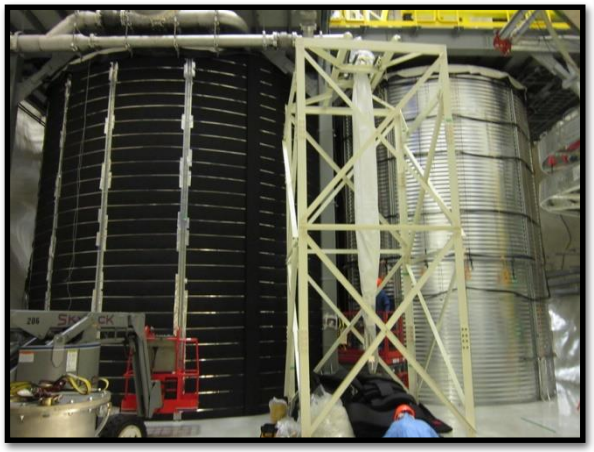
- Mechanical sander to clean inner surface
- Components selected for low radon emanation
- Remove 0.5-mm surface *in situ* with N_2 purge
- Cleans surface to bulk-level impurities
  (order 100,000 cleaner than SNO vessel)

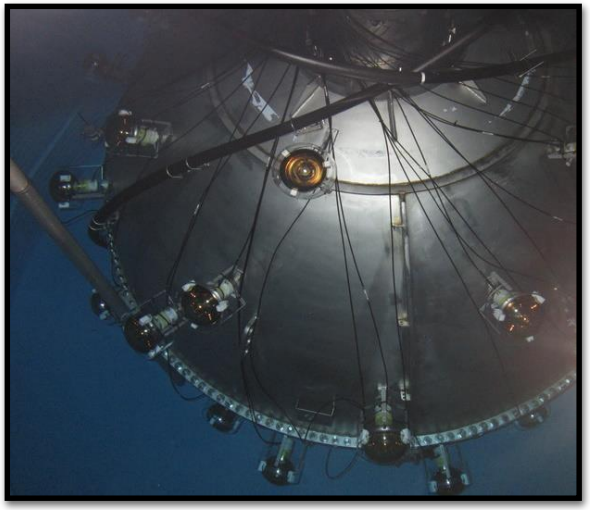


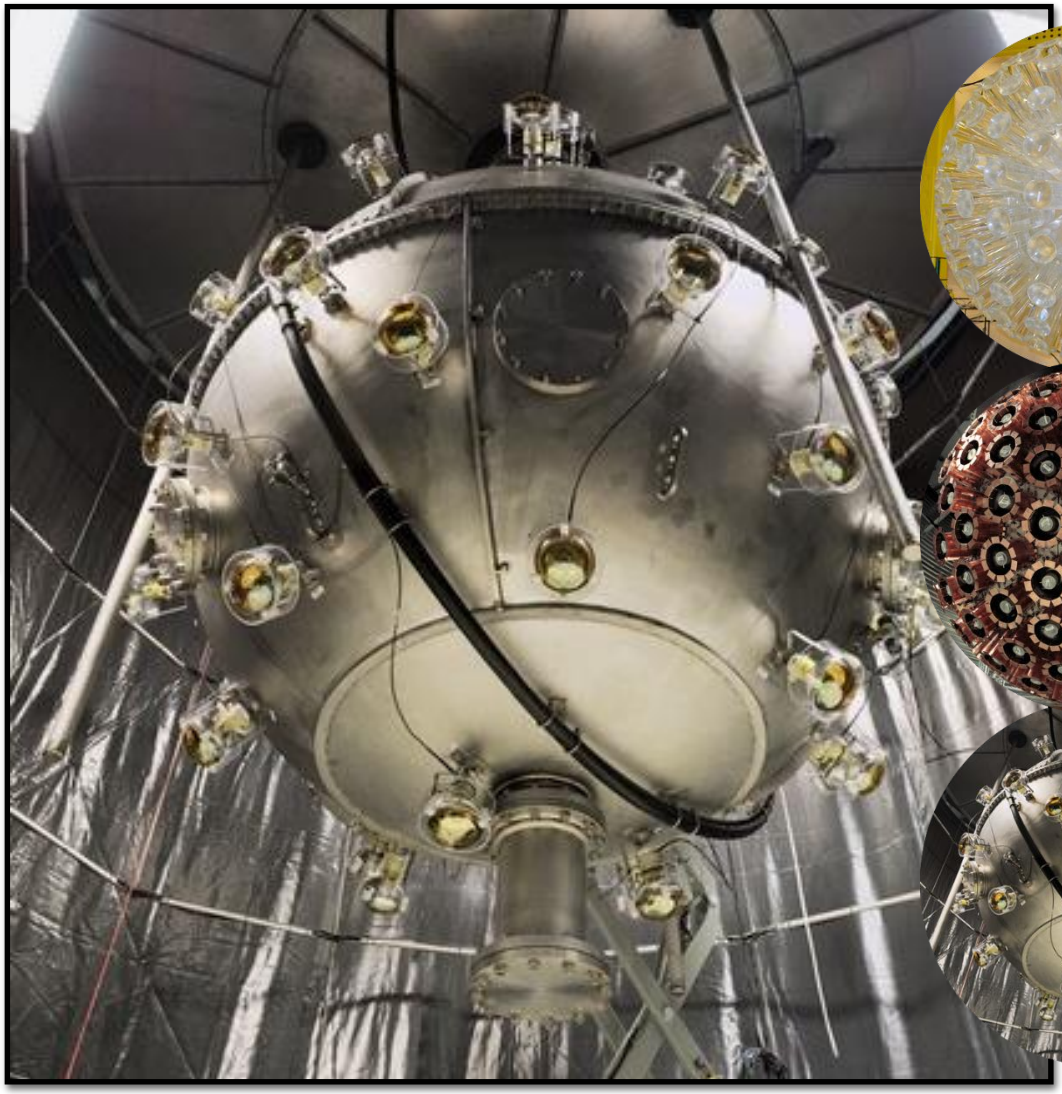


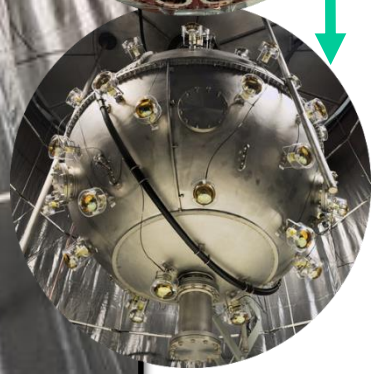


Construction of DEAP-3600 was completed in early 2016









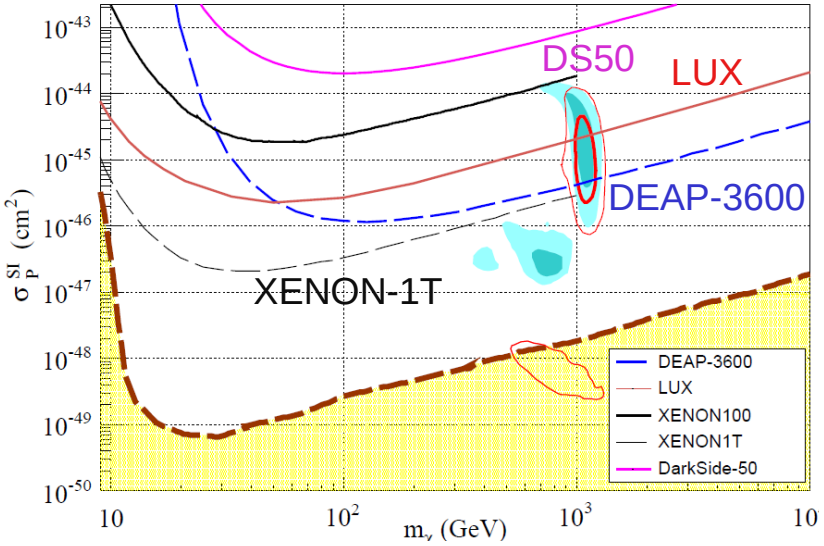
Mark Boulay

DEAP-3600 status

- Detector filled since Nov 1, 2016
- Collecting DM search data, so far > 0.5E6 kg-days raw exposure
- So far stable performance, good light yield
- Taking physics and calibration data, plan to

  continue data collection for ~4 years
- Working on the first analysis from the 1st fill data; physics publication expected early this year

Sensitivity with Argon



Argon has good sensitivity in high-mass region

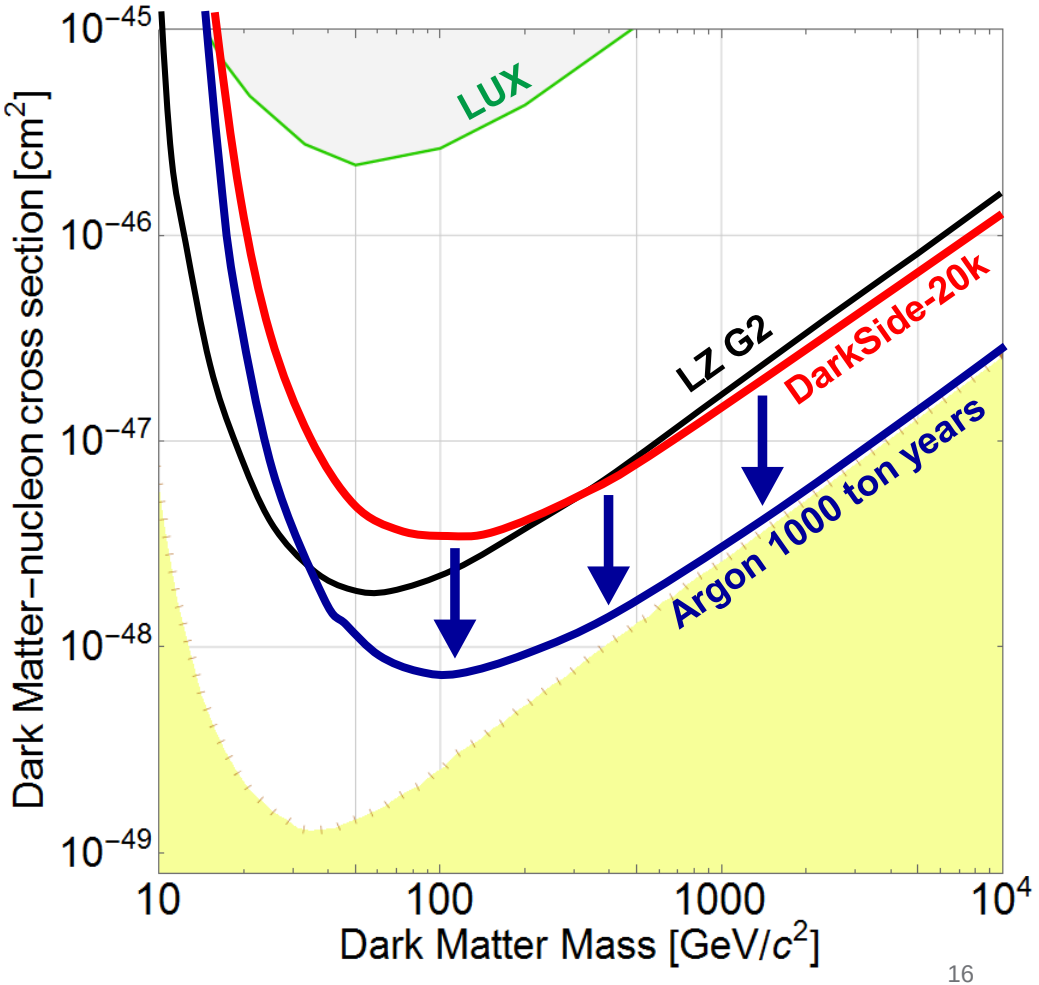
DS-20K (20 tonnes UAr) competitive with LZ – start operation 2021

1000-tonne years (future detector) reaches down to neutrino floor

Complimentary to xenon – only other target allowing such large exposure

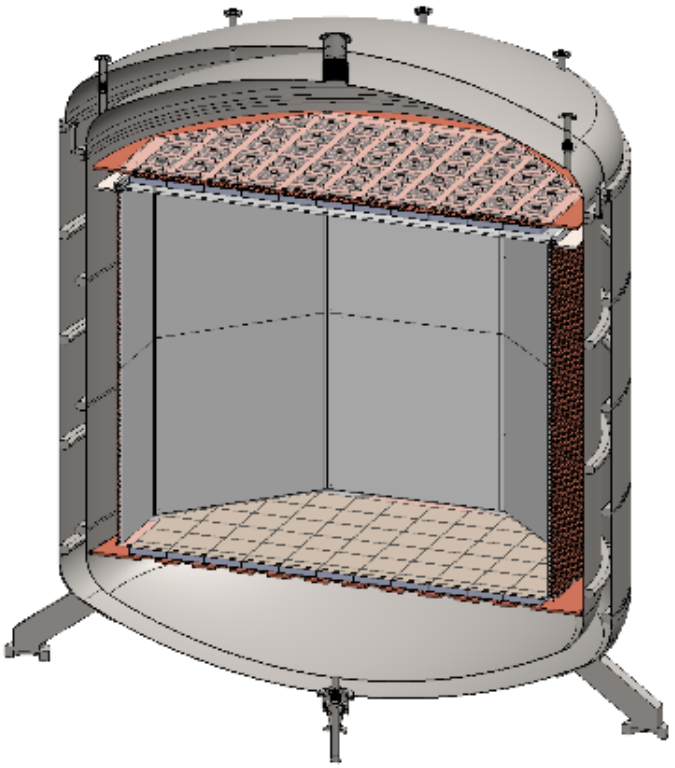
β/γ discrimination: solar pp neutrino ES background not a concern – in X1T, LZ expected dominant bkg at ½ event per tonne-year after recoil discrimination

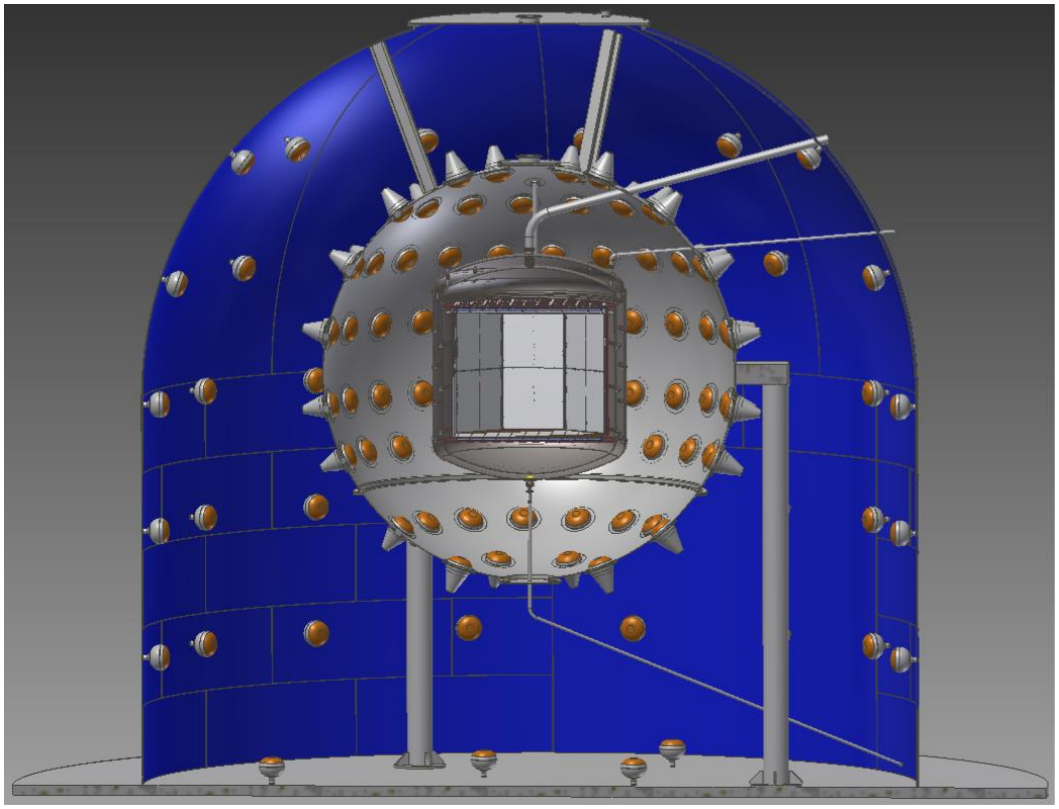
Spin-Independent ***High-Mass*** Region



Mark Boulay

DarkSide-20K: 20 tonne argon two-phase TPC at LNGS





- TPC scaled-up from DS-50
- Design is advanced “yellow-book 2016”, very high confidence in design
- 20 tonnes of low-radioactivity argon
- Collaboration with experience from DarkSide, DEAP, miniCLEAN, ArDM
- First large-scale use of SiPMs for light readout

DS-20K and beyond: An Ambitious Discovery Program

- Significant international collaboration
- Complementary to LHC searches (exploration of v. high masses with direct search)
- Sensitivity increase from 1 tonne × yr → 1,000 tonne × yr
- "Zero Background" necessary for a discovery program

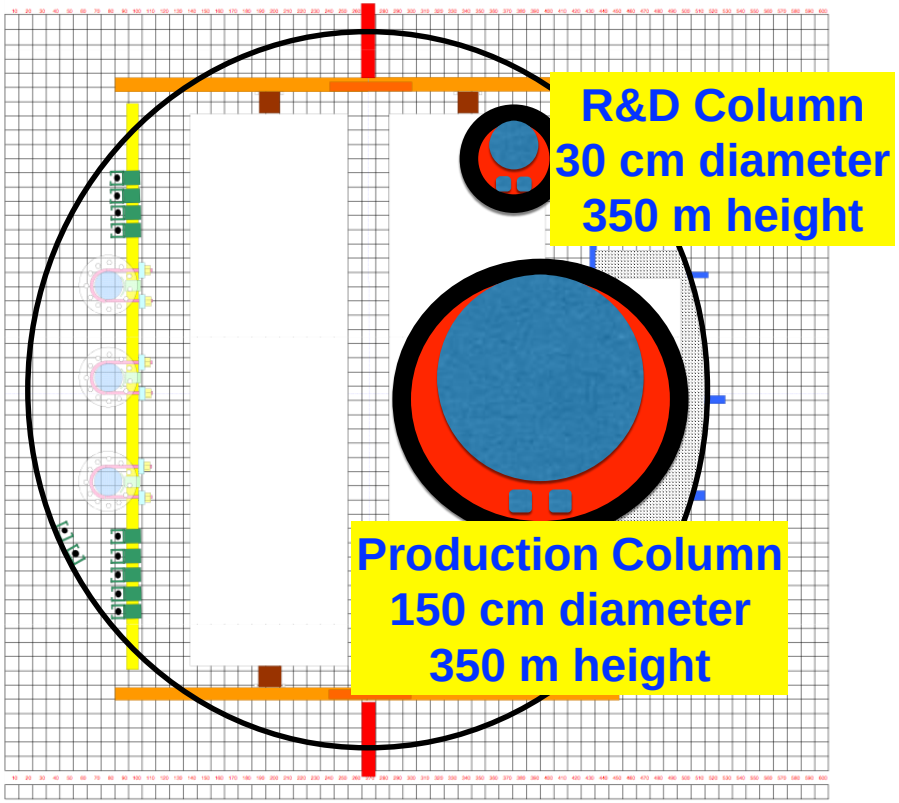
- Two crucial technologies
  - Liquid argon target depleted in the radioactive ^{39}Ar (underground argon: Urania and isotopic purification: Aria)

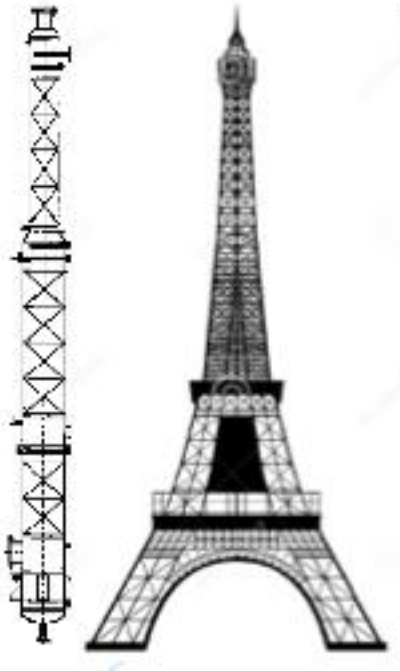
    (Underground argon: scale up facility to ~150 kg/day; total gas stream at current facility is ~3 tonnes per day)
  - SiPMs replacing cryogenic PMTs

Aria: Purification of argon (depletion of ^{39}Ar)

Prototype column allows 10 kg/day purification

Full column: 100 kg/day x10 reduction per pass

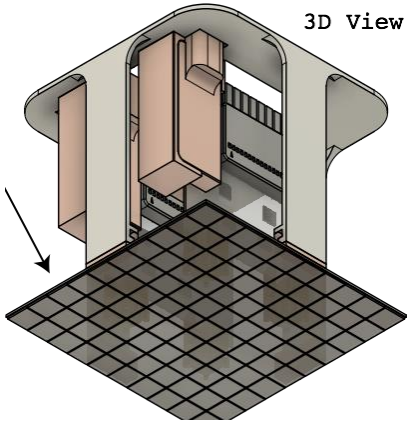




Ongoing Aria Module Testing at CERN

Development of large area SiPMs for DS-20K

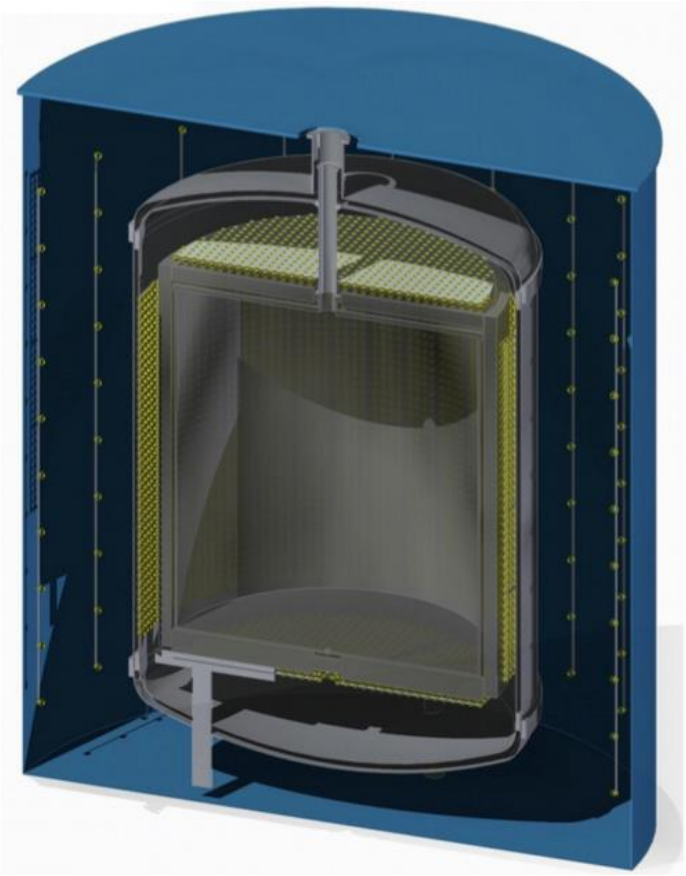
- Photon Detection Efficiency (PDE): 45% requirement met and surpassed
- Dark Count Rate (DCR): 0.1 Hz/mm^2 requirement met and surpassed
- Challenge in tiling due to 50 pf/mm^2 capacity. Signal-to-Noise Ratio (SNR) rapidly decreases with increasing surface. The steps:
  - 2×2 cm^2 tile: fully demonstrated September 2016
  - **5×5 cm^2 tile: fully demonstrated March 2017**



DS-20K SiPM tile

After DS-20K (Argo/DEAP-nT)

- Collaboration will pursue integrated program/common design allowing ktonne-year exposure (single-phase/dual phase both options considered)
- Plan for operation with low-radioactivity argon
- Sensitivity to neutrino floor for high-mass WIMPs
- Timescale follows DS-20K (mid-2020's)
- Site TBD
- Possibility for solar neutrino measurements
- Some R&D started in Canada, new Cryogenics Facility at Carleton, CAD development of digital SiPM array



Summary

Argon demonstrated to be an excellent target for DM search.
DarkSide demonstrated background-free operation with low-radioactivity argon. Sets the stage for future large-mass searches (DS-20K and beyond)

DEAP-3600 (3.6 tonnes argon) collecting data since late 2016.
Sensitivity in 2017 will reach current best limit with LUX at high mass.

Significant advances in light detection (SiPMs) and radioactivity control.

Significant global collaboration with extensive skills/experience toward:

DS-20K at LNGS (2021 operation)

Future multi-hundred-tonne detector (mid-2020's)

END