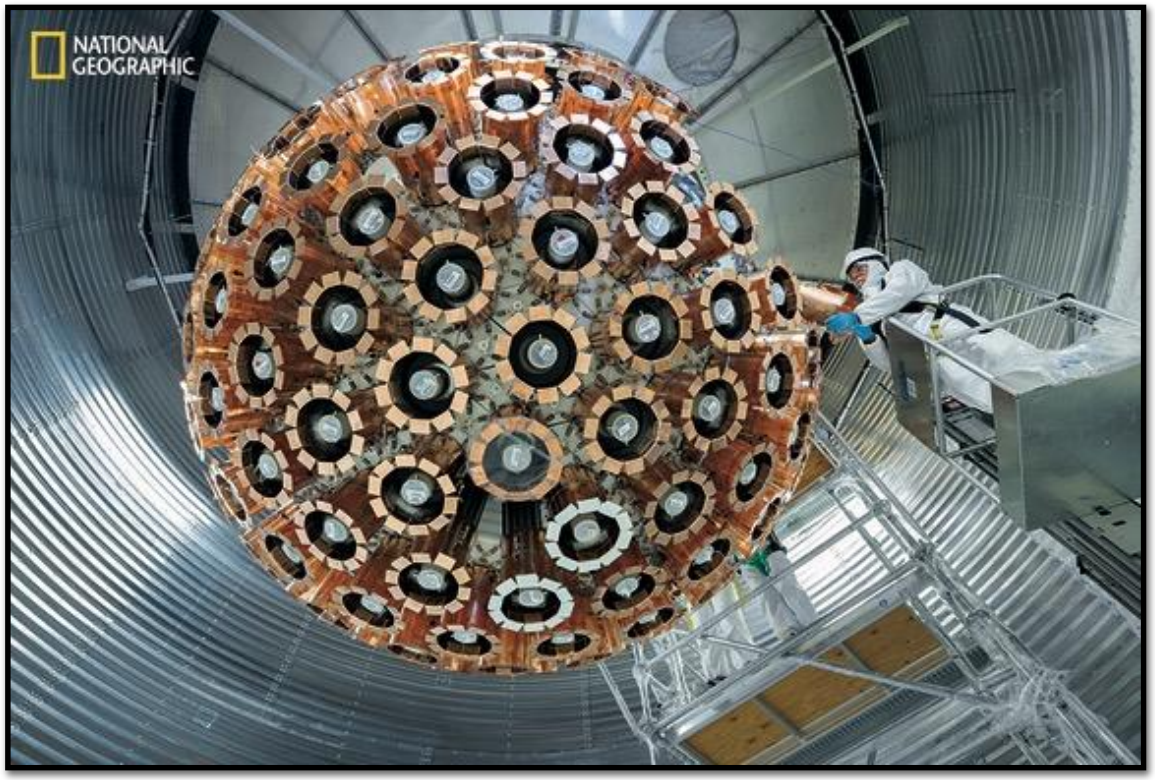
DEAP-3600 and future plans



- DEAP-3600 First Results
- New Global Argon Collaboration and DS-20k
- Multi-hundred tonne argon DM experiment
- New Liquid Noble Detector Facility at Carleton
- Conclusions

Mark Boulay

Carleton University
SNOLAB Future Projects
August 16, 2017

DEAP Collaboration: 75 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

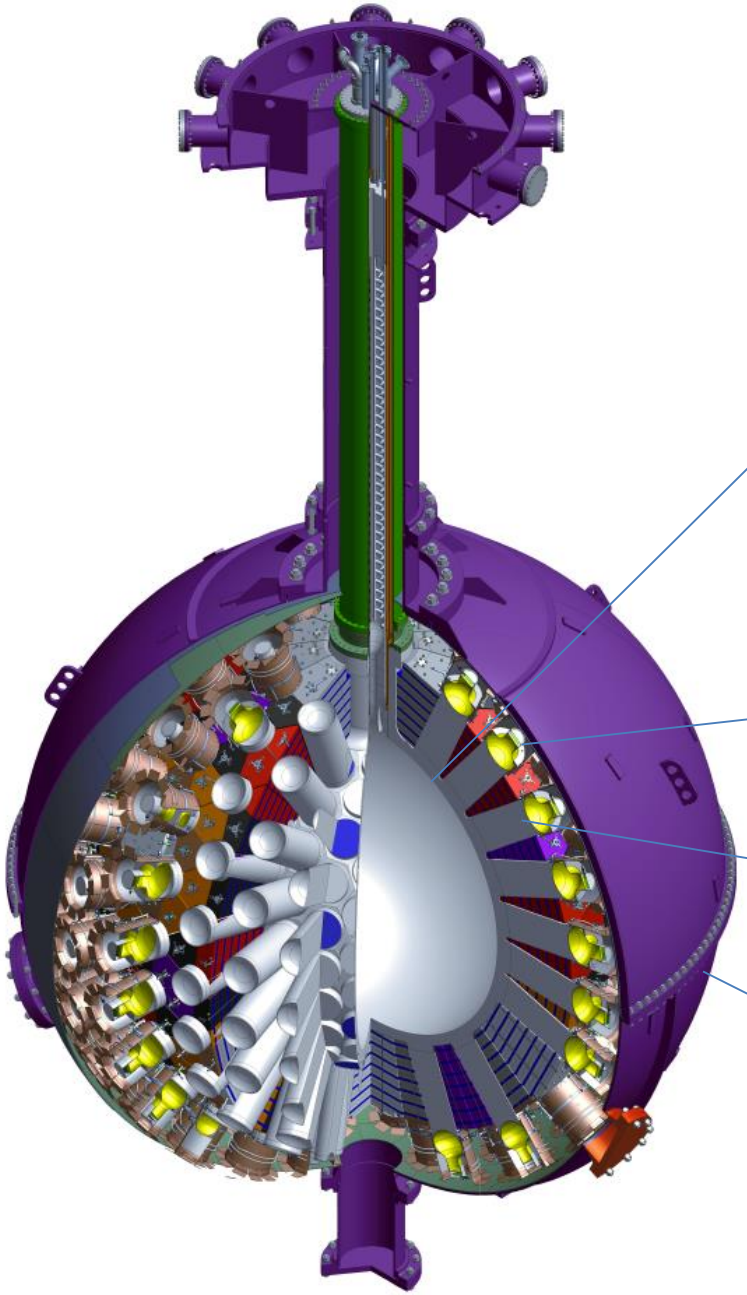
TRIUMF

University of Sussex

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Instituto de Física

DEAP-3600 Detector



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

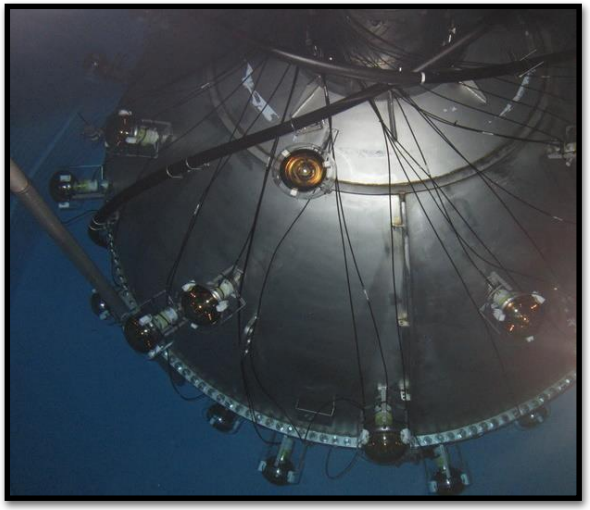
Vessel is “resurfaced”
in-situ to remove
deposited Rn daughters
after construction

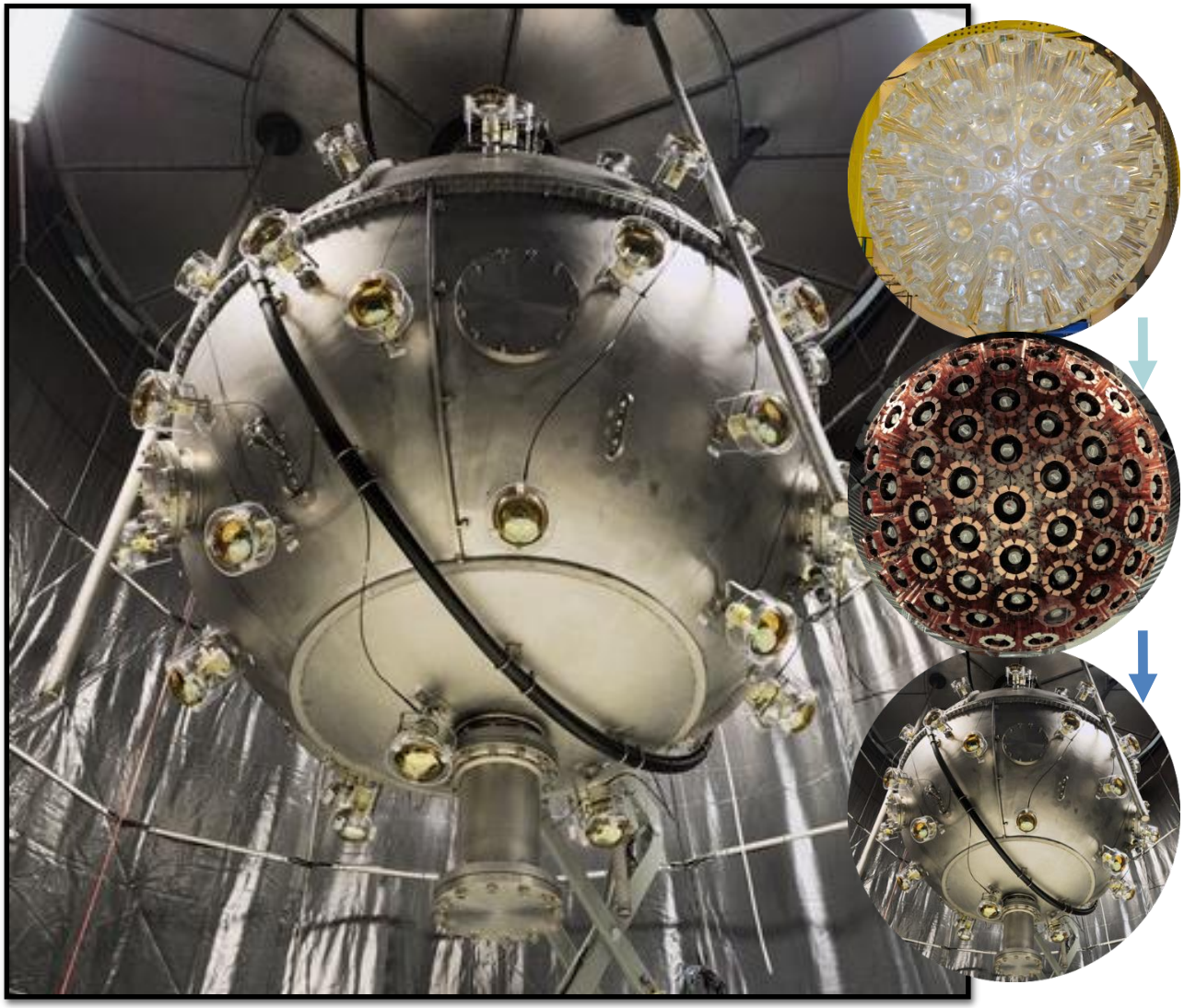
255 Hamamatsu
R5912 HQE PMTs 8-inch
(32% QE, 75% coverage)

50 cm light guides +
PE shielding provide neutron
moderation

Steel Shell immersed in 8 m
water shield at SNOLAB

Detector was filled with Liquid Argon by summer 2016

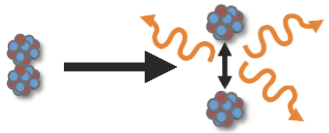




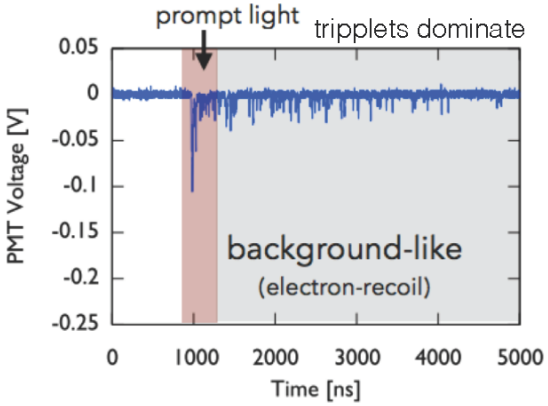
Experimental Signatures

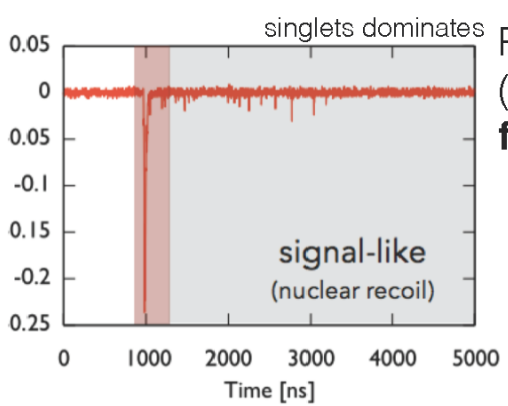
Ar scintillation:

- excimers are create



- singlet: 6 ns
- tripplet: 1500 ns
- wavelength: 128

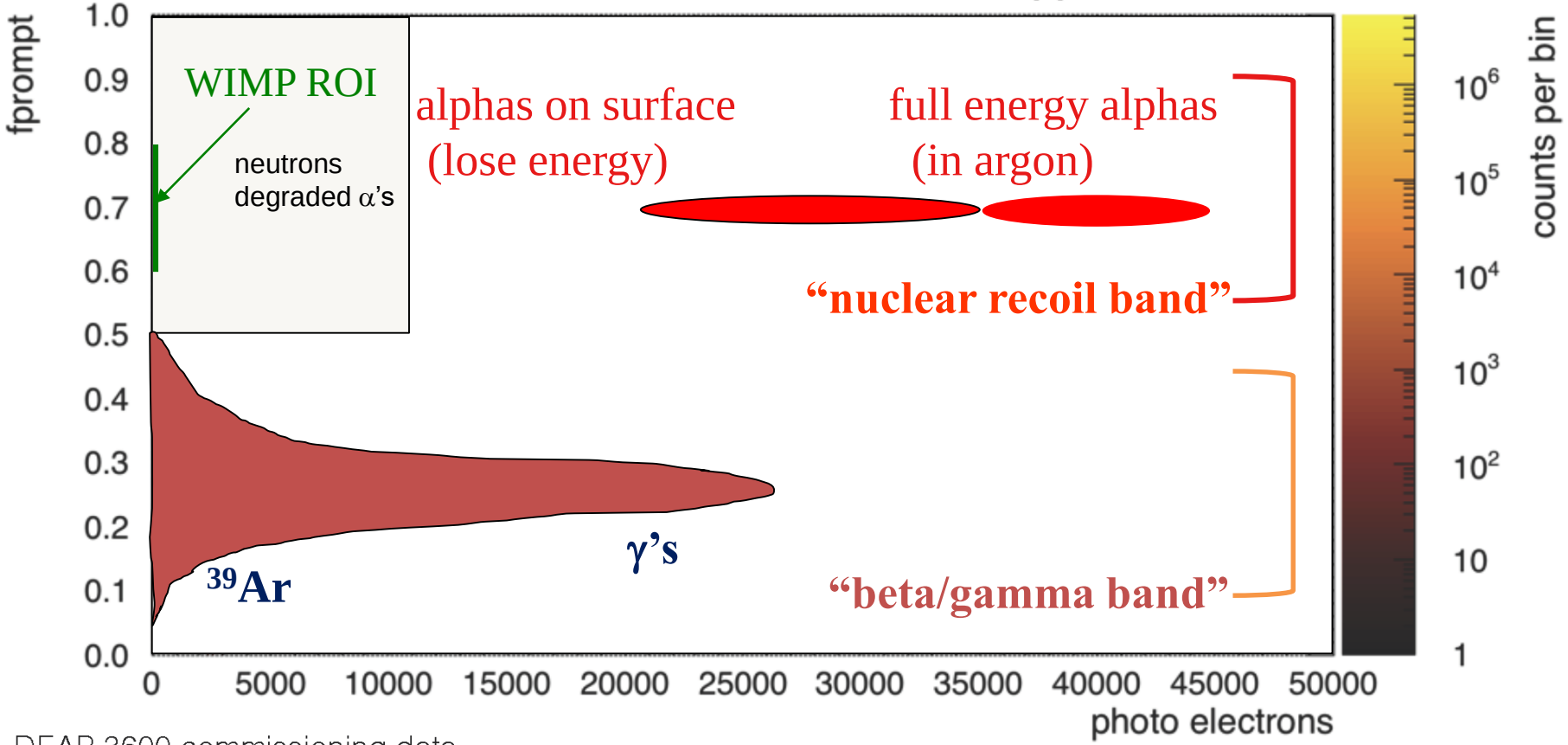




Pulse shape discrimination (PSD) parameter:

fprompt =

$$\frac{\text{prompt light (150 ns)}}{\text{total light (10000 ns)}}$$



DEAP 3600 commissioning data

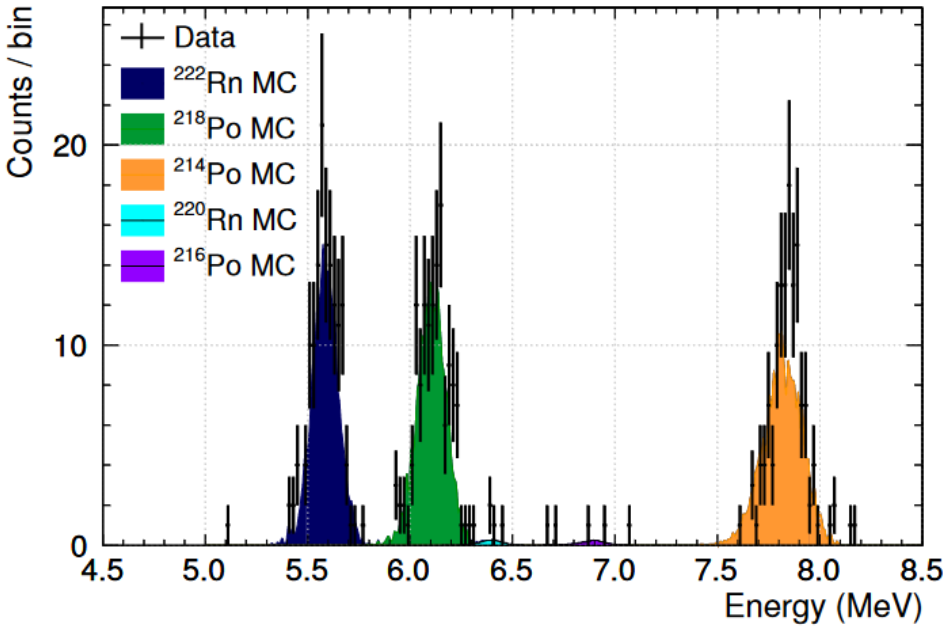
^{222}Rn in DEAP-3600

- Measuring the ^{222}Rn content in the bulk LAr shows the very competitive results
- Conclusion: ^{222}Rn induced background within expectations

^{222}Rn in Dark Matter experiments:

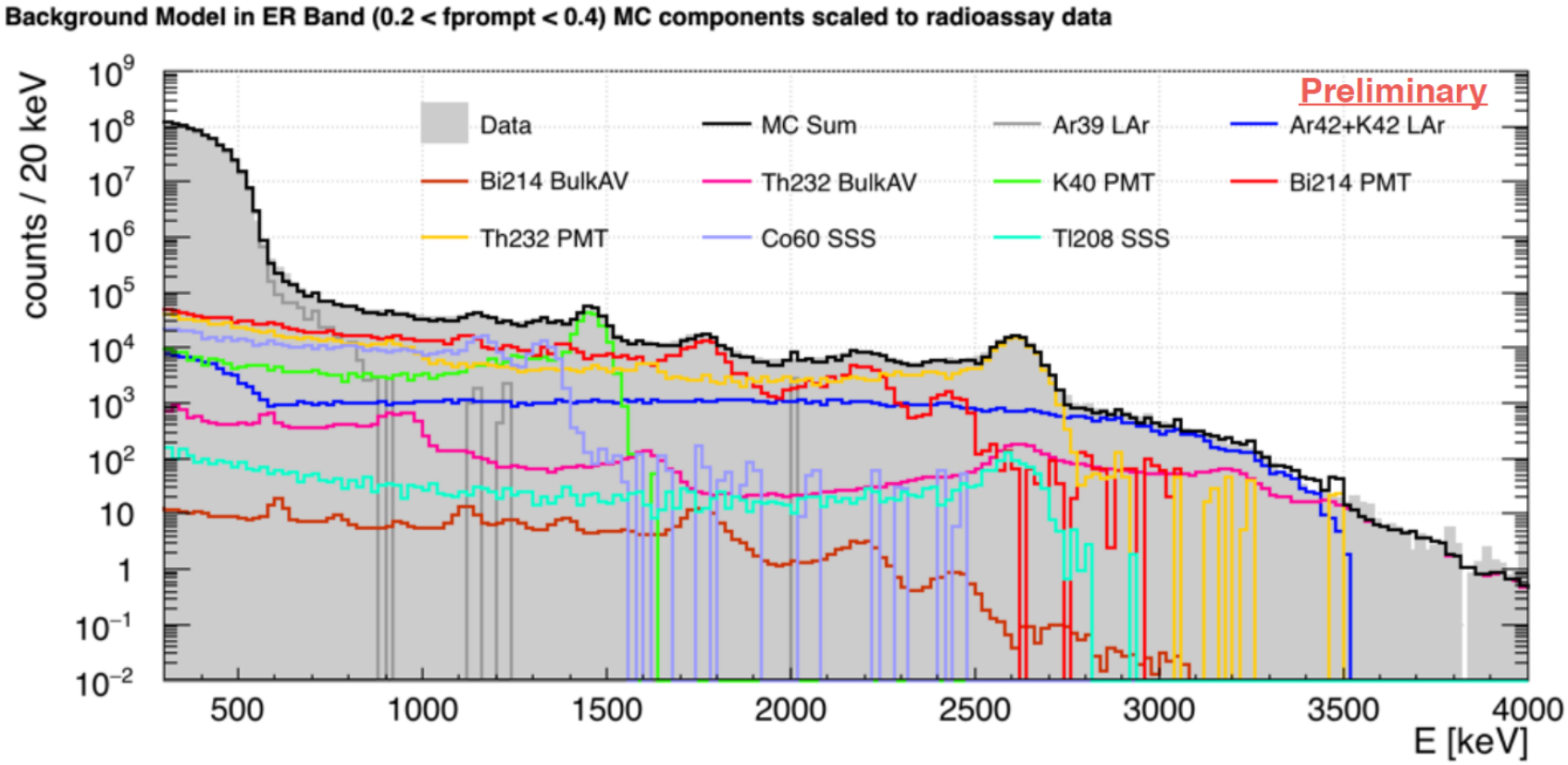
Experiment	Activity / rate	Target
DEAP-3600	≈0.2 μBq / kg	LAr
PandaX-II	6.6 μBq / kg	LXe
LUX	66 μHz / kg	LXe
XENON1T	10 μBq / kg	LXe

- PandaX-II: PHYSICAL REVIEW D 93, 122009 (2016)
- LUX: Physics Procedia 61 (2015) 658 – 665
- XENON1T: XeSAT 2017 talk [link]



30-300X lower radon levels than xenon DM experiments

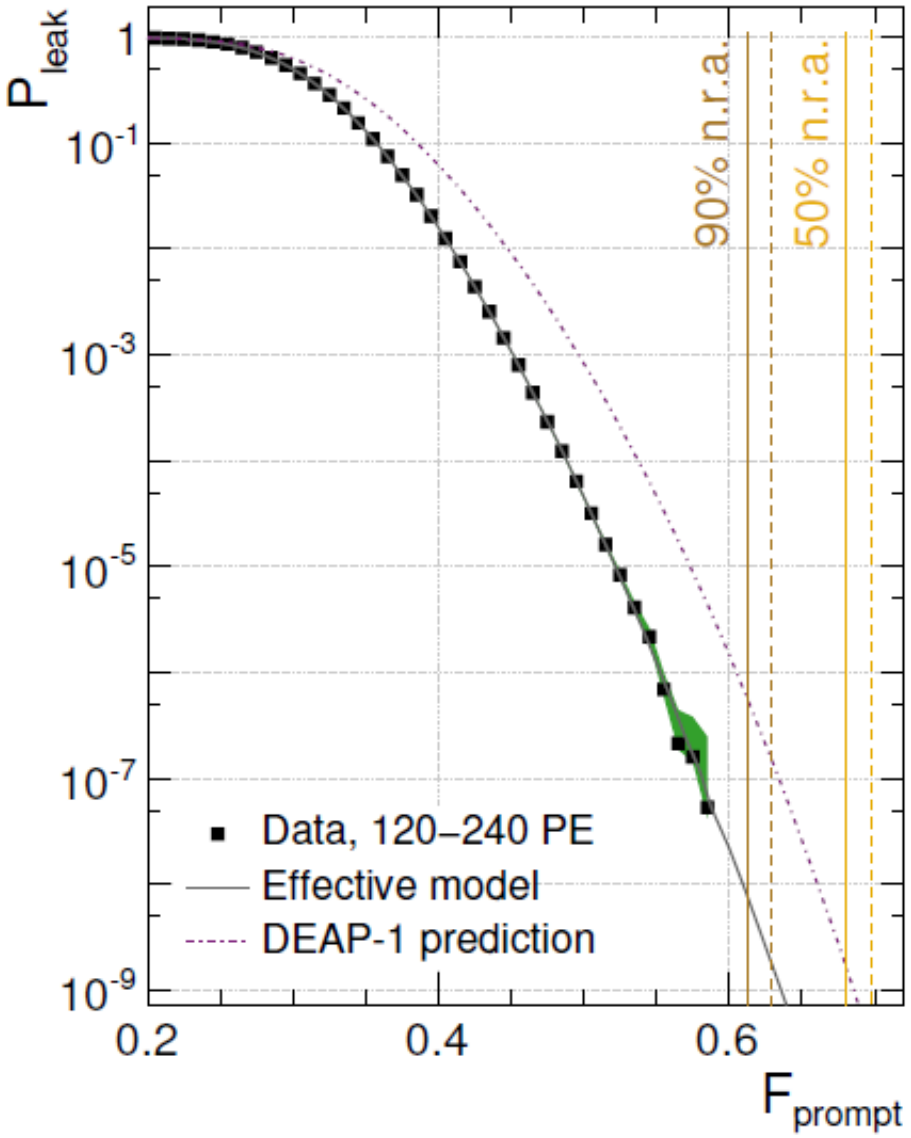
Gamma and Beta Background Model



MC Simulations scaled by radioactivity screening results

^{42}Ar produced through: successive n captures on ^{40}Ar (requires v. high n flux)
or
^{40}Ar(α,2p)^{42}Ar in upper atmosphere,
so underground argon may be very low in ^{42}Ar

Pulse-Shape Discrimination in DEAP-3600



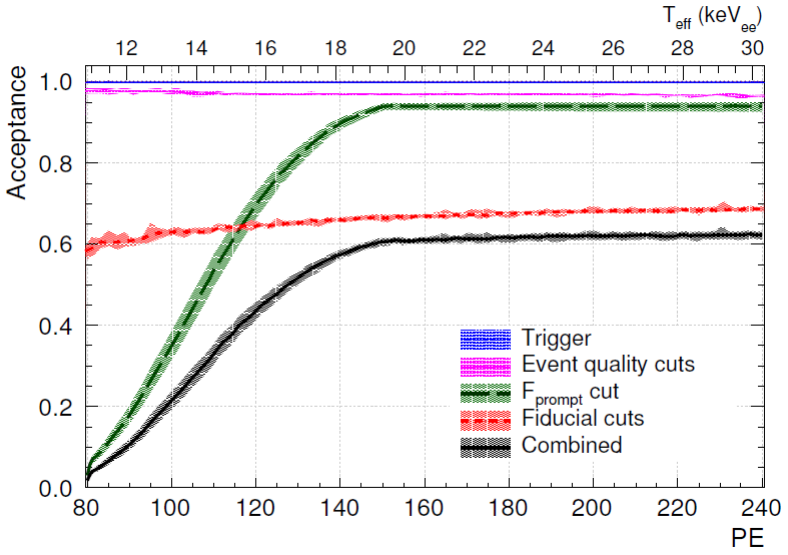
We observe good PSD of beta events down to 11 keVee!

Best ever demonstrated at low energy, expect to meet design goal for full sensitivity run

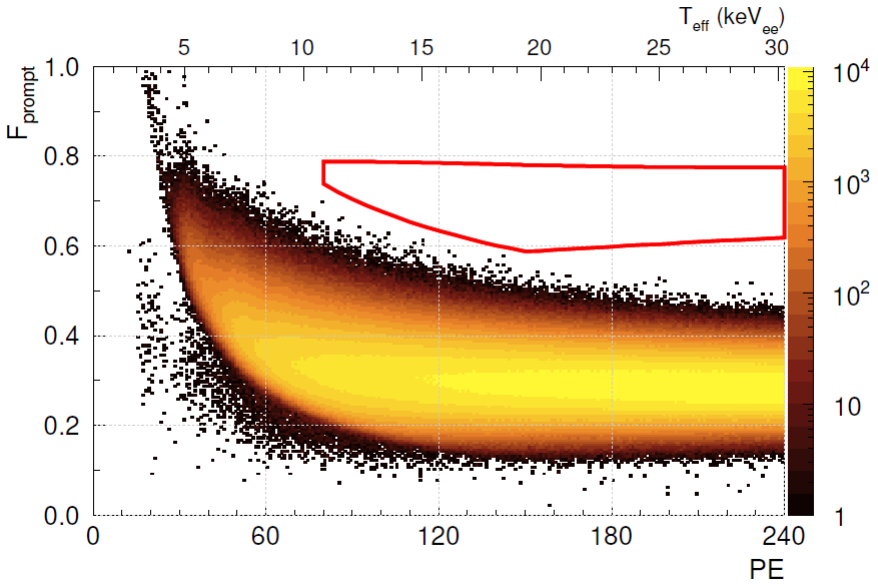
Combine this with low-radioactivity argon (depleted in ^{39}Ar):

can use PSD for WIMP search with **several hundred tonnes** of argon

First Dark Matter Search with DEAP-3600 – 9,870 kg-days



	Cut	Livetime	Acceptance %		$\#^{ROI}_{evt.}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58 ± 0.01		654
	Event time		99.85 ± 0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	0
	Total	4.44 d	96.94 ± 0.03	$66.91^{+0.20}_{-0.15}$	0



4.44 live days

Selected ROI for < 0.2 leakage from β's

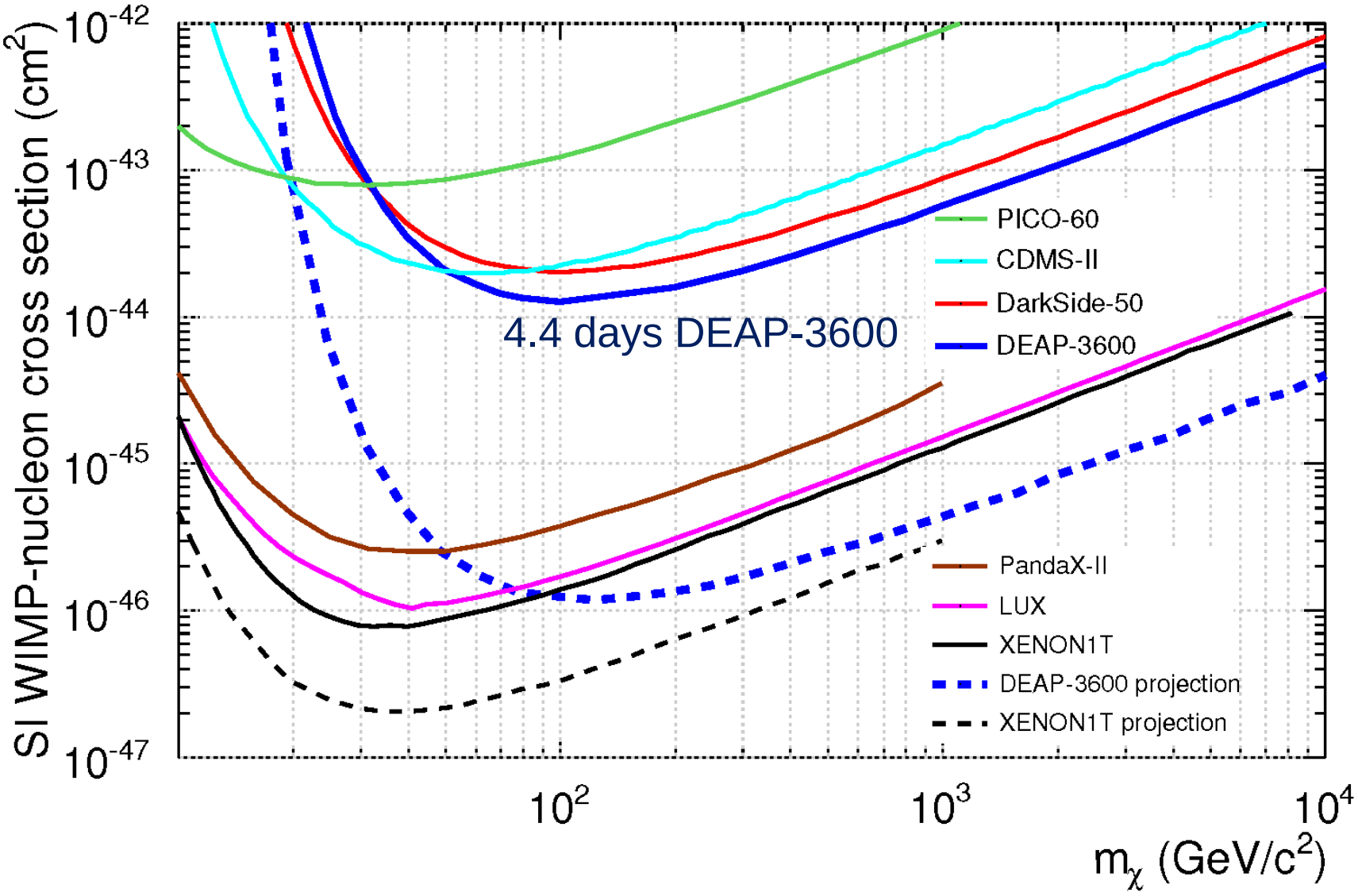
Developed prelim. cuts for instrumental and external-source events

2,223 kg fiducial mass

9,870 kg-day exposure

No events observed in ROI

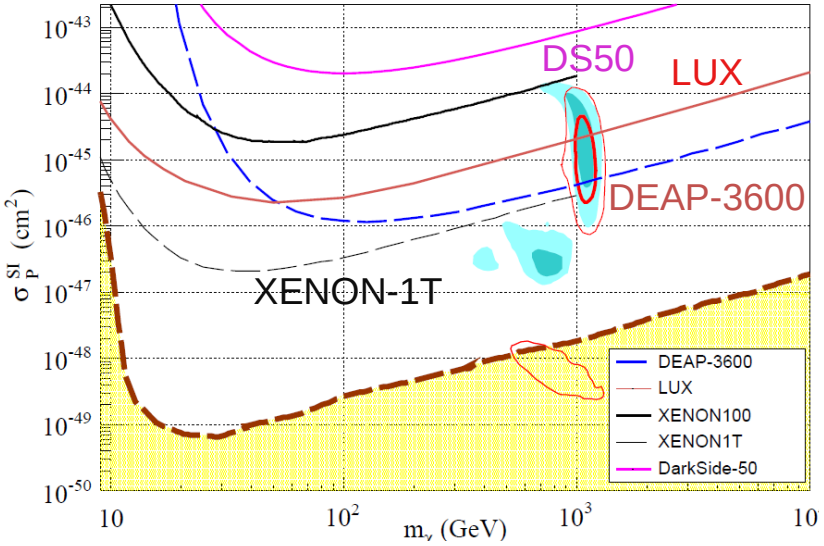
WIMP exclusion with DEAP-3600 (July 2017 result)



Summary of DEAP-3600

- First paper submitted to PRL July 2017 and on arxiv:
  - *4.4 live days, 9,870 kg-days, background-free, lower threshold and larger fiducial volume than design spec (2 tonne fiducial volume)*
  - *Best sensitivity with argon, first single-phase argon result, more sensitive for high-mass WIMPs than any other technique besides 2-phase xenon so far*
  - *PSD better than predicted from earlier estimates (lower electronics noise), best demonstration of low-energy PSD in argon*
  - *Lowest background radon of any noble liquid experiment: 20-300X lower than PandaX, LUX, XENON-1T*
- Currently in stable operation since Nov 1 2016, data collection, ~3/4 million kg-days, largest LB exposure of any DM experiment
- Plan to continue running until ~2020 for full sensitivity

Beyond DEAP-3600 – to the neutrino floor with argon



Argon has good sensitivity in high-mass region

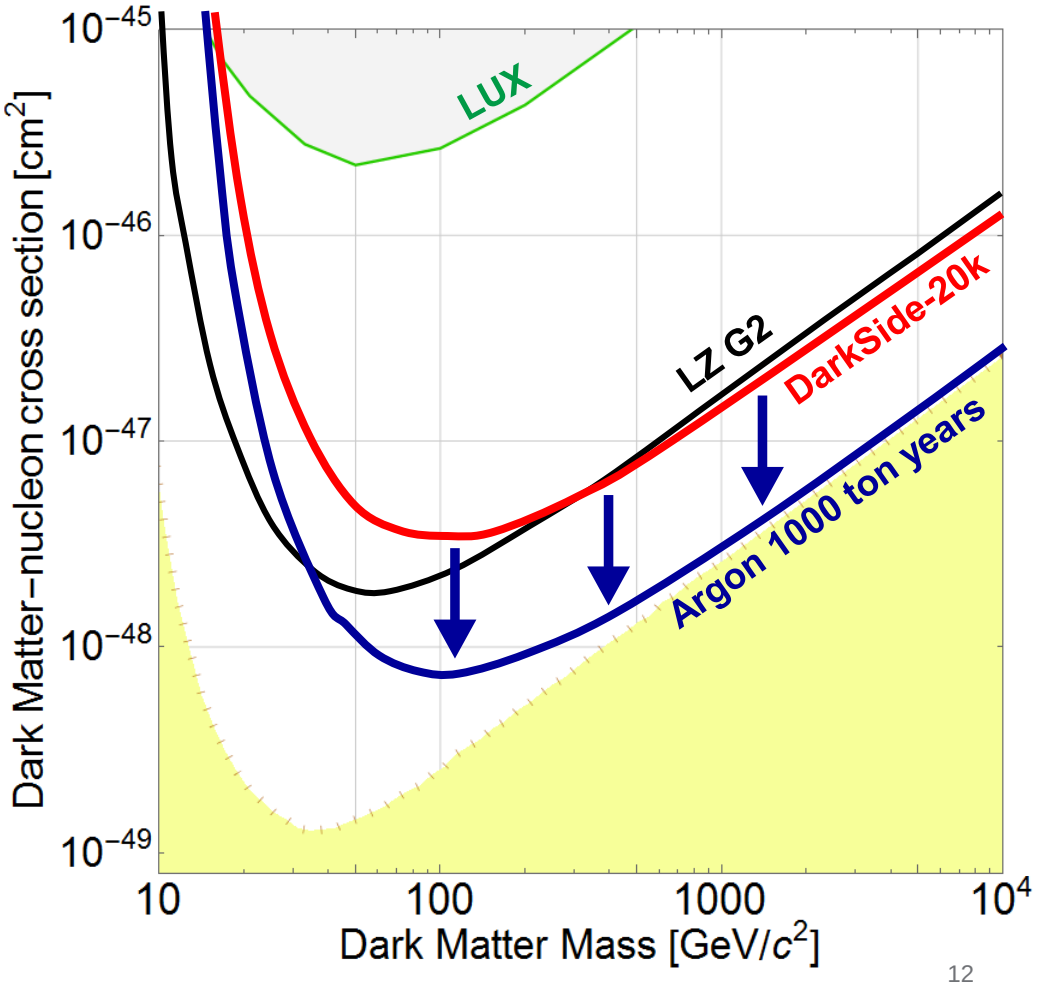
DarkSide-20k (20 tonnes argon) competitive with LZ – start operation @ LNGS in 2021

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

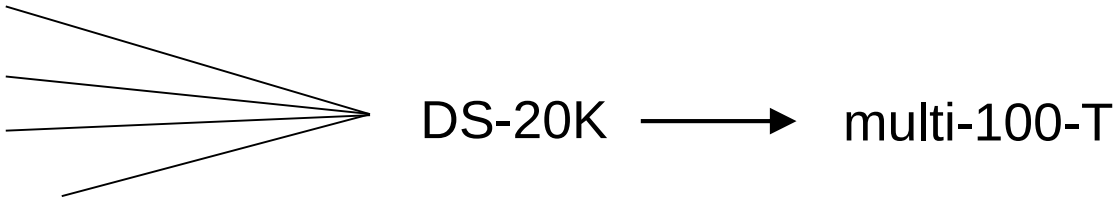
Spin-Independent ***High-Mass*** Region



New Global Argon Collaboration

Over 350 researchers from

- DarkSide
- DEAP
- ArDM
- MiniCLEAN



are joining to collaborate fully on future argon DM program:

- Completion of current science and R&D programs by each collaboration (DS-50, DEAP-3600, MiniCLEAN, ArDM)

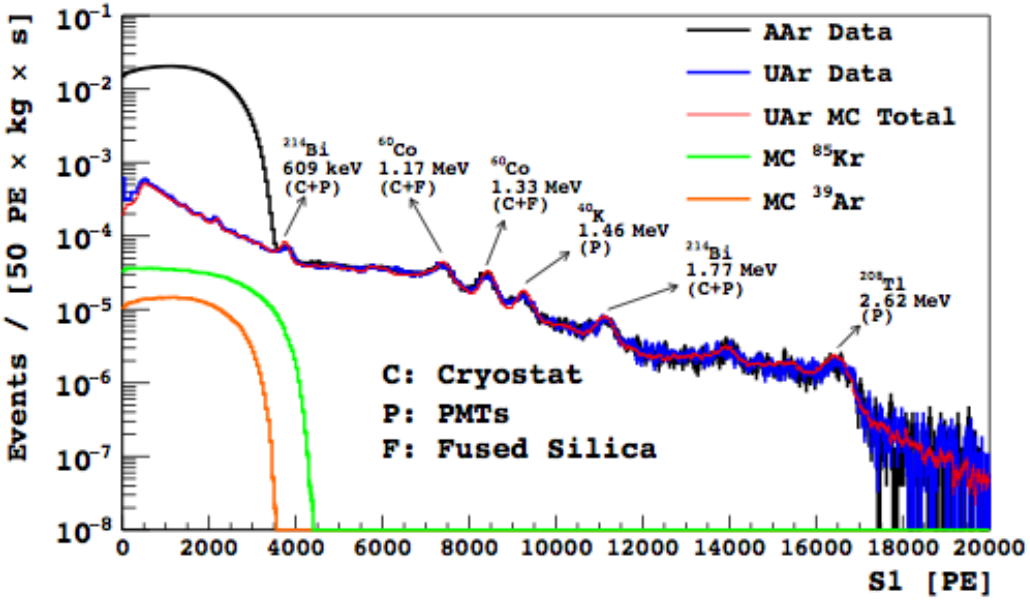
- Joint collaboration on **DS-20K at LNGS**, 20 tonnes of underground Ar in two-phase TPC (operation starting 2021) and SiPM photodetectors **(detailed talk on Thursday by Andrew Renshaw)**

- Joint collaboration on multi-hundred-tonne detector, site TBD (mid-2020's)

- Coalescence of the scientific community towards a single argon collaboration is supported by the Underground Labs: LNGS, LSC and SNOLAB. Program fosters collaboration between labs **and** scientists.

Underground Argon (UAr) – Critical for Future Program

- Underground argon depleted in ^{39}Ar by at least 1400
- Allows realization of very large argon detectors (20 tonnes-hundreds of tonnes)



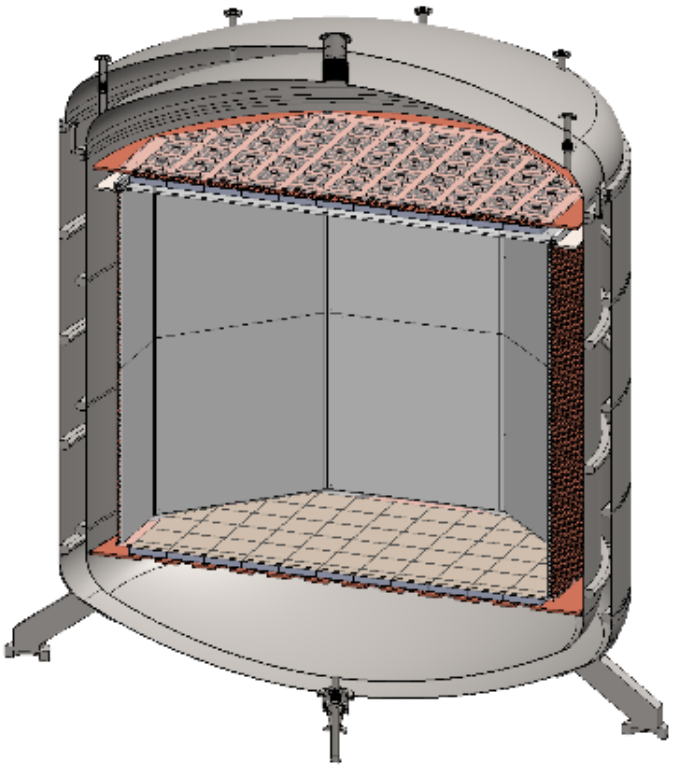
DS-50 results with atmospheric and UAr

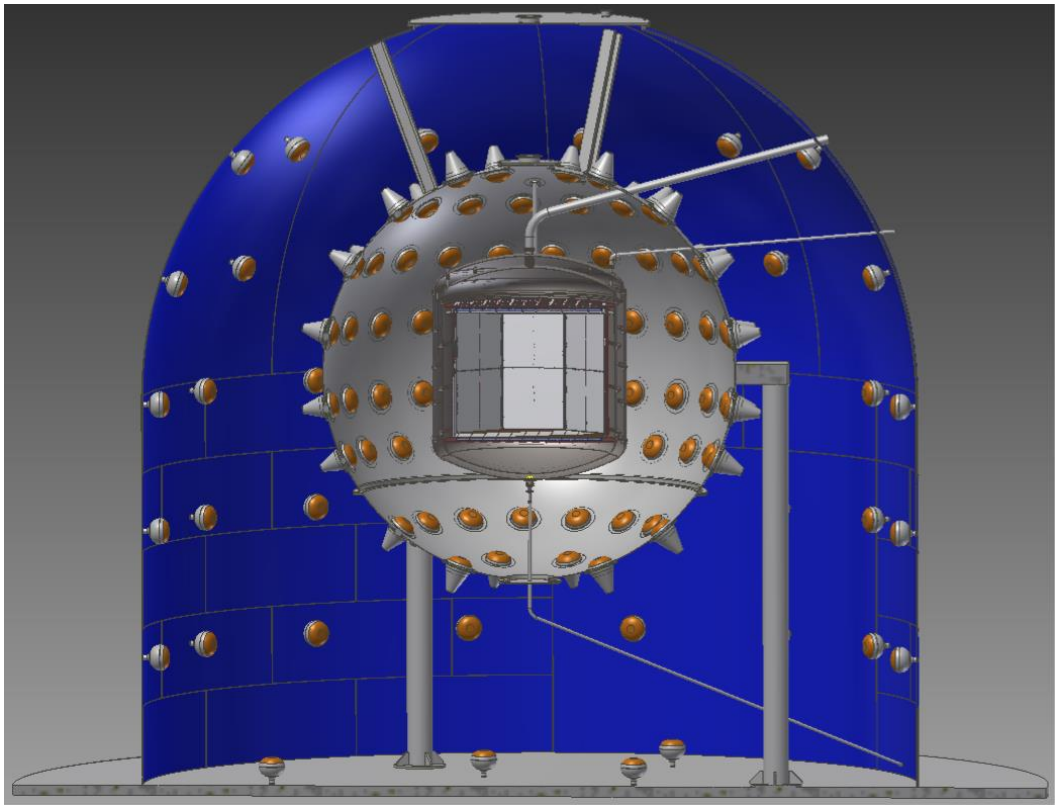
Development of *Urania* underground argon extraction facility

Cortez, CO, USA

~100 kg/day production

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

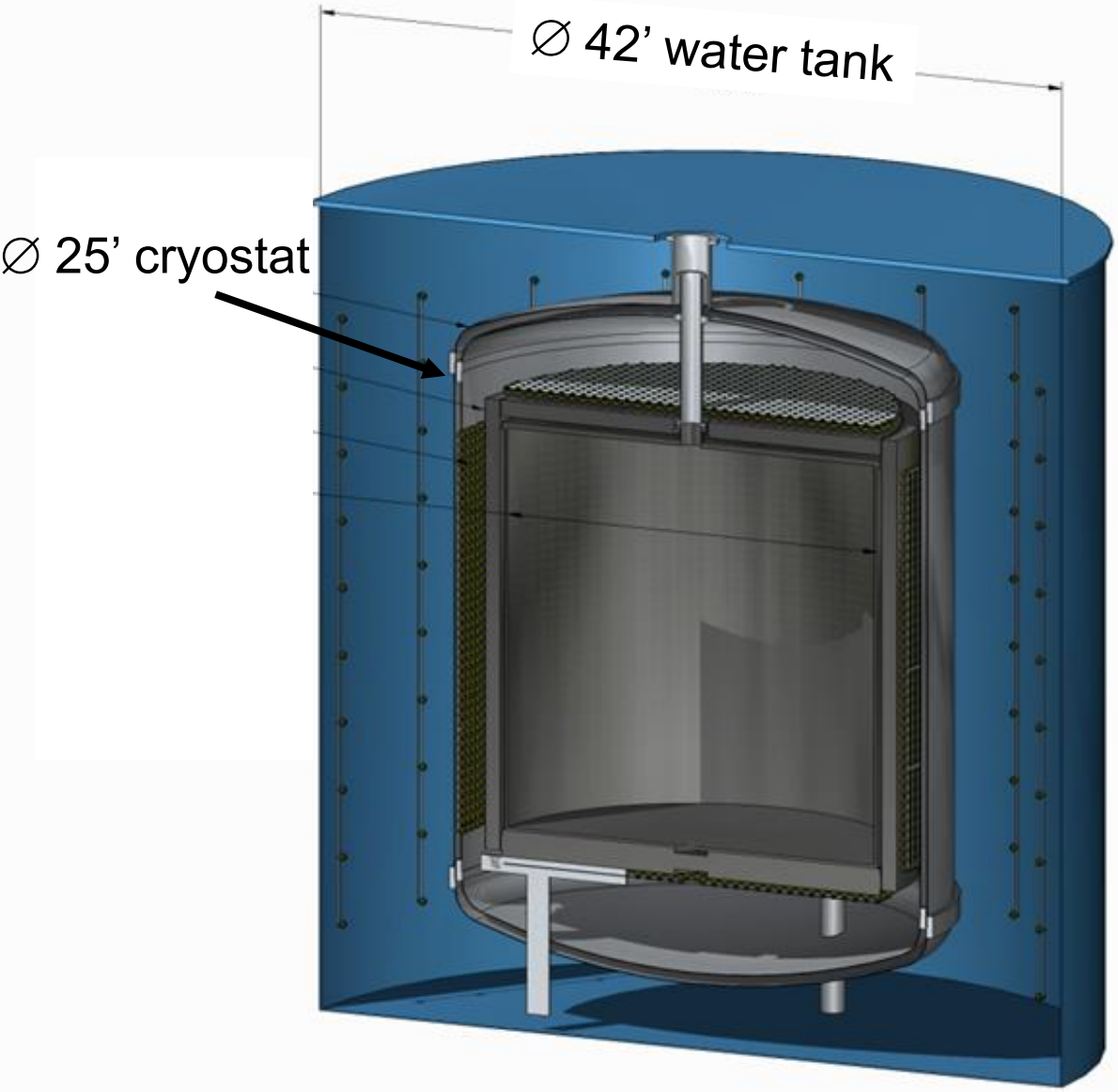




- TPC scaled-up from DS-50
- Design is advanced “yellow-book 2016”, very high confidence in design
- 20 tonnes of underground argon, start operation 2021
- Collaboration with experience from DarkSide, DEAP, miniCLEAN, ArDM
- First large-scale use of SiPMs for light readout

Multi-hundred tonne detector – concept for size only!

Design TBD, but will feature:



100’s tonnes low-radioactivity (underground) argon for ktonne-year exposure

Requires underground storage of argon target

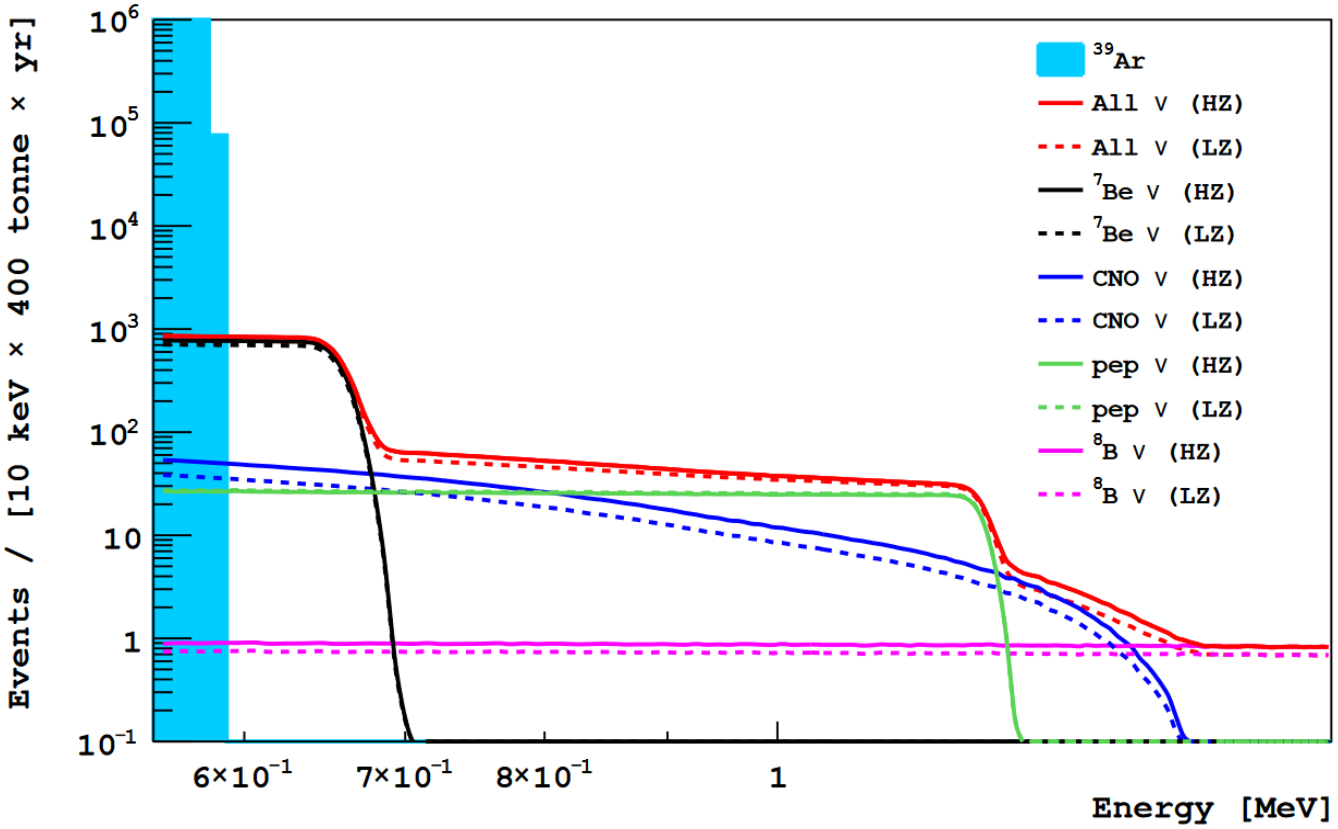
New collaboration will explore design options based on progenitors

Dimensions for reference:

300 tonnes liquid argon,
∅42’ outer water tank

(Cube Hall and CryoPit are ~∅ 50’ x 65’ high)

Solar neutrino-electron scattering in Liquid Argon



Source	LZ SSM Rate	HZ SSM Rate
^{7}Be	10,410	11,432
CNO	2,338	3,287
pep	4,018	3,908
^{8}B	127	153

ν events per ktonne-y

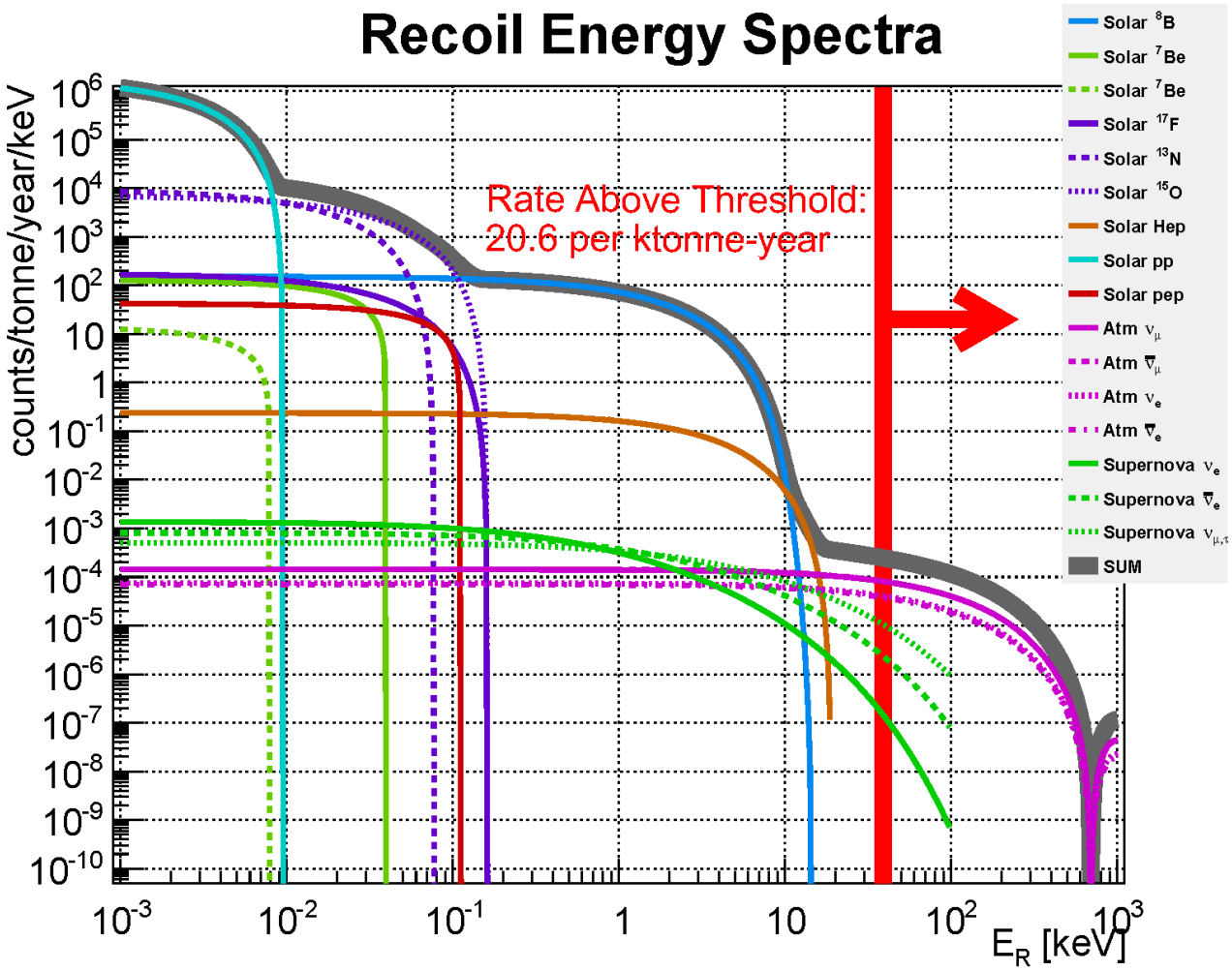
Solar neutrinos in argon; 1.3% energy resolution @ 1 MeV
(from arXiv:1510.04196)

~8000 pe/MeV

Good potential for solar ν measurements, would need to design for low γ bkg

Cosmogenic activation problematic for shallow depths

Coherent Neutrino Scattering in Liquid Argon



CNNS first observed August 2017! (Science Aug 3, 2017)

Well-understood prediction for internal recoils provides absolute cross-check for DM acceptance

21 events in ktonne-year exposure

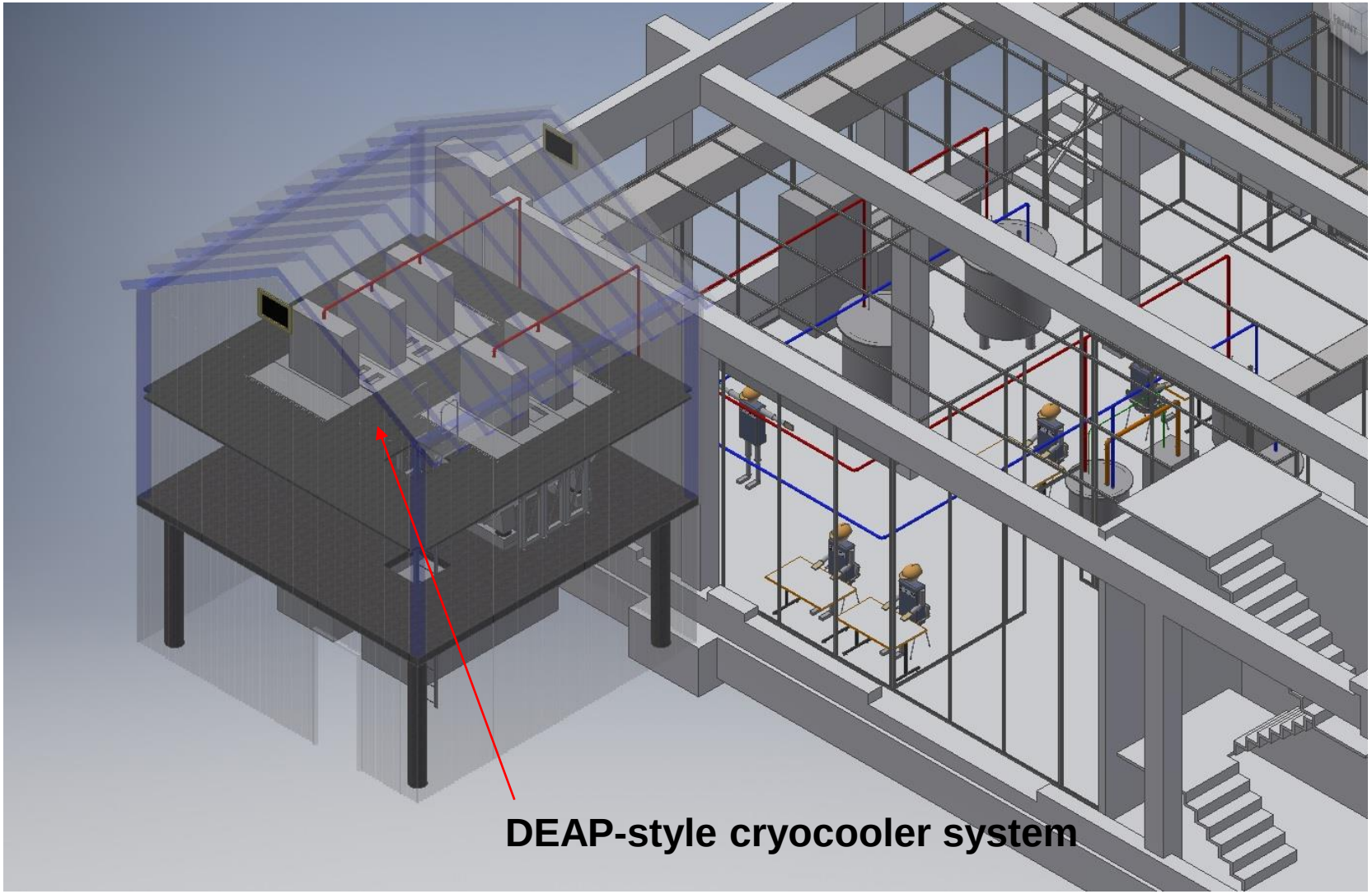
Noble Liquid Detector Facility (2017 CFI IF)

Carleton (lead)/TRIUMF/UBC/McGill/Sherbrooke – 9M$ 2017 CFI IF

“Cryogenic and Light Readout Facility for future development of Noble Liquid Detectors”

- Development of large area 3D SiPMs (10cm x 10cm tiles) – Sherbrooke (4 m^2 for nEXO, order 100 m^2 needed for large argon detector)
- New Cryogenic Facility will allow rapid R&D in noble liquids – Carleton
- Optics and UV light characterization – TRIUMF/UBC
- Characterization and testing of integrated large area 3D SiPMs - McGill

Cryogenics facility at Carleton (under development)



R&D program for future DM and $0\nu\beta\beta$ detectors with argon, xenon

Some Notes on New Noble Liquid R&D Program

- Develop future argon program, contributions to DS20k development (currently defining CAD contributions, likely to include contributions to underground argon program, critical for multi-hundred-tonne detector)
- Develop calibration sources useful for large noble liquid detectors
- Test ultimate energy resolution in argon, mixing xenon (~10%) or other materials in argon for possible $0\nu\beta\beta$ with multi-hundred tonne argon detector (requires designing for low γ backgrounds, and require underground argon also low in ^{42}Ar)
- Test spin-dependent targets in argon; test single-site/multi-site discrimination in argon
- Prototyping detector components, later fabricating them

Towards Multi-Hundred Tonne Argon Detector

2016/2017: CFI IF (9M$) for noble detector development, form joint collaboration for DS-20k (LNGS) and multi-hundred tonne detector. R&D for detector development.

… conceptual design of multi-hundred-tonne detector; DS20k activities, site selection; DEAP-3600 running…

2019: CFI request in support of: DS20k and underground argon, large detector design and consider infrastructure at SNOLAB for large detector

2021-22: CFI request in support of multi-hundred-tonne argon detector (CAD fraction, roughly 1/3 of total); need coordinated funding with international partners

… start of DS-20k running and end of nominal DEAP-3600 running…

2025'ish: multi-hundred tonne argon detector

Summary

DEAP-3600 collecting data since 2016

First analysis with 4.4 live days of data collected

DEAP-3600 data collection/analysis continues to 2020 for full sensitivity

Global argon collaboration forming, 350+ researchers, Canadians will collaborate on DS-20k at LNGS, ultimately on multi-hundred-tonne detector (site TBD, but would fit in Cube Hall or CryoPit)

Long-term argon program allows DM search to neutrino floor, positive measurement of CNNS events, measurement of solar neutrinos

New CFI IF facility allows testing ideas for $0\nu\beta\beta$ with argon, modifications for SD-sensitivity; development of design and techniques

Large (kton) ultralow background scintillation detector has many possibilities…

END

U.S. Cosmic Visions: New Ideas in Dark Matter
Workshop March 23-25th 2017

(abstract submitted to workshop defining joint collaboration)

Title: A Unified Program of Argon Dark Matter Searches: DarkSide-20k and Beyond

Abstract: Experimenters from four different argon dark matter searches are joining their forces to carry out a unified program for dark matter direct detection. The list includes researchers currently working on the ArDM experiment at LSC; on the DarkSide-50 experiment at LNGS; on the DEAP-3600 experiment at SNOLab; and on the MiniCLEAN experiment at SNOLab.

In 2015/2016 The DarkSide-50 experiment at LNGS produced two zero-background science results, along with a comparison of the results obtained with both atmospheric and underground argon fills, demonstrating the ability of large experiments to eliminate background from betas/gammas at the tens of ton-year exposure. The DEAP-3600 experiment at SNOLAB is the first tonne-scale experiment to achieve both stable operations and an extended physics run. DEAP-3600 has been collecting physics data with over 3 tonnes of argon since late 2016 and is expected to publish first results in 2017. After its recent commissioning in single phase, the ArDM experiment is preparing for a double phase run in 2017 with a liquid argon target mass of nearly 1 tonne. The MiniCLEAN experiment is currently filling with Liquid Argon and anticipates entering stable operations in April 2017.

Researchers from the four experiments will jointly carry out the DarkSide-20k experiment, a 20-tonne fiducial volume dual-phase TPC to be operated at LNGS with an underground argon fill, designed to collect an exposure of 100 tonne×years, completely free of neutron-induced nuclear recoil background and all electron recoil background. DarkSide-20k is set to start operating by 2021 and will have sensitivity to WIMP-nucleon spin-independent cross sections of 1.2×10^{-47} cm2 for WIMPs of 1 TeV/c2 mass, to be achieved during a 5 year run. An extended 10 year run could produce an exposure of 200 tonne×years, with sensitivity for the cross-section of 7.4×10^{-48} cm2, for the same WIMP mass. DS-20k will explore the WIMP-nucleon cross-section down to the edge of the 'neutrino floor', where coherent neutrino-nucleus scattering from environmental neutrinos induce nuclear recoils in the detector.

A second step in the program is the construction and operation of a detector with a fiducial mass of a few hundred tonnes, capable of collecting an exposure of several thousands of tonne×years, completely free of all backgrounds on top of CNNS. This follow-up experiment would also be capable of performing a set of very high precision measurement of several solar neutrino sources (location and laboratory t.b.d.). This includes exquisitely precise measurements of pep, CNO, as well as low energy 8B neutrinos, all in the region of transition between the vacuum- and matter-dominated regions of solar neutrino oscillations.