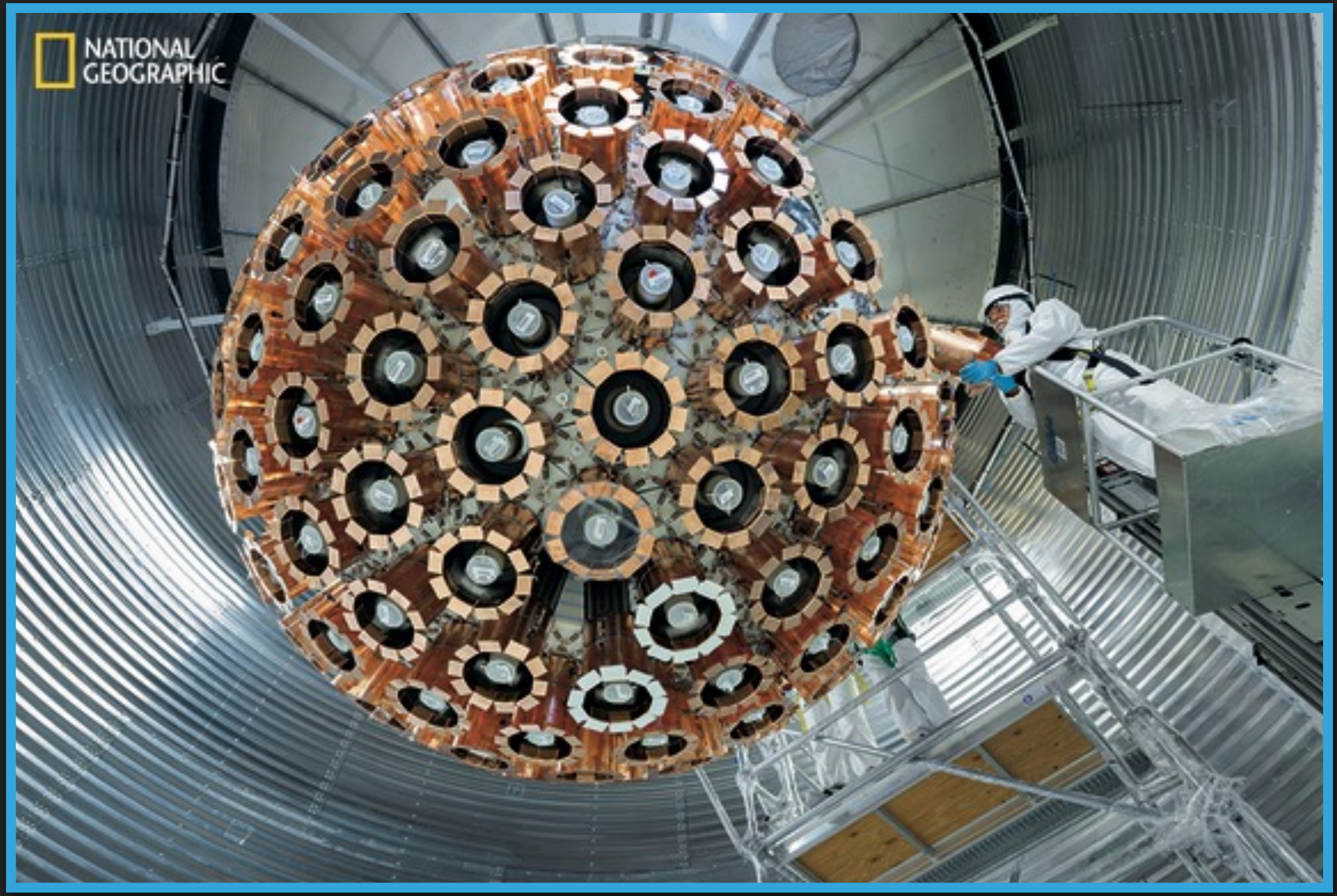


PIETRO GIAMPA

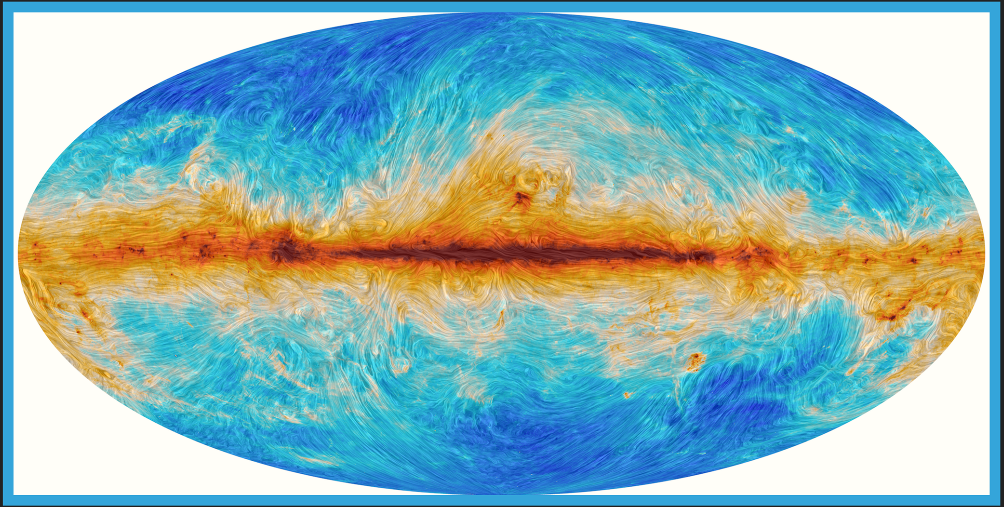
DARK MATTER SEARCHES WITH NOBLE GASSES

OUTLOOK

- Why and How do we look for Dark Matter ?
- Why using Noble gasses ?
- Towards a World Collaboration (Argon and Xenon)
- The DEAP-3600 Experiment
- The DarkSide20k Experiment
- The Xenon1T Experiment
- The LUZ/LZ Experiment
- Cryogenic Facility for liquid noble gasses @ Carleton
- Conclusions

WHY AND HOW DO WE LOOK FOR DARK MATTER ?

- Multiple “indirect” evidence.
  - Study of mass distribution in galaxy clusters.
  - Study of spiral galaxies rotational curves.
  - Gravitational lensing measurements in colliding clusters.
  - Study of the Cosmi-Microvawe-Background (CMB).
- ~27% of the Universe is Dark Matter.

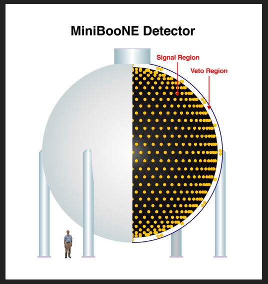


WHY AND HOW DO WE LOOK FOR DARK MATTER ?

There are three primary way to look for dark matter: direct detection, indirect detection and particle colliders.

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

SUPER K



Indirect Detection Experiments

DEAP 3600

darkside
two-phase argon TPC for Dark Matter Direct Detection

PICO

SuperCDMS
@ Queen's

SABRE

Xe
XENON
Dark Matter Project

LZ

PANDA X

Direct Detection Experiments

ATLAS EXPERIMENT

CMS
Compact Muon Solenoid

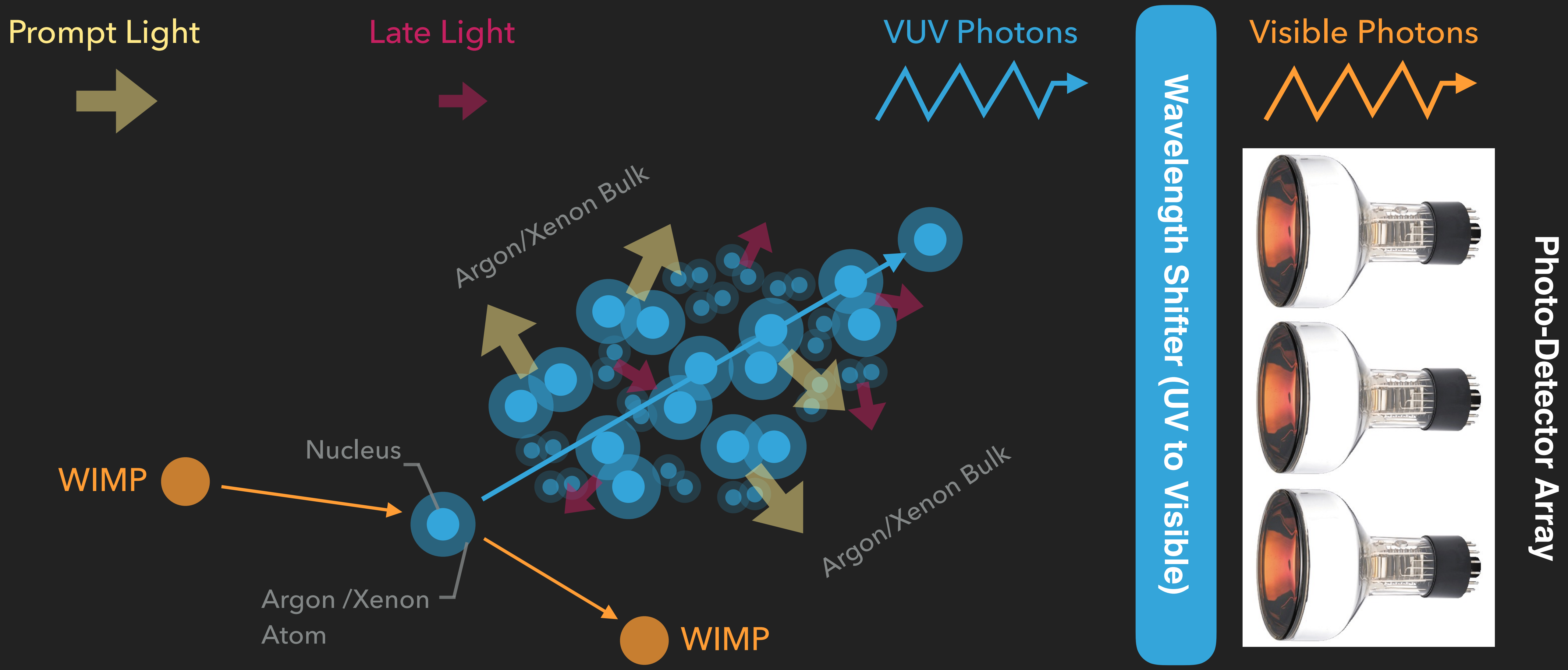
Belle II

Particle Colliders

🟥 Contributions from at least one Canadian institution.

NOBLE GASSES DIRECT DETECTION SEARCHES

Interactions between subatomic particles and argon or xenon nuclei generate UV scintillation light, with two different time constants.



Prompt Light

Late Light

VUV Photons

Wavelength Shifter (UV to Visible)

Visible Photons

Photo-Detector Array

Argon/Xenon Bulk

Argon/Xenon Bulk

Nucleus

WIMP

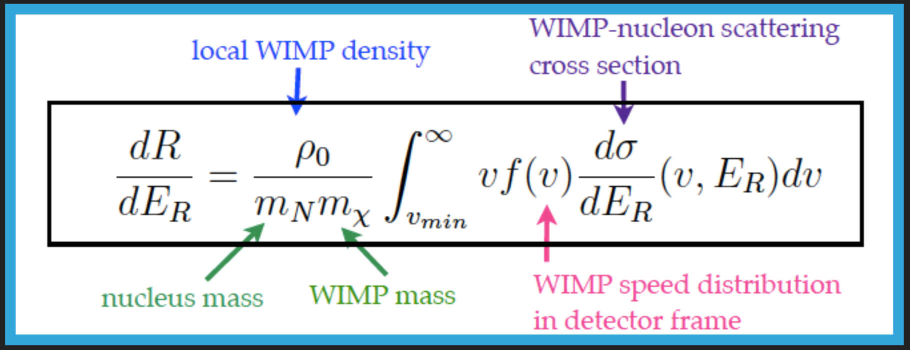
WIMP

Argon /Xenon Atom

NOBLE GASSES DIRECT DETECTION SEARCHES

Both Xenon and Argon have optimal properties to perform competitive Dark Matter searches.

Material	LXe	LAr
Atomic Number	54 🟩	18
Atomic Mass	131.3 🟩	40.0
Boiling Point	165 [k]	87 [k] 🟩
Atmospheric Fraction	0.09 [ppm]	9340 [ppm] 🟩
Scintillation Peak	178 [nm] 🟩	128 [nm]
Light Yield	4.2 PE/keV	7.5 PE/keV 🟩
Time Constant (Prompt/Late)	4 [ns] / 22 [ns]	7 [ns] / 1.6 [μs] 🟩
ER Rejection	1.1×10^3	1.0×10^{10} 🟩

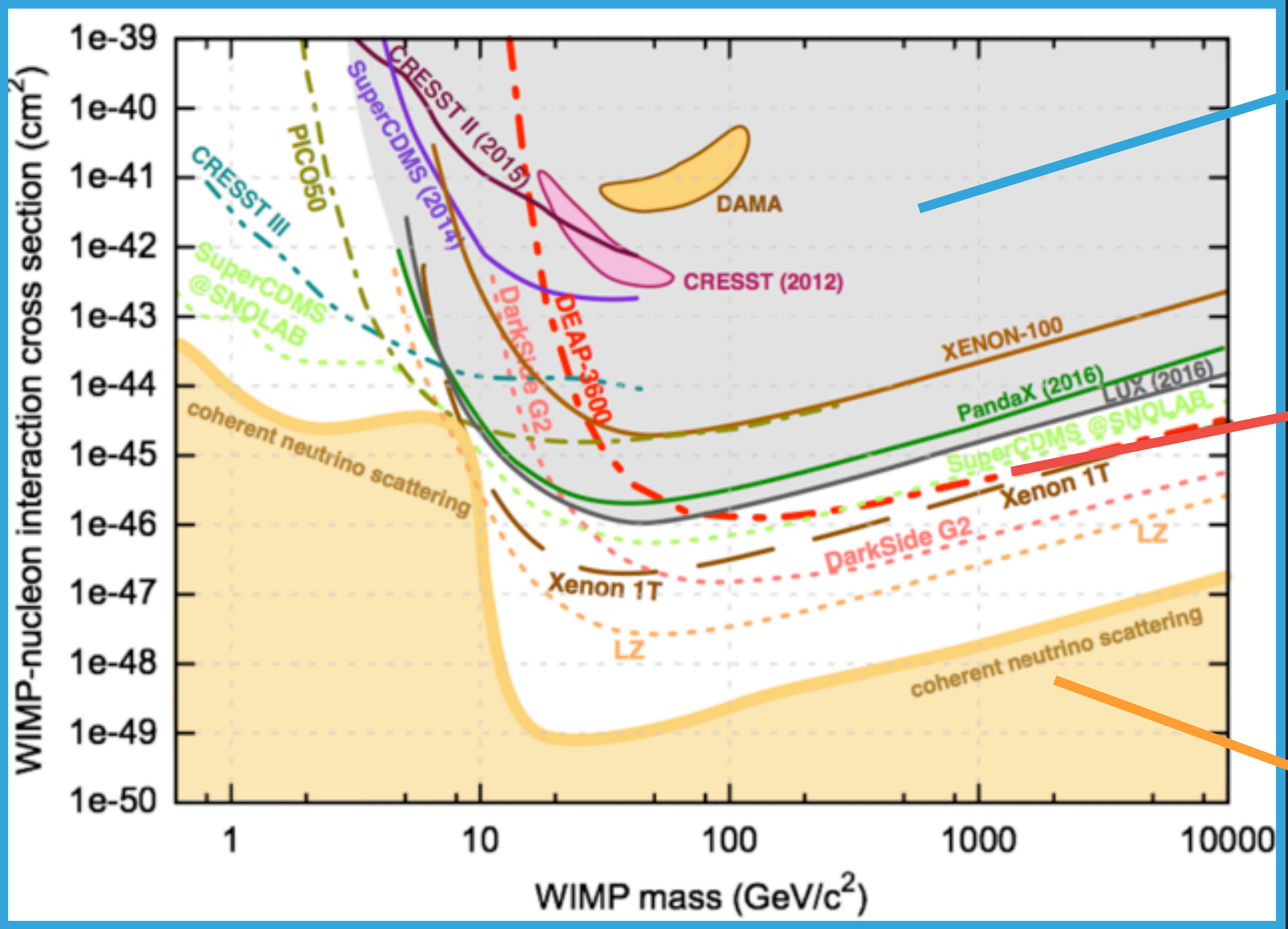


$$\frac{dR}{dE_R} = \frac{\rho_0}{m_N m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma}{dE_R}(v, E_R) dv$$

- Higher light yield and very strong Pulse-Shape Discrimination (PSD), make Argon very unique.
- Xenon gas is considerable more expensive than Argon gas. However, for large scale detector depleted argon is necessary, cost of production goes up when considering infrastructure (but the plant is getting built already).

NOBLE GASSES DIRECT DETECTION SEARCHES

Argon and Xenon compliment each other, and allow for reacher at a wide range of possible Dark Matter masses from few-GeV to TeV.



Parameter space excluded by previous experiments.

Current detector performance at par with the projected sensitivity for a 3 years tonne exposure. Quite competitive for very high masses (> TeV).

Expected appearance level for the unreducible neutrino coherent-elastic floor. DS20k should approach this level. The floor is dependent on the Dark Matter Halo model and target material.

TOWARDS A WORLD COLLABORATION

2017 2021

DarkSide-50

DarkSide20k

DEAP-3600

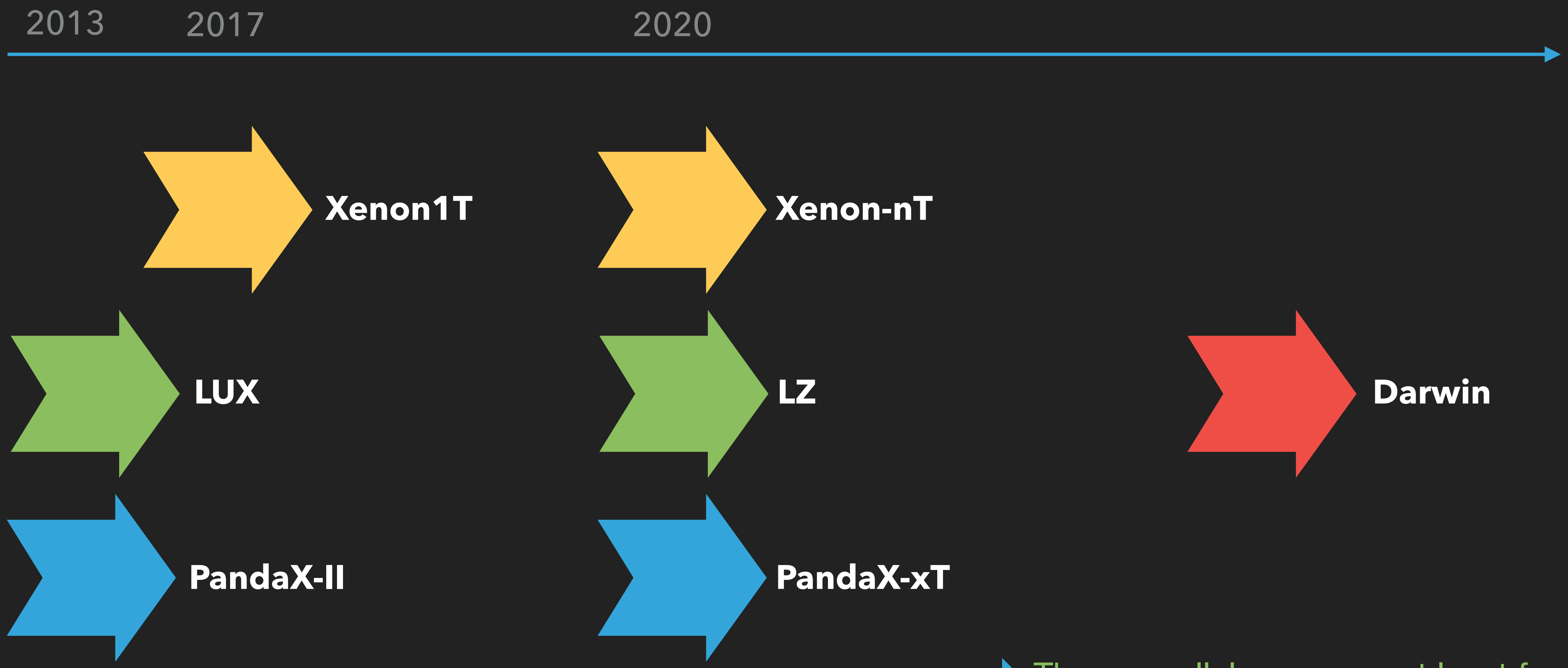
ARGO

ArDM

miniCLEAN

- DEAP-3600 science program till 2020, after 2020 possibility for depleted argon run (to be decided).
- Two-steps plan towards a world collaboration. DS20k is the intermediate step, a multi-hundred-tonnes argon experiment the final goal.
- First step towards the two-steps program is the completion of the analysis and science program of DEAP-3600, publication of results (same for other collaboration).

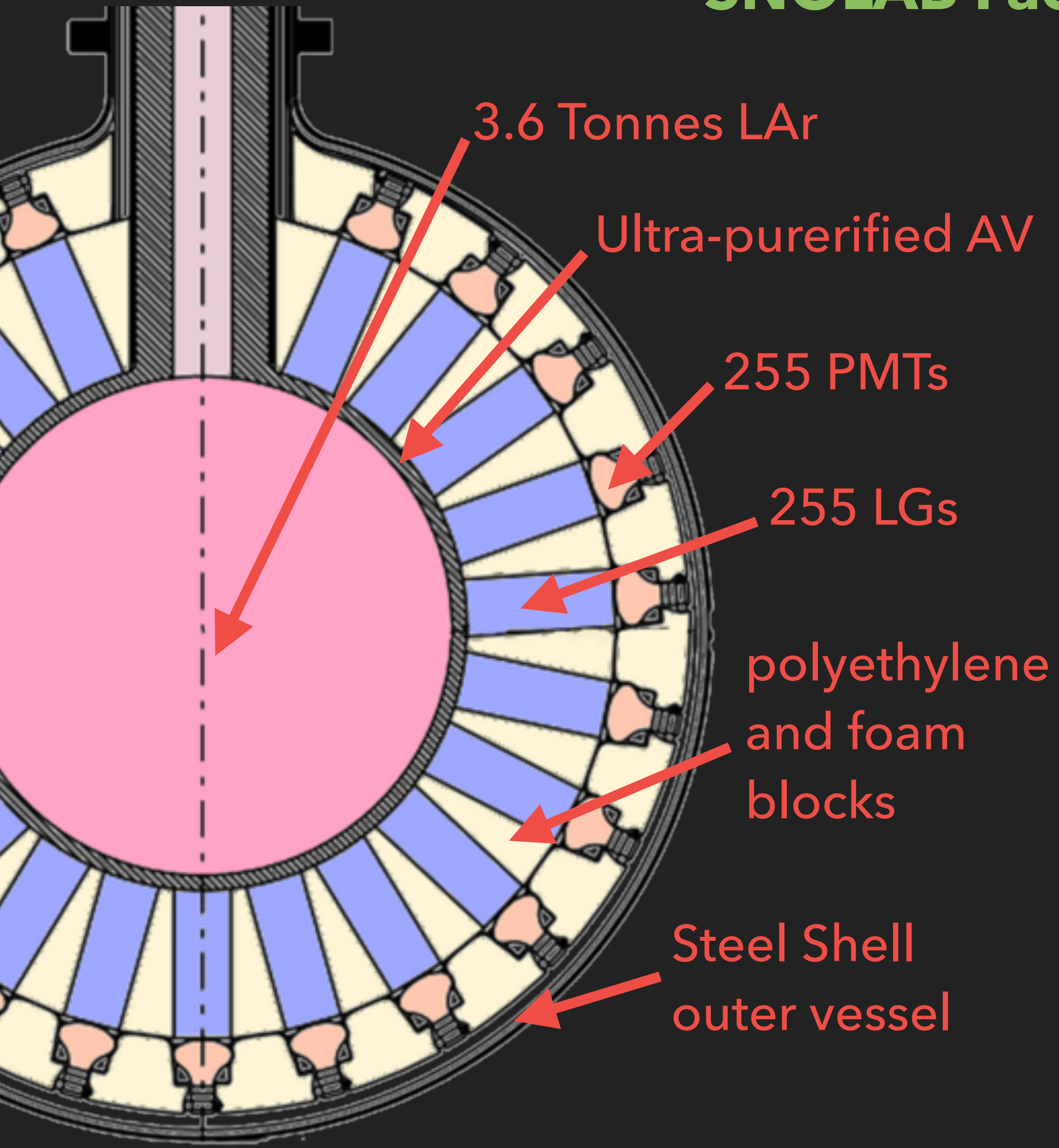
TOWARDS A WORLD COLLABORATION



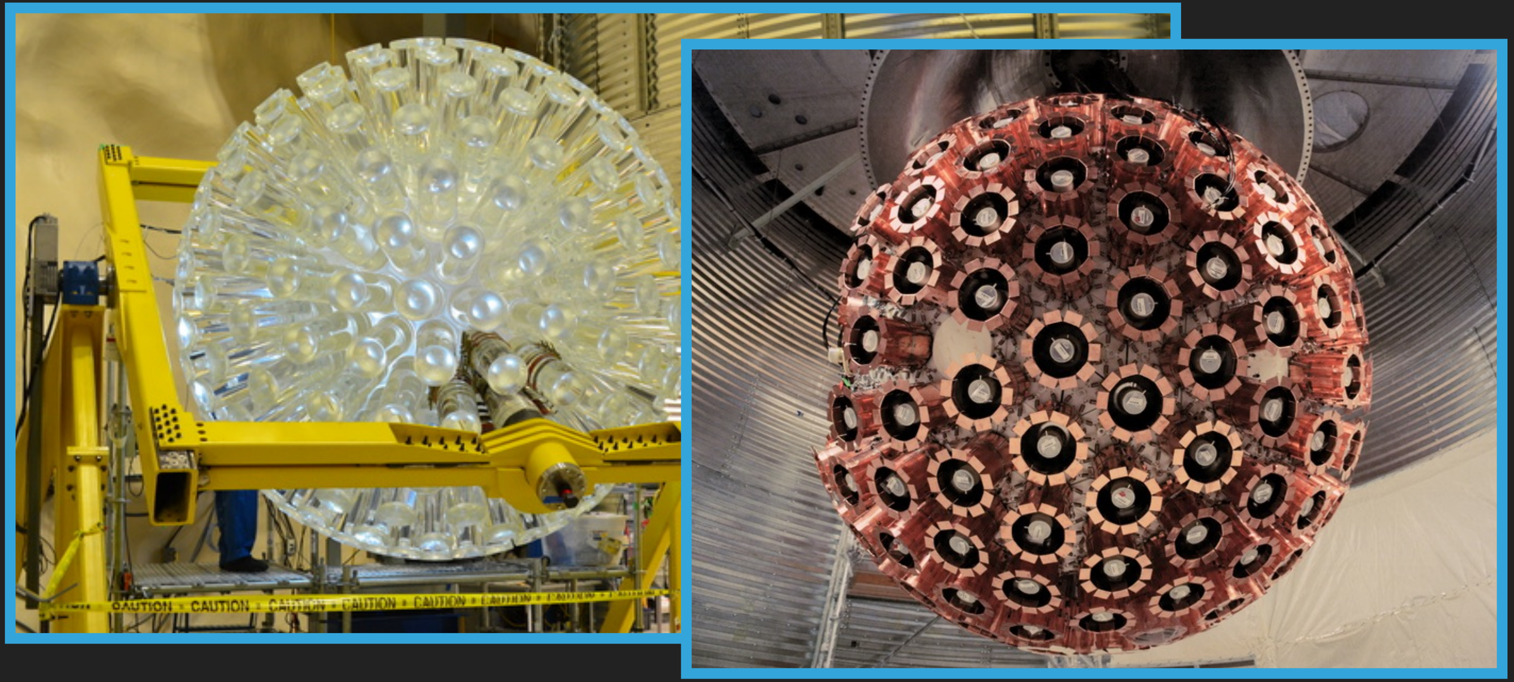
- Three parallel programs at least for the next generation.
- PandaX planning a neutrino-less double beta decay search.

THE DEAP-3600 EXPERIMENT

DEAP-3600 is Single-Phase LAr detector, located 2km underground at the SNOLAB Facility in Sudbury ON, Canada.

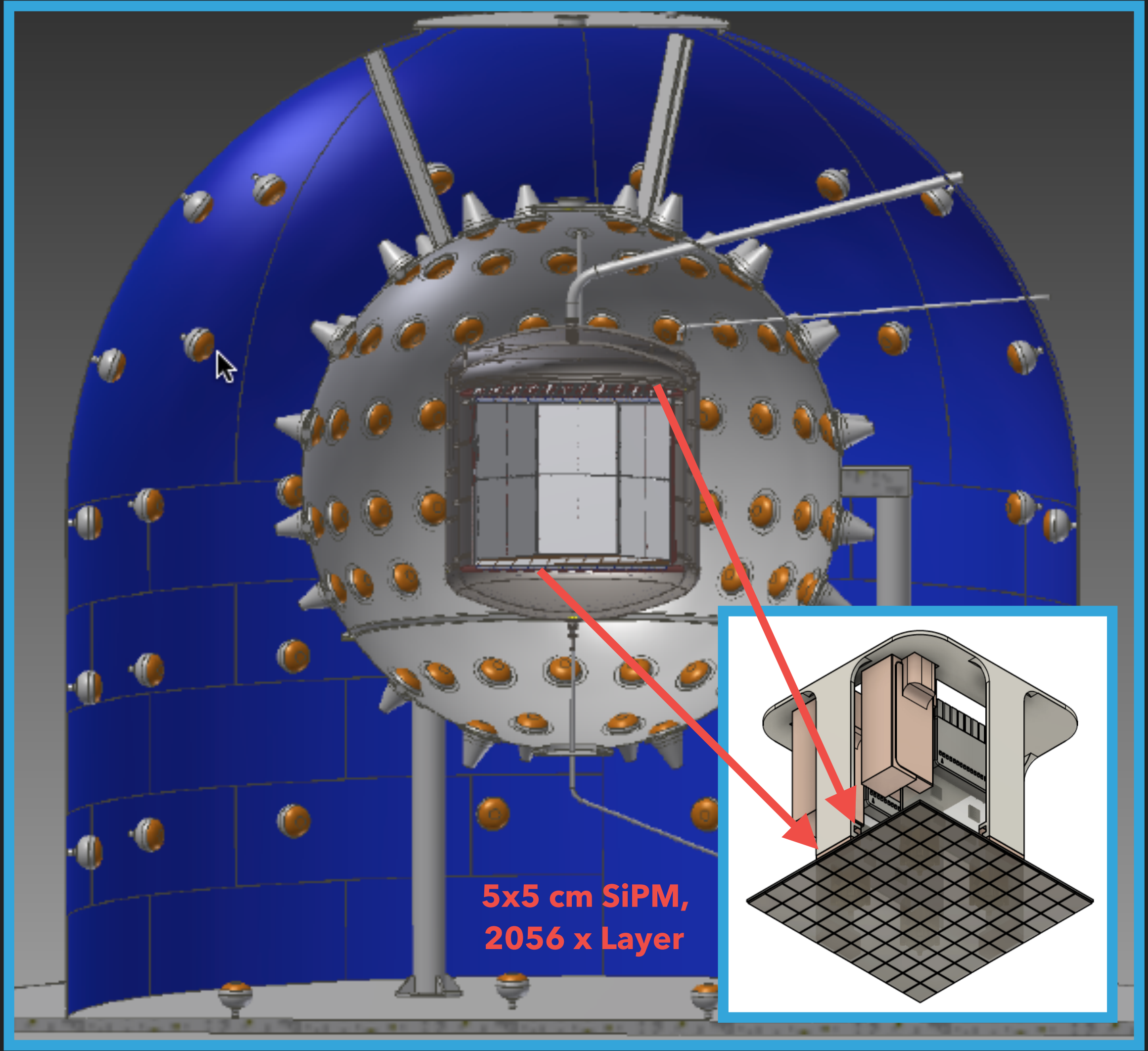


- Single-Phase liquid argon (LAr) detector.
- 3 microns layer of TPB wavelength shifter.
- High Light Yield (~7.8 PE/keV).
- First Dark Matter analysis results coming soon!!!

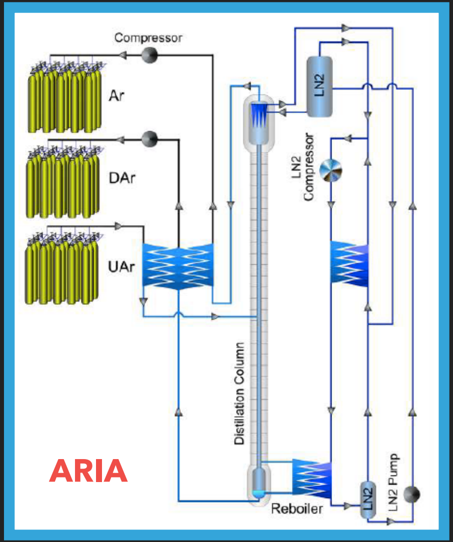


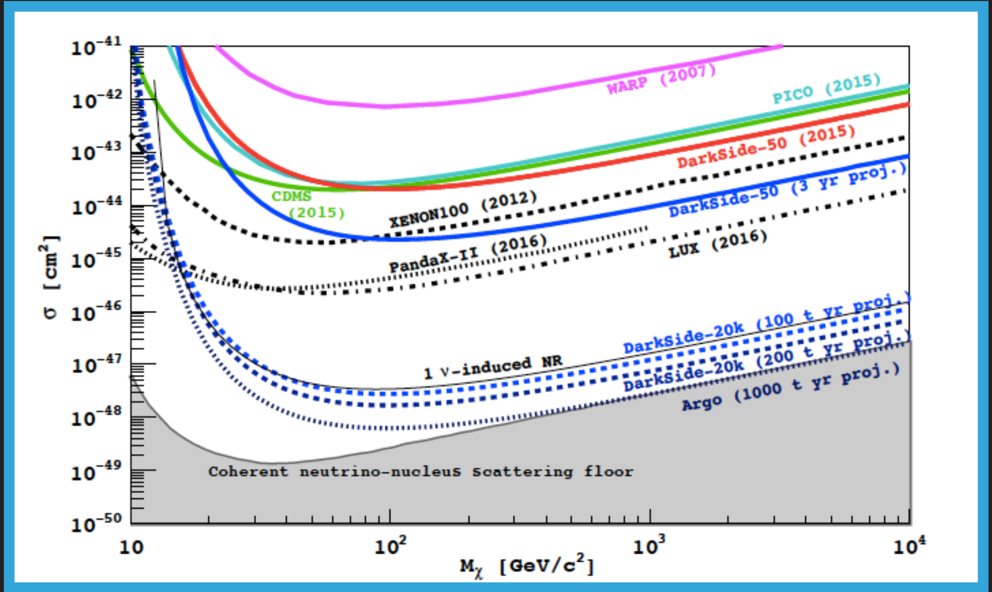
THE DARKSIDE-20K EXPERIMENT

DarkSide20k is Dual-Phase LAr TPC experiment, currently under development, to be constructed at LNGS in Assergi, Italy.



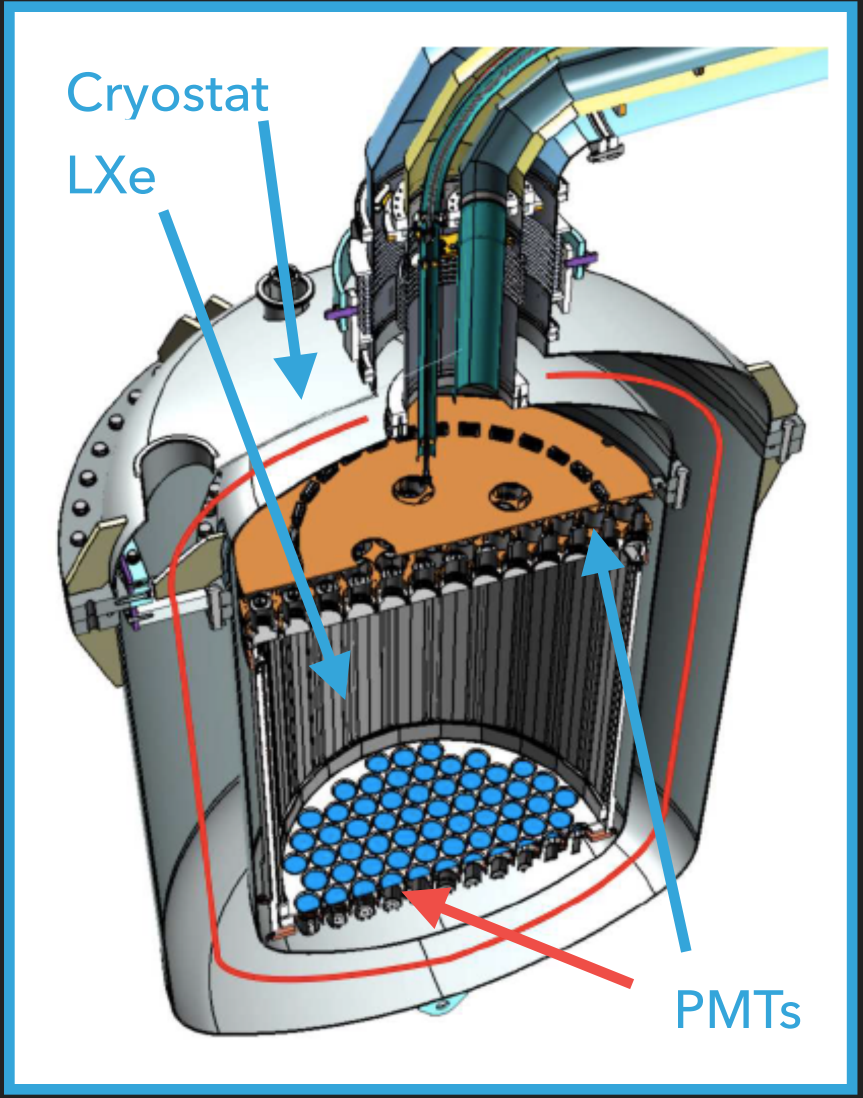
- Dual-phase LAr TPC, 30t total, 20t fiducial.
- 2.4 m tall octagonal TPC structure.
- First to R&D large area SiPM readout structure.
- Considerable effort in the production of depleted argon.



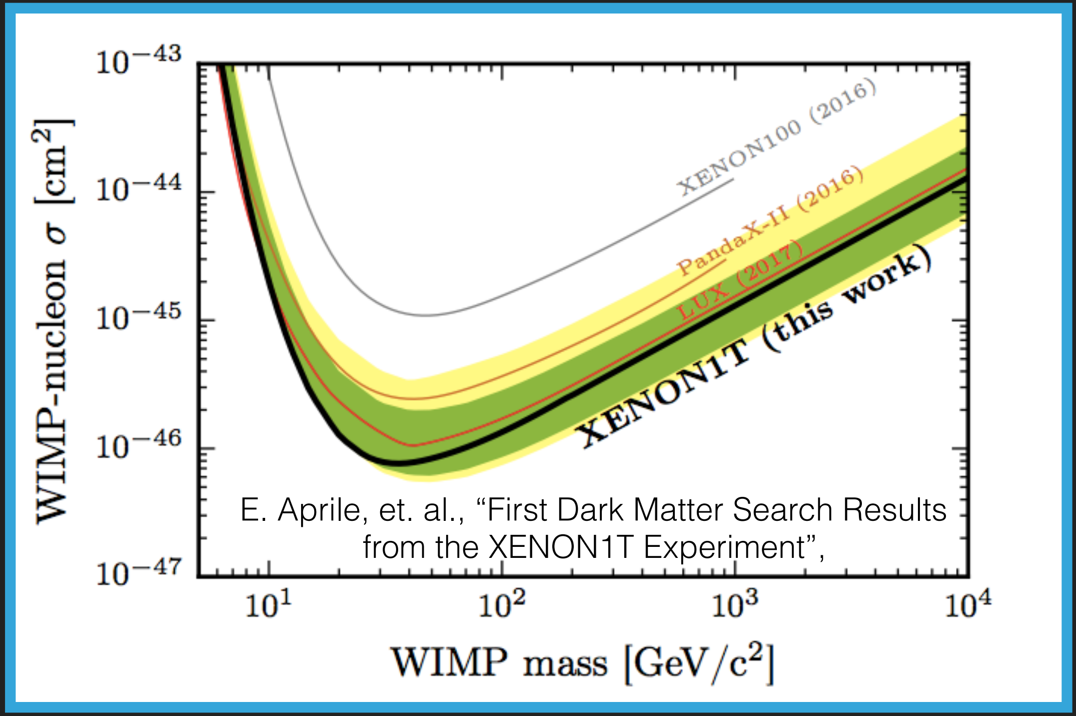


THE XENON1T / XENON-NT EXPERIMENT

Xenon1T(nT) is Dual-Phase Loe TPC experiment, located at LNGS, Currently undertaking long physics data campaign.



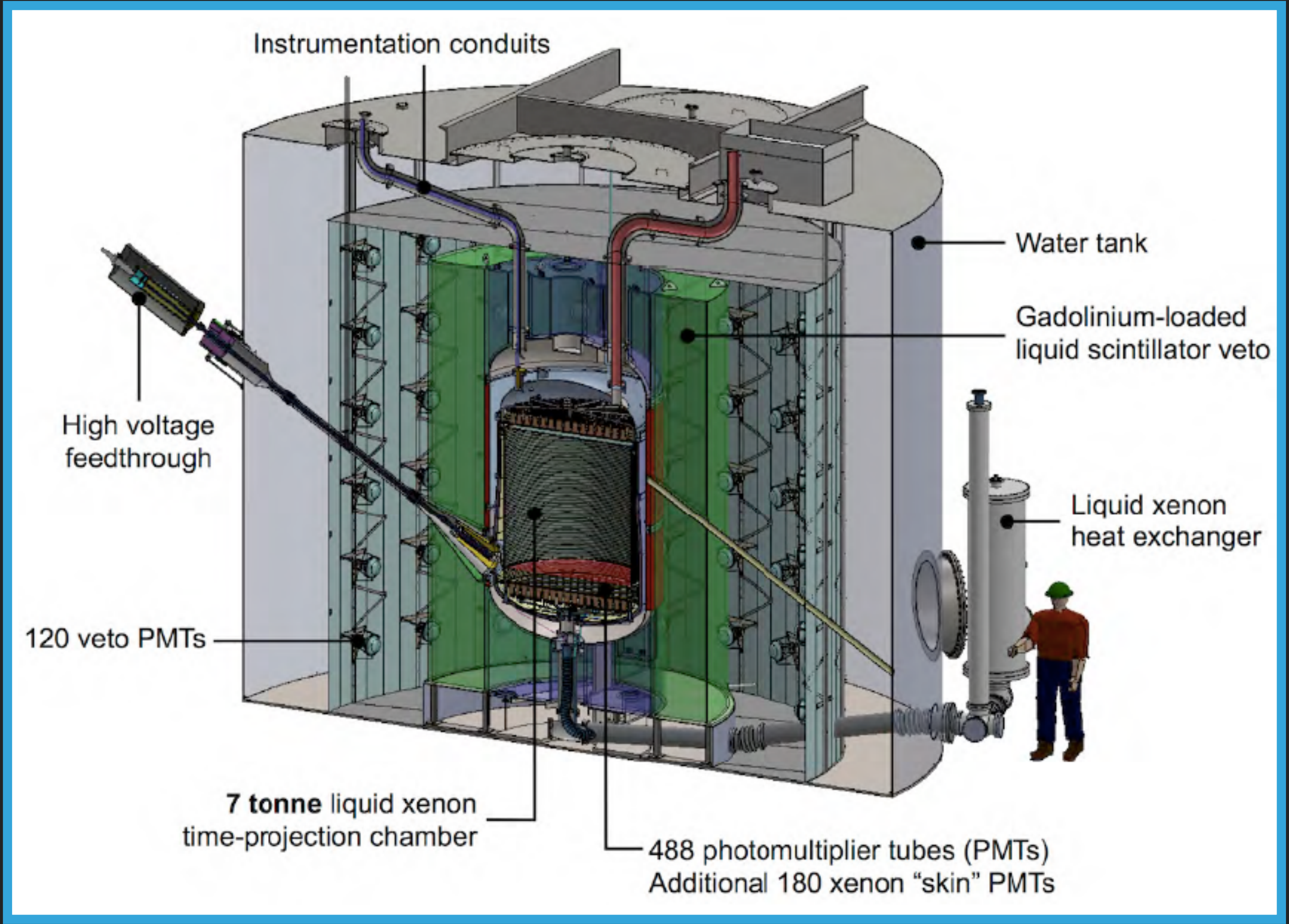
- Dual-phase LXe TPC, 3.5 Tonnes of total mass. Projected fiducial mass of 1T
- Xenon-nT would require a simple switch of the inner vessel, + 200 extra PMTs.
- Xenon-nT currently targets a total LXe mass of 7 Tonnes.



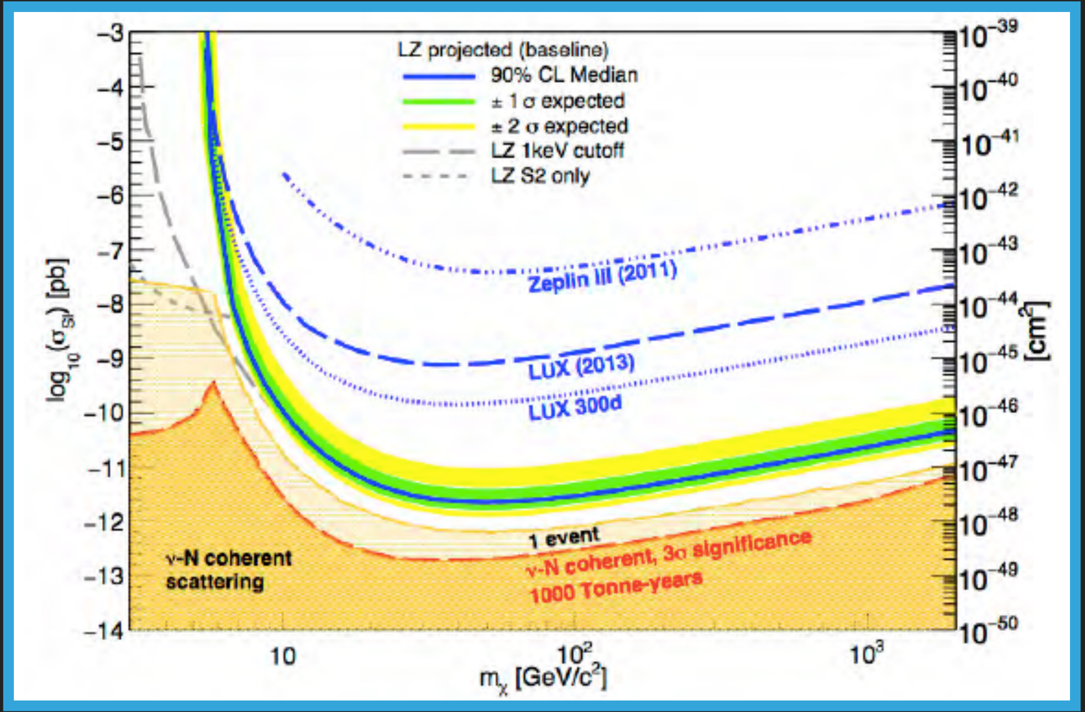
E. Aprile, et. al., “First Dark Matter Search Results from the XENON1T Experiment”,

THE LZ EXPERIMENT

LZ is Dual-Phase Loe TPC experiment, currently under development. Next generation of LUX and ZEPLIN Experiments.



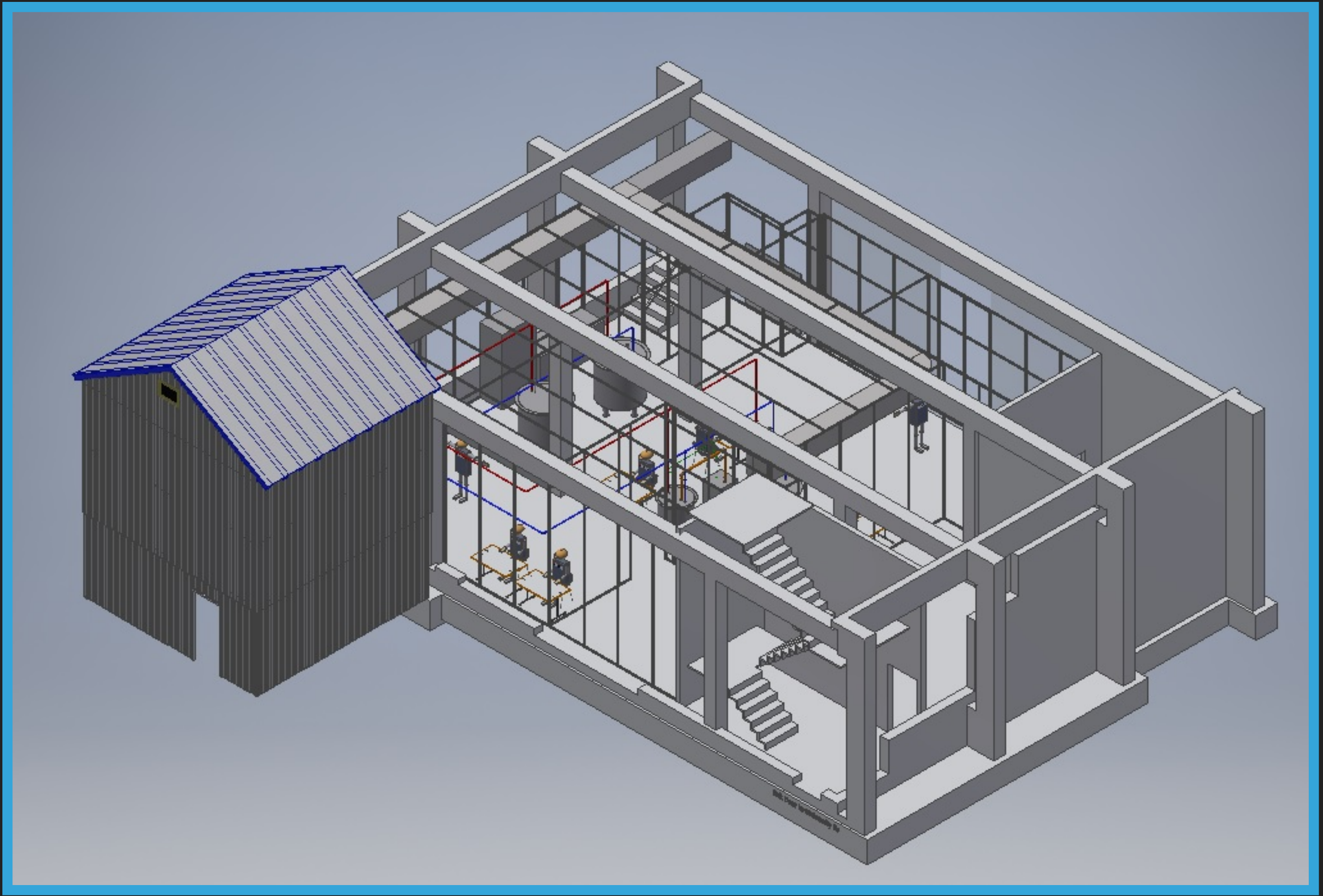
- Dual-phase LXe TPC, 7 Tonnes of total mass. Projected Fiducial 5.6 Tonnes.
- Ultra-purified Titanium Cryostat.

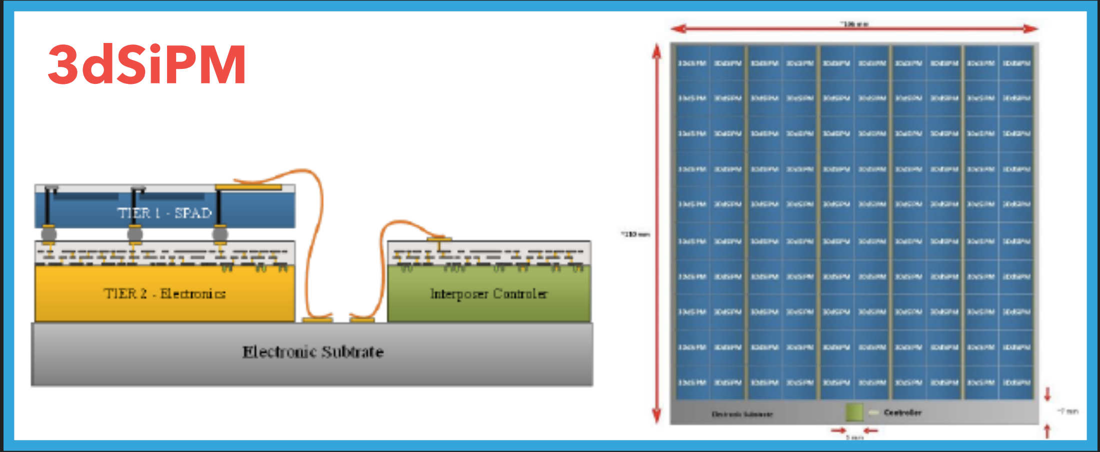


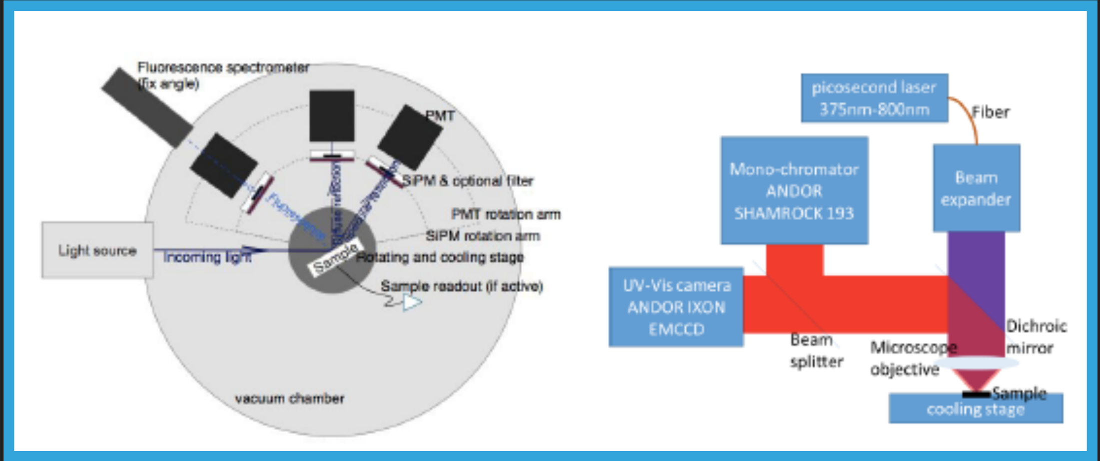
CRYOGENIC FACILITY FOR LIQUID NOBLE GASSES @ CARLETON

Allowing for testing of SiPM, Xe detector development for 0νββ, measurement of WLS coating in Ar, development of purification systems and background reduction, etc.

Leading Institutions: Carleton University, TRIUMF, University of Sherbrooke and McGill University.







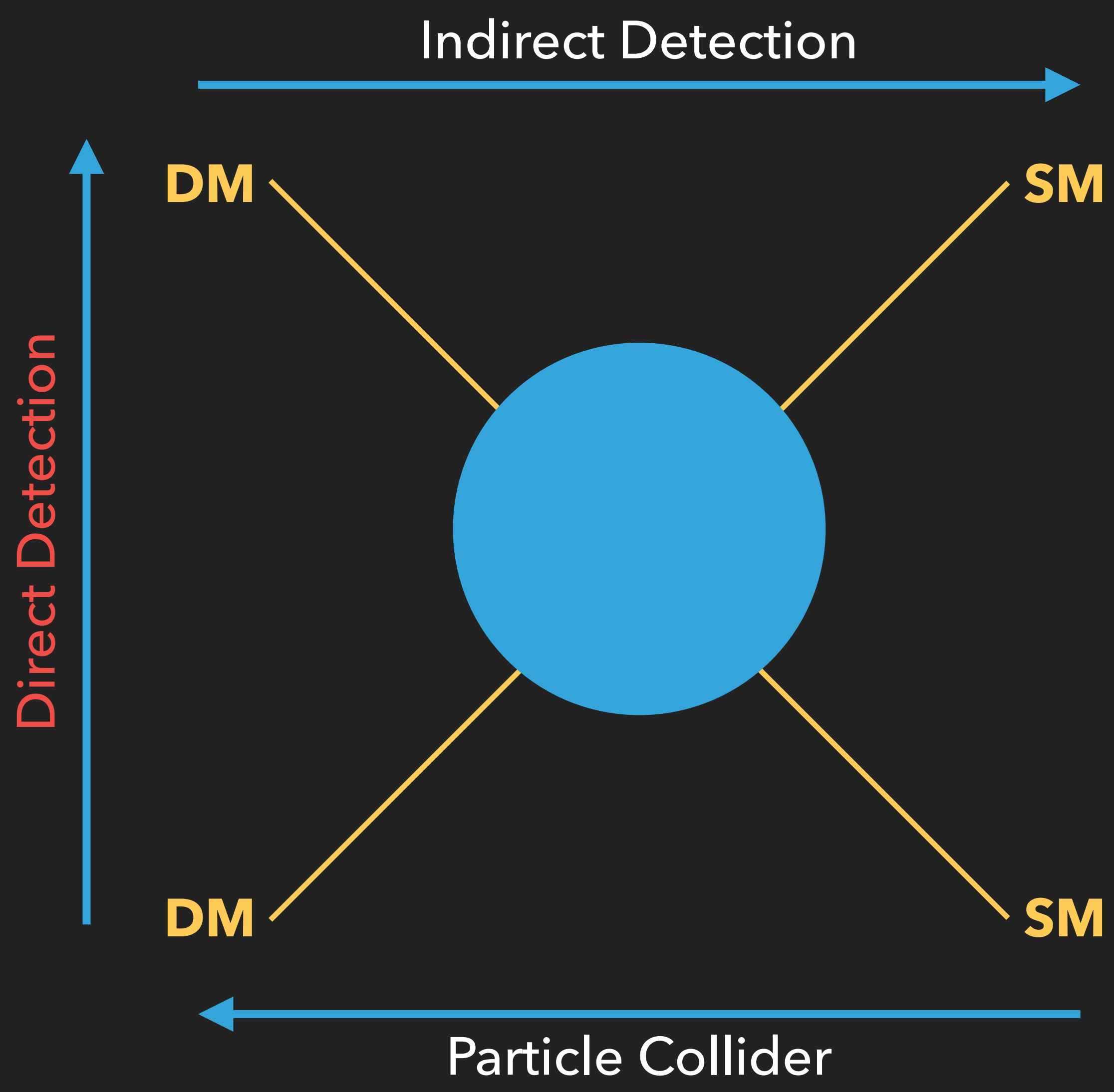
CONCLUSIONS

- The Dark Matter program in Canada is strong, but we need to continue building upon the Noble gas program to perform a competitive and compressive search across all WIMP masses (to complement PICO and SuperCDMS).
- Current generation of Noble gas experiments are all taking physics-trigger data (first round of publication mostly out).
- Lots of work is currently invested in the R&D for the future generations (intermediate and long term), for both Argon and Xenon based experiments. (R&D cryogenic facility @ Carleton).

BACKUP MATERIALS

WHY AND HOW DO WE LOOK FOR DARK MATTER ?

There are three primary way to look for dark matter: direct detection, indirect detection and particle colliders.



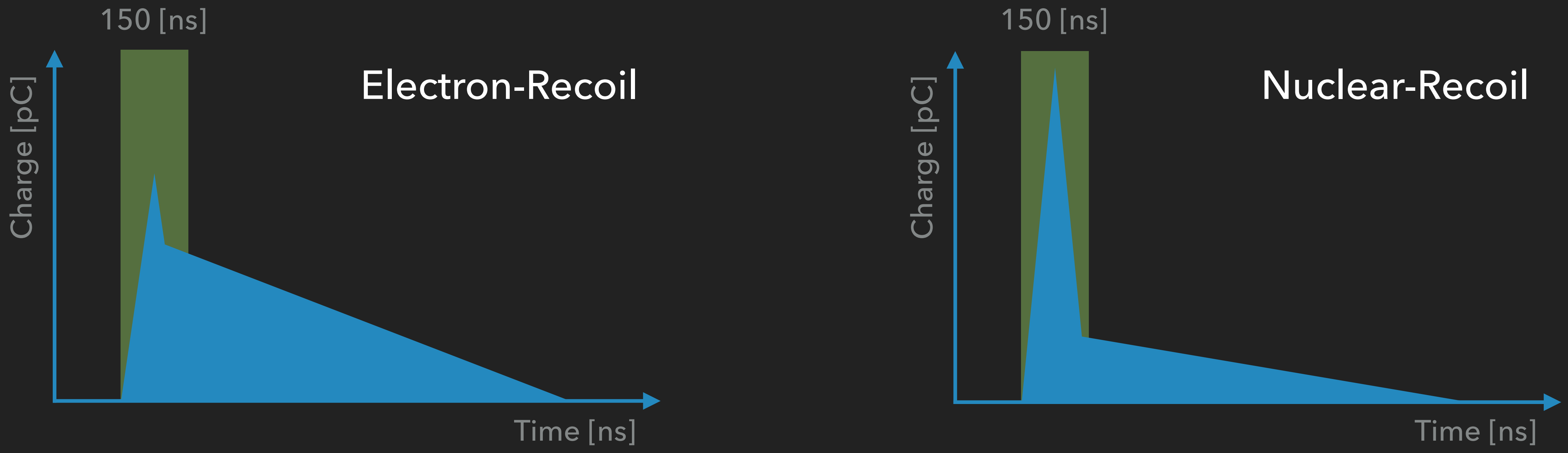
Indirect Detection : Dark Matter annihilation in space, looking for emitted photons. Dark matter particles create standard model particles.

Particle Colliders : Colliding standard model particles to recreate early universe condition and generate dark matter particles.

Direct Detection : Coherent elastic scattering or quasi-elastic scattering between dark matter particles and ordinary matter.

PULSE-SHAPE DISCRIMINATION PSD

Electronic and nuclear recoils probe different singlet-to-triplet ratios, which translate in a different amount of prompt and late scintillation light.

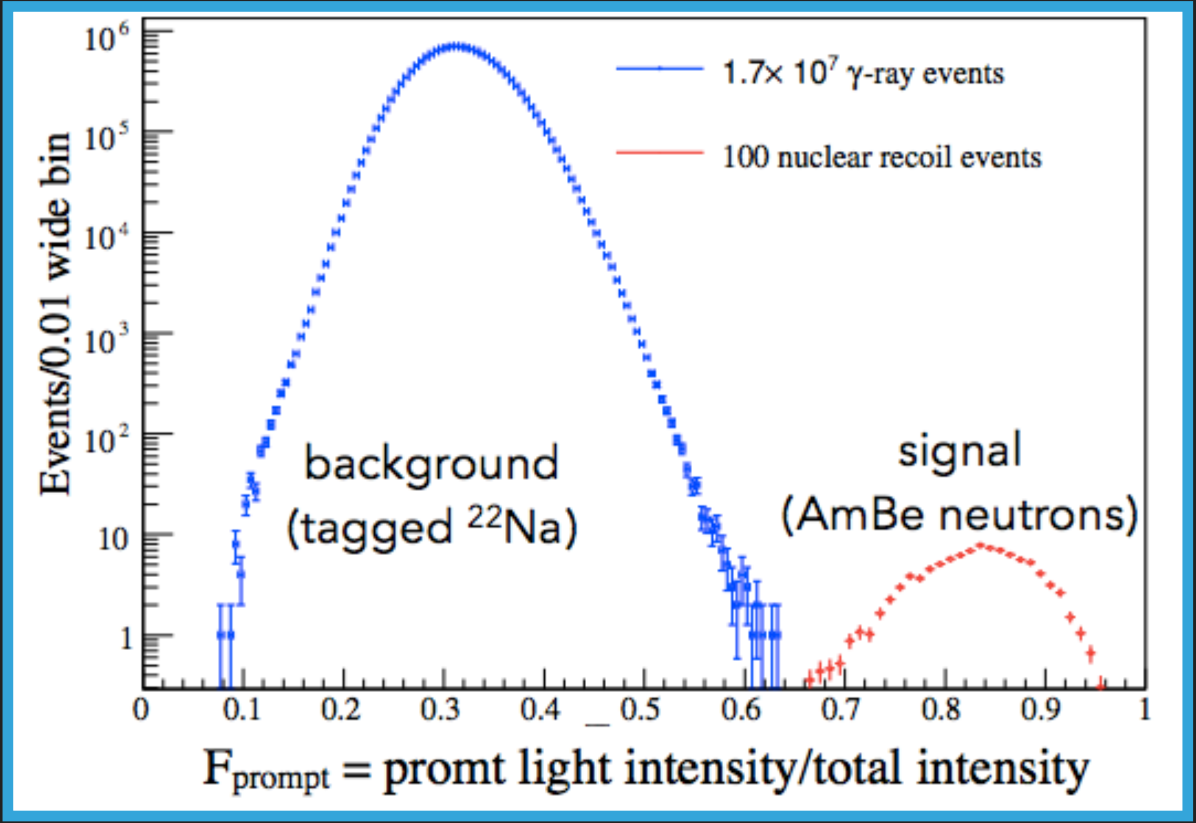


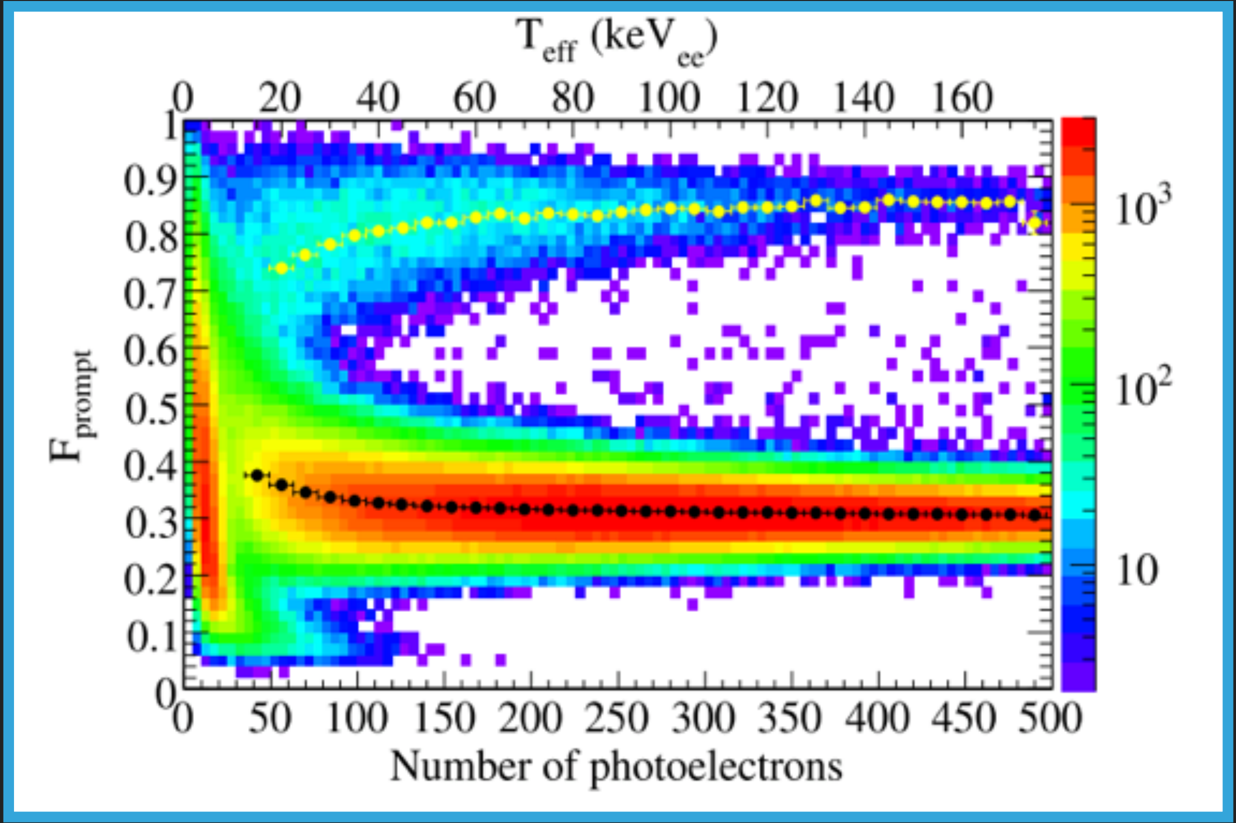
Pulse Shape Discrimination (PSD)

Fprompt = **Prompt light** / **Total Light**

PULSE-SHAPE DISCRIMINATION PSD

Pulse-Shape Discrimination can discriminate electron induced recoils over nuclear induced recoils with a projected rejection power of 10^{10}.

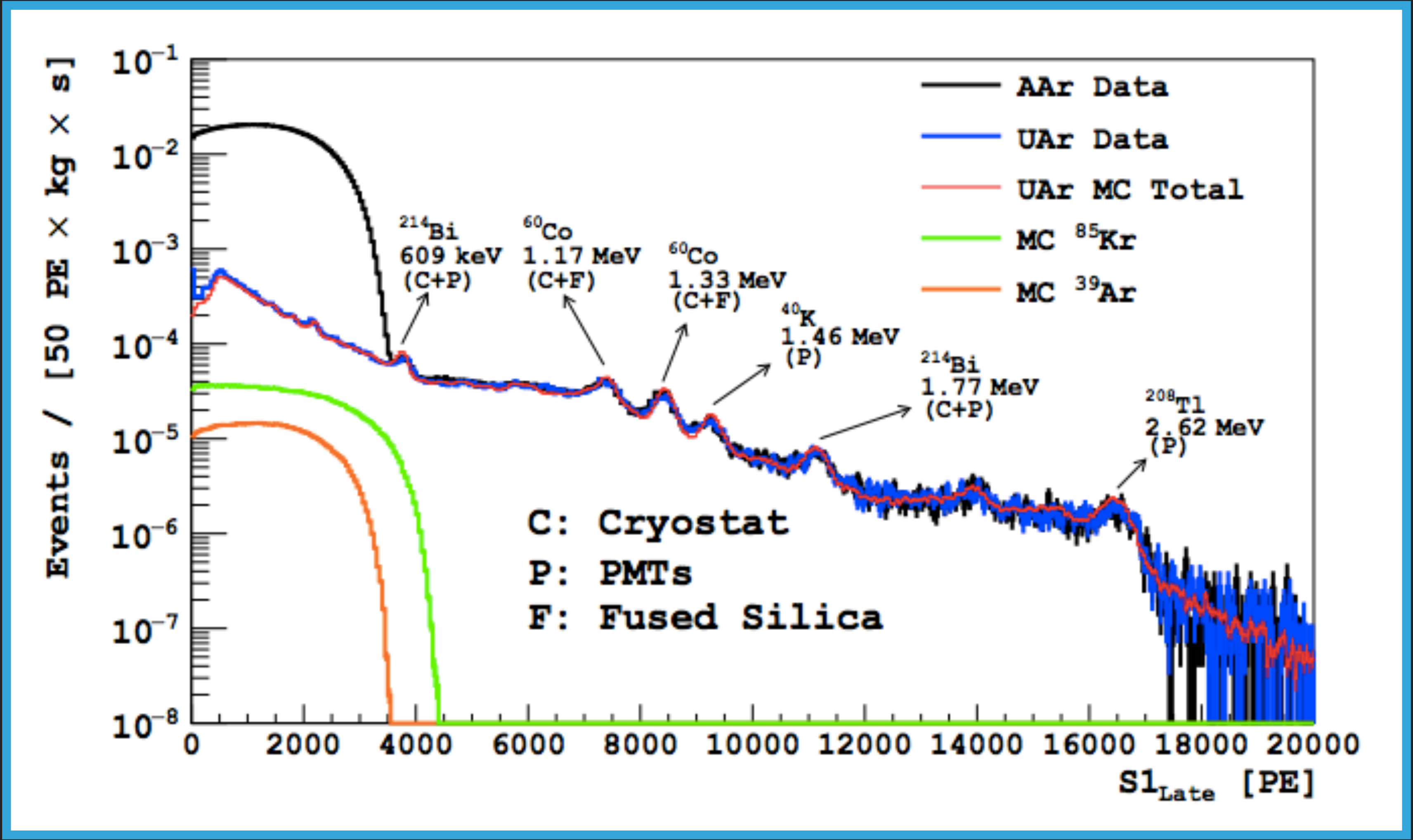




M. Kuzniak et al., “Measurement of the scintillation time spectra and pulse-shape discrimination of low-energy beta and nuclear recoils in liquid argon with DEAP-1,"”,Astroparticle Physics 85 (2016) 1-23

UNDERGROUND ARGON PERFORMANCE

The Urania project can produced up to 100 kg/day of UAr. The underground argon is shown to contain ^{39}Ar at a level reduced by a factor (1.4 ± 0.2) × 10^3 relative to atmospheric argon.



NOBLE GASES DIRECT DETECTION SEARCHES

XENON		ARGON	
PRO	CONS	PRO	CONS
▸ High atomic mass, can reach higher sensitivity with lower fiducial volume. ▸ Quite sensitive in the low WIMP mass range. Well developed technology. ▸ Good single-vs-multi scatter events. ▸ Can do Axions and modulation searches.	▸ Relative low light yield (4.2 PE/keV). ▸ ER/NR Rejection strong only works for dual-phase (dE/dx). ▸ Challenging to remove radiogenic contaminations (Rn, Kr). ▸ Limitation in TPC sizes due to diffusion (and recombination). ▸ Xe is quite expensive to buy ($$$).	▸ Great ER/NR Discrimination Power. High light yield (7.5 PE/keV). ▸ Can be used in both Single and Dual Phase. ▸ Easy to separate radiogenic contamination (Rn, Kr). ▸ Good Energy Resolution. ▸ Argon is relatively cost effective ($). ▸ Could perform Sterile neutrino searches.	▸ 39Ar beta-decay in natural Ar, 1Bq/Kg. ▸ Need of depleted Ar for tens-of-tonnes detectors. ▸ Lighter than Xe, therefore need more mass. ▸ historically high threshold, challenging to do few-GeV searches. ▸ Difficult to discriminate multi-scatter events, in Single-Phase. ▸ Difficult to perform Axion searches.