DARKSIDE: INTO THE FUTURE

Andrew Renshaw, for the expanding DarkSide Collaboration
University of Houston
SNOLAB Future Project Workshop, SNOLAB
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Why Liquid Argon

- Efficient scintillator
  - 40 photons/kev_{ee} @ 128 nm
  - Transparent to own scintillation light

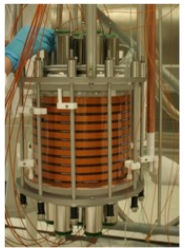
- Powerful PSD in the scintillation signal
  - Separate ER background from WIMP induced NR signal
  - Rejection factor > 10^8

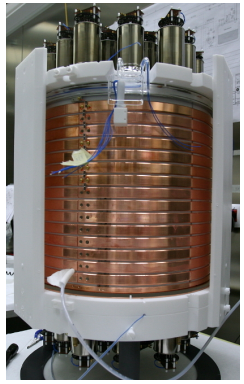
- High Ionization yield
  - Ionization energy ~ 10-20 eV with a high electron mobility
  - Further background discrimination with S2/S1

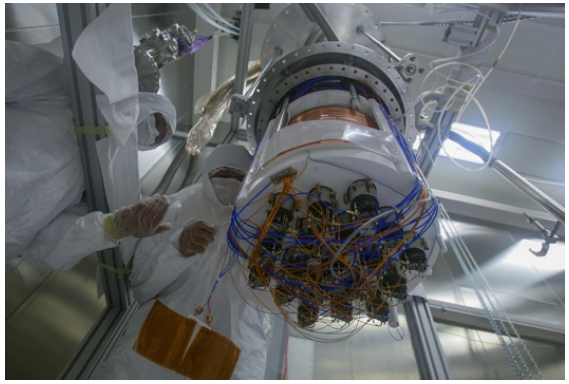
- Simple cryogenic and gas handling with inline filter
  - Easily purified to achieve long electron drift lengths

The DarkSide of Dark Matter Detection

Multi-stage program for direct detection of WIMP dark matter, global effort now becoming official and will guide the future:







- **DarkSide-10**: Two-phase TPC at LNGS
  - 10 kg full prototype
- **DarkSide-50**: Two-phase TPC at LNGS
  - Physics detector: 50 kg, physics goal ~ 10^{-45} cm^2 for 100 GeV WIMP
  - O(.01 tonne year) exposure
- **DarkSide-20k**: Two-phase TPC at LNGS, start of global argon program effort
  - 20 tonne fiducial volume, scalable detector: physics goal < 10^{-47} cm^2 for 100 GeV WIMP (approved by INFN in April 2017, global partnership now being formed among many countries)
- **Multi-hundred tonne detector:** to reach the neutrino floor, site TBD, global argon program effort
  - Will also observe and provide further insight to solar neutrinos

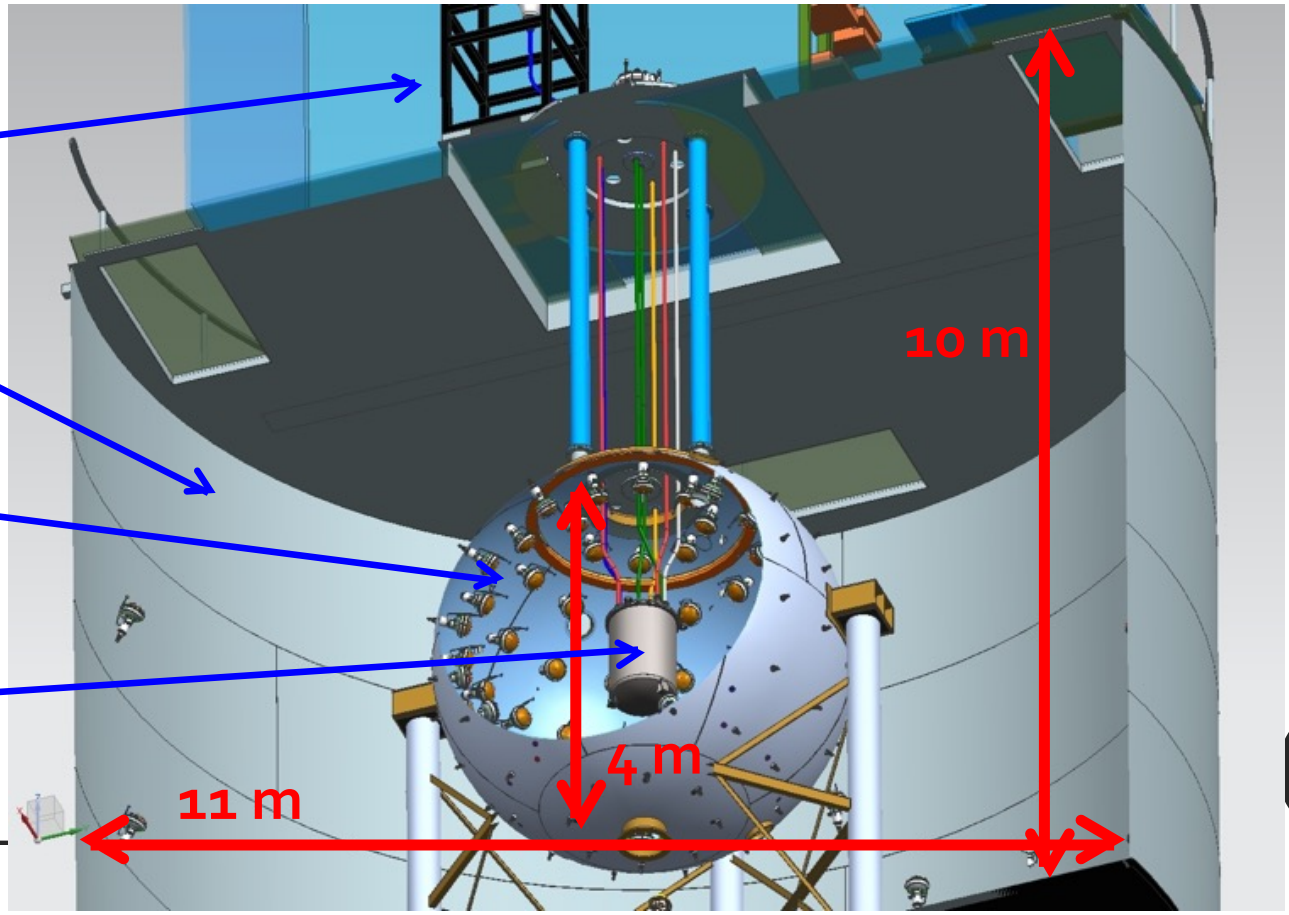
The DarkSide-50 Detectors

Rn-free clean room
(10-15 mBq/m^3 in 110 m^3)

Water Cherenkov muon veto:
1 kton H_2O

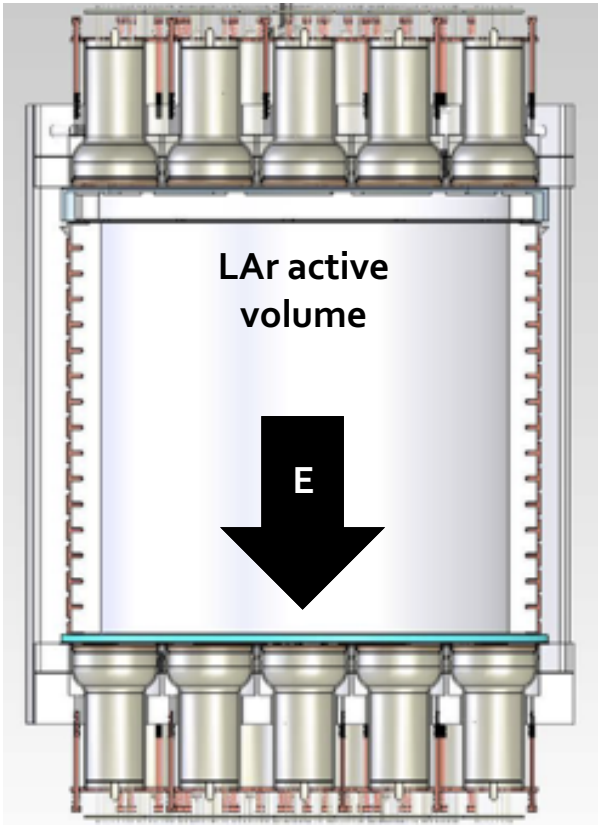
Boron-loaded liquid scintillator
~30 ton (50% TMB + 50% PC)

Two-Phase LAr TPC
50 kg active volume

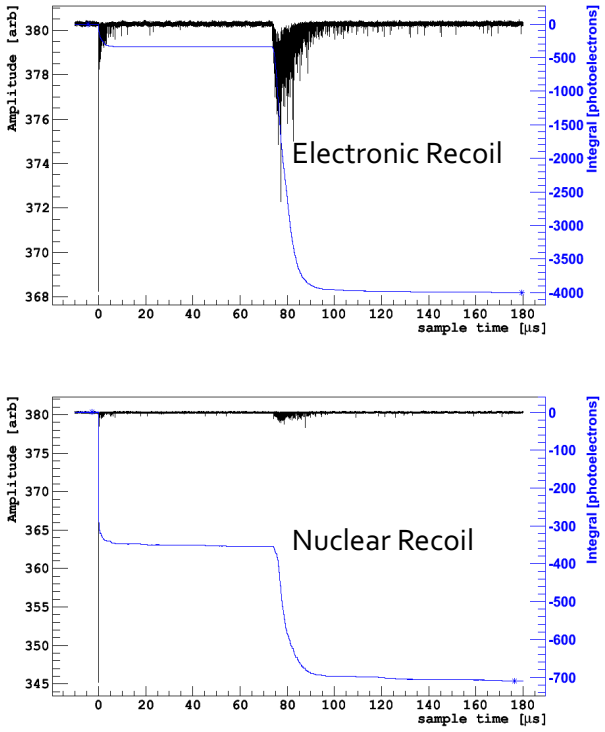


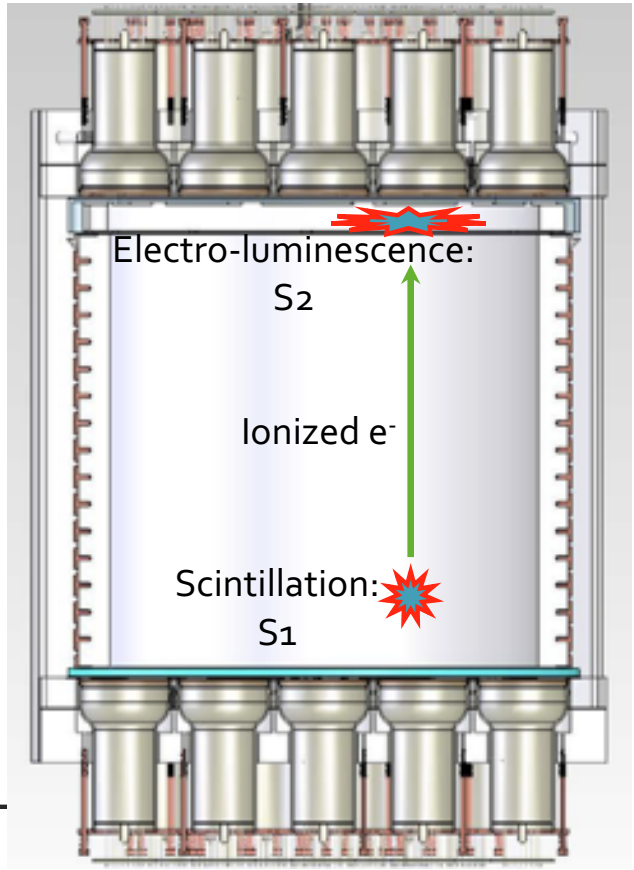
DS-50 LAr TPC

- PTFE Cylinder
  - h=36 cm, d=36 cm, 46 kg (44 kg fiducial), inner surface is coated with TPB
- 38 3" Hamamatsu PMTs:
  - R11065: 19(top) + 19(bottom)
  - Cold amplifier (low PMT HV)
- Cathode and anode windows:
  - Fused silica w/ ITO transparent layers (15 nm) & TPB
- Field shaping copper rings:
  - Uniform electric field: E_{drift}=220 V/cm E_{gas}= 2.8kV/cm
- Fused silica diving bell
  - Gas pocket holding for S2 signal



Two-Phase LAr Dark Matter Detectors

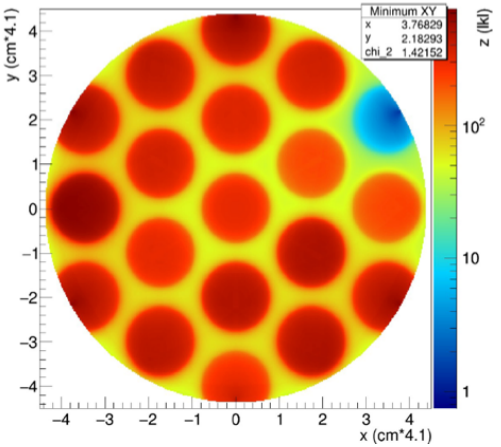




S2

S1

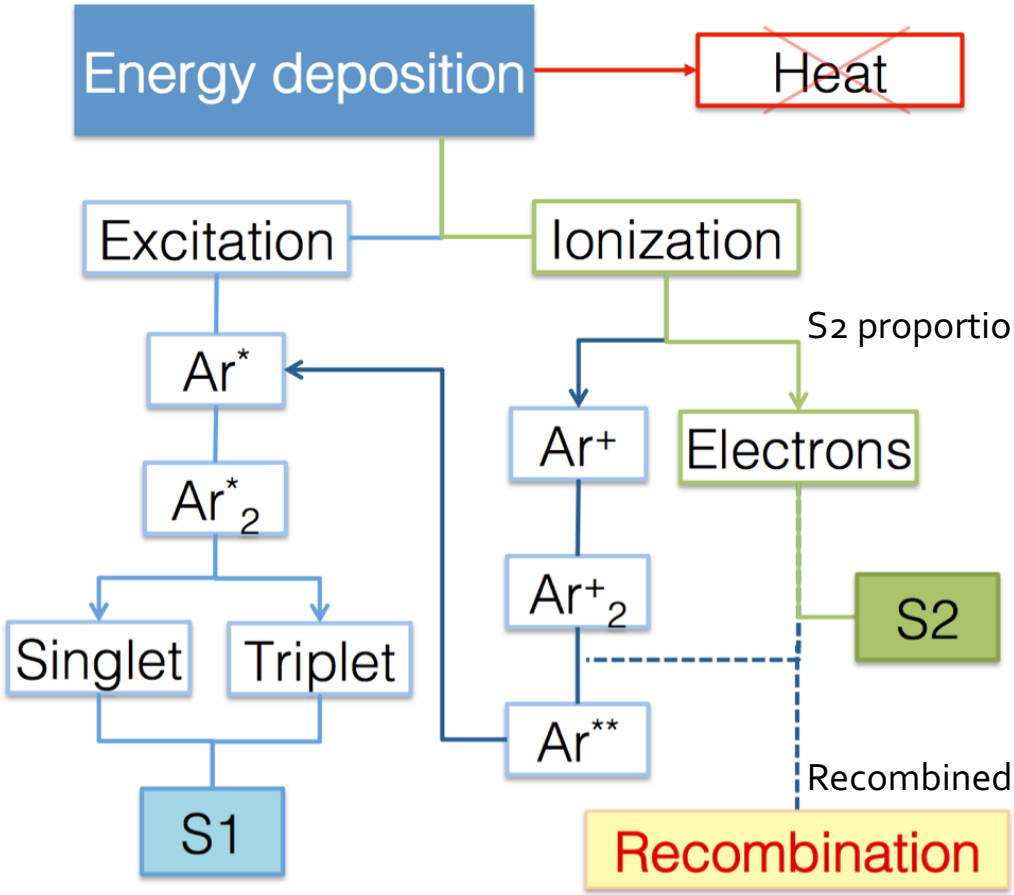
DS-50 Top Array PMT light fractions for S2 gives x,y location



The drift time gives the z-position with mm precision

PID in LAr vs. LXe

All excitons produce scintillation (S1)



S2 proportional to # of ionized e-

Recombined e--ion pair contribute to S1

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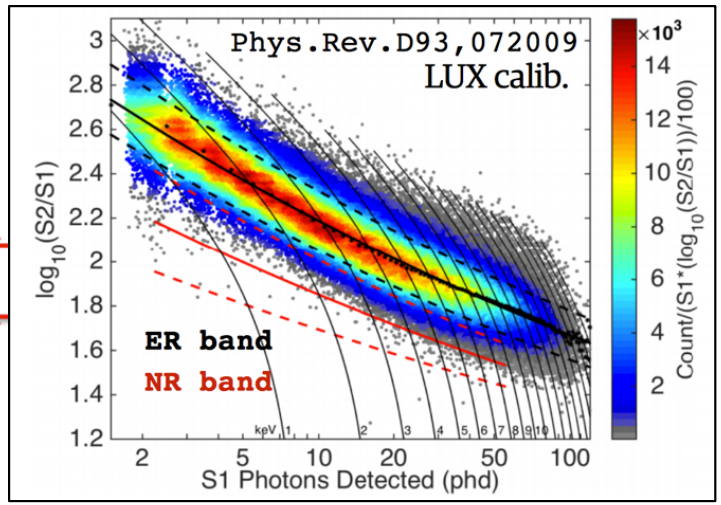

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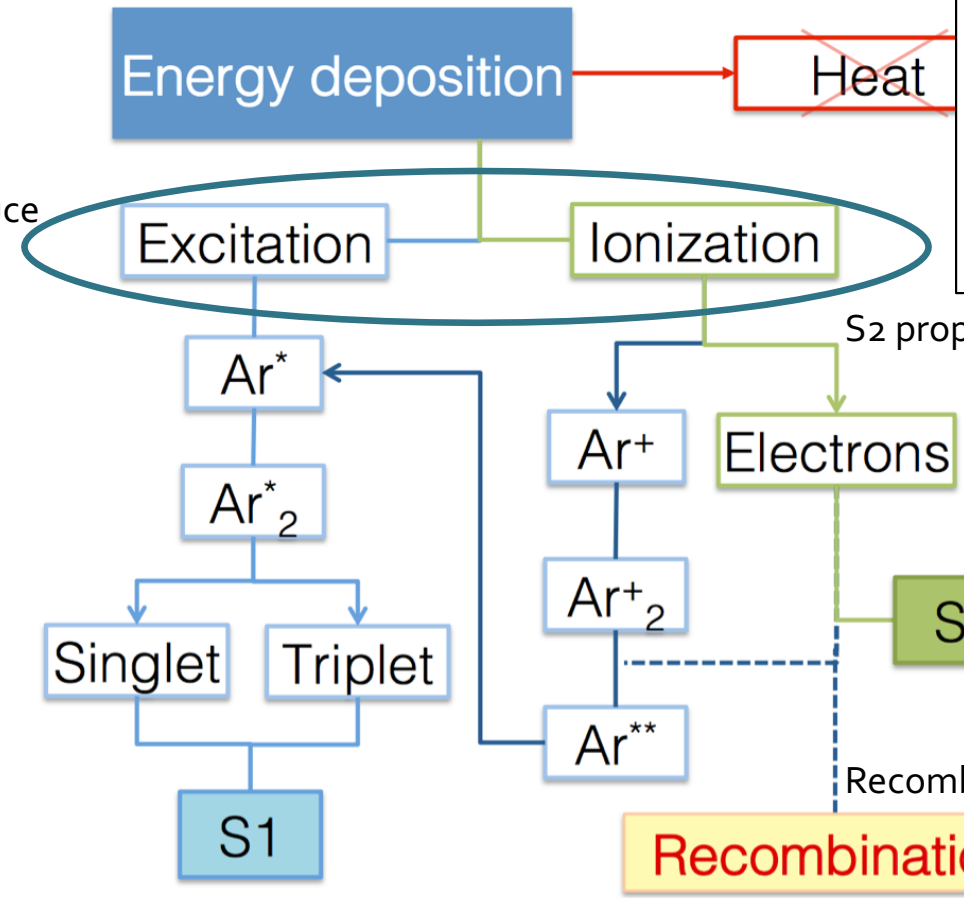
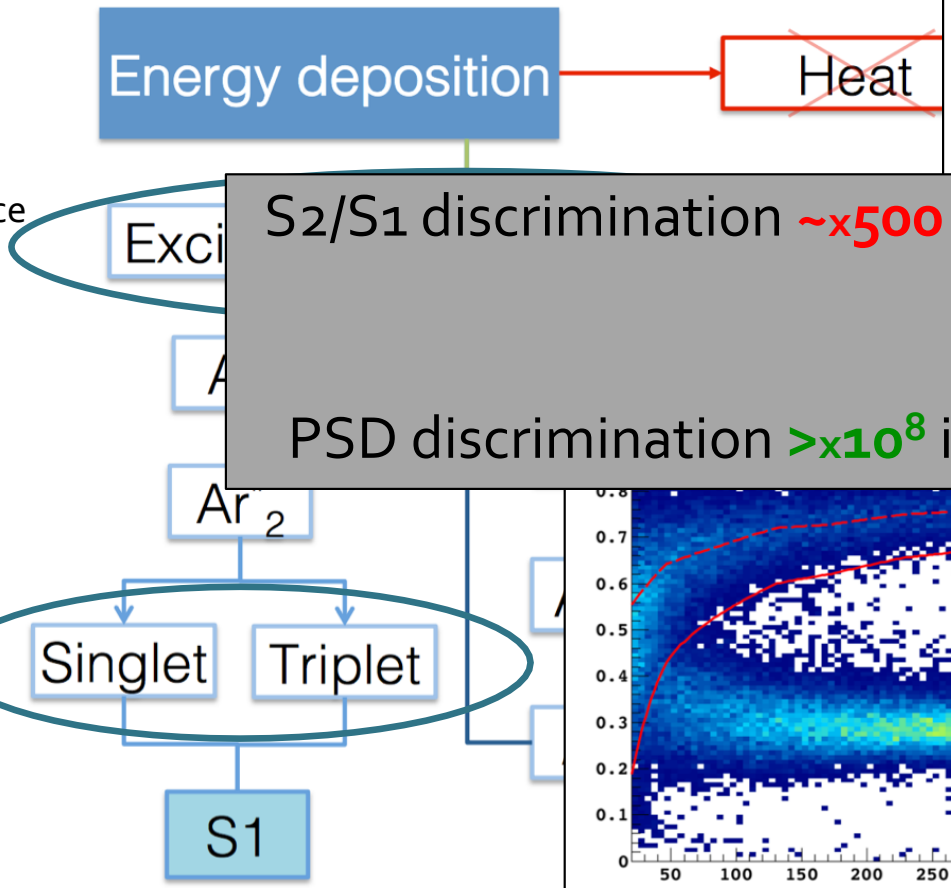


S2 proportional to # of ionized e⁻

Recombined e⁻-ion pair contribute to S1

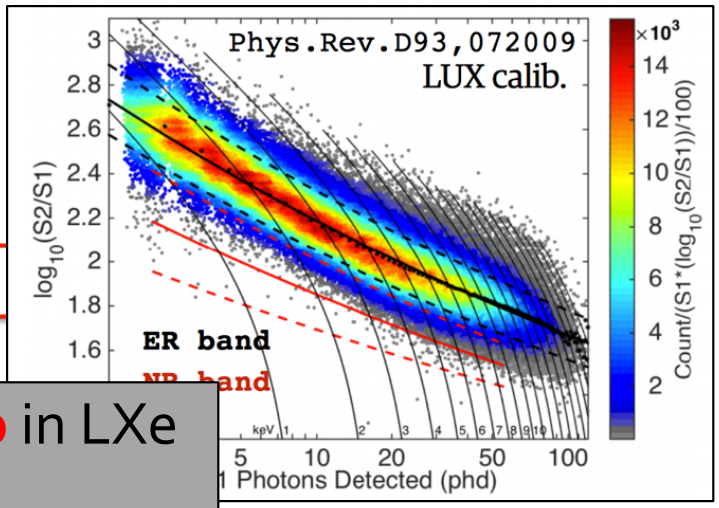
PID in LAr vs. LXe



All excitons produce scintillation (S1)

S2/S1 discrimination ~x500 in LXe

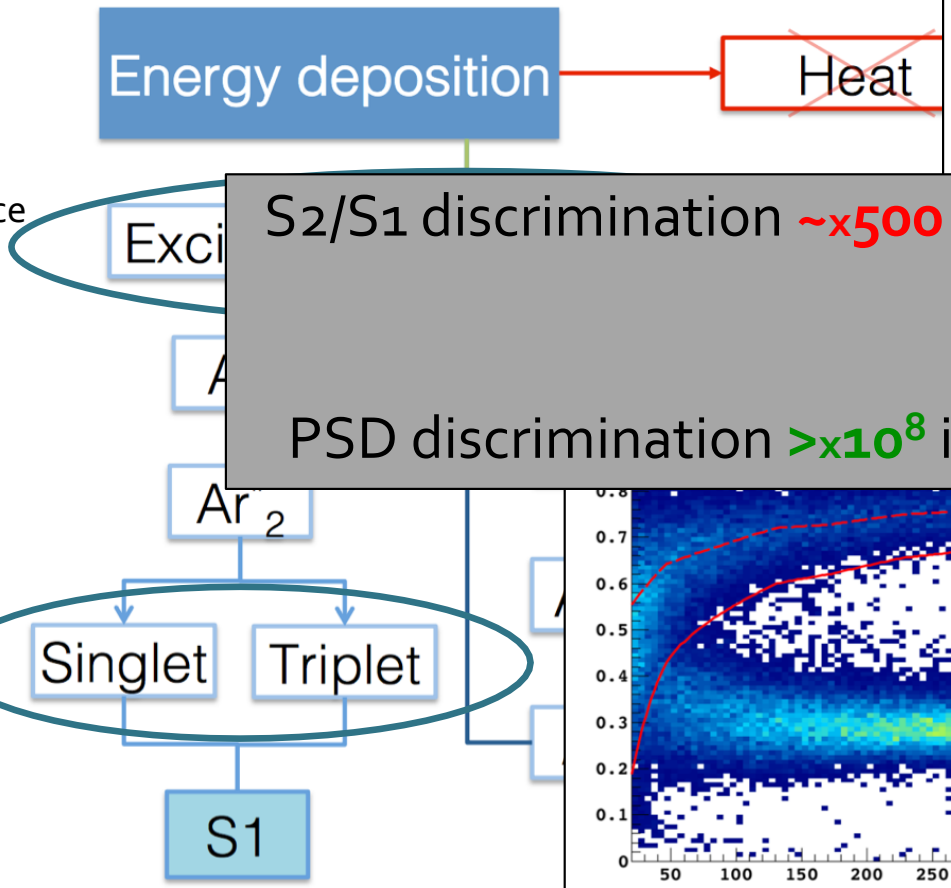
PSD discrimination >x10^8 in LAr



of ionized e-

tribute to S1

PID in LAr vs. LXe



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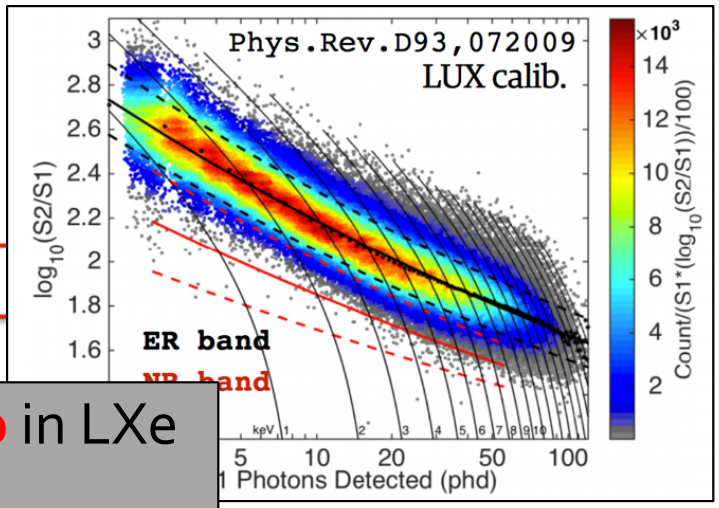


of ionized e-

tribute to S1

DarkSide-50 Veto Detectors:

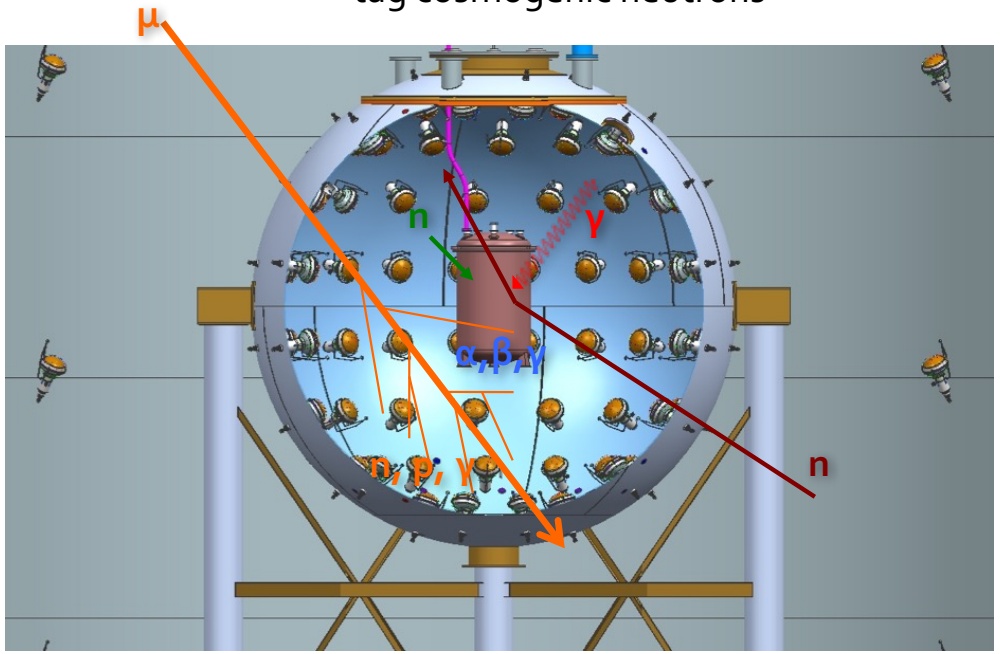
Liquid Scintillator Veto (LSV):

- 30 tonnes TMB+PPO+PC
- Neutron detector, capture on ^{10}B or thermalization signal

Water Cherenkov Veto (WCV):

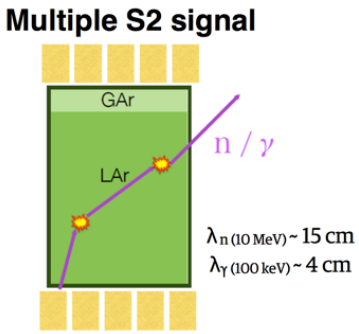
- 1000 tonnes H_2O
- Cosmogenic muon detector, tag cosmogenic neutrons

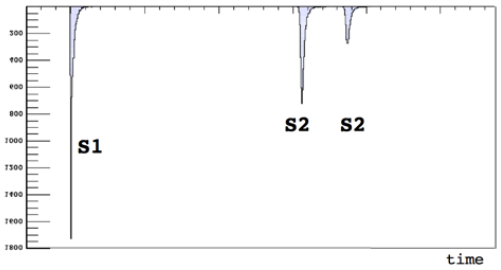
- Gamma, Betas, Alphas
  - Prompt light in LSV, PSD in LAr, long tail
- Radiogenic neutrons
  - Prompt and delayed light in LSV
- Cosmic muons
  - Prompt and delayed light in WCV, LSV
- Fast neutrons
  - Prompt light in LAr and LSV

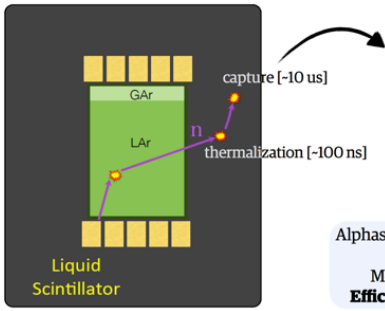


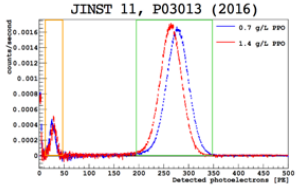
Background Mitigation / ID

- LNGS: Deep underground site to shield cosmic rays
- Screening and selection of detector materials
- Two-phase Ar TPC: 3D-TPC fiducialization; S1 PSD; multiple scatter cut
- Active boron-loaded liquid scintillator neutron veto → >99.1% neutron veto efficiency
- Water Cherenkov veto for muon detection and shielding
- Underground argon (UAr) with reduced ^{39}Ar









Alphas are quenched down to few tens of keV.

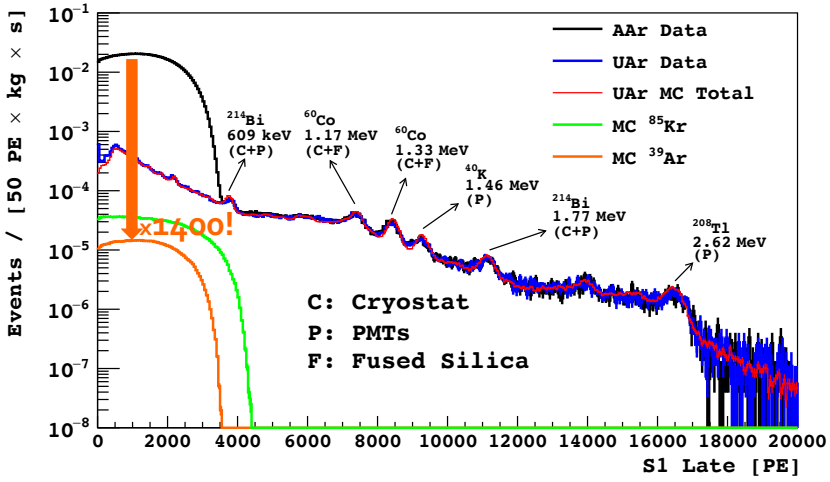
Measured light yield: **0.520 pe/keV**
Efficiency (rad n) **> 99.1 %** (capture only)

Scintillator cocktail: PC **+10-50% TMB** + PPO (wls)
(Trimethylborane, $B(CH_3)_3$. [^{10}B] in natural B ~ 20%)

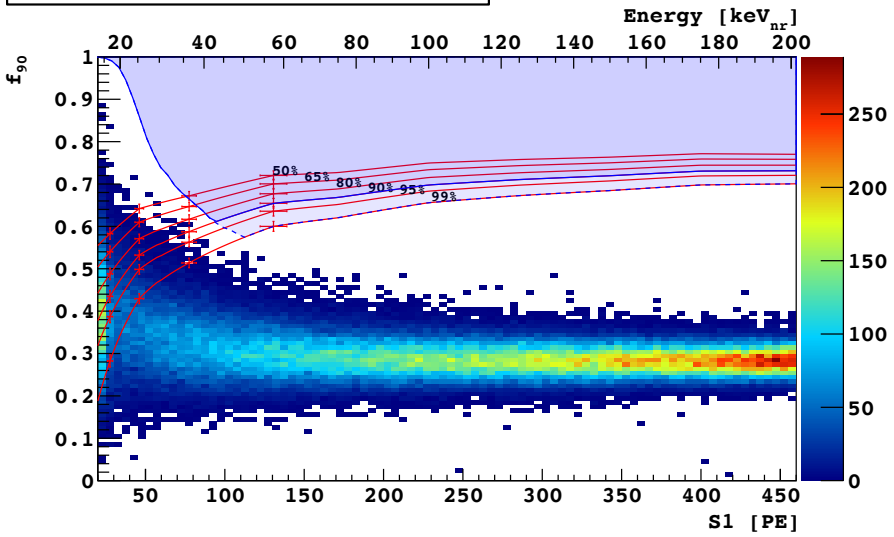
$$^{10}\mathrm{B} + n \rightarrow \begin{cases} ^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) & (6.4\%) \\ ^{7}\mathrm{Li}^{*} + \alpha\ (1471\ \mathrm{keV}),\ ^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li}\ (839\ \mathrm{keV}) + \gamma\ (478\ \mathrm{keV}) & (93.6\%) \end{cases}$$

Underground Argon (UAr)

- $^{40}Ar(n,2n)^{39}Ar$ occurs in the atmosphere → 1 Bq/kg
- Argon that has remained underground can therefore have extremely low levels of ^{39}Ar



2616 kg day UAr exposure



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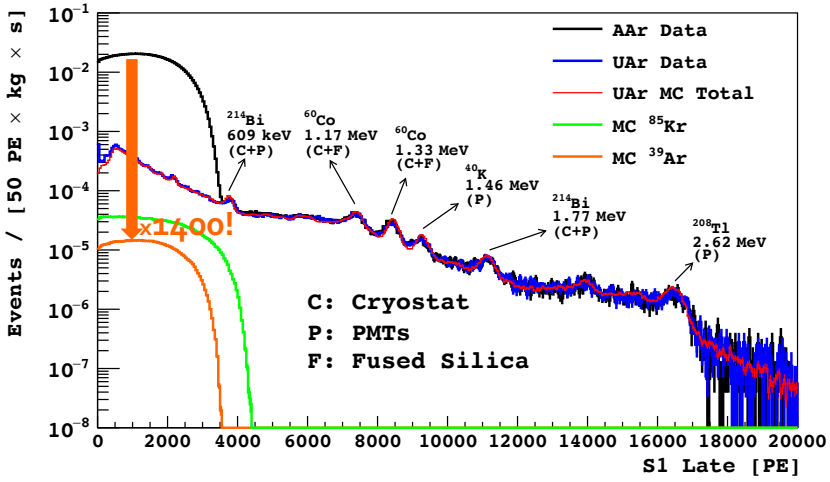

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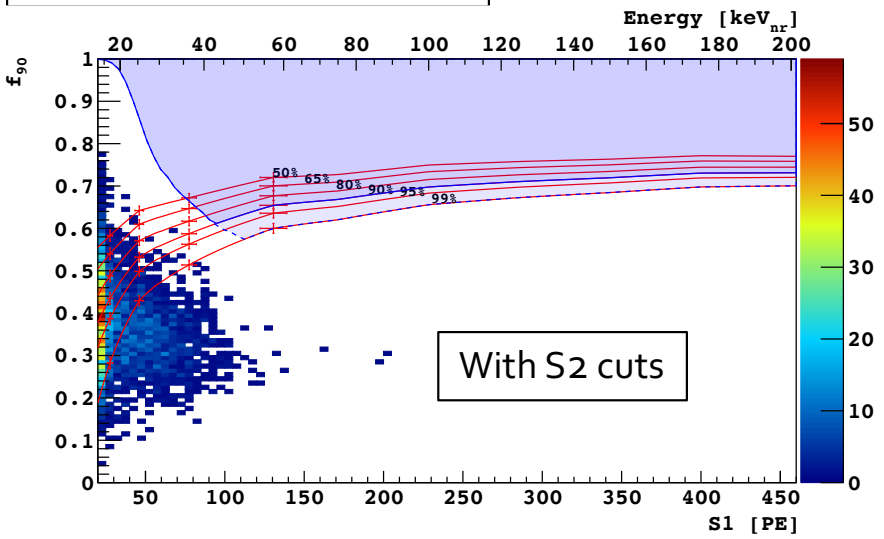


DarkSide-50 Summary

- In operation with atmospheric argon since Oct 2013, underground argon since April 2015
- Cryogenics and gas handling system very stable, electron lifetime > 5 ms (max drift 375 us)
- TPC HV system stable for years
- 1422 kg-days AAr + 2616 kg-days Uar, measured >x1400 reduction ^{39}Ar relative to AAr
- LY: 7.9 pe/keV$_{ee}$ @ null field, 7.0 pe/keV$_{ee}$ @ 200 V/cm (both for AAr and UAr)
- No remaining background in WIMP search region, in either exposure
- Blind analysis now ongoing → Updated results expected soon (>500 days lifetime)

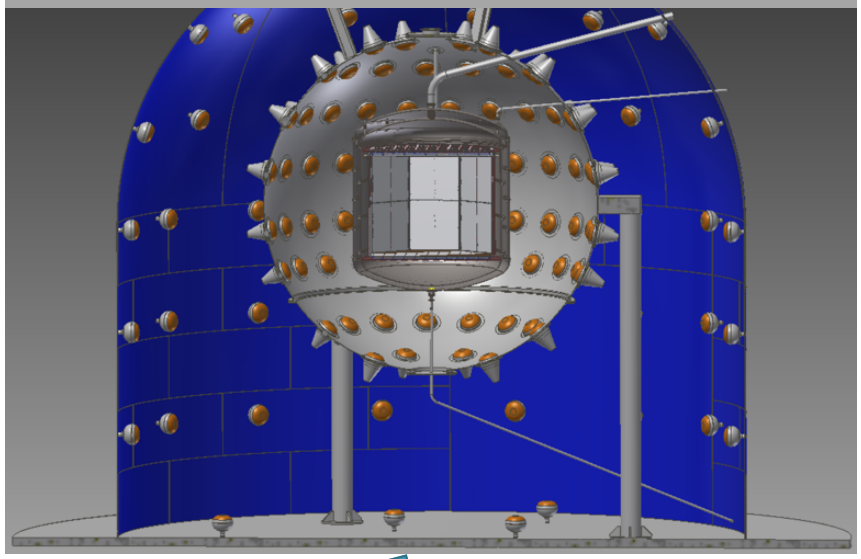
Global Argon Program

- Existing LAr collaborations unite:
  - DarkSide-50
  - DEAP-3600
  - ArDM
  - miniCLEAN

DS-20k Key Features

- Underground argon
  - 20 t fiducial (>30 t total)
- Custom silicon photomulitipliers
- High efficiency active vetoes
- LAB +TPB in LSV for safer operations

1st step: DarkSide-20k



Experimental Description now available at arXiv:1707.08145 (submitted to EPJ+)

2nd step: Multi-hundred tonne detector to reach to the neutrino floor

Full collaboration would support this effort, including the design choices and site selection

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1st step: DarkSide-20k

Canadian groups to formalize membership next month, currently converging on what the new contributions would be in several key areas

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2nd step: Multi-hundred tonne detector to reach to the neutrino floor

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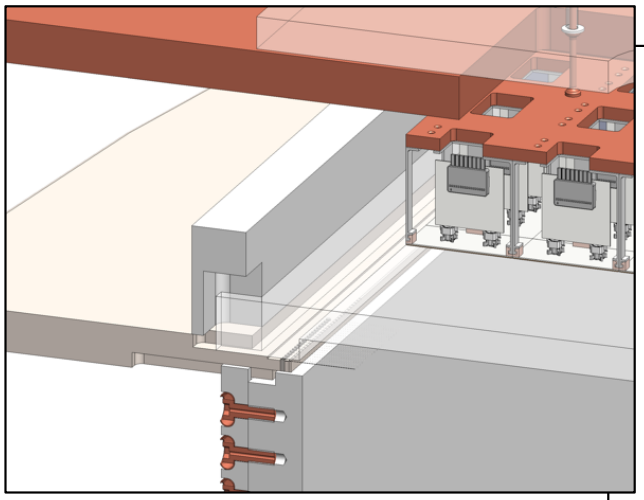
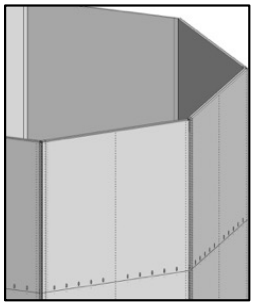
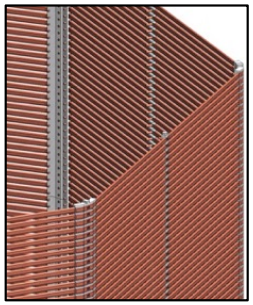
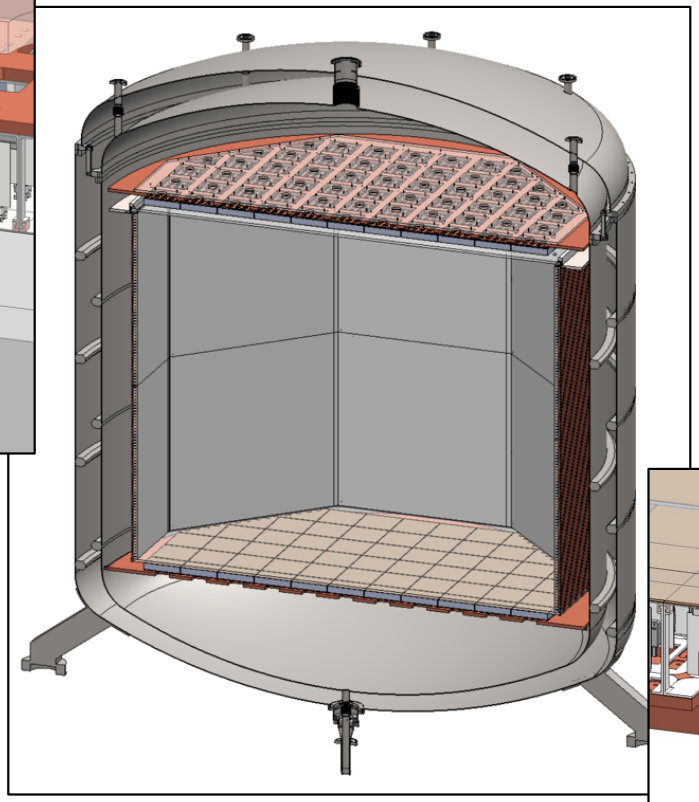
DS-20k TPC

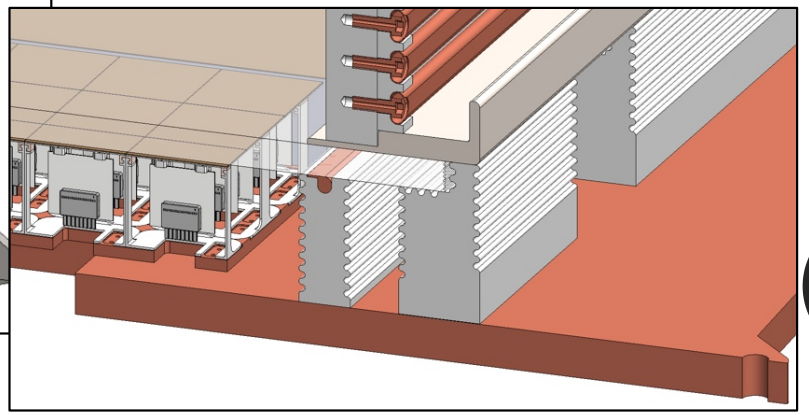






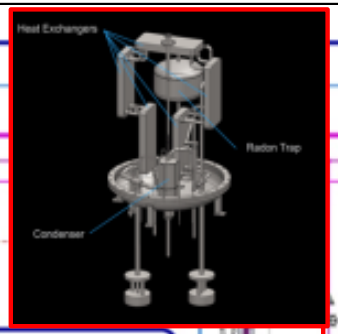


LAr TPC Dimensions	
Height	239 cm
Effective Diameter	290 cm
Active LAr Mass	23 t
Nominal TPC Fields and Grid	
Drift Field	200 V/cm
Extraction Field	2.8 kV/cm
Luminescence Field	4.2 kV/cm
Operating Cathode Voltage	−52 kV
Operating Extraction Grid Voltage	−3.8 kV
Operating Anode Voltage	ground
Electroluminescence Distance	7 mm
Grid Wire Spacing	3 mm
Grid Optical Transparency	98 %
SiPM Tiles	
Number of Tiles	5210
Size of Tiles	$50 \times 50\,\mathrm{mm}^2$



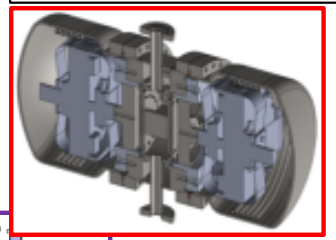
Cryogenics

Heat exchanger/condenser unit



Parameter	Value
LAr mass during normal operations	35 t
Maximum LAr mass that can be purified	50 t
Commissioning time	<60 days
LAr boiling threshold at 3 m depth	60 mW/cm^2
Condenser cooling power during normal operations	1.5 kW
Maximum heat load in LAr before bubbling at cryostat bottom	>5 kW
Total max. cooling power of the condenser	5 kW
Minimum condenser cooling power to hold LAr inventory	150 W
Minimum heat recovery efficiency of heat exchanger	>95 %
LAr purity required for stable S2 generation	<0.1 ppb O_2 (>5 ms equiv.)
Max. total radioactivity of the cryostat	<1 mBq/kg 238 U and 232 Th
Pressure inside cryostat during normal operations	15.6±0.1 psi (1.075±0.007 bar)
Pressure stability achieved in DarkSide-50	0.023 psi (RMS)
Vent pressure of spring-loaded pressure relief valves	1.6 bar
Max. pressure of cryostat safety rupture burst disks	1.7 bar
Max. LAr head height before H1D	1.5 m
Max. flow of gas from liquid and gas withdrawal loops	1000 std L/min
Max. flow rate through gas getter purifier	>1000 std L/min
Flow rate of cool GAr from detector ullage	350 std L/min
Flow rate of LAr from cryostat bottom	1 L/min (650 std L/min GAr flow equiv.)
Flow rate of GAr through single Q-drive pump	500 std L/min
Total number of Q-drive pumps for max. flow	2 pumps in parallel (+1 extra as a spare)
LAr pressure at input of H1D	0.8 bar
Pressure of GAr at output of Q-drive pumps	2.5 bar
Pressure of GAr after gas getter purifier	2.0 bar
Pressure of LAr/GAr after heat exchangers	1.2 bar
Total mass of LN_2 storage in cooling system	30 t
Efficiency of radon purification by activated charcoal trap	<2 μBq/kg after trap
Max. pressure of insulating vacuum volume and lines	1×10^{-5} mbar
Max. He leak rate at all welds and joints	2×10^{-9} std cm^3/s

Q-Drive gas pump, no leak

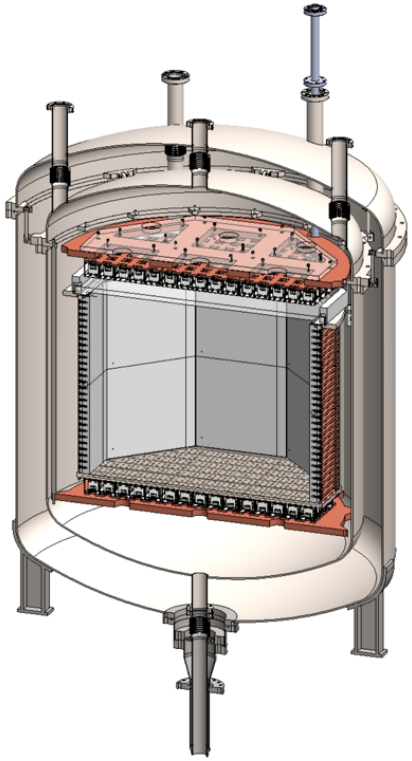


Detector and Purification

Recovery System

UCLA condenser

DS-Proto



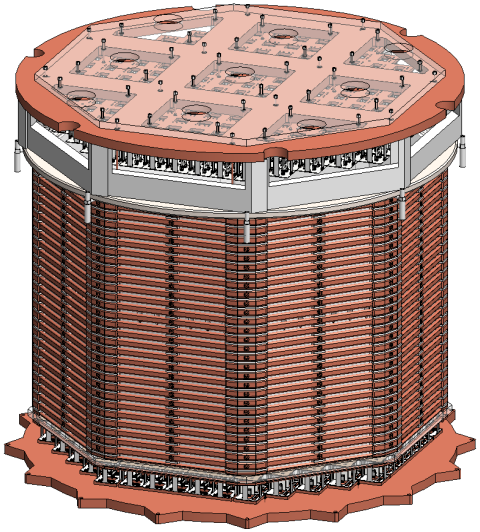
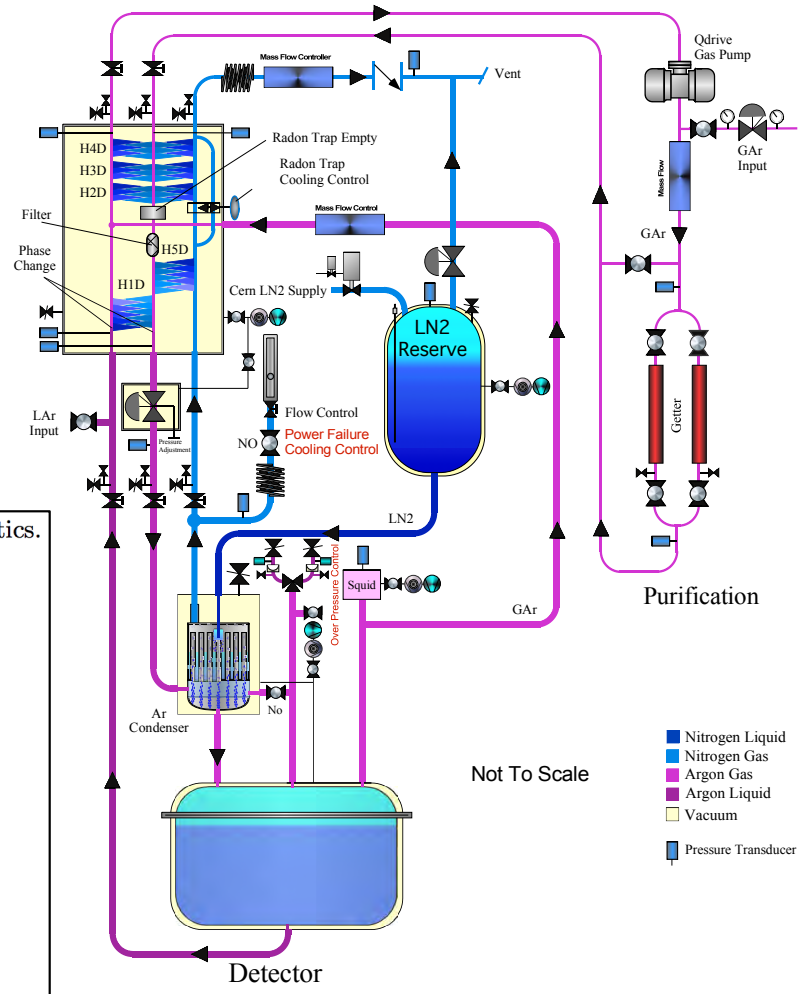
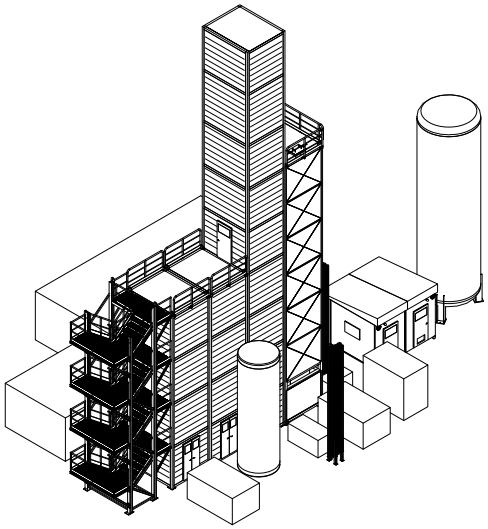


Table 8. DarkSide-Proto LAr TPC detector characteristics.

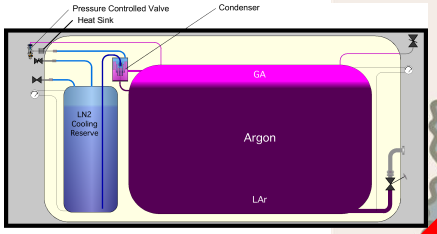
LAr TPC Dimensions	
Height	58 cm
Effective Diameter	72 cm
Total LAr Mass	800 kg
Nominal TPC Fields and Grid	
Drift Field	200 V/cm
Extraction Field	2.8 kV/cm
Luminescence Field	4.2 kV/cm
Operating Cathode Voltage	−15 kV
Operating Extraction Grid Voltage	−3.8 kV
Operating Anode Voltage	ground
Luminescence Distance	7 mm
Grid Wire Spacing	3 mm
Grid Optical Transparency	98 %
SiPM Tiles	
Number of Tiles	370
Size of Tiles	$50 \times 50\,\mathrm{mm}^2$

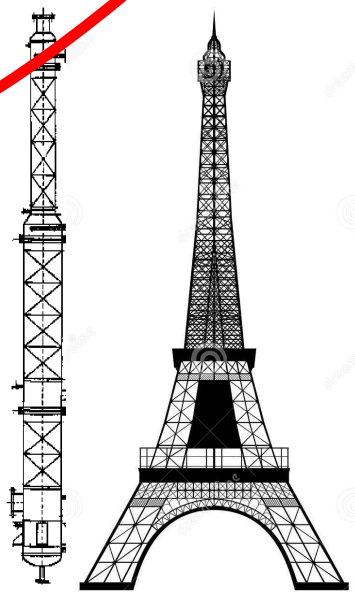


UAr for DS-20k



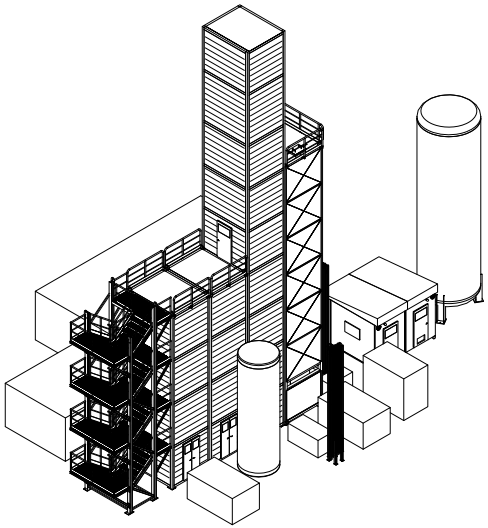
- Urania: procure 50 t of UAr from Co
- Extract 100 kg/day, 99.9% purity
- UAr transported to Sardinia for final chemical purification at Aria





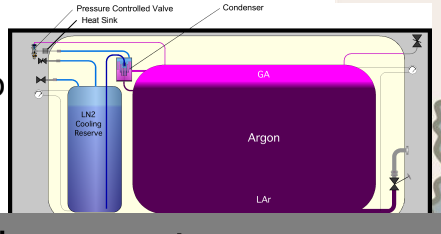
- Aria project: final chemical purification of the UAr
- Process O(1 t/day) with 10^3 reduction of all chemical impurities
- Ultimate goal - isotopically separate ^{39}Ar from ^{40}Ar

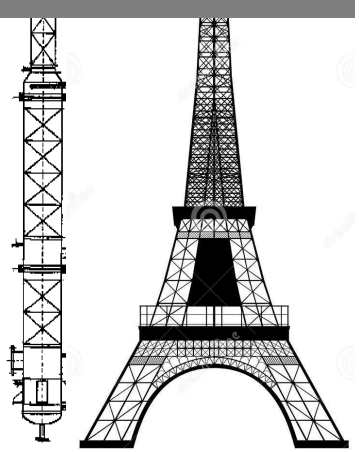
UAr for DS-20k



- Urania: procure 50 t of UAr from Co
- Extract 100 kg/day, 99.9% purity
- Canadian groups expected to continue to contribute to UAr effort in a significant way

  Future scale-up of extraction being considered for procurement of hundreds of tonnes of UAr

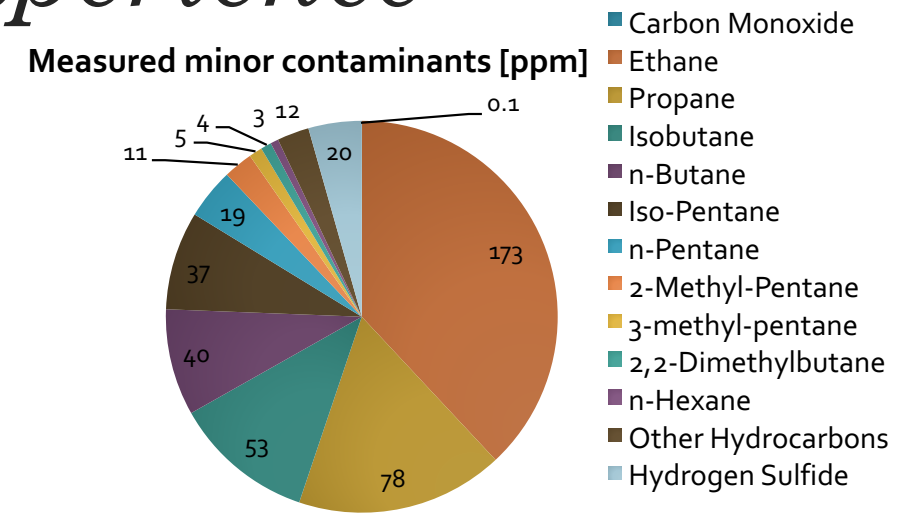




- Aria project: final chemical purification of the UAr
- Process O(1 t/day) with 10^3 reduction of all chemical impurities
- Ultimate goal - isotopically separate ^{39}Ar from ^{40}Ar

UAr Extraction Experience

- Vacuum Pressure Swing Adsorption (VPSA) Plant
  - Extraction of Ar from CO_2 well
  - Based on adsorption on zeolites
    - CO_2 removal
    - N_2 reduction
  - Primary output:
    - Ar, He, and N_2
  - Minor contaminations in output:
    - O_2, CO_2, CH_4, and higher hydrocarbons
- **Challenges:**
  - Operating R&D plant as production facility (equipment maintenance, etc.)
  - Lower production rate than expected
  - Zeolite poisoning
    - Reduced adsorption efficacy over time
    - 900 lbs of zeolite was replaced 3 times



Urania Plant

- Expanded UAr production, but same site as previous extraction (for DS-50)
- Basically the same input as previous VPSA plant (96% CO_2, ~400 ppm Ar)
  - Water and helium removed upstream, all other contaminations remain
- Minor contaminations study now in progress
  - Guide final process, equipment and materials design choices
  - Guide operations procedures

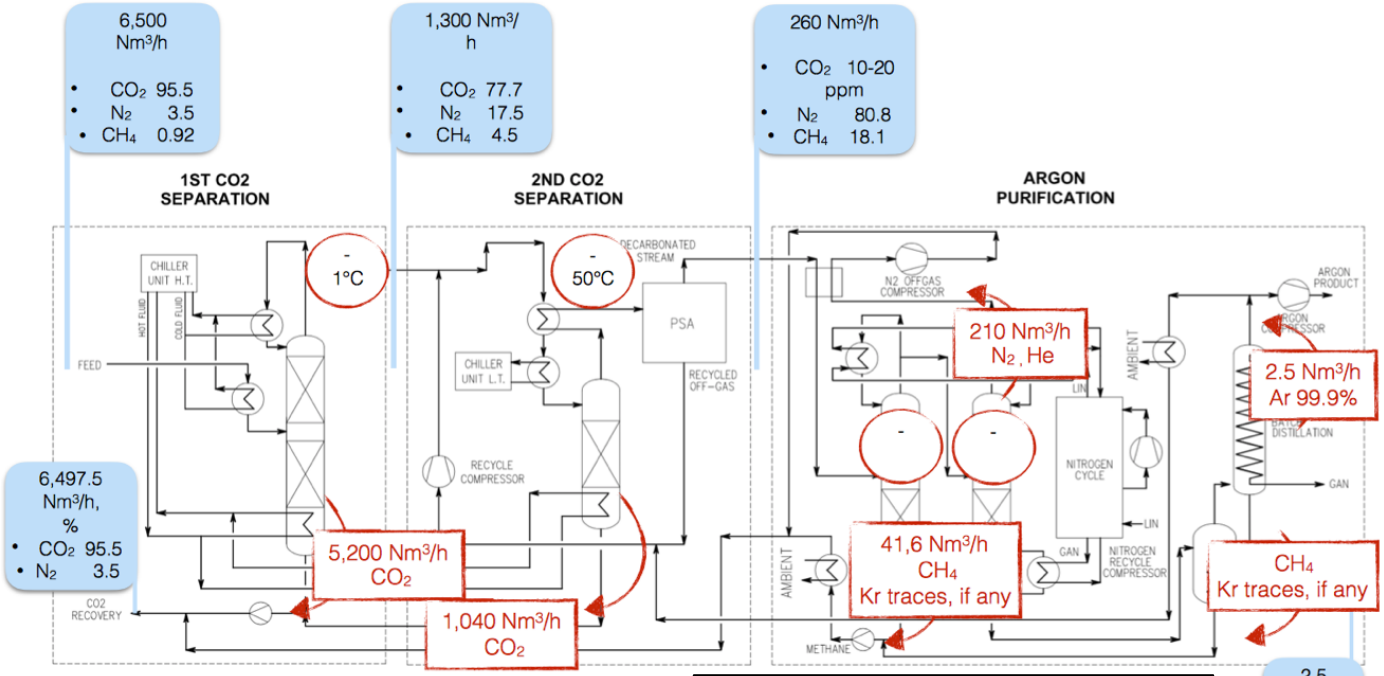
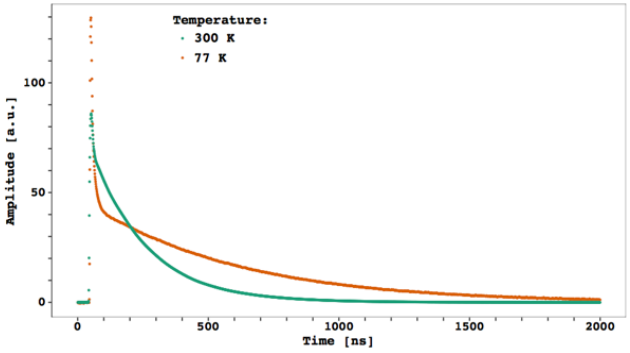


TABLE IX. Urania/Aria: Inlet purity required by the getter of DarkSide-20k.

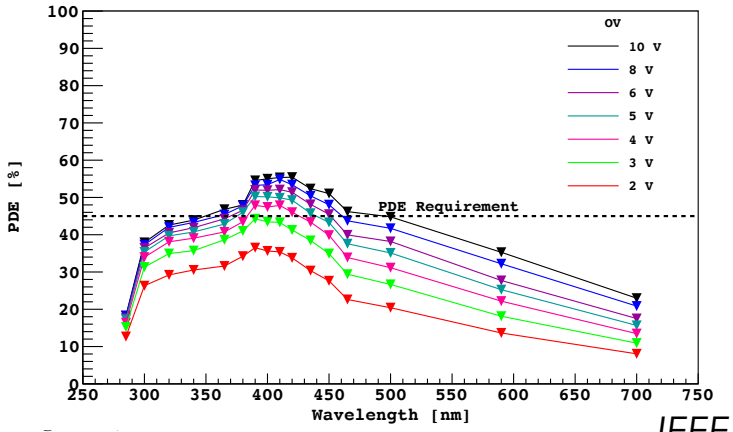
Element	Inlet Purity Requirements (ppm)
CH_4	<0.25
CO	<0.1
CO_2	<0.1
H_2	<1
H_2O	<1
N_2	<1
O_2	<1

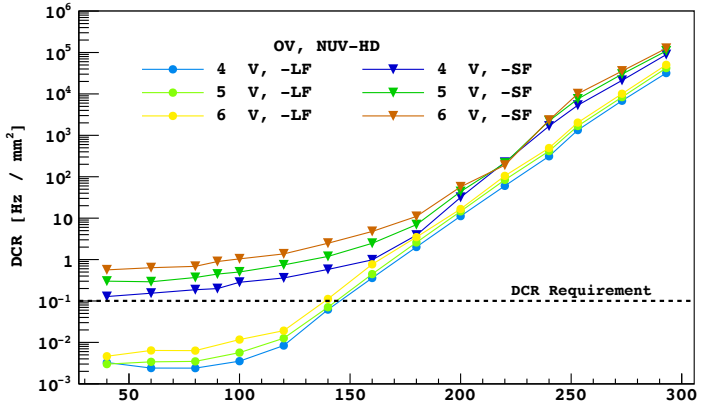
FBK NUV-HD Low-Field SiPMs



- PMTS → SiPMs:
  - Better PDE & single PE resolution, lower cost
  - Larger # readout channels, high capacitance per unit area

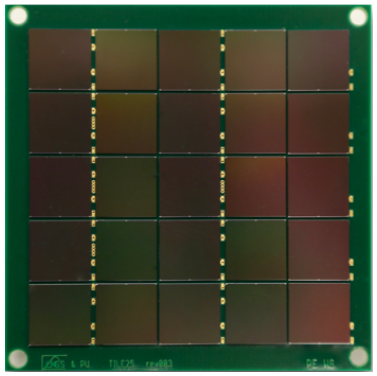
- 10 x 10 mm² SiPMs
- Peak efficiency in near UV
- Low field reduces dark rate



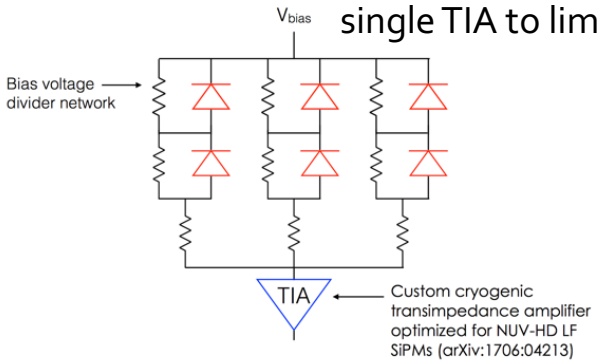


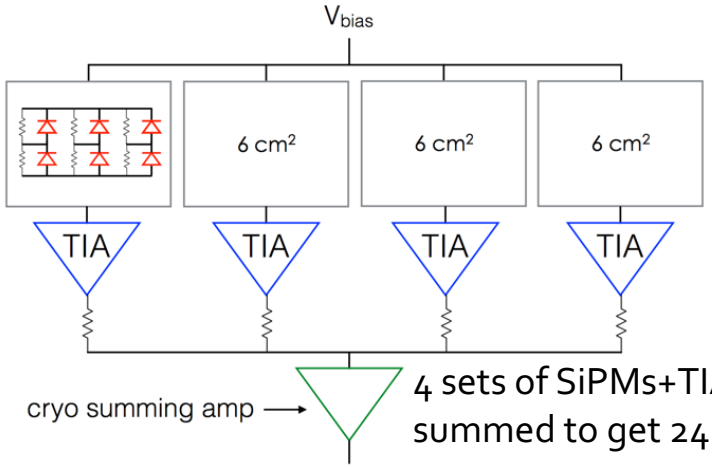
IEEE Trans. Electron Dev. 64 2, 2017

24 cm² Prototype Tile

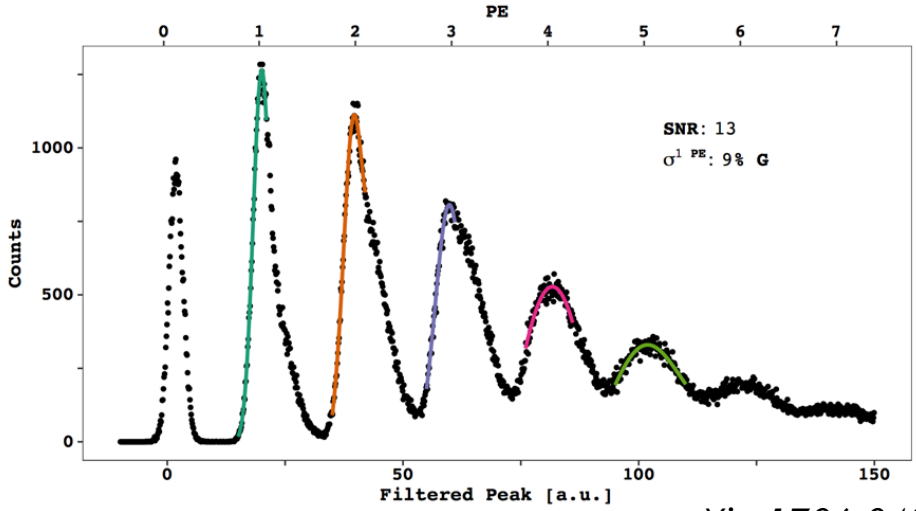


6 SiPMs summed to single TIA to limit noise

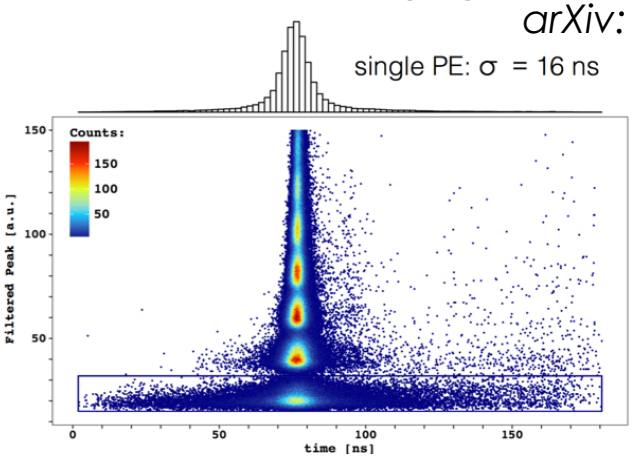




4 sets of SiPMs+TIA summed to get 24 cm²

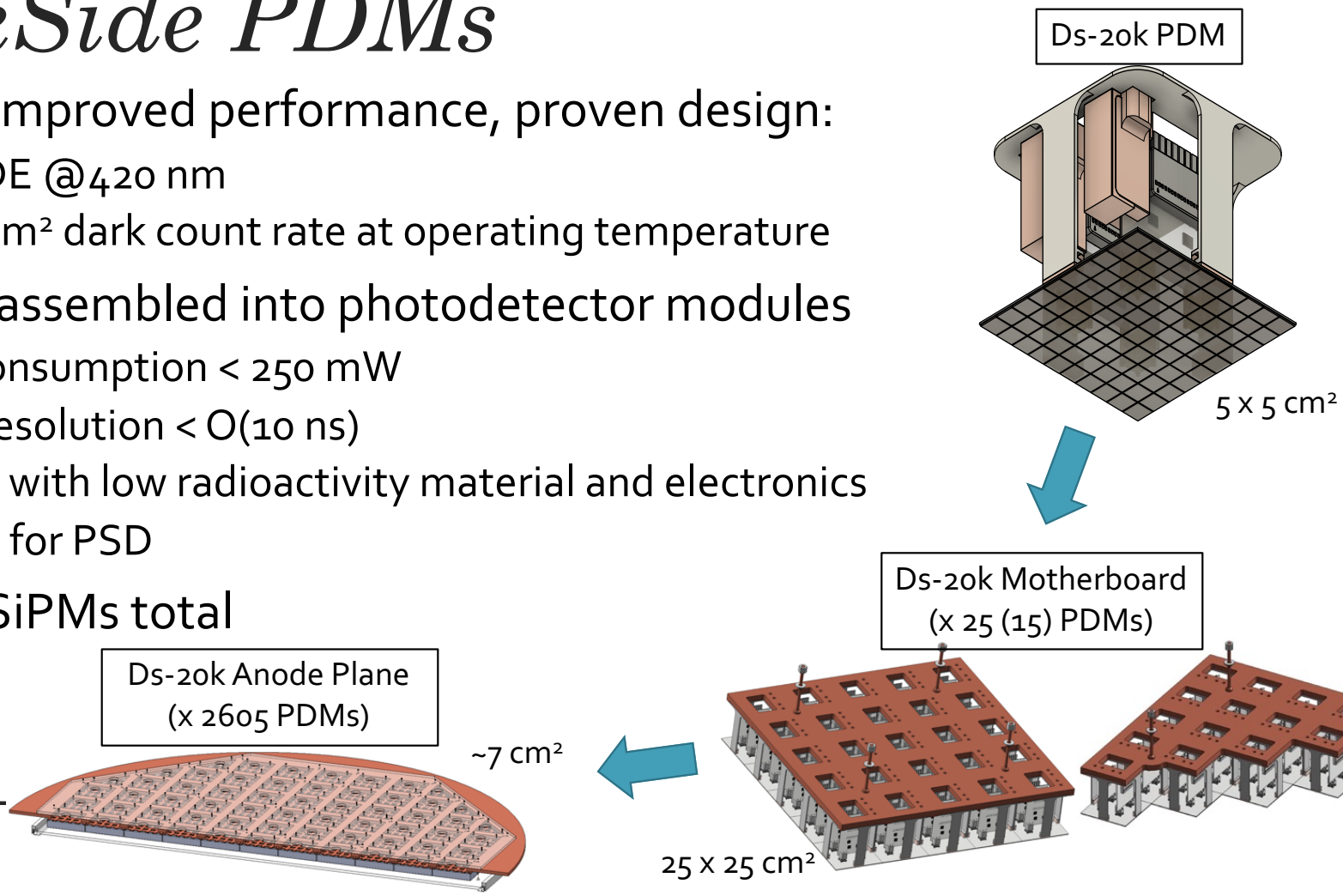


arXiv:1706:04220



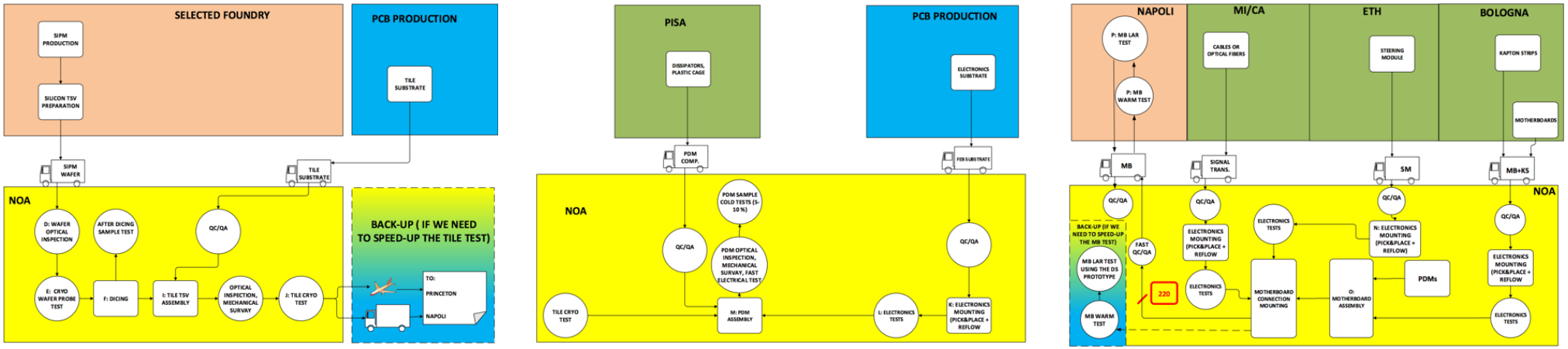
DarkSide PDMs

- SiPMs for improved performance, proven design:
  - >40% PDE @420 nm
  - 0.1 Hz/mm² dark count rate at operating temperature
- SiPM tiles assembled into photodetector modules
  - Power consumption < 250 mW
  - Timing resolution < O(10 ns)
  - 5 x 5 cm² with low radioactivity material and electronics
  - SNR > 13 for PSD
- ~14 m² of SiPMs total



Production of PDMs

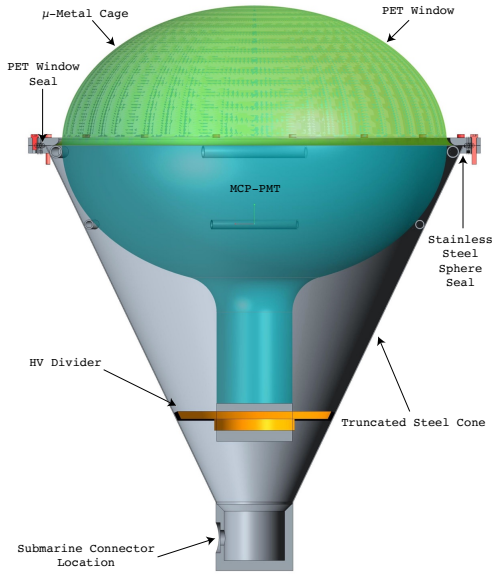
Nuova Officina Assergi (NOA) will be an LNGS facility where the first client will be DS-20k, for tiles packaging and production

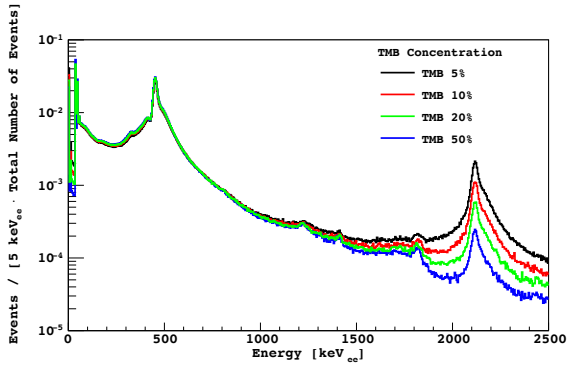


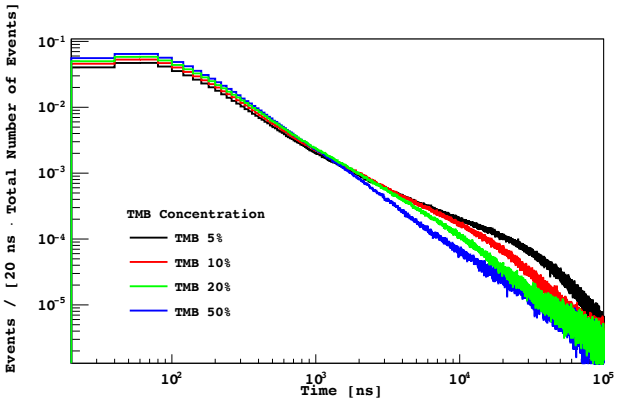
SiPM, tile, PDM, and motherboard testing to be done at LNGS and universities

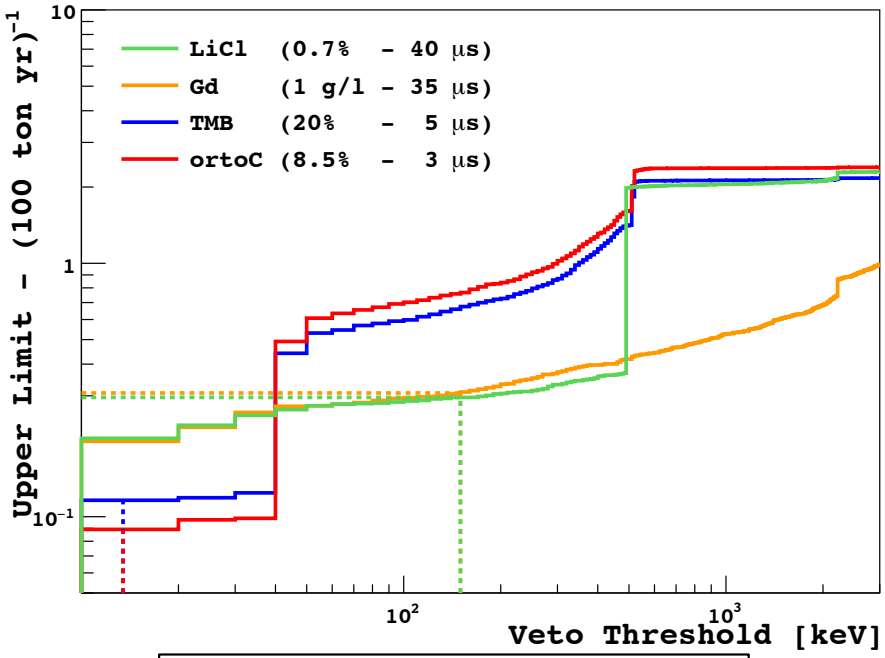
LSV Detector

20" MCP-PMTs (JUNO Tubes)

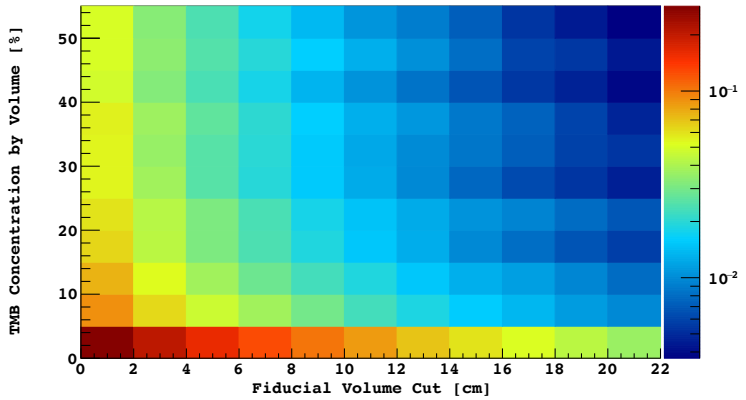






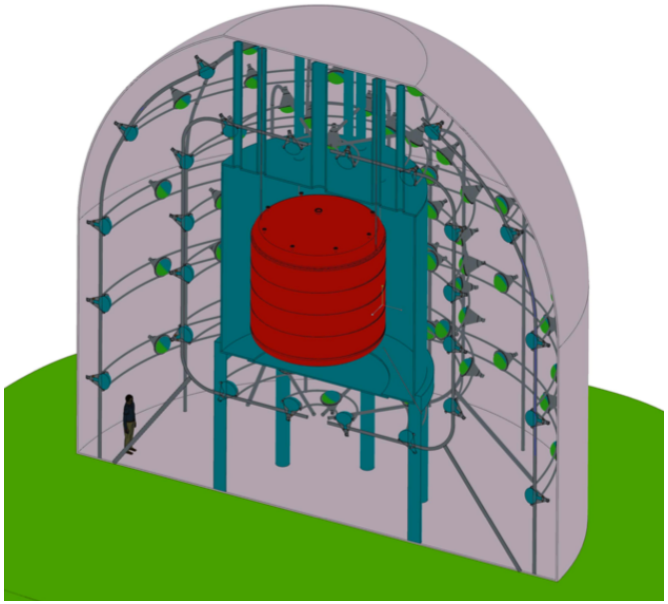


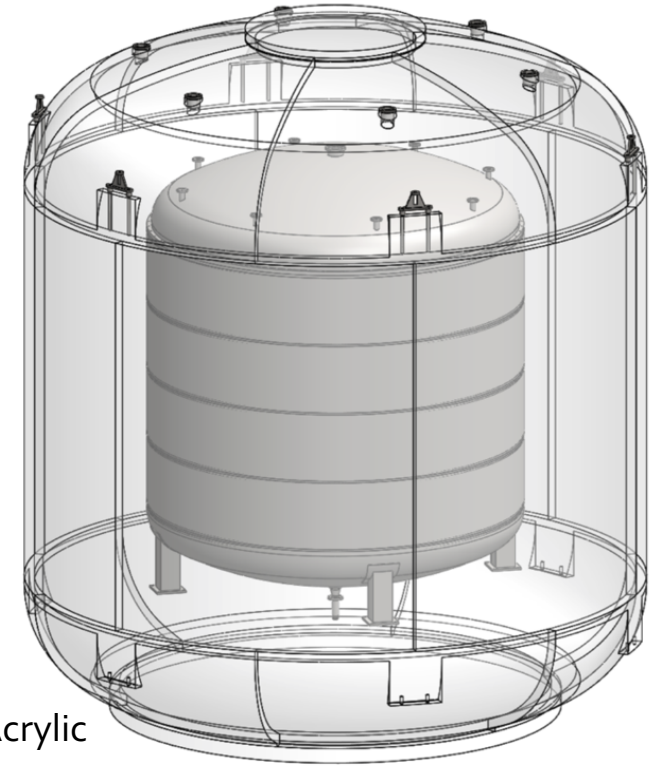
Remaining Neutron Background



TMB loading	τ	$7\,\tau$	mean num. coinc. (μ)	prob. random coinc. (P)
5%	22 μs	154 μs	~ 0.04	4 %
10%	11 μs	77 μs	~ 0.02	2.2 %
20%	5.5 μs	38.5 μs	~ 0.01	1.1 %

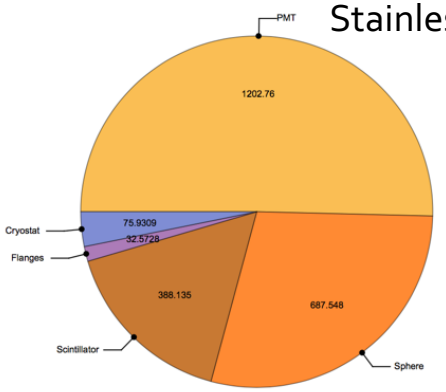
Reducing Veto Detector Event Rate



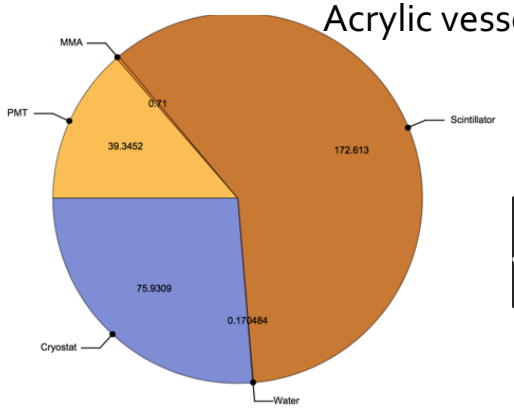


Event rate in LSV [Bq]

Stainless steel vessel

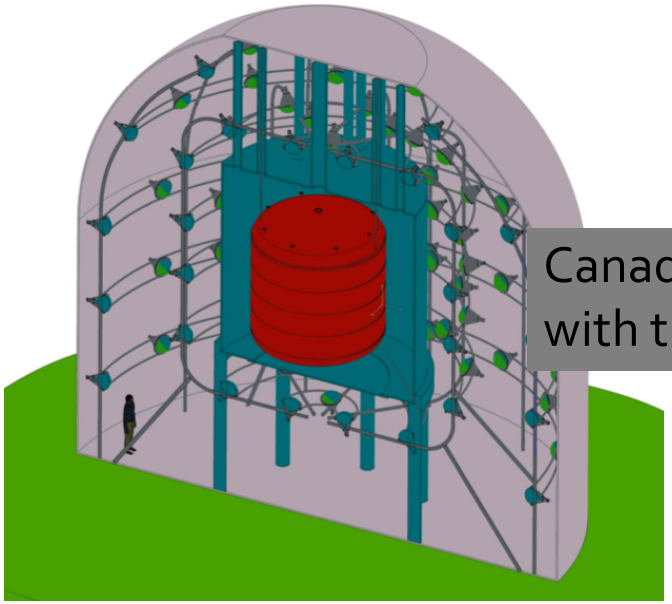


Acrylic vessel



NEW IDEA: Water buffer for LSV PMTs
→ Need a transparent LSV vessel → UVT Acrylic

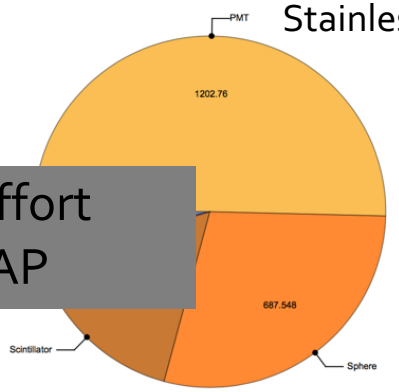
Reducing Veto Detector Event Rate



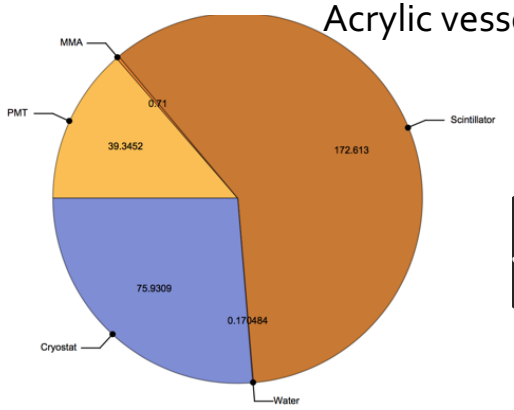
Canadian groups expected to lead this effort with their experience from SNO and DEAP

Event rate in LSV [Bq]

Stainless steel vessel



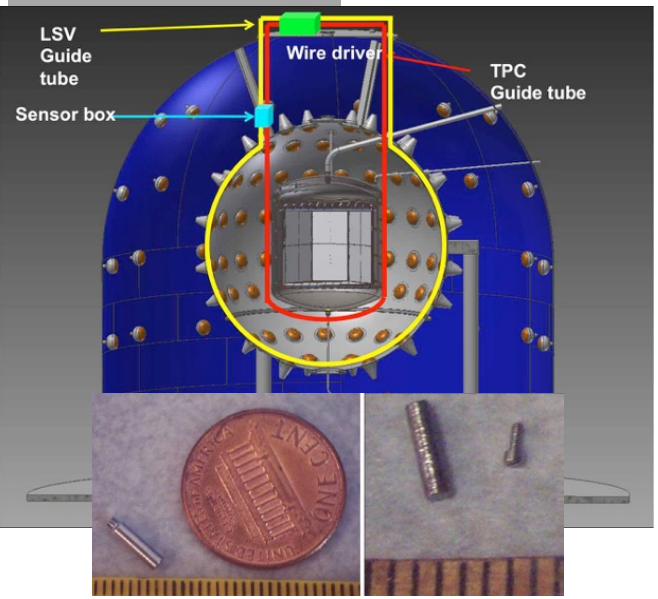
Acrylic vessel



NEW IDEA: Water buffer for LSV PMTs
→ Need a transparent LSV vessel → UVT Acrylic

Calibrations

Miniature Sources



Calibrations

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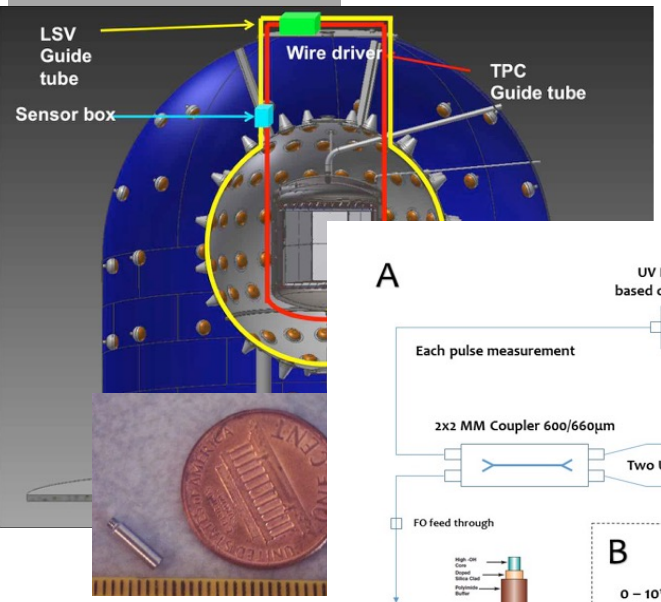
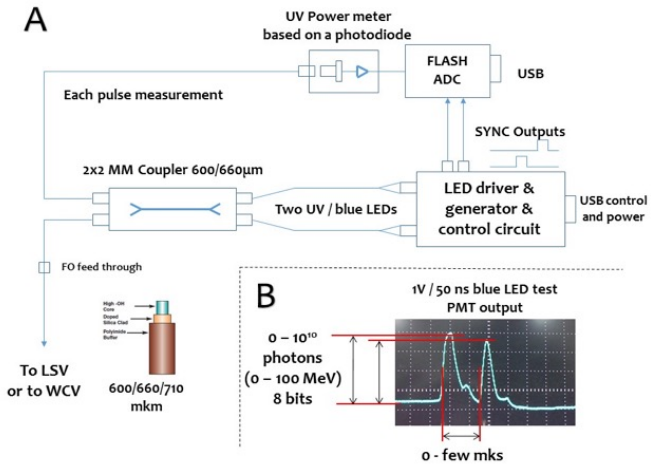
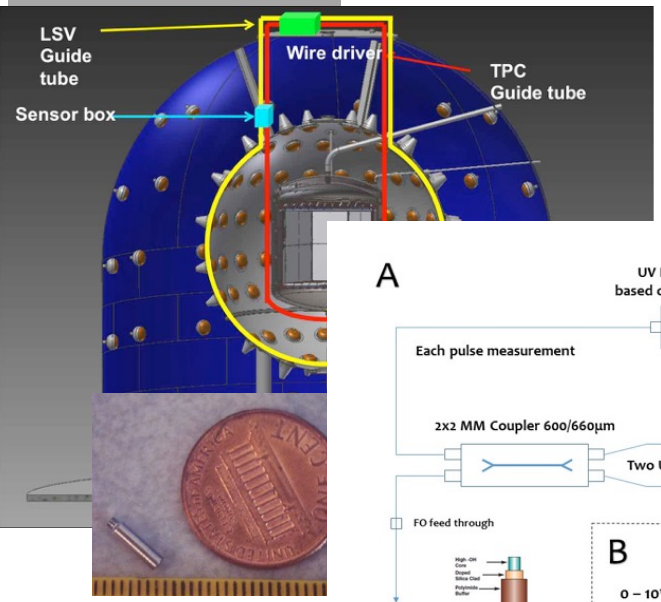


LEDs

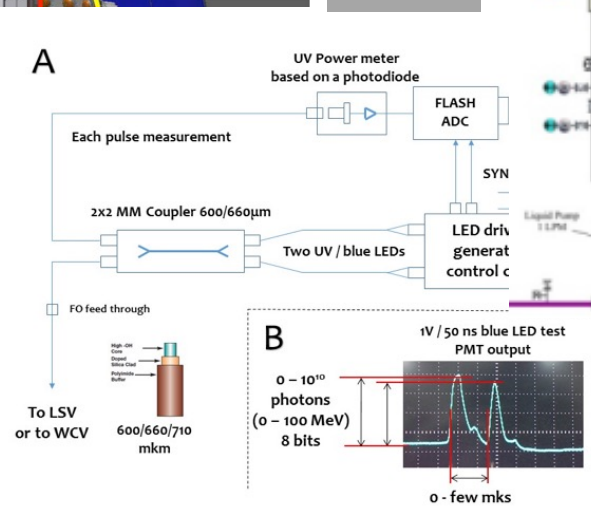


Calibrations

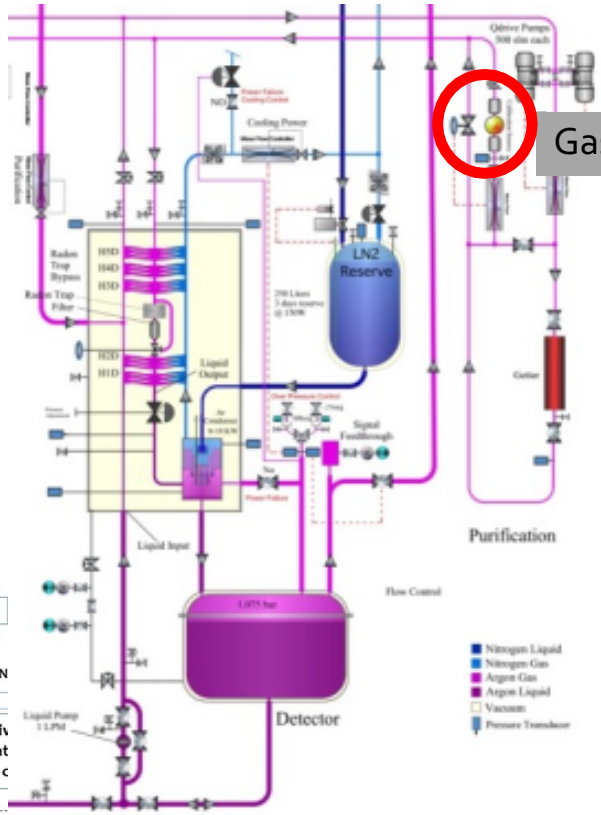
Miniature Sources



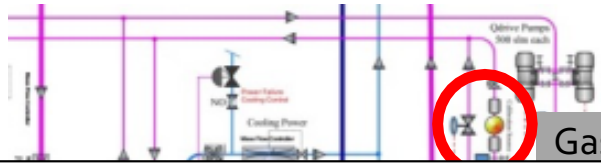
LEDs



Gas Sources



Calibrations

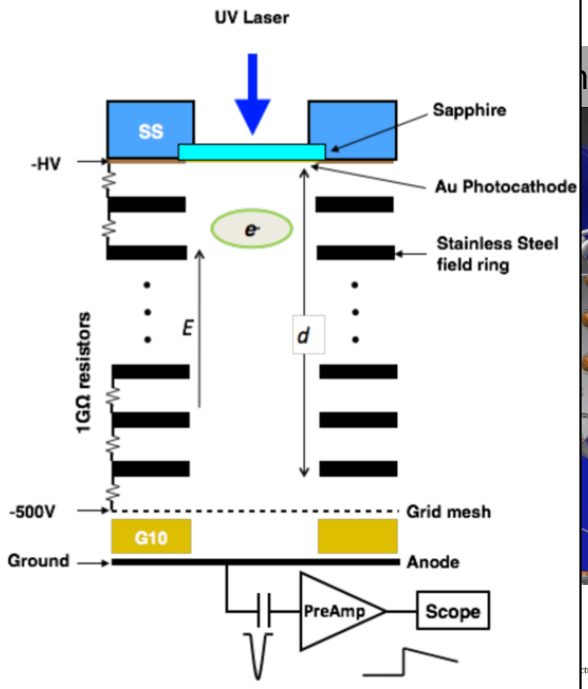


Gas Sources

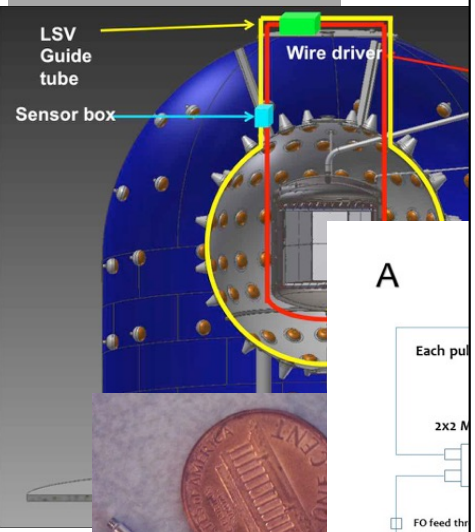
Photoelectric Point Sources

Used in LAr by many other experiments for example:

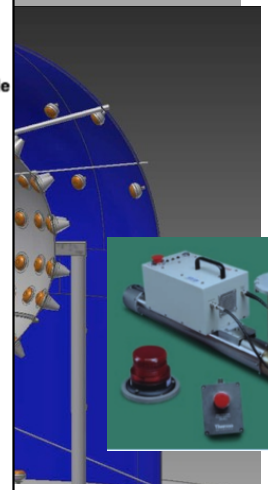
- 266 nm on opaque (Au on Cu) photocathodes: (Benetti et al, NIM A 332, 395 (1993));
- Xe flashlamp on opaque (Au on Al) photocathode: Adamowski et al, (J. Inst.9, P07005 (2014))
- 266 nm back-illuminating semi-transparent (Au on sapphire) photocathodes (Li et al, arXiv:1602.01884)

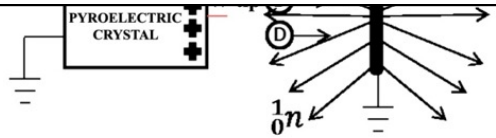


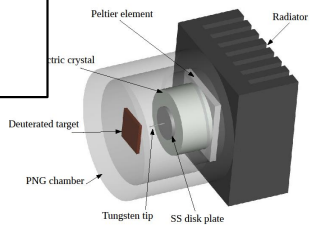
Miniature Sources



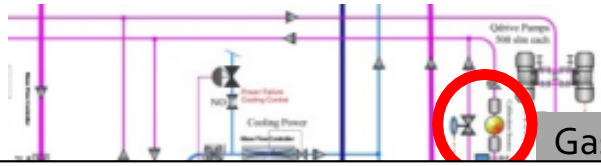
n Generators







Calibrations



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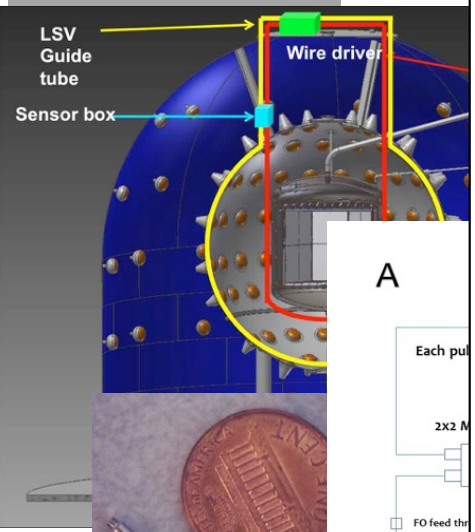

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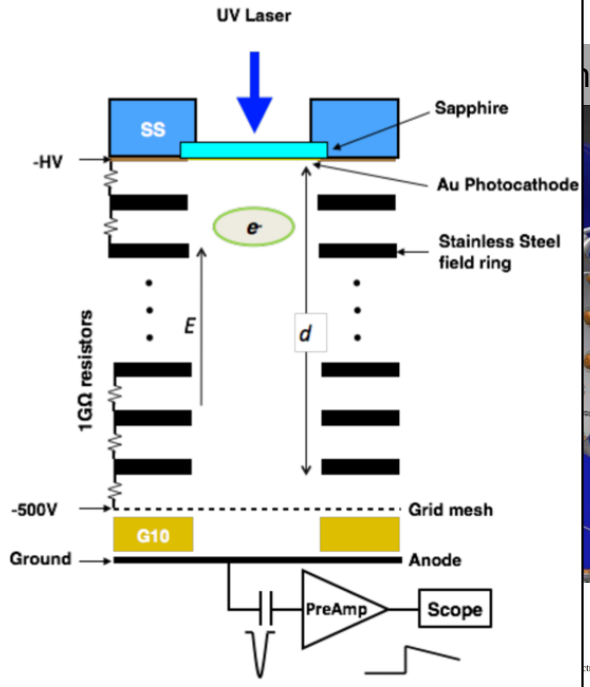
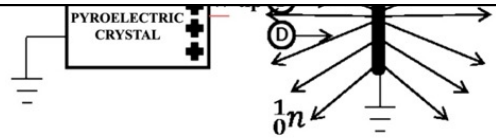
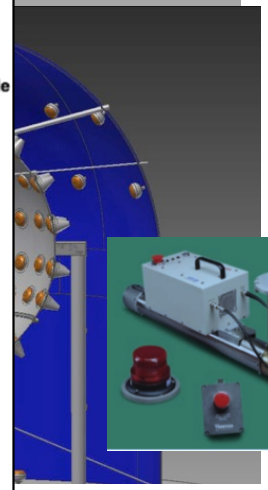
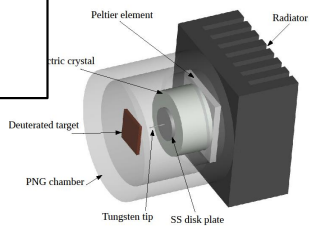


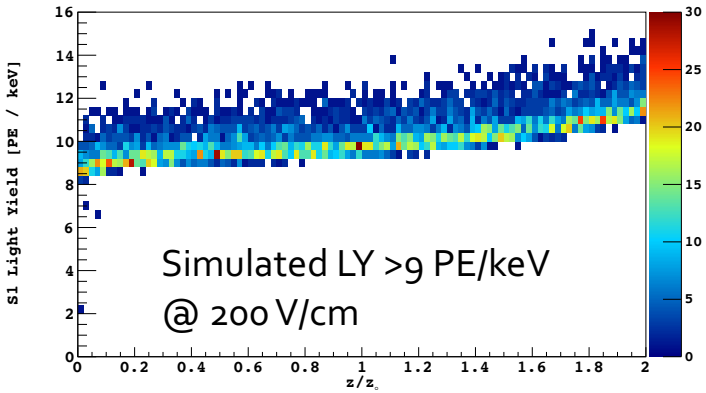


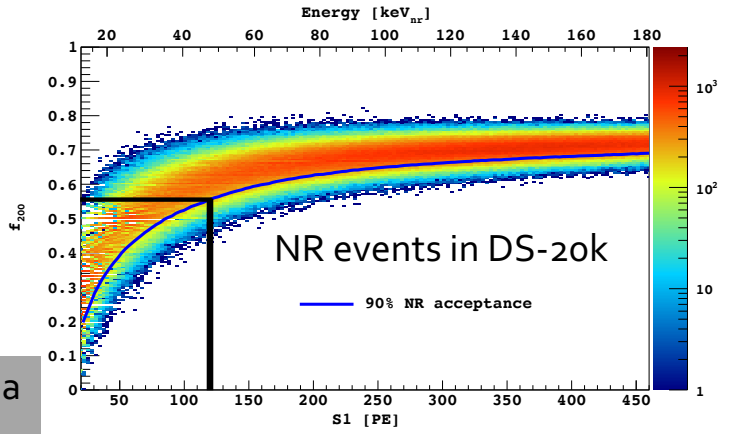
Generators



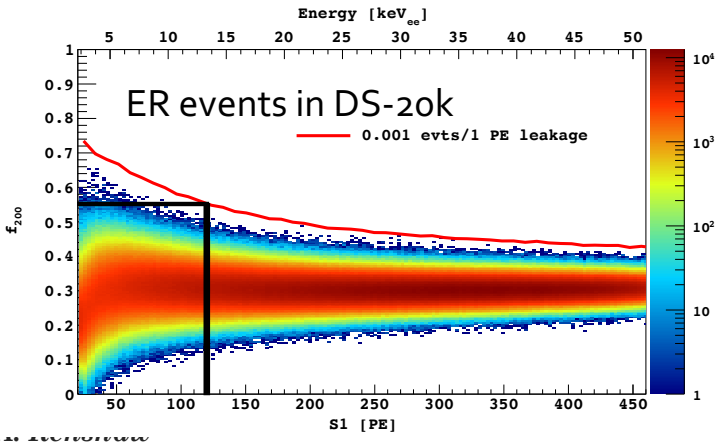


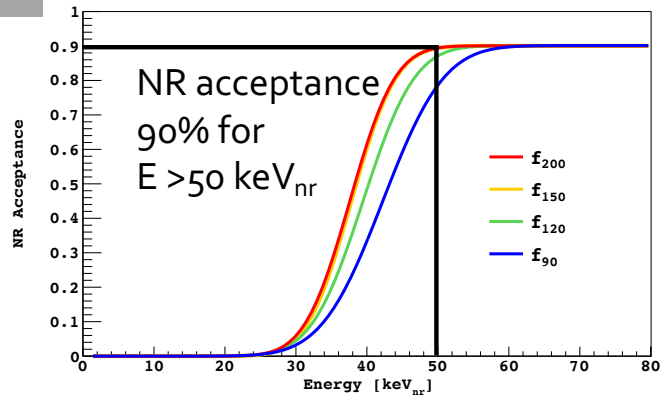
DarkSide-20k Expected Performance



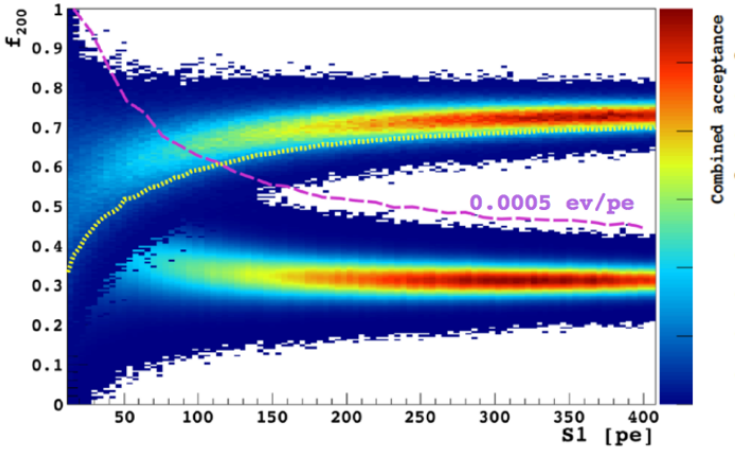


Plots produced via g4ds simulation package



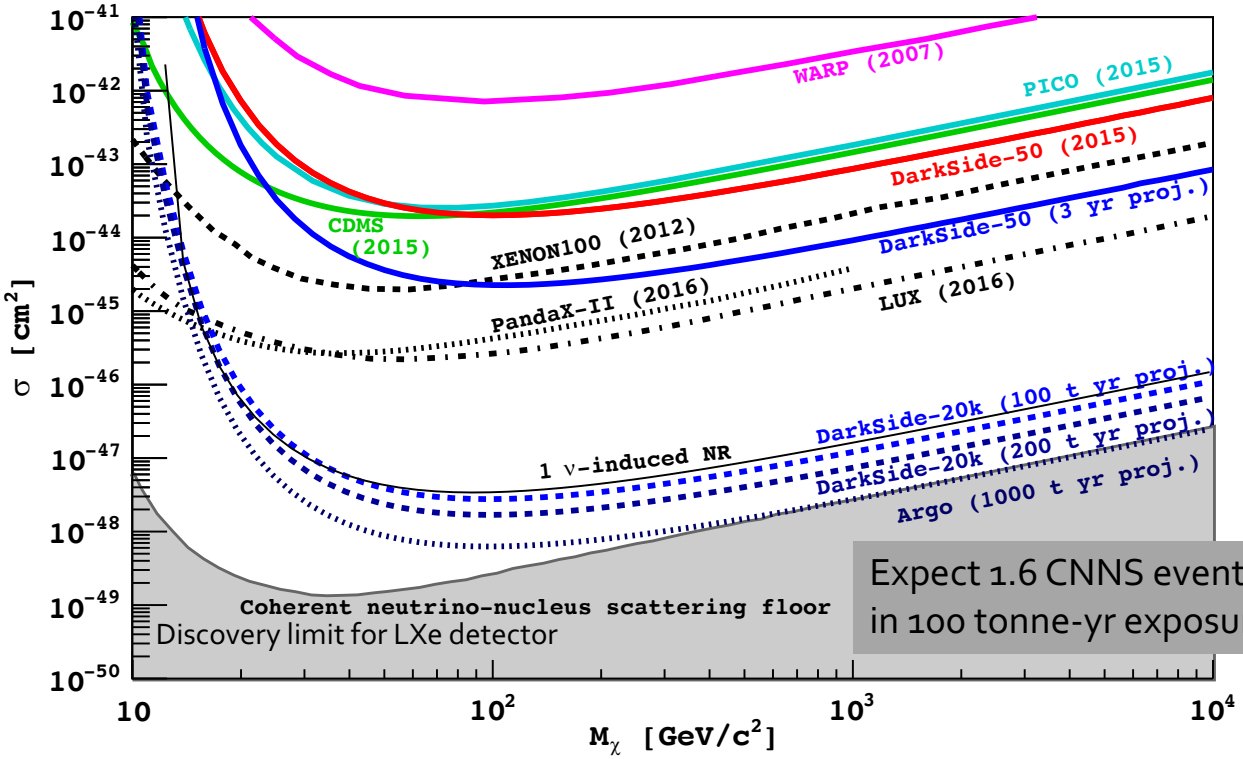


Dark Matter Sensitivity



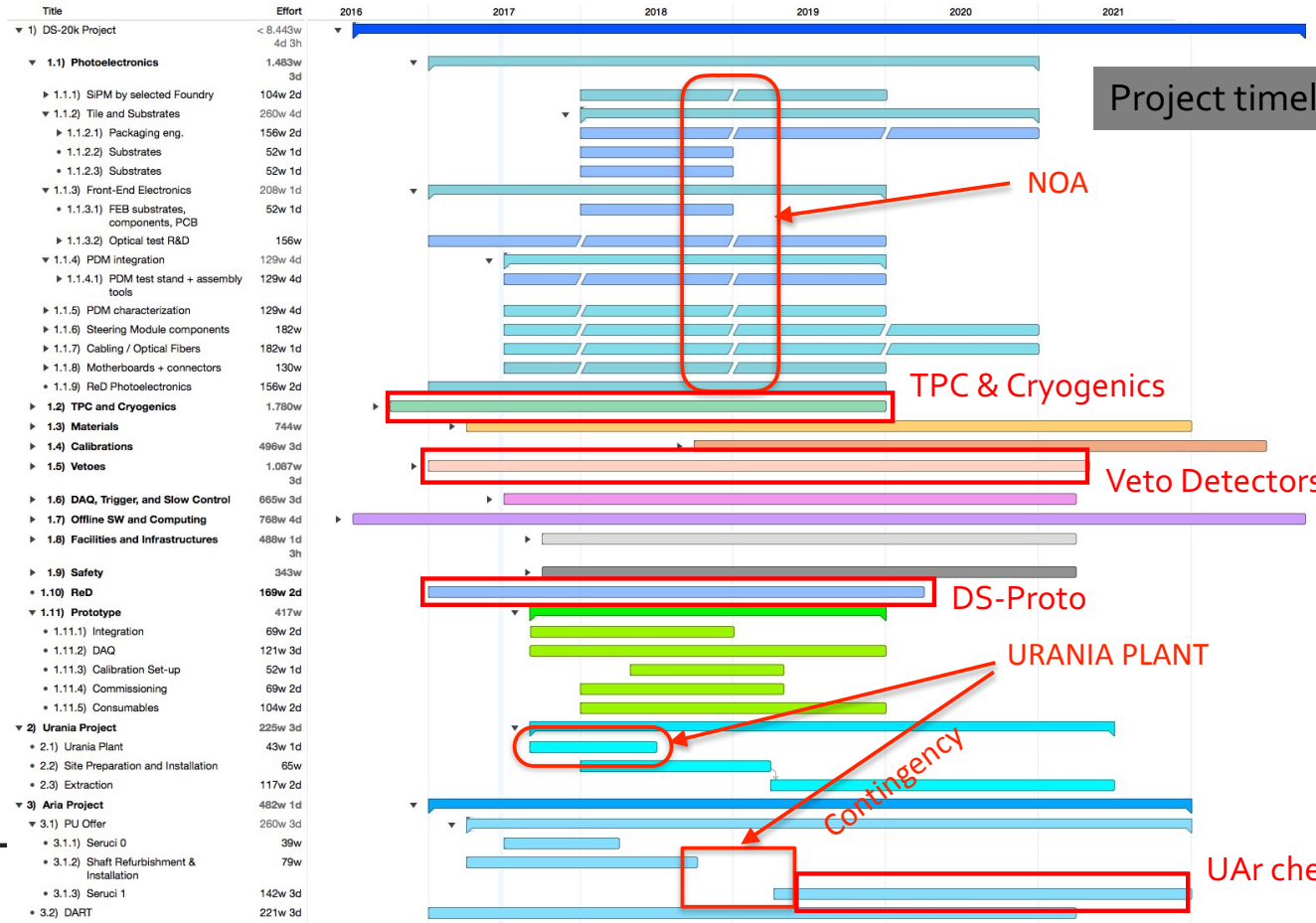
Simulate millions of ER&NR events to determine acceptance of each

Optimize PSD parameter for best sensitivity



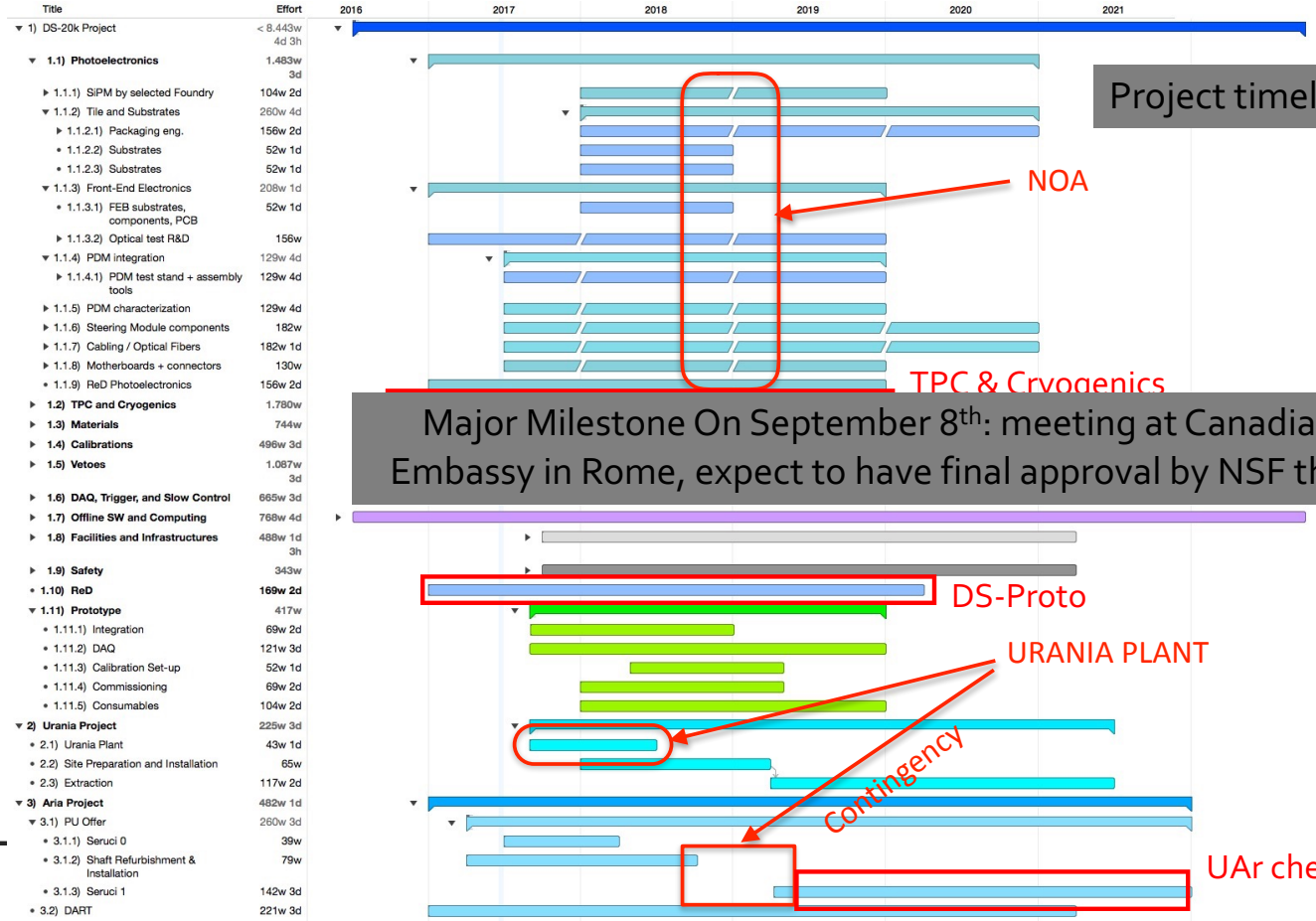
Expect 1.6 CNNS events in 100 tonne-yr exposure

Project Timeline



Project timeline has start of data taking in 2021

Project Timeline



Project timeline has start of data taking in 2021

Major Milestone On September 8th: meeting at Canadian Embassy in Rome, expect to have final approval by NSF then

DarkSide Collaboration

Thank You!