darkside
two-phase argon TPC for Dark Matter Direct Detection

The DarkSide Program

XVI LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS
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SLAC National Accelerator Center – CA, USA

Temple University – PA, USA

University of Arkansas – AR, USA

University of California – Los Angeles, CA, USA

University of Chicago - IL, USA

University of Hawaii – HI, USA

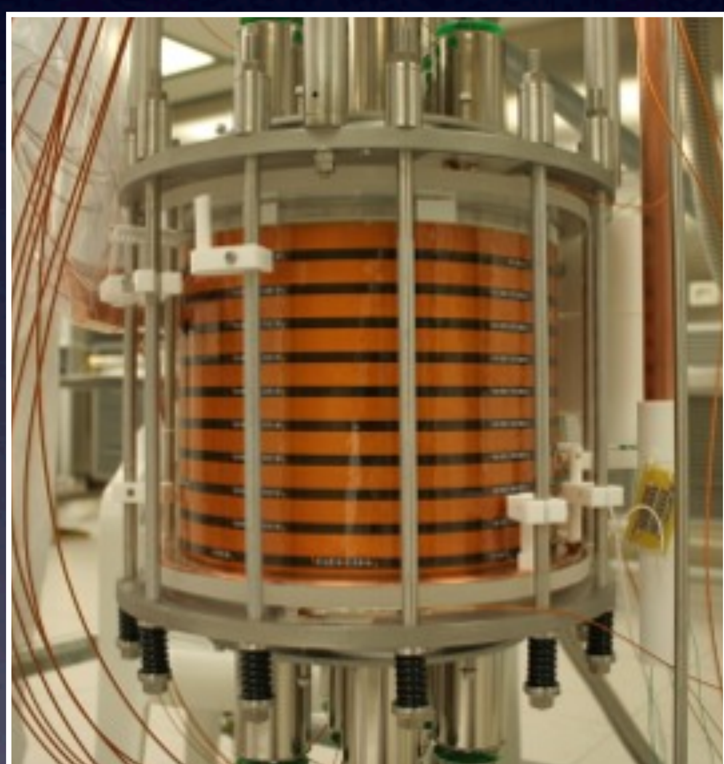
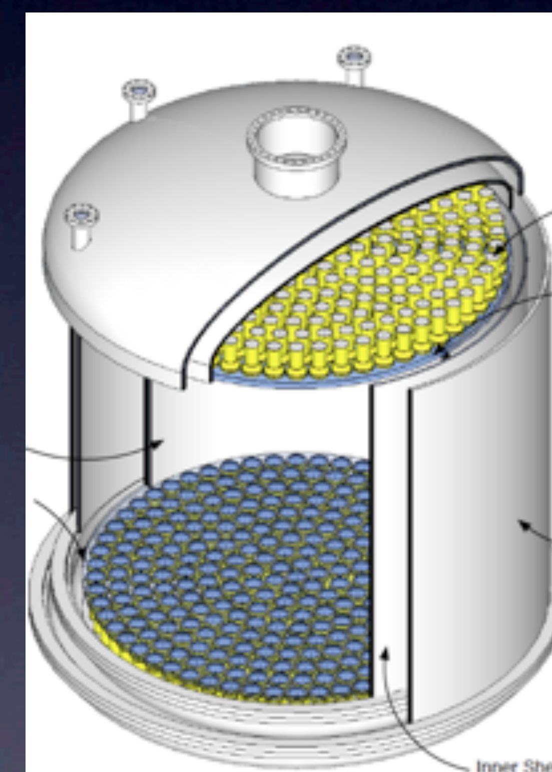
University of Houston – TX, USA

University of Massachusetts – MA, USA

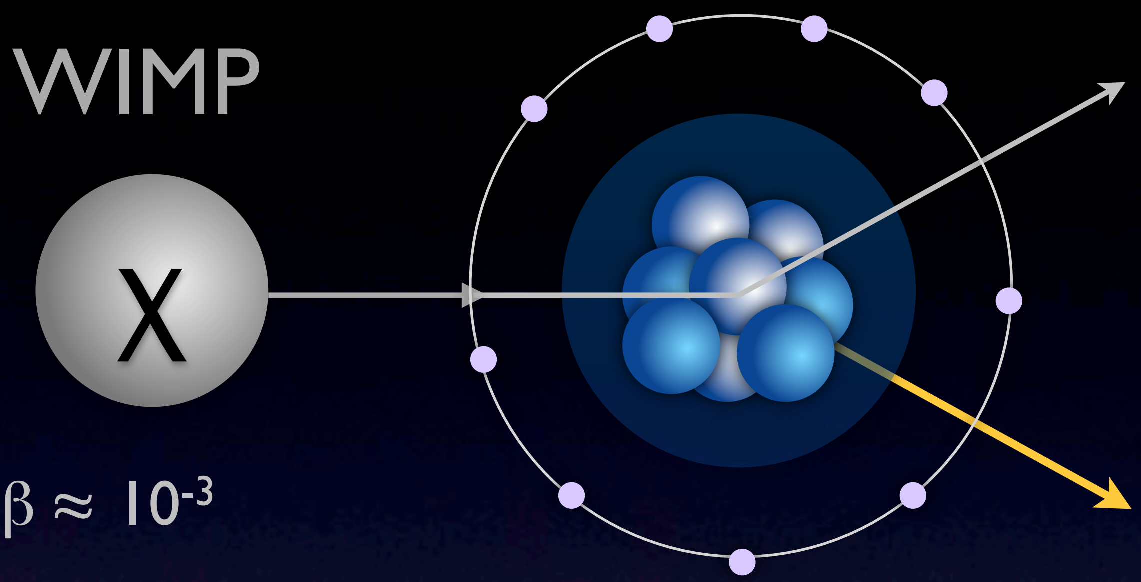
Virginia Tech – VA, USA

The DarkSide program at LNGS

A scalable technology for direct WIMP search:
2-phase low background argon TPC

DarkSide-10	DarkSide-50	DarkSide-G2
		
technical prototype no DM goal	sensitivity 10^{-45} cm^2	sensitivity 10^{-47} cm^2

WIMP direct detection requirements



$\beta \approx 10^{-3}$

$m_\chi \approx 100$ GeV

$\chi N \rightarrow \chi N$

elastic scattering off nuclei

Low energy nuclear recoils (< 100 keV)

Low rate (~1 event/ton/yr for $\sigma = 10^{-47}$ cm^2)

⇒ Maximize detector sensitivity

⇒ Background avoidance, rejection, measurement

Detector designed for unambiguous discovery

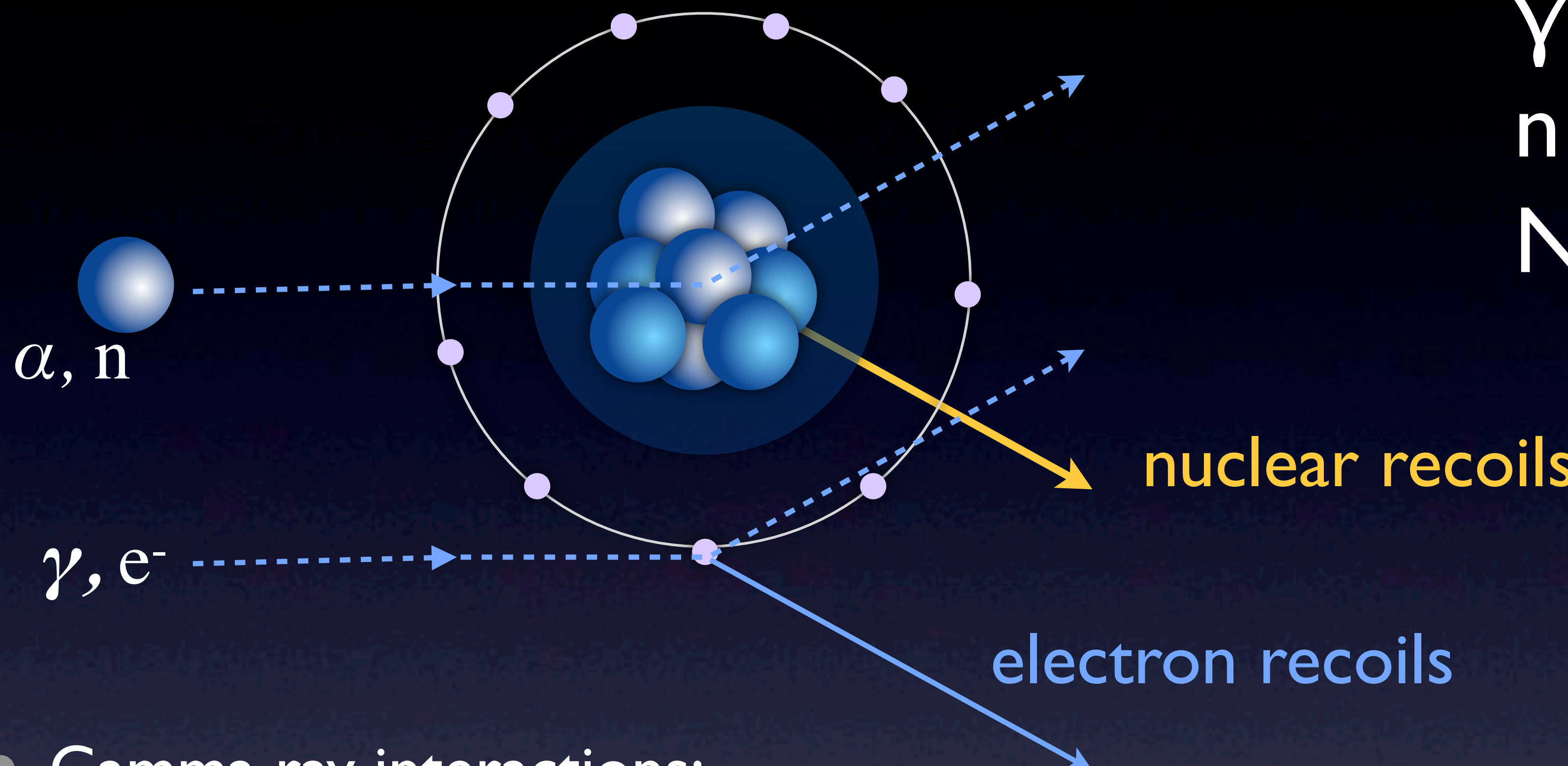
Background

from natural radioactivity:

$\gamma e^- \rightarrow \gamma e^-$

$nN \rightarrow nN$

$N \rightarrow N' + \alpha, e^-$



- Gamma ray interactions:

  mis-identified electrons mimic nuclear recoil signals

- Neutrons:

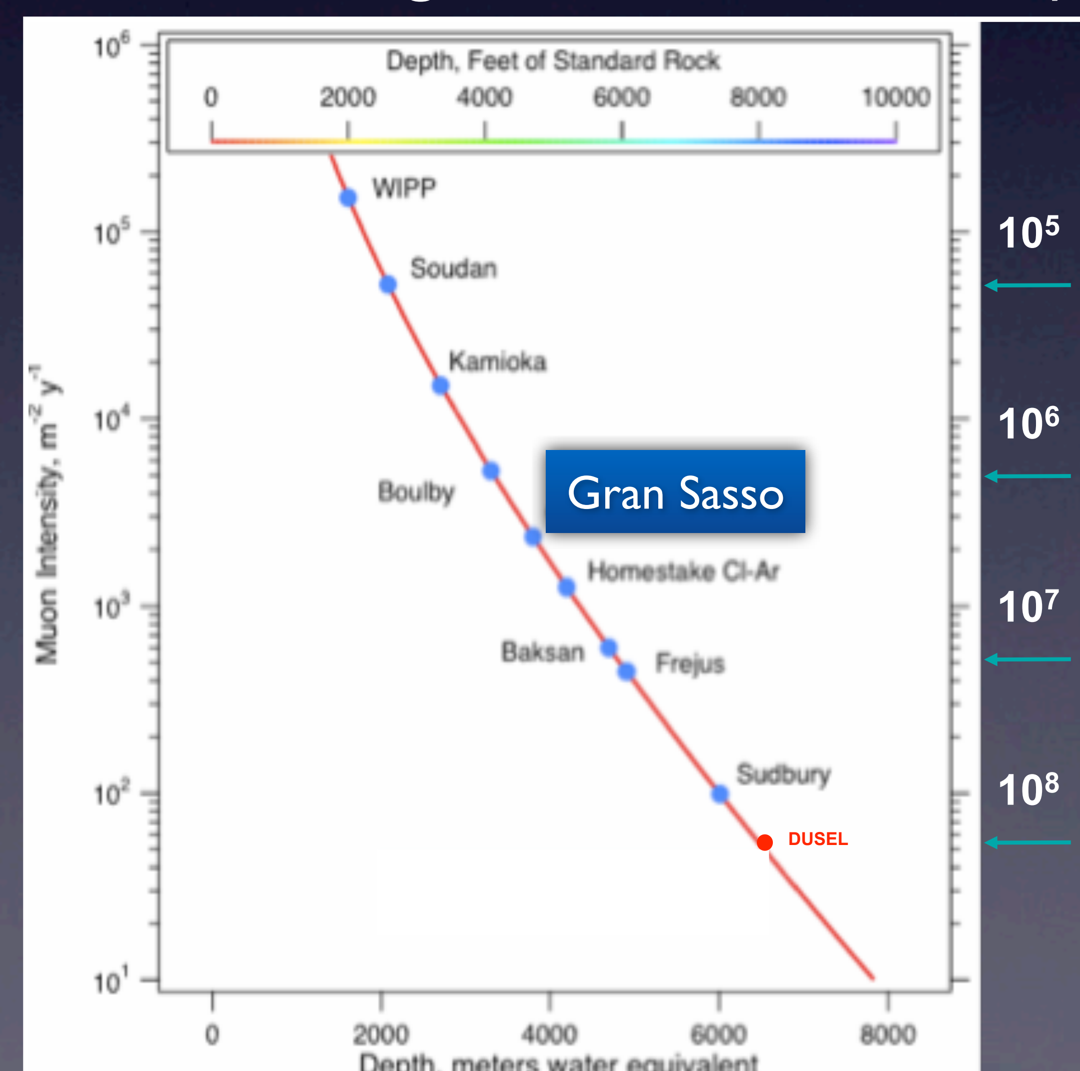
  (α,n), U, Th fission, cosmogenic spallation →

- Contamination:

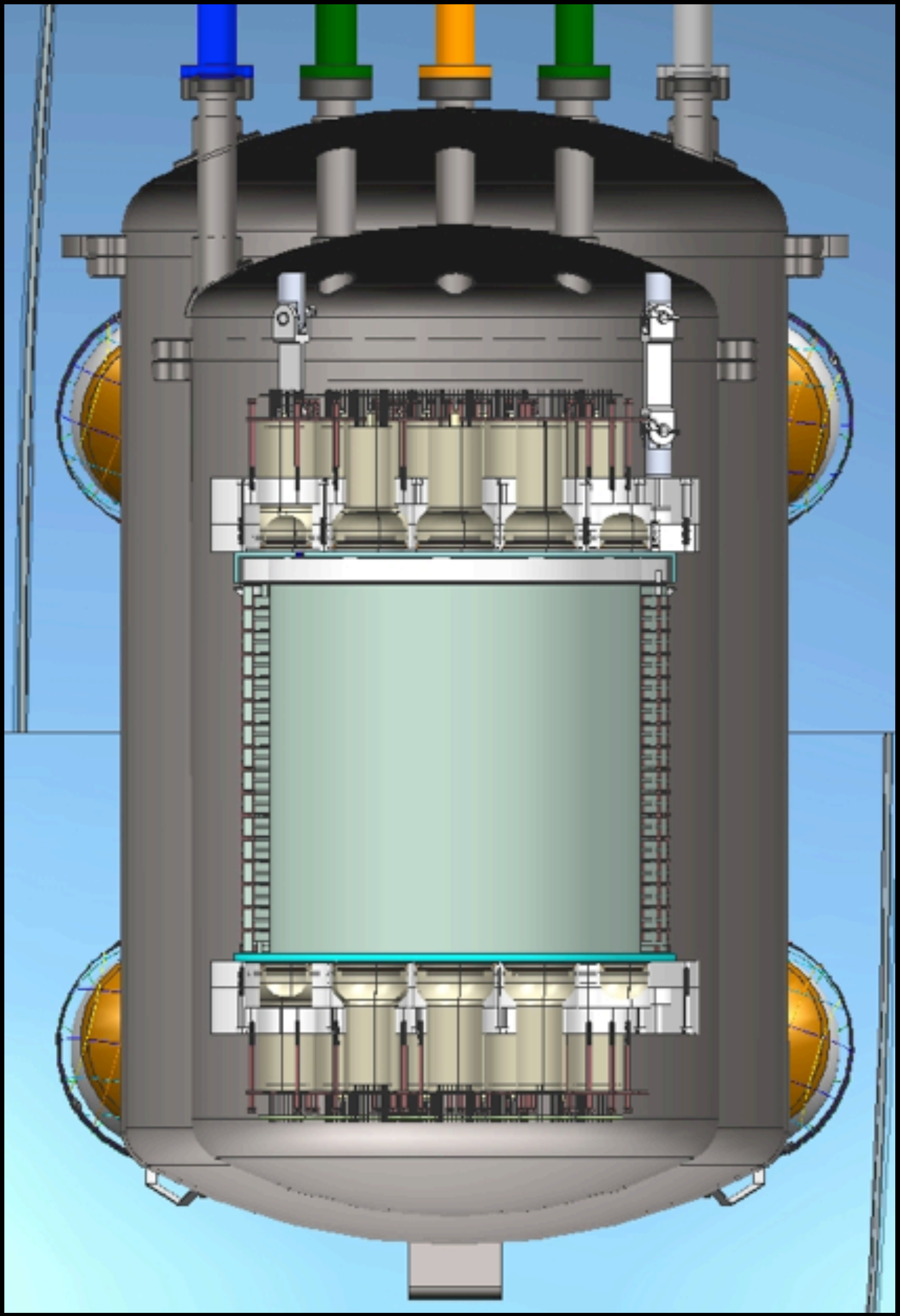
  ^{238}U and ^{232}Th decays, recoiling progeny mimic nuclear recoils

Underground labs

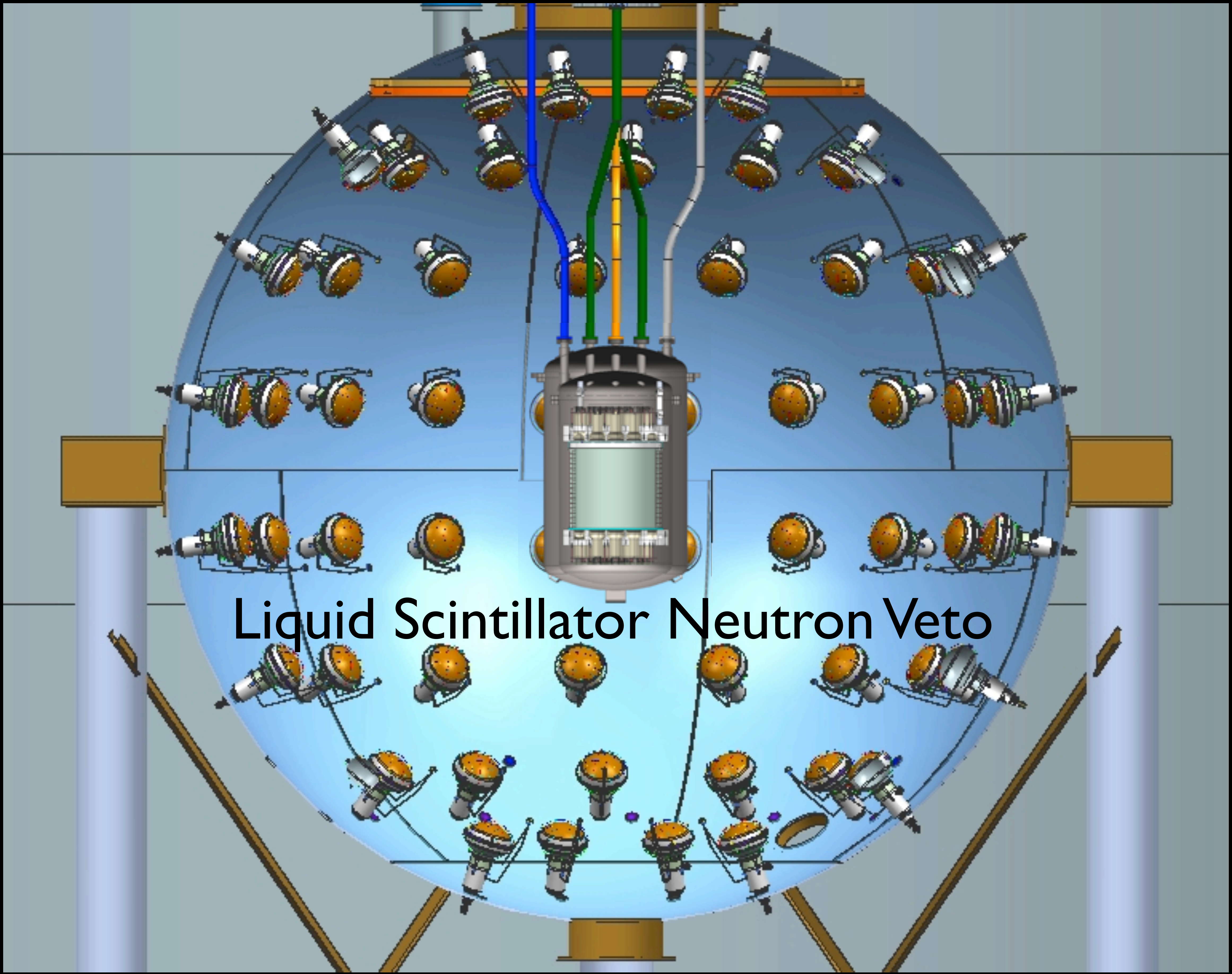
reduction of muon flux by:

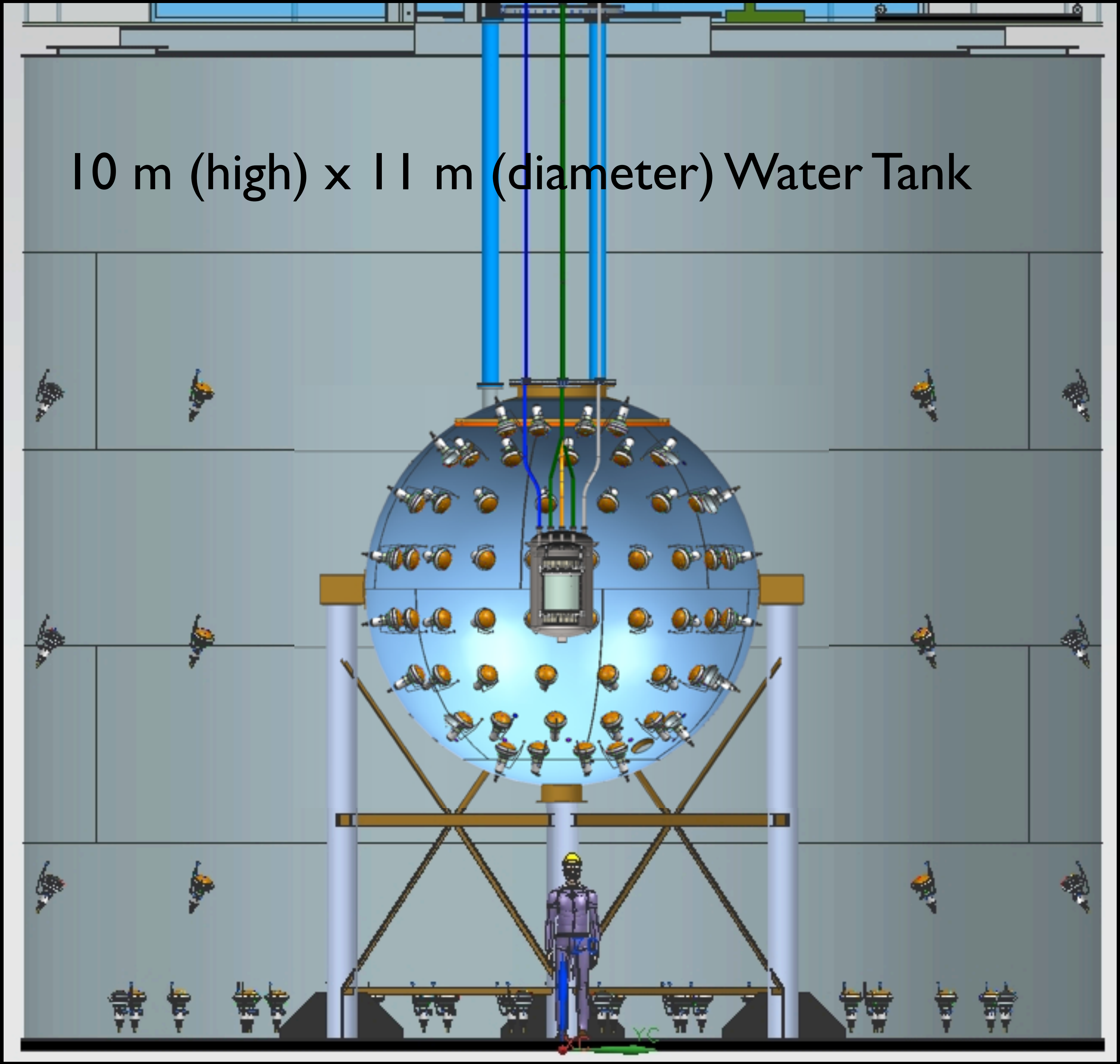


Liquid Argon TPC,
within a neutron veto,
within a muon veto,
under a mountain



Liquid Argon TPC & Cryostat


Liquid Scintillator Neutron Veto


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

Argon as target for DM detection

- Bright scintillator: Light Yield ~ 40 γ/keV and very transparent to its own scintillation light
- Relatively abundant (1% in atmosphere) and easy to purify
- Large mass detectors → scalability + self-shieding
- Possible scaling to multi-ton detectors: need to suppress ^{39}Ar
  - Underground argon (UAr): ^{39}Ar depletion factor >150
- Very powerful rejection capability for electron recoil background

^{39}Ar beta decays with 565 keV endpoint, with half-life 269 years

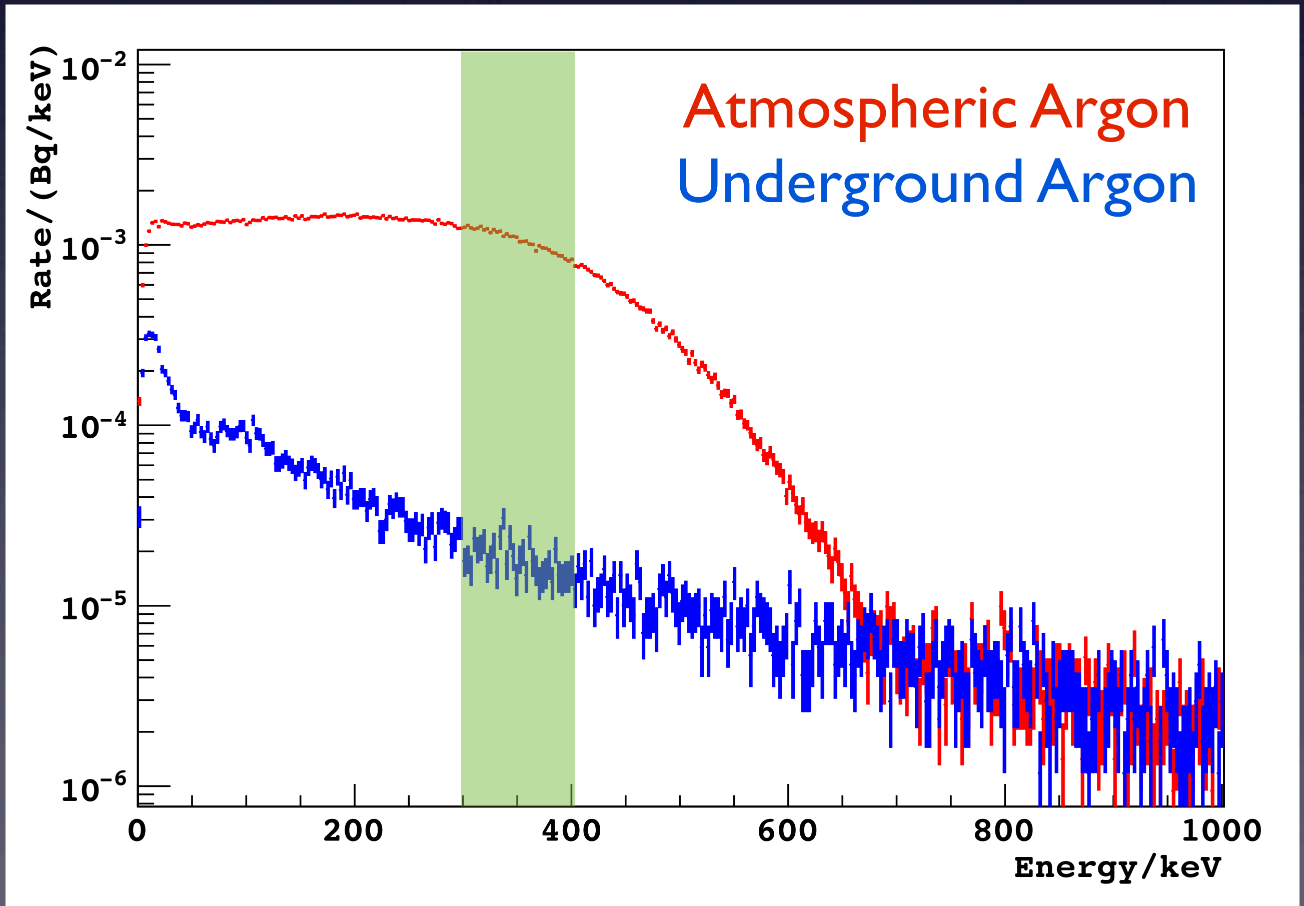
^{39}Ar production supported by cosmogenic activation via ^{40}Ar(n,2n)^{39}Ar

^{39}Ar activity in atmospheric argon ~1 Bq/kg

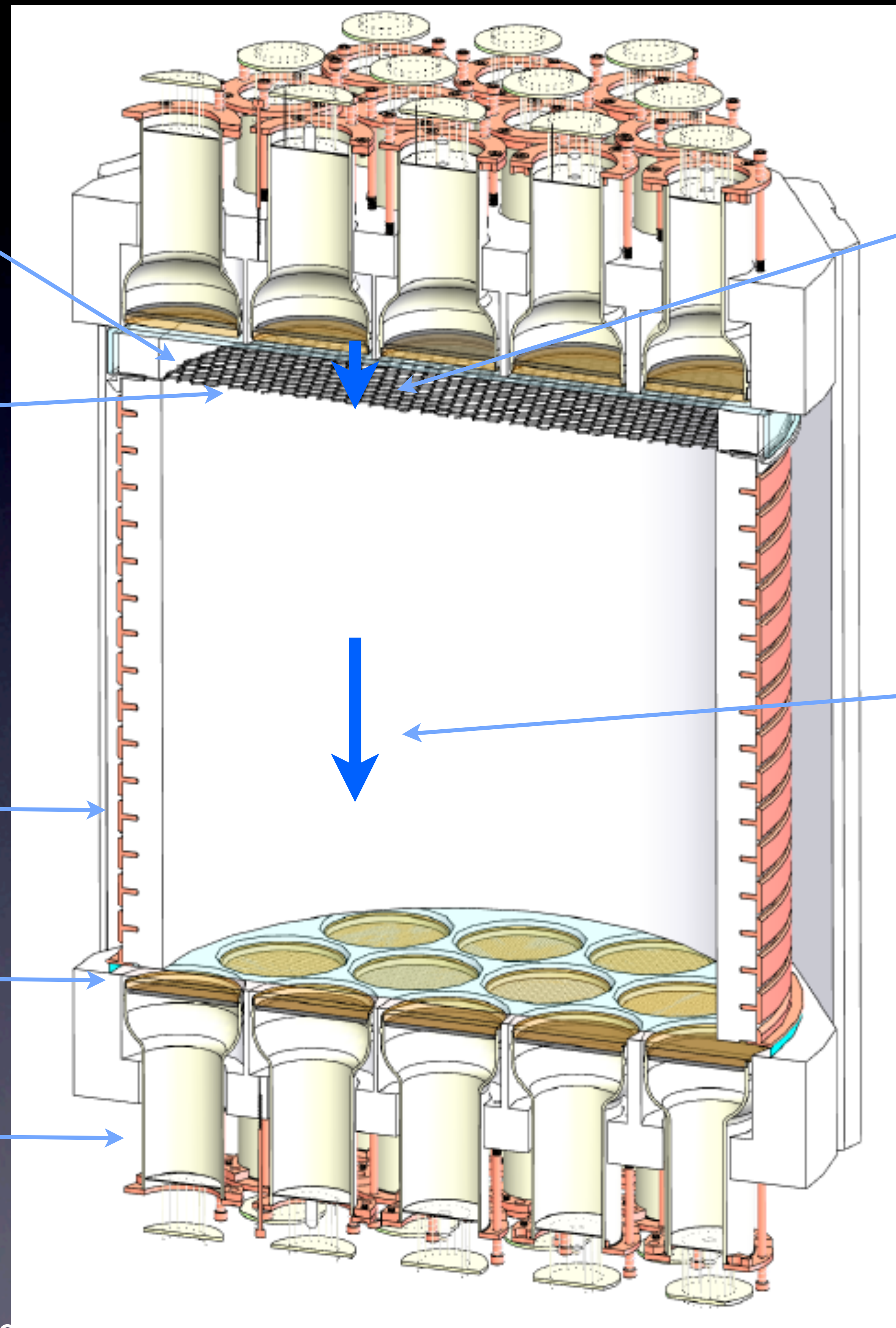
UAr ^{39}Ar activity <6.5 mBq/kg

150 of 150 kg collected

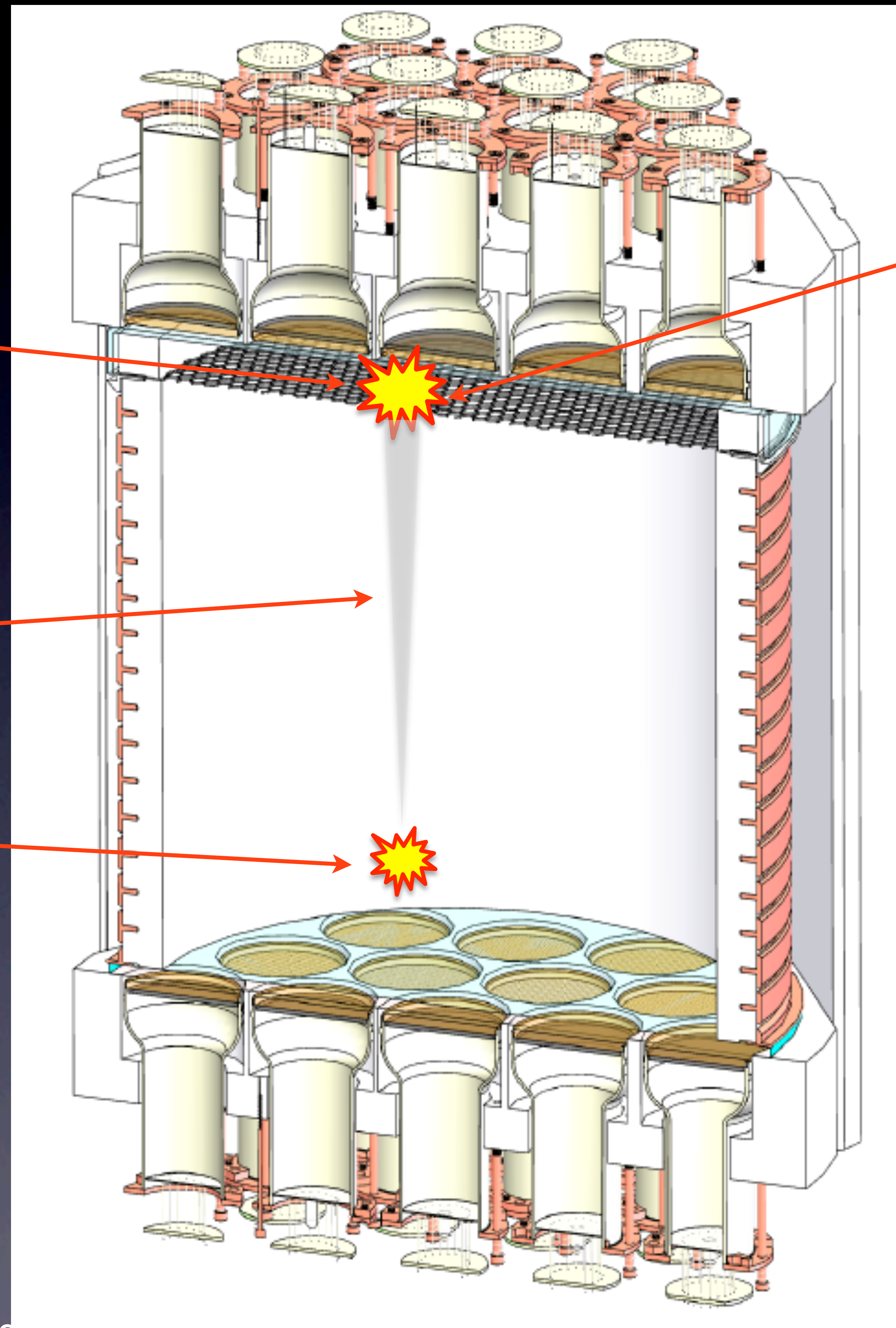
J.Xu et al. arXiv:1204.6011



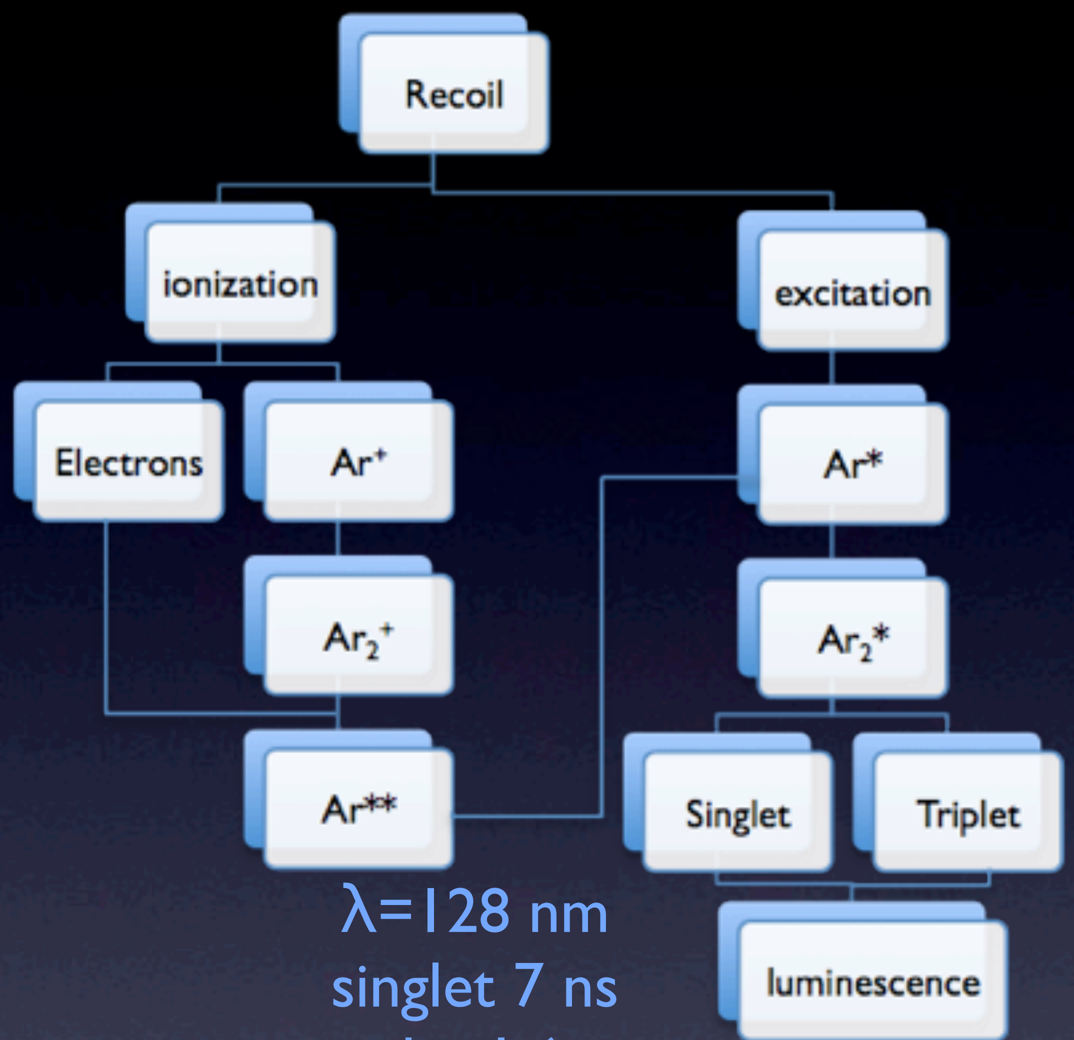
Two Phase Argon TPC



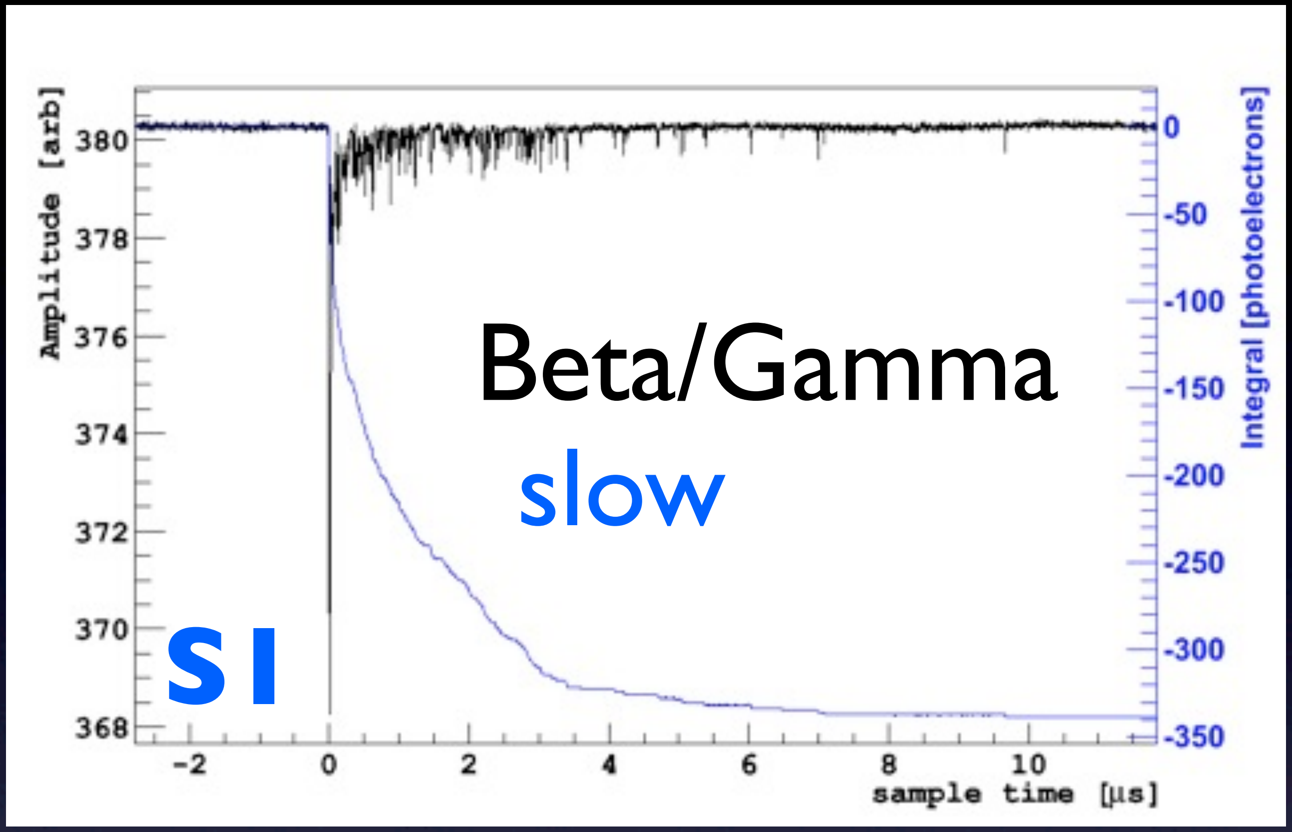
Two Phase Argon TPC

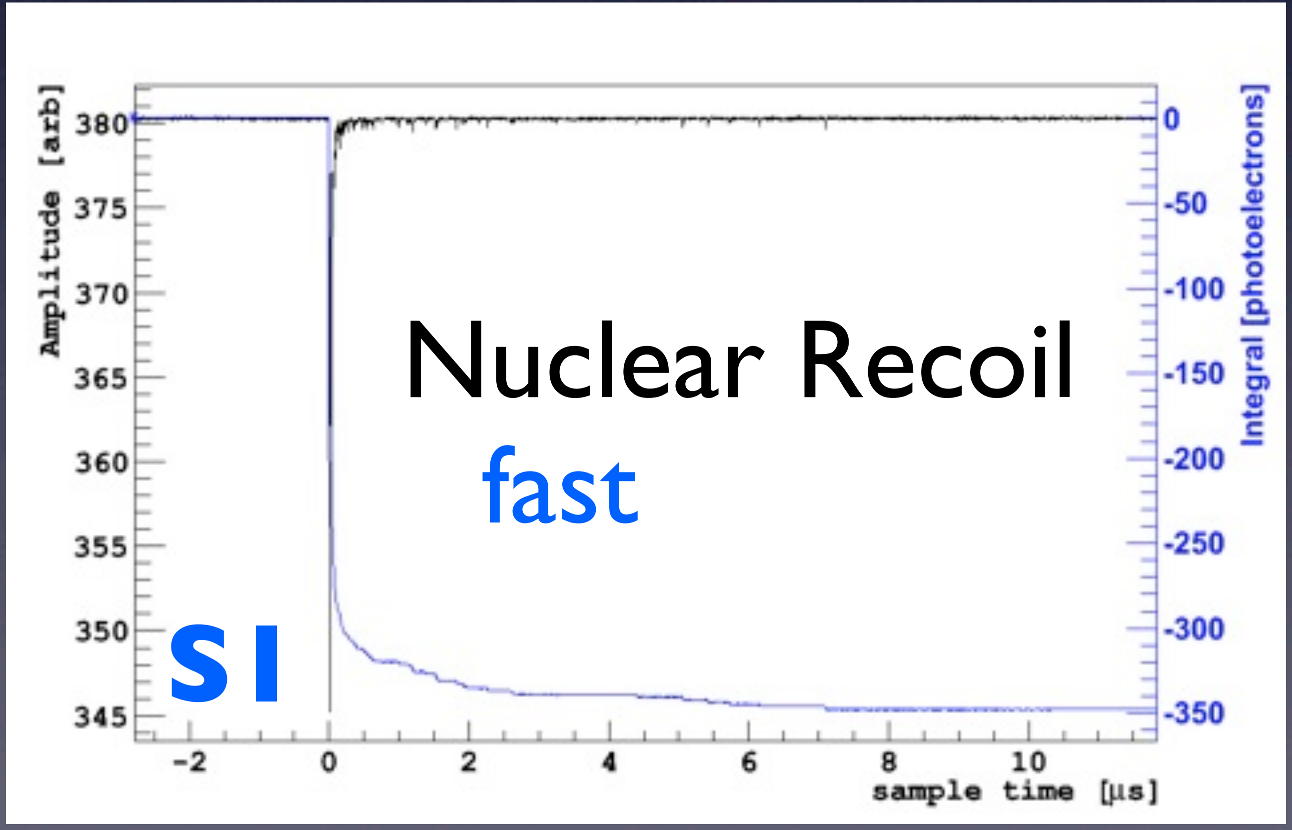


Background Discrimination: S1 Pulse Shape



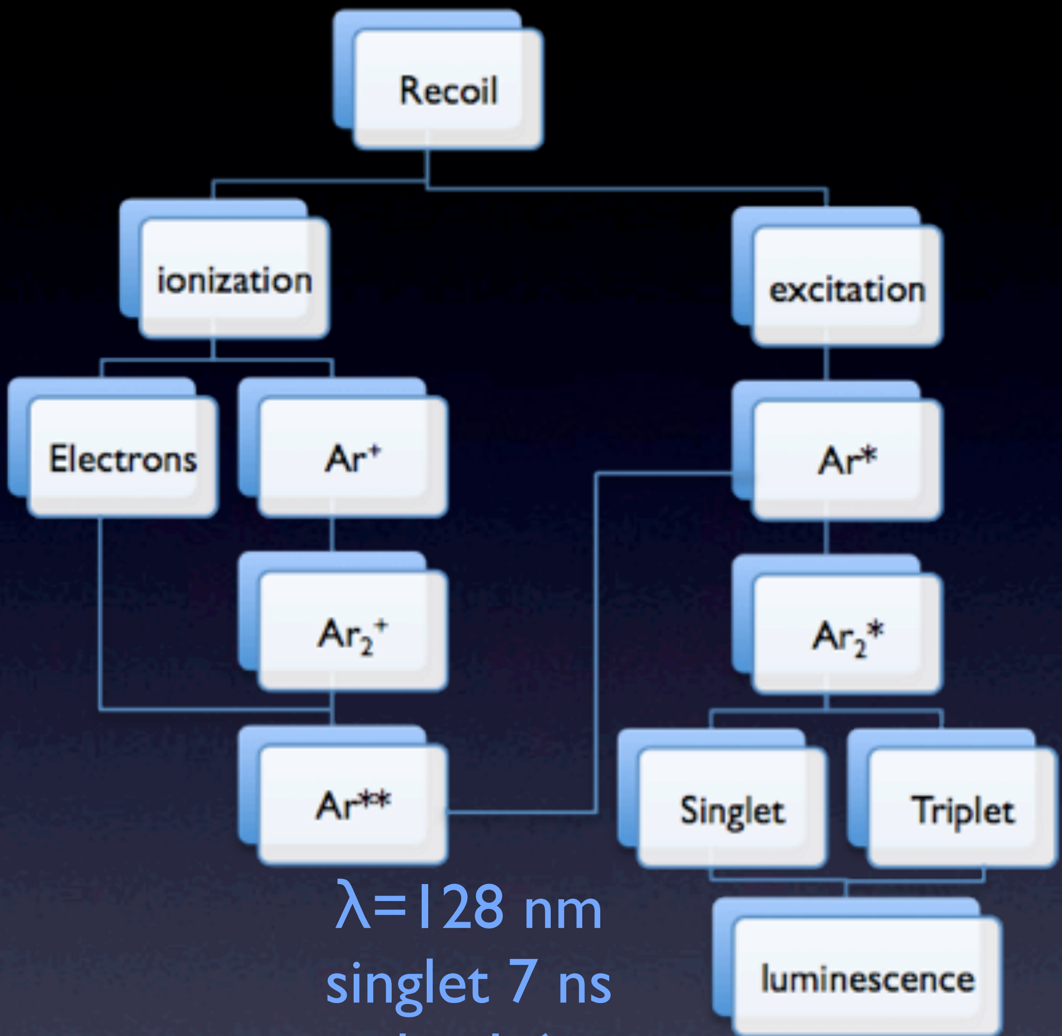
λ=128 nm
singlet 7 ns
triplet 1.6 μs





The ratio of light from singlet (~7 ns decay time) and triplet (1.6 μs decay time) depends on ionization density

Background Discrimination: S1 Pulse Shape



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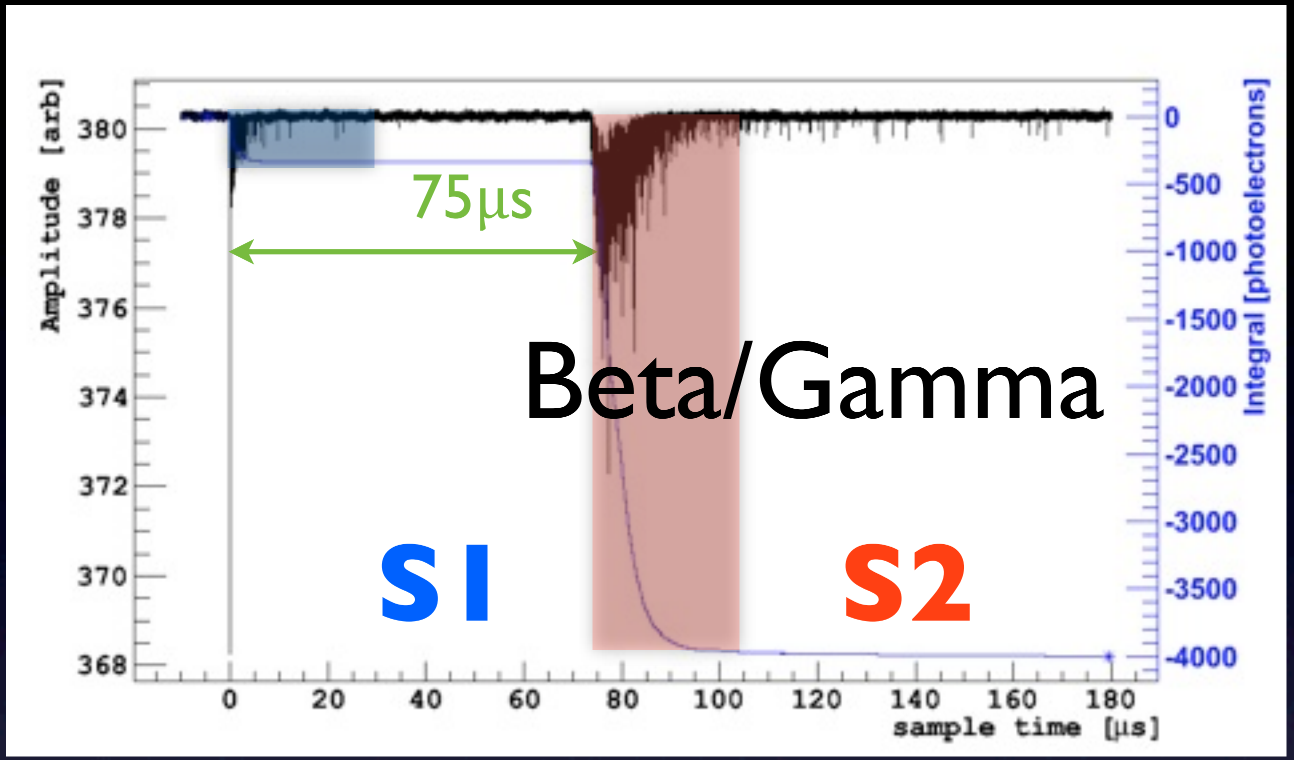
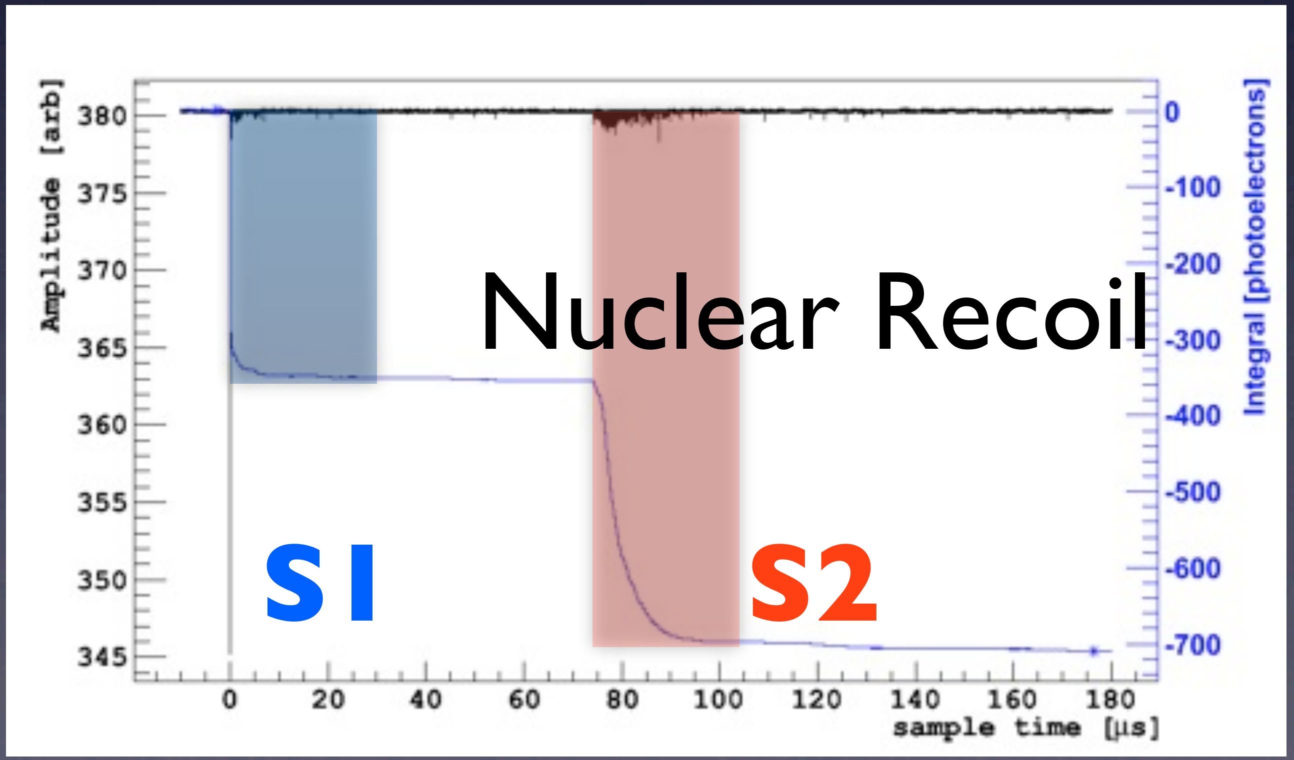




The recombination probability (and hence the ratio of S2:S1 light) also depends on ionization density

LAr TPC Background Discrimination

Shape of scintillation signal S1 (PSD)

Electronic and nuclear recoil events have different singlet to triplet ratio

➡ Rejection factor ≥10^8 for > 60 photoelectrons

WARP Astr. Phys 28, 495 (2008)

Ratio between Ionization and Scintillation (S2/S1)

Electronic and nuclear recoil events have different energy sharing

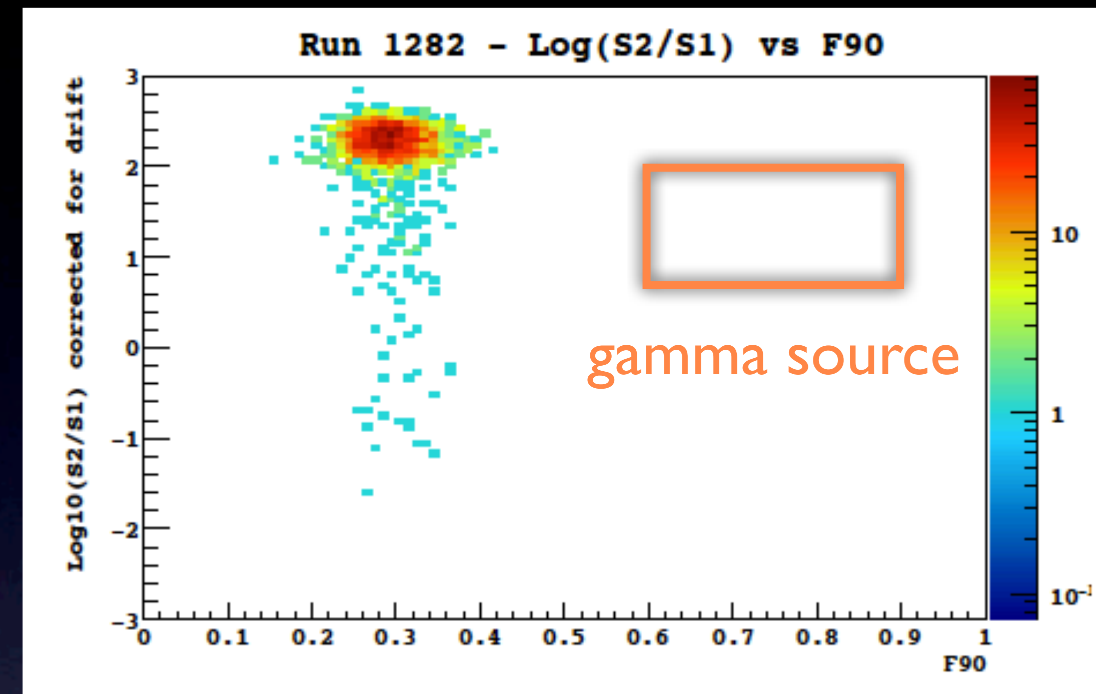
➡ Rejection factor ≥ 10^2-10^3

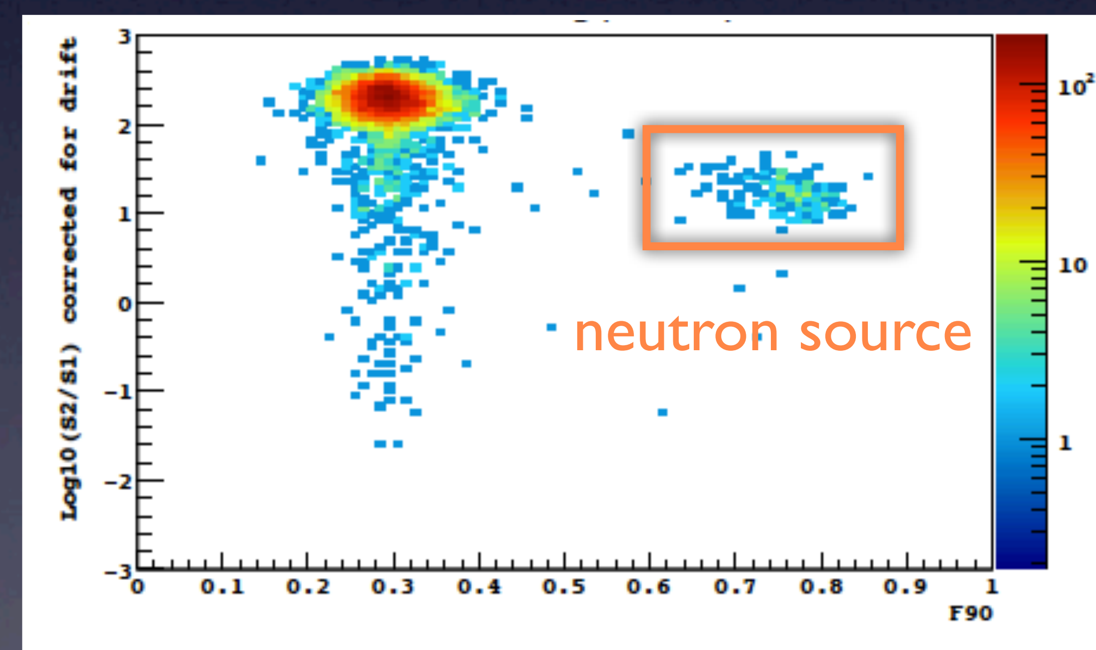
Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006

3D localization of the event

Allows for identification of surface bkgs (fiducialization)

0.7kV/cm drift, 2.7kV/cm extraction





➡ expect >10^{10} total electron/gamma background rejection

DarkSide-10 TPC

- Two phase Argon TPC prototype used to test new technological solutions for the DS program
- 10 kg active mass of Atm LAr + passive water veto
- 7 (top) + 7 (bottom) R11065 HQE Hamamatsu 3” PMTs
- ϕ 20 cm × 20 cm drift
- 2 cm gas gap

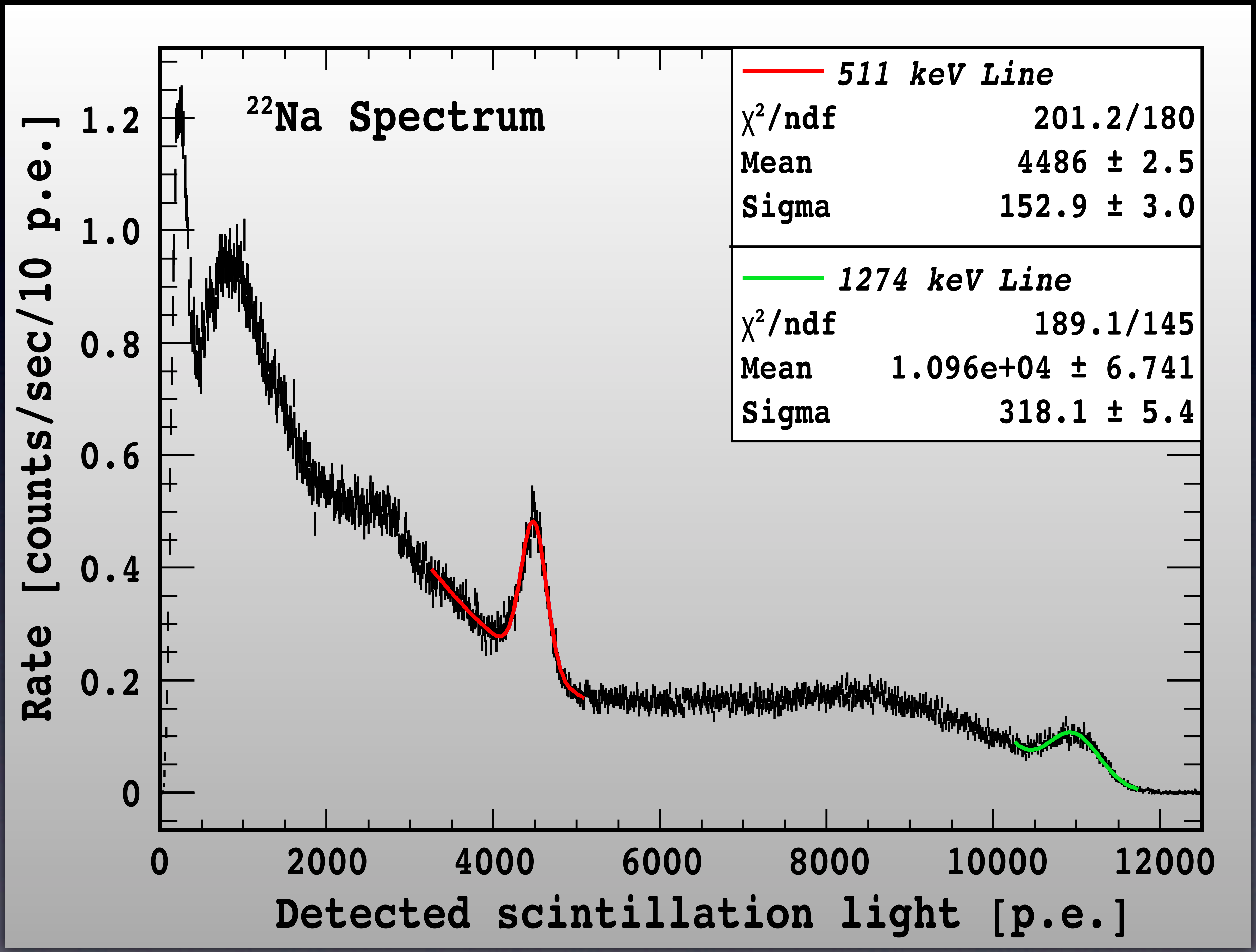
Not physics capable (a fraction of a neutron per day due to cryostat, feedthroughs, and shield)

✓ Demonstrate high LY

✓ Stable HHV system at 36kV

✓ Study discrimination, purity, electric field settings, levelling

DS-10 @ LNGS: Light Yield in single phase mode



T.Alexander et al. arXiv 1204.6218

LY=8.78 ± 0.01 p.e./keVee @ null field, gas pocket present

DarkSide-50 TPC

- 50 kg active mass of UAr
- 19 (top) + 19 (bottom) R11065 HQE Hamamatsu 3” PMTs
- ϕ 36 cm × 36 cm drift
- Lateral walls made of high reflectivity polycrystalline PTFE
- All inner surfaces coated with TPB
- Fused silica diving bell (top) and window (bottom) in front of the PMT arrays coated with ITO.

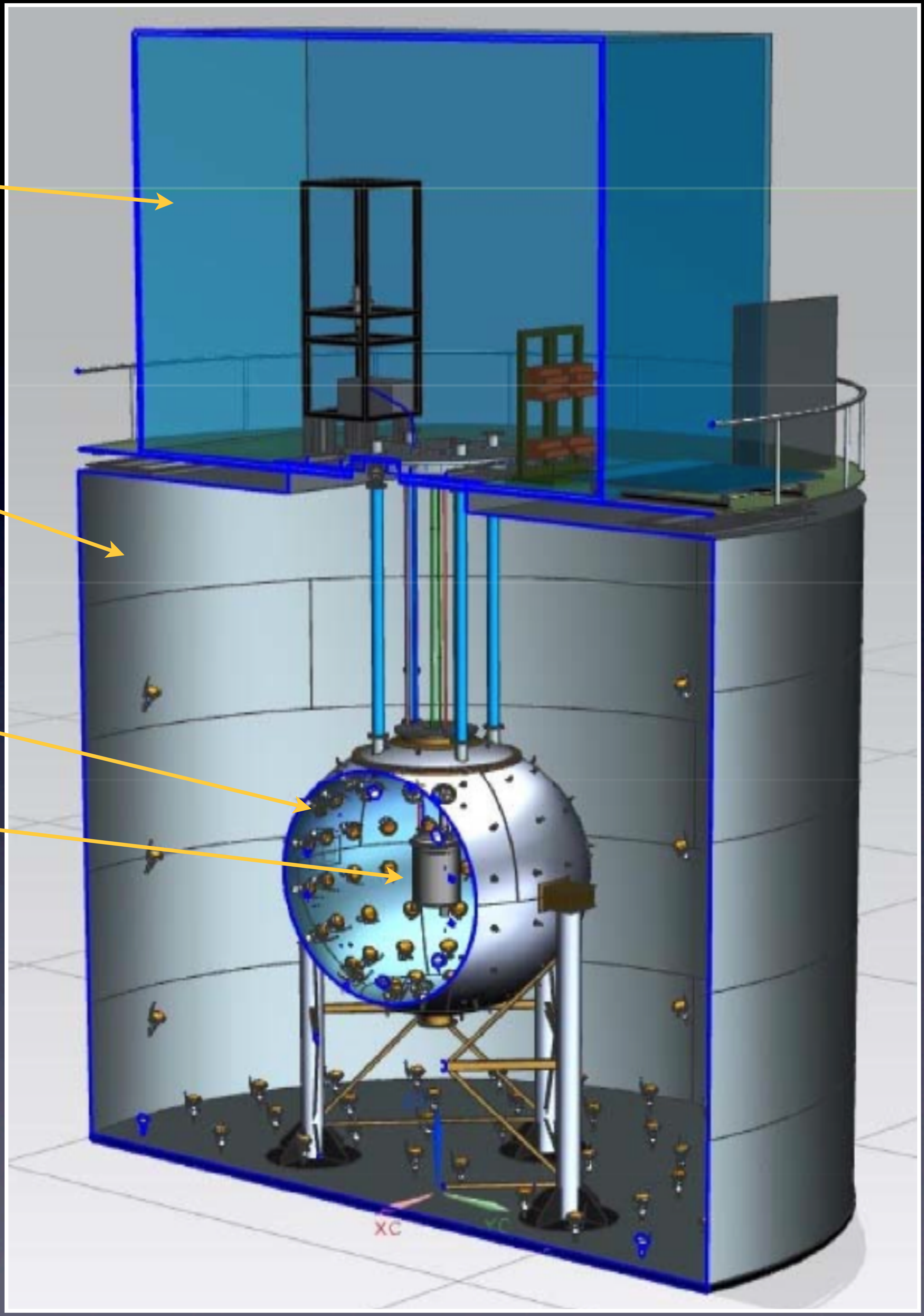
Designed to provide an extremely high light yield, decreasing the detection energy threshold

Radon-free clean assembly room
≤ 30 mBq/m^3 in >100 m^3
(CRH)

μ veto and cosmogenic neutron passive shield
1000 ton water Cherenkov
(Borexino CTF)

Radiogenic neutron veto
30 ton borated liquid scintillator
(LSV)

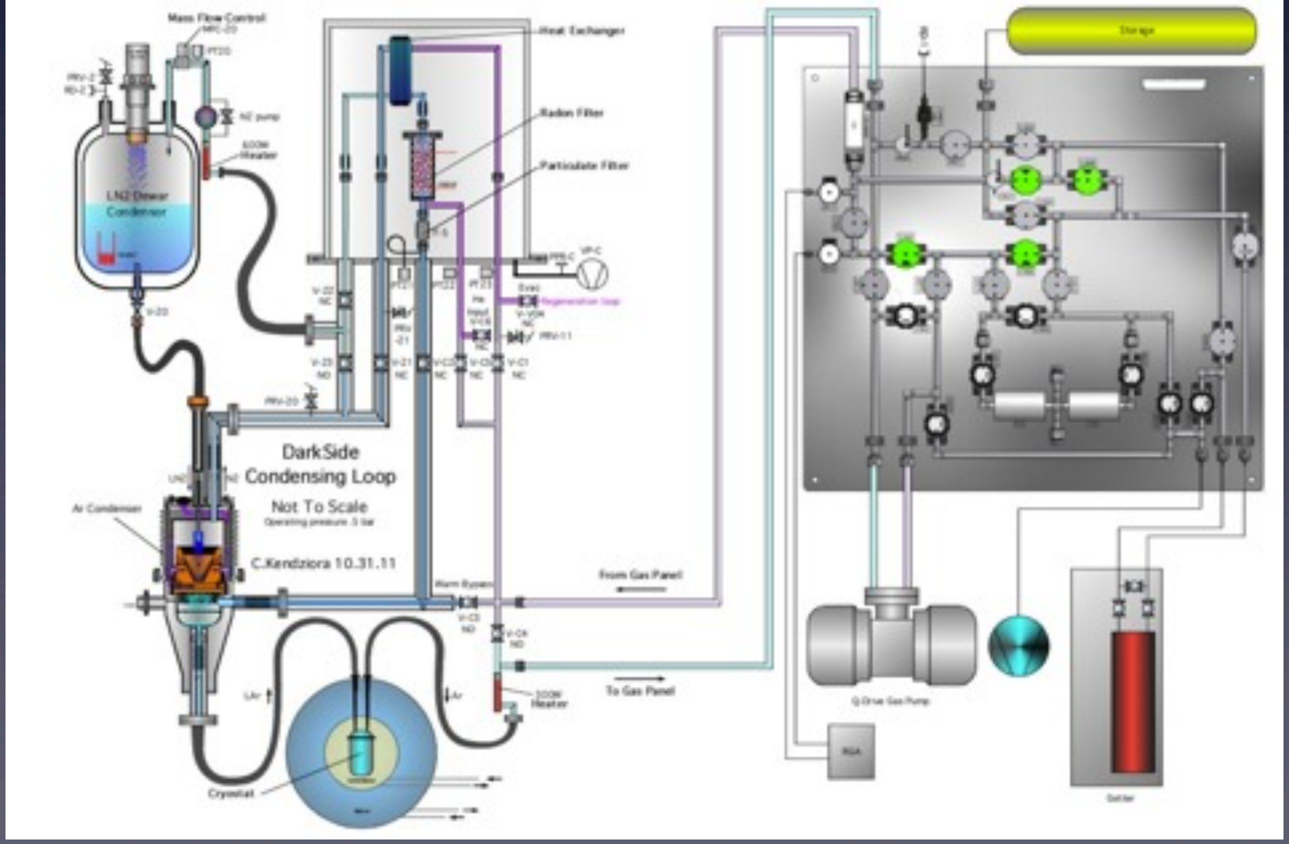
WIMP LAr detector
150 kg of UAr < 6.5mBq/kg
(DS-50 TPC)

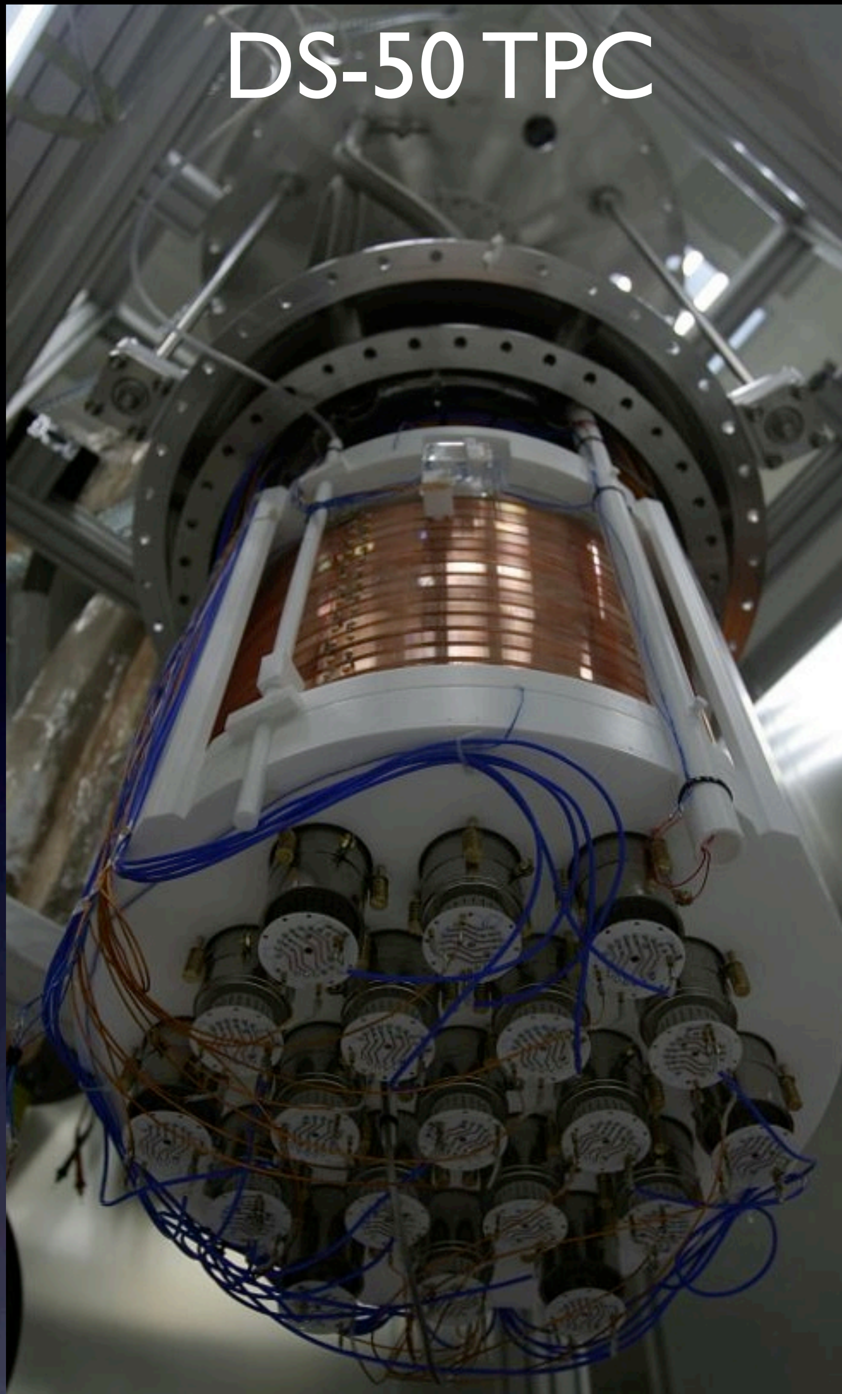


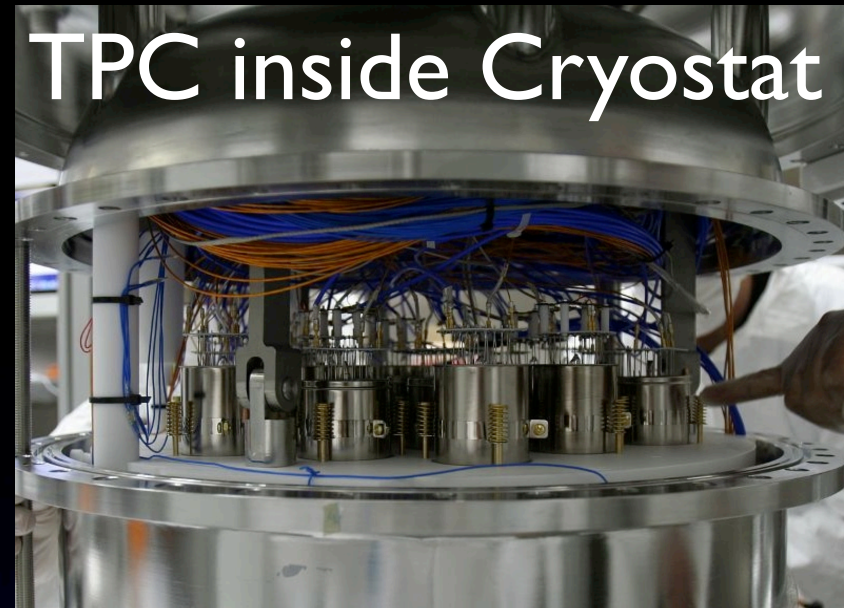
DarkSide design

- Class 10-100 clean room above Water Tank
  - ✓ Obtained Rn <30 mBq/m^3 in >100 m^3

- Ar recirculation and purification system
  - ✓ Cooling power 300 W
  - ✓ max rec. speed ~ 75kg/day







DS50-TPC Assembled, Deployed

TPC hanging in LSV

Water Tank & Liquid Scintillator Vessel with TPC umbilicals

DS-50 first test run

- ✓ Argon cooling, circulation, and purification system operated
- ✓ PMTs operated in liquid argon
- ✓ TPC Trigger and DAQ operated
- ✓ HV system operated at required field
- ✓ Dual phase operation achieved
- ✓ Pre-amps on PMT base (in-liquid) tested
- ✓ Remote levelling exercised

DS-50 second test run

- Replace bad PMTs
- Instrument all PMT bases with in-liquid pre-amps
- Install super-low radioactivity silica windows
- Fix weak points in the HV system
- Fix some heat leaks in the argon transfer lines
- Continuing improvements to theTrigger and DAQ

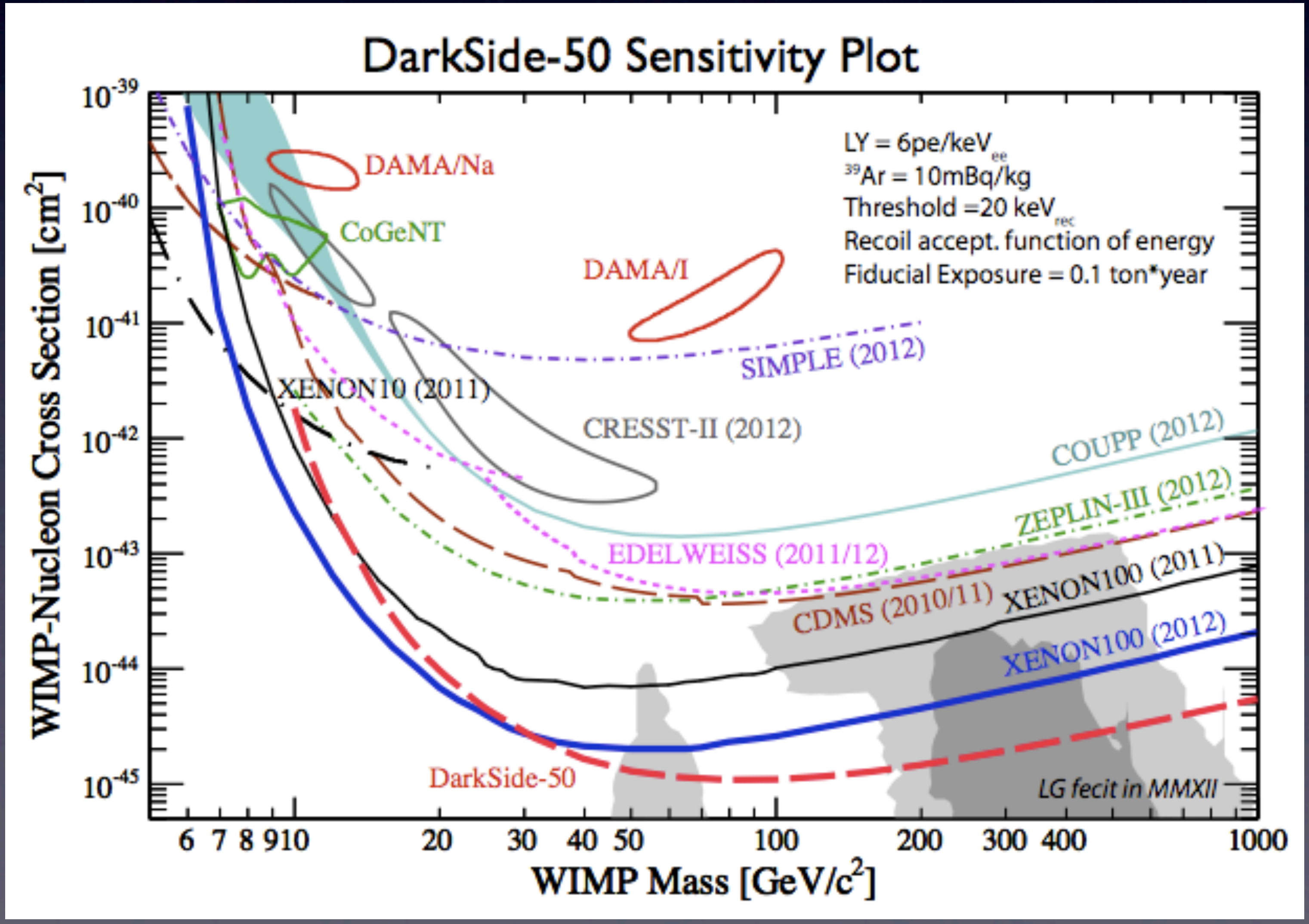
DS-50 Schedule

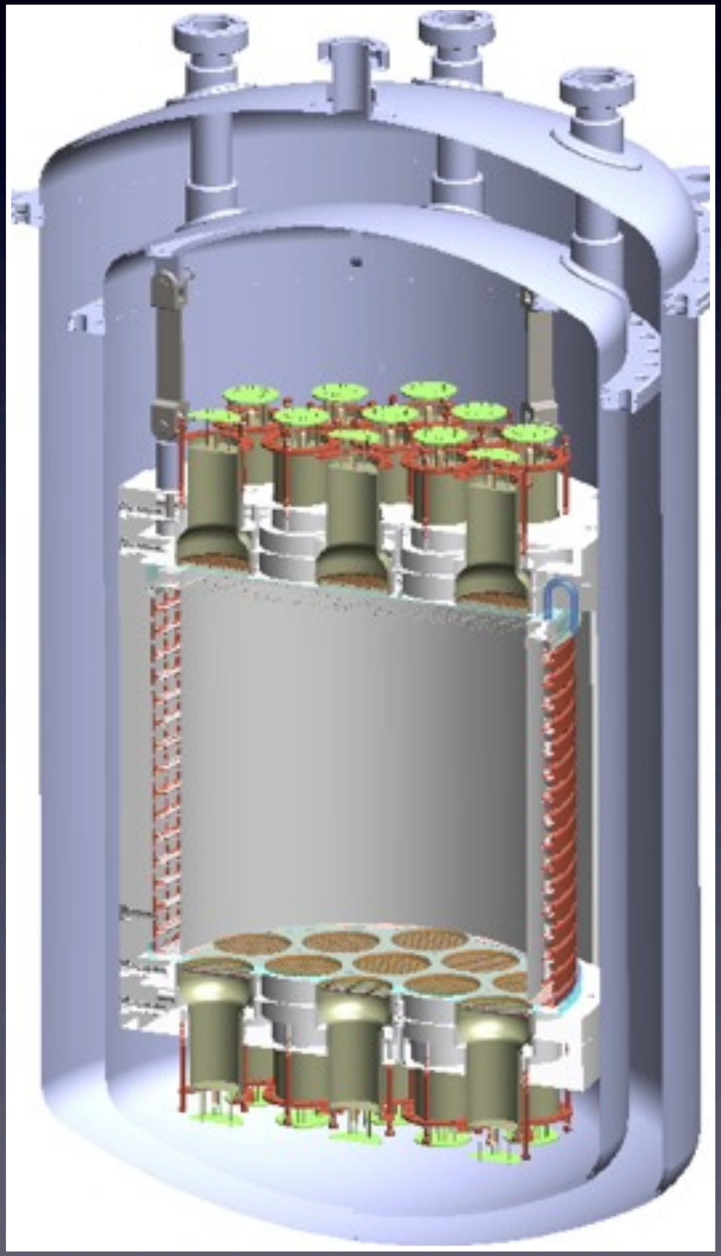
- 1st TPC test run (atm argon) ended June
- 2nd TPC test run starting now (atm argon)
- Fill Neutron Veto and Water Tank by end September
- Concentrate on background rejection performance
- Low radioactivity underground argon towards end of year

DS-50 projected sensitivity

$\sigma = 1 \times 10^{-45}\ \mathrm{cm}^2$ @ 100 GeV/c^2
0.1 ton x year exposure

Active: 50 kg
Fiducial: 33 kg

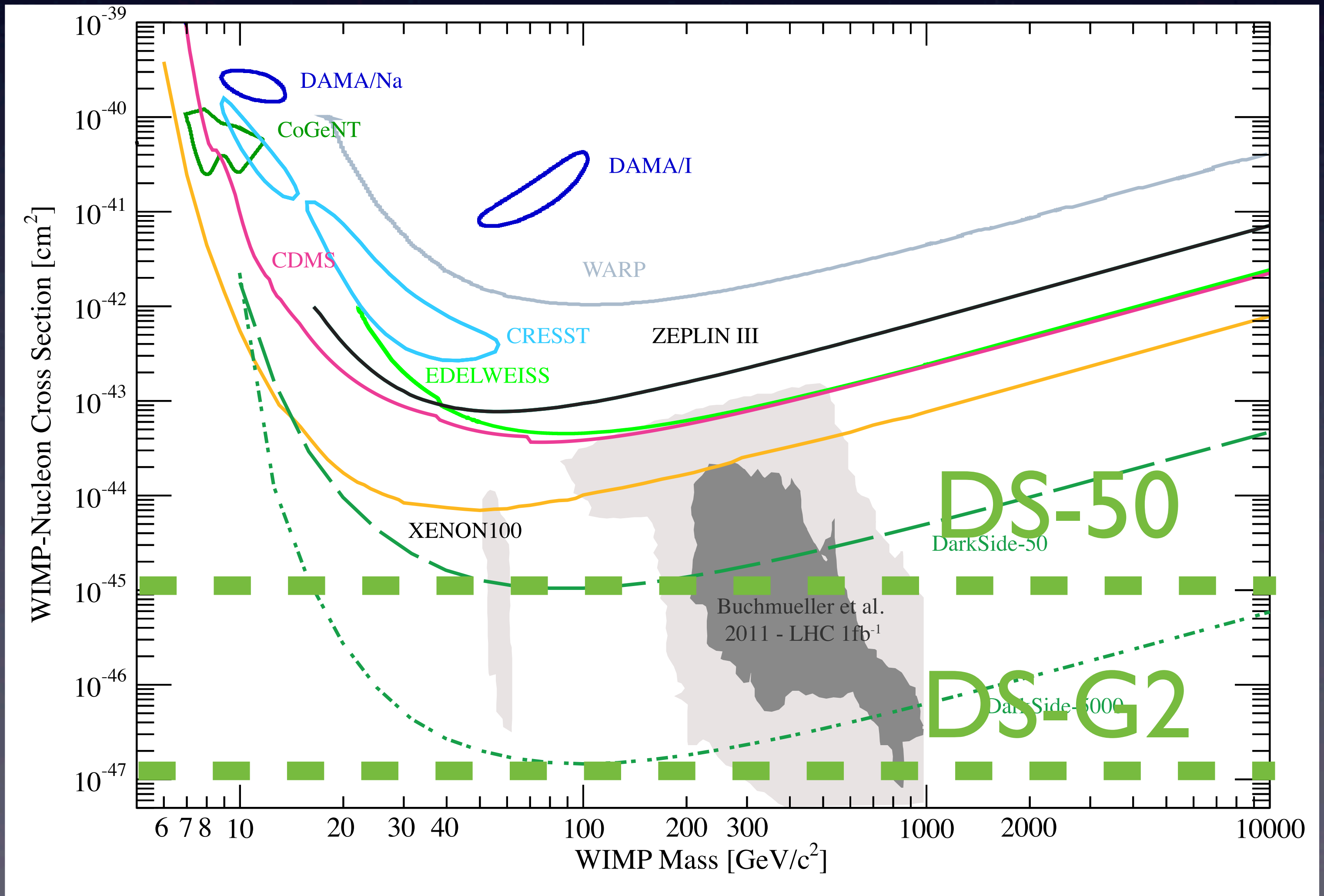


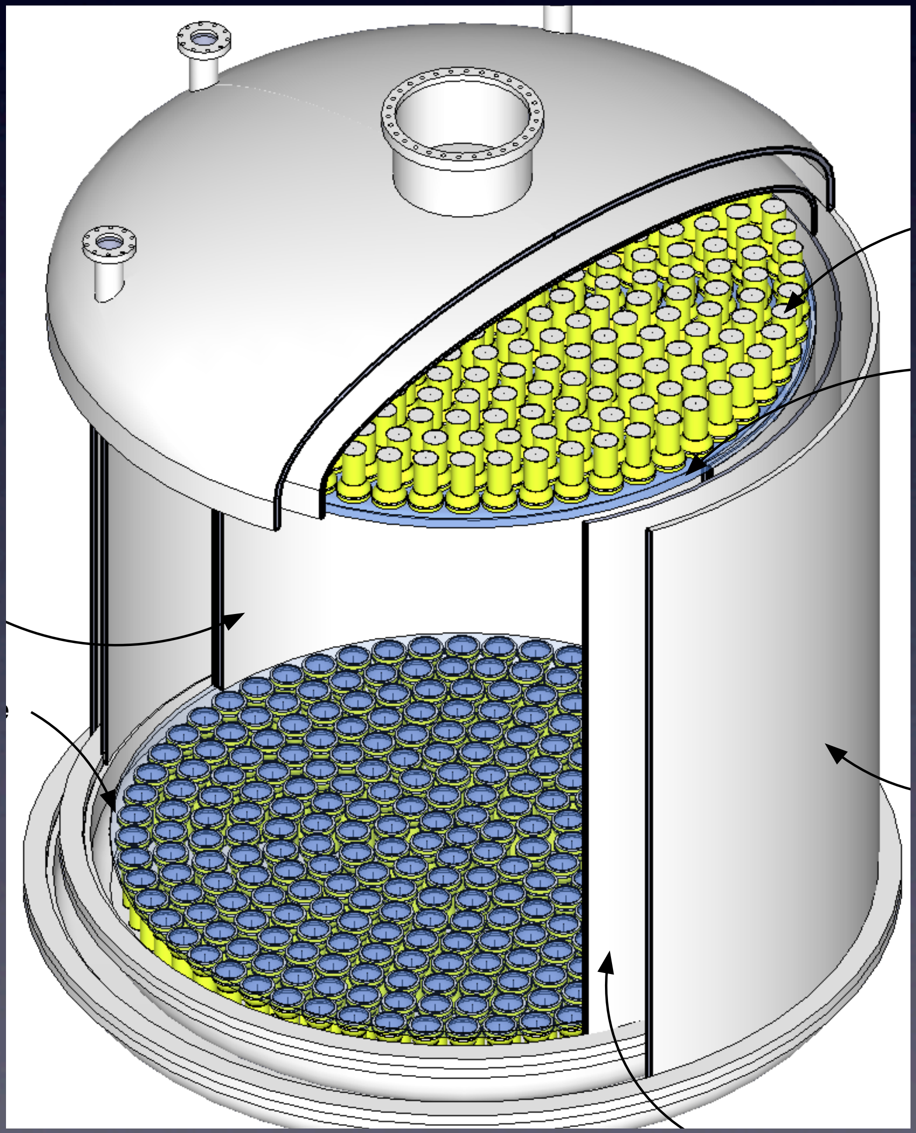


DS-G2 projected sensitivity

$\sigma = 1 \times 10^{-47}$ cm^2 @ 100 GeV/c^2
14 ton x year exposure

Total: 5 ton
Fiducial: 2.8 ton





Summary

DarkSide is a project for direct detection of dark matter with underground argon. The DarkSide-50 experiment at LNGS has a projected sensitivity of 10^{-45} cm^2.

DarkSide-50, is in the commissioning phase. The detector is housed in a 30-ton liquid scintillator neutron veto, which is in turn housed within a 1,000-ton water Cherenkov muon veto.

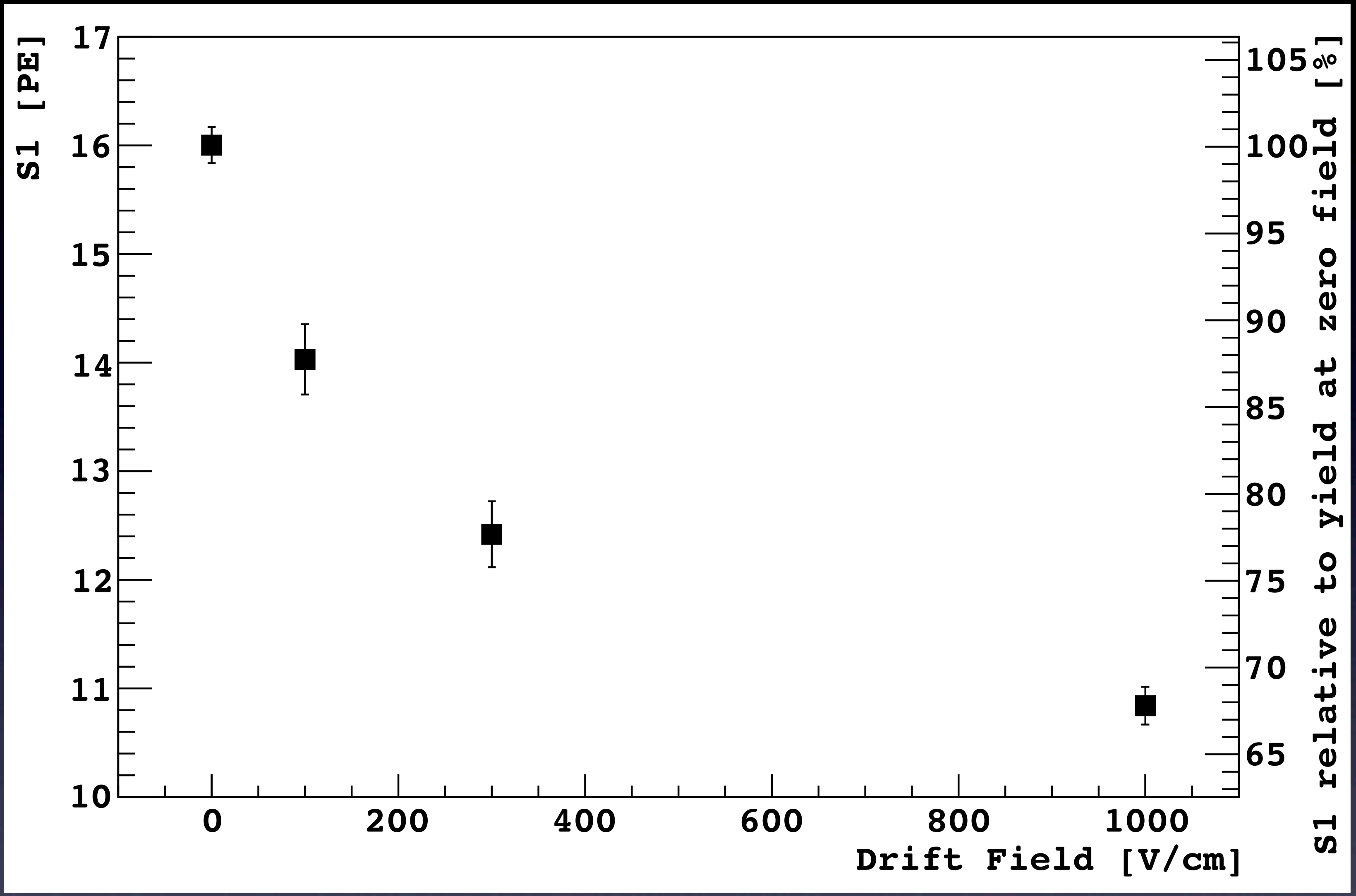
The underground argon is collected from a special well in Colorado. The DarkSide collaboration recently demonstrated that ^{39}Ar activity from the underground argon is less than 0.65% of the activity in atmospheric argon (corresponding to a reduction factor greater than 150.)

The DarkSide collaboration is also considering a proposal for a second generation detector, DarkSide-G2, with an active mass of 5 tons of underground argon. The sensitivity goal for DarkSide-G2 is 10^{-47} cm^2. DarkSide-G2 can be housed within the same neutron veto and cosmic muon veto already under construction for DarkSide-50.

Thank you.

Backup Slides

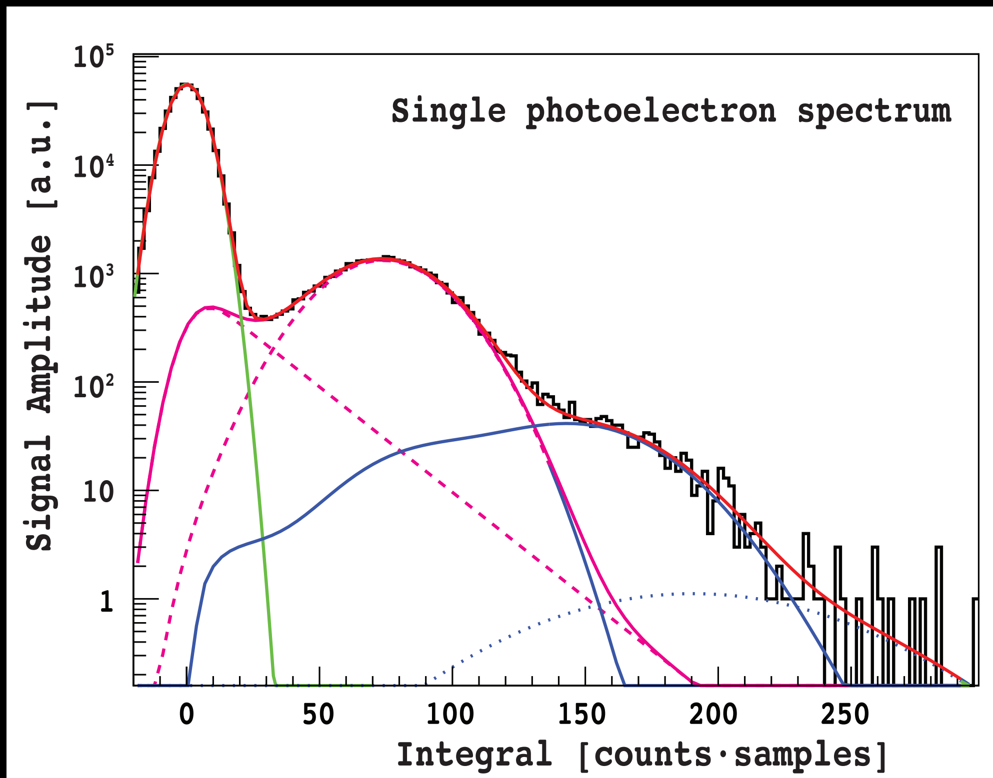
SCENE



arXiv:1306.5675

- Dual-phase LAr-TPC exposed to a low energy pulsed narrow band neutron beam @ Notre Dame
- LSci counters detect and identify neutrons scattered in the LAr-TPC target and select the energy of the recoiling nuclei
- A significant dependence on drift field of liquid argon scintillation from nuclear recoils of 11keV was observed.

Light Yield Measurements

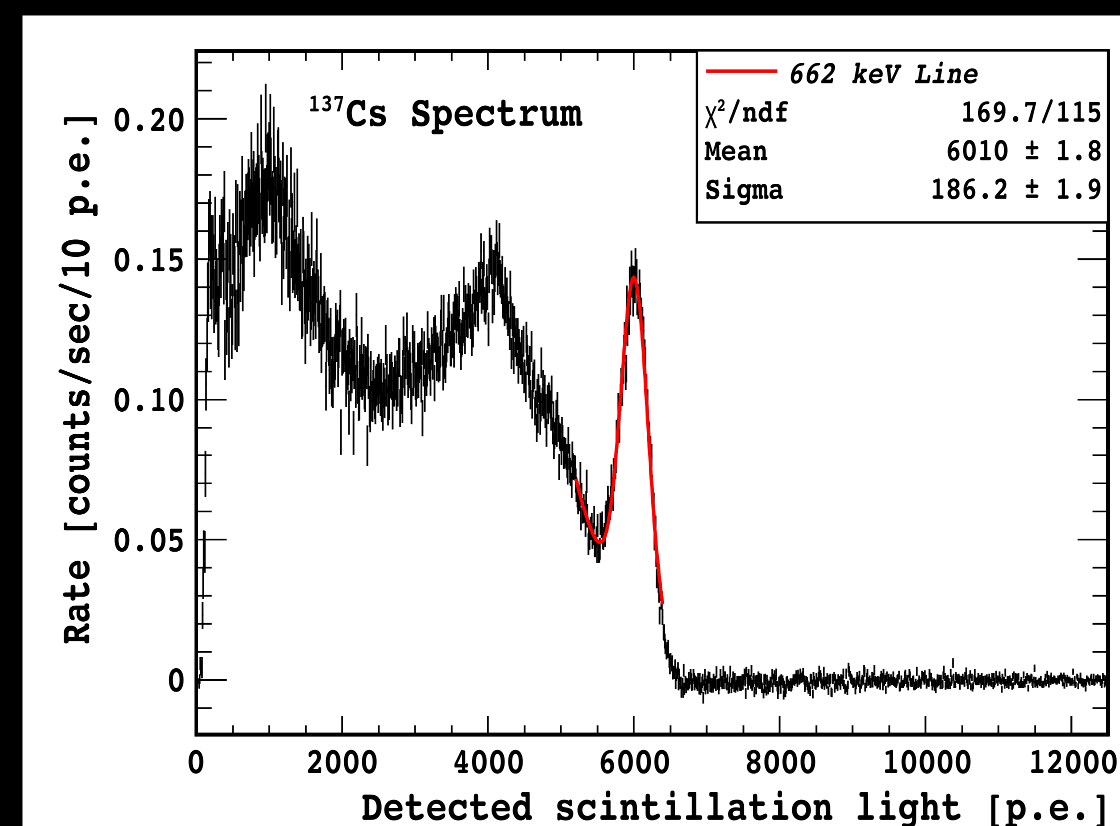


The single photoelectron response of each tube was measured using a fast, pulsed laser

Detector light yield was measured using a series of external γ sources at null field

arXiv:1204.6218 [astro-ph.IM]

Energy [keV]	L.Y. [p.e. / keV]	Resolution (σ)
122	8,87	5,2
511	8,78	3,4
662	9,08	3,1
1275	8,60	2,9
AVERAGE	8.9 +/- 0.4	



Darkside 10 Parameters

	Value
Active Volume Diameter	21 cm
Active Volume Height	23.5 cm
Active Volume Mass	~ 10 kg
Gas Height	2.0 cm
Drift Field (typical)	1.0 kV/cm
Extraction Field (typical)	3.8 kV/cm
Electroluminescence Field (typical)	5.7 kV/cm
Photocathode Coverage (Top/Bottom)	~ 60%
Photocathode Coverage (Total)	~ 22%
ITO Coating Thickness	15 nm
TPB Coating Thickness	~ 200 ug/cm^2
Grid Thickness	100 um
Grid Optical Transparency	89%
PMT Quantum Efficiency	~ 34% [30 - 36]

DarkSide 50
Inner Detector Parameters

Dimensions

• Active volume diameter	35.6 cm
• Active volume height	35.6 cm
• Gas pocket height	1.0 cm
• LAr above grid	0.5 cm
• TPC full height	69.0 cm

Masses

• Active LAr	49.4 kg
• Total LAr	~145 kg
• Main PTFE reflector	22.8 kg
• Total PTFE	59.2 kg
• Total fused silica	3.5 kg
• Copper field cage rings	23.5 kg
• 38 R11065 PMTs	7.9 kg

Other parameters

• Recirculation rate (min)*	15 slpm
(max)*	40 slpm
	=4.1 kg/h
• Drift field (typical)	1.0 kV/cm
• Extraction field (typ)	3.8 kV/cm
• Electroluminescent field	5.7 kV/cm
• Grid potential	−7.6 kV
• Cathode potential	−43.2 kV
• Photocathode coverage	~20%
of top and bottom	~60%

* Estimate

LSV and Water Cherenkov

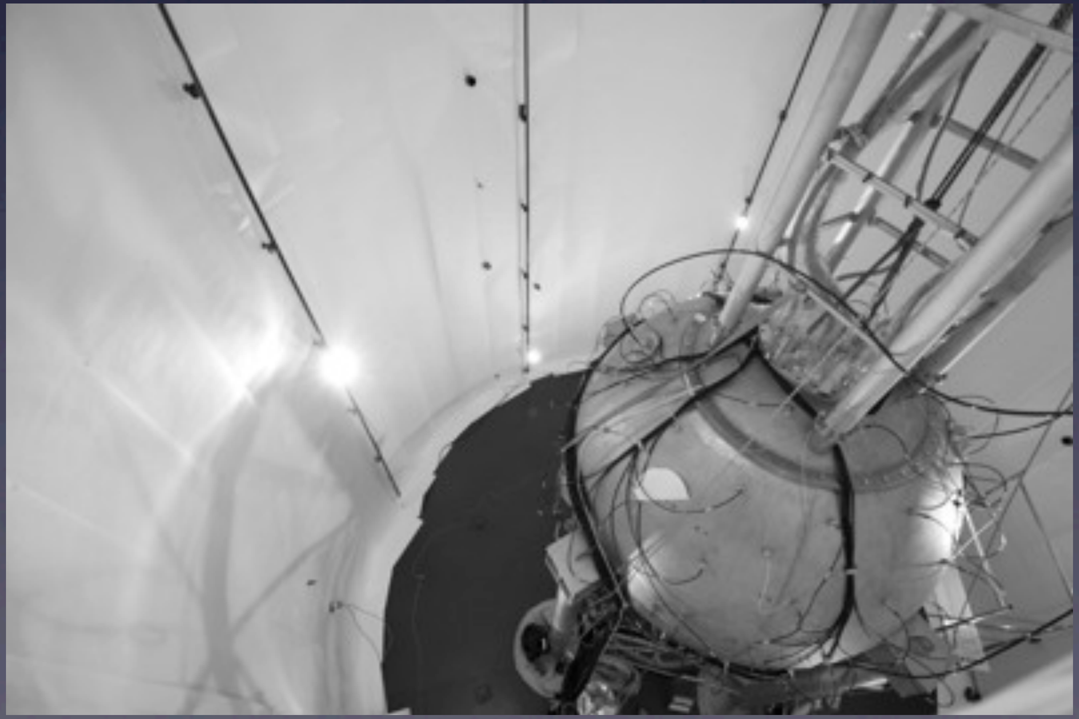
- The TPC is surrounded by a 30 ton boron-loaded liquid scintillator spherical veto, 4m diameter, instrumented with 110 low background 8” PMTs

  neutrons which escape the inner detector are detected via (n,α) reaction on ^{10}B

  >99.5% efficiency for radiogenic neutron detection, >95% for cosmogenic neutron detection A.Wright et. al, NIM A 644, 18 (2011)

- The LSV is installed inside a Water Cherenkov detector (Borexino CTF), 10 m height, 11 m diameter, filled with 1000 ton ultra-pure water, observed by 80 upward facing PMTs

  muon veto and passive shielding against external neutrons and gammas

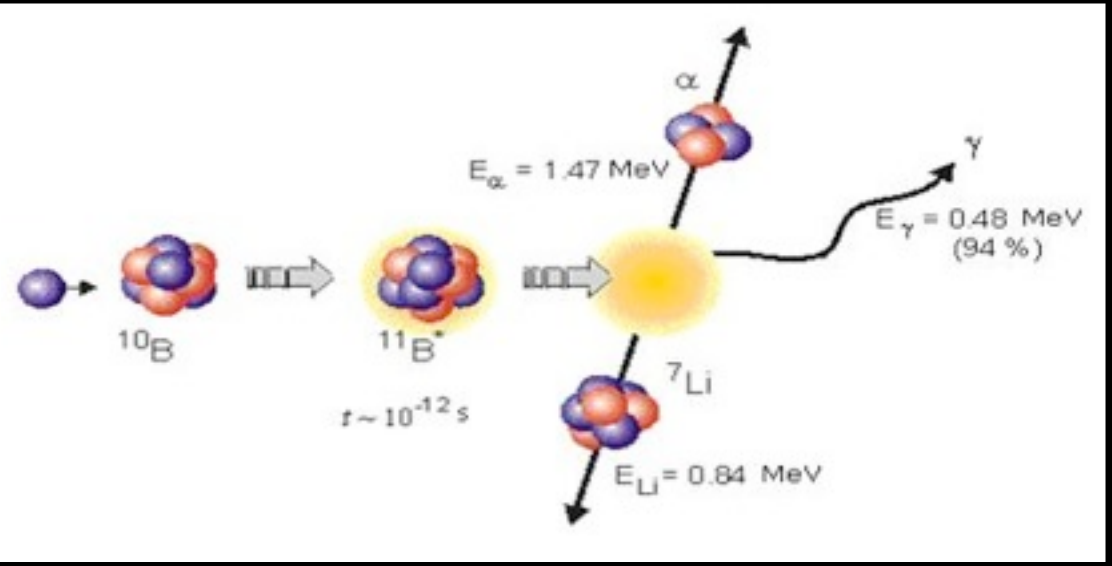


Liquid Scintillator Parameters

	Value
Diameter	4 m
8” PMTs	110
Photocathode Coverage	~ 7%
PMT Quantum Efficiency	> 30%
TMB Loading	50%
PPO Concentration	~3g/l

Borated Liquid Scintillator

- containing 1:1 PC + TMB scintillator
- High neutron capture cross section on boron allows for compact veto size
- Capture results in 1.47 MeV α particle - detected with high efficiency
- Short capture time (2.3 μs) reduces dead time loss



	Veto Efficiency
Radiogenic Neutrons	> 99.5%*
Cosmogenic Neutrons	> 95%

Nuclear Instruments and Methods A 644, 18 (2011)

*60 μs veto window (2% dead time)

Underground Argon

Underground Argon from CO_2 plant in Cortez Colorado

VPSA system (Cortez)
0.5 kg/day production
110 kg produced so far

arXiv:1204.6024 [astro-ph.IM]

Cryogenic Distillation system
0.9 kg/day production
70 - 81% efficiency
~ 19 kg produced so far

arXiv:1204.6061 [astro-ph.IM]

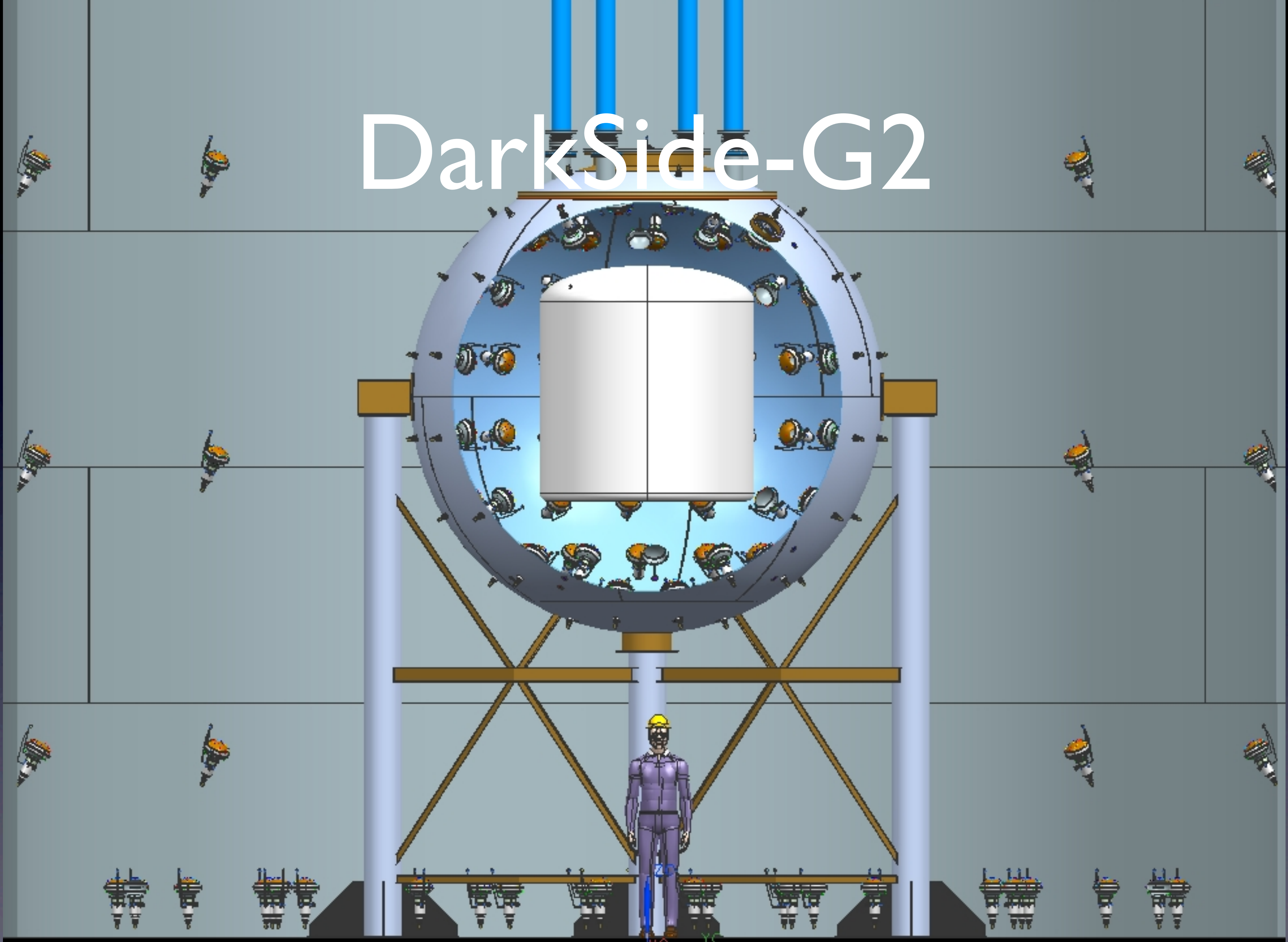
	CO_2 [%]	N_2 [%]	He [%]	Ar [%]
CO_2 Plant Output	96	2,4	0,4	0,06
VPSA output	~ 0	40	55	5
Cryogenic Distillation output	~ 0	< 0.05	~ 0	> 99.95

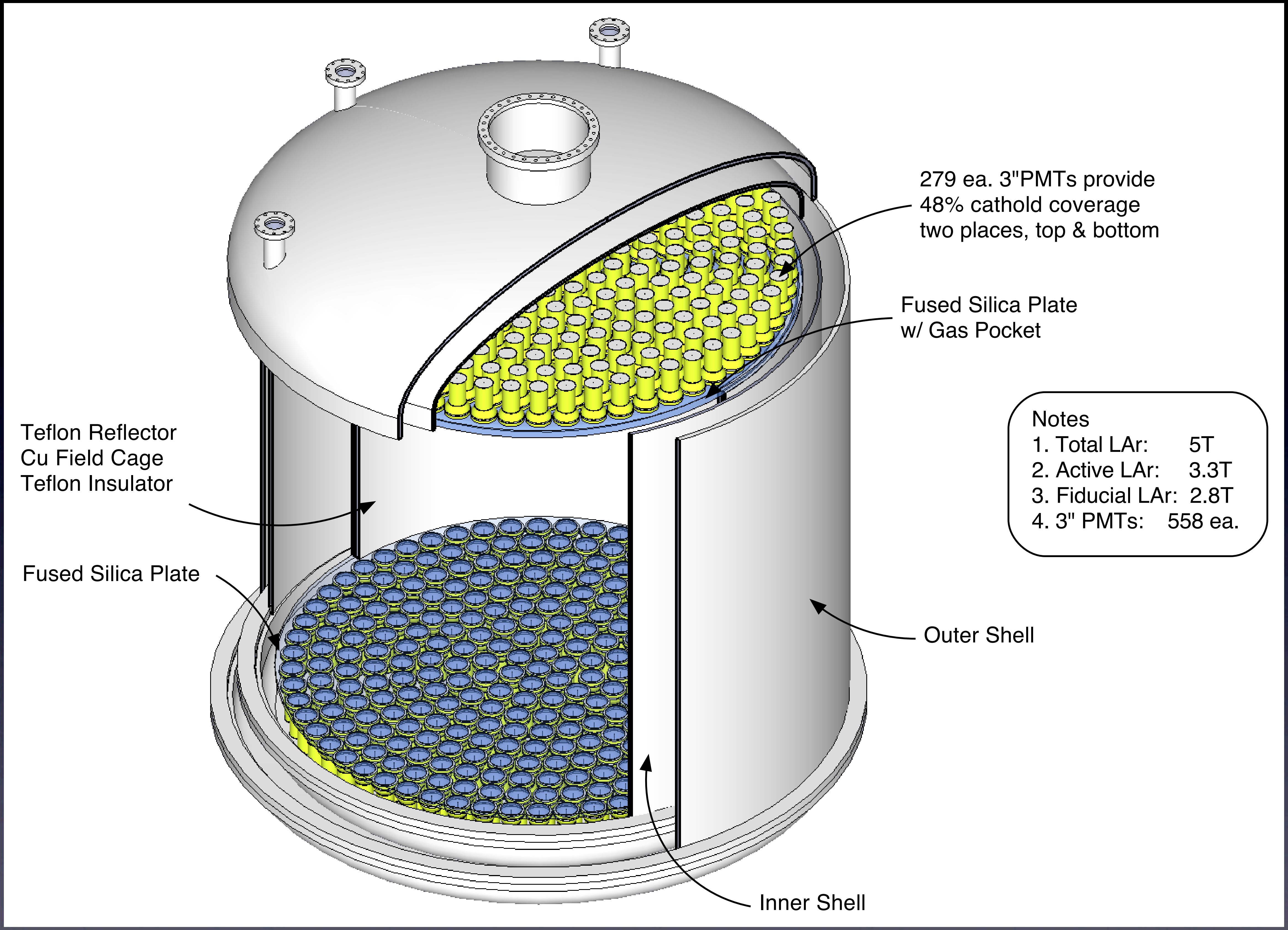
Expected Backgrounds

Detector Element	Electron Recoil Backgrounds		Radiogenic Neutron Recoil Backgrounds		Cosmogenic Neutron Recoil Backgrounds	
	Raw	After Cuts	Raw	After Cuts	Raw	After Cuts
^{39}Ar (<0.01 Bq/kg)	$<6.3\times10^{6}$	$<4\times10^{-3}$	–	–	–	–
Fused Silica	3.3×10^{4}	2.0×10^{-5}	0.17	4.3×10^{-4}	0.21	1.3×10^{-5}
PTFE	4,800	3.0×10^{-6}	0.39	9.8×10^{-4}	2.7	1.6×10^{-4}
Copper	4,500	2.8×10^{-6}	5.0×10^{-3}	1.3×10^{-5}	1.5	9.0×10^{-5}
R11065 PMTs	2.6×10^{6}	1.6×10^{-3}	19.4	4.8×10^{-2}	0.34	2.0×10^{-5}
Stainless Steel	5.5×10^{4}	3.4×10^{-5}	2.5	6.3×10^{-3}	30	0.0018
Veto Scintillator	70	4.3×10^{-8}	0.030	7.5×10^{-5}	26	0.0016
Veto PMTs	2.5×10^{6}	1.6×10^{-3}	0.023	5.8×10^{-5}	–	–
Veto tank	1.7×10^{5}	1.1×10^{-4}	6.7×10^{-5}	1.7×10^{-7}	19	0.0071
Water	6,100	3.8×10^{-6}	6.7×10^{-4}	1.7×10^{-6}	19	0.0071
CTF tank	8,300	5.1×10^{-6}	3.5×10^{-3}	8.7×10^{-6}	0.068	2.6×10^{-5}
LNGS Rock	920	5.7×10^{-7}	0.061	1.5×10^{-4}	0.31	0.012
Total	–	0.007	–	0.055	–	0.030

0.1 ton x year exposure, 30 - 200 keV$_r$ window,
50% nuclear recoil acceptance

DarkSide-G2





DS-G2 baseline design

Some of the technical challenges of DarkSide – G2 Inner Detector (Argon TPC)

G2 ~ 5 tonnes low radioactivity argon, 3 tonnes fiducial
(~ 33 times DS-50 in total mass, 60 times in fiducial, 15 times surface area, 1.2 m typical length)

Argon
provision of low radioactivity argon (< 1% atmospheric)
Purification
maintenance of chemical and radio purity

Cryostat & Cryogenics
Cryostat design materials for low radioactivity,
Stability of pressure in gas region
Thermodynamics for smooth liquid-gas interface

TPC
mechanical design,
Materials and assembly for low radioactivity,
electric fields design, (grids, windows)
Light collection (reflection)
levelling for uniform height gas region,
HV (~140 kV)