The Darkside Program

Depleted Argon Cryostat for Scintillation and Ionization Detection

Biagio Rossi

Princeton University
INFN Napoli

21th International Conference on Supersymmetry and Unification of Fundamental Interactions

ICTP Trieste

26-31 August 2013

DarkSide Collaboration

IHEP – Beijing, China
Université Paris Diderot, CNRS/IN2P3, CEA/IRFU, Observatoire de Paris, Sorbonne Paris Cité – Paris, France
IPHC, Université de Strasbourg, CNRS/IN2P3 – Strasbourg, France
INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
Università degli Studi and INFN – Genova, Italy
Università degli Studi and INFN – Milano, Italy
Università degli Studi Federico II and INFN – Napoli, Italy
Università degli Studi and INFN – Perugia, Italy
Università degli Studi Roma Tre and INFN – Roma, Italy
Jagiellonian University – Krakow, Poland
Joint Institute for Nuclear Research – Dubna, Russia
Lomonosov Moscow State University – Moscow, Russia
National Research Centre Kurchatov Institute – Moscow, Russia
Saint Petersburg Nuclear Physics Institute – Gatchina, Russia
KINR, NAS Ukraine – Kiev, Ukraine
Augustana College – SD, USA
Black Hills State University –SD, USA
Fermilab – IL, USA
Princeton University – NJ, USA
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

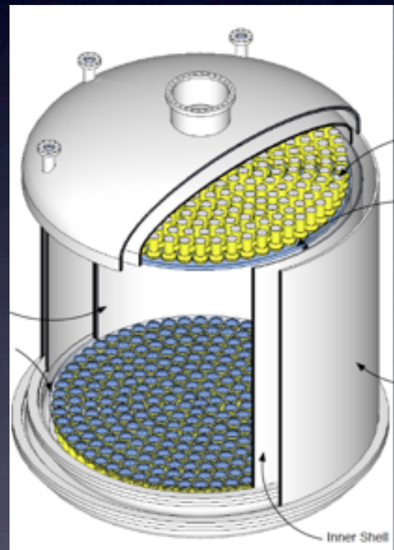
DarkSide-10

technical prototype
no DM goal

DarkSide-50

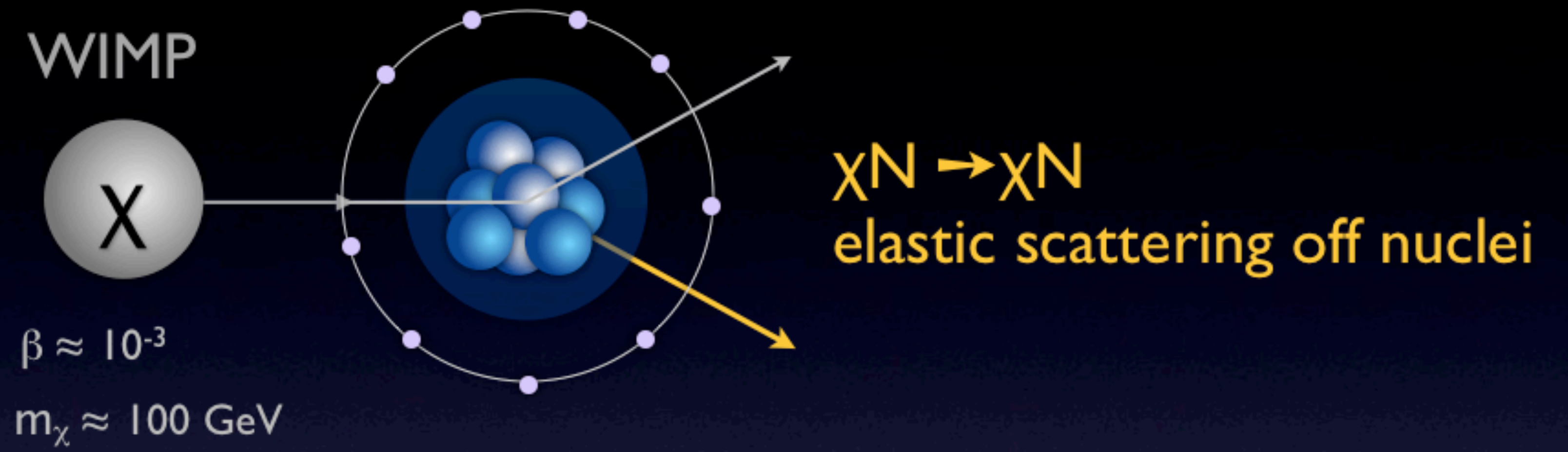
sensitivity
10^{-45} cm^2

DarkSide-G2



sensitivity
10^{-47} cm^2

WIMP direct detection requirements



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

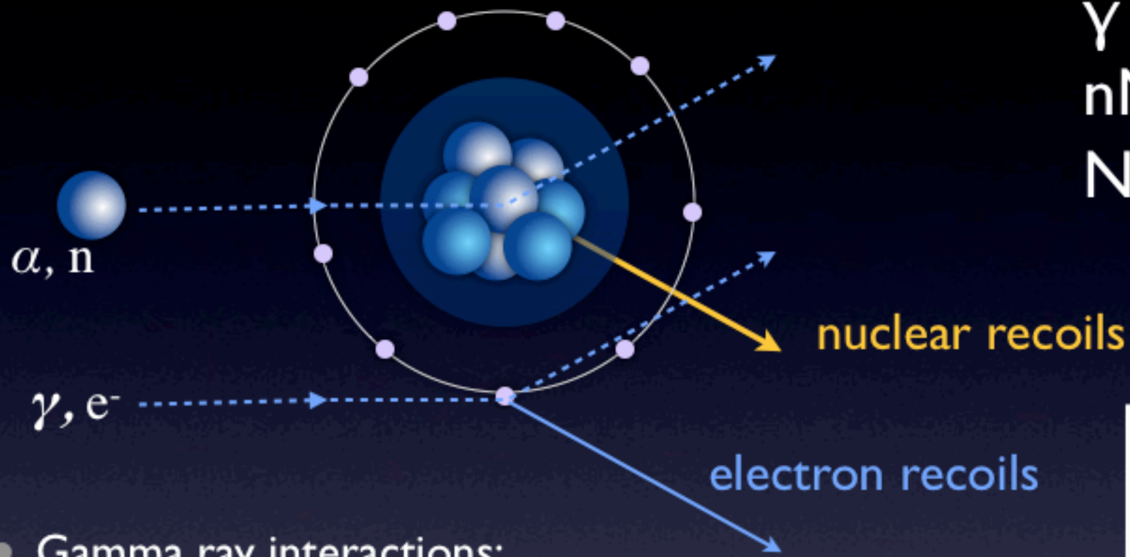
Background

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:

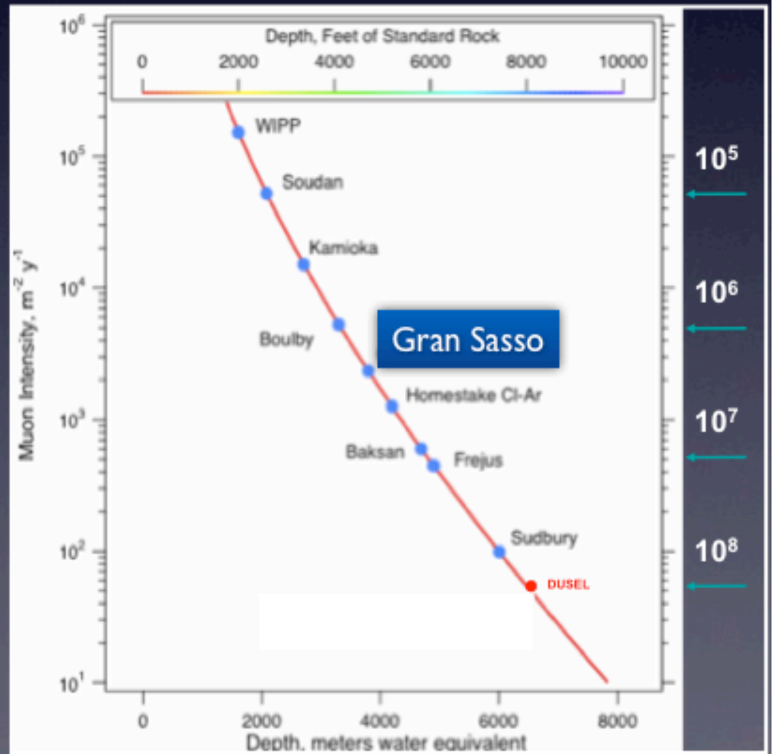
  (α,n), U, Th fission, cosmogenic spallation

- Contamination:

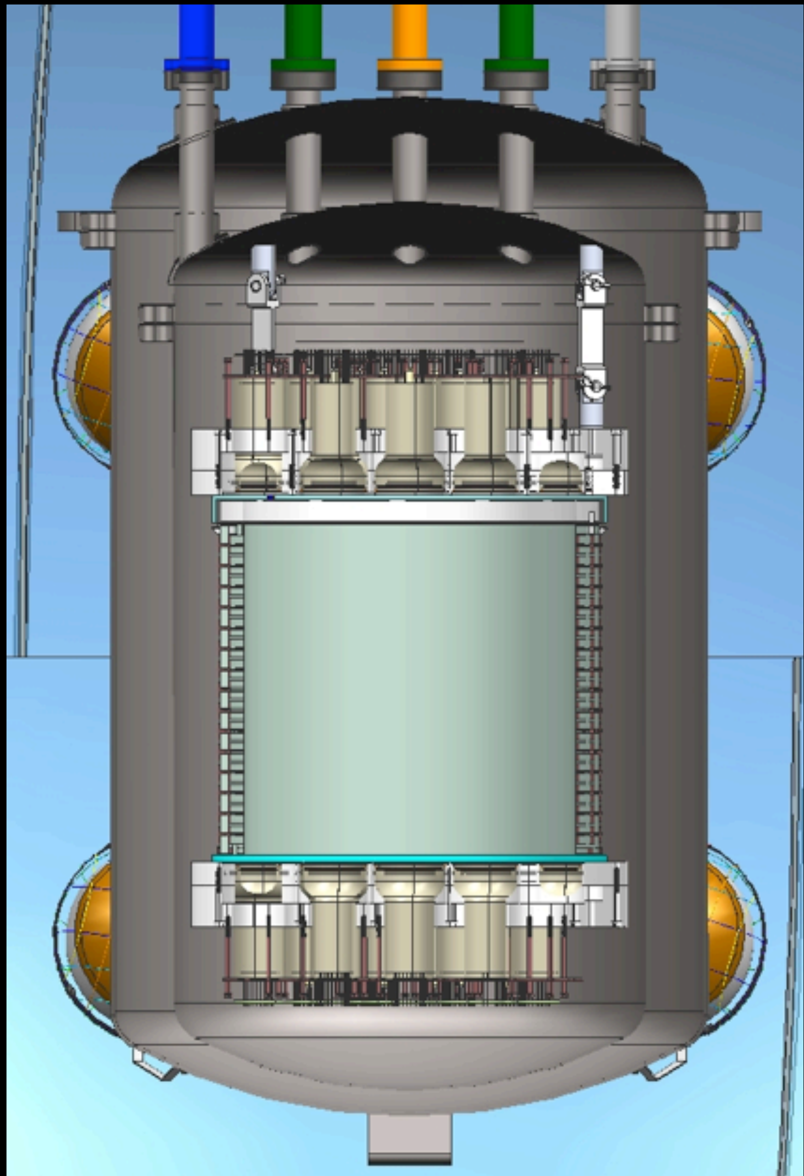
  ^{238}U and ^{232}Th decays, recoiling progeny mimic nuclear recoils

Underground labs

reduction of muon flux by:

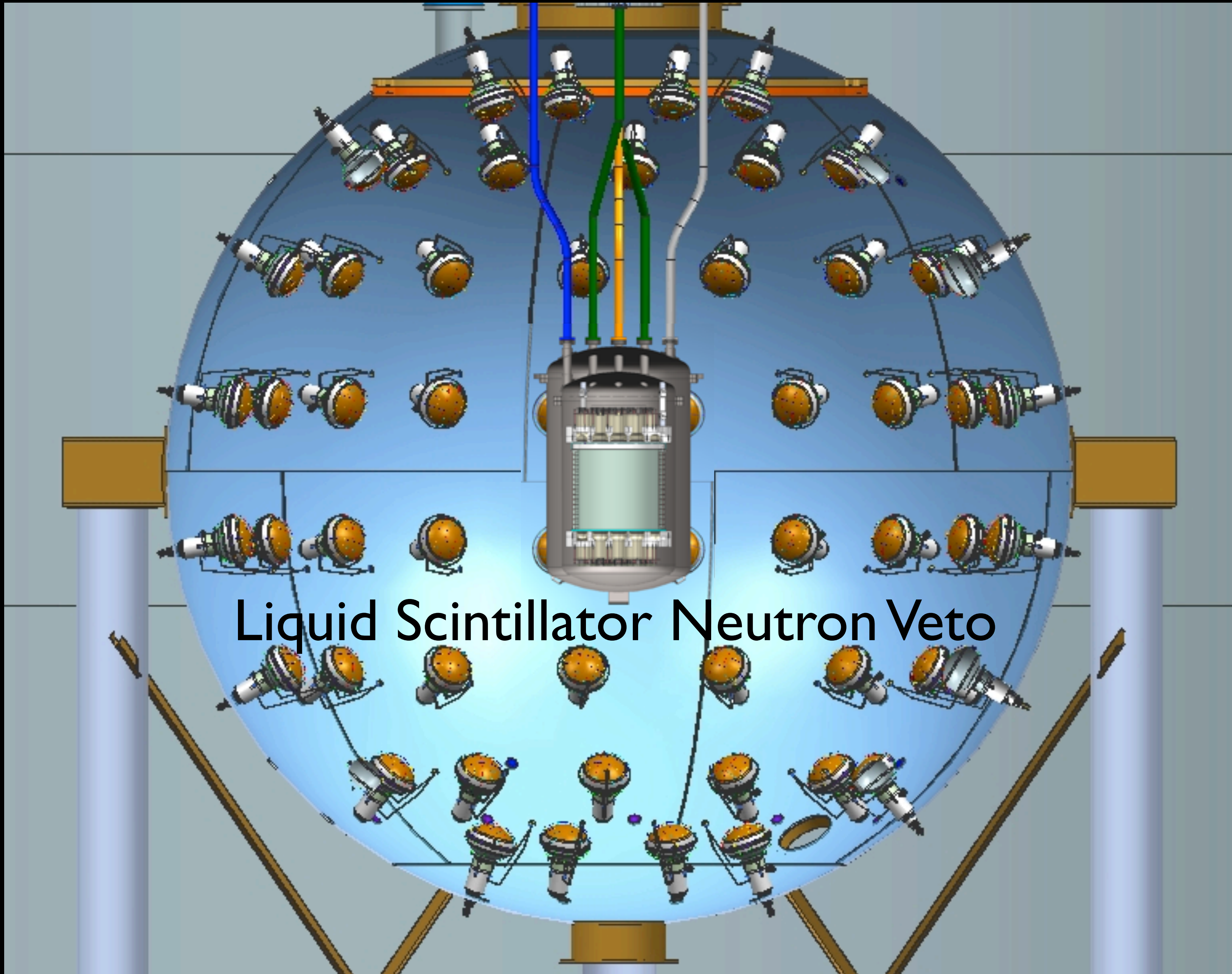


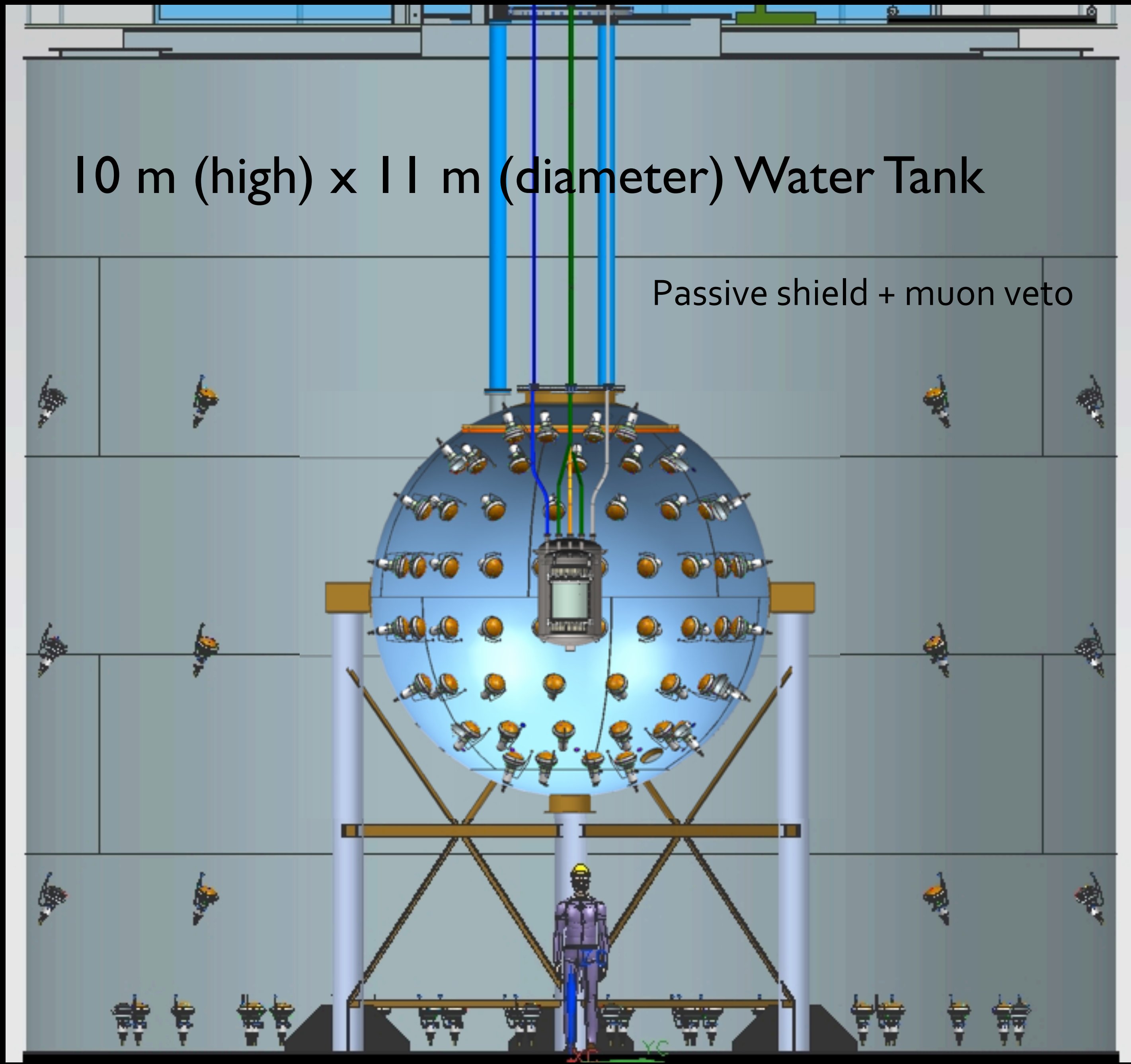
Liquid Argon TPC,
within a neutron veto,
within a muon veto,
under a mountain



Liquid Argon TPC & Cryostat

- Low radioactive materials
- Assembling in clean rooms


Liquid Scintillator Neutron Veto


10 m (high) x 11 m (diameter) Water Tank
Passive shield + muon veto

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

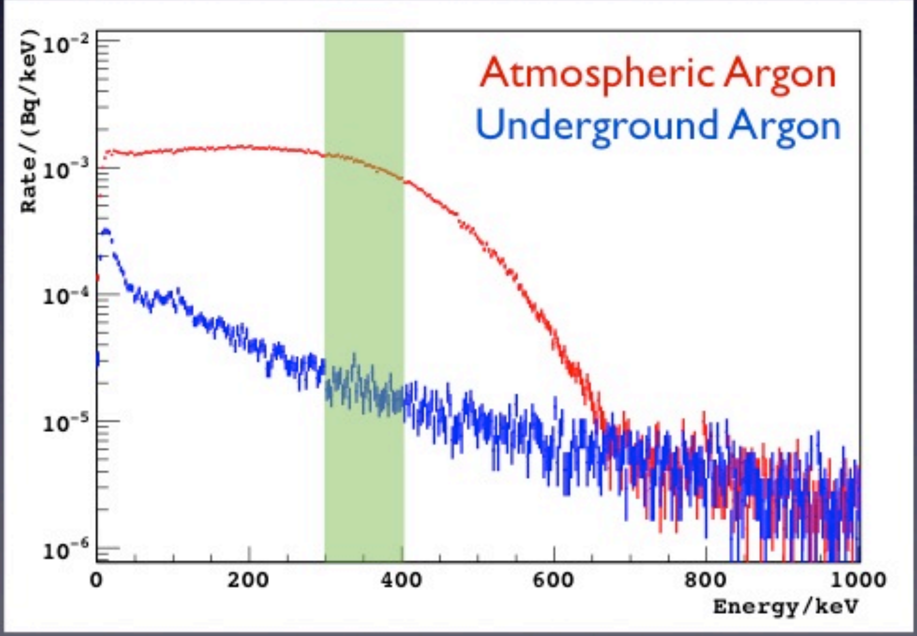
^{39}Ar production supported by cosmogenic activation via $^{40}Ar(n,2n)^{39}Ar$

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

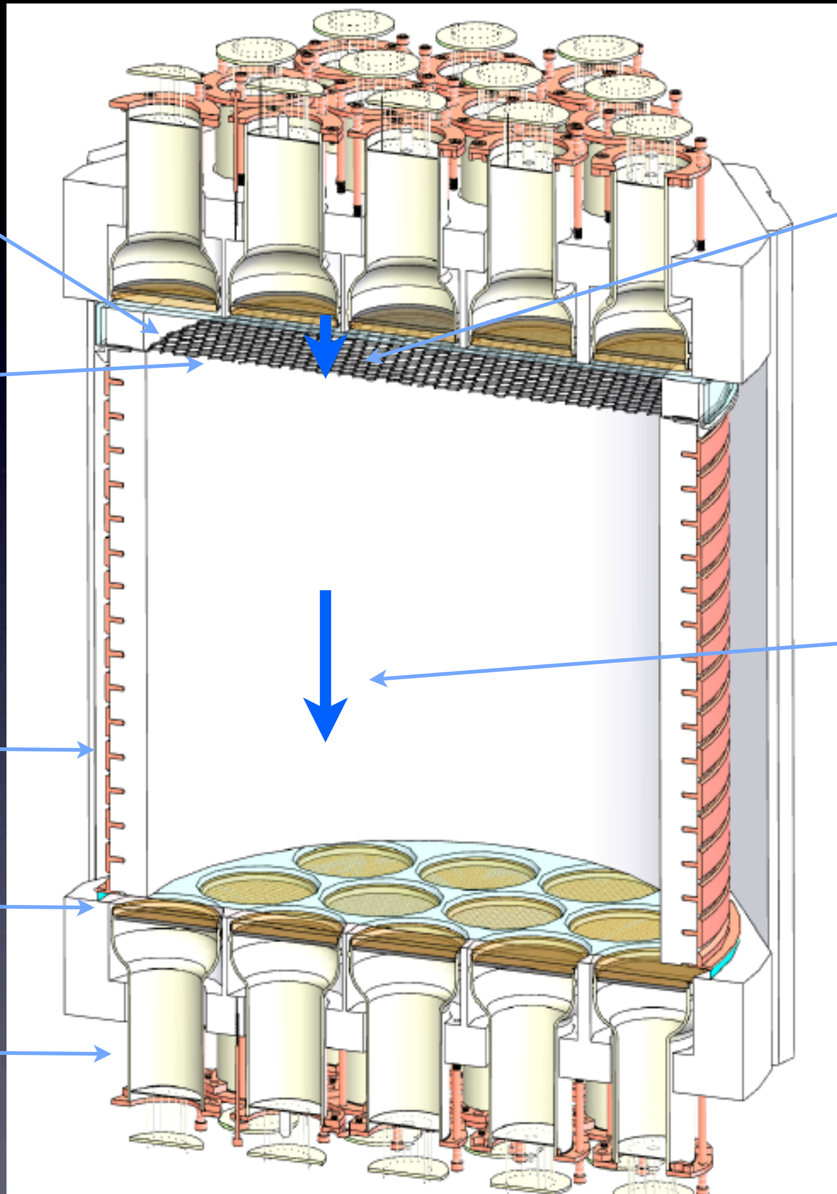
UAr ^{39}Ar activity <6.5 mBq/kg

150 of 150 kg collected

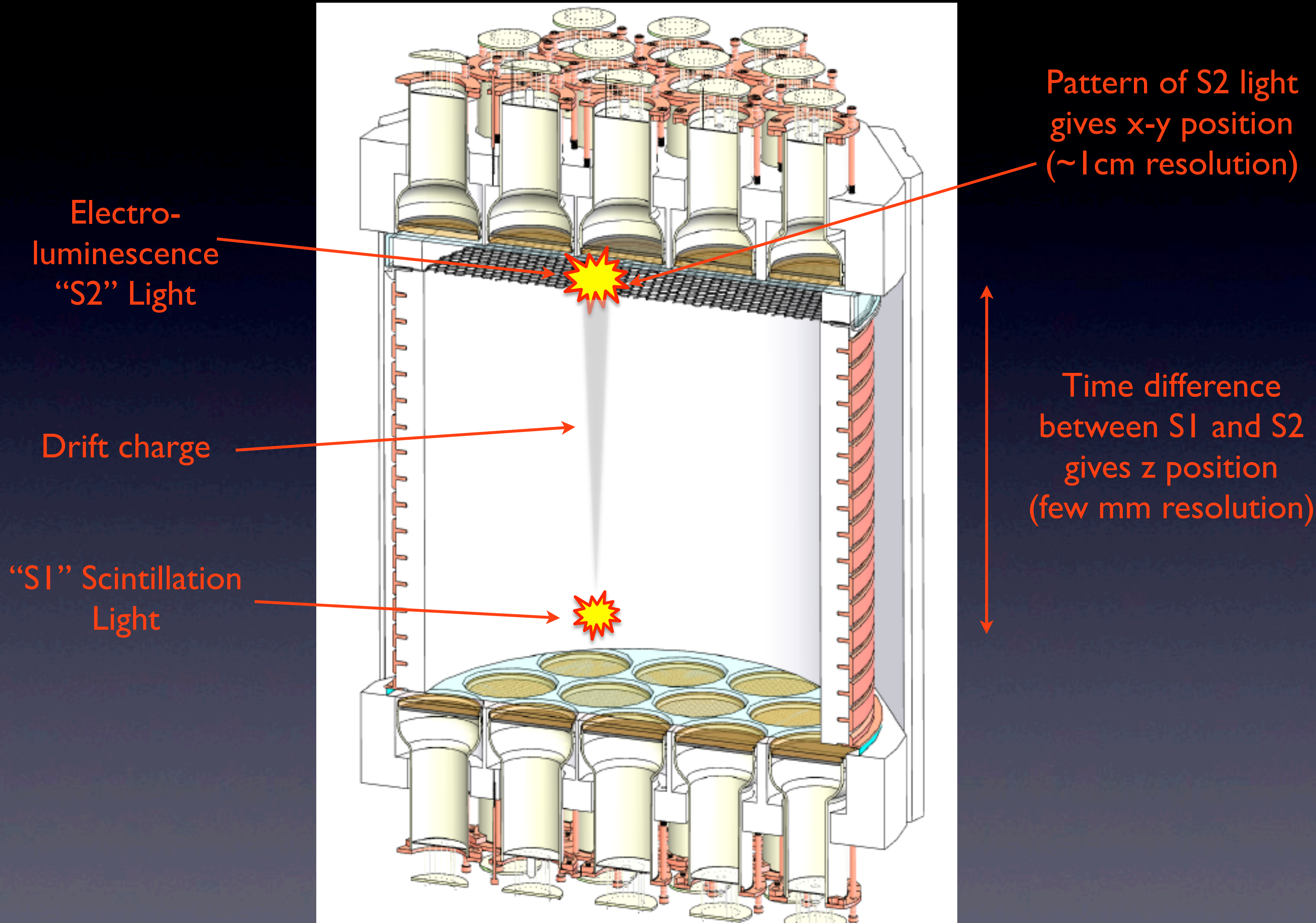
J.Xu et al. arXiv:1204.6011



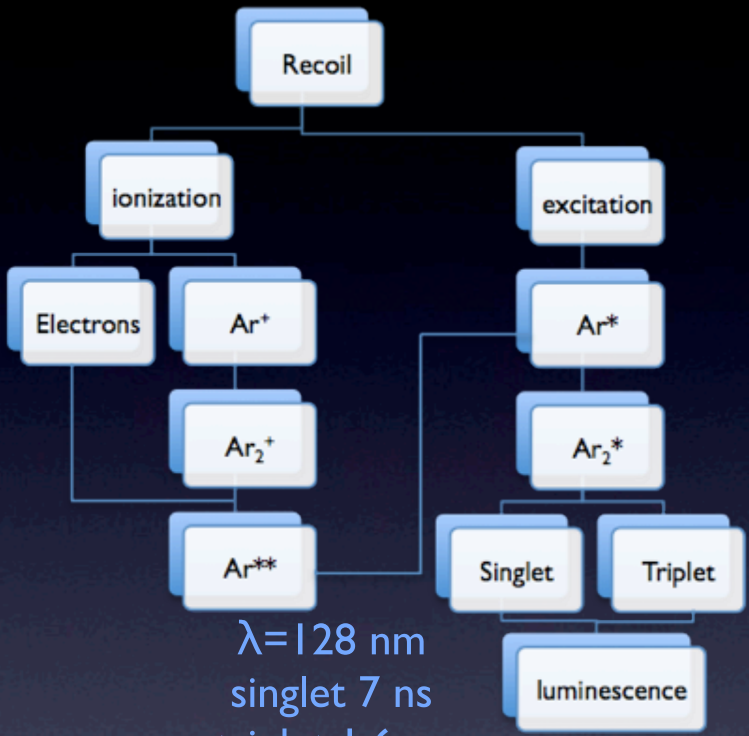
Two Phase Argon TPC



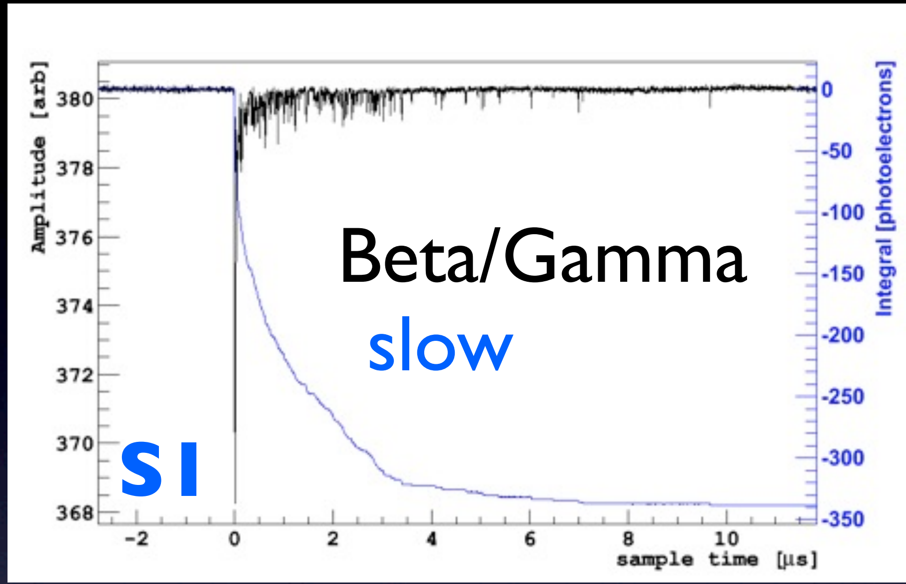
Two Phase Argon TPC

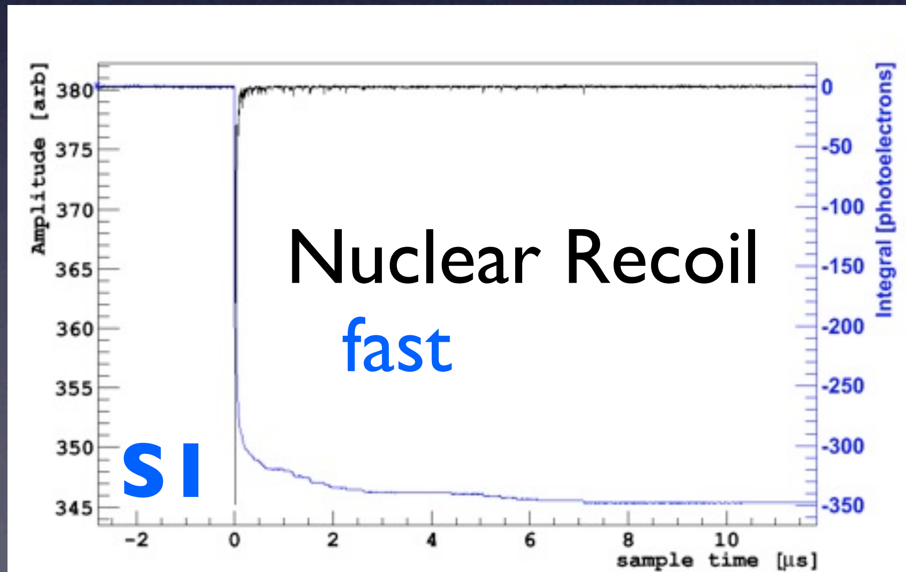


Background Discrimination: S1 Pulse Shape



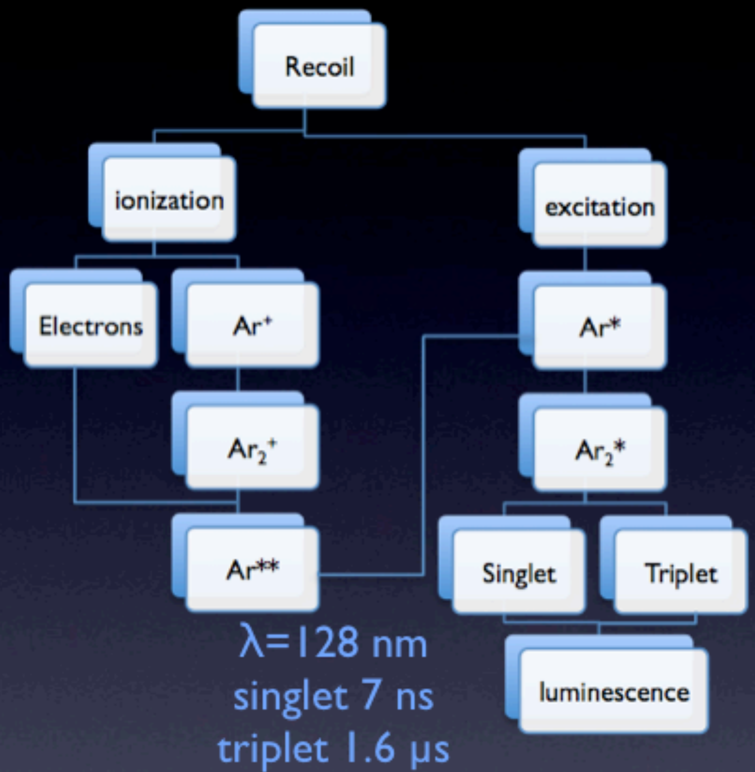
λ=128 nm
singlet 7 ns
triplet 1.6 μs

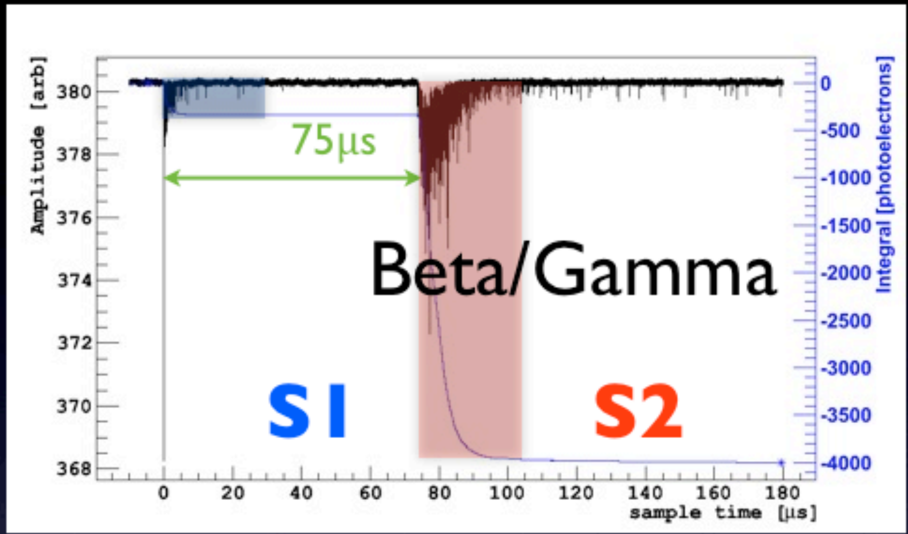


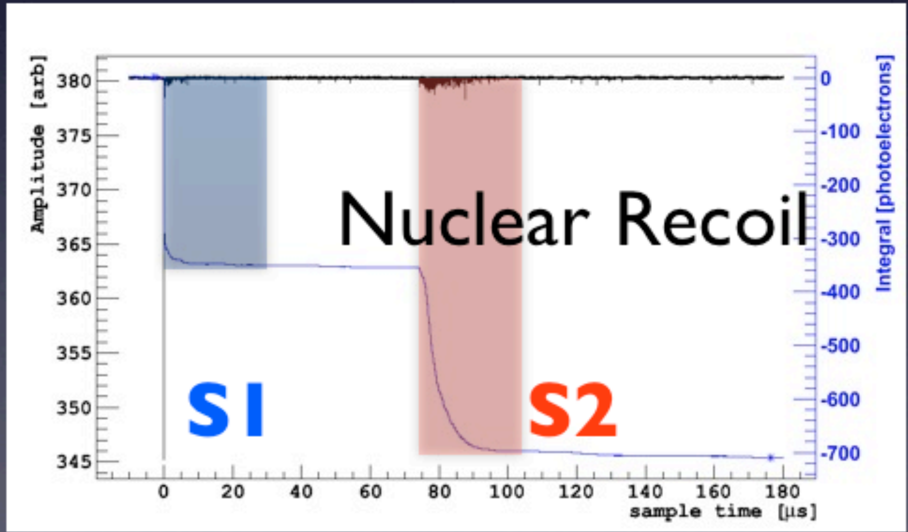


The ratio of light from singlet (~7 ns decay time) and triplet (1.6 μs decay time) depends on ionization density

Background Discrimination: S2/S1







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

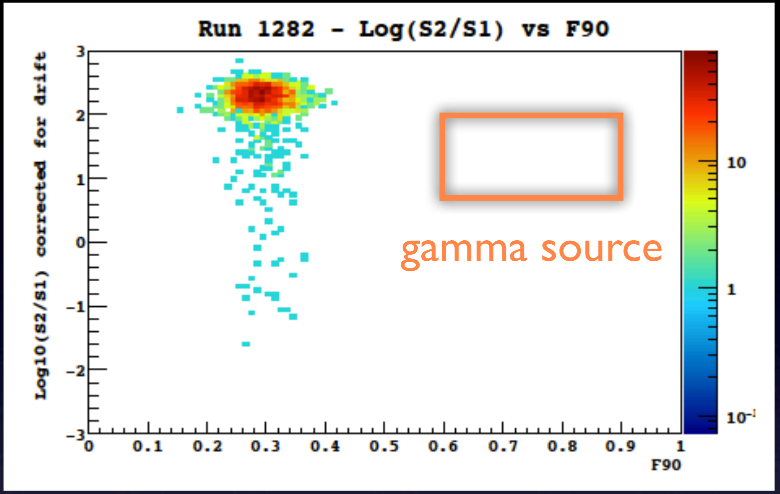
LAr TPC Background Discrimination

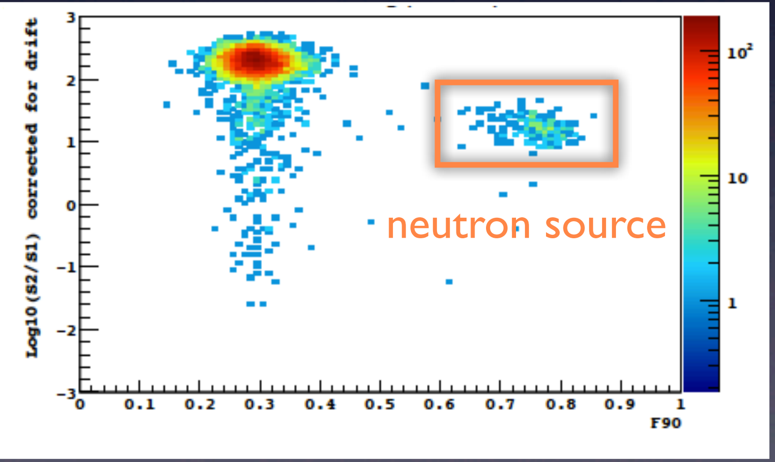
Shape of scintillation signal S1 (PSD)
Electronic and nuclear recoil events have different singlet to triplet ratio
➡ Rejection factor $\geq 10^8$ for > 60 photoelectrons
WARP Astr. Phys 28, 495 (2008)

Ratio between Ionization and Scintillation (S2/S1)
Electronic and nuclear recoil events have different energy sharing
➡ Rejection factor $\geq 10^2$-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

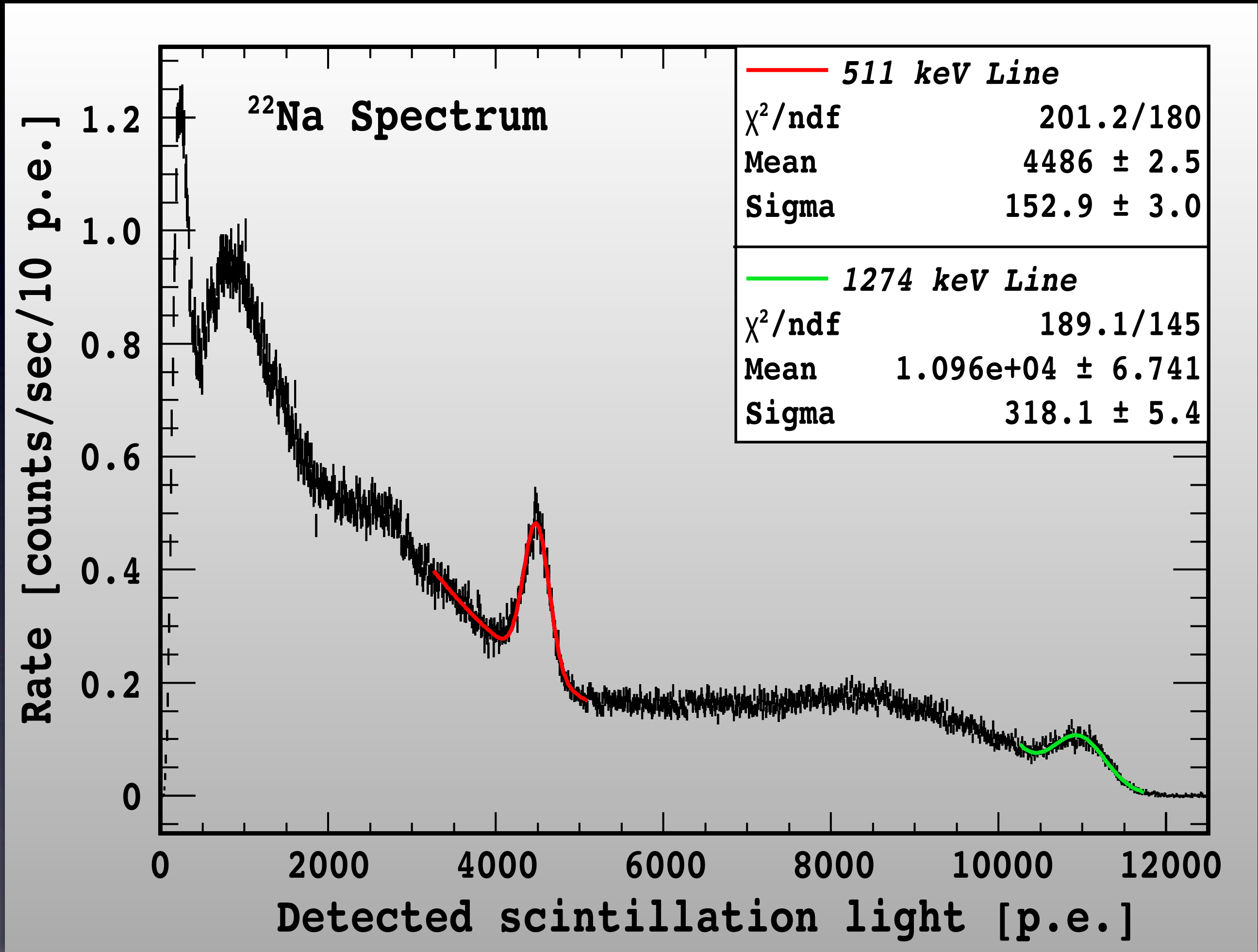
DarkSide-10 prototype

- 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
- Electric field: E_{drift}=1 kV/cm, E_{gas}~3 kV/cm
- 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



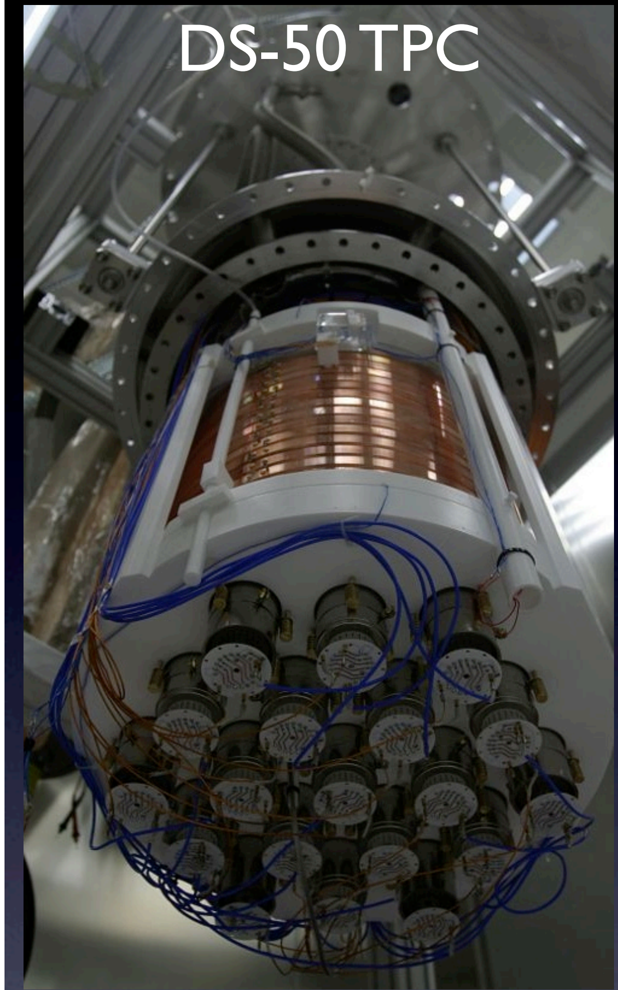
T.Alexander et al. arXiv 1204.6218

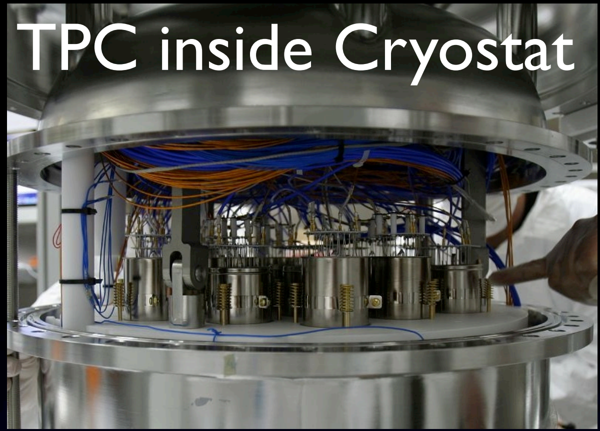
LY=8.78 ± 0.01 p.e./keVee @ null field, gas pocket present

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





DS50-TPC Assembled, Deployed

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

TPC hanging in LSV

View inside the Water Cherenkov

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 commissioning run

- Instrument all PMT bases with in-liquid pre-amps
- Install super-low radioactivity silica windows
- Fix some heat leaks in the argon transfer lines
- Continuing improvements to the Trigger and DAQ

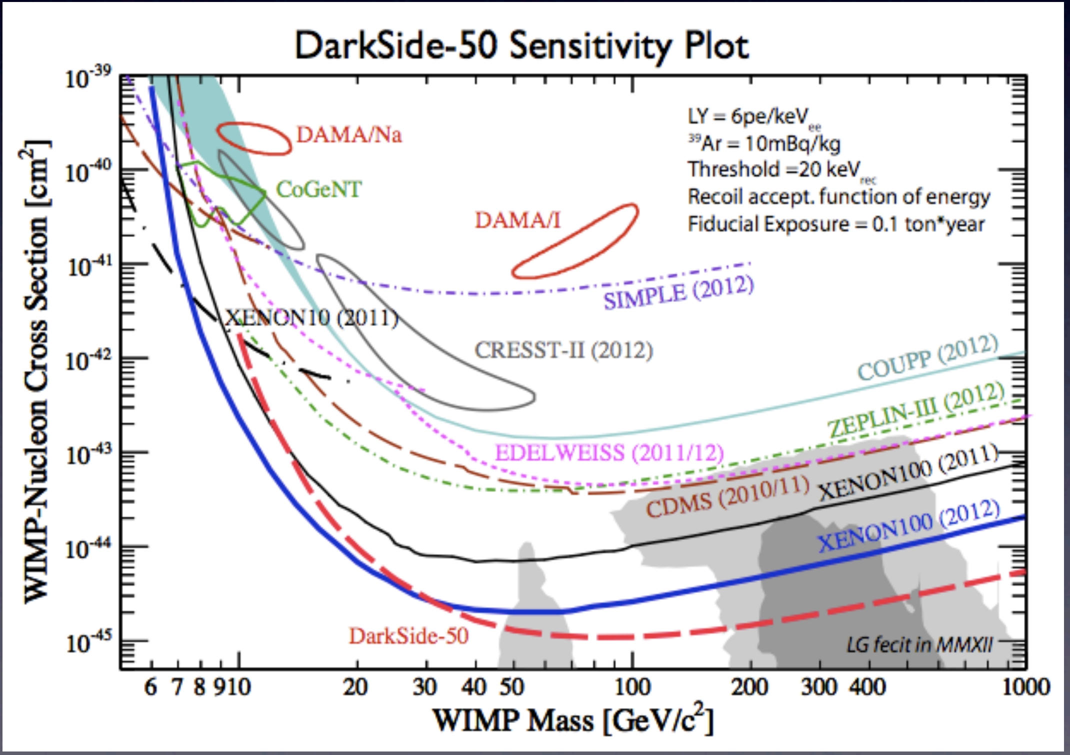
DS-50 Schedule

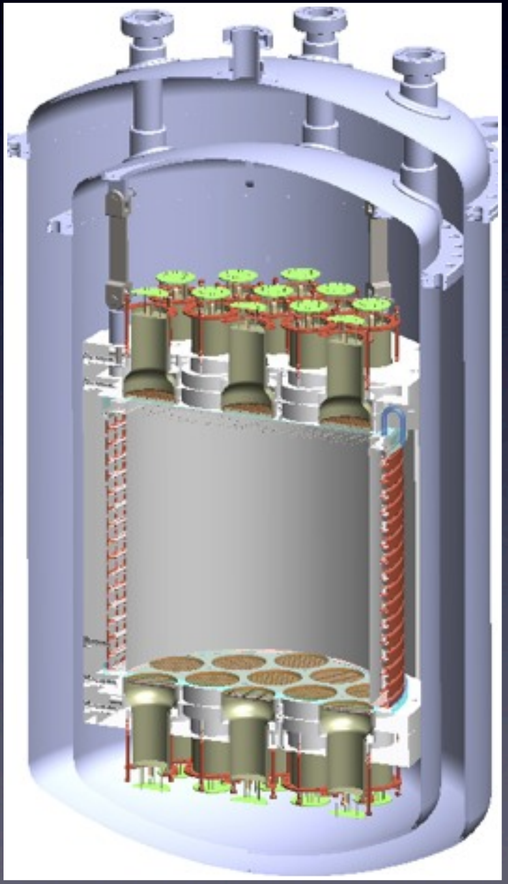
- 1st TPC test run (atm argon) ended June
- 2nd TPC test run starting now (atm argon)
- Fill Neutron Veto and Water Tank by end September
- Concentrate on background rejection performance
- Low radioactivity underground argon towards end of year

DS-50 projected sensitivity

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

Total: 50 kg
Fiducial: 33 kg

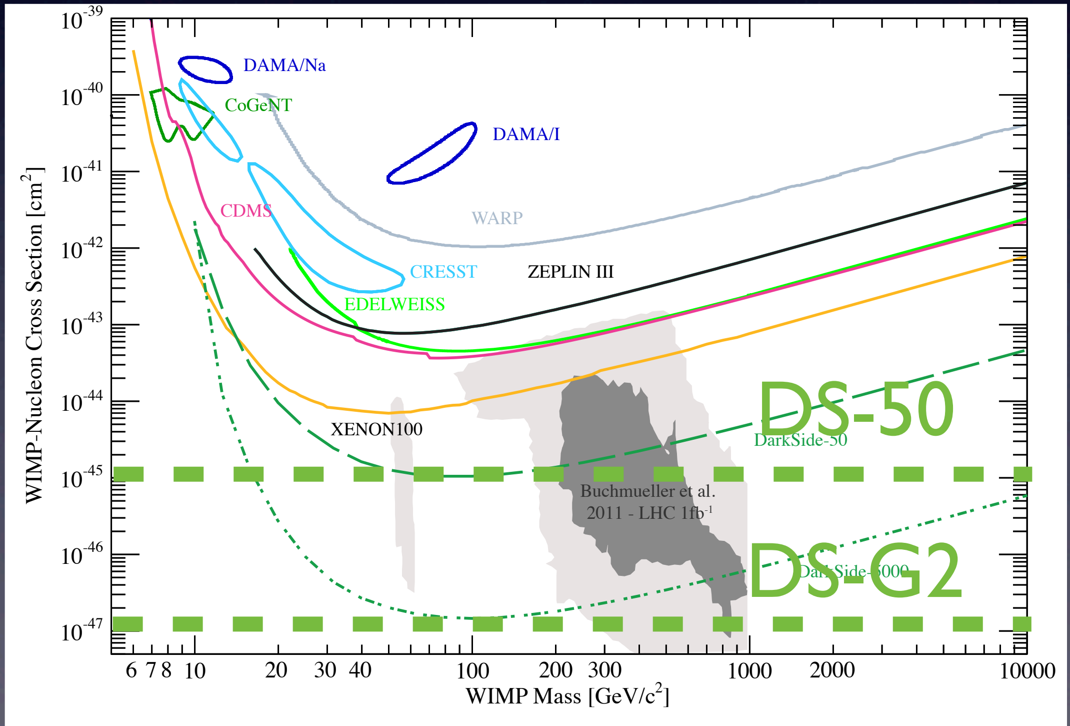


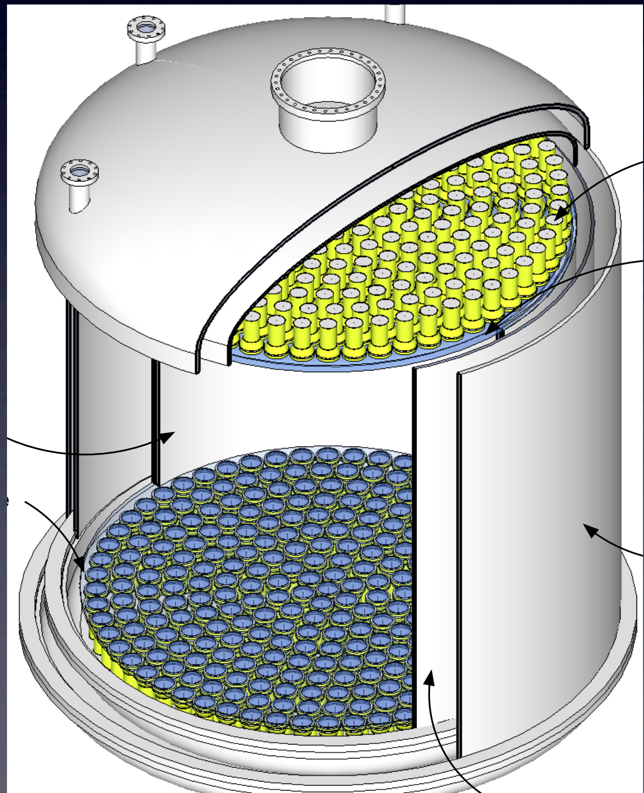


DS-G2 projected sensitivity

$\sigma = 1 \times 10^{-47}$ 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

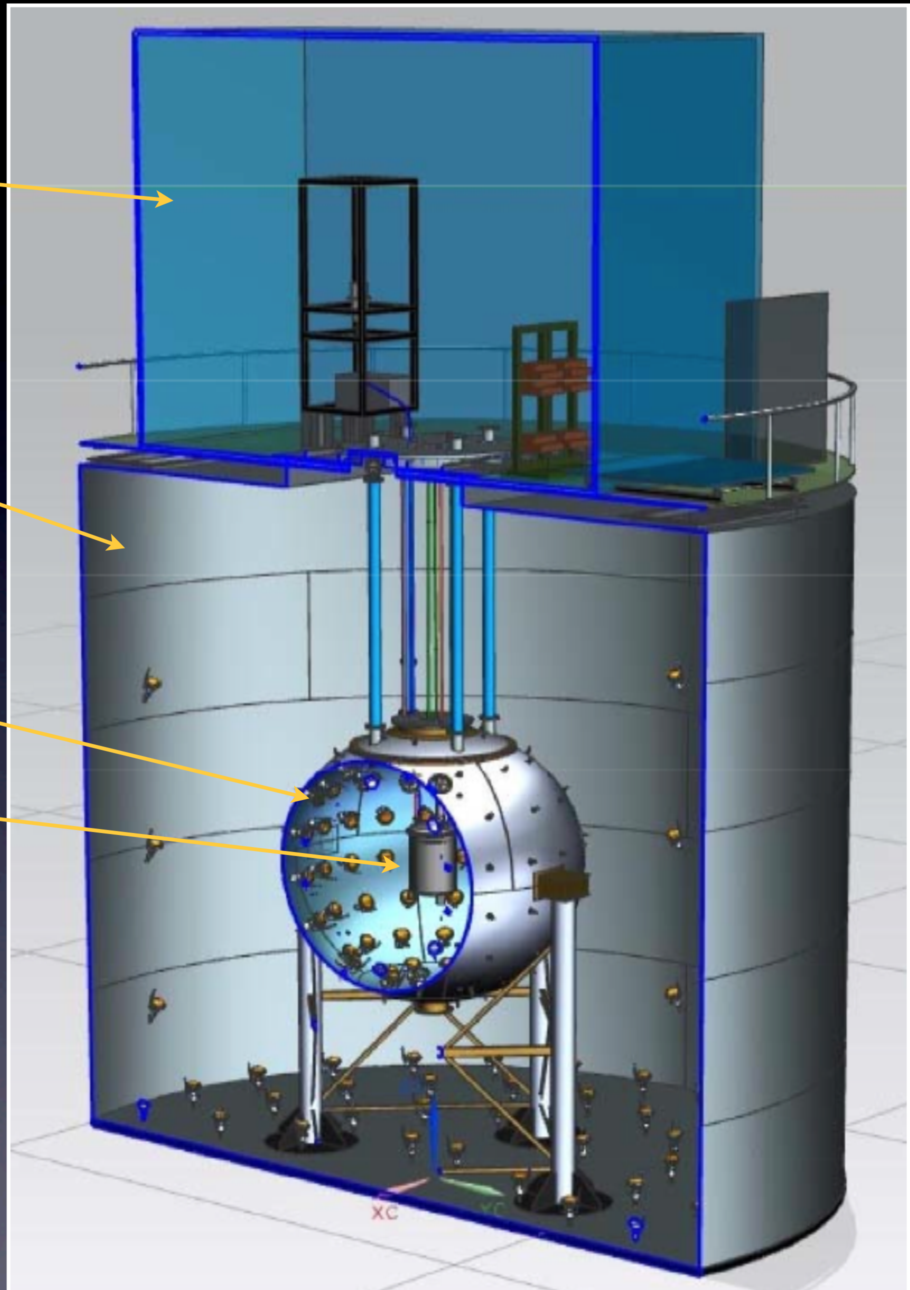
Backup

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)

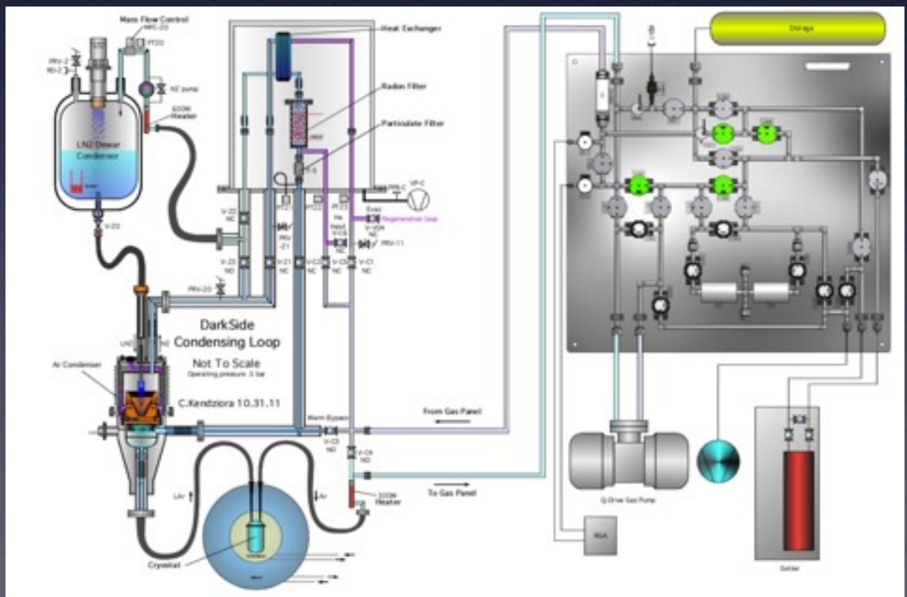
WIMP LAr detector
150 kg of UAr < 6.5mBq/kg
(DS-50 TPC)



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



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	2.5×10^{7}	$<1\times10^{-2}$	–	–	–	–
Fused Silica	3.6×10^{5}	1.4×10^{-4}	1.8	4.5×10^{-3}	2.3	1.4×10^{-4}
PTFE	306	1.2×10^{-7}	0.024	6.0×10^{-5}	0.17	1.0×10^{-5}
Copper	2,146	8.6×10^{-7}	0.0024	6.0×10^{-6}	0.72	4.3×10^{-5}
QUPIDs	7.0×10^{4}	2.8×10^{-5}	0.31	7.8×10^{-4}	0.34	2.0×10^{-5}
R11065 PMTs	2.6×10^{6}	1.0×10^{-3}	19.4	4.9×10^{-2}	0.34	2.0×10^{-5}
Titanium	2.4×10^{4}	9.6×10^{-6}	1.1	2.8×10^{-3}	13	7.7×10^{-4}
Veto Scintillator	70	2.8×10^{-8}	0.030	7.5×10^{-5}	26	0.0015
Veto PMTs	2.5×10^{6}	1.0×10^{-3}	0.023	5.7×10^{-5}	–	–
Veto tank	1.7×10^{5}	6.8×10^{-5}	6.7×10^{-5}	1.7×10^{-7}	19	0.0076
Water	6,100	2.4×10^{-6}	6.7×10^{-4}	1.7×10^{-6}	19	0.0076
CTF tank	8,300	3.3×10^{-6}	3.5×10^{-3}	8.7×10^{-6}	0.068	2.7×10^{-5}
LNGS Rock	920	3.7×10^{-7}	0.061	1.5×10^{-4}	0.31	0.012
Total	–	1.1×10^{-2} (1.2×10^{-2})	–	0.0082 (0.056)	–	0.030 (0.030)

TABLE I: A summary of the expected electron- and neutron-recoil backgrounds in 0.1 ton-yr of data from DarkSide-50 before and after applying the background rejection cuts described in the text (all units are events/(0.1 ton-yr)). The ^{39}Ar rates are given for the gas collected at Cortez (depletion factor of 25 or more). The "Total" row assumes the configuration with QUPIDs (numbers in parenthesis apply to the initial configuration with R11065 PMTs). Note that the majority of the entries in this Table are based on limits on, rather than measurements of, the radioactive contaminants in the different detector component materials.

Why Boron-loading?

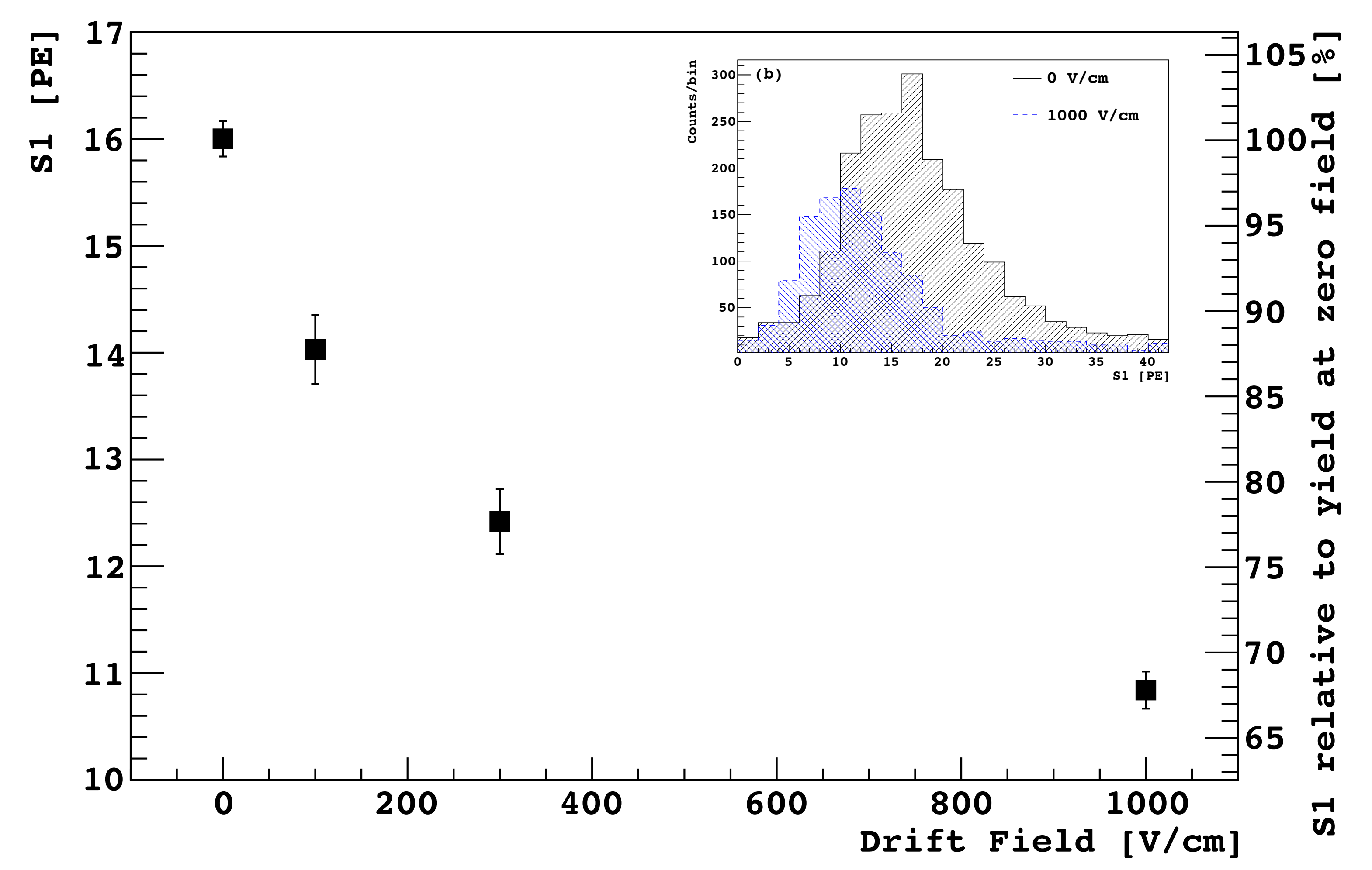
- High capture cross section on ^{10}B via

  $^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha \rightarrow {}^{7}Li + \alpha + 478\ \mathrm{keV}\ \gamma$ (93.7%)

  $\rightarrow {}^{7}Li + \alpha$ (6.4%)

- Recoil products can be detected directly (~50 keVee)
  - No need to contain neutron capture gamma rays
  - Makes smaller vetoes more efficient
- "Outcompete" neutron capture on inner detector components
- Reduce neutron capture time (~2 μs in boron scintillator vs. ~250 μs in pure scintillator)
  - Smaller veto windows reduces dead time from veto background rate
  - Allows simpler construction (e.g. 8" glass PMTs)
- Radiopure, optically efficient tri-methyl borate loaded scintillator was demonstrated for Borexino

Nuclear recoil scintillation yield for 11 keV vs drift field (SCENE)



We observe a clear dependence of Scintillation light from Nuclear Recoils in Liquid Argon on Drift Field