

Search for WIMP Dark Matter Particles with the DarkSide Detector

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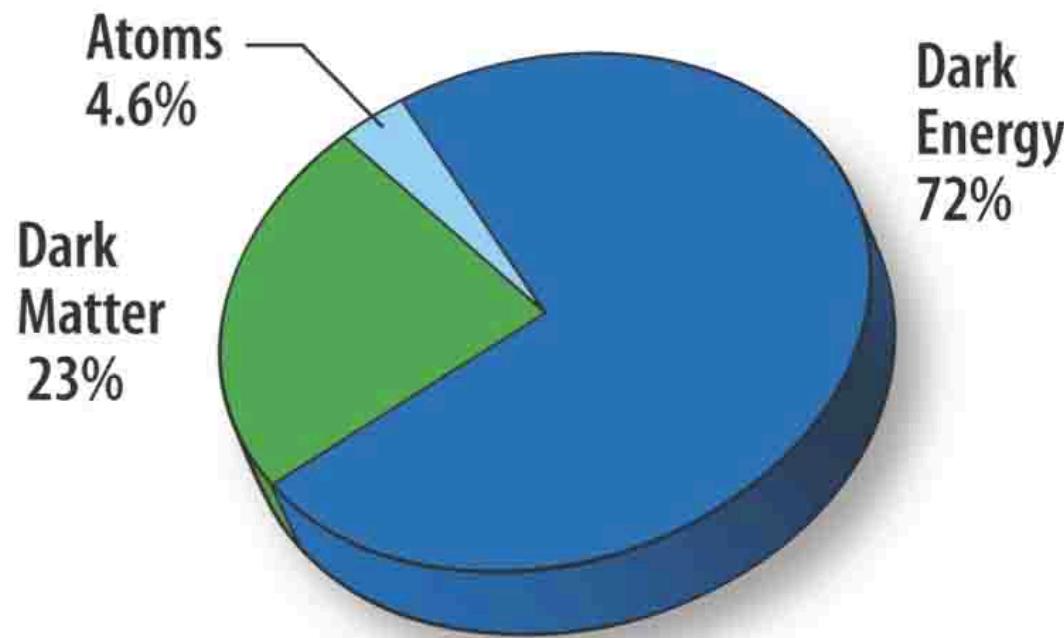
DarkSide Collaboration

NPB2012, Shenzhen, China

Existence of Dark Matter

- Galaxy Rotation Curve: Spiral galaxies
- Gravitational Lensing Effect: bullet cluster
- Wilkinson Microwave Anisotropy Probe: power spectrum

Composition of the Universe



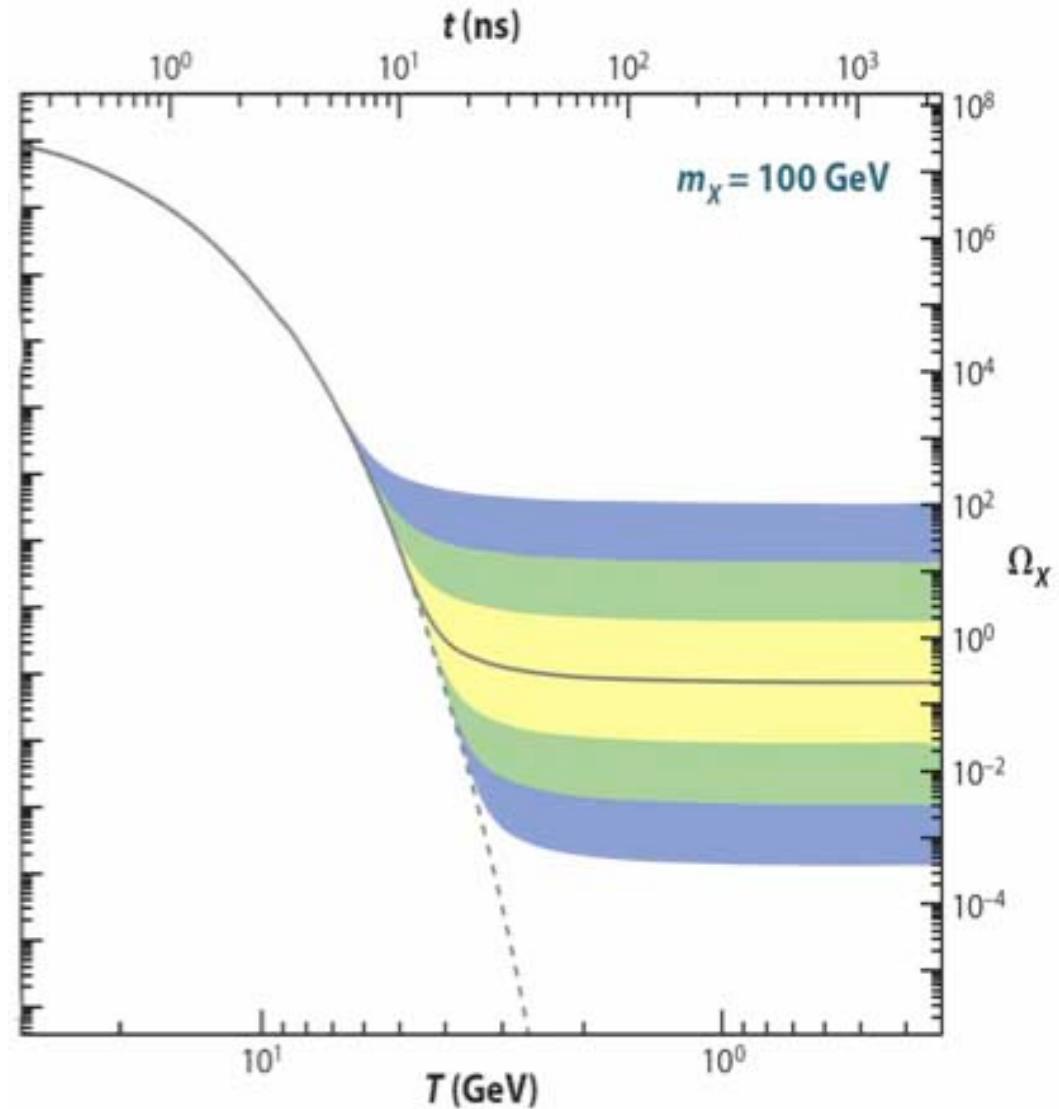
Weakly Interacting Massive Particle (WIMP)

Particle explanation
of dark matter.

WIMP miracle

Galaxy dark matter is
the thermal relics
of the big bang.

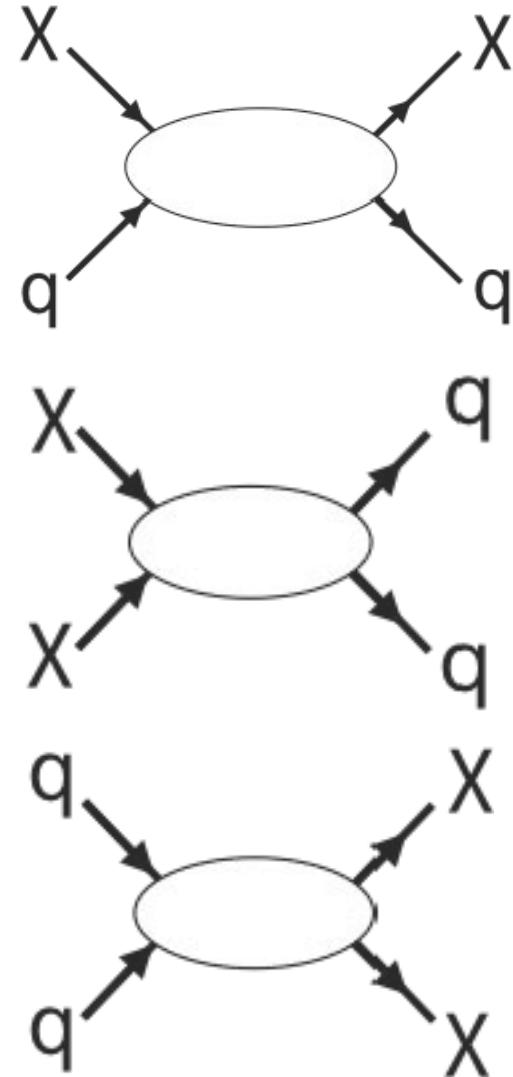
- Mass $\sim G_F^{-1/2}$
 $\sim 100\text{GeV}$
- Cross section
 $\sim < 10^{-44} \text{ cm}^2$
- Relic Density
 $\sim 0.3\text{GeV/cm}^3$



Search for WIMP Dark Matter

- Direct Search

WIMPs scatter with matter



- Indirect Search

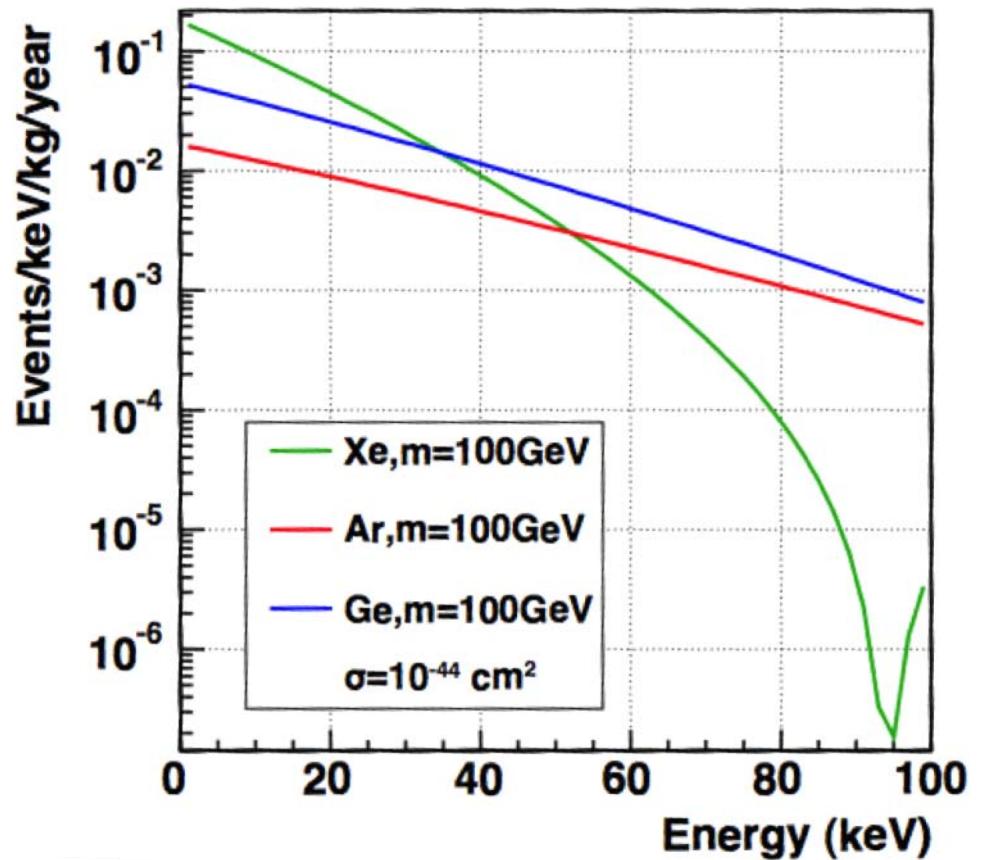
WIMPs annihilate in to matter

- Production in Accelerators

Matter annihilates into WIMPs

Challenge in Direct Search Experiments

- Low energy threshold
 $\sim < 100 \text{ keV}_r$
- small cross section
→ Large target mass needed
- Estimated signal rate
 $< 100 \text{ events/ton/yr}$
- Background rate:
U, Th, K: gamma, alpha, n
dust: $\sim 7000 \text{ events/mg/year}$
Cosmogenic Radioactivity
 $\sim 200 \text{ muon/m}^2/\text{s}$ at surface



The DarkSide Approach

DARCSIDE:

Depleted ARgon Chamber Sintillation&Ionization DEtection

- Two phase Argon Time projection chamber (TPC):
Combine scintillation to ionization (S1/S2) discrimination
from TPCs with pulse shape discrimination (PSD) from argon
scintillation
- Underground argon:
reduce intrinsic ^{39}Ar background by a factor of >150
- Active veto system:
greatly reduce radiogenic and cosmogenic neutron background
Measure background event rate in-situ

China



Institute of High Energy Physics, Beijing

Italy



Laboratori Nazionali del Gran Sasso, Assergi
Università degli Studi and INFN, Genova
Università degli Studi and INFN, Milano
Università degli Studi and INFN, Perugia

Università degli Studi Federico II and INFN, Napoli

Poland



Smoluchowski Institute of Physics, Krakow

Russia



Joint Institute for Nuclear Research, Dubna
Skobeltsyn Institute for Nuclear Physics, Moscow
National Research Centre Kurchatov Institute, Moscow
St. Petersburg Nuclear Physics Institute, Gatchina

Ukraine



Institute of Nuclear Research, Kiev

United Kingdom



University College London, London

United States



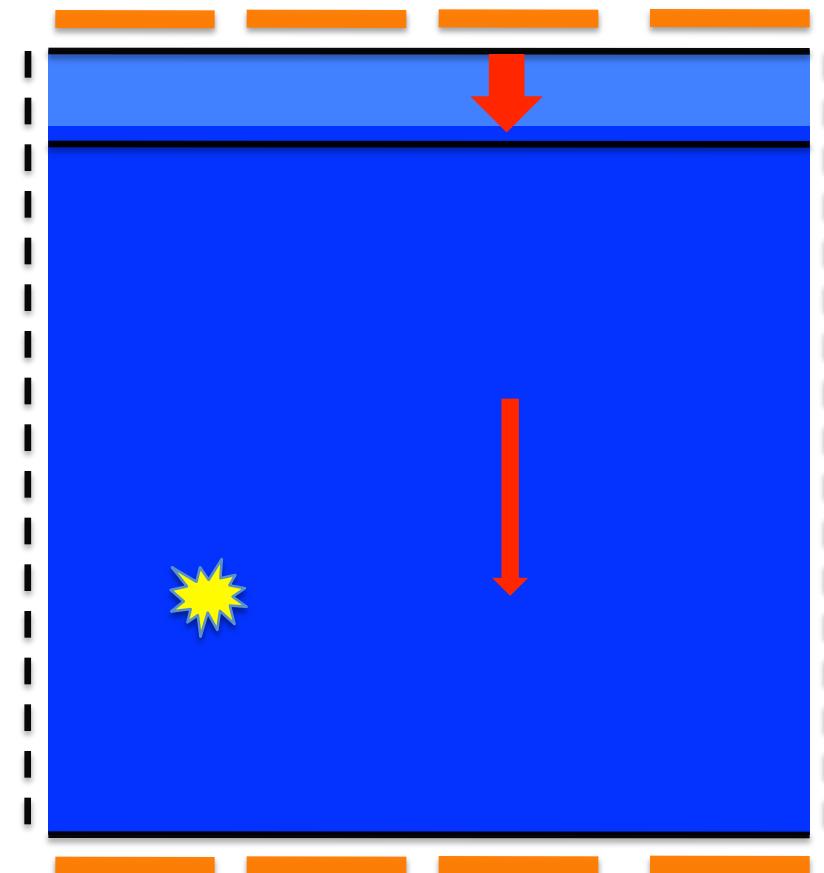
Augustana College, SD
Black Hills State University, SD
Drexel University, PA
Fermi National Accelerator Laboratory, IL
Princeton University, NJ
Temple University, PA
University of Arkansas, AR
University of California, Los Angeles CA
University of Houston, TX
University of Massachusetts, Amherst, MA
Virginia Tech, VA

Argon TPC – Scintillation Signal

Excitation and recombination of ionization in liquid argon produce UV scintillation light ($\sim 128\text{nm}$).
 $\sim 40\text{photons/keV}$

The scintillation light is wavelength-shifted into visible range and then gets recorded by PMTs

Scintillation signal proportional to event energy



Scintillation Pulse Shape Discrimination

Liquid Argon Scintillation: fast component (6-7ns)

Fast to slow

scintillation
amplitude
depends on
ionization
density

Electron/gamma:

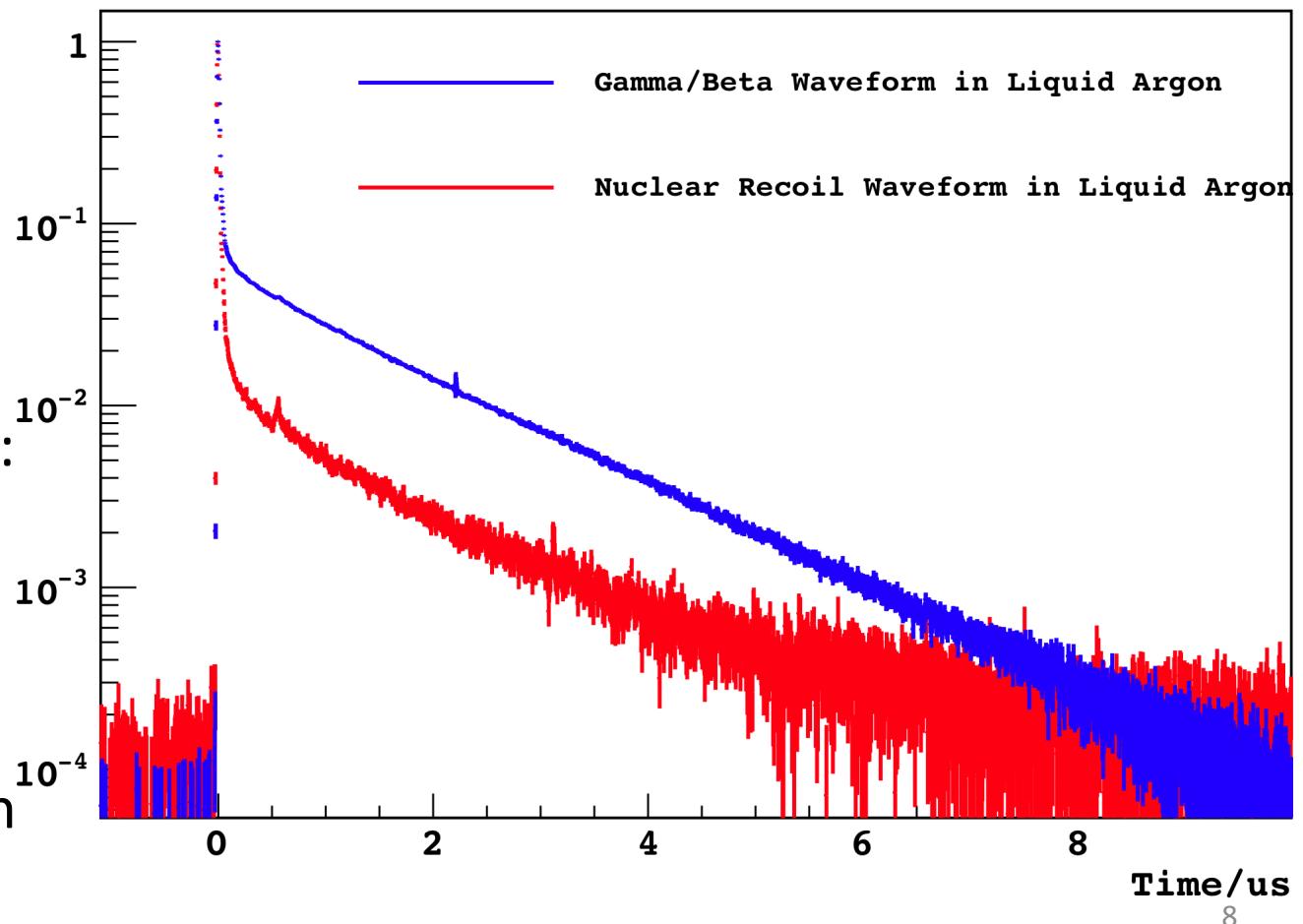
~1:3

Nuclear Recoil:

~3:1

$10^8\text{-}10^9$ Rejection

slow component (1.5-1.6us)



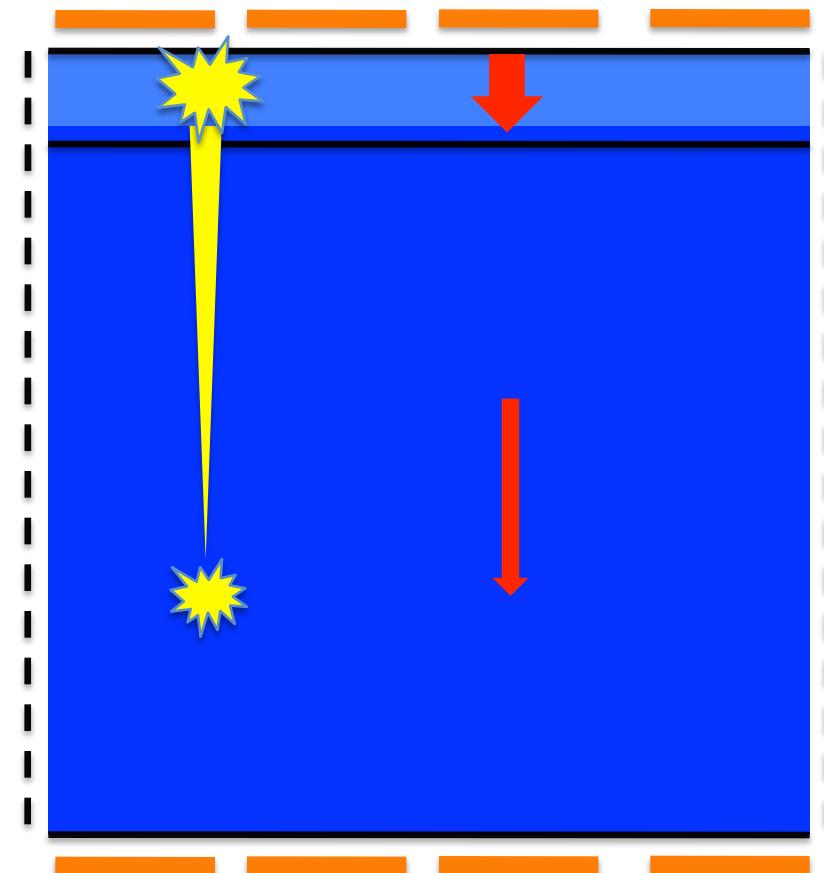
Argon TPC – Ionization Signal

An uniform electric field is applied to the argon volume using a field-shaping circuit

Remaining ionized electrons are drifted upwards to the gas phase.

An extraction field extracts electrons into the gas phase

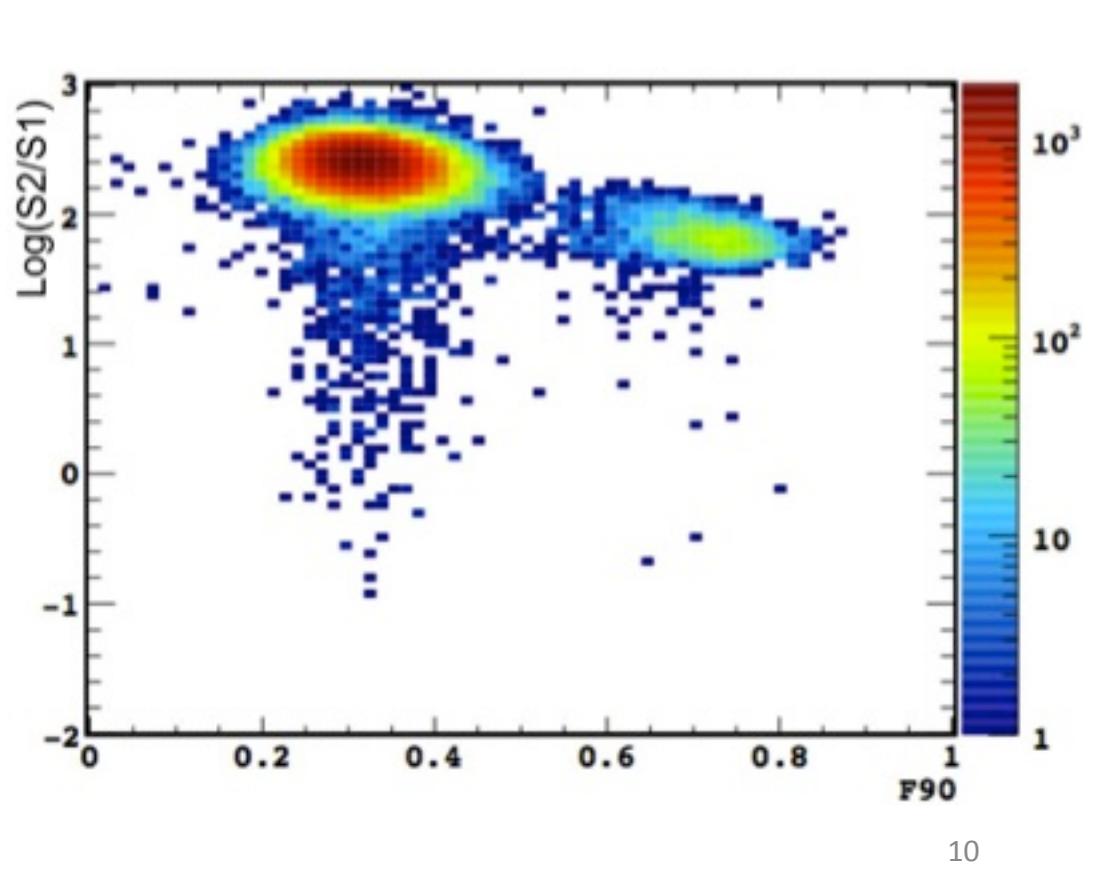
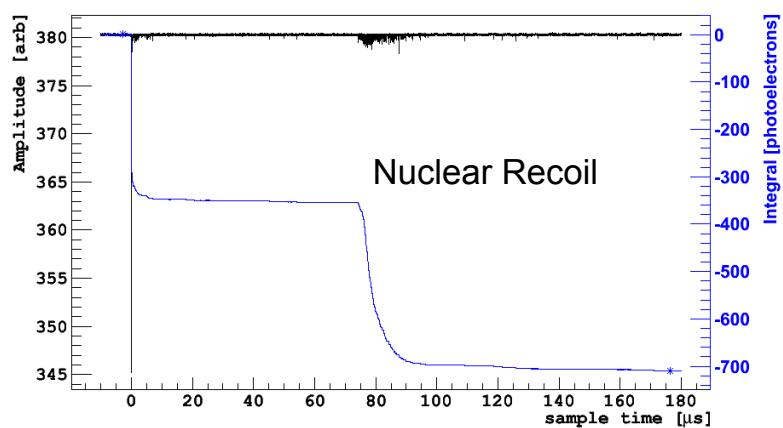
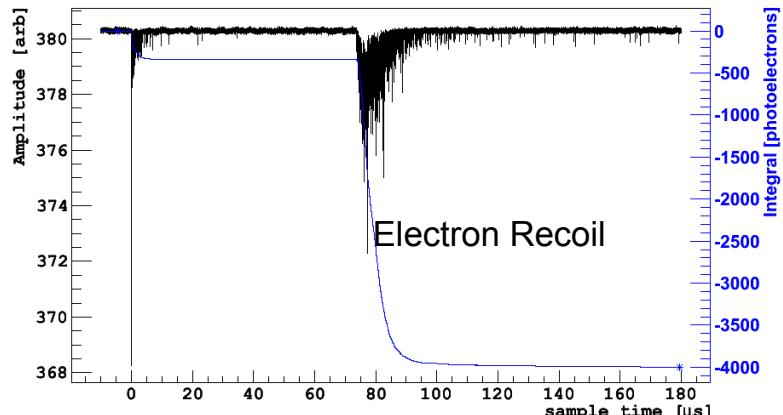
A multiplication field Accelerate electrons and produce argon gas scintillation light.



Ionization-Scintillation Discrimination

The recombination probability depends on the ionization density, and thus on the particle species.

Rejection power: 10^2 — 10^3



^{39}Ar Background

~1% of the atmosphere is argon.

Radioactive argon isotope ^{39}Ar in atmospheric argon:



$Q=565\text{keV}$, half life = 269yr

Production in the atmosphere

^{40}Ar ($n, 2n$) ^{39}Ar , mainly produced by cosmogenic neutrons

Equilibrium Rate:

$^{39}\text{Ar}/^{40}\text{Ar} \sim 8 \times 10^{-16}$, ~1 Bq/kg

Decay rate in a ton scale detector: $\sim 10^3$ Bq/kg, or 1ev/ms

Dimension of 1 ton detector: ~1m or ~1ms drift time

Events pileup due to the presence of ^{39}Ar could limit the size of liquid argon TPC to below 1ton

Argon from Underground Sources

Argon with low ^{39}Ar rate could be produced by centrifugation/thermal diffusion:

low production rate and high cost

Argon production underground



^{39}K (n, p) ^{39}Ar , (alpha, n), alpha from U, Th decays

^{40}Ar production rate \propto [K]

^{39}Ar production rate \propto ([U]+[Th]) \times [K]

Ratio $^{39}\text{Ar}/^{40}\text{Ar} \propto$ [U]+[Th]

U, Th concentration in continental crust: ~ppm

U, Th concentration in the mantle: ~ppb

^{39}Ar rate could be 1000 times lower in the mantle

Underground Argon Extraction



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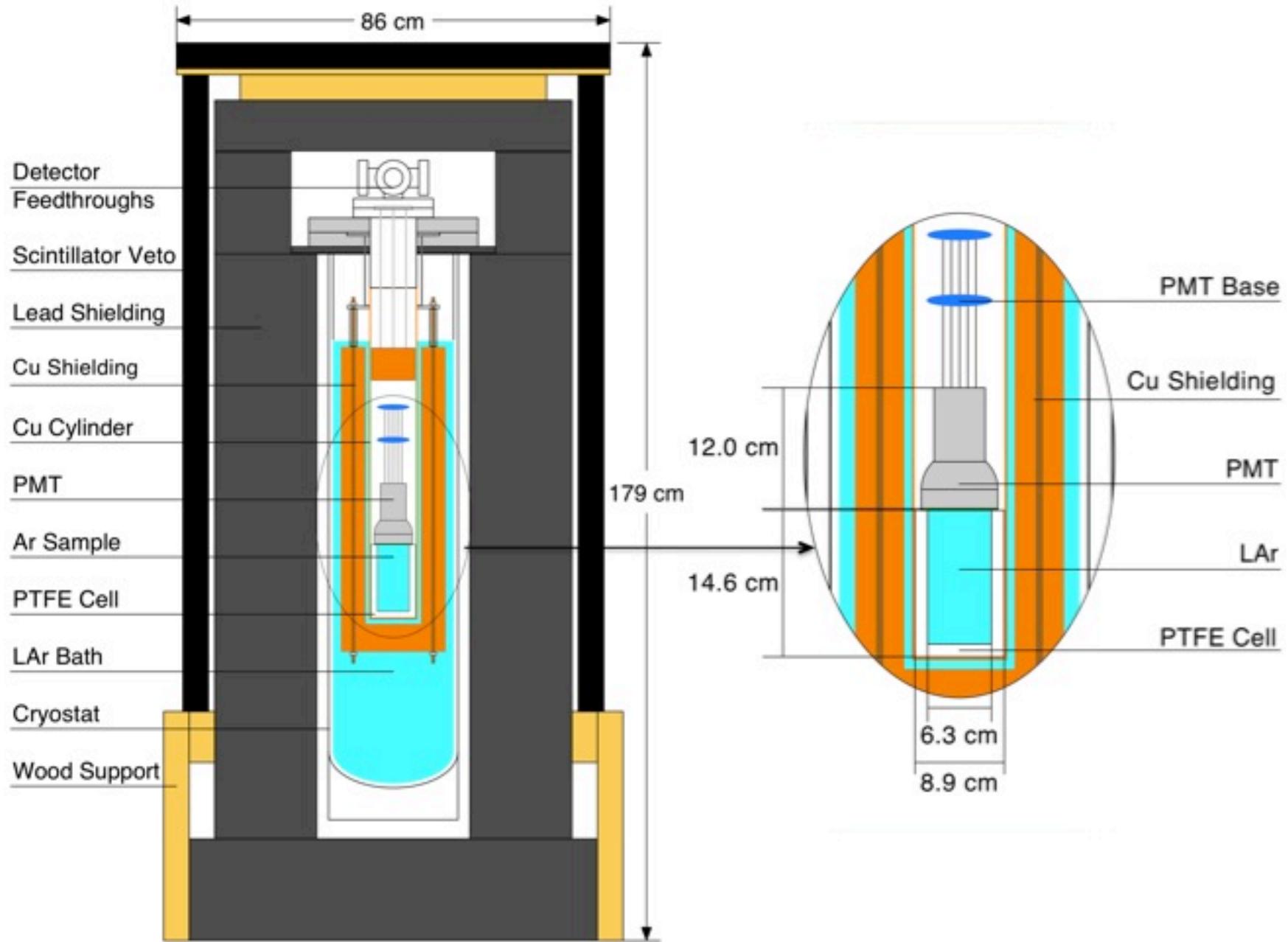


Vacuum Pressure Swing Adsorption

Cryogenic distillation

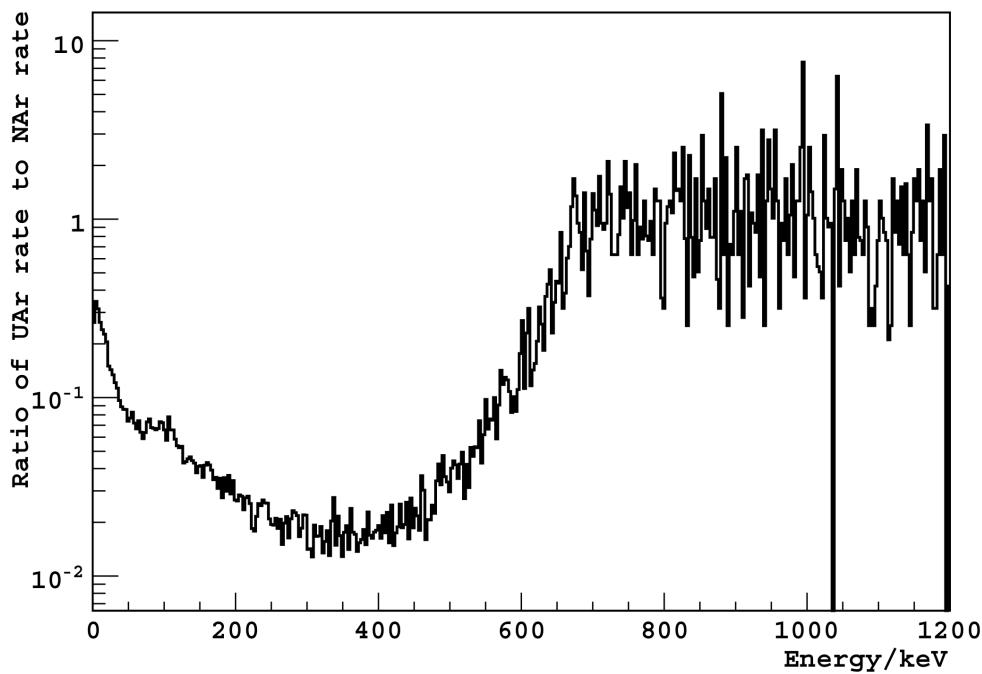
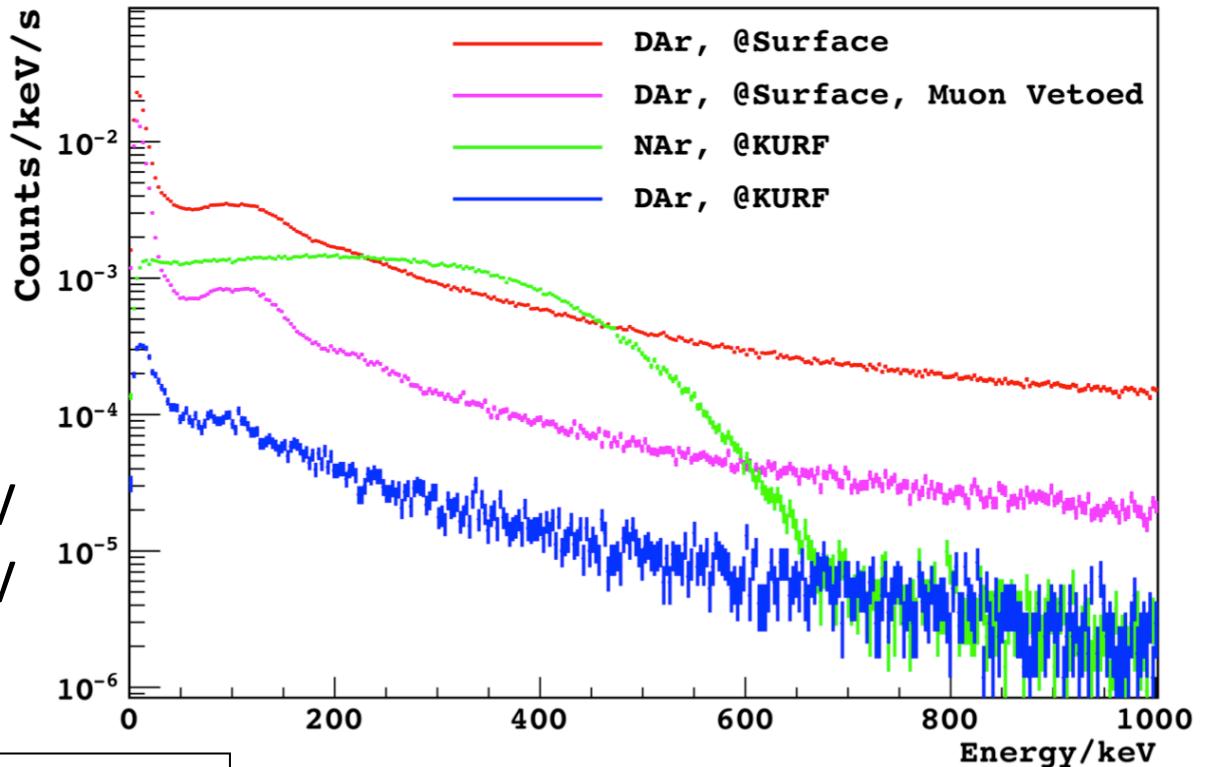
	CO ₂ [%]	N ₂ [%]	He [%]	Ar [%]
CO ₂ Plant Output	96	2.4	0.4	0.06
VPSA output	~ 0	40	55	5
Cryogenic Distillation output	~ 0	< 0.05	~ 0	> 99.95

Low Background Argon Detector



Energy Spectrum

Event rate in
underground argon
spectrum @KURF
 $\sim 2\text{mBq}$ in $(300, 400)\text{keV}$
 $\sim 20\text{mBq}$ in $(40, 800)\text{keV}$



Conservative Result from
direct rate analysis:
 $(1.71 \pm 0.05)\%$
assuming all is ^{39}Ar decay
ignoring background

^{39}Ar Results after background Subtraction

Estimated Background in the Detector:

Source	^{252}Cf	PMT	Base	Copper
Rate/mBq, (300, 400)keV	0.82 ± 0.16	0.29 ± 0.08	0.07 ± 0.02	0.41 ± 0.05

Event Rate in (300, 400)keV after Background Subtraction:

Underground argon data: 0.32 ± 0.23 mBq

Atmospheric argon data: 107.2 ± 1.9 mBq

Two sigma upper limit on the ^{39}Ar content in underground argon compared that in atmospheric argon:

0.65%

reduction factor of ~ 150

Active Scintillator Veto

- Active veto system:
 - Material purification/Passive shielding approaches to a limit
 - Background rejection & Background Measurement
- Pseudocumene (PC) + Tri-Methyl Borate (TMB), 1:1 mixture
 - ^{10}B , 20% BR, ~4000 barn neutron capture cross section
 - reduce capture time from ~250us to ~2.3us
- Reduce the size of the veto detector
 - $$\begin{aligned} ^{10}\text{B} + n &\rightarrow {}^7\text{Li (g.s.)} + \alpha \\ &\rightarrow {}^7\text{Li}^* + \alpha, {}^7\text{Li}^* \rightarrow {}^7\text{Li} + \gamma(478 \text{ keV}) \end{aligned}$$
 - (n, alpha) instead of (n, gamma) → small size adequate
 - ~50-60keV_{ee} energy deposition, ~30 p.e. well detectable

Schematic of the DS-50 Veto System

4m in diameter

110 8" PMTs

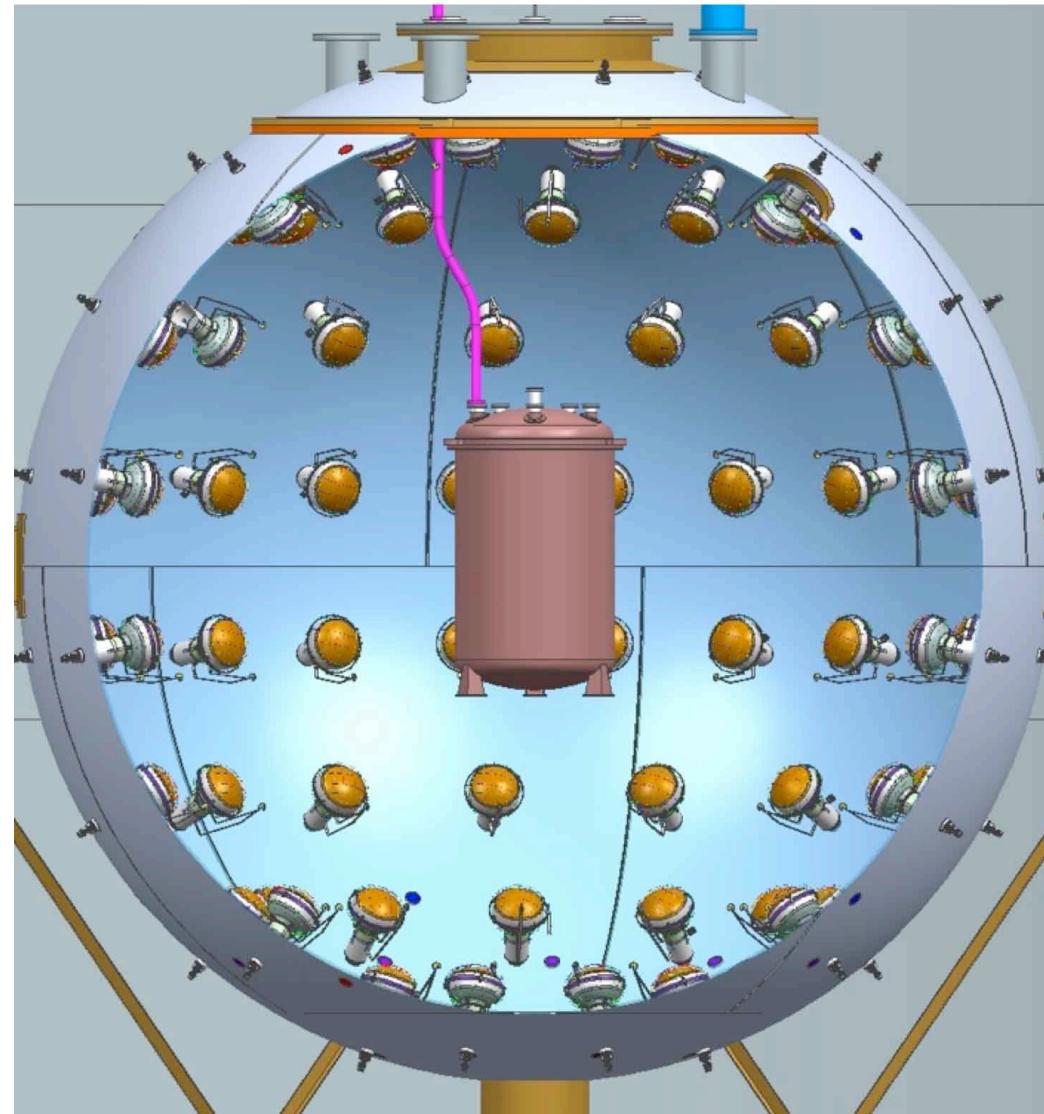
~7% Photocathode
coverage

50% PC + 50% TMB

PPO ~3g/L

Light yield required:
~0.5pe/keV

Confirmed with a 20L
test chamber
~1.5% photo-
cathode coverage



Veto Efficiency

Simulated veto efficiency: (60us veto window)

➤ Radiogenic neutrons: (alpha, n), fission neutrons

Typical energy <10MeV, Typical free path in LAr: ~15cm

Veto Efficiency: >99.5%

high detection efficiency + multiple hit cut + fiducial cut

➤ Cosmogenic neutrons:

High energy, low detection efficiency in LSV

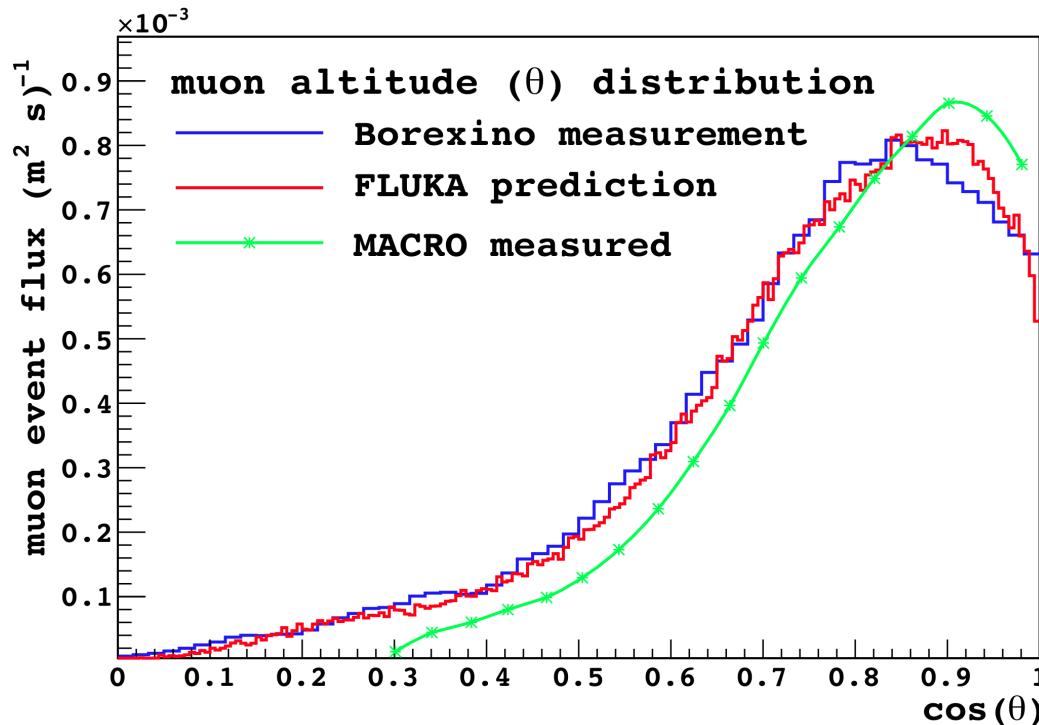
Veto Efficiency: >95%

Associated with muons → Higher detection efficiency if produced inside the detector

Cosmogenic Background

Fluka cosmogenic simulation + G4 detector simulation predicts
<0.1n/yr in ton scale detector with CTF water Cerenkov
detector + Liquid Scintillator Veto

Topology of Gran Sasso mountain and LNGS hall simulated
Combined simulation reproduces Borexino measurement



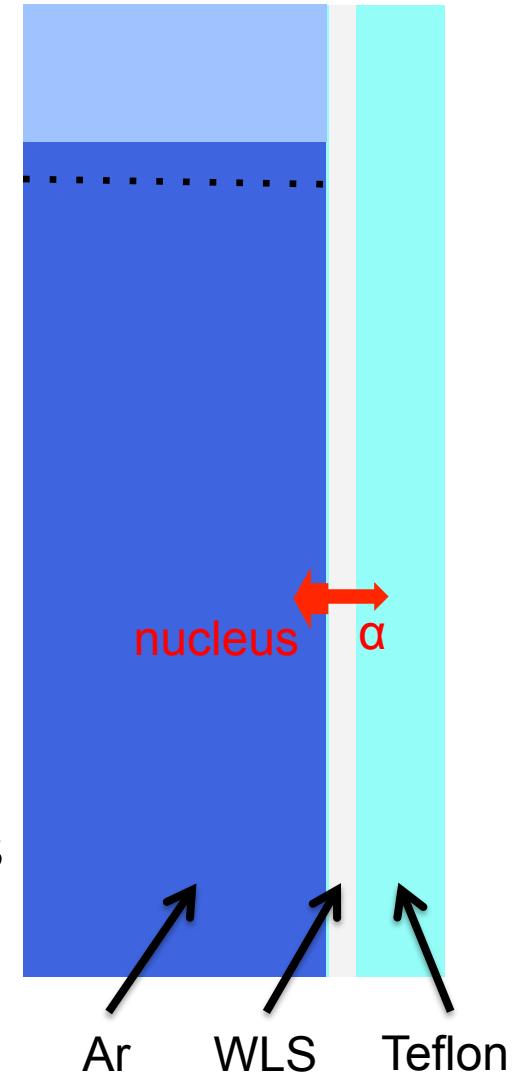
Surface Background Events

Radon and progenies on the detector surface

~10 decays/m²/day from Borexino and SNO
most above WIMP detection window

Surface Background Reduction Techniques:

- Assemble detector in Radon free clean room
- Remove events close to the surface with position reconstruction
- Implement a charge interception ring to block ionization signal or surface events
- Alpha scintillation in WLS changes the nucleus recoil waveform → PSD



DarkSide-10 Prototype

Prototype with ~10kg sensitive volume

7x2 Hamamatsu R11065 PMTs

Stable two phase operation

Printed field cage + ITO coated quartz cathode/anode

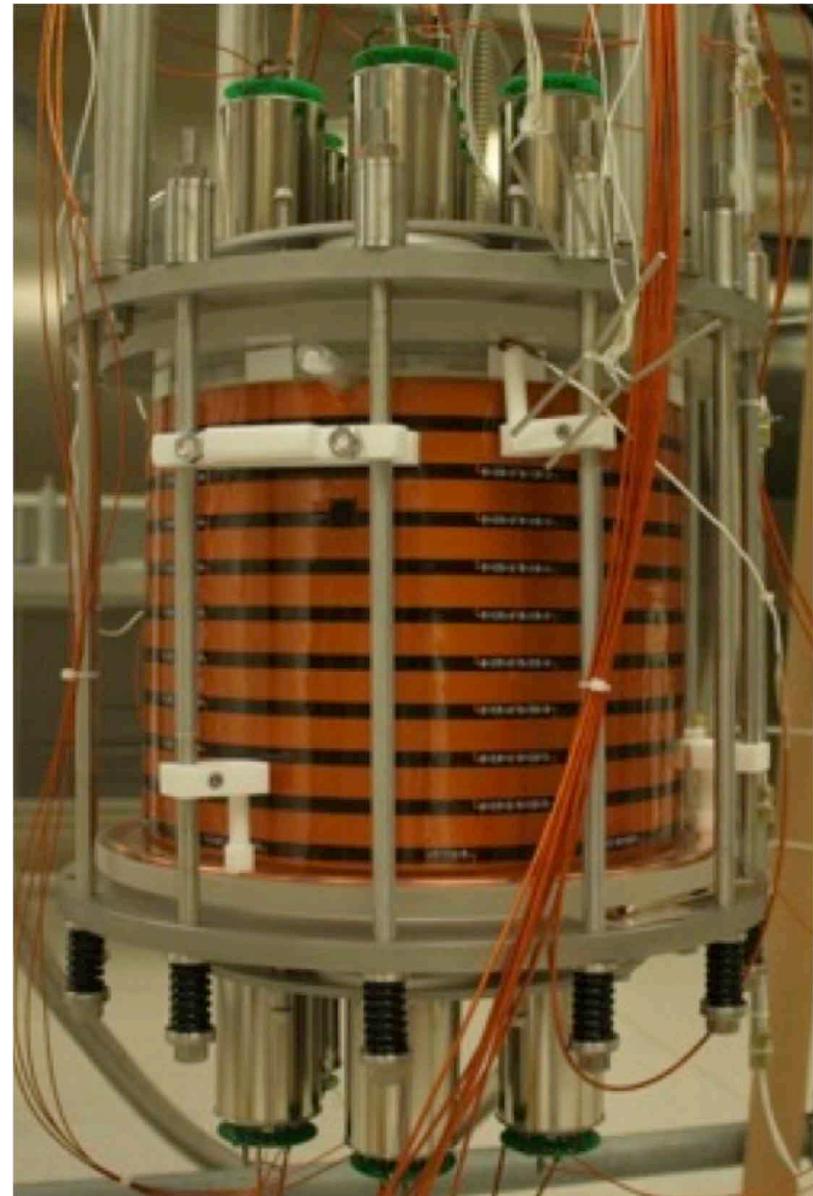
1kV/cm drift field, 3kV/cm extraction field

35kV HV system

High light yield at null field:

~9 p.e./keV for 3M foil

~7 p.e./keV for PTFE



DarkSide-50

~50kg Underground Argon

~30kg fiducial volume

19x2 3" Hamamatsu PMTs

Highly Crystalline PTFE Reflector

TPB wavelength shifter

Copper field cage

Quartz+ITO windows

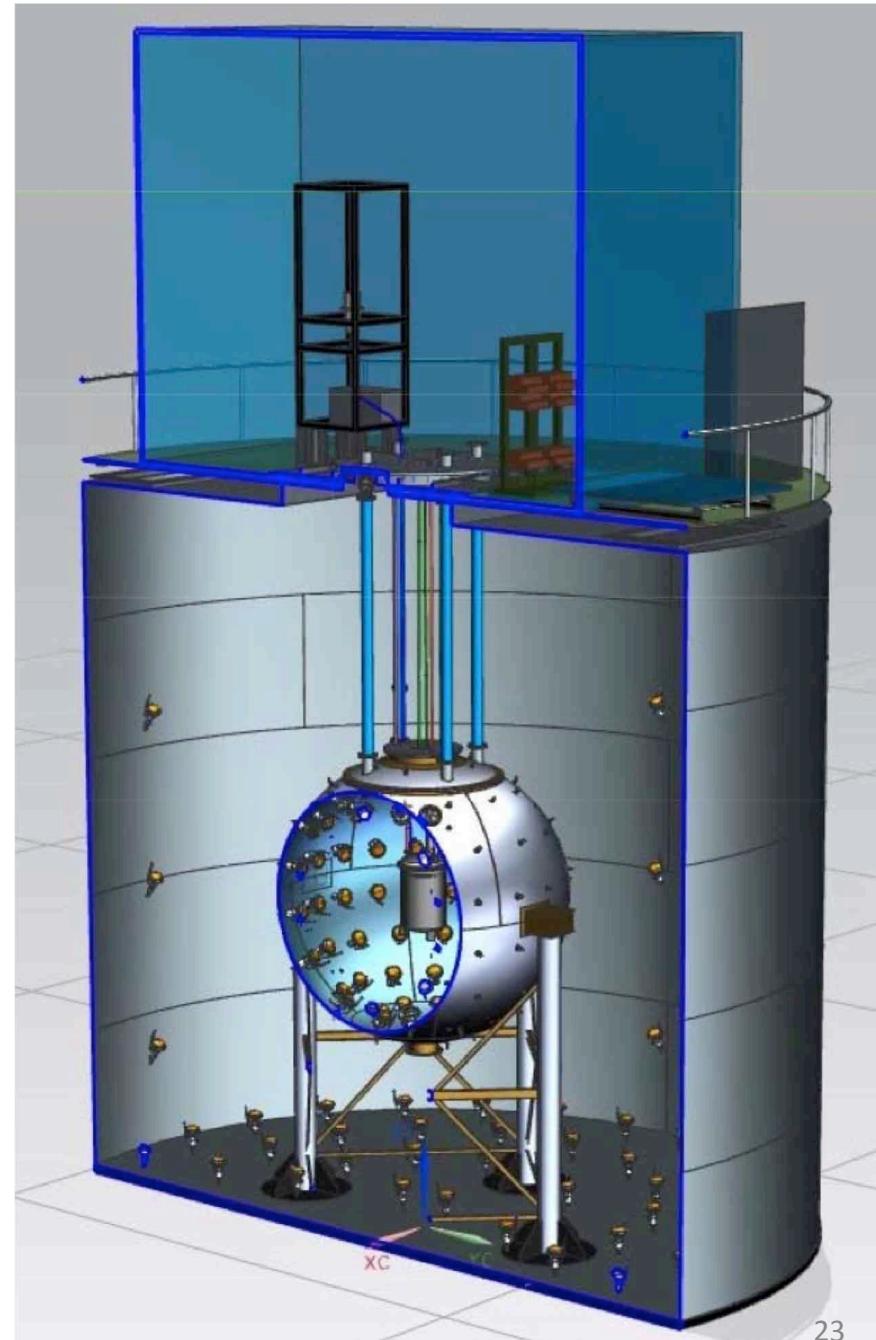
Scintillator Veto

110 8" PMTs

CTF water tank veto/shielding

80 8" PMTs, 11mx10m

Gran Sasso Lab, Italy

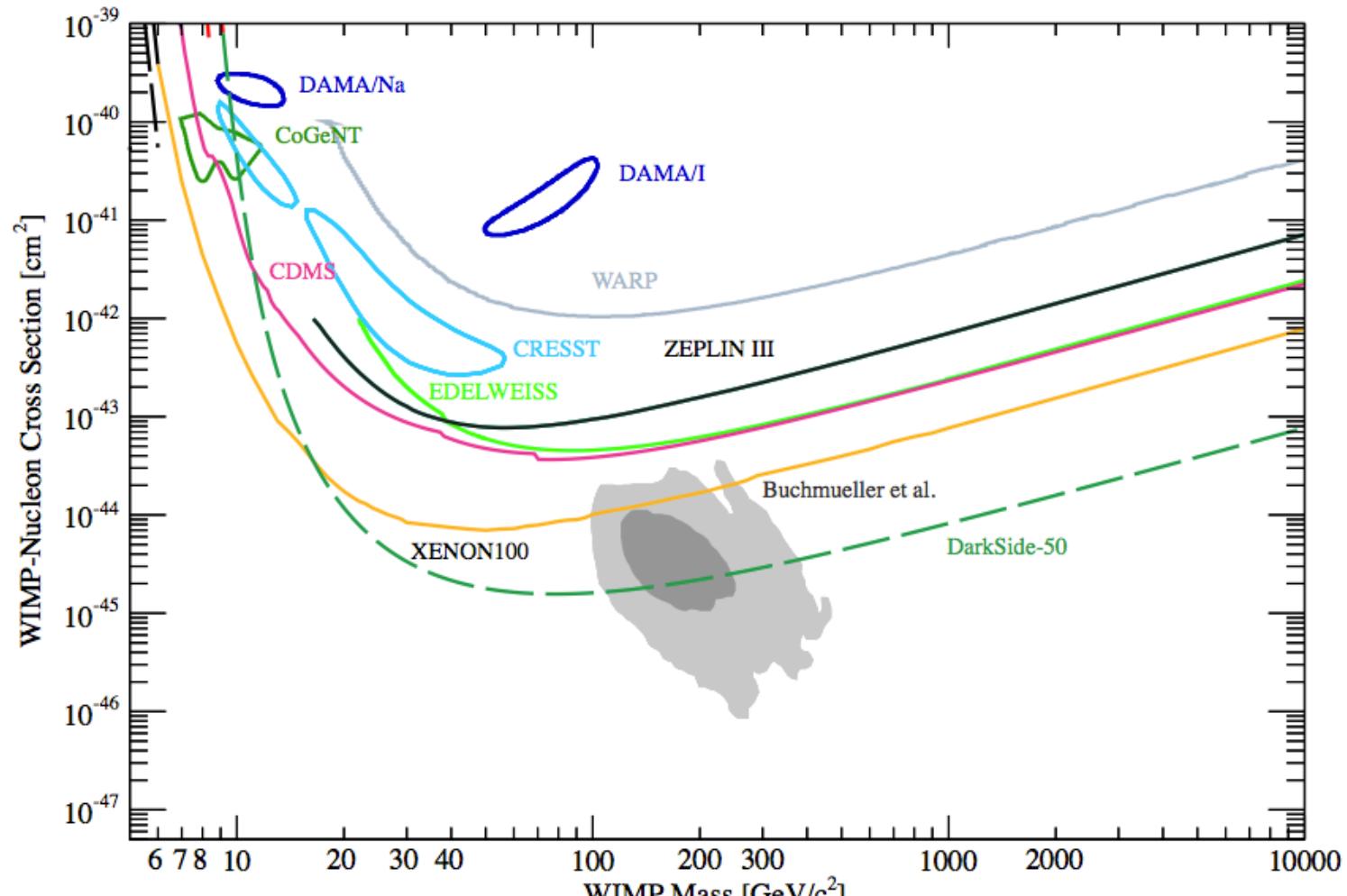


Expected Background in DS-50

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)	$<6.3 \times 10^6$	$<4 \times 10^{-3}$	—	—	—	—
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

3 year operation, 0.1ton x year exposure, 30keV_r-200keV_r energy window, 50% acceptance for nuclear recoil events

Expected Sensitivity of DS-50



3 years operation, 0.1 ton x year exposure

DarkSide ton-scale Detector (DS-G2)

~2m outer diameter

~5tons of underground argon

~3.3tons active, ~2.8 fiducial

279x2 3" PMTs

48% photocathode coverage

Highly crystalline PTFE Reflector

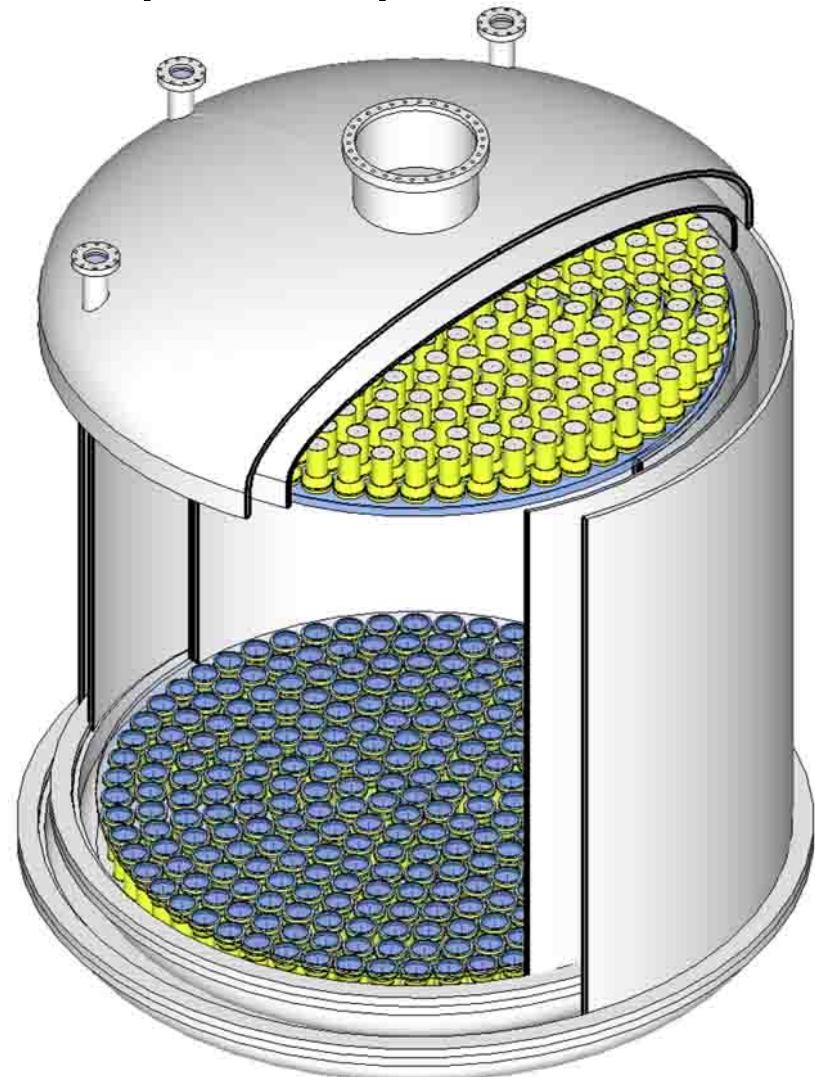
Cu field cage

ITO coated Fused silica plates

Scintillator Veto

Borexino CTF water tank

shielding/veto

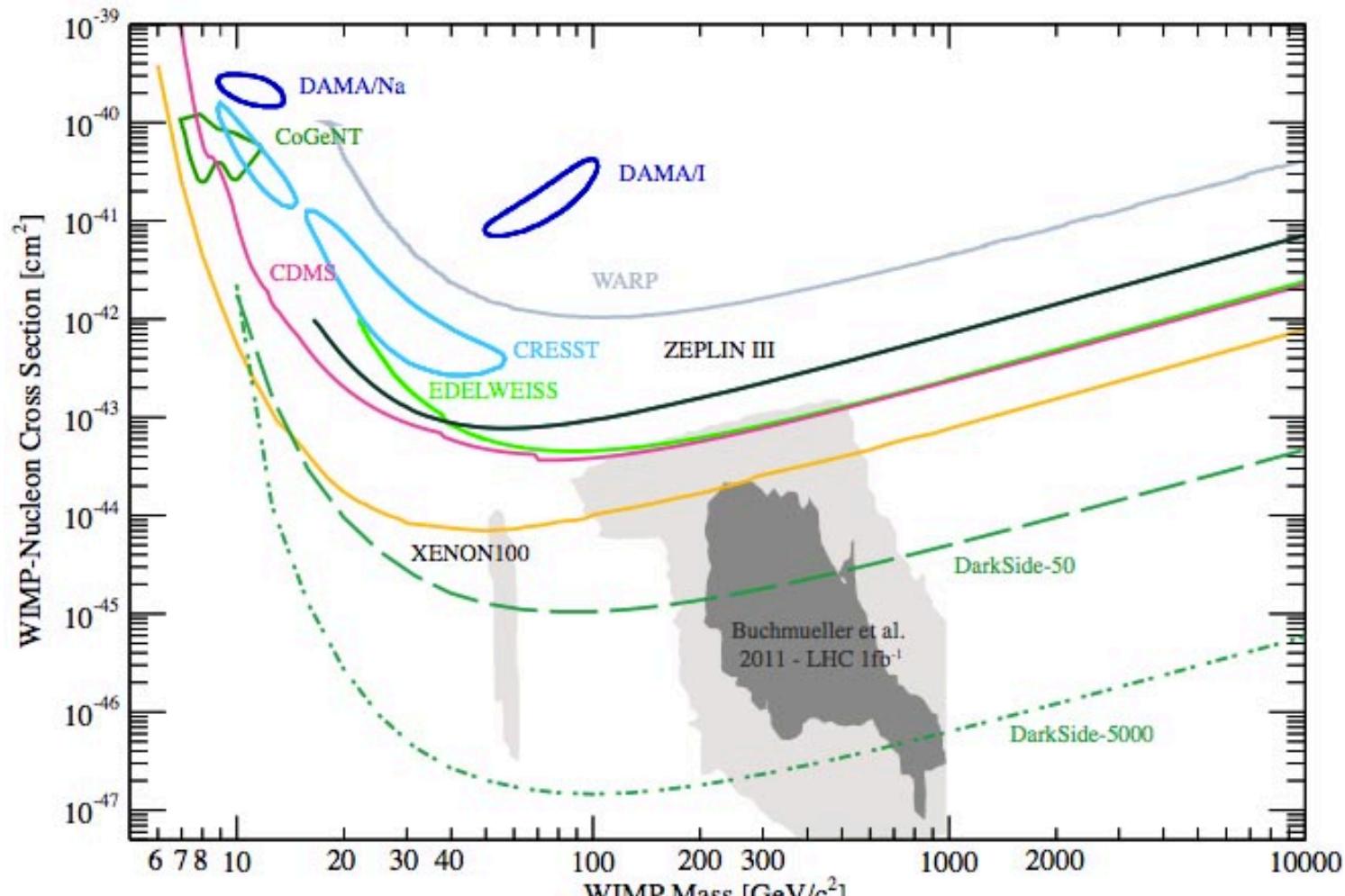


DS-G2 Background Estimation

Background Free operation Expected.

- ^{39}Ar background and Gamma Ray Background
 - PSD + S1/S2 + energy threshold
 - $6.5\text{mBq} + 6\text{p.e./keV} \rightarrow >30\text{keV}_r$
 - $1\text{mBq} + 9\text{p.e./keV} \rightarrow >20\text{keV}_r$
- Radiogenic neutron background:
 - LSV + multiple hit cut + fiducial cut: $<0.1\text{n/yr}$
- Cosmogenic neutron background:
 - Water Cerenkov detector + LSV: $<0.1\text{n/yr}$
- Surface Background: Expected to be low

Expected Sensitivity of DS-G2



5 years operation, ~ 14 ton \times year exposure

Timeline of the DarkSide Project

Summer 2012: Liquid Scintillator Veto -- Completed

Fall 2012: Complete construction of DS-50 Inner detector

Winter 2012: DS-50 Commissioning

2014: Complete design of DS-G2

2015: Start construction of DS-G2

Thank you!