

Fermilab



DarkSide-50: status of the detector and results

Yann Guardincerri on behalf of the DarkSide Collaboration

August 6th, 2016



DarkSide-50 Collaboration

● USA

- Augustana University
- Black Hills State University
- University of Chicago
- University of Hawaii
- University of Houston
- University of Massachusetts
- Princeton University
- Temple University
- UC Davis
- UCLA
- Virginia Tech
- FNAL, LANL, LLNL, PNNL, SLAC

● France

- APC Université Paris 7 Diderot
- LPNHE Paris
- Université de Strasbourg

● Italy

- INFN LNGS
- Gran Sasso Science Institute
- INFN and Università degli Studi
Cagliari, Genova, L'Aquila, Milano,
Napoli, Perugia and Roma 3

● Russia

- Joint Institute for Nuclear Research,
Dubna
- SINP, Lomonosov Moscow SU
- NRC Kurchatov Institute
- St. Petersburg NPI

● Brazil - Campinas

● China - IHEP

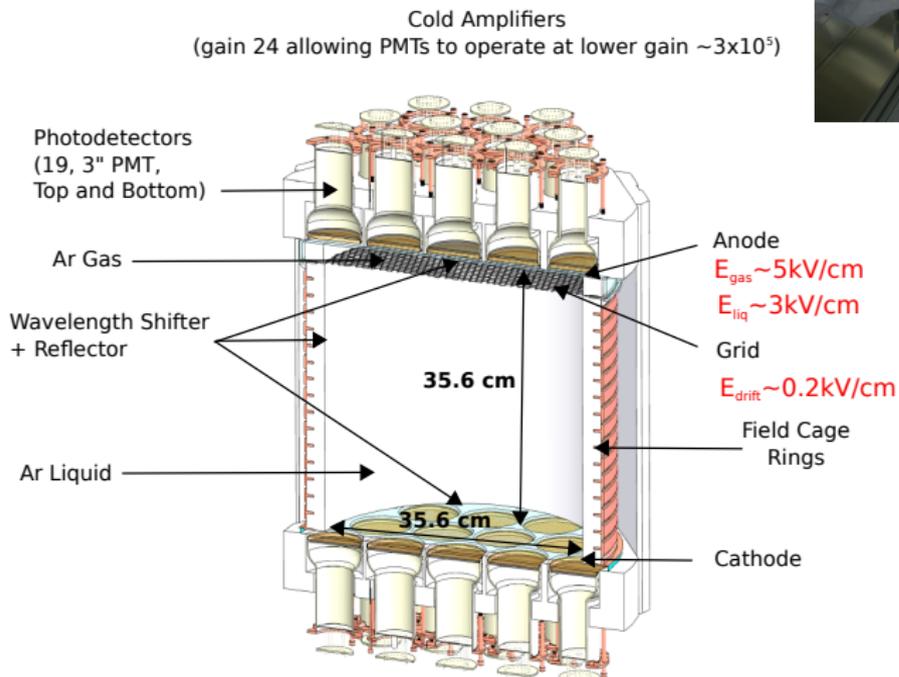
● Poland - Jagiellonian University

● Ukraine - Institute for Nuclear Research

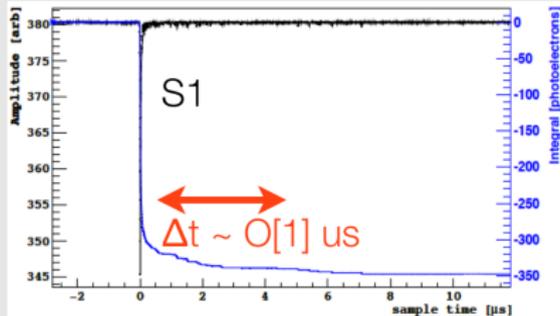
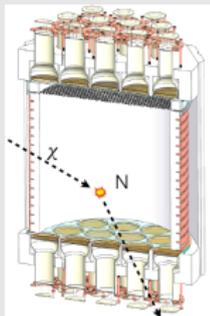
DarkSide: experiment concept

- **Direct detection search for WIMP dark matter.**
- **Based on a two-phase argon time projection chamber (TPC)**
- **Ultra low background**
 - Deep underground at LNGS
 - Low-background materials, including Ar target
- **Powerful background rejection**
 - Pulse Shape Discrimination (PSD)
 - Ionization/Scintillation ratio ($S2/S1$)
 - Surface rejection using 3D position reconstruction
- **Active neutron and muon vetoes**
 - In situ background measurement

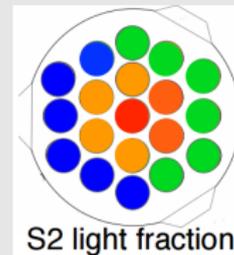
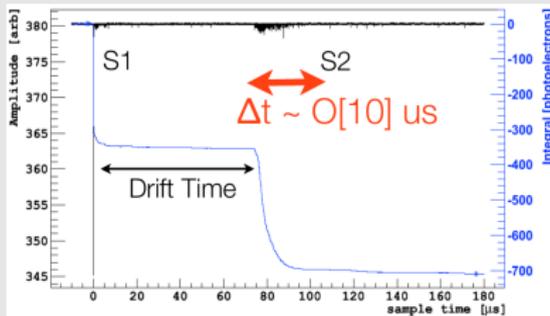
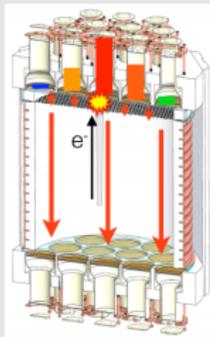
Two Phase Argon TPC



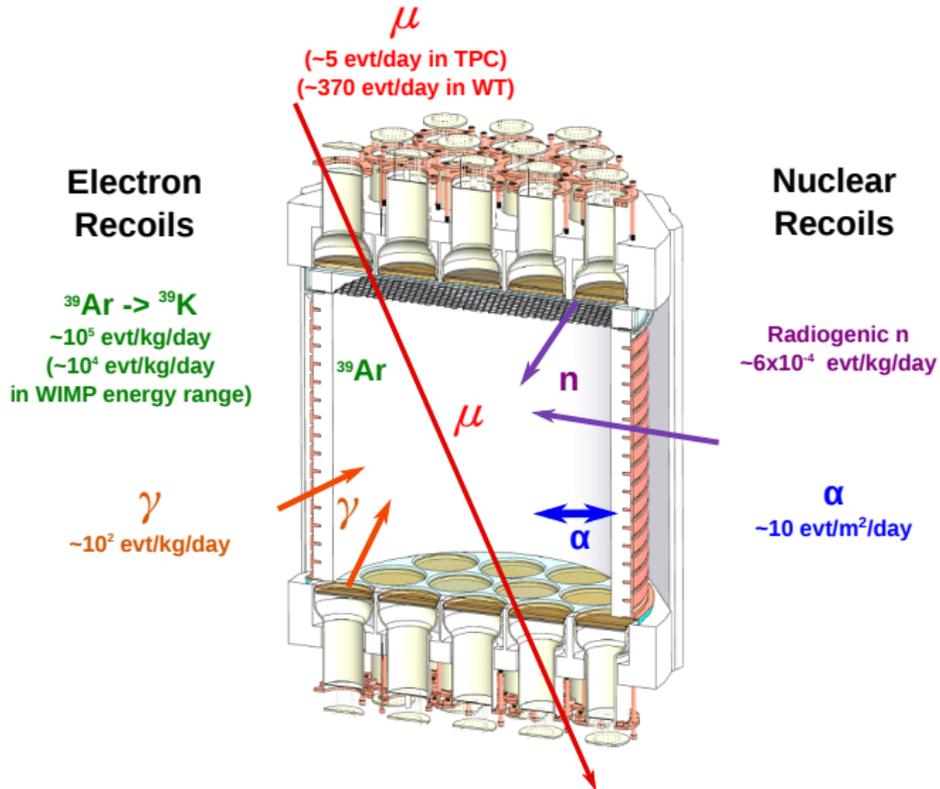
Nuclear Recoil excites and ionizes the liquid argon \Rightarrow scintillation light (S1)



e^- are drifted and then extracted into the gas region \Rightarrow electroluminescence (S2)



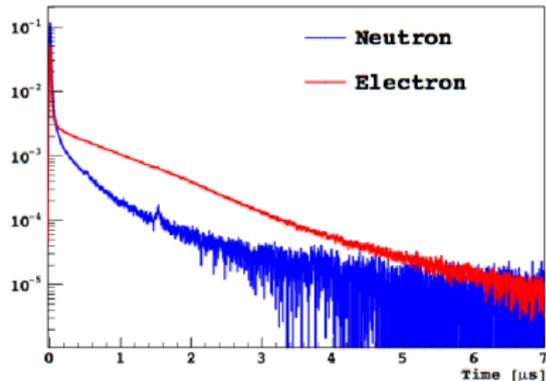
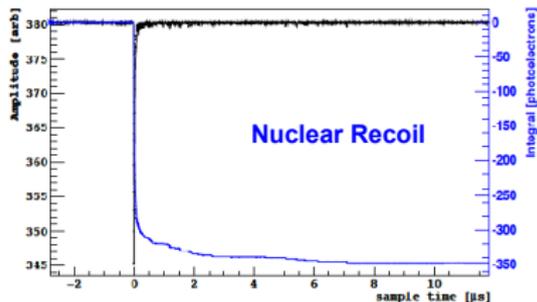
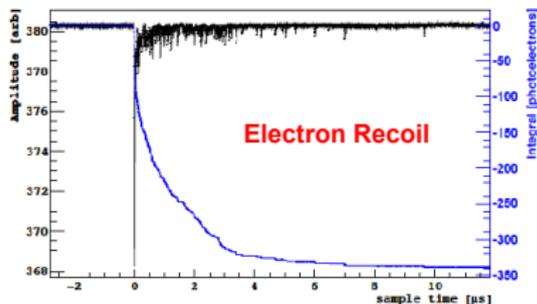
- Time between the S1 and S2 (Drift Time) gives z-position.
- Fraction of S2 in each PMT allows x-y position reconstruction.



$M_\chi = 100 \text{ GeV}, \sigma = 10^{-45} \text{ cm}^2 \rightarrow \text{WIMP Rate} \sim 10^{-4} \text{ ev/kg/day}$

Pulse Shape Discrimination

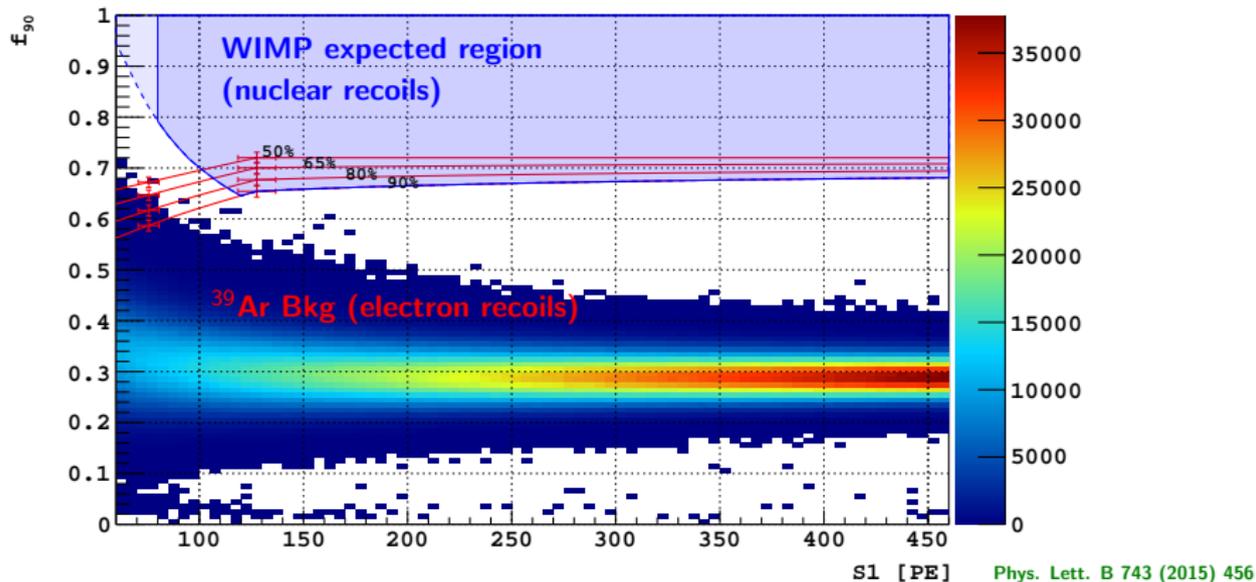
- Based on the primary scintillation signal in the liquid phase (S1)
- Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet ($\sim 6\text{ns}$) and triplet ($\sim 1500\text{ns}$) excitation states



PSD parameter

- F90: Ratio of detected light in the first 90 ns, compared to the total signal
- $F90 \sim$ Fraction of singlet states

Data taking with AtmAr started November 2013

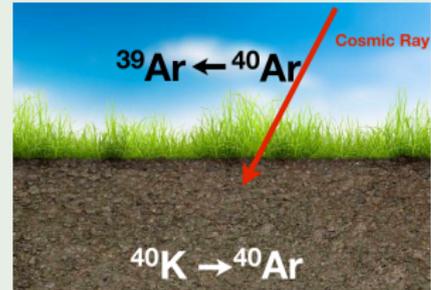


- There are 1.5×10^7 events dominated by ^{39}Ar .
- 0 events in WIMP search region
- f_{90} (+ z fiducialization + single scatters) suppress ER background **exceptionally**

Atmospheric Ar

How is it produced?

- ⁴⁰Ar produced underground through decay of ⁴⁰K
- ³⁹Ar is **cosmogenic** produced by ⁴⁰Ar(n,2n) interactions in the atm.



Production of UAr

1. Extraction at Colorado (CO₂ Well)



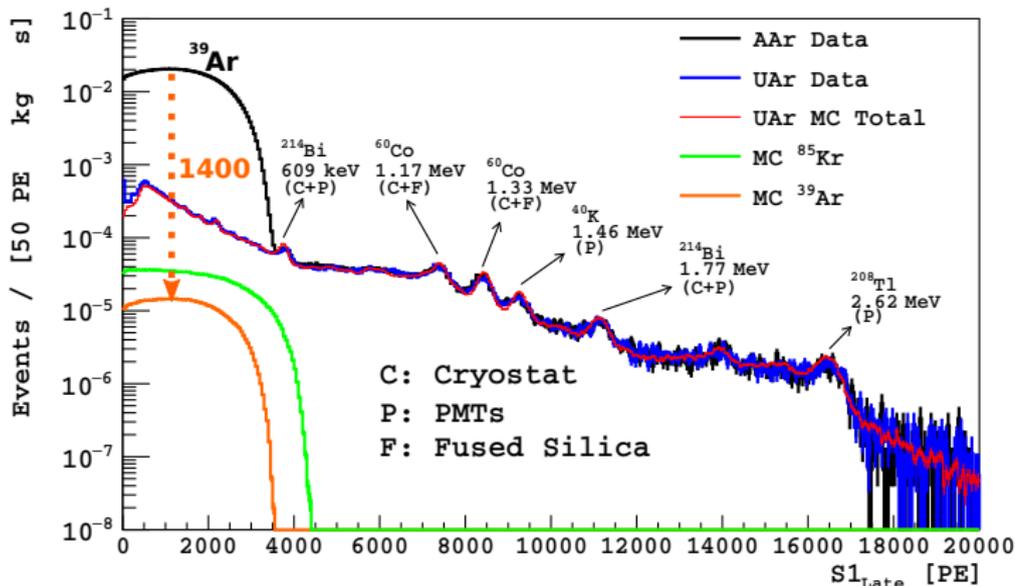
2. Purification at Fermilab



3. Shipped to LNGS



DS-50 filled with UAr in March 2015



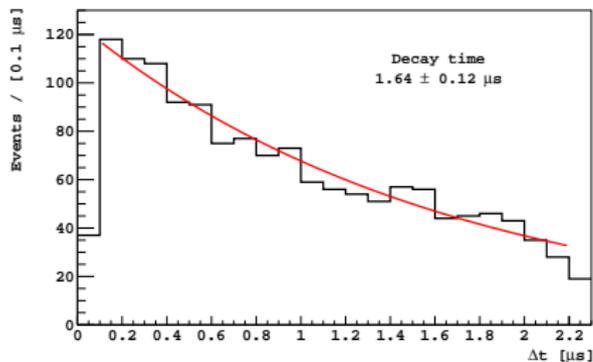
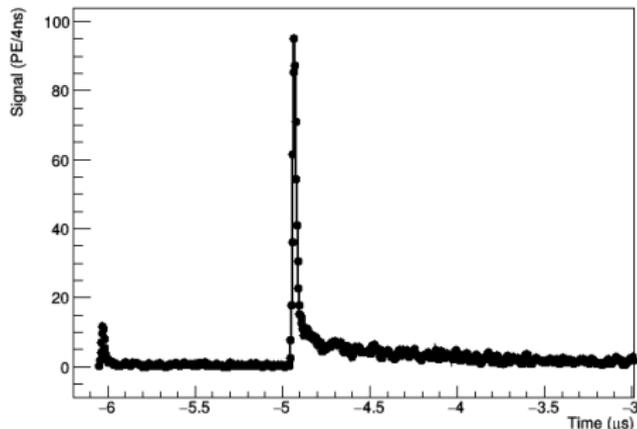
Phys. Rev. D 93 081101, 2016

- Fitted ⁸⁵Kr activity in UAU: 2.05 ± 0.13 mBq/kg
- Fitted ³⁹Ar activity in UAU: 0.73 ± 0.11 mBq/kg
- ³⁹Ar activity in AAU: 1000 mBq/kg

³⁹Ar reduction factor: **1400!!!**

^{85}Kr : 0.4% BR to ^{85m}Rb
($T_{1/2} = 1\mu\text{s}$, 514 keV γ)

Signature: two S1s ($\beta + \gamma$)
in delayed coincidence



Rates

This method: $1.92 \pm 0.05 \frac{\text{mBq}}{\text{kg}}$

Spectral fit: $2.05 \pm 0.13 \frac{\text{mBq}}{\text{kg}}$

Good Agreement!!!

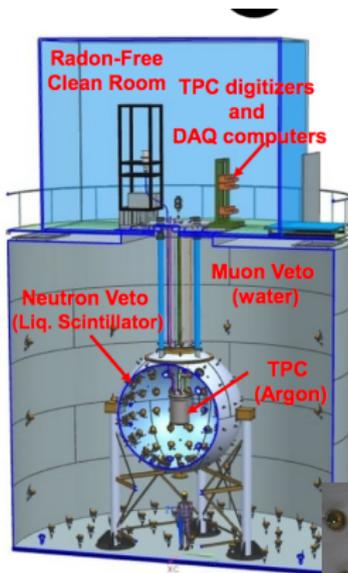
Neutron Rejection

Water Tank

- 11 m diameter x 10 m high
- 80 PMTs
- Active muon veto
 - tag cosmogenic neutrons
- Passive neutron and γ shielding

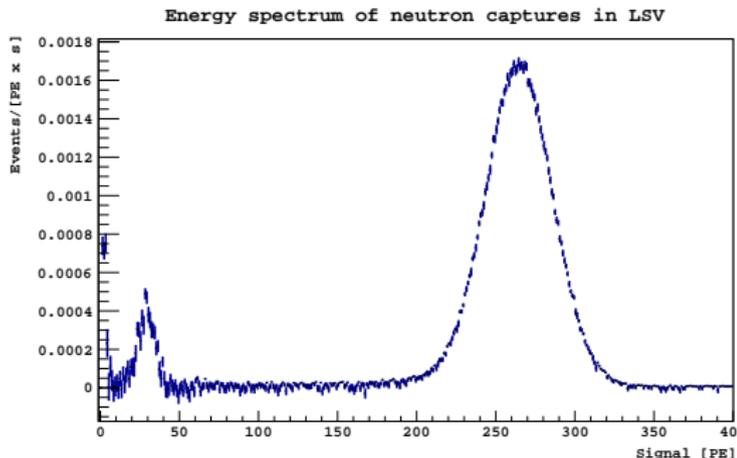
Liquid Scintillator Veto

- 4 m diameter sphere
- Boron-loaded: PC + TMB
- 110 8" PMTs
- Active neutron veto
 - tag neutrons in TPC
 - in situ measurement of neutron BG
- Passive neutron and γ shielding



Neutron calibration

- Goal - observe neutron captures on ^{10}B
 - 93.6%: $^{10}\text{B} + n \Rightarrow ^7\text{Li}^* + \alpha$
 $^7\text{Li}^* \Rightarrow ^7\text{Li} + \gamma$ (478 keV)
 - 6.4%: $^{10}\text{B} + n \Rightarrow ^7\text{Li}$ (1015 keV) + α (1775 keV)
 α (1775 keV) equivalent to 50–60 keVee

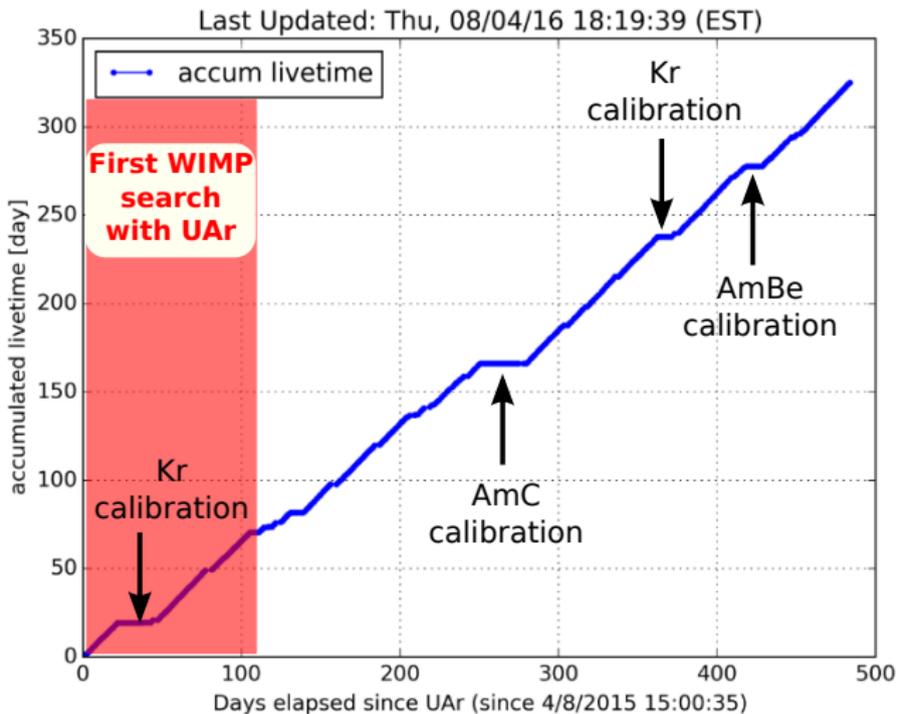


- Both channels detected
- Signals above LSV detection threshold

J. Instrum. 11 P03016, 2016

>99.1% efficiency to veto neutrons from neutron capture signals alone
(AmBe + simulation)

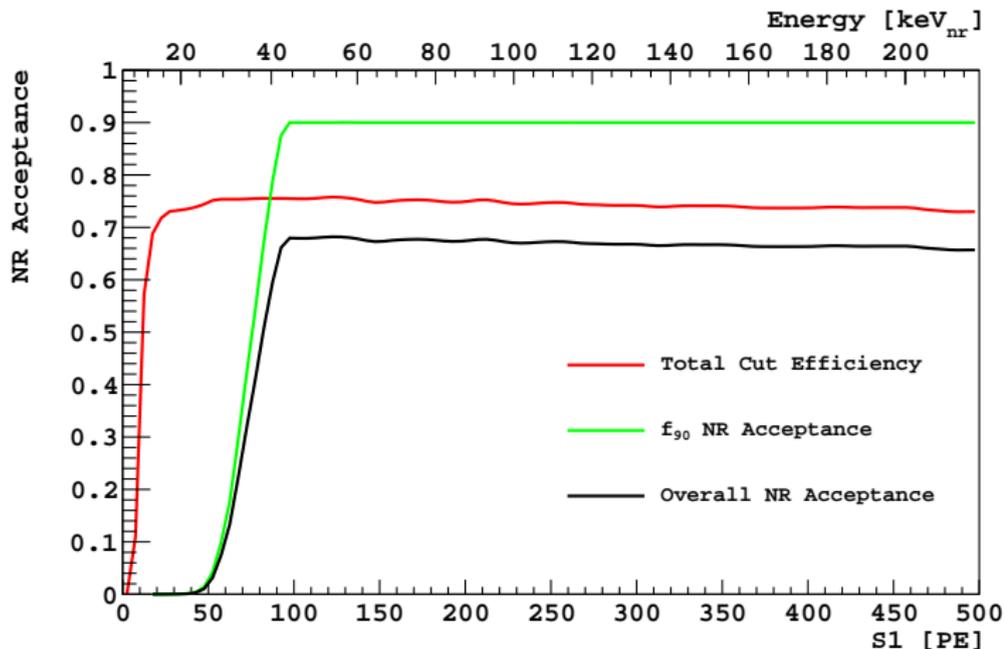
DM search with UAr began immediately after turning on fields.



~1.5 Hz trigger rate, predominantly ER events

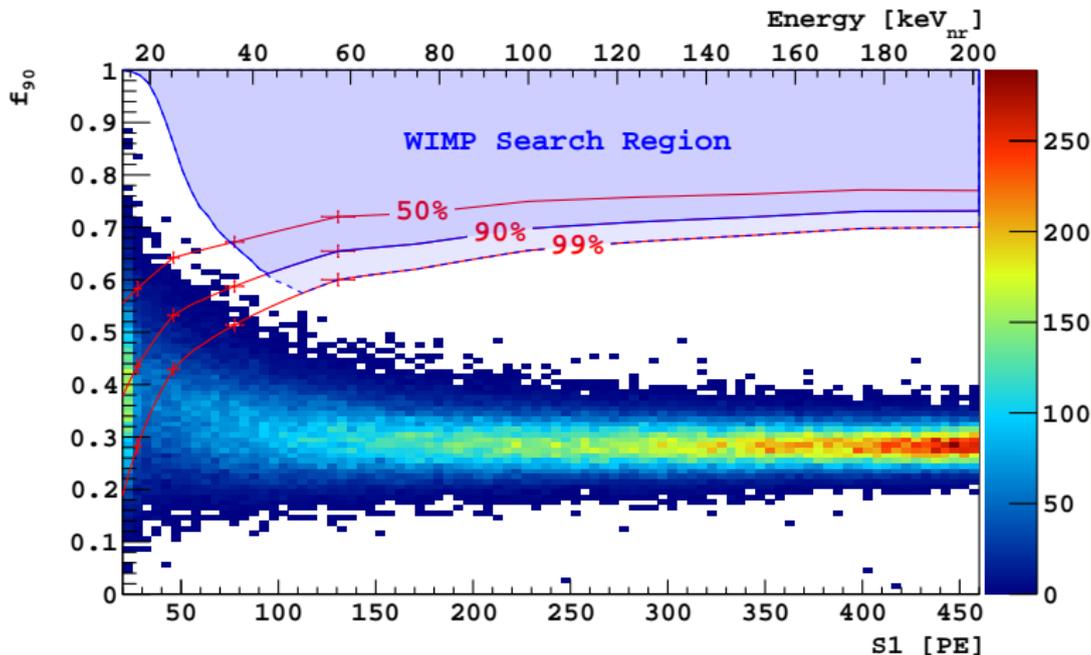
Nuclear recoil acceptance

- Cuts: select single scatters (single S1 + single S2) with no signal in veto.
- Efficiencies evaluated using UAr data + AmBe data + MC
- Dominant acceptance loss: accidental coincidences in veto

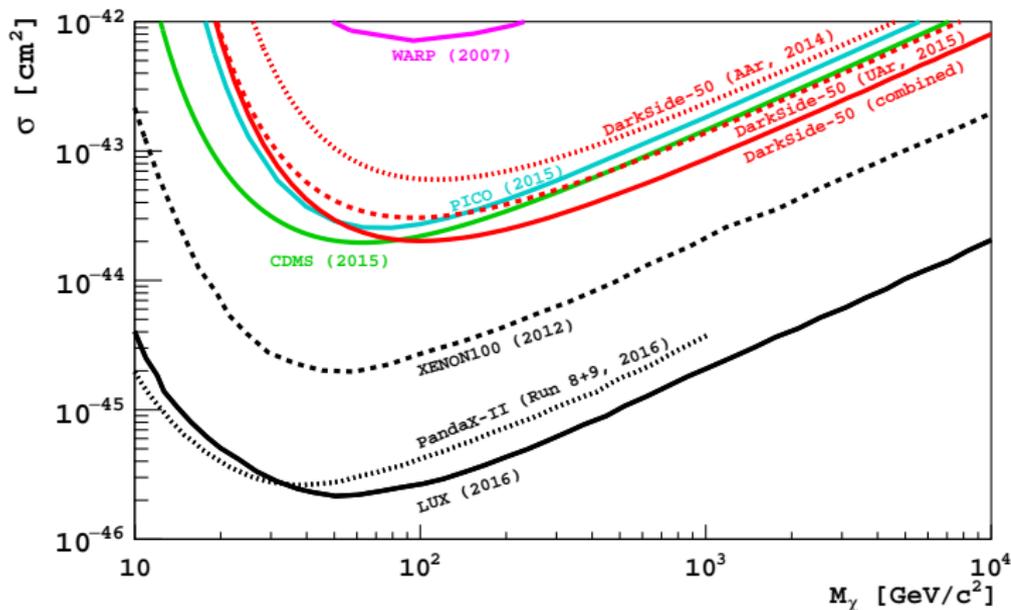


Dark Matter search with UAr

- 70.9 live-days
- 36.9 kg fiducial volume
- Expect <0.15 ER leakage events

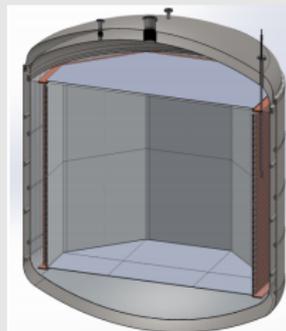


No events in the WIMP search region.



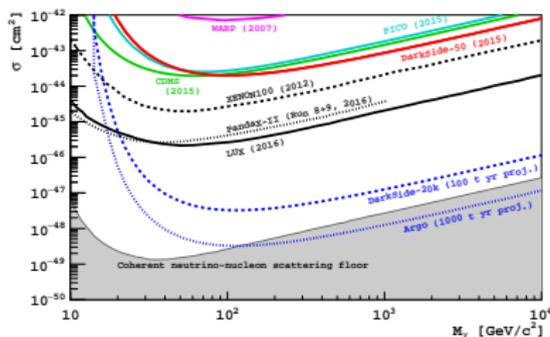
DarkSide-50:
best Argon limit,
second target above 100GeV/c²

- DarkSide-20k: 30 tonne (20 tonne fiducial) detector
- ARGO: 300 tonne (200 tonne fiducial) detector



Challenges

- Further depletion of ^{39}Ar : UAr (Urania Project) & Depleted Argon (Aria Project)
- Further reduction in surface contamination: SiPM & ultra-clean Titanium

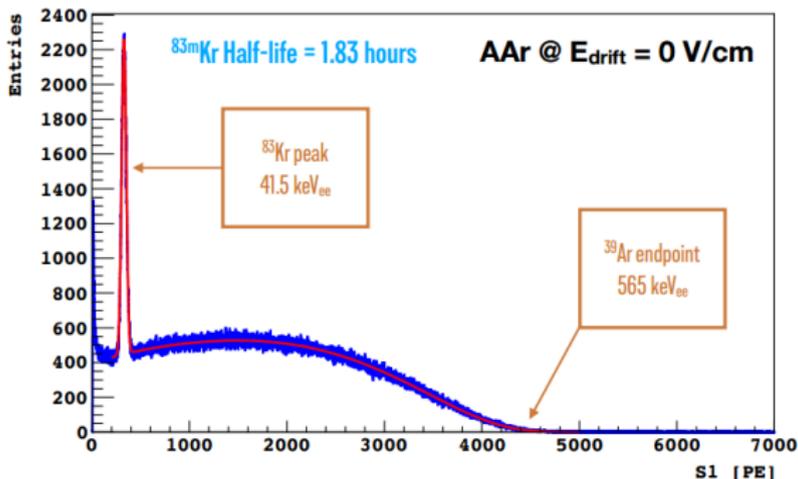


See poster by
Ed Hungerford:
The DarkSide 20k Experiment

- Running with AtmAr acquired 1.5×10^7 ^{39}Ar events with **0** in WIMP search region.
 - Exceptional ER background suppression
- Concentration of ^{39}Ar in UAr is **1400** times lower than in AAr.
- DarkSide-50 has the strongest WIMP limit among Ar target experiments.
- Currently in stable WIMP search mode.
 - Already acquired > 4 times more data previously published and first blinded WIMP search analysis coming soon!
- Future Liquid Argon TPC are planned to reach eventually the neutrino floor.

BACK UP SLIDES

- ^{39}Ar (565 keV_{ee} endpoint) present in AAr
- $^{83\text{m}}\text{Kr}$ gas deployed into detector (41.5 keV_{ee})

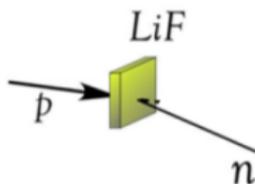


Fits to ^{39}Ar and $^{83\text{m}}\text{Kr}$ spectrum indicate
LIGHT YIELD: 7.9 ± 0.4 PE/keV_{ee} at zero field and 7.0 ± 0.3 PE/keV_{ee} at 200 V/cm

SCENE

Scintillation Efficiency of Nuclear Recoils in Noble Elements

Pulsed monoenergetic
proton beam



${}^7\text{Li}(p, n){}^7\text{Be}$
produces monoenergetic
low energy neutrons

2.3 MeV protons generate
 ~ 0.5 MeV neutrons

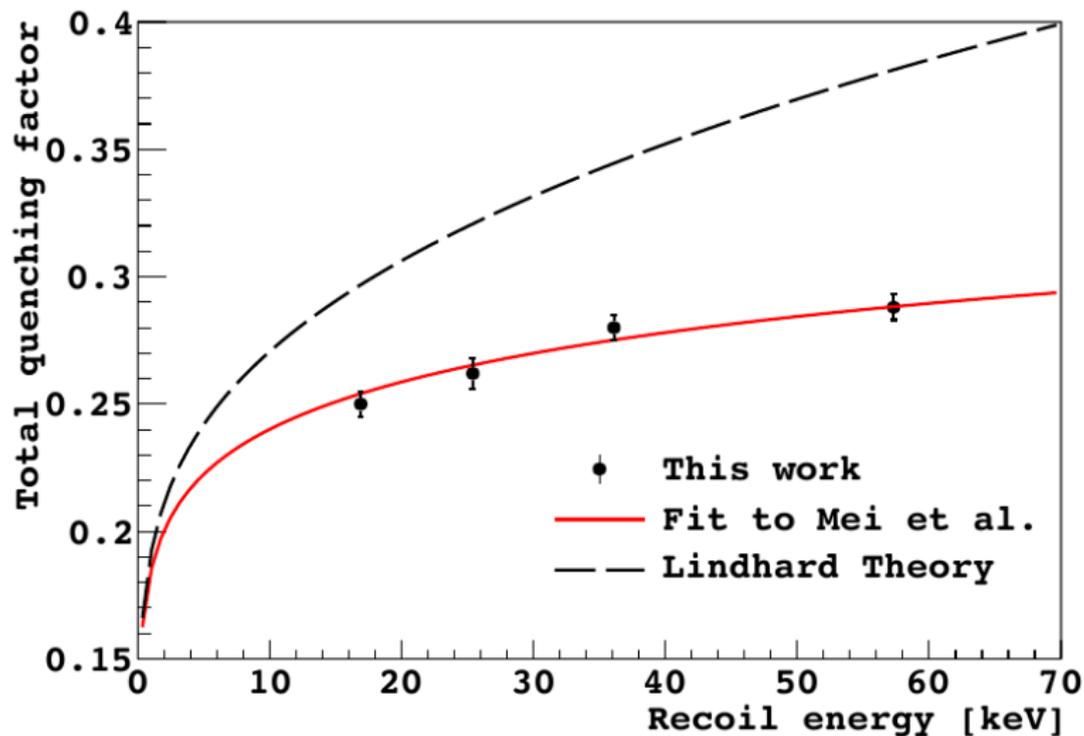


Scintillator cells at fixed
angles with respect to the
beam detect outgoing
neutrons

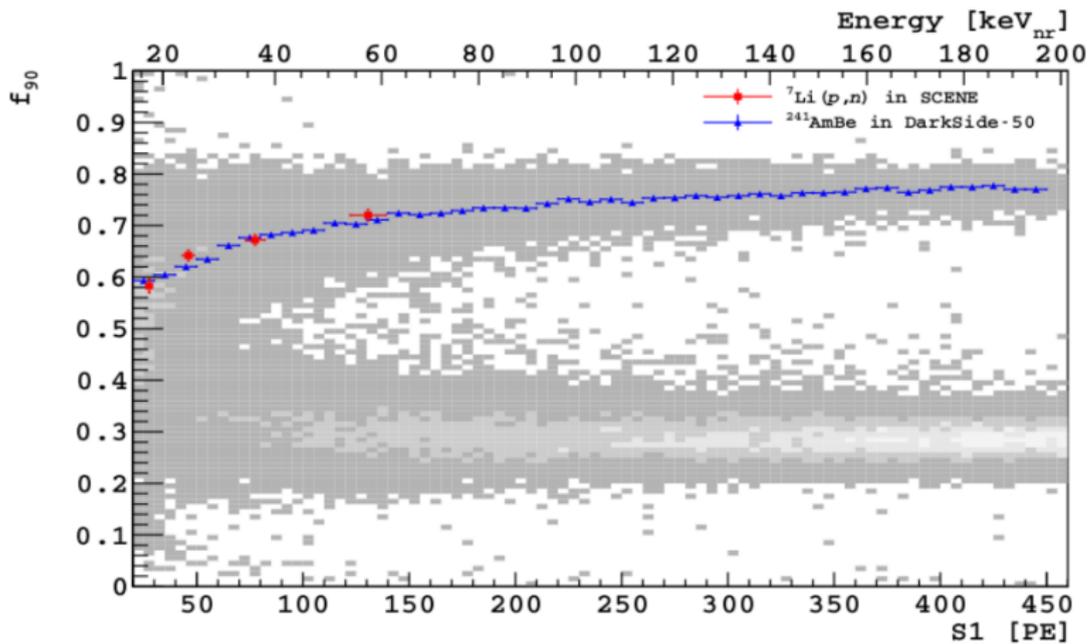
Angle θ determines
energy of the elastic
nuclear recoil in argon

θ

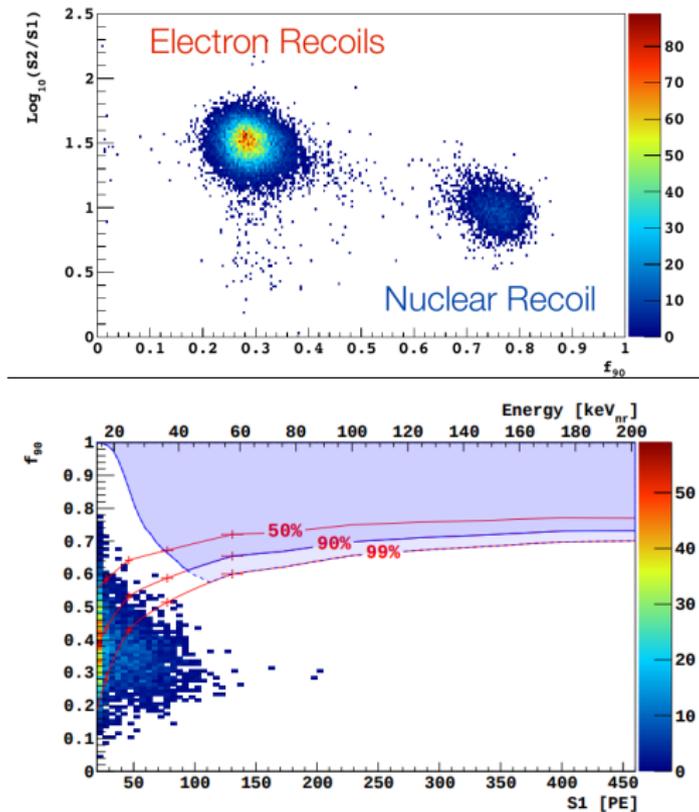
EJ301



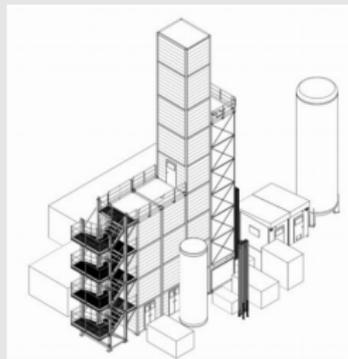
Nuclear recoil calibration f_{90} bands



Electron Recoil Discrimination: S2/S1



- Urania (Underground Argon)
- Expansion of the argon extraction plant in Cortez, CO
- Extract UAr at 100kg/day



- Aria (UAr Purification)
- Very tall (350m) cryogenic dist. column in the Seruci mine in Sardinia, Italy
- Chemical and isotopic purification of Underground Argon
- Factor 10 reduction *per pass*

