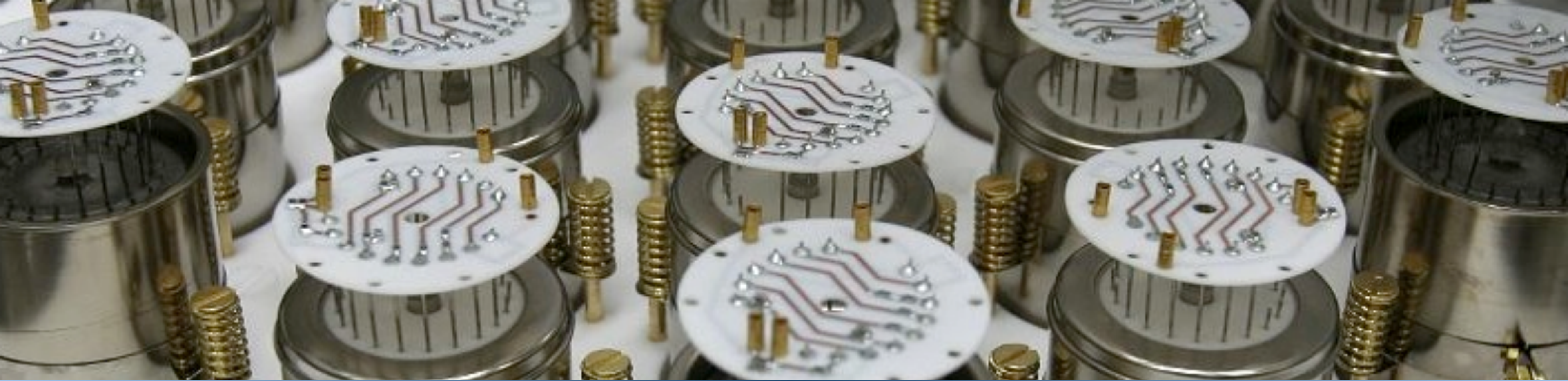


Direct search for Dark Matter with DarkSide

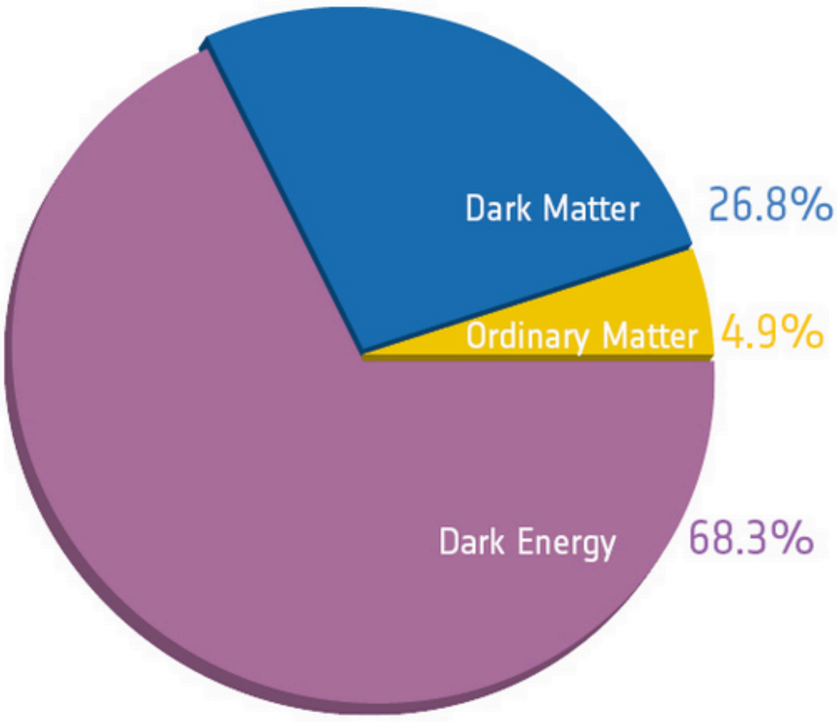
08/12/2014
P Agnes
Lab APC, Université Paris 7

JJC 2014 - Sète

Dark Matter

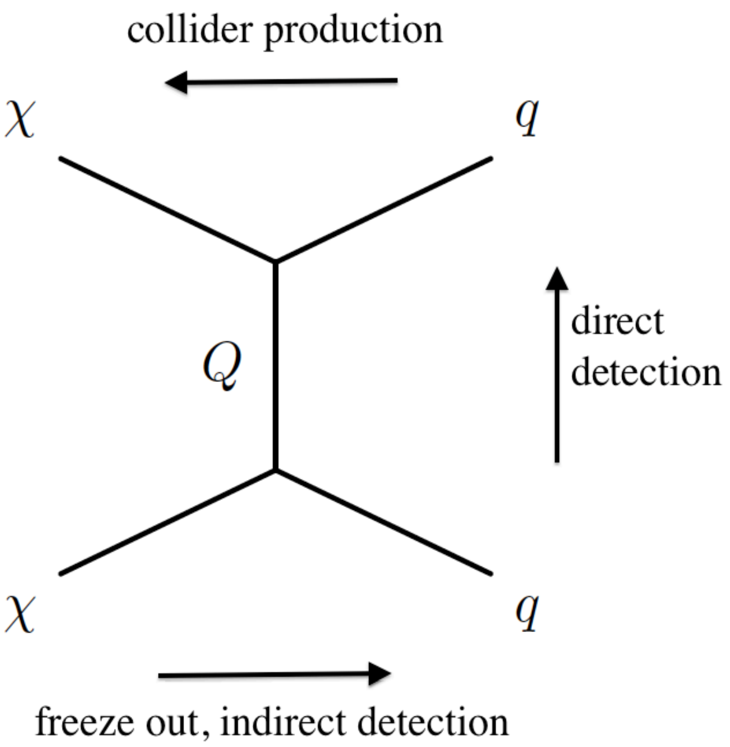
Several indirect observations:

- Galaxy clusters
- Galactic rotation curves
- Weak lensing
- Strong lensing
- Hot gas in clusters
- Bullet Cluster
- Supernovae
- CMB



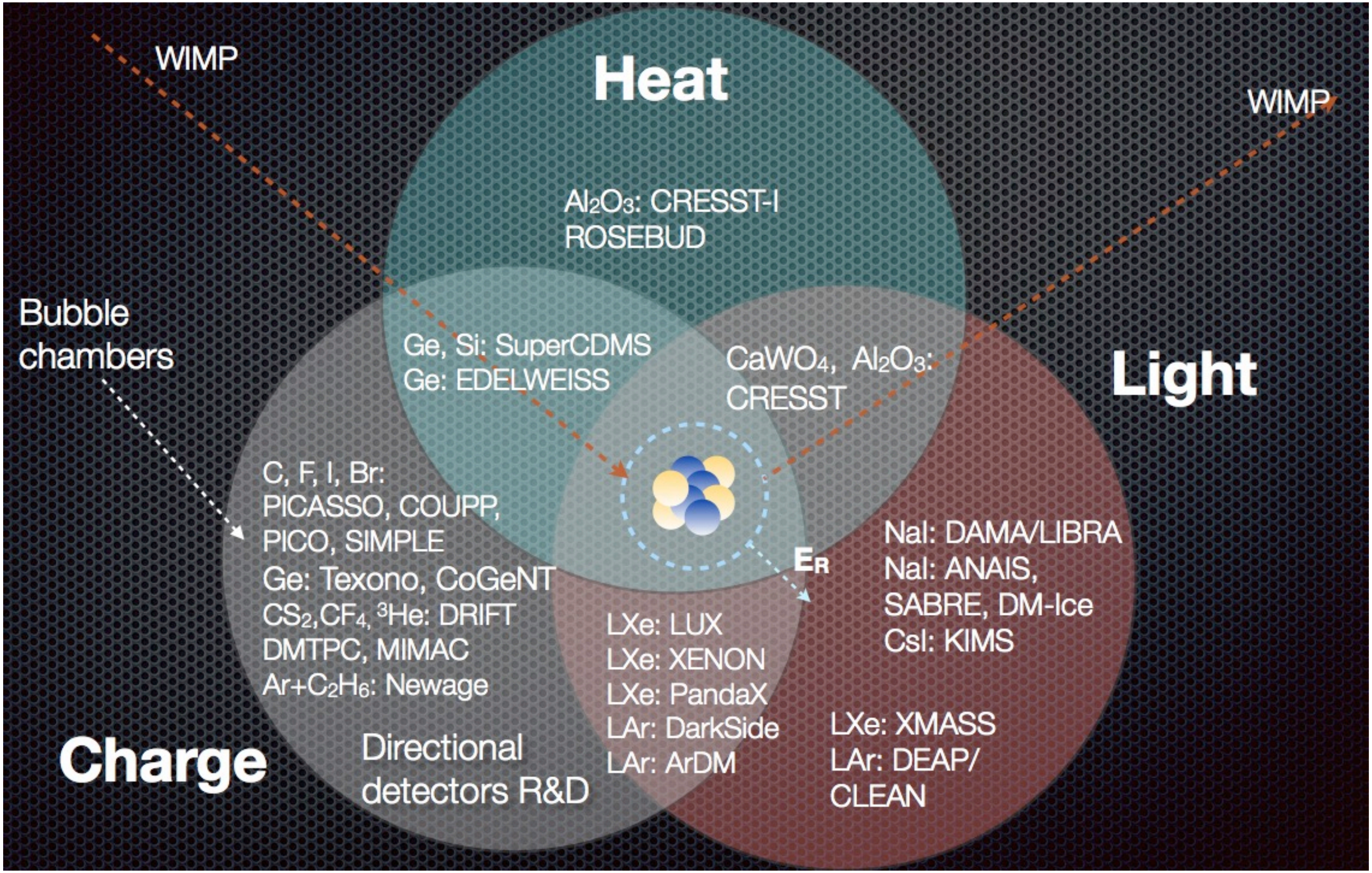
The Dark Matter candidate

The Dark Matter particle properties:
- It is **stable**
- It interacts through **gravitational** force
- It is electrically **neutral**
- It does not **strongly** interact
- It may **weakly** interact
- It should have a **directionality**



Weakly Interactive Massive Particles (WIMPs)

Techniques for Direct Detection of WIMPs



Direct Detection Requirements

Large masses

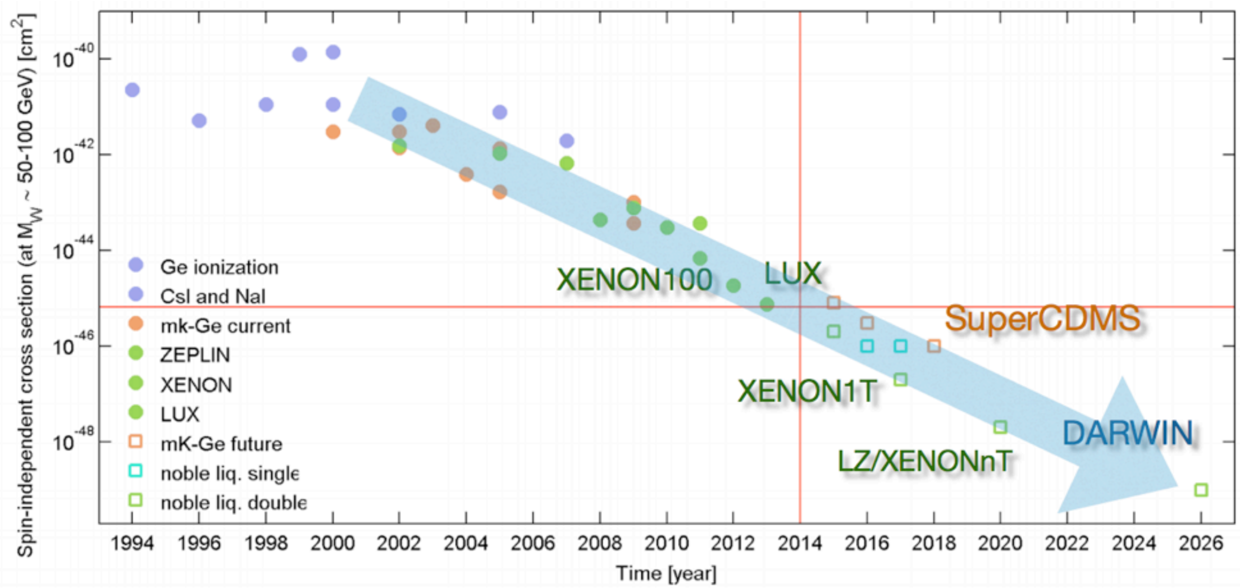
- Low rate (~1 event/ton/yr @ 10^{-47} cm^2 in noble liquids)

Low energy thresholds

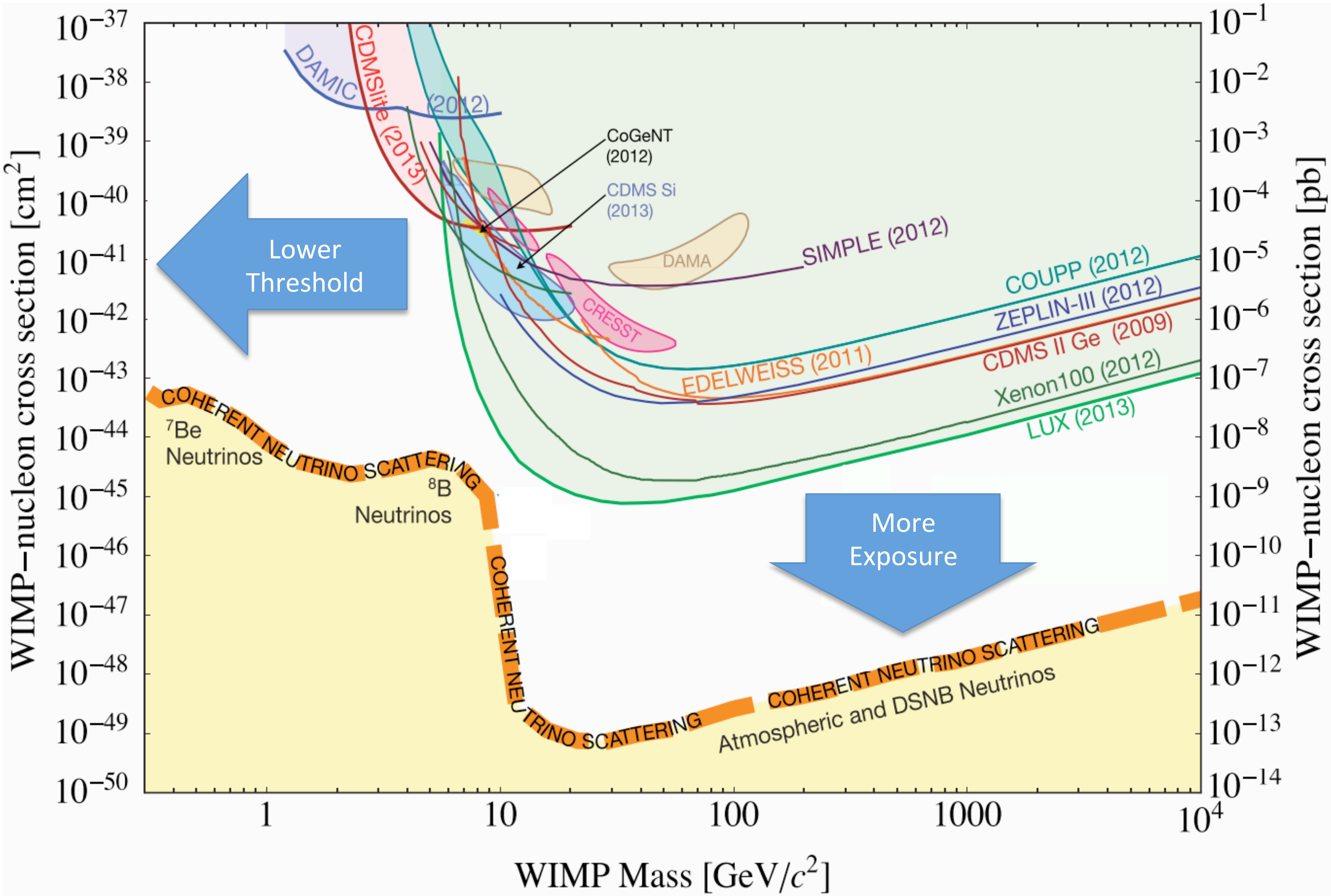
- Low energy nuclear recoils (< 100 keV)

Background suppression

- Deep underground
- Passive/active shielding
- Low intrinsic radioactivity
- Gamma background discrimination



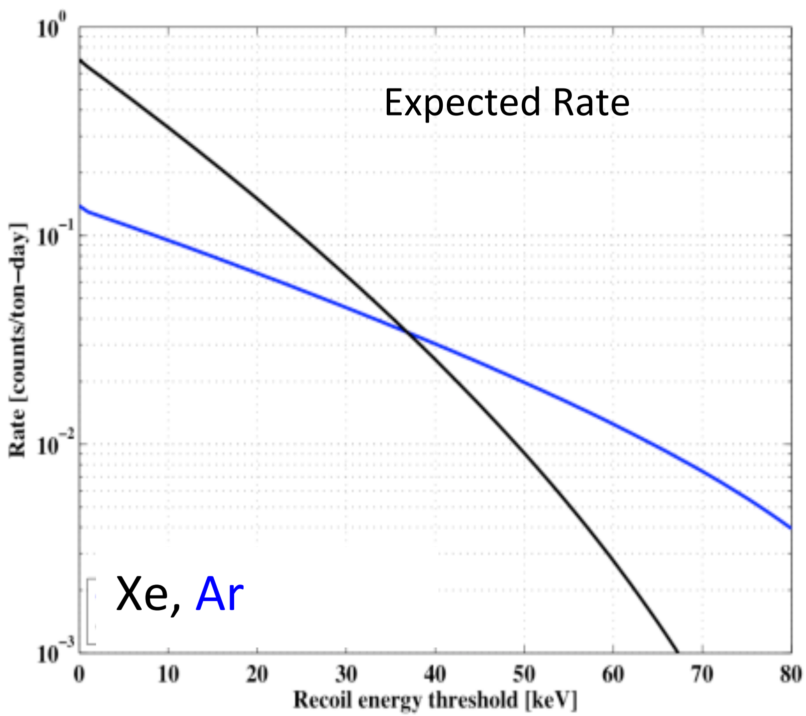
Current status of the Dark Matter Hunt



Noble liquids

Dense, relatively **inexpensive**, easy to **purify** (scalable to Large Masses)

High **ionization** (W~20 eV)
High **scintillation** yield (~40,000 photons/MeV)
Transparent to their own scintillation
High electron **mobility** and low electron **diffusion**
Discrimination: ionization/scintillation



Liquid Xenon
High intrinsic radio-purity

Liquid Argon
Discrimination: ionization/scintillation + **PSD**
Intrinsic contamination from ^{39}Ar
(it can be **depleted**)

Depleted Liquid Argon

Atmospheric Ar:

$^{39}Ar/^{40}Ar = 8 \times 10^{-16}$

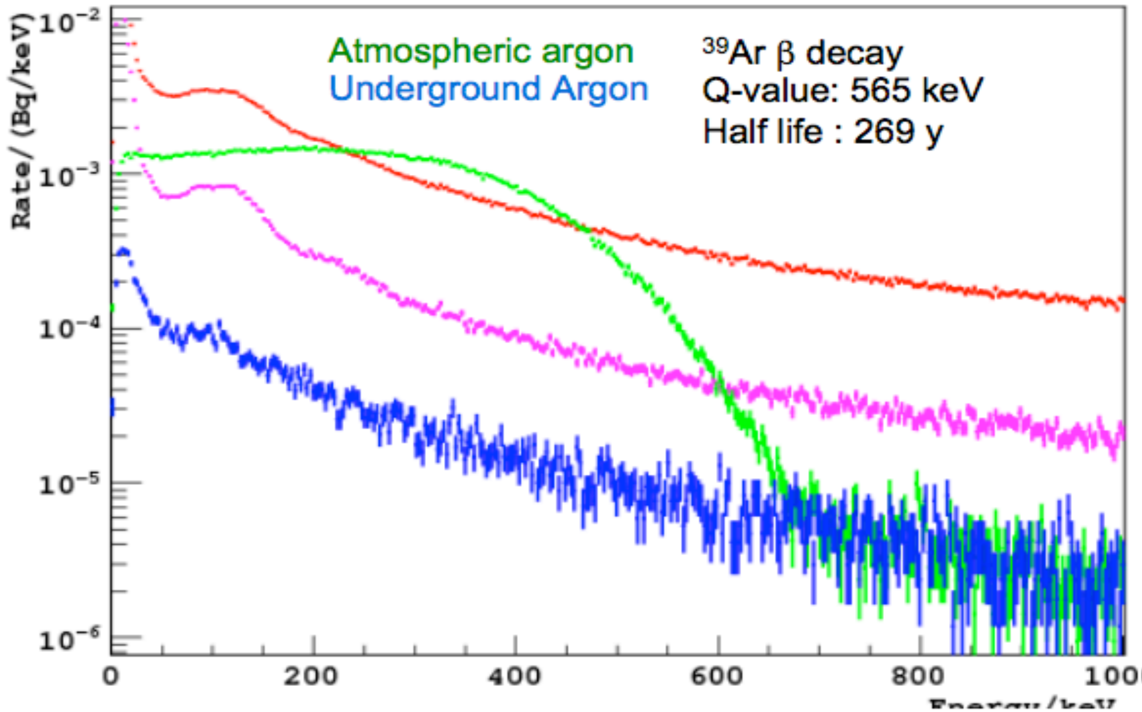
Rate ~ **1 Hz/kg**

Underground Argon:

^{39}Ar < **6.5 mBq/kg**

(arXiv:1204.6011)

arXiv:1204.60111

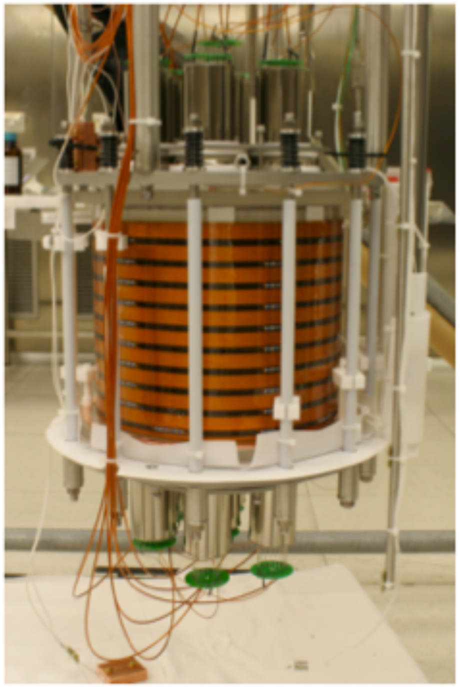


^{39}Ar Depletion: >150

The DarkSide program

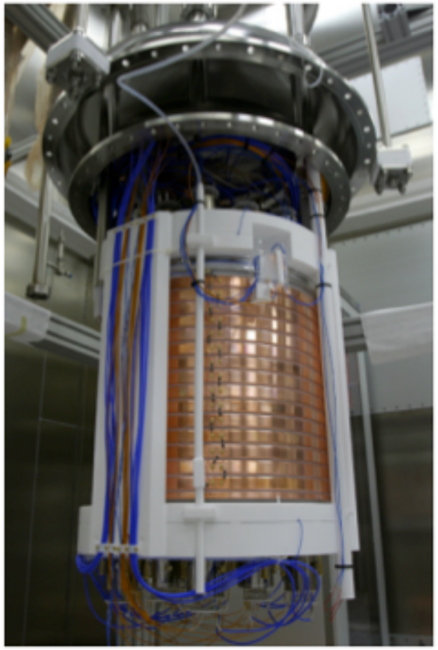
Double Phase Liquid Argon TPC, a staged approach:

DarkSide-10
2011-2013



@ Princeton

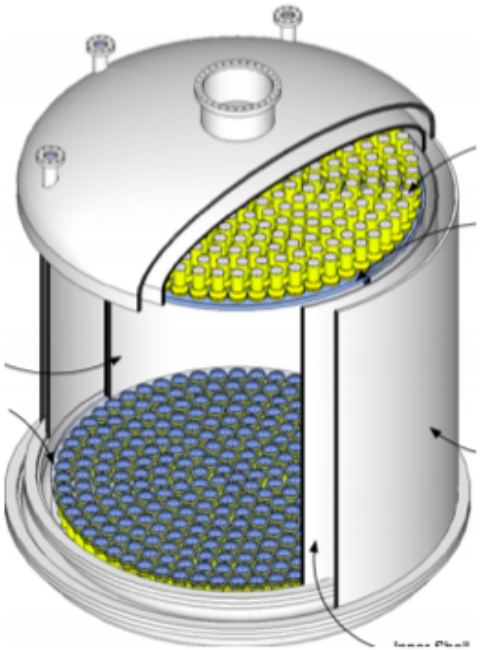
DarkSide-50
2013-201x



$\sim 10^{-45}$ cm^2

@ LNGS

DarkSide-G2
2016-2020



$\sim 10^{-47}$ cm^2

The DarkSide Collaboration

France
IPHC - Universite de Strasbourg, CNRS/IN2P3
APC - Universite Paris 7 Diderot, CNRS/IN2P3,CEA/IRFU
(LPNHE - CNRS/IN2P3, Université Pierre et Marie Curie)

Italy
INFN LNGS
Gran Sasso Science Institute
INFN and Universita degli Studi di Cagliari, Genova, Milano, Napoli

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

Poland
Jagiellonian University

Ukraine
Institute for Nuclear Research

China
IHEP Beijin

USA
Augustana College
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
PNNL, SLAC
FNAL, LANL, LLNL

DarkSide Guidelines

Main goal: a **bg-free experiment**

Background suppression

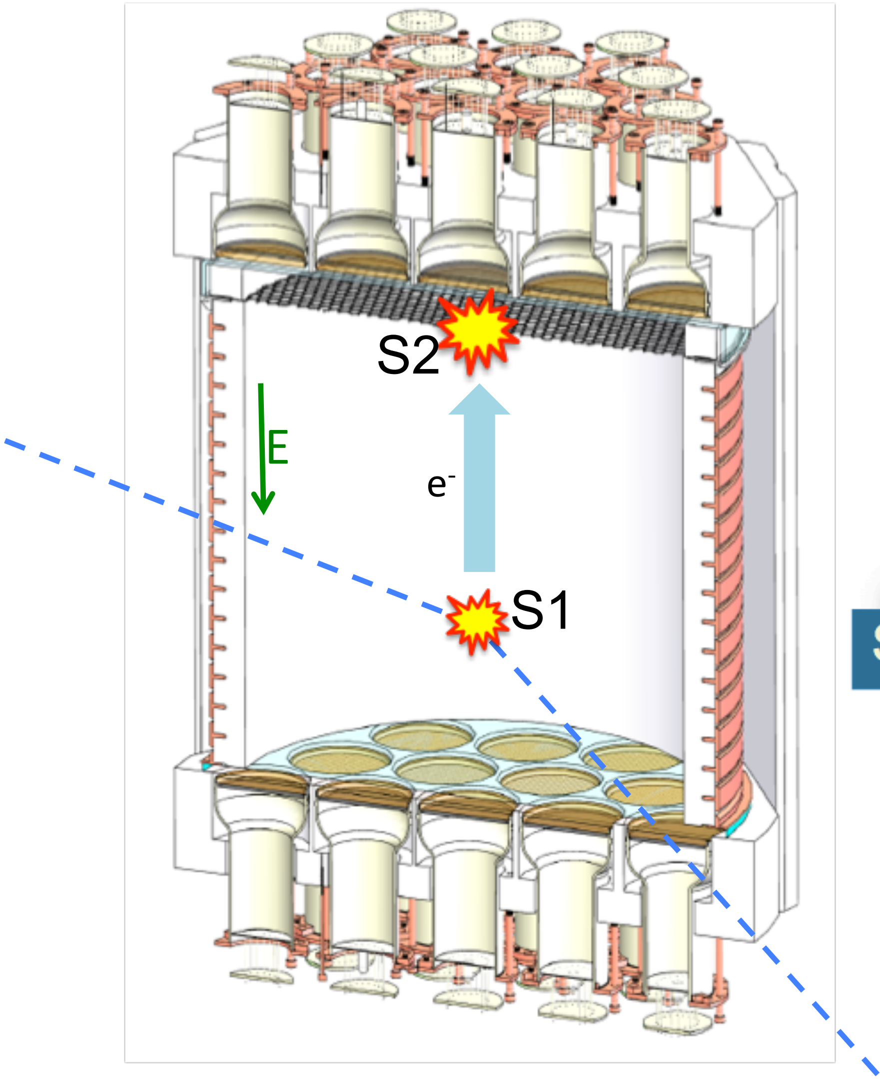
Ultra-low background materials
- Depleted Liquid Argon
- Low background photo-detectors
- Low background material components

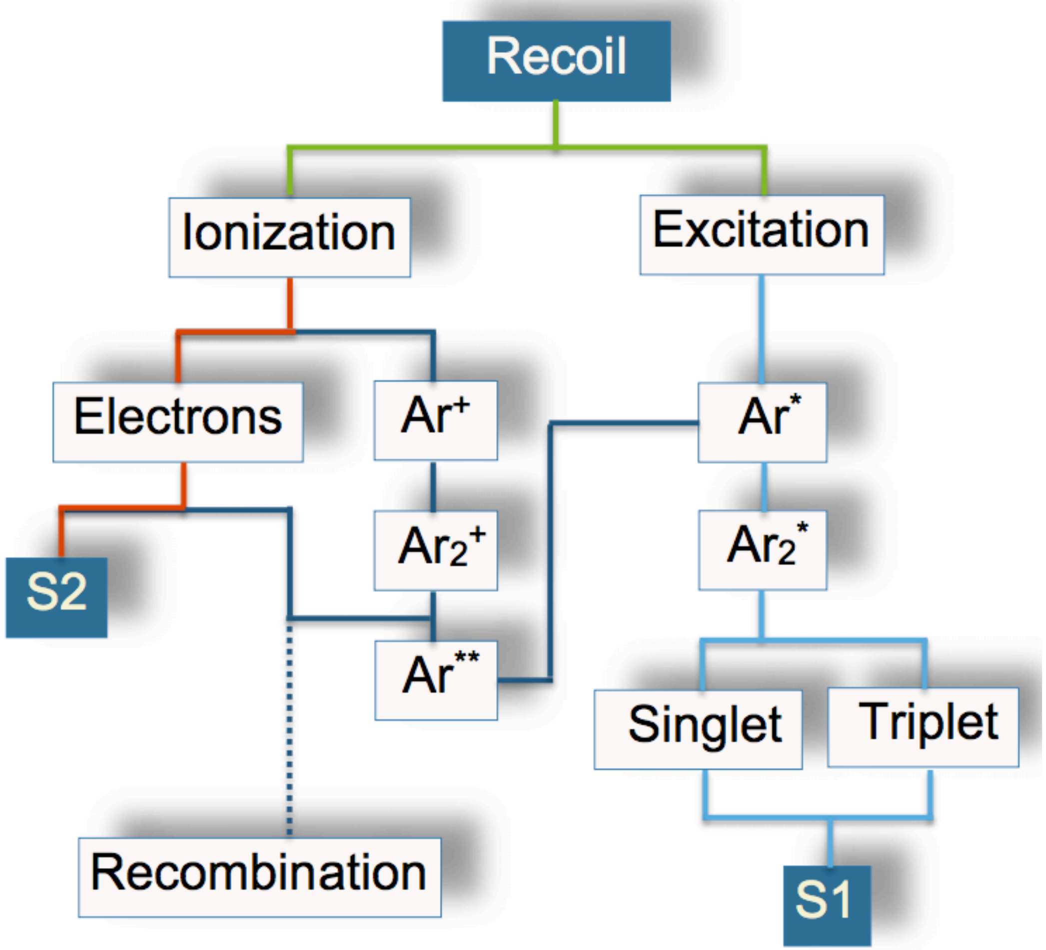
Active Shields
- Water Cherenkov against muons
- Borate Scintillator against muons and n
- Multiple scattering with the TPC

Residual background identification

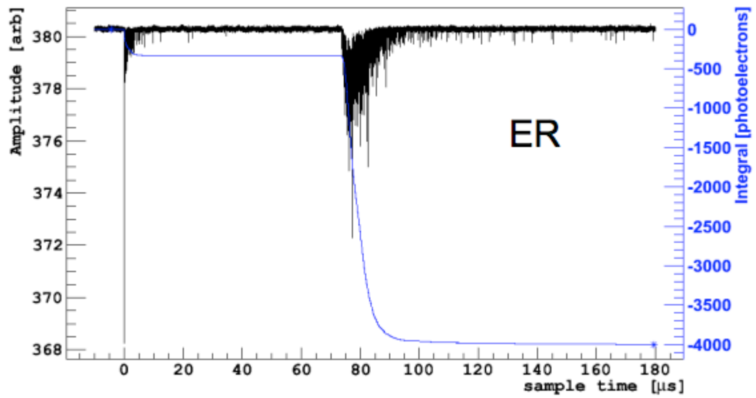
Background Identification
- Pulse shape Discrimination
- S2/S1 ratio
- Neutron flux with the Borate scintillator
- Position reconstruction

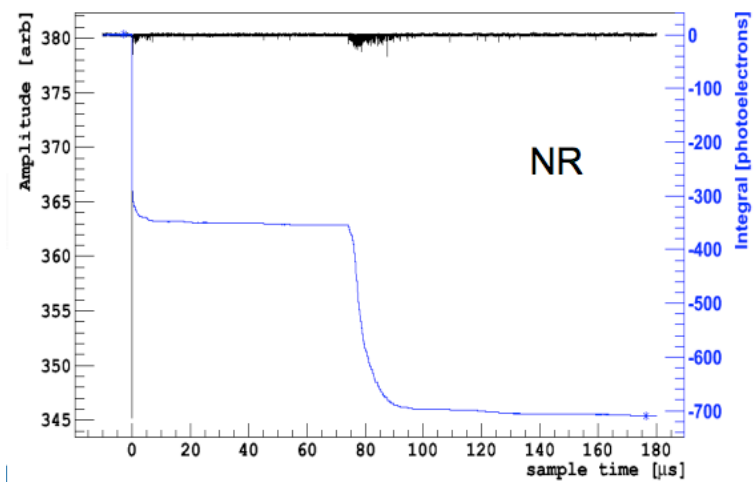
Detection signature

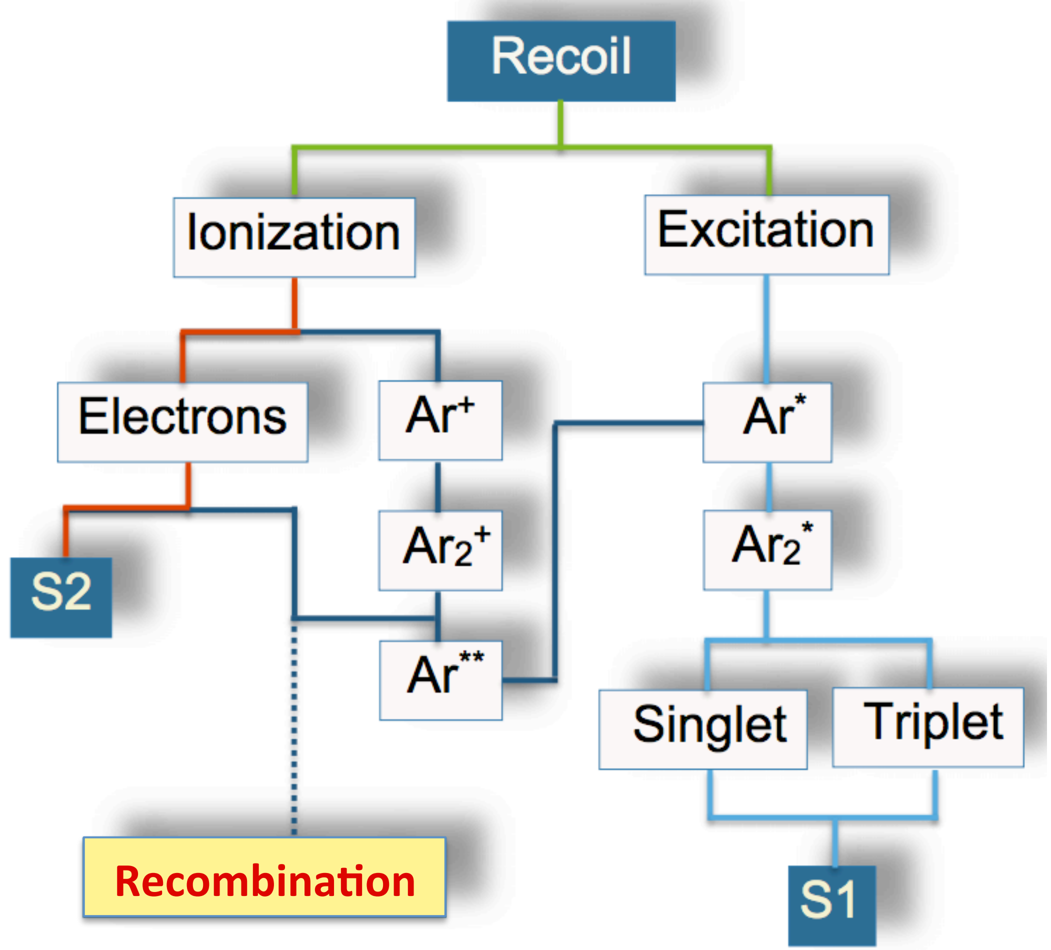




S2/S1 Ratio



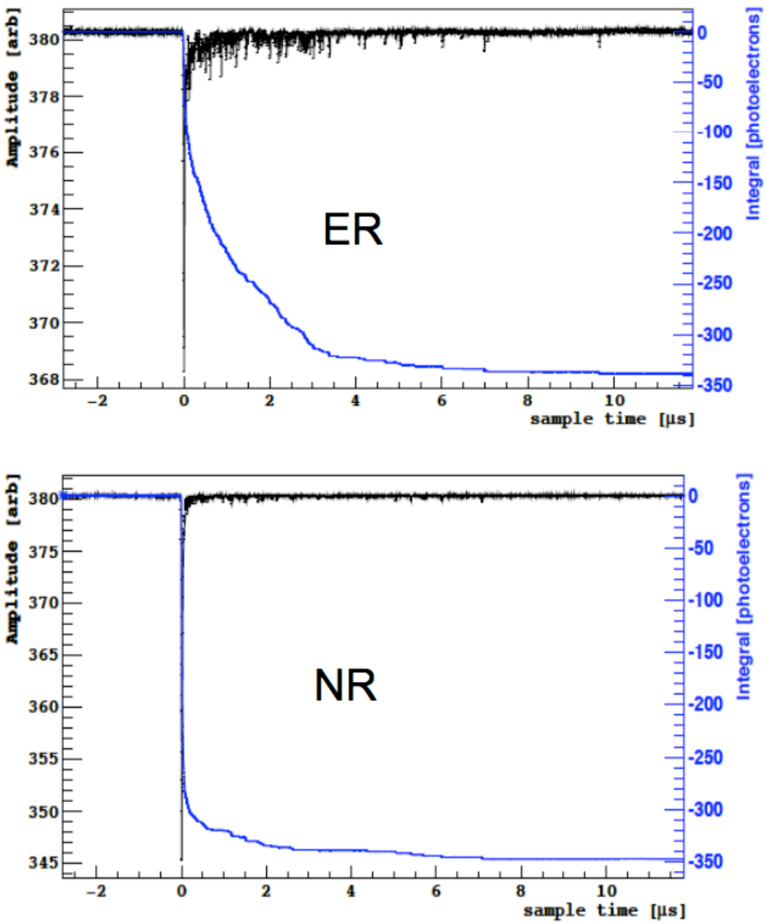


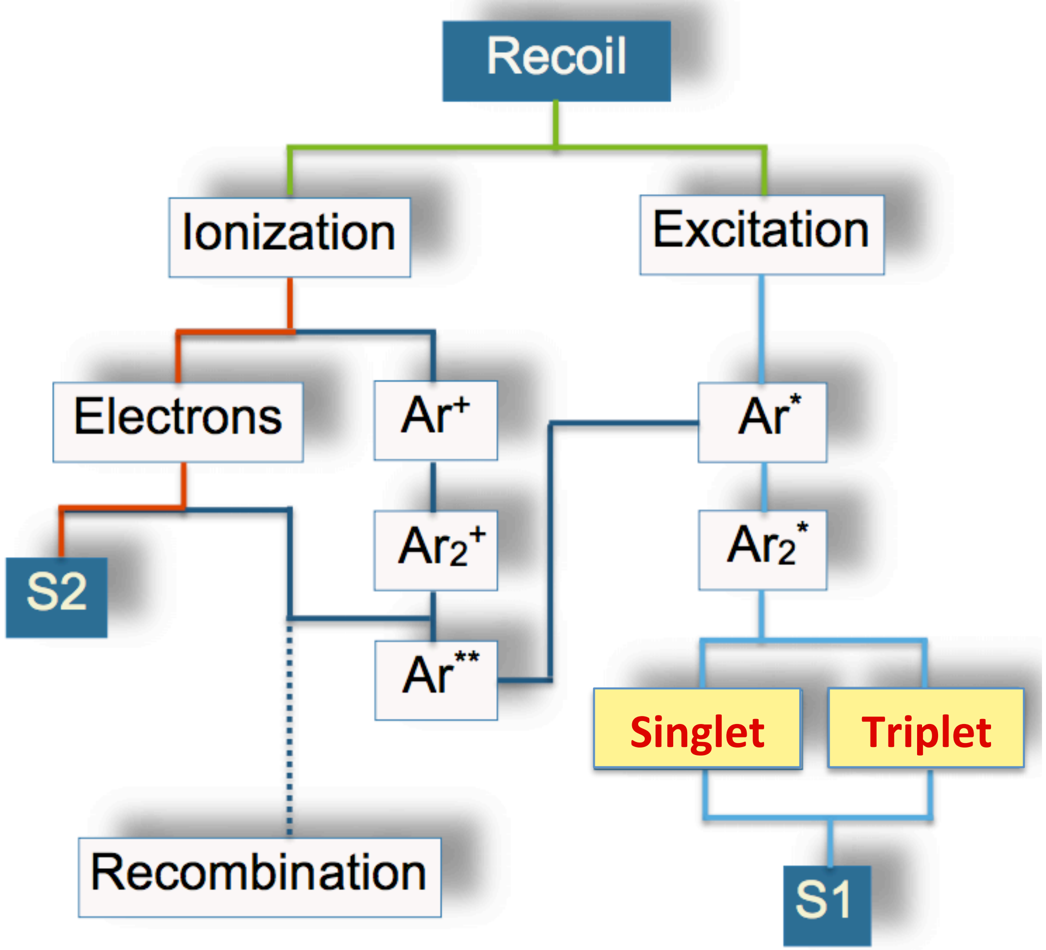


Rejection factor: 10^2 - 10^3

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

The Pulse Shape Discrimination





Rejection factor: ~10^8

WARP Astr. Phys 28, 495 (2008)

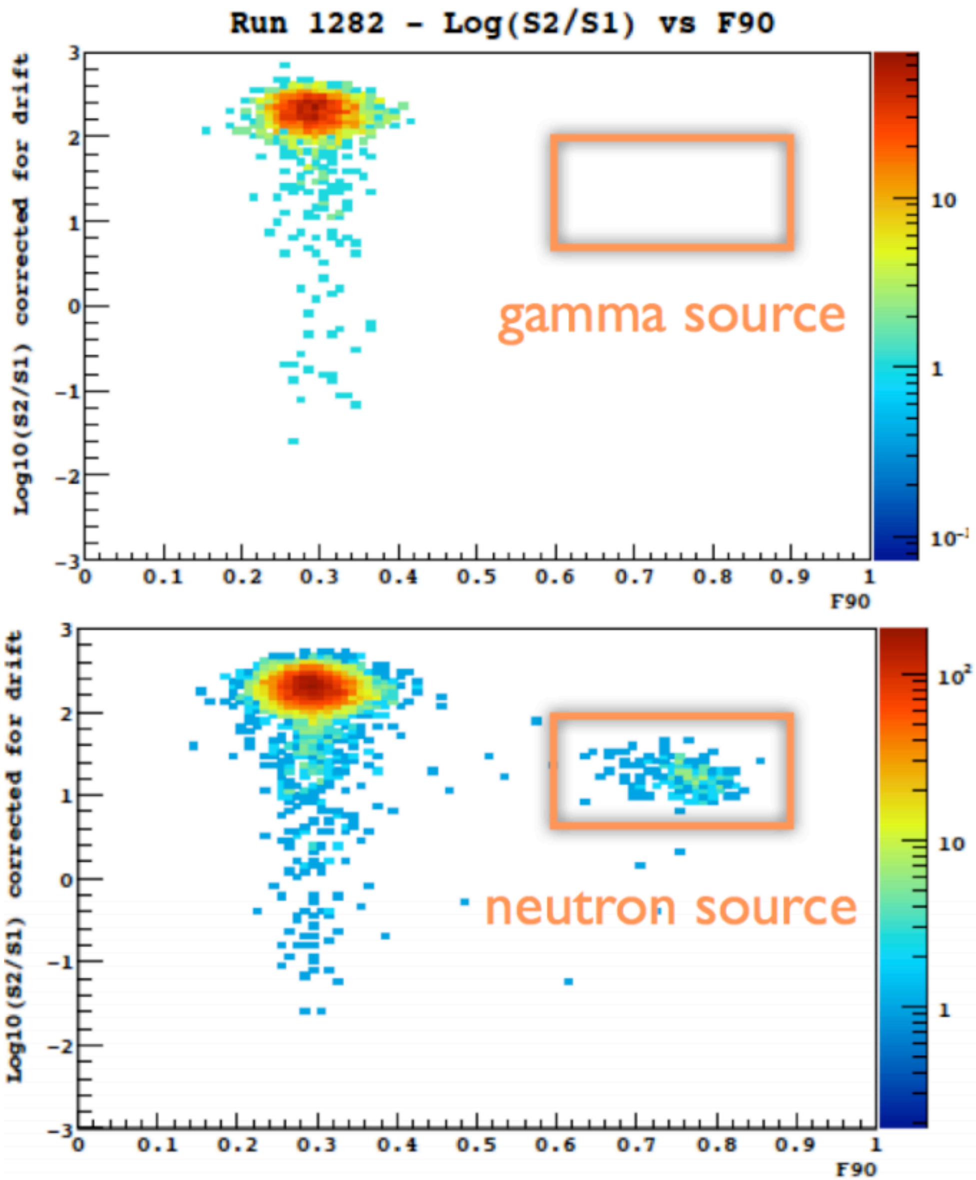
LXe $\tau_{singlet}$ = 2 ns
LXe $\tau_{triplet}$ = 22 ns

LAr $\tau_{singlet}$ = 7 ns
LAr $\tau_{triplet}$ = 1600 ns

The Total Discrimination

- S2/S1
- PSD
- Position Reconstruction
- TPC multi-site event

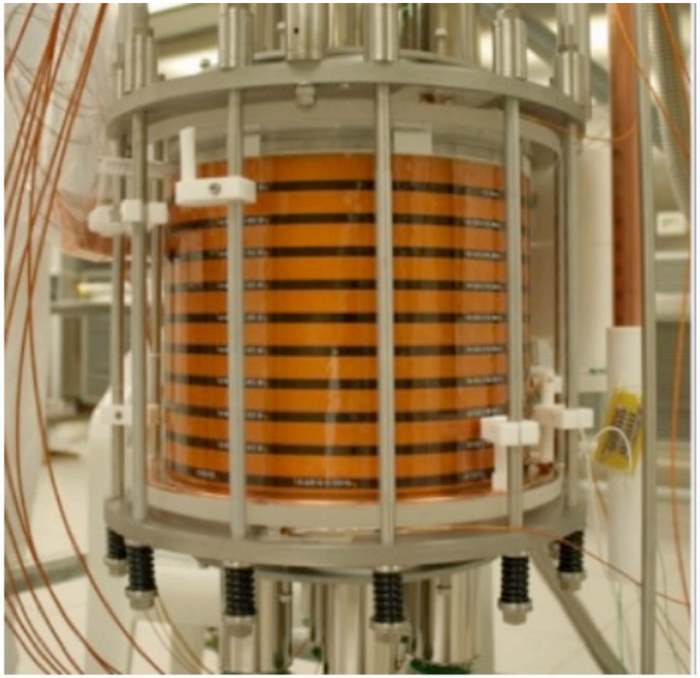
Expected bg discrimination > 10^{10}



Log (S2/S1) vs f90

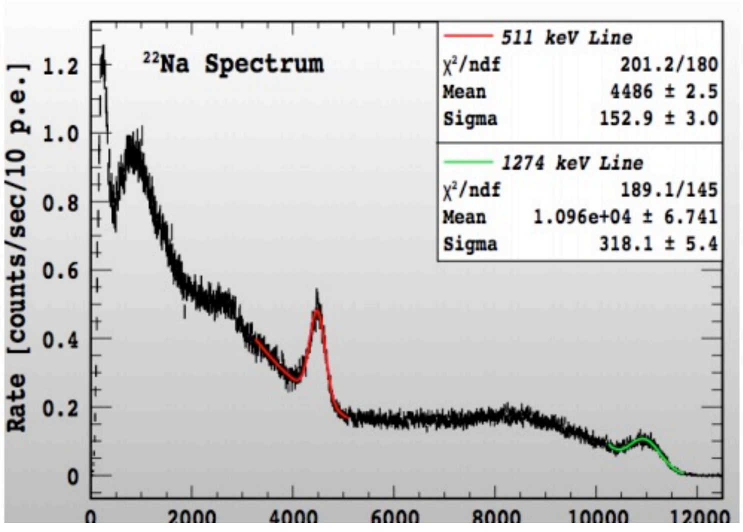
f90 = the fraction of S1 in the first 90 ns

DS-10 TPC



Double phase Argon TPC prototype
- Assembled in Princeton
- 10 kg active mass of Atmospheric Lar
- Passive water veto
- 7 top + 7 bottom R11065 HQE 3'' PMTs
- Electric field: Edrift = 1 kV/cm, Egas ~ 3 kV /cm
- 20 cm diamater, 20 cm height
- 2 cm gas gap

Goals:
- **High LY**: 8.78 ± 0.01 p.e./keVee @ null field
- Stable HHV at 36 kV
- **Good discrimination**
- Good purity
- Electric field settings



DS-50 Detector design

Installed ad hall C at LNGS

LAr TPC

- 36 cm x 18 cm radius
- 50 kg **UAr** (**36.9 kg fiducial mass**)
- 19 + 19 3'' PMTs
- Uniform Electric Field (200 V/cm)
- ~1 cm Gas Pocket
- Extraction Electric Field (2.8 kV/cm)
- Reflectors and TPB coating

Outer neutron veto

- 30 tons Liquid Scintillator (1:1 TMB + PC)
- 110 PMTs (LY = 0.5 pe/keV)
- 2 m radius

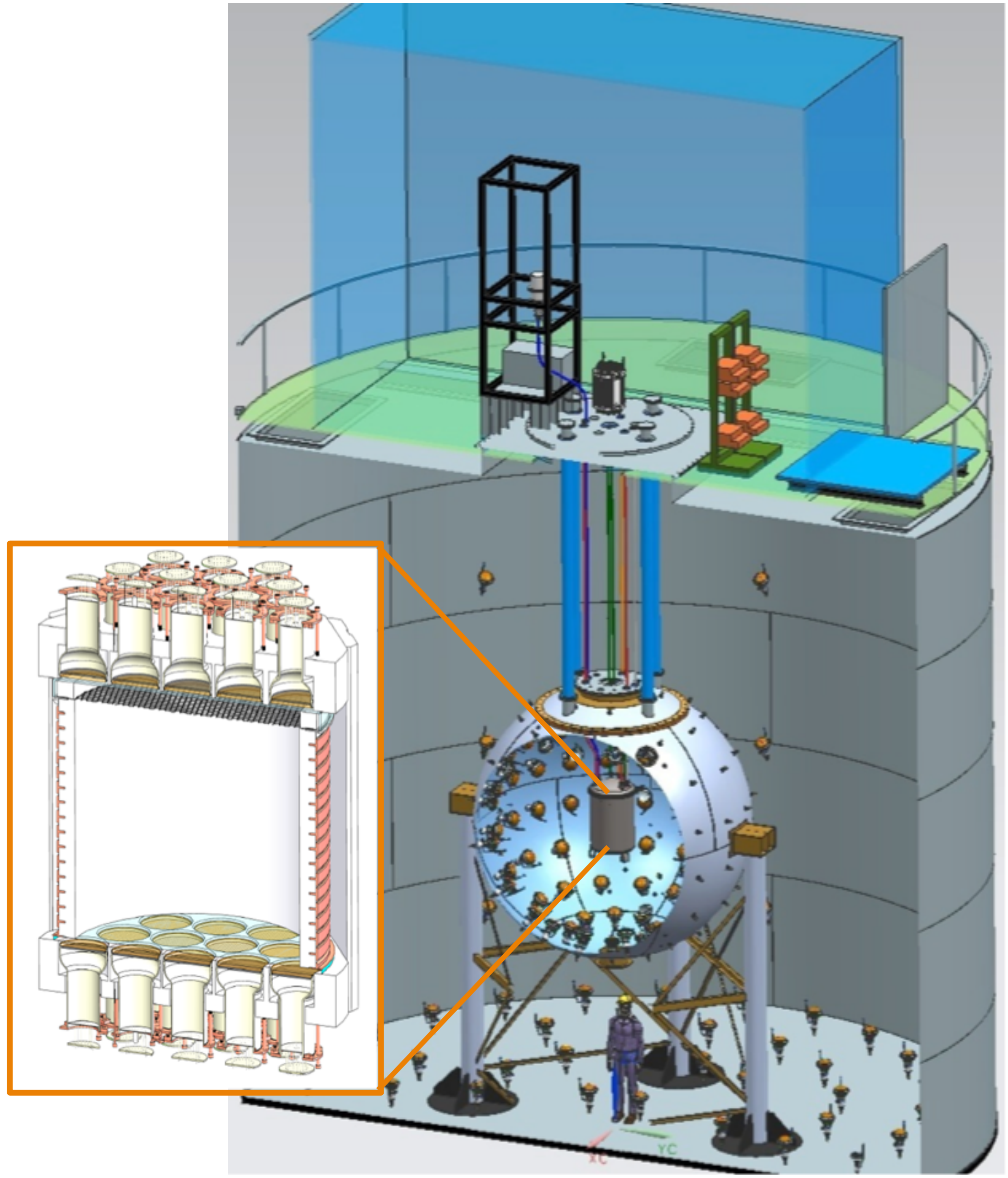
Water Cherenkov detector

- 80 PMTs
- 1 kt water, 5.5 m radius

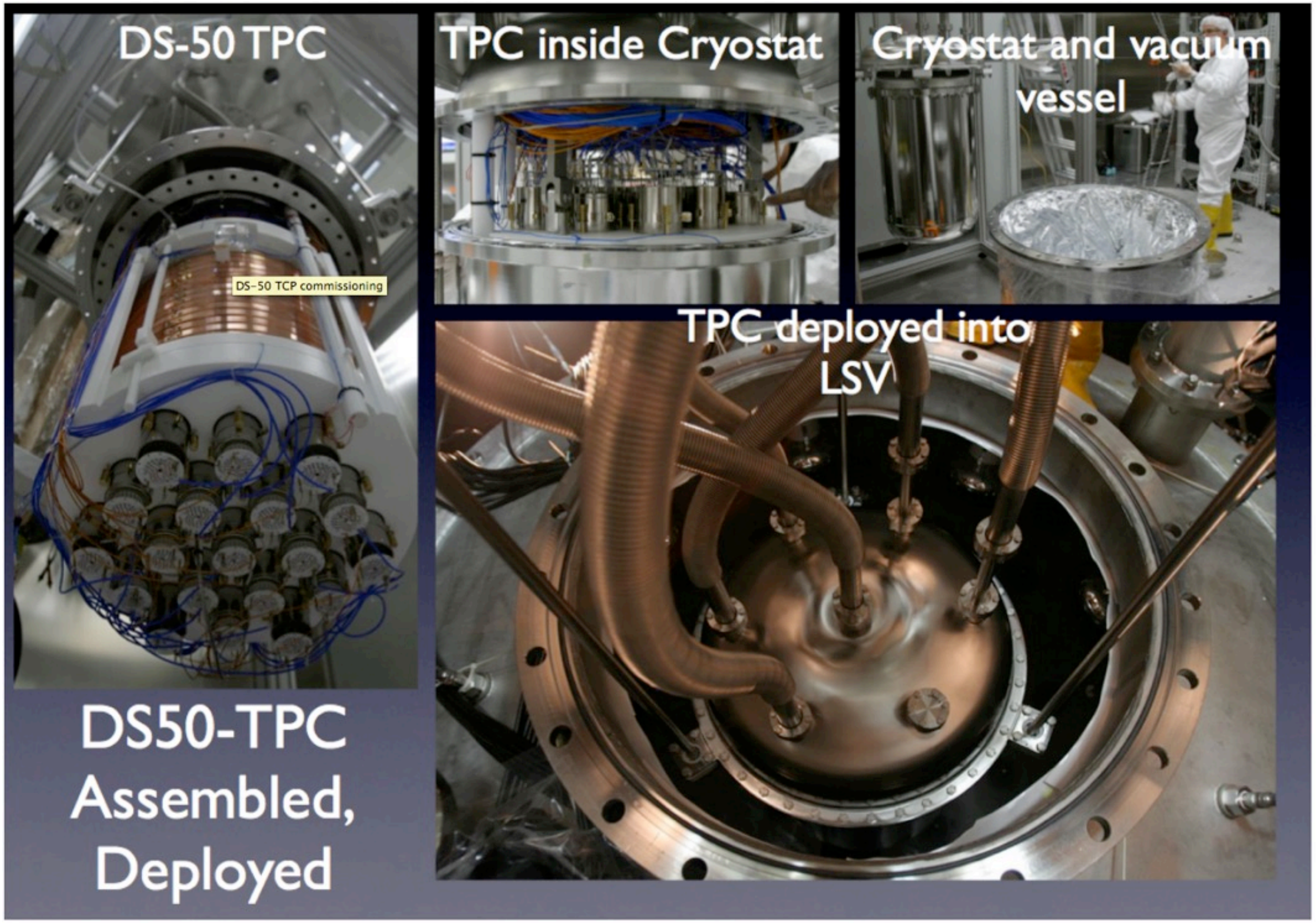
Veto's Rejection Efficiencies:

> 99.5% against Radiogenic neutrons

> 95% against Cosmogenic neutrons

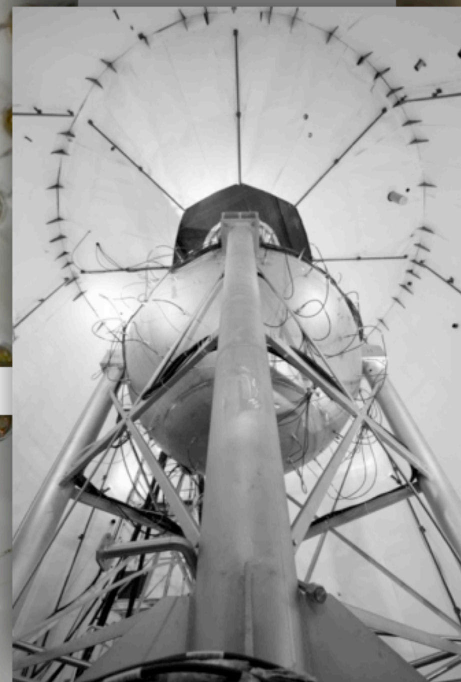


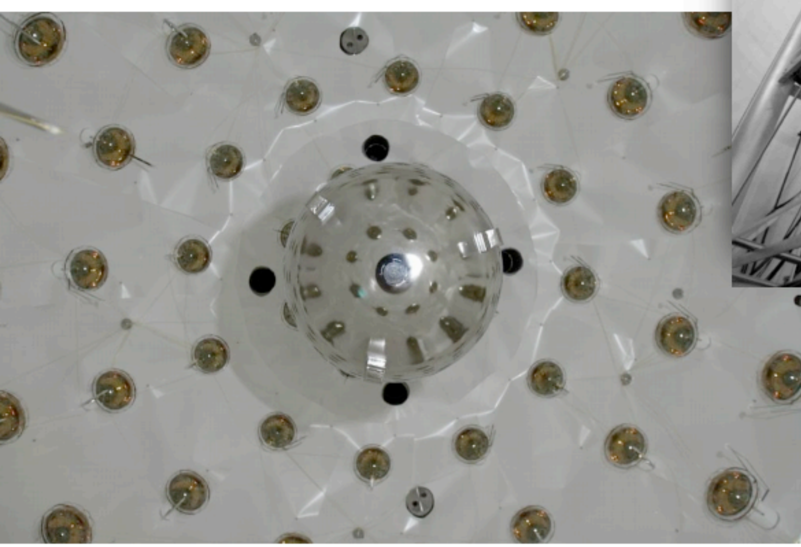
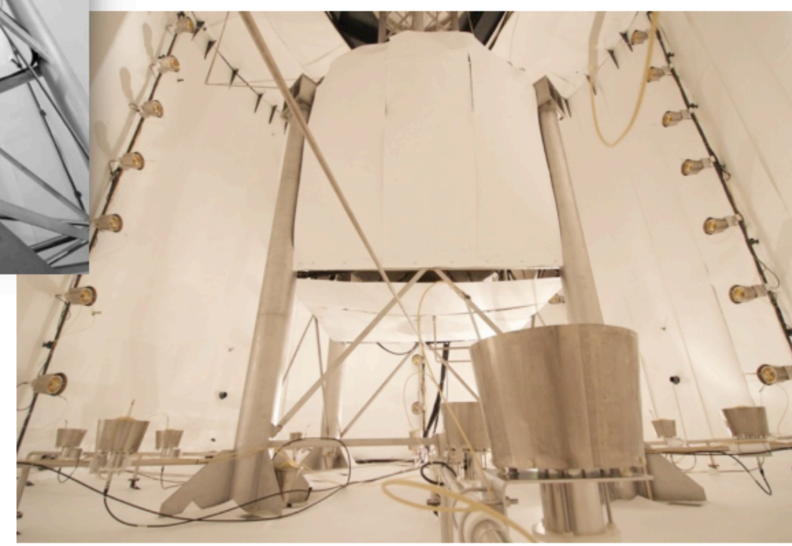
DS-50 TCP commissioning



Oct 2013: Start Data Taking
Oct 2014: First Physics Paper on arxiv

Veto commissioning

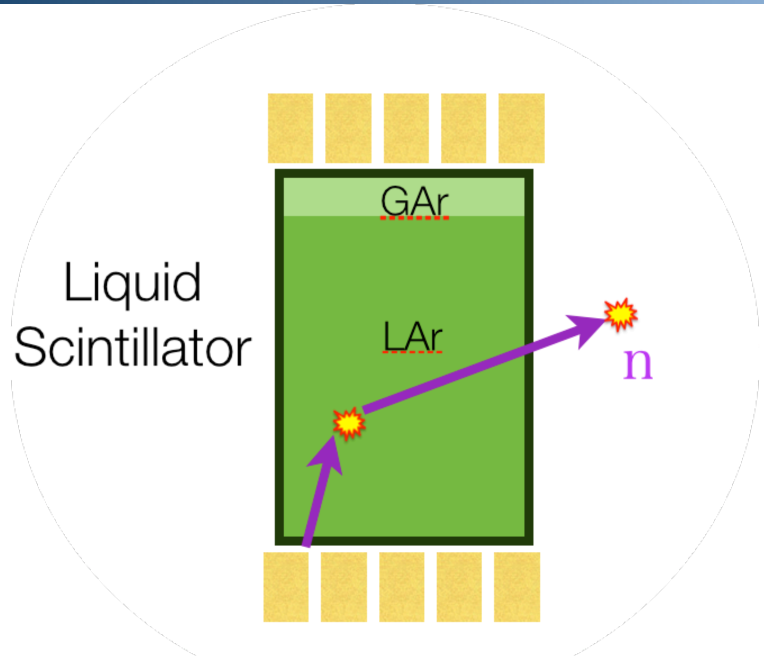
Veto commissioning

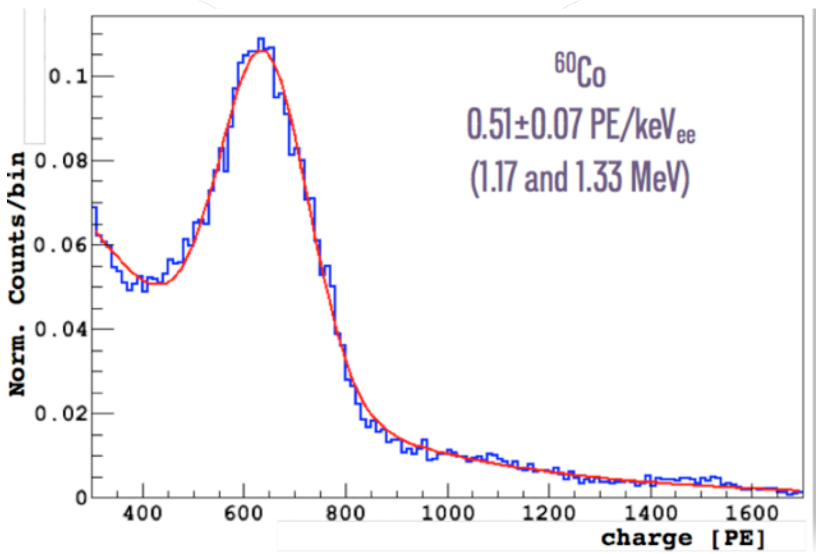
Looking for **coincidences** inside/outside the TPC (multiple interactions)

Light Yield
Liquid Scintillator LY **~ 0.5 pe/keV**, satisfactory for Veto requirements

Rate:
The background studies in the LSV evidenced a high rate due to ^{14}C

- Identified ^{14}C from **TMB**
- TMB **removed** and **purified**

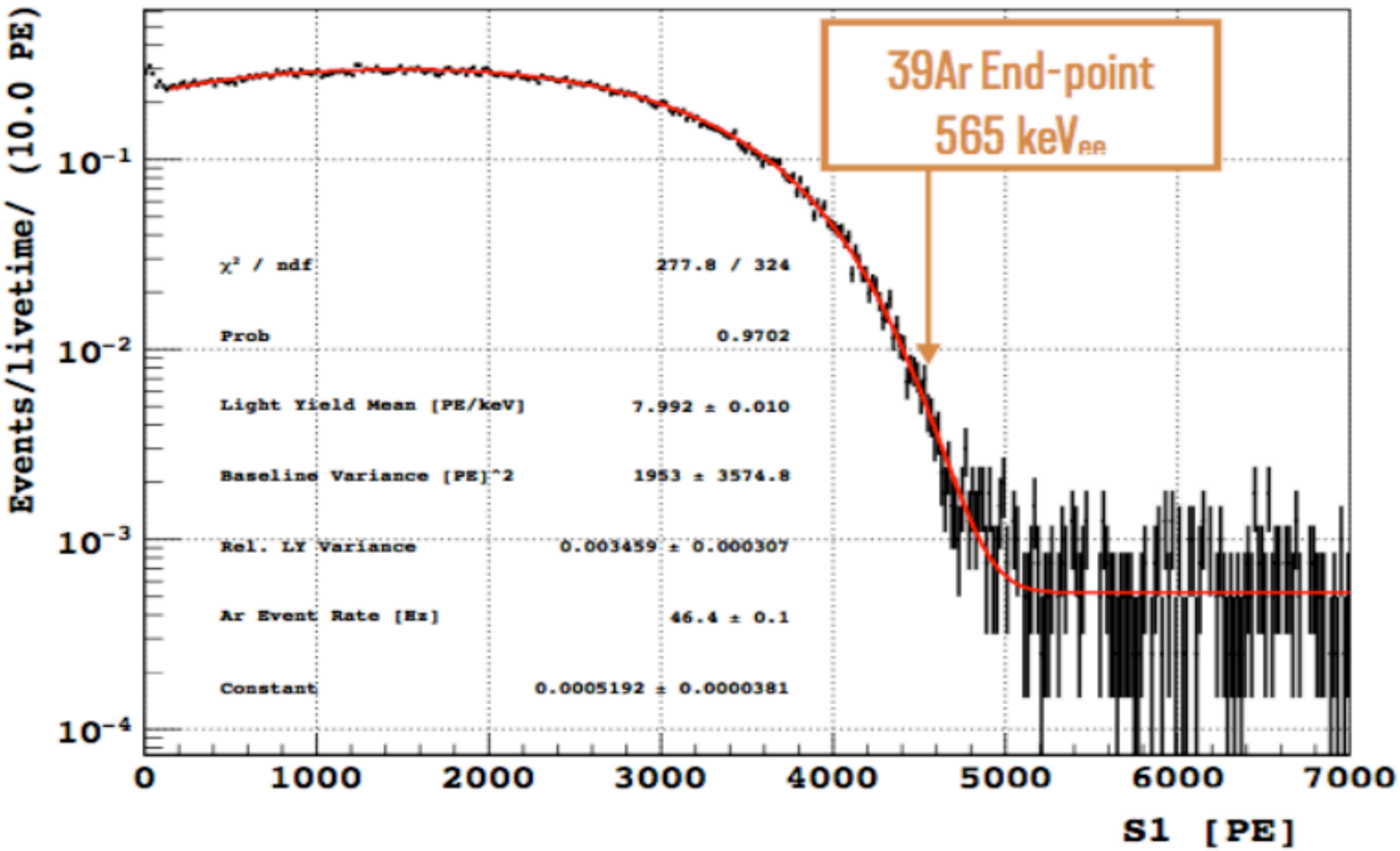




The ^{39}Ar spectrum

Currently running with
Atmospheric Argon (rich in ^{39}Ar)

Rate: ~ 1 Hz/kg

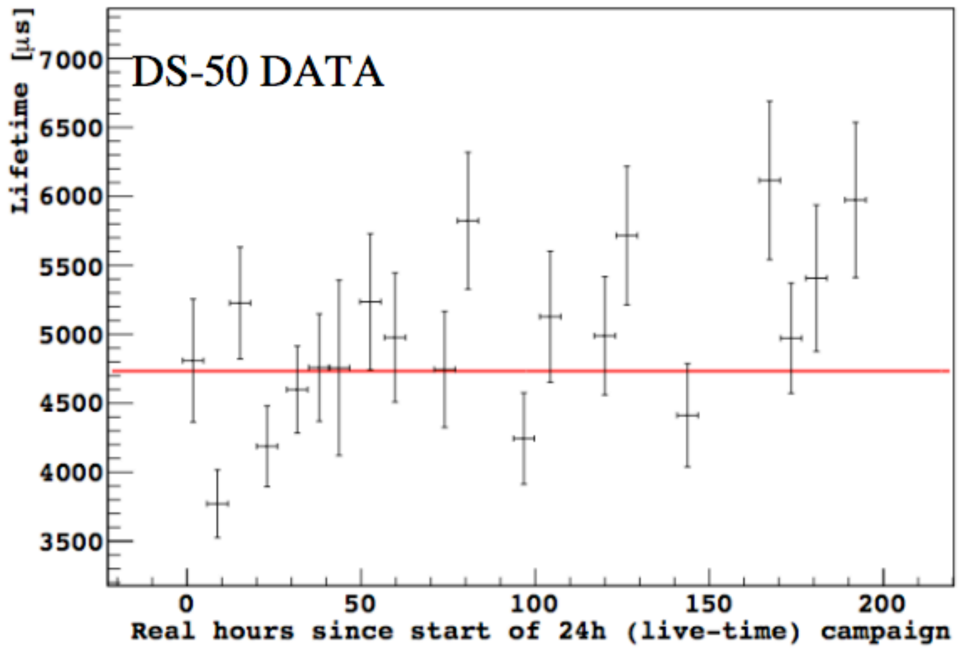


The electron lifetime

Electron lifetime: ~ 5 ms
Maximum drift time in the TPC
is 375 μs at 200 V/cm

Electron drift velocity = 0.93 mm/s

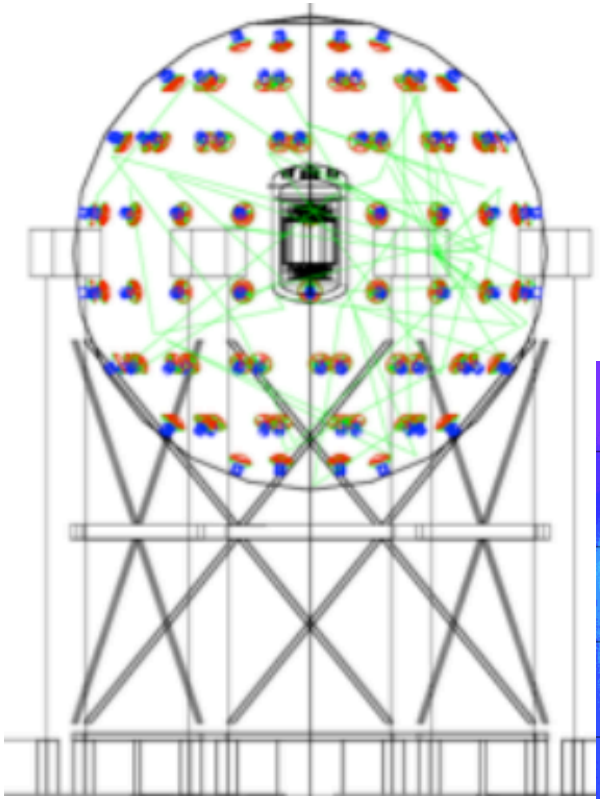
- High **Purity**
- **Stability** of the Electric Field

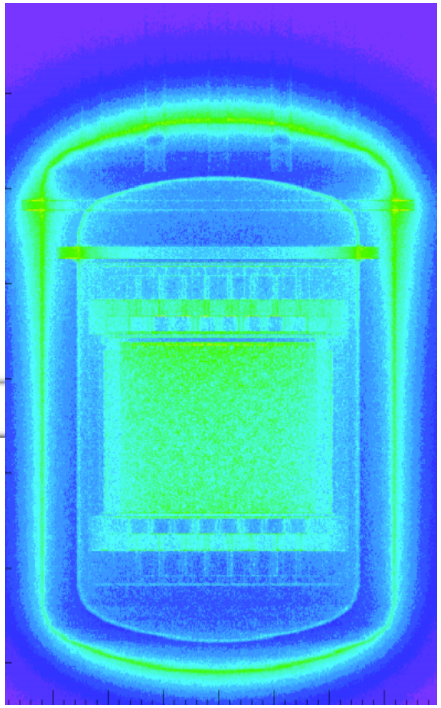


The DarkSide MC

Geant4 based simulation of the detector

Full geometry description of:
- DarkSide-10
- DarkSide-50
- Multiple DarkSide-G2 designs
- Neutron Veto
- Muon Veto

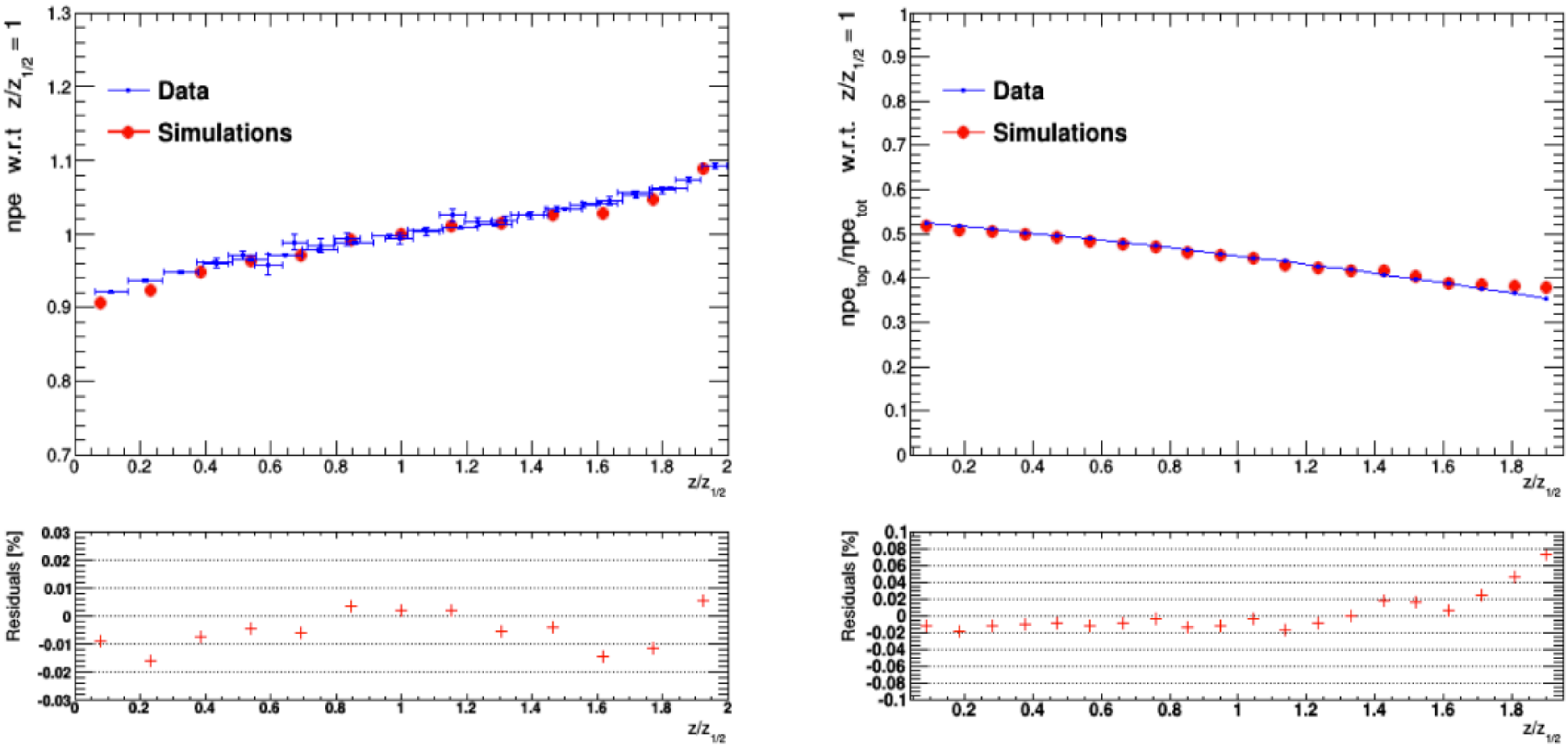




Single photon tracking
Full description of the optical
properties
Several generators
Three energy response model

Understanding the TPC

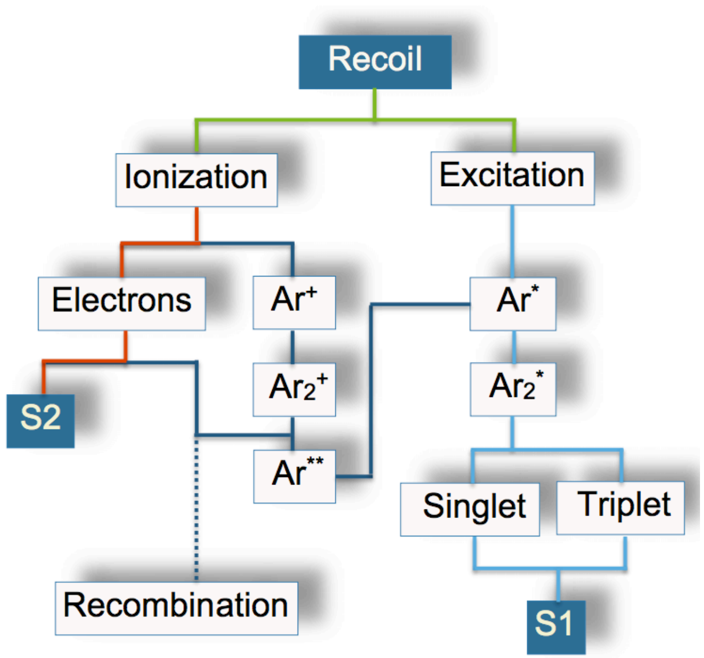
1. The internal optics description



Few percent accuracy, after the tuning of 36 optical parameters

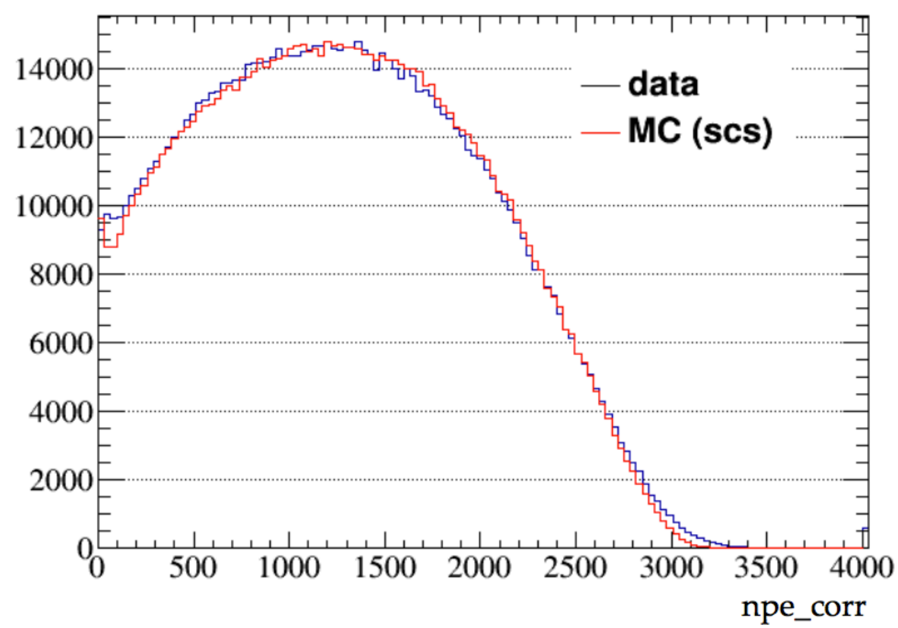
Understanding the TPC

2. The recombination model (for PSD)



The recombination probability is obtained **globally fitting** existing data from different data pools

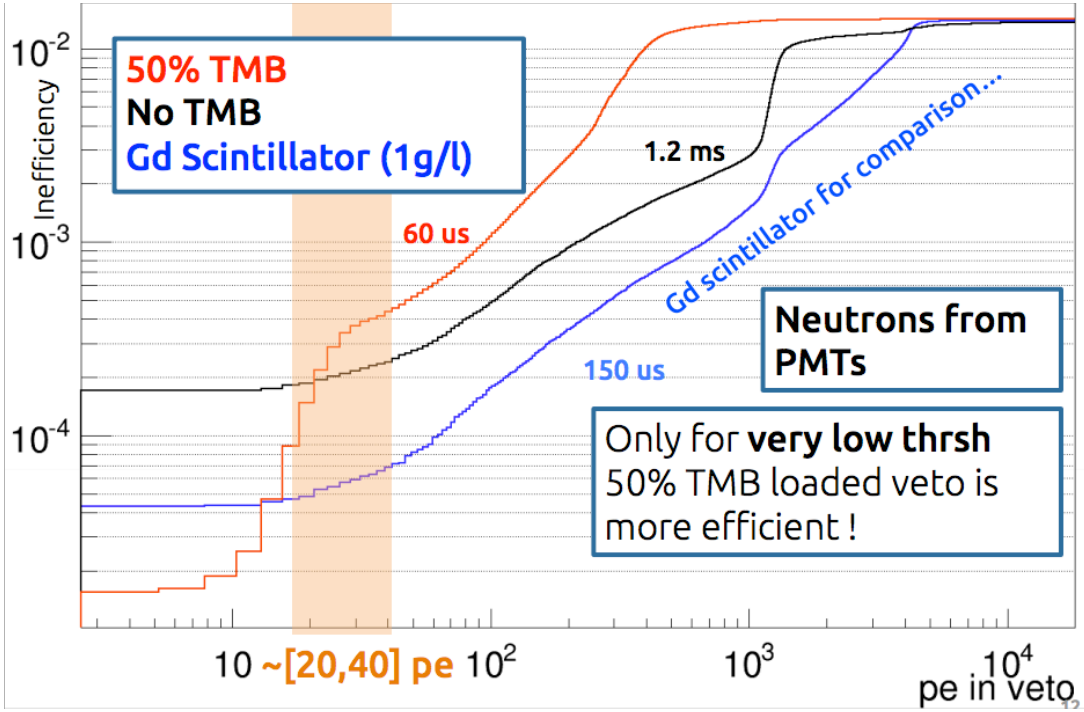
^{39}Ar spectrum



The neutron bg estimation

Starting from (alpha, n) spectra from TALYS, TRIM
Neutron propagation through the detector
Veto efficiency studies and **neutron bg** estimation

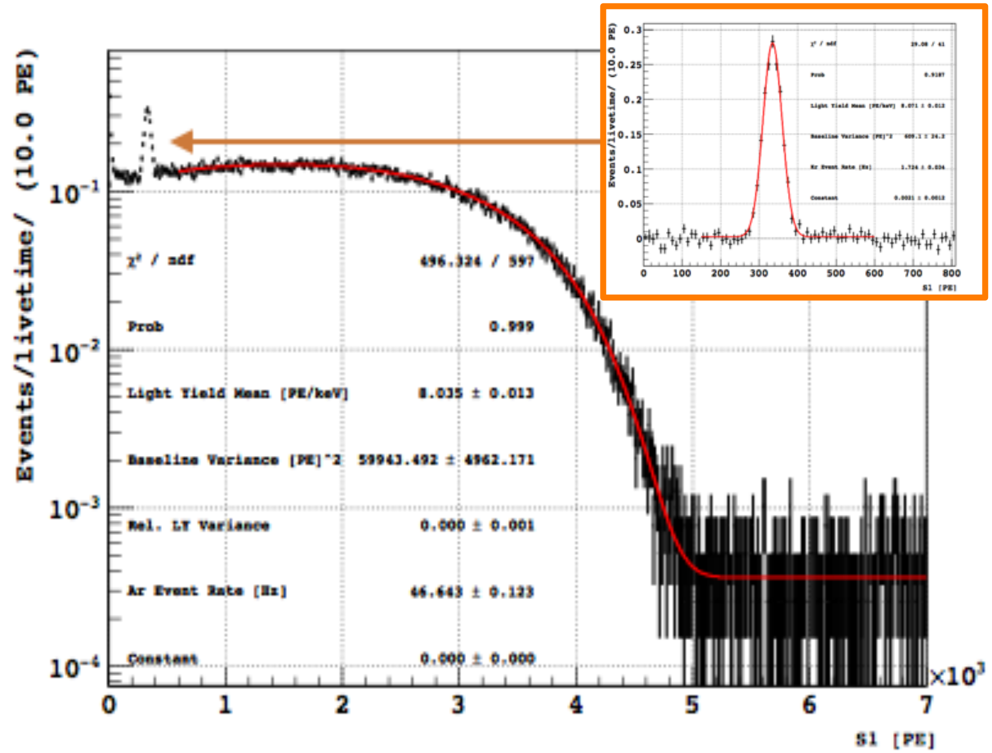
Material	Neutron yield (TALYS)
Cryostats (159.3 kg)	**< 34.1 n/y**
38 PMT	**100.3 n/y**
Fused Silica Windows (3.7 kg)	**0.17 n/y**
Teflon (50 kg)	**1.7 n/y**



TPC ER calibration

Presently running with Atmospheric Argon

Gaseous ^{83m}**Kr** injection:
41.5 keV peak



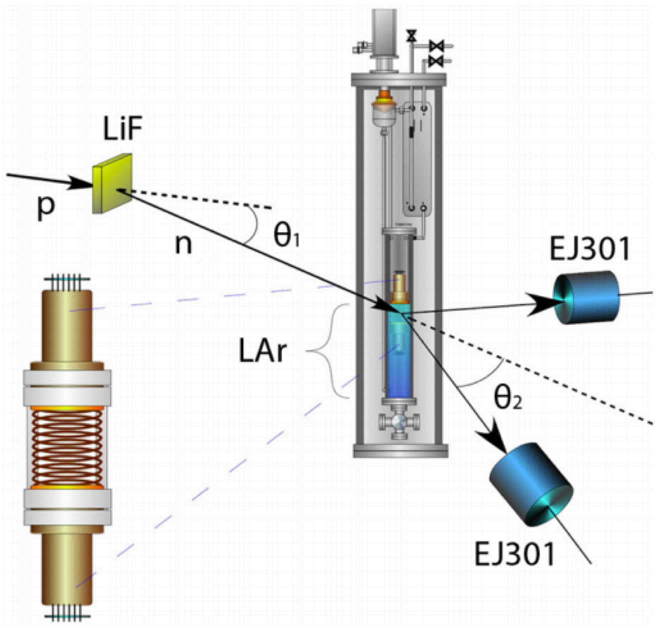
Average Light Yield:
7.9 +- 0.4 pe/keV at null field
~7.1 pe/keV at 200 V/cm
(the PSD is strongly dependent on the LY)

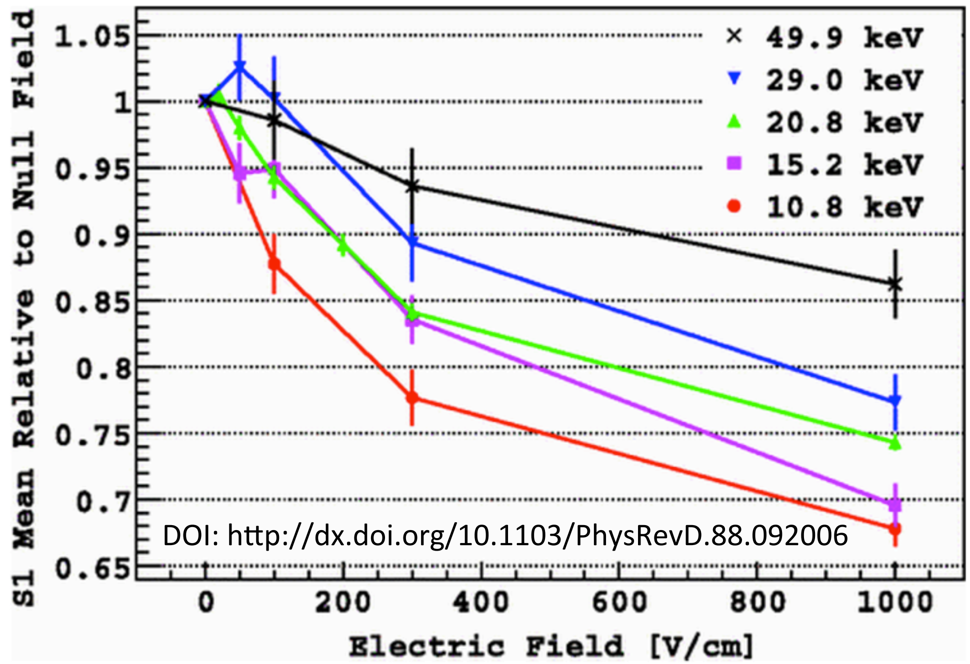
Calibrations with other sources are currently ongoing
^{57}**Co,** ^{133}**Ba, neutrons…**

TPC NR Calibration (from SCENE)

Need to study the response of the TPC to **single nuclear recoils** (expected from WIMPs)

SCENE Scintillation Efficiency of Nuclear Recoils in Noble Elements

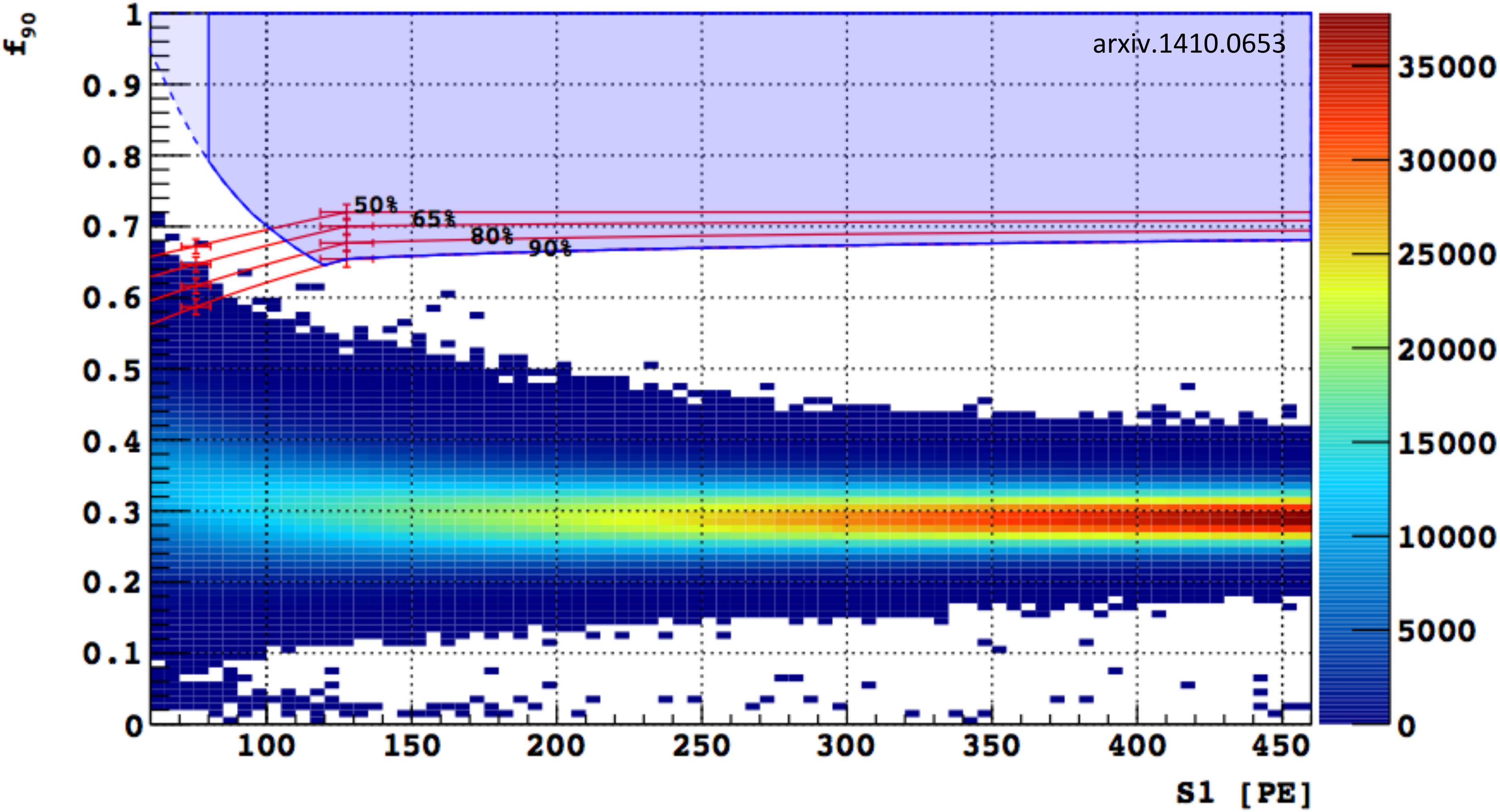




Neutron calibration in large detectors can be affected by **multiple interactions** of **neutrons**
SCENE has collected extremely pure samples of single nuclear recoils in a small TPC resembling DS-50 TPC design. We opted to use **SCENE data @ 200V/cm**, which we have access to

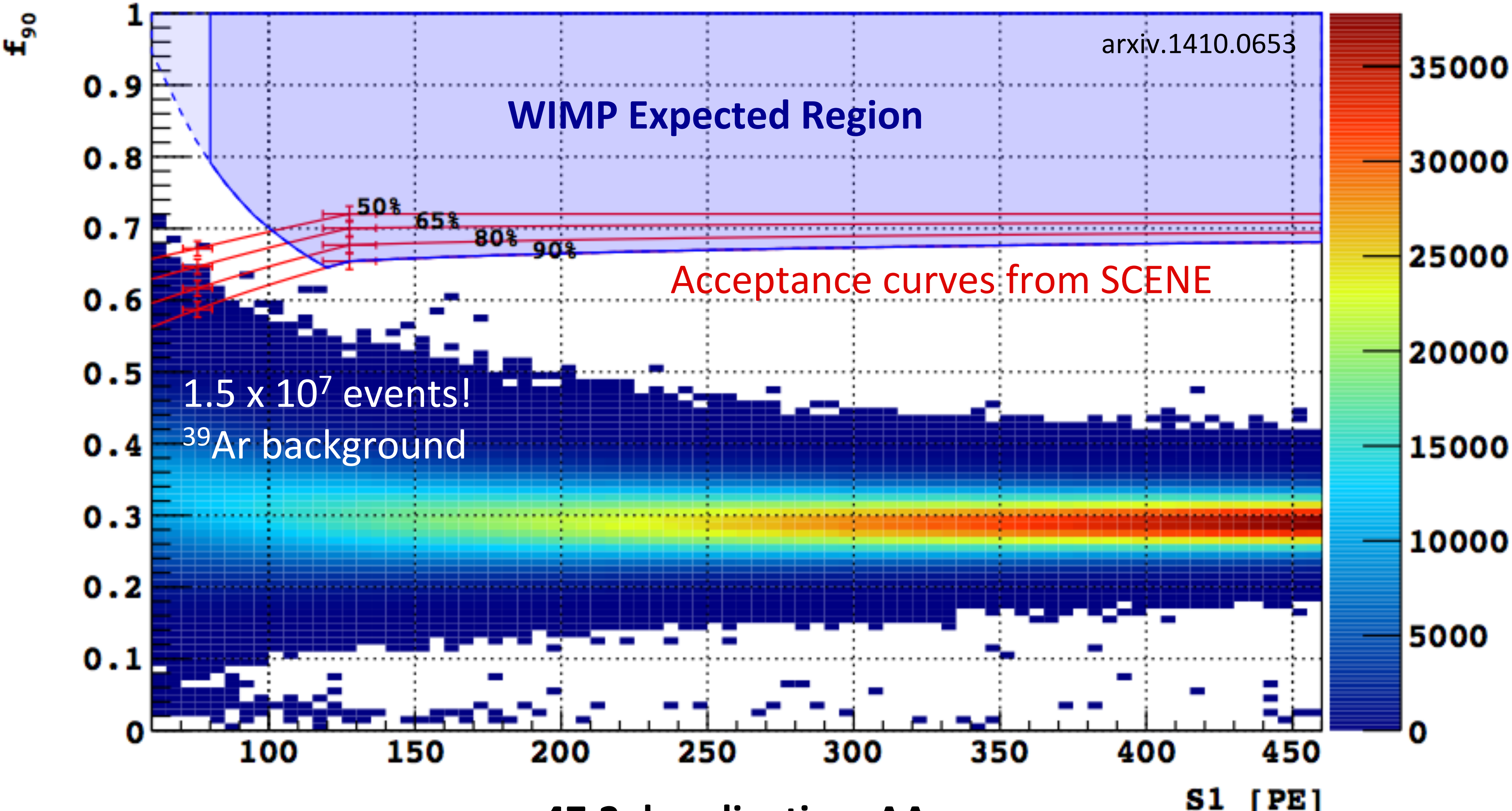
The first results (42.7 days)

PSD parameter: f90 = fraction of S1 in the first 90 ns



The first results (42.7 days)

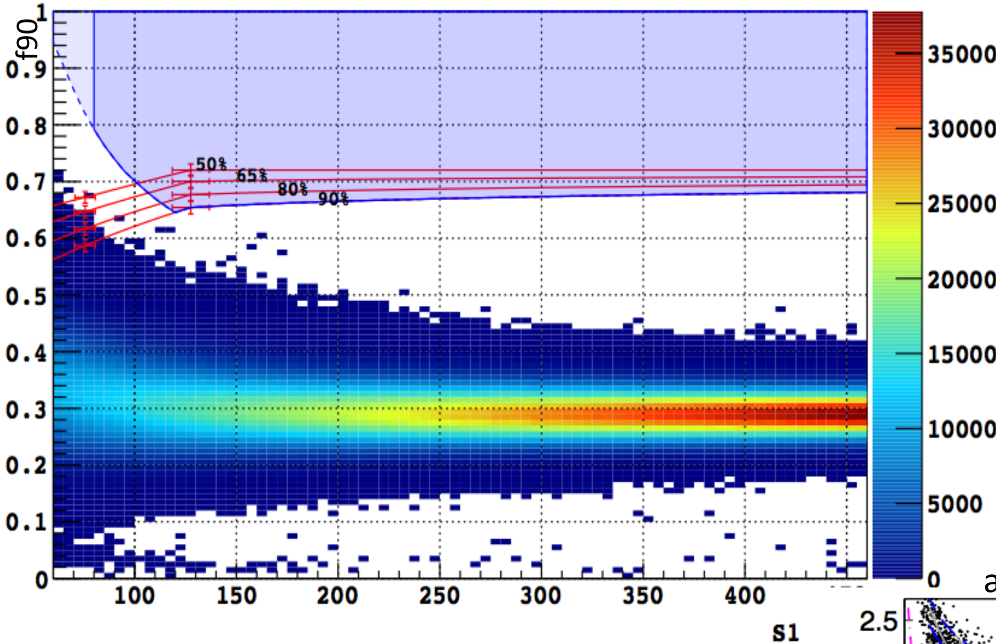
PSD parameter: f90 = fraction of S1 in the first 90 ns



47.2 days livetime AAr

Corresponding to 20 years of DS-50 with Underground Argon

Discrimination comparison

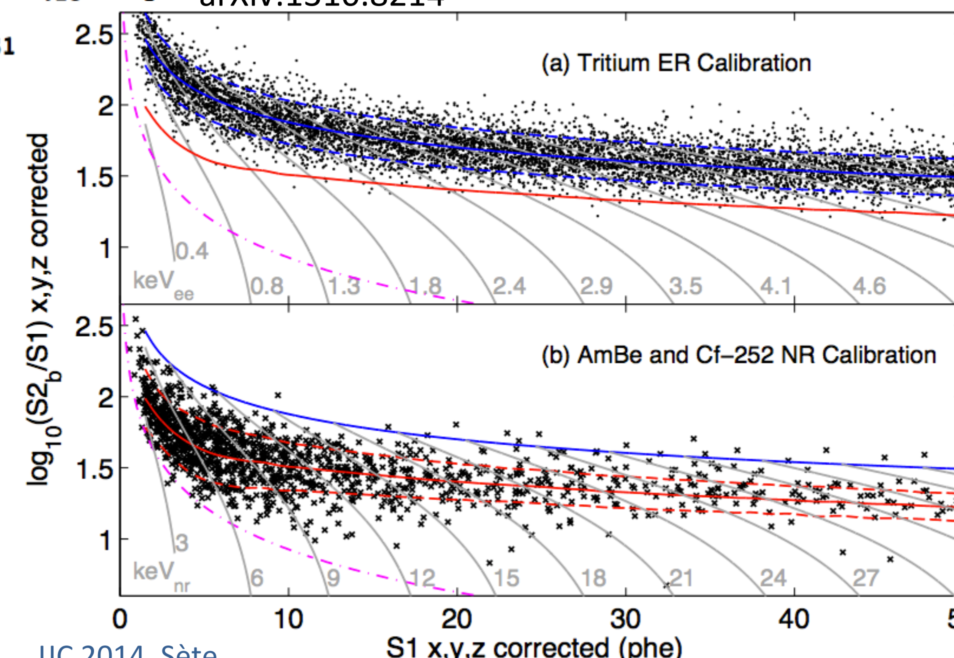


LAr → PSD disrimination
(S2/S1 not yet used)

No events close to the nuclear
Acceptance curves

arXiv:1310.8214

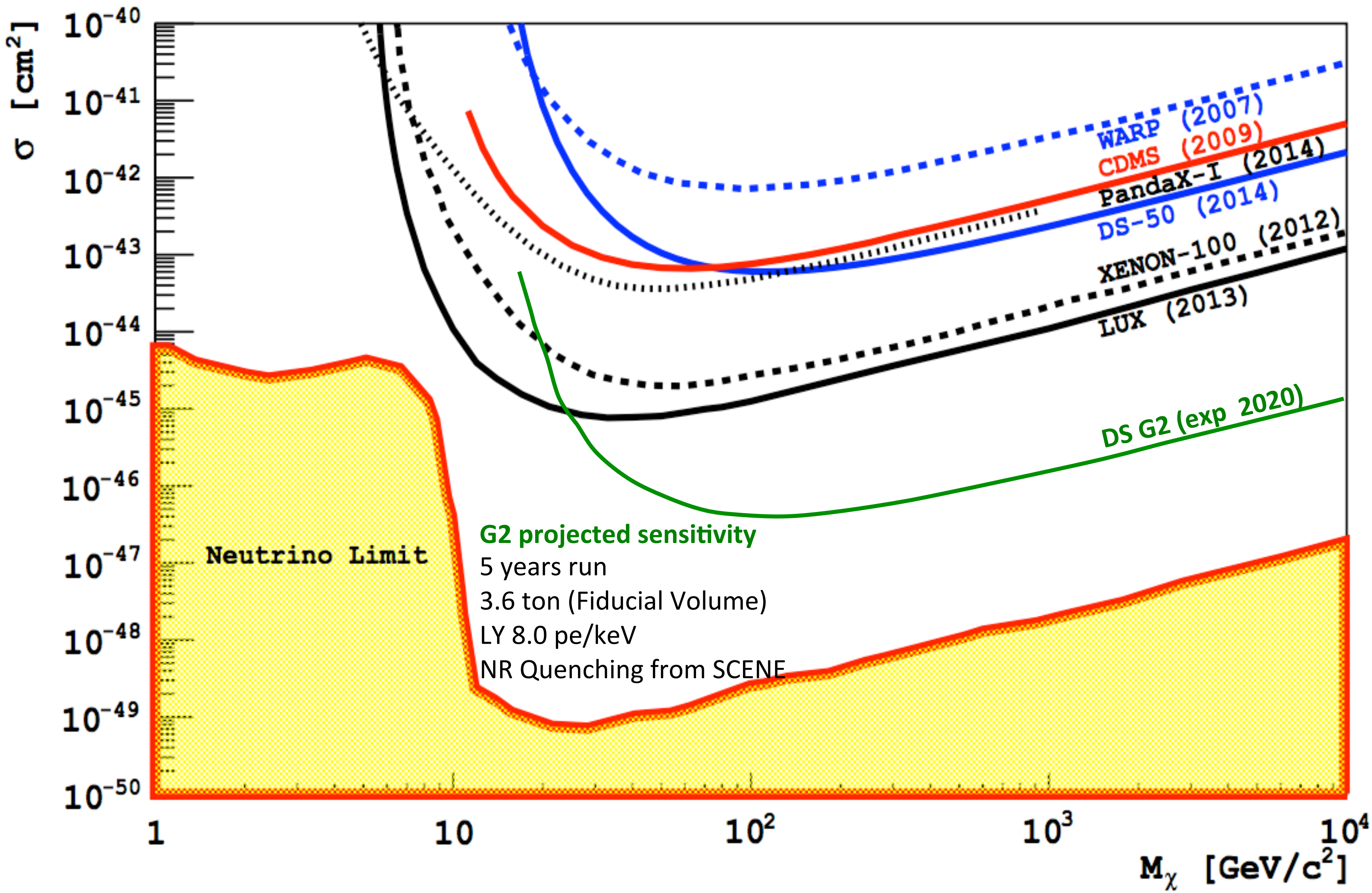
LUX calibration



LXe → S2/S1 discrimination

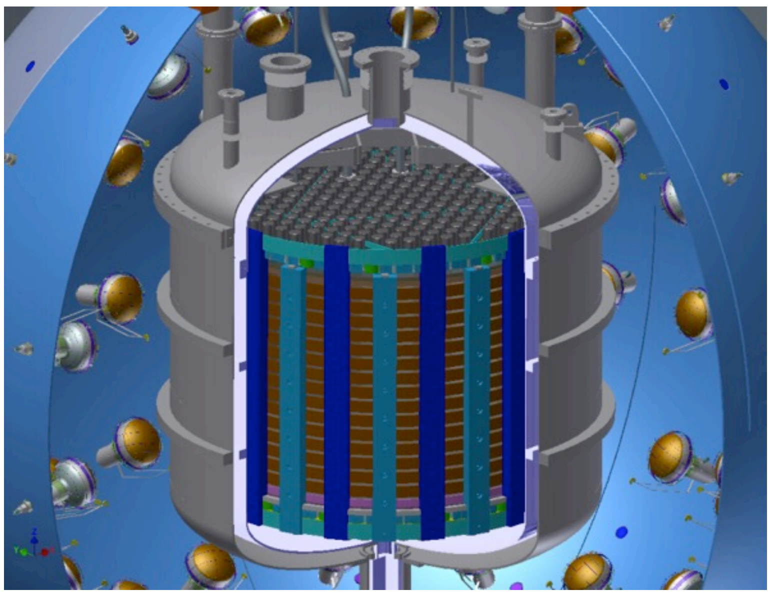
Blue Solid Line: ER mean
Red Solid Line: NR mean
Dashed lines: ±1.28 σ

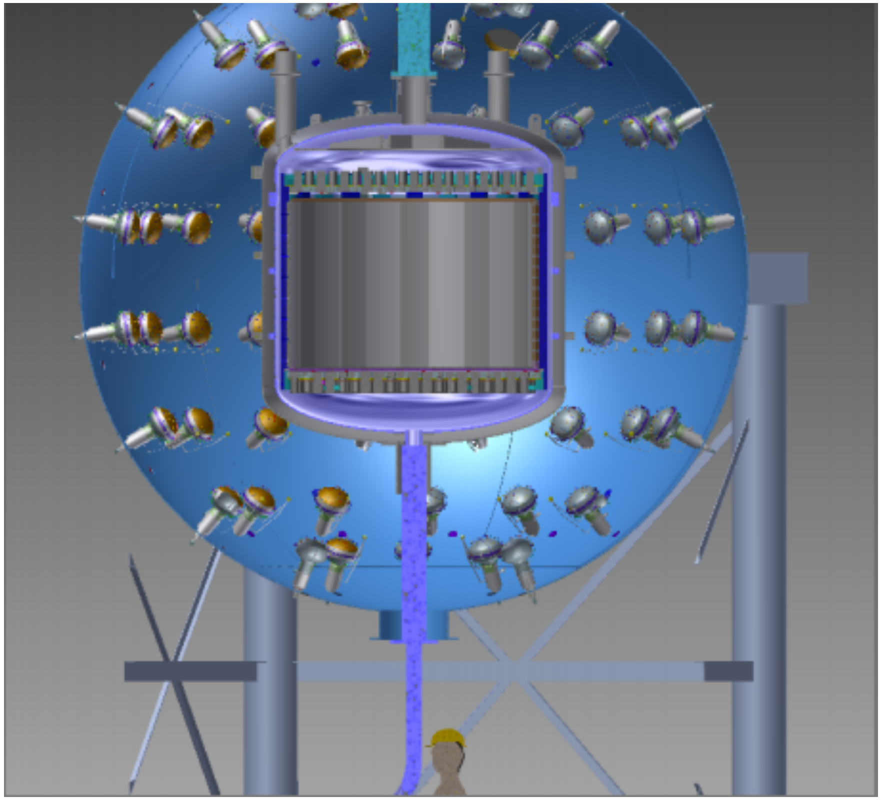
Present Limit and Projection



DarkSide G2

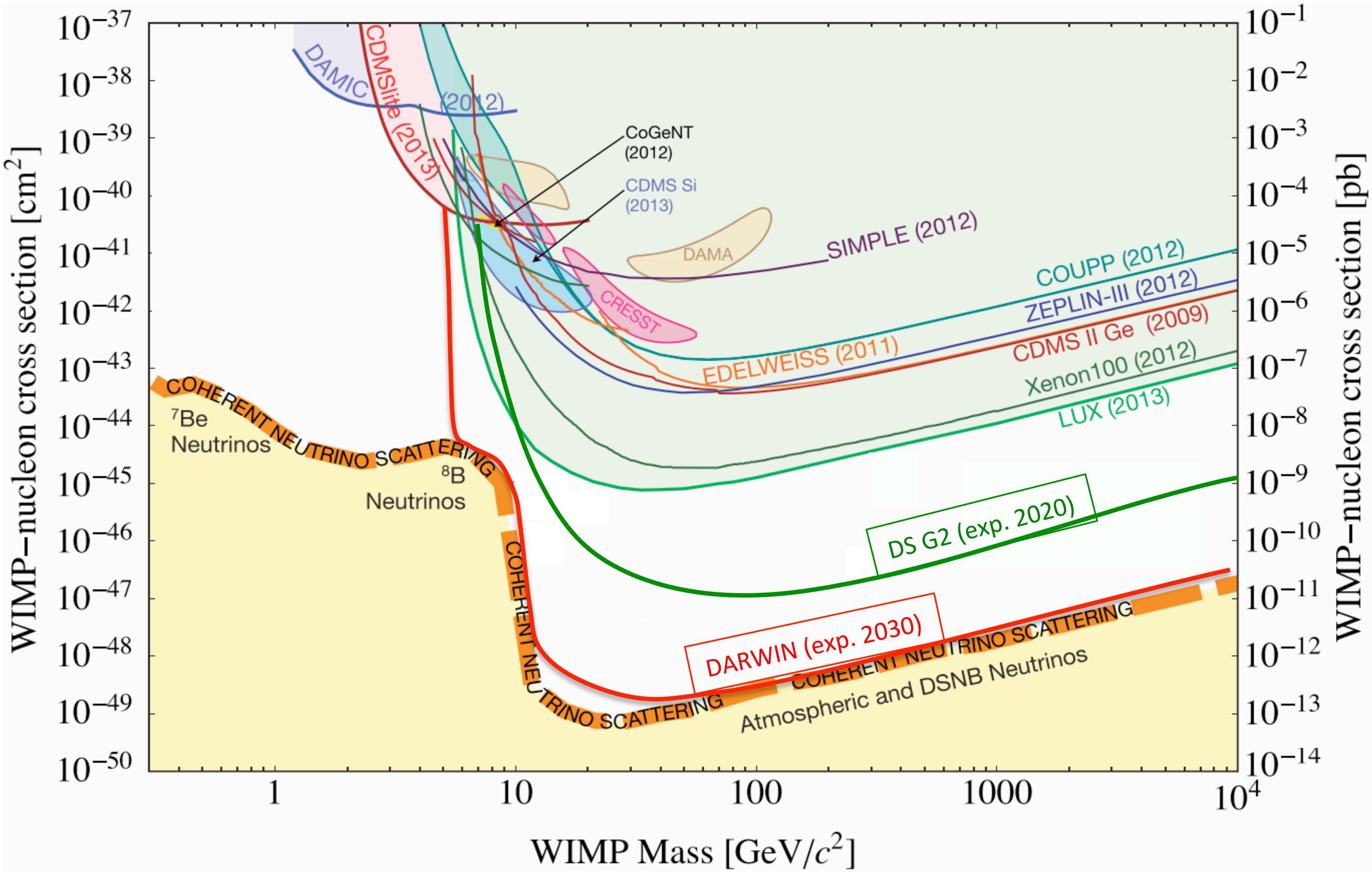
~3.8 ton: Active Uar mass.
 ~4.8 ton: total Uar mass.
30 ton boron-loaded liquid Scintillator Veto (LSV).
1,000 ton ultra pure water (WT).





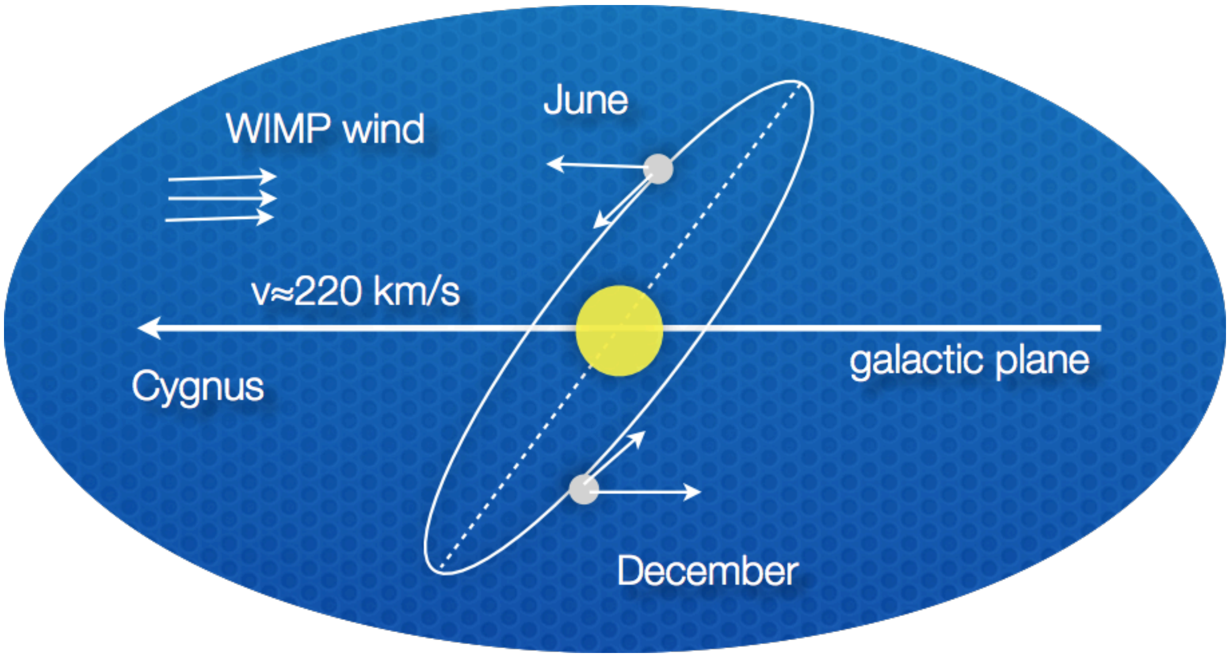
The same outer veto sphere

The future of Dark Matter search



Exploiting Directionality

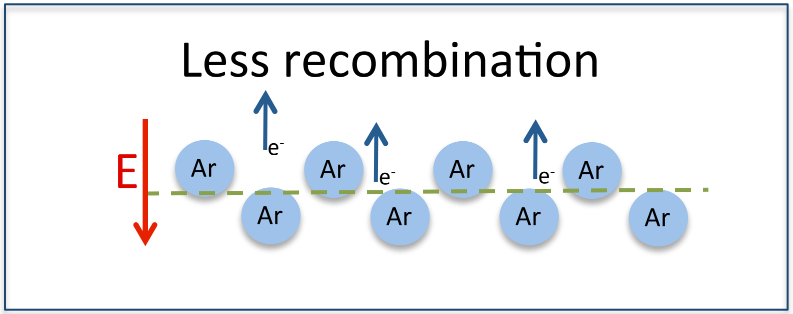
Expected seasonal rate **modulation**

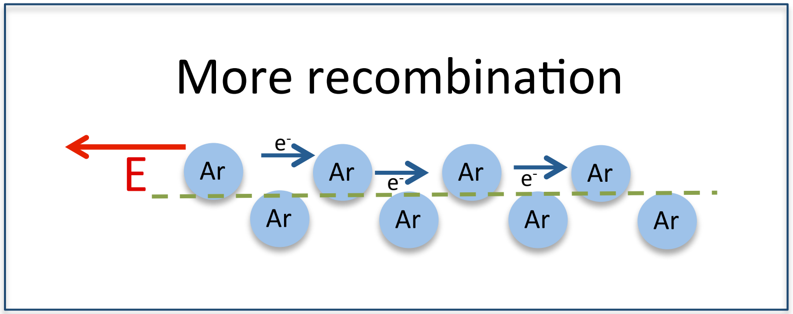


This effect might strengthen the significance of few WIMPs candidates if they will be observed in DS-G2

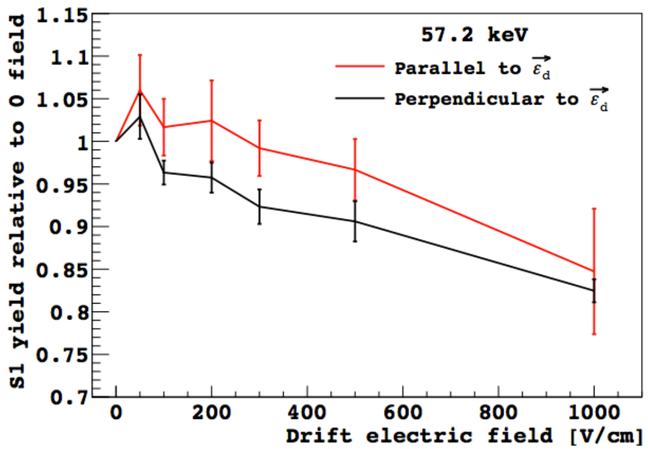
S1 is different if the electric field is parallel or perpendicular to the nuclear recoil **(in LAr only)**

Some weak hints of this effect in Lar observed in **SCENE**





Angular dependence from SCENE



http://arxiv.org/abs/1406.4825

Conclusions

The Liquid Argon TPC is **promising technique** for a large detector for **direct dark matter search**

DS-50 taking data since Oct 2013

(first results in ArXiv:1410.0653)

PSD is an effective bg rejection technique

Underground Argon expected for beginning next year

The **G2** phase design is currently under discussion