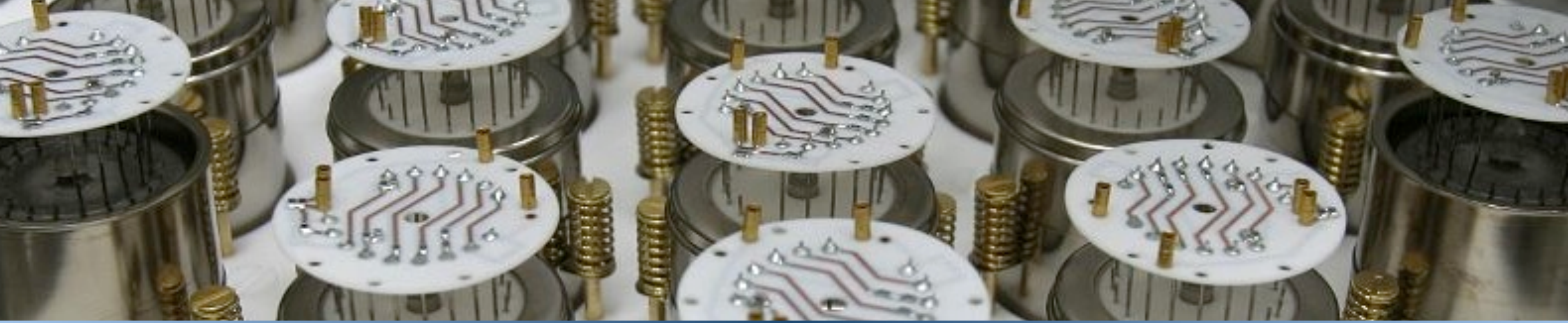


The first physics results from DarkSide

26/11/2014

P Agnes

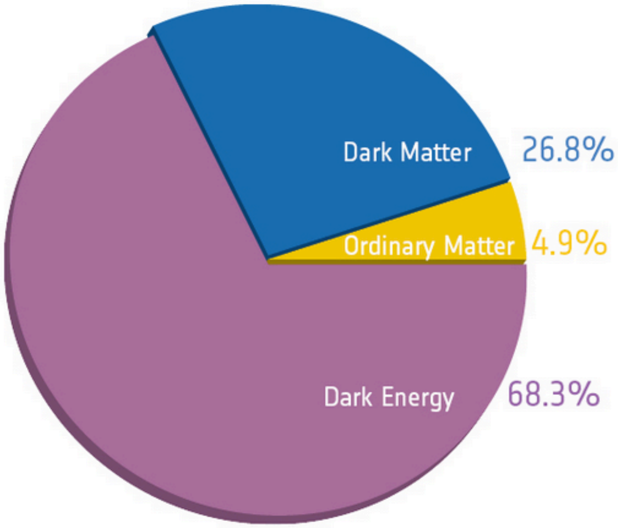
Lab APC, Université Paris 7

GdR Neutrino, Marseille

Dark Matter

Several indirect observations:

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



Dark Matter

Several indirect observations:
- Galaxy clusters
- Galactic rotation curves
- Weak lensing
- Strong lensing
- Hot gas in clusters
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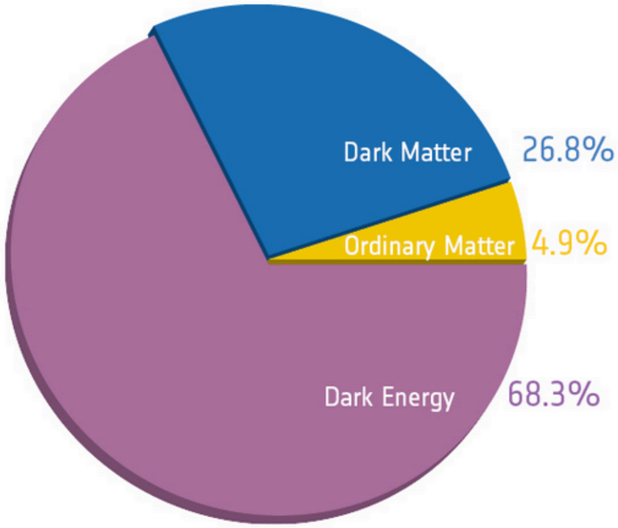
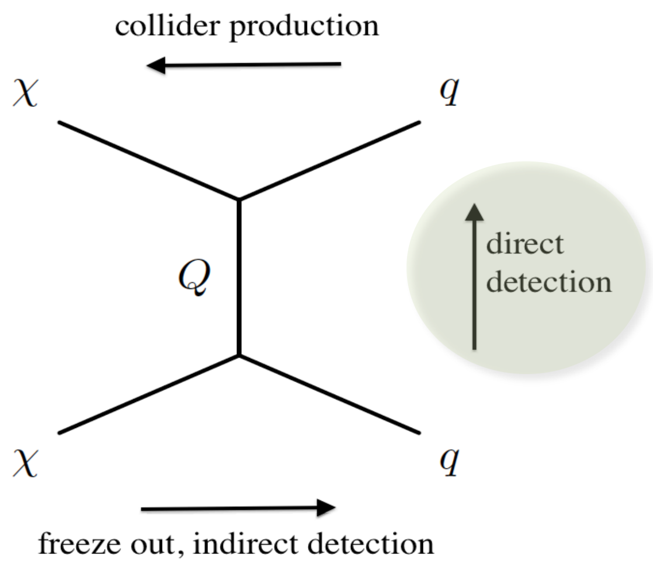


The Dark Matter particle properties:
- It is **stable**
- It interacts through **gravitational** force
- It is electrically **neutral**
- It does not interact **strongly**
- It may interact **weakly**
- It should have a **directionality**



WIMPs:
Weakly Interactive Massive Particles

Direct Detection Requirements

Large masses

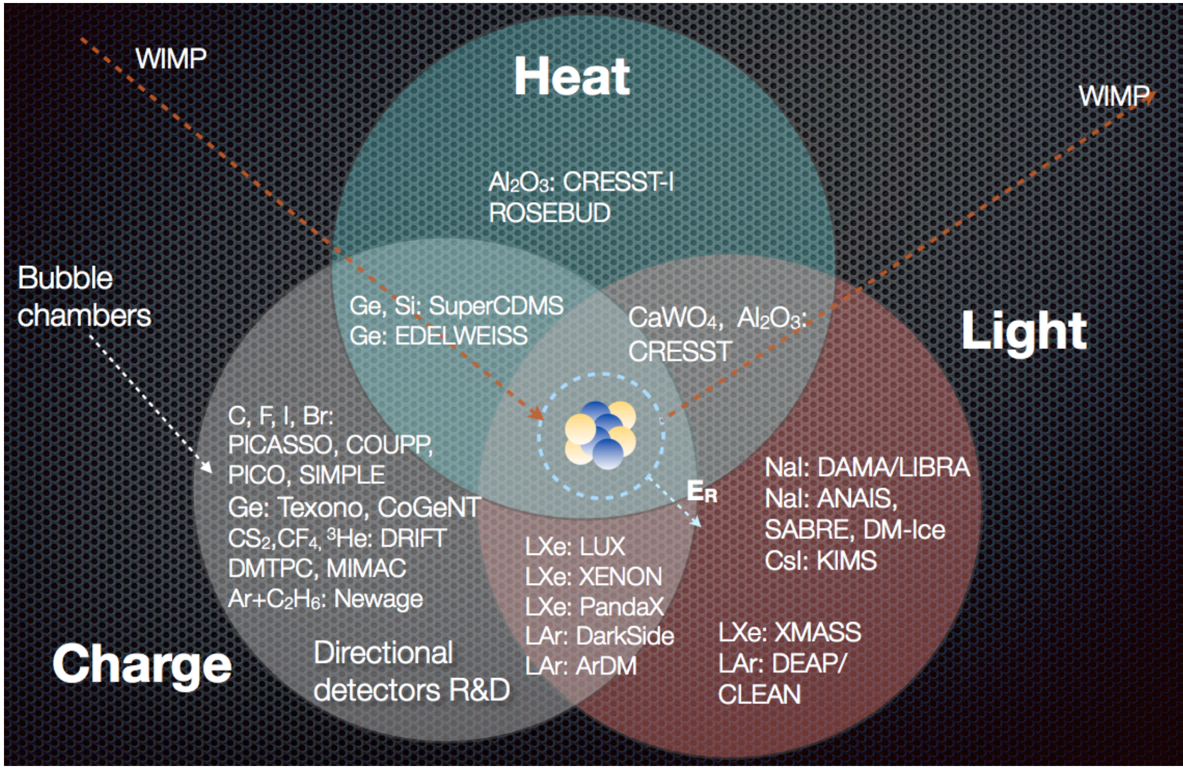
- Low rate (~1 event/ton/yr @ 10^{-47} cm^2 in noble liquids)

Low energy thresholds

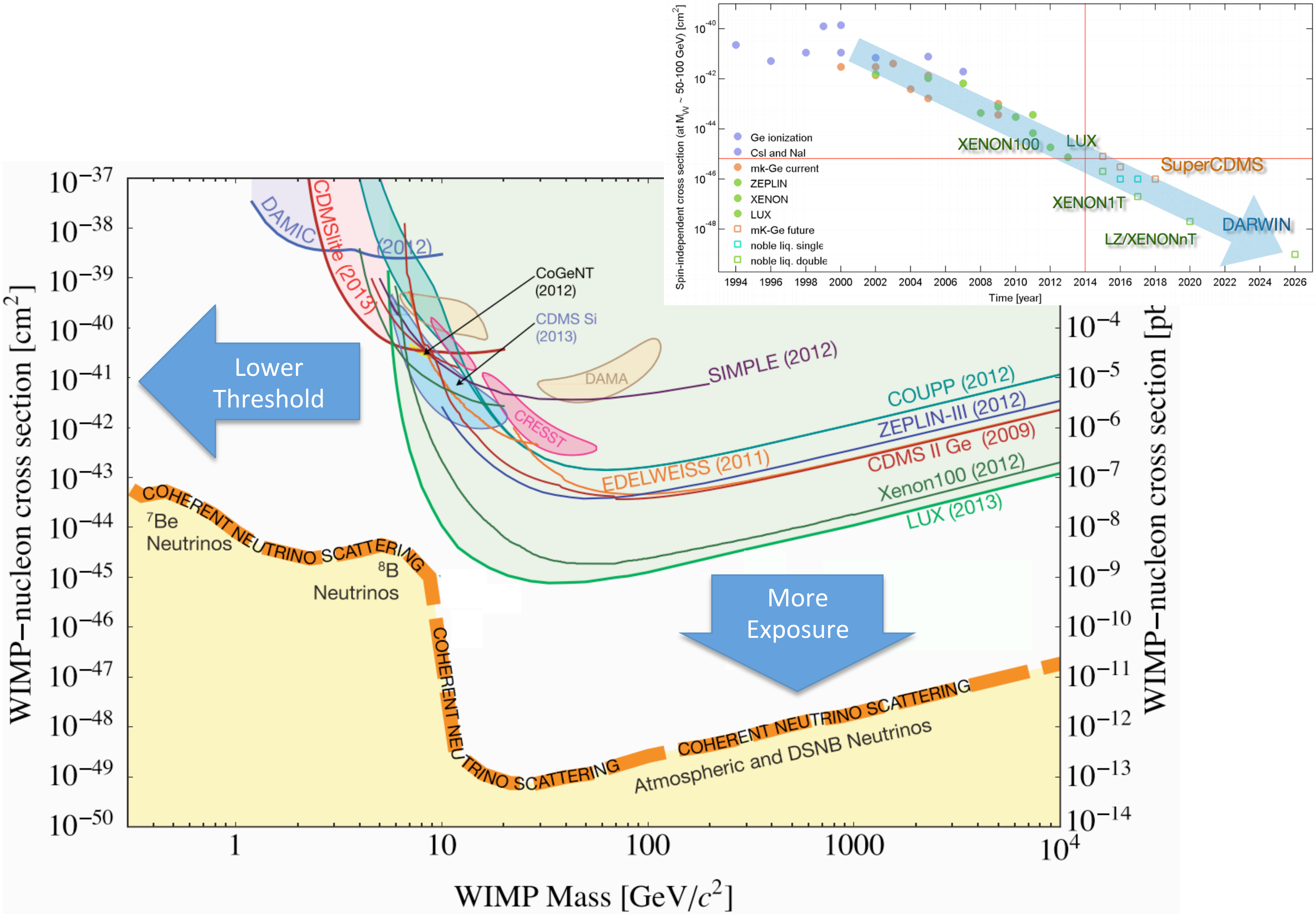
- Low energy nuclear recoils (< 100 keV)

Background suppression

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



Current status of the Dark Matter Hunt



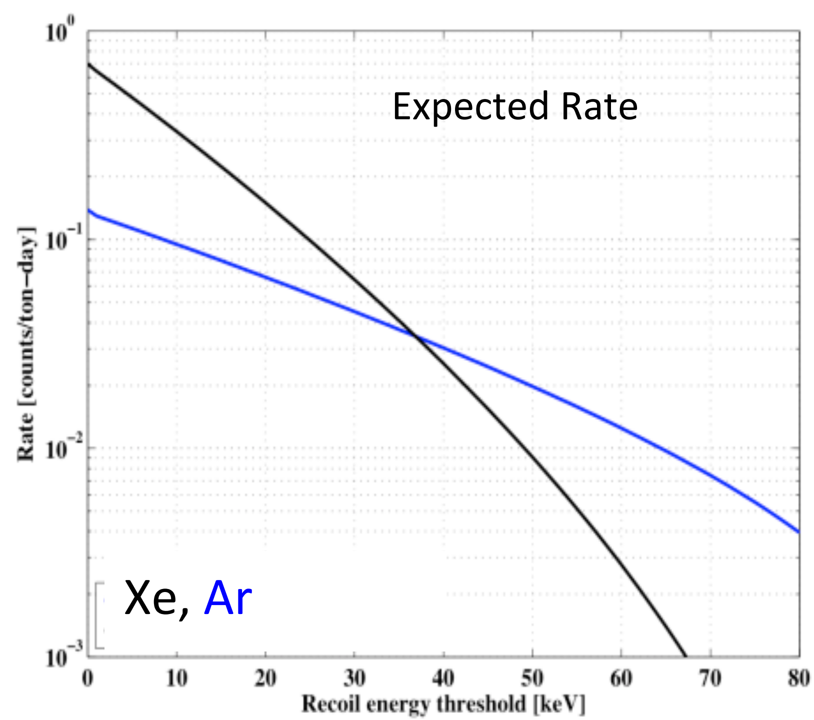
Noble liquids

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

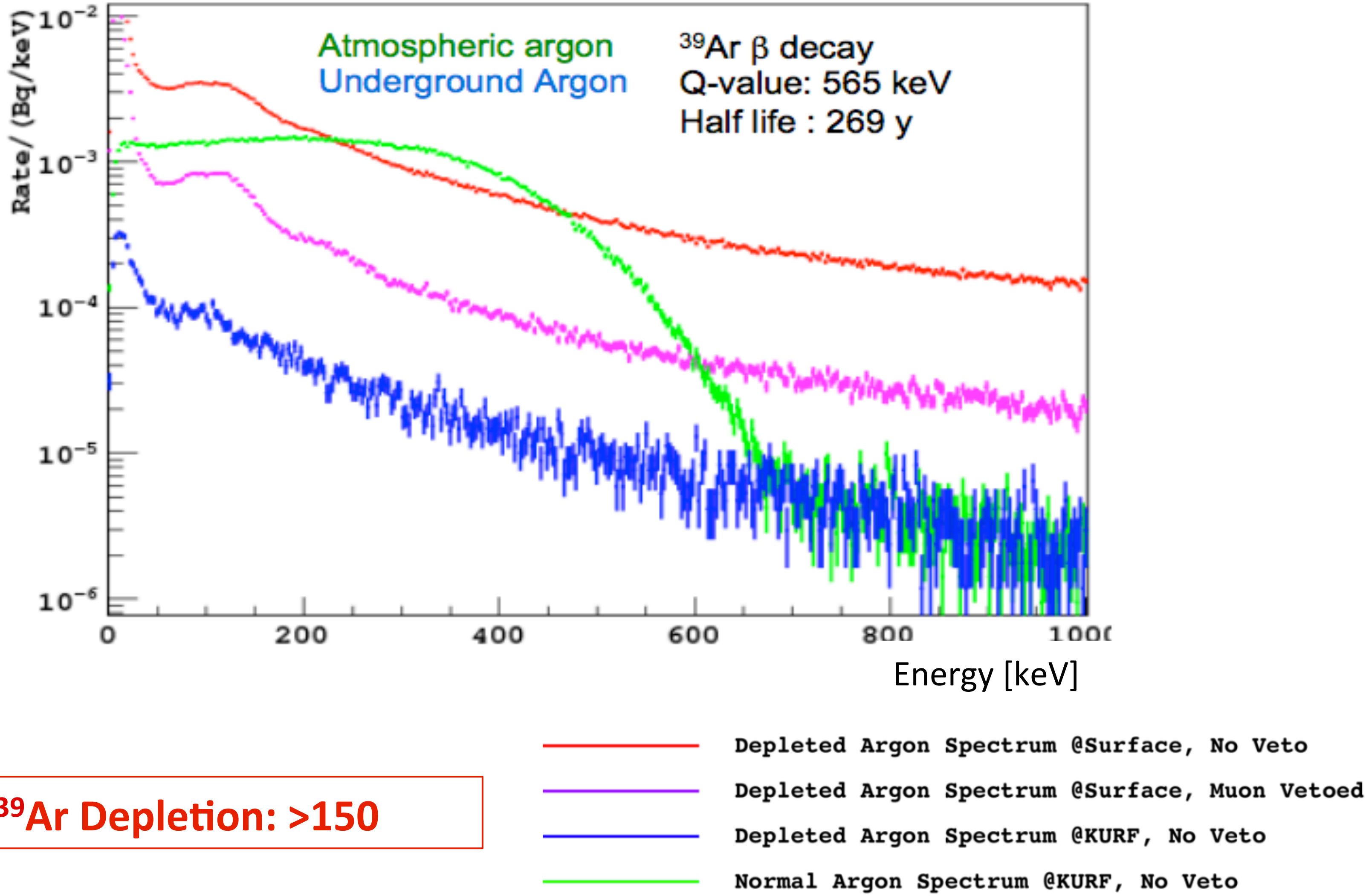
Liquid Xenon
High intrinsic radio-purity

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



Depleted Underground Ar

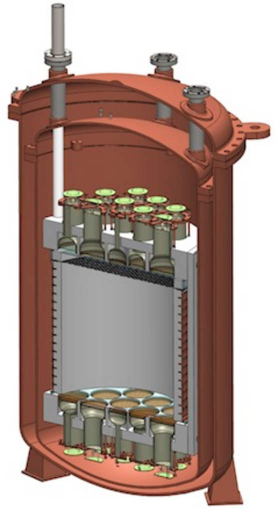
arXiv:1204.6011



^{39}Ar Depletion: >150

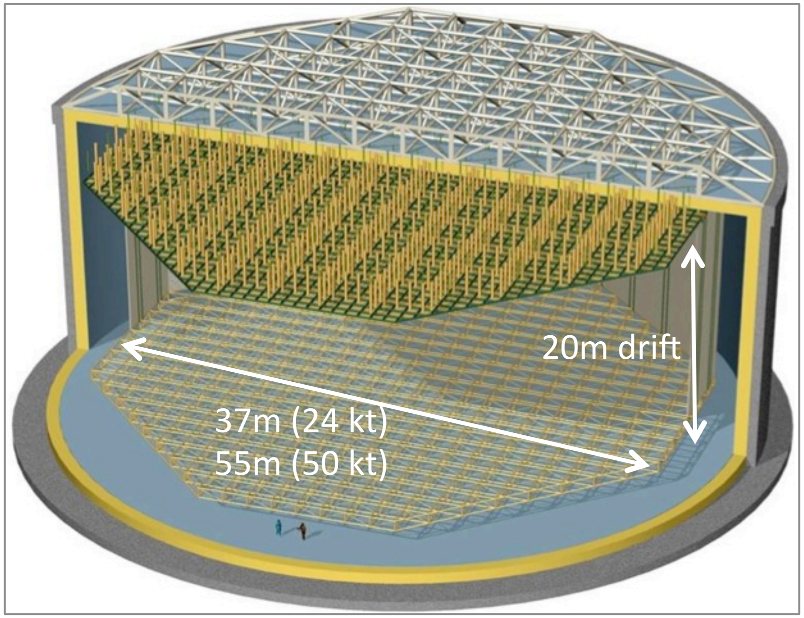
Double-phase Liquid Argon TPC

DarkSide-50
@LNGS

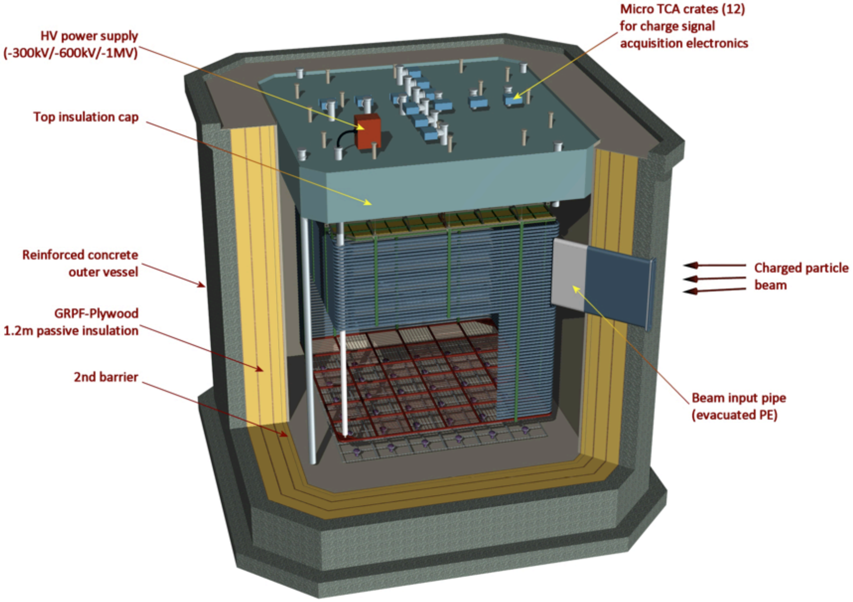


The DLAr-TPC technique is also foreseen for future large-scale **neutrino** detectors:
(different energy range, different charge readout system, etc…)

LBNO detector @Pyhäsalmi



WA105 demonstrator @CERN



The DarkSide Collaboration

France
APC - Universite Paris 7 Diderot, CNRS/IN2P3,CEA/IRFU
IPHC - Universite de Strasbourg, CNRS/IN2P3
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

The DarkSide Guidelines

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

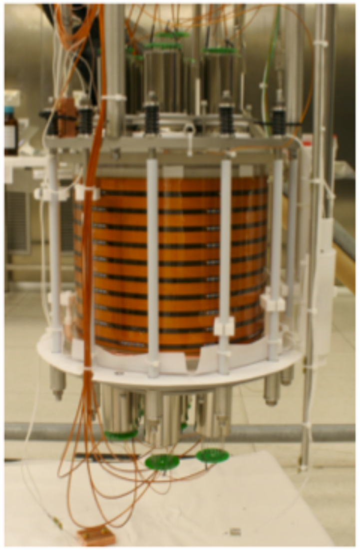
Residual background identification

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

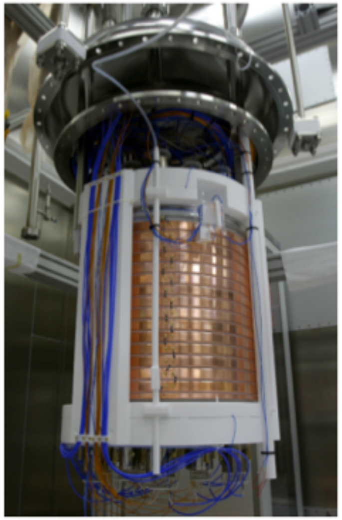
Main goal:
a **bg-free experiment**

Staged approach:

DarkSide-10
2011-2013

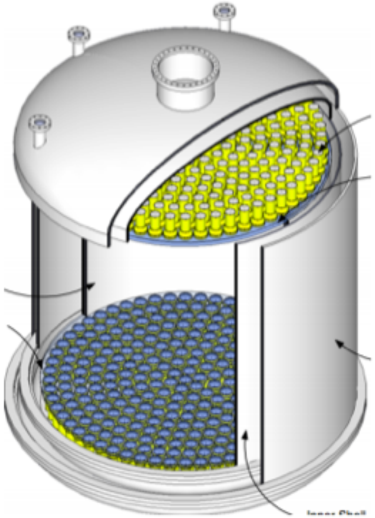


DarkSide-50
2013-201x



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

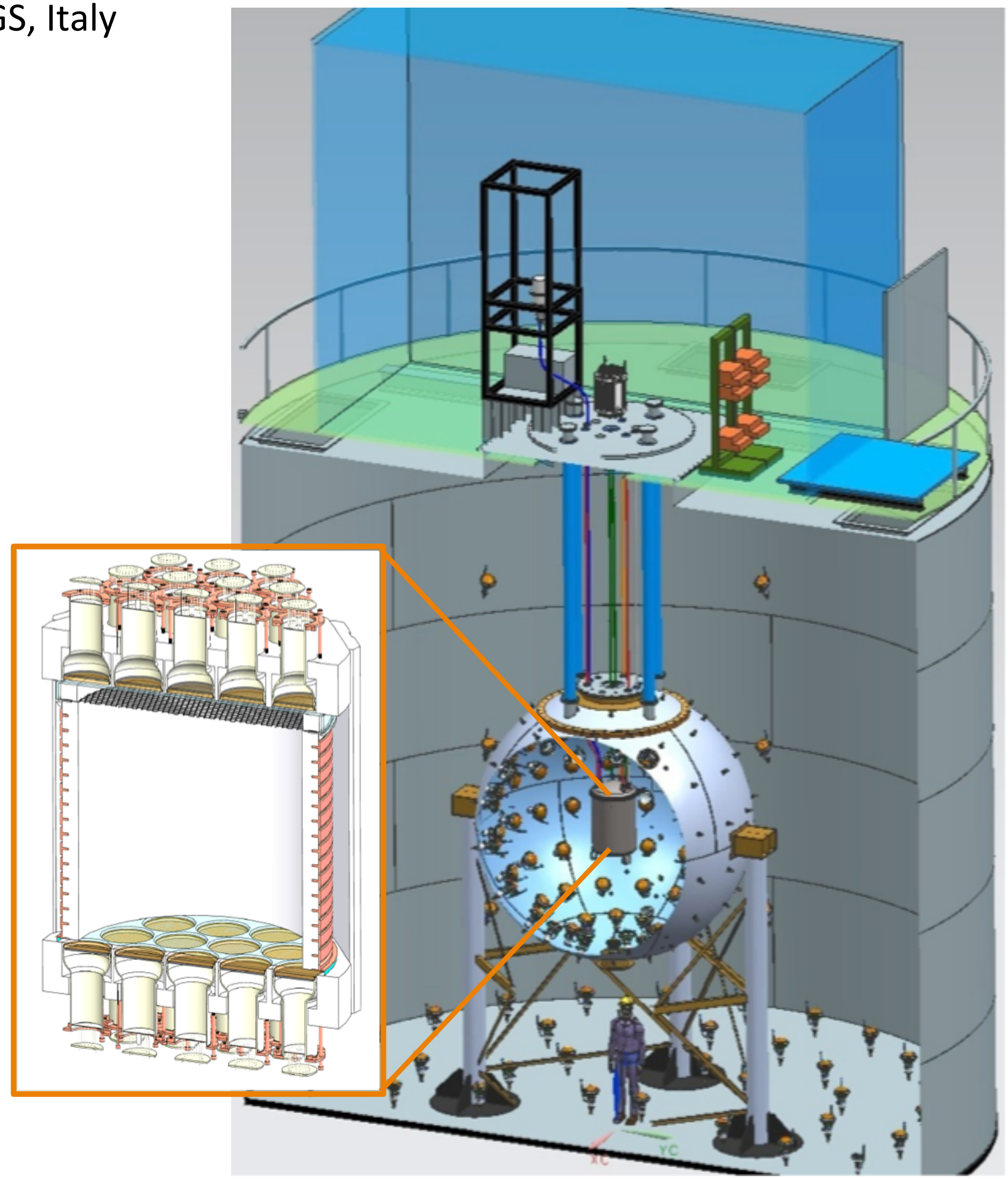
DarkSide-G2
2016-2020



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

DS50 Detector design

At *Laboratori Nazionali del Gran Sasso*, LNGS, Italy



LAr TPC

36 cm x 18 cm radius
50 kg LAr (**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

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

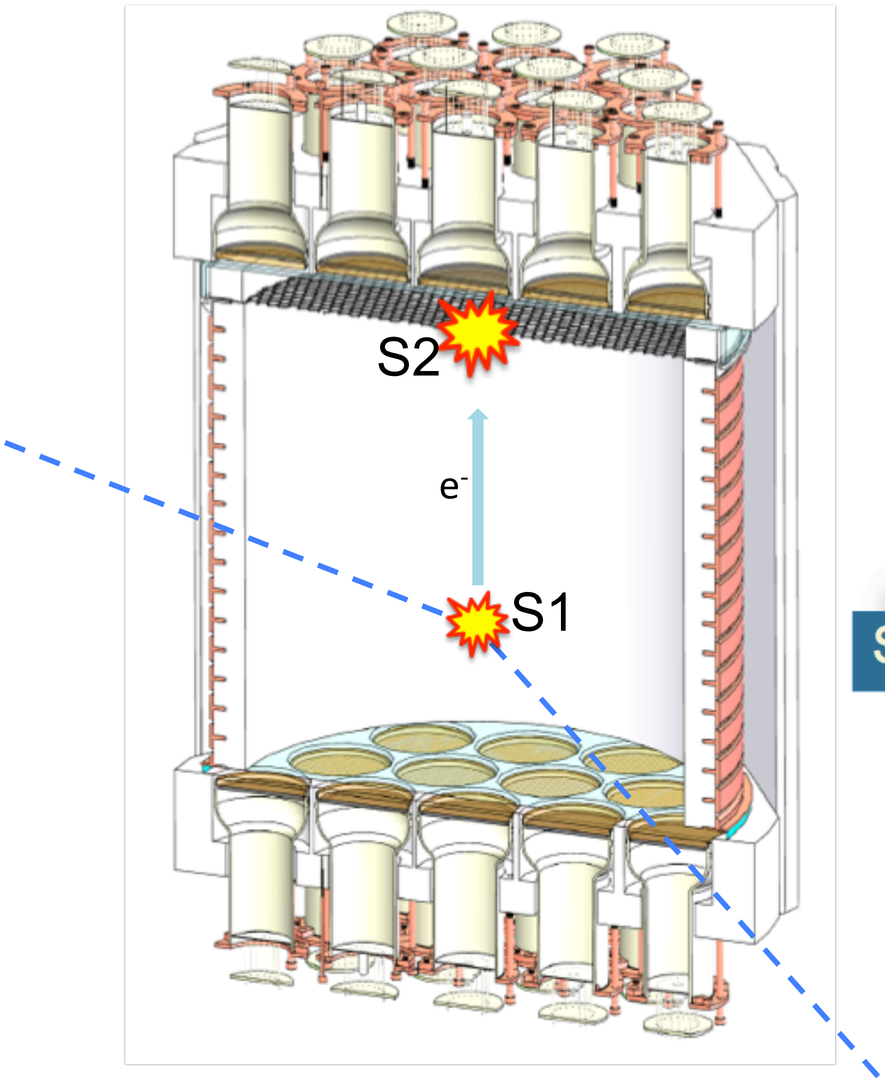
Water Cherenkov detector

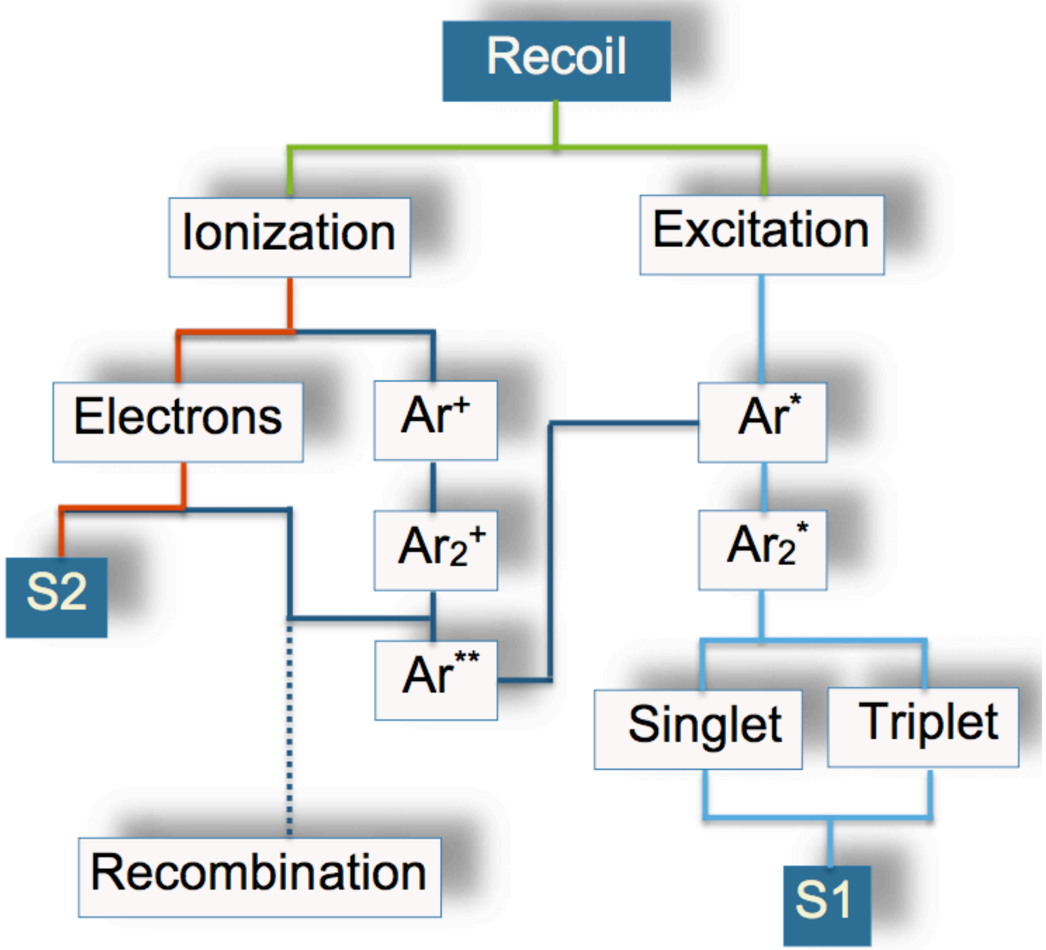
80 PMTs
1 kt water, 5.5 m radius

Veto's Rejection Efficiencies:

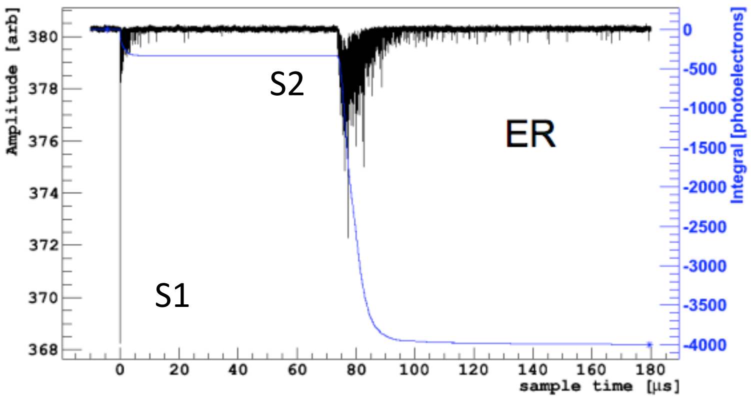
> 99.5% against Radiogenic neutrons
> 95% against Cosmogenic neutrons

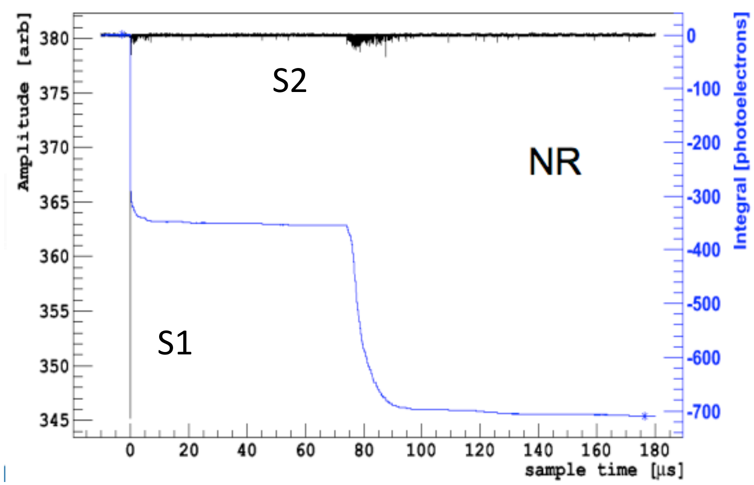
Detection signature

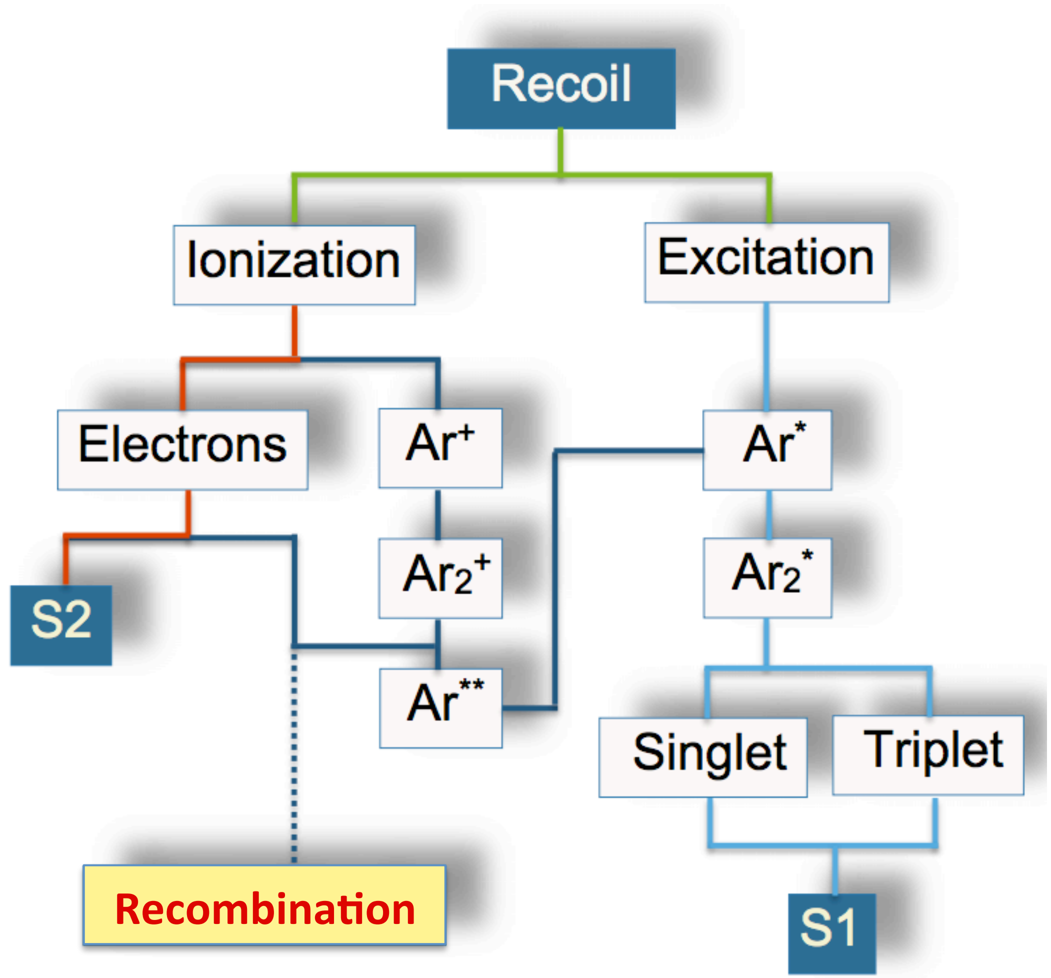




S2/S1 Ratio



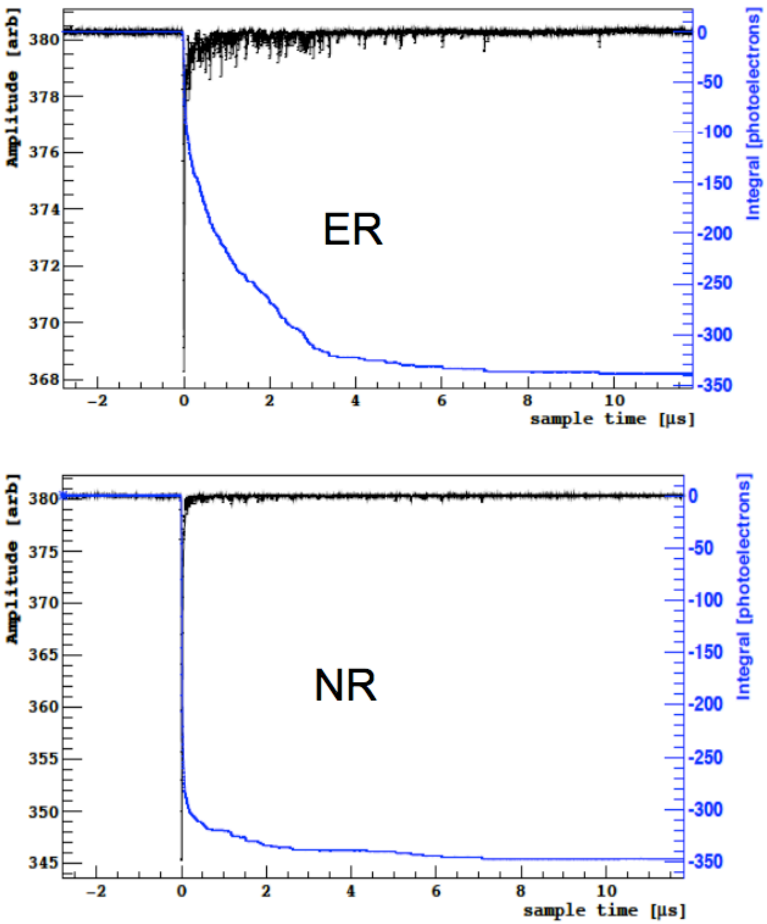


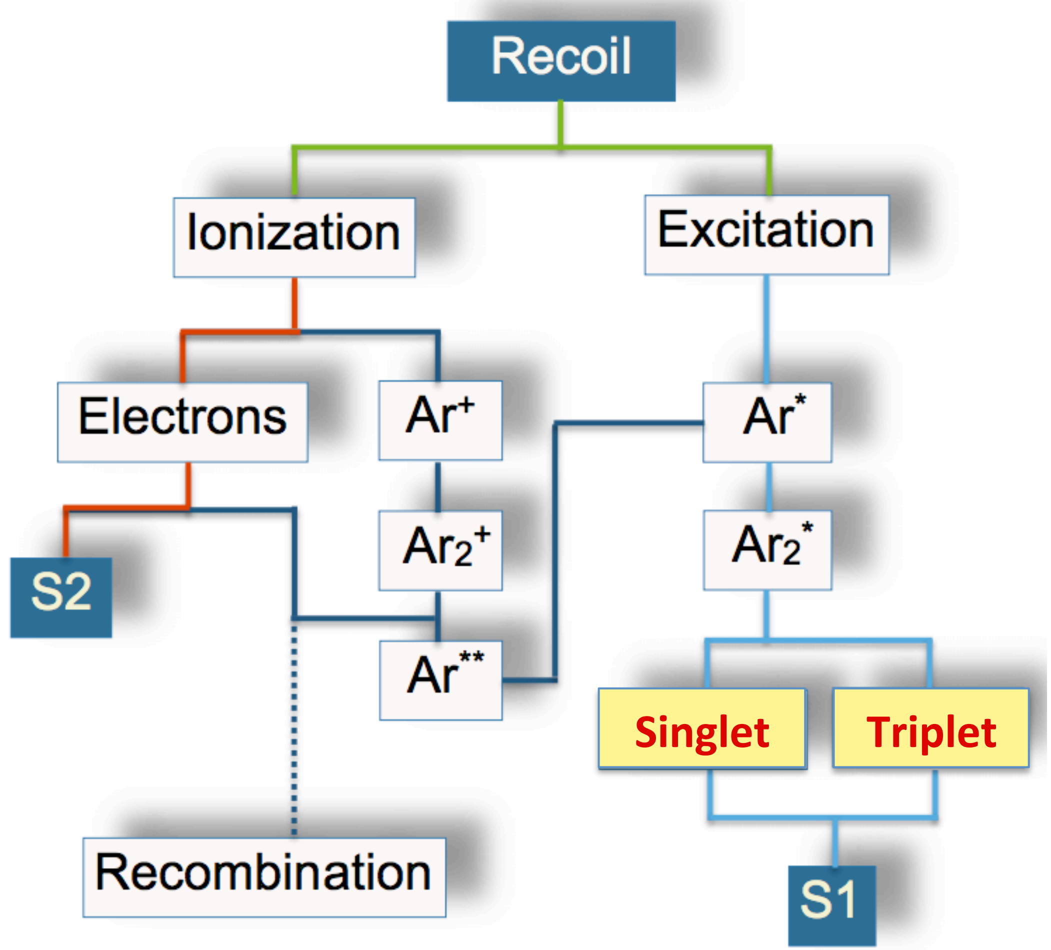


Rejection factor: 10^2 - 10^3

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

The Pulse Shape Discrimination





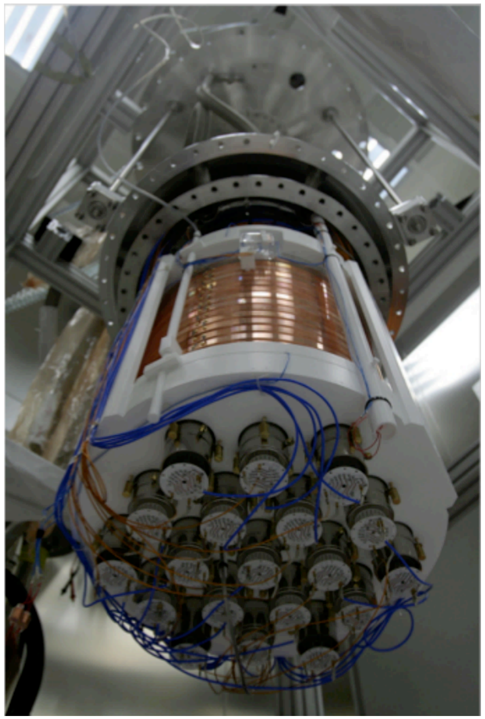
Rejection factor: ~10^8

WARP Astr. Phys 28, 495 (2008)

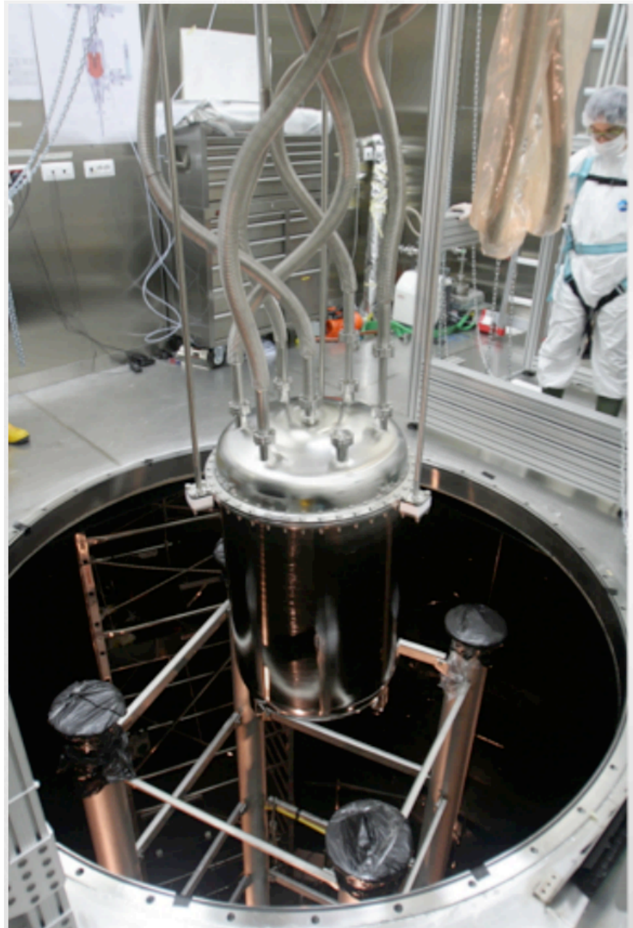
LXe $\tau_{singlet}$ = 2 ns
LXe $\tau_{triplet}$ = 22 ns

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

DS-50 TCP commissioning



Taking data since Oct 2013

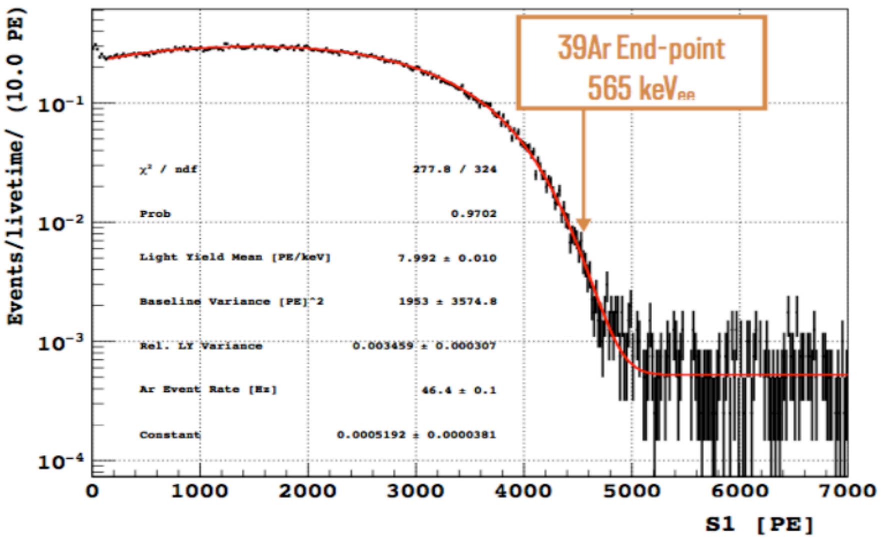


First physics results arxiv:1410.0653 (submitted to PLB)

The ^{39}Ar spectrum

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

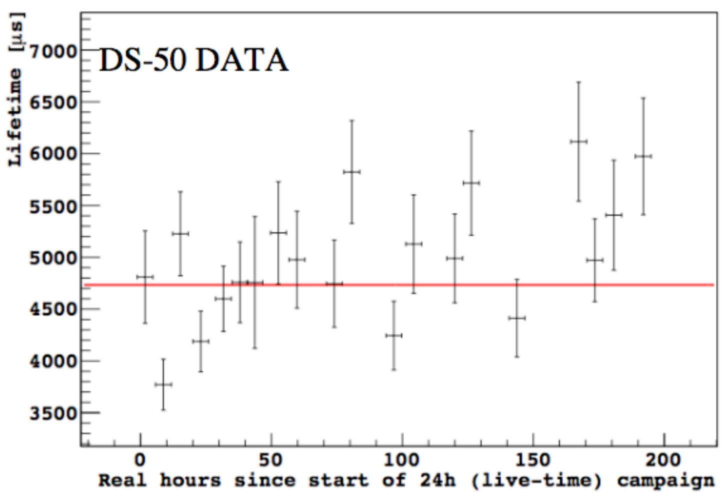
Rate: ~ 1 Hz/kg



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

Drift velocity 0.93 mm/mus

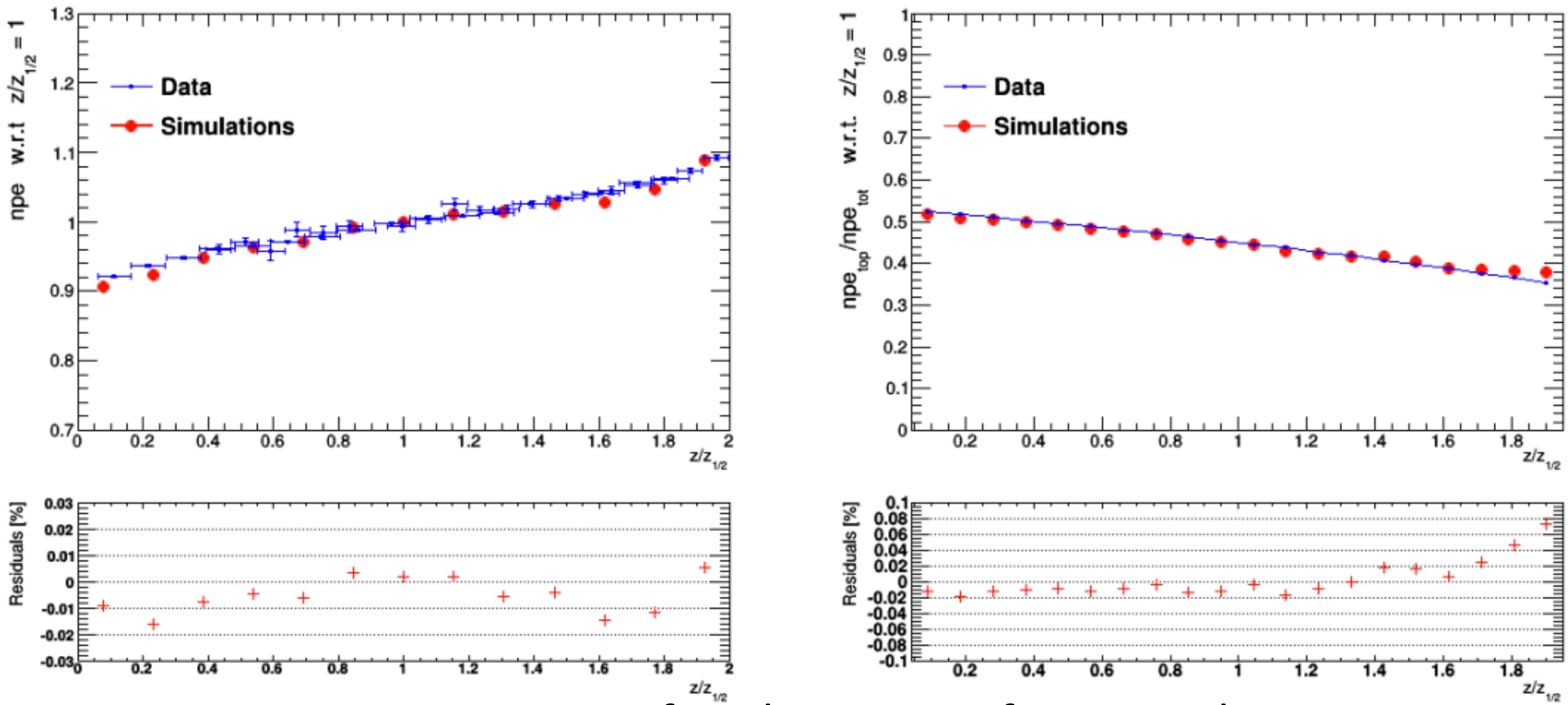
- High **Purity**
- **Stability** of the Electric Field



Understanding the TPC

APC, IPHC and LPNHE are leading the simulation group:
→ Development of the full **Geant4** simulation of the detector (particle tracking, optics)
→ Electronics simulation
→ Calibration

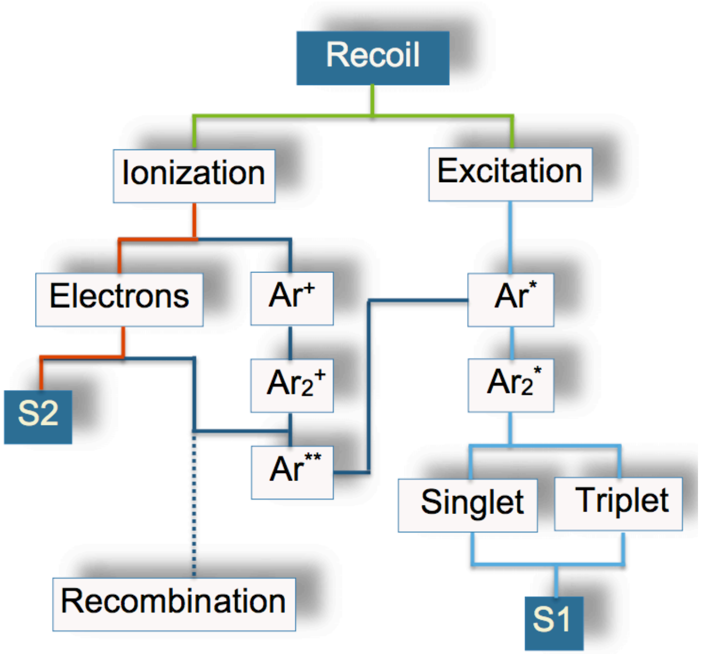
The internal optics description



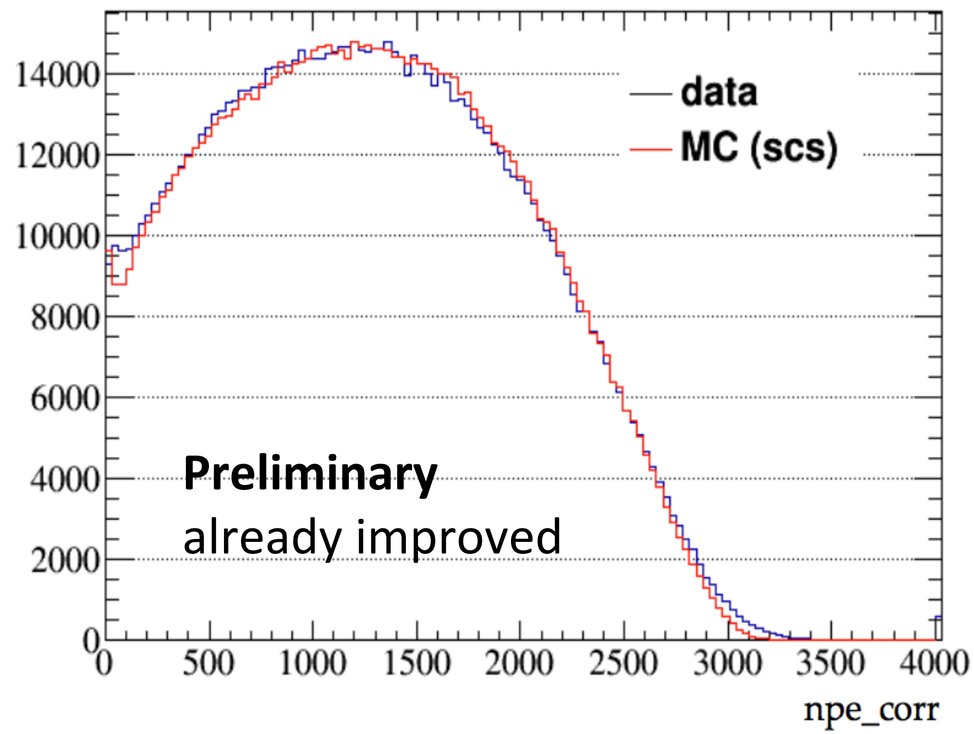
Few percent accuracy, after the tuning of 36 optical parameters

Understanding the TPC

The recombination model (for PSD)



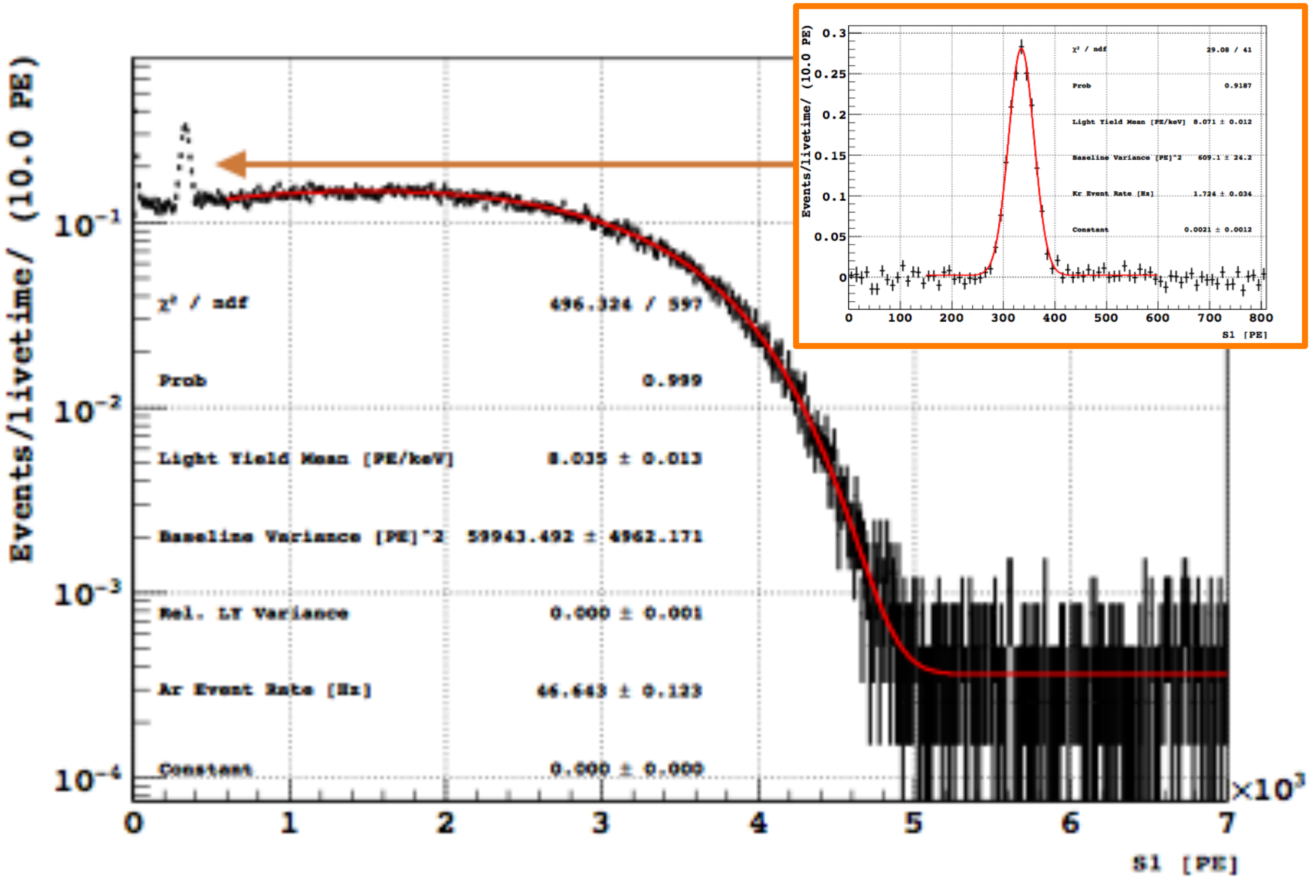
The recombination probability is obtained **globally fitting** existing data from different data pools



Electron Recoil calibration

Presently running with Atmospheric Argon

Gaseous ^{83m}**Kr** injection:
41.5 keV peak
HL ~ 1.8 h



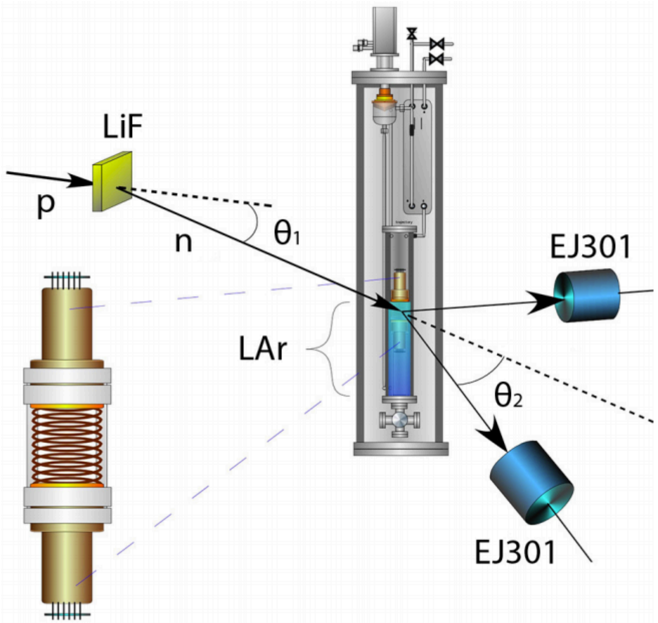
Average Light Yield:
~ 8.0 pe/keV at null field
~7.1 pe/keV at 200 V/cm

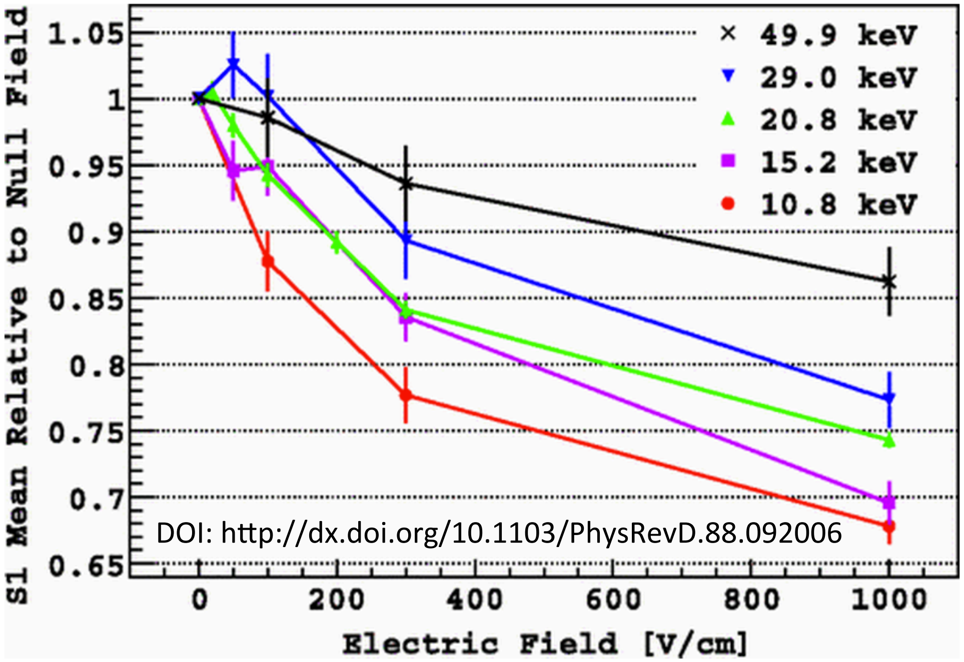
Calibration with other sources is currently ongoing
^{57}**Co**, ^{133}**Ba, neutrons…**

Nuclear Recoil Calibration (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



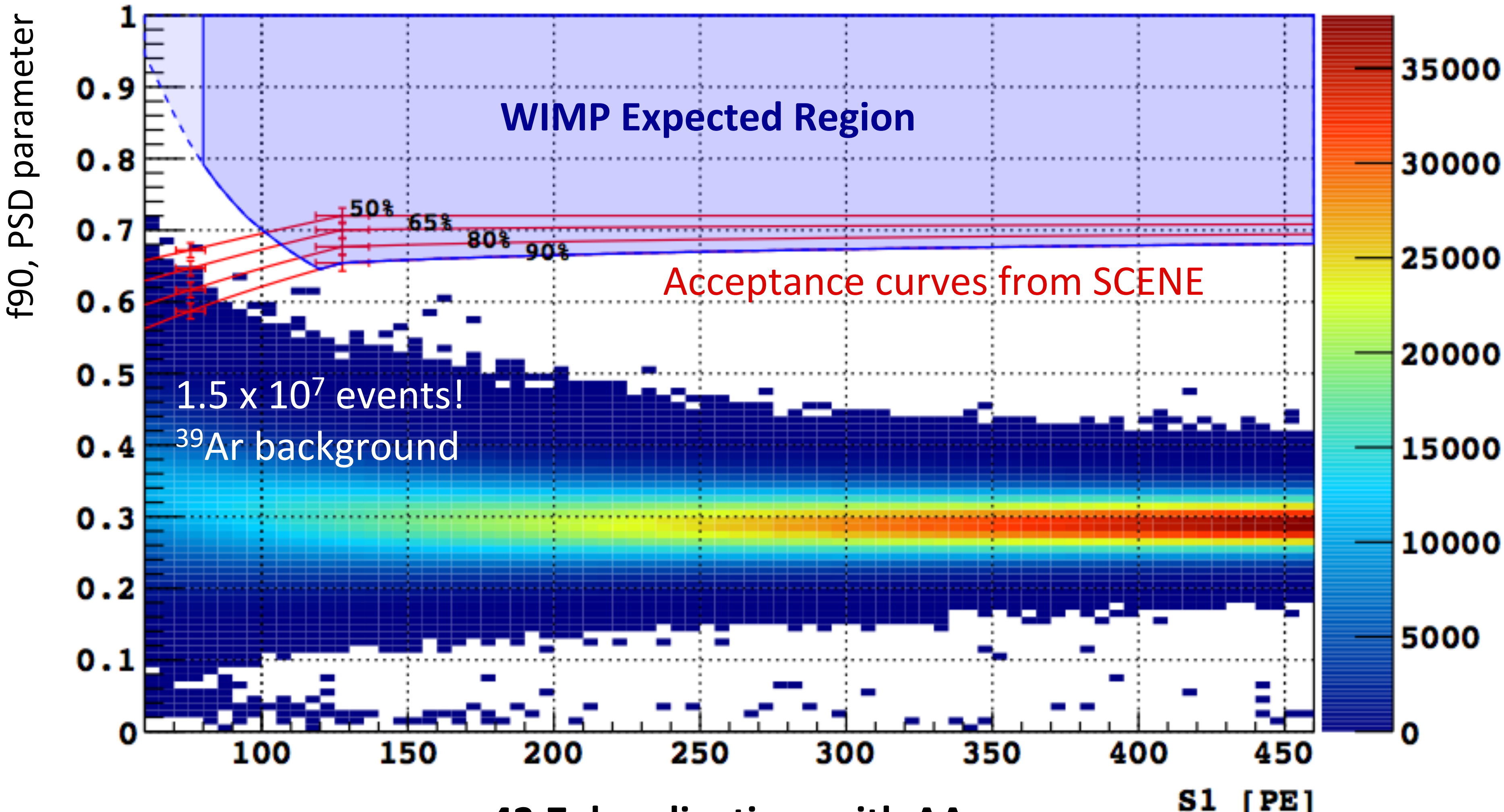


Neutron calibration in large detectors can be affected by **multiple interactions** of **neutrons**
SCENE has collected extremely pure samples of single nuclear recoils in a small TPC resembling DS-50 TPC design. We opted to use **SCENE data @ 200V/cm**

The first results (42.7 days)

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

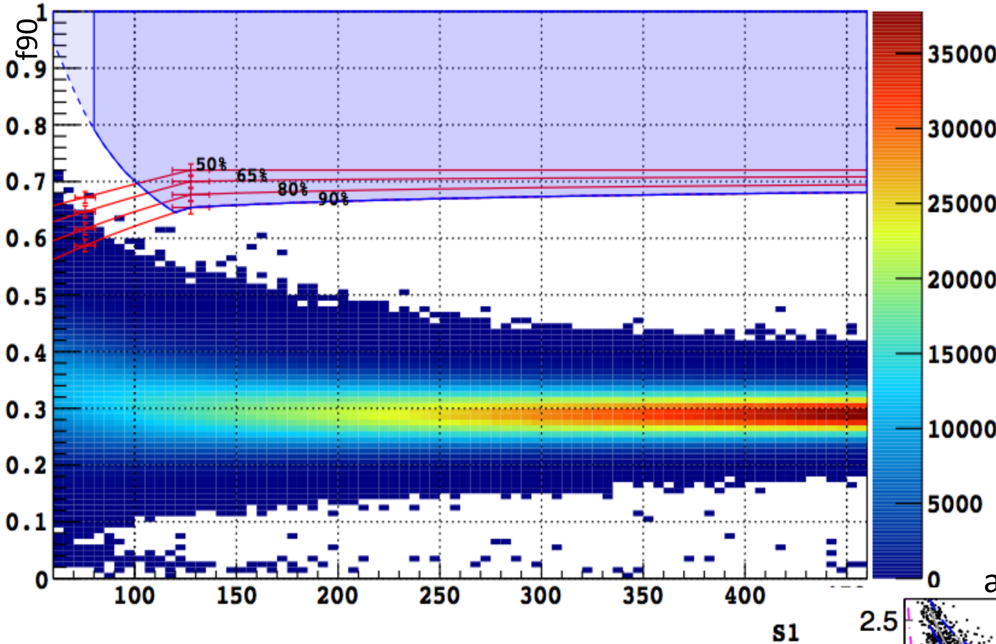
arxiv:1410.0653



42.7 days livetime with AAr

Corresponding to 20 years of DS-50 with Underground Argon

Discrimination comparison

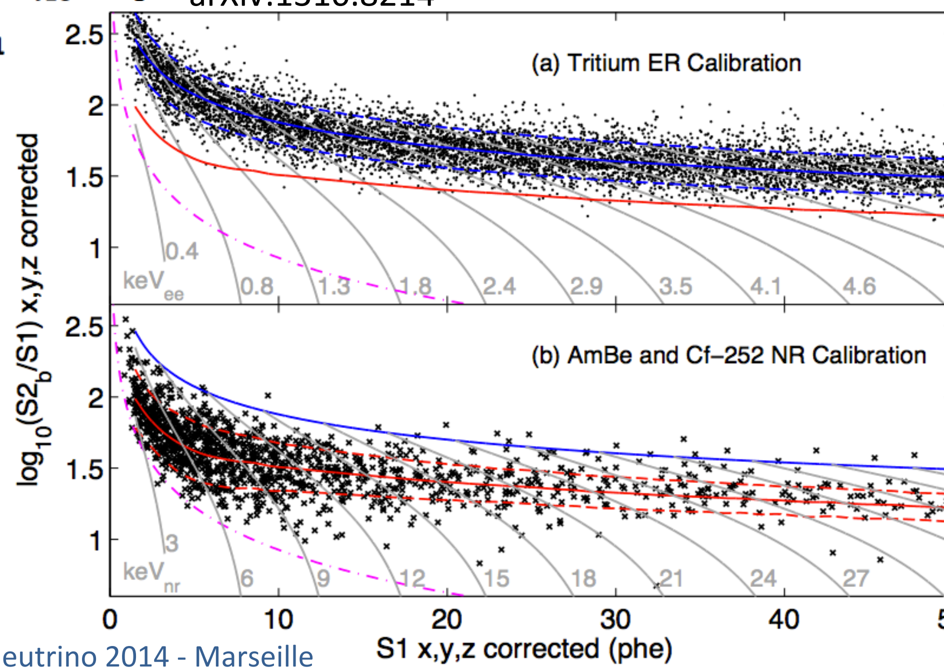


LAr → PSD disrimination
(S2/S1 not yet used)

No events close to the nuclear Acceptance curves

arXiv:1310.8214

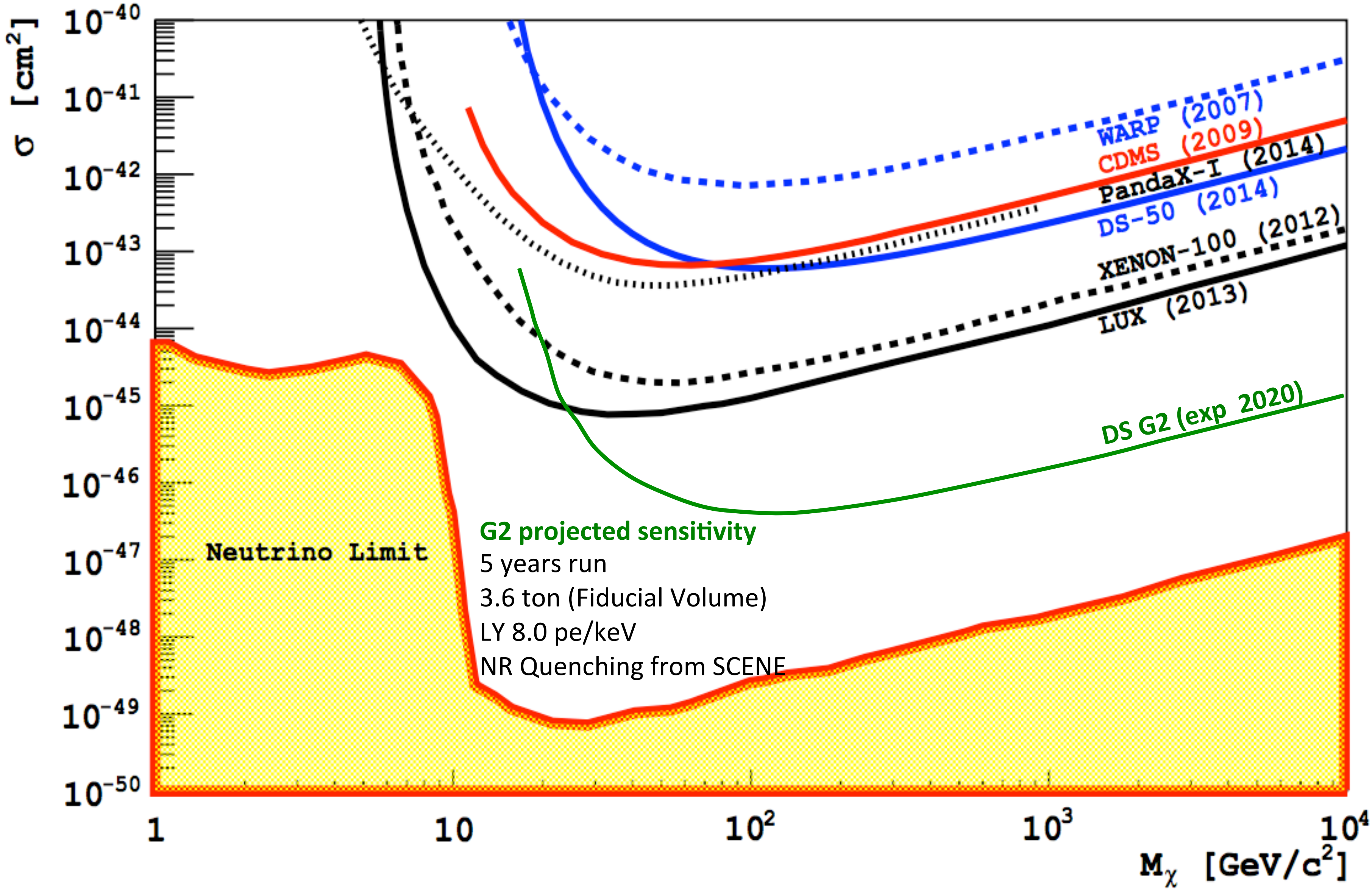
LUX calibration



LXe → S2/S1 discrimination

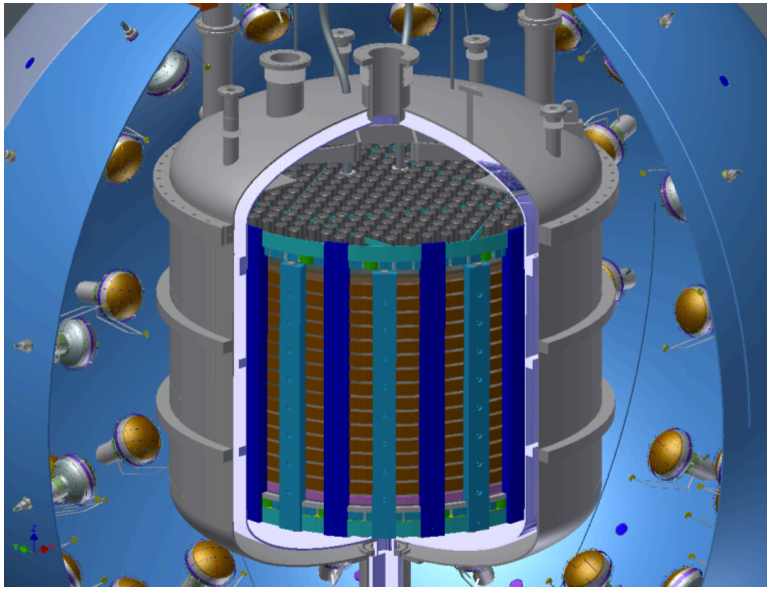
Blue Solid Line: ER mean
Red Solid Line: NR mean
Dashed lines: ±1.28 σ

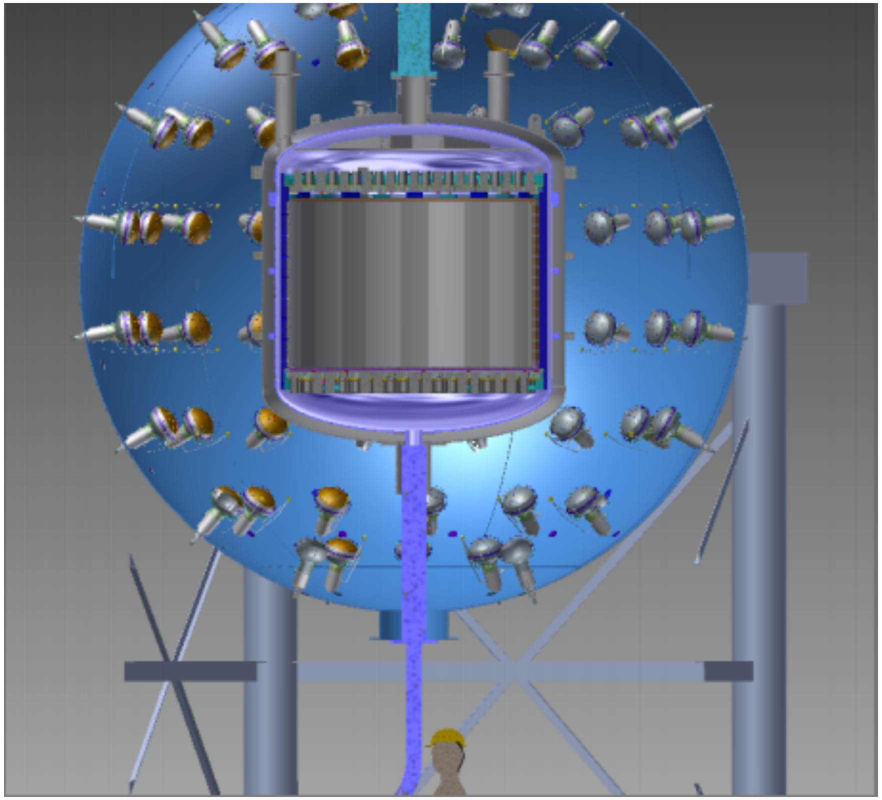
Present Limit and Projection



DarkSide G2

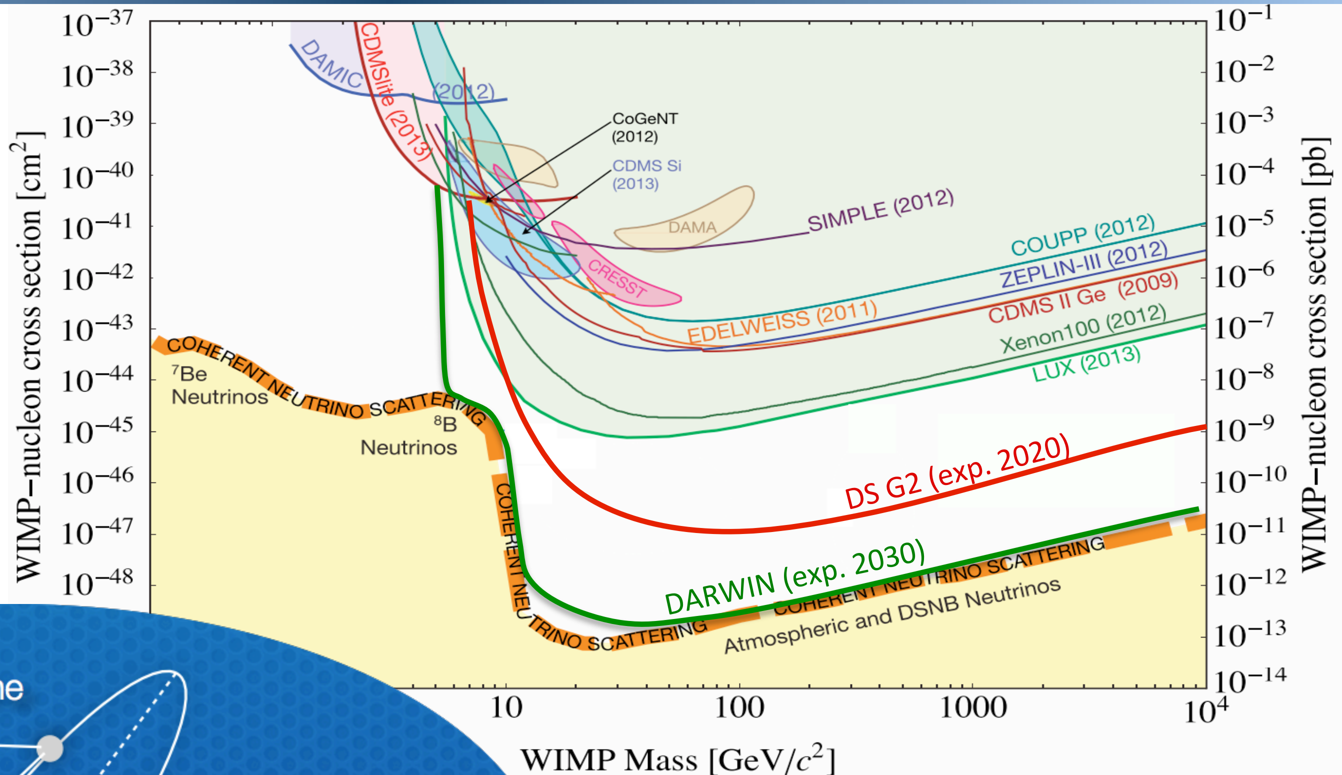
~3.8 ton: Active Uar mass.
~4.8 ton: total Uar mass.
30 ton boron-loaded liquid Scintillator Veto (LSV).
1,000 ton ultra pure water (WT).

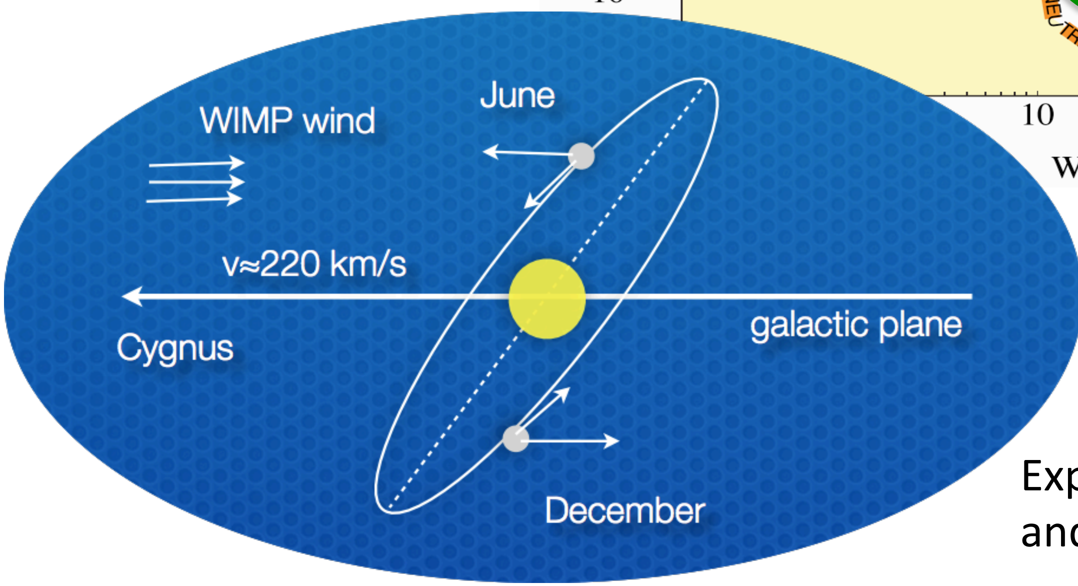




The same outer veto sphere

Exploiting Directionality





Expected seasonal rate **modulation** and **directional** signature

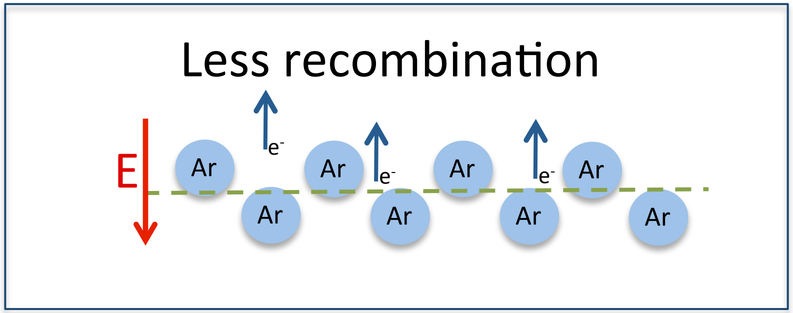
Directionality

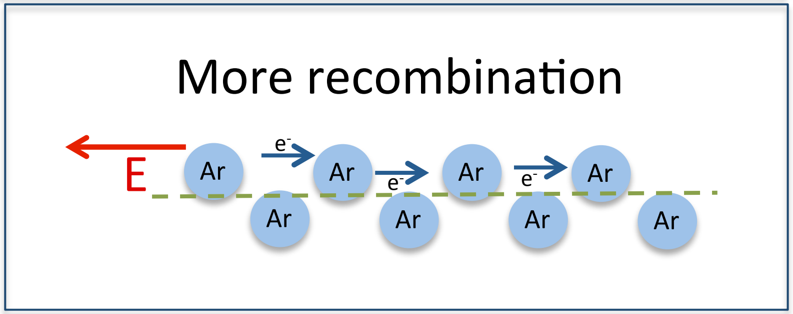
S1 is different if the electric field is parallel or perpendicular to the nuclear recoil **(in LAr only)**

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

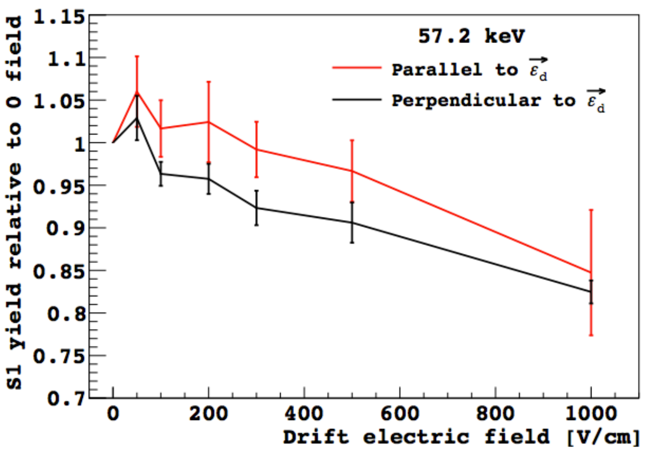
This effect might strengthen the significance of few WIMPs candidates if they will be observed in DS-G2

ANR pre-proposal submitted (APC, LPNHE, IPNO, IPHC)
→ Building of a small TPC
→ Study directionality with tests at IPNO beam





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 background rejection technique
- Extended calibration phase presently ongoing
- Underground Argon expected for beginning next year

French groups are active with leading roles in DarkSide

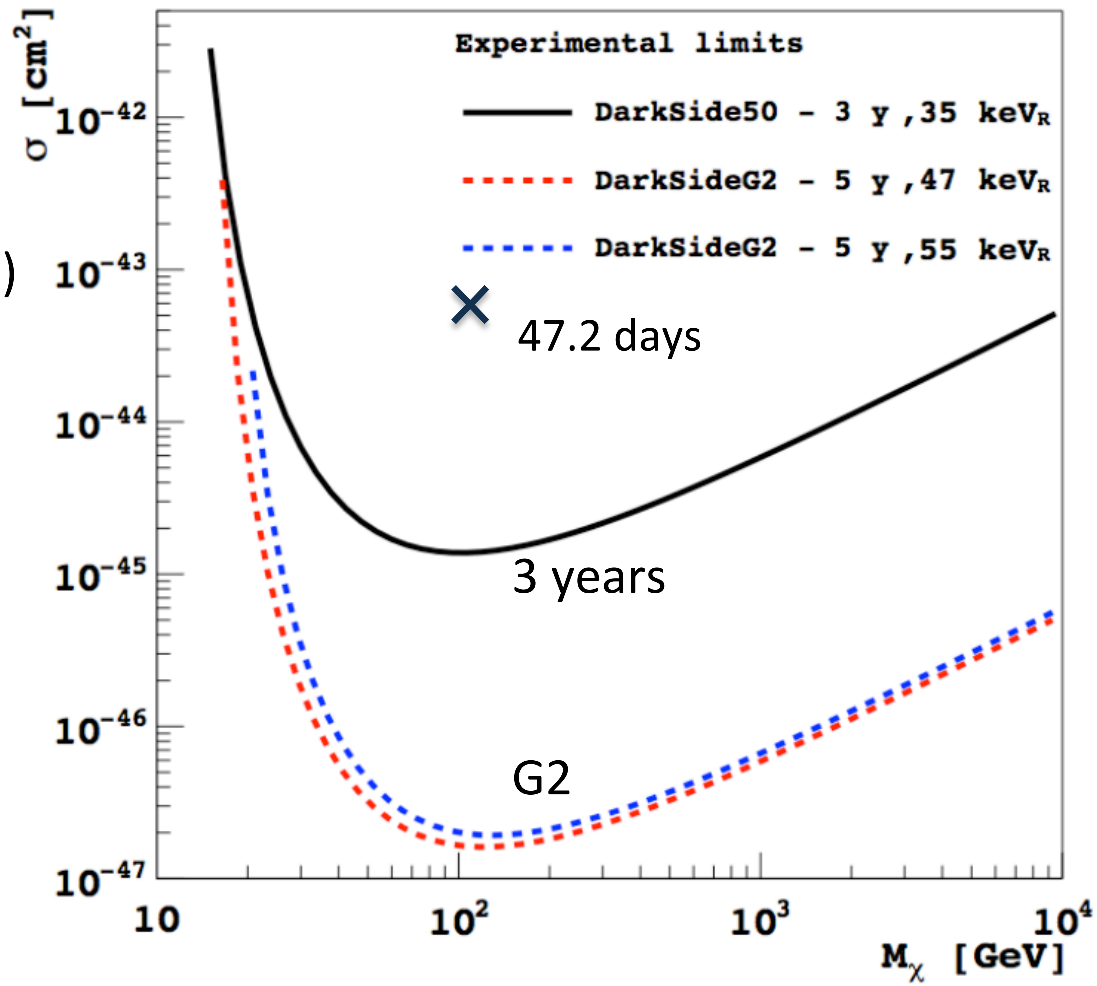
Darkside-G2 design under discussion

BackUp

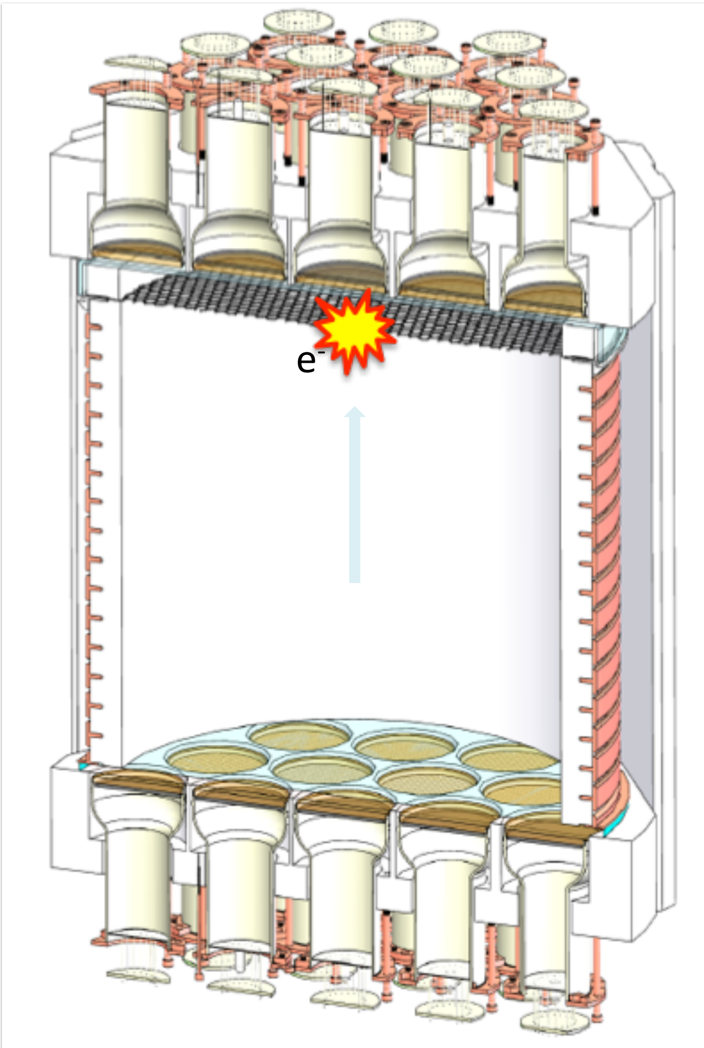
Present Limit and Projection

Present Limit
6.1×10^{-44} cm^2 at 100 GeV/c
(LUX: 7.6×10^{-46} cm^2 at 33 GeV/c)

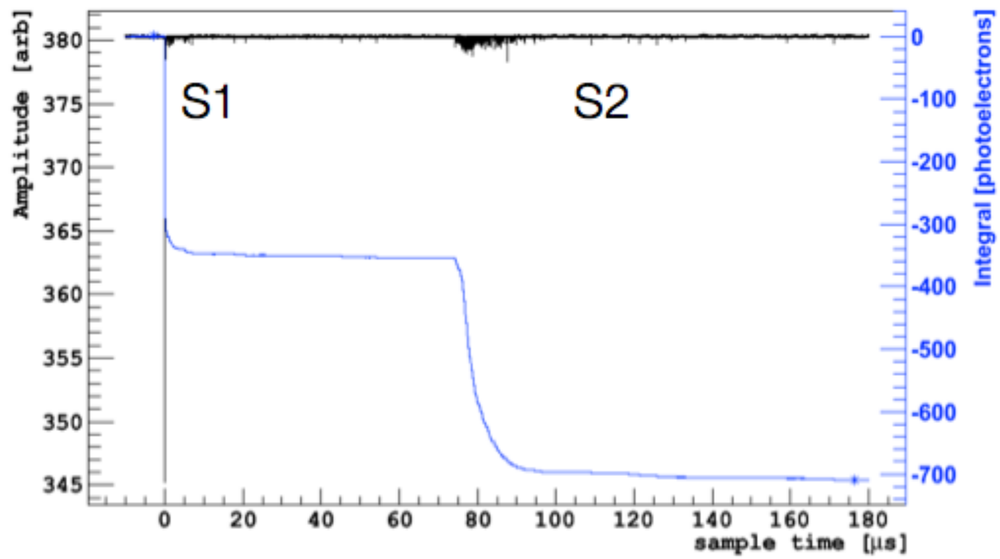
G2 projected sensitivity
Assumptions:
5 years run
3.6 ton (Fiducial Volume)
LY 8.0 pe/keV
NR Quenching from SCENE



Detection technique



The electrons are extracted into the gas region, where they induce **electroluminescence (S2)**



The time between the S1 and S2 signals gives the vertical position

Main Backgrounds to the WIMPs search

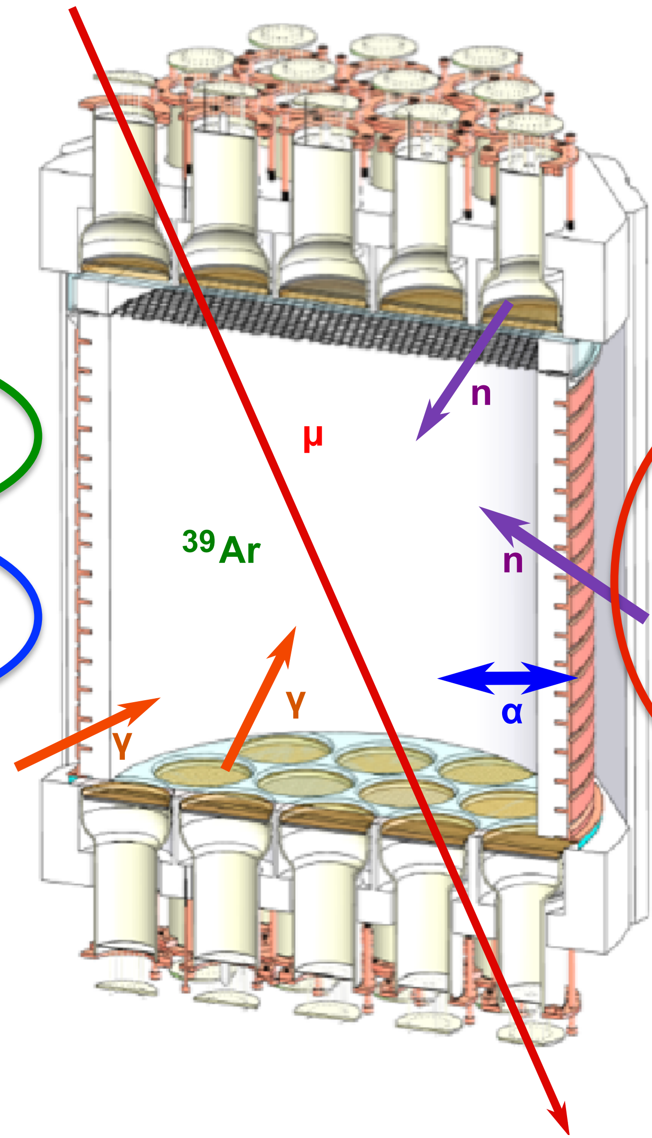
Underground Depleted Ar (DAr)

Electron Recoils

^{39}Ar
~10^4 evt/kg/day

γ
~10^2 evt/kg/day

Pulse shape discrimination (PSD)



Nuclear Recoils

Outer Neutron veto

μ
~30 evt/m^2/day

Radiogenic n
~6x10^{-4} evt/kg/day

α
~10 evt/m^2/day

[30, 200] keV$_{ee}$; **WIMP Rate ~ 10^{-4} evt/kg/day** (100 GeV, 10^{-45}cm^2)

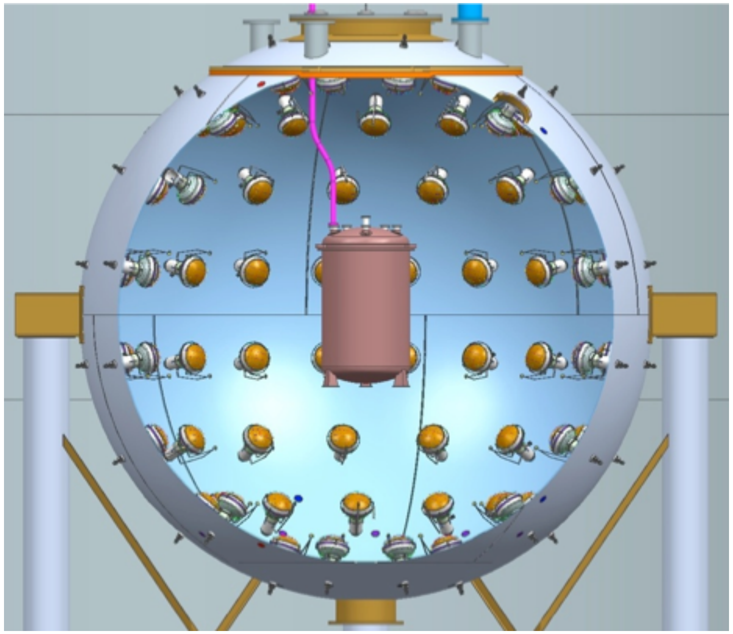
Outer Neutron Veto

4 m diameter, 1:1 TMB + PC

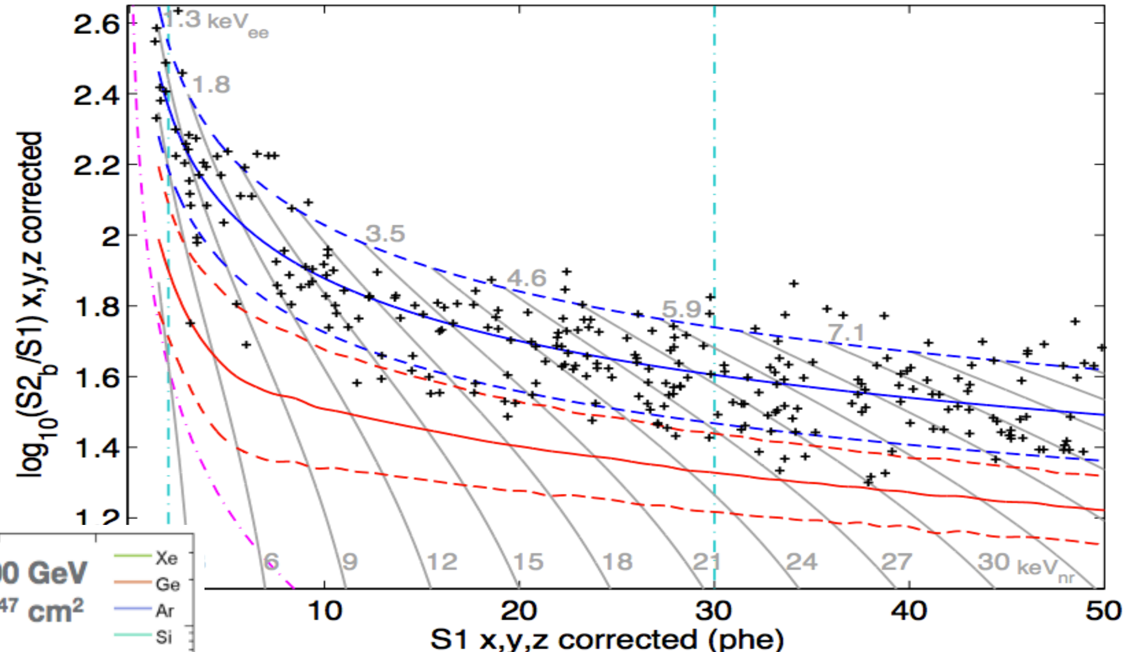
Instrumented with 110 8" PMTs

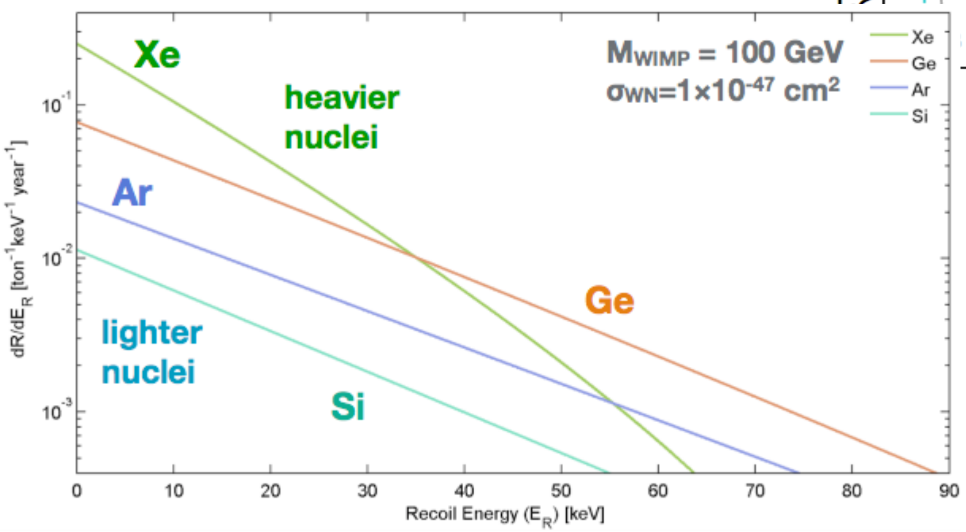
Liquid scintillator allows coincident veto of neutrons in the TPC and provides ***in situ* measurement of the neutron background rate**

^{14}C content (~10^{-13} $^{14}C/^{12}C$, ~120kHz) is too high (~98% efficiency) to achieve design efficiency (~99.5%).
The current TMB will be replaced with new **low ^{14}C TMB**.



LUX WIMPs search





The Pulse Shape Discrimination

Light Emission via Excitation

$e^- + Ar \rightarrow Ar^* + e^-$

$Ar^* + Ar \rightarrow Ar_2^*$

$Ar_2^* \rightarrow Ar + Ar + \text{photon}$

Light Emission via Ionization

$e^- + Ar \rightarrow Ar^+ + 2e^-$

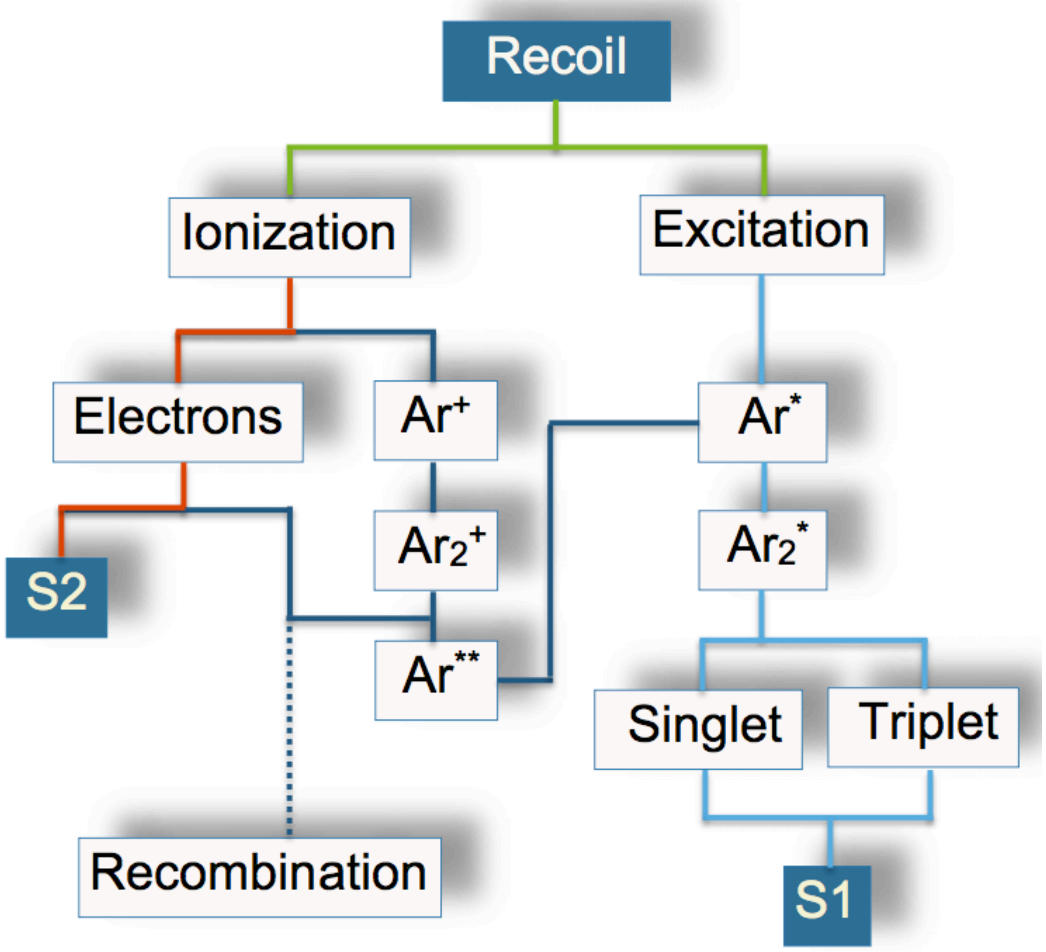
$Ar^+ + Ar + Ar \rightarrow Ar_2^+ + Ar$

$e^- + Ar_2^+ \rightarrow Ar^{**} + Ar$

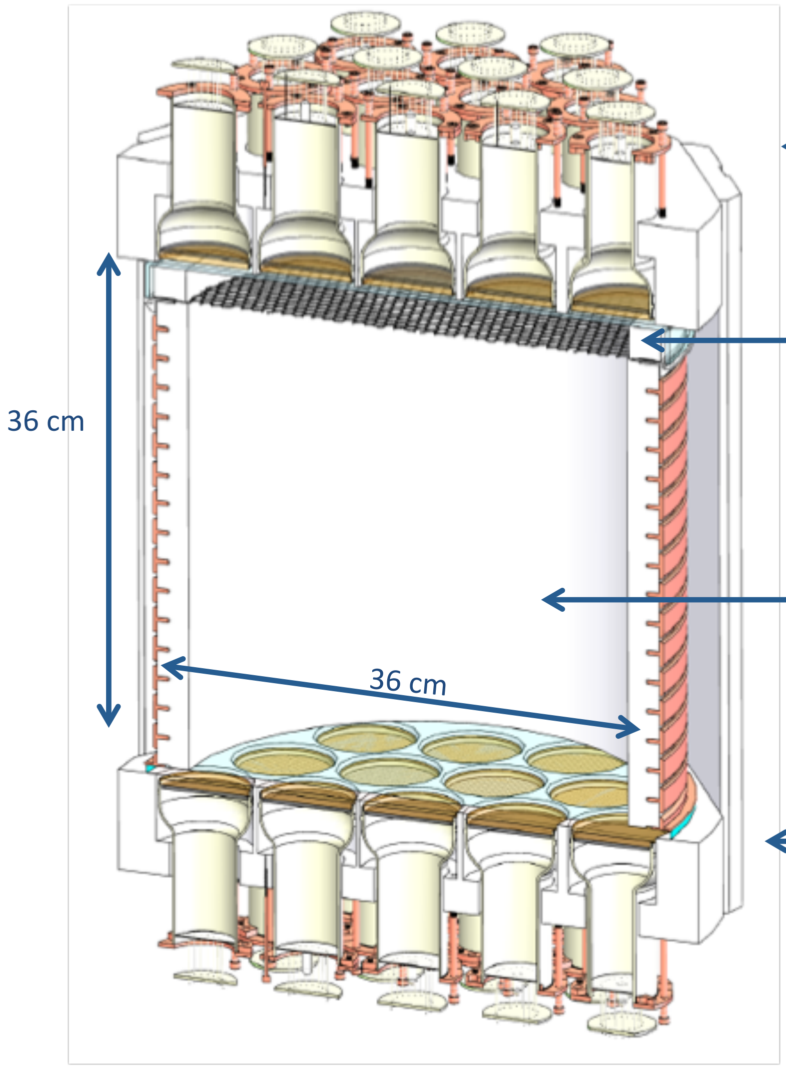
$Ar^{**} + Ar \rightarrow Ar^* + Ar + \text{heat}$

$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar + \text{heat}$

$Ar_2^* \rightarrow Ar + Ar + \text{photon}$



DS50 TPC



19 PMTs

Gaseous Argon Volume
Height = ~ 1 cm
E = 2.8 kV/cm

Liquid Argon Volume
E = 200 V/cm

19 PMTs

All the walls are covered with WLS + reflector

PSD extrapolation in DS-G2