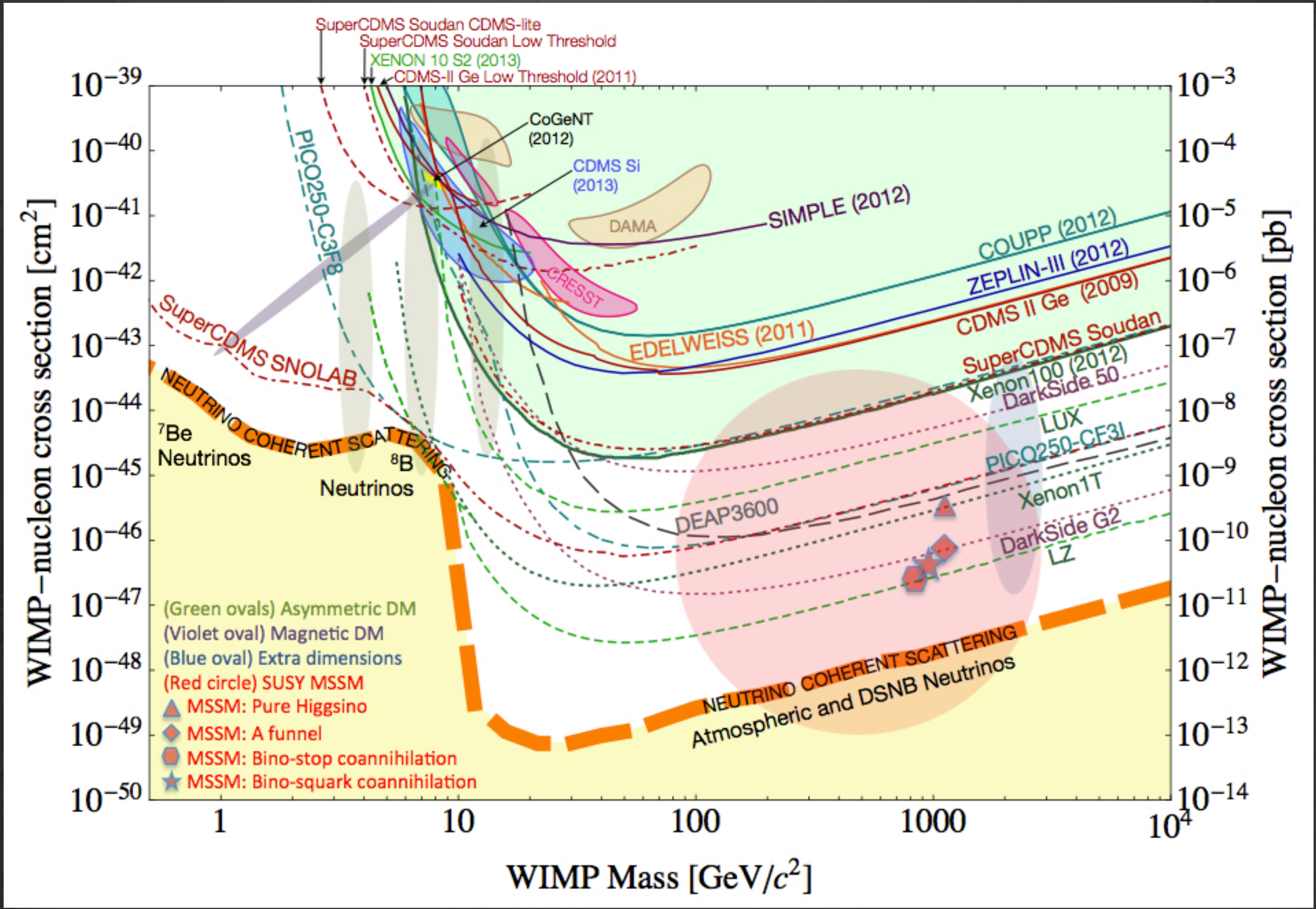
Direct Dark Matter Search with DarkSide

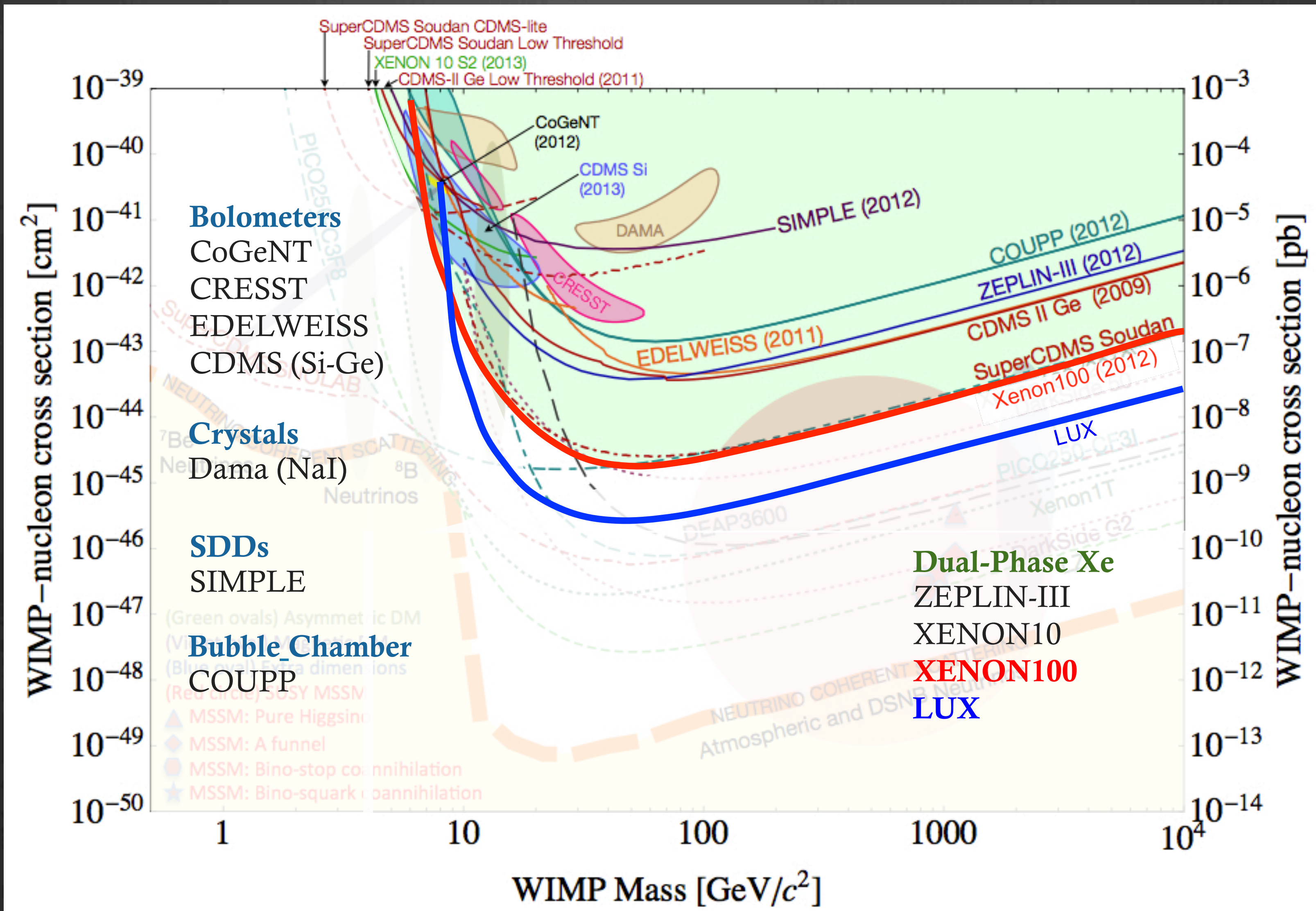
P. Agnes[1], D. Franco[1], C. Jollet[2], A. Meregaglia[2],
S. Perasso[1], A. Tonazzo[1]

[1] APC, Univ Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, Sorbonne Paris Cité
[2] IPHC, Univeristé de Strasbourg

The WIMP Hunt



The WIMP Hunt



What About **Argon**?

High Natural **Abundance**

- Atmosphere and Underground
- Relative low cost

Good Optical Properties

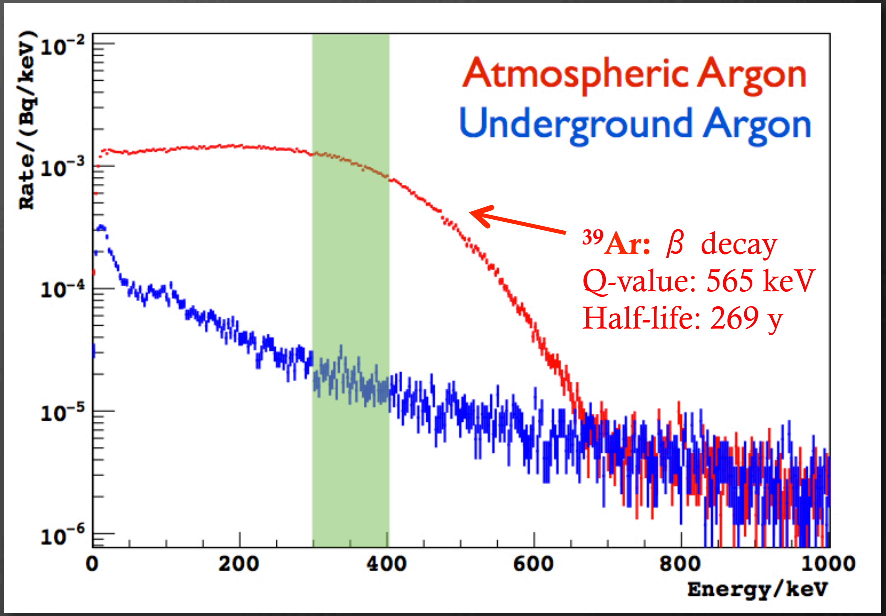
- High Photon Yield: **40 ph./keV**
- High transparency to self-emitted light

Pulse Shape Discrimination

- $\tau_{\text{singlet}} = 7$ ns, $\tau_{\text{triplet}} = 1.5\ \mu$s
- Very high PSD capability

Radiopurity

- Underground Argon depleted in ^{39}Ar



A(^{39}Ar) in AtmAr < **1 Bq/kg**

A(^{39}Ar) in UdgAr < **6.5 mBq/kg**

LAr DM experiments:

Deap-CLEAN, ArDM, **DarkSide**

The DarkSide Collaboration

Ukraine
KINR, NAS Ukraine – Kiev

CHINA
IHEP – Beijing

POLAND
Jagiellonian University – Krakow

FRANCE
APC, Univ Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, Sorbonne Paris Cité
IPHC, Université de Strasbourg, CNRS/IN2P3 – Strasbourg

USA
Augustana College – SD
Black Hills State University – SD
Fermilab – IL
Princeton University – NJ
SLAC National Accelerator Center – CA
Temple University – PA
University of Arkansan – AR
University of California – Los Angeles, CA
University of Chicago – IL
University of Hawaii – HI
University of Houston – TX
University of Massachusetts – MA
Virginia Tech – VA

ITALY
INFN Laboratori Nazionali del Gran Sasso – Assergi
Università degli Studi and INFN – Genova
Università degli Studi and INFN – Milano
Università degli Studi Federico II and INFN – Napoli
Università degli Studi and INFN – Perugia
Università degli Studi Roma Tre and INFN – Roma

RUSSIA
Joint Institute for Nucelar Research – Dubna
Lomonosov Moscow State University – Moscow
National Research Centre Kurchatov Institute – Moscow
Saint Petersburg Nuclear Physics Institute – Gatchina

The DarkSide Program: A Reminder

Past

DS10

10 kg LAr TPC prototype

No Physics Goals
R&D

Present

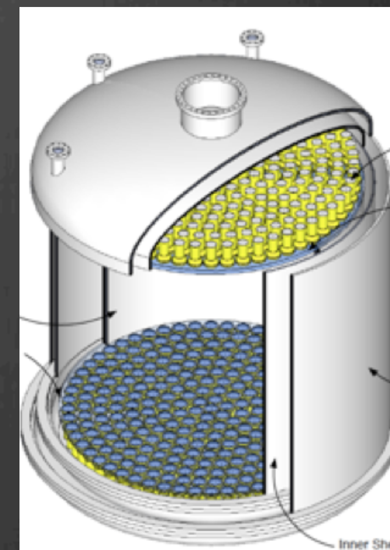
DS50

50 kg LAr TPC (33 kg FV)

Sensitivity
10^{-45} cm^2 @ 100 GeV/c^2

0.1 ton x year exposure

Future



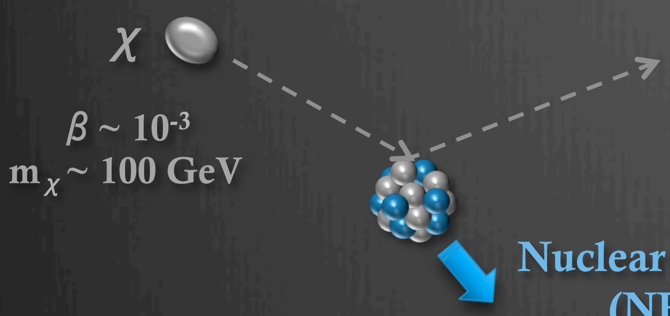
DS-G2

5 ton LAr TPC (2.8 ton FV)

Sensitivity
10^{-47} cm^2 @ 100 GeV/c^2

14 ton x year exposure

WIMP Signature



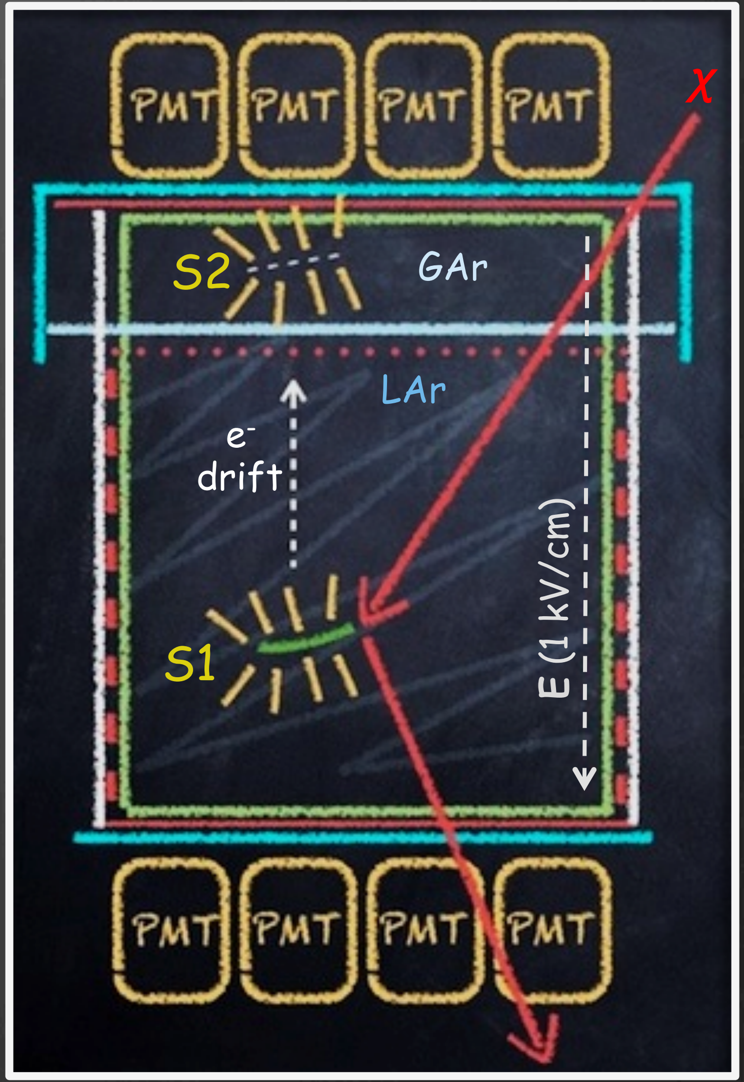
Nuclear Recoil (NR)

$E_{NR} < 100$ keV

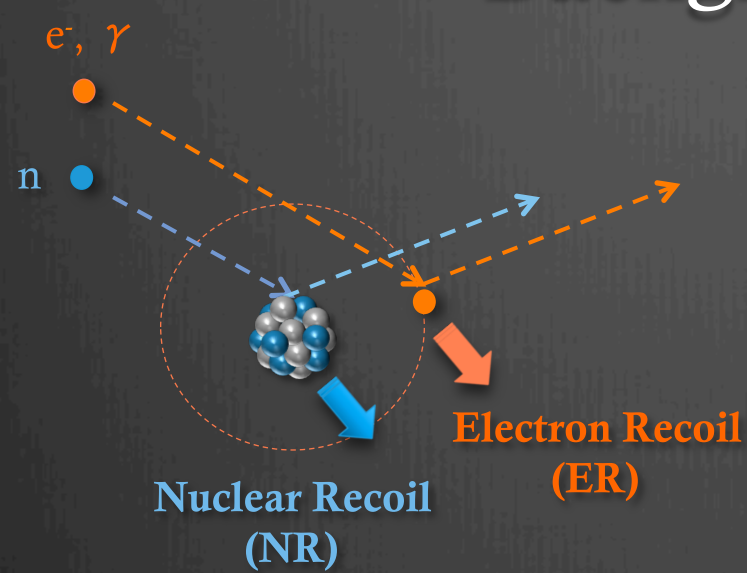
Expected Rate @ $\sigma = 10^{-47}$ cm^2

1 event / ton / year !!!!

-> exceptional **background** suppression and monitoring



Background



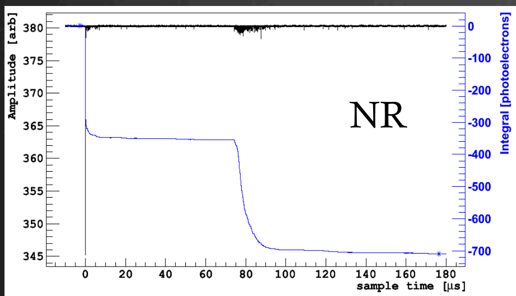
Background Sources

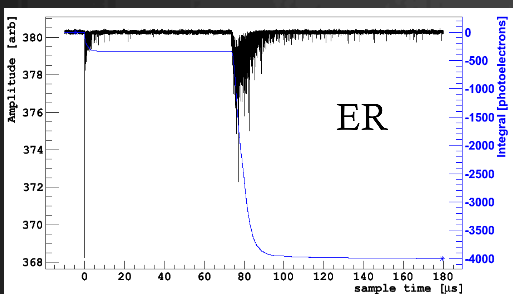
- Neutrons/Gammas from the rock
- Cosmogenic Spallation Neutrons
- Radioactivity
  - $\gamma + e^- \rightarrow \gamma + e^-$
  - $n + N \rightarrow n + N$
  - $N \rightarrow N' + \alpha, e^-$

Electron Recoils can be mis-identified as Nuclear Recoils → Extreme radiopurity; Effective ER/NR discrimination

Nuclear Recoils from neutrons are similar to the signal from WIMPs → Active external volumes (shield and veto) to suppress/veto the *n* background

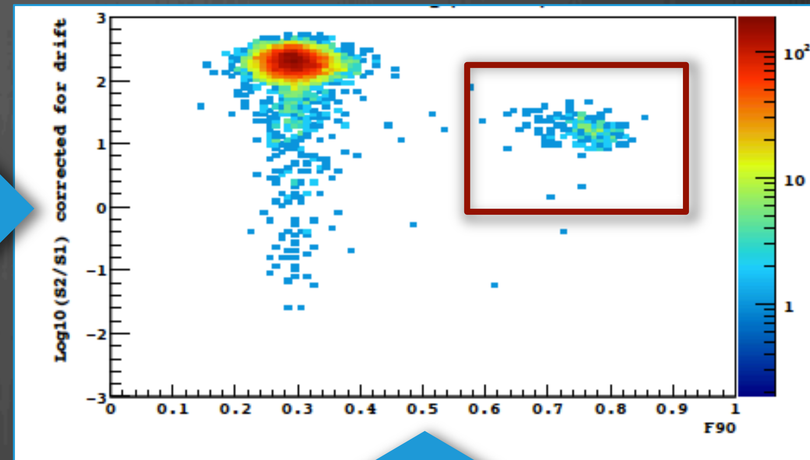
Background Rejection in the TPC





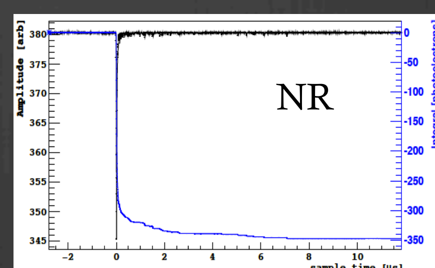
S2/S1

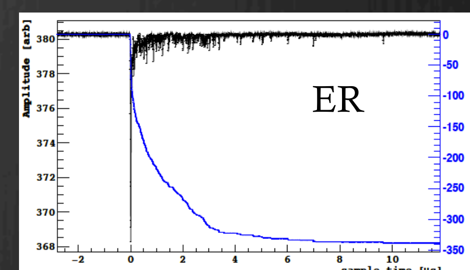
Rejection factor: **$10^{2\text{-}3}$**



S1 Pulse Shape Discrimination

Rejection factor: **10^8** @ npe > 60





Position Reconstruction

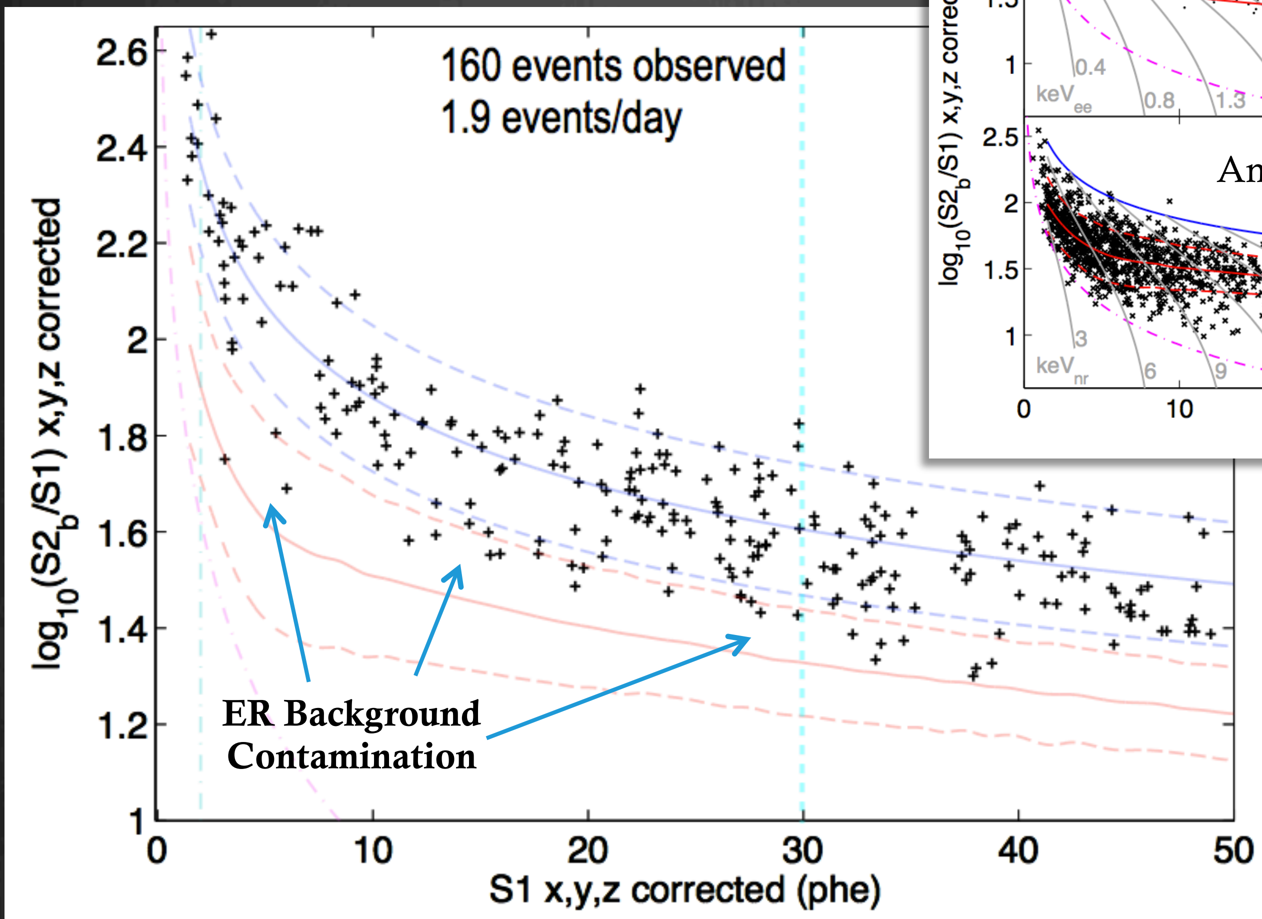
- Fiducialization (Rejection of Surface Radioactivity)
- Multiple Scattering (neutrons)

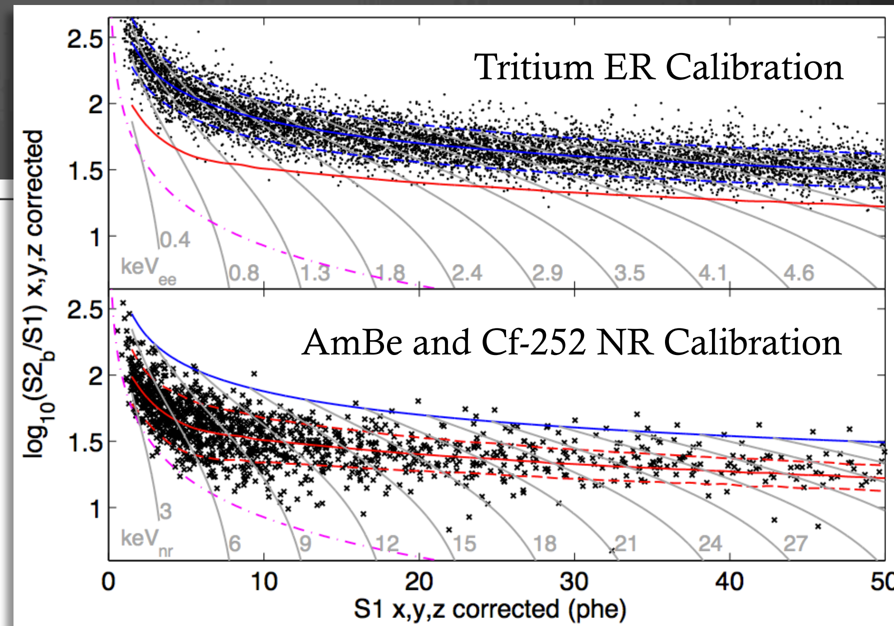
Overall Rejection Factor > 10^{10}

LUX Results

LUX: Dual-phase Xe TPC

First result presented on Oct 30, 2013





arXiv:1310.8214

DarkSide **Active** Neutron Veto

Allows to veto neutrons in the TPC and to perform an ***in situ*** measurement of the neutron background

Sphere (4 m diam.) instrumented with 110 8" PMTs

- Liquid Scintillator: **1:1 PC + TMB (~5% B)**

Neutron Capture on ^{10}B

- High Cross Section
- Short Capture Time (2.3 μs)
- Reaction Products: 1.47 MeV α's

Veto Efficiency of Radiogenic n > 99.5%
of Cosmogenic n > 95%

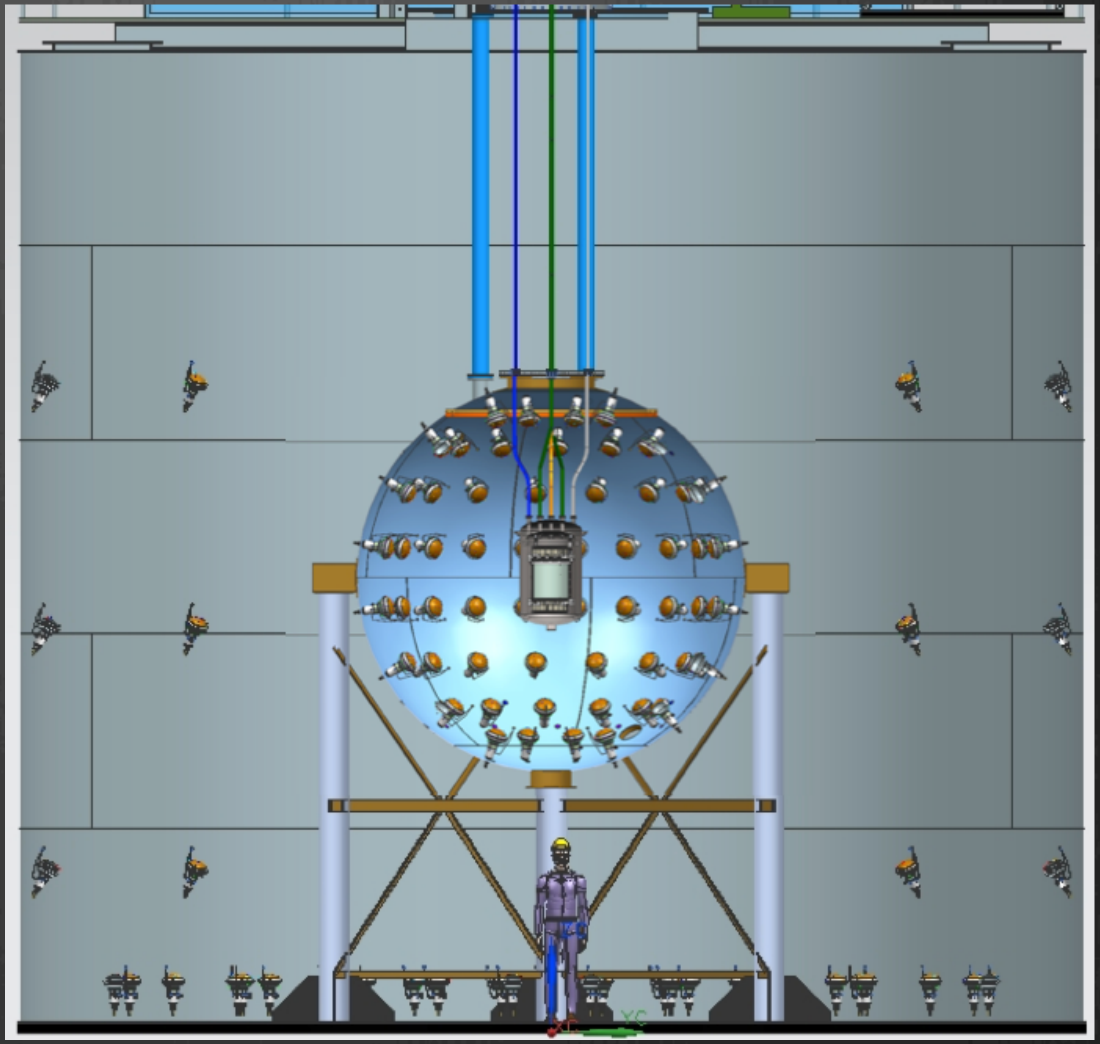
Active Water Tank

Borexino CTF

- 10 m diam. × 11 m. height
- 1000 tons water
- 80 PMTs

Acts as

- n and γ passive shield
- **Active** muon and cosmogenic veto (~99% efficiency)



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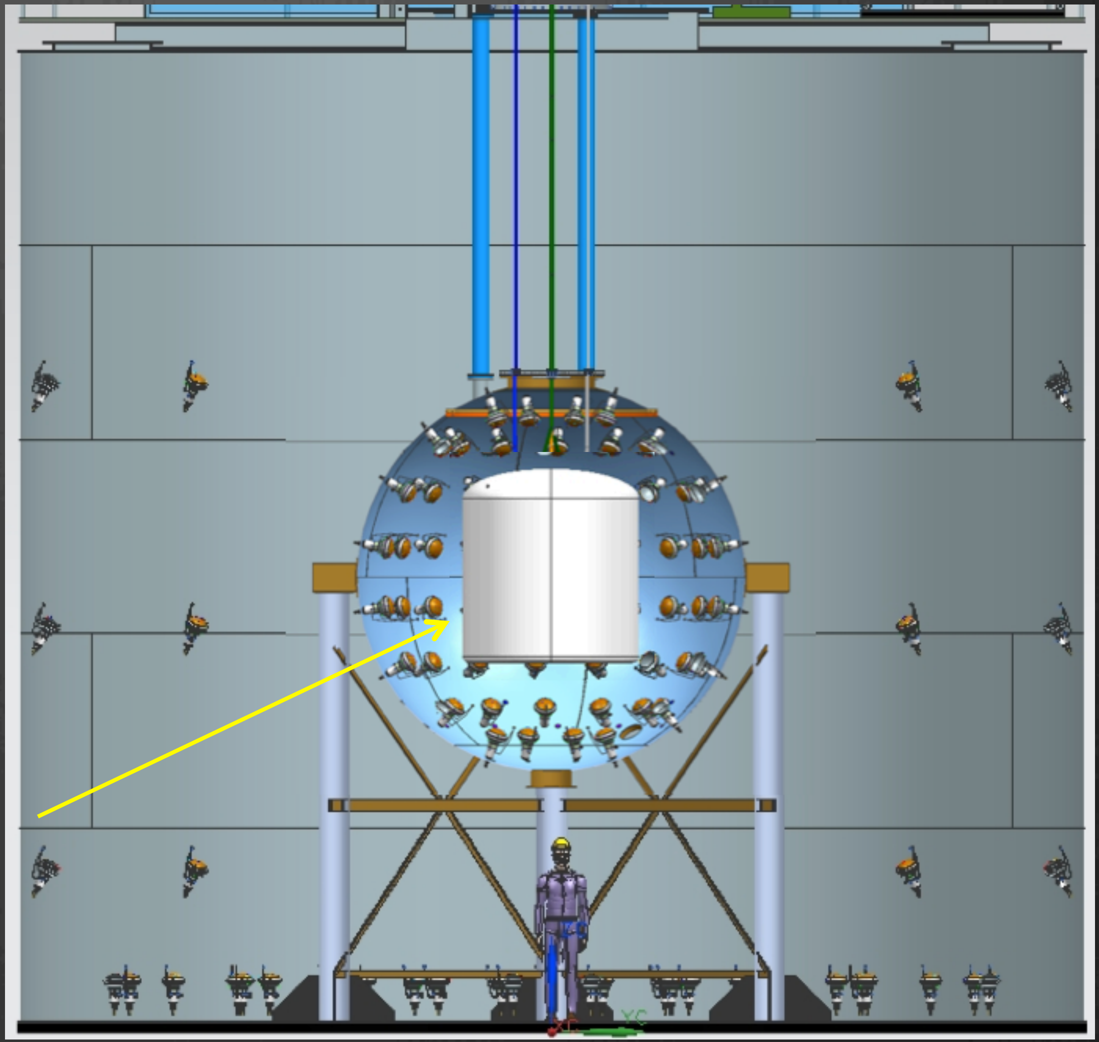
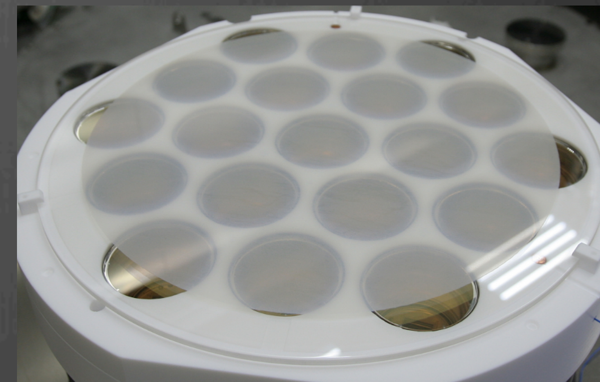
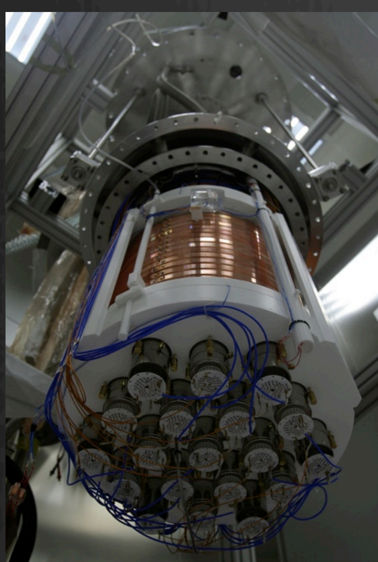
Water Tank and Neutron Veto are designed to host the G2 TPC without modifications

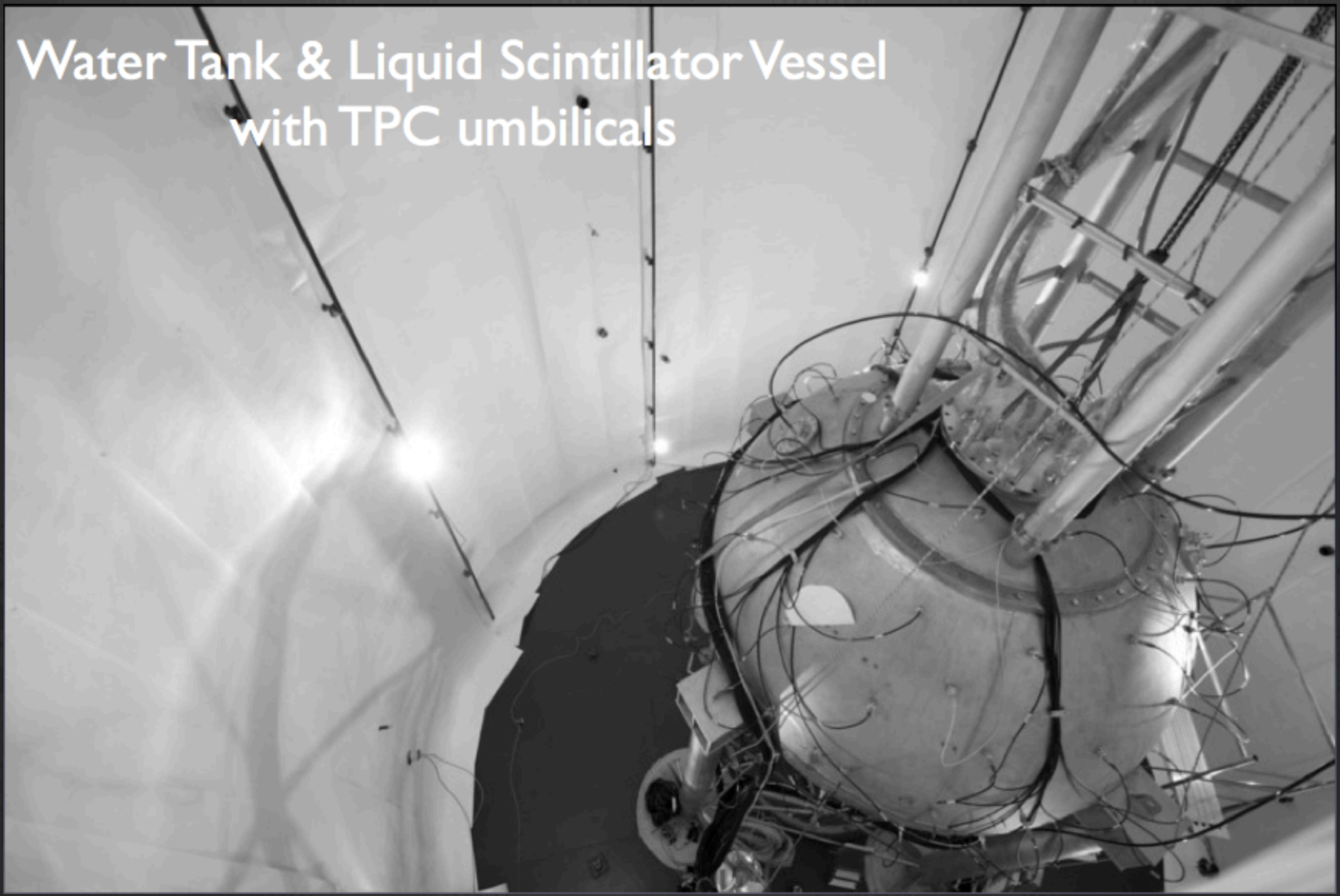


TPC and Neutron Veto





Water Tank


Water Tank & Liquid Scintillator Vessel
with TPC umbilicals

Our Role in DarkSide

Local participation of two Institutes: **IPHC** and **APC**

Officially accepted in the collaboration

Tasks

- Monte Carlo Generation and Tracking
- Study of Low-Energy Scintillation Mechanism
- Data Analysis (pulse finder, energy calibration with MC, electronics simulation)
- Precision QE measurement at LAr temperature
- Test of photosensors at LAr temperature

G4DS: Geant4-based MC

Entire framework developed at APC – IPHC

Full particle and photon tracking

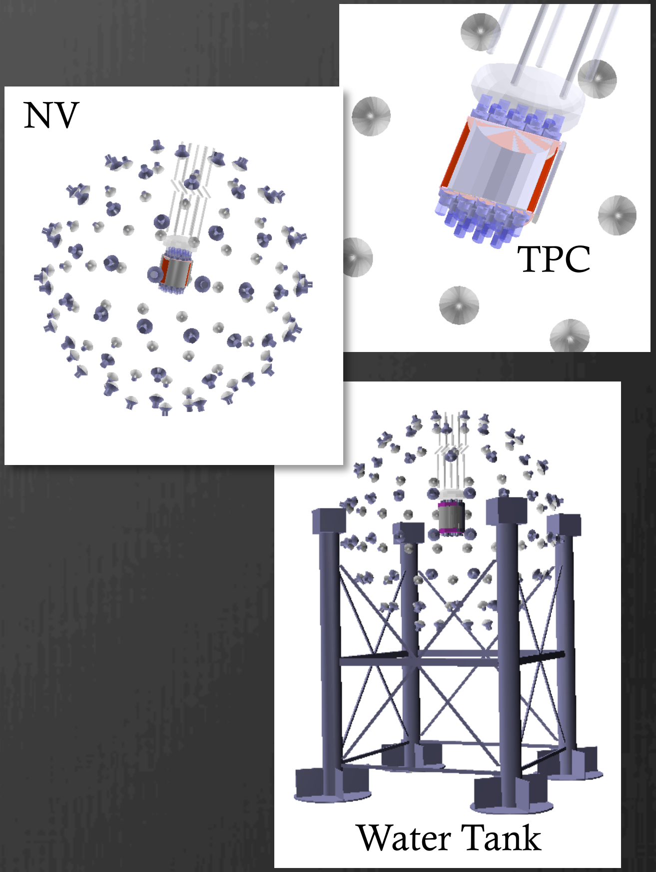
Multiple generators

- e.g. n from the rock, cosmic μ at LNGS, radioactive decay chains

Multiple **Physics Lists**

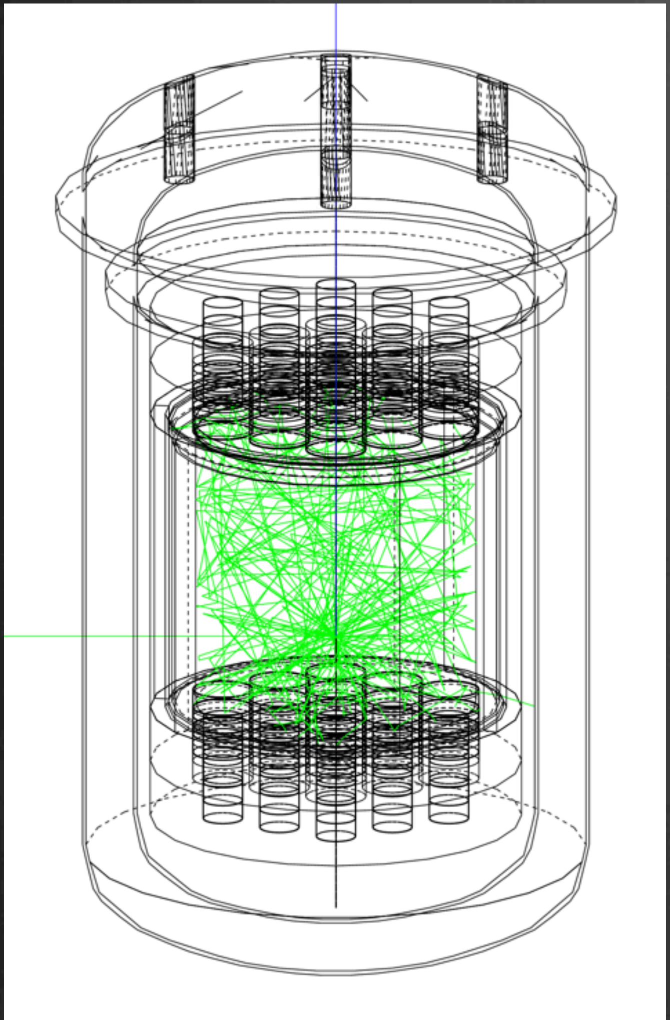
- e.g. Livermore, QGSP_BERT_HP, QGSP_BIC_HP

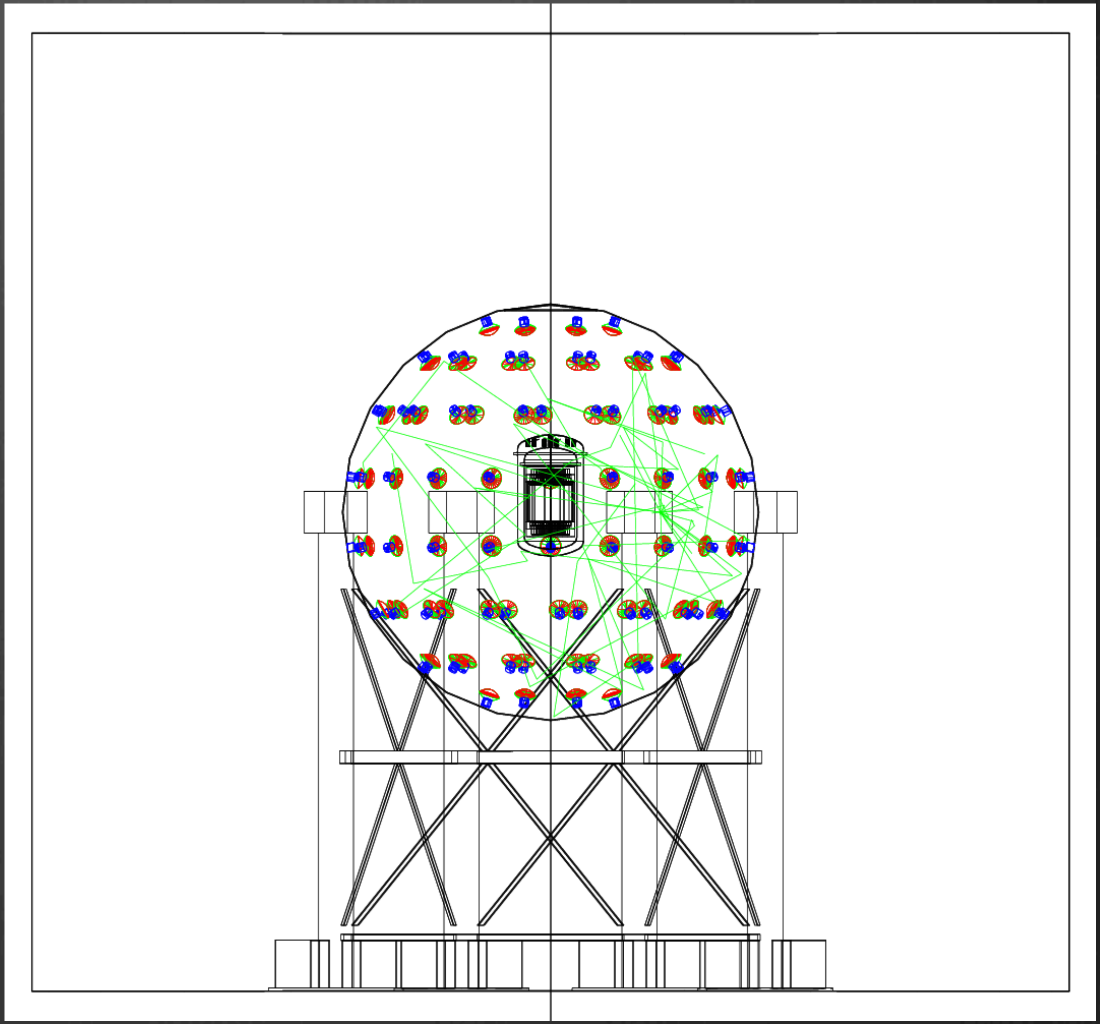
Strong efforts in describing **low-energy physics** (next slides)



Complete description of DS10, DS50, DSG2 and vetoes

G4DS at Work

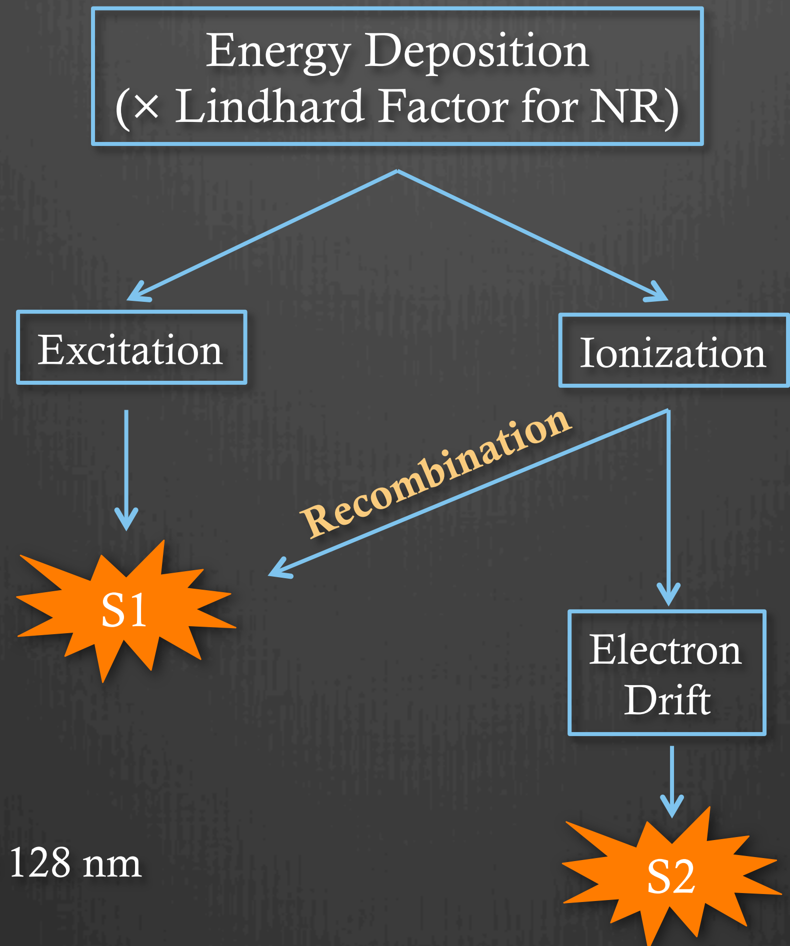




A Dedicated Effort on Ar Scintillation

Light Emission via Excitation

$$e^- + R \rightarrow R^* + e^-$$
$$R^* + R \rightarrow R_2^{*,\nu}$$
$$R_2^{*,\nu} + R \rightarrow R_2^* + R$$
$$R_2^* \rightarrow R + R + h\nu$$

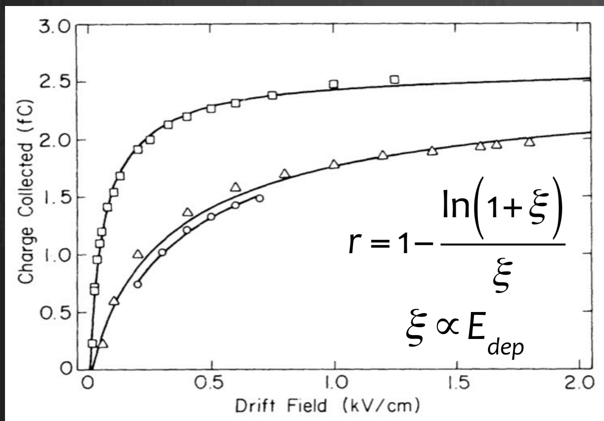


Light Emission via Ionization

$$e^- + R \rightarrow R^* + 2e^-$$
$$R^+ + R + R \rightarrow R_2^+ + R$$
$$e^- + R_2^+ \rightarrow R^{**} + R$$
$$R^{**} + R \rightarrow R^* + R + heat$$
$$R^* + R + R \rightarrow R_2^* + R + heat$$
$$R_2^* \rightarrow R + R + h\nu$$

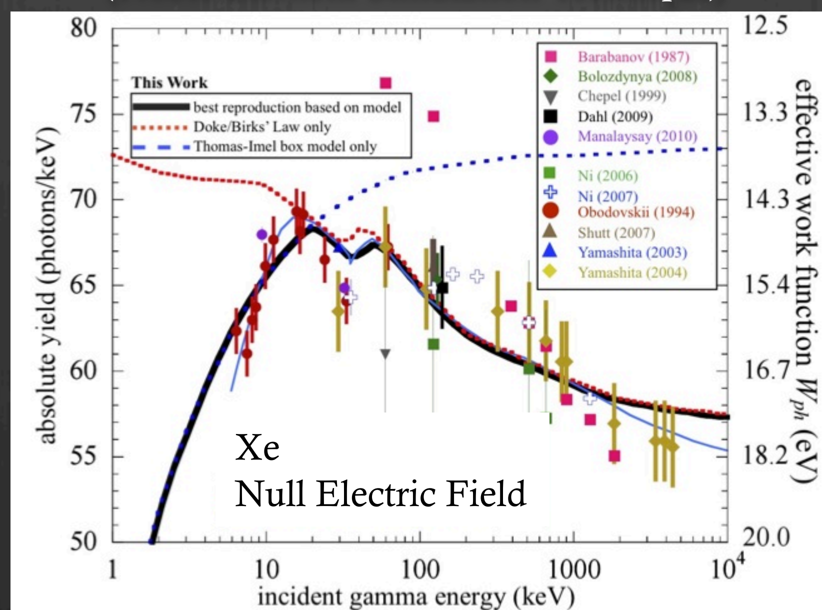
Photon wavelength λ = 128 nm

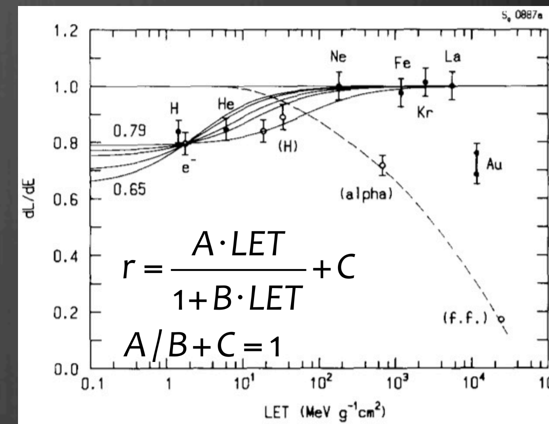
Models of Recombination Probability *r*



Thomas – Imel Model
(Box Model)

from **NEST**
(Noble Element Simulation Technique)





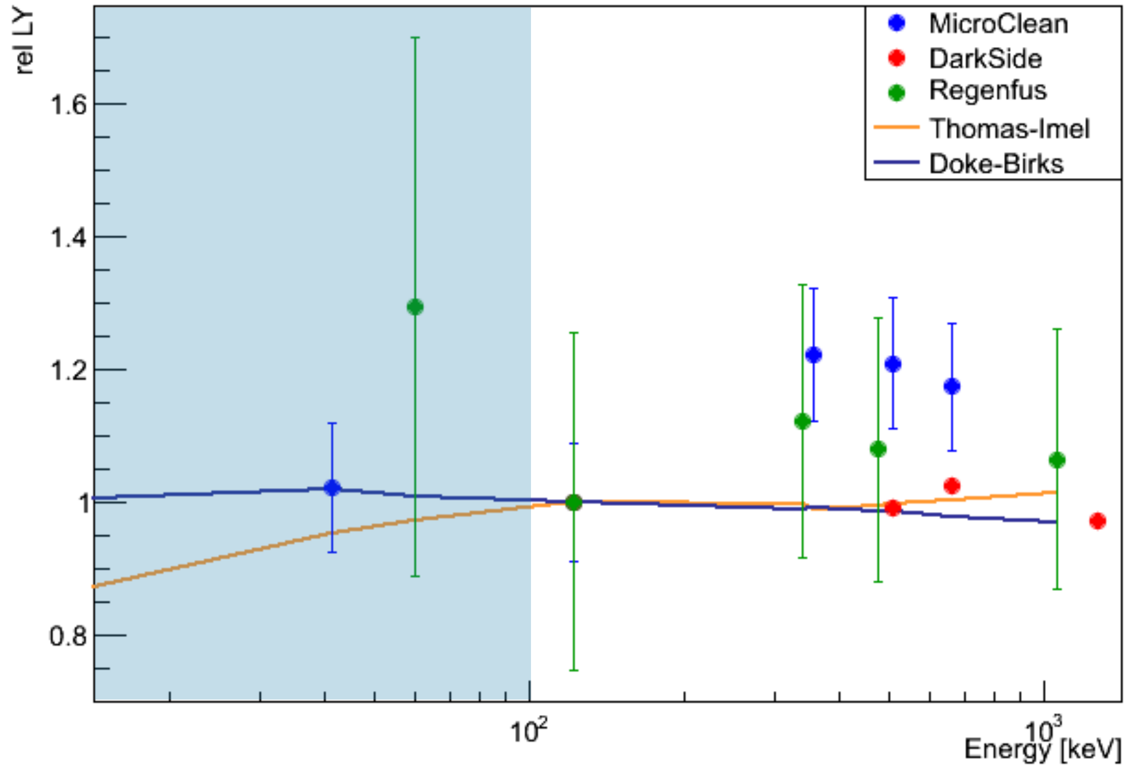
Doke – Birks Model
(Cylinder Model)

if En. Dep.
Size < λ_{therm}

if En. Dep.
Size > λ_{therm}

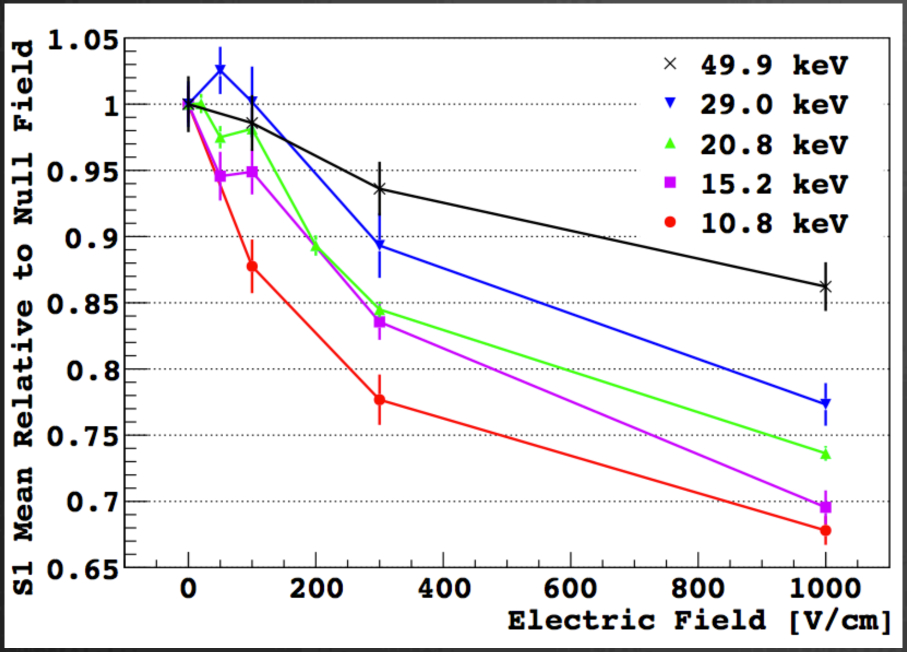
Scintillation Models in LAr

LY/keV (relative to ^{57}Co 122 keV line) for **ER** at **Null Field**

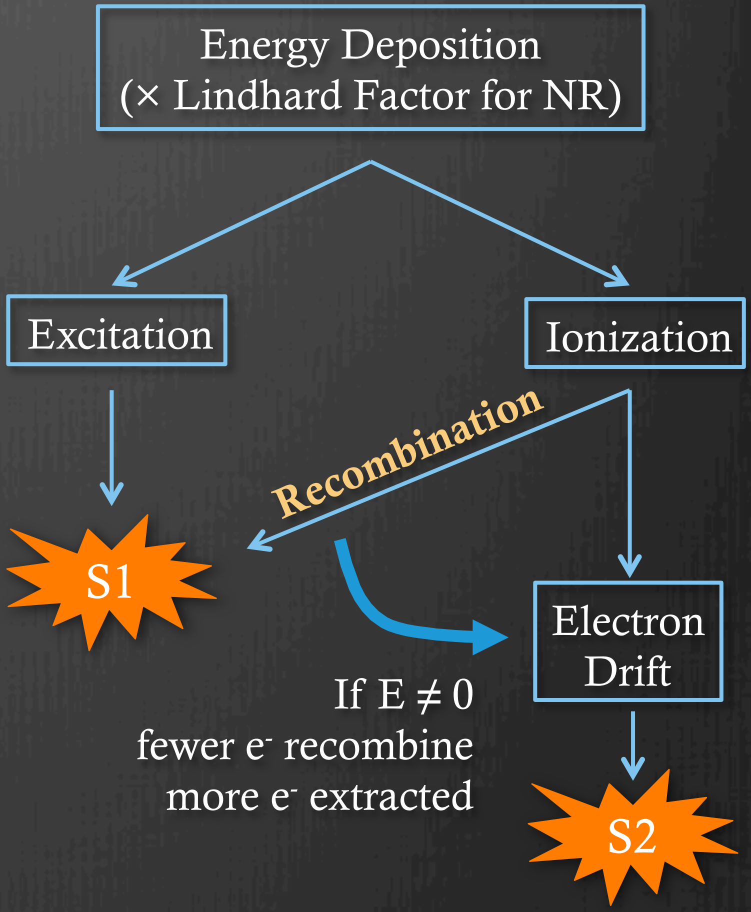


MicroClean: PRC81, 045803 (2010)
DarkSide: arXiv:1204.6218v2
Regenfus: arXiv:1203.0849v1

S1 at Non-Null Electric Field



Measured in **SCENE** in **LAr**
arXiv:1306.5675



Tasks for the Next-Future (I)

Data Analysis

- Simulation of the **electronics**
- **Energy calibration with MC**: Energy Scale and Resolution, Dependence on the Electric Field
- Pulse Finder

Study of **LAr scintillation response**

- **E**lectron **R**ecoil energies (**10 - 100 keV**) at several **E field** intensities
- No Nuclear Recoils (Lindhard Factor additional d.o.f.)
- Comparison with MC simulation

Proposal submitted to ANR

Task for the Next-Future (II)

Precision measurement of PMT **Photon Detection Efficiency** at LAr temperature

- High precision technique (integrating sphere - APC patent) for a calibrated light source
- Wavelengths from UV to visible @ SPE level

Test of **photosensors** at LAr temperature

- **SiPM**, hybrid APDs, CCD cameras
- Provide high photon detection efficiency, high time/spatial resolution (-> directional information), low costs

Conclusions

Current DarkSide Phase: **DS50**

- Final Goal: DS - G2 (5 tons)
- Data taking started in October '13
- Sensitivity 10^{-45} cm^2 at 100 GeV/c^2 with 3 years of data taking

IPHC and APC **officially in the Collaboration**

Fully involved in the development of Monte Carlo (**g4ds**) and **data analysis**

Future hardware tasks: **photosensors characterization** at LAr temperature