Direct Dark Matter Detection

Aldo Ianni,

Canfranc Laboratory

10th Dec., 2015

IFAE, Barcelona

Outline

- Introduction
- Direct Detection of Dark Matter
- A detailed example: DarkSide
- Conclusions

In brief: evidence of Dark Matter

- Spiral galaxies **rotation curves**: $\Omega_{halo} \sim 10\Omega_{stars}$ **(Ω_{matter}>0.1)**
- **Clusters of galaxies**: Ω_{matter}**~0.2-0.3**
- **CMB anisotropy and BB nucleosynthesis**:

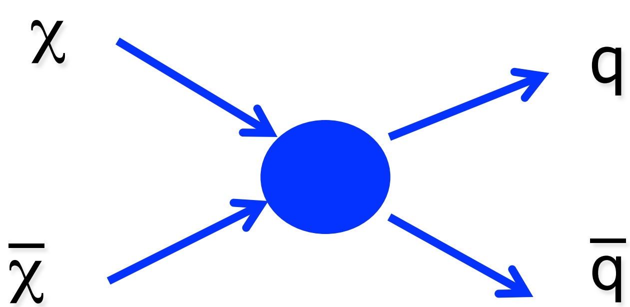
  Ω_{matter}**~0.27**, $\Omega_{baryons}$~0.04
  - **~85% of mass in the Universe is dark and non-baryonic**
  - **$<\rho_{DM}> \sim 0.23\rho_{crit} \sim 10^{-6}$ GeV/cm^3**
  - around our Sun: **$\rho_{DM\text{-}Sun} \sim$ 0.3-0.4 GeV/cm^3**
- **Large Scale Structures**:
  - Formation of structures by gravitational clustering support evidence of “cold” DM

Summary of DM properties

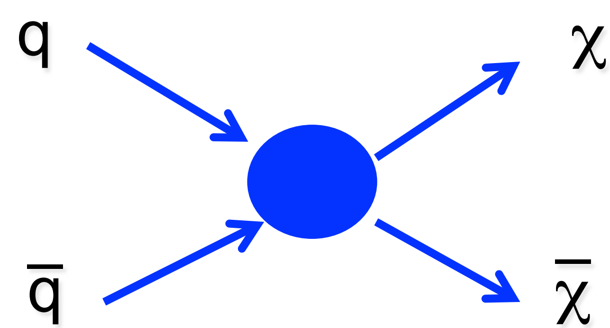
- **DM evidence** based on gravitational interaction
  - This paradigm shows some subtle points
    - Discrepancies between N-body simulations and astrophysical observations
- DM makes up ~**85% of matter** in the Universe
- **DM could be made by unknown** particle(s)
  - WIMPs, axions, …
- These particles are neutral and **gravitationally interacting.** What about:
  - Self interactions ??
  - Dissipative processes ??
- $\boldsymbol{\Omega_{DM} \sim 5\Omega_b\ (m_p\rho_{DM}/\rho_b \sim 5 GeV/c^2)}$
  - Baryon density is asymmetric. What about DM density?
- **Cold** (p/m <<1 at CMB formation)
- **Stable** or very long lived (> 10^{10} years)

The quest for Dark Matter

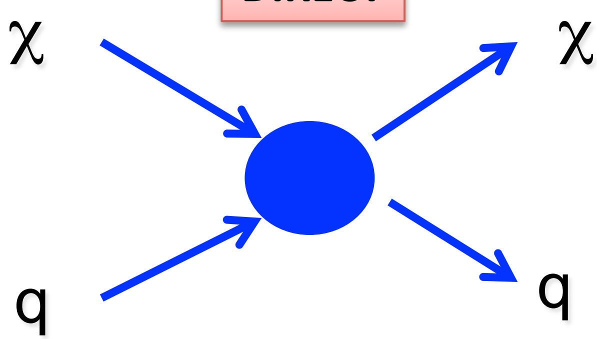
INDIRECT



COLLIDER



DIRECT



χ = DM particle
q = Standard Model particle

DM particle candidates

- **WIMPs**
  - Weakly Interacting Massive Particles:
    for the last ~ 20 years the main scenario for DM direct detection
  - Mass ~ 1 – 100 GeV/c^2
  - Local number density ~ $10^5 – 10^7$ cm^{-3}
- **Axion-like particles**
  - the interest in these particles as DM candidates
    is growing

$$\Omega_a \approx \left(\frac{10^{-5}\ \mathrm{eV}}{m_a} \right)^{\frac{7}{6}}$$

  - QCD axions as DM with mass ~ 10 – 100 μeV
  - Local number density ~ $10^{12} – 10^{15}$ cm^{-3}

The quest for axions as DM

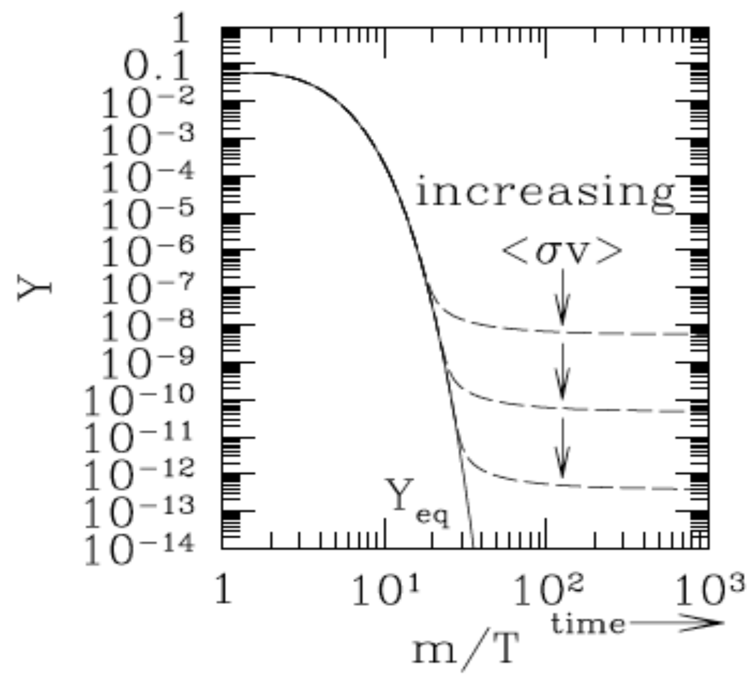
- The only experiment in operation at present is **Axion DM eXperiment (ADMX)** a cryogenic microwave cavity in 8T magnetic field sensitive to ~100 MHz
  - improving performances for GHz range sensitivity
- **CAST-CAPP** and **RADES** (UZ and IFIC Valencia)
  - Microwaves cavitities in CAST magnet with GHz sensitivity
  - Prototypes installed and tested in 2016
- **Dielectric resonant cavities** with sensitivity at 10-100 μeV (mainly MPI, Munchen)
- Quest for Axions (**QUAX**) at INFN and Univ. of Padova
  - Probe axion-electron coupling by detecting spin flip induced in a magnetic field on a target "magnetic sample"

WIMPs

- A general class of weakly interacting massive (1GeV – 10 TeV) particles not from the Standard Model

- Assuming thermal equilibrium in the early Universe and non-relativistic decoupling, the energy density for these relic particles is predicted to be:

  - $\Omega_\chi \sim 0.2$ **for** $\sigma \sim 10^{-36} cm^2$
  - **Electroweak-scale cross section can reproduce correct relic density**



"Standard" cross-section

Spin Independent interaction: $$\sigma^{SI}(E_r) = \sigma_p^{SI}\left[Z + (A - Z))\frac{f_n}{f_p}\right]^2 \left(\frac{\mu}{\mu_p}\right)^2 F_{SI}^2(E_r)$$

with F(0) = 1. So for the "standard" $f_p = f_n$, $\boldsymbol{\sigma^{SI} \sim A^2}$

Spin Dependent interaction: $$\sigma^{SD}(E_r) = \sigma_p^{SD}\frac{4}{3}\frac{J+1}{J}\left(\langle S_p\rangle + \langle S_n\rangle\frac{f_n}{f_p}\right)^2 \left(\frac{\mu}{\mu_p}\right)^2 F_{SD}^2(E_r)$$

$\boldsymbol{\sigma^{SI}/\sigma^{SD} \sim A^2}$

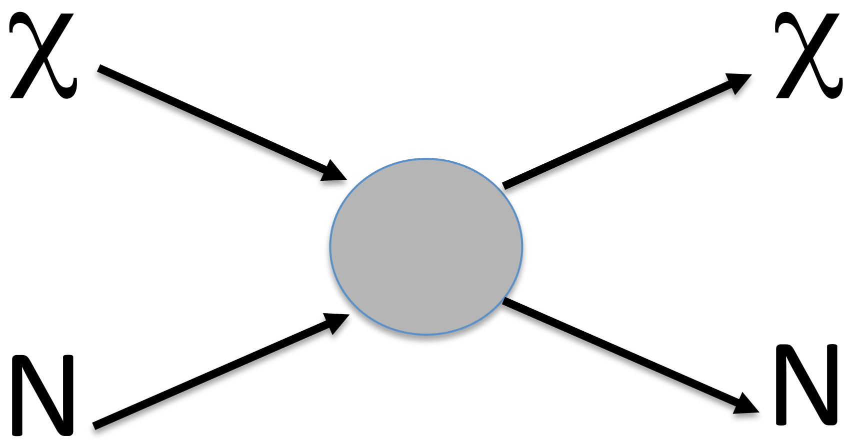
Deviations from the "standard" scenario are considered:

- Isospin Violating Interactions, f_n/f_p ~ -0.7
  - reduces the coupling with Xe target
- f_n/f_p ~ -0.8 reduces the coupling with Ge target
- Electromagnetic coupling
- …

Important to use different target detectors

Direct Search for WIMPs: nuclear recoil tagging

Goodman and Witten, PRD31, 1985



$$E_{recoil} = \frac{m_N M_\chi^2}{\left(m_N + M_\chi\right)^2} v^2 (1 - \cos\theta^*)$$

$$v \sim 300 \text{ km/s} \quad \beta \sim 10^{-3}$$

$$E_{recoil} \sim 1 - 100 \text{ keV}$$

$$\frac{\lambda}{2\pi} = \frac{h}{p} = \frac{\hbar c}{mc^2\beta} \approx \frac{197 \cdot 10^{-13}\,\text{MeVcm}}{100\text{GeV } 10^{-3}} \approx 2 \cdot 10^{-13}\, cm$$

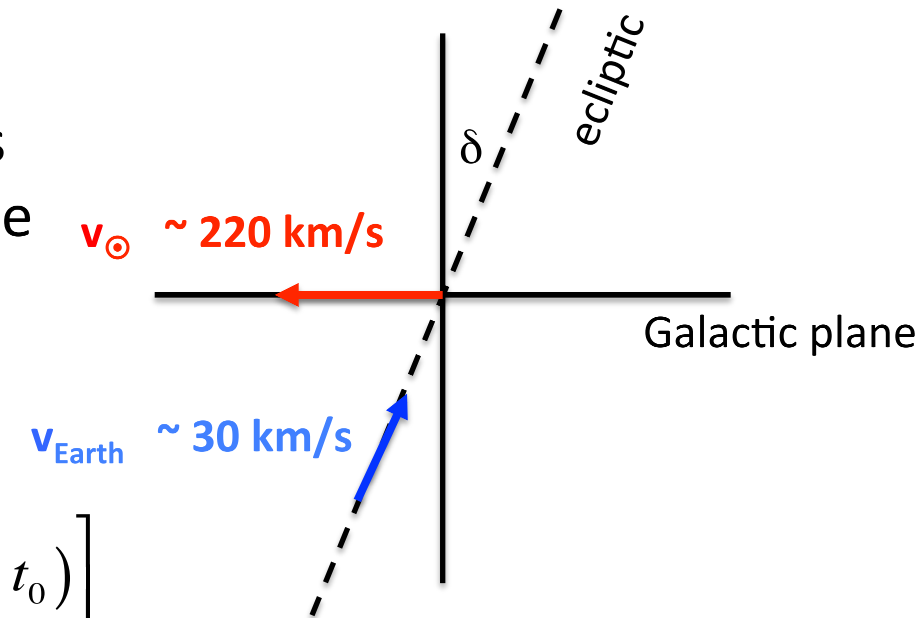
$$\frac{dR}{dE} = N_t \frac{\rho_\chi}{m_\chi} \frac{m_N}{\mu_n^2} A^2 \sigma_{\chi n} F^2(E) \int_{v \geq v_{\min}(E)} d^3v \frac{f(v)}{v}$$

$$f(v) = \begin{cases} \frac{1}{N} e^{-\left(\frac{\left|v_\chi + v_{sun} + v_{Earth}\right|}{v_0}\right)^2}, & \left|v_\chi + v_{sun} + v_{Earth}\right| < v_{esc} \\ 0, & \text{elsewhere} \end{cases}$$

- 170 km/s < v_0 < 270 km/s
- 450 km/s < v_{esc} < 650 km/s
- ρ_χ ~ 0.3 Gev/cm^3
- F(E) = nuclear form factor
- f(v) = velocity distribution of WIMPs in the galaxy

Annual Modulation of WIMP interaction rate

The WIMPs interaction rate is oscillating during one year due to the relative motion of the Sun with respect to the halo reference frame



$$\mathrm{v}_{\chi}(t) = \mathrm{v}_{\mathrm{sun}} + \mathrm{v}_{\mathrm{earth}} \sin\delta \cos\left[\frac{2\pi}{T}(t - t_0)\right]$$

$$\mathrm{v}_{\chi}(t) \sim 220 + 15\cos\left[\frac{2\pi}{365}(t - 153)\right] \ \mathrm{km/s}$$

$$\mathrm{R}(\mathrm{E}_r, t) = R_0(E_r) + R_1(E_r)\cos\left[\frac{2\pi}{365}(t - 153)\right]$$

Expected modulation (at **% level**) of

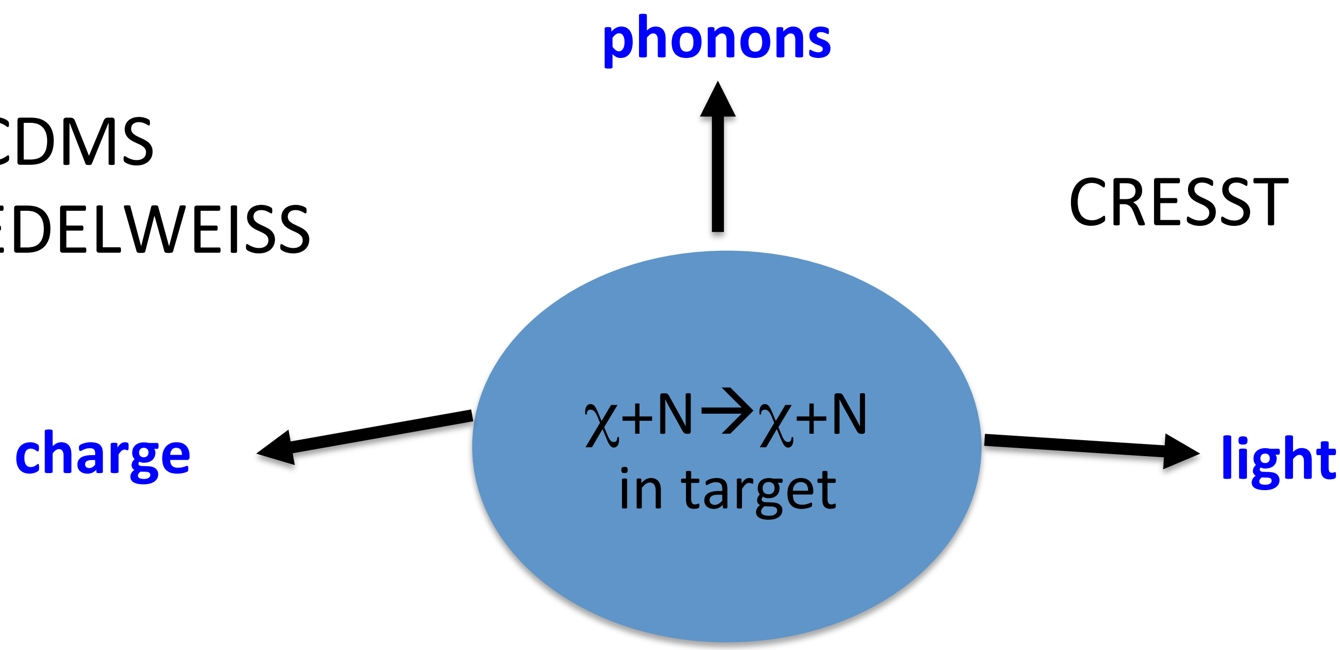
1. rate
2. spectral shape

This is a **model independent signature**

WIMPs Detection Methods

CDMS
EDELWEISS

CRESST



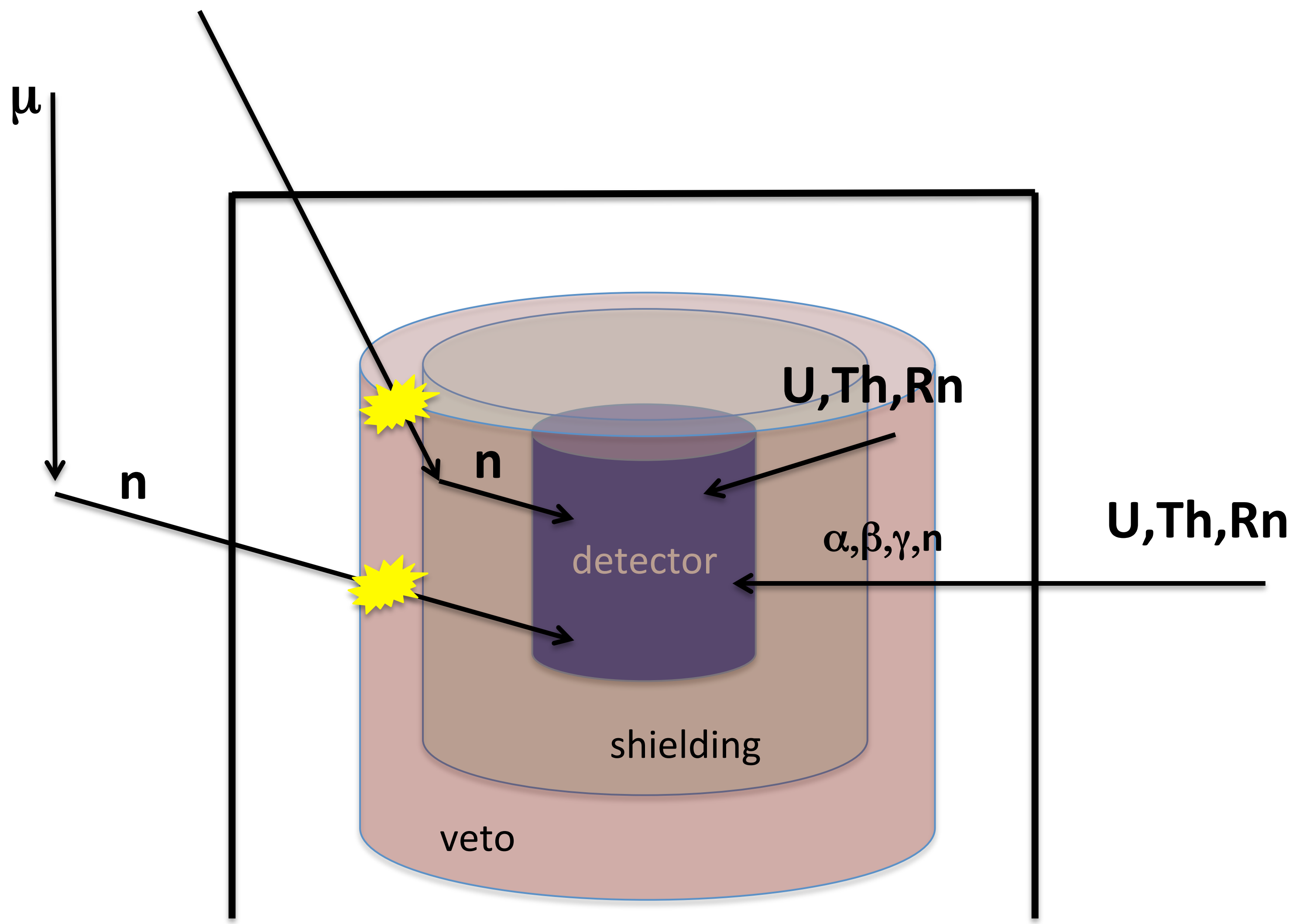
DAMA
ANAIS
DEAP
XMASS
KIMS

Xenon, LUX
ArDM, DarkSide

Technologies

- **Cryogenic solid state**
  - Ionization spectrometer + bolometer operated at < 100mK
  - CDMS(Si and Ge); CRESST(Ca); EDELWEISS(Ge)
- **Two-phase TPC with LXe** (XENON100, LUX) **or LAr** (DarkSide, ArDM)
  - Scintillation + ionization
- **Superheated liquid**
  - Nuclear recoil induce bubble nucleation
- **Scintillator crystal detectors**
  - DAMA/LIBRA (NaI), CoGeNT (Ge),CDEX(Ge), KIMS(CsI), XMASS(LXe), DEAP(LAr)
- **Spherical gas TPC**
  - Use H, He, Ne

Background

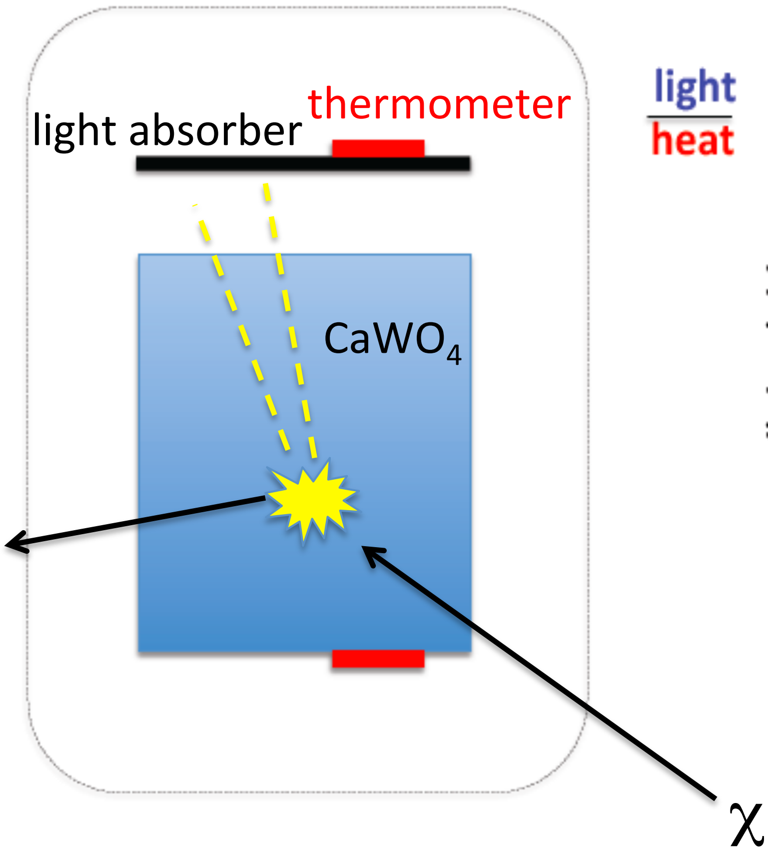


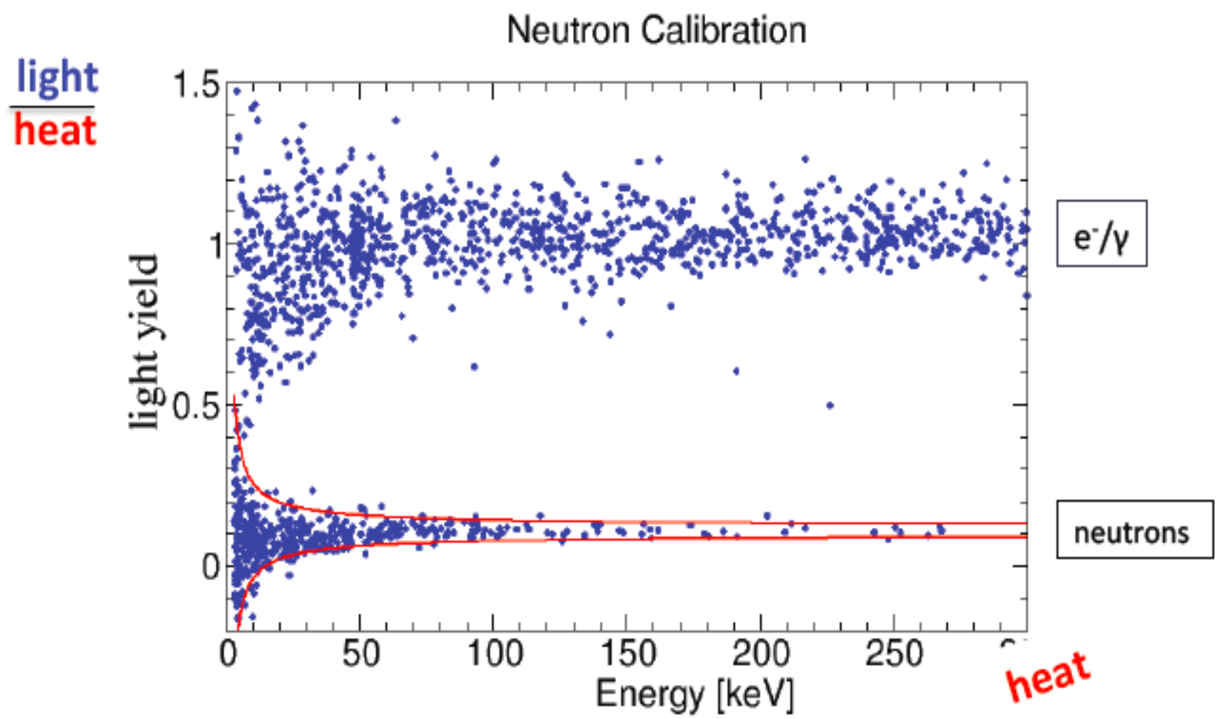
WIMPs signal and background

- **Signal**
  - Low energy nuclear recoils (1 – 100 keV)
  - Low rate (~ few counts/year/ton at 10^{-47} cm^2)
  - No specific features in recoils spectrum

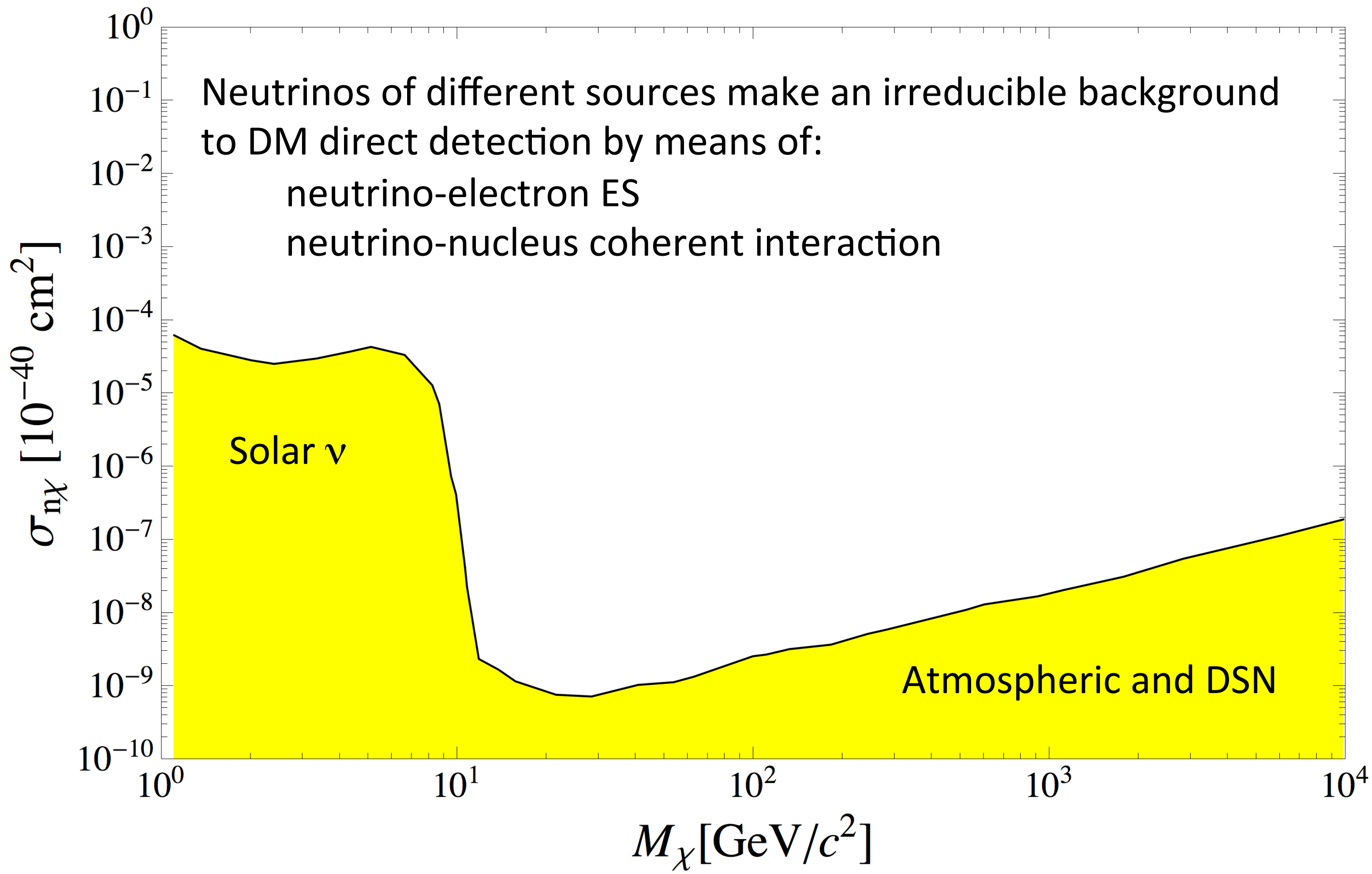
- **Background**
  - Electron Recoils (**ER**) from e, γ radioactivity
    - ✓ can be rejected by a number of discrimination cuts
  - Nuclear Recoils (**NR**) from **radiogenic and cosmogenic neutrons**
  - **Solar/Atmospheric neutrinos**:
    - ✓ Elastic Scattering interactions will limit the sensitivity depending on the ER rejection power of the experiment
    - ✓ Neutrino-nucleus coherent interactions set the limiting sensitivity

Background rejection: an example with CRESST





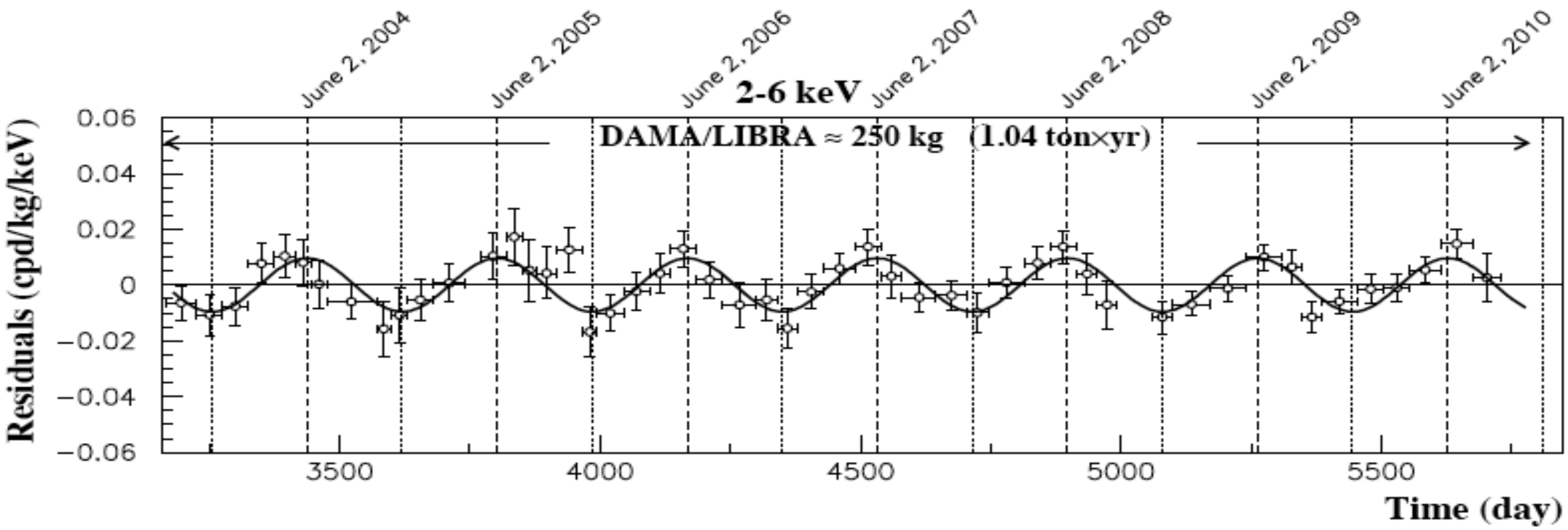
"Neutrino floor" for DM



DAMA/LIBRA

- **DAMA**
  - Low radioactivity 100 kg NaI array operated from 1996 to 2002 at Gran Sasso
  - Measures scintillation in crystal
  - No discrimination between ER and NR
  - Exposure = 0.29 ton-year
  - Positive signal for annual modulation
- **LIBRA**
  - 250 kg NaI array operated since 2003
  - Exposure = 1.04 ton-year
  - Positive signal for annual modulation

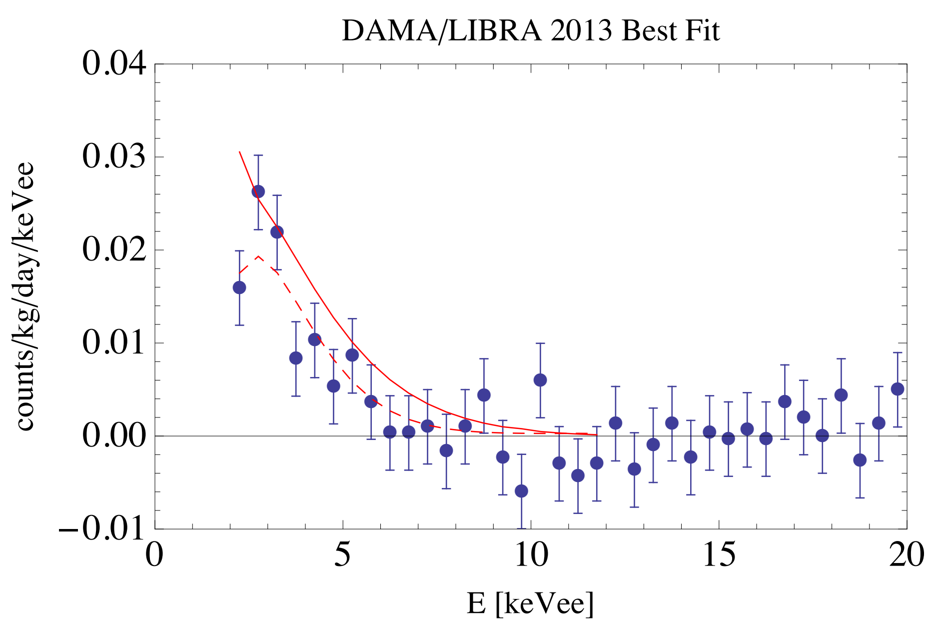
DAMA/LIBRA: results

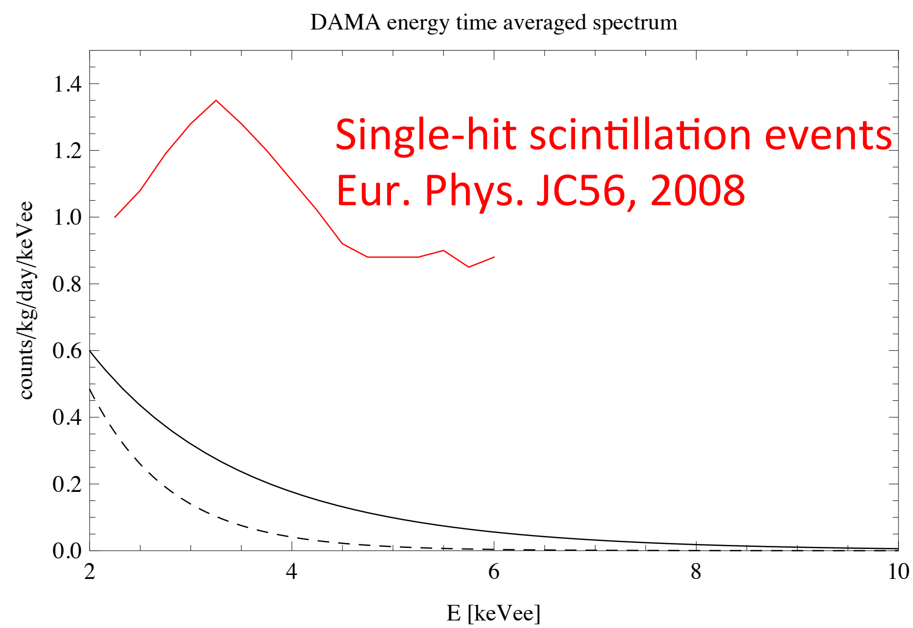


- Modulation observed over 14 cycles
- Cumulative exposure = 1.33 ton-year
- Significance of modulation signal is 9.3σ
- Modulation amplitude in [2,6]keV = 0.0112±0.0012 cpd/kg/keV
- Phase = 144±7 days
- Period = 0.998 ± 0.002 year

DAMA/LIBRA: WIMPs fit

Target	LY [pe/keV]	Threshold ER [keVe]	Threshold NR [keVr]	σ/E
NaI(Tl)	5.5-7.5	2	6.7(Na) 22(I)	~7% at 60keV

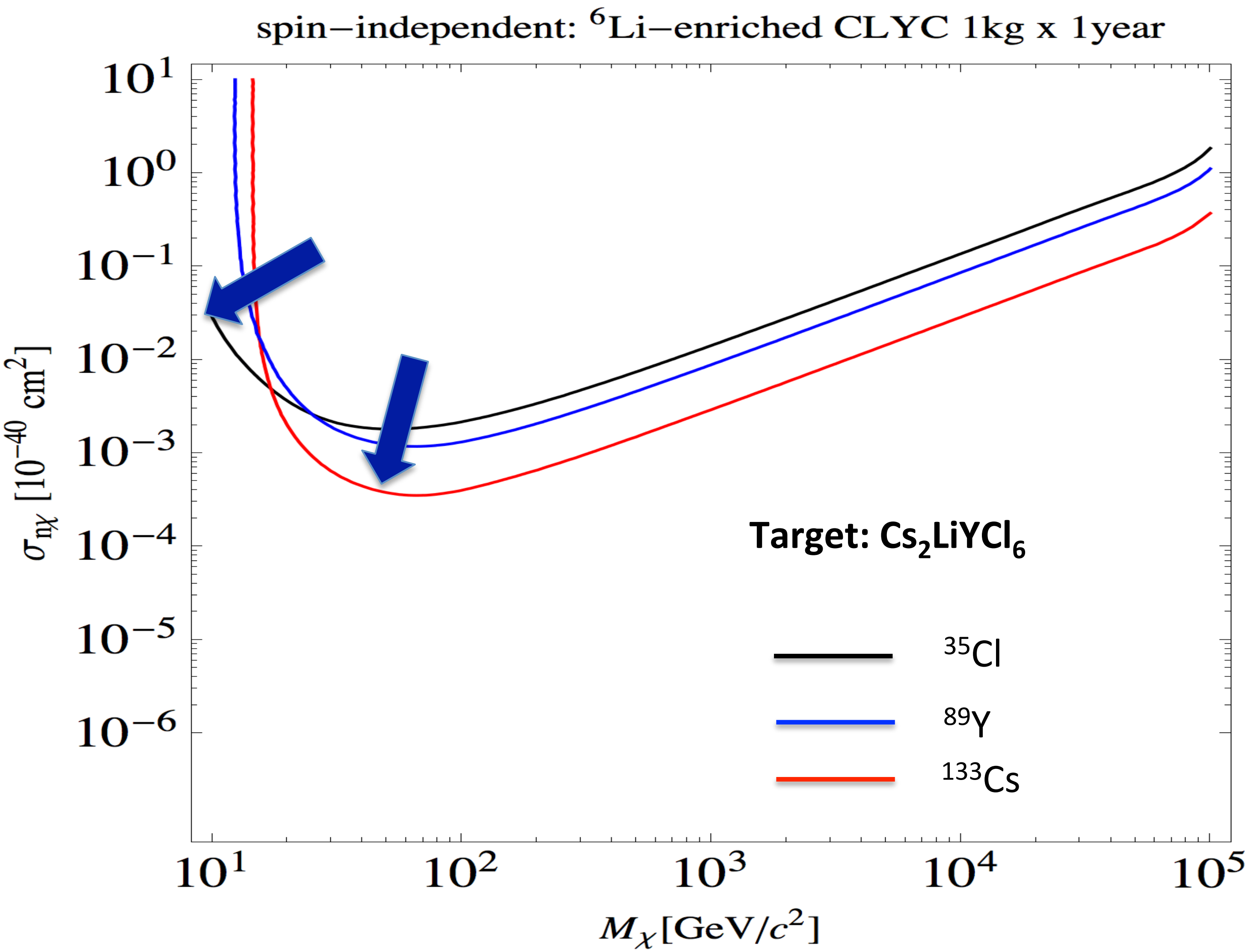




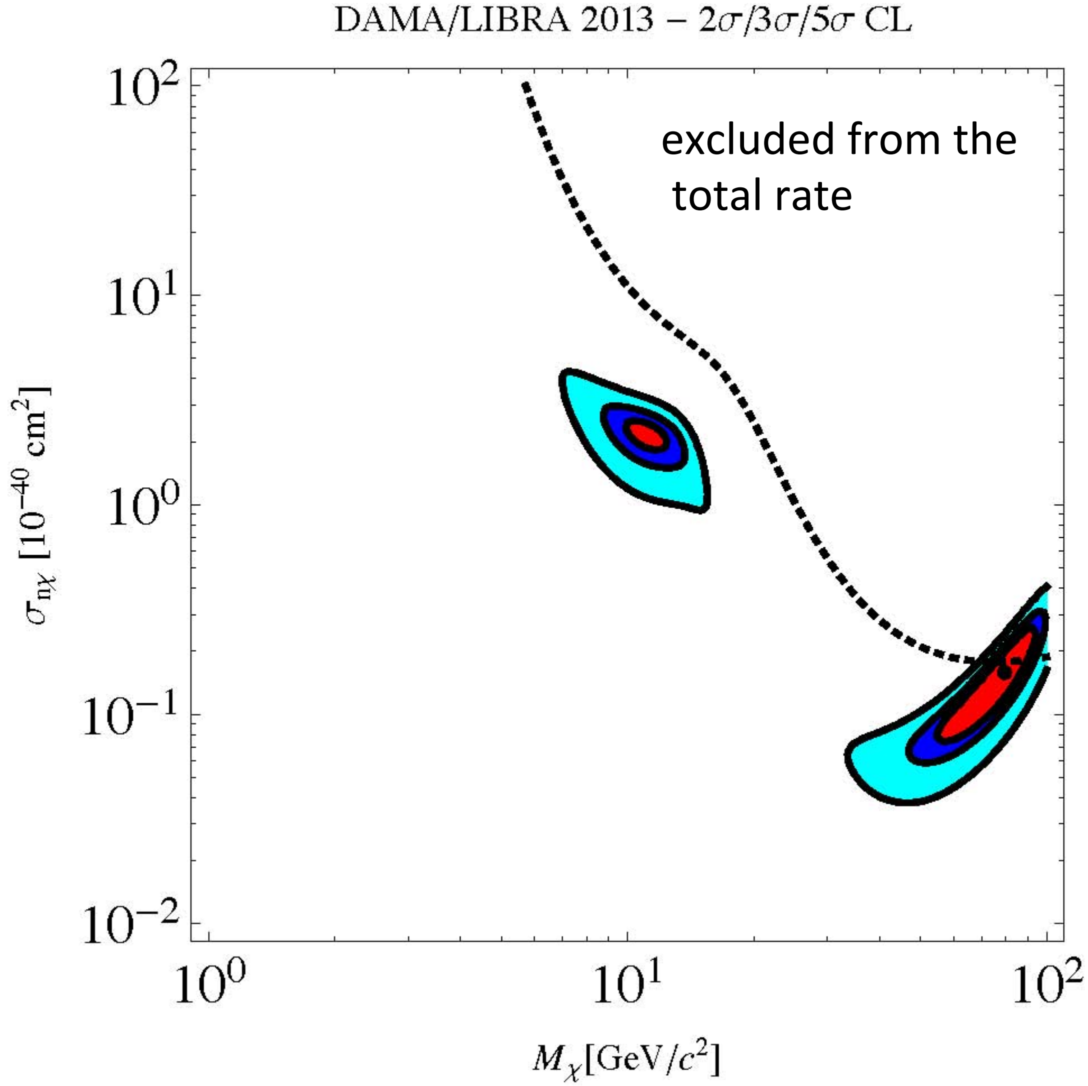
——— M_χ = 12 GeV/c^2 $\sigma_{\chi p}$ = 1.5×10^{-41} cm^2 χ^2/Ndof = 1.02

– – – – – M_χ = 8.6 GeV/c^2 $\sigma_{\chi p}$ = 1.9×10^{-41} cm^2 χ^2/Ndof = 1.69

Exclusion plot: example



DAMA/LIBRA fit for "standard" SI WIMPs



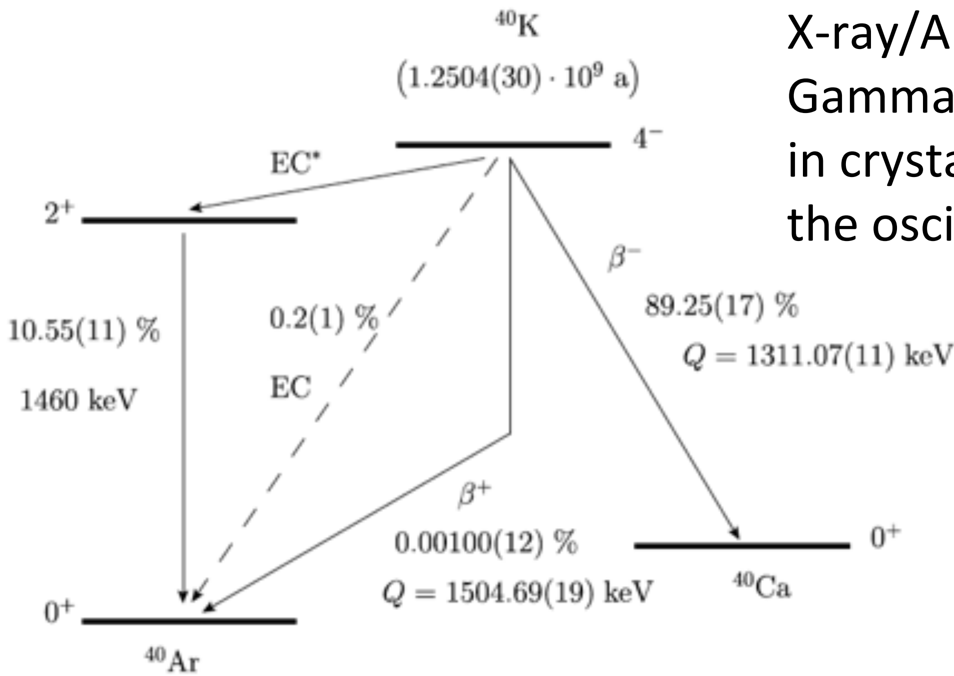
KIMS-CsI

- Korea Underground Lab.

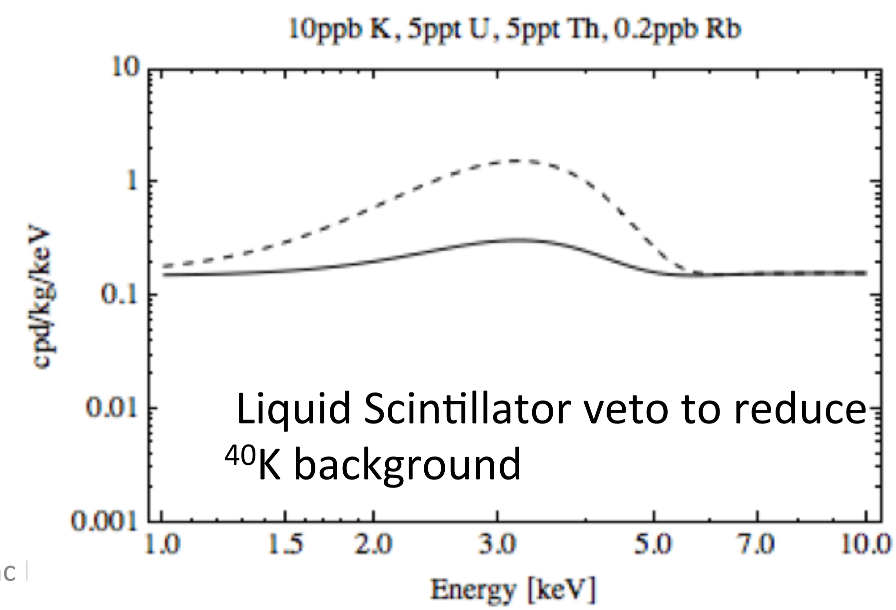
- 12 crystals of CsI – 104.4 kg
  - Thereshold 1.5 keV
  - Background ~ 2 cpd/keV/kg
  - 2.5 years of data
  - PSD cut applied

- Result: mean amplitude in 3-6 keV is 0.008 ± 0.068 cpd/keV/kg

Considerations on NaI(Tl) detectors for DM



X-ray/Auger at 3keV with 1460keV
Gamma-ray from ^{40}K contamination
in crystal gives a peak right where
the oscillation amplitude has a maximum

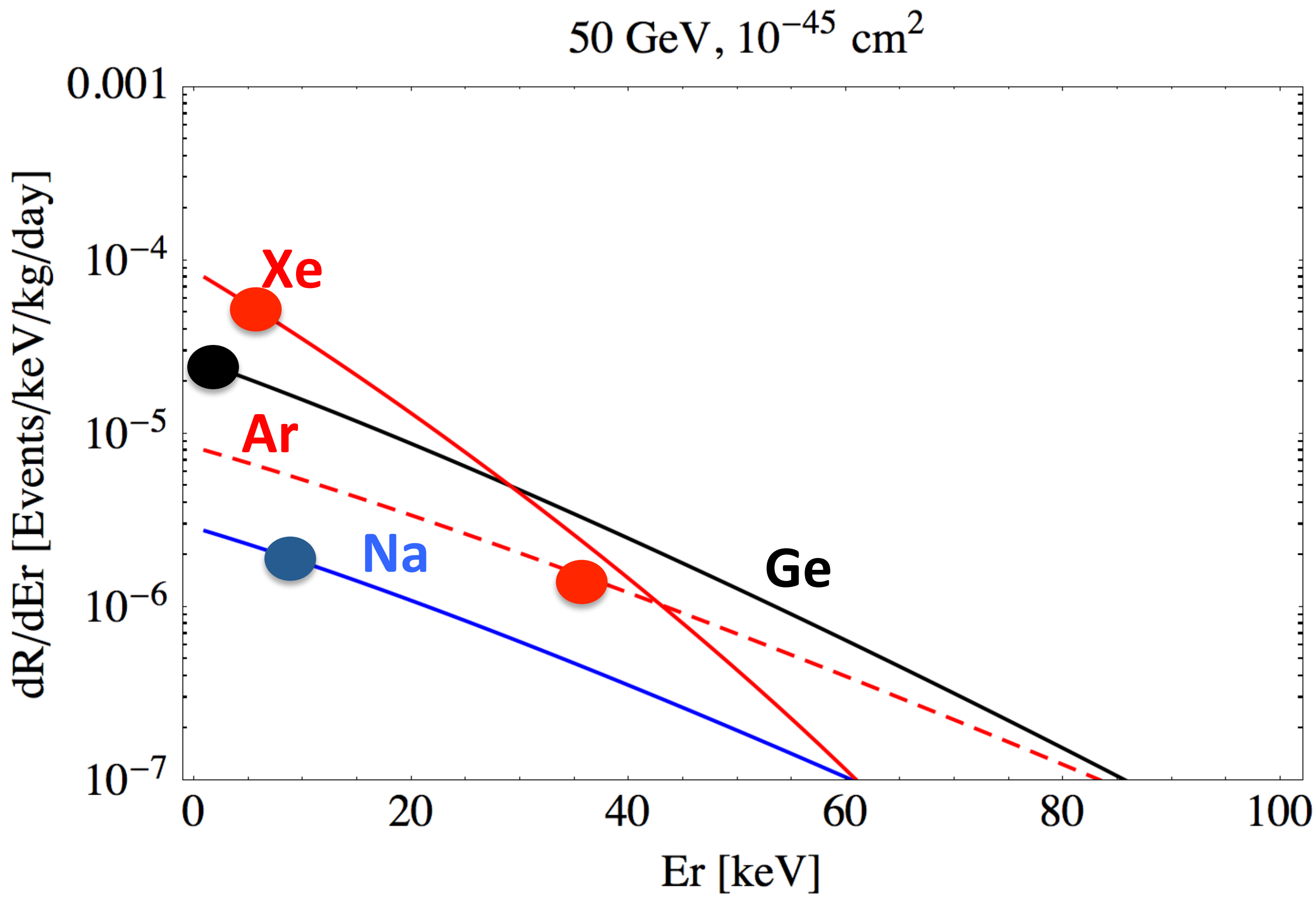


Liquid Scintillator veto to reduce
^{40}K background

NaI(Tl) detectors for DM search

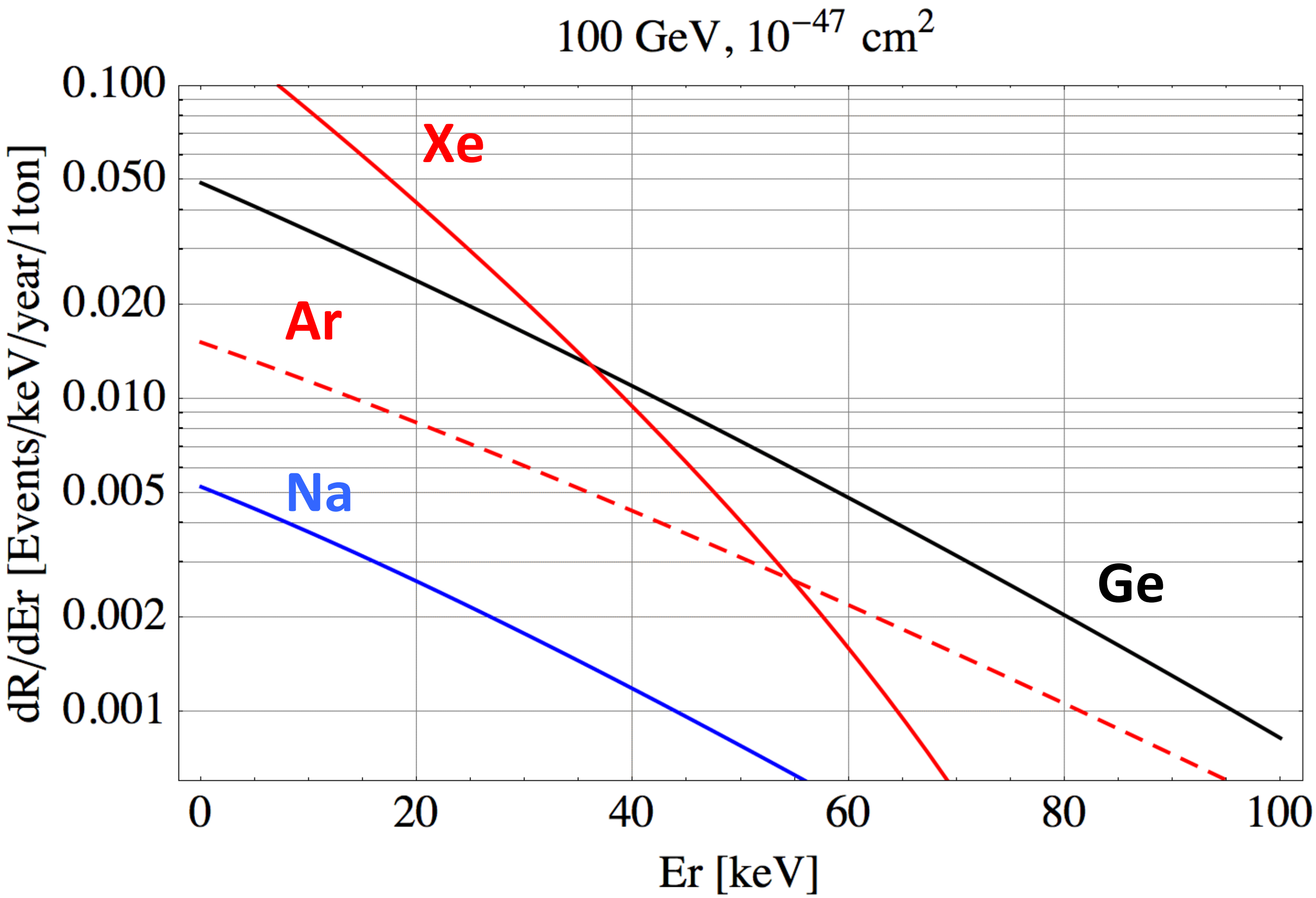
- **DAMA/LIBRA** in operation
  - Total rate in ROI ~ 1 cpd/kg/keV (1 DRU)
- **ANAIS** at Canfranc (see Miguel Angel OLIVAN at this meeting)
  - 112 kg of NaI(Tl) in 2016
- **SABRE** at LNGS and Stawell (Australia)
  - ~60 kg NaI(Tl) + Liquid Scintillator active veto
  - 2016 crystal characterization
- **KIMS-NaI**
  - 200 kg x 3 years in Yangyang (Korea)
  - Liquid Scintillator active veto
  - 2016 crystal characterization
- **PICO-LON** in Kamioka
  - 200 kg NaI(Tl) target mass
  - 2016 crystal characterization/run
- **ALL efforts have**
  - **> 10 p.e./keV yield**
  - **Issues with intrinsic radiopurity from ^{40}K, ^{210}Pb, …**
  - **Cosmogenic background will delay physics run by 1-2 years since t_0**

WIMPs Recoil Spectrum [1]



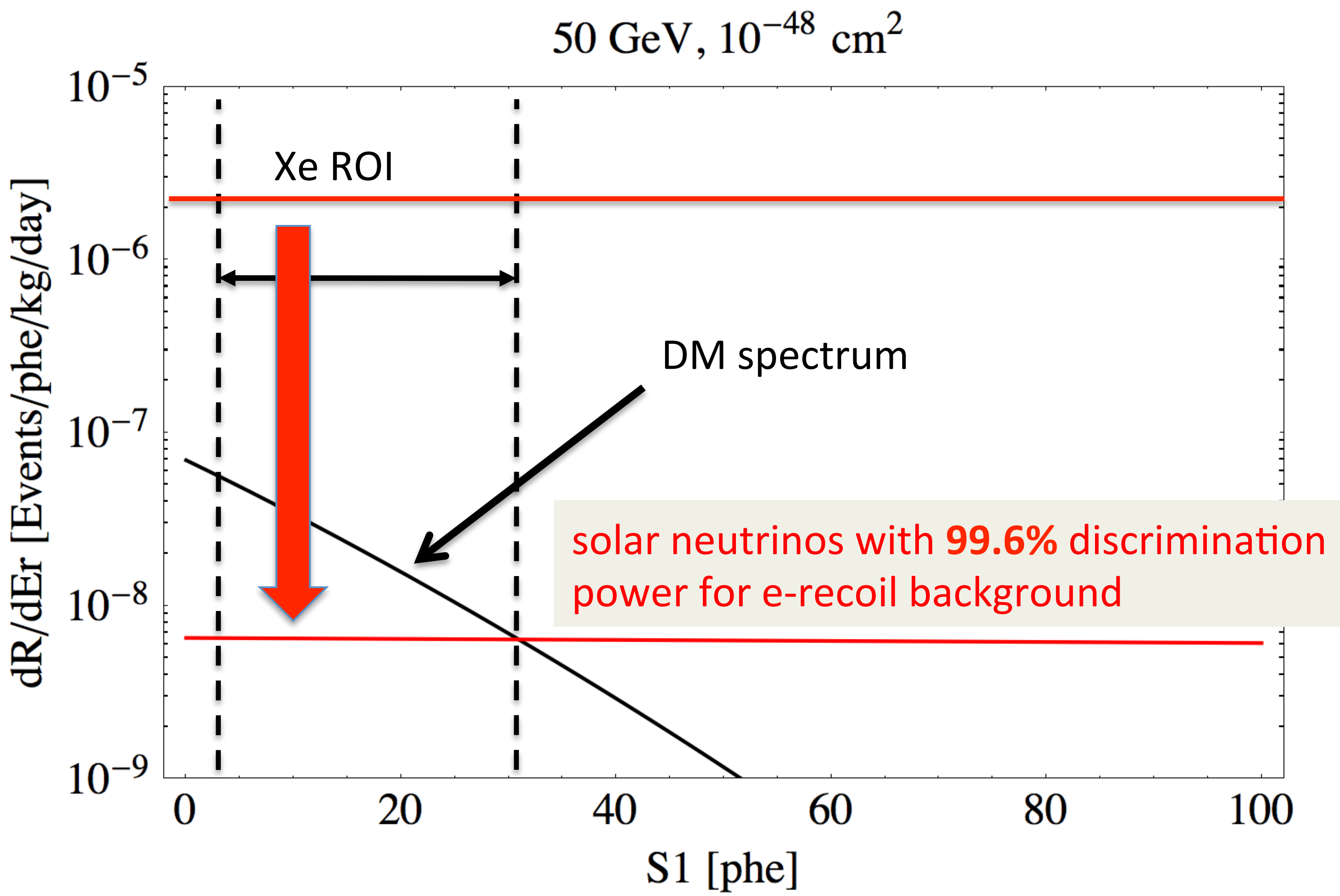
0.3 events/kg/year in Xe for 10^{-45} cm^2 and 50 GeV/c^2

WIMPs Recoil Spectrum [2]



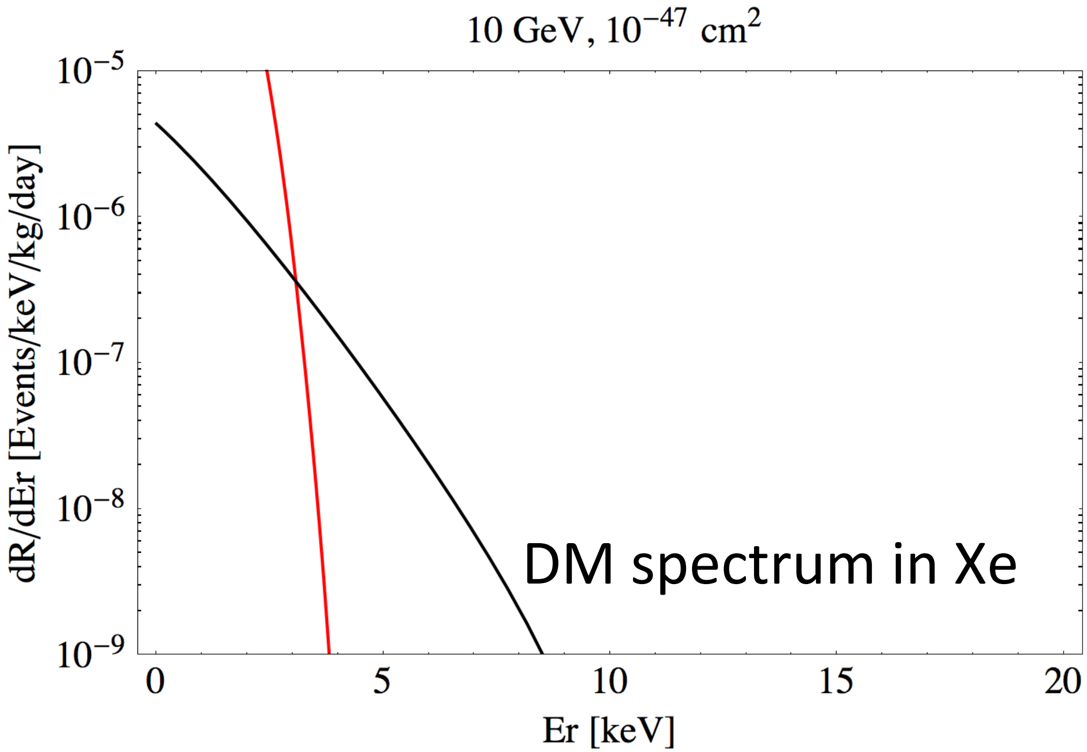
2 events/ton/year in Xe for 10^{-47} cm^2 and 100 GeV/c^2

Solar Neutrinos as Background in ER channel



Solar Neutrinos Background in the NR channel

- ν-nucleus coherent scattering
  - Maximum recoil energy for ^8B neutrinos = 4.3 keV
  - Flux of ^8B ~ 6×10^6 cm^{-2}s^{-1}



China Dark Matter EXperiment (CDEX) @ CJPL

- China **Jin-Ping Laboratory** (CJPL)
  - 2400 m depth with 6 μ/m^2/month
  - 6x6x40(L) m^3 Hall in operation
  - new excavation underway
    - Four 14x14x130(L) m^3 Halls ready in 2016
- CDEX
  - 1kg Ge detector with NaI(Tl) anti-compton and muon veto
  - Next future development
    - 10/100 kg Ge detector in LN or LAr

CDEX sensitivity

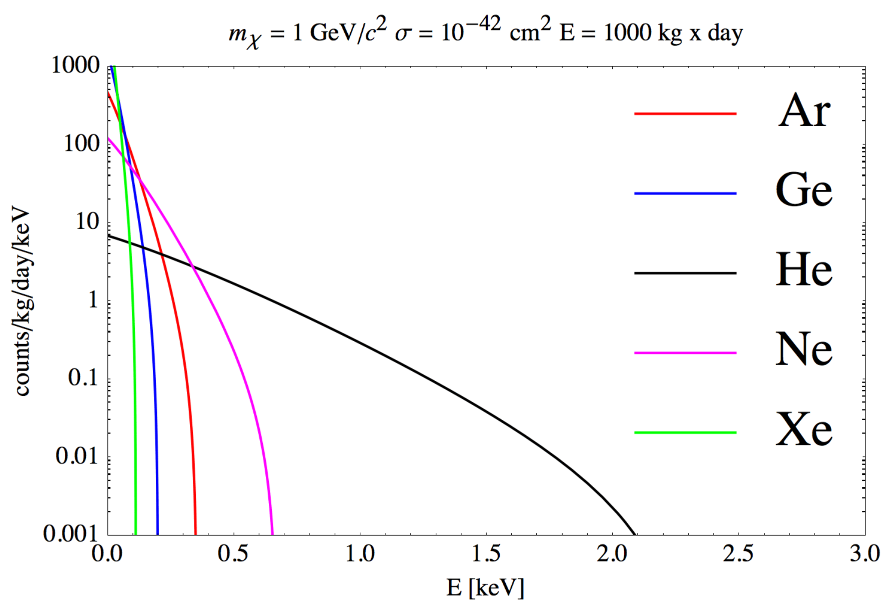
Search for **low mass WIMPs**

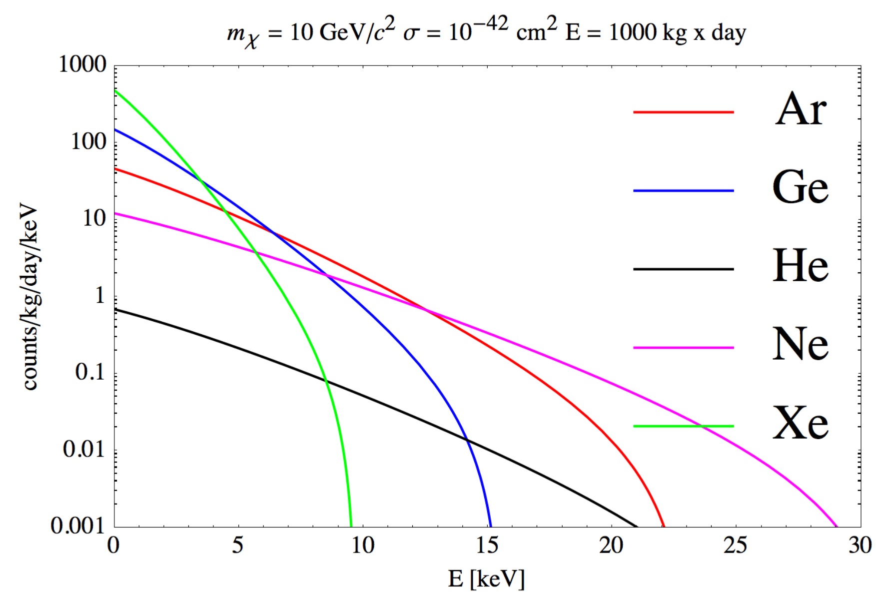
- Use background subtraction based on
  - muon veto + very low muon flux at CJPL
  - anti-compton veto
  - PSD to reject surface background from pulse timing amplitude features

- Sensitivity
  - CDEX-1 (current result) with threshold at 500 eV and 4 cpd/kg/keV: ~10^{-41} cm^2 @ 8 GeV/c^2
  - CDEX-1 with threshold at 100 eV and 1 cpd/kg/keV: ~$3x10^{-42}$ cm^2 @ 2-10 GeV/c^2
  - CDEX-10 with threshold at 100 eV and 0.1 cpd/kg/keV: ~$3x10^{-43}$ cm^2 @ 2-10 GeV/c^2
  - CDEX-1000 with threshold at 100 eV and 0.01 cpd/kg/keV: ~10^{-44} cm^2 @ 8 GeV/c^2
    - Implies underground Ge growth

Very Low Mass WIMPs

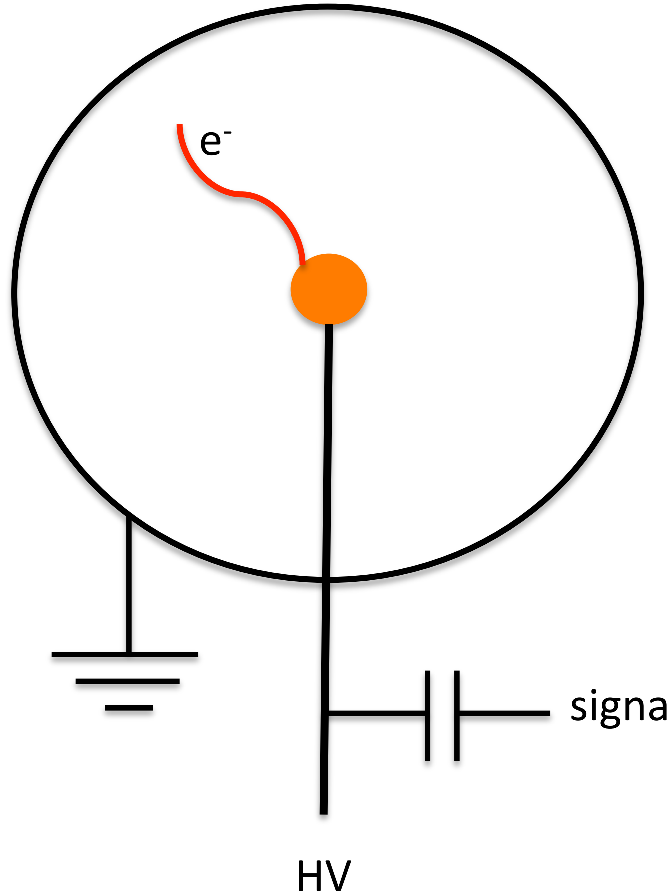
- Spherical TPC for very low mass WIMPs
  - Goal: search for WIMPs in the range 0.1 – 5 GeV/c^2
- Detector: spherical TPC with light target nuclei (He, Ne)
- Original idea: I. Giomataris (JINST 3,2008) and SEDINE detector at LSM





The NEWS-SNO project

- Based on the idea of a Spherical Gas Detector
- Large spherical cavity in ultrapure Cu on ground potential
- Small number of materials: high radiopurity
- Sphere inside Water Tank
- Small spherical sensor at high voltage (> 1kV)
  - 10 bar operating pressure
  - << 1keV thereshold (tested with ^{37}Ar at 260 eV)
  - Ionization with drift of charge toward the center and amplification of signal close to detector
  - Diffusion time and risetime distribution allows PSD between ER and NR



Liquid Noble Gases Detectors

- **Single phase** (XMASS, DEAP, …)
  - 4π geometry for high light collection
  - Prompt, S1, signal + PSD

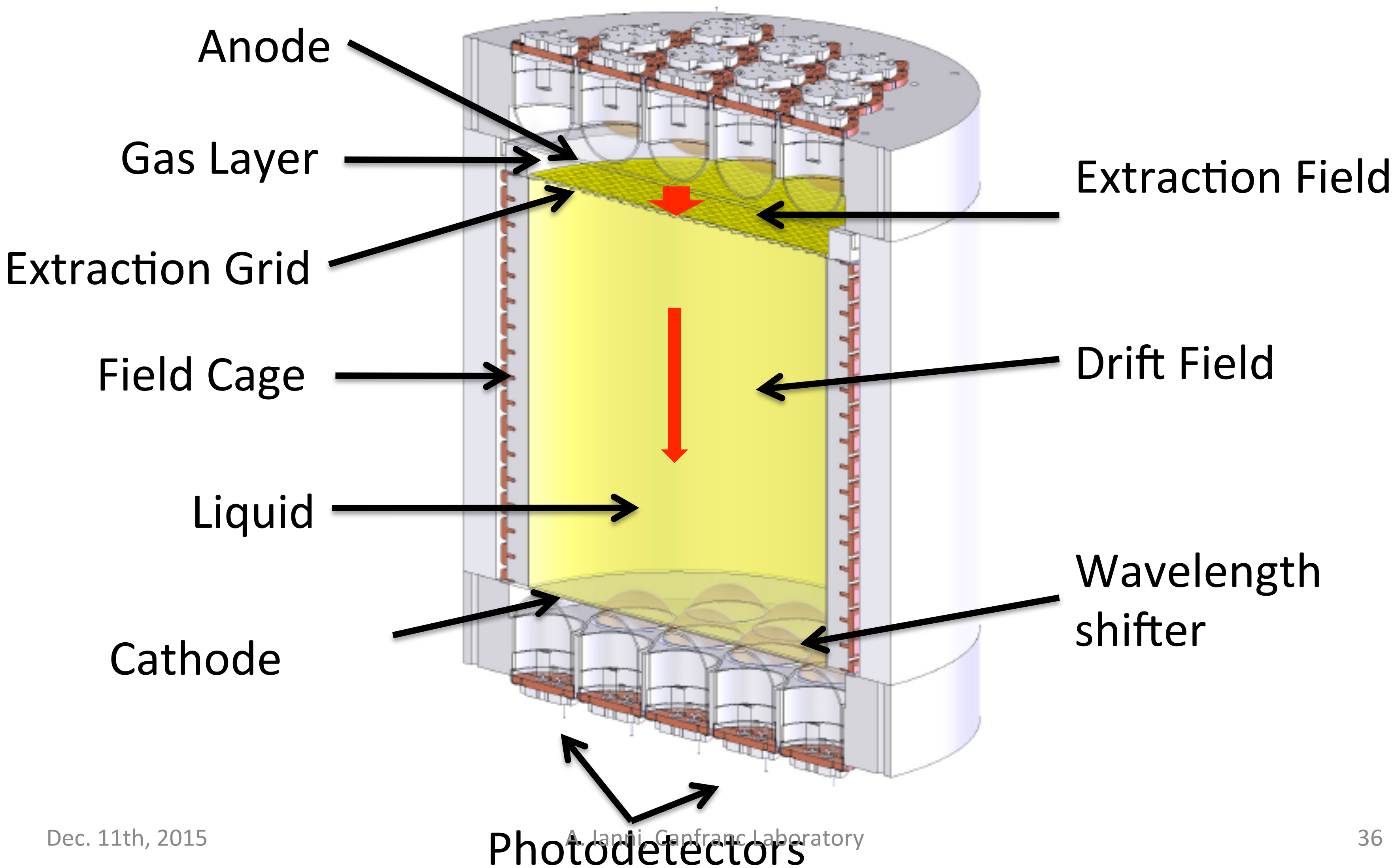
- **Two-phase** (Xe1t, LUX, ArDM, DarkSide …)
  - Cylindrical geometry with a TPC
  - Prompt, S1, and delayed, S2, signals + PSD

- Locate cryostat inside a Water Cherenkov muon veto with passive or active neutron shielding/ veto

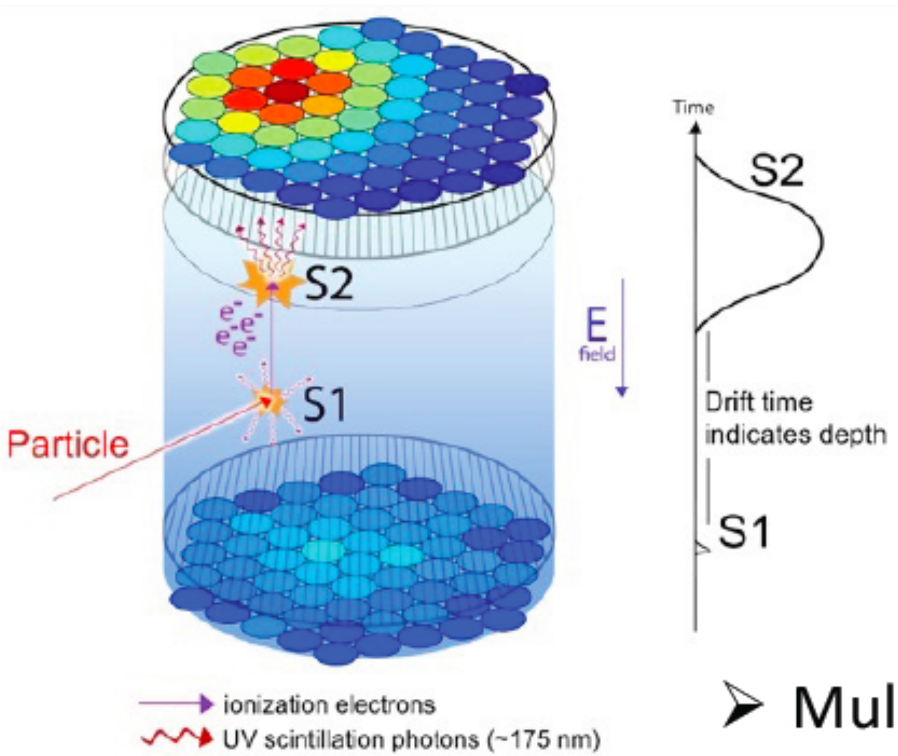
Argon and Xenon Complementarity

- Ar spin-independent interaction
- Xe also spin-dependent
  - ^{129}Xe (J=1/2, 26.2%) and ^{131}Xe (J=3/2, 21.8%)
- Xe more sensitive at lower masses
- Ar more sensitive at greater masses

Double-Phase TPC



Two-phase LXe TPC



- Primary scintillation light ("S1") at the particle - Liquid Xe interaction vertex
- Electrons extracted from the interaction drifted by electric field to the surface and into the Gas Xe. Proportional scintillation light ("S2")

➢ Multiple scatter event identification (via S2)
➢ 3-D localisation of each vertex (via S1 and S2)
➢ ER/NR discrimination (via S2/S1)
➢ Sensitivity to single electrons (S2)

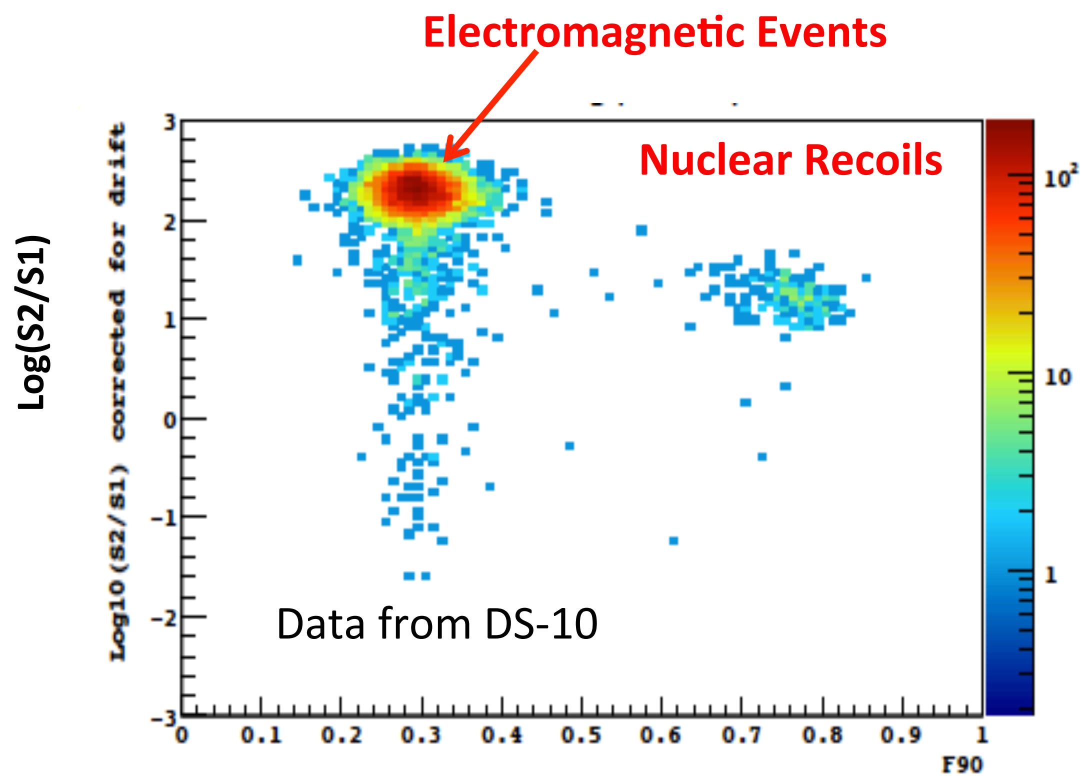
P. Beltrame

Two-phase TPC at Work: figure-of-merit for background discrimination

Background reduction performed by exploiting

a) Pulse shape of S1 through a parameter which measures the fraction of fast to slow component in scintillation.
F90 = Int_S1(<90ns) / Int_S1(all)

b) S2/S1: larger for e-like

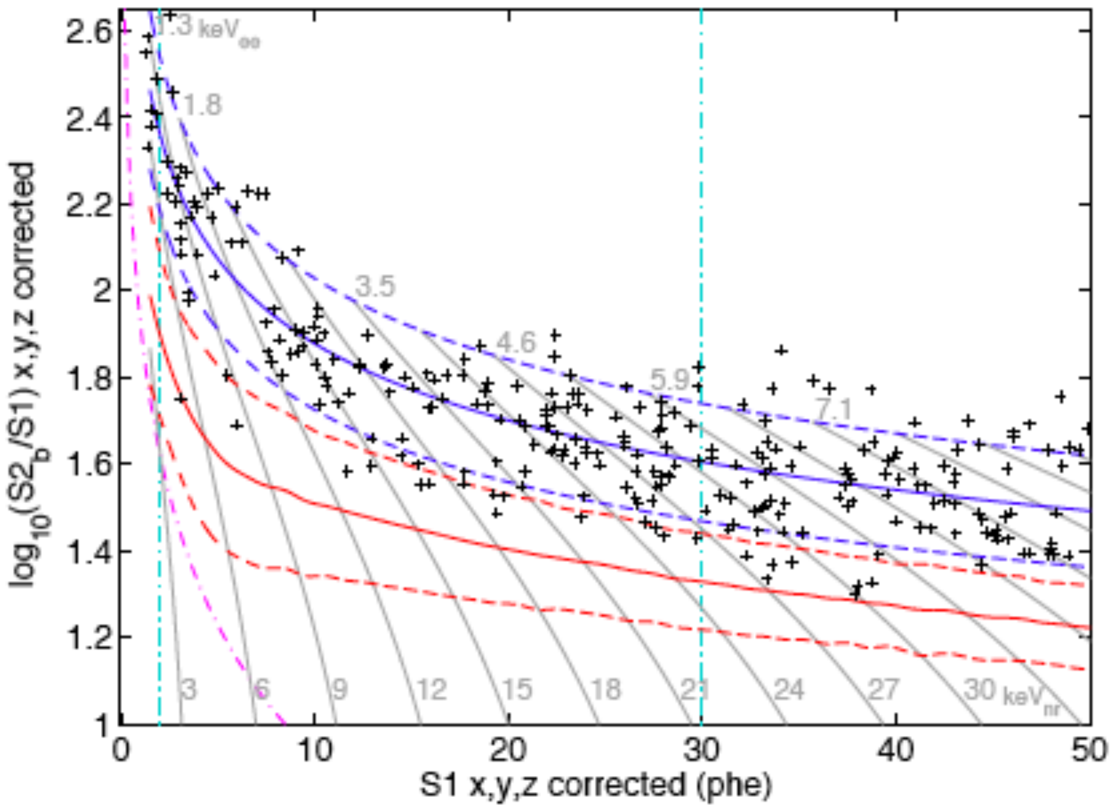


LXe program on DM

- **LUX @ Homestake**
  - 250 kg dual-phase LXe TPC with two 61-array PMTs in Water Tank
  - 85.3 days and 118.3 kg exposure
  - 2-30 phe window
  - 8.8 phe/keVee yield at null field for 122 keV gamma-ray
  - No events observed with 50% NR acceptance and 0.64±0.16 events of ER background
  - Best limit on WIMP spin-independend search (**7.6×10^{-46} cm^2 at 33 GeV/c^2**)
  - LUX will turn into **LUX-ZEPLIN** (> 2018) with 7 tons LXe and **Gd-loaded LS**
- **XENON1t @ Gran Sasso**
  - Under construction at LNGS
  - 3.5ton LXe in Water Tank in total for projected sensitivity at ~ 10^{-47} cm^2
  - Based on success of XENON100 with 225days × 34kg
- **XMASS @ Kamioka**
  - 835 kg (100 kg fiducial) single-phase in Water Tank
  - First commissioning with unexpected background
  - Under refurbishment

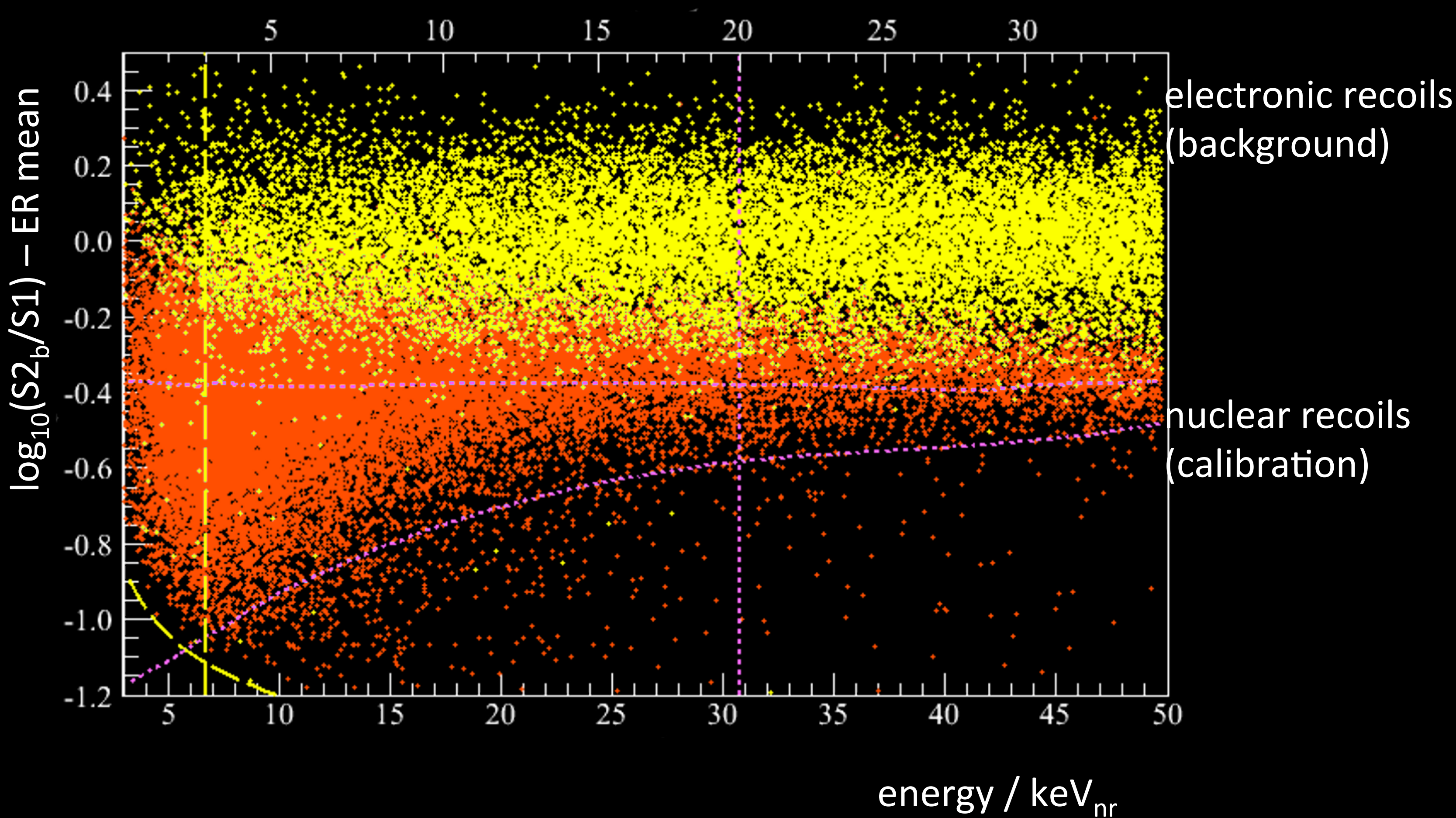
LUX 2013 results

- 118 kg and 85.3 days



Discrimination using S2/S1 in XENON100

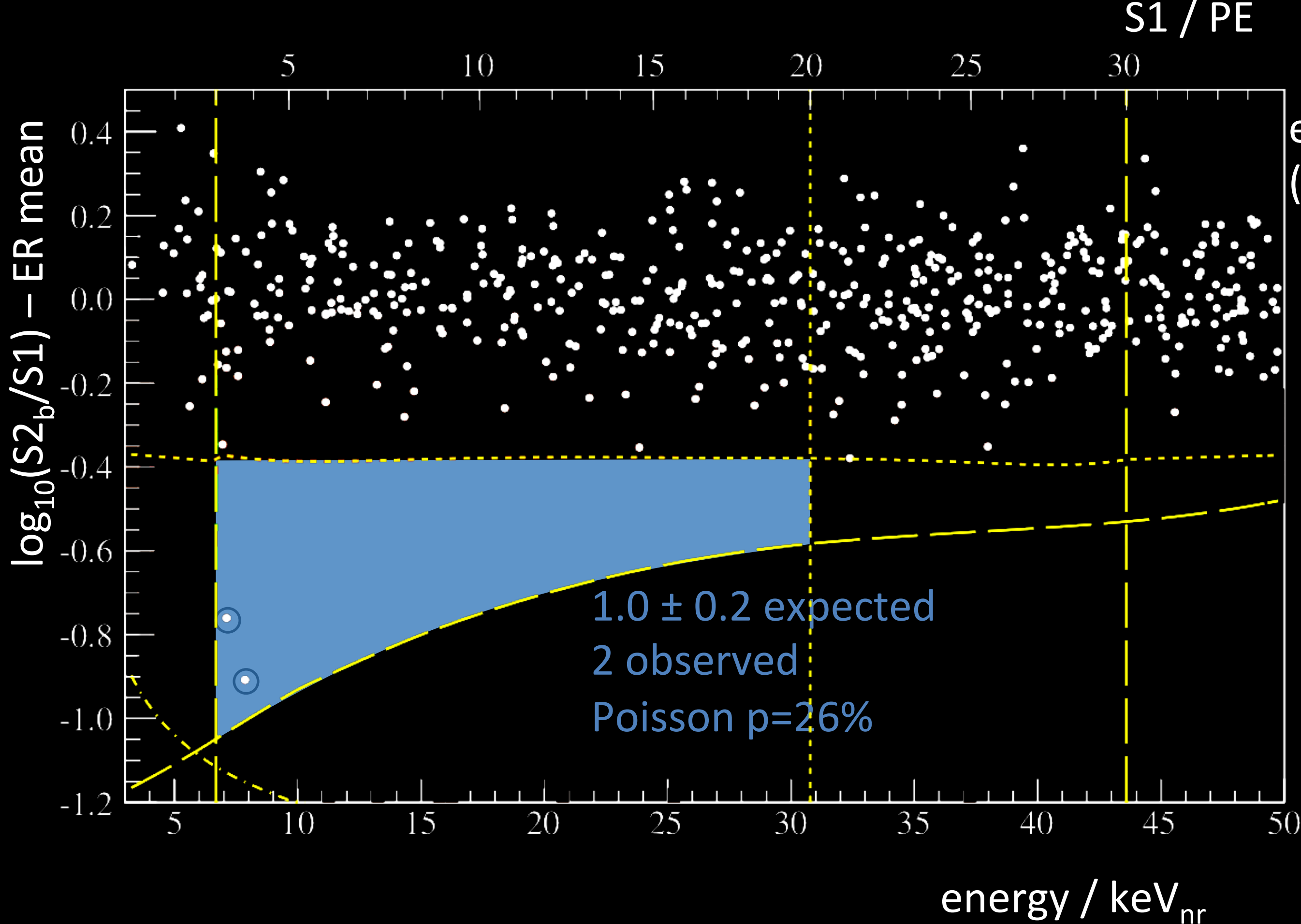
^{60}Co, ^{232}Th and ^{241}AmBe calibration



99.5% ER rejection @ 50% NR acceptance

XENON100: No Signal Observed

225 live days, 34kg fiducial:

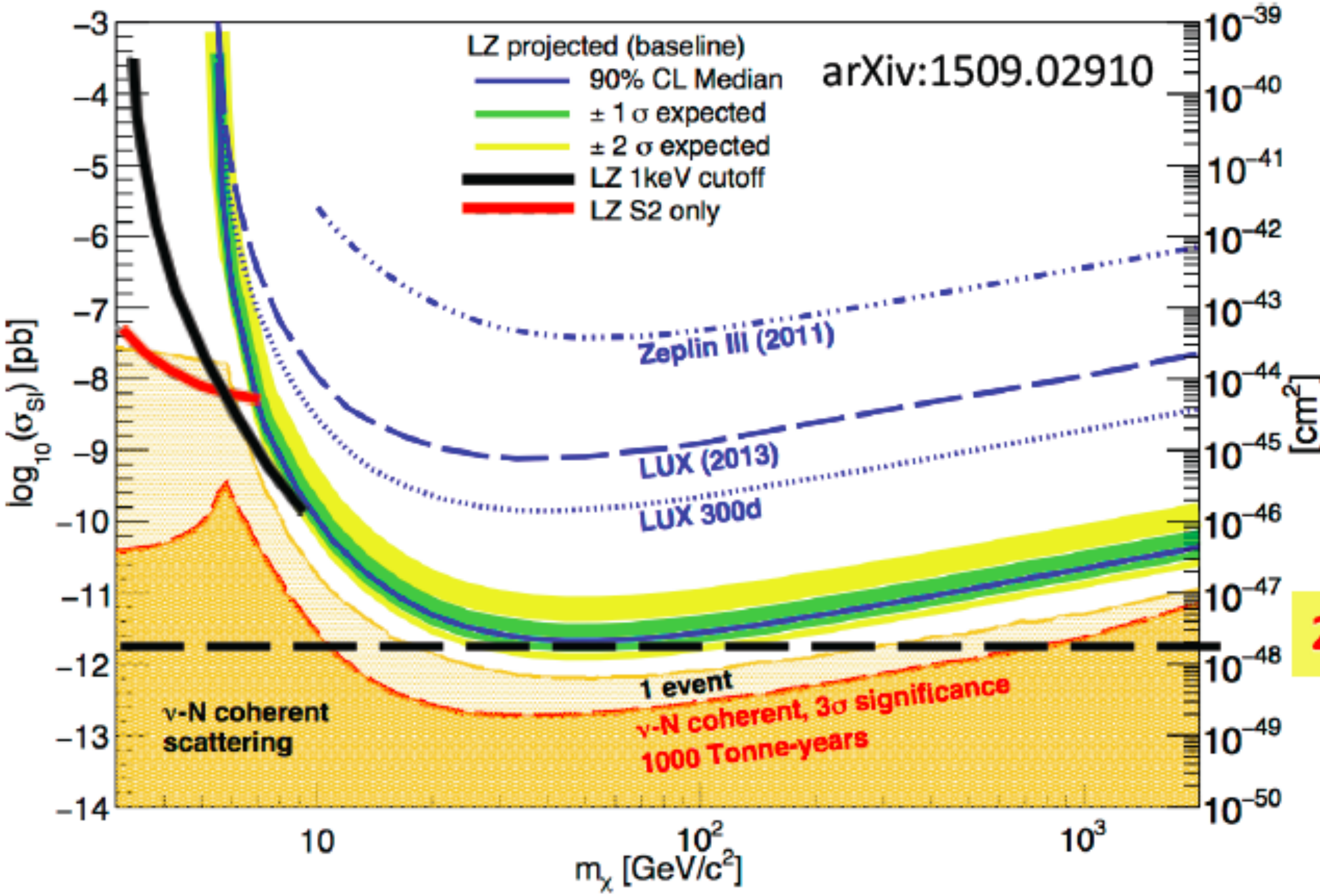


electronic recoils (background)

likelihood analysis: background-only p-value

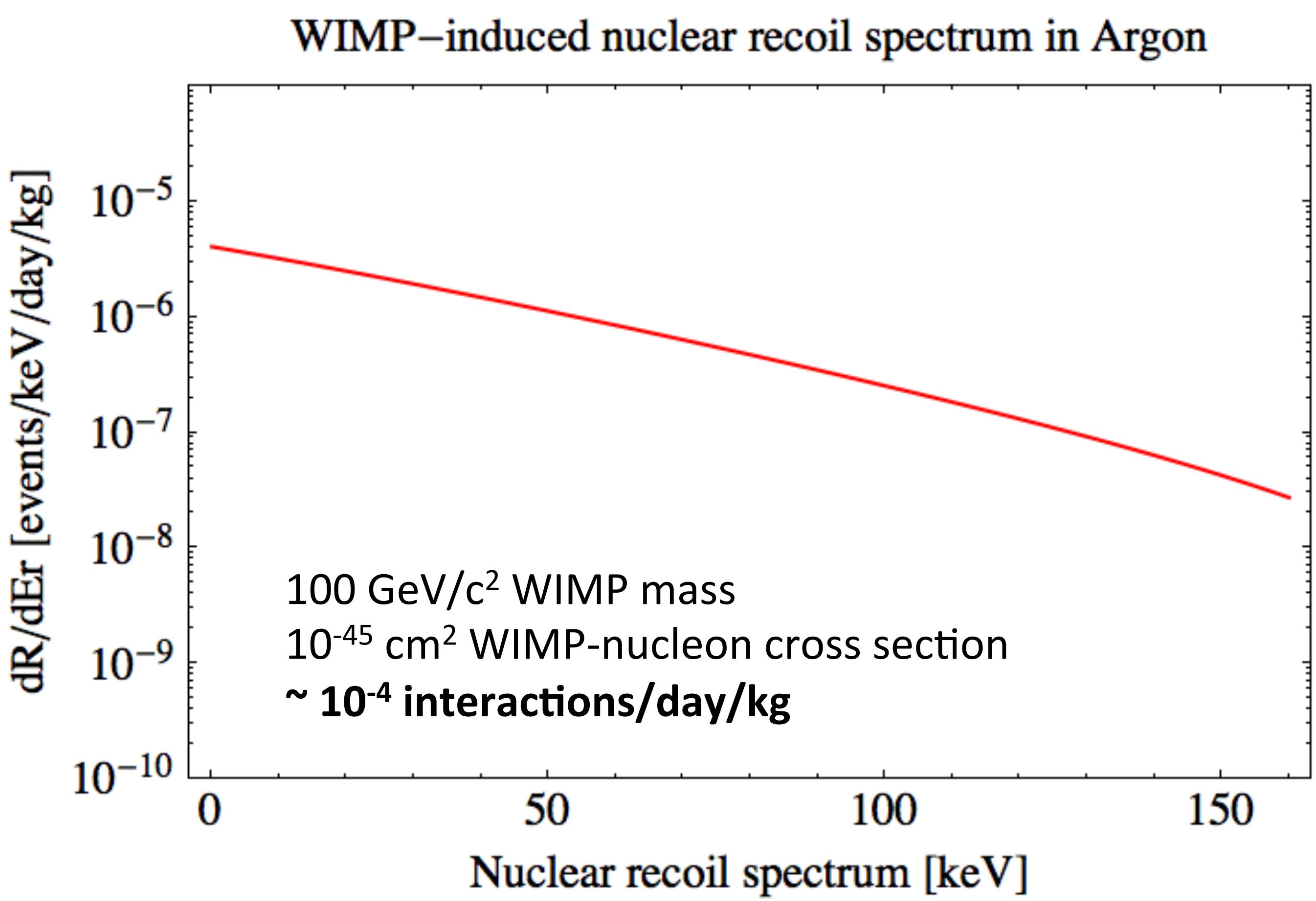
arXiv:1207.5988

Ultimate goal with LXe



2×10^{-48} cm^2

Expected WIMPs Signal in LAr

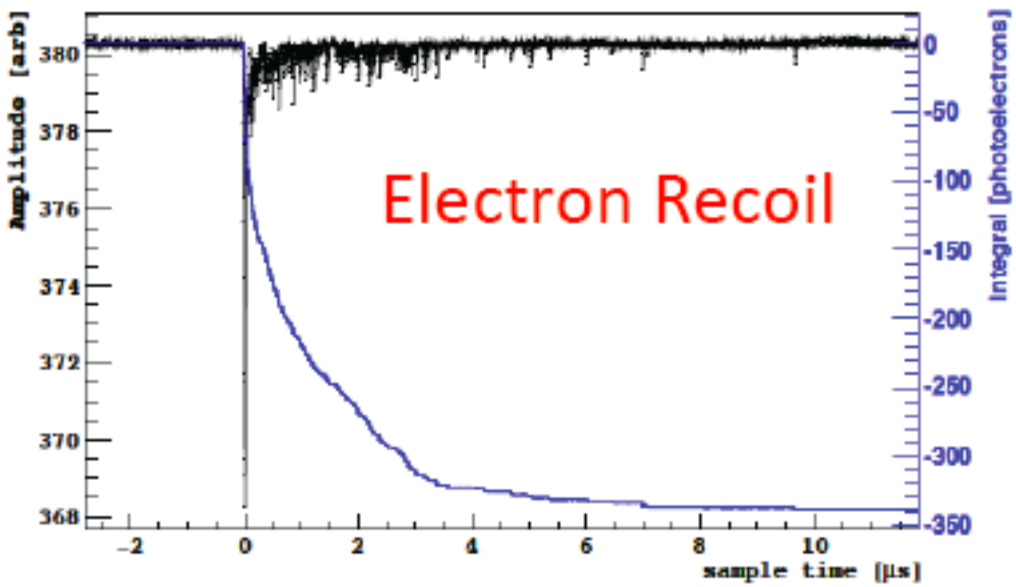


Exposure of 1 ton-year gives about 40 events with these assumptions
Exposure of 50 kg x 3 years gives about 5 events

The problem of ^{39}Ar

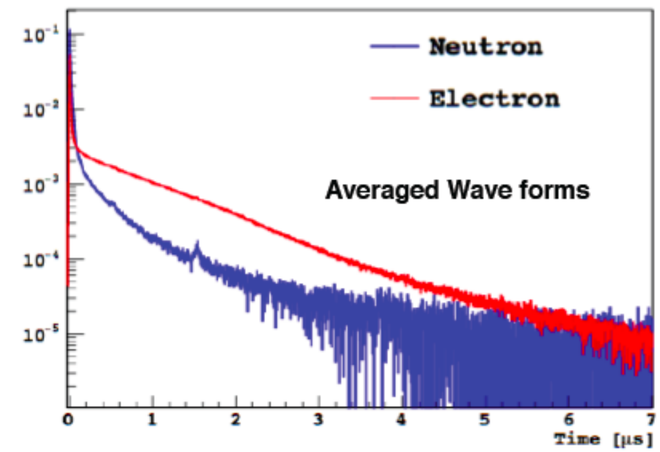
- Ar is naturally present in the atmosphere at 1% level
- Atmospheric Ar contains ^{39}Ar which is formed by cosmic muon interactions
  - $^{40}Ar(n,2n)^{39}Ar$
- ^{39}Ar is a β decay emitter with Q_{β}=565 keV and $T_{1/2}$=269 years
- ^{39}Ar is at the level of 1 Bq/kg
  - ~ 9×10^{4} decays/kg/day
  - WIMPs(100GeV, 10^{-45} cm^{2}) ~ 10^{-4} events/kg/day

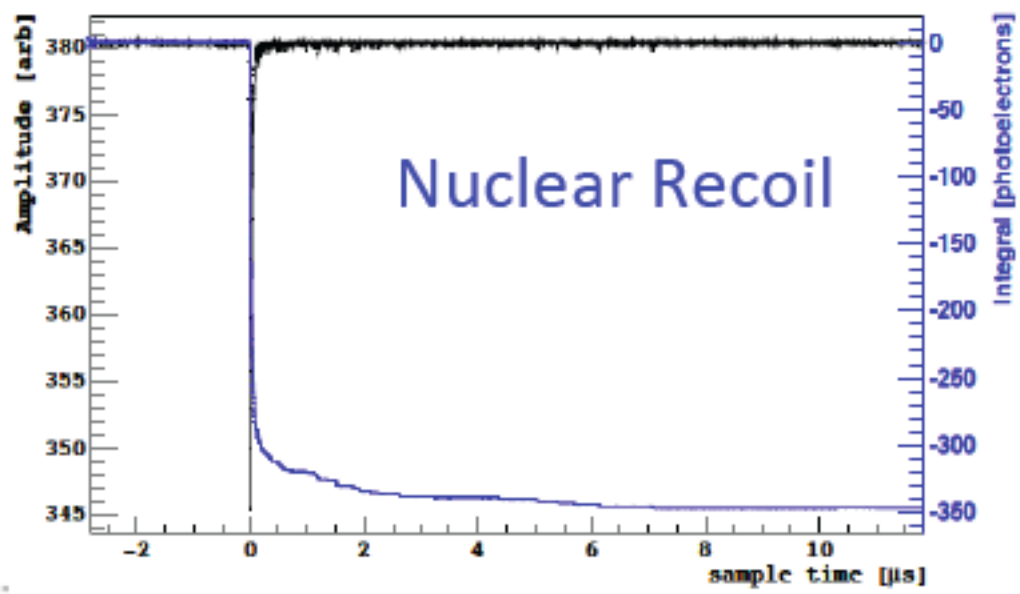
Pulse Shape Discrimination in LAr

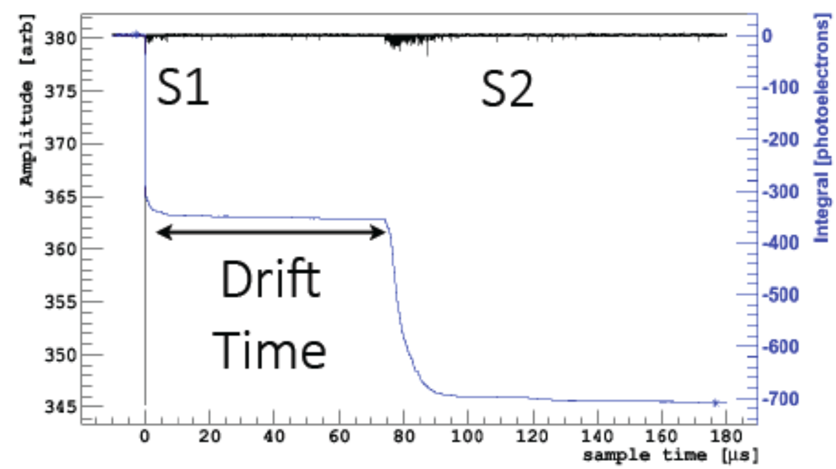


$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1500$ ns







Pulse Shape Discrimination in LAr

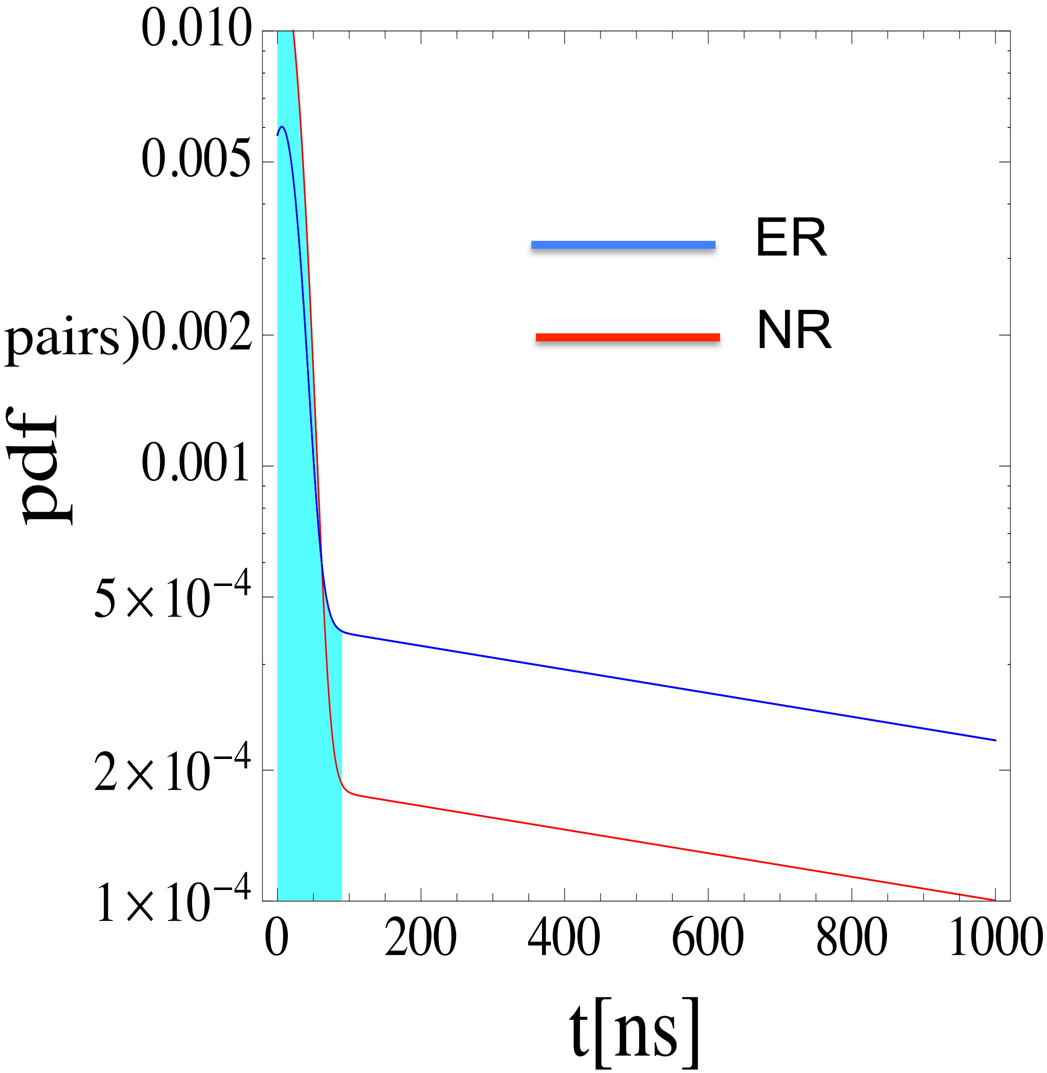
$$f(t) = \left(\frac{q}{\tau_F} e^{-t/\tau_F} + \frac{1-q}{\tau_S} e^{-t/\tau_S} \right)$$

$$\tau_F = 6ns$$

$$\tau_S = 1600ns$$

$$q = \begin{cases} 0.3 \text{ ER (low density e-ion pairs)} \\ 0.7 \text{ NR} \end{cases}$$

$$f_{90} = \frac{\int_0^{90ns} dt\, f(t)}{\int_0^{\infty} dt\, f(t)} = \begin{cases} 0.3 \text{ ER} \\ 0.7 \text{ NR} \end{cases}$$



Underground Argon

- ^{40}Ar produced from ^{40}K
- The Earth is reach in ^{40}K in underground
- ^{40}Ar moves into the atmosphere and makes ^{39}Ar with muons interactions
- Underground Ar is expected to be much less contaminated in ^{39}Ar, due to the lower muon flux
- However, ^{39}Ar underground can be produced by radiogenic neutrons interactions
  - $^{39}K(n,p)^{39}Ar$
- **Recipe**: go deep underground where surrounding rocks are poor in U and Th

Underground Argon

- In exhaust stream gas (CO_2) of commercial mining facilities Ar at 400-600ppm level
  - In DS extraction site: CO_2 plant output, CO_2(96%)+N_2(2.4%)+He(0.4%)+Ar(0.06%)

- Make on-site preconcentration to ~40,000ppm, then cryogenic distillation at FNAL
  - After distillation: CO_2(~0)+N_2(<0.05%)+He(~0)+Ar(>99.95%)

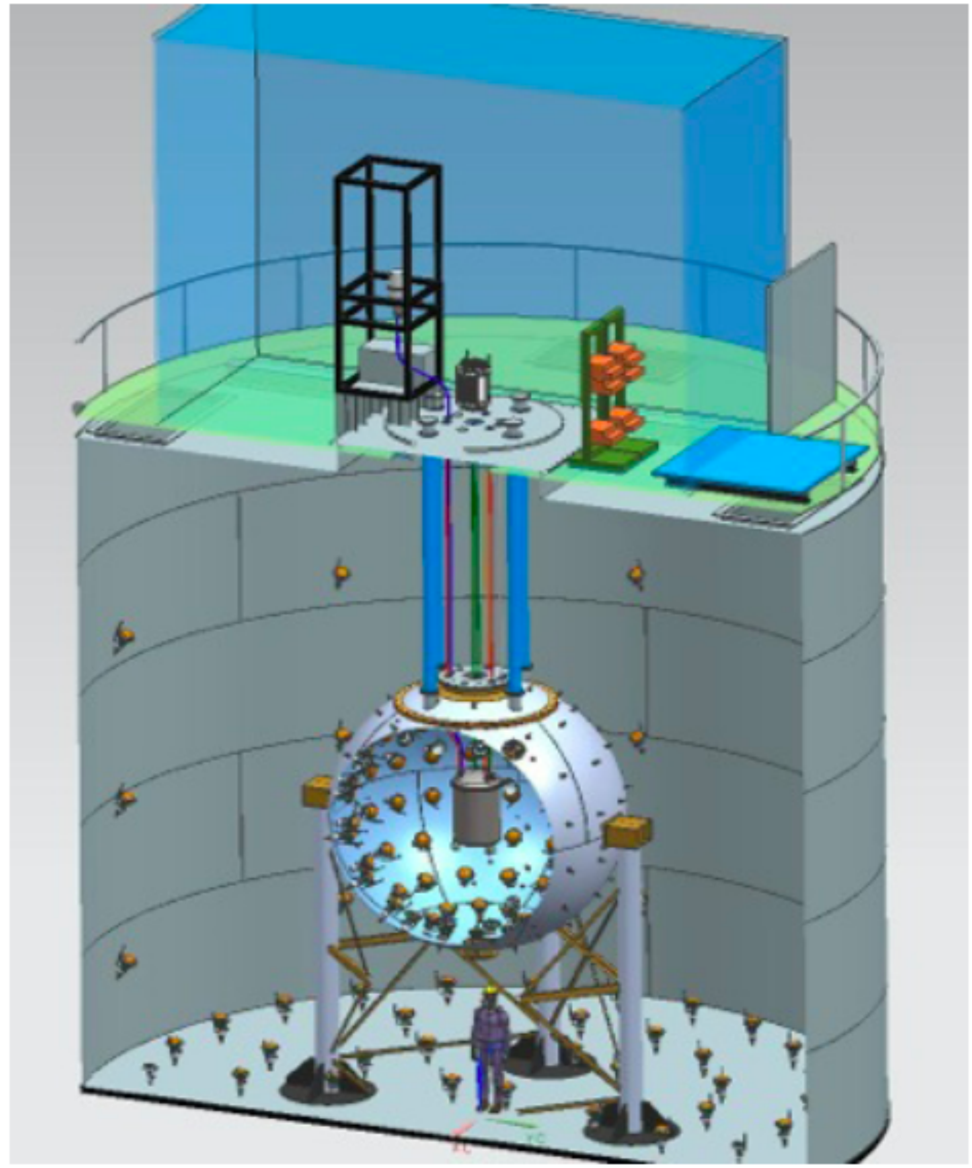
- Purified depleted argon produced at 1 kg/day

- ^{39}Ar depleted at <0.6% level wrt atmospheric level
  - ~500 decays/kg/day
  - For WIMPs ~ 10^{-4} interactions/kg/day

- Use LAr scintillation properties to perform background reduction
  - Prompt signal PSD shows: 90% n-recoil acceptance with <10^{-5} e-recoil leakage

DarkSide-50

- **Cryostat**
  Double wall low background Stainless Steel vessel; the Internal Cryostat has the capacity of 150L;
- **Neutron Vito**
  Stainless Steel Sphere with d = 4m filled with 30t of 50%PC +50%TMB+PPO mixture.
  ***1.5m** of shielding*.
  Viewed by **110 8" PMTs**;
- **Water Tank**
  Stainless Steel cylindrical Tank (h=10m, d=11m) filled with 1000t of HPWater
  ***3m** of shielding*.
  Viewed by **80 8" PMTs**;

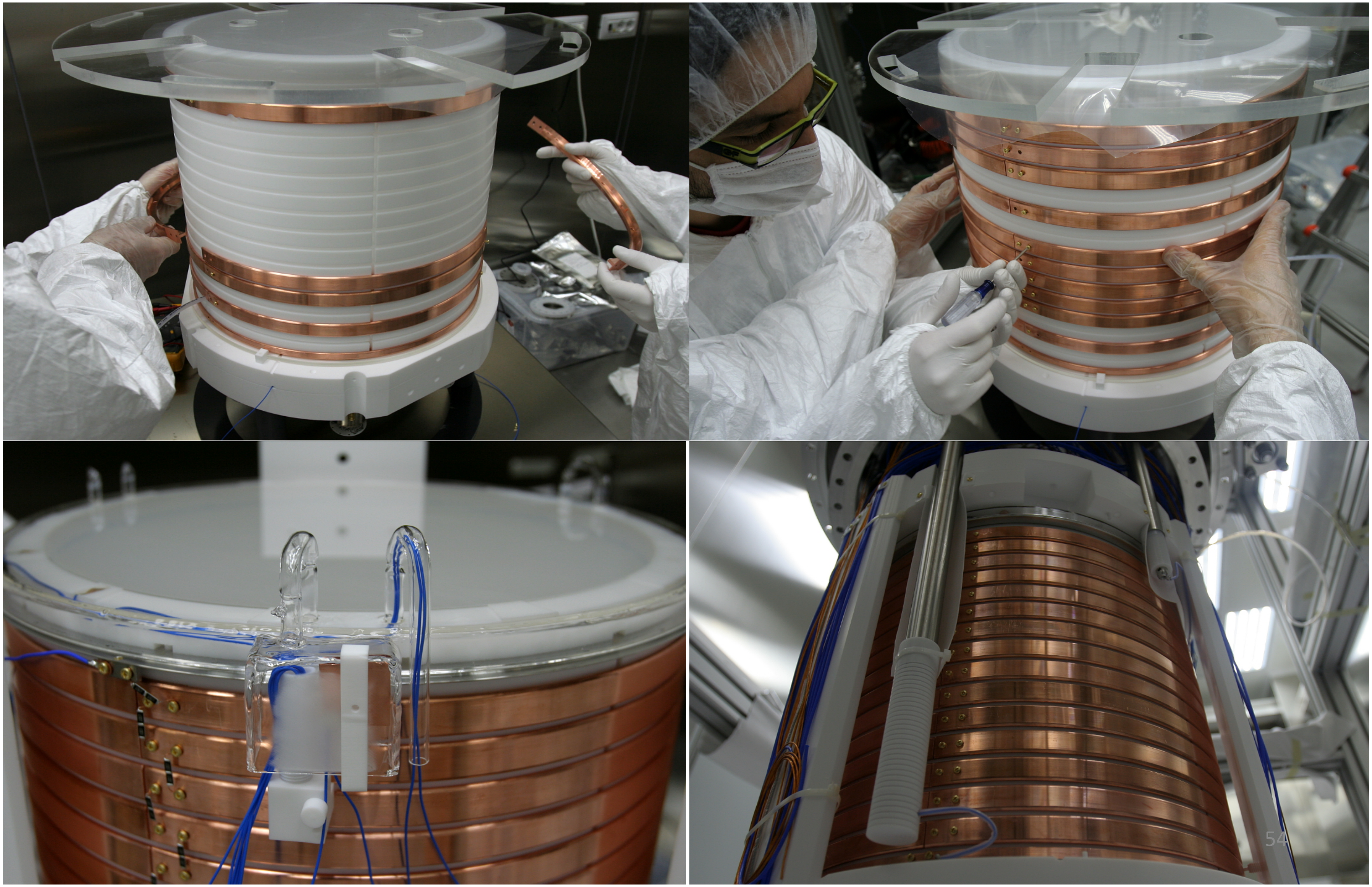


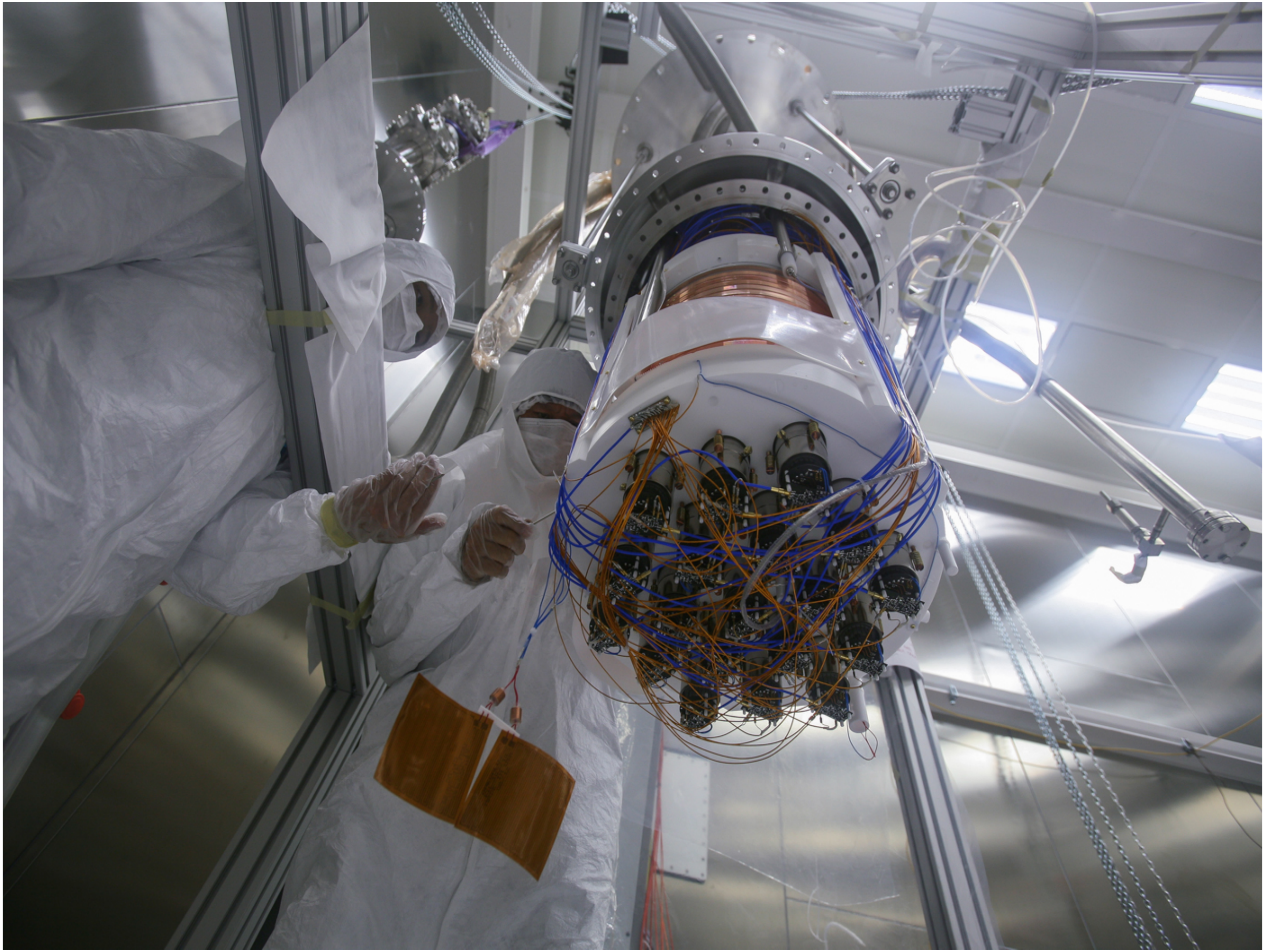

Water Cherenkov

TPC hanging in LSV

Total inventory of the devices
110 new PMTs for the neutron veto
80 old PMT from CTF for the muon veto
plus a few spares

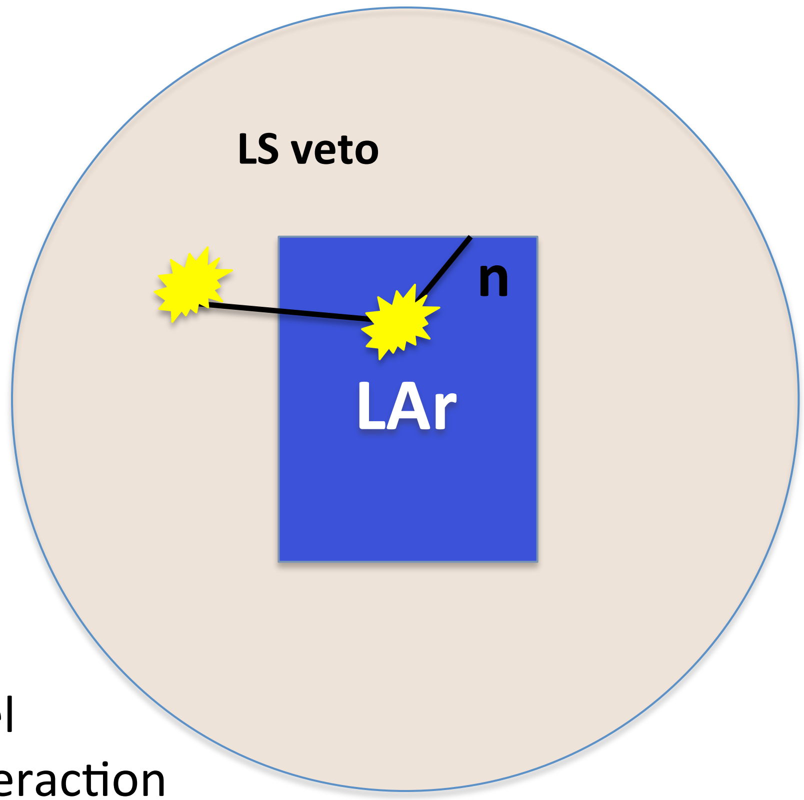
DS-50 TPC





Interior of CR1 completed

The Neutron Veto: general idea



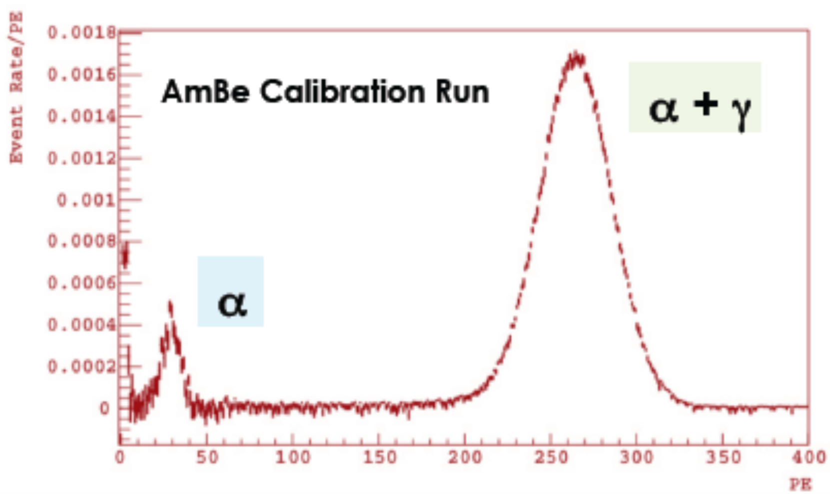
A radiogenic neutron
from the cryostat steel
or PMTs makes an interaction
in LAr (WIMP-like) and later
is captured in the LS veto.
This type of event is rejected.

The Neutron Veto in DarkSide50

n + ^{10}B → ^{7}Li (1015 keV) + α (1775 keV) (6.4%)

n + ^{10}B → $^{7}Li^{*}$ (839 keV) + α (1471 keV) (93.7%)

$^{7}Li^{*}$ → ^{7}Li + γ (478 keV)



Neutron Veto Efficiency

Efficiency from capture signal alone at > 99%
(from calibrations and simulations)

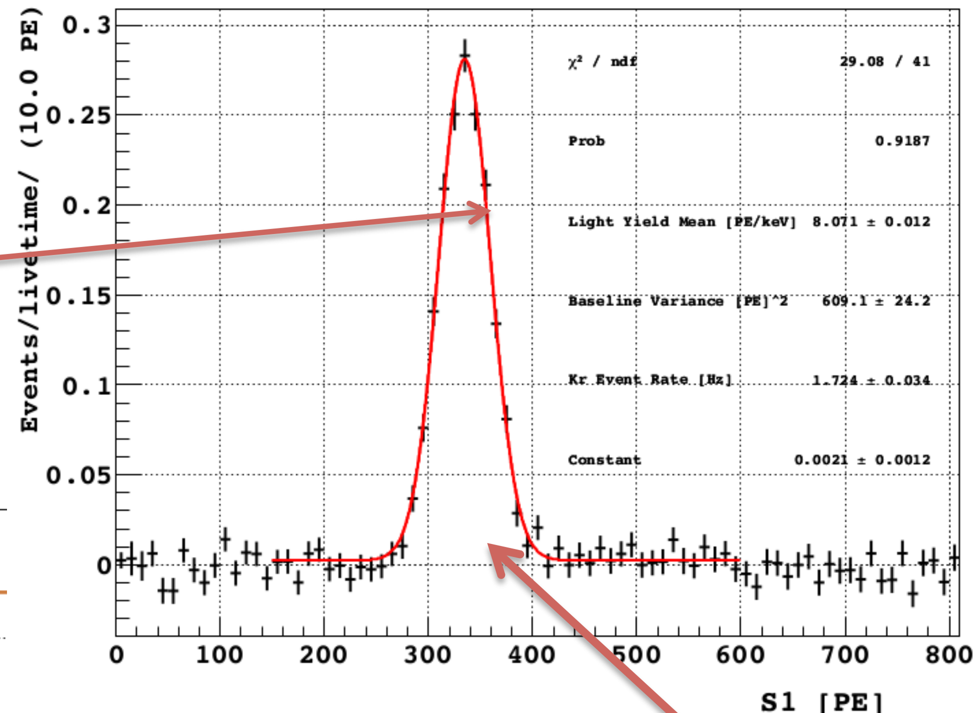
- ~0.6% of lost neutrons because of escaping proton capture gamma
- ~0.05% of neutrons leave no signal in LSV at all

Larger total efficiency due to thermalization signal

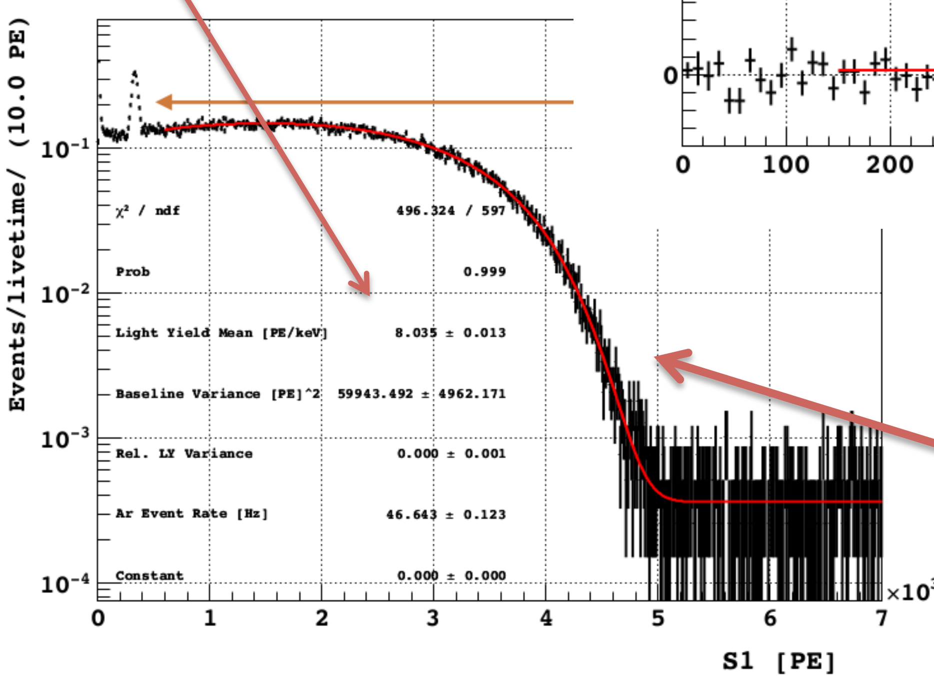
Cut at 1 PE threshold: ~0.9% acceptance loss

Light yield @ null field

Light Yield = 7.9 ± 0.4 pe/keV$_{ee}$
at **null field**

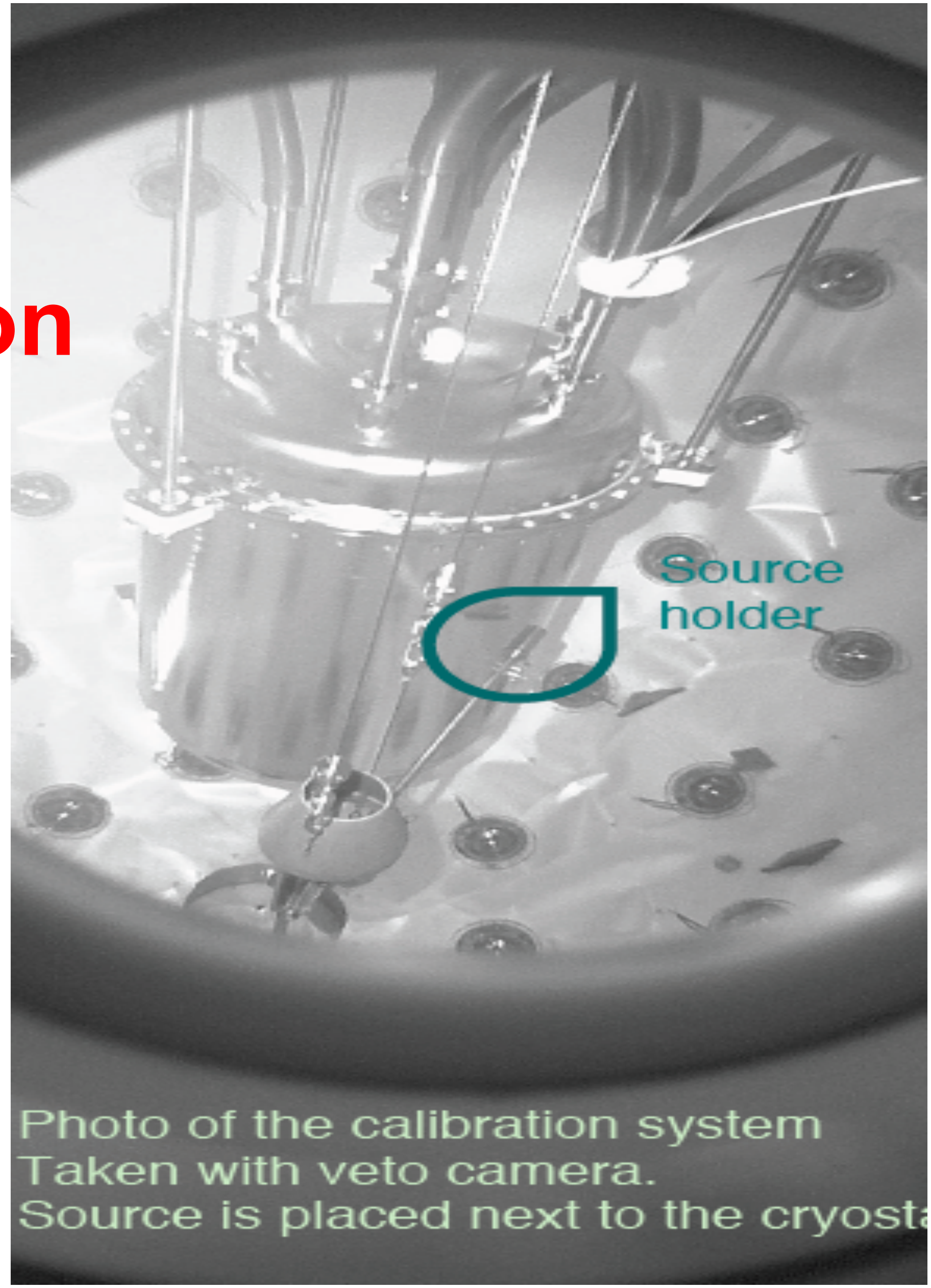


^{83m}Kr peak
41.5 keV, $T_{1/2}$=1.83h

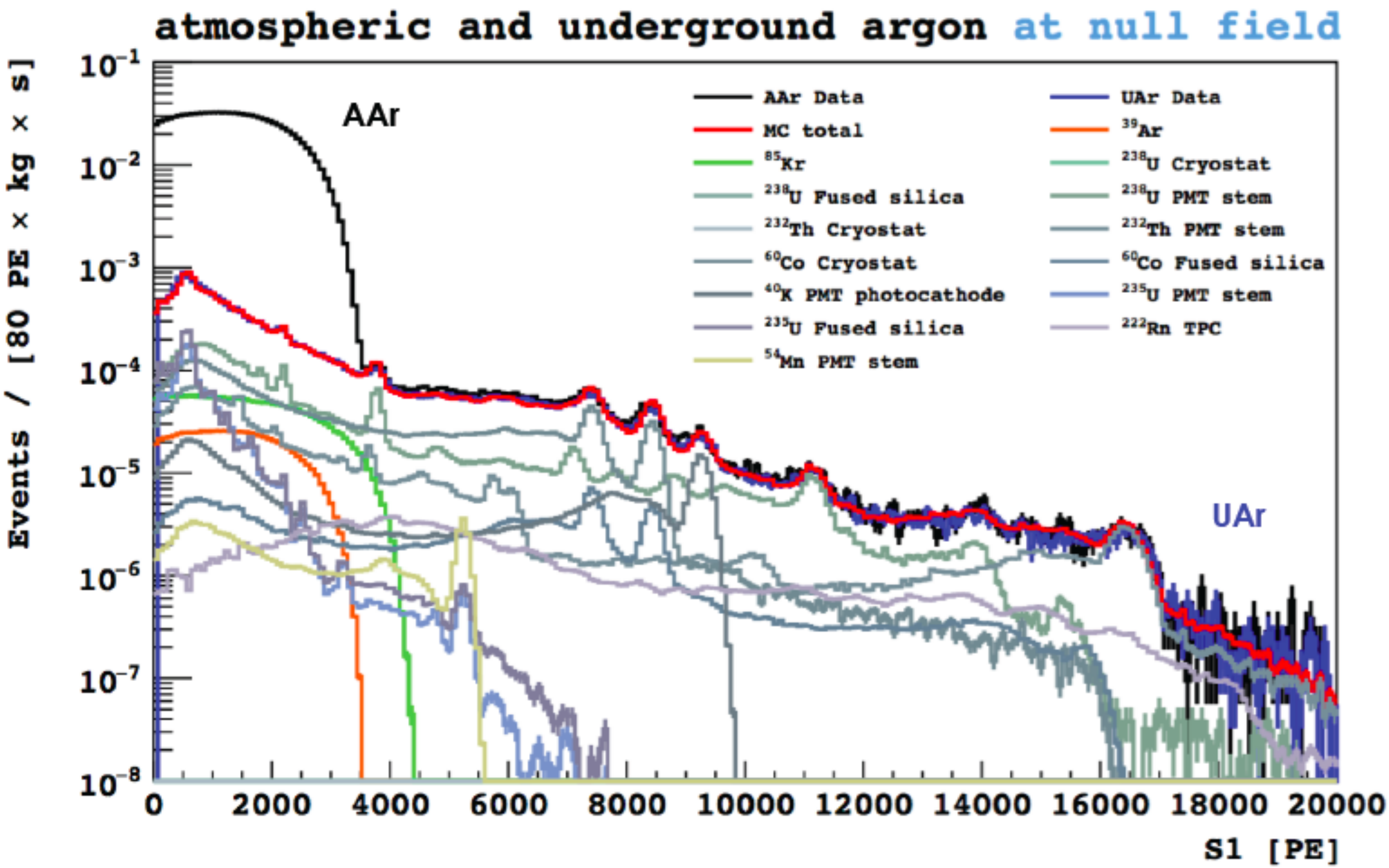


^{39}Ar spectrum
565 keV

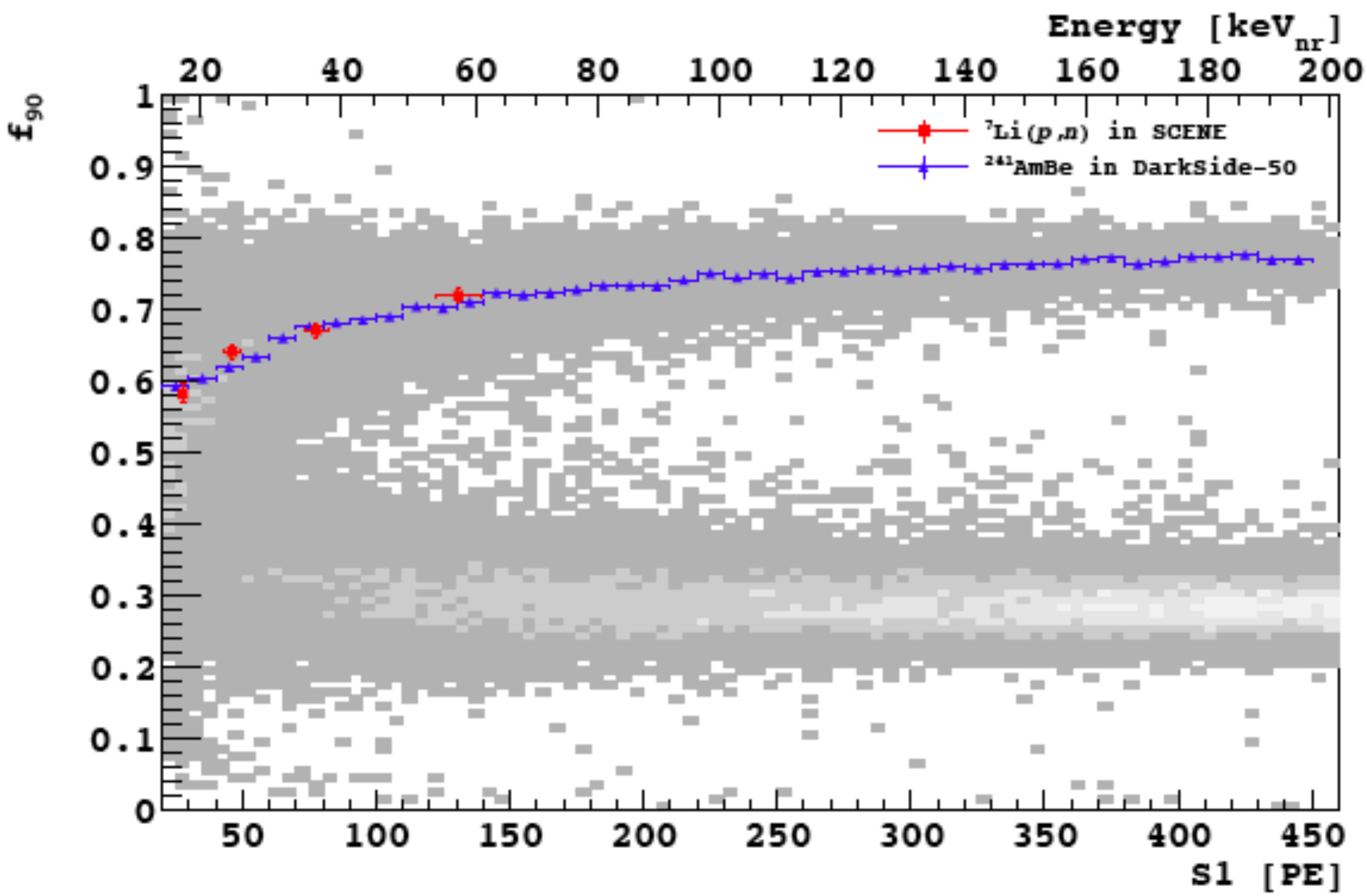
Source insertion system



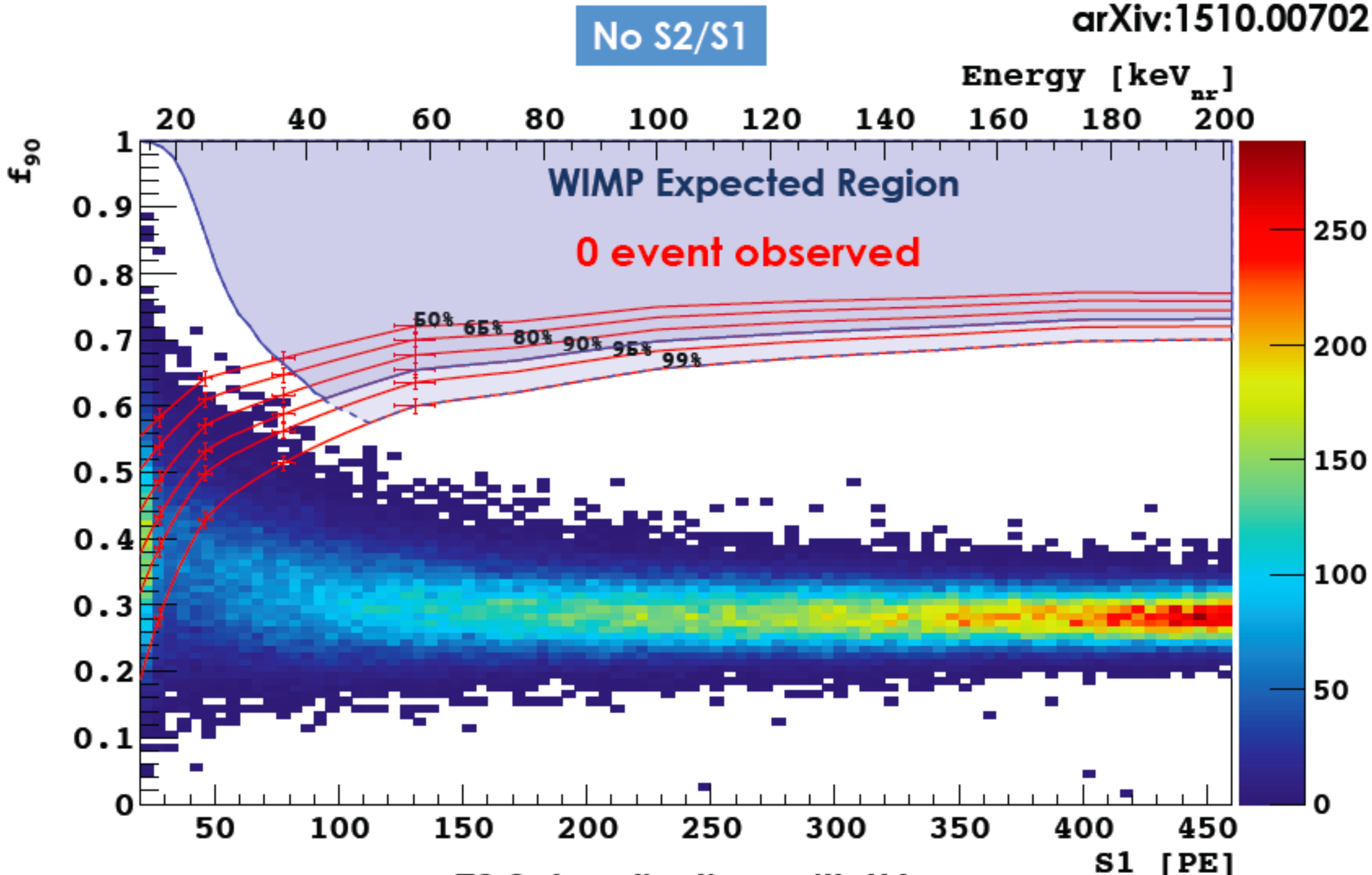
The Depleted Argon in DarkSide50



DarkSide-50 ER and NR calibrations

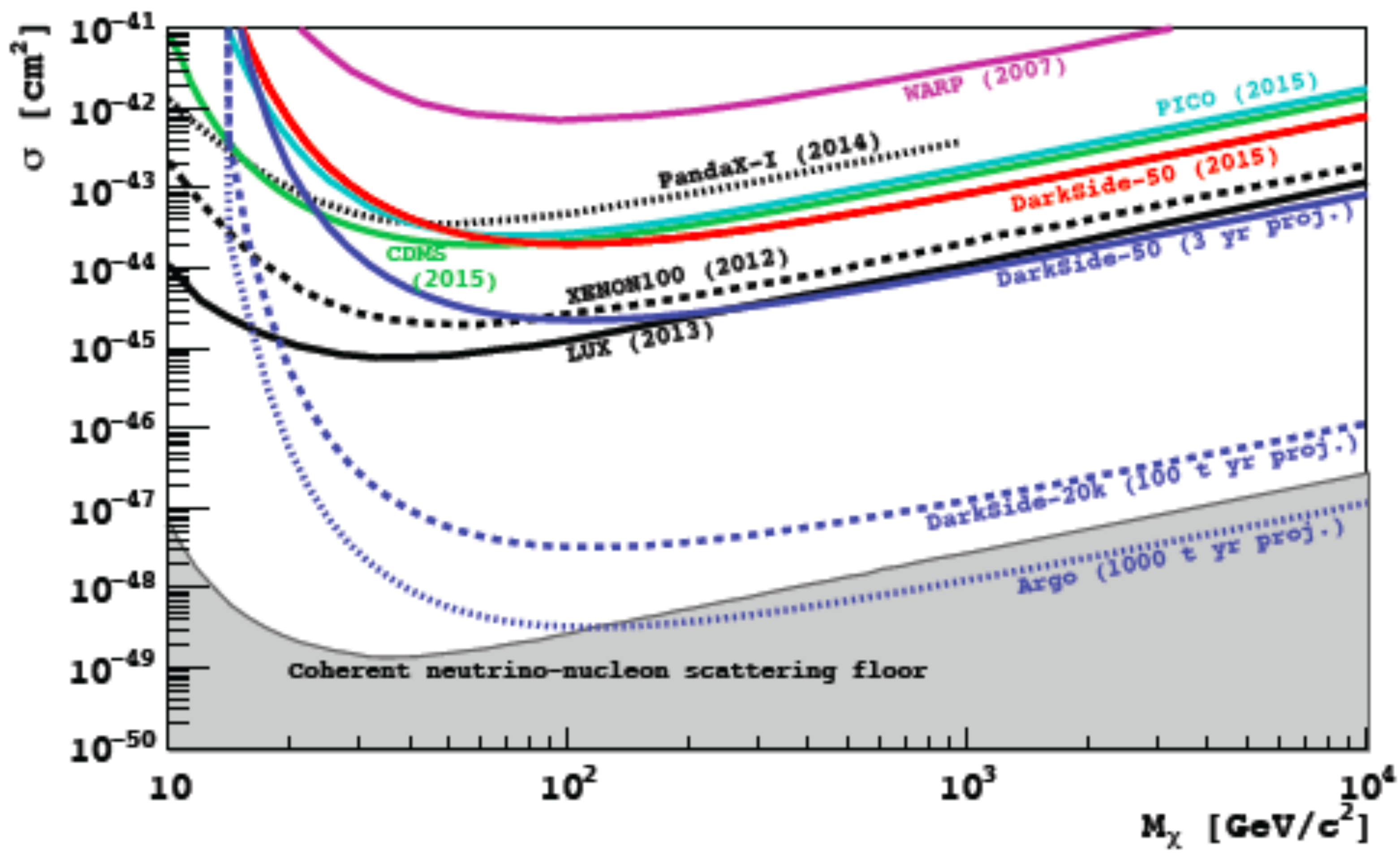


PSD in LAr TPC

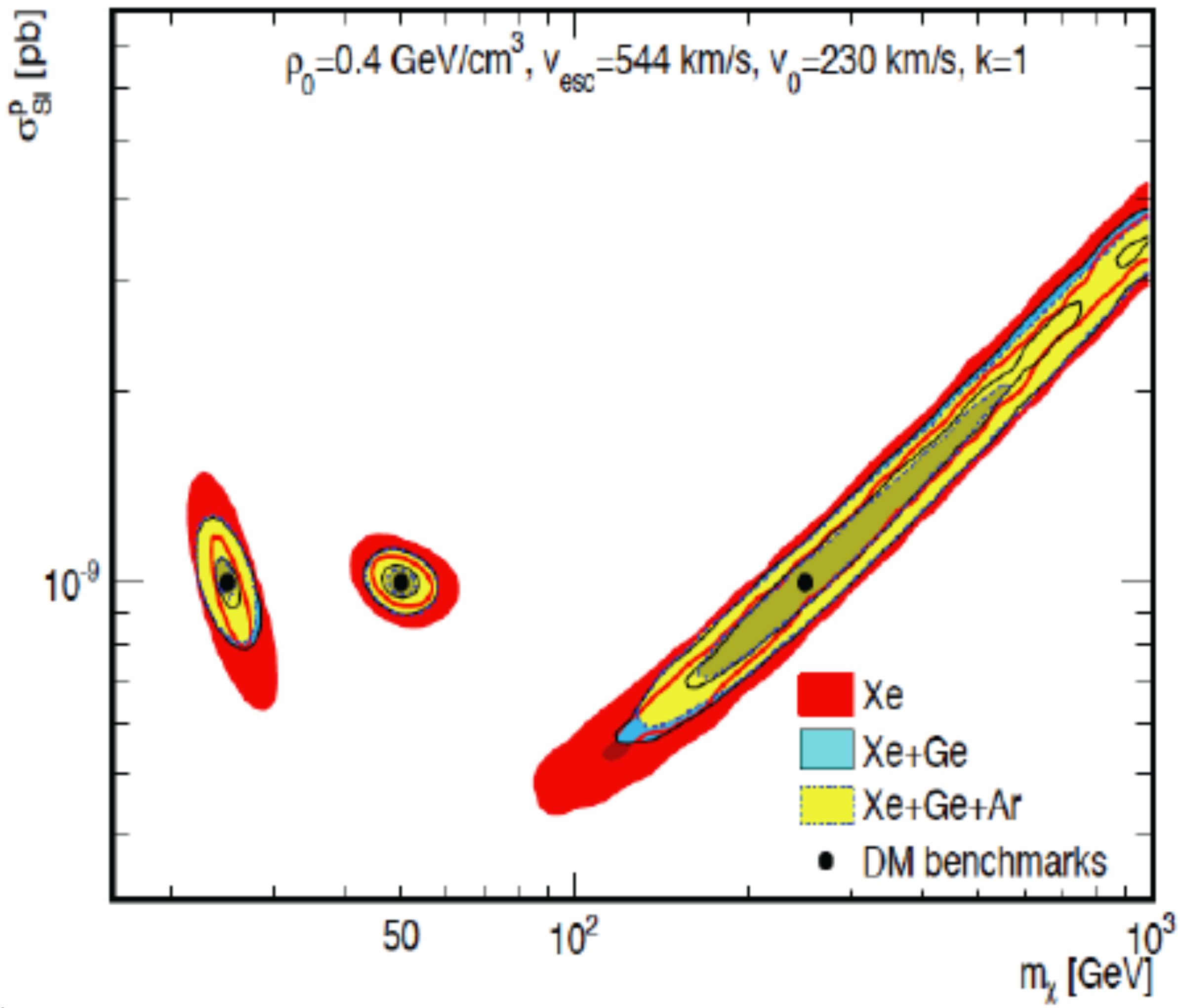


70.9 days livetime with UAr

Ultimate goal with LAr for DM



In case of discovery



Pato et al., arXiv:1012.3458

Conclusions [1]

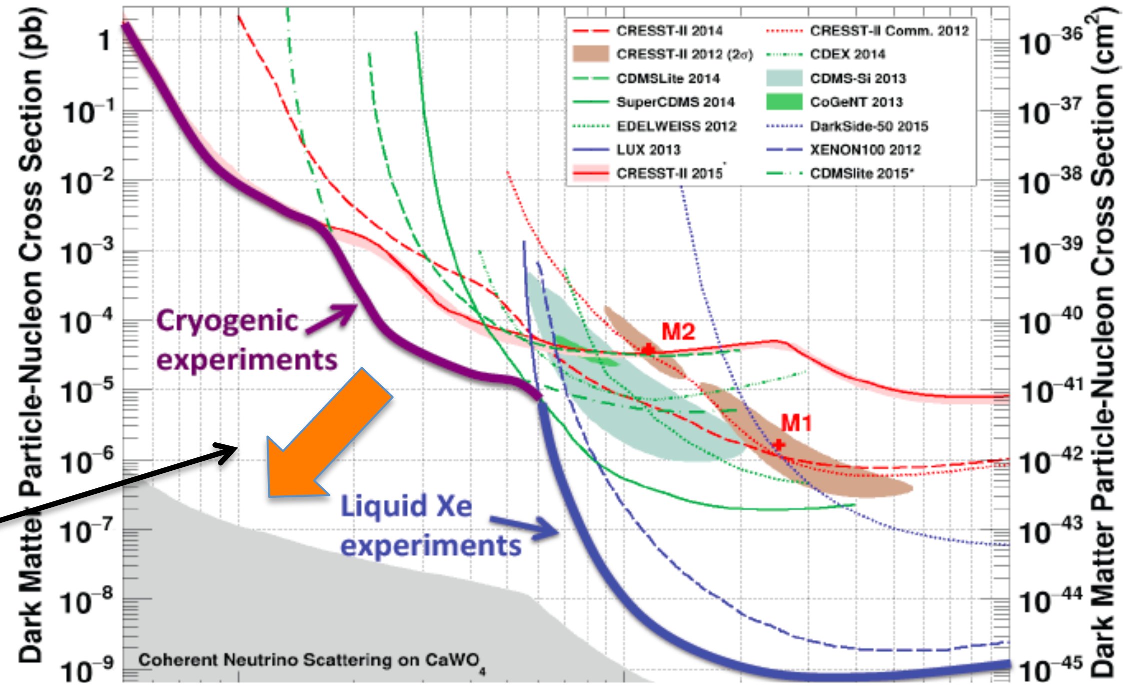
- We are searching in the "dark"
  - we do not know the interaction process
  - we do not know the interacting particle features
  - we use "guidelines" from our poor understanding of DM
- Recipe:
  - probe as much as possible the space of parameters
  - search for WIMPs and axions
- Ultimate goal:
  - establish particle nature of DM
  - determine properties of interaction to understand characteristics of DM particles

Conclusions [2]

- A huge effort underway on Direct Dark Matter search for Axions and WIMPs (mainly)
  - in 10 years sensitivity improved by a factor ~10^6
- Experimental development for WIMPs have shown
  - Two-phase TPC can perform strong background reduction
    - LXe : ER rejection factor ~ 300
    - LAr : ER rejection factor (only S1) ~ 1.6×10^7
- LAr and LXe are complementary for large masses
- Bolometric and HpGe detectors for low masses (1 – 10 GeV/c^2)
- Null experiments not in agreement with positive and model independent observation (DAMA/LIBRA)
- Efforts to test DAMA/LIBRA result underway

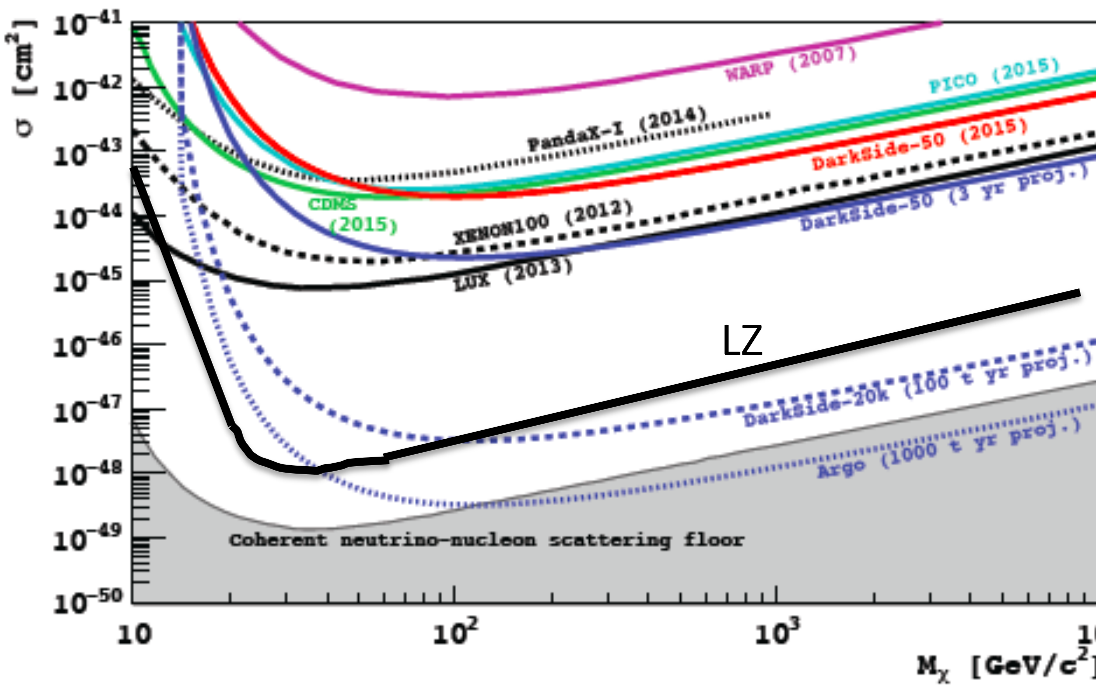
Perspectives in
~ 10 years time scale

Low WIMP masses



Improving detector
Performances
(example CDEX-100)

Large WIMP masses



Thank you

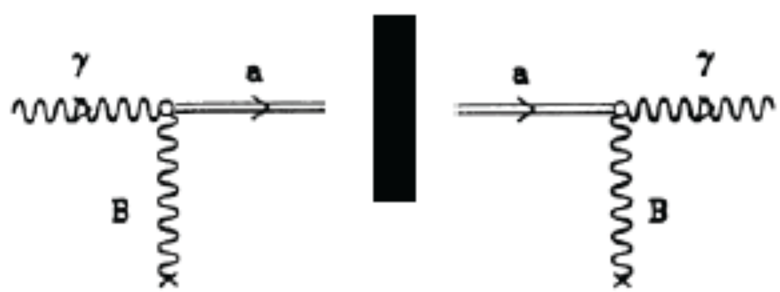
“Standard” Direct Axions Searches

Searching for axions and ALPs

- **Haloscope**: Axion DM eXperiment (ADMX)
  - resonant conversion of axion to photons in a microwaves cavity permeated by a strong magnetic field (B = 8 Tesla)
  - Enhancement when photon’s frequency corresponds to cavity’s resonant frequency’s, Q ~ 10^6 [Sikivie, PRL 51, 1415, 1983]

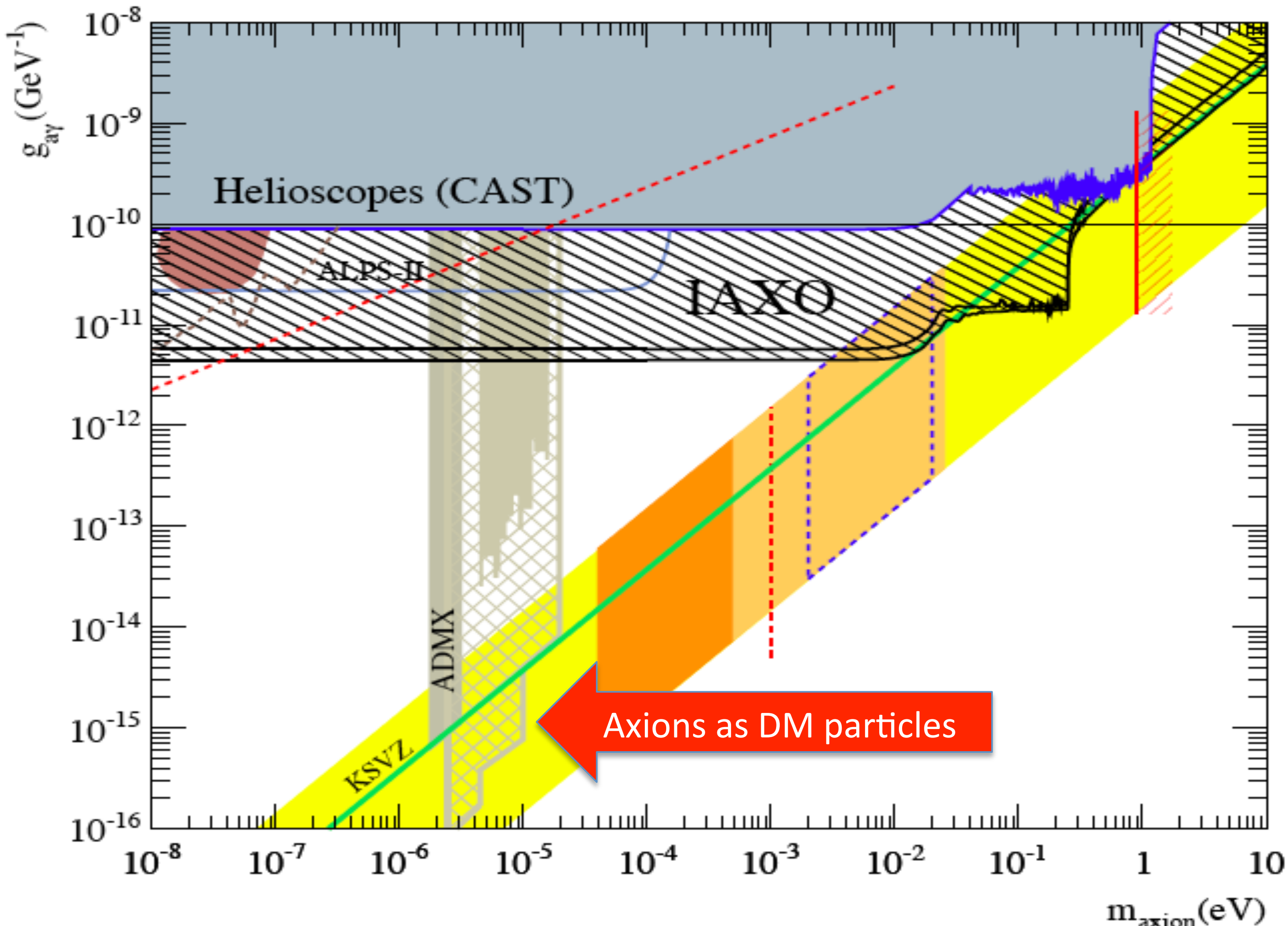
$$h\nu = m_a c^2 \left(1 + \frac{1}{2}\beta^2\right)$$

- **Helioscope**: CAST (2003 – 2015) -> IAXO
- **Photon regenerations**: OSQAR, ALPs-II



$$P(\gamma \rightarrow a \rightarrow \gamma) \propto \left(g_{a\gamma} B L\right)^4 \left|F(q)\right|^4$$

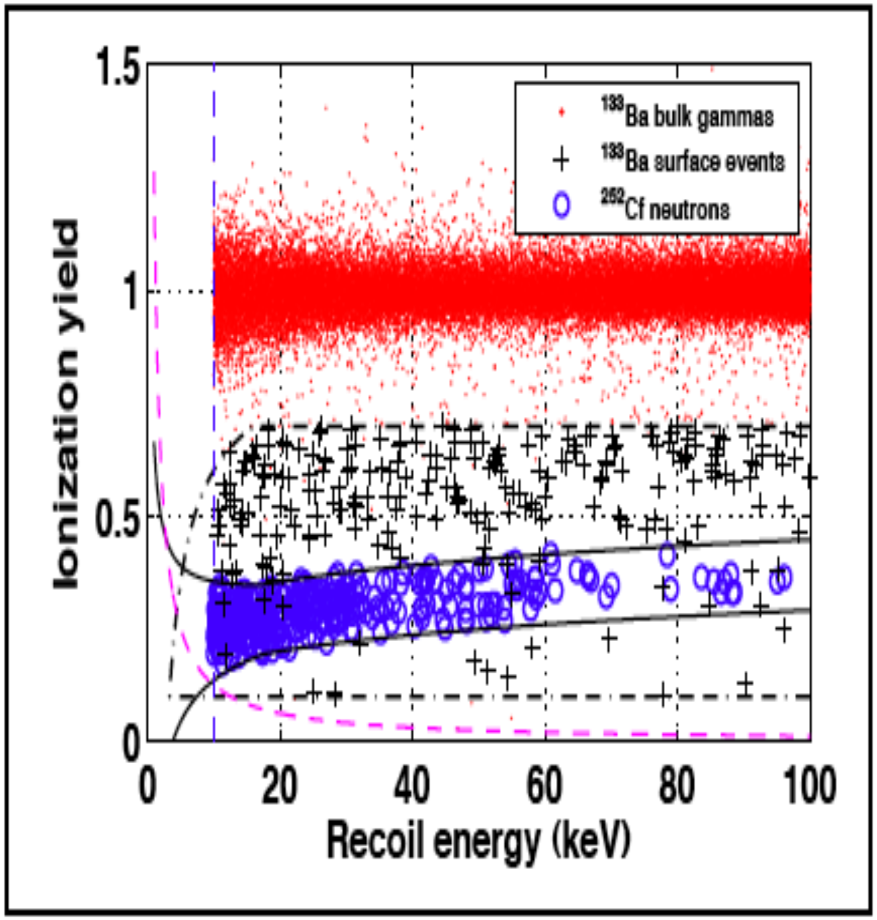
Axions searches: sensitivities

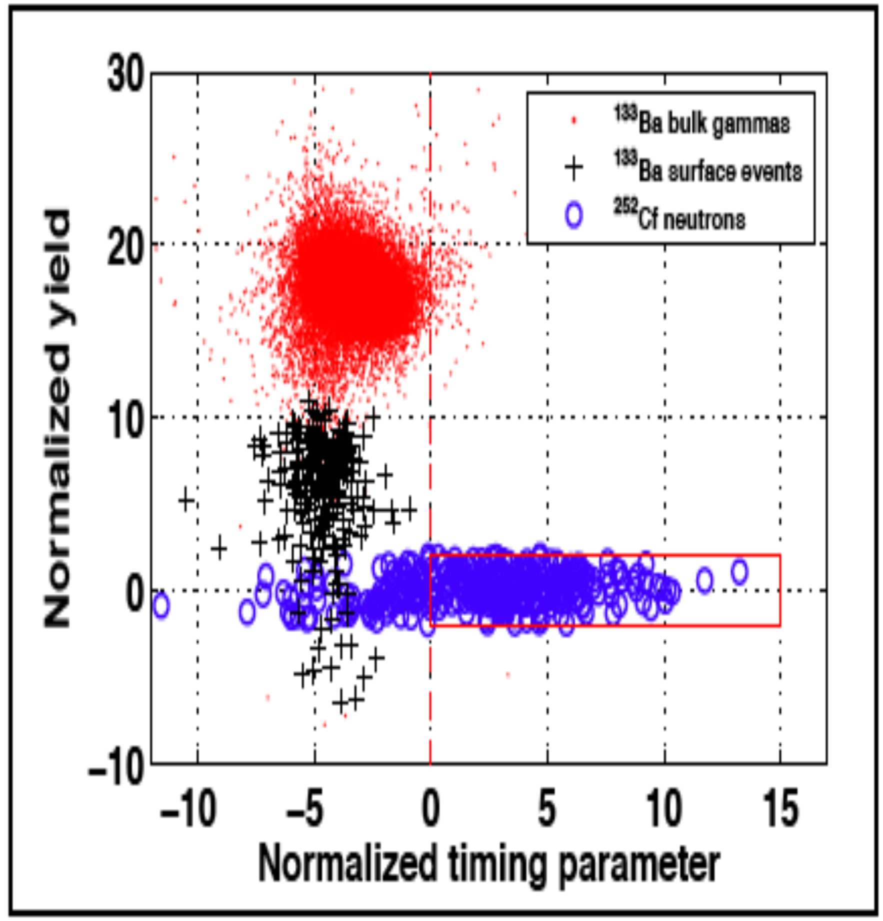


CDMS II

- 30 detectors (19 Ge, 11 Si) in Soudan Underground Lab (4.6 kg Ge + 1.2 kg Si)
- Data taking finished, moving to SuperCDMS (260 kg Ge array @ SNOlab)
- Measures ionization and phonons (TES read-out)
- Discrimination
  - NR yield ~ 0.3
  - ER yield ~ 1
  - Surface events rejected by timing properties of phonon and charge pulses + electric field profile

CDMS II Discrimination



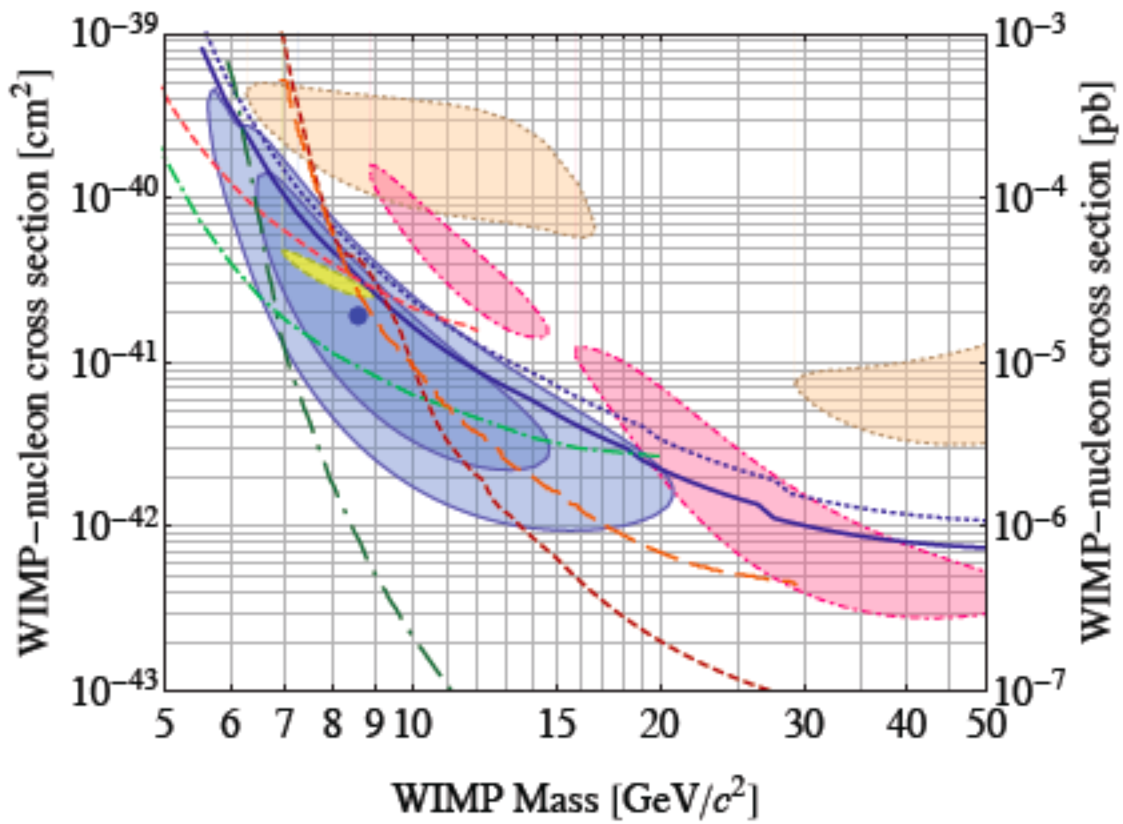


CDMS II – Si results

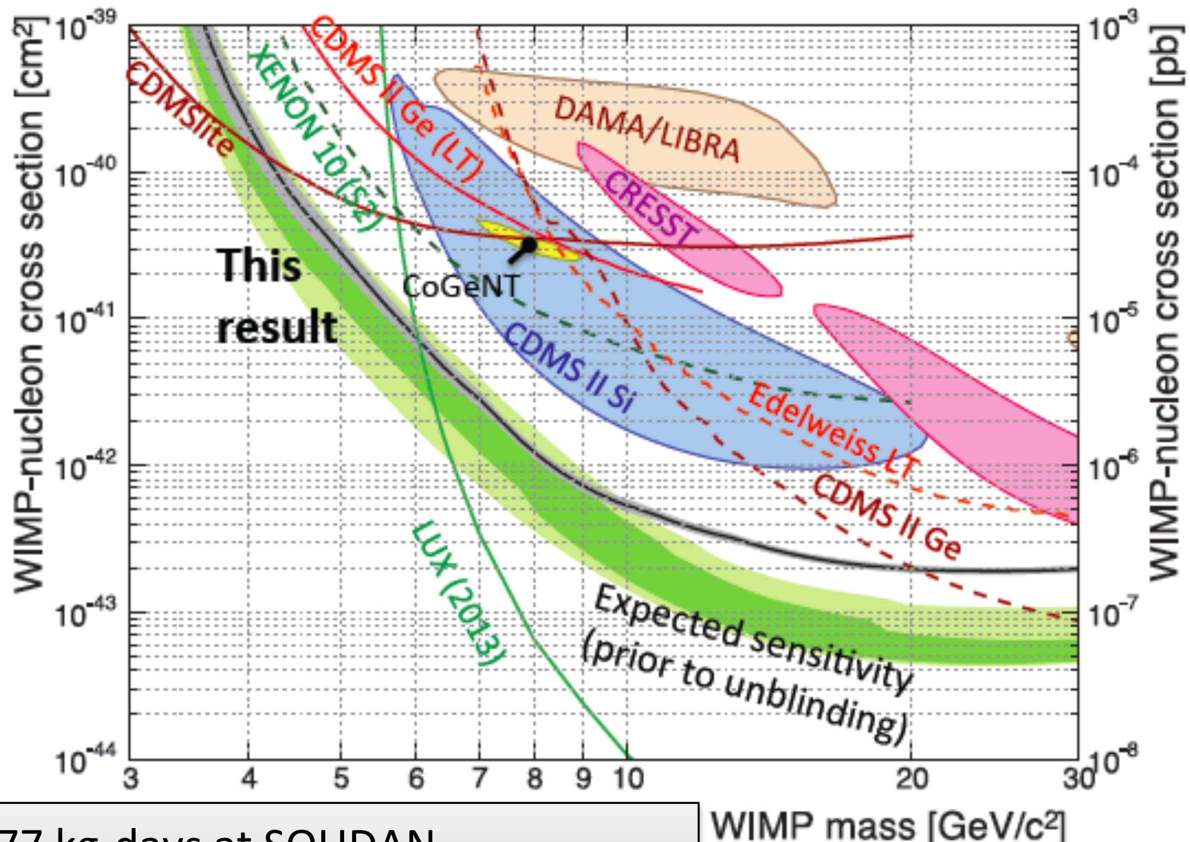
- 140.2 kg-day
- 3 events observed
- Surf. backg. ~ 0.4
- n backg < 0.13
- 0.08 NR from ^{210}Pb
- p-value for null

hypothesis is 0.19%

- **Best-fit**:
  - M_χ = 8.6 GeV/c^2
  - $\Sigma_{\chi p}$ = 1.9×10^{-41} cm^2



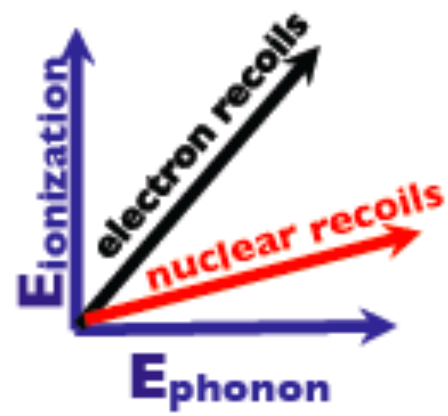
SuperCDMS: SI constraint at low mass



577 kg-days at SOUDAN underground site
Threshold at 1.6 keVr

11 candidates seen
Expected backg. = $6.6^{+1.1}_{-0.8}$

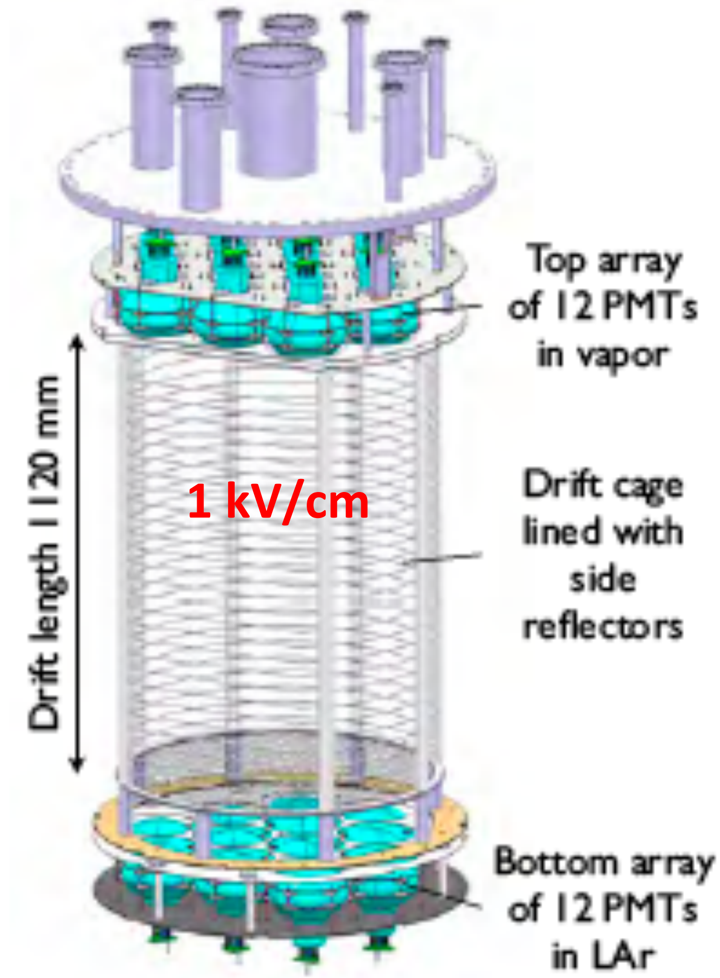
Feldman-Cousin gives a 90% CL upper limit at 11.2



Liquified noble gases as WIMPs target

	Ar	Xe	Ne
Atomic number	18	54	10
Mean atomic mass	40	131.3	20.2
Melting point @ 1atm [K]	83.8	161.4	24.6
Density for liquid [g/cm^3]	1.40	2.94	1.21
Volume fraction in atmosphere [ppm]	9340	0.09	18.2
Scintillation λ [nm]	128	178	78
Scint. fast component [ns]	7	3	
Scint. Slow component [ns]	1600	27	

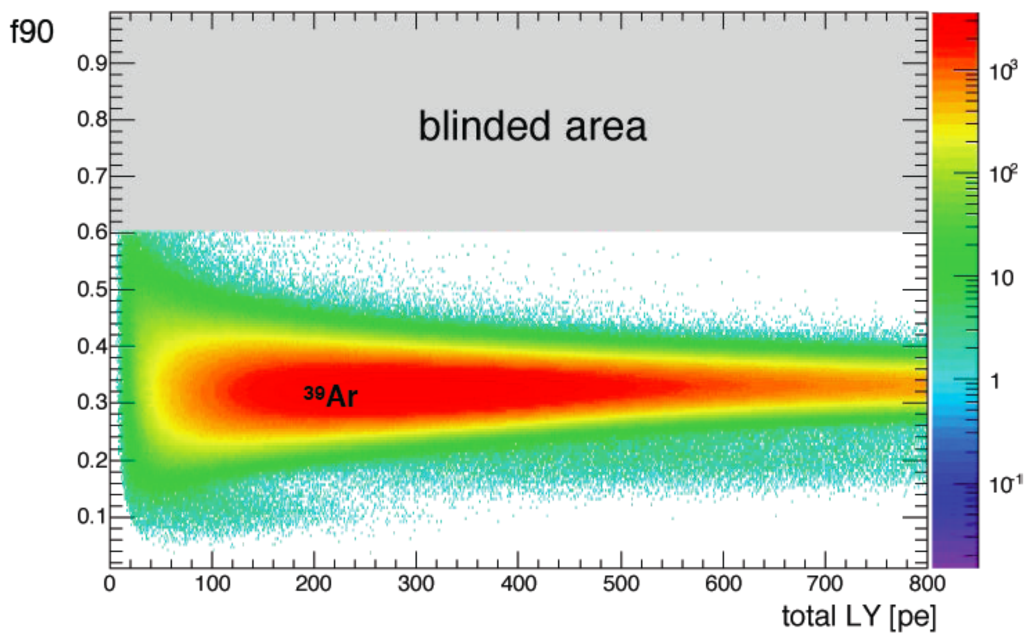
ArDM at LSC



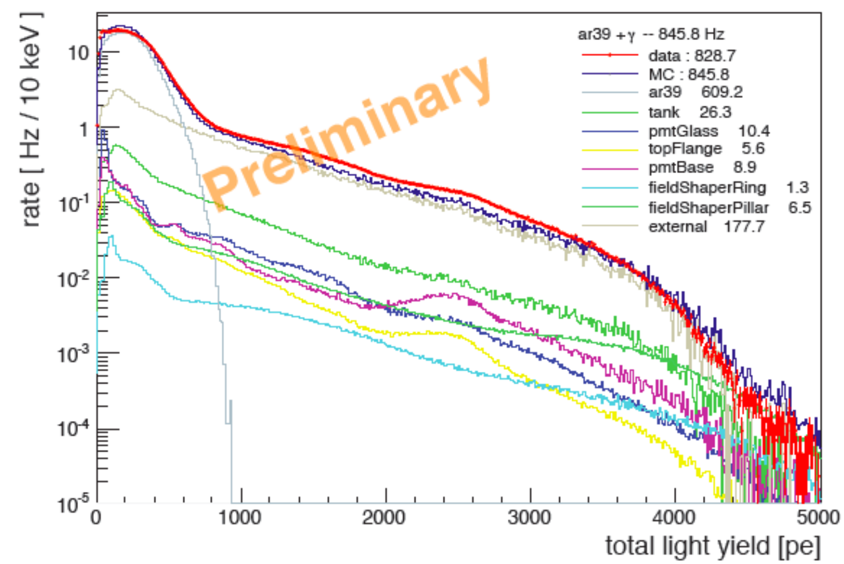
2 tons LAr TPC
LAr active mass is 870 kg

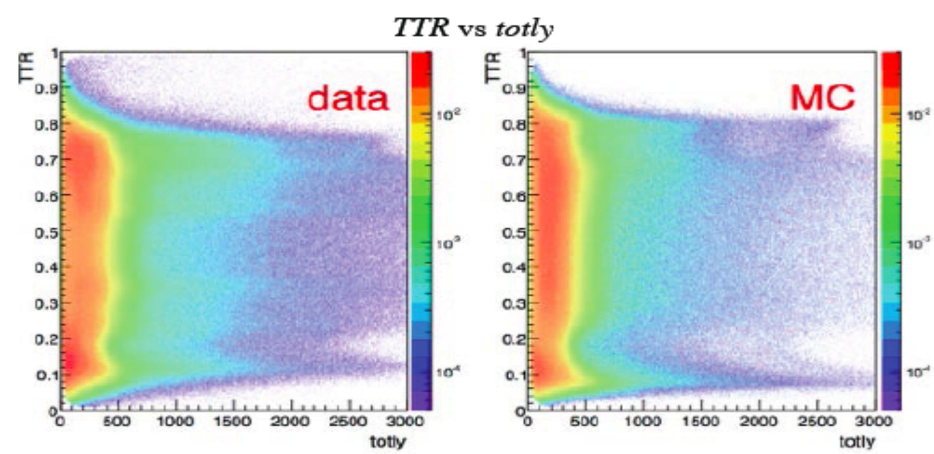
ArDM: performances of Run I

PSD with only S1



Data vs Monte Carlo for backgrounds study





Cryogenic for DS-50 TPC