

**darkside**

two-phase argon TPC for Dark Matter Direct Detection



# Dark Matter searches with the DarkSide LAr TPC

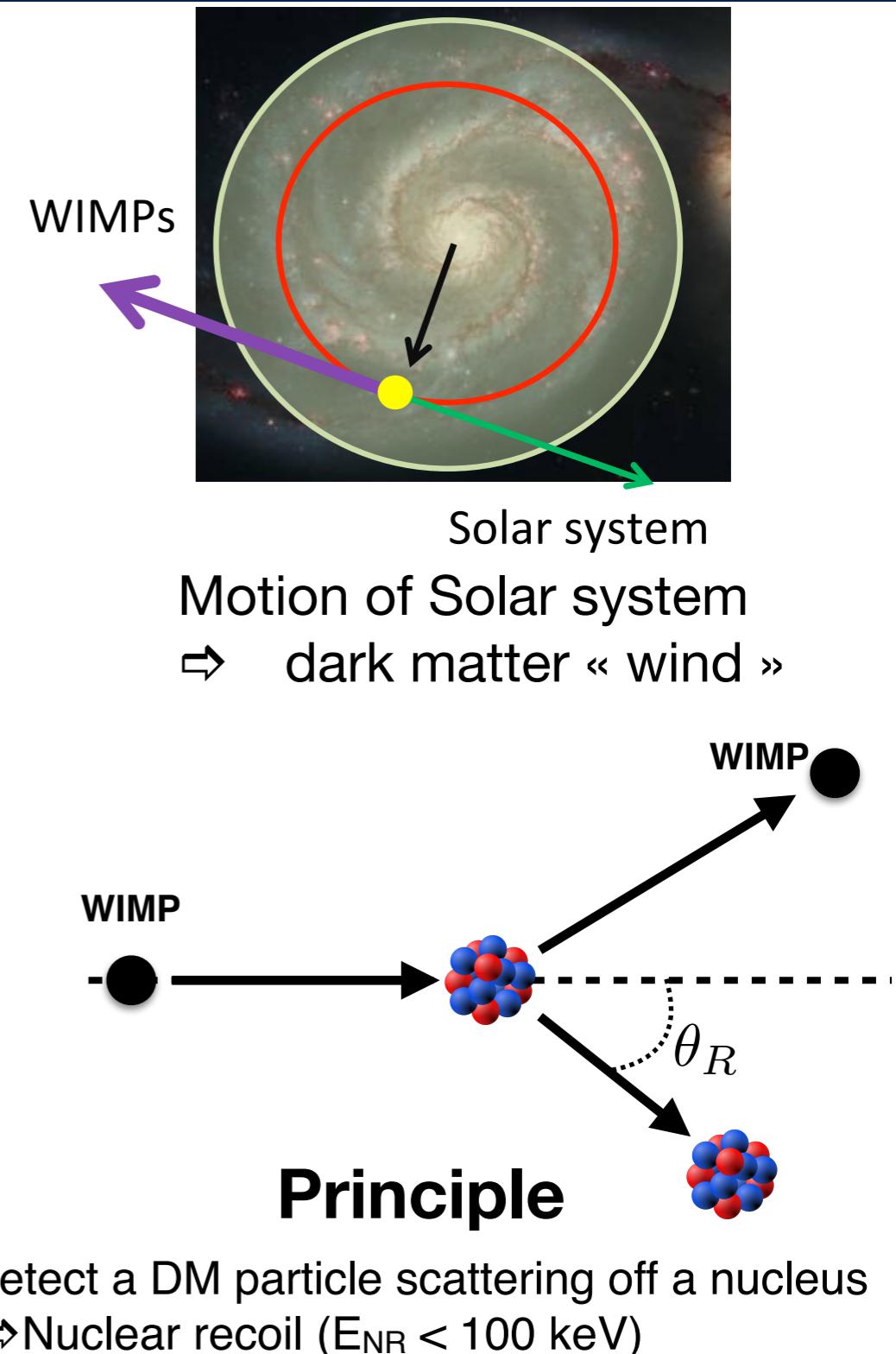
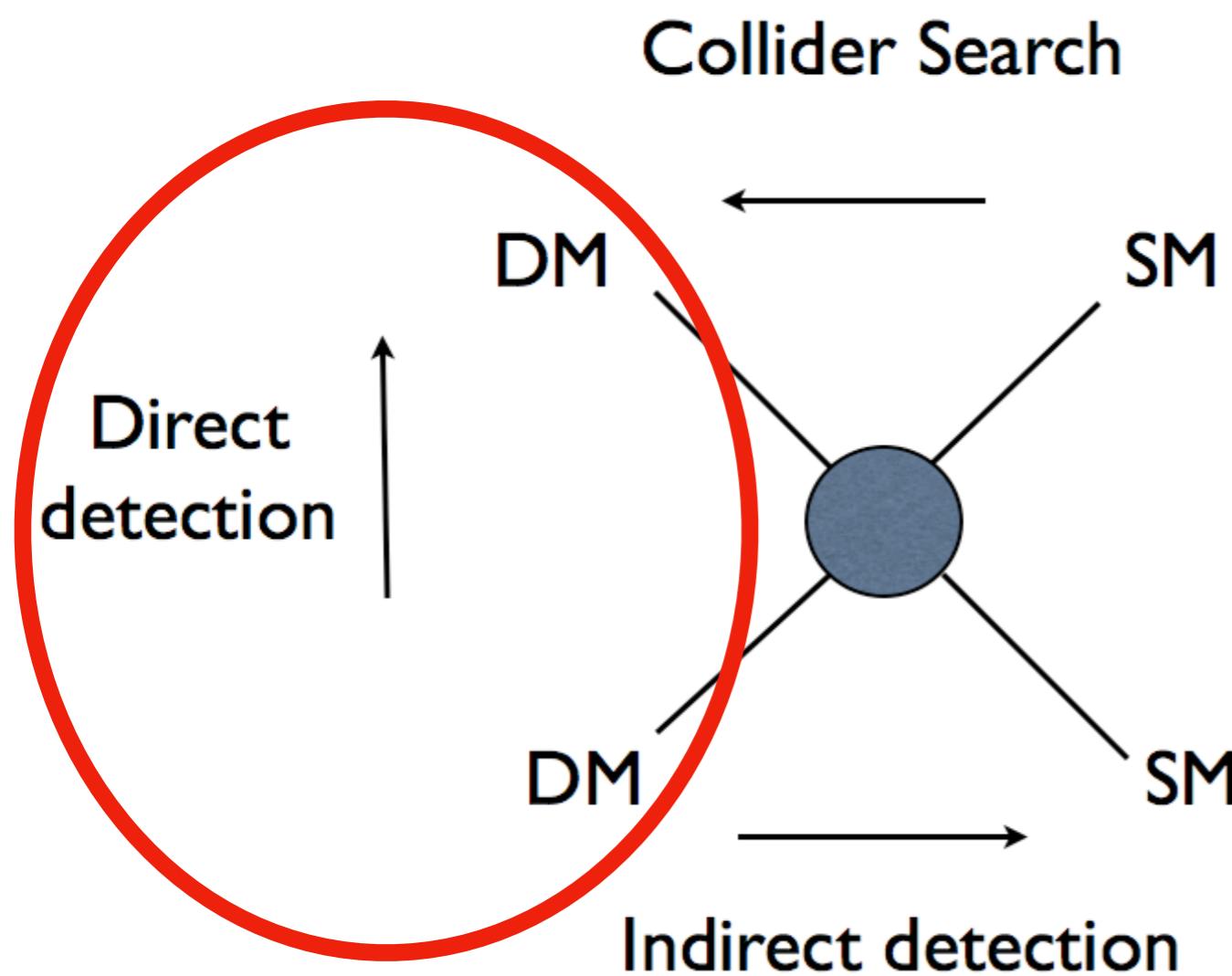
Anyssa Navrer-Agasson

On behalf of the DarkSide Collaboration

*IRN TeraScale, Annecy - May 20, 2019*

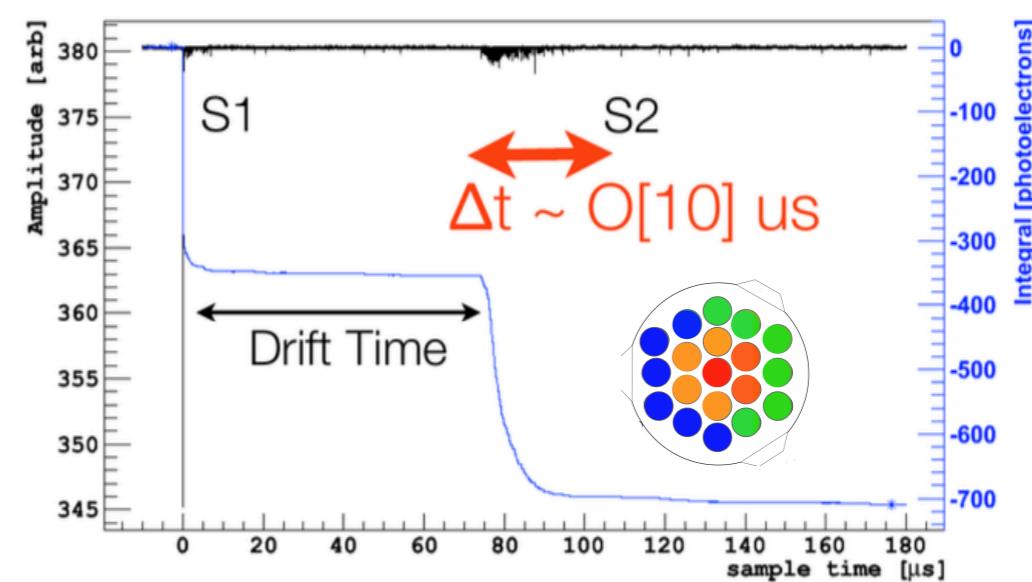
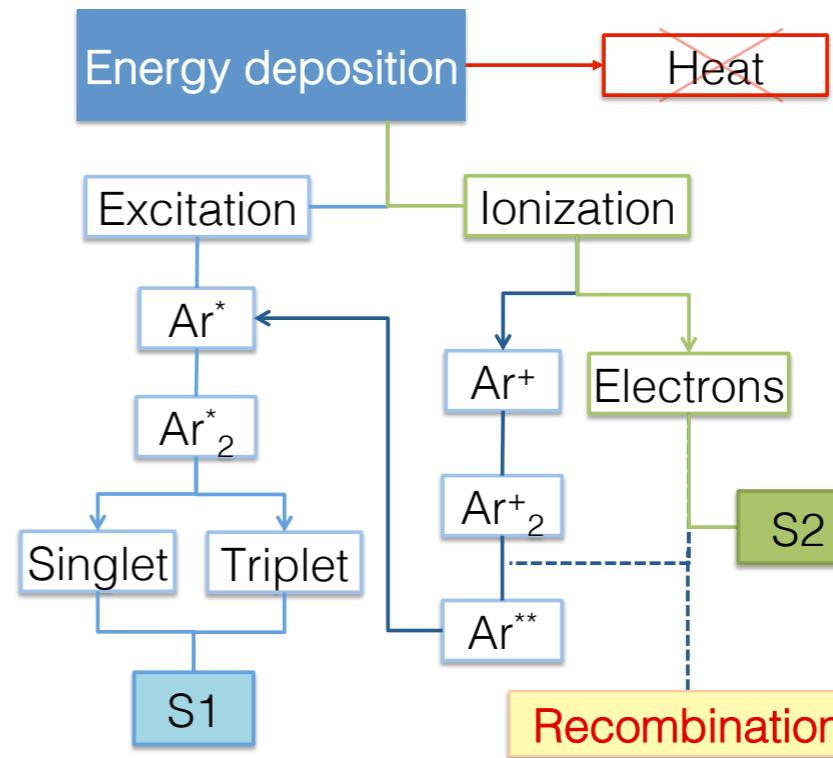
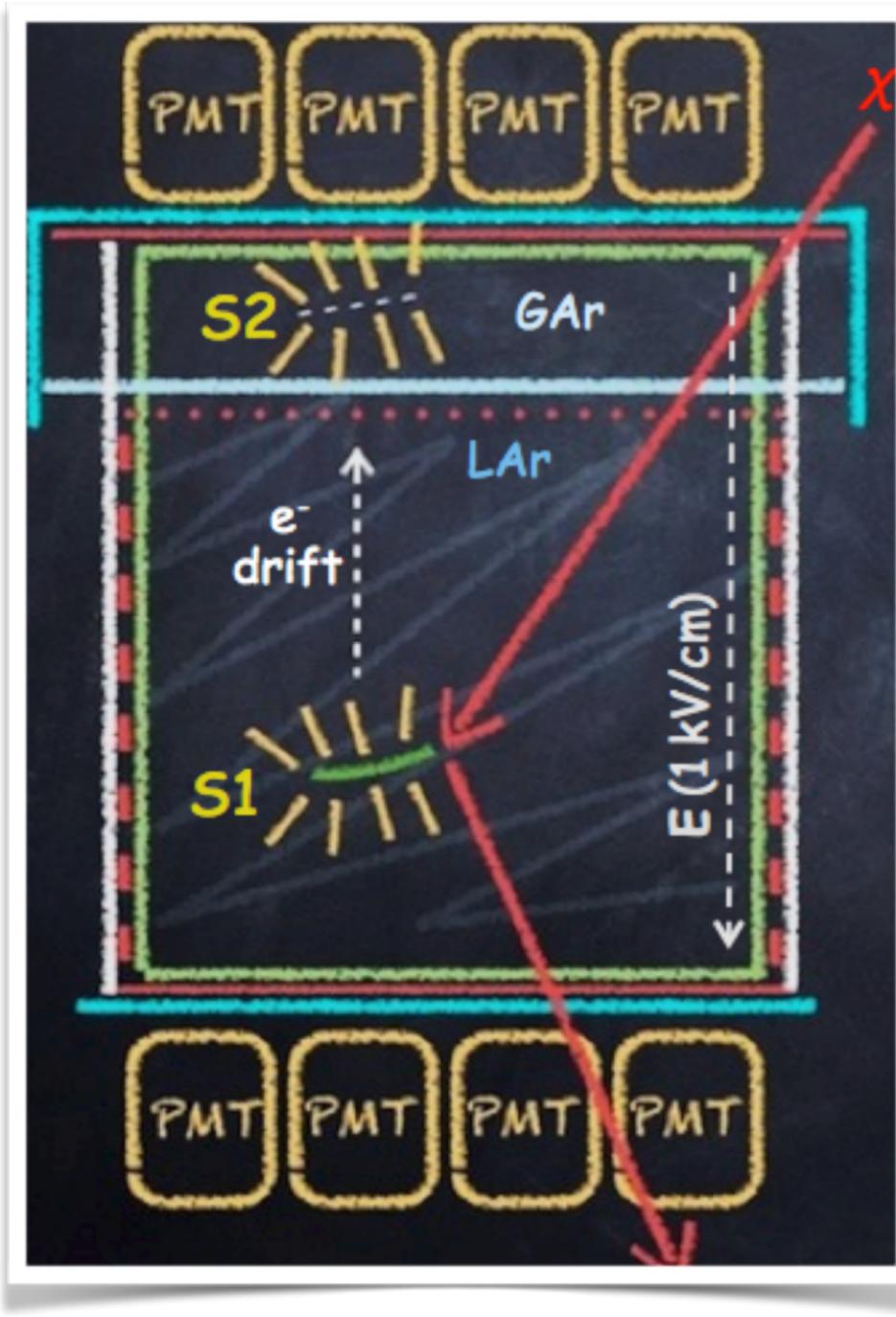


# Direct dark matter search

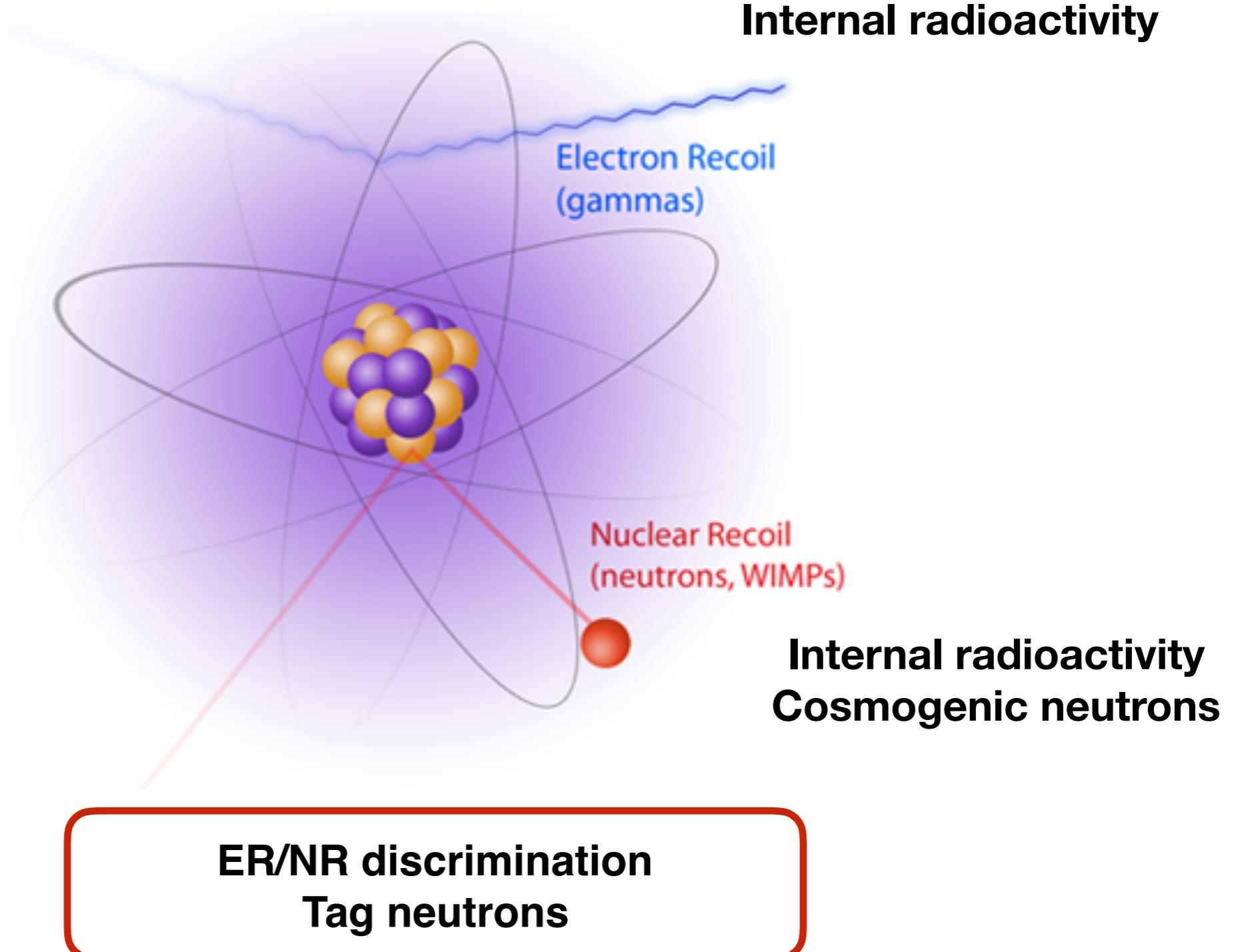


# Dual-phase LAr TPC

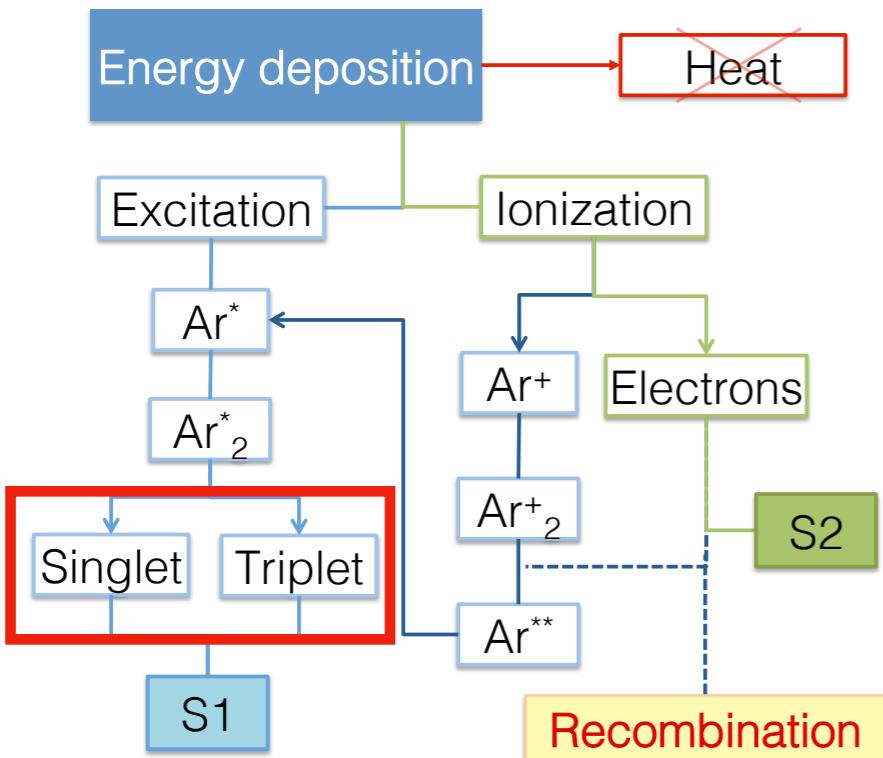
Dual phase Liquid Argon Time Projection Chamber



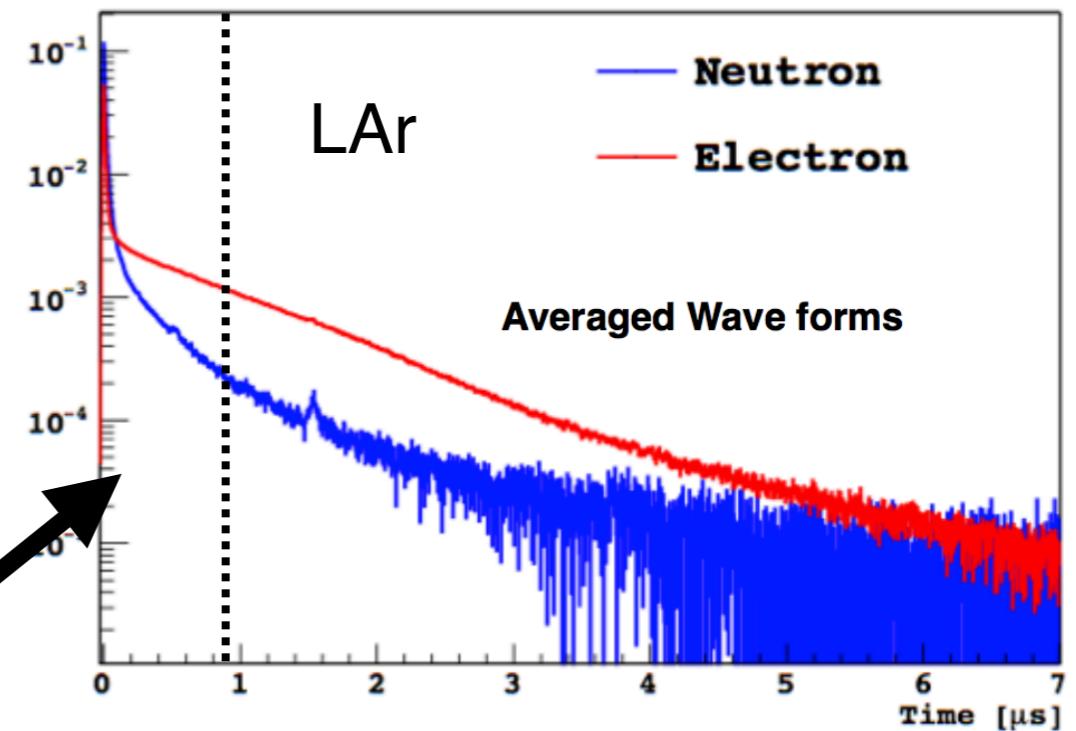
# LAr TPC backgrounds



# ER/NR discrimination



Pulse Shape Discrimination

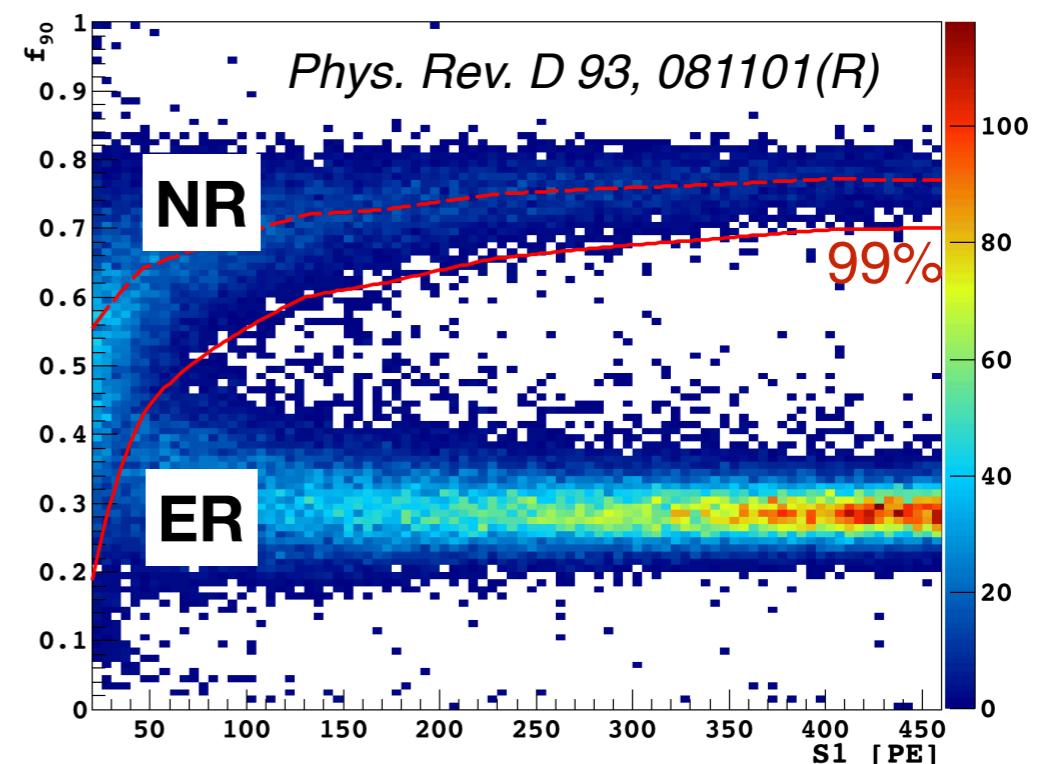


PSD parameter  $f_{90}$  :  
fraction of light seen in the first 90 ns

	Singlet	Triplet
Time constant	~7 ns	~1.6 μs
Population ratio for Electron ionizing	33%	67%
Population ratio for Nucleus ionizing	75%	25%

Liquid Ar ER rejection factor:  $\sim 10^8$

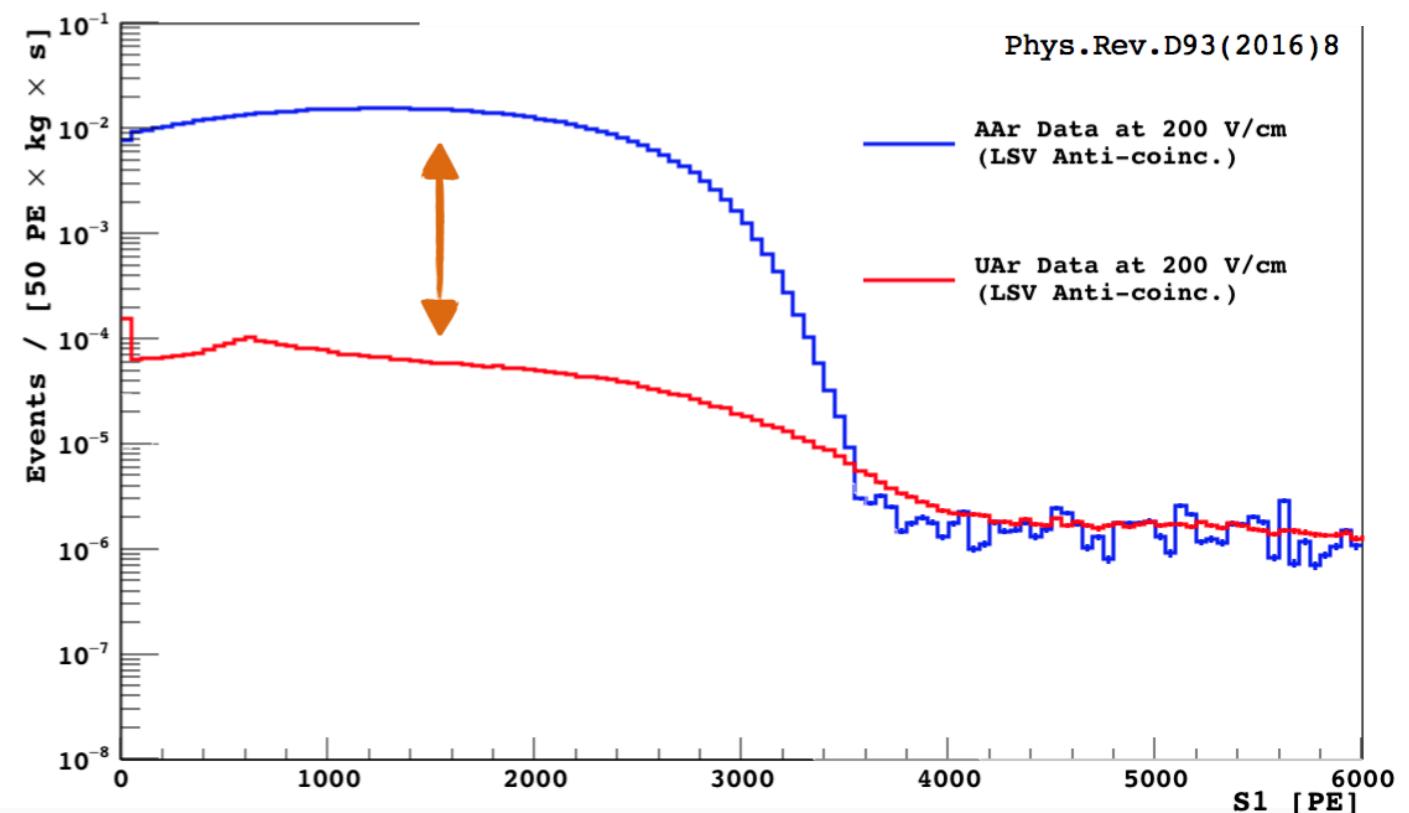
WARP Astr. Phys 28, 495 (2008)



# Underground Argon

- $^{39}\text{Ar}$  is a beta emitter
- Atmospheric argon is easy to obtain and inexpensive but high  $^{39}\text{Ar}$  contamination
- $^{39}\text{Ar}$  is produced by cosmogenic activation: underground argon (UAr) is shielded and  $^{39}\text{Ar}$  quantity depleted
- DarkSide demonstrated a depletion factor of  $\sim 1400$  in underground argon
- Results presented in this talk are obtained with UAr data

P. Agnes *et al*, Phys.Rev.D93 (2016) 8

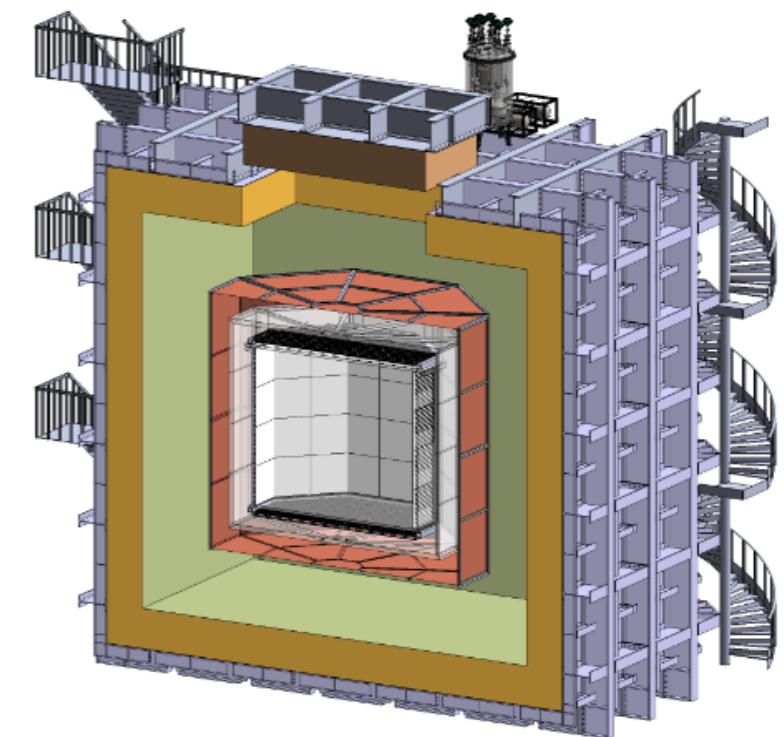


# **DarkSide experiment**

# The DarkSide program



**DarkSide-10**



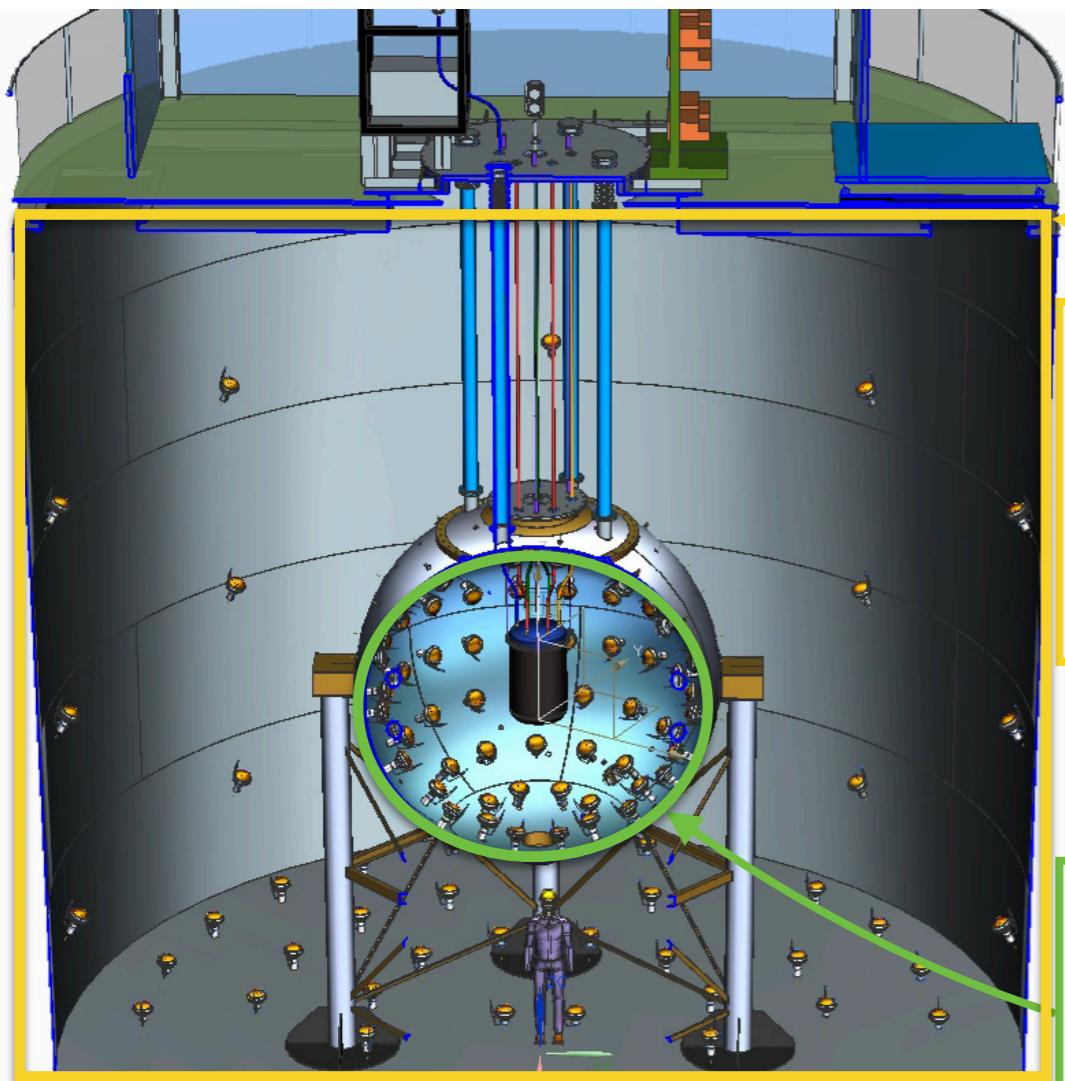
**DarkSide-20k**

# DarkSide-50 TPC

- 36 cm height, 36 cm diameter
- 50kg active mass (37 kg fiducial)
- 38 high quantum efficiency PMTs (19 top + 19 bottom)
- Inner surfaces coated with TPB (wavelength shifter)

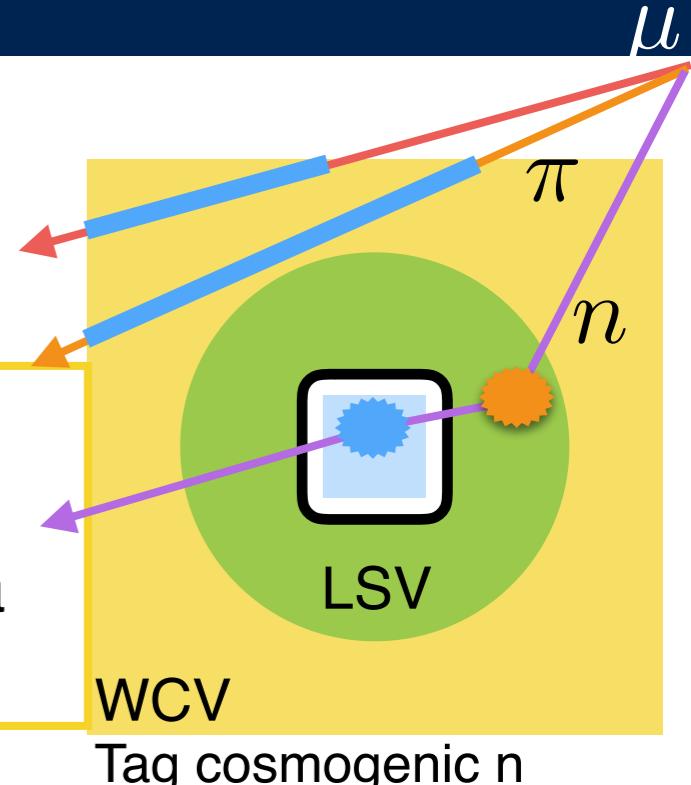


# Active vetoes



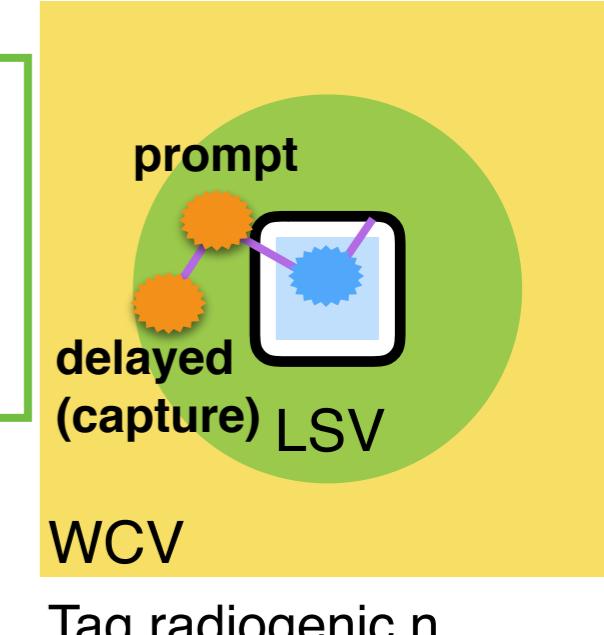
## Water Cherenkov Veto:

1kT ultra pure water  
Tag cosmogenic neutrons via muons



## Liquid Scintillator Veto:

30-tonne liquid scintillator  
Tag neutrons from TPC via neutron capture

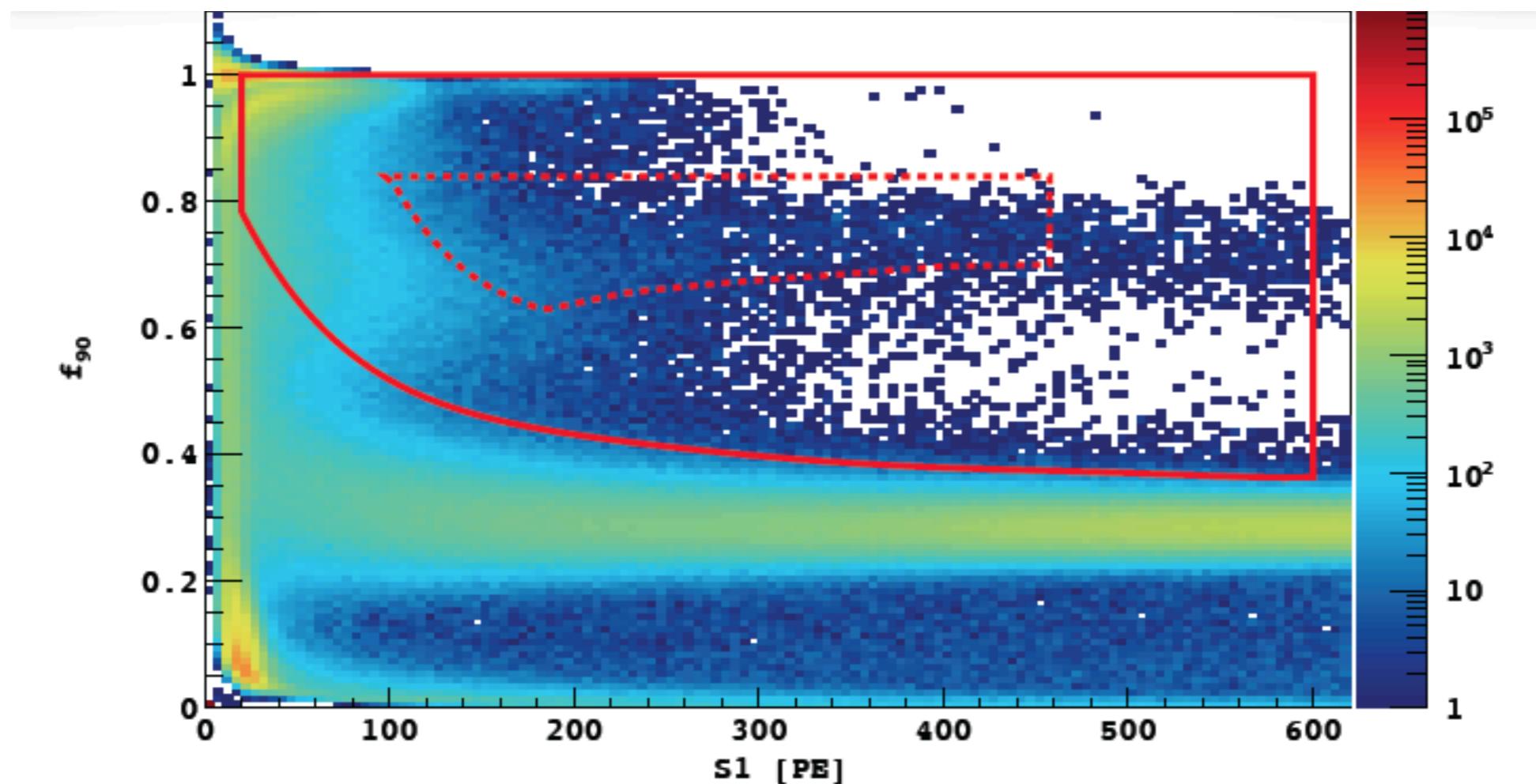


## Veto's Rejection Efficiencies (AmBe measurement + Monte-Carlo):

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

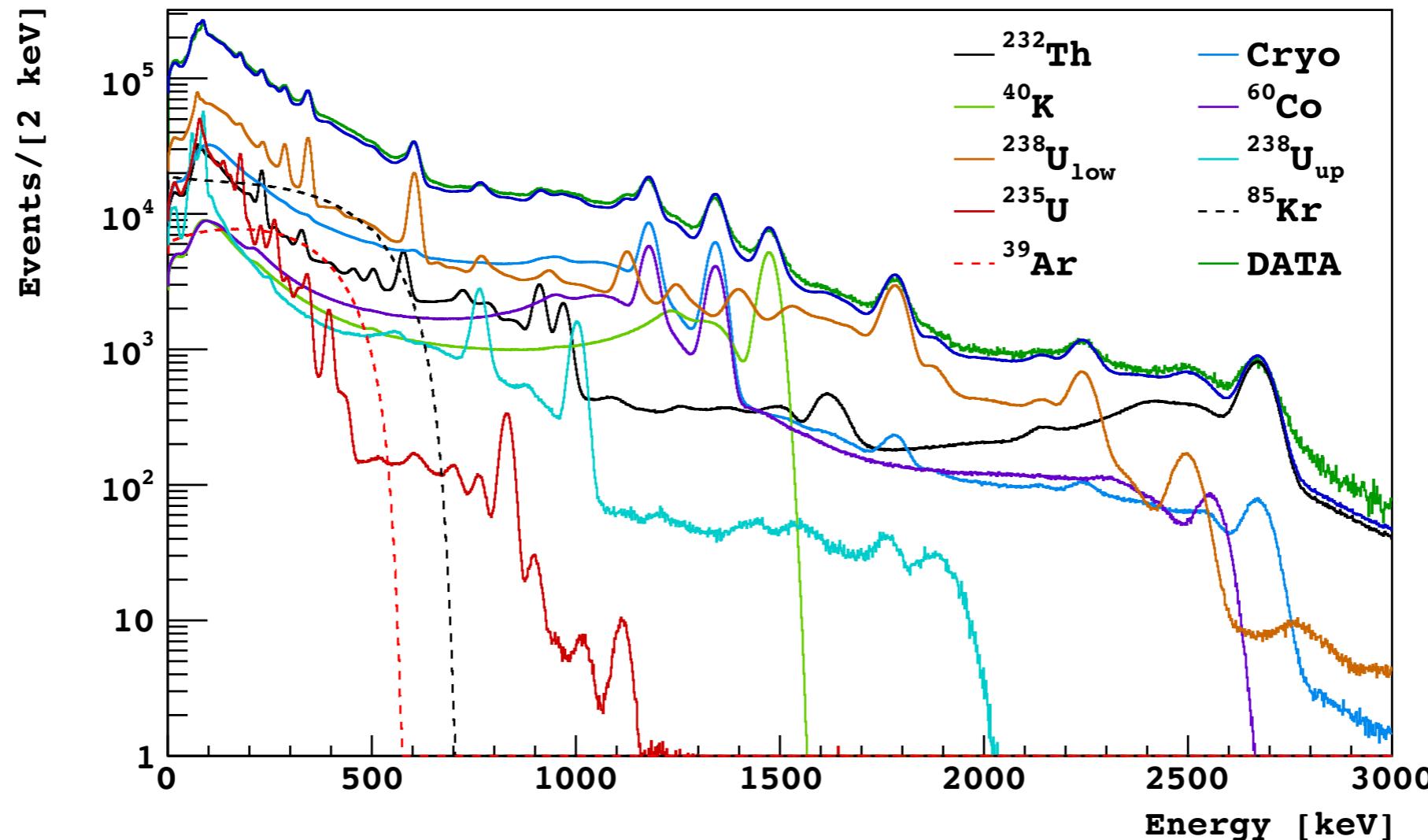
# **High mass WIMP searches**

# 532 live days blind analysis



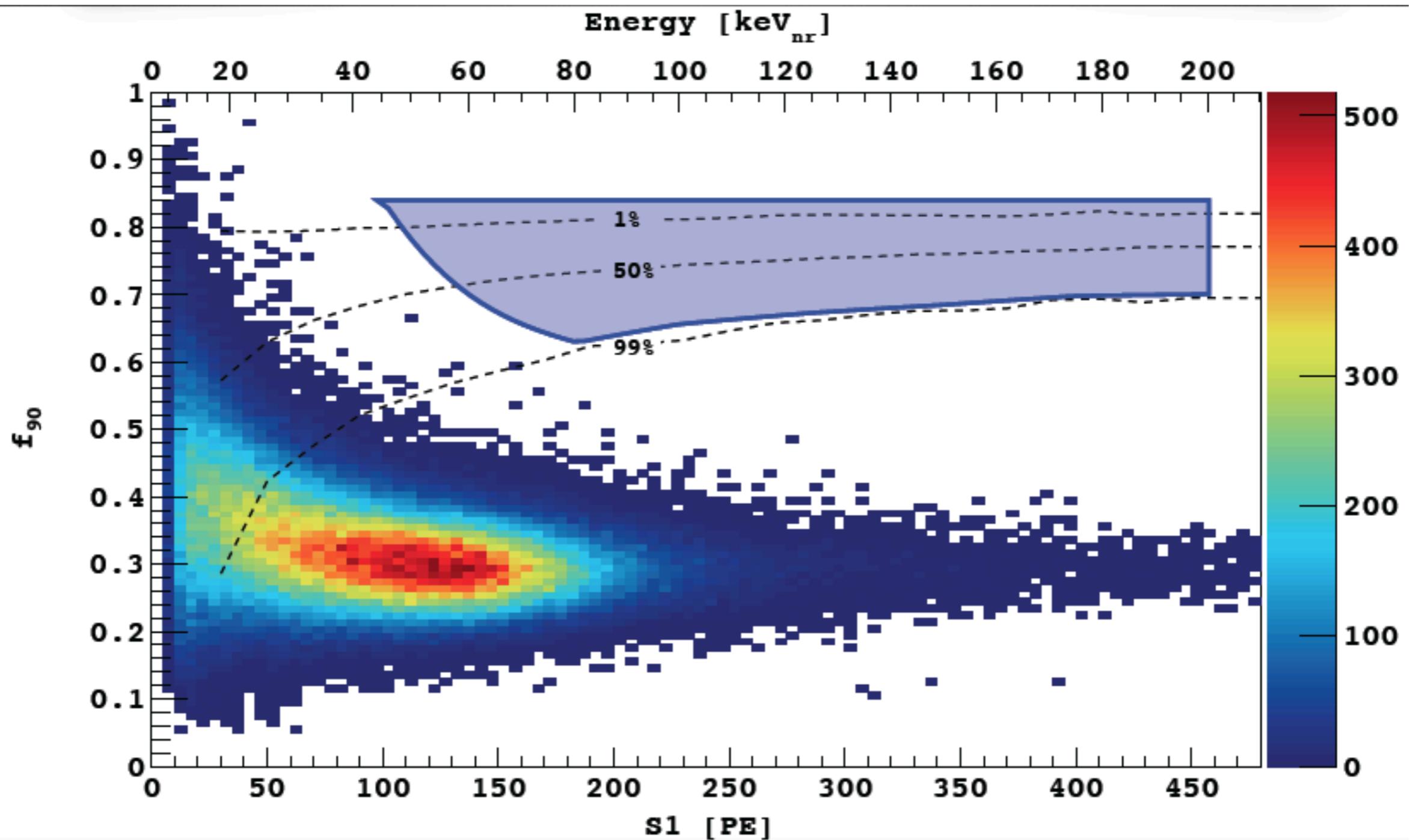
**Goal : analysis with < 0.1 background events in the search box. (Chosen box: dashed red)**

# Background spectral fit

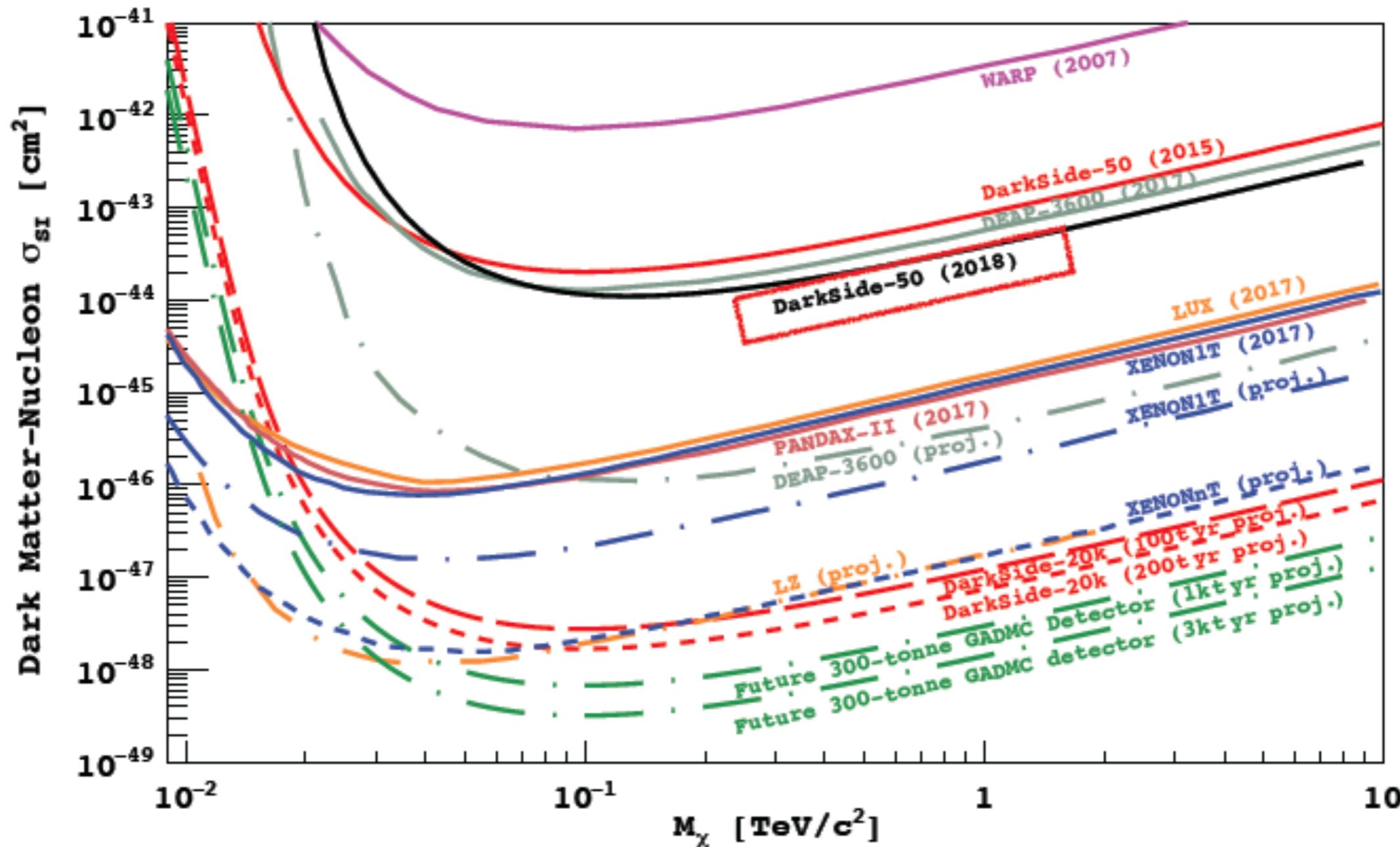


Background activities evaluated with a spectral fit with the DS50 MC model

# Final data set



# 90% CL exclusion limits



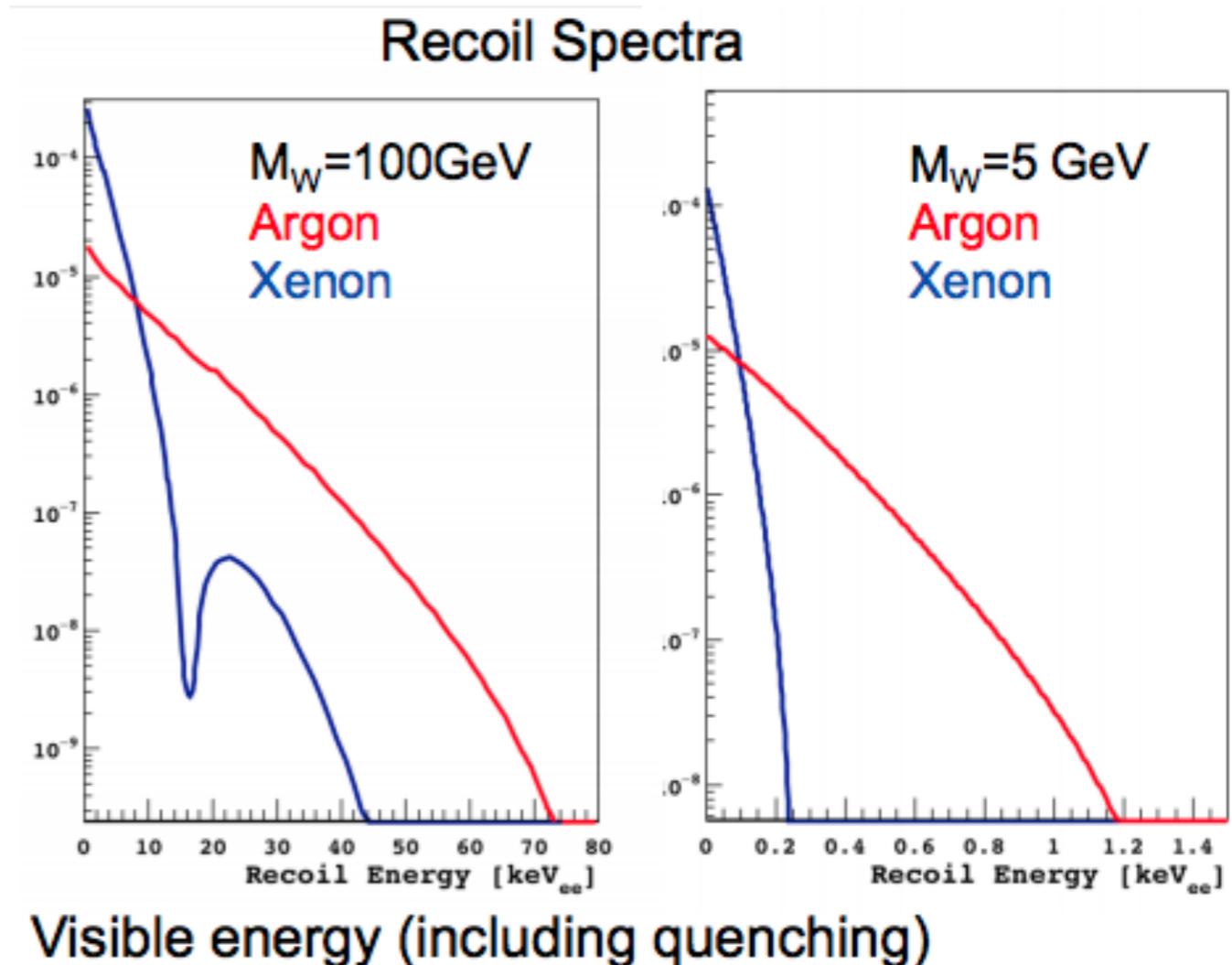
# **Low mass WIMP searches**

# Low mass WIMPs in LAr

- No pulse shape discrimination at low energies
- S1 threshold at  $2 \text{ keV}_{\text{ee}} \sim 6 \text{ keV}_{\text{nr}}$

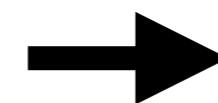
**BUT**

- LAr is lighter than LXe
  - For a given WIMP mass, larger energy deposited

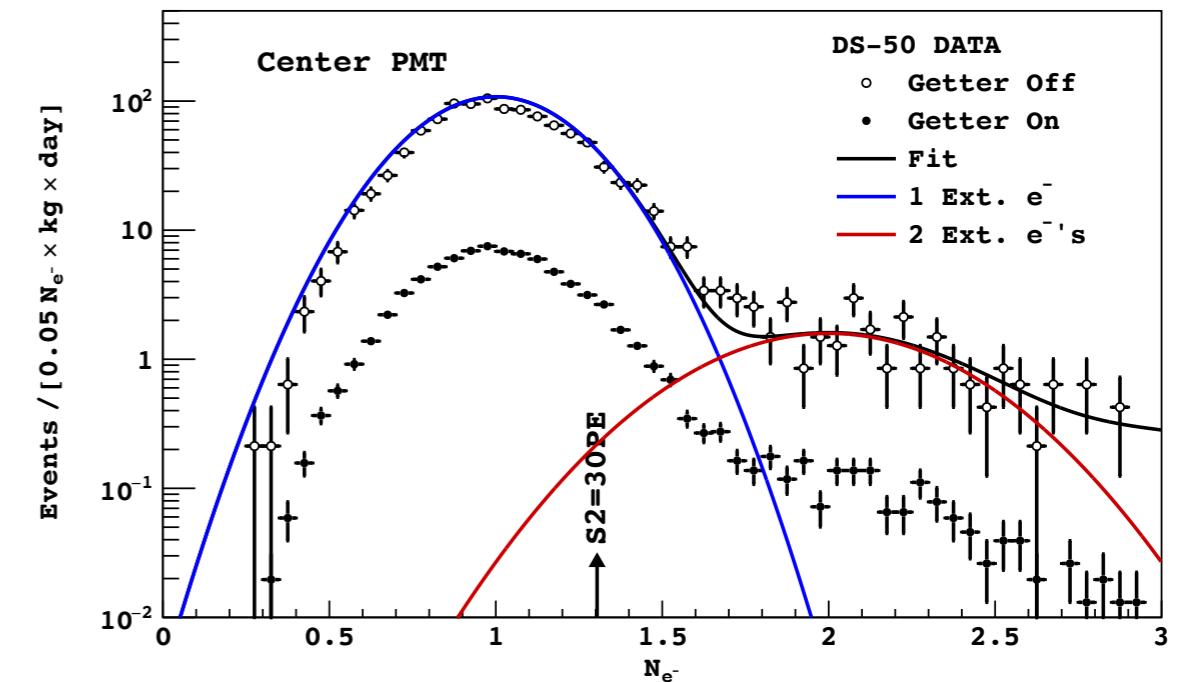
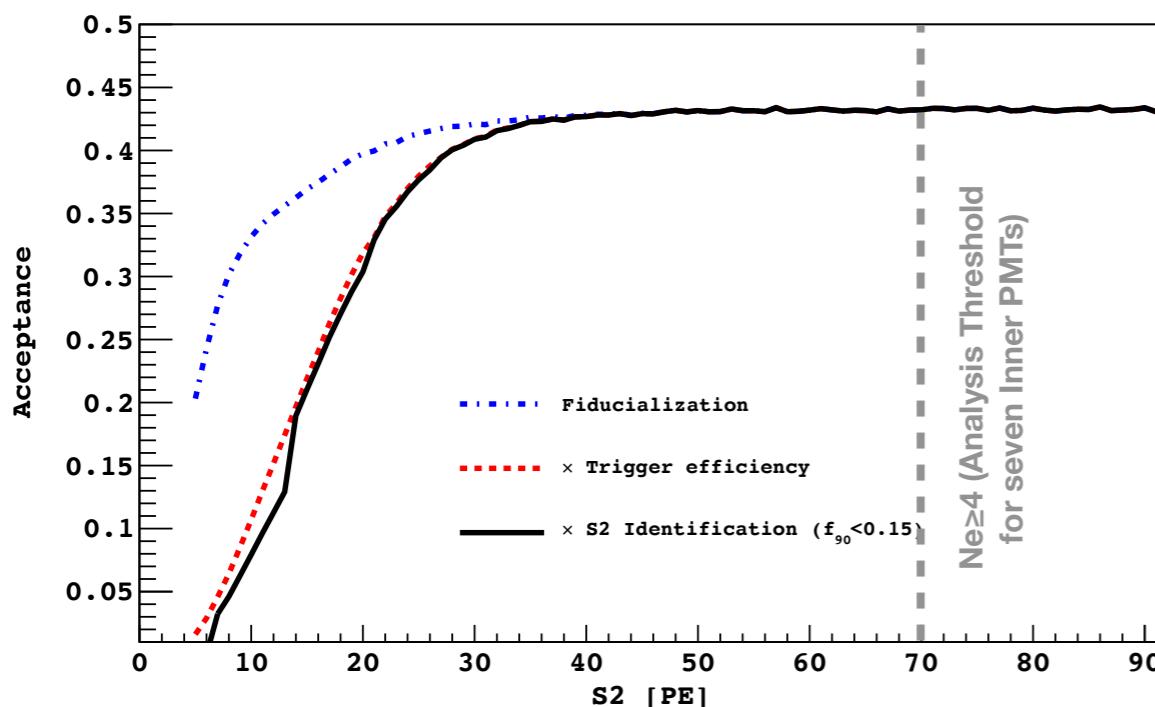


# Ionization signal (S2) in LAr

- High detection efficiency down to low energies
- No dark rate in the PMTs at 88K
- Sensitive to single electrons extracted in the gas phase ( $1 e^- = 23 \pm 1$  PE)



**S2 analysis threshold : 0.4 keV<sub>nr</sub>**



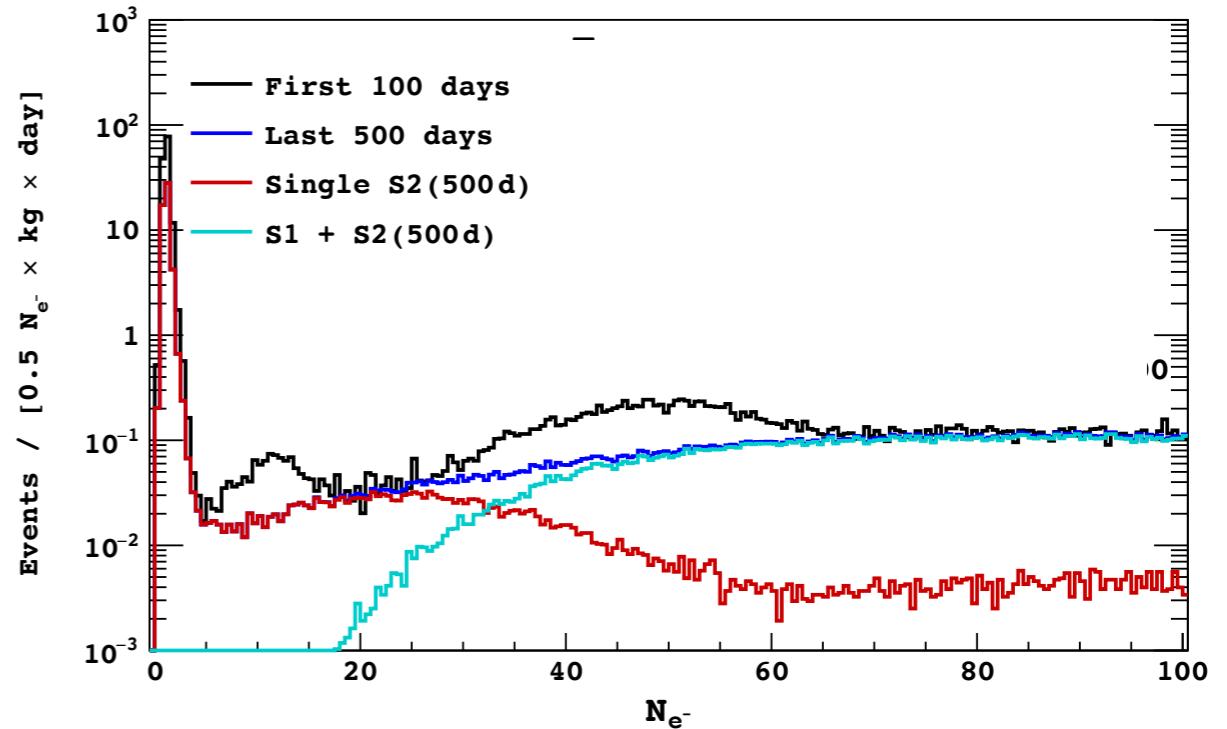
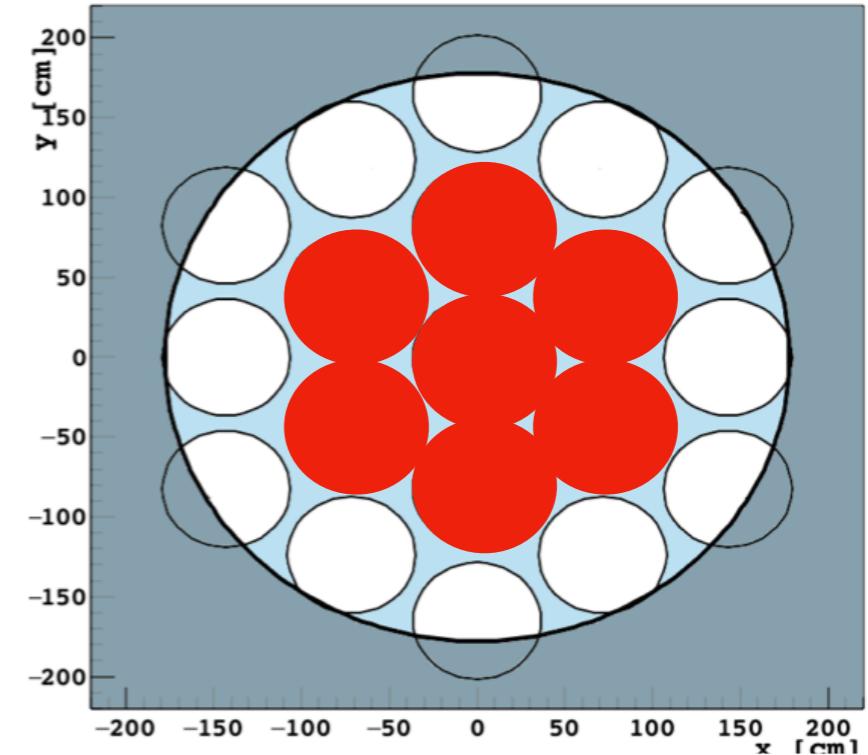
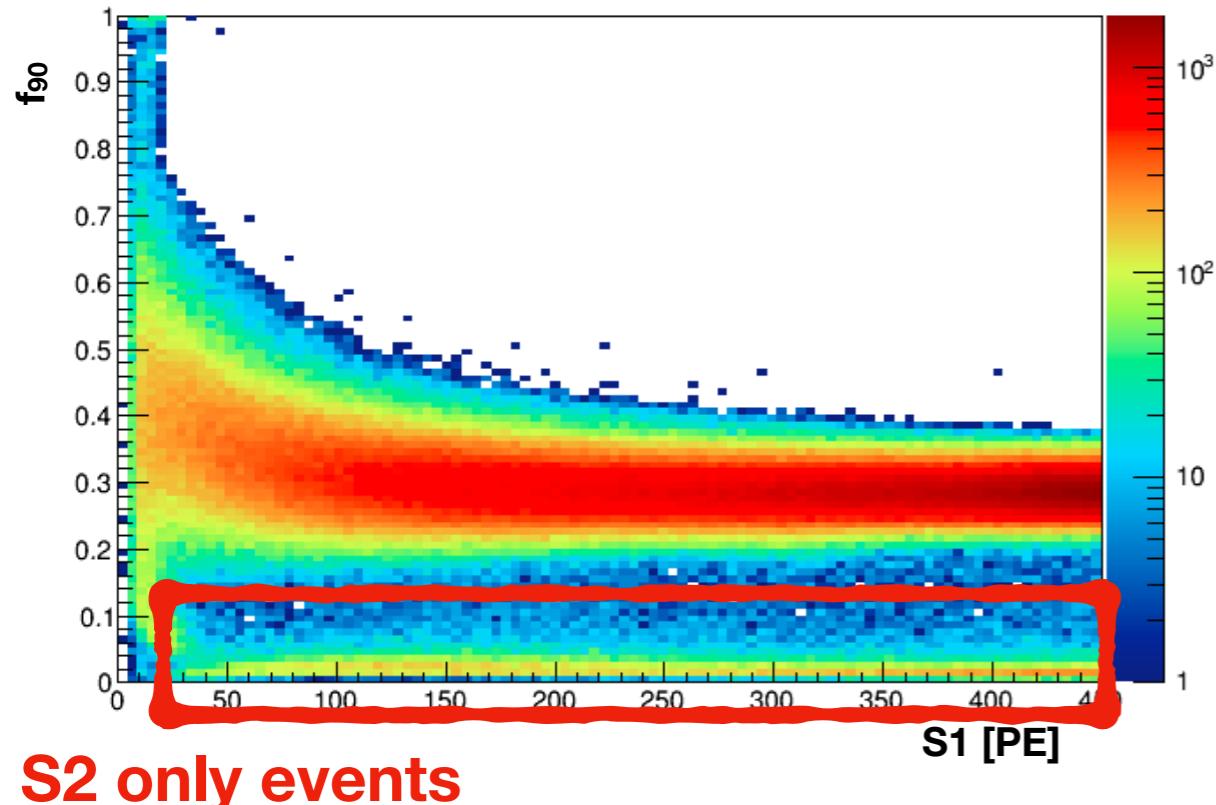
**S2-only analysis allows to set a lower analysis threshold**



**Low mass WIMPs searches accessible**

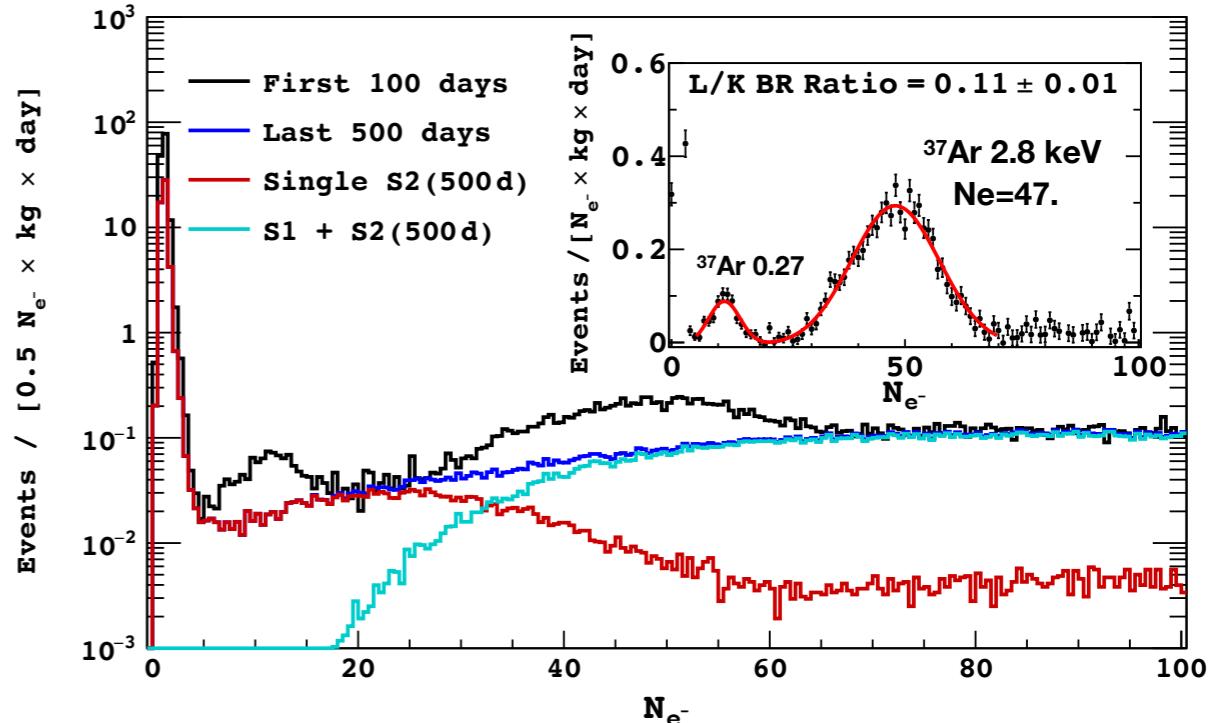
# Data selection

- PMT with the most light has to be one of the central one (red PMTs)
- Require  $f_{90} < 0.15$  for S2 pulse
- Correct S2 for position and saturation effects



# ER energy scale

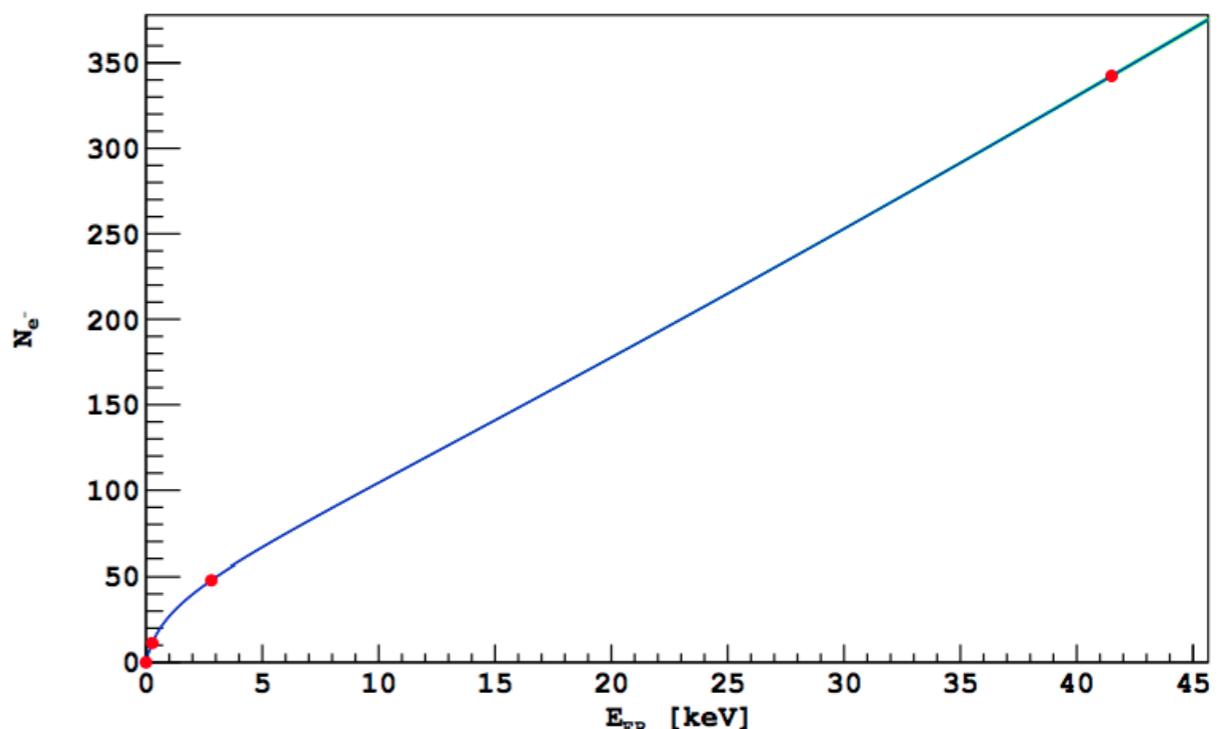
- Presence of  $^{37}\text{Ar}$  in the first 500 days of the data (37 days half-life)
- Two x-rays at 0.27 keV and 2.82 keV
- Excellent calibration source
  - 0.27 keV  $\rightarrow$  S2-only region
  - 2.82 keV  $\rightarrow$  S1+S2 region



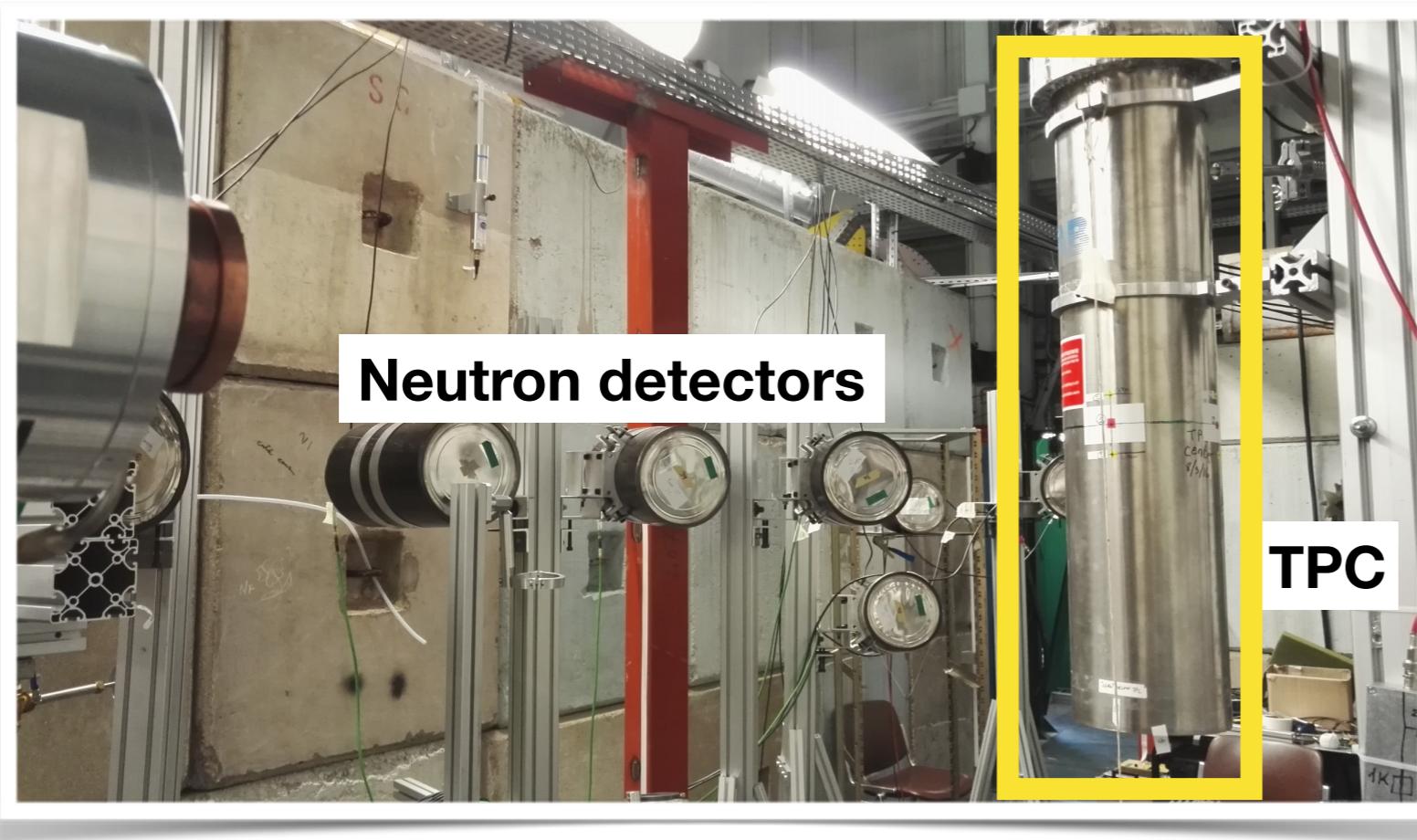
$$E = 0.27 \text{ keV} \rightarrow N_e = 11$$

$$E = 2.82 \text{ keV} \rightarrow N_e = 49$$

Combined with  $^{83\text{m}}\text{Kr}$  at 41 keV  
 $\rightarrow$  ER energy scale

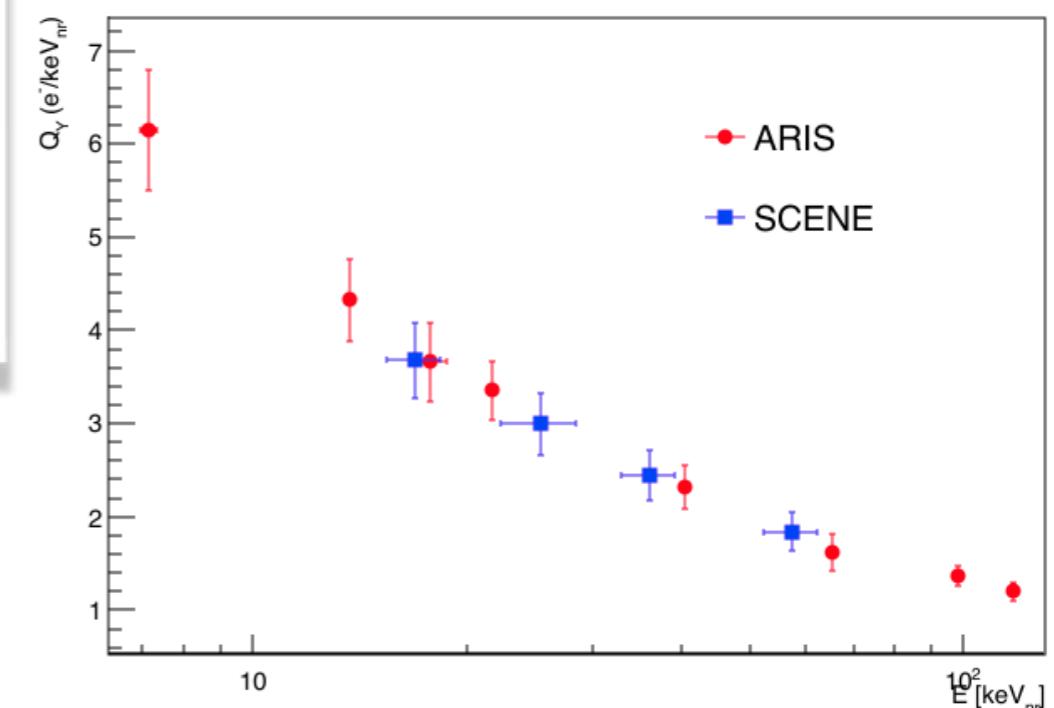
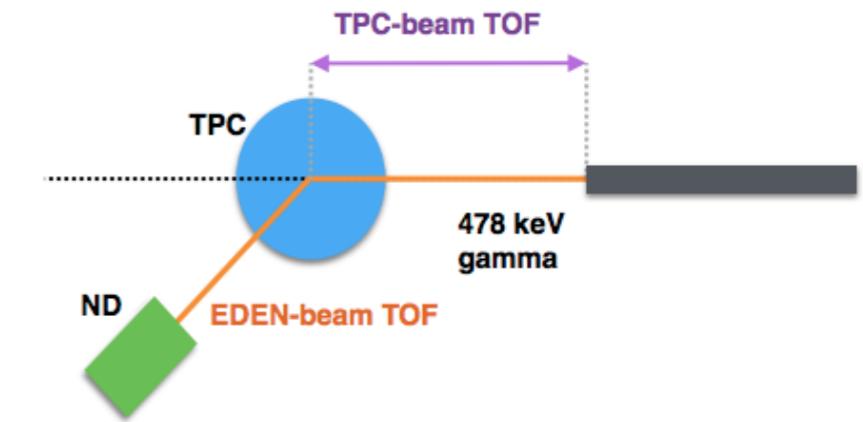


# LAr response to NR : ARIS experiment



<http://aris.in2p3.fr>

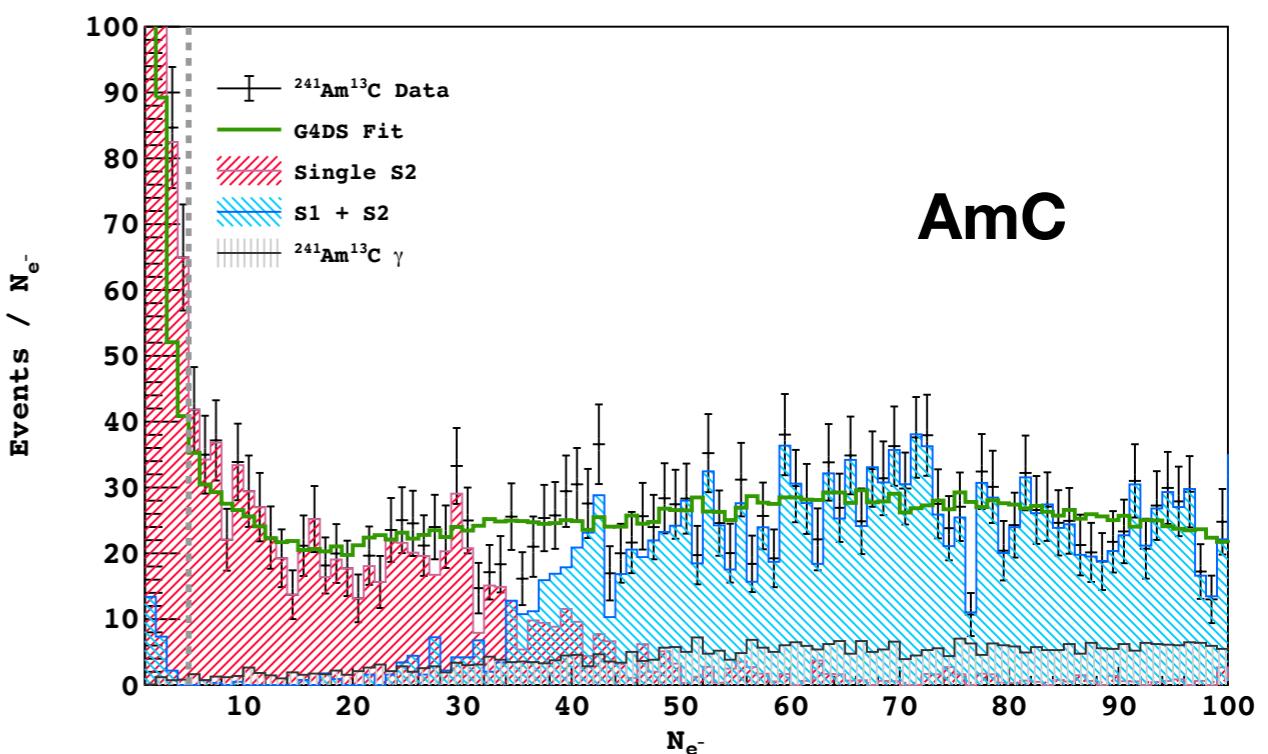
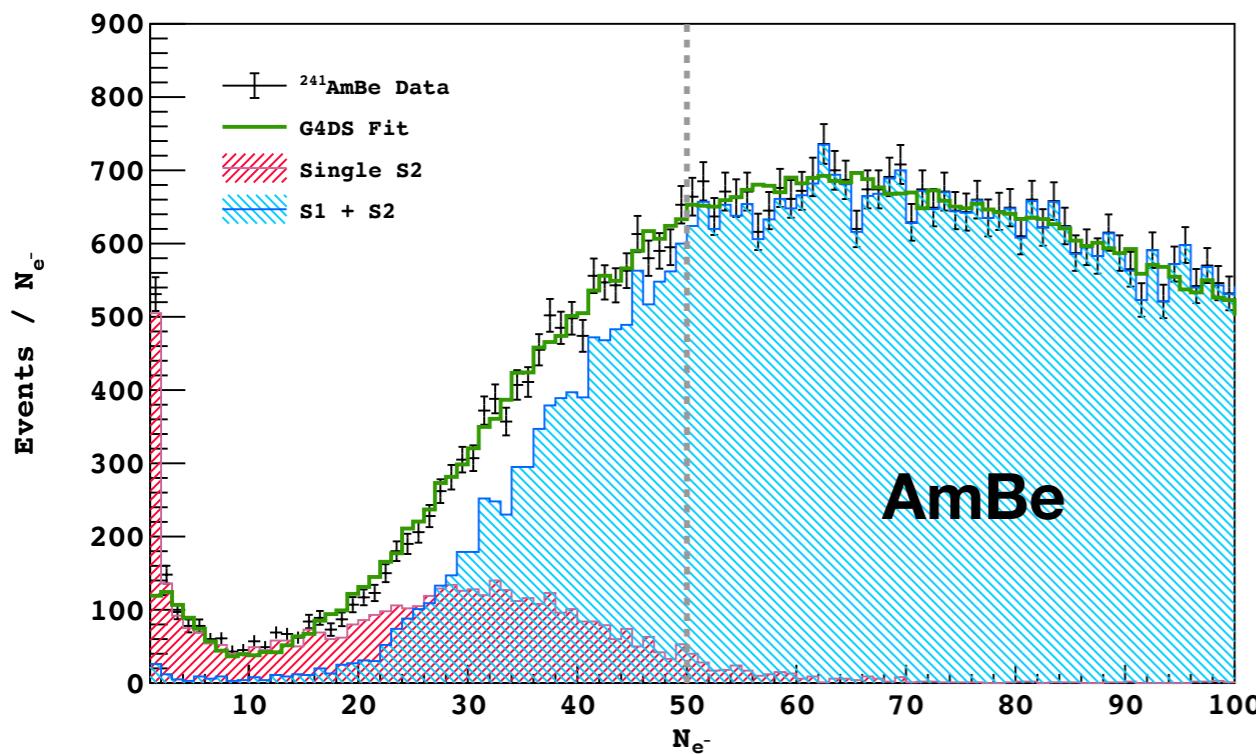
12 days of data taking  
in October 2016



**Measurement of scintillation for NR and ER and NR quenching  
Recoil energies from 7 keV<sub>nr</sub> to 120 keV<sub>nr</sub>**

# NR energy scale: AmBe/AmC

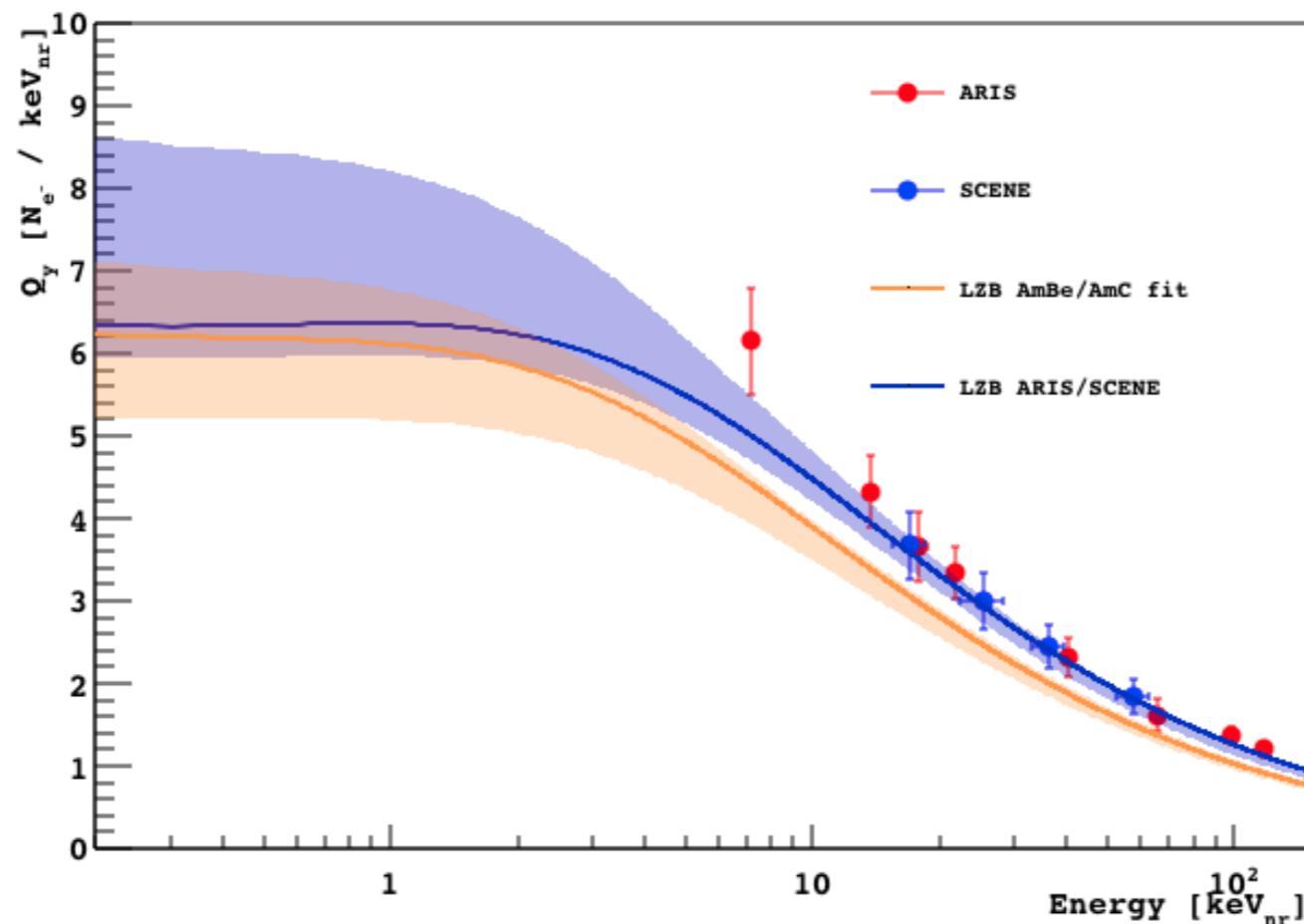
In-situ measurement of the ionization model for NR with AmBe and AmC sources



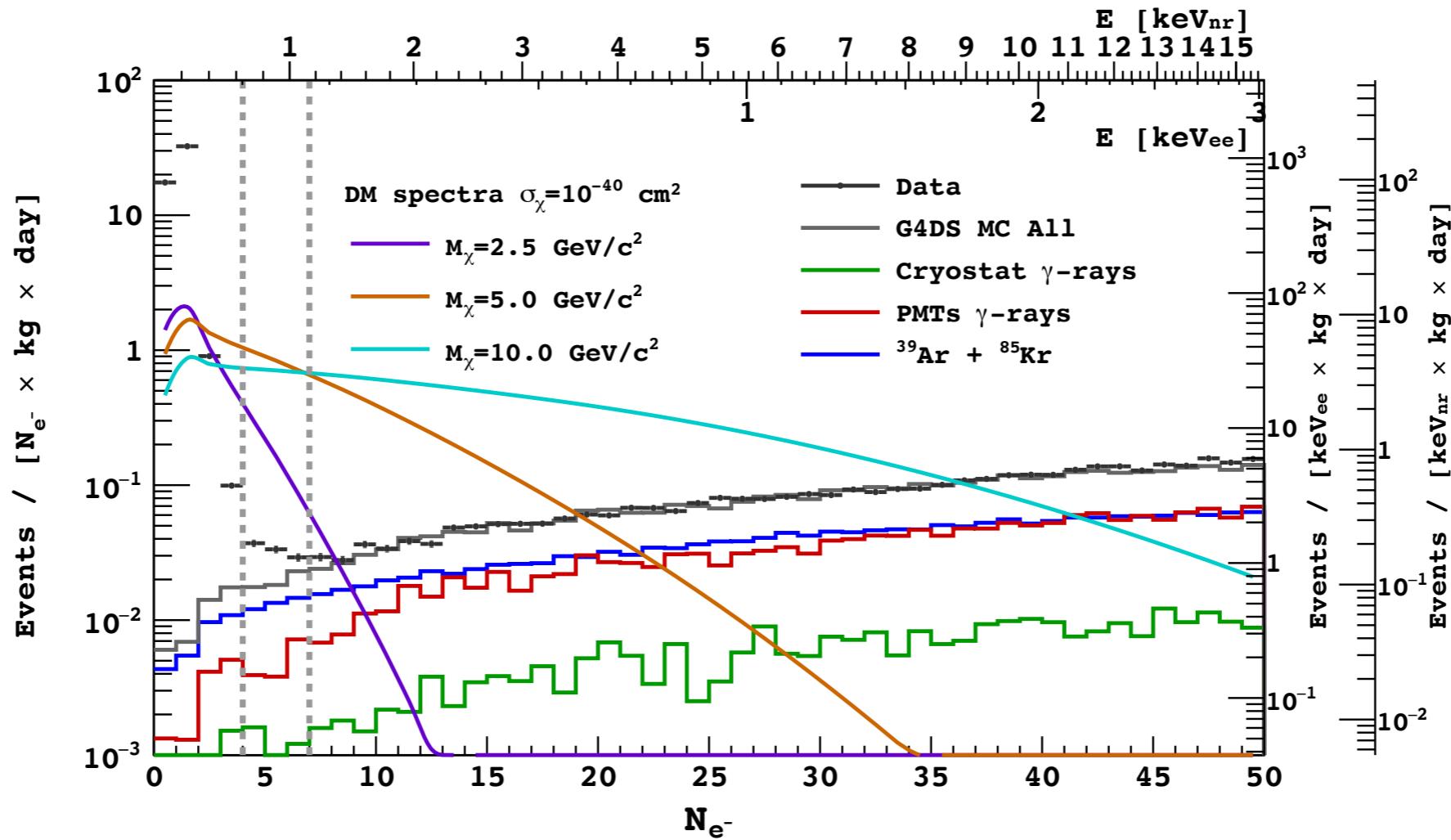
- DS-50 MC model fit to the calibration data
- Allows to directly measure the ionization response down to the low mass WIMPs energy of interest

# NR energy scale

- 20% difference between ARIS and AmBe/AmC measurements
- Use AmBe/AmC yield in the analysis
  - Lower Qy hence conservative limit

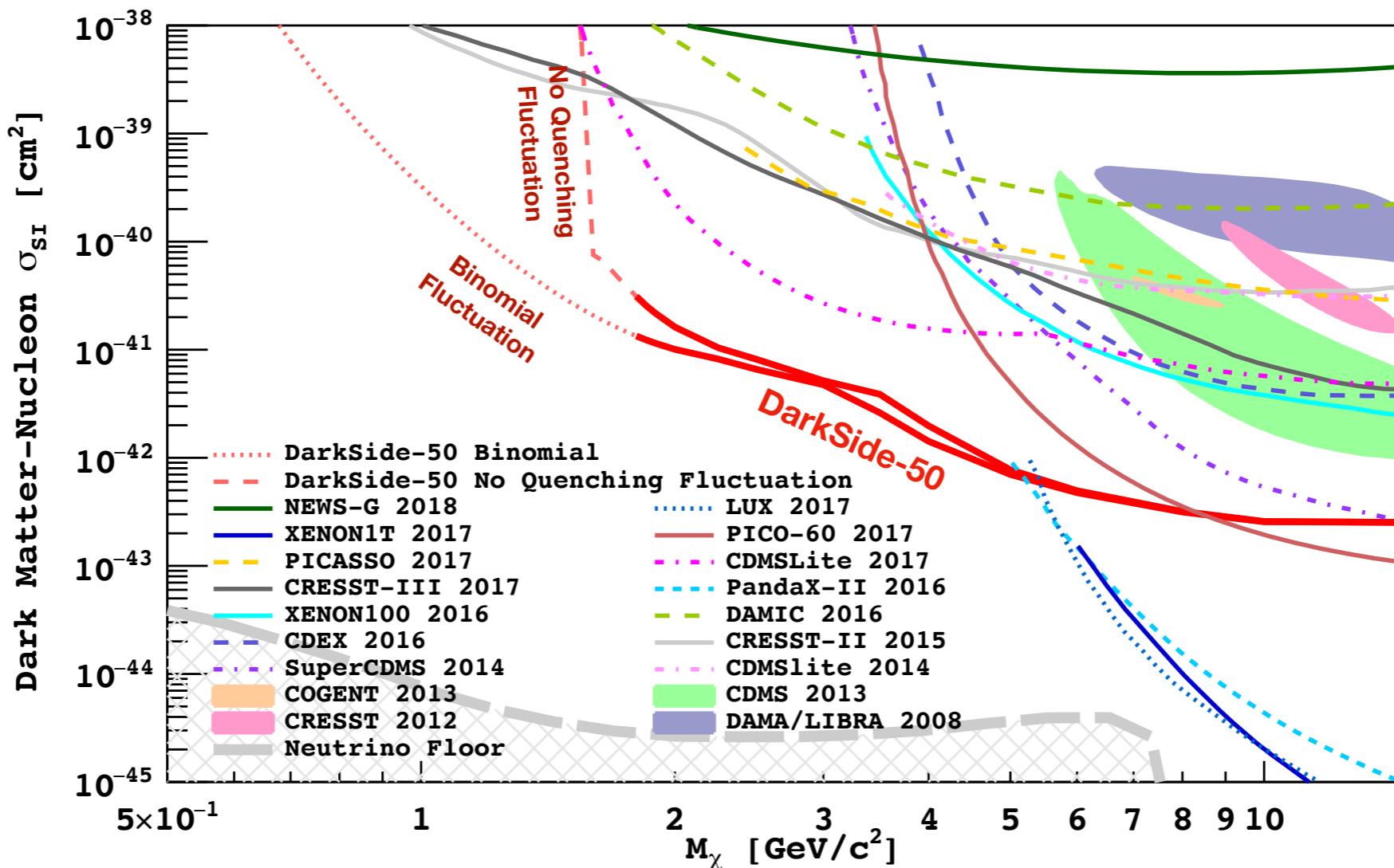


# Low energy backgrounds



- $N_{e^-} < 4$  ( $E < 0.6 \text{ keV}_{\text{nr}}$ )  $\rightarrow$  dominated by trapped electrons  $\rightarrow$  region not used in the analysis
- $N_{e^-} \geq 7$   $\rightarrow$  background reproduced by MC component measured by high energy spectral fit
  - Dominated by  $^{85}\text{Kr}$  and  $^{39}\text{Ar}$
- $4 < N_{e^-} < 7$   $\rightarrow$  excess of the data with respect to the MC likely due to the trapped electrons that are not modeled

# 90% CL exclusion limits

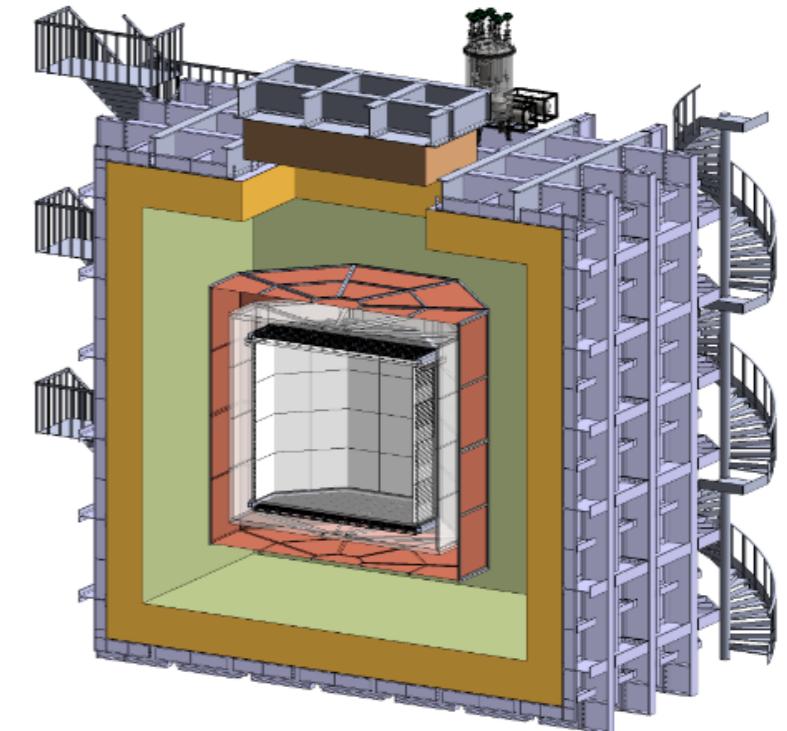


- Profile likelihood analysis → uncertainties from WIMP signals and backgrounds
- Two low energy fluctuations scenarios:
  - No fluctuations
  - Binomial fluctuations
- Improve limits by 1 order of magnitude in the region below 6 GeV

# Future: DarkSide-20k

## DarkSide-20k:

- 30 tons of LAr —> ~20 tons fiducial
- Underground & depleted argon (URANIA+ARIA)
- Photosensor: SiPM

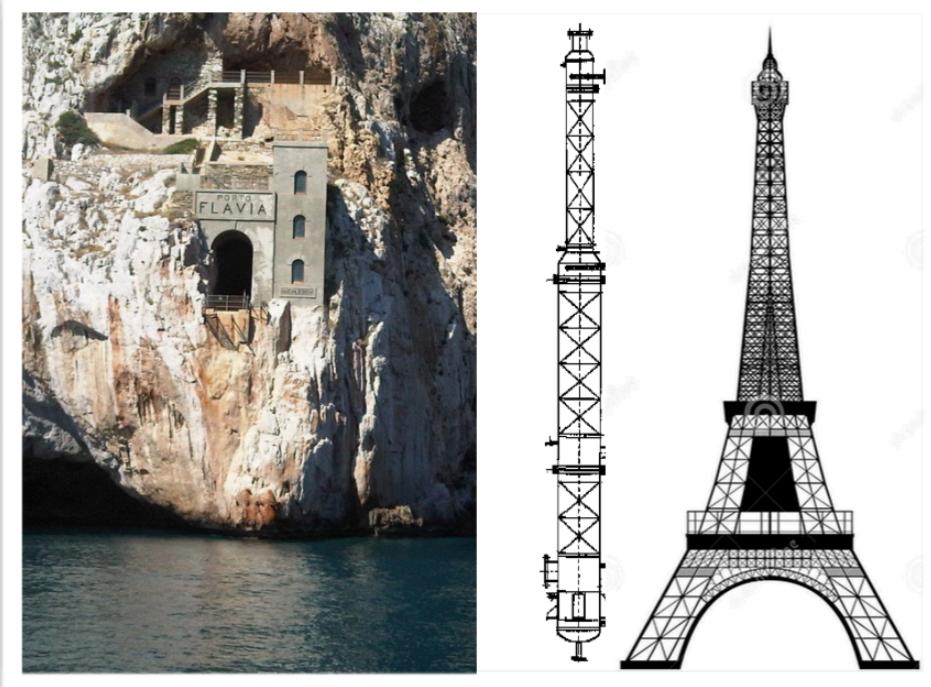


## Requirements:

All instrumental backgrounds must be  
**lower than 0.1 evts / 100 t.y**

## ARIA (UAr purification):

300 m tall column in the Seruci mine in Sardinia (Italy) for high-volume **chemical and isotopic purification of underground argon**



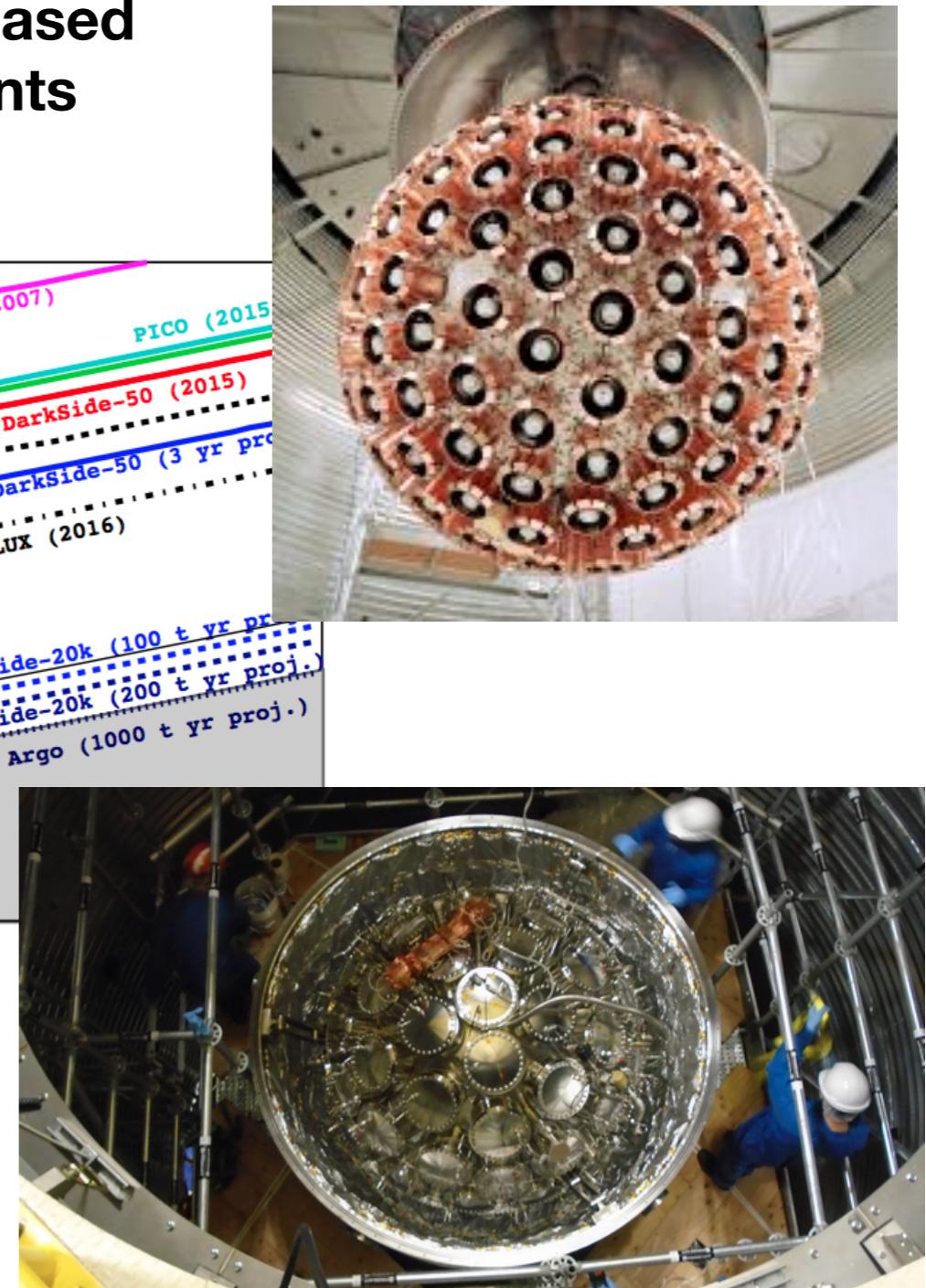
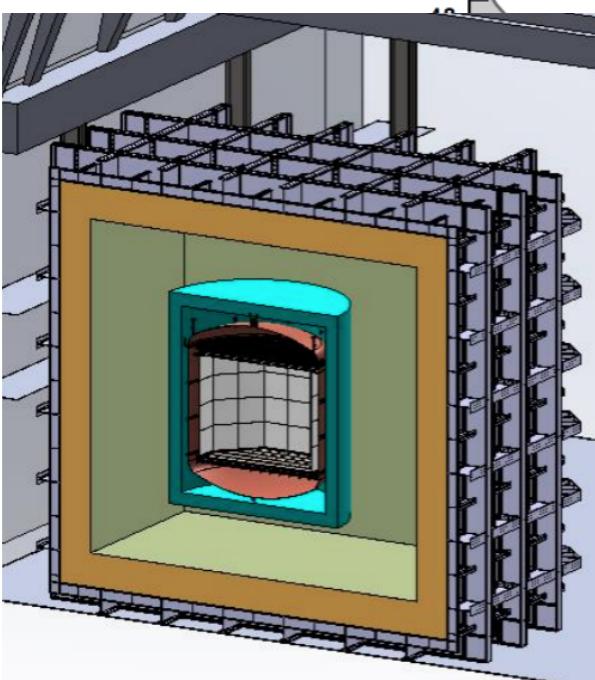
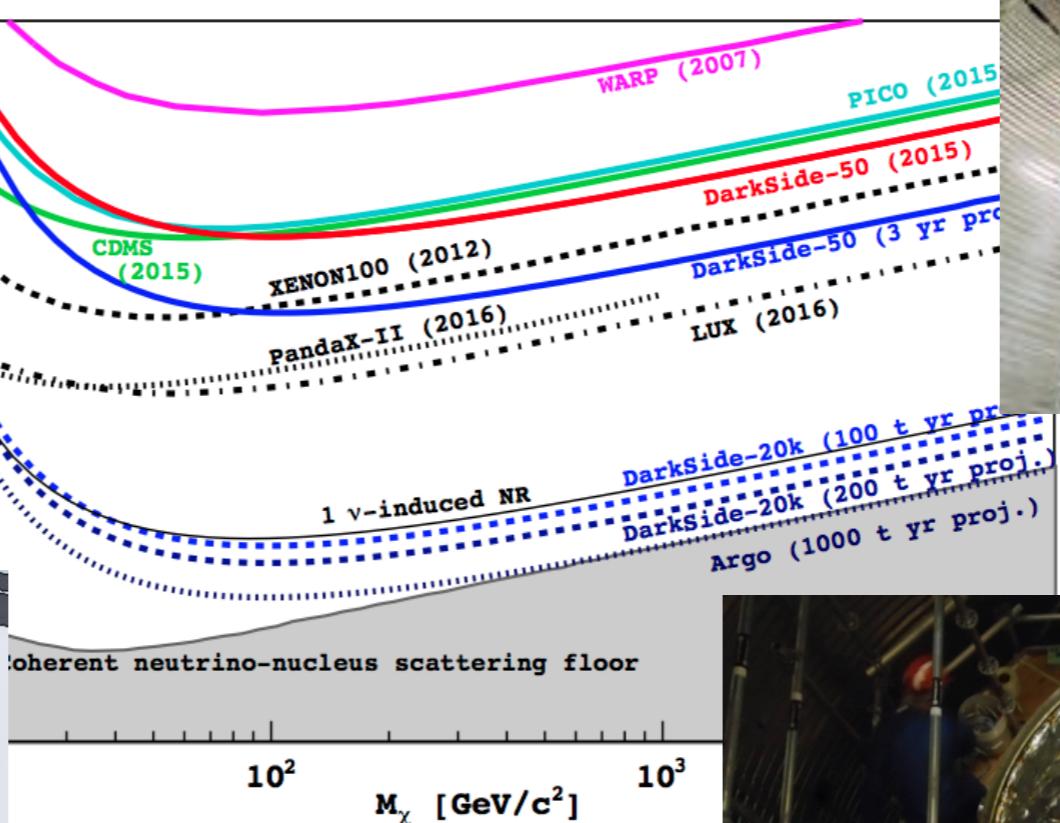
## Urania (UAr extraction):

Colorado UAr production facility.  
Production: 100 kg/d

# Future: the Global Argon Dark Matter Collaboration



Global effort of all LAr-based  
dark matter experiments

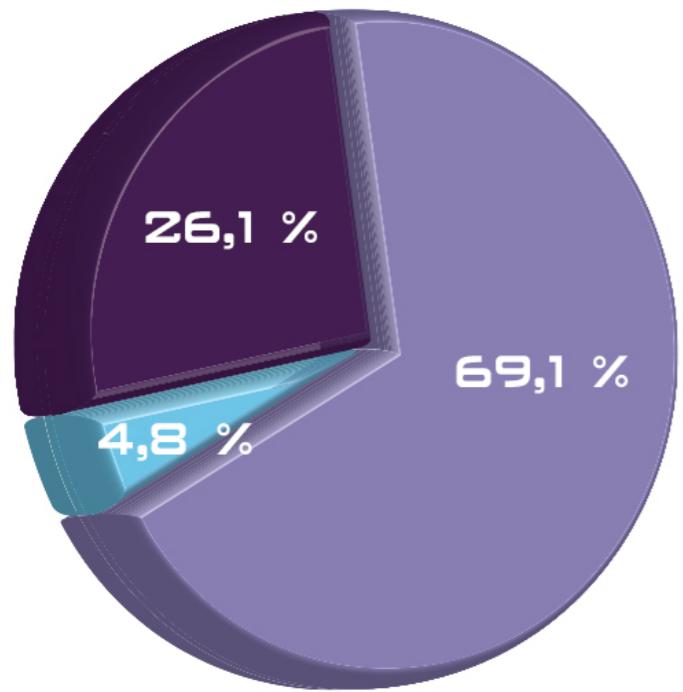
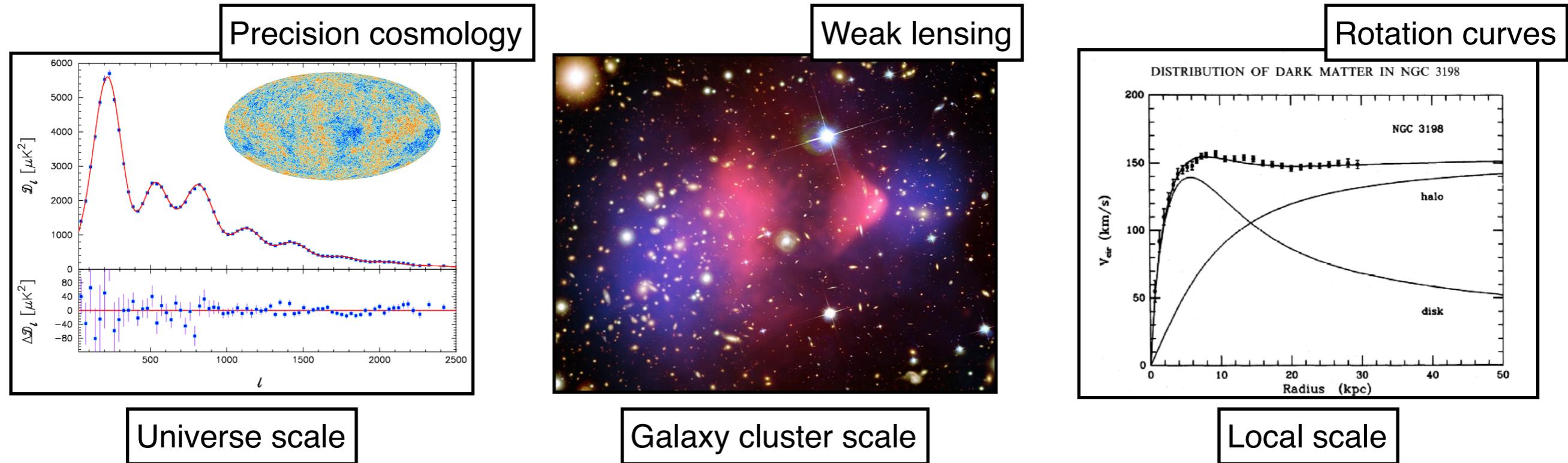


# Conclusions

- DarkSide-50 is a very successful detector
  - **Background free search for high mass WIMPs** -> pave the way for DarkSide-20k
  - **Best world limits for low mass WIMPs** -> noble liquids are the leading technology in this mass range also
    - Important to do more measurement of LAr response to NR at low energies
- **DarkSide-20k is moving forward, will start in 2021**
  - DEAP-3600, MiniCLEAN, ArDM and CERN joined the project
- Final goal: **300t Argon observatory for Dark Matter and Neutrinos**

# **Backup slides**

# The Dark Matter enigma

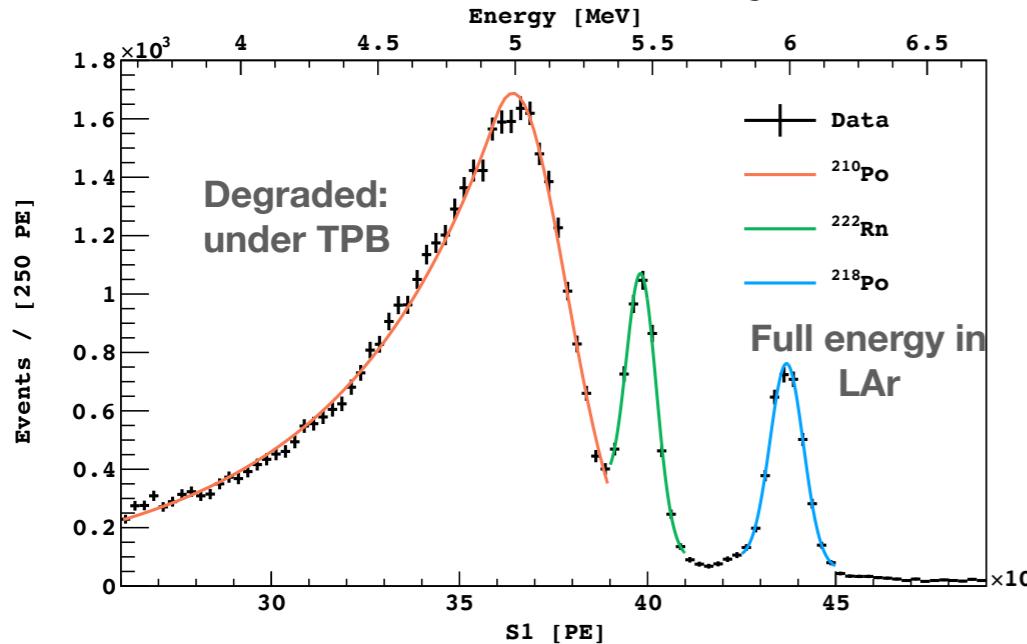


- Dark matter
- Baryonic matter
- Dark energy

**Weakly Interacting Massive Particles**  
are one of the main DM candidates

# NR background

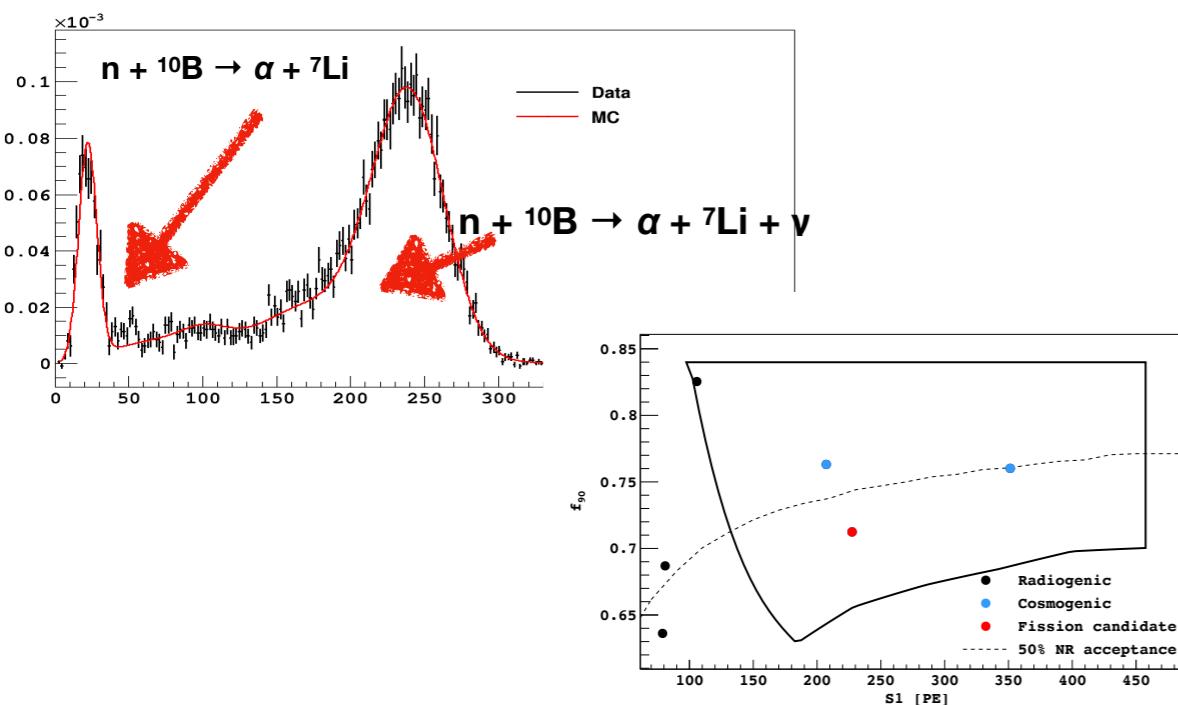
## Surface $\alpha$ decays



Surface  $\alpha$  decays  $\rightarrow$  expect  $< 0.001$

- \* Well above the WIMP search region ( $S_1 < 460$ )
- \* Small or no  $S_2$  for events with large  $R$
- \* Long scintillation tail from TPB

## Neutrons



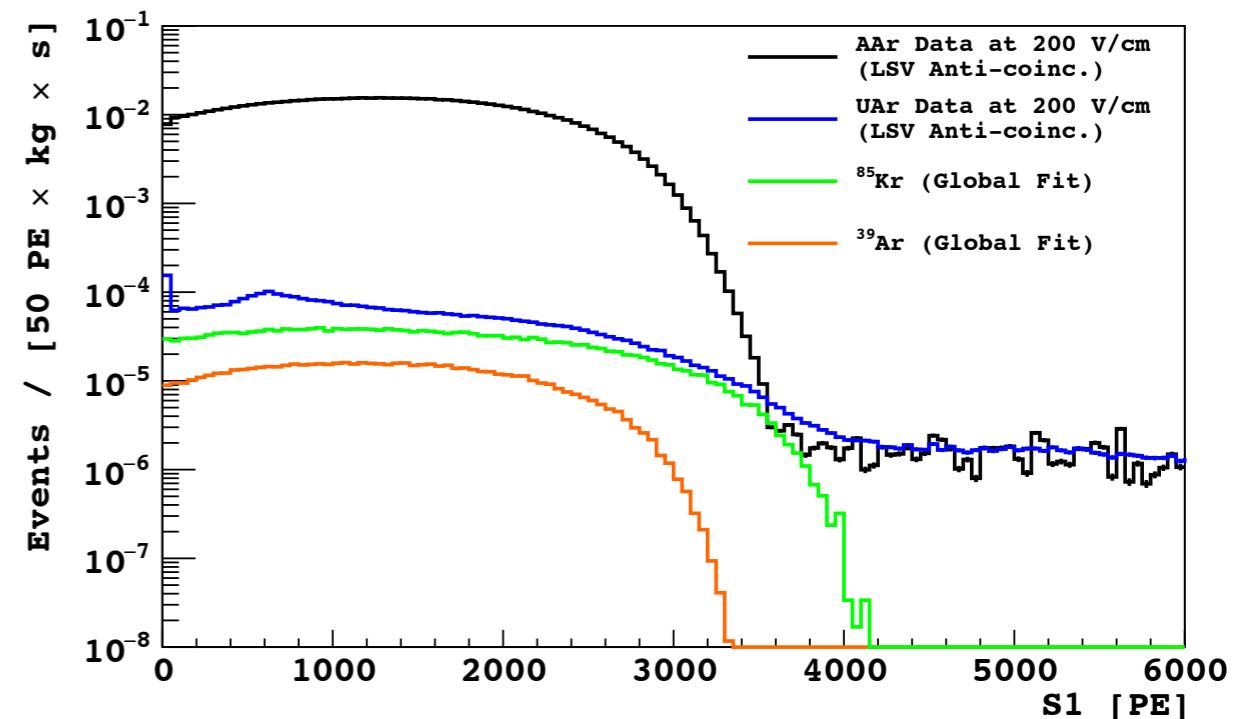
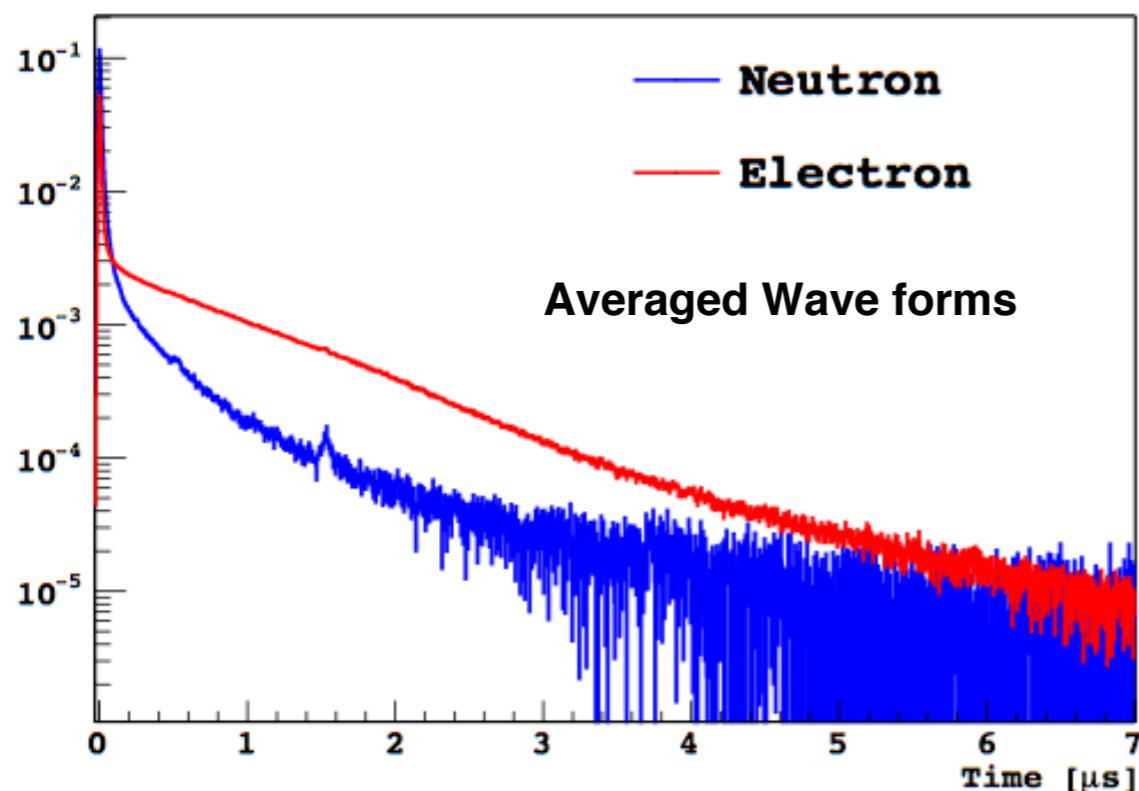
Neutrons (cosmogenic or radiogenic)  $< 0.005$

- \* Cosmogenics: Water Cherenkov Veto  $\rightarrow$  completely negligible
- \* Radiogenics: LS Veto and multi-scatter events in the TPC
- \* Measured LSV tagging efficiency with Am-C source for TPC single-NR:  $0.9964 \pm 0.0004$
- \* Neutrons are counted to confirm prediction

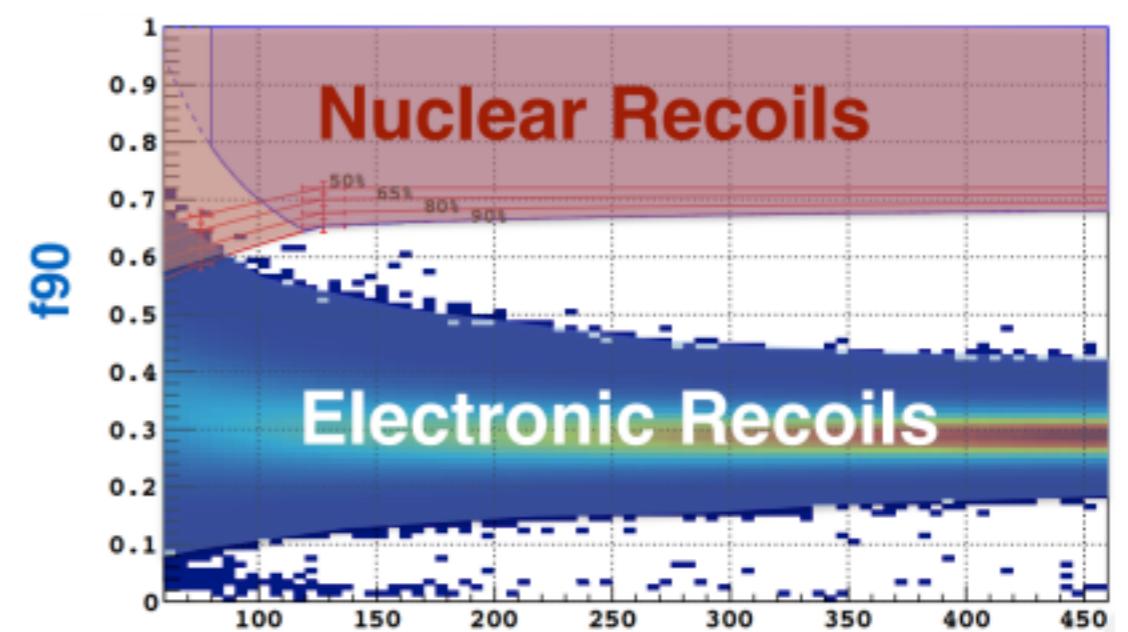
# ER background

ER rejection:

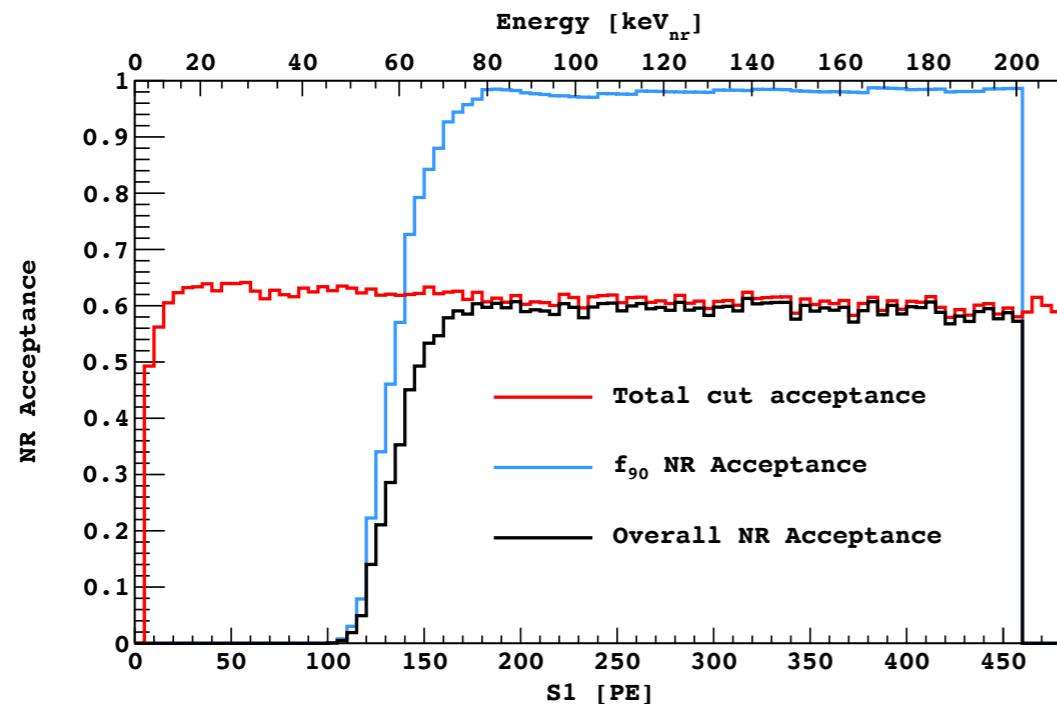
- \* Underground Ar → reduce Ar39 by a factor of 1400
- \* PSD:  $f_{90} = S1$  fraction in first 90 ns
  - \* Allow to distinguish ER from NR with a discrimination power of  $>1.5 \times 10^7$



In previous DS-50 papers the WIMP acceptance region was designed with the requirement of having  $<0.1$  background events from pure ER



# Background estimates and acceptance



Background	Events surviving all cuts
Surface Type 1	$0.0006 \pm 0.0001$
Surface Type 2	$0.00092 \pm 0.00004$
Radiogenic neutrons	<0.005
Cosmogenic neutrons	<0.00035
Electron recoil	$0.08 \pm 0.04$
<b>Total</b>	<b><math>0.09 \pm 0.04</math></b>

Design goal achieved

Cut	Livetime/Acceptance
All channels	545.6 d
Baseline	545.6 d
Time since prev	545.3 d
Veto present	536.6 d
Cosmo activ	532.4 d
Muon signal	0.990
Prompt LSV	0.995
Delayed LSV	0.835
Preprompt LSV	0.992
N pulses	0.978
S1 start time	1
S1 saturation	1
Min uncorr S2	0.996
xy-recon	0.997
S2 F90	1
Min corr S2/S1	0.995
Max corr S2/S1	0.991
S2 LE shape	1
S1 <sub>p</sub> max frac	0.948
S1 TBA	0.998
Long S1 tail	0.987
Radial cut	0.84
S1 NLL	>0.99
Combined	0.609

# Why noble liquid ?

Good target for DM searches: **relatively dense** and easy to purify

High **ionisation** yield ( $W \sim 10\text{-}20 \text{ eV}$ )

High **scintillation** yield ( $> 50,000 \text{ photons/MeV}$ )

**Transparent** to their own scintillation light

**Liquid Xenon** (LUX, XENON, PandaX)

Higher sensitivity to low masses (lower th.)

More dense (self-shielded)

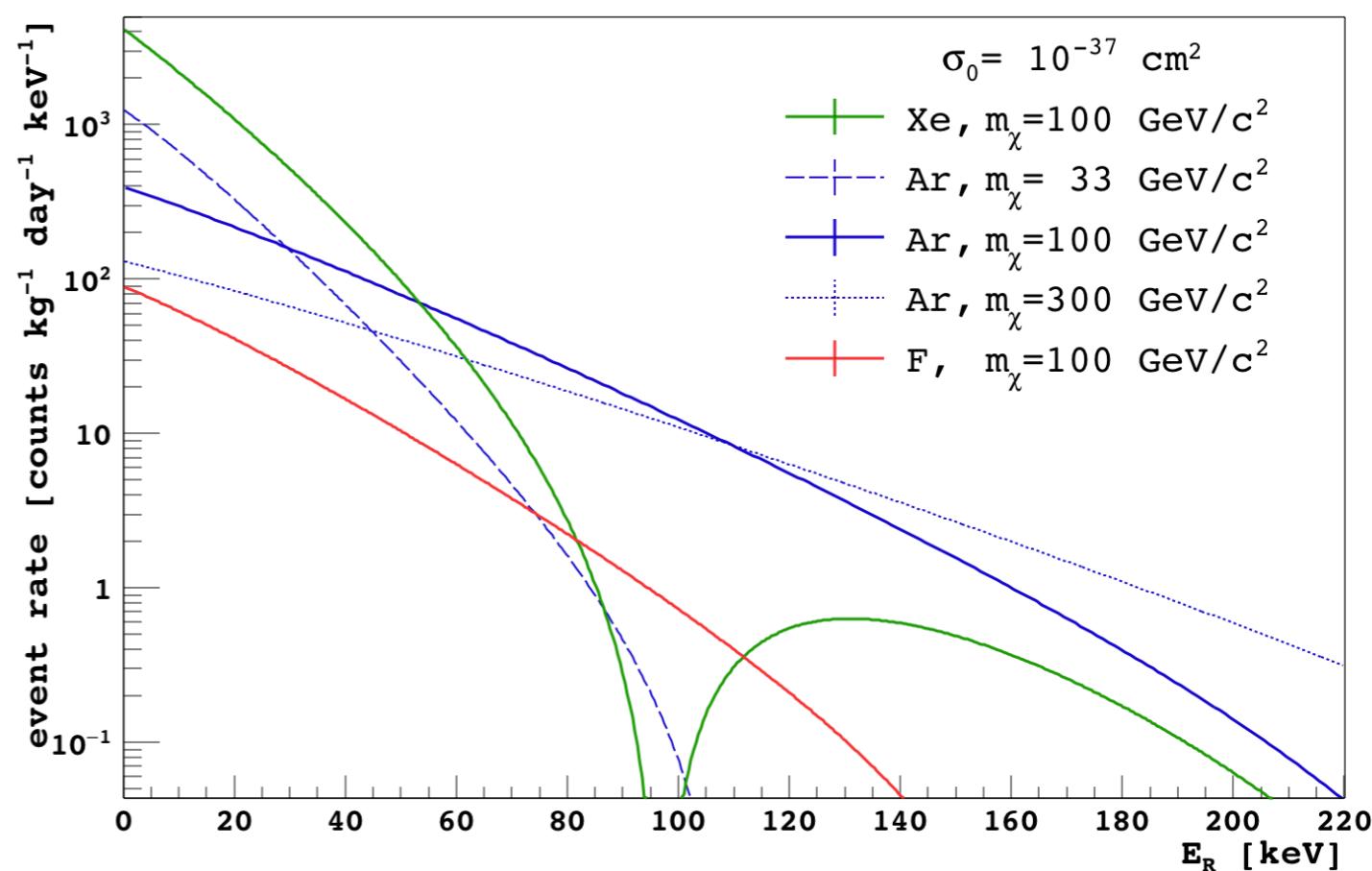
High intrinsic radio-purity

**Liquid Argon** (DarkSide, DEAP, ArDM)

**Intrinsic contamination from  $^{39}\text{Ar}$**

**Better ER/NR discrimination:**

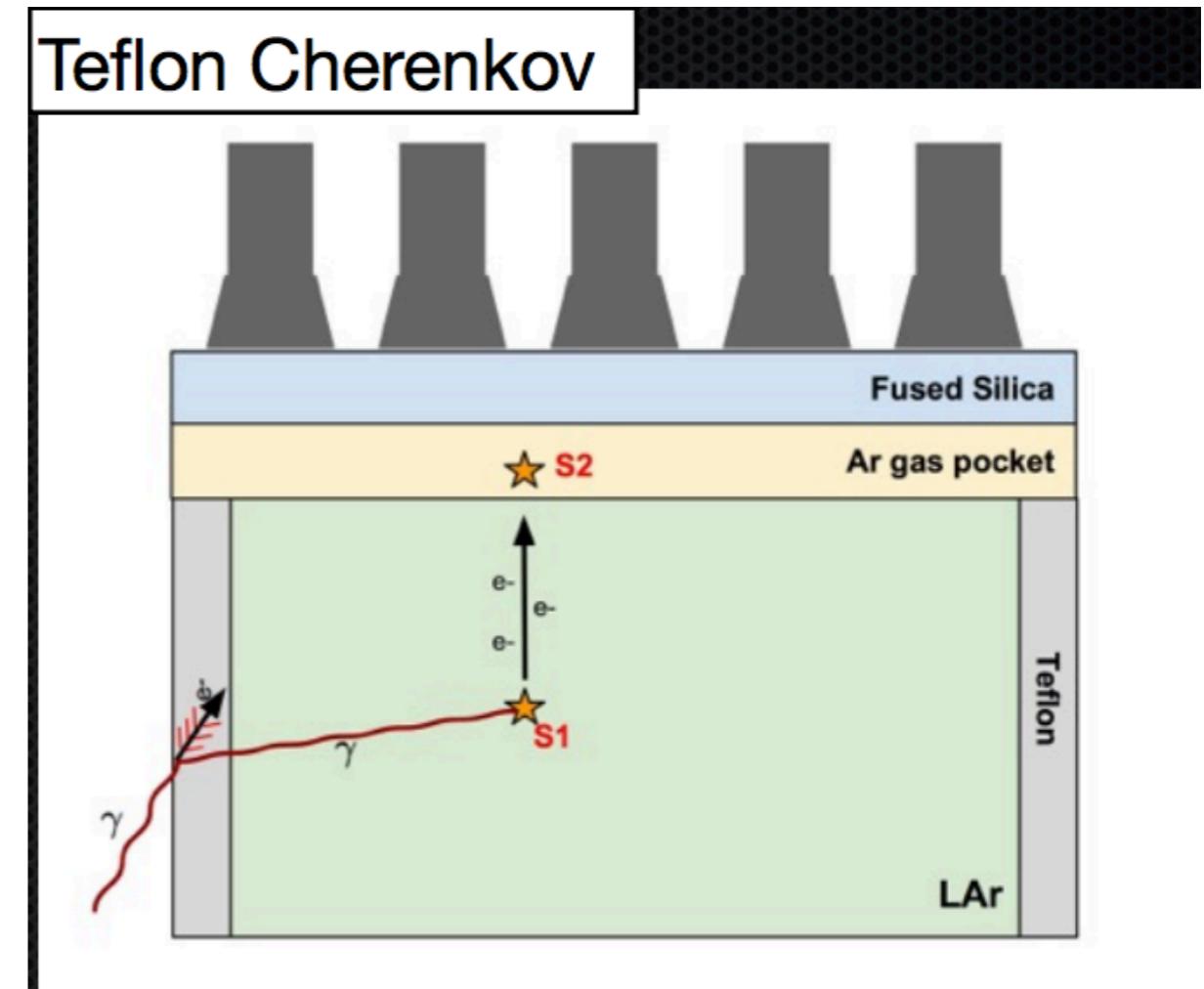
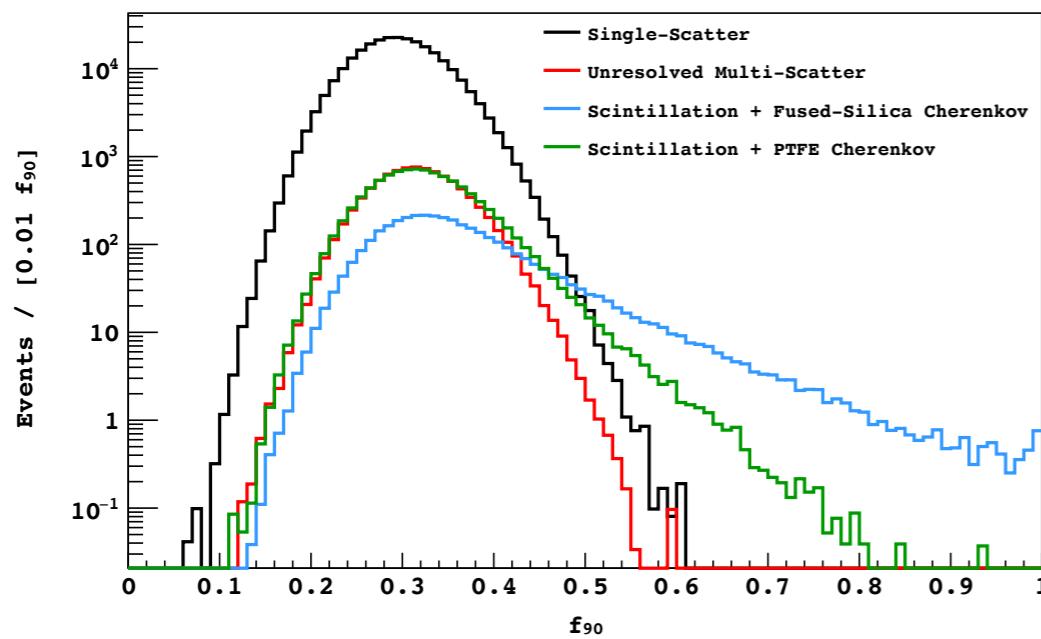
ionisation/scintillation + PSD



# ER +Cerenkov background

\*Another source of background has extensively studied: ER + Cherenkov

- \* Cherenkov light is all prompt → combined with an ER they enhance the f<sub>90</sub> from ER
- \* In the blind analysis some cuts have been implemented to reject ER+Cherenkov (radial cuts, Top/Bottom asymmetry vs tdrift, S1 prompt, ...)

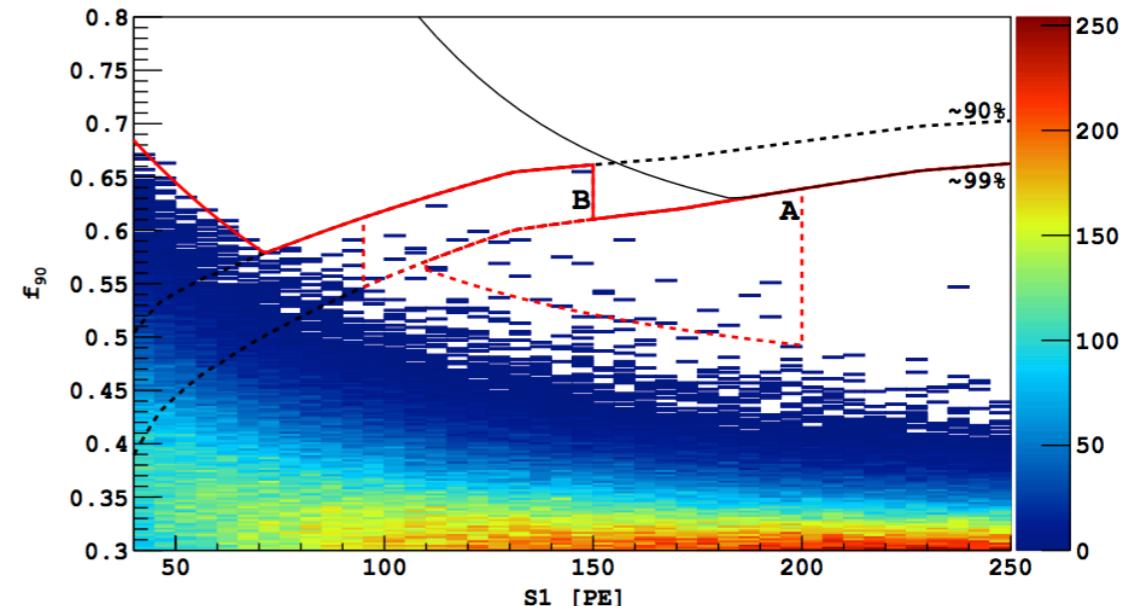
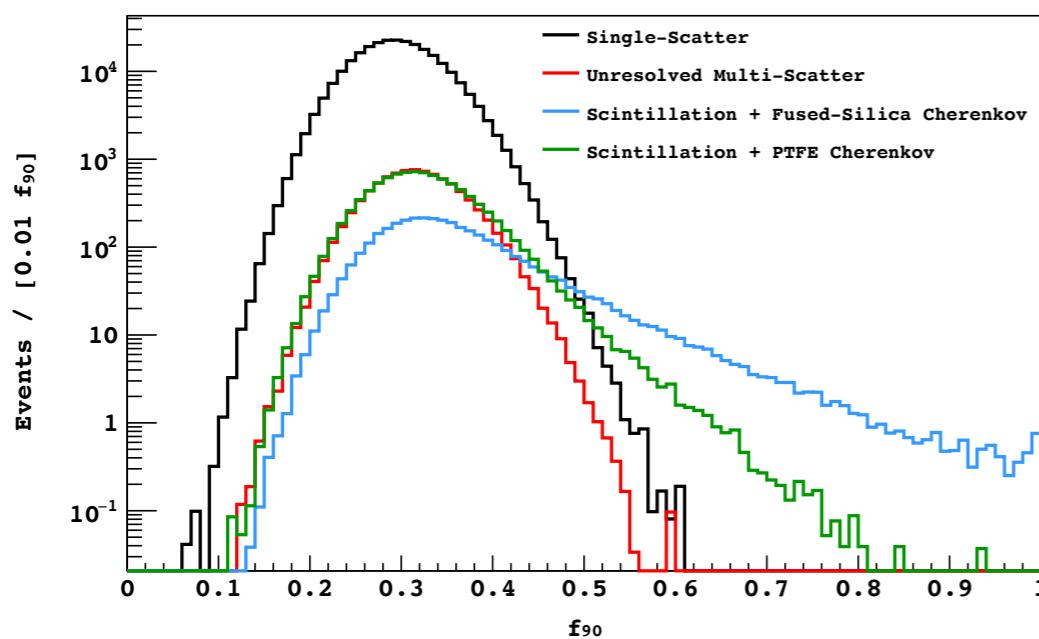


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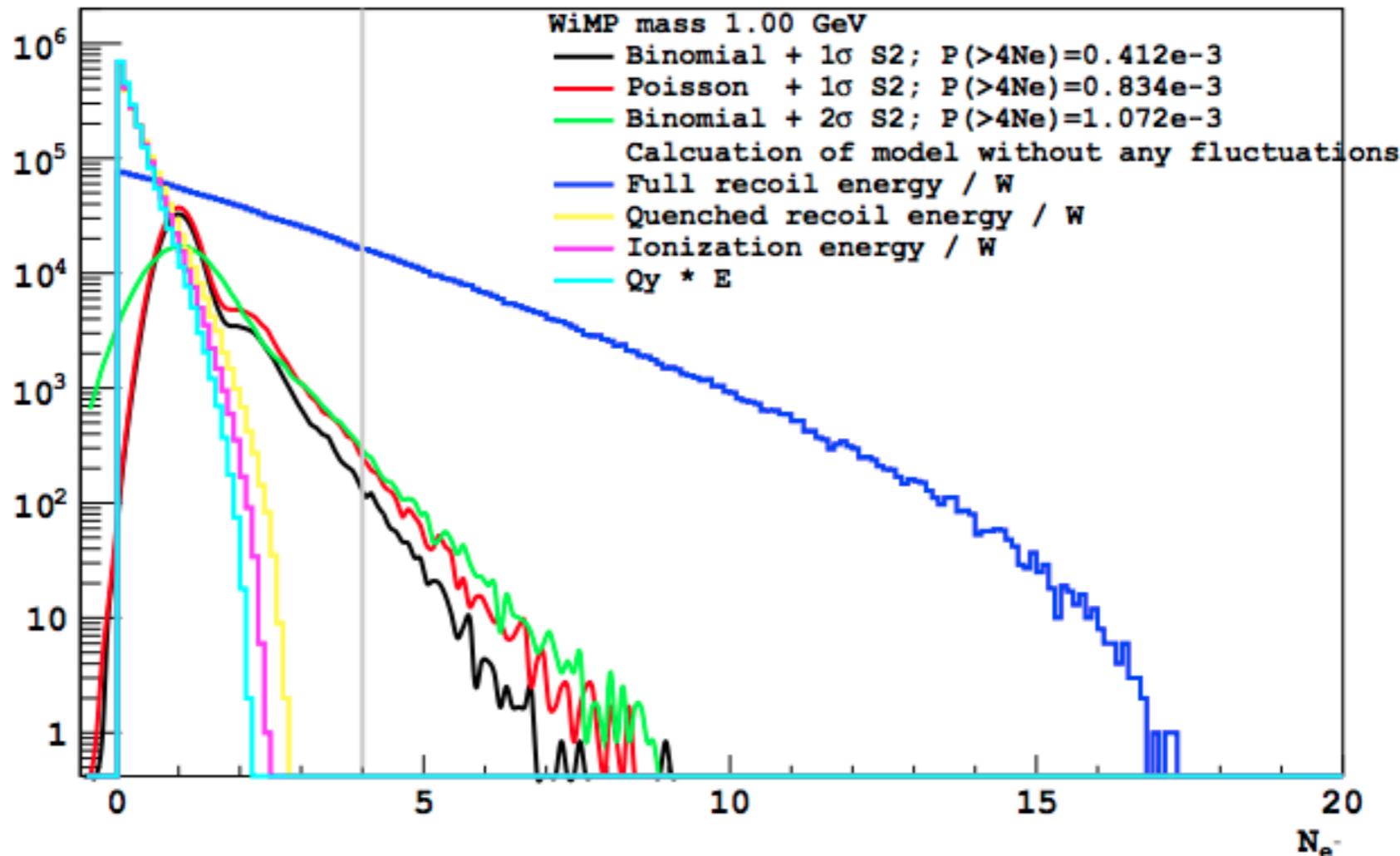
	A	B
Data	24	9
Model	13.3	8.7

\*Combining A and B we have 33 events, 14 of them surviving a radial cut → rejection factor of the radial cut

\*Factor of 1.5 discrepancy between data and model is taken into account when drawing the box

\*ER + Cherenkov is the dominant background for DS-50

# Low energy fluctuations



- For very low mass WIMPs, the recoil energy is always below 4 Ne
- Can exceed this value thanks to fluctuations in the quenching, recombination or ionization processes
  - No modeling (binomial is a hypothesis)
- Due to the lack of knowledge, no limit claimed below  $M_{\text{WIMP}} = 1.8 \text{ GeV}$

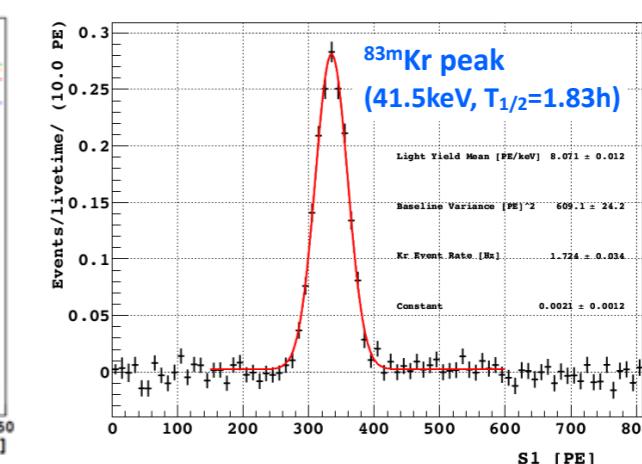
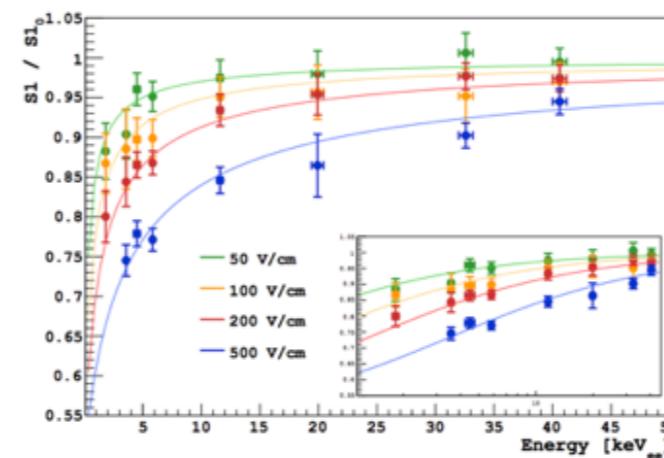
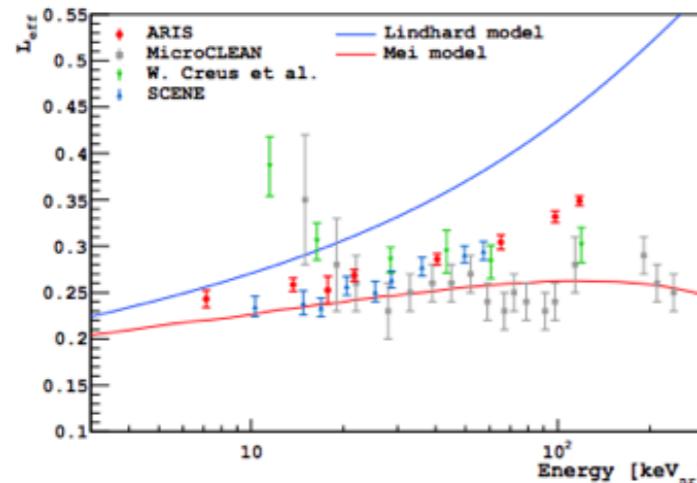
# NR energy scale: ARIS

$$S1_{DS50} (Enr) =$$

$$L_{eff} = S1^{0V} / (E_{nr} \times LY_{ARIS})$$

$$\times S1^{200V} / S1^{0V} \times E_{nr}$$

$$\times LY^{0V}_{DS50}$$



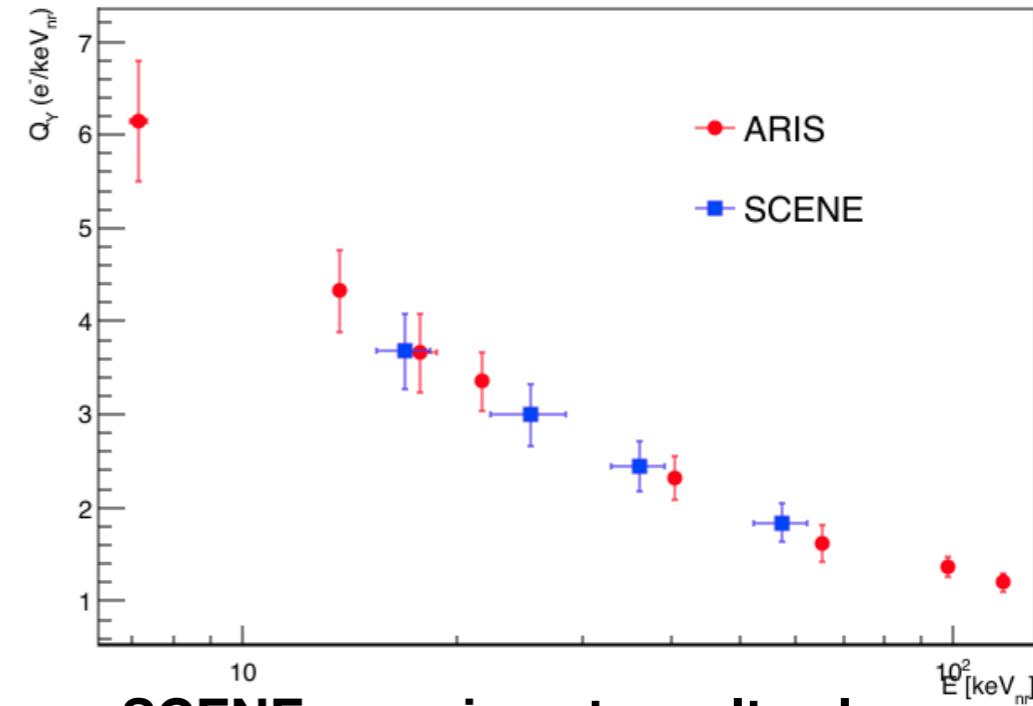
**S1 in DS-50 reconstructed using ARIS  $L_{eff}$**



**S2 derived from  $S2/S1$  vs  $S1$  from AmBe in DS50 data**



**Ionization yield in DS-50**



**SCENE experiment results also considered (direct ionization measurement)**

# Sub-GeV Dark Matter

- Light dark matter scatters off electrons → signal is ER
- Use same spectrum and two different form factors

