Study on low energy events in liquid argon for dark matter searches

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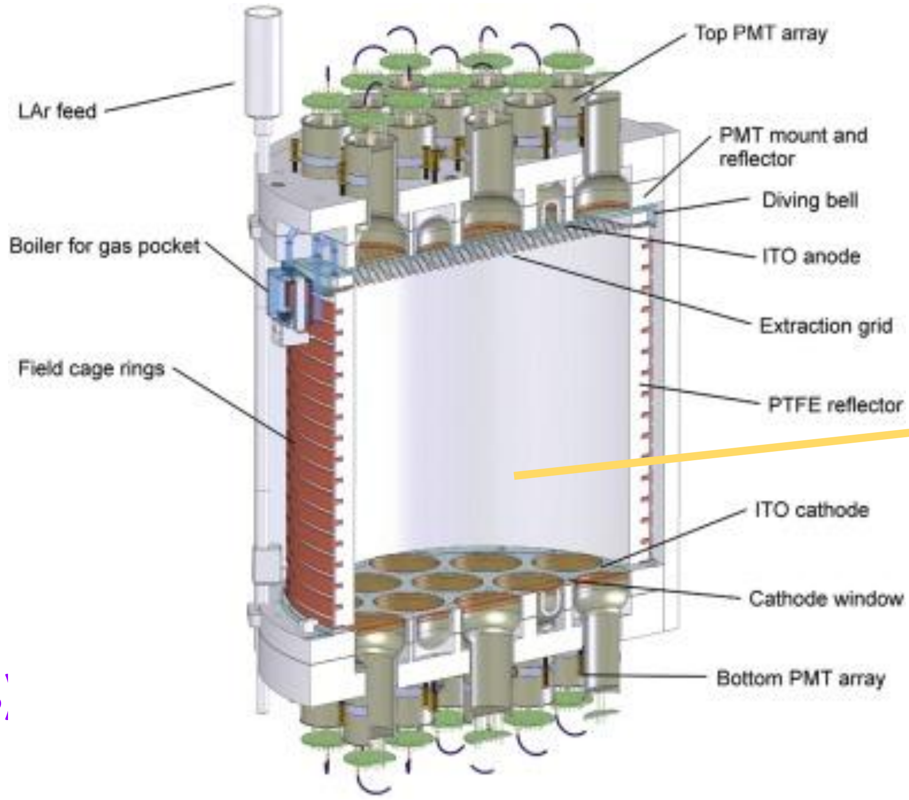
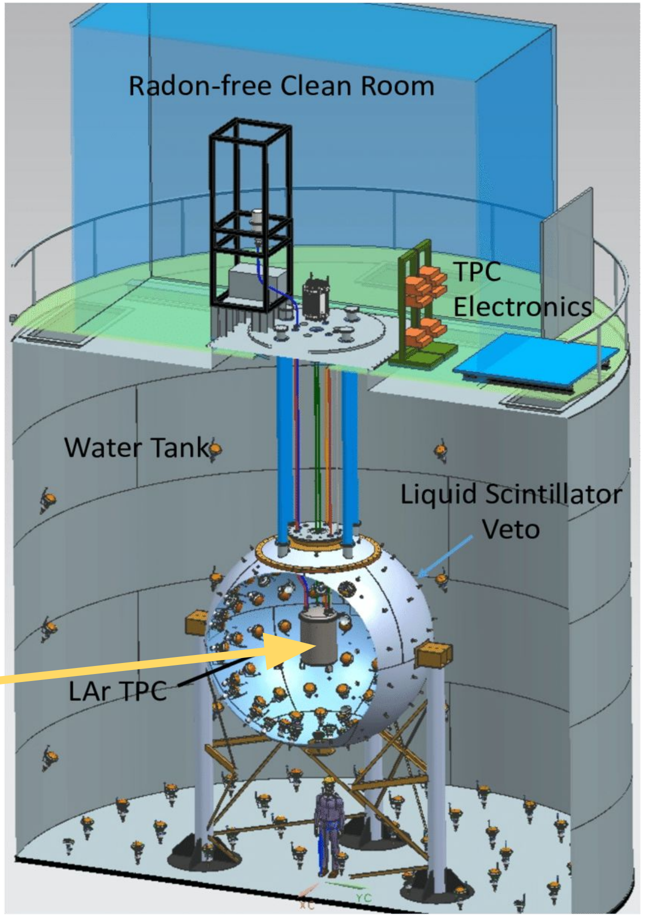
1. Checking the purity level of LAr in DarkSide-50 experiment

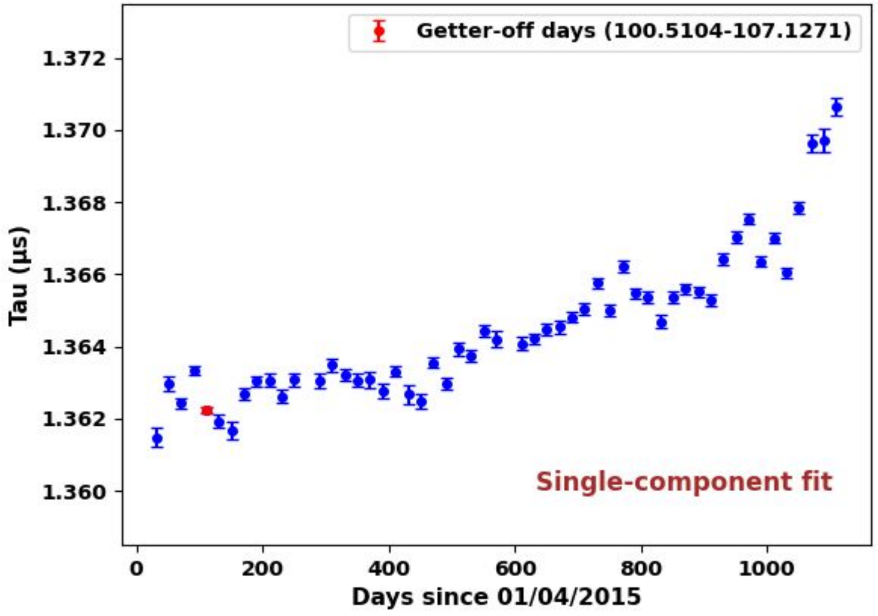
- LAr dual-phase time projection chamber (LAr TPC) at LNGS
- 46.4 ± 0.7 kg active target of UAr
- Readout from 19×2 PMTs
- UAr data collected from 2015 to 2018
- DM + Ar ⟹ Nuclear Recoils (NR)
- Primary scintillation signal ⟹ **S1**
- S1 light yield in DS-50 ⟹ 7.9 PE/keV
- S1 ⟹ Singlet (~ 6 ns), **triplet (~ 1.5 μs)** components.

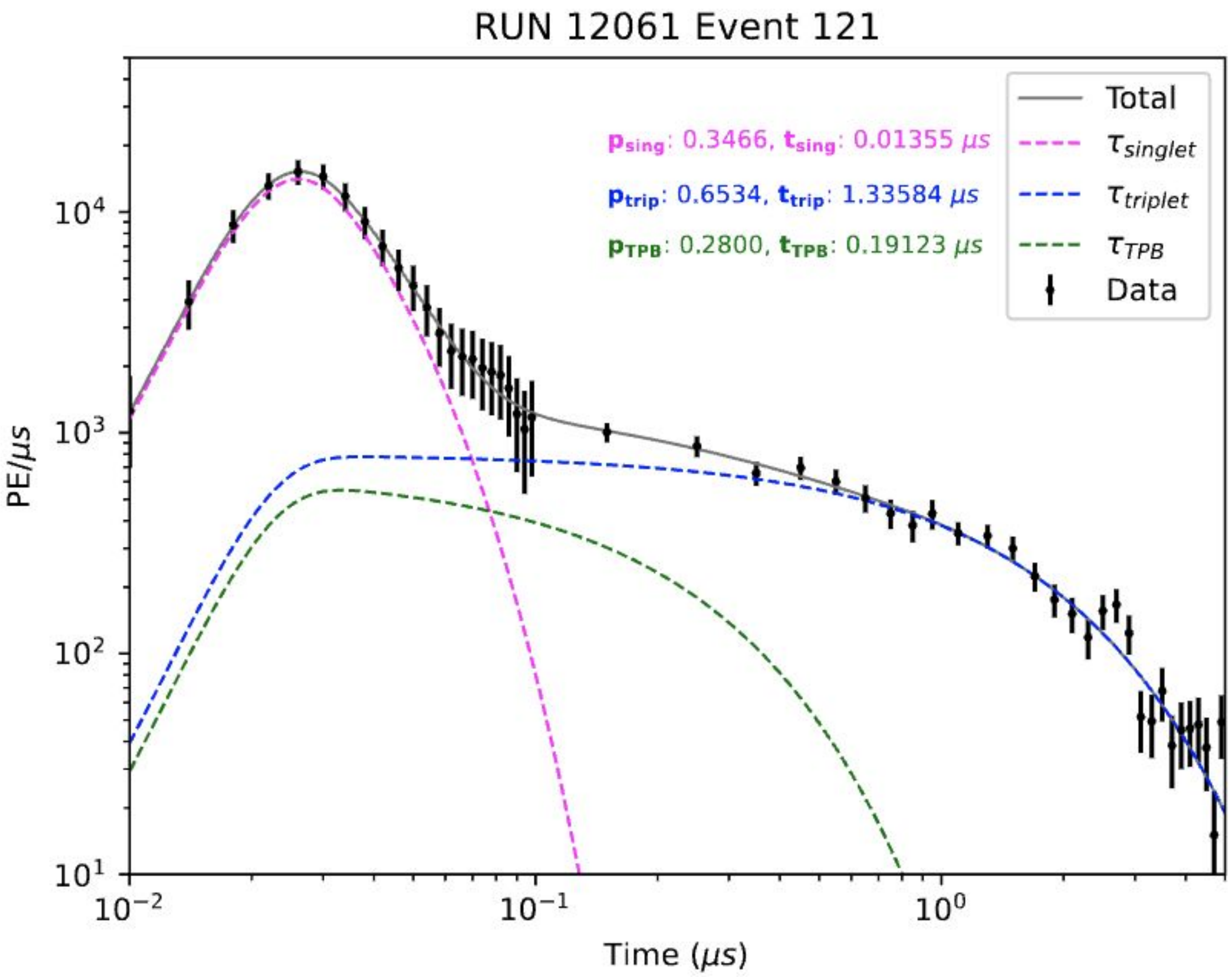




Impurities in DS-50 and its effects on S1 signal

- Impurities, such as N_2, at the ppm level causes **reduction of scintillation**, by suppressing lifetime of the triplet component (see arXiv:0804.1217v1 [nucl-ex] 8 Apr 2008).
- Analyzed 3-year data taken from DS-50 to check this effect.
- No degradation in triplet lifetime was observed, which may indicate that **the concentration of N_2 is very low (<ppm) in DS-50.**





2. Study of S3 signals (echoes) in order to estimate g2 parameter in ReD experiment

- Dual-phase TPC filled with LAr and equipped with cryogenic SiPMs.
- A single electron is extracted in the gas phase to create an S3 event ⟹ **Spurious electron (SE)** events
- S3 signals allow an independent measurement of the **S2 gain (g2)**
- g2 ⟹ Photoelectron yield per extracted electron in gas phase
- **g2 = S3/e⁻**

Ne = S2/g2

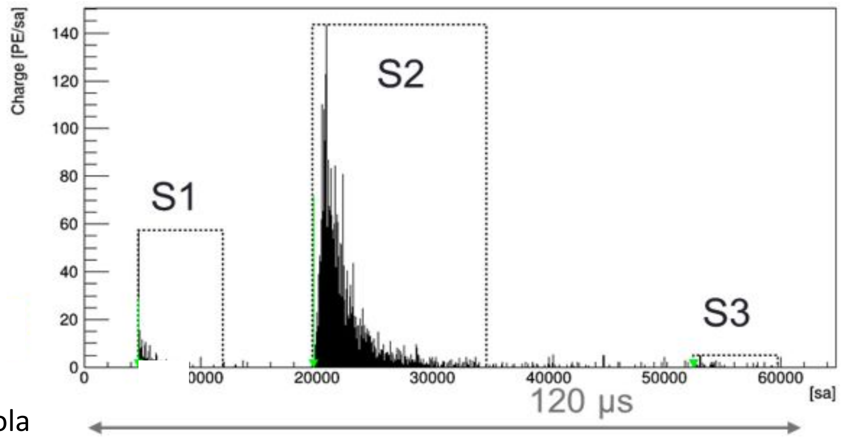
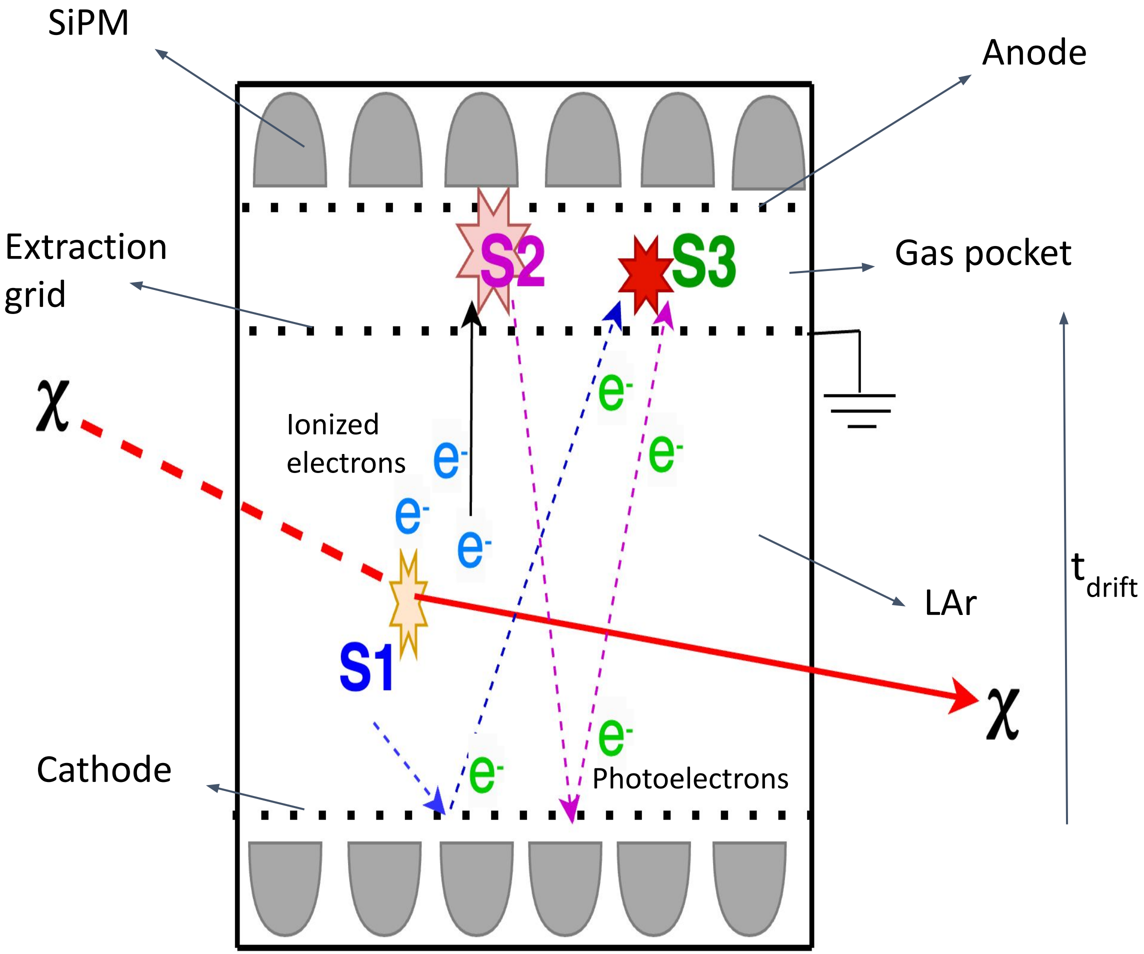
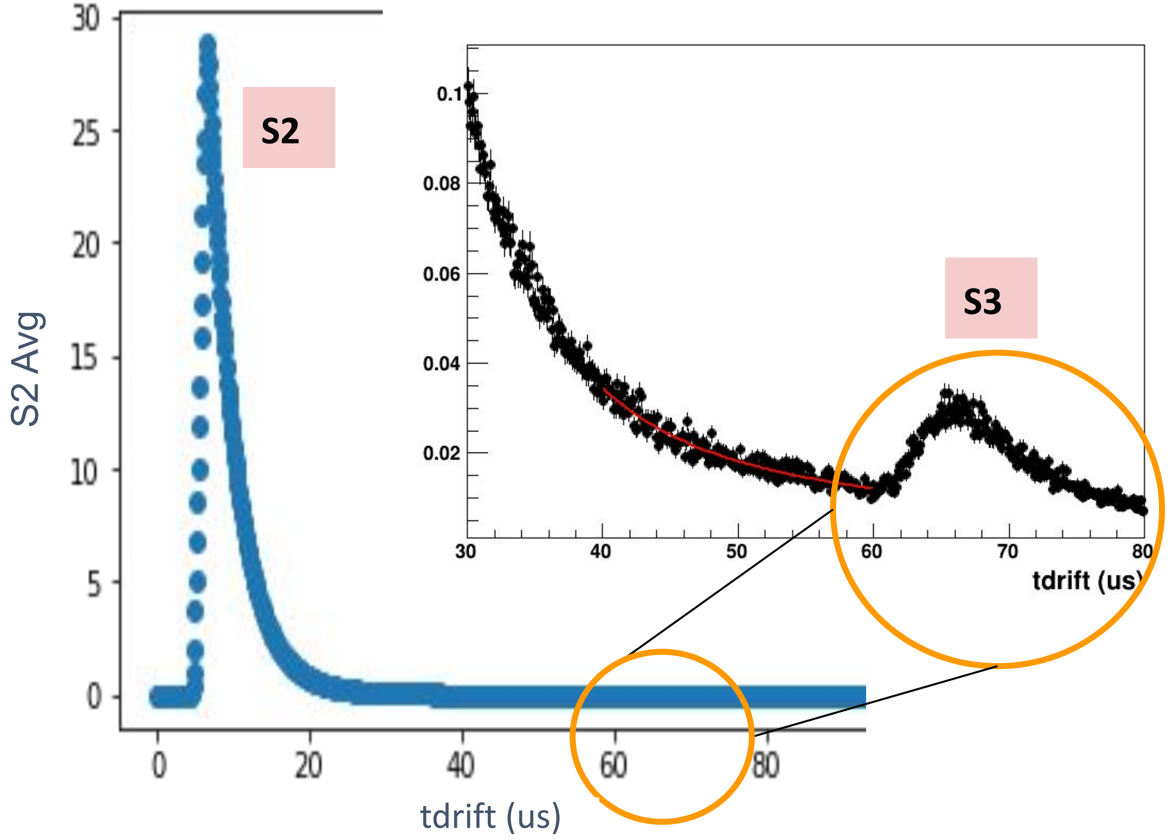


Image credits:
Luciano Pandola

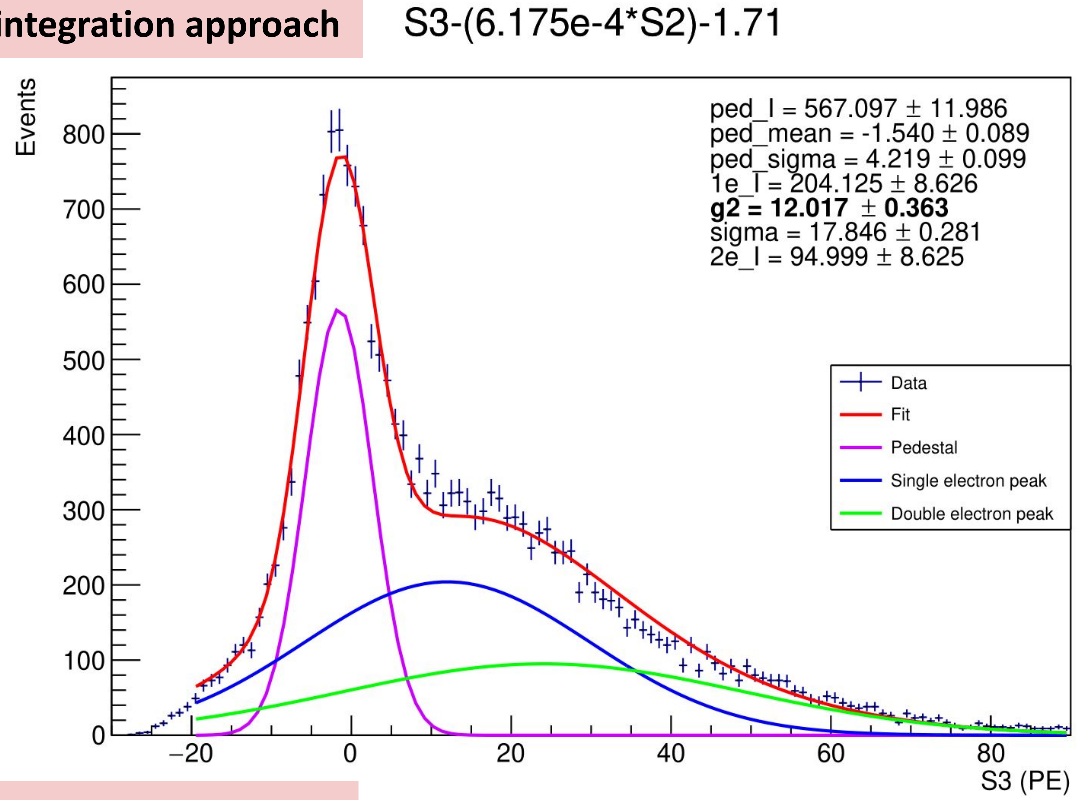


Determination of g2

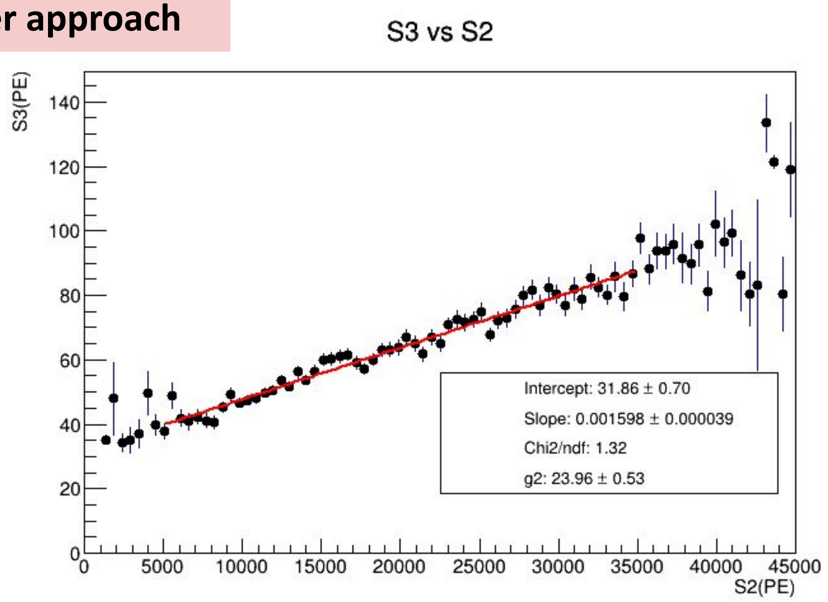
- **g2 ⟹ e^-/keV**
- S3 pulse found around **t_{drift} = 62 μs**
- Fixed-window integration done for S2 correction from S3 signal.
- g2 measured in pulse-finder method : 23.96 ± 0.53 PE/e-
- g2 measured in fixed-window method : **12.0 ± 0.36 PE/e-**
- Estimated g2 from Monte Carlo : **15 PE/e-**



Fixed-window integration approach



Pulse finder approach



Summary

- No degradation in triplet lifetime was observed in DS-50 , which may indicate that **the concentration of N_2 is very low (<ppm) in DS-50.**
- Analysis is done for the determination of g2 parameter using ^{241}Am source. Calculated **g2** using fixed-window integration method: **12.1 ± 0.36 PE/e-.** Comparison with MC is ongoing.

Upcoming tasks:

- Discussions are presently in progress regarding the design and construction of a TPC at AstroCeNT.
- vPDU testing at Cezamat.

References

- P. Agnes et al. (The DarkSide Collaboration), JINST, 12, P12011 (2017).
- WArP Collaboration, Effects of Nitrogen contamination in liquid Argon, arXiv:0804.1217v1 [nucl-ex] 8 Apr 2008.
- E. Sanchez Garcia (The DarkSide Collaboration), DArT, a detector for measuring the 39Ar depletion factor, arXiv:2001.08077v1 [physics.ins-det] 22 Jan 2020.
- P. Agnes et al. (The ReD Collaboration), Performance of the ReD TPC, a novel double-phase LAr detector with Silicon Photomultiplier Readout, arXiv:2106.13168v1 [physics.ins-det] 24 June 2021

Extra-curricular activities 2023

1. Attended "**Summer School** on Particle Physics" at ICTP in Italy in June 2023.
2. Attended and presented a poster during **summer school** in "MAYORANA School and Workshop" event in Modica, Italy in July 2023.
3. Attended **workshop** in "MAYORANA School and Workshop" event in Modica, Italy in July 2023.
4. Volunteered at the opening day of "27th Science Festival at Warsaw", as part of the **public outreach program** on September 2023.
5. Attended and presented a poster during "LIDINE 2023" **conference** in Madrid, Spain on September 2023.
6. Attended and passed 6 interdisciplinary/ specialized **lectures** from GeoPlanet doctoral school.

Thank You!

Backup

Impurities in DS-50 and its effects on S1 signal

- Argon was constantly circulated through a circulation loop in gas phase containing a **hot getter**.
- For maintenance purposes, the inline getter was bypassed for about 5 days (120 hours).
- Impurities in DS-50 ⟹ N_2, O_2, H_2O, CO, etc.
- Impurities, such as **N_2**, at the ppm level causes **reduction of scintillation** (see arXiv:0804.1217v1 [nucl-ex] 8 Apr 2008).
- Quenching of light yield in N_2-contaminated LAr is expected.

$$Ar_2^* + N_2 \Longrightarrow 2Ar + N_2$$

- N_2 contamination in LAr ⟹ **Suppression in lifetime of the triplet component**.

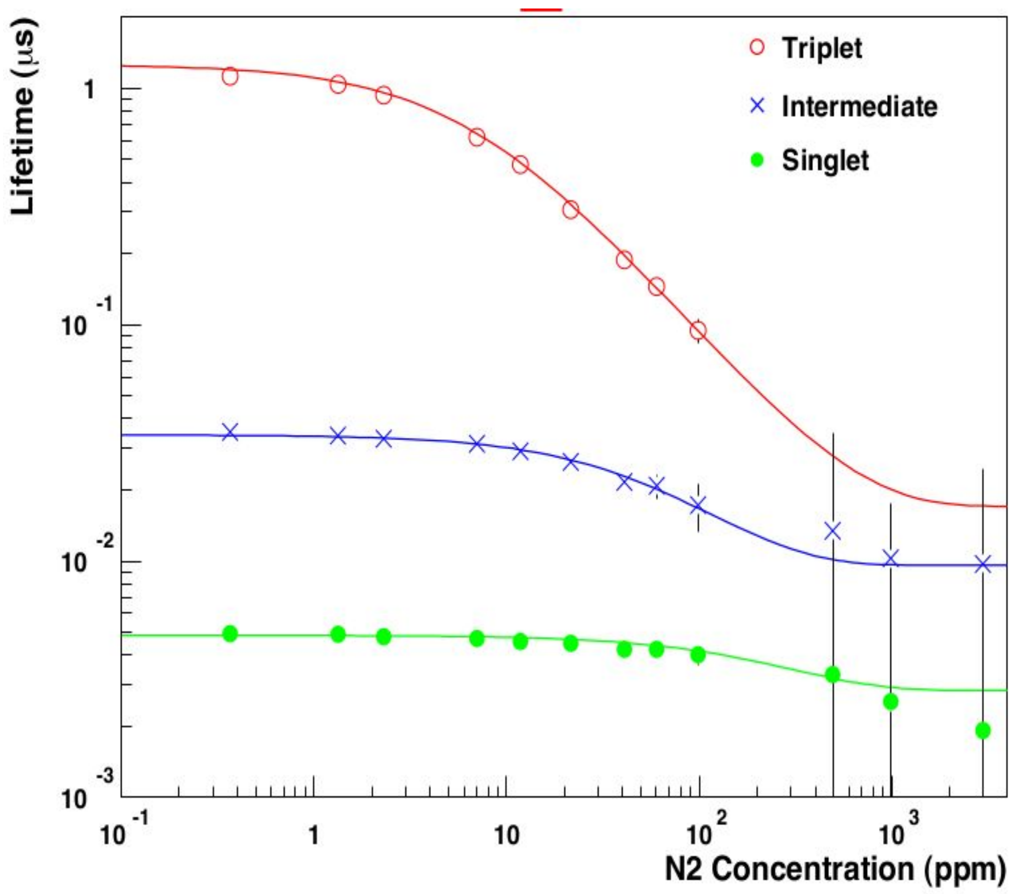


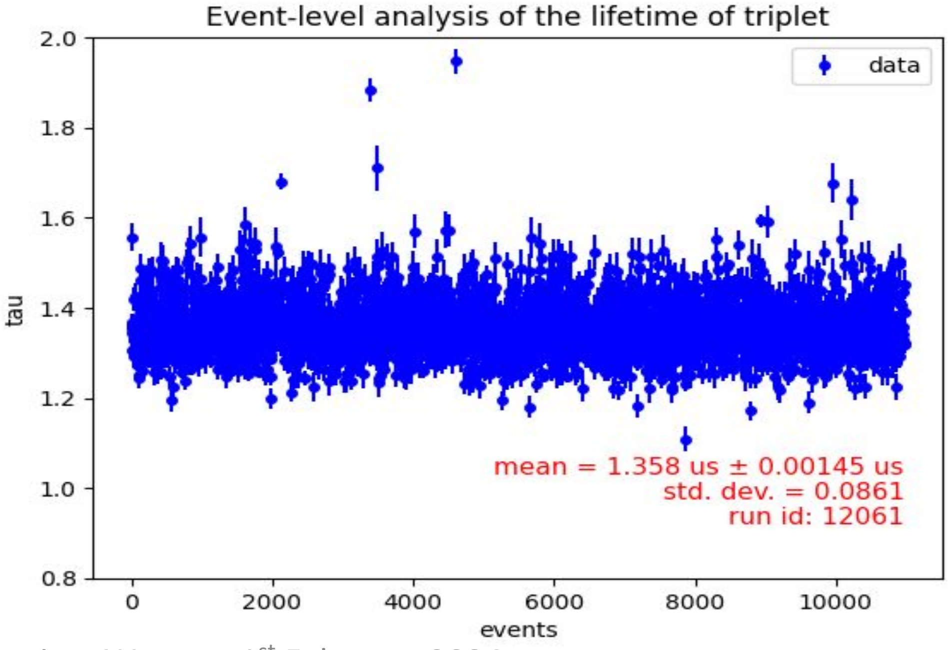
Image credit: arXiv:0804.1217v1 [nucl-ex] 8 Apr 2008

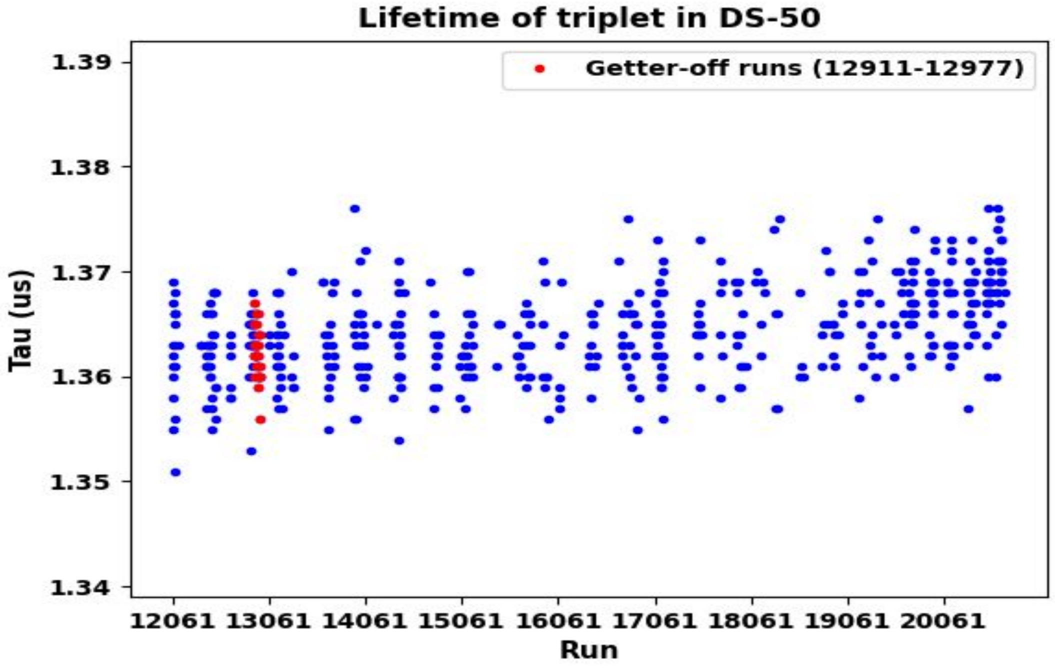
Effects of impurities on triplet lifetime in DS-50

Checking the effect on lifetime of the S1 triplet component event-wise and run-wise using the 3-year data taken from DS-50.

<u>Selection cuts applied:</u>

- $\Delta t > 20 \times 10^{-3}$
- $0.15 < s1\_f90 < 0.5$
- $s2 > 0$
- tdrift >10
- $s1 > 1000$
- $0 < s1\_fwhm < 0.04$

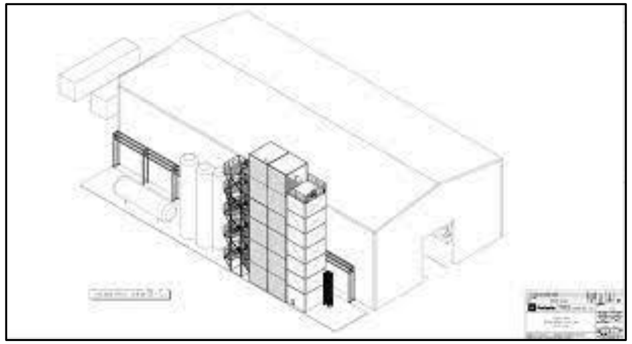




- Getter-off runs: **12911-12977**
- Gradual increase of tau after the getter was turned back on
- **No significant decrease of tau** during getter-off period
- **The concentration of N_2 is very low (<ppm) in DS-50**

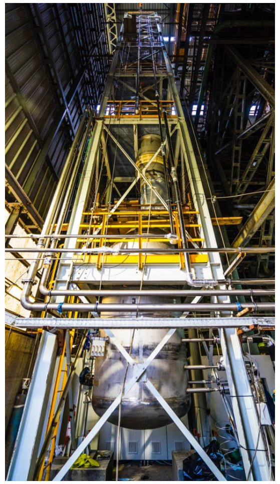
Pure UAr for DarkSide-20k

A full new UAr extraction and purification plan has been designed and is being constructed for DS-20k.



URANIA
Colorado, USA

- Designated extraction plant in Colorado, USA
- Extraction of argon from CO_2 wells
- Capable of extracting UAr at rate of 300 kg/day with 99.99% purity

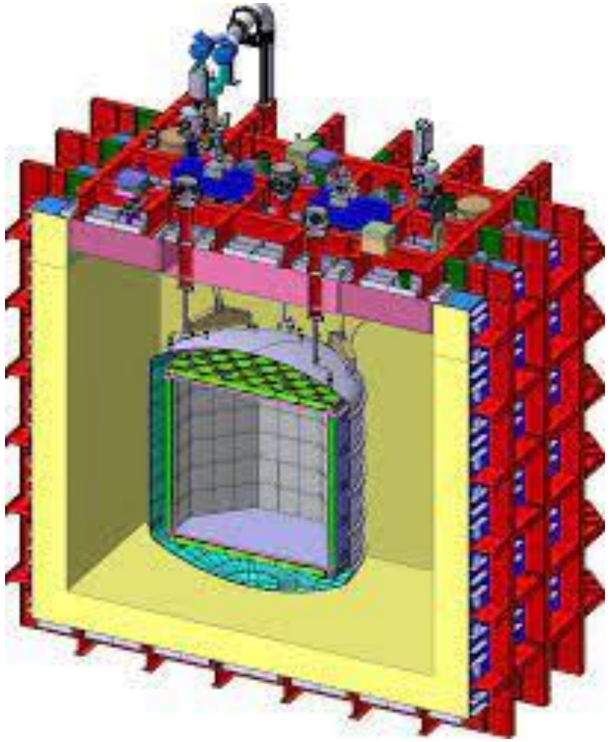


ARIA
Sardinia, Italy

- Cryogenic distillation plant
- Chemical purification at the rate of 1000 kg/day
- Ar purity close to 100%

DArT
LNS, Spain

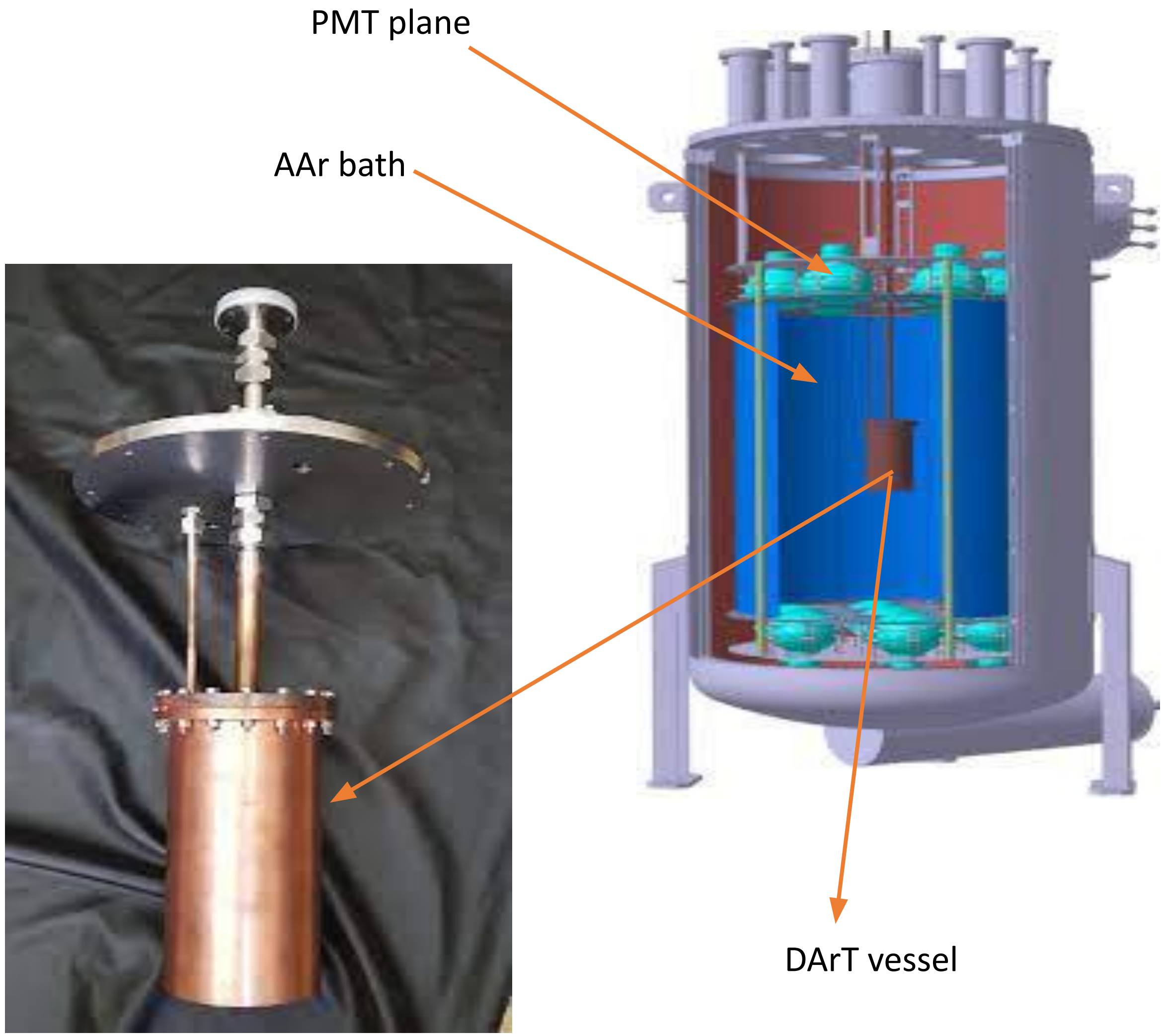
- Quality assurance of UAr for ^{39}Ar measurement
- Single-phase LAr detector with active volume of approx. 1L
- DS-20k, and for future Ar experiments as well.



DARKSIDE-20k Project
LNGS, Italy

DArT in ArDM

- DArT is a low-background detector designed to measure the ^{39}Ar depletion factor of UAr
- Small target filled with 1.5 kg of liquified UAr, readout by two SiPMs
- Located at Canfranc Underground Laboratory (LSC), Spain
- It has been designed to be installed inside ArDM (Argon Dark Matter) detector, which is now used as an active veto for DArT.
- DArT is a **single-phase detector**



Electron lifetime for purity check in DArT UAr

- Contaminants in LAr ⟹ N_2, O_2, CO, etc.
- The lifetime of electron can get affected by electronegative impurities, such as O_2 in LAr by recombination
- **Impure LAr ⟹ Shorter electron lifetime**
- Electron lifetime is evaluated using S2 measurements on 20-days interval
- DArT is a single-phase detector ⟹ **No S2** signal Hence, we cannot measure electron lifetime directly in DArT
- In DS-50, the getter-off runs **did not show degradation** of electron lifetime.

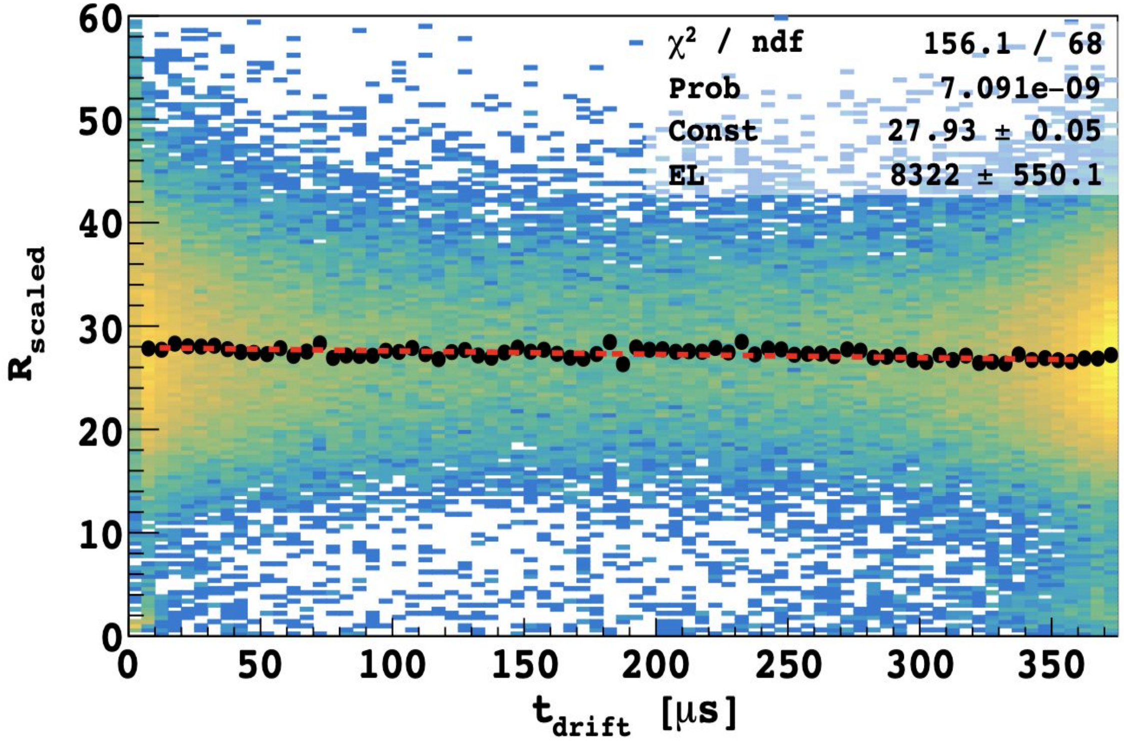


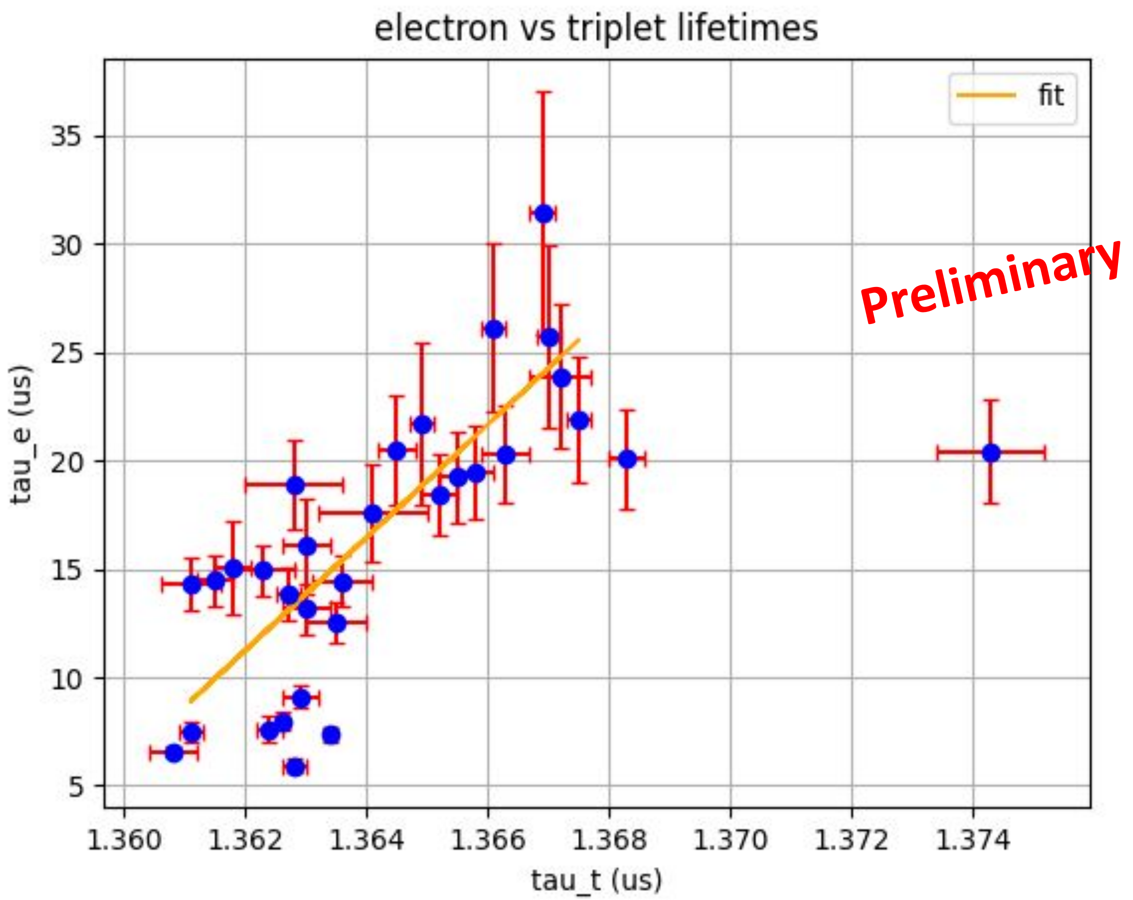
Image credit: Masayuki Wada

Correlation between triplet lifetime and electron lifetime

- DArT ➡ Triplet lifetime values

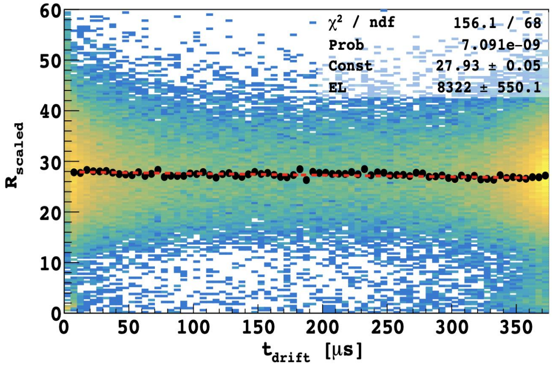
  DS-50 ➡ Triplet lifetime, electron lifetime values

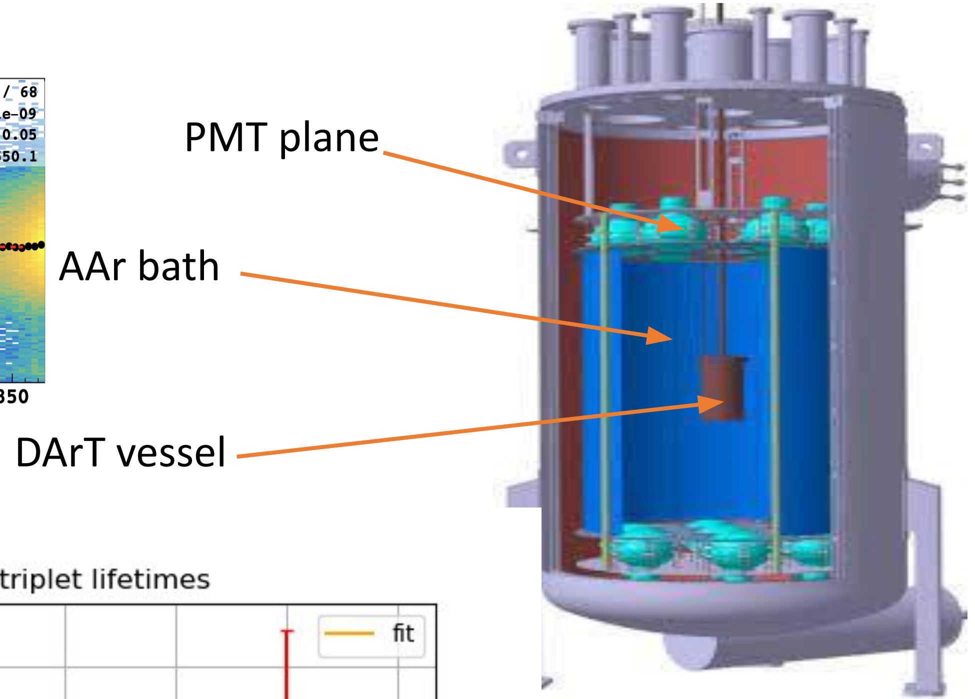
- Analysis has been made to check if any correlation between triplet lifetime and electron lifetime exists in DS-50 experiment
- Found a **linear correlation between both lifetimes in DS-50**, but not yet confirmed the impurity causing the relation
- Assuming the correlation in DS-50 is caused by the same impurity, we apply this relation in DArT, and estimate the electron lifetime in DArT
- Comparing electron lifetime of DArT with that of DS-50, to understand the purity of UAr used in DArT
- Awaiting for the data from DArT

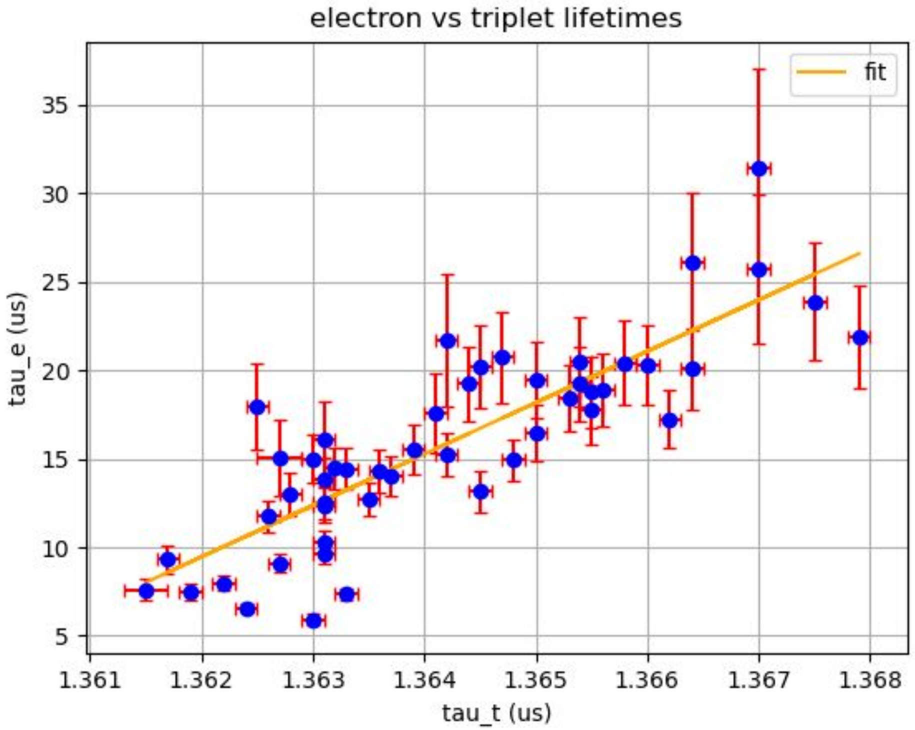


2. Checking electron lifetime for purity check in DArT UAr

- **DArT** is a single-phase detector (no S2 signal) filled with 1.5 kg of liquified UAr, readout by two SiPMs.
- **Impure LAr** ⟹ **Shorter electron lifetime**
- Correlation between triplet lifetime and electron lifetime in DS-50 suggests a **linear correlation**, but the impurity causing this relation is yet to be confirmed.
- Assuming the correlation in DS-50 is caused by the same impurity, we apply this relation in DArT, estimating the electron lifetime in DArT and comparing it with that of DS-50 to understand the purity of UAr used in DArT.

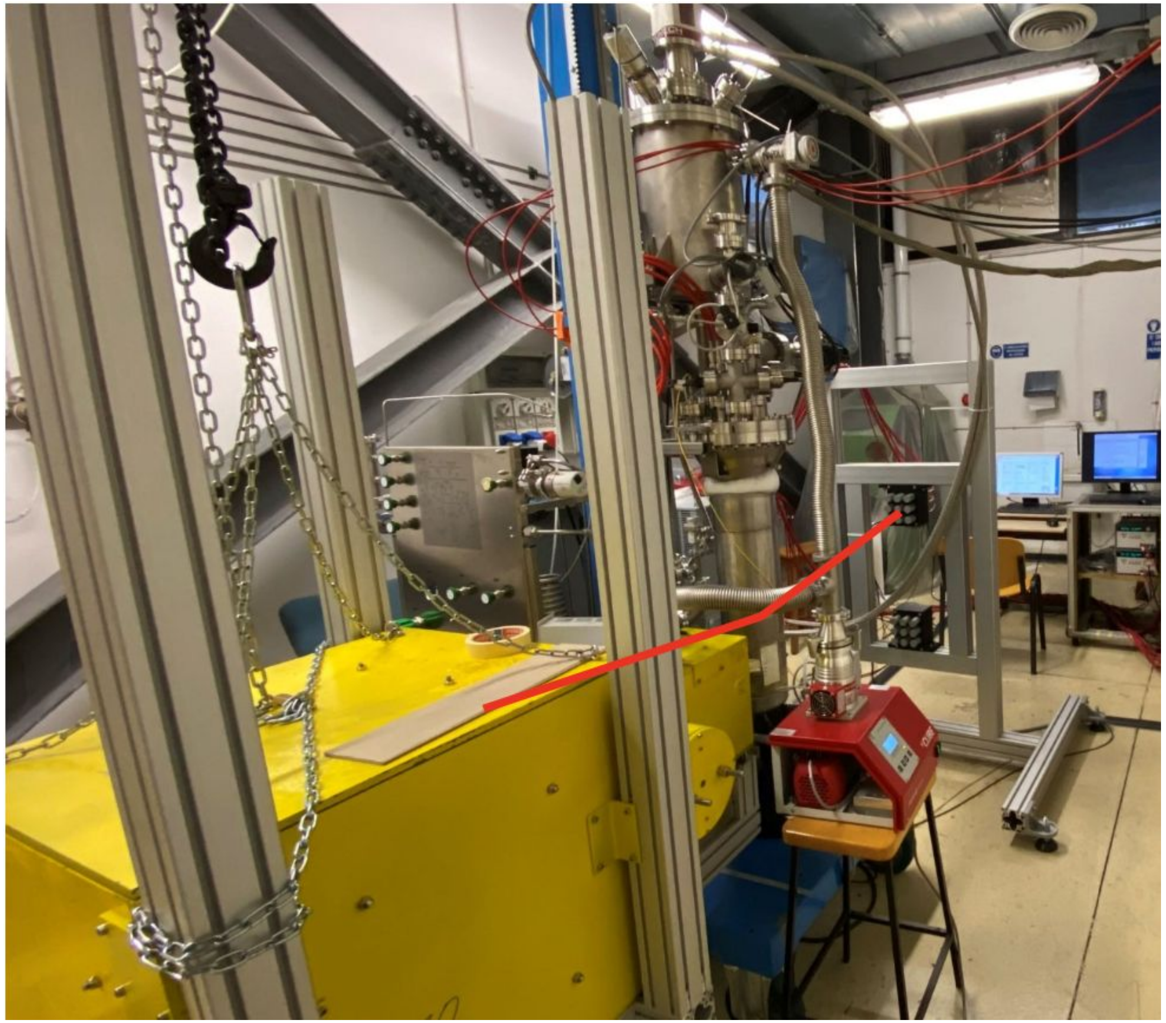






Recoil Directionality (ReD) experiment

- Dual-phase TPC filled with LAr and equipped with cryogenic SiPMs
- Main two goals of ReD project:
  - To check if the dual-phase LAr TPC has sensitivity to the direction of Ar recoil
  - To characterize the response of LAr TPC for **NRs to very low-energy recoils** (<few keV)
- Working principle:
  - Neutrons from ^{252}Cf source are directed towards the TPC at an angle.
  - Neutron spectrometer to detect neutrons scattered off-Ar



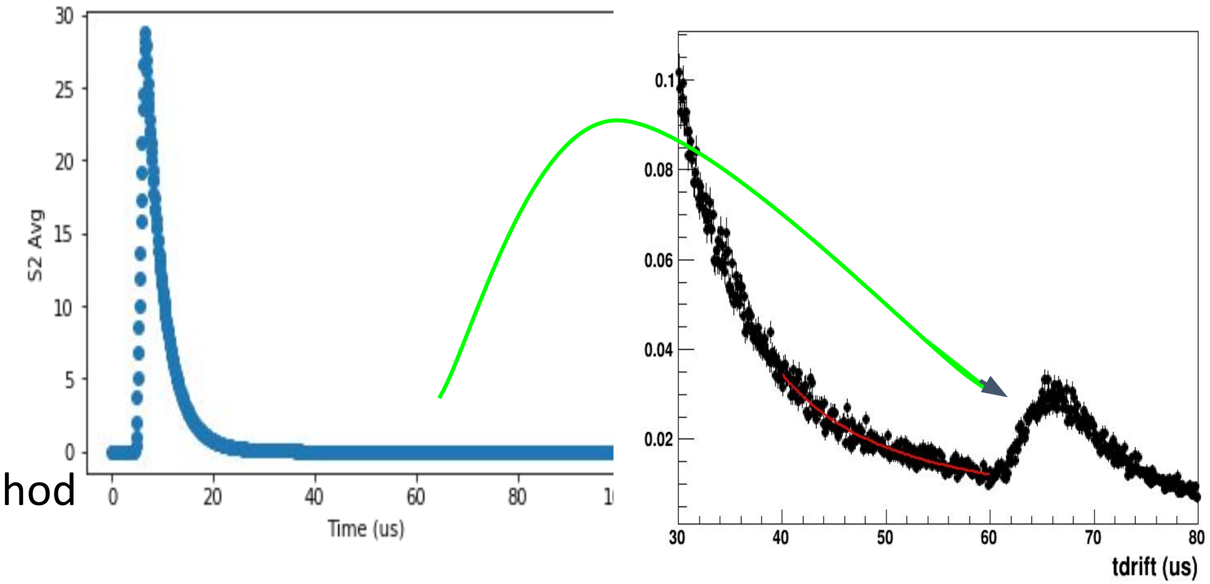
Determination of g2

- **g2 ⟹ e^-/keV**
- SE events obtained during **getter-off time** period.
- Source used is ^{241}Am
- Long acquisition window (60000 samples, 120 μs)
- S3 pulse found around $\mathbf{t_{drift} = 62\ \mu s}$
- g2 ⟹ Pulse-finder method or fixed-window integration method
- Special pulse-finder, which lowers the threshold.
- Fixed-window integration done for S2 correction from S3 signal.
- qw[0] ⟹ [45-60]μs
- qw[1] ⟹ [60-90]μs
- Noise could spoil the SE peak in fixed-window method.
- g2 measured in pulse-finder :

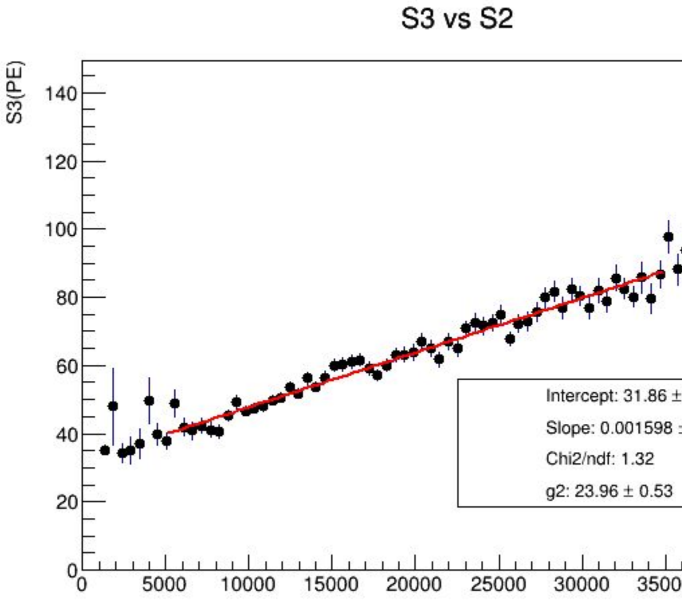
  23.96 ± 0.53 PE/e-

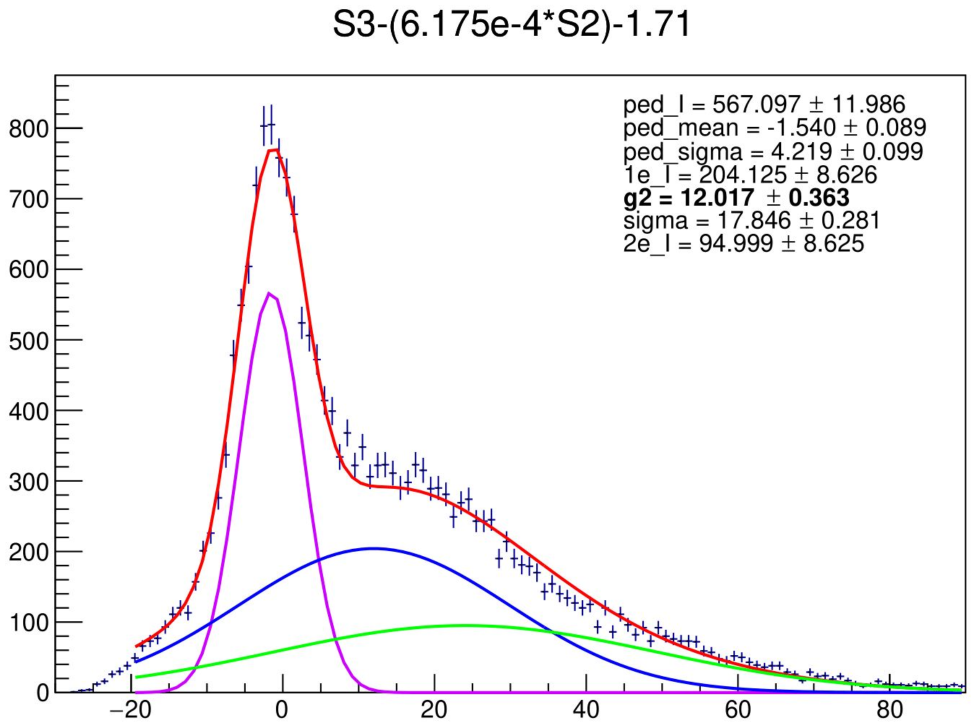
  Estimated g2 (Maximo's MC)

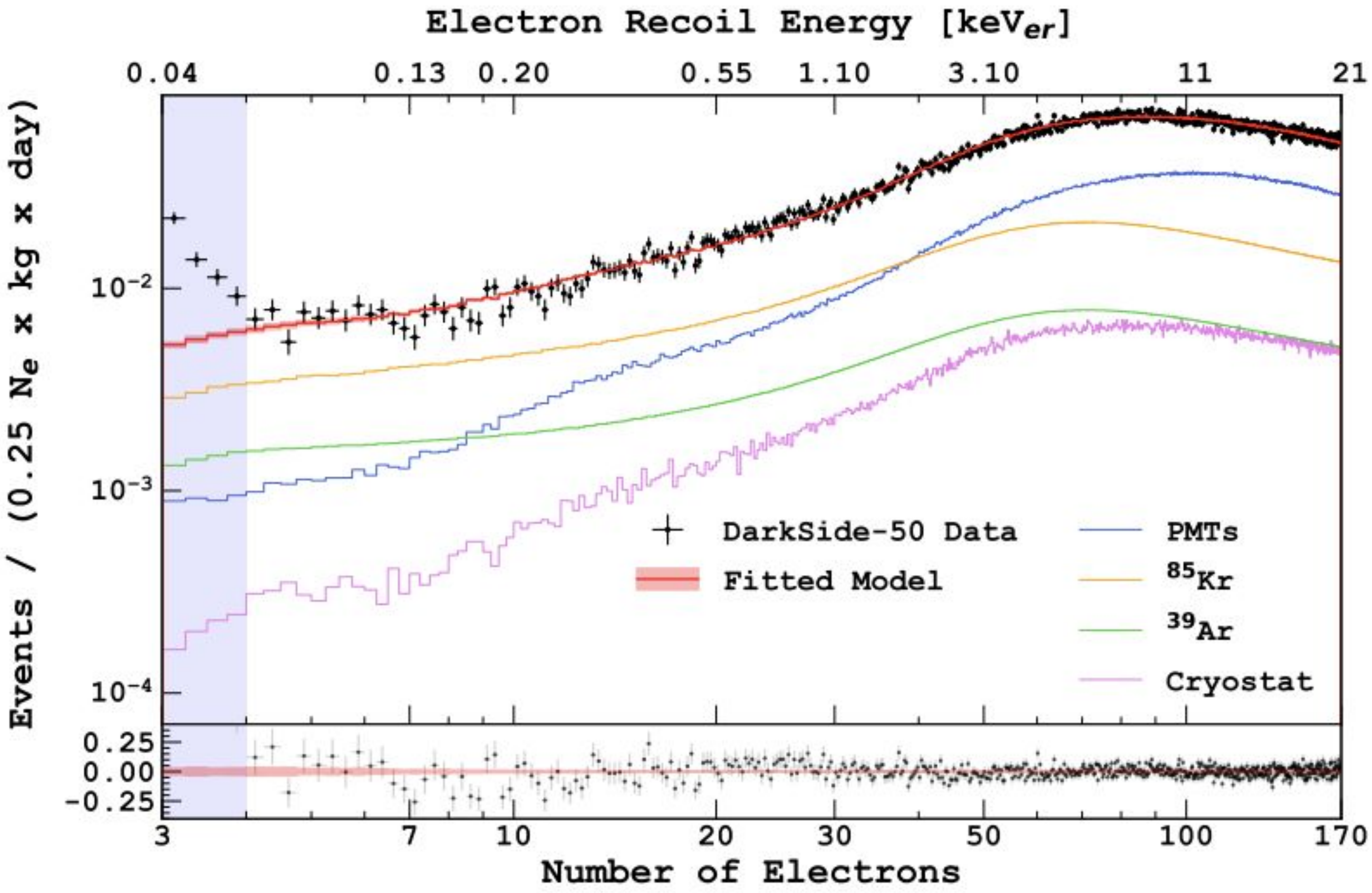
  15 PE/e-

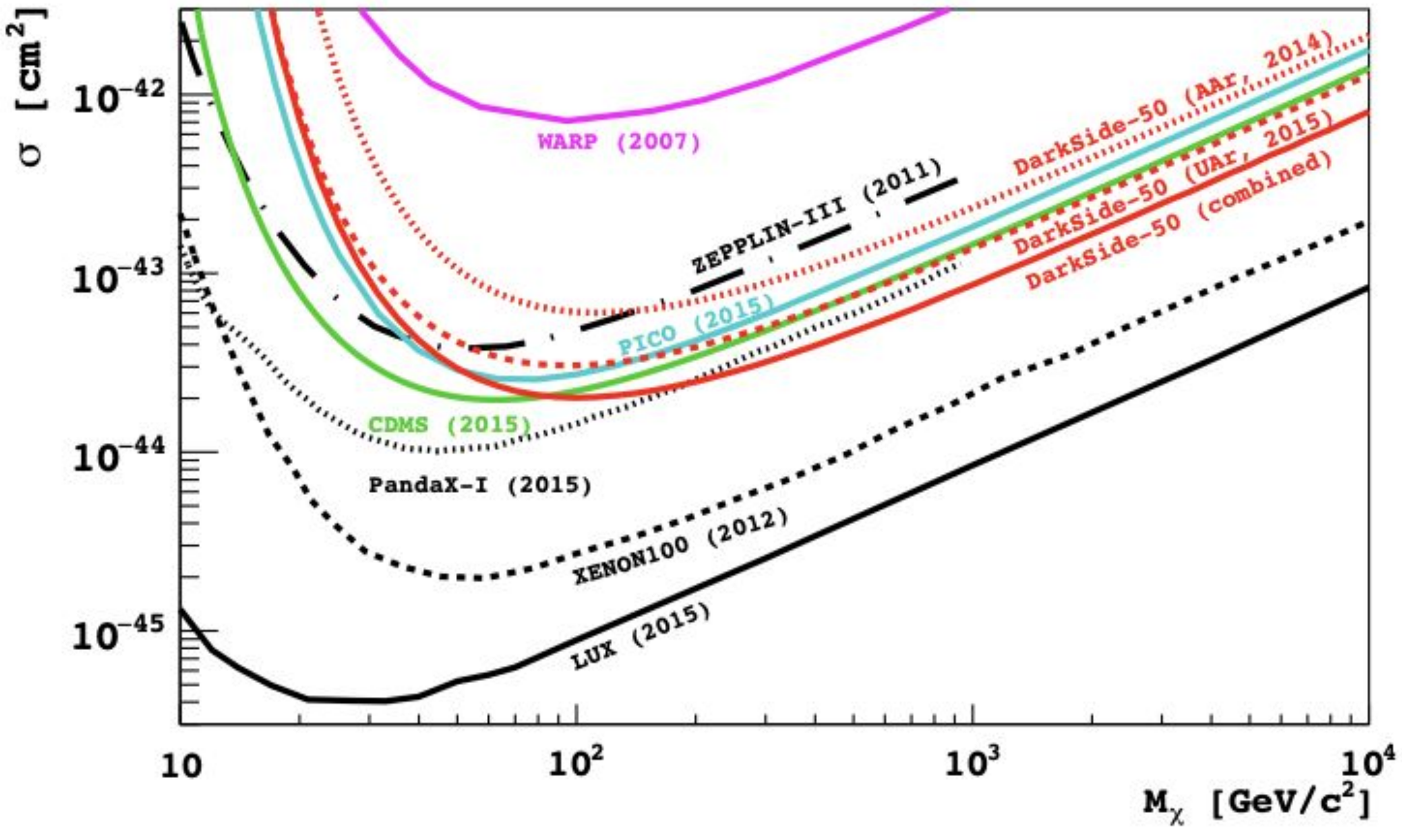


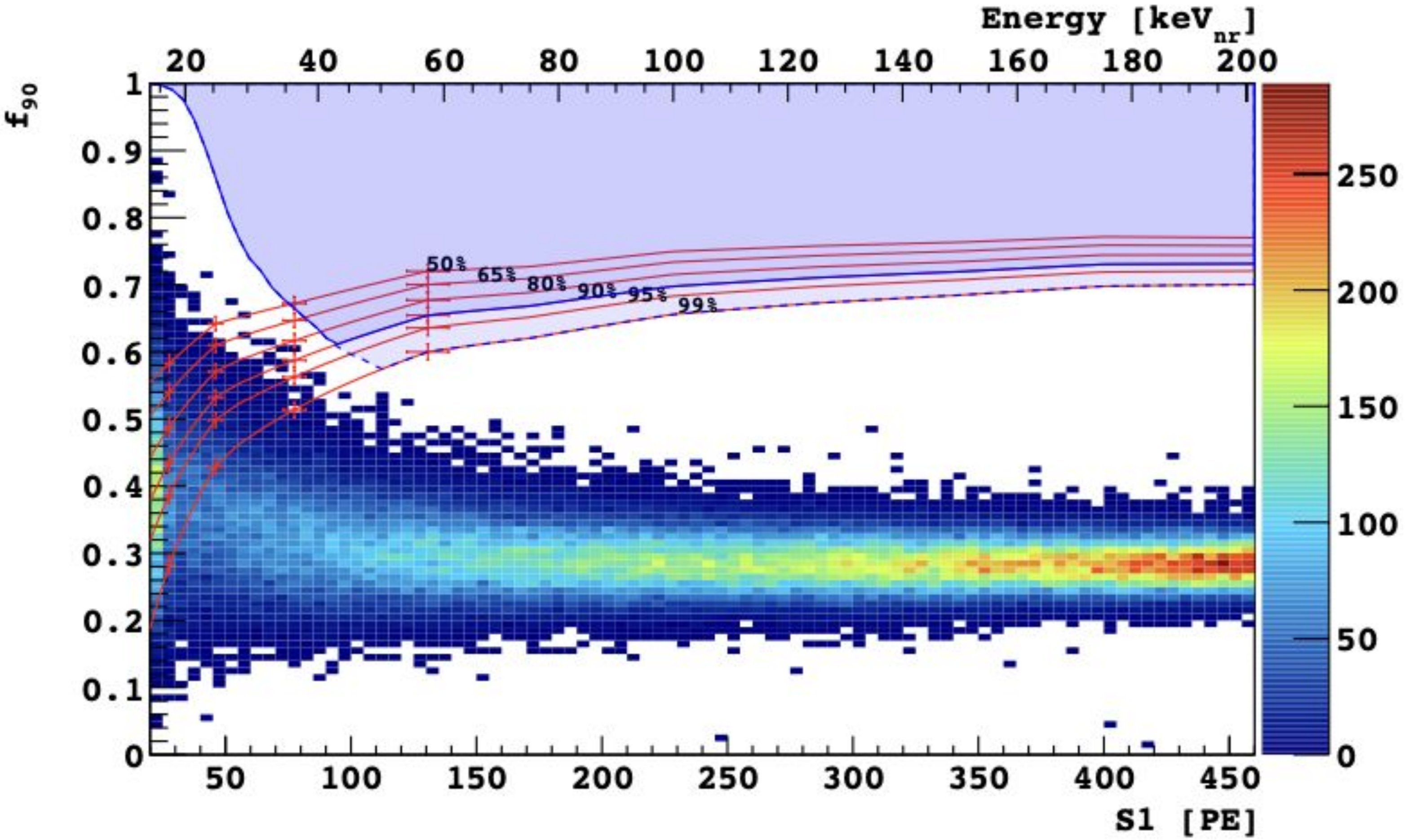
Pulse finder approach






Electron Recoil Energy [keV$_{er}$]
0.04
0.13
0.20
0.55
1.10
3.10
11
21
Events / (0.25 N_e x kg x day)
10^{-2}
10^{-3}
10^{-4}
DarkSide-50 Data
Fitted Model
PMTs
^{85}Kr
^{39}Ar
Cryostat
0.25
0.00
-0.25
3
7
10
20
30
50
100
170
Number of Electrons


σ [cm²]
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10
10²
10³
10⁴
Mχ [GeV/c²]
WARP (2007)
ZEPPLIN-III (2011)
DarkSide-50 (AAr, 2014)
DarkSide-50 (UAr, 2015)
DarkSide-50 (combined)
PICO (2015)
CDMS (2015)
PandaX-I (2015)
XENON100 (2012)
LUX (2015)


Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f_{90}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
250
200
150
100
50
0