darkside
two-phase argon TPC for Dark Matter Direct Detection

Dark Matter searches with the DarkSide LAr TPC

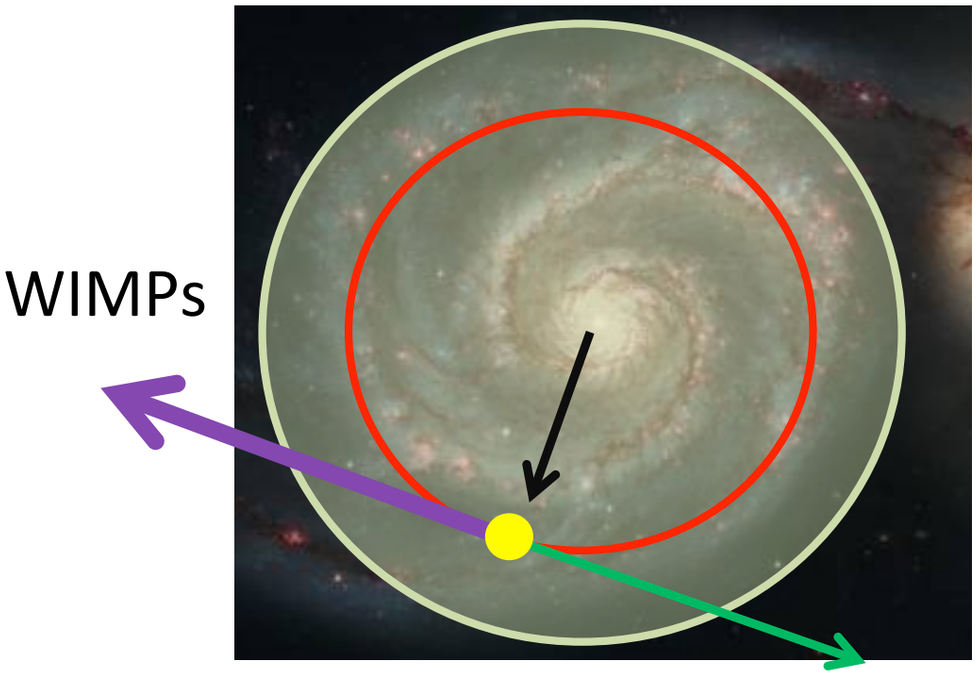
Anyssa Navrer-Agasson
On behalf of the DarkSide Collaboration

PALS, Paris - September 26, 2019

LPNHE PARIS

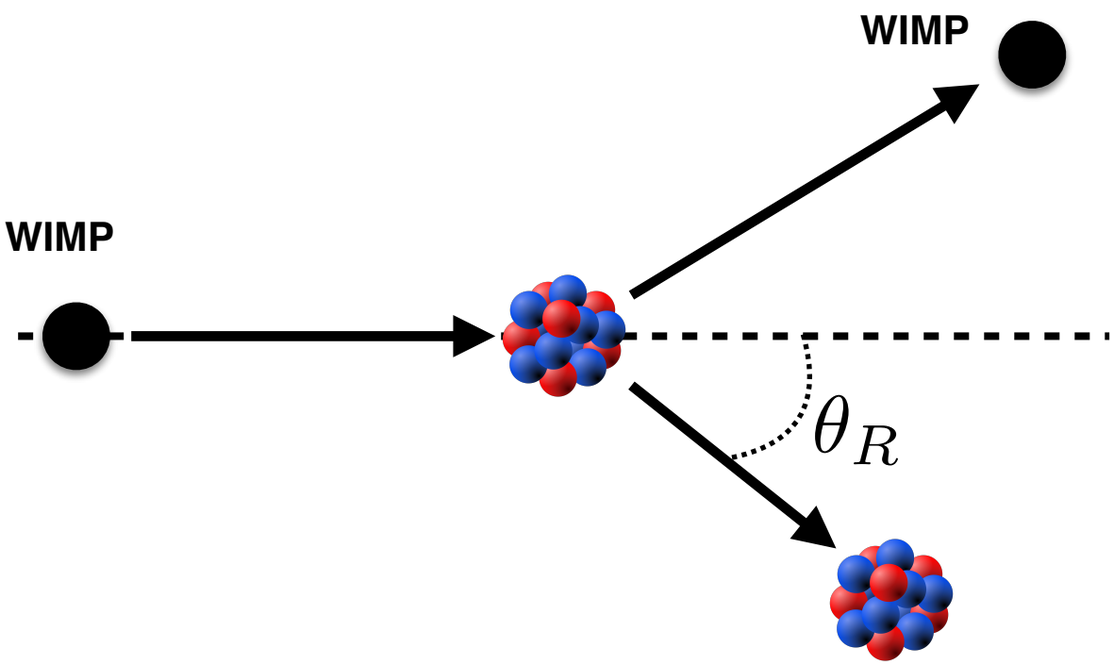
cnrs

Direct dark matter search



Solar system

Motion of Solar system
⇨ dark matter « wind »



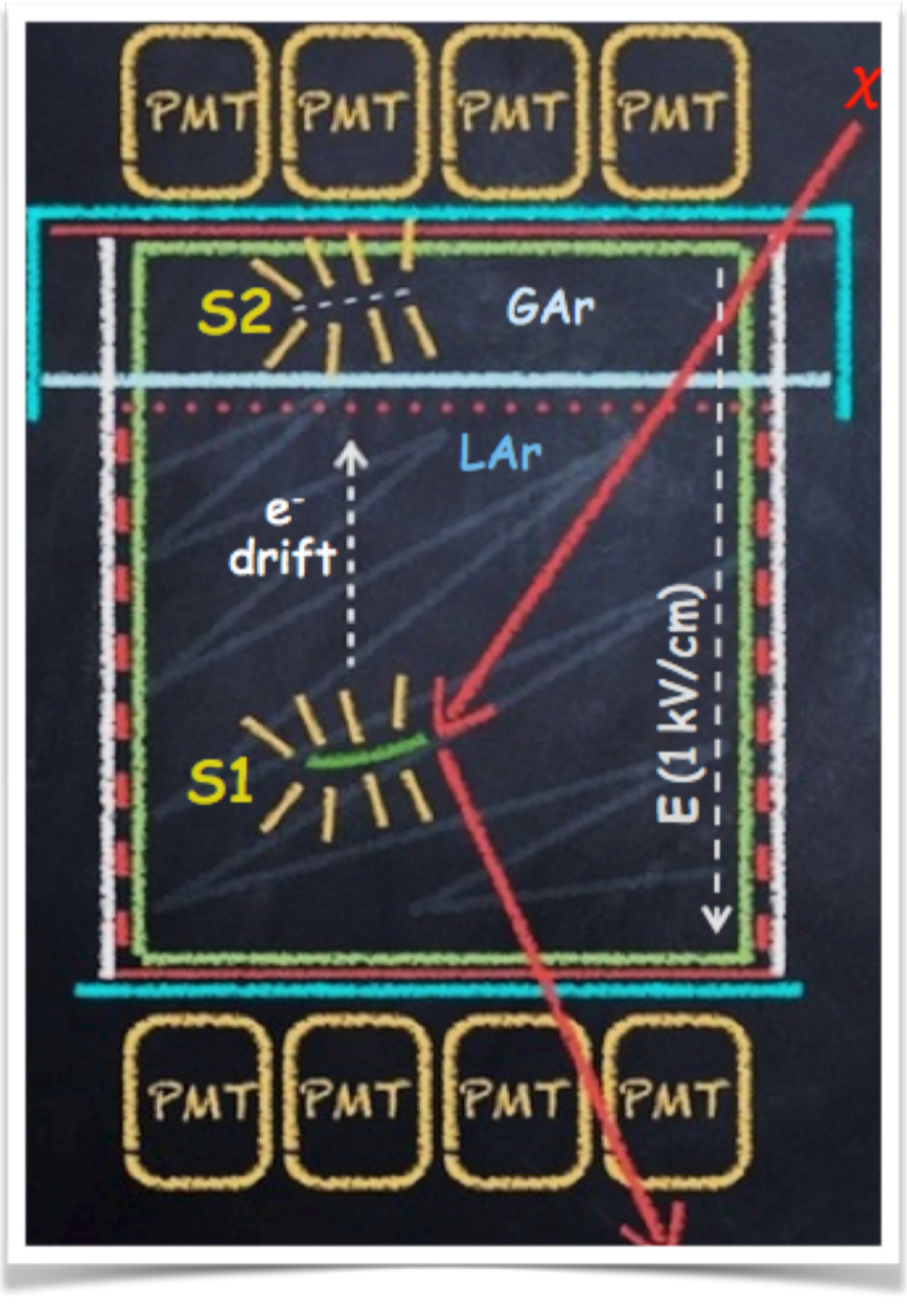
Principle

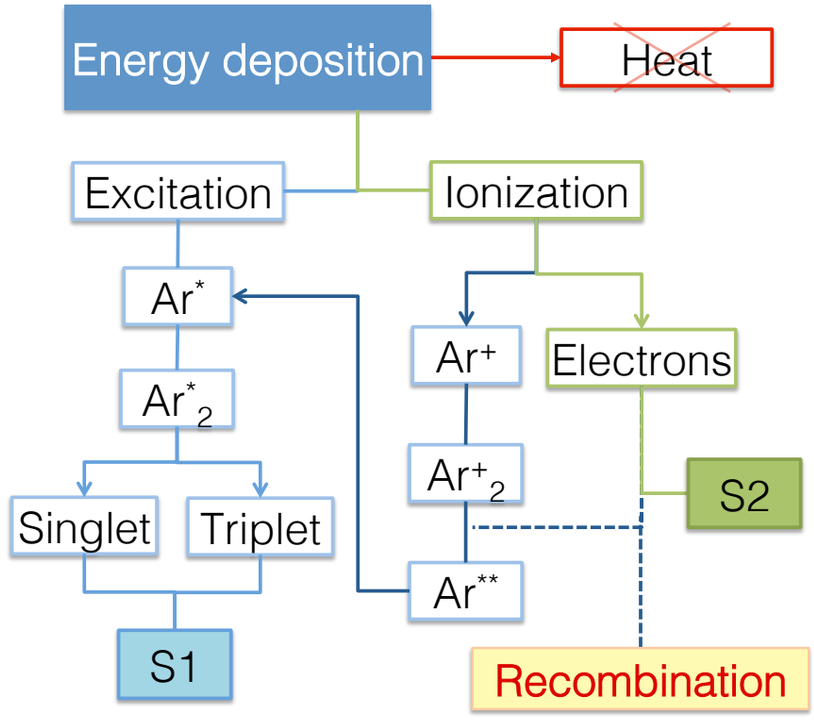
Detect a DM particle scattering off a nucleus
⇨Nuclear recoil (E_{NR} < 100 keV)

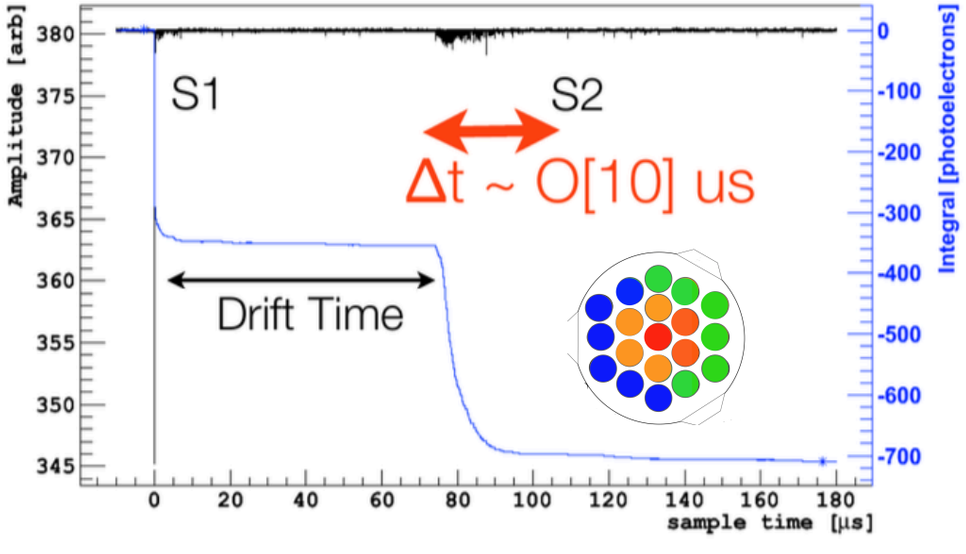
Weakly Interacting Massive Particles
are one of the main DM candidates

Dual-phase LAr TPC

Dual phase **L**iquid **Ar**gon **T**ime **P**rojection **C**hamber

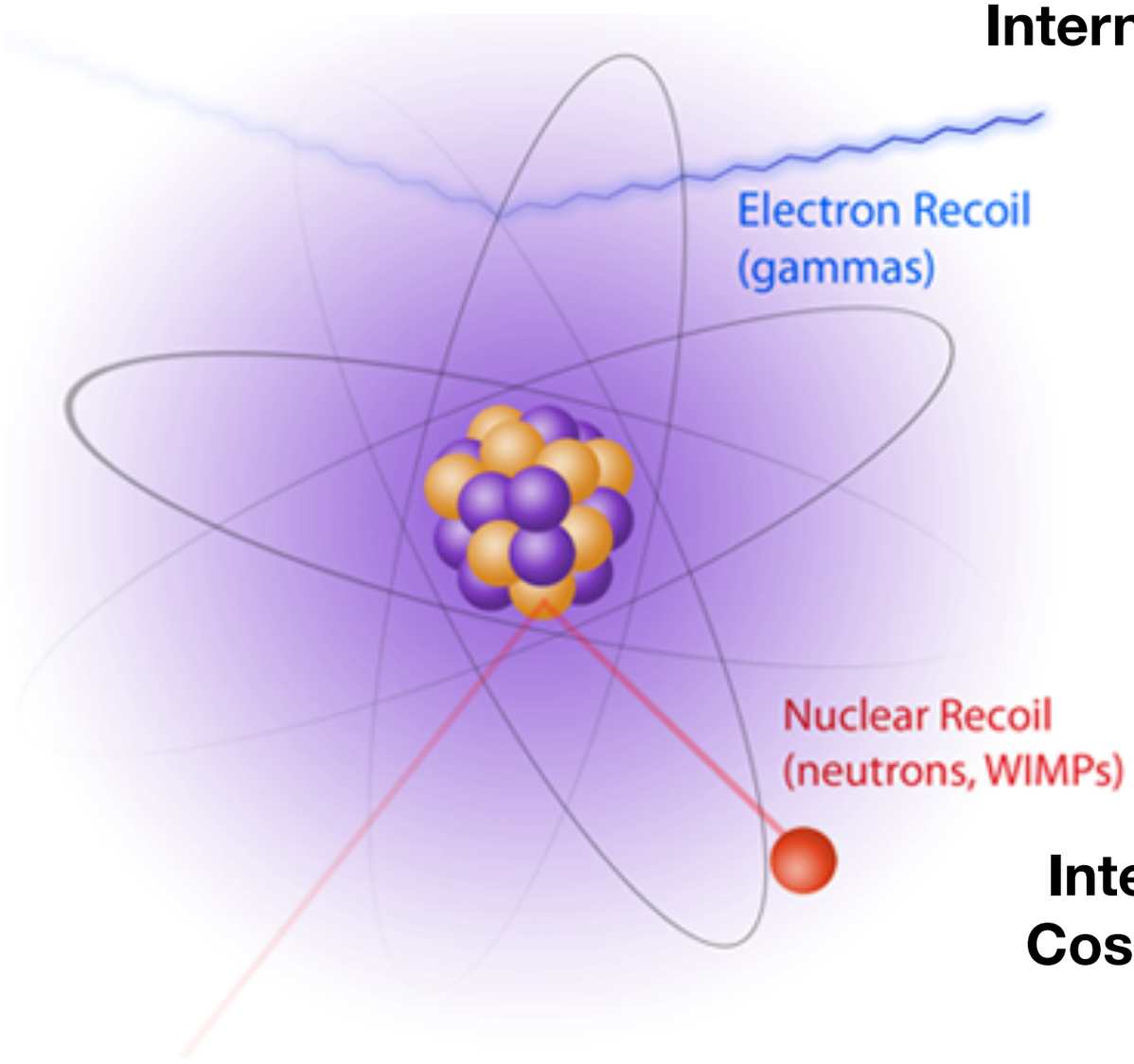






LAr TPC backgrounds

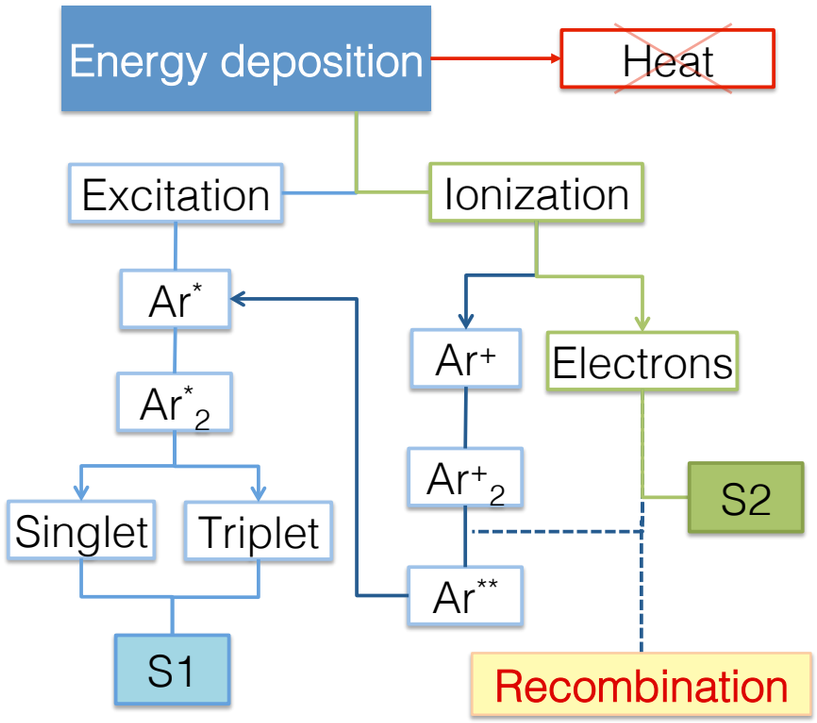
Internal radioactivity



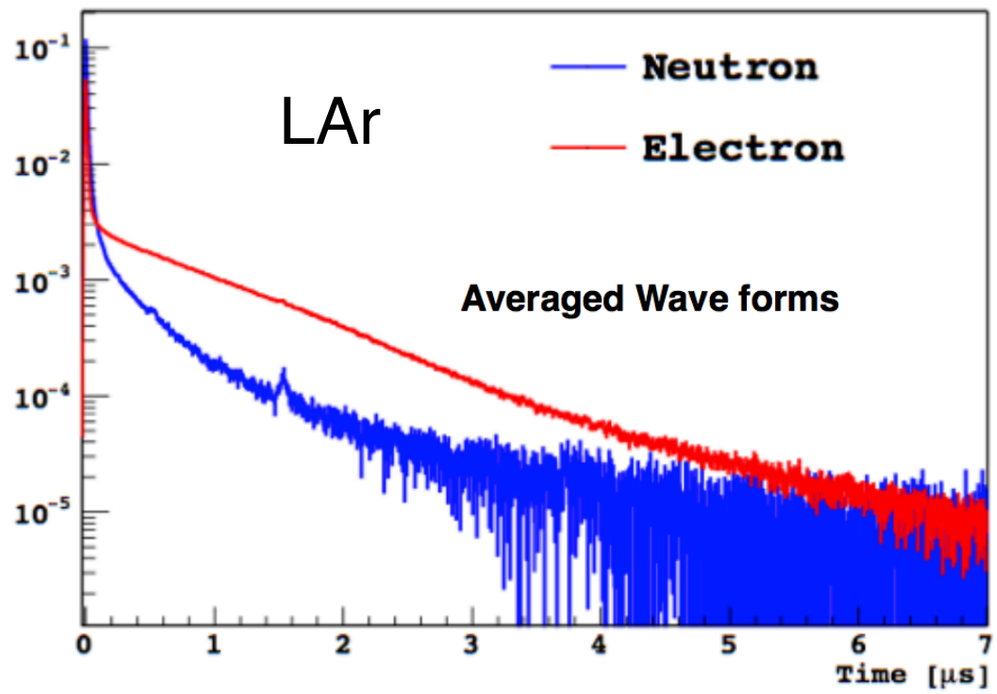
Internal radioactivity
Cosmogenic neutrons

ER/NR discrimination
Tag neutrons

ER/NR discrimination

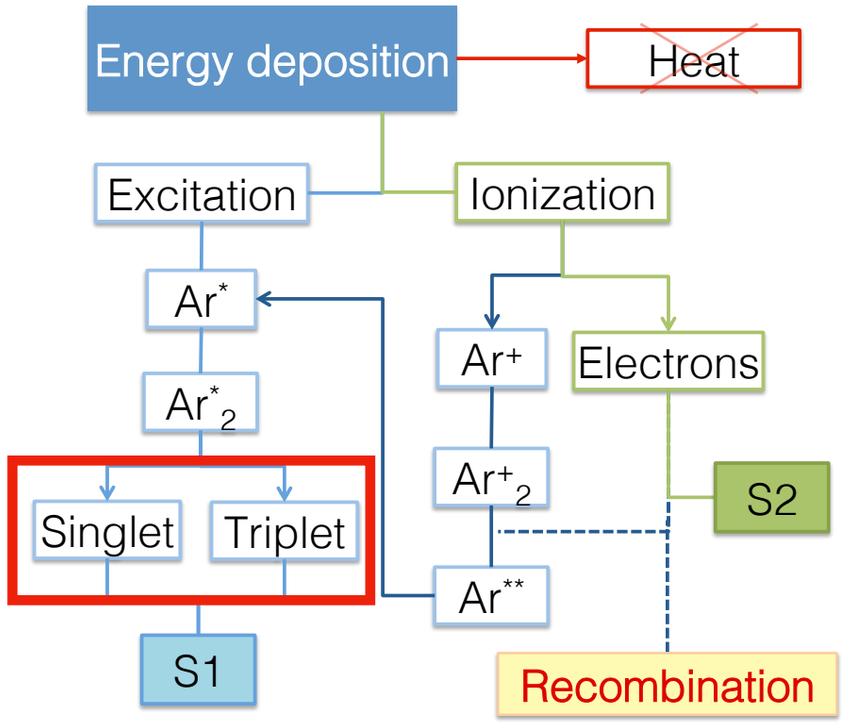


Pulse Shape Discrimination

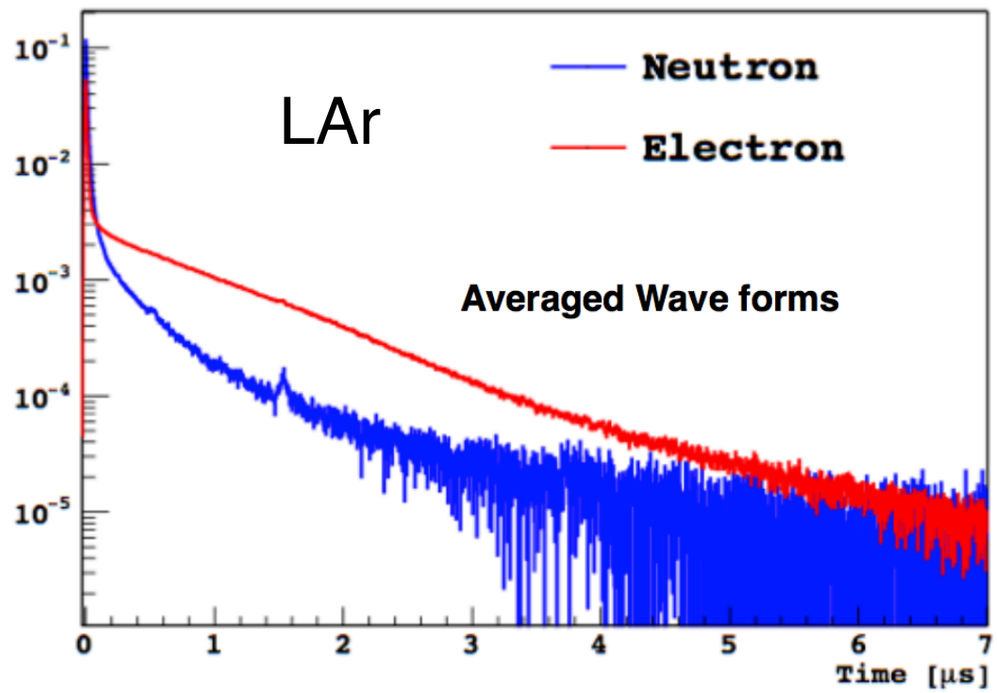


	Singlet	Triplet
Time constant	~7 ns	~1.6 μs
Population ratio for Electron ionizing	33%	67%
Population ratio for Nucleus ionizing	75%	25%

ER/NR discrimination

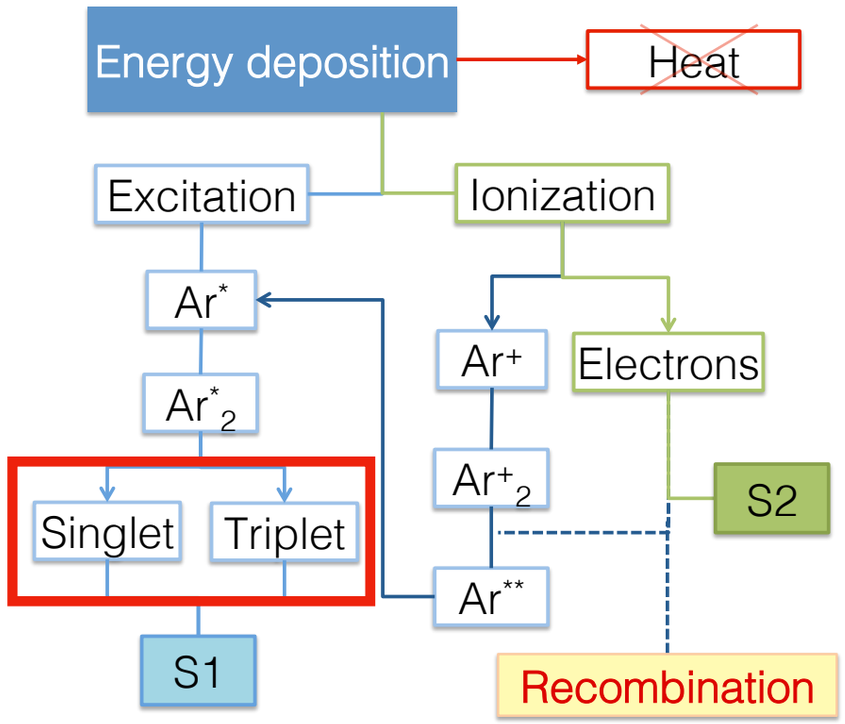


Pulse Shape Discrimination

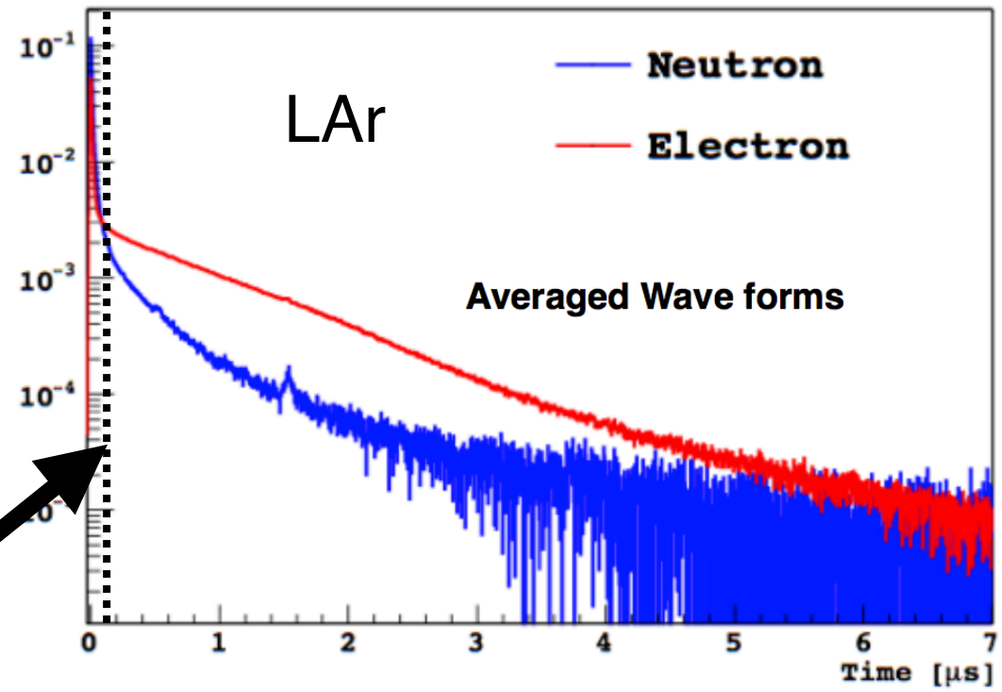


	Singlet	Triplet
Time constant	~7 ns	~1.6 μs
Population ratio for Electron ionizing	33%	67%
Population ratio for Nucleus ionizing	75%	25%

ER/NR discrimination

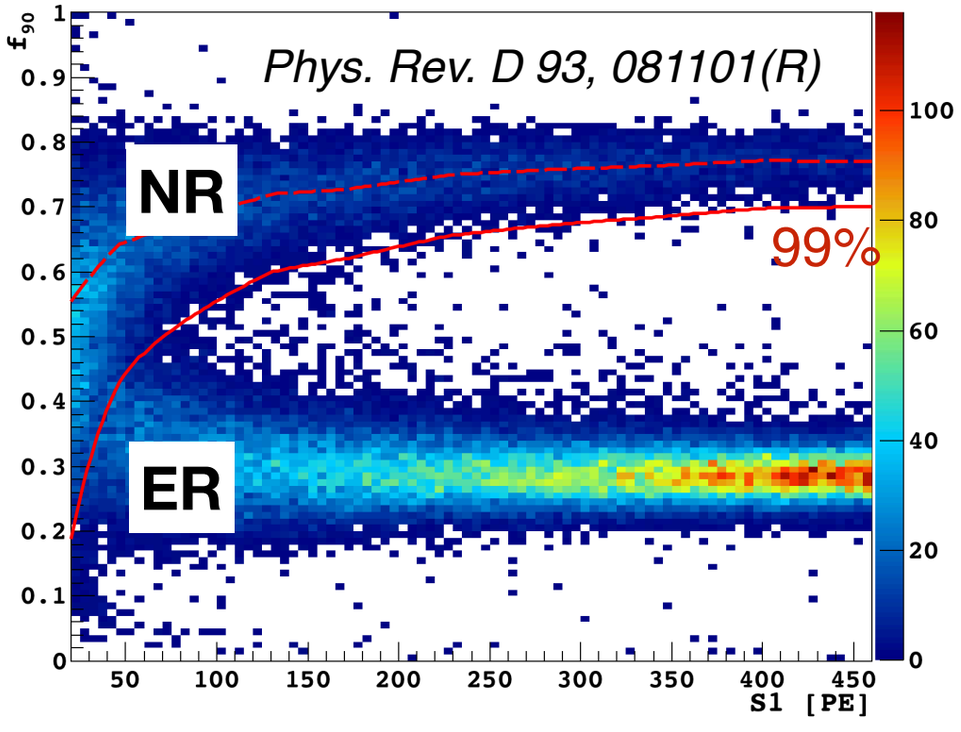


Pulse Shape Discrimination



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%

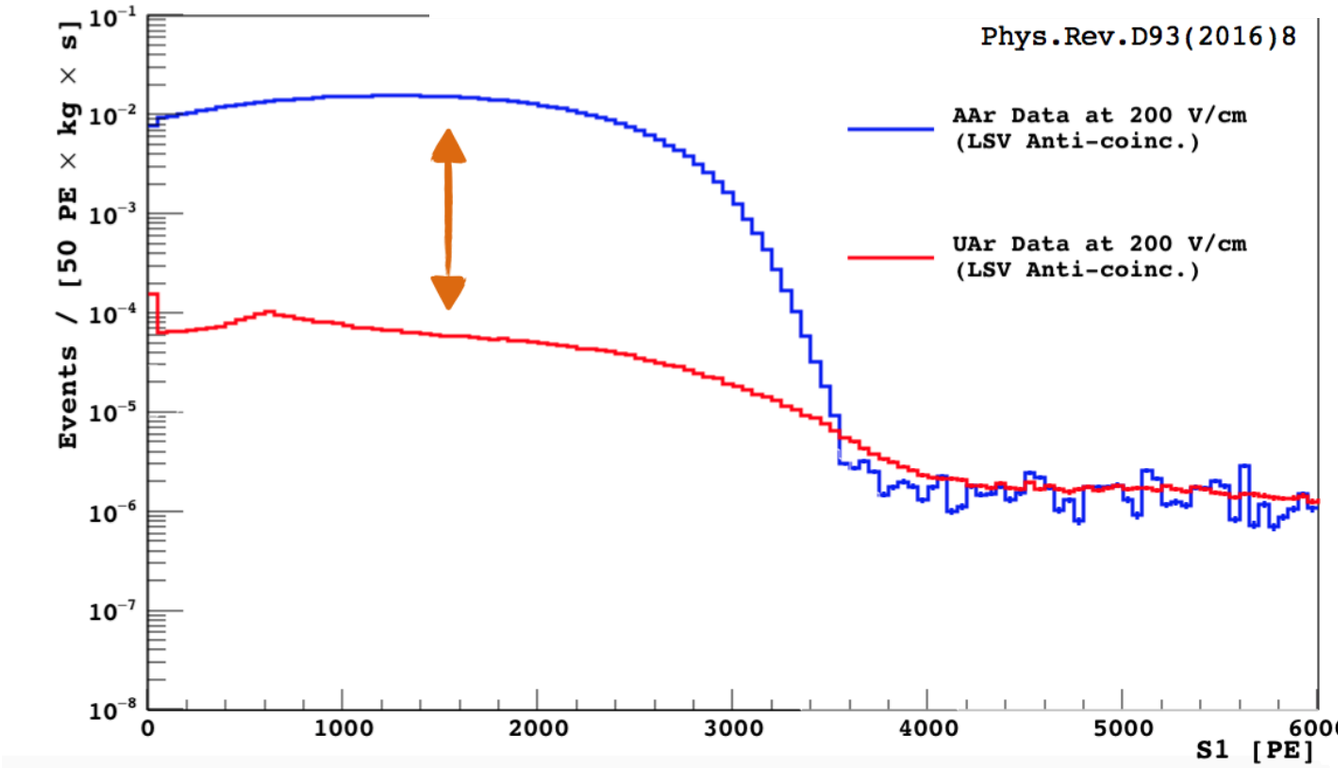


LAr ER rejection factor: ~10^7

Underground Argon

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

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



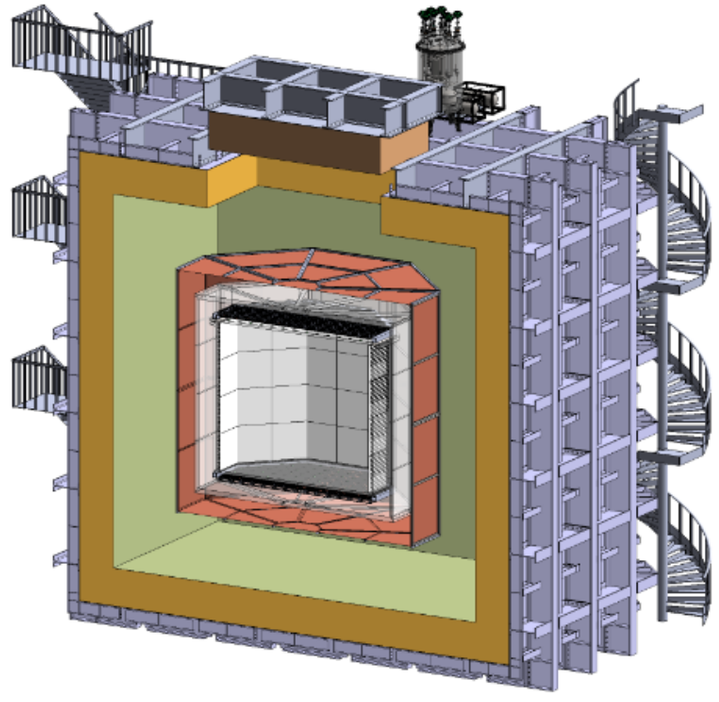
DarkSide experiment

The DarkSide program

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022

DarkSide-10

DarkSide-50

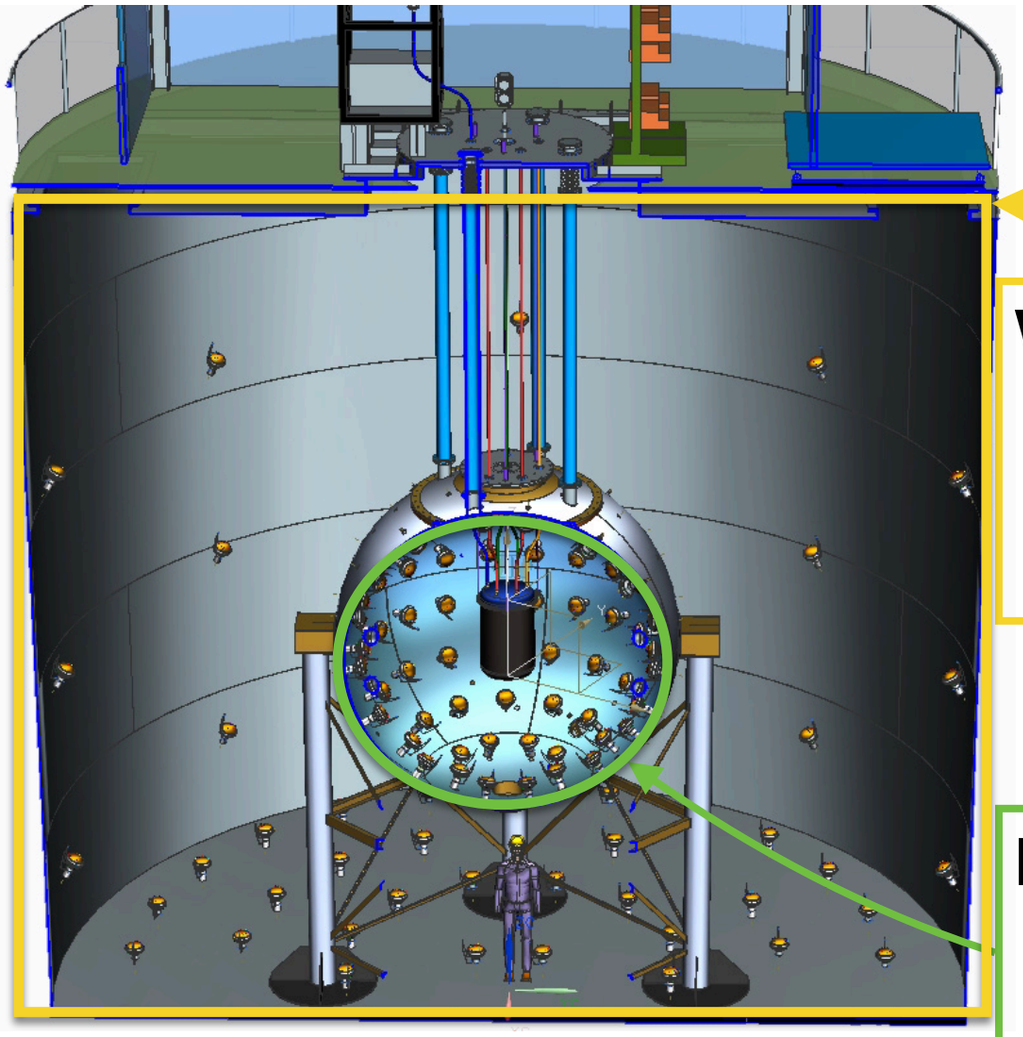


DarkSide-20k

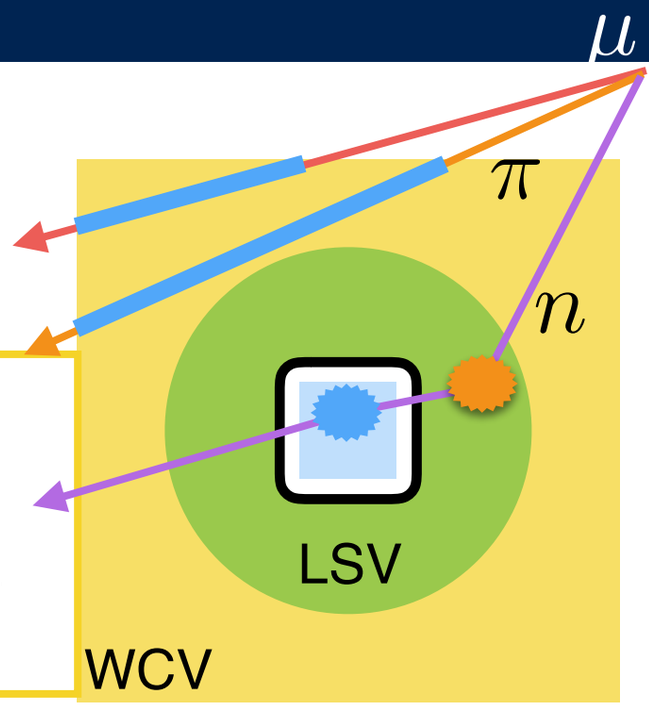
DarkSide-50 TPC

- 36 cm height, 36 cm diameter
- 50kg active mass (37 kg fiducial)
- 38 high quantum efficiency PMTs (19 top + 19 bottom)
- Drift field: 200 V/cm

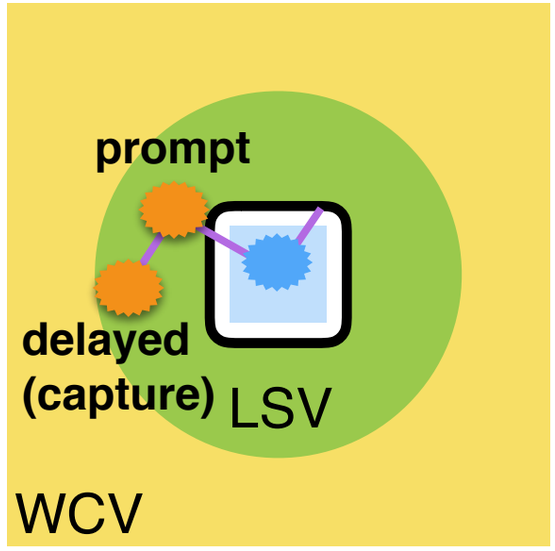
Active vetoes



Water Cherenkov Veto:
1kT ultra pure water
Tag cosmogenic neutrons via muons

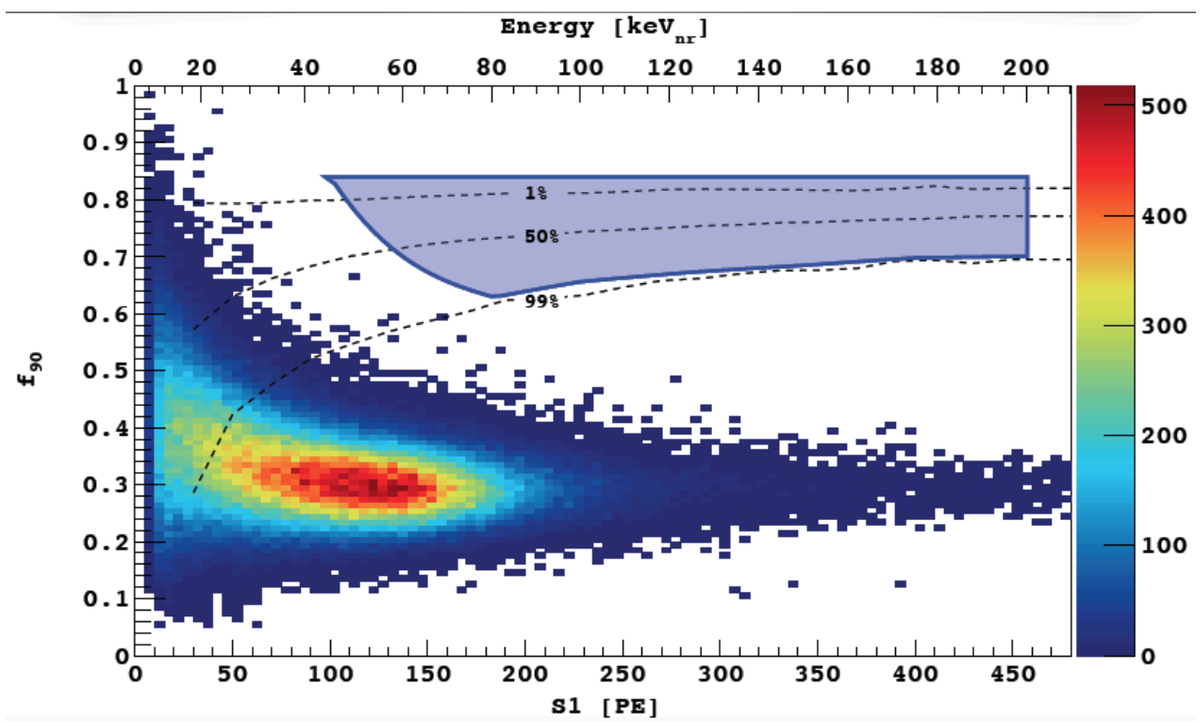


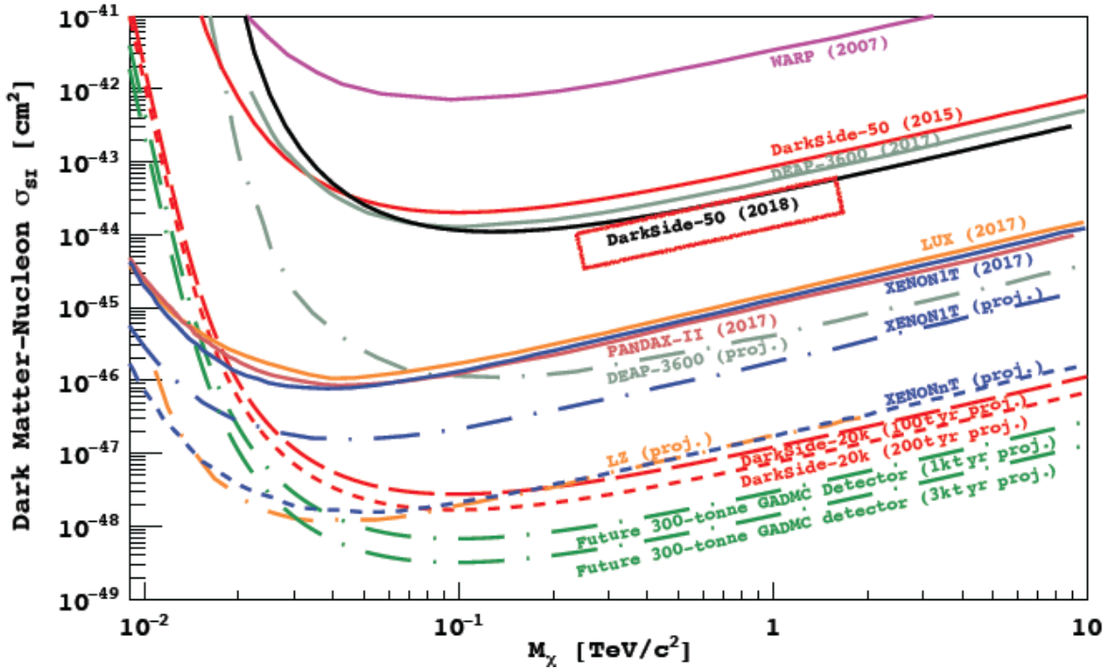
Liquid Scintillator Veto:
30-tonne liquid scintillator
Tag neutrons from TPC via neutron capture



Veto's Rejection Efficiencies (AmBe measurement + Monte-Carlo):
> 99.5% against Radiogenic neutrons
> 95% against Cosmogenic neutrons

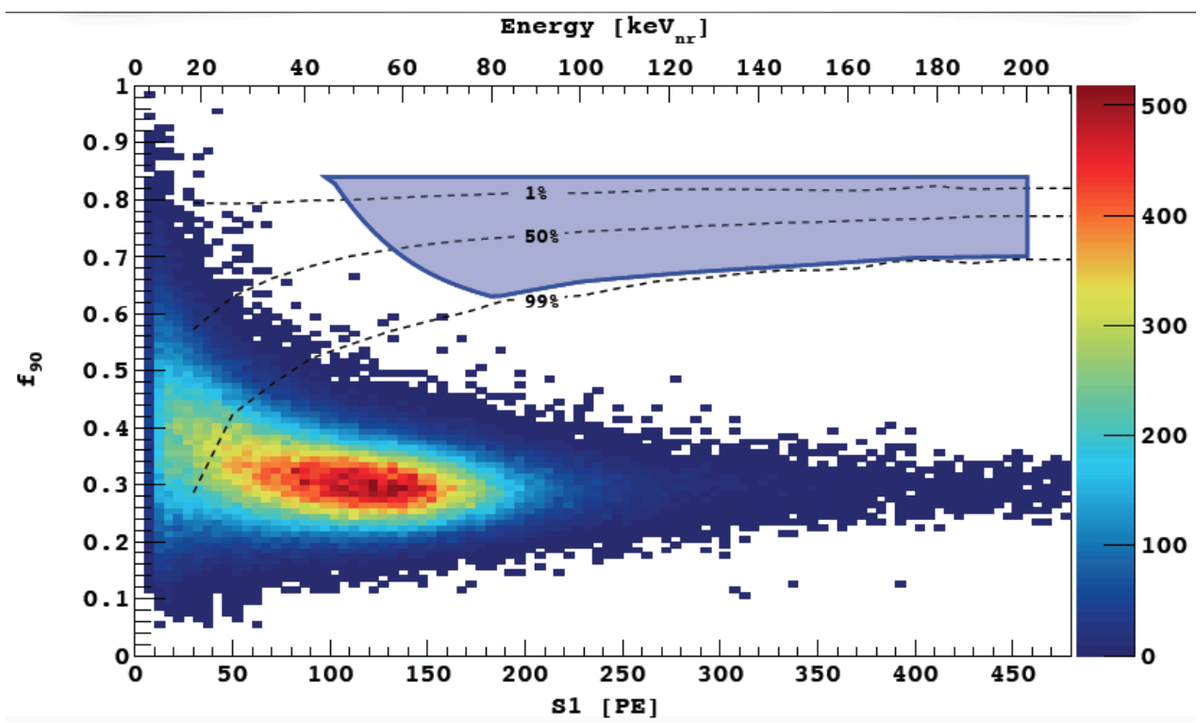
532 live days blind analysis

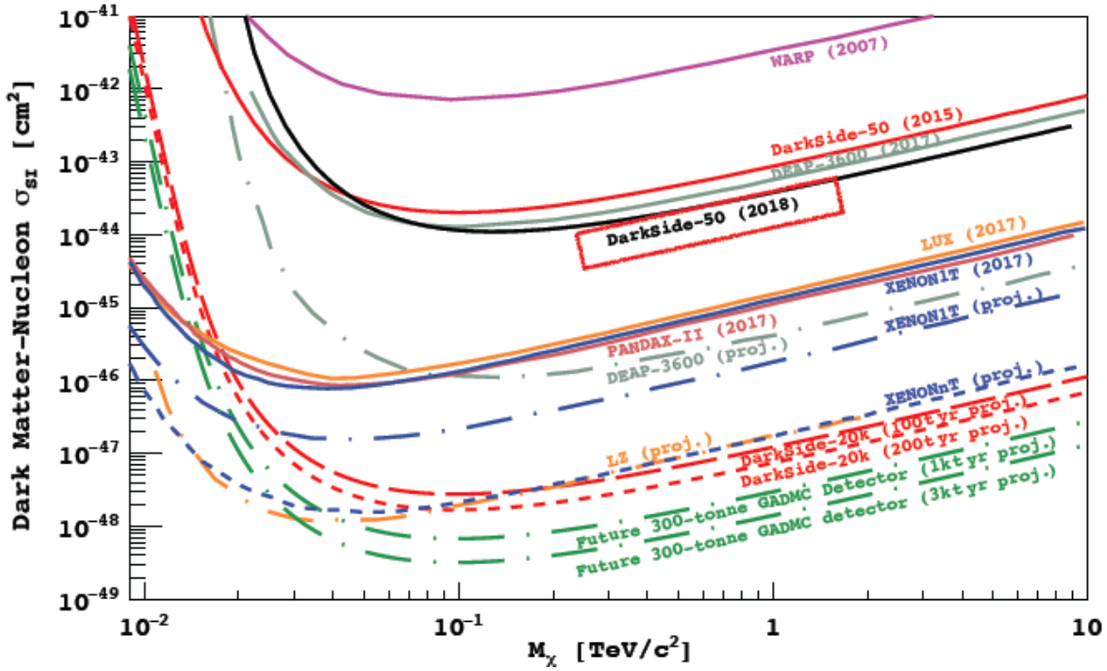




532 live days blind analysis

- **Background free analysis !**
- **Can be extrapolated to higher active masses**





Low mass WIMPs search

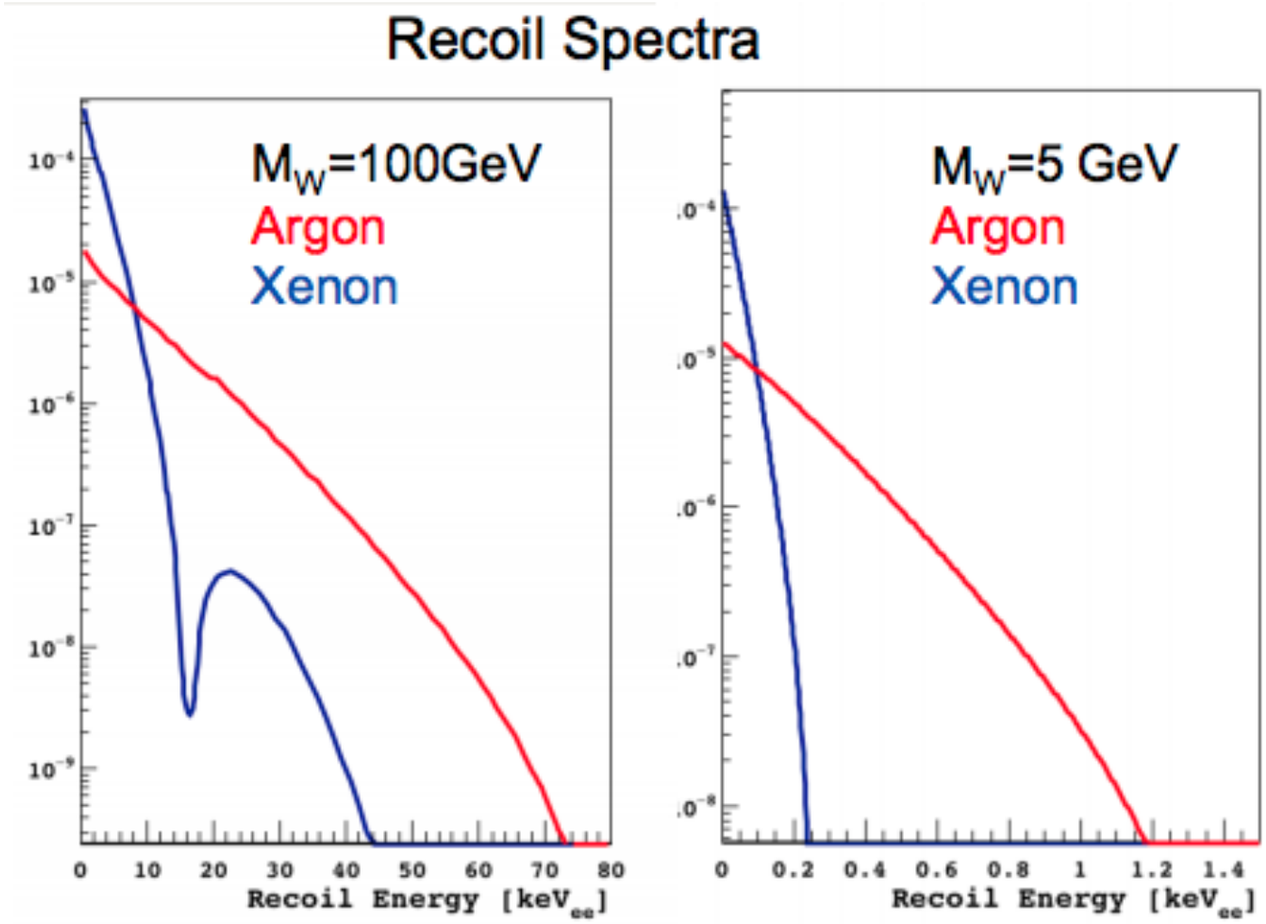
Low mass WIMPs in LAr

- S1 threshold at 2 keV_{ee} (~ 6 keV_{nr})
- No pulse shape discrimination at low energies

BUT

- Successful attempts in LXe
- Ar is lighter than Xe

→ For a given WIMP mass, larger energy deposited

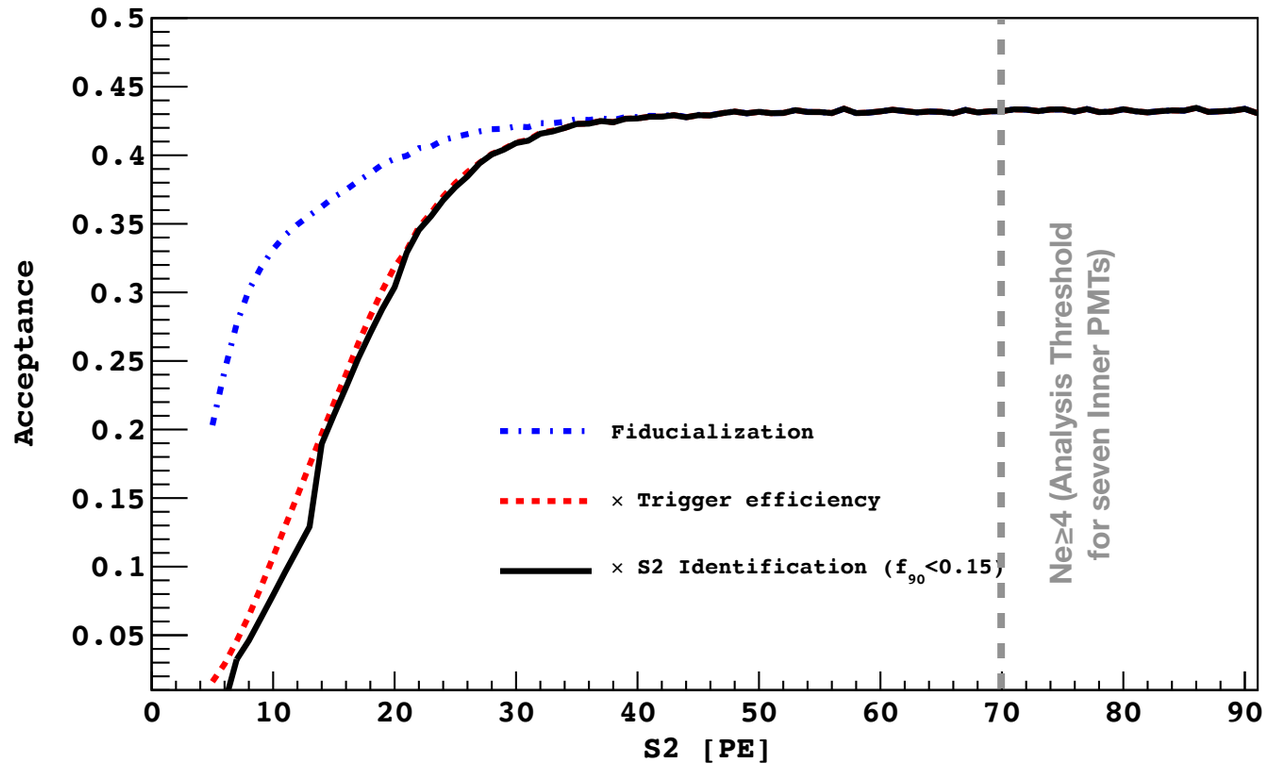


Visible energy (including quenching)

Ionization signal (S2) in LAr

- High detection efficiency down to low energies
- Sensitive to single electrons extracted in the gas phase

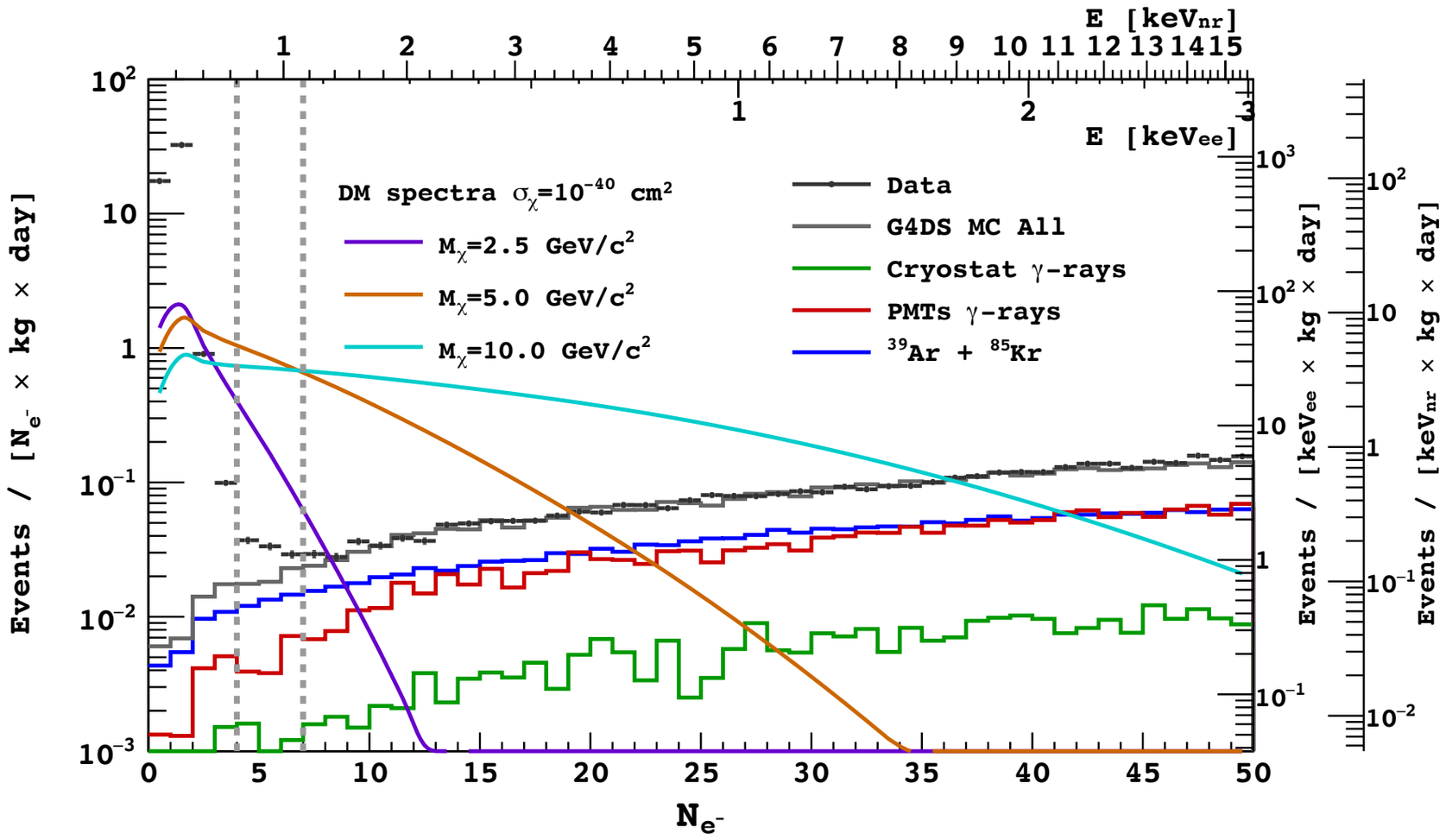
→ **S2 analysis threshold : 0.6 keV$_{nr}$**



S2-only analysis allows to set a lower analysis threshold

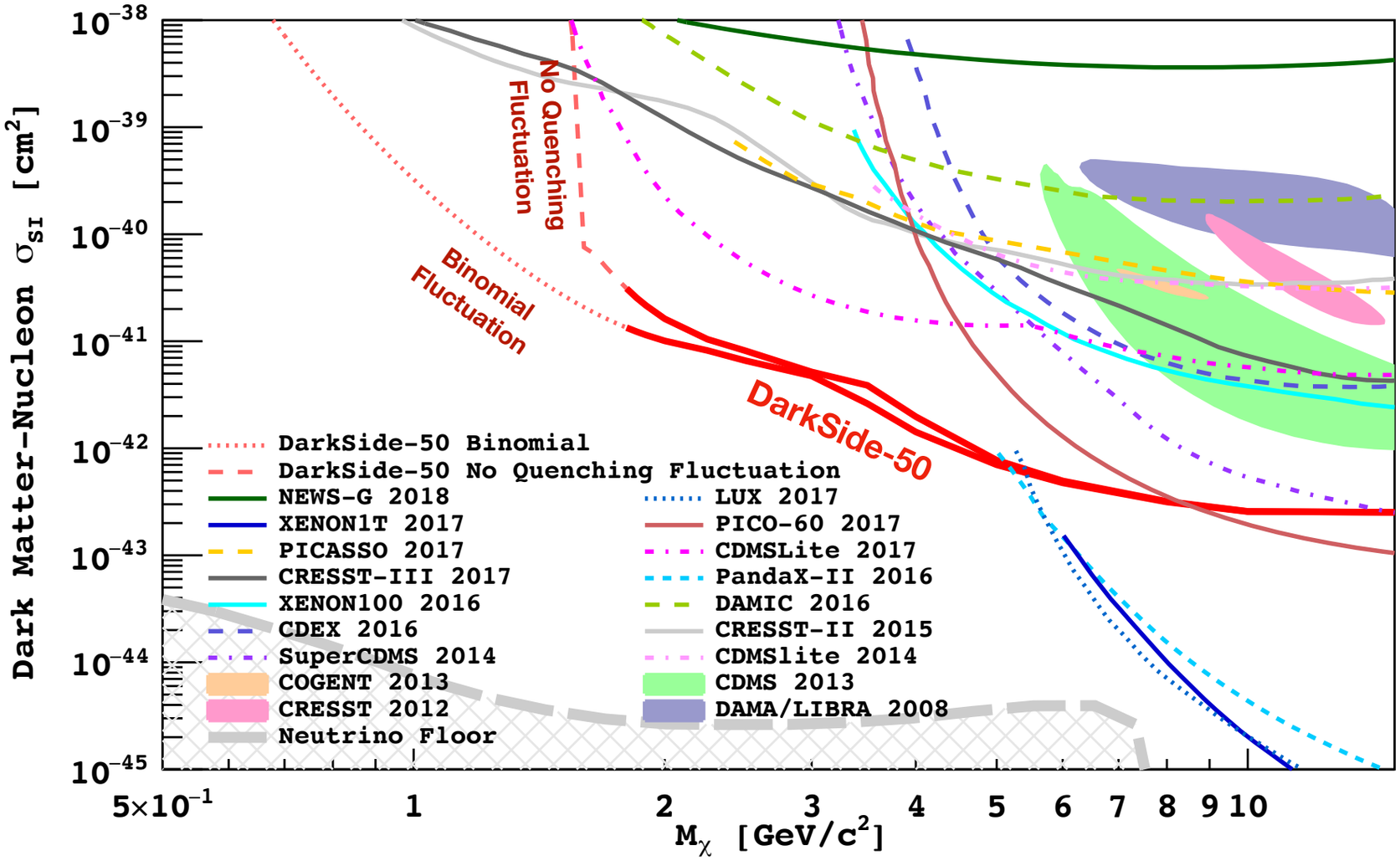
→ **Low mass WIMPs searches accessible**

Low energy backgrounds



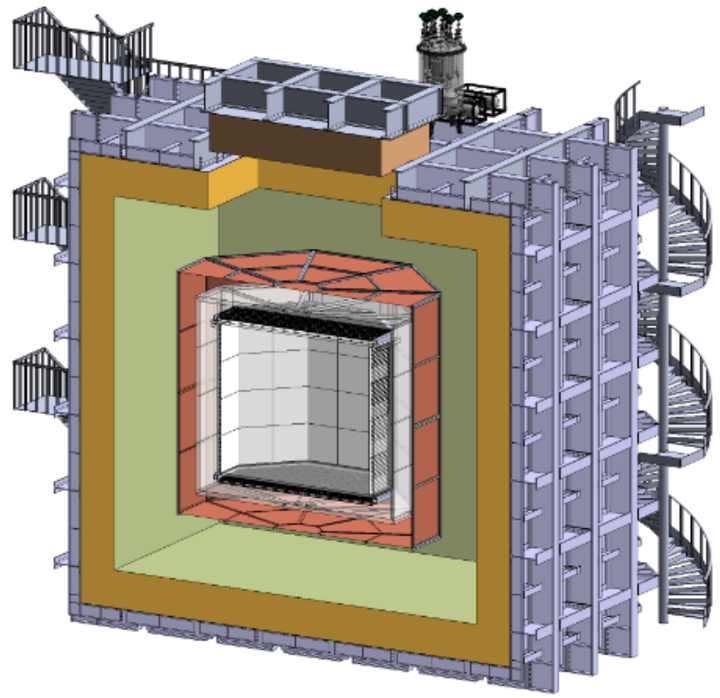
- **Ne < 4** (E < 0.6 keV_{nr}) → dominated by trapped electrons→ region not used in the analysis
- **Ne >= 7** → background reproduced by MC component measured by high energy spectral fit
  - Dominated by ^{85}Kr and ^{39}Ar
- **4 < Ne < 7** → excess of the data with respect to the MC likely due to 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/c^2

Future: DarkSide-20k

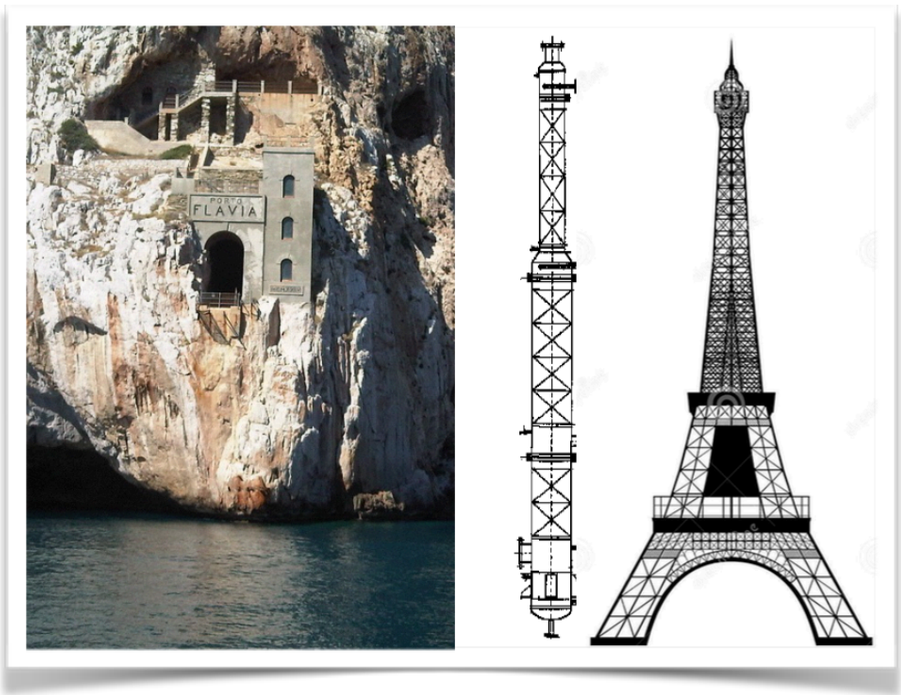


DarkSide-20k:

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

ARIA (UAr purification):

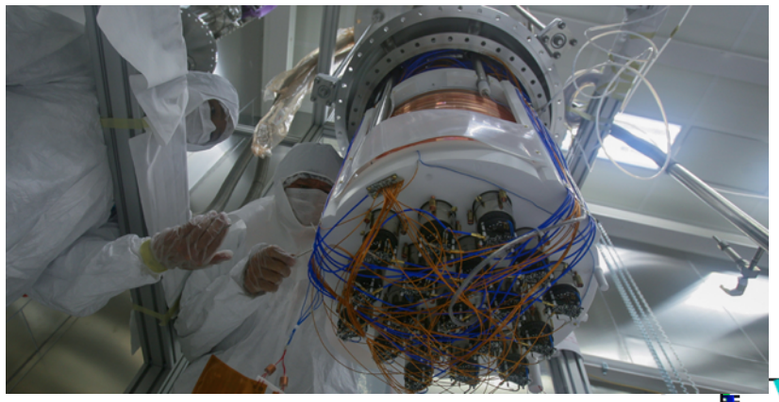
300 m tall column in the Seruci mine in Sardinia (Italy) for high-volume **chemical and isotopic purification** of **underground argon**



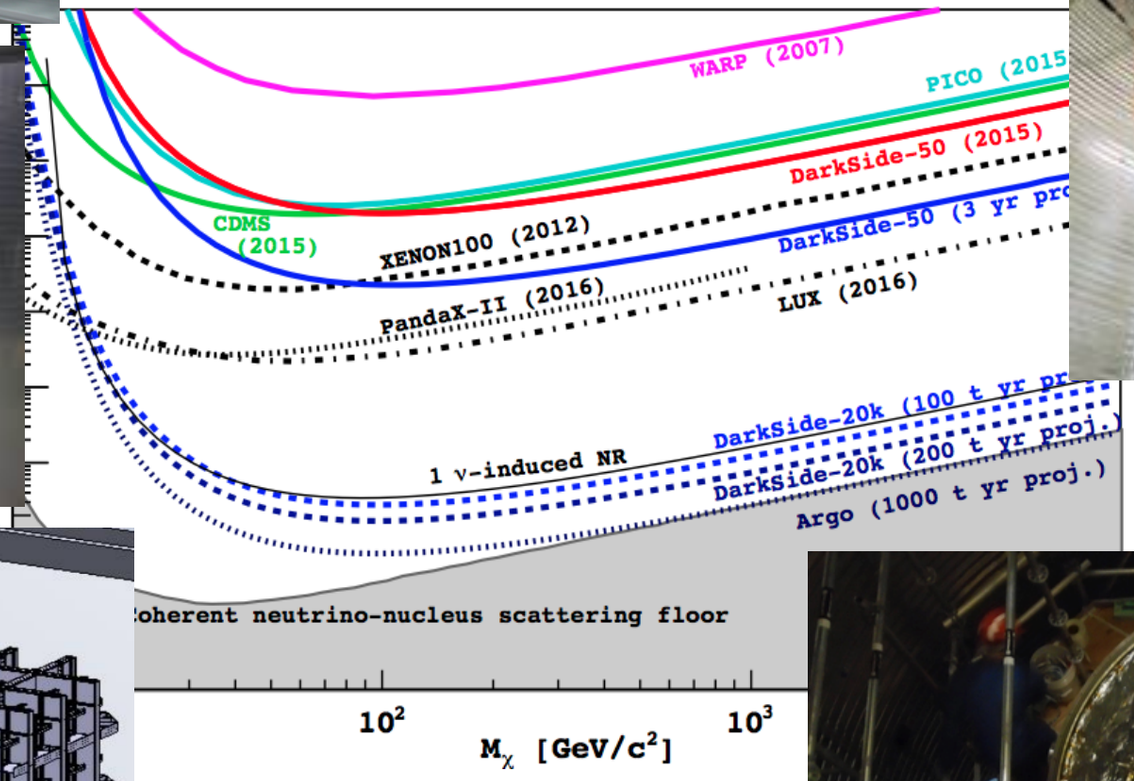
Urania (UAr extraction):

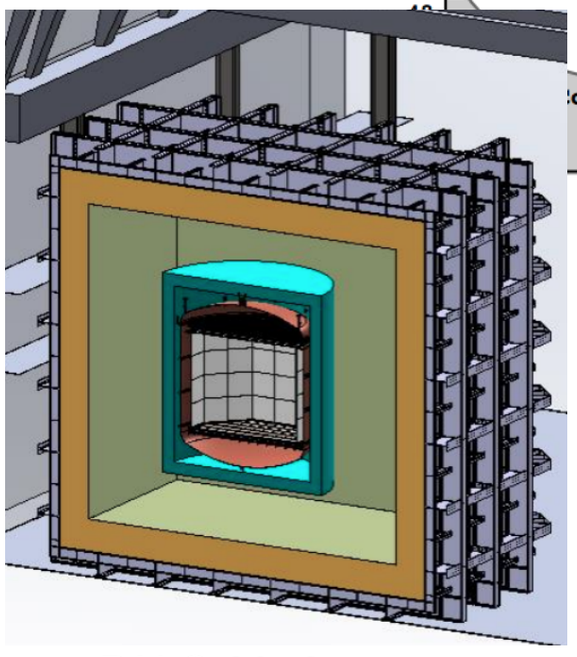
Colorado UAr production facility.
Production: 100 kg/d

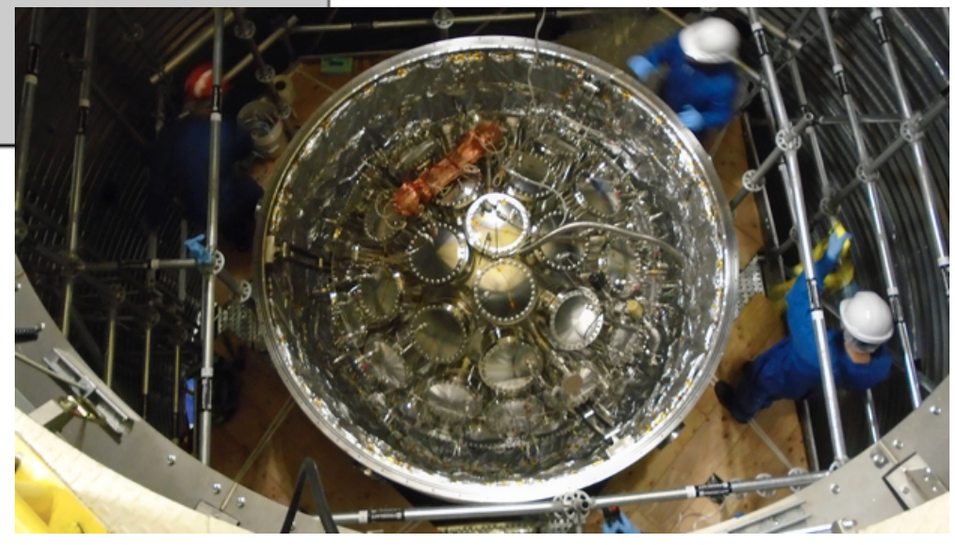
Future: the Global Argon Dark Matter Collaboration



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**

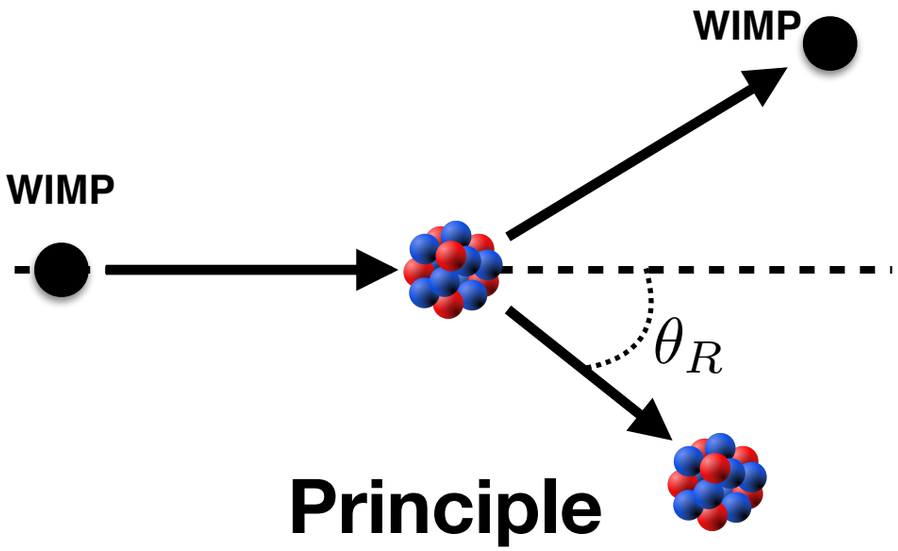
  ➡ DEAP-3600, MiniCLEAN, ArDM and CERN joined the project

- Final goal: **300t Argon observatory for Dark Matter and Neutrinos**

Thank you for your attention

Backup slides

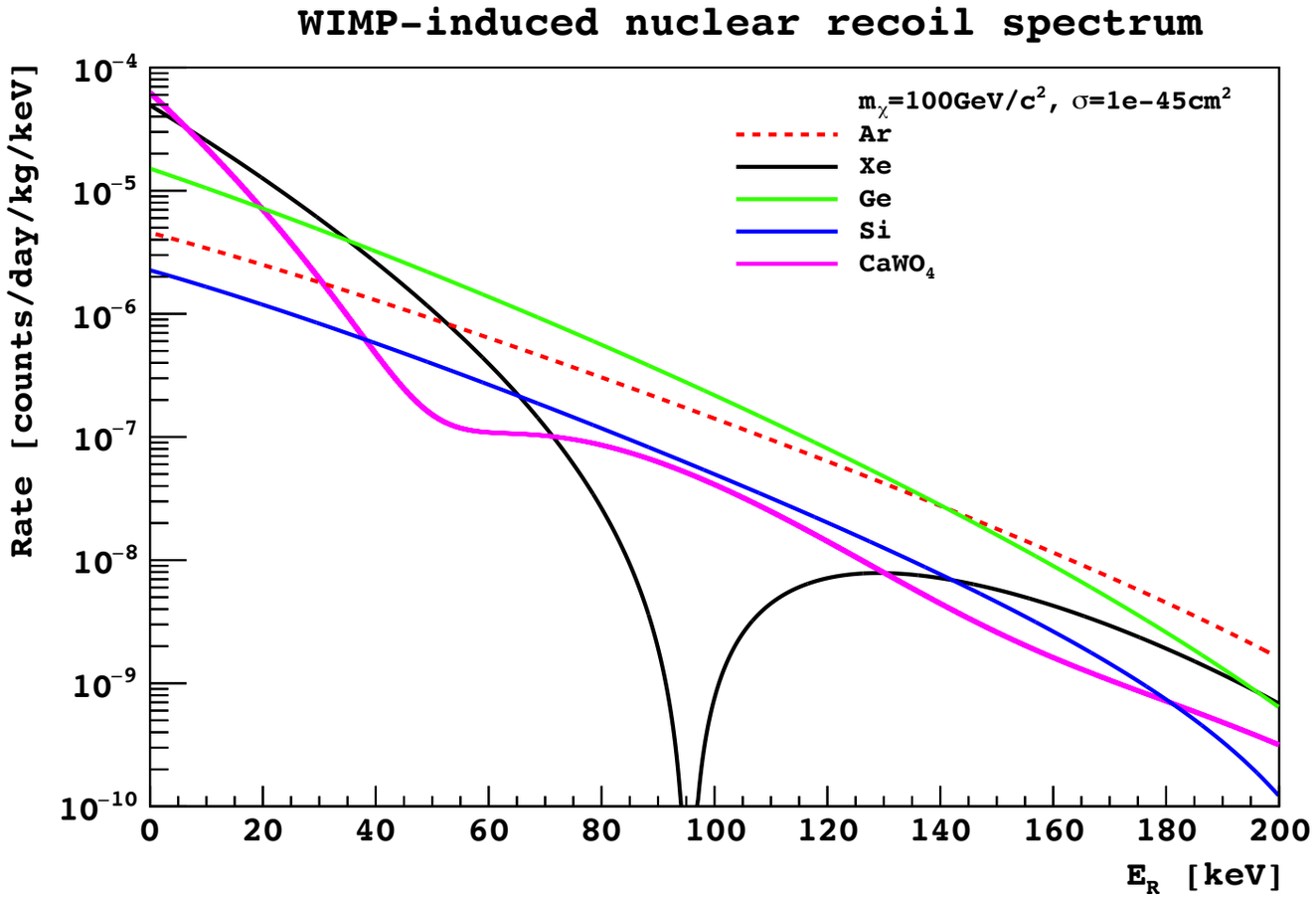
Direct dark matter search



Principle

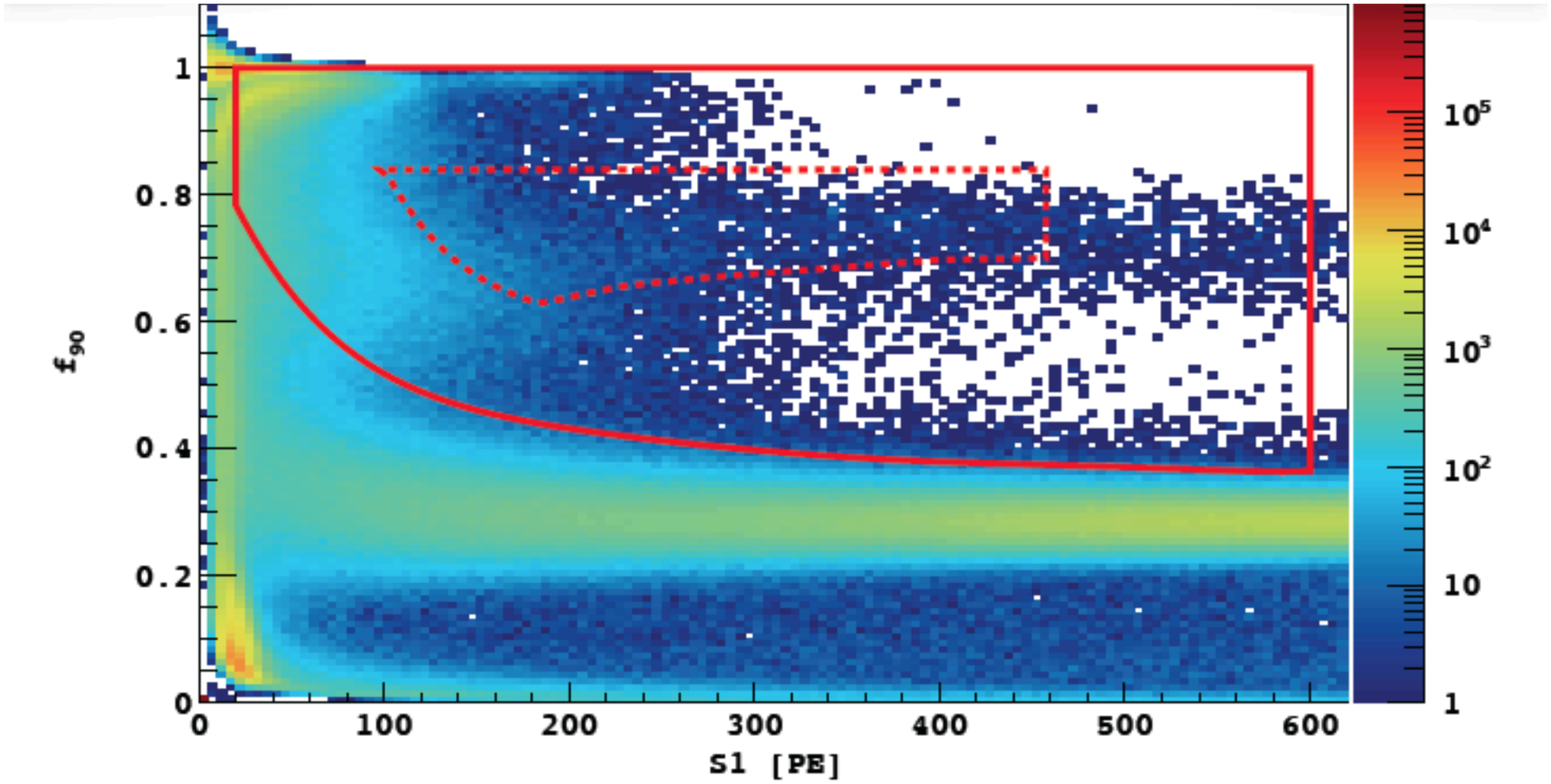
Detect a DM particle scattering off a nucleus
⇨Nuclear recoil

$$\frac{dR}{dE_R} \propto \frac{m_N}{\mu^2 m_\chi} \rho_0 \sigma(q) \int_{v_{min}}^{v_{esc}} \frac{f(v)}{v} d^3v$$



Weakly Interacting Massive Particles
are one of the main DM candidates

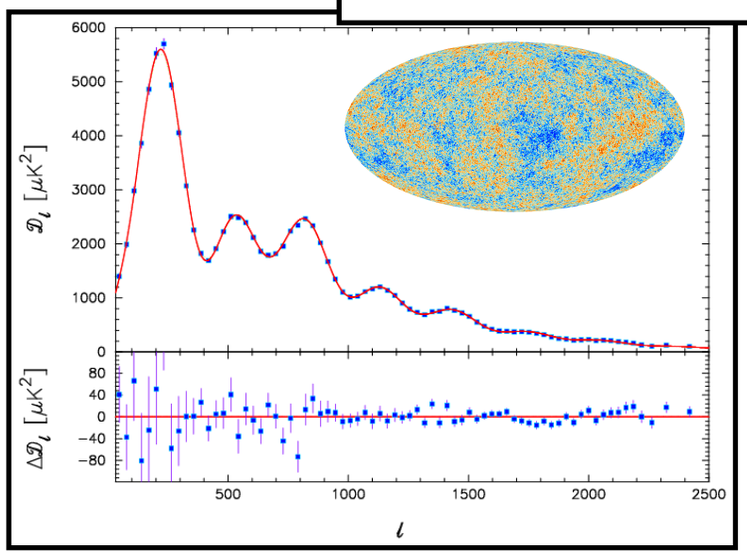
532 live days blind analysis



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

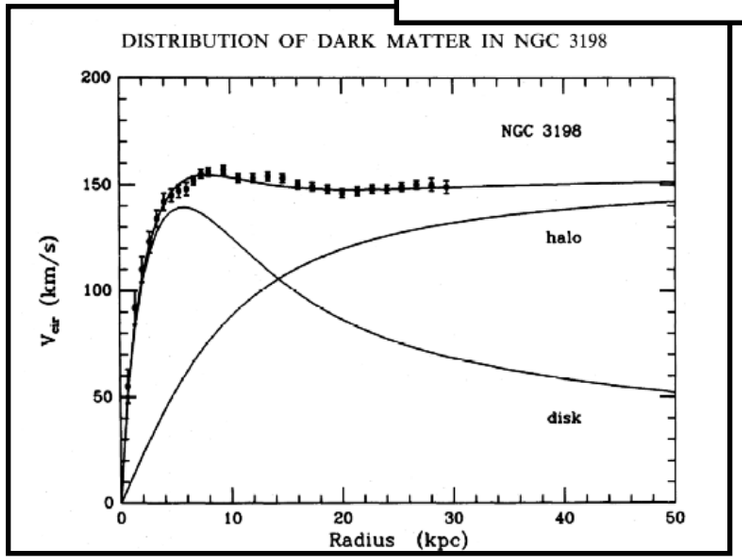
The Dark Matter enigma

Precision cosmology

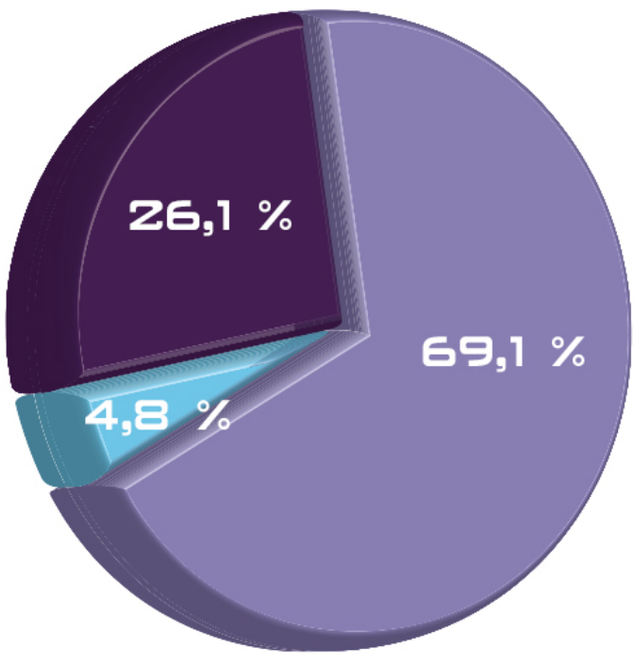


Weak lensing

Rotation curves



Universe scale



Galaxy cluster scale

Dark matter

Baryonic matter

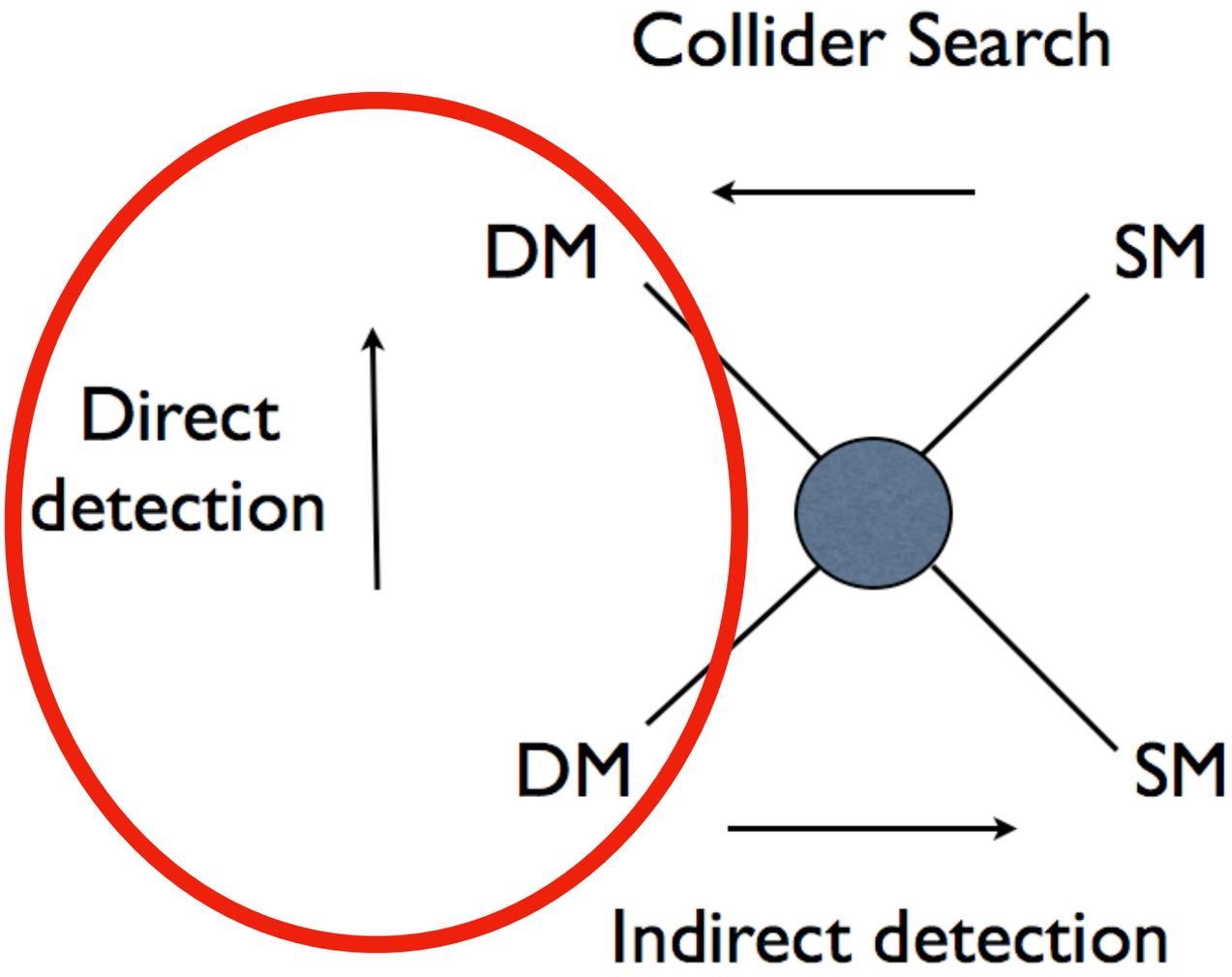
Dark energy

Local scale

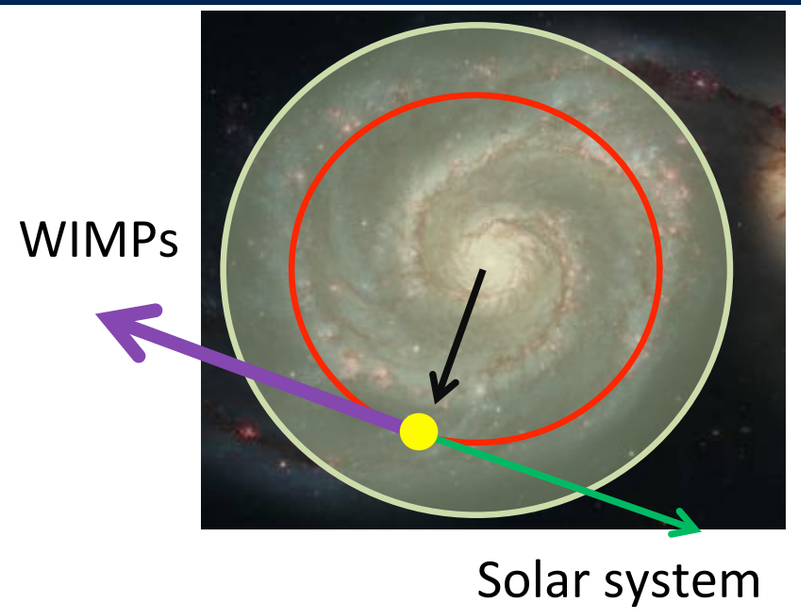
and others….

Weakly Interacting Massive Particles are one of the main DM candidates

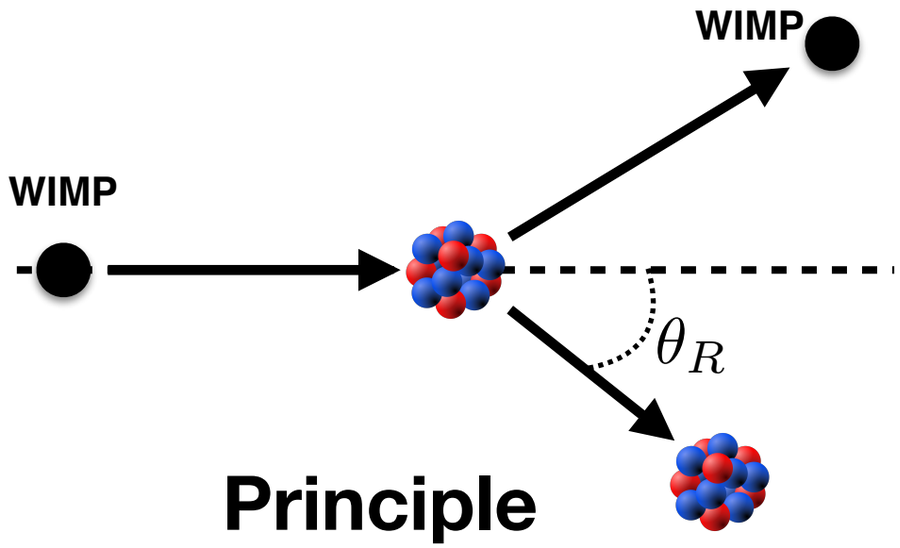
Direct dark matter search



Weakly Interacting Massive Particles
are one of the main DM candidates



Motion of Solar system
⇨ dark matter « wind »



Principle

Detect a DM particle scattering off a nucleus
⇨Nuclear recoil (E_{NR} < 100 keV)

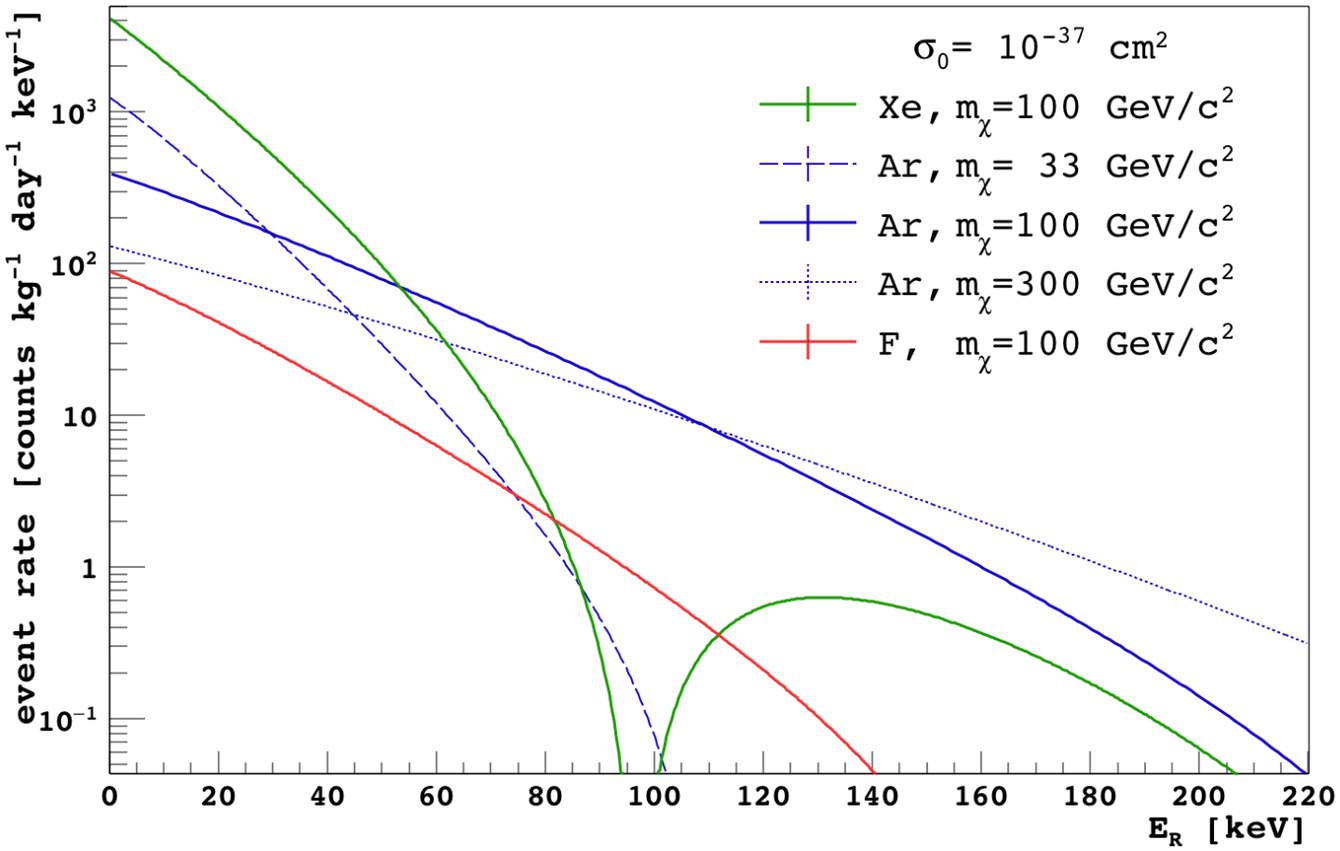
Why noble liquid ?

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

High **ionisation** yield (W ~ 10-20 eV)
High **scintillation** yield (> 50,000 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

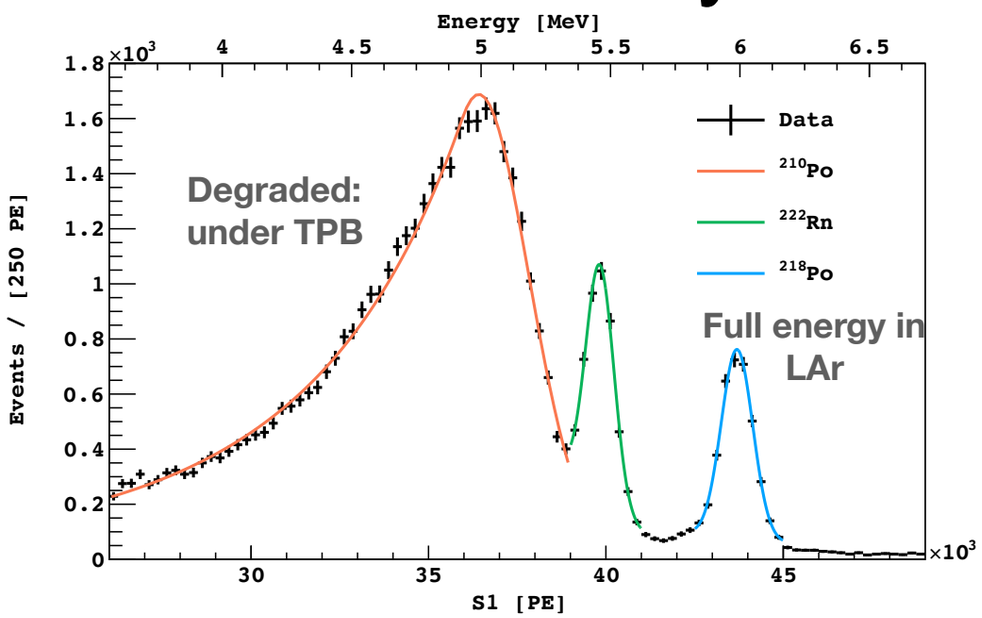
Liquid Argon (DarkSide, DEAP, ArDM)
- **Intrinsic contamination from ^{39}Ar**
- **Better ER/NR discrimination:**
  - ionisation/scintillation + **PSD**



High mass WIMPs search

NR background

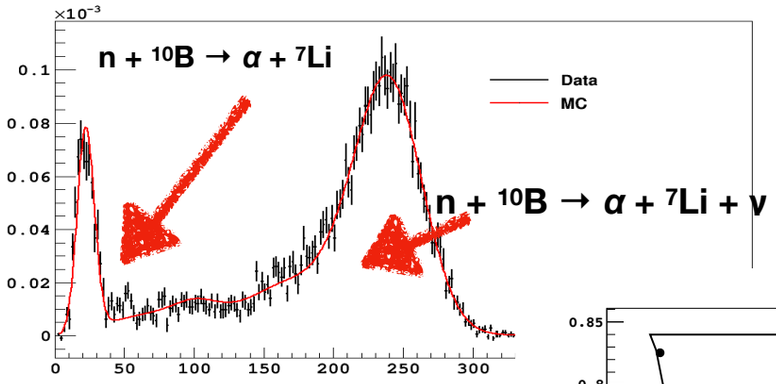
Surface α decays

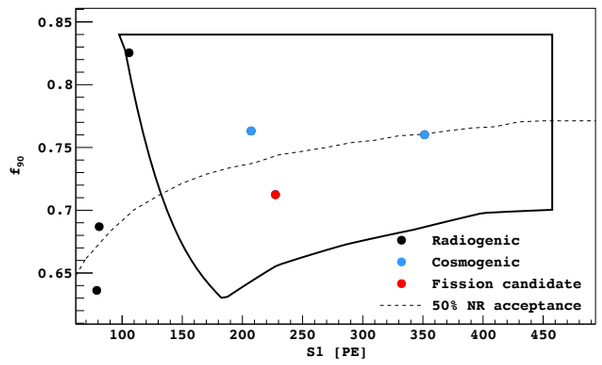


Surface α decays → expect < 0.001

- Well above the WIMP search region (S1 < 460)
- Small or no S2 for events with large R
- Long scintillation tail from TPB

Neutrons





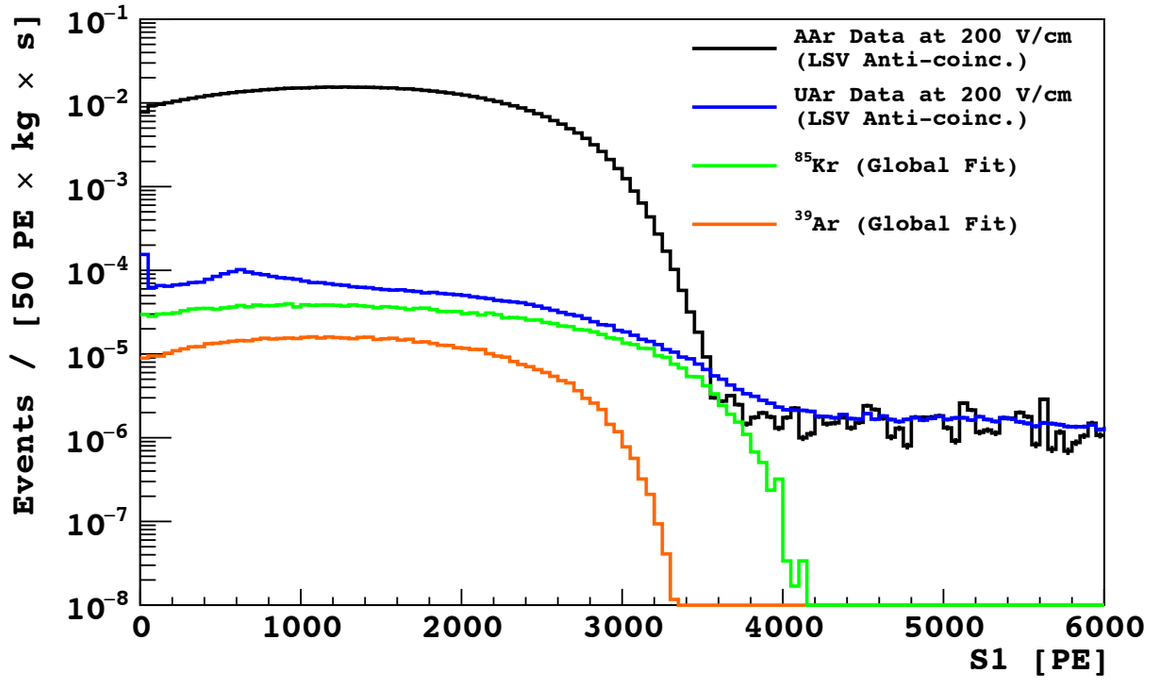
Neutrons (cosmogenic or radiogenic) < 0.005

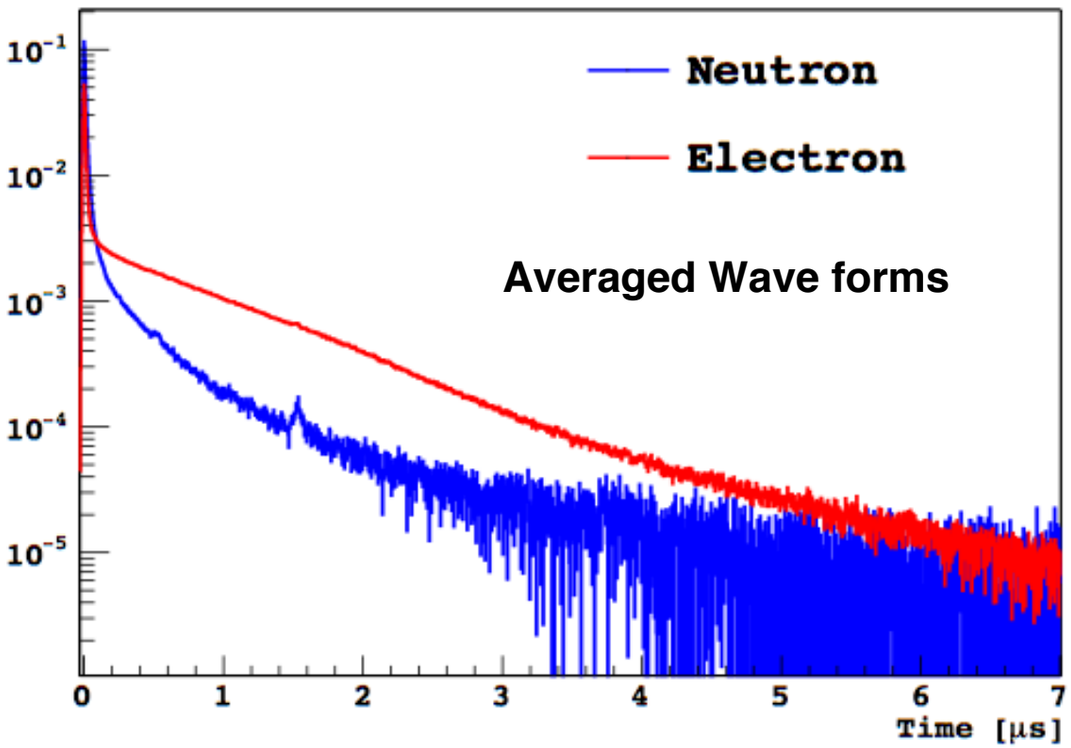
- Cosmogenics: Water Cherenkov Veto → completely negligible
- Radiogenics: LS Veto and multi-scatter events in the TPC
- Measured LSV tagging efficiency with Am-C source for TPC single-NR: 0.9964±0.0004
- Neutrons are counted to confirm prediction

ER background

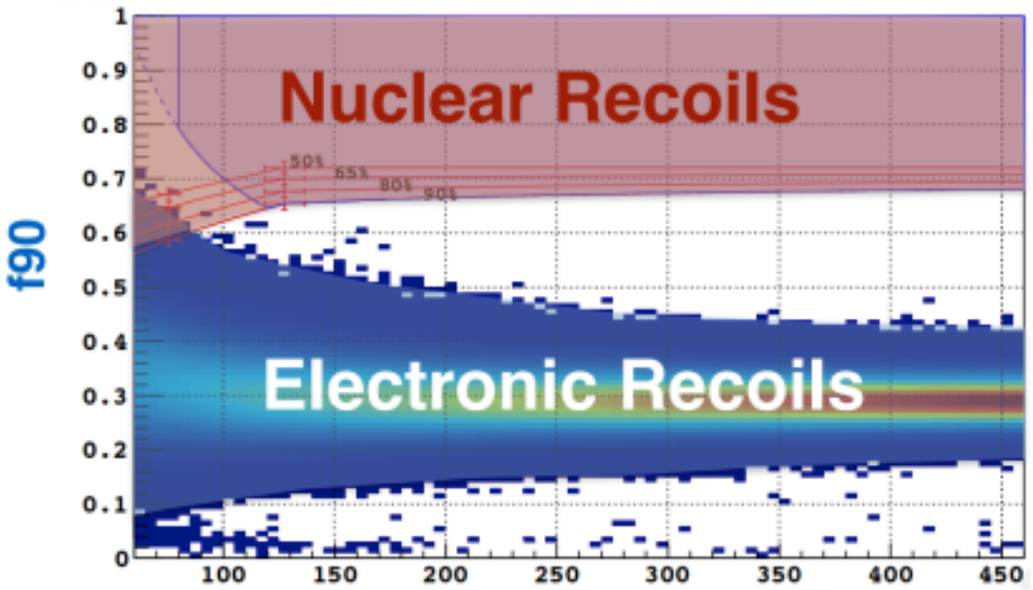
ER rejection:

- 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 >1.5x10^7

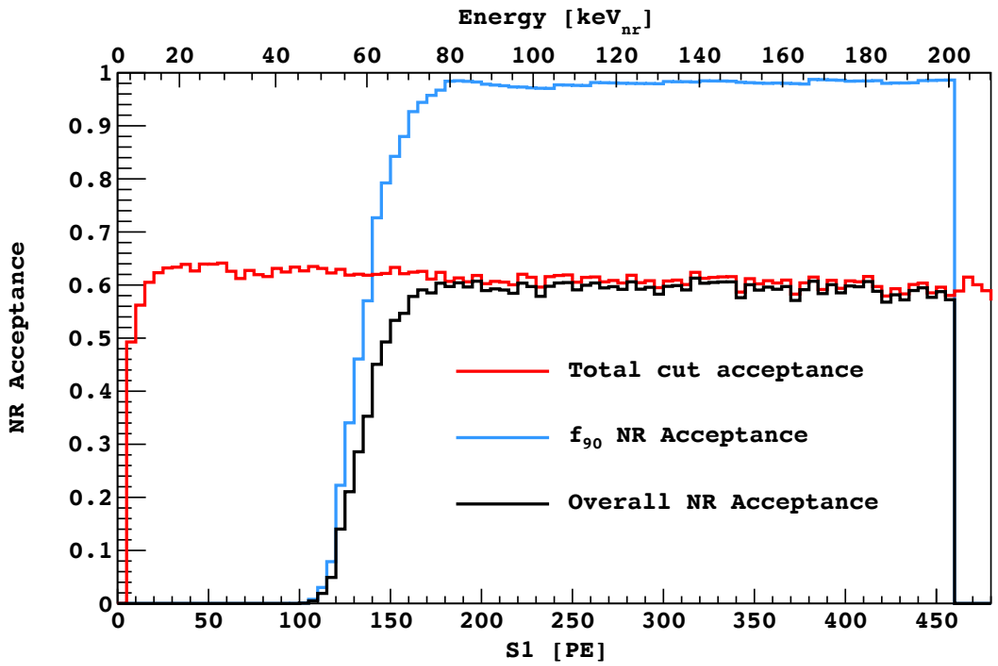




In previous DS-50 papers the WIMP acceptance region was designed with the requirement of having <0.1 background events from pure ER



Background estimates and acceptance



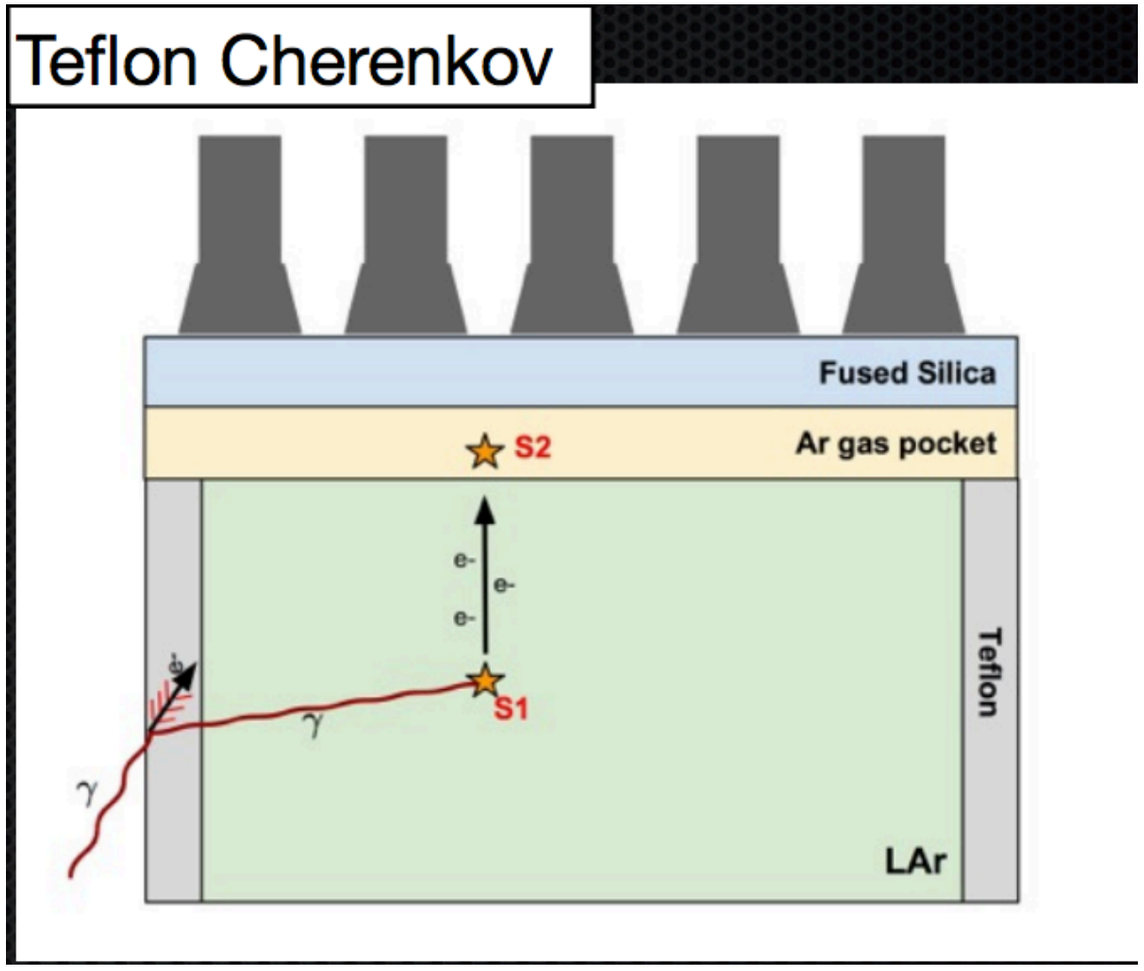
Background	Events surviving all cuts
Surface Type 1	0.0006 ± 0.0001
Surface Type 2	0.00092 ± 0.00004
Radiogenic neutrons	< 0.005
Cosmogenic neutrons	< 0.00035
Electron recoil	0.08 ± 0.04
Total	0.09 ± 0.04

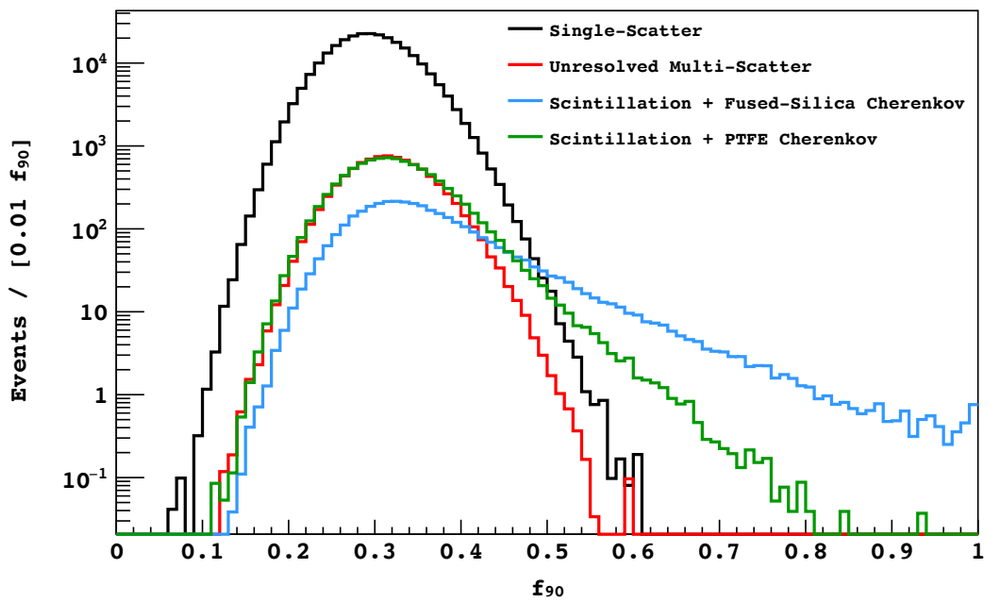
Design goal achieved

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
$S1_p$ max frac	0.948
S1 TBA	0.998
Long S1 tail	0.987
Radial cut	0.84
S1 NLL	>0.99
Combined	0.609

ER +Cerenkov background

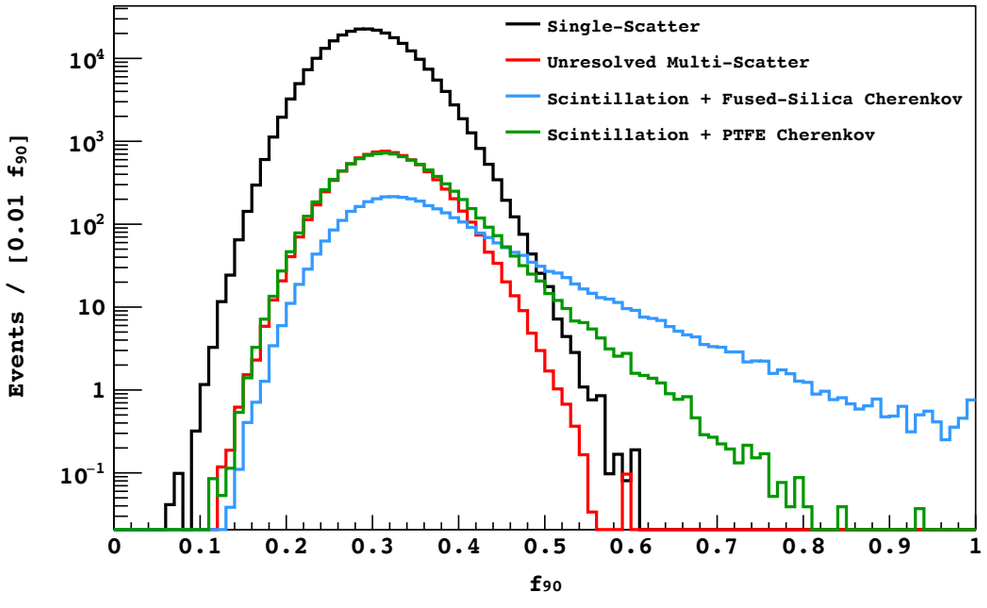
- Another source of background has extensively studied: ER + Cherenkov
  - Cherenkov light is all prompt →combined with an ER they enhance the f90 from ER
  - In the blind analysis some cuts have been implemented to reject ER+Cherenkov (radial cuts, Top/Bottom asymmetry vs tdrift, S1 prompt, …)

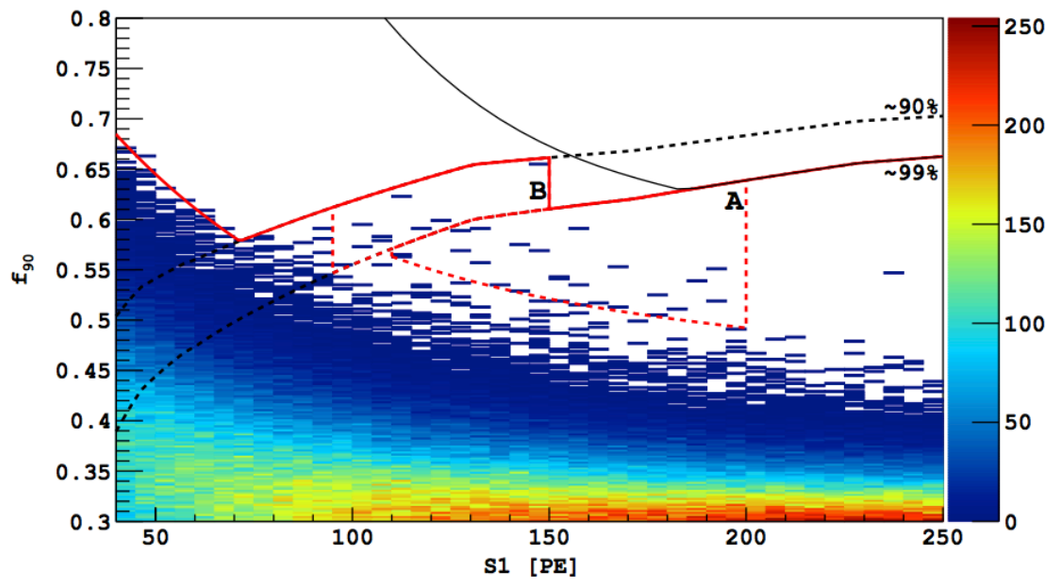




ER +Cerenkov background

- Another source of background has extensively studied: ER + Cherenkov
  - Cherenkov light is all prompt →combined with an ER they enhance the f90 from ER
  - In the blind analysis some cuts have been implemented to reject ER+Cherenkov (radial cuts, Top/Bottom asymmetry vs tdrift, S1 prompt, …)





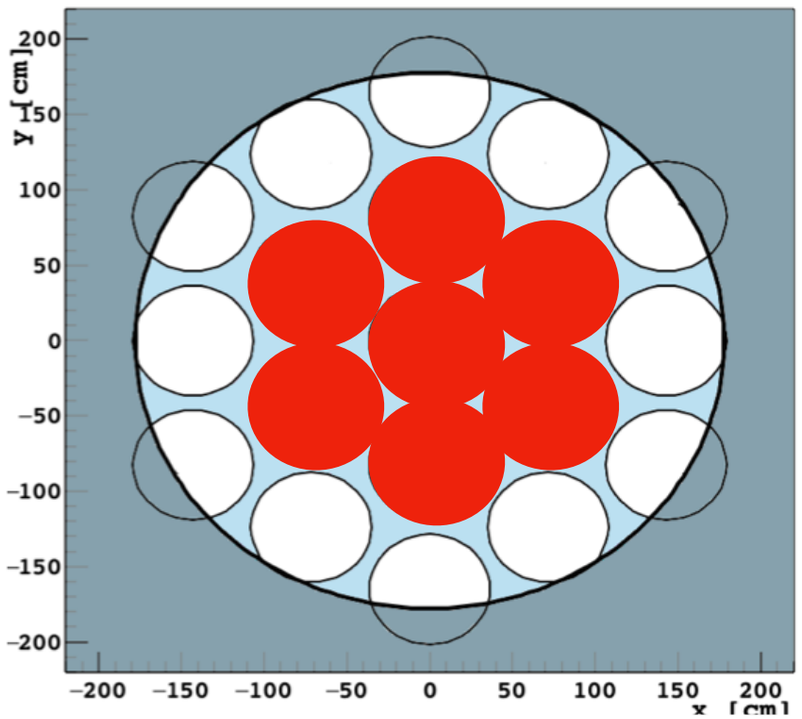
	A	B
Data	24	9
Model	13.3	8.7

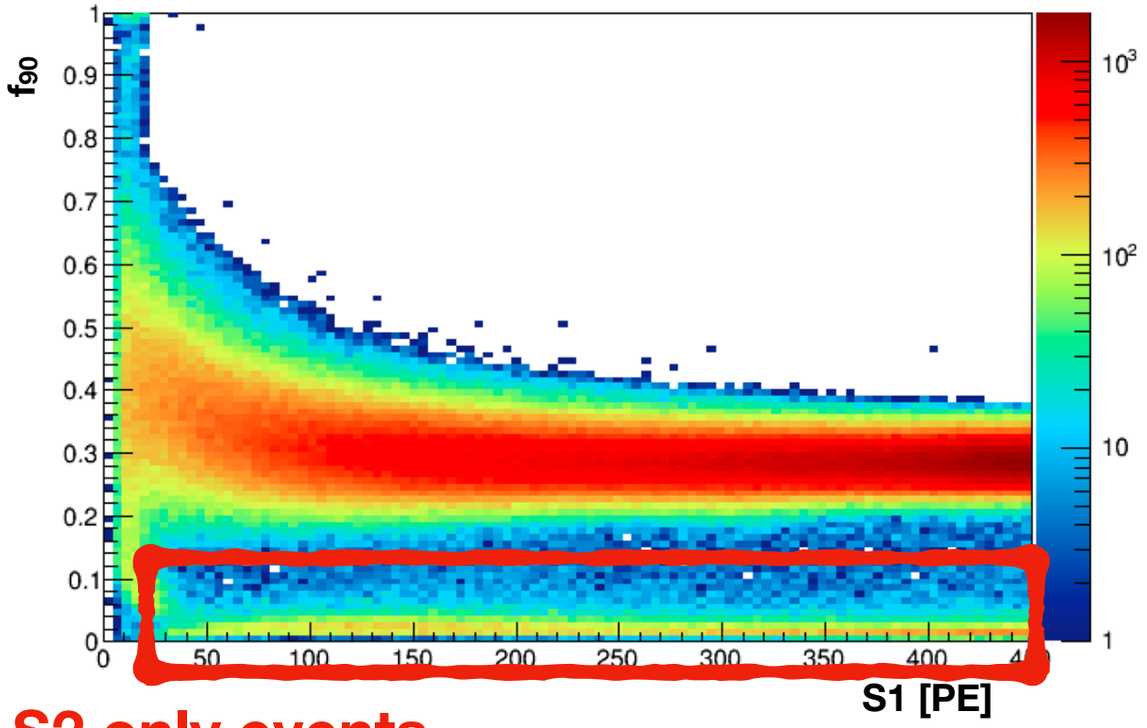
- Combining A and B we have 33 events, 14 of them surviving a radial cut → rejection factor of the radial cut
- Factor of 1.5 discrepancy between data and model is taken into account when drawing the box
- ER + Cherenkov is the dominant background for DS-50

Low mass WIMPs search

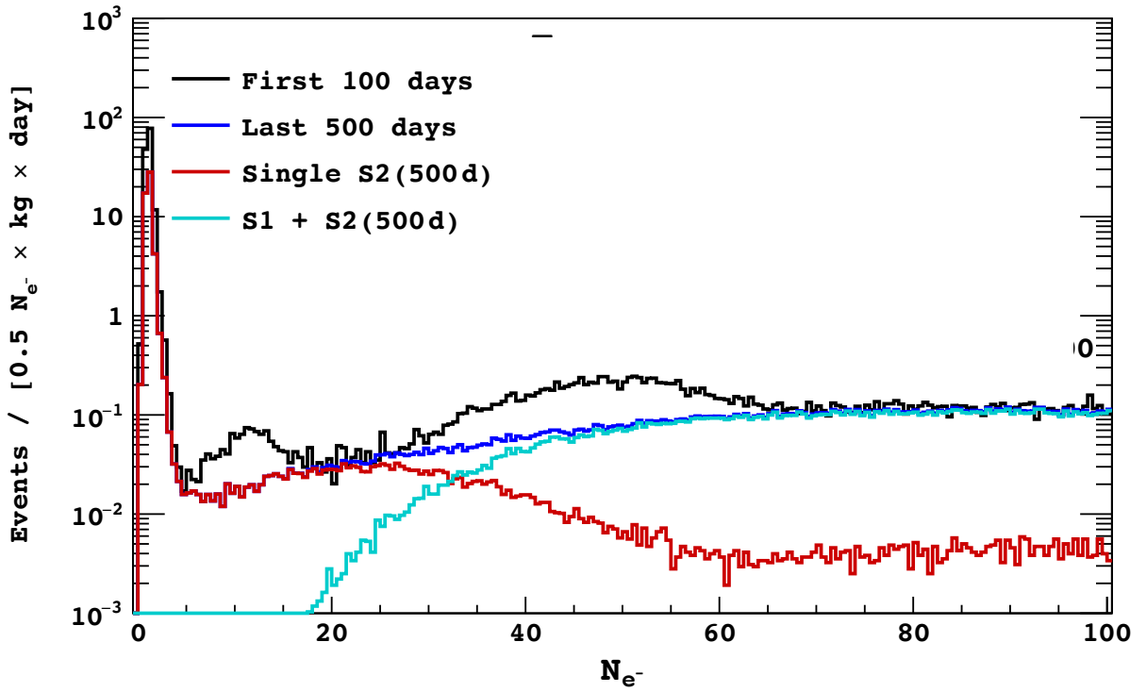
Data selection

- 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





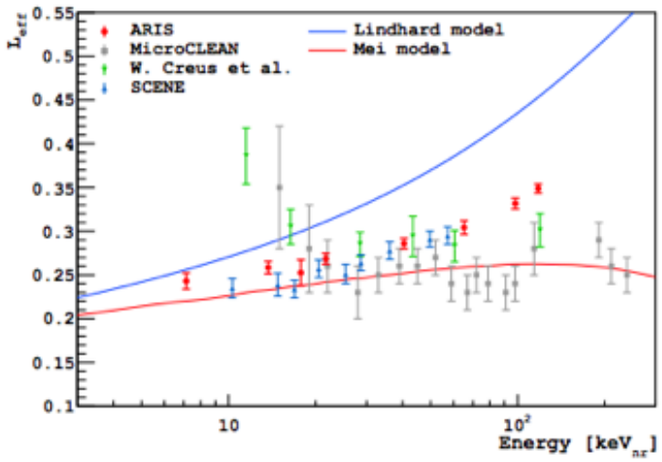
S2 only events

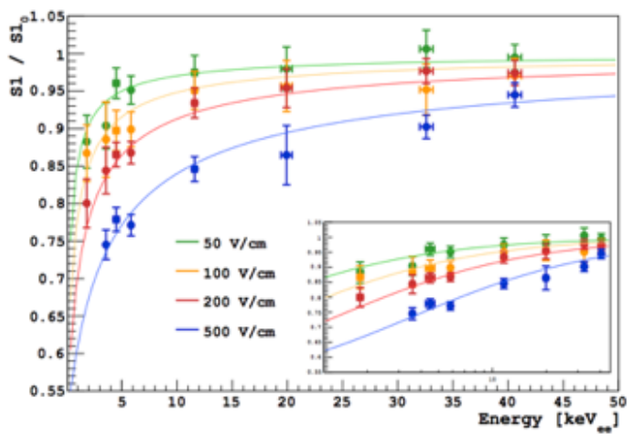


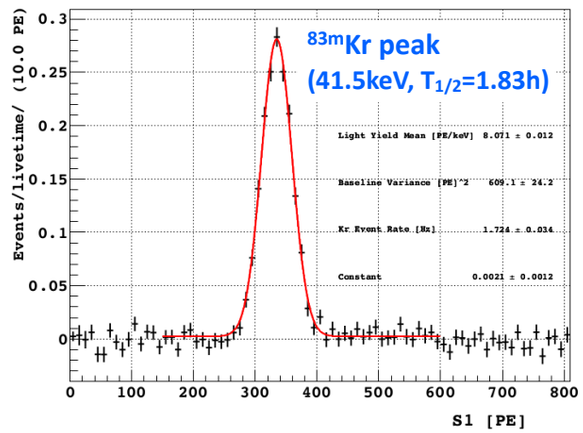
NR energy scale: ARIS

$S1_{DS50}$ (Enr) =

Leff = $S1^{0V}$ / (E_{nr} x LY_{ARIS}) x $S1^{200V}$/ $S1^{0V}$x E_{nr} x LY^{0V}_{DS50}







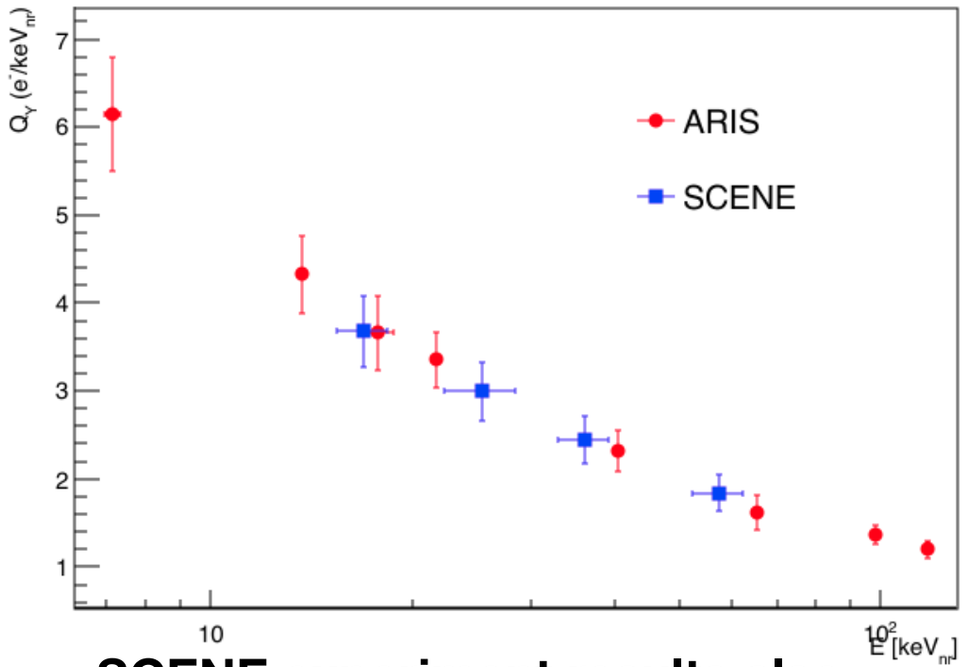
S1 in DS-50 reconstructed using ARIS L_{eff}

↓

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

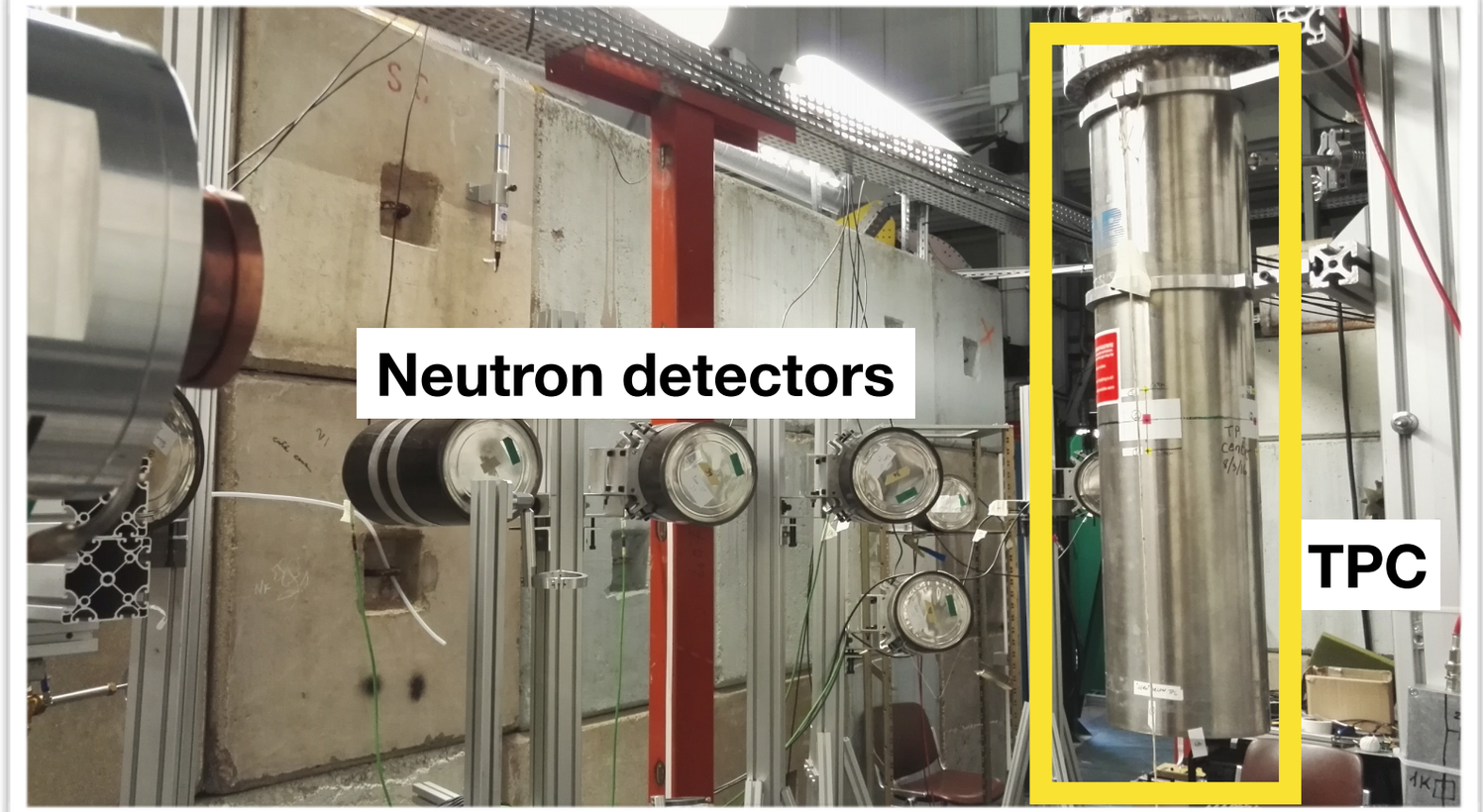
↓

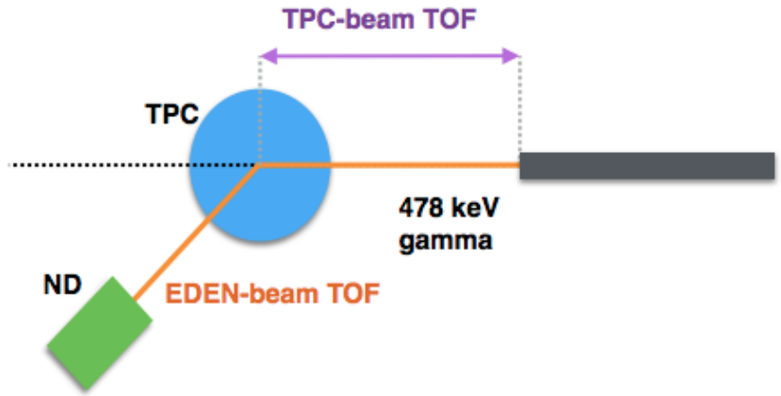
Ionization yield in DS-50

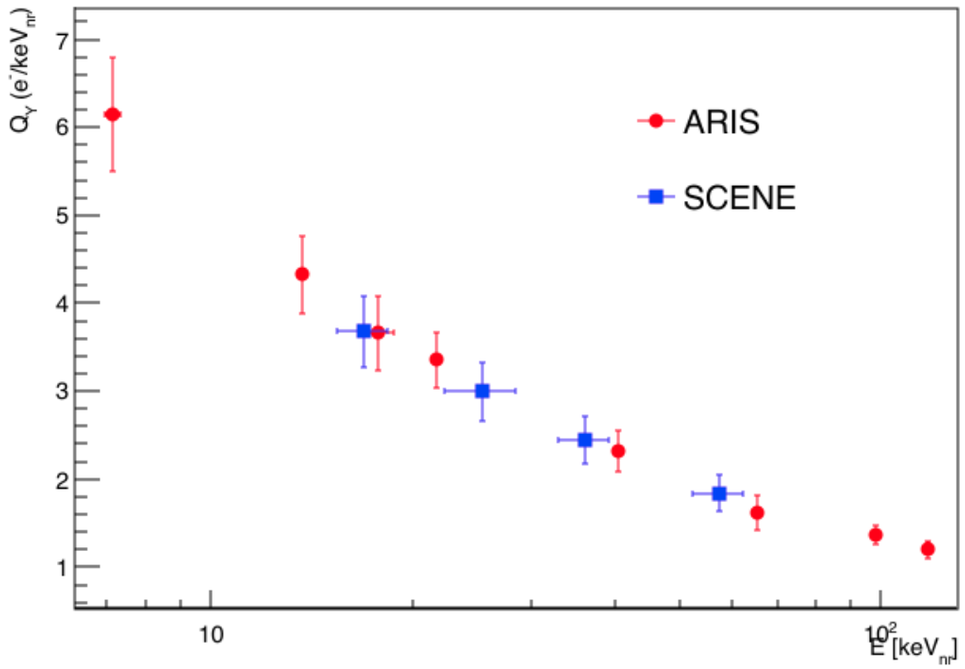


SCENE experiment results also considered (direct ionization measurement)

LAr response to NR : ARIS experiment







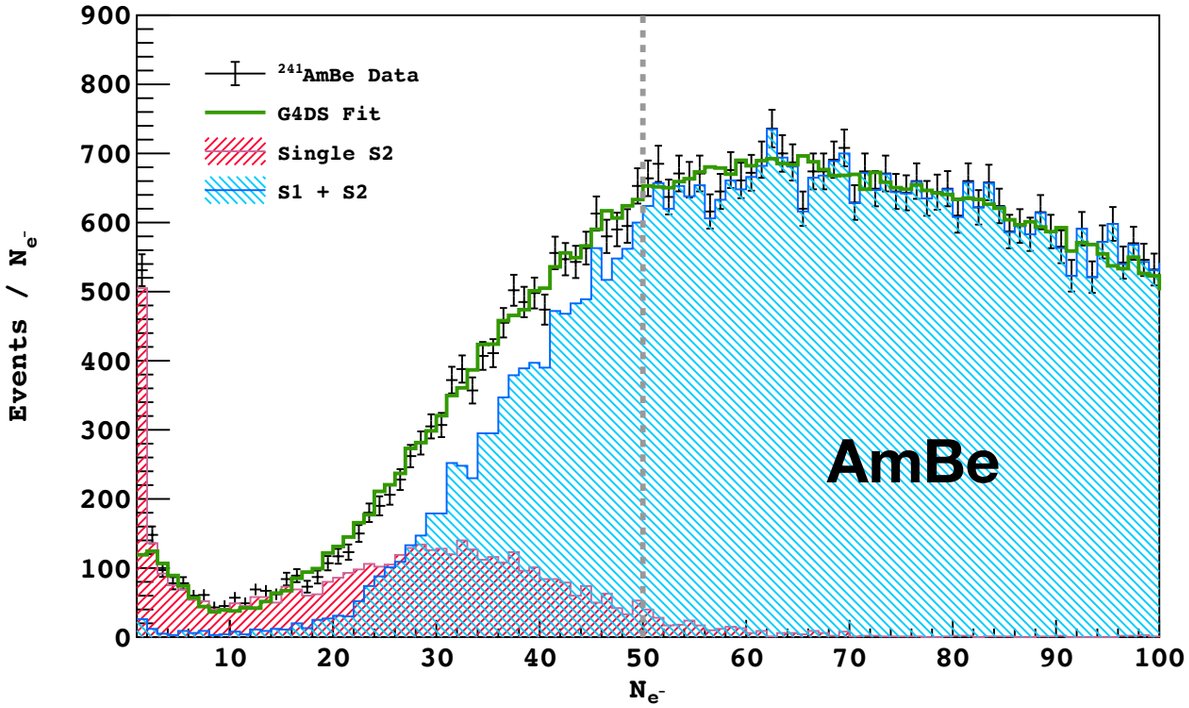
12 days of data taking
in October 2016

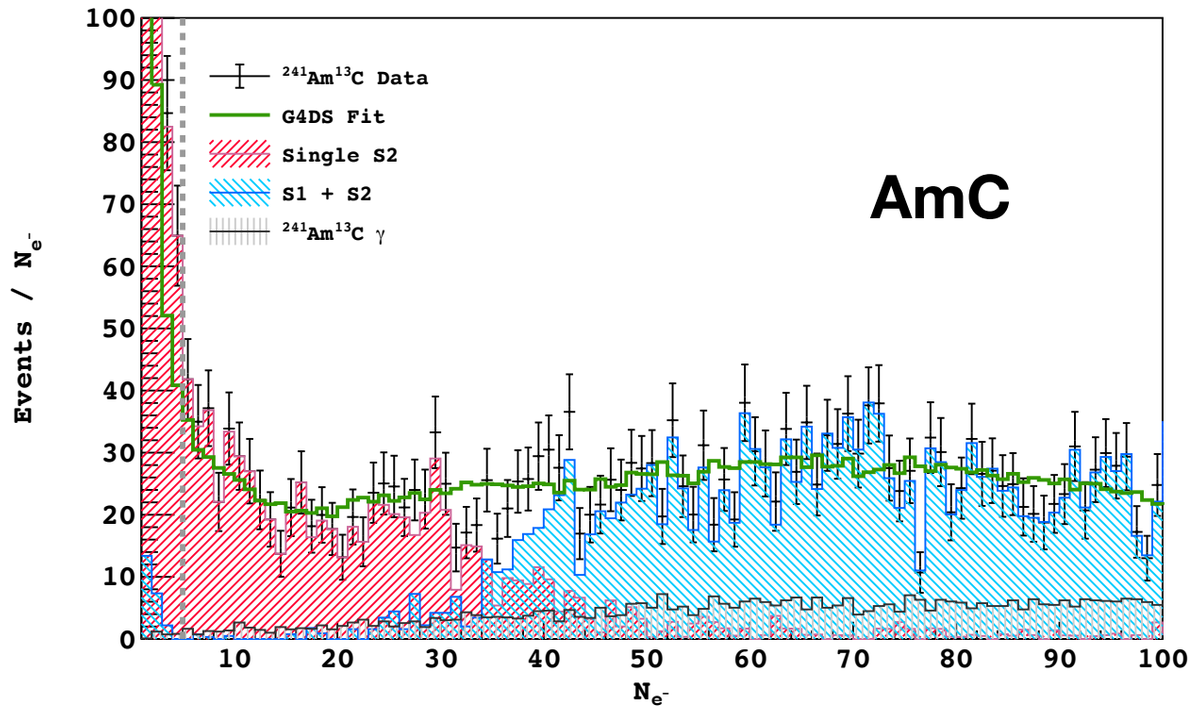
http://aris.in2p3.fr

Measurement of scintillation for NR and ER and NR quenching
Recoil energies from 7 keV_{nr} to 120 keV_{nr}

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

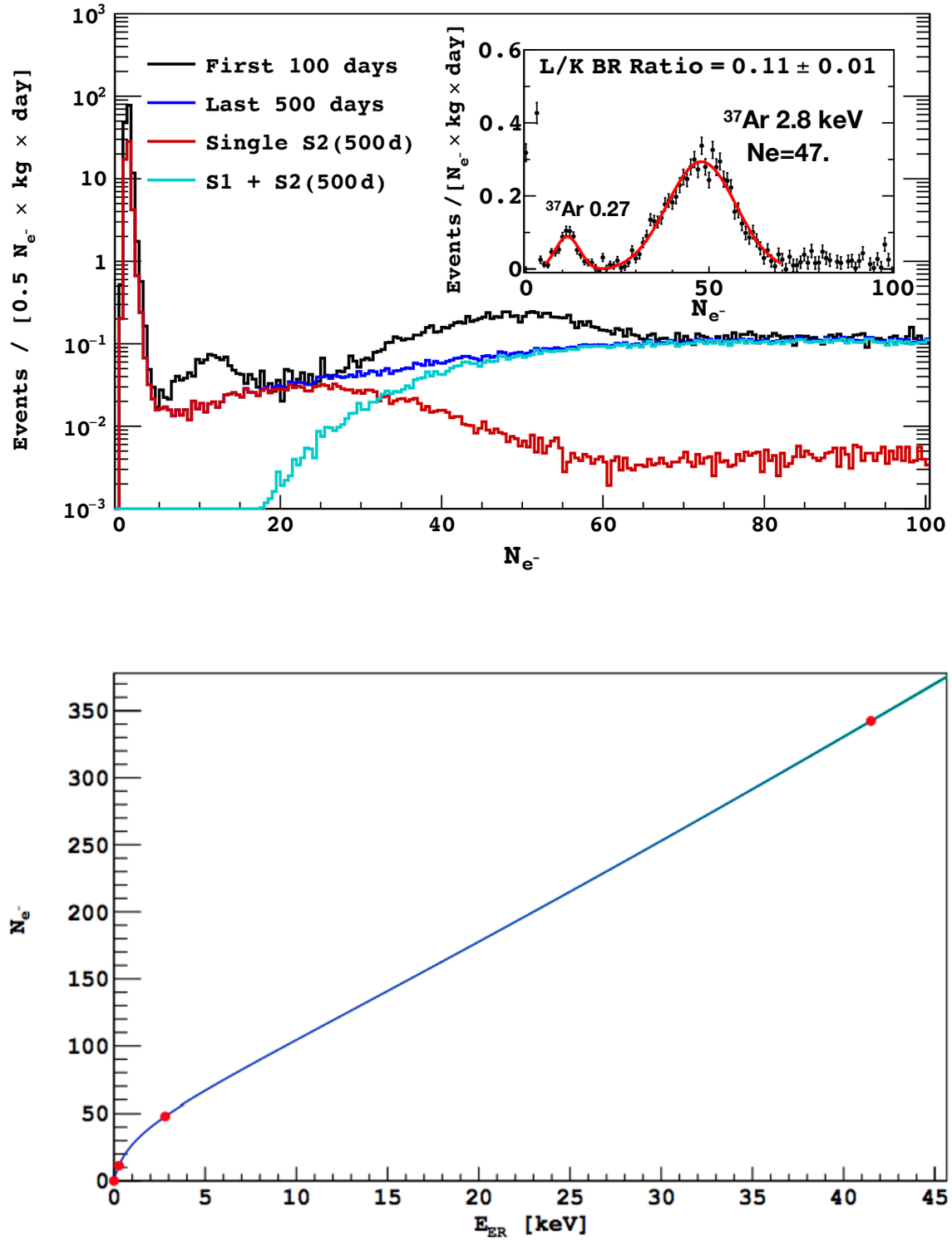
ER energy scale

- Presence of 37Ar 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 → S2-only region
  - 2.82 keV → S1+S2 region

E = 0.27 keV → Ne = 11

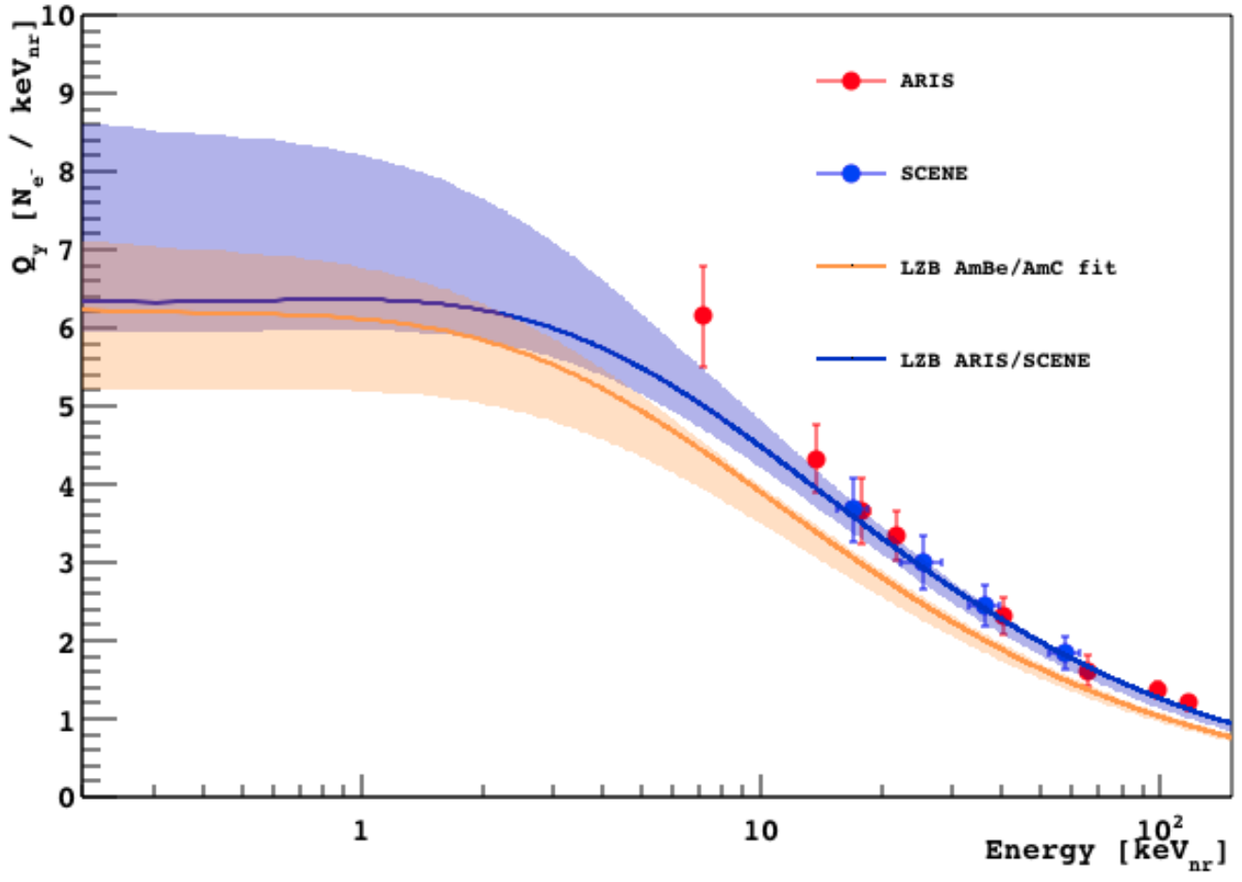
E = 2.82 keV → Ne = 49

Combined with ^{83m}Kr at 41 keV
→ ER energy scale

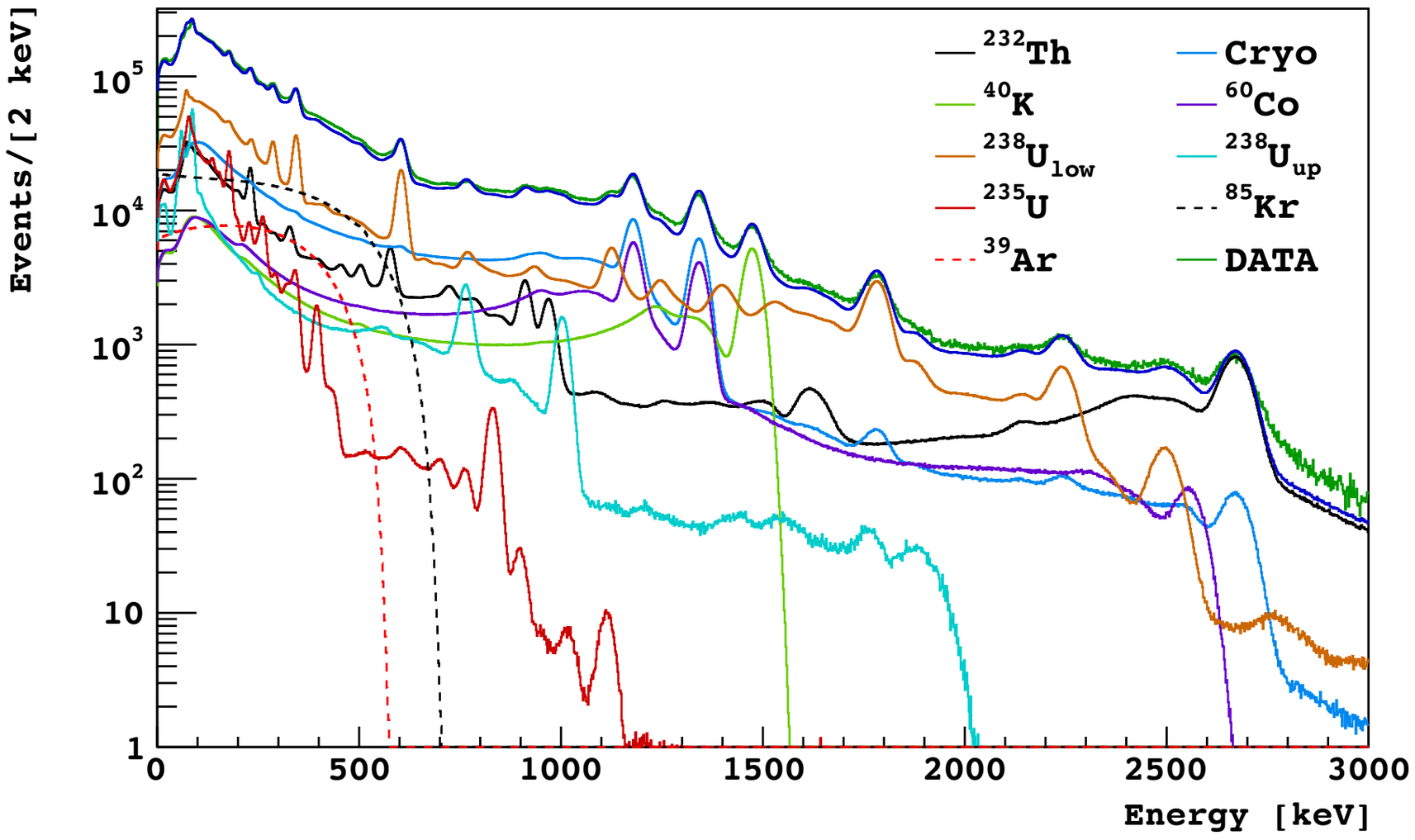


NR energy scale

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

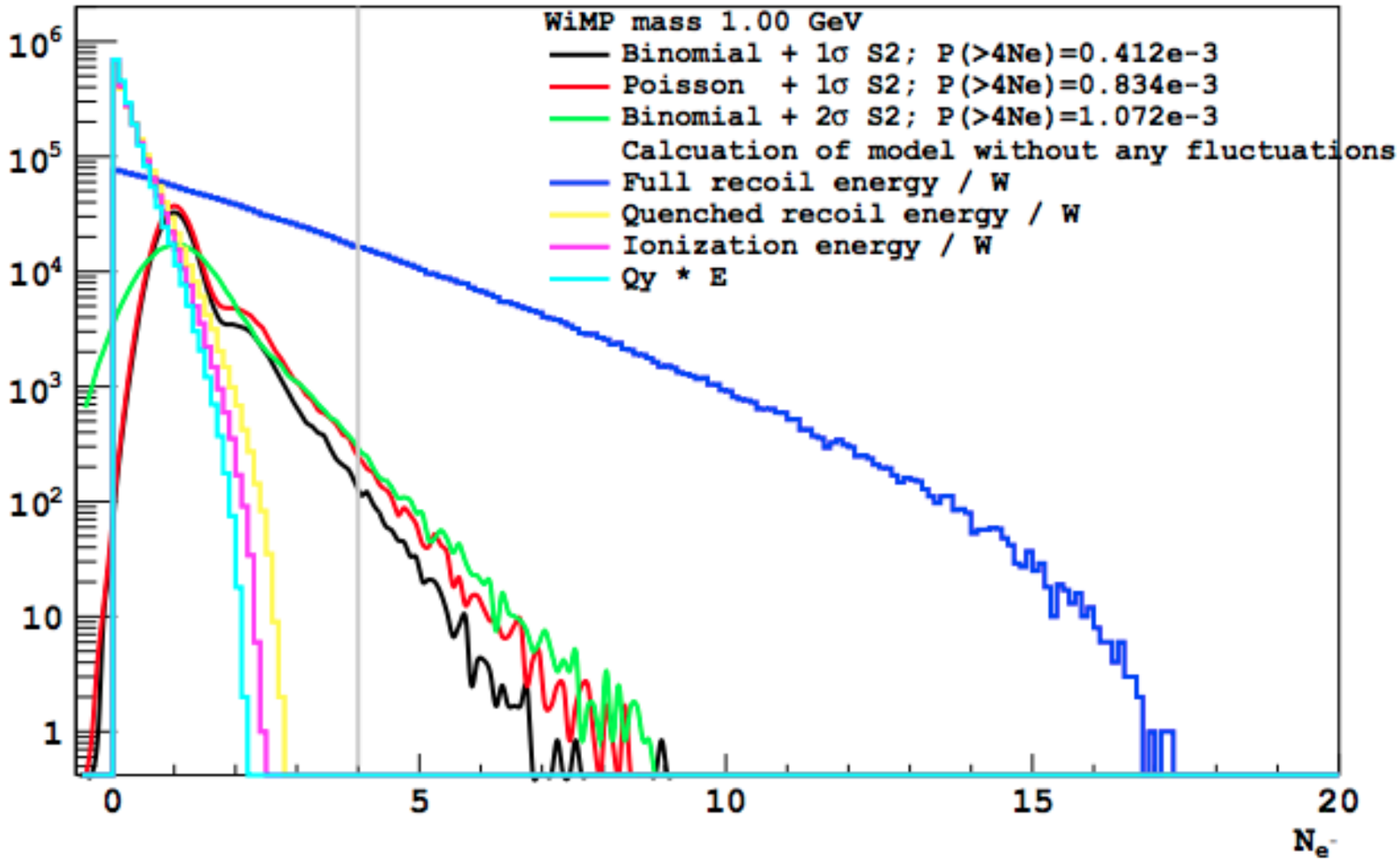


Background spectral fit



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

Low energy fluctuations

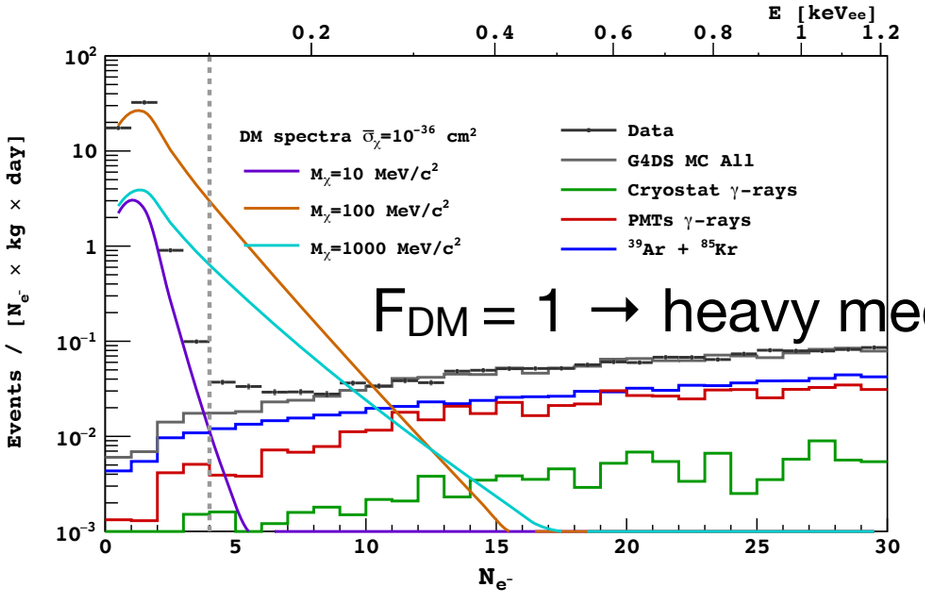


- For very low mass WIMPs, the recoil energy is always below 4 Ne
- Can exceed this value thanks to fluctuations in the quenching, recombination or ionization processes
  - No modeling (binomial is a hypothesis)

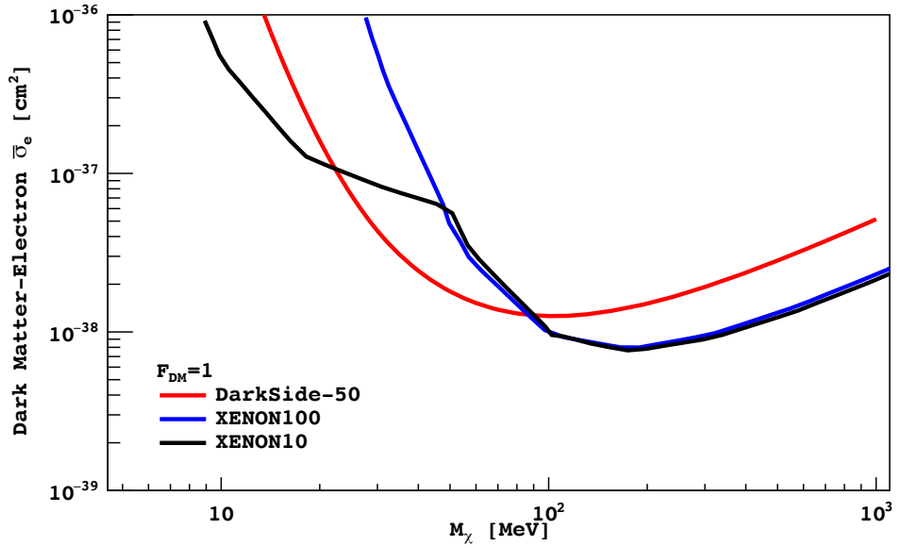
- Due to the lack of knowledge, no limit claimed below M_{WIMP} = 1.8 GeV

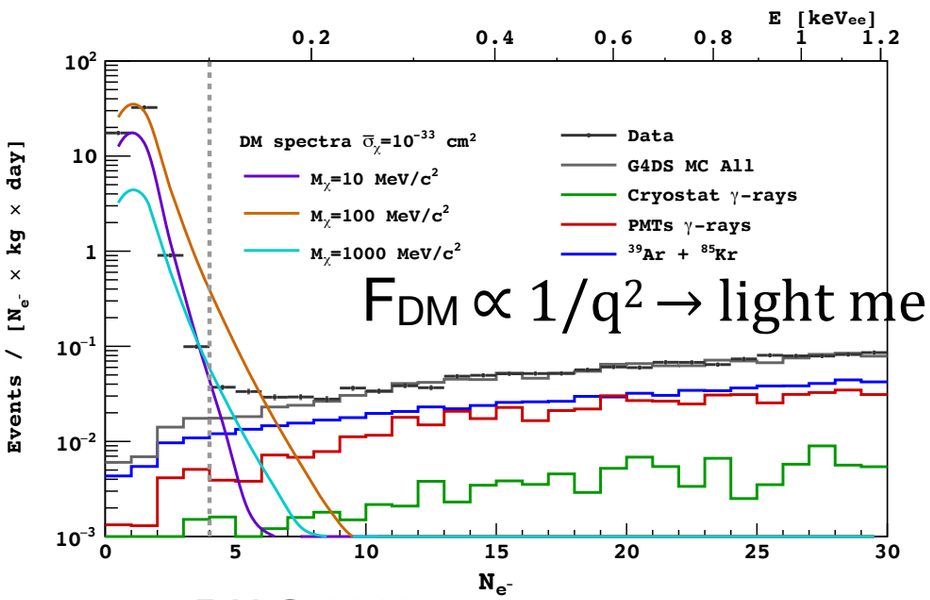
Sub-GeV Dark Matter

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



$F_{DM} = 1 \rightarrow$ heavy mediator





$F_{DM} \propto 1/q^2 \rightarrow$ light mediator