DarkSide
the quest for dark matter with liquid argon

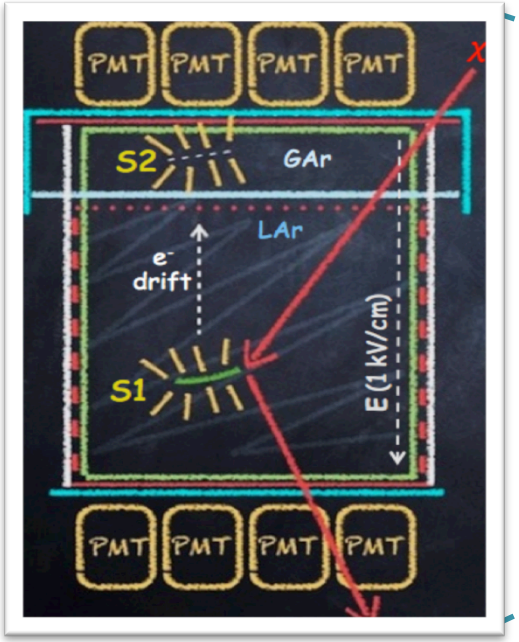
D. Franco

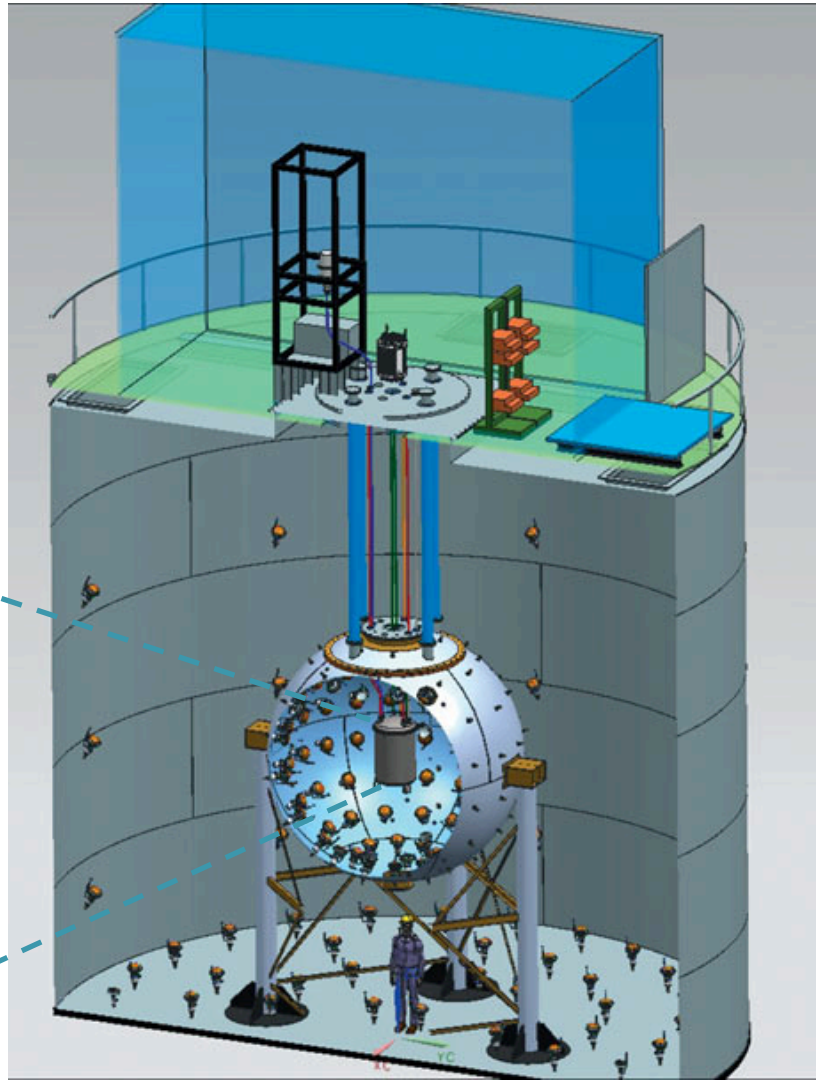
Instrumentation Days on Gaseous Detectors - 2018

DarkSide-50

DarkSide-50 is

- a **50 kg** dual-phase Liquid **Argon** TPC
- Using Underground Argon: **depleted in ^{39}Ar**
- In a **30 ton** borated liquid scintillator **neutron veto**
- In a **1000 ton Water** Cherenkov Veto
- **Underground** in Gran Sasso National Lab, Italy





DarkSide-50 Performance

S1 and S2 Yields:

- S1 Yield ~7.9 pe/keV at null field
- S1 Yield **~7.0 pe/keV** at 200 V/cm at 41 keV_{ee}
- Light collection efficiency ~ 16%
- Ionization Work Function ~ 23.4 eV
- S2 yield **~23 pe / e^-**

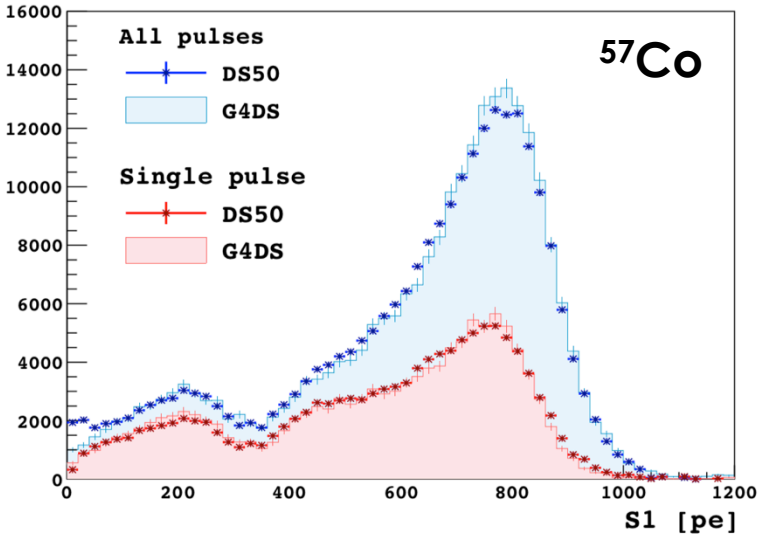
Electron lifetime > 10 ms
Maximum drift time: 376 μs at 200 V/cm
Drift velocity: 0.93 mm /μs

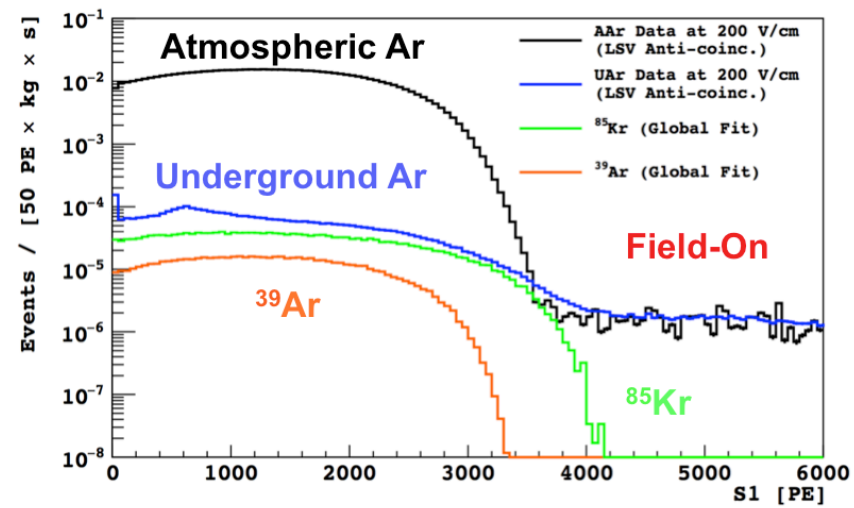
Position reconstruction:

- Resolution in Z **~1 mm**
- Resolution in XY **<1 cm**

^{39}Ar depletion factor in UAr ~**1400** (~0.7 mBq/kg)

Full characterization of the detector response with **Monte Carlo** (JINST 12 (2017) P10015)





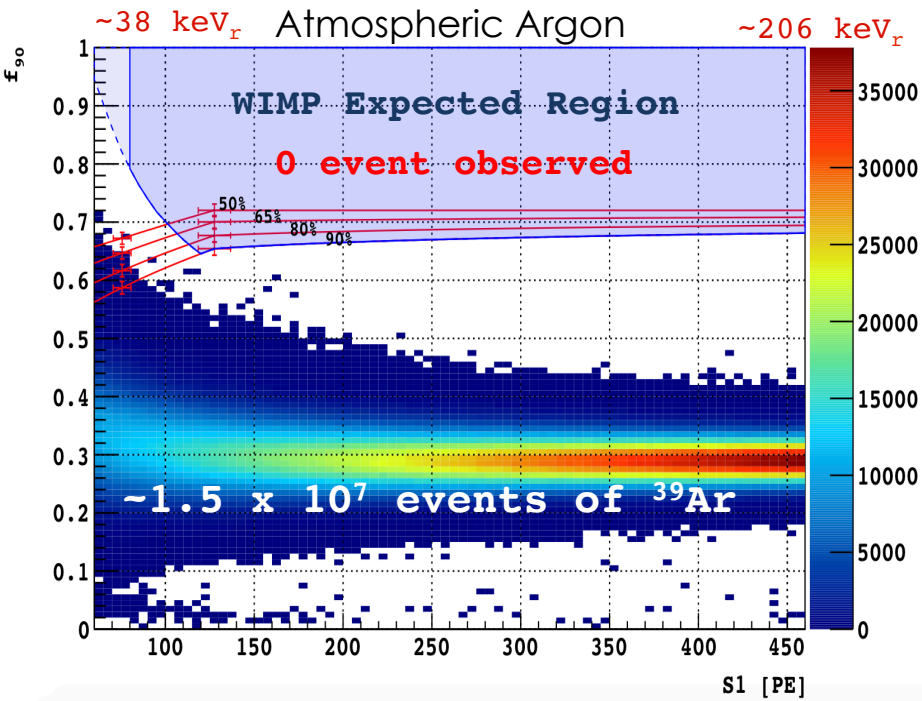
Advantages of Using Argon

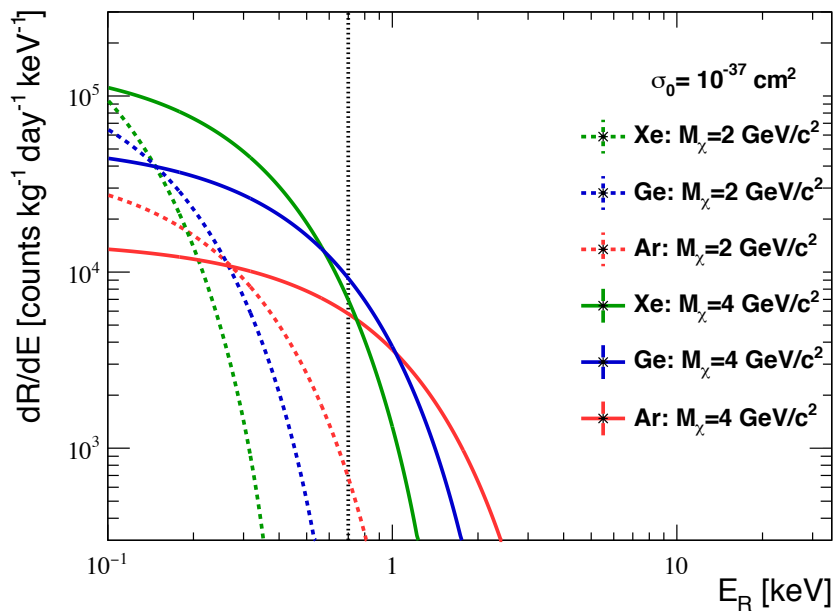
High Mass WIMPs: > 20 GeV/c²

- Range: **45-200 keV$_{nr}$**
- S1 and S2 signals
- Excellent Pulse Shape Discrimination
- **Background free (<0.1 events) analysis**

Low Mass WIMPs: < 20 GeV/c²

- Range: **0.7-15 keV$_{nr}$**
- Ionization signal only
- Profile Likelihood Analysis
- **Lighter nucleus, larger recoil energy**



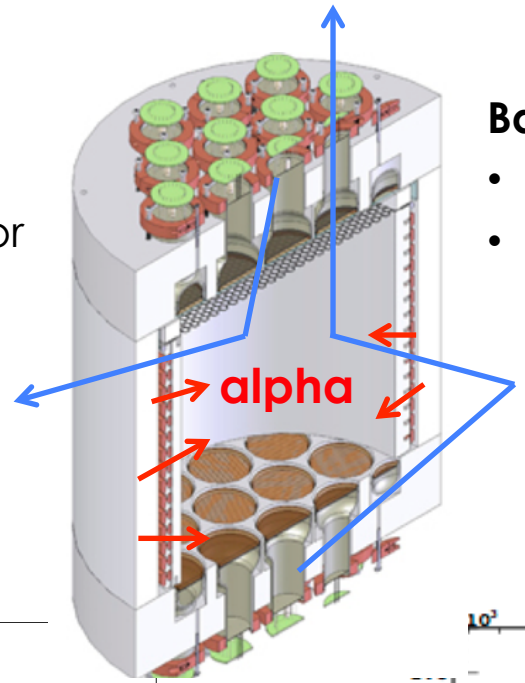


Nuclear Recoil Backgrounds

Neutrons

Background rejection:

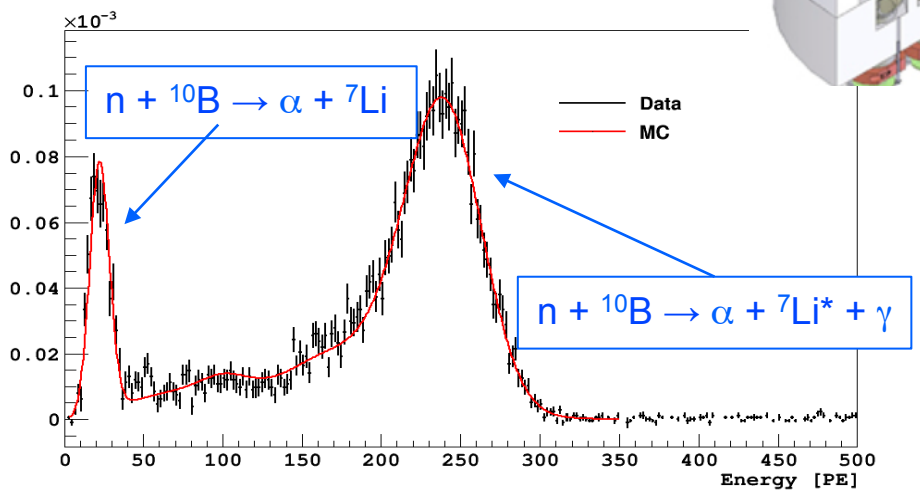
- TPC: multi-scatter
- LS Veto: efficiency from Am-C for TPC single-NR: **0.9964±0.0004**
- Water Cherenkov Veto
- Neutrons in data counted

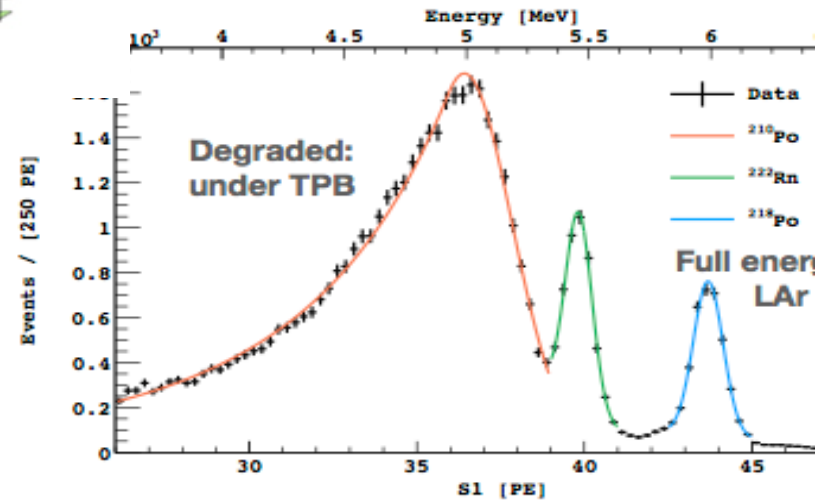


Alpha's

Background rejection:

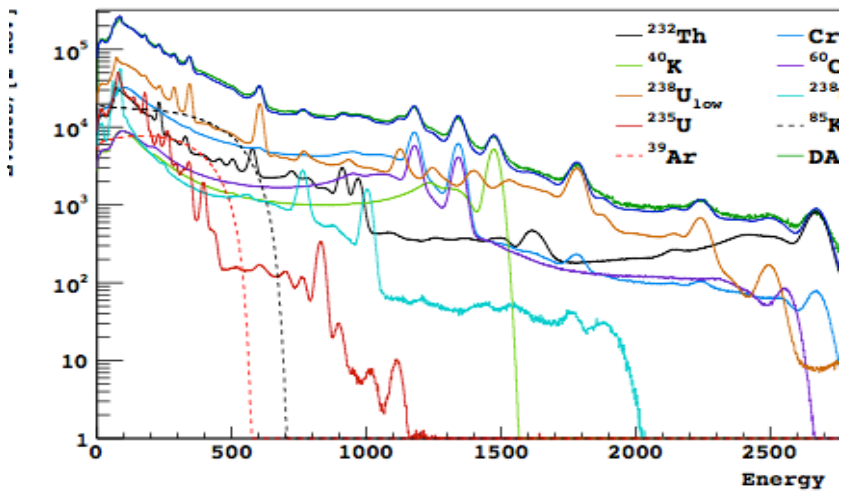
- Small fraction at low energies
- Self-vetoing in DS-50!
  - Small or no S2
  - Long S2 tail from TPB fluorescence





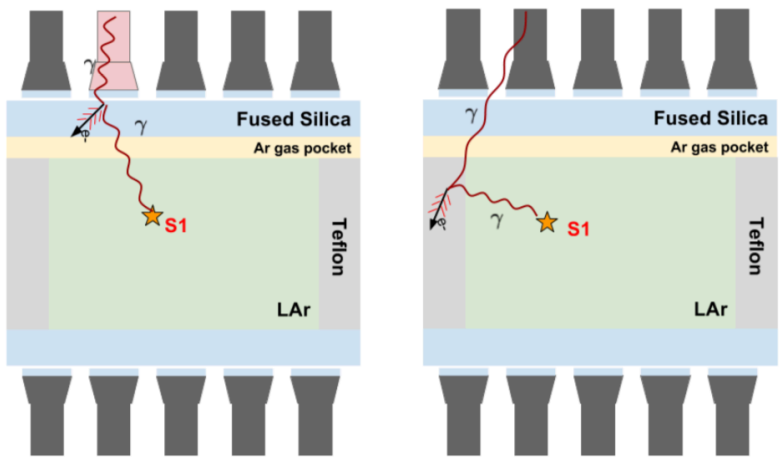
Electron Recoil Backgrounds

Internal ^{39}Ar and ^{85}Kr
External gammas

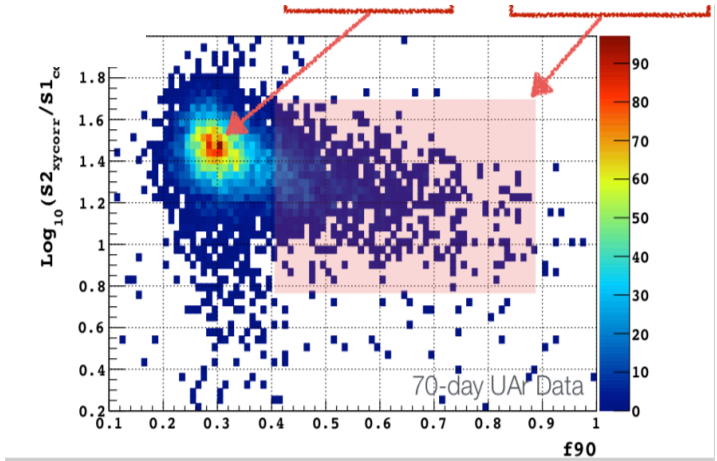


Energy [keV]

Cherenkov



Fused Silica Cherenkov BG Teflon Cherenkov BG

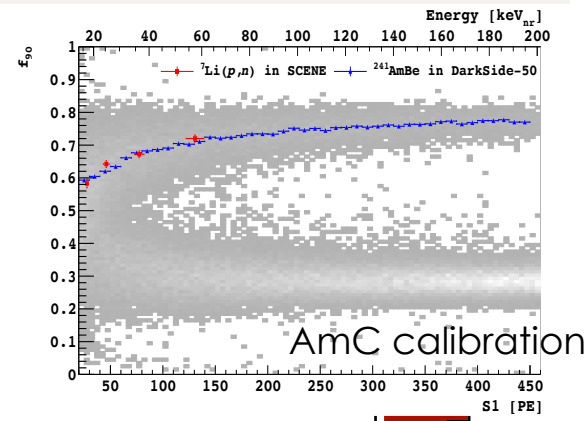


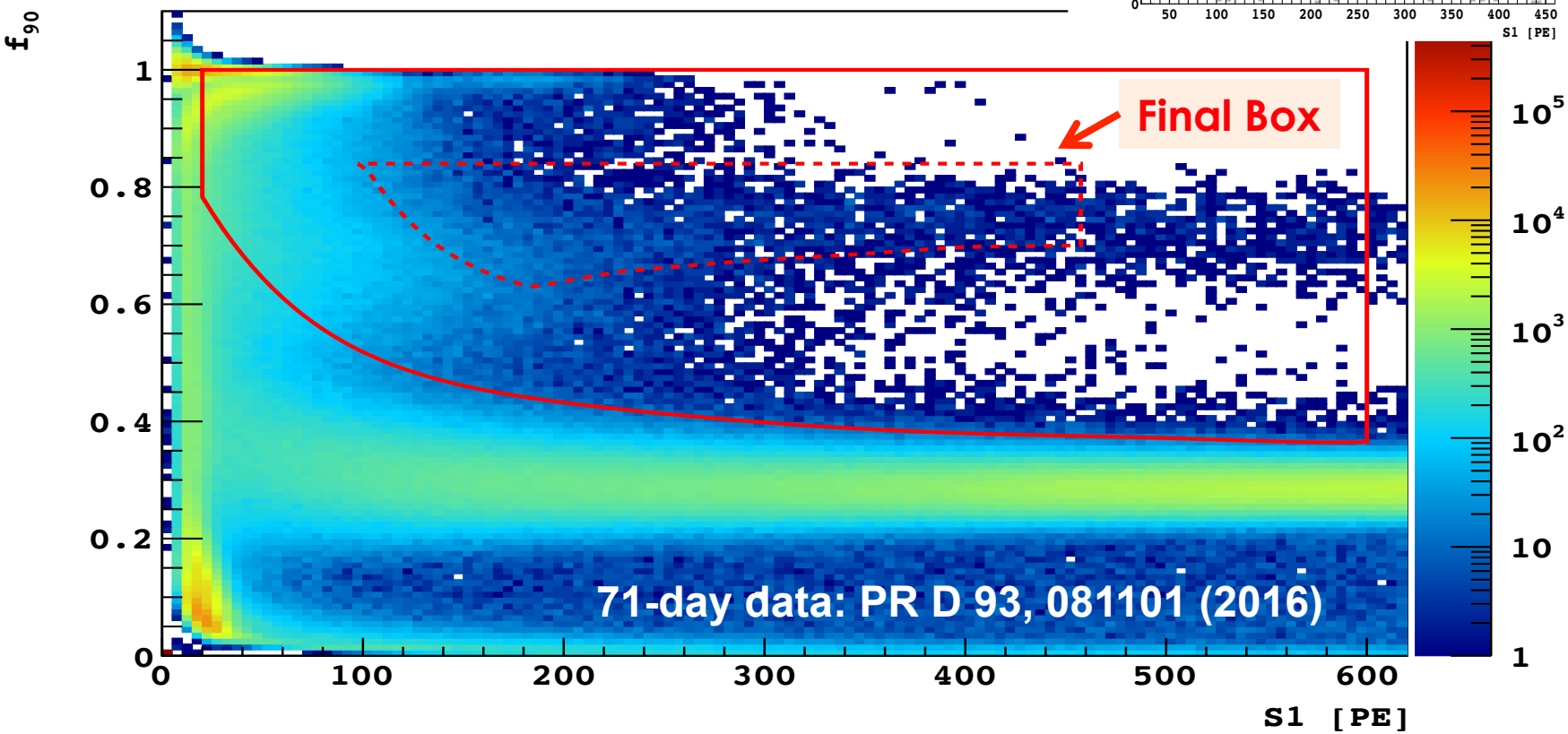
Background rejection:

- Underground Ar
- **S1 fraction in max PMT**
- PSD: f_{90} = S1 fraction in first 90 ns
  * Design cut to reduce ER to <0.08 event of background

High Mass: Blind Analysis

Goal: design an analysis that will have <0.1 event of background in 534 live-days





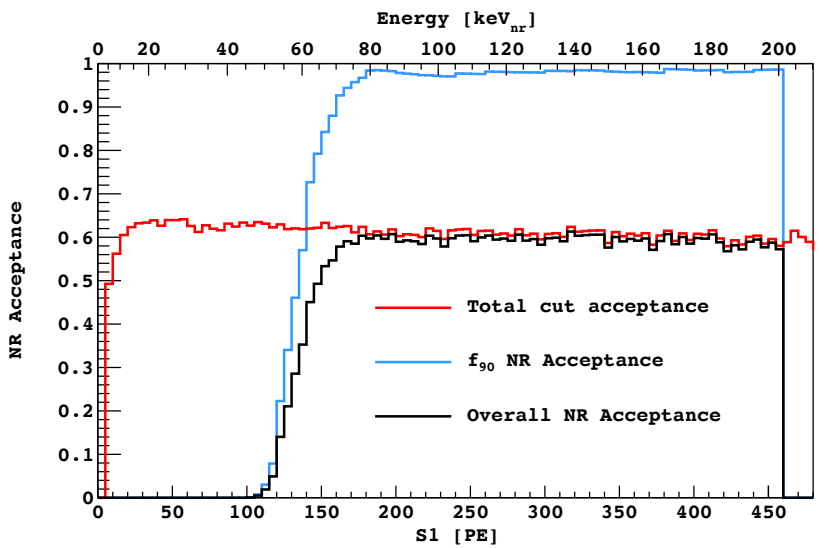
High Mass: Background and Acceptance

Expected background

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

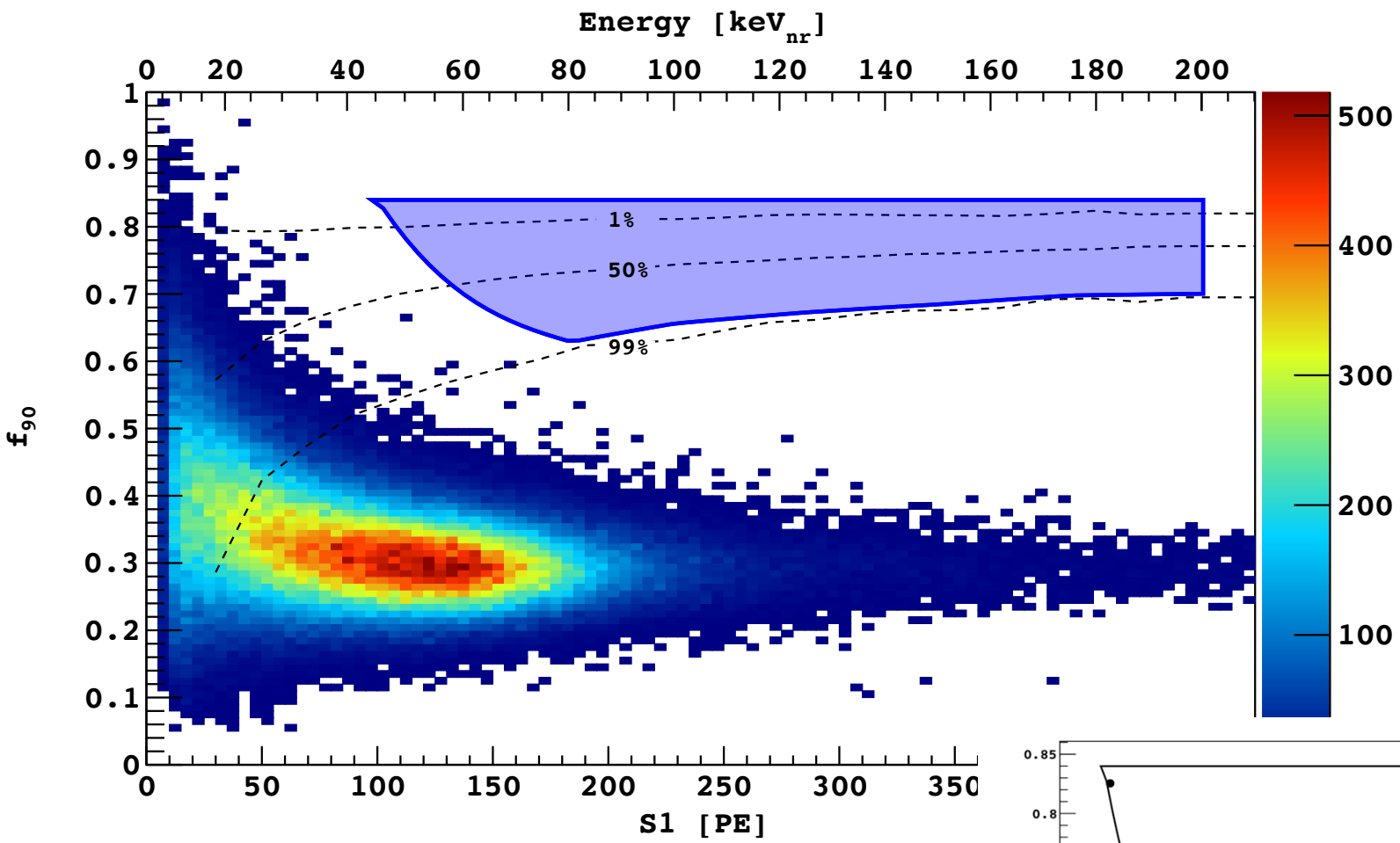
Goal < 0.1 events achieved: open the box!

WIMP Acceptance

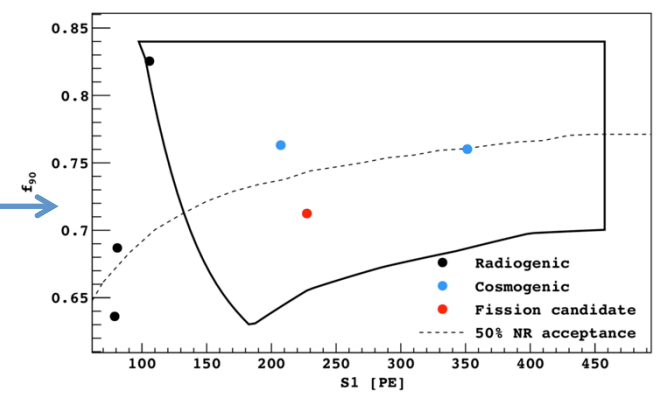


~0.6: dominated by PSD ER rejection

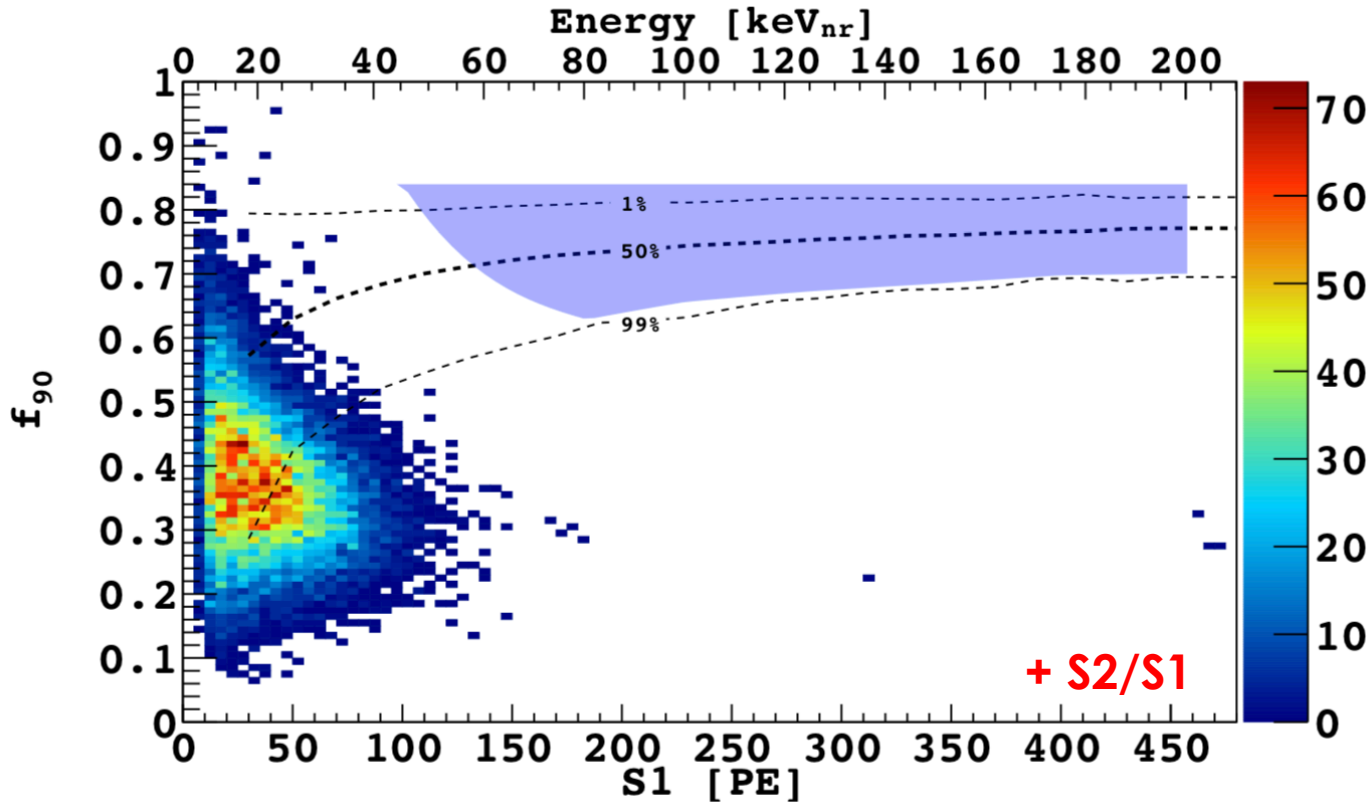
High Mass: 0 events

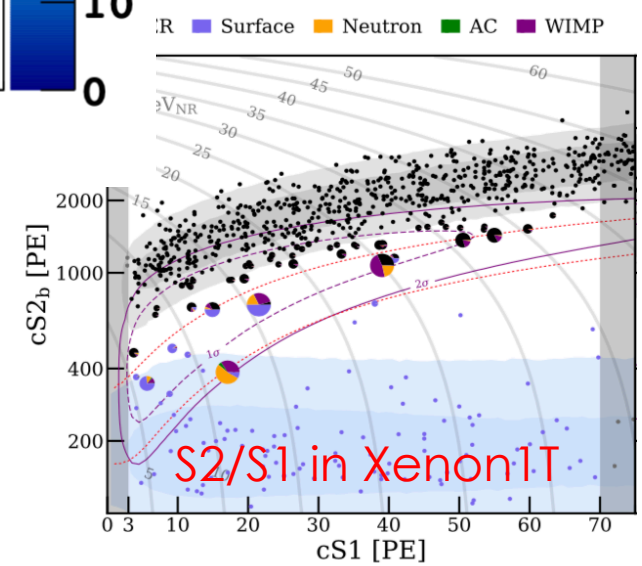


4 events identified as neutrons before the veto cuts
Consistent with expectations



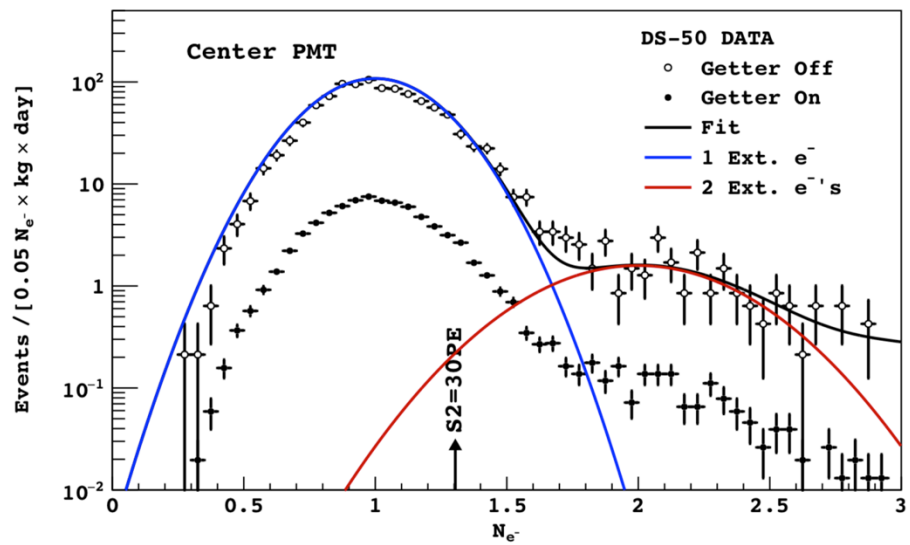
High Mass: 0 events



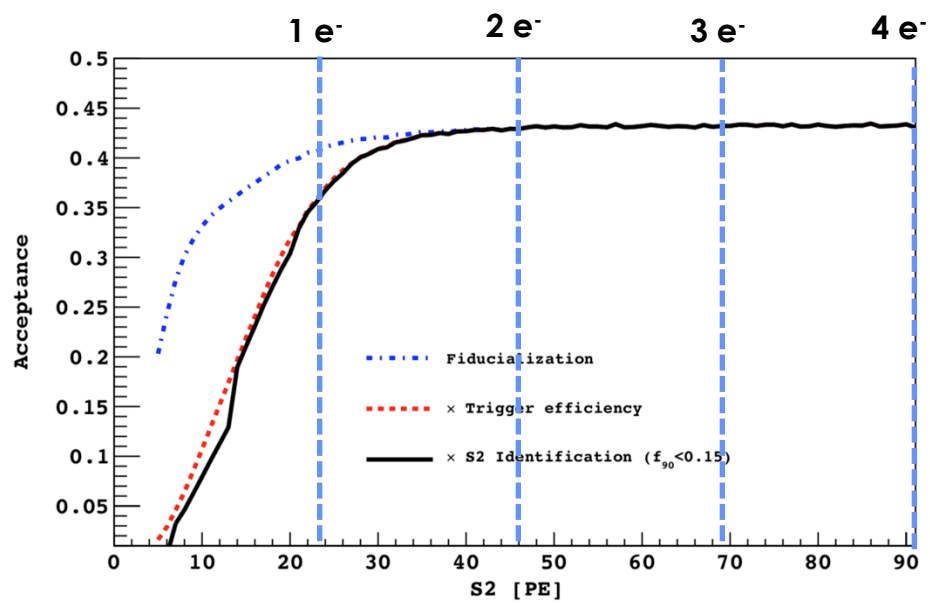


Low Mass: Ionization Signal Only

Single and double electrons events

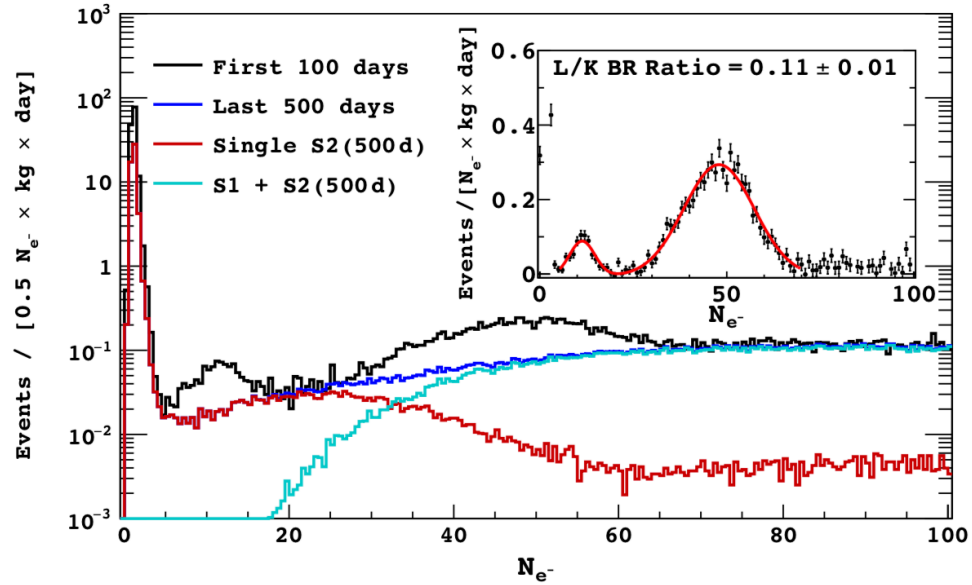


Threshold at 4 e⁻: 100% efficiency



Low Mass: Electron Recoil Scale

Excellent low-energy ER calibration peak from ^{37}Ar ($t_{1/2}$ = 37d).



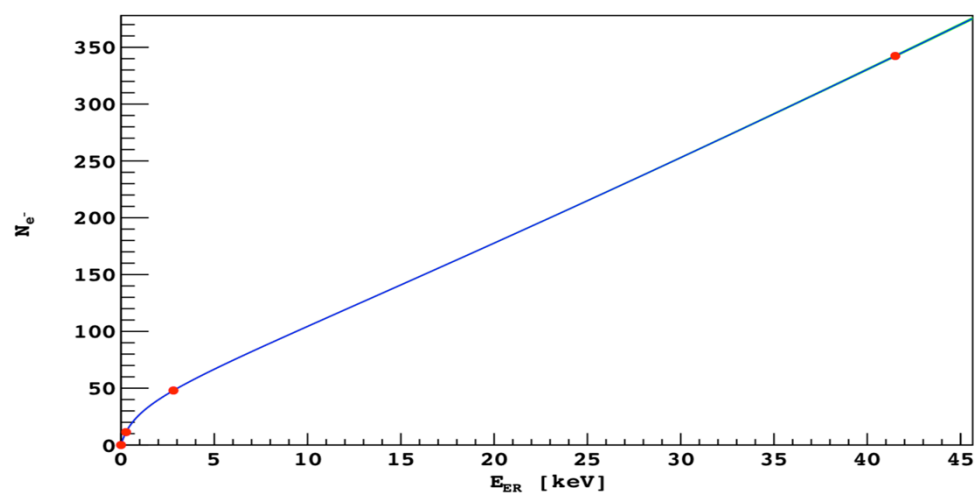
^{37}Ar lines

E = 0.27 keV → Ne = 11

E = 2.8 keV → Ne = 47.9

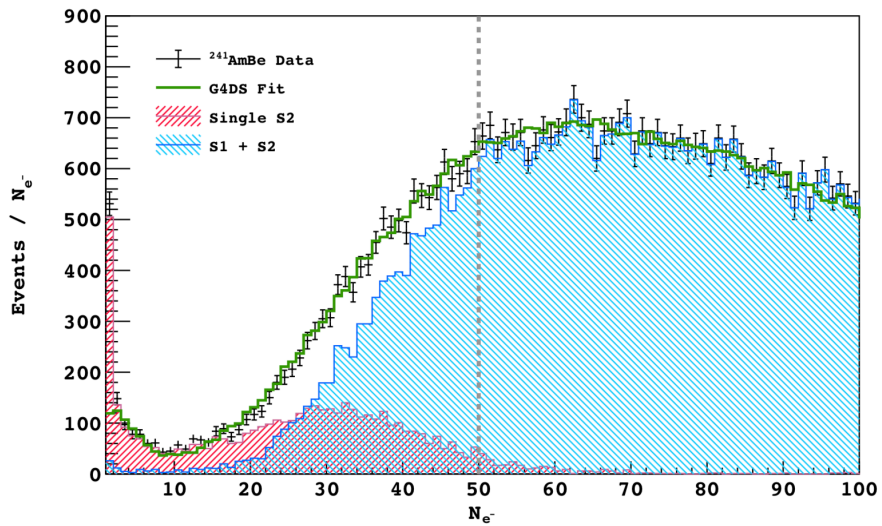
^{83m}Kr line

E = 41.5 keV → Ne ~ 350

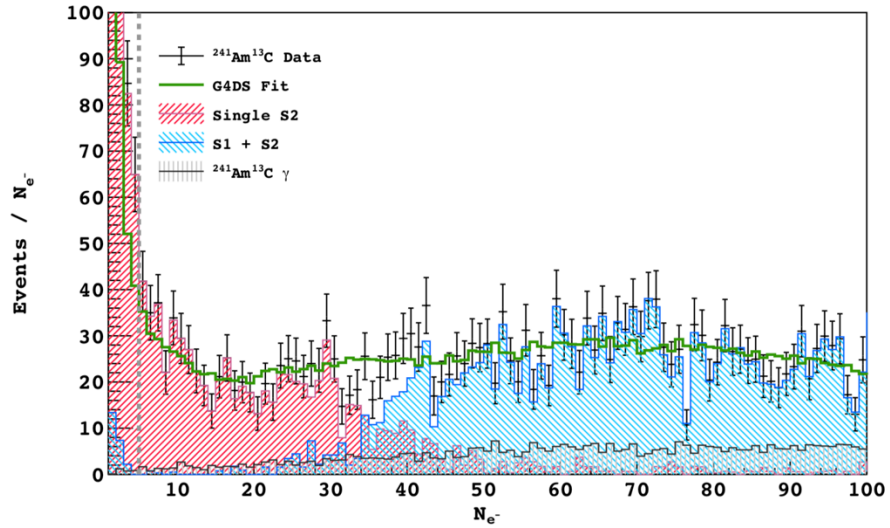


Low Mass: Nuclear Recoil Scale

AmBe



AmC



AmBe neutrons selected in coincidence with 4.4 MeV gamma in the veto

Random/correlated background strongly suppressed

Strong inefficiency for S2 only events

No gamma emission correlated with AmC (alpha,n) reaction

Gammas from ^{241}Am decay accounted with MC

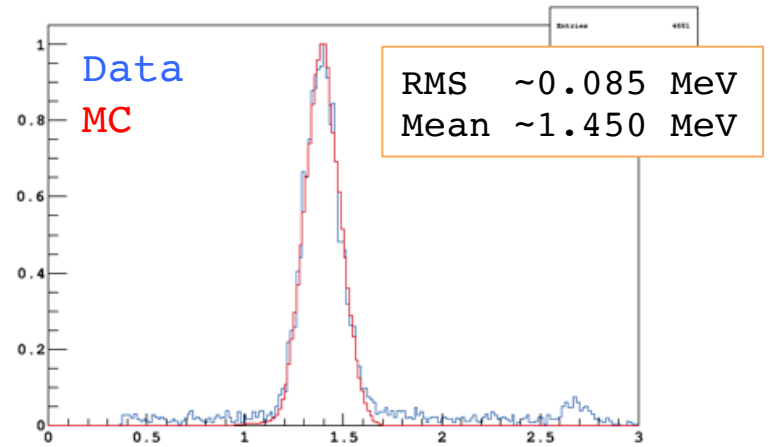
Accidentals subtracted using UAr normalized by the exposure

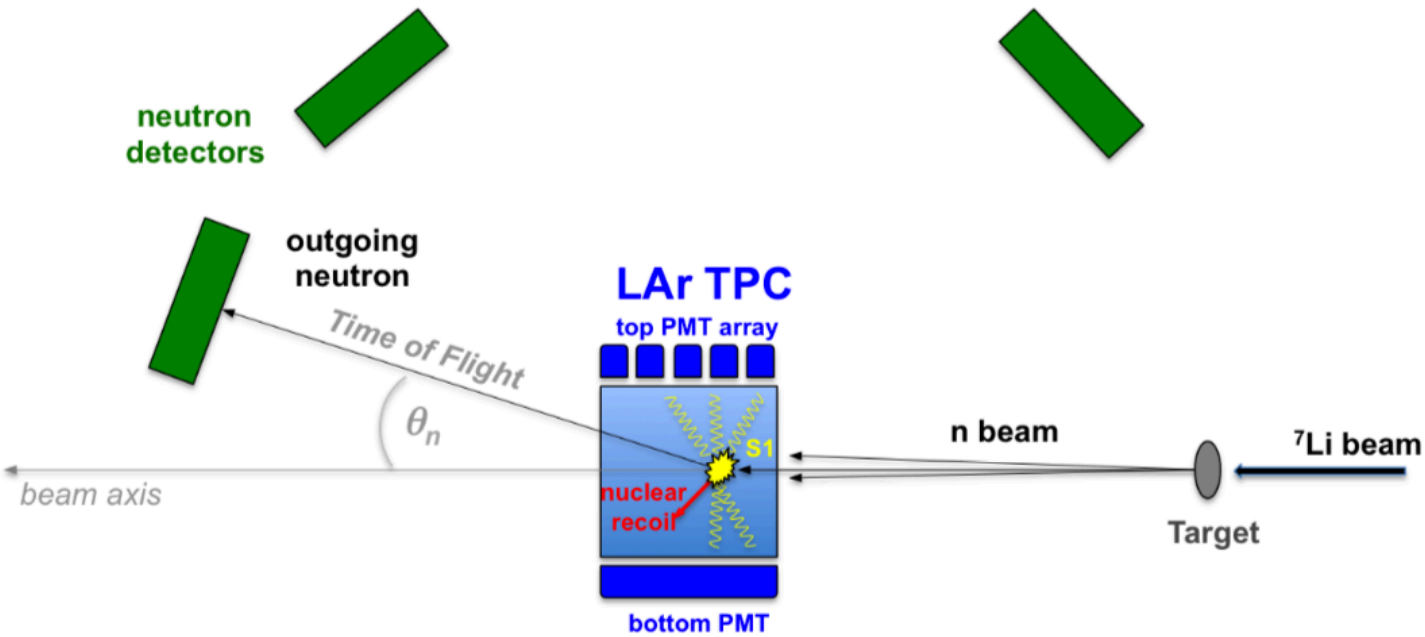
No inefficiency

LICORNE: inverse $^{7}Li(p,n)^{7}Be$

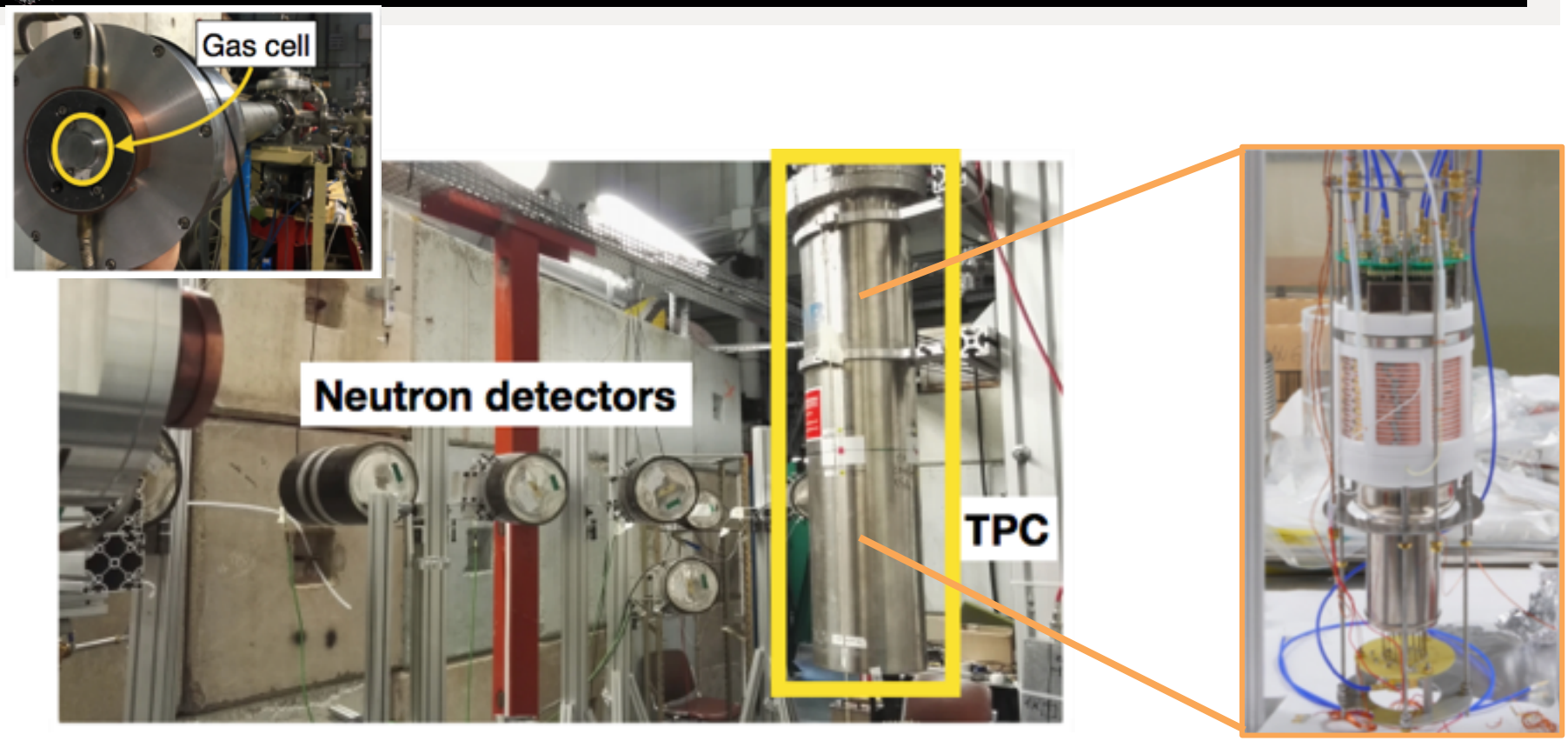
LICORNE is **ideal** because:
- Pulsed (1.5 ns width)
- Monochromatic
- Collimated
- Emits also correlated 478 keV gammas

But
- Close to the reaction threshold (~13.096 MeV)
- Need specific calibration at each run



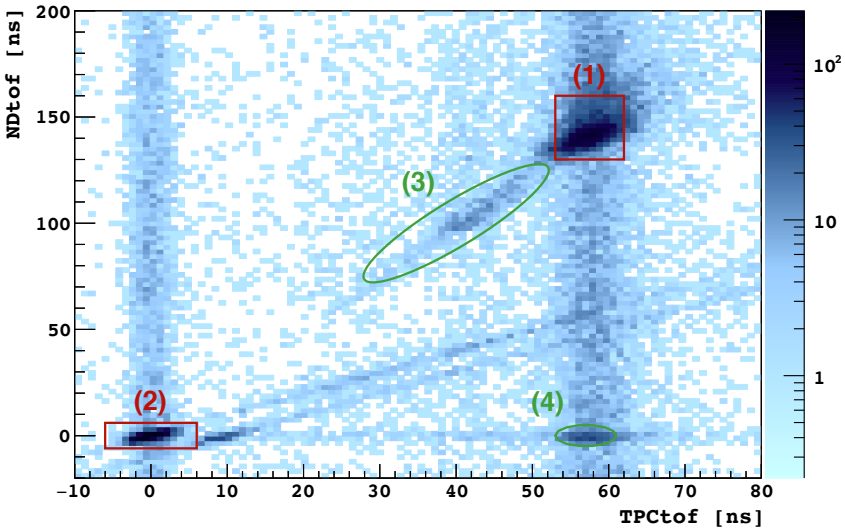


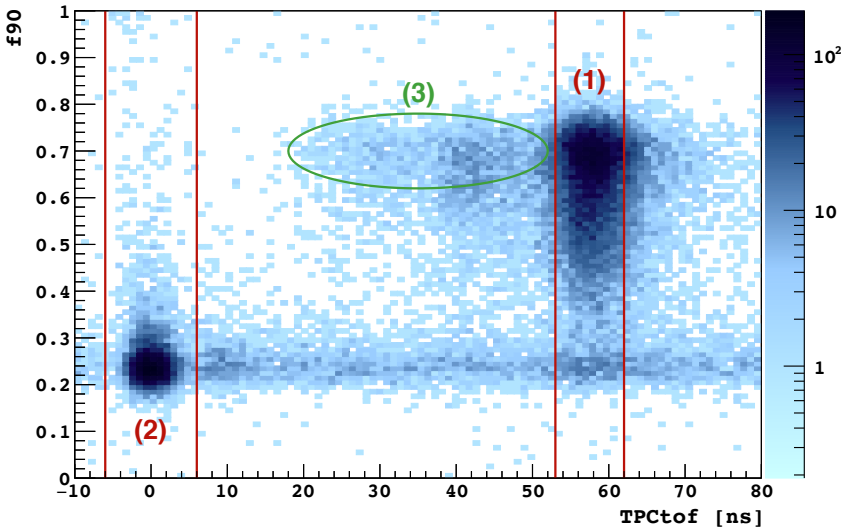
ARIS @ LICORNE

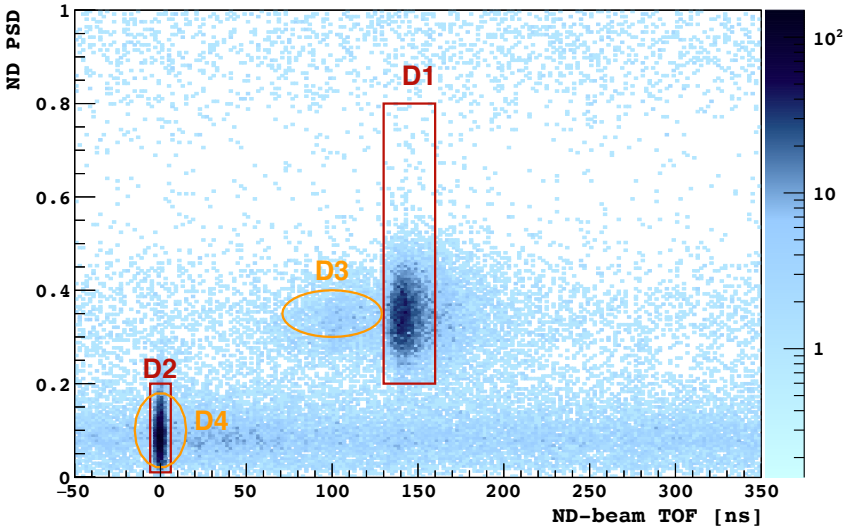


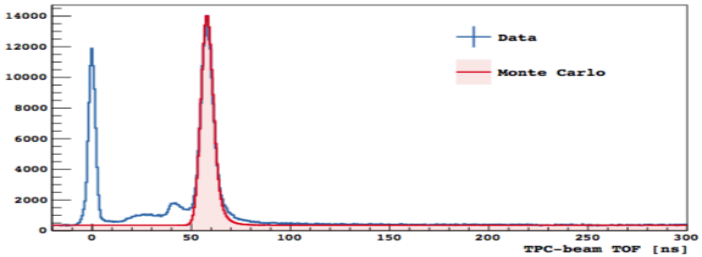
- ~0.5 kg of LAr
- PTFE reflector with TPB coated surface
- 7 Hamamatsu 1'' PMTs on top, one 3'' PMT on bottom
- Ability to create a gas pocket for dual-phase running
- Anode/Cathode created with ITO plated fused-silica windows
- Grid 1 cm below the anode provides bias for electron extraction

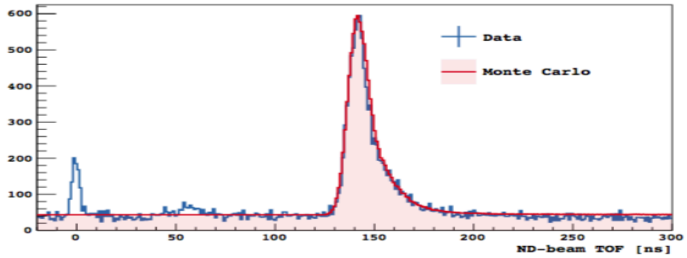
ARIS Performance



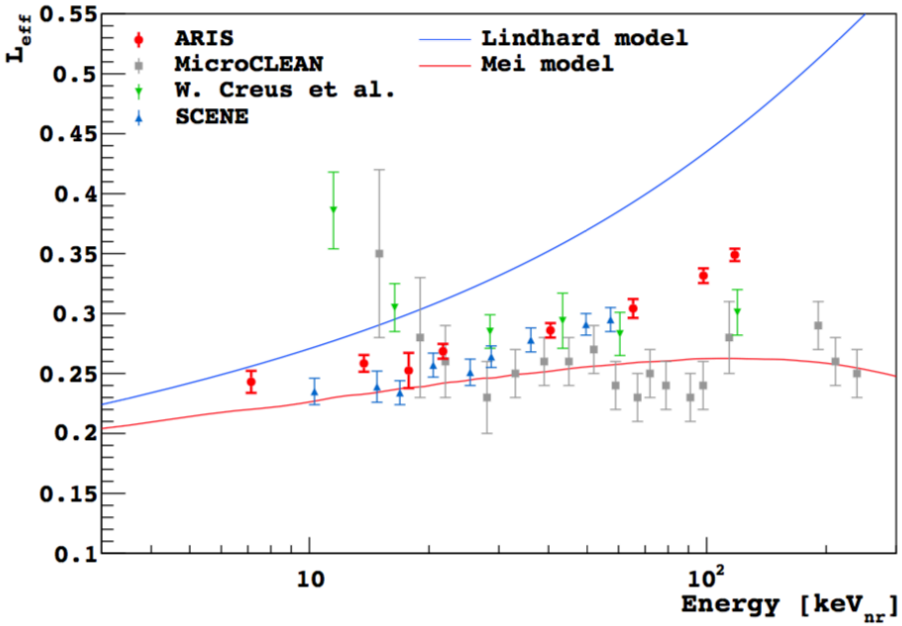






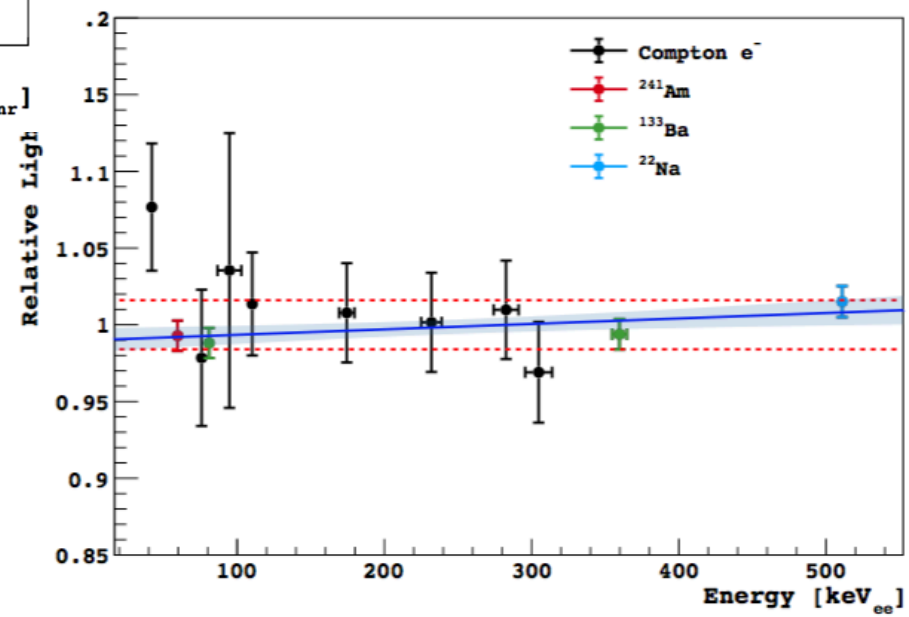


ARIS Results at Field Off

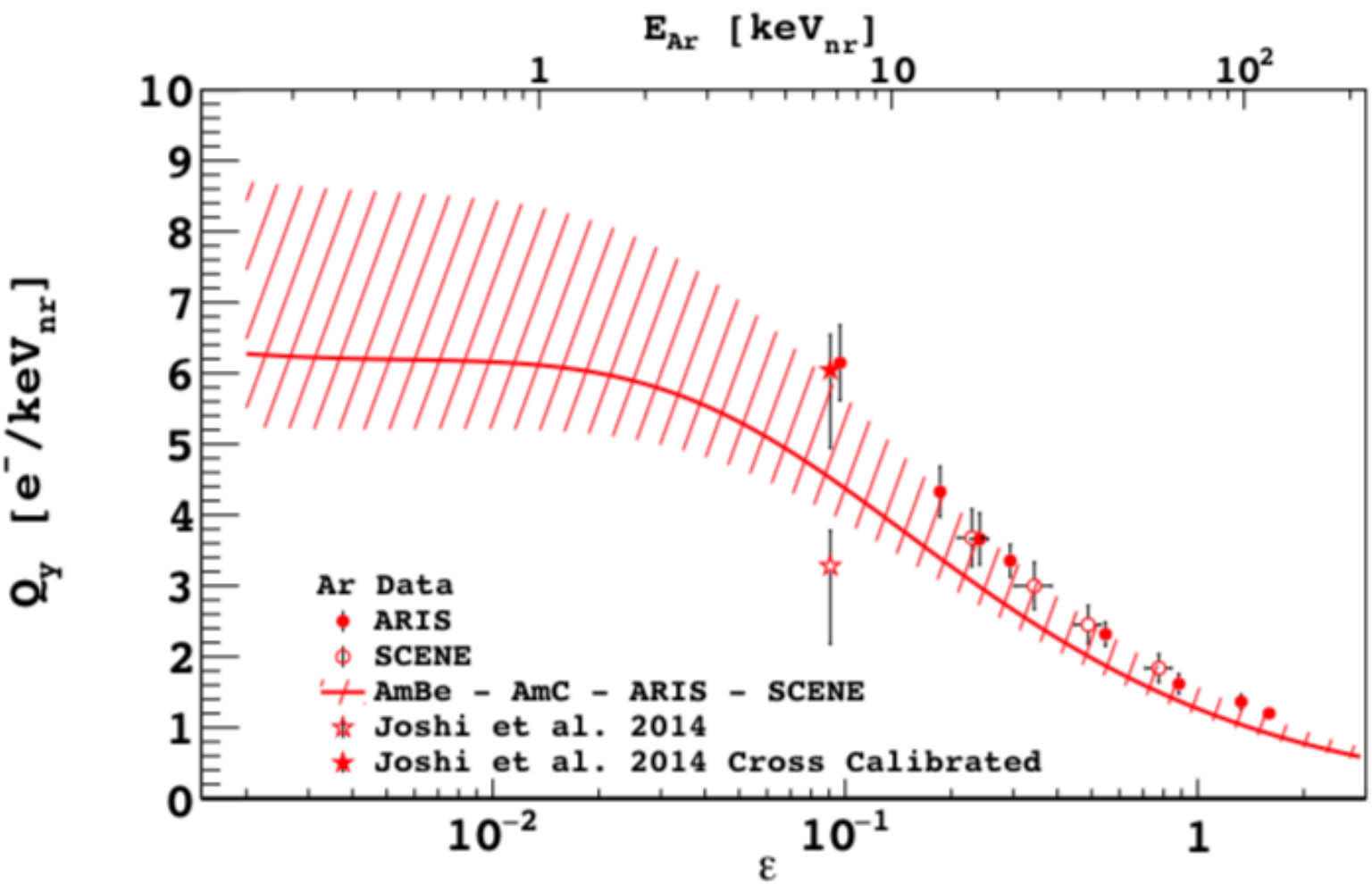


Most accurate measurement of the **nuclear recoil quenching** at field off

First experimental proof of the **linearity of the LAr scintillation at field off** at 1.6% level (90% CL) between 40 and 500 keV

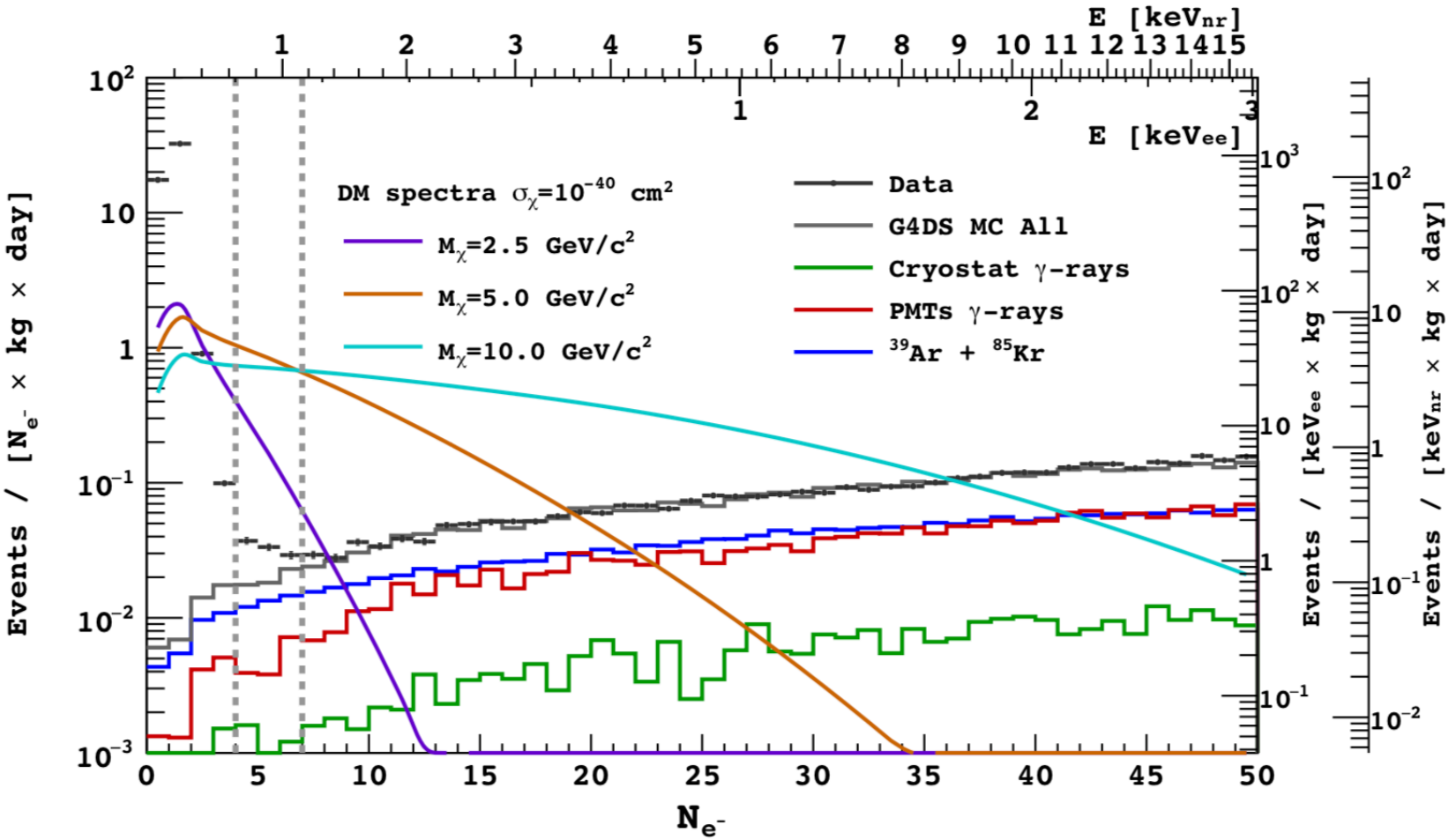


Low Mass: Nuclear Recoil Scale



$a = 0.626 a_0 Z^{-1/3}$ Is the Thomas–Fermi screening length

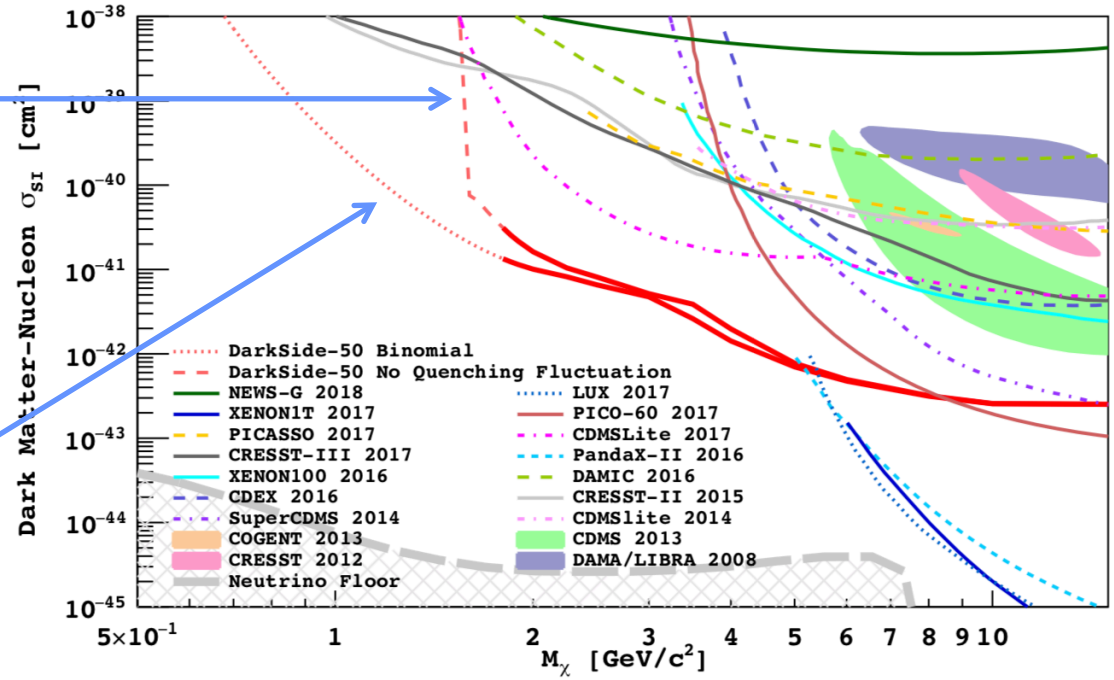
Low Mass: Background



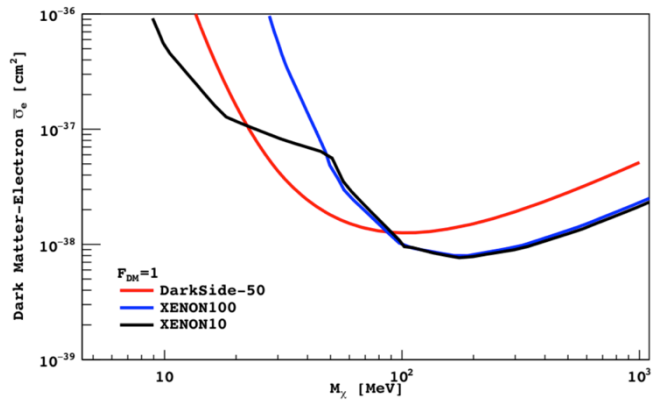
Low Mass: Results

Assuming quenching a non-stochastic process

Assuming binomial quenching fluctuations

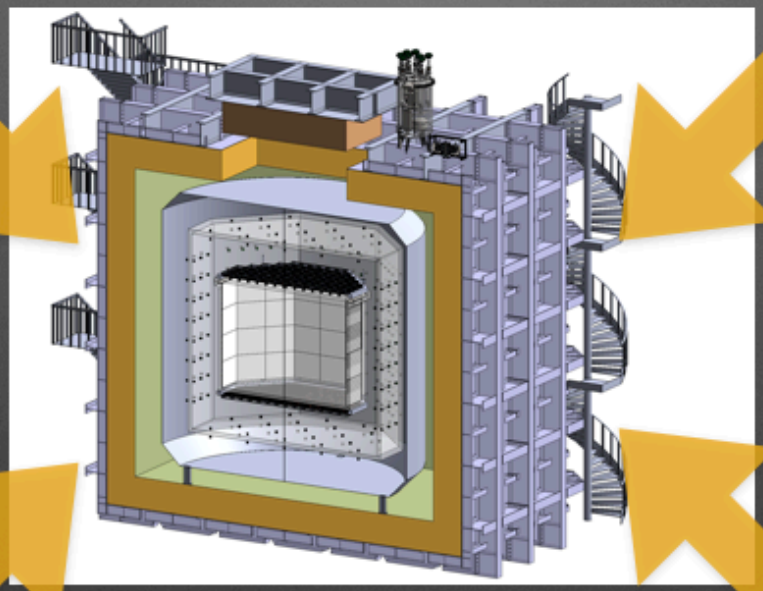


Changing model from WIMP-nucleus to **WIMP-electron** interaction, and assuming heavy mediator

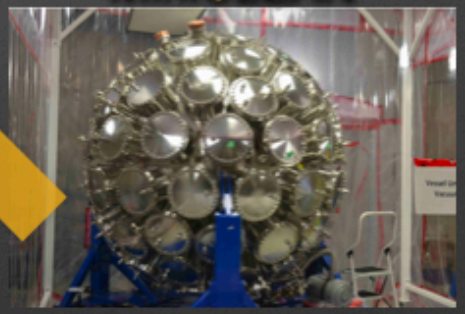


The Global Argon Dark Matter Collaboration

DarkSide-20k



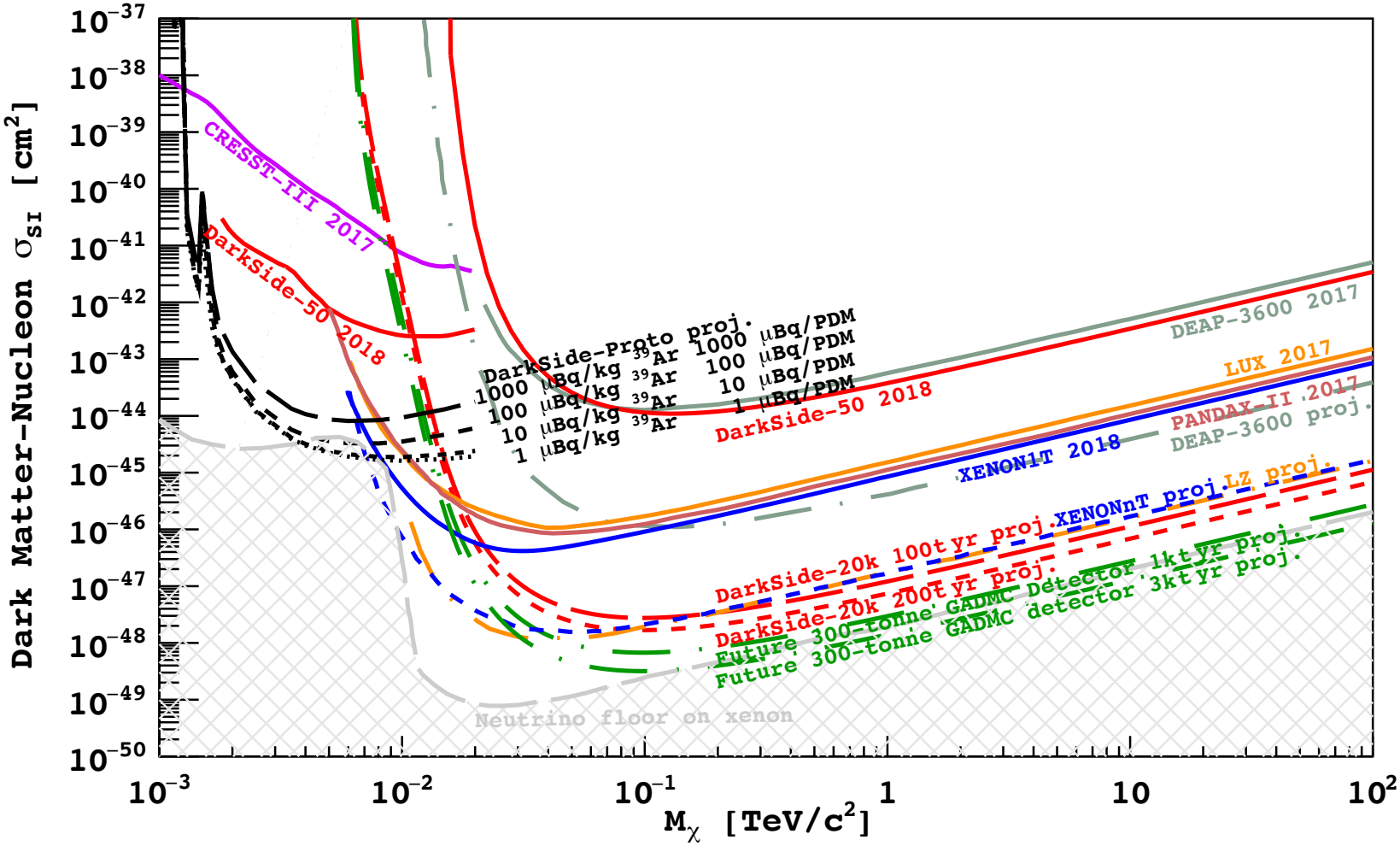
Access to DEAP-3600 data



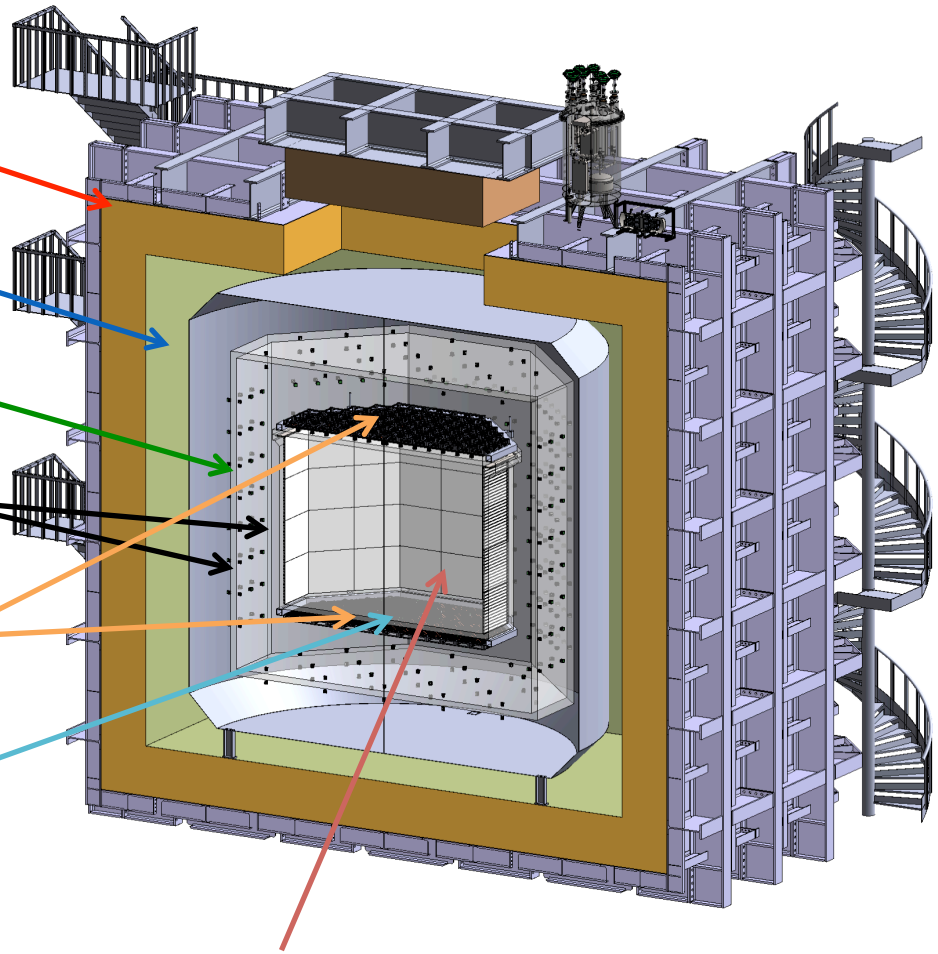
CERN Neutrino Platform joined DarkSide-20k → many synergies with DUNE (DS-20k cryostat will be the same of protoDUNE)

DS-20k collaboration
350 scientists
13 countries

Down to the Neutrino Floor



New Design


DUNE-like cryostat
Atmospheric LAr bath
Neutron moderator loaded with Gd
Active LAr vetoes
SiPMs
"Naked" TPC, enveloped in an acrylic vessel
Underground argon

FBK SiPM

Surface: 50x50 mm²
In order to contain the number of channels. Foreseen number: 5210

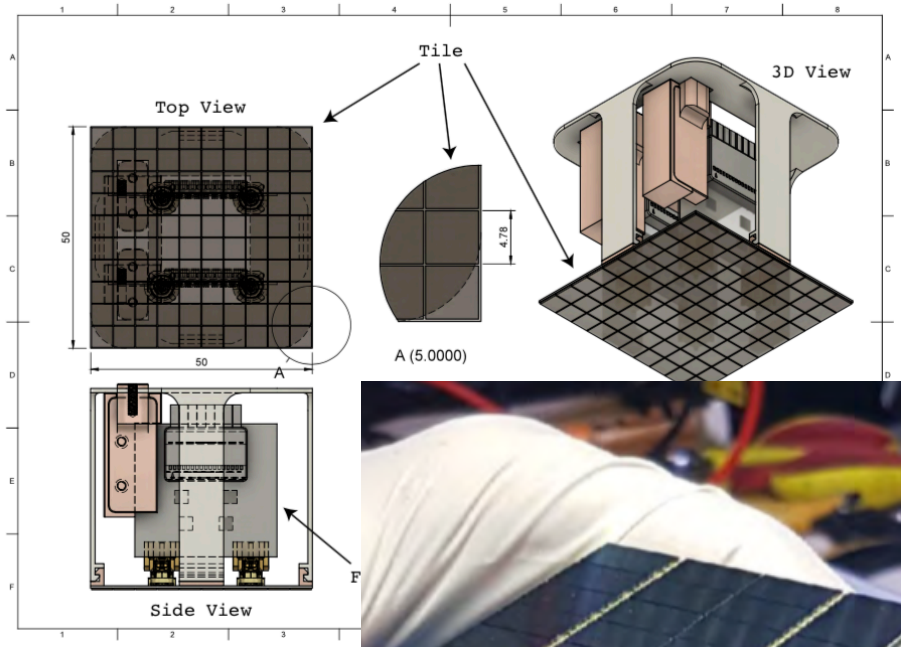
PDE: ≥ 40%
Higher PDE wrt Hamamatsu PMTs together with higher active area coverage will boost the light yield.

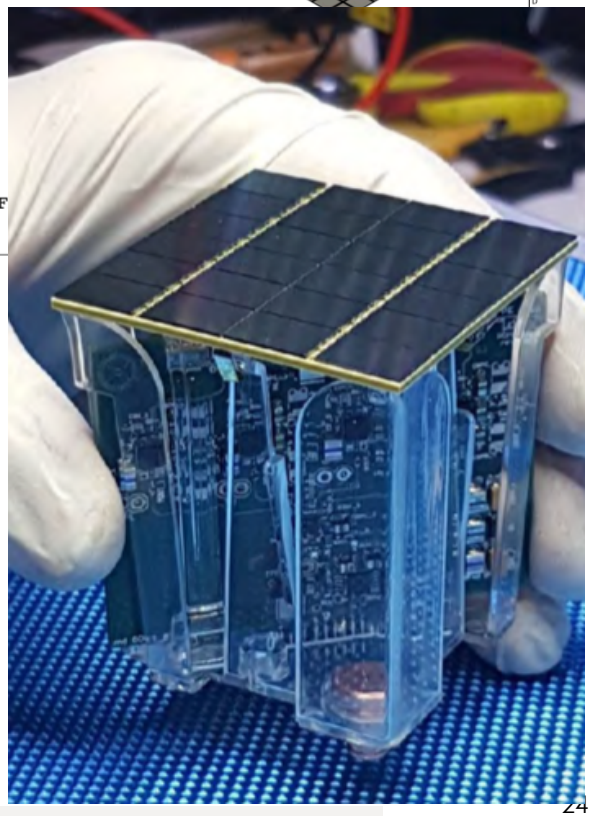
Overall Noise Rate: <0.1Hz/mm²
DCR+TCN+BN <250Hz/PDM ⇒ SNR_{PDM} > 8

Higher rates would impact on trigger efficiency and PSD power.

Time resolution: O(10ns)
Necessary to keep the ER/NR discrimination power with f_{prompt}.

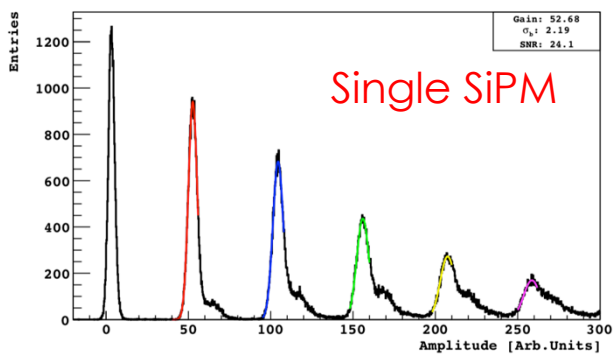
Dynamic Range: ≥ 50PE
Precise S2 reconstruction.

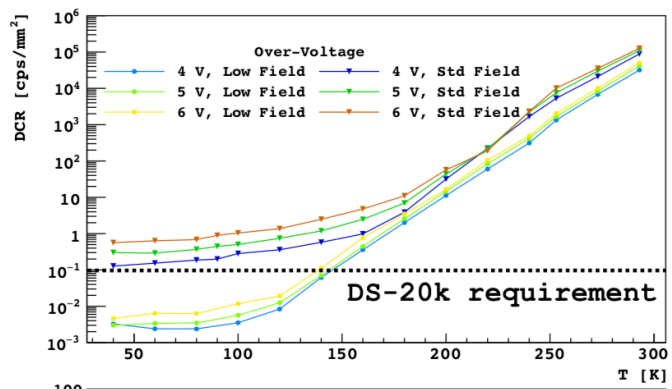


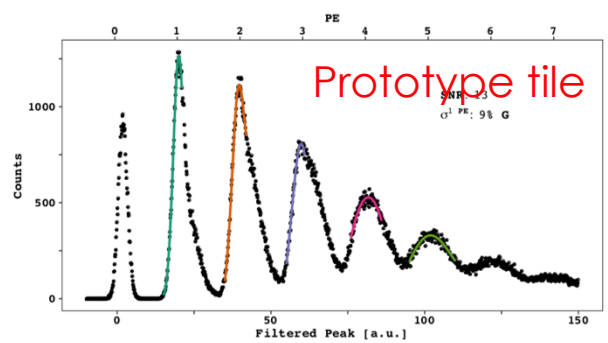


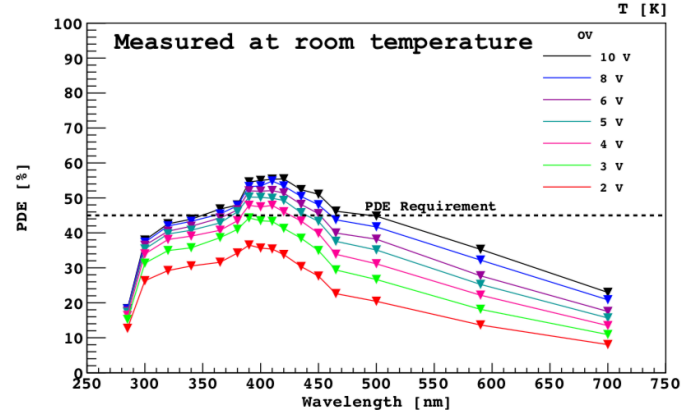
FBK SiPM

	DS-20k requirement	SiPM tile (PDM)	
Surface	5x5cm^2	24cm^2 prototype 25cm^2 final PDM	✓
Power dissipation	<250mW	~170mW	✓
PDE	>40%	$50\% \cdot \varepsilon_{geom} = 45\%$	✓
Noise Rate	<0.1cps/mm^2	0.004cps/mm^2	✓
Time Resolution	O(10ns)	16ns	✓
Dynamic Range	>50	~100	✓

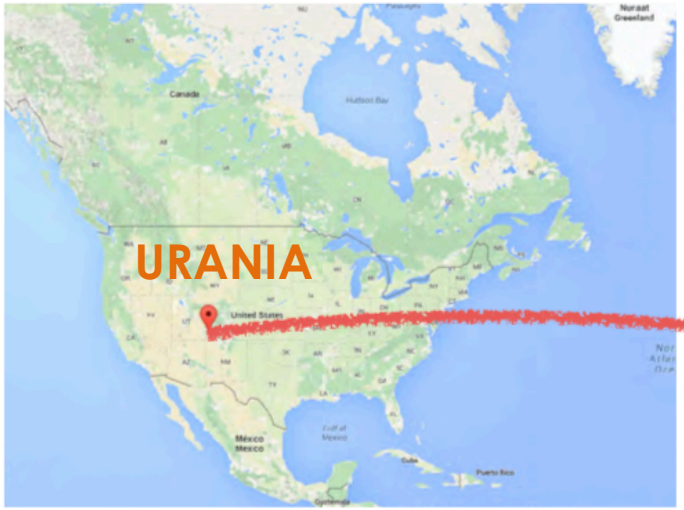


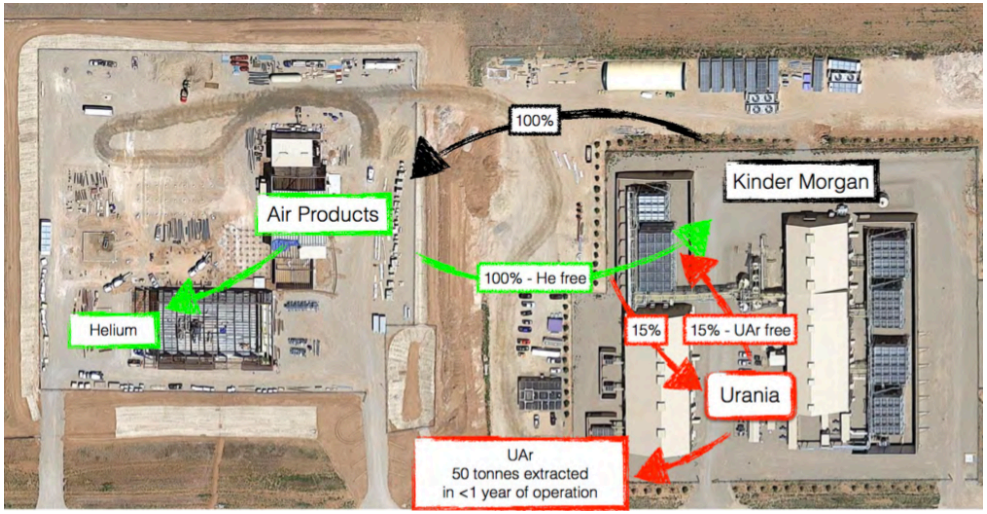


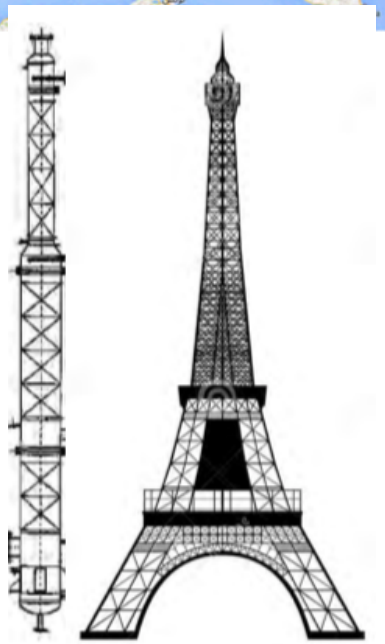


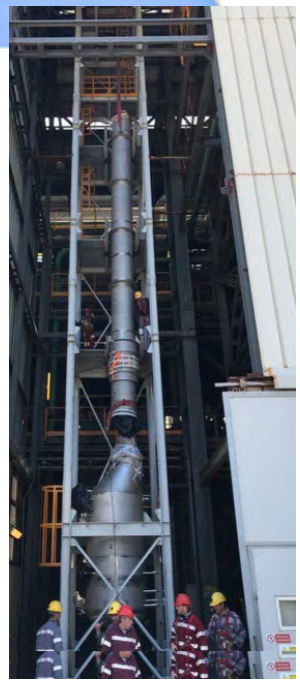


Underground Argon





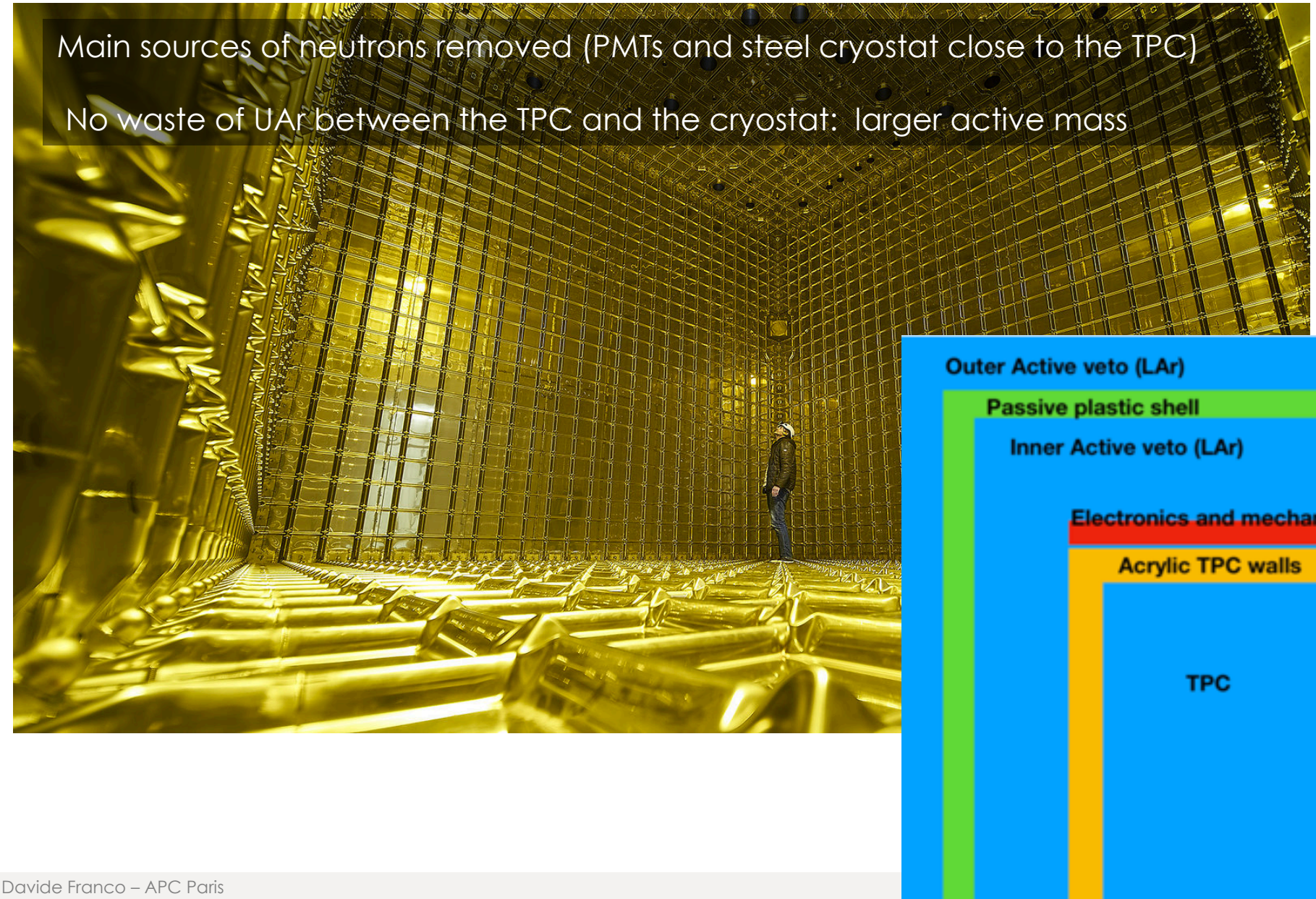




The DUNE cryostat and the veto

Main sources of neutrons removed (PMTs and steel cryostat close to the TPC)

No waste of UAr between the TPC and the cryostat: larger active mass

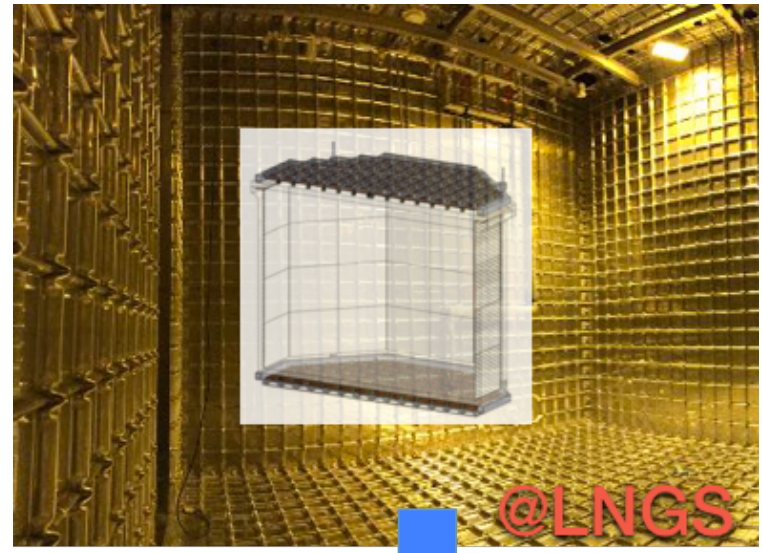


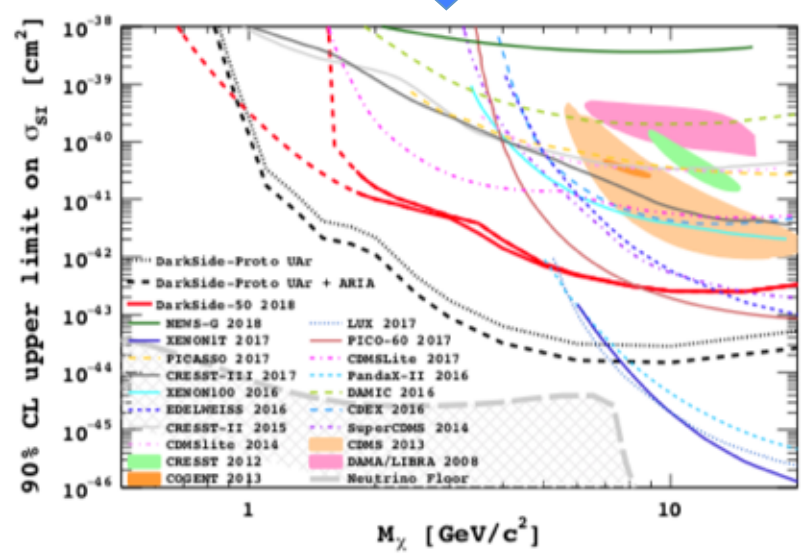
DS-Proto: 1-ton prototype

DS-Proto

(?)

DS-LowMass

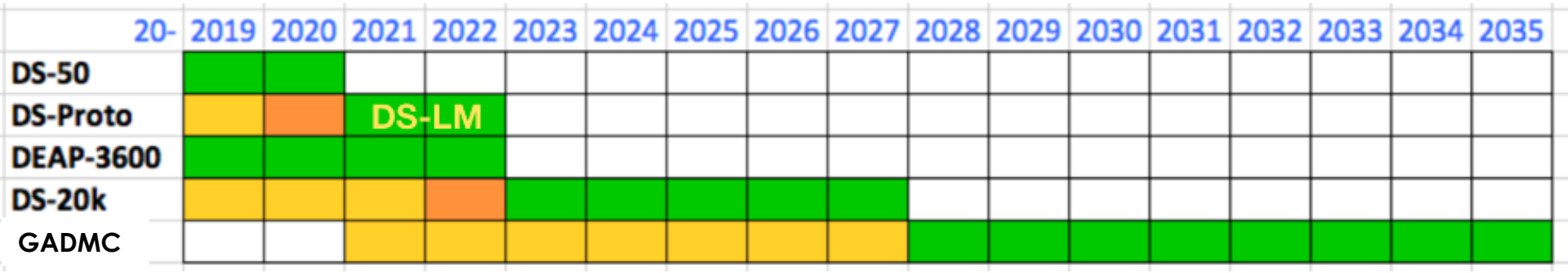




Test of the DS-20k technology: SiPM, electronics, cryogenics, ….

Tuning of S2 amplification factor

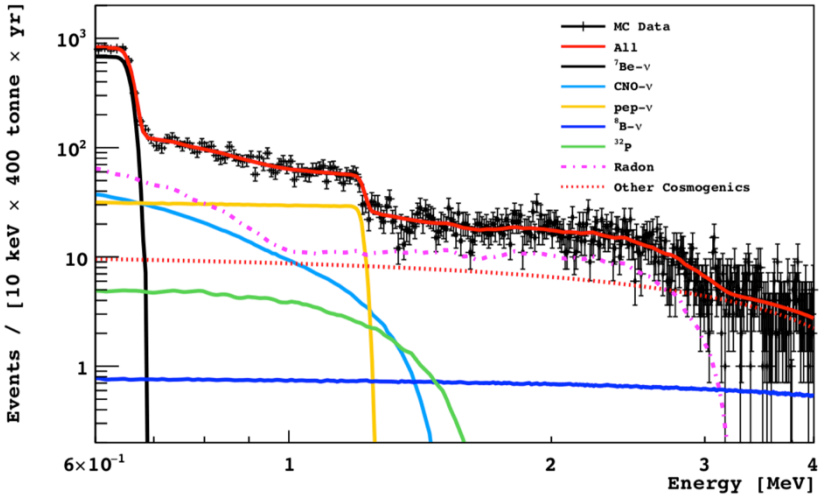
DarkSide Program



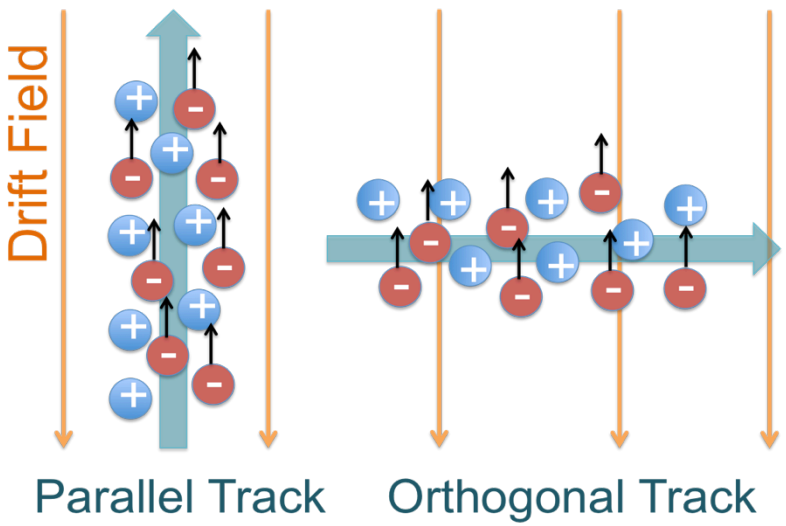
GADMC

- **400 tonnes** detector
- **Background-free** (<0.1 background events) in the high-mass WIMP range
- Possible location at **SNOLab**: letter of intent for collecting and stocking UAr at SNOLab
- Additional strong physics case with **CNO solar neutrinos**

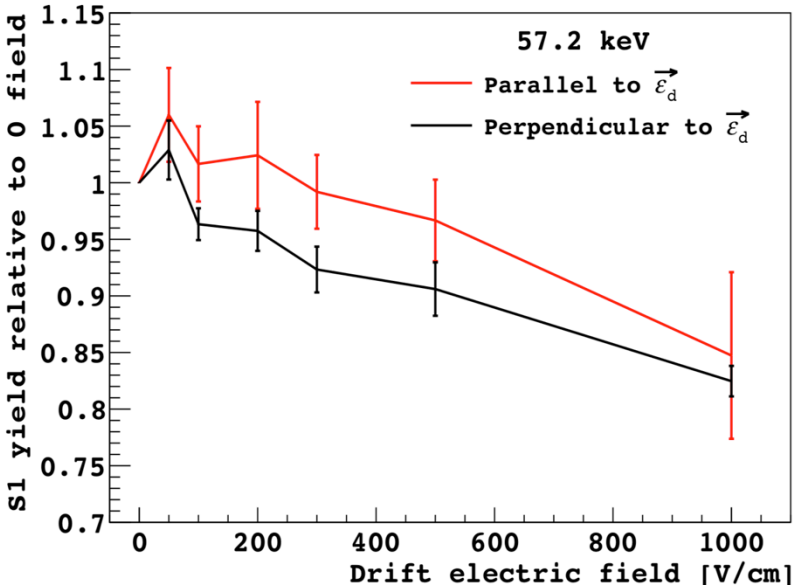
Potential in CNO neutrinos



Below the neutrino floor? Directionality!



An hint from SCENE



Directional signature by looking at recombination effect variation as function of the track orientation with respect to the direction of the field

Conclusions

- **Best limits below 5 GeV**: Phys. Rev. Lett. 121 (2018) 081307
- Improved limits in the **sub-Gev** region: Phys. Rev. Lett. 121, 111303 (2018)
- **0 background** in the high mass region: arXiv:1802.06994 (submitted to PRD)

A Single (Unique?) Global Program for Direct Dark Matter Searches
ArDM + DarkSide + DEAP + MiniCLEAN

Currently taking data: ArDM, DarkSide-50, DEAP-3600

Next step: **DarkSide-20k** at LNGS (2022-)

Intermediate step: **DarkSide-LowMass** at LNGS (2020) ?

Last Step: **400 tonnes** detector, location t.b.d (2027-)

Back Up

NR S2 Fluctuation