Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Dark Matter searches with LAr

DEAP3600 - DarkSide - DArT

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Atracción de Talento PostDoc
CIEMAT - Lab. Sub. Canfranc

17th MultiDark WS - 26/01/2021

Why Liquid Argon?

Liquid scintillator low-E threshold, scalable, affordable

+ **Pulse shape discrimination**
  Scintillation has two main components:

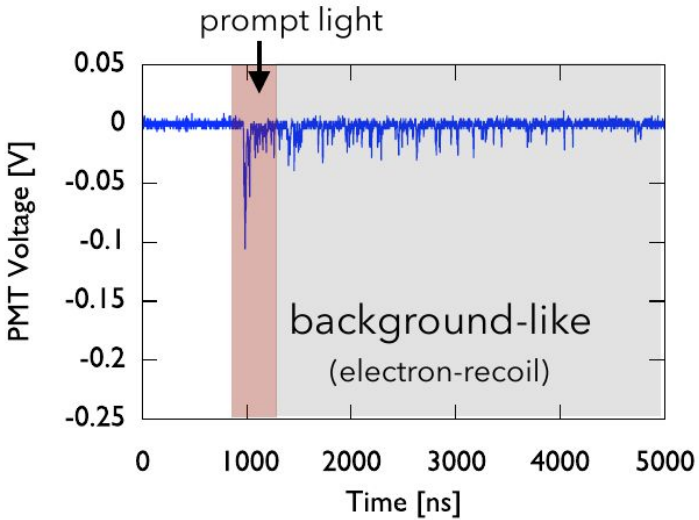
Slow component: ~ µs
Fast component: ~ ns

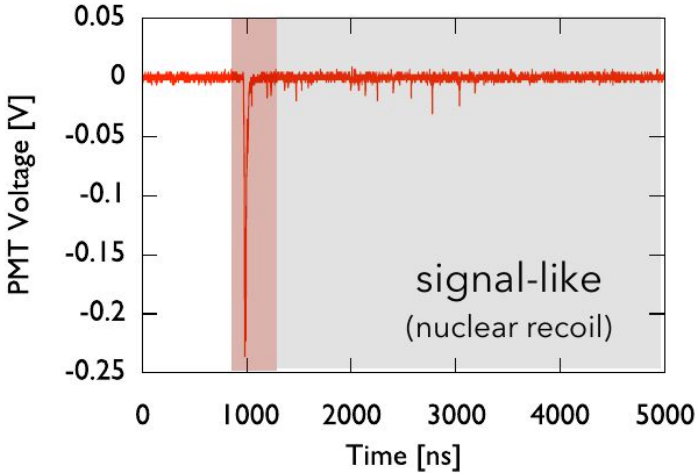
SC dominates in electron recoils (bkg)
FC dominates in nuclear recoils (signal)

+ allows **different concepts of detector**

  Single-phase: DEAP-3600, DArT

  Double-phase TPC: DarkSide-20k (+ionization)





DEAP-3600 (single phase)

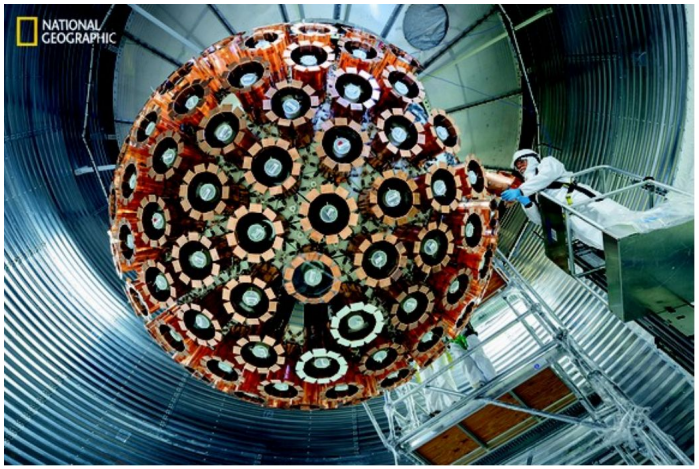
Located 2 km underground @ SNOLAB
3.3 tons of LAr inside an acrylic sphere of 85 cm radius seen by 255 PMTs.

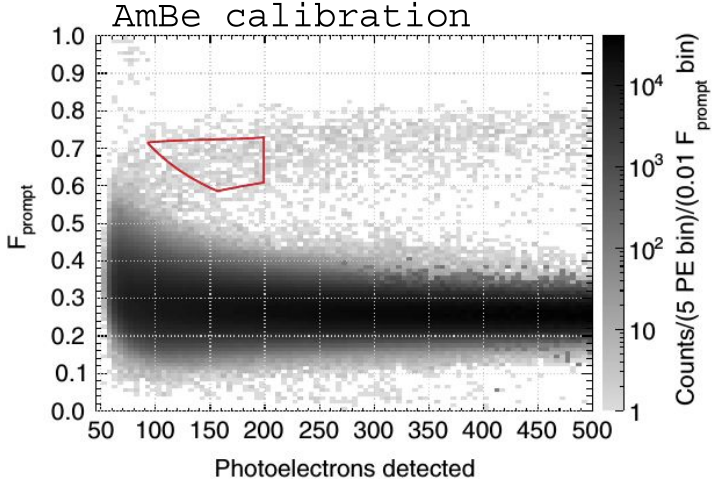
Analysis of pulse shape allows for a suppression in ER backgrounds of 4×10^{-9} with 90% NR-acceptance:
Eur. Phys. J. C80, 303 (2020)

Analysis of EM backgrounds:
Phys. Rev D 100, 072009 (2019)

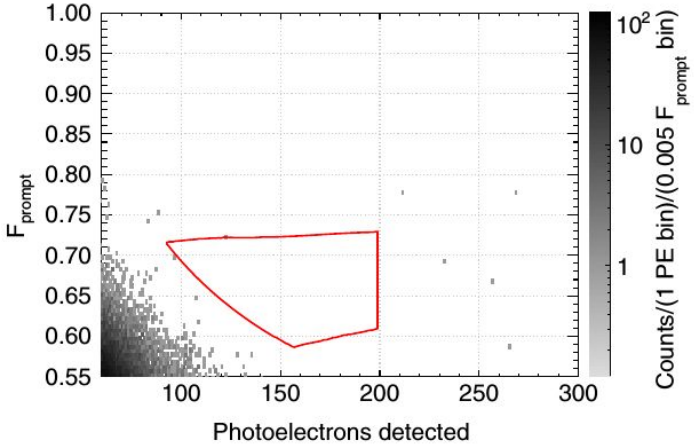
All these efforts necessary for the WIMP searches:

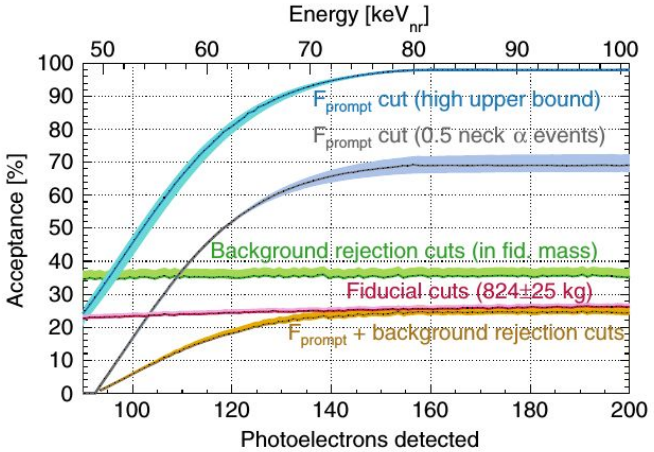
Phys. Rev D 100, 02204 (2019)

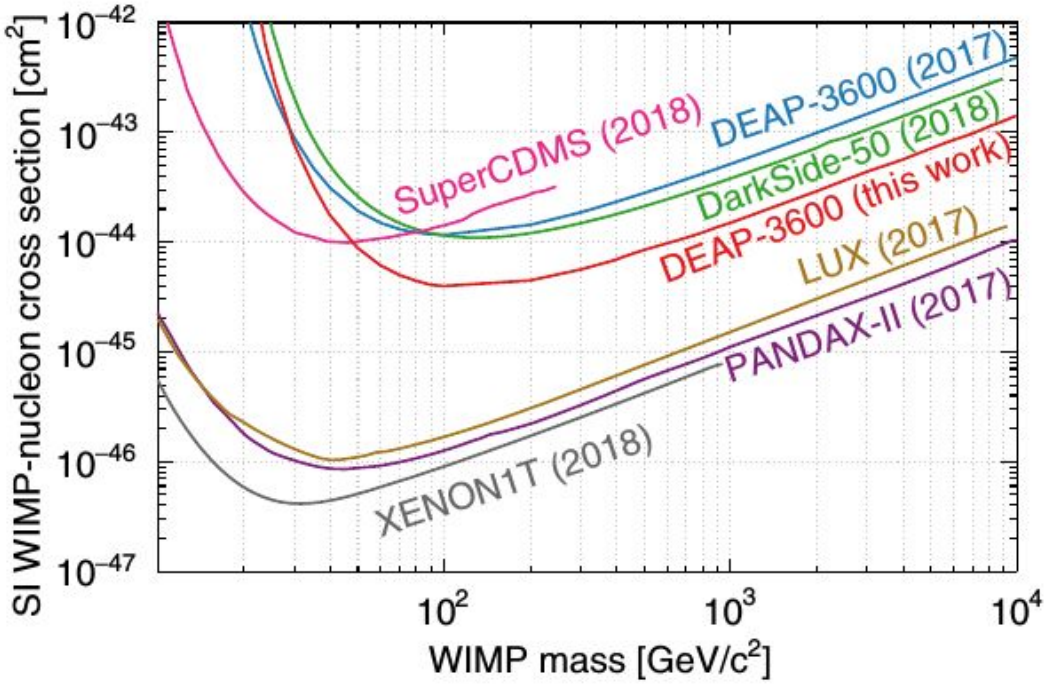




DEAP-3600: WIMP search







main efforts to recover acceptance:

HW upgrades **+ Machine learning**

\+ x5 amount of data (until DS-20k)

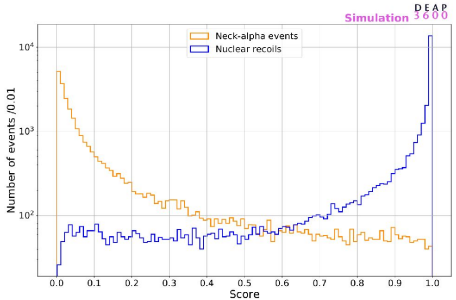
DEAP-3600: Background rejection with Machine learning

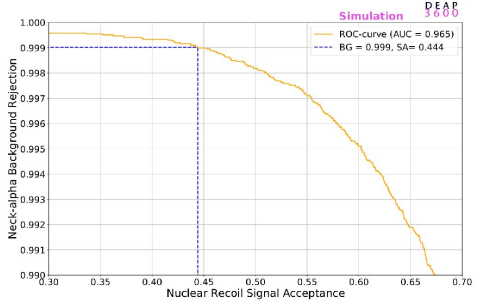
Alphas from the neck produce NR-like signal + misreconstruction inside the active target.

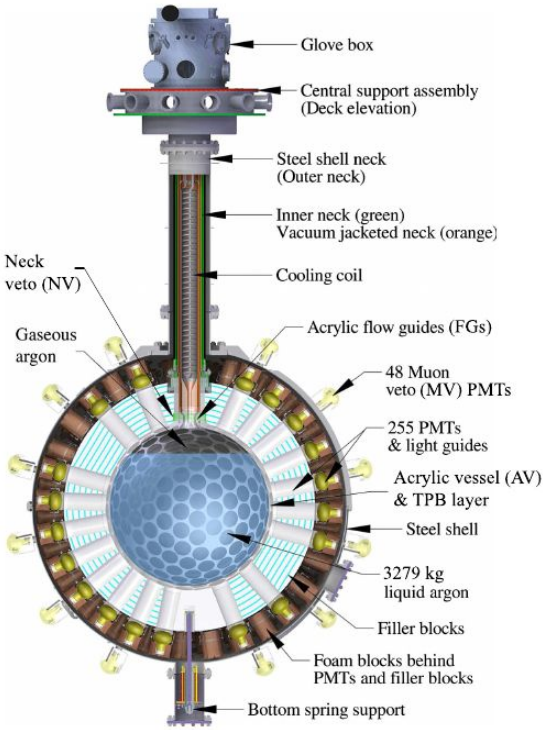
Random Forest + Boosted decision trees + **Neural network approach**

Reduce the leakage by x10

Increase acceptance by a factor ~3







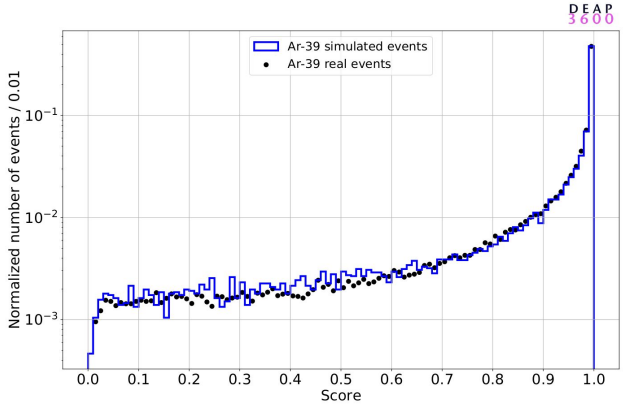
DEAP-3600: Background rejection ML

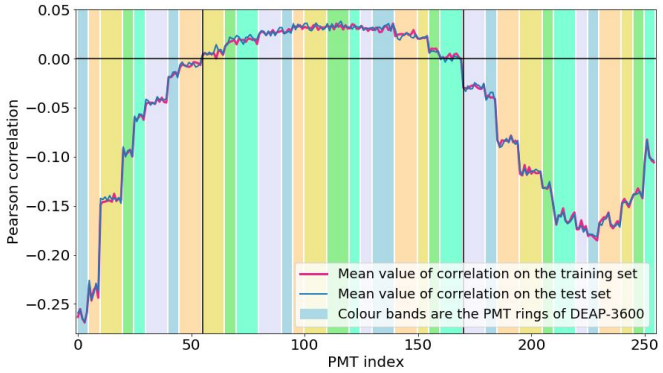
We are currently facing "the" question with ML approaches, i.e. **validation and understanding systematic effects:** MC vs data.

We are also putting some effort into XAI ("opening the black box"):

- What are the features that the NN is learning from?
- Do these match with our expectations?
- Can we provide the data to the NN in a better way?

Presented in Hybrid Artificial Intelligence Systems 2020





DEAP-3600 beyond WIMPs

In principle, good capabilities for SN neutrinos and ^{8}B:
Our ER bkg ends at 2.6 MeV, bkg-free measurement above.

Ongoing analyses for exotic DM (boosted DM, MIMPs, warm sterile neutrinos).

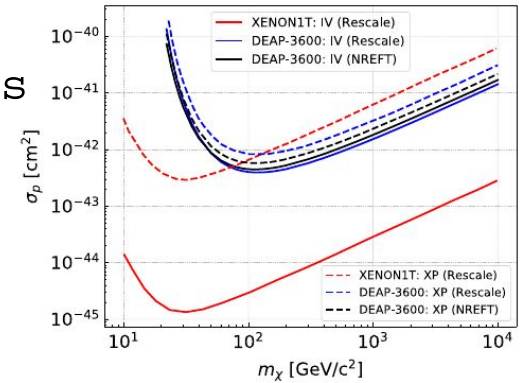
Ongoing analysis for solar axions at 5.5 MeV

Recent review of the assumptions into the exclusion curves:

- different EFT approaches to the DM-nucleus interaction
  IS-violating (Xe+Ar) and other operators...
- Consequences of different DM halo structures
  Gaia sausage, streams, non-Maxwellian…

$$\frac{dR}{dE_R} = \frac{\rho_T}{m_T}\frac{\rho_\chi}{m_\chi}\varepsilon(E_R)\int_{v_{\min}}^{\infty} v f_\chi^{\oplus}(\vec{v})\frac{d\sigma}{dE_R}d^3\vec{v}$$

Phys. Rev. D 102, 082001 (2020)

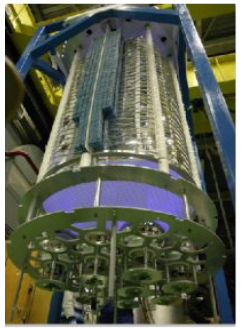


The Global Argon Dark Matter Collaboration

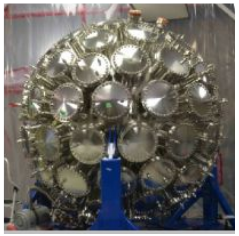
DS50

DEAP-3600

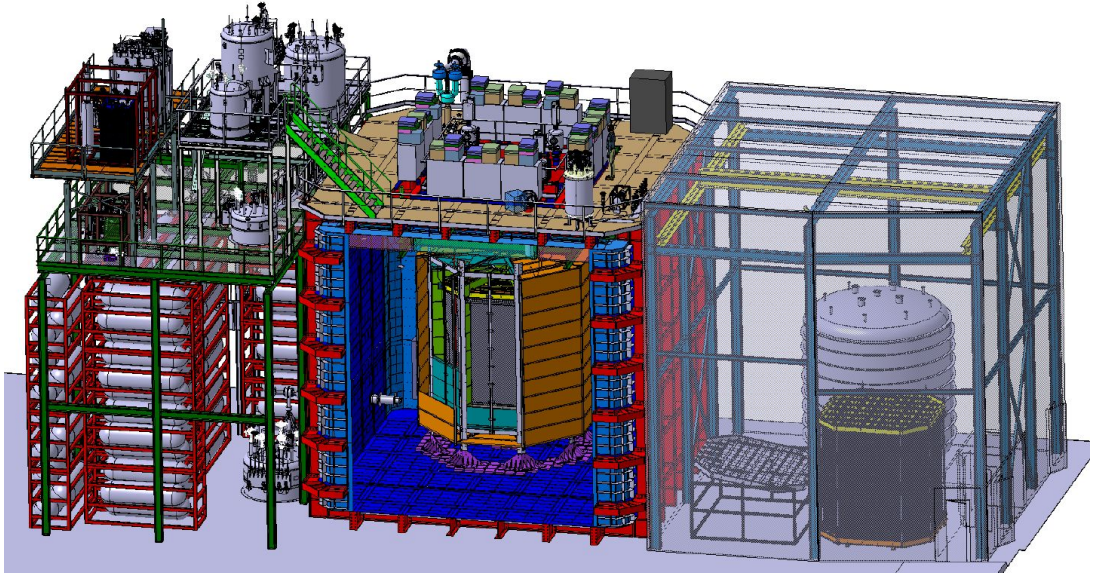
ArDM



MiniClean



DarkSide-20k @ LNGS + ARGO @ SNOLAB



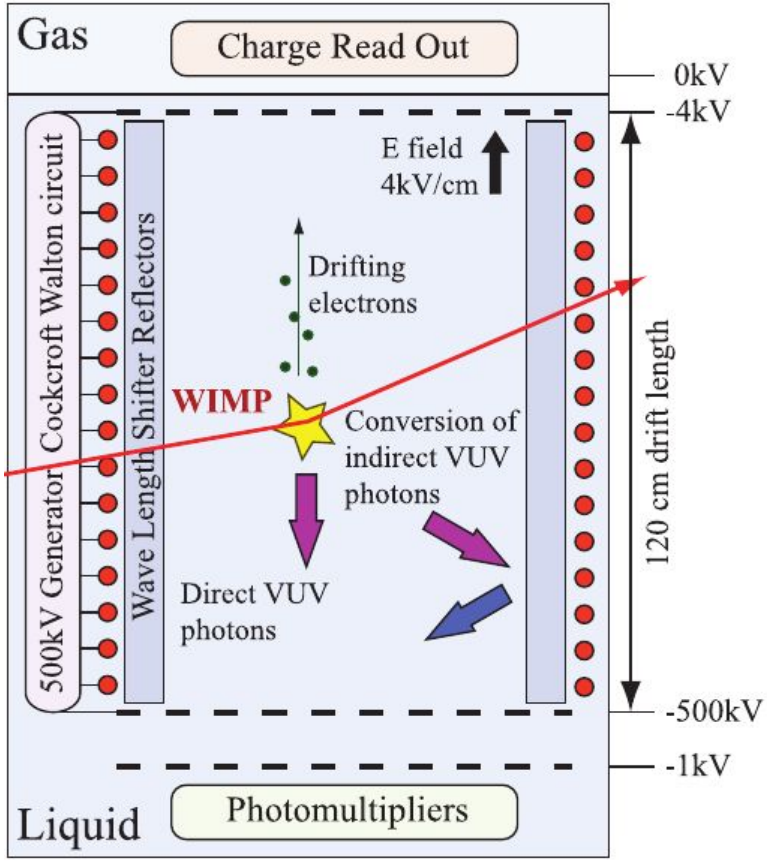
DarkSide-20k

Dual-phase
Time Projection Chamber:

- Direct scintillation (S1)

- e^- from ionization drift to the gas phase where a second flash (S2) is induced

Excellent position reconstruction and background mitigation



DarkSide-20k @ LNGS

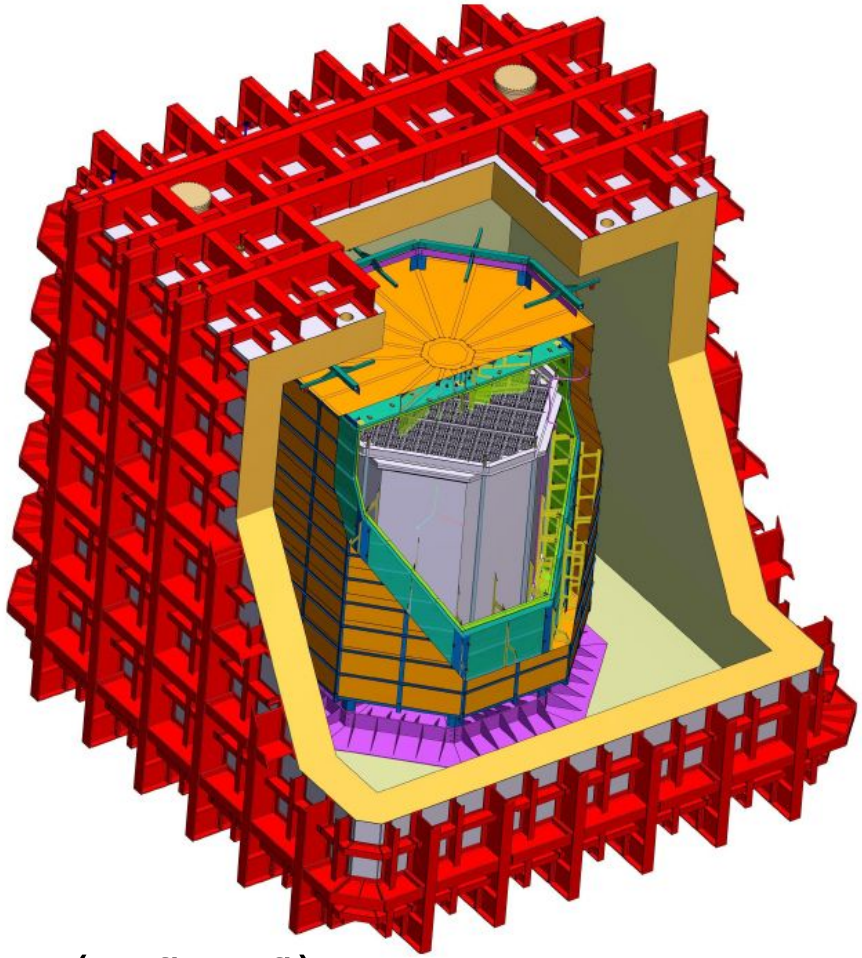
50 ton TPC (20 fiducial)

Seen by 8400 SiPM modules
20.16 m2 sensitive area

Octogonal sealed acrylic TPC
with Underground argon

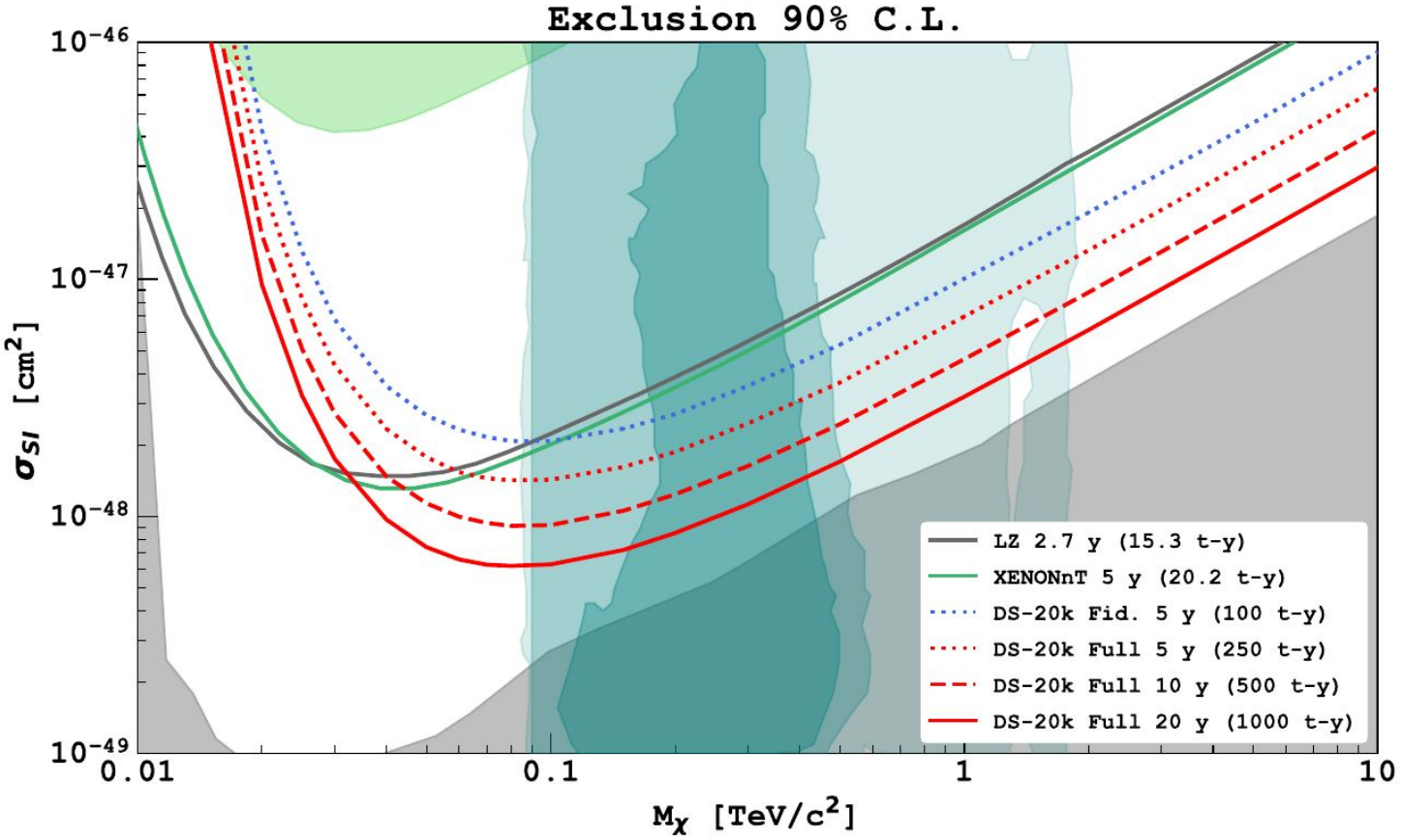
~600 tons of Atmospheric Ar
for shield + veto
+ Gd-loaded PMMA for n-capture

Cryostat à la DUNE



goal < 0.1 total bkg events in 10 y (+ CEvNS)

DarkSide-20k prospects



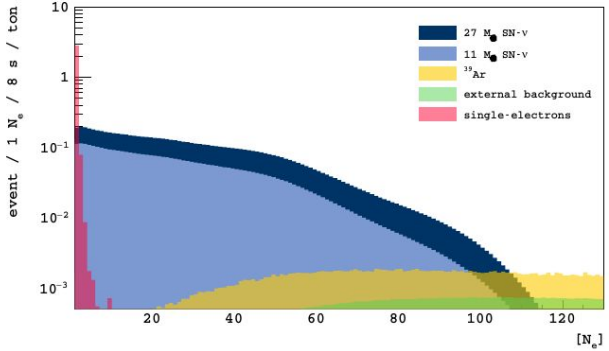
DarkSide-20k beyond WIMPs

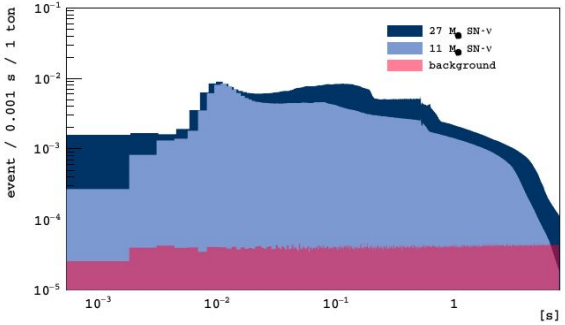
Low-mass DM: As DS50 showed, good potential in the 10^{-2}-10^{1} GeV/c^2 mass region.

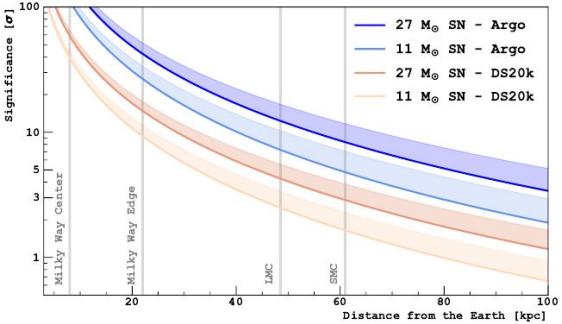
Phys. Rev. Lett. 121, 081307 (2018)

Phys. Rev. Lett. 121, 111303 (2018)

SuperNova neutrinos: Extremely good capabilities for the detection of SN-neutrinos arXiv: 2011.07819 (accepted JCAP)







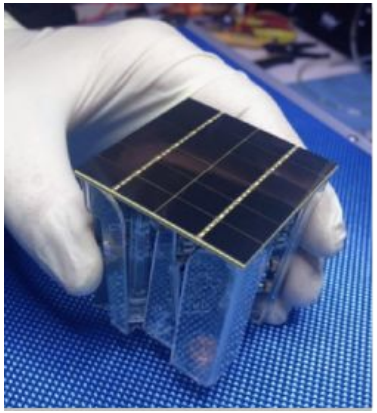
DarkSide-20k enabling technologies

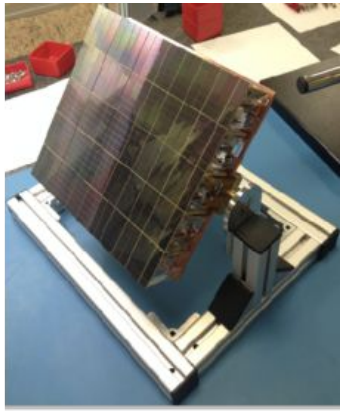
The SiPMs (radiopurity, performance, occupancy)

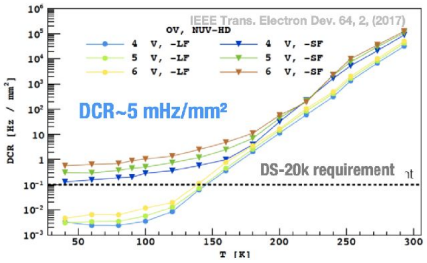
The selection of radiopure components

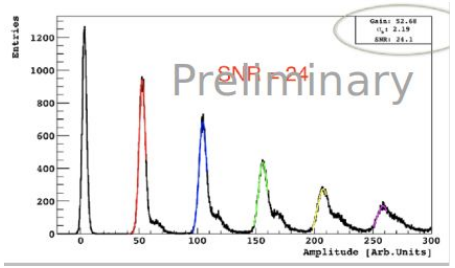
The use of underground argon with depleted ^{39}Ar content (reduction > 1400)

(among others)









Photodetection efficiency ~50%
Fill factor 90%
Dark count rate < 10^{-2} Hz/mm^2
Timing better than 10 ns
Single PE resolution

DarkSide-20k materials campaign

ER backgrounds might reduce the detector performance

Neutrons producing an untagged single-recoil in the fiducial volume are background.

Th and U impurities produce α: ICPMS, HPGe, **Po extraction**
Seldom studied in bulk contamination, >20% of our bkg.

These α can induce (α,n) in the materials they are produced:
Nuclear physics calculation + simulation: Recent development of SaG4n
Nucl. Instrum. Methods A 960, 163659 (2020)

These n have a probability of leaking as signal in the ROI. G4DS

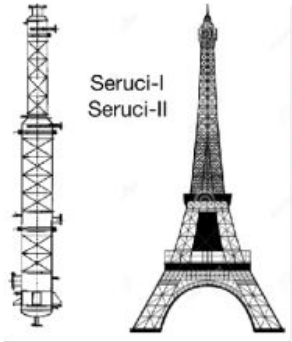
The materials campaign: 4 years working on this and still + 3 years for the experiment to start taking data. Leading roles by CIEMAT and LSC.

Production
URANIA – Colorado, USA

- Underground argon extraction (purity 99.9%, 250 kg/day)

Purification
ARIA – Sardinia, Italy

- Distillation with a 350m tall column (~tonne/day)
- Isotopic separation of ^{40}Ar and ^{39}Ar



- Factor 1000 reduction of chemical impurities

DArT in ArDM @ LSC

The top priority on terms of purity: **the Ar itself**

DArT will measure adequacy of batches before filling:

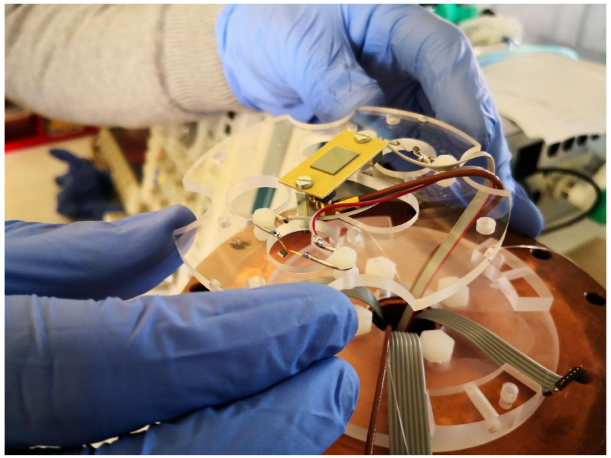
+2 kg LAr in Cu vessel

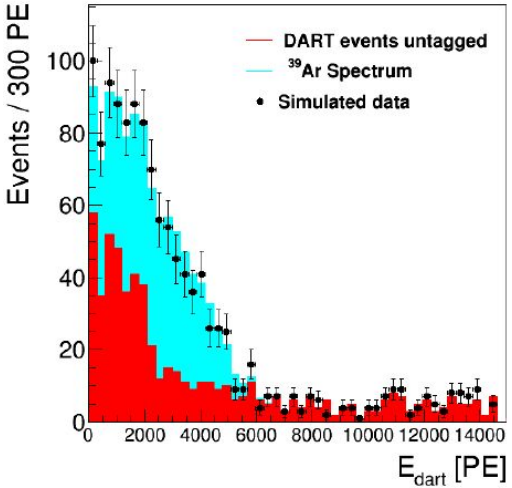
+seen by 2-4 SiPMs

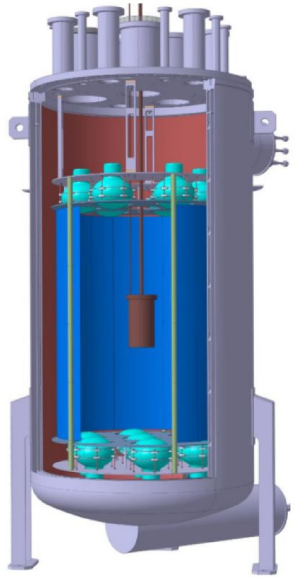
+inside 1 ton of LAr [**ArDM**]

+Extra Pb belt for gamma shield

JINST15 P02024 (2020)





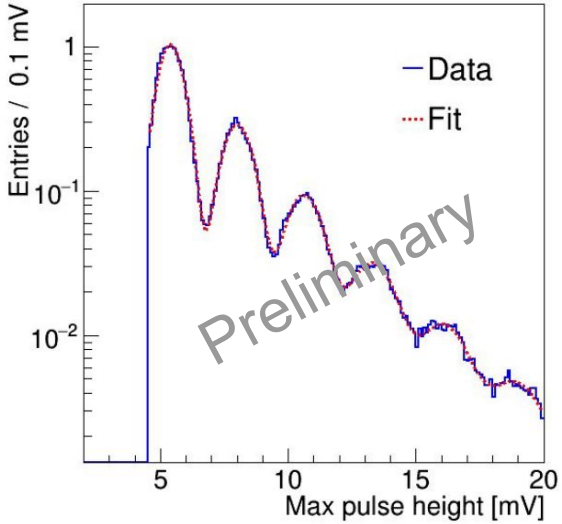


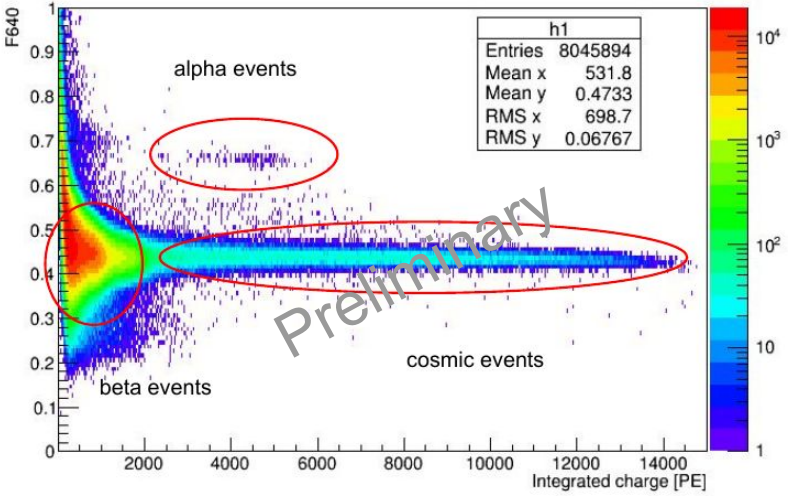
DArT @ CIEMAT

Passed surface tests, ready for being moved to **LSC** to start underground activity:

performing measurements o ^{39}Ar spectrum in atmospheric Argon.

People (me) permanently based @ Lab Sub Canfranc to undertake this task





Conclusions and remarks

DM-searches with LAr are solid and increasing momentum.
Bkg-free measurement potential (other than CEvNS)

Variety of targets will be essential to understand any findings in the future

The Spanish DM-LAr community (CIEMAT, LSC & U. Zaragoza) has significant expertise potentially useful in other searches [materials, radiopurity, (α,n)...]

Thanks for your attention