The APC Neutrino Group

Conseil Scientifique APC
March 2020

The Neutrino Group

11 permenents + 2 volunteers	Position	HDR
M. Cribier	Emeritus	
J. Dawson	CR	
D. Franco	CR	X
A. Kouchner	PR	X
D. Kryn	benevole	
T. Lasserre	CEA	X
M. Obolensky	benevole	
T. Patzak	PR	X
S. Sacerdoti	CR	
A. Tonazzo	PR	X
V. Van Elewyck	MCF	
F. Vannucci	Emeritus	
D. Vignaud	Emeritus	

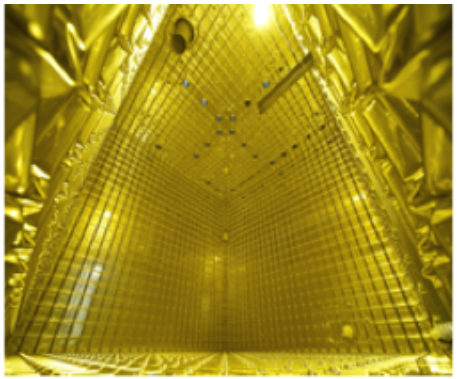
2 Postdocs	Experiment	Period	Grant
R. Le Breton	ORCA	2017/2020	ANR
G. De Gwenhael	ORCA	2019/2021	LabEx

9 PhD	Experiment	Period	Cotutelle
R. Bajou	DUNE	2019/2022	
E. Chardonnet	DUNE	2018/2021	
Y. Han	JUNO	2017/2020	
T. Hugues	DarkSide	2019/2023	Poland (*)
M. Lai	DarkSide	2017/2020	Italy
L. Maderer	ORCA	2019/2022	
C. Thien Nhan	ORCA	2018/2021	
J. Rode	DarkSide	2019/2022	
F. Versari	ORCA	2017/2020	Italy

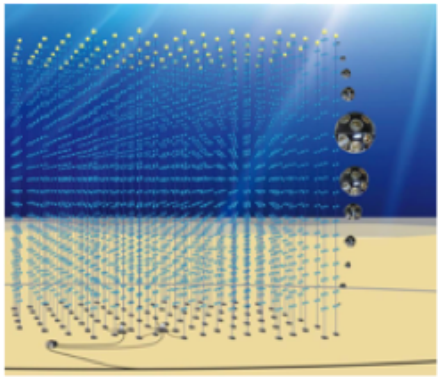
(*) in partnership with Astrocent

Evolution since 2017

DUNE/WA105

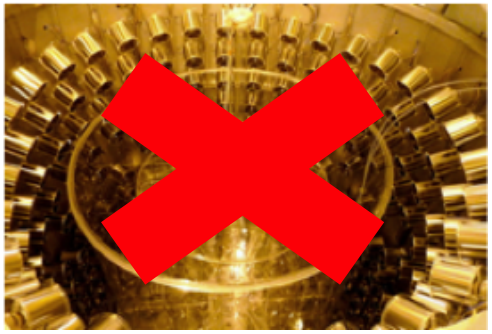


ORCA

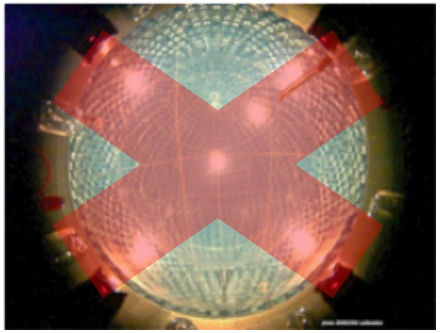


DarkSide

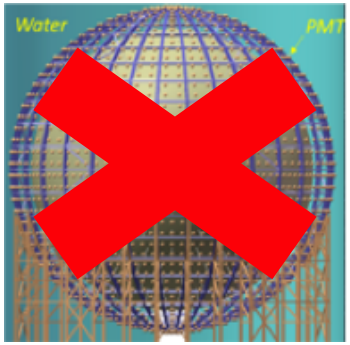
Double Chooz



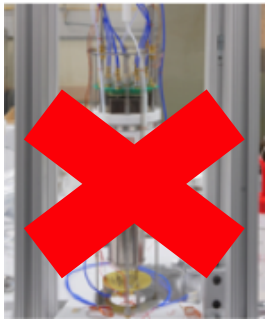
Borexino/SOX



JUNO



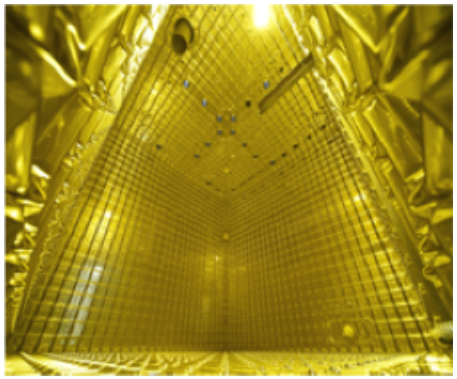
LIQUIDO



ARIS

Neutrino Group Experiments: 2019

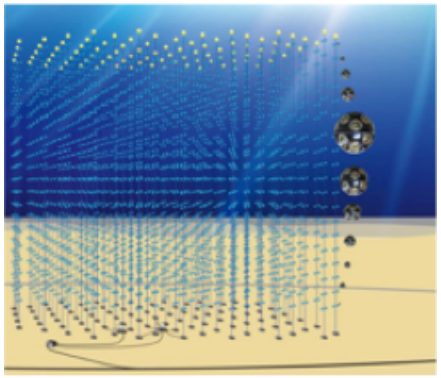
DUNE/WA105



Oscillation physics
- Search for leptonic CP violation
- Determine the neutrino mass hierarchy
- Precision PMNS measurements

Supernova physics
Solar neutrinos
Baryon number violation

ORCA



Oscillation physics
- Determine the neutrino mass hierarchy
- Precision PMNS measurements

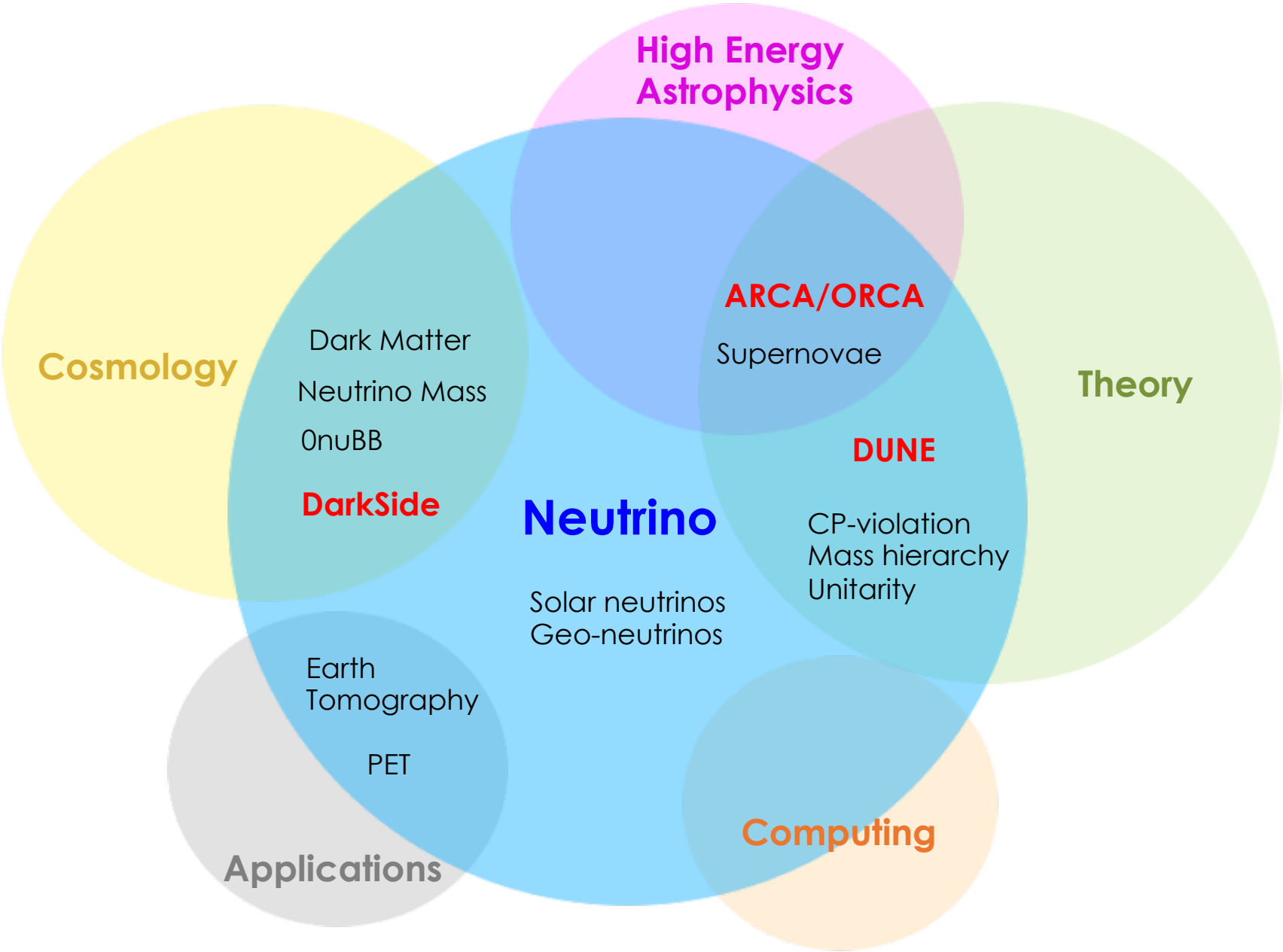
Supernova physics
Neutrino astronomy (AHE)
Earth tomography

DarkSide

Direct Dark Matter Search:
- Low/high mass WIMPs
- Boosted dark matter
- Axions

Supernova physics
Solar neutrinos
0nBB
Positron Emission Tomography

Integration in the APC universe



The Timeline

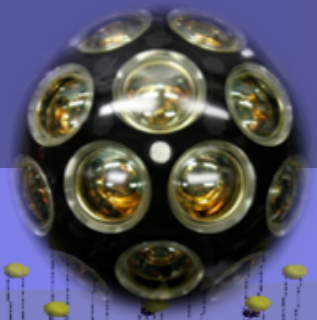
Design | Construction | Data taking

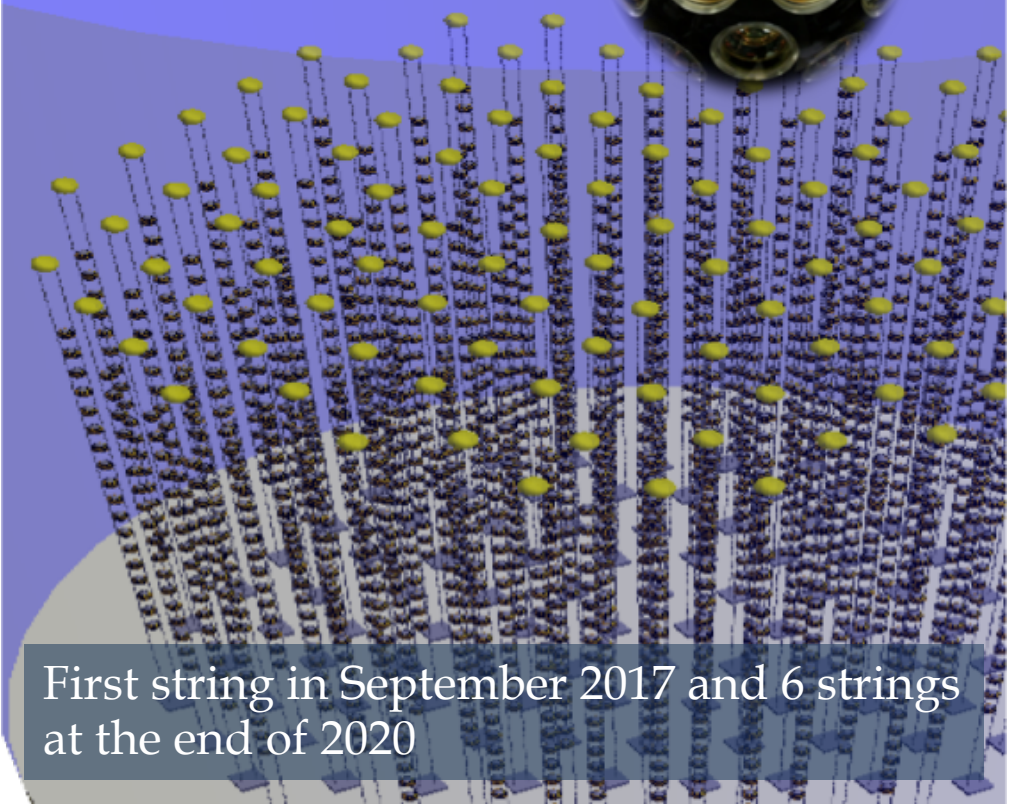
Projets	2018	2019	2020	2021	2022	2023	2024
DUNE	WA105	WA105	WA105	WA105			
	DUNE	DUNE	DUNE	DUNE	DUNE	DUNE	DUNE
KM3NeT	ANTARES						
	ORCA Phase 1			ORCA Phase 2			
		ORCA	ORCA	ORCA	ORCA	ORCA	ORCA
DarkSide	DS50	DS50	DS50				
	DS-PROTO	DS-PROTO	DS-PROTO	DS-PROTO	DS-PROTO	DS-PROTO	
	DS20k	DS20k	DS20k	DS20k	DS20k	DS20k	DS20k

ORCA @ APC

Some number:

- **5.7 Mt** instrumented volume
- **115** x 200-m long strings (DU)
- **18** DOMs / DU
- **31** PMTs / DOM
- **64k x 3″ PMTs**





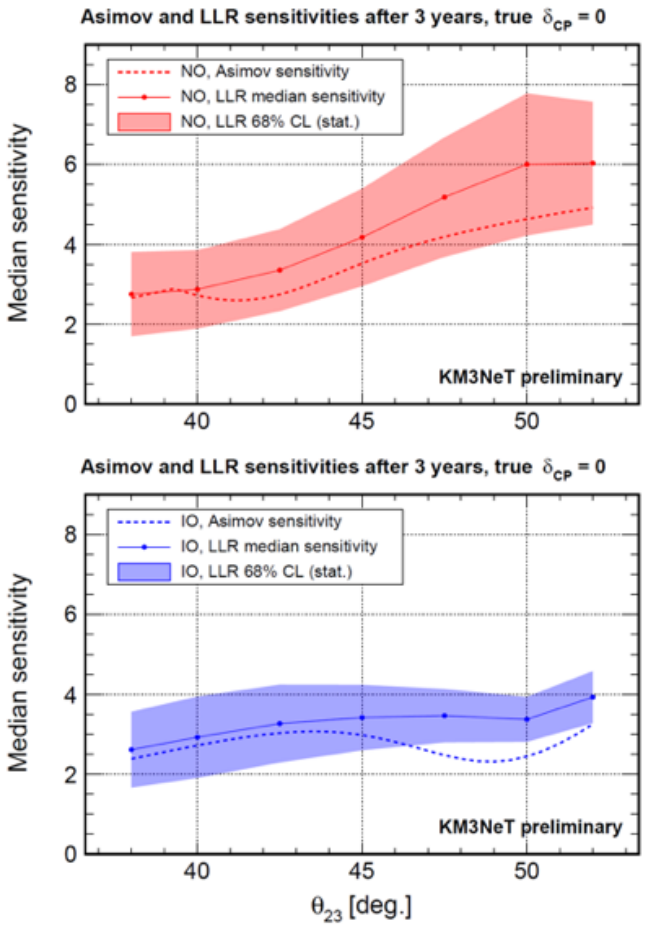
First string in September 2017 and 6 strings at the end of 2020

- M. Lindsey Clark **Technical Project Manager** since 2018
- **Neutrino Physics**: **MH + oscillation parameters** (N. Chau, Christine Nielsen)
- **Earth science**: **neutrino tomography** (V. Van Elewyck + E. Kaminski and J. Badro from IPGP)
- **Neutrino astronomy**: **Supernovae neutrinos** (M. Colomer) and **GeV neutrinos** (G. de Wasseige, V. Van Elewyck)
- **Detector monitoring**: **charge/time calibration** (A. Creusot)
- **Instrumentation**: **DOM characterization**, **Calibration Units**, **Quality Control** (A. Creusot, R. Le Breton, C. Boutonnet, C. Champion, S. Colonges, L. Confucius, A. Ilioni, M. Lindsey Clark)

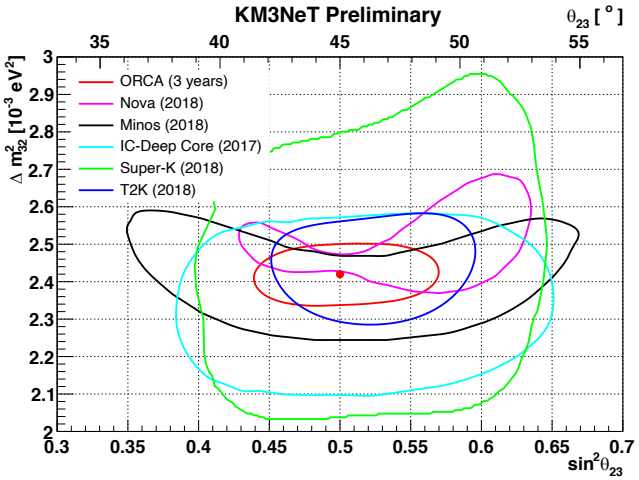
ORCA: neutrino oscillations

oscillations of 1-100 GeV atmospheric neutrinos crossing the Earth

Neutrino Mass Hierarchy



Theta23



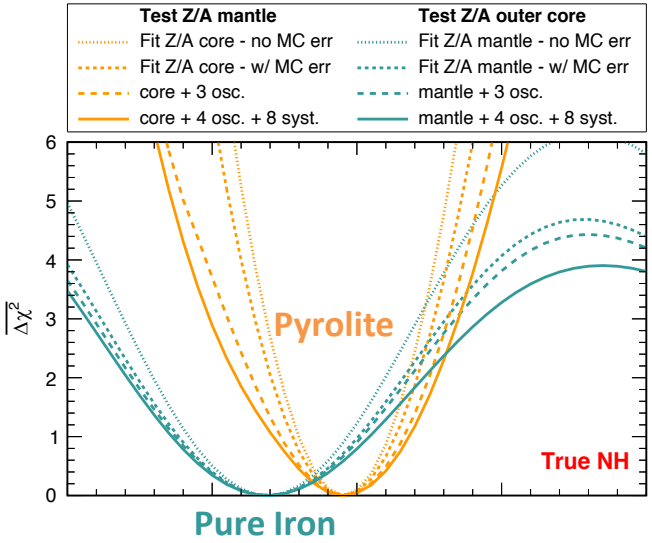
@APC

Development of a complete simulation chain including detector response => official ORCA sensitivity for NMH, oscillation parameters, + systematics studies

Neutrino oscillation tomography of the Earth

sensitive to the electron density => allows for few % accuracy on Earth core and mantle compositions with GeV neutrino oscillations

In collaboration with E. Kaminski, J. Badro (IPGP)

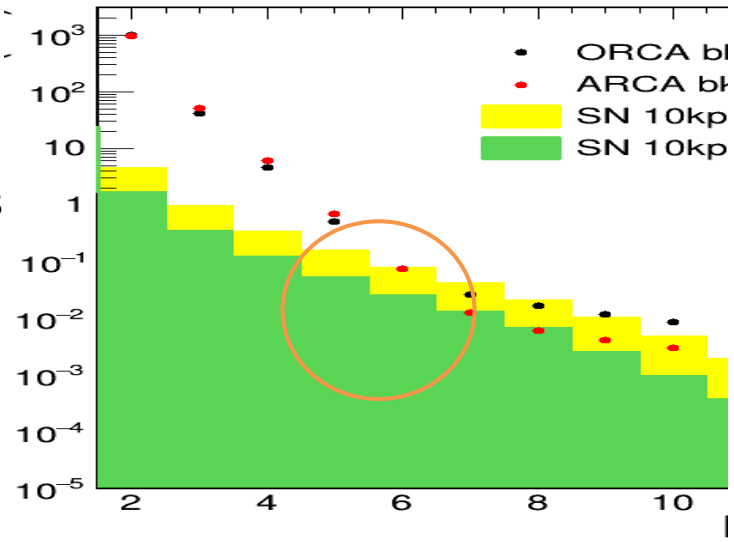


Supernovae neutrino detection

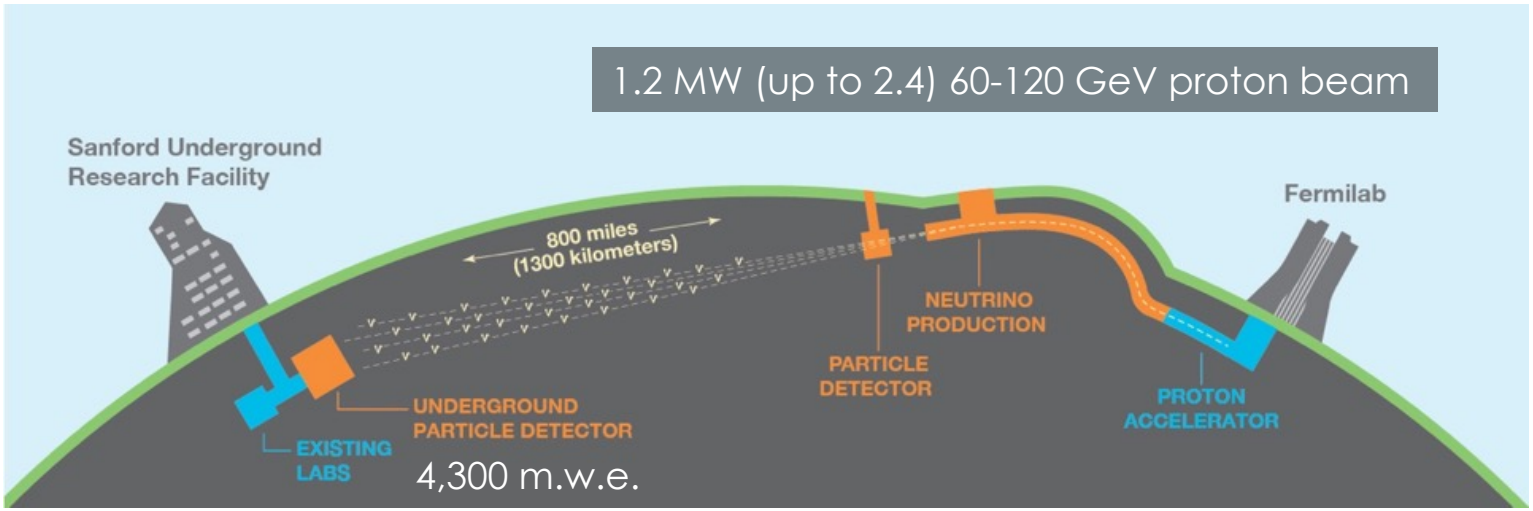
MeV neutrino burst observed with increase in PMT counting rates

background rejection by requesting O(ns) coincidences between 6-10 PMTs on same DOM

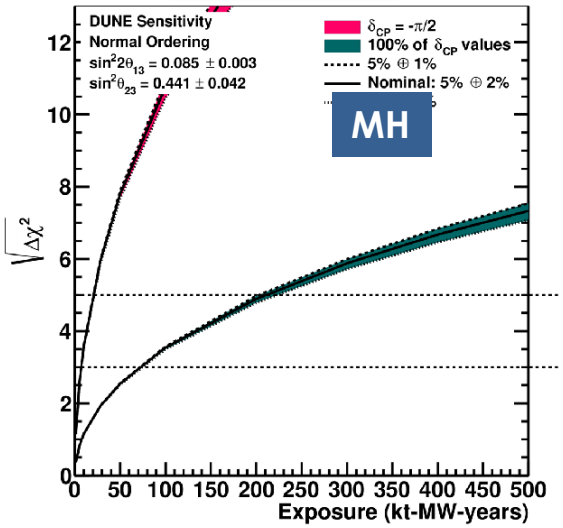
In collaboration with T. Foglizzo (AIM)

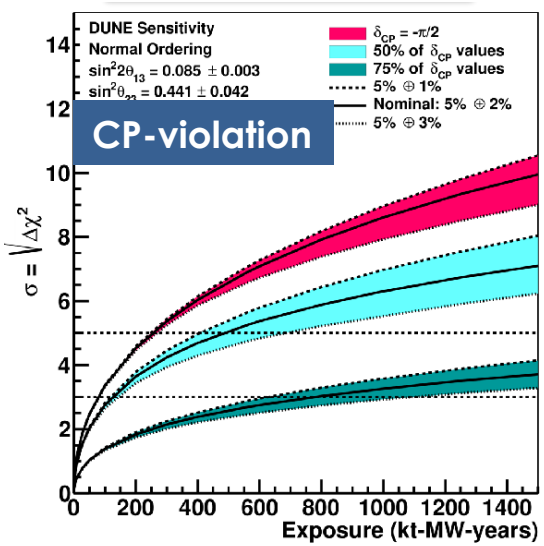


DUNE



4 x 10 kt fiducial mass liquid argon TPC modules, two technologies: Single Phase and Dual Phase

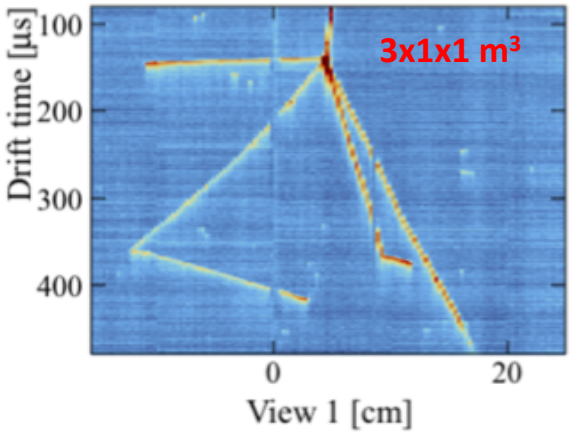




- Unitarity test
- Proton decay
- Supernova neutrinos
- Astroparticle
- Exotic physics

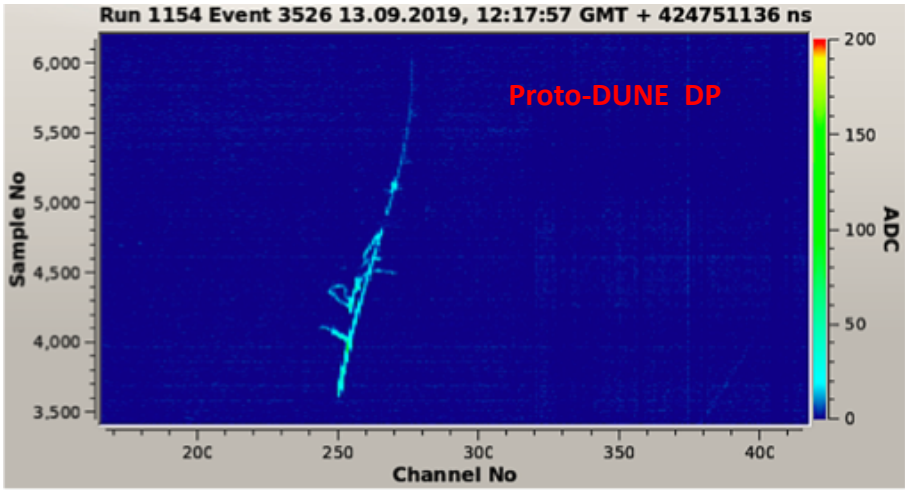
DUNE @ APC

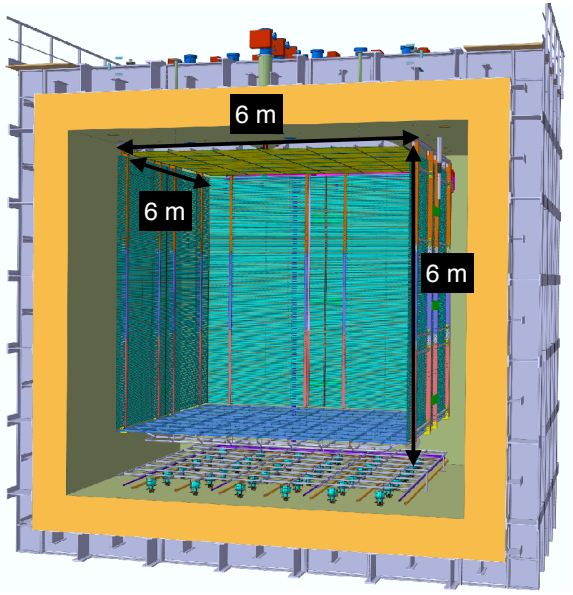
3x1x1 m^3 in 2017 => A 4 tonne demonstrator for large-scale dual-phase LAr TPCs, B. Aimard et al.. arXiv:1806.03317, JINST 13 (2018) no.11, P11003.



Proto-DUNE DP taking data since September 2019
APC technical contribution with light readout board (J. Dawson) + run coordinators (J. Dawson, S. Sacerdoti, A. Tonazzo)

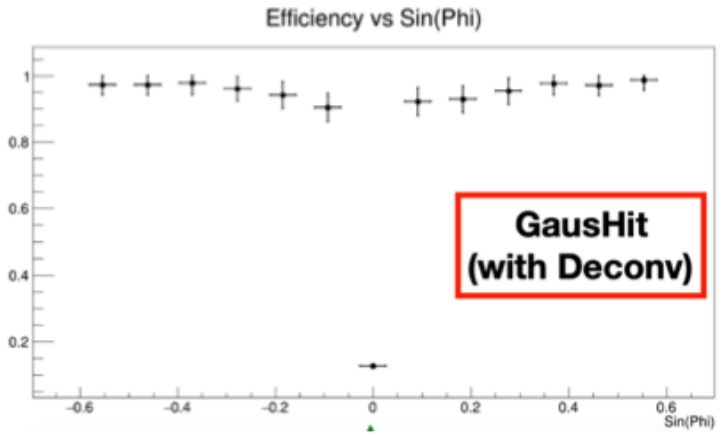
Preparation for **DUNE**:
- TDR: published (FERMILAB-DESIGN-2018-02 arXiv:1807.1033)
- DP TDR: J. Dawson co-editor of the electronics chapter (to be published)

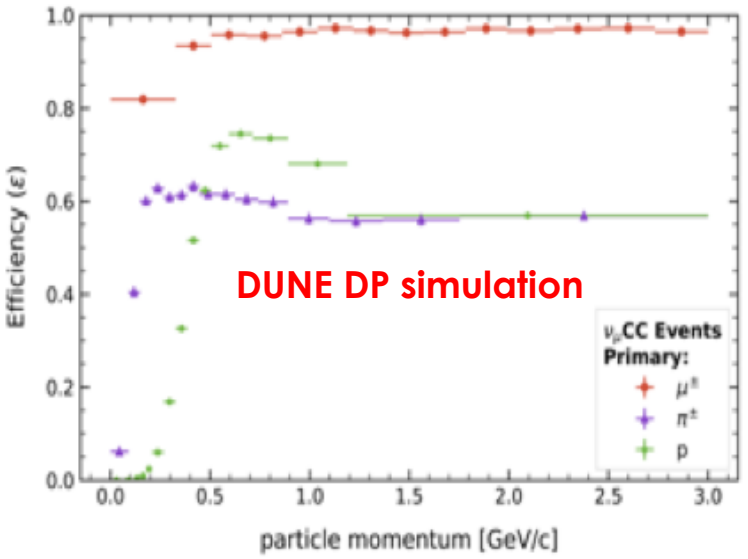




DUNE @ APC

- **T. Patzak**: member of IB
- **A. Tonazzo**: member of Speaker Committee
- **J. Dawson** co-convener dual-phase proto analysis
- **S. Sacerdoti**: analysis of slow-control parameters / performance
- **R. Bajou** and **E. Chardonnet**:
  - track reconstruction + particle identification with cosmic muons in proto-DUNE DP
  - integration in LArSoft, development of PANDORA algorithms for DP
- **A. Scarpelli** - PhD 2016-2019:
  - Leading role in 3x1x1 analysis
  - First benchmark DP - specific studies for physics performance
  - CNN particle identification and event classification





DarkSide @ APC

The team:

- ☑ **APC**: D. Franco, A. Tonazzo + 3 PhD (M. Lai, J. Rode, T. Hugues)
- ☑ L1 WBS Manager "Science, Simulation, and Computing"
- ☑ D. Franco: **National Coordinator** in France:
  - ☑ APC + LPNHE + CPPM
  - ☑ CPT – MINES ParisTech (P. Stringari, M. Campestrini) for Ar-Xe mixture
  - ☑ Technical support for beam tests by **IPNO** (M. Lebois, J. Wilson)

French main contributions to (among 18 publications since 2013):

- ☑ Pulse shape discrimination for a **background-free** experiment PLB 743 (2015) 456
- ☑ **Solar neutrino** physics in a large LAr detector JCAP 1608 (2016) 8, 017
- ☑ ^{39}Ar depletion faction in **underground argon** PRD 93 (2017) 081101
- ☑ **Simulation** and LAr response model JINST 12 (2017) P10015
- ☑ Most accurate constraint of **LAr response** with ARIS, PRD 97 (2018) 11 112005
- ☑ World **best exclusion limit for 1.8-6 GeV WIMPs** PRL 121 (2018) 081307
- ☑ Extension of existing **exclusion limit to WIMP-electrons** PRL 121 (2018) 111303

DarkSide-50

Detector

- 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 at Gran Sasso National Lab, Italy

Performance

S1 and S2 Yields:

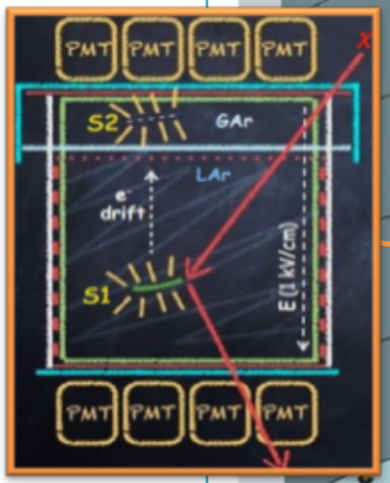
- S1 Yield ~7.9 pe/keV at null field
- S1 Yield **~7.0 pe/keV** at 200 V/cm
- S2 yield **~23 pe / e^-**

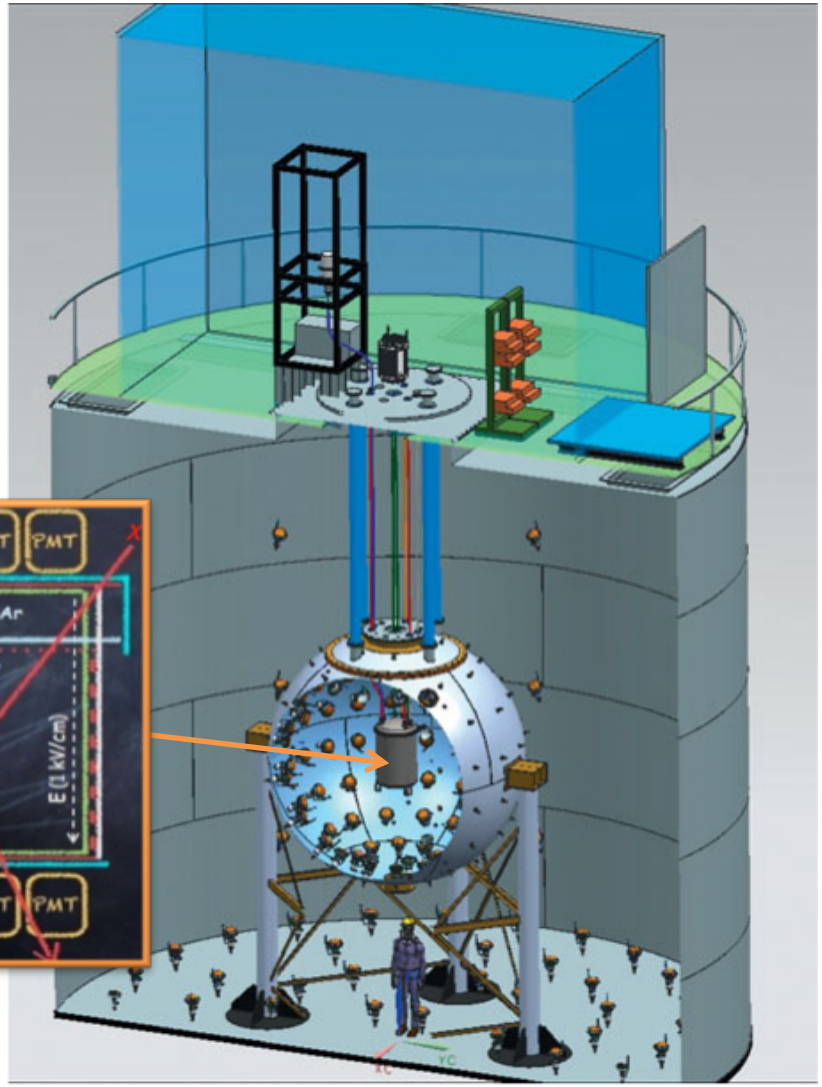
Electron lifetime > 10 ms
Maximum drift time: 376 μs

Position reconstruction:

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

Neutron Veto Rejection Efficiency: 99.6%





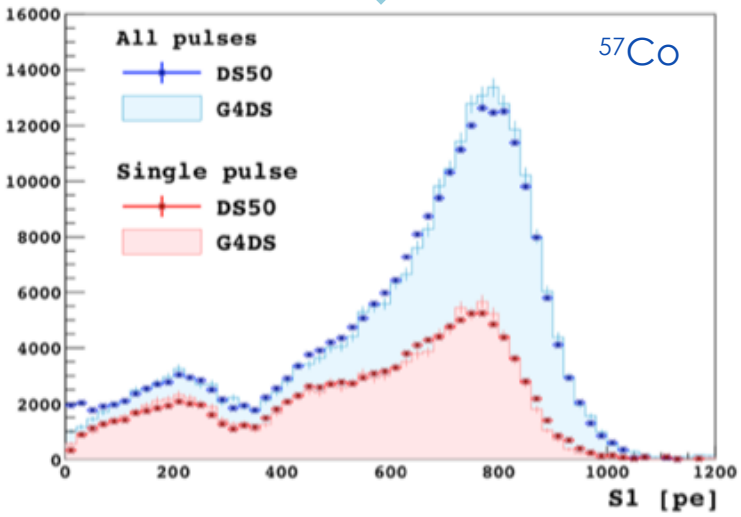
^{39}Ar issue: fixed!

G4DS

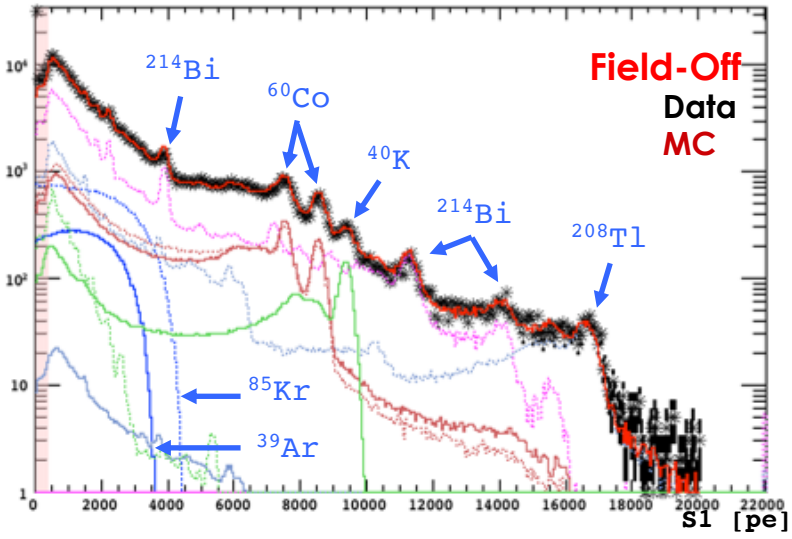
the DarkSide Monte Carlo package

- ☑ PARIS: custom made LAr scintillation-ionization response model
- ☑ Percent level accuracy in energy scale and resolution

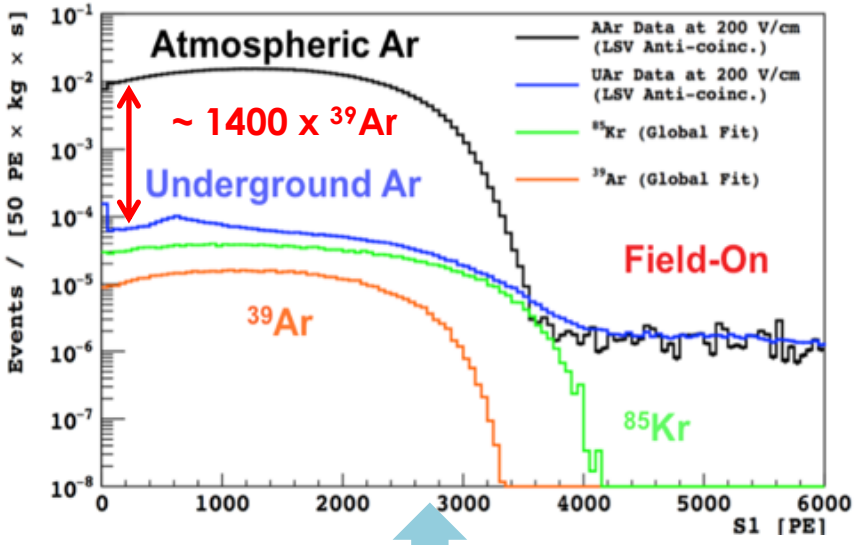
Calibration



Fit

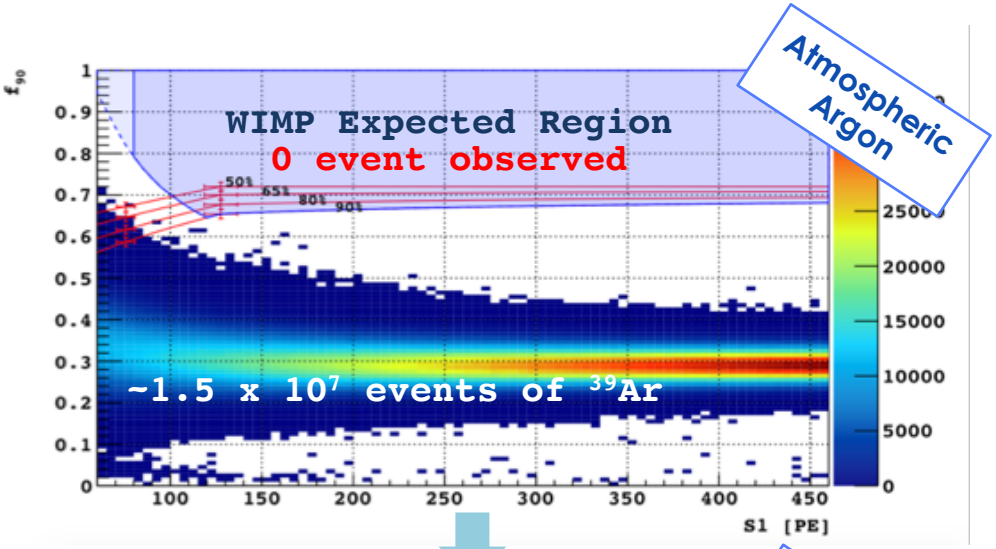


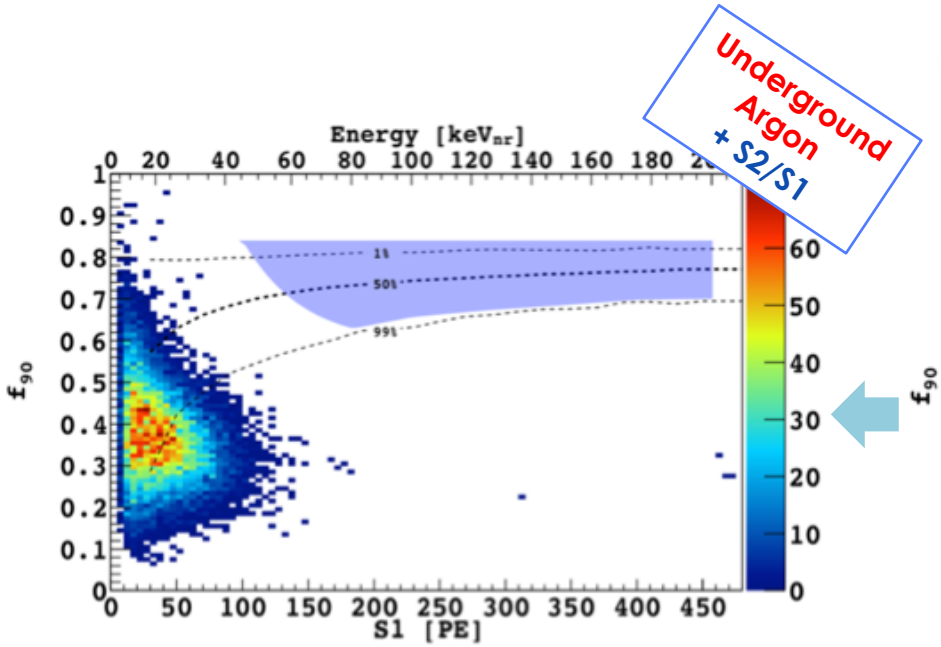
Result

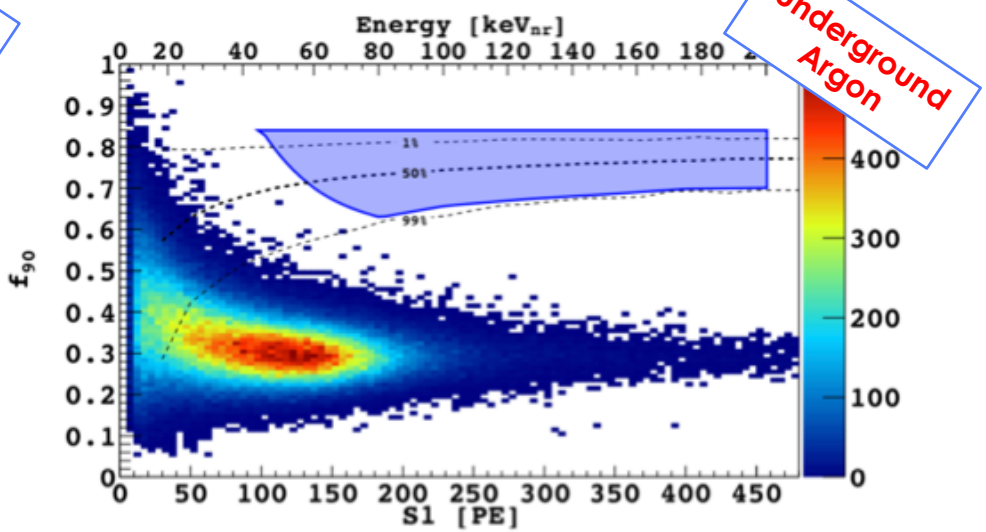


A background-free experiment

- ☑ **Pulse shape discrimination (f90)** power demonstrated with atmospheric argon
- ☑ **Blind analysis** in the ~532 days analysis
- ☑ **f90 analytical model by** APC





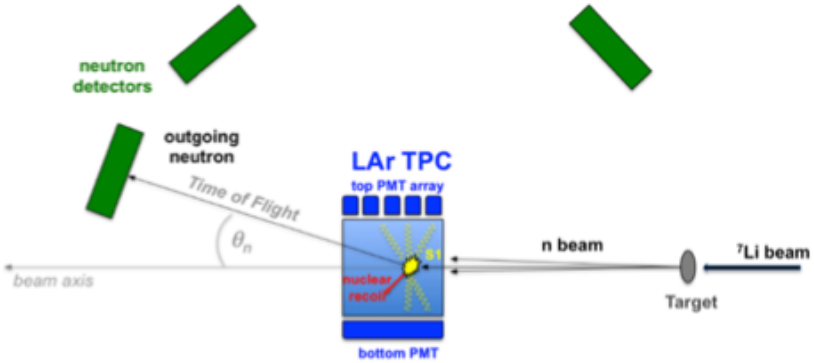


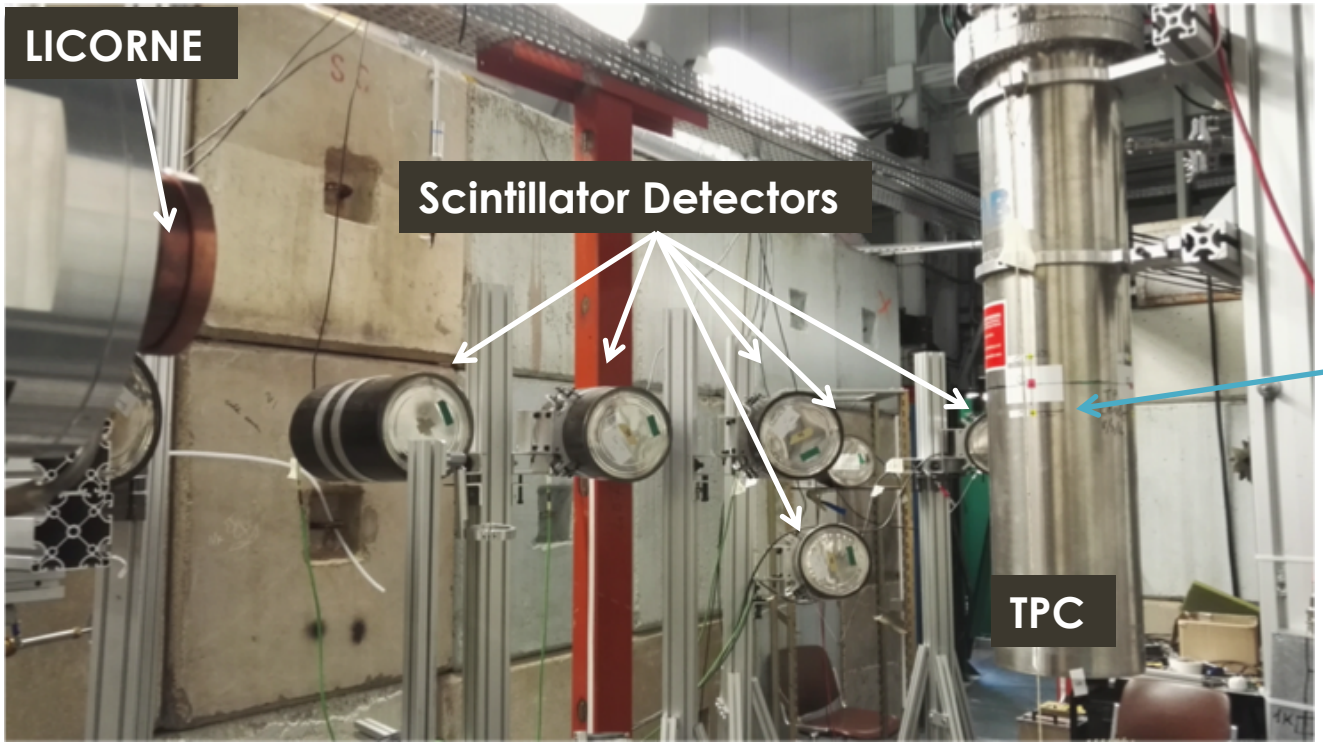
Background-free over more than 530 days!

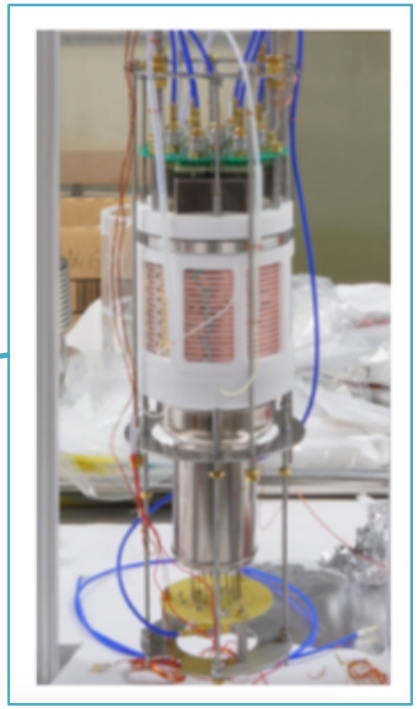
ARIS @ IPNO

LICORNE source: **inverted ^{7}Li(p,n)^{7}Be** reaction

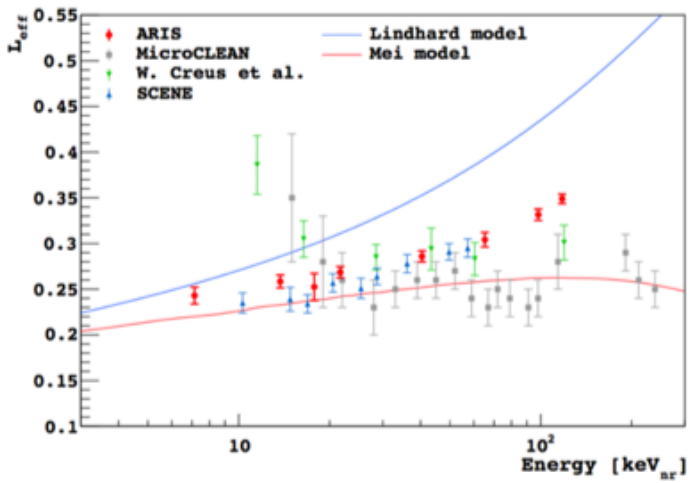
- ☑ Pulsed (1.5 ns width)
- ☑ Monochromatic: <6% (μ~1450 keV σ~85 keV)
- ☑ Collimated: < 2 degrees
- ☑ Correlated 478 keV gammas: ER calibration





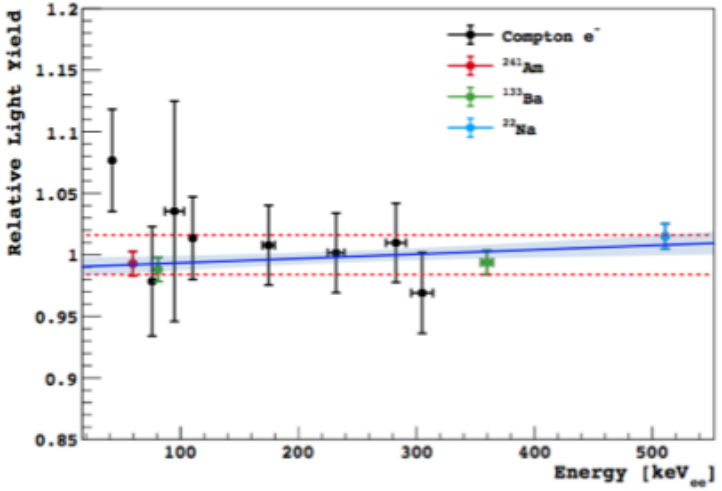


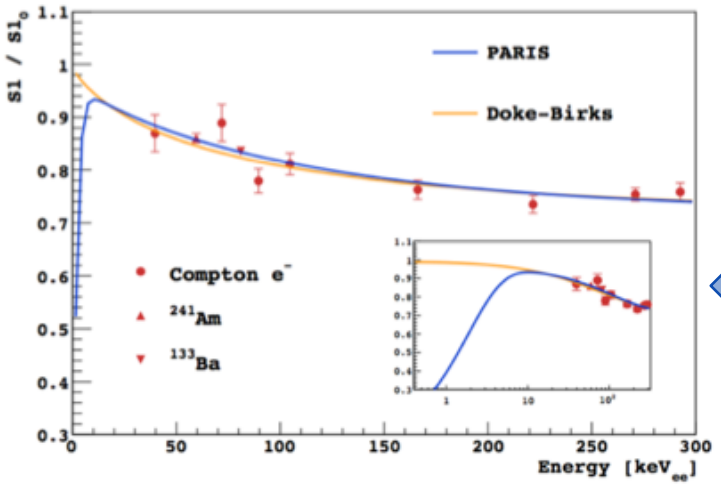
ARIS Results



Most accurate measurement of the **quenching** effect: **crucial for the low-mass analysis**

Best constraint on **linearity** of LAr response to ER at field-off

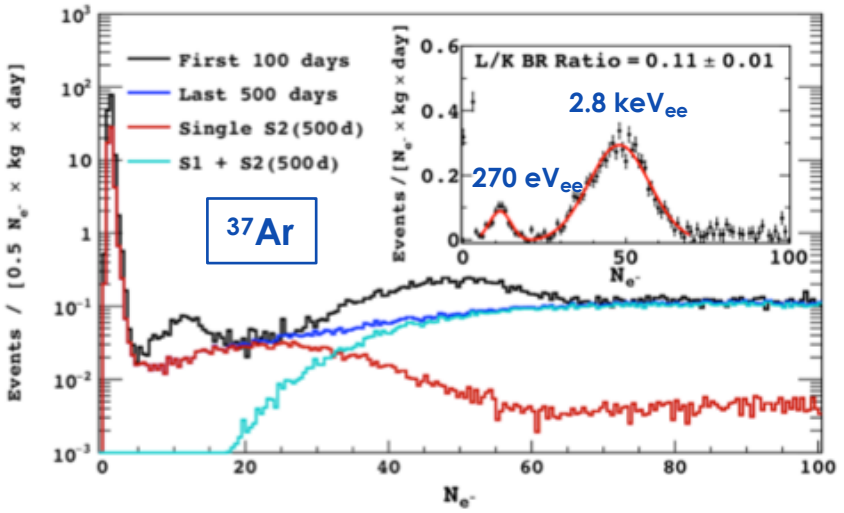


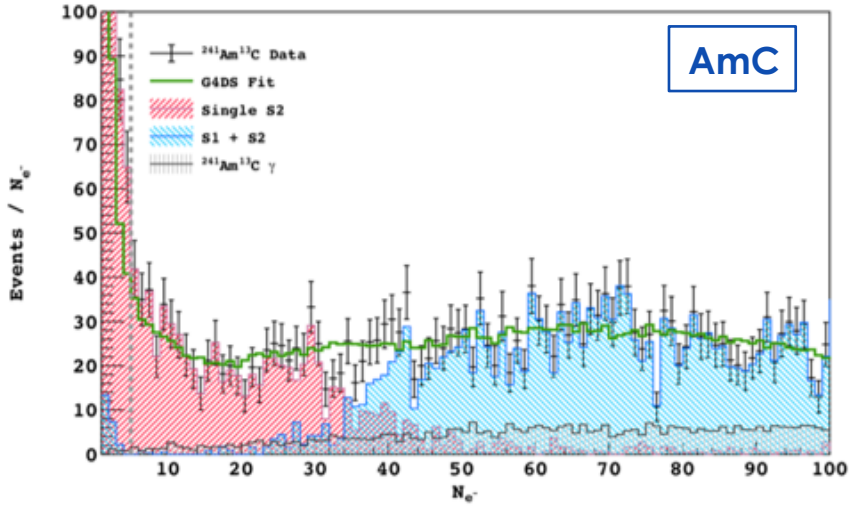


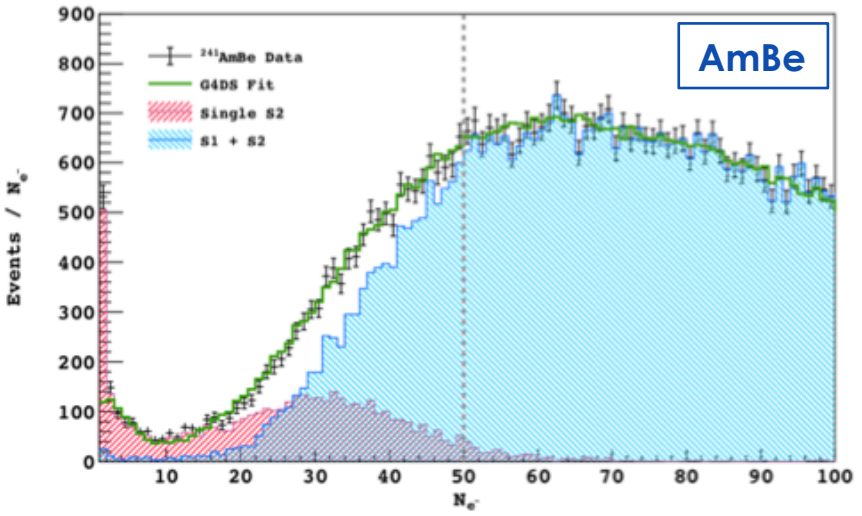
Excellent agreement with the **PARIS** model

Low Mass: ER/NR Response

- ☑ **100%** trigger efficiency at ~1.5 e^-
- ☑ Analysis threshold at 4 e^-: **~100 eV** or ~600 eVnr
- ☑ ER calibration with **^{37}Ar**: 270 eV and 2.8 keV
- ☑ NR calibration with ***in situ*** AmC and AmBe neutron sources
- ☑ Beam experiment results (**ARIS** + SCENE)

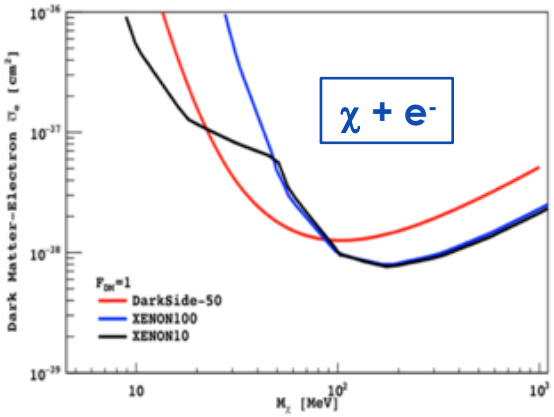


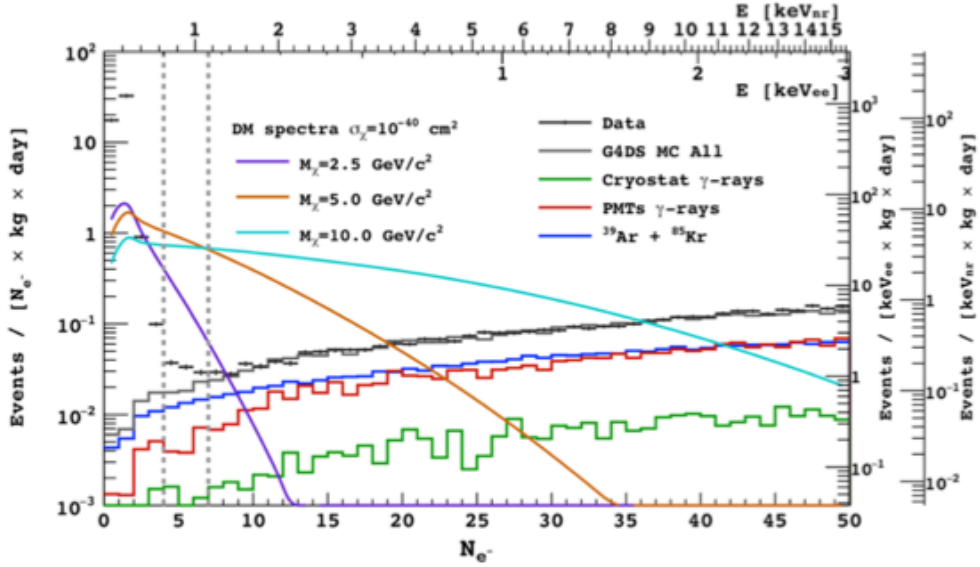


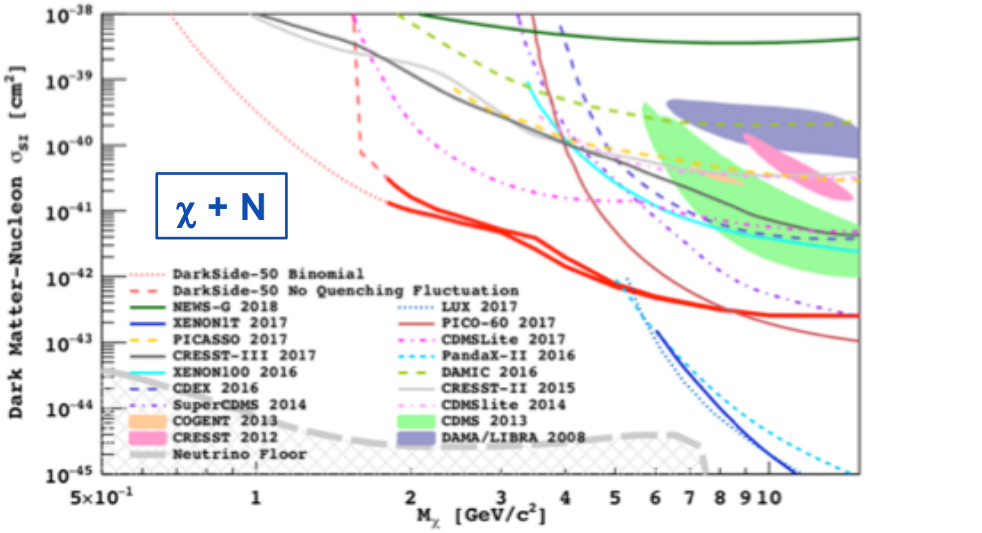


Low-Mass: Best Limit

- ☑ **Background model** simulated with G4DS, extrapolated from the high energy range
- ☑ **Excellent agreement** down to 7 electrons and excess between 4 and 7 electrons conservatively attributed to DM
- ☑ **Best limits to WIMPs-nucleus <6 GeV/c²** limited at 1.8 GeV/c² because of the unknown quenching fluctuation model
- ☑ Improved limits in the **WIMP-electron scattering** assuming heavy mediator





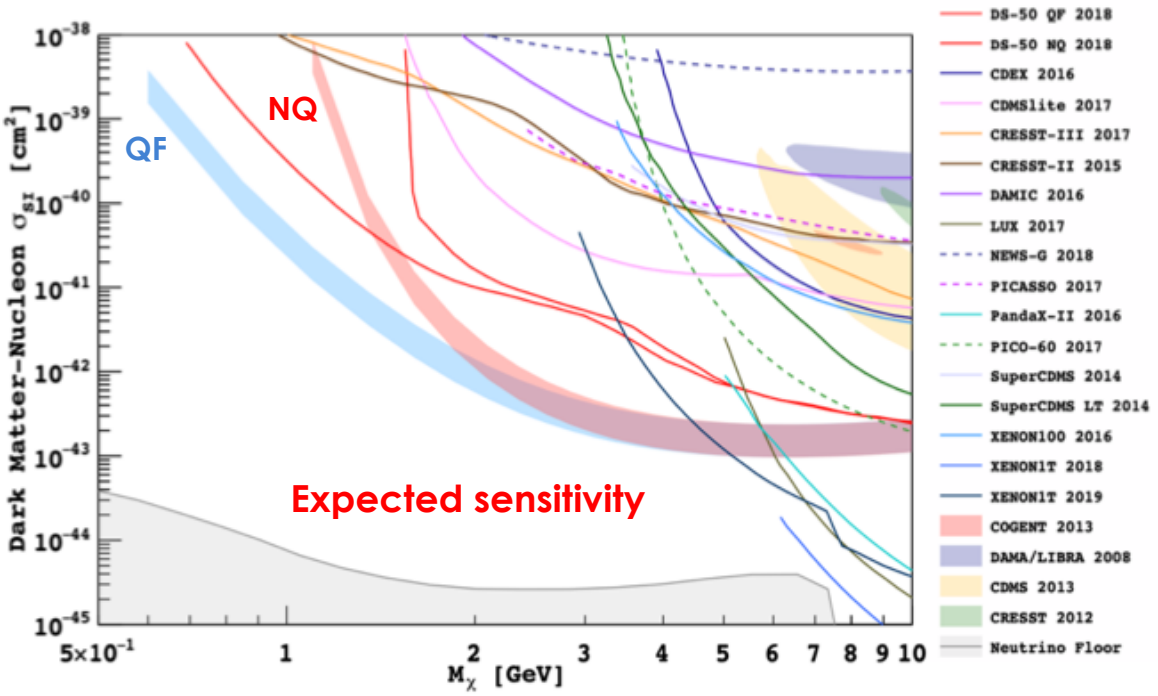


Low-Mass: new analysis framework

Limits with:
- HistFactory
- Bayesian
- Yellin (in progress)

Models:
- WIMP – nucleus interactions
- WIMP – electron interactions
- Migdal effect
- Modulations
- Solar and galactic axions via axio-electric effect

DS50:
- New ER calibration
- New NR calibration
- New background model from screening materials
- New detector response
- New data selection
- 50% more statistics

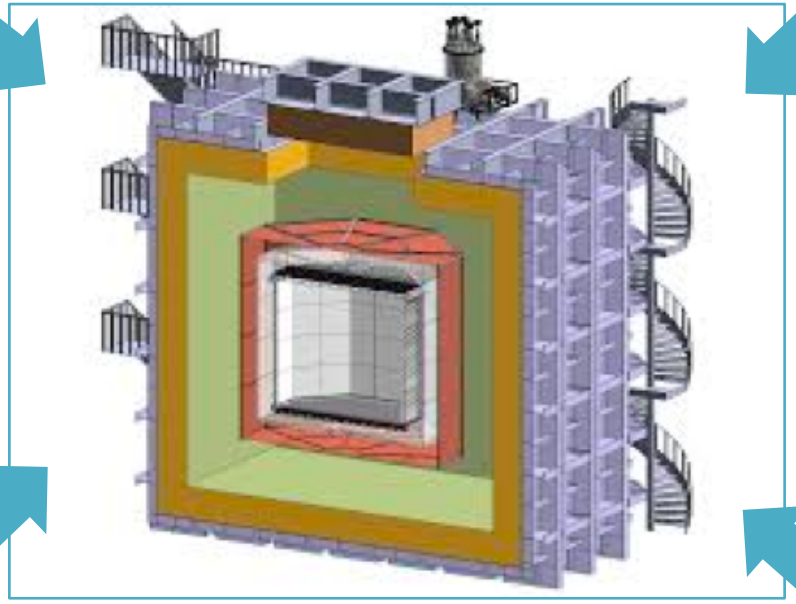


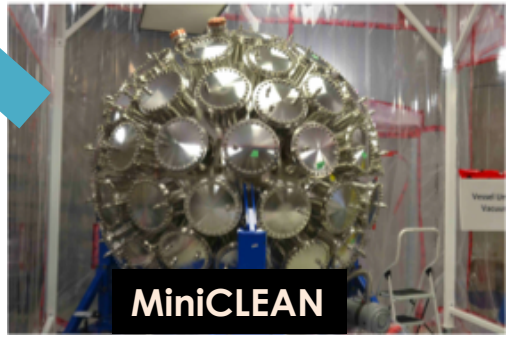
3 papers expected in 2020:
- Low-energy calibration (down to ~75 eVee)
- New low-mass limits
- New "exotic" limits

Next generation (DS-Proto/DS-20k/ARGO):
- Ready to evaluate sensitivities for each model

The Global Argon Dark Matter Collaboration

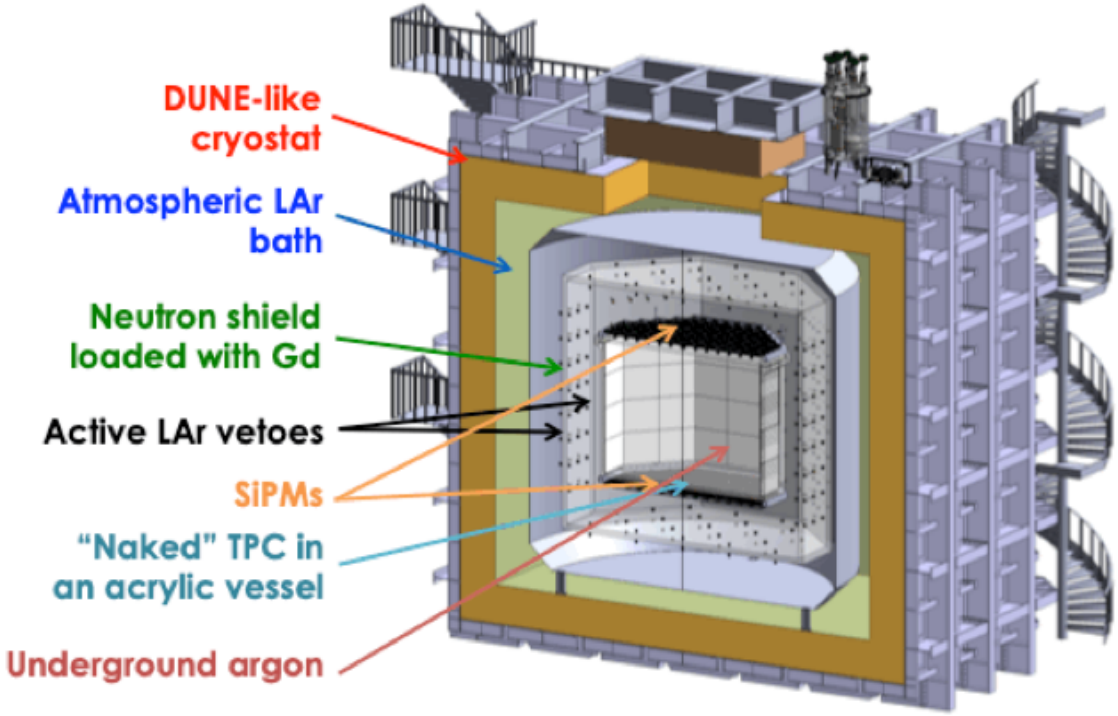
DarkSide-20k





~450 scientists
~70 institutes
+ Neutrino Platform

Design for a large mass bg-free LAr TPC



TPC: cryostat + teflon vessel => **only acrylic vessel**

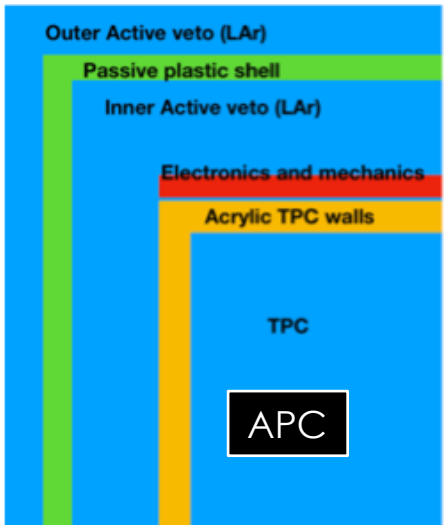
- ☑ Almost doubled the target mass (no UAr buffer): ~35 tonnes
- ☑ Removed cryostat, among the main sources of radiogenic neutrons

Photo-sensors: ~**15 m^2 of SiPMs**

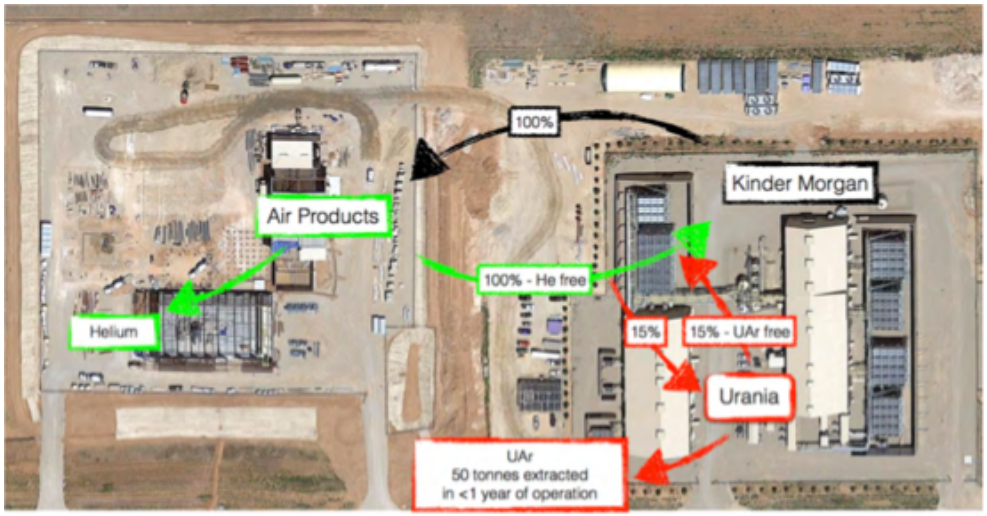
- ☑ **Radiopure** and limited amount of material
- ☑ High photodetection **efficiency**

Vetoes: **LAr bath + moderator in acrylic loaded with Gd**

- ☑ **Neutron veto conceptual design by APC&LPNHE**
- ☑ **DUNE-like cryostat** (GTT patent)
- ☑ CERN Neutrino Platform technical support
- ☑ No organic scintillators



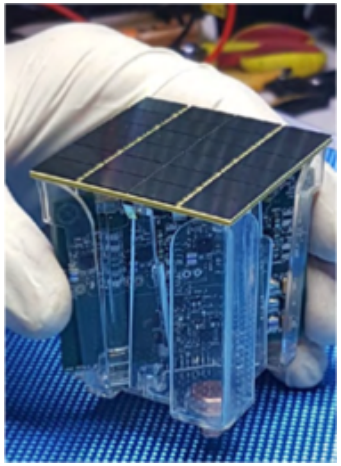
Underground/Depleted Argon

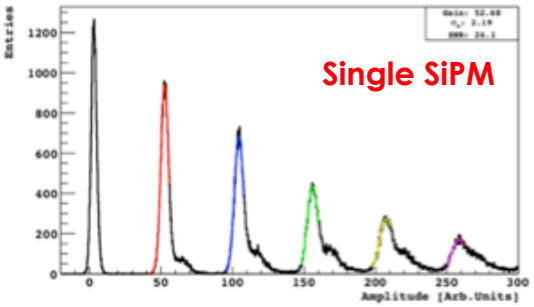


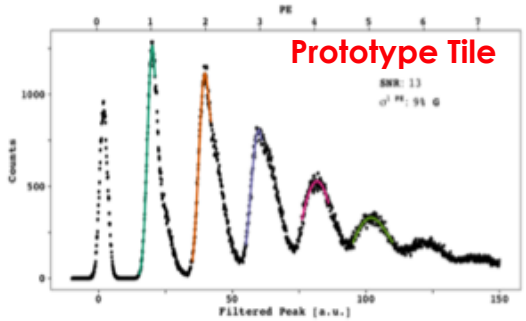
FBK NUV-HD SiPM

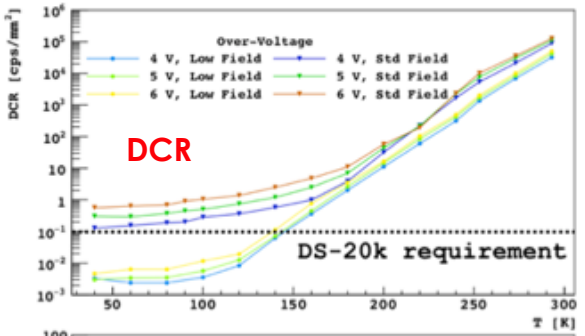
- ☑ Strict collaboration with Fondazione Bruno Kessler (**FBK**): development of specific SiPM for LAr (50 PDM under way)
- ☑ The FBK technology on transfer to **LFoundry** for mass production (starting April 2019)
- ☑ Packaging of 240,000 SiPMs at **NOA**, a facility funded at LNGS

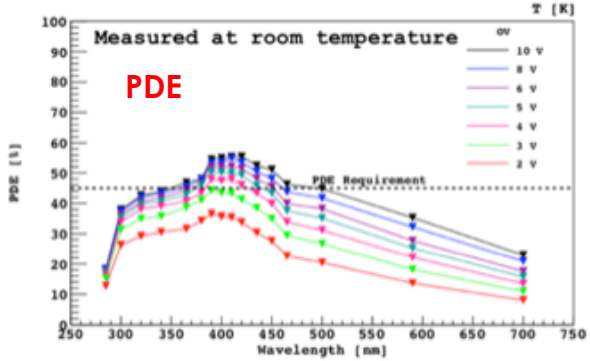
	DS-20k requirement	SiPM tile (PDM)	
Surface	5x5cm²	24cm² prototype 25cm² final PDM	✓
Power dissipation	<250mW	~170mW	✓
PDE	>40%	50% · ε_{geom} = 45%	✓
Noise Rate	<0.1cps/mm²	0.004cps/mm²	✓
Time Resolution	O(10ns)	16ns	✓
Dynamic Range	>50	~100	✓



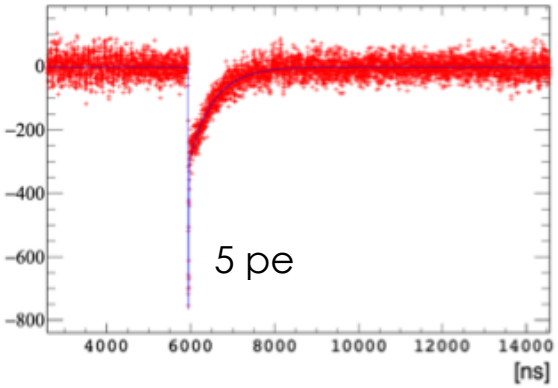






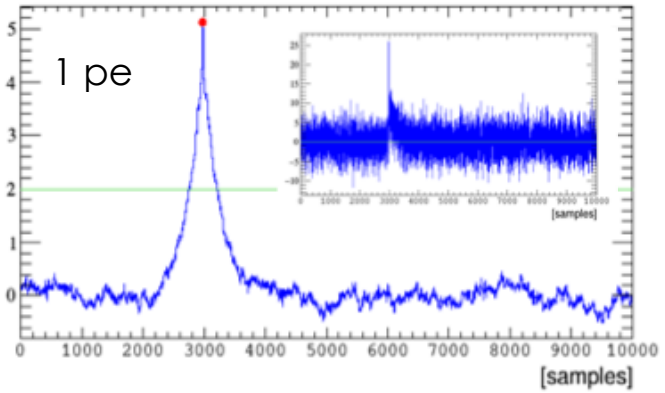


Data Reconstruction

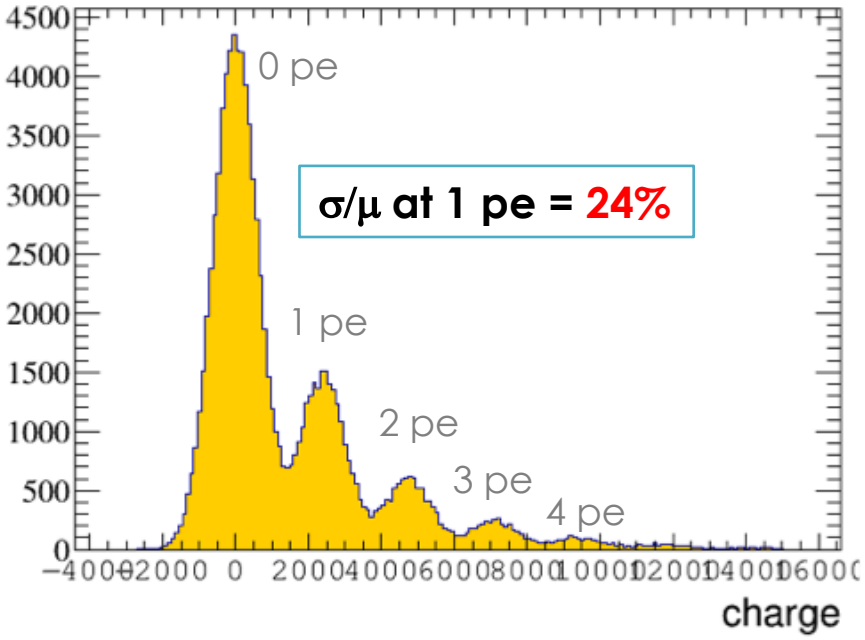


Matched filter

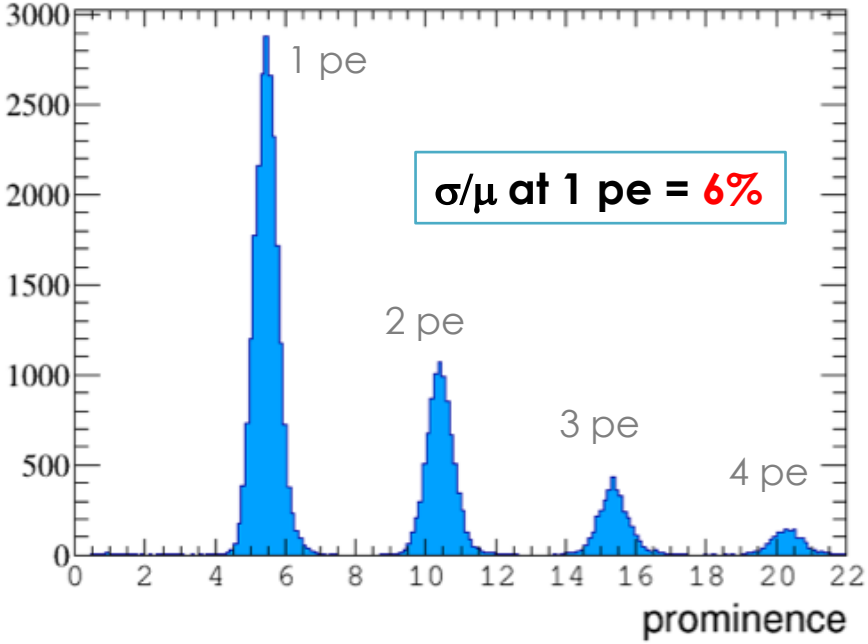
Sigma = 7.5 ns
Tau Slow = 575 ns
Slow component = 94%



Charge Integration

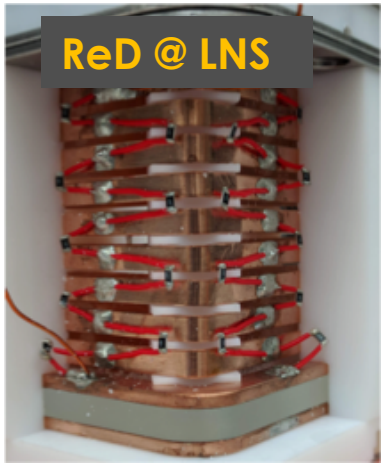


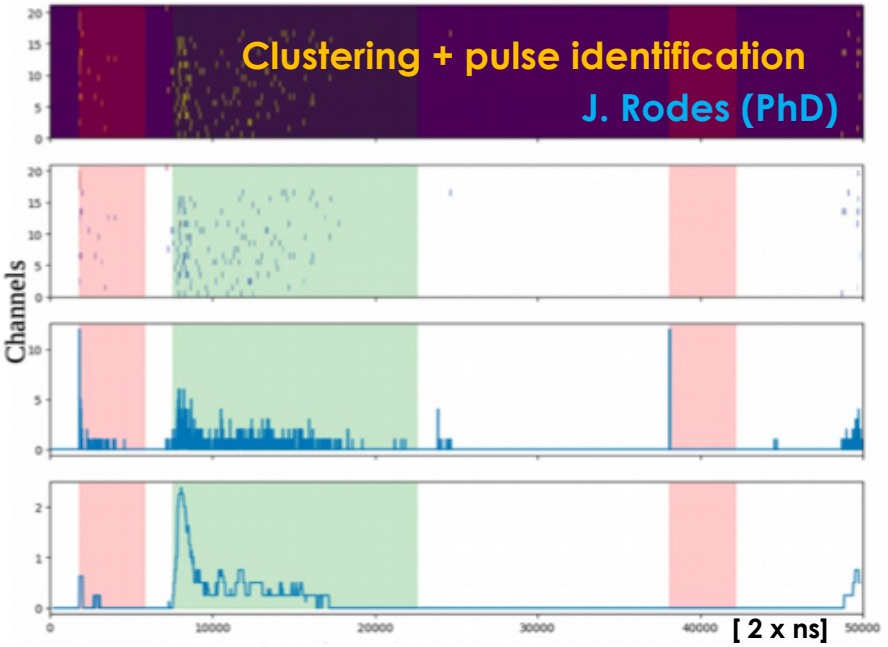
Filtering

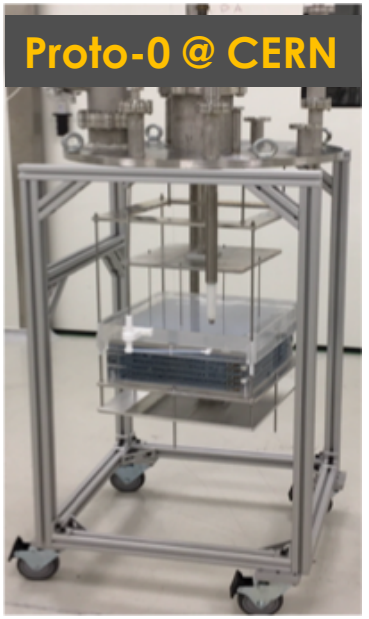


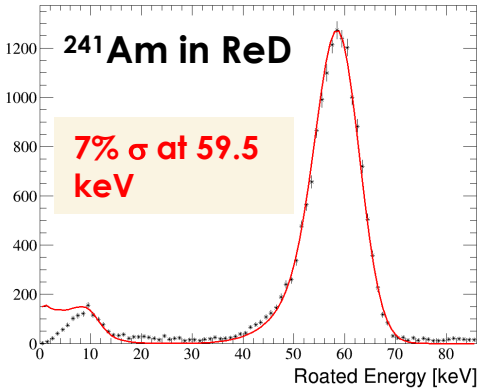
Offline

Offline software reconstruction for **ReD** => **PROTO-0** => **PROTO-1** => **DS-20k**







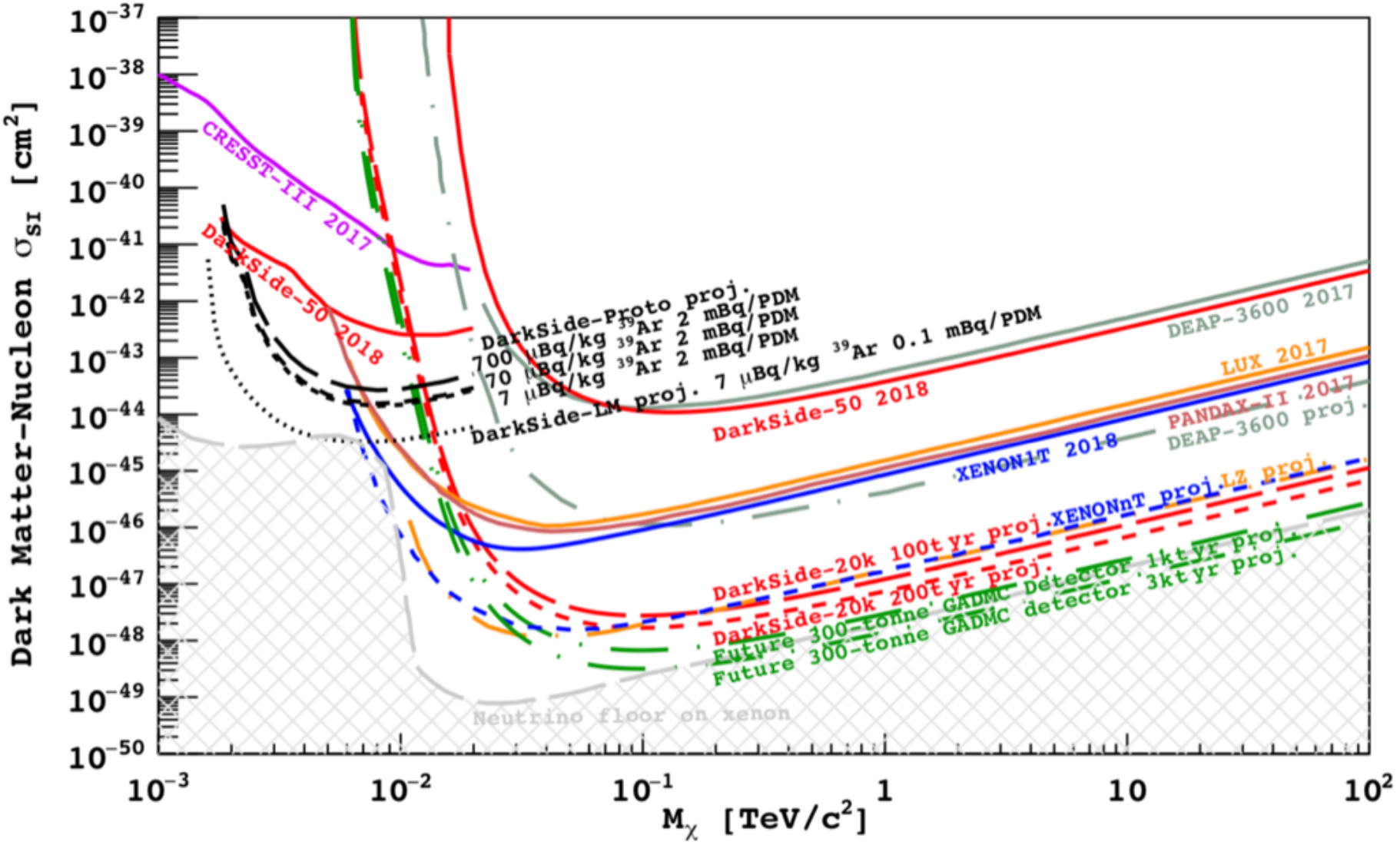


Successful reconstruction but need optimization in CPU time

New request for adapting this approach to the "online"

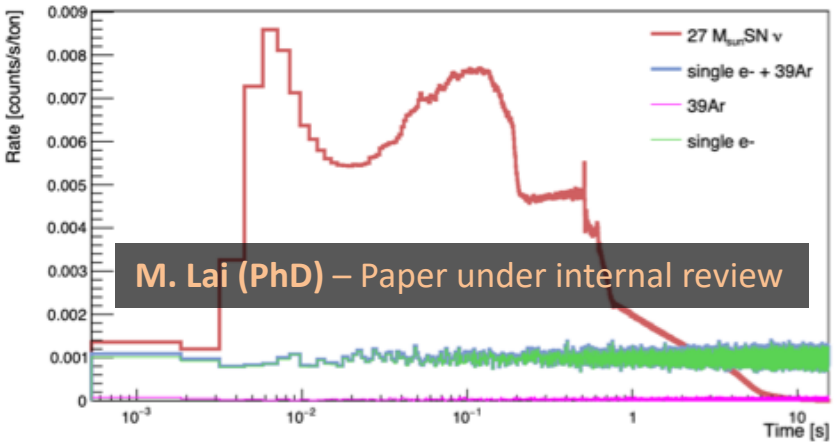
Big effort in computing for handling 8,000 channels in DS-20k

Toward the Neutrino Floor

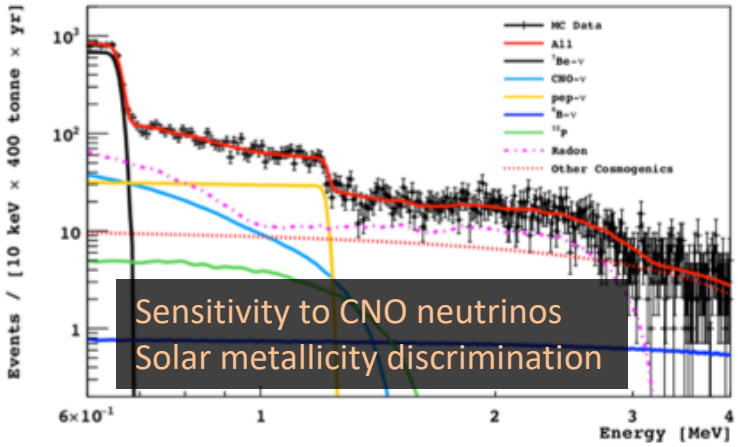


APC DarkSide program beyond dark matter

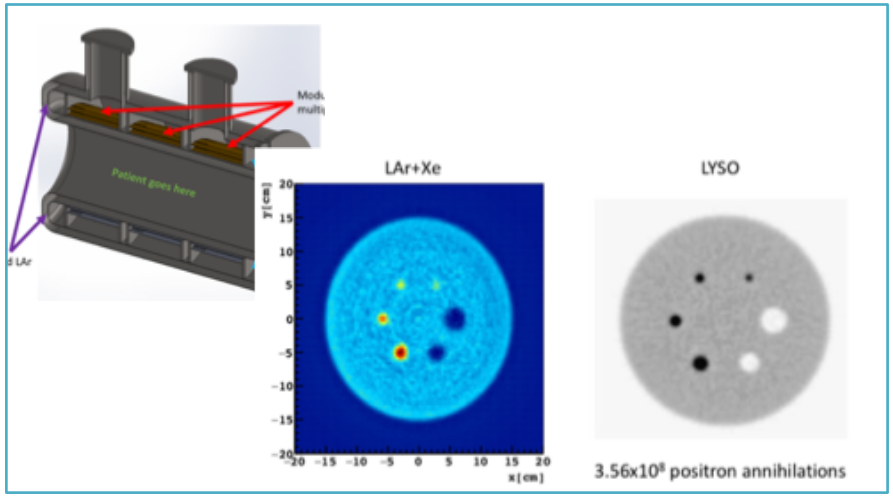
Supernova neutrinos via coherent scattering



Solar neutrino with ARGO



PET based on LAr + O(ppm) Xe



LAr + 5-10% ^{136}Xe: 0νββ

- Radon suppression
- Low temperature => SiPM
- Cryogenic veto => material minimization
- Xe acts as wavelength shifter => no need of TPB
- how to dissolve Xe at 20% molar fraction? => MINES ParisTech / CPT

Conclusions and Prospects

DarkSide

- ☑ **Background-free** experiment for high mass WIMP thanks to pulse shape discrimination in S1 (unique to LAr)
- ☑ **Best limit** in the low mass 1.8-6 GeV window
- ☑ Strong WIMP **discovery potential** in the next decade (from 1 GeV to 10 TeV)
- ☑ New opportunities also in looking for **low-energy astroparticle and medical applications**
- ☑ Potential **synergies with DUNE**: astroparticle physics, cryostat and cryogenics, optical simulations, photo-collection efficiency, calibrations