Direct WIMP search with DarkSide

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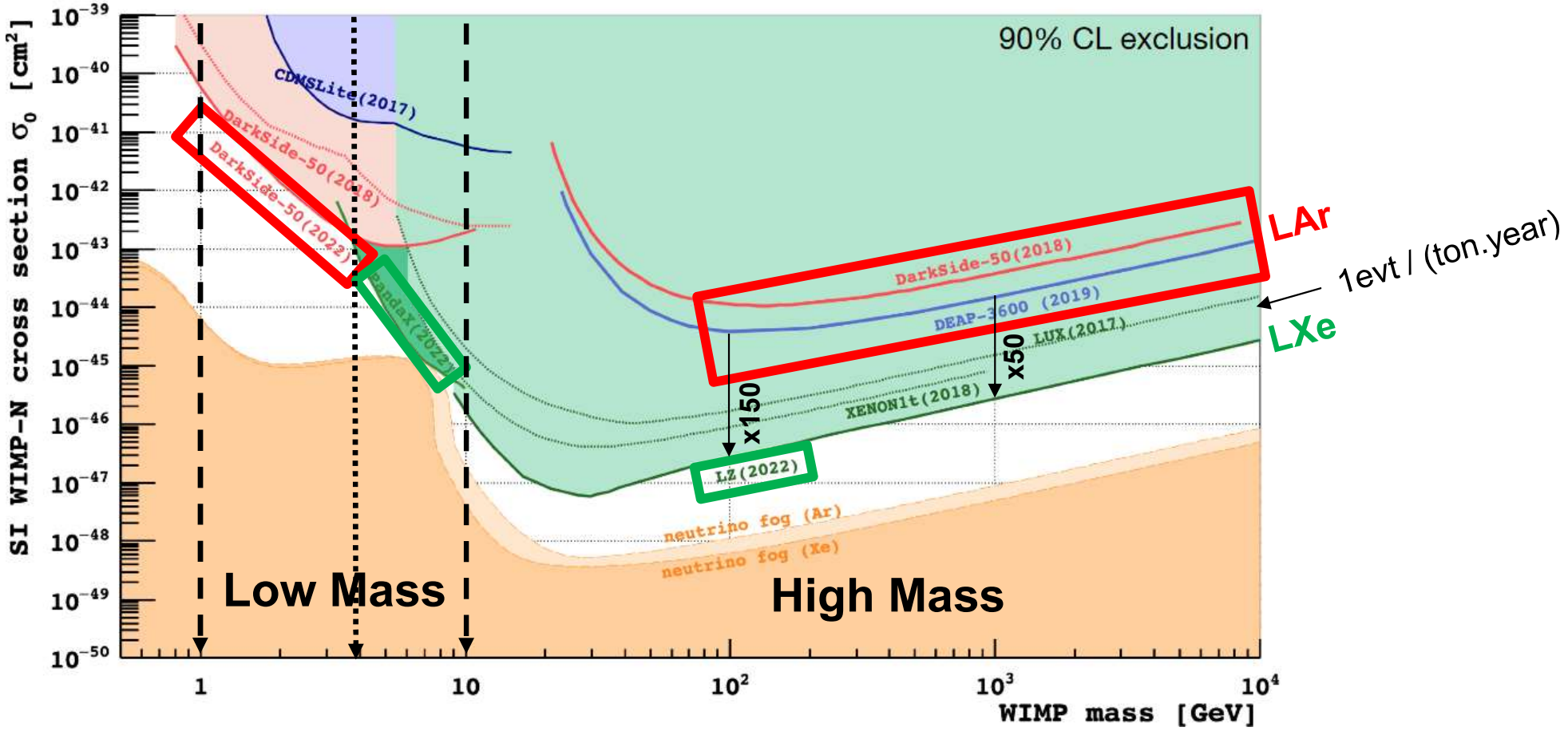
On Behalf of the DarkSide IN2P3 team

1- Scientific context
2- Bright sides of DarkSide
3- Status of DarkSide-20k
4- IN2P3 contributions and resources
5- Conclusions

Conseil scientifique IN2P3, 23 octobre 2023

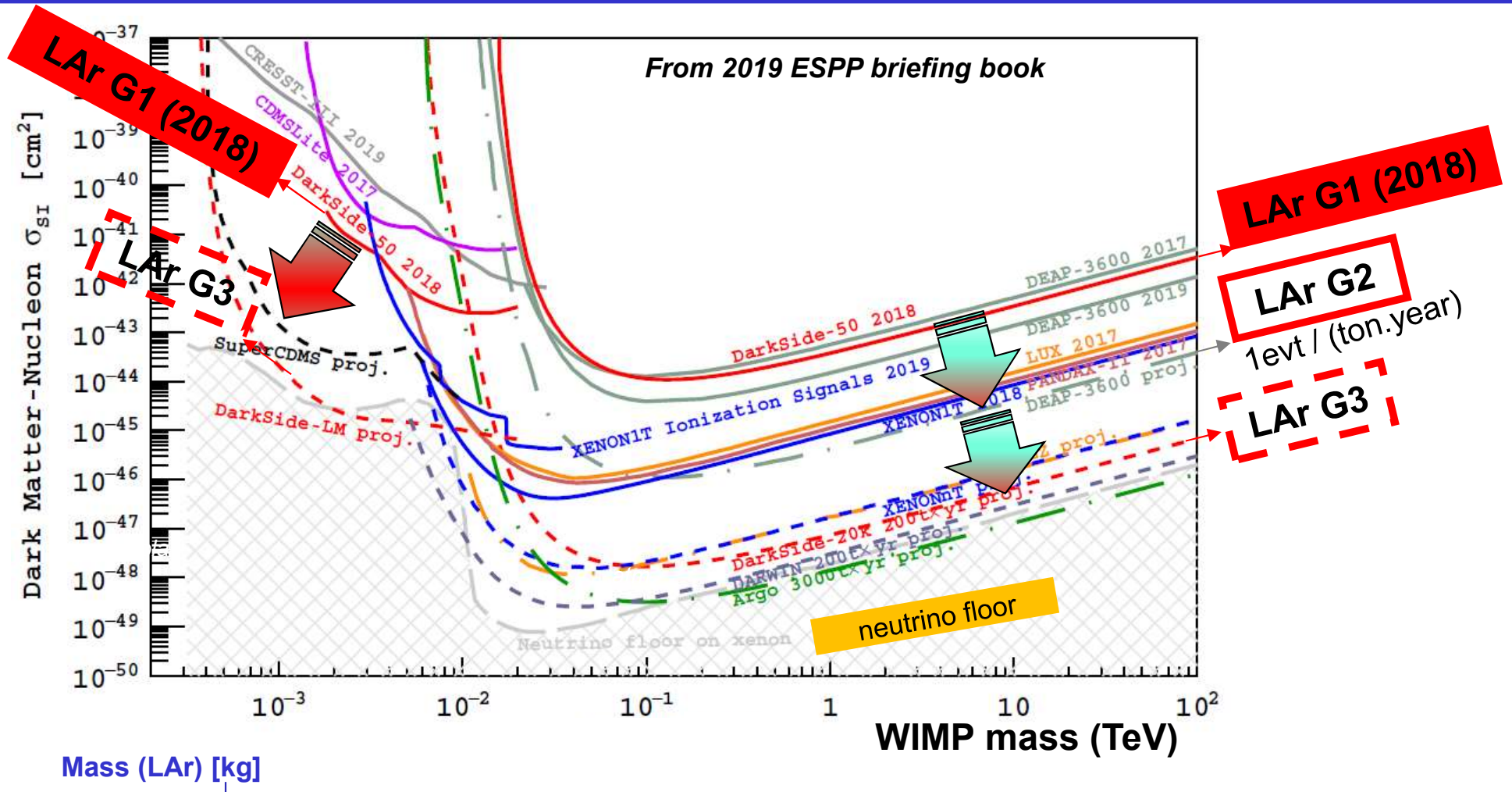
Status of WIMP search

- Spin-independent (SI) WIMP-nucleon interaction



Xe/LAr dual phase TPCs lead the WIMP search from 1 GeV → 10 TeV

Status WIMP search with LAr



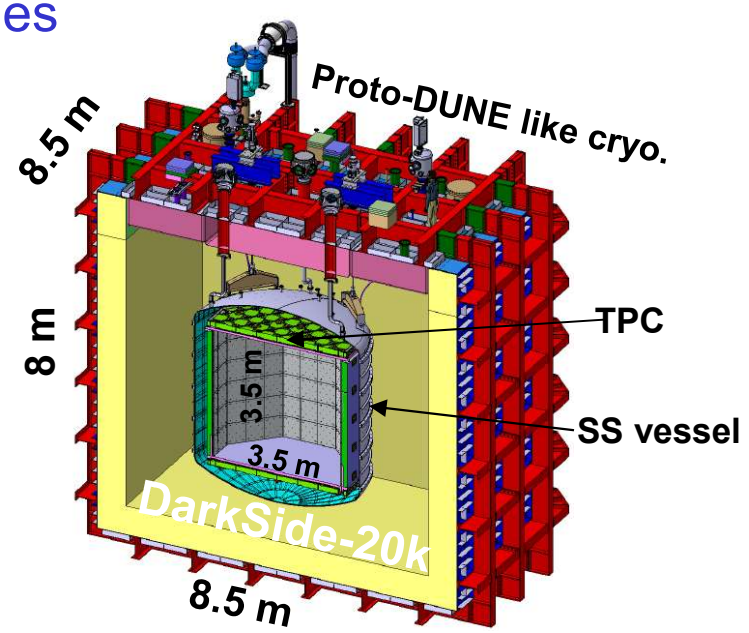
Mass (LAr) [kg]

- ✓ **G1=DarkSide-50** : 2 runs **2013-14, 15-17** *[low+high mass]* → Publications 2015, 2018, 2023
- ✓ **G2=DEAP-3600** : 2 runs **2016-20**, 24-26 *[high mass]* → Publications 2017, 2019
- ✓ **G3=DarkSide-20k**: Started construction in 2022 → Start data taking in 2027

Bright sides of DarkSide (1)

❑ LAr Technology is scalable and mature

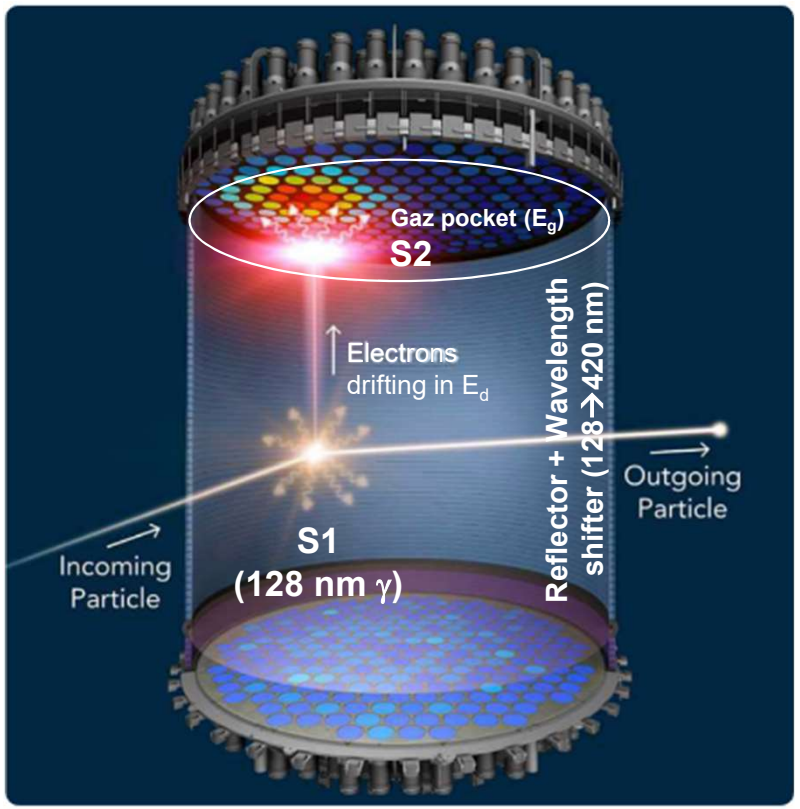
- One world-wide collaboration (GADMC): 300 people
- Funding: Italy (INFN), United States (DOE, NSF), Canada (CFI), UK (STFC)
- DarkSide-20k profit from best G1 and G2 technologies



Lab (fid. data)	LNGS (0.05 ton.year)		SNOLab (10 ton.year)		LNGS (200 ton.year)
TPC target	50 kg purified Ar	x70 →	3.6 t *Atmosph. Ar*	x14 →	50 t purified Ar
TPC wall	*Stainless Steel*		Acrylic		Acrylic
TPC nb ch.	*38 PMT*	x7 →	*255 PMT*	x8 →	200k **SiPM** → 2100 channels
TPC techno	Dual Phase		*Single Phase*		Dual Phase
Veto	*Scint (30 t) + Water (1000 t)* [inner] [outer]		*Water (250 t)*		LAr in vessel (50 t) + **ProtoDUNE** (650 t) [inner] [outer]

Bright sides of DarkSide (2)

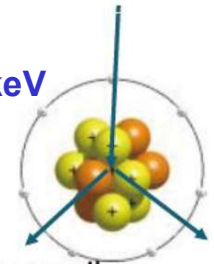
- **DS-20k can be optimized to be ER background free** *(at high WIMP mass)*
  - Combining two signals: prompt **scintillation** (S1) and delayed **ionization** (S2)



E_d=200 V/cm [E_g~3kV/cm]

GeV WIMP

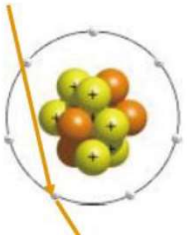
E_{NR}=1-100 keV



WIMP signal

Nuclear Recoil (NR):
- fast scintillation (6ns)
- few ionization electrons
- large quenching (loss in elastic nuclei collisions)

Gammas / **Electrons**



Electron recoil (ER):
- slow scintillation (1600 ns >>NR)
- many ionization electrons (>NR)
- no quenching (<NR)

ER bkg ≠ WIMP Signal

- ✓ Single scatter
- ✓ Fiducial volume *(r, z)*
- ✓ Use purified argon
- ✓ S2/S1 (ER) >> S2/S1(NR)
- ✓ S1 pulse shape discrimination (PSD)

Bright sides of DarkSide (2)

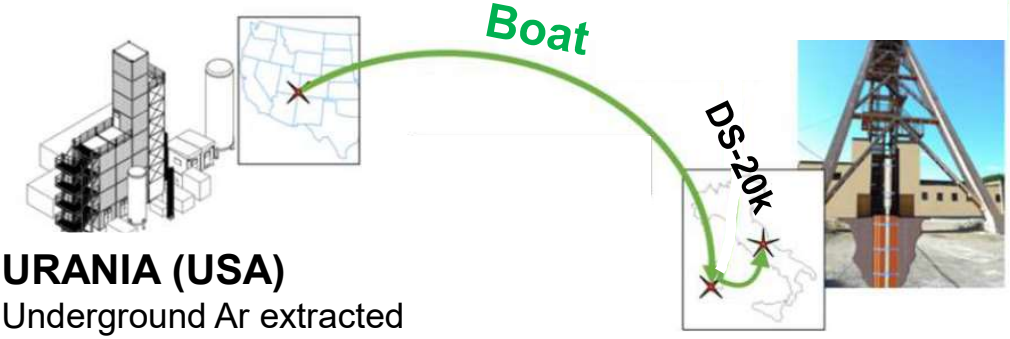
❑ DS-20k: ER background removal strategy

- Fiducial volume, purified argon *(depleted in ^{39}Ar cosmogenic argon)*, S2/S1, S1 PSD

r-30cm, z-70cm → 20 t Ar — <1 mBq/kg — β, $T_{1/2}$=269 year, ~1 Bq/kg — $R_{ER}=10^3$

^{39}Ar rejection measured **R_{39Ar}= 1.4±0.2 10^3**

PRD **93** (2016) 081101



URANIA (USA)
Underground Ar extracted from a CO2 well in exploitation

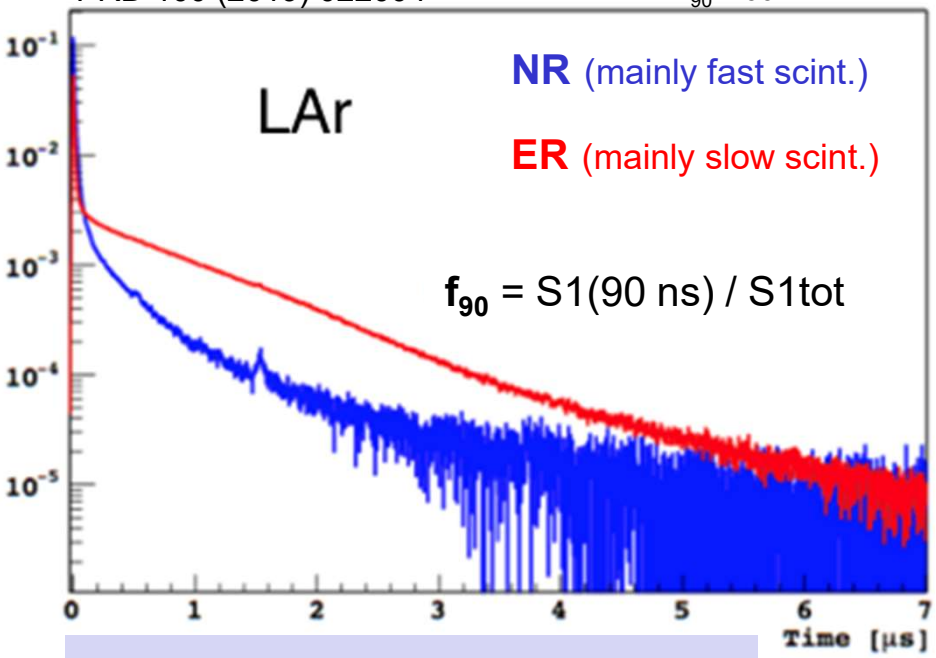
ARIA (Italy)
Cryogenic distillation column

Residual ^{39}Ar activity ~30 Hz in DS-20k TPC

½ of the TPC ER background before PSD

ER rejection measured **$R_{ER}>10^8$ (90% ε_{sig})**

PRD 100 (2019) 022004 — f_{90} > 60%

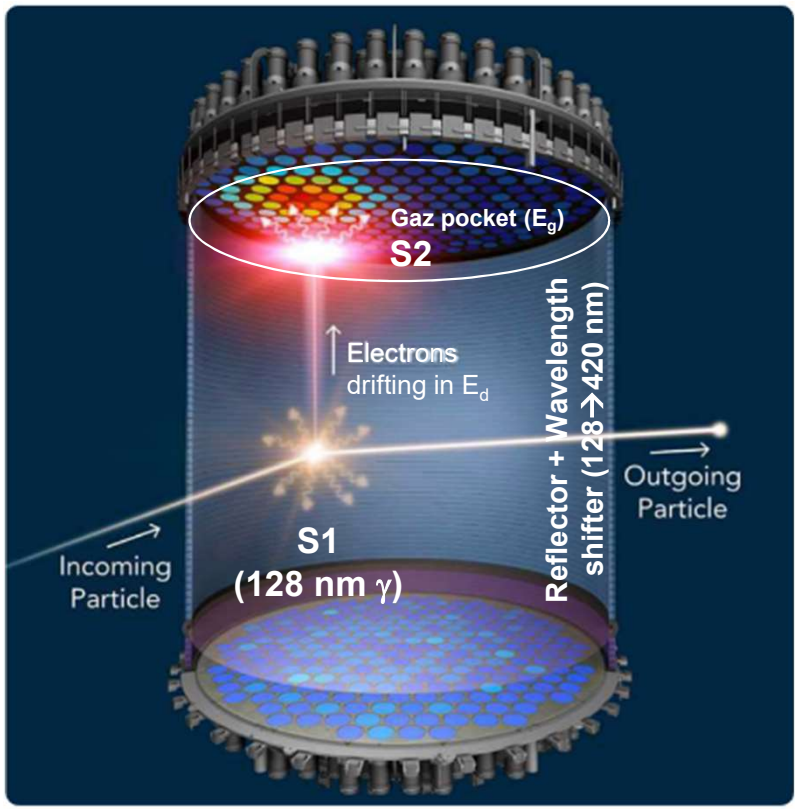


Unique discriminating power
(intrinsic to Ar, not present for Xe)

ER background < 0.1 evt in 10 years of running *(200 ton.year)*

Bright sides of DarkSide (2)

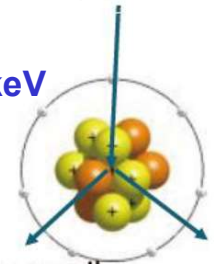
- **DS-20k can be optimized to be NR background free** *(at high WIMP mass)*
  - Combining two signals: prompt **scintillation** (S1) and delayed **ionization** (S2)



E_d=200 V/cm [E_g~3kV/cm]

GeV WIMP

E_{NR}=1-100 keV

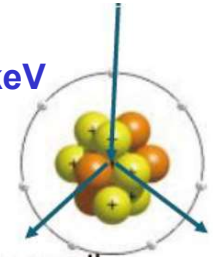


WIMP signal

Nuclear Recoil (NR):
- fast scintillation (6ns)
- few ionization electrons
- large quenching (loss in elastic nuclei collisions)

MeV Neutron

E_{NR}=1-100 keV



Neutron ≠ WIMP Signal

✓ Deep Underground expt.
✓ Material selection + assay
✓ Single scatter
✓ Neutron veto around TPC

Nuclear Recoil (NR):
- fast scintillation
- few ionization electrons
- large quenching

Bright sides of DarkSide (2)

❑ DS-20k: NR background removal strategy

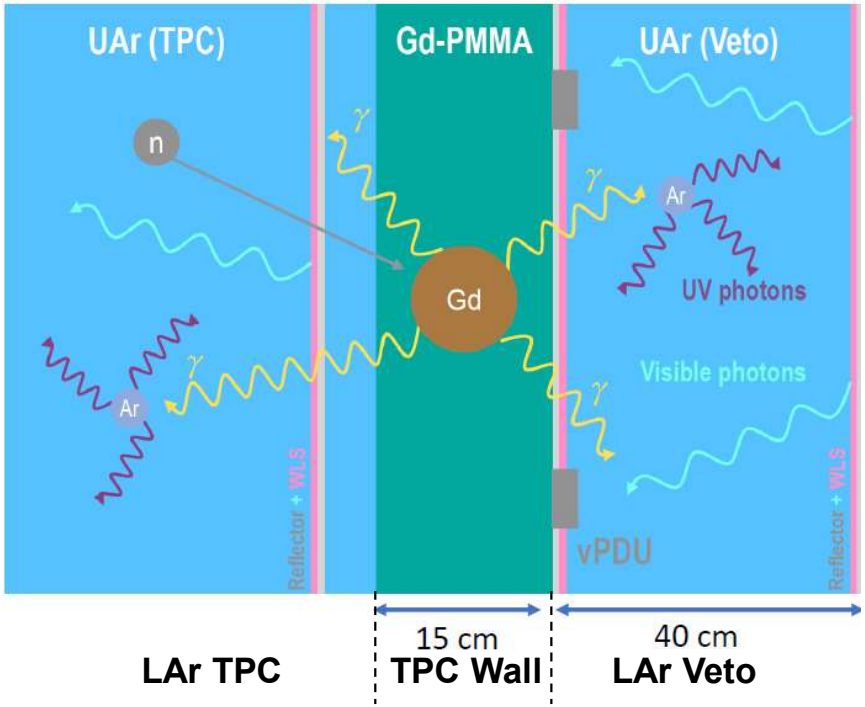
- LNGS, material selection + cleaning + assay, single scatter, neutron veto

< mBq/kg, U+Th activity → $O(10^{-7})$ n / decay, E ~ MeV

^{222}Rn daughters

O(500)

Neutron moderated by **acrylic** and captured by **Gd** (→≤8 MeV γ)



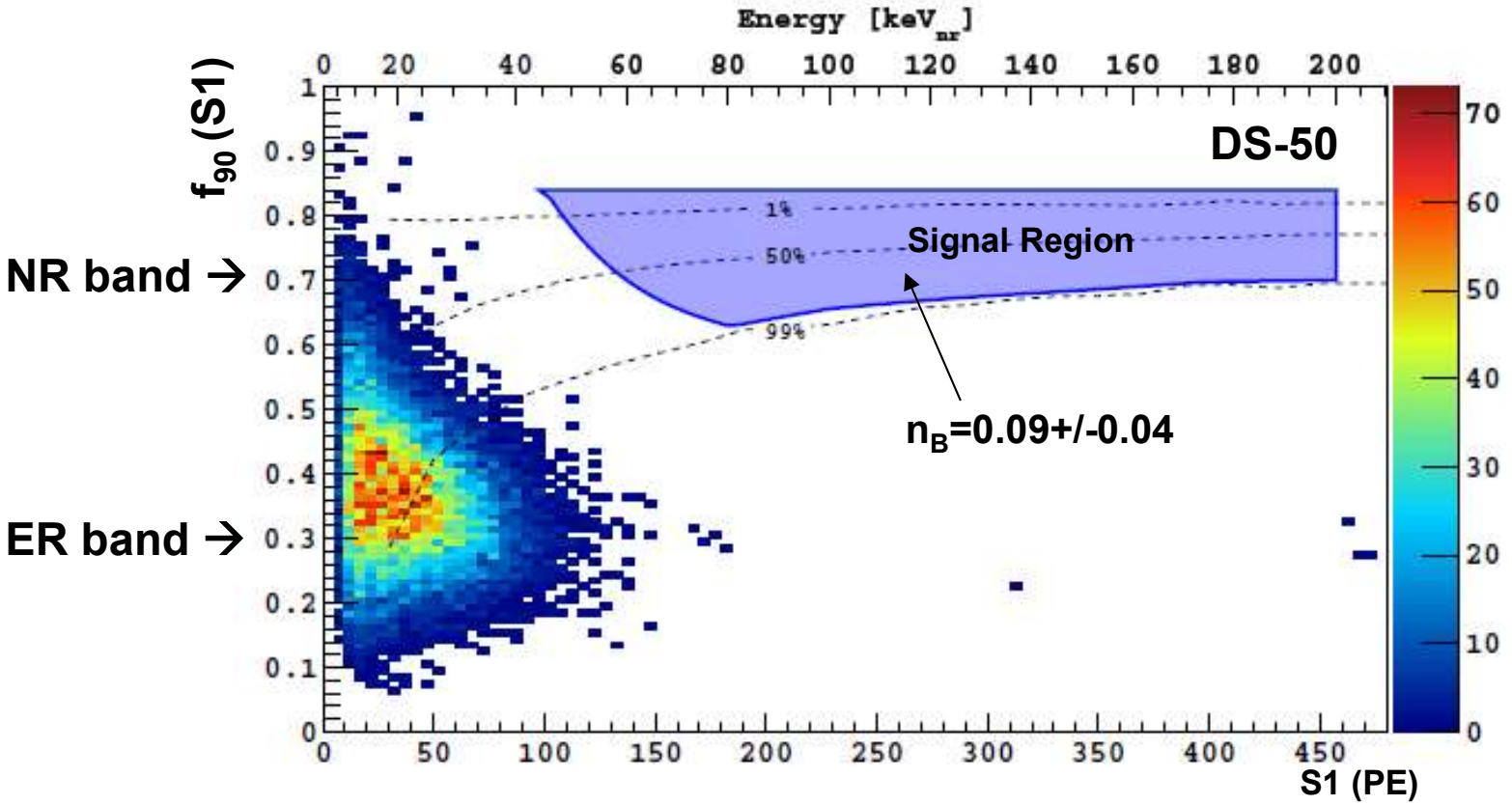
NR background ~0.1 evt in 10 years of running *(200 ton.year)*

Mainly Photo detectors electronics and cryostat

Bright sides of DarkSide (2)

❑ DS-20k: overall background

- DS 50 results validates the strategy with **0.05 ton.year** PRD 98 (2018) 102206
- Confirmed by DEAP3600 with **2.1 ton.year** PRD 100 (2019) 022004



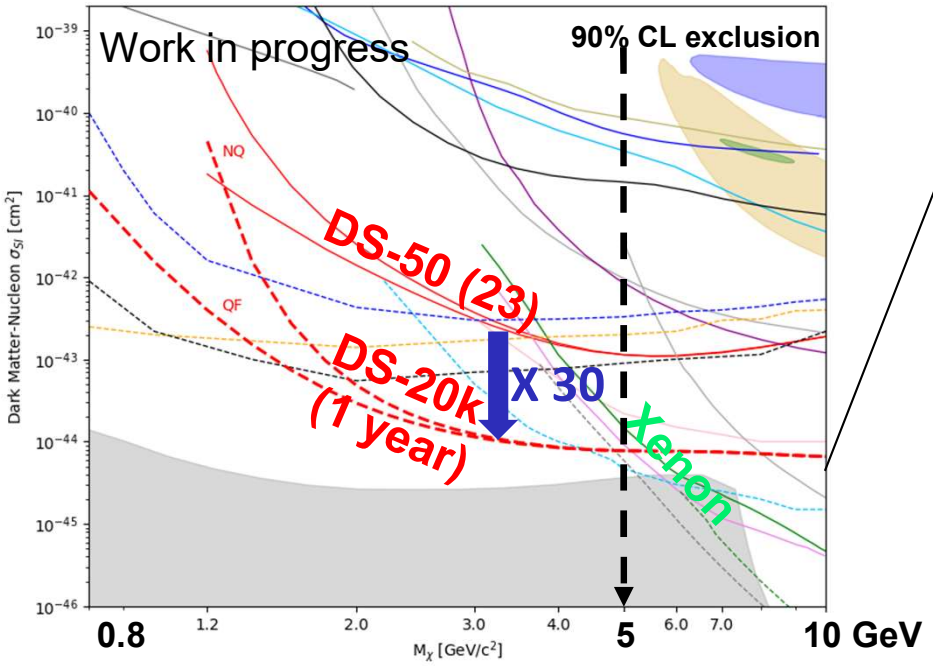
Expect ~0.1 bkg* event in 10 years of running *(200 ton.year)*

** Note: expect ~3 irreducible evts from ν NR*

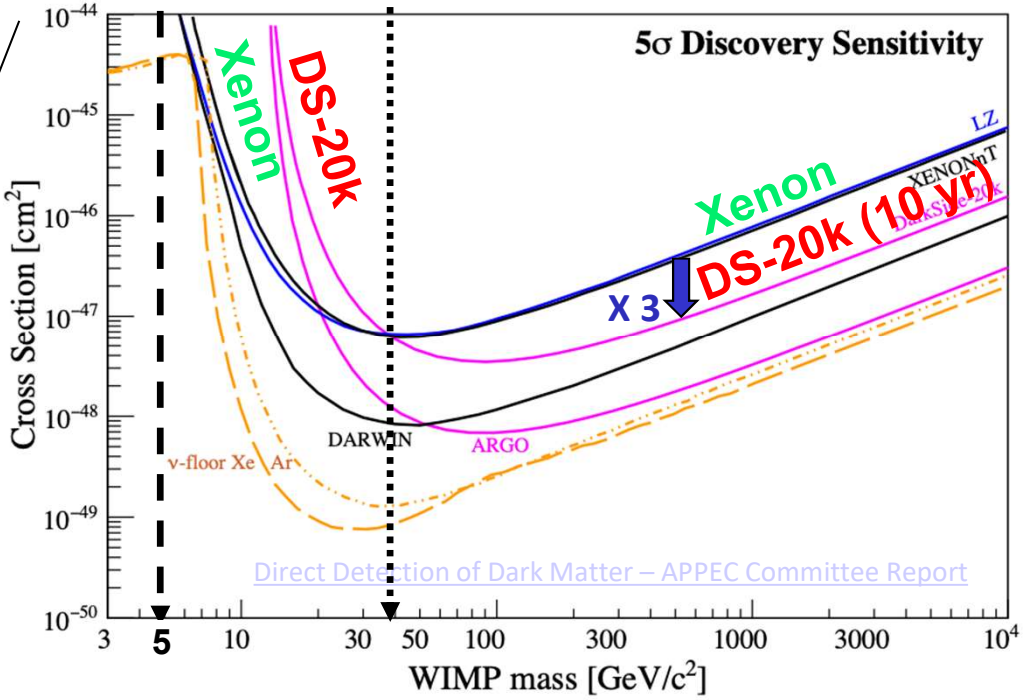
Bright sides of DarkSide (3)

- **Very good sensitivity at low and high mass WIMP**

Low Mass WIMP sensitivity



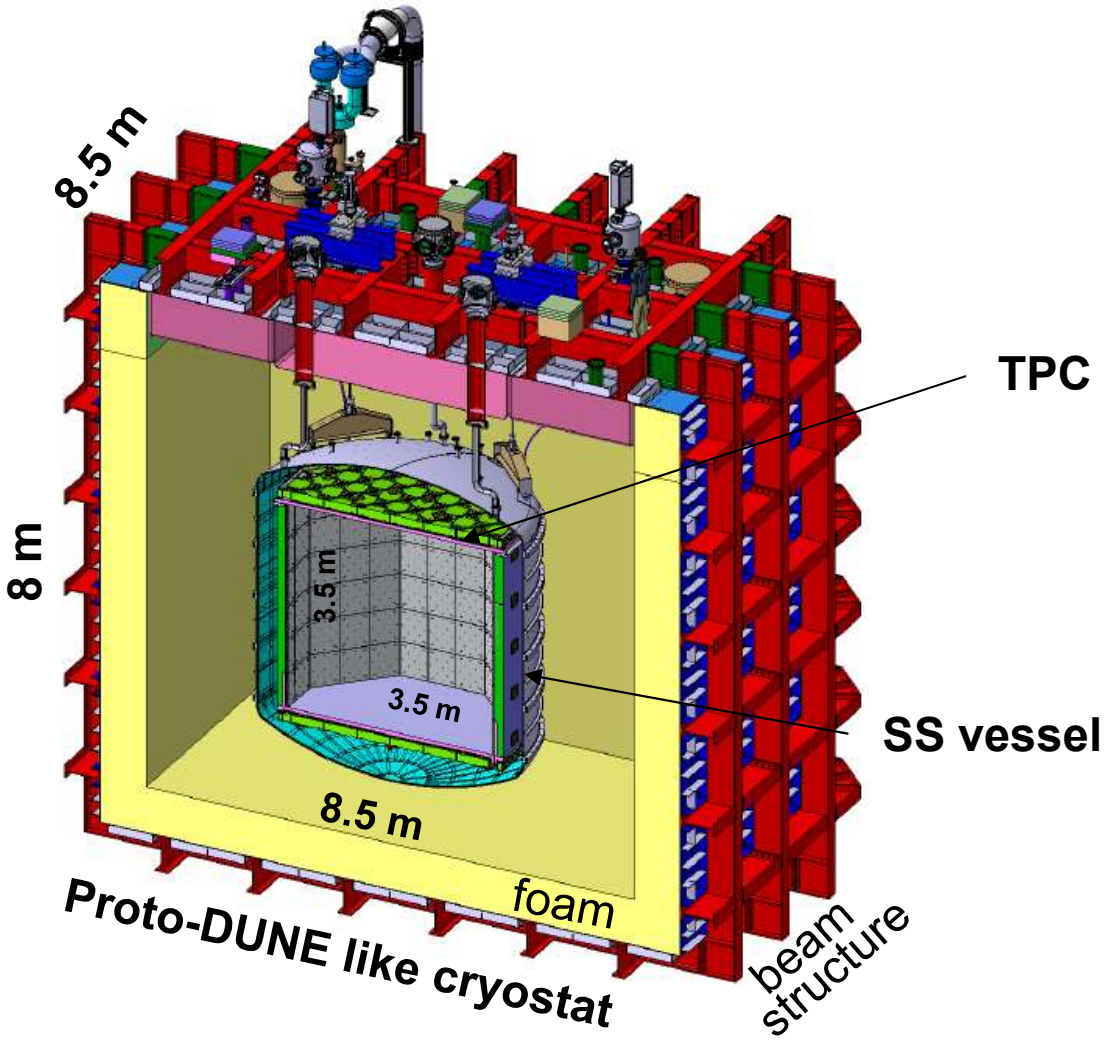
High Mass WIMP discovery potential



DS-20k and Xenon experiments complementary

APPEC 2017 recommendation *: "strategy aimed at realizing worldwide at least one ultimate Dark Matter detector based on xenon (~50 tons) and one based on argon (~300 tons), as advocated by DARWIN and Argo."*

Status of DS-20k

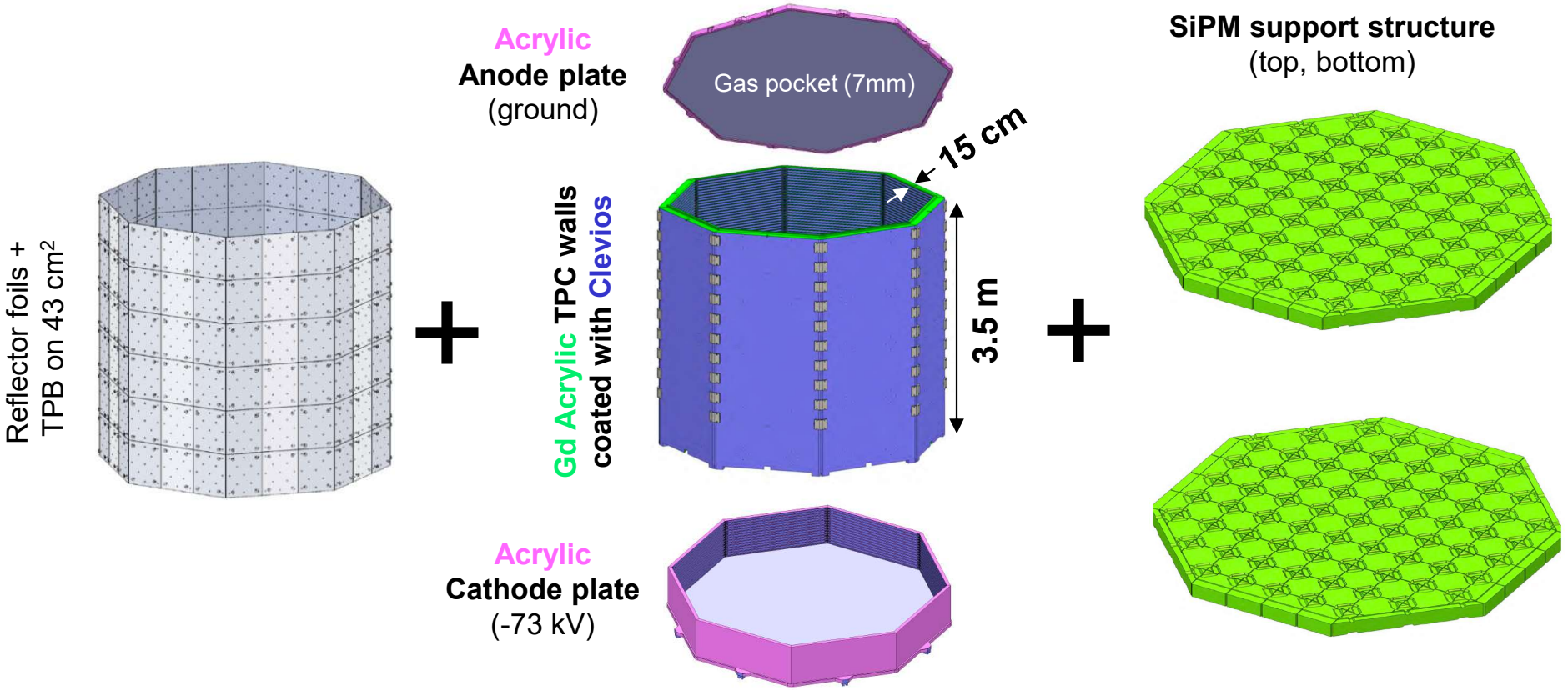


Construction started at LNGS

Status of DS-20k (1/4)

❑ Inner detector design (TPC + veto)

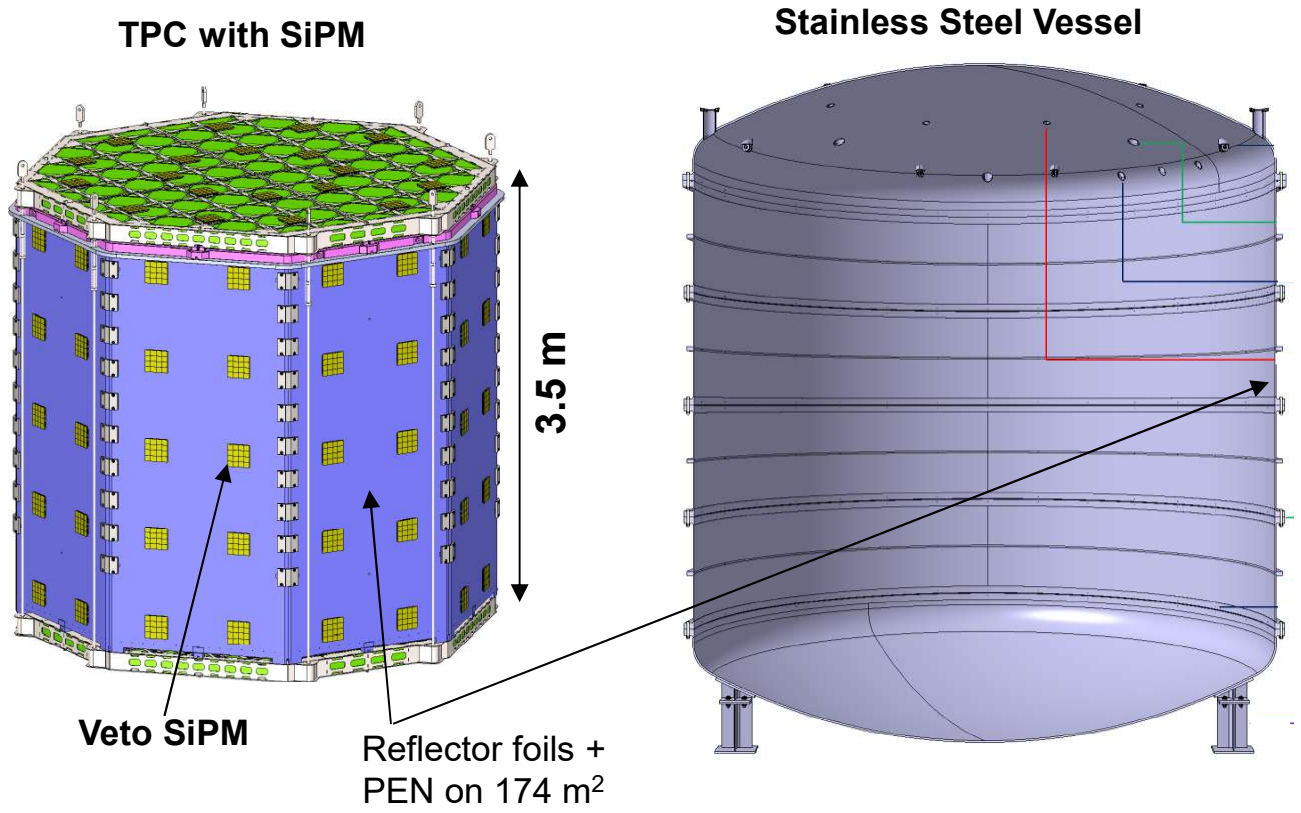
- Compact and simple
  - ✓ Only one passive material to lower the background : 11 tons of **acrylic** **doped with Gd** *(TPC walls, SiPM support structure)* coated with **Clevios** for HV *(TPC walls, anode+cathode plates)*
  - ✓ Add reflector foils (*3M ESR)* and TPB (*128 nm → 420 nm)*



Status of DS-20k (1/4)

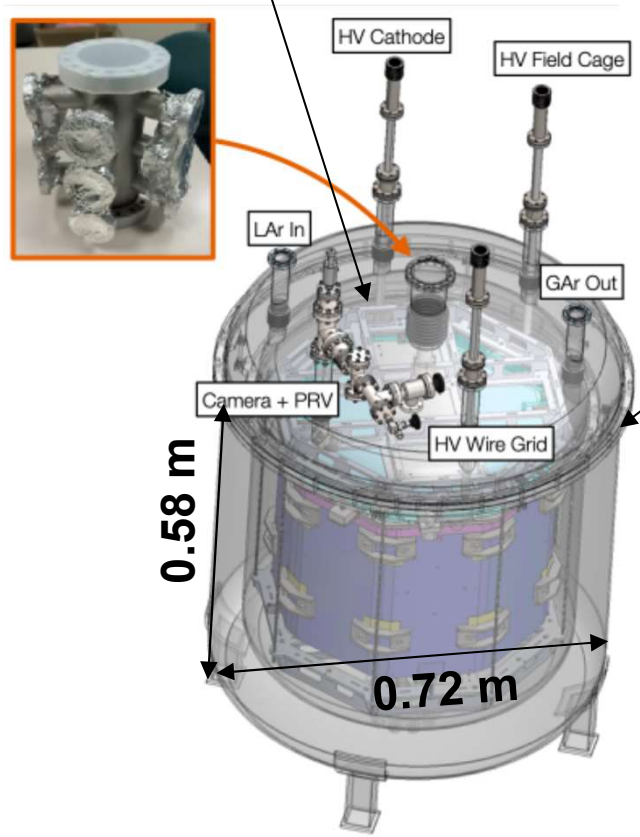
❑ Inner detector design (TPC + veto)

- Compact and simple
  - ✓ Only one passive material: 11 tons of acrylic
  - ✓ TPC – SS vessel gap used for the veto: instrumented with SiPMs



Status of DS-20k (1/4)

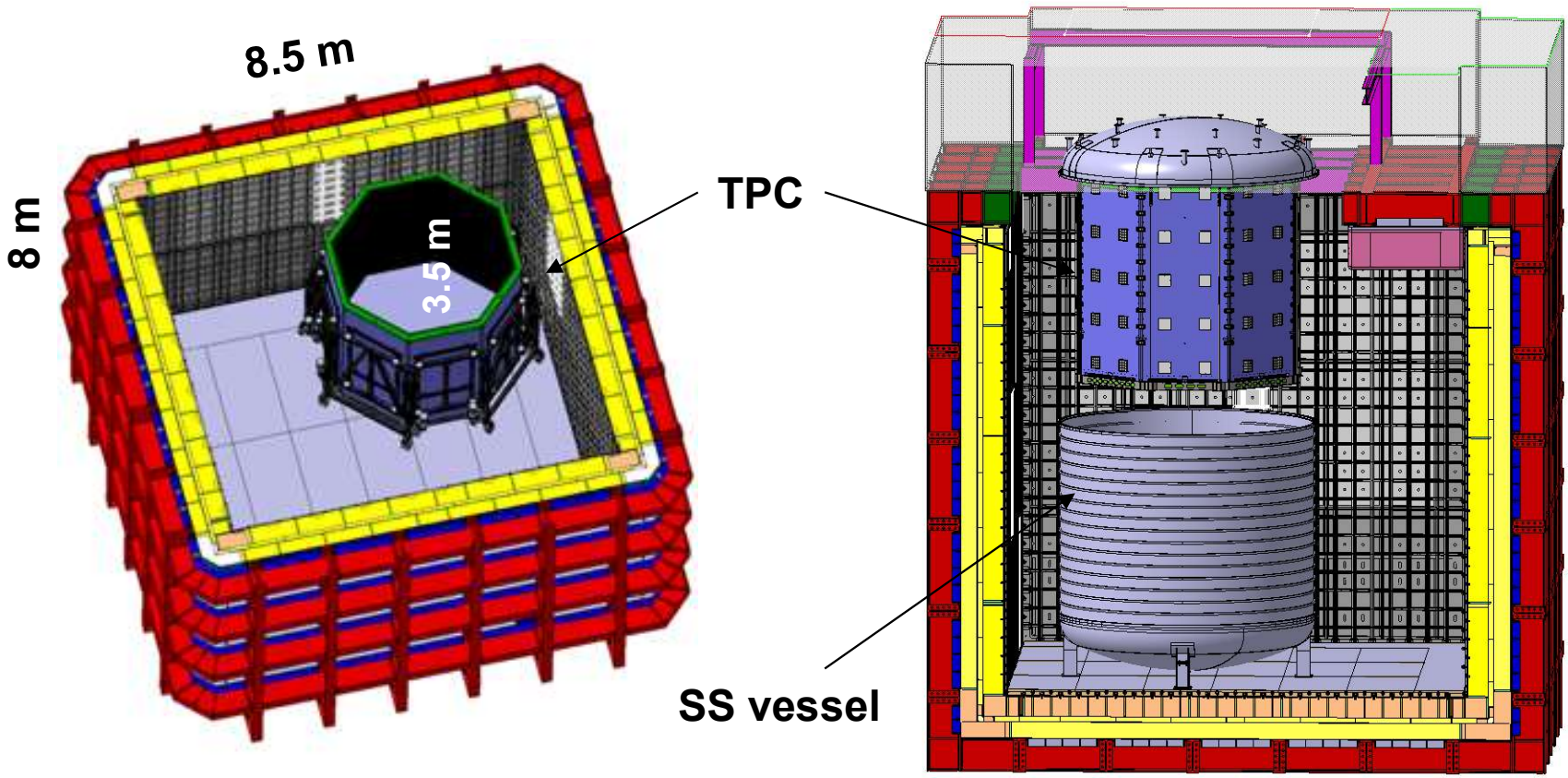
- **Inner detector validation**
  - with a mock-up (1/5) and final cryogenic system at LNGS in 2024



1ton Ar SS cryostat

Status of DS-20k (1/4)

- Inner detector will be integrated directly in protoDUNE cryostat

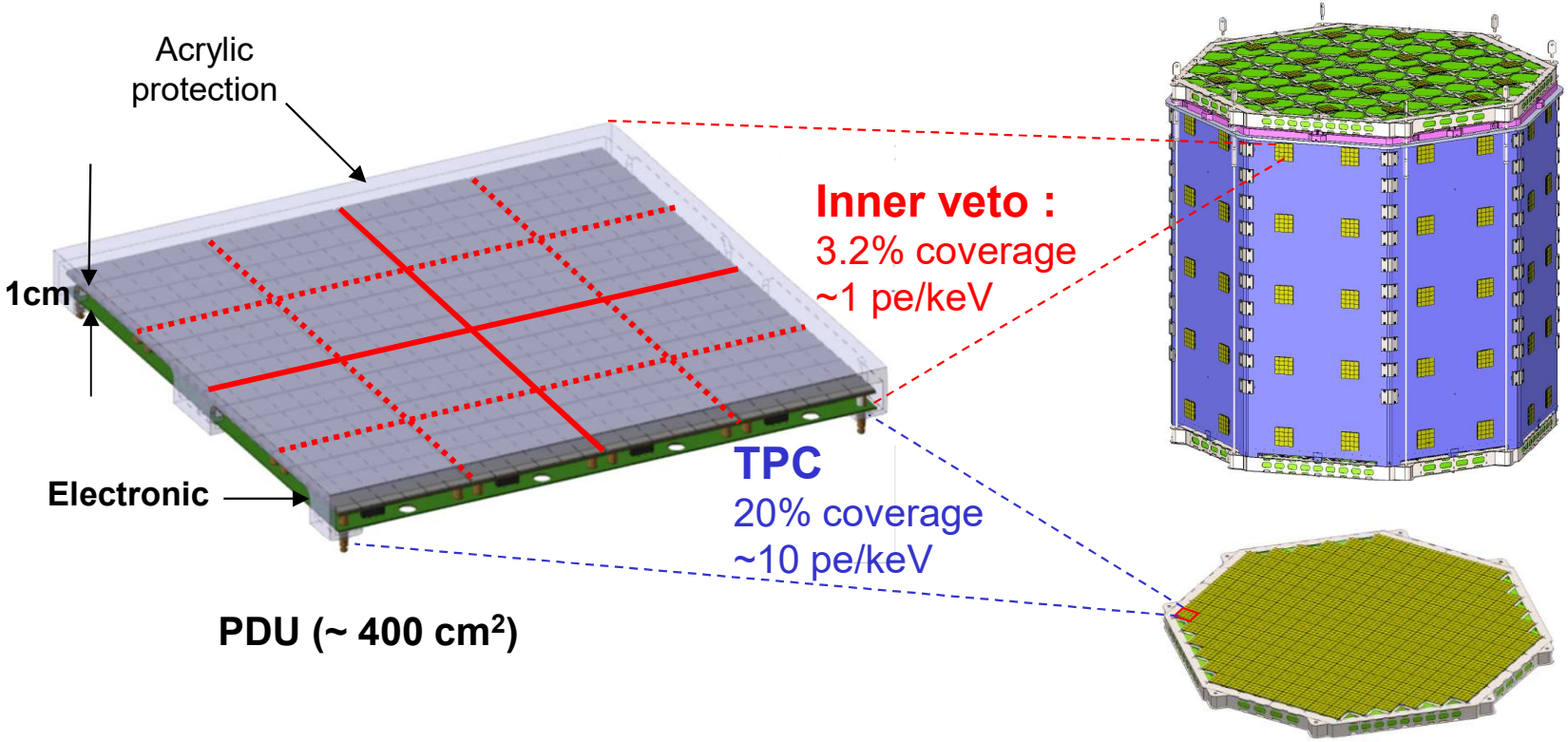


Inner detector integration should be completed by mid 2026

Status of DS-20k (2/4)

❑ Photo detectors

- Custom cryogenic SiPMs developed in collaboration with FBK *(PDE >40%, SNR>8 @ 87K, Low dark count rate < 0.1 Hz/mm^2, Time resolution < 30 ns, Gain >10^6)*
- Grouped in Photo detector unit (PDU) with ~400 SiPMs read by 4 channels

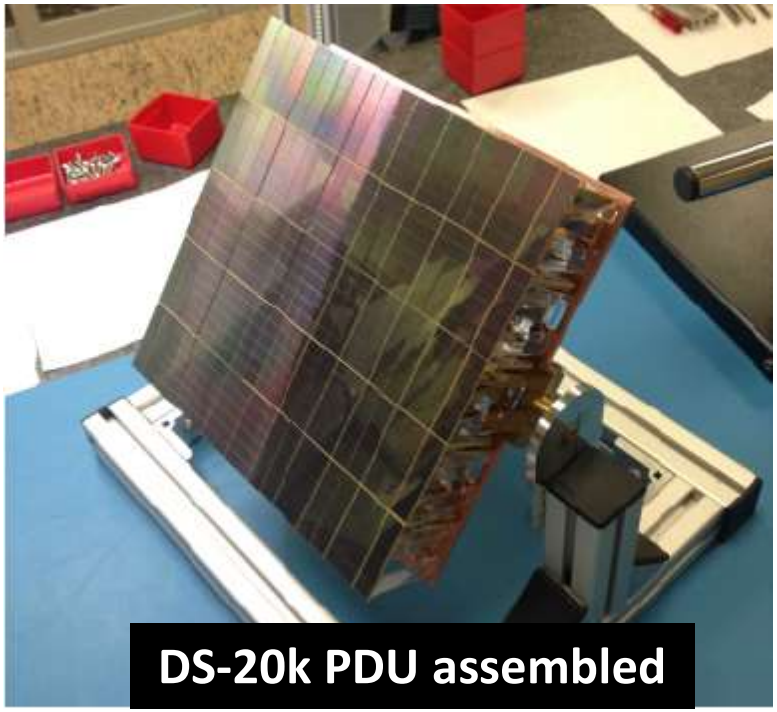


- Outer Veto : 8 arrays lowered from the proto-DUNE flanges *(0.5% cov., ~1 pe/MeV)*

>24 PDU, ~1 m^2, **100 ch.**

Status of DS-20k (2/4)

- **Photo detector production**
  - **270 000** SiPMs produced at Lfoundry in **2022**
  - TPC: started SiPM packaging inc. electronics at LNGS
  - Veto: similar sites ready in UK / Poland


DS-20k PDU assembled

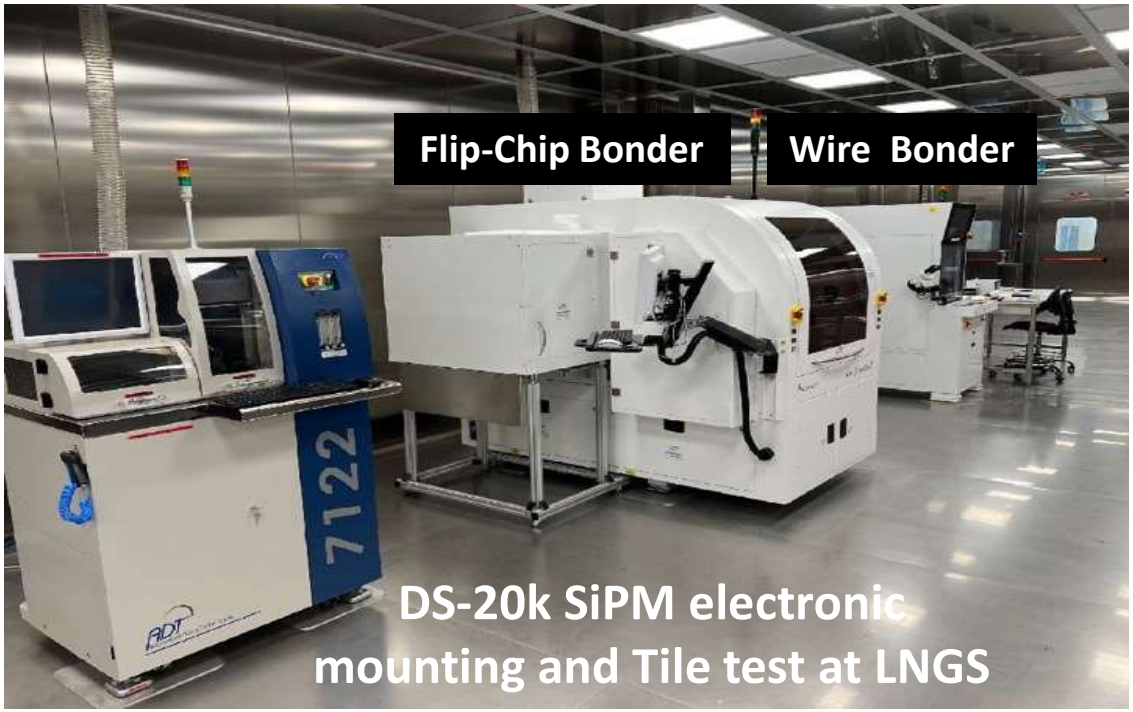
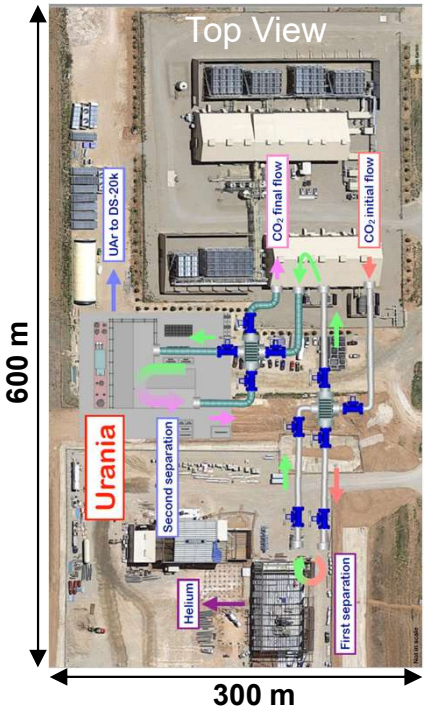


Photo detectors should be ready by 2025

Status of DS-20k (3/4)

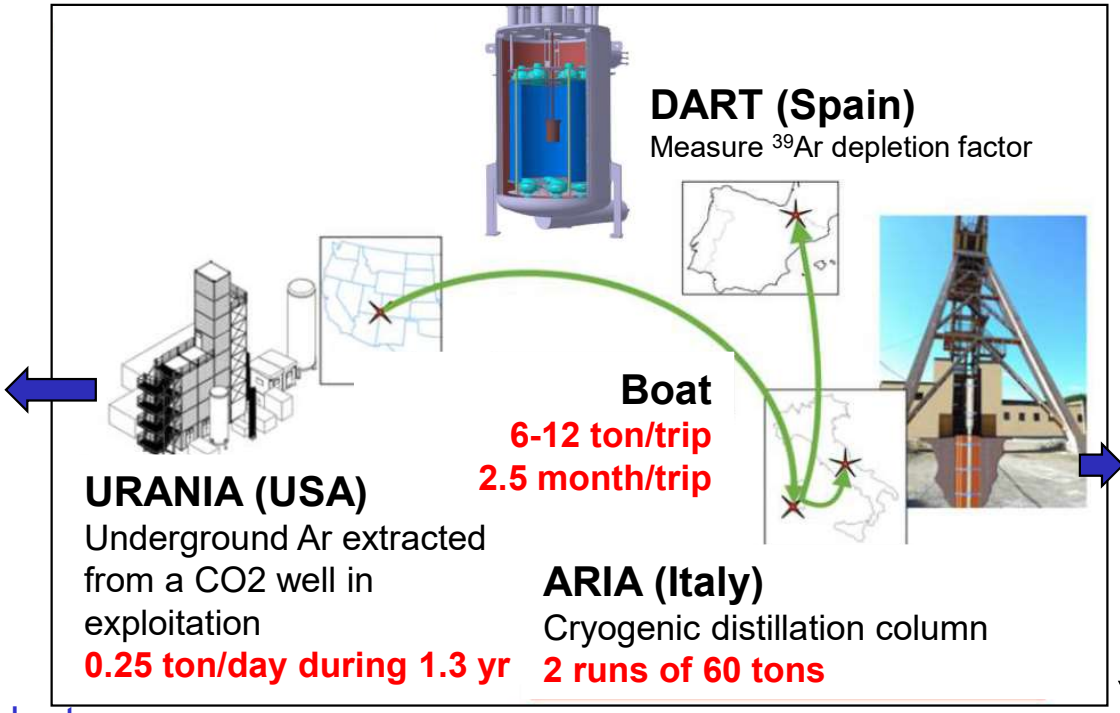
❑ Underground Argon (UAr) extraction and purification

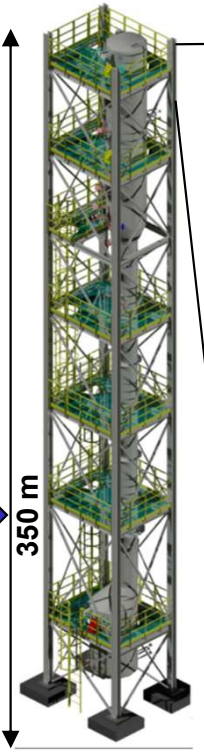
1- Civil engineering defined



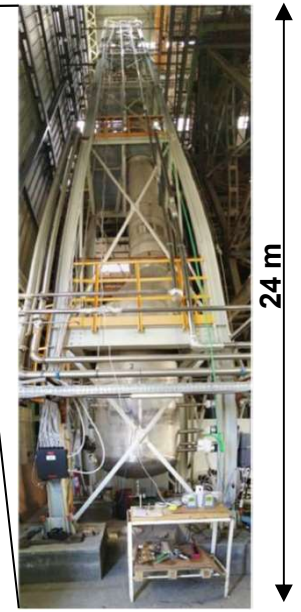
2- Extraction plant available, to be assembled in spring 24

JINST **15** (2020) P02024





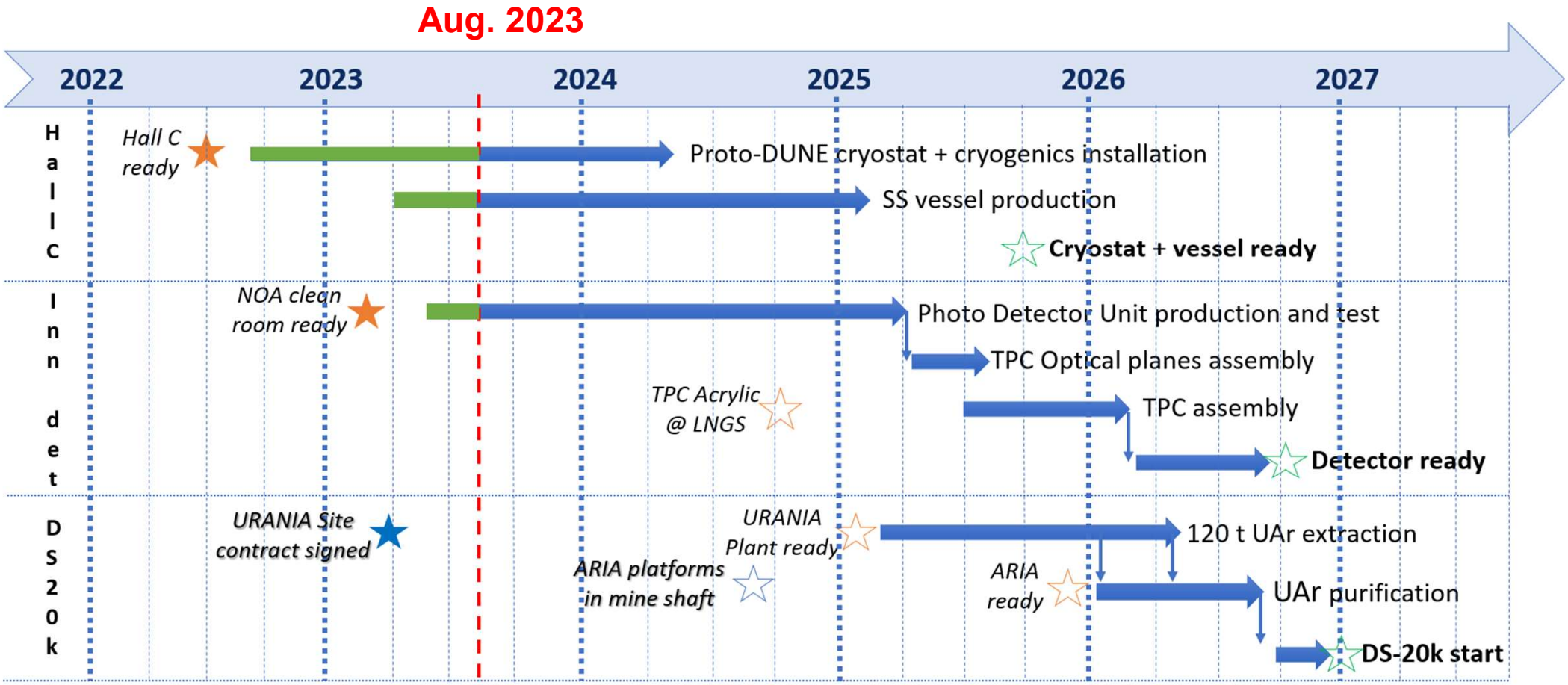
Mine shaft cleaned



Demonstrator tested in 2020
EPJC 81 (2021) 359
^{40}Ar, ^{38}Ar, ^{36}Ar separated
EPJC 83 (2023) 453

UAr extraction should start early 2025

Status of DS-20k (4/4)



Largest TPC ever built for Dark Matter searches
Next 3 years crucial. First data expected for 2027

DarkSide IN2P3

❑ History

- 2012 : APC joined
- 2014 : LPNHE joined
- 2016 : DarkSide IN2P3 Master Project
- 2018 : CS-IN2P3

CS-IN2P3
28.10.2018

DarkSide est basé sur une technologie différente, compétitive également, et se positionne sur un réel potentiel de découverte.

Aujourd'hui, parmi les projets de détection directe de matière noire présentés, seuls XENON et DarkSide-50 sont opérationnels et au niveau de la rude concurrence internationale, dans des domaines de masse différents. La participation à ces projets est à soutenir et à renforcer en développant les équipes actuelles.

- 2020 : CPPM joined
- 2023 : Fiche Projet accepted. First IN2P3 budget
- 2024 : ANR FIDAR accepted (350 k€, 2 PhD students)

Coherent program towards first DS-20k physics

LAr response **model**

DS-20k signal/event **reconstruction**

DS-20k TPC **calibration**

Physics

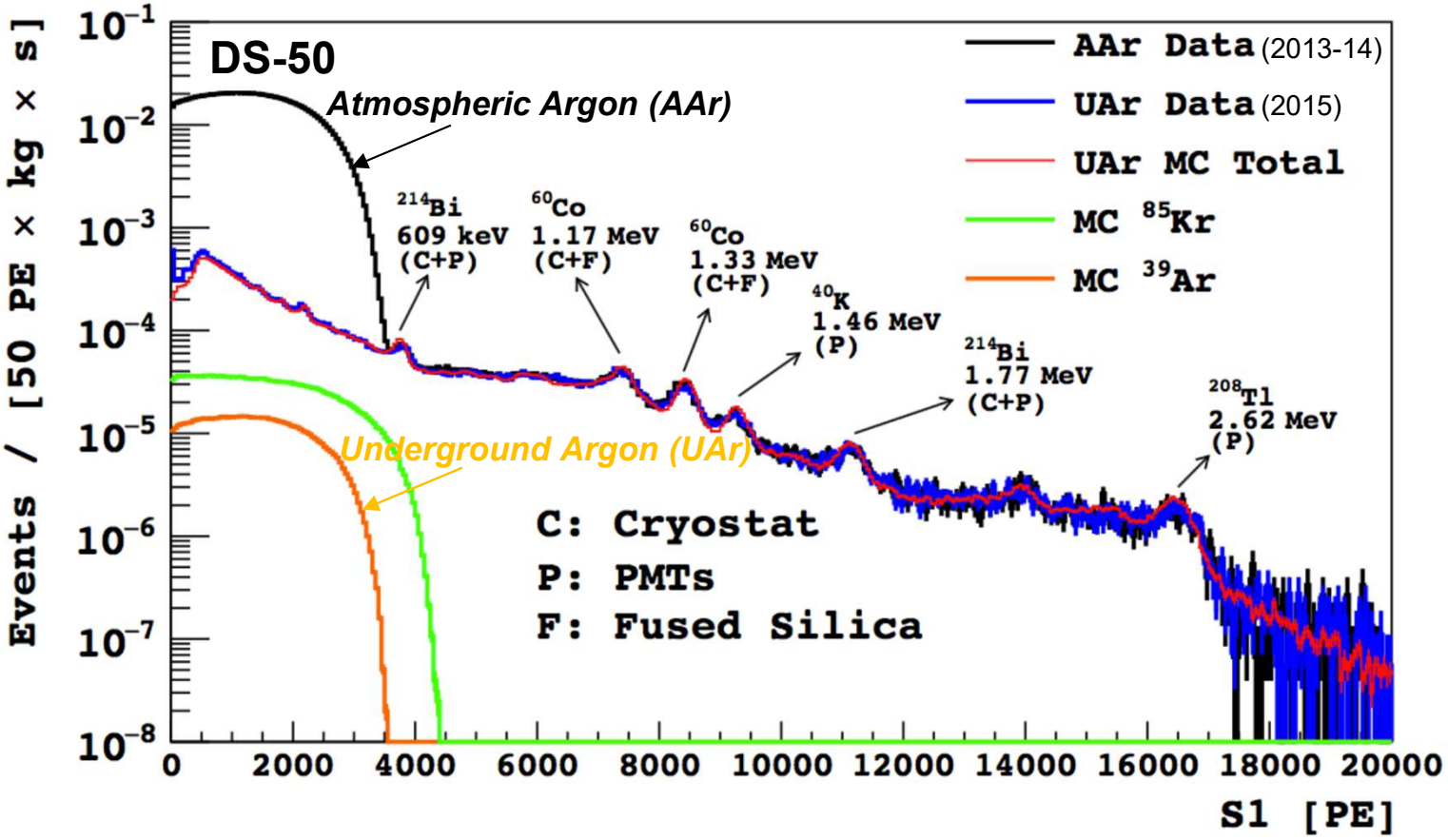
DS-50 Low Mass
DS-20k sensitivity

DS IN2P3: LAr model (1/5)

- **DarkSide MC + define the LAr response model**
  - Model validated with data
    - ✓ Excellent Data-MC agreement with DS-50
    - ✓ Measurement of ^{39}Ar suppression factor in UAr (1400±200)

APC, LPNHE

PRD **93** (2016) 081101
JINST **12** (2017) P10015



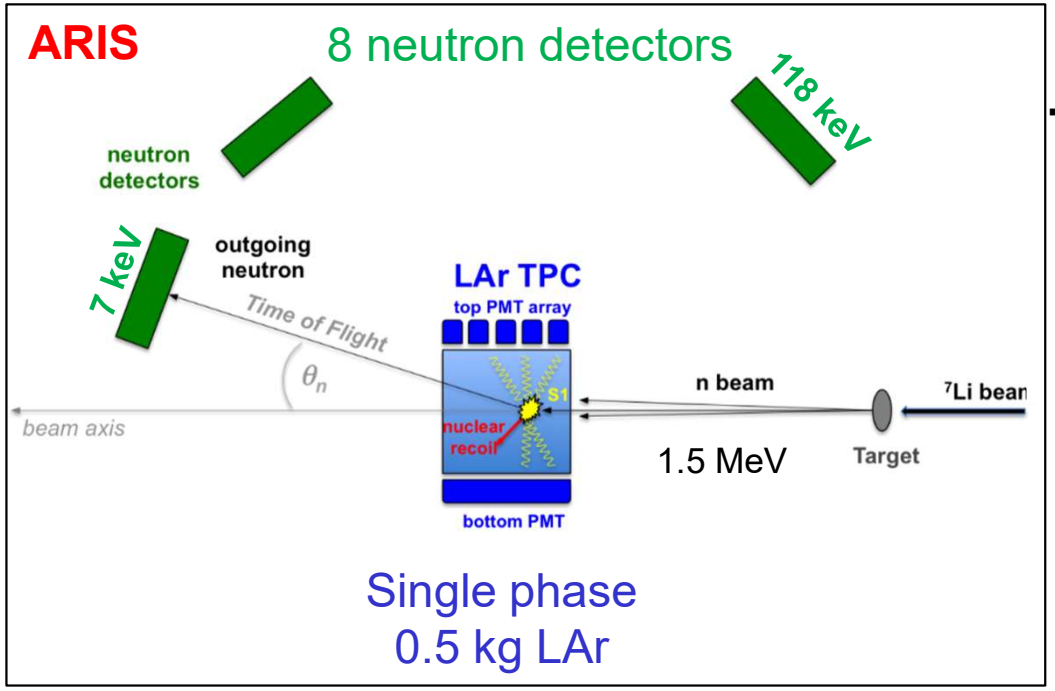
DS IN2P3: LAr model (2/5)

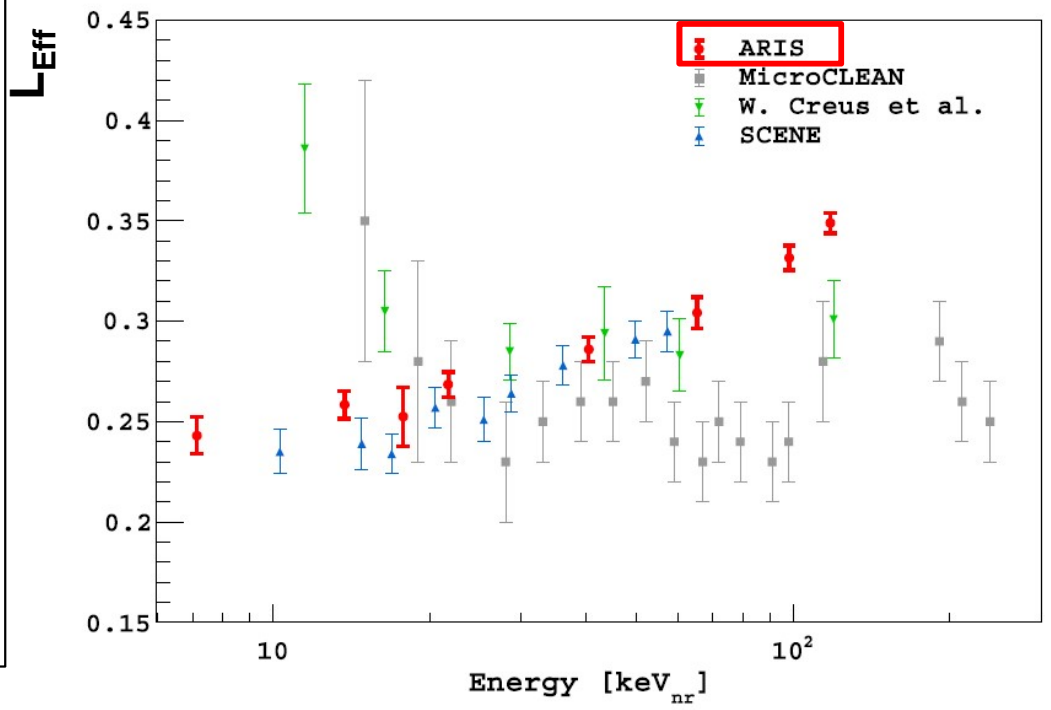
❑ ARIS: test the LAr response model

- Use neutron beam from ALTO facility at IPNO
- **Most accurate** measurement of the NR quenching effect (L_{eff})
  - ✓ 2-3 more precise than the other experiments
  - ✓ first measurement below 10 keV

APC, LPNHE, UCLA, Princeton, Napoli, LNGS, UC Davis

PRD **97** (2018) 112005
JINST **16** (2021) P11026





DS IN2P3: LAr model (3/5)

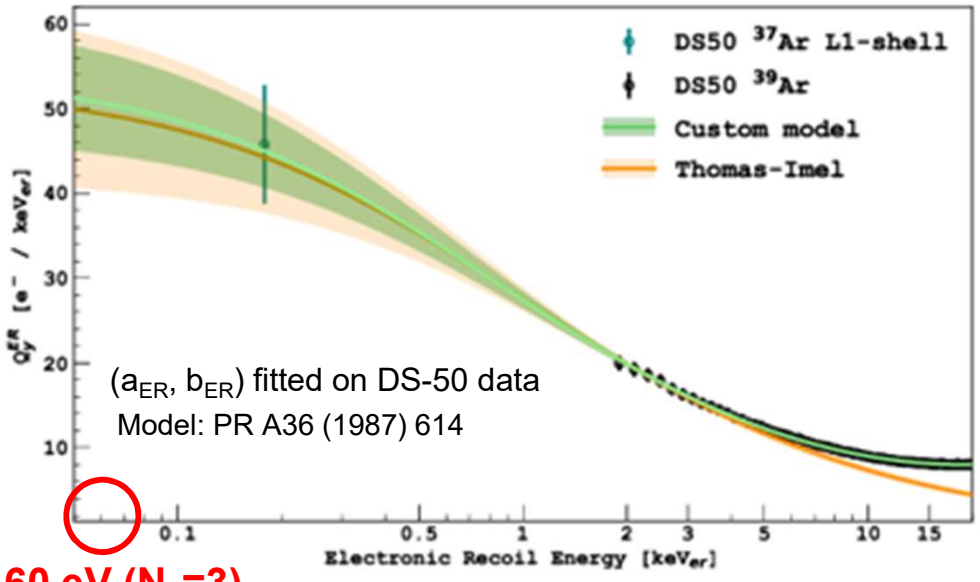
❑ Improve the LAr response model

APC, CPPM, LPNHE

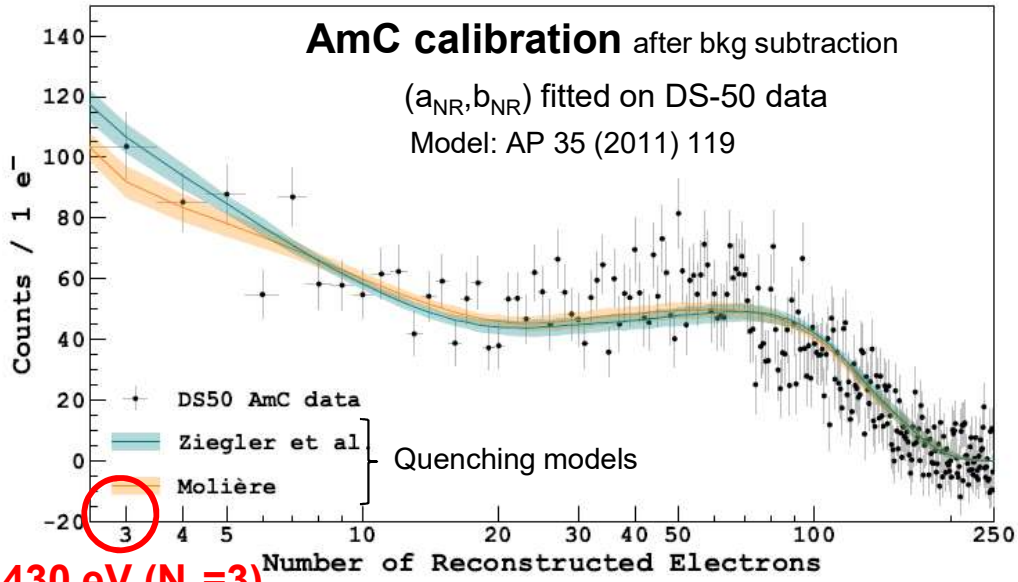
PRD **104** (2021) 082005

- Special effort < 10 keV to measure ionization yield
  - ✓ Using **DS-50 data**: ^{37}Ar, ^{39}Ar, calibration with AmC, AmBe
  - ✓ Ionization yield (Q) generic model with 2 free parameters:
    Q ~ ln(1+aE)/bE, $Q_{E\to 0}$ = a/b

Ionization Yield Model for ER and NR



60 eV (N_e=3)



430 eV (N_e=3)

DS IN2P3: LAr model (4/5)

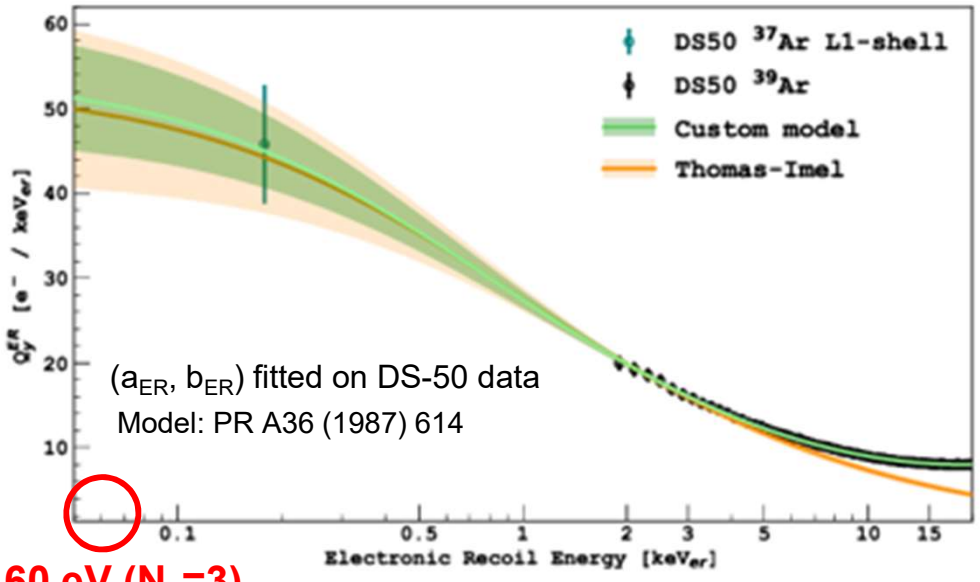
❑ Improve the LAr response model

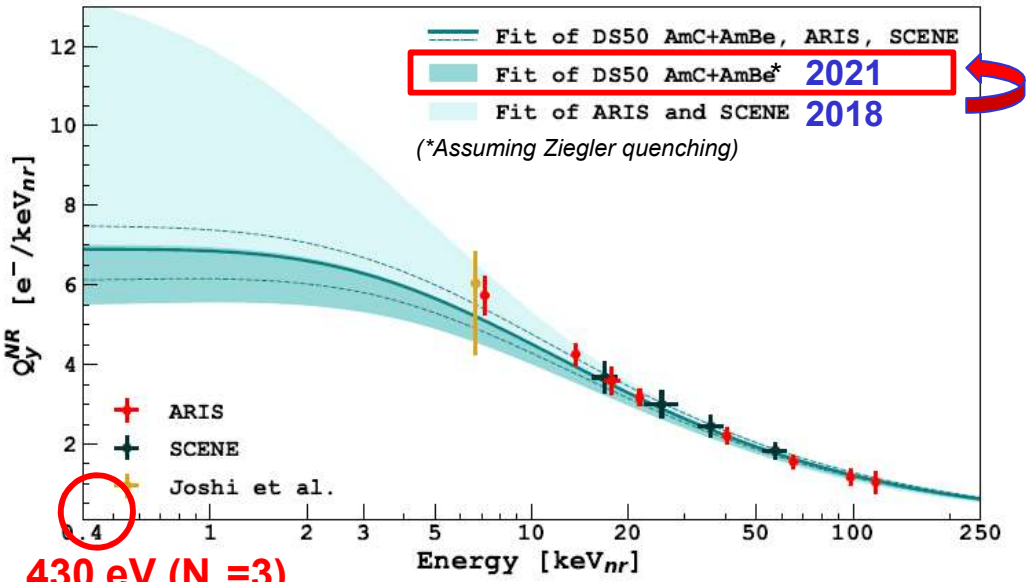
APC, CPPM, LPNHE

PRD **104** (2021) 082005

- Special effort < 10 keV to measure ionization yield
  - ✓ Using **DS-50 data**: ^{37}Ar, ^{39}Ar, calibration with AmC, AmBe
  - ✓ At very low energy all primary electrons visible :
    Q= **(1-r) Ni/E,** $r_{E\to 0}$ = e-ion recombination ~ 0

Ionization Yield Model for ER and NR



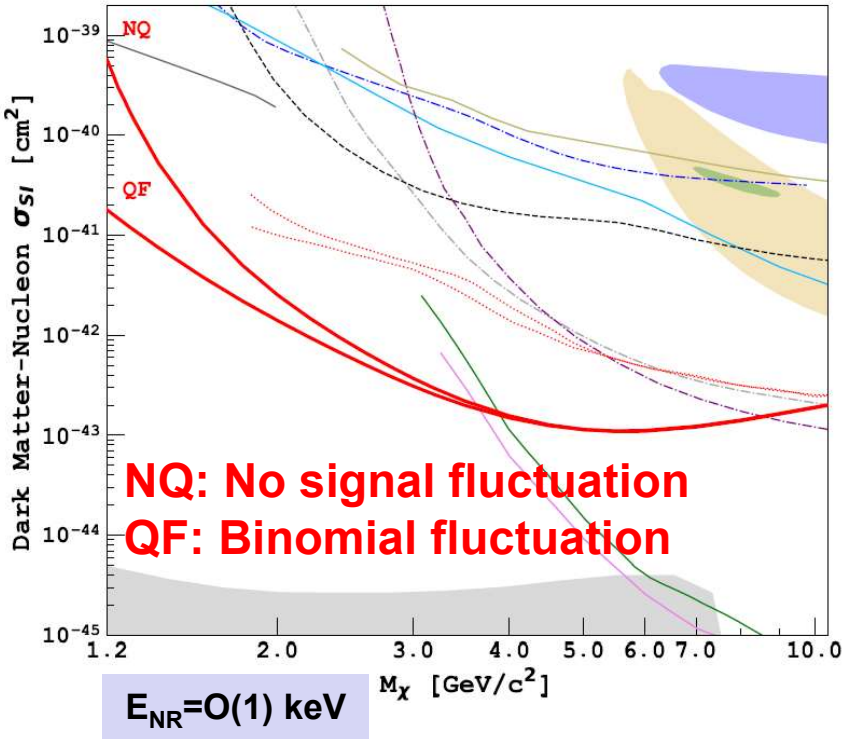


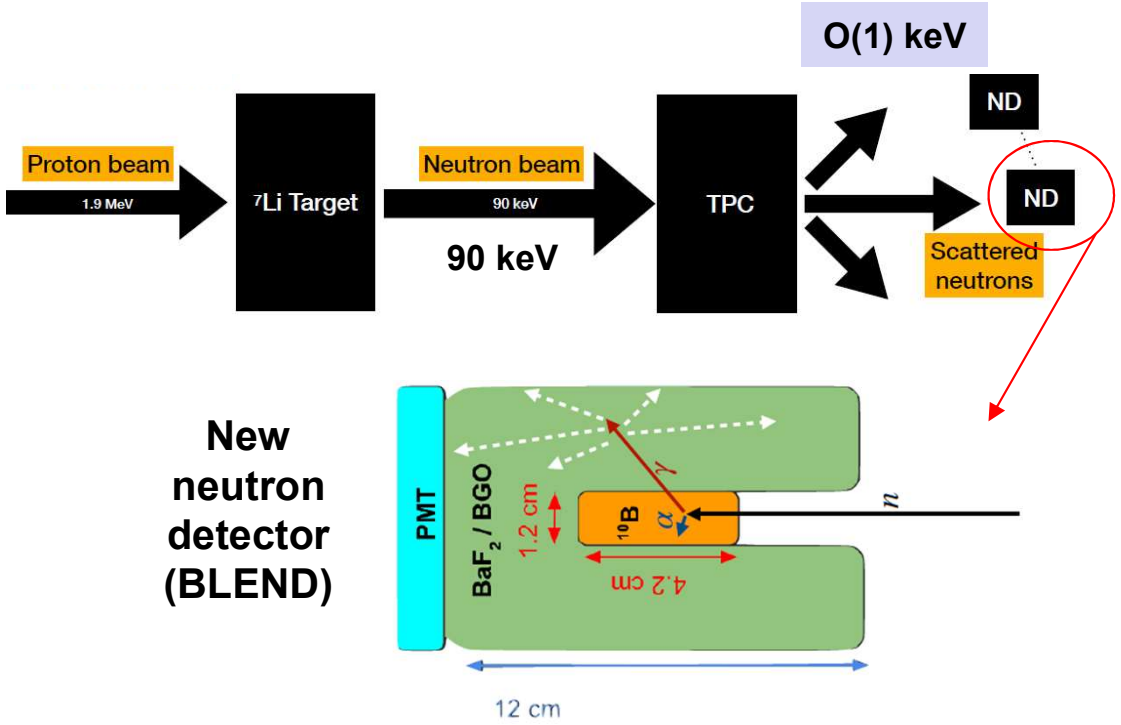
Measurement of Ionization Yield at low E central for low mass WIMP search

DS IN2P3: LAr model (5/5)

- **Improve the LAr response model**
  - Special effort < O(1) keV to measure NR signal fluctuation
    - ✓ No theory prediction exists …
    - ✓ Take data with 3 days of beam at ALTO (2024)

APC, CPPM, VT, UCDavis, GSSI, Princeton, Astrocent





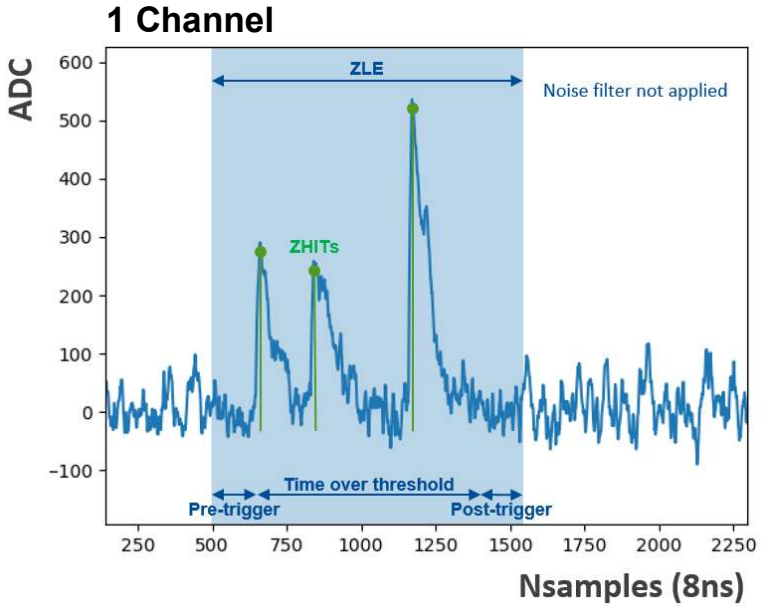
Strong IN2P3 leadership *(under APC responsability)*

DS IN2P3: Reconstruction

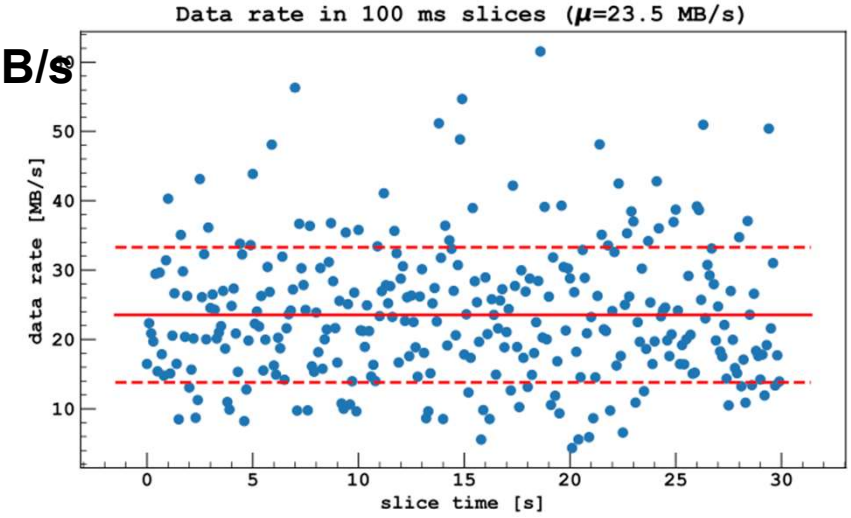
❑ DS-20k signal processing and event reconstruction

APC, CPPM

- Fast online signal processing *(inc. SiPM elec. description adjusted with proto data)*
  - ✓ Matched filter + custom hit finder applied on time slot with activity
  - ✓ Emulate the DAQ (inc. pile-up) → meet data output rate (< 60 MB/s)



60 MB/s



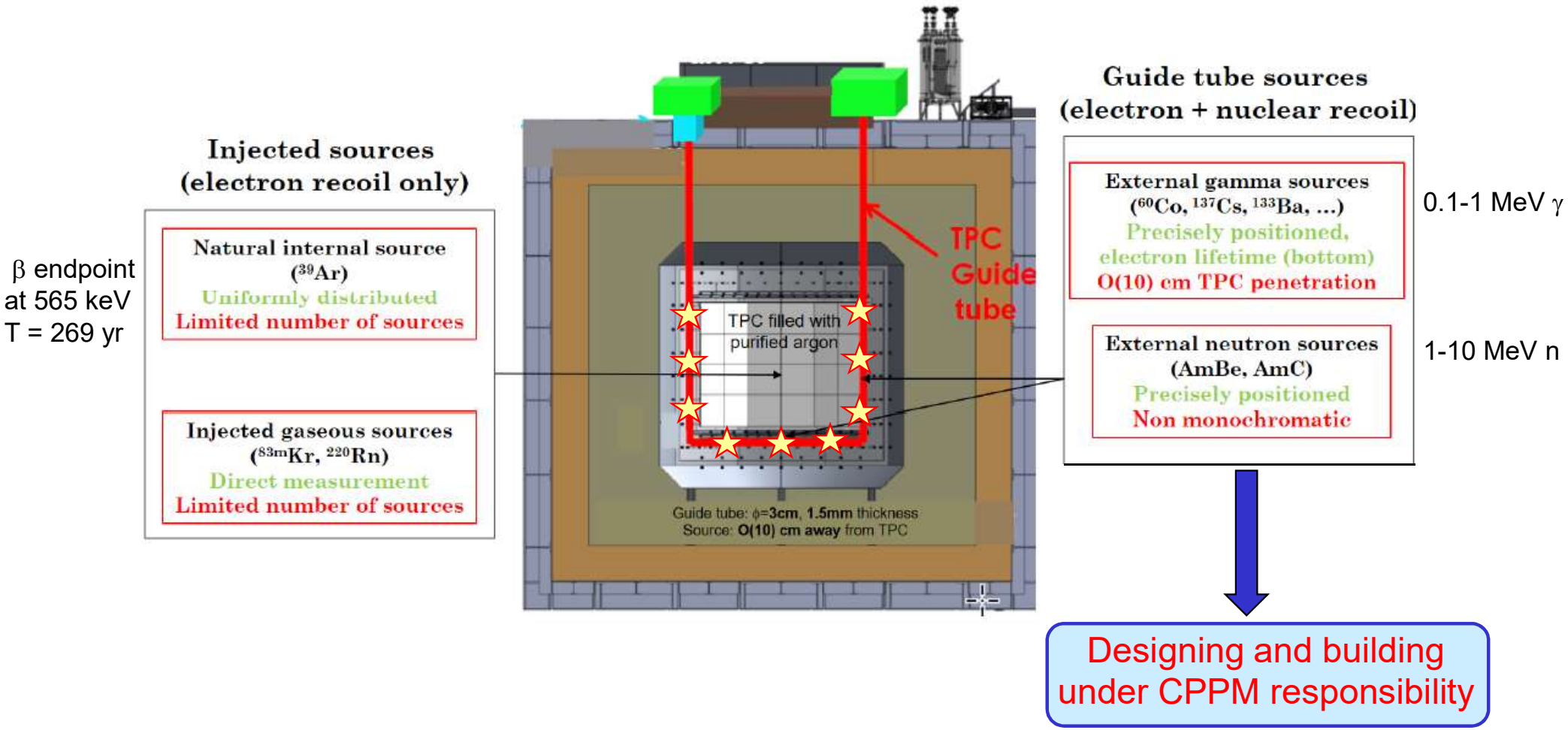
- Offline pulse reconstruction and event builder
  - ✓ S1 and S2 identification and association, 3D position, energy reconstruction… at work

Strong IN2P3 contribution *(APC responsible for the Offline)*

DS IN2P3: Calibration (1/5)

❑ DS-20k guide tube calibration system

- Two complementary approaches : injected and external sources



DS IN2P3: Calibration (2/5)

❑ DS-20k guide tube calibration system

CPPM, UH

- Designing and building the TPC calibration system
  - ✓ Simulation studies: established a first tentative calibration program of O(1) month, studied impact on veto light yield, bkg induced by calibration tubes, …

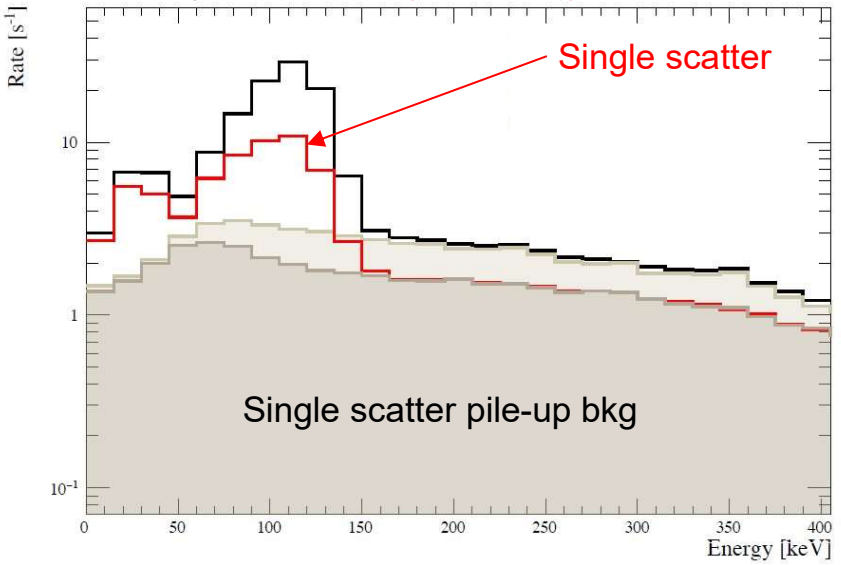
ER Sources

Source	^{57}Co	^{133}Ba	^{22}Na	^{137}Cs	^{60}Co
Energy (keV)	122	356	511	662	1173
Activity (side) (kBq)	18	1.9	0.36	2.2	0.36
Activity (bottom) (kBq)	100	5.0	0.67	4.6	0.6
Time per position (side) (h)	2.5e-2	1.4	2.1	3.1	7.3
Time per position (bottom) (h)	3.4e-2	2.2	2.5	4.7	9.1
Duration of calibration (h)	3.84	18.72	23.52	36	74.4

NR Sources

Source	AmBe	AmC
Initial energy (MeV)	[0.2, 12]	[2, 7]
Activity (side) (kBq)	0.14	0.15
Activity (bottom) (kBq)	0.18	0.18
Time per position (side) (h)	19	28
Time per position (bottom) (h)	23	25
Duration of calibration (day)	8	10

18 kBq ^{57}Co source *(122 keV γ)* at the TPC side

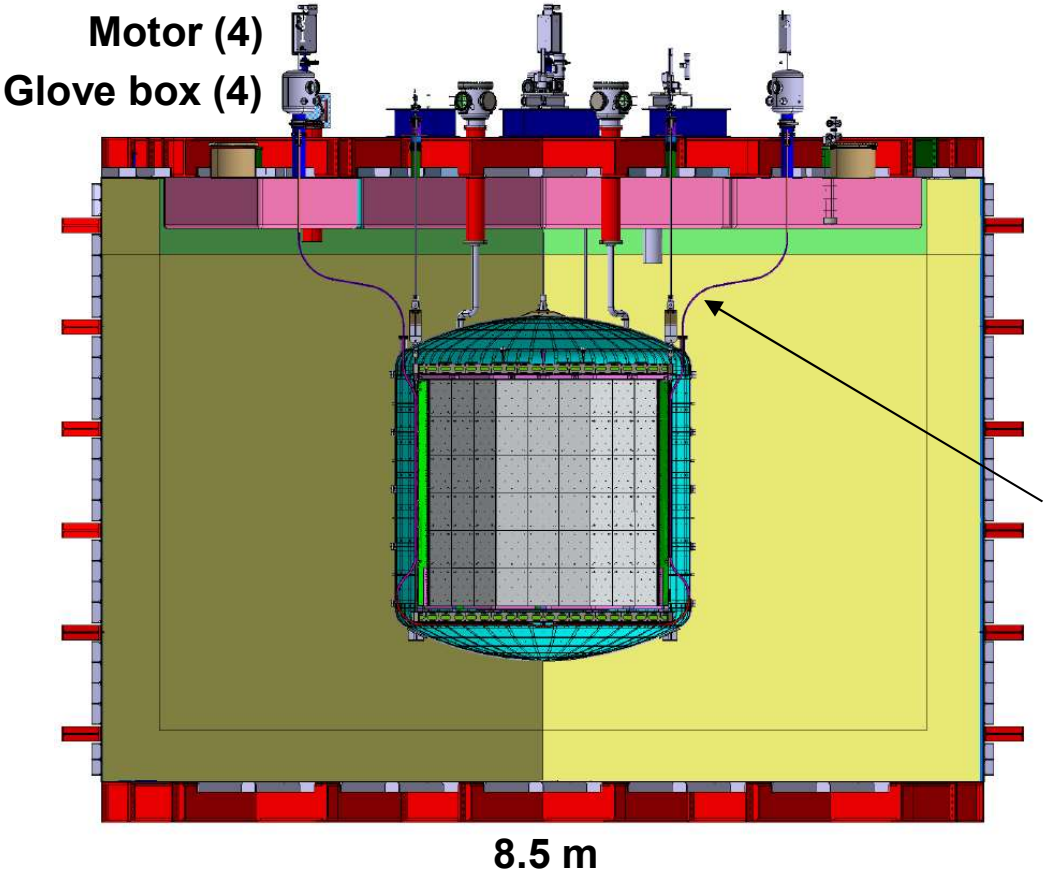


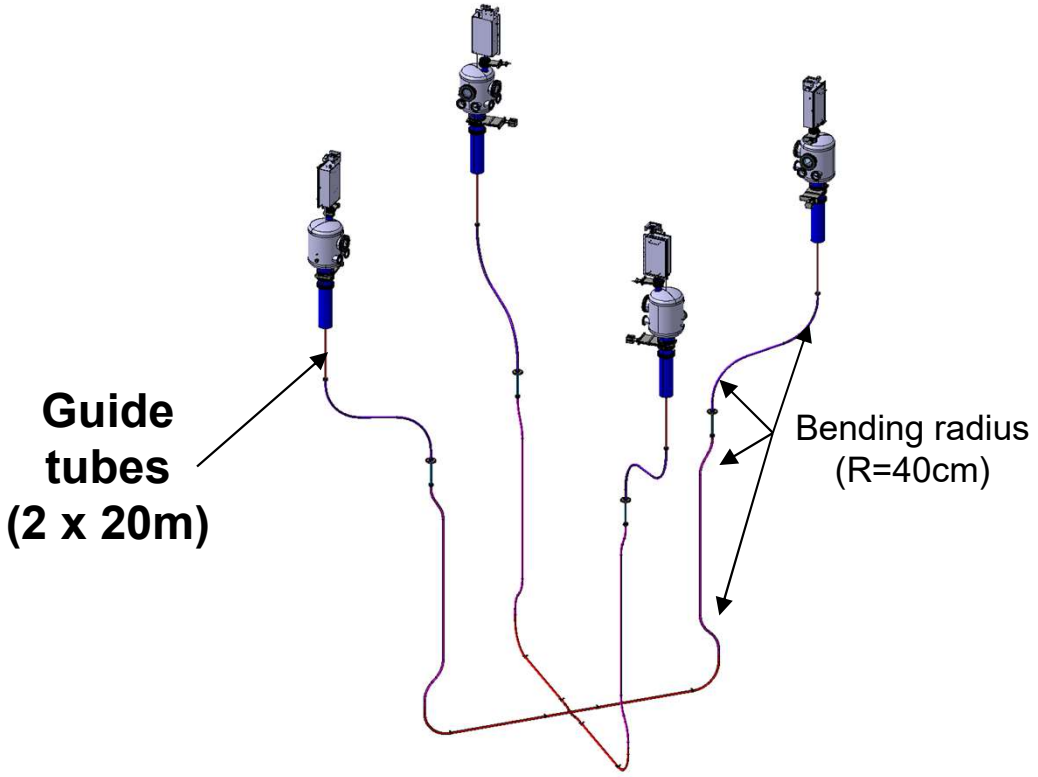
DS IN2P3: Calibration (3/5)

❑ DS-20k guide tube calibration system

CPPM, QU, LNGS

- Designing and building the TPC calibration system
  - ✓ Simulation studies
  - ✓ Conceived the guide tube system *(now included in the DS-20k CAD)*





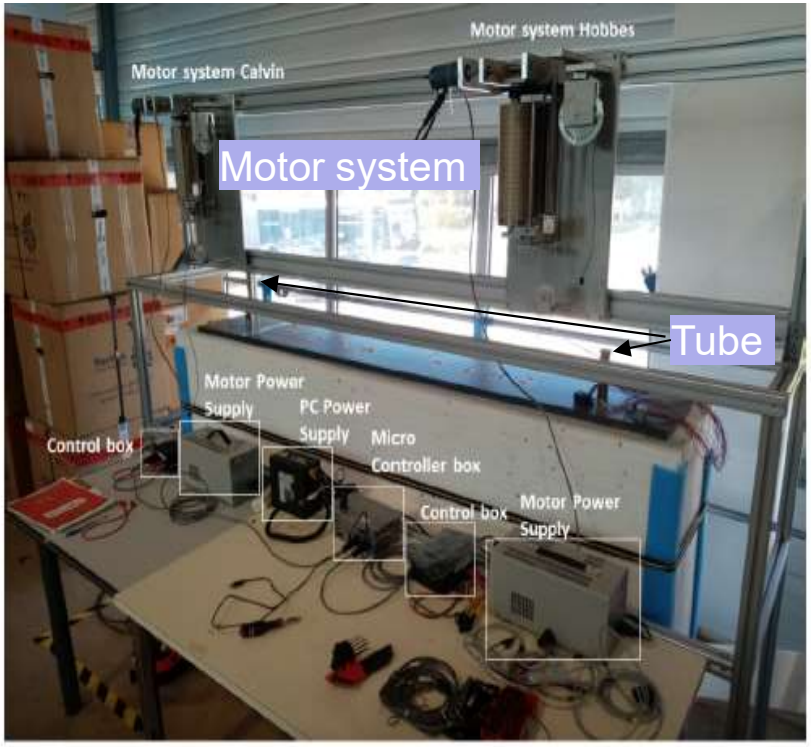
DS IN2P3: Calibration (4/5)

❑ DS-20k guide tube calibration system

CPPM, QU

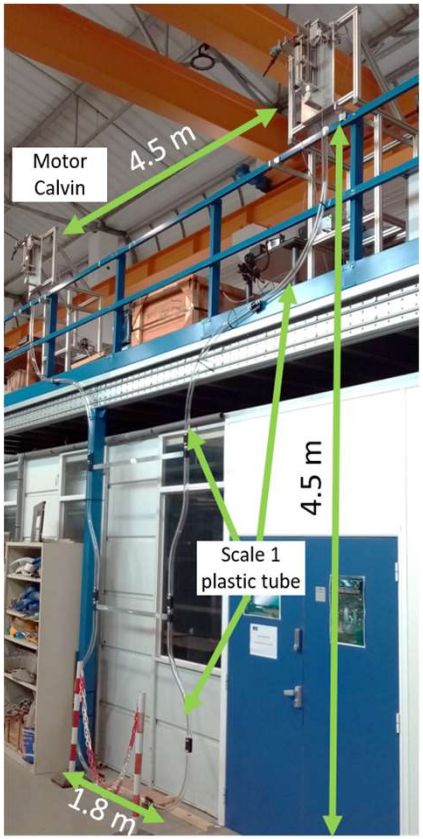
- Designing and building the TPC calibration system
  - ✓ Simulation studies
  - ✓ Conceived the guide tube system
  - ✓ Realized **3 Mock-Ups** (*1 tube, 2 motor system*) to validate the concept

MU at LN2 *(CPPM, 3x8 hours, 2022-23)*



MU at LN2, LAr *(CERN, 1 month, 2023)*

Scale 1 MU at warm
(CPPM, 2023)



DS IN2P3: Calibration (5/5)

❑ DS-20k guide tube calibration system

- Designing and building the TPC calibration system
  - ✓ Simulation studies
  - ✓ Conceived the guide tube system
  - ✓ Realized **3 Mock-Ups** (*1 tube, 2 motor system*) to validate the concept

	LAr	LN2	LN2	LAr	
	DS-20k	MU_CS	MU_CL		MU_W
	Requirements / Performance				
Speed of the source (cm/s)	> 1	3	1		2
Position accuracy (cm)	±1	±1	1		±1
Tension (N)	< 150	25-40	15-30		60-90
Ice formation (block)	No	No	Yes but sublimated	No	NA NA
Total distance for all sources (m)	160 (/yr)	> 100	800	100	> 100
Total nb of back&forth / tube	4 (/yr)	44	280	35	>6

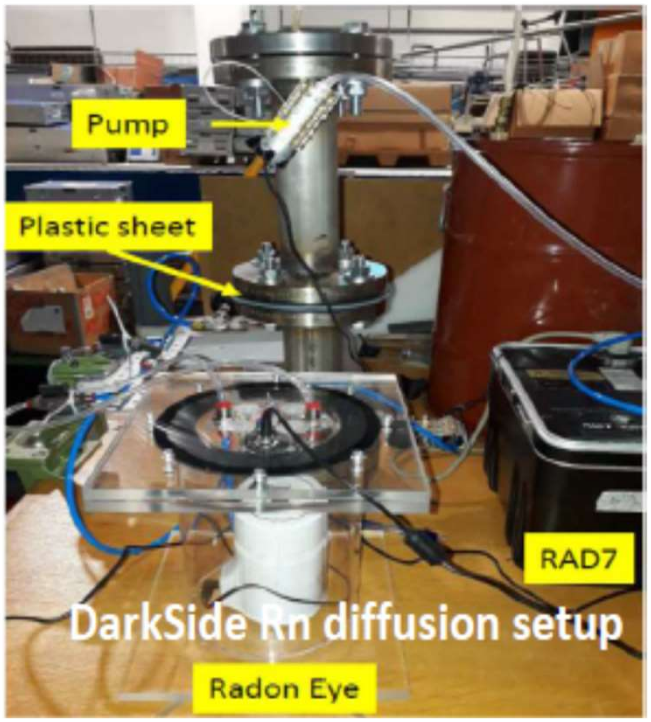
FDR passed successfully in Sep. 2023
(CPPM responsible of the calibration system)

DS IN2P3: Radon

❑ Reduction of radon contamination in DS-20k

CPPM, JU

- Radon progeny [^{210}Pb, ^{210}Po] plates-out on detector material surfaces exposed to air → n bkg [α 5, 8 MeV]
  - ✓ Limit the exposure time by using hermetic plastic bags
- Radio purity assay program developed
  - ✓ Plateau Radon at CPPM participates to this effort with its radonisation chamber
  - ✓ Test and validate special plastic bags use for transport and storage



Radonisation Chamber

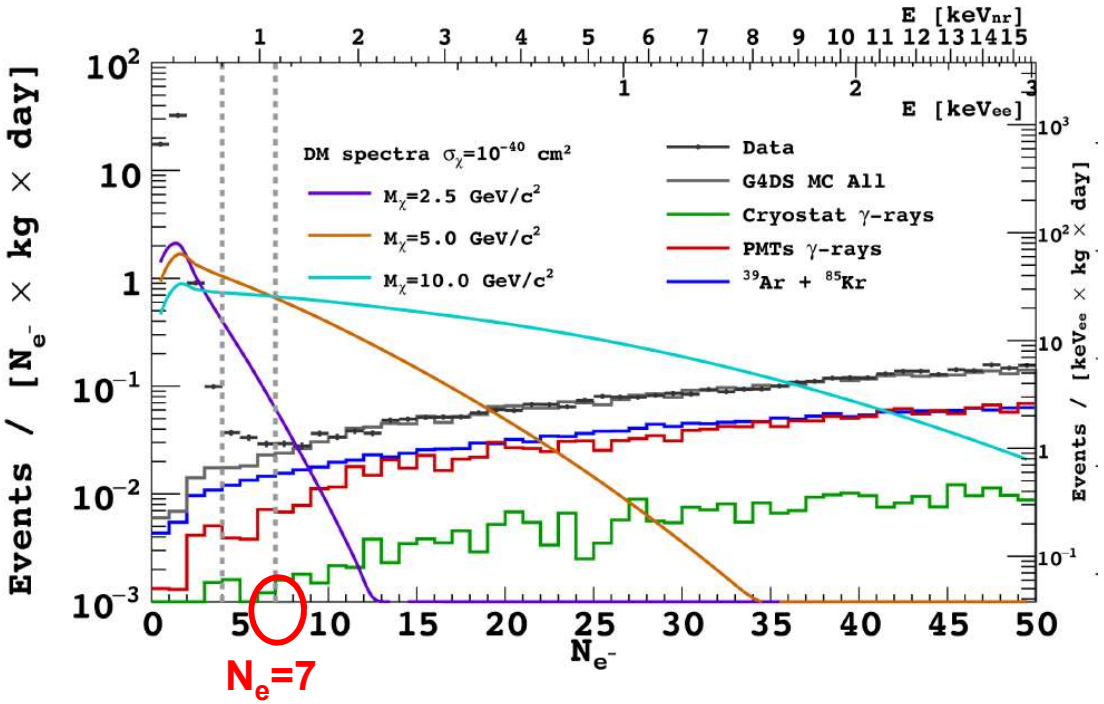
IN2P3: DS-50 physics (1/5)

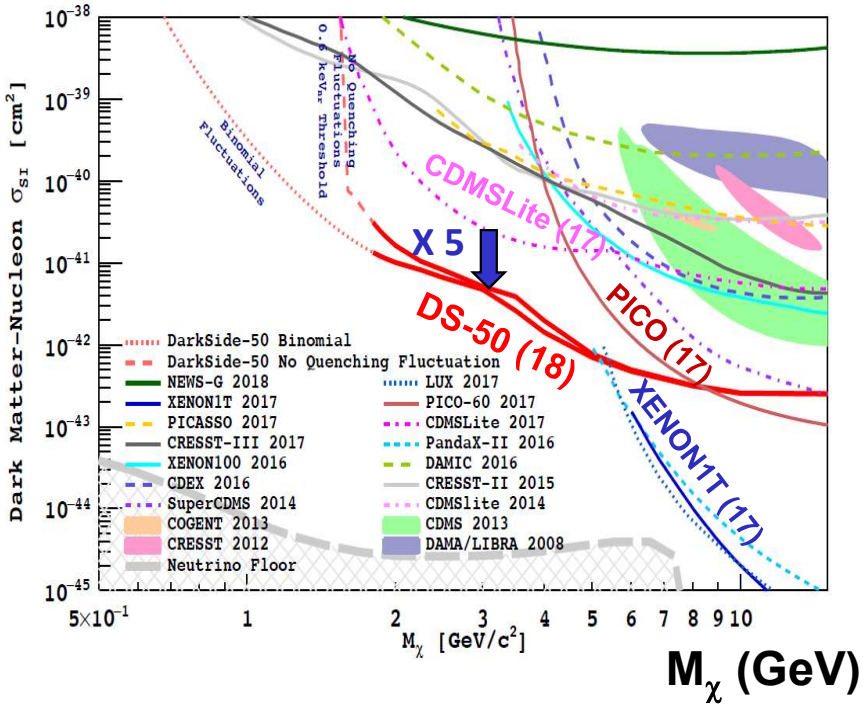
❑ Low mass (<10 GeV) WIMP search

APC, Princeton, USP

- First analysis (S2-only) in 2018
  - ✓ Very good signal / background separation at low N_e
  - ✓ Good background description for $N_e \geq 7$
  - ✓ Break the paradigm that only solid-state techno. is sensitive to this range

PRL **121** (2018) 081307
PRL **121** (2018) 111303





M_χ (GeV)

DarkSide-50 world leading in 1-5 GeV WIMP in 2018 *(IN2P3 leading the effort)*

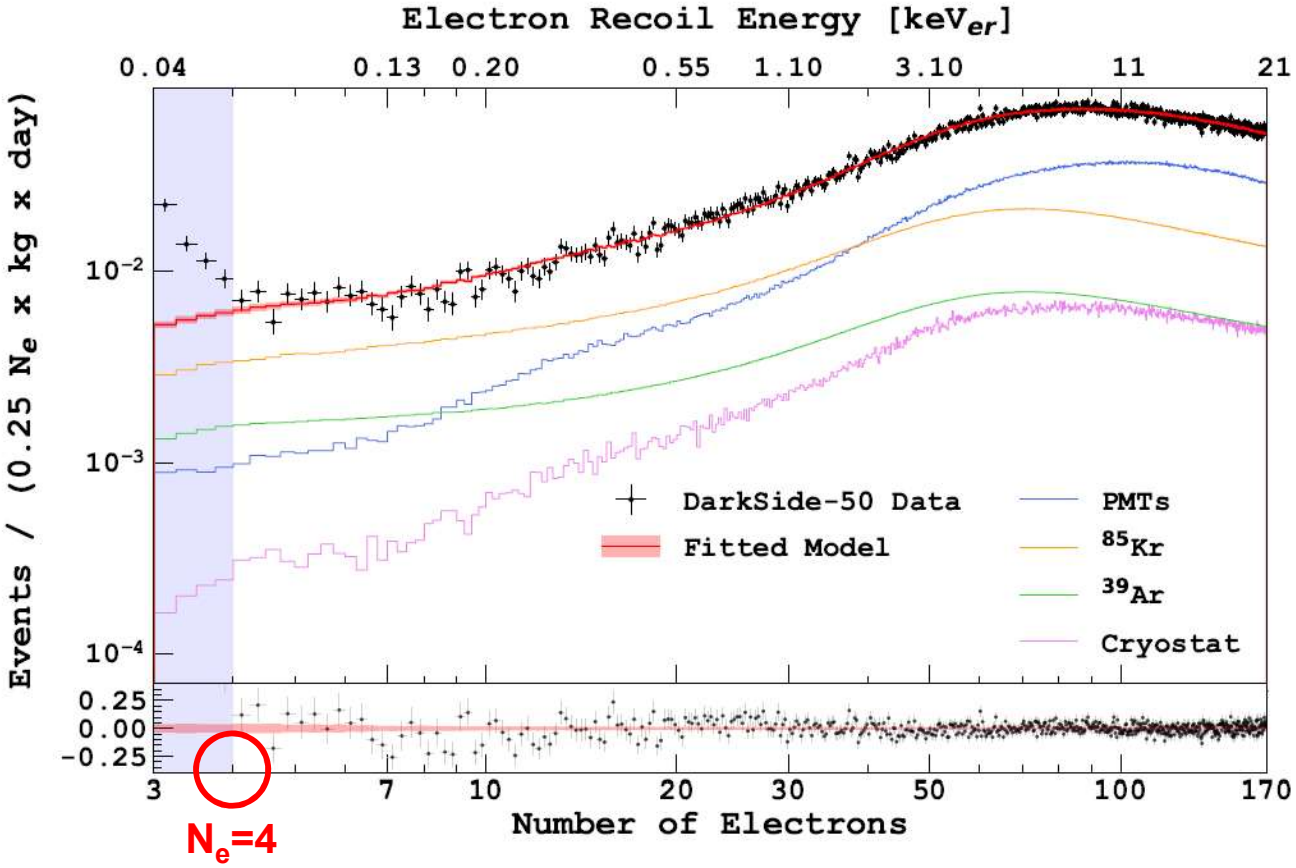
IN2P3: DS-50 physics (2/5)

❑ Low mass (<10 GeV) WIMP search

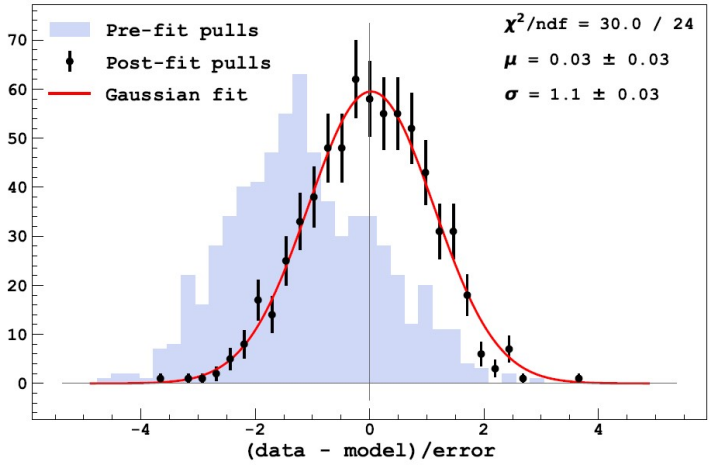
APC, CPPM, GSSI

PRD **107** (2023) 063001

- Re-analysed DS-50 data
  - ✓ Various improvements *(enlarging Ne range, improve selection + syst.)*
  - ✓ Use **improved ionisation yield models** *(Sl.22-23)*
  - ✓ Very good description of the bkg down to Ne≥4



Residuals



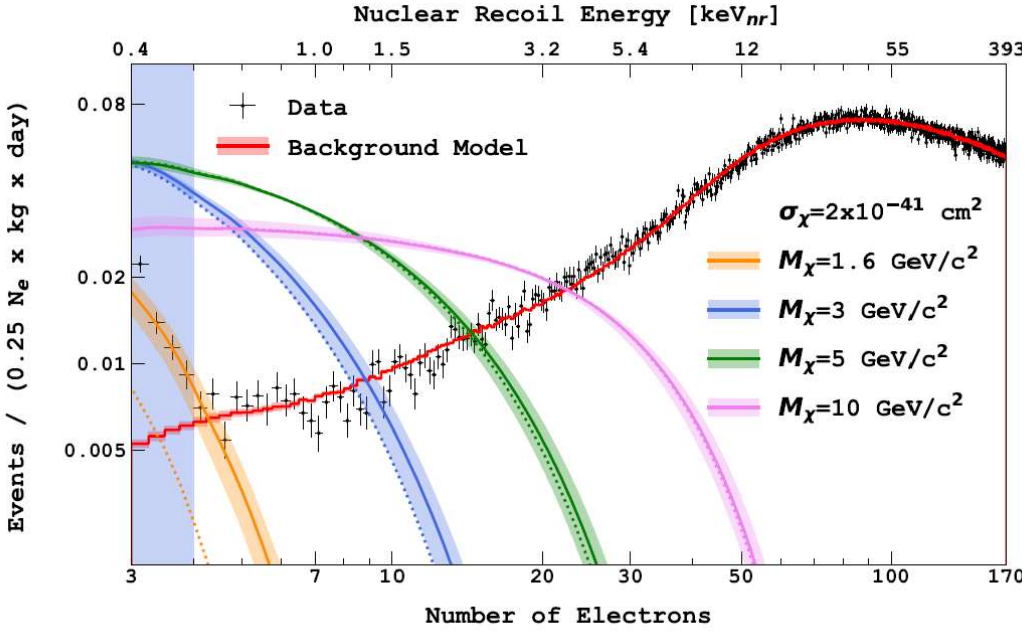
IN2P3: DS-50 physics (3/5)

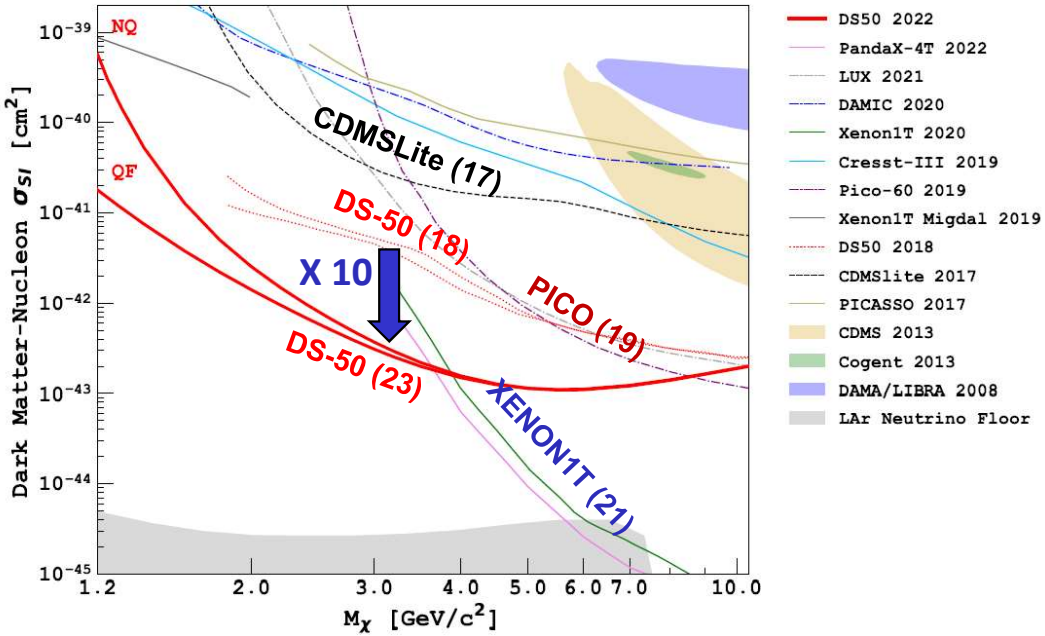
❑ Low mass (<10 GeV) WIMP search

APC, CPPM, GSSI

- Re-analysed DS-50 data
  - ✓ Improve separation between NR signal and ER background
  - ✓ World best limit 1.2-3.6 GeV *(x10 gain wrt 2018)*

PRD **107** (2023) 063001





DarkSide-50 world leading in 1-4 GeV WIMP in 2023 *(IN2P3 leading the effort)*

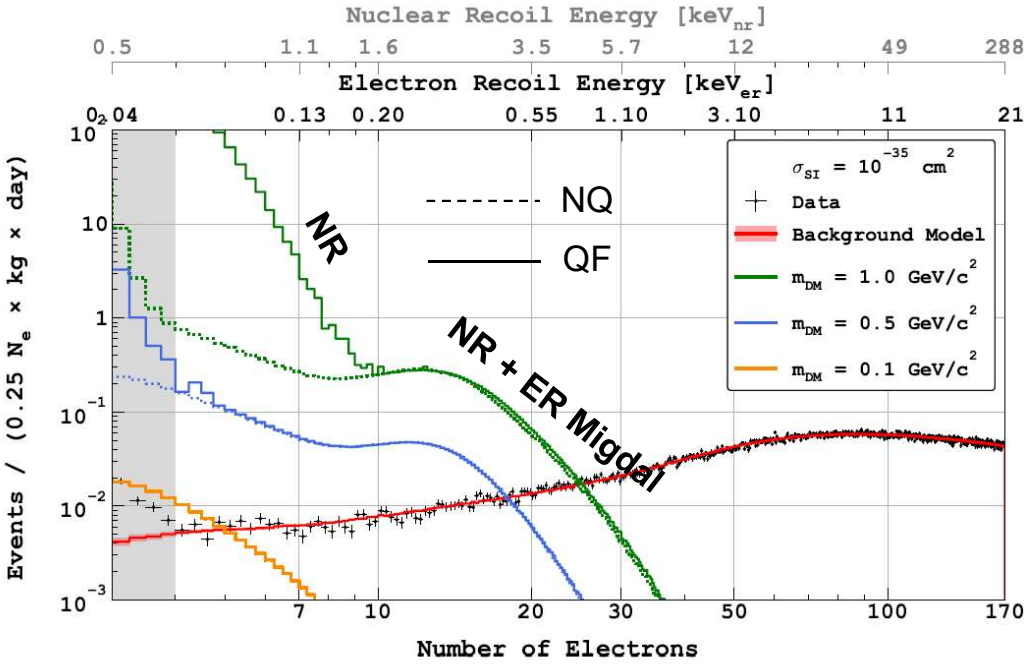
IN2P3: DS-50 physics (4/5)

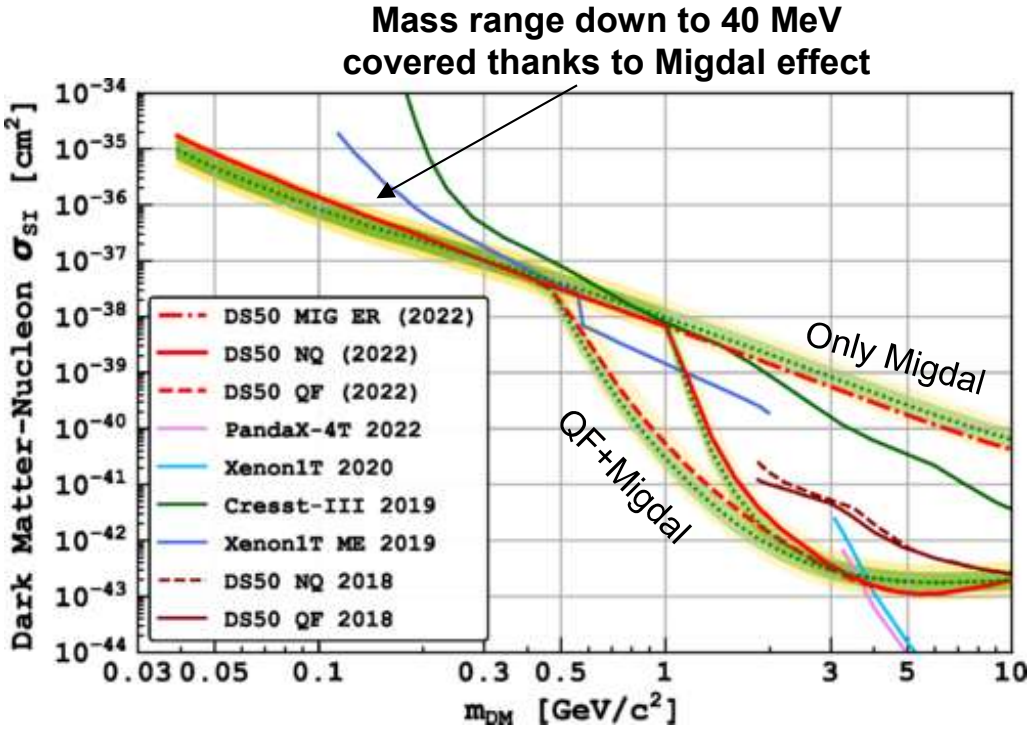
❑ Low mass (<10 GeV) WIMP search

APC, CPPM, UCDavis, Romal, GSSI, Astrocent

PRL **130** (2023) 101001

- WIMP scattering could come with extra ionization (few Ne)
  - ✓ Interpretation accounting for a possible ER Migdal effect
  - ✓ Add extra sensitivity to lower mass WIMP





Assuming ER Migdal effect, DS-50 world leading down to 40 MeV WIMP

IN2P3: DS-50 physics (5/5)

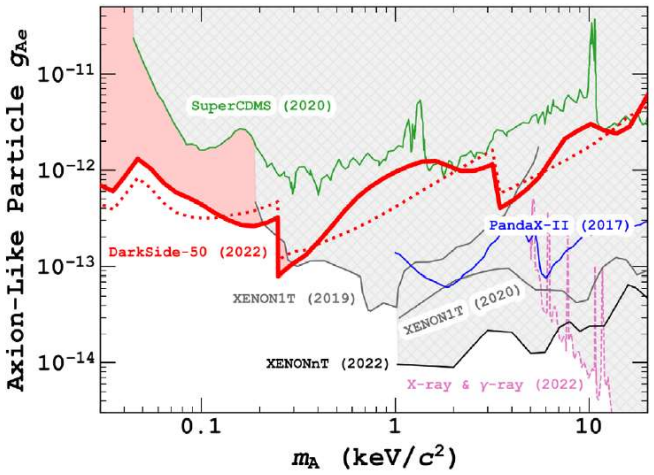
- **(very) low mass Dark Matter search**
  - Can create an ionization signal (few Ne) ...
  - … to which this analysis can be sensitive

APC, CPPM, UCDavis, Romal, GSSI, Astrocent

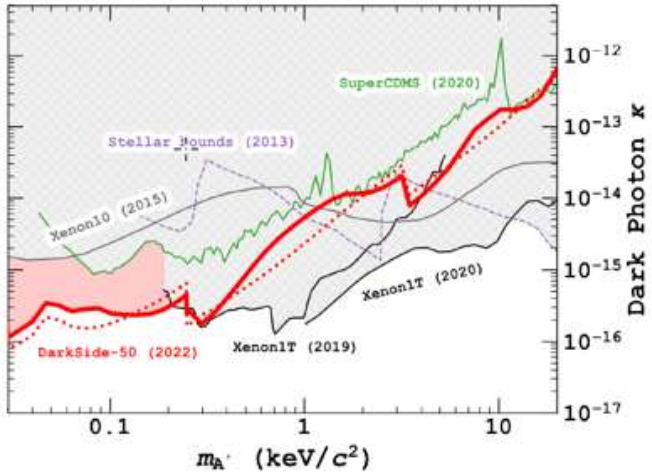
PRL **130** (2023) 101002

Axion Like Particle

Absorption by electrons of Ar atom → Monoenergetic signal

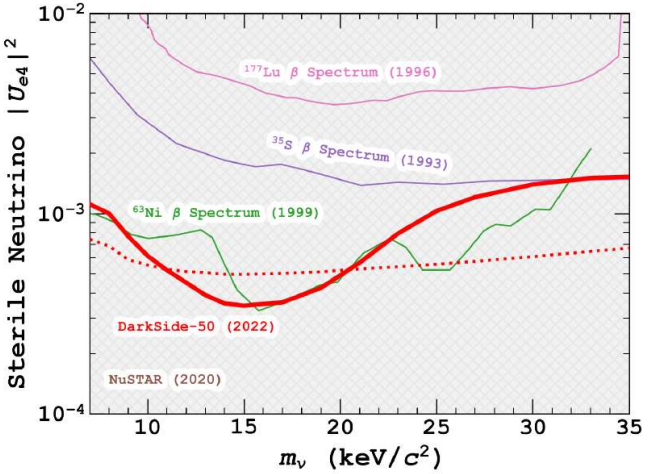


Dark Photon



Sterile Neutrino

Inelastic scattering $\nu_s + e \rightarrow \nu_e + e$



DS-50 also sensitive to galactic ALP, DP, sterile ν in the (sub-)keV regime

Light Dark Matter in back-up

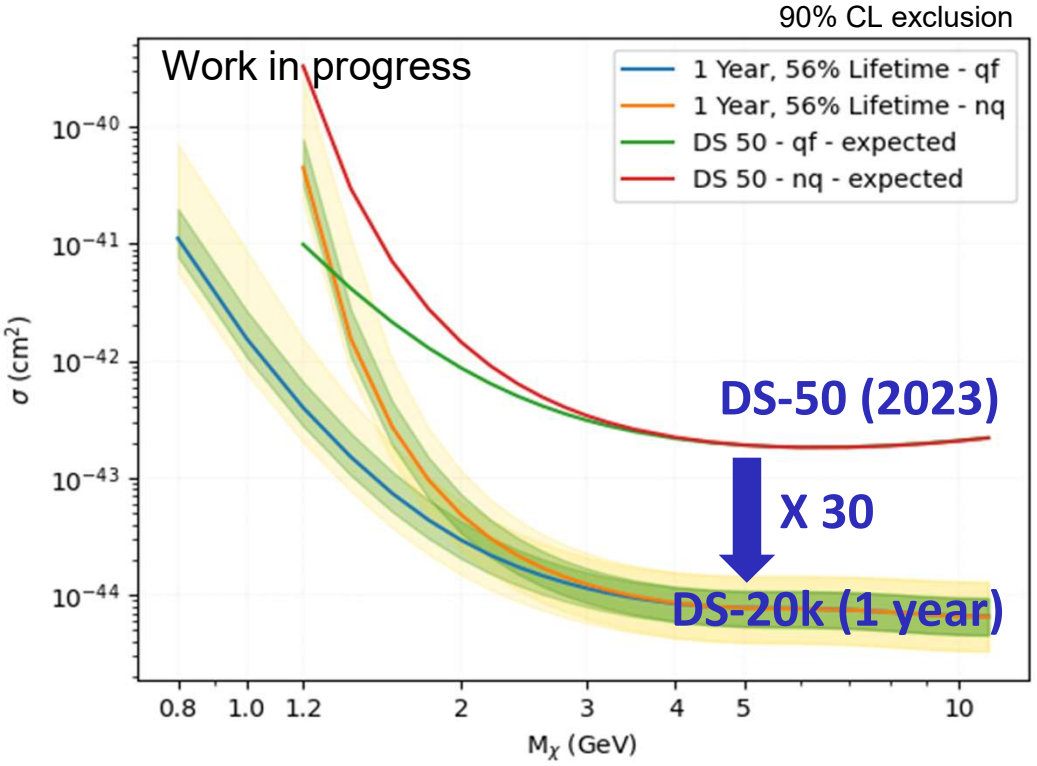
IN2P3: DS-20k physics (1/3)

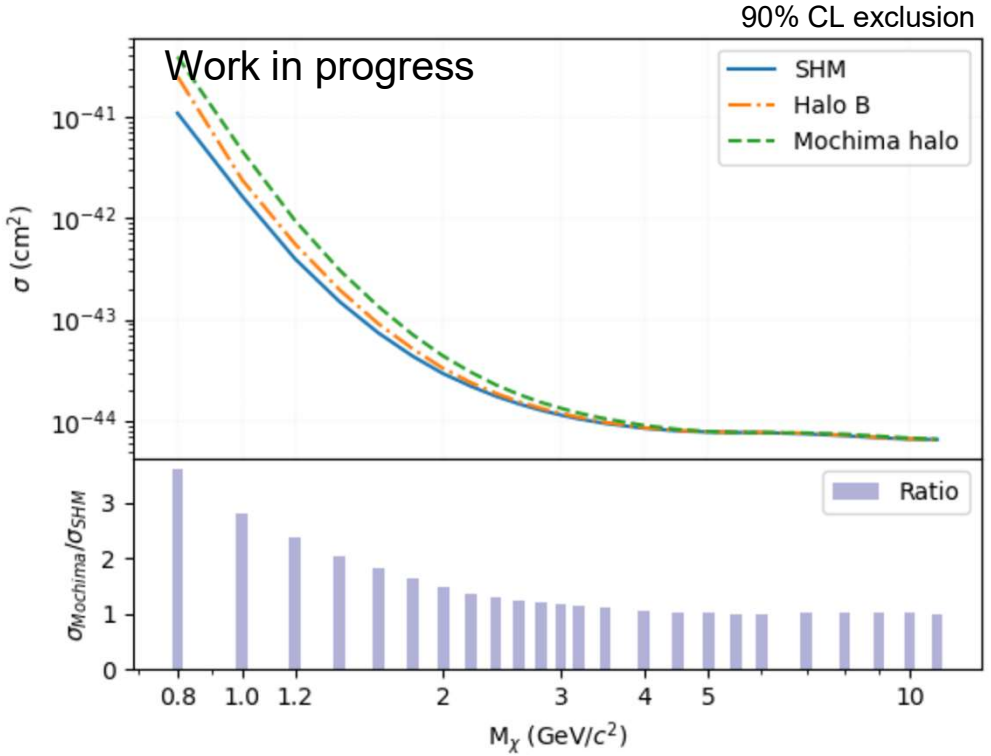
❑ Sensitivity to low mass WIMP (<10 GeV)

CPPM, APC

Paper in preparation

- Largely inspired by DS50 analysis
  - ✓Strong reduction of TPC external background → ^{39}Ar "only" bkg
  - ✓Fully benefit from the LAr volume increase (x1000)
  - ✓Improve also sensitivity to ALP, DP, Sterile ν, LDM
- Impact from the galactic halo assumptions
  - ✓Dedicated studies with LAM (INSU), CPT (INP) and LUPM (IN2P3)





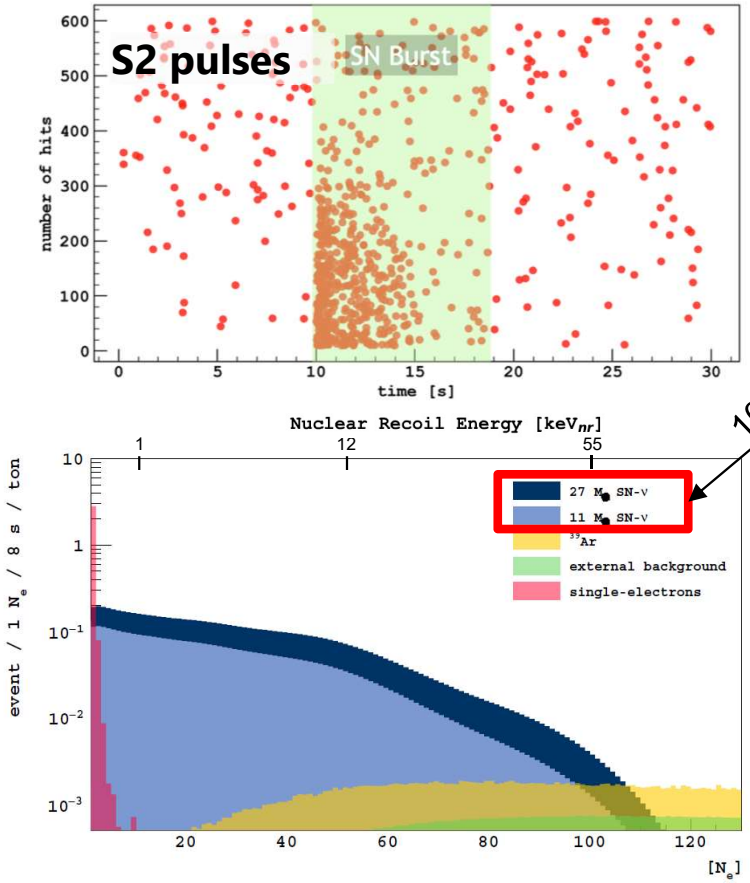
IN2P3: DS-20k physics (2/3)

❑ Sensitivity to Supernovae ν in the milky way

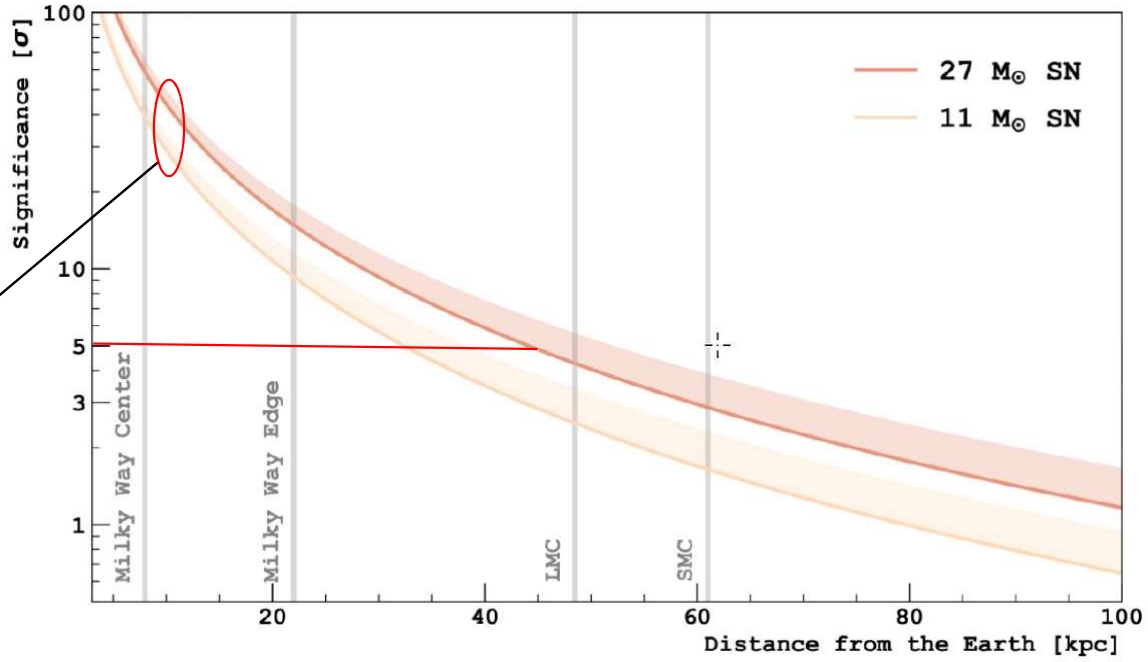
APC, Cagliari

JCAP **03** (2021) 043

- Benefit also from low mass WIMP analysis
  - ✓ E_{NR} ≈ 1-10 keV: coherent elastic ν-nucleus scattering
  - ✓ Insensitive to ν flavor and higher cross-section wrt water Cerenkov, scintillator O(10) MeV



10 kpc



~45 kpc

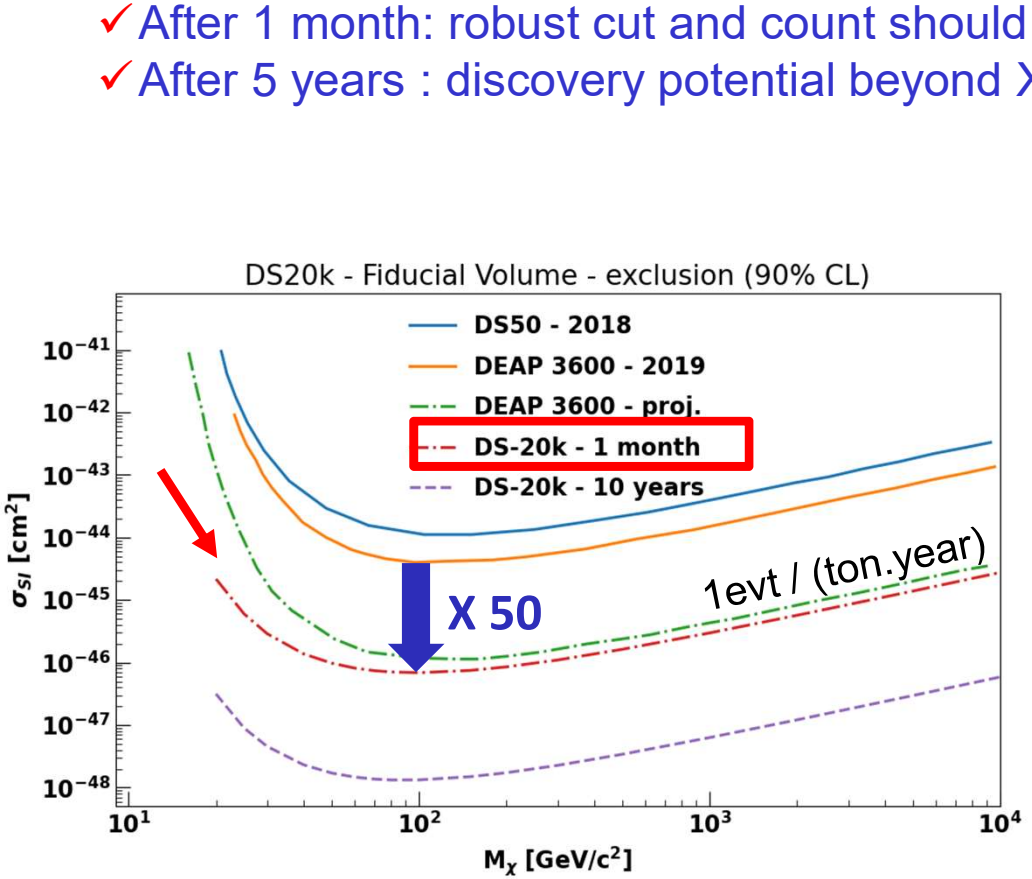
IN2P3: DS-20k physics (3/3)

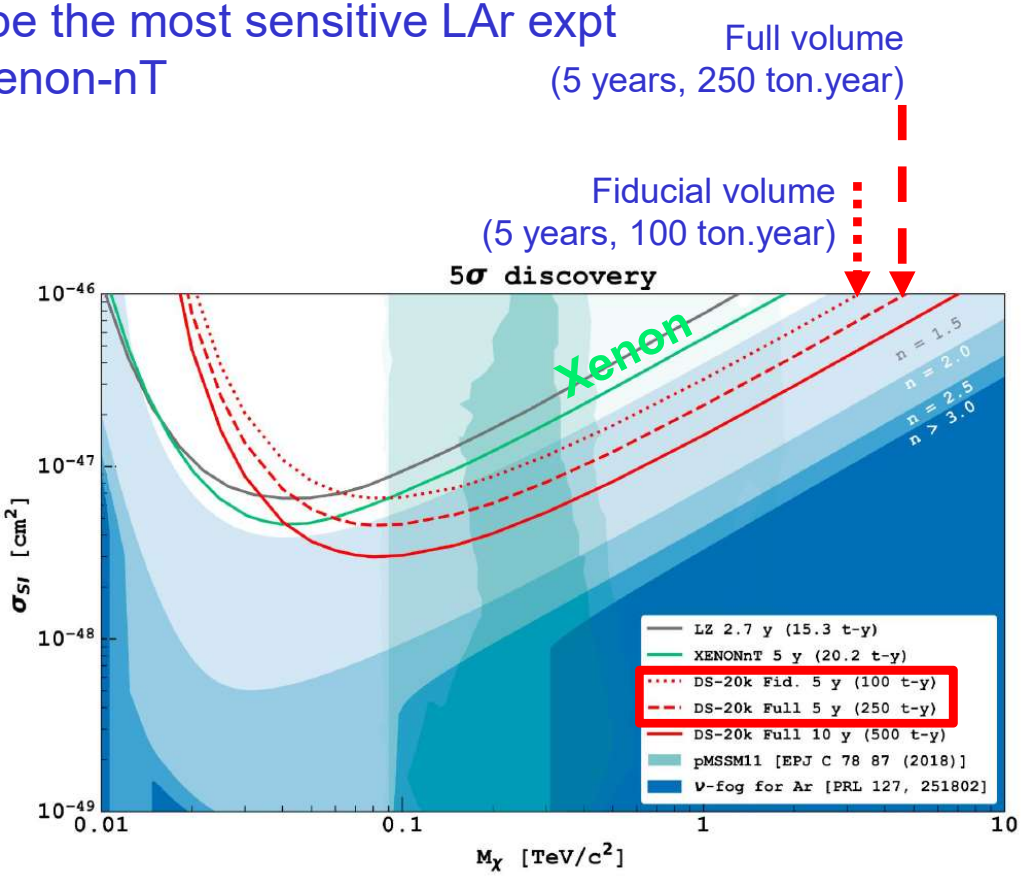
❑ Sensitivity to high mass WIMP

APC, GSSI

Paper in preparation

- Very large improvement in the >50 GeV mass range
  - ✓Assumes detector background free in fiducial volume (20 t)
  - ✓After 1 month: robust cut and count should be the most sensitive LAr expt
  - ✓After 5 years : discovery potential beyond Xenon-nT





DS IN2P3: Physics Summary

Dark Matter (since 2018 CS)

WIMP (Spin Independent)

NR

High Mass WIMP — TeV

Paper in preparation

Low Mass WIMP — GeV

PRD **107** (2023) 063001
PRL **130** (2023) 101001

Paper in preparation

LDM — MeV

ER

ALPs, DP, ν_s — keV

PRL **130** (2023) 101002

Paper in preparation

DS-50

DS-20k

ν

NR

Supernovae neutrino

JCAP 03 (2021) 043

ER

Solar neutrinos
(need 3x300 kton.year exposure)

JCAP 08 (2016) 017

R&D

ANR X-ArT
LabEx BLEND

IN2P3 strong implication in physics

DarkSide IN2P3 responsabilities

❑ Responsibilities in DarkSide





Retired in 2023 →

Name	Date	Task
P. Barrillon	2023-	Technical coordinator of DarkSide-France
D. Franco	2016-	L1 manager of "Science, simulation and computing"
	2016-	Member of the Institute, Executive and Management boards
	2016-20	Coordinator of DarkSide-France, National contact physicist
F. Hubaut	2020-	Member of the Institute Board
E. Le Guirriec	2020-	Czar of the group at CC-IN2P3
P. Pralavorio	2021-23	Member of the Editorial Board
	2023-25	Member of the Financial and Advisory Board
	2023-	Coordinator of DarkSide-France, National contact physicist
I. Wingerter-Seez*	2021-22	Member of the Review Office, Executive and Management boards
	2021-22	Coordinator of DarkSide-France, National contact physicist

❑ Implications in many Working Packages (WP)

- Coordination the WP activity of GDR DUPHY
  - ✓ WP2 (Low radioactivity techniques)
  - ✓ WP3 (Detection of rare-events)
  - ✓ WP4 (Simulation & Analysis)
- Coordination of ECFA Noble Liquid WP (3.2) in DRD2 Liquid detector

DarkSide IN2P3 HR

	Nom des personnes	Statut	2021	2022	2023	2024	2025	2026
Phycisists	**APC**		**230%**	**350%**	**300%**	**335%**	**335%**	**310%**
	M. D. Franco	DR2	100%	100%	100%	100%	100%	100%
	Mme A. Tonazzo	Prof.	10%	10%	10%	10%	10%	10%
	M. T. Hessel	PhD	25%	100%	100%	75%		
	M. T. Hugues (cot. ASTROCENT)	PhD	25%	50%	40%			
	Mme E. Nikoloudaki	PhD			25%	100%	100%	75%
	Mme J. Rode (cot. LPNHE)	PhD	50%	40%				
	Thèse ANR	PhD				25%	100%	100%
	Stagiaires	M2	20%	50%	25%	25%	25%	25%
	CPPM		**295%**	**345%**	**295%**	**345%**	**345%**	**345%**
	M. J. Busto	Prof.	20%	20%	20%	20%	20%	20%
	M. Y. Coadou	CR			50%	100%	100%	100%
	M. F. Hubaut	DR1	50%	50%	50%	50%	50%	50%
	M. P. Pralavorio	DR2	50%	50%	50%	50%	50%	50%
	Mme I. Wingerter-Seez	DRCE	100%	100%				
	Mme M. van Uffelen	PhD	25%	100%	100%	75%		
	Thèse ANR	PhD				25%	100%	100%
	Stagiaires	M2	50%	25%	25%	25%	25%	25%
	Laboratoire LPNHE		**70%**	**55%**	**0%**	**0%**	**0%**	**0%**
	M. C. Giganti	CR	20%	15%	0%	0%		
	Mme J. Rode (cot. APC)	PhD	50%	40%				
	TOTAL (FTE)		**5.95**	**7.50**	**5.95**	**6.80**	**6.80**	**6.55**
Engineers	**CPPM**		**80%**	**80%**	**90%**	**90%**	**90%**	**90%**
	M. Pierre Barrillon	IR	20%	20%	20%	20%	20%	20%
	M. Emmanuel Le Guirriec	IR	40%	40%	50%	50%	50%	50%
	M. Jérôme Royon	AI	20%	20%	20%	20%	20%	20%
	LPNHE		**20%**	**0%**	**0%**	**0%**	**0%**	**0%**
	M. Olivier Dadoun	IR	20%	0%	0%	0%		
	TOTAL (FTE)		**1.00**	**0.80**	**0.90**	**0.90**	**0.90**	**0.90**

in 2023

- **2 labs** (APC, CPPM)
  - ✓LPNHE stopped in 2023
- **9 permanent** staff
  - ✓2 professors
  - ✓4 researchers
  - ✓3 engineers
- **3 PhD** students / year
- **2 internships** of master 1 or 2 / year at APC, CPPM or CERN

5% of DS-20k

7-8 FTE / year since 2020
(3 Phys. + 3 PhD + 1 Eng.)

➔ **Request a postdoc for 2024**

DarkSide IN2P3 Funding

IN2P3

Type	Financements	2021	2022	2023	2024	2025	2026
Equipements		**- €**	**- €**	**9,000 €**	**9,000 €**	**- €**	**- €**
Calibration mock-up @ CERN	IN2P3	- €	- €	5,000 €	3,000 €		- €
Tubes DS20k	IN2P3		- €	4,000 €	6,000 €		
Fonctionnement		**- €**	**- €**	**- €**	**8,000 €**	**8,000 €**	**8,000 €**
MoU - Fond Commun Constr.	IN2P3				8,000 €	8,000 €	8,000 €
Missions		**1,750 €**	**1,750 €**	**14,750 €**	**26,000 €**	**31,000 €**	**28,000 €**
Collaboration (CPPM)	IN2P3	- €	- €	4,000 €	10,000 €	10,000 €	10,000 €
Opération (CPPM)	IN2P3			4,000 €	10,000 €	15,000 €	10,000 €
Collaboration (APC)	IN2P3			5,000 €	6,000 €	6,000 €	8,000 €
COPIN-IN2P3	IN2P3	1,750 €	1,750 €	1,750 €			
TOTAL		**1,750 €**	**1,750 €**	**23,750 €**	**43,000 €**	**39,000 €**	**36,000 €**

→ Still under discussion

Others

Equipements		**11,100 €**	**10,000 €**	**25,000 €**	**5,000 €**	**2,000 €**	**2,000 €**
Neutron detector & RD	Labex APC			15,000 €			
Calibration mockup	RP CPPM	1,000 €					
Calibration mockup	IPhU@AMU	10,100 €	5,000 €	5,000 €			
Calibration mockup	MITI		5,000 €	5,000 €			
Calibration DS20k + info	ANR FIDAR				5,000 €	2,000 €	2,000 €
Missions		**1,700 €**	**15,000 €**	**16,000 €**	**7,000 €**	**8,000 €**	**25,000 €**
Collaboration (APC)	Labex APC		5,000 €	5,000 €			
Collaboration (CPPM)	iPhU@AMU+MITI	700 €	9,000 €	11,000 €	2,000 €		
Collaboration (LPNHE)	RP LPNHE	1,000 €	1,000 €				
Collaboration + opération	ANR FIDAR				5,000 €	8,000 €	25,000 €
Personnels		**14,300 €**	**43,000 €**	**44,500 €**	**58,000 €**	**84,000 €**	**84,000 €**
Thèse Marie van Uffelen	iPhU@AMU	10,000 €	40,000 €	40,000 €	30,000 €		
2 Thèses	ANR FIDAR				28,000 €	84,000 €	84,000 €
Visiteurs étrangers	IPhU@AMU	2,300 €	2,100 €	4,500 €			
Stages	IPhU@AMU	2,000 €					
Stages	RP CPPM		900 €				
TOTAL		**27,100 €**	**68,000 €**	**85,500 €**	**70,000 €**	**94,000 €**	**111,000 €**

- Funded by IN2P3 since 2023

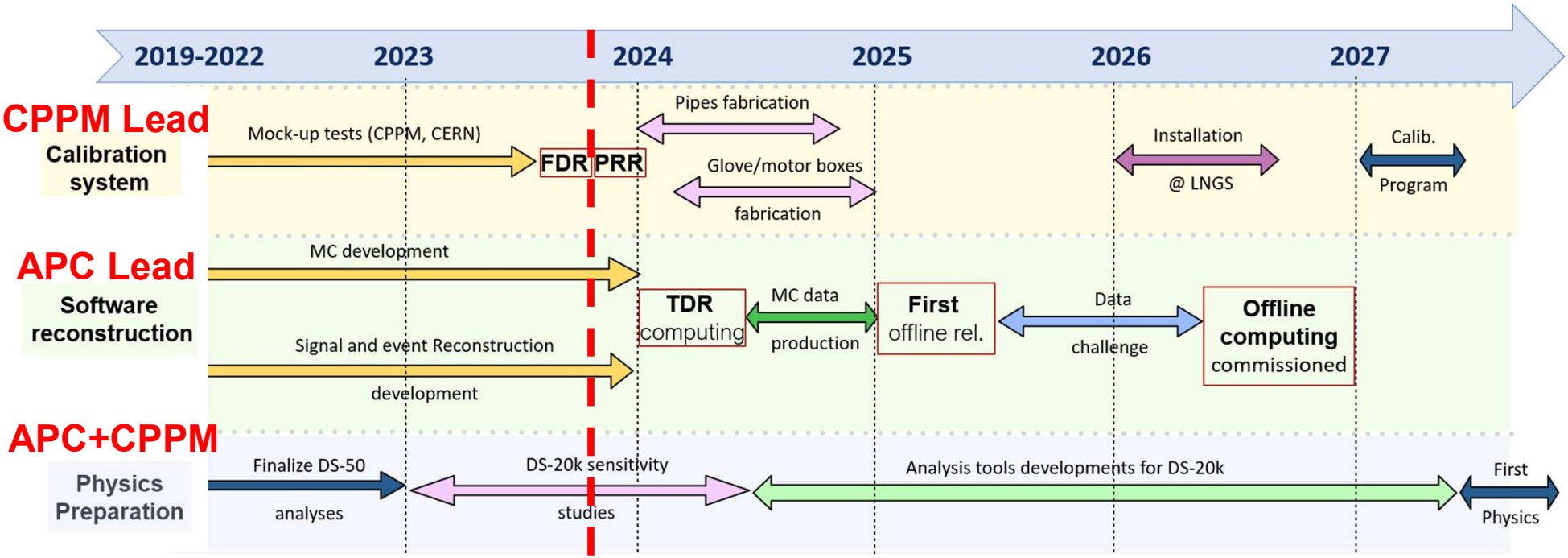
0.2% of DS-20k total budget *(110 M€ consolidated)* provided by IN2P3

- IPHU (2021-24)*: 1 PhD + 30 k€
- Labex APC (2022-): 25 k€
- CNRS-MITI (2022-23)**: 20 k€
- ANR (2024-27) : 2 PhDs + 58 k€

* with LAM (INSU), LUPM (IN2P3) and CPT (INP)
** with LAM (INSU) and LUPM (IN2P3)

Conclusions

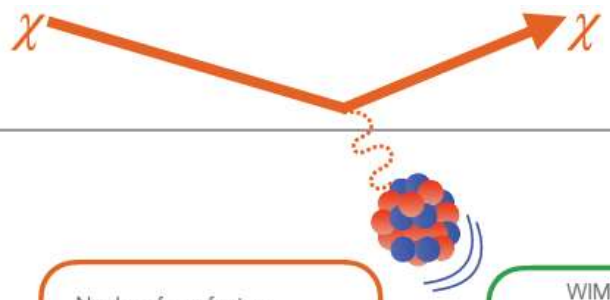
- **DS-20k: next generation of LAr dual phase TPC**
  - Start installation @ LNGS in Sep. 2022. First physics run foreseen in 2027
- **IN2P3 coherent program to prepare first physics with DS-20k**
  - Leadership in DS-50 **physics analysis** and DS-20k sensitivity
  - **Simulation tools** for calibration strategy and signal/evt reconstruction
  - **Calibration data** to validate *in-situ* reconstruction and first physics strategy



BackUp

WIMP Signal

WIMP Signal



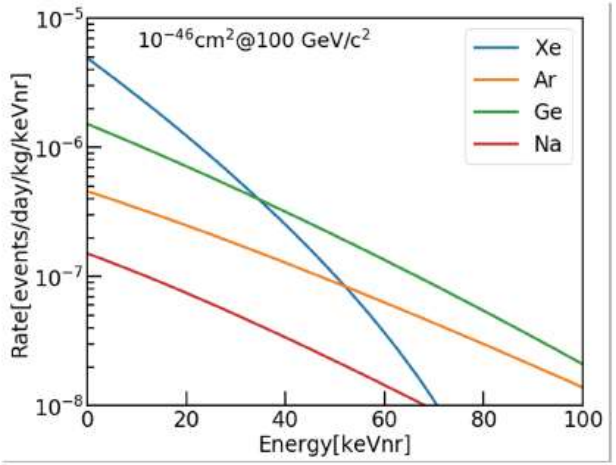
$$\frac{dR}{dE_r} \propto \frac{\sigma^p_{SI}}{2\mu^2_{\chi p} M_\chi} \times A^2 |F(E_r)|^2 \times \rho_0 \int_{v_{min}}^{\infty} \frac{f_1(v)}{v} dv$$

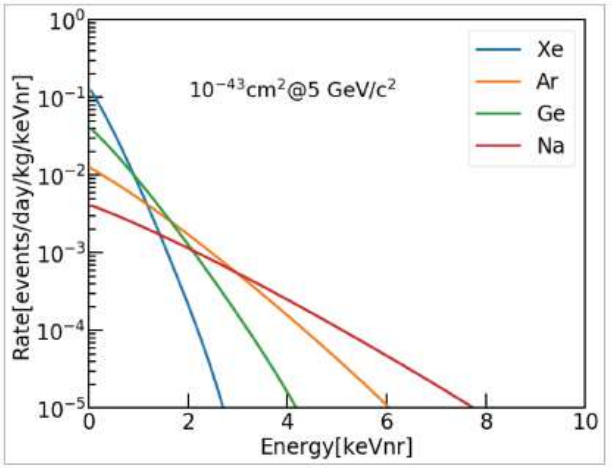
- σ^p_{SI}: WIMP-nucleon cross section
- $2\mu^2_{\chi p}$: WIMP-nucleon reduced mass
- M_χ: WIMP mass
- $A^2 |F(E_r)|^2$: Nuclear form factor
- A: Atomic mass
- ρ_0: Local WIMP mass density
- $f_1(v)$: WIMP velocity distribution

PHYSICS

TARGET MATERIAL

ASTROPHYSICS





GADMC

A union of 4 collaborations, with over 400 scientists, spanning over 100 institutions across 13 countries

DarkSide-50: LNGS

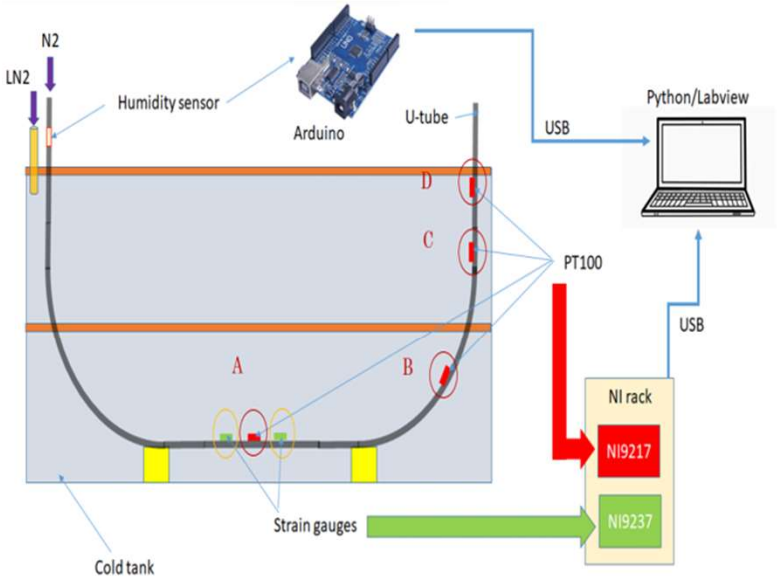
ArDM: Canfranc

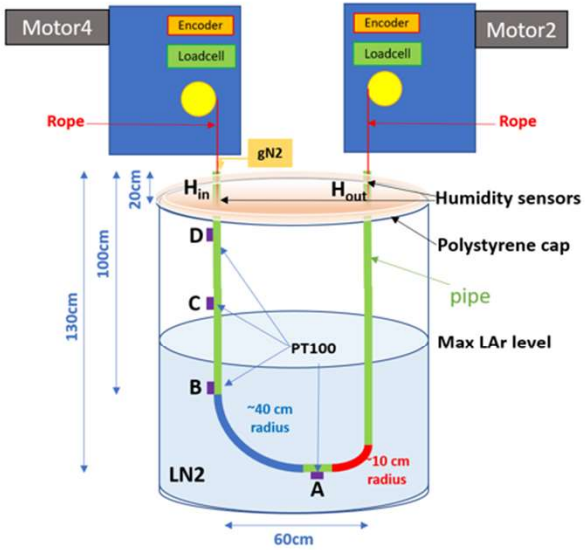
DEAP: SNOLAB

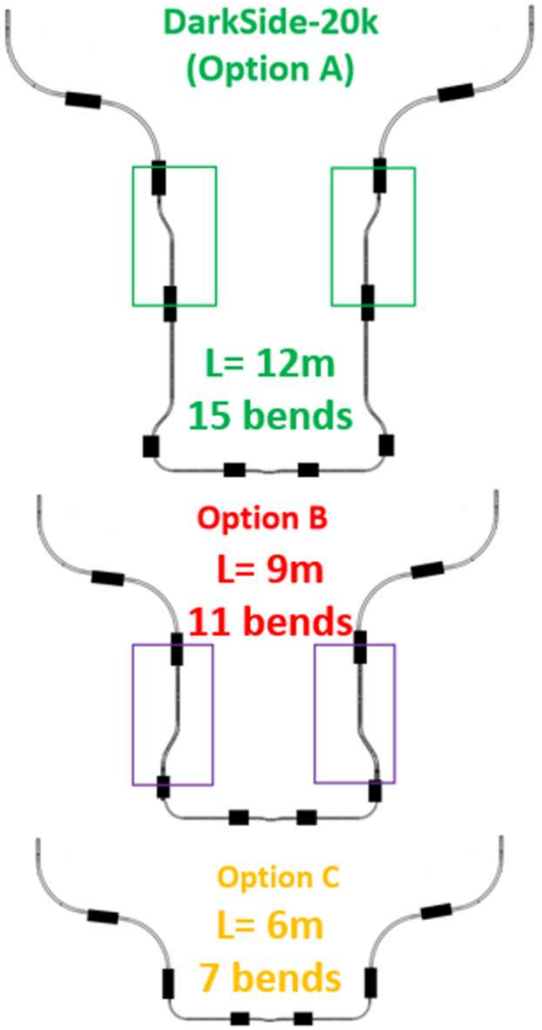
MiniClean: SNOLAB

INFN · INNOVATION.CA · U.S. DEPARTMENT OF ENERGY Office of Science · NSF · Science & Technology Facilities Council · IN2P3 · Institute of High Energy Physics Chinese Academy of Sciences

DS-20k Calibration

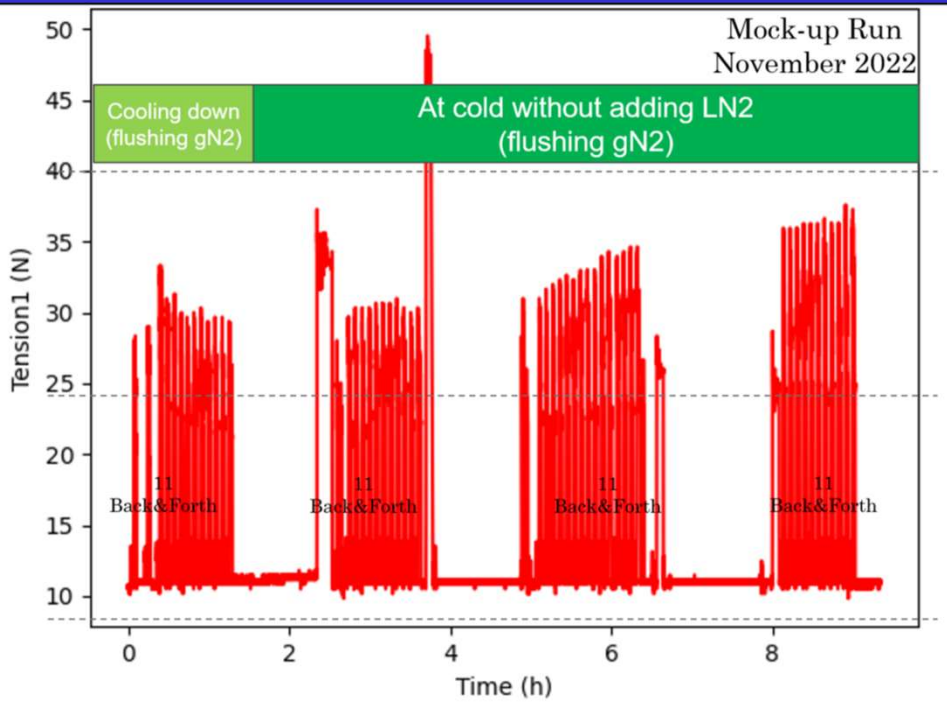


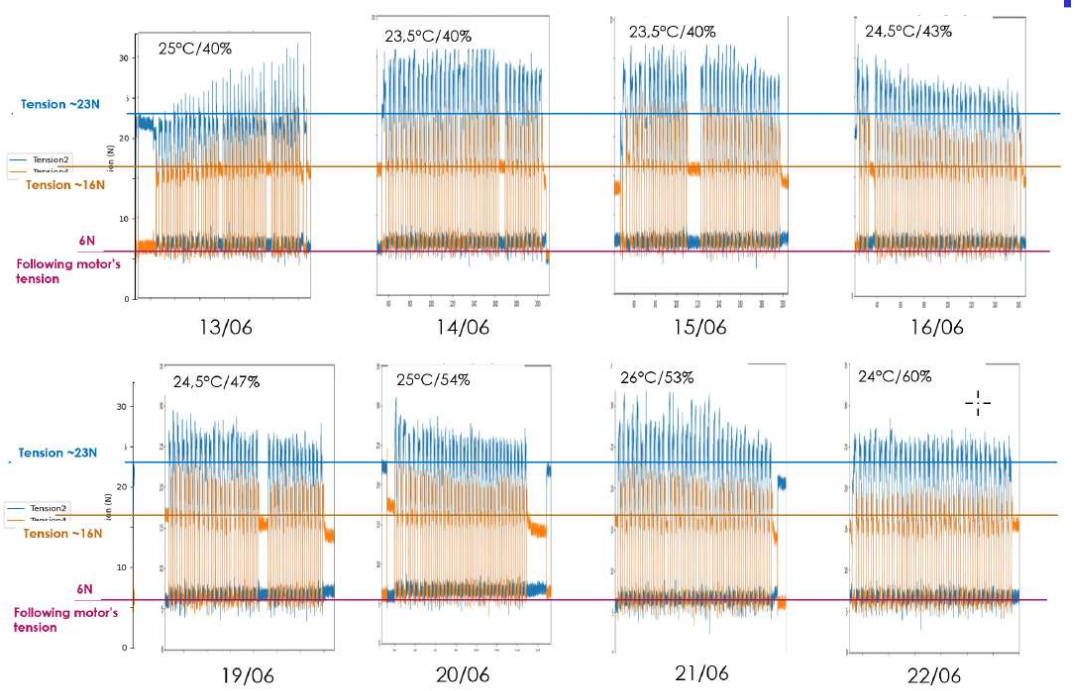




	LAr	LN2	LN2	LAr	
	DS-20k	MU_CS	MU_CL		MU_W
	Requirements / Performance				
Speed of the source (cm/s)	> 1	3	1		2
Position accuracy (cm)	±1	±1	1		±1
Tension (N)	< 150	25-40	15-30		60-90
Ice formation (block)	No	No	Yes but sublimated	No	NA NA
Total distance for all sources (m)	160 (/yr)	> 100	800	100	> 100
Total nb of back&forth / tube	4 (/yr)	44	280	35	>6

DS-20k Calibration





	LAr	LN2	LN2	LAr	
	DS-20k	MU_CS	MU_CL		MU_W
	Requirements / Performance				
Speed of the source (cm/s)	> 1	3	1		2
Position accuracy (cm)	±1	±1	1		±1
Tension (N)	< 150	25-40	15-30		60-90
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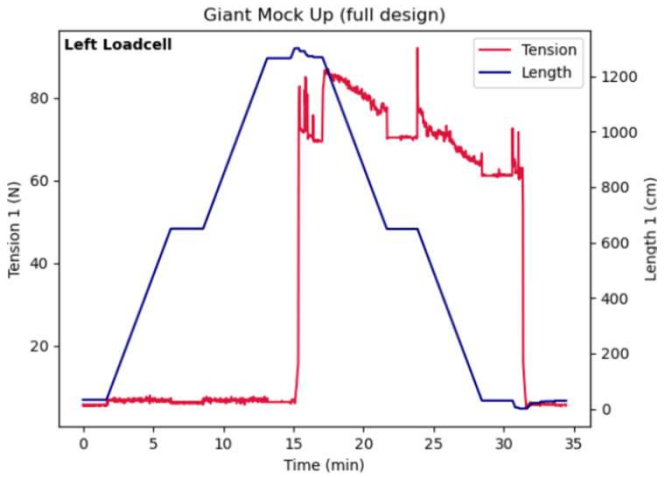


Light Dark Matter

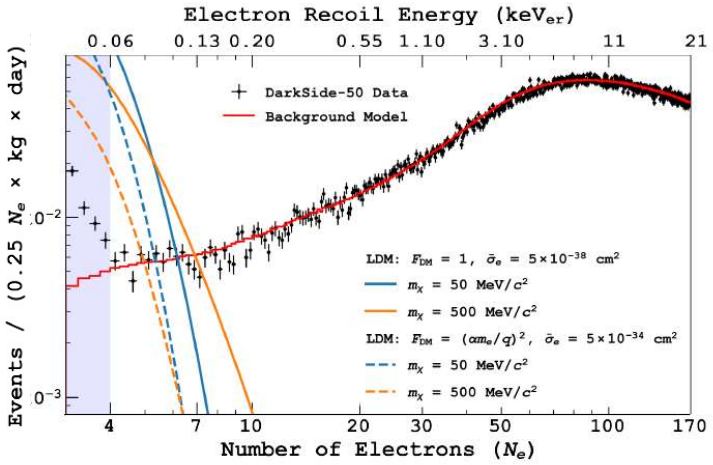
❑ Low mass (<10 GeV) WIMP search

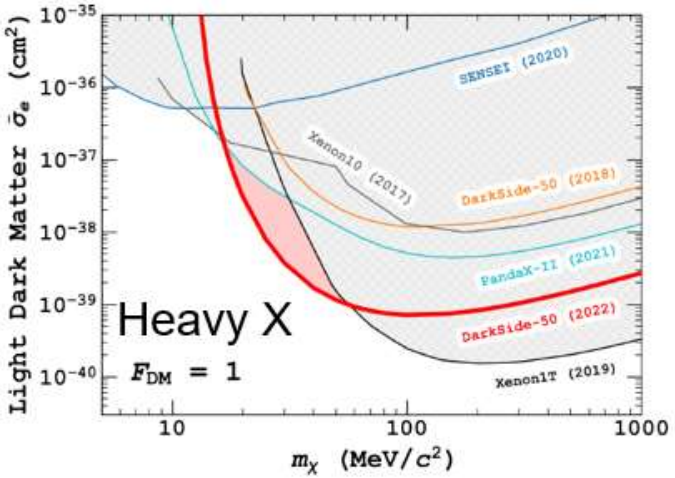
- Re-analysed DS-50 data, published in 2023
  - ✓ Improve analysis → describe bkg Ne≥4
  - ✓ Interpretations with light dark matter

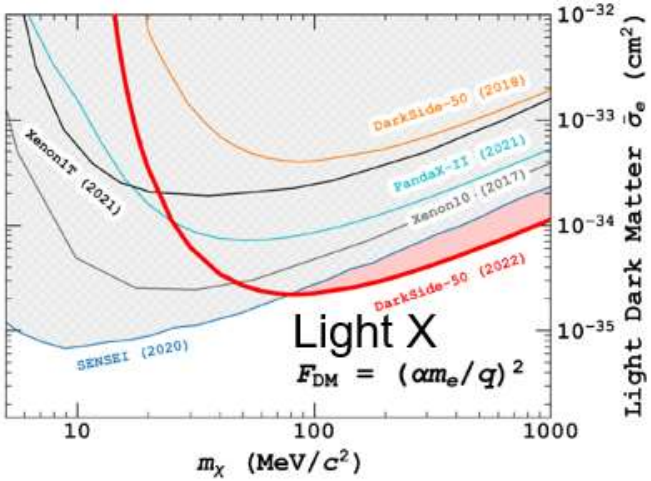
APC, CPPM, UCDavis, Romal, GSSI, Astrocent

PRL **130** (2023) 101002

New Mediator X ($\chi + e \rightarrow X \rightarrow \chi + e$)







DarkSide-50 world leading in 20-50 (100-1000) MeV for heavy (light) X

Solar Neutrino

❑ Sensitivity studies

- Solar neutrinos via elastic scattering
  - ✓ Need >1 kton.year exposure to be competitive with Bx
  - ✓ E > 600 keV (^{39}Ar): 7Be (2%), pep (9%), CNO (15%)

APC

JCAP **08** (2016) 017