

IPHU-018 : Direct search for WIMP Dark Matter

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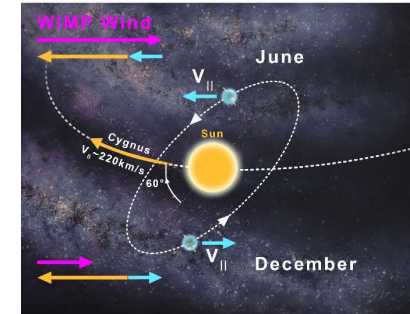
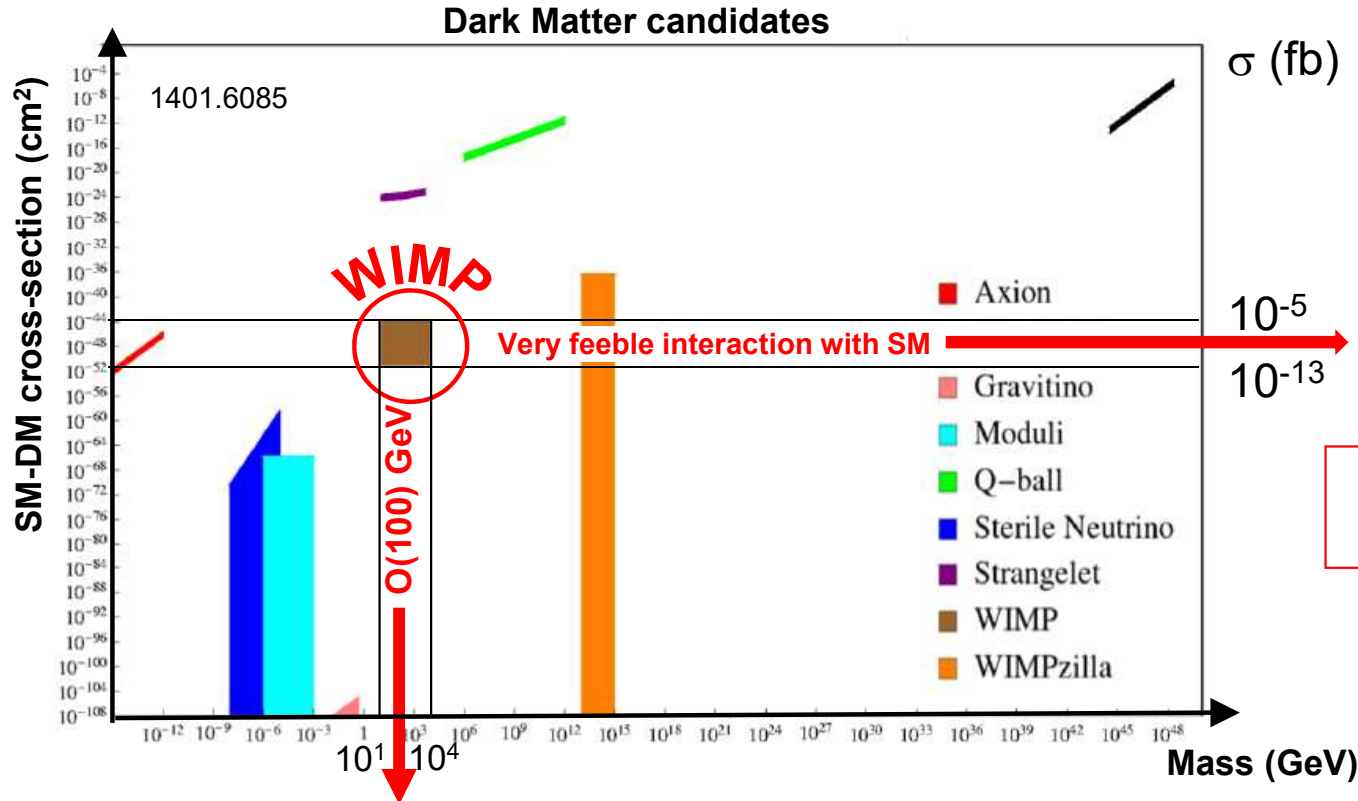


- 1- Status of direct WIMP searches
- 2- DarkSide-20k experiment
- 3- IPhU Project : Status and prospects
- 4- Conclusions

WIMP Dark Matter challenges

□ **WIMP is one of the best motivated candidate**

Lattice QCD SM-DM computation (CPT)



is balanced by the abundance of WIMPs in the galactic halo

Description of the local galactic halo (LAM, LUPM)

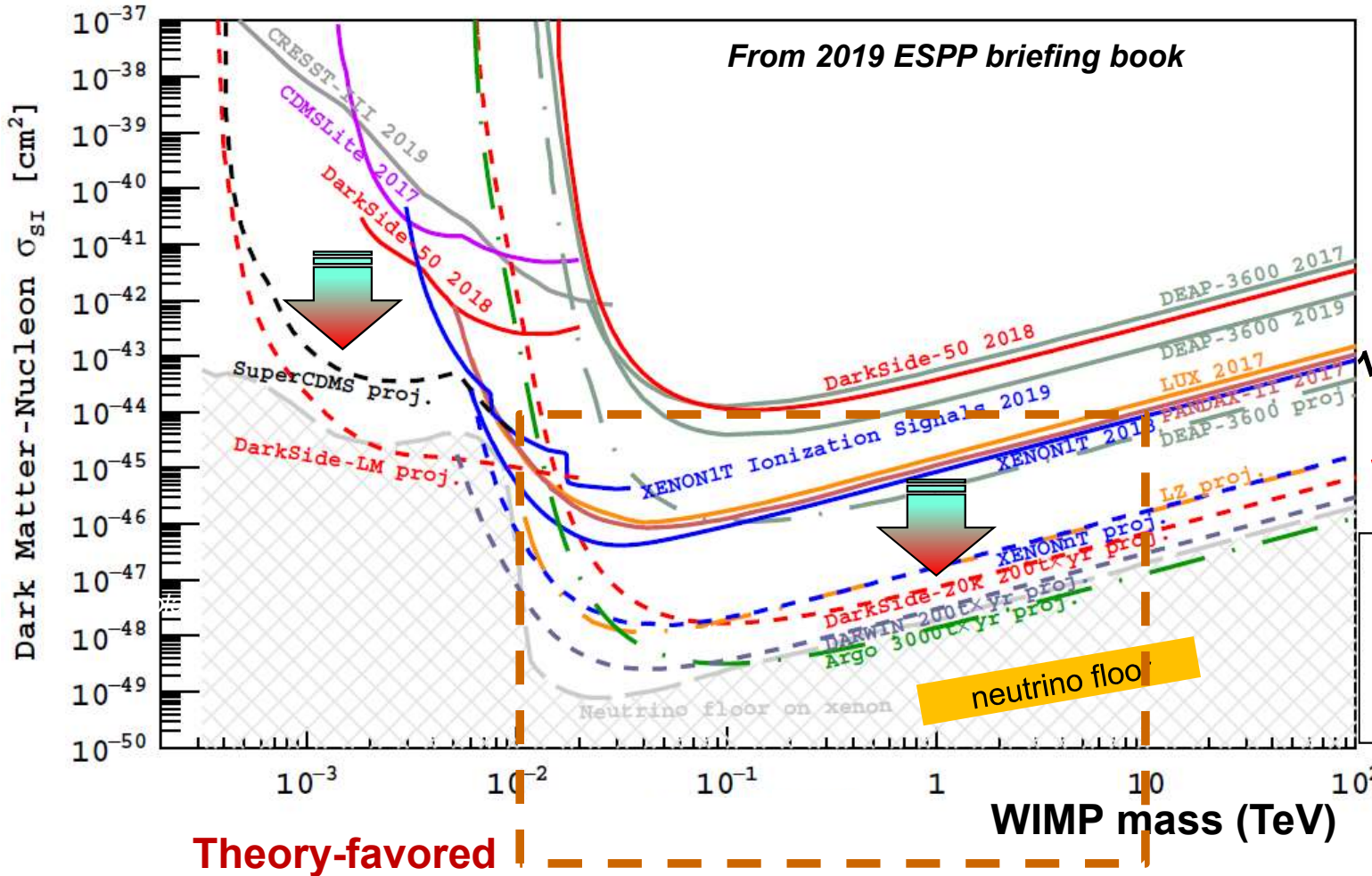
- High mass → visible signal
- $O(10^{-3})/\text{cm}^3$ → Low occupancy
- Large detector → background

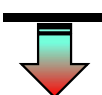

Detector with large volume and very low background (CPPM)

DarkSide-20k

Regroup 4 labs (7 physicists + 1 PhD). Financed for 4 years (2021-24)

WIMP Search



 Current limits
 Proj. limits

APPEC 2017 recommendation :
 "strategy aimed at realising 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."

L = Liquid

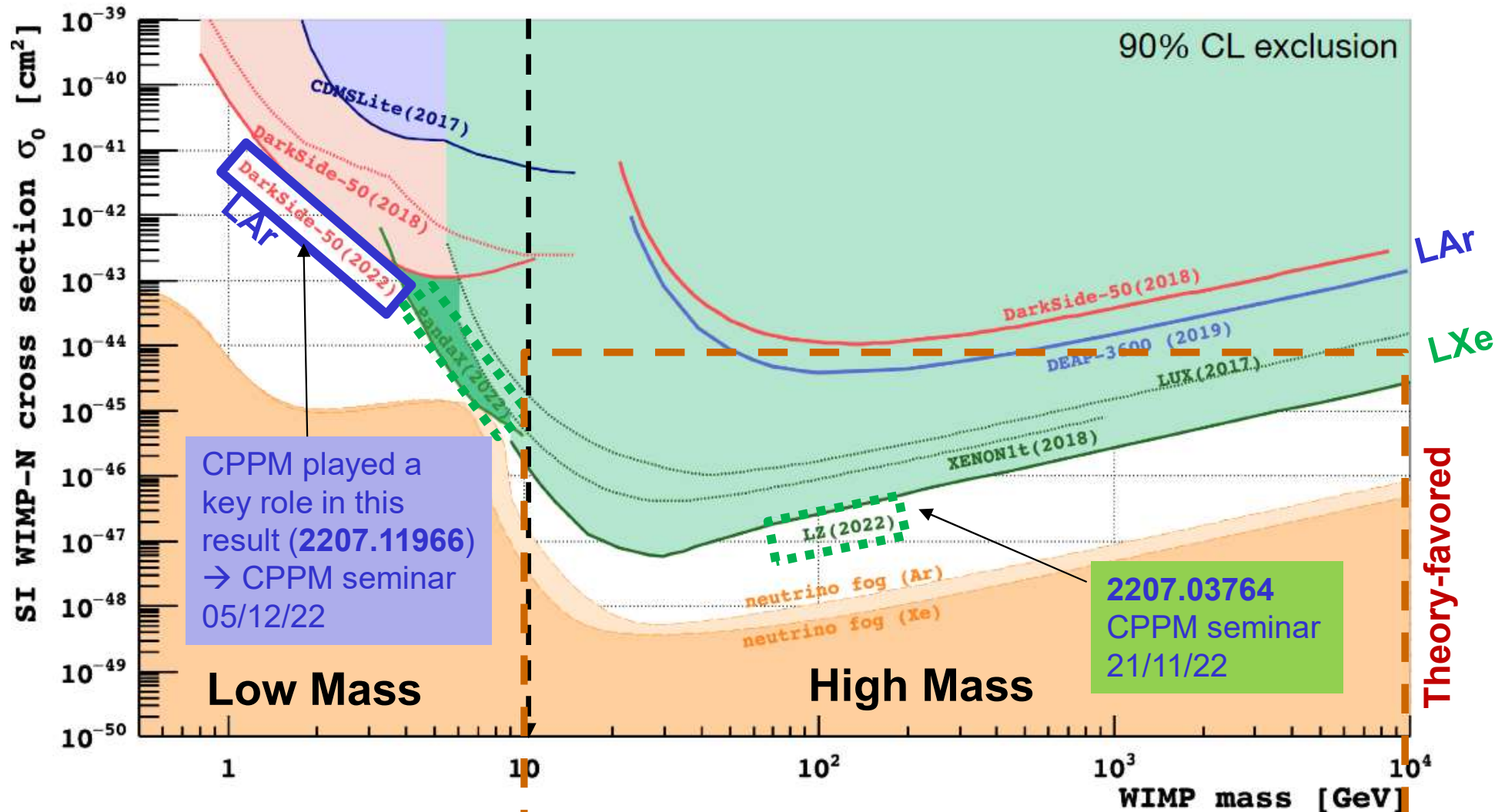
TPC = Time Projection Chamber

LXe/LAr dual phase TPCs lead the WIMP search from GeV \rightarrow 100 TeV

Xenon-1T, LUX, Panda-X, LZ, Xenon-nT, Darwin / DarkSide-50, DarkSide-20k, Argo

WIMP Search in 2022

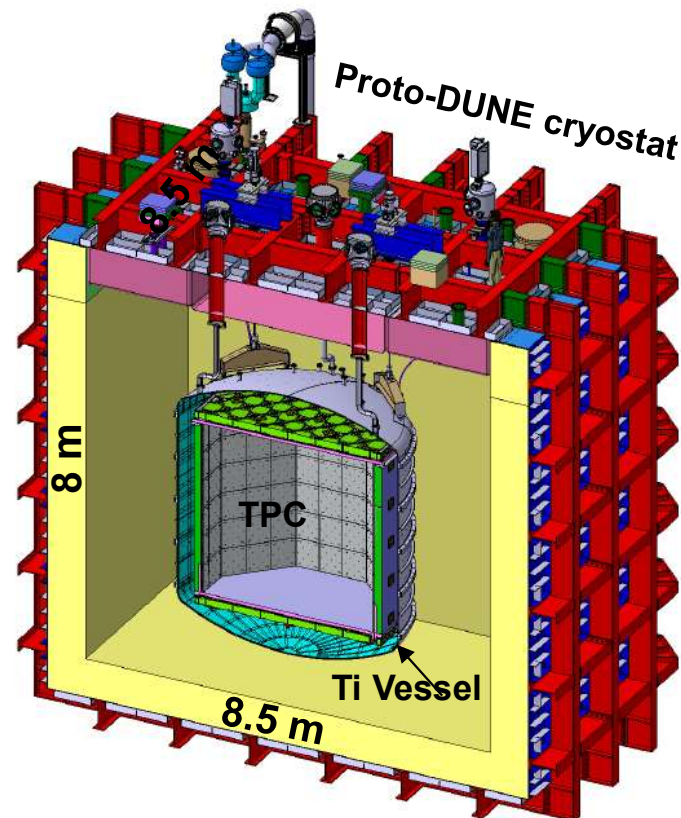
- **Very hectic competition between the Dual Phase TPC experiments**
 - One order of magnitude improvement in 1 GeV -- 10 TeV since one year !



DarkSide-20k

❑ Located in Grand Sasso underground lab (Italy)

- Installation: started in September 2022 and planned to be completed by end 2026
- Physics: first run in 2027



Main Characteristics:

- 350 collaborators
- **Dual Phase TPC**
- Inner/outer neutron veto
- 100 t Purified Ar (Ti vessel)
- **250k SiPM → 2500 Ch.**

Bright sides

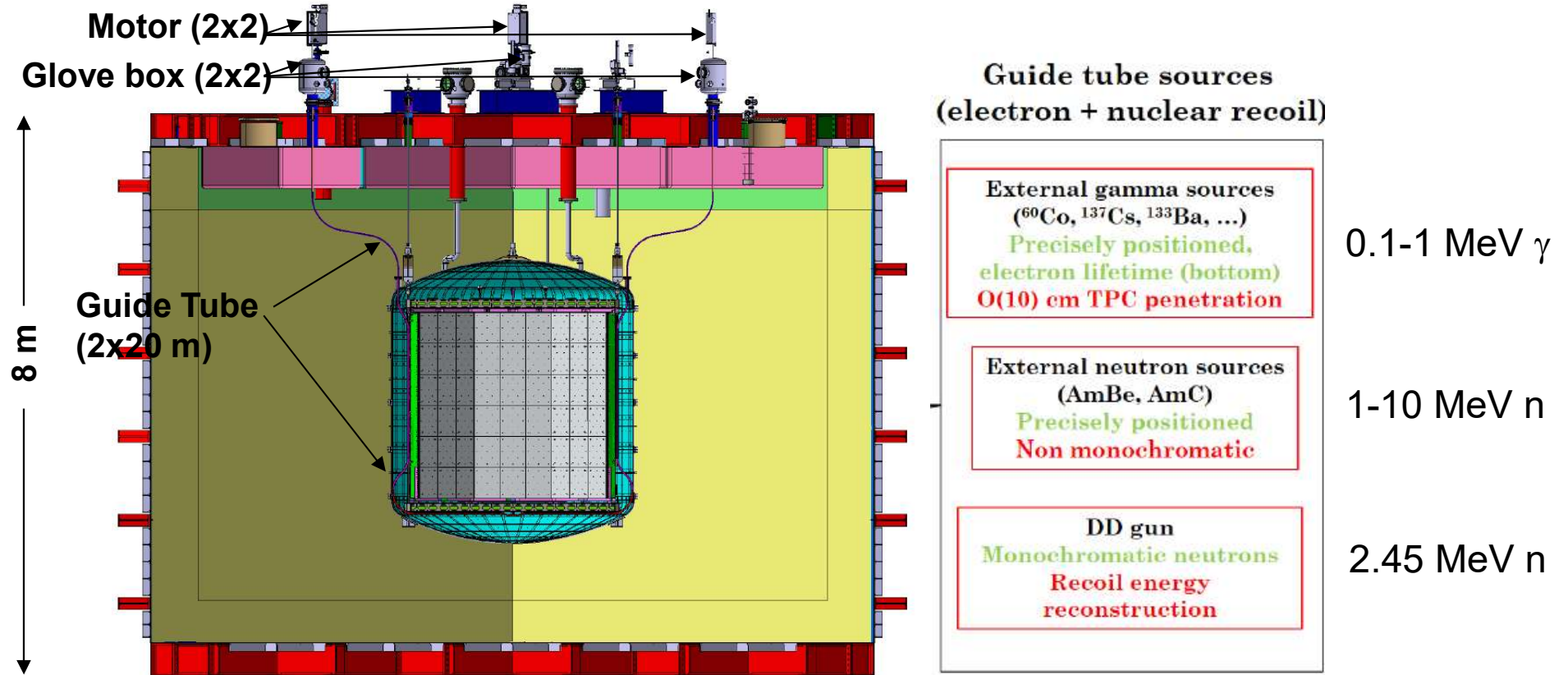
- Background free at high WIMP mass (>100 GeV)
- Run 10 years (200 t.yr)
- High discovery potential (GeV \rightarrow 100 TeV)

Will be the largest TPC ever build for Dark Matter searches !

DS-20k Calibration (1/4)

□ CPPM responsible for the TPC calibration system

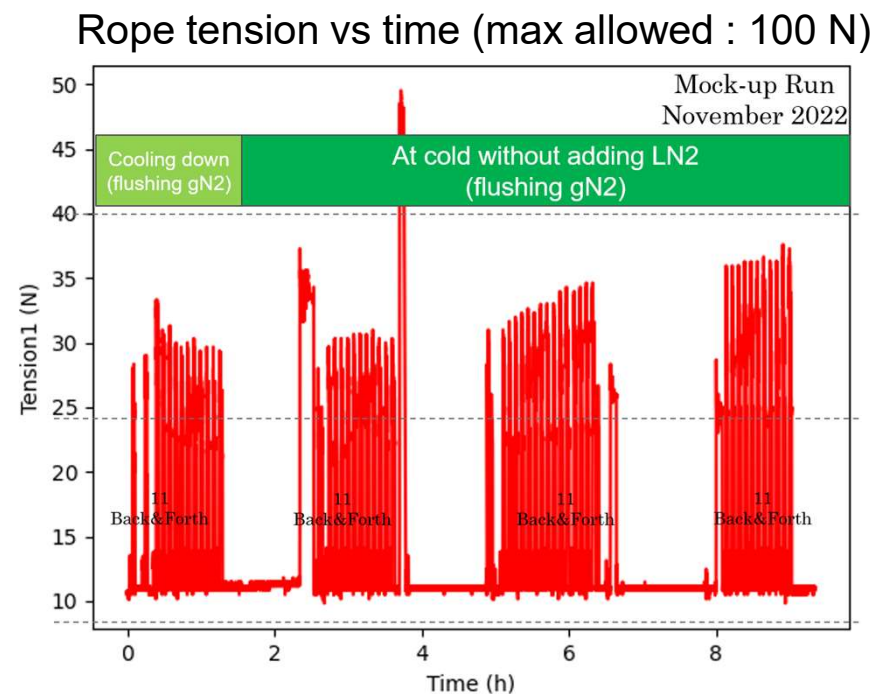
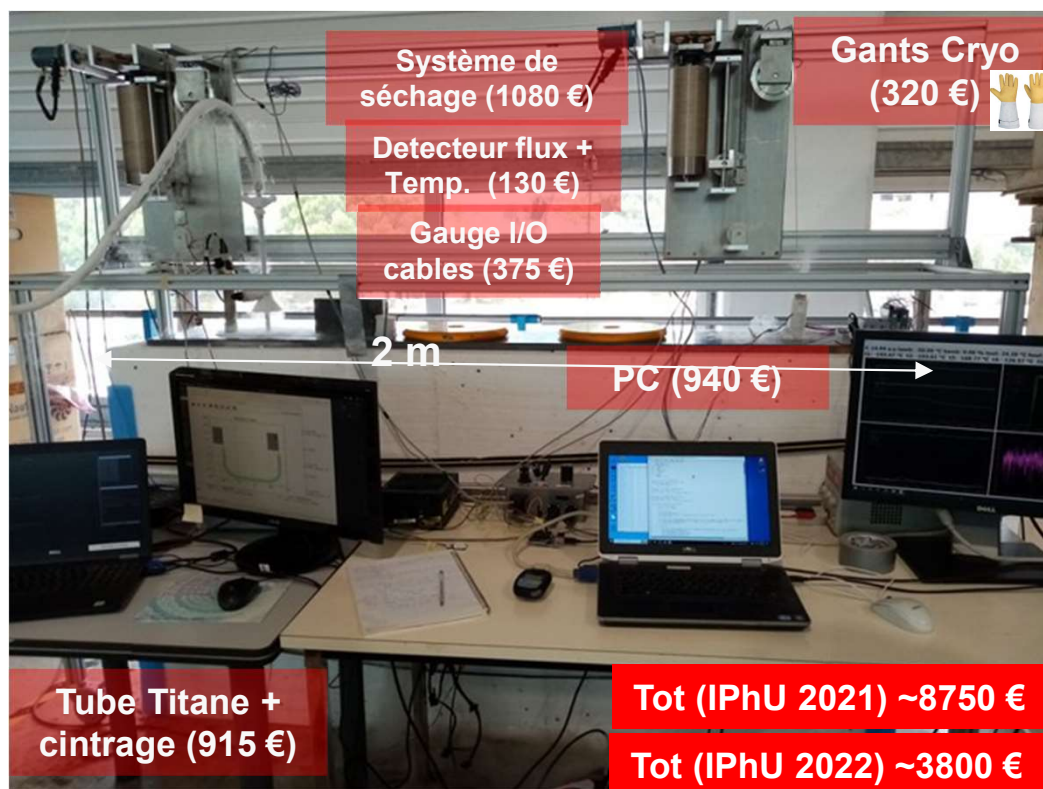
- Goal : circulate radioactive sources in a guide tube around the TPC (TDR 2021)
- 2021 : Establish the calibration program (*using Geant4 simulation*) → *See Marie pres. last year. She will present in Young Scientist Forum of Moriond EW*
- 2022-23 : Have to validate the design with mock-ups



DS-20k Calibration (2/4)

❑ (cold) mock-up built at CPPM to validate the design

- U-tube of 4 m length put in 100 l LN₂ tank. Pseudo sources circulated by the 2 motors
- Set-up completed in May 2022 → 3 weeks of visitor from Queen's U (Canada) paid by IPhU
- 2 runs at 77K in Sep and Nov 2022 → Validation of the principle. No ice block formation



Mock-up now fully equipped and functioning (mainly) thanks to IPhU !

DS-20k Calibration (3/4)

- ❑ (warm, scale 1:1) mock-up built at CPPM to validate the design
 - Will be complete in Feb 2023



Goals :

- Exercise the calibration system (same as for short cold run) for a **DS20k length including all bends (15)**
- **Check the installation of the system in real conditions**
- **Transparent plastic** allows to see the source position
 - Specifications for the **source size** (length + diameter)
 - Will serve as input for the **source fabrication**

DS-20k Calibration (4/4)

□ Budget requested in 2023 to complete the validation of calibration syst.

- Final runs of the mock-ups
- Warm tests at CPPM on Scale 1:1 03/2023
- Cold tests at CPPM 03/2023

- Adapt system for long run
- Long duration runs at CERN Summer 2023

Amounts in €	Requested for 2023
Equipment	5000
Computing	0
Travel expenses	1000
Colloquia	1000
Operating budget	1000
TOTAL	8000

Request a (very experienced) visitor from Queen's University

Laboratories involved (acronyms): CPPM and Queen's University (Toronto Canada)

Duration of stay (up to 3 months): 2 weeks

Expected starting date: March 2023

Lab where the visitor will be administratively located (acronym): CPPM

Collaborators (name, first name – lab acronym - email - phone):

Skensved Peter – QU - skensved@queensu.ca - +1 613-533-2676

DS-20k Radon bkg mitigation

❑ Radon contamination could be a major background in DS20k

- Radon progeny ^[²¹⁰Pb, ²¹⁰Po] plates-out on detector material surfaces exposed to air → n bkg
 - ✓ Limit the exposure time by using hermetic plastic bags (transport + storage) [α 5, 8 MeV]
- Plateau Radon at CPPM participates to the radio purity assay program of DS-20k
- Request a visitor from IEA Prague (Czech Rep.)
 - ✓ Design an effective and low background radon filtering device



Laboratories involved (acronyms): CPPM and Institute of Experimental and Applied Physics
(Prague - Czech Republic)

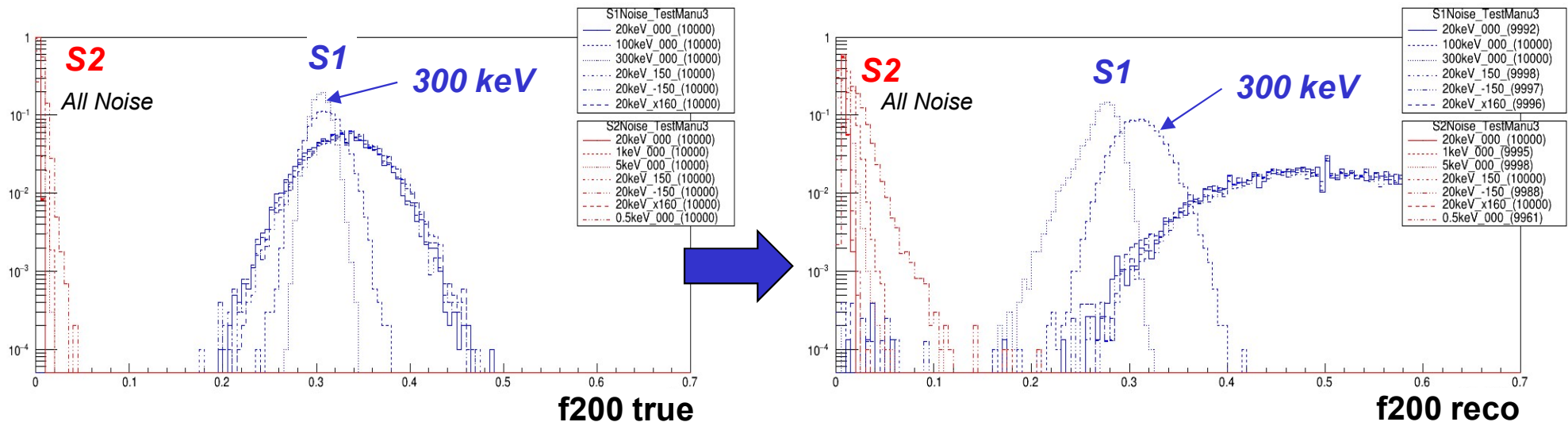
Duration of stay (up to 3 months): 2 months
Expected starting date: May 2023
Lab where the visitor will be administratively located (acronym): CPPM

Collaborators (name, first name – lab acronym - email - phone):
Fadahat Mamedov – IEAP - fadahat.mamedov@utef.cvut.cz - +420 224 359 233

DS-20k Signal reconstruction

□ Optimize signal / background separation

- WIMP interaction with LAr atom → Scintillation (S1) and Ionisation (S2) → cluster of PhotoElectrons in the SiPMs
- Improve S1 – S2 separation using **full DS20k simulation**
- Illustration with the fraction of Photo-Electrons in first 200 ns of the cluster (f_{200})

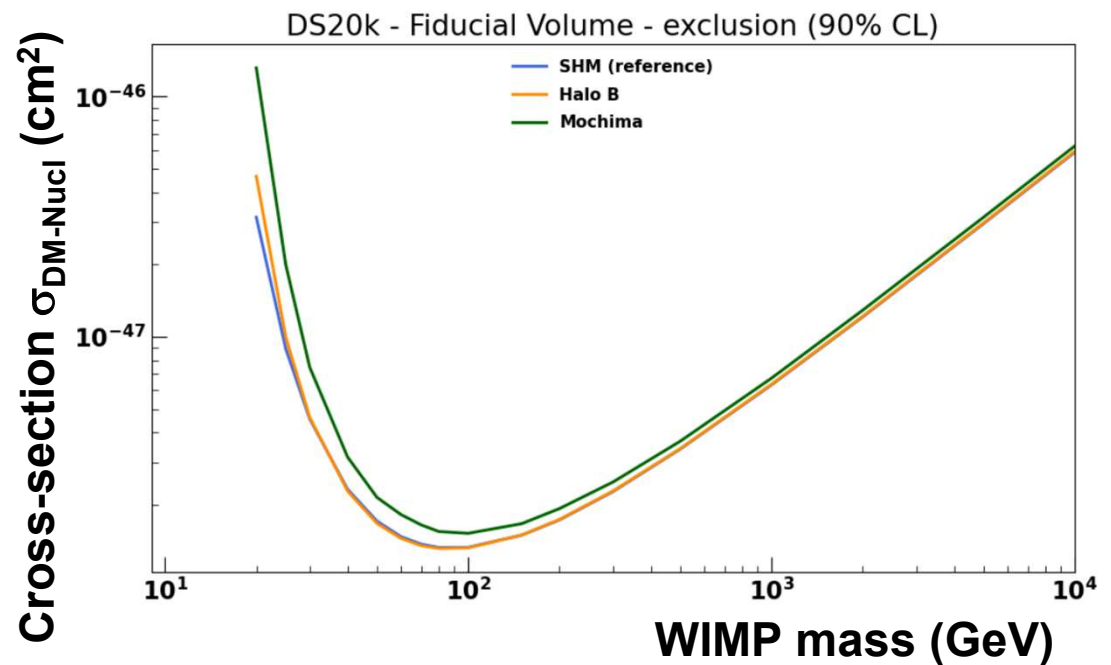
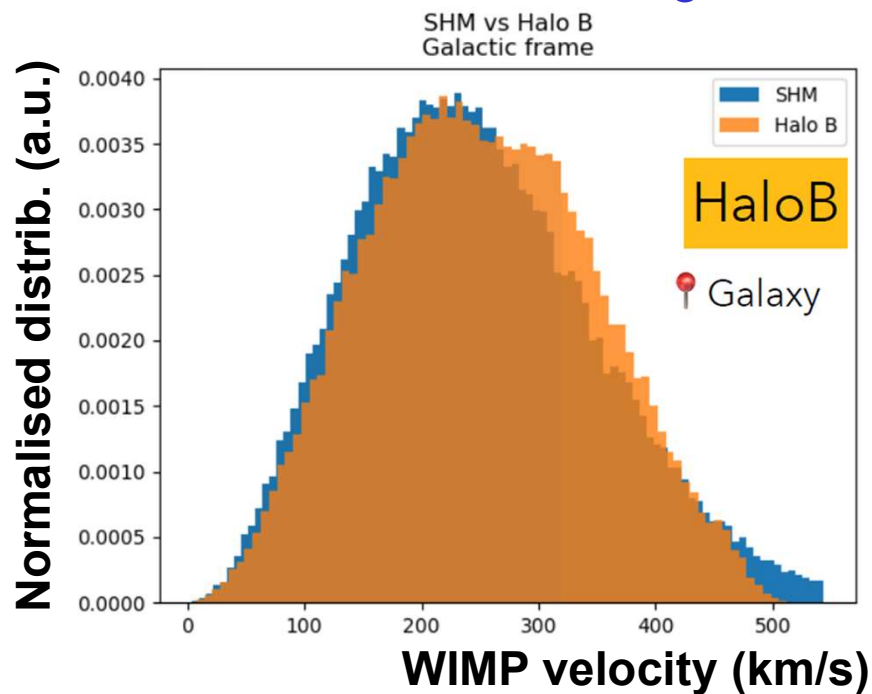


Reinforce this activity in 2023 (arrival of Y. Coadou from ATLAS)

Pheno work

□ Impact of astrophysical assumptions on DarkSide-20k sensitivity

- Vary parameters of “Standard Halo Model” SHM
- Generate more realistic inputs than the SHM using semi-analytical approaches and cosmological hydrodynamics simulations of spiral galaxies
- Illustration: one cosmological simulation and impact on sensitivity



[See presentation by Marie](#)

Conclusions

□ Direct Search for WIMP Dark Matter project

- Equip the DS-20k calibration mock-ups
 - ✓ First successful tests in 2022. Plan to complete the validation in 2023
 - ✓ Would benefit from a visitor (2 weeks) in March 2023
- Reduction of Radon bkg for DS-20k : would benefit from a visitor (8 weeks) in May 2023
- First complete study on DS-20k signal reconstruction : more to come in 2023
- Progresses on galactic modelling impact on DS-20k sensitivity thanks to synergy between LAM, CPPM and CPT : 2 meetings in 2022, main contribution from Marie
- Scientific life: 2 seminars on WIMP most sensitive 22 analyses, DM lectures in ED (J. Lavalle)

Name	Position ¹	Laboratory	#PM ² 2023	Nature of the contribution to the project
F. Hubaut	DR	CPPM	3	Optimal algorithms for S/B separation, Calibration of DarkSide-20k
P. Pralavorio	DR	CPPM	3	Optimal algorithms for S/B separation, Calibration of DarkSide-20k
Y. Coadou	CR	CPPM	3	Optimal algorithms for S/B separation
J. Busto	PR	CPPM	3	Calibration of DarkSide-20k, Radon measurements
M. Van Uffelen	PhD	CPPM/LAM	12	DarkSide-20k calibration, S/B separation and phenomenology
E. Nezri	CR	LAM	4	Improved modelling of the galactic halo
L. Lellouch	DR	CPT	1	Fully-controlled QCD uncertainties on WIMP-nucleus cross-sections
J. Lavalle	DR	LUPM	2	Improved modelling of the galactic halo

Back-up

IPhU018 project

❑ Accepted Apr. 2021 for 4 years

- 4 labs (inc. CPPM, LAM and CPT) → 7 people. Organized 2 meetings in 2022
- One PhD has also been granted : Marie Van Uffelen (Oct. 2021 – Oct. 2024)

IPhU science working group(s) involved:
Astroparticle and HE Universe Galaxies and Cosmology Particle Physics
Quantum Field Theory and Quantum Gravity

Project title: Direct search for WIMP dark matter

Project time frame:
Start date: 01/01/2021 duration (months): 48

Project coordination:
Coordinator's name: Pascal Pralavorio
Lab/team: CPPM/Matière Noire email: pralavor@cprm.in2p3.fr tel: 04 91 82 72 69

List of other teams involved:

Lab/team: CPPM/Matière Noire	Team project leader: Fabrice Hubaut
Lab/team: LAM/GECO	Team project leader: Emmanuel Nezri
Lab/team: CPT/PP	Team project leader: Laurent Lellouch
Lab/team: LUMP/IFAC	Team project leader: Julien Laval

Two main goals

Reduce exp. DS20k syst.
Calibration + Optimal signal /
bkg separation (using AI)

Reduce theory syst.
Improve knowledge on WIMP
local density / WIMP speed /
WIMP -- Argon atom interaction

**Prepare at best the WIMP searches in DarkSide-20k
using new close exp / theory connections provided by IPhU**

But du projet

With this project, we propose to prepare at best the direct searches for WIMPs that will be performed in the near future, through synergetic experimental and theoretical contributions.

Expérimental :

- Calibration
 - Séparation optimale entre signal et bruit de fond (utilisant AI)
- *Réduction des systématiques venant de l'expérience*

Théorie :

- Amélioration de la connaissance de la densité locale / distribution de la vitesse des WIMPs
 - Meilleure compréhension des interaction WIMP- noyau Ar
- *Réduction des systématiques venant de la théorie*

F. Hubaut	Optimal algorithms for signal/background separation (axis 1, see section 5)	E. Nezri	Improved modelling of the galactic halo (axis 2, see section 5)
P. Pralavorio	Optimal algorithms for signal/background separation (axis 1, see section 5)	L. Lellouch	Fully-controlled QCD uncertainties on WIMP-nucleus cross-sections (axis 2, see section 5)
I. Wingerter-Seez	Calibration of DarkSide-20k (axis 1, see section 5)	J. Lavalle	Improved modelling of the galactic halo (axis 2, see section 5)

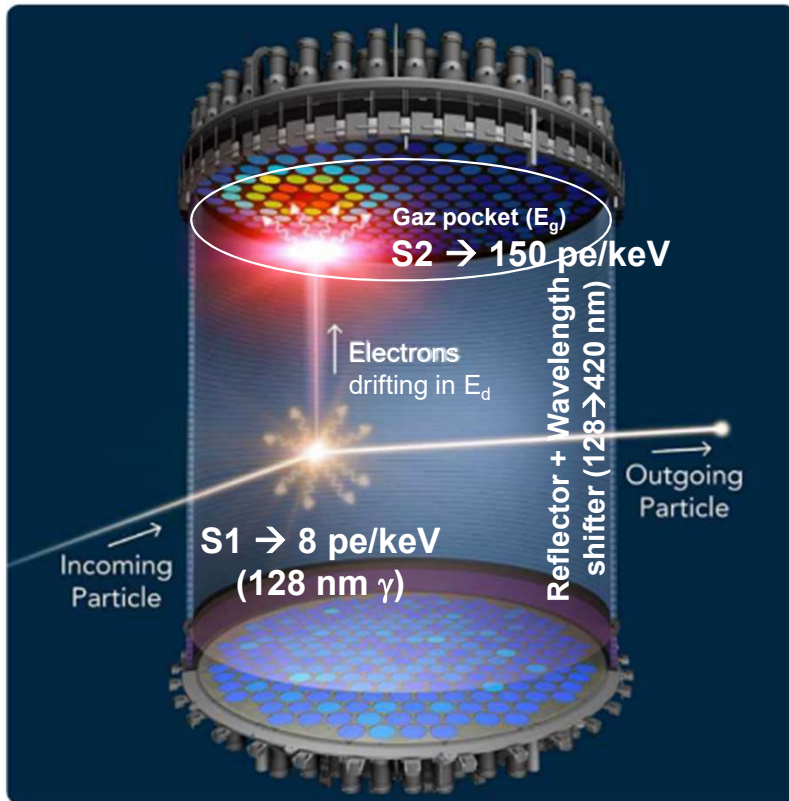
Etre prêt pour contribuer aux premières analyses

DarkSide-20k principles

Next generation Liquid Argon dual phase experiment

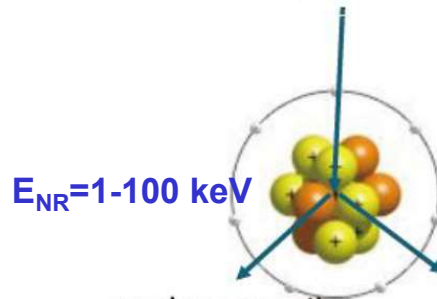
- Dual phase combines scintillation signal (S1) and ionization signal (S2)

TPC Principles



* 100 keV photon in DarkSide-20k, $E_d=200$ V/cm [$E_g\sim 3$ kV/cm]
 Note: 80% of electrons recombined with $Ar^+ \rightarrow \gamma$

WIMPs/Neutrons



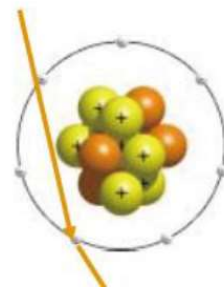
Nuclear Recoil (NR):

- fast. scint. (6ns)
- few ionization el.

NR bkg irreducible \rightarrow mitigate it !

- ✓ Deep Underground expt.
- ✓ Material selection + assay
- ✓ Neutron veto around the TPC

Gammas / Electrons



Electron recoil (ER):

- slow scint. (1600 ns)
- many ionization el. (5xNR)

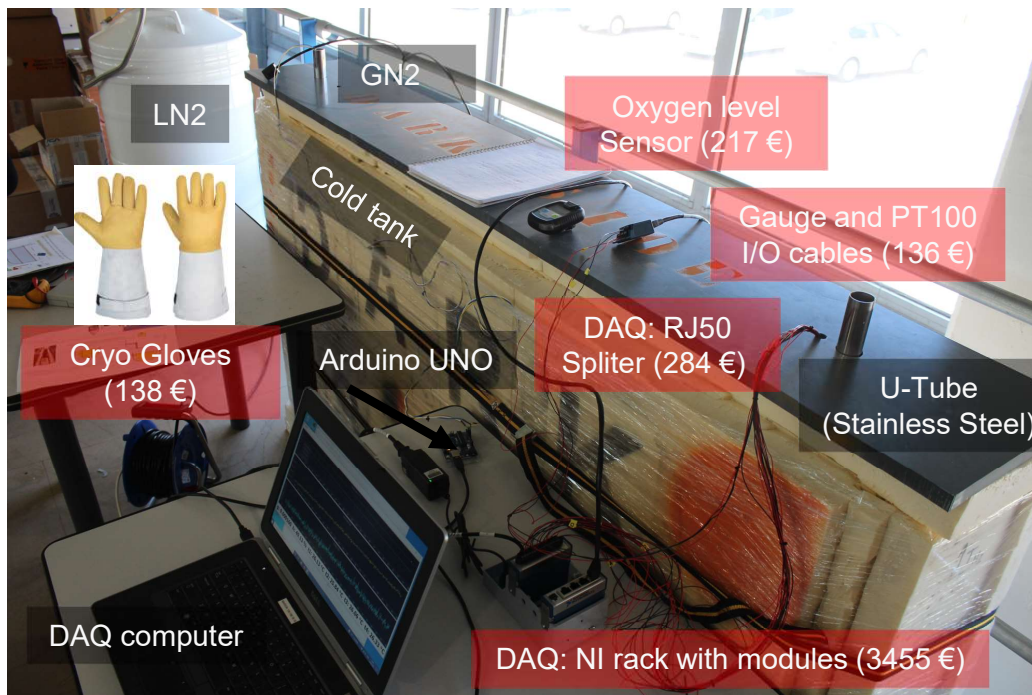
ER bkg fully reducible by analysis

- ✓ Purified argon (esp in ^{39}Ar)
- ✓ $S2/S1$ (ER) \gg $S2/S1$ (NR)
- ✓ S1 pulse shape less peaky than NR

Reminder: Mock Up in 2022

Contrib IPhU (Prix HT)

Set-up for the cold test (July 2021)



Set-up (as of January 2022)

