DarkSide-20k : status and French contributions

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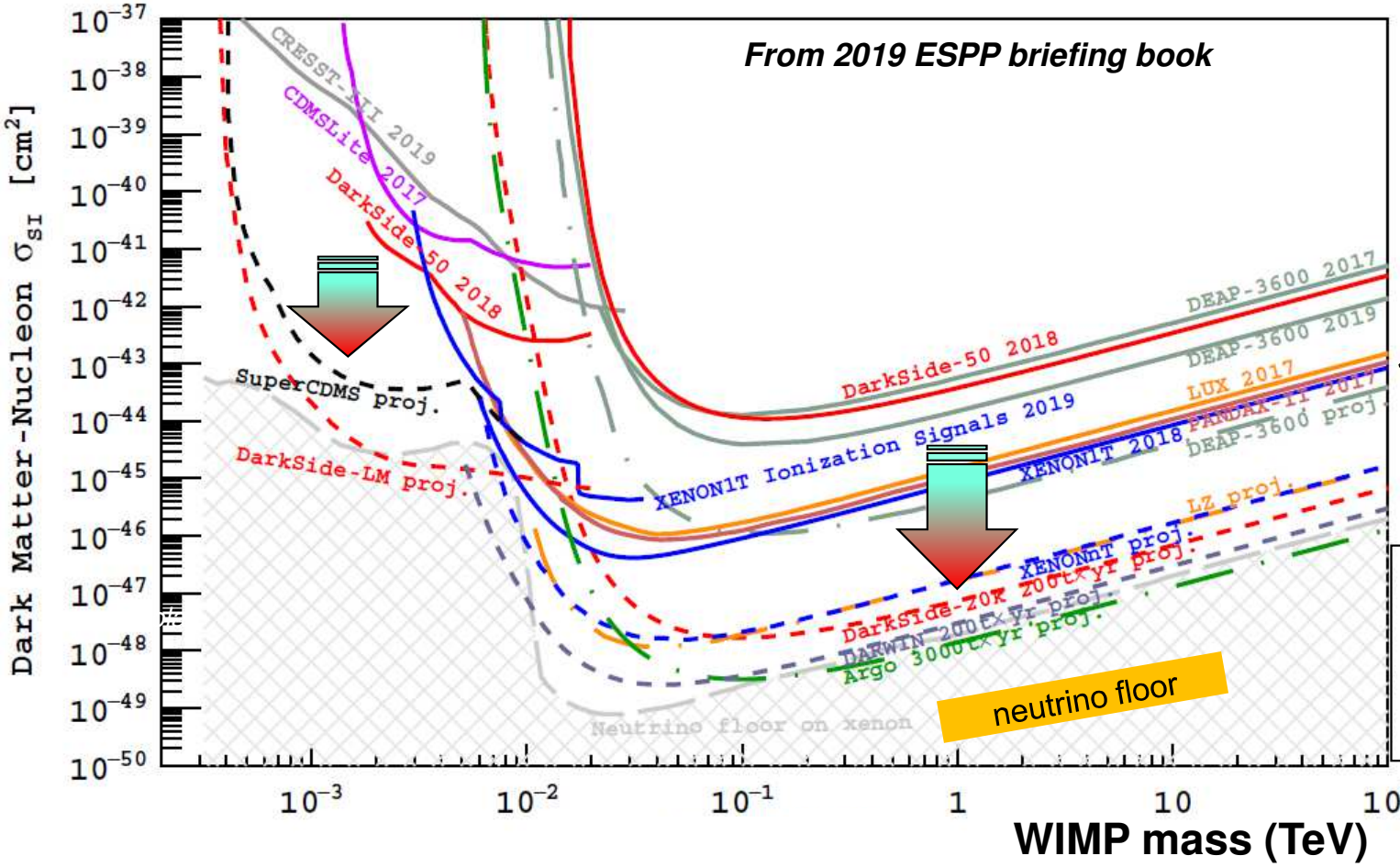
1- Scientific context
2- Bright sides of DarkSide
3- Status of DarkSide-20k
3- French contributions to DarkSide-20k
4- Conclusions

WIMP Search Status and Future

❑ Spin-independent (SI) processes

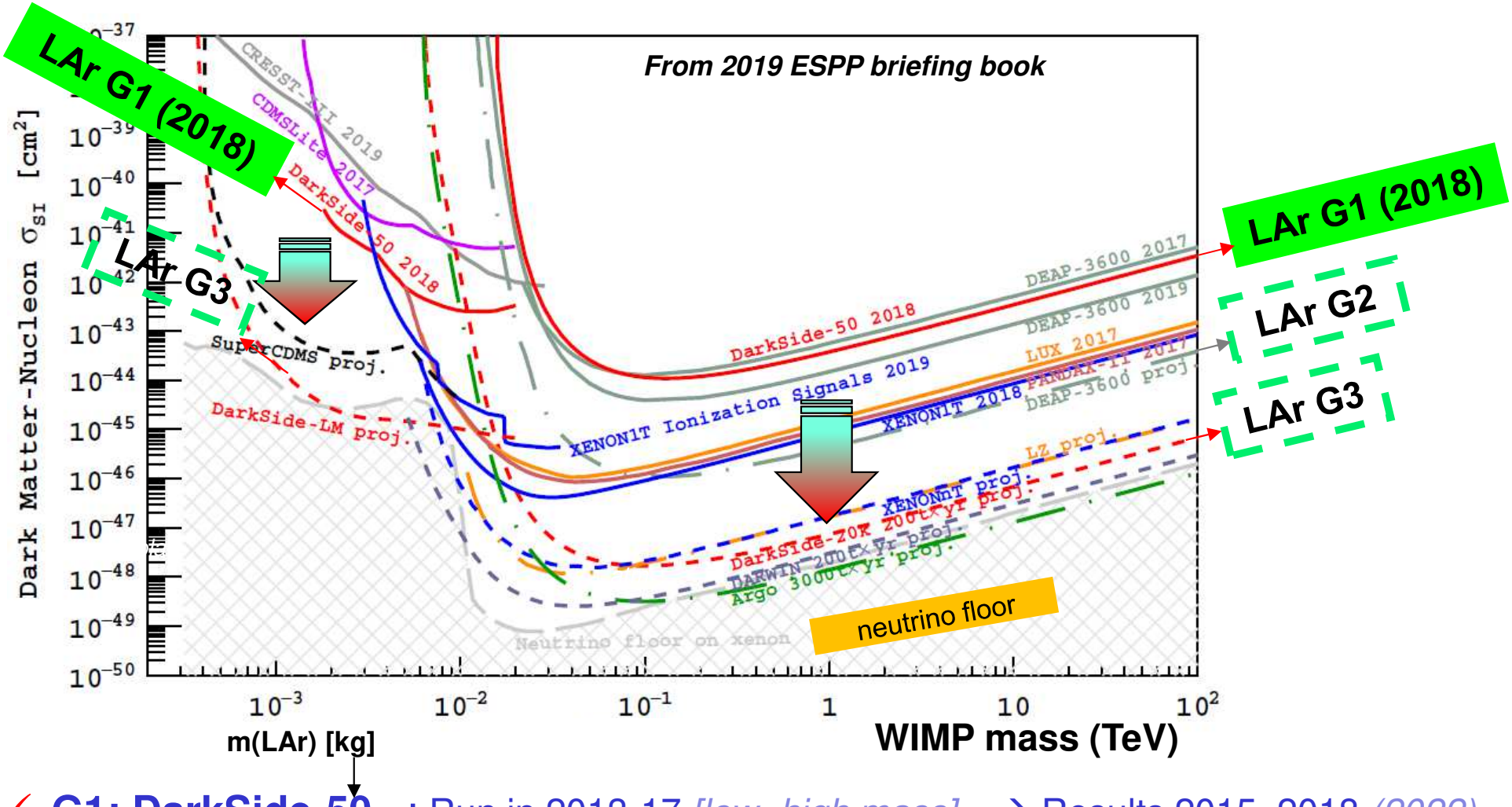


APPEC 2017 recommendation *: "strategy aimed at realising worldwide at least one ultimate Dark Matter detector based on xenon (~ 50 tons) and one based on argon (~ 300 tons), as advocated by DARWIN and Argo."*

Xe/LAr dual phase TPCs lead the WIMP search from GeV → 100 TeV

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

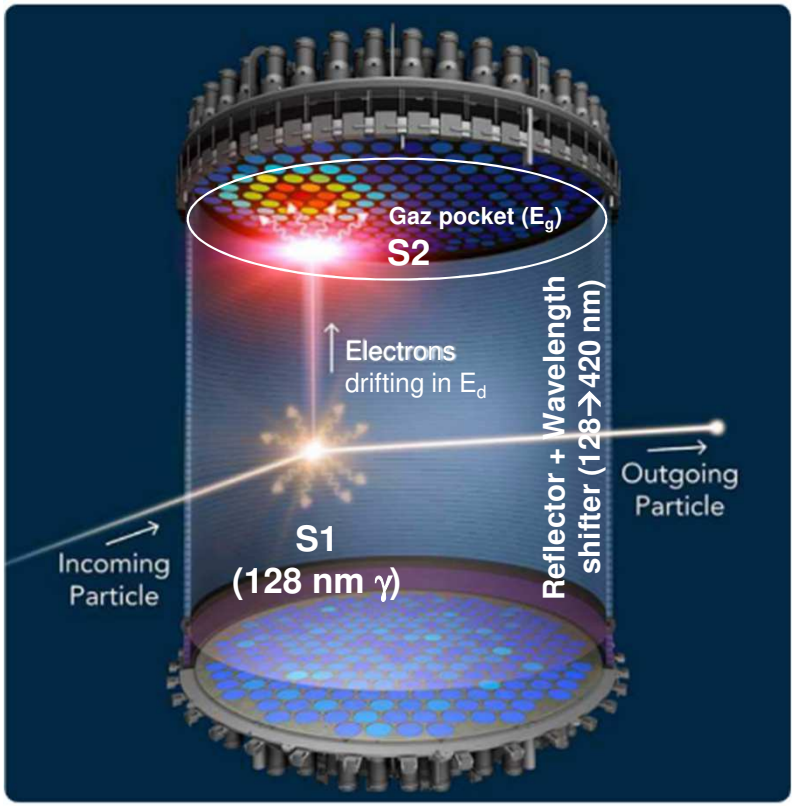
WIMP LAr Search Status



- ✓ **G1: DarkSide-50** : Run in 2013-17 *[low+high mass]* → Results 2015, 2018 *(2022)*
- ✓ **G2: DEAP 3600** : Run 2016-22 *[high mass]* → Results 2017, 2019 *(2024)*
- ✓ **G3: DarkSide-20k** : Start construction in 2022 → Start data taking in 2026

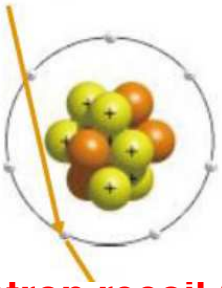
Dual Phase LAr TPC principles

- Cryostat hosting a Time Projection Chamber (TPC) equipped with photo-multipliers (top/bottom)
- 2 signals: prompt **scintillation** (S1 ~45 γ / keV*) and delayed **ionization** (S2 ~5 e^- / keV*)
  ~8 pe / keV
  Gaz pocket : ~1500 γ / keV → ~150 pe / keV



* 100 keV photon in DarkSide-20k, E_d=200 V/cm [E_g~3kV/cm]
Note: 80% of electrons recombined with Ar^+ → γ (see p.26)

Gammas / **Electrons**



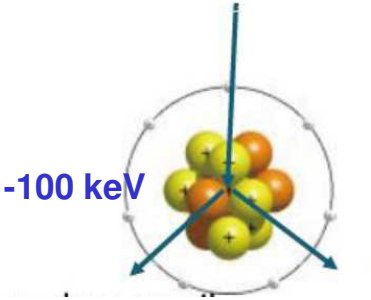
Electron recoil (ER):
- slow scint. (1600 ns)
- many ionization el. (5xNR*)

ER bkg reducible

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

WIMPs/Neutrons

E_{NR}=1-100 keV



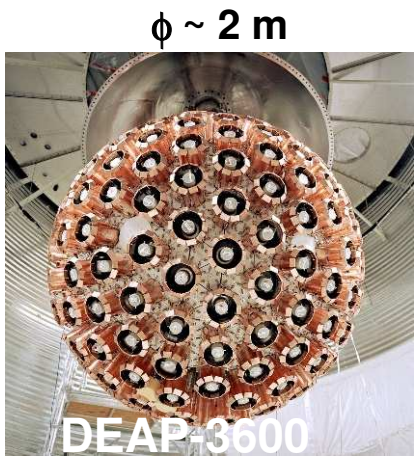
Nuclear Recoil (NR):
- fast. scint. (6ns)
- few ionization el.

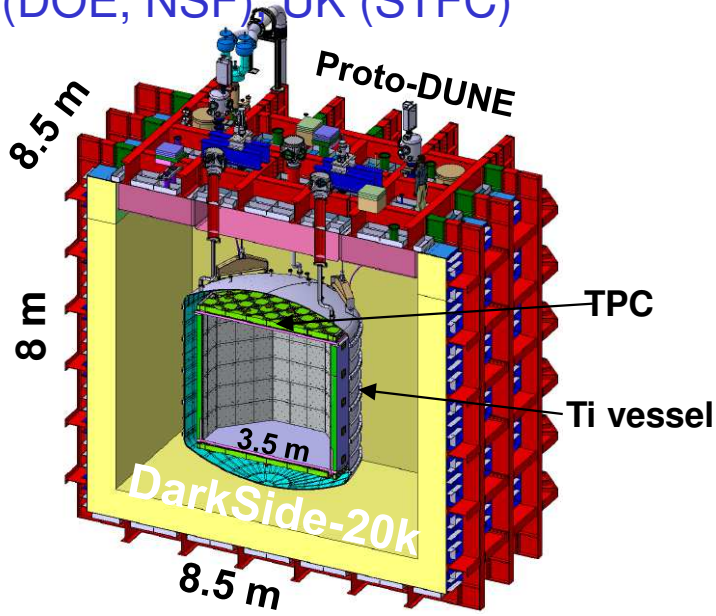
NR bkg irreducible

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

Bright sides of DarkSide (1/4)

- **Technology is now mature**
  - DarkSide-20k scales from G1 and G2 running expts
  - Only one global collaboration (GADMC): 350 people, profit from best technologies
  - Fundings from Canada (CFI), Italy (INFN), United States (DOE, NSF), UK (STFC)



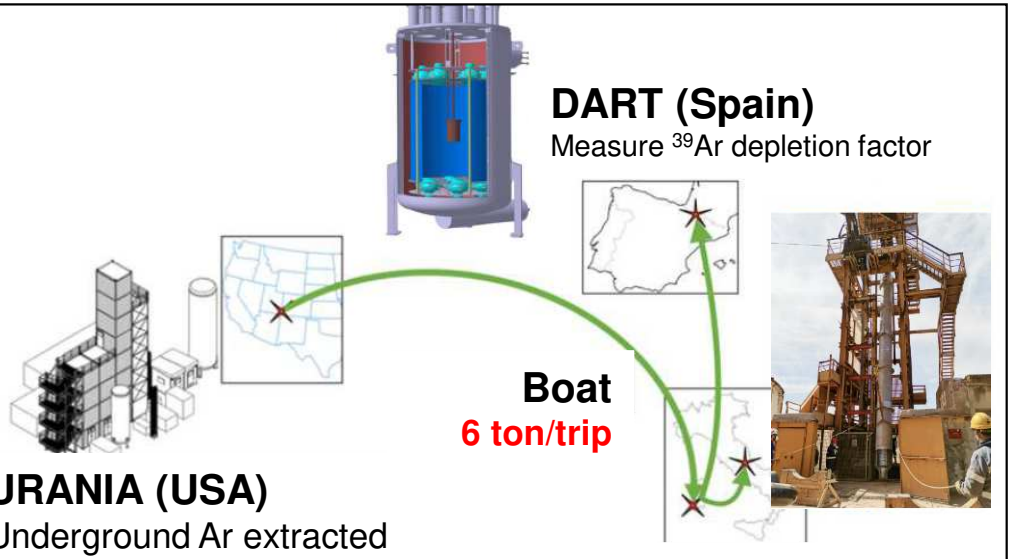


Lab (fid. data)	LNGS (0.05 t.yr)		SNOLab (3 t.yr)		LNGS (200 t.yr)
TPC target	50kg Purified Ar	x70 →	3.6 t *Atmosph. Ar*	x14 →	50 t Purified Ar
TPC wall	*Stainless Steel*		Acrylic		Acrylic
TPC nb ch.	*38 PMT*	x7 →	*255 PMT*	x8 →	~200k SiPM → ~2000 channels
TPC techno	Dual Phase		*Single Phase*		Dual Phase
Veto	*Scint (30 t) + Water (1000 t)* [inner] [outer]		*Water (250 t)*		Ar in vessel (30 t) + ProtoDUNE (700 t) [inner] [outer]

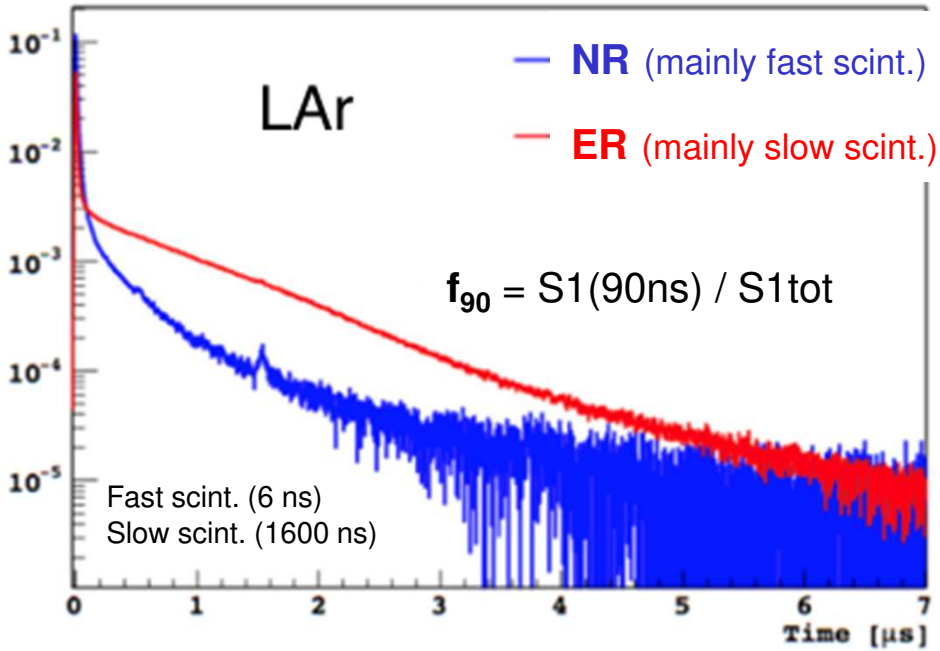
Bright sides of DarkSide (2/4)

- **Optimized to be background free for high mass WIMP search**
  - **Selection**: 70 (30) cm away in z (r) from the TPC walls → 20 t UAr, single scatter
  - **ER background suppression**: purified argon (depleted in ^{39}Ar cosmogenic argon), S2/S1, S1 Pulse Shape Discrimination (PSD) <1 mBq/kg β, $T_{1/2}$=269 year, ~1 Bq/kg R=10^3

Purified argon ($R_{39Ar}>10^3$)



S1 Pulse Shape Discrimination ($R_{ER}>10^8$)*

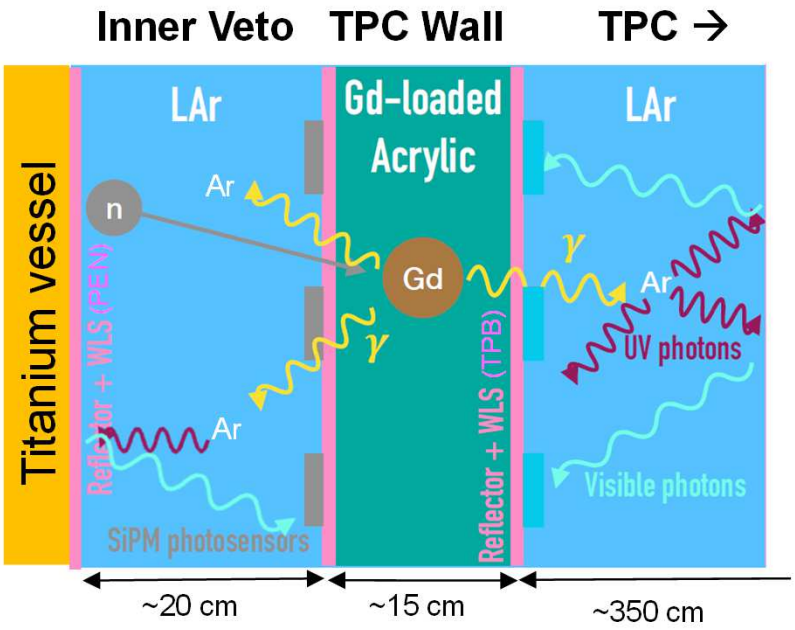


* PSD measurement by DEAP-3600 in PRD 100 (2019) 022004

ER background <<0.1 event in 200 ton.year

Bright sides of DarkSide (2'/4)

- **Optimized to be background free for high mass WIMP search**
  - **Selection**: 70 (30) cm away in z (r) from the TPC walls → 20t Ar, single scatter
  - **ER background suppression**: purified argon, S2/S1, S1 PSD → **negligible**
  - **NR background suppression**: LNGS, material selection+cleaning+assay, neutron veto

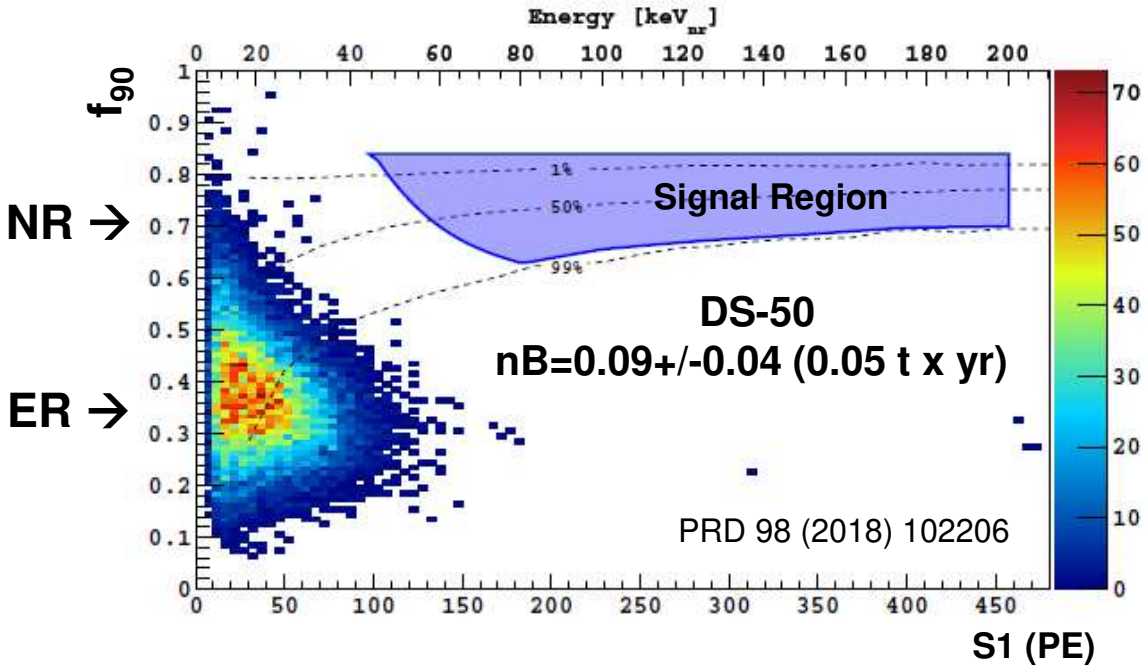


Veto: **2000 pe / MeV** (3.2% SiPM coverage of 175 m^2 surface)

<mBq/kg ^{238}U, ^{235}U, ^{232}Th activity → O(10^{-7}) n / decay, E ~ MeV

^{222}Rn daughters

O(500) Neutron moderated by Acrylic Captured by Gd → ≤ 8 MeV γ



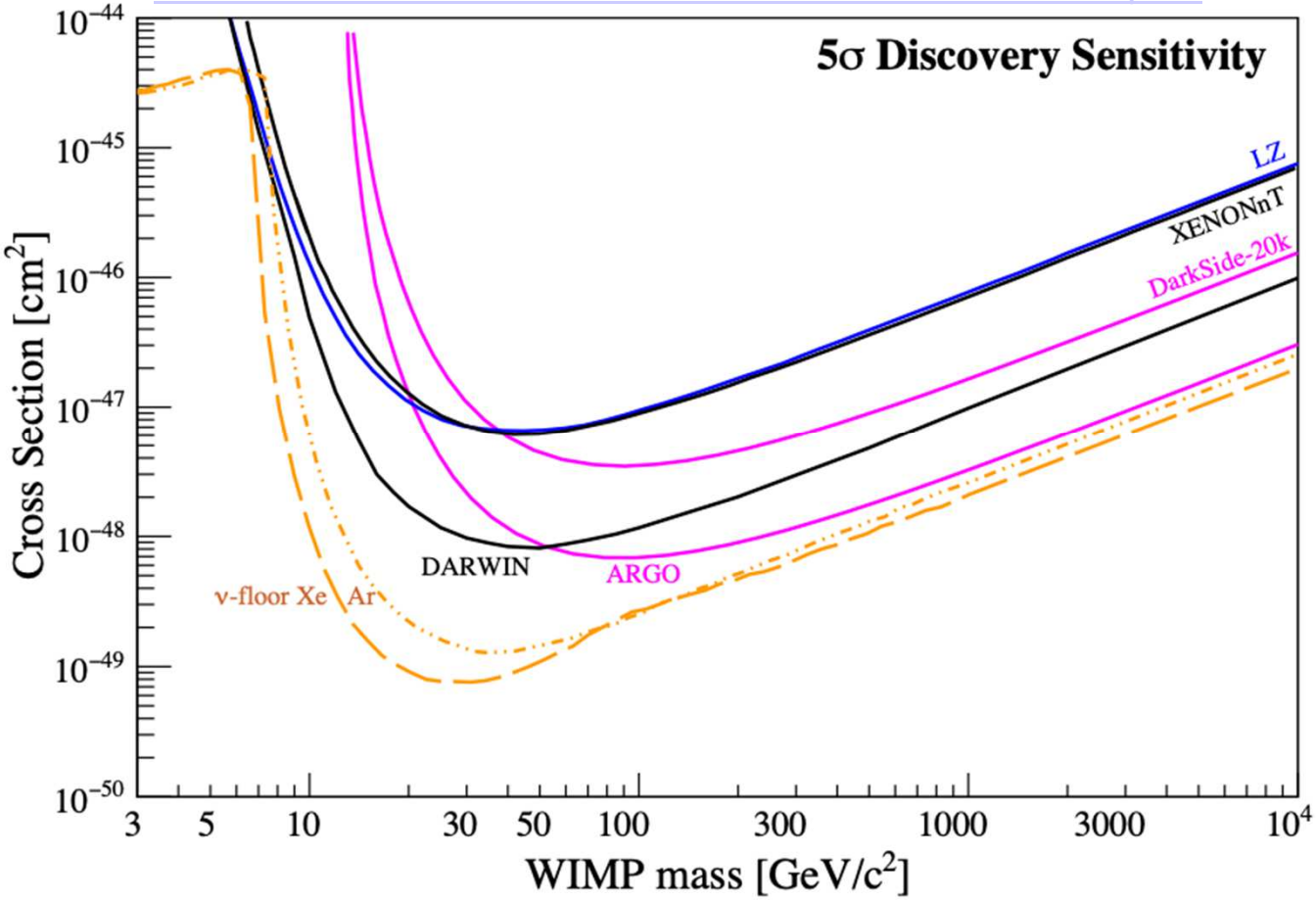
Expect ~0.1 bkg event in 10 years of running (200 ton.year)*

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

Bright sides of DarkSide (3/4)

- **Good discovery potential of high mass WIMP**

Direct Detection of Dark Matter – APPEC Committee Report



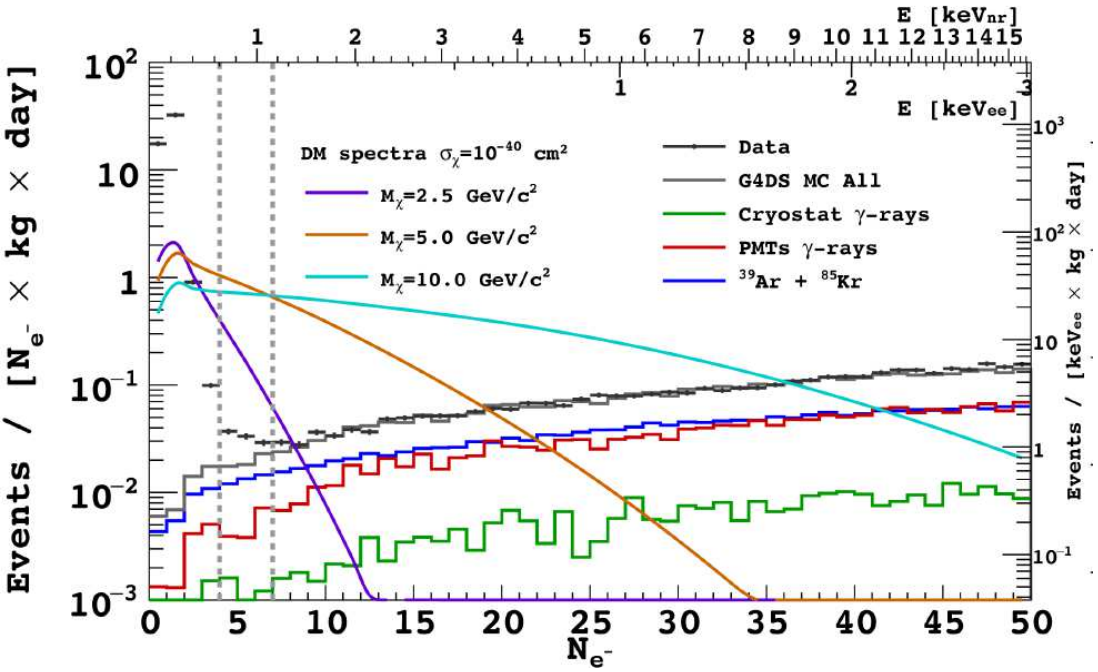
DarkSide-20k and Xenon expts complementary for high mass WIMPs

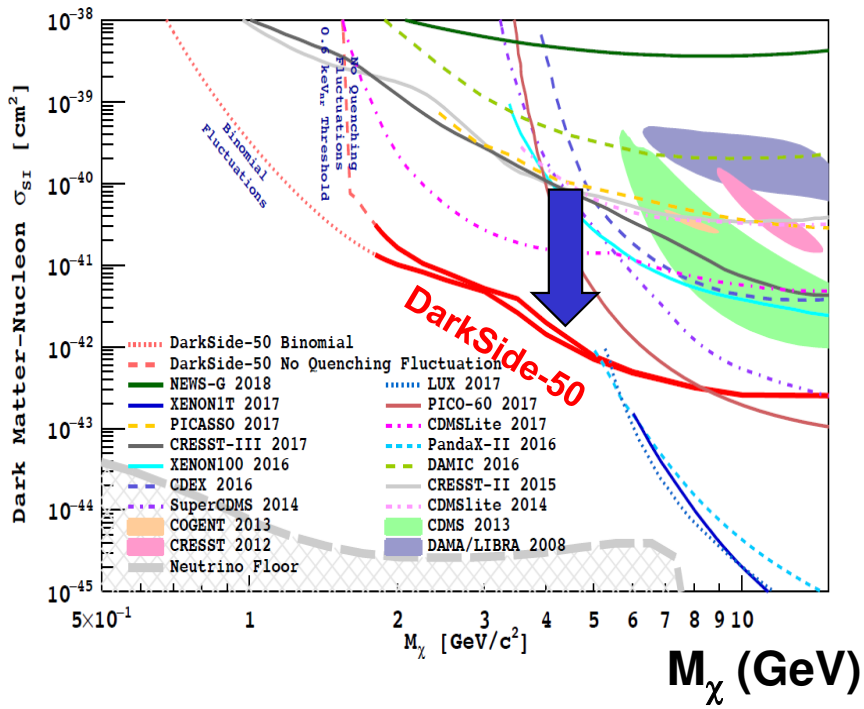
Bright sides of DarkSide (4/4)

❑ Bonus: very sensitive to low mass (1-5 GeV) WIMP

- S2-only APC, LPNHE leadership : ARIS measurements @ IPNO + analysis
  - ✓ Very good signal / background separation at low N_e
  - ✓ Good background description for $N_e \geq 7$

PRL **121** (2018) 081307





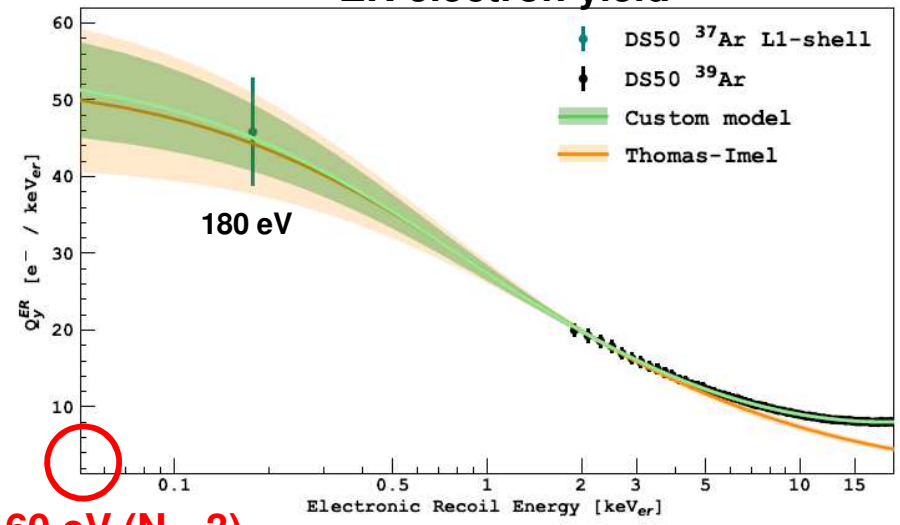
DarkSide-50 world leading sensitivity in 1-5 GeV WIMP (since 2018)

Bright sides of DarkSide (4'/4)

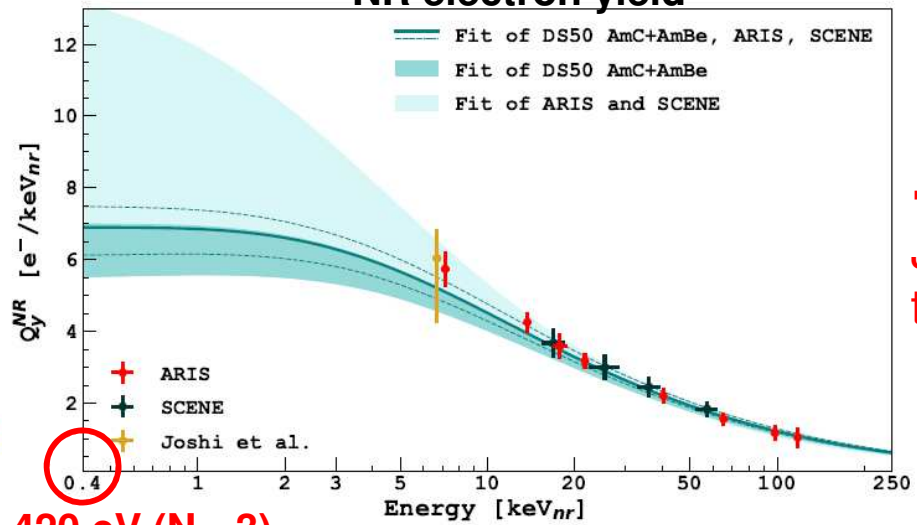
❑ Bonus: very sensitive to low mass (1-5 GeV) WIMP

- S2-only: signal / background separation at low Ne, good description of background
- Re-Analyse DS50 calib. data APC, CPPM : 3/5 main authors
  - ✓ Find 2-param. model to describe ER and NR e- yield down to 3 'primary' e-
  - ✓ Reduce systematics uncertainties
  - ✓ Confirm that el-ion recomb. is ~0 at very low E → All 'primary' electrons visible !

ER electron yield PRD **104** (2021) 082005 **NR electron yield**



60 eV (N_e=3)



420 eV (N_e=3)

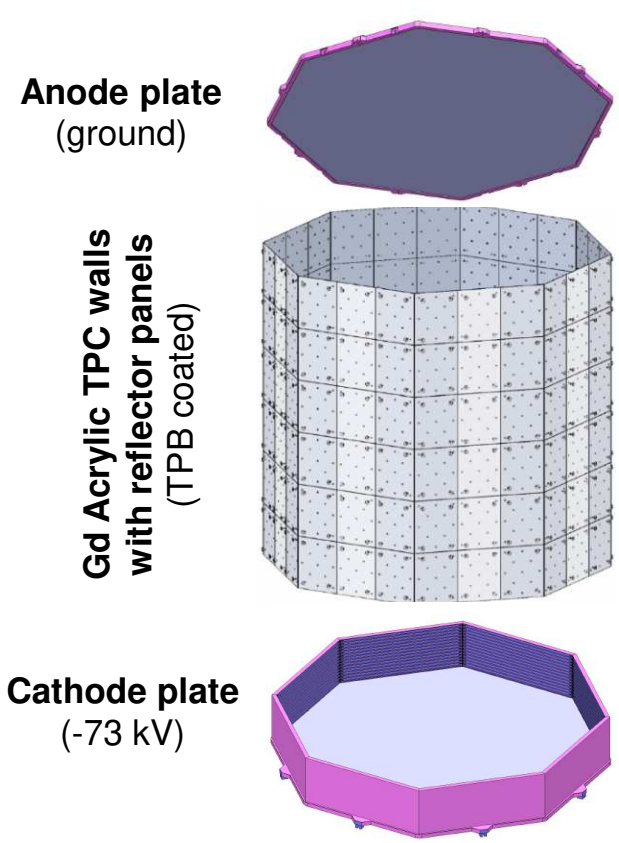
➔ See Julie Rode talk (Wed.)

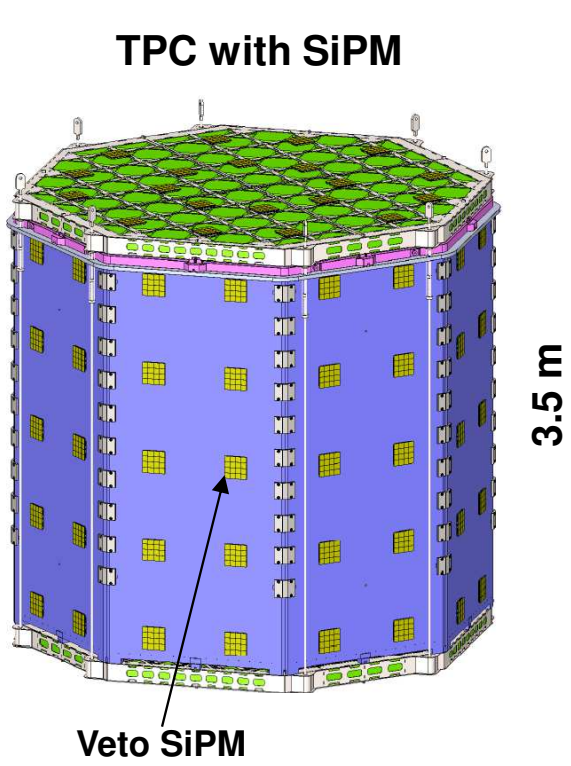
- 2022: New low mass WIMP results (DS50, projected sensitivity for DS20k)
  APC, CPPM : 3 of the main authors

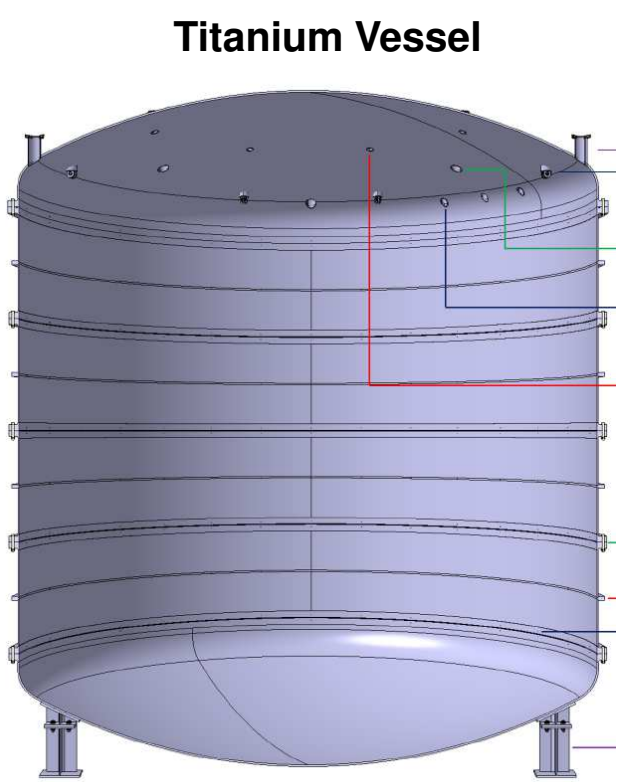
IN2P3 leadership in the low mass WIMP analyses

Status of DarkSide-20k (1/4)

- **Titanium vessel hosts the inner detector (TPC + veto)**
  - High degree of integration in the TPC : compact and simple
    - ✓ TPC walls also serve as overall mechanical structure, Faraday cage, grounding, …
    - ✓ Minimize type and amount of passive material to lower the background *(e.g. same acrylic used for TPC walls & SiPM support structure [with 2% Gd], anode and cathode plates [with Clevios for HV])*
  - TPC – Ti vessel gap used for the veto : instrumented with SiPMs



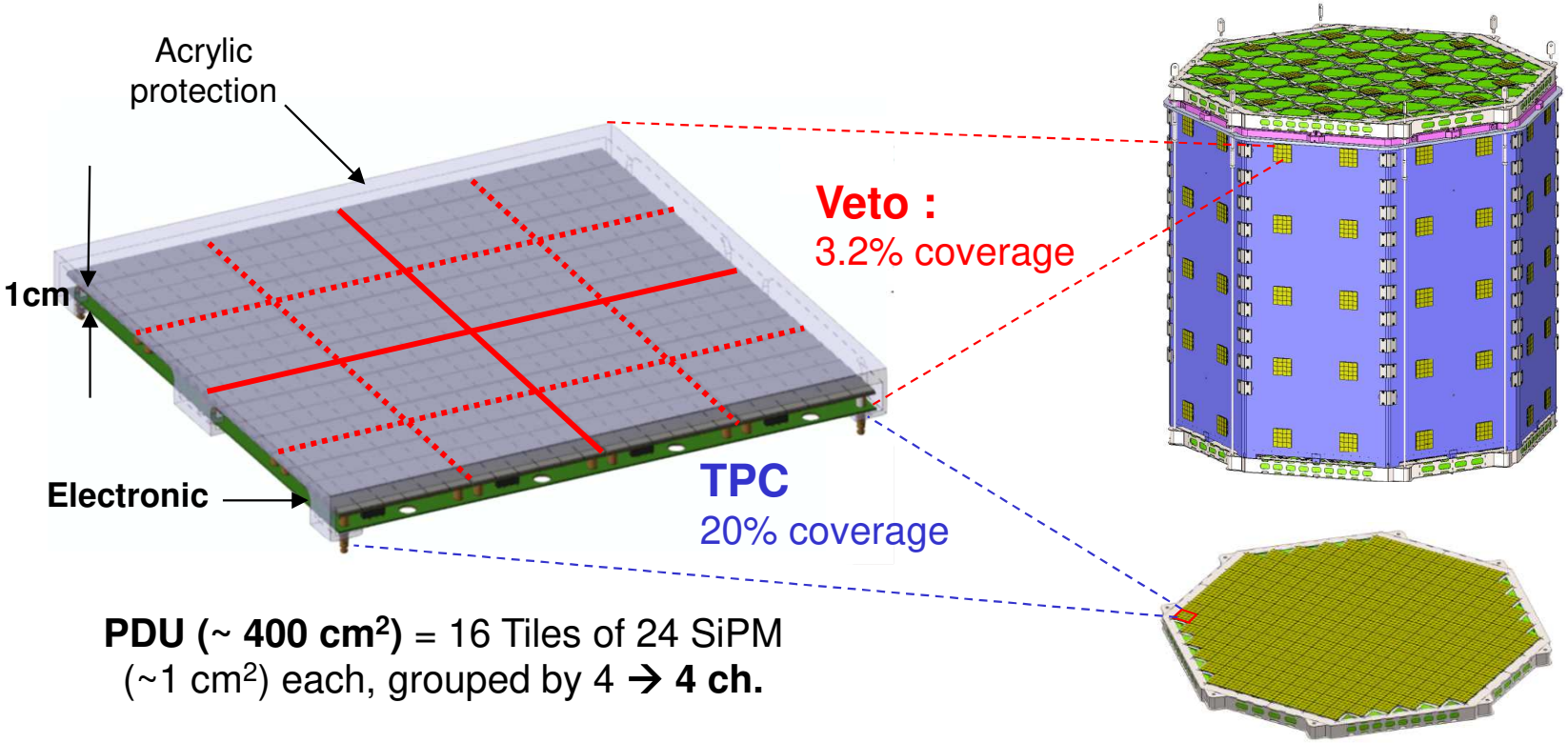




Status of DarkSide-20k (2/4)

❑ Photosensors

- Custom cryogenic SiPMs developed in collaboration with FBK *(PDE ~45% at 420 nm Low dark count rate <20 cps, 3.5 ns time resolution)*. Production at LFoundry.
- PDU = SiPM packaging inc. electronics in LNGS *(TPC)* and UK *(Veto) :* SNR=8
- Installation outside the TPC *(inner veto)* and top/bottom inside the TPC *(TPC)*



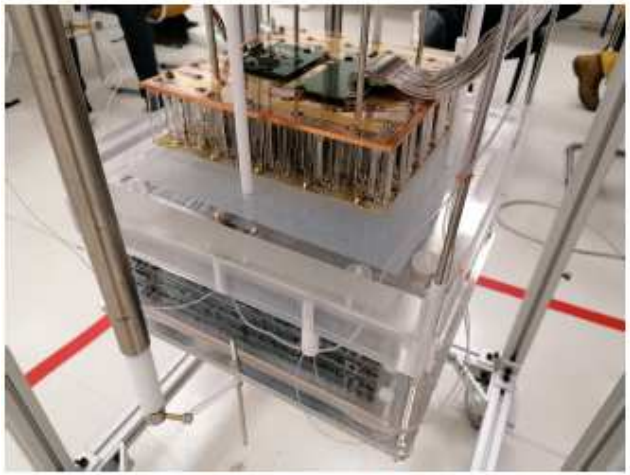
- Outer Veto : arrays lowered from the proto-DUNE flanges *(0.5% coverage, 1 pe/MeV)*

Status of DarkSide-20k (3/4)

❑ Prototyping

- Validate technological choices (e.g. integrated TPC)
- Test the cryogenic system for the TPC (at CERN)
- Measure on-site performance of the SiPM → input for simulation

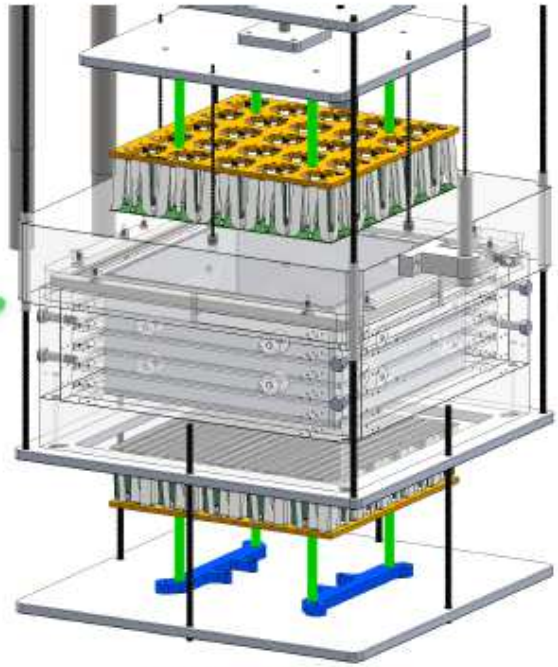
October 2019



Proto-0 at CERN

25x25x10 cm^2
1 PDU

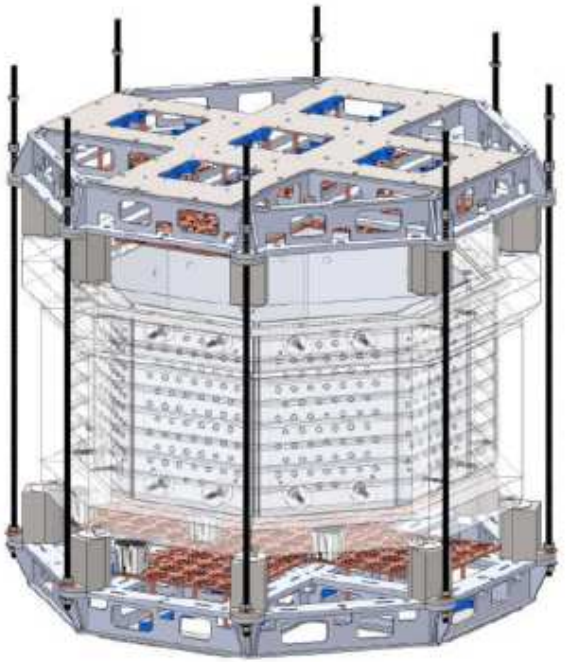
Spring 2022



Proto-0 at Naples

25x25x10 cm^2
2 PDUs

from Summer 2022

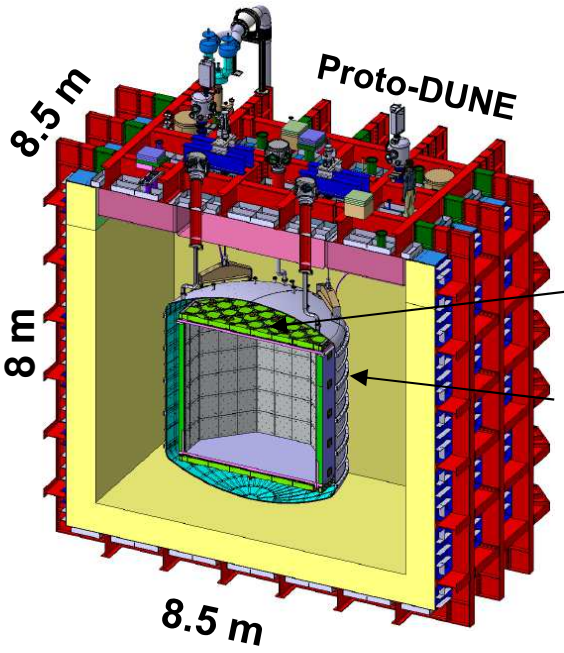


Proto-1T at CERN

60x60x40 cm^2
10 PDUs

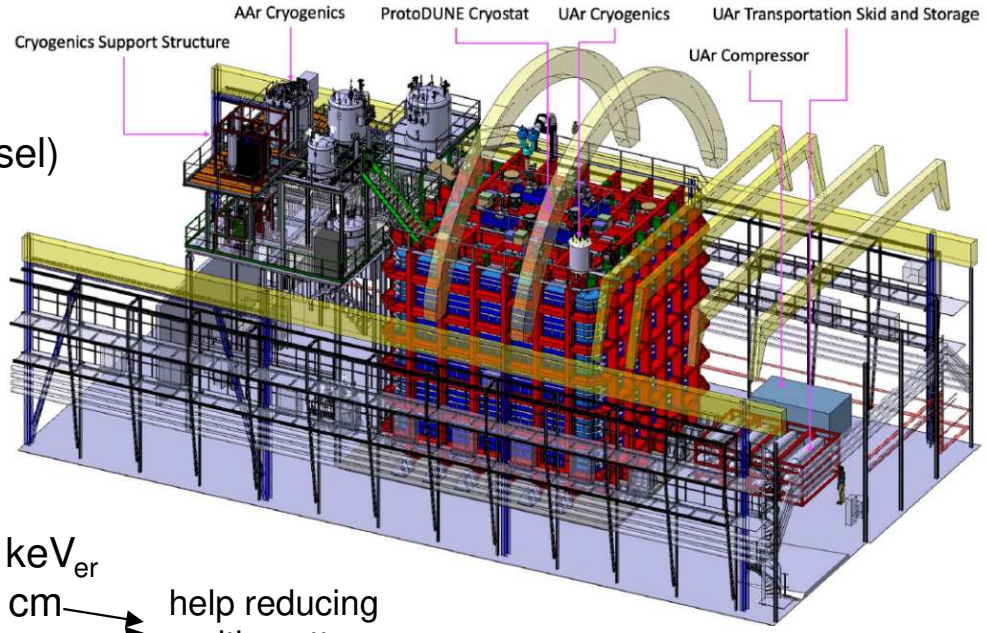
Status of DarkSide-20k (4/4)

- **Overview → TDR to be released this week**
  - Installation: start in 2022 at LNGS and completed by 2025
  - Physics: first run in 2026. Run during 10 years (→ 200 t.yr)



Main Characteristics:
- Dual Phase
- 100 t Purified Ar (in Ti vessel)
- ~250k SiPM → ~2500 Ch.

Hall C in LNGS



Performance:
- Time resolution ~ 10ns
- E resolution : 3.5% at 100 keV_{er}
- X-Y Position resolution ~ 1cm → help reducing multi-scatter
- Z position resolution ~ 1mm → help reducing multi-scatter
- Electron lifetime > 5 ms (max drift time ~ 4ms)
  <0.06 ppb O_2

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

France in DarkSide-20k

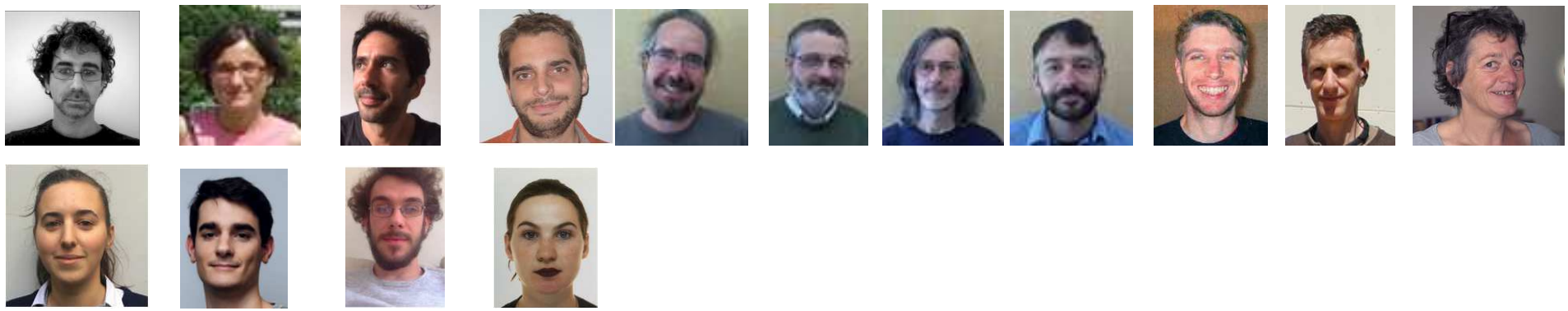
History

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

CS-IN2P3
28.10.2018

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
- 2021 : 3 labs, 15 people (~ 8 FTE) including 4 students *(2 arrived in Oct. 2021)*

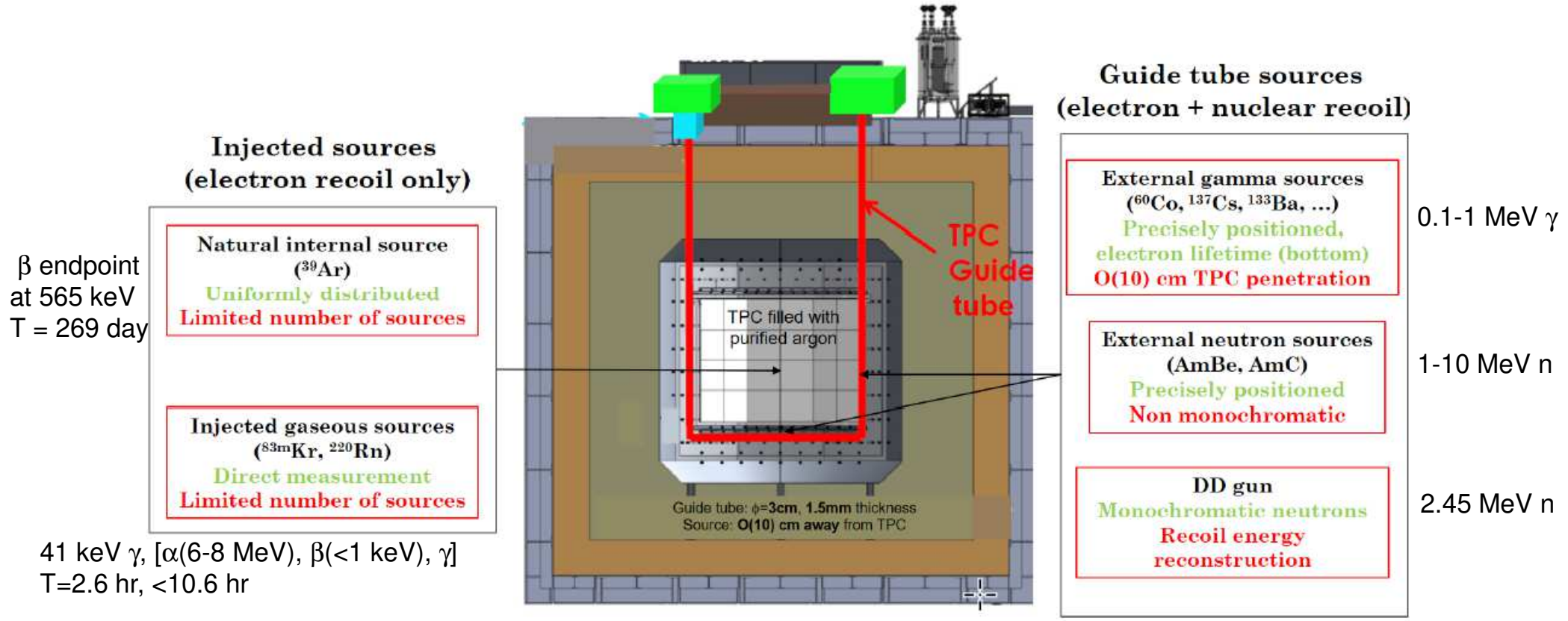


- 2022 : Mines/Paris Tech will join (Participation in Aria)

DarkSide-20k IN2P3 contrib. (1/3)

❑ Calibration

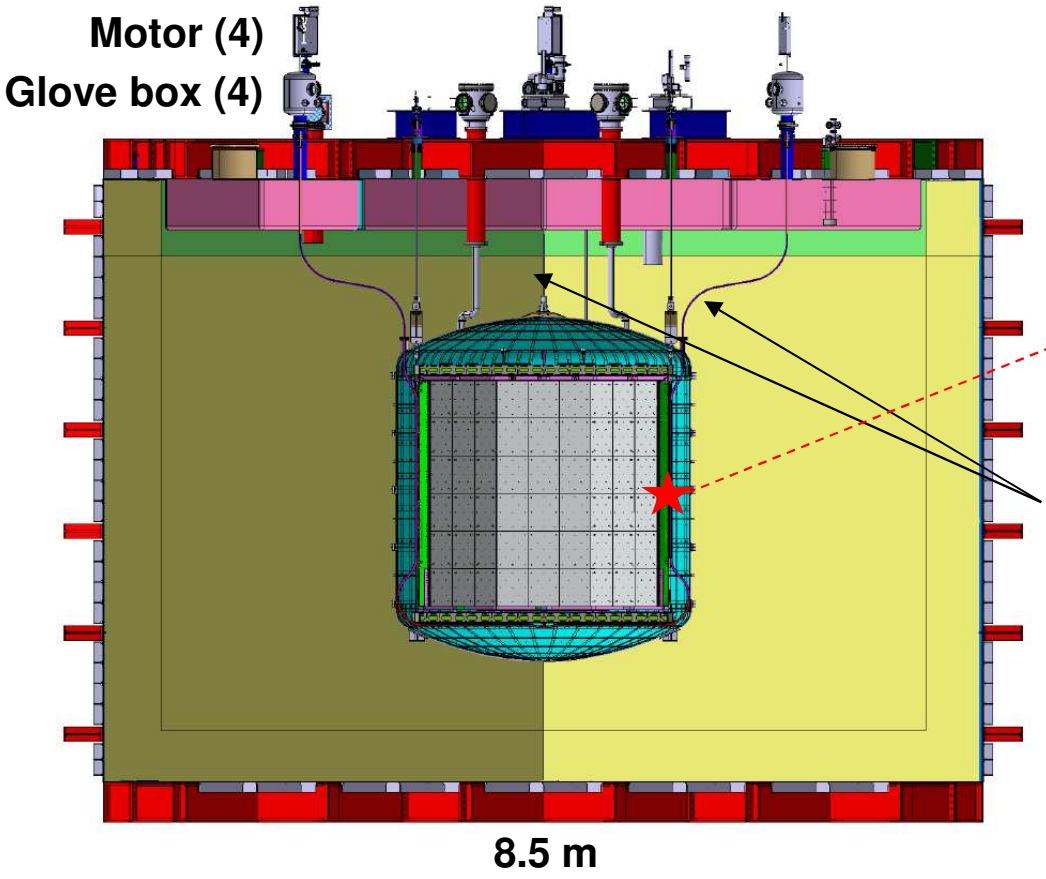
- Expertise in calibration with DarkSide-50 (see before)
- Responsible for the TPC calibration system in DarkSide-20k
  - ✓ Establish the calibration program *(with University of Hawaii)*

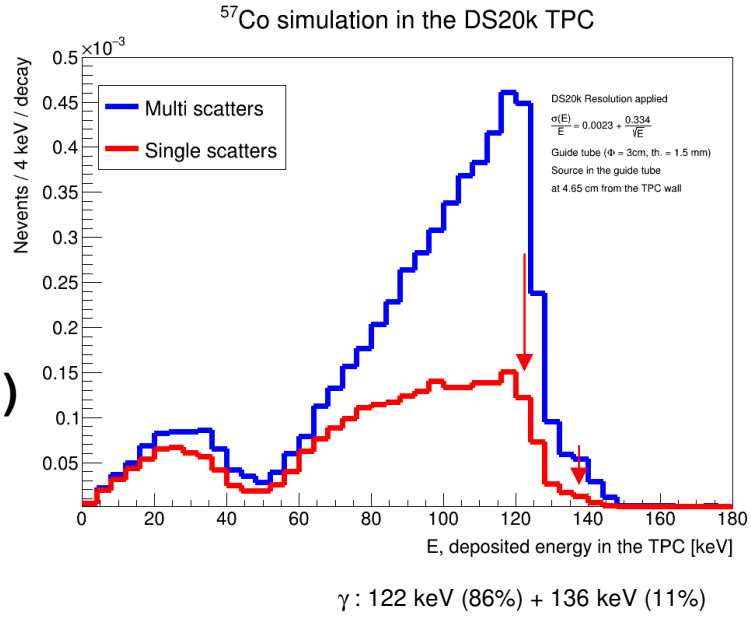


DarkSide-20k IN2P3 contrib. (1'/3)

❑ Calibration

- Expertise in calibration with DarkSide-50 (see before)
- Responsible for the TPC calibration system in DarkSide-20k
  - ✓ Establish the calibration program *(with University of Hawaii)*
  - ✓ Conceive and construct the guide tube system *(with LNGS + Queen's University)*



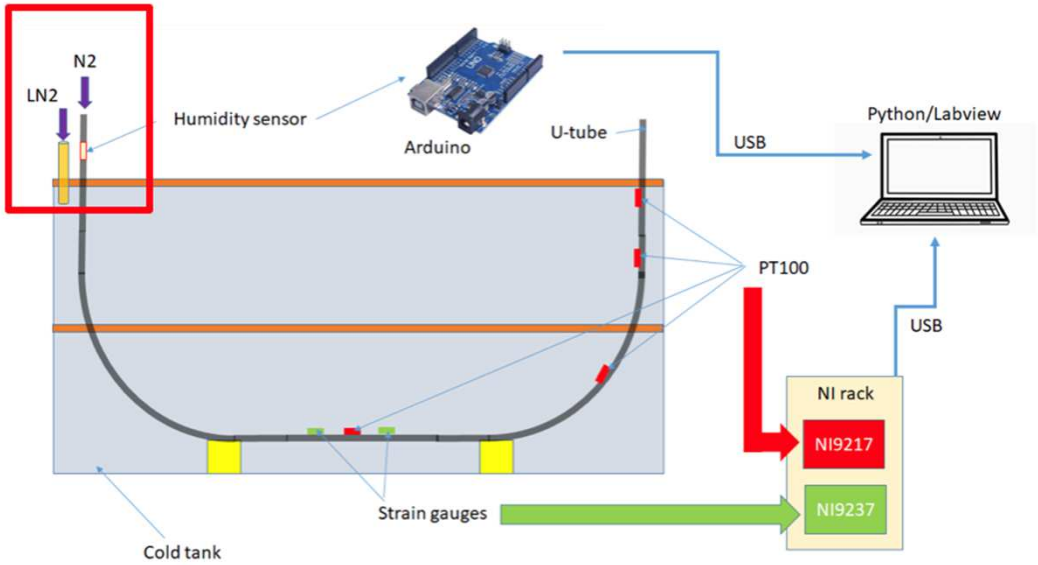


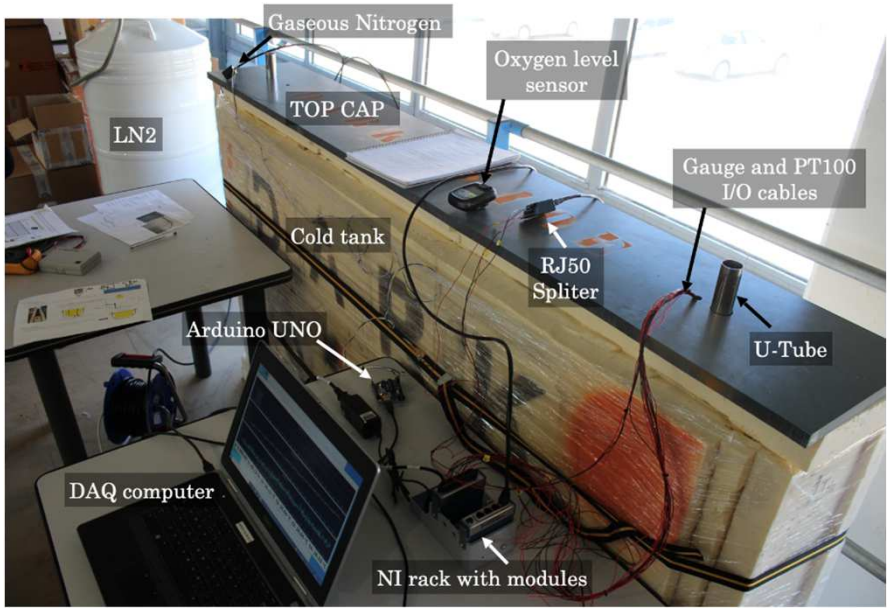
γ : 122 keV (86%) + 136 keV (11%)

DarkSide-20k IN2P3 contrib. (1’’/3)

❑ Calibration

- Expertise in calibration with DarkSide-50 (see before)
- Responsible for the TPC calibration system in DarkSide-20k
  - ✓ Establish the calibration program *(with University of Hawaii)*
  - ✓ Conceive and construct the guide tube system *(with LNGS + Queen’s University)*
  - ✓ Build a mock-up in 2021 @CPPM to demonstrate feasibility *(with Queen’s University)*



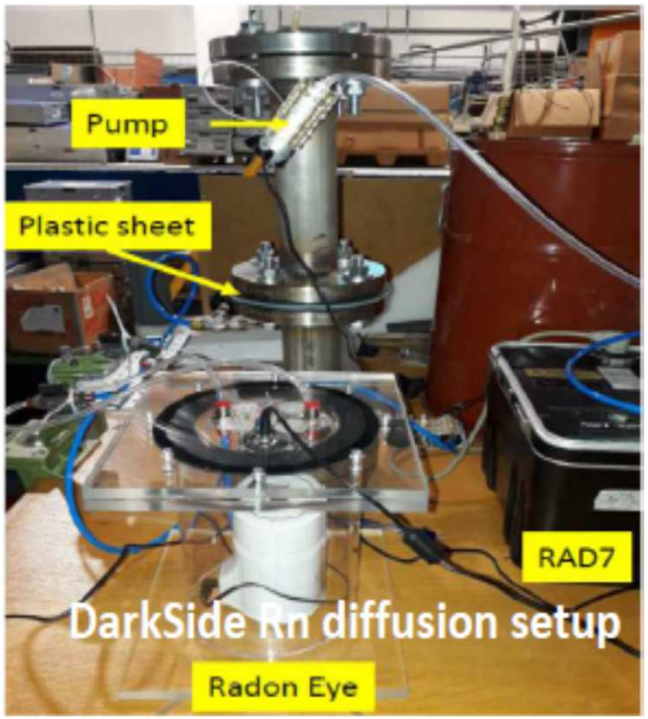


Next steps : Long runs with mock-up and then installation at LNGS

DarkSide-20k IN2P3 contrib. (2/3)

❑ Radon contamination

- 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 (transport + storage)
- Radio purity assay program developed in DarkSide-20k
  - ✓ Plateau Radon at CPPM participates to this effort with its radonisation chamber
  - ✓ Also measure radon diffusion vs air humidity *(impact radon transparency)* from plastic bags



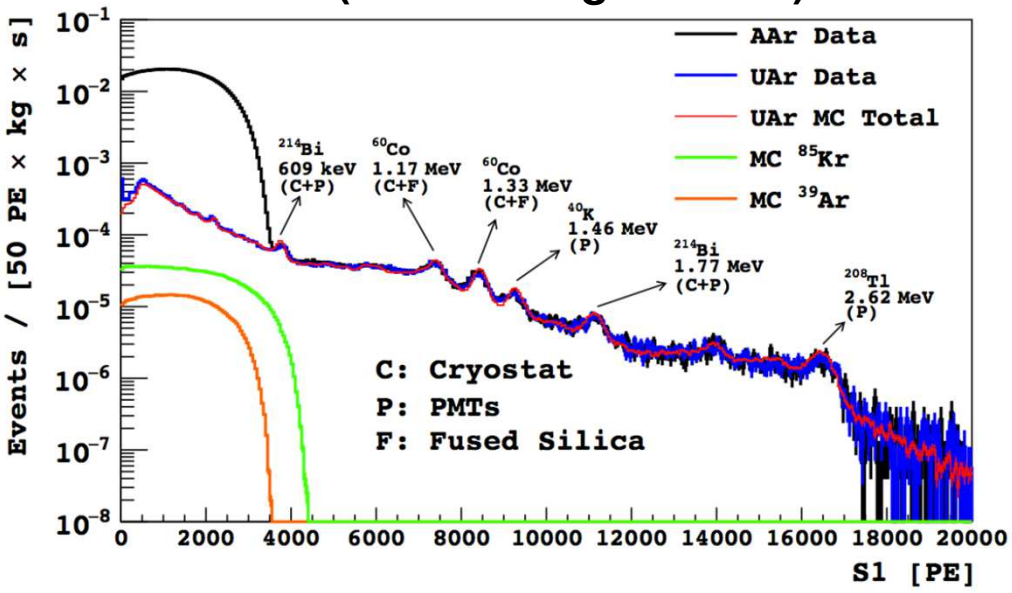
Radonisation Chamber

DarkSide-20k IN2P3 contrib. (3/3)

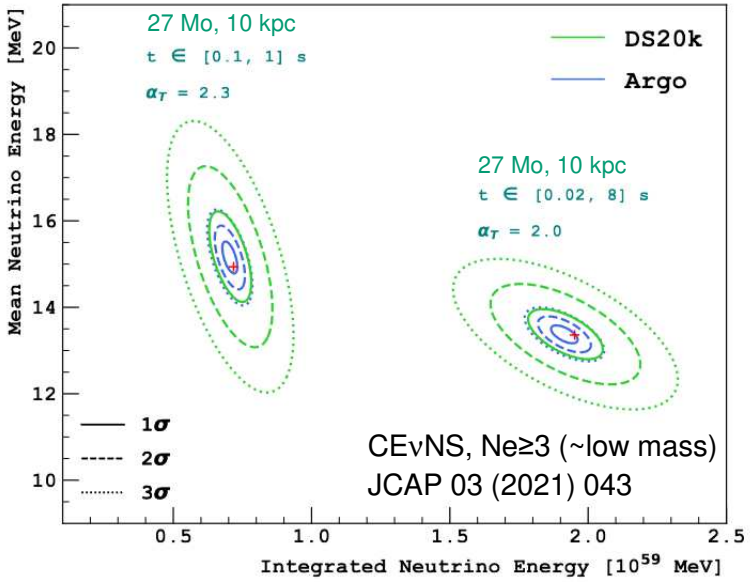
❑ Simulation, Data analysis

- Science / Offline manager of DarkSide-20k *(Davide Franco APC)*
- Develop code of LAr response and light detection in Geant4 JINST 12 (2017) 10, P10015
  - ✓ Check Data-MC agreement with DS50 and assess DarkSide-20k sensitivity
- Develop code of full signal reconstruction *(inc. SiPM elec. description adjusted with proto data)*
  - ✓ PDU laser calibration, hit finder, pulse finding and ID (S1 vs S2), pile-up, …

DS50 (Data-MC agreement)



Core collapse neutrinos (simu)



IN2P3 French labs lead software (simu + reco)

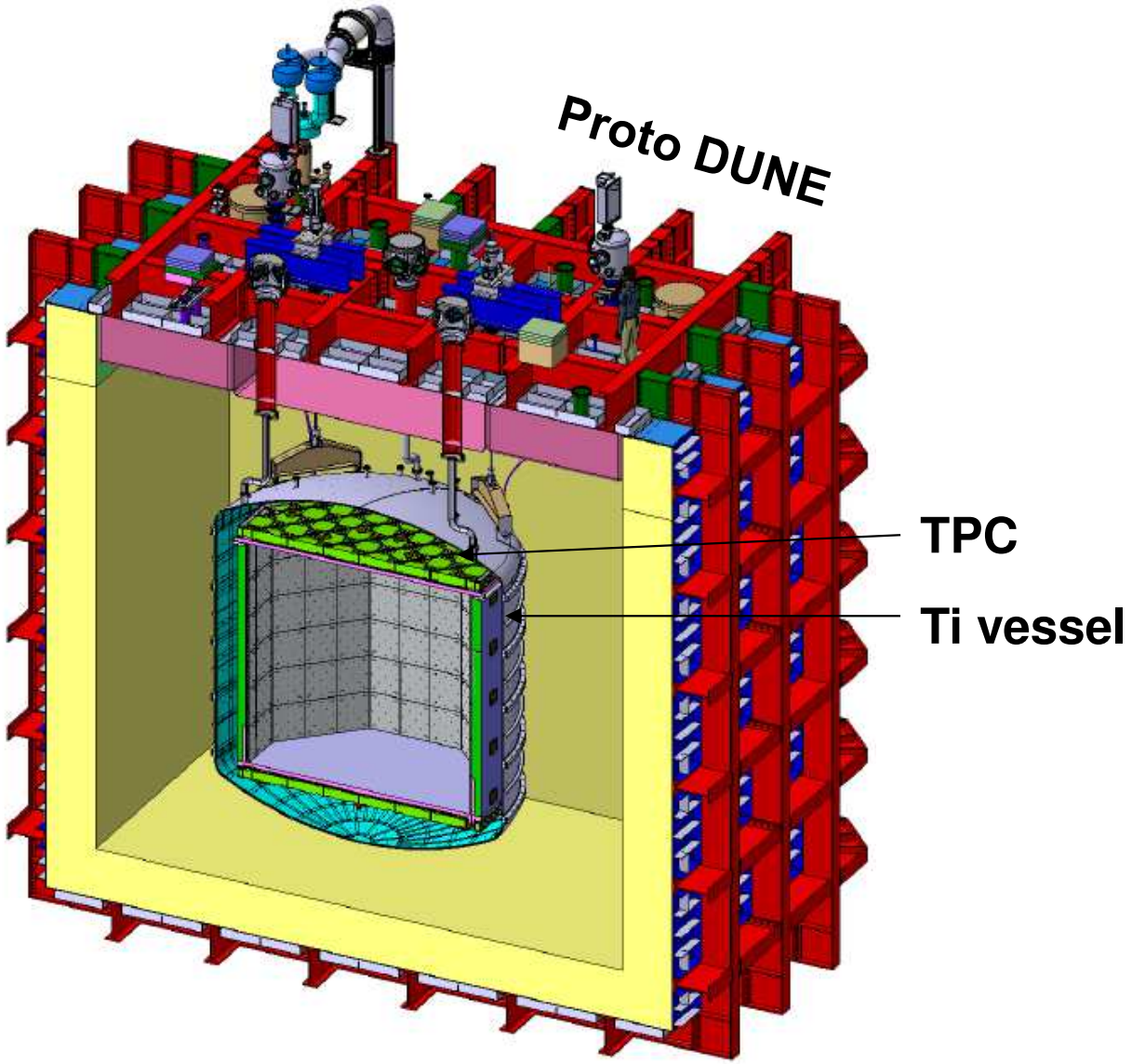
Conclusions

- **DarkSide-20k : next generation of LAr dual phase TPC**
  - Only one world wide collaboration, already funded
  - Background free experiment for high mass WIMP search → high discovery potential
  - Finalization of the design → TDR to LNGS 01/12/2021
  - Start installation at LNGS in 2022. First physics run in 2026

- **DarkSide-20k : IN2P3 contributions central for first physics**
  - **3 labs** (APC, LPNHE, CPPM): 15 people (~8 FTE) including 4 PhD students
  - **Hard**: Responsible of the DS-20k TPC calibration system. Radon expertize
  - **Soft**: Responsible of DS-20k offline *(G4 simulation, signal reconstruction)*
  - **Phys**: Leader of the ongoing low mass WIMP search in DS-50

BackUp

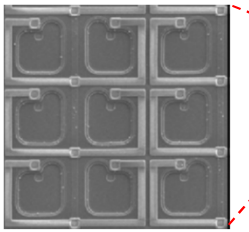
DS20k



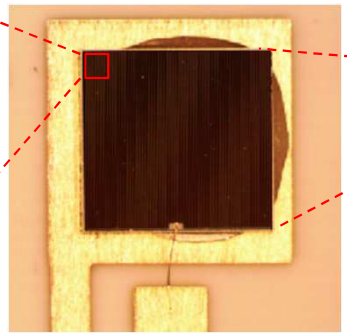
DarkSide-20k SiPM

❑ Photosensors

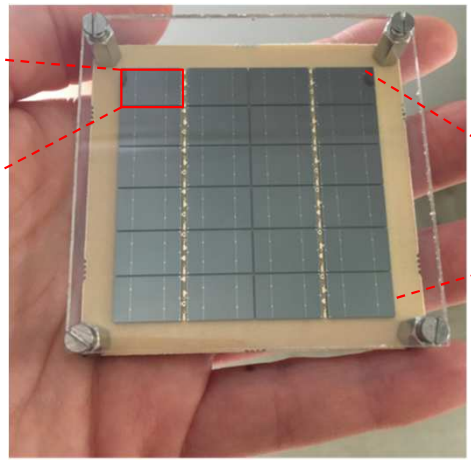
- Custom cryogenic SiPMs developed in collaboration with FBK (Italy) : PDE ~45%, Low dark count rate <20 cps, 10 ns timing resolution
- PDU = SiPM packaging inc. electronics in LNGS (TPC) and UK (Veto)



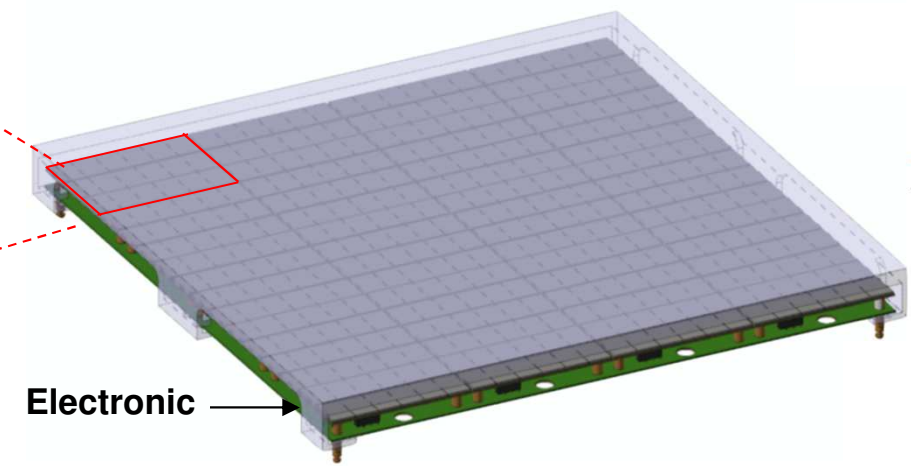
Single SPAD
(~ 25 μm²)



Single SiPM
(~ 1 cm²)

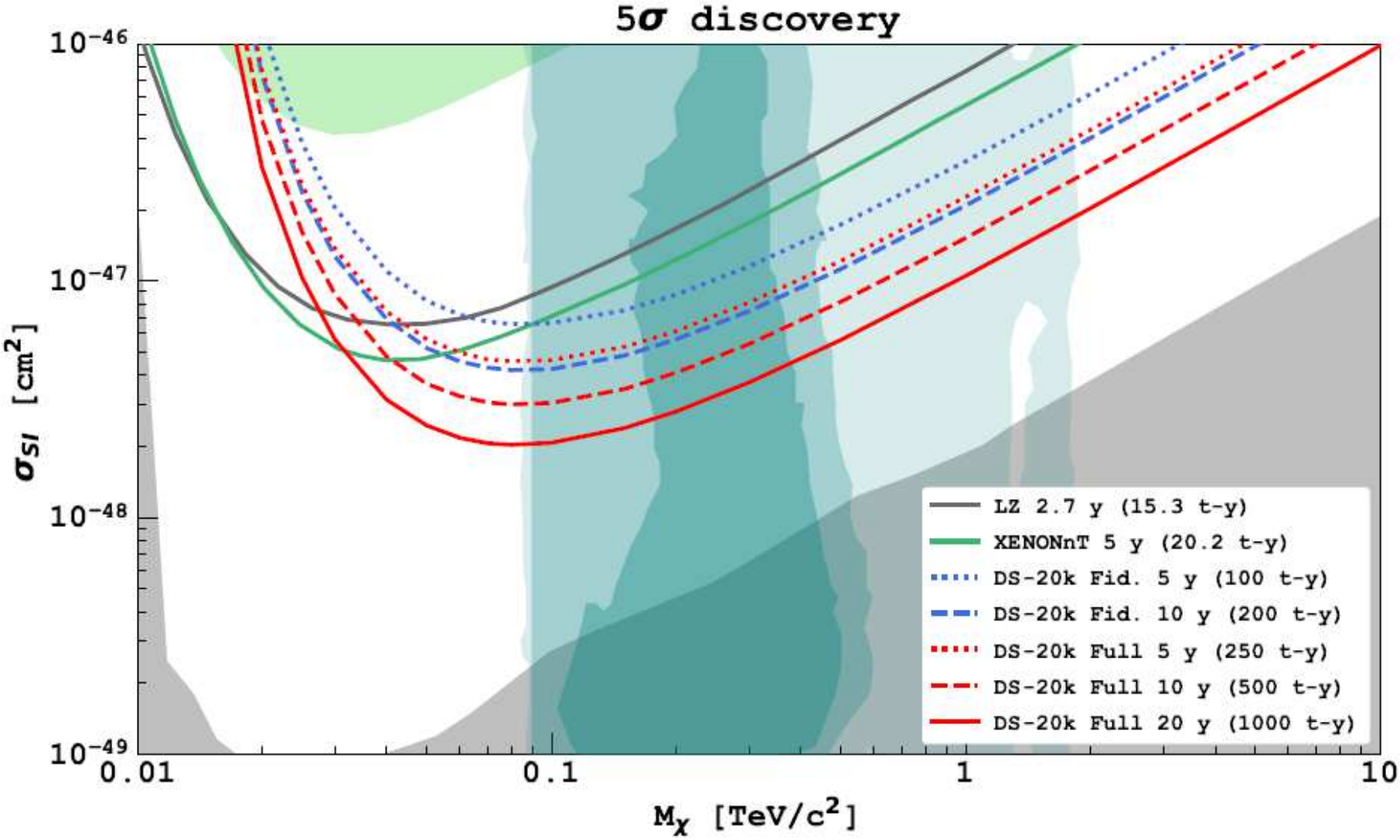


Tile = 24 SiPM
(~ 25 cm²)

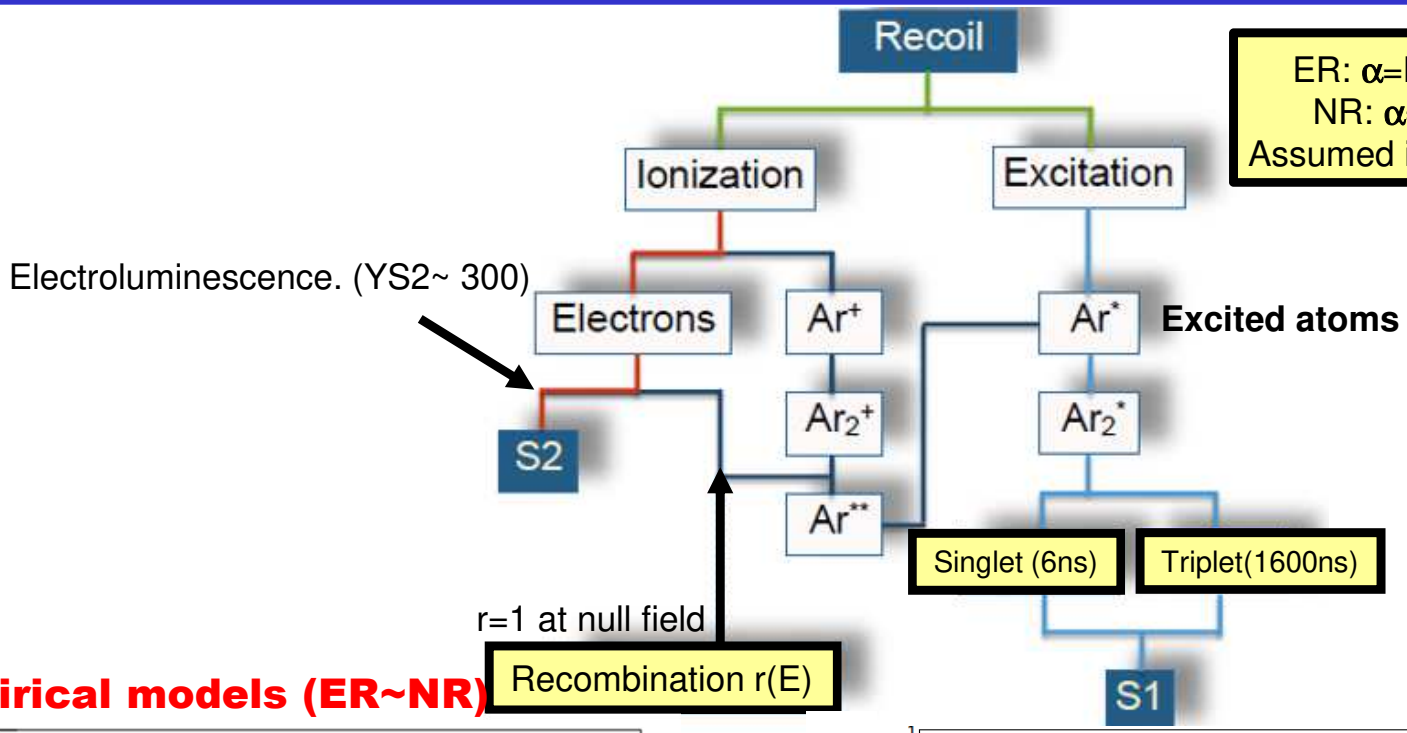


PDU = 16 Tiles (~ 400 cm²)
grouped by 4 → 4 channels

DS20k discovery potential



DS20k simulation (1/2)

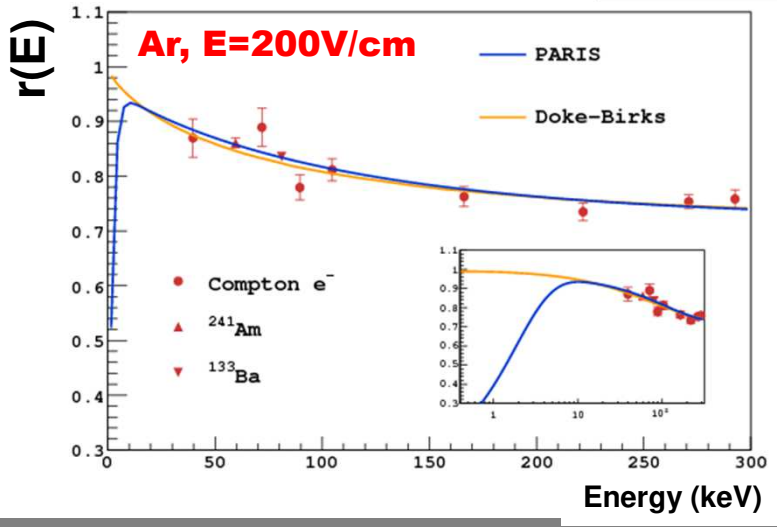


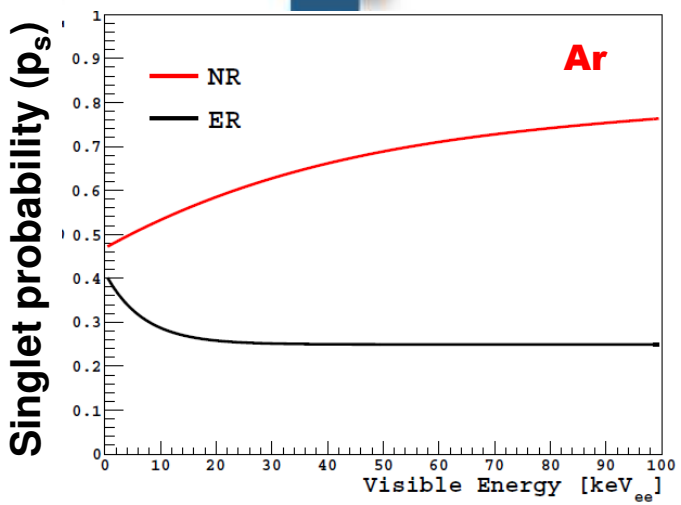
ER: $\alpha=N_{ex}/N_{ion}$~ **0.21**
NR: $\alpha=N_{ex}/N_{ion}$ ~ **1**
Assumed independent of E

[based on 70s/80s measurements]

NIM A269 (1988) 291
PhysRev A9 (1974) 1438
PhysRev B13 (1976) 1649

Empirical models (ER~NR)

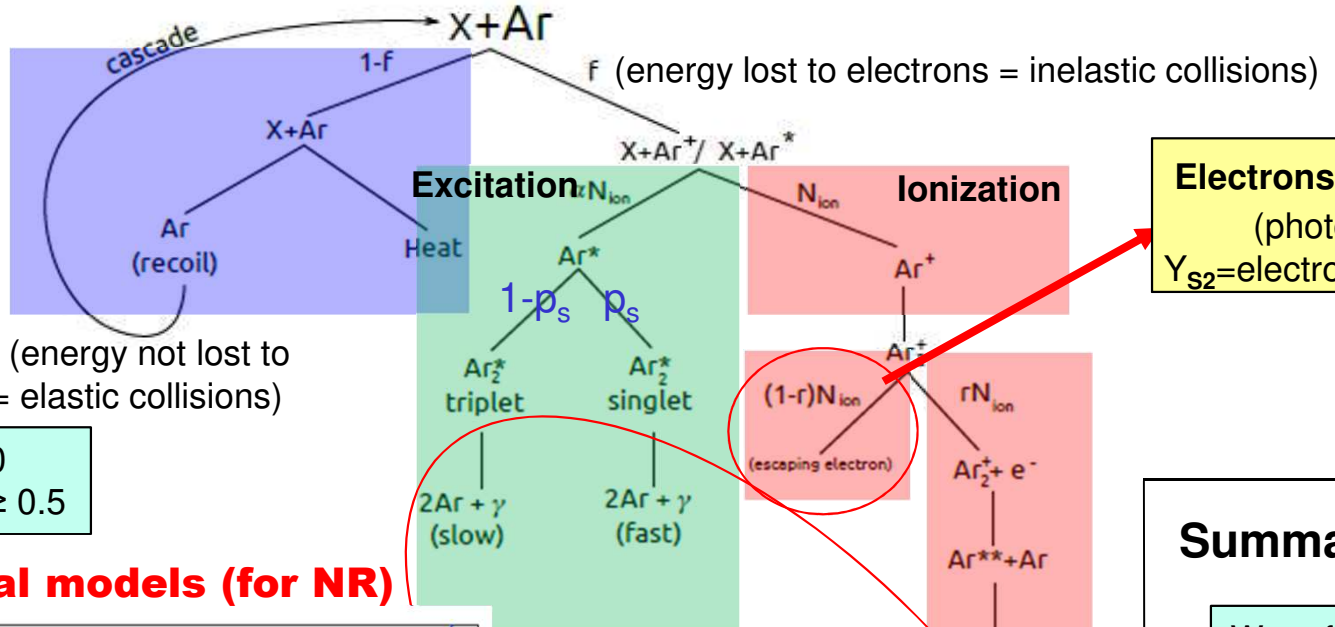




NR=mainly singlet
→ peaky signal

ER=mainly triplet
→ scattered signal

DS20k simulation (2/2)



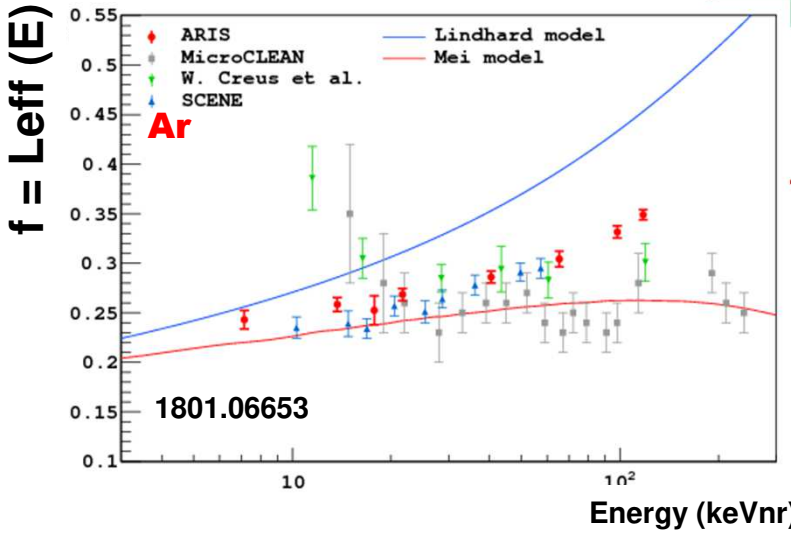
Quenching (energy not lost to electrons = elastic collisions)

ER: 1-f=0
NR : 1-f ≥ 0.5

Electrons S2 = N_{ion}-r(E)N_{ion} (photons [128 nm] → x Y_{S2}=electroluminescence yield)

Photons (128 nm) **S1** =N_{ex}+r(E)xN_{ion}

Empirical models (for NR)



Summary ER:

W = effective work to extract one quantum (ex or ion) = **19.5 eV**

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E_{dep}=W(N_{ex}+N_{ion})

W(N_{ex}+r(E)N_{ion}) → S1

W x Y_{S2}[1-r(E)]N_{ion} → S2