



DarkSide-20k and the Direct Dark Matter Search with Liquid Argon

darkside
two-phase argon TPC for Dark Matter Direct Detection



Luigi Rignanese on behalf of the DarkSide collaboration
ICHEP2020 28/07/2020
Zoom ID: 571 186 4633



Outline

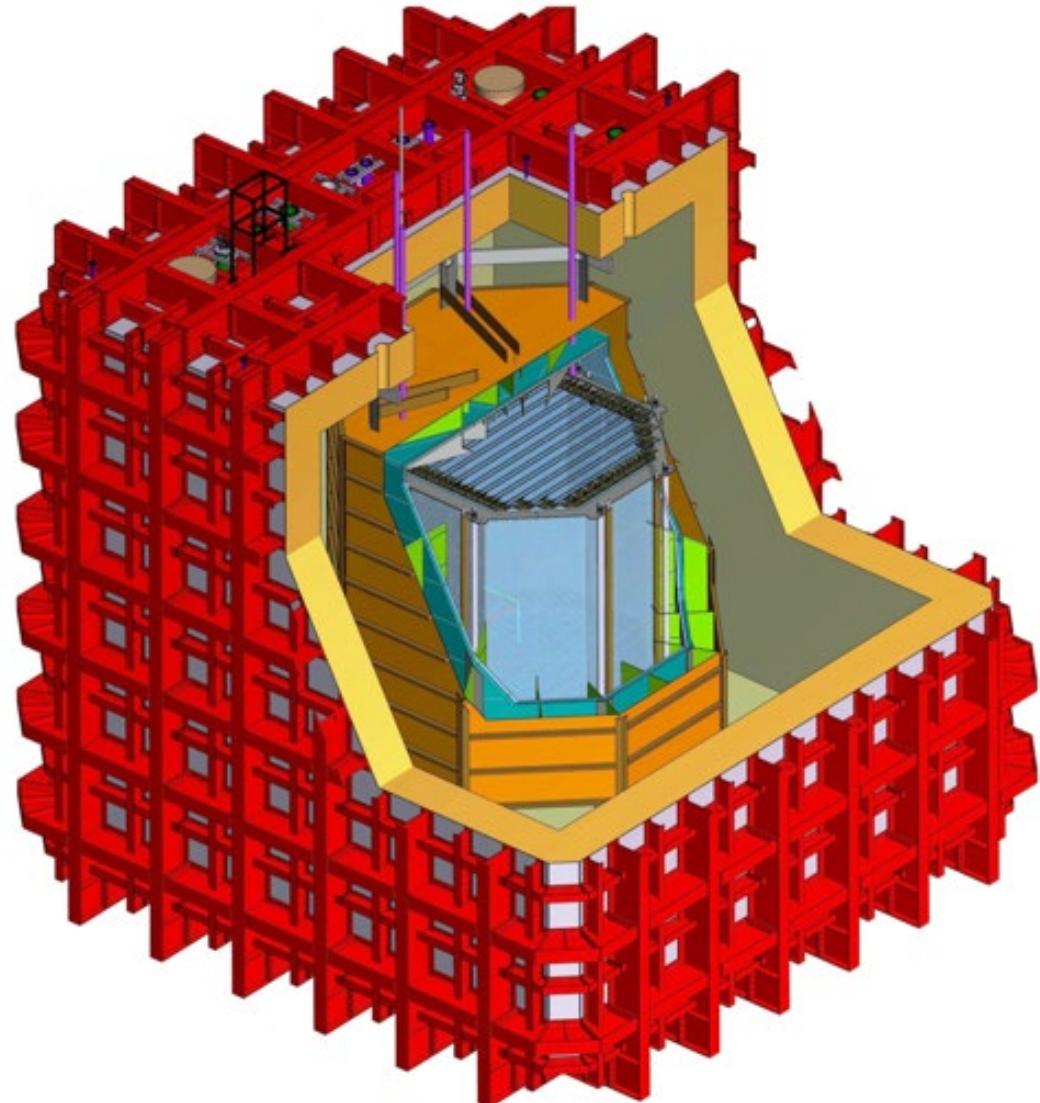
DarkSide and the GADMC

Dual phase Argon TPC

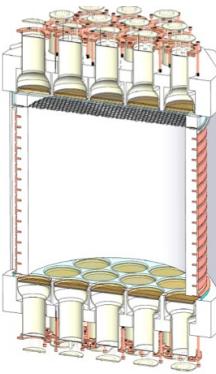
DarkSide-50

Bigger is better

Darkside-20k



DarkSide is multi-stage program that aims to the direct detection of **Dark Matter**, by operating a dual phase **Underground Argon (UAr)** time projection chamber (**TPC**), at the underground **Laboratori Nazionali del Gran Sasso**.

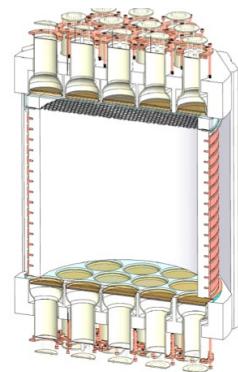


DS-50
50Kg LAr

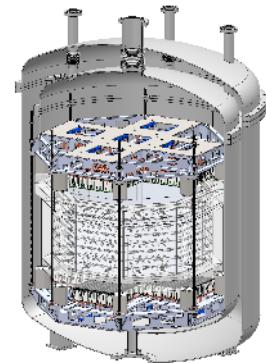
DarkSide and the GADMC



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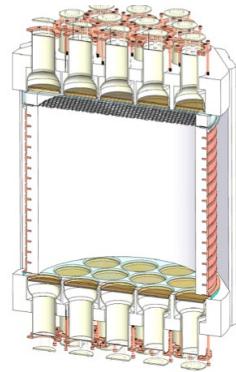


DS-proto-1t
175Kg LAr

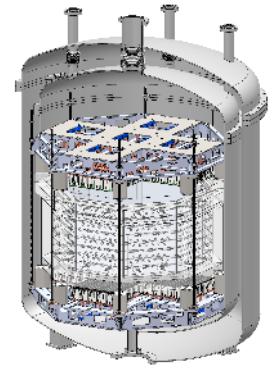
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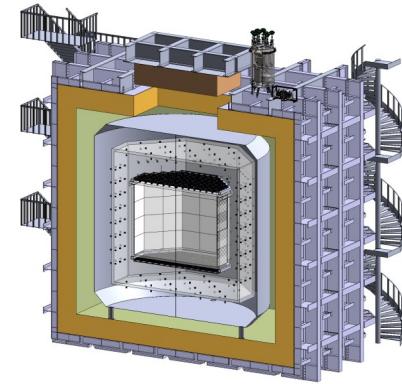
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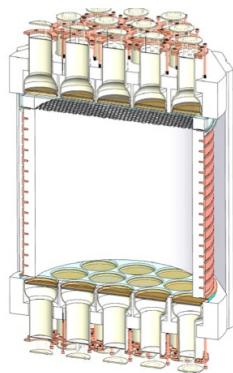


DS-20k
50ton LAr

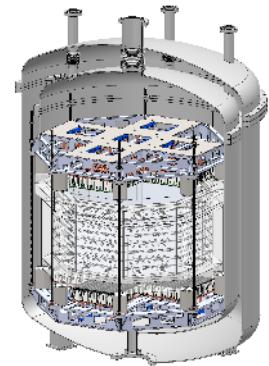
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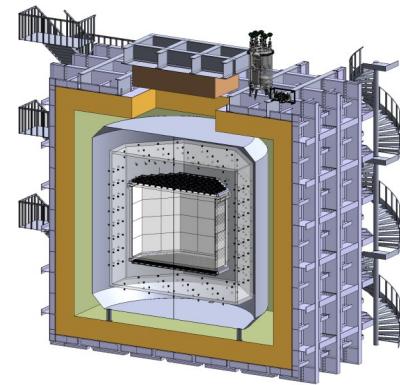
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DS-50
50Kg LAr



DS-proto-1t
175Kg LAr



DS-20k
50ton LAr



~300ton LAr

59 institutions

More than 400 researchers

14 countries: Brazil, Canada, China, France, Greece, Russia, Italy, Mexico, Poland, Romania, Spain, Switzerland, UK, USA.

DarkSide and the GADMC



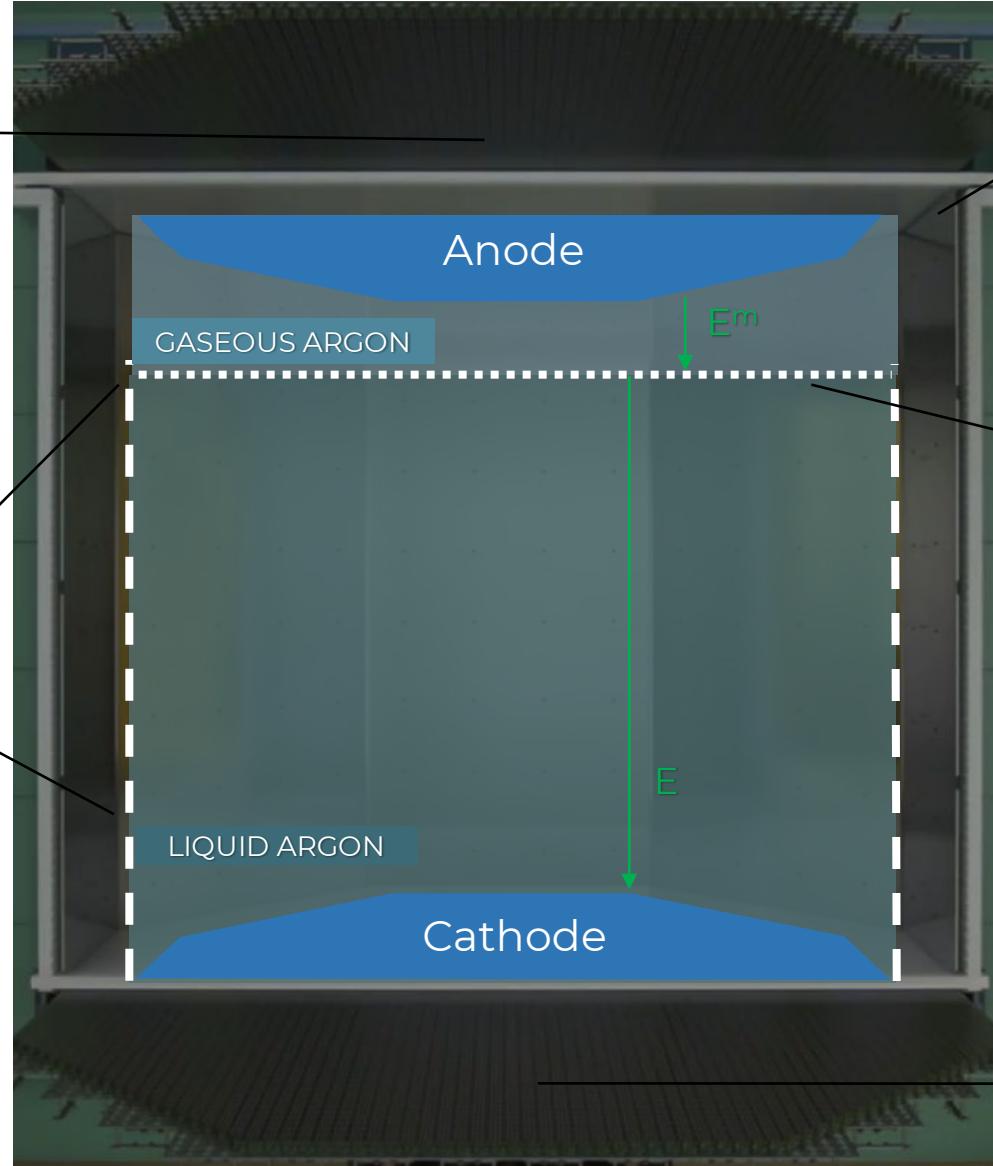
Top photodetection plane

TPC vessel

Field cage rings

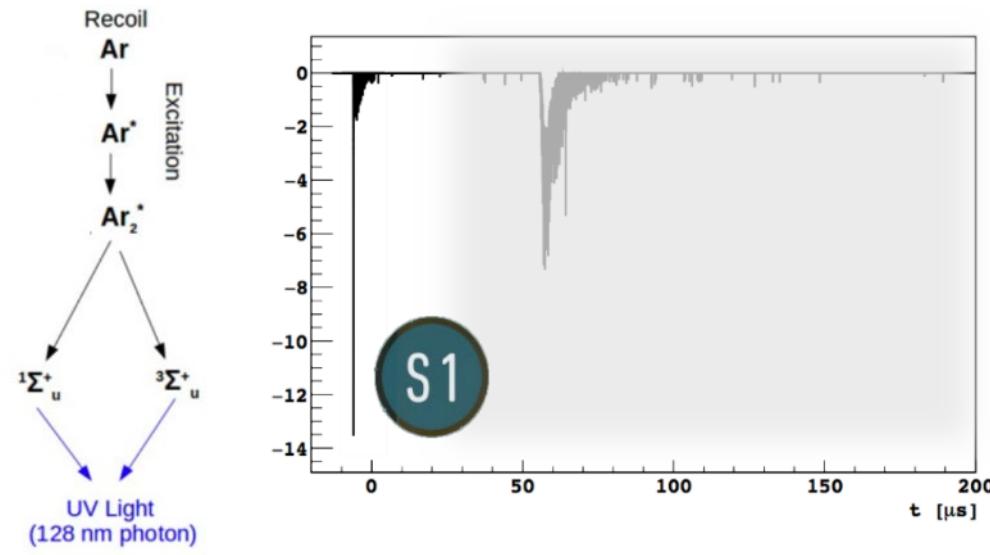
Wire extraction grid

Bottom photodetection plane



Dual phase Argon TPC



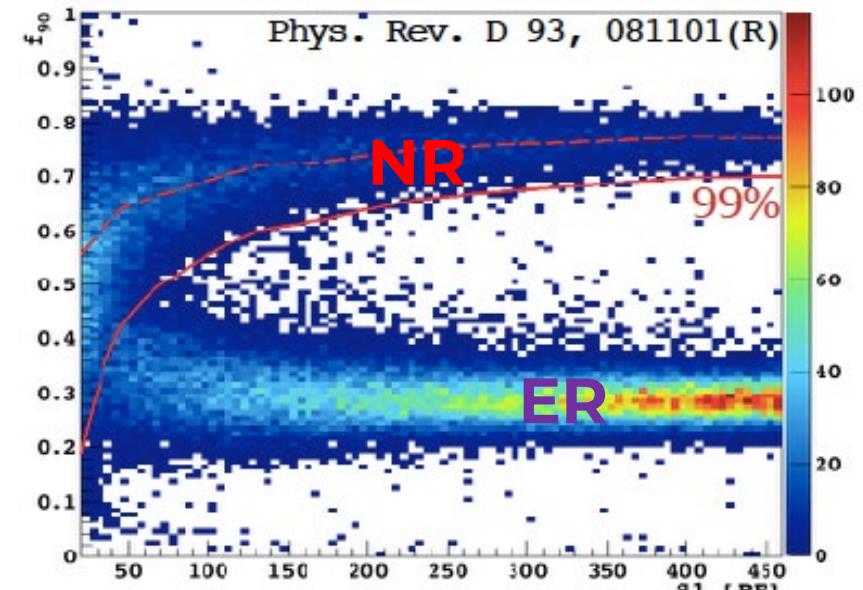
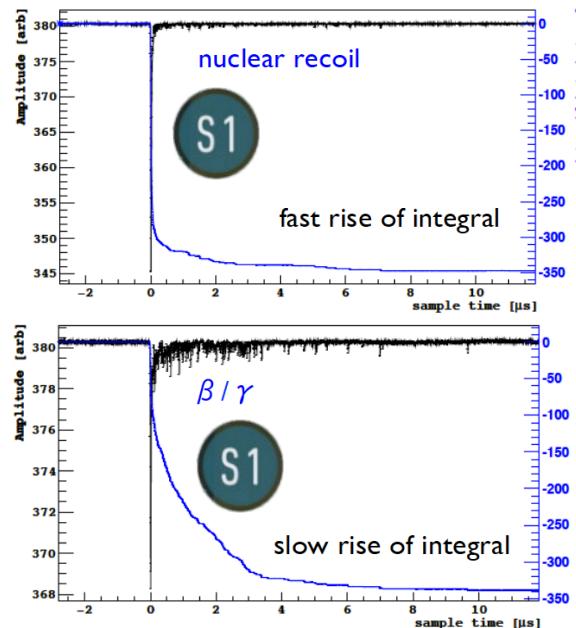
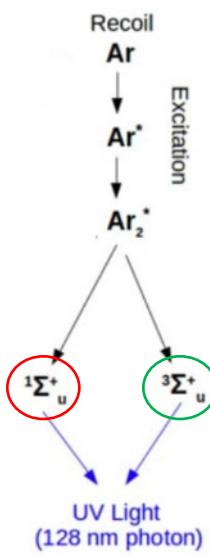
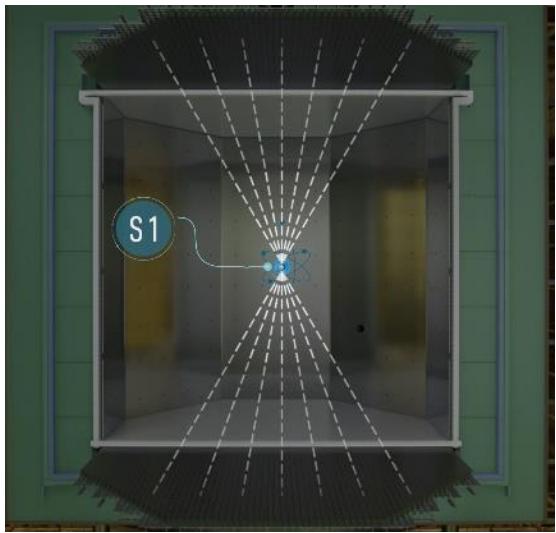


Dual phase Argon TPC S1

Videos from the DS [web page](#)

Luigi Rignanese rignanes@bo.infn.it
ICHEP2020 28/07/2020





Very different decay times of **singlet** (~7ns) vs. **triplet** (~1.6μs) state.

Electron **R**ecoils cause a higher fraction of **triplet** states than **N**uclear **R**ecoils.

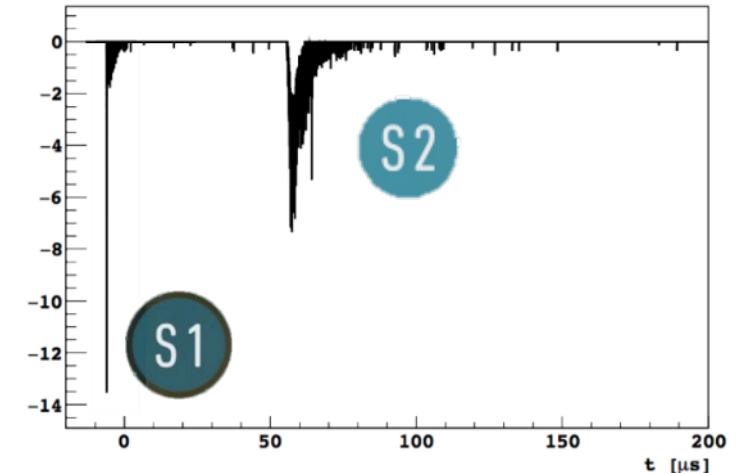
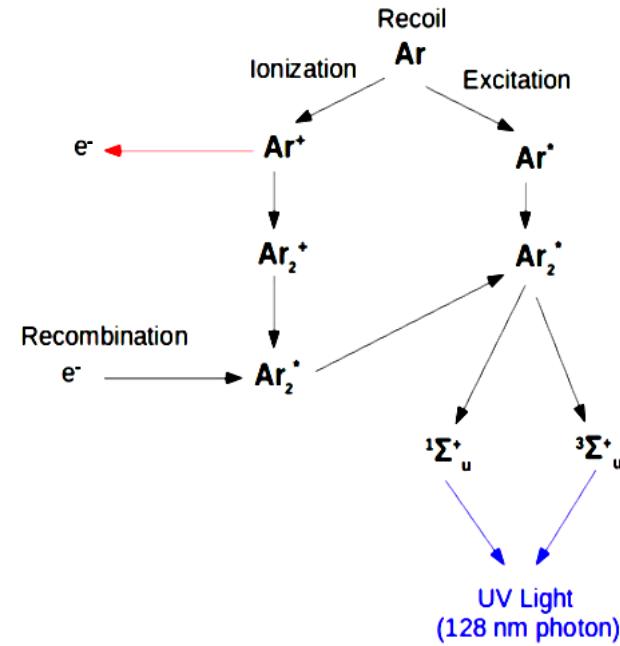
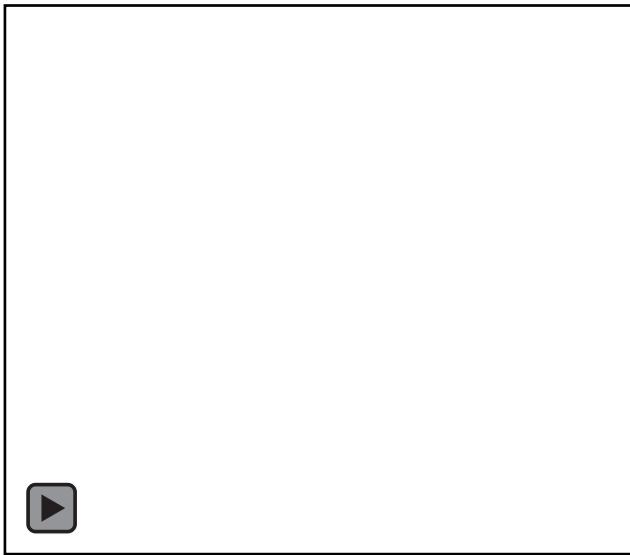
The resulting signals have different shapes that can be discriminated by using **PSD** techniques (f_{90} fraction of signal in the first 90ns).

NR band from the AmBe calibration
ER band from β - γ backgrounds.

Exceptional discrimination up to 10^9
(from DEAP-3600@SNOLAB)

Dual phase Argon TPC **S1**





S2 proportional electroluminescence allows **xy** reconstruction. By the **S2-S1 time difference** the **z** coordinate of the interaction can be calculated.
Gain on ionization signal (**S2**) allows to easily detect **single ionization electrons** resulting in a lower the detection threshold (**Low Mass DM**)

Dual phase Argon TPC S2



- **High scintillation yield** ~ 40 γ/keV
- Broad **recoil energy spectrum** (0-100 keV)
- **87K** boiling point close to N
- Powerful **PSD** in the scintillation signal (S1)
- If chemically pure, **ionization** can be drifted for **long distances**
- **Efficient scintillator** (128nm), self transparent **but WLS** needed (TPB shift to 420nm)
- **Most abundant** noble gas in the atmosphere

Dual phase Argon TPC why Ar?



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→ **High mass LAr detectors!**

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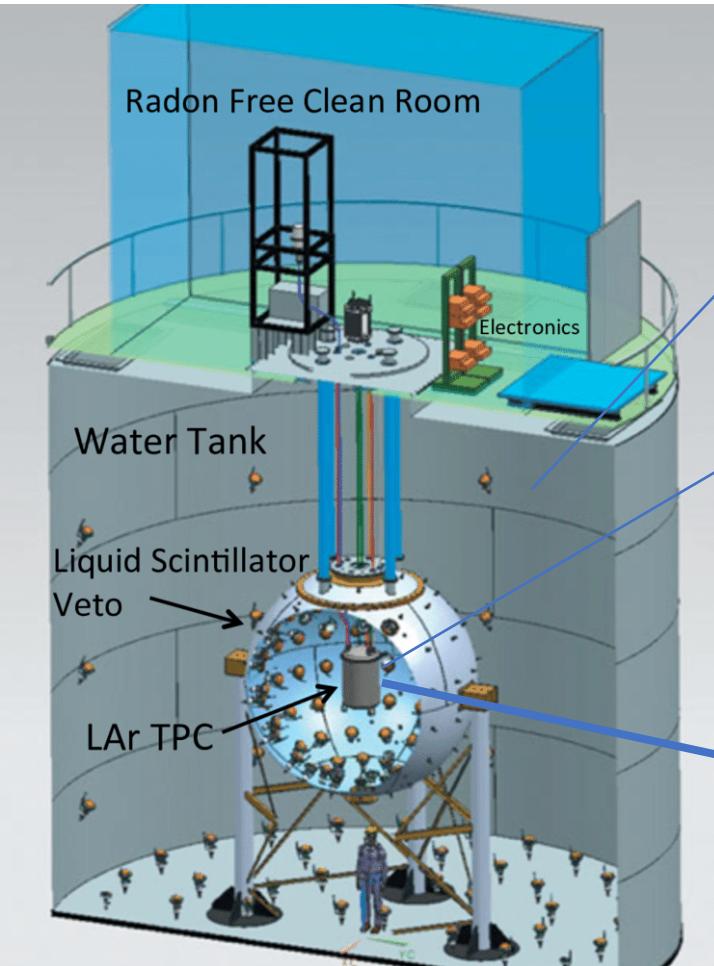
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→ **High mass LAr detectors!**

However, cosmogenic **^{39}Ar** contamination in atmospheric argon limits the size of liquid argon dark matter detectors due to pile-up. **^{39}Ar** beta emitting radioactive isotope. Relative abundance **10^{-15}g/g** ^{39}Ar . **1Bq/kg** activity, **269y** half-life.

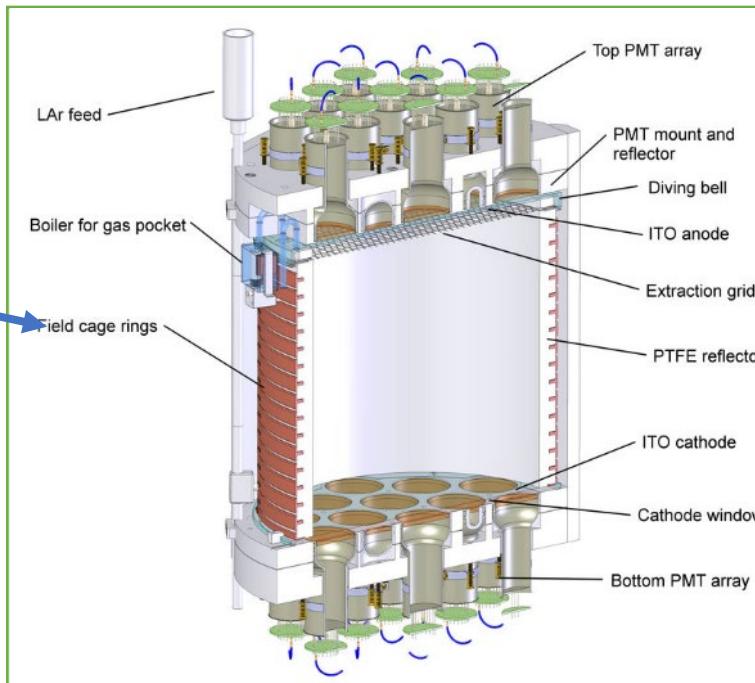
Dual phase Argon TPC why Ar?





Water Cherenkov detector (passive shield and μ VETO)
Stainless steel vessel filled with **1kt** of ultra pure water.
80 8" PMTs.

Liquid scintillator detector (γ, n VETO)
30t Boron loaded scintillator.
110 8" PMTs



TPC housed in stainless steel cryostat
PTFE cylinder \varnothing **36.5 cm x 36.5 cm**
with the inner surfaces **coated** with
TPB (128nm to 420nm).
38 3" Hamamatsu R11065 PMTs (**19** on
top and **19** on **bottom**).
Filled with **46kg** of **Underground**
Argon (UAr).

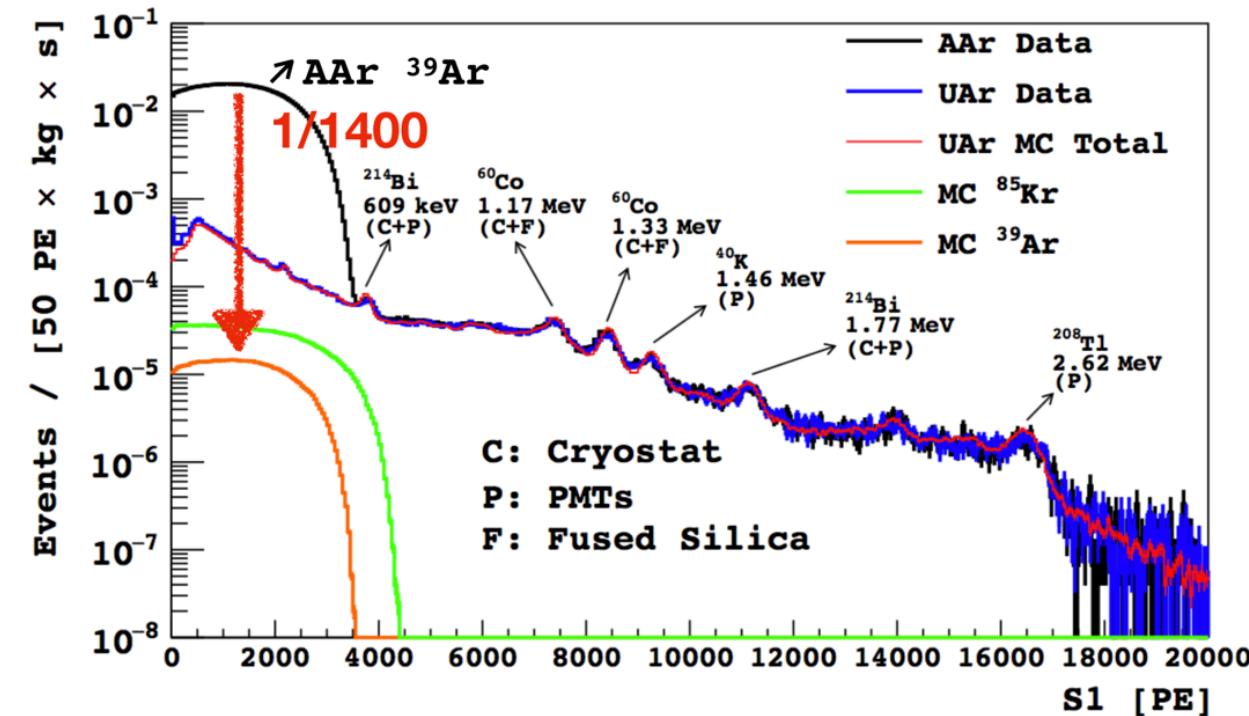
DarkSide-50@LNGS

DarkSide-50 found the ^{39}Ar level to be far reduced in **UAr** when compared to atmospheric argon

Ar extracted from CO_2 wells in **Colorado**



Further purified via a **cryogenic distillation** column at **Fermilab**



UAr: $^{39}\text{Ar} < 0.07\%$ of AAr

DarkSide-50 Underground Argon



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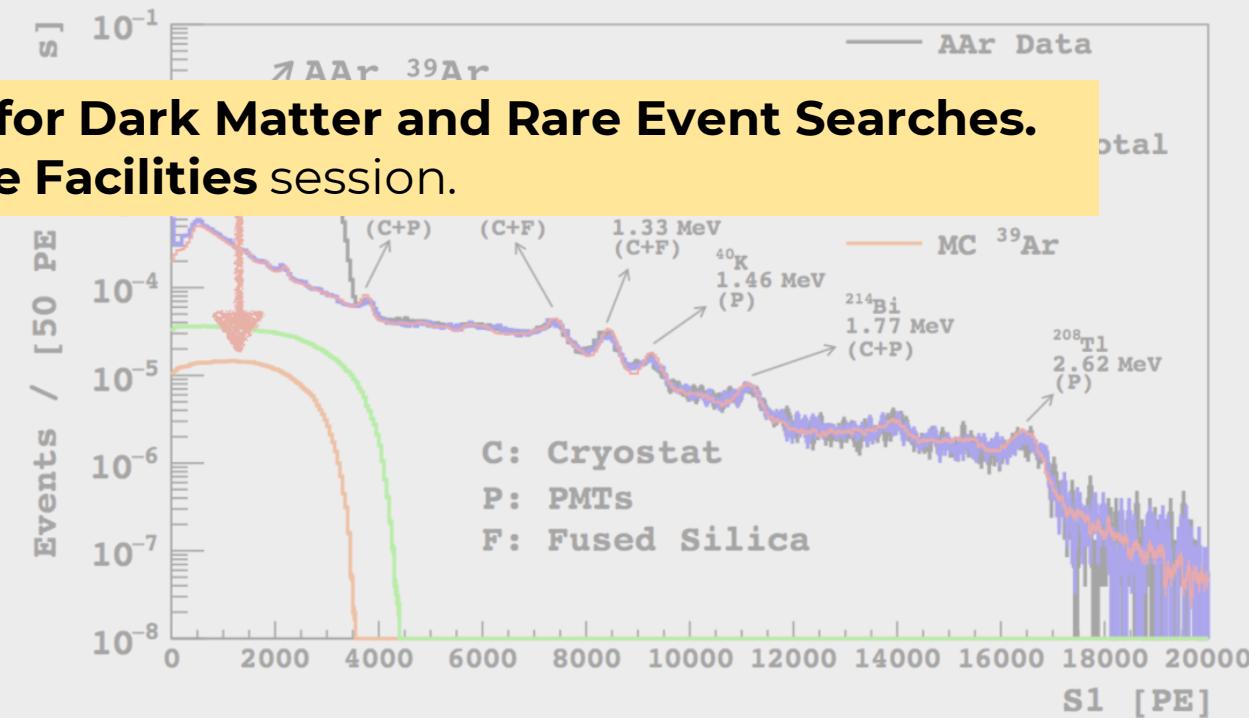
Ar extracted from **CO₂** wells in **Colorado**



Brianne Hackett, **Low Radioactivity Argon for Dark Matter and Rare Event Searches.**
30 Jul 2020, 12:15 at the **Detectors for Future Facilities** session.



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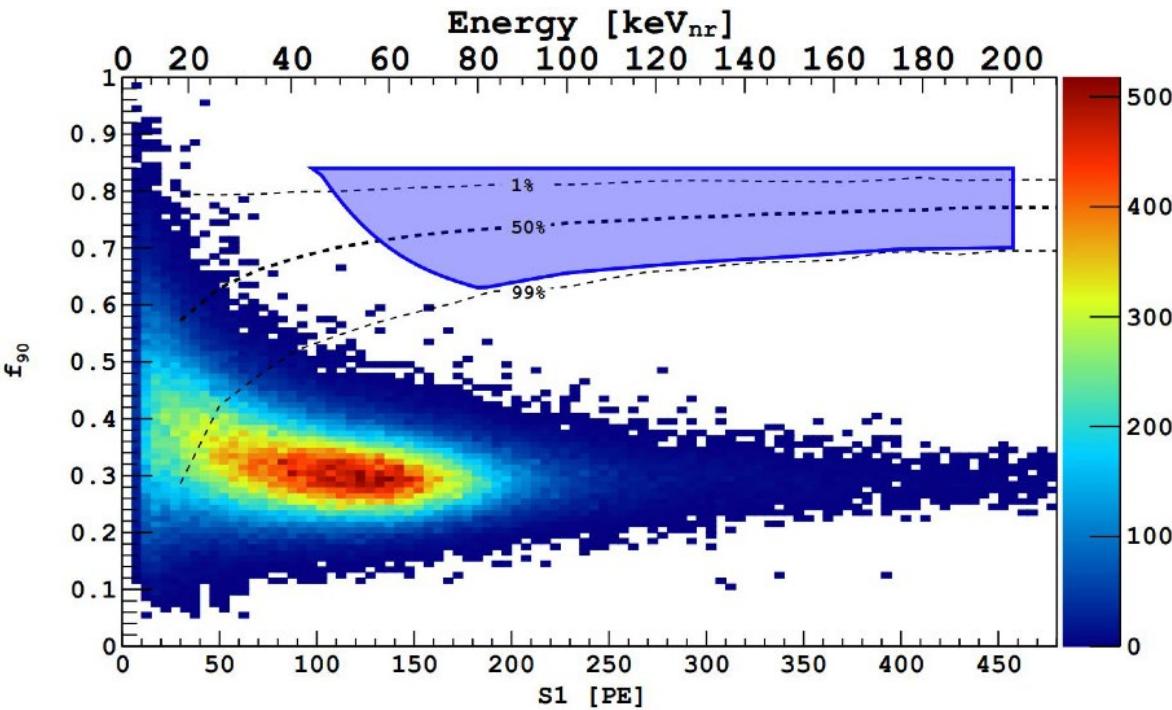


DarkSide-50 Underground Argon



- Exposure = 532 live days x 46 kg
- Underground Ar (UAr) activity $\sim 0.7 \text{ mBq/kg}$
- LY $\sim 8 \text{ photoelectrons/keV@null field}$

Observed events in the f90 vs. S1 plane surviving all cuts (VETO+analysis) in the energy region of interest.

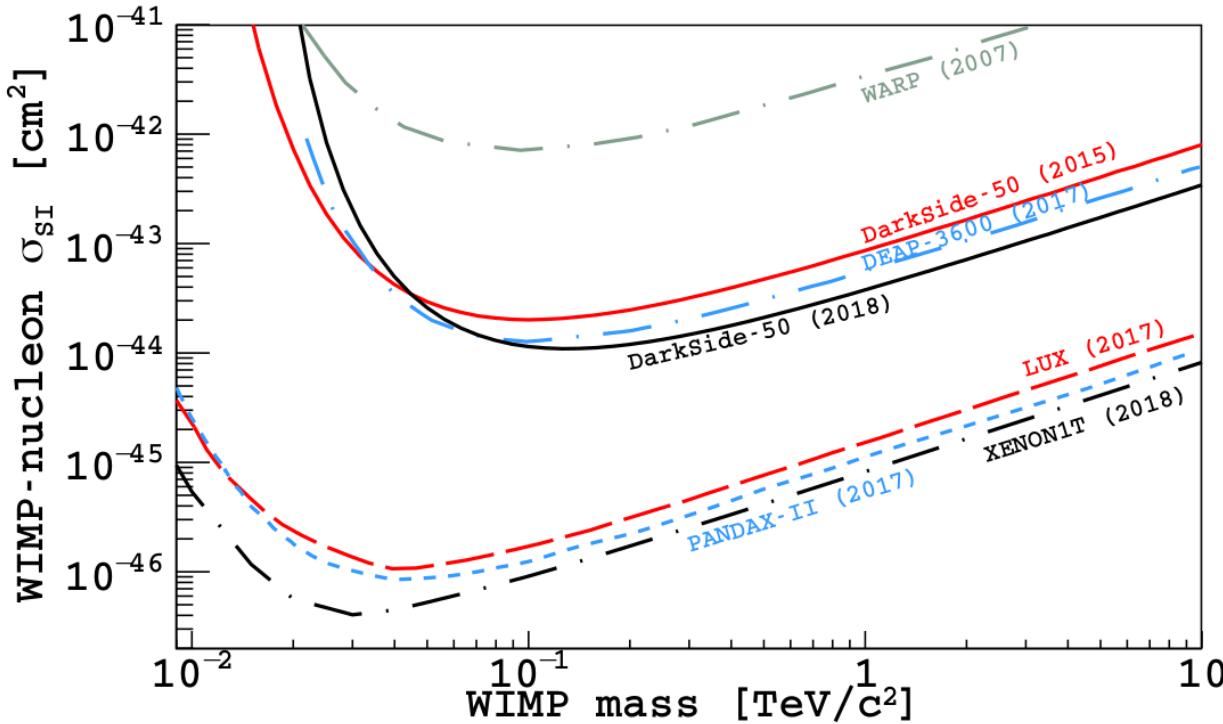


Background	Estimated # surviving all cuts
Cosmogenic neutrons	$< 3 \times 10^{-4}$
Radiogenic neutrons	$< 5 \times 10^{-3}$
Surface α	1×10^{-3}
Cherenkov + scintillation	0.08
Total	0.09 ± 0.04

< 0.1 background events remaining in **WIMP search region**

DarkSide-50 Results





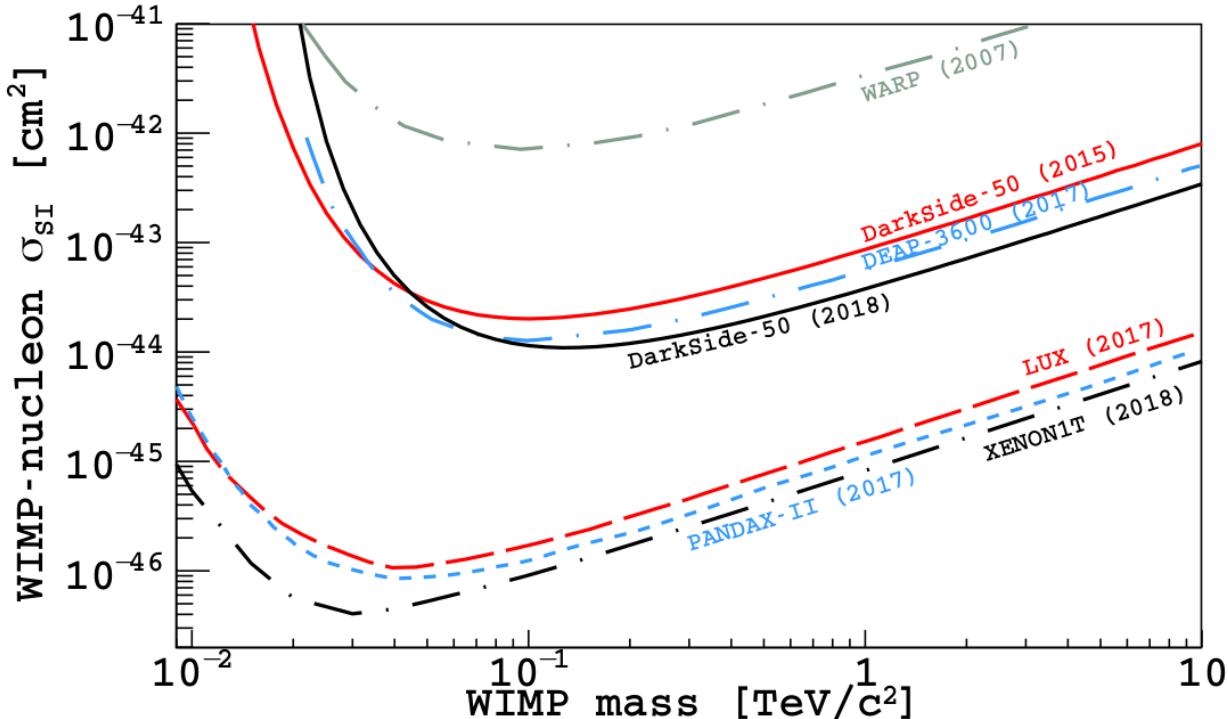
High Mass DM exclusion limit results:

WIMP-nucleon cross section > **$1.1 \times 10^{-44} \text{ cm}^2$**
@ $100 \text{ GeV}/c^2$

Physical Review D 98 (10), 102006 (2018) [arxiv:1802.07198](https://arxiv.org/abs/1802.07198)

DarkSide-50 Exclusion limits





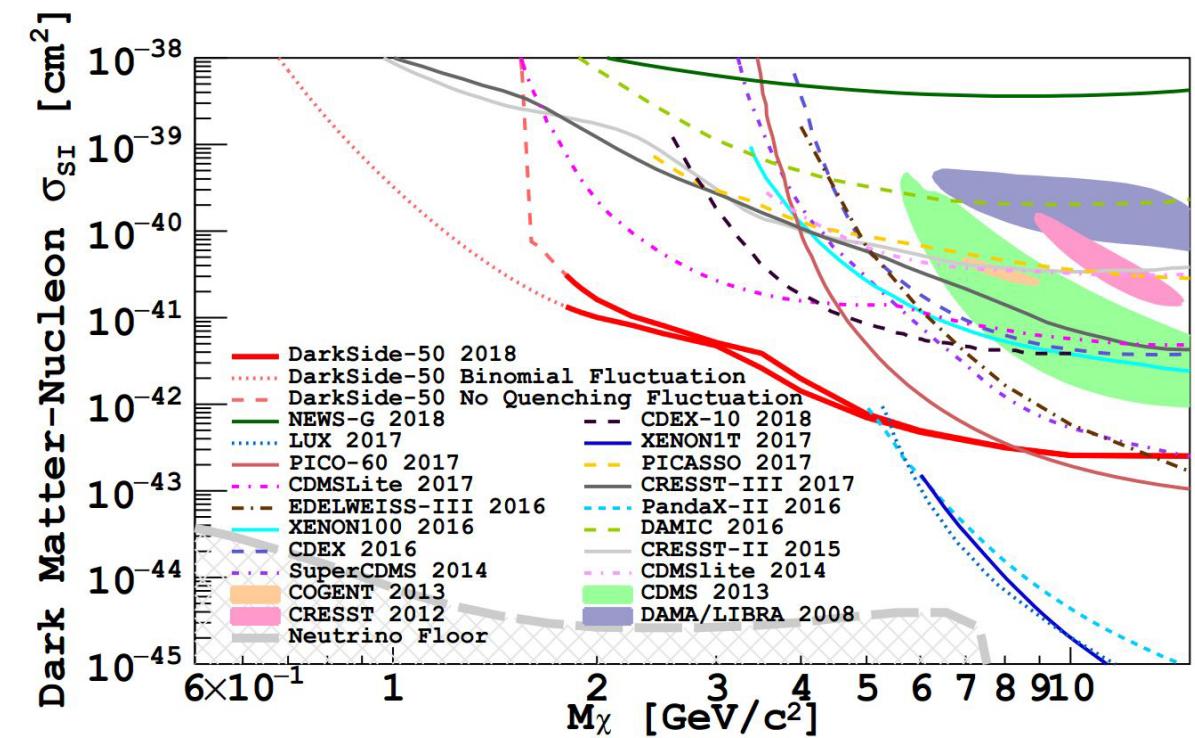
Low Mass DM exclusion limit (S2 only analysis) results:

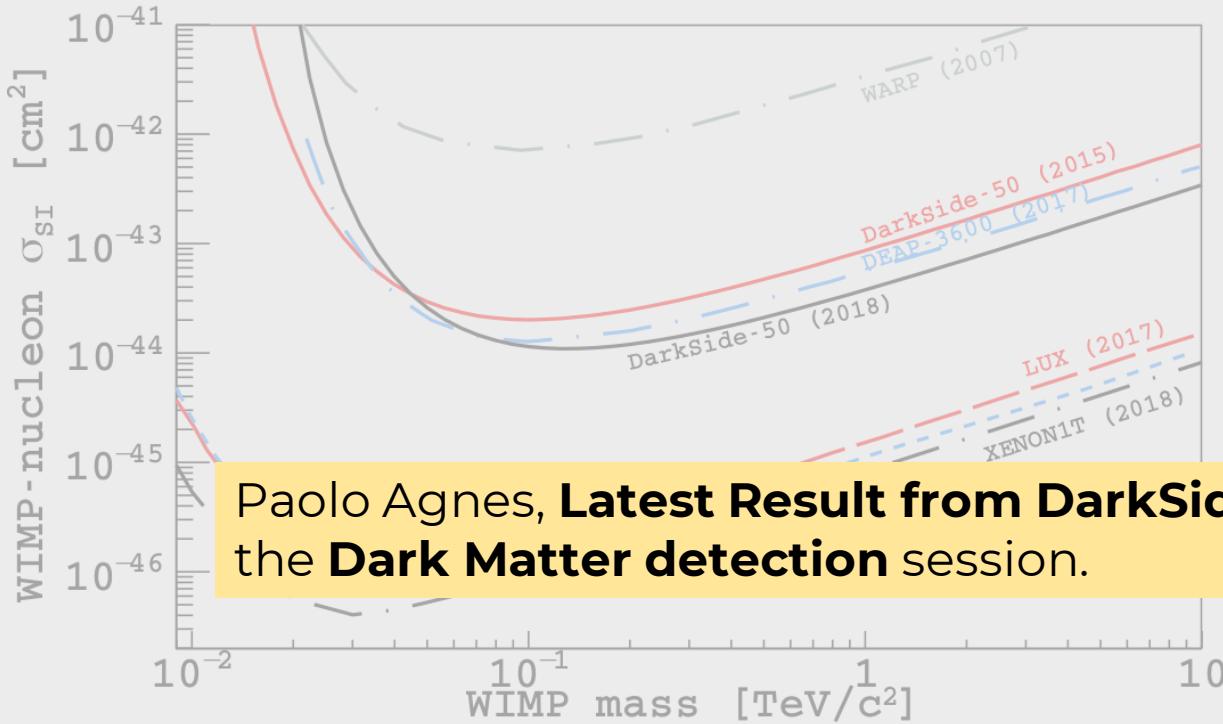
Leading limit in the field for **WIMP-nucleon** interactions in the **1.8-6 GeV/c 2 mass range**

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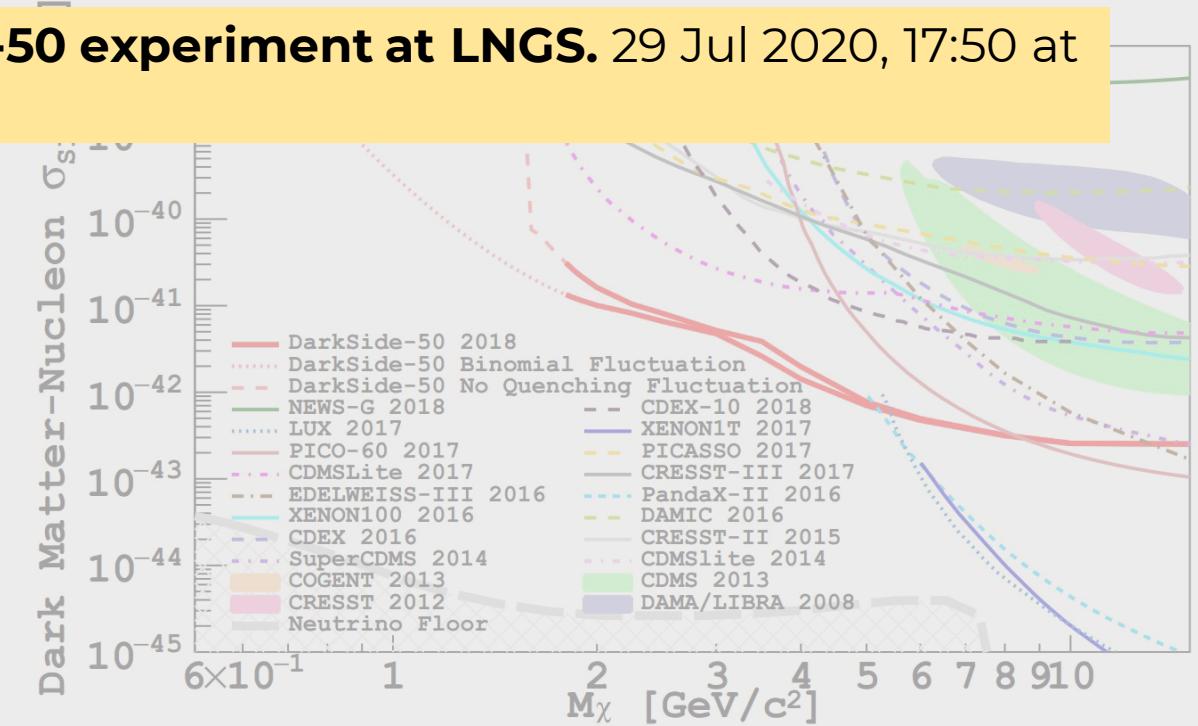
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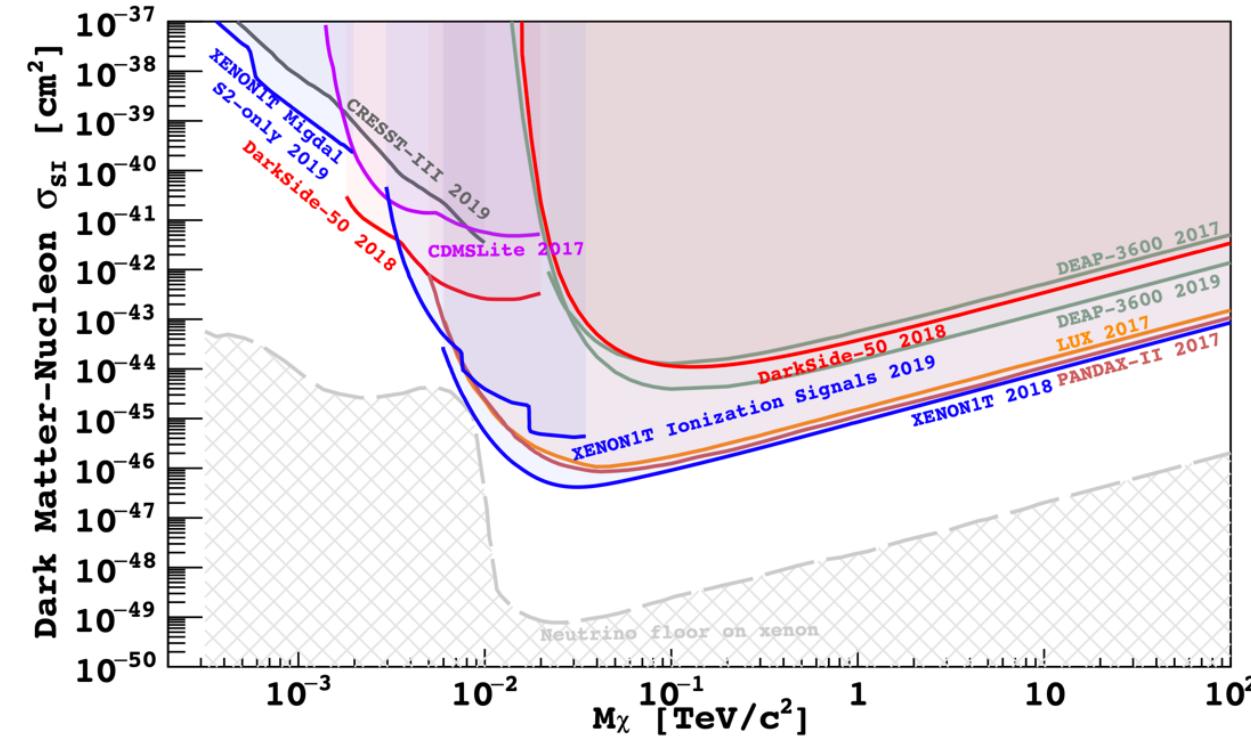
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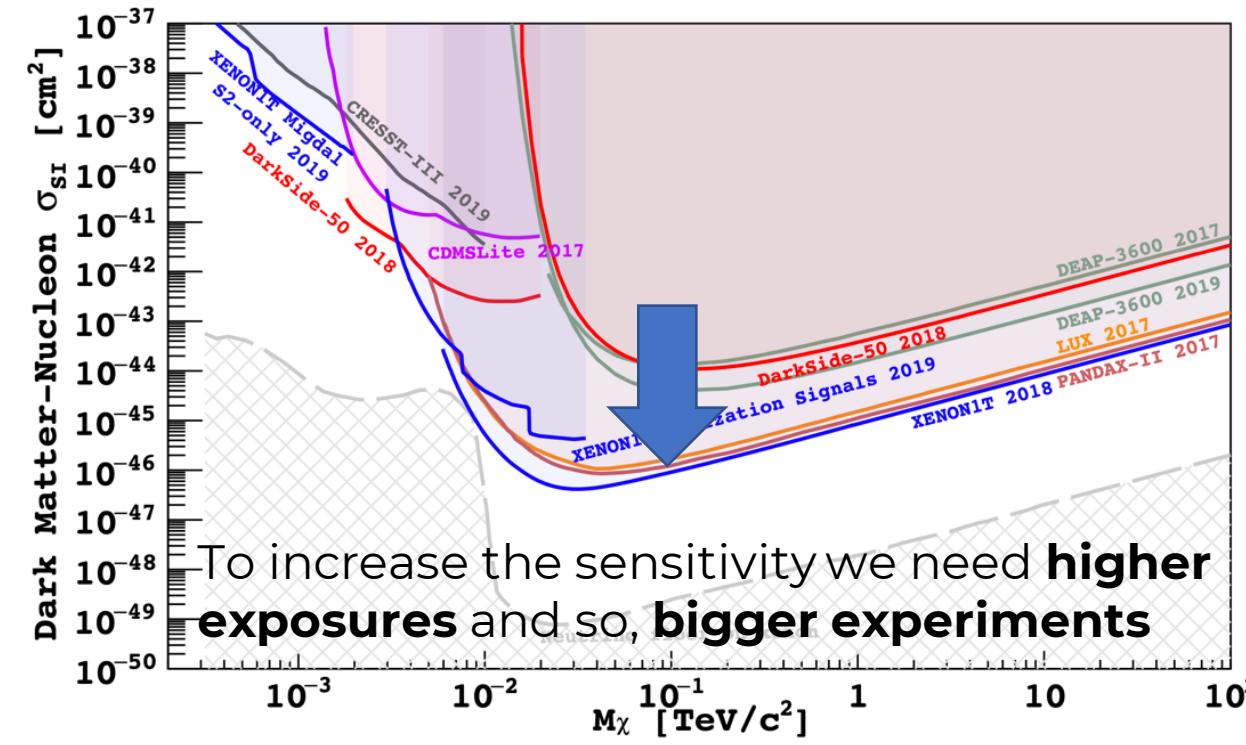




Several experiments put an **upper limit**.

Bigger is better

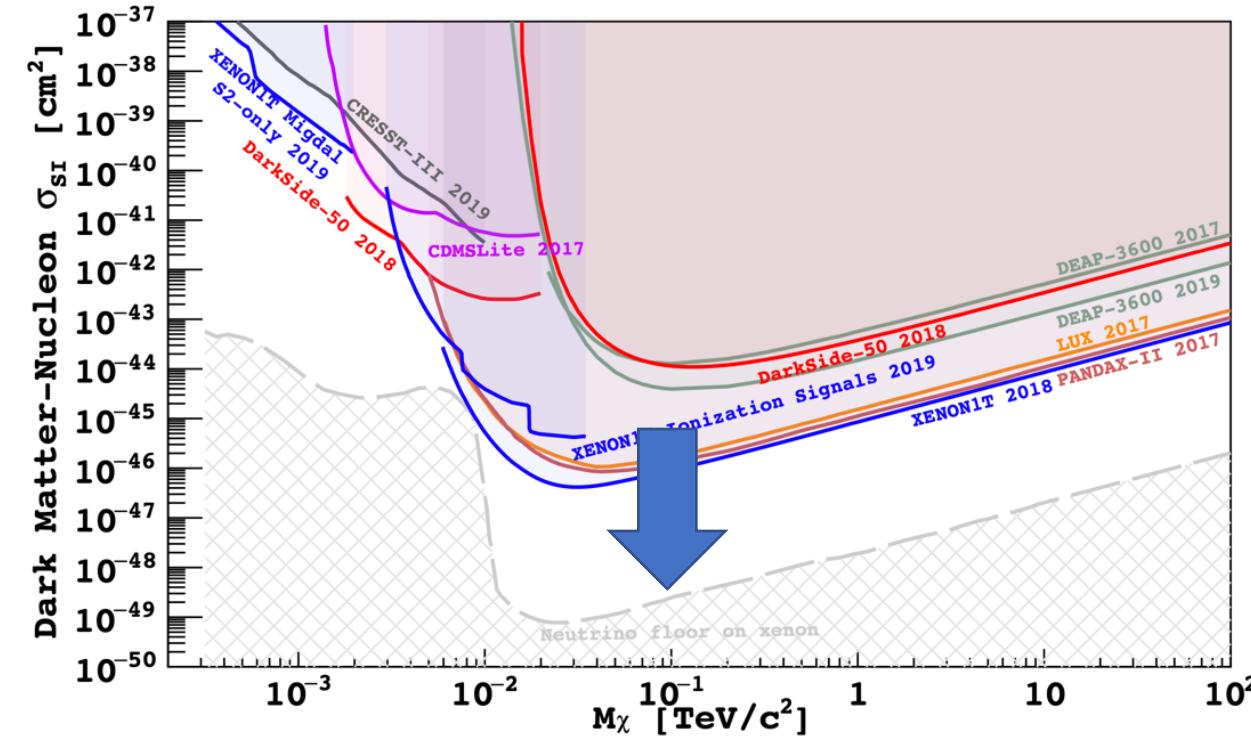




Several experiments put an **upper limit**.
But a big region remain unexplored.

Bigger is better



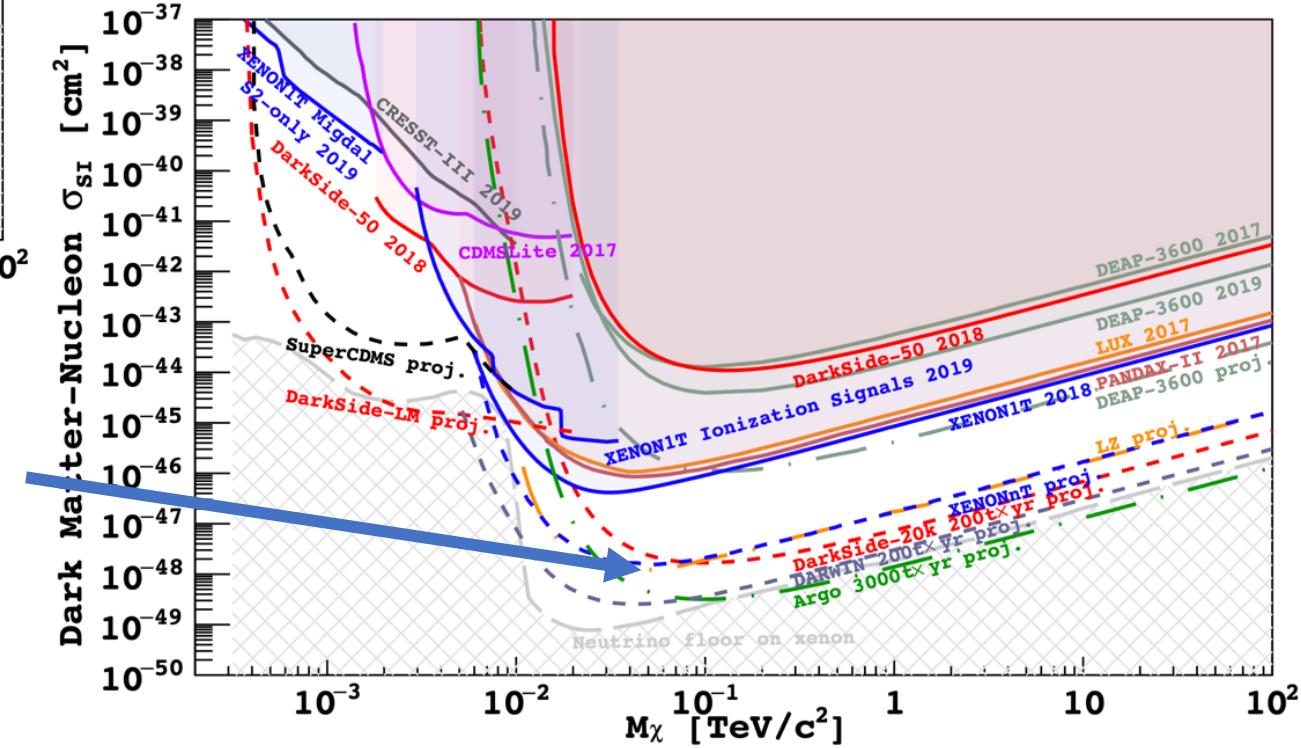


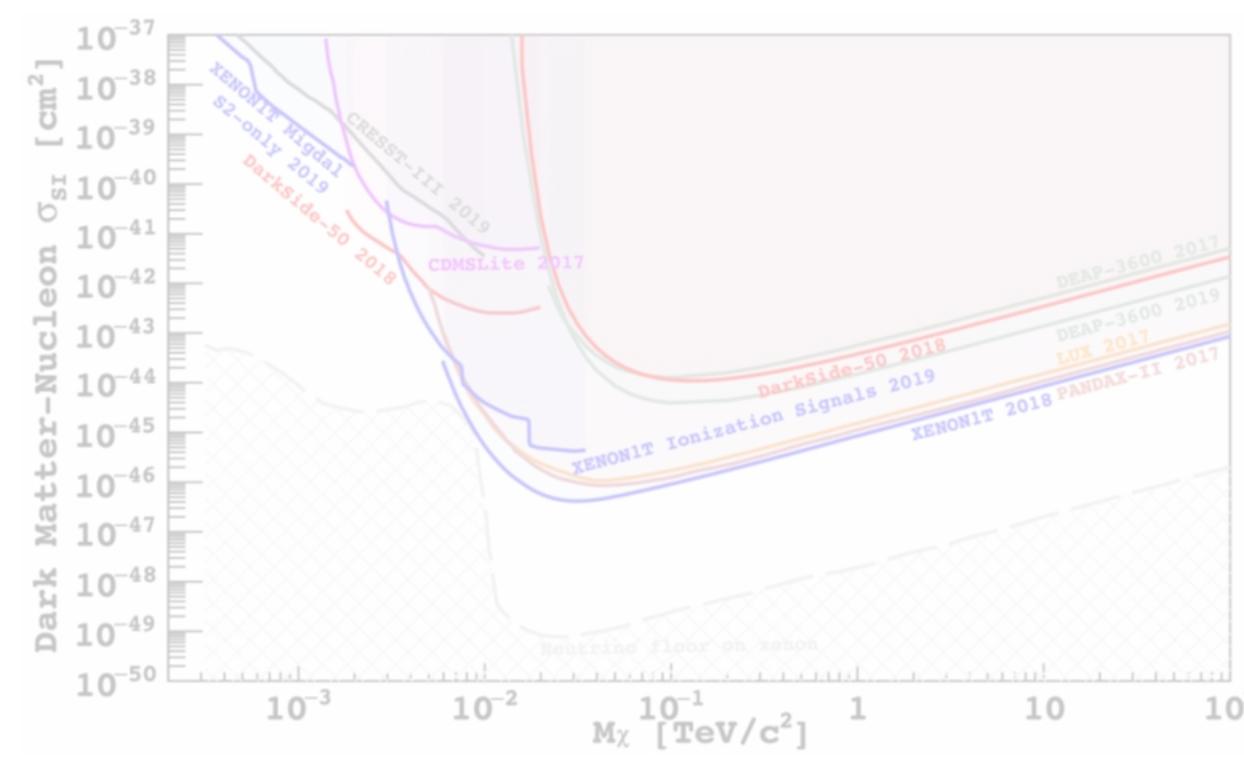
To increase the sensitivity we need **higher exposures** and so, **bigger experiments**:

@100 GeV:

- DS-20k: $2 \times 10^{-48} \text{ cm}^2$ (200 t x yr)
- Argo (300 t): $3 \times 10^{-49} \text{ cm}^2$ (3000 t x yr)

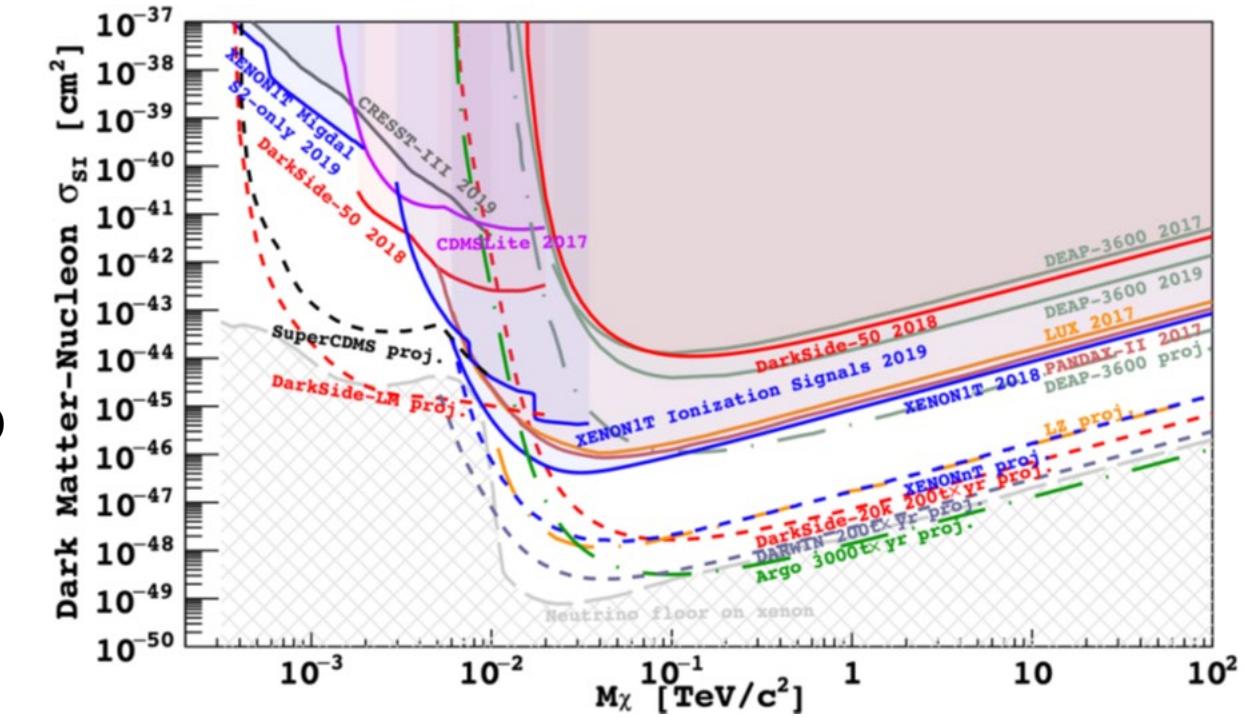
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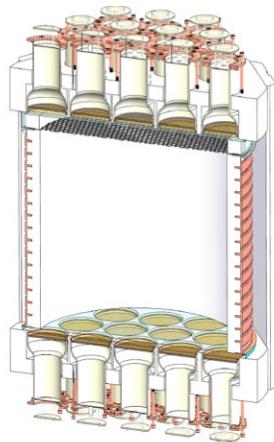
Assuming the same background condition as **DS-50**
<0.1 event

Bigger is better but keep it clean



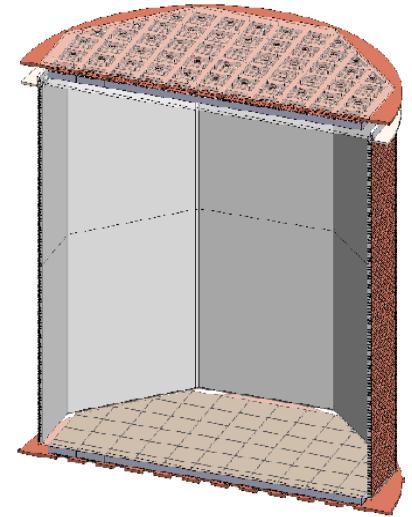
DarkSide50 TPC

- **46kg** active mass of **UAr**
- **ø 36.5 cm x h 36.5 cm**
- **<0.1 event of background**
- **0.17m²** light detection coverage



DarkSide-20k TPC

- **50t** active mass of **UAr**
- **ø 3.6 m x h 3.5 m**
- **<0.1 event of background**
- **20m²** light detection coverage



DarkSide-20k The challenge of scaling from 50kg to 50t

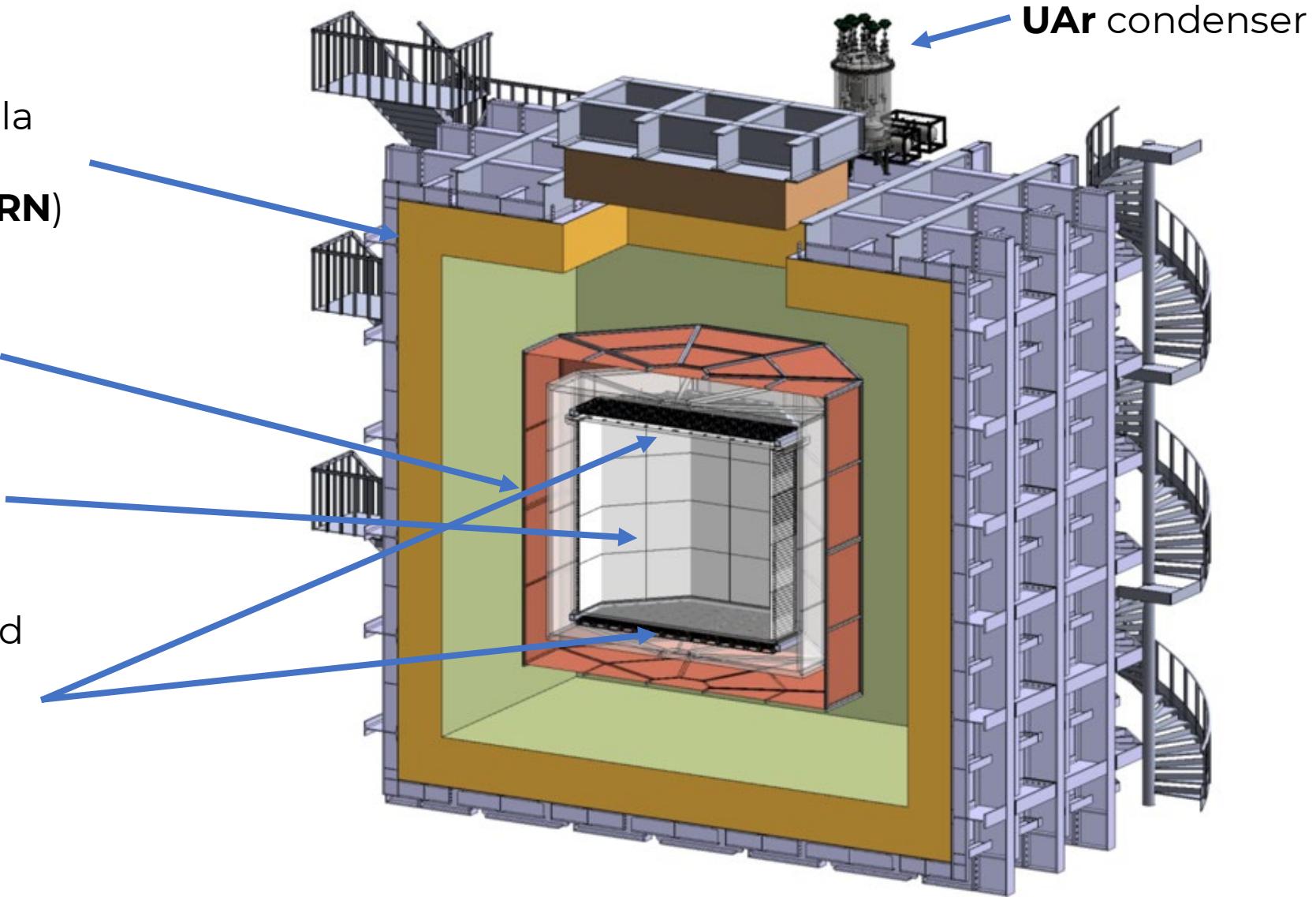


**Membrane Cryostat à la
ProtoDUNE**
(Neutrino Platform @**CERN**)

Neutron VETO in
300t **AAr**

Sealed **Acrylic TPC**
(50t **UAr**)

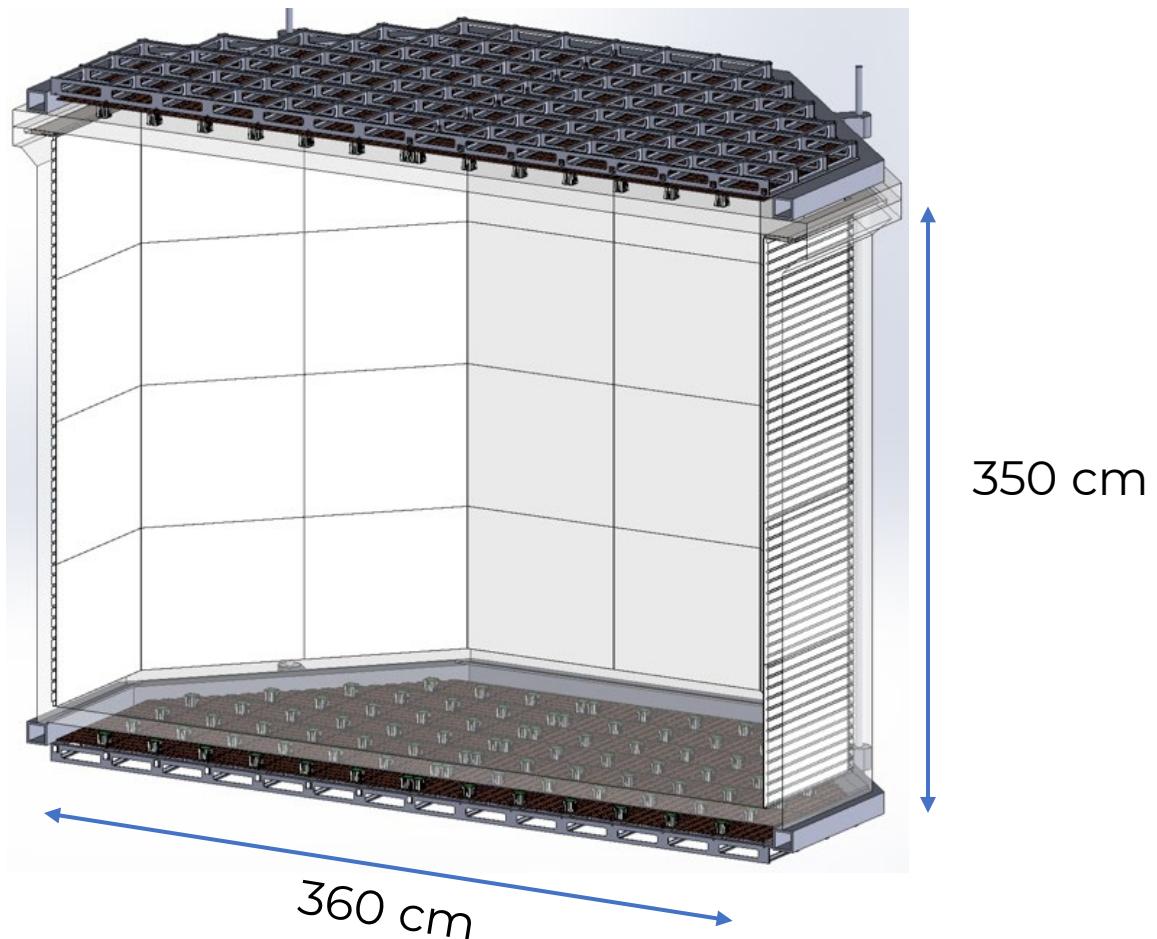
Detection planes based
on ~200000 Silicon
photo multipliers
(SiPM)



DarkSide-20k@LNGS



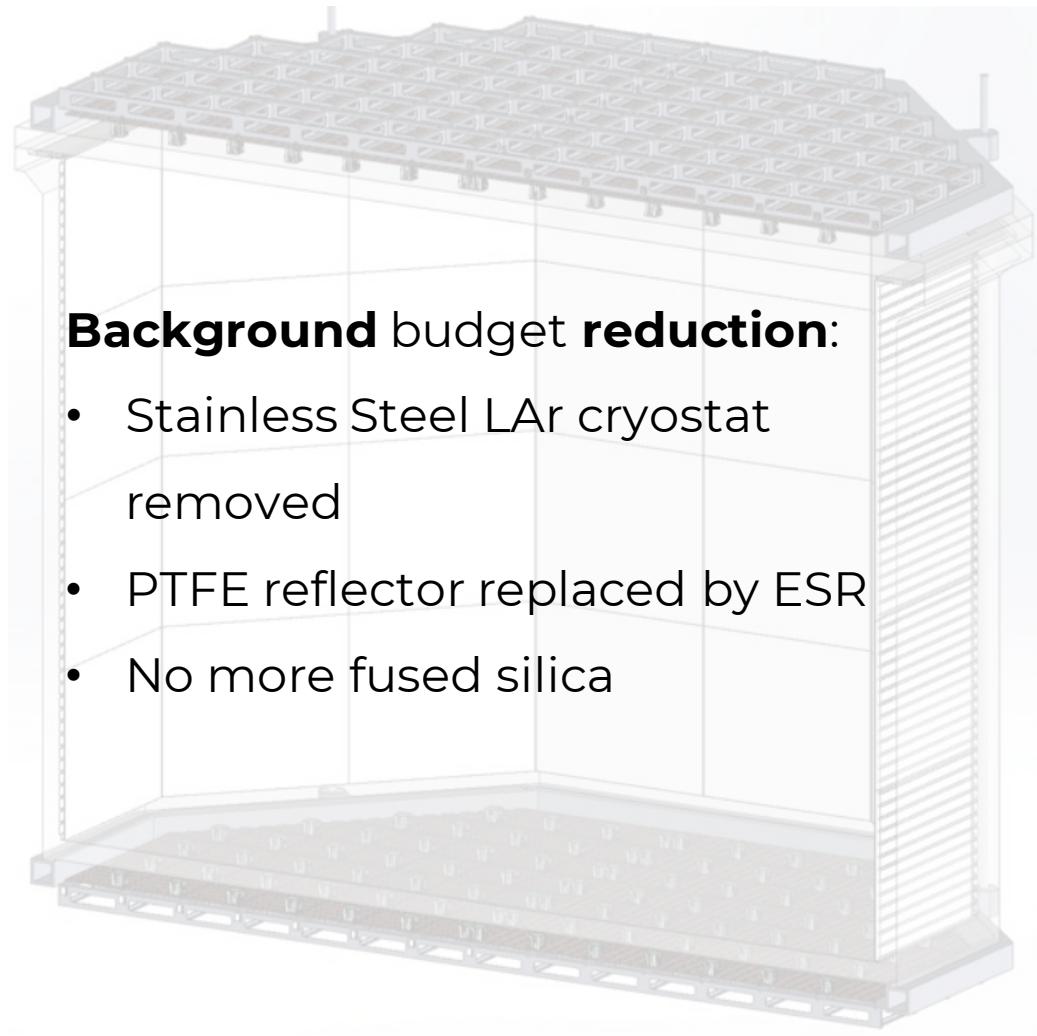
- 50t of depleted **UAr**
- Octagonal **sealed acrylic TPC**
- **Clevios** conductive polymer **coating** for anode, cathode and field cage rings
- Enhanced Specular Reflector
- **TPB coated as WLS.**



DarkSide-20k TPC



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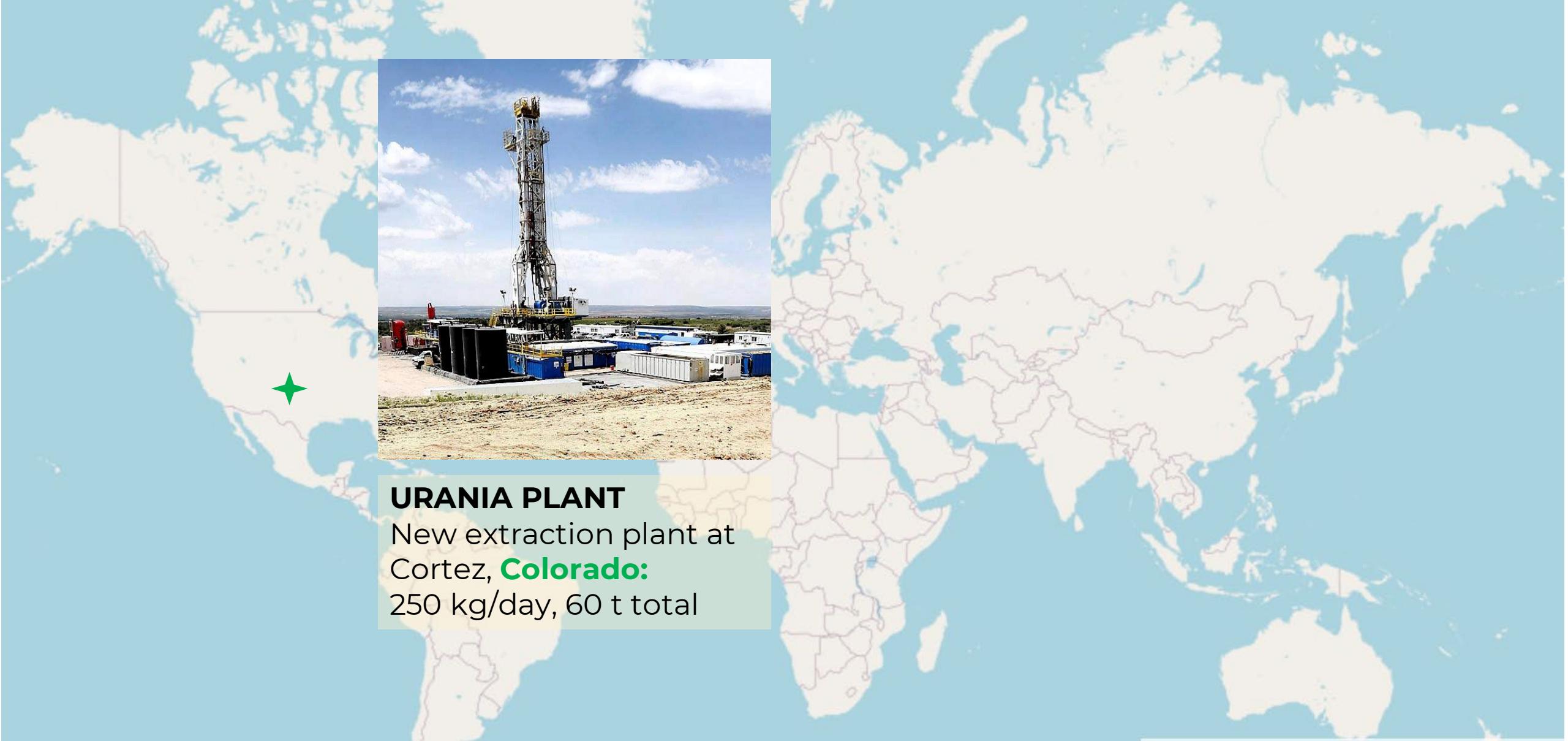


Background budget reduction:

- Stainless Steel LAr cryostat removed
- PTFE reflector replaced by ESR
- No more fused silica

DarkSide-20k TPC





URANIA PLANT

New extraction plant at
Cortez, **Colorado**:
250 kg/day, 60 t total

DarkSide-20k ARIA, URANIA and DArT





DarkSide-20k ARIA, URANIA and DArT

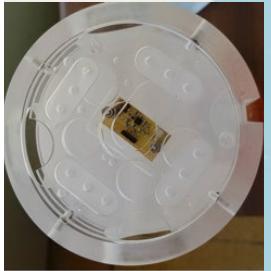
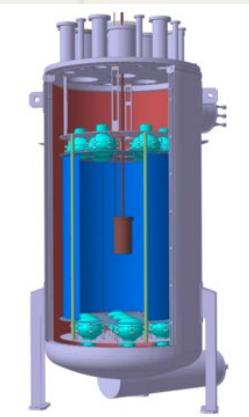
Luigi Rignanese rignanes@bo.infn.it
ICHEP2020 28/07/2020



ARIA

New **distillation column**, 350m tall installed in the coal mine well in Nuraxi Figus, **Sardinia**. **UAr** will be **chemically distilled** at a rate of **1t** per day. Further ^{39}Ar reduction factor 10 per pass can be achieved (most important in low mass DM search).



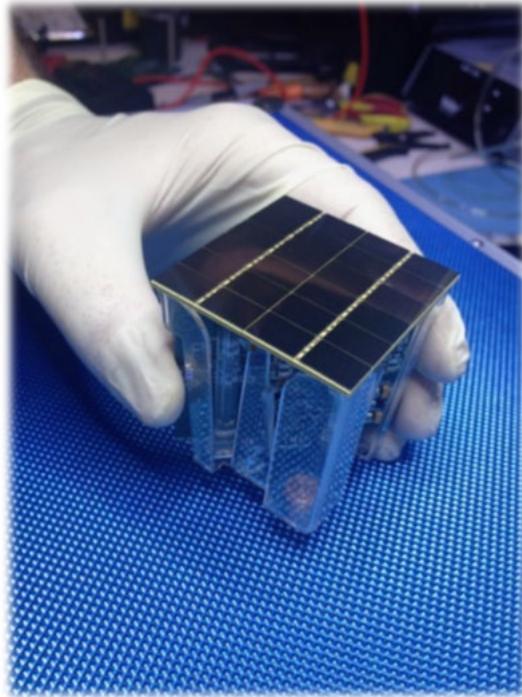


DArT

Measure the remaining activity of the UAr ^{39}Ar depleted at the **Canfranc Underground Laboratory (Aragon)**.
[C.E. Aalseth et al 2020 JINST 15 P02024](#)

DarkSide-20k ARIA, URANIA and DArT





PROS

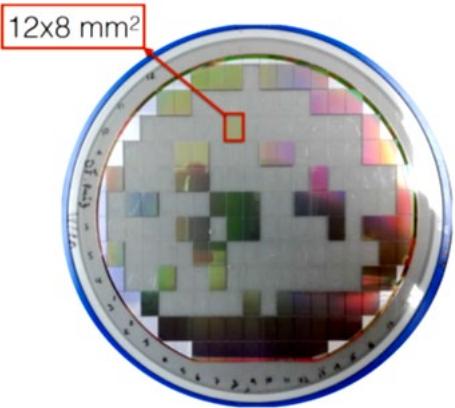
- Cryogenic temp stability
- Better single photon resolution
- Low voltage operation
- **Lower background** (Si intrinsically radiopure)
- Lower cost

CONS

- High dark rate
- Small area $\approx \text{cm}^2$
- High output capacitance for large devices

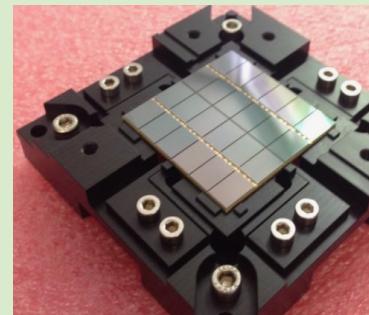
DarkSide-20k PMT → SiPM $0.17\text{m}^2 \rightarrow 20\text{m}^2$





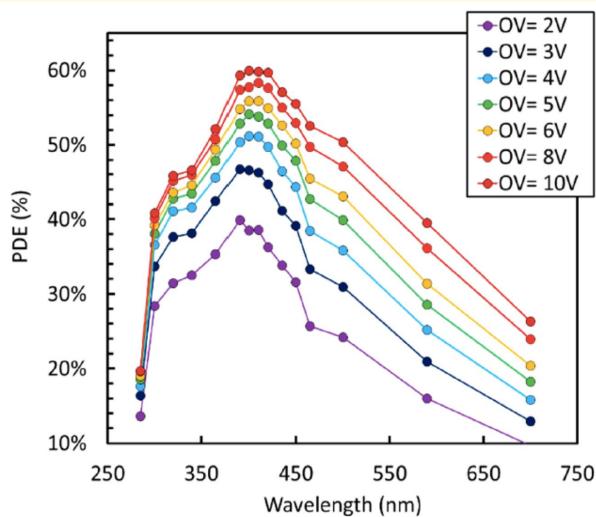
NUV-HD-CRYO 12 x 8 mm²

SiPMs optimized for **LAr** temperature, designed in collaboration with [FBK](#), are now mass produced by [LFoundry](#)



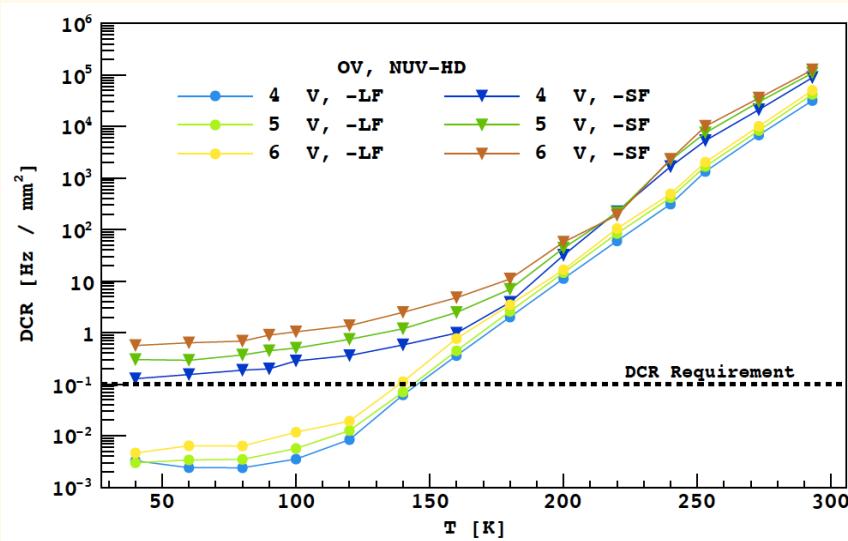
24cm² TILE formed by **24 SiPMs** in **4 quadrants** grouped in a 2s3p config

Photo detection efficiency (PDE)



[Sensors \(Basel\). 2019;19\(2\):308.](#)

DCR reduction by using the low field technology



[F.Acerbi et al., IEEE Trans. Electron Dev. 64, 2, \(2017\), 521-526](#)

DS-20k requirements:
PDE>40%
DCR<0.1Hz/mm²

NUV-HD-Cryo	
293 K	77 K
Breakdown Voltage (V_{BD})	32.8 V
V_{BD} temperature coefficient	35 mV/°C
DCR (5 V)	100 kHz/mm ²
Quenching resistor	1.6 MΩ
CT probability (5 V)	9%
AP probability (5 V)	<1%
OV_{max}	25 V
Recharge time constant	65 ns
Peak PDE (5 V, 410 nm)	48 %

[Sensors \(Basel\). 2019;19\(2\):308.](#)

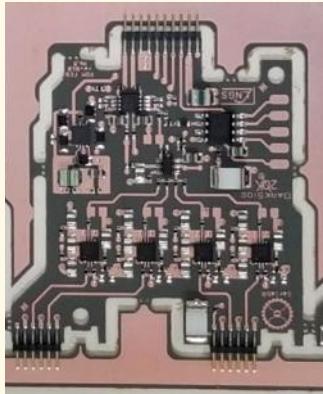
DarkSide-20k NUV-HD-CRYO SiPM



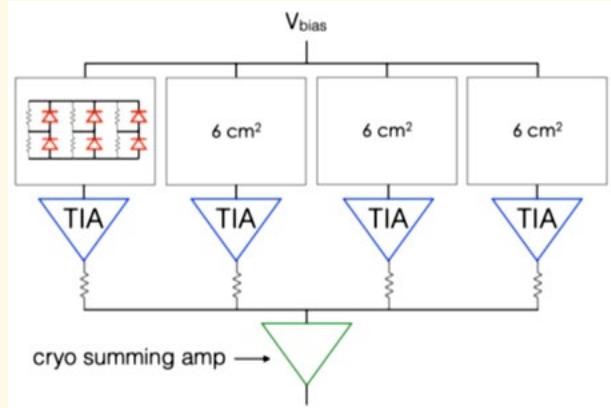
Front end electronics developed by the collaboration
@LNGS.

SiPM can be considered as a **current generator** with an
output capacitance $\sim 50\text{pF/mm}^2$

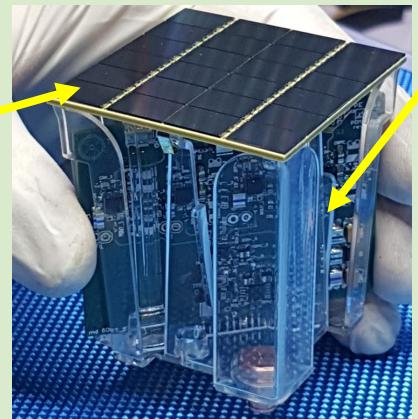
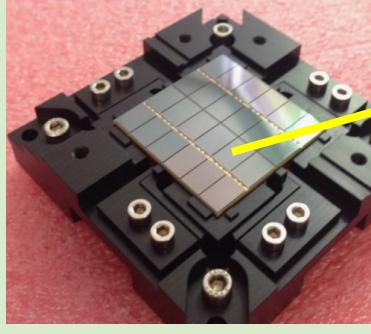
- Transimpedance amplifier (**TIA**) with high bandwidth and low noise for each quadrant of the tile
- Each **TIA** is summed into a single differential output
- **Si/Ge** technology active components
- All the components are **screened** for radio activity



FEB with low activity substrate (Piralux)



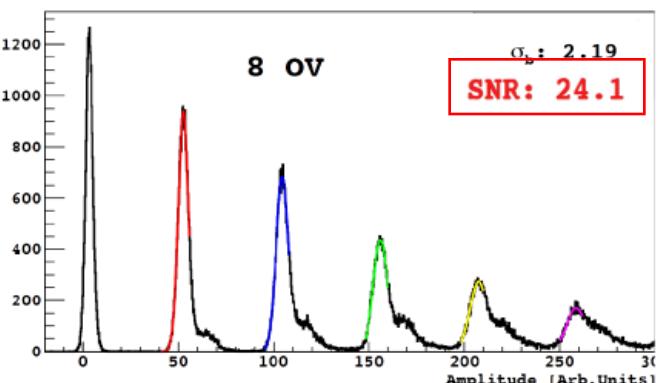
[IEEE Trans.Electron.Dev. 64 2, 521-526](#)
[IEEE Trans.Nucl.Sci. 65 \(2017\) 1, 591-596](#)
[IEEE Trans.Nuc.Sci. 65, no. 4, pp. 1005-1011, April 2018](#)



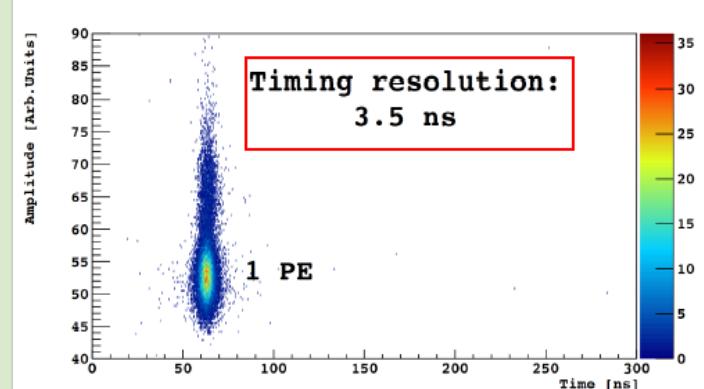
25cm² **SiPM TILE**

Photo Detection
Module (**PDM**)

SNR DS-20k requirements: >10

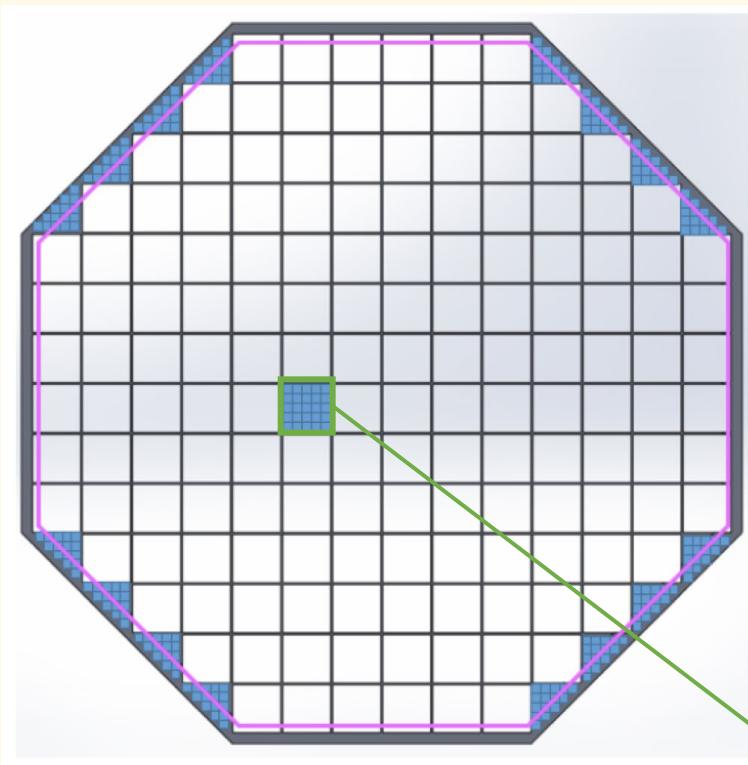


Timing res DS-20k requirements O(10ns)

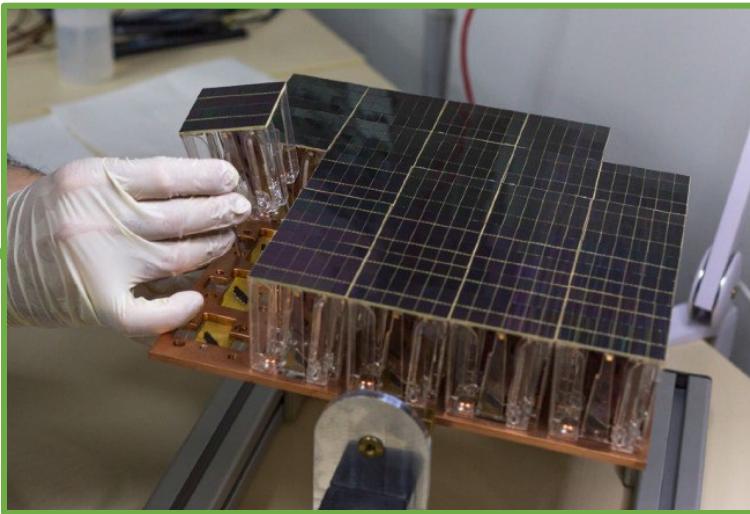


DarkSide-20k Cryogenic electronics and PDM

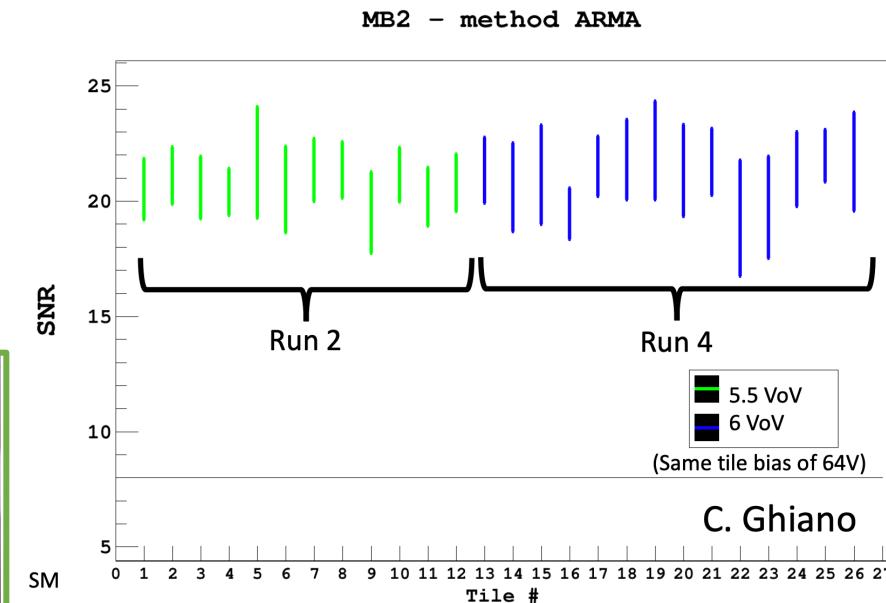
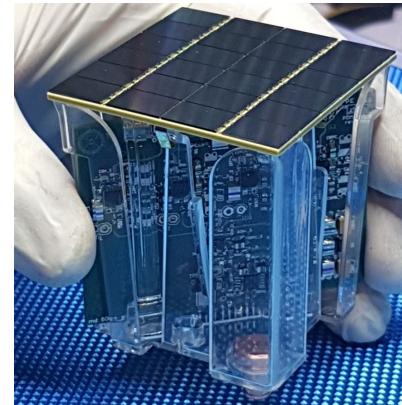




Each **detection plane** is composed by **4140 PDMs** grouped in **344** Photo Detection Units (**PDUs**)



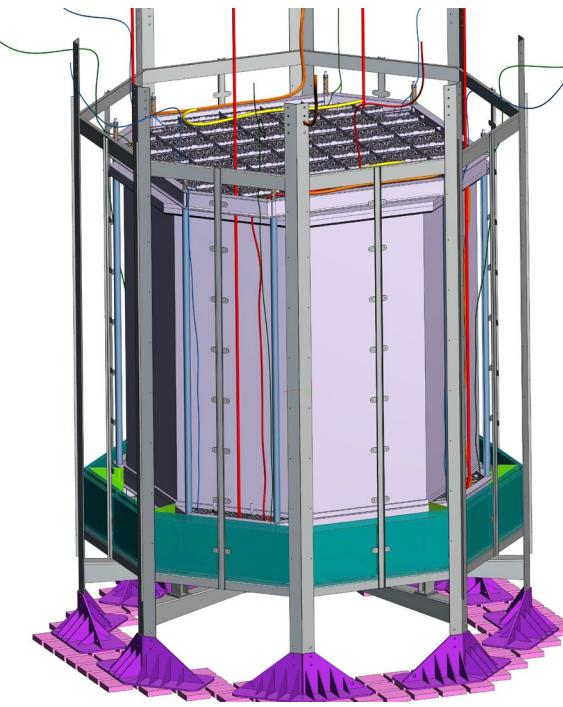
PDU: 25x25x5cm 25ch



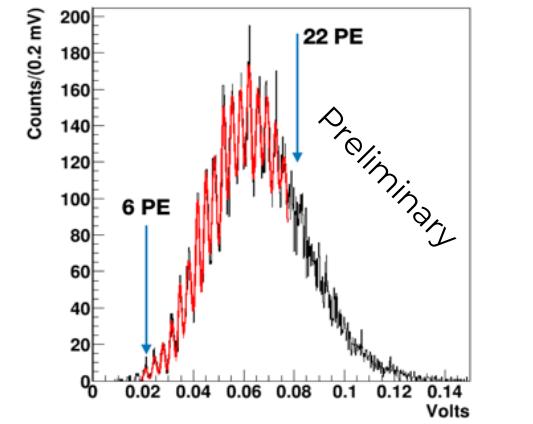
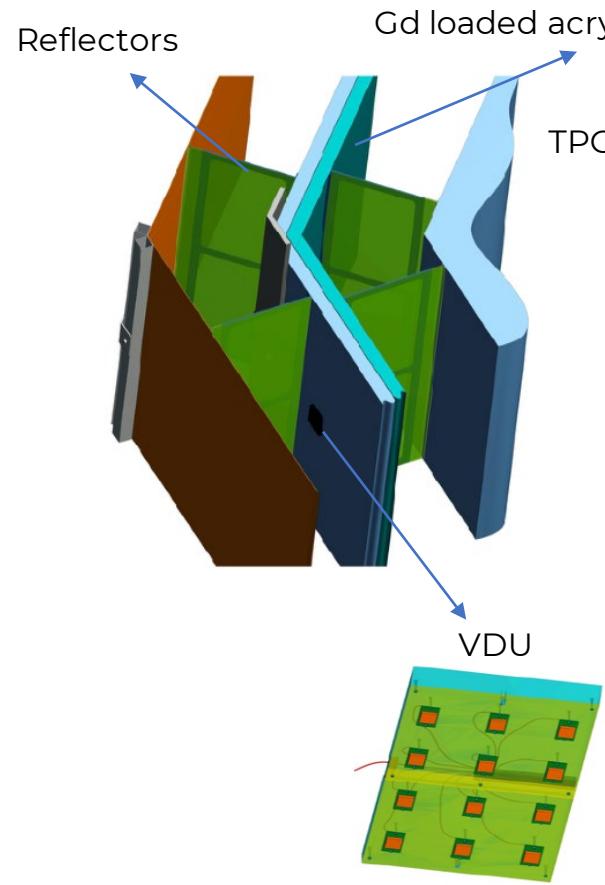
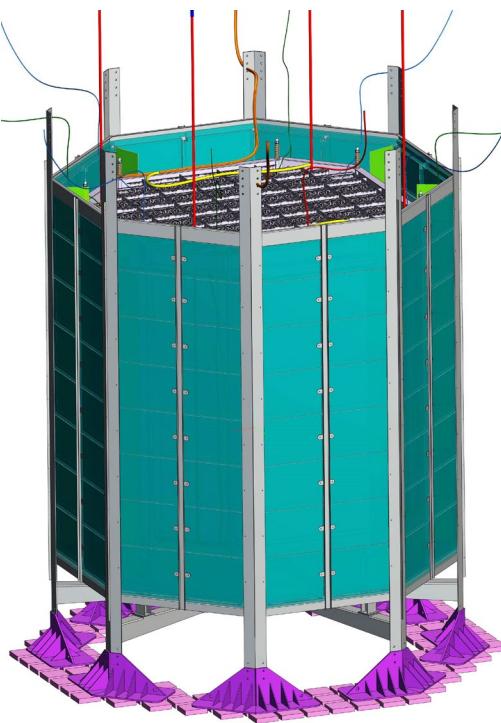
DarkSide-20k Detection plane modularity (PDU)



- Due to recent environmental regulation at LNGS, **no** more **liquid organic scintillators** are allowed.
- The DS-20k active **VETO** will use 300t **liquid AAr** contained in a 10cm thick Gadolinium doped (4%) acrylic vessel surrounding the TPC.
- Scintillation light is produced in the liquid AAr by the **gamma cascade** due to Gd **neutron capture**
- Light is detected by ~3000 **VDUs** (Veto Detection Units equipped with SiPMs and integrated front-end electronics) placed on the acrylic panels



DarkSide-20k VETO



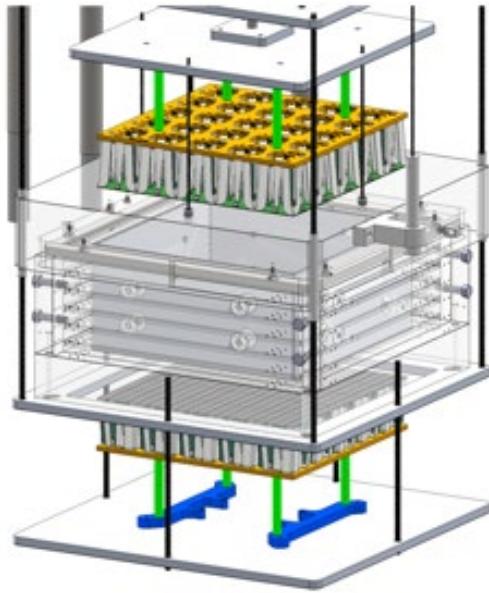
High dynamic range electronics



Material	Mass [tonne]	^{238}U [mBq/kg]	^{226}Ra [mBq/kg]	^{232}Th [mBq/kg]	Neutrons $[10 \text{ yr}]^{-1}$	$+\text{TPC}$ $[200 \text{ t yr}]^{-1}$	$+\text{TPC+veto}$ $[200 \text{ t yr}]^{-1}$
TPC Vessel	2.7	1.2×10^{-2}	10	4.1×10^{-3}	1.1×10^3	0.17	1.7×10^{-2}
TPC SiPMs	0.12	-	-	-	1.1×10^4	0.16	1.6×10^{-2}
TPC Electronics	1.0	-	-	-	2.5×10^4	0.36	3.6×10^{-2}
TPC Mechanics	1.1	3.9	3.9	1.9	1.8×10^3	1.8×10^{-2}	2.0×10^{-3}
Veto SiPMs+elec.	0.40	-	-	-	1.3×10^4	0.10	1.0×10^{-2}
Veto Acrylic	13	1.2×10^{-2}	10	4.1×10^{-3}	5.2×10^3	4.2×10^{-2}	4.0×10^{-3}
Veto Reflectors	1.0	1.2×10^{-2}	1.0	4.1×10^{-3}	4.0×10^2	2.4×10^{-2}	2.0×10^{-3}
Veto Steel	1.1	3.9	3.9	1.9	1.8×10^3	1.4×10^{-2}	1.0×10^{-3}
$\text{Gd}_2(\text{SO}_4)_3$ α 's on self	0.26	7.0	7.0	0.2	2.1×10^2	2.0×10^{-3}	$<1.0 \times 10^{-3}$
$\text{Gd}_2(\text{SO}_4)_3$ α 's on PMMA	0.26	7.0	7.0	0.2	7.2×10^2	6.0×10^{-3}	1.0×10^{-3}
Copper Cage	1.0	0.30	0.30	2.0×10^{-2}	1.2×10^1	$<1.0 \times 10^{-3}$	$<1.0 \times 10^{-3}$
Cryostat Steel	250	50	1.0×10^3	3.9	1.0×10^6	-	$<1.0 \times 10^{-3}$
Cryostat Insulation	40	3×10^3	8.0×10^3	3.0×10^3	8.0×10^7	-	$<1.0 \times 10^{-3}$
Total						0.9	0.09

DarkSide-20k Background budget estimation



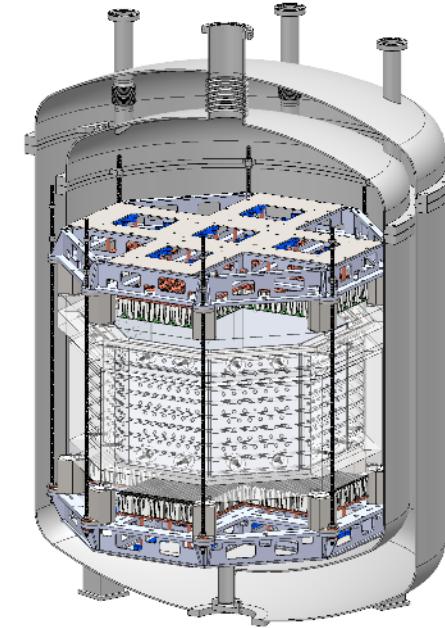


Proto-0@CERN

Integrates the same **technologies** of **DS-20k** in an atomic scale.

First LAr run to test:

- 2 PDUs
- Acrylic TPC



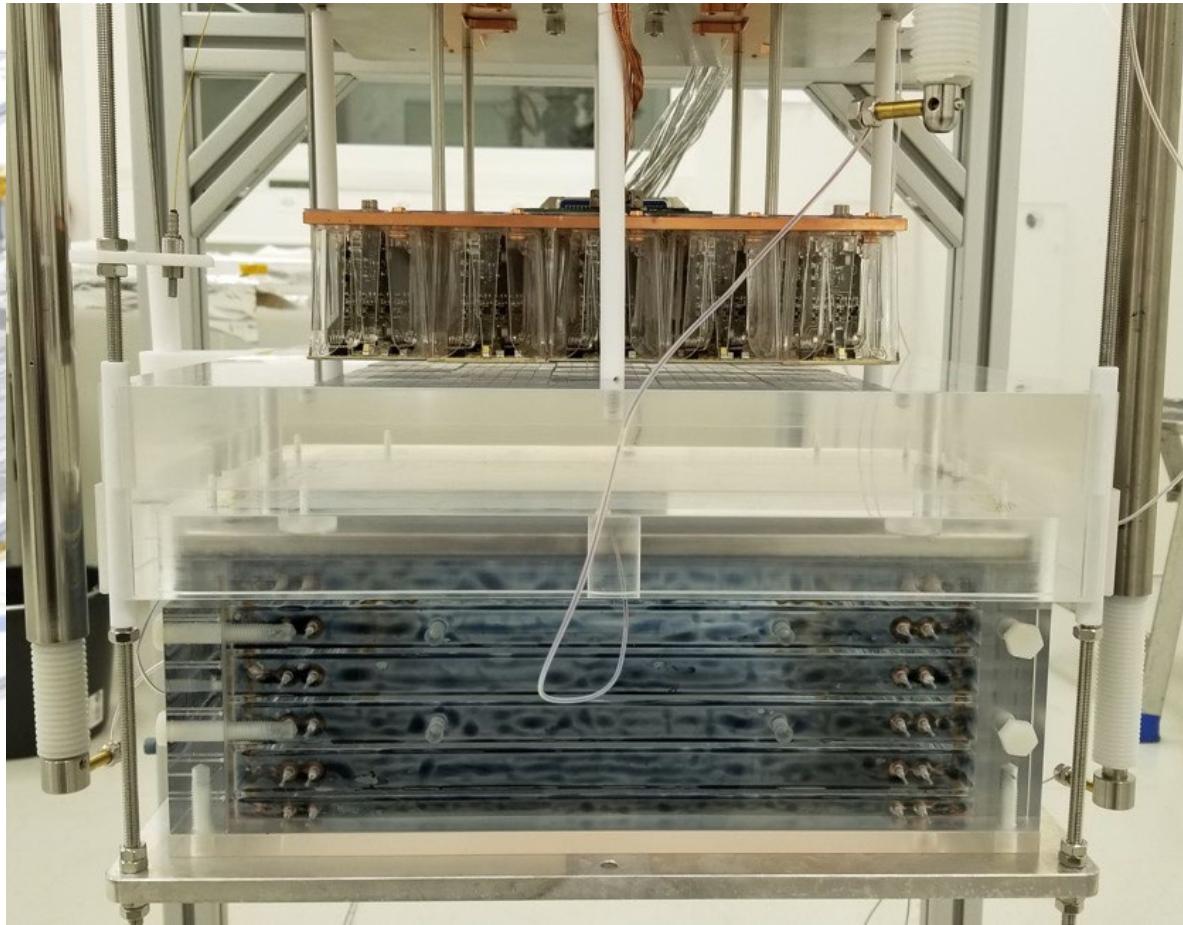
Proto-1T@CERN

Scaled down version of **DS-20k**.

- 175kg of active LAr
 - 370 PDMS
 - ø 72 cm x h 58 cm acrylic sealed TPC
- Long term test:
- PDUs
 - Signal transmission and DAQ
 - Reconstruction software
 - S1 LY, S2 response

DarkSide-20k Proto-0, Proto-1T





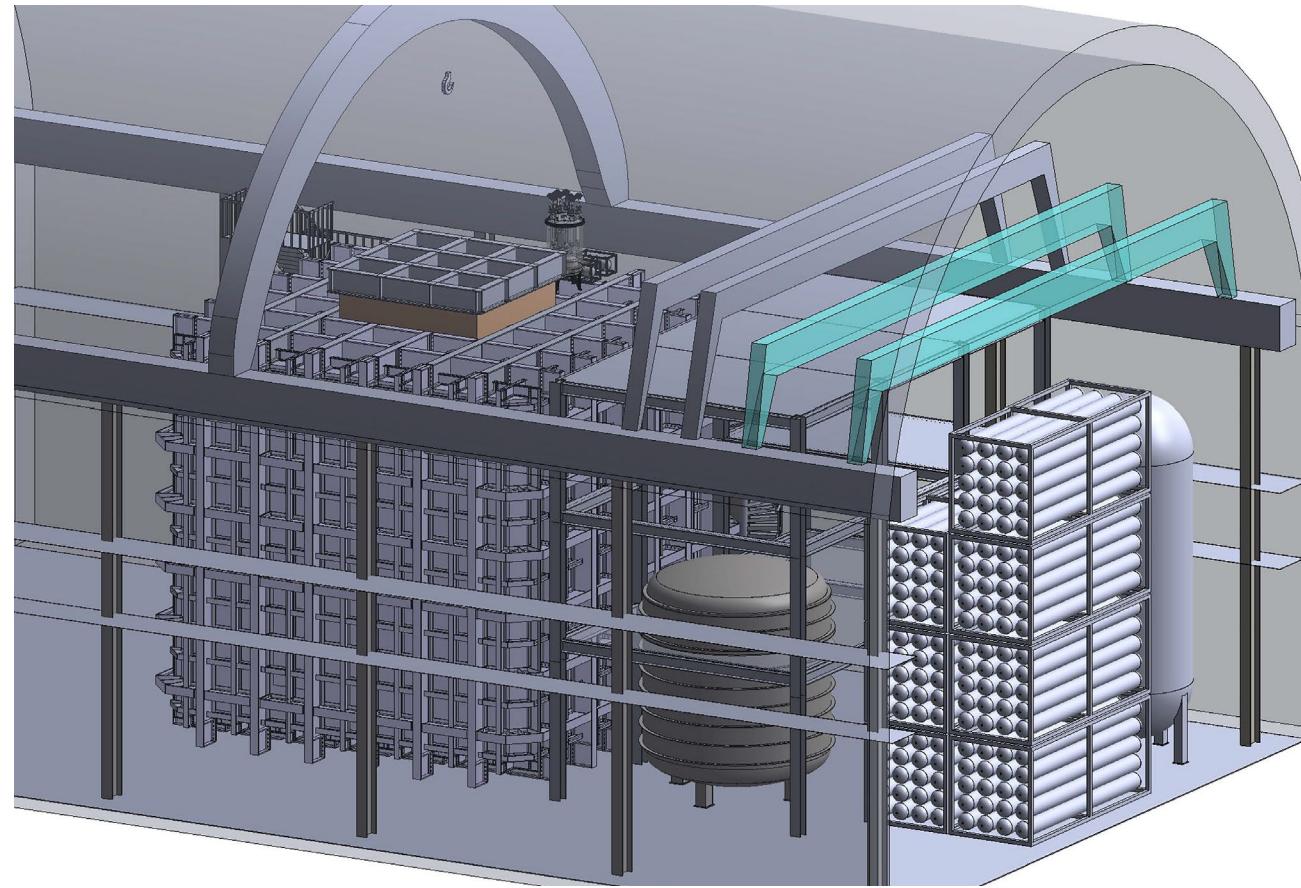
Proto-0 activities and **Proto-1T** assembly are currently suspended due to the COVID-19 situation.

DarkSide-20k Proto-0, Proto-1T



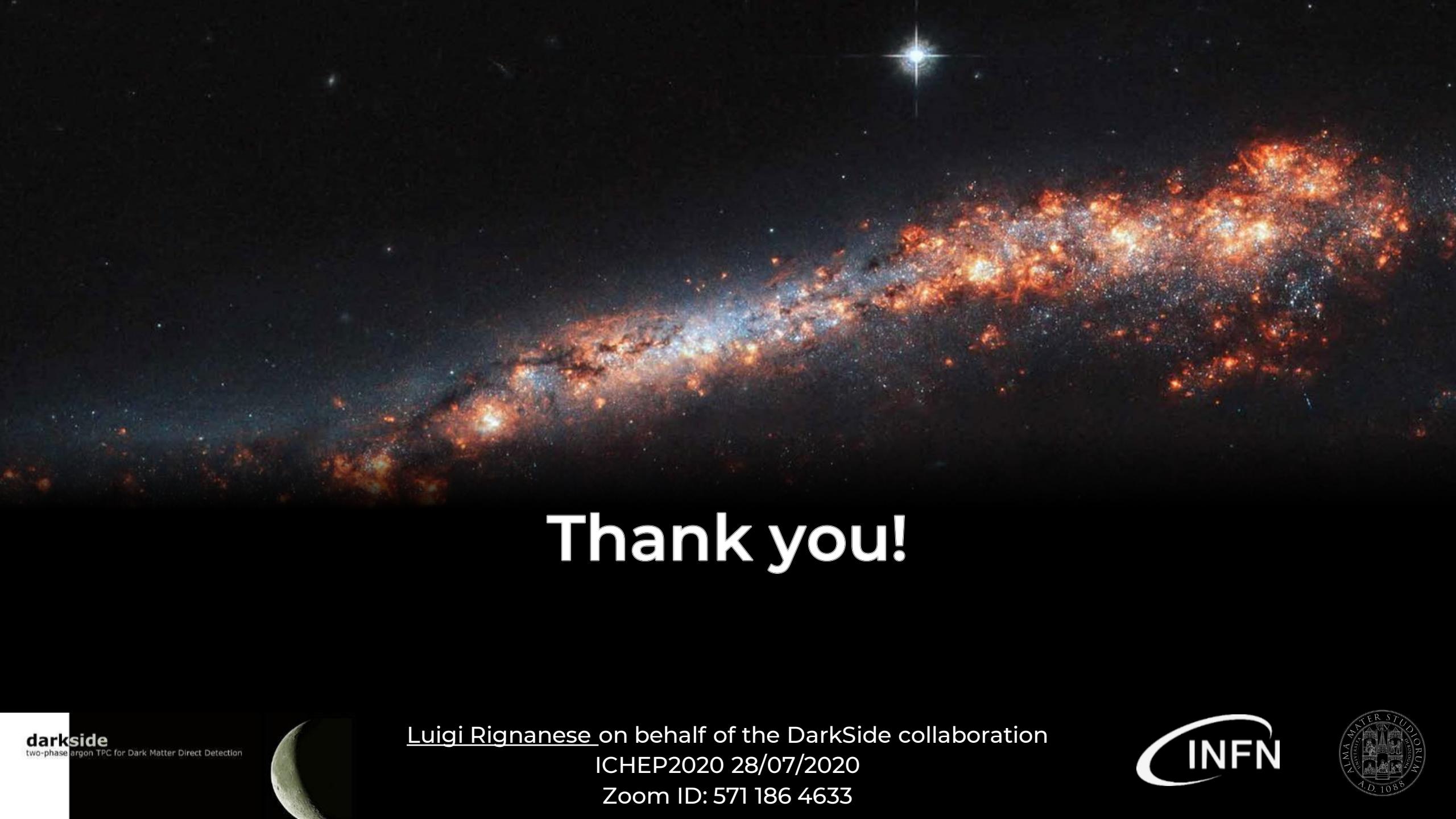
Dual phase Argon TPCs are proving to be reliable detectors for direct **DM searches**.
DarkSide-20k within the **GADMC** is pushing towards the key technologies:

- **^{39}Ar depleted UAr**
- **Acrylic TPC**
- Large scale solid state PMTs
(SiPMs) cryogenics detectors
- Low noise high bandwidth cryo-compatible **electronics**
- Active **neutron VETO** using AAr and Gd doped acrylic with **SiPM** readout



DarkSide-20k Summary

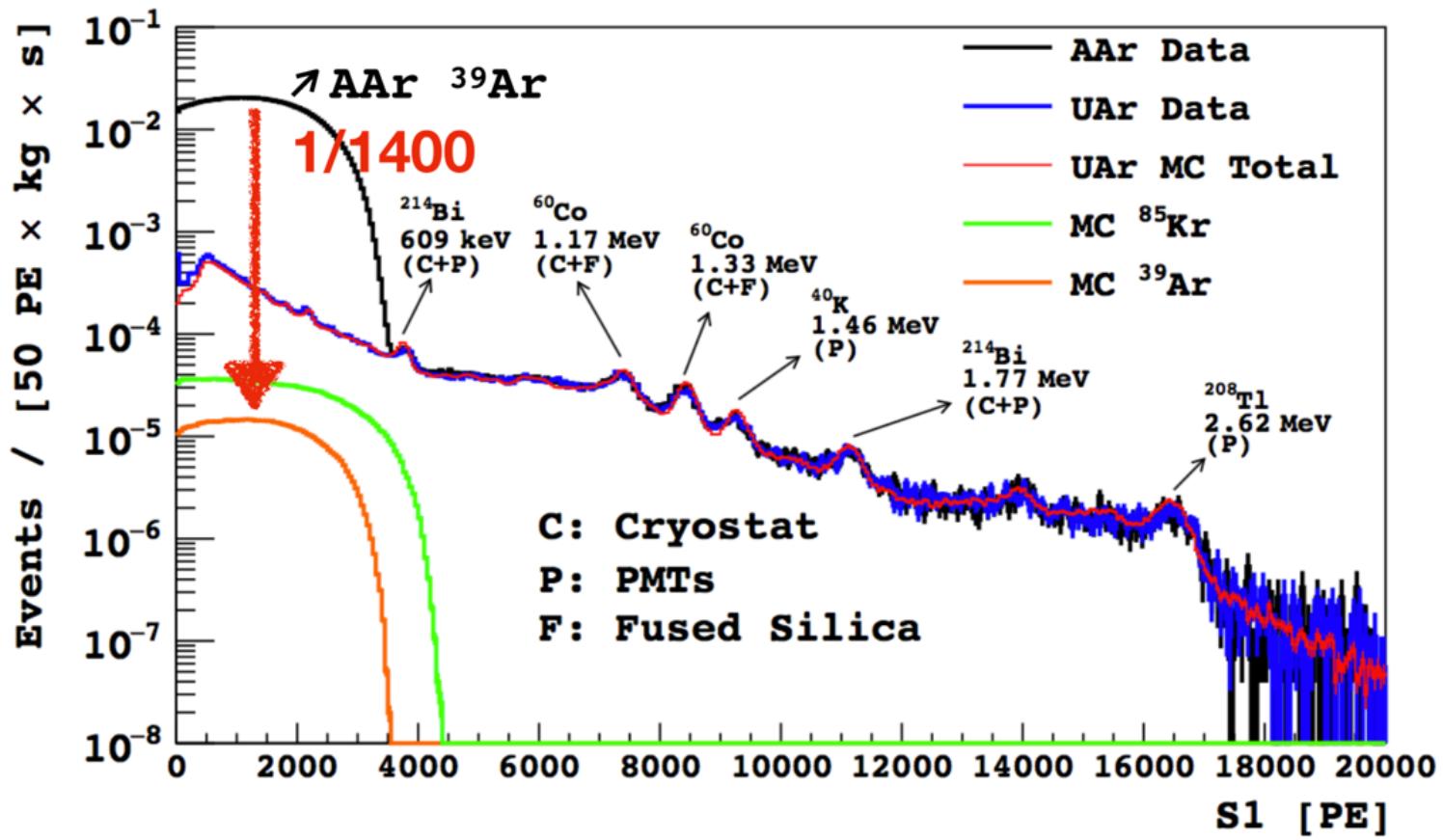




Thank you!

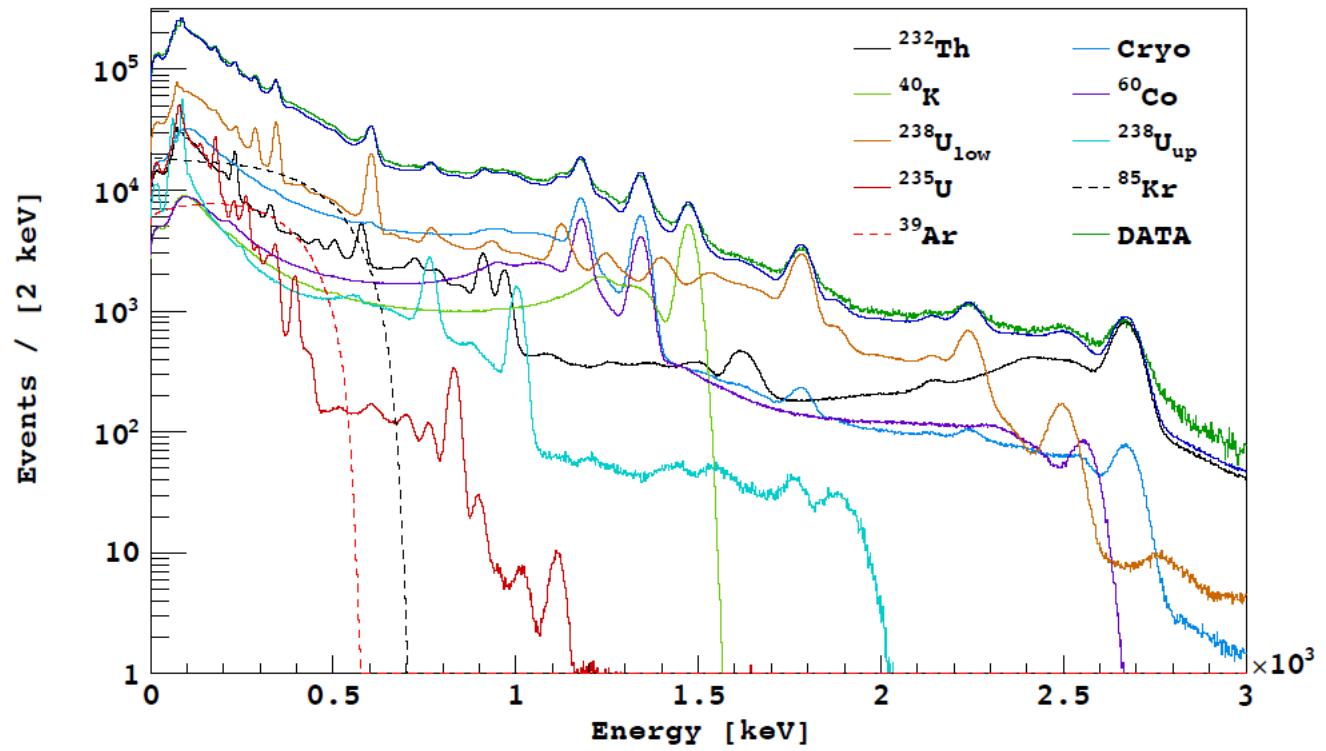
Luigi Rignanese on behalf of the DarkSide collaboration
ICHEP2020 28/07/2020
Zoom ID: 571 186 4633





DarkSide-20k Backup





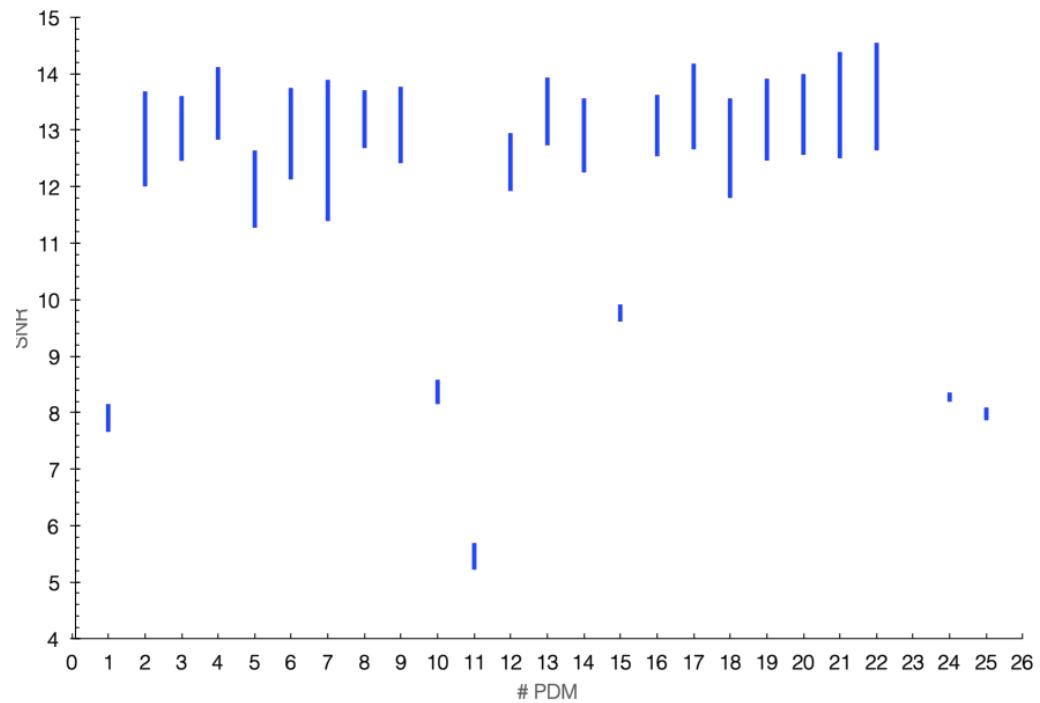
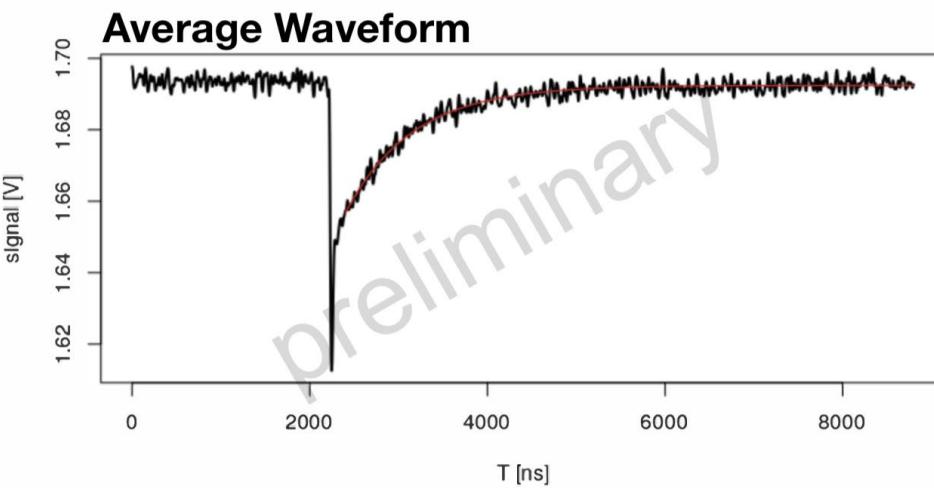
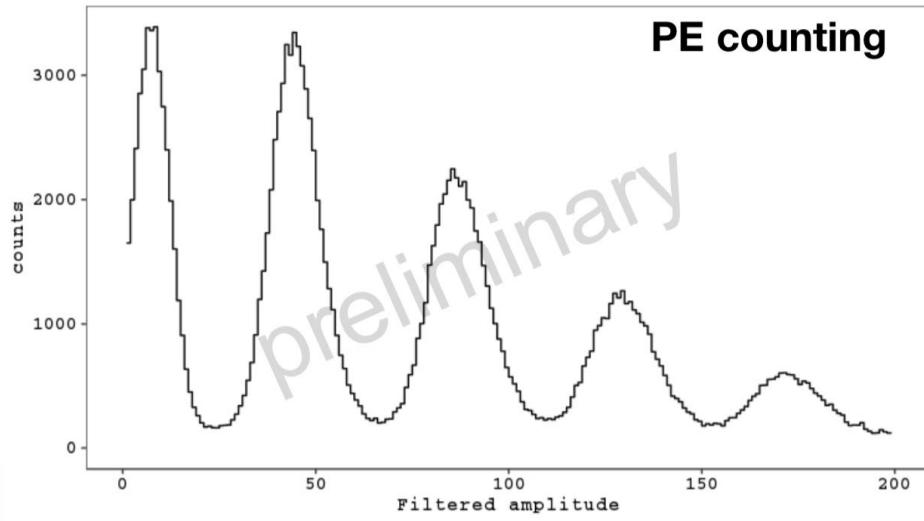
DarkSide-20k Backup



	liquid Ar	liquid Xe
Z (A)	18 (40)	54 (131)
temperature	87 K (close to nitrogen)	166 K
density	1.4 g/cm ³	3.1 g/cm ³
ionisation yield	42 e ⁻ /keV	64 e ⁻ /keV
scintillation yield	40 γ /keV	46 γ /keV
scintillation wavelength	128 nm	178 nm
radio-purity	^{39}Ar contamination, can be reduced	intrinsically pure
pulse-shape discrimination	yes (singlet ~7 ns, triplet ~1600 ns)	very limited (singlet ~2 ns; triplet ~27 ns)
sensitivity	better for $m_{\text{WIMP}} > 100 \text{ GeV}$ spin-independent only	also to low masses and spin-dependent

DarkSide-20k Backup





DarkSide-20k Backup

