MANCHESTER 1824
The University of Manchester

Science & Technology Facilities Council

Direct dark matter detection with the DarkSide experiment: UK status and plans

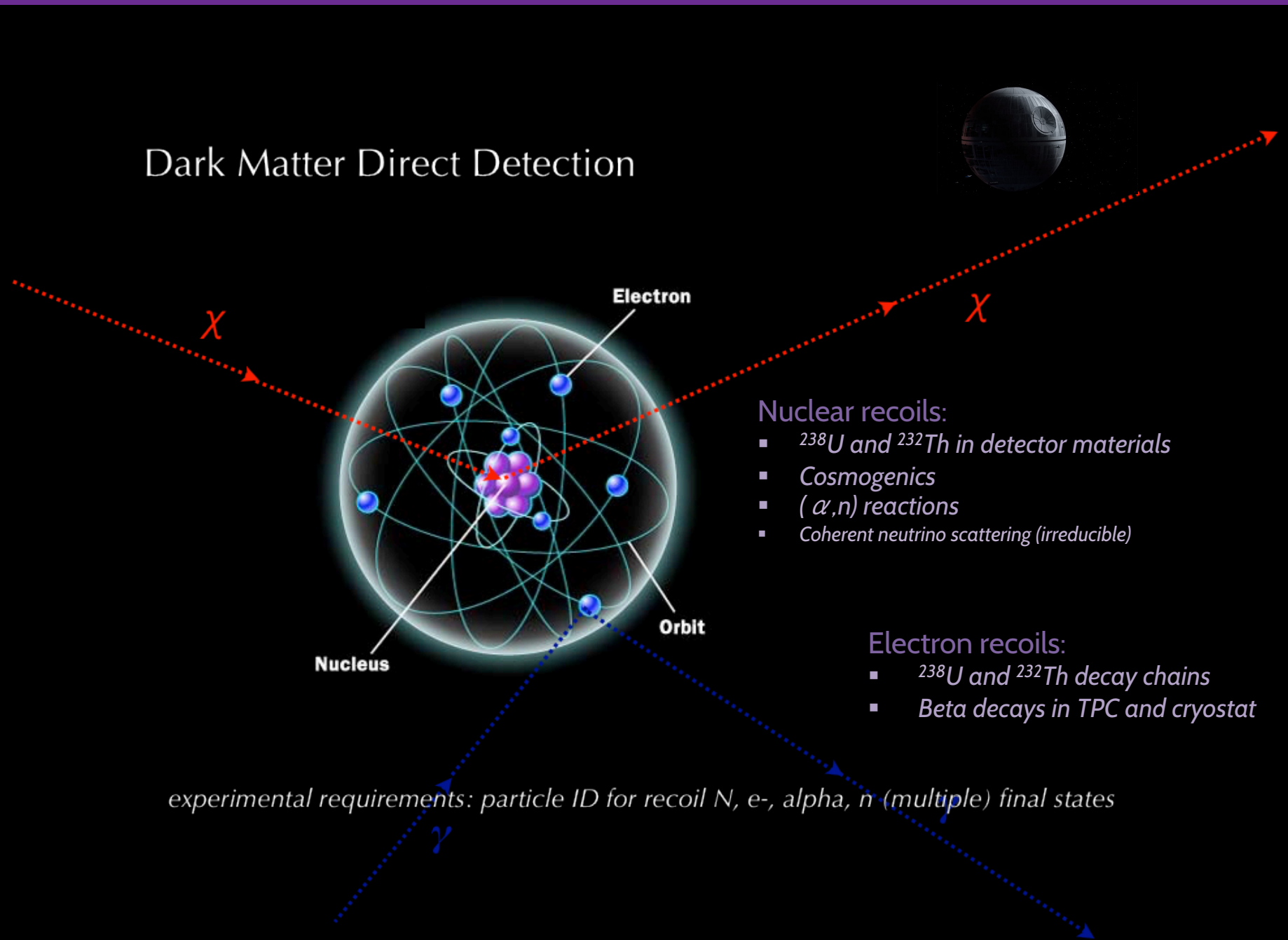
Darren Price, University of Manchester

Dark Matter UK meeting, King's College London, April 11th 2019

@darrenprice

darren.price@cern.ch

Direct DM detection in DarkSide



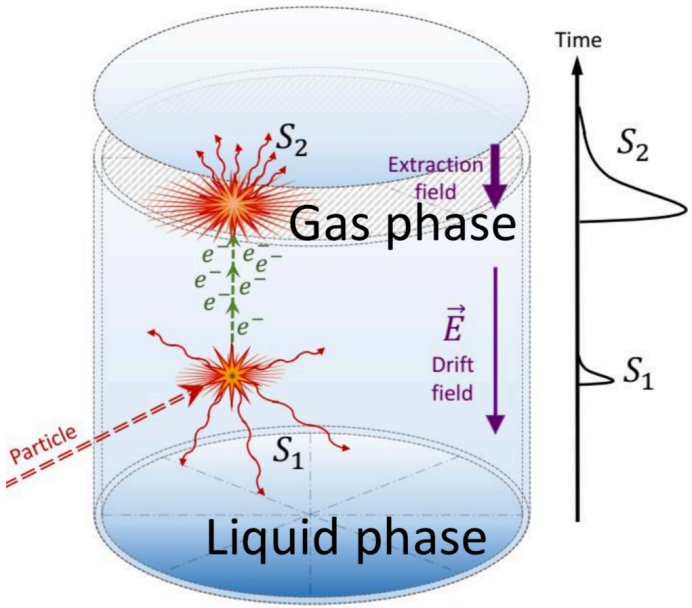
Direct DM detection in DarkSide

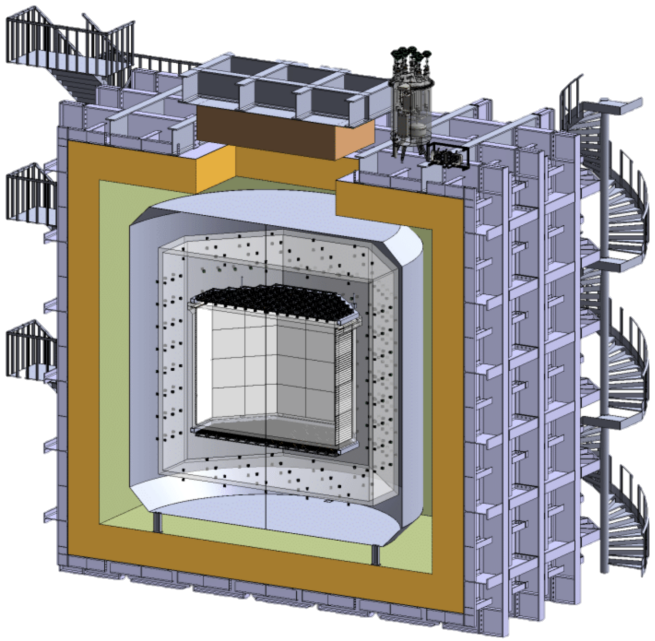
DarkSide-20k is primarily a 50 T dual-phase Liquid Argon TPC.

- Physics data-taking timescale 2022–2027.
- Expected sensitivity two orders of magnitude above current experiments at 1 TeV WIMP mass, with sensitivity from sub-GeV to the multi-TeV regime.

DarkSide-20k aims to be a background-free detector

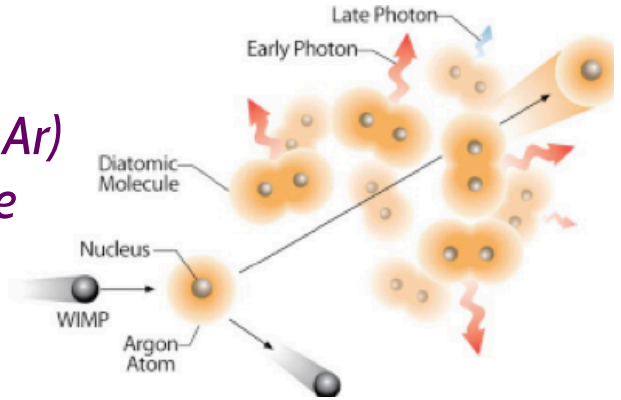
- Expected background with full exposure <0.1 events.

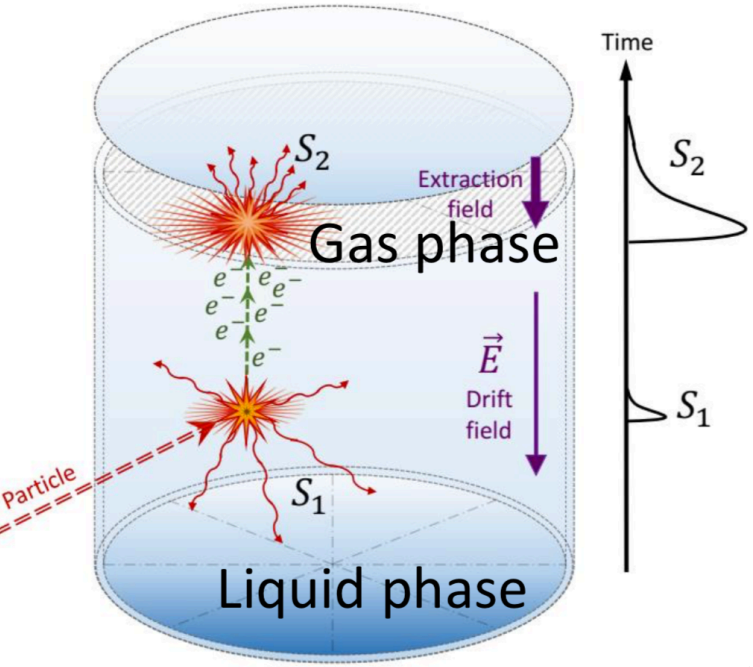


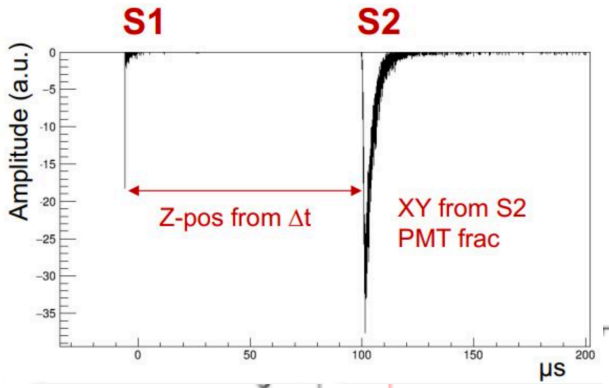


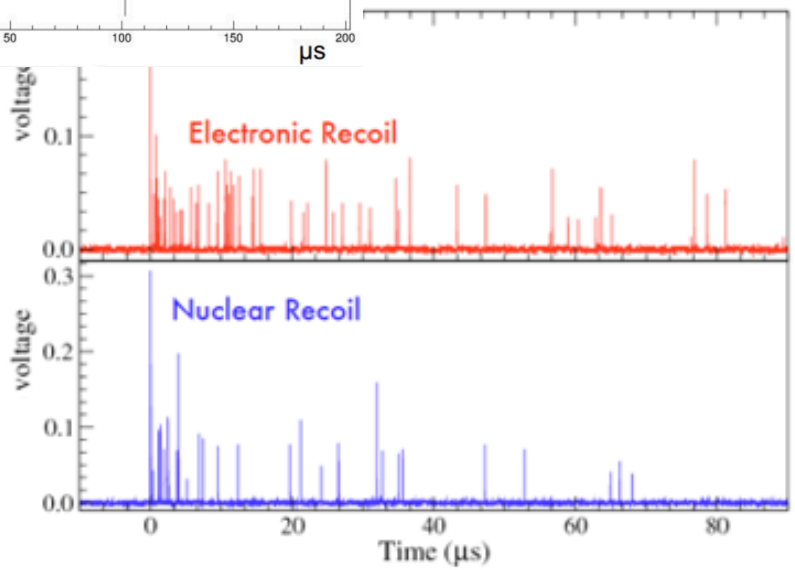
DM signature: scattering on LAr target

- *S1 pulse: primary scintillation in Liquid Argon (LAr)*
- *S2 pulse: secondary scintillation in Ar gas phase*
- Drift time: z position, S2 light: x-y coordinate





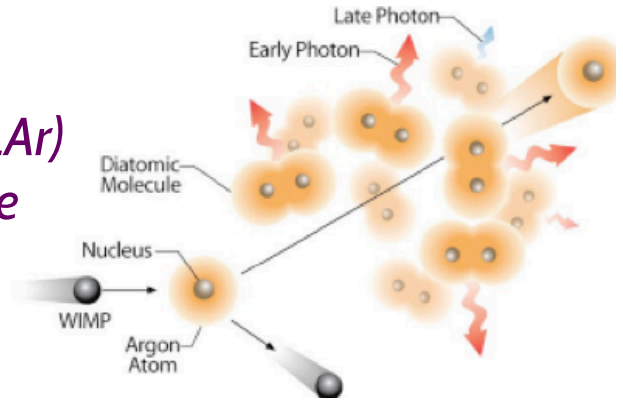


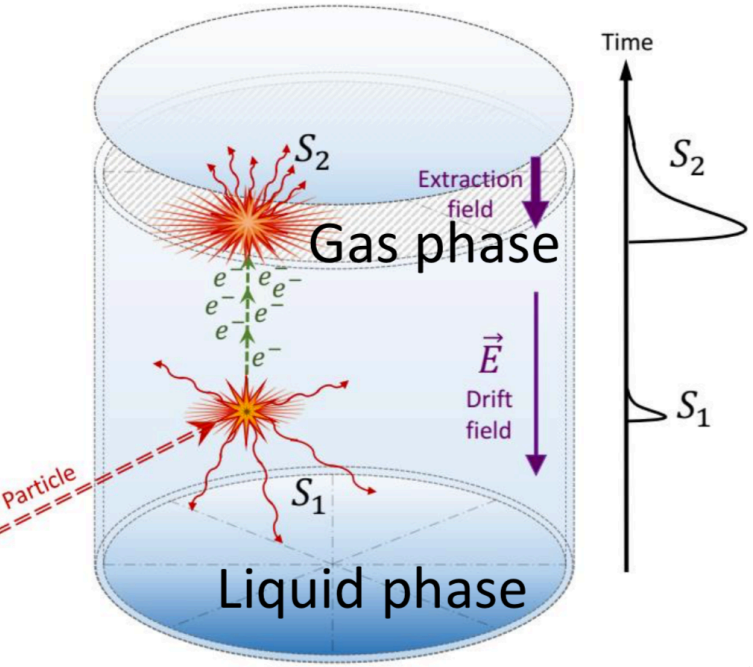


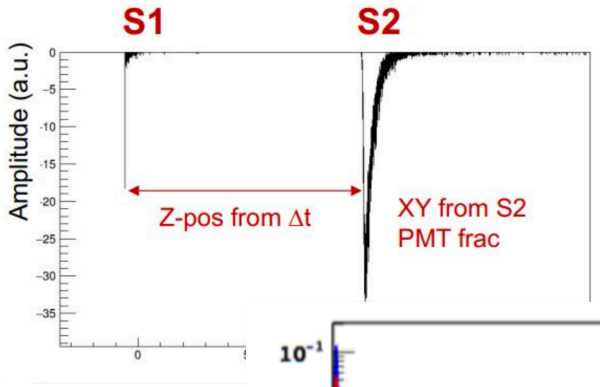
DM signature: scattering on LAr target

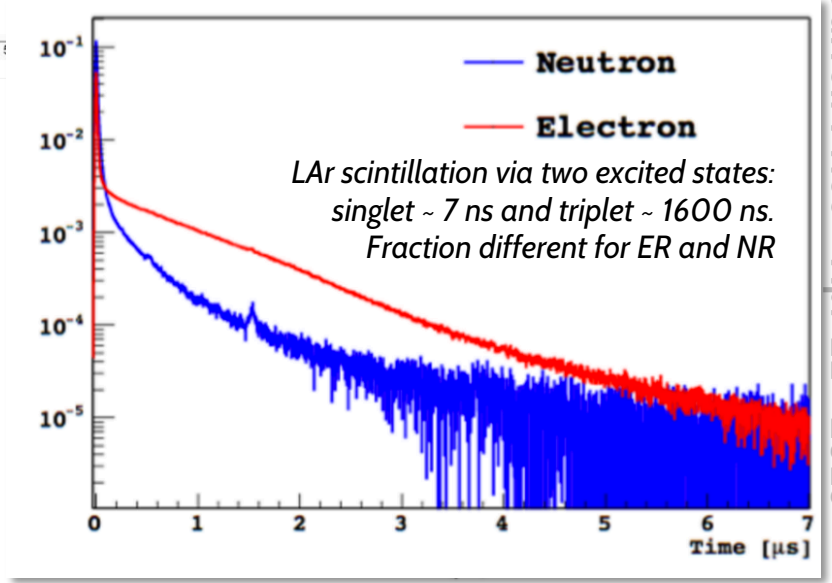
- *S1 pulse: primary scintillation in Liquid Argon (LAr)*
- *S2 pulse: secondary scintillation in Ar gas phase*

- Drift time: z position, S2 light: x-y coordinate
- Timing and pulse shape discrimination





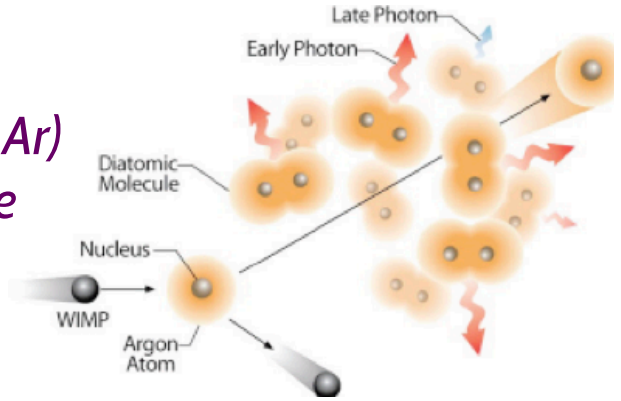


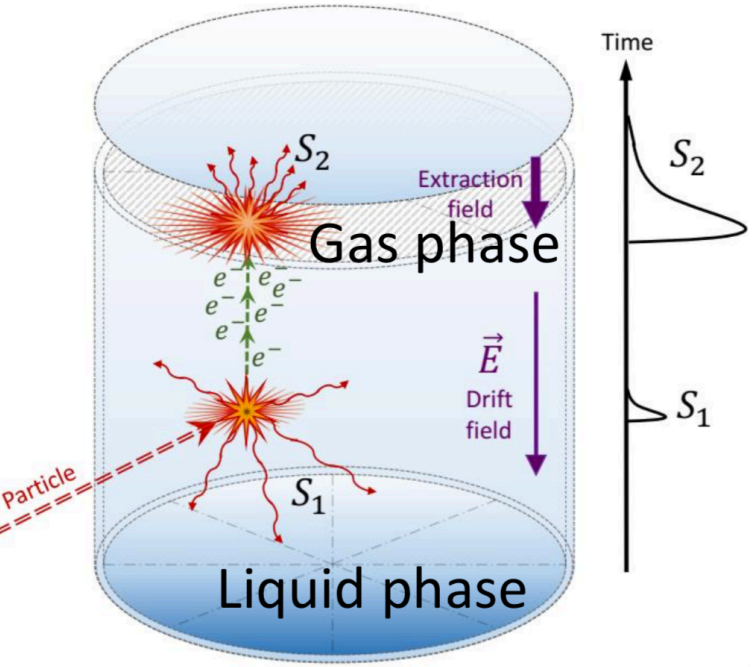


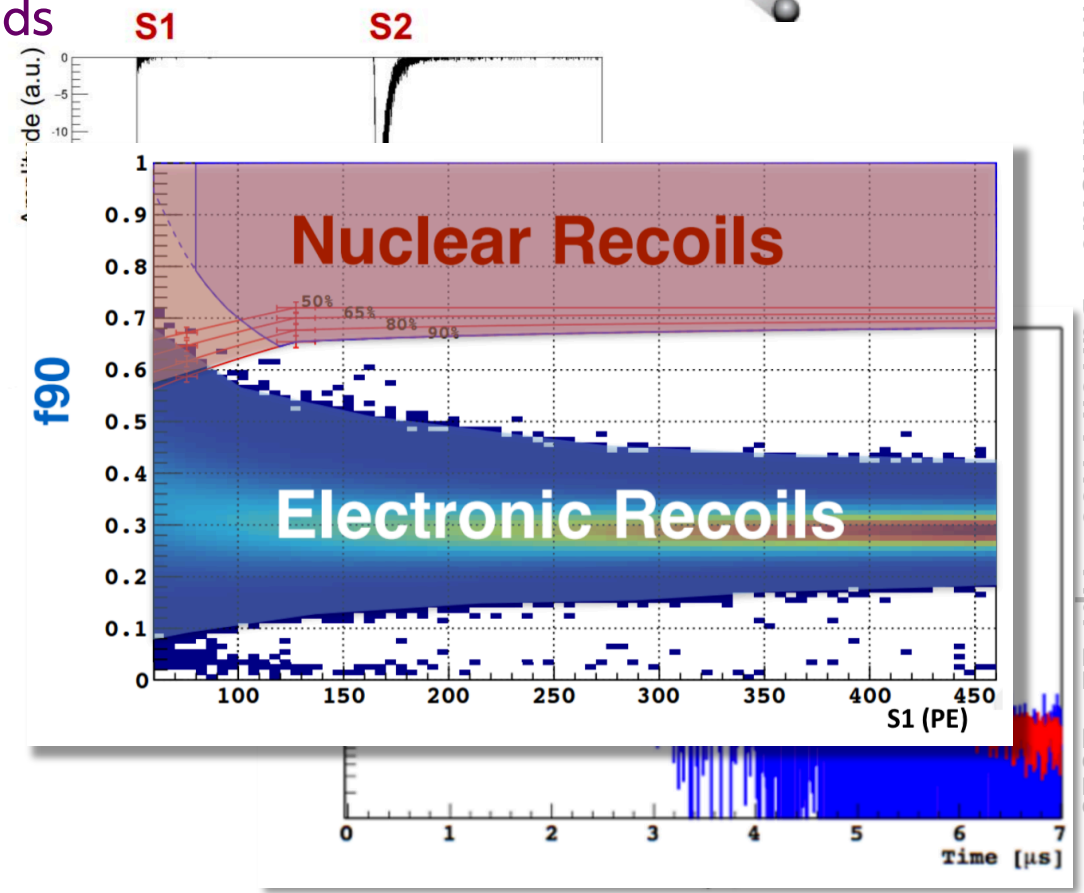
DM signature: scattering on LAr target

- *S1 pulse: primary scintillation in Liquid Argon (LAr)*
- *S2 pulse: secondary scintillation in Ar gas phase*

- Drift time: z position, S2 light: x-y coordinate
- Timing and pulse shape discrimination
- Veto nuclear recoil backgrounds





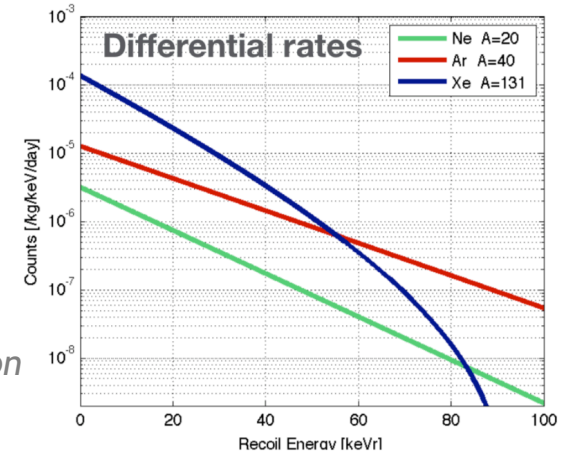


Direct DM detection: why Argon?

What does Argon bring to direct DM detection?

- High ionisation yield (S2/S1) – ×500 LXe
- Powerful PSD for background rejection > 10^8 in LAr
- Efficient scintillator (128 nm): self-transparent
- Potential to achieve zero-background in full exposure
- Easily purified: long electron lifetime
- Availability & low cost: future scalability

- Nuclear form factor: better performance in Ar at high mass for non-standard DM
- DM signals on multiple media beneficial to resolve DM properties
- Different recoil spectra to Xe for same DM scatter



Natural radioactive isotopes not present in Xe need to be controlled: underground Argon!

URANIA: 90 T / yr long term with 99.9% purity
ARIA: distillation column processing 1 T / day with 10^3 impurity reduction

DarkSide-20k recent history

DarkSide-20k represents a consolidation of the worldwide LAr dark matter search programme

2016: consolidation of global Ar dark matter collaborations (ArDM, DarkSide-50, DEAP, MiniCLEAN)

2017: INFN/NSF approval, project kick-off attended by NSF, DOE, CFI, INFN, STFC, CNRS, Poland, Russia, China, Spain, LNGS, CanFranc, SNOLAB

2018: Capital contributions now from Italy, Canada, US, China, Brazil and Argentina.

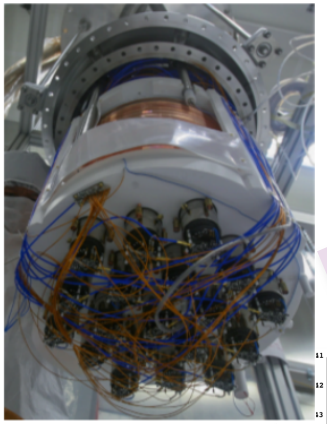
2018: DarkSide-20k a CERN recognised experiment

and now?...

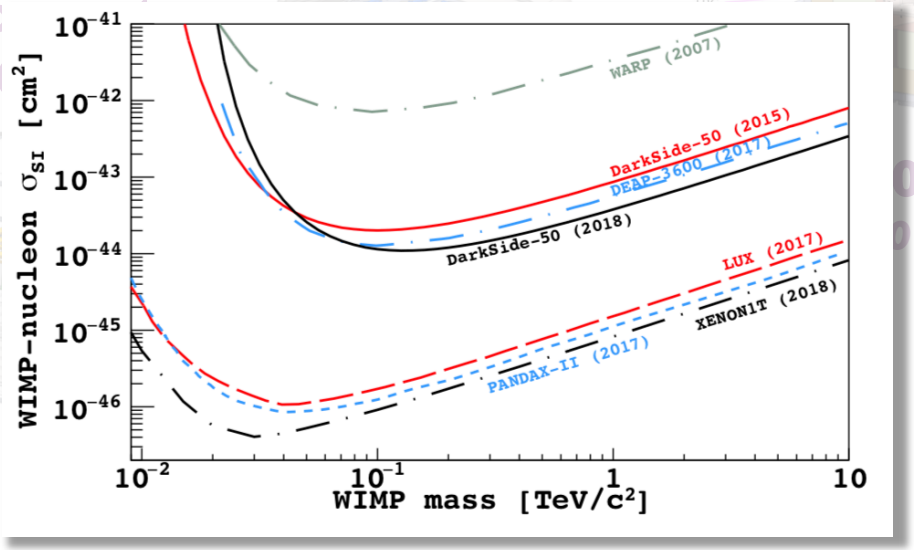
The path to the DarkSide(-20k)

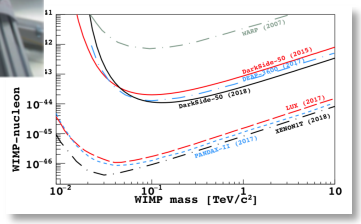
- ***DarkSide-50 published results of 532 days of data in 2018***
- *Null result but delivering on promise of zero-background experiment*
- *Best LAr–DM limits*
- *Demonstrated viability of UAr target, PSD performance, and veto*

DarkSide-50



50 kg



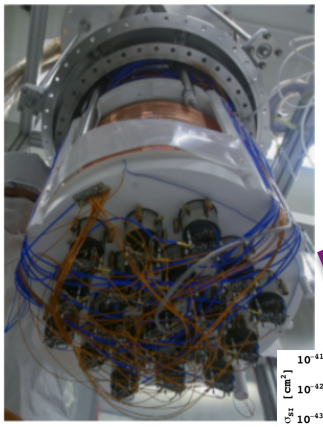


Staged programme towards DarkSide-20k…

The path to the DarkSide(-20k)

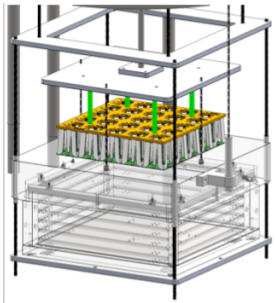
- ***DarkSide pre-prototype under construction at CERN***
  Test of cryogenics system, SiPMs, electronics and calibration/tuning of S2 amplification

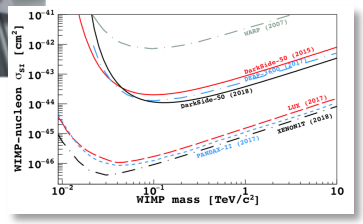
DarkSide-50



50 kg

DS proto-proto 2019





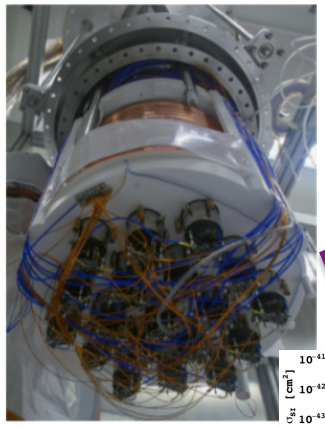
1 tonne

50 tonnes
(40 T fiducial)

The path to the DarkSide(-20k)

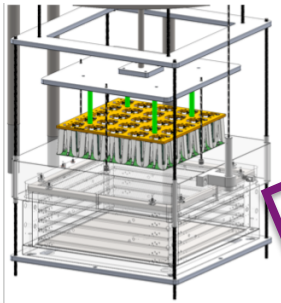
- *Full 1 T prototype with first 370 production PDMs and full DAQ readout will be assembled at CERN (later moved to LNGS)*

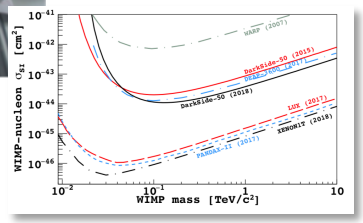
DarkSide-50



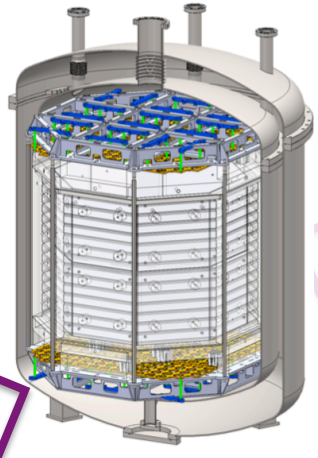
50 kg

DS proto-proto 2019

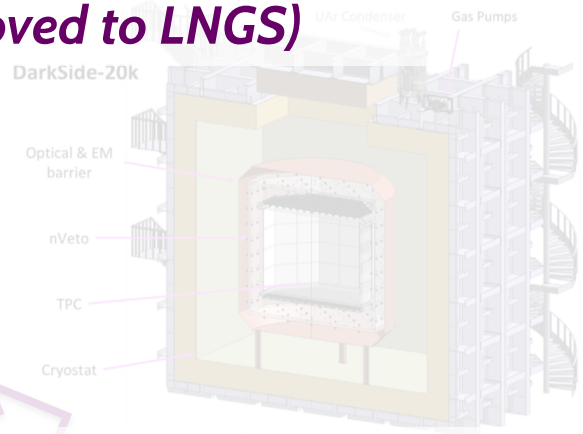




DS proto-1T 2020



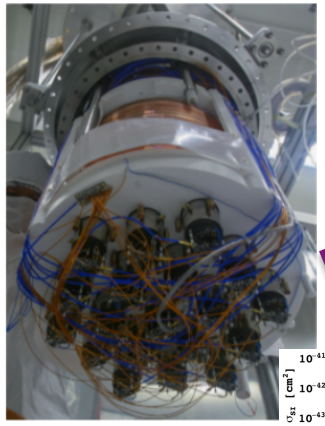
1 tonne



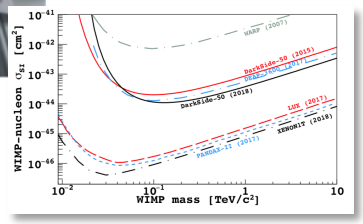
Construction and commissioning of cryogenics system with support of CERN

The path to the DarkSide(-20k)

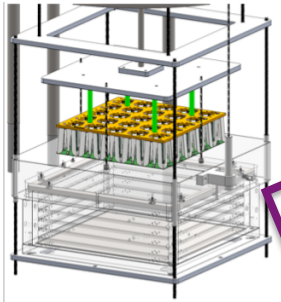
DarkSide-50



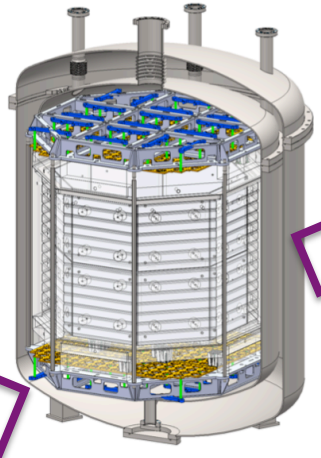
50 kg



DS proto-proto 2019

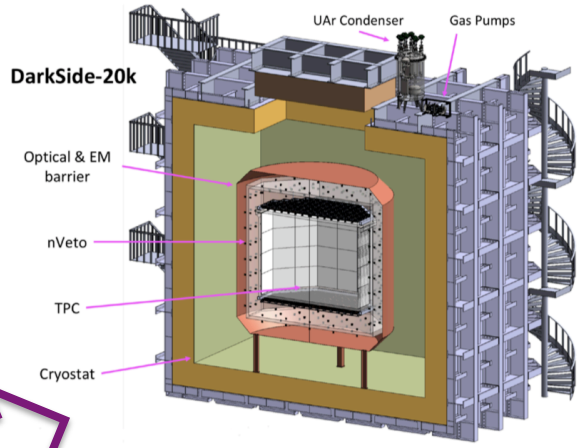


DS proto-1T 2020



1 tonne

DarkSide-20k 2022—2027



50 tonnes

(40 T fiducial)

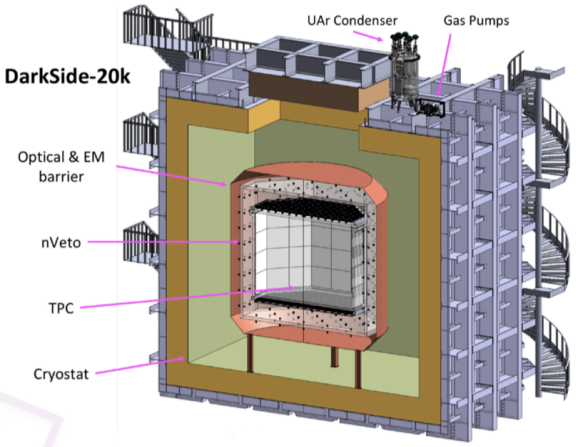
The path to the DarkSide(-20k)

DarkSide-20k:

- *TPC filled with UAr instrumented with 8,920 radiopure PDMs (1 PDM = 24 SiPMs)*
- *Doubled target mass to 50 tonnes from design*
- *Surrounded by acrylic vessel (no cryostat)*
- *Neutron veto: Gd doped acrylic with two active AAr layers read out via another 3,000 PDMs (active volume 600 tonnes)*
- *Surrounded by a copper cage*
- *Hosted in a proto-DUNE like cryostat*

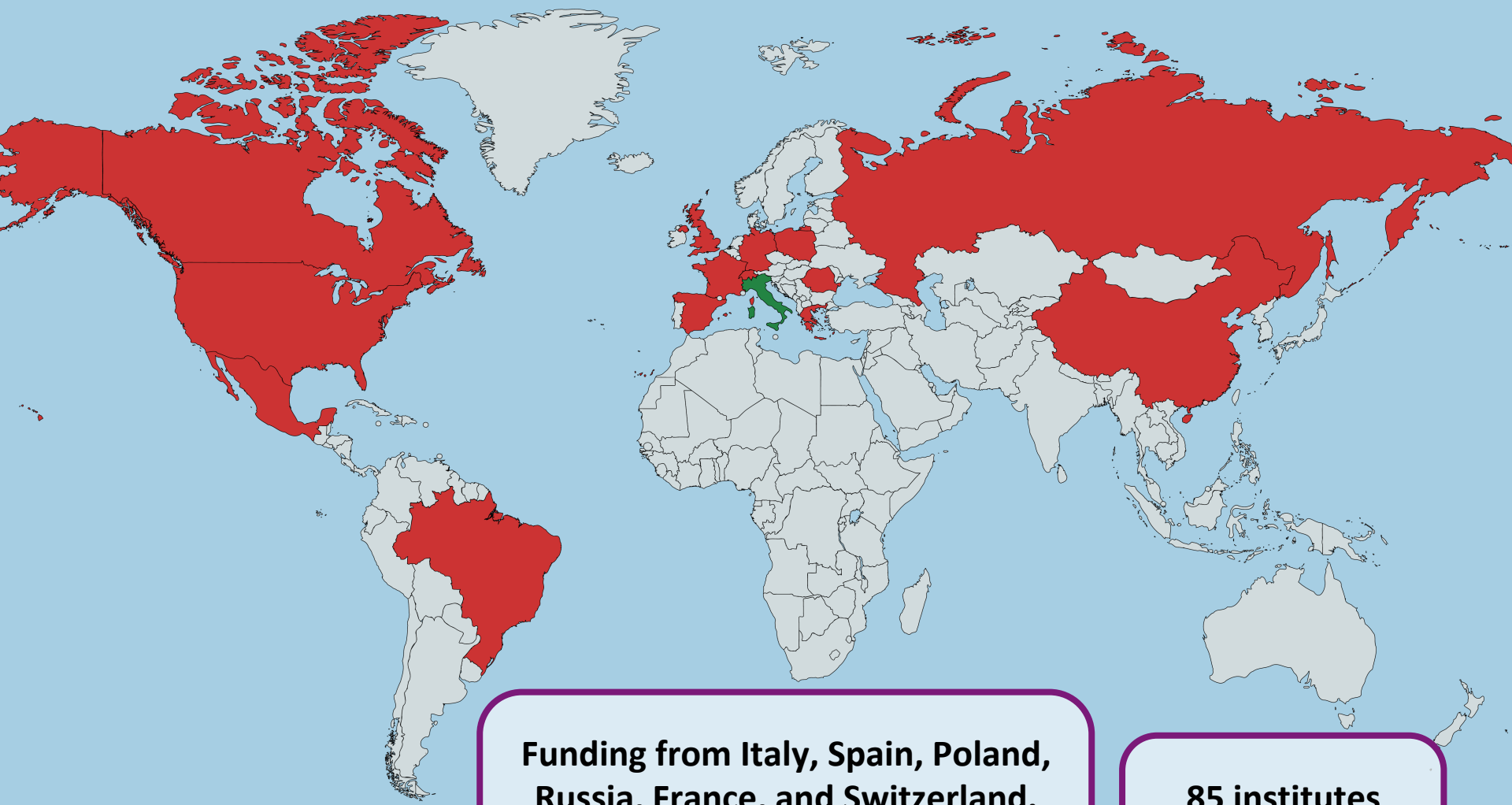
Construction and installation planned for 2020/21

DarkSide-20k
2022—2027



50 tonnes
(40 T fiducial)

The DarkSide Collaboration

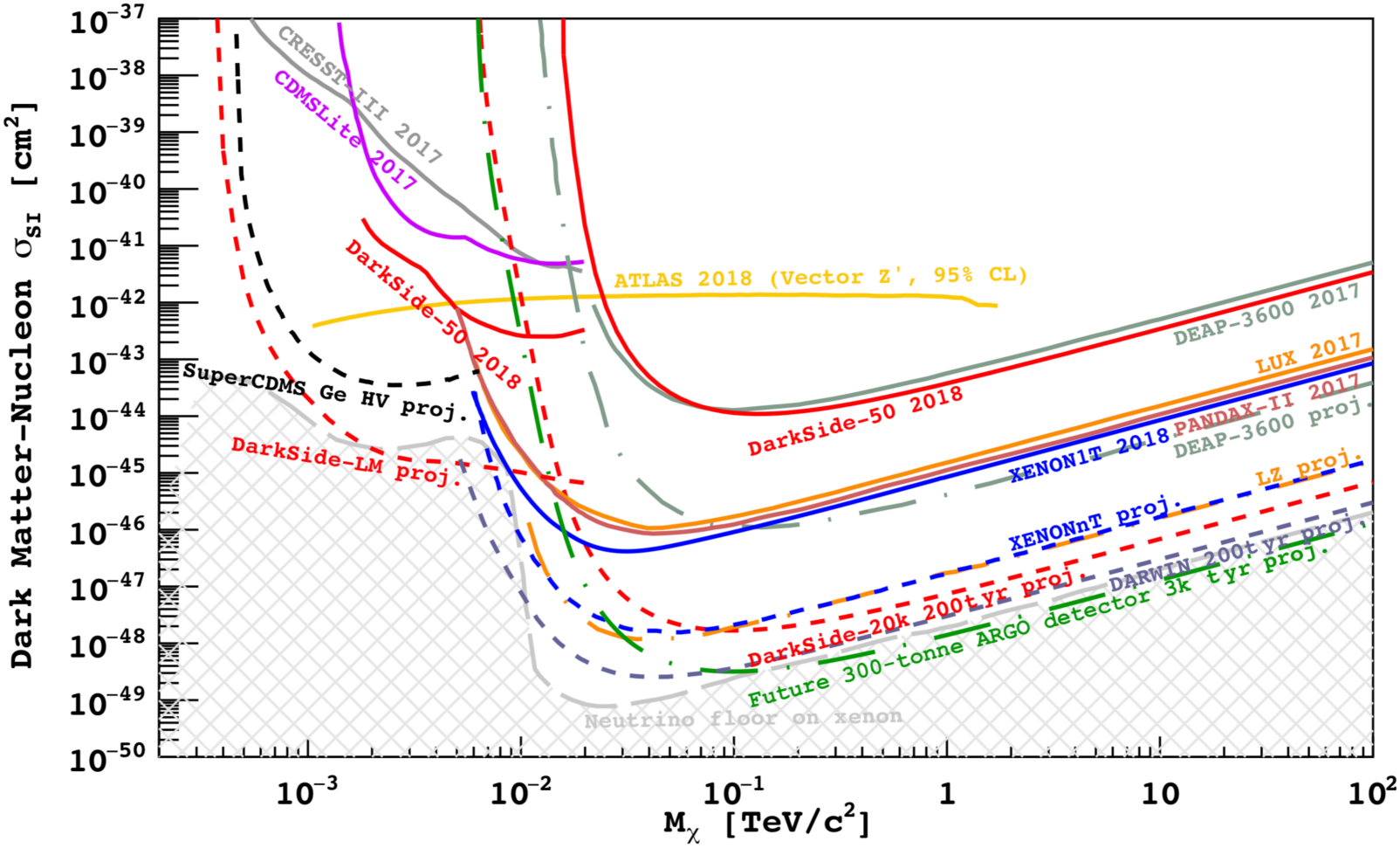


Funding from Italy, Spain, Poland, Russia, France, and Switzerland. Capital contributions from Canada, US, China, Brazil and Argentina.

85 institutes
15 countries
O(350) people

Current and future WIMP sensitivity

Expected spin-independent DM-nucleon scattering cross-section discovery sensitivity of current and future DD experiments



DarkSide-20k Liquid Argon Neutron Veto

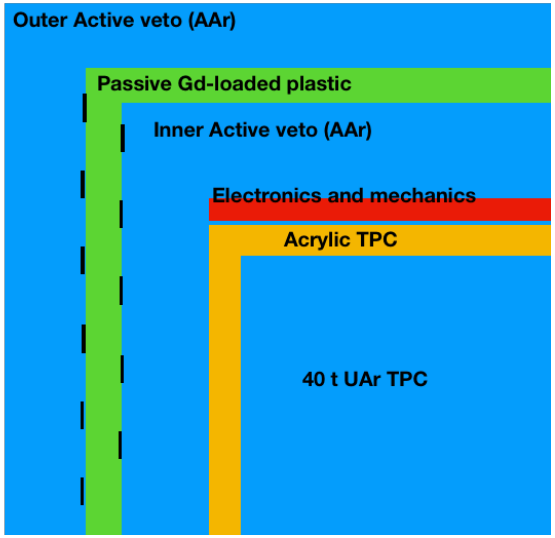
Liquid Argon Neutron Veto is key to achieving design sensitivity

- Cryostat Proto-DUNE design delivered by CERN Neutrino Platform and DarkSide-20k project office at CERN
  Allows elimination of Liquid Scintillator Veto and water tank
- Design makes use of ultra-radiopure acrylic (DEAP) and Gd (SuperK)

- Must achieve 90% neutron capture efficiency:
  - *High energy γ from capture on Gd or LAr*
  - *Scintillation light recorded on Gd-mounted SiPMs*
  - *Current simulations indicate design will achieve required performance*

	Fraction of Untagged event[%]
Gd	5.5%
Ar	9.1%
H	57.7%
TPC SiPM Cu	22%

Table from slides of Daria Santone at IoP HEPP meeting



DarkSide-20k Silicon Photosensors

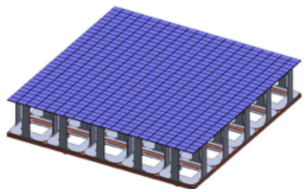
Performance of radiopure low noise high efficiency silicon photosensors underpins DarkSide-20k physics reach

- SiPM **radiopurity** one order of magnitude greater than PMTs
- **Compact**, allowing for increased coverage
- Expect **low noise** < 1 Hz/mm^2
- Expected **photon efficiency** of ~50%
- **Time resolution** of 10 ns
- SiPM customisation for **cryogenic** temperatures:

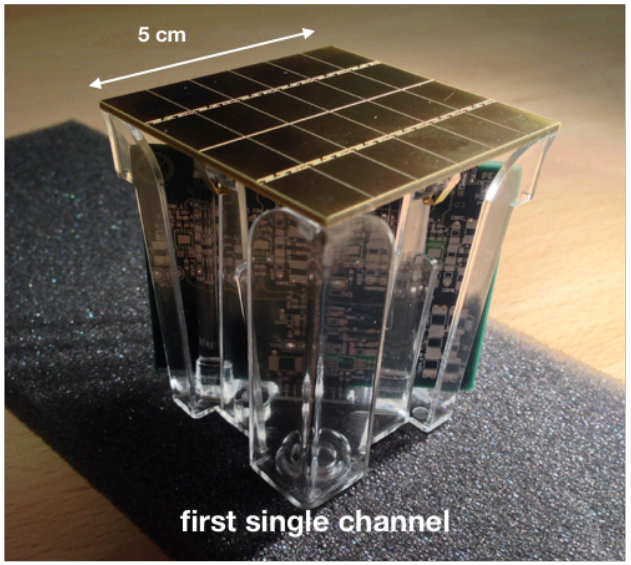
Technology transfer from Fondazione Bruno Kessler (FBK) to LFoundry for mass production has occurred

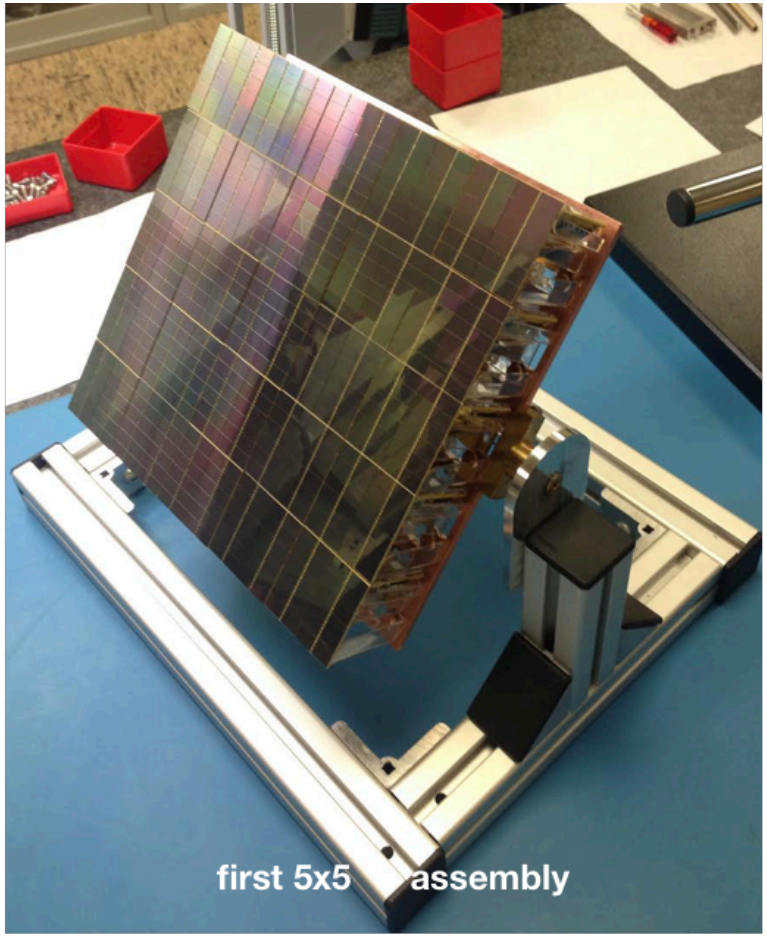
Packaging of tiles and cold electronics in PDMs at LNGS-funded NOA facility (~250,000 SiPMs)

- **SiPMs** arranged in 6x4 arrays with FEB into photodetector module (**PDM**)
- **Motherboards** contain 25 **PDMs** arranged in 5x5 matrix



Successful construction of the first photodetector module in March 2018





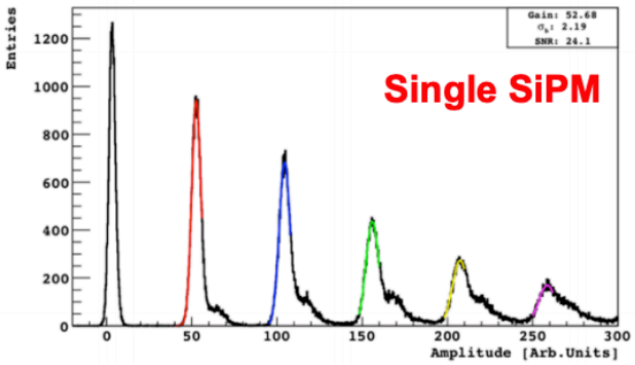
Construction of the first motherboard with 25 PDMs in September 2018

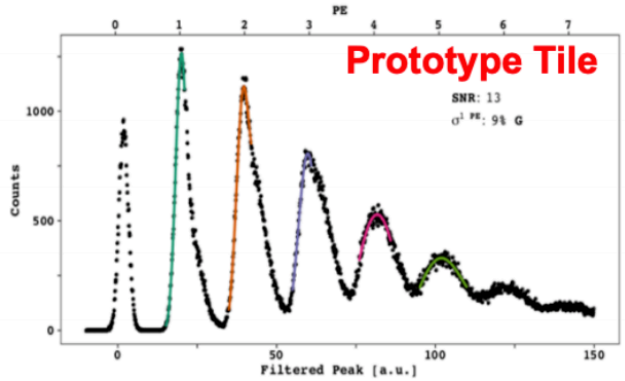
- First SiPM tests at -40°C resulted in 50% photon efficiency
- Two motherboards now produced

DarkSide-20k Silicon Photosensors

SiPM production / performance:

- SiPMs meet design requirements in tests
- Photoelectronics production on schedule, mass production in progress





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

DarkSide-20k Silicon Photosensors

Prototype studies

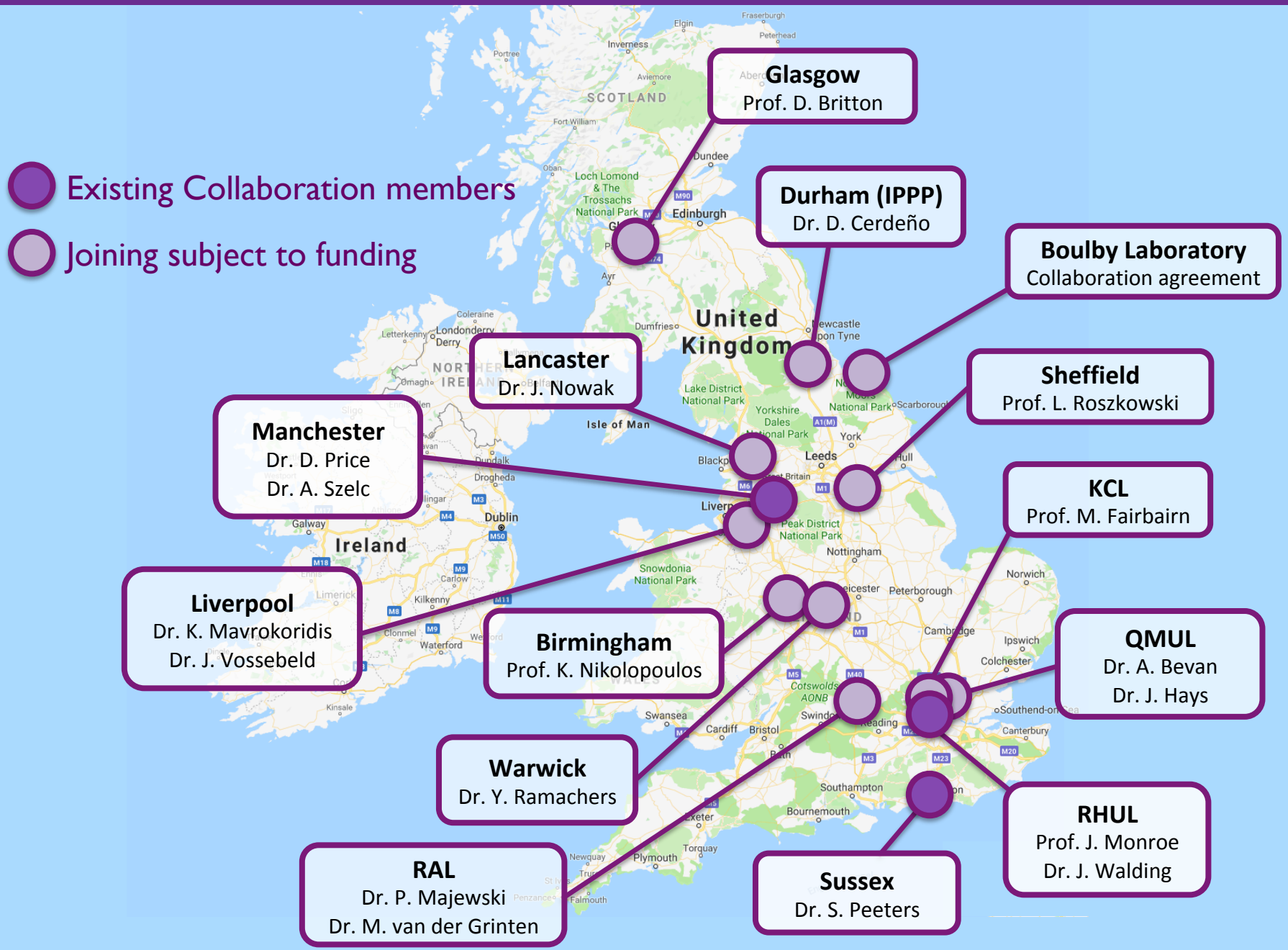
- Two motherboards complete: fabricated and now tested at CERN
- Proto-0 open Argon bath; DAQ development happening now
- Test planes of photosensors at CERN and then move to Gran Sasso

Mass production

- Wafers being shipped to Princeton for dicing and bump/wire-bonding
- Technician from Manchester on secondment to Princeton from May–September this year: knowledge exchange and participation in production
- All technicians and engineers will spend 6 months to a year training at NOA* facility to ensure cross-site quality control

* *Nuova Officina Assergi*

DarkSide-20k UK participation

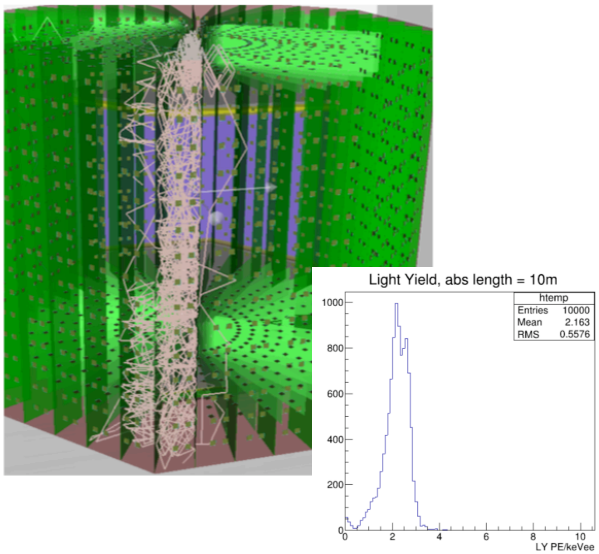


UK current activities on DarkSide

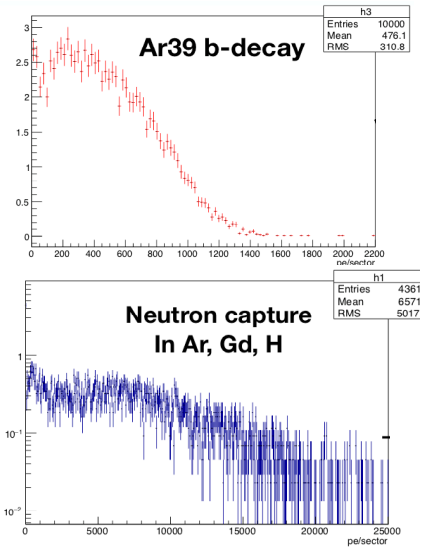
UK collaborators hold leadership positions in the Technical Board, Resource Board, Editorial Board, and working group management of DarkSide (veto, calibrations, simulations…)

- *DS-50 data analysis at Manchester (Chris Goodwin)*
- *DS-20k ongoing veto design/simulation and performance studies at RHUL and Manchester (Daria Santone, Samuel Hill, Niamh Fearon)*
- *DS-20k dark matter / supernova neutrino sensitivity studies*
- *DS-20k SiPM instrumentation production*
- *DS-20k distributed computing*

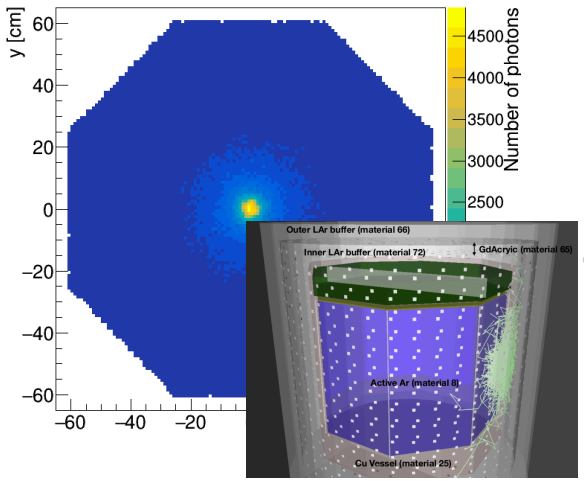
Light yield in segmented detector simulation
Samuel Hill (PhD; RHUL)



Veto light yield / performance
Daria Santone (PDRA; RHUL)



Large-scale photon efficiency simulation
Supernova neutrino studies
Niamh Fearon (Masters; Manchester)



UK funding for DarkSide

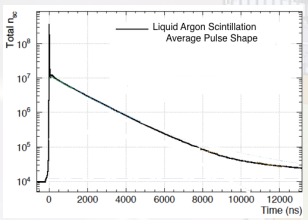
SiPM instrumentation submitted as part of Strategic Priorities funding bid (TERAS) [cross-experiment]: evaluated as one of seven high priority projects for 'Big Ideas'

DarkSide-20k Statement of Interest submitted to both STFC Particle Astrophysics and Particle Physics Advisory Panels

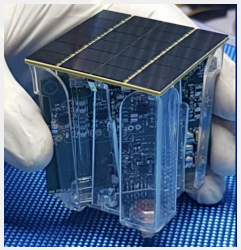
- Expect to hear back soon (hopefully with a request to move to full proposal!)
- Timescales for PPRP review and decision will exceed start dates for DarkSide-20k UK commitments
- In the case of positive full review hope to secure funding earlier to enable e.g. engineering work on PDM production to begin in late 2019

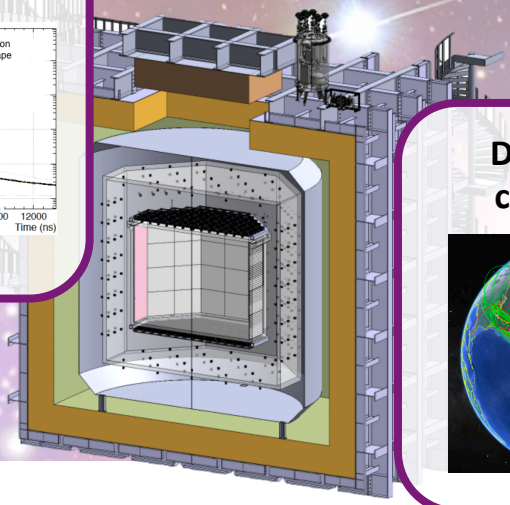
DS20k: PPRP proposal for UK work packages

SiPM calibration

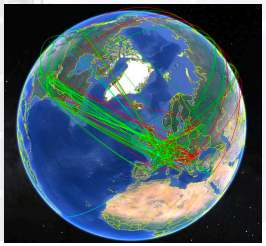


Veto readout

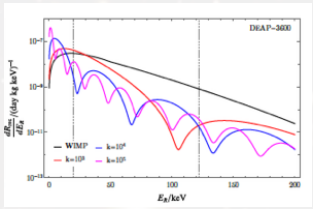




Distributed computing



Searches beyond WIMPS



- **Lead the LAr veto readout and responsibility for photosensor calibration critical to goal of zero-background experiment.**
  Propose to deliver 3000 large area SiPMs, starting from foundry wafer through sensor calibration.
  Benefit from development/retention of expertise in low-noise high detection efficiency sensor technology
- **Distributed computing challenges at the level of LHC.**
  Leverage existing UK expertise and leadership
- **Expand DM (and neutrino) physics programme of experiment.**
  Synergies with DUNE and existing DM programme
- **Positions UK for strong future exploitation programme.**

Summary

Future looks bright for physics on the DarkSide

- Staged development of DarkSide-20k detector through 2021
- 40 T fiducial background-free LAr TPC DM search
- Photosensor production has begun, testing at design performance

UK funding bid in progress with 14 institutes participating

- Opportunity for UK to play a long-term leading role in DarkSide-20k from construction/calibration to data acquisition / physics outputs
- Builds on:
  - *World-leading capabilities in Si detector production,*
  - *Previous investment in Si infrastructure and protoDUNE/SBND*
  - *UK capabilities in low background experiments*

Leading sensitivity to DM in 2022—2027, complementary to LHC, Xe programme

Wide physics case beyond standard WIMP DM: non-standard DM signatures, sterile neutrinos, supernovae, CNO neutrinos