Low radioactivity Argon and SiPMs at cryogenic temperatures for the next generation dark matter searches

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on behalf of the DarkSide collaboration

see also the talk of Jeff Martoff

596. Darkside Status and Prospects, Dark Matter Session, 6/7
(New) Argon Collaboration

Researchers from
- DarkSide
- DEAP
- ArDM
- MiniCLEAN

DS-20K → multi-100-T

Planning to collaborate on future program:
- Completion of current science and R&D programs by each collaboration (DS-50, DEAP-3600, MiniCLEAN, ArDM)
- Joint collaboration on DS-20K at LNGS, including Low Radioactivity Argon (operation starting 2021) and SiPM photodetectors
- Joint collaboration on future multi-hundred-tonne LAr detector, site TBD (mid-2020's)
Scaling to large masses—> background suppression capability: argon is very well suited to this due to PulseShapeDiscrimination (PSD) capability
Backgrounds to DM search: e- recoils and nuclear recoils

For Ar detectors the dominant e- recoil background is due to the cosmogenic $^{39}$Ar, with atmospheric or natural Ar having a radioactivity of 1Bq/Kg

To reject e- background PulseShapeDiscrimination (PSD) is used based on different time response of scintillation to e- and nuclear recoils

fraction of S1 light in 200ns
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DarkSide-20k 10p.e./KeV
Two crucial technologies

*Liquid argon target depleted in the radioactive $^{39}$Ar, with respect to the $1Bq/Kg$ of the atmospheric argon (AAr)*

$\rightarrow$ allows to keep PSD thresholds low

$\rightarrow$ mandatory to **reduce pile-up** for dual phase argon detectors above the few 100Kg,

*Cryogenic SiPMS replacing PMTs*

$\rightarrow$ higher light yield (#PE/KeV), essential to keep PSD threshold low, low cost for large areas, very low dark noise, very low radioactivity background (with radio-pure substrates), long term stability
The DarkSide-20k inner detector

- 2x7m$^2$ SiPM planes
- 23t UAr active
- 30t UAr
- Electroluminescence in the gas: $S_2$
- Prompt scintillation: $S_1$
- TPB coating WLS 128nm (UV) $\rightarrow$ ~420nm (blue)
The Urania project@Kinder Morgan Doe Canyon Facility, CORTEZ, CO (USA)

e EXTRACTION OF 50t OF UAr FROM CO₂ DEEP WELLS WHERE COSMIC RAYS HARDLY MAKE ANY ³⁹Ar

STARTING FROM 95% CO2 AND 440ppm OF UAr!

NEW PLANT, FUNDED, BUT THE DESIGN STILL TO BE FINALISED AND BUILT
For DarkSide-50, about 70Kg of underground argon (UAr) were extracted with a pilot plant.

UAr vs AAr in DS-50: \((0.73 \pm 0.11) \times 10^{-3} \text{Bq/Kg vs 1Bq/Kg}\)
The (new) argon path

Urania

UAр

Purified UAр
(with Seruci-II purified and DAr)

Aria
The Aria project: includes regional funds from Sardinia, Italy

$^{39}$Ar isotopic separation with cryogenic distillation $\rightarrow$ factor 10 suppression per pass (from UAr to DAr)

CarboSulcis mine in Nuraxi-Figus

The Seruci-I column:

350m height, 30cm diameter
CERN: leak tests; 11/30 already successfully tested
first step to be performed soon: installation and test of a 28m tall test column Seruci-0 in a surface building at the mine
For DarkSide-20k:

Seruci I —> removal of chemical impurities to make the UAr detector grade with 2 passes at 1t/day with 85% recovery —> inlet purity required by DS20k getters of order 0.25-1ppm

For future DM projects:

A wider diameter column Seruci II (yet to be funded) —> 150Kg/day isotopic distillation of $^{39}$Ar and chemical purification

A measuring device:

The measurement of $^{39}$Ar content in the argon coming from Urania and Aria is planned with a specific innovative device named DART based on LAr active vetoing approach
A new SiPM development at FBK/INFN TIFPA (Italy)

NUV-HD-LF working at cryogenic temperatures

Low field SPADs, near UV (410nm) peak efficiency, 25μm cell size

Regional funds from Abruzzo, Italy—>

— SiPM large scale production in a foundry (yet to be selected)

— NuovaOfficinaAssergi at LNGS for assembly
24 cm² tiles equipped with 1x1 cm² SiPMs fully working
The tile is readout by 4 TransImpedanceAmplifiers (large detector C of 50 pF/mm²) with discrete components to be mounted on radio-pure substrates (under R&D)
...to assembled as self-consistent one-channel units PhotonDetectorModules, replacing 3” PMTs
Photon Detection Efficiency (PDE): 45% requirement met and surpassed

Dark Count Rate (DCR): 0.1 Hz/mm$^2$ requirement met and surpassed

250mW power/consumption/PDM

20ns time resolution
requirement is SNR>8 after digital filtering allows to work as single photon counter
In summary, I described two very innovative projects conceived for DarkSide-20K with far reaching consequences in Particle Physics and beyond

**Broader impact:**

Aria project —> production of stable isotopes for medicine and energy production such as $^{13}$C, $^{18}$O, $^{15}$N

SiPMs—> other experiments such as direct DM searches, $\nu$-less double-$\beta$ decay experiments, neutrino physics, $\gamma$-ray telescopes, imaging in nuclear medicine but ultimately also auto-motive and others