DIRECTIONAL DARK MATTER SEARCH WITH THE NEWSdm EXPERIMENT

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on behalf of the NEWSdm Collaboration

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NEWSdm COLLABORATION

70 physicists
14 institutes

ITALY
INFN e Univ. Bari,
LNGS, INFN e Univ. Napoli,
INFN e Univ. Roma
GSSI Institute

JAPAN
Chiba, Nagoya

SOUTH KOREA
Gyeongsang

RUSSIA
LPIRAS Moscow, JINR Dubna
SINP MSU Moscow, INR Moscow
Yandex School of Data Analysis

TURKEY
METU Ankara

Website: news-dm.lngs.infn.it
POWER OF DIRECTIONALITY

- Impinging direction of DM particle is (preferentially) opposite to the velocity of the Sun in the Galaxy, i.e. from Cygnus Constellation

- Unambiguous proof of the galactic origin of Dark Matter

- Unique possibility to overcome the “neutrino floor”, where coherent neutrino scattering creates an irreducible background
DIRECTIONAL APPROACH

Current approach: low pressure gas detectors
- Small achievable detector mass due to the low gas density
- Recoil track length $O(\text{mm})$

Use solid target:
- Large detector mass
- Smaller recoil track length $O(100 \ \text{nm})$

very high resolution tracking detector

Nuclear Emulsion based detector
acting both as target and tracking device
NEWSm PRINCIPLE

- **Aim**: detect the direction of nuclear recoils produced in WIMP interactions
- **Target**: nanometric nuclear emulsions acting both as target and tracking detector
- **Background reduction**: neutron shielded surrounding the target
- **Fixed pointing**: target mounted on **equatorial telescope** constantly pointing to the Cygnus Constellation
- **Location**: Gran Sasso Underground Laboratory
NIT: NANO EMULSION IMAGING TRACKERS

A long history, from the discovery of the Pion (1947) to the discovery of $\nu_\mu \rightarrow \nu_\tau$ oscillation in appearance mode (OPERA, 2015)

- Nuclear emulsions: AgBr crystals in organic gelatine
- Passage of charged particle produce *latent image*
- Chemical treatment make Ag grains visible

- New kind of emulsion for DM search
- Smaller crystal size
TRACK LENGTHS OF WIMP-INDUCED NUCLEAR RECOILS

Inaccessible with standard optical techniques due to diffraction limit

Super-resolution needed in order to measure track lengths shorter than 200 nm
READEOUT TECHNOLOGY

New optical techniques at the nanometric scale

Optical microscope installed in Napoli INFN Laboratory

INFN Patent (2016)
N. 102016000132813
PHASE 1: SHAPE ANALYSIS

- Elliptical fit to measure the shape anisotropy

Correlation between track lengths measured by X-ray microscopy and ellipticity obtained with optical analysis

Correlation between readout efficiencies and track lengths for different ellipticity thresholds

100 keV Carbon

σ=16°
PHASE 2: BEYOND DIFFRACTION LIMIT

- Idea: use the plasmon resonance effect to overcome the diffraction limit
- Generated by a light wave trapped within conductive nanoparticles smaller than the wavelength of light
- Resonant frequency strongly depends on the composition, size, geometry, dielectric environment and distance between nanoparticles
- Occurs in the visible region for Ag and Au nanoparticles!
- Improve resolution by analyzing scattered light polarization and spectrum
SUPER RESOLUTION ANALYSIS

NIM A 824 (2016) 600–602


Rotating polarizer

Beam

1150 nm

Carbon ions 100 keV

Carbon ions 60 keV

Barycenter shift
BS = 100 nm

pol angle
SUPER RESOLUTION ANALYSIS

Long BS event (moving)

BS = 48 nm

Reconstructed image

SEM image

SR-SEM COMPARISON

Track length measured by Super Resolution optical microscope and by

Accuracy: 28 nm ≈ pixel size (27.5 nm)
Resolution: 80 nm (Nyquist theorem)

<table>
<thead>
<tr>
<th>Pearson Coefficient</th>
<th>Matched</th>
<th>Unmatched</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td>0.912</td>
<td>-0.009</td>
</tr>
<tr>
<td>Width</td>
<td>0.713</td>
<td>-0.007</td>
</tr>
</tbody>
</table>

\( r^2 \) / ndf  5.119 / 8
Constant  24.56 ± 3.30
Mean  -2.449 ± 3.073
Sigma  28.24 ± 2.73
TECHNICAL TEST
**TECHNICAL TEST**

- **Aim**: measure the detectable background from environmental and intrinsic sources and validate estimates from simulations
- Confirmation of a negligible background will pave the way for the construction of a **pilot experiment** with an exposure on the **10 kg year** scale
- Pilot experiment will act as a **demonstrator** to further extend the mass range

**Experimental setup:**
- shield from environmental background
- cooling system to ensure required temperature to NIT emulsions

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Polyethylene slabs 40 cm-thick - absorb environmental and cosmogenic neutrons
Lead bricks 10 cm-thick - absorb environmental photons
NEWSm FACILITY @LNGS

- Emulsion facility recently installed in Hall F of Underground Gran Sasso Lab
- Emulsion production machine installed and fully operational
- First emulsion batches ever produced in INFN Laboratories used for 10g test

Gel production machine produced in Japan and certified compliant to EU safety

Gel production room
NEWSdm CURRENT SETUP

- Experimental setup in Hall C, close to Borexino
- Assembly of the setup in March 2021
- Test measurements ongoing
DESIGN OF THE PILOT EXPERIMENT (10kg)
Design of shield and equatorial telescope

- 1 m polyethylene shield
- Motorised equatorial telescope to compensate for Earth rotation
- Target extraction from the top, directly going into emulsion facility
NEuSdm INTERMEDIATE AND FINAL GOALS

• First **directional** dark matter detector with a 10 kg solid target
• Explore the DAMA region with a completely different technique based on the *visual* observation of recoil tracks in emulsion
• First high-sensitivity spin-independent measurement with a directional approach
• First step in the application of the emulsion technology, scalable to larger masses
• Longer term: overcome the neutrino floor

90% C.L. upper limits for the NEuSdm detector with an exposure of 10 kg year in the zero-background hypothesis

90% C.L. upper limits for the NEuSdm detector with an exposure of 10 ton year in the zero-background hypothesis  \(\text{Eur.Phys.J. C78 (2018) no.7, 578}\)
CONCLUSIONS

• A novel approach for **directional Dark Matter searches** is proposed in NEWSdm
• Use of fine-grained **nuclear emulsion** as target and tracking system
• Breakthrough in readout technologies to go beyond optical resolution
• Prepare a 10 kg scale (pilot) experiment as a demonstrator of the technology
• Aim: large mass scale detector to go beyond “neutrino floor”