NUCLEAR EMULSIONS FOR WIMP SEARCH
directional measurement

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on behalf of the NEWS*dm* Collaboration

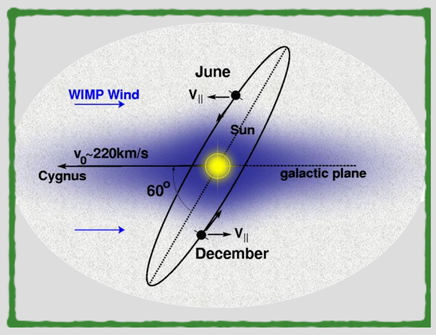
Directional Dark Matter searches

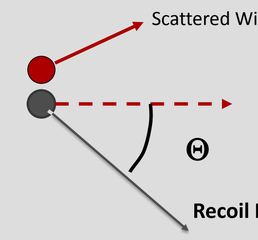
The IDEA

Earth revolution gives seasonal modulation

Due to solar system movement in the galaxy, the WIMP Flux is expected to be **not isotropic @earth**.

A directional measurement would provide a **strong signature** and an unambiguous proof of the galactic origin of DM





WIMP cross-section with nuclei ∝ A^2

Experimental approach

Current experimental approach: low pressure gaseous detector

- Targets: CF4, CF4+CS2, CF4 + CHF3
- Recoil track length O(mm)
- Small achievable detector mass due to the low gas density

⇒Sensitivity limited to spin-dependent interaction

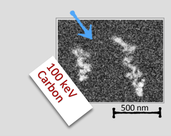
Use solid target:

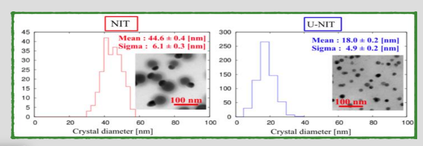
✓ Large detector mass
✓ Smaller recoil track lenght O(100 nm)
→ very high resolution tracking detector

Nuclear Emulsion based detector acting both as target and tracking device

NIT (*N*ano *I*maging *T*racker)

new kind of emulsion for DM search with smaller crystal size (Natsume et al, NIM A575 (2007) 439)





Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

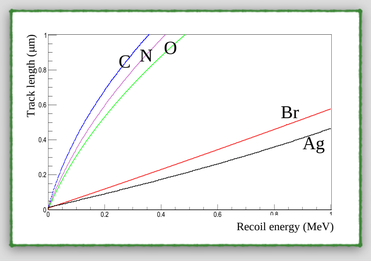
(a) Constituents of nuclear emulsion

Element	Mass Fraction	Atomic Fraction
Ag	0.44	0.12
Br	0.32	0.12
I	0.019	0.003
C	0.101	0.172
O	0.074	0.129
N	0.027	0.057
H	0.016	0.396
S	0.003	0.003

(b) Elemental composition

AgBr-I: sensitive elements
Organic gelatine: retaining structure
PVA to stabilise the crystal growth

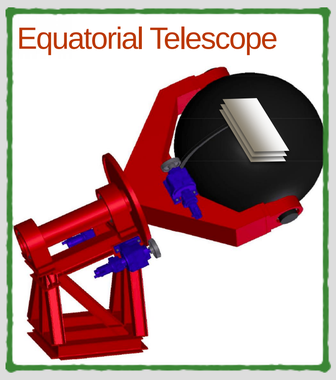
Heavy nuclei
Light nuclei



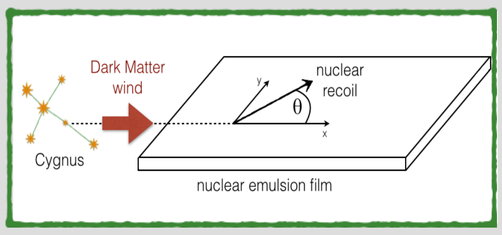
Each nucleus gives a different contribution to the overall sensitivity:
lighter nuclei (longer range at the sme recoil energy → sensitivity to low WIMP mass

NEWS*dm* project

Equatorial Telescope

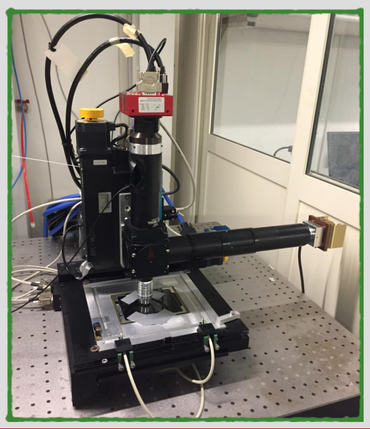


The NEWSdm principle



- **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 **shield** surrounding the target
- **Fixed_pointing**: target mounted on **equatorial telescope** constantly pointing to the Cygnus Constellation
- **Location**: Underground Gran Sasso Laboratory

Emulsion readout: optical microscope with light polarizer



Measurement of intrinsic radioactivity

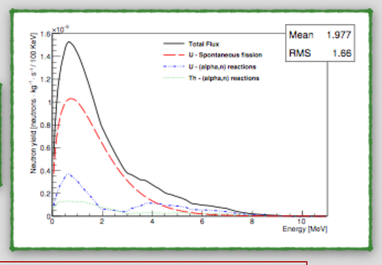
evaluation of the neutron yield (NEWSdm Collaboration, Astroparticle Physics 80 (2016) 16)

Nuclide	Contamination [ppb]	Activity [mBq/Kg]
Gelatine		
^{232}Th	2.7	11.0
^{238}U	3.9	48.1
PVA		
^{232}Th	< 0.5	< 2.0
^{238}U	< 0.7	< 8.6
AgBr-I		
^{232}Th	1.0	4.1
^{238}U	1.5	18.5

^{238}U: 1.87 ppb (23.1 mBq/kg)
^{232}Th: 1.26 ppb (5.1 mBq/Kg)

Background yield from the intrinsic radioactive contamination of NIT:
~1.2 n/kg year

Process	SOURCES simulation [n · kg^{-1} · y^{-1}]	Semi-analytical calculation [n · kg^{-1} · y^{-1}]
(α, n) from ^{232}Th chain	0.12±0.04	0.10±0.03
(α, n) from ^{238}U chain	0.27±0.08	0.26±0.08
Spontaneous fission	0.79±0.24	0.82±0.24
Total flux	1.18±0.35	1.18±0.35



From simulation: detectable neutron induced background

ε ~ 1% → ~ 0.01 n/(Kg year)

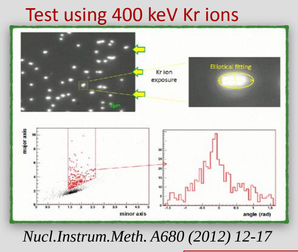
Neutron background from intrinsic radioactivity negligible up to ~10 kg year

Emulsion readout strategy

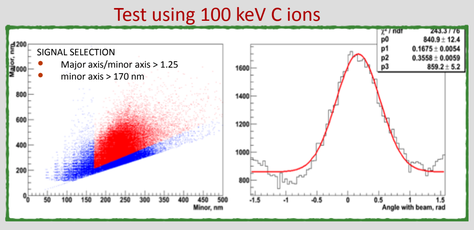
STEP 1

- Scanning with **optical microscope** and **shape recognition analysis**
- Automatic selection of candidate signals by optical microscopy
- Selection of clusters with elliptical shape: major axis along track direction
- Background: spherical cluster
- Resolution 200 nm (one order of magnitude better than the OPERA scanning system), scanning speed 20 cm^2/h

Test using 400 keV Kr ions



Test using 100 keV C ions

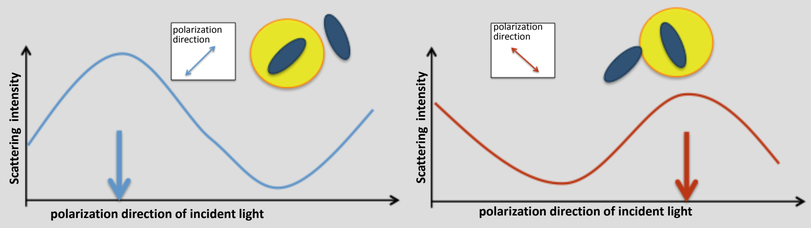


Nucl.Instrum.Meth. A680 (2012) 12-17

OVERALL ANGULAR RESOLUTION
$\sigma^2 = \sigma^2_{intrinsic} + \sigma^2_{scattering}$
σ = 360 mrad

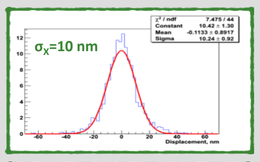
STEP2

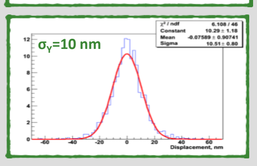
- Exploit the **resonant light scattering** occurring when the light is scattering off a nanometric metallic (silver) grains are dispersed in a dielectric medium
- Sensitive to the shape of nanometric grains: when silver grains are **not spherical**, the resonant response depends on the polarization of the incident light.
- Each grain is emphasized at different polarization values
- Scanning with **light polarized at different angles**, of candidates selected by shape analysis

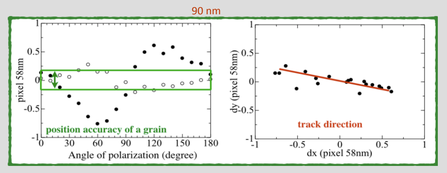


PERFORMANCES

- Taking multiple measurements over the whole polarization range produces a displacement of the barycenter of the cluster
- Application of resonant light scattering to an elliptical cluster
- Measure the displacement of cluster barycenter as a function of polarization angle (dx, dy)



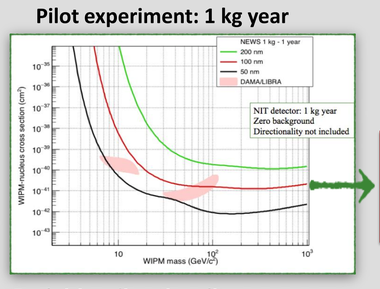




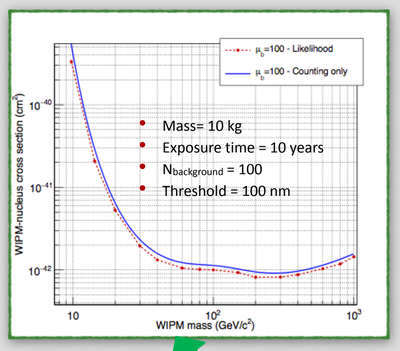
- ✓ **Measurement of track slope and length beyond optical resolution**
- ✓ **Unprecedented accuracy of 10 nm achieved on both coordinates**
- ✓ **Intrinsic angular resolution (measured with neutron test beam):**
  $\sigma_{intrinsic}$ = 235 mrad =13°

Sensitivity

Pilot experiment: 1 kg year

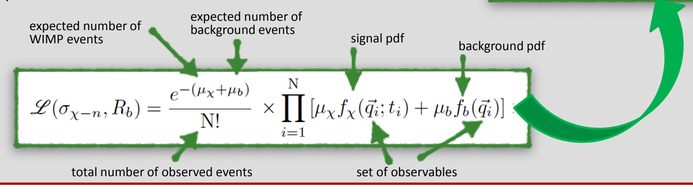


Where we are now



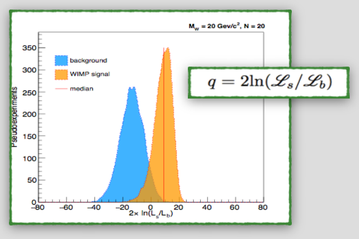
Exploiting directionality

evaluation of upper limit and sensitivity based on the profile likelihood ratio test:

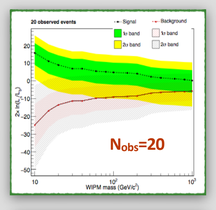


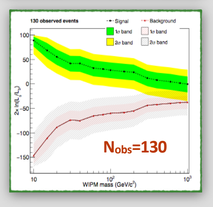
Discovery potential

- Test anisotropy of observed signal
- Unambiguous proof of WIMP origin of recoil signal
- Signal/background hypothesis separation



- 20 events required to prove that data are not compatible with background at 3σ CL for M_W<20 GeV/c^2
- 130 events give 3σ CL in the whole WIMP mass range

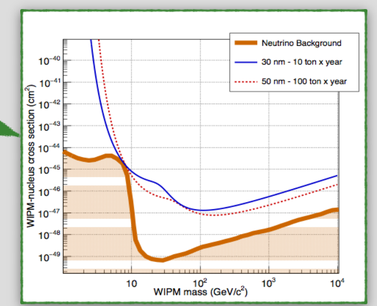




Towards the neutrino floor

- Discrimination based on measurement of recoil direction
- Unique possibility to search for WIMP signal beyond "neutrino floor"

Neutrino coherent scattering indistinguishable from WIMP interactions,
Phys.Rev.D89 (2014) no.2, 023524
(Xe/Ge target)



REQUIREMENTS

- Larger mass scale detector
- Reduction of track length threshold

The neutrino bound is reached with:
- ✓ **10 ton x year exposure if 30 nm threshold**
- ✓ **100 ton x year exposure if 50 nm threshold**

A. Di Crescenzo, N. Di Marco *et al.*, NEWSdm Collaboration, arXiv:1705.006130

Conclusions

- 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
- Neutron background from intrinsic radioactivity negligible up to ~10 kg year
- Prepare a kg scale (pilot) experiment as a demonstrator of the technology
- Aim: large mass scale detector to go beyond "neutrino floor"
- Status:
  - ✓ Letter of Intent submitted to LNGSC in 2015
  - ✓ First technical test performed in March 2017
  - ✓ TDR in preparation

LNGS-LOI 48/15

NEWS: Nuclear Emulsions for WIMP Search
Letter of Intent
(NEWS Collaboration)

A. Aleksandrov[b], A. Anokhina[n], T. Asada[k], D. Bender[p], I. Bodnarchuk[m], A. Buonaura[b,h], S. Buontempo[b], M. Chernyavskii[o], A. Chukanov[m], L. Consiglio[b,h], N. D'Ambrosio[e], G. De Lellis[b,h], M. De Serio[a,g], A. Di Crescenzo[b,h], N. Di Marco[e], S. Dmitrievski[m], T. Dzhatdoev[n], R. A. Fini[a], S. Furuya[k], G. Galati[b,h], V. Gentile[b,h], S. Gorbunov[o], Y. Gornushkin[m], A. M. Guler[p], H. Ichiki[k], C. Kamiscioglu[p], M. Kamiscioglu[p], T. Katsuragawa[k], M. Kimura[k], N. Konovalova[o], K. Kuge[l], A. Lauria[b,h], P. Loverre[d,j], S. Machii[k], A. Managadze[n], P. Monacelli[d,j], M. C. Montesi[b,h], T. Naka[k], M. Nakamura[k], T. Nakano[k], A. Pastore[a,g], D. Podgrudkov[n], N. Polukhina[o], F. Pupilli[f], T. Roganova[n], G. Rosa[d,j], O. Sato[k], T. Shchedrina[o], S. Simone[a,g], C. Sirignano[c,i], A. Sotnikov[m], N. Starkov[o], P. Strolin[b,h], Y. Tawara[k], V. Tioukov[b], A. Umemoto[k], M. Vladymyrov[o], M. Yoshimoto[k], S. Zemskova[m]

https://arxiv.org/pdf/1604.04199.pdf

NEWSdm Collaboration: 70 physicists, 14 institutes

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