NEWS:
Nuclear Emulsions for Wimp Search

NATALIA DI MARCO
LABORATORI NAZIONALI DEL GRAN SASSO - INFN

ON BEHALF OF THE NEWS COLLABORATION

Italy
- Napoli University “Federico II”
- LNGS – INFN
- Bari University
- Roma University “La Sapienza”

Japan
- Nagoya University
- Chiba University

Russia
- JINR Dubna
- Moscow State University
- Lebedev Physical Institute

Turkey
- METU, Ankara
Directional DM searches

- Solar system movement in the galaxy → WIMP Flux not isotropic @ Earth.
- Directional measurement as a strong signature and unambiguous proof of the galactic DM origin

Current 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
The NEWS idea

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

**NIT: Nano Imaging Tracker**, AgBr crystal size $\sim 40 \text{ nm}$

<table>
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<tr>
<th>Constituent</th>
<th>Mass Fraction</th>
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<tbody>
<tr>
<td>AgBr-I</td>
<td>0.78</td>
</tr>
<tr>
<td>Gelatin</td>
<td>0.17</td>
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<tr>
<td>PVA</td>
<td>0.05</td>
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</table>

(a) Constituents of nuclear emulsion

<table>
<thead>
<tr>
<th>Element</th>
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<th>Atomic Fraction</th>
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<td>Br</td>
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<tr>
<td>I</td>
<td>0.019</td>
<td>0.003</td>
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<tr>
<td>C</td>
<td>0.101</td>
<td>0.172</td>
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<tr>
<td>O</td>
<td>0.074</td>
<td>0.129</td>
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<tr>
<td>N</td>
<td>0.027</td>
<td>0.057</td>
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<tr>
<td>H</td>
<td>0.016</td>
<td>0.396</td>
</tr>
<tr>
<td>S</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

(b) Elemental composition

N. Marco
Read-out of submicrometric tracks

1) Signal preselection
Resolution: 200 nm
Speed: ~20 mm²/h

2) Signal confirmation
Resolution: 30 nm
Speed: ~ (200μm)²/100 s

Test using 400 keV Kr ions

Optical images

X-ray images
noise
Random fog
track
track
track (3 grain)

218 nm
318 nm
602 nm
80 keV C ions

Direction detected!

Neutron test Beam

\[ \sigma^2 = \sigma_{\text{intrinsic}}^2 + \sigma_{\text{scattering}}^2 \]

\[ \sigma^2 = 350 \text{ mrad} \]

\[ \sigma = 235 \text{ mrad} = 13^\circ \]
Read-out of submicrometric tracks

Efficiency versus track length

\[ \varepsilon \approx 100\% \text{ above } \sim 200 \text{ nm} \]

\[ e > 1.25 \]

Efficiency versus C energy

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Read-out of submicrometric tracks

1) Signal preselection: optical microscope + shape analysis

2) Signal confirmation: optical microscope + polarized light

Resolution O(10nm)!

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Expected Background

- Environmental radioactivity
- Radon and its progeny
- Cosmic rays
- Neutrons from natural fission, (a,n) reactions and from cosmic ray muon spallation and capture
- Radioimpurities in detector or shielding components
Intrinsic Neutron Yield

Intrinsic radioactive contaminant contribution have been estimated @LNGS using:

1. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Chemistry Service)
2. g-spectrometry with Ge detector @ STELLA Facility (SubTErranean Low Level Assay)

Activity measured with ICP-MS:
- $^{238}\text{U}$: $23\pm7\text{ mBq/kg}$
- $^{232}\text{Th}$: $5.1\pm1.5\text{ mBq/kg}$

SOURCES-based simulation: $1.2\text{ n/kg/year}$

G4-based MC:
- $20.4\%$ of neutrons interact producing nuclear (56%), proton (44%) and a (0.2%) recoils

Cut on the track length:
- $5\%\div10\%$ of the intrinsic neutron flux contributes to the background
- A further reduction of $70\%$ can be achieved exploiting the directionality information ($-1 < F < 1$) $\Rightarrow 0.02 \div 0.03\text{ n/year/Kg}$
Experimental Set-UP

Target: 1 Kg of NIT
Shielding: 4 ton

1. Internal sphere: 30 cm diameter, holding the target.
   1 kg: 100, 50 µm thick, NIT films
   25 x 25 x 0.5 cm³
   + OPERA-like films

Wimp’s wind

1. Plexiglass/nylon sphere: sealed from air and flushed with HP N₂

2. External sphere: 50 cm thick PE shielding
Experimental Set-UP

- Water Option

To Celestial North Pole

5 m

2.5 m

φ 5 m
Schedule for 1 Kg Pilot Experiment

<table>
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<tr>
<th>Quality check</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
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<tr>
<td>Procurement of raw material</td>
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<td>Radioactivity measurements</td>
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<td>10 gr sample test and analysis I</td>
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<td>Pouring facility</td>
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<td>Clean room design &amp; construction (gel production)</td>
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<td>Commissioning</td>
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Physics Reach

NIT detector: 1 kg x 1 year
Zero background hypothesis
Directionality not included
A novel approach for **directional Dark Matter searches** is proposed in NEWS

- Novel nuclear emulsion technique with nanometric spatial resolution
- The use of a solid target would allow to explore the low cross section sector in the phase space indicated by recent direct search experiments but using a complementary and powerful approach
- Breakthrough in optical microscope readout technologies
- Current level of neutron background from intrinsic radioactivity allows the design of ~ 10 kg detector
- Prepare a kg scale (pilot) experiment soon (2018) as a demonstrator of the technology and the first spin-independent search of this kind
- Letter of Intent submitted to INFN
NEWS: Nuclear Emulsions for WIMP Search
Letter of Intent
(NEWS Collaboration)

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\textsuperscript{o}LPI-Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
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55 physicists
backup
Directional DM searches

Depending on the unknown WIMP-nucleon cross section, directional detection may be used to: exclude Dark Matter, discover galactic Dark Matter with a high significance or constrain WIMP and halo properties.

**Figure 1.** (Left) WIMP flux for an isothermal spherical halo. (Right) WIMP-induced recoil distribution. Recoils maps are produced for a $^{19}$F target, a 100 GeV·c$^{-2}$ WIMP and considering recoil energies in the range $5$ keV $\leq E_R \leq 50$ keV. Figures extracted from [12].
PRODUCTION PROCESS

Crystal formation

\[ \text{AgNO}_3 + \text{KBr} \rightarrow \text{AgBr} \downarrow + \text{KNO}_3 \]

Control the AgBr crystal size
Temperature, insertion speed
Concentration of chemical, pAg control, rotation speed etc.

wash/salt reduction

Chemical for precipitation
Reduction of other salt

Apply

emulsion

Nuclear Emulsion
Control of dry condition
Temperature, humidity, Thickness etc.

Base film

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PRODUCTION IN NAGOYA

**Emulsion Production**
Addition of AgNO₃ and NaBr
AgNO₃ + NaBr → AgBr + NaNO₃
control of AgBr crystal size, density

**Desalination**
Reduction of Na⁺, NO₃⁻

**Sensitization**
Au+ S sensitization
→ tuning of the sensitivity
(grains/microns at given dE/dx)
Nuclear Emulsion Production

Production time: 4h ~100g/batch ⇒ ~1 kg/week detector production

For dark matter

Mr. Kuwabara
FujiFilm Engineer

35nm crystal
70nm crystal
100nm crystal
200nm crystal

500nm

Natsume et al., NIM A575 (2007) 439
**Ultra-Nano Imaging Tracker**

<table>
<thead>
<tr>
<th></th>
<th>NIT</th>
<th>U-NIT</th>
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<tr>
<td>AgBr density</td>
<td>12 AgBr/µm</td>
<td>29 AgBr/µm</td>
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<table>
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<tr>
<th>Range threshold</th>
<th>Carbon Energy</th>
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<tr>
<td>200 nm</td>
<td>75 keV</td>
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<tr>
<td>100 nm</td>
<td>35 keV</td>
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<tr>
<td>50 nm</td>
<td>15 keV</td>
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Physics Reach

DATA listed top to bottom on plot

NEWS-10Kg-200nm_
DAMA/LIBRA, 2008, with ion channeling, 3sigma, SI
NEWS-25Kg-200nm_
DAMA/LIBRA, 2008, no ion channeling, 3sigma, SI
NEWS-10Kg-100nm_
NEWS-25Kg-100nm_
NEWS-10Kg-50nm_
NEWS-100Kg-100nm_
NEWS-25Kg-50nm_
NEWS-100Kg-50nm_
Expected angular distribution
example with $M = 25$ GeV

- Range $> 150$ nm
Evolution of the scanning speed

Speed in cm²/ hour

- **TS (TTL)**: 0.003, 1983
- **NTS (CPLD)**: 0.082, 1994
- **UTS (FPGA)**: 1, 1998
- **S-UTS (FPGA) 2010 Running**: 72
- **HTS (GPGPU) 2011 Development**: ~2000 m²/year

- **Evolution**:
  - ~20 m²/year
  - ×100 increase

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Scanning with optical microscope and shape recognition analysis

100x objective lens with high N.A.

Bonito CL/CMC-4000 CMOS Camera
4 Mpix, @100 fps

Magnifying lens, Nikon VM C-2.5x

100W Halogen Lamp

Resolution: 28 nm/pixel
View Size: 65.2 x 48.3 µm²

Nikon Oil Objective 100x, 1.45 N.A., Plan Apo

Test using 400 keV Kr ions

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Selection of C Ion Tracks with Shape Analysis

Signal selection:
- Major/minor > 1.25
- width > 190 nm

$\sigma^2 = \sigma^2_{\text{intrinsic}} + \sigma^2_{\text{scattering}}$

$\sigma^2 = 350 \text{ mrad}$

Direction detected!
SELECTION OF C ION TRACKS WITH SHAPE ANALYSIS

Direction detected!

60 keV C ions

Signal selection:
• Major/minor > 1.25
• minor > 170 nm

\[ \sigma^2 = \sigma^2_{\text{intrinsic}} + \sigma^2_{\text{scattering}} \]

\[ \sigma^2 = 360 \text{ mrad} \]
Intrinsic Angular resolution As a By-Product of the Neutron Studies
**NEUTRON TEST BEAM @ FNS (JAPAN)**

Japan Atomic Energy Research Institute

**Emitted neutron energy**

\[
\Theta_n = 38^\circ \quad E_n = 3.12 \text{ MeV}
\]

\[
\Theta_n = 70^\circ \quad E_n = 2.78 \text{ MeV}
\]

\[
D + D \xrightarrow{50\%} ^3He + n(2.45\text{MeV})
\]

\[
E_n = \frac{E_i}{8} \sqrt{2 + \frac{19.6}{E_i(\text{MeV})} + \cos^2 \theta + \cos^2 \phi}
\]
NEUTRON TEST BEAM ANALYSIS

\[ \frac{dE}{dx} \]

\[ E_p = 1.55 \text{ MeV} \]

\[ 10 \mu m \]

\[ 31.3 \mu m \]
0.65 µm

$E_p = 65$ keV
INTRINSIC ANGULAR RESOLUTION

- Neutron test Beam sample (FNS exposure)
- Compare clusters with elliptical ($e > 1.1$) shape with the proton recoil direction
- Scattering contribution negligible

\[ \sigma = 235 \text{ mrad} = 13^\circ \]
2.8 MeV Neutron Energy Measurement

- Measurement of track length and angle
- Proton energy using the energy-range relation (SRIM)
- \( \Rightarrow \) Neutron energy

\[ E_n = \frac{E_p}{\cos^2 \vartheta} \]

Neutron energy:

\[ 2.8 \pm 0.2 \text{MeV} \]

Resolution \( (\sigma/E) = 7\% \)
Imaging Beyond Optical Resolution:
2014 Nobel Prize in Chemistry

Fluorescent molecule


Using fluorescence

Optical resolution ~10 nm
Resonant Light Scattering From Ag Nanoparticles

Nano-metal in medium $\varepsilon_d$  Oscillation of e-cloud

Scattering spectrum depends on the light polarization and on the grain shape

$E_l$ is resonance enhanced

$E_l = \frac{3\varepsilon_d(\lambda)}{\varepsilon_m(\lambda) + 2\varepsilon_d(\lambda)} E_0$

$\varepsilon_m(\lambda_l) + 2\varepsilon_d(\lambda_l) \approx 0$

$E_l$ intensity of inside metal


Ag 100 nm spherical
no polarizing property

Ag 100 nm spheroidal
polarizing property

The polarization dependence of the resonance frequencies strongly reflects the shape anisotropy
Silver Grains Building Up Tracks

TEM image of Carbon track after development

30keV Carbon ion vertical implanted

Surface of emulsion

500nm

Shape different from each other

Optical response strongly depends on the polarization of incident light
TEM image of Carbon track after development

30keV Carbon ion vertical implanted

Surface of emulsion 500nm

Shape different from each other

Optical response strongly depends on the polarization of incident light
Silver Grains Building Up Tracks

TEM image of Carbon track after development

30keV Carbon ion vertical implanted

Surface of emulsion 500nm

Shape different from each other

Optical response strongly depends on the polarization of incident light

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MICROSCOPE UPGRADE

Rotate by 180° with 10° steps
change the direction of polarization and measure the track

Optical system

Xenon-Mercury Lamp

λ~550nm

Band-path filter

Polarizer

mirror

Obj. lens NA1.4

Sample

Camera

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MEASUREMENTS WITH RESONANCE EFFECT

Images with different polarization

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MEASUREMENTS WITH RESONANCE EFFECT

Evaluation of the position accuracy with a single grain

\[ \sum_i X_i/N \]

polarization angle \( i \)

\( i \in \{0, \pi/18, \pi/9, \ldots, \pi\} \)

\((X_i, Y_i)\) cluster position

\[ dX_i = X_i - \sum_i X_i/N \]

\[ dY_i = Y_i - \sum_i Y_i/N \]
**A Track Made Of Two Grains**

\[ e = 1.49 \]

without polarizer

Track validated by elliptical shape analysis

\[
\begin{align*}
\text{Angle of polarization (degree)} & \\
\text{pixel 58nm} & \\
\text{dx} & \bullet \\
\text{dy} & \circ
\end{align*}
\]

\[
\begin{align*}
\text{Linear fit slope} & = \text{track direction} \\
\text{dy (pixel 58nm)} & \\
\text{dx (pixel 58nm)} & \circ
\end{align*}
\]

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A Two-Grains Track

\[ e = 1.27 \]

without polarizer

Discarded by ellipticity cut (1.4)

Position accuracy of a grain

Track length = 90 nm

Track direction
**Single Grain For Accuracy Evaluation**

Ag 60nm

Position accuracy of one grain

Polarization angle (degree)

dx (pixel 58nm)

dy (pixel 58nm)

dx

dy

-1
-0.5
0
0.5
1

1μm

dx

dy

-1
-0.5
0
0.5
1

1μm

dx

dy

-1
-0.5
0
0.5
1

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Unprecedented accuracy of 10 nm achieved on both coordinates

Breakthrough
Target options

1) Wimp’s wind

1 kg: 100, 50 μm thick, NIT films 25 x 25 x 0.5 cm³

2) MIP em.
NIT em.

Muon

3) NIT em
MIP em
Base
MIP em
NIT em

1sc
2dc
3dc
4dc
5sc
Equatorial Telescope

• Mechanics:
  2 motorized axes (Polar and Declination) equipped with precise encoders for position monitoring. (Final precision 1°)

• Surface Calibration
  1. Follow the position of a star in the Cygnus constellation; measure position parameters in order to apply corrections to mechanics and electronic system.
  2. Use throughout the whole day to study systematic effects.

• Underground installation
  Align the mount using existing high precision reference points.

• Materials
  Screening of all the materials used in the telescope is foreseen in order to evaluate their intrinsic radioactivity.
γ background
Electron rejection power

A rejection power $O(10^6)$ is needed:

- Chemical treatment (Tetrazolium-compounds)
- Cryogeny
- Discrimination in the read-out phase
α particles

Sources: 238U, 232Th chains and 222Rn

SRIM simulation

3D track range discrimination

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<th>Daughter</th>
<th>Decay Mode</th>
<th>Energy</th>
<th>Half Life</th>
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<td>234Pa</td>
<td>234U</td>
<td>β</td>
<td>2.20</td>
<td>6.70 hr</td>
</tr>
<tr>
<td>234U</td>
<td>230Th</td>
<td>α</td>
<td>4.86</td>
<td>2.45×10⁸ yr</td>
</tr>
<tr>
<td>230Th</td>
<td>226Ra</td>
<td>α</td>
<td>4.77</td>
<td>7.54×10⁴ yr</td>
</tr>
<tr>
<td>226Ra</td>
<td>222Rn</td>
<td>α</td>
<td>4.87</td>
<td>1.60×10³ yr</td>
</tr>
<tr>
<td>222Rn</td>
<td>218Po</td>
<td>α</td>
<td>5.59</td>
<td>3.82 d</td>
</tr>
<tr>
<td>218Po</td>
<td>214Pb</td>
<td>α</td>
<td>6.12</td>
<td>3.10 min</td>
</tr>
<tr>
<td>214Pb</td>
<td>214Bi</td>
<td>β</td>
<td>1.02</td>
<td>26.8 min</td>
</tr>
<tr>
<td>214Bi</td>
<td>214Po</td>
<td>β</td>
<td>3.27</td>
<td>19.9 min</td>
</tr>
<tr>
<td>214Po</td>
<td>210Pb</td>
<td>β</td>
<td>7.88</td>
<td>0.164 ms</td>
</tr>
<tr>
<td>210Pb</td>
<td>210Bi</td>
<td>β</td>
<td>0.0635</td>
<td>22.3 yr</td>
</tr>
<tr>
<td>210Bi</td>
<td>210Po</td>
<td>β</td>
<td>1.43</td>
<td>5.01 d</td>
</tr>
<tr>
<td>210Po</td>
<td>206Pb</td>
<td>α</td>
<td>5.41</td>
<td>138 d</td>
</tr>
<tr>
<td>206Pb</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Parent</th>
<th>Daughter</th>
<th>Decay Mode</th>
<th>Energy</th>
<th>Half Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>232Th</td>
<td>228Ra</td>
<td>α</td>
<td>4.08</td>
<td>1.41×10¹⁰ yr</td>
</tr>
<tr>
<td>228Ra</td>
<td>228Ac</td>
<td>β</td>
<td>0.0459</td>
<td>5.75 yr</td>
</tr>
<tr>
<td>228Ac</td>
<td>228Th</td>
<td>β</td>
<td>2.12</td>
<td>6.25 hr</td>
</tr>
<tr>
<td>228Th</td>
<td>224Ra</td>
<td>α</td>
<td>5.52</td>
<td>1.91 yr</td>
</tr>
<tr>
<td>224Ra</td>
<td>220Rn</td>
<td>α</td>
<td>5.79</td>
<td>3.63 d</td>
</tr>
<tr>
<td>220Rn</td>
<td>216Po</td>
<td>α</td>
<td>6.40</td>
<td>55.6 s</td>
</tr>
<tr>
<td>216Po</td>
<td>212Pb</td>
<td>α</td>
<td>6.91</td>
<td>0.145 s</td>
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<tr>
<td>212Pb</td>
<td>212Bi</td>
<td>β</td>
<td>0.570</td>
<td>10.6 hr</td>
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<tr>
<td>212Bi</td>
<td>212Po</td>
<td>β</td>
<td>64.06%</td>
<td>2.25</td>
</tr>
<tr>
<td>212Po</td>
<td>208Tl</td>
<td>α</td>
<td>35.94%</td>
<td>6.21</td>
</tr>
<tr>
<td>208Tl</td>
<td>208Pb</td>
<td>β</td>
<td>5.00</td>
<td>3.05 min</td>
</tr>
<tr>
<td>208Pb</td>
<td></td>
<td></td>
<td></td>
<td>stable</td>
</tr>
</tbody>
</table>

Neutron production through (α,n) reactions
Environmental neutron flux

Light materials are effective moderators for fast neutrons: 50 cm of polietilene (PE, C2H4) $\rightarrow$ reduction in the neutron flux of a factor $O(10^4)$

The opportunity to add a thin (1÷2 cm) layer of Cadmium to capture thermalised neutrons is under study.
Intrinsic neutron yield

The intrinsic emulsion radioactivity is responsible of an irreducible neutron yield through \((\alpha, n)\) and 238 U spontaneous fission reaction

Intrinsic radioactive contaminant contribution have been estimated @LNGS using:
1. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Chemistry Service)
2. \(\gamma\)-spectrometry with Ge detector @ STELLA Facility (SubTErranean Low Level Assay)

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Contamination ([10^{-9} \text{ g g}^{-1}])</th>
<th>Activity ([\text{mBq kg}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AgBr-I</td>
<td></td>
</tr>
<tr>
<td>(^{232}\text{Th})</td>
<td>1.0</td>
<td>4.1</td>
</tr>
<tr>
<td>(^{238}\text{U})</td>
<td>1.5</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>Gelatin</td>
<td></td>
</tr>
<tr>
<td>(^{232}\text{Th})</td>
<td>2.7</td>
<td>11.0</td>
</tr>
<tr>
<td>(^{238}\text{U})</td>
<td>3.9</td>
<td>48.1</td>
</tr>
<tr>
<td></td>
<td>PVA</td>
<td></td>
</tr>
<tr>
<td>(^{232}\text{Th})</td>
<td>&lt; 0.5</td>
<td>&lt; 2.0</td>
</tr>
<tr>
<td>(^{238}\text{U})</td>
<td>&lt; 0.7</td>
<td>&lt; 8.6</td>
</tr>
</tbody>
</table>

1) ICP-MS:
238U: 23±7 mBq/kg
232Th: 5.1±1.5 mBq/kg

Table 4: Results obtained by ICP-MS in terms of contamination and activity for the different constituents of the nuclear emulsion. The estimated uncertainty is 30%. The upper limits on PVA are evaluated at 95% CL.
Intrinsic neutron yield

<table>
<thead>
<tr>
<th>Process</th>
<th>SOURCES simulation [kg(^{-1}) y(^{-1})]</th>
<th>Semi-analytical calculation [kg(^{-1}) y(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>((\alpha, n)) from (^{232})Th chain</td>
<td>0.12</td>
<td>0.10±0.03</td>
</tr>
<tr>
<td>((\alpha, n)) from (^{238})U chain</td>
<td>0.27</td>
<td>0.26±0.08</td>
</tr>
<tr>
<td>Spontaneous fission</td>
<td>0.79</td>
<td>0.8±0.3</td>
</tr>
<tr>
<td>Total flux</td>
<td>1.18</td>
<td>1.2±0.4</td>
</tr>
</tbody>
</table>

F. Pupilli et al., *Intrinsic neutron background of nuclear emulsions for directional Dark Matter searches*, to be submitted to Astrophysical Journal

![Graph showing neutron yield vs. energy](image-url)
Intrinsic neutron yield

GEANT4 simulation:
20.4% of neutrons interact producing nuclear (56%), proton (44%) and $\alpha$ (0.2%) recoils

Figure 2: Track length (left) and energy spectrum (right) for proton recoils produced by elastic (blue curve) and inelastic (red curve) processes.

Figure 3: Track length (left) and energy spectrum (right) for heavy (blue curve) and light (red curve) nuclei.
Intrinsic neutron yield

- 5%÷10% of the intrinsic neutron flux contributes to the background
- A further reduction of 70% can be achieved exploiting the directionality information (-1 < Φ < 1)

\[ \Rightarrow 0.02 \div 0.03 \text{ n/year/Kg} \]

Table 6: Fraction of detectable neutron-induced recoils as a function of the read-out threshold.

<table>
<thead>
<tr>
<th>Threshold [nm]</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.100</td>
</tr>
<tr>
<td>100</td>
<td>0.075</td>
</tr>
<tr>
<td>150</td>
<td>0.060</td>
</tr>
<tr>
<td>200</td>
<td>0.052</td>
</tr>
</tbody>
</table>