# Directional detection of DM with a nuclear emulsion based detector (NEWSdm)

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on behalf of the NEWSdm Collaboration

XIII$^{th}$ Rencontres du Vietnam
Neutrinos 2017
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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**
- Nagoya University
- Chiba University

**Russia**
- LPIRAS Moscow
- JINR Dubna
- SINP MSU Moscow
- INR Moscow
- Yandex School of Data Analysis

**S. Korea**
- Gyeongsang

**Turkey**
- METU

LNGS-LOI 48/15

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

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Submitted to Gran Sasso Scientific Committee at the end of 2015

http://news-dm.lngs.infn.it/

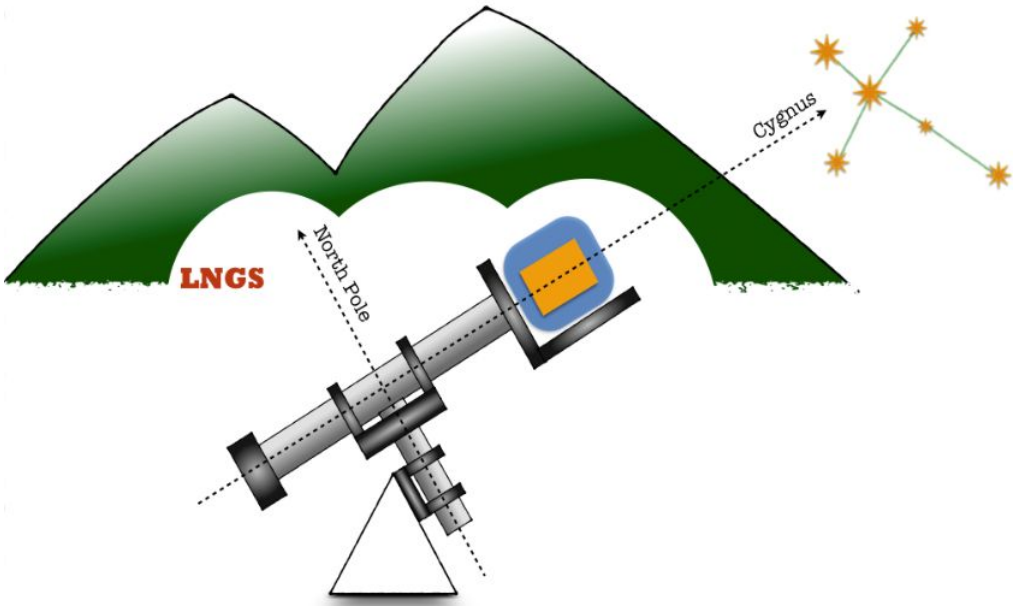
https://arxiv.org/pdf/1604.04199.pdf

# Outline

- The NEWSdm idea:

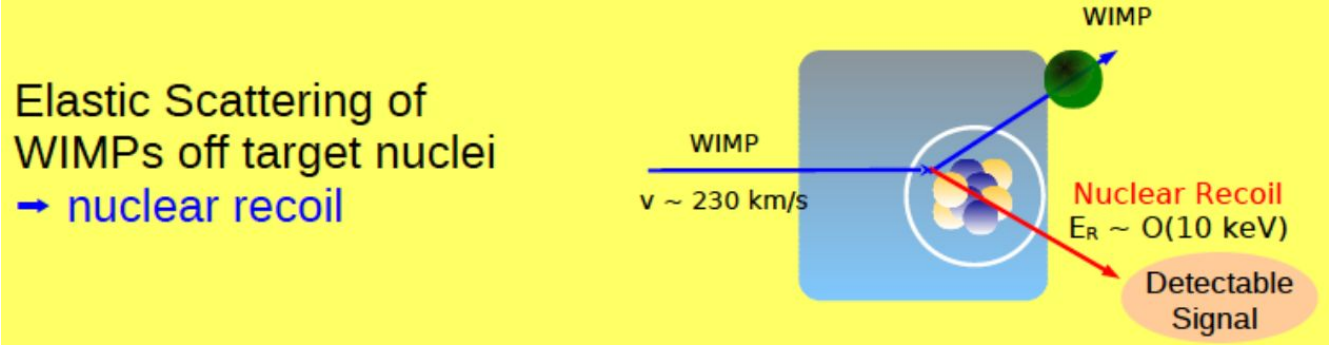
  a novel approach to **directional** detection of Dark Matter

- High Resolution Nuclear Emulsion: NIT
- Detection principle
- Sensitivity
- Current Status of the experiment
- Conclusions and perspectives



# Experimental challenges

**WIMPs:** extremely small scattering rate, small energy of the recoil nucleus, and subtle signatures…

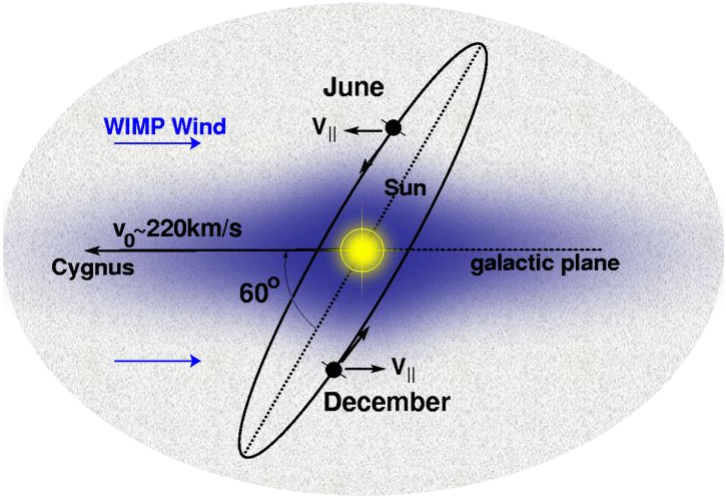



**Requirements:**

- Low (keV) energy threshold
- Large target mass
- Suppression of background from radioactivity and cosmic rays (α,β,γ, neutrinos)
  - Deep sites
  - Passive/Active shielding
- Discrimination of the residual background
  - Use WIMPs signatures:
    - Nuclear recoils
    - Absence of multiple scattering
    - Annual modulation
    - **Directionality**

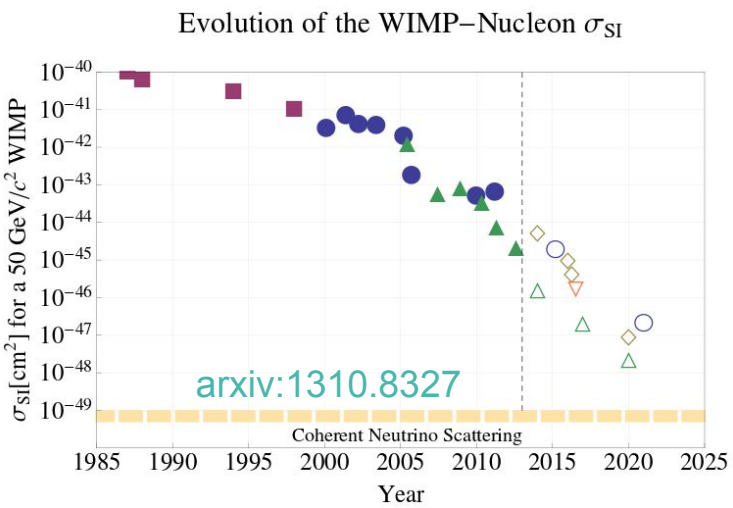
# Power of directionality

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

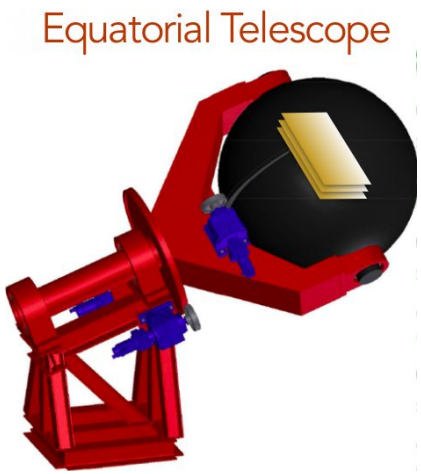


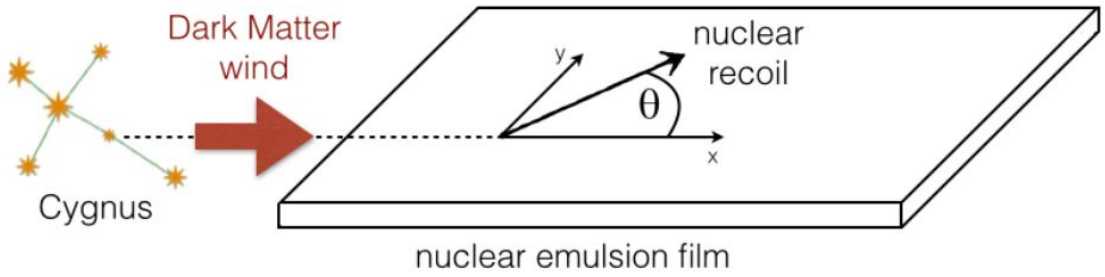

- Unambiguous proof of the galactic origin of DM

- Unique possibility to overcome the "neutrino floor" where coherent neutrino scattering creates an irreducible background



# The NEWSdm principle



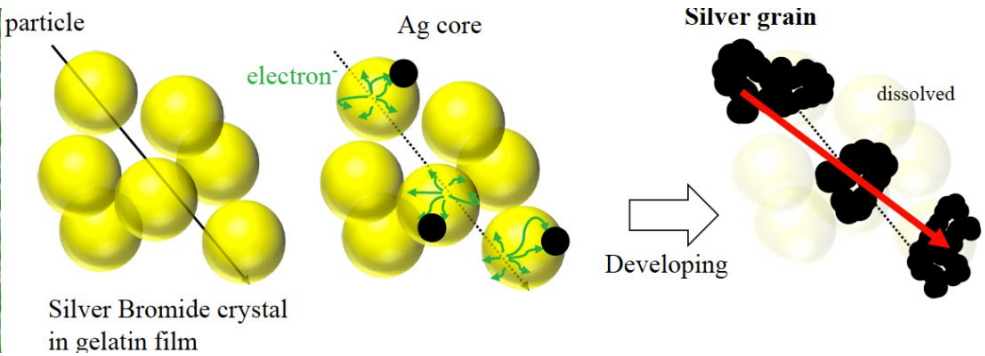

**Aim:** Detect the direction of the **nuclear recoils** produced in WIMPs interactions

**Target:** nanometric nuclear emulsions acting both as target and tracking detector

**Background reduction:** location in Underground Gran Sasso Laboratory and neutron **shield** surrounding the target

**Fixed pointing:** target mounted on **equatorial telescope** constantly pointing to the Cygnus Constellation

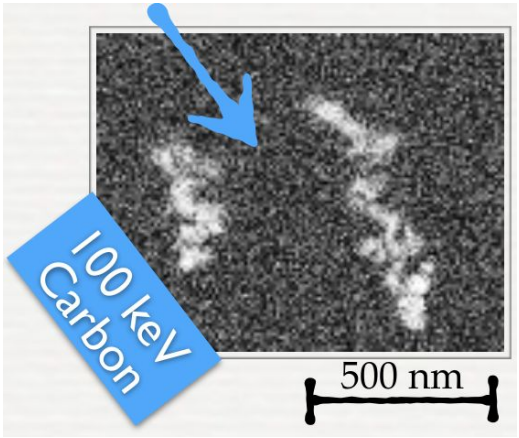
# NIT: Nano Imaging Tracker

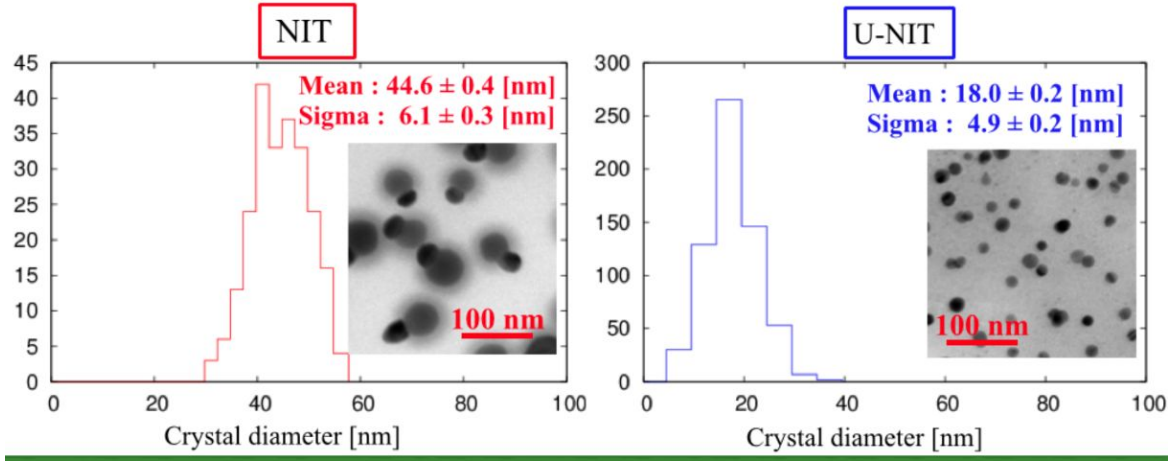



Emulsion is used in particle physics since Pion discovery (1947), and the recent result is $\nu_\mu \rightarrow \nu_\tau$ oscillation discovery in appearance mode (OPERA, 2015)

- Nuclear emulsions: ArBr 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



# NIT: Nano Imaging Tracker

| Constituent | Mass Fraction |
|---|---|
| AgBr-I | 0.78 |
| Gelatin | 0.17 |
| PVA | 0.05 |

**Lighter nuclei gives longer range at the same recoil energy**

↓

**Sensitivity to low WIMP mass**

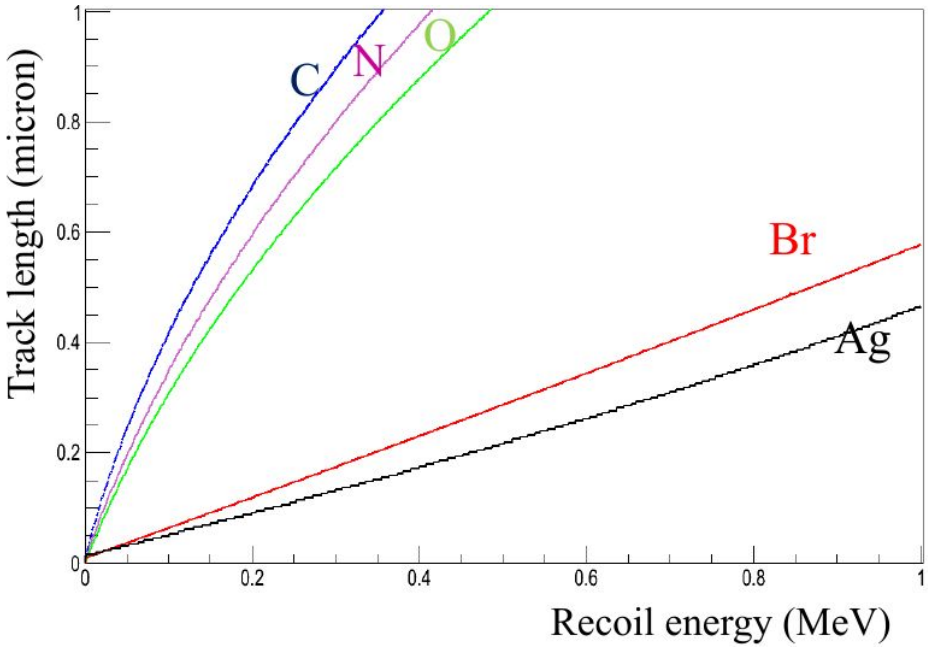
| Element | Mass Fraction | Atomic Fraction |
|---|---|---|
| Ag | 0.44 | 0.10 |
| Br | 0.32 | 0.10 |
| I | 0.019 | 0.004 |
| C | 0.101 | 0.214 |
| O | 0.074 | 0.118 |
| N | 0.027 | 0.049 |
| H | 0.016 | 0.410 |
| S | 0.003 | 0.003 |

**ArBr-I:** sensitive element

**Organic gelatine:** retailing structure

**PVA** to stabilise the crystal growth

Each nucleus gives a different contribution to the overall sensitivity



# Track identification

**Challenge:** detect tracks with lengths comparable/shorter than optical resolution

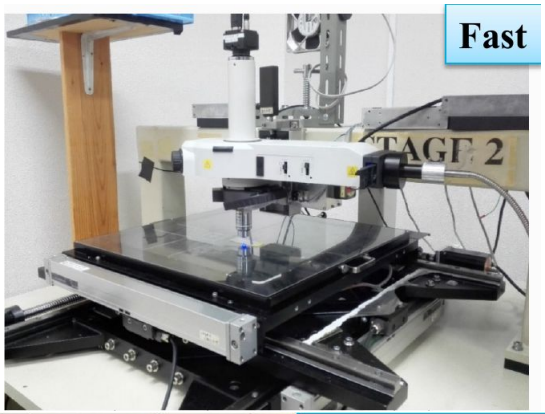
**Strategy:** two-step approach

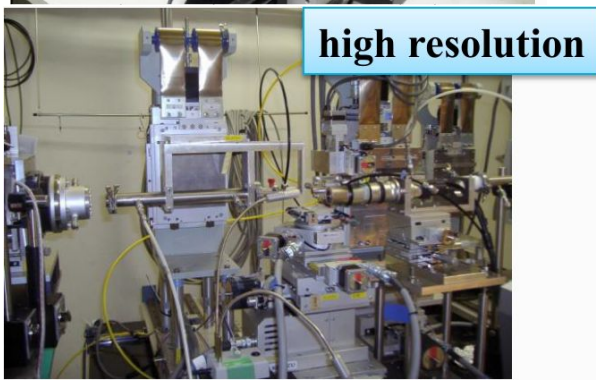
**Step 1: Fast pre-selection** of the candidate signal tracks

- Optical microscope

**Step 2: Signal Confirmation**: event by event scanning with higher resolution optics

- X-ray microscopes
- Optical microscope with polarized light



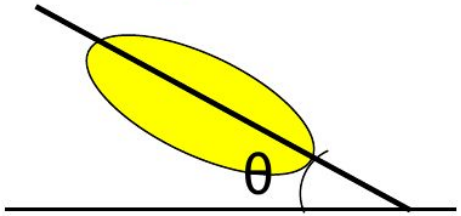



# Readout strategy

## **Step 1:** candidate identification

- Scanning with **optical microscopes** and **shape recognition analysis**
- Automatic selection of candidates signals by optical microscopy
- Selection of clusters with elliptical shape: major axis along track direction
- Background: single grain of spherical shape
- 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



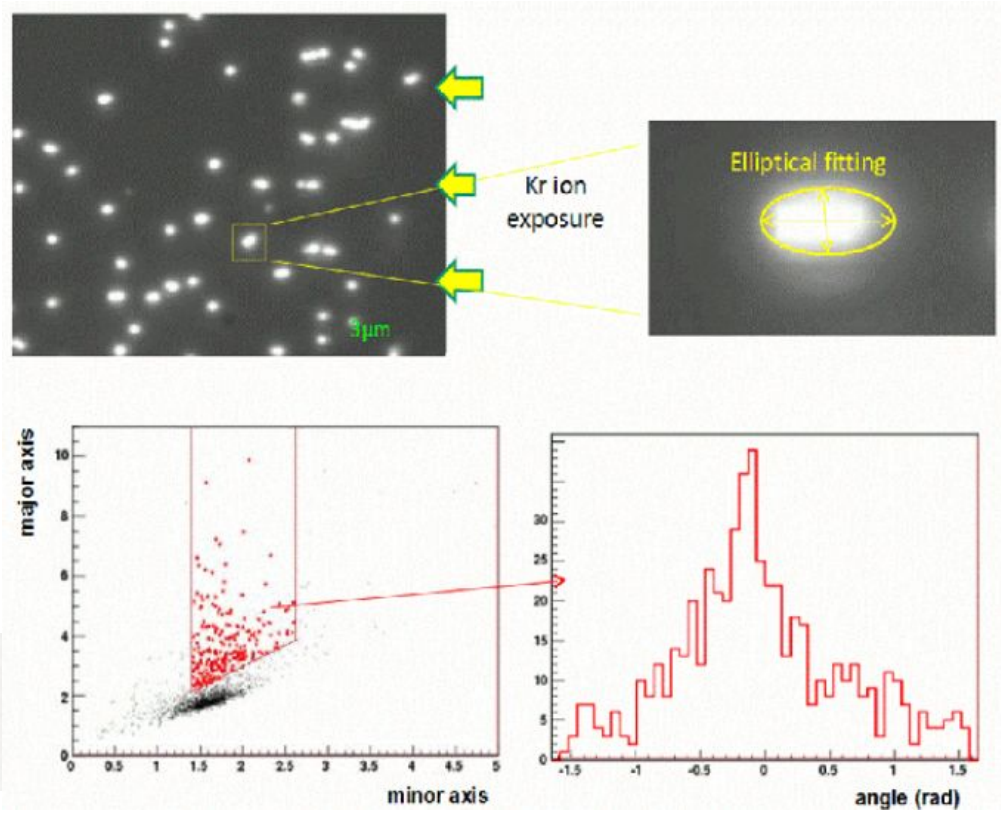

Direction detected!

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

OVERALL ANGULAR RESOLUTION

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

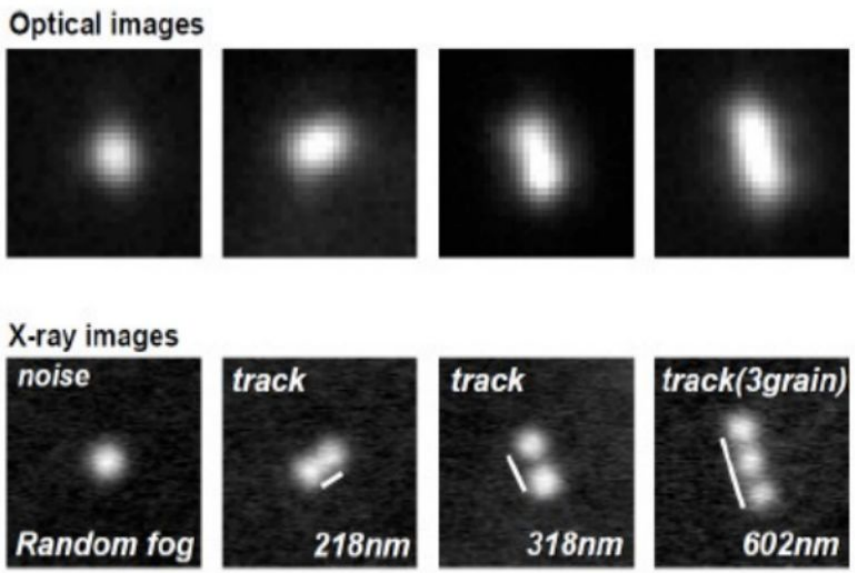
$$\sigma = 360 \text{ mrad}$$



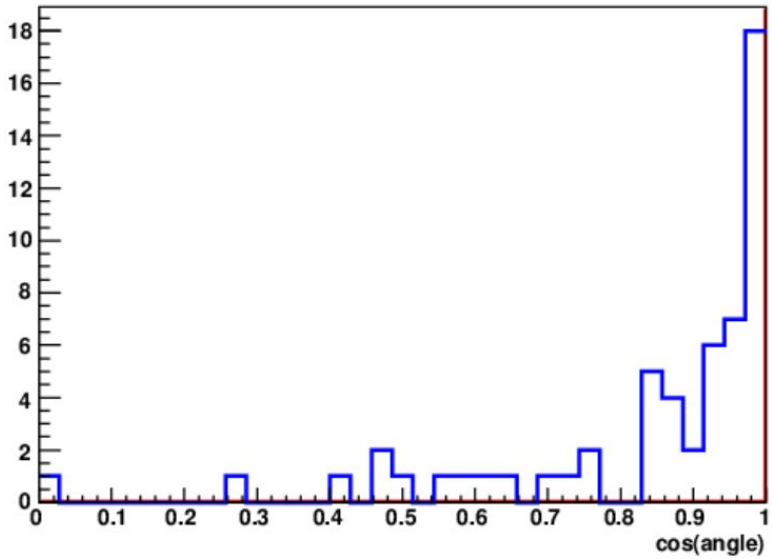
# Readout strategy

## **Step 2:** candidate validation

- Scanning with X-ray microscope of preselected zones
- Pin-point check at X-ray microscope of candidate signals selected by optical readout
- Resolution ~30 nm



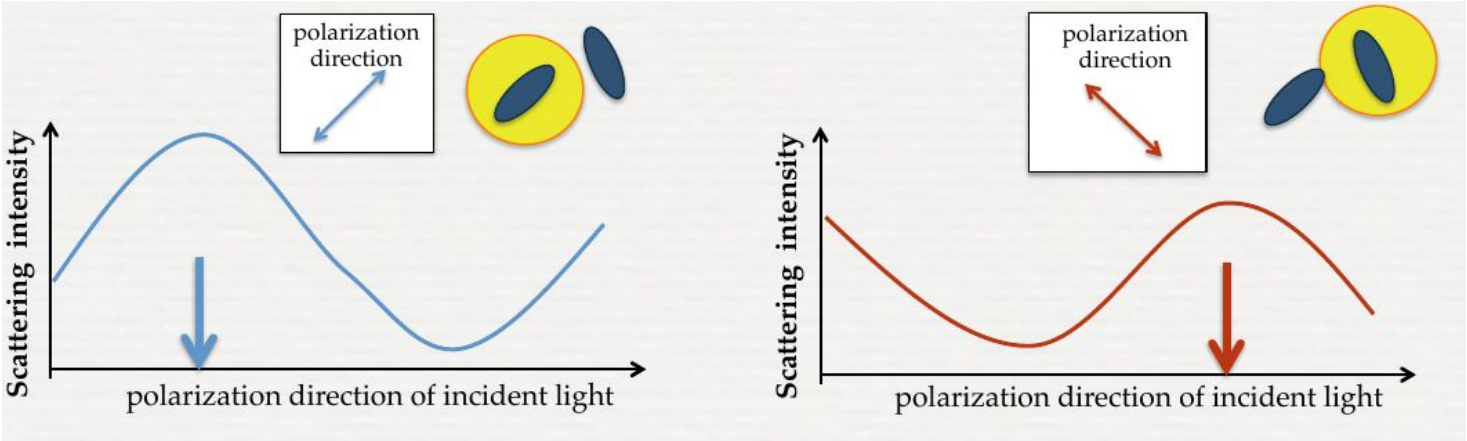

Matching efficiency 99% (572/579)




- Slow analysis speed
  - the analysis of few hundred μm$^2$ takes about 100 s
- Need of external X-ray guns

# Readout strategy: resonant light scattering

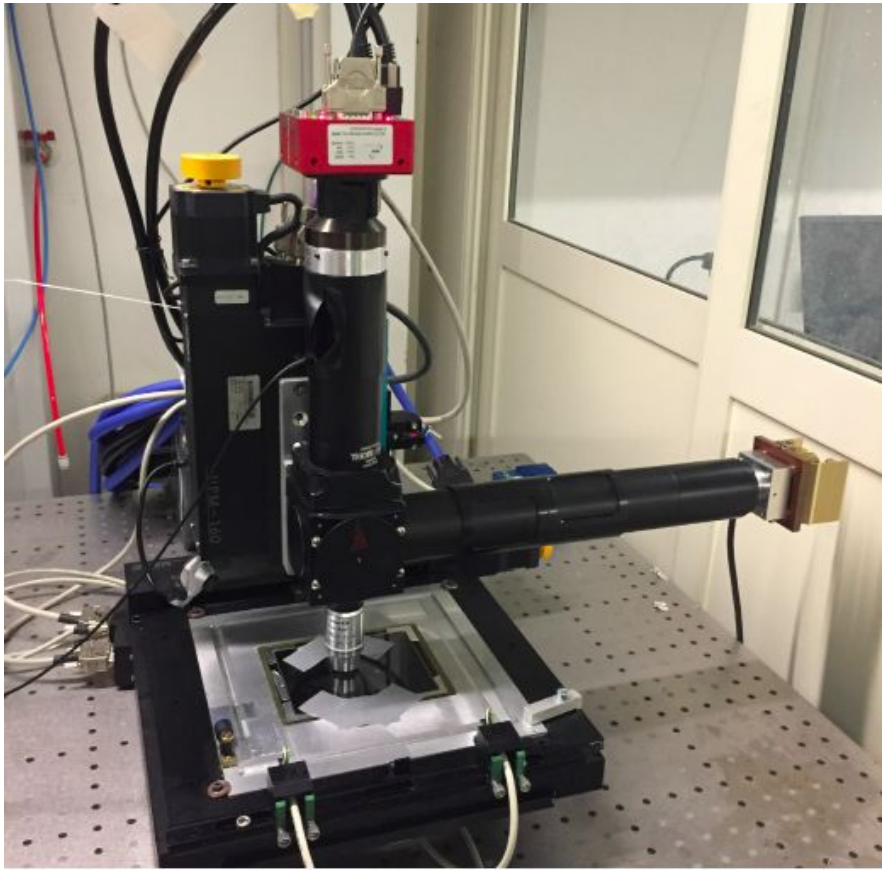
- Occurring when the light scattering off a nanometric metallic (silver) grains are dispersed in a dielectric medium (Applied Phys Letters 80 (2002) 1826)
- Sensitive to the shape of nanometric grains: when silver grains are not spherical, the resonant response depends on the polarization of the incident light
- Each grain is emphasized at different polarization value

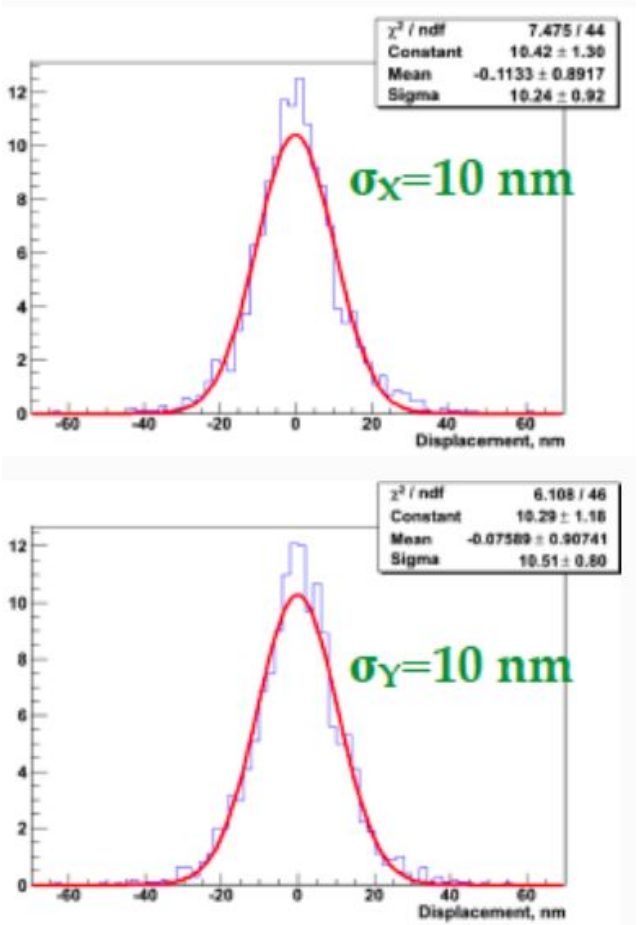



- Taking multiple measurement over the whole polarization range produces a displacement of the barycenter of the cluster

# Readout strategy: resonant light scattering

Optical microscope assembled






**Breakthrough**

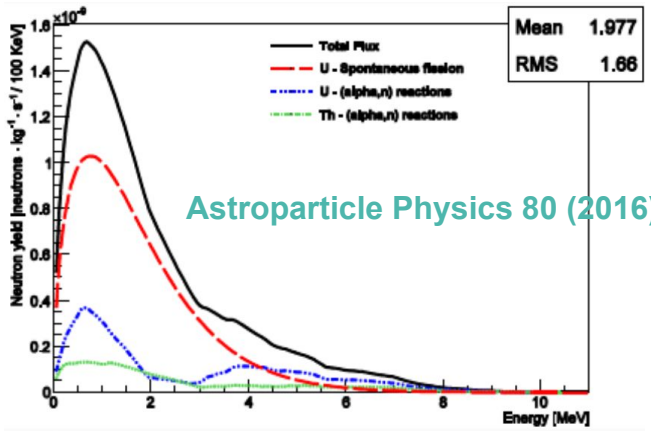
Unprecedented accuracy of **10 nm** achieved on both coordinates

# Sensitivity: background study

Two main background categories have to be taken into account:

- The environmental or external background
  - Can be significantly reduced by placing the detector underground, and designed an appropriate shield against the nature radioactivity
- The intrinsic one
  - Is an irreducible source of radiation: it is therefore crucial to control the radioactivity of the materials used for the construction of both the detector and the structure of the apparatus

| 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 |



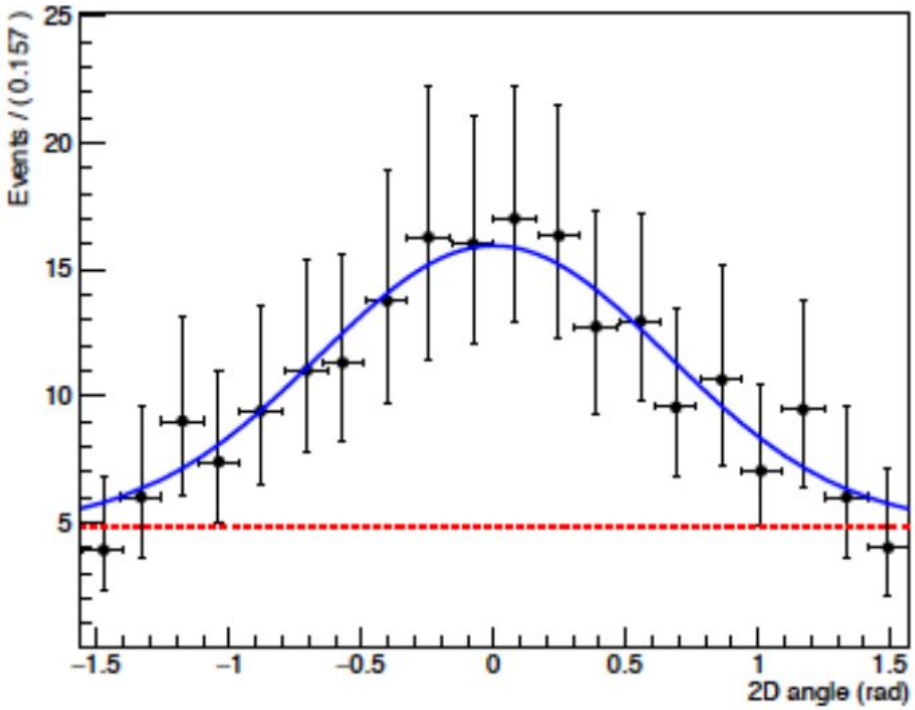

Astroparticle Physics 80 (2016) 16-21

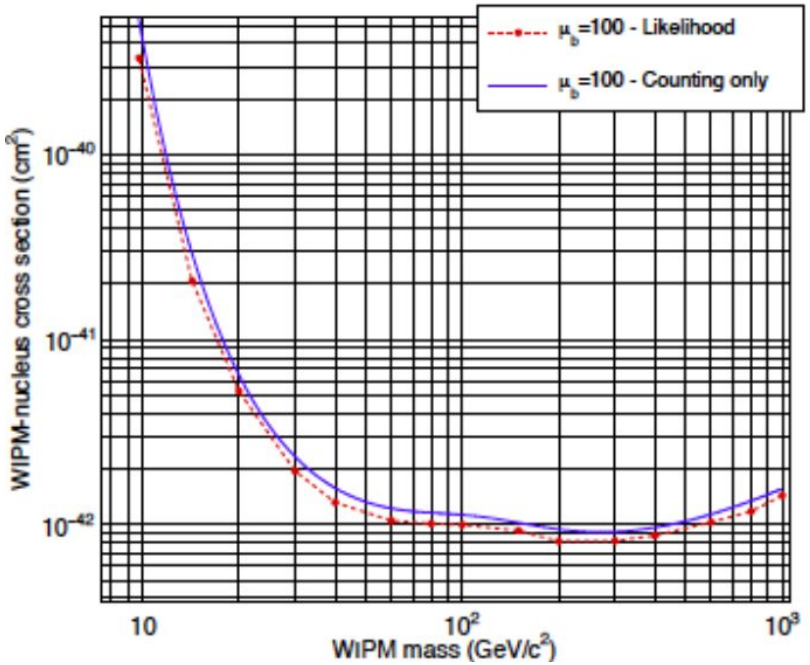
BG yield from the intrinsic radioactive contamination of NIT: ~1.2 n/kg year
Neutron BG from intrinsic radioactivity negligible upto ~10 kg year

# Sensitivity: exploit directionality

- Evaluation of upper limit and sensitivity based on the profile likelihood ratio test

- Mass = 10 kg
- Exposure time = 10 years
- $N_{background}$ = 100
- Threshold = 100 nm

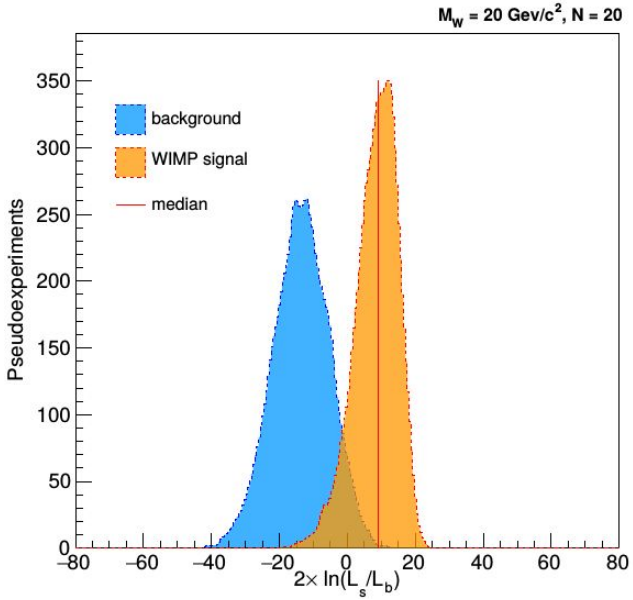


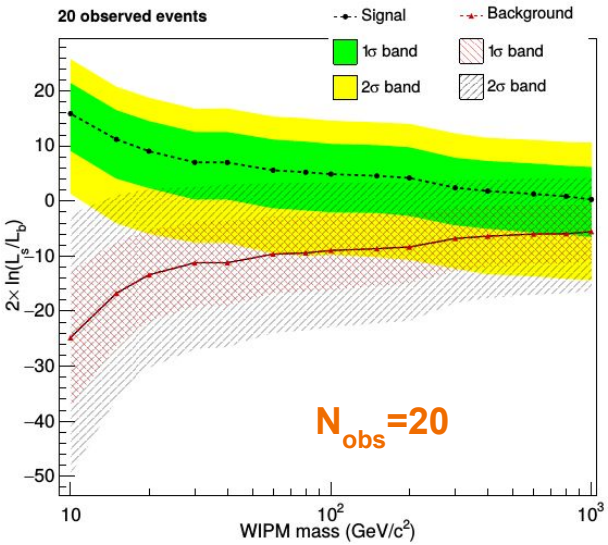



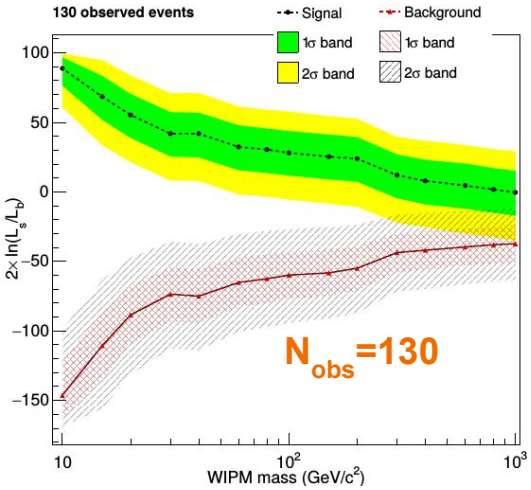

2D angular distribution of 100
WIMPs-induced recoils and 100 BG events

# Sensitivity: WIMPs signal identification

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



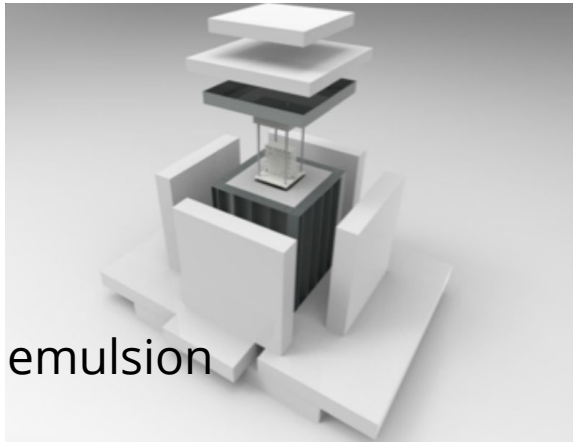




- 20 events are required to prove that data are not compatible with background at 3σ CL for $M_W$<20 GeV/c$^2$
- 130 events gives 3σ CLin the whole WIMP mass range

# Current status of the experiment

**Technical test is ongoing**

- **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 **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 emulsion
  - Polyethylene slabs 40 cm-thick **absorb environmental and cosmogenic neutrons**
  - Lead brick 10 cm-thick - **absorb environmental photons**

# Current status of the experiment


Installed in underground Gran Sasso INFN Laboratories in March 2017

# Conclusions

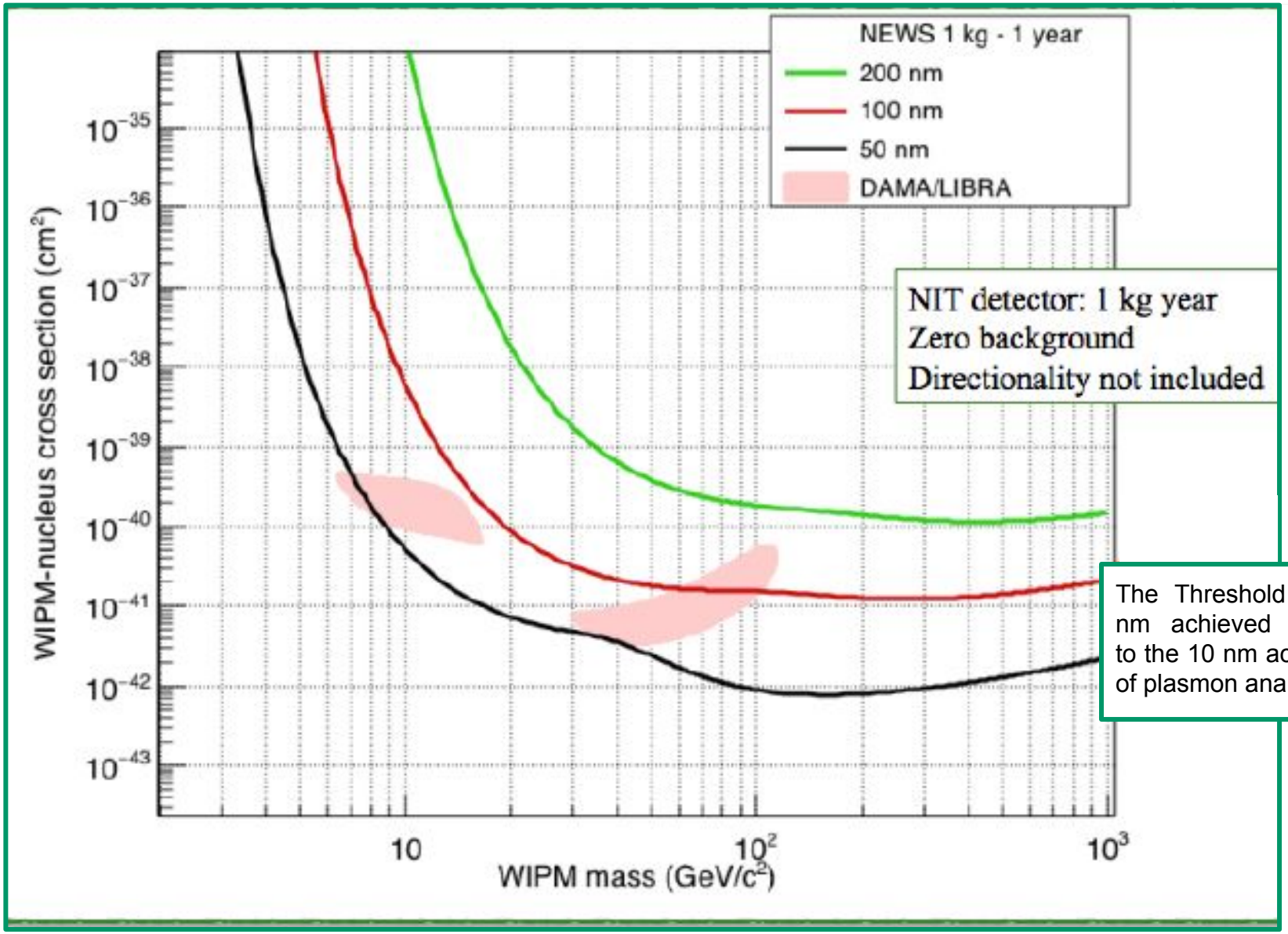
- A novel approach for **directional Dark Matter searches** is proposed in NEWSdm
- Use of fine-grained **nuclear emulsion** as target and tracking system
- Breakthrough in readout technologies allows to go beyond optical resolution
- **R&D phase (2016-2018) funded in view of the pilot experiment**
- **Prepare a kg scale (pilot) experiment as a demonstrator of the technology and the first spin-independent search of this kind**
- **TDR in preparation**

# Thank you for your attention!


Part of NEWSdm Collaboration when test started in LNGS

# Backup slides

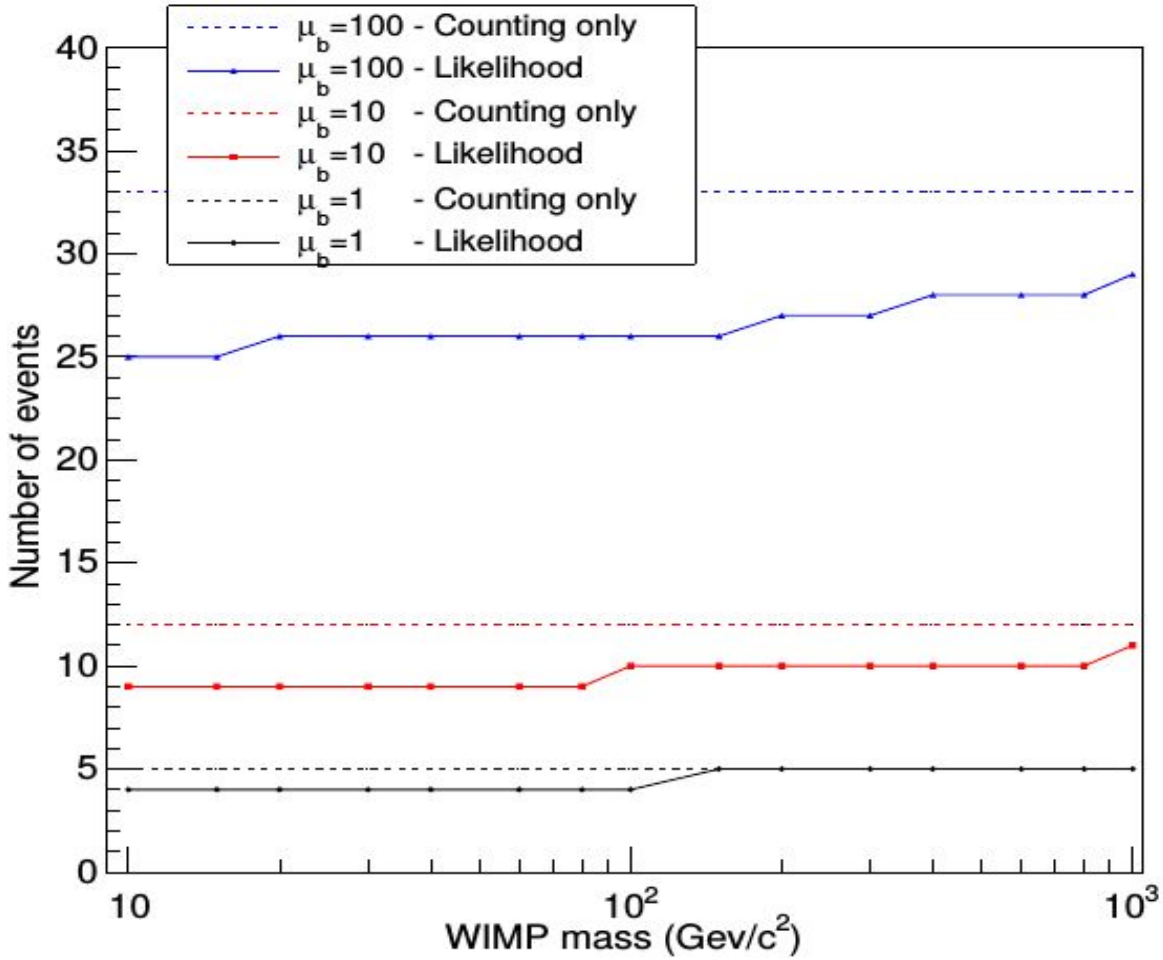
# Physics goal




The Threshold of 50 nm achieved thanks to the 10 nm accuracy of plasmon analysis

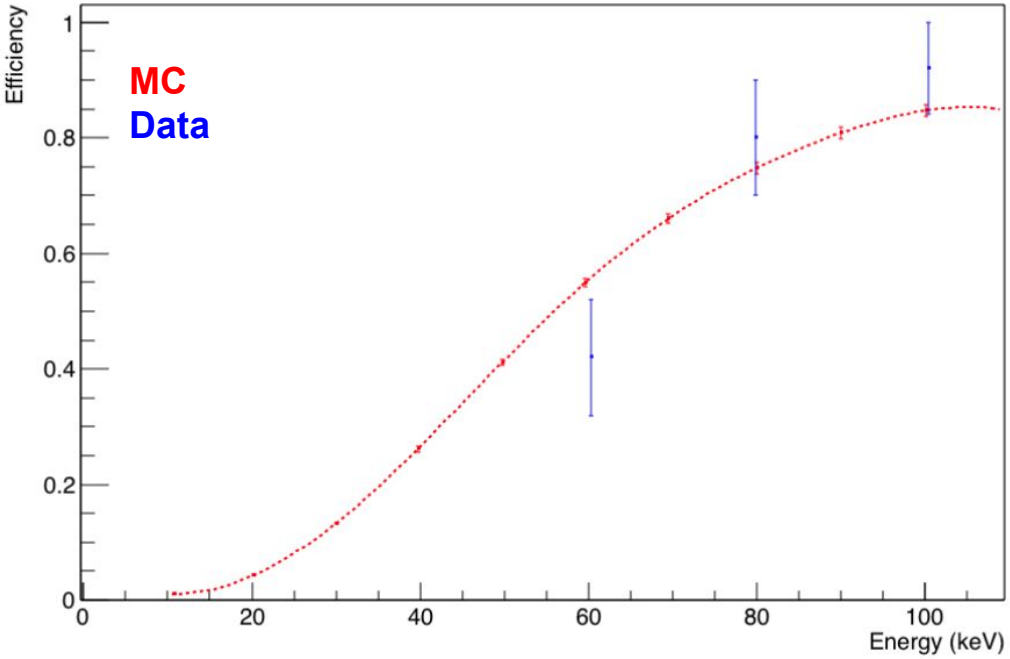
# Sensitivity

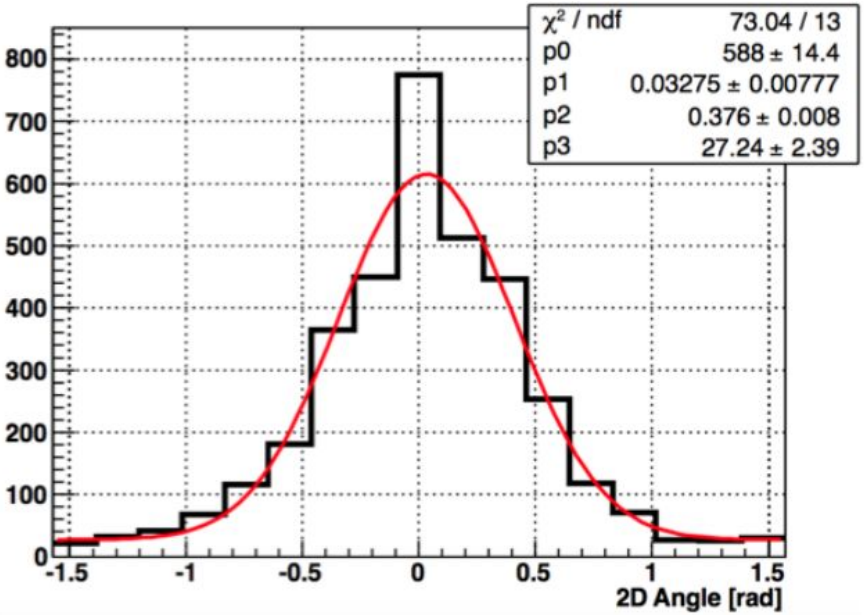
Minimum number of signal events required to get a 3σ evidence as a function of the WIMP mass (arXiv: 1705.00613)



# Efficiency and angular resolution

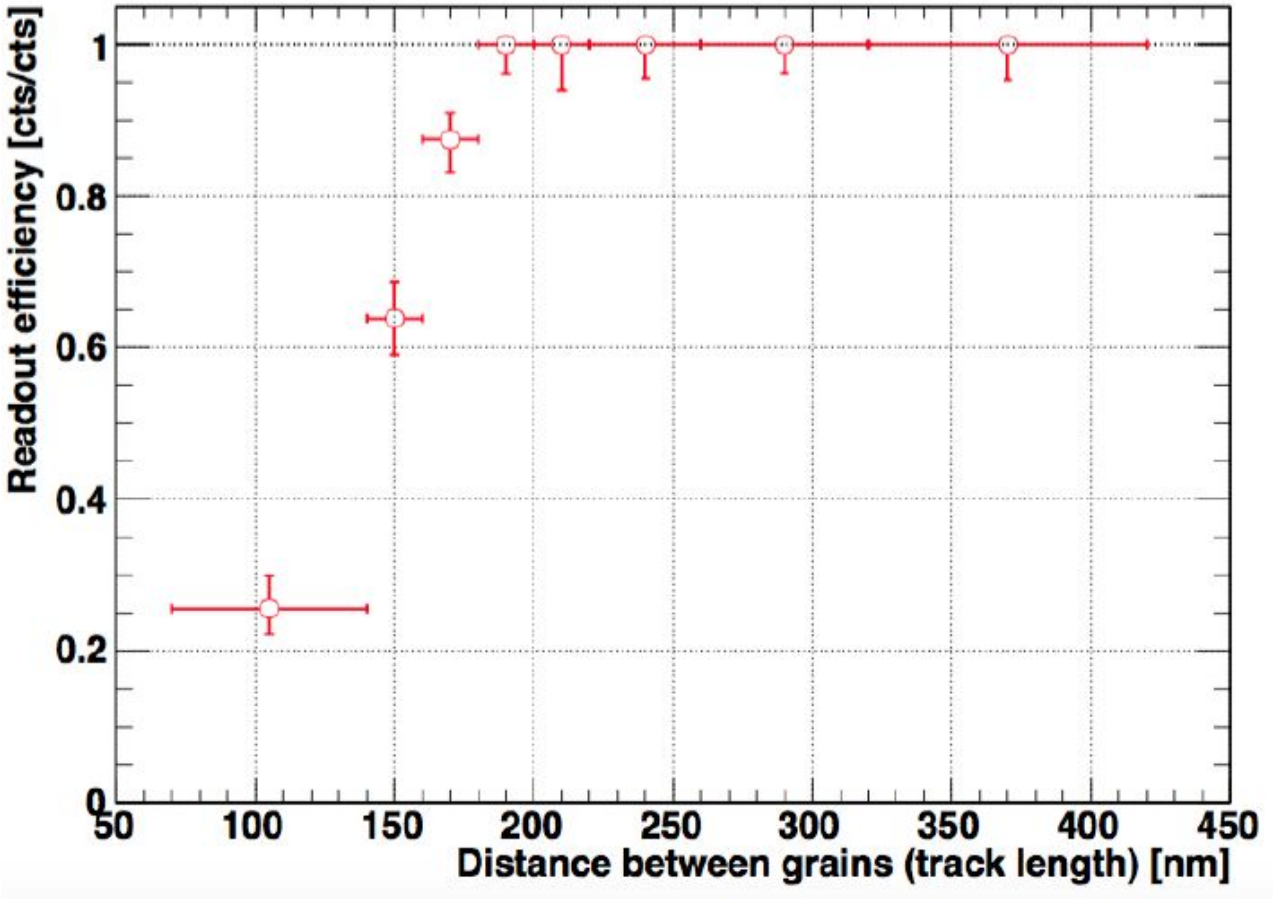
- Low energy 60-100 keV carbon exposure test using NIT-40
- Ellipticity cut >1.25
- 80% tracking efficiency at 80 keV
- 340 mrad (20 degree) angular resolution at 80 keV



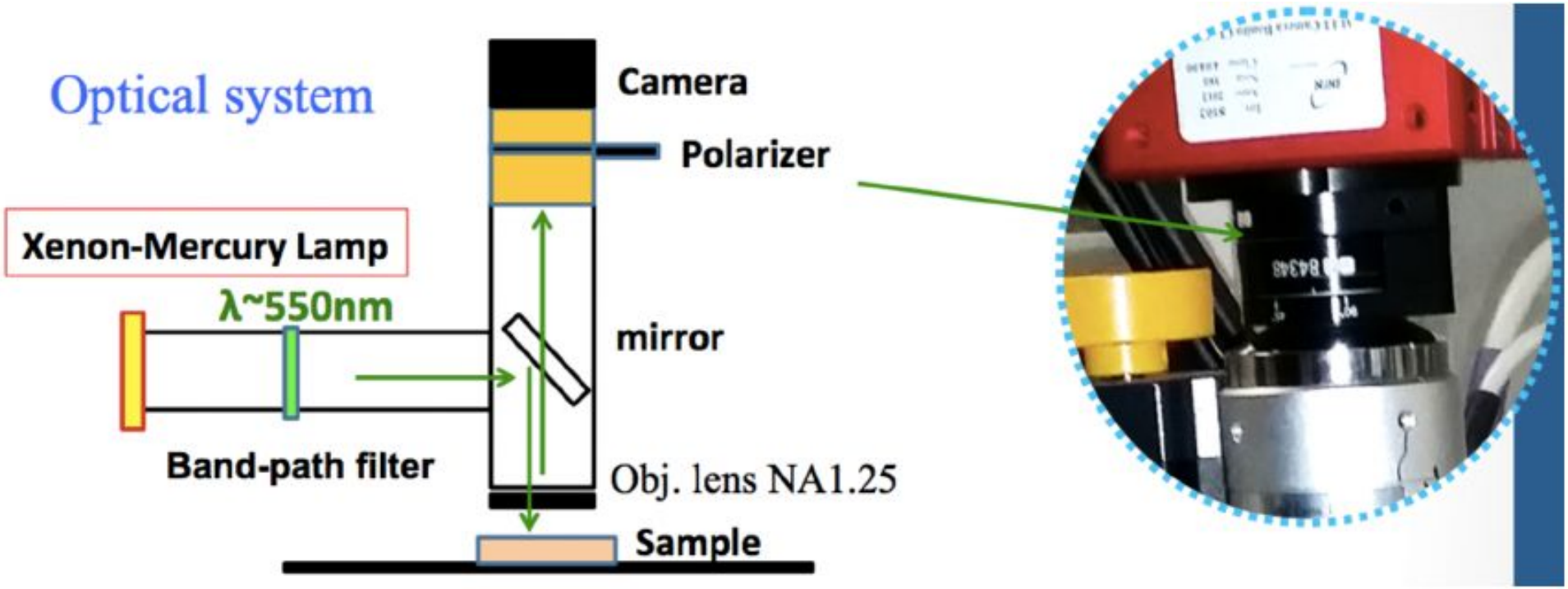



# Efficiency

Efficiency of the elliptical fit analysis versus the track length when an ellipticity of 1.25 is used as a threshold

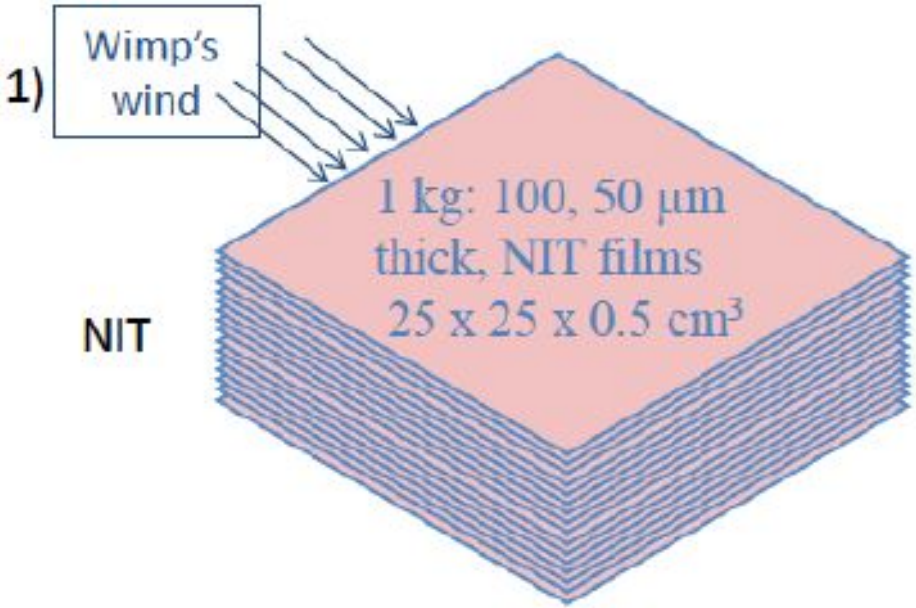


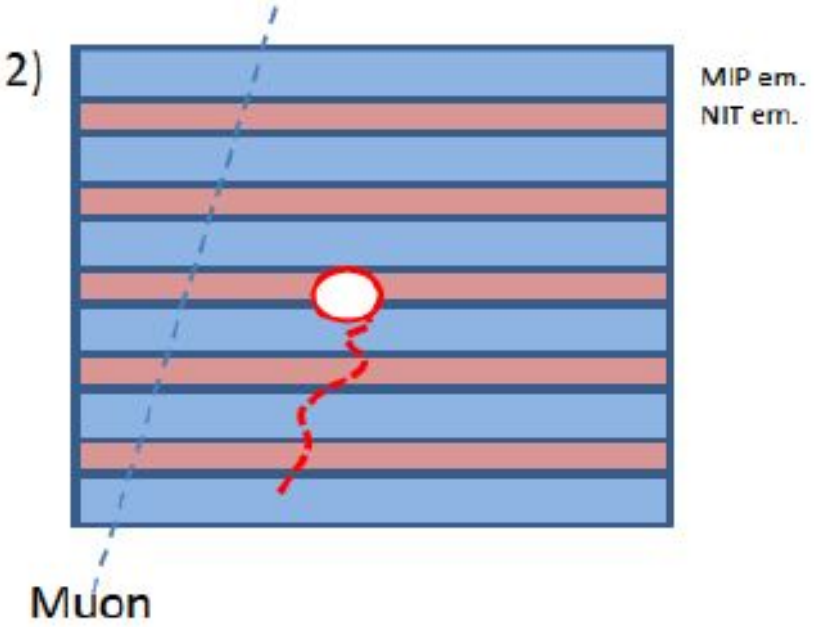
# Resonant light scattering

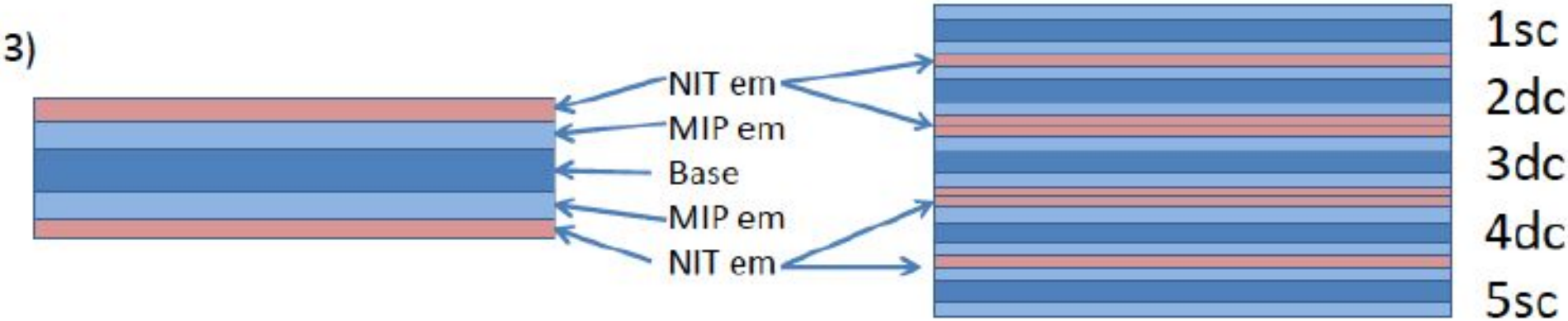



Optical microscopes have been equipped with a polarization filter. The polarization direction can be changed by rotating the polarizer. The rotation is at the moment done by hand while it's automation is being designed.

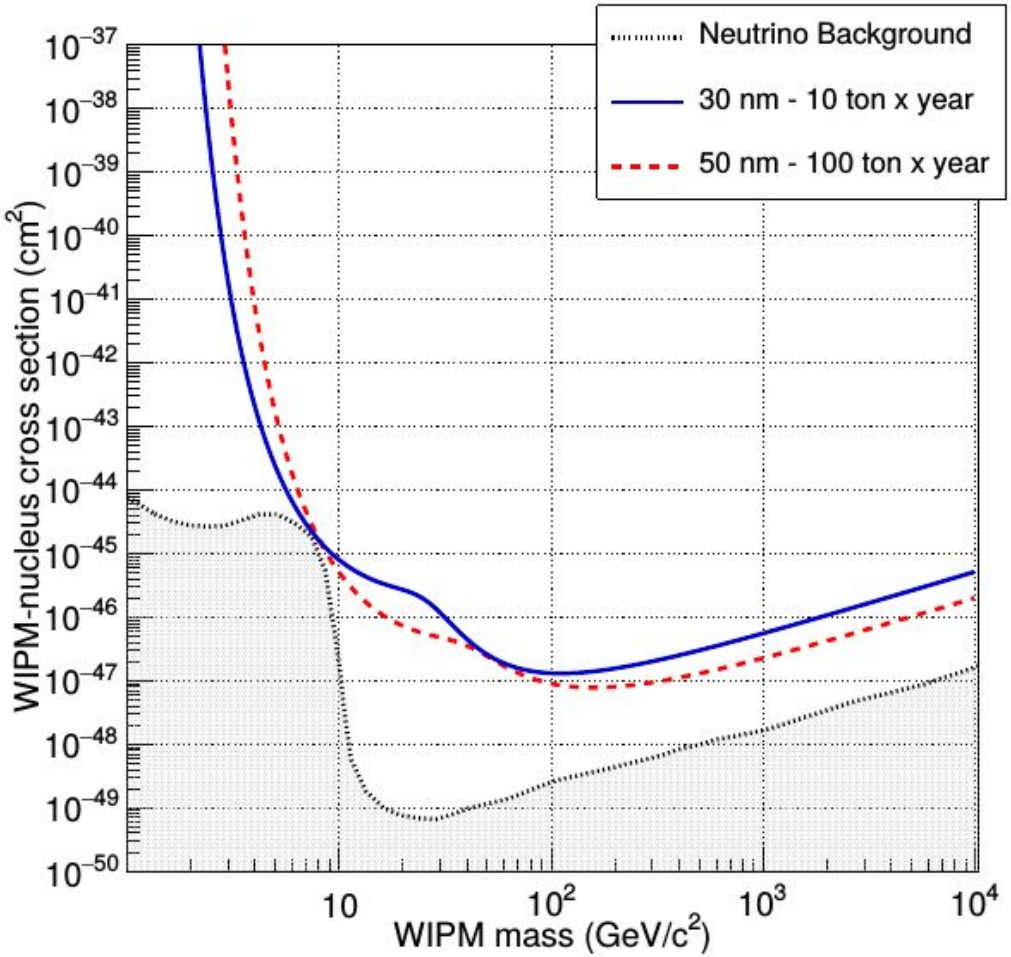
# Target design



# Neutrino Floor




The neutrino bound is reached by NEWSdm with:

10 ton * year with 30 nm threshold

100 ton * year with 50 nm threshold

# NEWSdm time schedule