NUCLEAR EMULSIONS FOR WIMP SEARCH
directional measurement

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Laboratori Nazionali del Gran Sasso - INFN

on behalf of the NEWSdm Collaboration

LETTER OF INTENT

- Submitted to Gran Sasso Scientific Committee at the end of 2015

LNGS-LOI 48/15

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

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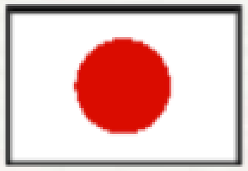
https://arxiv.org/pdf/1604.04199.pdf

NEWSdm Collaboration
60 physicists, 14 institutes

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



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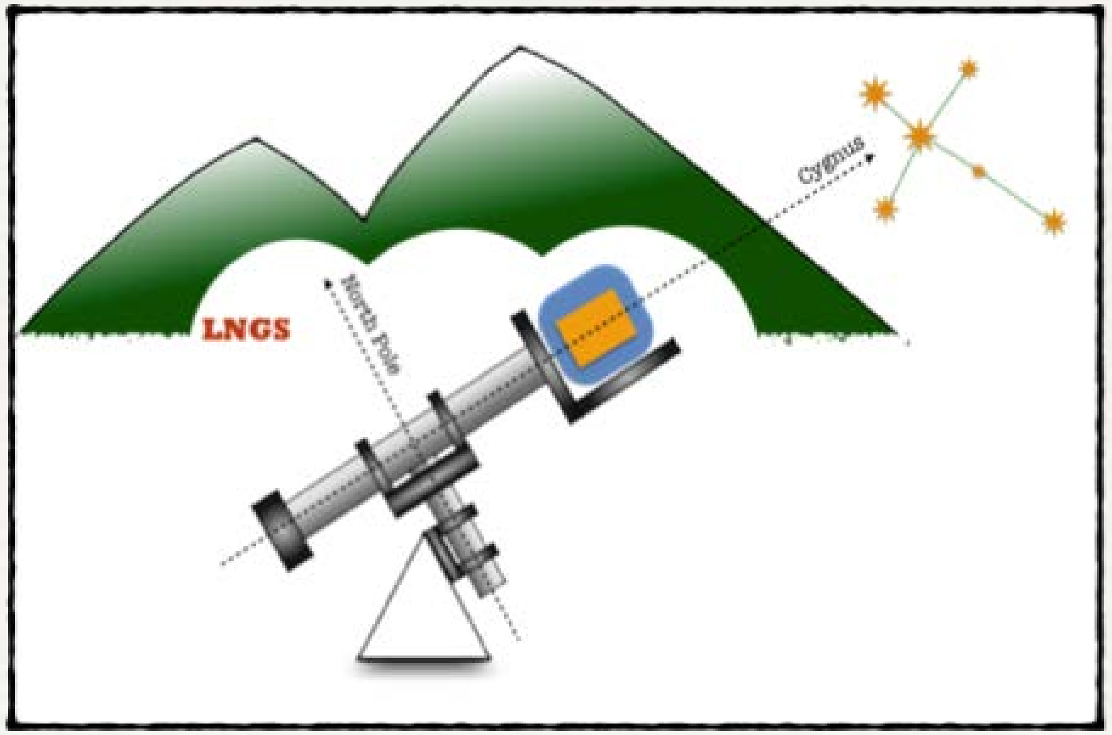
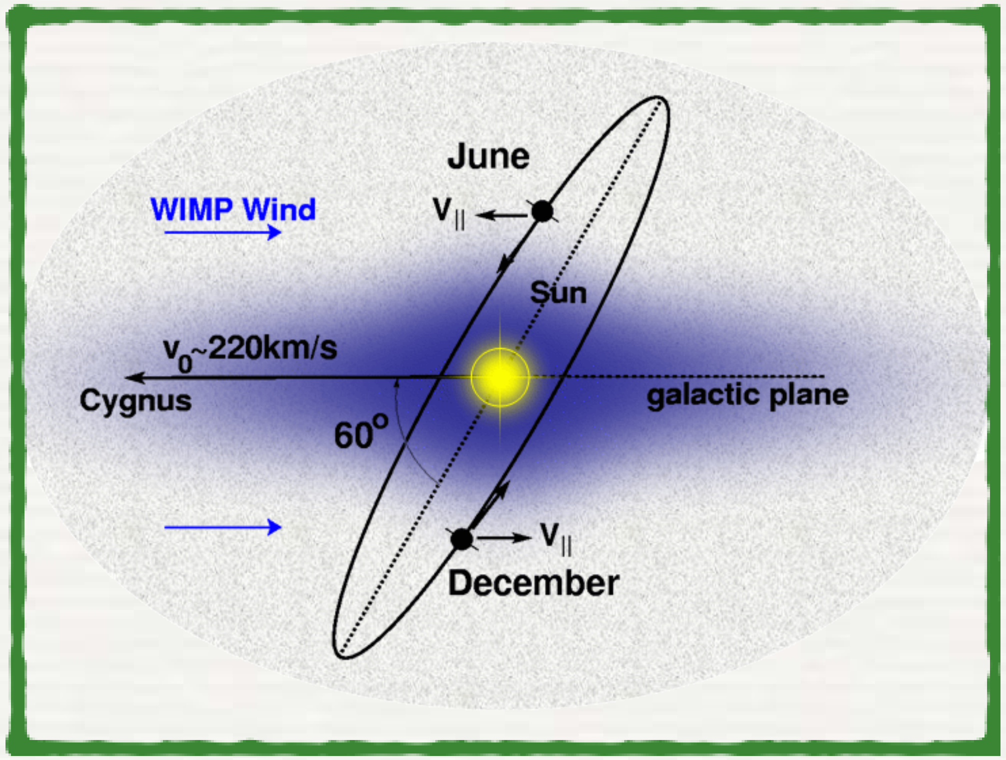
OUTLINE

- The NEWSdm idea:
  a novel approach to ***directional*** detection of Dark Matter
- High Resolution Nuclear Emulsions: NIT
- Detection principle
- Background studies andSensitivity
- Current status of the experiment
- Conclusions



POWER OF DIRECTIONALITY

- Direction of DM particle is (preferentially) opposite to the motion (velocity) of the Sun (… and Earth) in the Galaxy.



- The motion of the Earth trough the galaxy creates an apparent wind of Dark Matter particles. Correcting for Earth's rotation around its axis, this wind shows a rather narrow angular distribution.

- Directional measurement would provide a strong signature and unambiguous proof of the galactic origin of Dark Matter

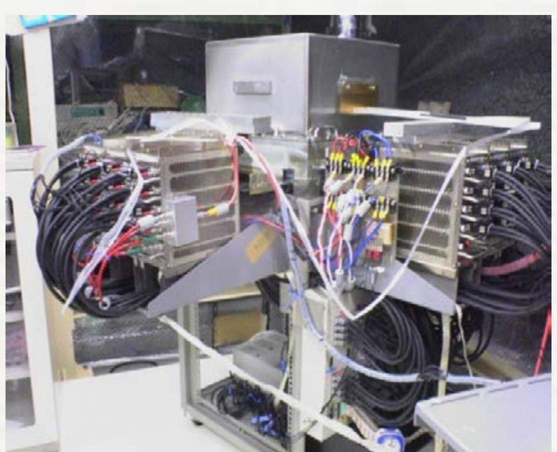
DIRECTIONAL DARK MATTER SEARCHES

Current approach:

low pressure gaseous detectors

- Targets: CF4, CF4+CS2, CF4 + CHF3
- **Recoil track lengths … order of the millimeter**
- **Small achievable detector mass due to the low gas density**

⇒Sensitivity limited to spin-dependent interaction



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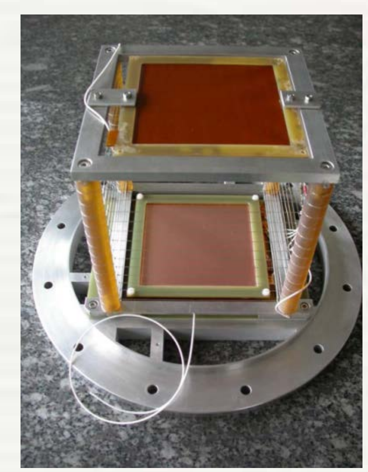
DM-TPC@ USA

DRIFT @ UK



MIMAC@ France

DIRECTIONAL APPROACH: NEWSdm

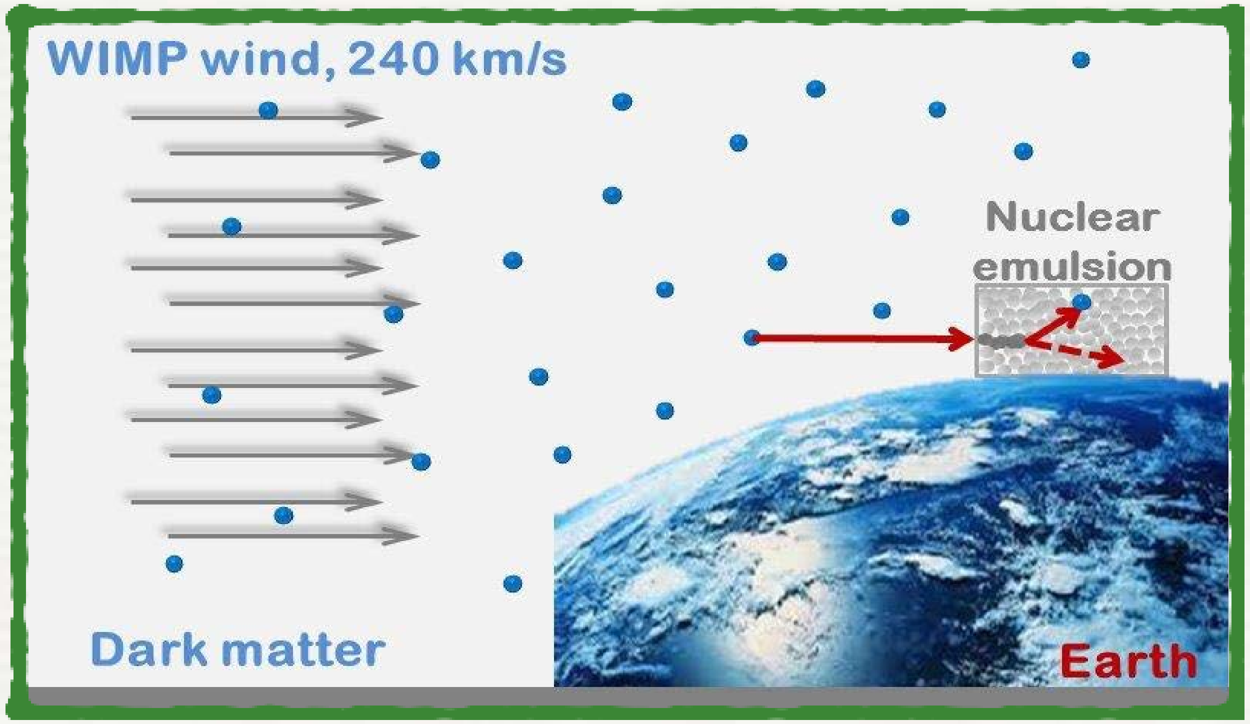
Use solid target:

- Large detector mass
- Smaller recoil track length … order of a few hundred nanometer

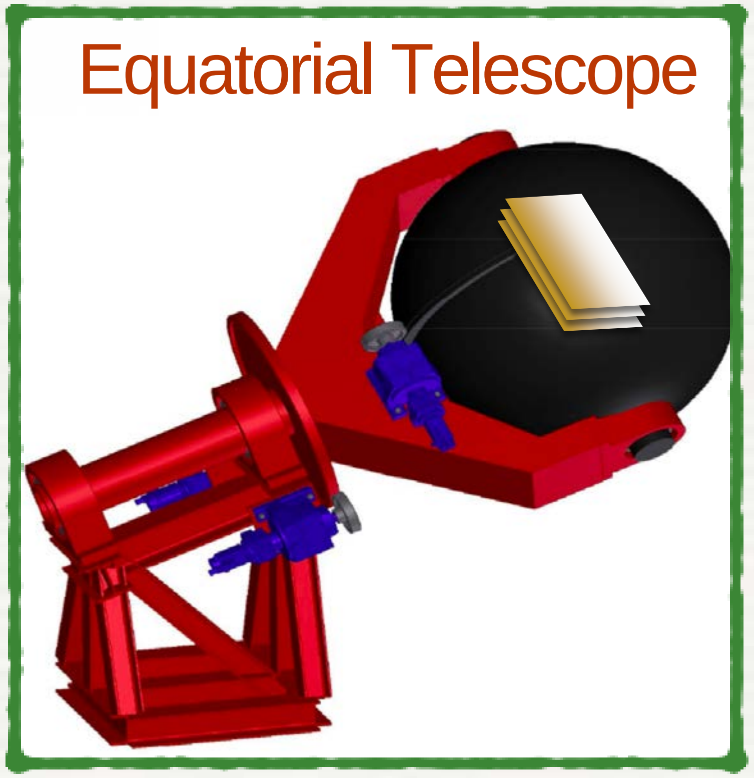
very high resolution tracking detector needed

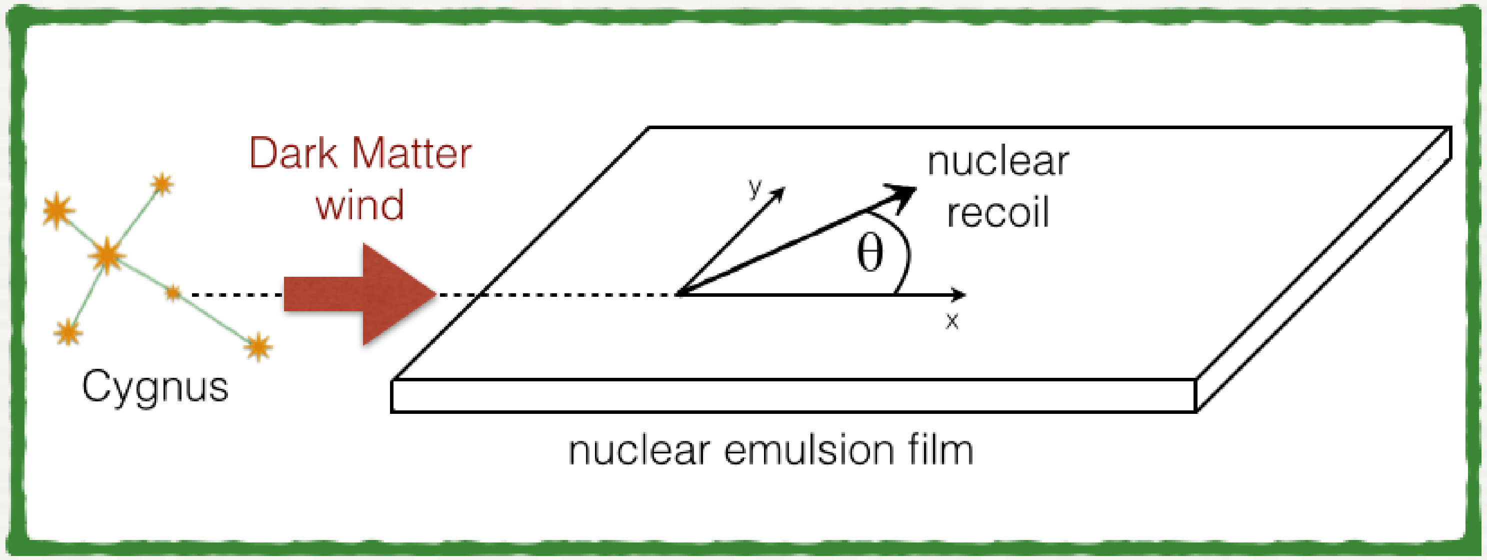
NEWSdm Idea →

Nuclear Emulsion based detector acting both as target and tracking device



THE NEWSdm PRINCIPLE



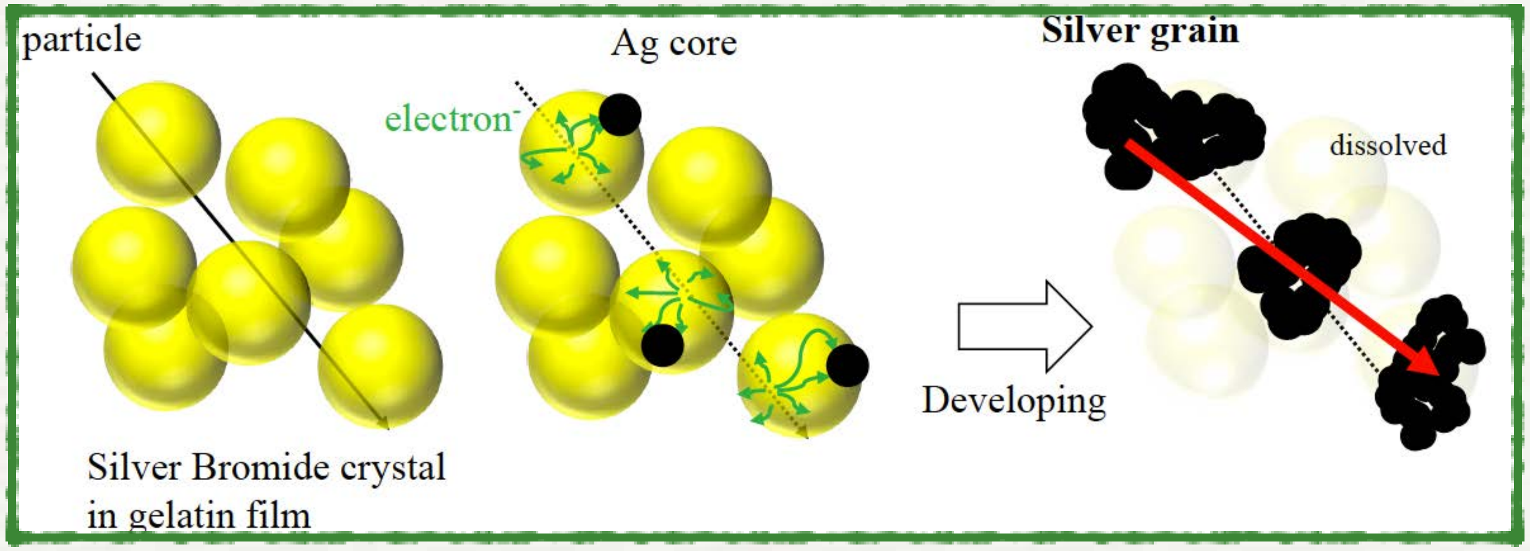


- **Aim:** detect the **direction** of **nuclear recoils** produced in WIMP interactions
- **Target:** nanometric nuclear emulsions (acting both as target and tracking detector)
- **Background reduction:** neutron **shied** surrounding the target
- **Fixed pointing:** target mounted on **equatorial telescope** constantly pointing to the Cygnus Constellation, where the WIMP wind is supposed to come, compensating Earth's rotation.
- **Location:** Underground at Gran Sasso Laboratory

HIGH RESOLUTION NUCLEAR EMULSION

NIT: NANO EMULSION IMAGING TRACKERS

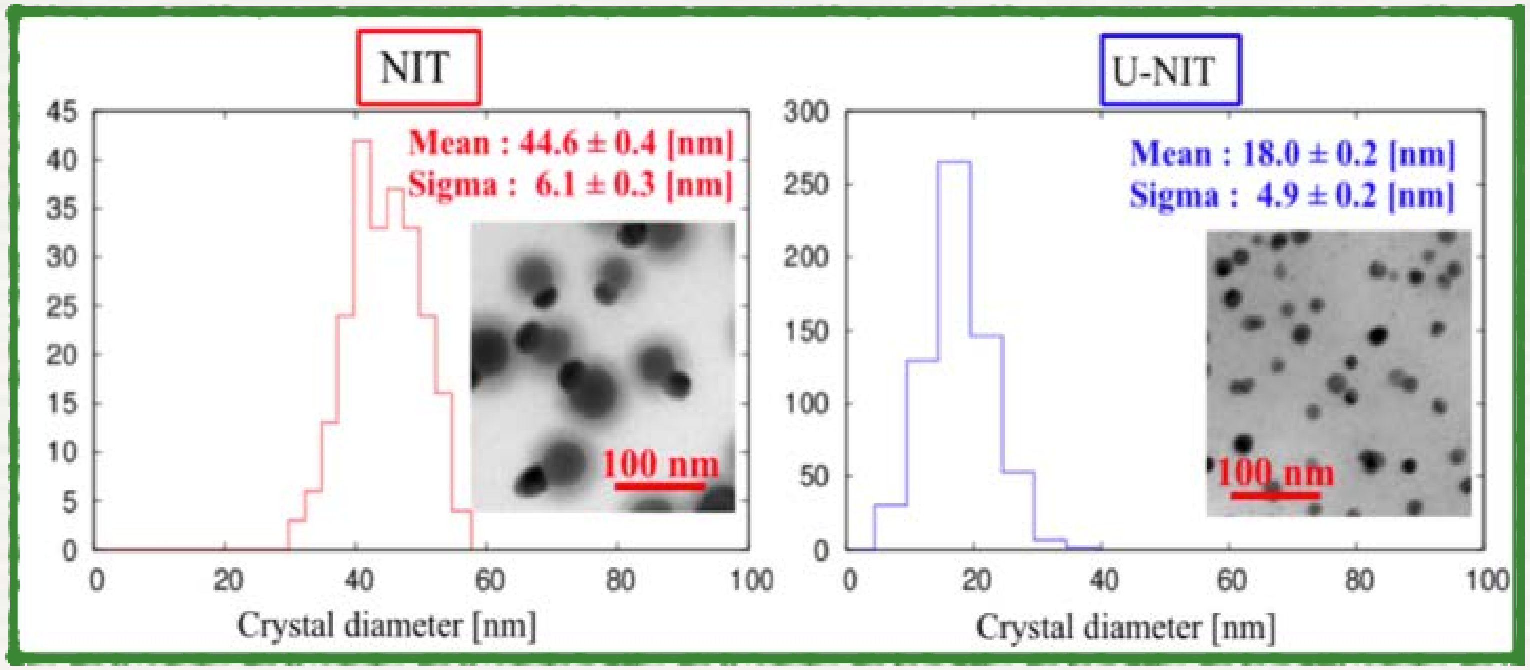
- New kind of emulsion were developed for DM search
- Smaller crystal size



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 gelatin
- Passage of charged particle produce *latent image*
- Chemical treatment makes Ag grains visible

- Last developments have produced



Reconstruction of trajectories with path lenght shorter than 100 nm is possible

NIT EMULSIONS

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

(a) Constituents of nuclear emulsion

AgBr-I: sensitive elements
Organic gelatin: retaining structure
PVA to stabilize the crystal growth

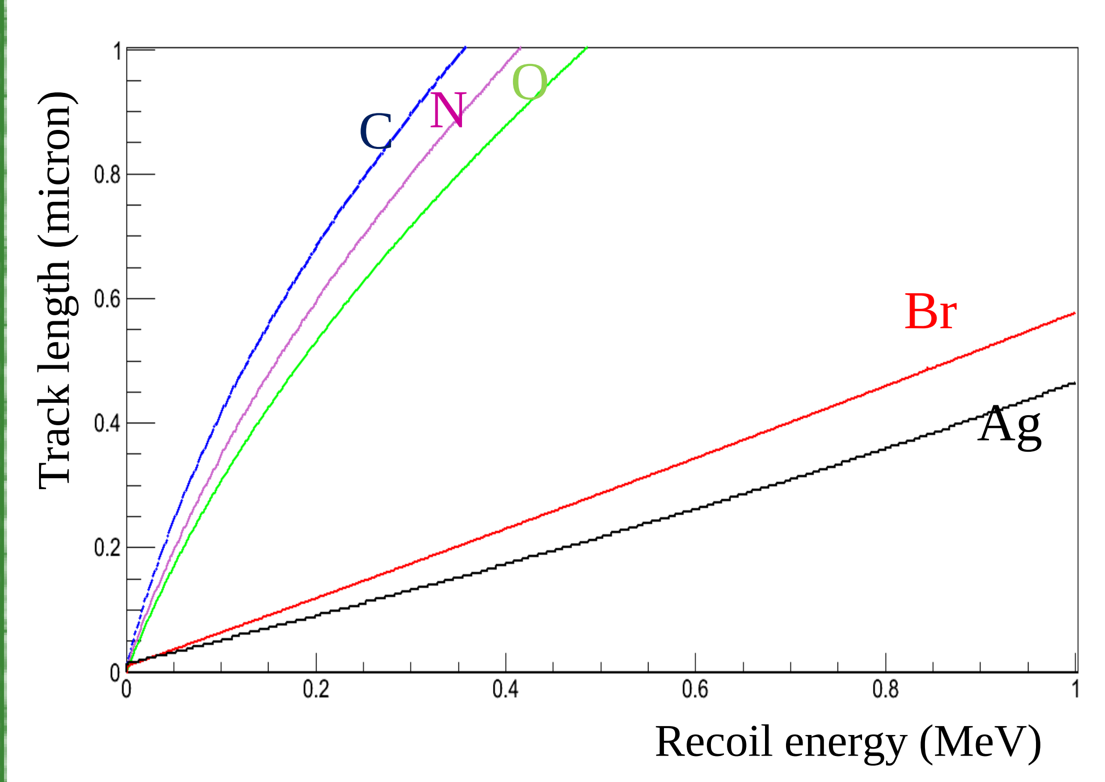
Each nucleus gives a different contribution to the overall sensitivity

heavy nuclei

light nuclei

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



Lighter nuclei

(longer range at same recoil energy)

Sensitivity to low WIMP mass

Readout Technology

TRACK IDENTIFICATION

- **Challenge: detect tracks with lengths comparable/shorter than optical resolution**
- **Strategy: two-steps approach**

STEP 1

CANDIDATE IDENTIFICATION WITH OPTICAL MICROSCOPES

Pros: Fast scanning, profiting of the improvements driven by the OPERA experiment, dedicated measurement stations in each lab

Limit: Resolution ~ 200 nm

STEP 2

CANDIDATE VALIDATION

X-ray microscope

Pros: High resolution ~ 50 nm or better

Cons: extremely slow and not convenient (needs an external lab)

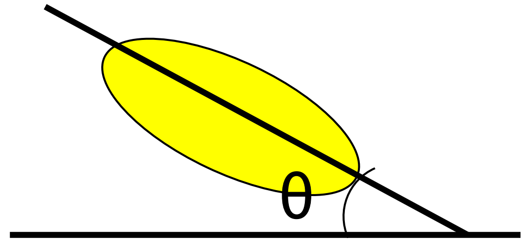
Possible option: New technology using optical microscopes

READOUT STRATEGY

STEP 1: CANDIDATE IDENTIFICATION

- Automatic scanning with **optical microscope** and **shape recognition analysis**
- 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), current scanning speed 20 cm^2/h

Test using 400 keV Kr ions



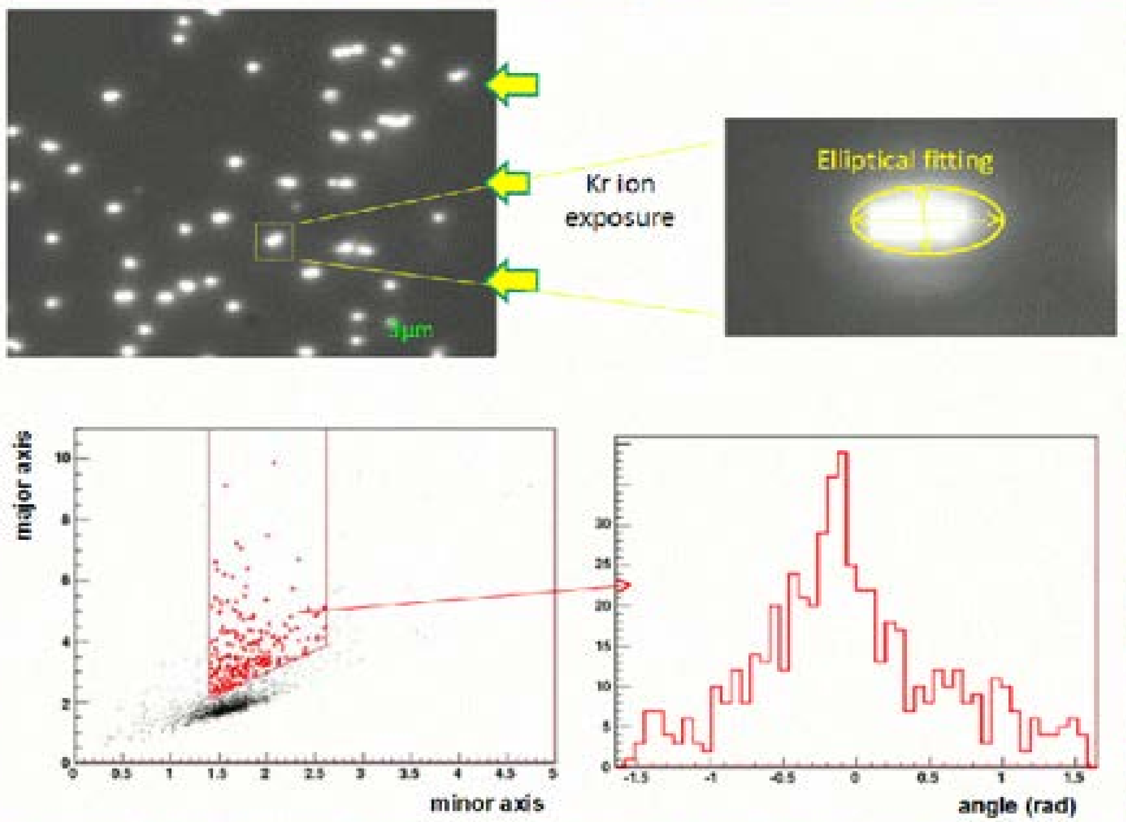
Direction detected!

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

OVERALL ANGULAR RESOLUTION

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

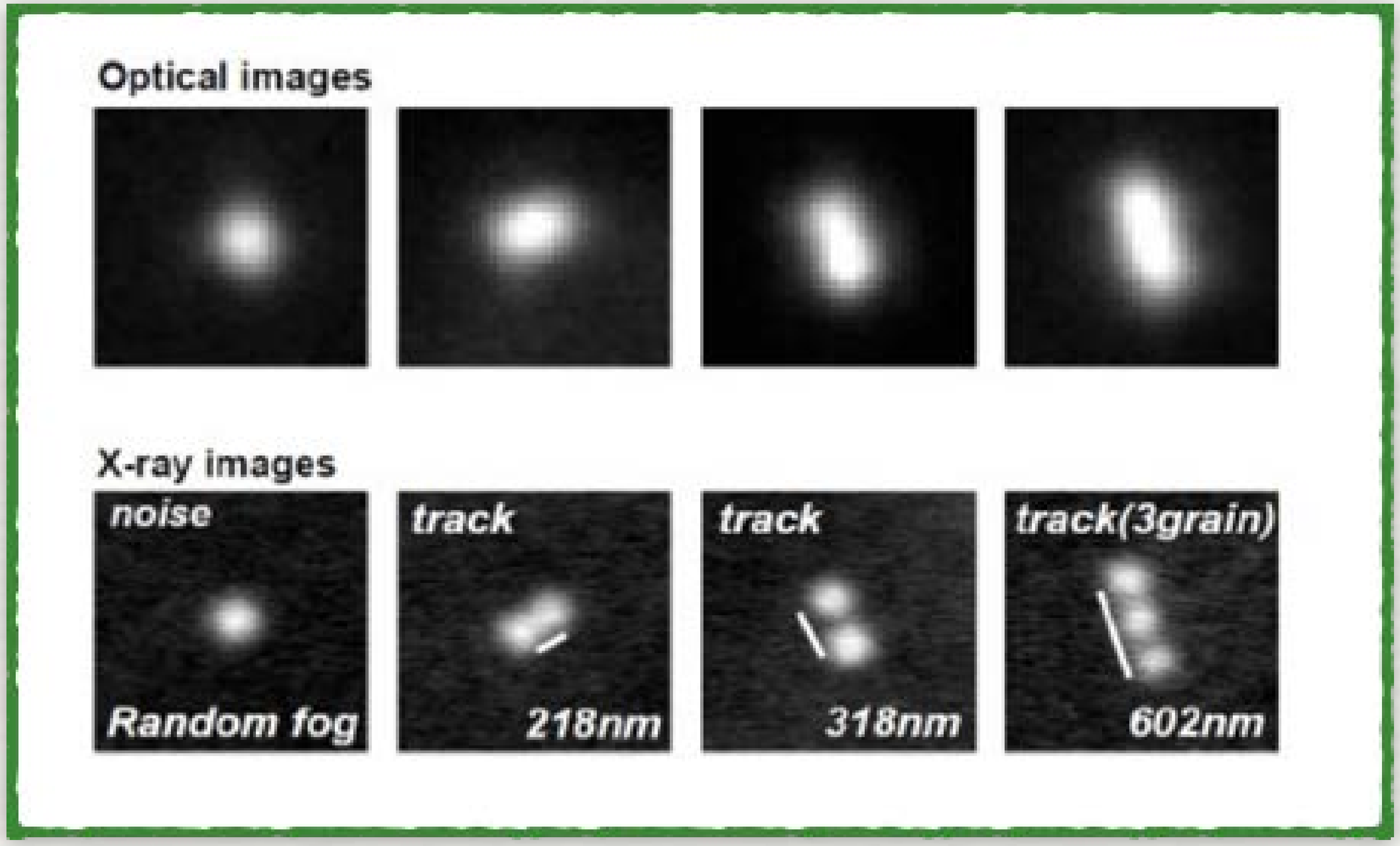
$\sigma = 360$ mrad



READOUT STRATEGY

STEP 2: CANDIDATE VALIDATION

- Scanning with **X-ray microscope** of preselected zones
- Pin-point check of candidate signals.
- Resolution ~30 nm



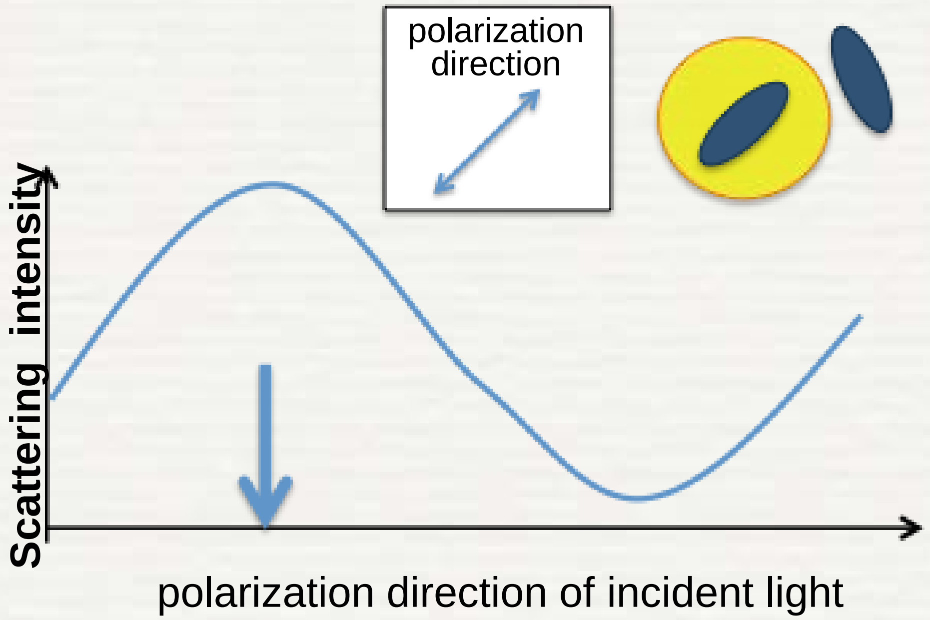
Matching Efficiency
99%
(572/579)

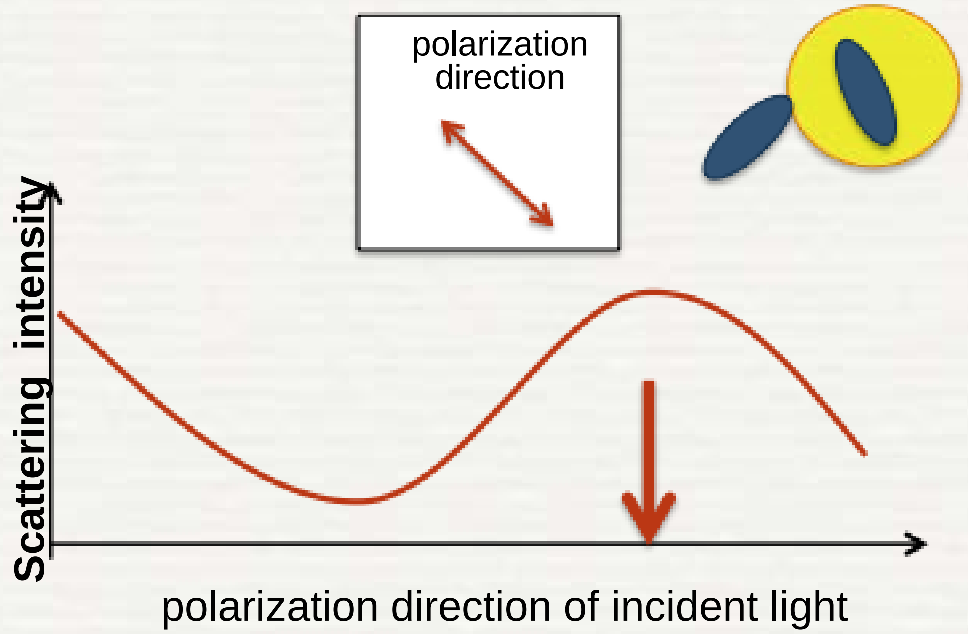
- **Slow analysis speed on selected sample (few hundred μm^2 in about 100 s)**

Resonant Light Scattering

Alternative to X-ray: optical microscope with rotating polarizer

- Occurring when nanometric metallic (silver) grains are dispersed in a dielectric medium *(Applied Phys Letters 80 (2002) 1826).* LPRS (Localized Surface Plasmom Resonance)
- 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

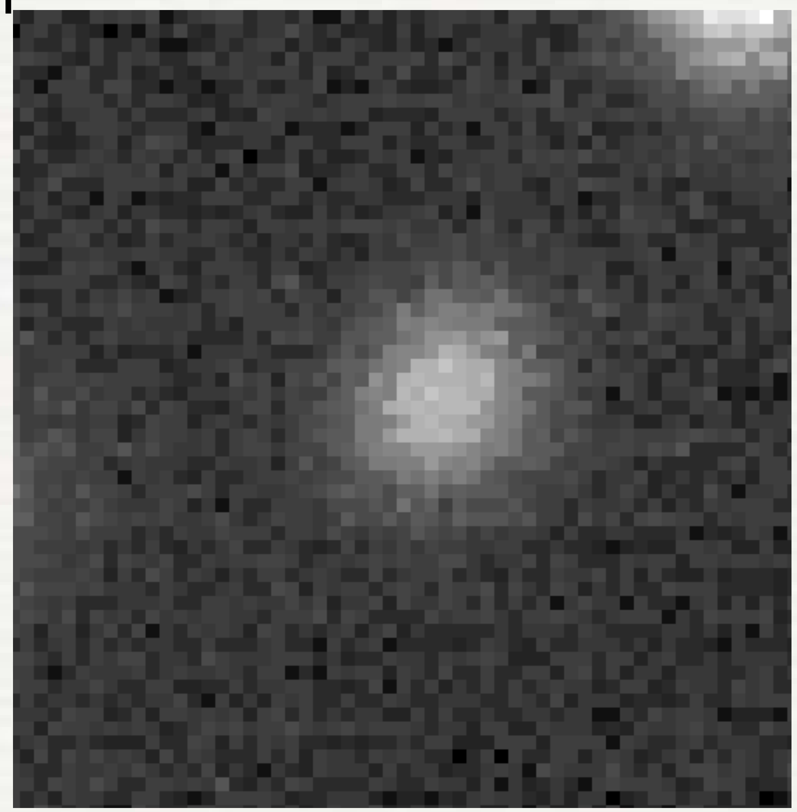


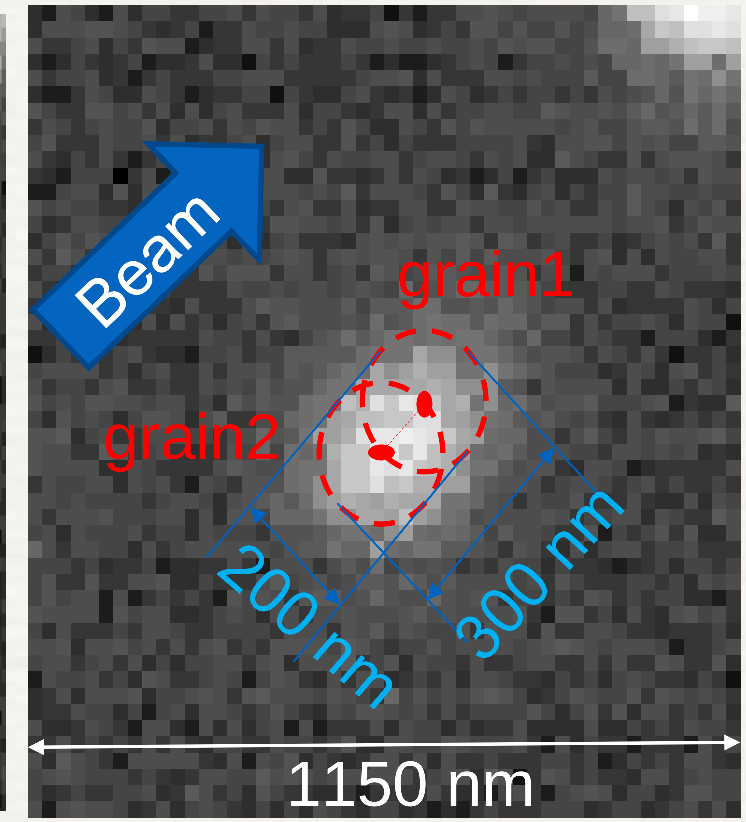


TRACK RECONSTRUCTION USING POLARIZED LIGHT

When grains are too close to be resolved a single elliptical cluster is seen

A track made of two grains

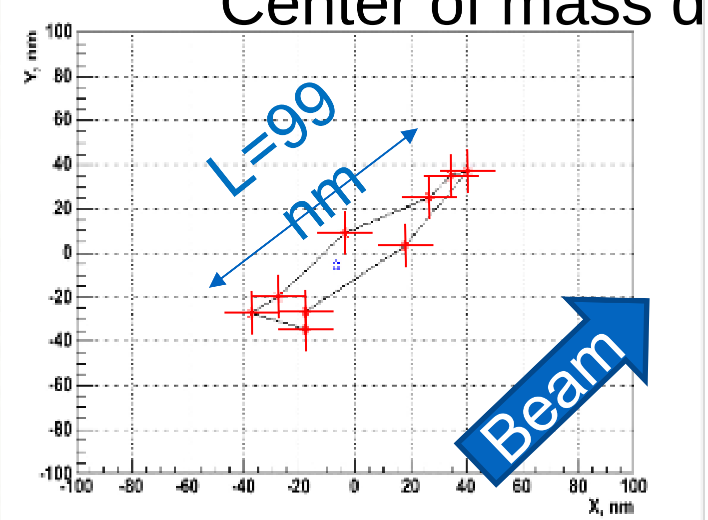


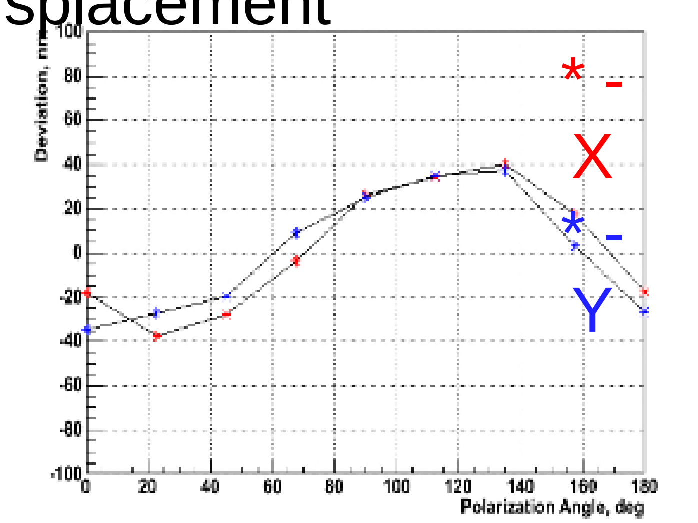


Using polarized light
the mass center
of the track starts to “oscillate”
with the rotation of polarizer

Emulsion fixed
Rotating polarizer filter

Center of mass displacement

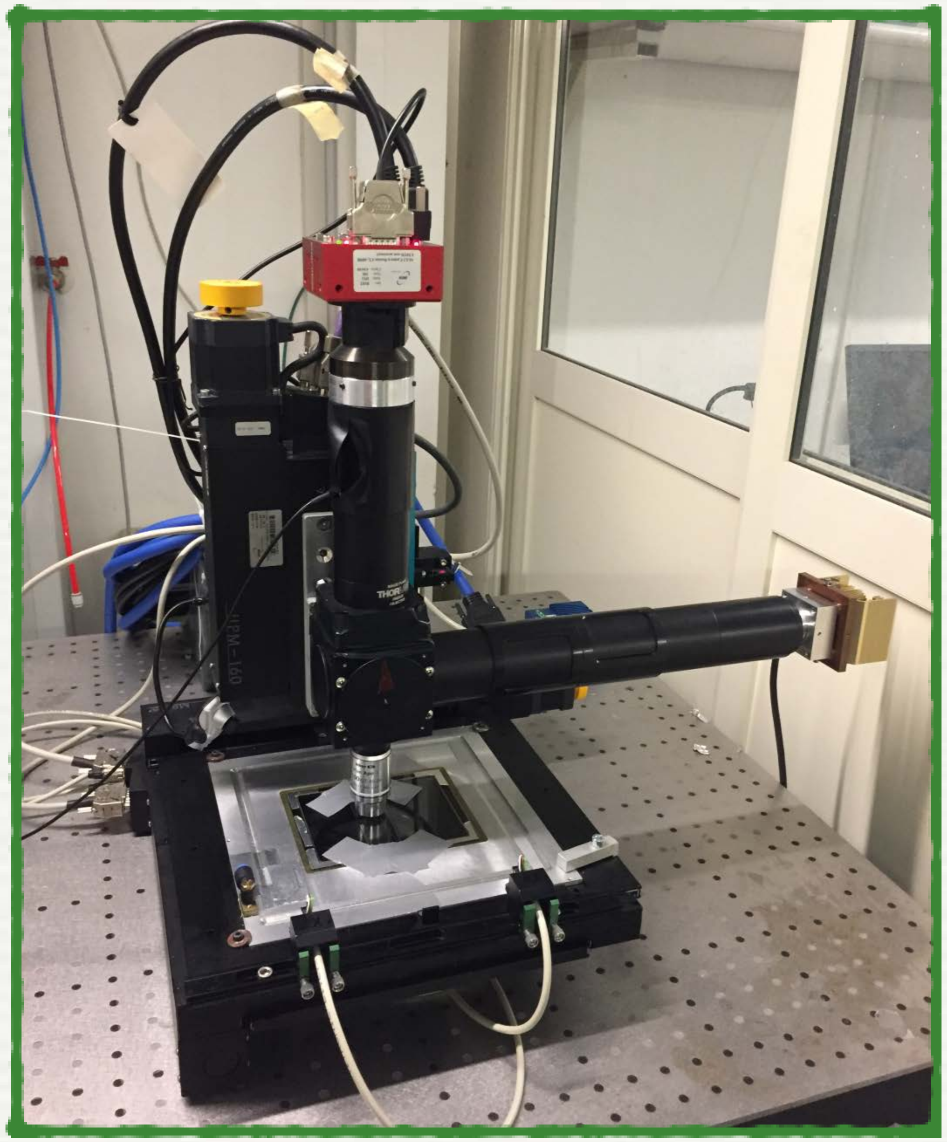




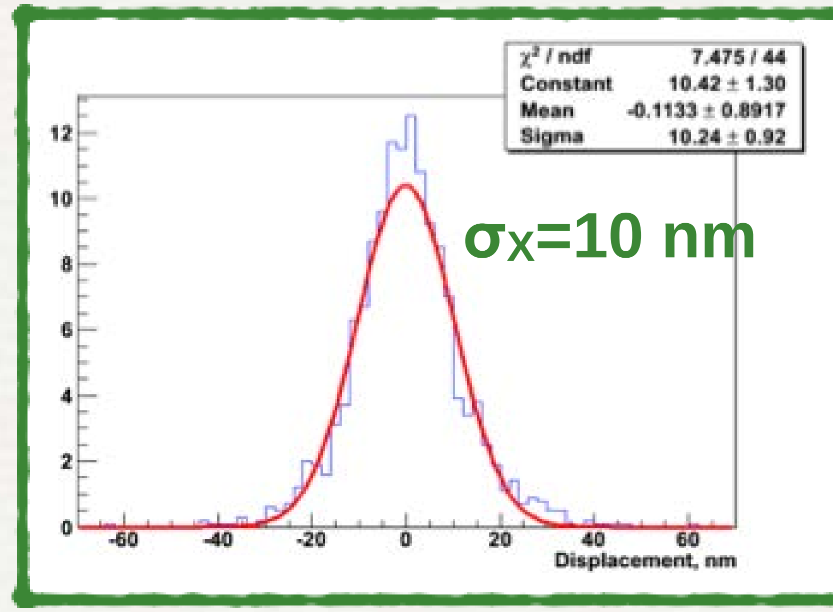
Taking multiple measurements over
the whole polarization range
gives information about displacement
of the barycenter of the cluster

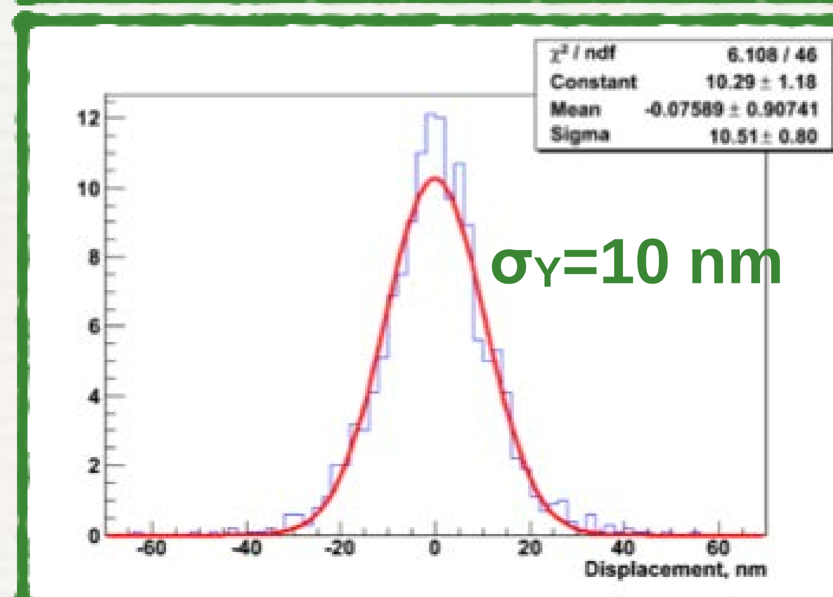
Position Accuracy

- Optical microscope with rotating polarizer



- Exploiting resonant light effect





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

Breakthrough

BACKGROUND STUDIES

BACKGROUND STUDIES

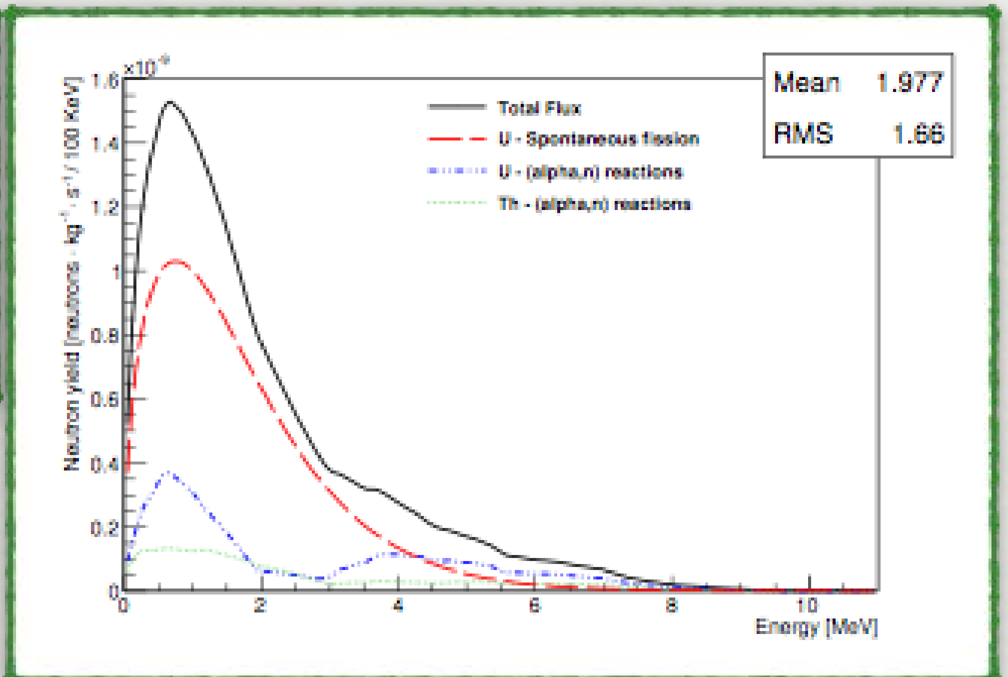
- Measurement of intrinsic radioactivity: neutrons

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 $[n \cdot kg^{-1} \cdot y^{-1}]$	Semi-analytical calculation $[n \cdot kg^{-1} \cdot y^{-1}]$
(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

$\varepsilon \sim 1\% \rightarrow \sim 0.01 \text{ n/kg year}$

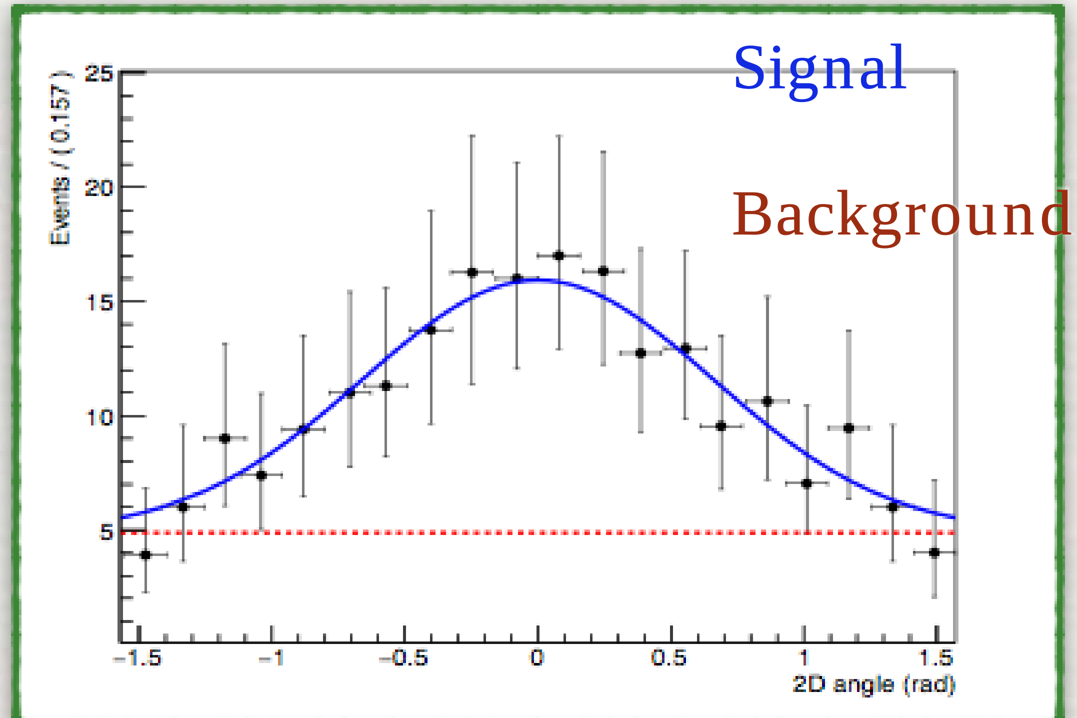
Neutron background from intrinsic radioactivity negligible up to ~10 kg year

NEWSdm Collaboration
Astroparticle Physics 80 (2016) 16

NEWSdm
SENSITIVITY

EXPLOIT DIRECTIONALITY

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



- Likelihood function

expected number of WIMP events

expected number of background events

signal pdf

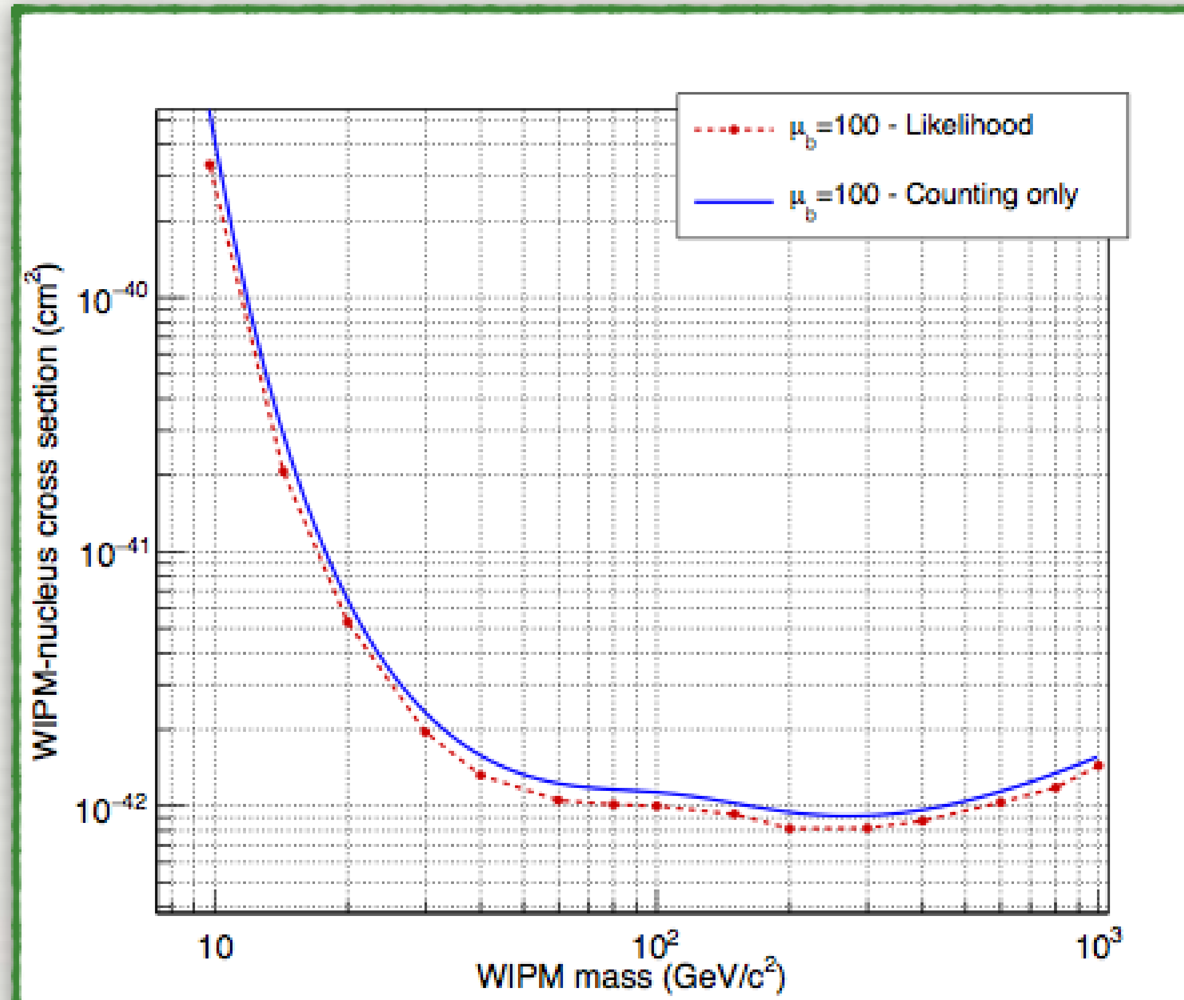
background pdf

$$\mathscr{L}(\sigma_{\chi-n}, R_b) = \frac{e^{-(\mu_\chi+\mu_b)}}{N!} \times \prod_{i=1}^{N} [\mu_\chi f_\chi(\vec{q}_i; t_i) + \mu_b f_b(\vec{q}_i)]$$

total number of observed events

set of observables

- Mass = 100 kg * 1 year
- $N_{background}$ = 100 (events)
- Threshold = 100 nm

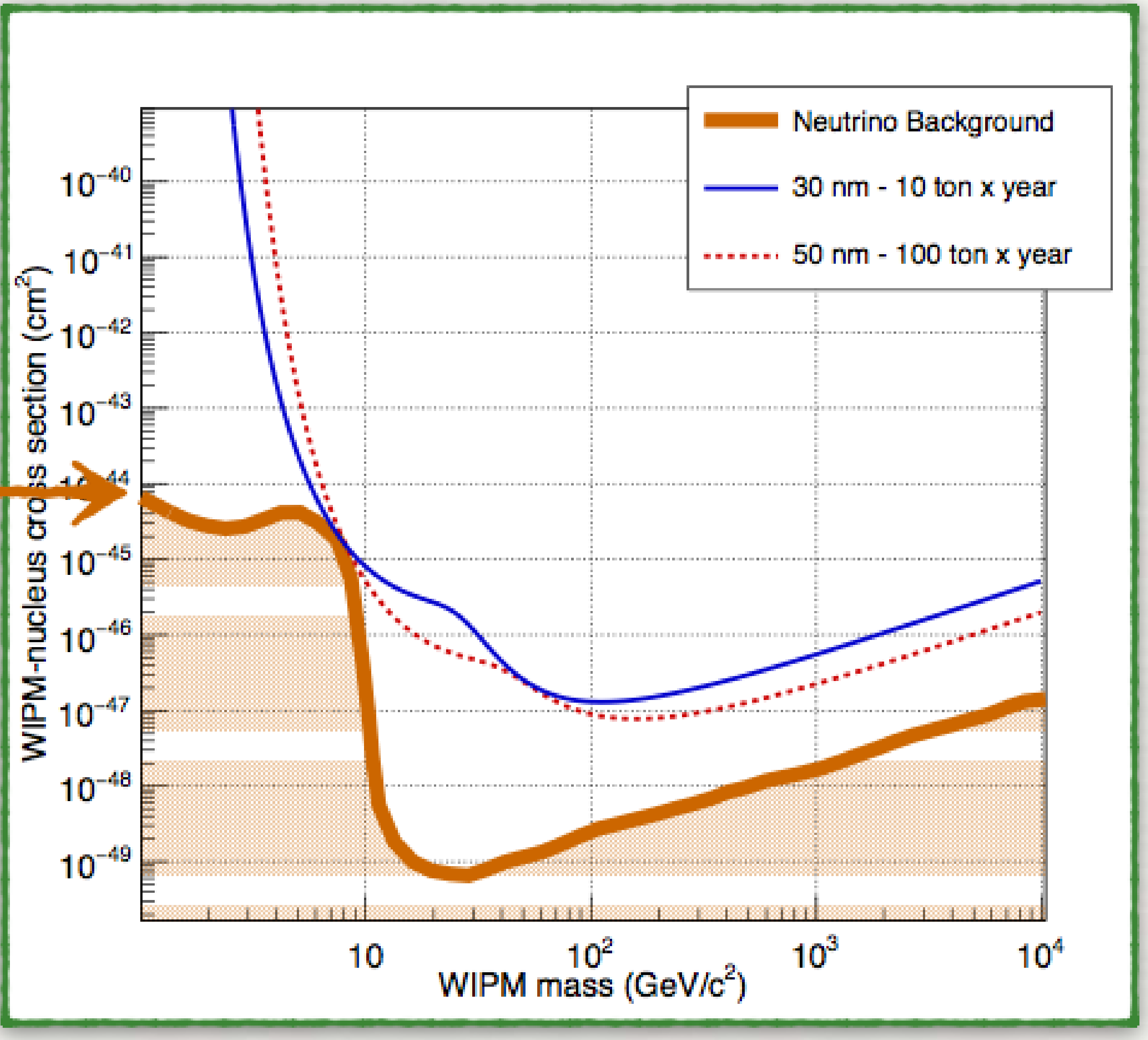


Expected exclusion curve

TOWARDS 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

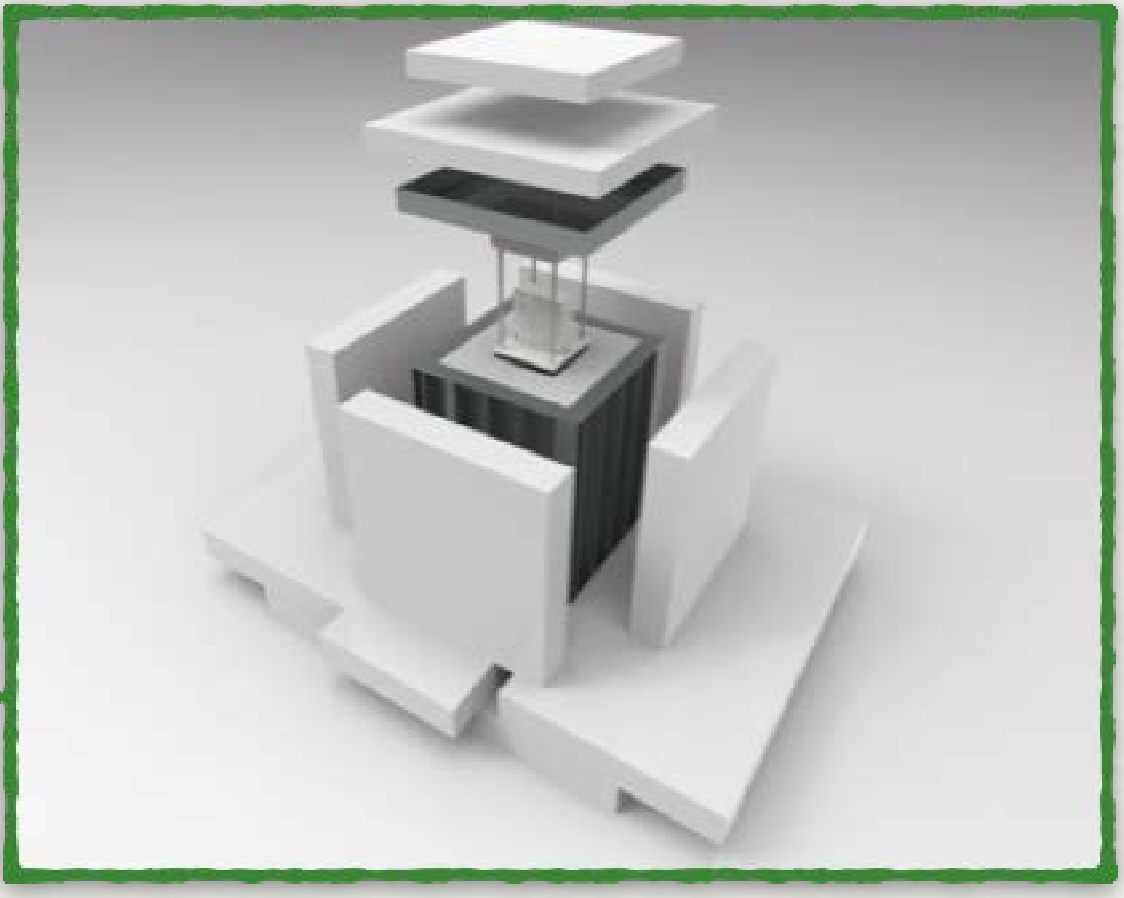
Current Status Of The Experiment

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 **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

Polyethylene slabs 40 cm-thick - absorb environmental and cosmogenic neutrons
Lead bricks 10 cm-thick - absorb environmental photons



TECHNICAL TEST

- 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 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

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*part of the Collaboration when test started in LNGS

THANK YOU FOR YOUR ATTENTION