NEWSdm

Nuclear Emulsions for WIMP Search with Directional Measurement

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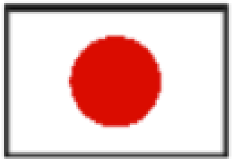
On behalf of the NEWSdm Collaboration

WIN 2019, Bari 2019 June 5th

NEWSdm COLLABORATION

75 physicists
14 Institutes

ITALY
University and INFN Bari
LNGS, Gran Sasso
University and INFN Napoli
INFN Roma



JAPAN
Chiba, Nagoya, Toho

SOUTH KOREA
Gyeongsang University

RUSSIA
LPI RAS Moscow
JINR Dubna
SINP MSU Moscow
INR Moscow
Yandex School of Data Analysis

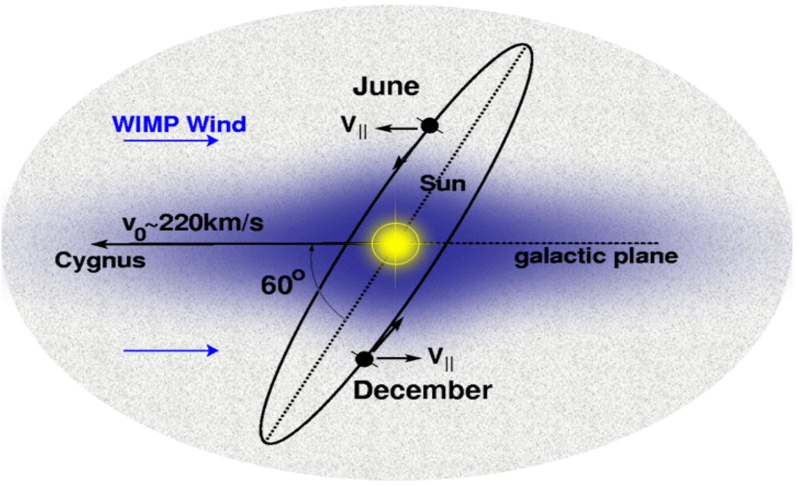
TURKEY
METU Ankara

Website: news-dm.lngs.infn.it

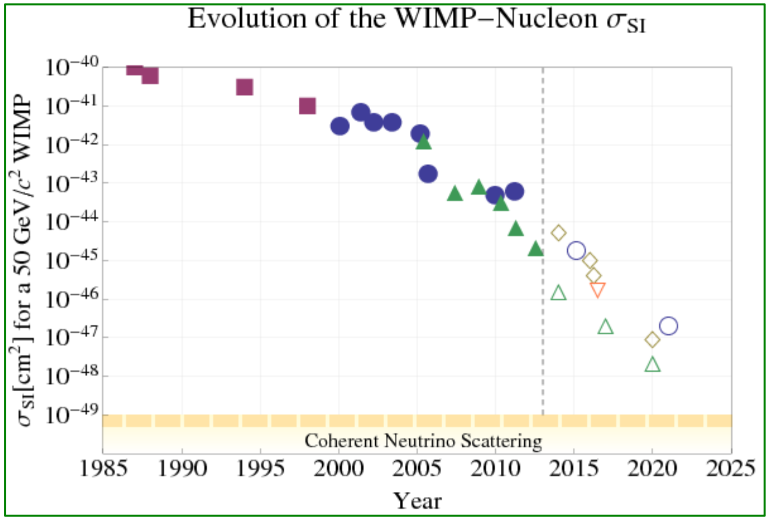
Letter of intent: https://arxiv.org/pdf/1604.04199.pdf

POWER OF DIRECTIONALITY

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

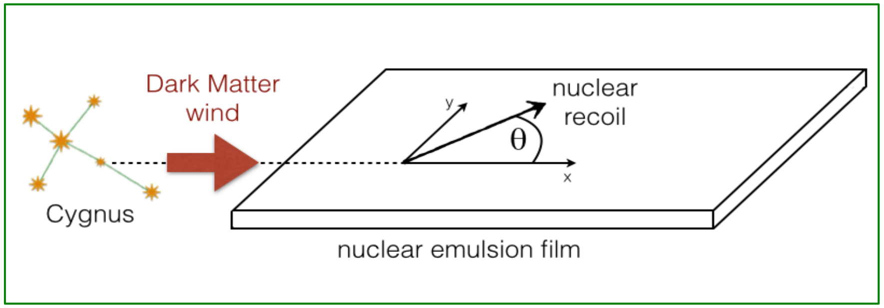


- Directional measurement would provide a strong signature and unambiguous proof of the galactic origin of Dark Matter

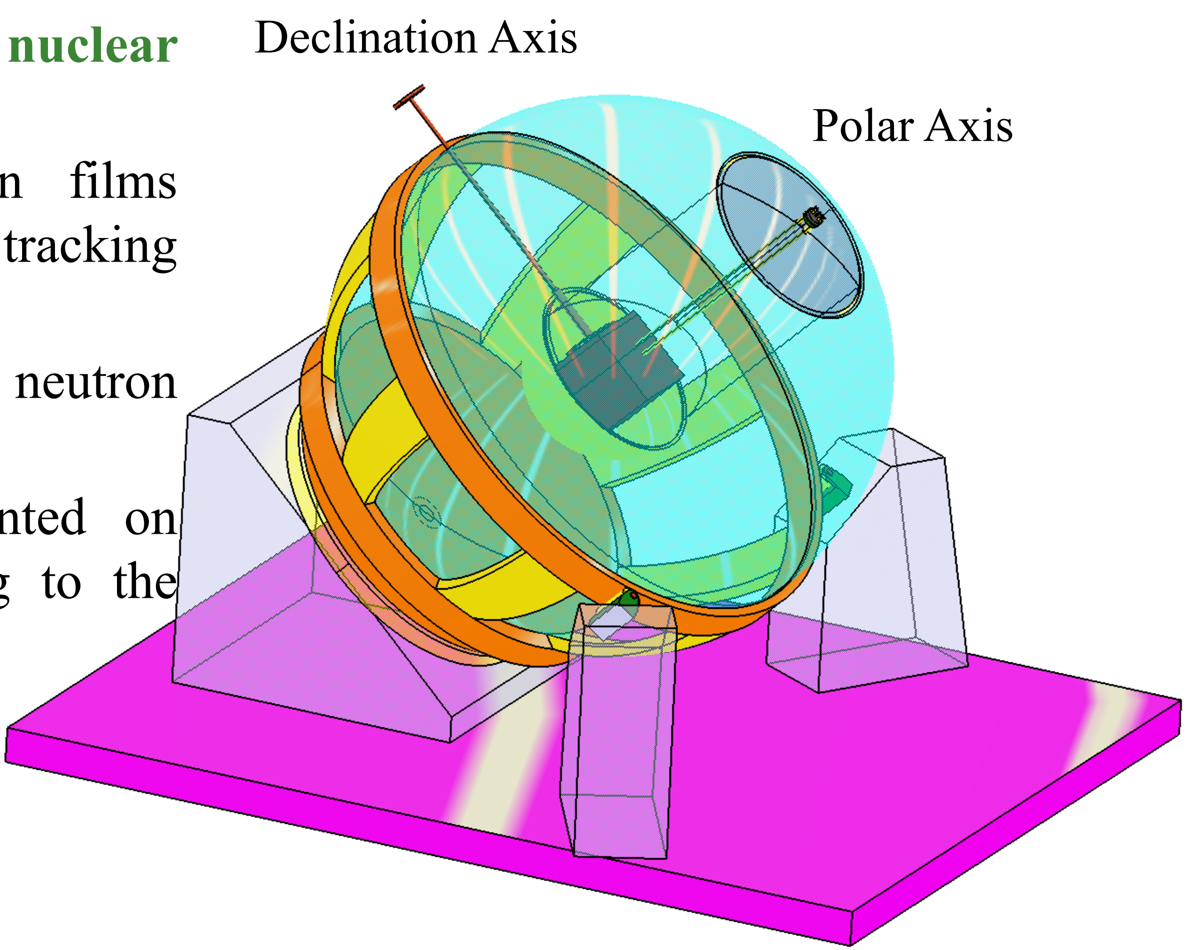


- Unique possibility to overcome the "neutrino floor", where coherent neutrino scattering creates an irreducible background

NEWSdm PRINCIPLE



- **<u>Aim</u>**: detect the direction of **nuclear recoils**
- **<u>Target</u>**: nanometric emulsion films acting both as target and tracking detector
- **<u>Background reduction:</u>** neutron **shield** surrounding the target
- **<u>Fixed pointing</u>**: target mounted on **equatorial telescope** pointing to the Cygnus Constellation
- **<u>Location</u>**: Underground labs



NIT EMULSIONS (Nano Imaging Tracker)

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

(a) Constituents of nuclear emulsion

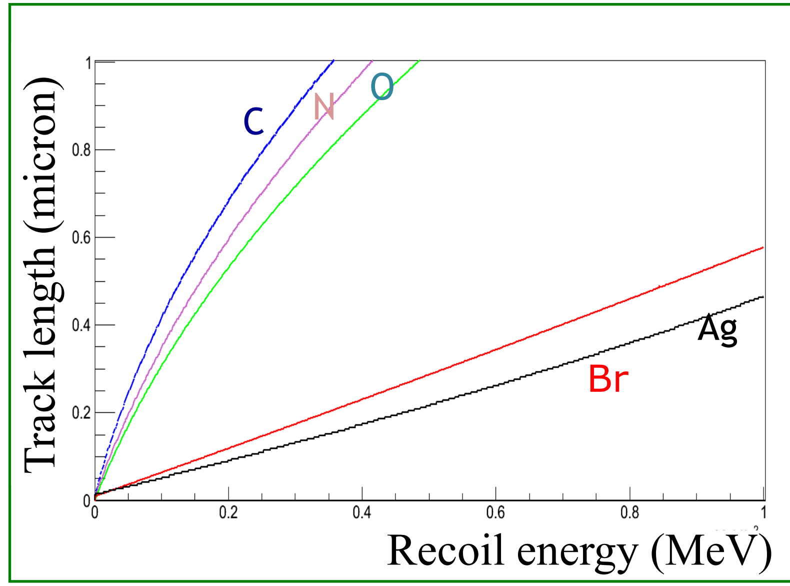
AgBr-I: sensitive elements
Organic gelatine: retaining structure
PVA to stabilise the crystal growth

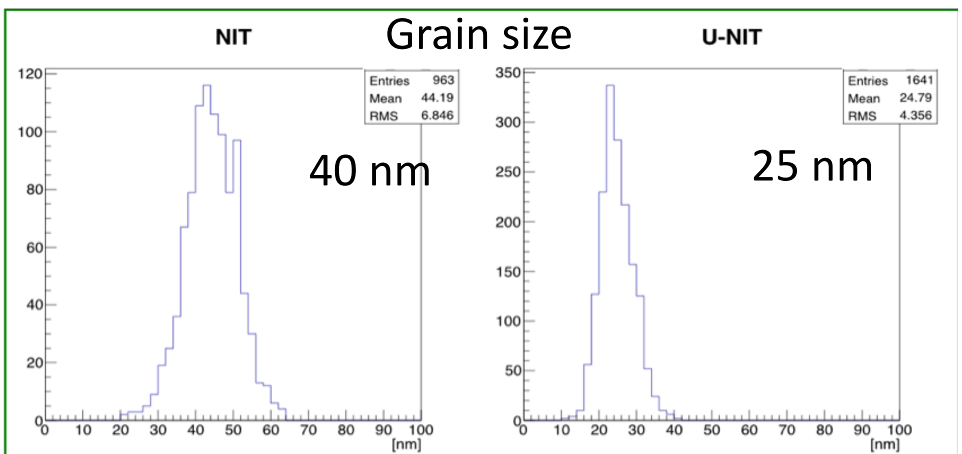
heavy nuclei

light nuclei

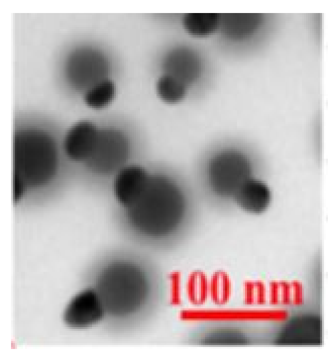
Element	Mass Fraction	Atomic Fraction
Ag	0.44	0.12
Br	0.32	0.12
I	0.019	0.003
C	0.101	0.172
O	0.074	0.129
N	0.027	0.057
H	0.016	0.396
S	0.003	0.003

(b) Elemental composition

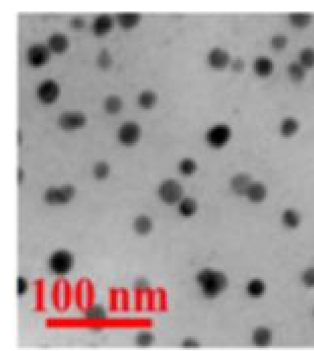




NIT

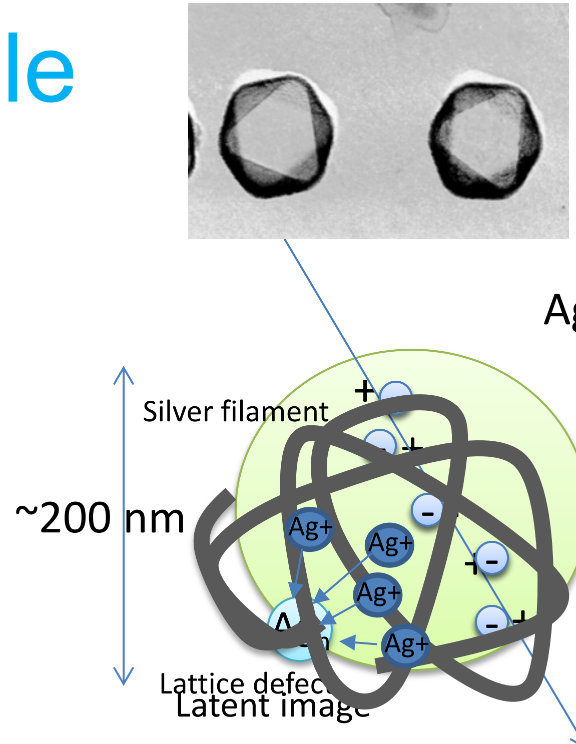


U-NIT

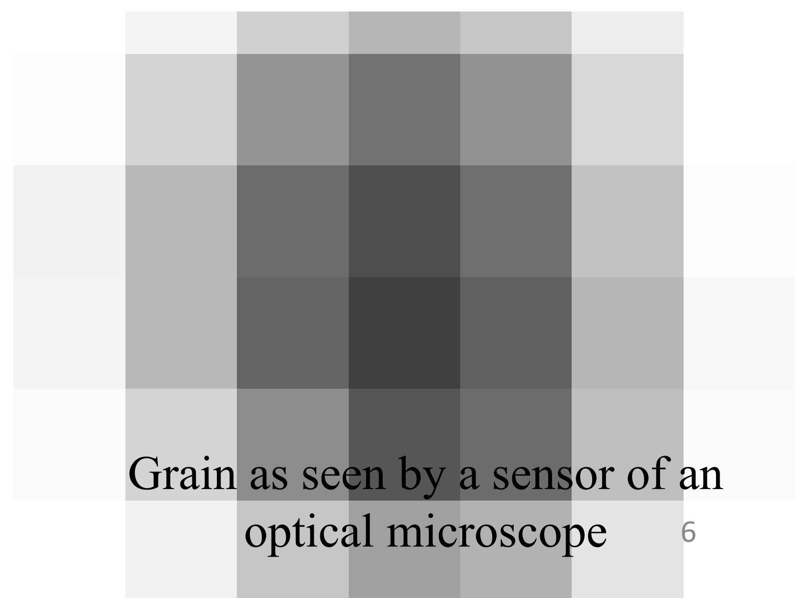


Detection principle

1. Ionization induced by a particle
   – 2.6 eV band gap
2. Electrons trapped at a lattice defect on the crystal surface
   – Attract interstitial silver ions
   – Produce a "latent image"
3. Chemical amplification of signal
   – Development → silver filaments
   – 10^7 - 10^8 amplification
4. Dissolve crystals
5. Observe it at optical microscopes



AgBr crystal



Grain as seen by a sensor of an optical microscope

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,

Limit: Resolution ~ 200 nm

STEP 2

CANDIDATE VALIDATION

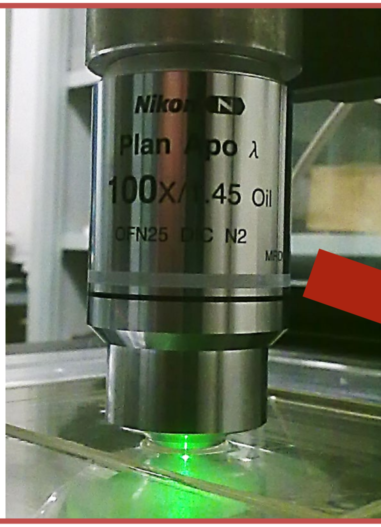
Super resolution microscope (resonant light scattering)

Pros: High resolution

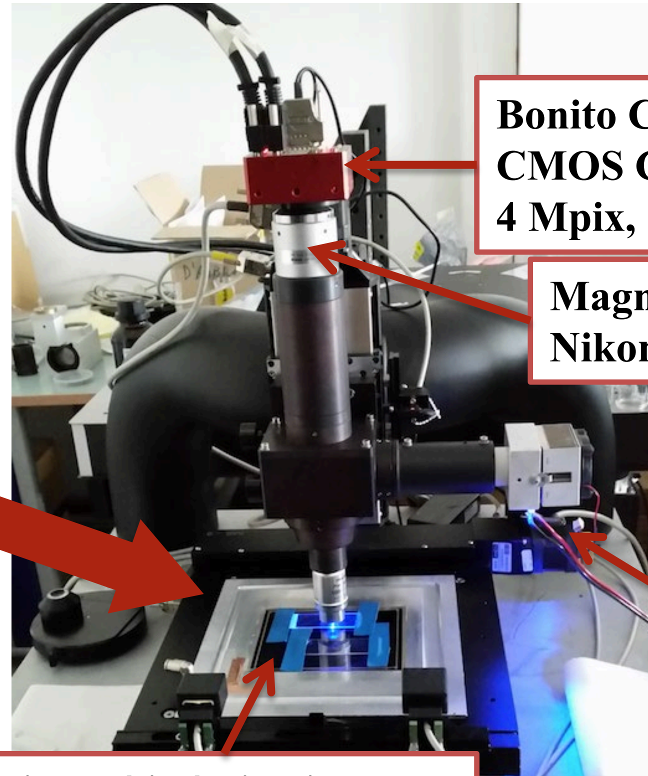
Cons: Relatively slow

OPTICAL MICROSCOPE READ-OUT: STEP 1

100x objective lens with high N.A.



Resolution: 28 nm/pixel
View Size: 65.2 x 48.3 μm^2



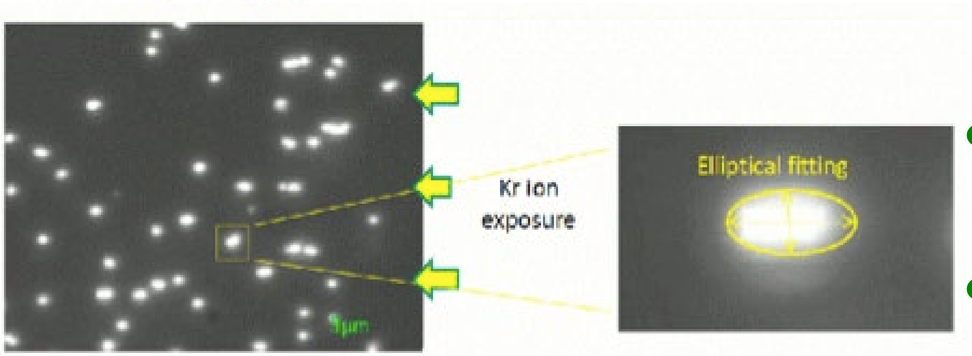
Bonito CL/CMC-4000
CMOS Camera
4 Mpix, @100 fps

Magnifying lens,
Nikon VM C-2.5x

LED
light

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

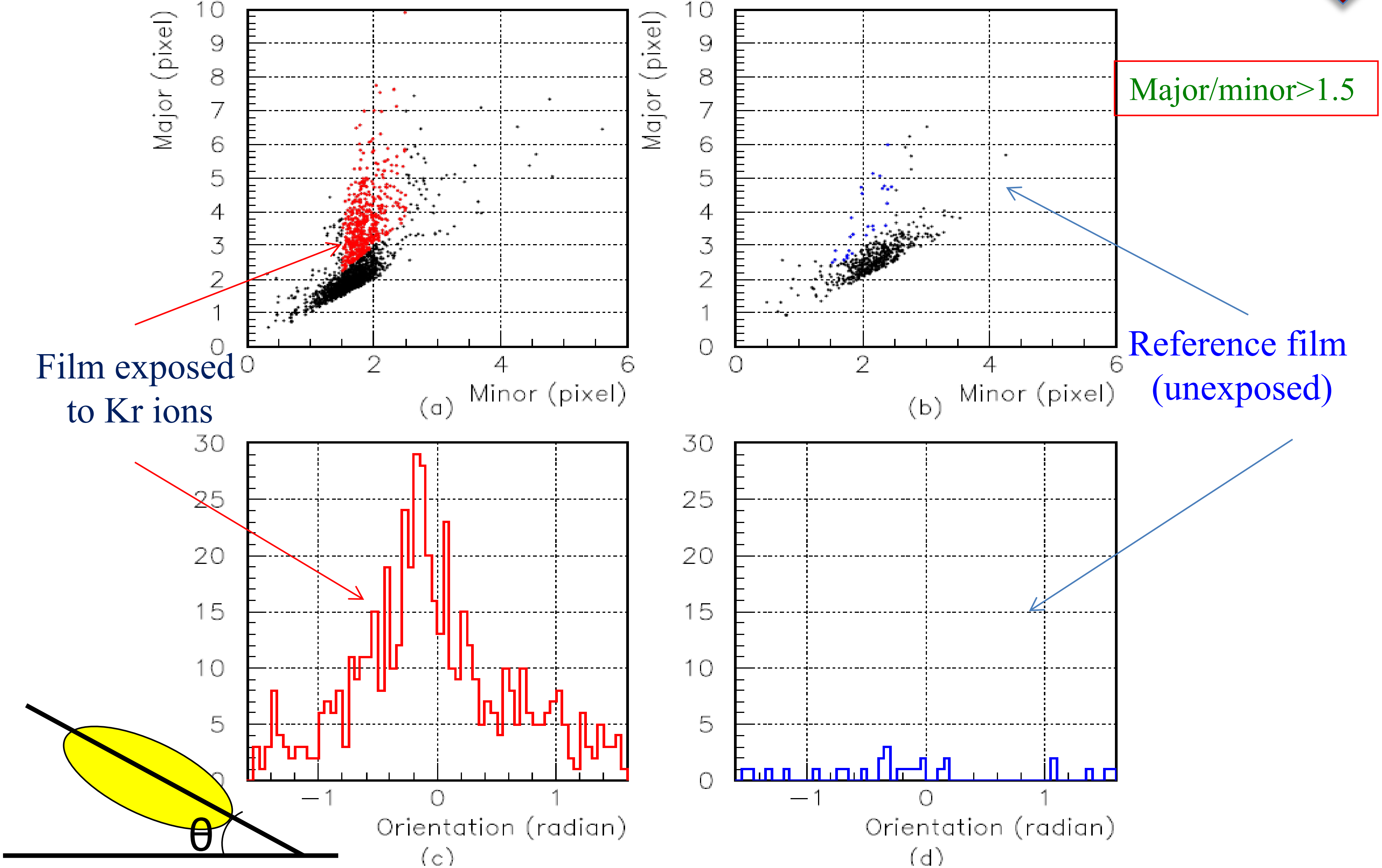
Test using 400 keV Kr ions



Scanning with **optical microscope** and **shape recognition analysis**

- Selection of clusters with elliptical shape: major axis along track direction
- Background: spherical cluster

Selection of Kr ion tracks with shape analysis

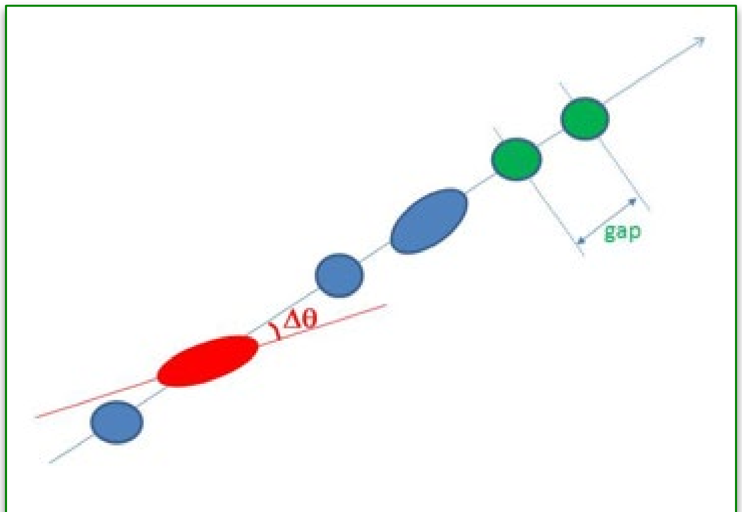


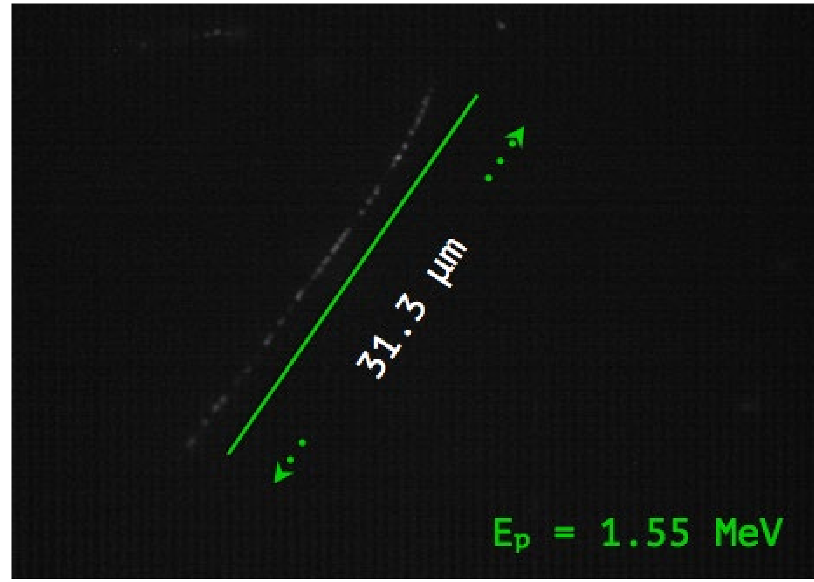
Direction detected!

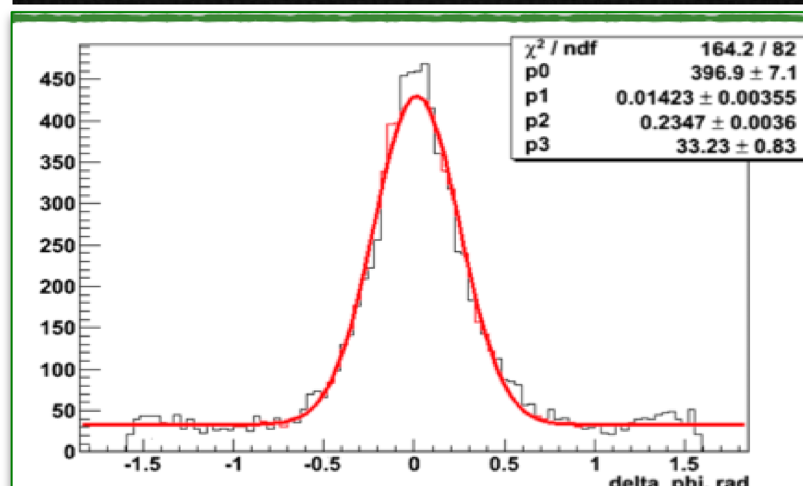
NIM A680 (2012) 12-17

INTRINSIC ANGULAR RESOLUTION

- Neutron test beam sample: exposure at FNS (Japan)
- Compare clusters with elliptical (e > 1.1) shape with the proton recoil direction
- Scattering contribution negligible



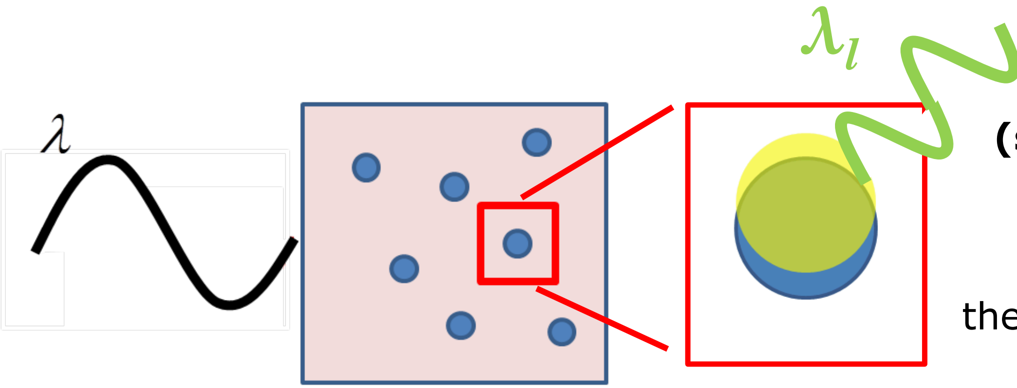




INTRINSIC ANGULAR RESOLUTION
σ = 235 mrad = 13°

Beyond Optical Resolution: New Technologies

Resonant Light Scattering From Ag Nanoparticles



Occurring when nanometric metallic (silver) grains are dispersed in a dielectric

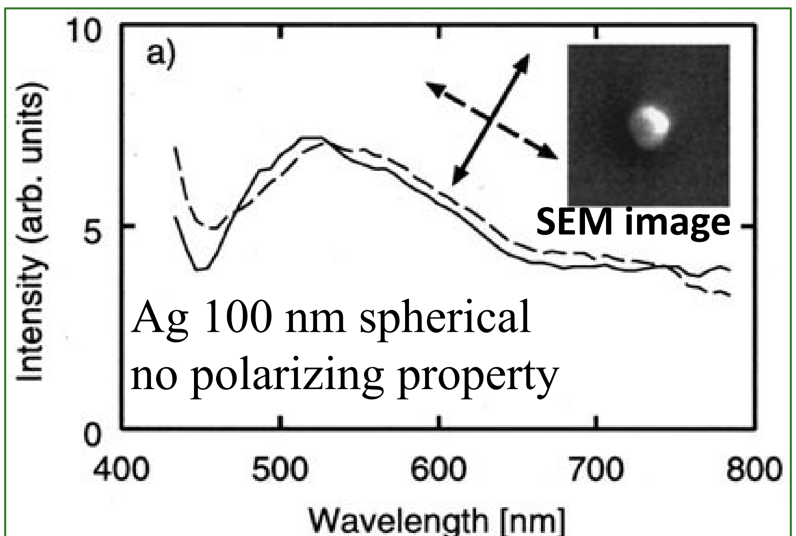
Sensitive to the shape of nanometric grains: when silver grains are **not spherical**, the resonant response depends on the polarization of the incident light.

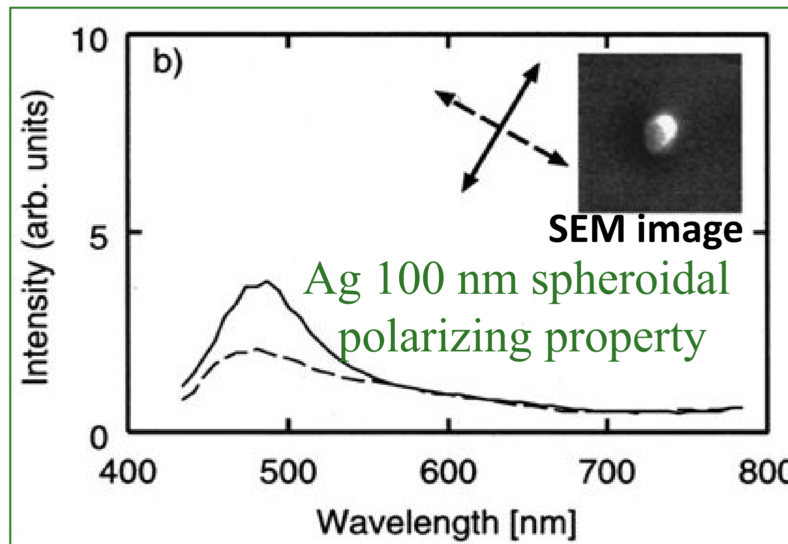
Nano-metal in medium ε_d

Oscillation of e-cloud

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

H.Tamaru et al ., Applied Phys Letters 80, 1826 (2002)





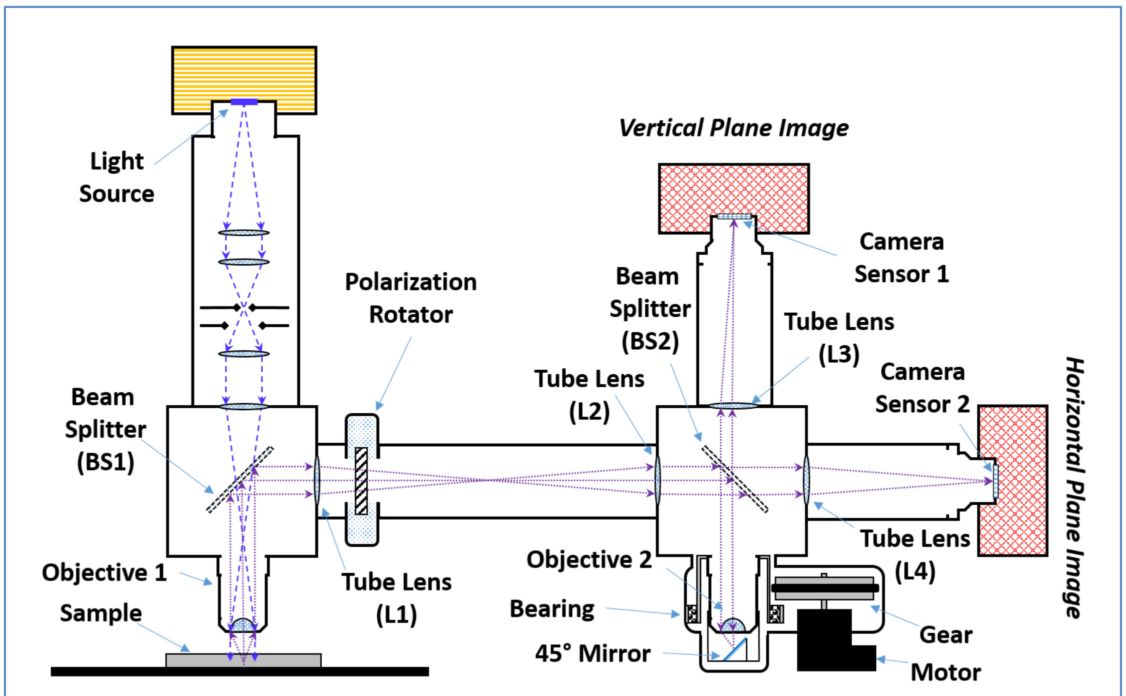
The polarization dependence of the resonance frequencies strongly reflects the shape anisotropy

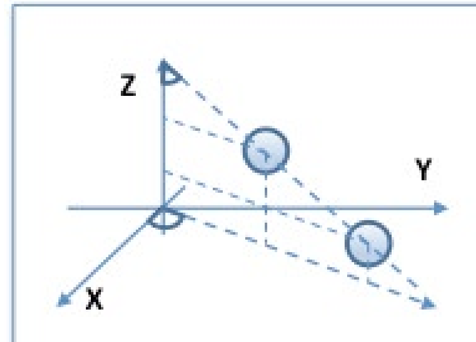
SUPER RESOLUTION MICROSCOPE WITH 3D RECONSTRUCTION

WO/2018/122814 (PATENT) – Method and optical microscope for detecting particles having sub-diffractive size

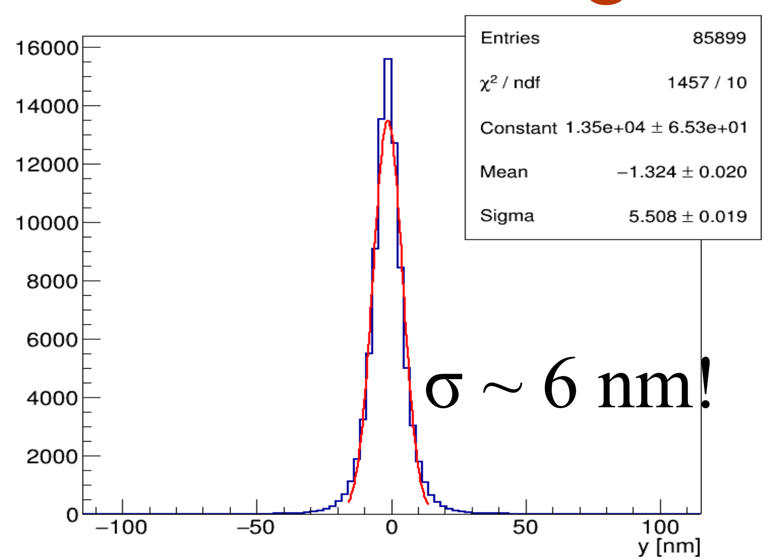
A. Alexandrov, G. De Lellis, V. Tioukov, N. D'Ambrosio

Optical microscope using two orthogonal camera and rotating polarizer filter





Breakthrough



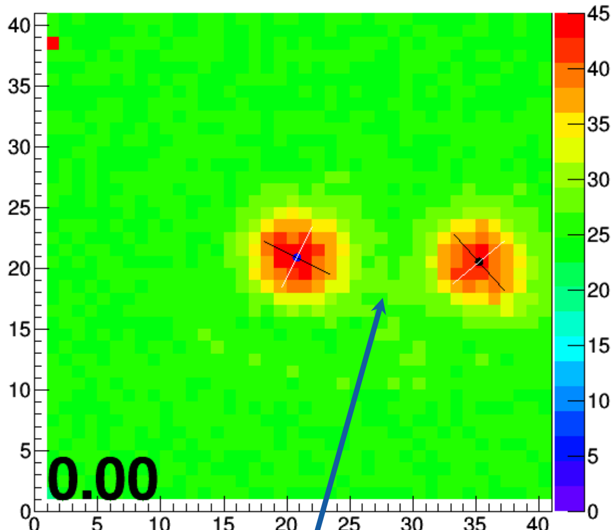
$\sigma \sim 6$ nm!

STEP2: PLASMON ANALYSIS

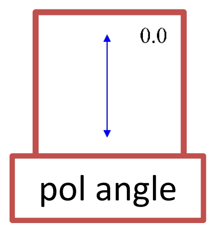
Data categories:

1. **Micro-tracks**: two or more grains aligned
2. **isolated** grains
   - Multi-grain clusters ($\geq$ 2 brightness peaks) $\longrightarrow$ microtracks
   - Moving grains ($\Delta s > \Delta s_{thr}$) $\longrightarrow$ nanotracks
   - Static grains ($\Delta s < \Delta s_{thr}$) $\longrightarrow$ background

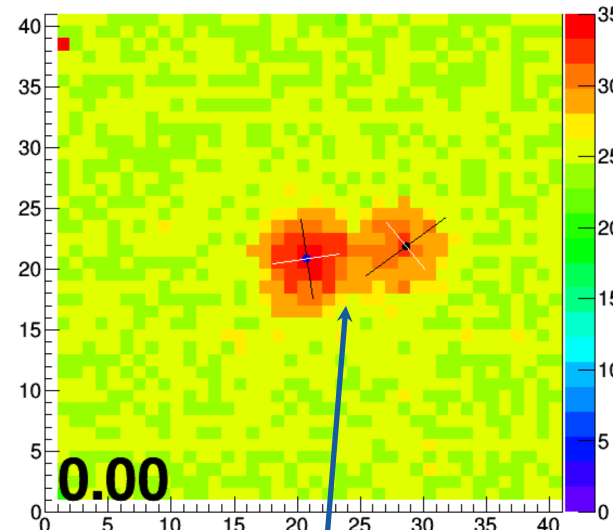
MICROTRACKS



Empty space between two grains



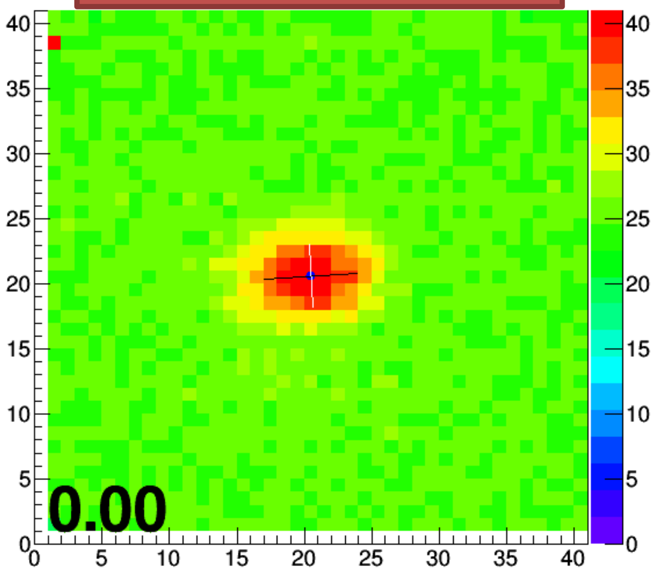
MULTI-GRAIN CLUSTERS

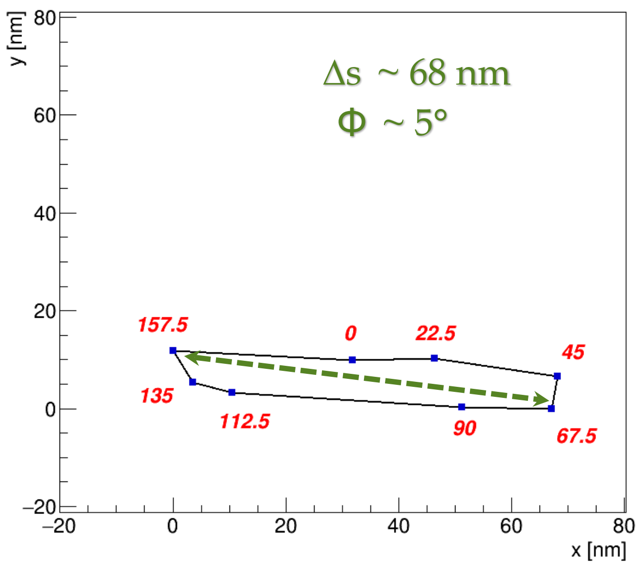


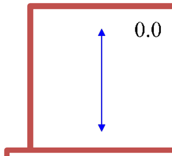
A single grain is reconstructed

STEP2: PLASMON ANALYSIS

MOVING GRAIN

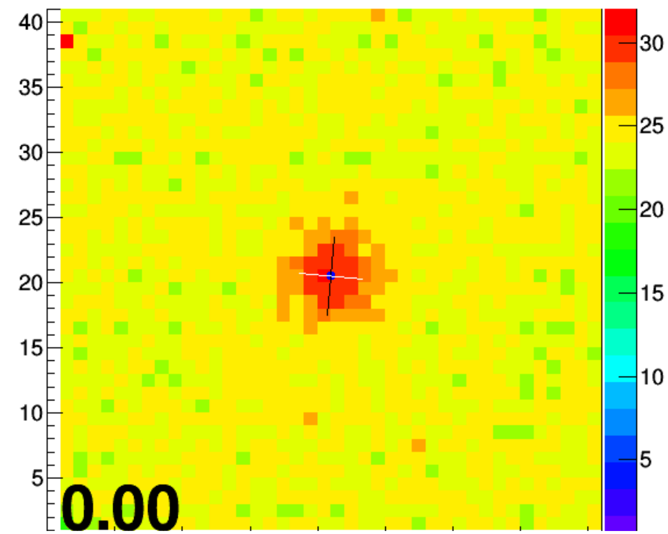


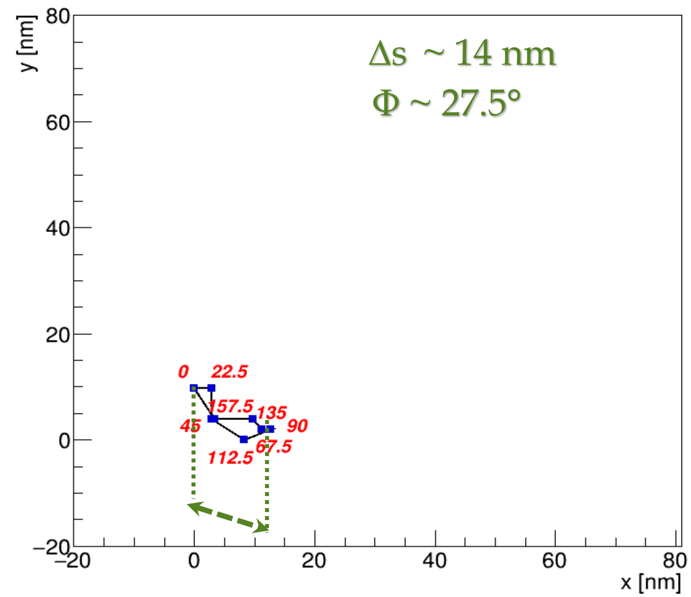




pol angle

STATIC GRAIN

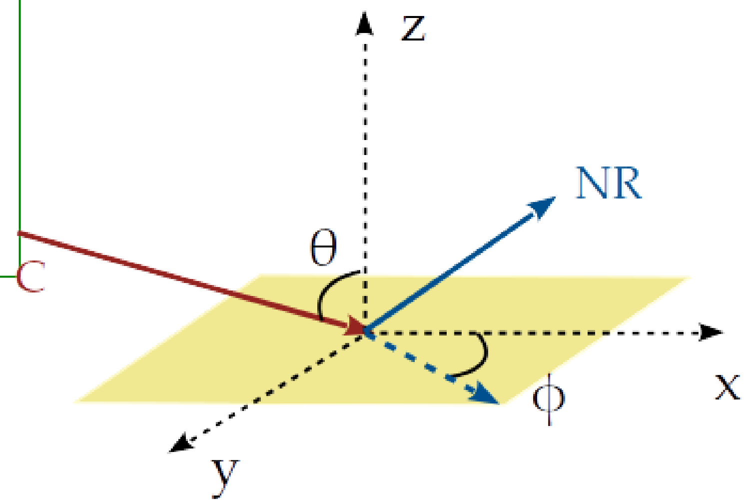




CARBON ION SAMPLES

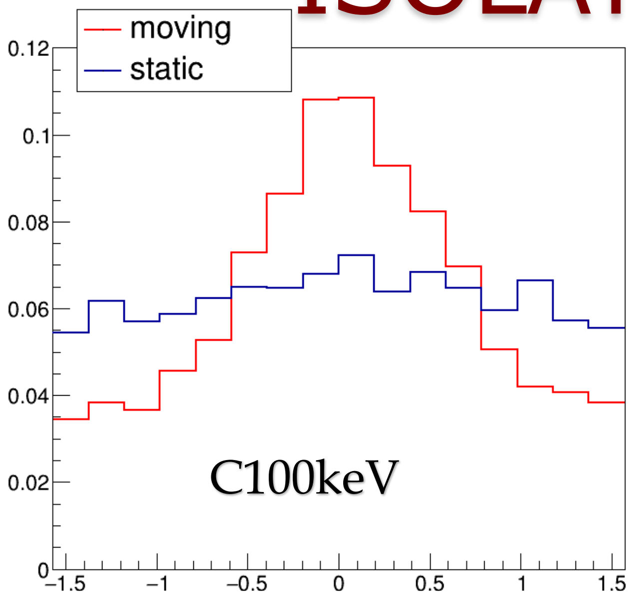
Plasmon analysis with C-Ion samples

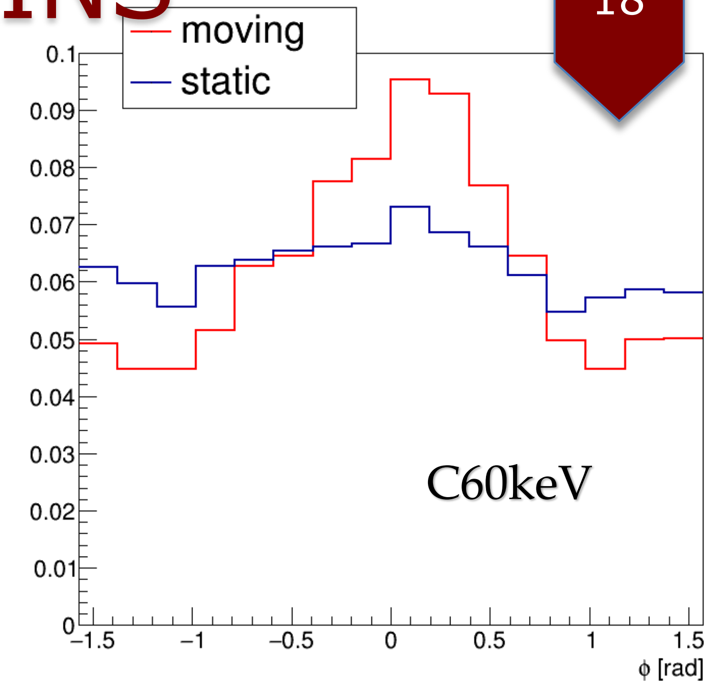
C-Ion samples (vacuum implantation)
100keV (Horizontal ~ 80°)
60keV (Horizontal ~ 80°)
30keV (Horizontal ~ 80°)
10keV (Vertical ~ 10°)

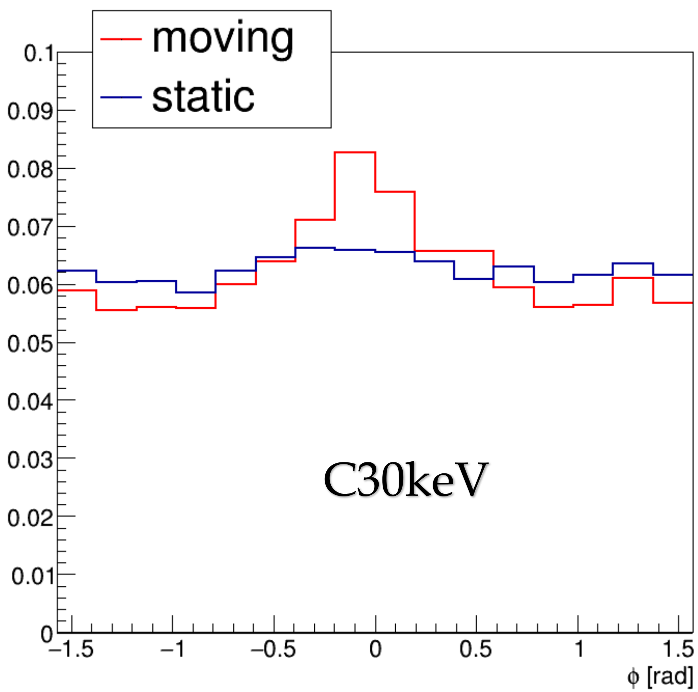


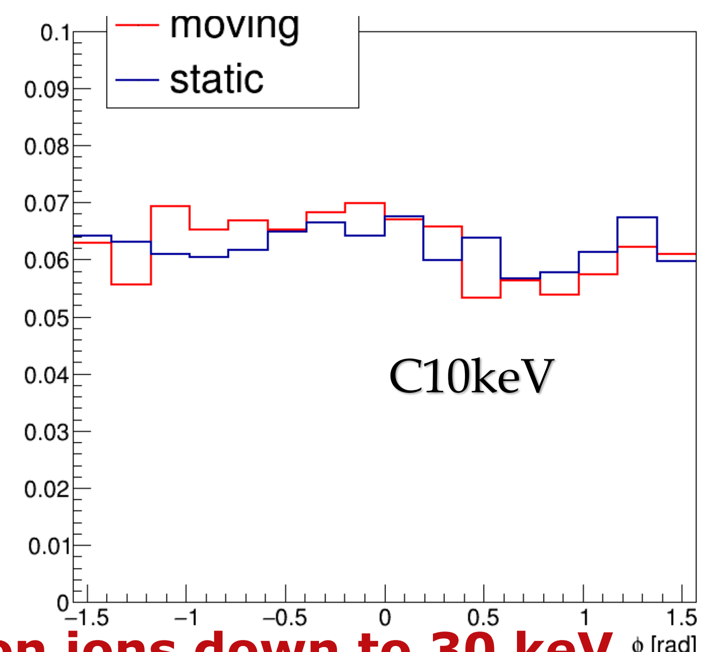
Horizontal exposures to produce nanotracks in NIT with a preferred direction (signal-like samples)
Vertical exposure to produce in most cases one grain in NIT with an isotropic direction (background-like sample)

ISOLATED GRAINS









Directionality demonstrated with Carbon ions down to 30 keV

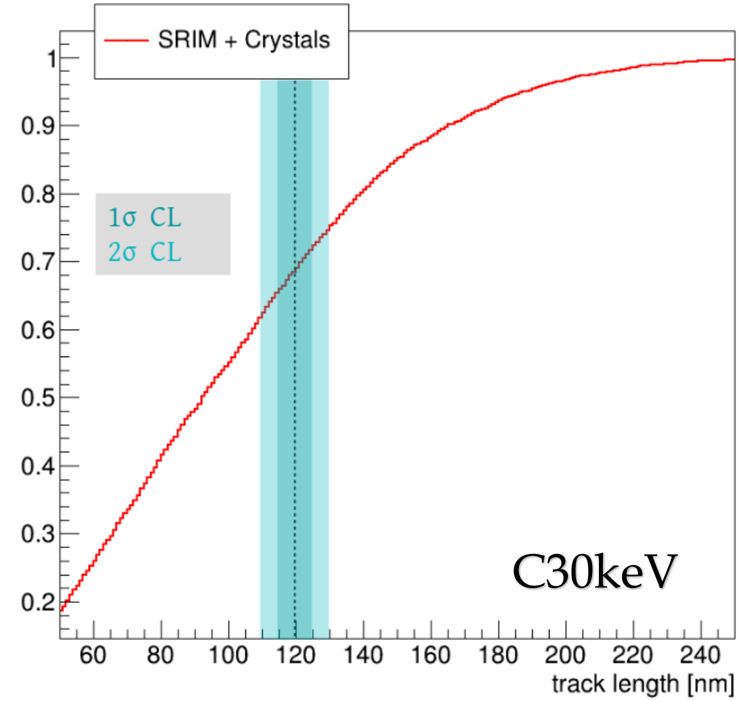
EFFICIENCY OF PLASMON ANALYSIS

$$\epsilon_{pl} = \frac{N_{multi-grain} + N_{moving}}{N_{tot}}$$

C100keV:	48 %
C60keV:	40%
C30keV:	31%

Plamon analysis essential for 30keV Carbon detection

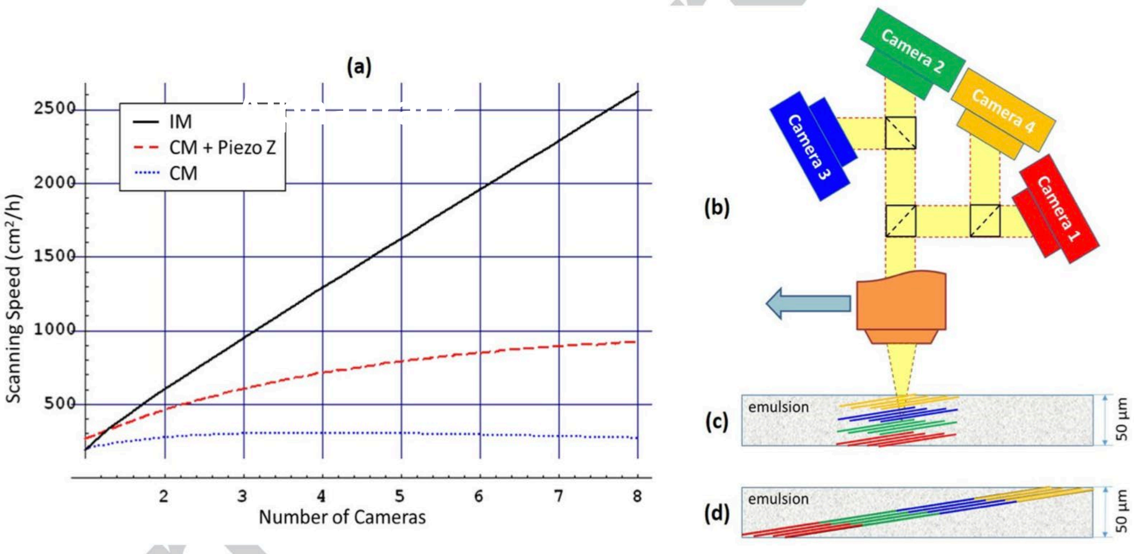
efficiency → track length threshold



track length threshold (120±5) nm

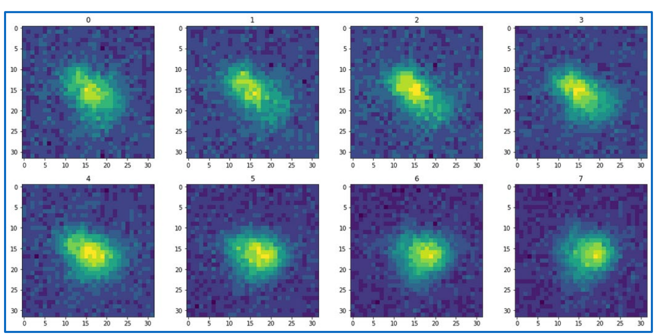
Further threshold lowering using U-NIT with larger granularity

Beyond Optical Resolution: New Technologies under test

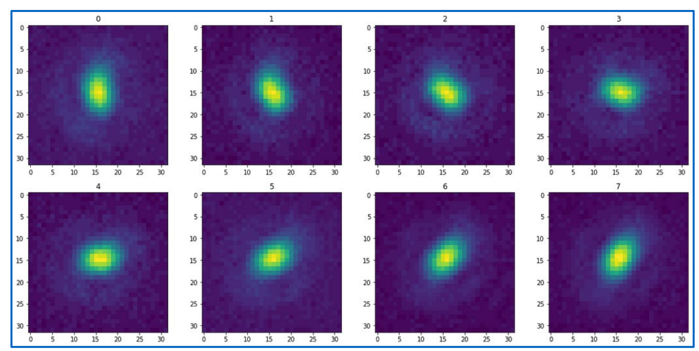


Multi-Camera System
+
Scanning technique using inclined focus plane

- Machine learning approach



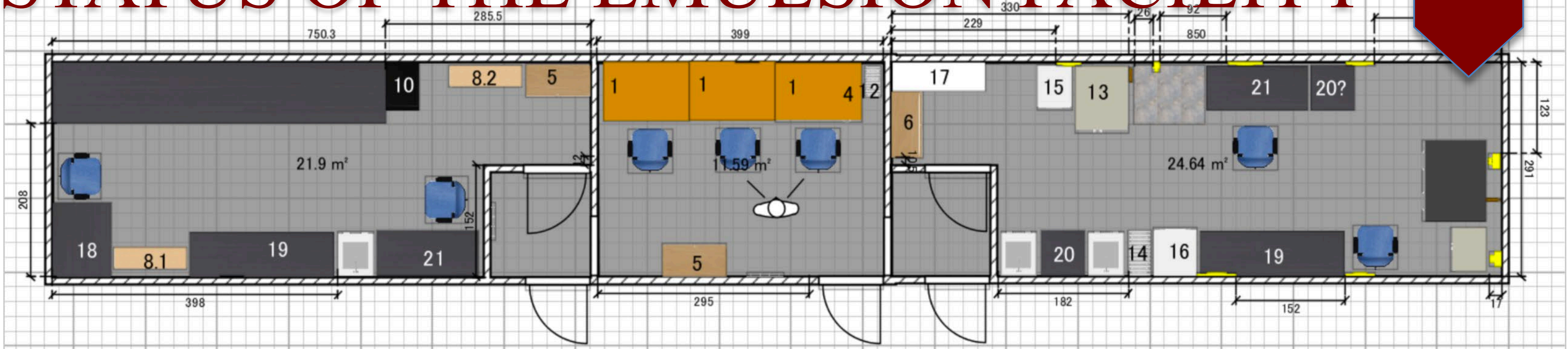
C100keV



Fog

- Localised Surface Plasmon Resonance
  using Colour Camera -> relation between colour and grain size

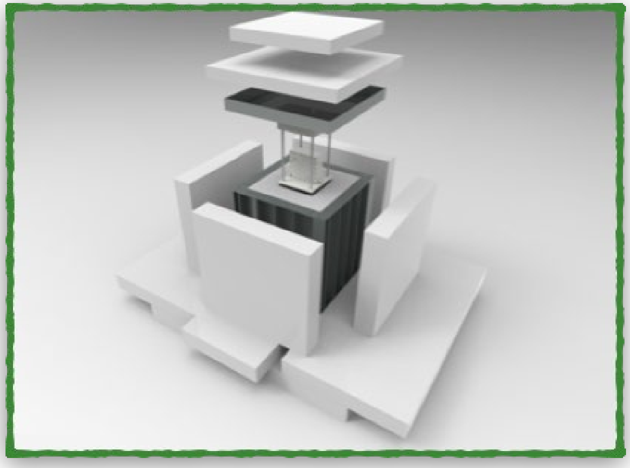
STATUS OF THE EMULSION FACILITY



Technical Test at LNGS

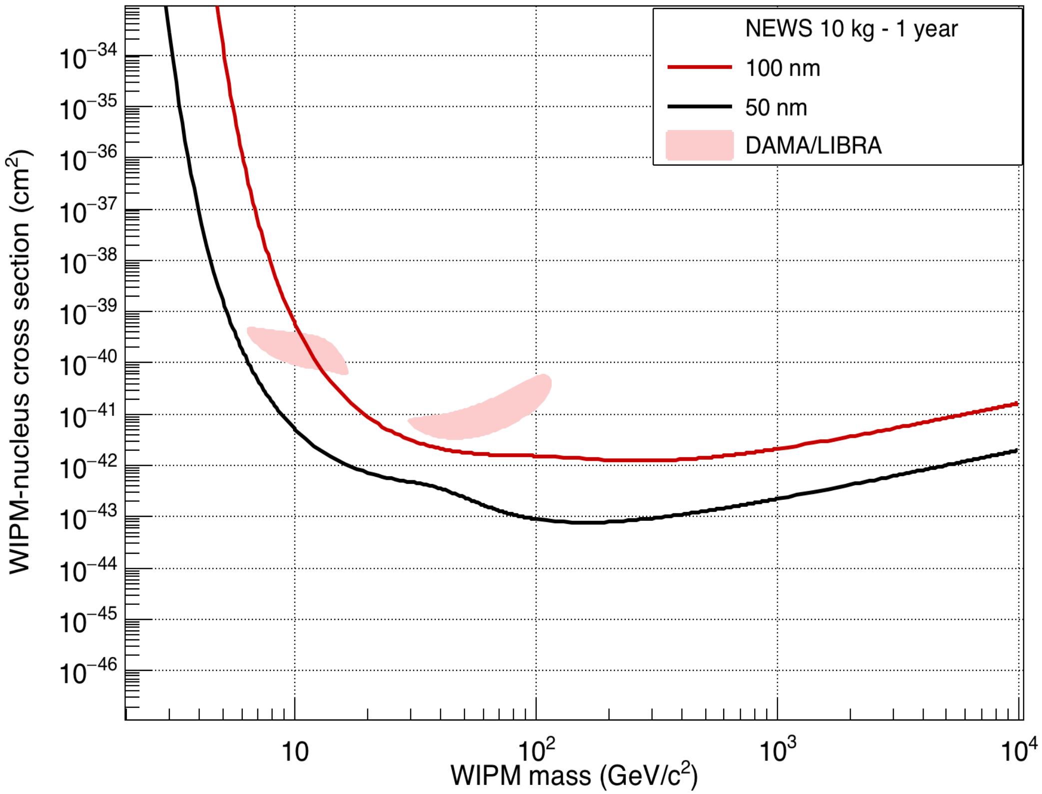
- **Aim**: measure the detectable background from environmental and intrinsic sources and validate estimates from simulations
- Confirmation of a negligible background will pave the way for the construction of a **pilot experiment** with an exposure on the **kg year** scale
- Pilot experiment will act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

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



NEWSdm SENSITIVITY

SENSITIVITY OF A PILOT EXPERIMENT



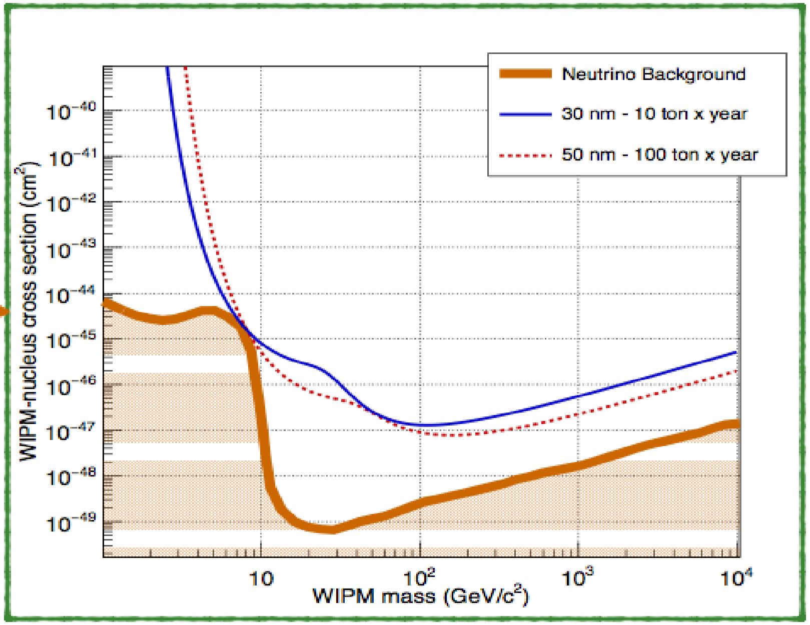
- 10kg x year experiment
- Zero background assumed
- Directionality not exploited

TOWARDS NEUTRINO FLOOR

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

NEWSdm Collaboration
Eur.Phys.J. C78 (2018) no.7, 578

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

Conclusion And Perspectives

- Nuclear emulsions with nanometric grains pave the way for a directional dark matter search with high sensitivity
- Breakthrough in readout technologies provide 3D and head/tail discrimination with high sensitivity
- Neutron background from intrinsic radioactivity negligible up to ~ 10 kg year, without any care on the material choice
- Machine learning approach to handle the complexity of the information
- Experimental tests this Summer in Gran Sasso to reproduce the full analysis chain
- Prepare a few kg scale detector as a demonstrator of the technology and for the first physics run
- TDR expected by Summer 2019