



# DIRECTIONAL DARK MATTER SEARCH WITH NEWS<sub>DM</sub>

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# NEWSdm COLLABORATION

Nuclear Emulsion WIMP Search directional measurement

81 physicists  
23 institutes



## JAPAN

Chiba, Nagoya, Toho, Tsukuba



## RUSSIA

LPI RAS Moscow  
JINR Dubna  
SINP MSU Moscow  
INR RAS Moscow  
NUST MISiS Moscow  
NRU HSE Moscow



## ITALY

LNGS, GSSI  
INFN: Napoli, Roma, Padova  
Univ.: Napoli, Roma, Padova,  
Potenza, Benevento



## SOUTH KOREA

Gyeongsang University



## TURKEY

METU Ankara



Website: [news-dm.lngs.infn.it](http://news-dm.lngs.infn.it)

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

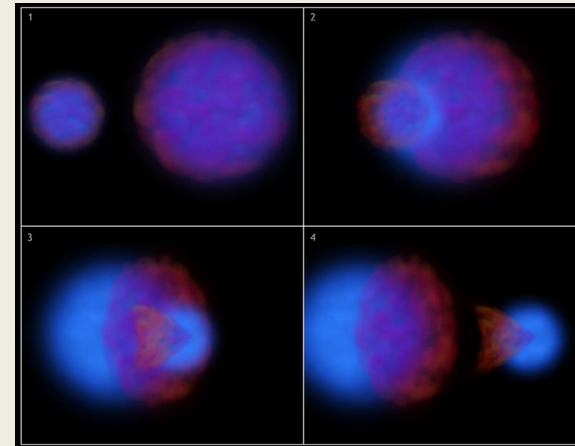
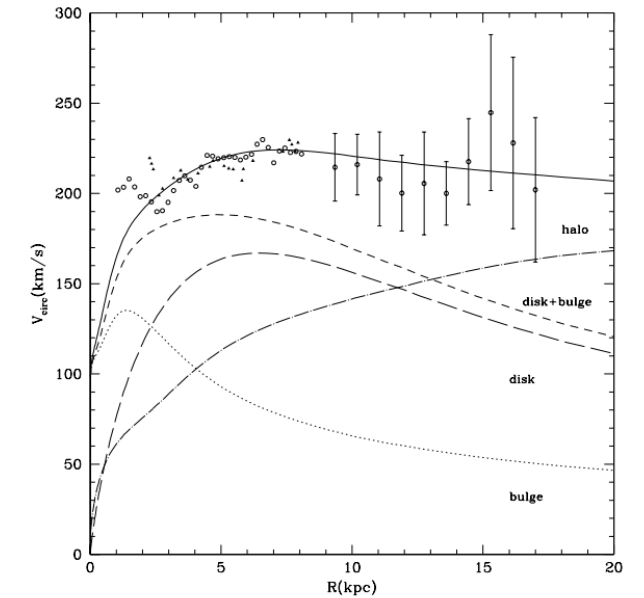
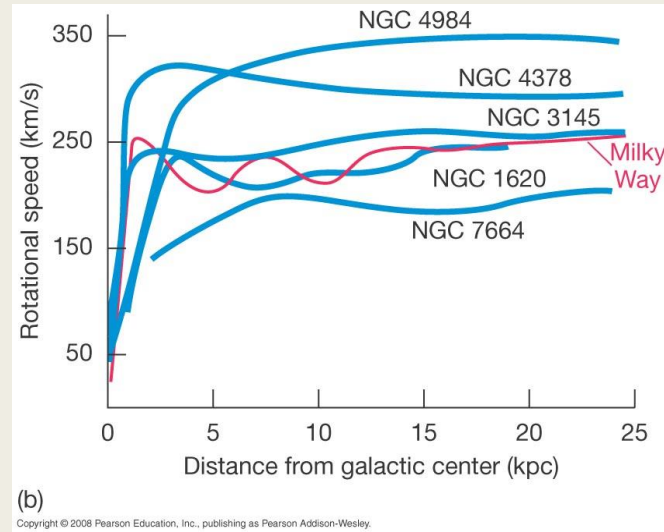
# Dark Matter

- Dark matter is a hypothetical form of matter thought to account for approximately 85% of the matter in the universe.

Main characteristics:

- *Stable* at the cosmological scale
- *Electrically neutral* but interacts gravitationally and (presumably) weakly
- *Non-relativistic and heavy*

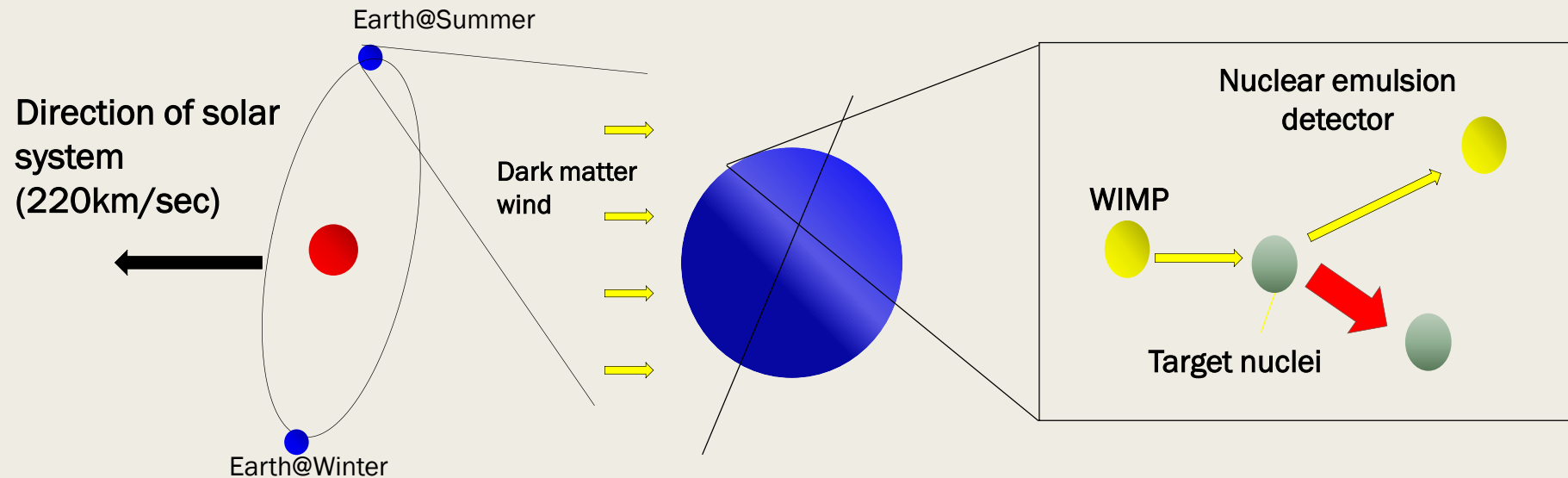
One of possible candidate is WIMP (Weakly Interacting Massive Particle)



Experimental evidences:

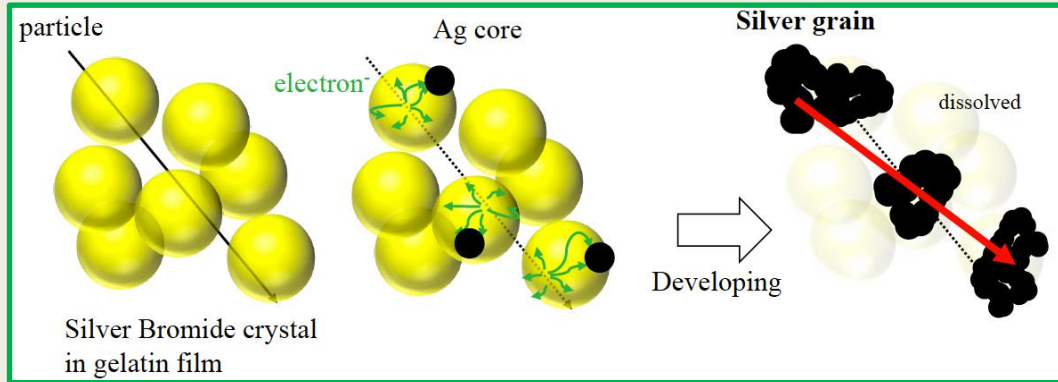
- Structures and rotational anomalies of galaxies
- Gravitational lensing
- Large-scale structures formation

# WIMP directional detection



- Strong correlation between the direction of WIMP and scattered nuclei → **strong signature** and **unambiguous proof** of the galactic DM origin
- Unique possibility to overcome the “neutrino floor”, where coherent neutrino scattering creates an irreducible background
- **Nuclear Emulsion** is a high-density solid-state medium → large mass with a compact detector

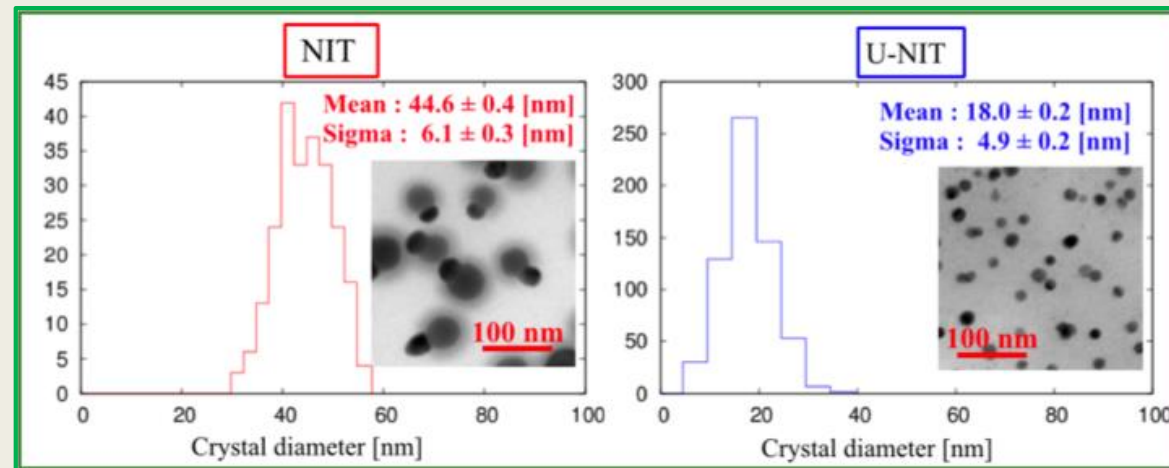
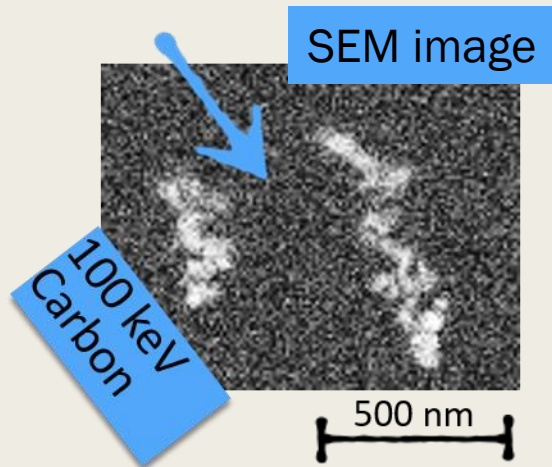
# NIT: Nano emulsion Imaging Trackers



A long history, from the discovery of the **Pion (1947)** to the discovery of  $\nu_\mu \rightarrow \nu_\tau$  oscillation in appearance mode (**OPERA, PRL 115 (2015) 121802**)

- Nuclear emulsions: AgBr crystals in organic gelatine
- Passage of charged particle produce *latent image*
- Chemical treatment make Ag grains visible

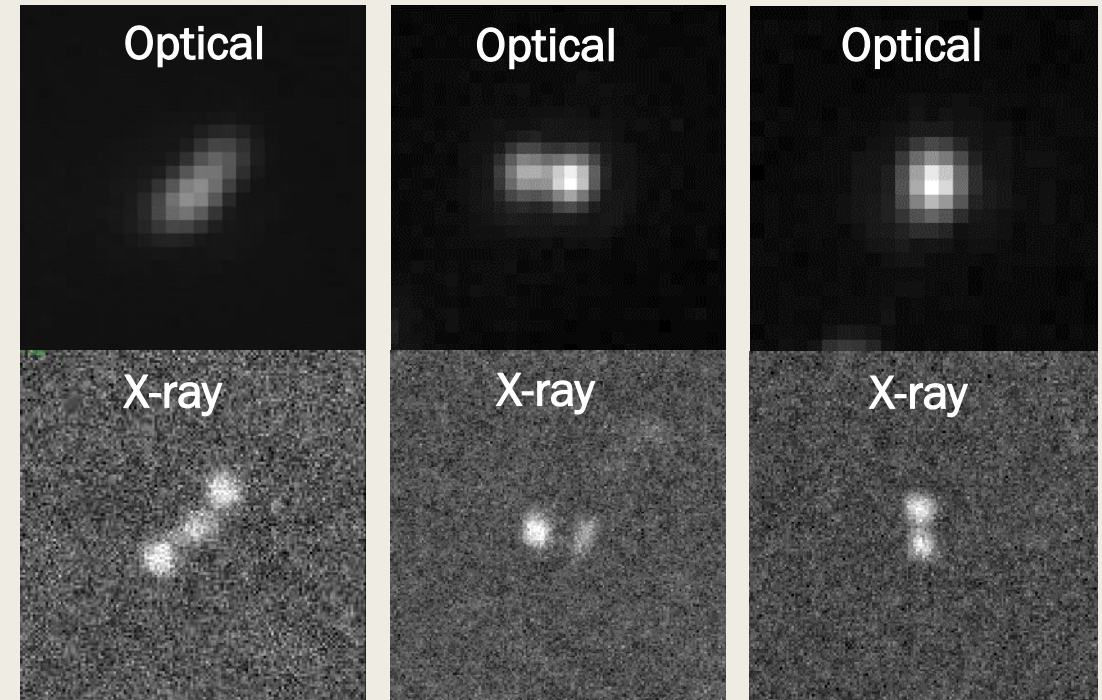
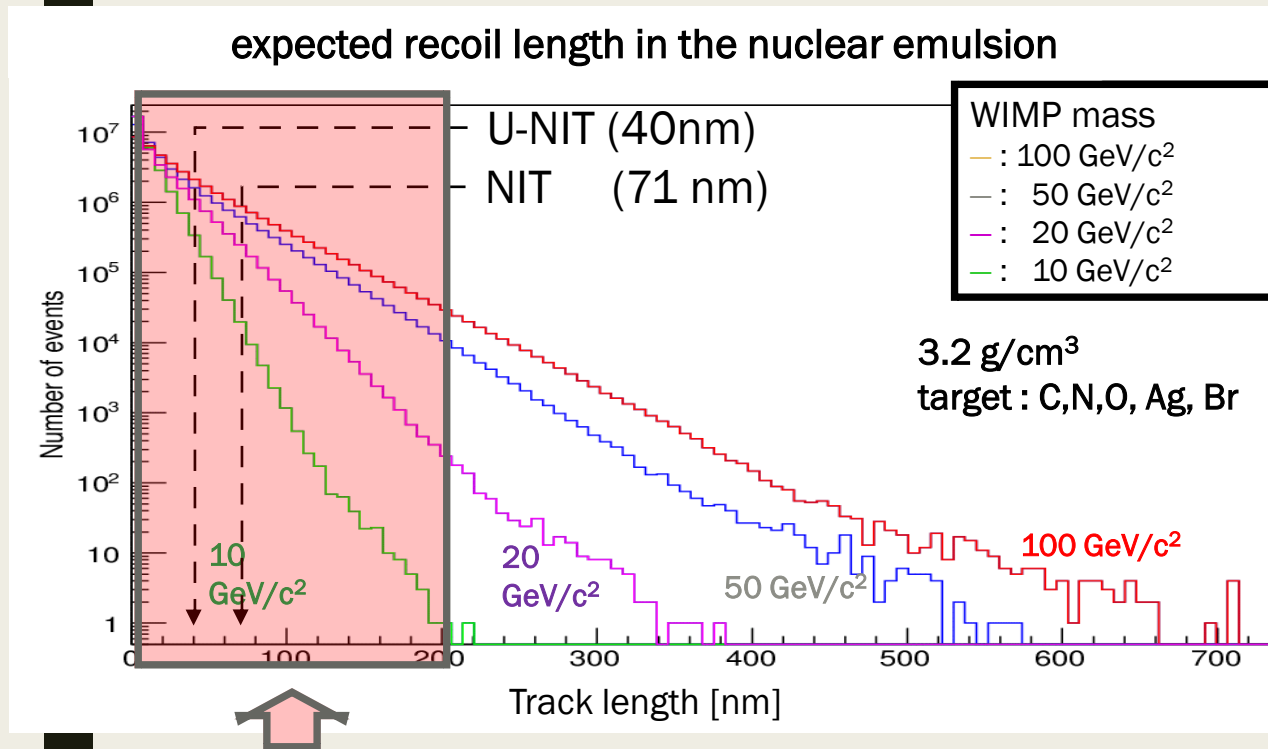
- New kind of emulsion for DM search
- Smaller crystal size



Granularity = 71 nm

Granularity = 40 nm

# Directional detection challenge



L = 380 nm

L = 265 nm

L = 160 nm

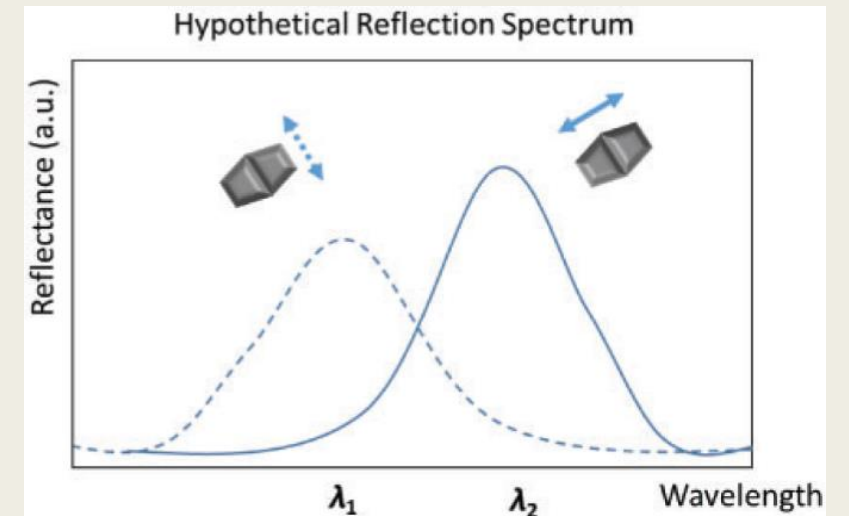
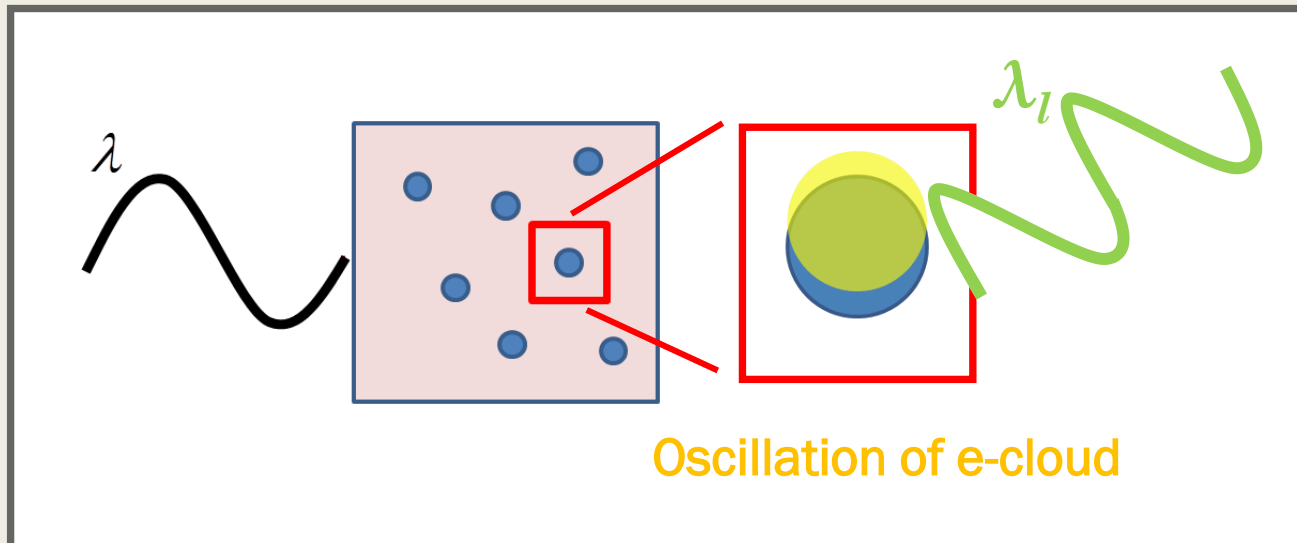
Inaccessible due to diffraction limit

Need **super-resolution** to measure tracks shorter than 200 nm



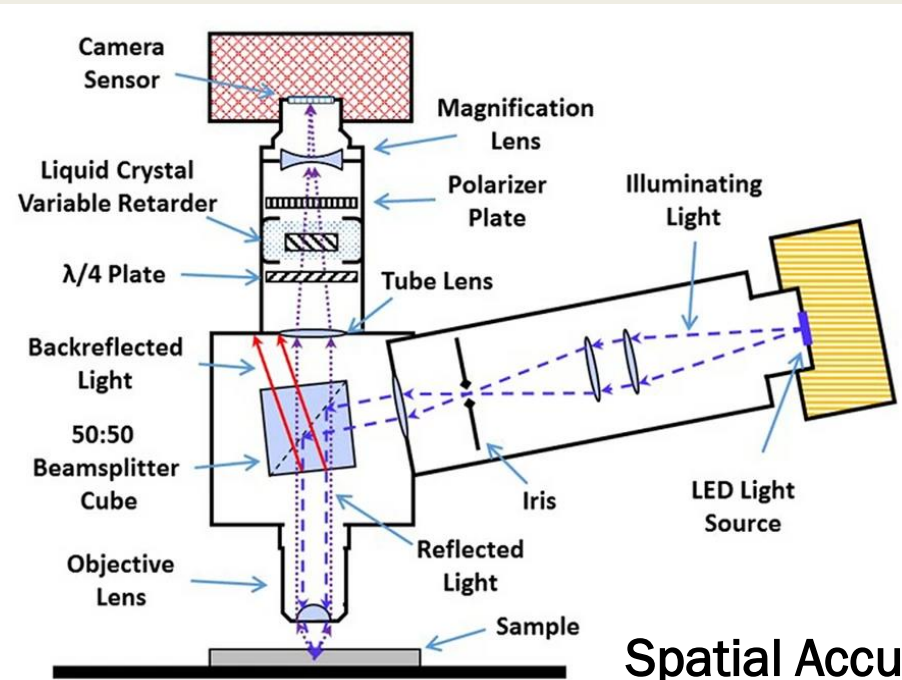
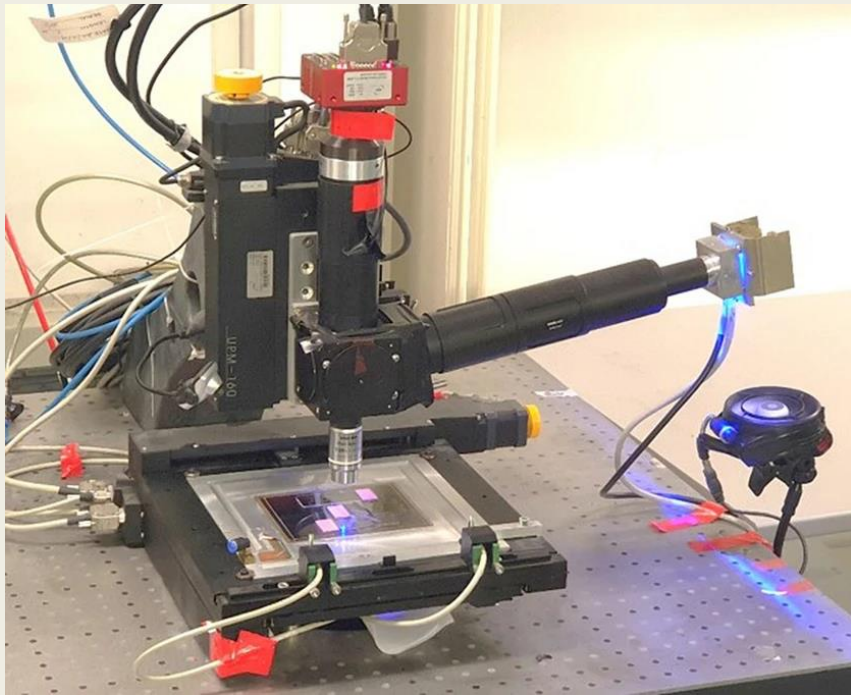
# Optical readout beyond the diffraction limit

- Super-resolution idea: use the **plasmon resonance** effect to overcome the diffraction limit:
  - *generated by a light wave trapped within conductive nanoparticles smaller than the wavelength of light*
  - *resonant frequency strongly depends on the composition, size, geometry, dielectric environment and distance between nanoparticles*
  - *occurs in the visible region for Ag and Au nanoparticles!*
  - *improve resolution by analyzing scattered light **polarization** and **spectrum***



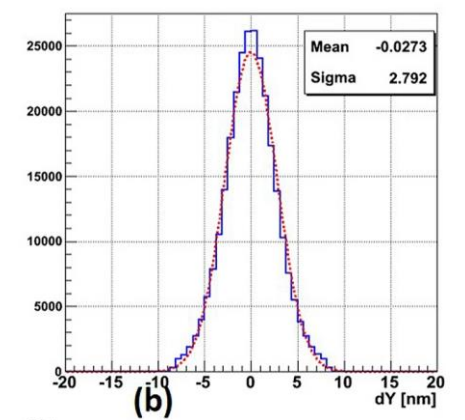
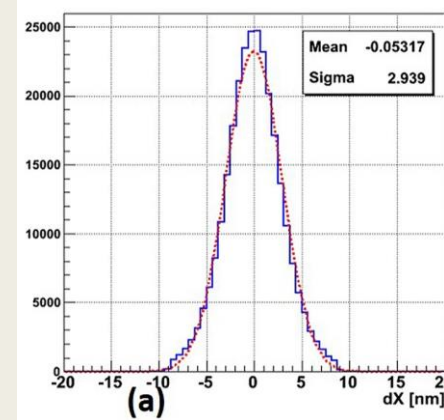
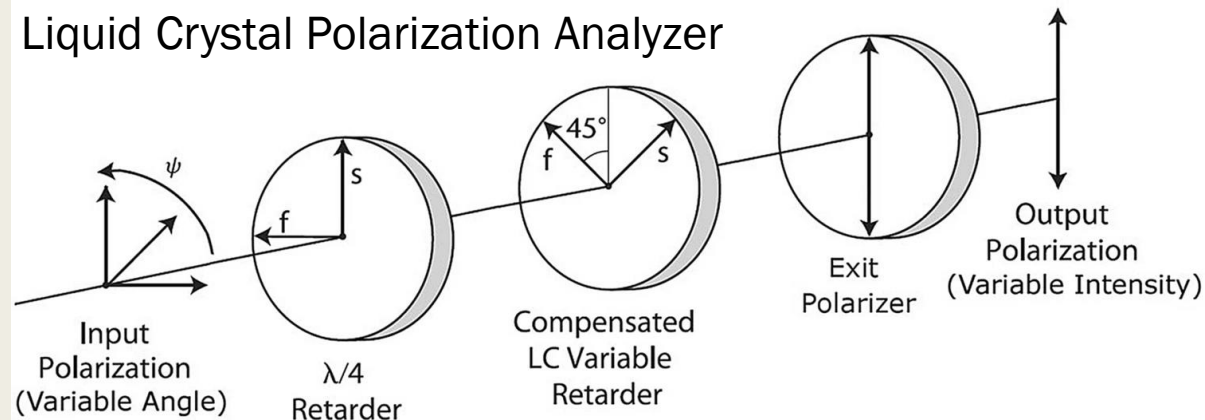
# Super-resolution microscope

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Spatial Accuracy = 3 nm

## Liquid Crystal Polarization Analyzer





Original scene  
(upolarized illumination)



Modulated (rotating polarizations)



Modulate the intensity of each pixel  
in the image:

$$I_{\theta} = a \cos[2(\theta - \varphi)] + b$$

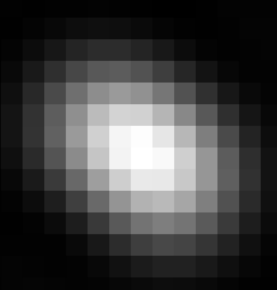
$\theta$  - polarization angle

$\varphi$  - pixel "phase",

$b$  - pixel brightness mean,

$a$  - pixel brightness change  
amplitude

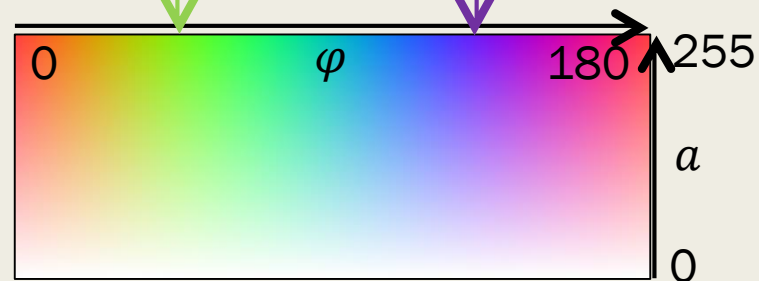
Microscope



Reconstructed scene



Joint Image  
Deconvolution



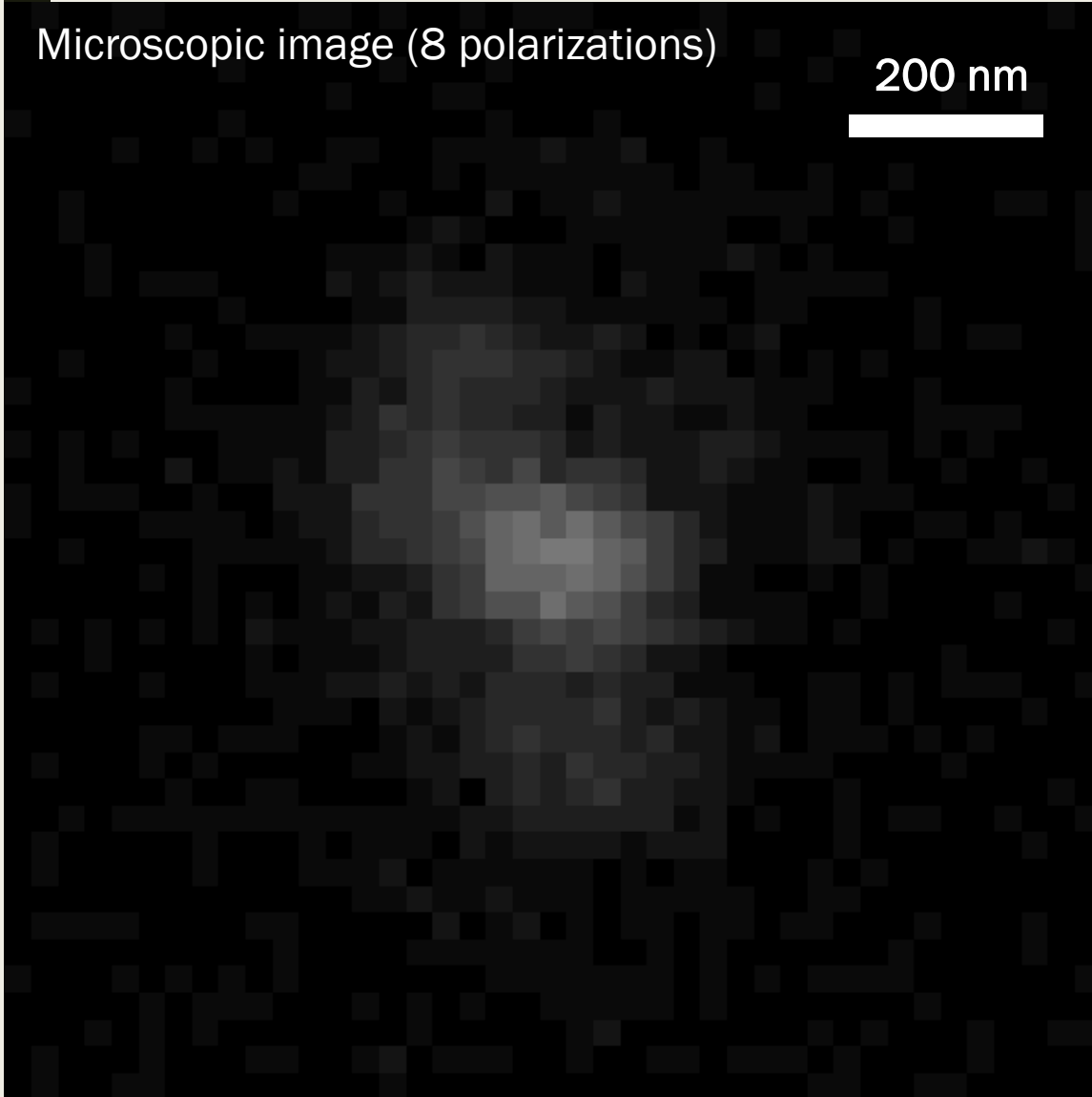
$a + b = \text{pixel brightness}$   
 $a = \text{pixel color saturation}$   
 $\varphi = \text{pixel color}$

# Joint image deconvolution

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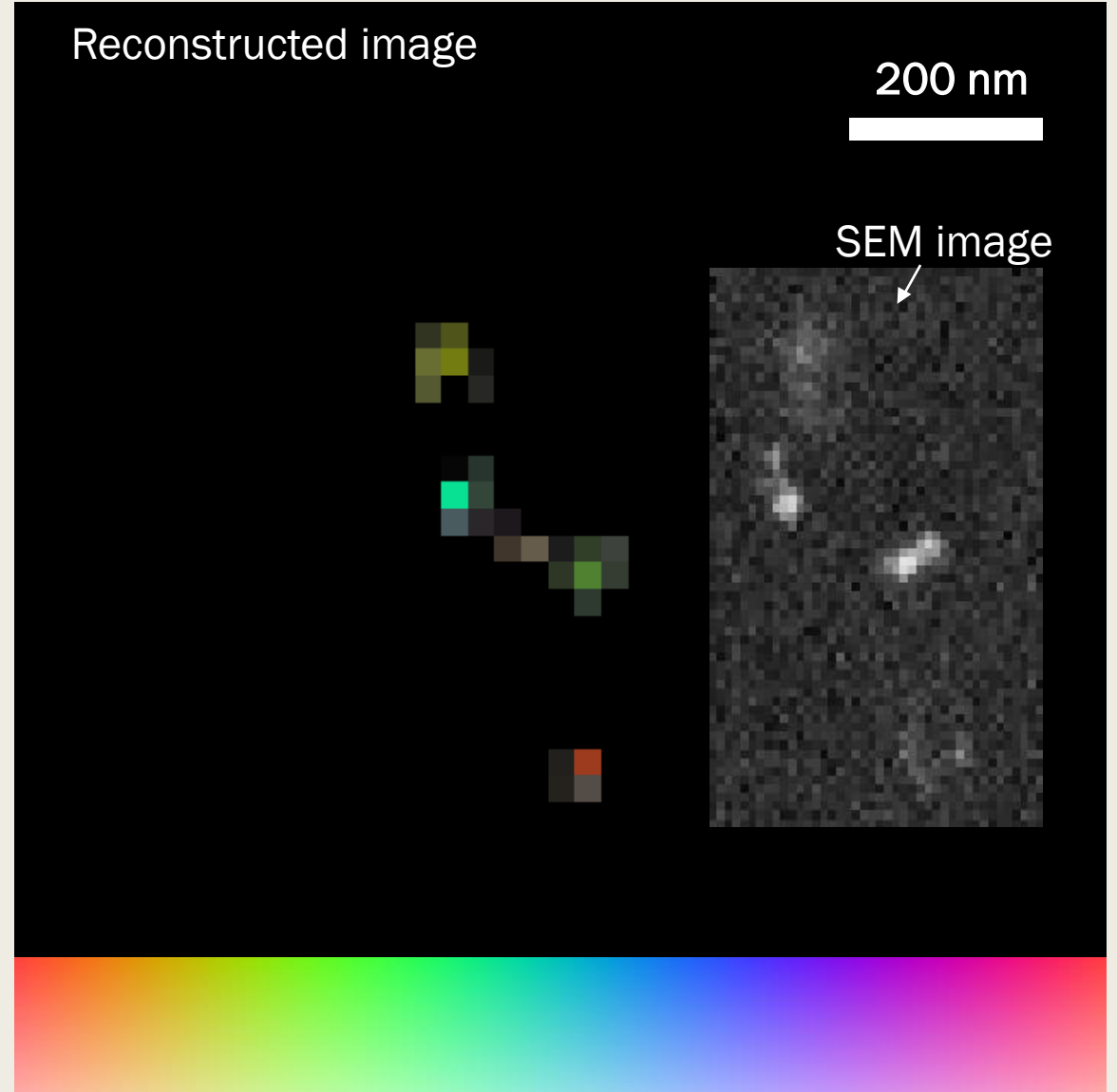
Microscopic image (8 polarizations)

200 nm



Reconstructed image

200 nm



# Joint image deconvolution

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Microscopic image (8 polarizations)

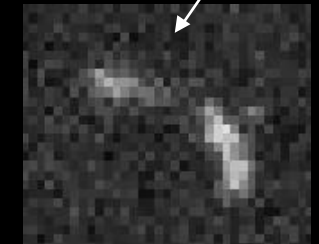
200 nm

Barycenter  
Shift = 48 nm

Reconstructed image

200 nm

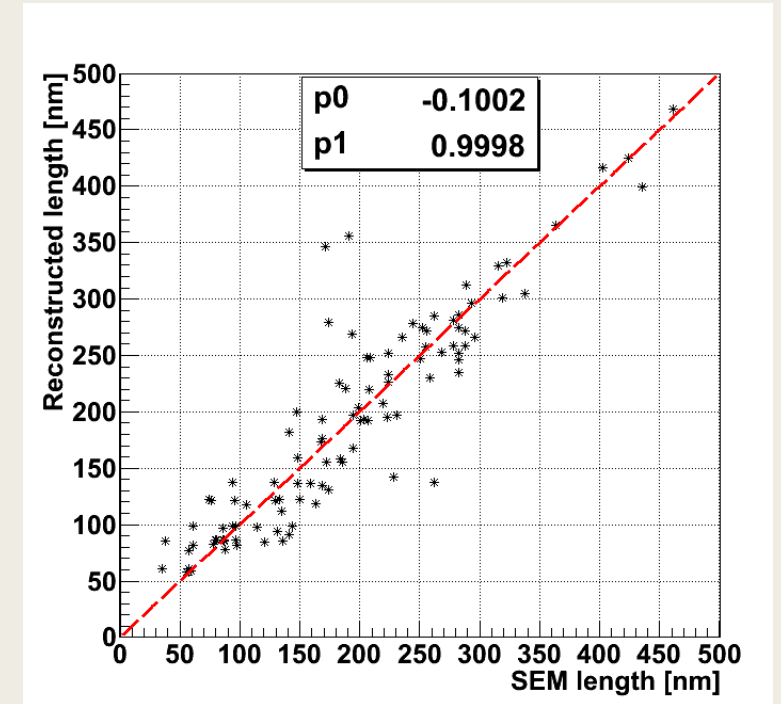
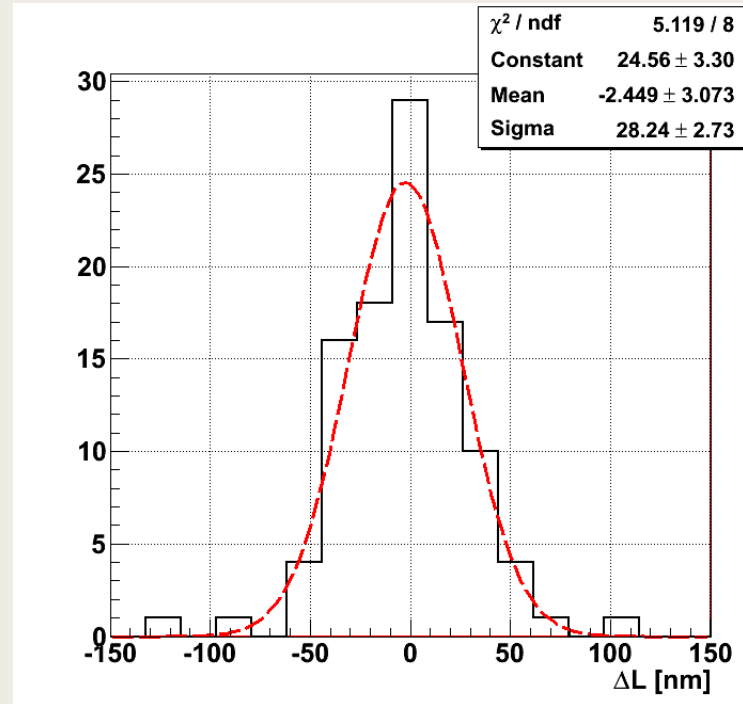
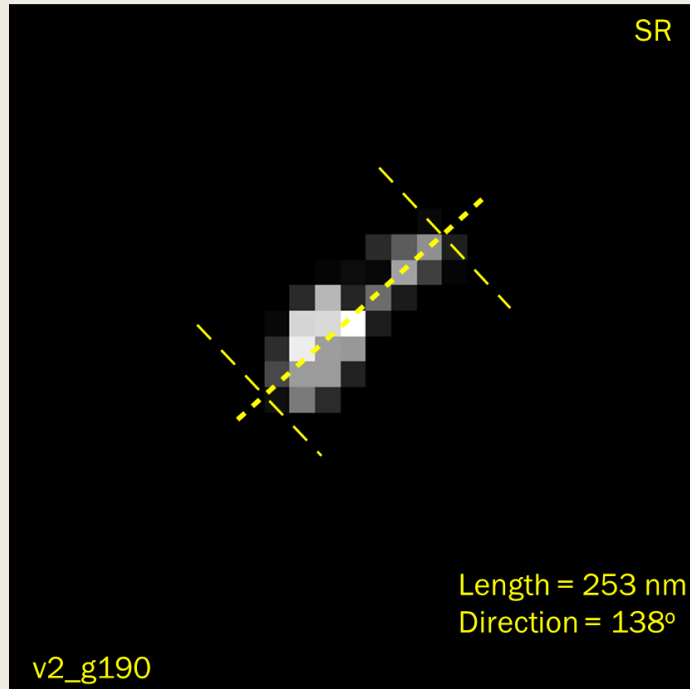
SEM image





# Joint Image Deconvolution

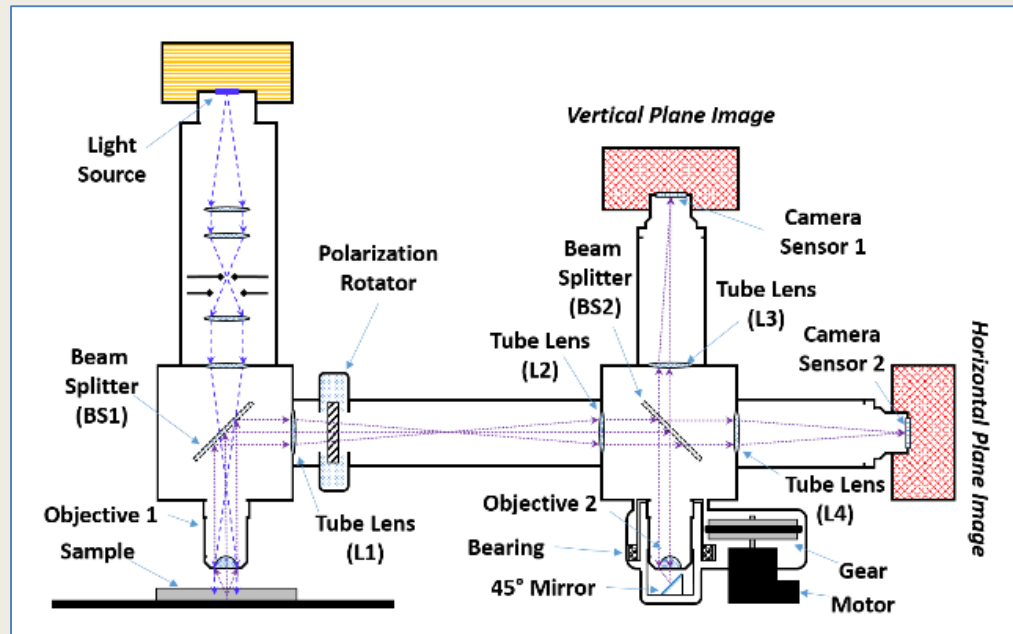
## Event Length comparison with SEM



Length accuracy: 28 nm  $\approx$  pixel size (27.5 nm)  
Spatial resolution: 80 nm (Nyquist theorem)

Pearson Coefficient	Matched	Unmatched
Length	0.912	-0.009
Width	0.713	-0.007

# Measurement in 3D



International Patent No. WO/2018/122814

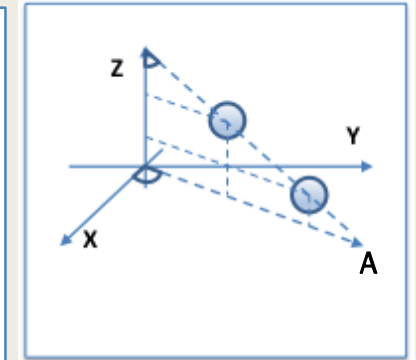
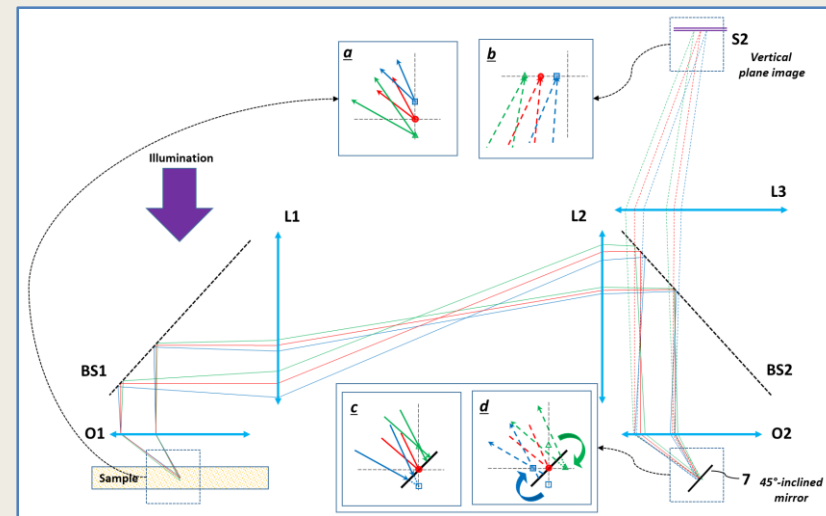
World Intellectual Property Organization [CH] | <https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2018122814>

**1. (WO2018122814) METHOD AND OPTICAL MICROSCOPE FOR DETECTING PARTICLES HAVING SUB-DIFFRACTIVE SIZE**

PCT Biblio. Data | Description | Claims | Drawings | National Phase | Notices | Documents

Latest bibliographic data on file with the International Bureau [Submit observation](#) [PermaLink](#)

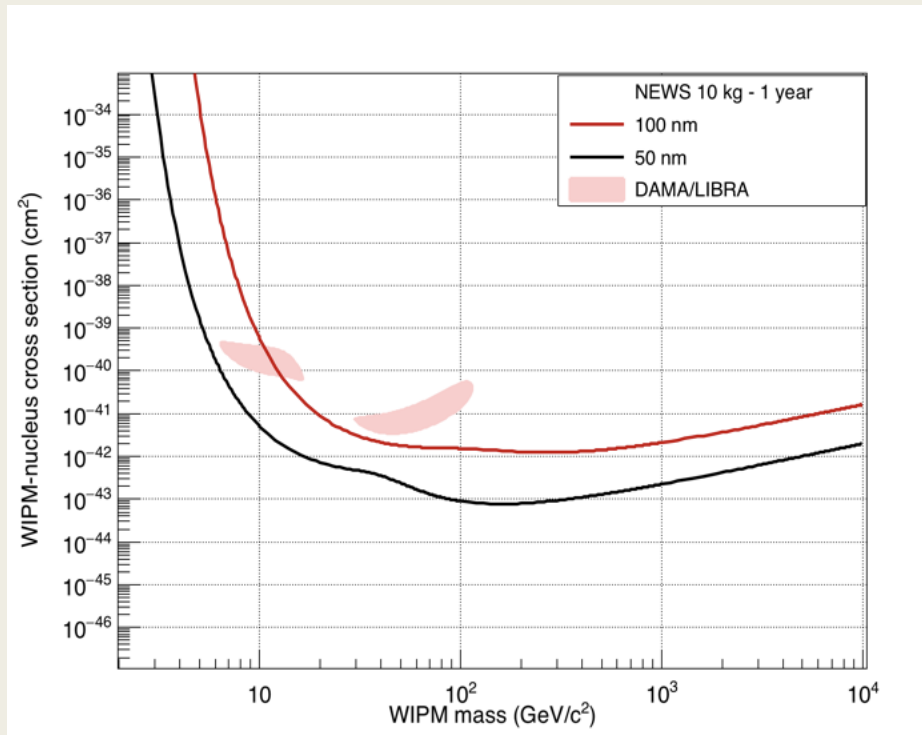
Pub. No.: WO/2018/122814 International Application No.: PCT/IB2017/058544  
 Publication Date: 05.07.2018 International Filing Date: 30.12.2017  
 IPC: G02B 21/00 (2006.01), G02B 21/36 (2006.01) [?](#)  
 Applicants: ISTITUTO NAZIONALE DI FISICA NUCLEARE [IT/IT]; Via Enrico Fermi, 40 00044 Frascati (rM), IT  
 Inventors: DE LELLIS, Giovanni; IT  
 ALEXANDROV, Andrey; IT  
 TIOUKOV, Valeri; IT  
 D'AMBROSIO, Nicola; IT



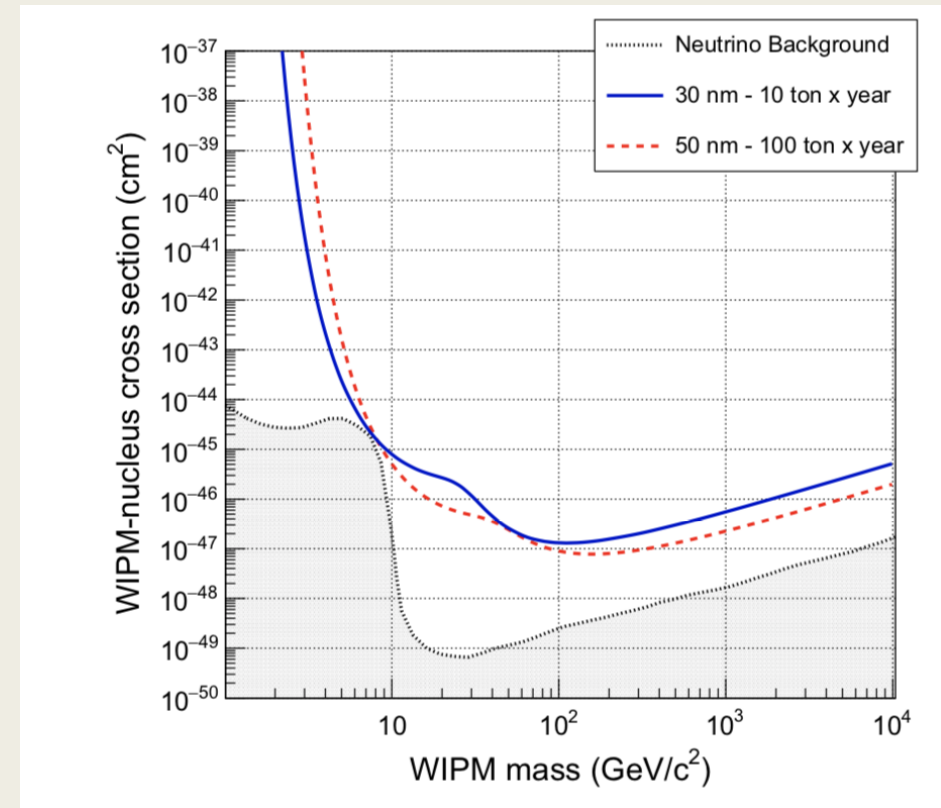
Two focal planes:  
 Horizontal: XY  
 Vertical: ZA

# NEWSdm intermediate and final goals

- First **directional** dark matter detector with a 10 kg solid target
- Explore the DAMA region with a completely different technique based on the *visual* observation of recoil tracks in emulsion
- First high-sensitivity spin-independent measurement with a directional approach
- First step in the application of the emulsion technology, scalable to larger masses
- Longer term: overcome the neutrino floor



90% C.L. upper limits for the NEWSdm detector with an exposure of 10 kg year in the zero-background hypothesis



90% C.L. upper limits for the NEWSdm detector with an exposure of 10 ton year in the zero-background hypothesis





# THANK YOU FOR ATTENTION!

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Andrey ALEXANDROV (on behalf of the NEWSdm collaboration)

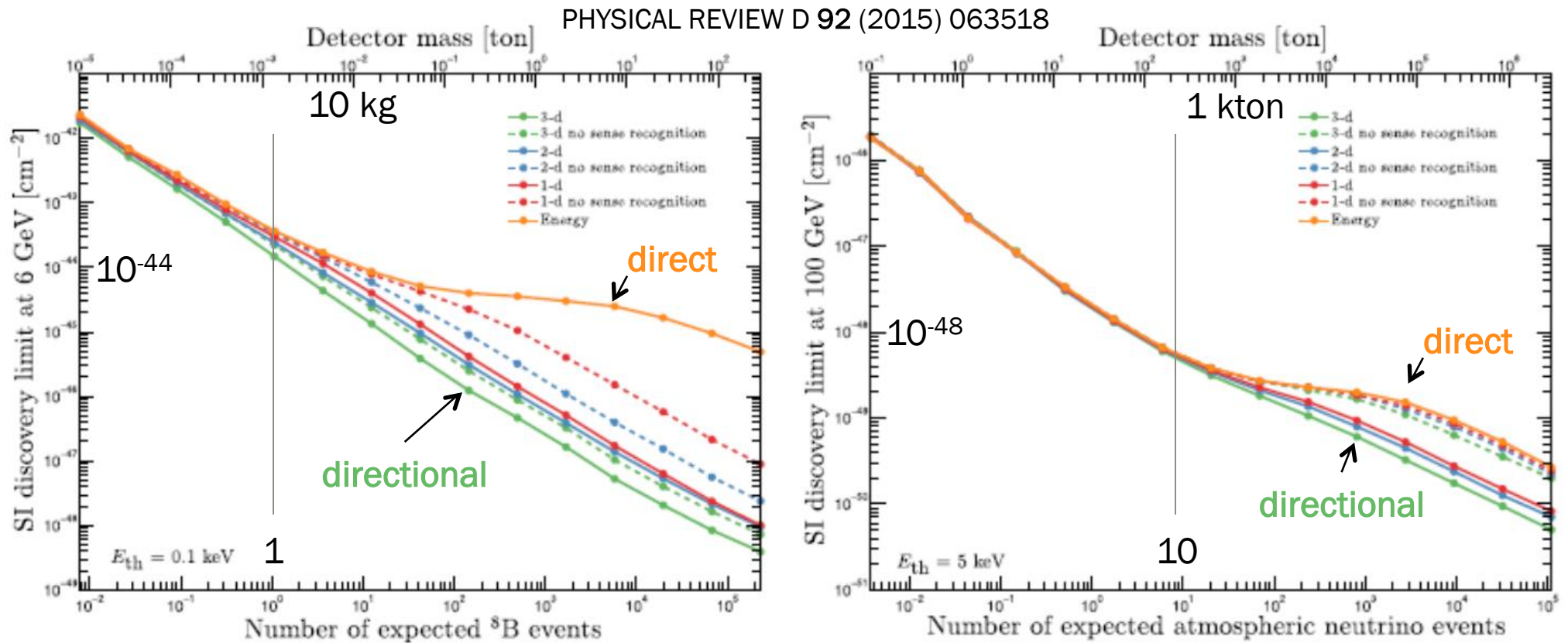
[andrey.alexandrov@na.infn.it](mailto:andrey.alexandrov@na.infn.it)

The image features two thick black L-shaped corner brackets. One is positioned in the top-left corner, and the other is in the bottom-right corner. They are oriented towards each other, framing the central text.

**BACKUP SLIDES**



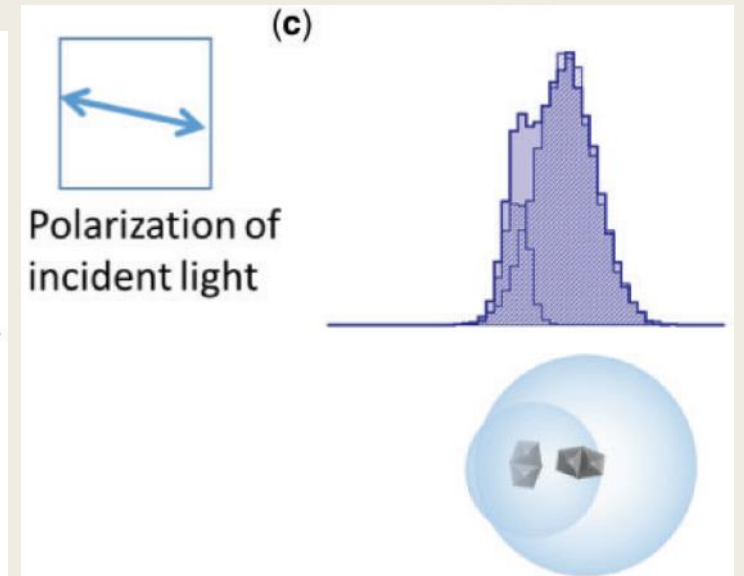
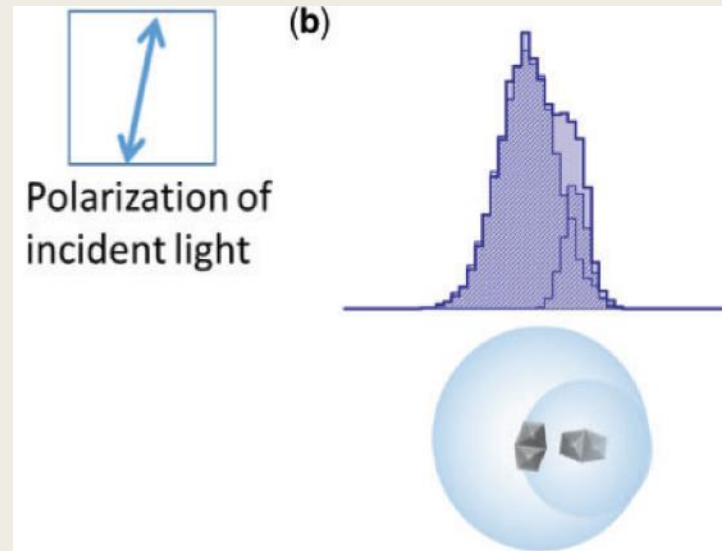
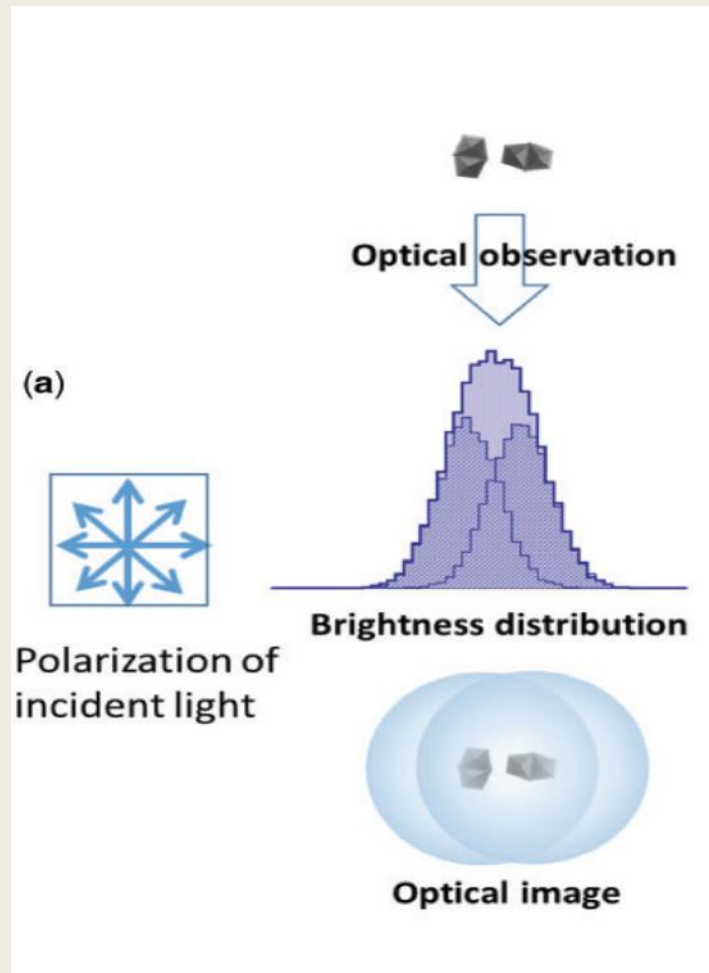
# Importance of the directional detection



Need 3D with sense recognition for best results!



# Optical readout beyond the diffraction limit



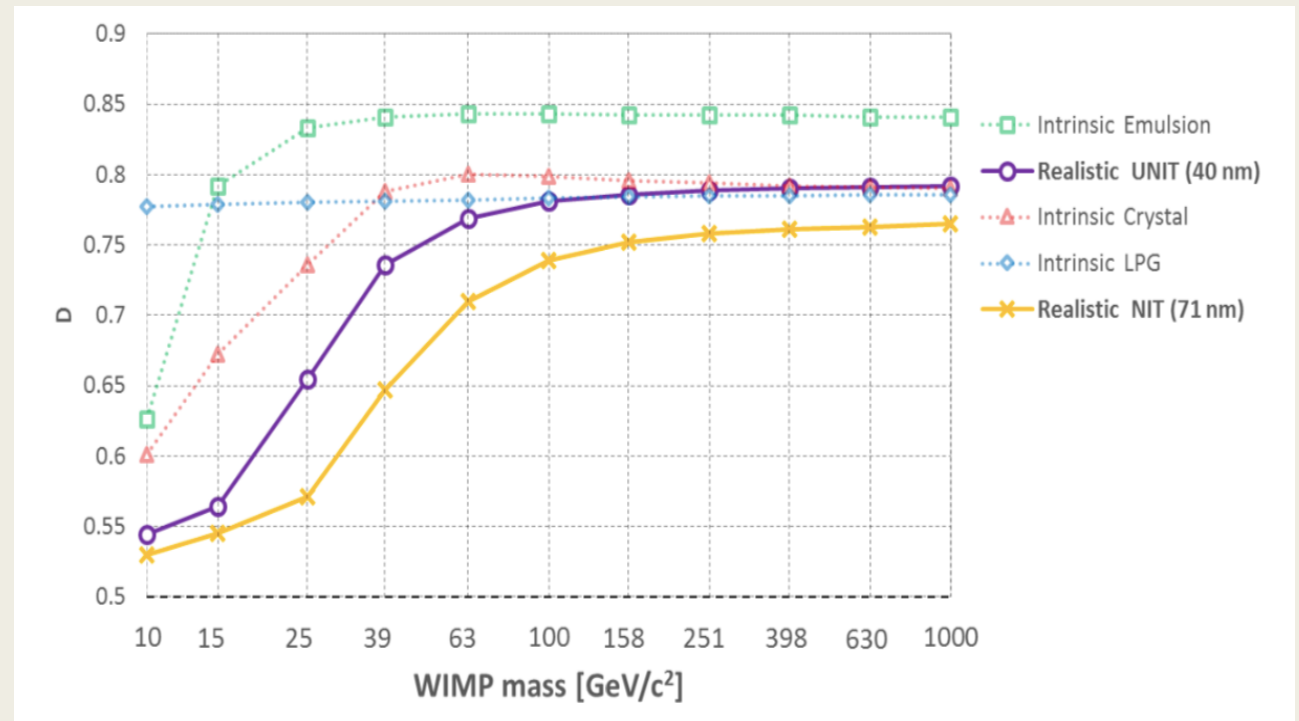
*PTEP*, Vol. 2019 Issue 62019, 063H02

# Directionality preservation of nuclear recoils

- Performance in the measurement of the recoil direction and comparison with other techniques
- Simulation of nuclear emulsion granularity: volume filled with AgBr crystals described as spheres of diameters  $44 \pm 7$  nm for NIT,  $25 \pm 4$  nm for U-NIT

- Evaluation of energy-weighted cosine distribution

$$D = \frac{\sum_{i=0}^{N_{collisions}} \Delta E_i \cos \theta_i}{\sum_{i=0}^{N_{collisions}} \Delta E_i} = \frac{\langle \Delta E \cos \theta \rangle_{track}}{\langle \Delta E \rangle_{track}}$$

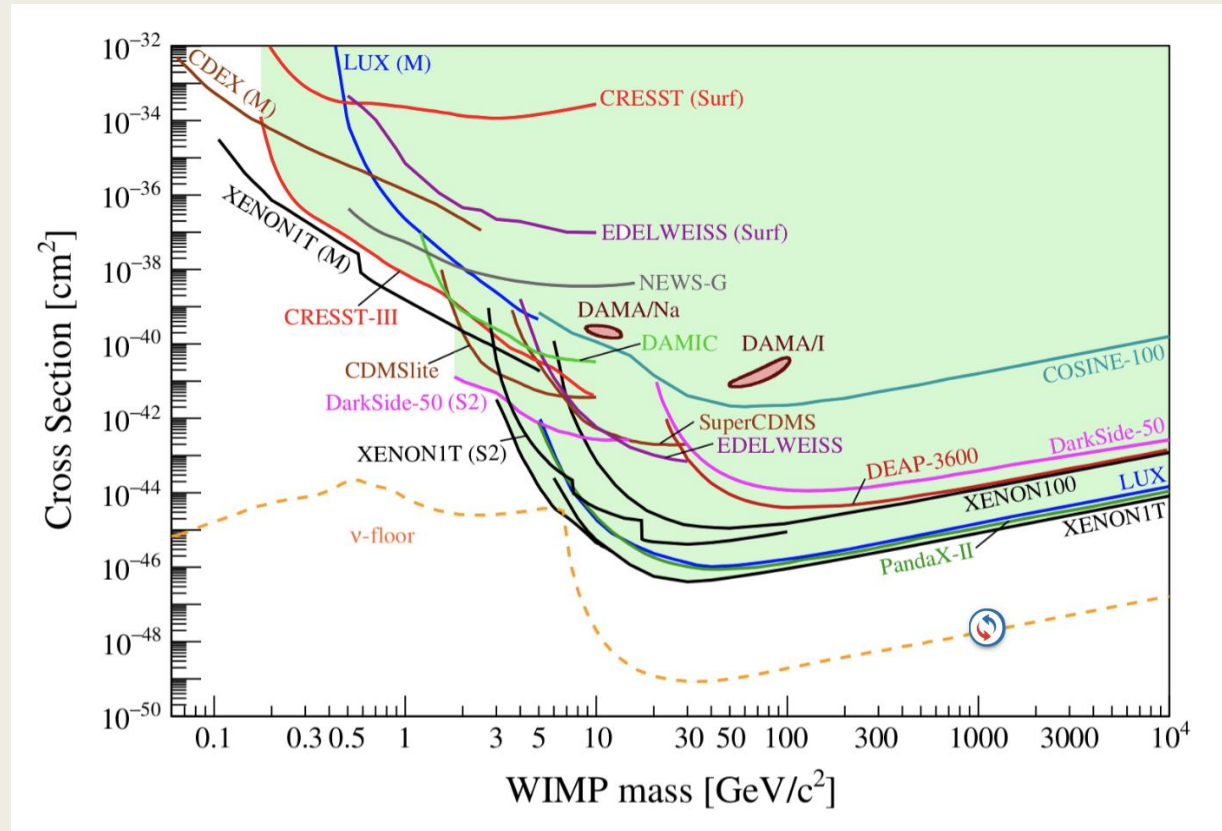


Realistic distribution of mean values of weighted-cos $\vartheta$  for NIT and U-NIT, compared with other detectors

A. Alexandrov, G. De Lellis, A. Di Crescenzo, A. Golovatiuk and V. Tioukov, «Directionality preservation of nuclear recoils in an emulsion detector for directional dark matter search» JCAP 04 (2021) 047

# Direct Dark Matter searches

- Current status of searches for spin-independent elastic WIMP-nucleus scattering assuming the standard parameters for an isothermal WIMP halo



Direct Detection of Dark Matter – APPEC Committee Report

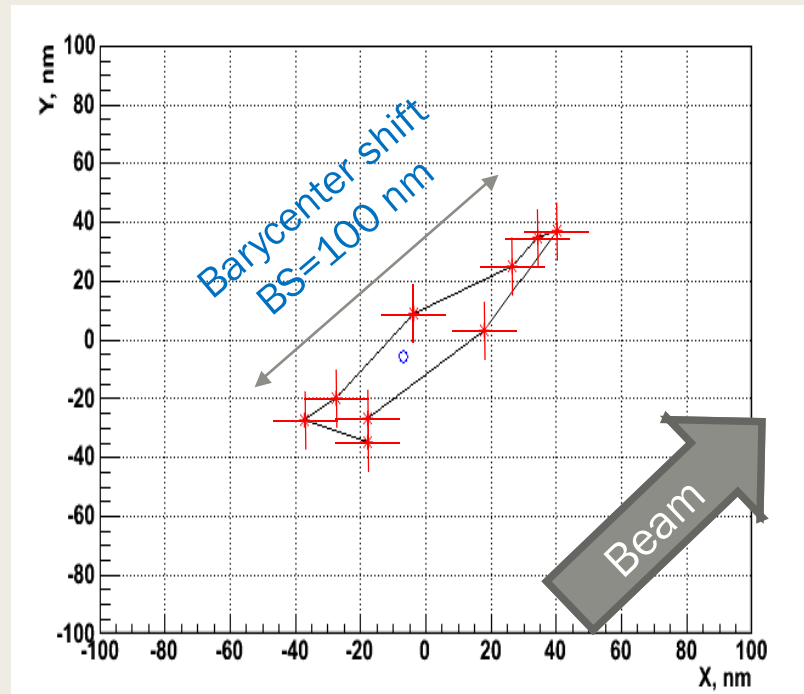
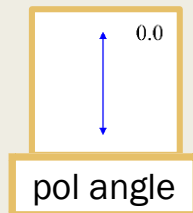
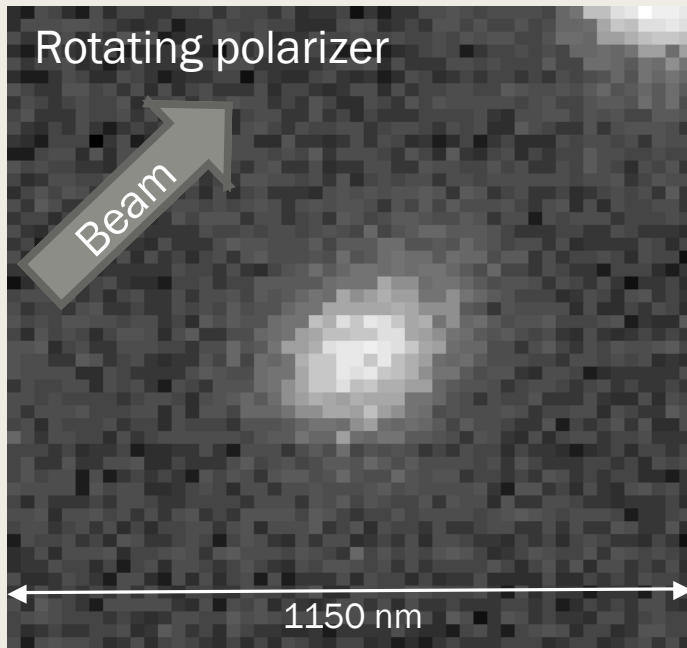
[https://www.appec.org/wp-content/uploads/2021/04/appec\\_dm\\_report\\_2020\\_ga\\_approved.pdf](https://www.appec.org/wp-content/uploads/2021/04/appec_dm_report_2020_ga_approved.pdf)

arXiv: 2104.07634



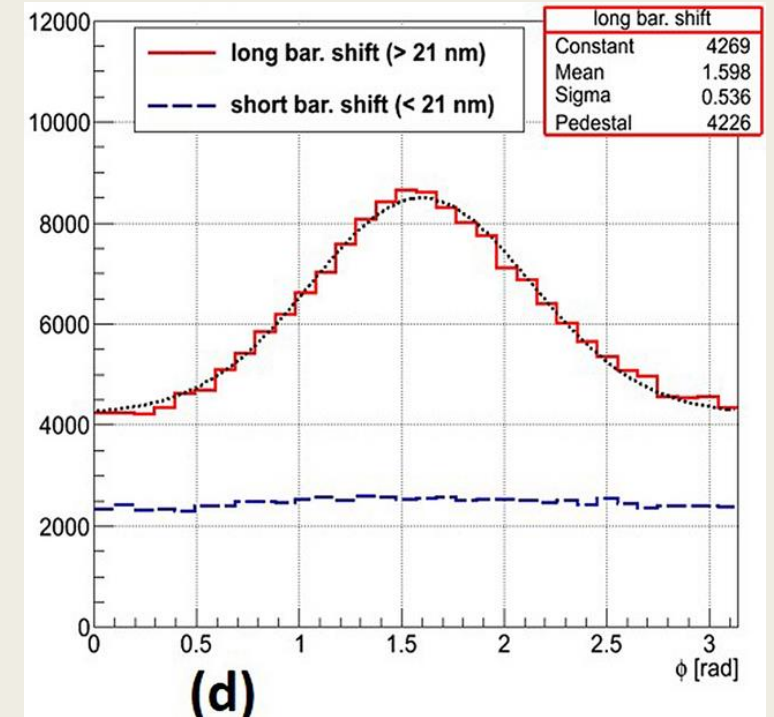
# Barycenter shift analysis

NIM A 824 (2016) 600–602



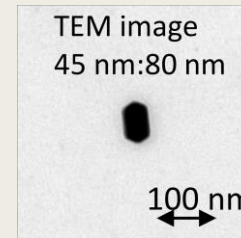
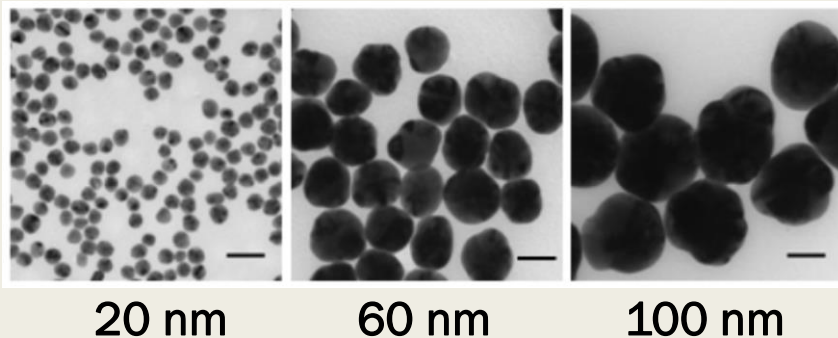
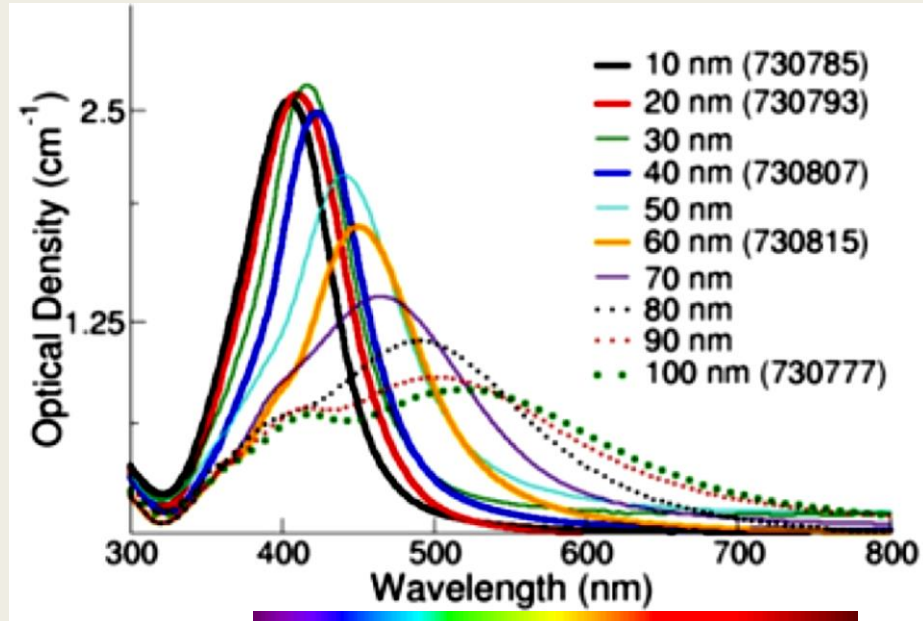
Carbon ion  
100 keV

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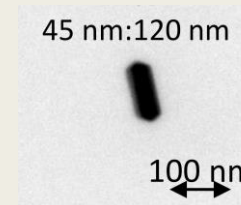
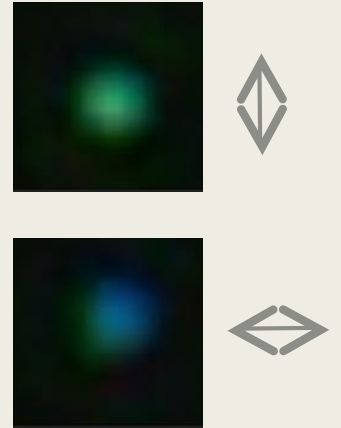
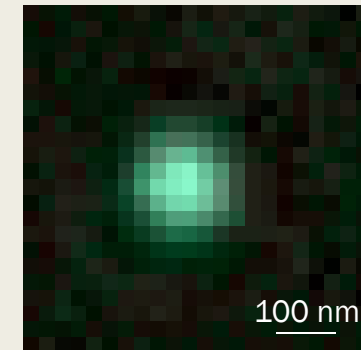
Carbon ions  
60 keV

# Plasmon resonance wavelength dependency



~45 nm : blue  
~80 nm : green

\*polarization rotating



~45 nm : blue  
~120 nm : orange

\*polarization rotating

