# DIRECTIONAL DARK MATTER SEARCH WITH NEWSDM

Andrey ALEXANDROV (on behalf of the NEWSdm collaboration)

I.N.F.N. and University of Naples, Italy
National University of Science and Technology 'MISiS', Moscow, Russia
Lebedev Physical Institute (LPI RAS), Moscow, Russia

# 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

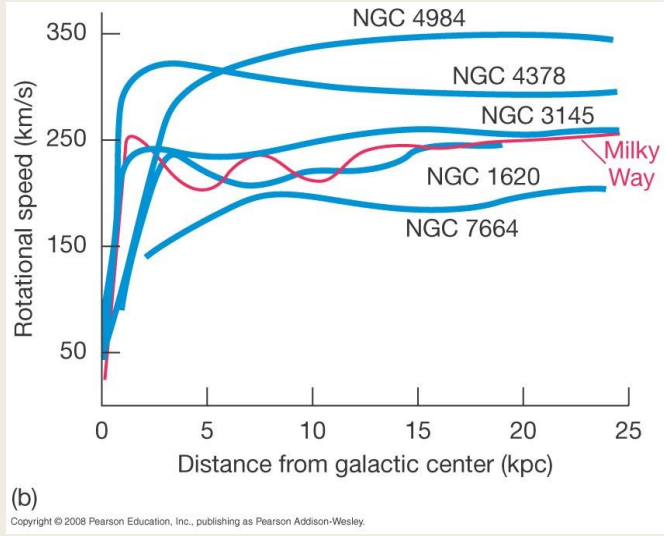
**TURKEY**
METU Ankara

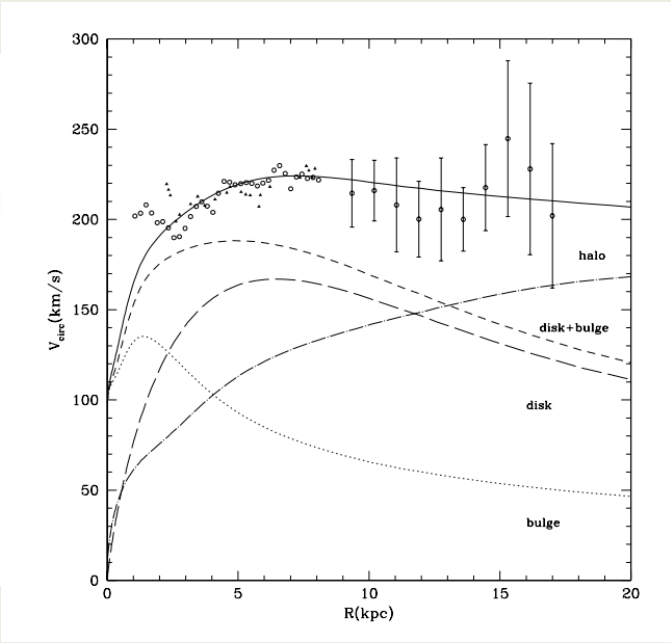
Website: news-dm.lngs.infn.it

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

# Dark Matter

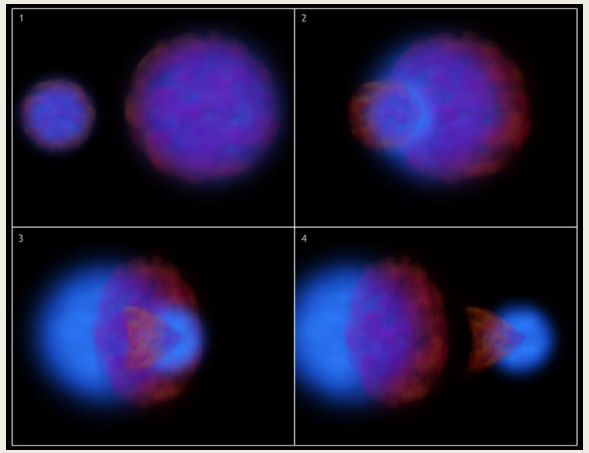
- Dark matter is a hypothetical form of matter thought to account for approximately 85% of the matter in the universe.




Main characteristics:

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

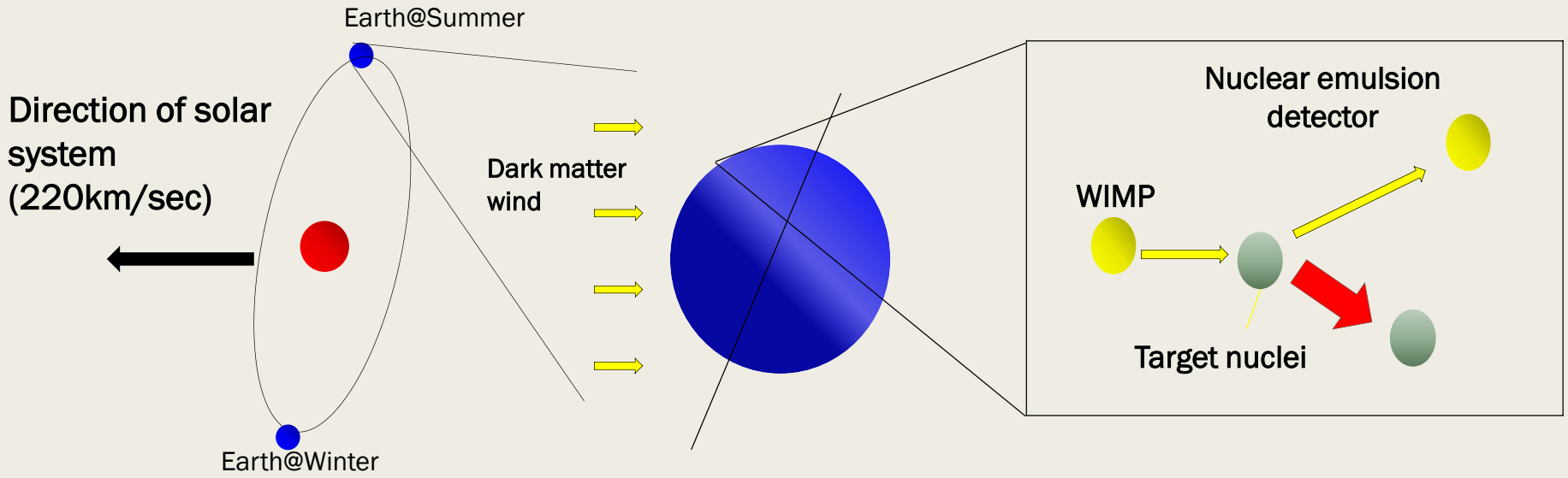


One of possible candidate is WIMP (Weakly Interacting Massive Particle)

**Experimental evidences:**

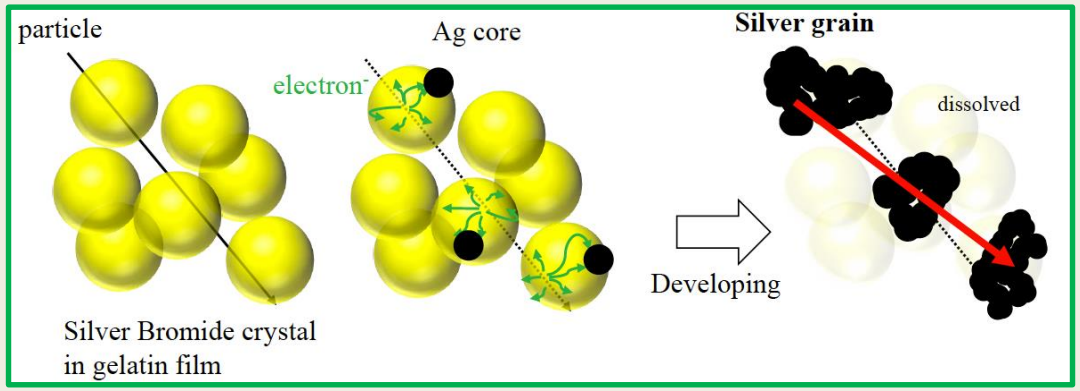
- Structures and rotational anomalies of galaxies
- Gravitational lensing
- Large-scale structures formation

# 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

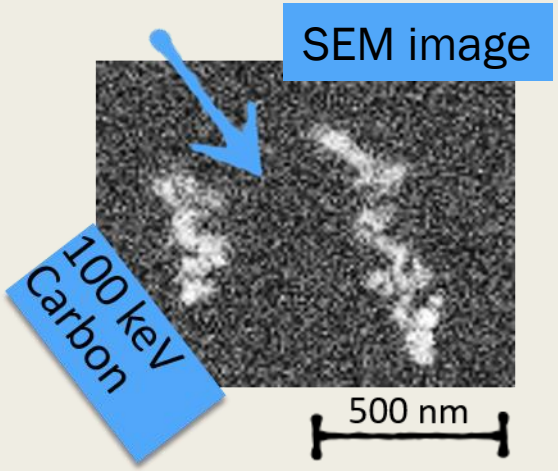
# NIT: Nano emulsion Imaging Trackers

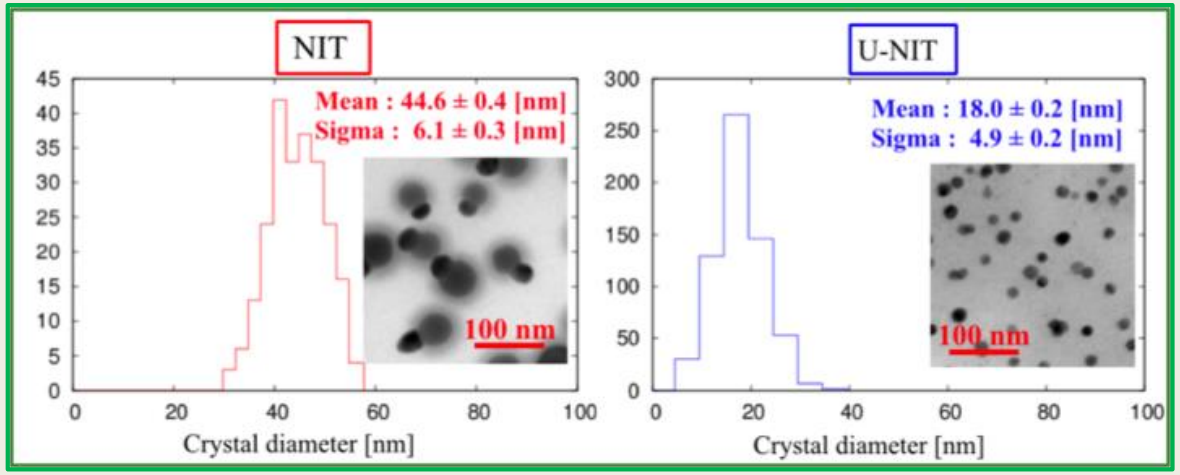



A long history, from the discovery of the Pion (1947) to the discovery of $\nu_\mu \rightarrow \nu_\tau$ oscillation in appearance mode (OPERA, PRL 115 (2015) 121802)

- 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

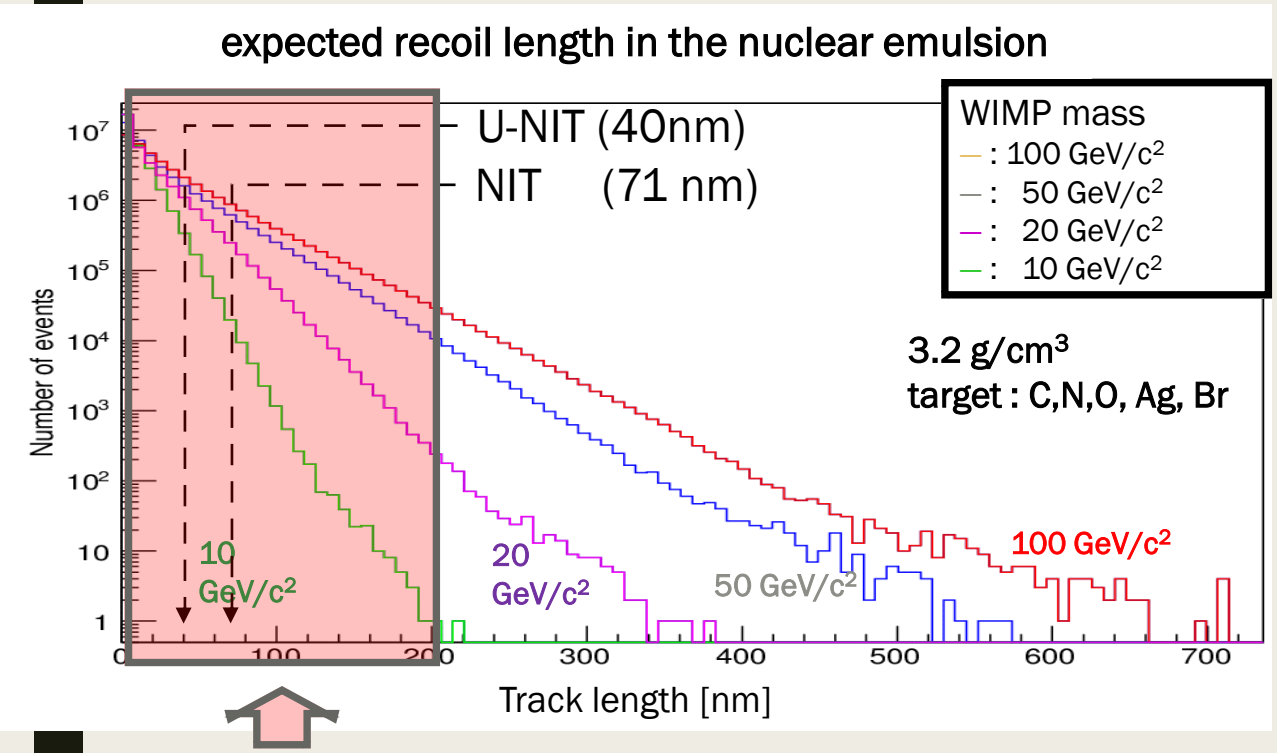


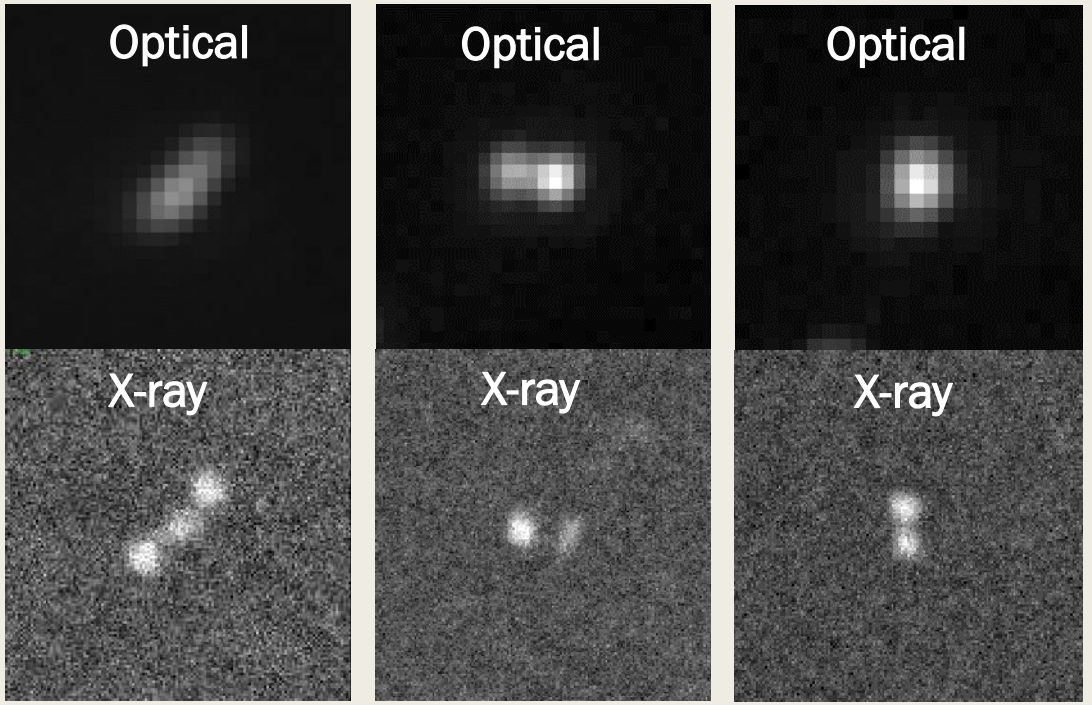

Granularity = 71 nm

Granularity = 40 nm

# Directional detection challenge




Inaccessible due to diffraction limit

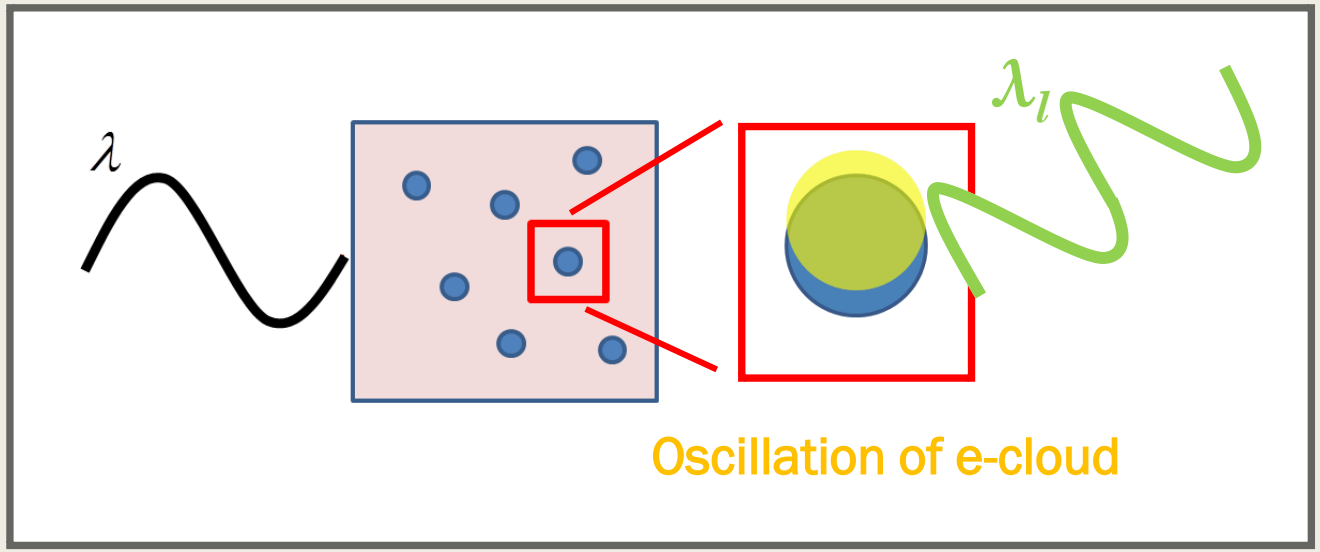


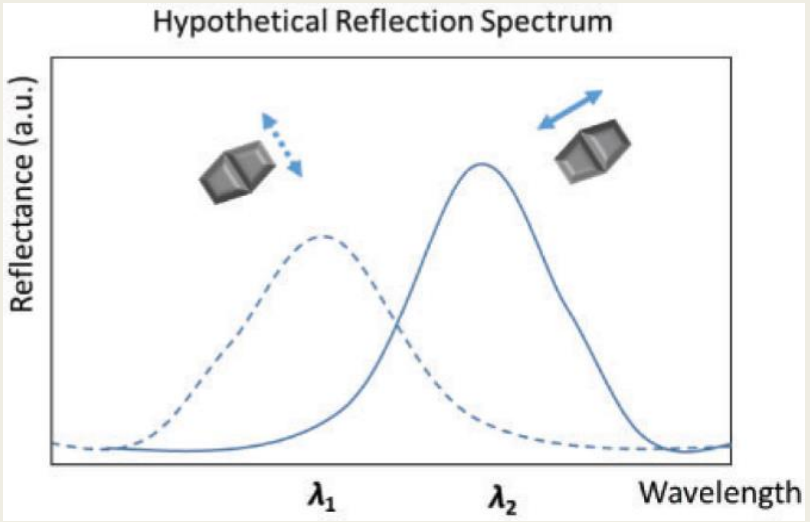

L = 380 nm L = 265 nm L = 160 nm

Need super-resolution to measure tracks shorter than 200 nm

# Optical readout beyond the diffraction limit

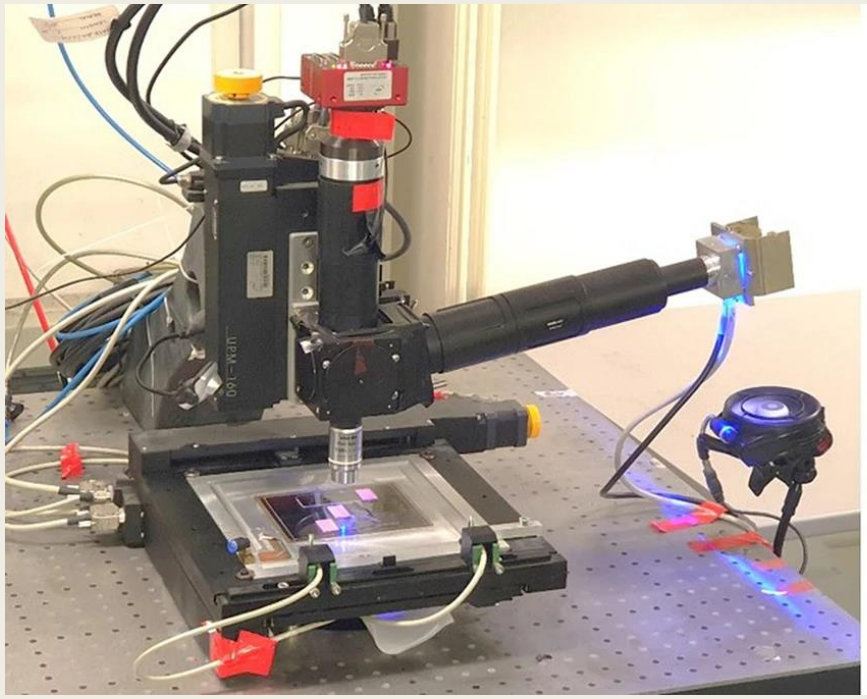
- Super-resolution idea: use the **plasmon resonance** effect to overcome the diffraction limit:
  - *generated by a light wave trapped within conductive nanoparticles smaller than the wavelength of light*
  - *resonant frequency strongly depends on the composition, size, geometry, dielectric environment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

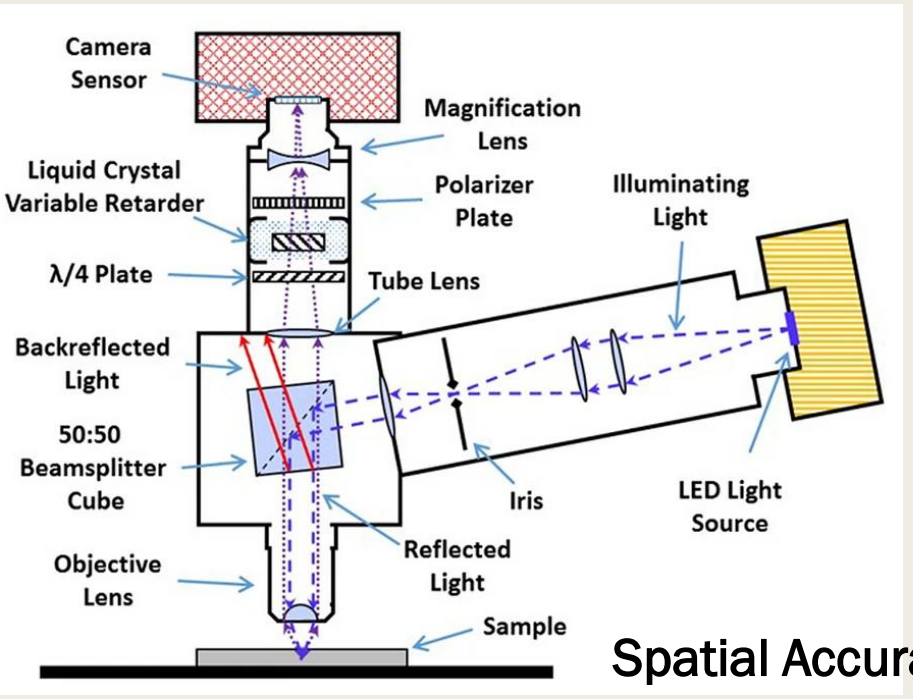


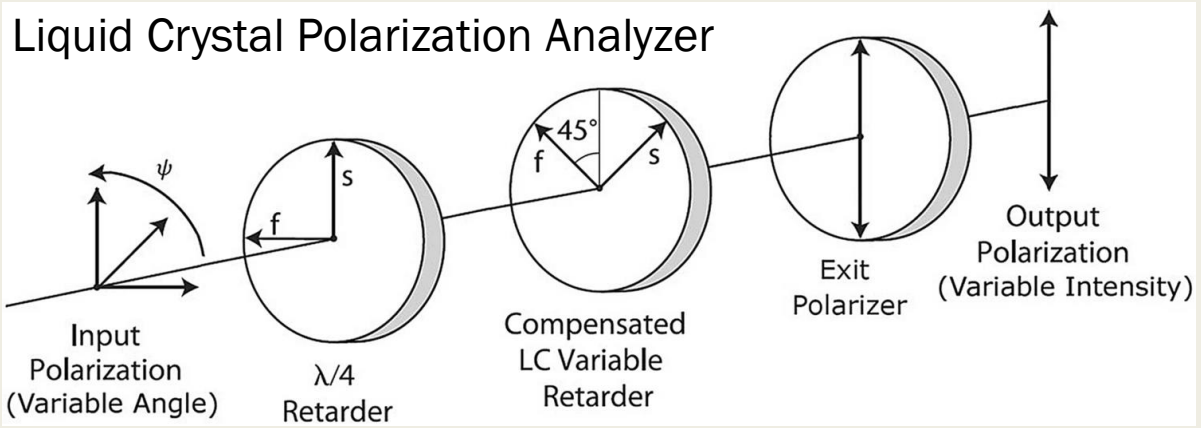
# Super-resolution microscope

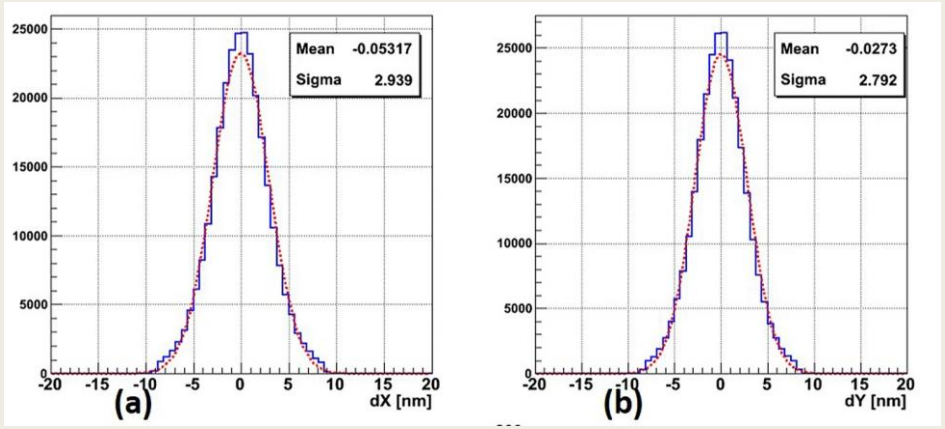
Sci. Rep. **10** (2020) 18773






Spatial Accuracy = 3 nm



Original scene
(upolarized illumination)

Modulated (rotating polarizations)

$\otimes PSF$

Microscope

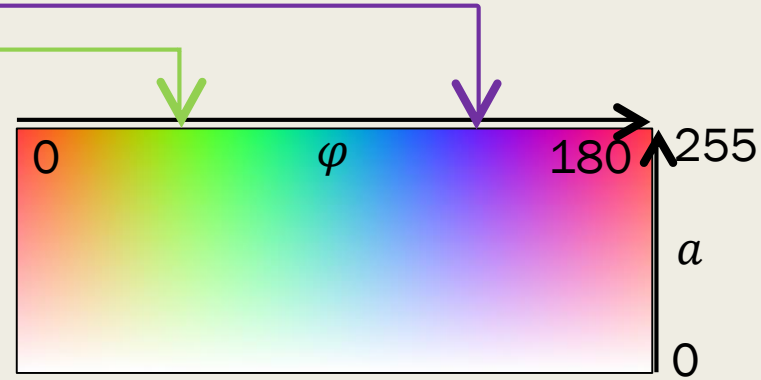
Reconstructed scene

Joint Image Deconvolution

Modulate the intensity of each pixel in the image:

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

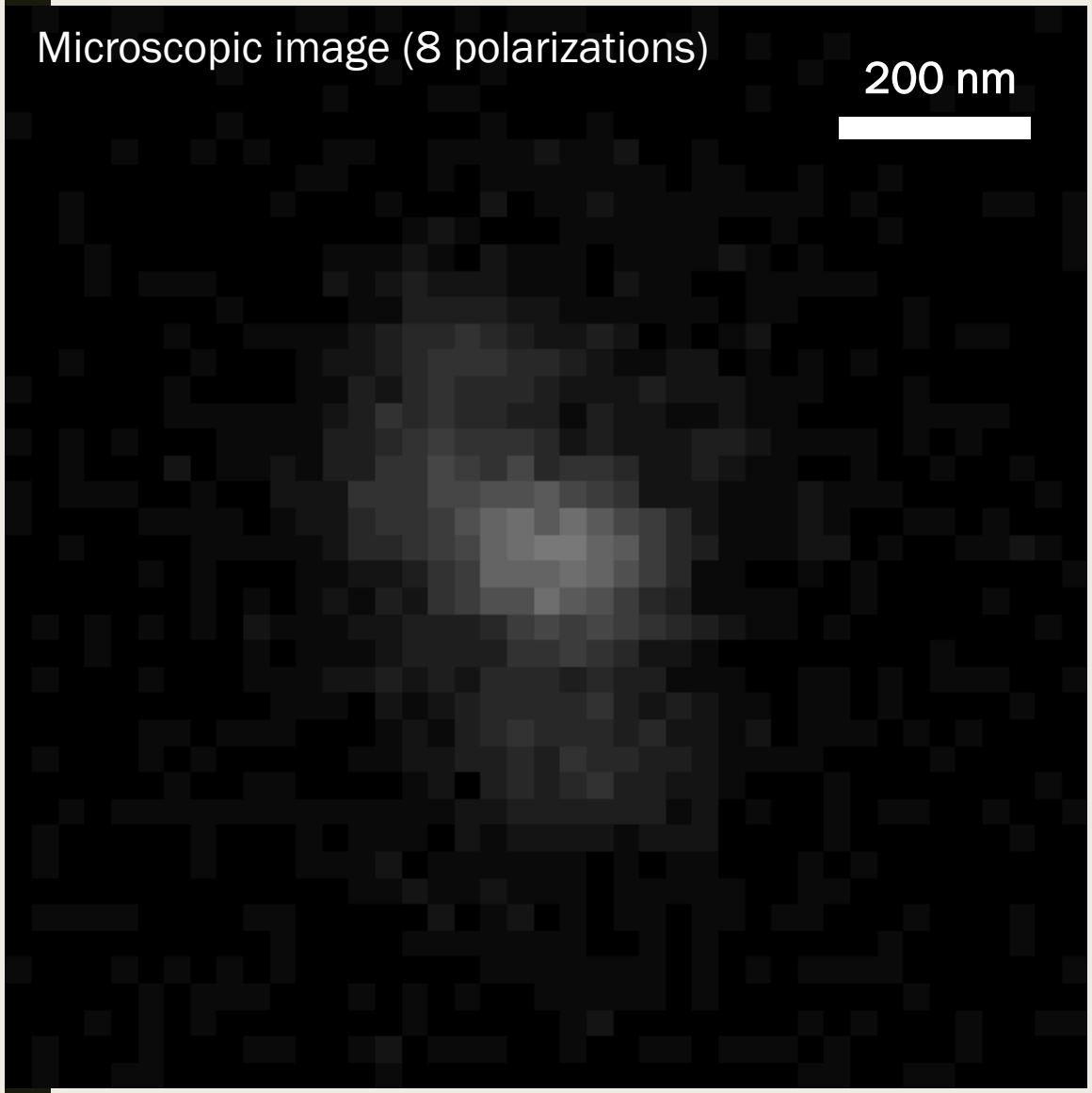
$\theta$ – polarization angle
$\varphi$ – pixel “phase”,
$b$ – pixel brightness mean,
$a$ – pixel brightness change amplitude

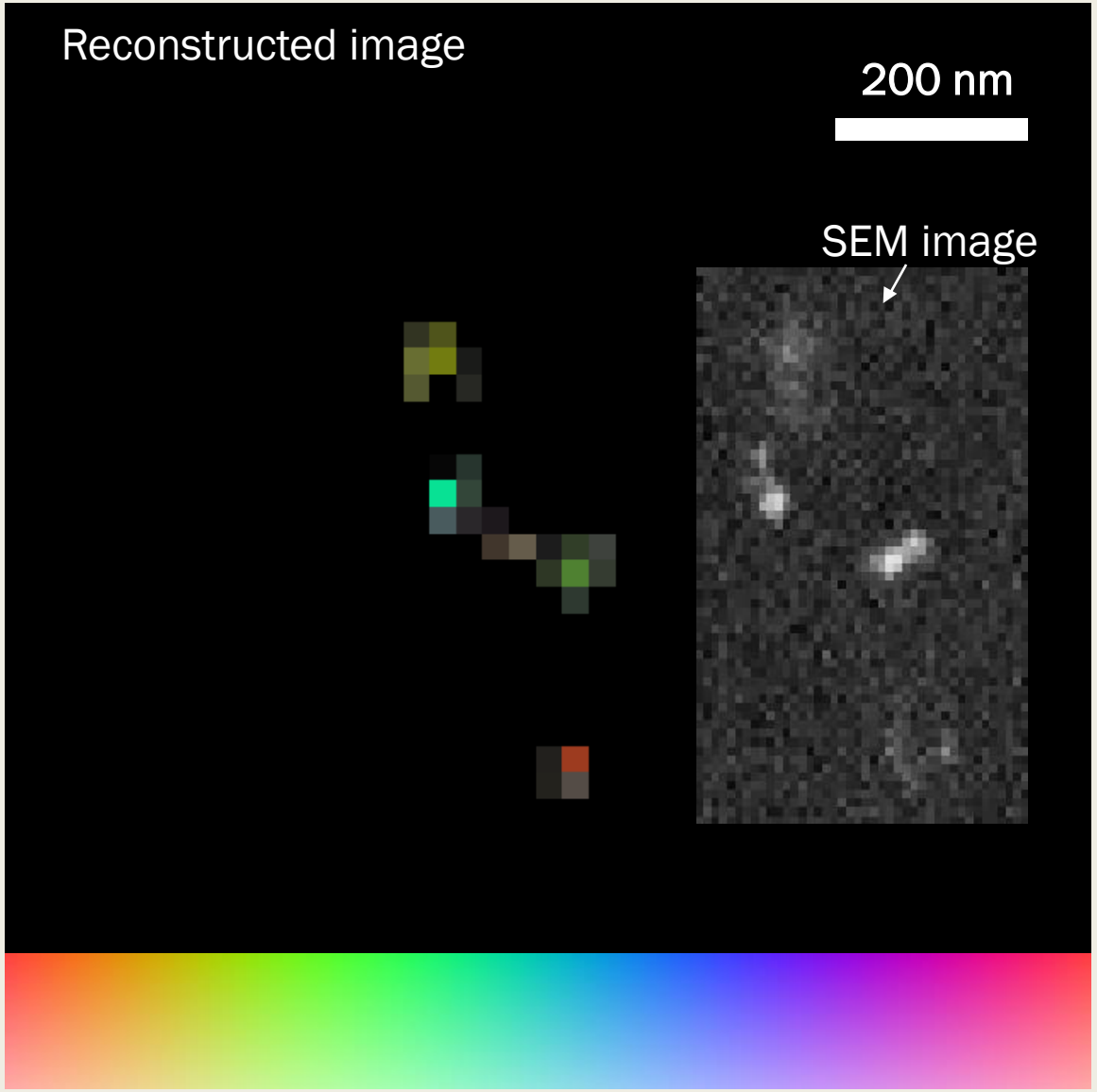



$a + b = pixel\ brightness$
$a = pixel\ color\ saturation$
$\varphi = pixel\ color$

# Joint image deconvolution

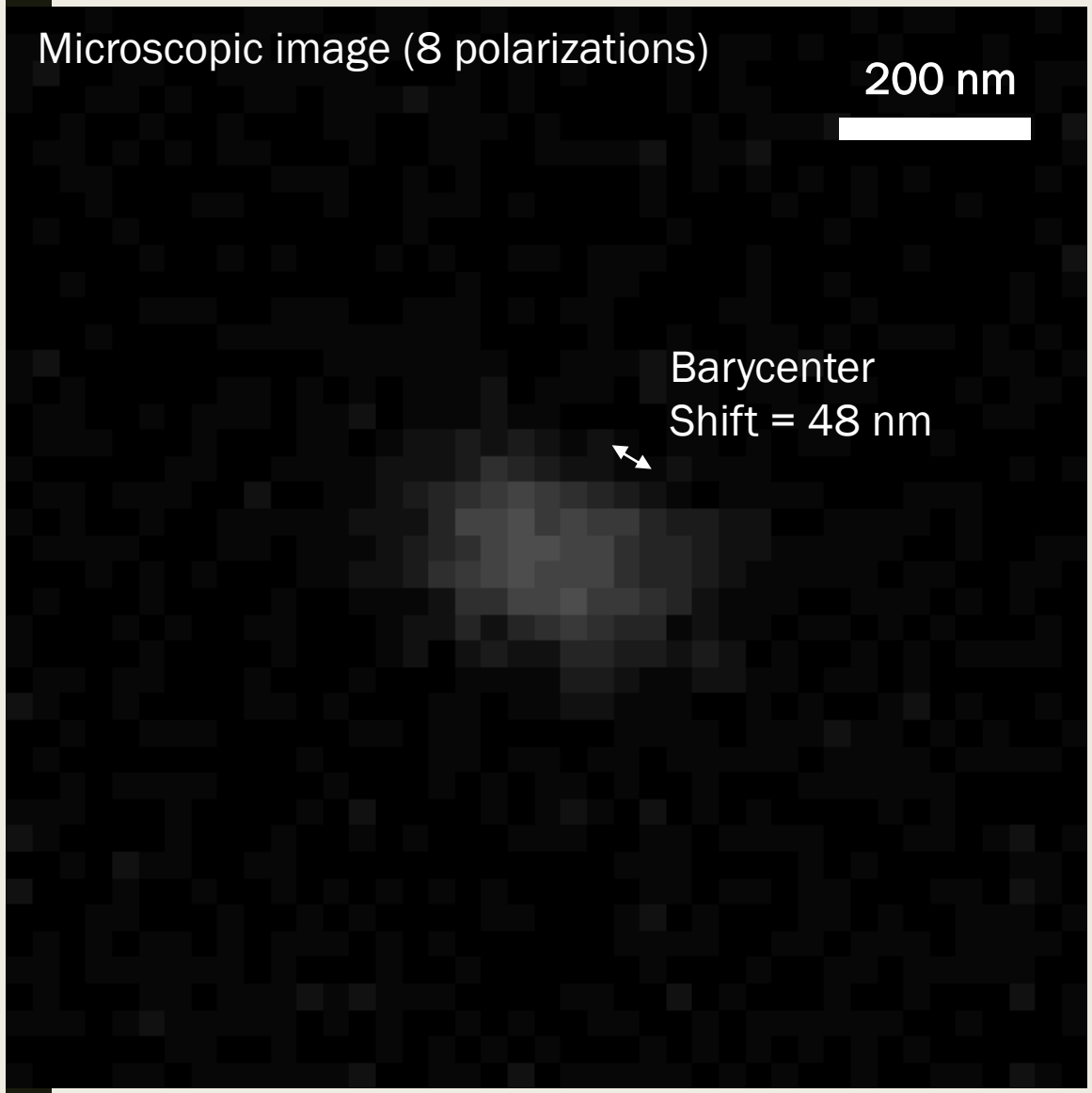
Sci. Rep. **10** (2020) 18773

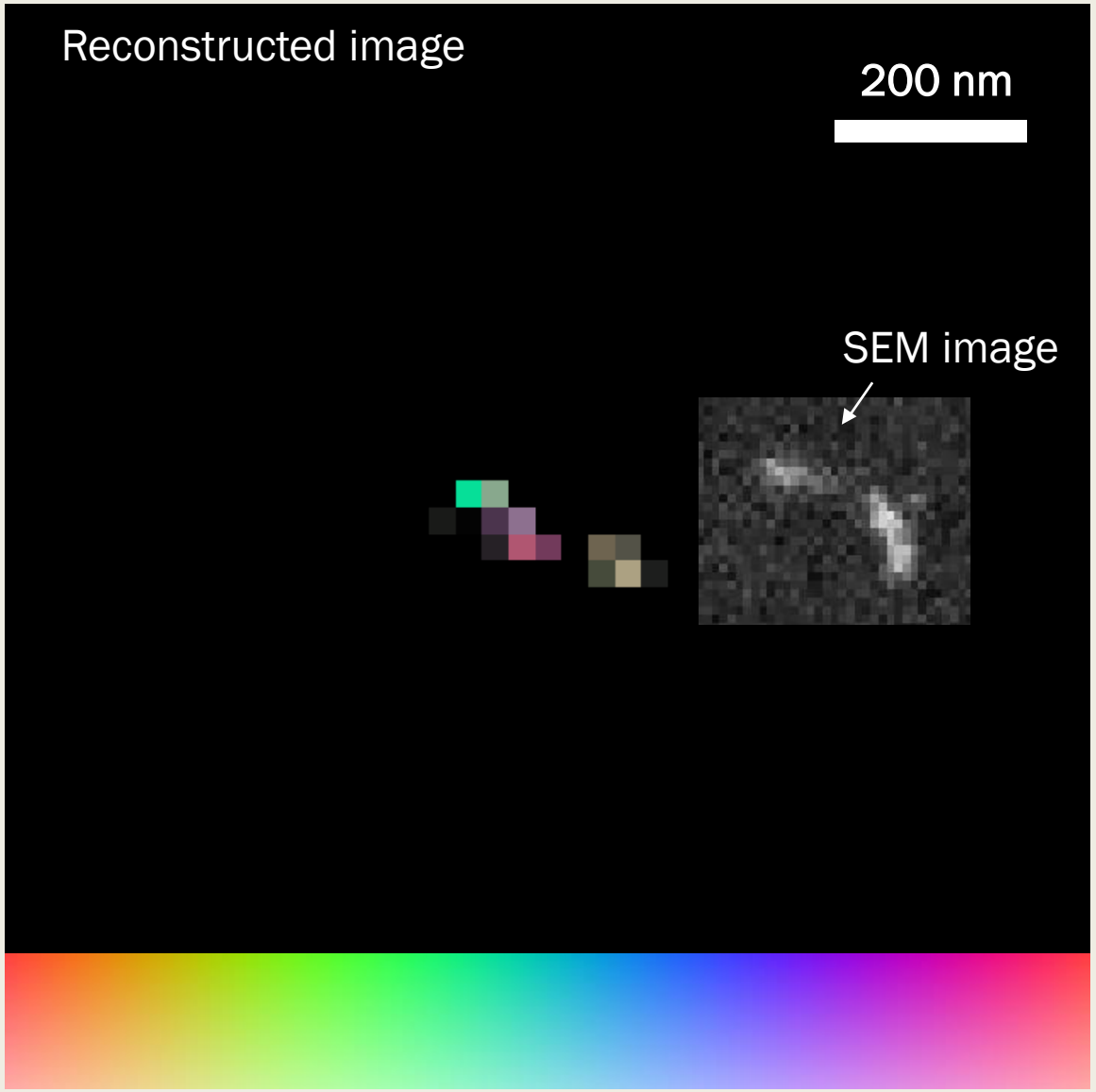


# Joint image deconvolution

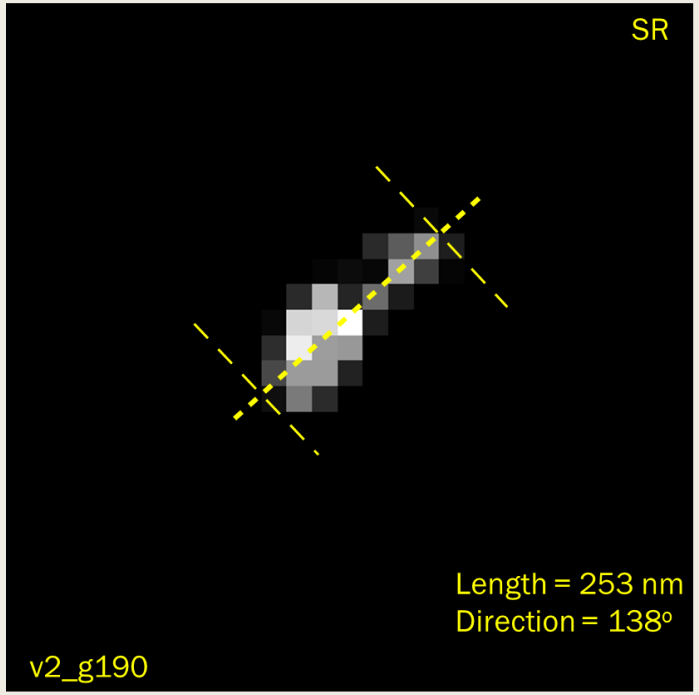
Sci. Rep. **10** (2020) 18773

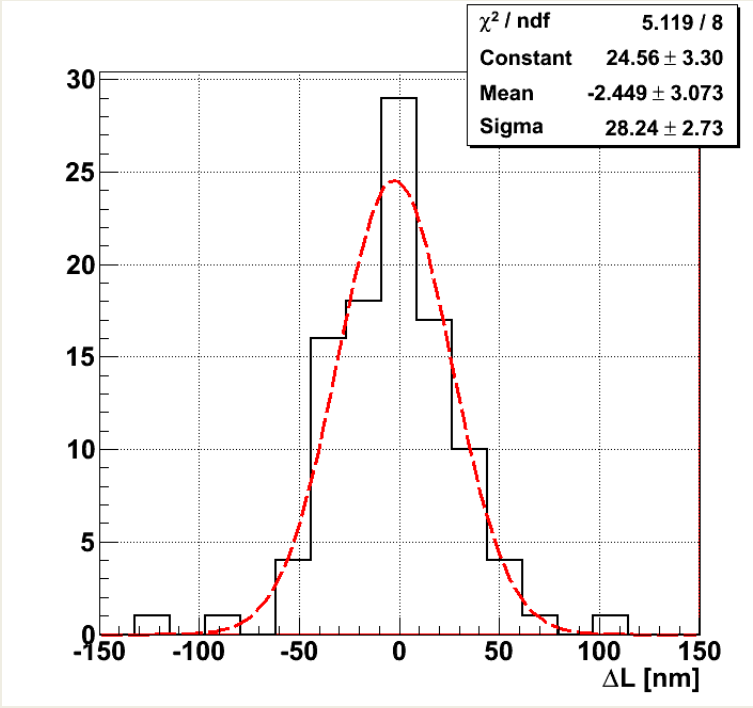


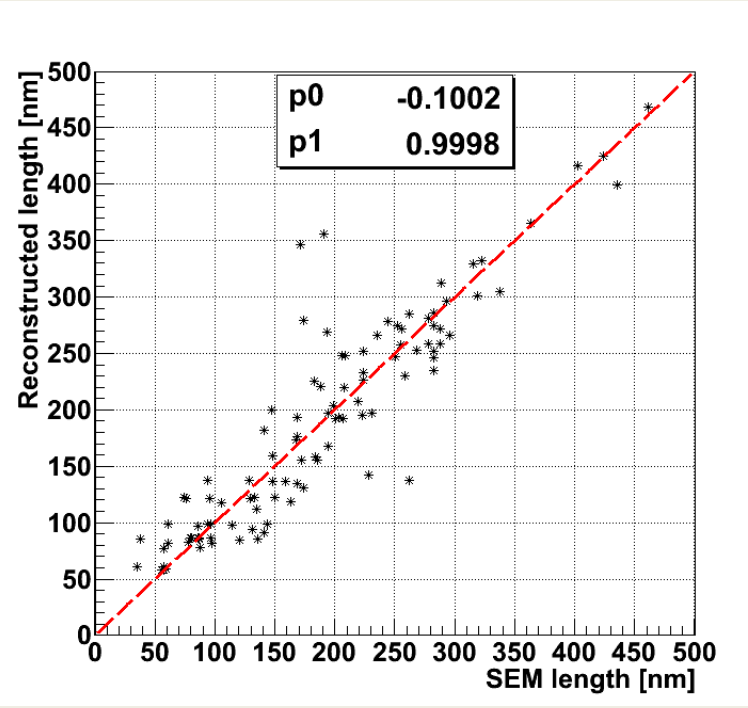



# Joint Image Deconvolution

## Event Length comparison with SEM



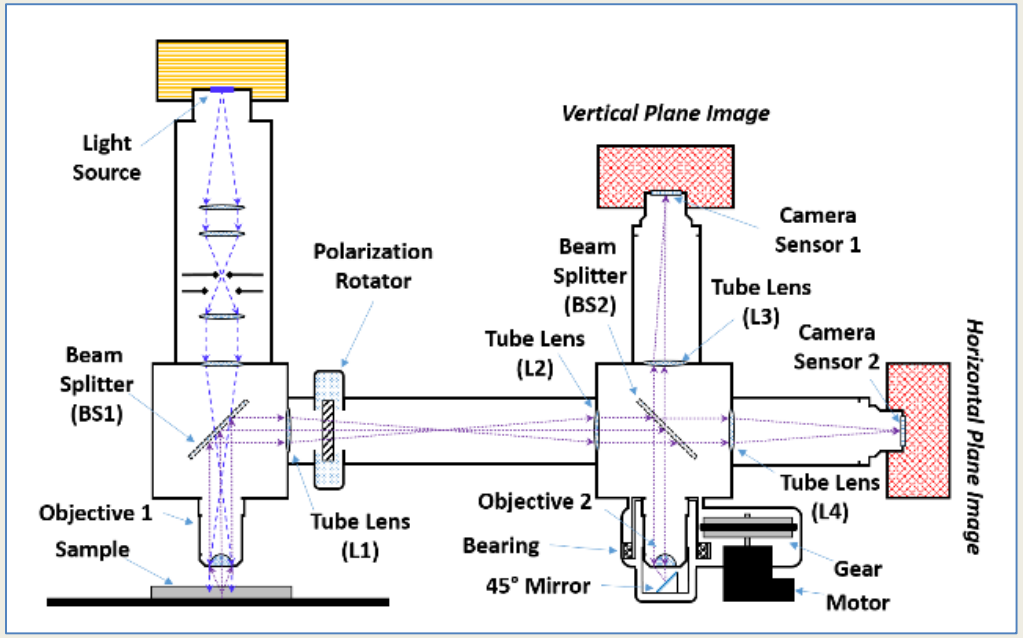




**Length accuracy: 28 nm ≈ pixel size (27.5 nm)**

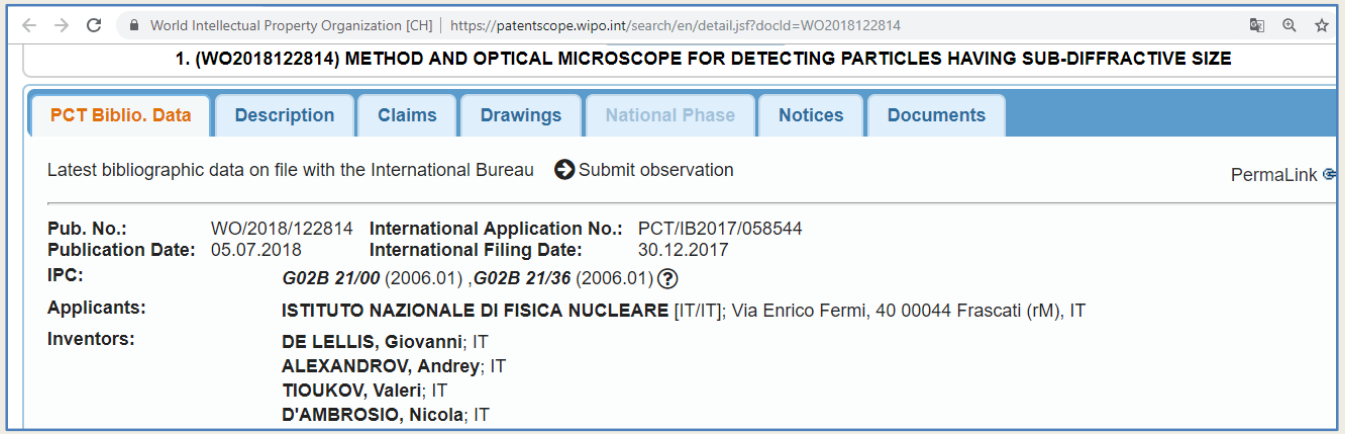
**Spatial resolution: 80 nm (Nyquist theorem)**

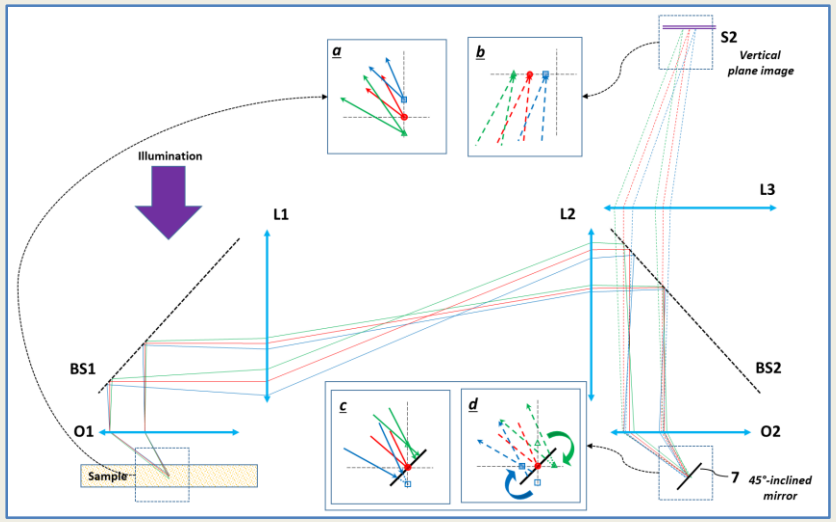
| Pearson Coefficient | Matched | Unmatched |
|---|---|---|
| Length | 0.912 | -0.009 |
| Width | 0.713 | -0.007 |

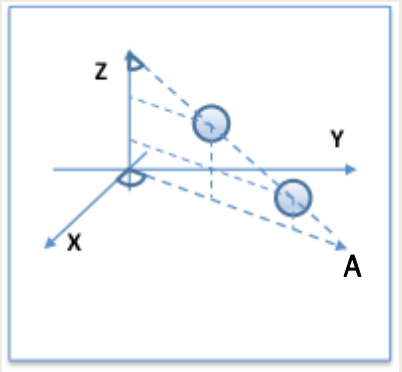
# Measurement in 3D




International Patent No. WO/2018/122814



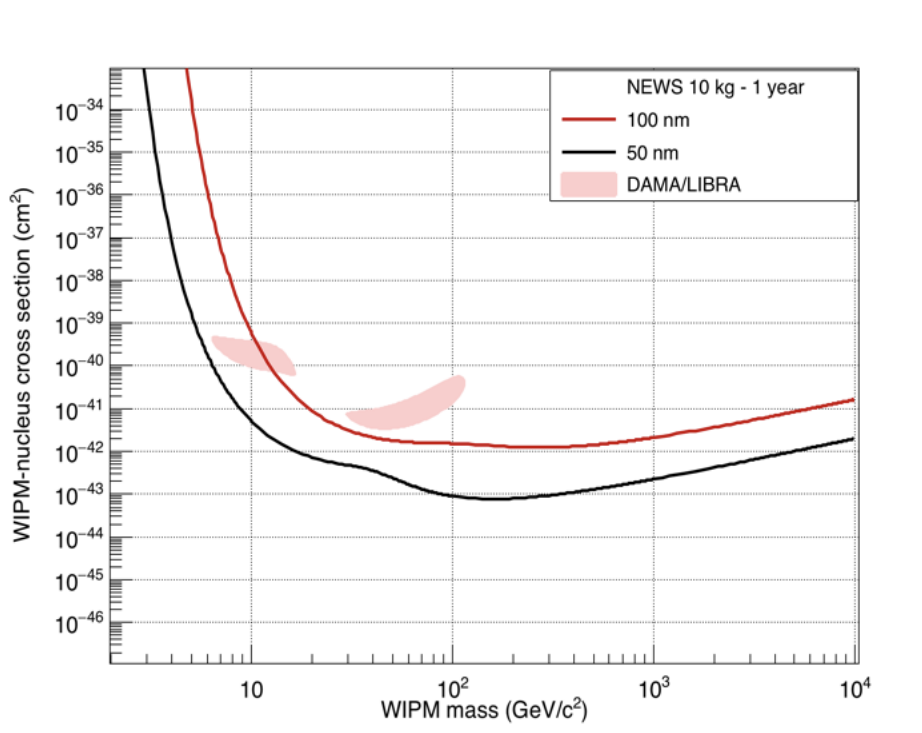



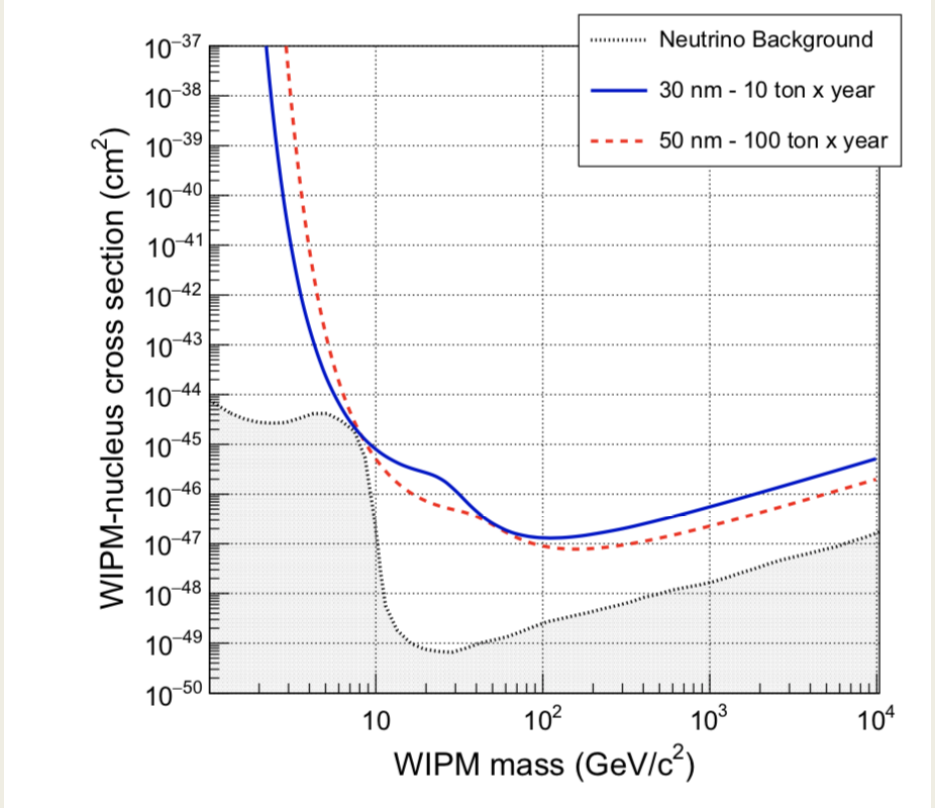

Two focal planes:
Horizontal: XY
Vertical: ZA

# 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!

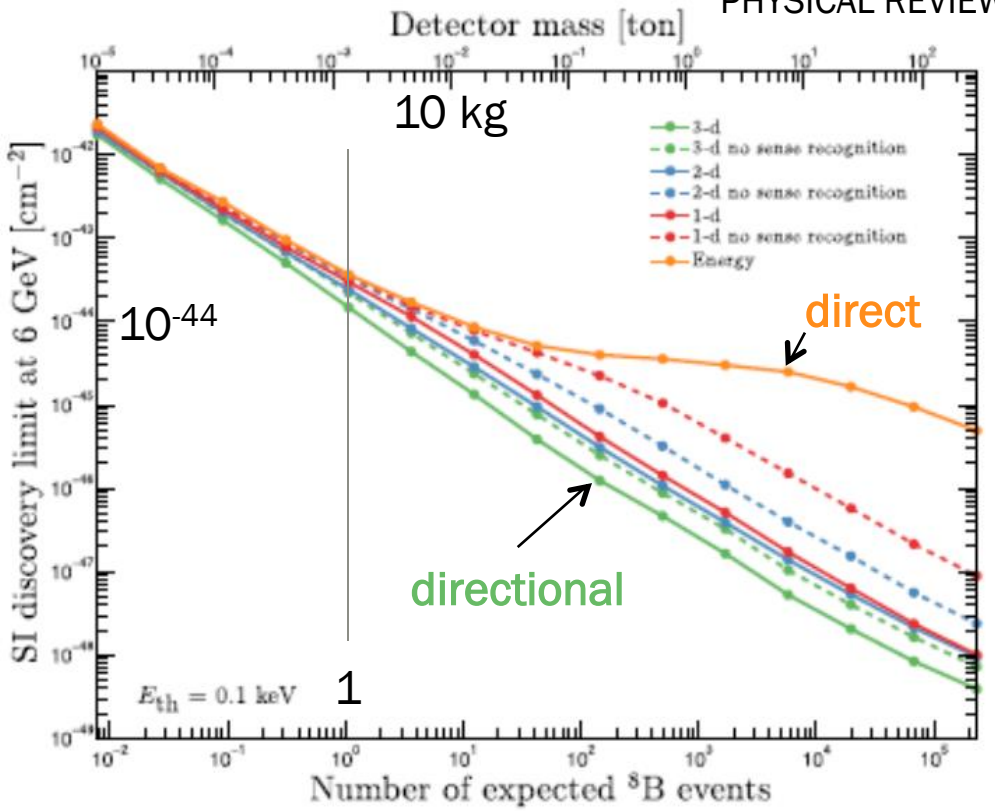
Andrey ALEXANDROV (on behalf of the NEWSdm collaboration)

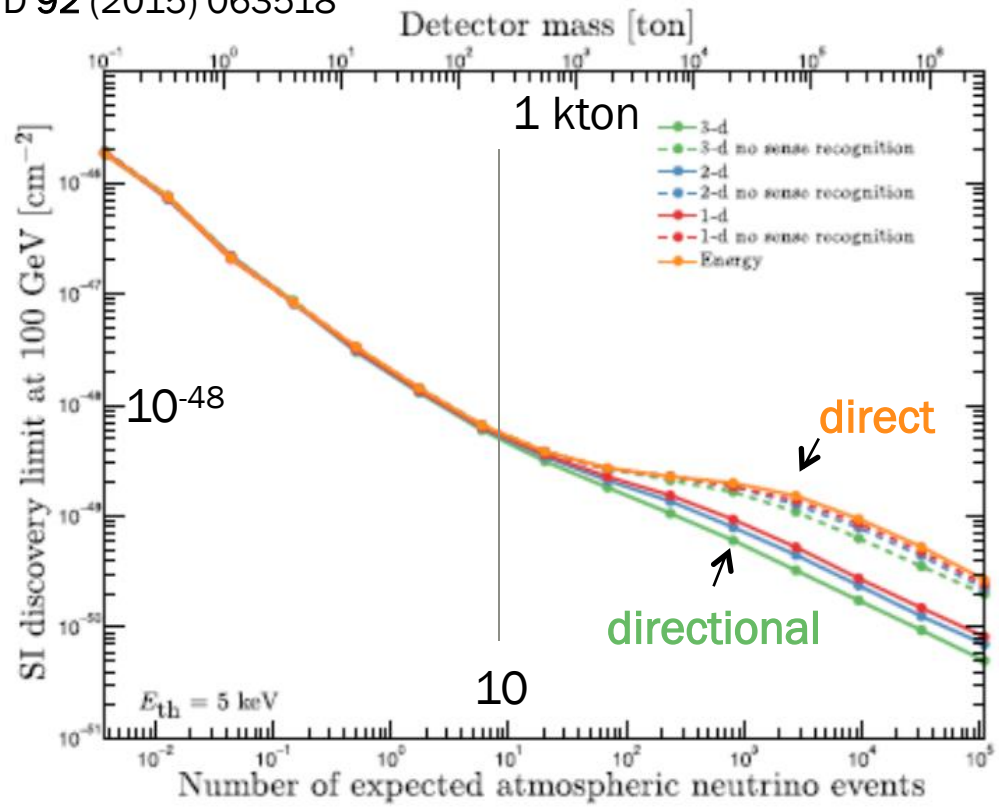
andrey.alexandrov@na.infn.it

# BACKUP SLIDES

# Importance of the directional detection

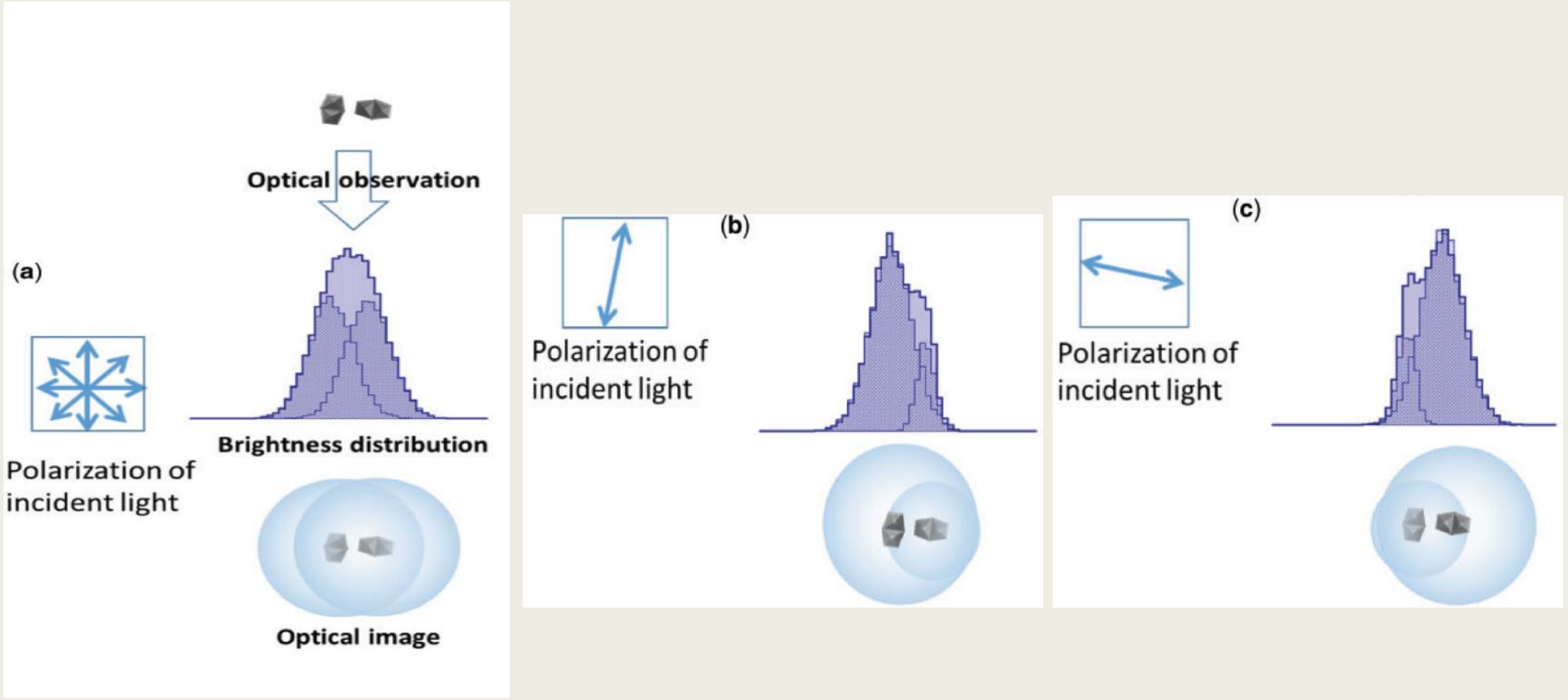
PHYSICAL REVIEW D **92** (2015) 063518




Need 3D with sense recognition for best results!

# Optical readout beyond the diffraction limit



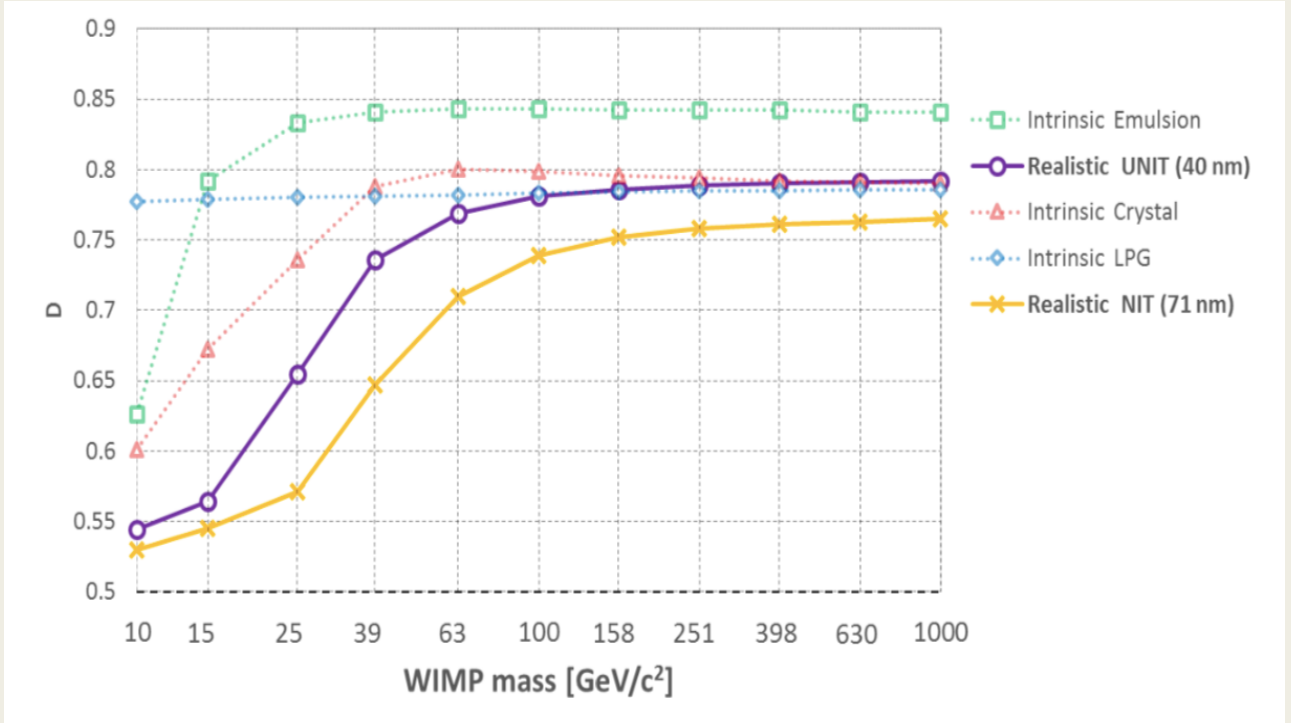

*PTEP,* Vol. 2019 Issue 62019, 063H02

# 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±7 nm for NIT, 25±4 nm for U-NIT

- Evaluation of energy-weighted cosine distribution

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

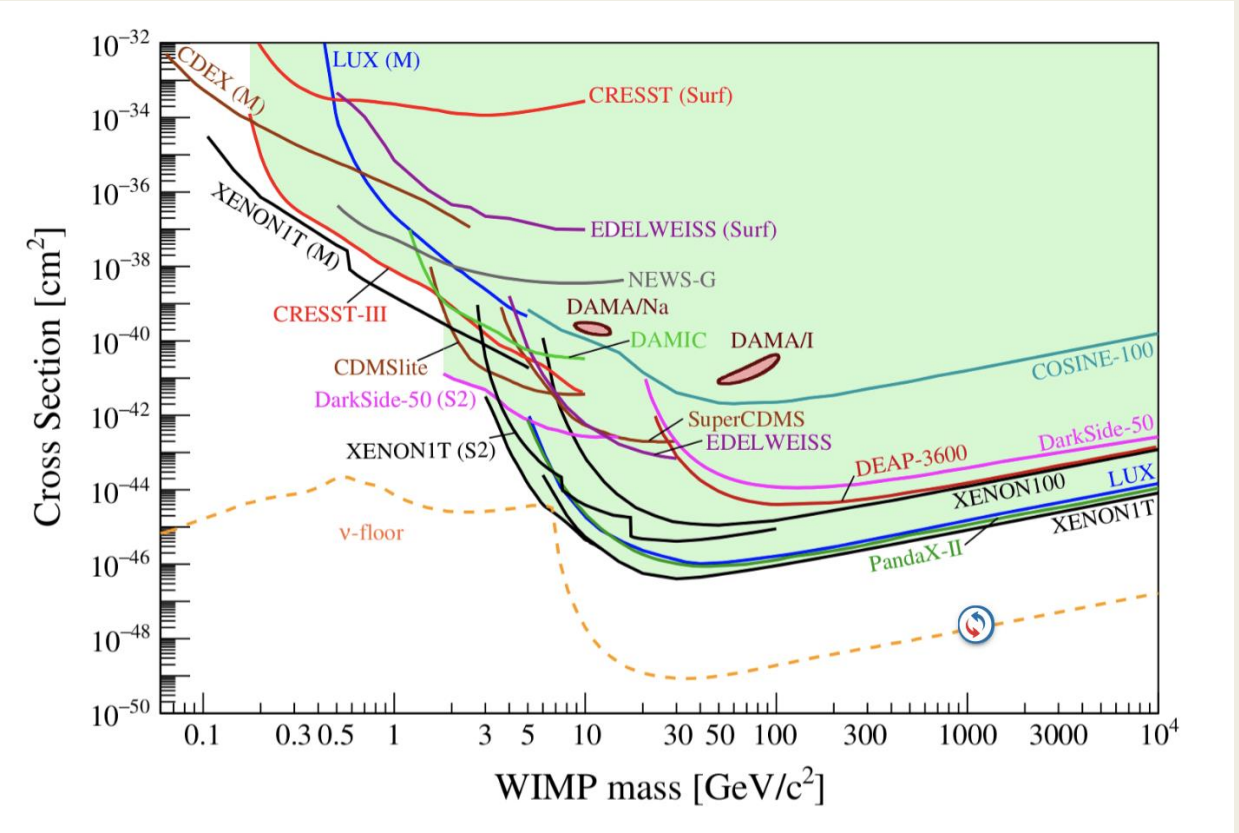



*Realistic distribution of mean values of weighted-cos$\vartheta$ for NIT and U-NIT, compared with other detectors*

*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

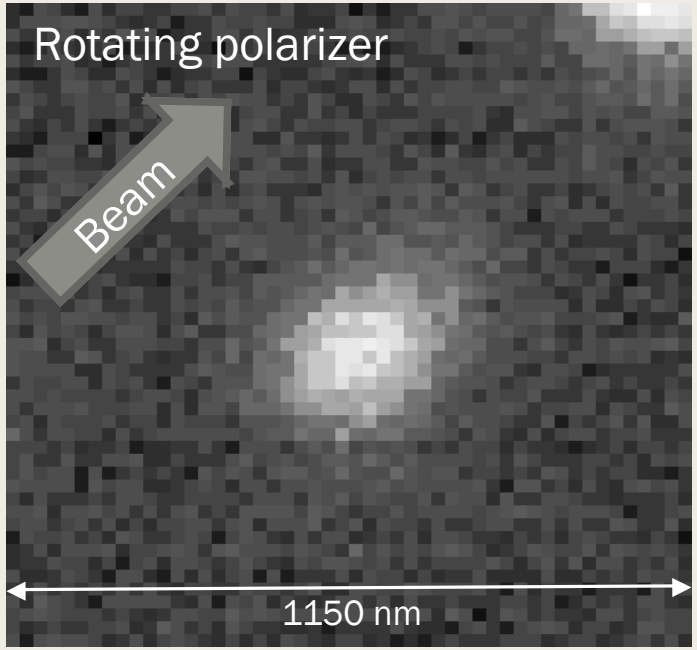
- Current status of searches for spin-independent elastic WIMP-nucleus scattering assuming the standard parameters for an isothermal WIMP halo

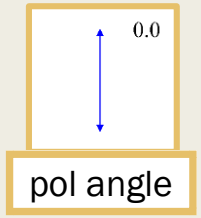


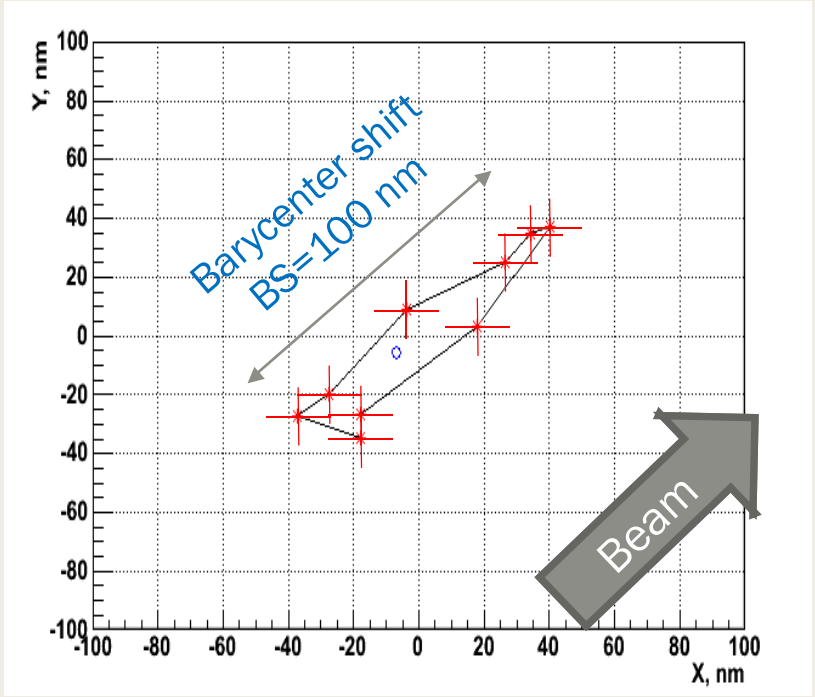

Direct Detection of Dark Matter – APPEC Committee Report
https://www.appec.org/wp-content/uploads/2021/04/appec_dm_report_2020_ga_approved.pdf
*arXiv: 2104.07634*

# Barycenter shift analysis

NIM A **824** (2016) 600–602

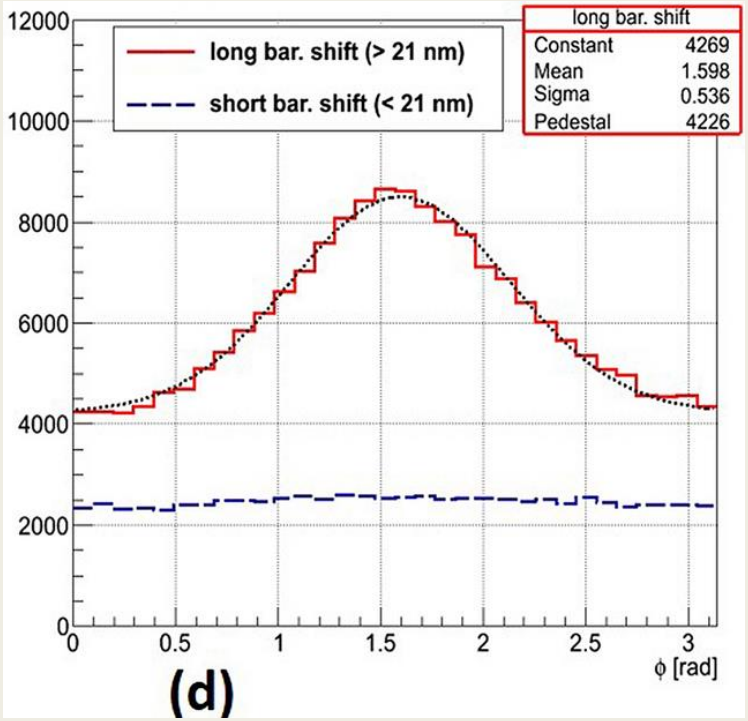


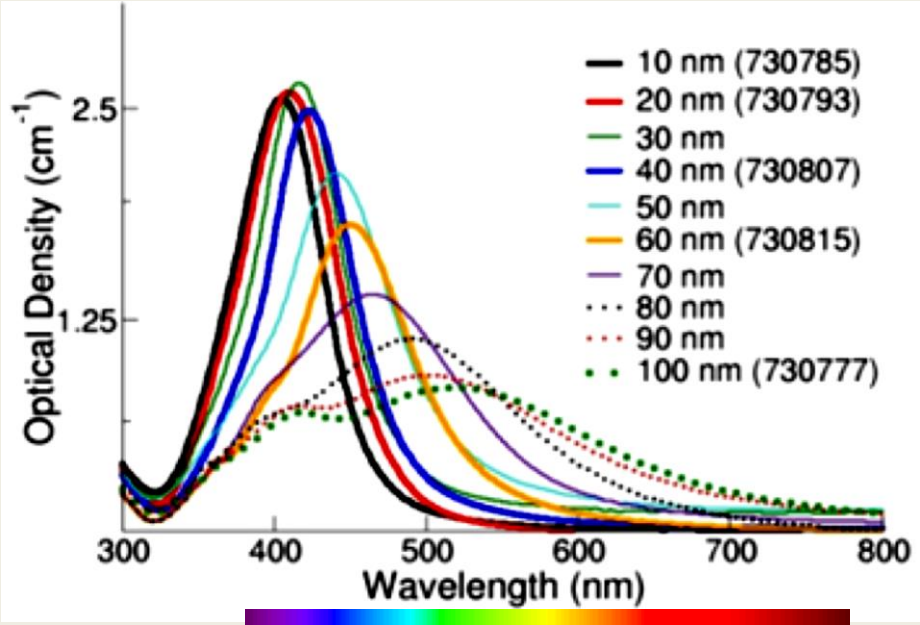

Carbon ion
100 keV

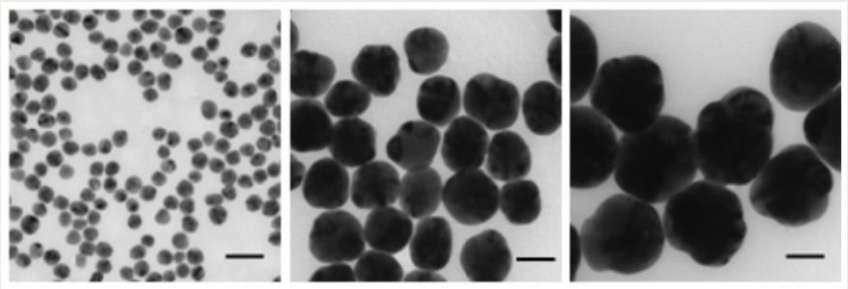
Sci. Rep. **10** (2020) 18773



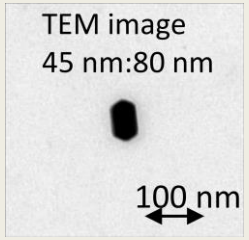

Carbon ions
60 keV

# Plasmon resonance wavelength dependency



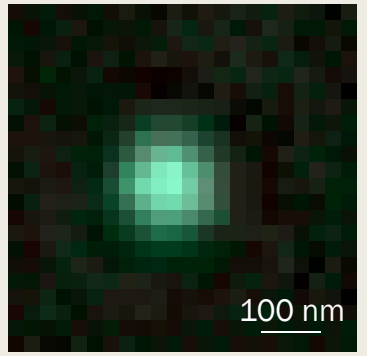



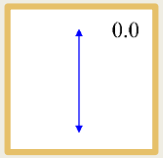
20 nm 60 nm 100 nm

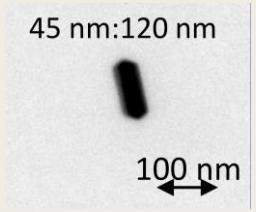



~45 nm : blue
~80 nm : green

*polarization rotating




~45 nm : blue
~120 nm :orange

*polarization rotating