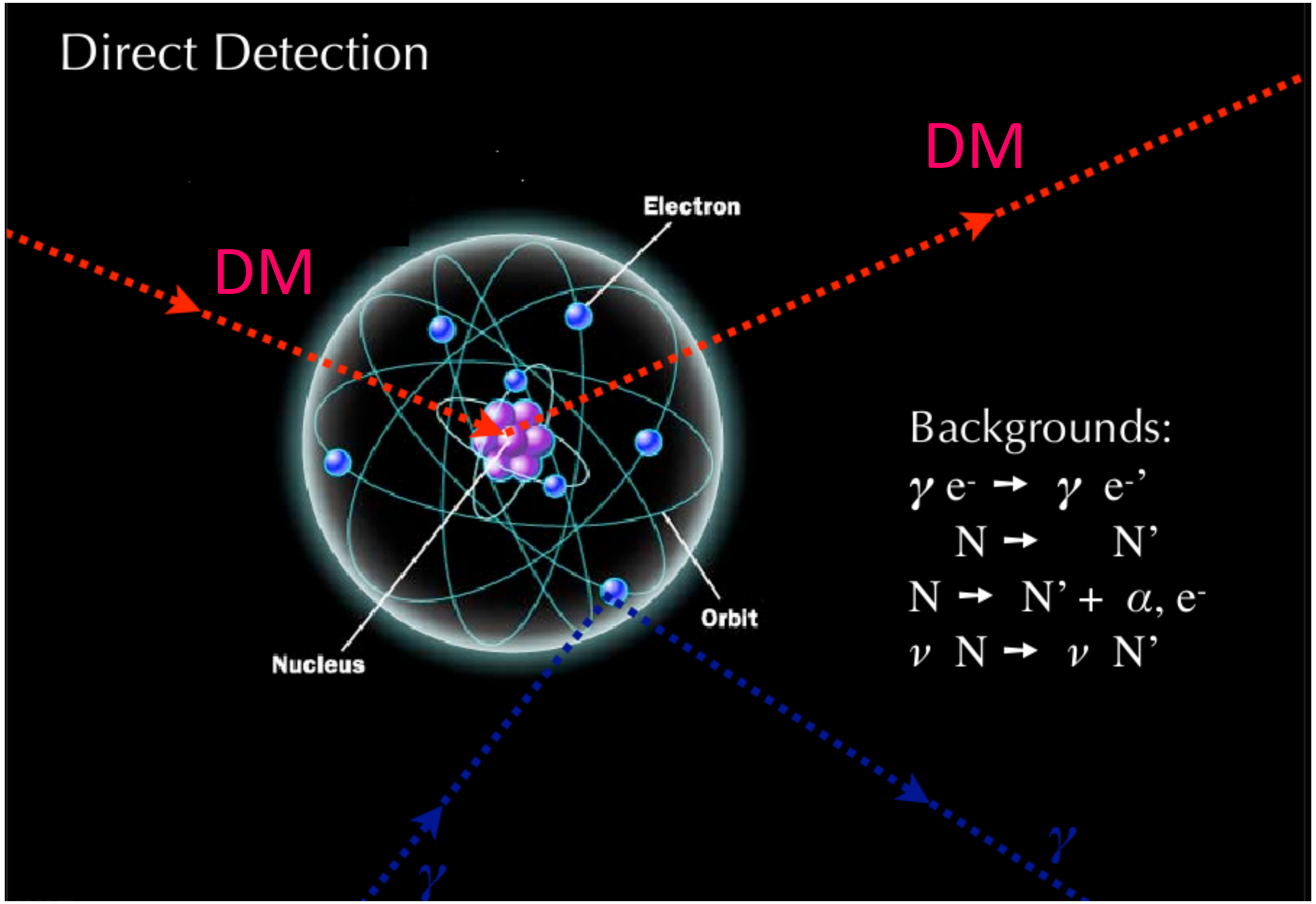
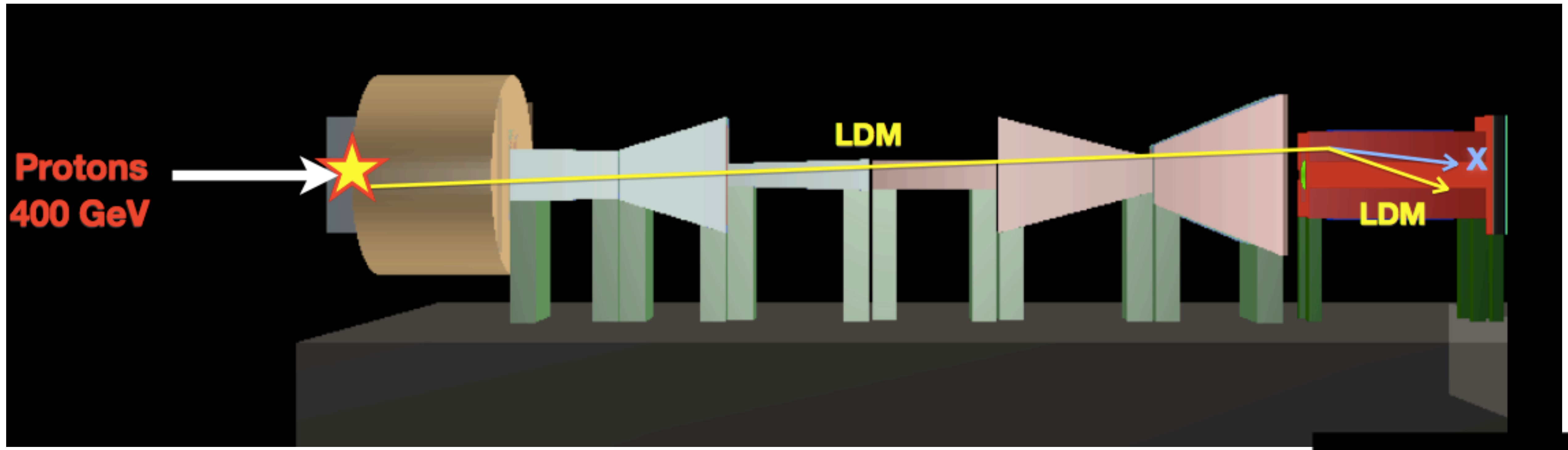
Dark Matter search with emulsion detectors

Video of the lecturer



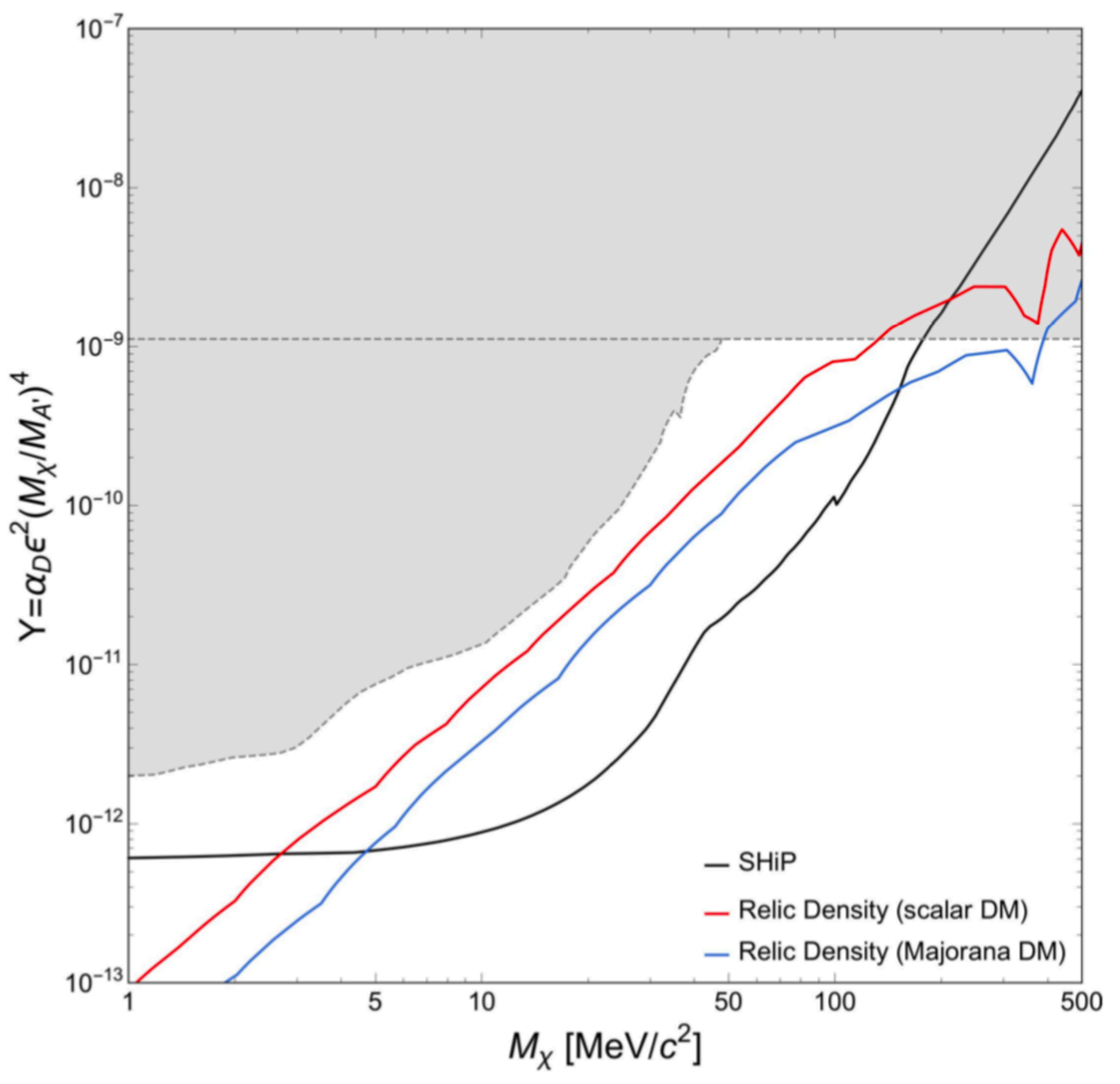
Dark matter search at the accelerators

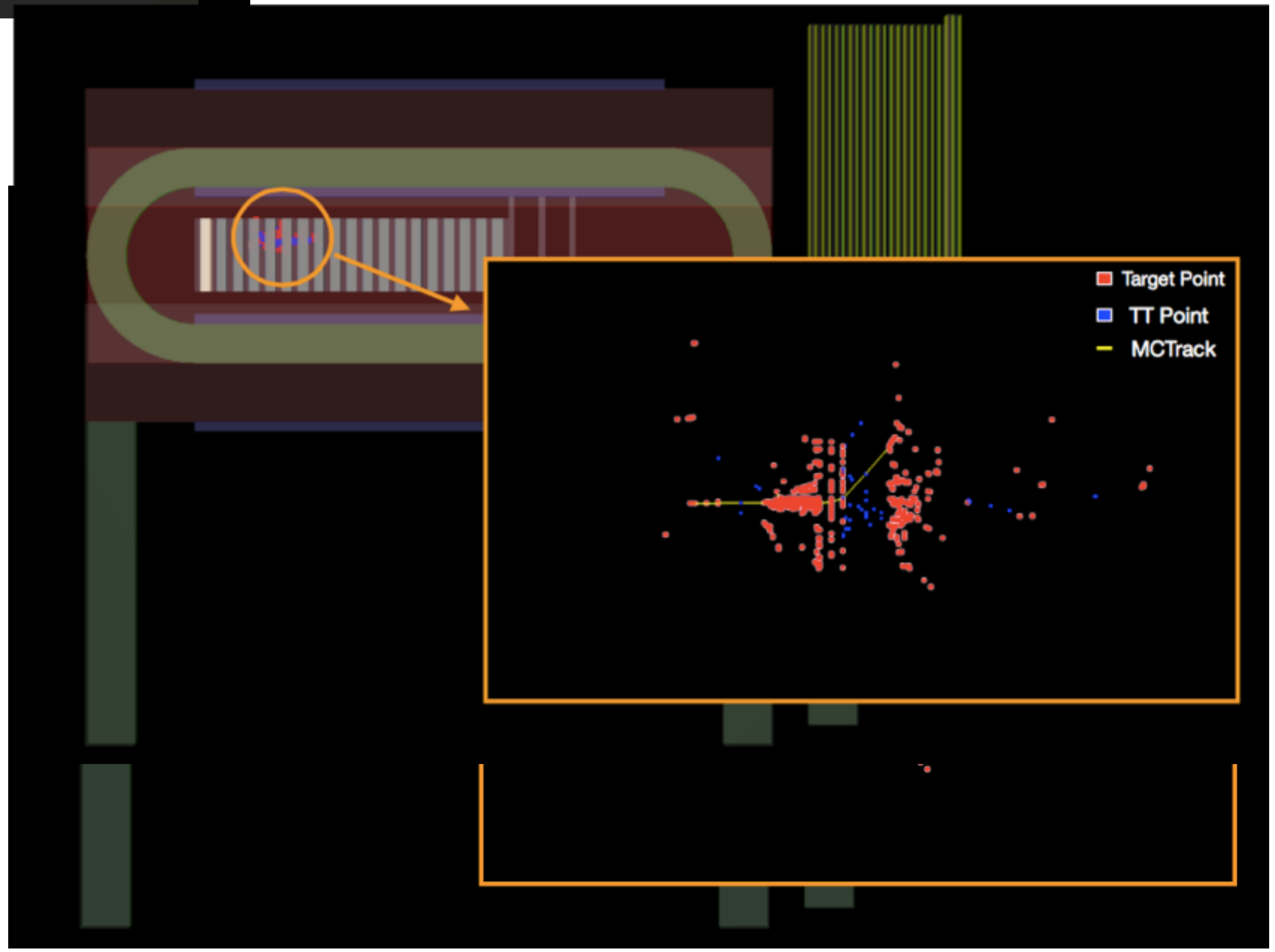
Video of the lecturer



$$\chi e^- \to \chi e^-$$

Ultra-relativistic dark matter



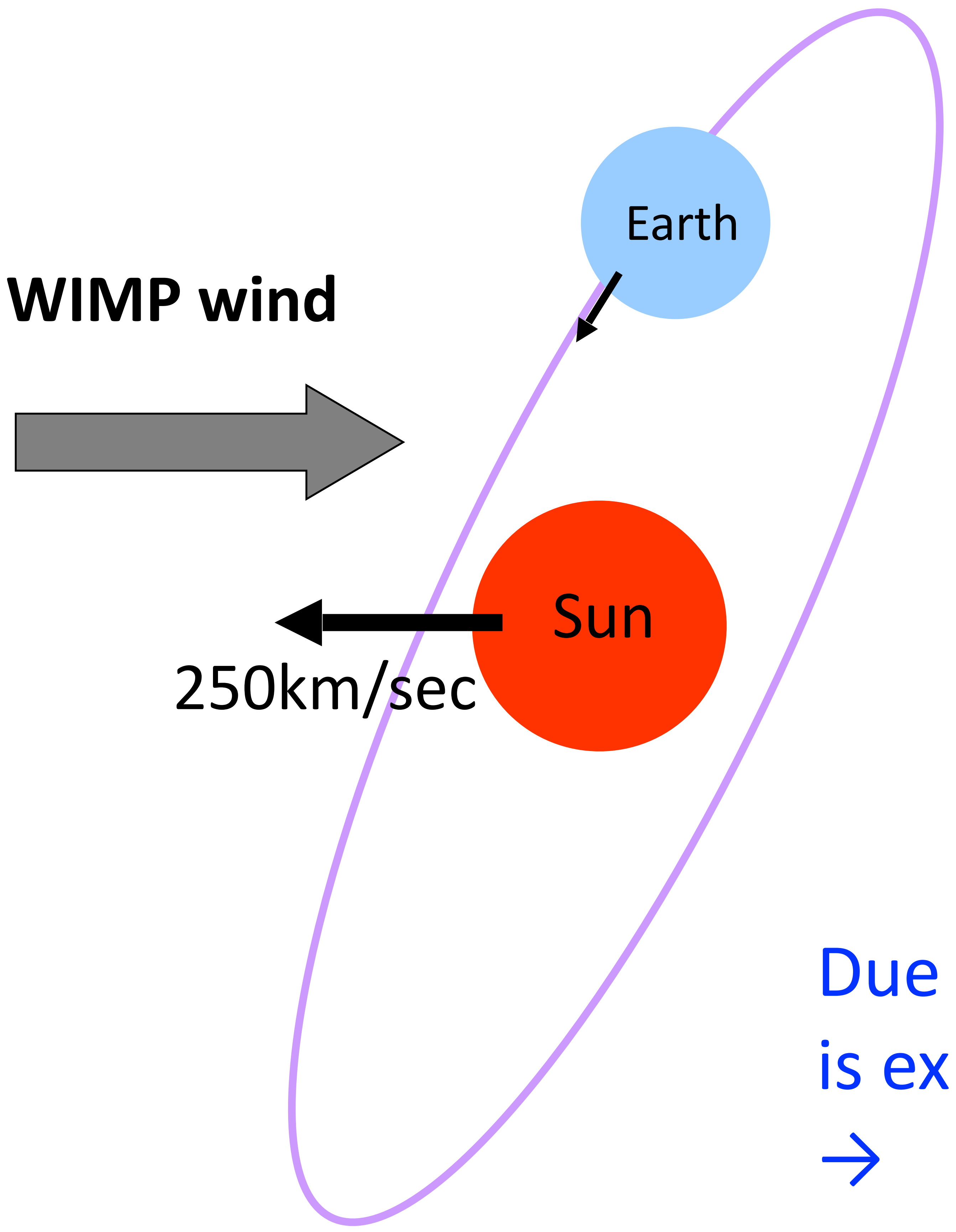


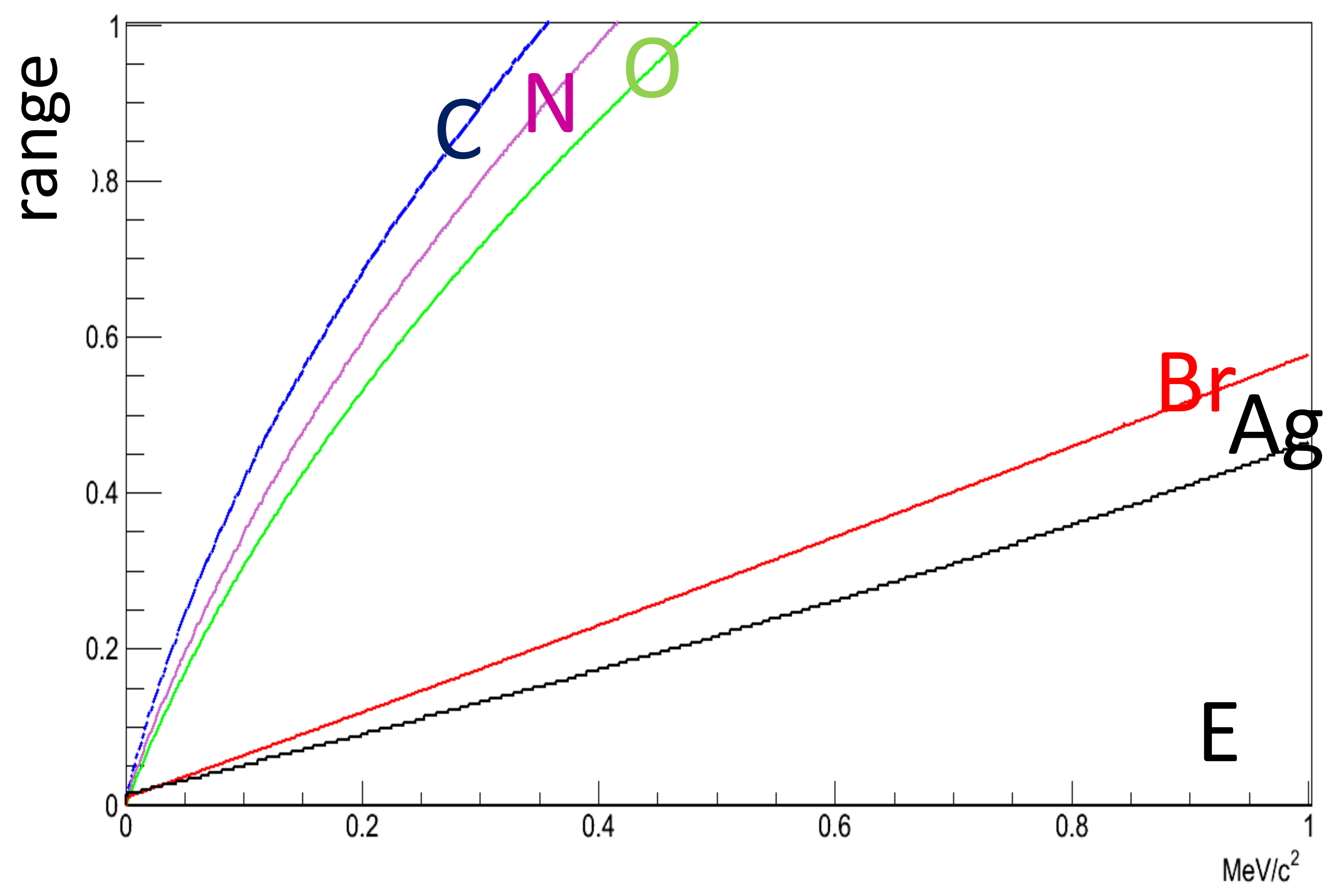
Nuclear recoils induced by galactic dark matter scattering in the emulsion

Video of the lecturer

Speed limited by the escape velocity in the galaxy!

$$E = \frac{1}{2} m_{DM} \times v_{DM}^2 = \frac{1}{2} 100\text{GeV} \times 10^{-6} = 50\text{keV}$$





Due to solar system movement in galaxy, WIMP flux is expected to be not isotropic on the Earth

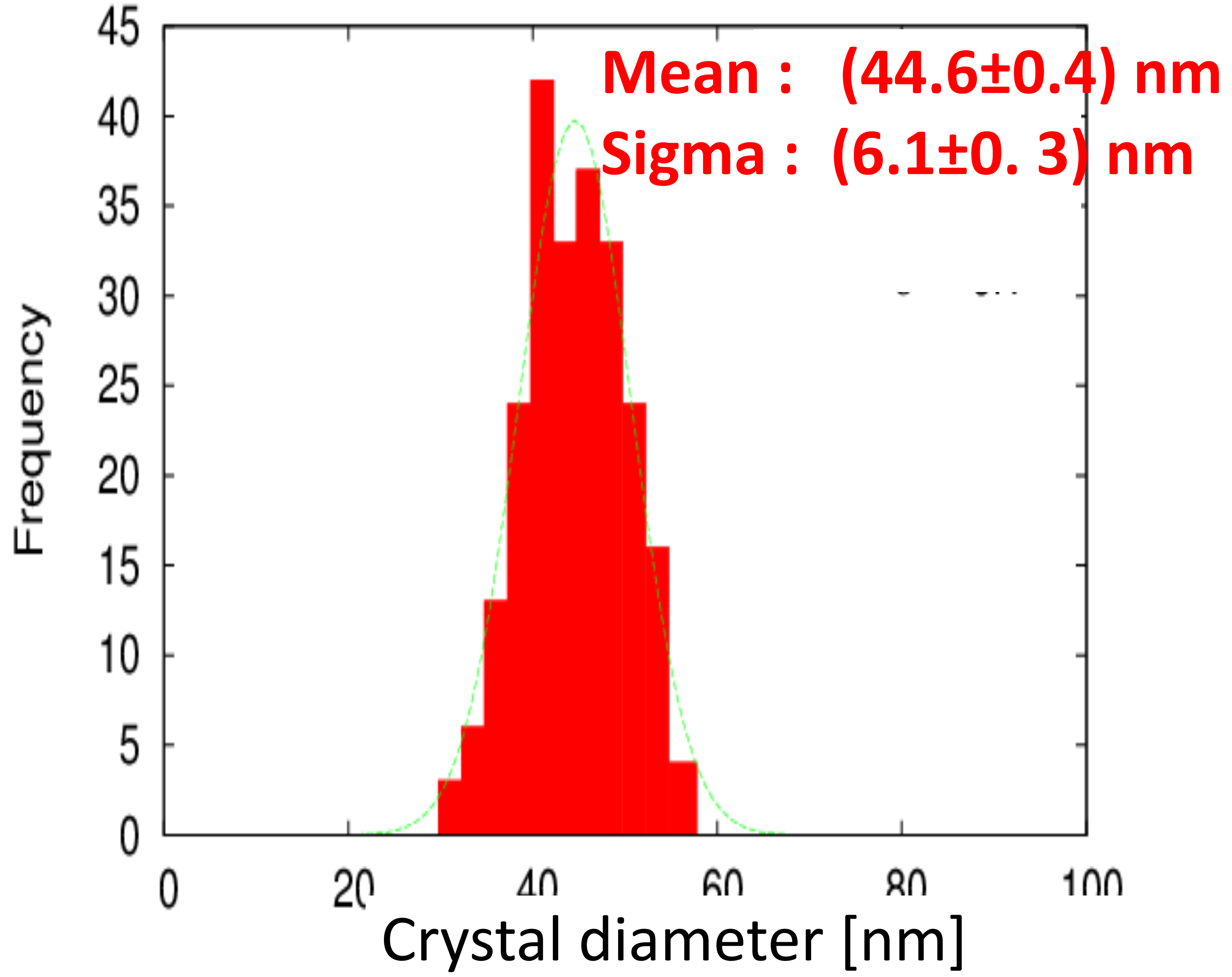
→ direction measurement!

Typical crystal size for a new type of emulsion film

Video of the lecturer

NIT

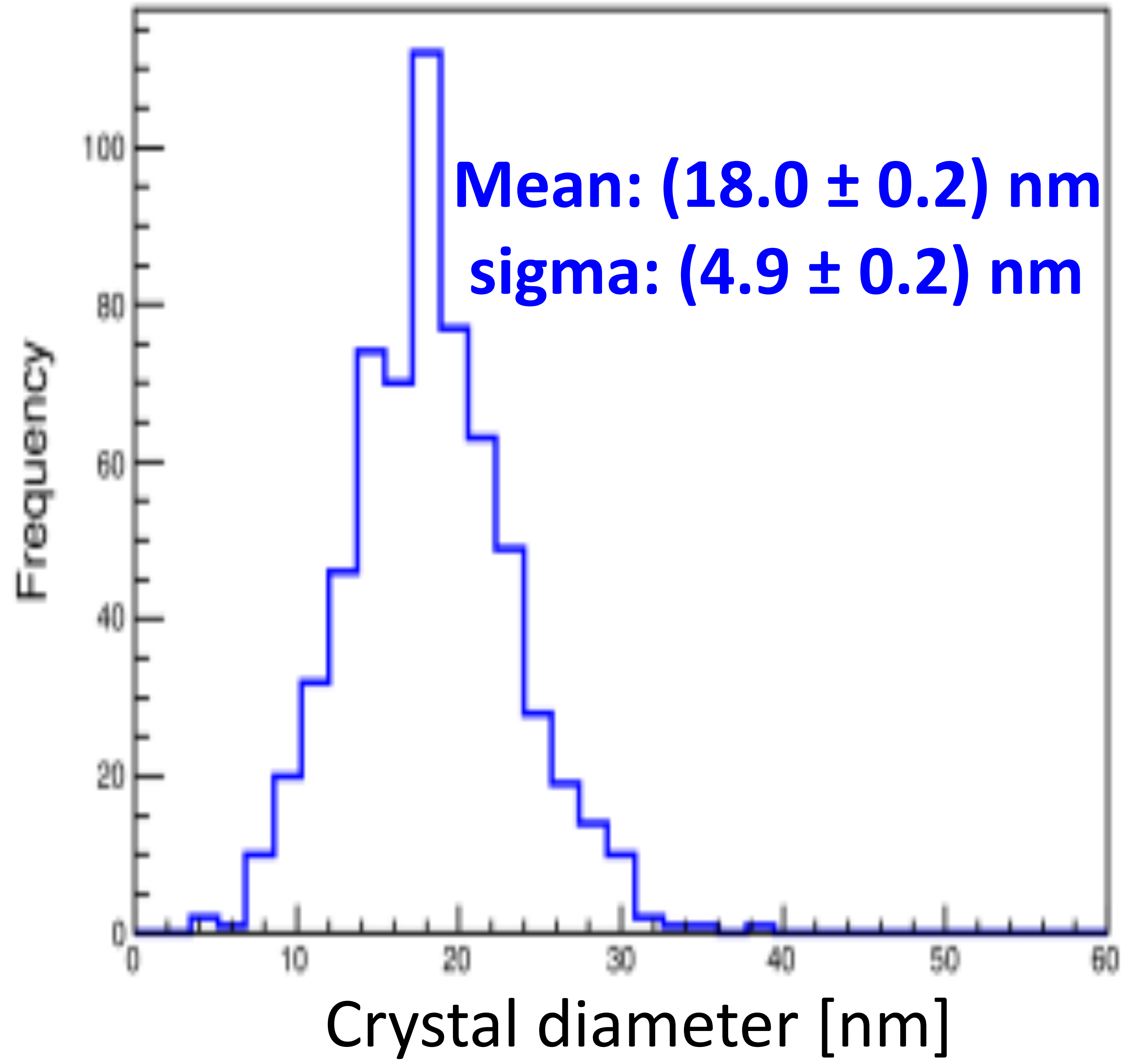
Current emulsion sample



	NIT	U-NIT
AgBr density	11 AgBr/μm	29 AgBr/μm

U-NIT

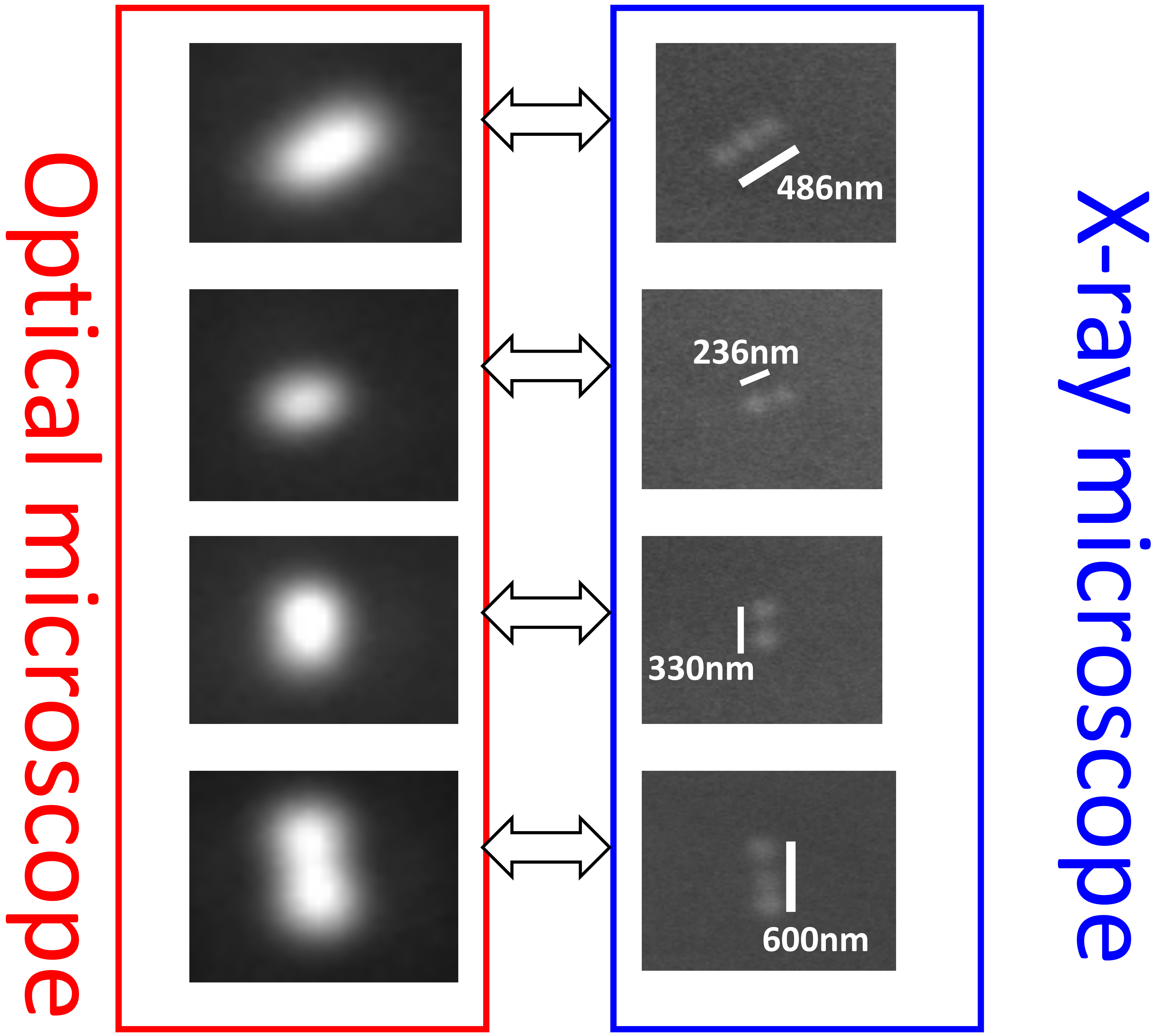
Finest grain emulsion



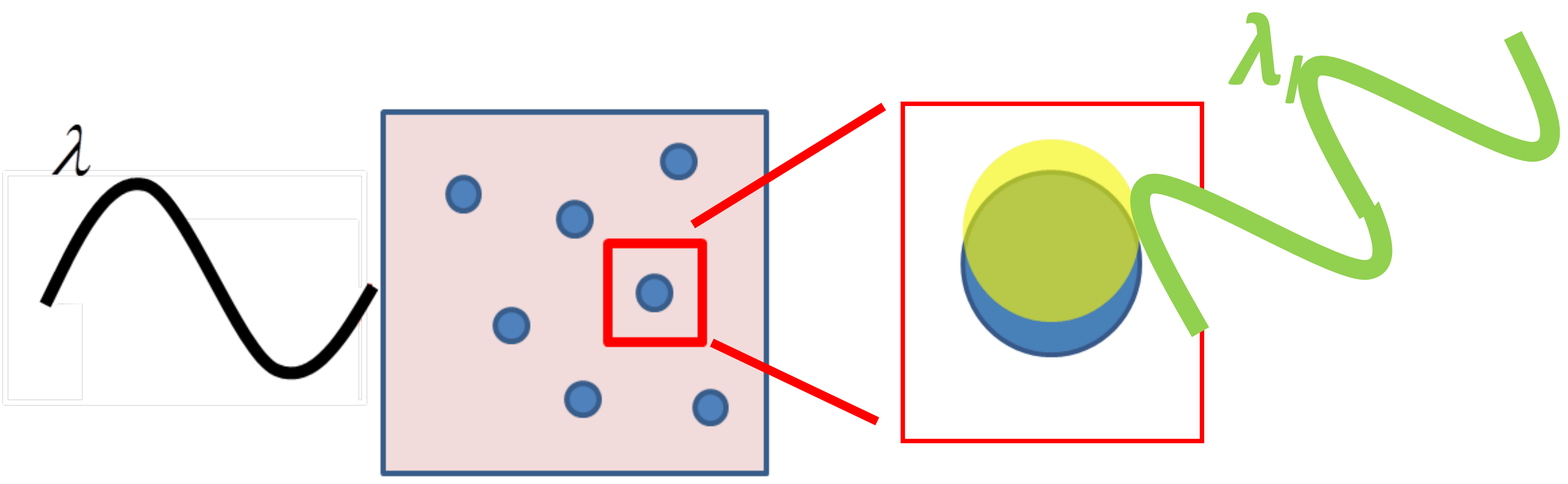
Range threshold	Carbon Energy
200 nm	75 keV
100 nm	35 keV
50 nm	15 keV

Nanometric nuclear recoils in the emulsion

Video of the lecturer



Resonant light scattering



Nano-metal in medium ε_d Oscillation of e-cloud

$$E_l = \frac{3\varepsilon_d(\lambda)}{\varepsilon_m(\lambda) + 2\varepsilon_d(\lambda)} E_0$$

E_l intensity inside the metal

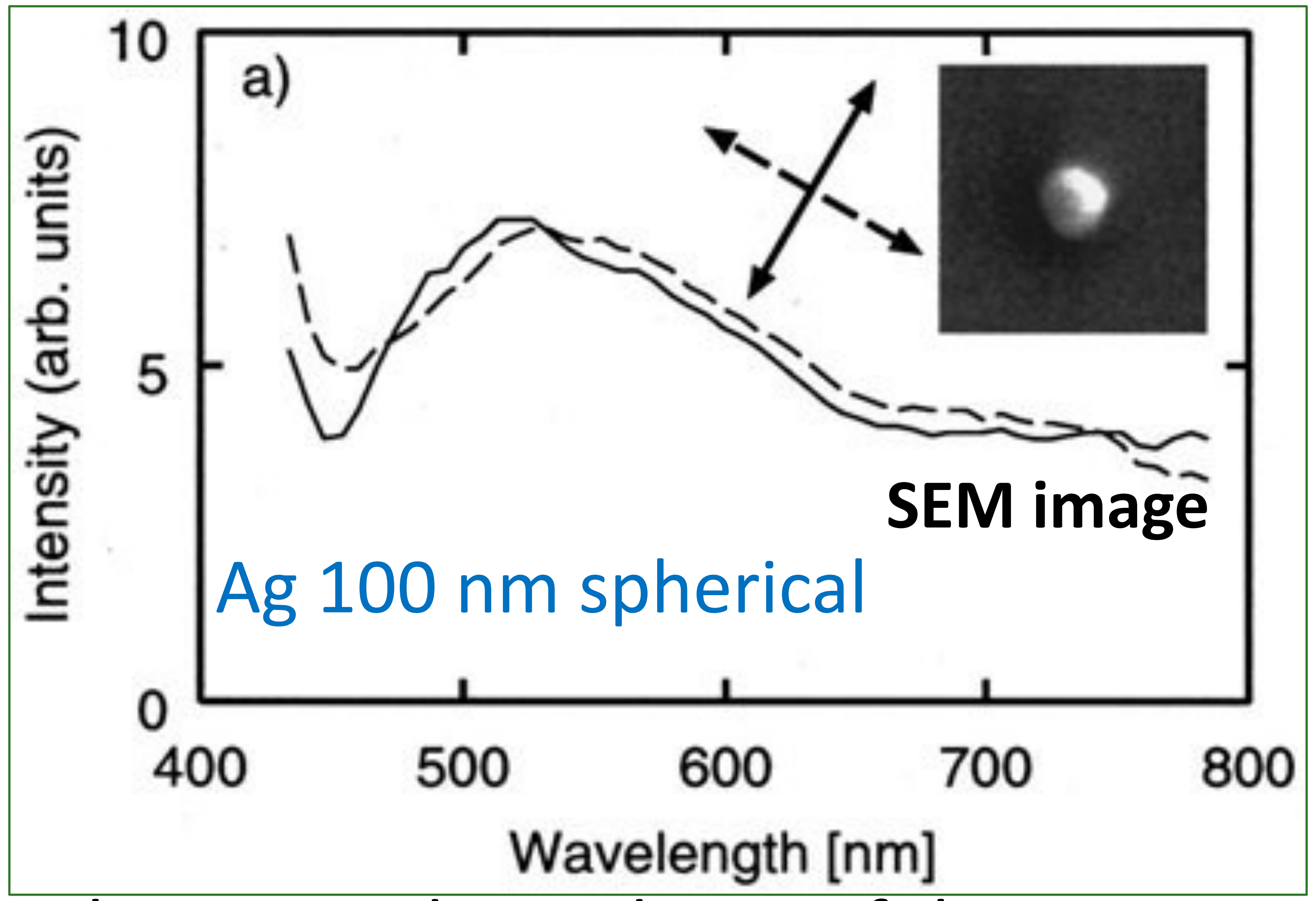
$$\varepsilon_m(\lambda_l) + 2\varepsilon_d(\lambda_l) \approx 0$$

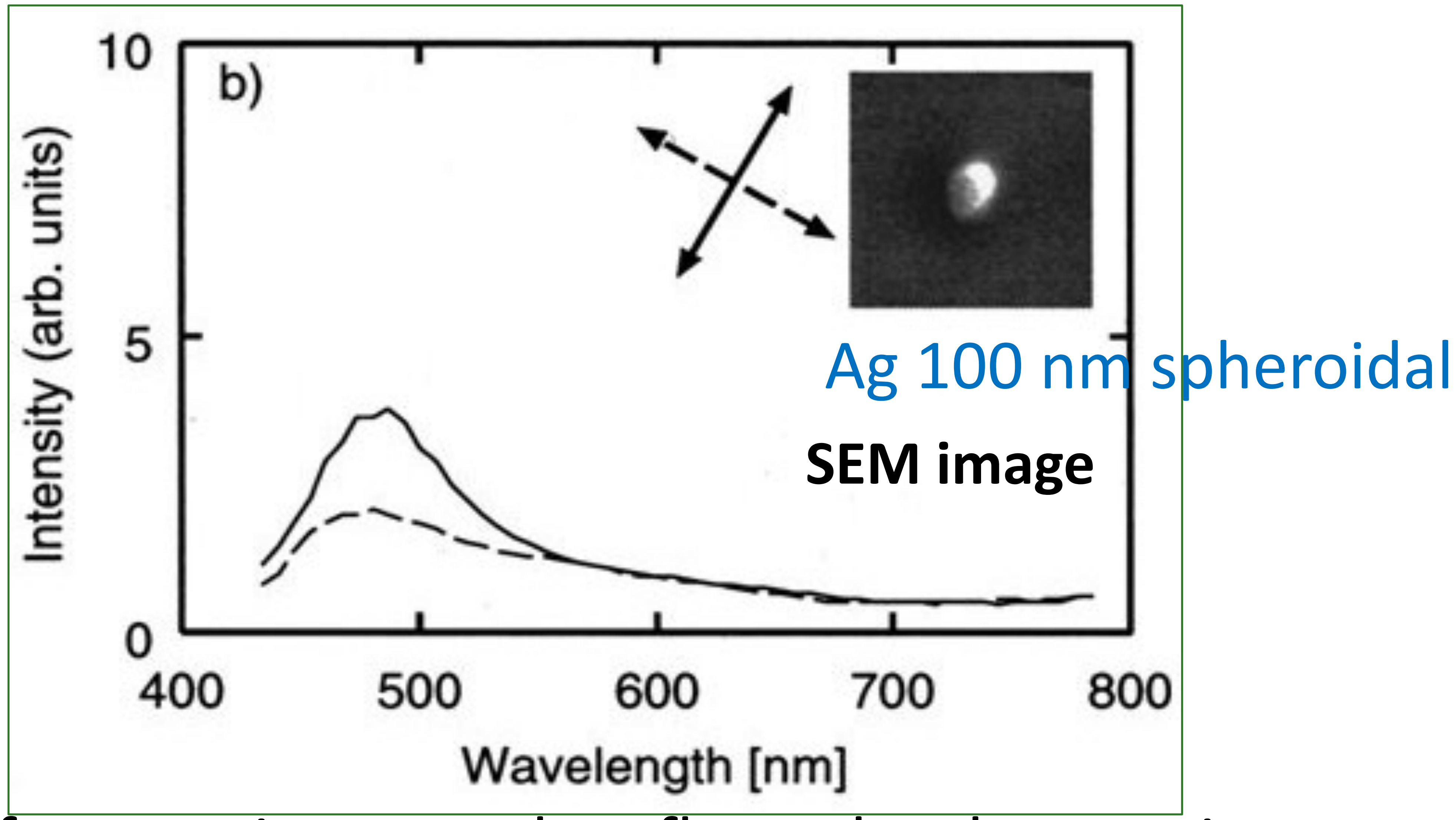
***E_l* is resonance enhanced**

Video of the lecturer

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

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



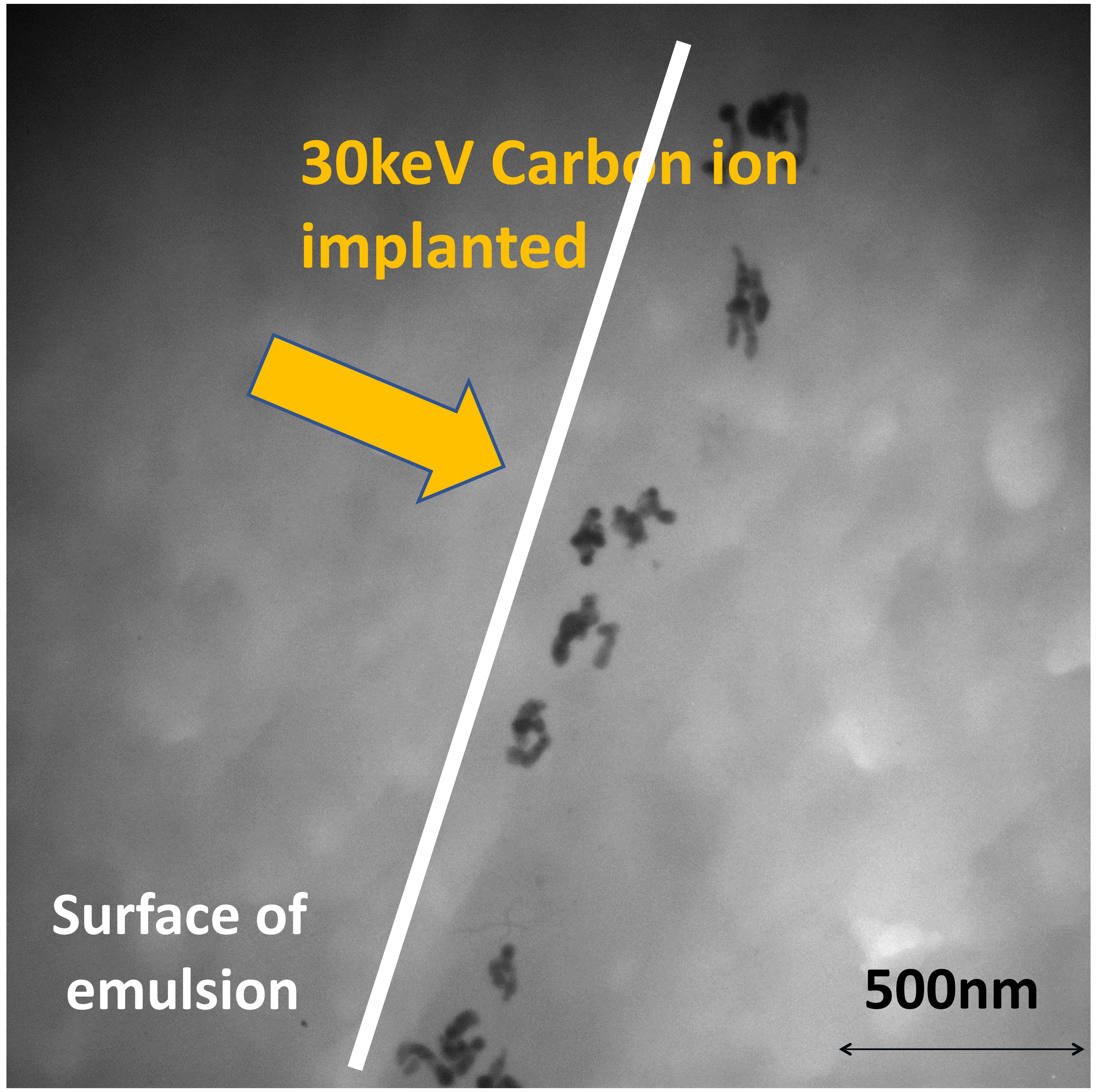


The polarization dependence of the resonance frequencies strongly reflects the shape anisotropy

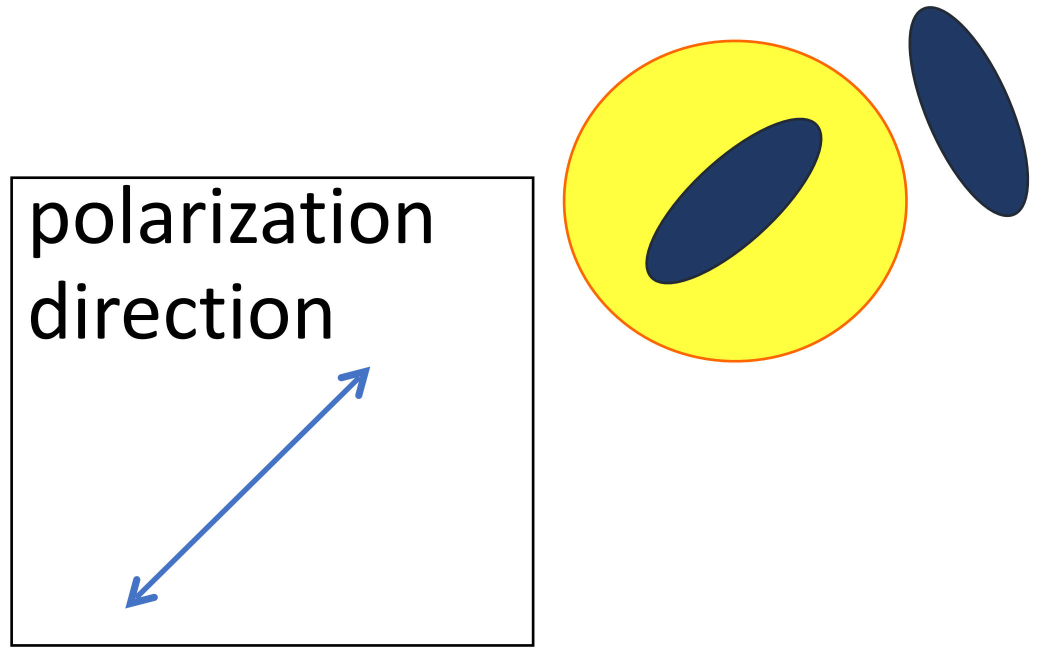
Resonant light scattering: silver grains

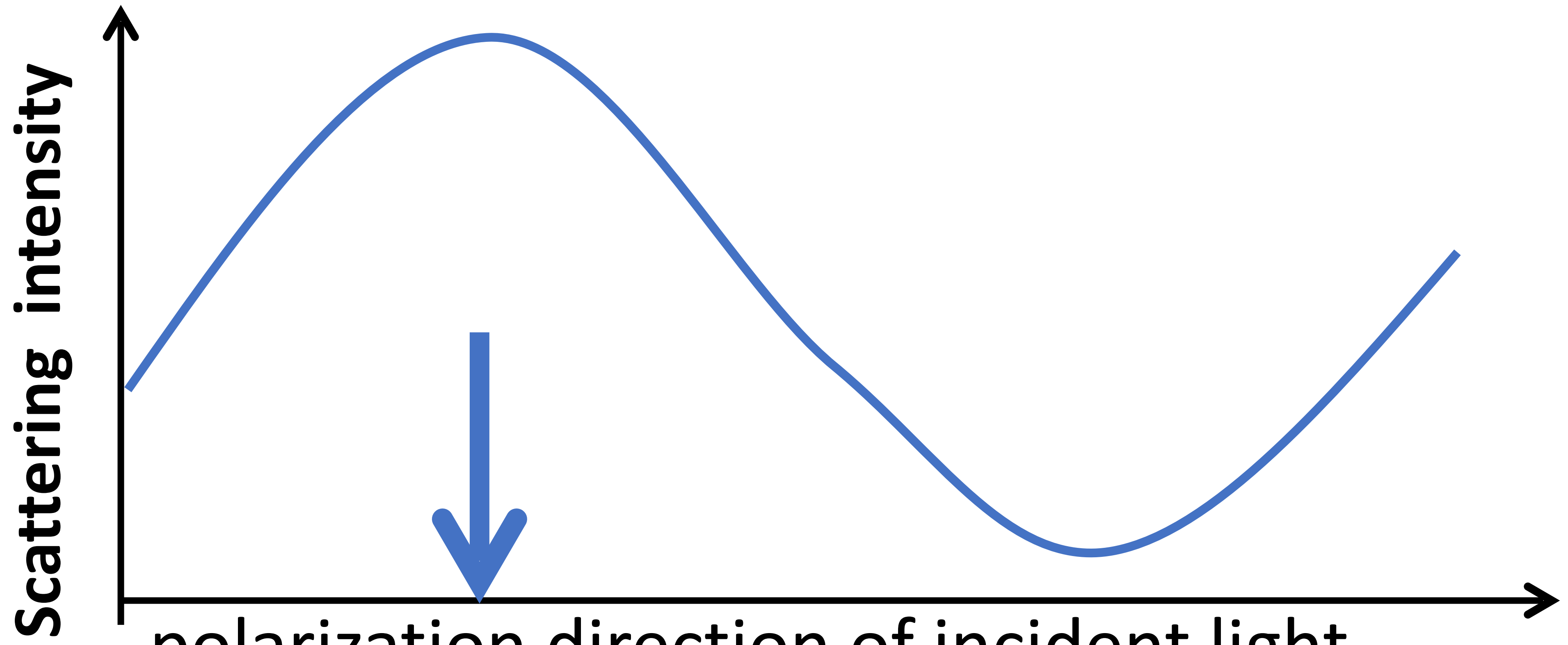
Video of the lecturer

TEM image of Carbon track after development



Different orientation



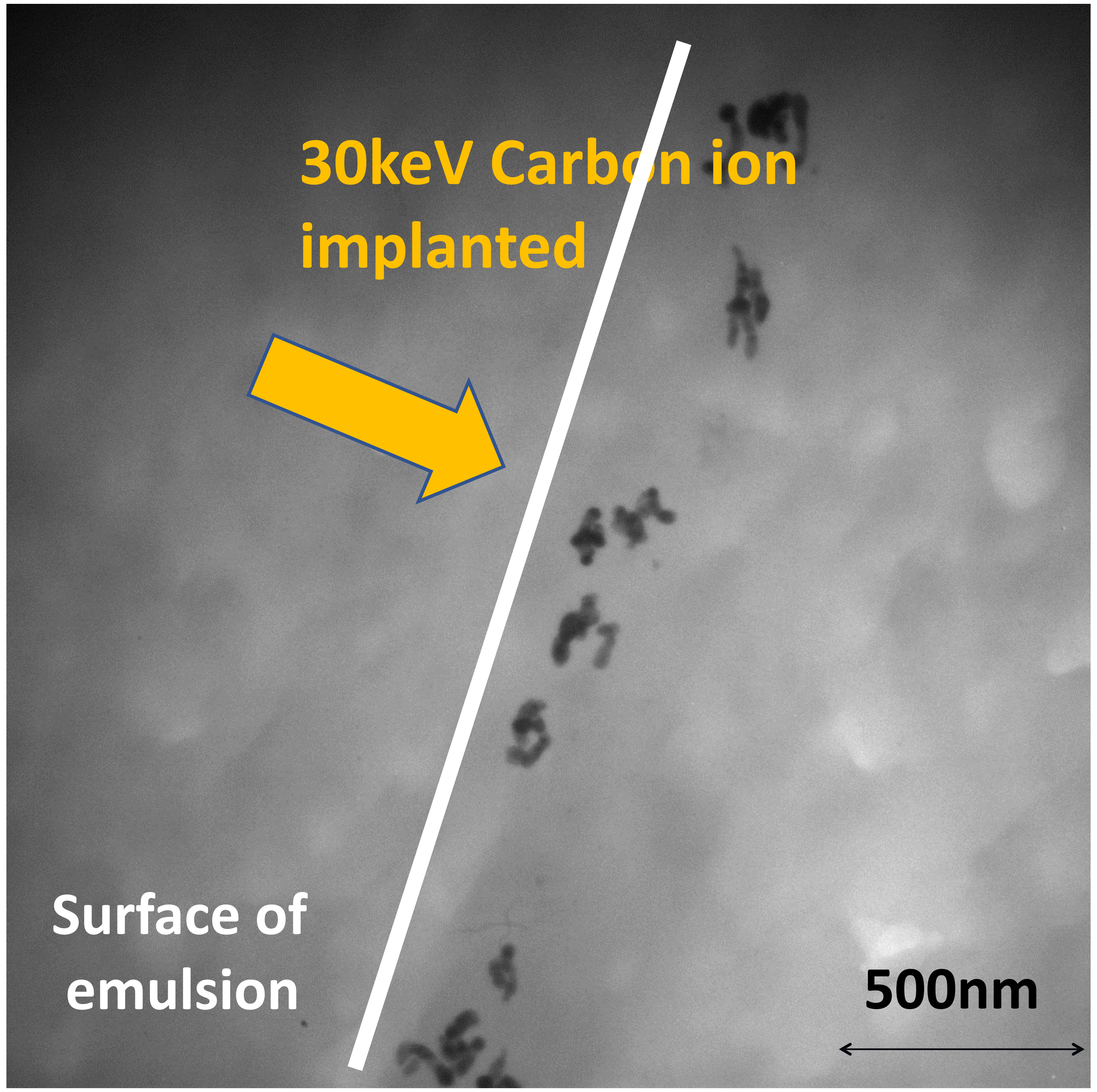


Optical response strongly depends on the polarization of incident light

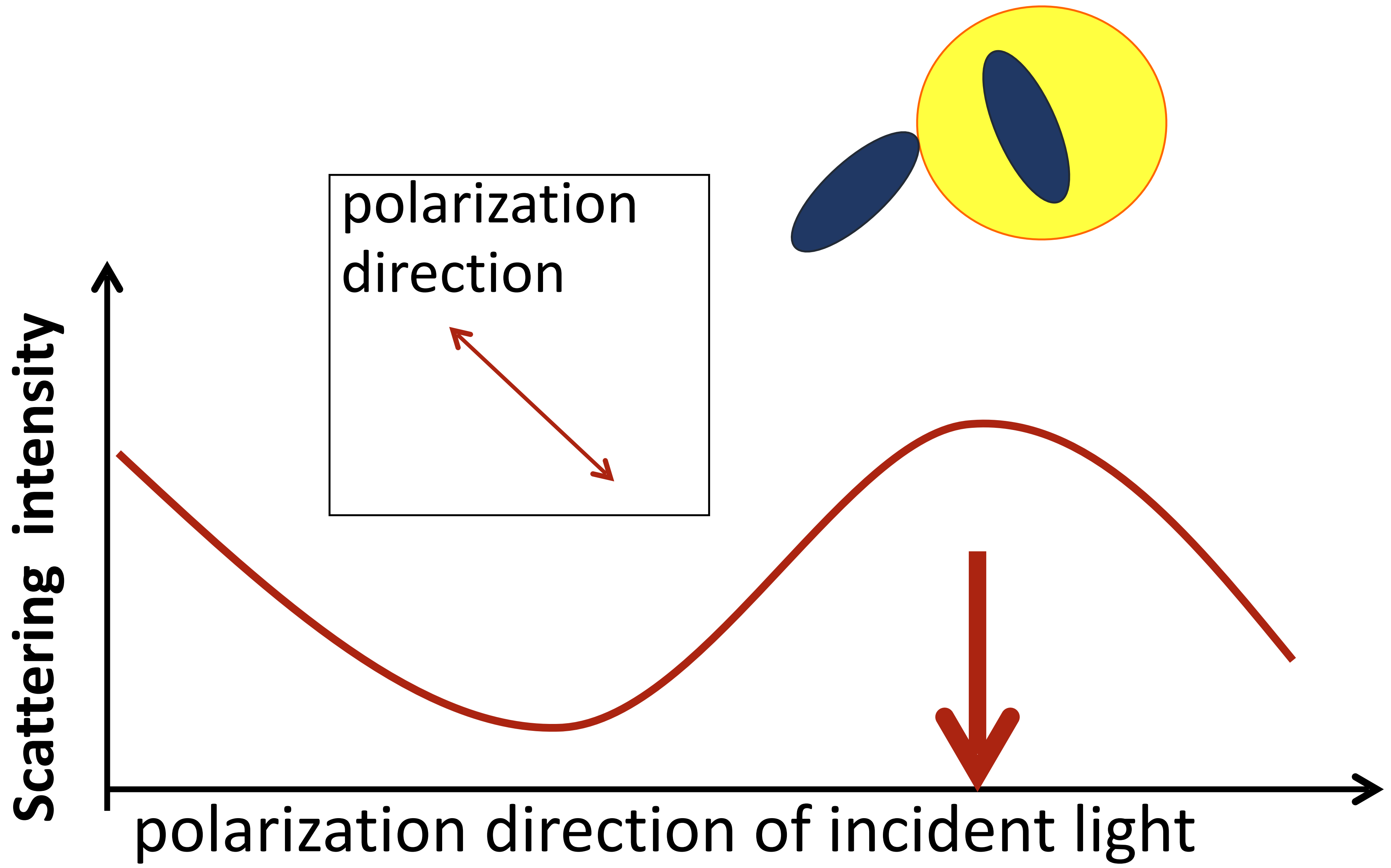
Resonant light scattering: silver grains

Video of the lecturer

TEM image of Carbon track after development

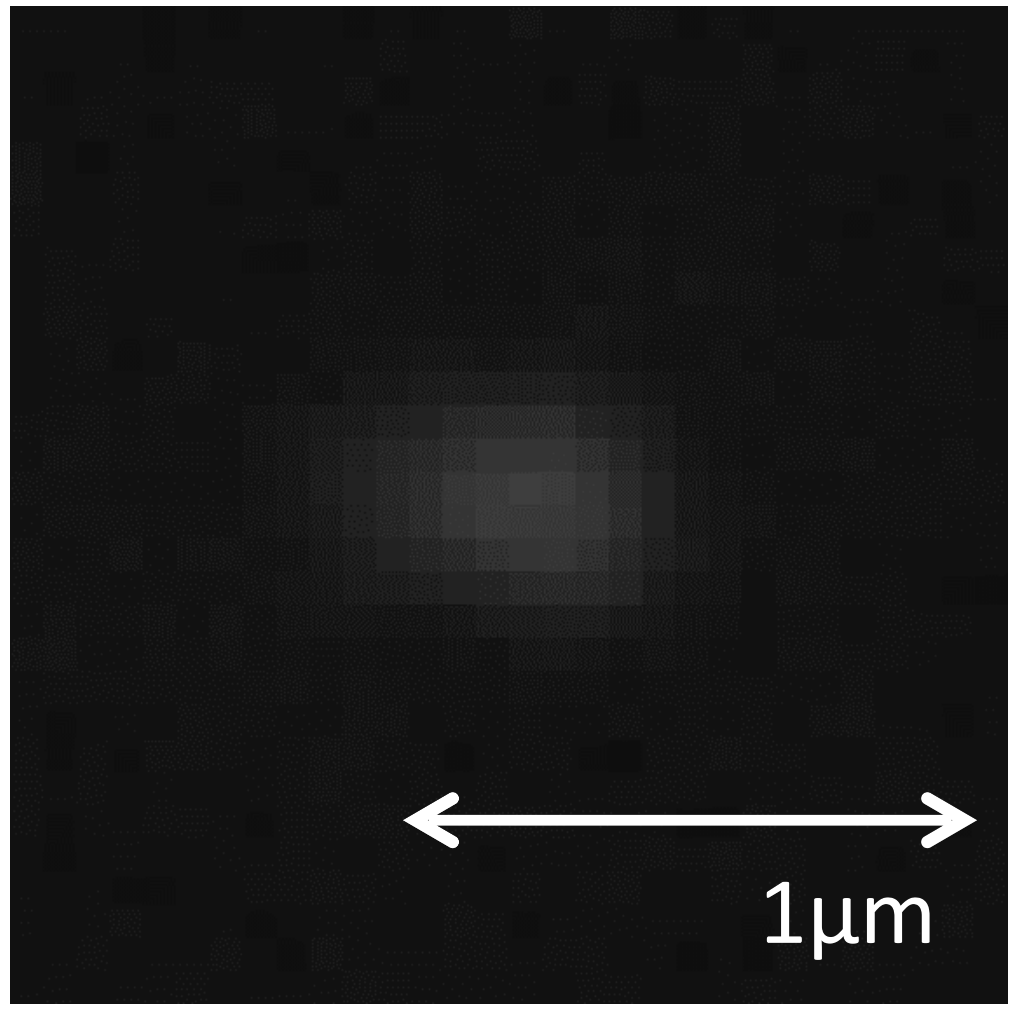


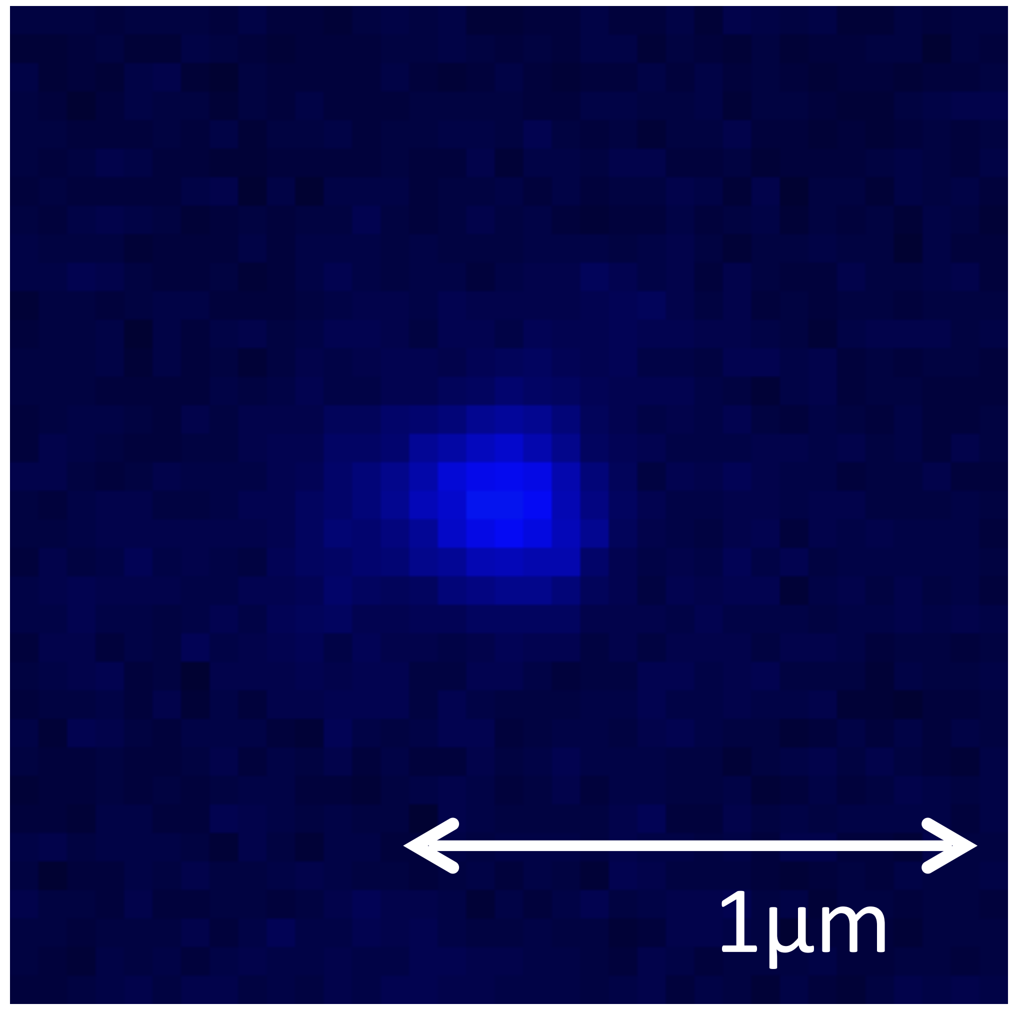
Different orientation



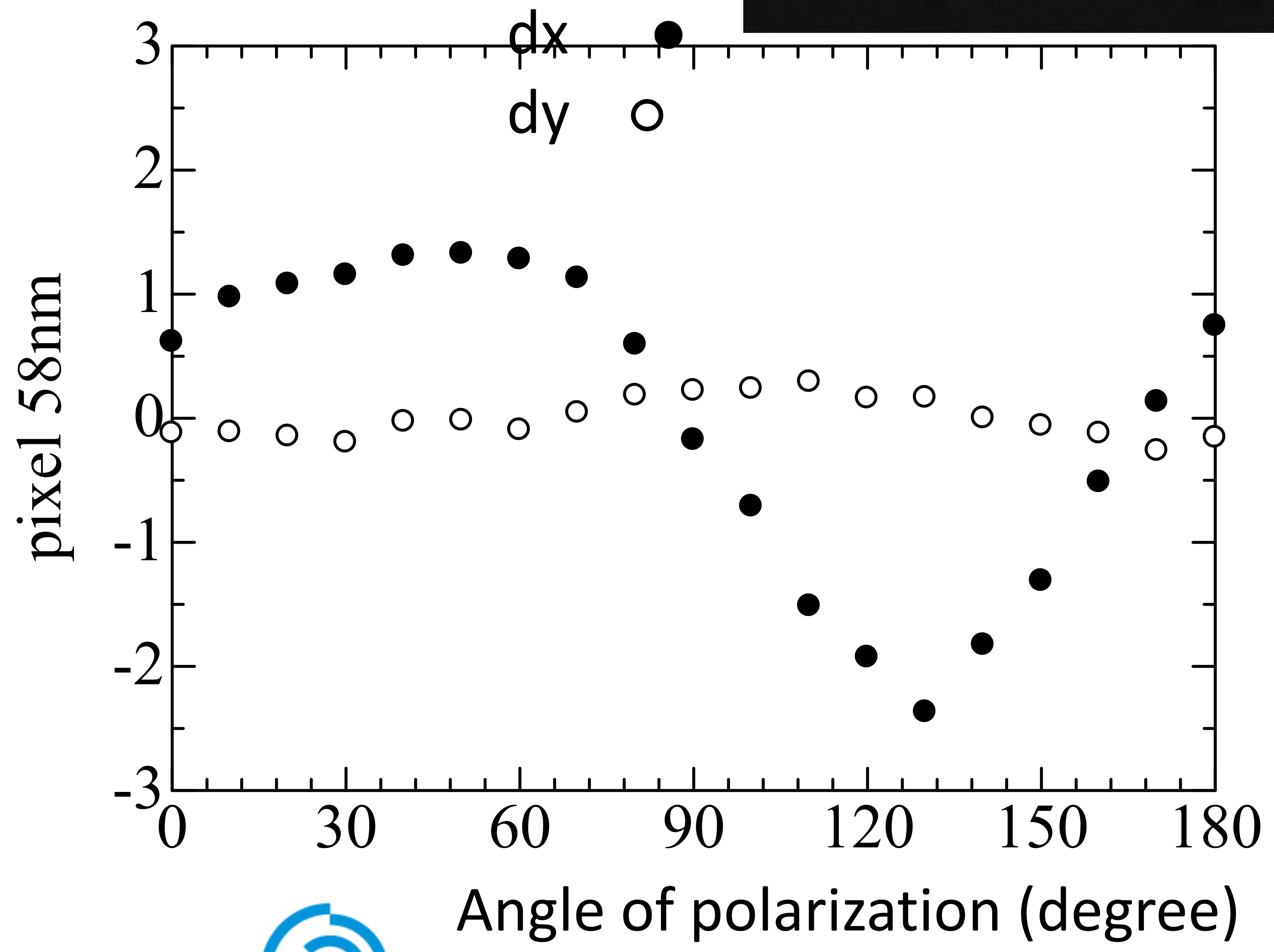
Optical response strongly depends on the polarization of incident light

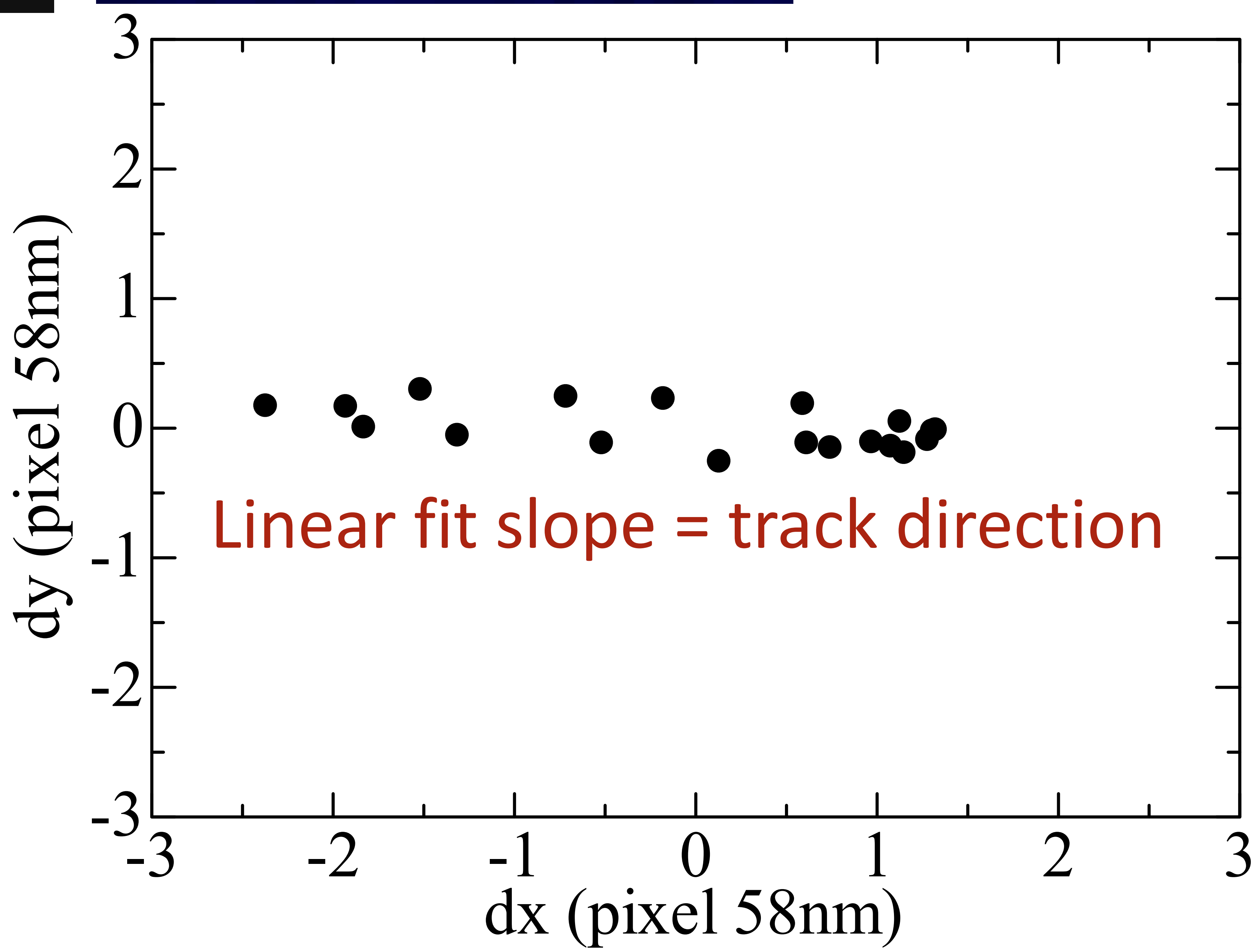
Two grains building up a track





Video of the lecturer

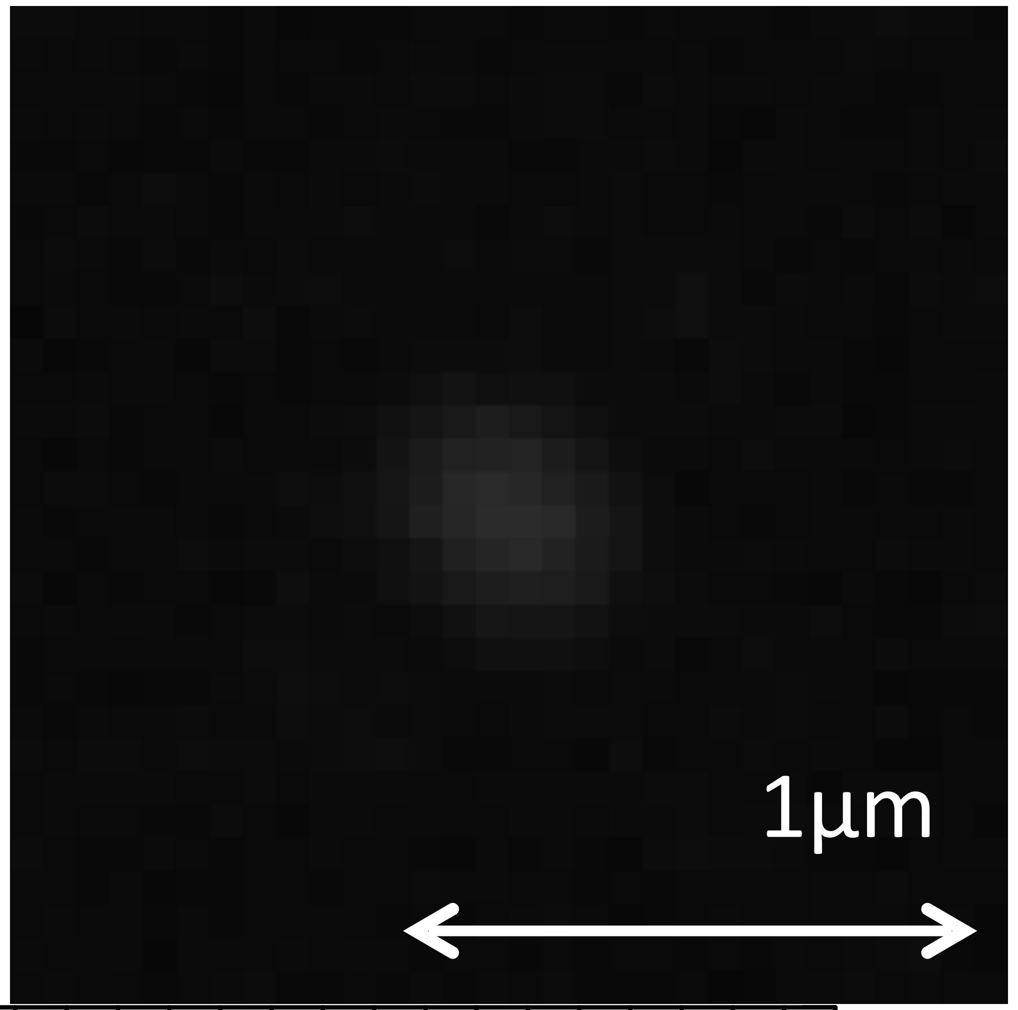


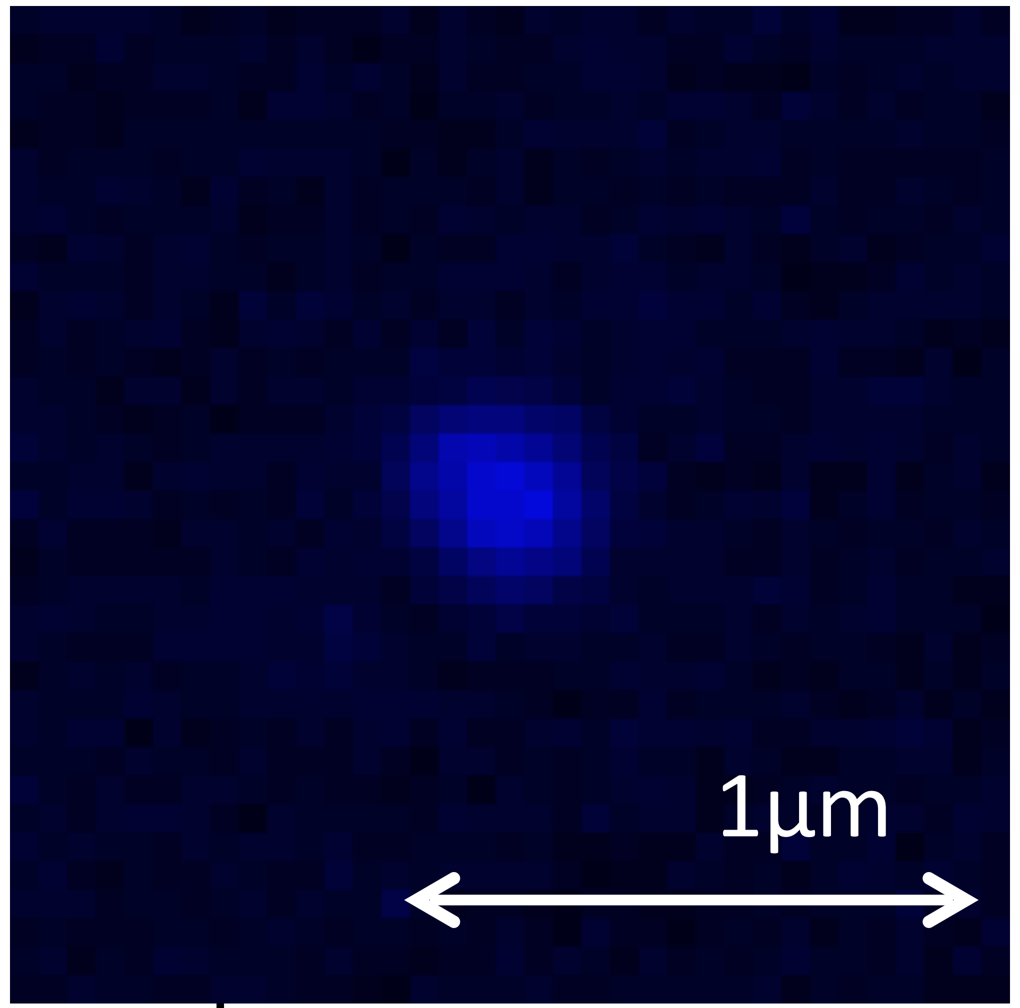


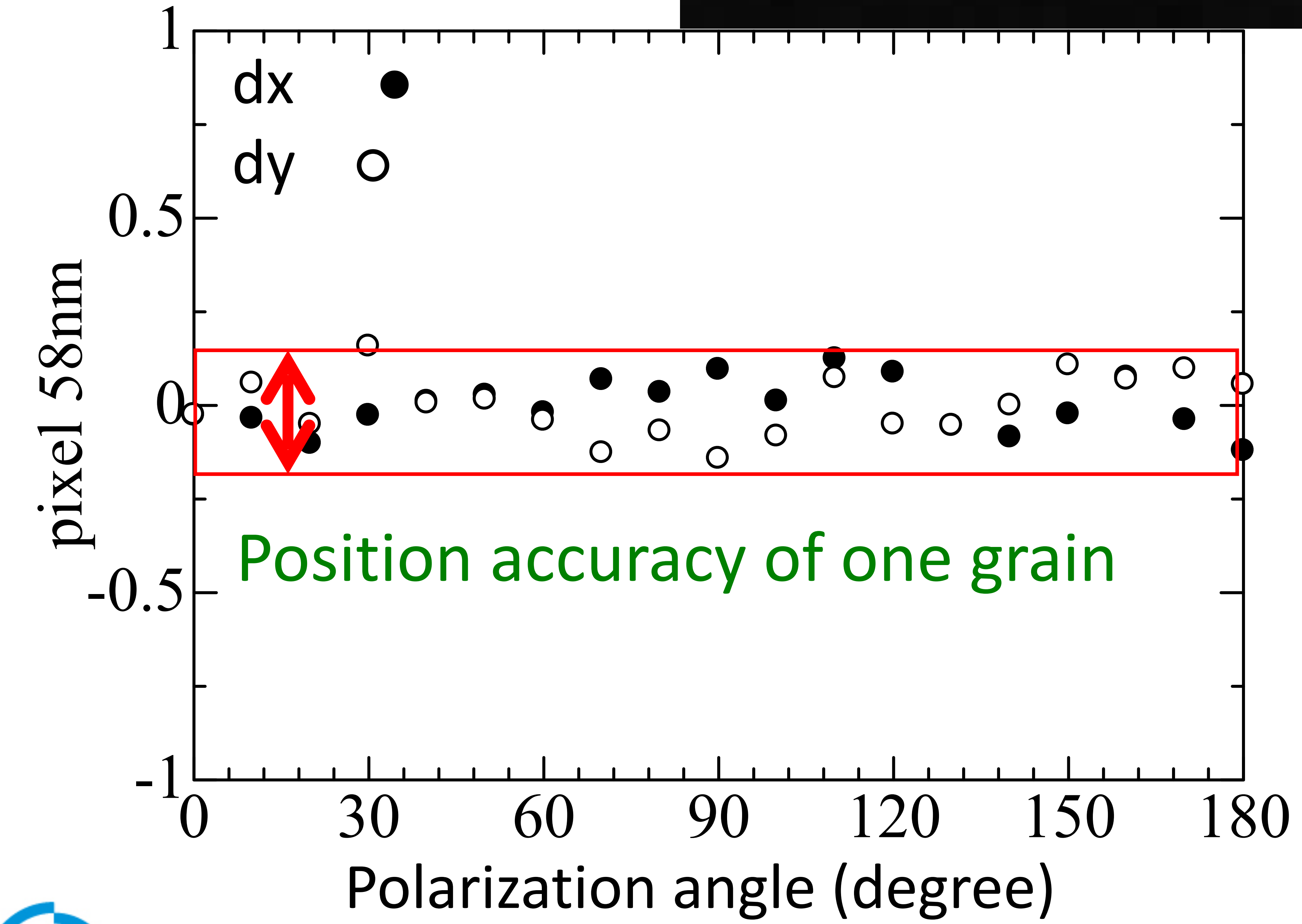
Single grain: accuracy

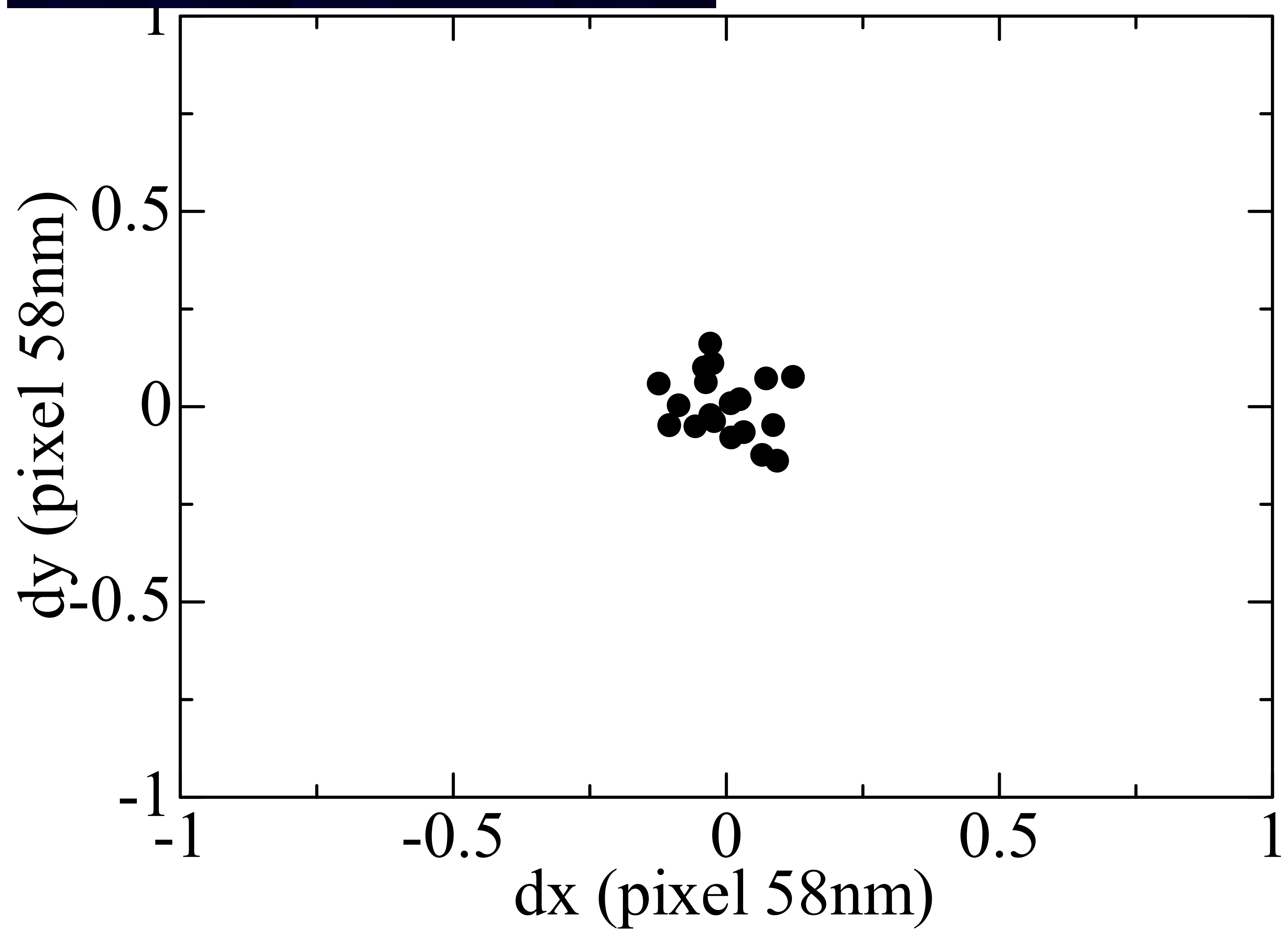
Video of the lecturer

Ag 60nm







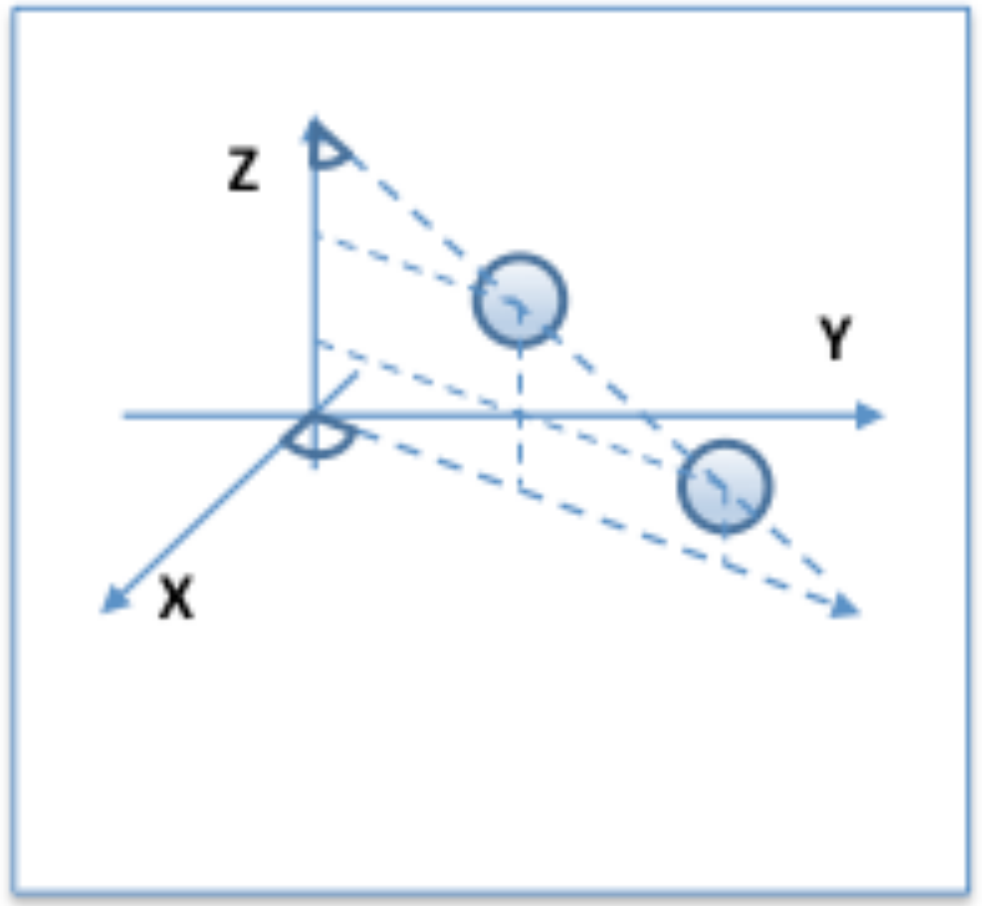


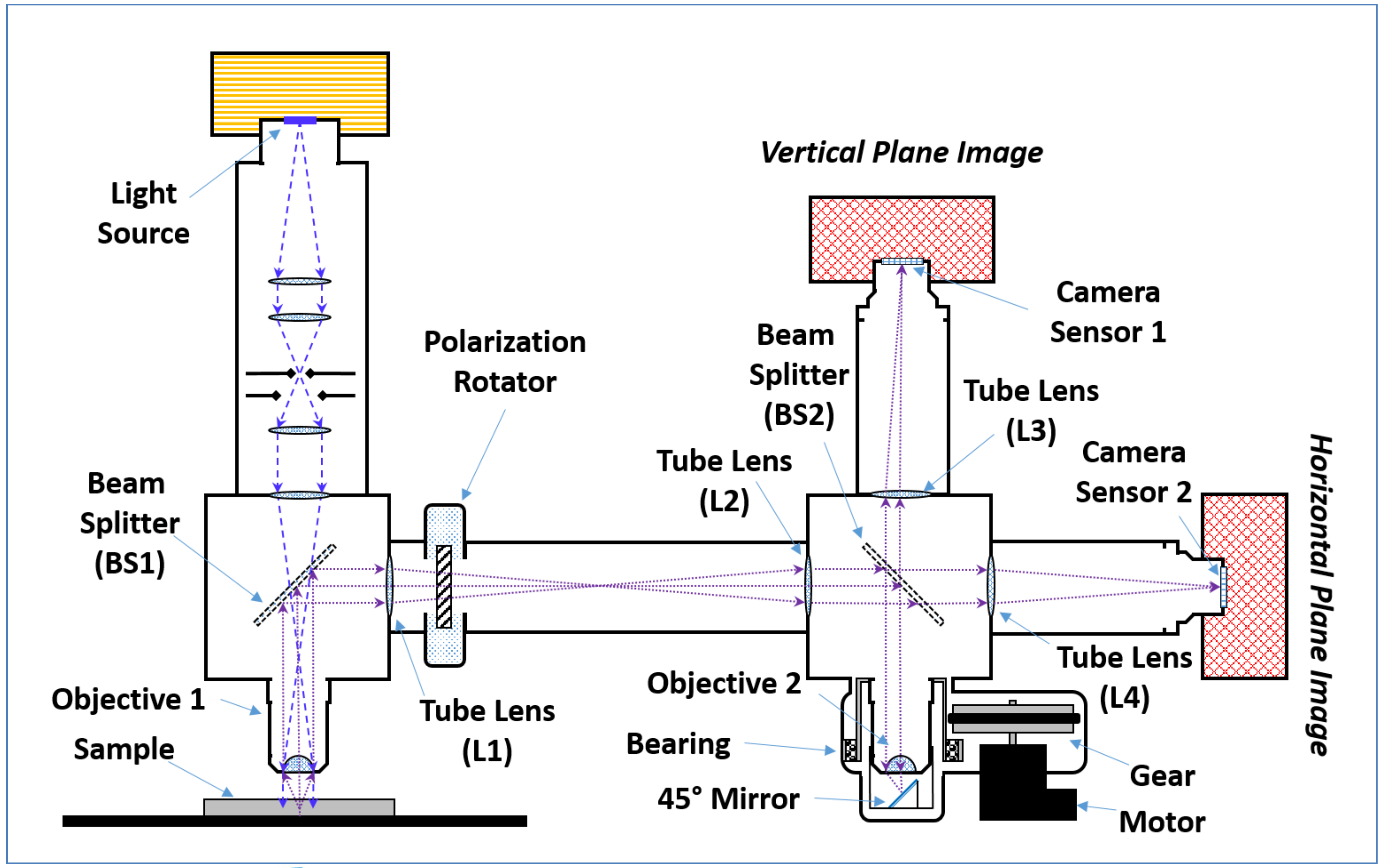
Super-resolution microscope

Int.Class	Appl.No	Title / Applicant	Ctr	PubDate / Inventor
1. WO/2018/122814		METHOD AND OPTICAL MICROSCOPE FOR DETECTING PARTICLES HAVING SUB-DIFFRACTIVE SIZE	WO	05.07.2018

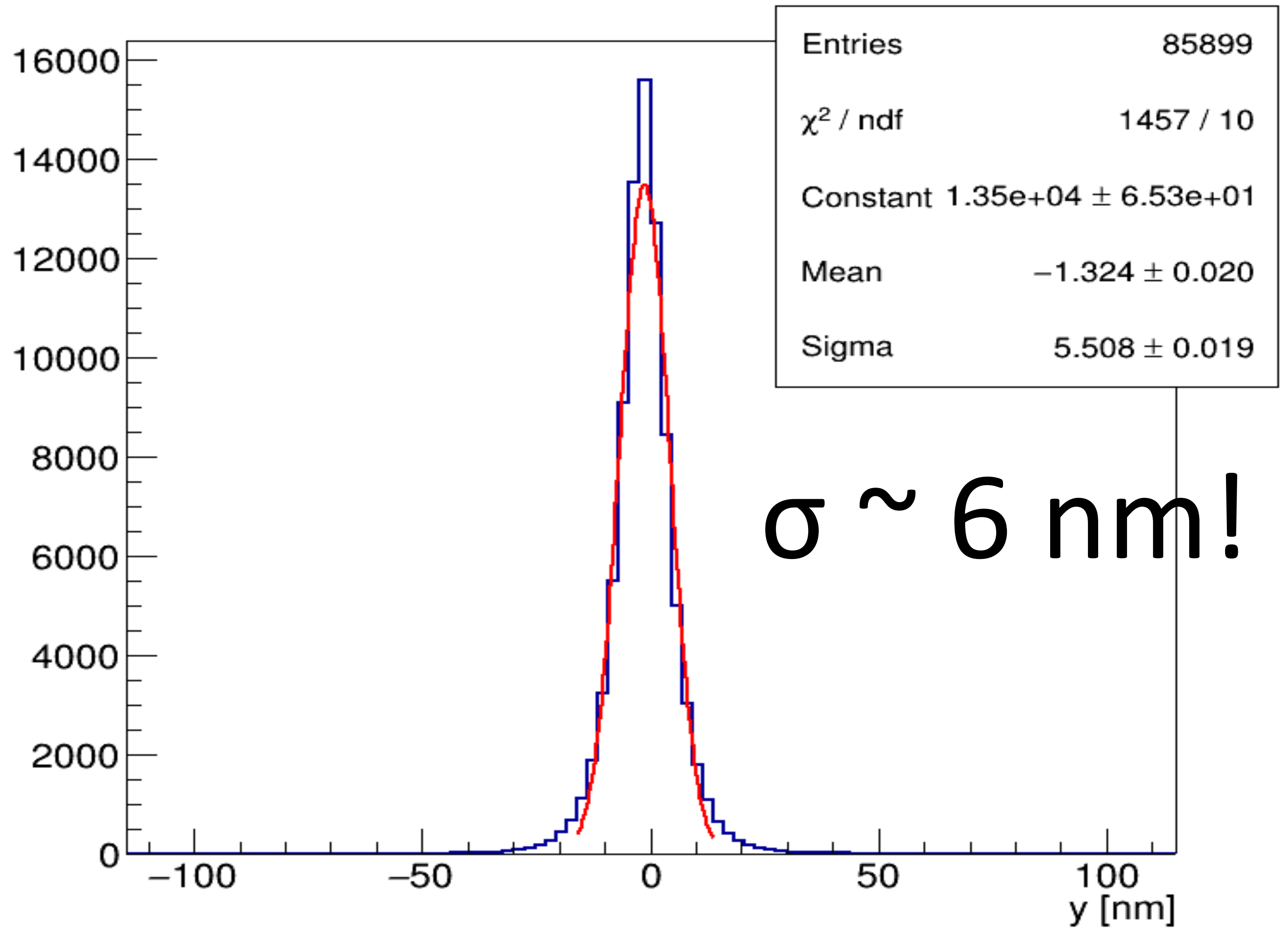
Pub. No.: WO/2018/122814 **International Application No.:** PCT/IB2017/058544
Publication Date: 05.07.2018 **International Filing Date:** 30.12.2017
IPC: *G02B 21/00* (2006.01) ,*G02B 21/36* (2006.01)
Applicants: **ISTITUTO NAZIONALE DI FISICA NUCLEARE** [IT/IT]; Via Enrico Fermi, 40 00044 Frascati (rM),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

Video of the lecturer





Breakthrough



$\sigma \sim 6$ nm!

Super-resolution with plasmon analysis

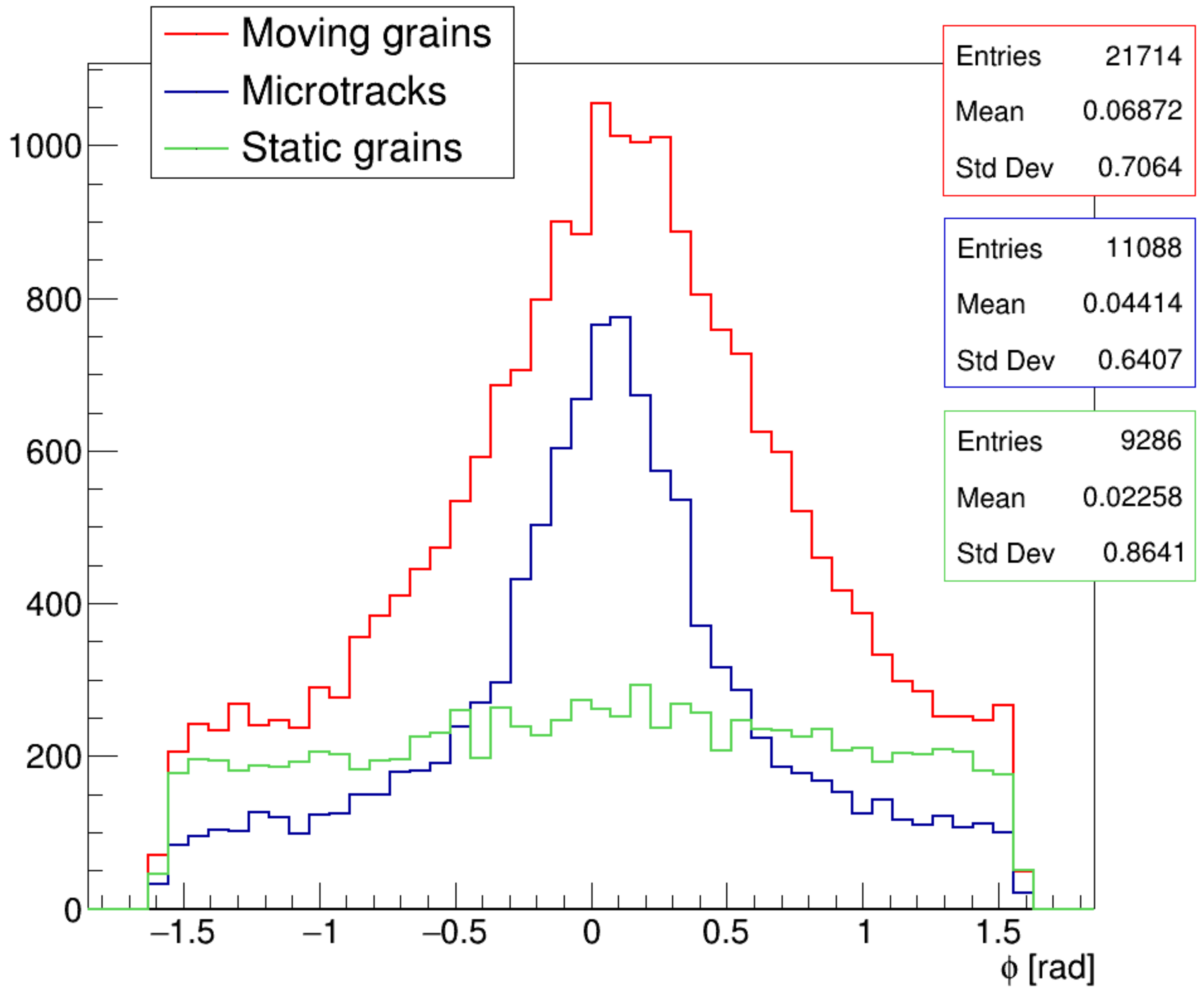
Horizontal ions, signal-like events

Video of the lecturer

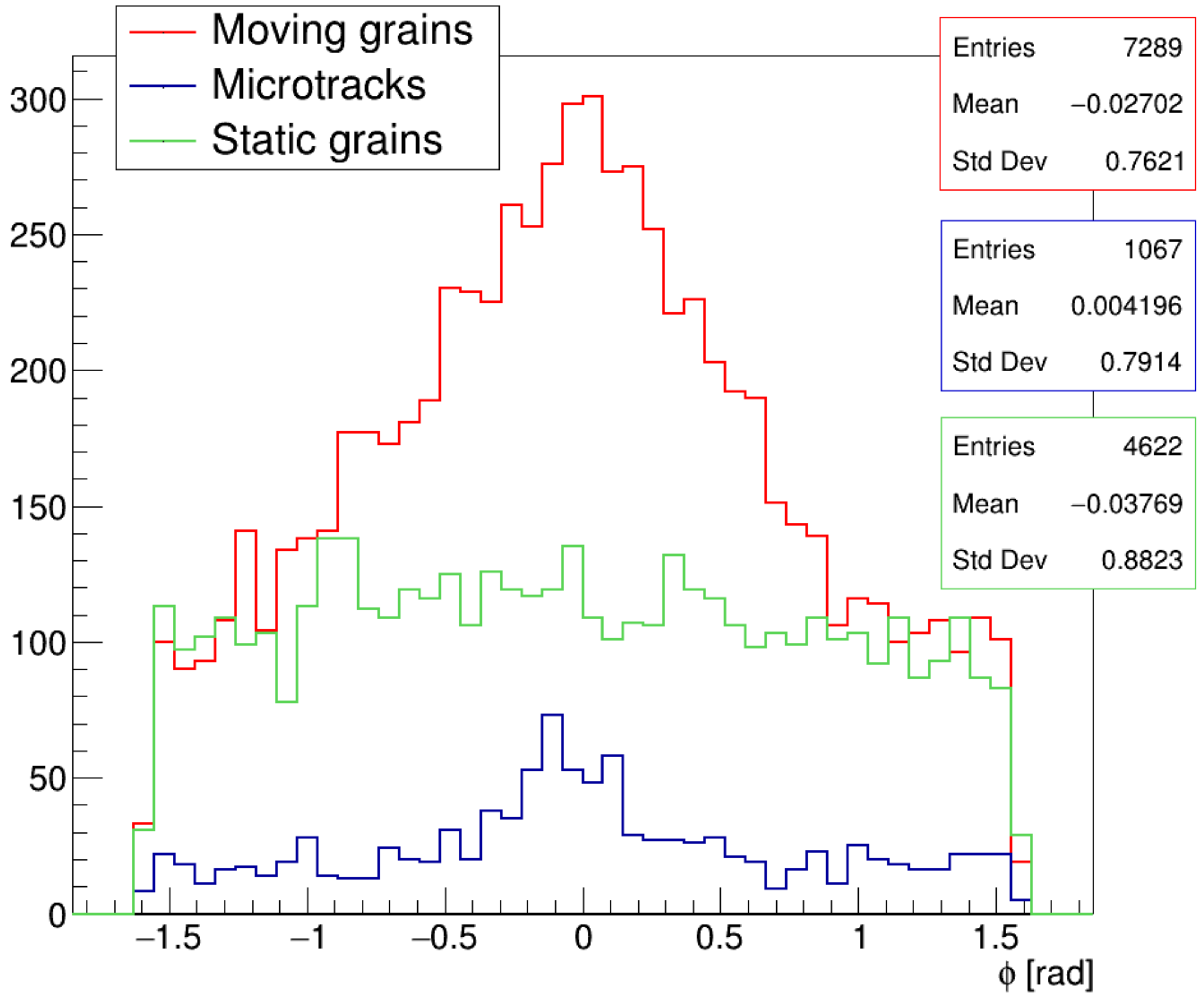
Barycenter displacement > 3σ **(Moving)**

Barycenter displacement ≤ 3σ **(Static)**

100 KeV



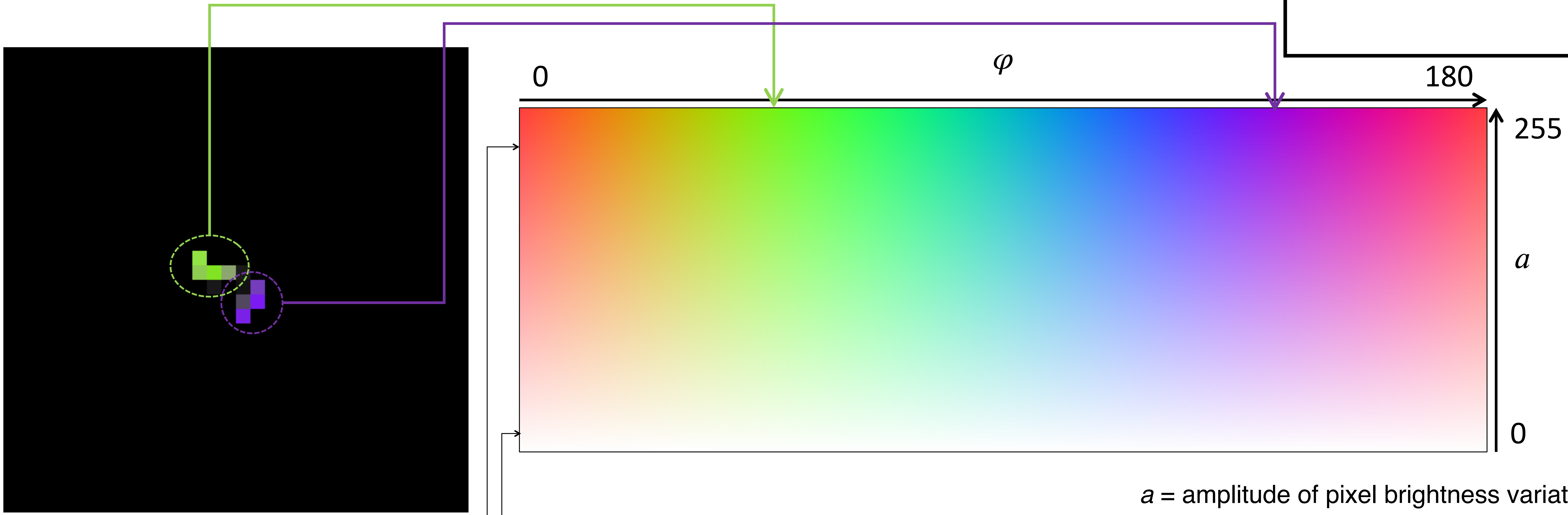
60 KeV



Super-resolution plasmic imaging microscopy for a sub micron tracking emulsion detector, PTEP (2019) 063H02

Super-resolution analysis with plasmon analysis

Video of the lecturer



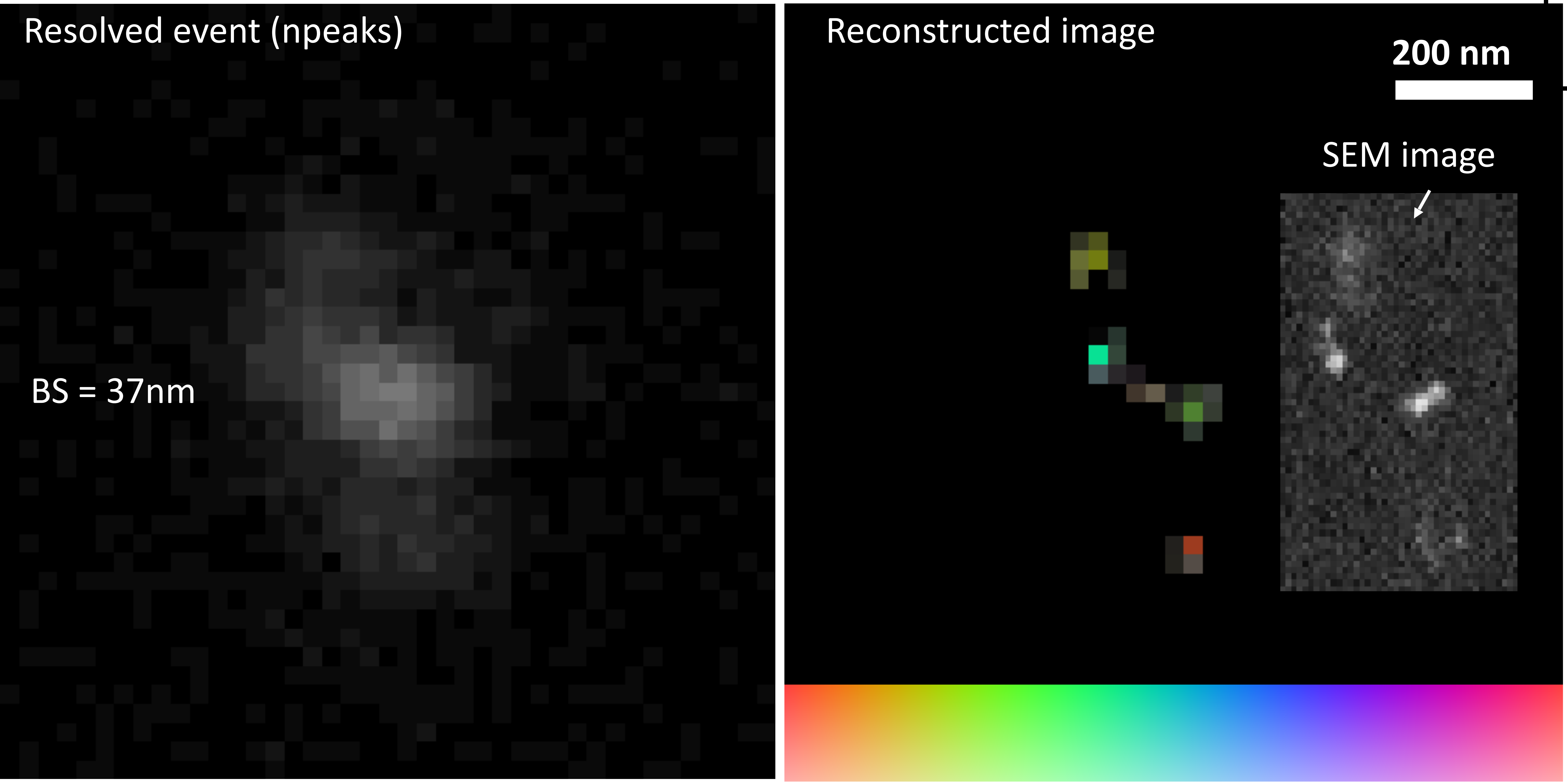
Intensity $I_\theta = b + a\cos 2(\theta - \varphi)$

a = amplitude of pixel brightness variation
b = mean pixel brightness
φ = pixel “phase”
θ = polarization angle

Non-metallic or spherical NPs
Silver grain filaments

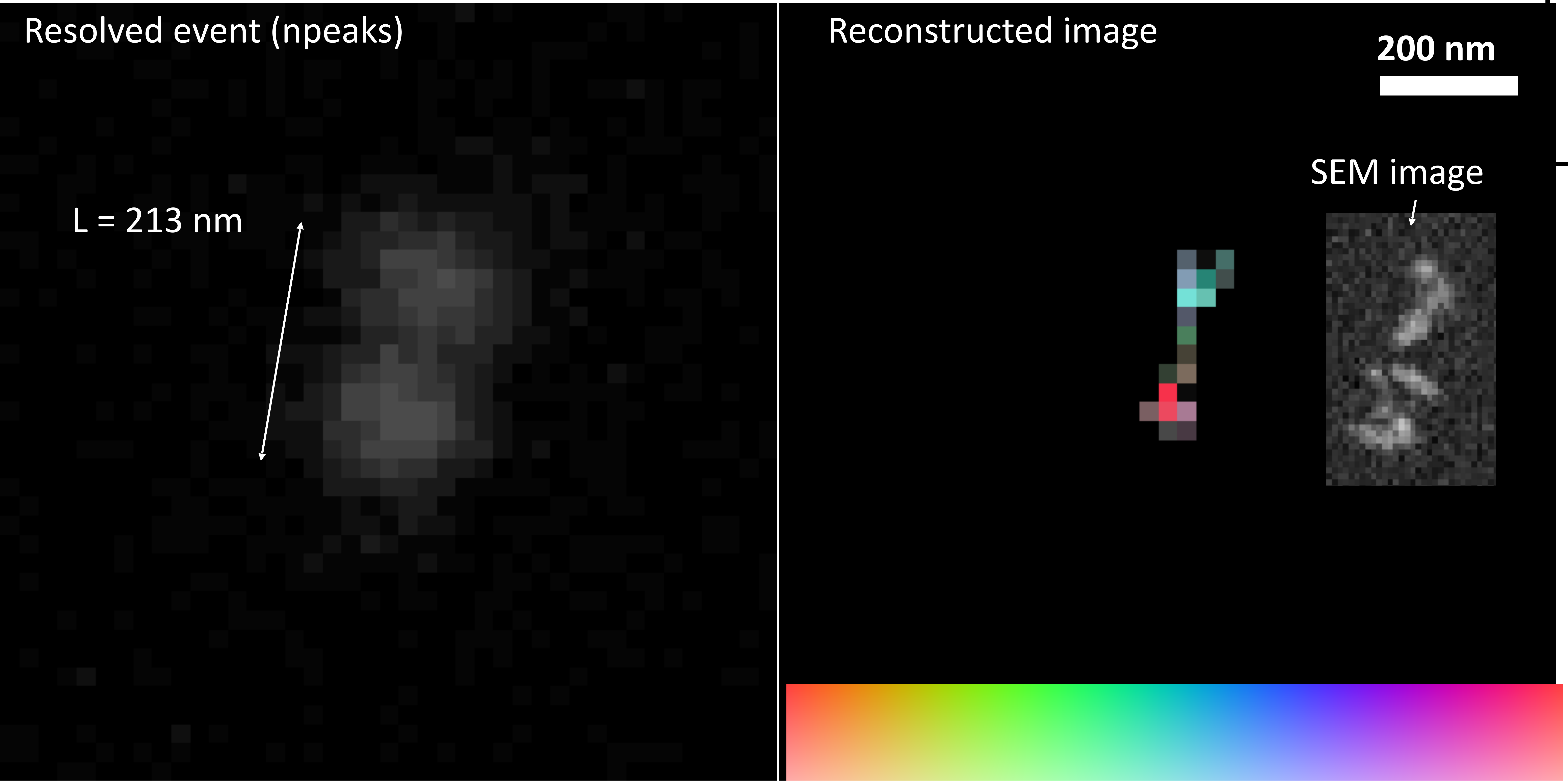
Super resolution imaging

Video of the lecturer



Super resolution imaging

Video of the lecturer



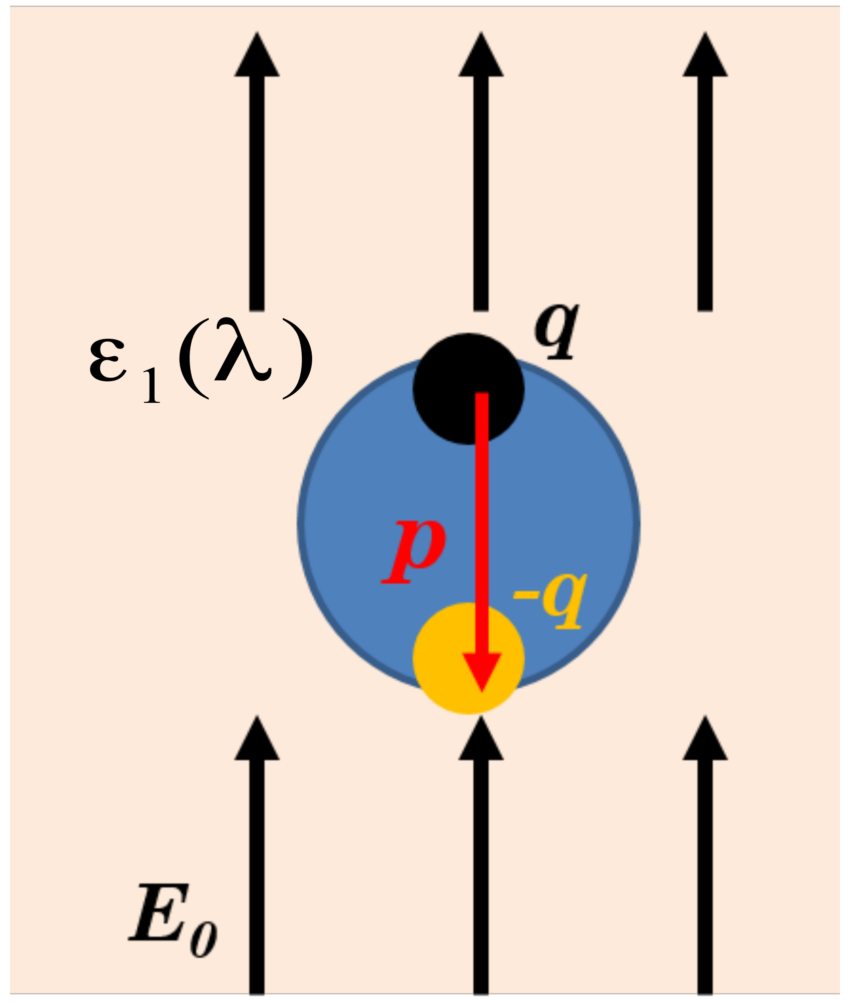
Super-resolution high-speed optical microscopy for fully automated readout of metallic nanoparticles and nanostructure
Scientific Reports 10 (2020) 18773

Super-resolution with plasmon analysis

Video of the lecturer

R = 45 nm → blue
H = 80 (120) nm → green (red)

Annu. Rev. Phys. Chem. 58 (2007) 267-297



dipole in metallic particle

dipole moment

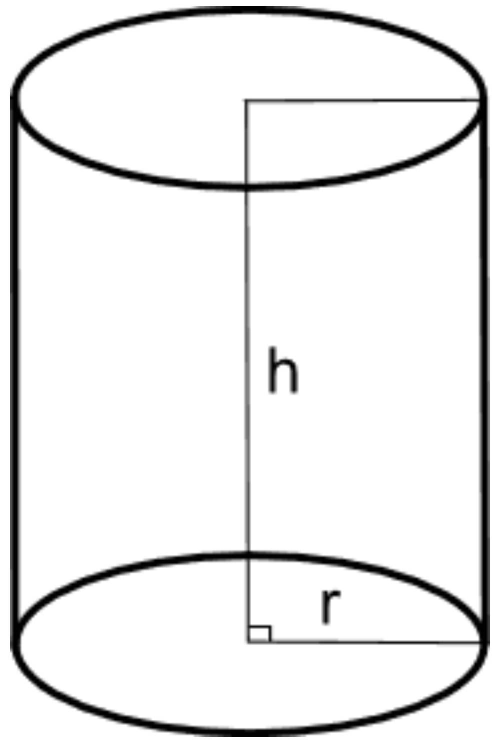
$$p = 4\pi\varepsilon_m a^3 \frac{\varepsilon_1(\lambda) - \varepsilon_m(\lambda)}{\varepsilon_1(\lambda) + 2\varepsilon_m(\lambda)} E_0$$

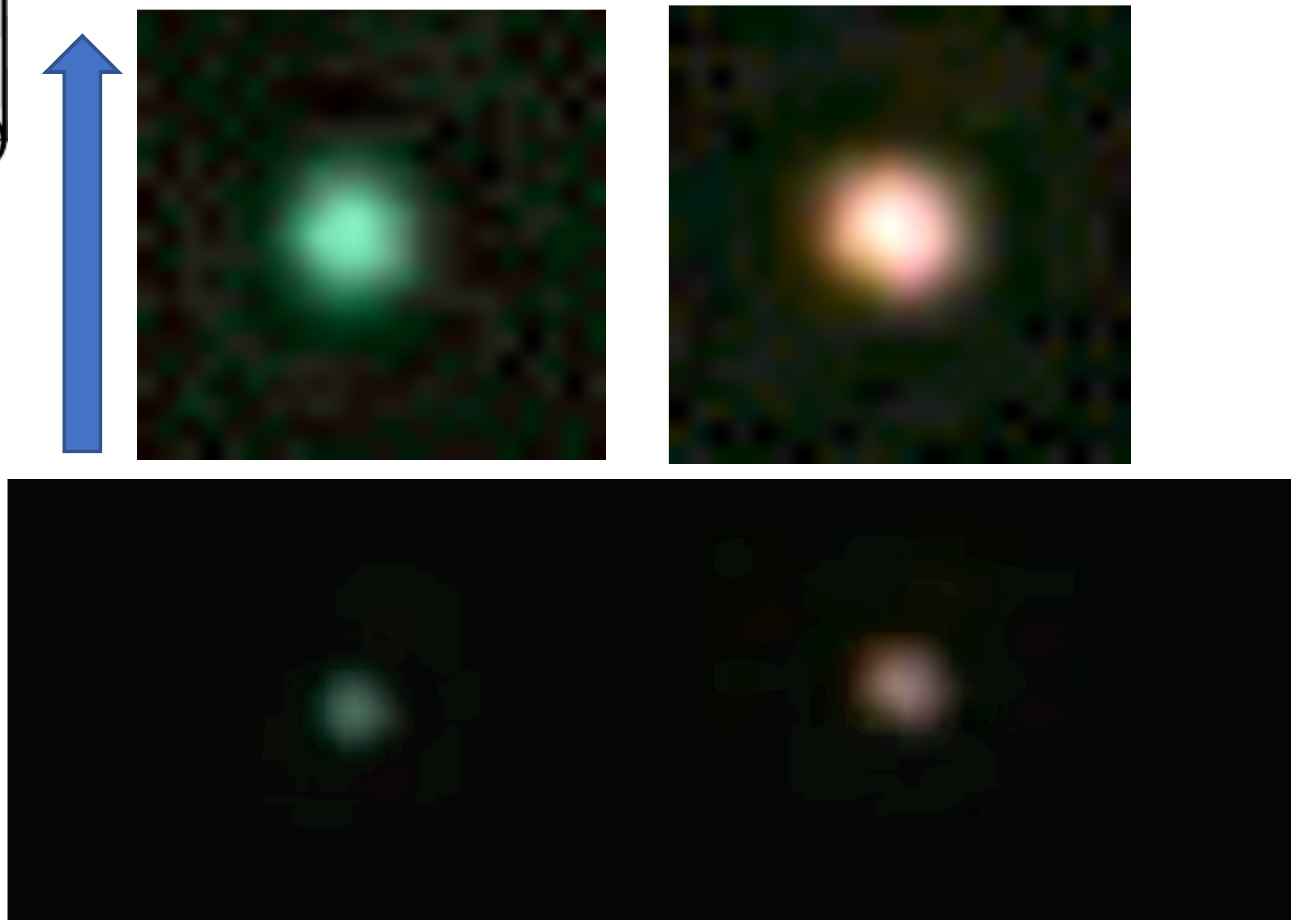
resonance

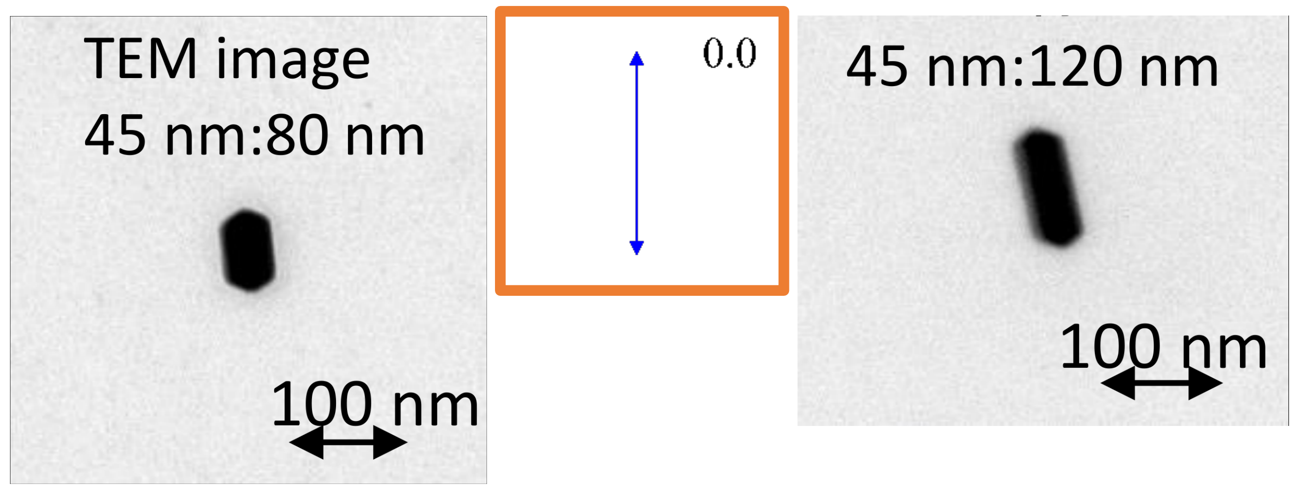
$$\varepsilon_1(\lambda_l) + 2\varepsilon_m(\lambda_l) \approx 0$$

Appl. Phys. Lett. 80, 1826 (2002)

Ag grain size → resonance wavelength







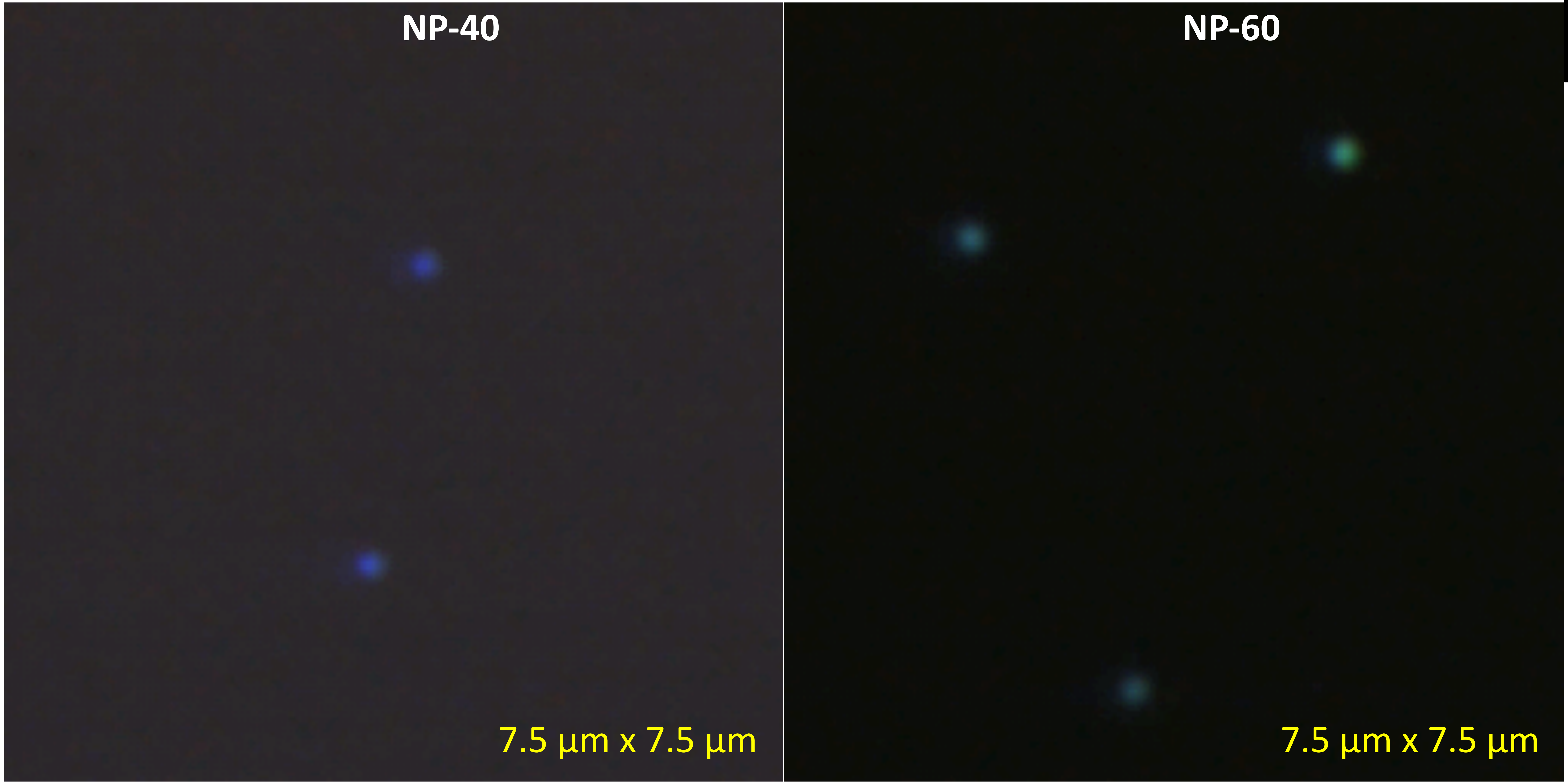
metallic particle

Super-resolution with plasmon analysis

Video of the lecturer

40 nm diameter

60 nm diameter

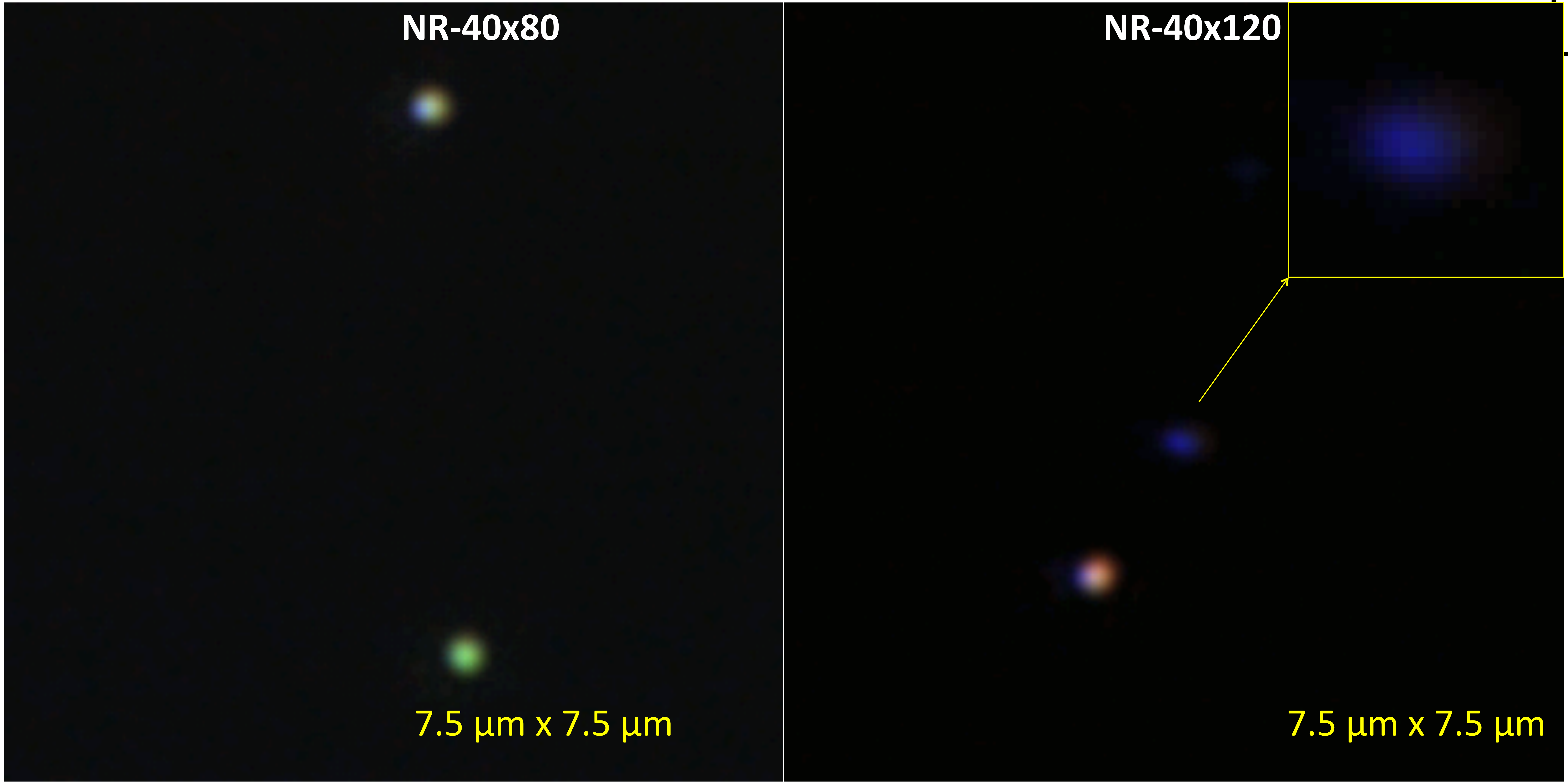


Super-resolution with plasmon analysis

Video of the lecturer

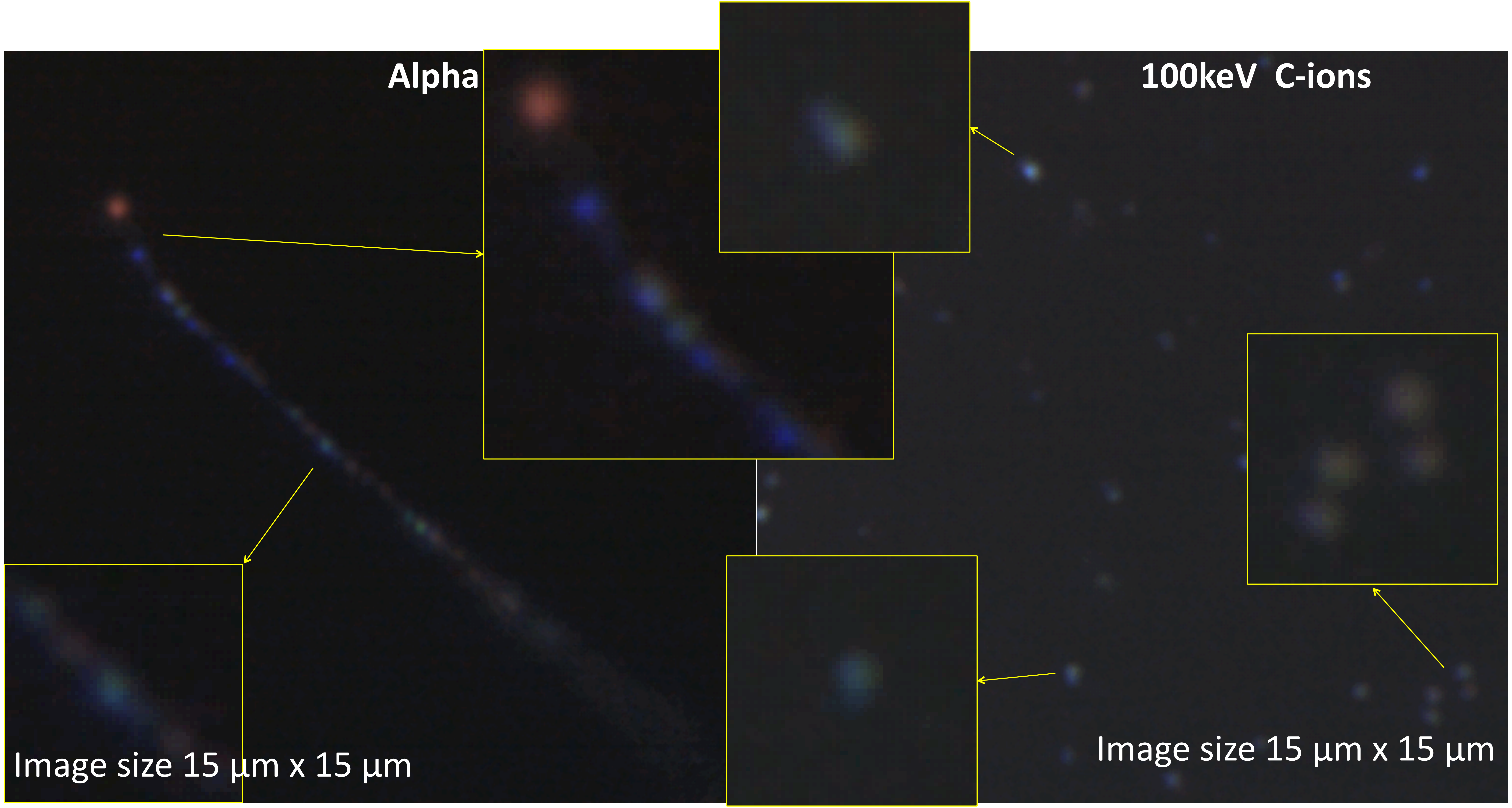
40 nm diameter, 80 nm height

40 nm diameter, 120 nm height



Super-resolution with plasmon analysis

Video of the lecturer

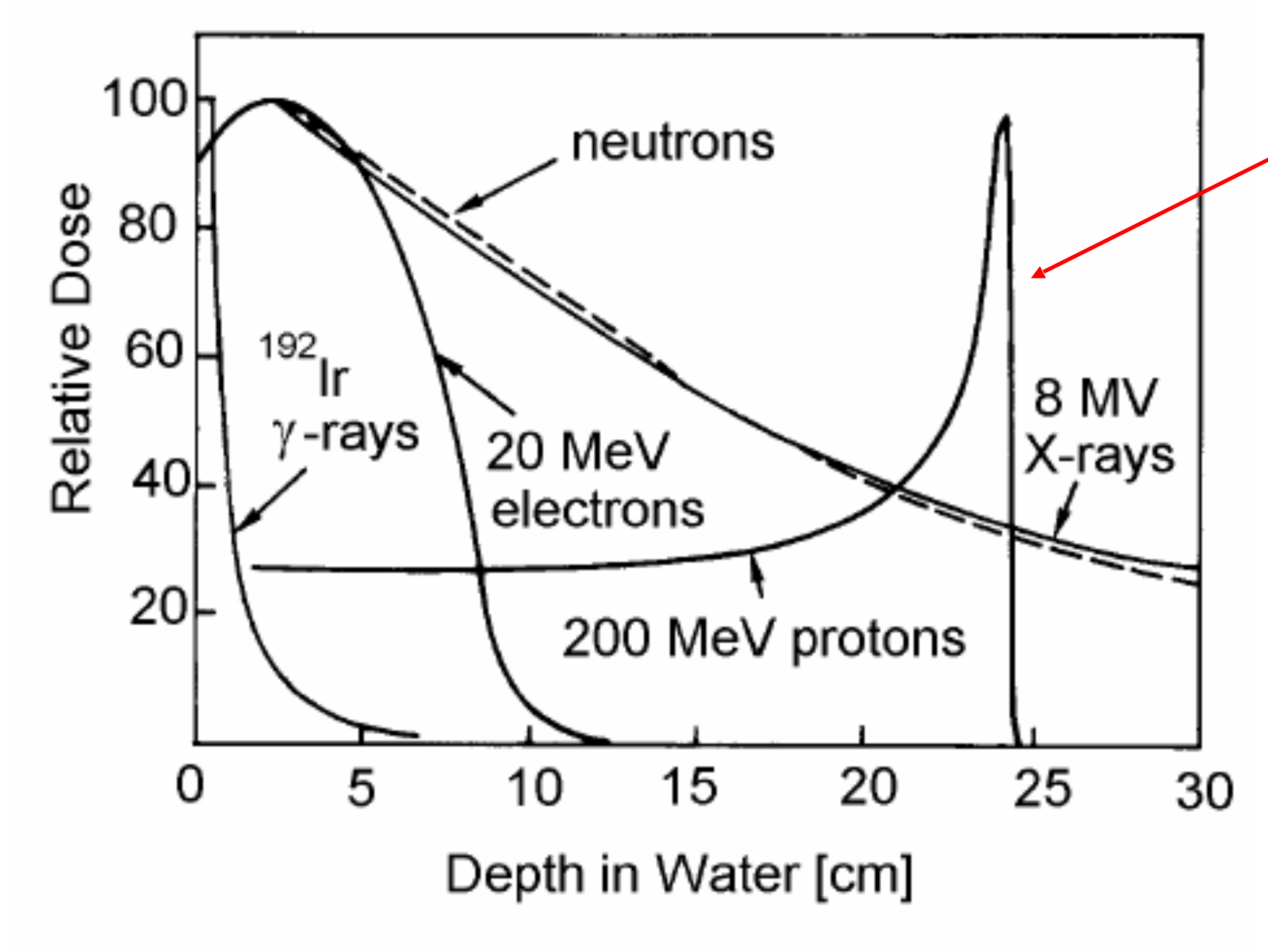


Emulsions in applied Science

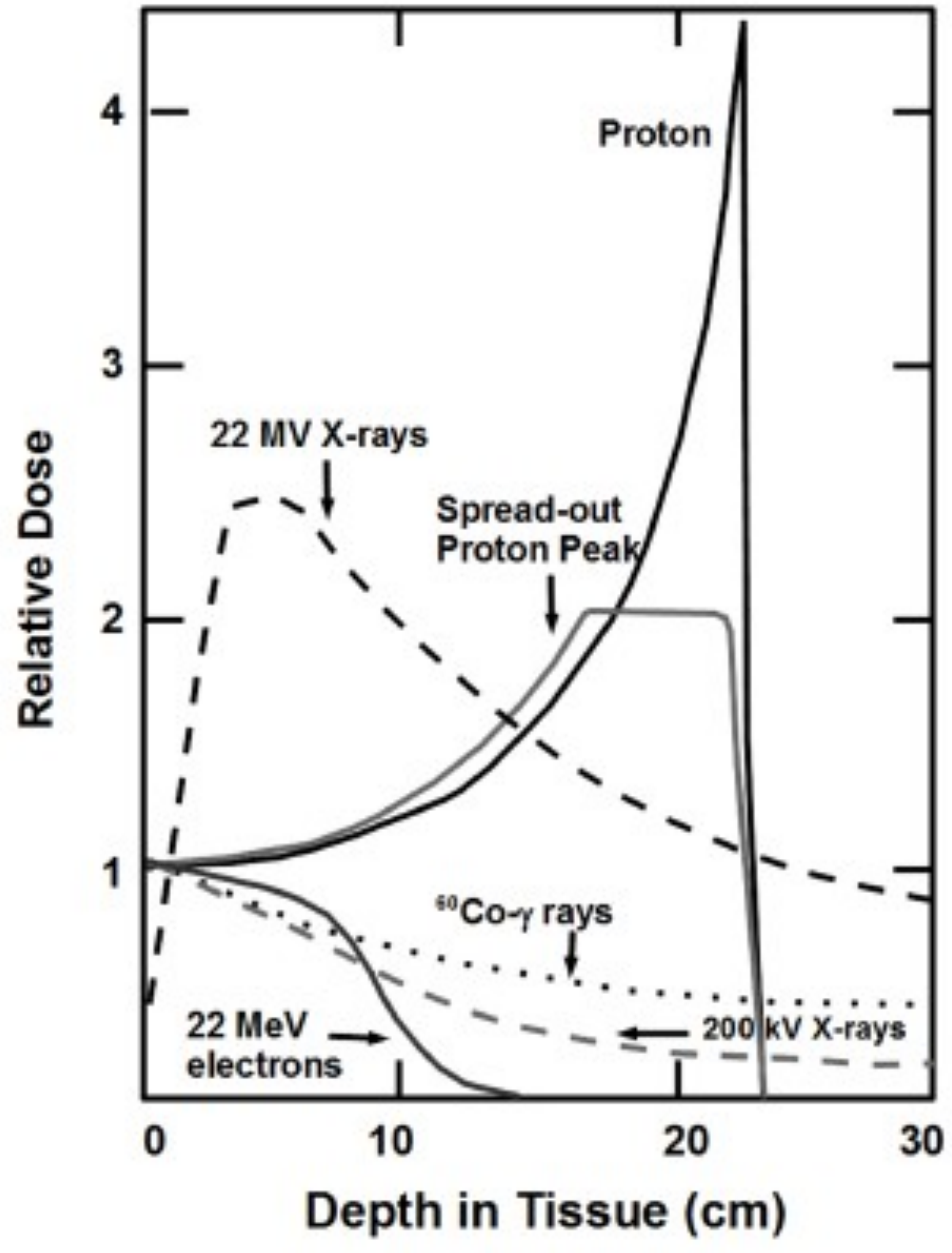
Video of the lecturer

Emulsions for medical applications

Video of the lecturer



Protons and ions used in hadron-therapy (Bragg peak)

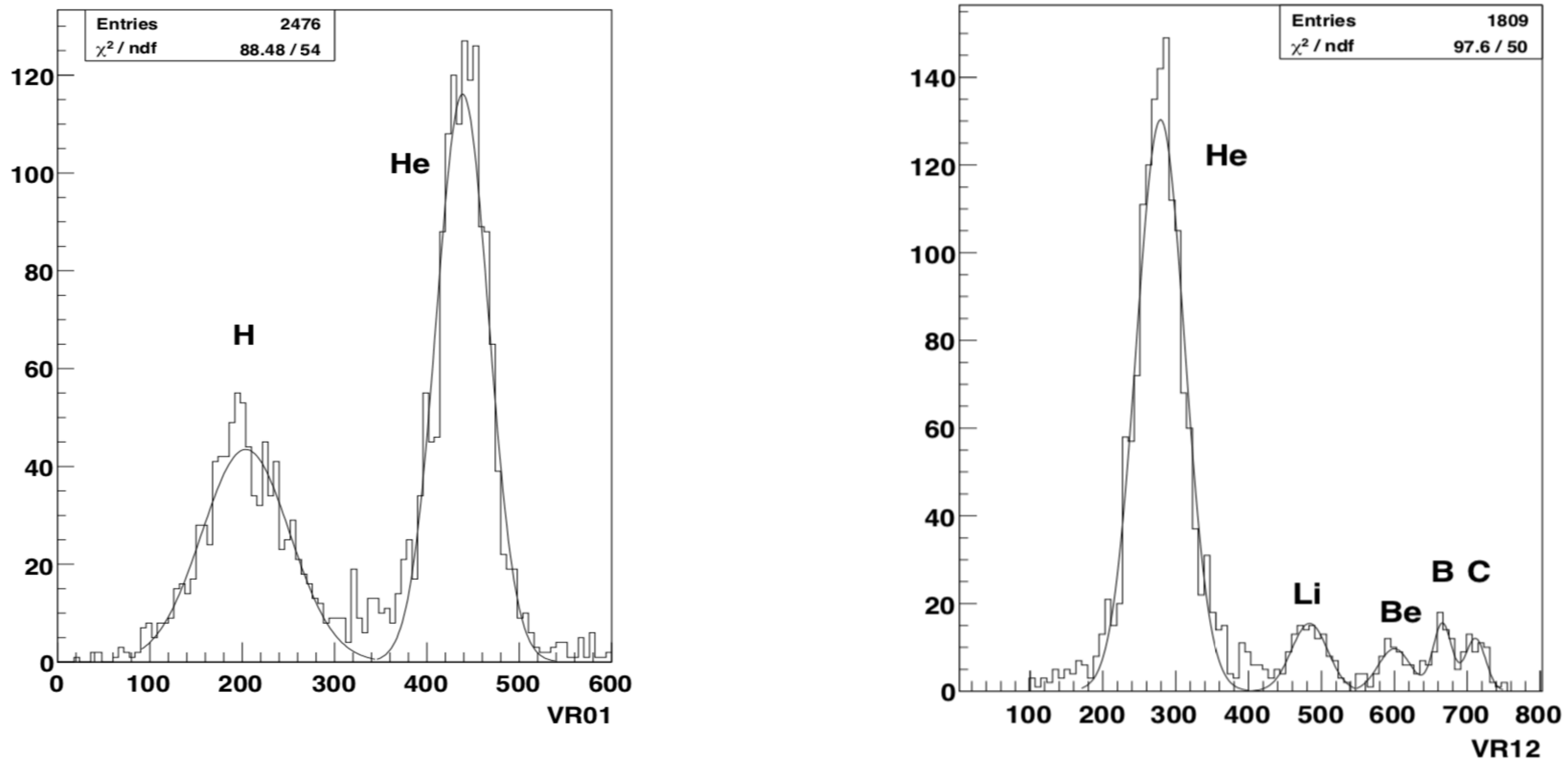


Scarce knowledge of the interaction along their path

Identification of fragments through the measurement of their ionization

Video of the lecturer

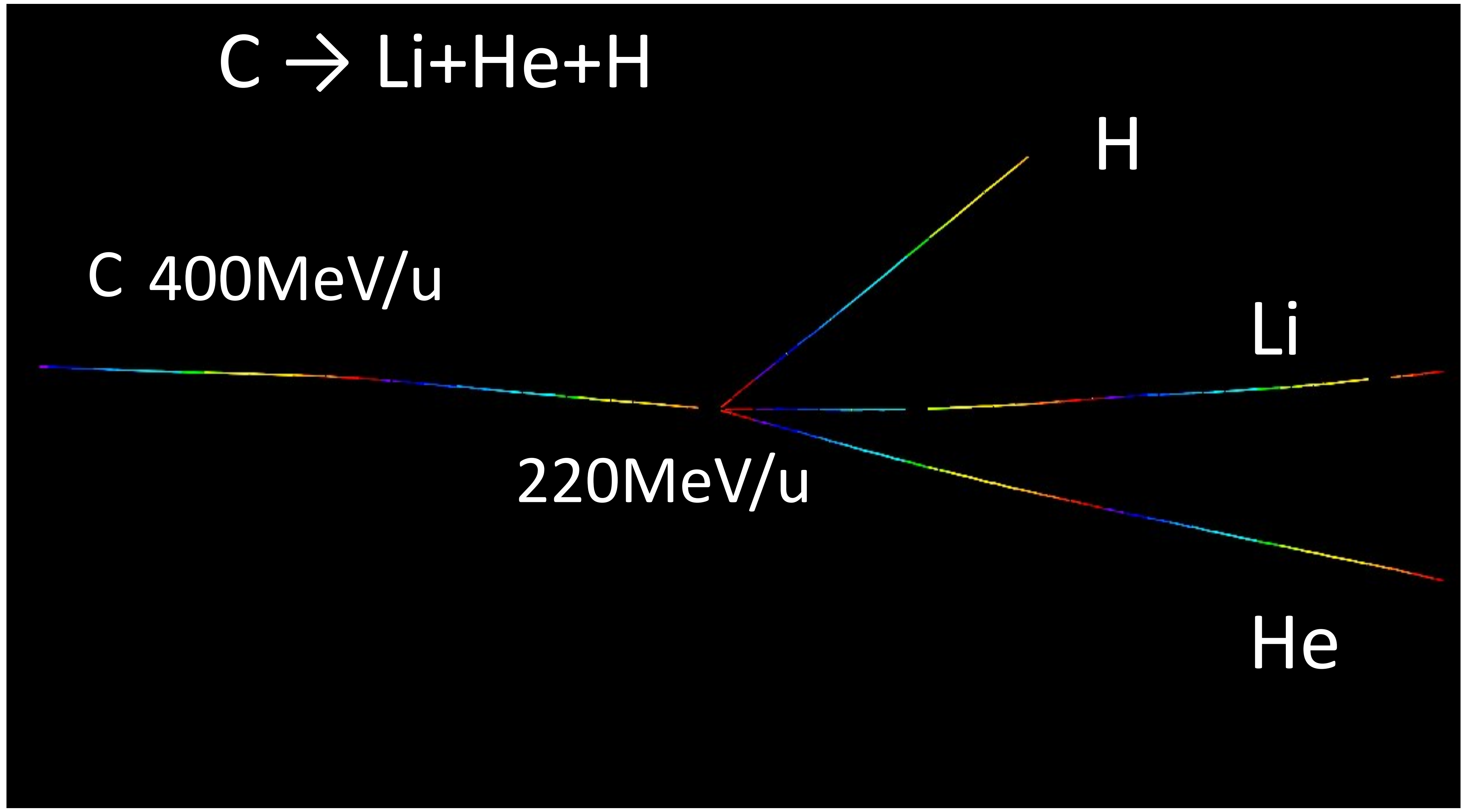
G. De Lellis et al., JINST 12 (2007) P08013

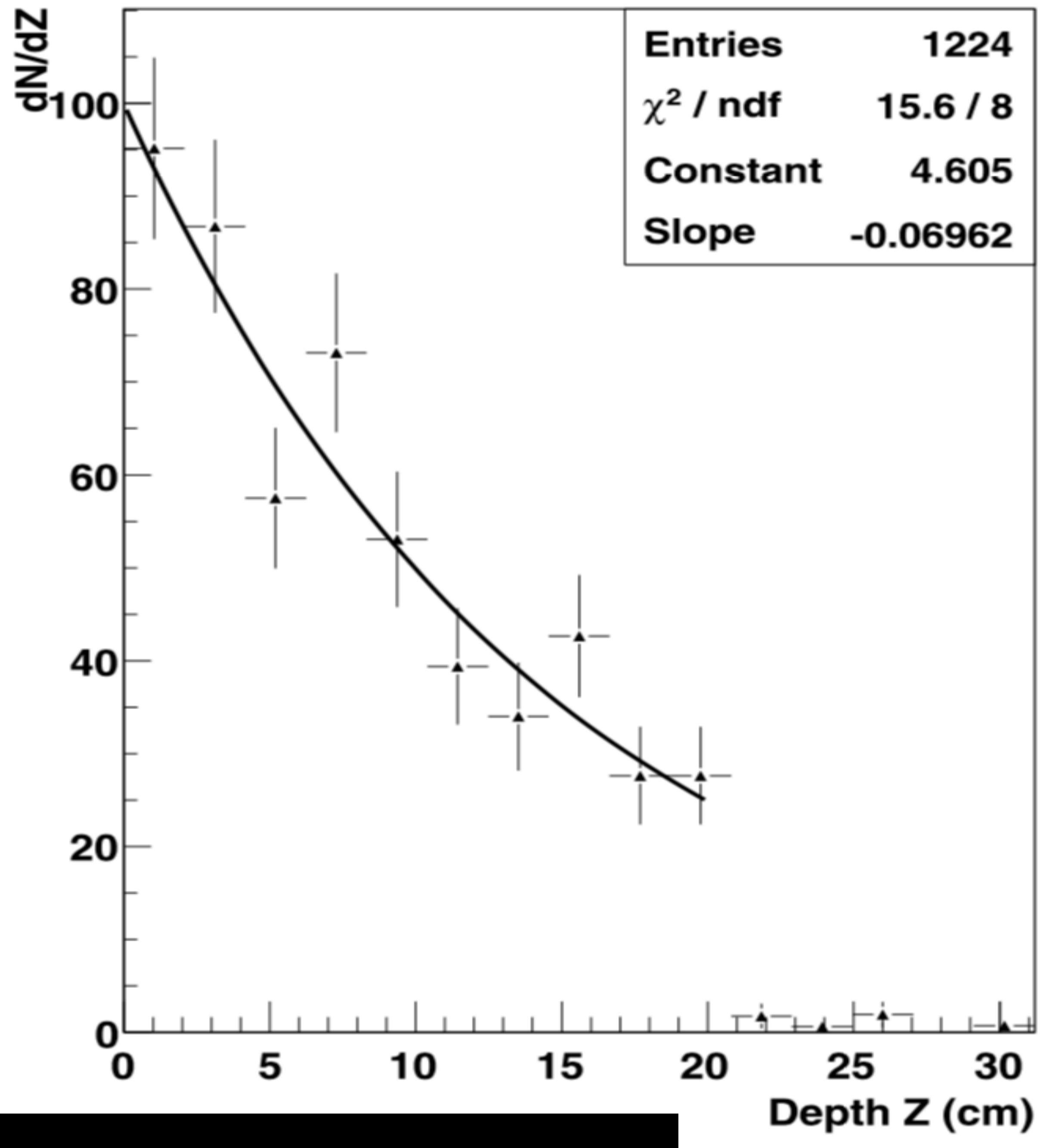


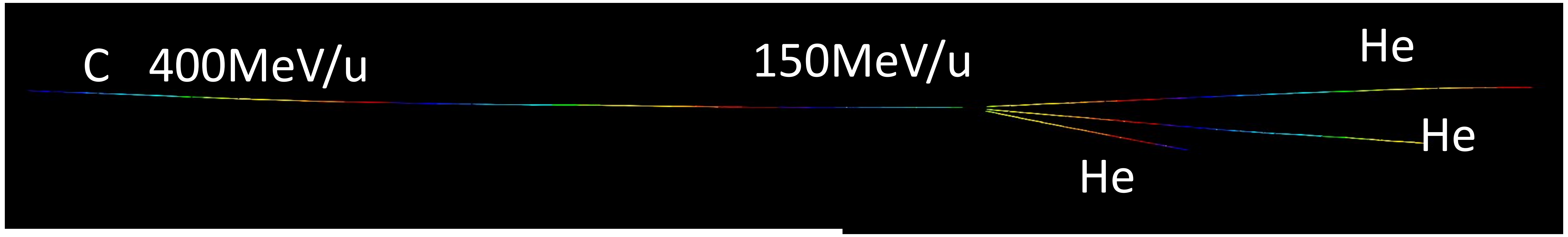
Study of Carbon ion interactions

G. De Lellis et al., Nucl. Phys. A853 (2011) 124

Video of the lecturer







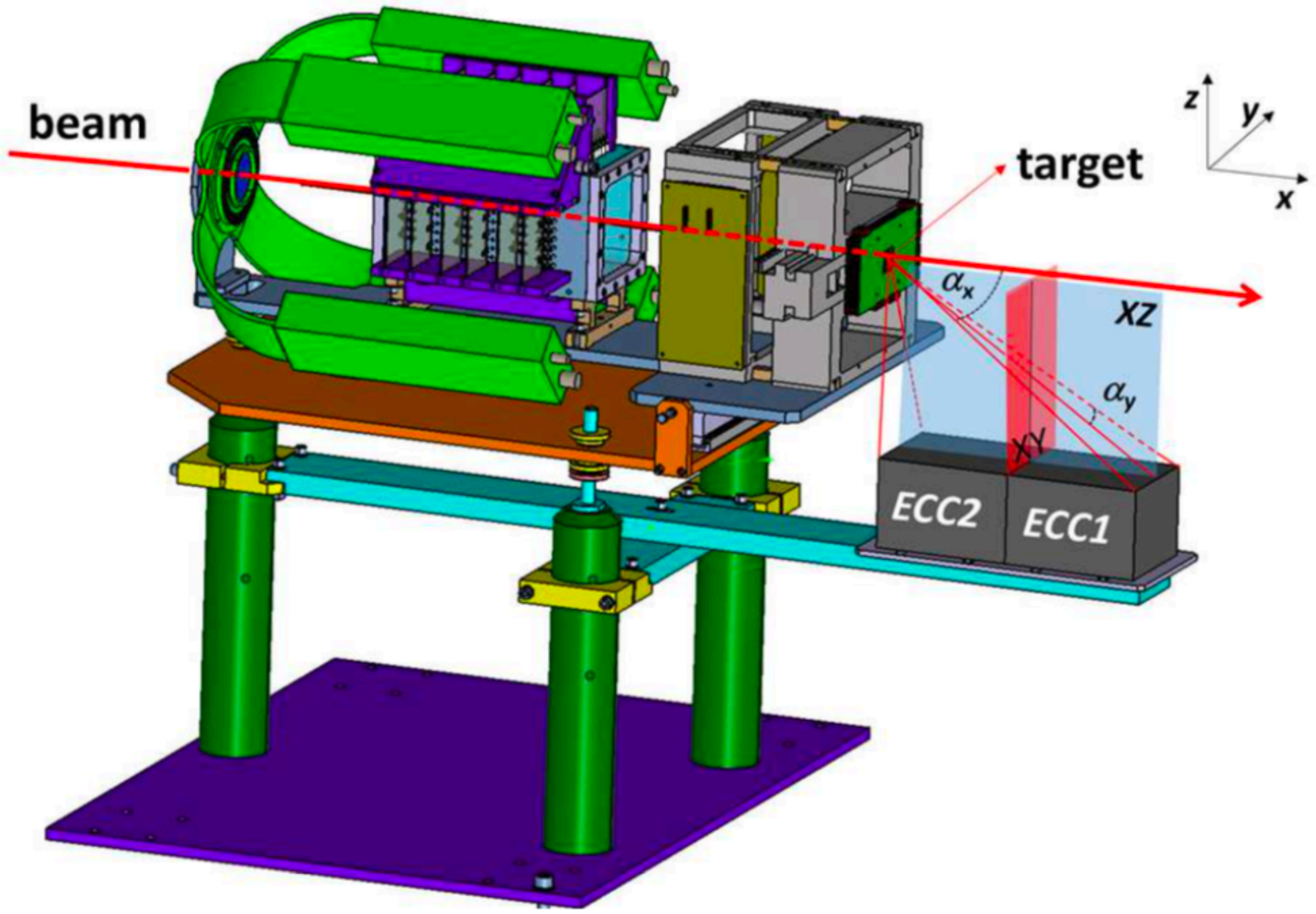
$$\sigma_{tot} = (18420 \pm 380_{stat} \pm 1840_{sys})\ \text{mbarn}$$

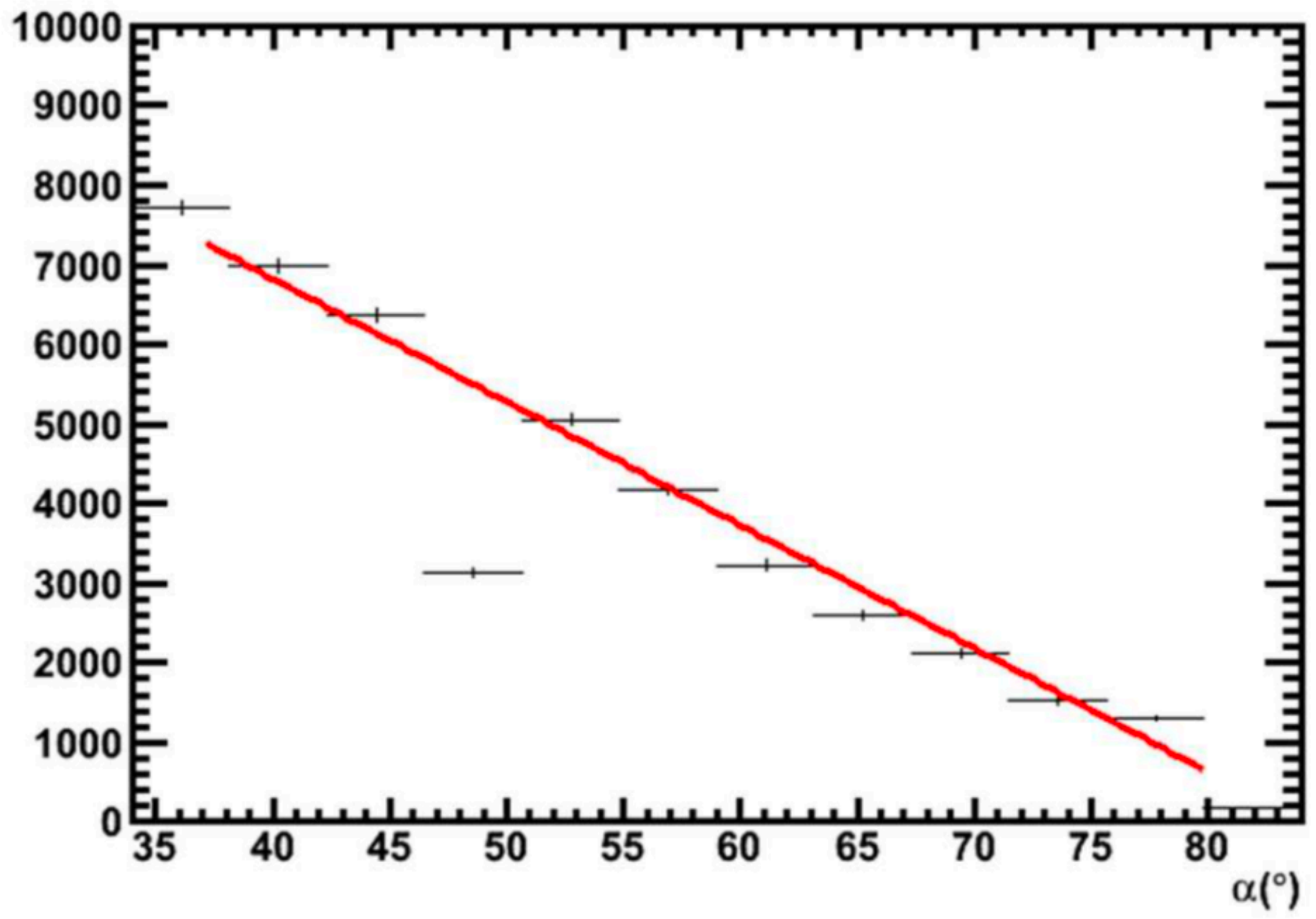
$$\sigma(\Delta z = 1) = (2510 \pm 140_{stat} \pm 250_{sys})\ \text{mbarn}$$

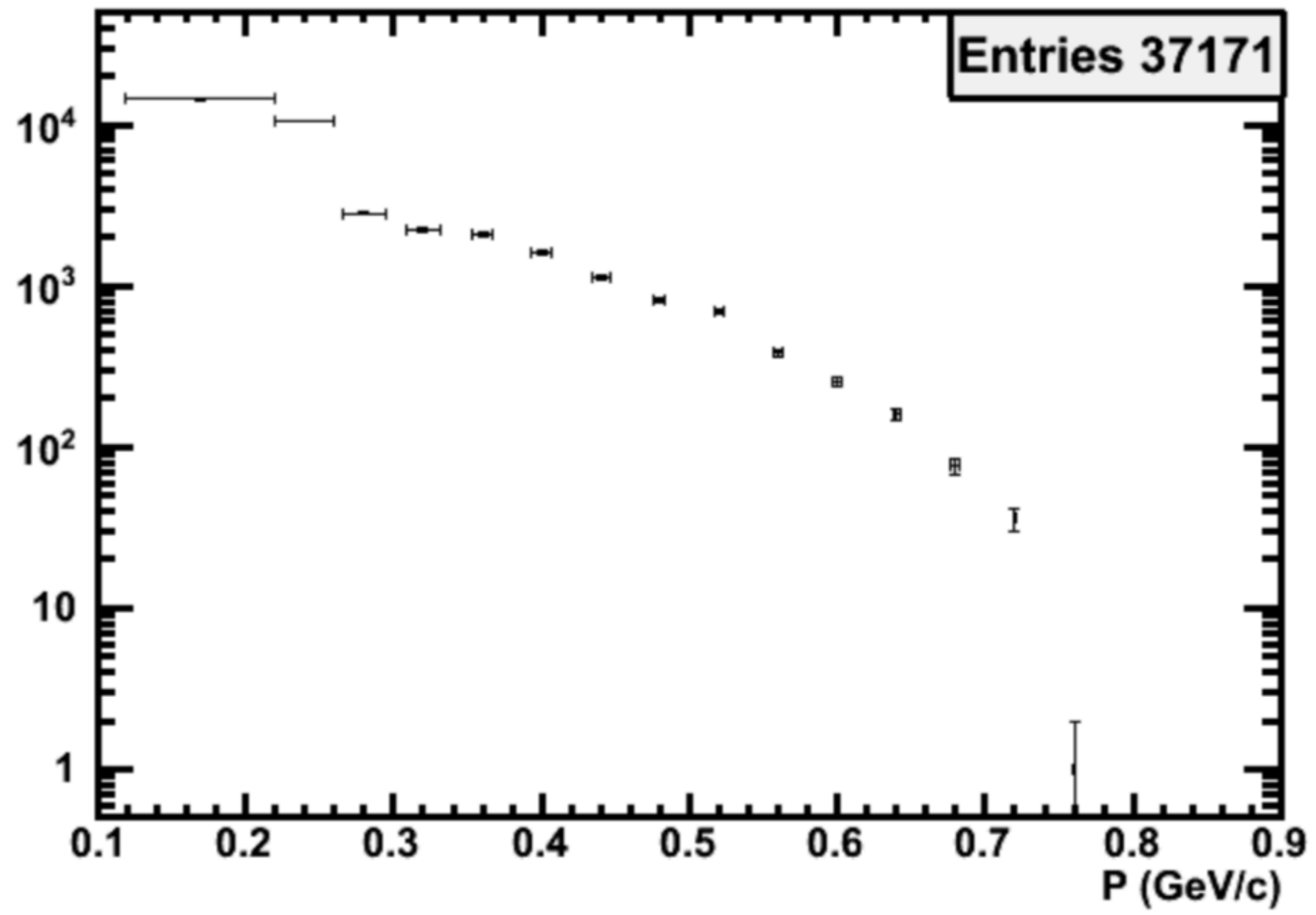
Momentum and angular distribution of fragments

Video of the lecturer

G. De Lellis et al., Meas. Sci. Technol. 26 (2015) 094001
G. De Lellis et al., JINST 12 (2017) P08013
M. C. Montesi et al., Open Physics 17 (2019) 233



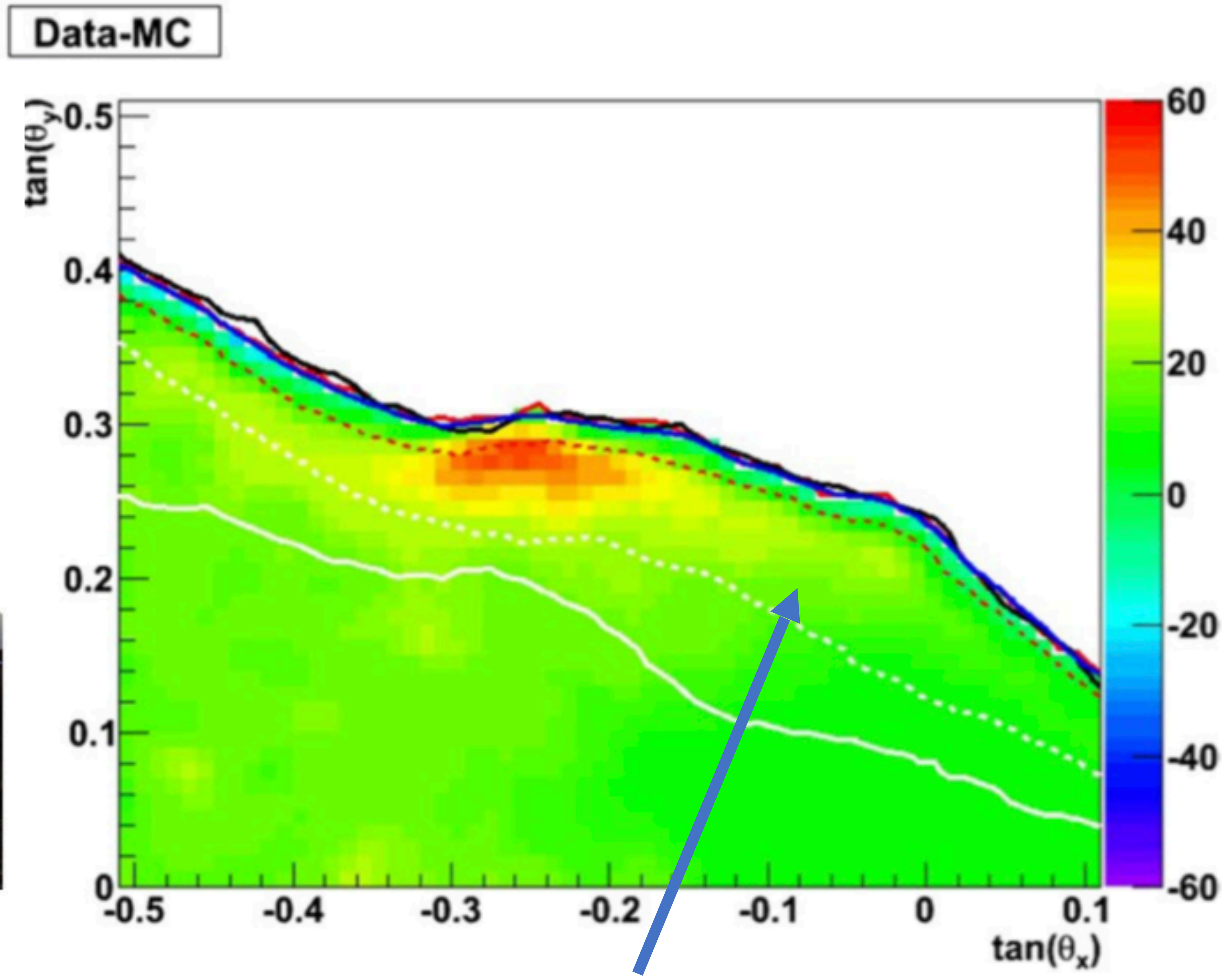




Investigation of Stromboli volcano

Video of the lecturer

Scientific **RepoRts** |
(2019) 9:6695 | https://doi.org/10.1038/s41598-019-43131-8



SCIENTIFIC REPORTS

OPEN **First muography of Stromboli volcano**

A region with lower density is found
V. Tioukov, A. Alexandrov, G. De Lellis et al., Scientific Reports 9 (2019) 6695

Summary of measurement performance

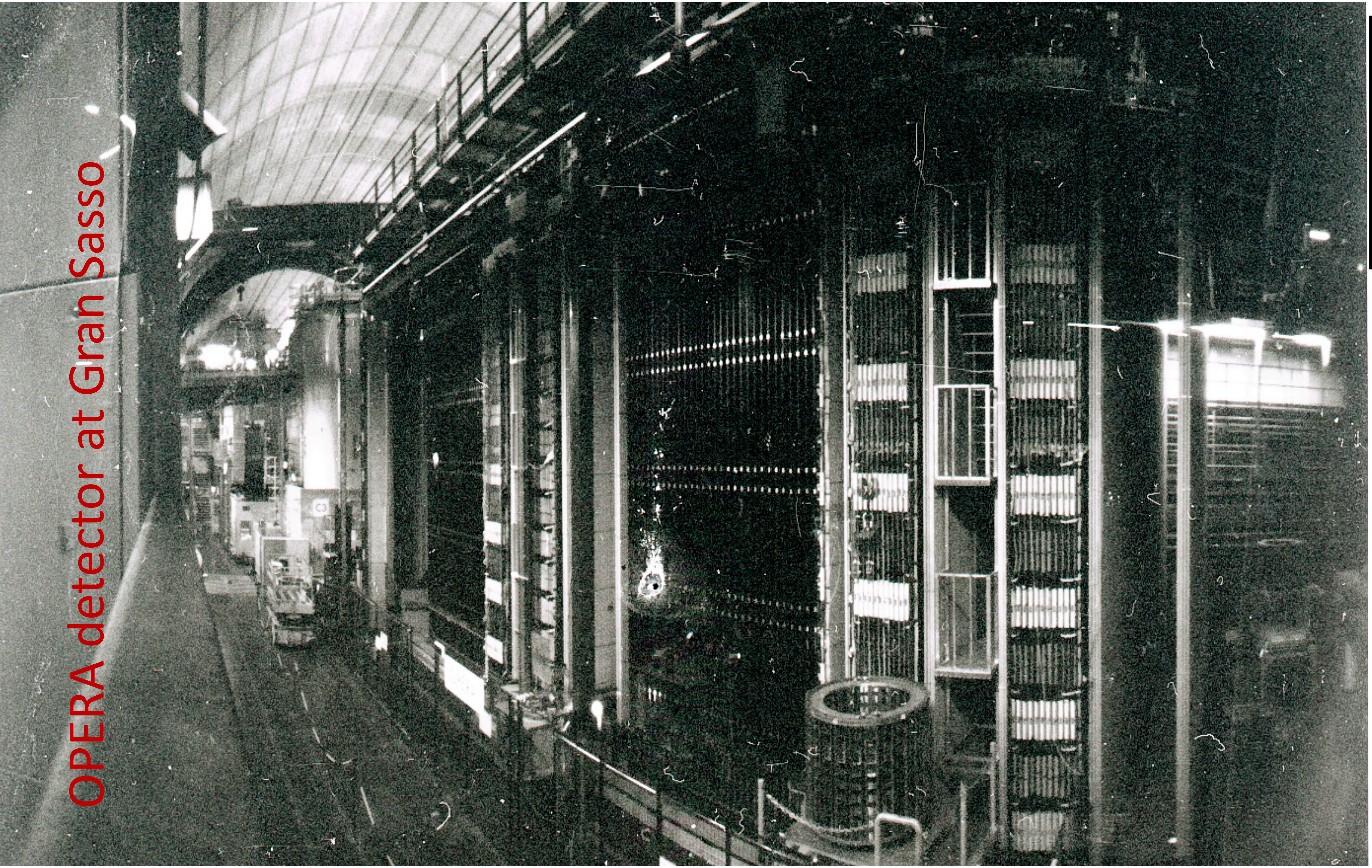
Video of the lecturer

Observable	Method	Range	Notes
τ (lifetime)	Flight length, $<\vartheta>$	$10^{-16} \div 10^{-11}$ s	
Momentum	MCS	$0.5 \div 10$ GeV	pion
Momentum	range	<500 MeV	
Energy	Shower counting, calorimetry	$1 \div 20$ GeV	electron
Z (charge)	Ionization	$1 \div 6$	nuclei
A (mass number)	Range, MCS	$1 \div 12$	nuclei
Kinetic energy	Nanometric range	≥30 keV	Carbon
e/π^0 separation	γ conversion	No threshold	
μ/π separation	Range, topology	No threshold	Dense material

A few textbook references

Video of the lecturer

- P.H. Fowler, D.H. Perkins and C.F. Powell, The study of elementary particles by the photographic method, Pergamon Press (1959).
- W.H. Barkas, Nuclear research emulsion, Academic Press, New York, 1973.
- Tadaaki Tani, Photographic Science, Advances in Nanoparticles, J-Aggregates, Dye Sensitization, and Organic Devices, Oxford University Press (2011), ISBN: 9780199572953.
- G. De Lellis et al., Nuclear Emulsions in Particle Physics Reference Library, volume 2 Detectors for Particles and Radiation, Fabjan and Schopper Editors (2020) Springer



Video of the lecturer

Image taken using OPERA emulsion film with pinhole handmade camera (Di Ferdinando)

QUIZ - 3

- Explain what is normally limiting the resolution for nuclear emulsion to half a micron or so and how to achieve the nanometric accuracy

- List one technique used to investigate the internal structure of a volcano

- List the main advantage of an emulsion-based detector for medical applications

A few problems as homework

Video of the lecturer

- Calculate the data capacity of a double-sided emulsion film with 50 μm thick sensitive layers and 12.5 x 10 cm^2 surface for OPERA, NIT and U-NIT emulsion types. Hint: assume that 1 AgBr Crystal is equal to 1 bit of information
- Calculate the probability to reconstruct a background track in a 100μm thick emulsion layer, assuming that the transverse accuracy is 1μm, the random fog (spurious grain) level is 7 grains/1000 μm^3 and a track is made of at least 5 grains. Hint: assume that the track is straight and that the number of grains is described by a Poisson distribution.