NEWSdm

Nuclear Emulsions for Wimp Search With directional measurement

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on behalf of the NEWSdm Collaboration

15th International Conference on Topics in Astroparticle and Underground Physics
TAUP2017, Sudbury, Canada

THE NEWSdm COLLABORATION

70 physicists, 14 Institutes, 5 Countries





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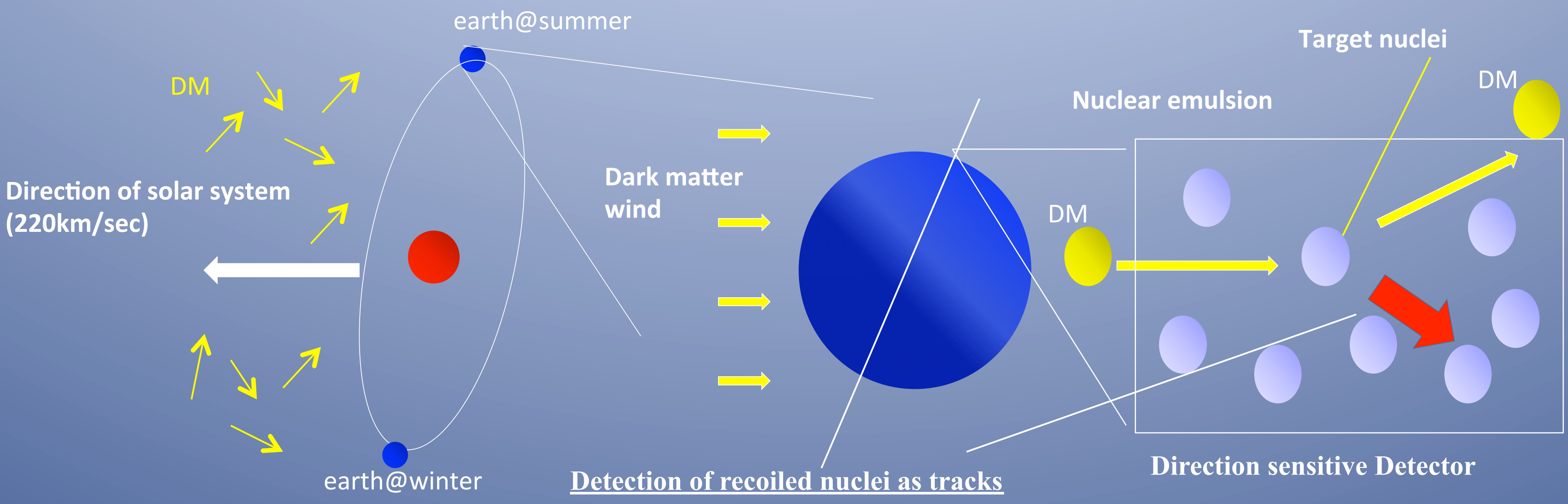
http://news-dm.lngs.infn.it

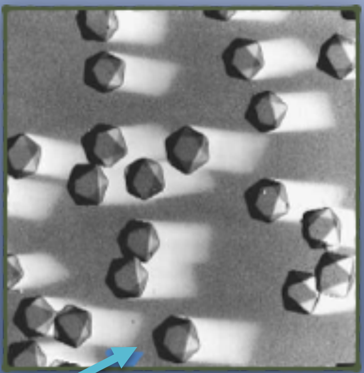
LoI under review by the LNGS Scientific Committee
https://arxiv.org/abs/1604.04199

Directional signature in the Wimp Search



- Solar system movement in the galaxy → WIMP flux not isotropic @ Earth.
- Directional measurement as a strong signature and unambiguous proof of the galactic DM origin
- Nuclear emulsions is a solid detector → high sensitivity with a compact detector
- Modular design → Scalability → high mass
- Challenge: very short recoil track lengths, O(100 nm)

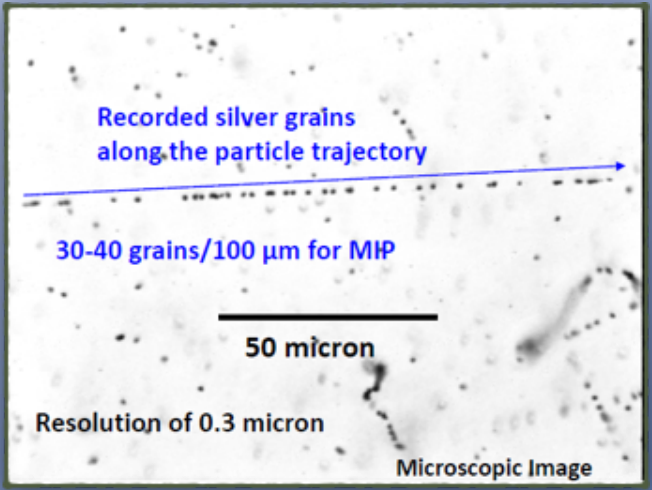
Nuclear Emulsions



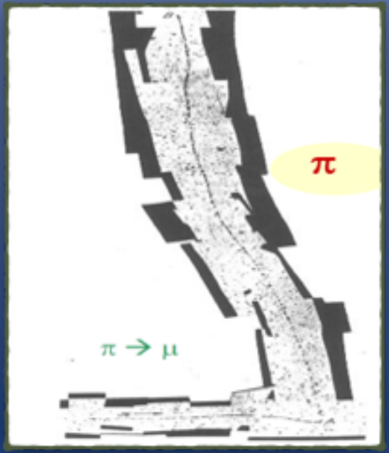
$AgBr$ crystal size 0.2-0.3 μm

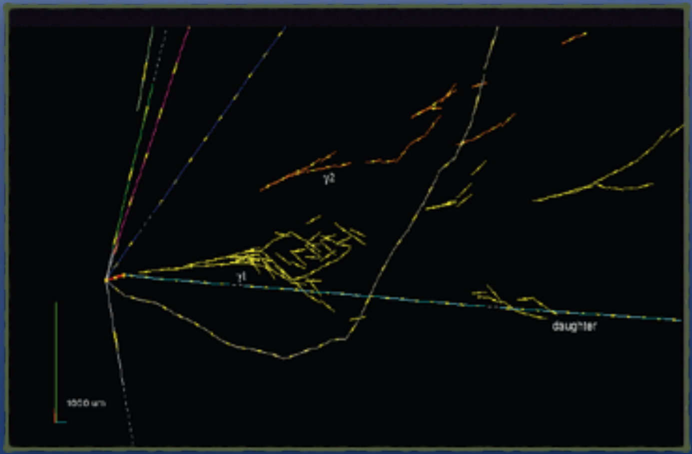
After the passage of charged particles through the emulsion, a latent image is produced.

The emulsion chemical development makes Ag grains visible with an optical microscope



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**)



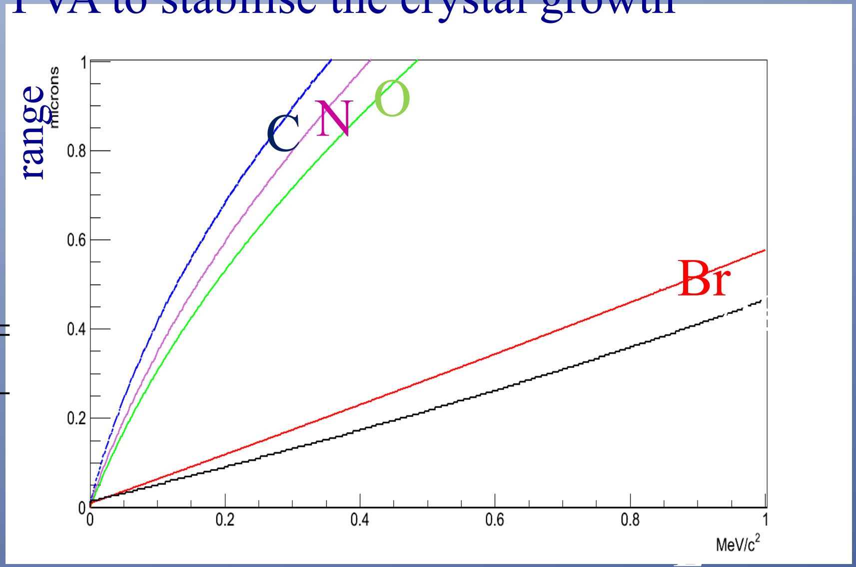


Nuclear emulsions

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

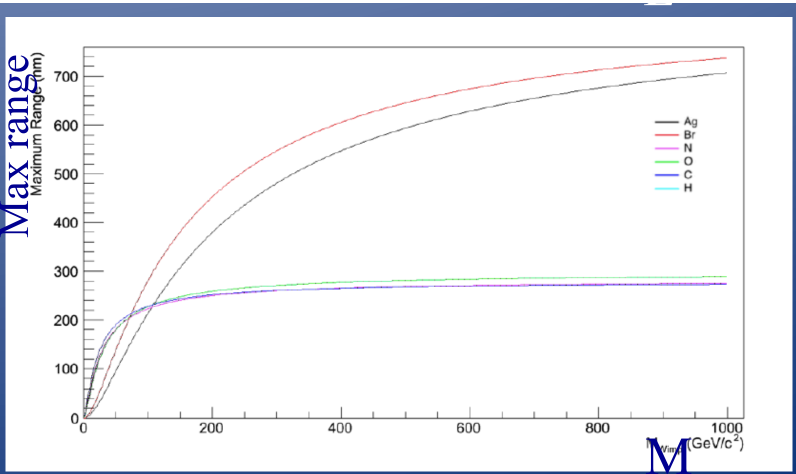
Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

(a) Constituents of nuclear emulsion



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

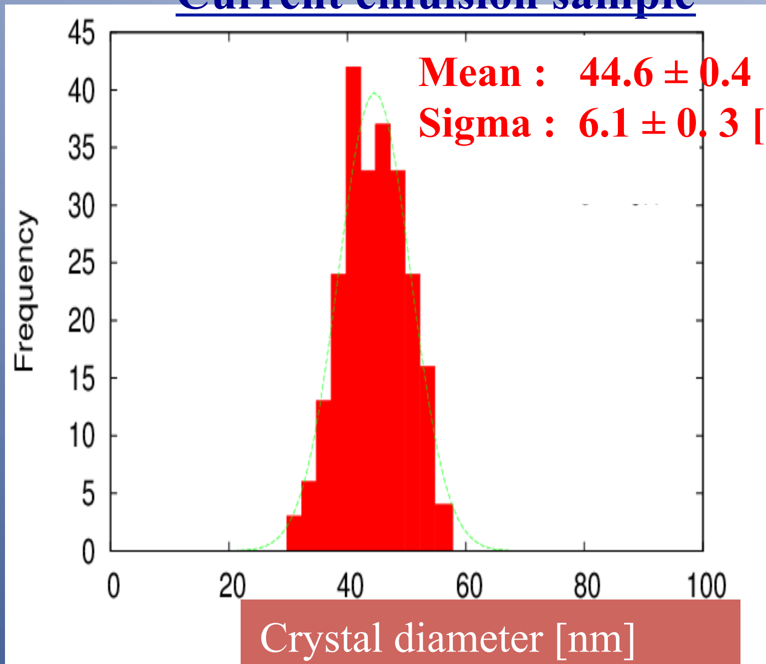


Both light and heavy nuclei

(Ultra-) Nano Imaging Tracker

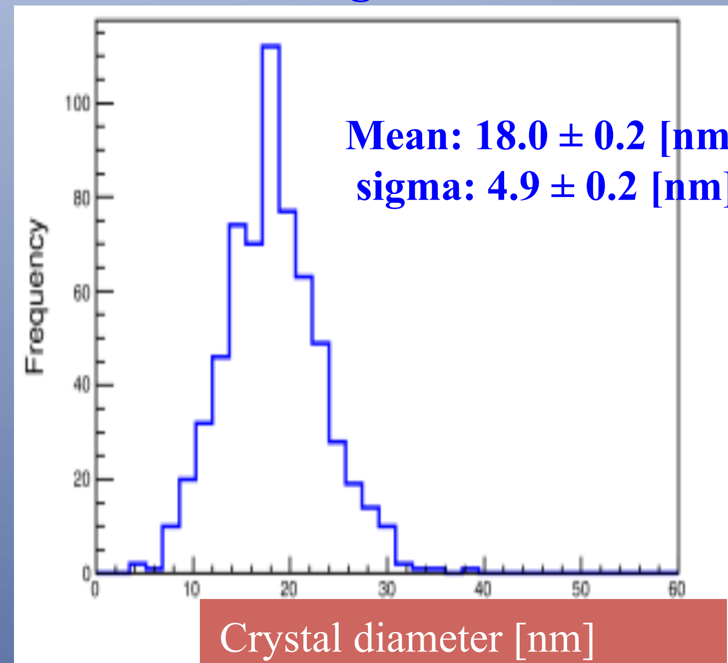
NIT

Current emulsion sample



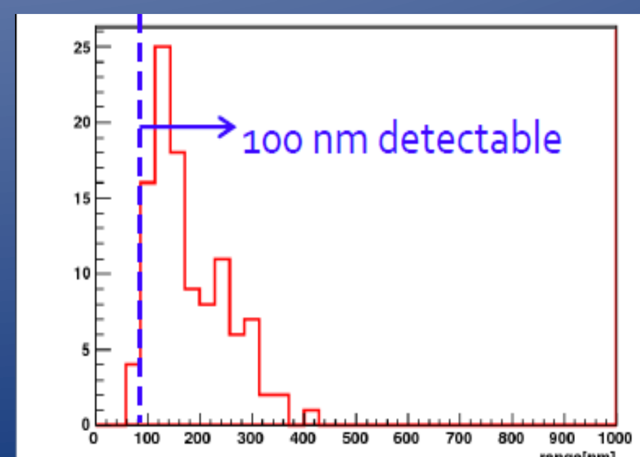
U-NIT

Finest grain emulsion



	NIT	U-NIT
AgBr density	12 AgBr/μm	29 AgBr/μm

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

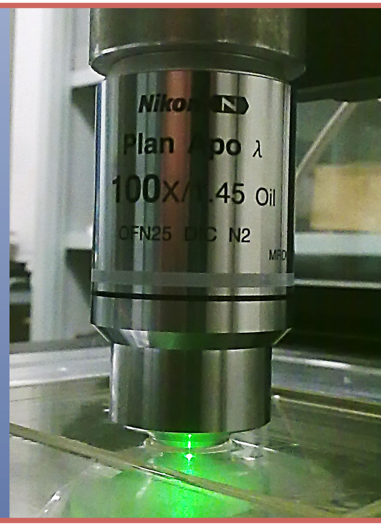


Detect tracks when their lengths become comparable/shorter than the optical resolution

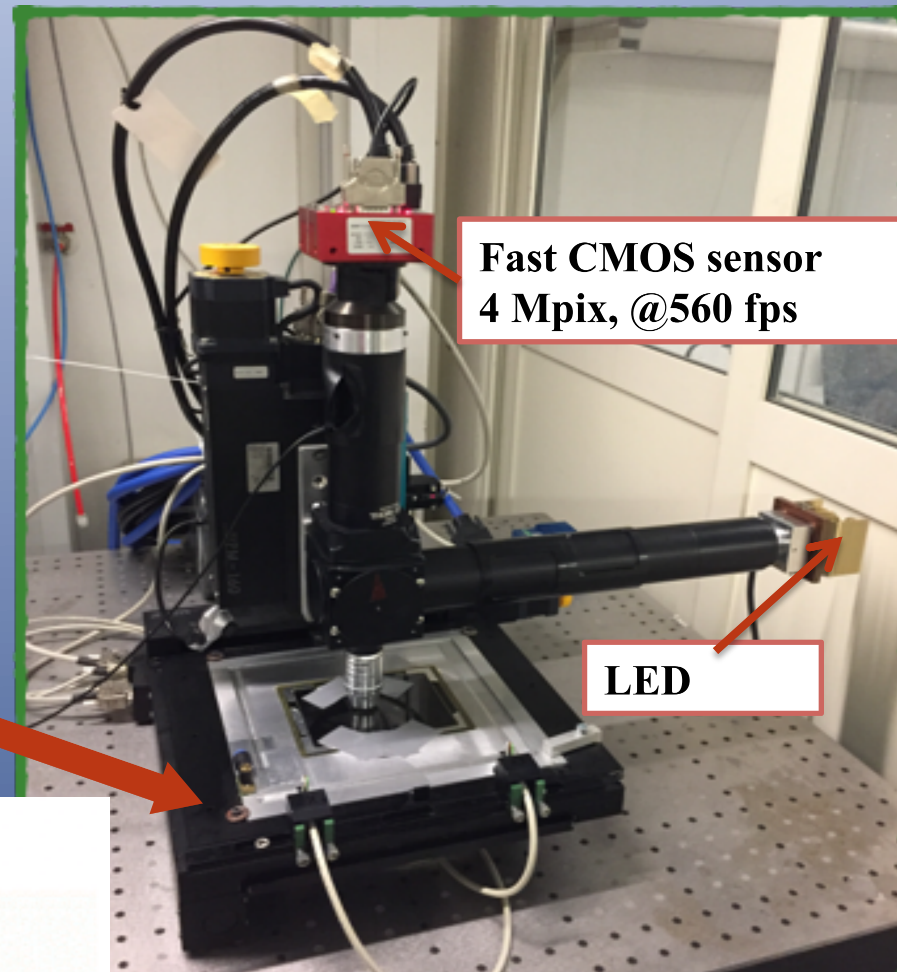
- Optical microscopes
  - Pros: Fast scanning profiting of the improvements driven by the OPERA experiment, dedicated measurement stations in each lab
  - Cons: Resolution with "standard" technologies ~ 200 nm → need a breakthrough in the technology
- X-ray microscopes
  - Pros: High resolution ~ 50 nm or better
  - Cons: extremely slow and not convenient (need an external lab)

Optical Microscope Read-out: Step 1

100x objective lens with high N.A.

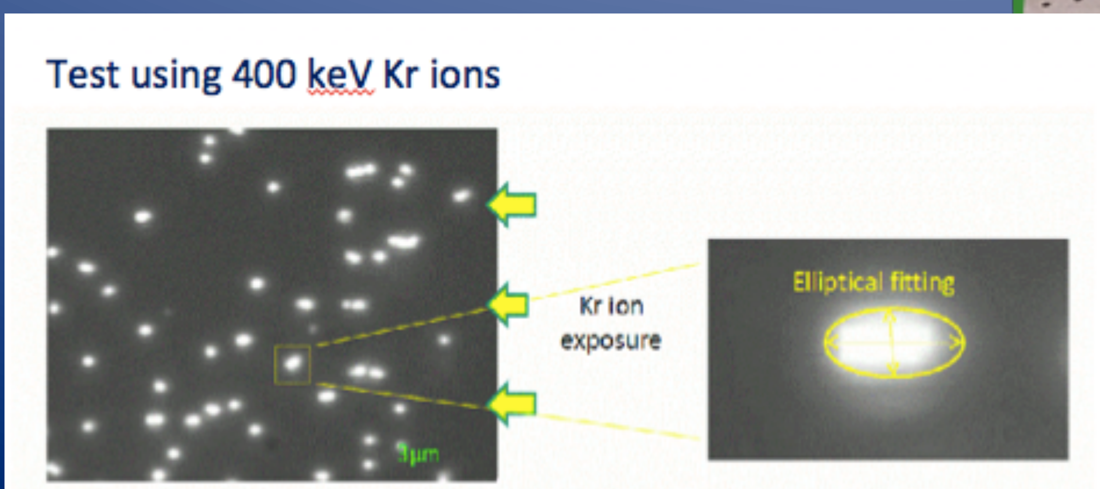


Resolution: 30 nm/pixel
View Size: 65 x 50 μm²



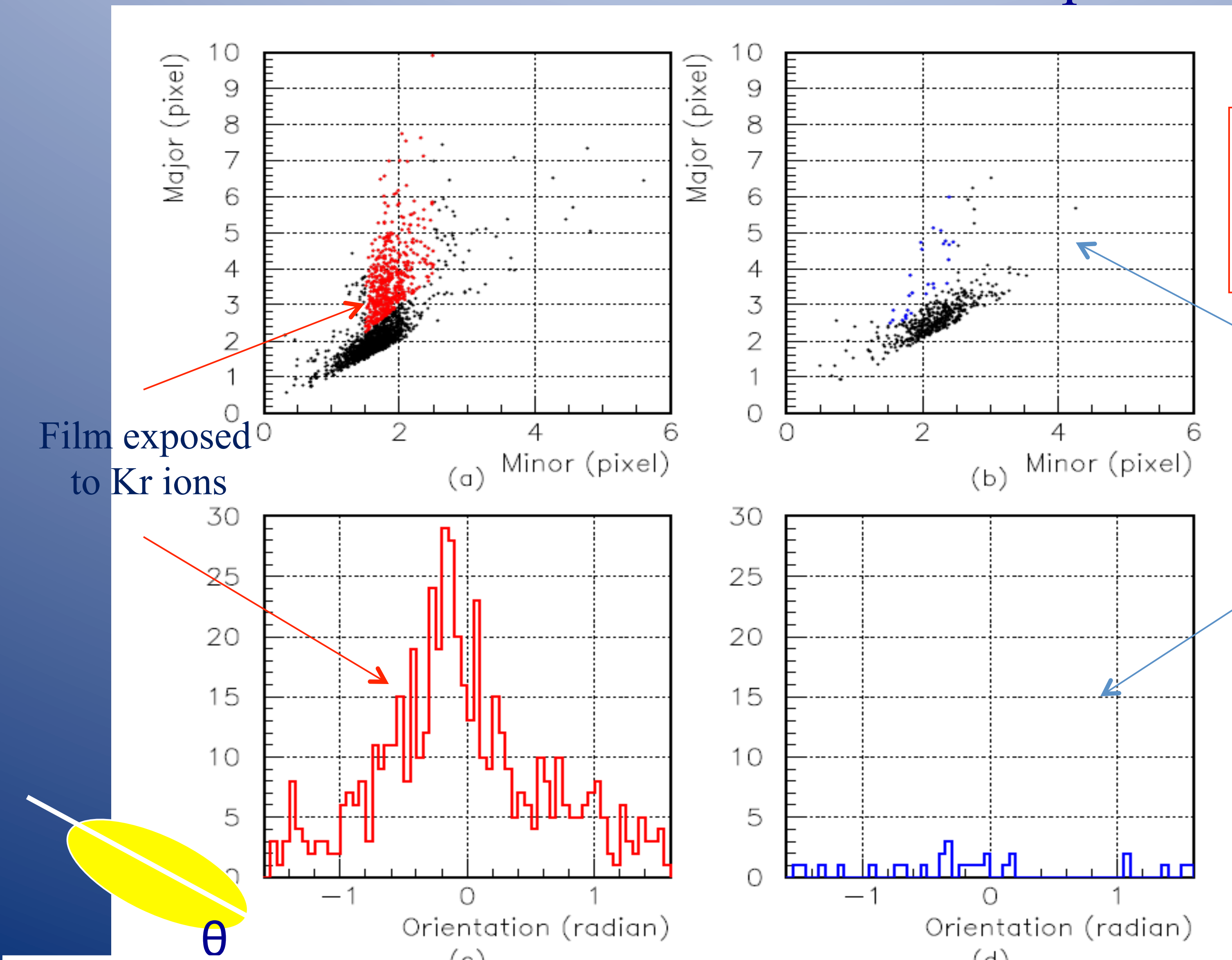
Fast CMOS sensor
4 Mpix, @560 fps

LED



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

Selection of Kr ion tracks with shape analysis



Major/minor>1.5

1.4<minor <2.6

pixel > 40

Film exposed to Kr ions

Reference film (unexposed)

Direction detected!

NIM A680 (2012) 12-17

Intrinsic Angular resolution As a By-Product of the Neutron Studies

NEUTRON TEST BEAM @ FNS (JAPAN)

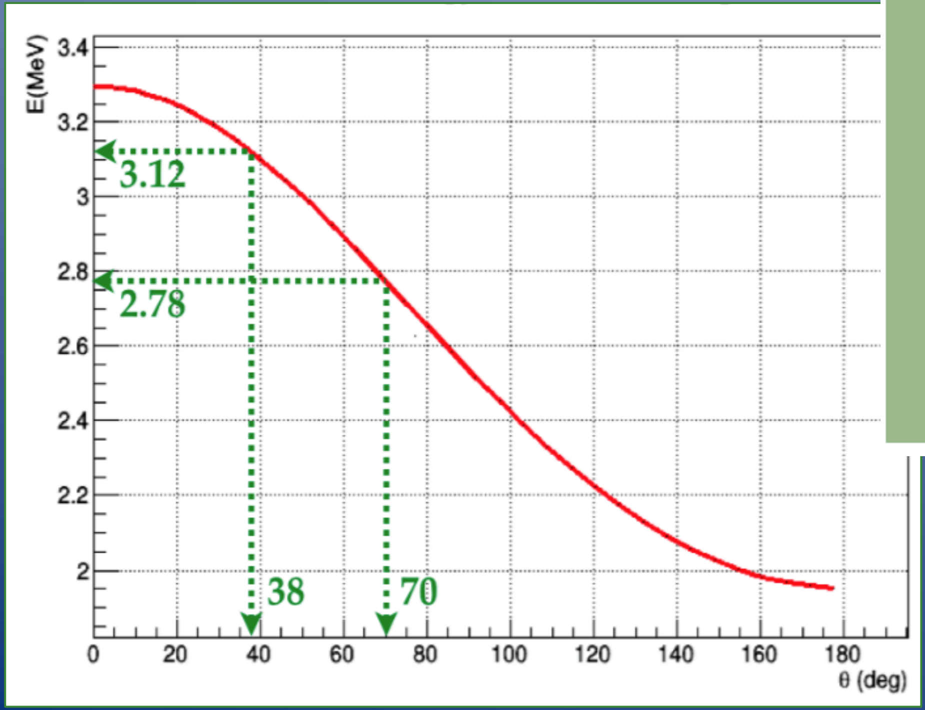
Japan Atomic Energy Research Institute

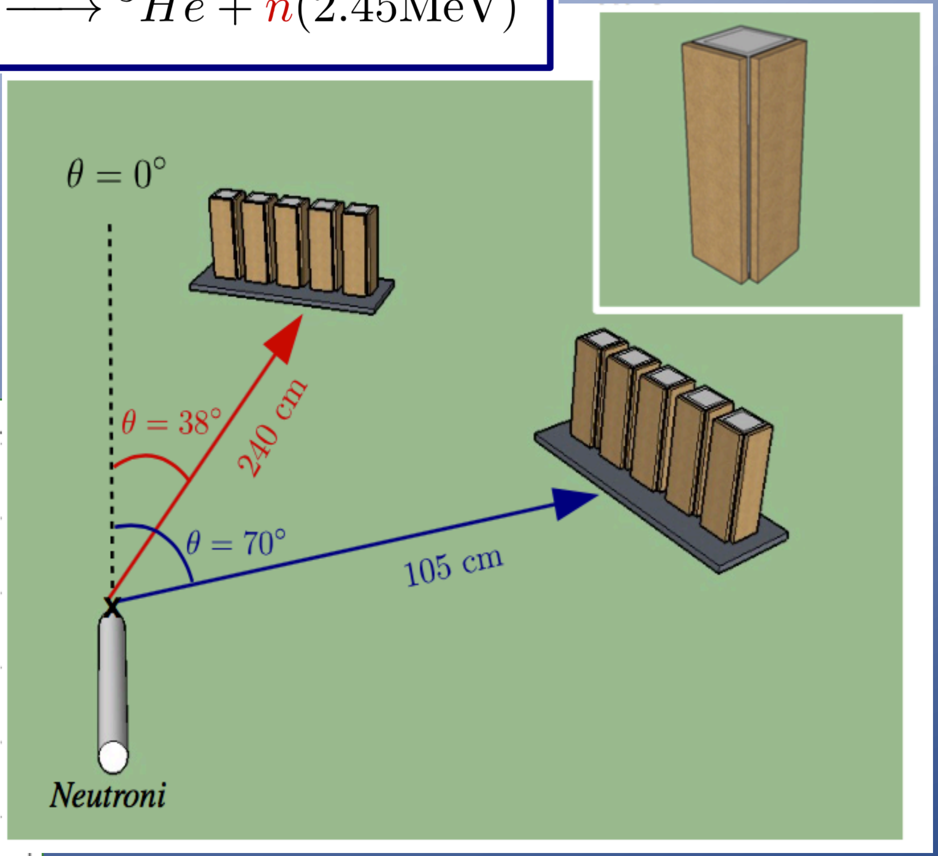
Emitted neutron energy

$\Theta_n = 38°$
$E_n = 3.12$ MeV

$\Theta_n = 70°$
$E_n = 2.78$ MeV

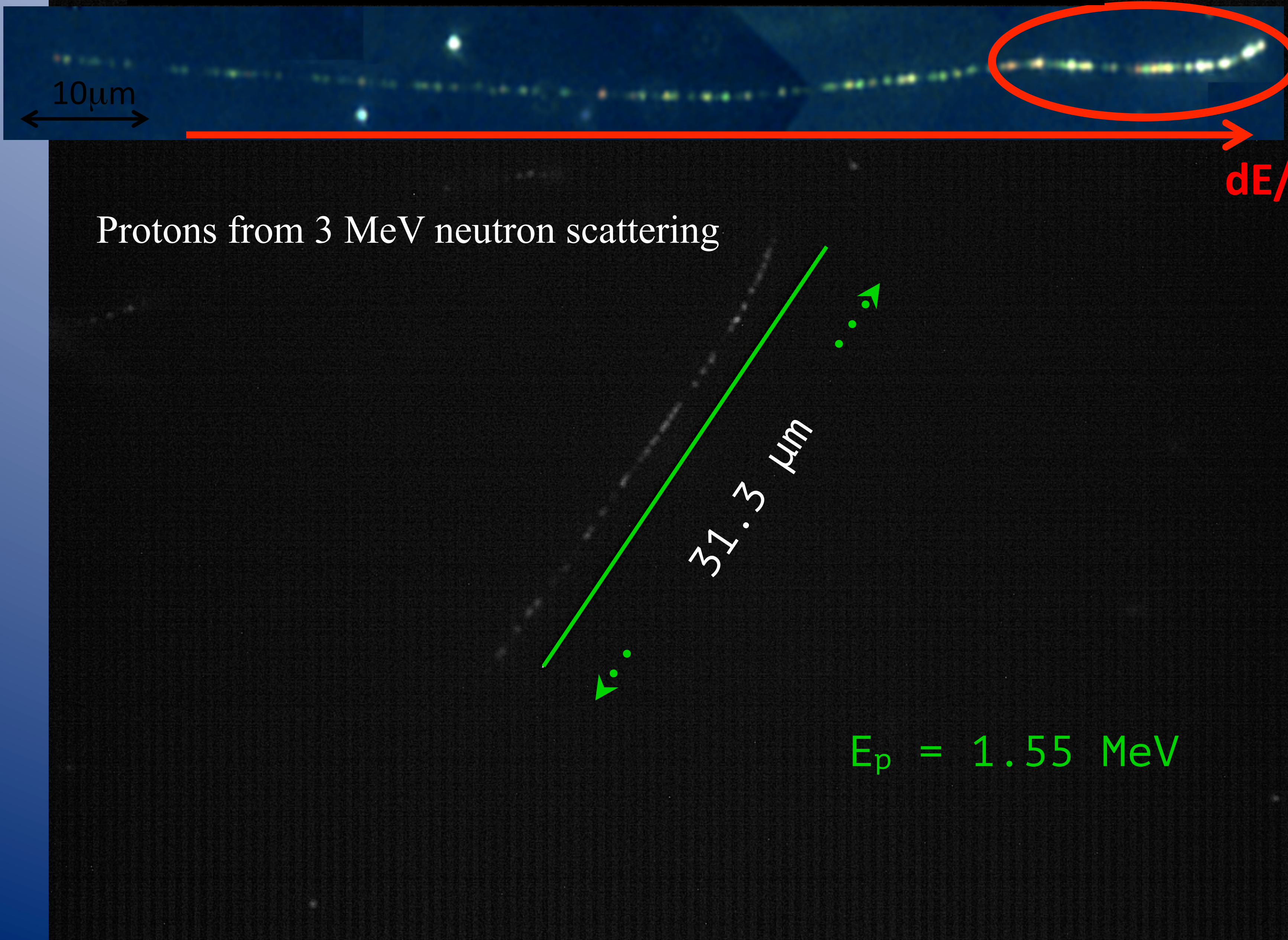
$$D + D \xrightarrow{50\%} {}^3He + n(2.45\text{MeV})$$





Emitted neutron energy

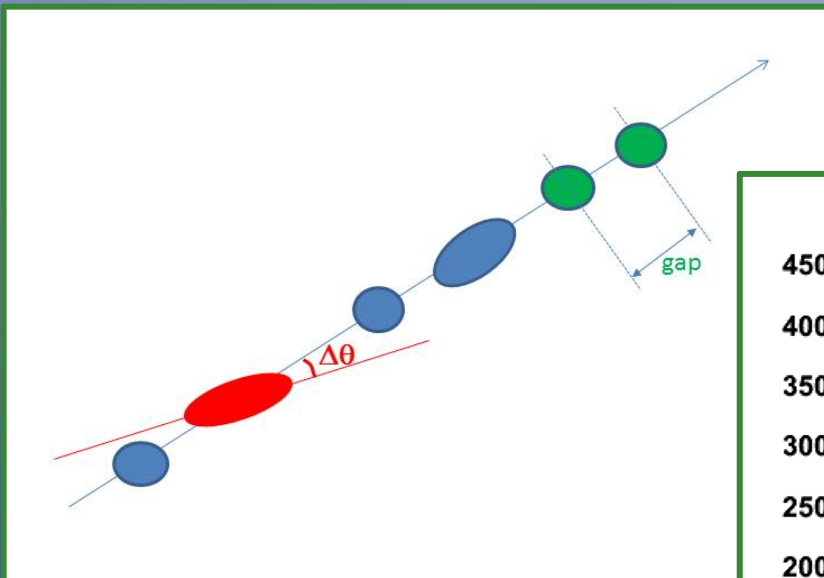
Neutron test beam analysis



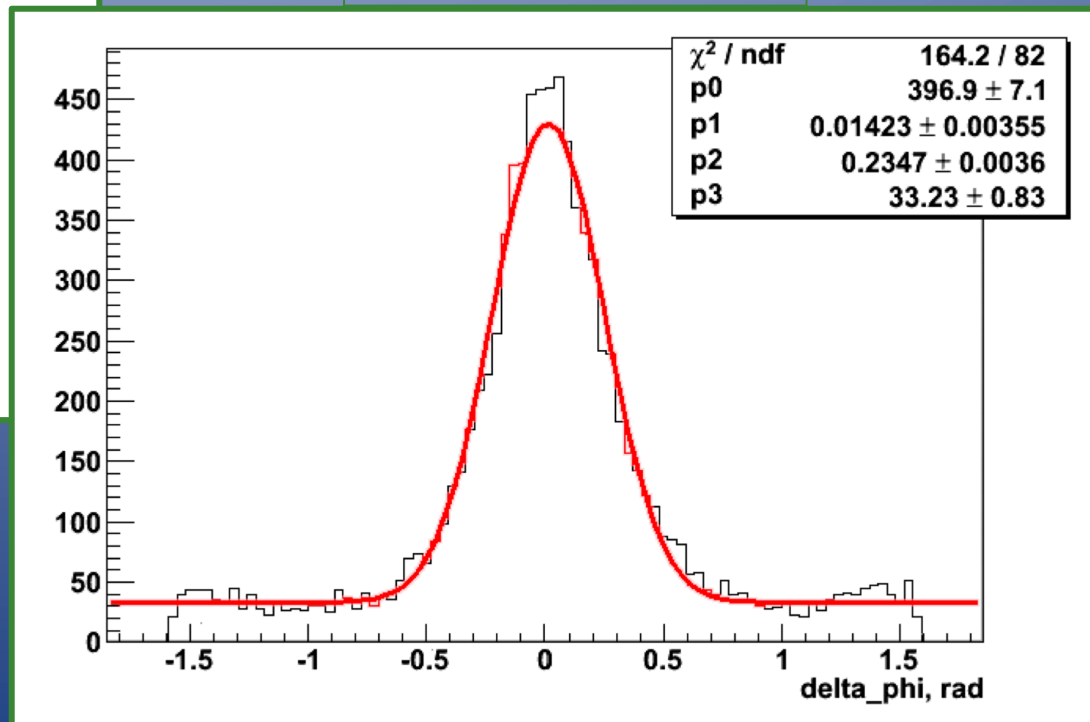
Protons from 3 MeV neutron scattering

Intrinsic Angular Resolution

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



σ = 235 mrad = 13°



BEYOND OPTICAL RESOLUTION

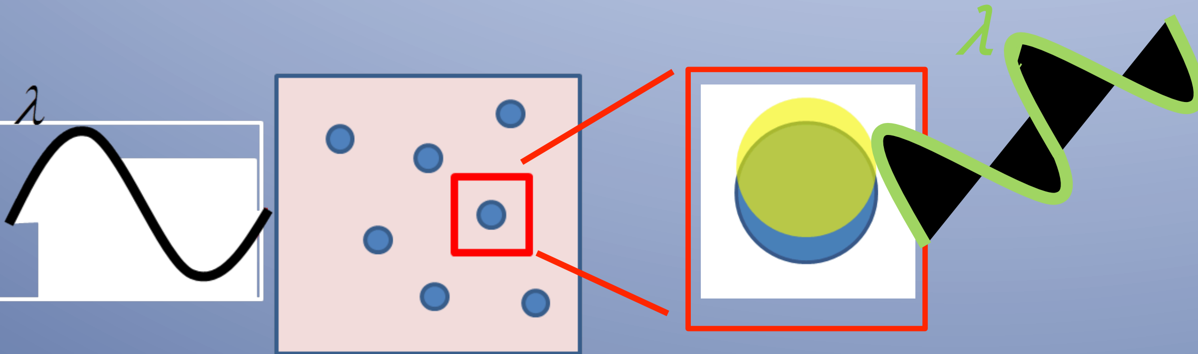
X-ray microscope

- Slow analysis speed
- Need of external X-ray guns

Optical microscope

- New technologies

Resonant Light Scattering From Ag Nanoparticles



Nano-metal in medium ε_d **Oscillation of e-cloud**

E_l **intensity**

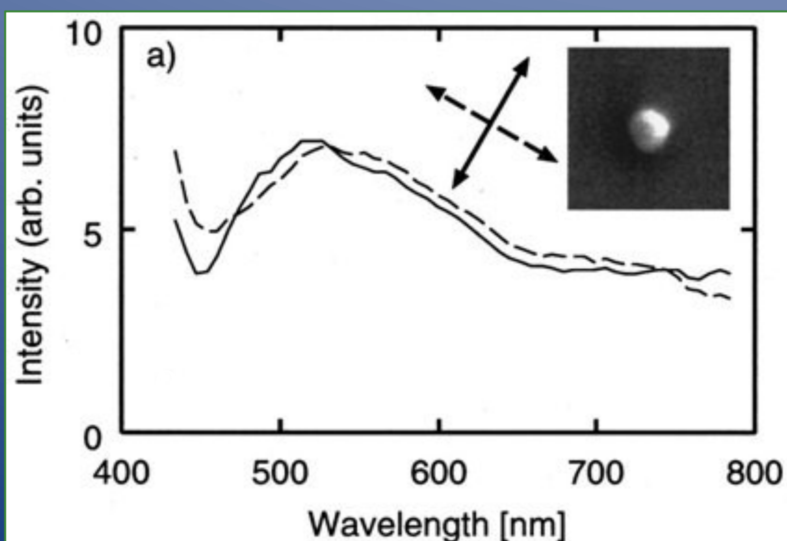
$$E_l = \frac{3\varepsilon_d(\lambda)}{\varepsilon_m(\lambda) + 2\varepsilon_d(\lambda)} E_0$$

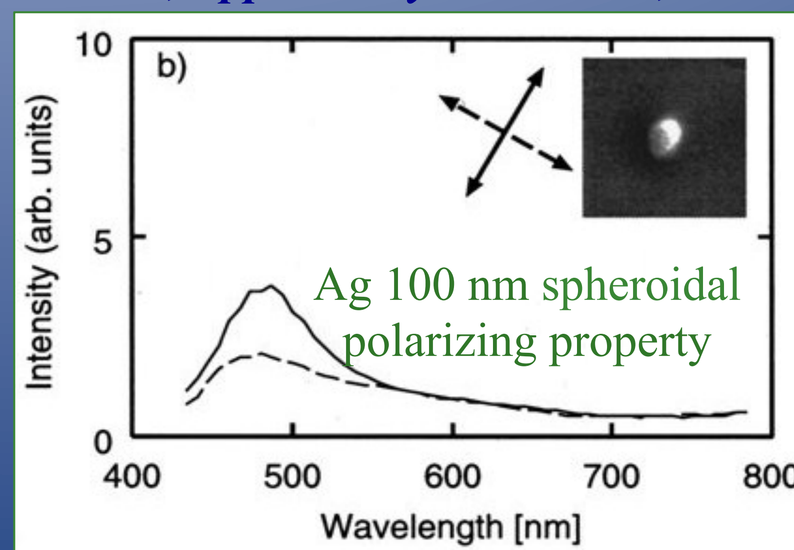
$$\varepsilon_m(\lambda_l) + 2\varepsilon_d(\lambda_l) \approx 0$$

E_l is resonance enhanced

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

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

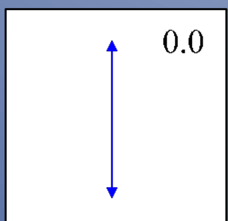


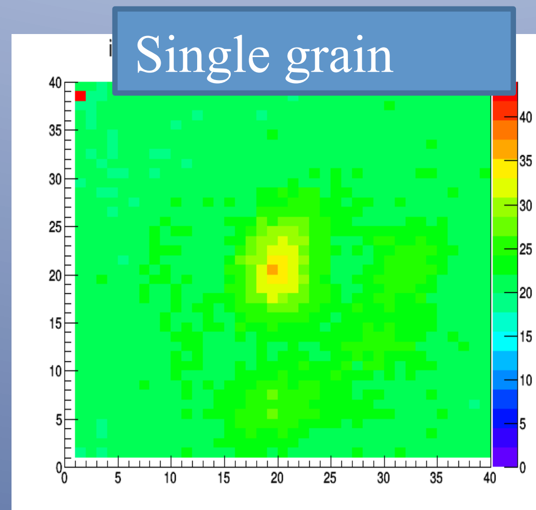


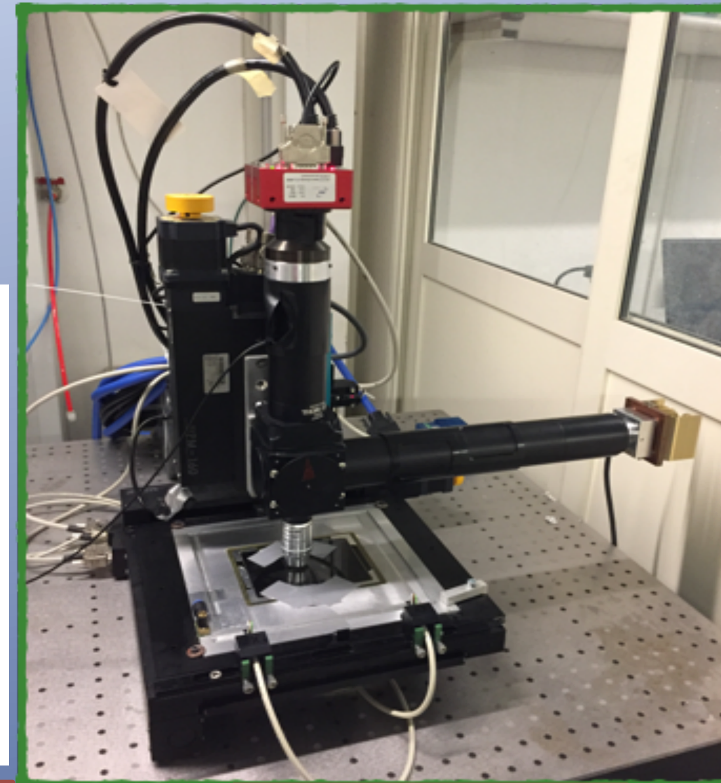
The polarization dependence of the resonance frequencies strongly reflects the shape anisotropy

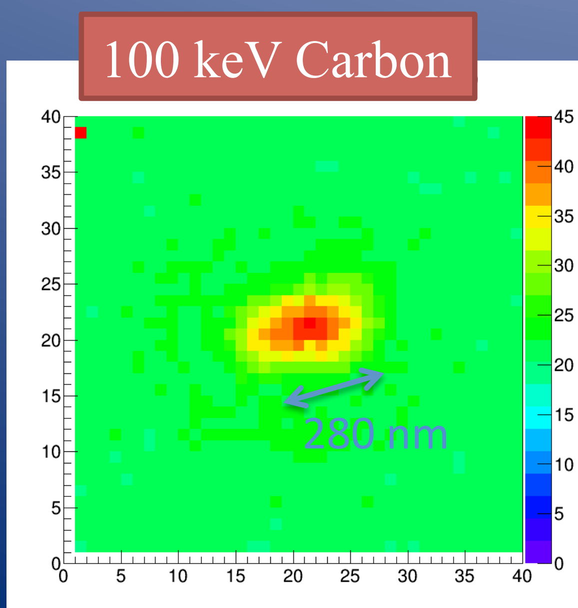
New Microscope

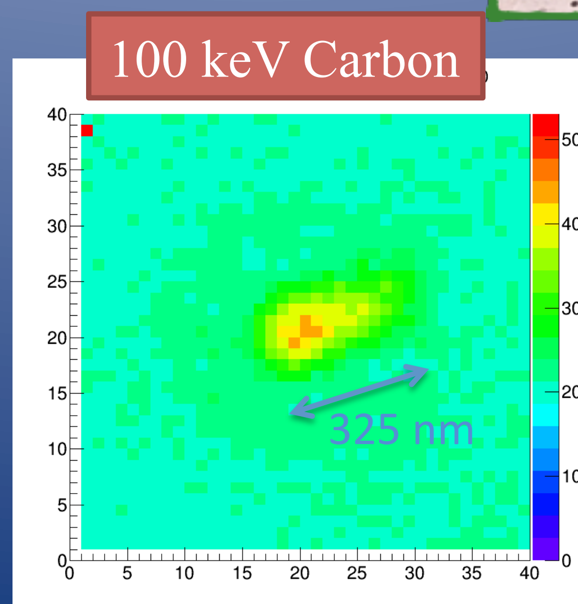
- Equipped with liquid crystal polarizer

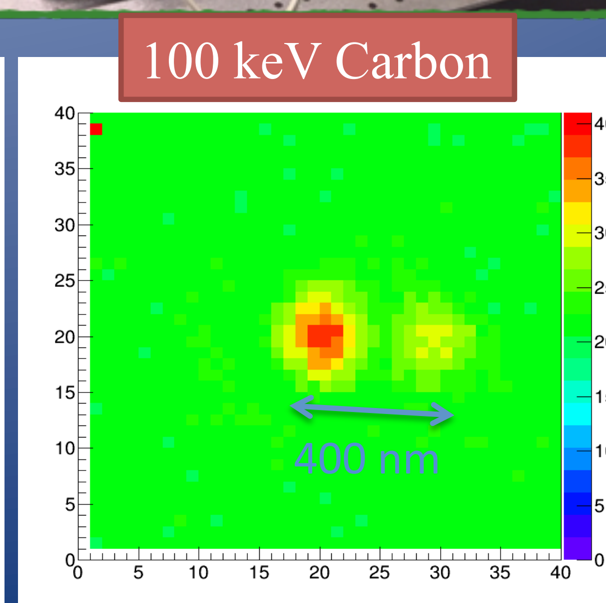




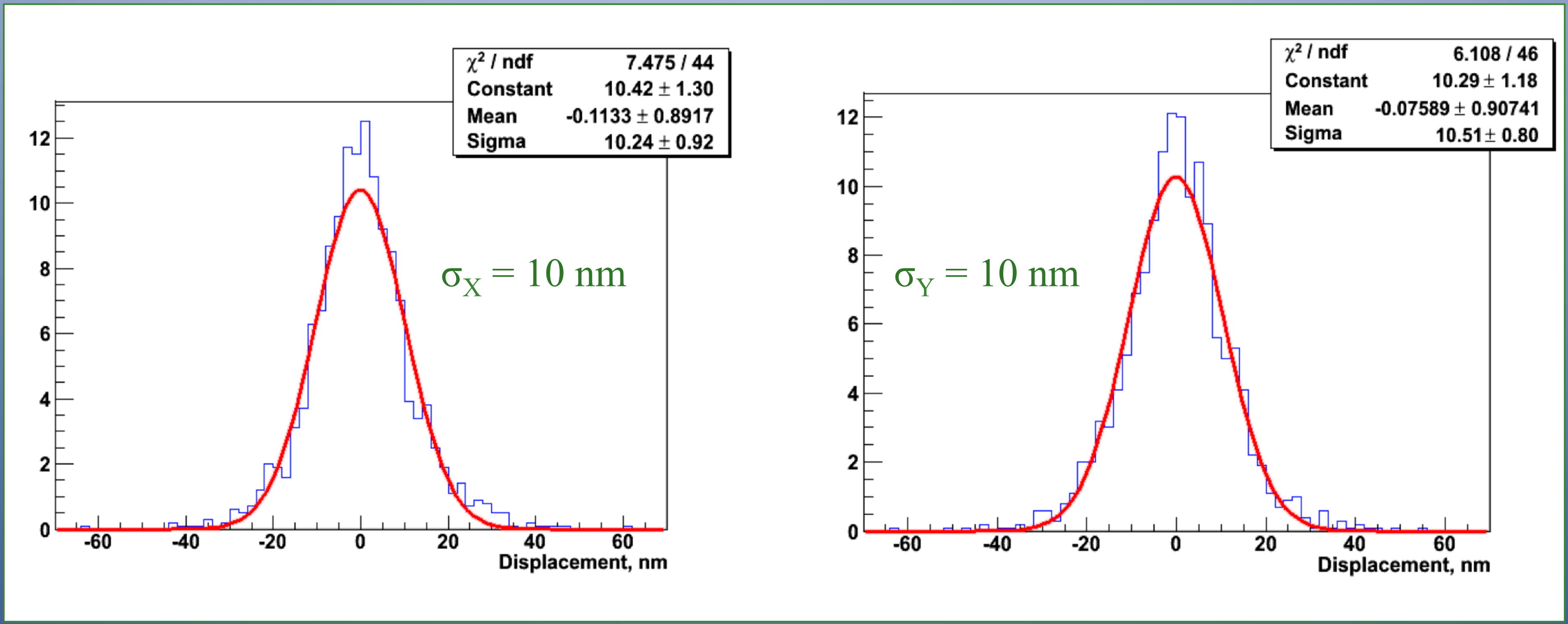








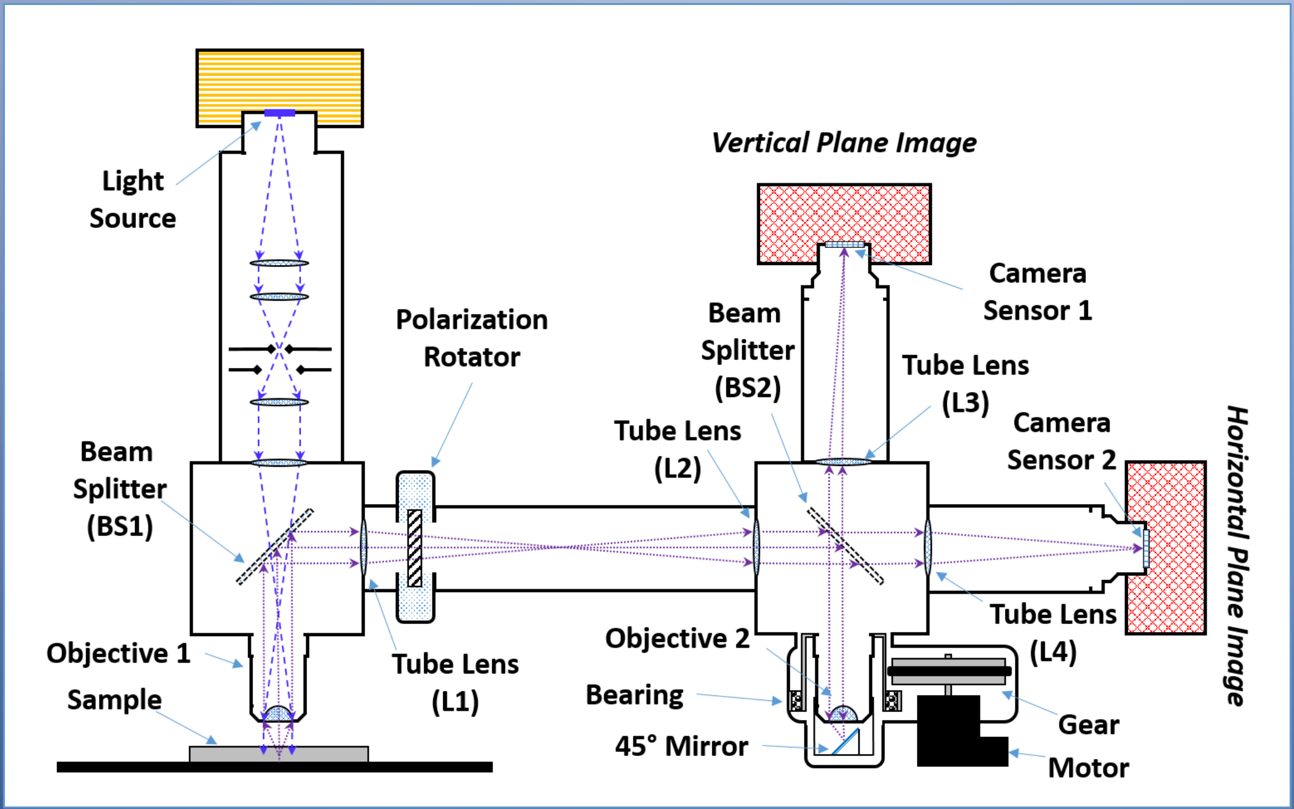
POSITION ACCURACY



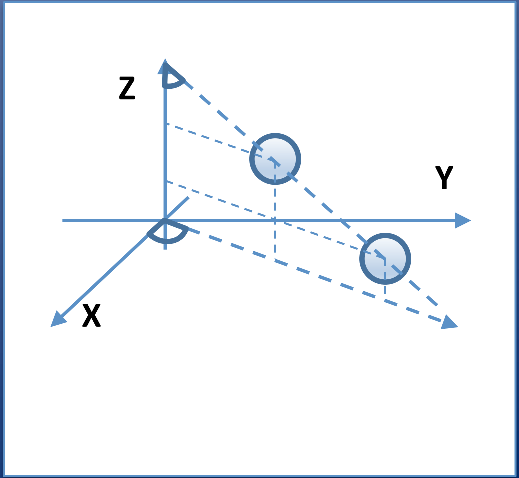
(pixel size 28 nm)

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

3D Nanometric Readout

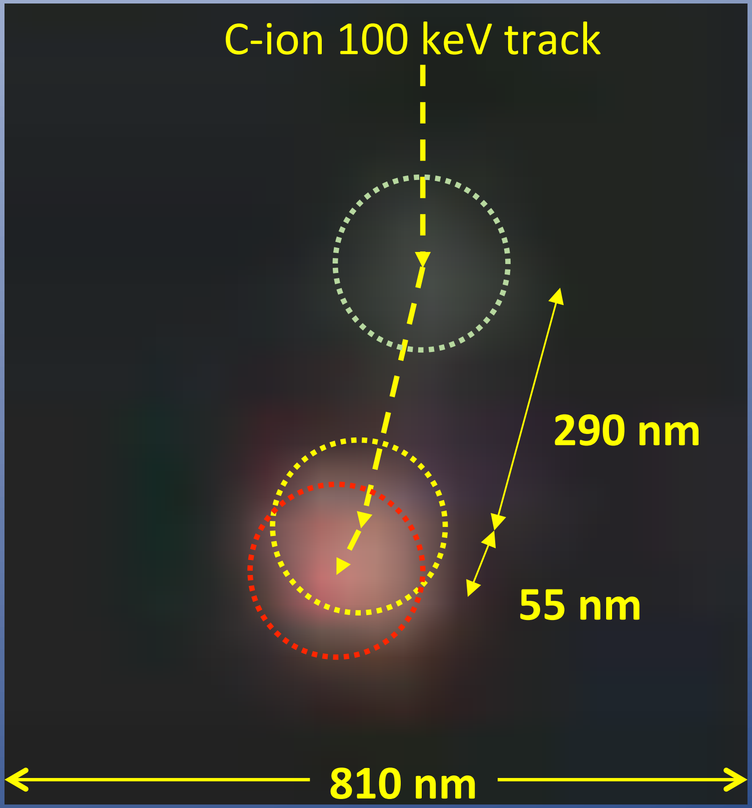


- Perform plasmon analysis in horizontal plane
  - Measure ϕ angle
- Rotate mirror to make the vertical plane coincide with the prediction's direction (ϕ)
- Perform plasmon analysis in vertical plane
  - Measure θ angle
  - Measure 3D length



MULTI-WAVELENGTH PLASMON RESONANCE ANALYSIS

- LSP Resonance wavelength provides new information
- Depends on grain size and shape
- Larger energy loss → more latent images produced → larger and longer grains → red shift of the resonant wavelength
- Redder at the stopping point
- Head-tail discrimination!



Background Study

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

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

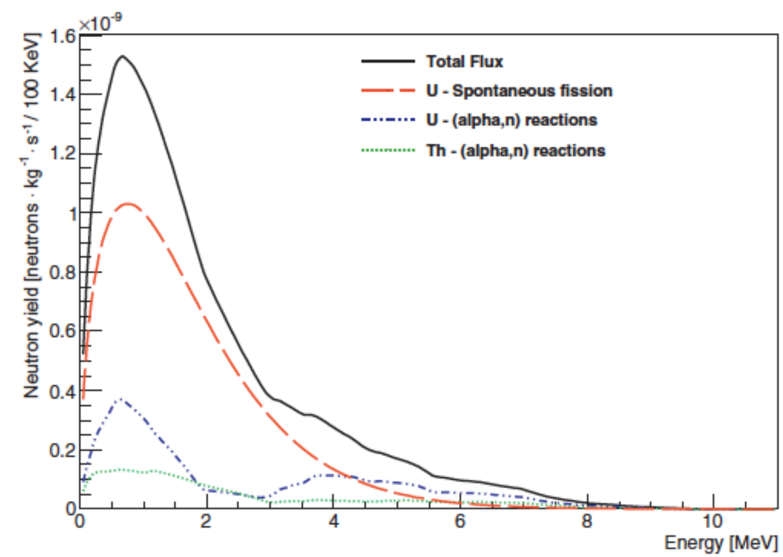
(a) Constituents of nuclear emulsion

^{238}U: 1.87 ppb (23.1 mBq/kg)
^{232}Th: 1.26 ppb (5.1 mBq/Kg)

Process	SOURCES simulation [kg^{-1} y^{-1}]	Semi-analytical calculation [kg^{-1} y^{-1}]
(α, n) from ^{232}Th chain	0.12 ± 0.04	0.11 ± 0.03
(α, n) from ^{238}U chain	0.27 ± 0.09	0.26 ± 0.08
Spontaneous fission	0.8 ± 0.3	0.8 ± 0.3
Total flux	1.2 ± 0.4	1.2 ± 0.4

$$\varepsilon \simeq 5\% \rightarrow 0.06 \div 0.11\, n/(kg \cdot year)$$

Astroparticle Physics 80 (2016) 16–21



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Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

ELSEVIER

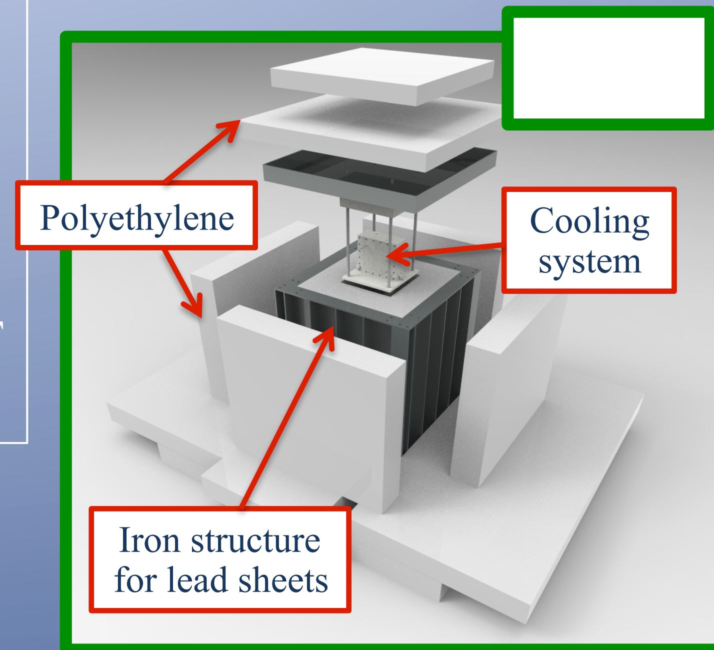
Intrinsic neutron background of nuclear emulsions for directional Dark Matter searches

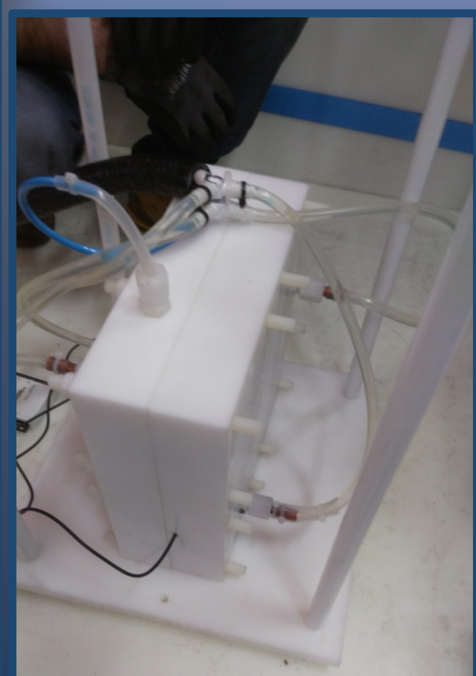
CrossMark

Facility And Detectors At LNGS

Facility and Detector Underground at LNGS

- Construction and installation of the shield in LNGS Hall B
- First technical test performed in February 2017
- Test of the cooling system and temperature monitoring
- New emulsion facility being prepared in the Hall-F underground

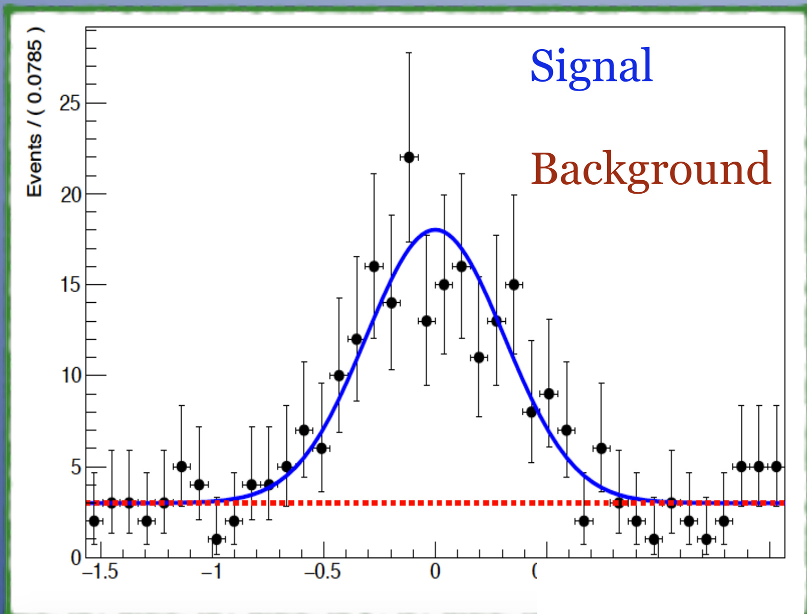




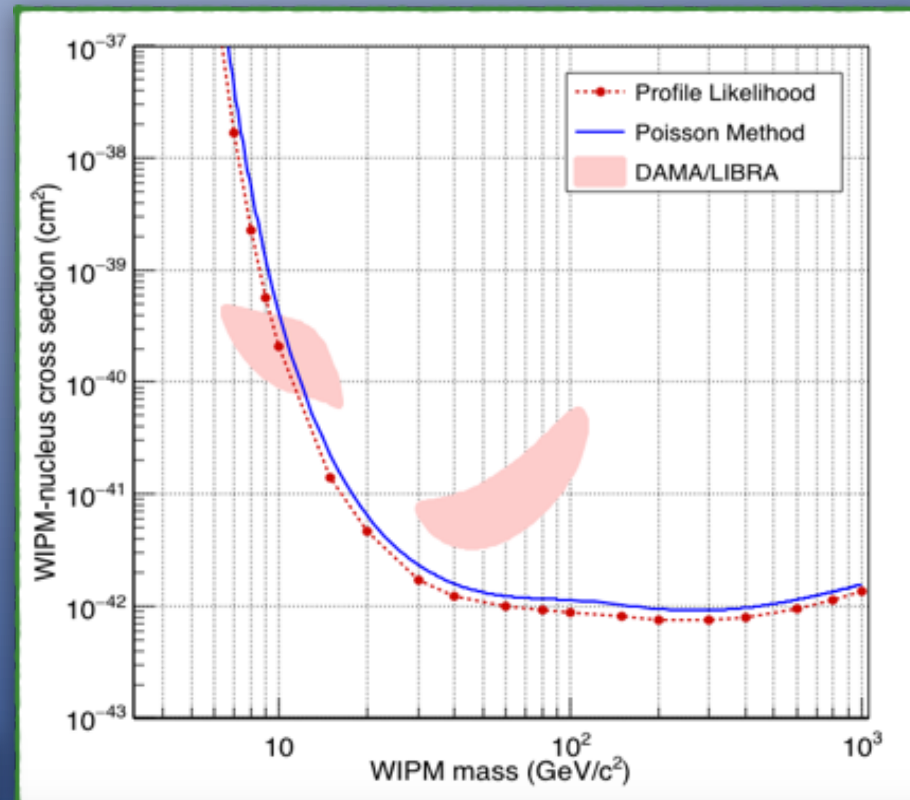
SENSITIVITY

Exploit Directionality

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



- Exposure = 100 kg years
- $N_{background}$ = 100
- Threshold = 100 nm



- Likelihood function

expected number of WIMP events

expected number of background events

signal pdf

background pdf

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

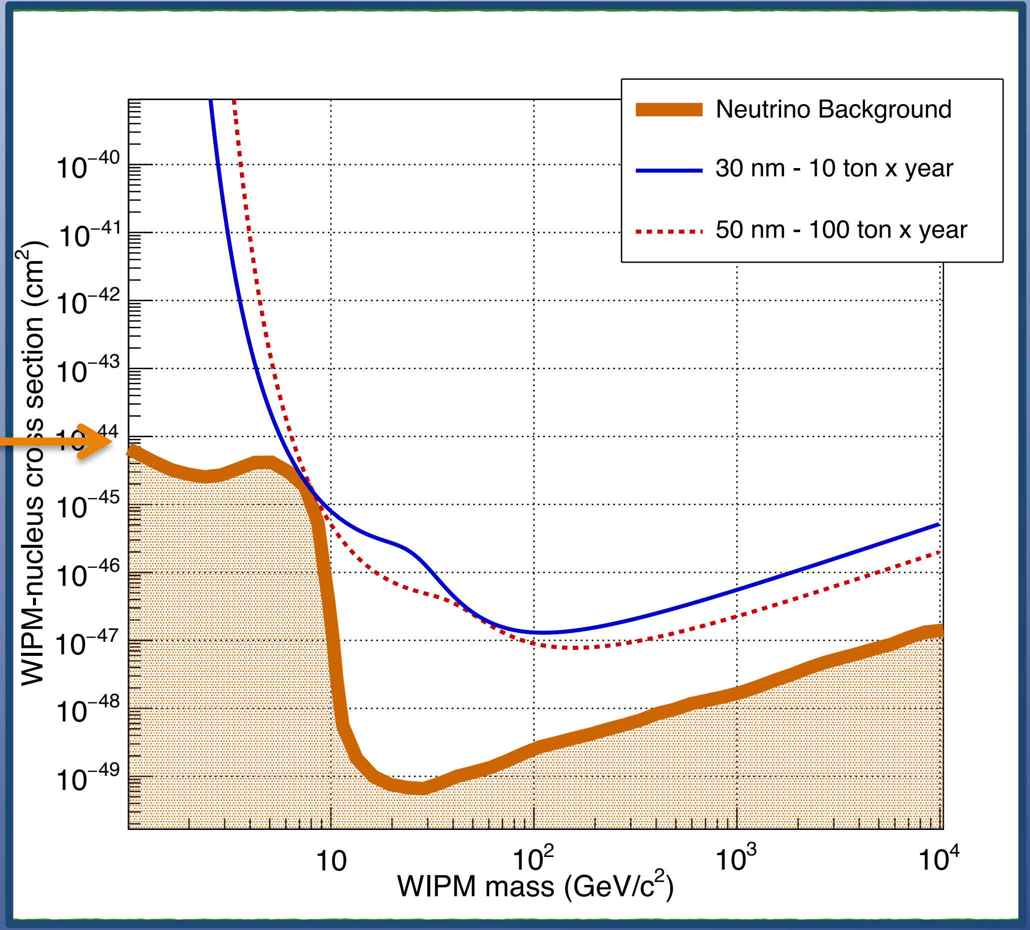
total number of observed events

set of observables

TOWARDS THE 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
- Lowering the 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

https://arxiv.org/pdf/1705.00613.pdf

Conclusion And Perspectives

- Nuclear emulsions with nanometric grains pave the way for a directional dark matter search with high sensitivity
- Breakthrough in readout technologies for optical microscopes push the track length threshold down → higher sensitivity
- 3D reconstruction and hints for head-tail discrimination
- Without any treatment, neutron background from intrinsic radioactivity negligible up to ~ 10 kg year
- Prepare a few kg mass detector as a demonstrator of the technology and the first spin-independent search of this kind
- R&D phase (2016-2018) funded in view of the pilot experiment