NEWS: Nuclear Emulsions for Wimp Search

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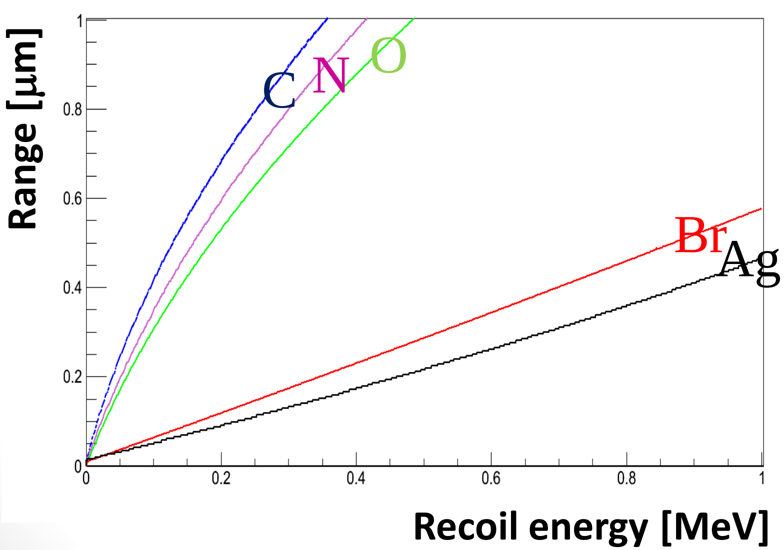
on behalf of

Italy
- **Napoli University “Federico II”**
- **LNGS – INFN**
- **Bari University**
- **Roma University “La Sapienza”**

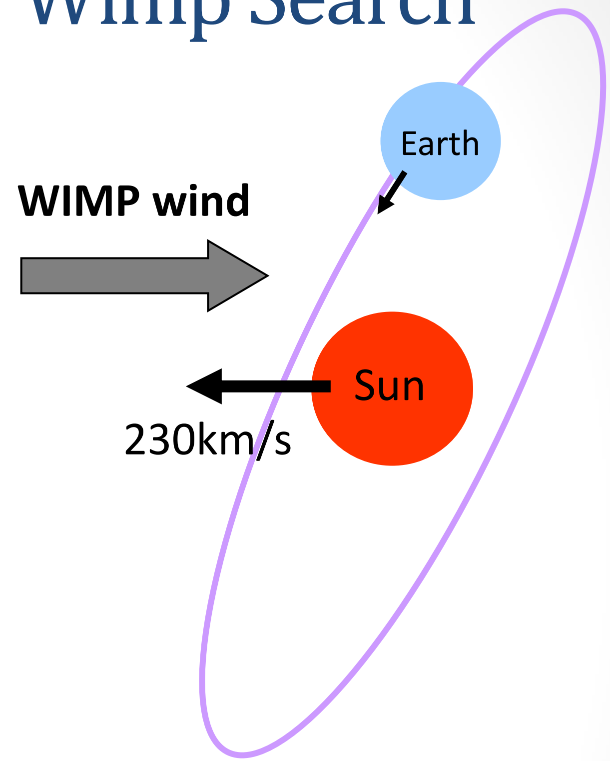
Japan
- **Nagoya University**

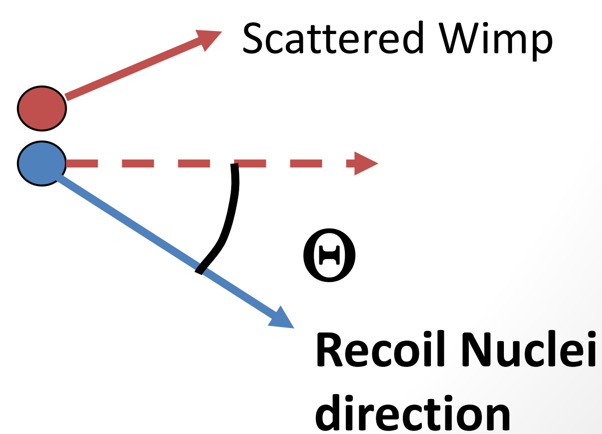
NEWS: Nuclear Emulsions for Wimp Search

- Solar system movement in the galaxy → WIMP Flux is expected to be **not isotropic @earth**.
- Directional measurement for a **strong signature** and unambiguous proof of the galactic DM origin
- Use nuclear emulsions, i.e. solid detector → incomparably more sensitive than gas detectors
- Short recoil track length O(100 nm)

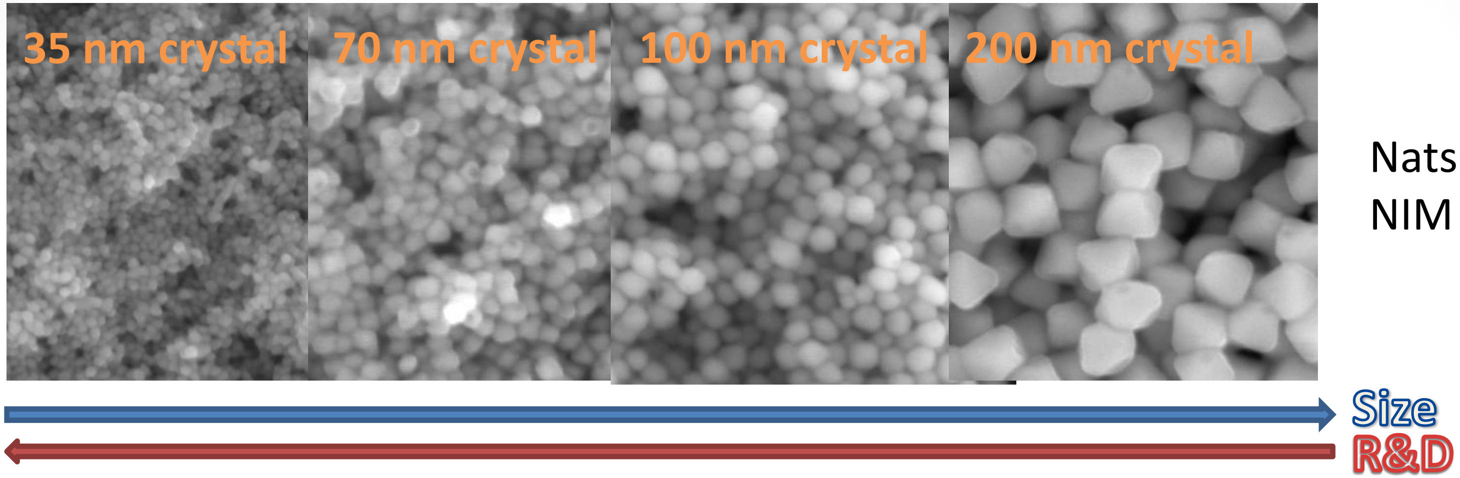


Both light and heavier nuclei



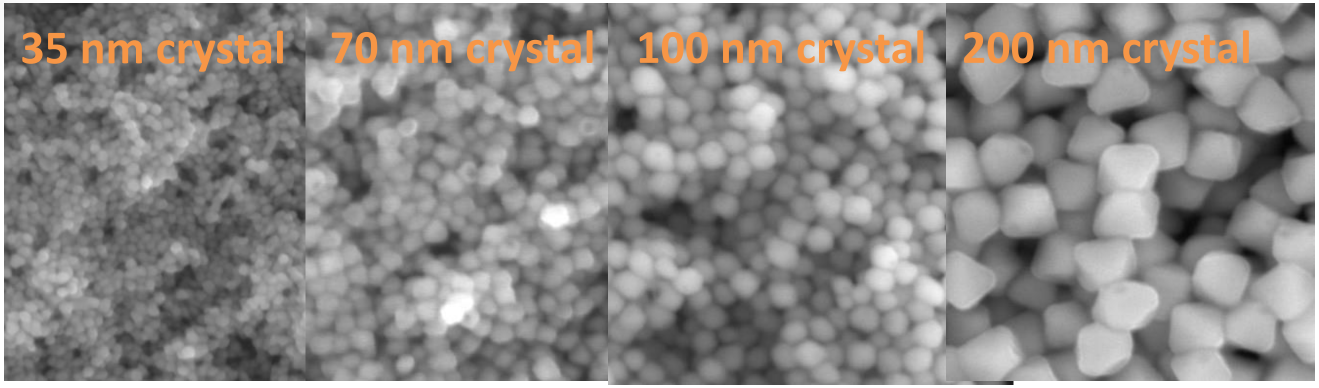


NIT emulsion films: Nano Imaging Trackers

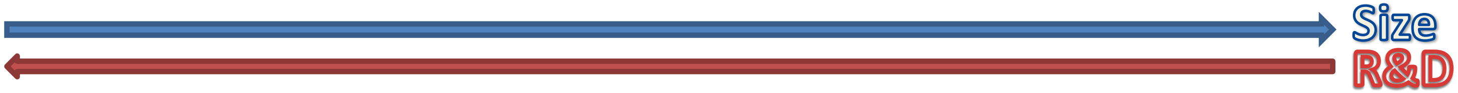


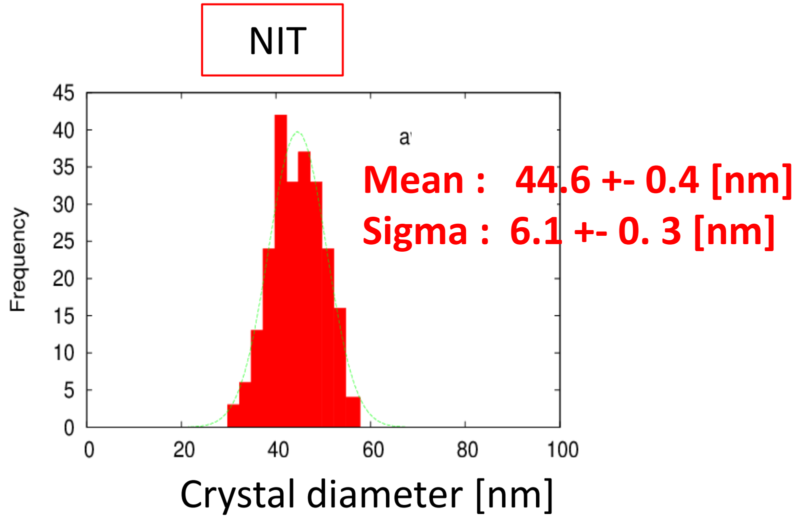
Natsume et al,
NIM A575 (2007) 439

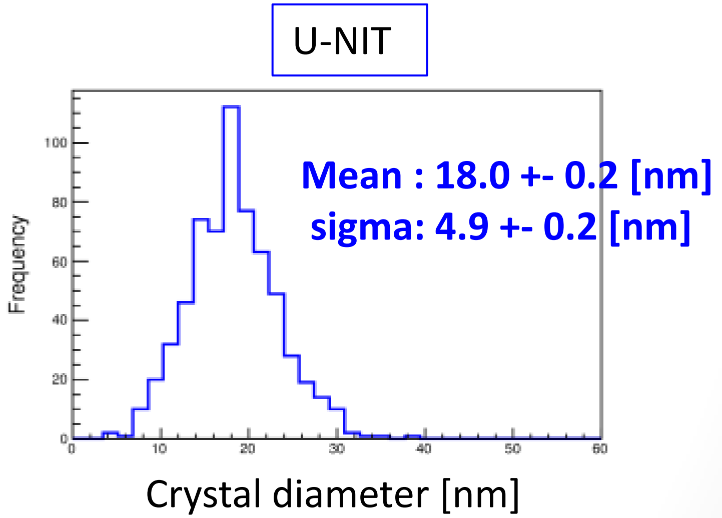
NIT emulsion films: Nano Imaging Trackers



Natsume et al,
NIM A575 (2007) 439







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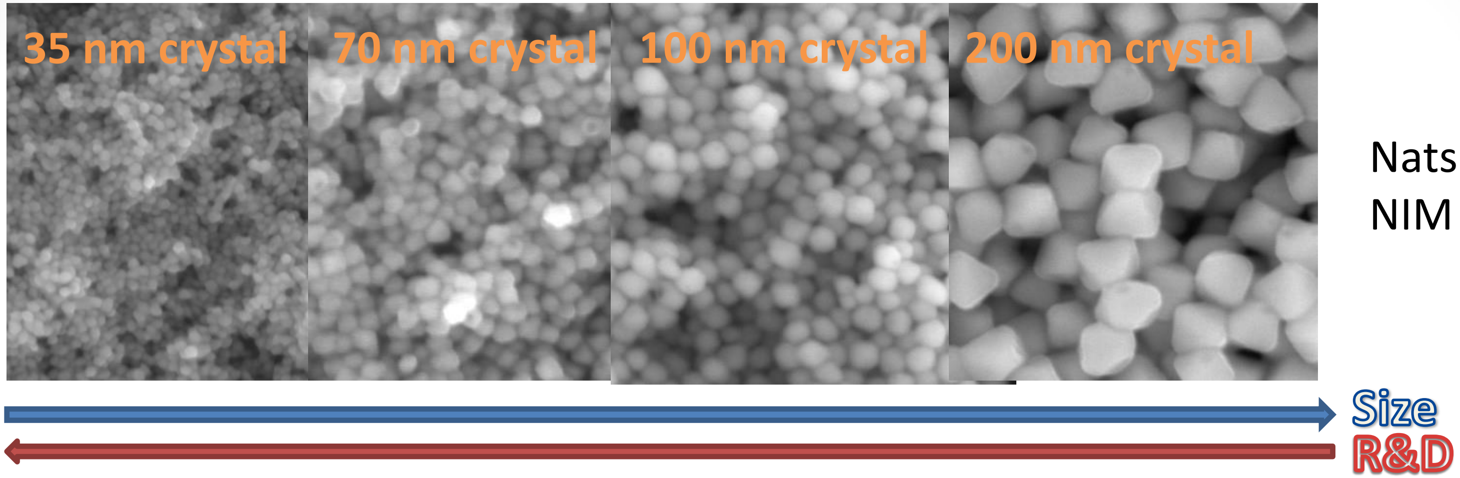

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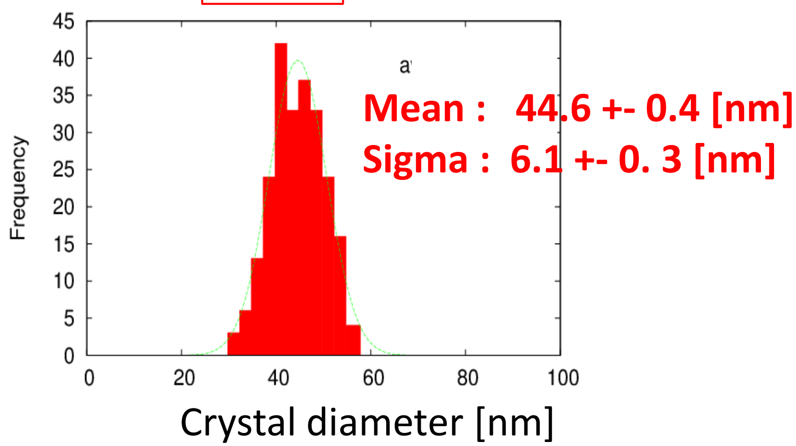
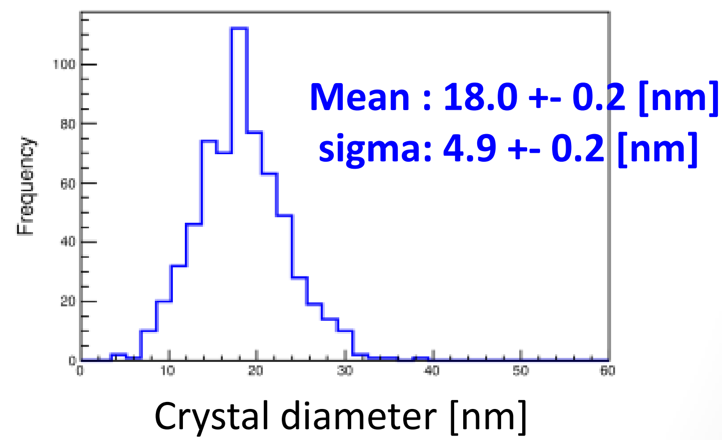
NIT

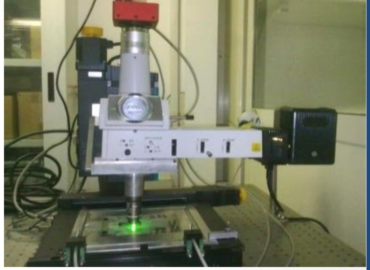


U-NIT



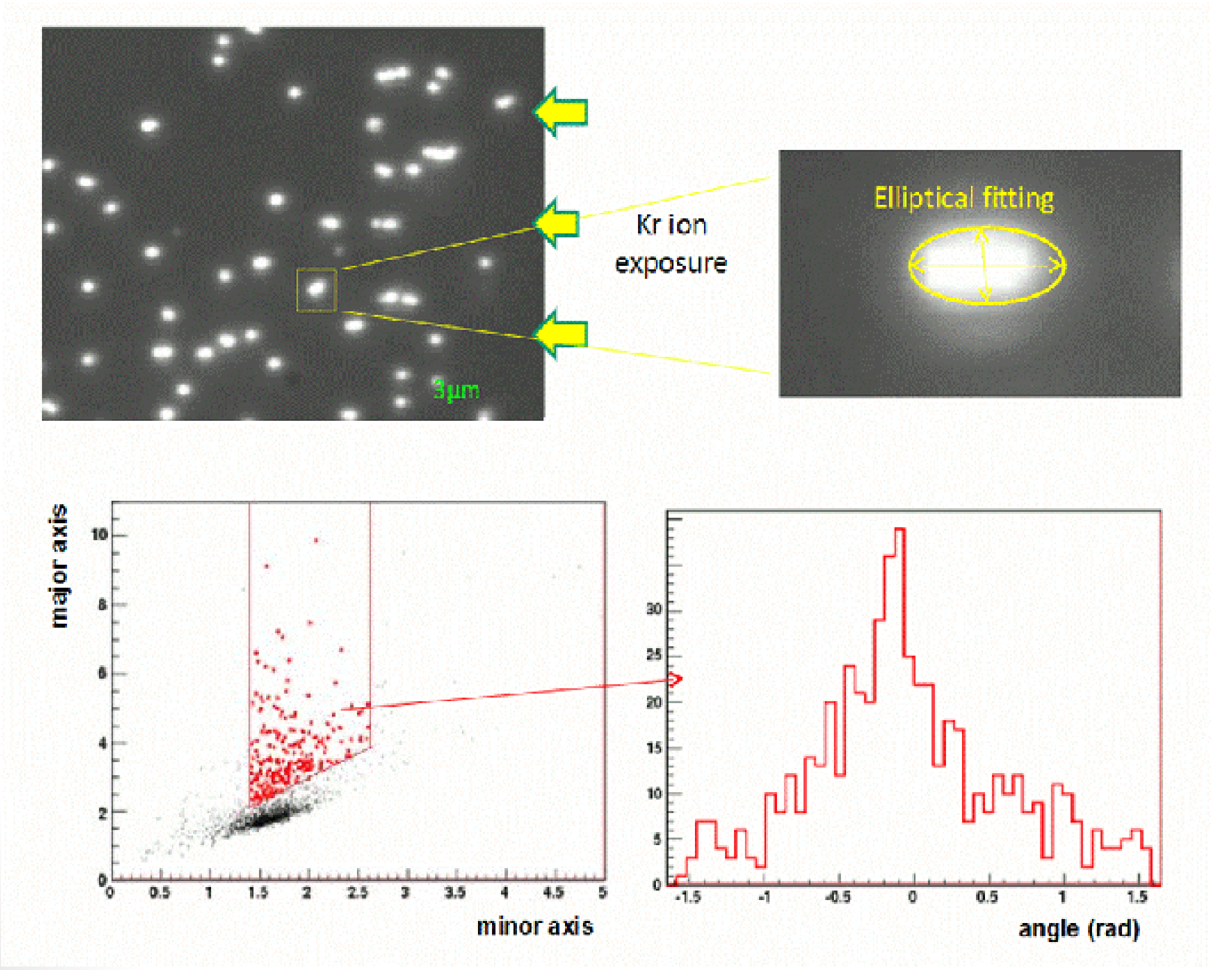
	NIT	U-NIT
AgBr density	12 AgBr/µm	29 AgBr/µm
Detectable range	> 200 nm	> 100 nm
Tracking E threshold	> 80 keV@C	> ~ 30 keV@C

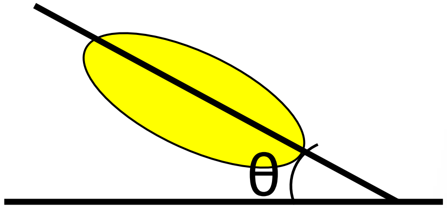
Concept of readout: step I



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

Test using 400 keV Kr ions

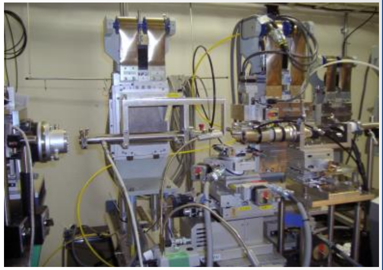




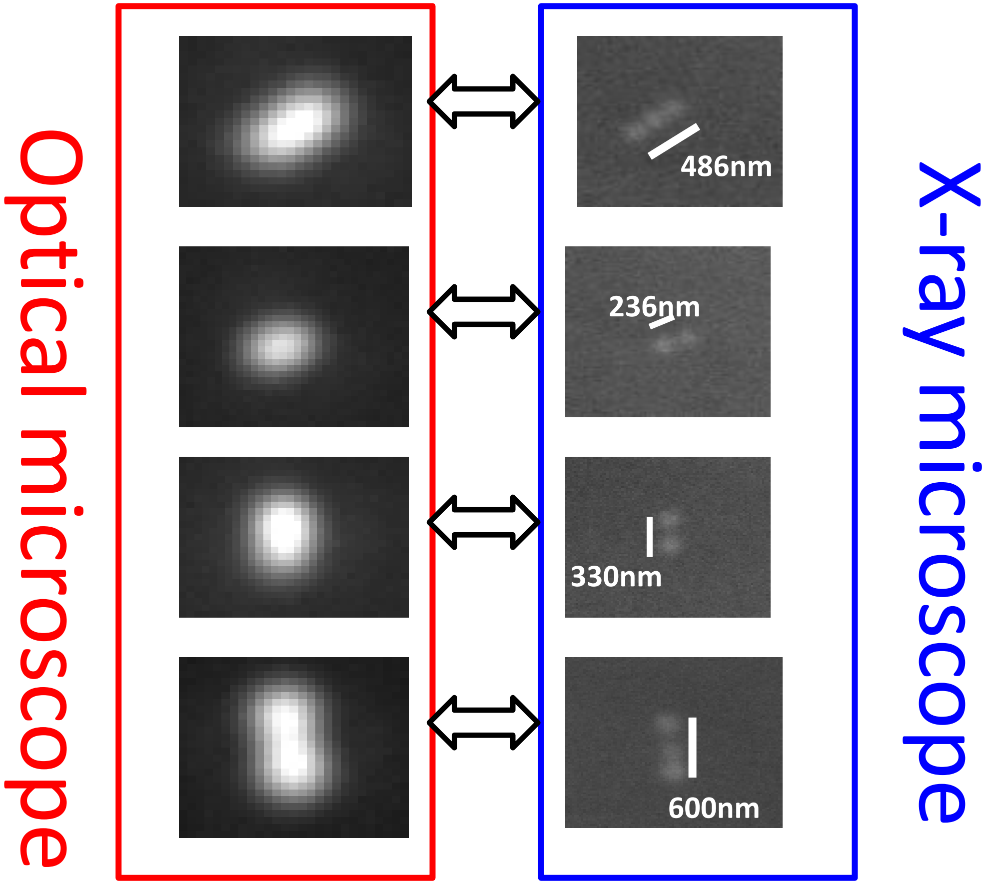
Direction detected!

Nucl.Instrum.Meth. A680 (2012) 12-17

Concept of readout: step II

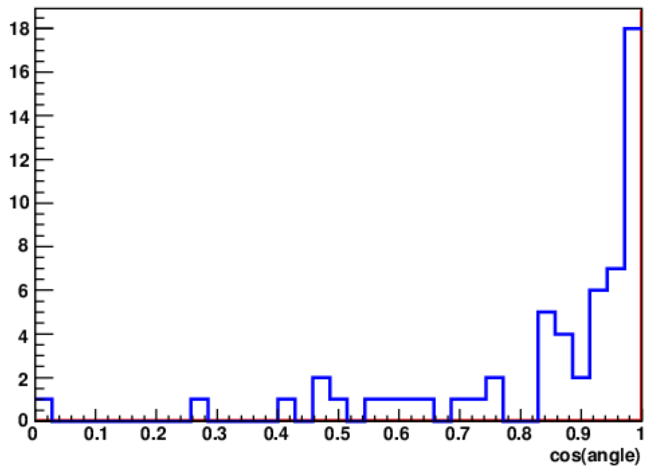


Scanning with **X-ray microscope** of preselected zones



Matching of recoiled tracks between Optical and X-ray microscope

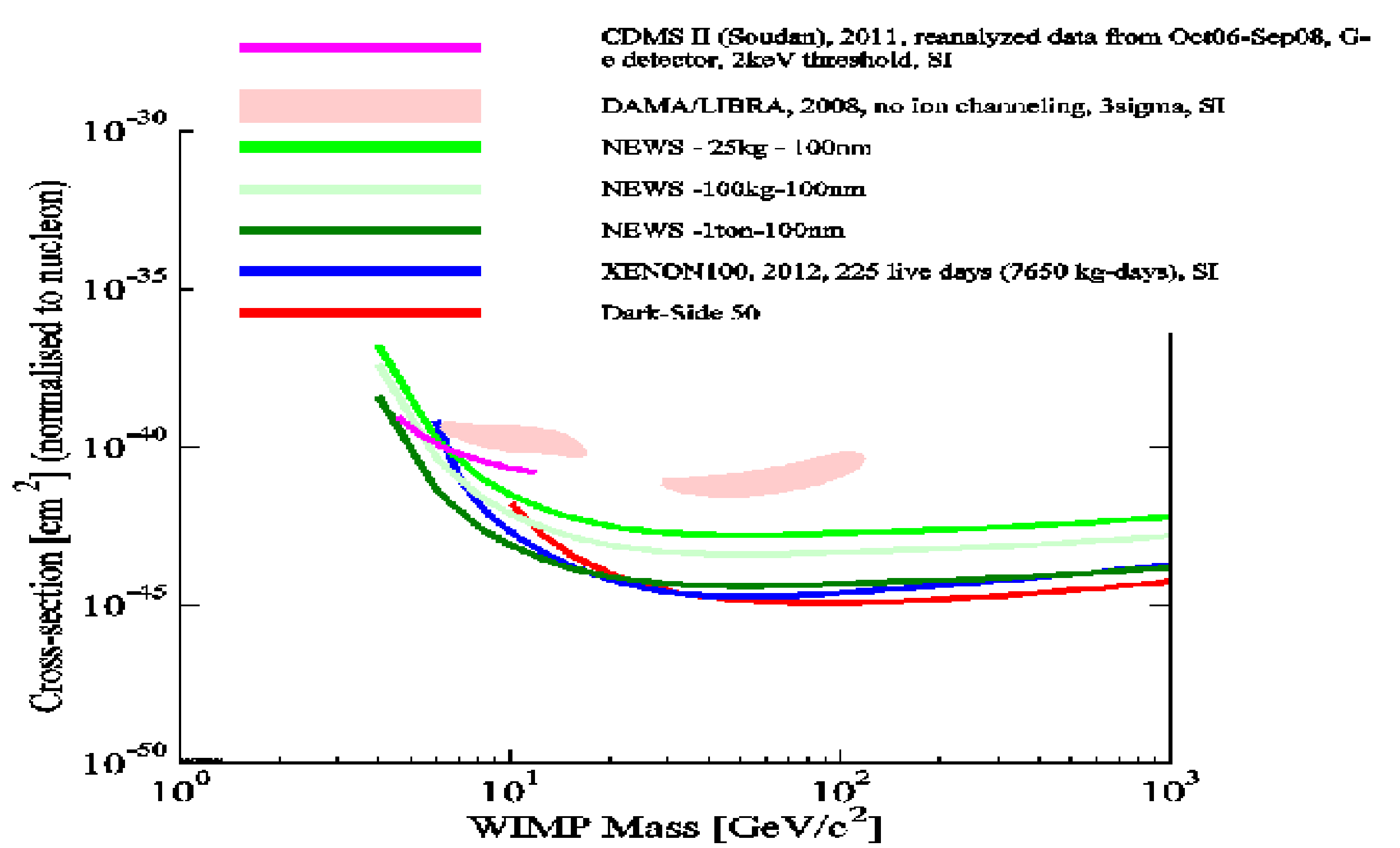
Success rate of matching
572/579=99%



	angular resolution [degrees]
optical microscope	31.4 +- 4.7 degree @original range: 150-250nm
X-ray microscope	16.8+-2.9 degree @original range: 150-250nm

Sensitivity

- Zero-background hypothesis
- 90% C.L.
- 100 nm tracking threshold
- directionality information not included



R&D activity

- Optical read-out system
- Measurement of sub-micrometric length tracks:
  angular resolution and efficiency evaluation
- Intrinsic background measurement
- External background evaluation
- MC simulation
- NIT technology

- Future?

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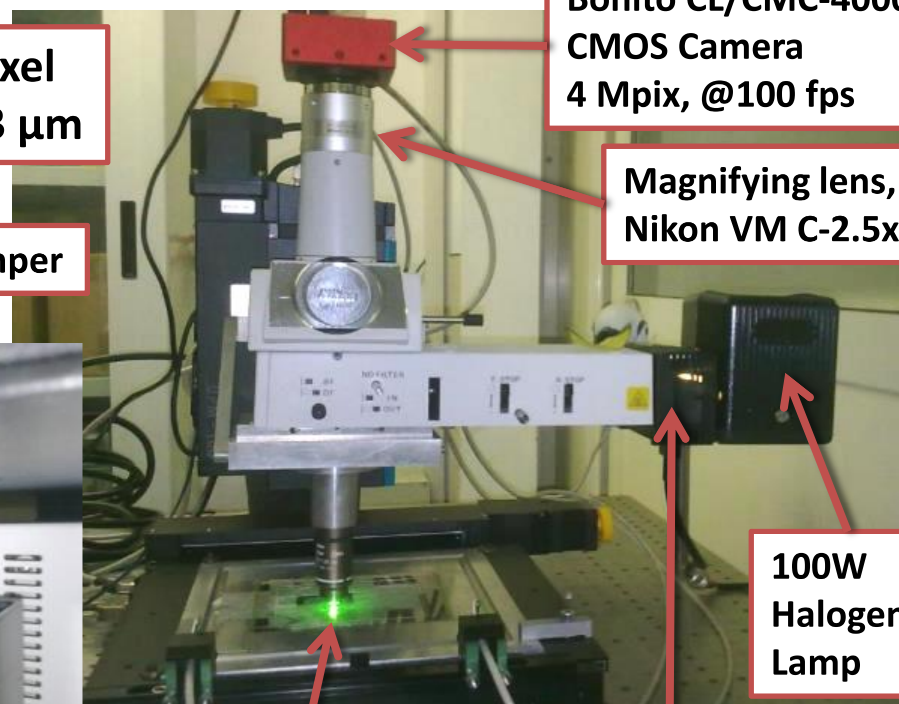
Optical read-out system

Goal -> emulsion scanning system with 200nm spatial resolution and $20cm^2/h$ speed (=0.5 Kg/year)

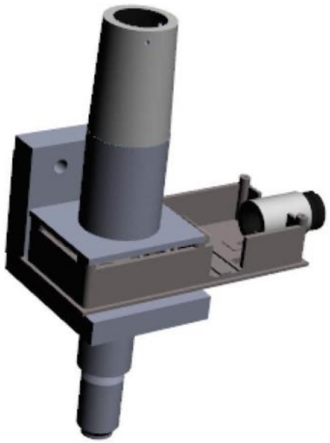
Microscope with EPI illumination : 2014 prototype

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



Scanning speed and further upgrades

RESOLUTION	Field of view (micron^2)	Speed (kg/y)	Frame rate
4 Mpix Mikrotron 4096 X 3072 12 Mpix	204 x 153	0.5	560 f/s CoaXPress 180 f/s CoaXpress



Custom mechanics for the optical path

- More rigid
- Lighter
- Custom LED
- Tune magnification through the camera position
- Tune the illumination optical path

Repeatability 0,2 micron (1)
Yaw 20 microrad (500)

X-Y stage

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NIT as sub-micrometric tracking detector

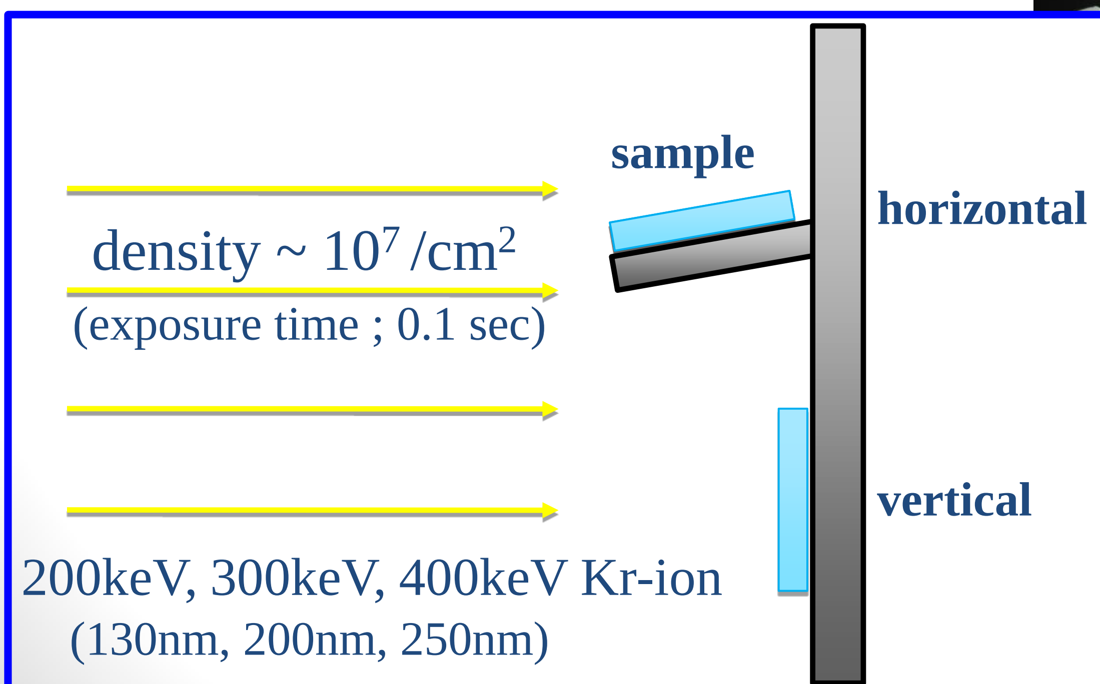
Demonstrators:

Slow Ion implantation

Neutron test beam

Slow Ion Implantation

- gas: **Kr** or **C**
- Energy: **30 ~ 200 [keV]** * ion valence
  →min 5 keV (Feb 2014, upgrade)
- implantation density > $\mathbf{10^7\ /cm^2}$



"Simulation" of WIMP-induced nuclear recoil

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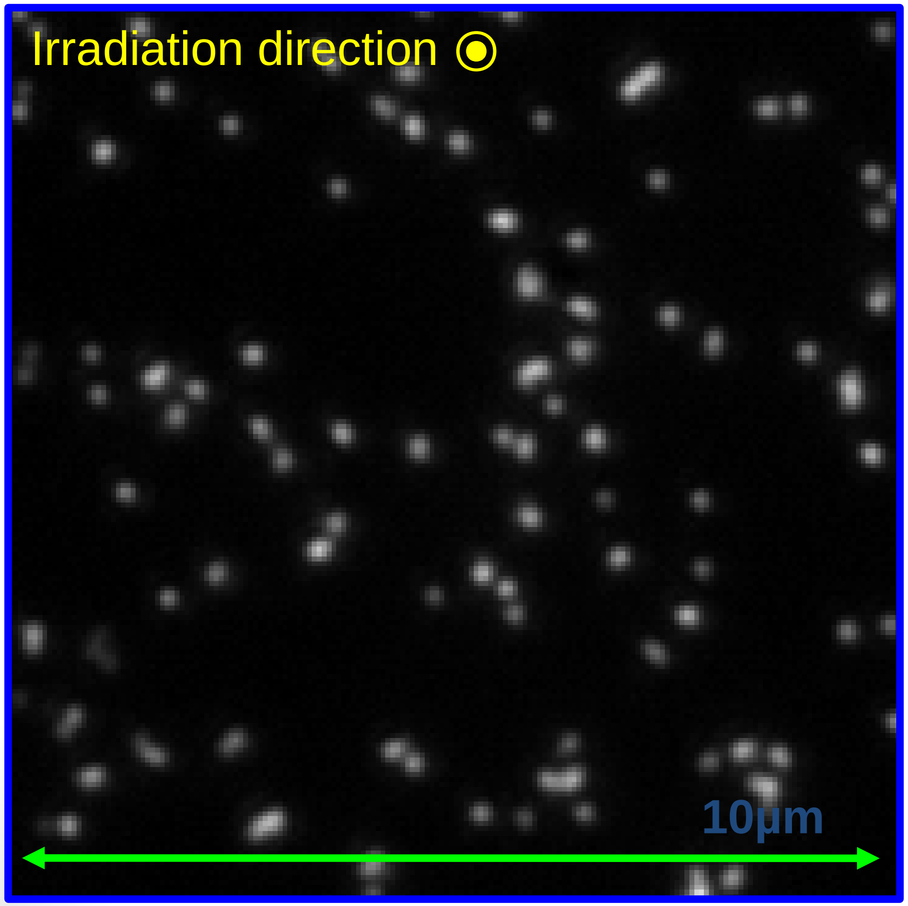
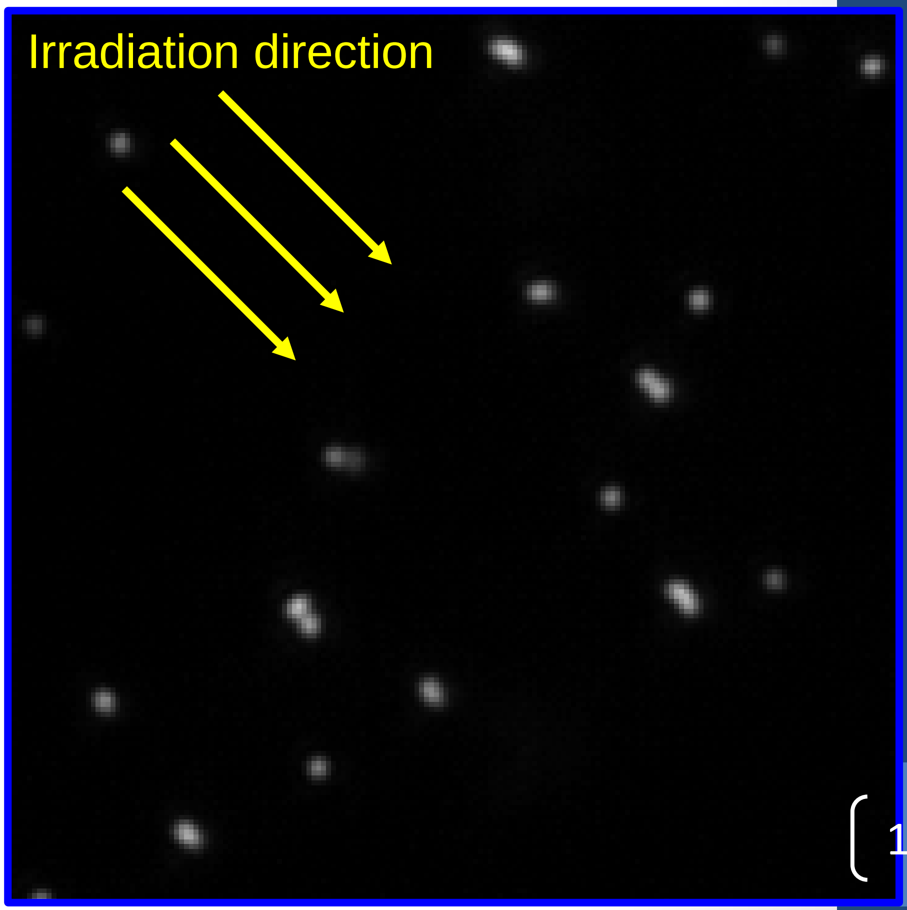
Slow Ion Implantation

- gas: **Kr** or **C**
- Energy: **30 ~ 200 [keV]** * ion valence

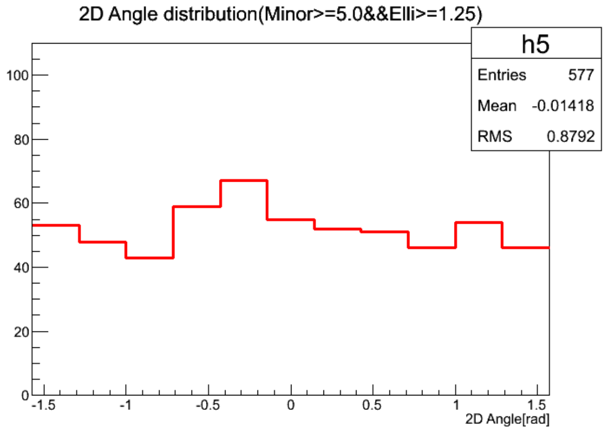


Vertical
Kr 400keV

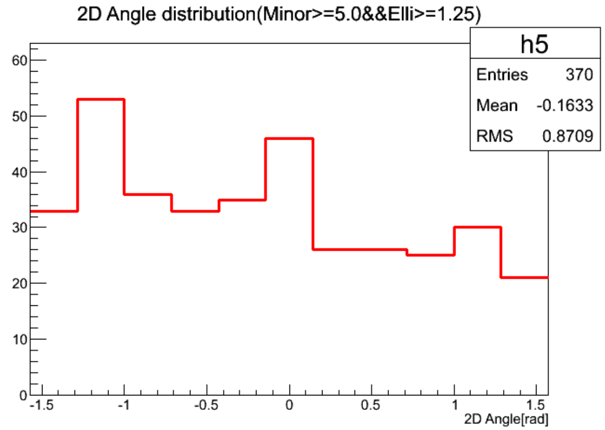


Horizontal
Kr 400keV

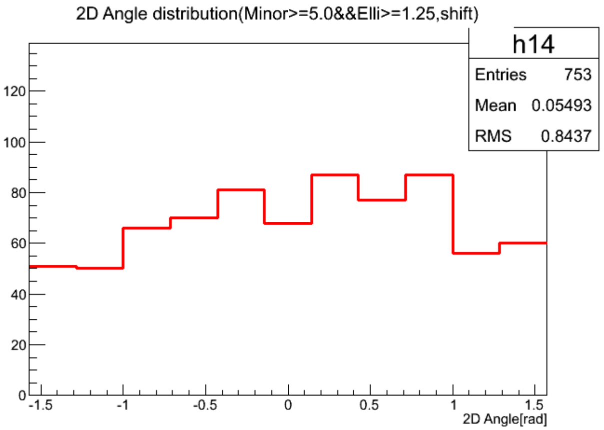
Angular distribution



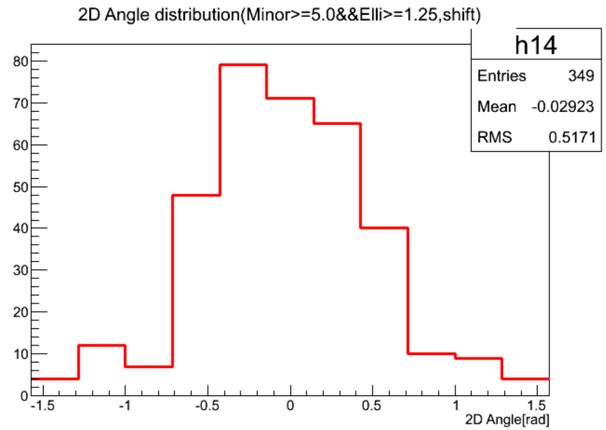
Vertical 400keV



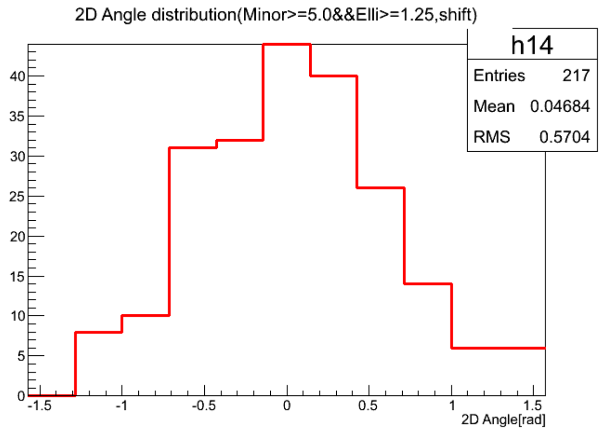
Vertical 300keV



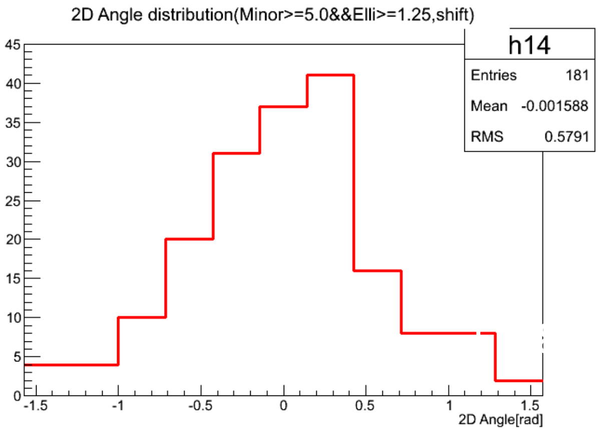
Vertical 200keV



Horizontal 400keV

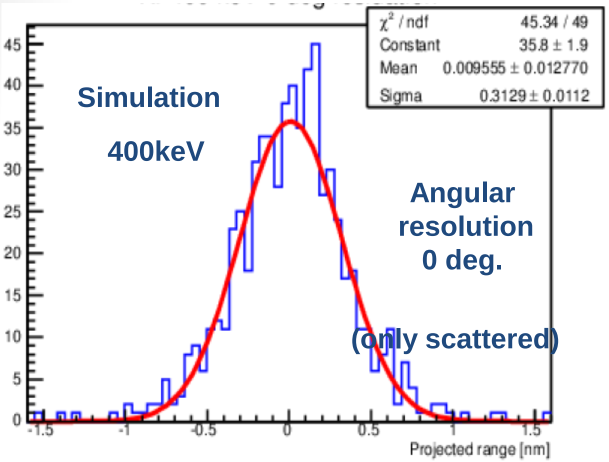


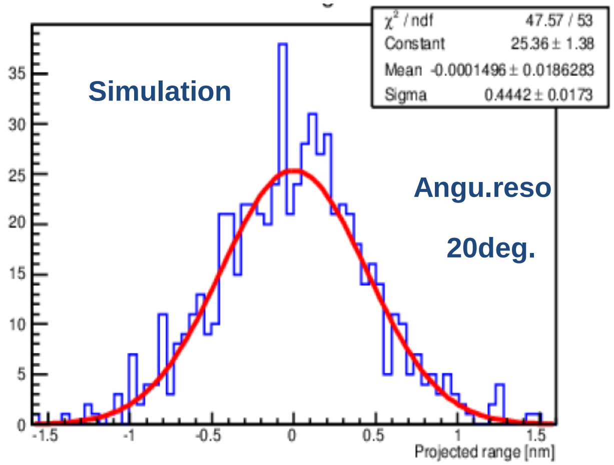
Horizontal 300keV

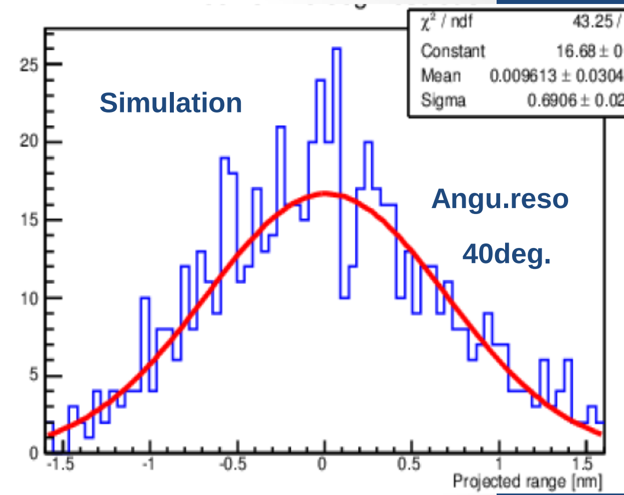


Horizontal 200keV

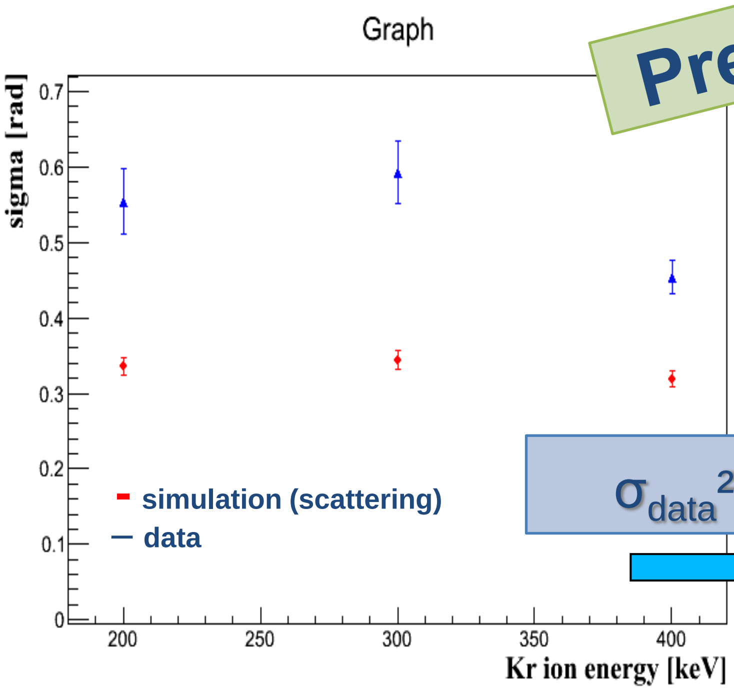
Angular distribution



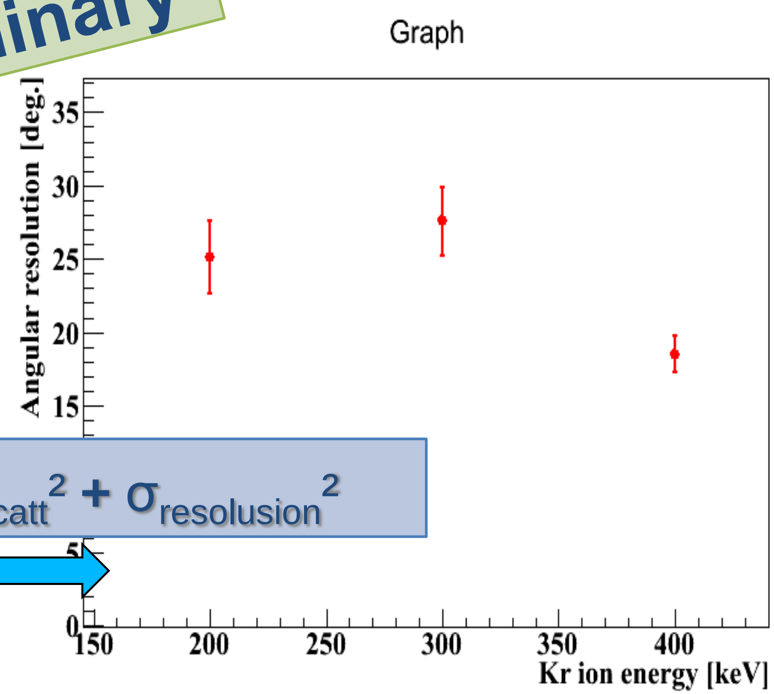




Preliminary



$$\sigma_{data}^2 = \sigma_{scatt}^2 + \sigma_{resolusion}^2$$

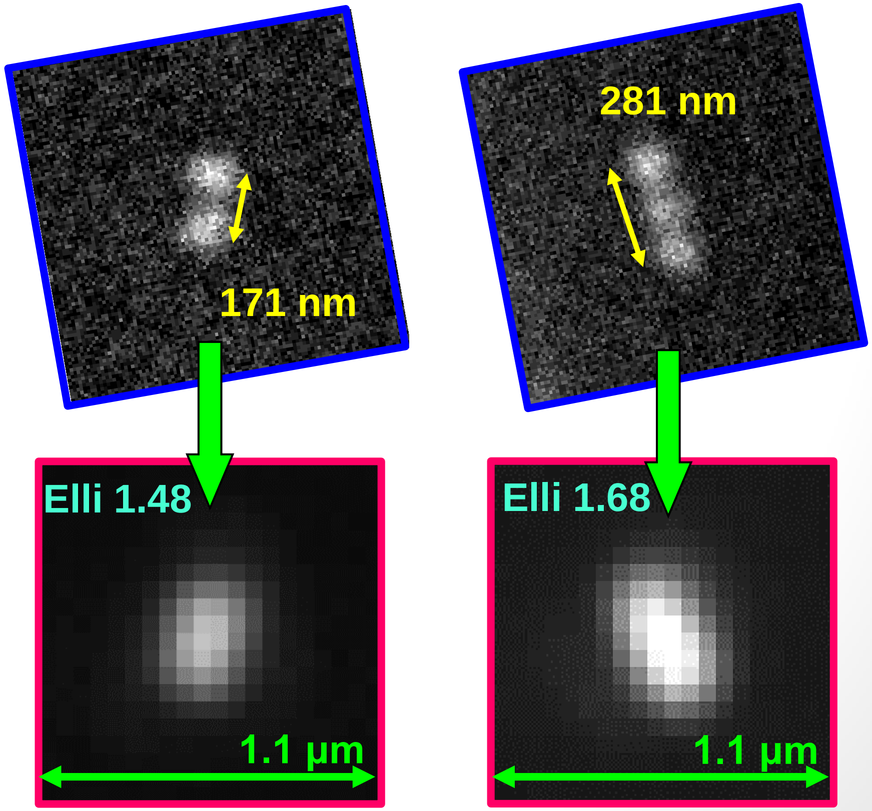


Efficiency evaluation

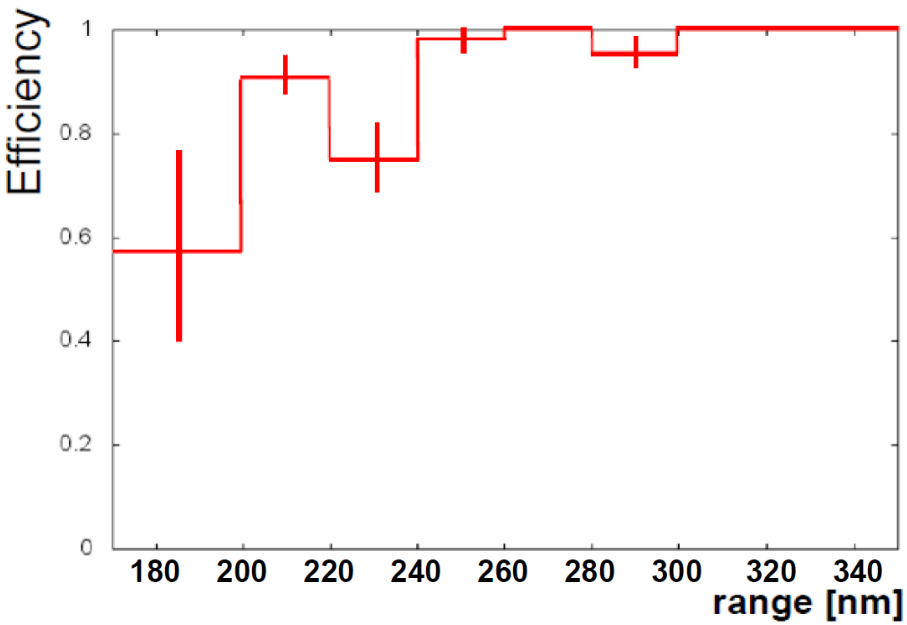
- First scan: X-ray microscope with sequence mode (Area scan)
  & selection of the candidate (Track like)
- Second scan: Optical microscope by pin-point check
  & Ellipse fit

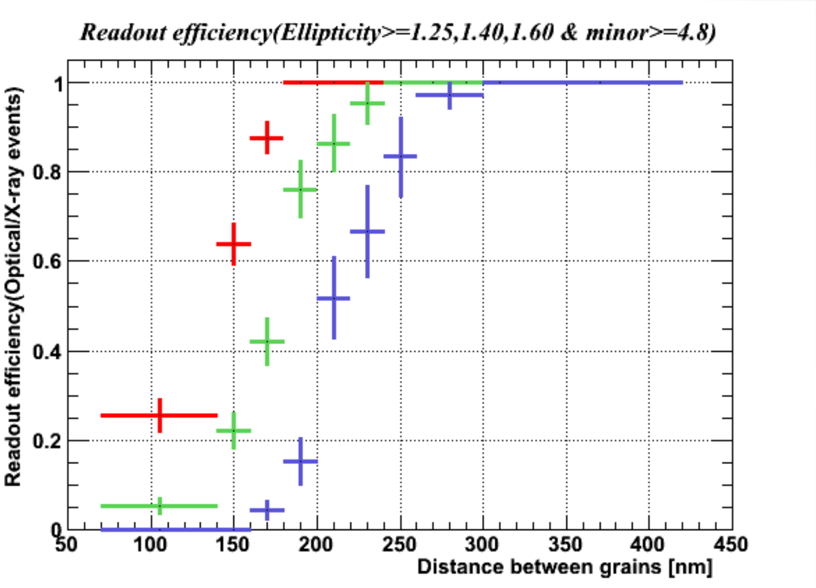
X-ray MS

- 10.83nm / pix
- 2048 x 2048 pix CCD



Efficiency evaluation





- 2012 data
- Elli>=1.25
- Track length: 180~340nm
- Grain size ~200nm
- NA1.25 & λ ~ 550nm

- New data
- Elli>=1.25, 1.40, 1.60
- Track length: 50~450nm
- Grain size ~100nm
- NA1.45 & λ ~ 440nm

R&D activity

- Optical read-out system
- Measurement of sub-micrometric length tracks:

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- Intrinsic background measurement
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Intrinsic radioactive contamination

Gelatin sample	**Contamination [ppb]**	**Activity [mBQ/kg]**
Th	2.7	11
U	3.9	48

PVA	**Contamination [ppb]**	**Activity [mBQ/kg]**
Th	<0.5	<2
U	<0.7	<9

AgBrI	**Contamination [ppb]**	**Activity [mBQ/kg]**
Th	1	4
U	1.5	18

Polystyrene	**Contamination [ppb]**	**Activity [mBQ/kg]**
Th	0.019	0.08
U	0.009	0.11

Costituent	**Mass fraction**
AgBrI	0.813
Gelatin	0.1253
PVA	0.0617

From ^{238}U: 1.75 ppb (21.6 mBq/kg)
From ^{232}Th: 1.18 ppb (4.8 mBq/Kg)

Mass spectrometry measurements

Uncertainty on contamination : 30%

Conversion factors: 1 Bq/Kg(^{232}Th) = 246 ppb(^{232}Th) ; 1 Bq/Kg(^{238}U) = 81 ppb(^{238}U)

Intrinsic neutron background

1) n from spontaneous fission

The only relevant contribution comes from ^{238}U
(fission probability/decay negligible for other elements)

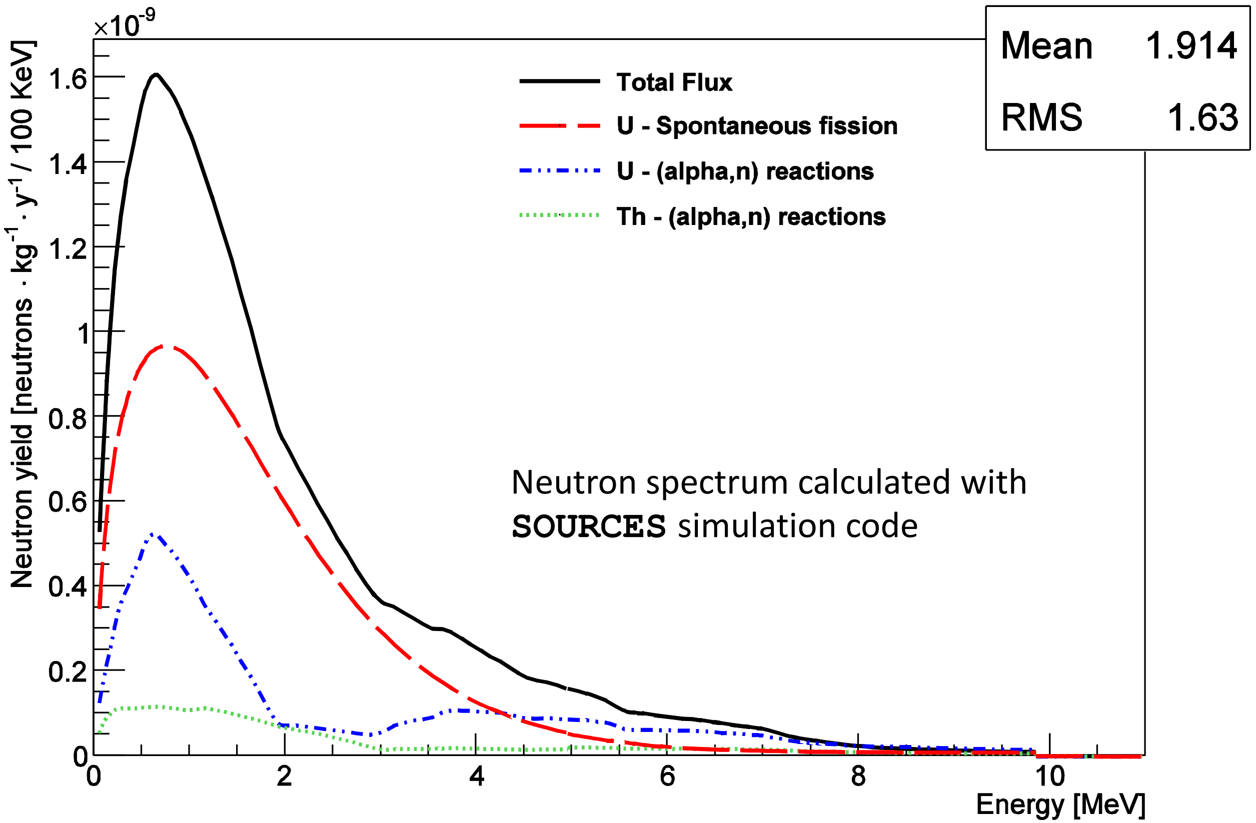
2) (α,n) reactions by α from ^{238}U and ^{232}Th chains

Element	Spontaneous Fission Rate	
	[fissions/g/s]	fissions/decay
^{226}Ra	0.6	2×10^{-11}
^{232}Th	5.72×10^{-8}	1.41×10^{-11}
^{231}Pa	5×10^{-3}	3×10^{-12}
^{234}U	9×10^{-3}	4×10^{-11}
^{235}U	0.40×10^{-3}	5.0×10^{-9}
^{238}U	6.78×10^{-3}	5.45×10^{-7}

Cross-check with γ spectroscopy

- Secular equilibrium valid for AgBr-I "potassium free" powder
- Evidence for broken secular equilibrium at ^{226}Ra for Gelatine P6406. The measured activity is ~ 20 times less → to be estimated (conservative assumption)
- Emulsion film thickness not enough to stop all α particle; → overestimation of the neutron flux (conservative assumption)

Intrinsic neutron background



Process	SOURCES calculation ($n\ kg^{-1}\ y^{-1}$)	calculation by hand ($n\ kg^{-1}\ y^{-1}$)
Spontaneous fission	0.745	0.768
(α,n) from ^{232}Th-chain	0.109	0.100
(α,n) from ^{238}U-chain	0.328	0.325
Total flux	1.182	1.193

External neutron sources

- Neutrons from environmental radioactivity

To be made negligible with appropriate shielding

- Cosmic muon-induced neutrons

Preliminary estimation; underground expected to be less than intrinsic radioactive contamination

Approximations and assumptions:

Neutron differential spectrum: 10^{-5} n/μ/g/cm^2/MeV

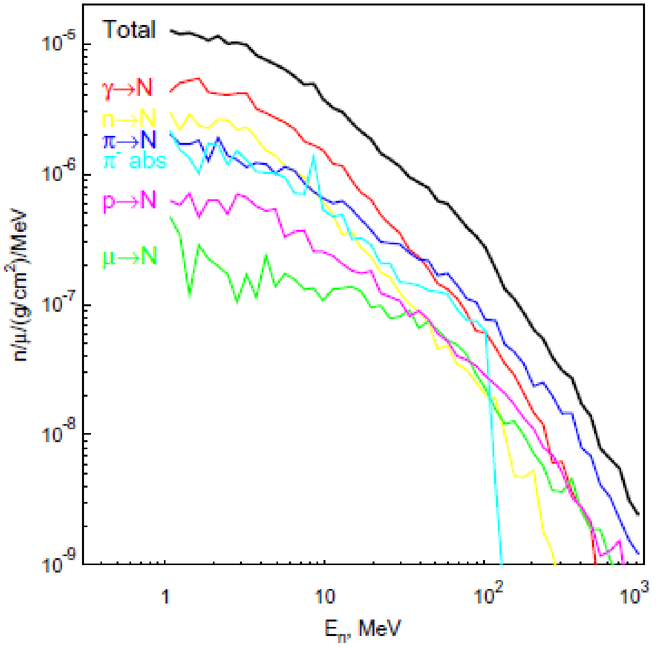
Material used in the simulation is C_nH_{2n}

Muon flux: 1/m^2/h

Neutron flux: 0.009 n/kg/y/MeV

Integrating from 0 to 10 MeV → ~ 0.05 n/kg/y

Differential energy spectrum of neutrons induced by 280 GeV muons



A. Lindote et al., Astroparticle Phys.31 (2009) 366

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2014 - 2015 activity

- New film production @ LNGS (underground)
- Slow Ion implantation @ EU (C ion – 80KeV)
- Further studies with neutron source (^{241}AmBe) @ LNGS
- X-ray microscopy for cross-check and final angular resolution
- Measurement of the LNGS underground neutron flux (directionality)

Hardware developments:

- High resolution mechanics