NEWS: Nuclear Emulsion Wimp Search

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Bari, Gran Sasso, Nagoya (Japan), Napoli

Outline

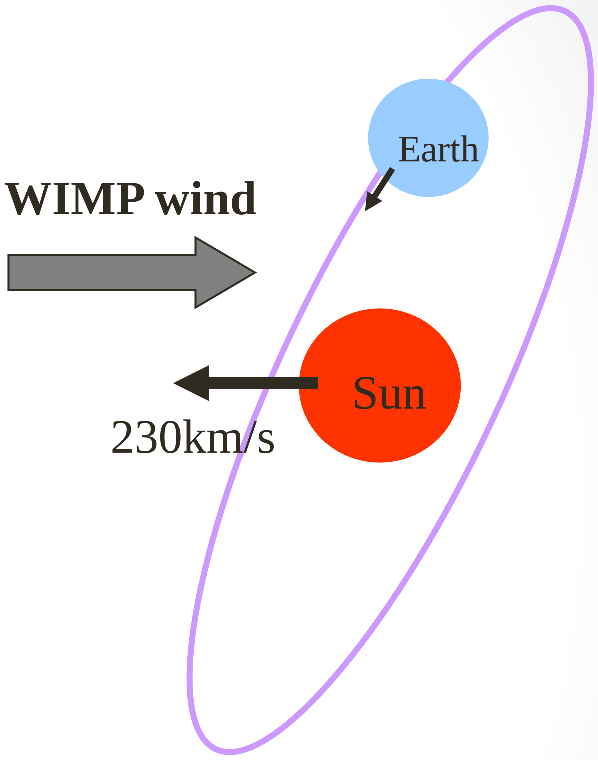
- Directional Dark Matter Searches
- The NEWS idea:
  a novel approach to directional detection of DM
- High Resolution Nuclear Emulsions: NIT
- Detection Principle
- NEWS R&D actvity – update on neutron bkg

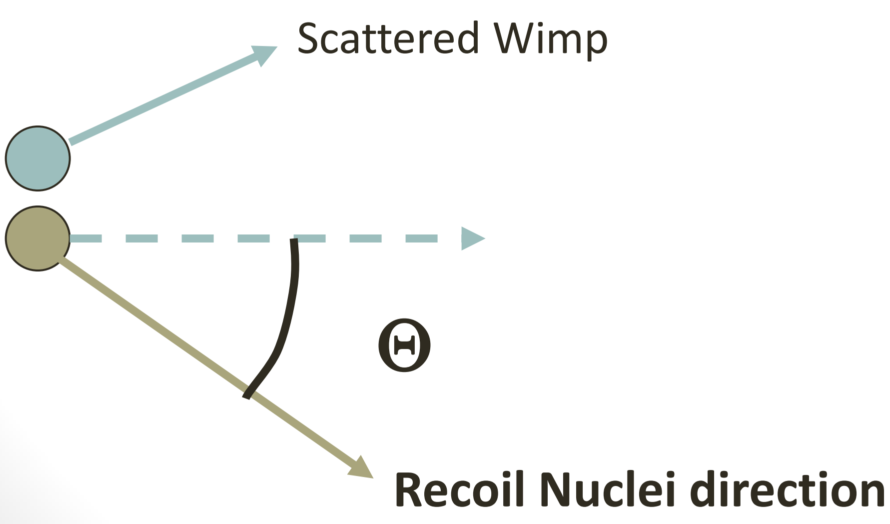
Directional Dark Matter Searches

Earth revolution gives seasonal modulation

Due to solar system movement in the galaxy, the WIMP Flux is expected to be not isotropic @earth.

A directional measurement would provide a strong signature and an unambiguous proof of the galactic origin of DM





WIMP cross-section with nuclei $\propto A^2$

Directional Dark Matter Searches

Use solid targets:

- Large detector mass
- Smaller recoil track lenght O(100 nm) → very high resolution tracking detector

Nuclear Emulsion based detector acting both as target and tracking device

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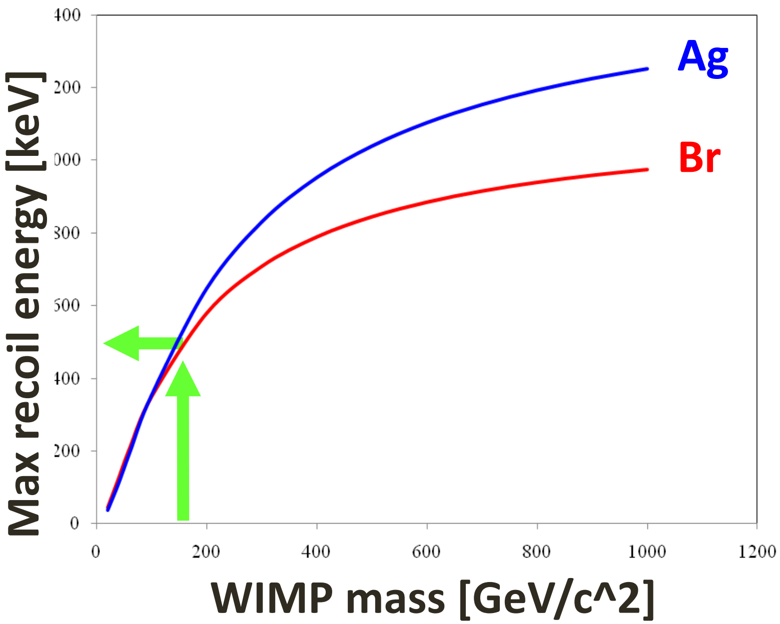
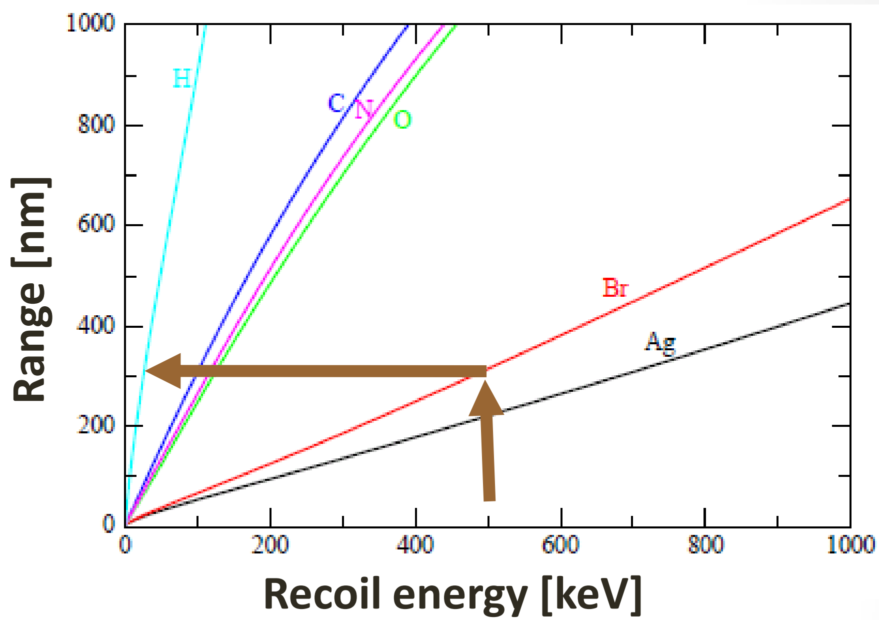
Nuclear Emulsion





WIMP velocity < 800 km/sec

Take e.g. $\mathbf{M_{WIMP}}$ **~ 150 GeV/c²**

Recoil energy < 500 keV

Br range < 300 nm

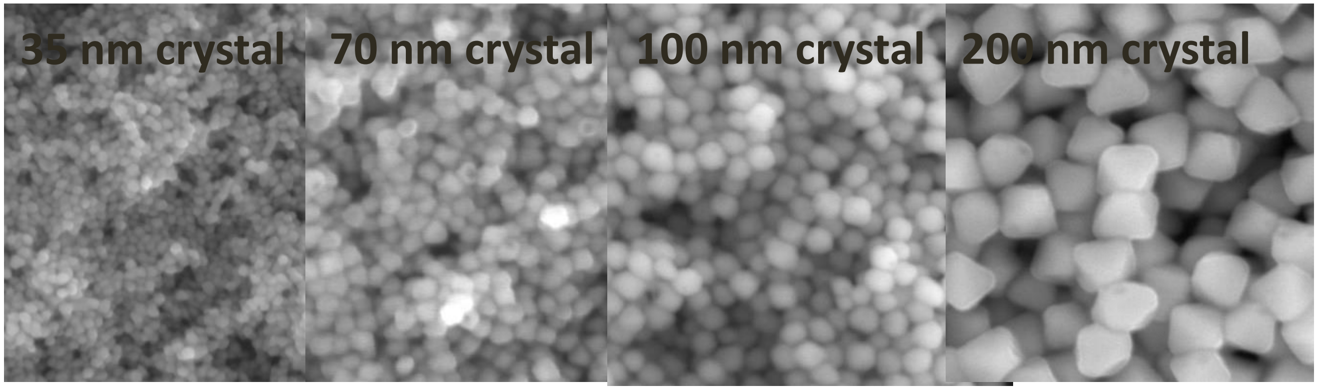
Lighter nuclei (longer range at same recoil energy)

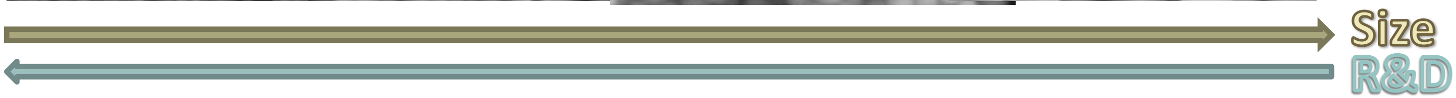
Sensitivity to low WIMP mass

OPERA emulsion films:

Silver grain size ~ 200 nm → too large to record nanometric nuclear recoils

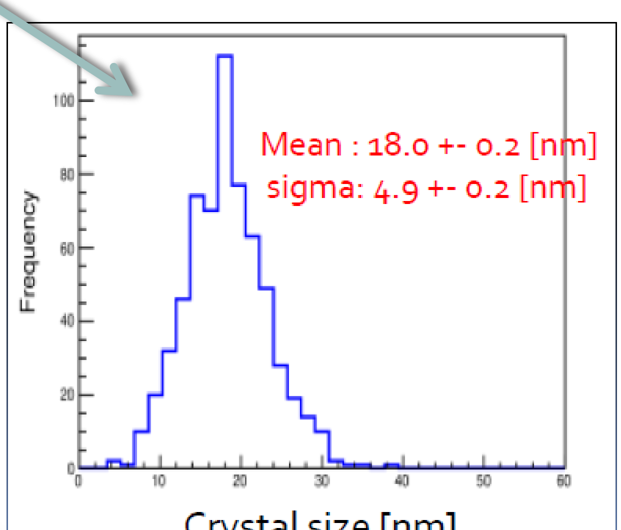
NIT emulsion films: Nano Imaging Trackers



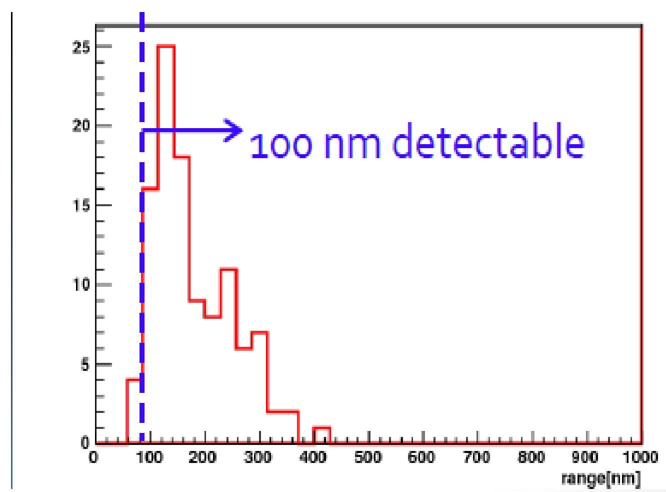


Natsume et al, NIM A575 (2007) 439

Recent developments

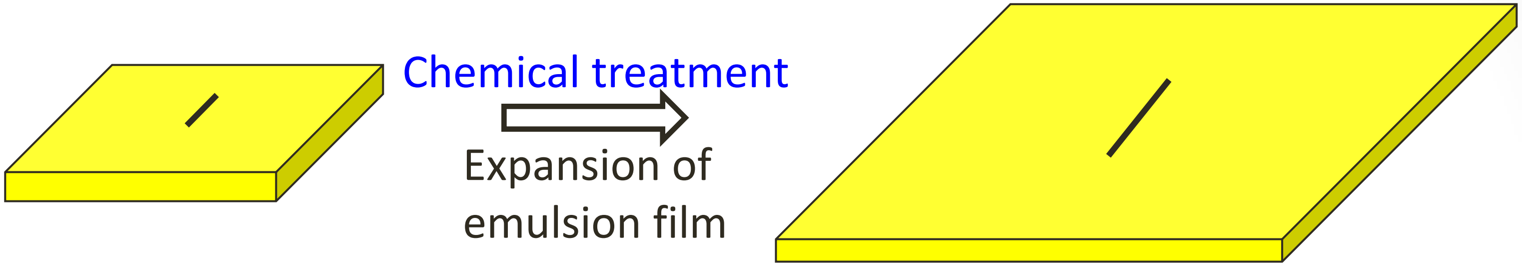


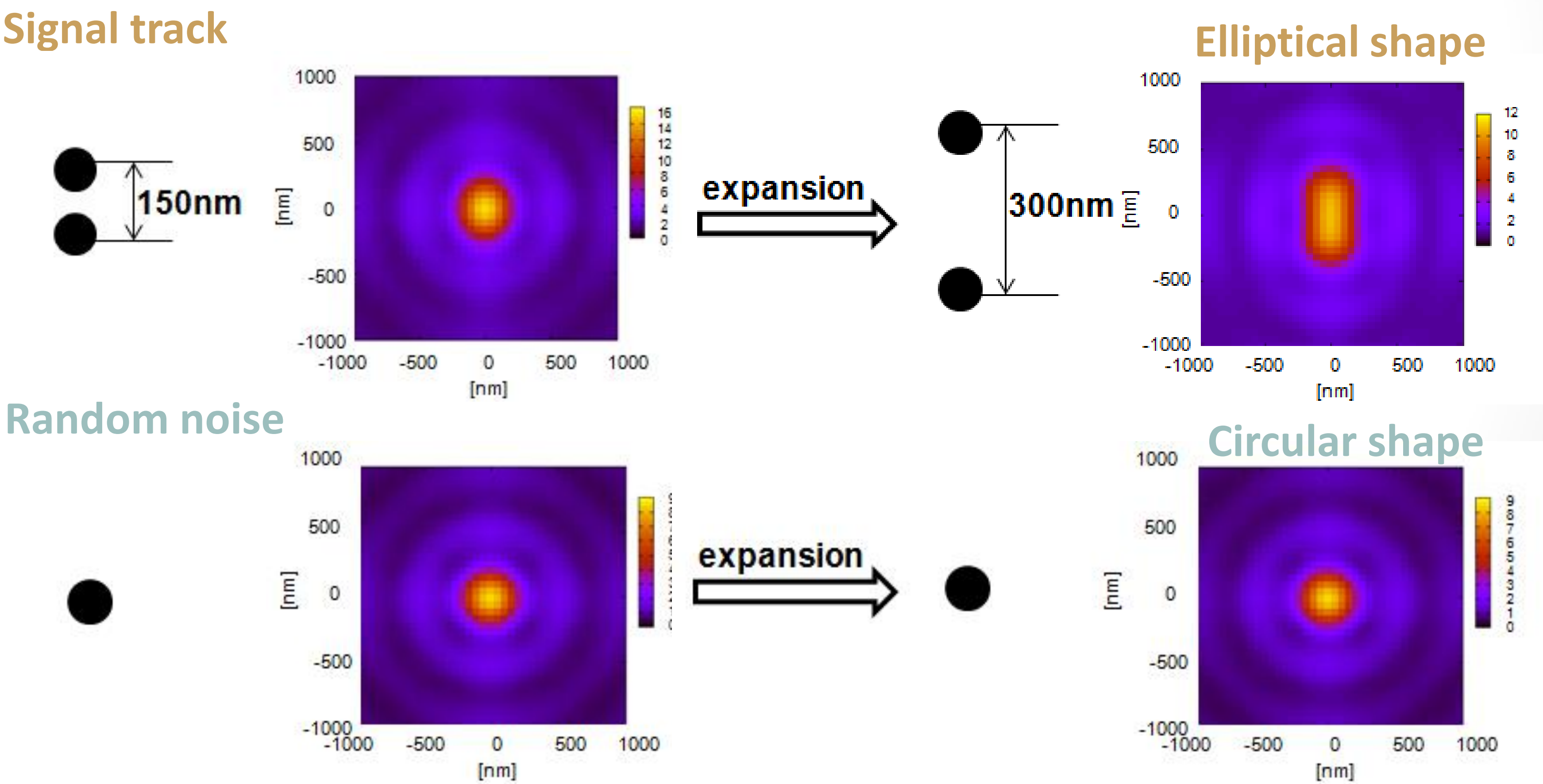
Range distribution [nm]



Concept of readout: film expansion

T. Naka et al., NIMA581 (2007) 761



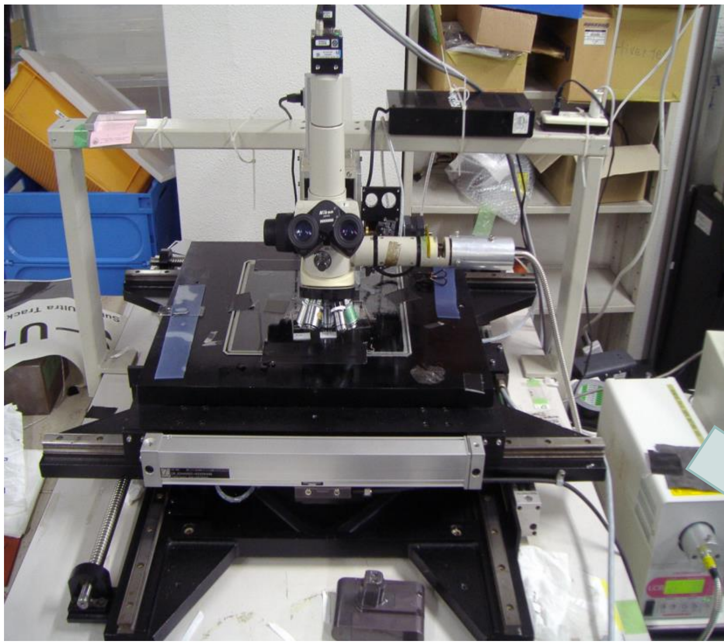


Concept of readout: scanning system

Two-step read-out:

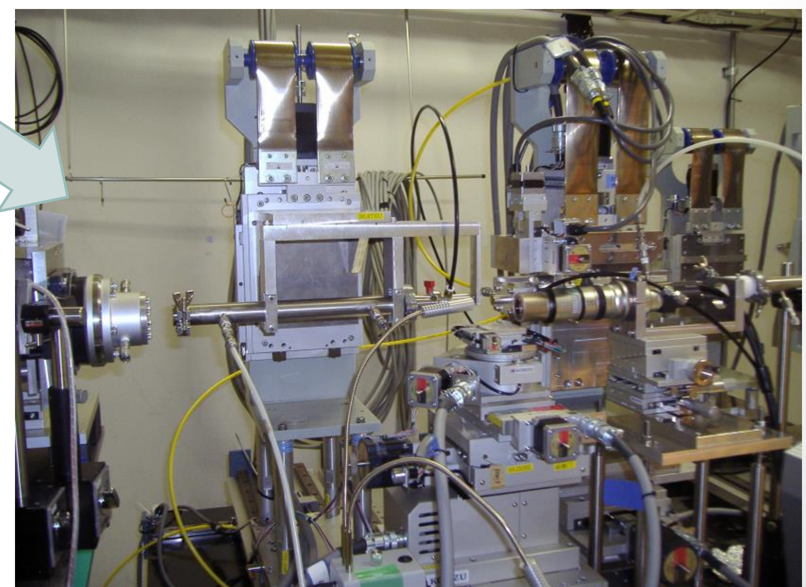
i. Pre-selection of candidate signal tracks with the optical microscopes

ii. Final confirmation of signal with X-ray microscopy



Optical Readout

Automatic selection of candidate signals by optical microscopy. Full area scan. Resolution 200 nm, scanning speed 20 cm^2/h

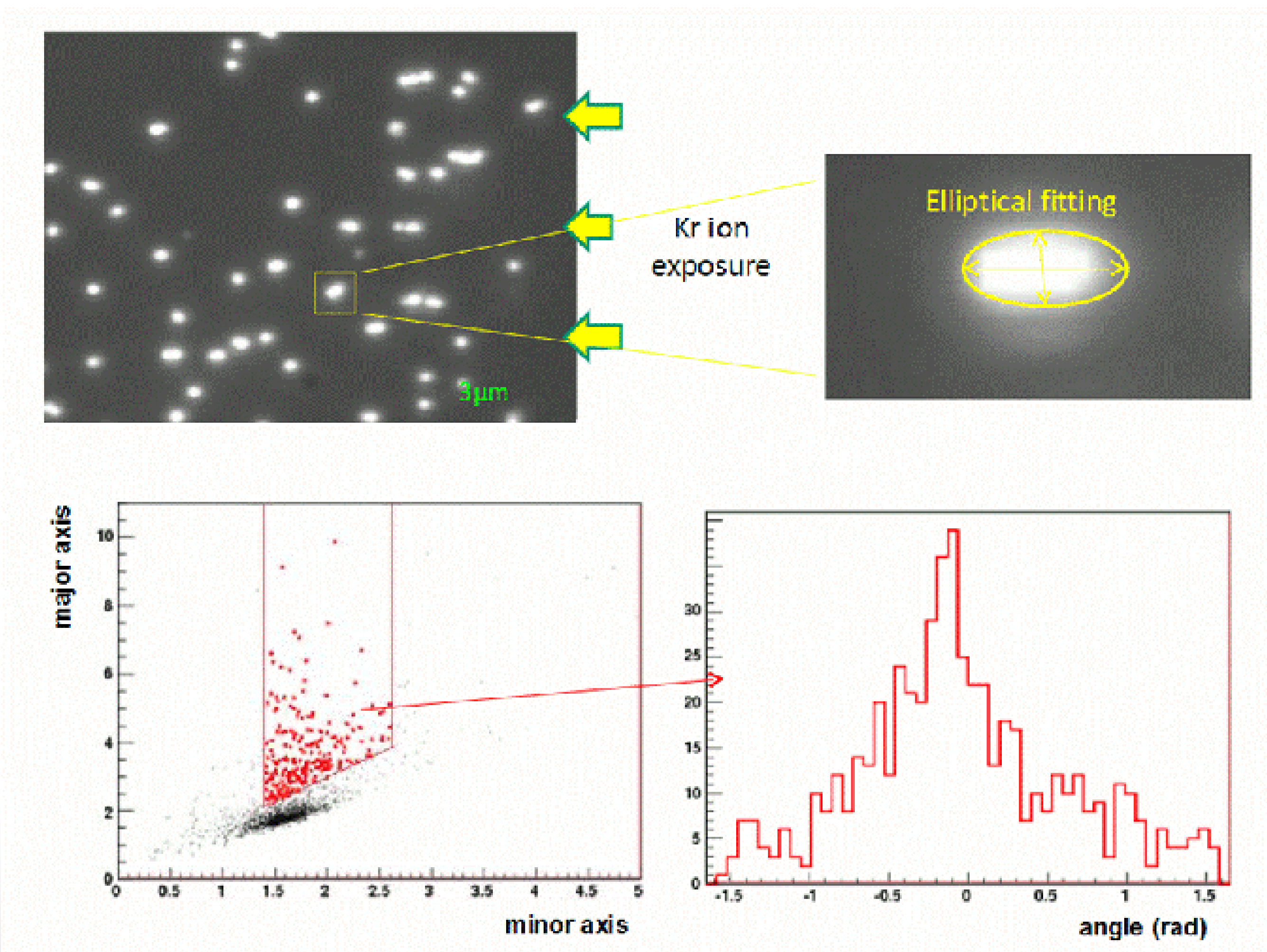


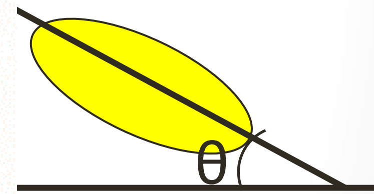
X-ray Readout

Pin-point check at X-ray microscope of candidate signals selected by optical readout . Resolution ~ 30 nm

Concept of readout:
step I, shape recognition

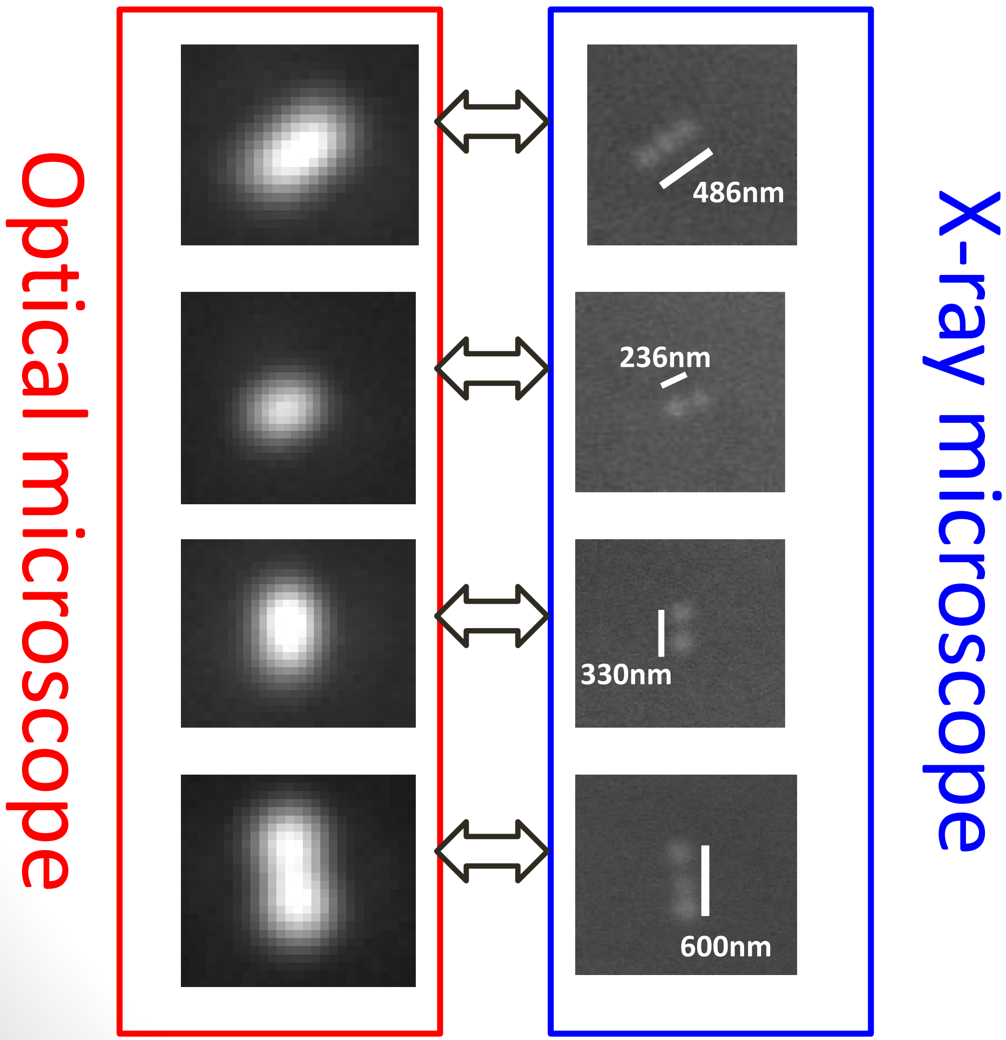
Test using 400 keV Kr ions





Direction detected!

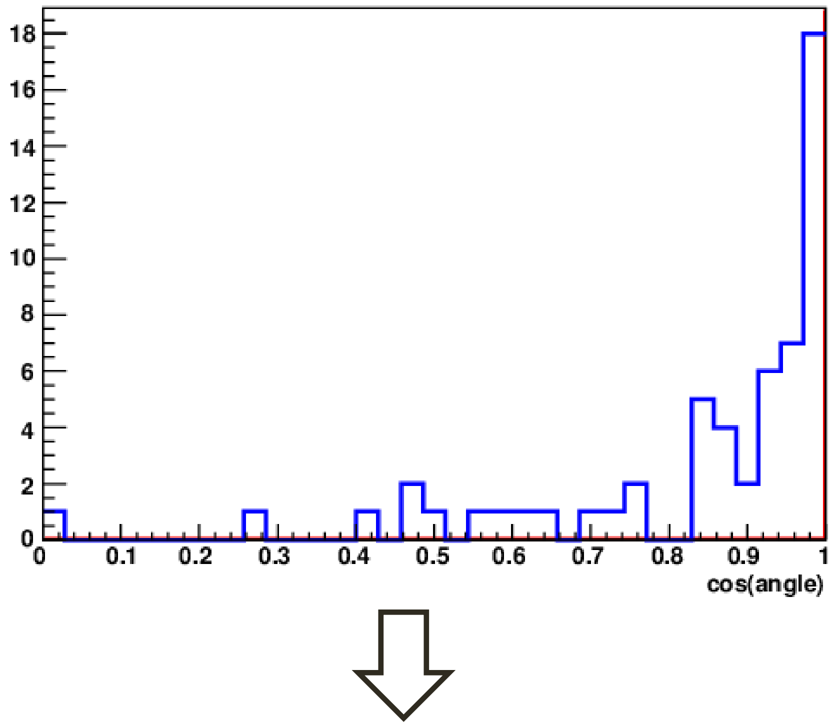
Concept of readout:
step II, X-ray microscopy



Matching of recoiled tracks between Optical and X-ray microscope

Success rate of matching
572/579=99%

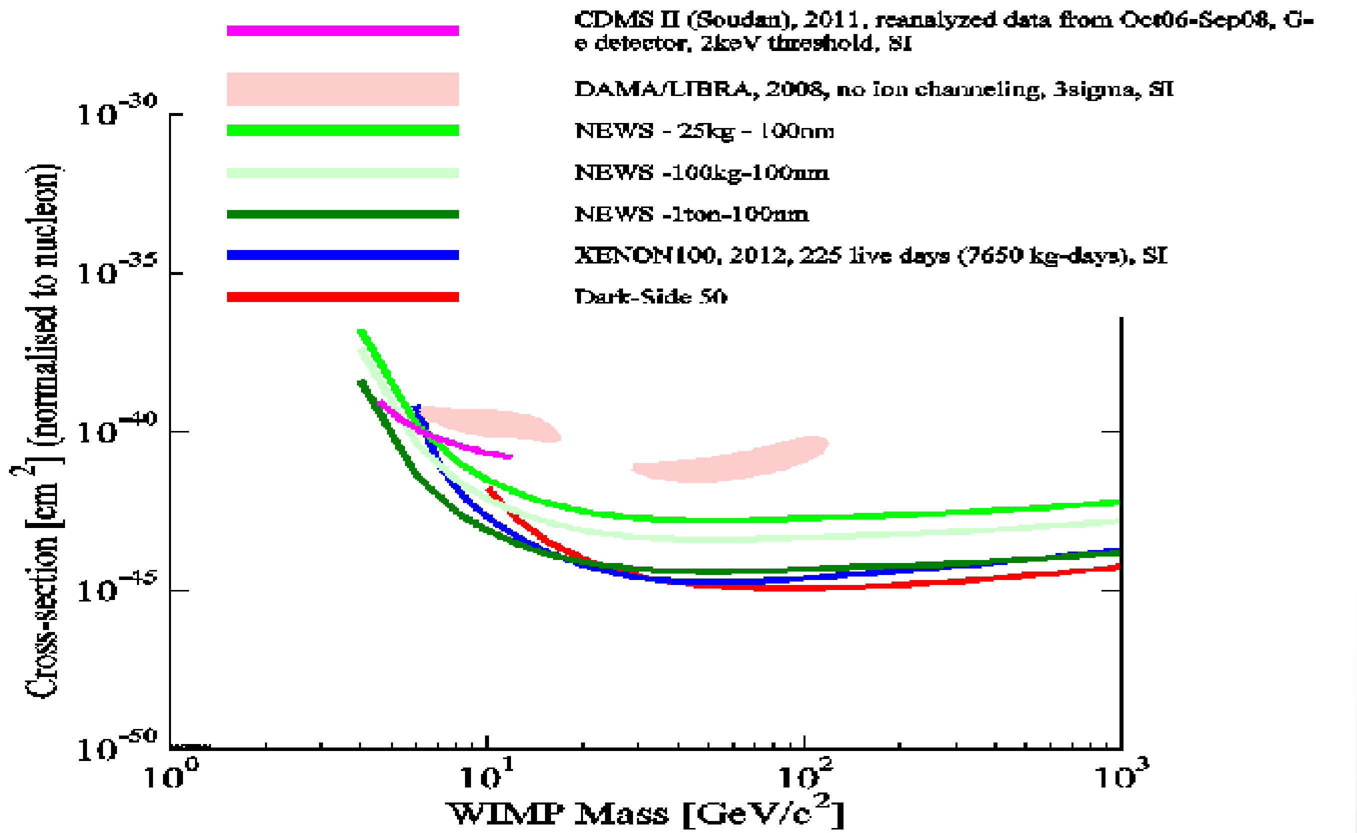
Concept of readout:
step II, X-ray microscopy



	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

- NIT technology assessment
- Optical read-out system
- X-ray read-out system
- Neutron background estimation
- Angular resolution measurement, Neutron test beam
- Full MC simulation

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For the other items, refer to G.De Lellis presentation @ WhatNext DM SeeVogh Meeting on 18 March 2014

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

Mass spectrometry measurements @ LNGS

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 radioactive contamination

Costituent	Mass fraction
AgBrI	0.813
Gelatin	0.1253
PVA	0.0617

Weighting by mass fractions (Polystyrene is negligible)

Total contamination from ^{238}U: 1.75 ppb (21.6 mBq/kg)

Total contamination from ^{232}Th: 1.18 ppb (4.8 mBq/Kg)

Intrinsic neutron background

1) n from spontaneous fission

$$R = A \times \psi \times n$$

A = activity (decay/s)
Ψ = fission probabiliy/decay
n = average number of neutrons/fission = (2.07 for ^{238}U)

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}

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

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

Parent	Daughter	Decay Mode	Energy [MeV]	Half Life
^{238}U	^{234}Th	α	**4.27**	4.47×10^{9} yr
^{234}Th	^{234}Pa	β	0.273	24.1 d
^{234}Pa	^{234}U	β	2.20	6.70 hr
^{234}U	^{230}Th	α	**4.86**	2.45×10^{5} yr
^{230}Th	^{226}Ra	α	**4.77**	7.54×10^{4} yr
^{226}Ra	^{222}Rn	α	**4.87**	1.60×10^{3} yr
^{222}Rn	^{218}Po	α	**5.59**	3.82 d
^{218}Po	^{214}Pb	α	**6.12**	3.10 min
^{214}Pb	^{214}Bi	β	1.02	26.8 min
^{214}Bi	^{214}Po	β	3.27	19.9 min
^{214}Po	^{210}Pb	α	**7.88**	0.164 ms
^{210}Pb	^{210}Bi	β	0.0635	22.3 yr
^{210}Bi	^{210}Po	β	1.43	5.01 d
^{210}Po	^{206}Pb	α	**5.41**	138 d
^{206}Pb				stable

Parent	Daughter	Decay Mode	Energy [MeV]	Half Life
^{232}Th	^{228}Ra	α	**4.08**	1.41×10^{10} yr
^{228}Ra	^{228}Ac	β	0.0459	5.75 yr
^{228}Ac	^{228}Th	β	2.12	6.25 hr
^{228}Th	^{224}Ra	α	**5.52**	1.91 yr
^{224}Ra	^{220}Rn	α	**5.79**	3.63 d
^{220}Rn	^{216}Po	α	**6.40**	55.6 s
^{216}Po	^{212}Pb	α	**6.91**	0.145 s
^{212}Pb	^{212}Bi	β	0.570	10.6 hr
^{212}Bi	^{212}Po	β 64.06%	2.25	60.6 min
	^{208}Tl	α 35.94%	**6.21**	
^{212}Po	^{208}Pb	α	**8.96**	299 ns
^{208}Tl	^{208}Pb	β	5.00	3.05 min
^{208}Pb				stable

$$R = B \times y$$

Branching ratio

$$y = \sum_i y_i(E_i) \times \zeta_i$$

$$y_c = \sum_{i,j} \frac{w_j S_j^m(E_i)}{S_c^m(E_i)} y_{i,j}(E_i)$$

B: activity of the chain (***assuming secular equilibrium***)

Index i running over nuclides in the chain

Index j running over elements in the compound

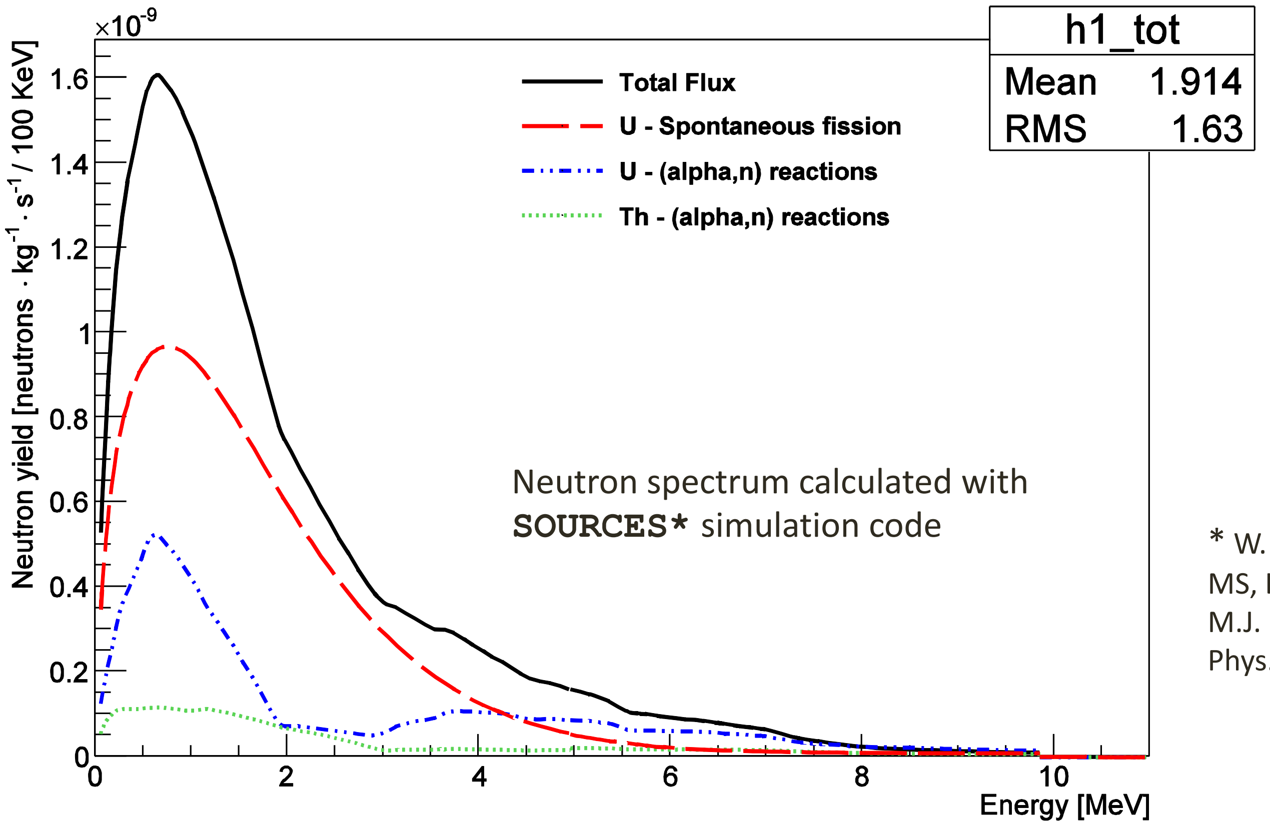
S: mass stopping power for alpha particles

w: mass fraction for each element

y: neutron yield for each element

y taken from *Heaton et al., NIMA276 (1989) 529*

Intrinsic neutron background



Neutron spectrum calculated with **SOURCES*** simulation code

* W. Wilson et al., LA-13639-MS, Los Alamos (1999); M.J. Carson et al., Astroparticle Phys. 21 (2004) 667

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

Other neutron sources

- Cosmic muon-induced neutrons

Under evaluation; in underground sites is expected be less that the one from intrinsic radioactive contamination (preliminary estimation)

- Neutrons from enviromental radioactivity

Should be reduced to a negligible level with appropriate shielding; under study.