NEWS:
Nuclear Emulsions for Wimp Search

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ON BEHALF OF THE ***NEWS COLLABORATION***

OutLine

- Directional Dark Matter Searches
- The NEWS idea:

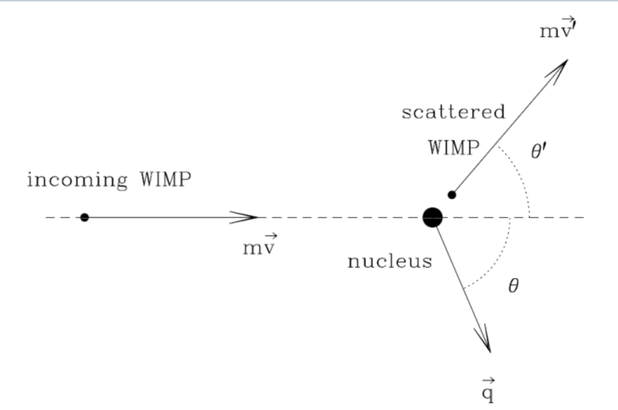
  a novel approach to ***directional*** detection of DM
- Experimental Concept
- Expected Background
- Experimental Set-up
- Schedule of the project and Physics Reach

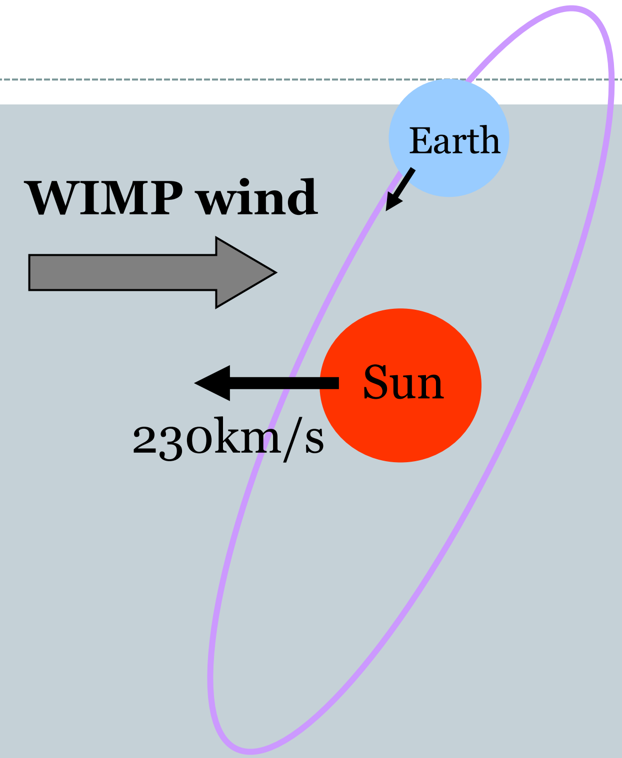
Directional DM searches

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





D. N. Spergel, Phys. Rev. D37 (1988)

WIMP cross-section with nuclei ∝ A^2

Directional DM searches

Depending on the unknown WIMP-nucleon cross section, directional detection may be used to : exclude Dark Matter, discover galactic Dark Matter with a high significance or constrain WIMP and halo properties.

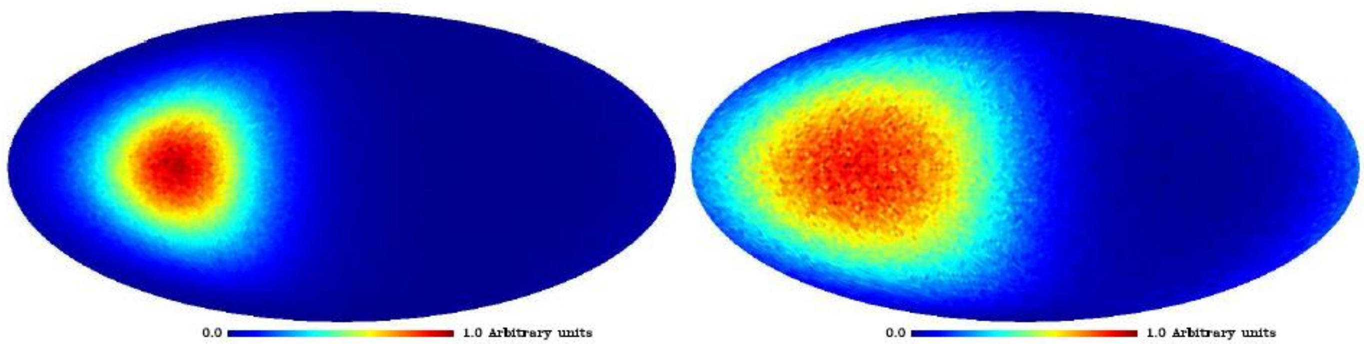


Figure 1. (Left) : WIMP flux for an isothermal spherical halo. (Right) WIMP-induced recoil distribution. Recoils maps are produced for a ^{19}F target, a 100 GeV.c^{-2} WIMP and considering recoil energies in the range 5 keV $\leq E_R \leq$ 50 keV. Figures extracted from [12].

F. Mayet, J.Phys.Conf.Ser. 469 (2013) 012013

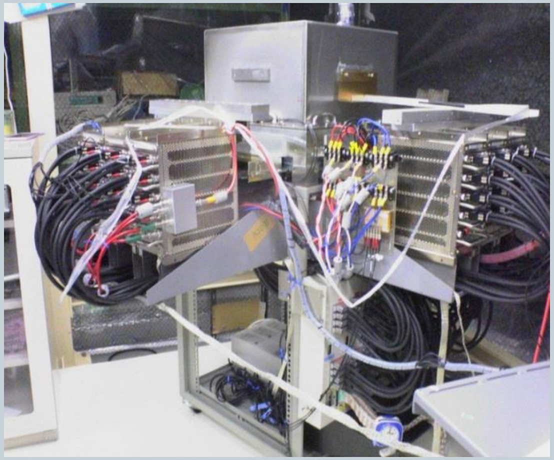
Directional DM searches

Current approach:

low pressure gaseous detector

- Targets: CF_4, CF_4+CS_2, $CF_4 + CHF_3$
- Recoil track length O(mm)
- Small achievable detector mass due to the low gas density

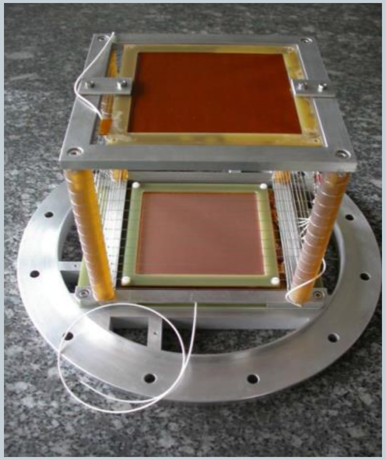
⇒Sensitivity limited to spin-dependent interaction



NEWAGE@ Japan

DM-TPC@ USA

DRIFT @ UK



MIMAC@ France

The NEWS idea

Use solid target:

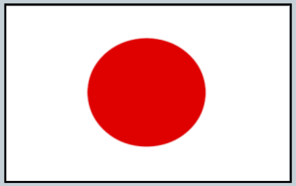
- Large detector mass
- Smaller recoil track lenght O(100 nm)

→ very high resolution tracking detector

Nuclear Emulsion based detector acting both as target and tracking device

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

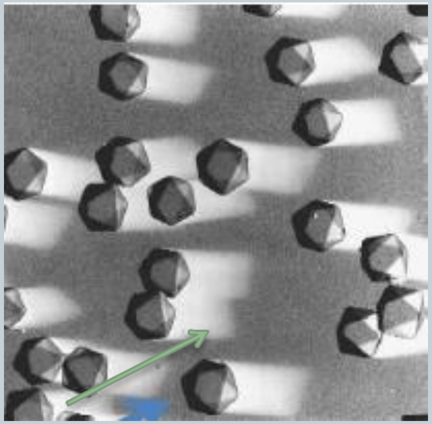
Japan
- **Nagoya University**
- **Chiba University**



Russia
- **JINR Dubna**
- **Moscow State University**
- **Lebedev Physical Institute**

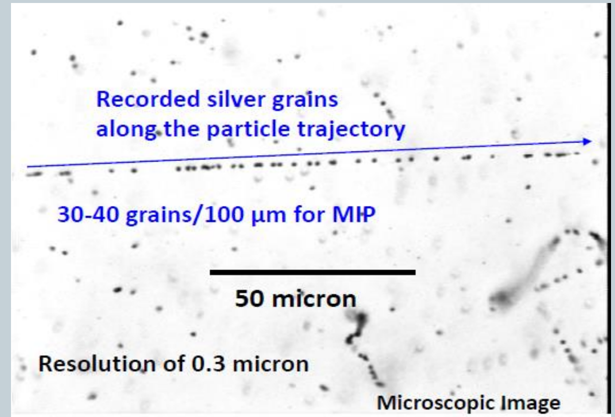
Turkey
- **METU, Ankara**

Nuclear Emulsion



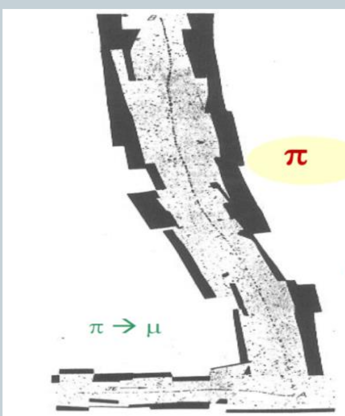
After the passage of charged particles through the emulsion, a **latent image** is produced.

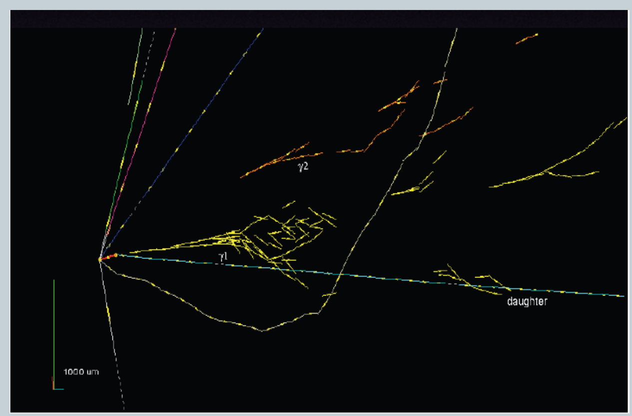
The emulsion chemical development makes Ag grains visible with an **optical microscope**



AgBr crystal size 0.2-0.3 μm

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**) (see Komatsu-san's and Di Crescenzo's talks)





Nuclear Emulsion as Target for WIMPs

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

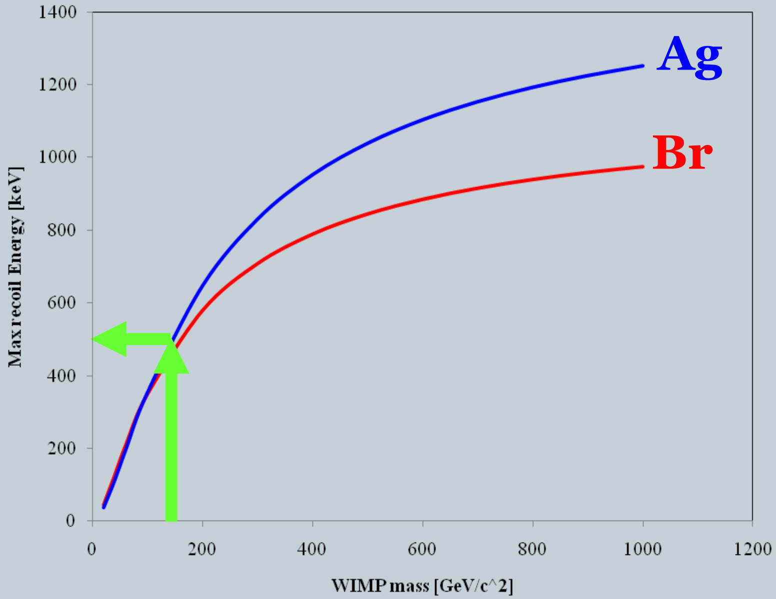
(a) Constituents of nuclear emulsion

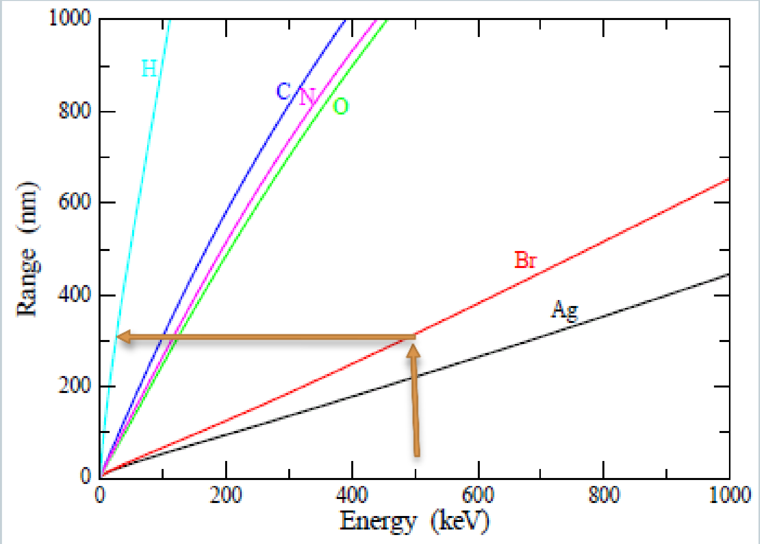
Element	Mass Fraction	Atomic Fraction
Ag	0.44	0.12
Br	0.32	0.12
I	0.019	0.003
C	0.101	0.172
O	0.074	0.129
N	0.027	0.057
H	0.016	0.396
S	0.003	0.003

(b) Elemental composition

A WIMP with a mass in the GeV-TeV range has a mean momentum of few tens of MeV and the energy transferred to the scattered nucleus of the target is O (100 KeV)

Nuclear Emulsion as Target for WIMPs

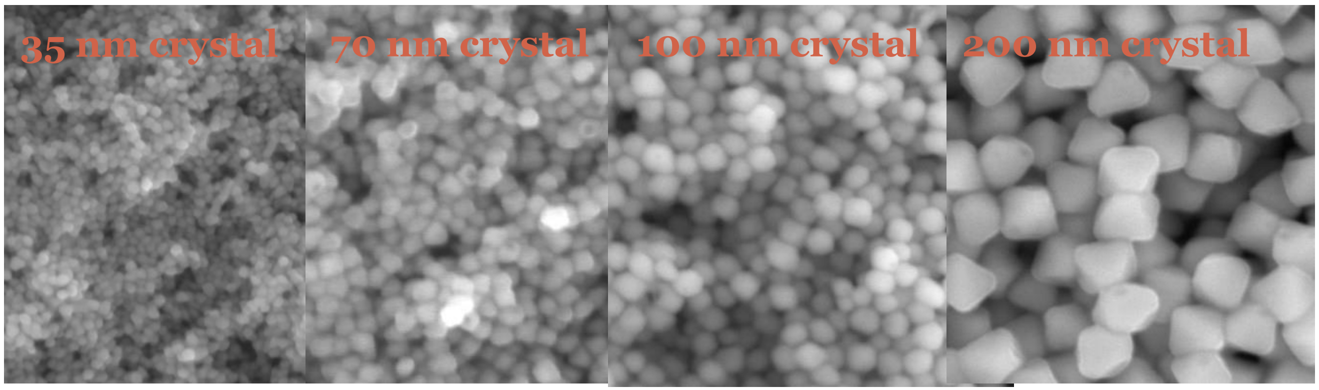




Take e.g. **M_{WIMP} ~ 150 GeV/c²** (**v_W** < 800 km/sec) → **Recoil energy < 500 keV**
→ **Br range < <u>300 nm</u>**

OPERA emulsion films:
Silver grain size ~200 nm → too large to record nanometric nuclear recoils

Nano Imaging Tracker: NIT

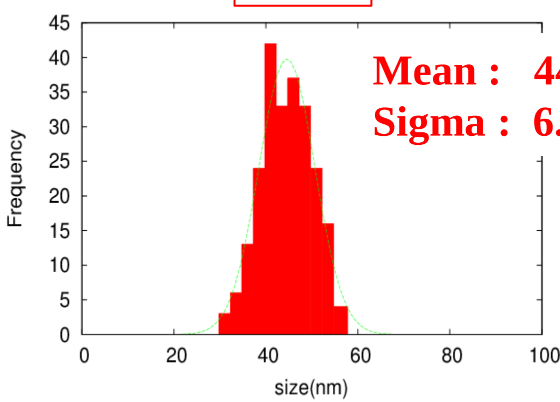


Natsume et al, NIM A575 (2007) 439

Size

R&D

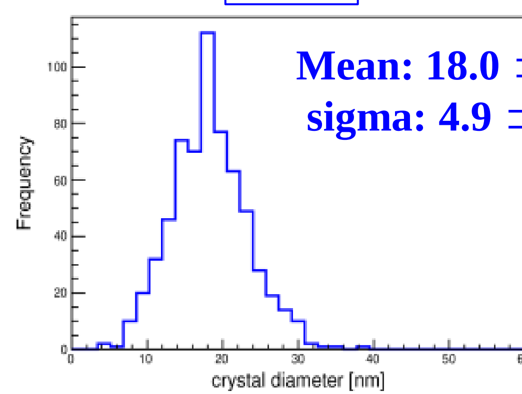
NIT



Mean : 44.6 ± 0.4 [nm]

Sigma : 6.1 ± 0. 3 [nm]

U-NIT



Mean: 18.0 ± 0.2 [nm]

sigma: 4.9 ± 0.2 [nm]

Read-out of submicrometric tracks

Current optical read-out systems:

- European Scanning System (ESS, Europe)
- Super-Ultra Track Selector (S-UTS, Japan)

Performances: 1 μm, 1mrad, O(100 cm^2/h)

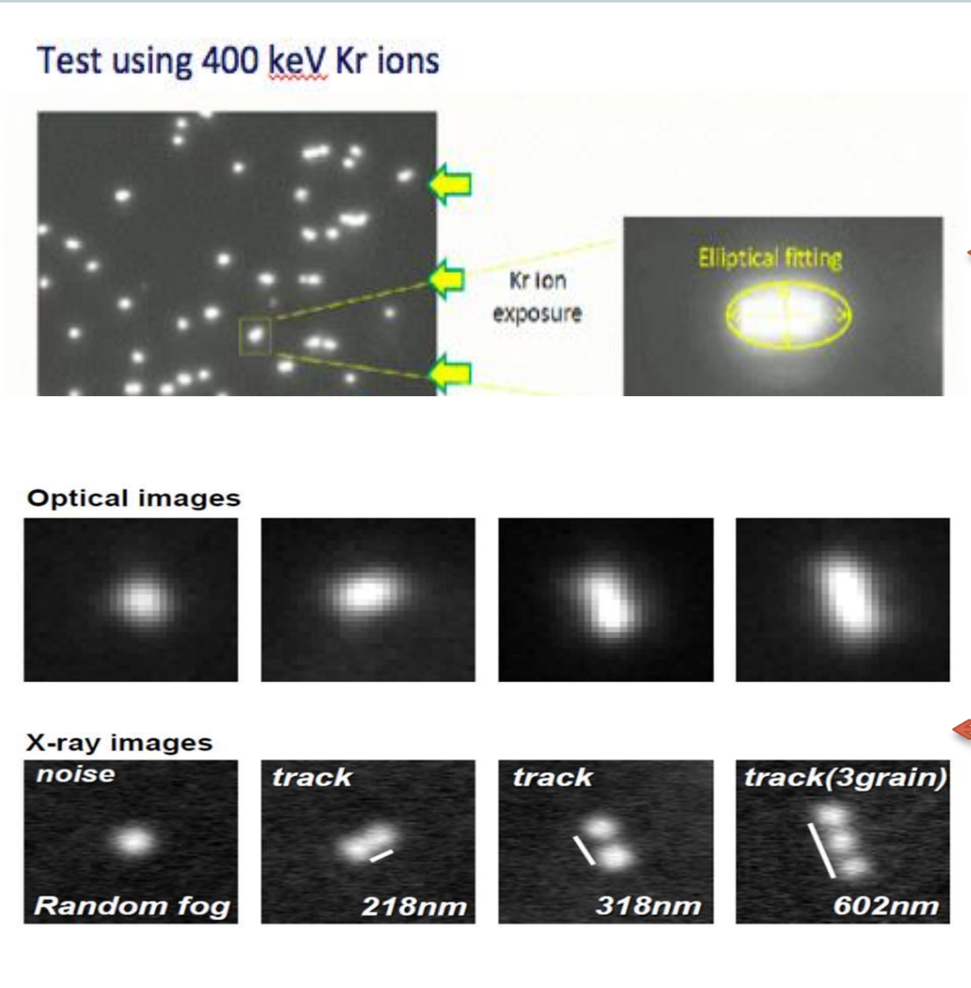
Not enough…

Two step read-out:

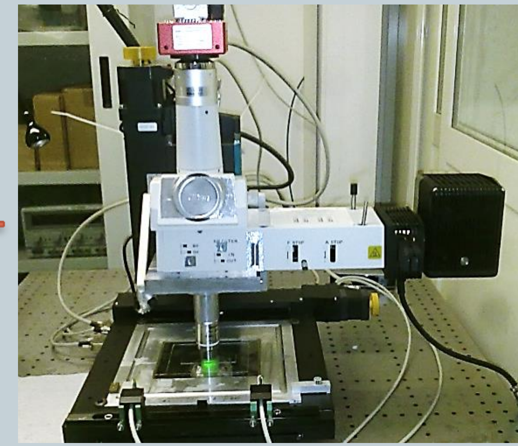
1. Signal preselection: fast scanning with (relatively) poor spatial resolution (200 nm).

2. Signal confirmation with slow, high resolution (50 nm) scanning systems (X-ray microscope, optical microscope with polarized light)

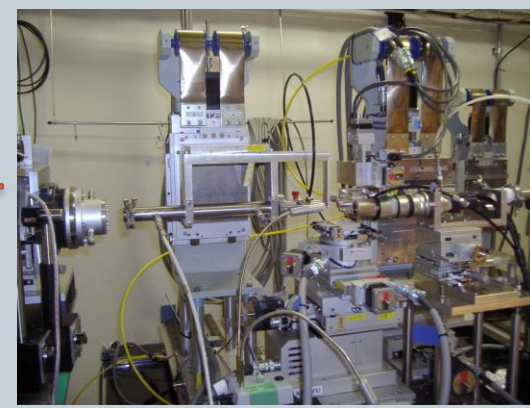
Read-out of submicrometric tracks



1) Signal preselection

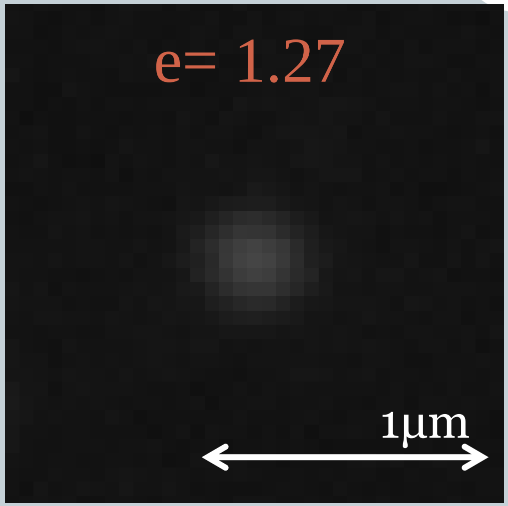


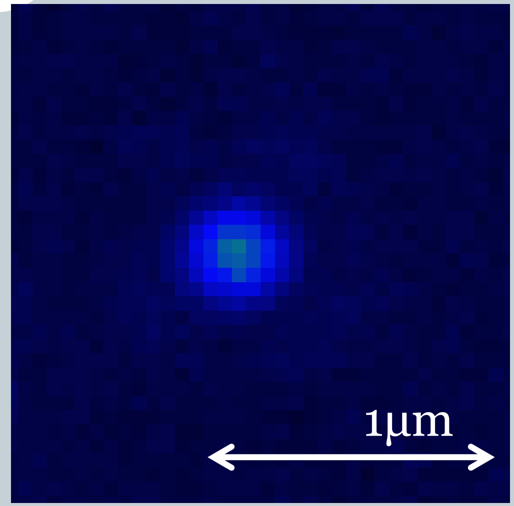
2) Signal confirmation



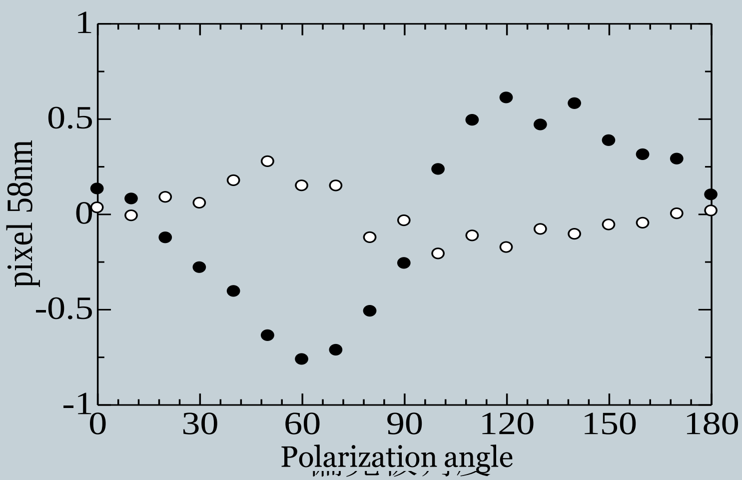
Read-out of submicrometric tracks

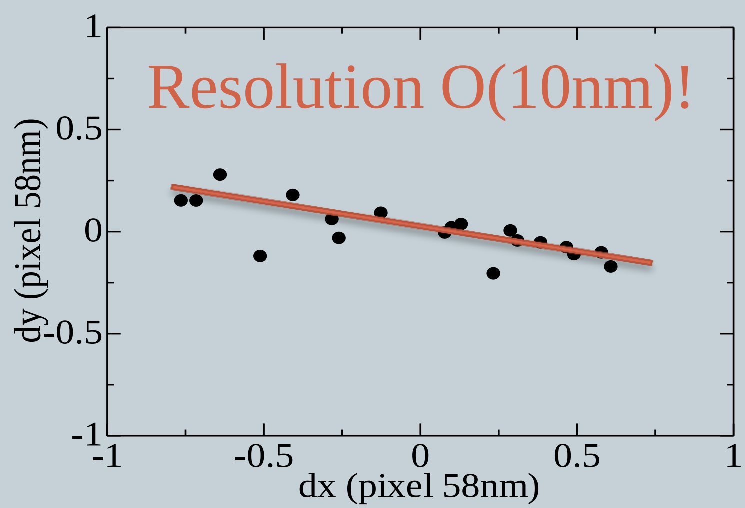
1) Signal preselection: optical microscope + shape analysis



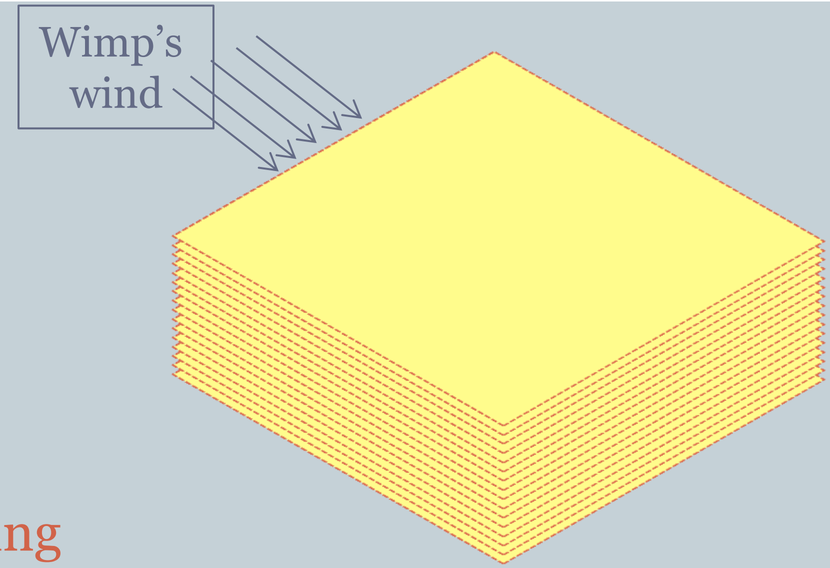


2) Signal confirmation: optical microscope + polarized light





Experimental concept



1. Target:

   1 kg: 100, 50 μm thick, NIT films

   25 x 25 x 0.5 cm^3

   + OPERA-like films

2. Equatorial telescope:

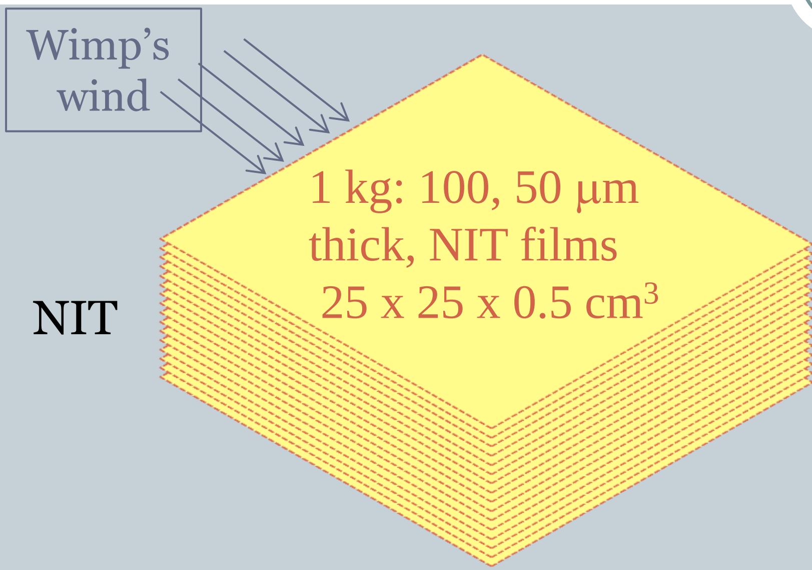
   absorbs the earth rotation thus keeping fixed the target orientation towards the Cygnus constellation

2. Background badget evaluation

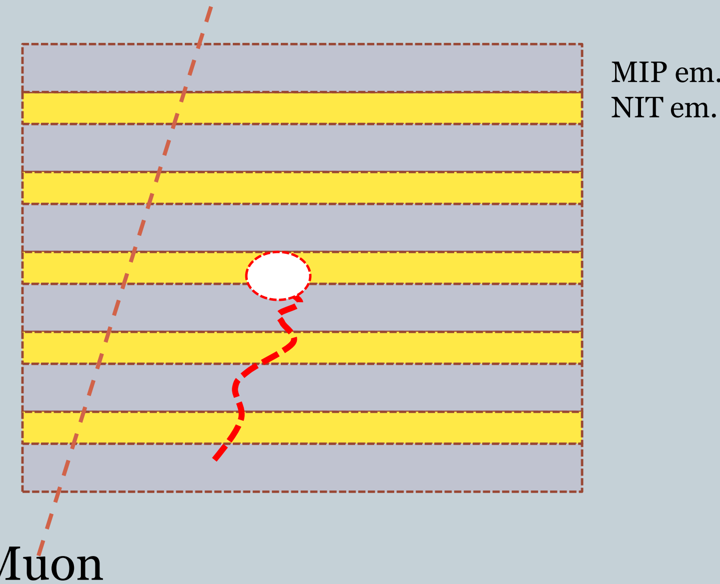
   signal rate 1 /kg/day << expected background

Target options

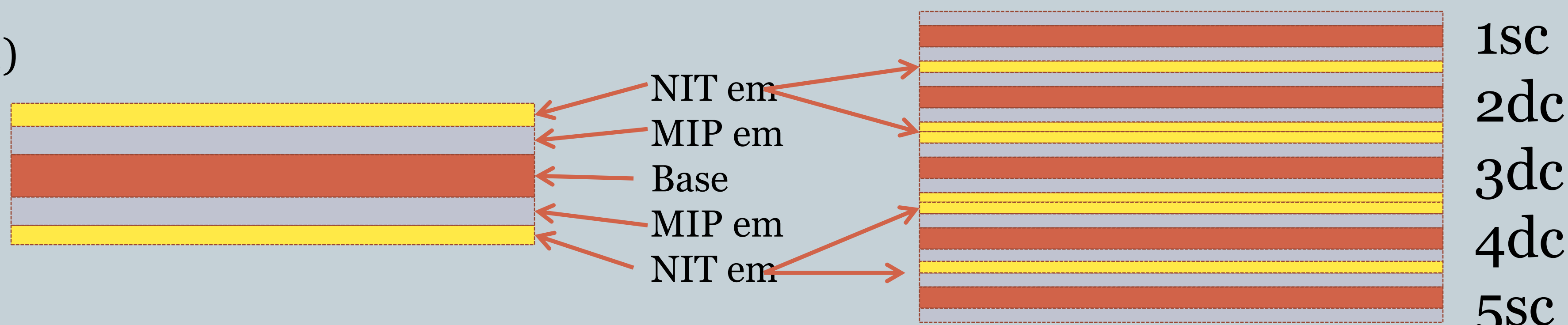
1)



2)



3)

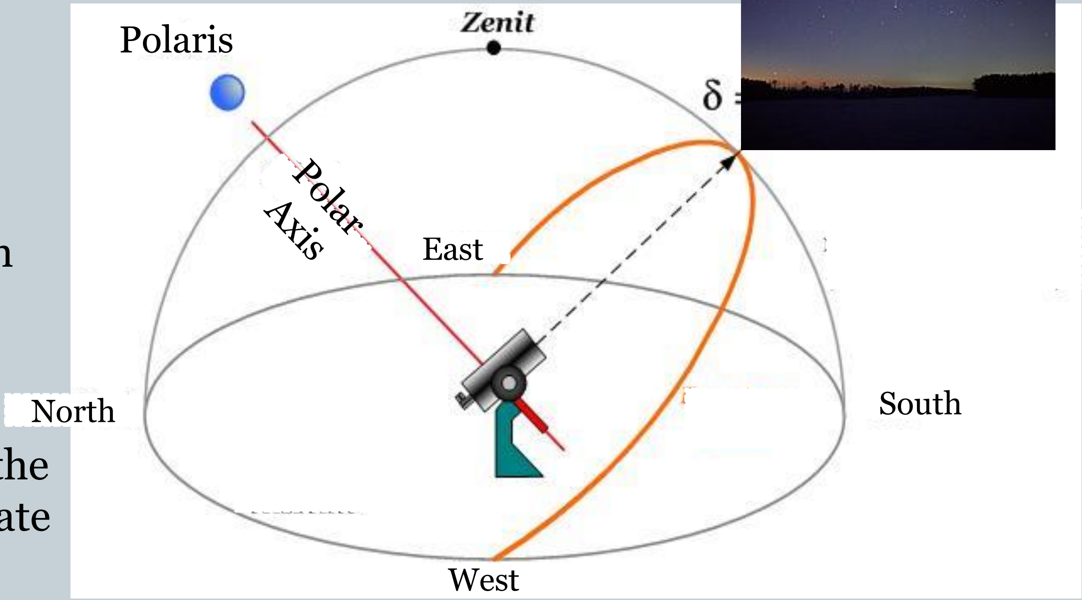


Equatorial Telescope

- Mechanics:

 2 motorized axes (Polar and Declination) equipped with precise encoders for position monitoring. (Final precision 1°)

- Surface Calibration
  1. Follow the position of a star in the Cygnus constallation; measure position parameters in order to apply corrections to mechanics and electronic system.
  2. Use throughout the whole day to study systematic effects.



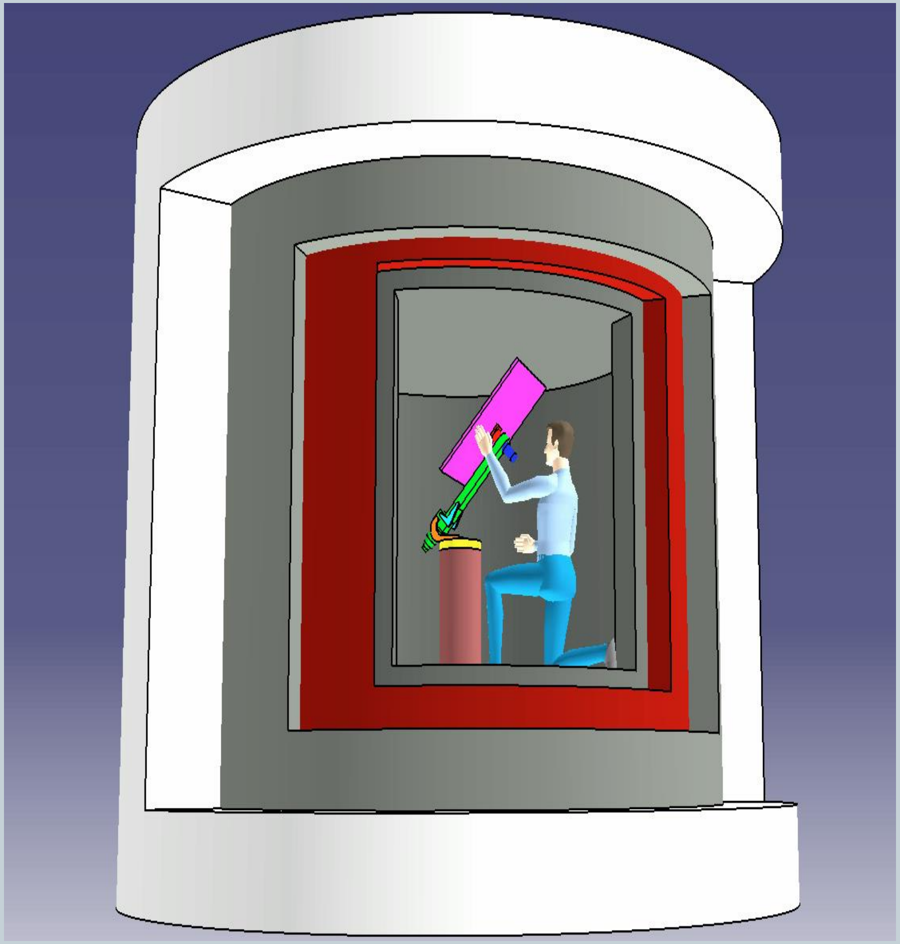
- Underground installation

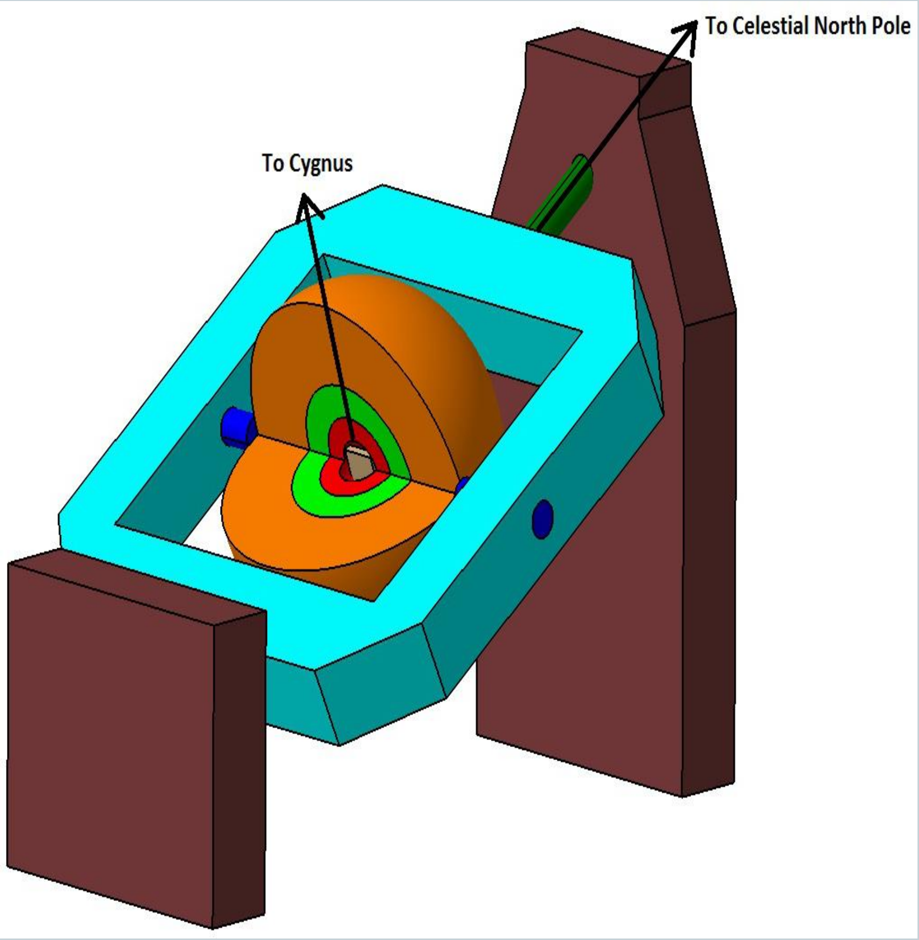
 Align the mount using existing high precision reference points.

- Materials

screening of all the materials used in the telescope is foreseen in order to evaluate their intrinsic radioactivity.

Equatorial Telescope

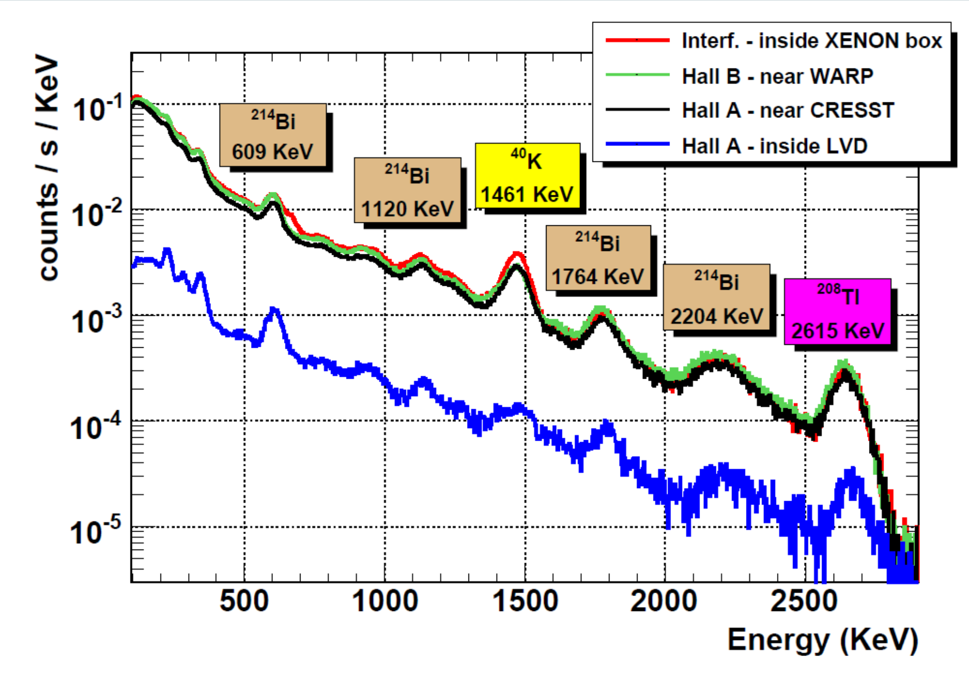




Expected Background

- Environmental radioactivity
- Radon and its progeny
- Cosmic rays
- Neutrons from natural fission, (a,n) reactions and from cosmic ray muon spallation and capture
- Radioimpurities in detector or shielding components

γ background



γ radiation emitted durinng the decay of natural radioativity

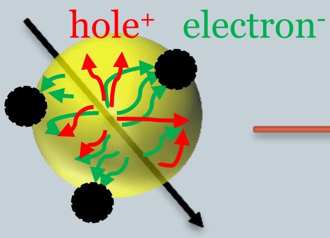
(^{238}U, ^{232}Th and its unstable daughters)

$$l = \lambda(E_\gamma) \ln f, \; f > 1$$

At 100 keV (2.615 MeV), attenuation by a factor $f = 10^5$ requires:

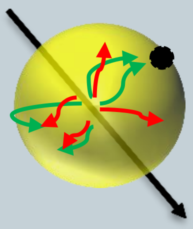
- 67(269) cm of H2O
- 2.8(34) cm of Cu
- 0.18(23) cm of Pb.

Electron rejection power



Signal event (recoiled nuclei)

- de/dx : 100~1000 keV/µm

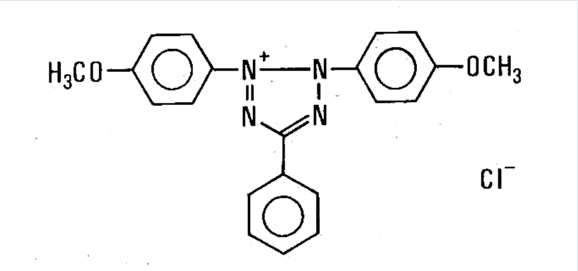


Background event (electron)

- de/dx : 1~10 keV/µm

A rejection power O(10^6) is needed:

- Chemical treatment (Tetrazolium-compounds)
- Cryogeny
- Discrimination in the read-out phase



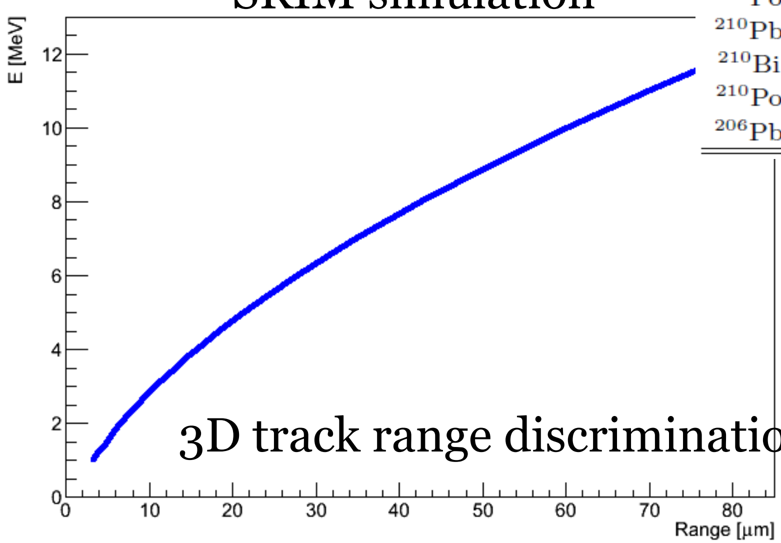
α particles

Sources: 238U, 232Th chains and 222Rn

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

SRIM simulation



3D track range discrimination

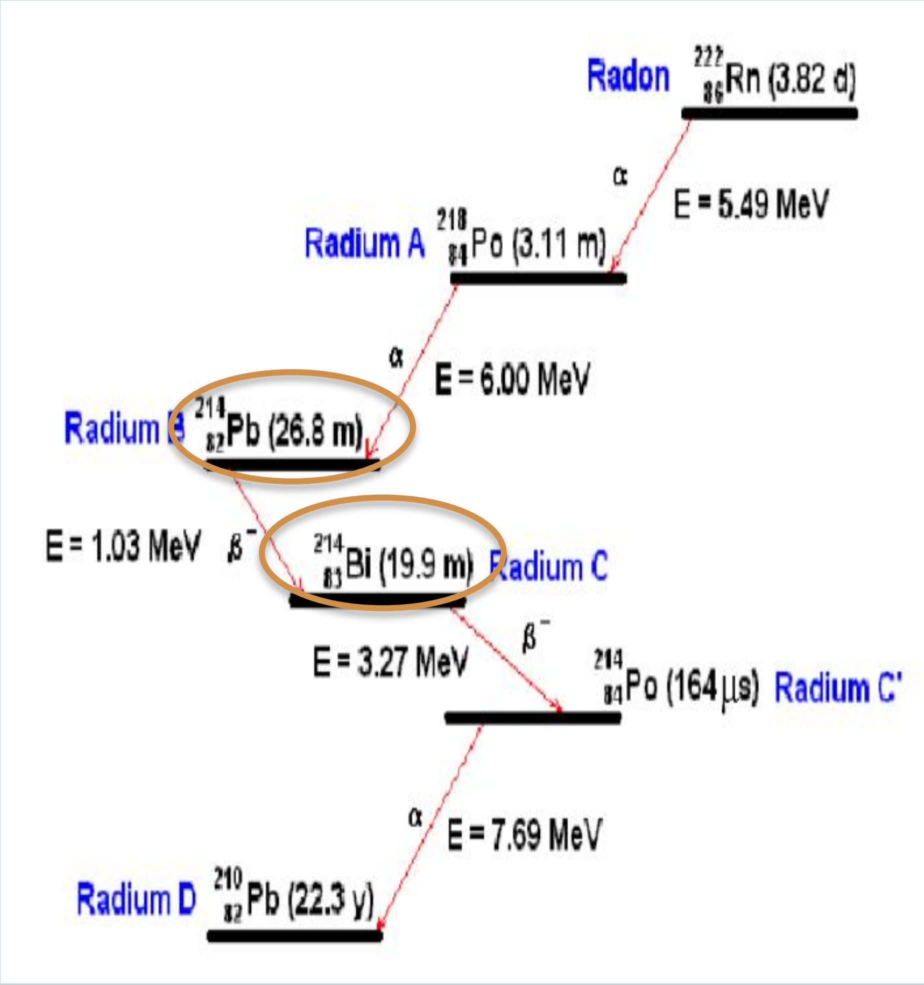
Neutron production throught (α,n) reactions

α particles

RADON:

The noble gas **^{222}Rn ($T_{1/2}$=3.8 d)**, a pure α-emitter. It is released by surface soil and is found in the atmosphere everywhere

The detector has to be kept sealed from air and flushed with HP N_2



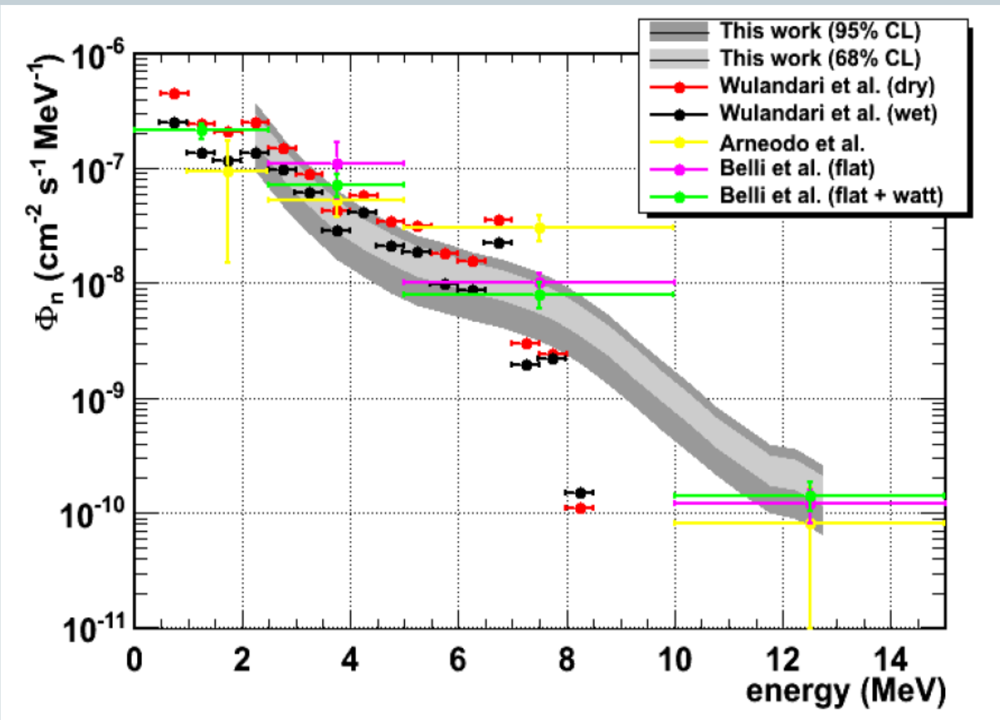
Neutrons

Neutrons contribute to the background of low-energy experiments in different ways: directly **through nuclear** recoil in the detector medium, and indirectly, through the **production of radio nuclides** inside the detector and its components (inelastic scattering of fast neutrons or radiative capture of slow neutrons can result in the emission of γ radiation).

Neutron sources:

- Energetic tertiary neutrons are produced by cosmic-ray muons in nuclear spallation reactions with the detector and laboratory walls;
- In high Z materials, often used in radiation shields, nuclear capture of negative muons results in emission of neutrons;
- Natural radioactivity has a neutron component through spontaneous fission and (α, n)-reactions.

Environmental neutron flux



$\Phi_n = 10^{-6}$ cm^{-2} s^{-1}MeV^{-1}

NIT 1 kg: 25 x 25 x 0.5 cm^3

~ 41000 n/MeV/y

Light materials are effective moderators for fast neutrons: 50 cm of polietilene (**PE, C2H4**) → reduction in the neutron flux of a factor O(10^4)

The opportunity to add a thin (1÷2 cm) layer of **Cadmium** to capture thermalised neutrons is under study.

Intrinsic neutron yield

The intrinsic emulsion radioactivity is responsible of an irreducible neutron yield through (α, n) and 238 U spontaneous fission reaction

Intrinsic radioactive contaminant contribution have been estimated @LNGS using:

1. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Chemistry Service)
2. γ-spectrometry with Ge detector @ STELLA Facility (SubTErranean Low Level Assay)

Nuclide	Contamination [10^{-9} g g^{-1}]	Activity [mBq kg^{-1}]
	AgBr-I	
^{232}Th	1.0	4.1
^{238}U	1.5	18.5
	Gelatin	
^{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

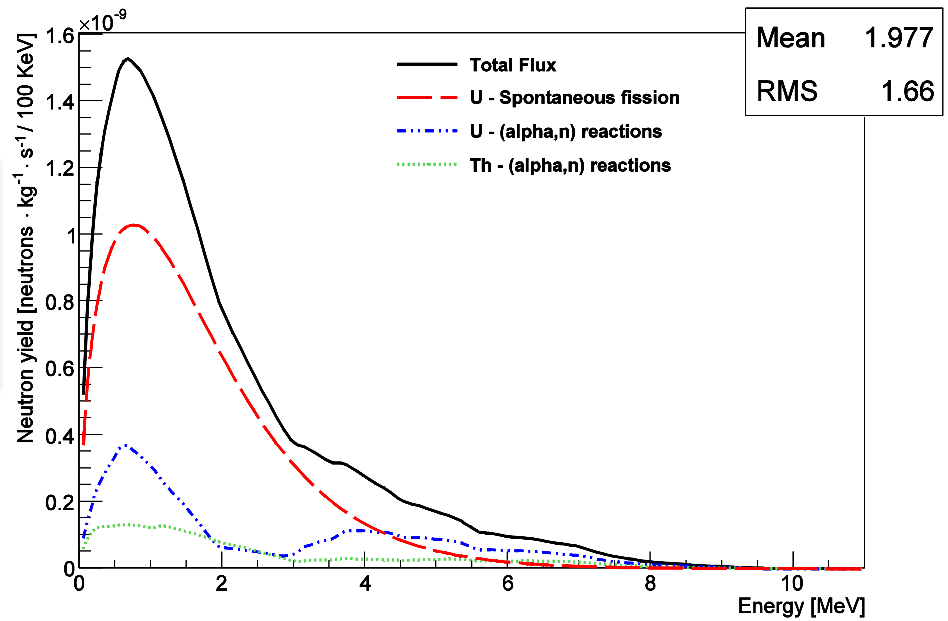
Table 4: Results obtained by ICP-MS in terms of contamination and activity for the different constituents of the nuclear emulsion. The estimated uncertainty is 30%. The upper limits on PVA are evaluated at 95% CL.

1) ICP-MS:
238U: 23±7 mBq/kg
232Th: 5.1±1.5 mBq/kg

Intrinsic neutron yield

Process	SOURCES simulation $[kg^{-1}\ y^{-1}]$	Semi-analytical calculation $[kg^{-1}\ y^{-1}]$
$(\alpha$, n) from ^{232}Th chain	0.12	0.10±0.03
$(\alpha$, n) from ^{238}U chain	0.27	0.26±0.08
Spontaneous fission	0.79	0.8±0.3
Total flux	1.18	1.2±0.4

F. Pupilli et al. , *Intrinsic neutron background of nuclear emulsions for directional Dark Matter searches*, to be submitted to Astrophysical Journal



Intrinsic neutron yield

GEANT4 simulation:

20.4% of neutrons interact producing nuclear (56%), proton (44%) and α (0.2%) recoils

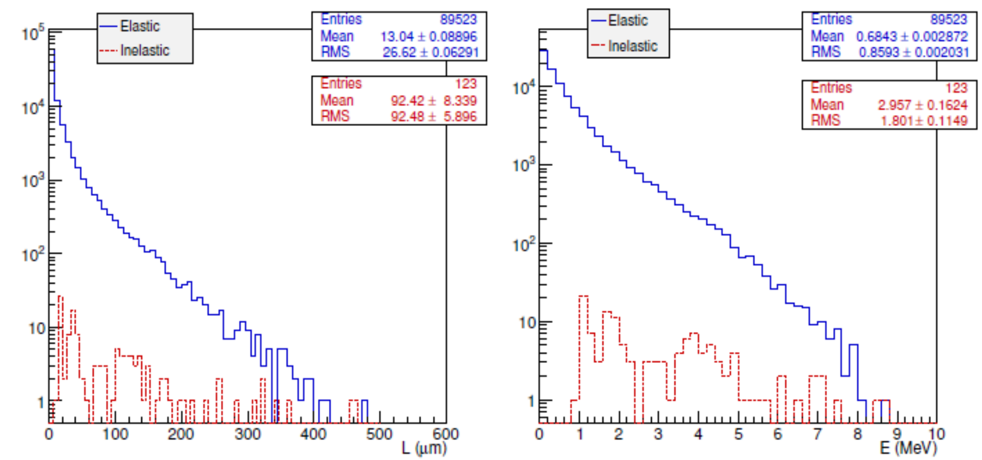


Figure 2: Track length (left) and energy spectrum (right) for proton recoils produced by elastic (blue curve) and inelastic (red curve) processes.

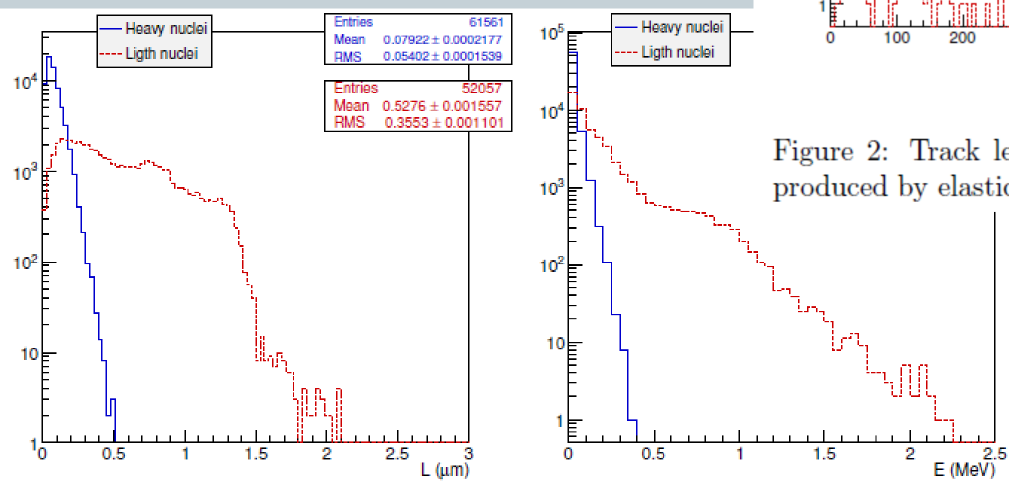


Figure 3: Track length (left) and energy spectrum (right) for heavy (blue curve) and light (red curve) nuclei.

Intrinsic neutron yield

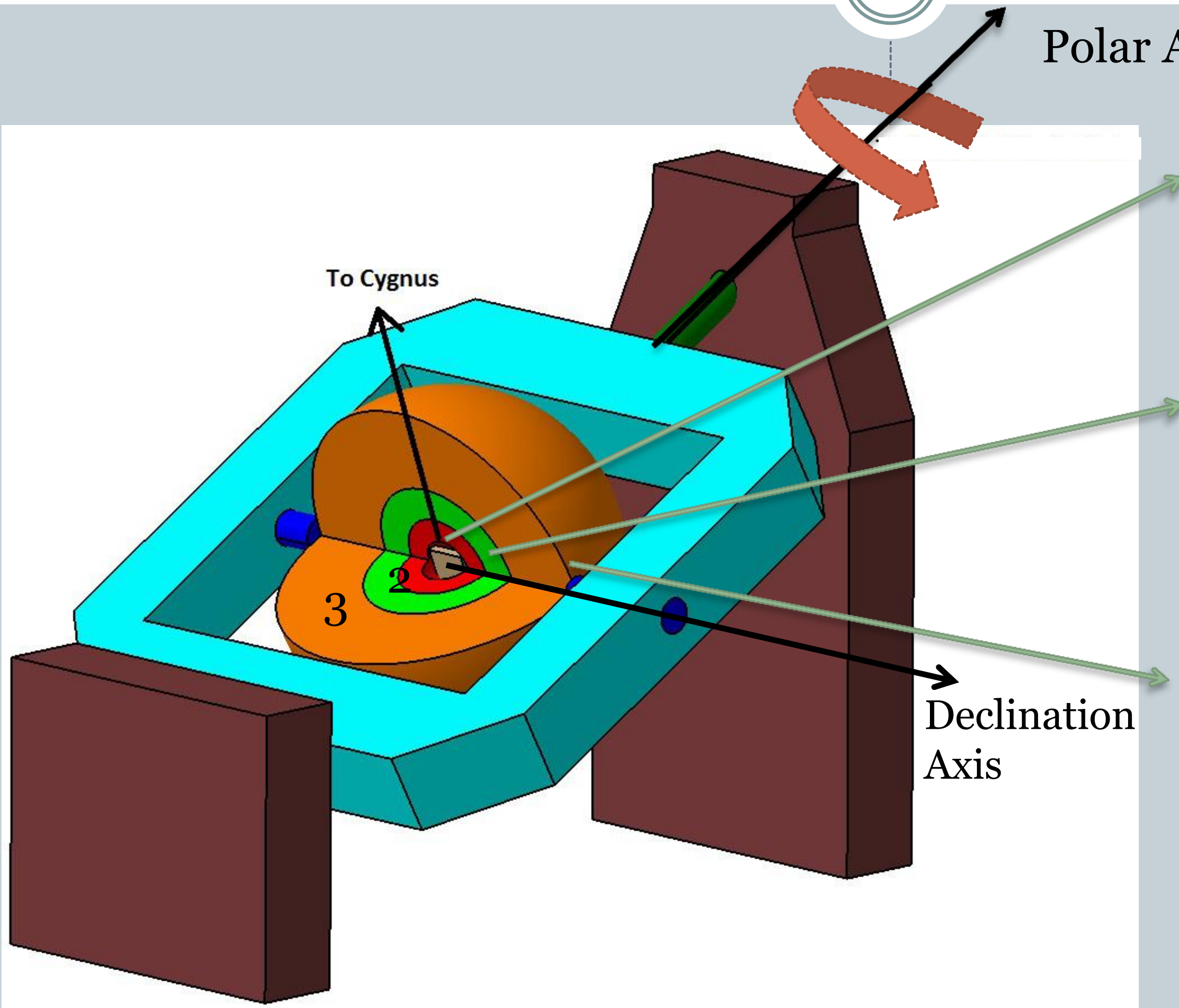
Threshold [nm]	Fraction
50	0.100
100	0.075
150	0.060
200	0.052

Table 6: Fraction of detectable neutron-induced recoils as a function of the read-out threshold.

- 5%÷10% of the intrinsic neutron flux contributes to the background
- A further reduction of 70% can be achieved exploiting the directionality information ($-1 < \Phi < 1$)

→ 0.02 ÷ 0.03 n/year/Kg

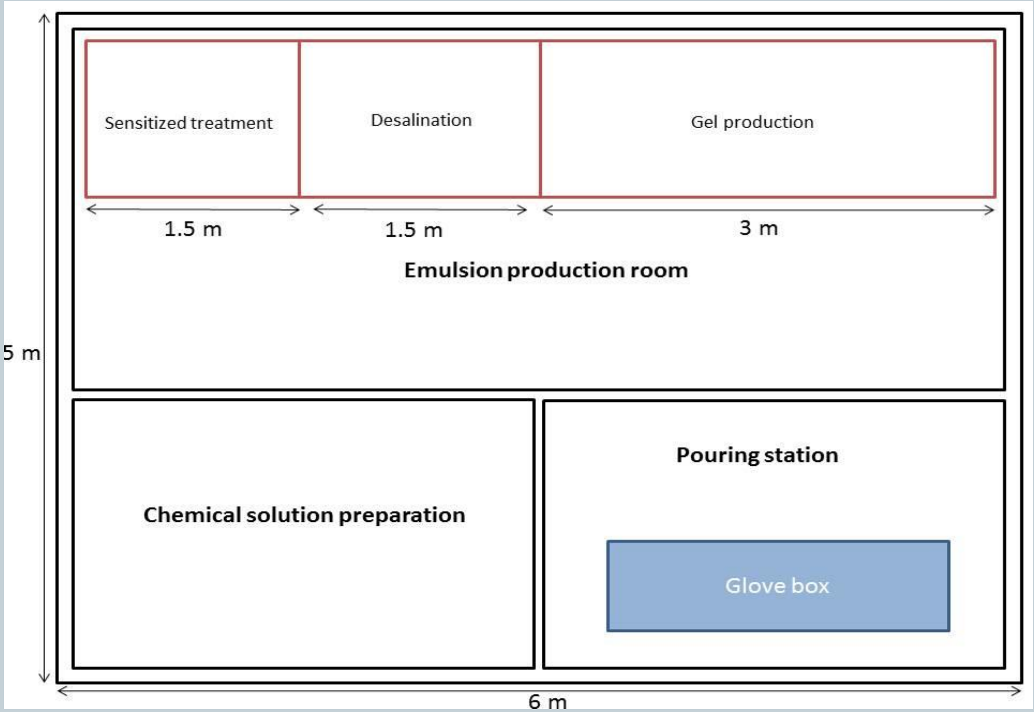
Experimental Set-UP



1. Internal phere: 30 cm diameter, holding the target
2. Plexiglass/nylon sphere: sealed from air and flushed with HP N_2
3. External sphere: 50 cm thick PE shielding

Target: 1 Kg of NIT
Shielding: 4 ton

Underground Emulsion Facilities



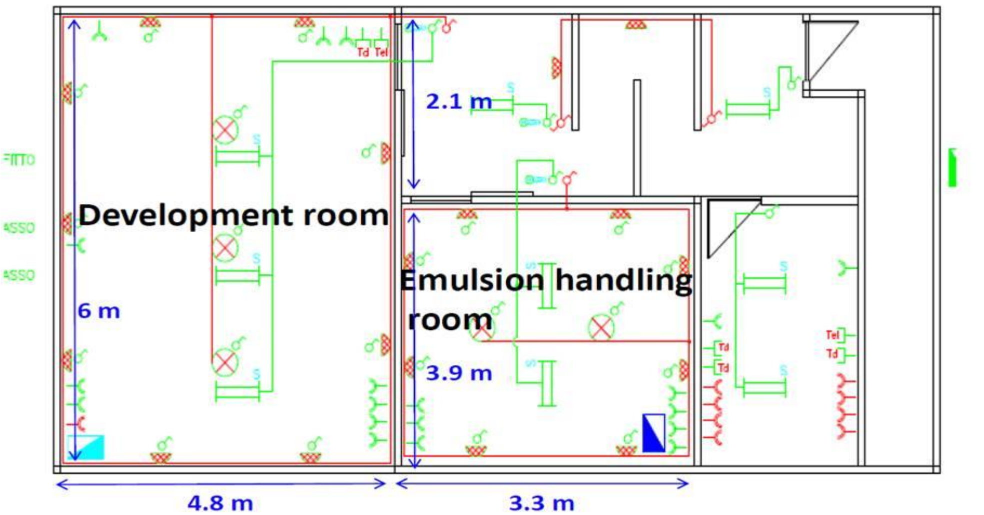
NIT Production Facility:

i. gel production room
ii. chemical preparation room,
iii. pouring station

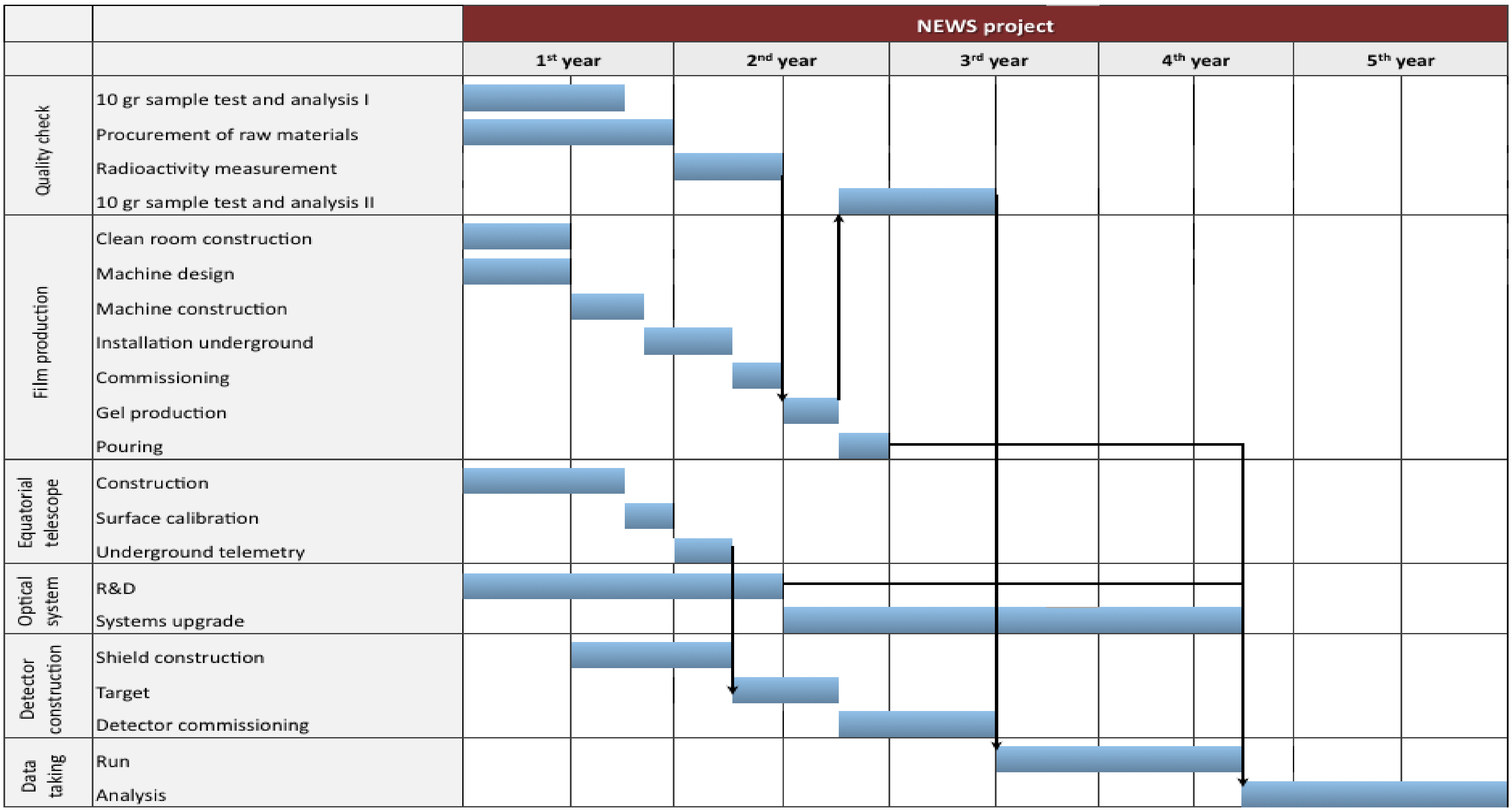
(dark) Clean Room (class 1000)

Underground Emulsion Facilities

OPERA emulsion facility in LNGS Hall B

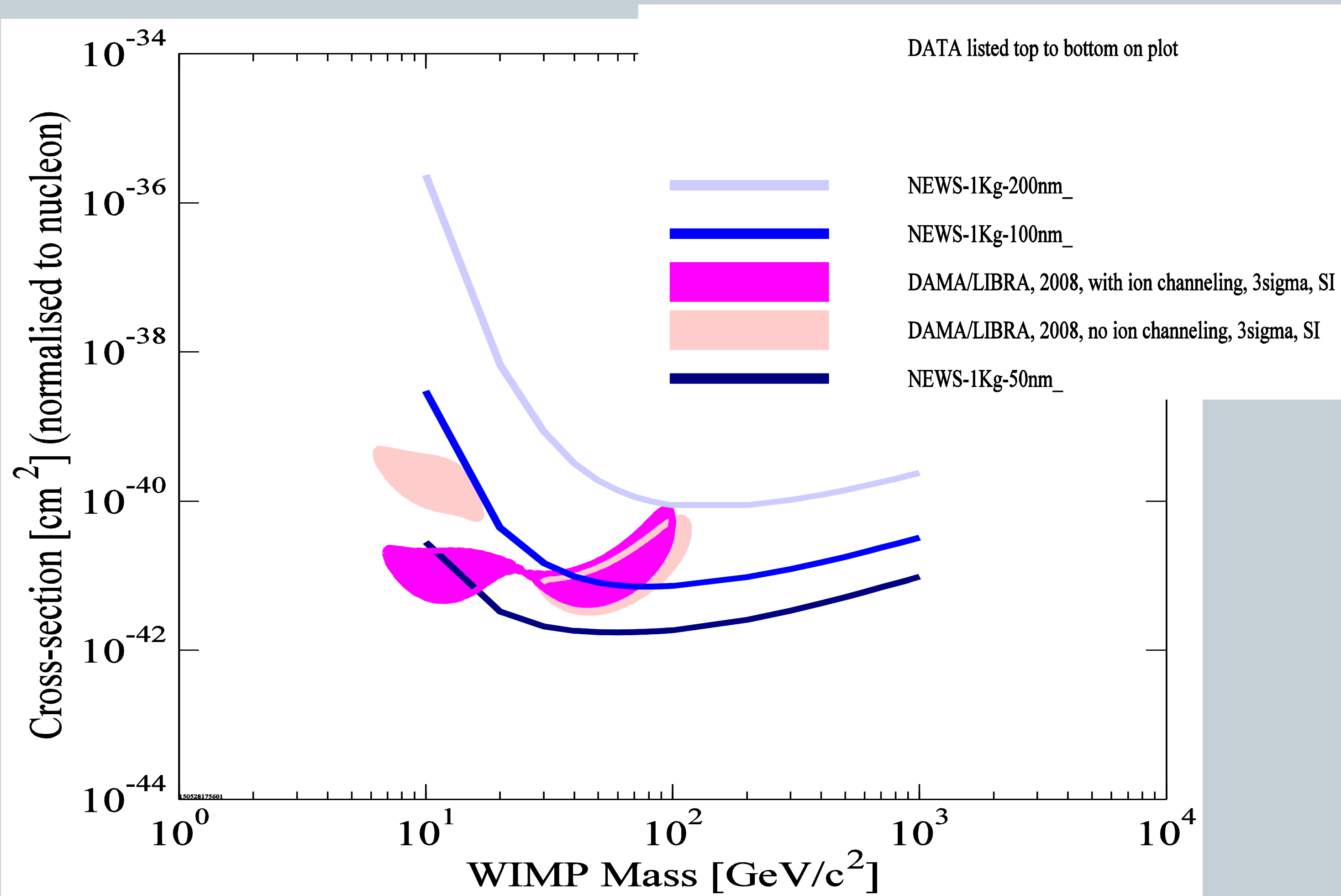


Schedule



NEWS project
1st year
2nd year
3rd year
4th year
5th year
Quality check
10 gr sample test and analysis I
Procurement of raw materials
Radioactivity measurement
10 gr sample test and analysis II
Film production
Clean room construction
Machine design
Machine construction
Installation underground
Commissioning
Gel production
Pouring
Equatorial telescope
Construction
Surface calibration
Underground telemetry
Optical system
R&D
Systems upgrade
Detector construction
Shield construction
Target
Detector commissioning
Data taking
Run
Analysis

Physics Reach



Conclusions

- A novel approach for **directional Dark Matter searches** is proposed in NEWS
- Novel nuclear emulsion technique with nanometric spatial resolution
- The use of a solid target would allow to explore the low cross section sector in the phase space indicated by recent direct search experiments but using a complementary an powerful approach
- Read-out system based both on optical (200 nm resolution) and X-ray microscopy (30 nm resolution)

Preliminary schedule → Pilot Experiment in 2018 with 1 Kg target mass.