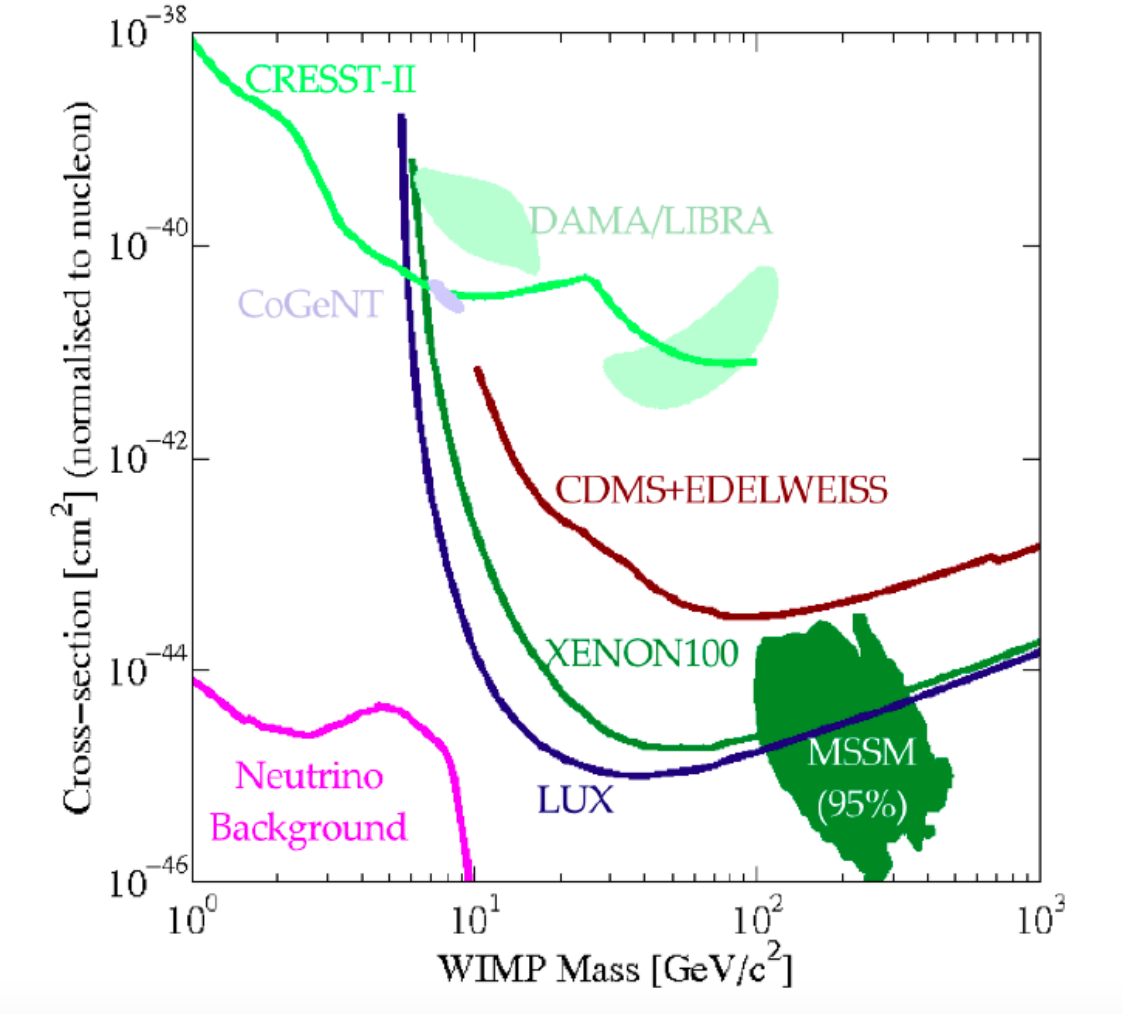
NEWS: Nuclear Emulsion WIMP Search

Masahiro Yoshimoto (Nagoya University)

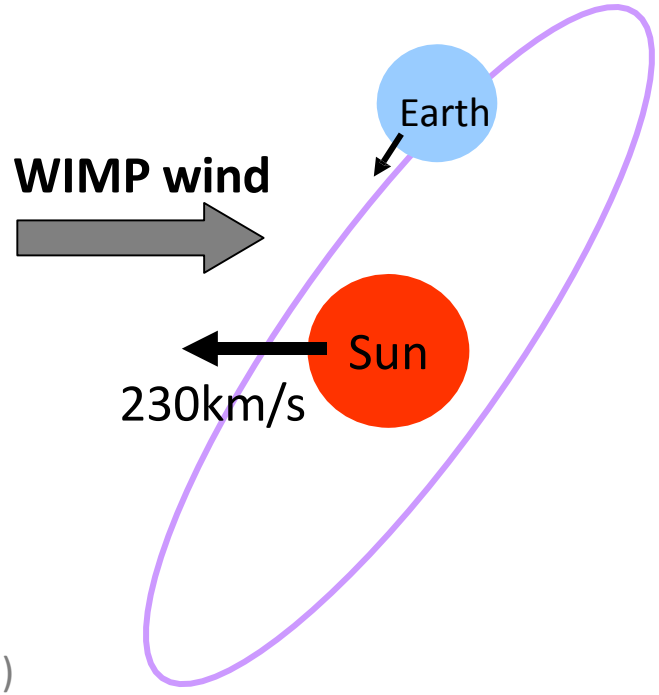
and NEWS collaboration

Dark matter search



Directional DM search

- A seasonal modulation by Earth revolution.
- A **directional** modulation by motion of Solar System.



- The direction of nuclear recoil is expected to have a **strong modulation**.

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

- The directional search is a prove of **WIMP and halo properties**.

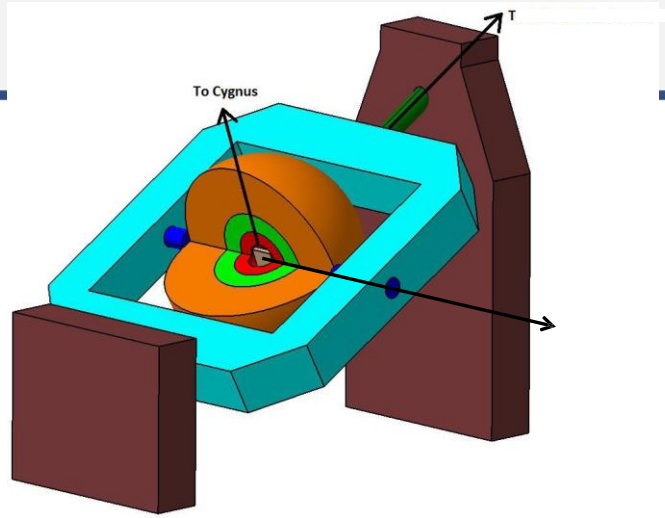
F. Mayet, J.Phys.Conf.Ser. 469 (2013) 012013

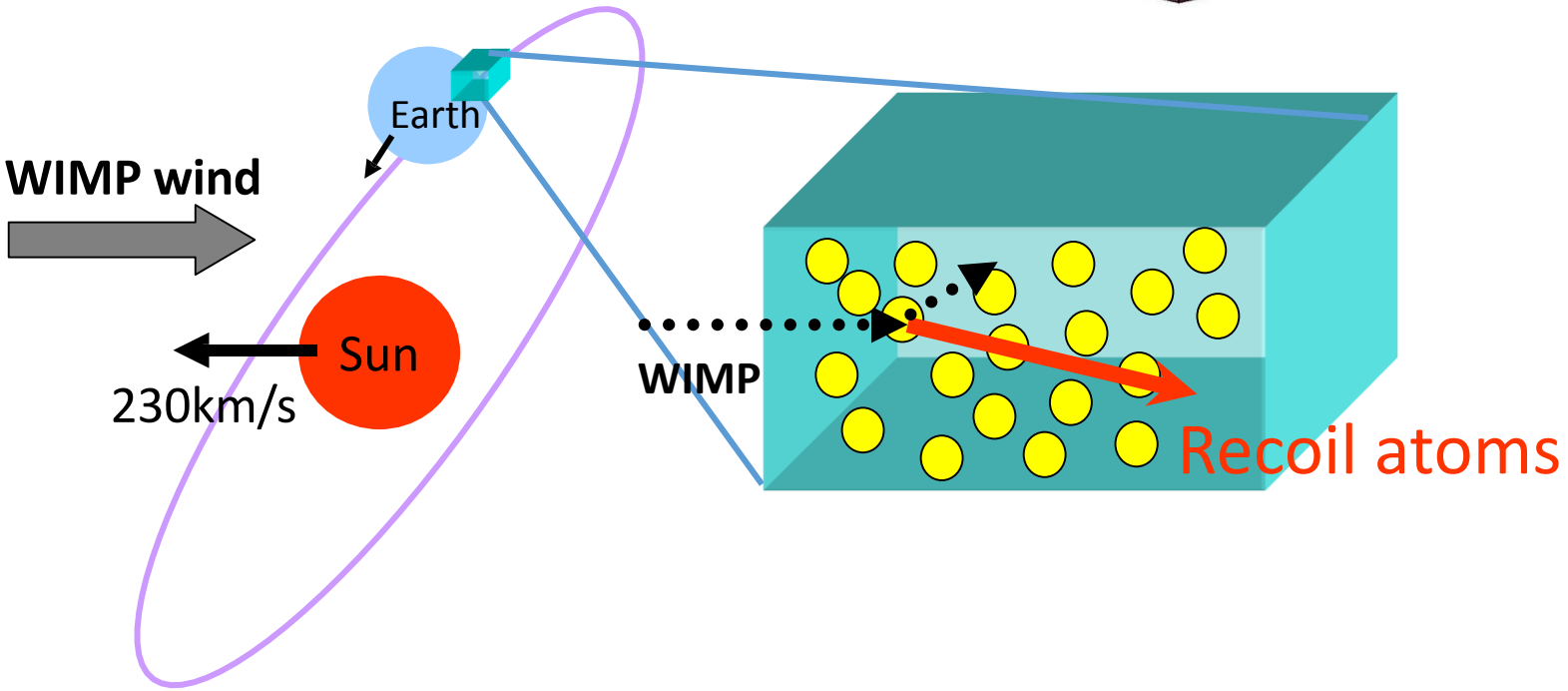
-> Gas-TPC detector

Concept of NEWS

- **N**uclear **E**mulsion for **W**IMP **S**earch
- Targets: Ag, Br, C (N,O)
- high density (solid), spin-independent

equatorial telescope





LOI is submitted to LNGS science committee

NEWS: Nuclear Emulsions for WIMP Search
Letter of Intent
(NEWS Collaboration)

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, Napoli, Italy
, Padova, Italy
, Roma, Italy
sso, Assergi (L'Aqu
ti, Frascati (Roma)
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derico II di Napoli,
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Academy of Sciences
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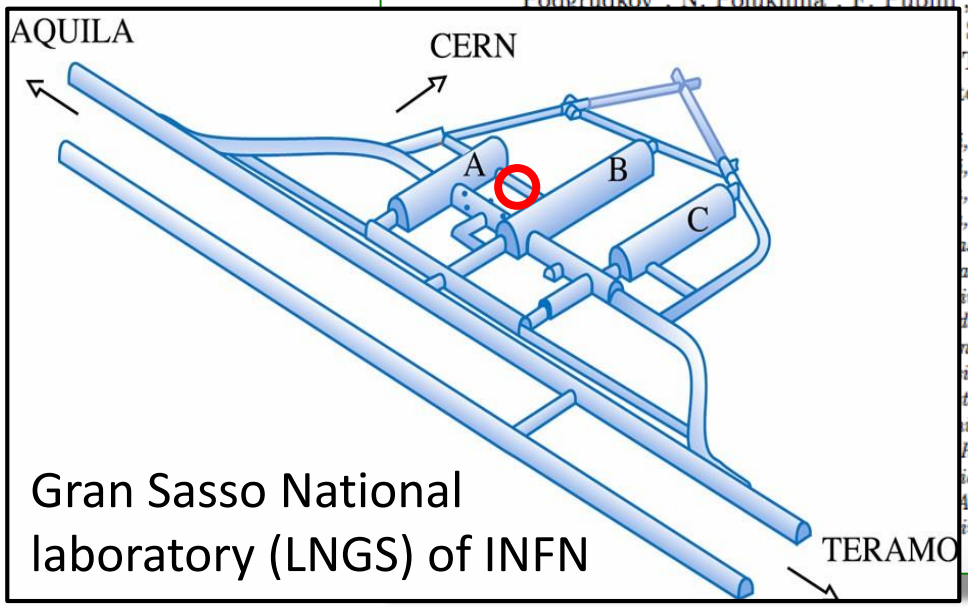
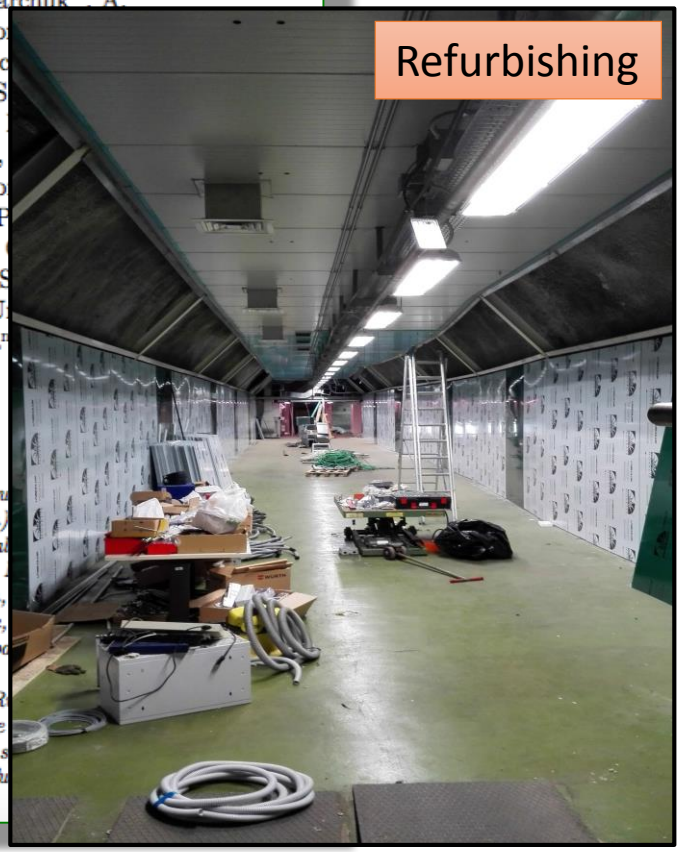
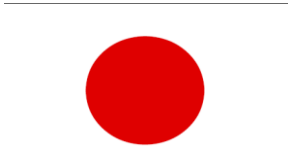


Gran Sasso National laboratory (LNGS) of INFN

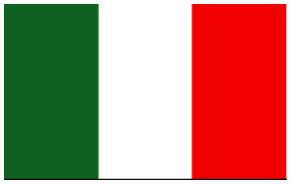


arXiv:1604.04199

The NEWS Collaboration



Japan
Chiba,
Nagoya



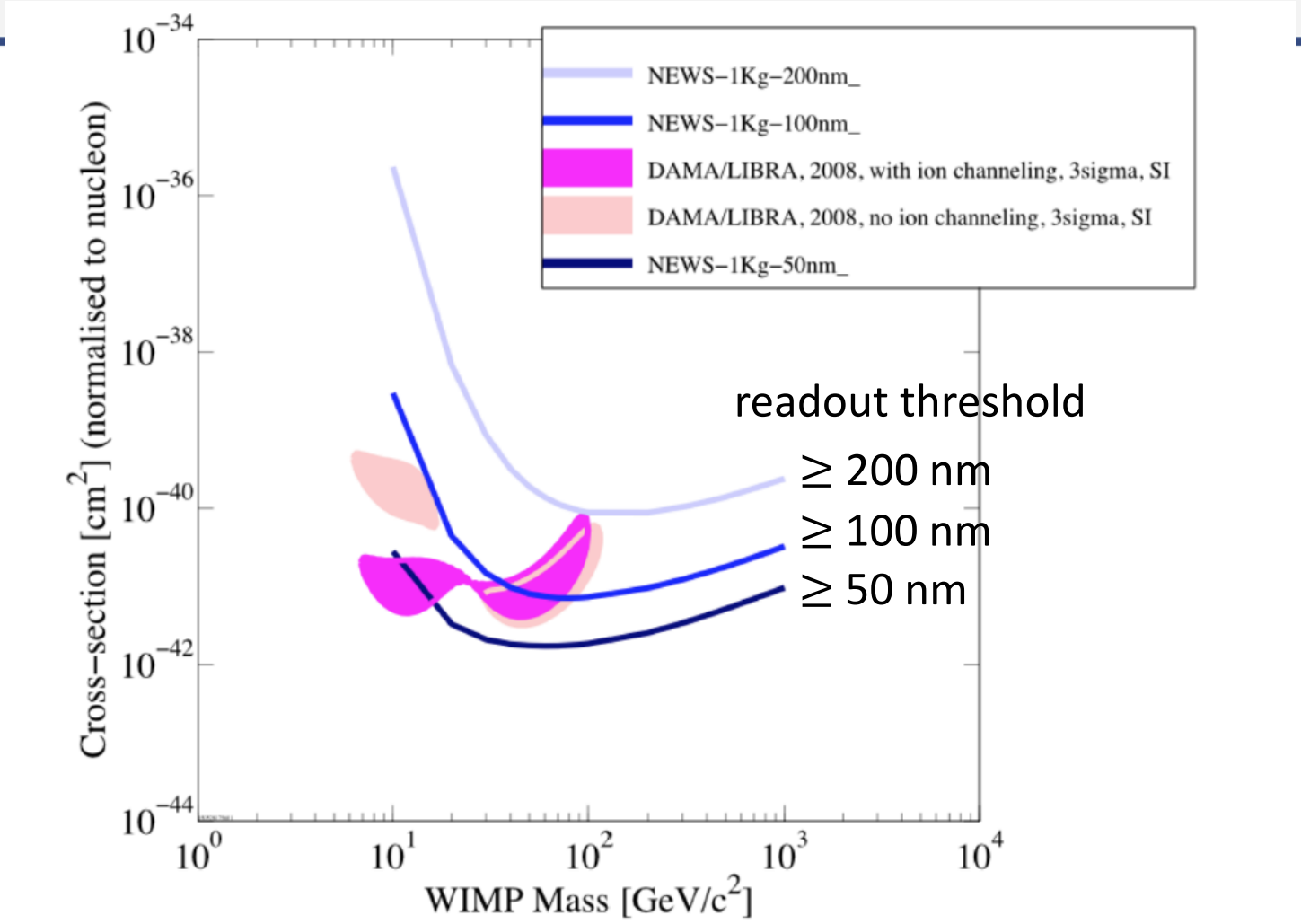
Italy
Bari,
LNGS,
Naples,
Padova,
Rome

Russia
LPI RAS
Moscow,
JINR Dubna,
SINP MSU
Moscow

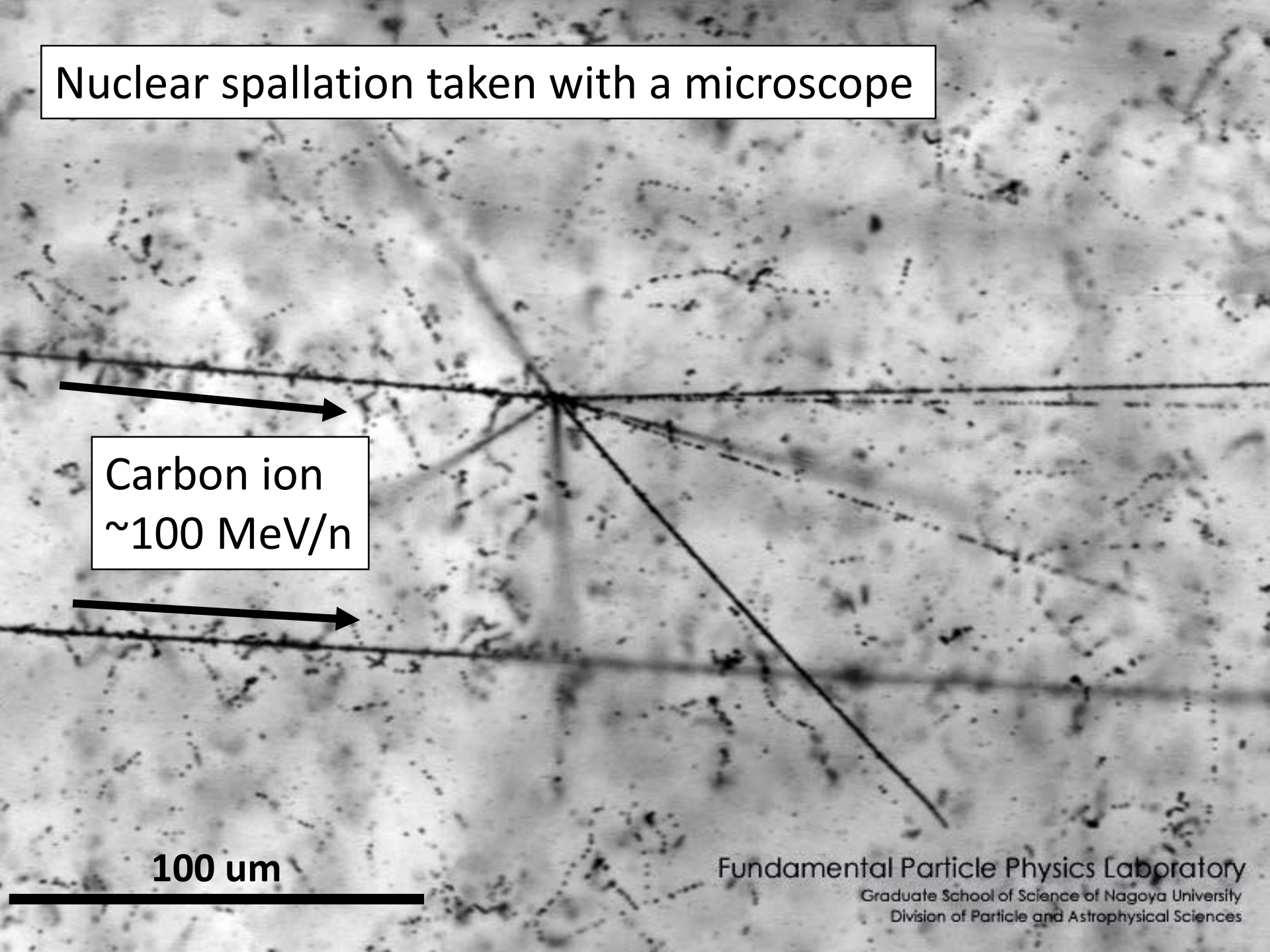
Turkey
METU Ankara

~60 physicists

Physics aims



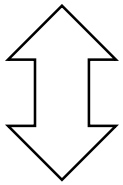
The 90% C.L. upper limits for a NIT emulsion with an exposure of **1 Kg·year** in the **zero background hypothesis**. The directionality information is not included.


Nuclear spallation taken with a microscope
Carbon ion
~100 MeV/n
100 um
Fundamental Particle Physics Laboratory
Graduate School of Science of Nagoya University
Division of Particle and Astrophysical Sciences

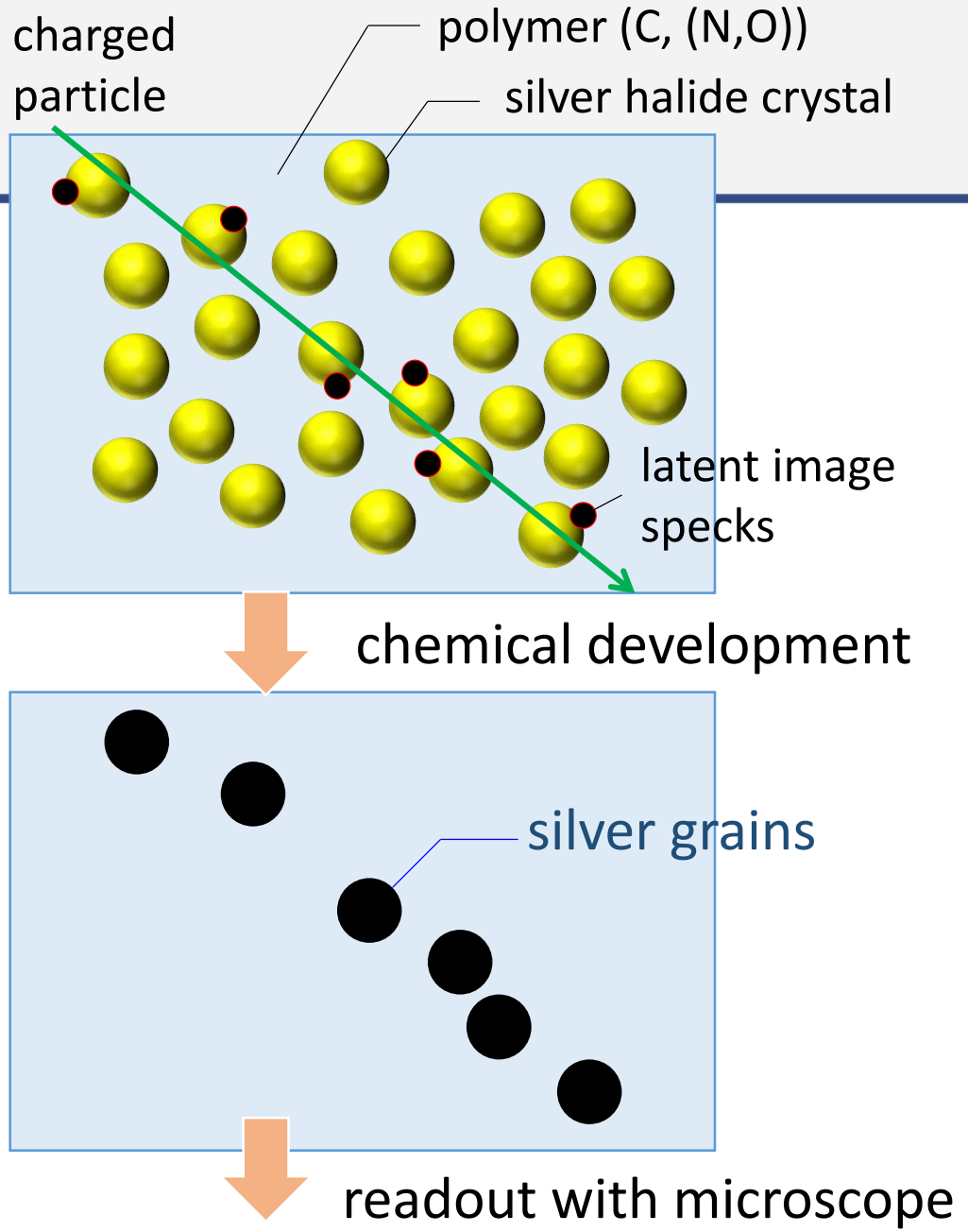
Nuclear emulsion

- 3D tracking detector
- easy to enlarge a detector mass
- low cost (1k€ / 1Kg)
- no time resolution

Crystal size : 200 nm



WIMP-induced recoils are $\mathcal{O}$ (10 – 100 nm) track length.

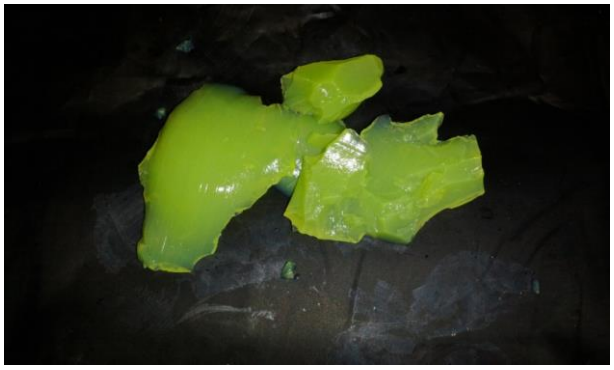


Fine grained nuclear emulsion

- R&D emulsion specialized in DM search by ourselves from 2010.

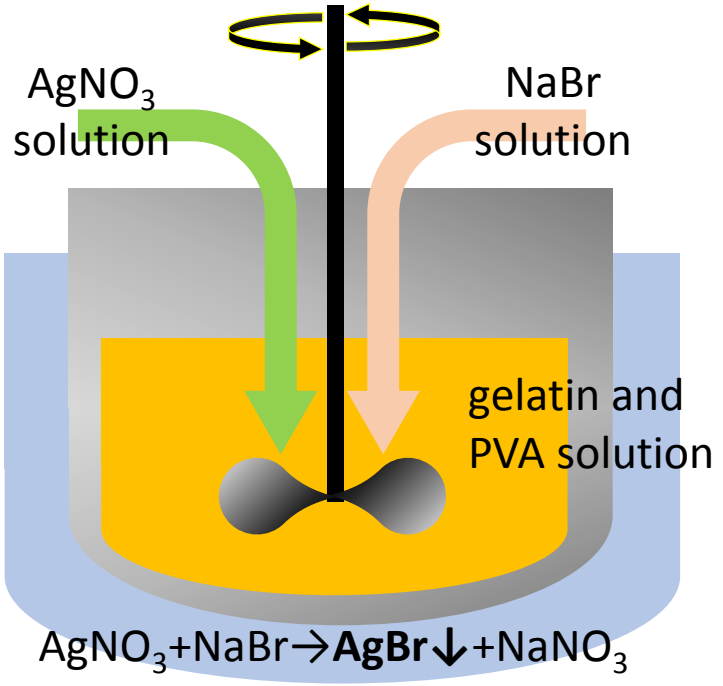
production machine in Japan

gel stage



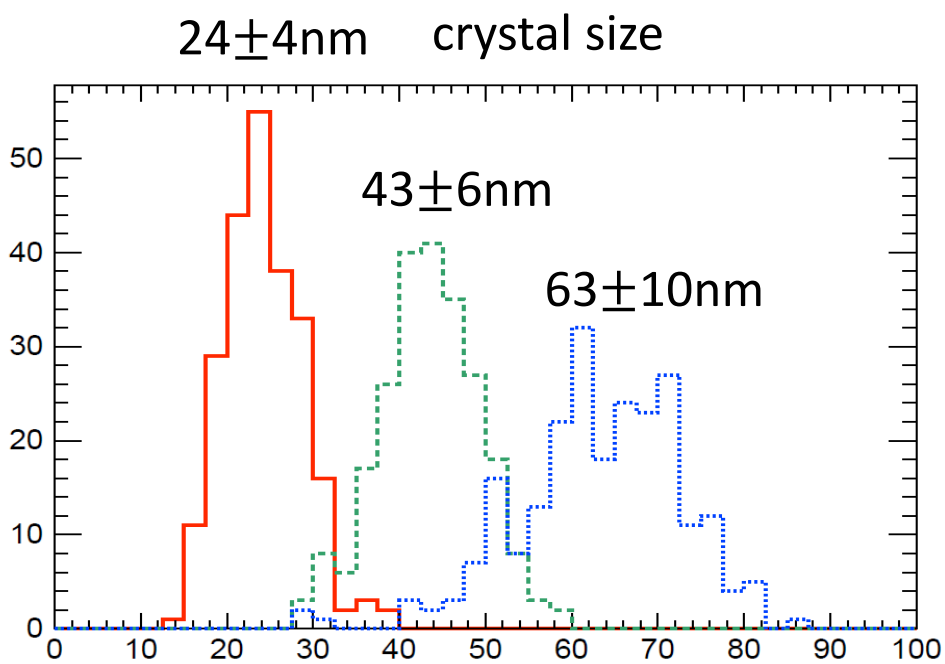
pour on a support plate & dry

solid state

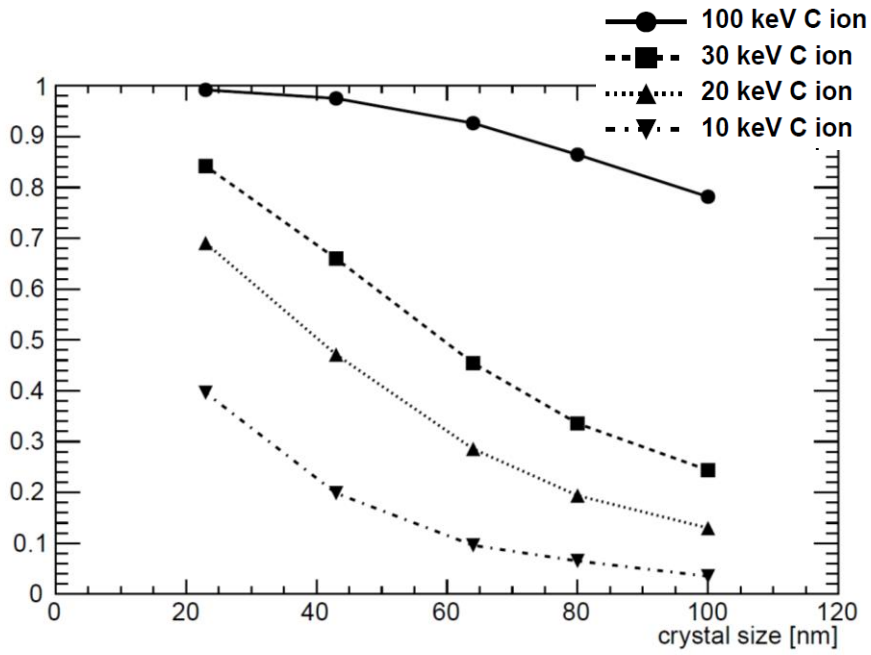


Fine grained nuclear emulsion

- Silver halide crystal size has been controllable
  - 20 – 60 nm (NIT type)
  - not sensitive to MIP



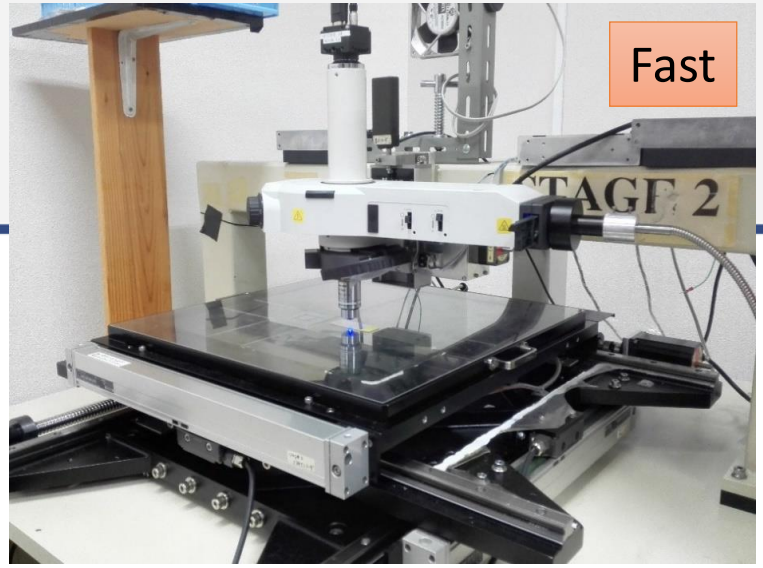
probability of penetrating two grains



Readout system

- total volume scanning
  - optical microscope
- event by event scanning

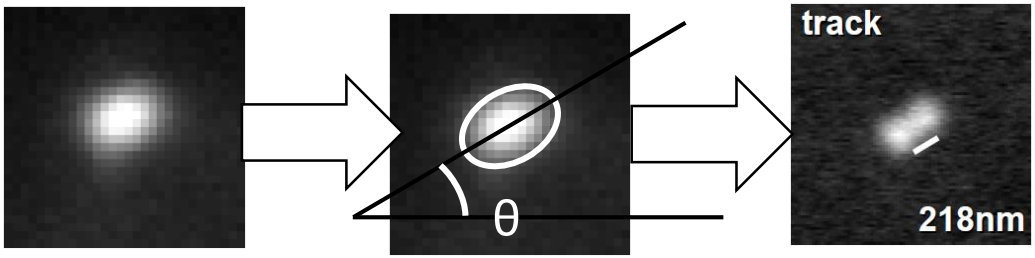
  with higher resolution optics
  - X-ray microscope
  - plasmon resonance



automated scanning stage
resolution ~200 nm

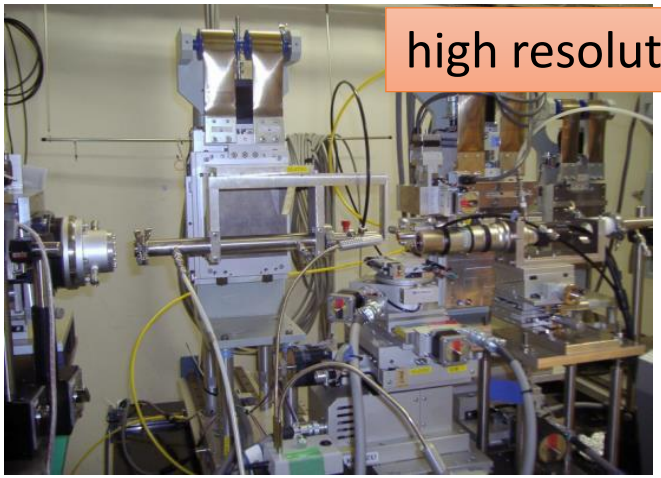
@ NIT-40

Fitting an ellipse



optical

X-ray



X-ray microscope
resolution 70 nm

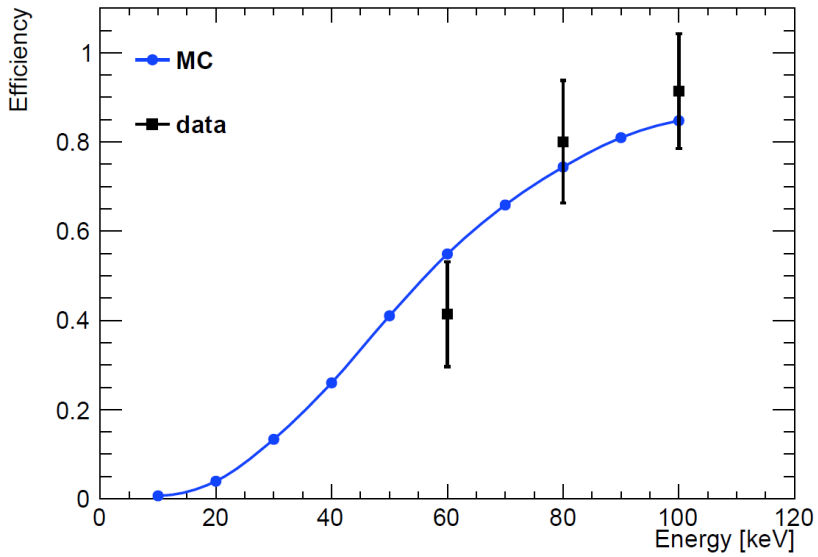
T. Naka, el al. Rev.Sci.Instrum. **86** (2015) 073701

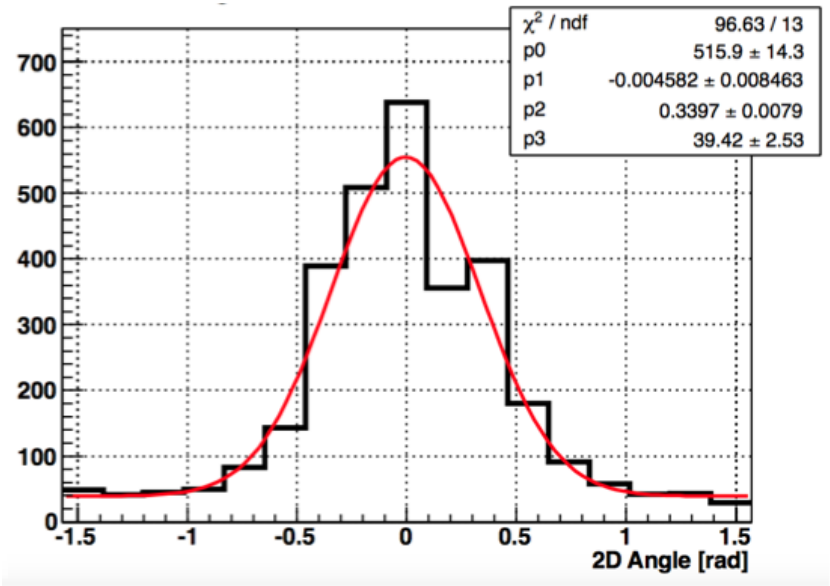
Efficiency and angular resolution

@ NIT-40 emulsion
@ optical microscope

- Low energy **60 – 100 keV carbon** exposure test
- Ellipticity cut > 1.25
- 80% tracking efficiency @80 keV
- 340 mrad (**20 degree**) angular resolution@ 80 keV

$$Eff. = \frac{\#\ of\ selected\ events}{\#\ of\ irradiated\ events}$$





Background study

- NIT emulsion radioactivity

	U-238	Th-232	K-40	C-14
activity [mBq/kg]	27	6	35	**24000**
process	α decays (alpha, n) reaction		β, γ decays	β decays

- alpha-ray: rejection by track length difference
- (α, n) reaction: 0.11 neutron-induced recoils /kg /year

A. Alexandrov *et al,* Astropart.Phys. **80** (2016) 16-21.

- beta-ray: $R_\beta < 10^{-8}$ electron rejection power is required
  - NIT emulsion has $R_\beta < 10^{-6}$
  - a desensitization by cryogenic approach
  - a change in gelatin source (cattle bone -> petroleum-derived)

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
- Grains generated at random
- Fake signal from raw materials or production process

Conclusion

➢NEWS experiment

-> A novel approach for directional dark matter searches

➢Concept

-> A solid detector would allow to explore spin-independent 10 – 1000 GeV/c^2 WIMP mass region.

➢NIT emulsion

-> 20 – 60 nm crystal size emulsion is available.

➢Sensitivity to low energy ions

-> **80%** tracking efficiency and **20 degree** angular resolution have been confirmed @ 80 keV carbon ions.

➢Preliminary schedule

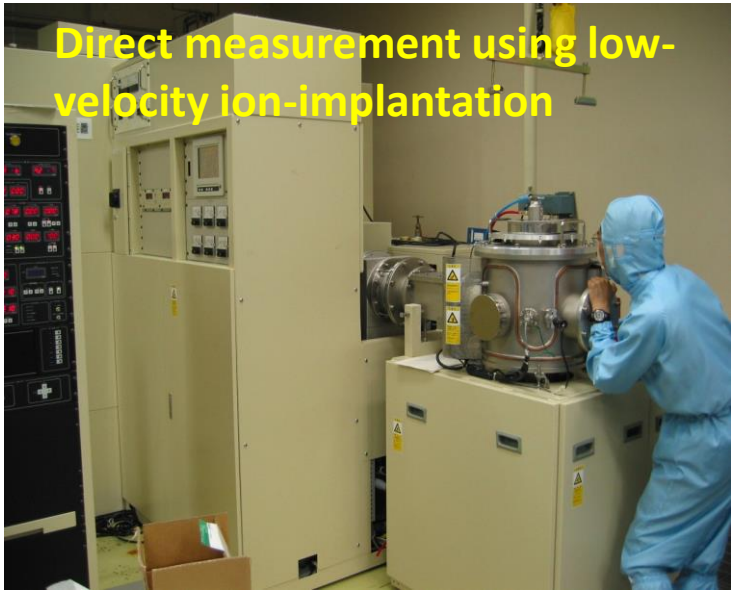
-> **Pilot Experiment in 2018 with 1 Kg target mass.**

- バックアップ

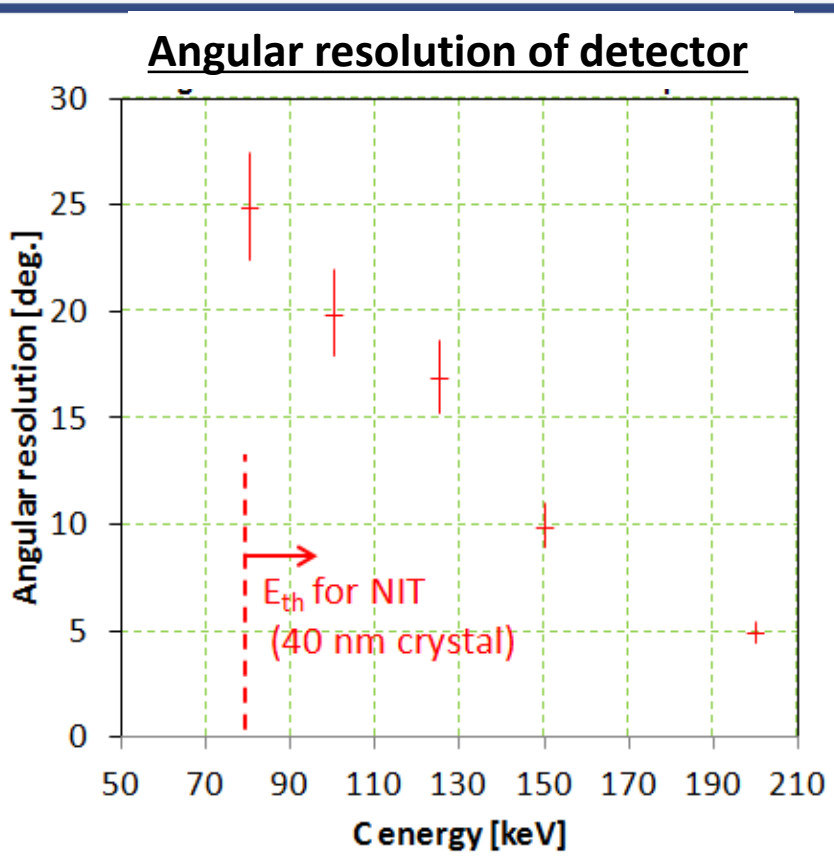
Cost

- NIT emulsion costs ~1 keuro/1 Kg.
- Clean room and other facility costs 100 – 250 keuro.
- Equatorial telescope with shielding costs ~300 keuro.
- Microscope readout system costs ~700 keuro.

Angular resolution for 40 nm crystal NIT

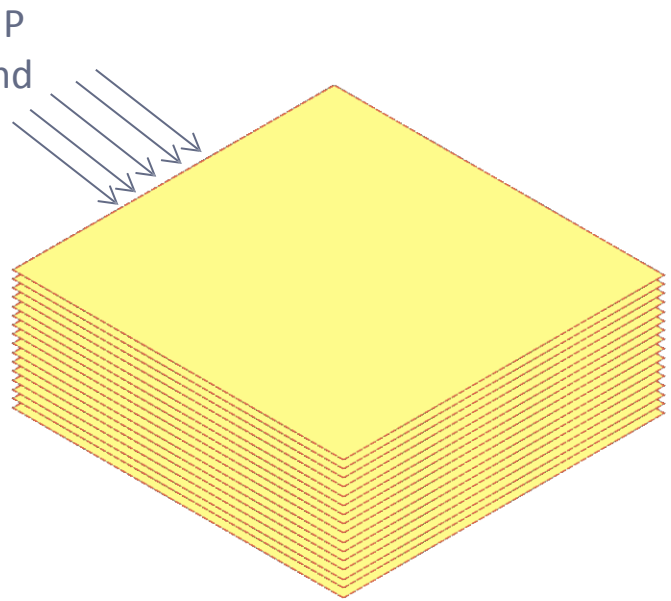


Accelerate voltage : > 10 keV (Max.200 kV)
Type of ions : C, O, Ar (from CO_2/Ar gas)
Kr (from Kr gas), F, B (from BF_3 gas)
IT is good calibration for sirect detection of nuclear recoil because of uniform direction and energy.



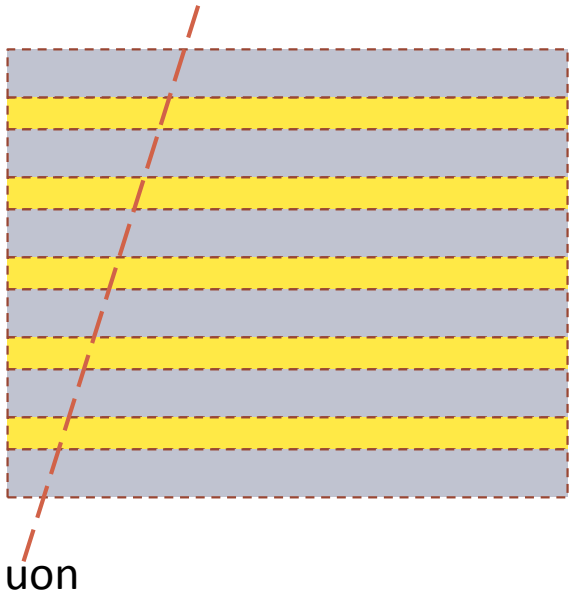
passive veto for cosmic ray

1)



1 kg:
100, 50 μm thick NIT films
25 x 25 x 0.5 cm^3

2)



MIP emulsion has a sensitivity of MIP and proton recoil.

Directional DM search

- The directional search is a prove of WIMP and halo properties.

identify Weakly Interacting Massive Particle (WIMP) events as such. 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. We review the discovery reach of Dark Matter directional detection.

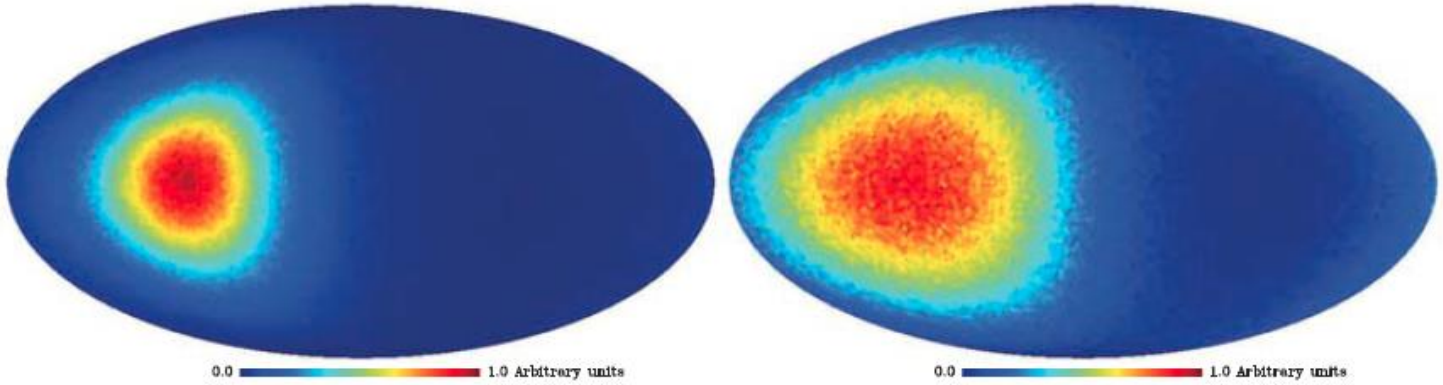
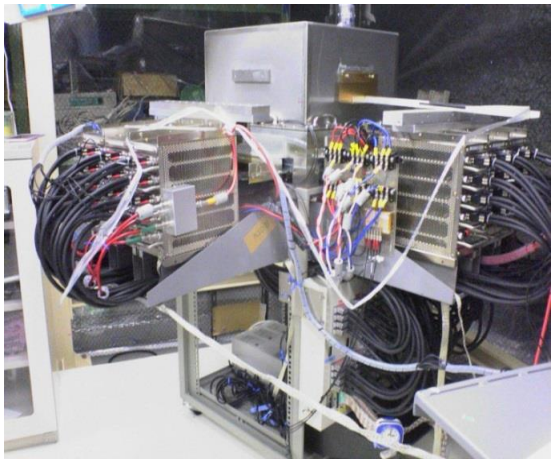


Figure 1. (Left) : WIMP flux for an isothermal spherical halo. (Right) WIMP-induced recoil distribution. Recoils maps are produced for a ^{19}F target, a 100 GeV.c^{-2} WIMP and considering recoil energies in the range 5 keV $\leq E_R \leq$ 50 keV. Figures extracted from [12].

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

Directional DM searches

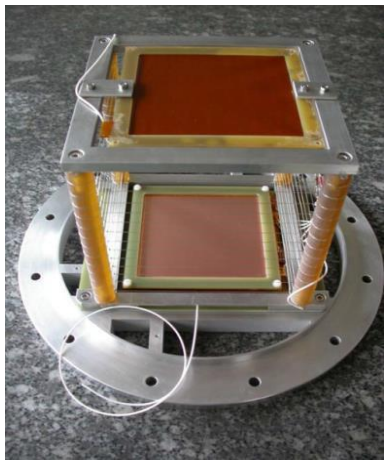
- Gas TPC
- Target: CF_4, CS_2+CF_4, CF_4+CHF_3, SF_6
- head-tail sensitivity
- low density, spin-dependent



NEWAGE@ Japan

DM-TPC@ USA

DRIFT @ UK



MIMAC@ France

. . .

CYGNUS-TPC

Head – tail recognition

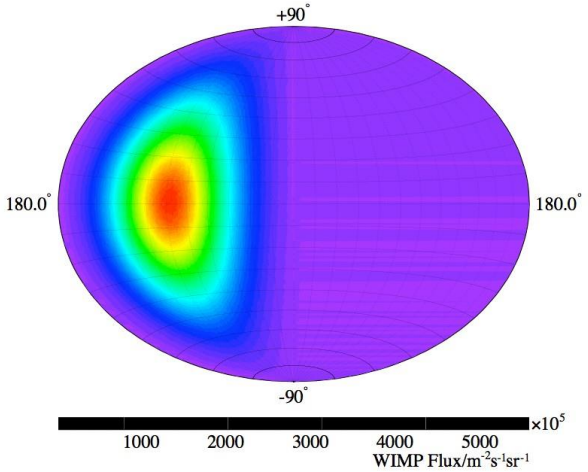
- Impossible for each event

Power of Directionality

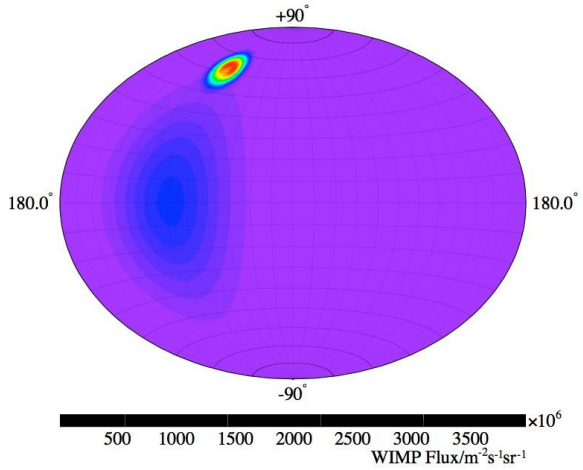
Talk by Neil Spooner
2016 May 11-13

- Potential for WIMP "Astronomy"

Standard Halo

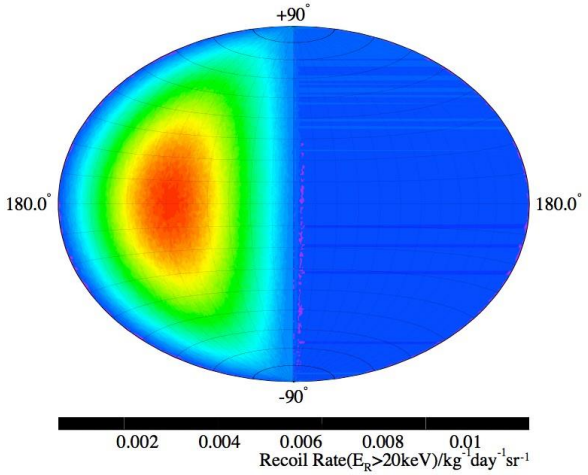


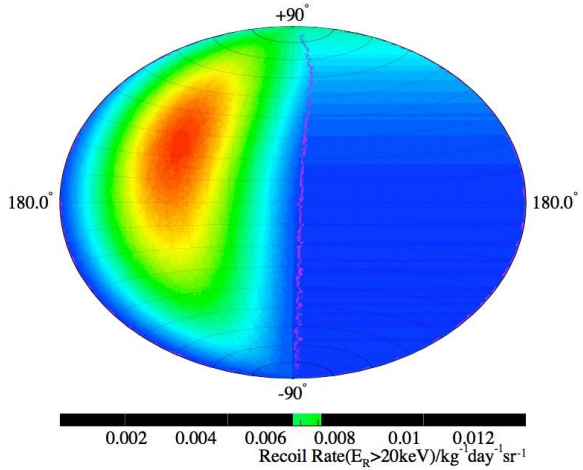
With Sagittarius Stream



WIMP flux

S recoil flux





Simulations by Ben Morgan (Sheffield)

WIMP mass -> max. recoil length -> carbon k.En

Maximum WIMP velocity
WIMP mass

Carbon 30 keV 100 keV 120 keV

Maximum WIMP-induced recoil length of Carbon and Silver nuclei for three different WIMP masses.

Recoil nucleus	WIMP mass (GeV)		
	10	100	1000
	Maximum recoil length (nm)		
C	100	350	430
Ag	11	140	480

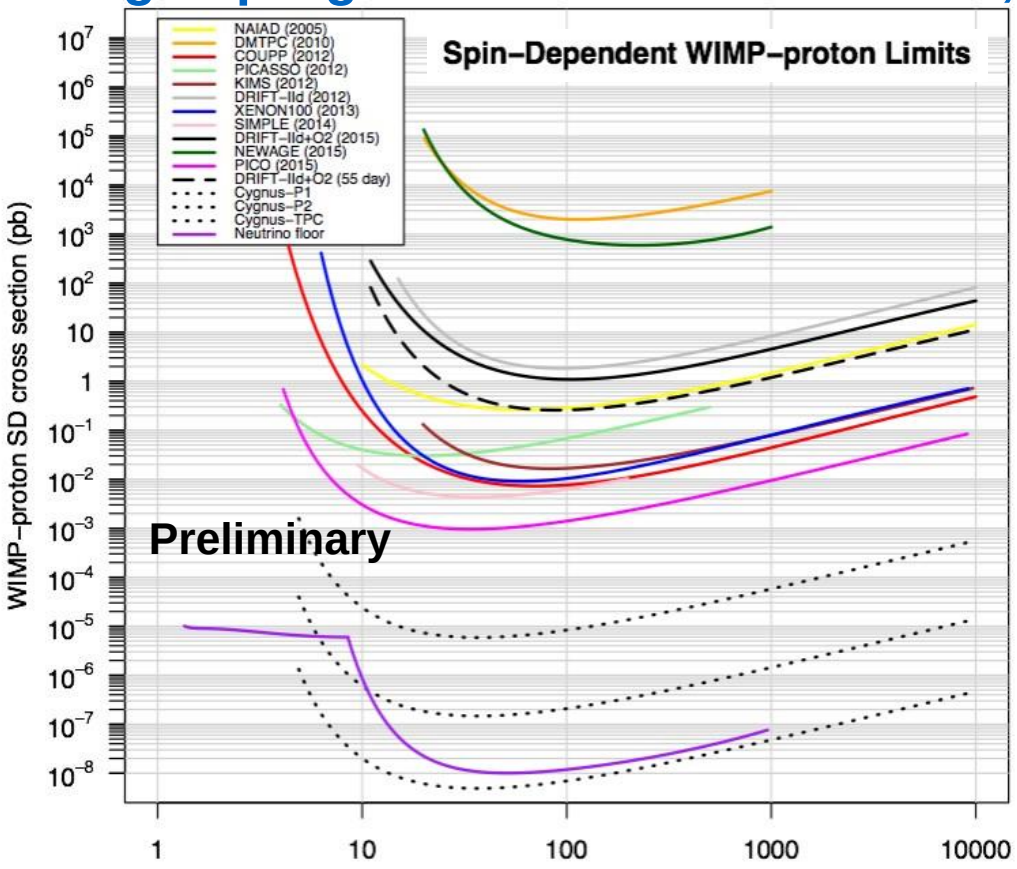
Element	Mass fraction [g g^{-1}]	Atomic fraction
Ag	0.44	0.10
Br	0.32	0.10
I	0.019	0.004
C	0.101	0.214
O	0.074	0.118
N	0.027	0.049
H	0.016	0.410
S	0.003	0.003

(b) Elemental composition

CYGNUS-TPC Global Conce

Talk by Neil Spooner
2016 May 11-13

- SF_6 target (~x5 more F per volume than current)
- Fiducialisation, -ve ion drift, head-tail sensitivity
- Multi-tonne, multi-underground site,
- Staged programme - low WIMP mass, high WIMP mass



Australia, China, France, Italy, Japan, UK, US

~Current state

CYGNUS - Pathfinder 1

CYGNUS - Pathfinder 2

CYGNUS - TPC