Directional Dark Matter Search and Velocity Distribution

Keiko I. Nagao 長尾 桂子

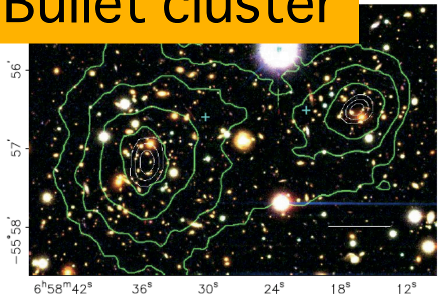
(National Institute of Technology, Niihama College, Japan)

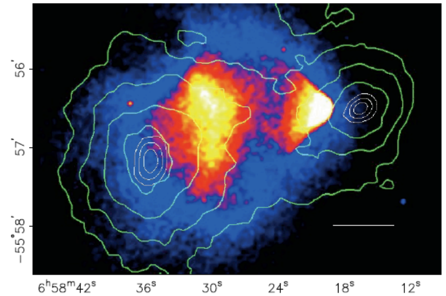
Collaboration with

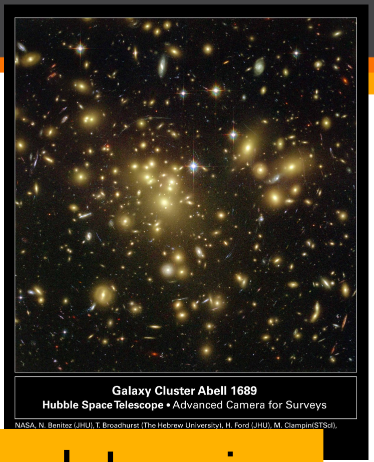
Tatsuhiro Naka (Nagoya Univ.) and Mihoko Nojiri (KEK & IPMU)

Dark Matter

Bullet cluster



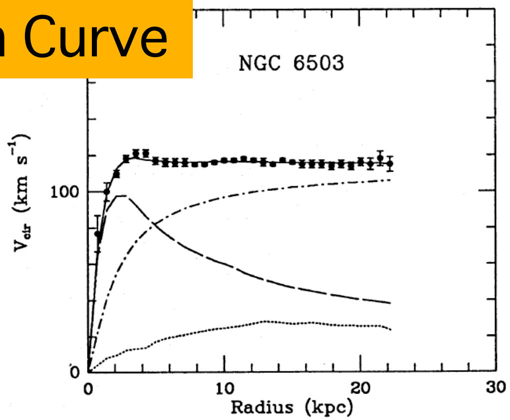




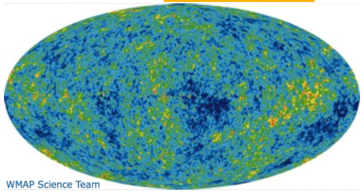
Weak Lensing

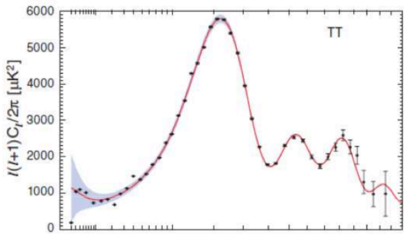
Evidences

Galactic Rotation Curve



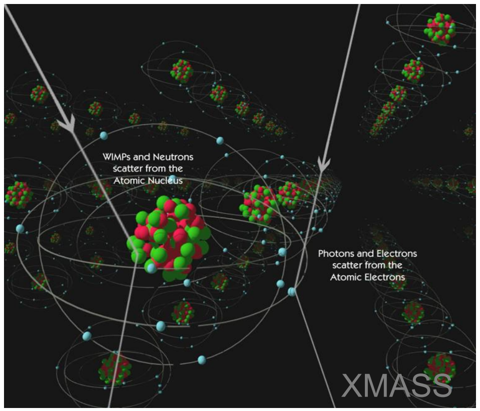
CMB



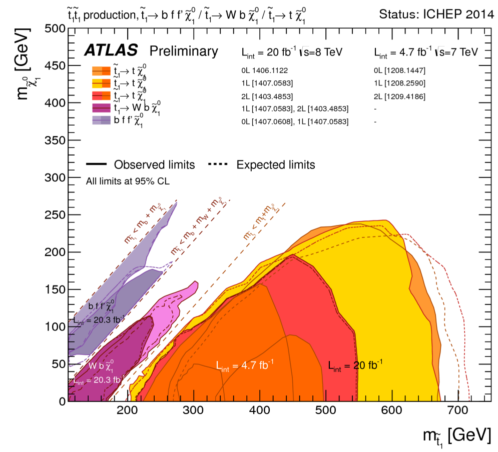


Constraints for DM

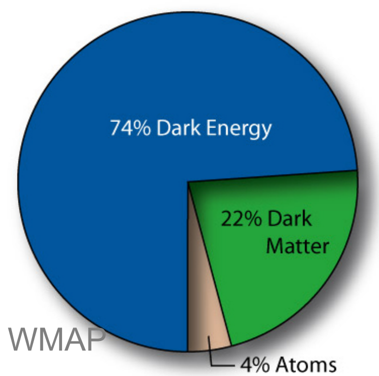
- Direct Detection



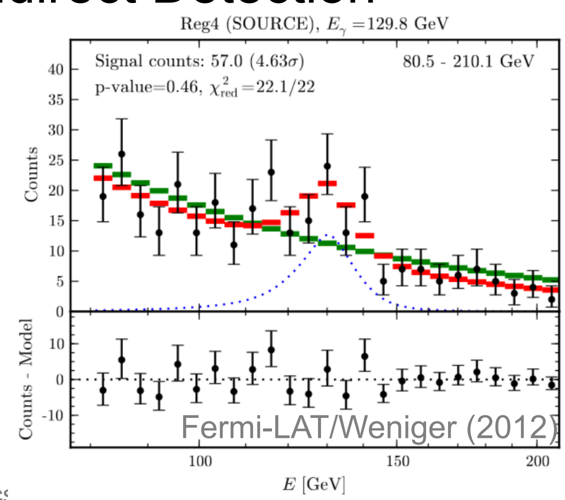
- Collider



- Relic Abundance

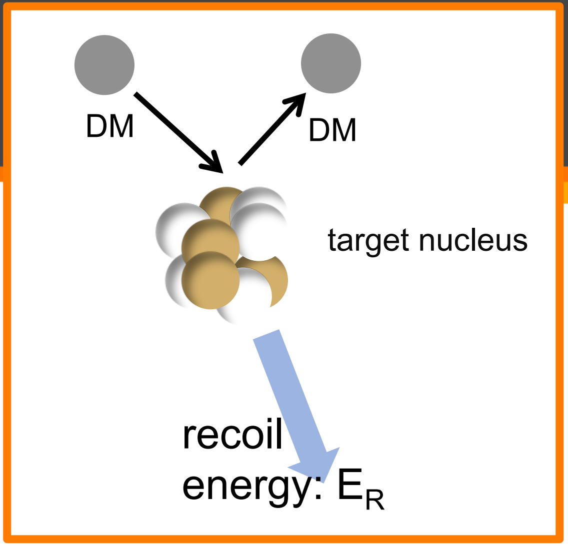


- Indirect Detection



Direct Detection

- Direct search for DM
  - Detecting the recoil energy that a DM particle scatters a target nucleon.
  - CDMS, XENON, LUX, …



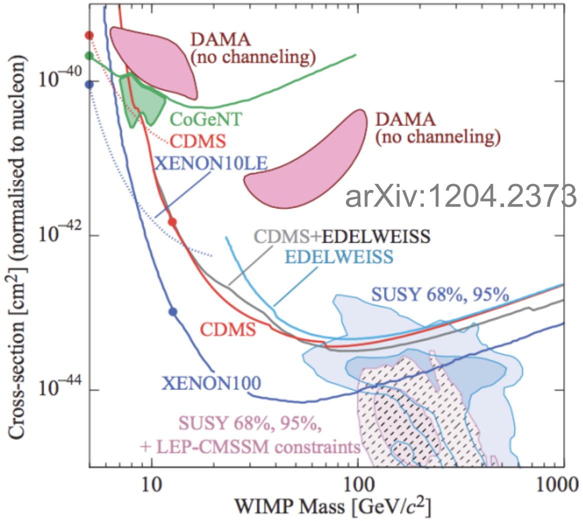
- Constraint for DM-nucleon interaction cross section can be obtained from the event number

$$R = N_T n_\chi \int_{E_{R,\min}} dE_R \int_{v_{\min}}^{v_{\max}} d^3v \; f(v) \frac{\tilde{\sigma}_A m_A}{2 v \mu_A^2}$$

Experiment

Astronomy

Particle + nuclear phys.



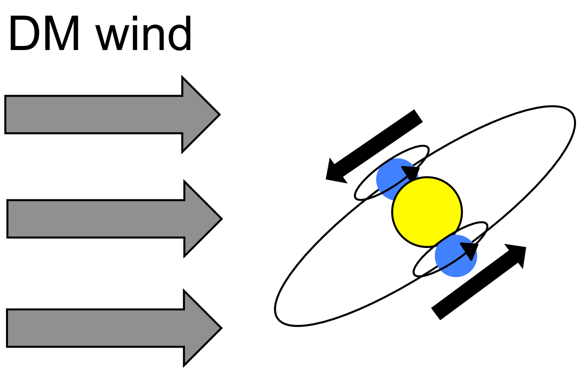
OUTLINE

1. ~~Introduction~~
2. Directional Dark Matter Detection
3. Velocity Distribution of Dark Matter
4. Nuclear Emulsion Detector
5. Velocity Distributions in Directional Detector

To next generation: Directional detection

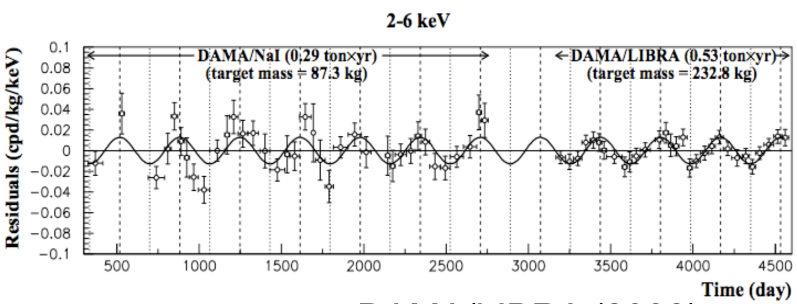
■ Directional Detection

- detecting not only the recoil energy but also direction where DM comes from.



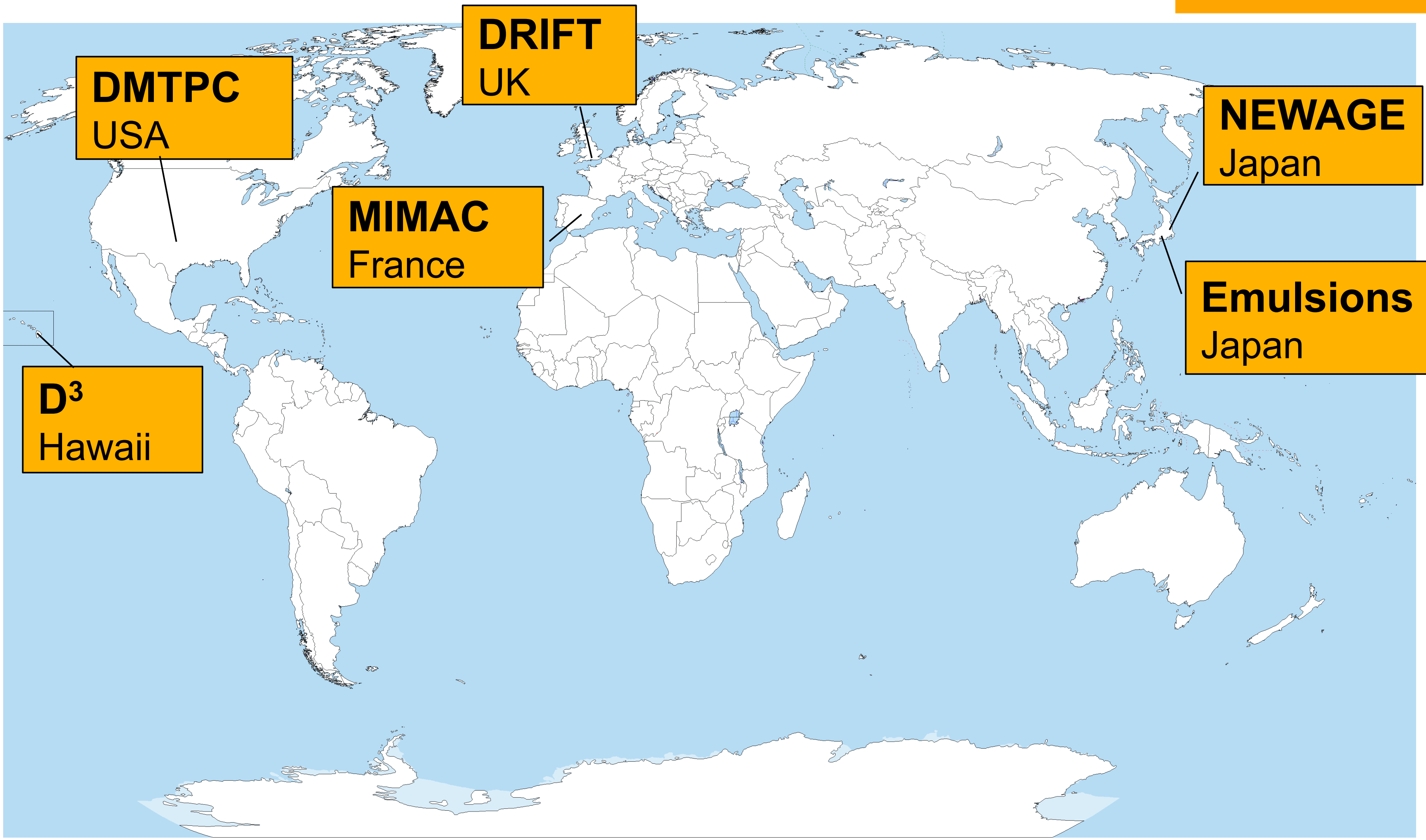
■ Advantages

- **Powerful back ground rejection**
  BG is isotropic, on the other hand DM signal is expected to come from the direction of the cygnus.
- **Annual Modulation**
  Direction of DM wind toward the Earth seasonally changes.
- **Daily oscillation**
  The Earth's rotation can also changes the number of DM signals.

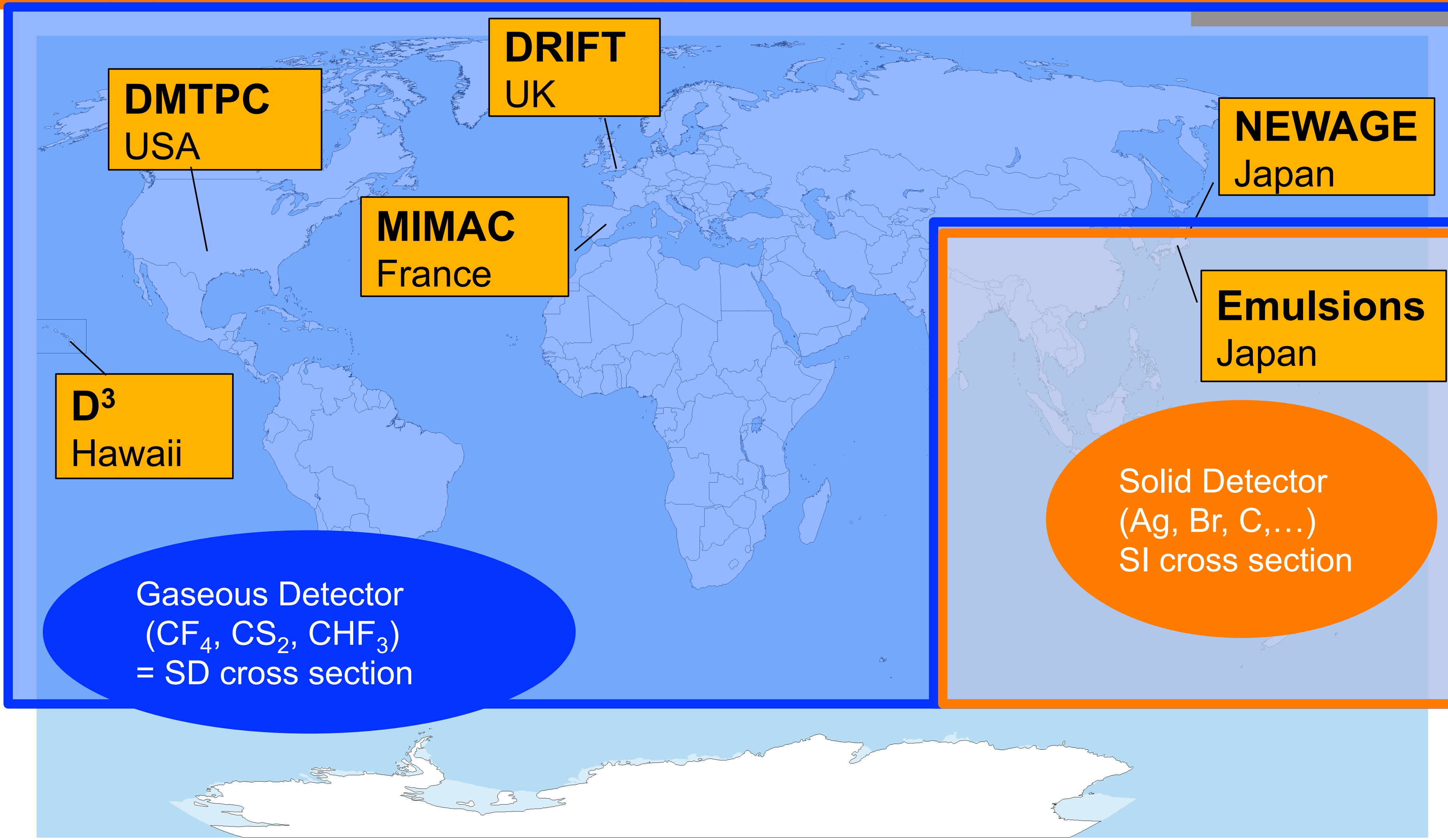


DAMA/LIBRA (2008)

Directional Searches



Directional Searches



We can be more ambitious?

We can be more ambitious?

Being more ambitious…

- Velocity distribution

  In the directional DM search, **it can be possible to make a constraint for f(v)**.

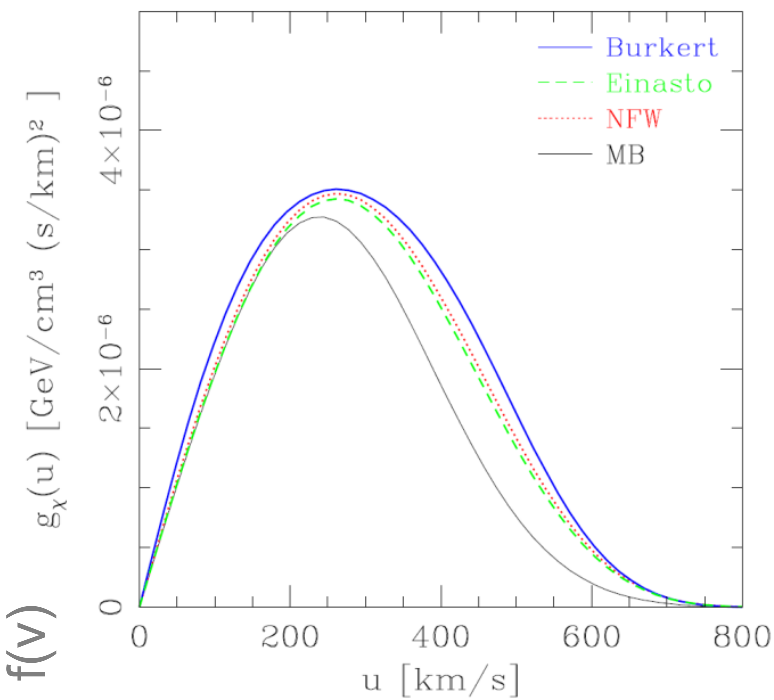
- Constraint from direct detections depends on DM distribution

$$R = N_T n_\chi \int_{E_{R,\min}} dE_R \int_{v_{\min}}^{v_{\max}} d^3v \; f(v) \frac{\tilde{\sigma}_A m_A}{2 v \mu_A^2}$$

Experiment — Astronomy — Particle + nuclear phys.

- We should know correct DM distribution to derive appropriate constraints for the interaction.

DM Velocity Distribution -Standard Distribution-



Catena and Ullio (2012)

- Maxwell distribution

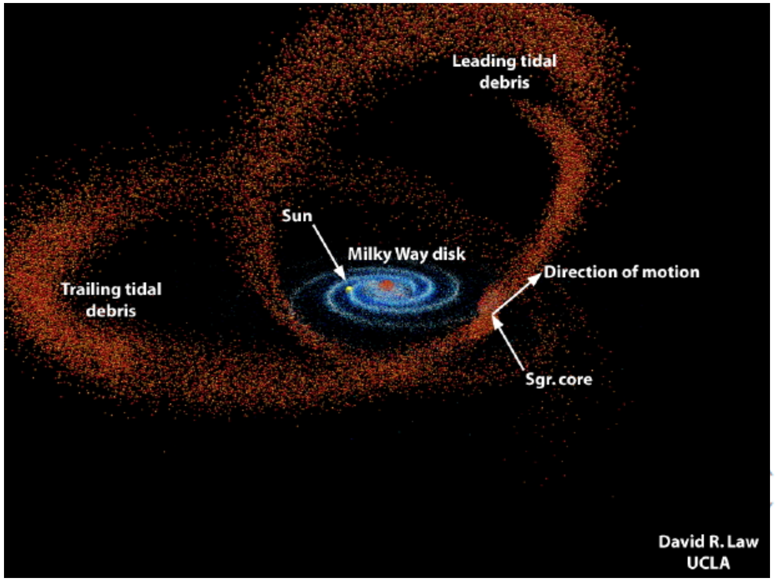
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$

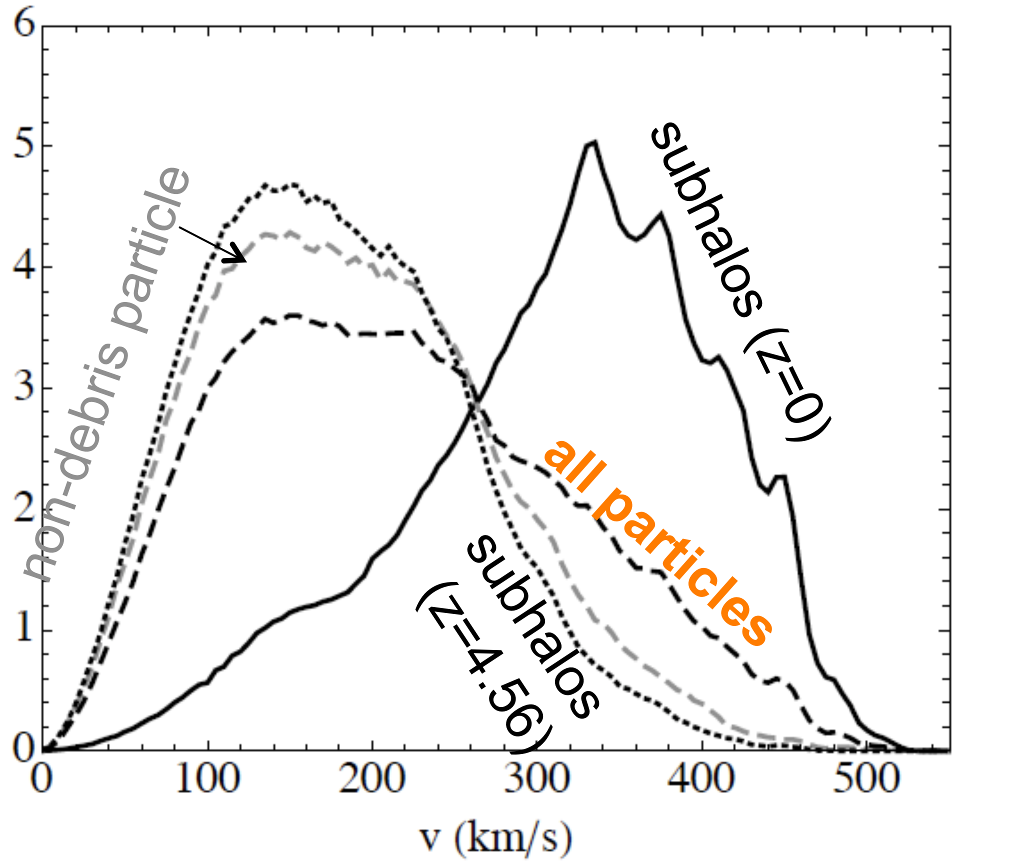
v_0: velocity of the Solar system
v_E: Earth's velocity relative to DM

- Is DM distribution surely this kind of shape?

Debris Flow

- N-body simulation in which subhalos falling into the Milky Way

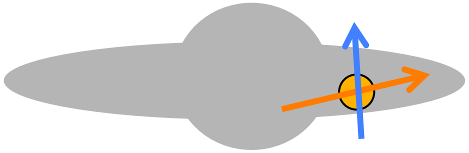


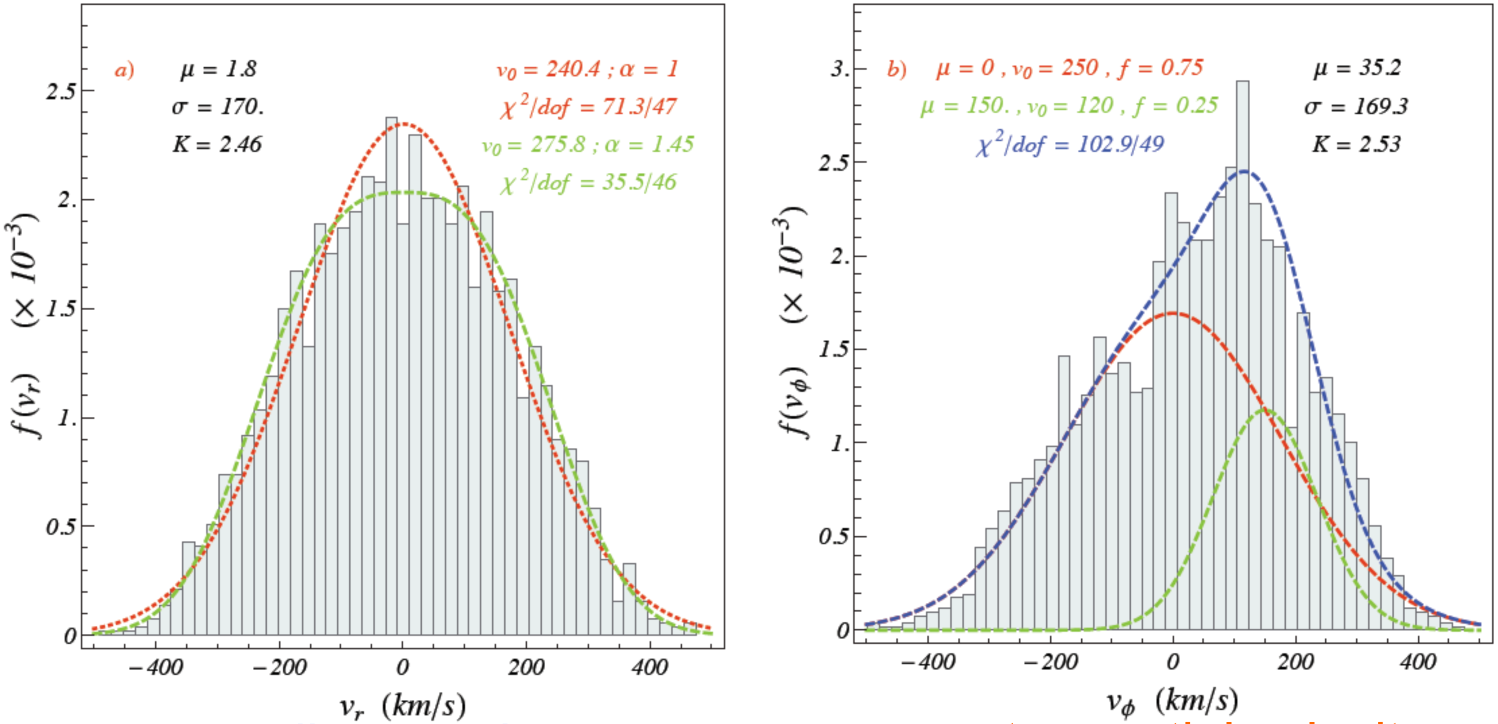


Kuhlen, Lisanti & Spergel (2012)

Co-rotating DM

- N-body simulation including baryons and gas
  - DM co-rotates with baryons in the galaxy.
  - Anisotropic distribution





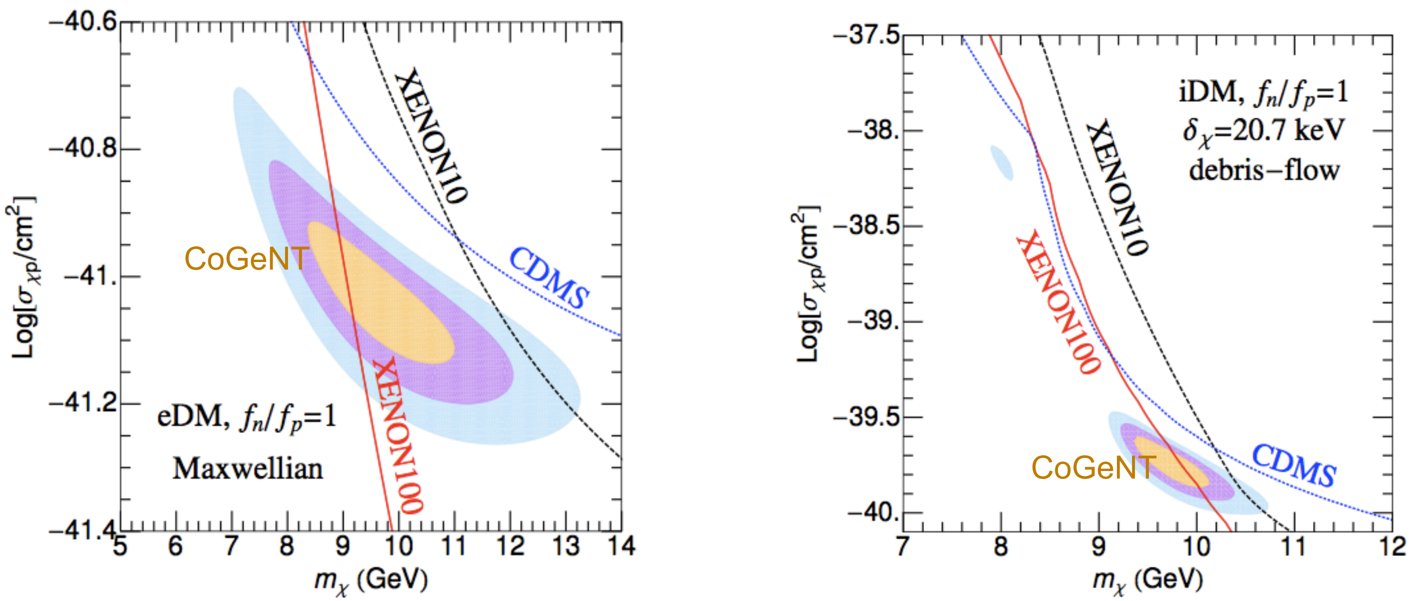
radial velocity

tangential velocity

Ling, Nezri, Athanassoula & Teyssier (2009)

Distribution changes the constraint for interaction

- Applying non-standard distribution (with other factors, like isospin violating, inelastic scattering…) can improve the situation to explain the discrepancy between positive and negative results of direct searches.



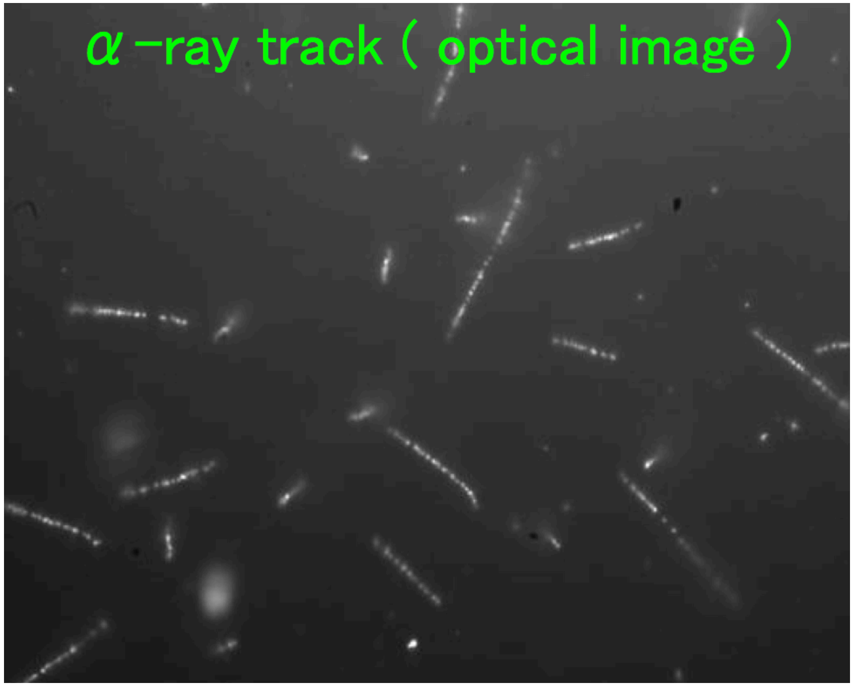
Cline,Liu, Xue (2012)

Nuclear Emulsion Detector

Nuclear Emulsion

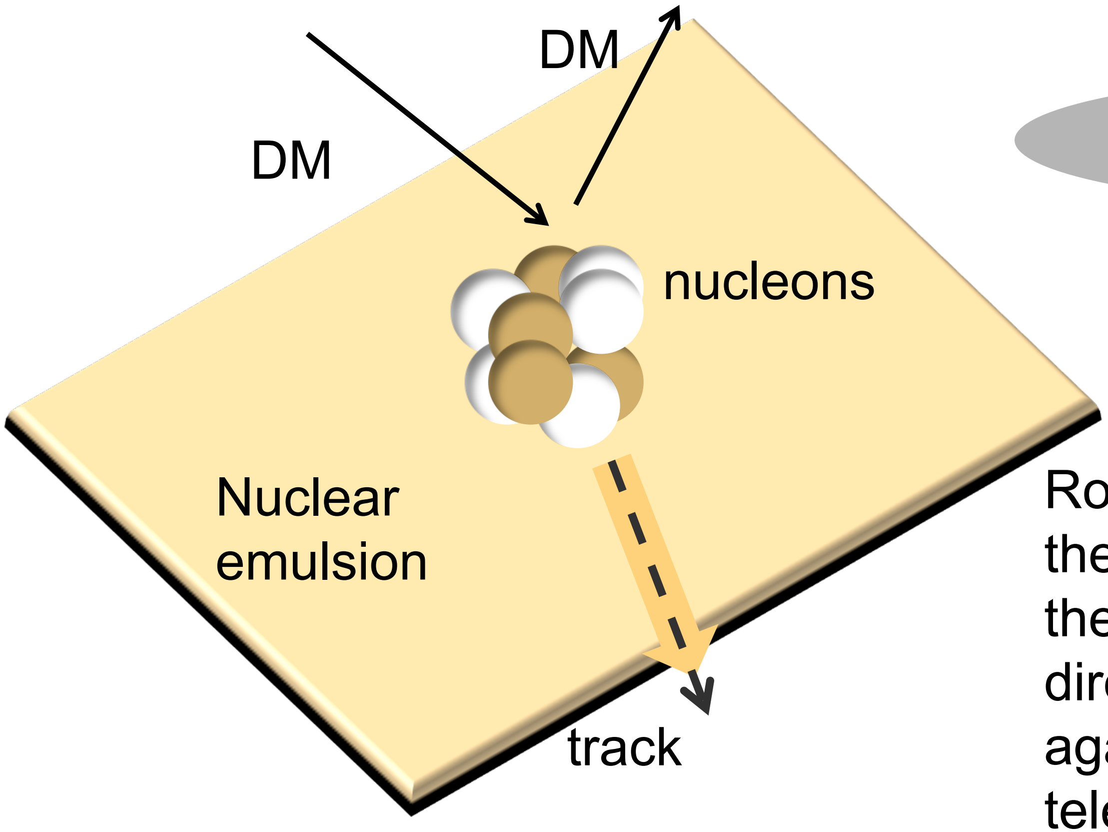
- Nuclear Emulsion
  - A kind of photographic film
  - 3D tracking detector for charged particle:

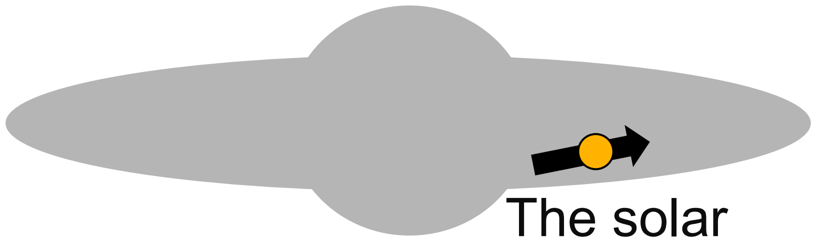
    Charged particle can expose silver halide crystals (AgBr) in films. After development treatment, the track appears as silver grains.



Concept of DM detection with nuclear emulsion

- Detection of **recoiled nucleus** from DM-nucleon scattering

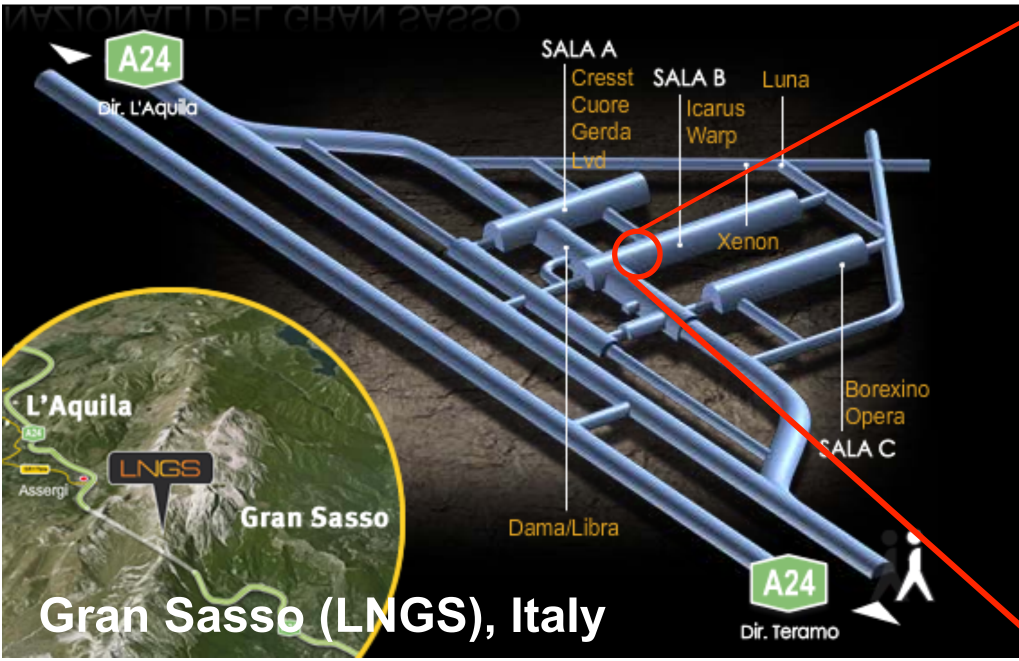


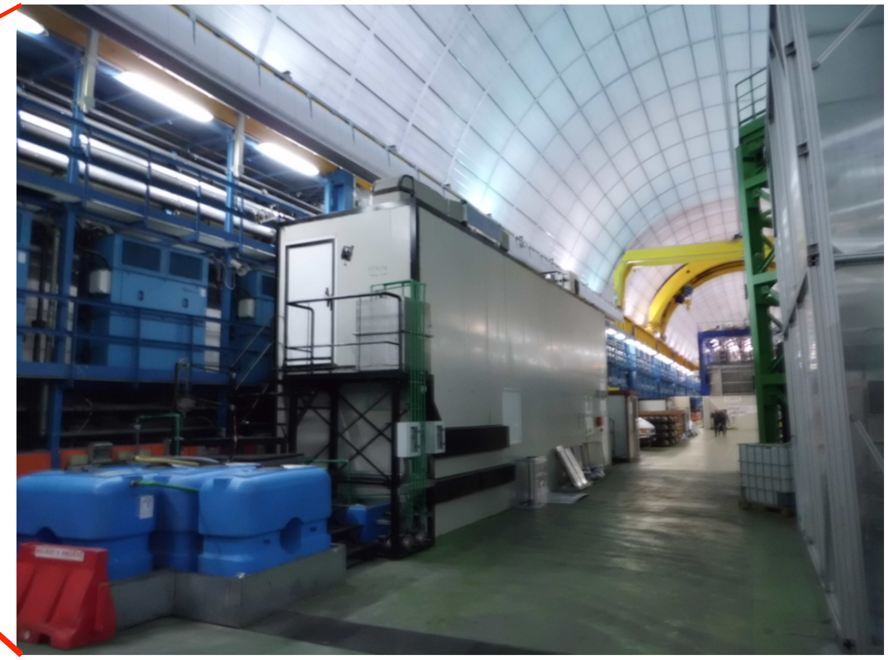


Rotation of the Earth can change the direction of detector toward the DM wind, however, detector direction can be kept to be against DM wind by an equatorial telescope.

Nuclear Emulsion Detector (I)

- Underground facility which had been used for OPERA project
- In research & development
- Taking BG data





GROUP:
- **Nagoya University**
- Napoli university
- Padova university
- LNGS

Nuclear Emulsion Detector (II)

- Advantages
  - High sensitivity :

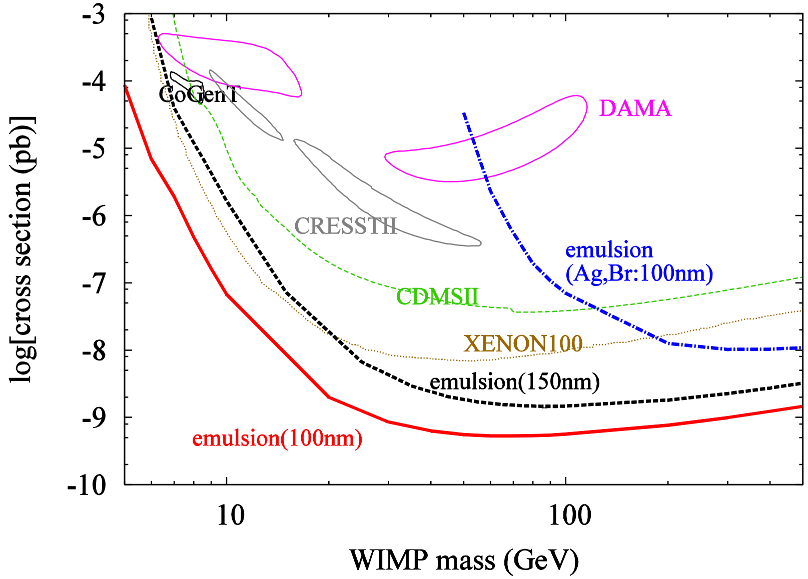
    solid target + large mass

    (O(100) kg)
  - High spatial resolution

    Angular resolution: 15-20°

    Spatial resolution: 100 nm
  - Low cost (150,000 yen/kg

    ～41,500 NTD/kg)



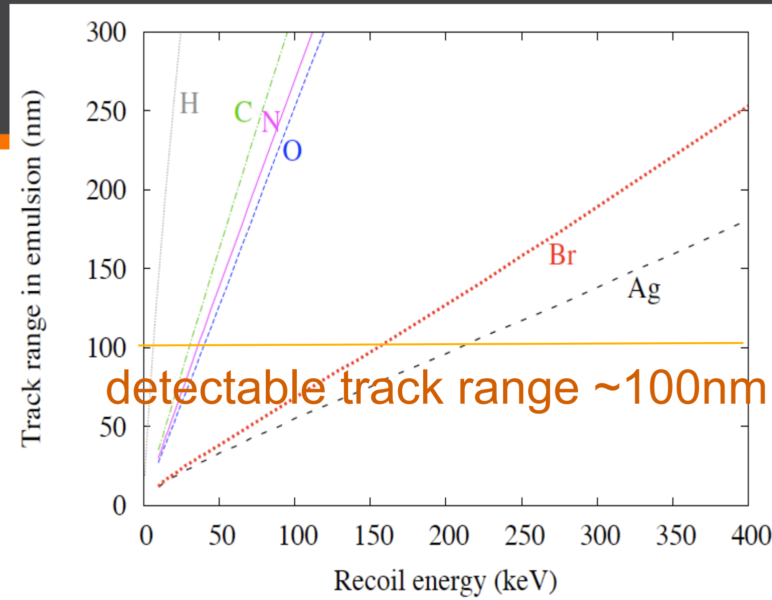
1000kg・year, 90%C.L.

Energy threshold

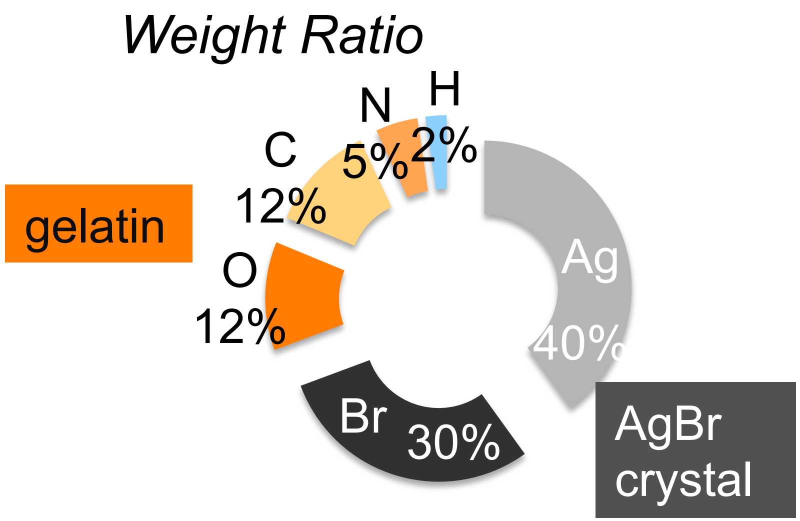
- Target
  - Ag, Br, C, N, O
  - Energy threshold : depends on target

    (~33 keV for C, N, O and

    ~150 keV for Ag, Br)



- For O(10)-O(1000)GeV mass DM
  – Typical recoil energy :O(1)-O(100)keV
  – Required resolution is submicron (~O(100)nm) track length

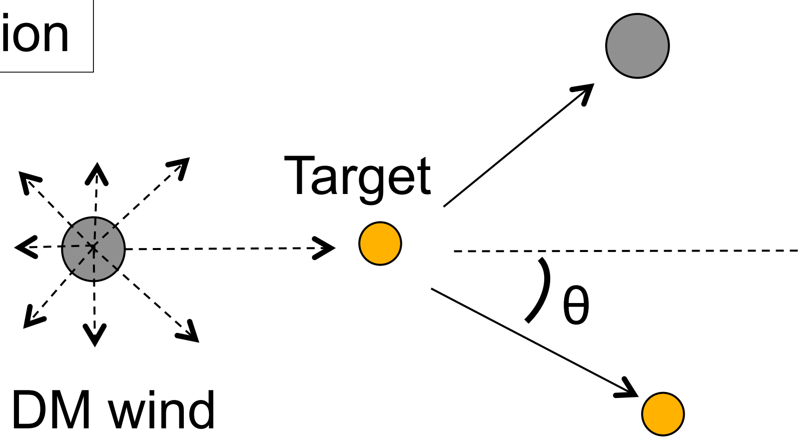


Velocity Distribution observed in the Directional Detector

Can we distinguish the velocity distribution?

- In the directional direct search, we can see both the scattering angle and the recoil energy.

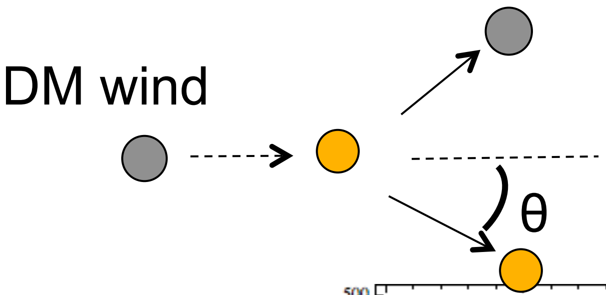
Calculation



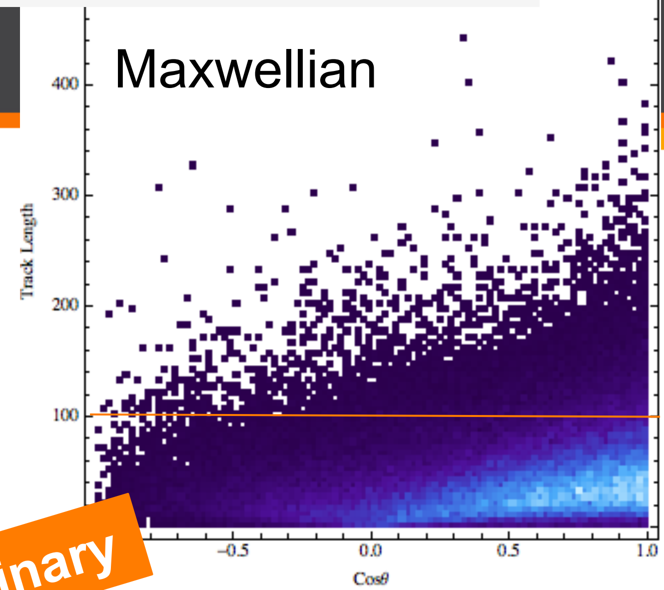
- Monte Carlo simulation
- Simple elastic scattering
- Scattering angle– Recoil energy (track length) distribution

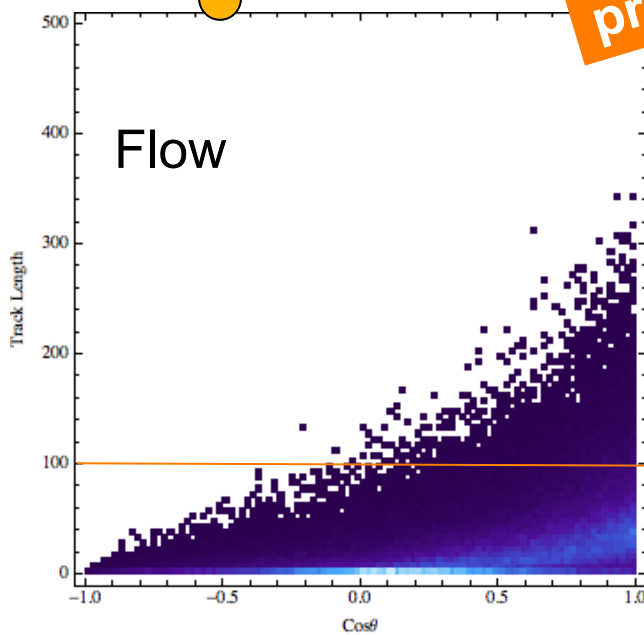
Track Length for light DM

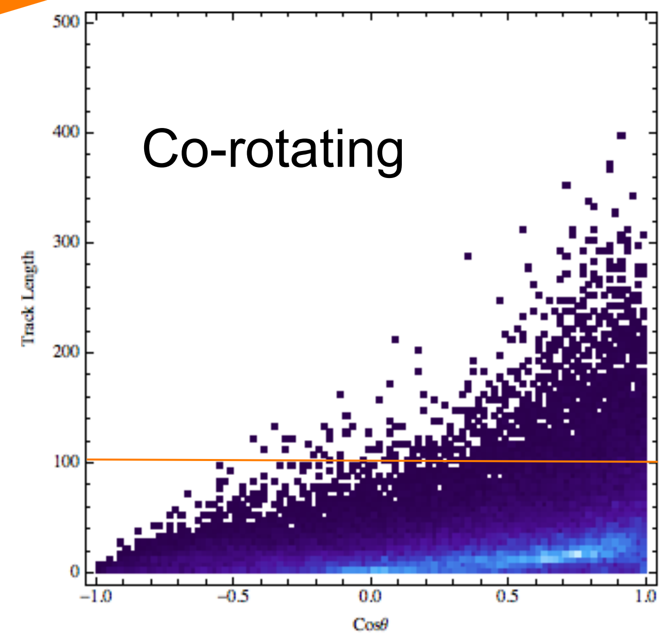
- DM mass :200 GeV
- Target: realistic component of emulsion (Ag, Br, C, N, O)



cos(θ) - track length [nm]



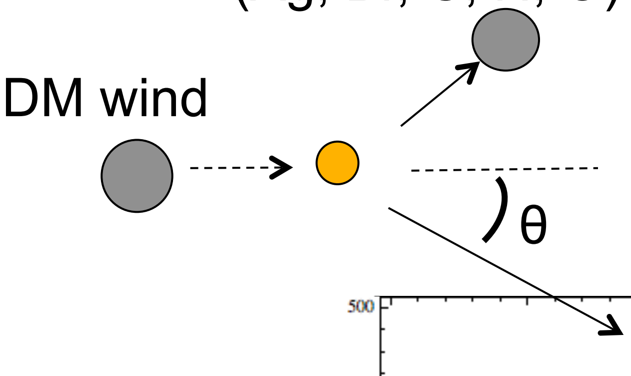




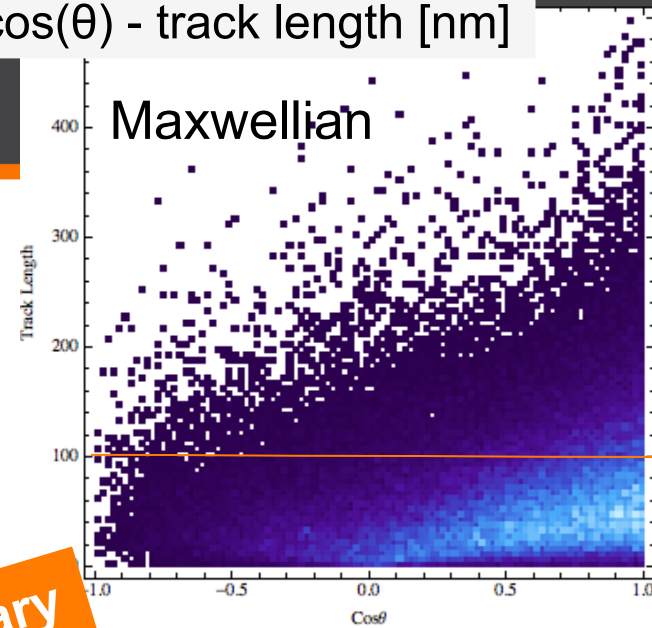
preliminary

Track Length for heavy DM

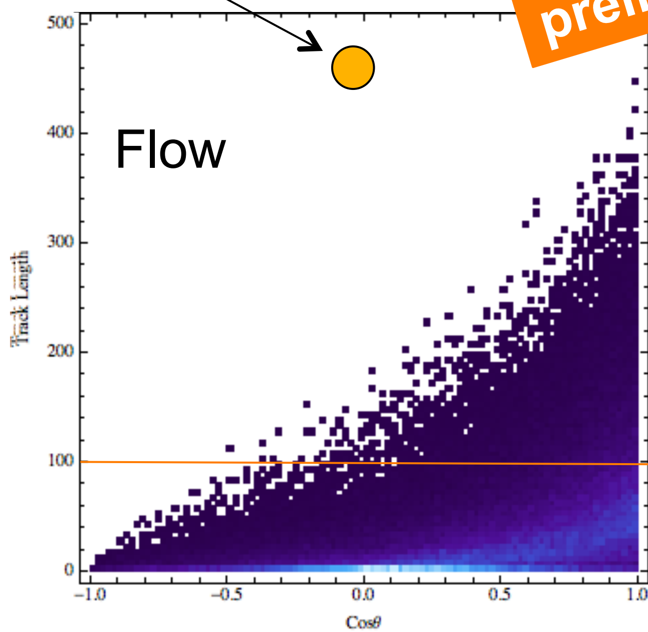
- DM mass :800 GeV
- Target: realistic component of emulsion (Ag, Br, C, N, O)

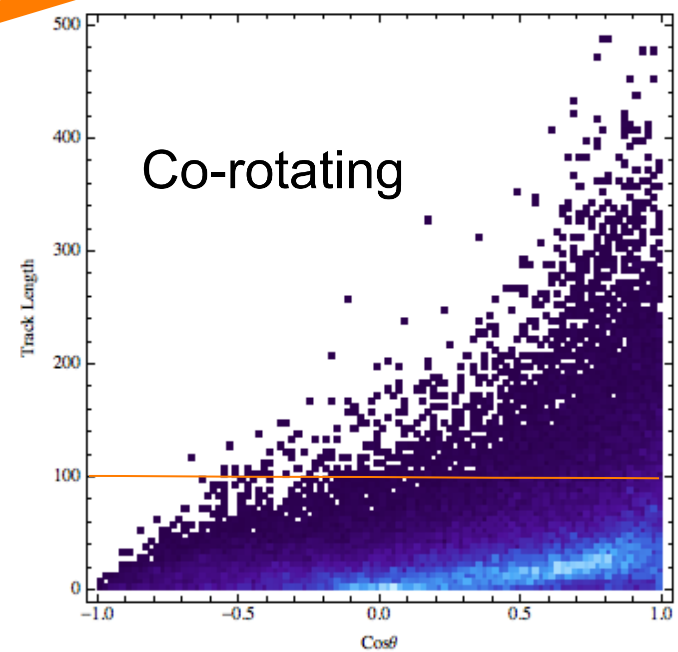


cos(θ) - track length [nm]



preliminary





Summary & Discussion

- I discussed the possibility to distinguish the distribution models of dark matter in the direct detection, focusing on the nuclear emulsion experiments.
- Distribution shape of the scattering angle and the energy density is affected by the distribution model. If the number of DM signal is enough, it seems possible to give a constraint for the velocity distribution model.

Backup Slides

Inelastic DM (iDM)

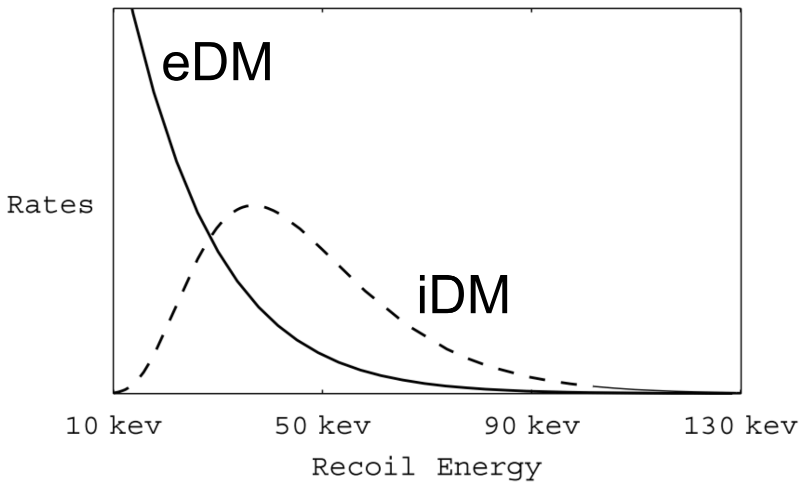
Hall, Moroi, Murayama 1997
Smith, Weiner 2001

- mass degenerate DMs (χ, χ^*)

$\chi + N \rightarrow \chi^* + N$ $\quad (m_{\chi^*} = m_\chi + \delta, \ \delta \sim 100\text{-}150 \text{ keV})$

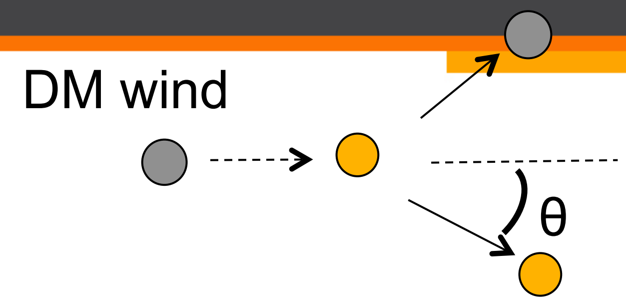
- ✓ inert doublet model (Arina, Ling, Tytgat 2009)
- ✓ magnetic inelastic DM (Chang, Weiner, Yavin 2010)
- ✓ composite inelastic dark matter (Alvesa et al. 2010)
- … etc.

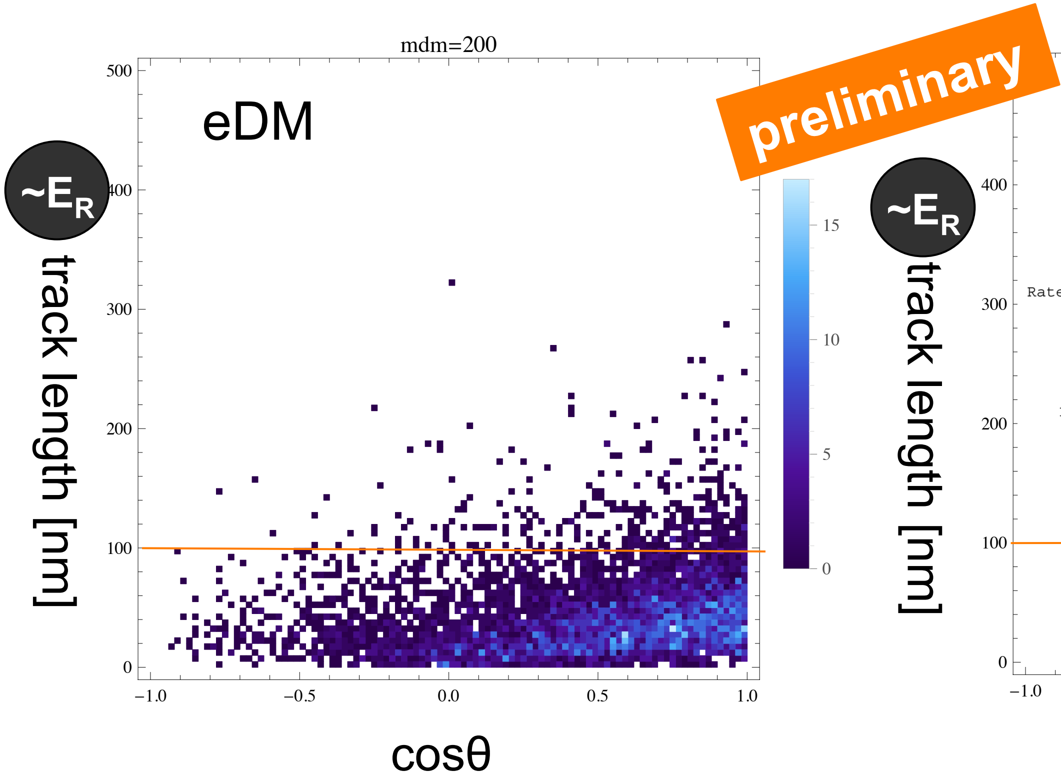
- Recoil Energy

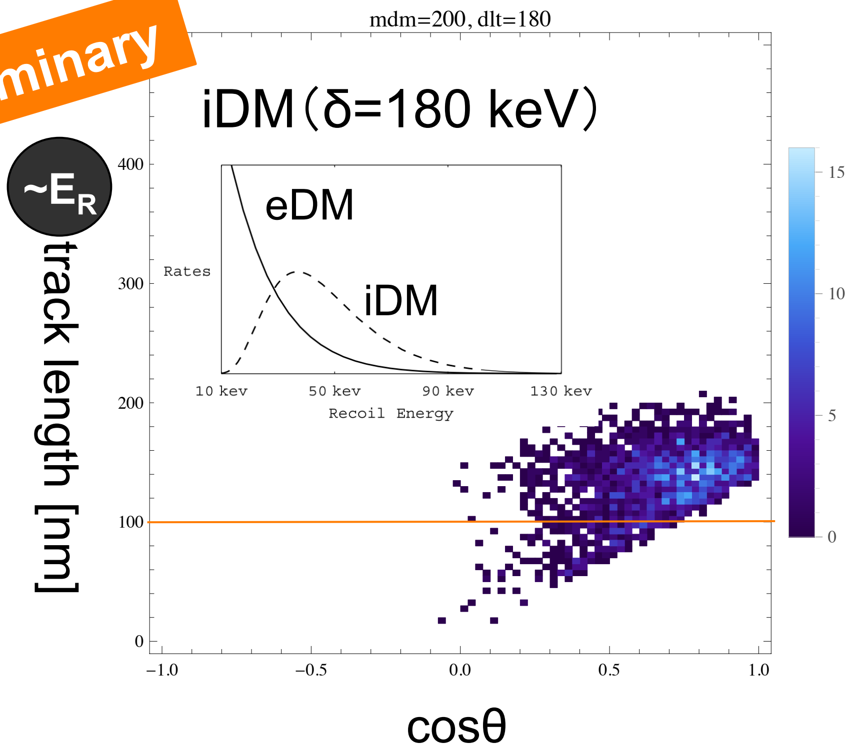


Event Distribution

- DM mass : 200 GeV
- Target :Ag, Br, C, N, O







BG rejection -summary-

- Radioactive sources from outside : β, p, μ
  - Sensitivity control, point-like signal
- Internal BG sources : β, (γ)
  - ^{40}K mixed in when KBr→AgBr, can be avoided by using NaBr instead of KBr
  - ^{14}C (β-ray induced by γ makes the grains which has Plasmon resonance effects, i.e., we can distinguish them by color obs.)
- Neutron from rocks
  - Neutron shield, sensitivity control
- Others
  - Underground, isotoropic angular distribution

Contents of nuclear emulsion

		Weight(%)	A_i(abundance)	
AgBr crystal	Ag	39.65	107(51.84)	109(48.16)
	Br	29.01	79(50.69)	81(49.31)
gelatin	O	11.76	16	
	C	11.72	12(98.9)	13(1.1)
	N	4.57	14	
	H	2.27	1	
	S	0.05	32(95.02)	34(4.2)
	I	0.96	127	

Periodic Table