Measuring Velocity Distribution of Dark Matter by Directional Detection

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Collaboration with

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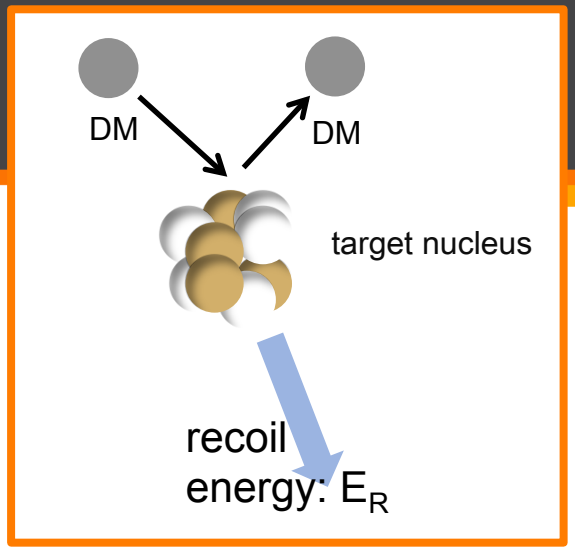
Direct Detection



- Direct search for DM
  - Detecting the recoil energy that a DM particle scatters a target nucleon.

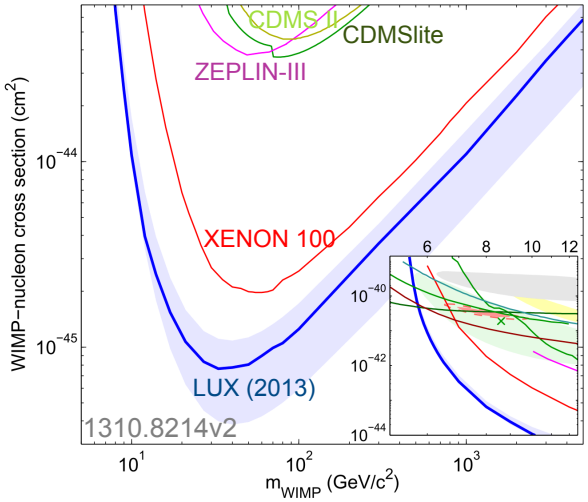
- Constraint for DM-nucleon interaction cross section can be obtained from the event number

Particle + nuclear phys.

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

Experiment

Astronomy



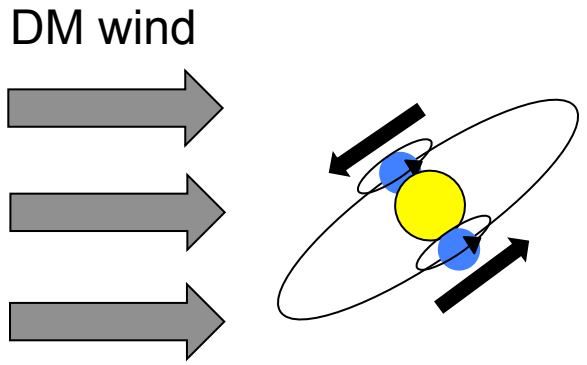
OUTLINE

1. ~~Introduction~~
2. Directional Dark Matter Detection
3. Velocity Distribution of Dark Matter
4. NEWS: Nuclear Emulsion Detector
5. Velocity Distribution Observed in the Directional Detector

To next generation: Directional detection

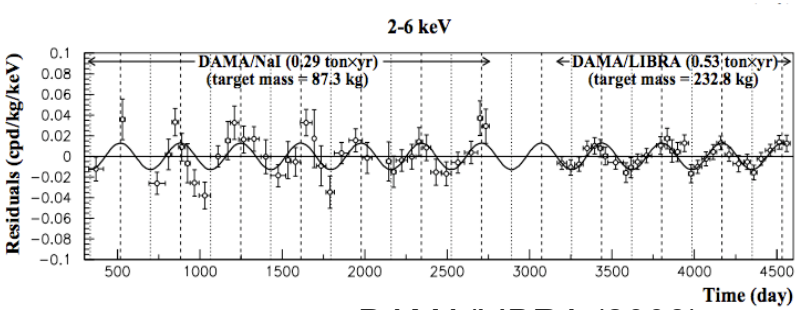
■ Directional Detection

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



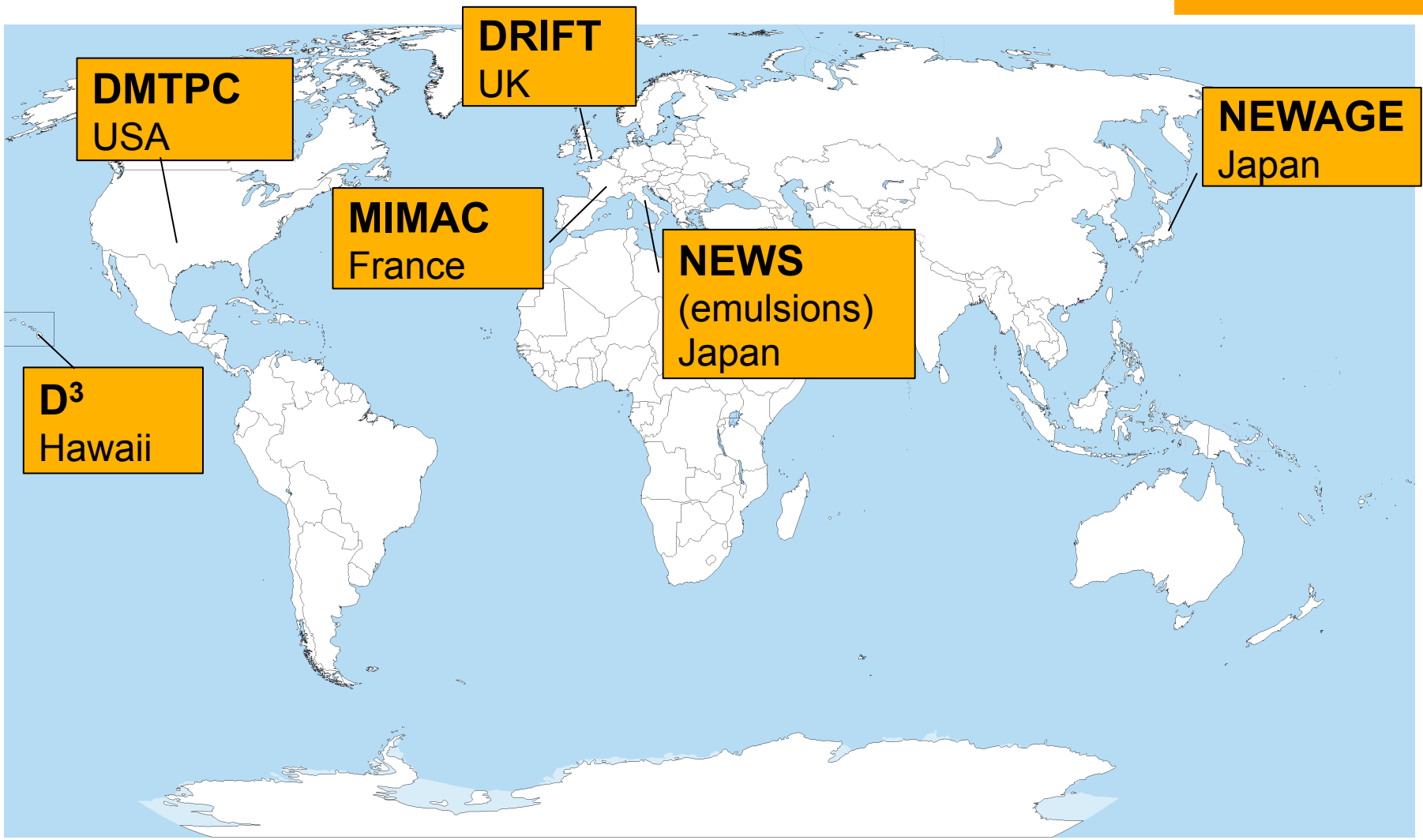
■ Advantages

- **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.

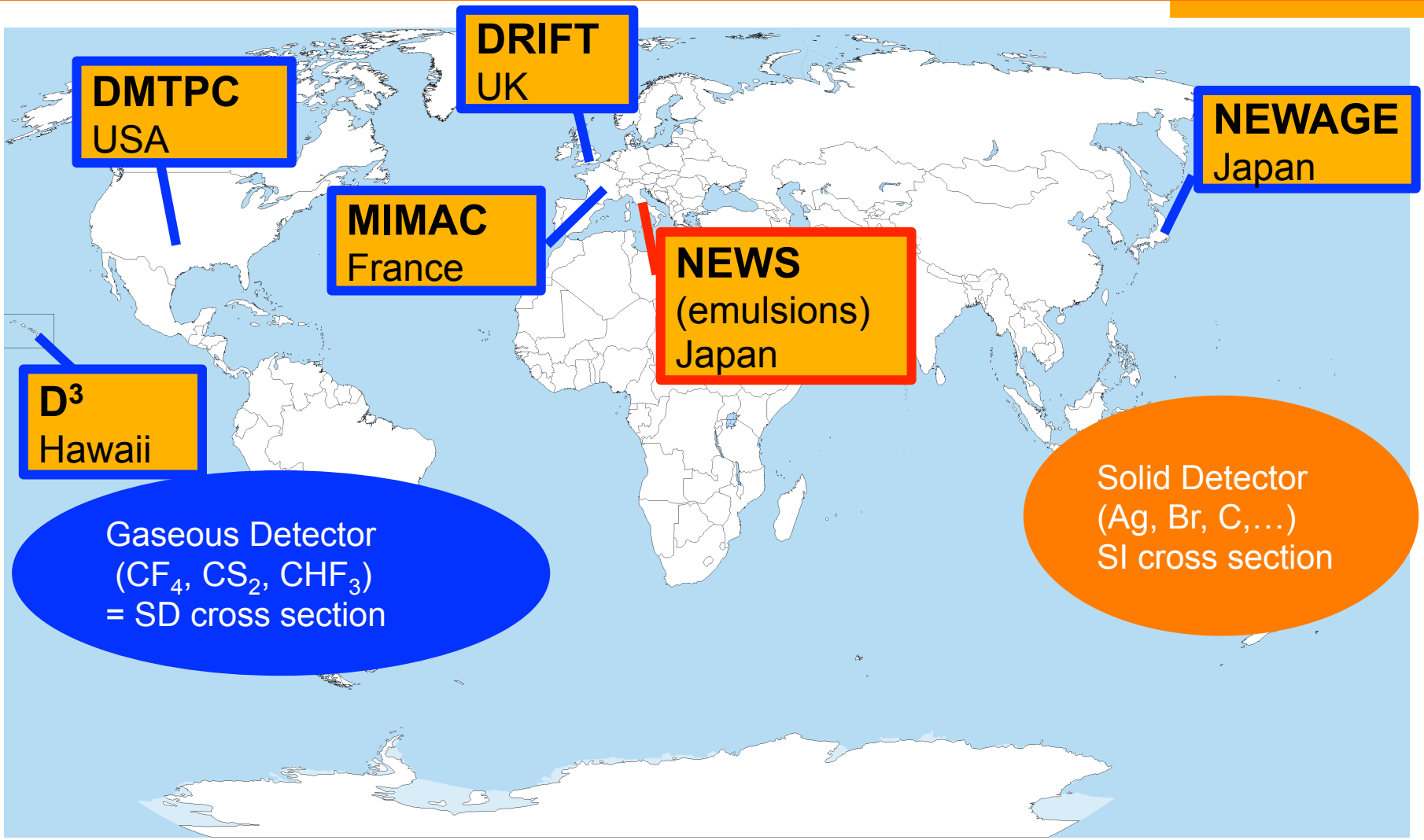


DAMA/LIBRA (2008)

Directional Dark Matter Searches



Directional Searches



We can be more ambitious?

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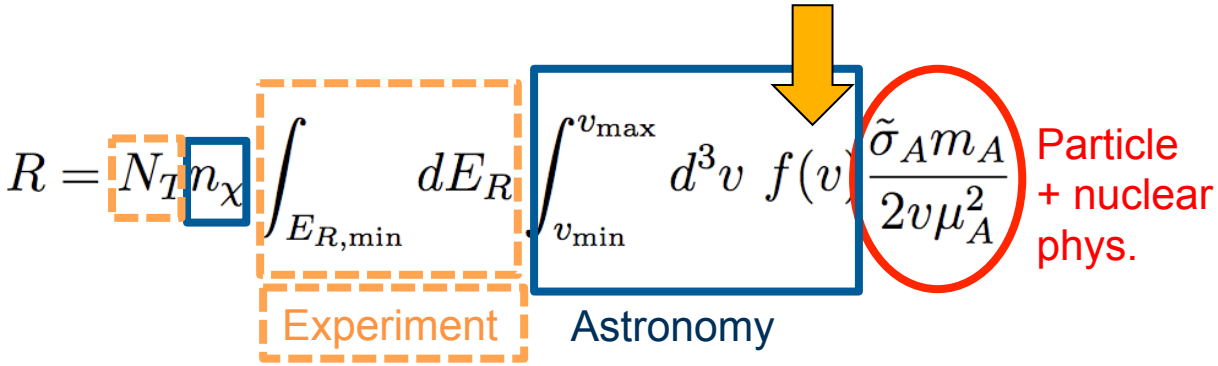
More ambitious…

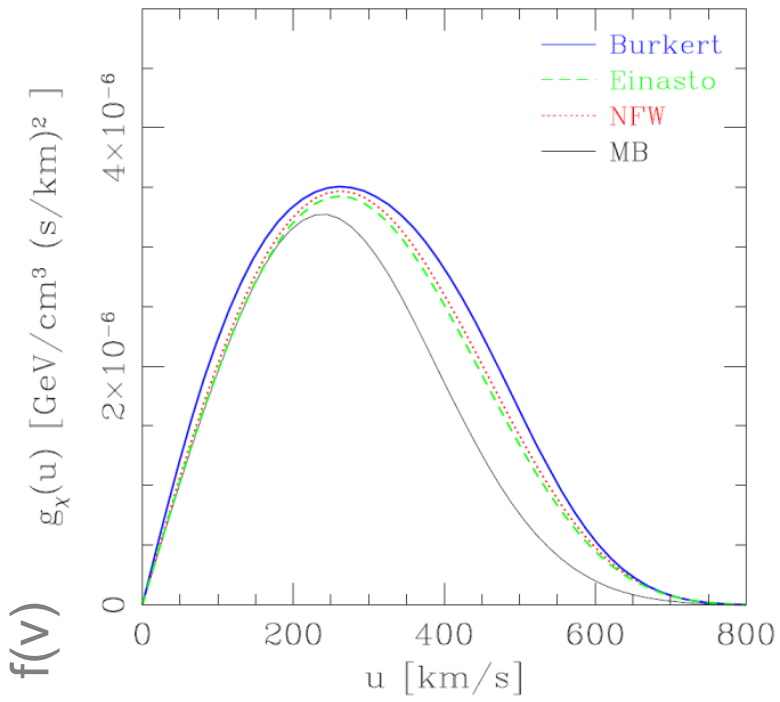
- Velocity distribution
  In the directional DM search, **it can be possible to make a constraint for f(v)**.

- Constraint from direct detections depends on DM distribution



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

DM Velocity Distribution -Standard Distribution-



Catena and Ullio (2012)

- Maxwell distribution

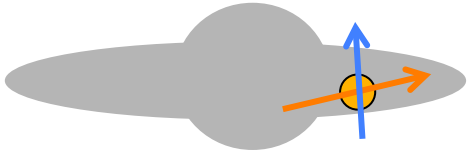
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$

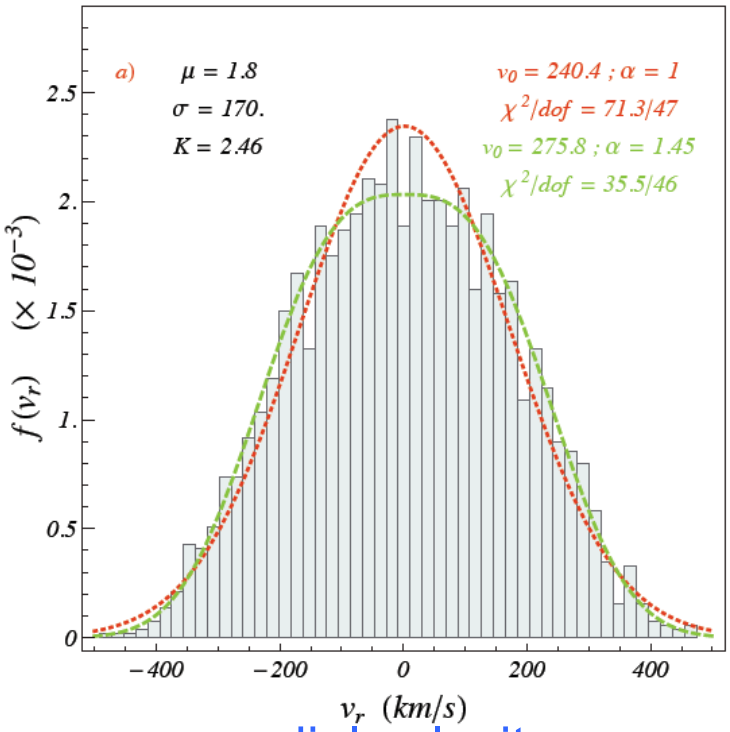
v_0: velocity of the Solar system
v_E: Earth's velocity relative to DM

- Is distribution surely isotropic?

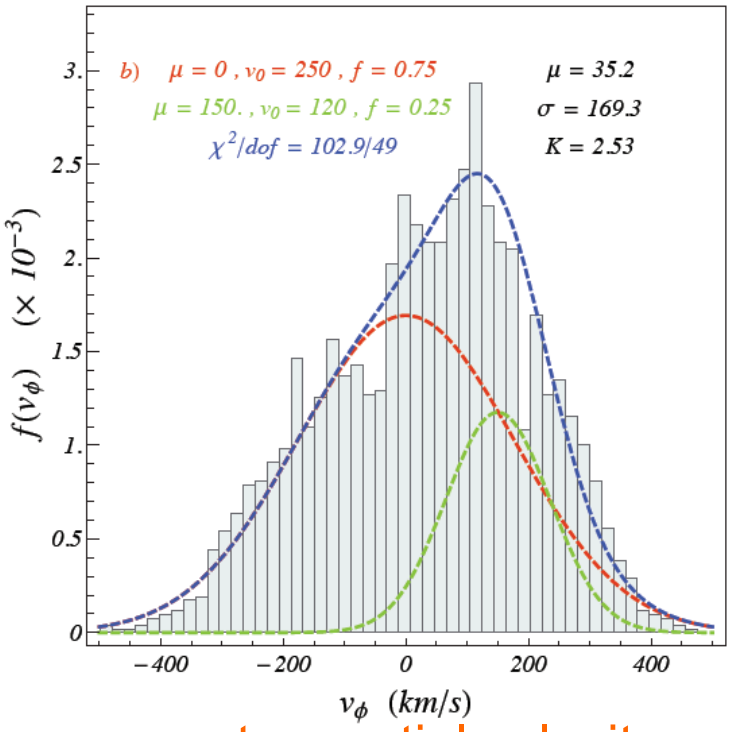
Co-rotating DM

- 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)

NEWS: Nuclear Emulsion Detector

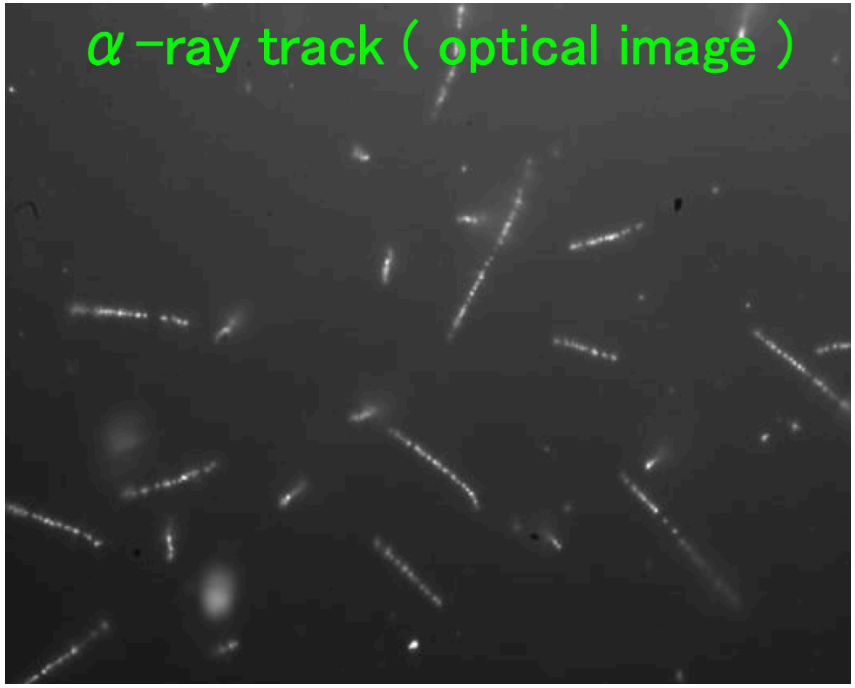
talk by Murat Ali Guler
in last session today

Nuclear Emulsion

– A kind of photographic film

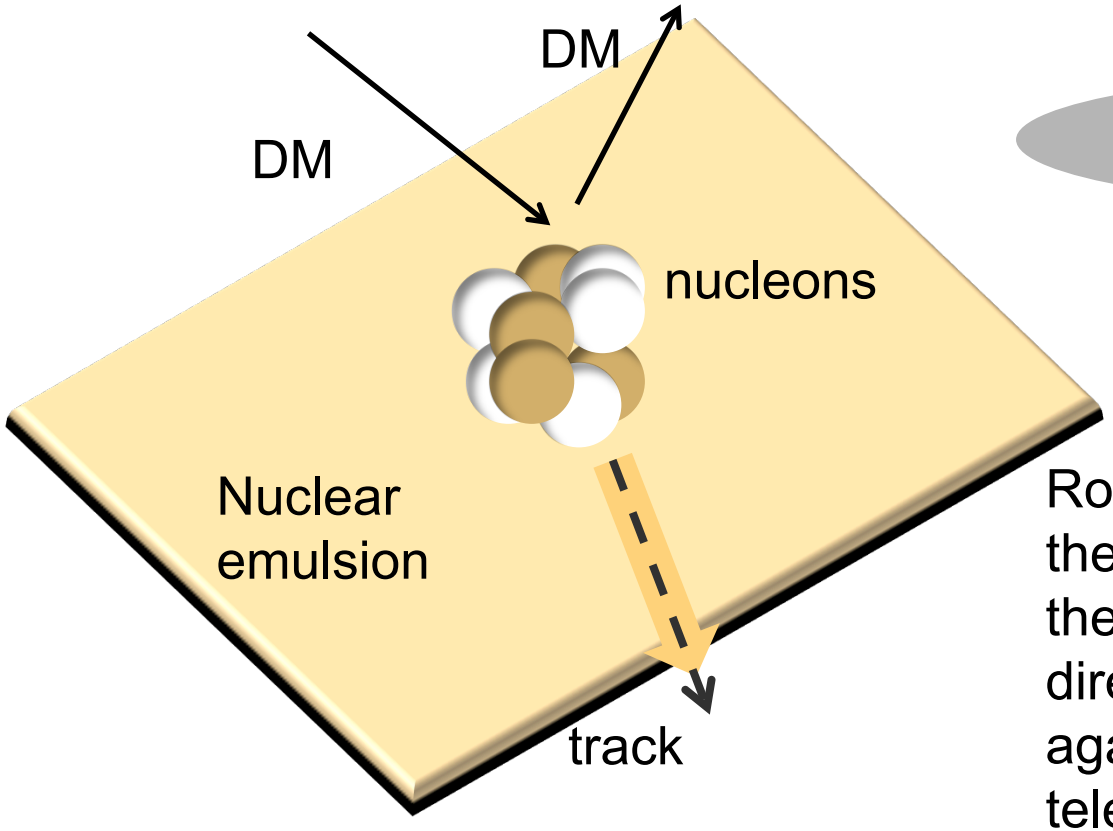
– 3D tracking detector for charged particle:

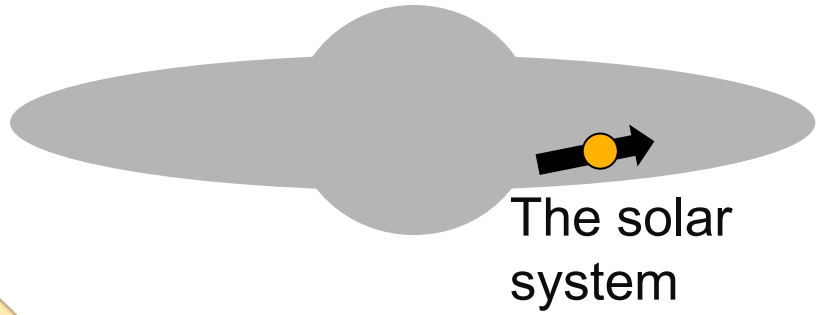
Charged particle can expose silver halide crystals (AgBr) in films. After development treatment, the track appears as silver grains.



Concept of DM detection with nuclear emulsion

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

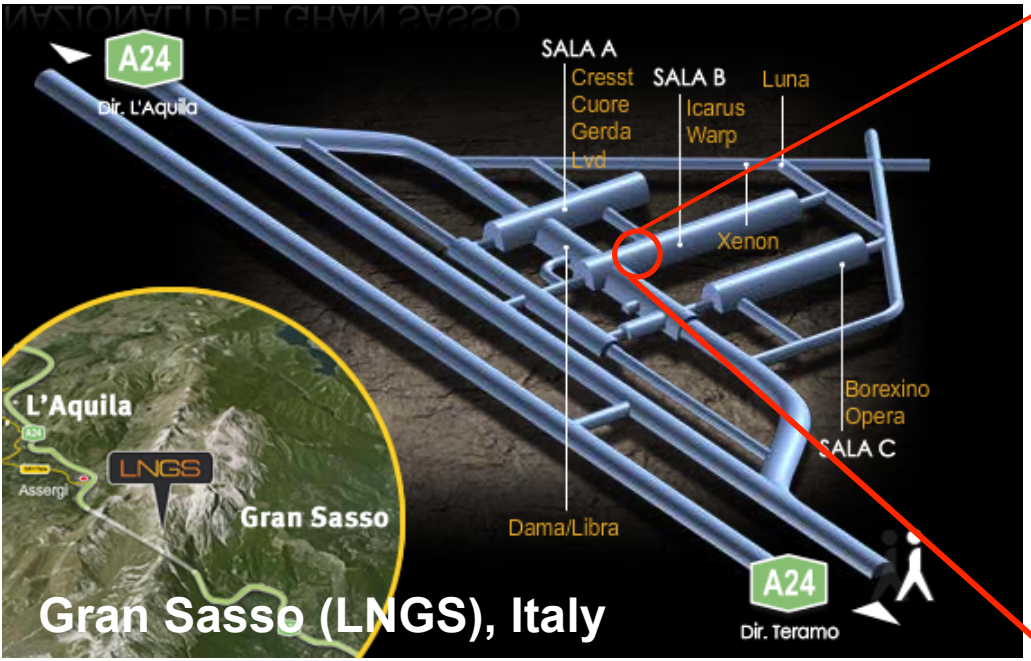


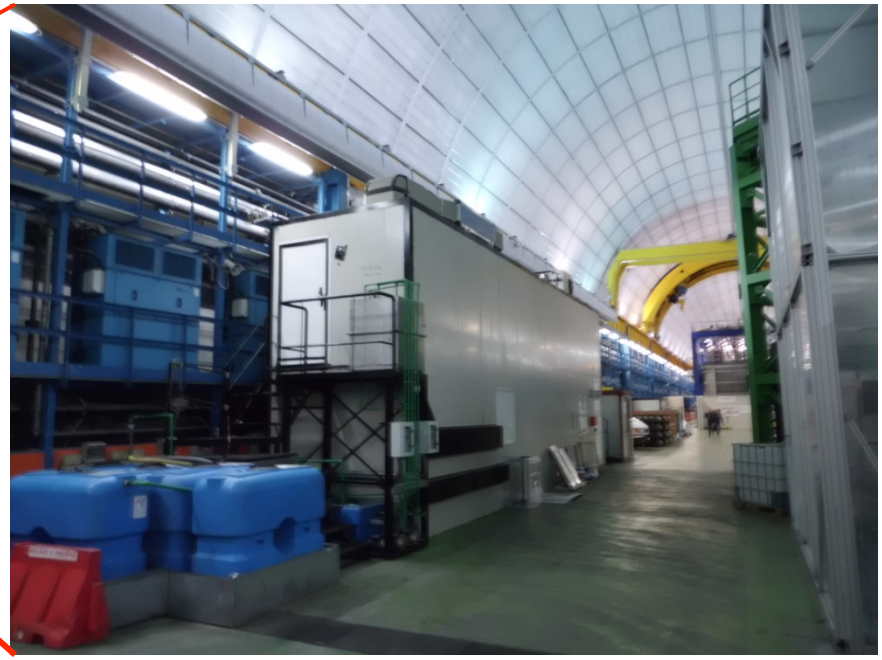


Rotation of the Earth can change the direction of detector toward the DM wind, however, detector direction can be kept to be against DM wind by an equatorial telescope.

NEWS (Nuclear Emulsions for WIMP Search)

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





NEWS (Nuclear Emulsions for WIMP Search) II

- High sensitivity :

  solid target + large mass (O(100) kg)

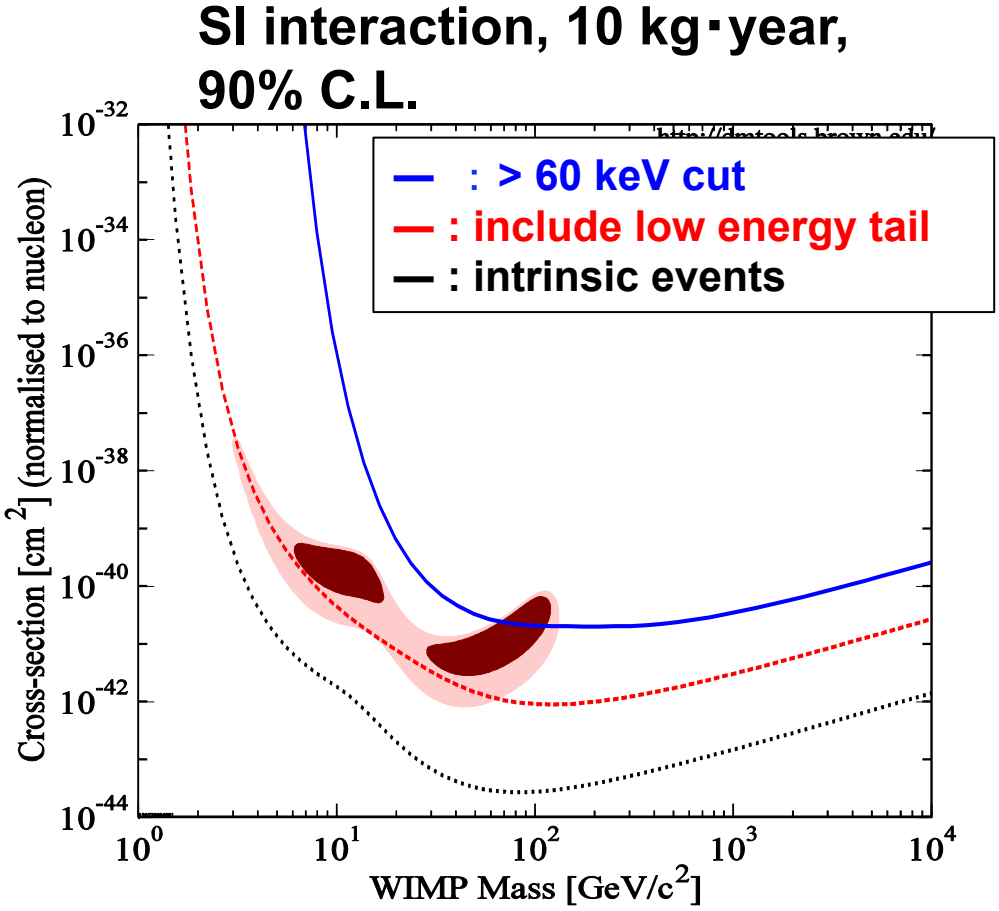
- High spatial resolution

  Angular resolution: 35°

  Spatial resolution: 50 nm

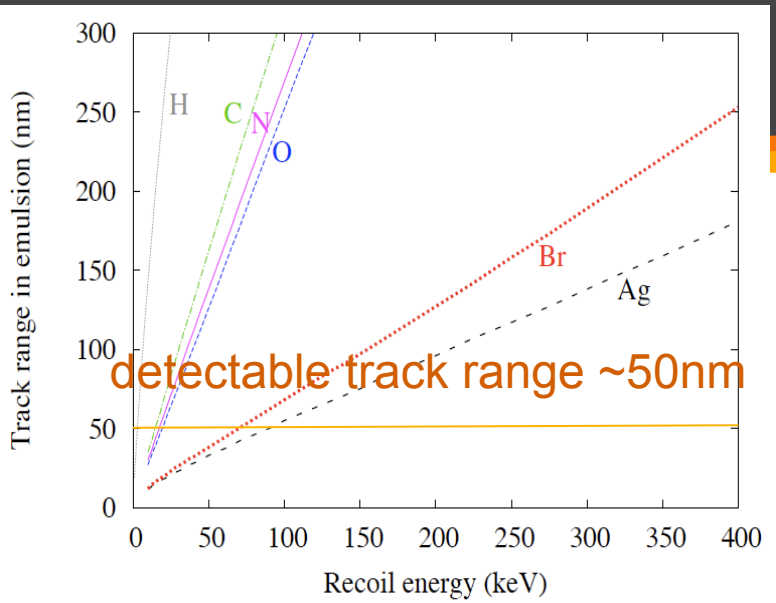
- Low cost

  150,000yen/kg~1500$/kg

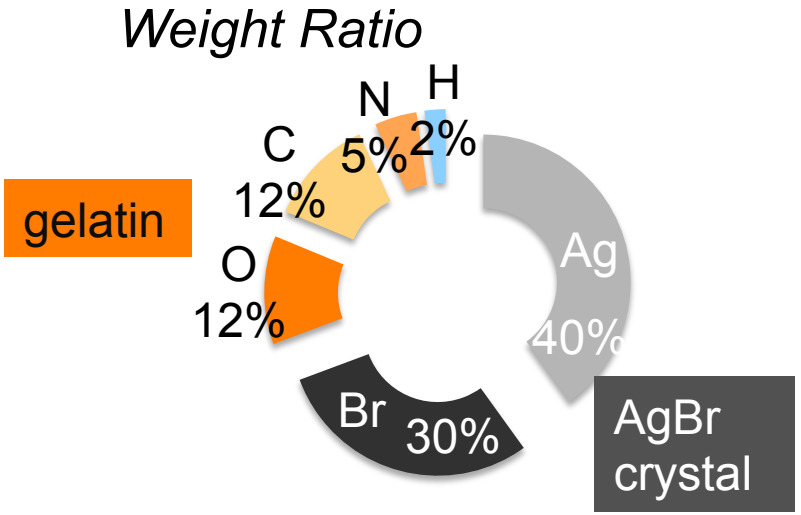


Energy threshold

- Target
  - Ag, Br, C, N, O
  - Energy threshold : depends on target
    (~20 keV for C, N, O and
    ~60 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

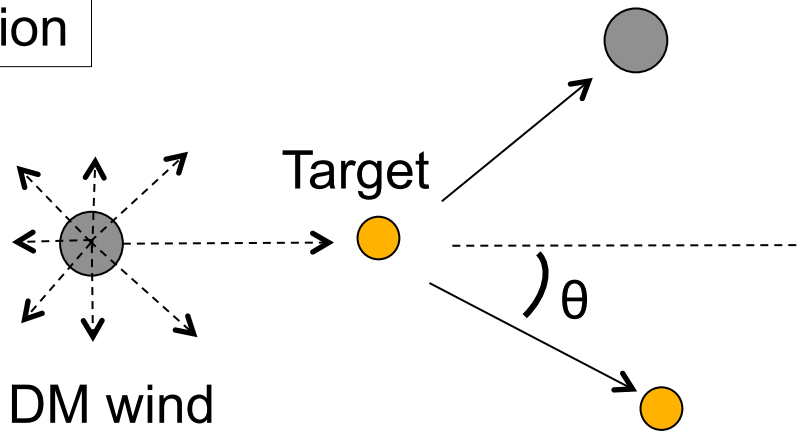


Velocity Distribution observed in the Directional Detector

Can we distinguish the velocity distribution?

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

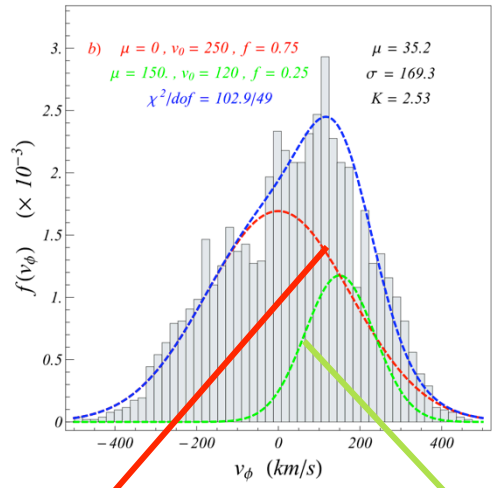
Calculation



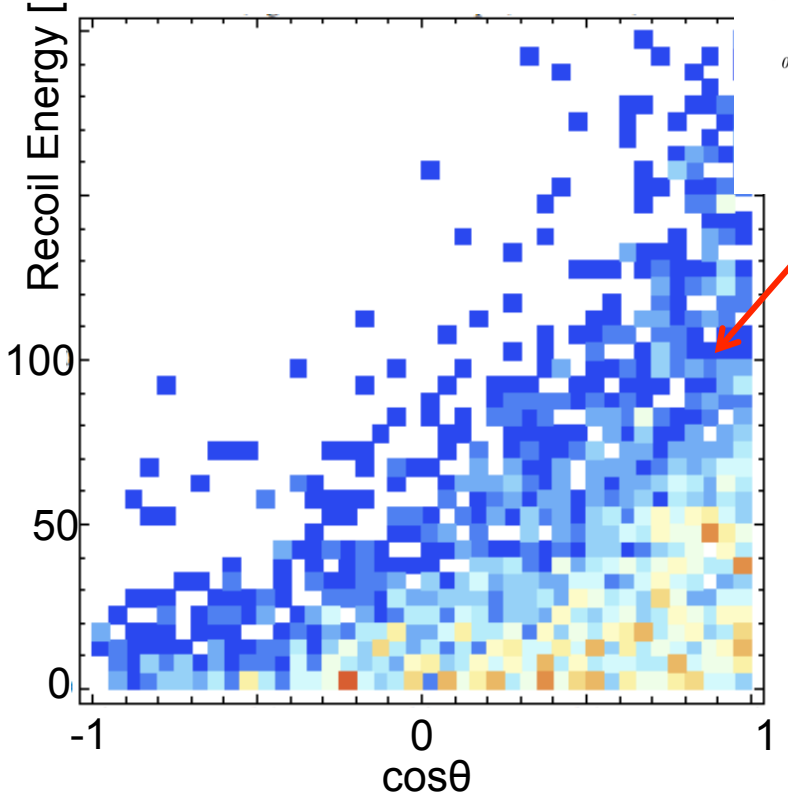
- Monte Carlo simulation
- Simple elastic scattering
- Scattering angle– Recoil energy (track length) distribution

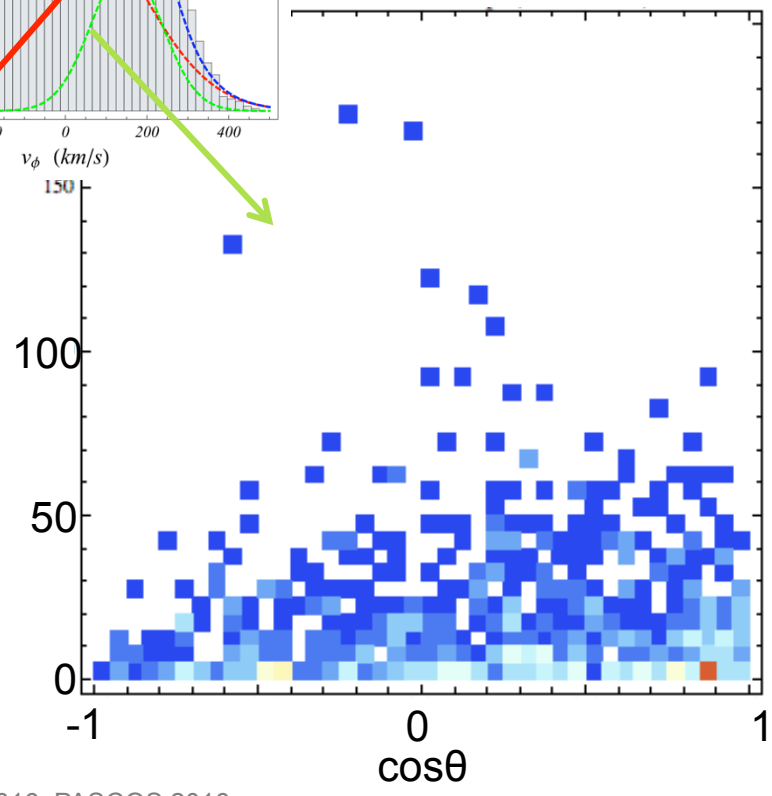
Anisotropy in the directional detection

Anisotropic component of double Gaussian gives small E_R signals, even in cosθ<0 region.

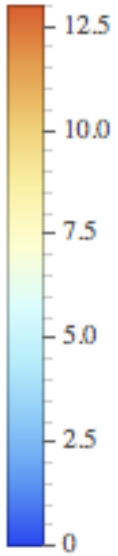


target: Ag
$\sigma=10^{-45}cm^2$
/kg/yr

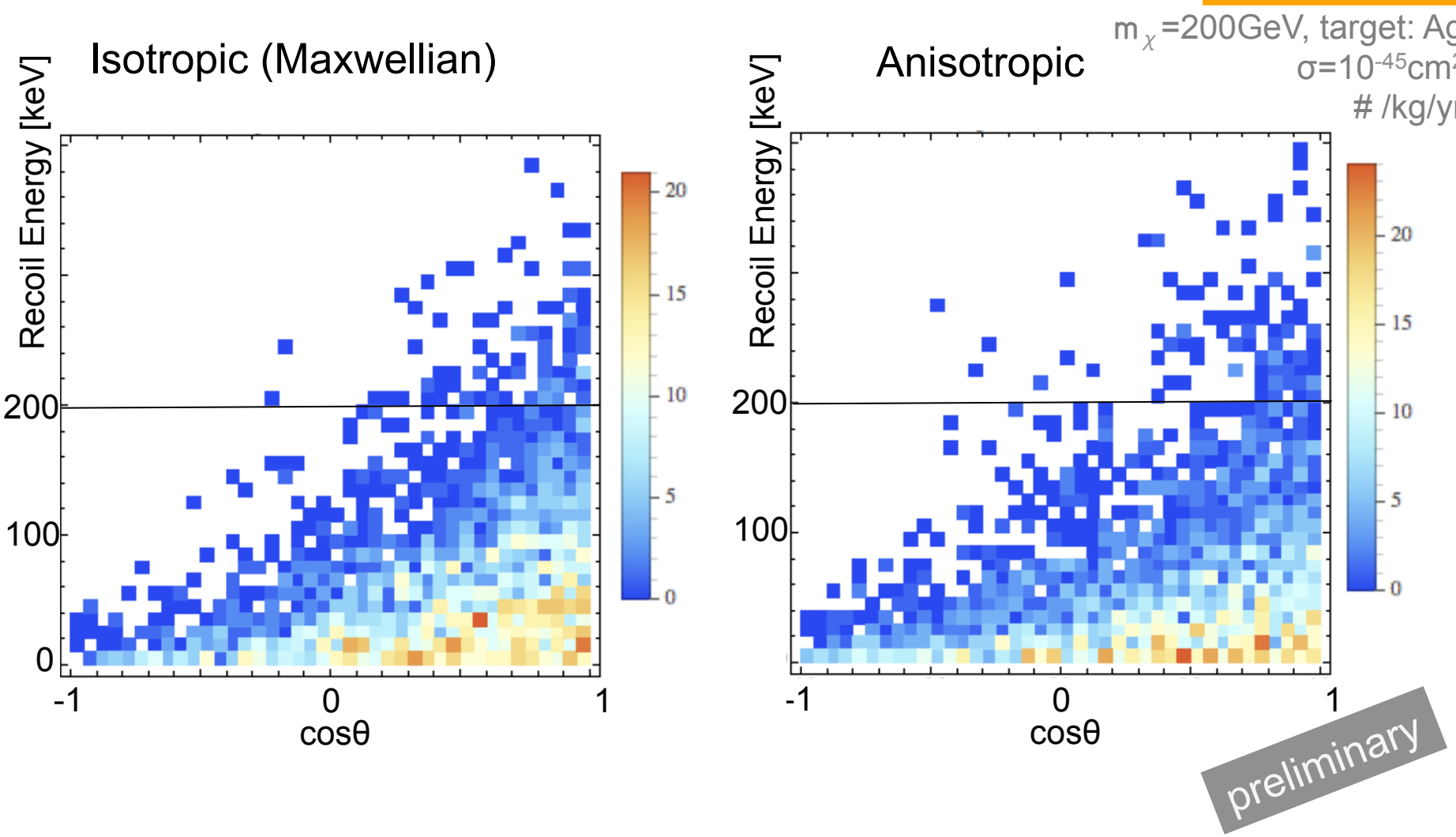




#signal



Anisotropy in the directional detection (2)

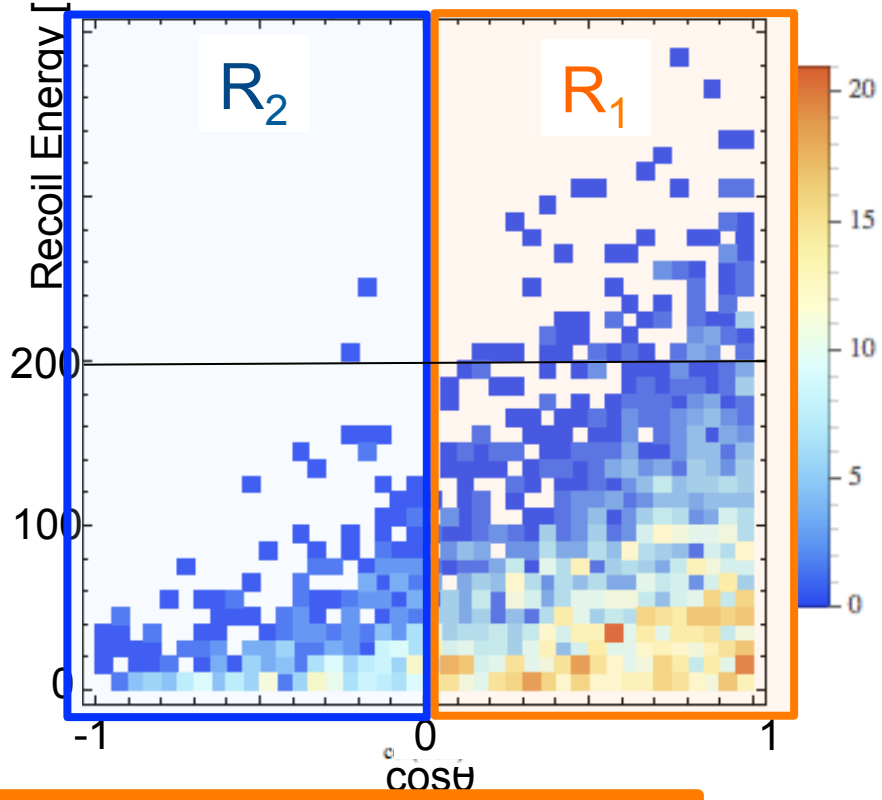


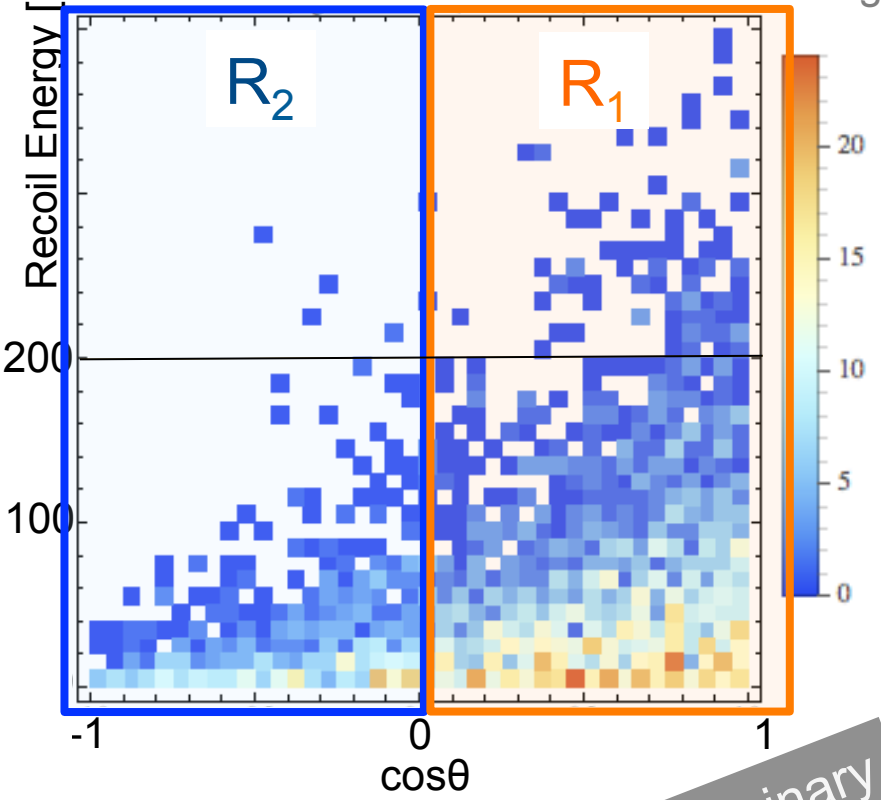
Anisotropy in the directional detection (2)

Isotropic (Maxwellian)

Anisotropic

m_χ=200GeV, target: Ag
$\sigma=10^{-45}cm^2$
/kg/yr





preliminary

$$R = \frac{R_1}{R_2} = \frac{\#\text{signal } (\cos\theta>0)}{\#\text{signal } (\cos\theta<0)}$$

R=77.1

R=14.2

Summary & Discussion

- I discussed the possibility to distinguish the distribution models of dark matter in the direct detection, focusing on the NEWS (emulsion).
- Signal number of $\cos\theta>0$ is larger for isotropic distribution case than that for anisotropic case, which is useful to distinguish two models.

Backup Slides

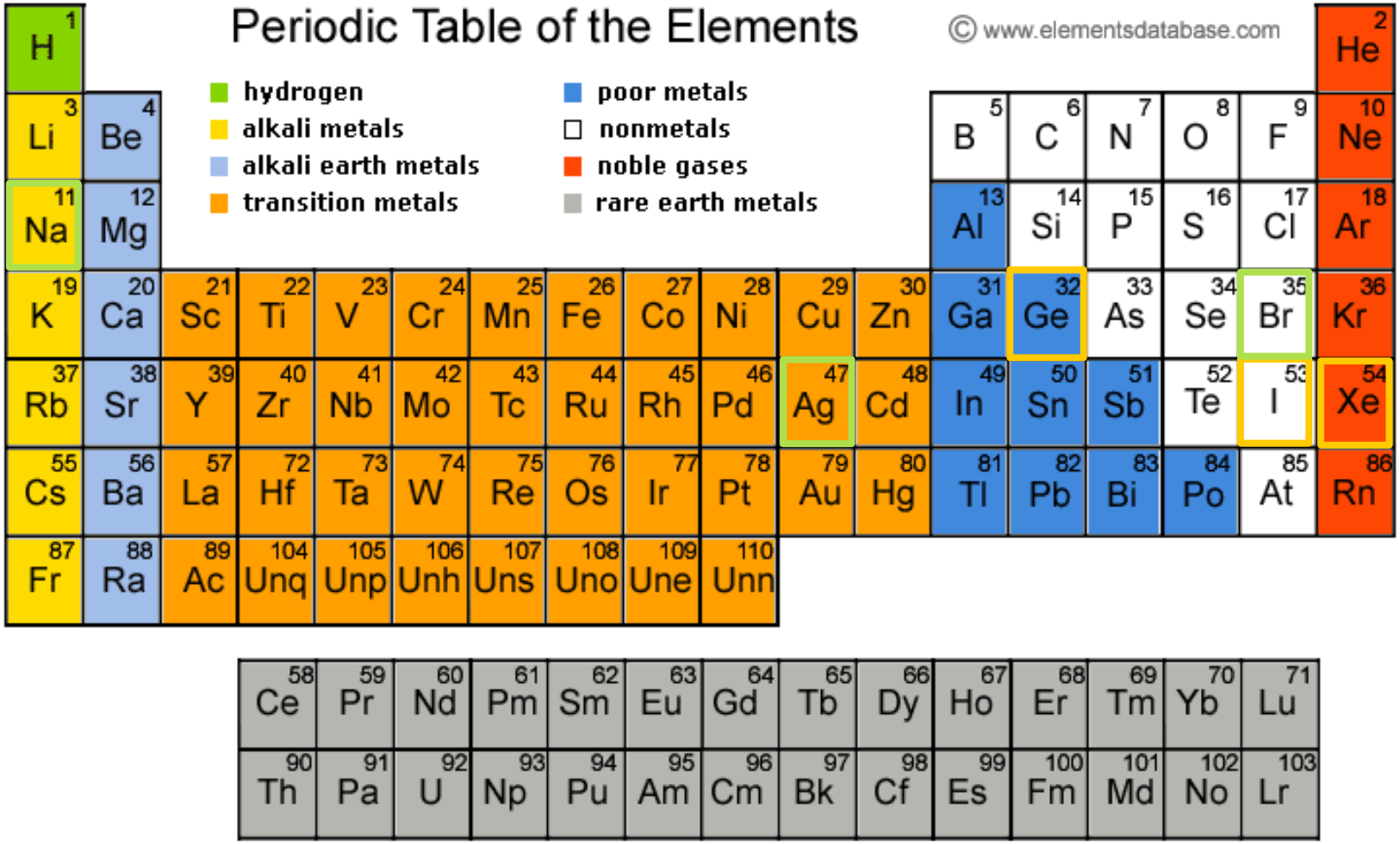
BG rejection -summary-

- 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

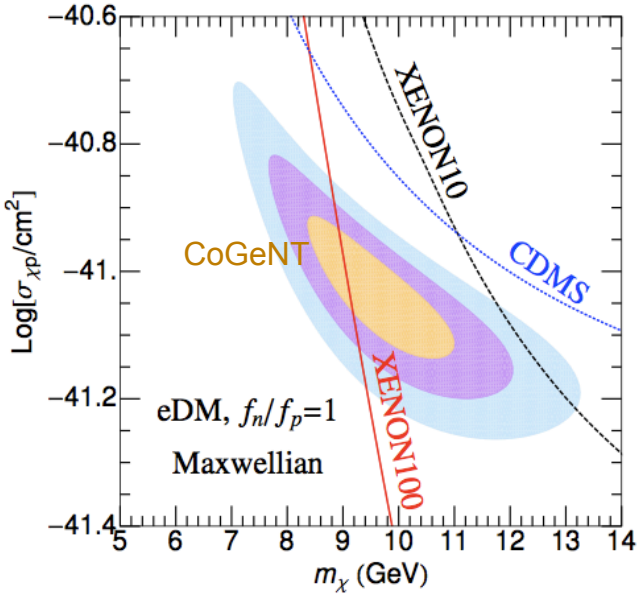
		Weight(%)	A_i(abundance)	
AgBr crystal	Ag	39.65	107(51.84)	109(48.16)
	Br	29.01	79(50.69)	81(49.31)
gelatin	O	11.76	16	
	C	11.72	12(98.9)	13(1.1)
	N	4.57	14	
	H	2.27	1	
	S	0.05	32(95.02)	34(4.2)
	I	0.96	127	

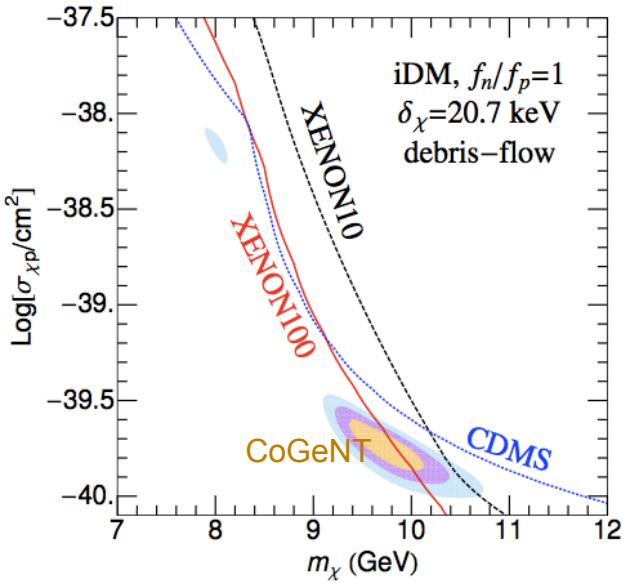
Periodic Table



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)