Keiko Nagao
(Okayama Univ. of Sci.)
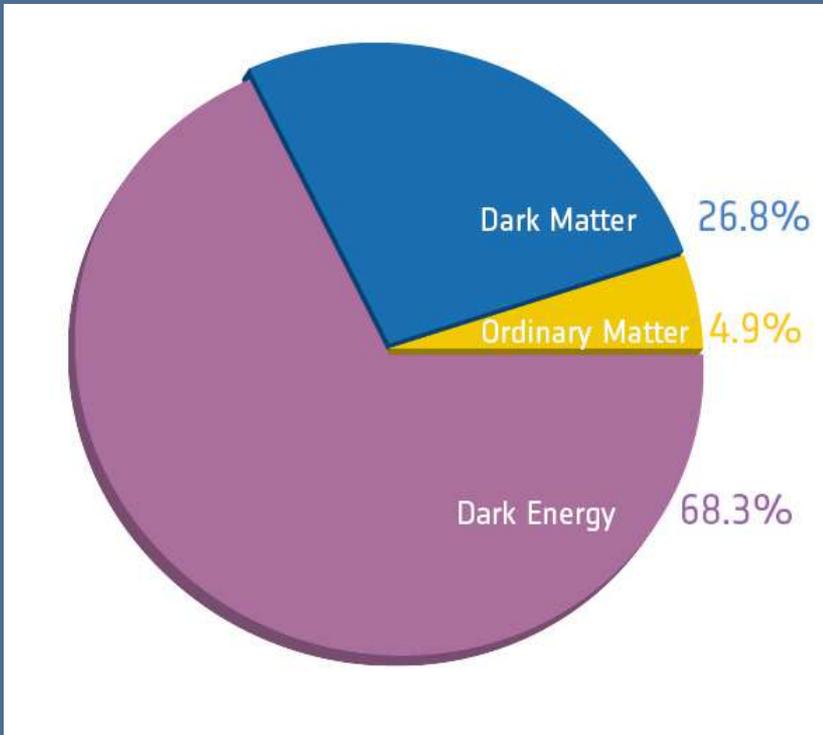
Shikoku seminar
Kochi Univ.
08 Dec 2019

Discrimination of Dark matter mass and distribution by directional detection

Outline

Dark Matter

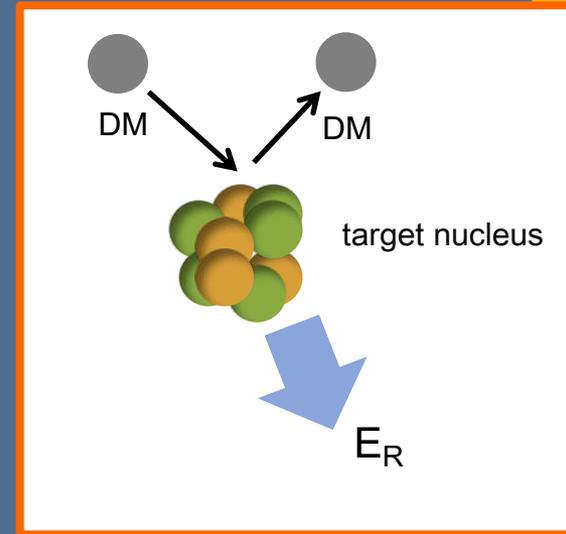Dark Matter 26.8%

Ordinary Matter 4.9%

Dark Energy 68.3%

- Weakly Interacting Massive Particles (WIMPs)
- Axions
- Primordial black holes
- Modified Gravity
- ......

Direct Detection

□ Detect recoil energy of DM-target scattering

DM → DM
target nucleus
E_R

Underground facilities (a partial list)
It has been proven that underground facilities are very important for varieties of science!
For scientific reasons, It would be very nice if there is (at least) one in the Southern hemisphere...

TAUP2017 Kajita-san's talk

Constraint from Direct Detection

$$R \propto N_T N_\chi f(\vec{v}) \langle v \rangle \sigma$$

$$\Longrightarrow \frac{dR}{dE_R} = \frac{N_T \rho_0}{m_\chi} \int^{v_{\max}} d\vec{v} \, f(\vec{v}) |\vec{v}| \frac{d\sigma(\vec{v})}{dE_R}$$

R Event rate
N_T # of target particles
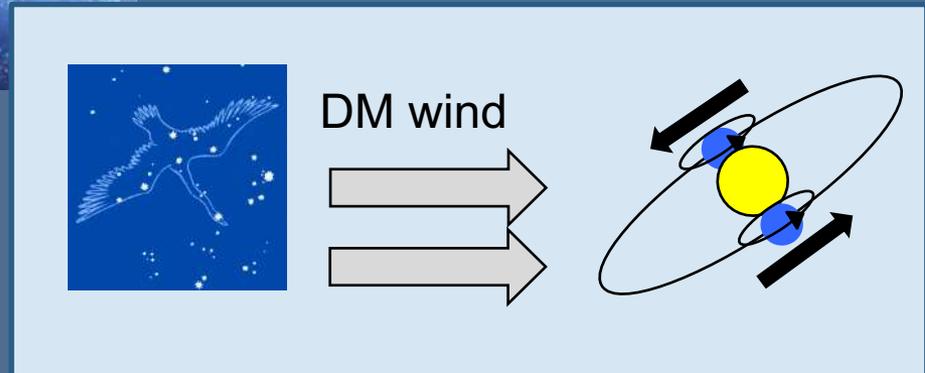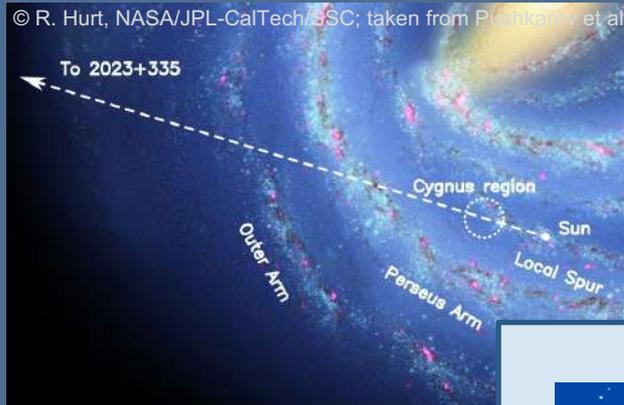$N_\chi = \dfrac{\rho_0}{m_\chi}$ # of WIMP
$f(\vec{v})$ Velocity distribution
$\langle v \rangle$ Averaged WIMP velocity
σ Cross section for DM-nucleus scattering

Directional Detection

☐ detect not only the recoil energy but also direction where DM comes from.

© R. Hurt, NASA/JPL-CalTech/SSC; taken from Pushkarev et al.
To 2023+335
Cygnus region
Sun
Outer Arm
Local Spur
Perseus Arm

DM wind

Directional Searches

DMTPC

DRIFT

MIMAC

NEWAGE

NEWSdm

D³

talk by J. Monroe
in Astroparticle phys

talk by T.Ikeda
in CYGNUS 2017

talk by N.Spooner
in CYGNUS 2017

talk by A.Um...
in CYGNUS 2017

talk by S.Vahsen
in CYGNUS 2017

talk by D.Santos
in CYGNUS 2017

D³ - micro

Hawaii

Gas Detector
(CF_4, CS_2, CHF_3)
SD cross section

Solid Detector
(Ag, Br, C,…)
SI cross section

(not complete list)

7

Outline

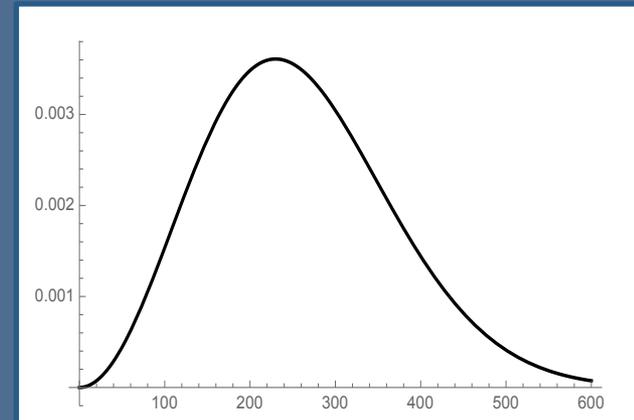# Standard velocity distribution

■ **Maxwell–Boltzmann (MB) distribution**

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

$$\frac{dR}{dE_R} = \frac{N_T \rho_0}{m_\chi} \int^{v_{\max}} d\vec{v}\, f(\vec{v}) |\vec{v}| \frac{d\sigma(\vec{v})}{dE_R}$$
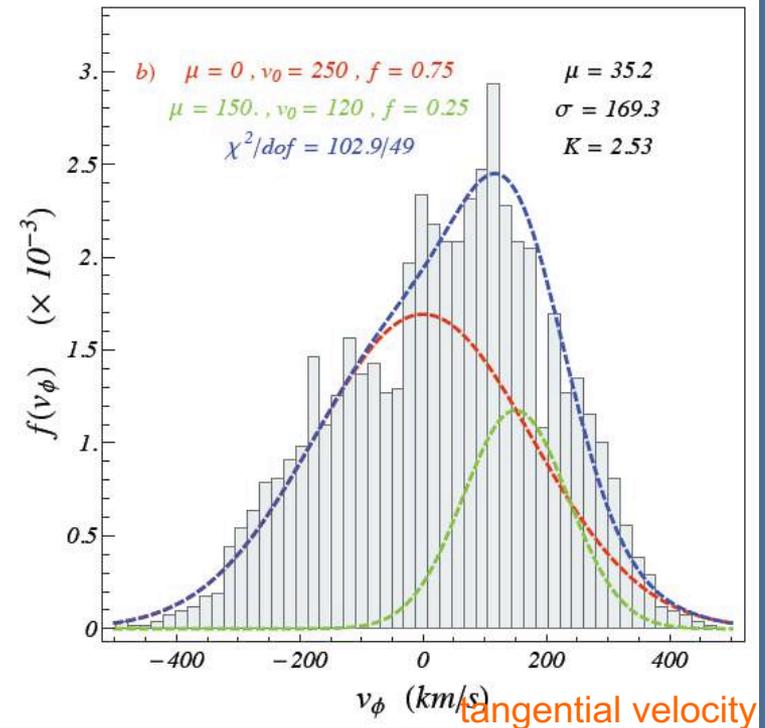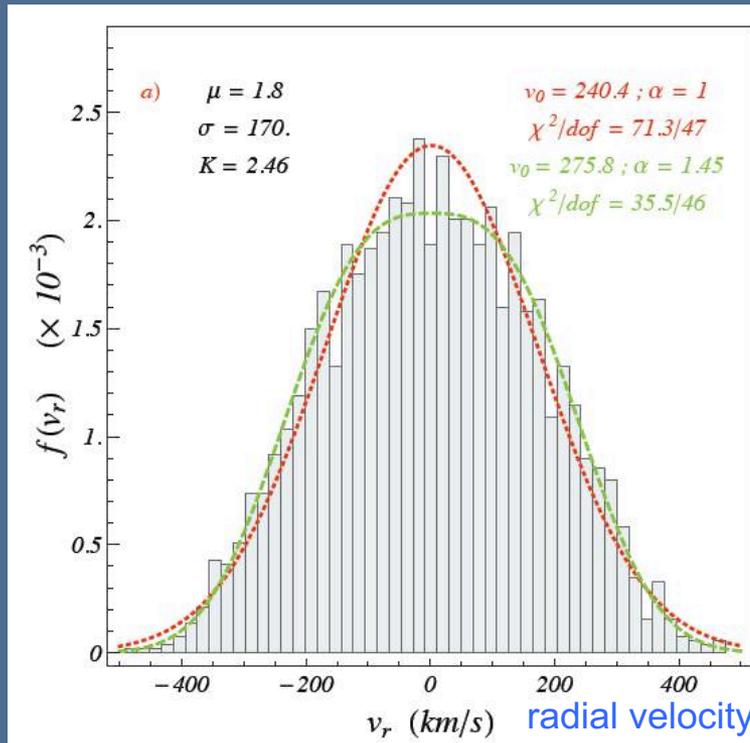

➢ isotropic MB distribution is commonly supposed in direct detections

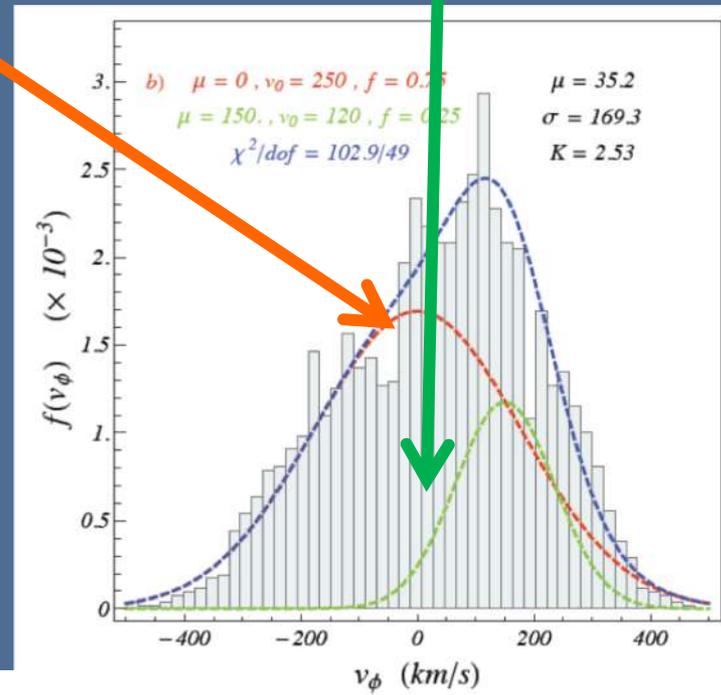# Simulation including baryons and gas

the Galaxy

the Solar system

radial velocity

tangential velocity

Ling, Nezri, Athanassoula & Teyssier (2009)

cf. David R. Law (2009) …

Anisotropic component

$$f(v_\phi) = \frac{1-r}{N(v_{0,\text{iso.}})} \exp\left[-v^2/v^2_{0,\text{iso.}}\right] + \frac{r}{N(v_{0,\text{ani.}})} \exp\left[-(v-\mu)^2/v^2_{0,\text{ani.}}\right]$$

isotropic

anisotropic

□ Tangential velocity
  - anisotropy parameter r
  - r=0.25 is suggested by
    simulation

b) $\mu = 0$, $v_0 = 250$, $f = 0.75$ $\mu = 35.2$
$\mu = 150.$, $v_0 = 120$, $f = 0.25$ $\sigma = 169.3$
$\chi^2/dof = 102.9/49$ $K = 2.53$

Simplified Goal

Isotropic
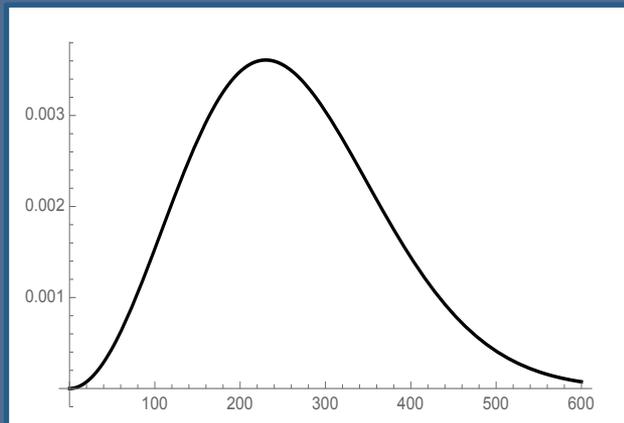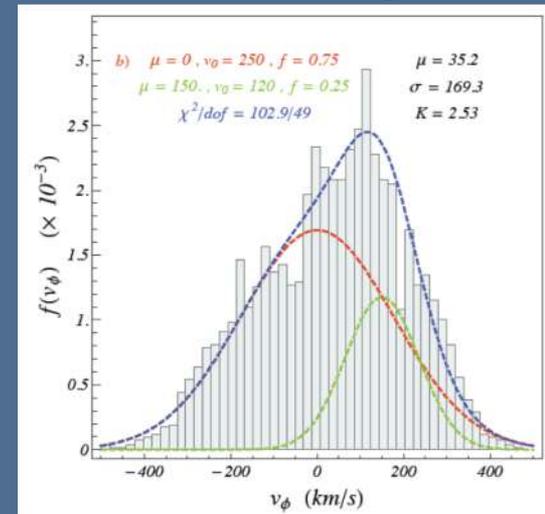
OR

Anisotropic

(AND M$_{DM}$)

Outline

cf.
Ben Morgan, Anne M. Green, Neil J. C. Spooner (2004)
Ole Host, Steen H Hansen (2007)
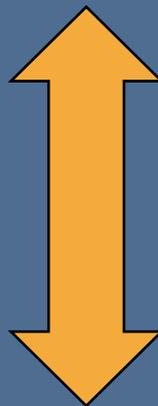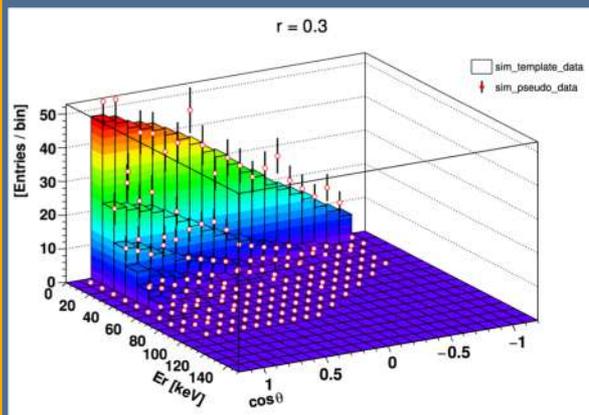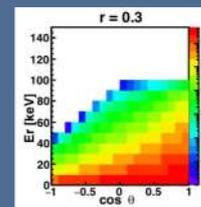
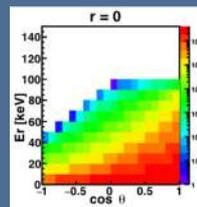# Numerical Simulation of Scattering

DM wind $f(v)$

Target

θ

E_R
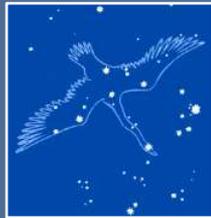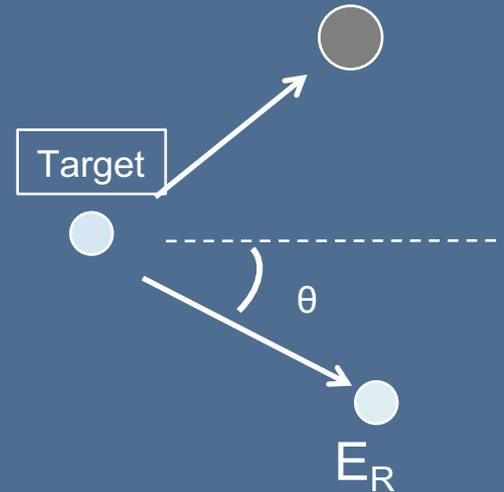
- **Monte Carlo simulation of scattering supposing f(v)**
  - E_R and θ are obtained
  - Elastic scattering, No BG, Perfect resolution
  - Target : F (light) /Ag (heavy)

Strategy for discrimination

ideal "**template**"
Many Data
(#10^8)

r = 0.3
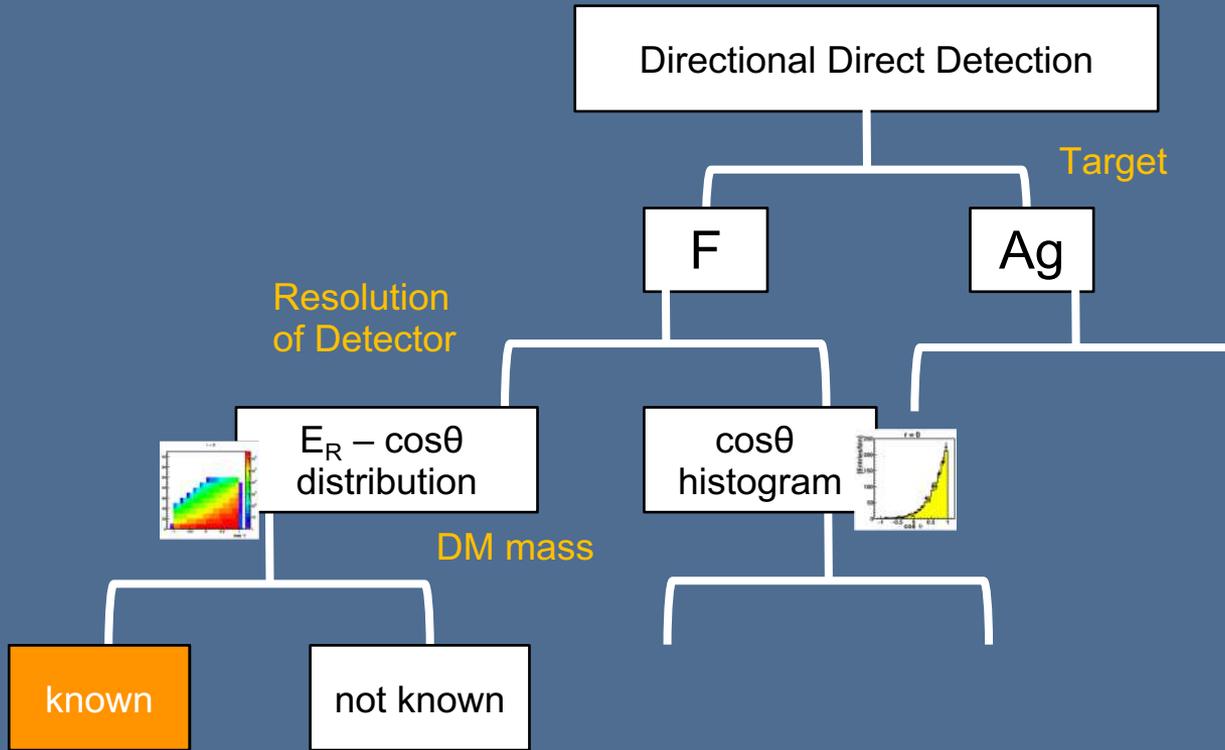
Which template is
more similar
to pseudo-exp?

☐ Likelihood estimation

$$\mathcal{L} = \prod_{\text{bins}} P(r \mid \text{pseudo}, \text{template})$$

☐ χ2 test

$$\chi^2 = \sum_{\text{bins}} \frac{(\text{pseudo} - \text{template})^2}{\text{pseudo}}$$
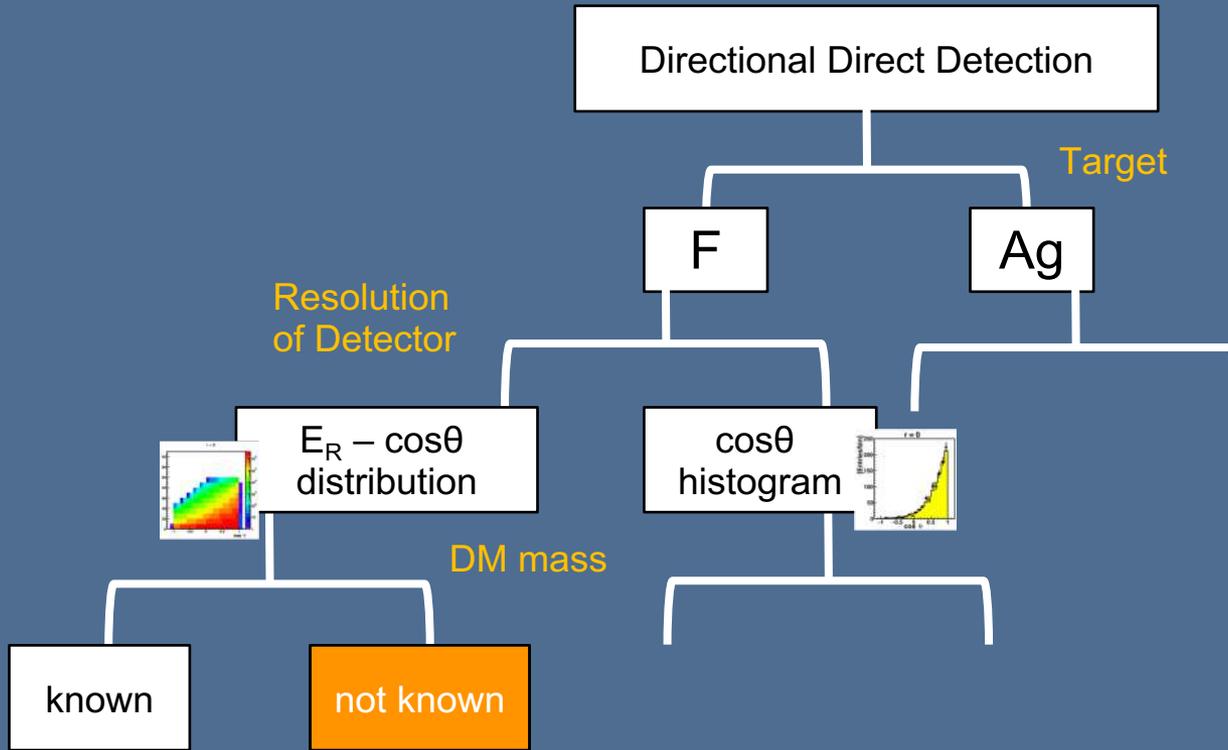
"**pseudo-experimental**" data
Fewer Data
(#10^3-10^4)

Summary of Branches

6×10^3 (ER-angle) / 5×10^3 (angle only) for F
6×10^4 (ER-angle)/ 2×10^4 (angle only) for Ag.

(arXiv:1707.05523)

Summary of Branches

Directional Direct Detection

Target

F   Ag

Resolution
of Detector

$E_R - \cos\theta$
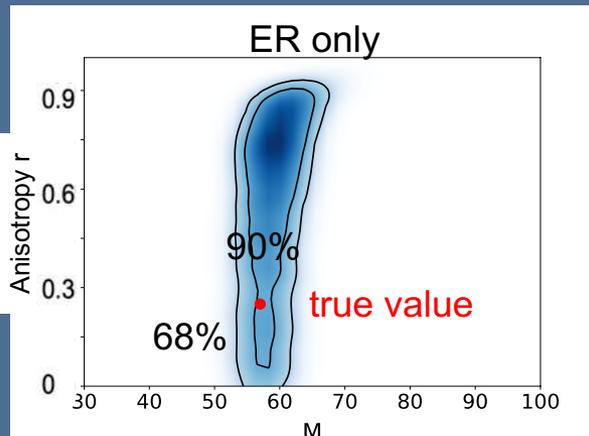distribution

$\cos\theta$
histogram

DM mass

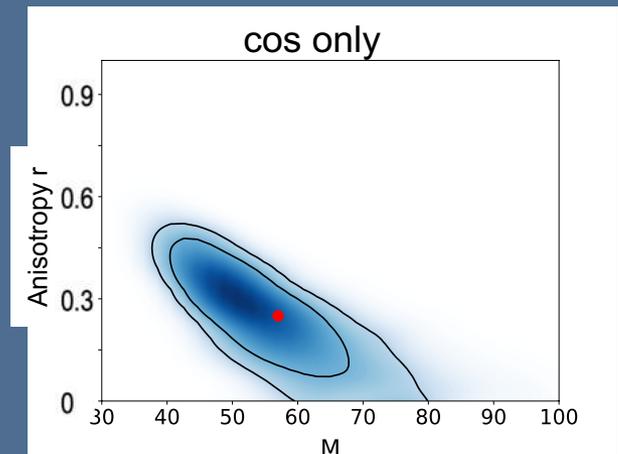known   not known

What if M_{DM} is not known?

☐ Likelihood method

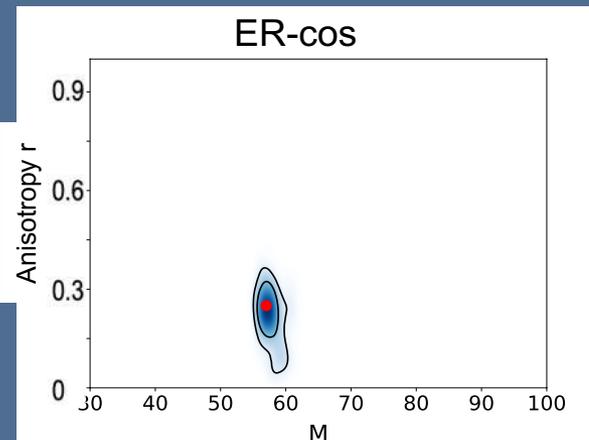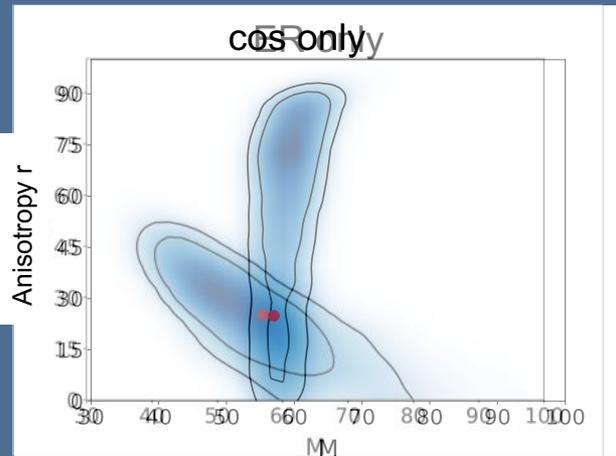Ethr=50keV (F)
M_{dm}=60GeV
#event: 1000

ER only

☐ Anisotropy is not discriminated only by E_R.

☐ Constraint for mass by directionality histogram is not so strictly.

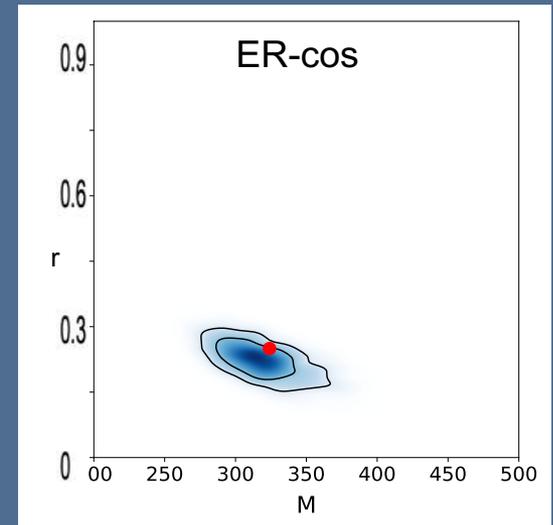cos only
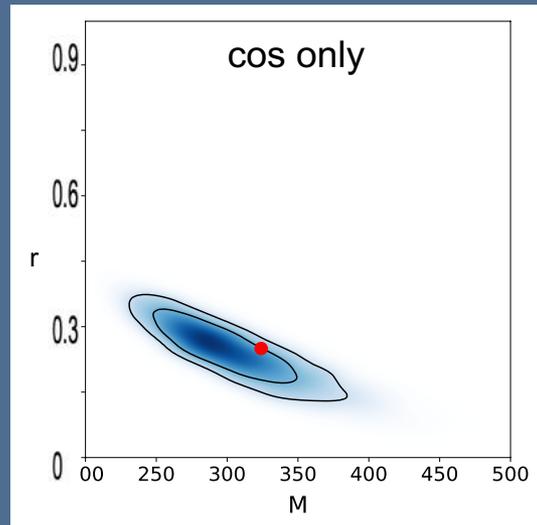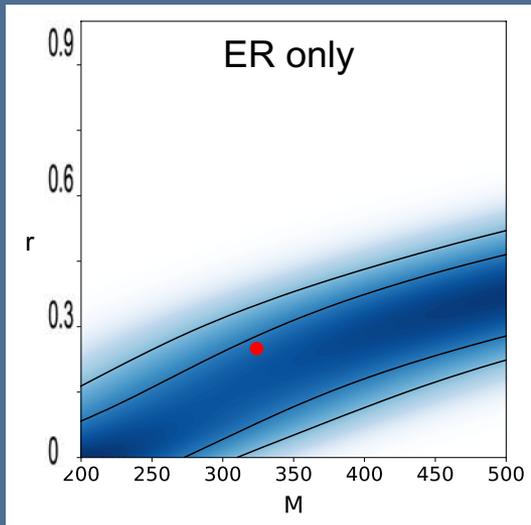
What if M_{DM} is not known?

☐ Likelihood method

Ethr=50keV (F)
M_{dm}=60GeV
#event: 1000

☐ We need both E_R and directional information to give constraint for both anisotropy and mass at the same time.

What if M_{DM} is not known? (Ag)

□ Likelihood method

Ethr=50keV (Ag)
M_{dm}=300GeV
#event: 10000

Summary

- Possibility to figure out DM mass and anisotropy of DM distribution is discussed.

- If DM mass is known by other searches, we can discuss the anisotropy once $O(10^3\text{-}10^4)$ event is obtained in directional detection. With optimized threshold of detectors, angular distribution may be better than energy-angular distribution.

- Even if M_{DM} is not known, once **both** E_R and angular information are obtained we can give constraints for M_{DM} and distribution.

Thank you for your attention.