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Keiko Nagao
(Okayama Univ. of Sci., Japan)

長尾 桂子
(岡山理科大学)

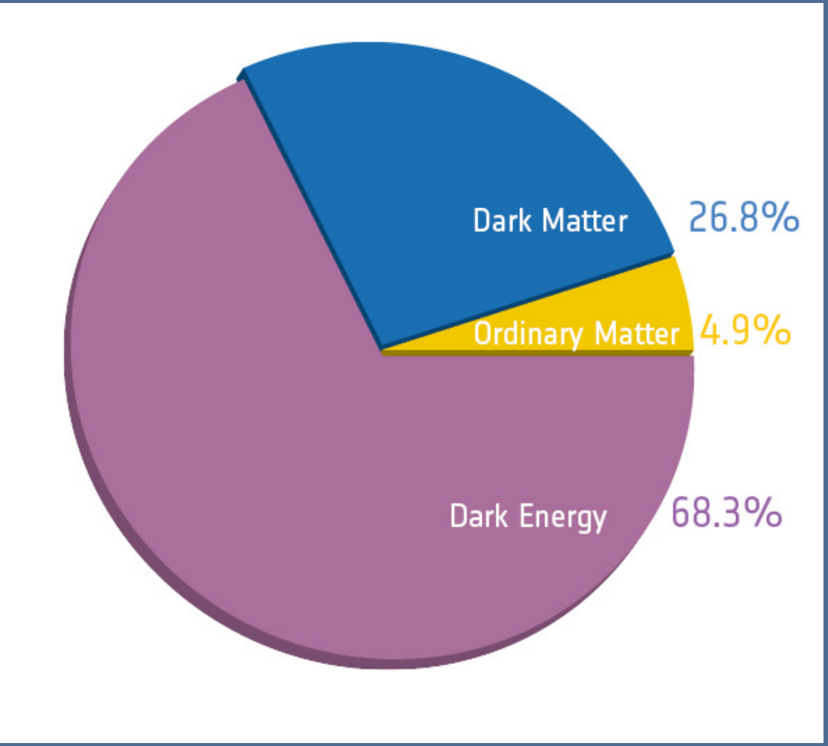
Discriminating WIMP Mass and Anisotropy with Directional Detector

based on arXiv:1707.05523 (accdepted to Physics of the Dark Universe);
KN, R. Yakabe (Kobe Univ.), T. Naka (Nagoya Univ., Toho Univ.), K. Miuchi (Kobe Univ.)
work in progress
KN, T. Ikeda (Kobe Univ.), R. Yakabe, T. Naka, K. Miuchi

Outline

1. Introduction
2. Anisotropy of velocity distribution
3. Numerical Results
4. Summary

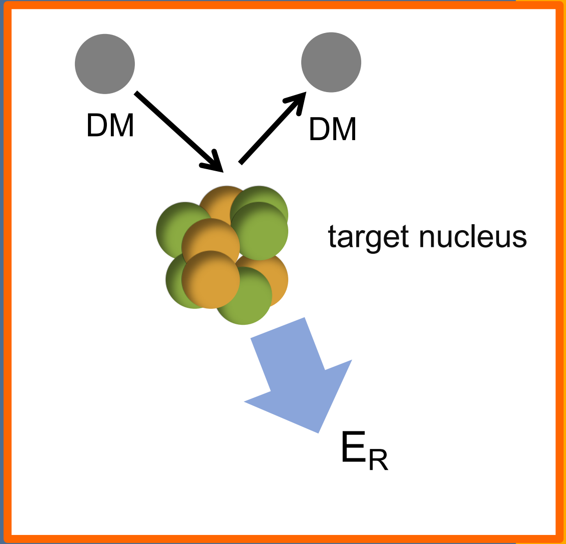
Dark Matter



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

Direct Detection

- Detect recoil energy of DM-target scattering



Constraint from Direct Detection

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

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

R Event rate

N_T # of target particles

$N_\chi = \frac{\rho_0}{m_\chi}$ # of WIMP

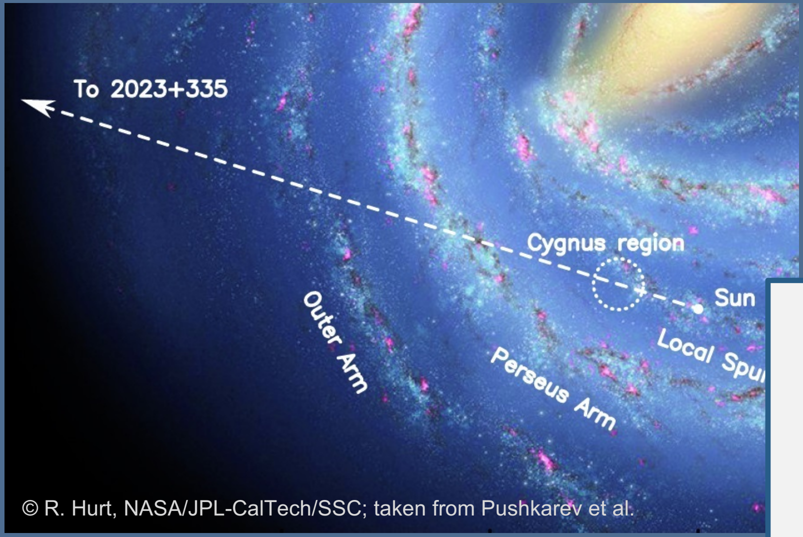
$f(\vec{v})$ Velocity distribution

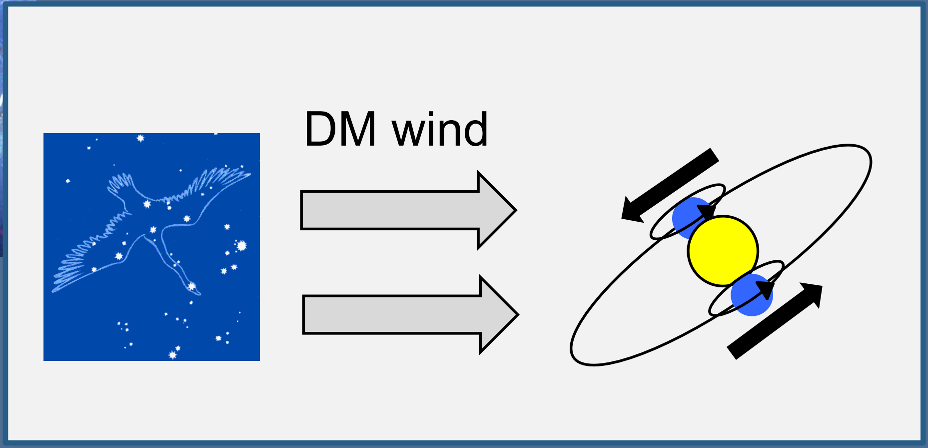
$\langle v \rangle$ Averaged WIMP velocity

σ Cross section for DM-nucleus scattering

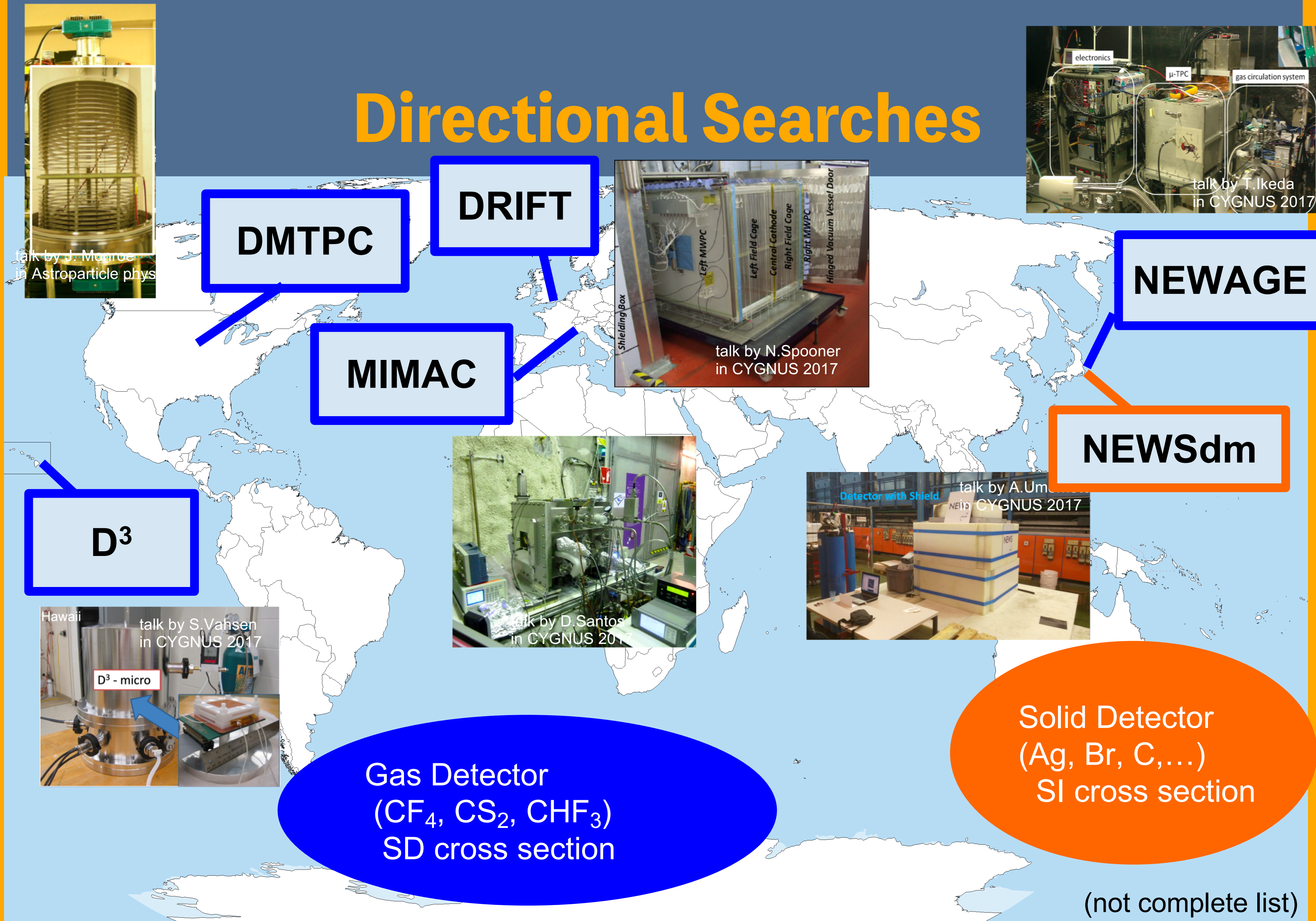
Directional Detection

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





Directional Searches



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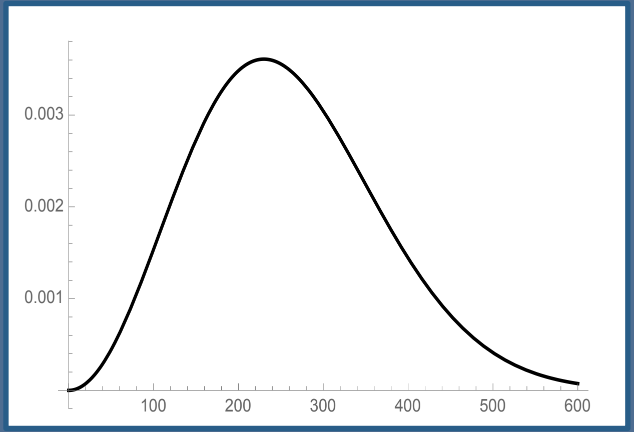
Standard velocity distribution

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

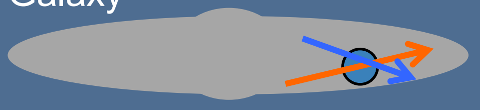
$$\frac{dR}{dE_R} = \frac{N_T \rho_0}{m_\chi} \int^{v_{\max}} d\vec{v}\; f(\vec{v}) |\vec{v}| \frac{d\sigma(\vec{v})}{dE_R}$$

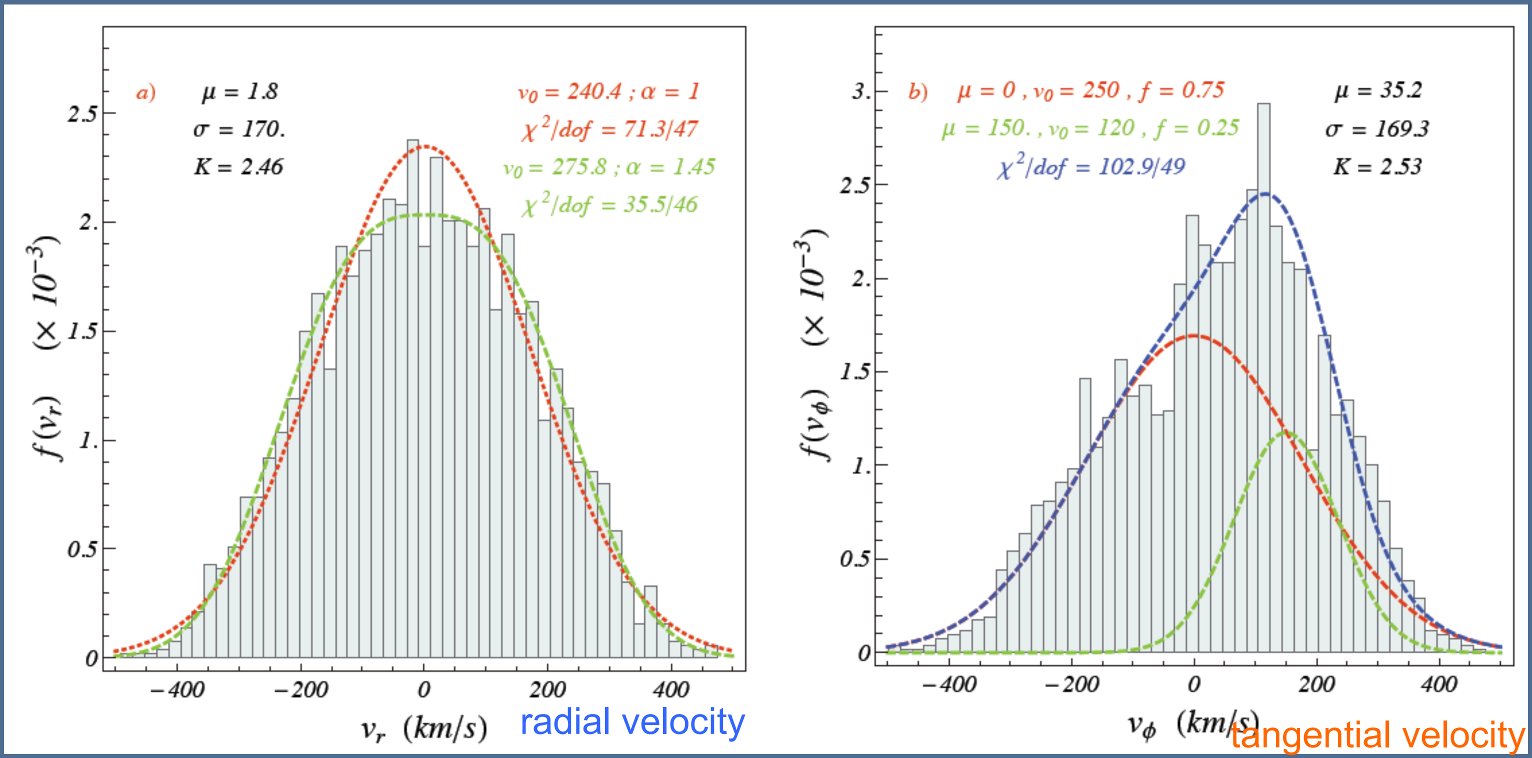
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$



➢ isotropic MB distribution is commonly supposed in direct detections

Simulation including baryons and gas





Ling, Nezri, Athanassoula & Teyssier (2009)

cf. David R. Law (2009) …

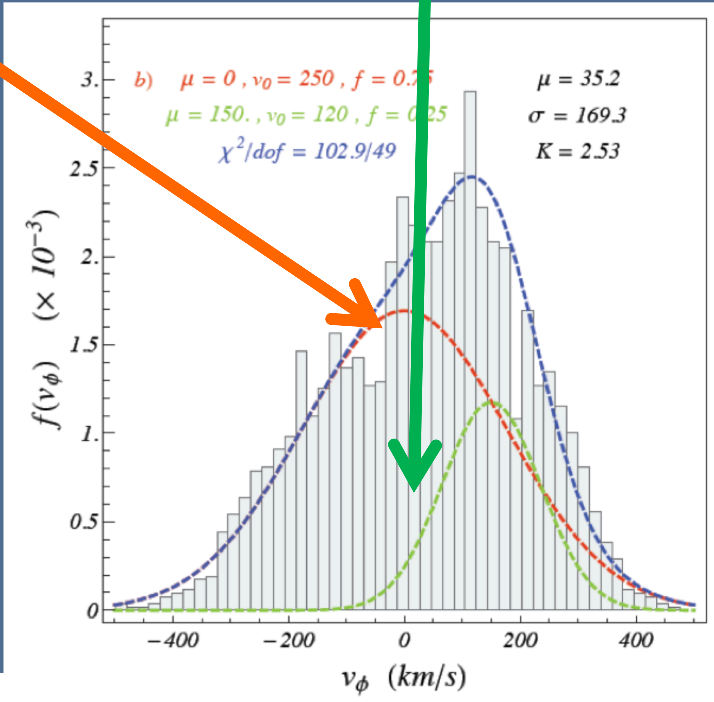
Anisotropic component

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

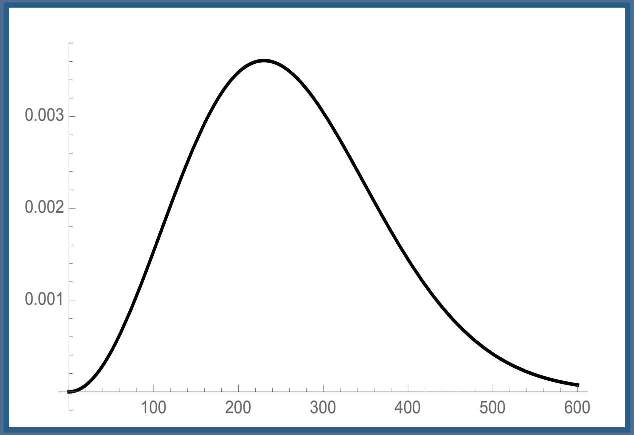
isotropic

anisotropic

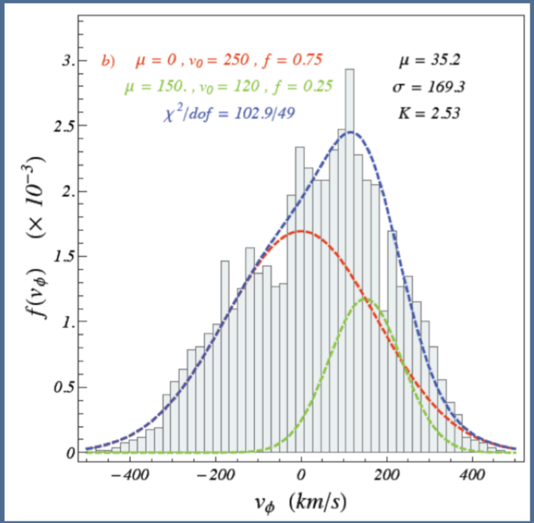
- Tangential velocity
  - anisotropy parameter r
  - r=0.25 is suggested by simulation



Simplified Goal



OR

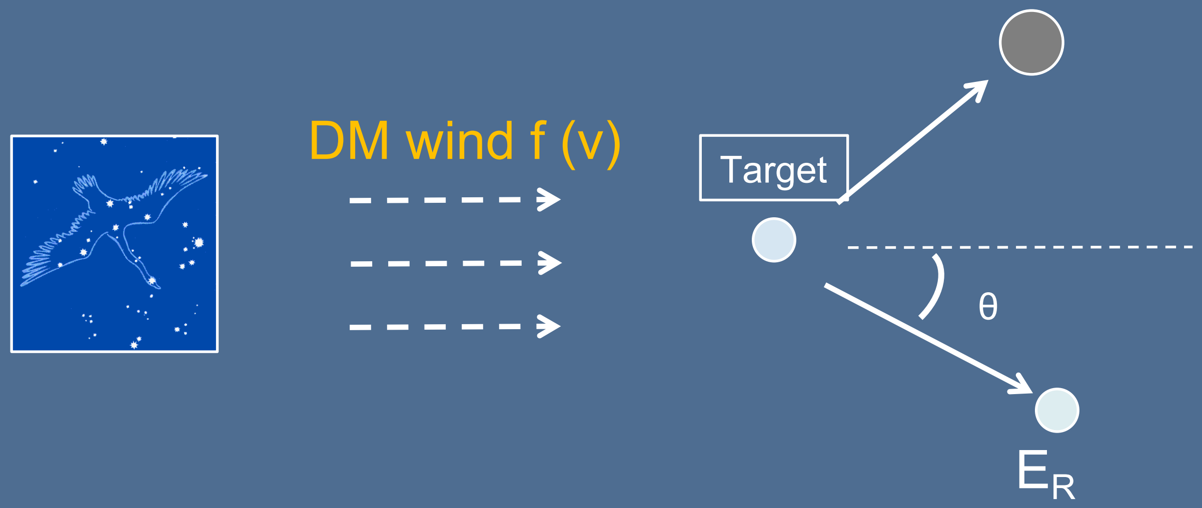


AND M_{DM}

Outline

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

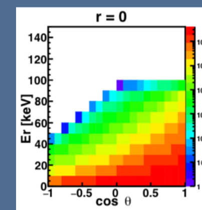
Numerical Simulation of Scattering

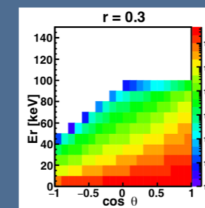


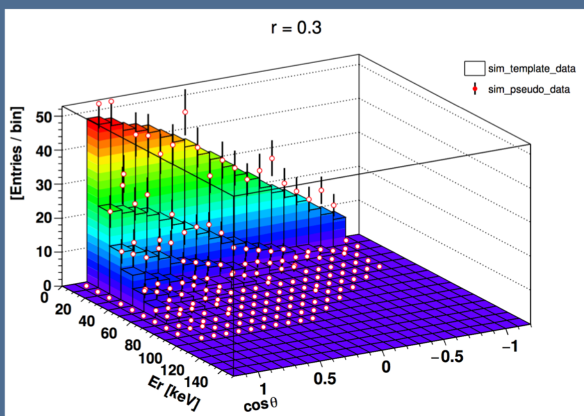
- **Monte Carlo simulation of scattering supposing f(v)**
  - E_R and θ are obtained
  - Elastic scattering, No BG, Perfect resolution
  - Target : F (light) /Ag (heavy)

Strategy for discrimination

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







Which template is more similar to pseudo-exp?

- Likelihood estimation

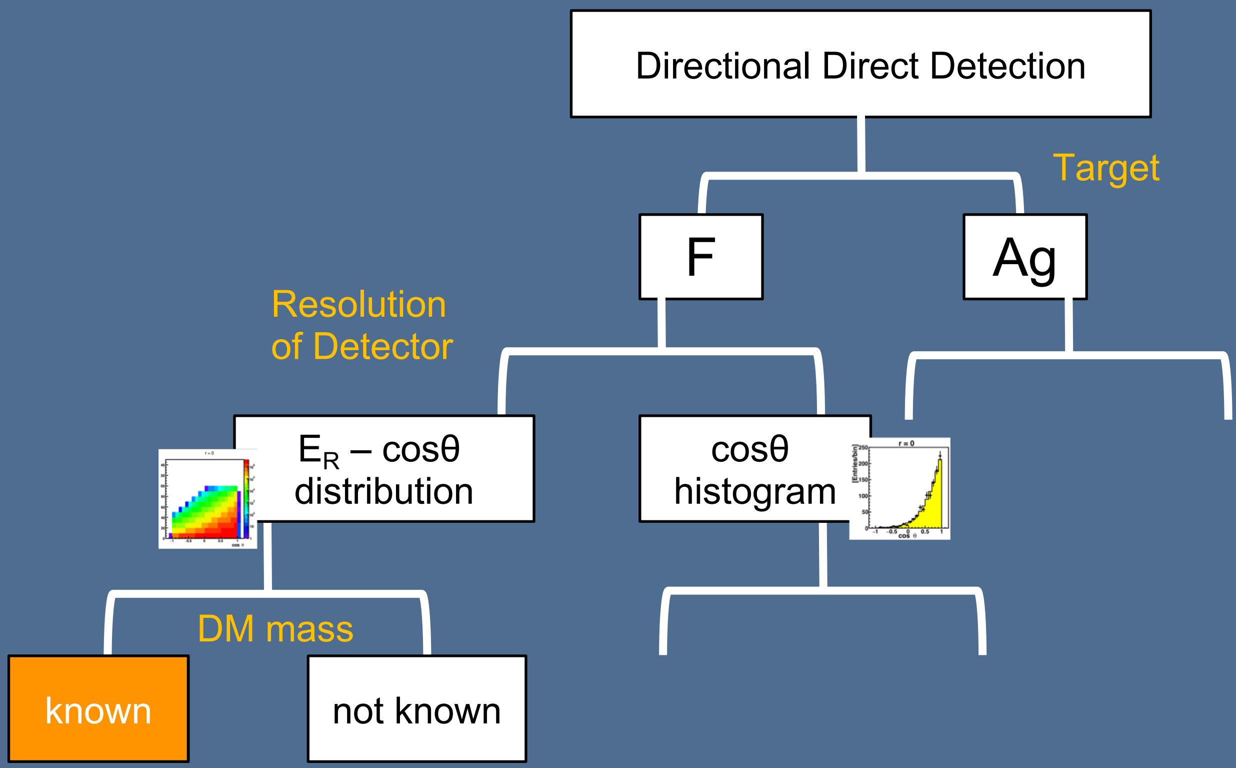
$$\mathcal{L} = \prod_{\text{bins}} P(r \mid \text{pseudo}, \text{template})$$

"**pseudo-experimental**" data
Fewer Data
(#10^3-10^4)

- χ2 test

$$\chi^2 = \sum_{\text{bins}} \frac{(\text{pseudo} - \text{template})^2}{\text{pseudo}}$$

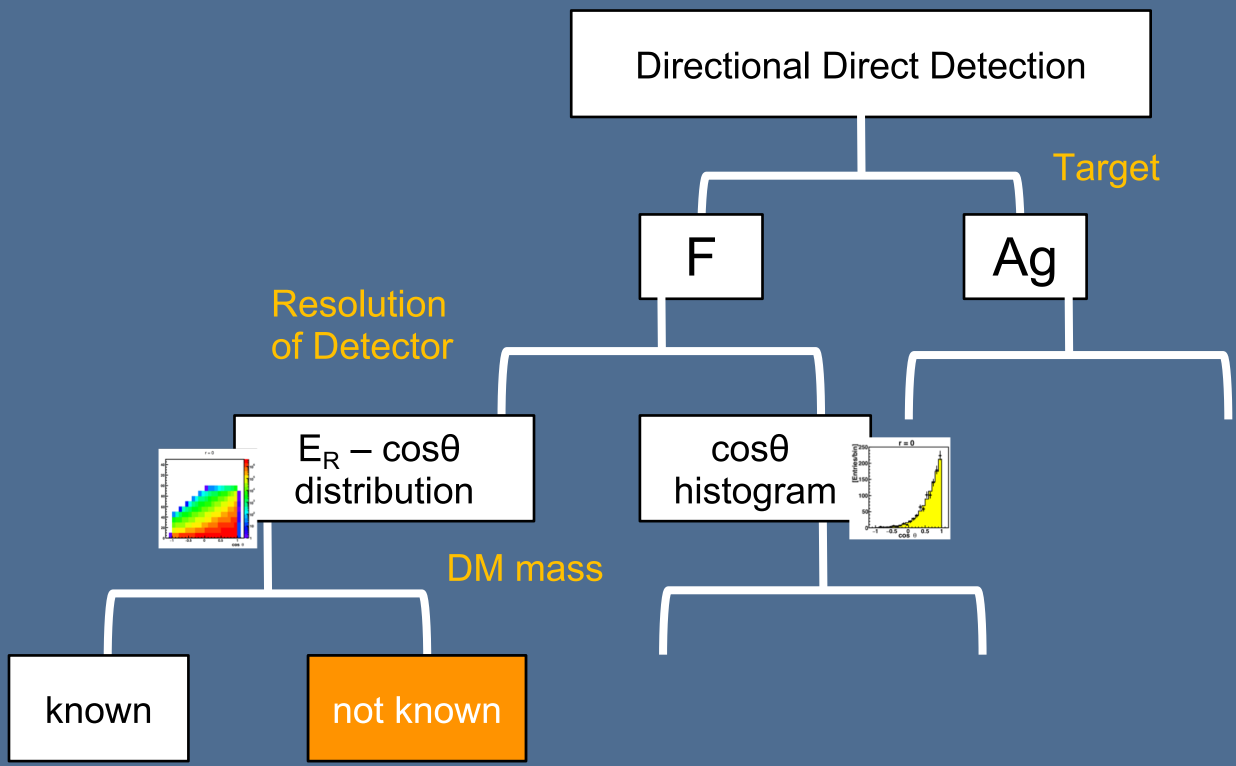
Summary of Branches



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)

Cases



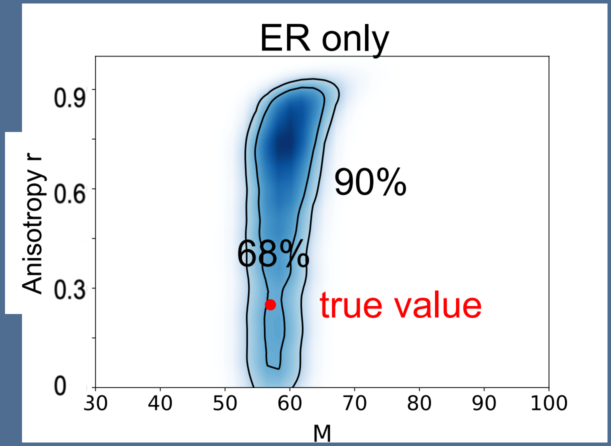
Directional Direct Detection
Target
F
Ag
Resolution of Detector
E_R – cosθ distribution
cosθ histogram
DM mass
known
not known

cf. Samuel K. Lee and, Annika H.G. Peter
arXiv:1202.5035

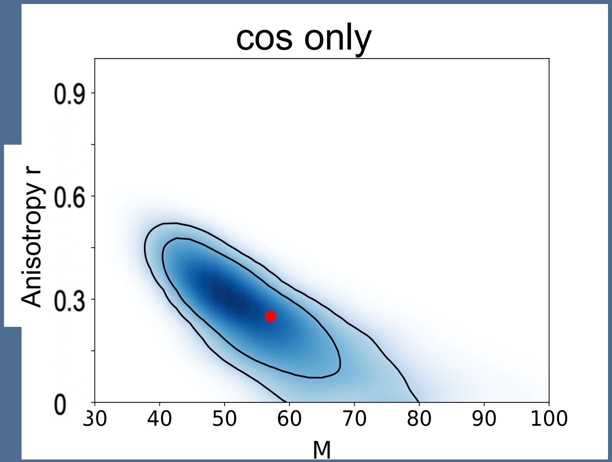
What if M_{DM} is not known?

- Likelihood method

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



- Anisotropy is not discriminated only by E_R.

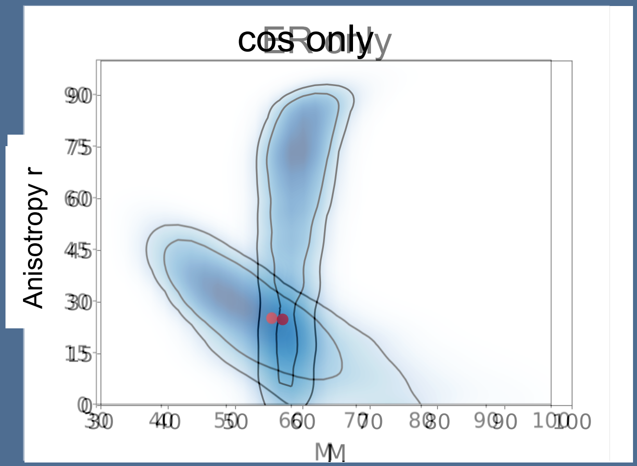


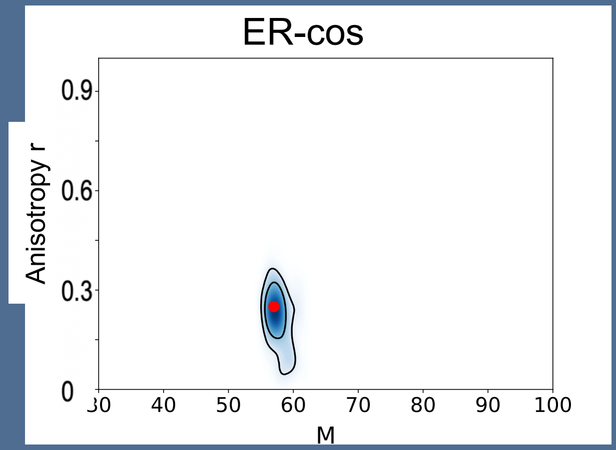
- Constraint for mass by directionality histogram is not so strictly.

cf. Samuel K. Lee and, Annika H.G. Peter
arXiv:1202.5035

What if M_{DM} is not known?

- Likelihood method

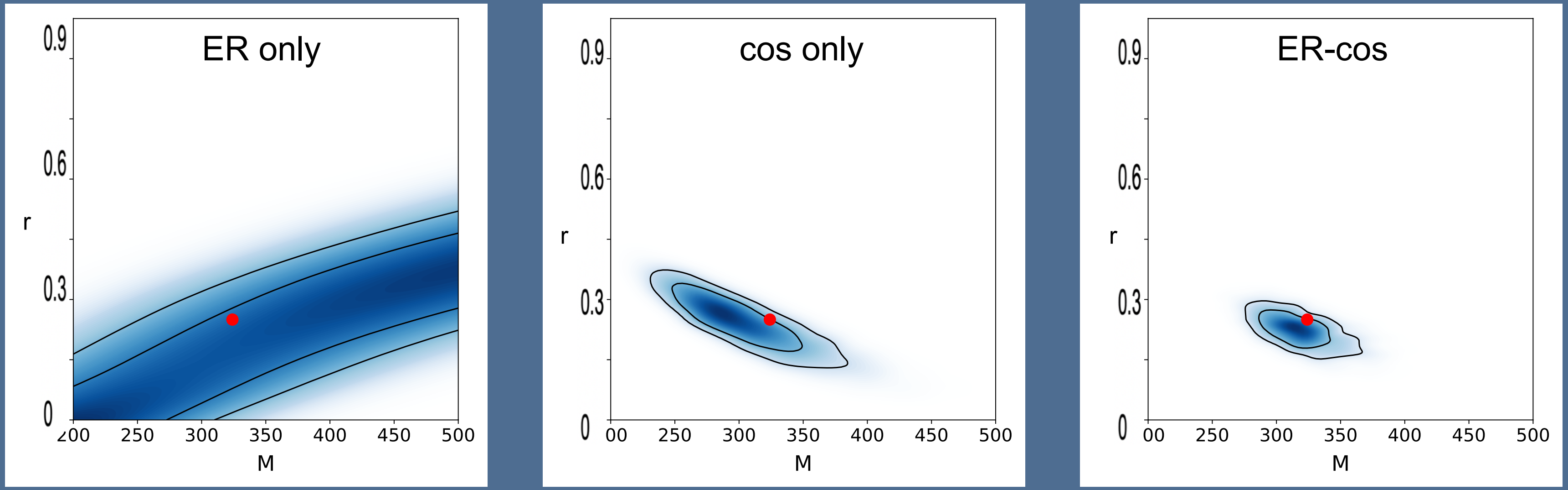




Ethr=50keV (F)
M_{dm}=60GeV
#event: 1000

- 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.
- 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.