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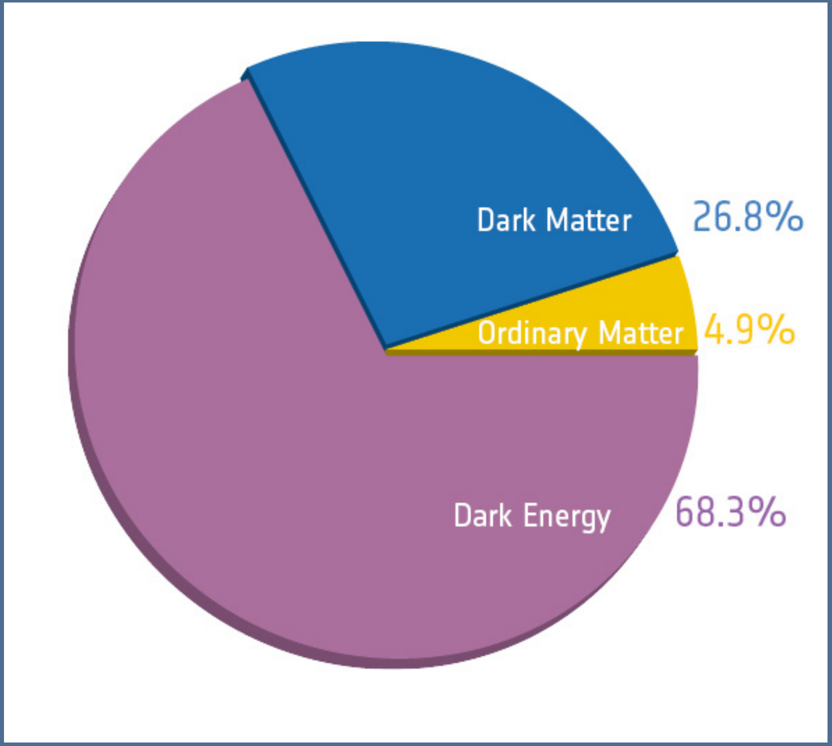
NCTS Dark Physics workshop
9 Jan. 2019

Anisotropy of dark matter velocity distribution and directional detection

based on arXiv:1707.05523;
KN, R. Yakabe (Kobe Univ.), T. Naka (Toho Univ.), K. Miuchi (Kobe Univ.)
work in progress;
KN, T. Ikeda (Kobe Univ.), R. Yakabe, T. Naka, K. Miuchi

Outline

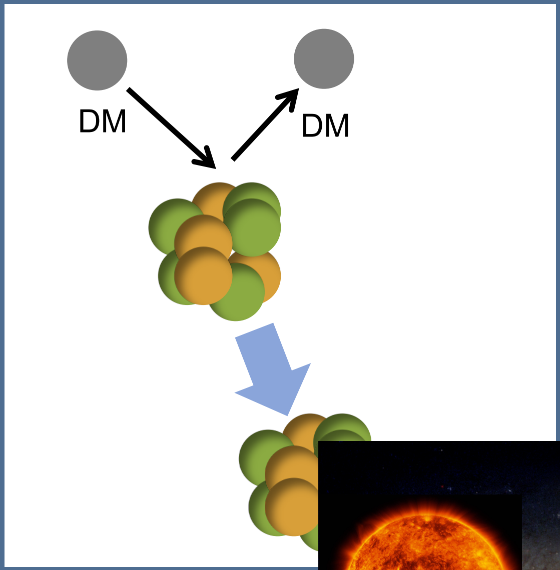
Dark Matter



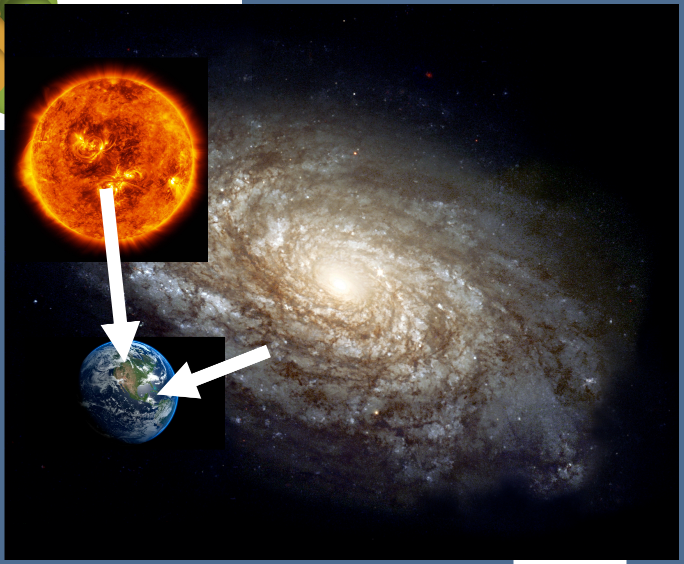
CANDIDATES

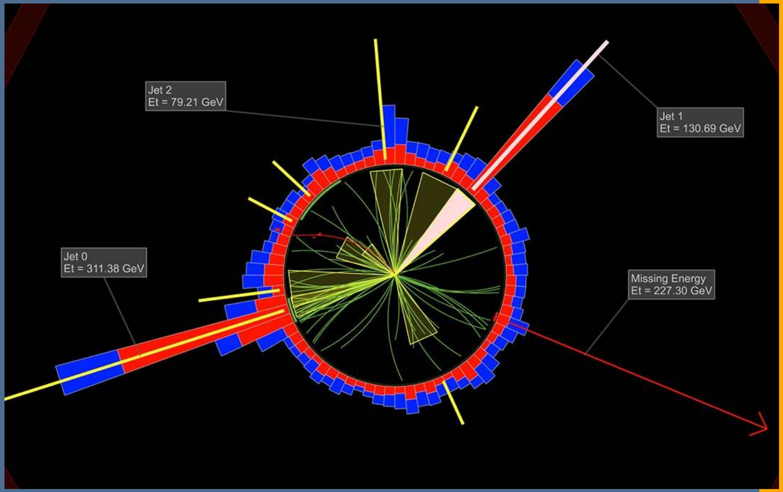
- Weakly Interacting Massive Particles (WIMPs)
- Axions
- Primordial black holes
- Modified Gravity
- ……

Detection



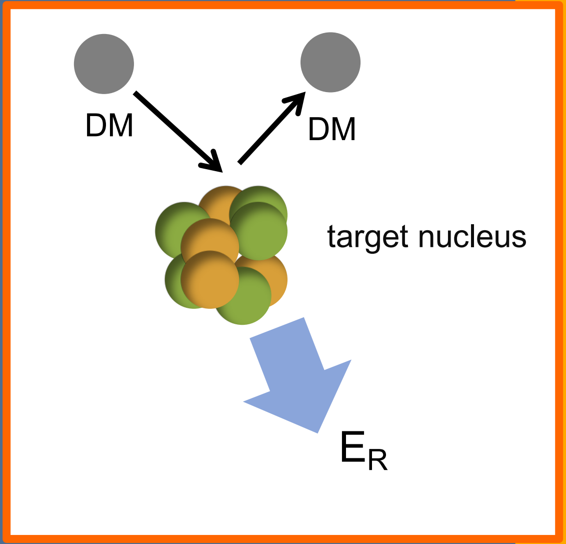
- direct detections
- indirect detections
- collider searches





Direct Detection

- Detect recoil energy of DM-target scattering



Constraint from Direct Detection

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

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

R Event rate

N_T # of target particles

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

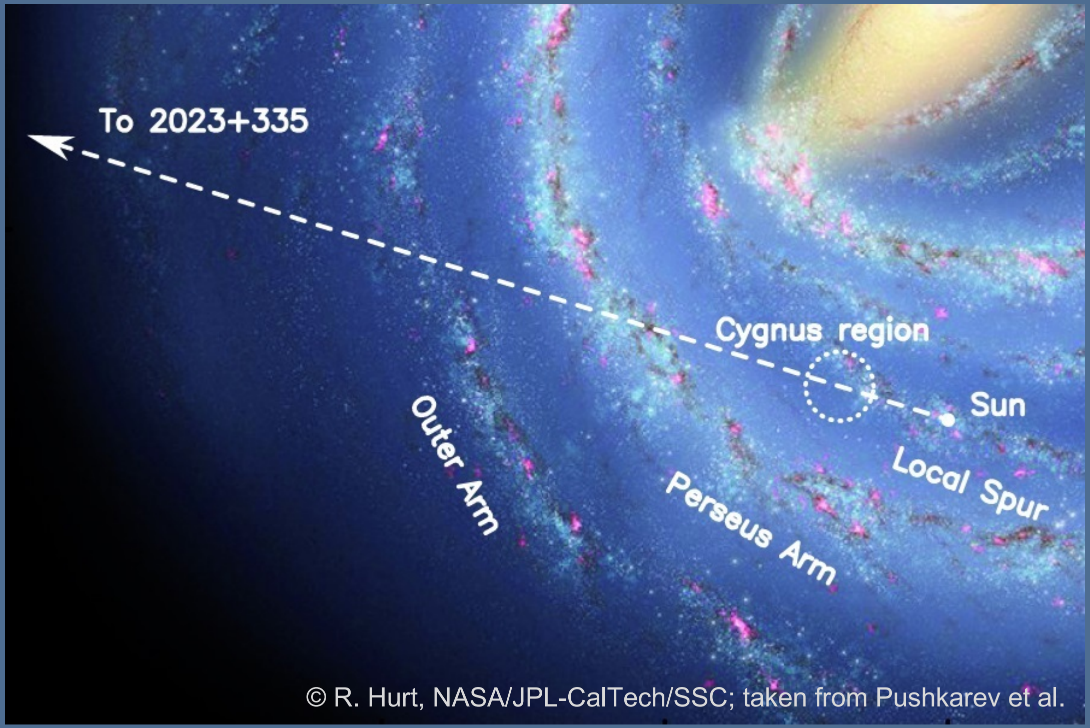
$f(\vec{v})$ Velocity distribution

$\langle v \rangle$ Averaged WIMP velocity

σ Cross section for DM-nucleus scattering

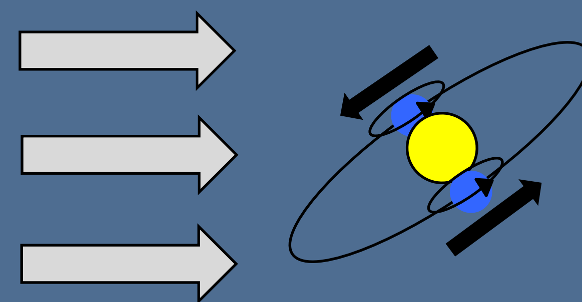
Directional Direct Detection

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

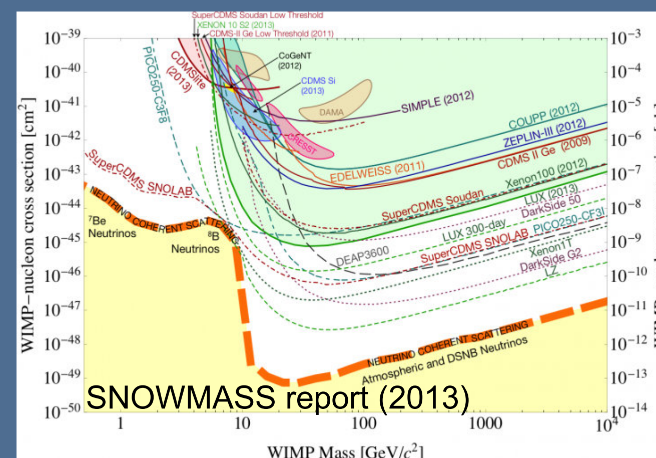


Directionality

DM wind

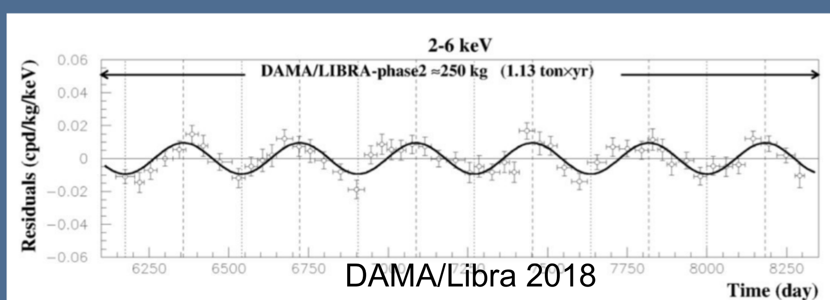


- BG rejection
  - BG : isotropic(?)
  - DM signal : from the Cygnus

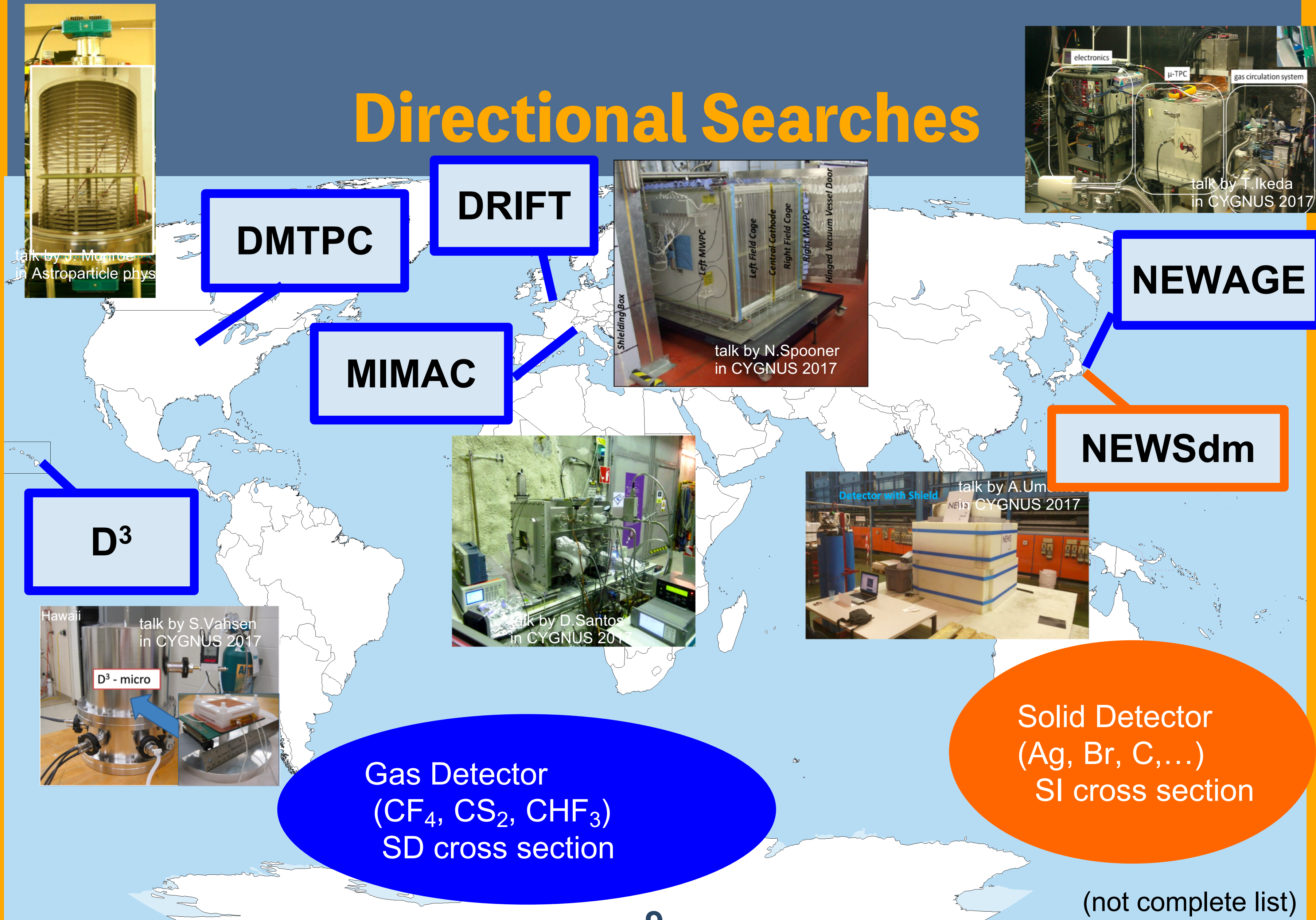


- Neutrino Floor

- Test DAMA



Directional Searches



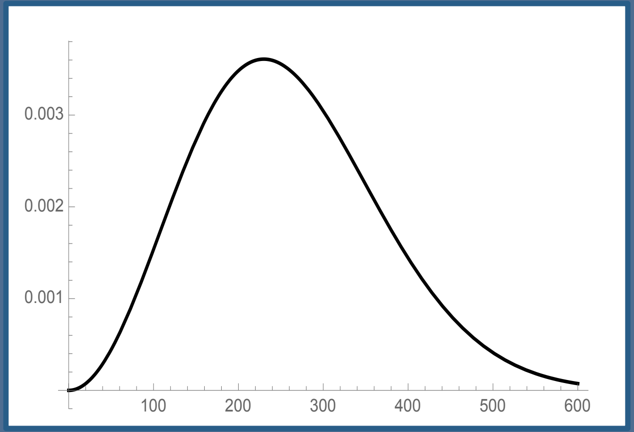
Outline

Standard velocity distribution

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

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

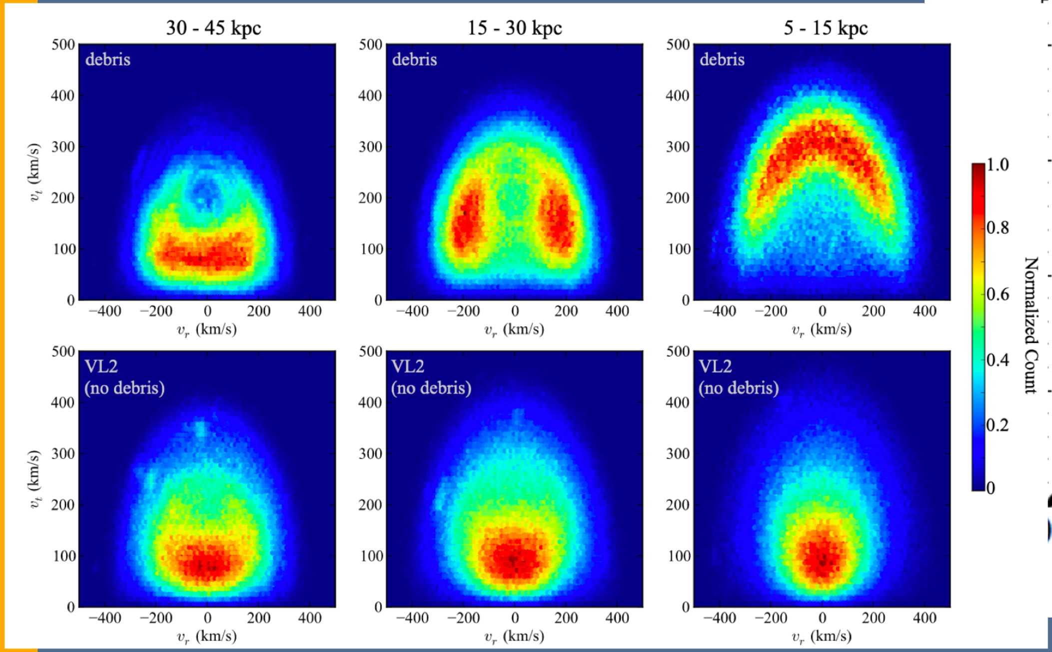
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$



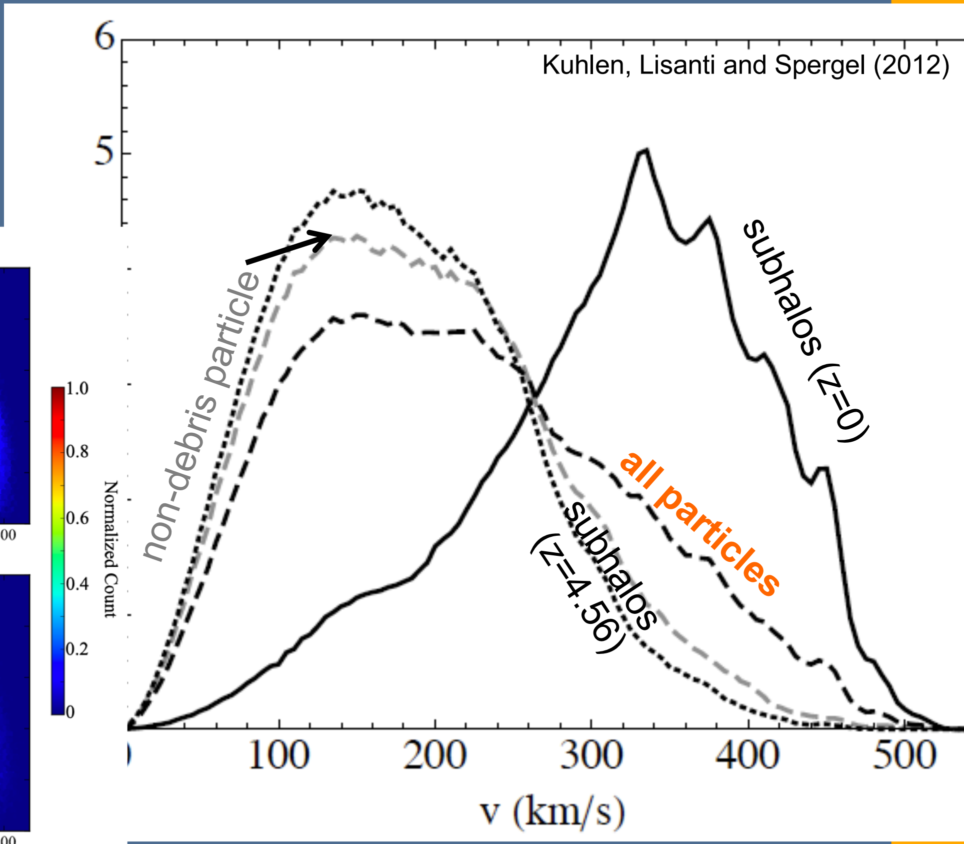
➢ isotropic MB distribution is commonly supposed in direct detections

Debris Flow

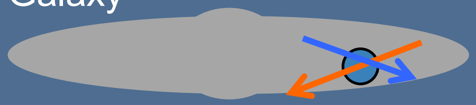
- **Some N-body simulations suggest anisotropy**

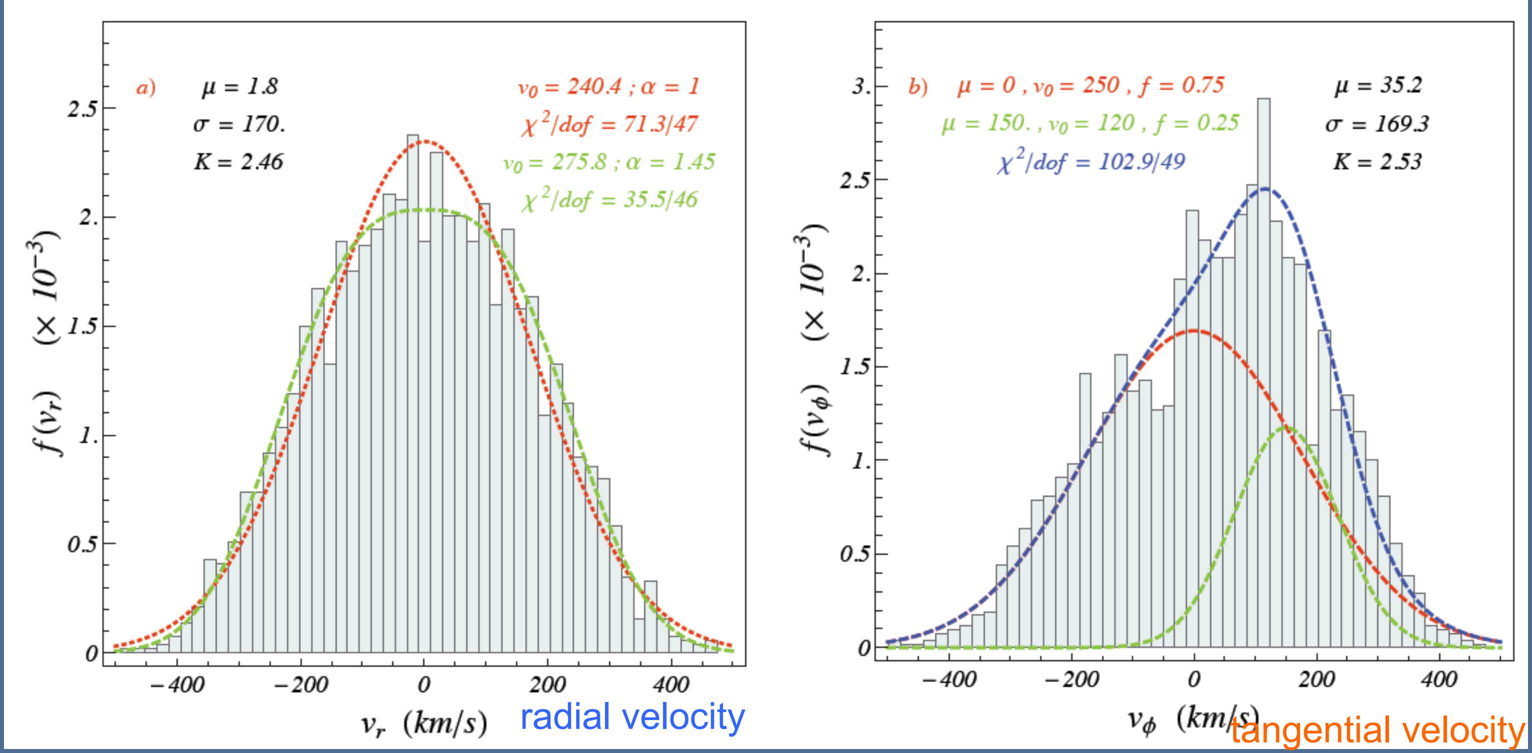


Lisanti and Spergel (2011)



Simulation including baryons





Ling, Nezri, Athanassoula & Teyssier (2009)
cf. David R. Law (2009) …

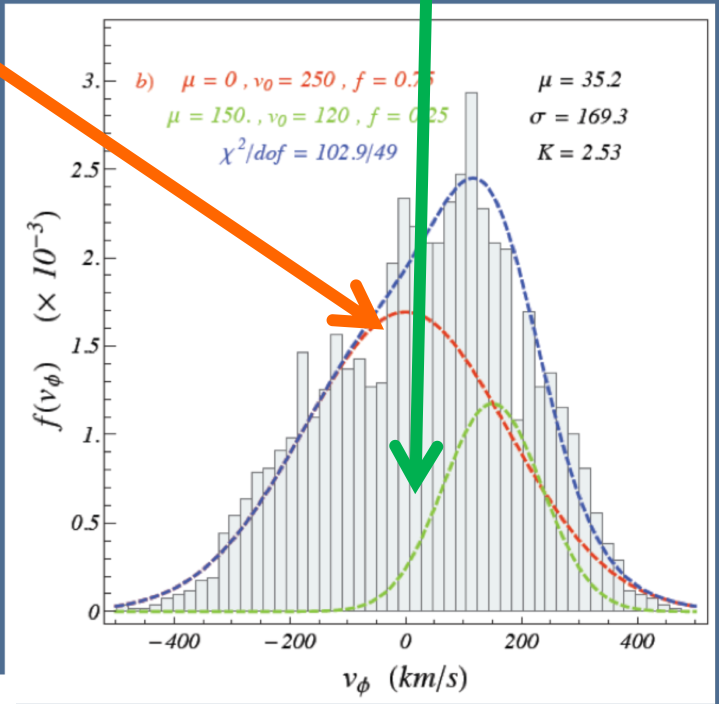
Anisotropic component

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

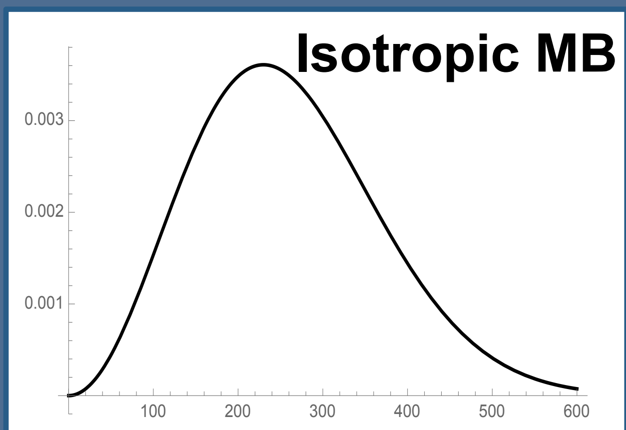
isotropic

anisotropic

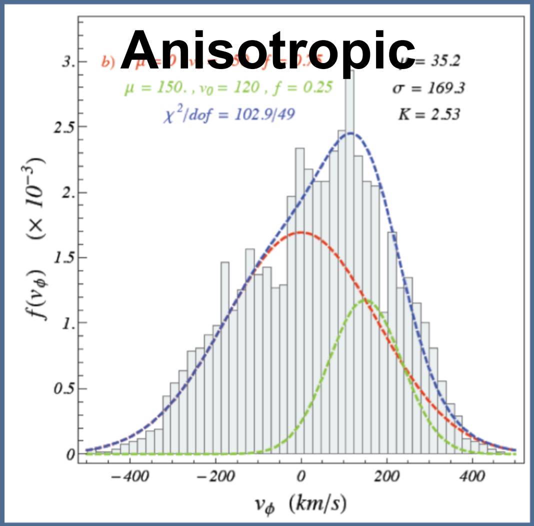
- Tangential velocity
  - anisotropy parameter r
  - r=0.25 is suggested by simulation



Simplified Goal



OR



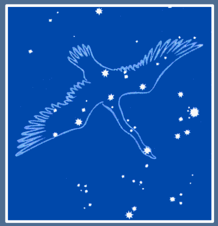
(AND M_{DM})

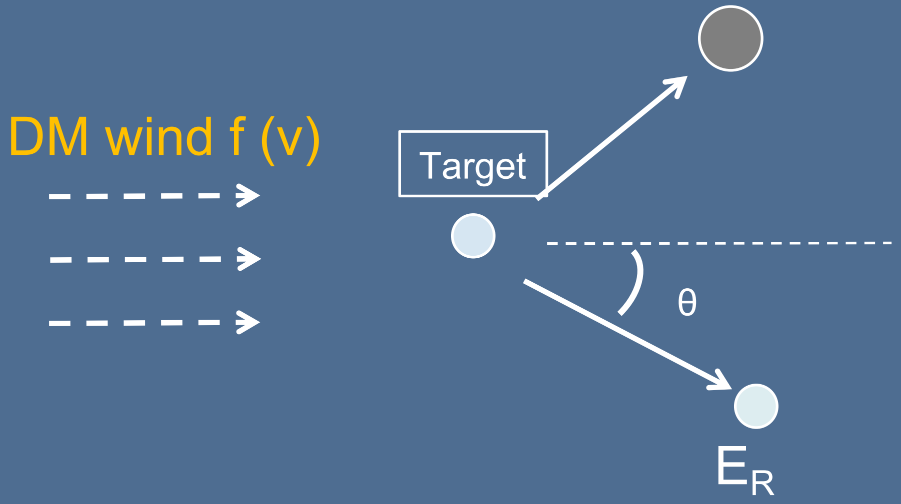
Outline

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

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

Numerical Simulation of Scattering





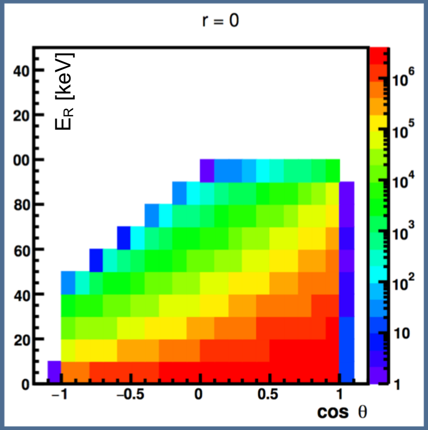
- **Monte Carlo simulation of scattering supposing f(v)**
  - E_R and θ are obtained
  - Elastic scattering, No BG, Perfect resolution
  - Target : F (light) /Ag (heavy)

Analysis

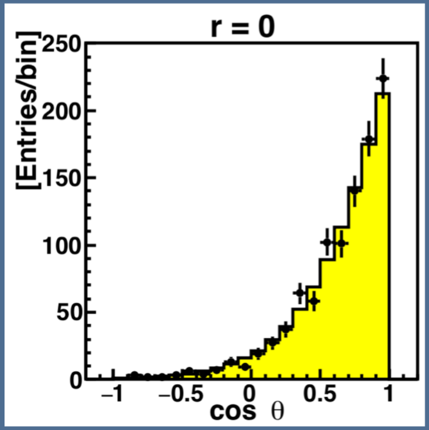
- **depends on resolutions of a detector**

Energy resolution :OK
Angular resolution :OK

Energy resolution :NG
Angular resolution :OK



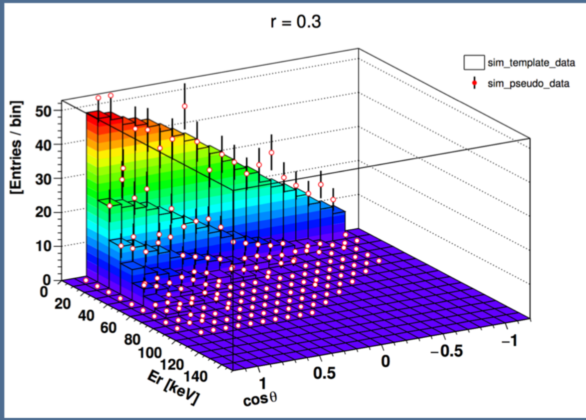
E_R-cosθ
energy-angular distribution

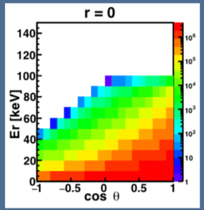


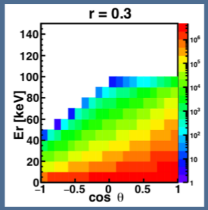
cosθ
angular histogram

Strategy for discrimination

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







Which template is more similar to pseudo-exp?

- Likelihood estimation

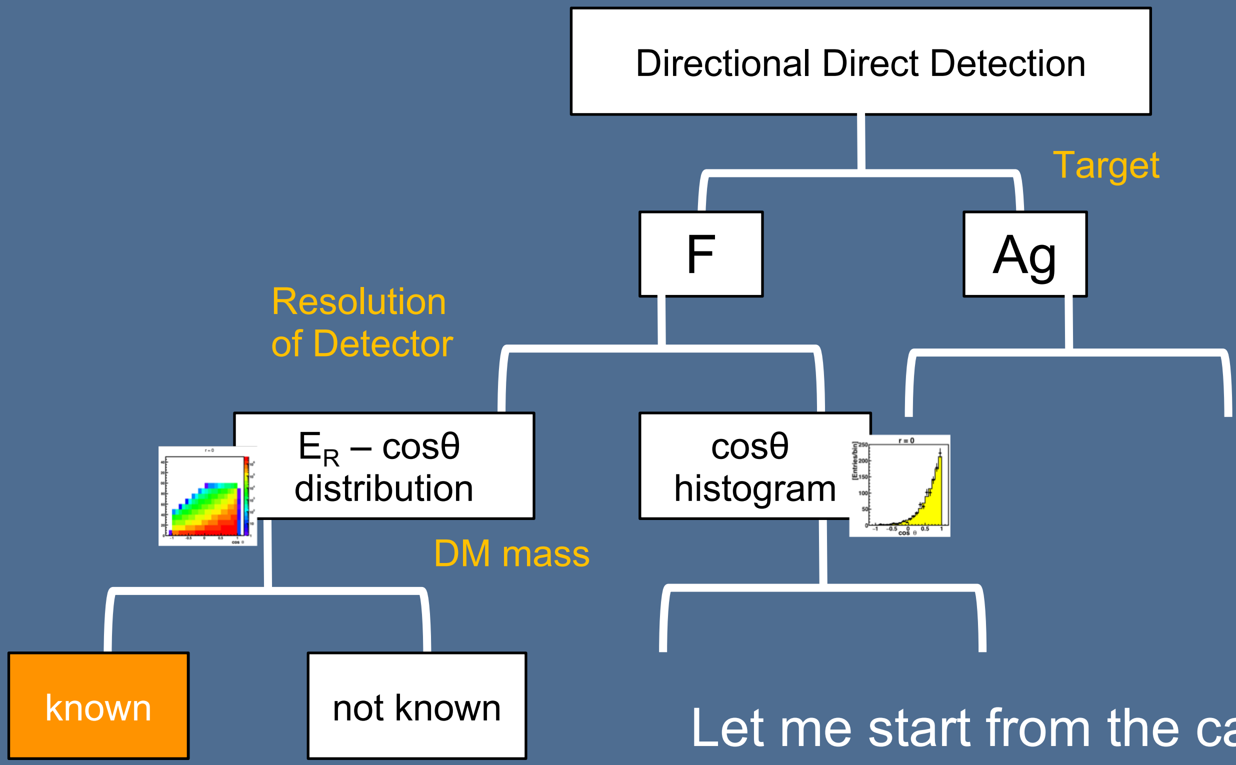
$$\mathcal{L} = \prod_{\text{bins}} P(r \mid \text{pseudo}, \text{template})$$

- χ2 test

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

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

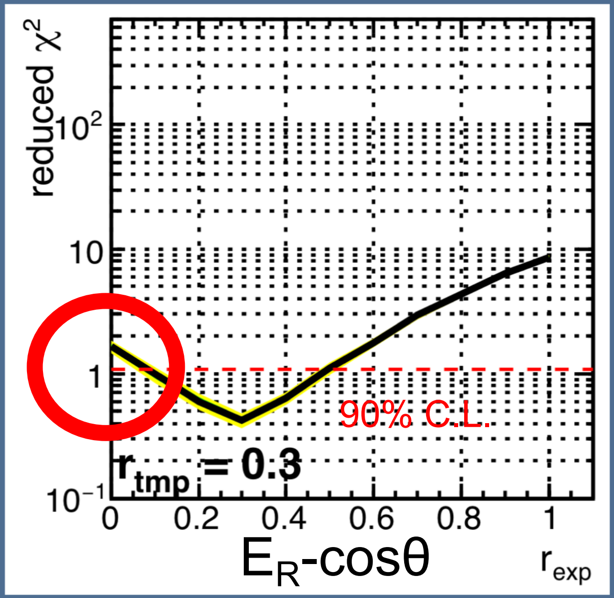
Summary of Branches

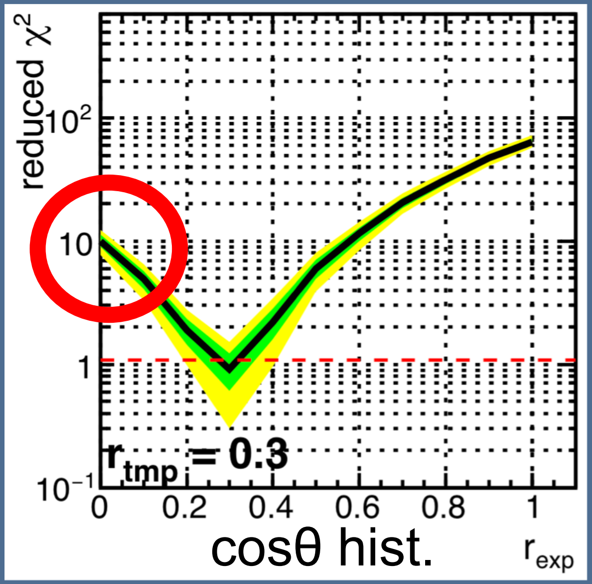


Let me start from the case that M_{DM} is known by collider search:
e.g. $M_{DM} \sim 3M_A$
i.e. 60GeV (F) / 300GeV (Ag)

If anisotropic distribution is realized

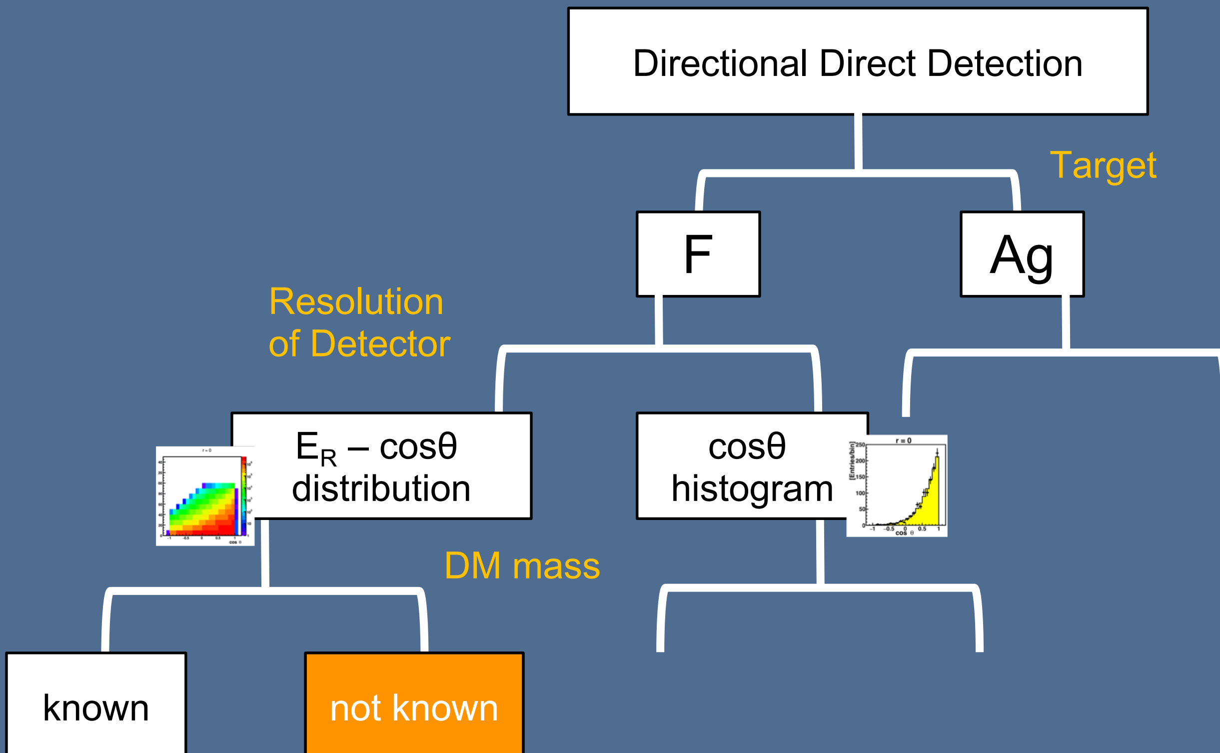
Ethr=50keV (Ag)
M_{dm}=300GeV





- Required #event to exclude isotropic case are
  6×10^3 (ER-cos) / 5×10^3 (cos only) for target F
  6×10^4 (ER-cos)/ 2×10^4 (cos only) for target Ag.

Cases



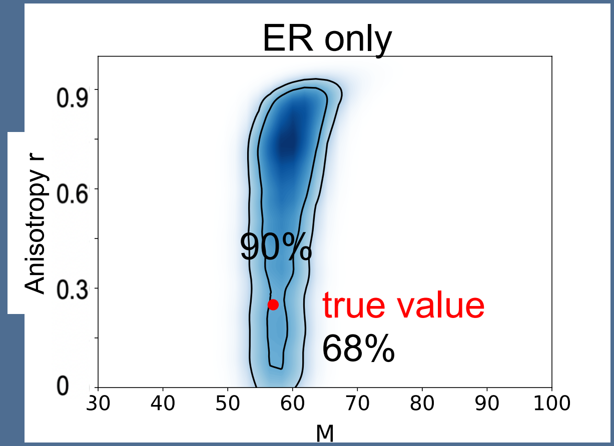
Directional Direct Detection
Target
F
Ag
Resolution of Detector
E_R – cosθ distribution
cosθ histogram
DM mass
known
not known

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

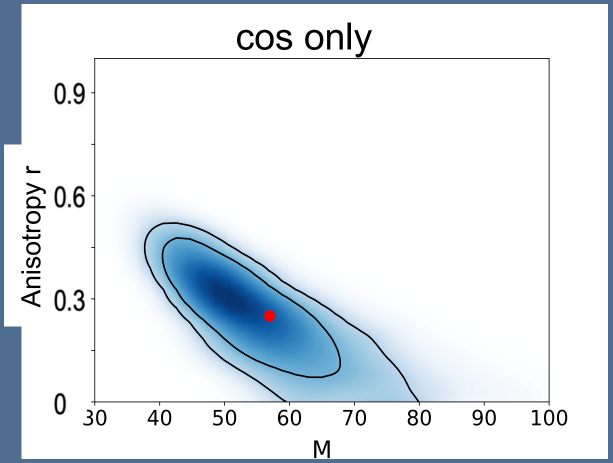
What if M_{DM} is not known?

- Likelihood method

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



- Anisotropy is not discriminated only by E_R.

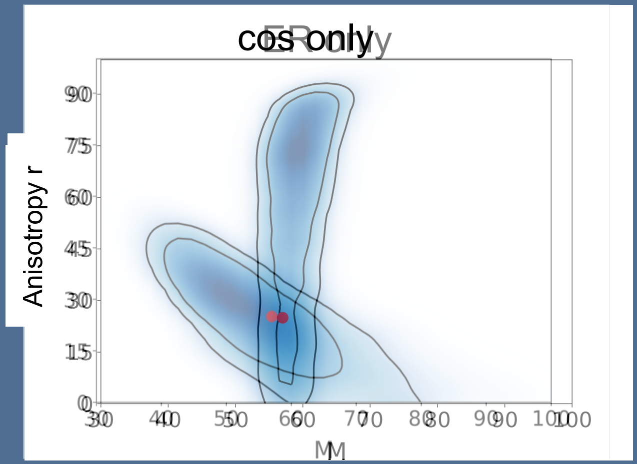


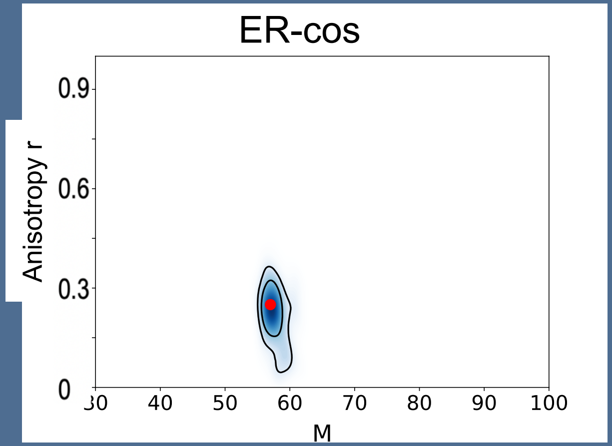
- Constraint for mass by directionality histogram is not so strictly.

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

What if M_{DM} is not known?

- Likelihood method

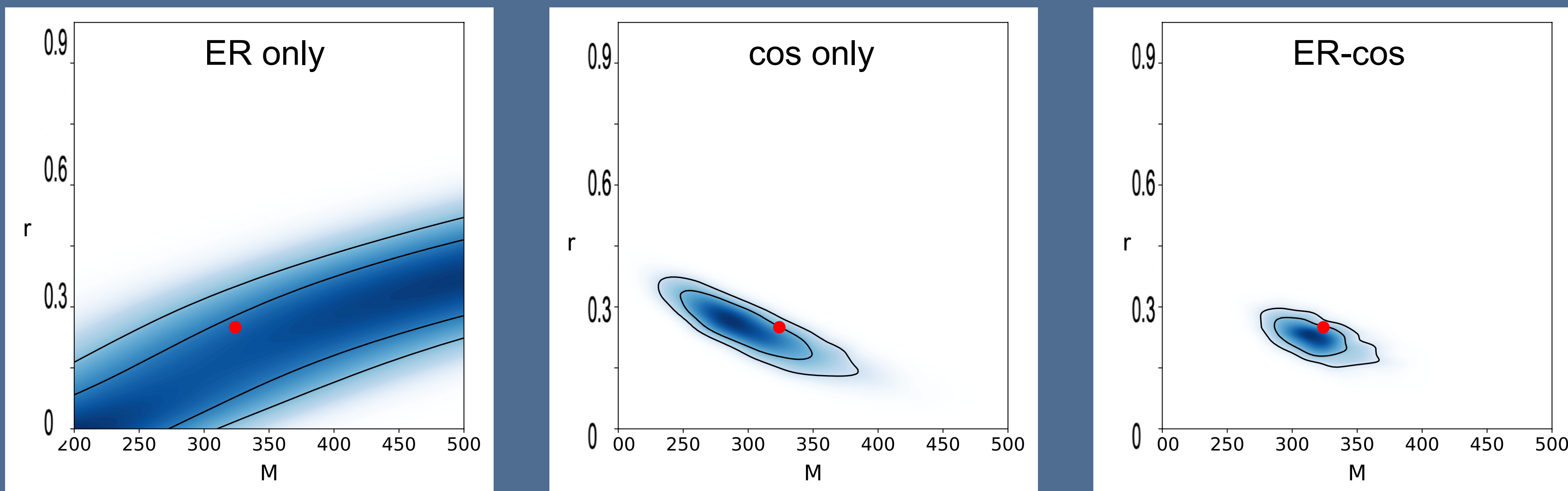




Ethr=50keV (F)
M_{dm}=60GeV
#event: 1000

- 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, we can discuss the anisotropy once $O(10^3\text{-}10^4)$ event is obtained in directional detection. With the optimized analysis to M_{DM}, angular hist. works as well as energy-angular dist.
- 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.