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Dark matter mass and distribution by directional detection

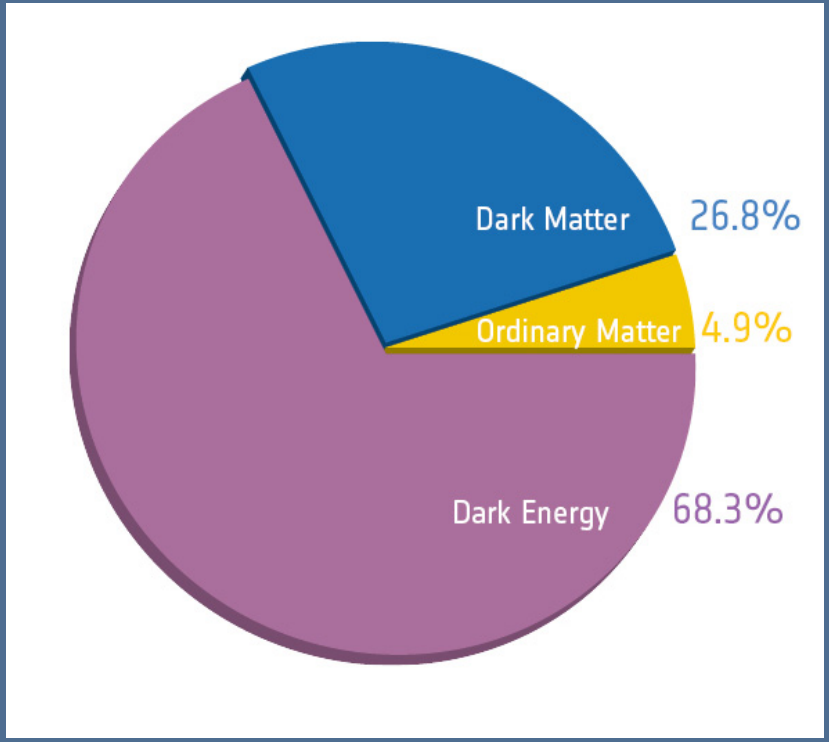
… talk is based on arXiv:1707.05523;
KN, T. Ikeda, R. Yakabe, T. Naka, K. Miuchi

5th International Workshop on
Dark Matter, Dark Energy and Matter-Antimatter Asymmetry
Dec. 29, 2018

Outline

1. Introduction
2. DM Distribution
3. Numerical Results
4. Summary

Dark Matter



- Stable
- Electrically neutral, weakly interacting
- Non-relativistic
- No candidate in SM

- WIMP? Axion (-like particle)? or …?

Direct Detection

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

R Event rate

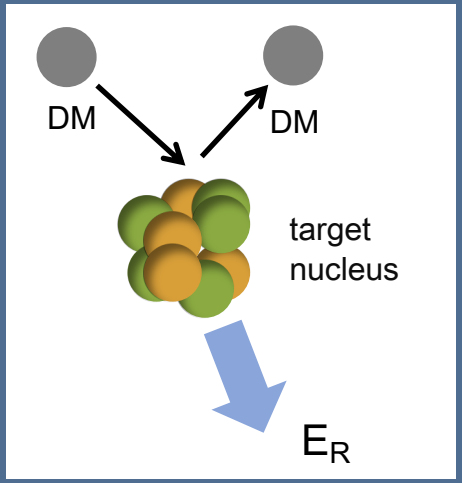
N_T # of target particles

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

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

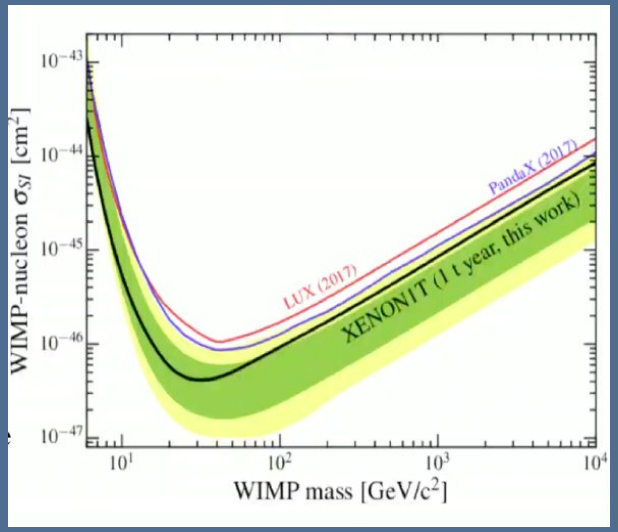
$\langle v \rangle$ Averaged WIMP velocity

σ Cross section for DM-nucleus scattering

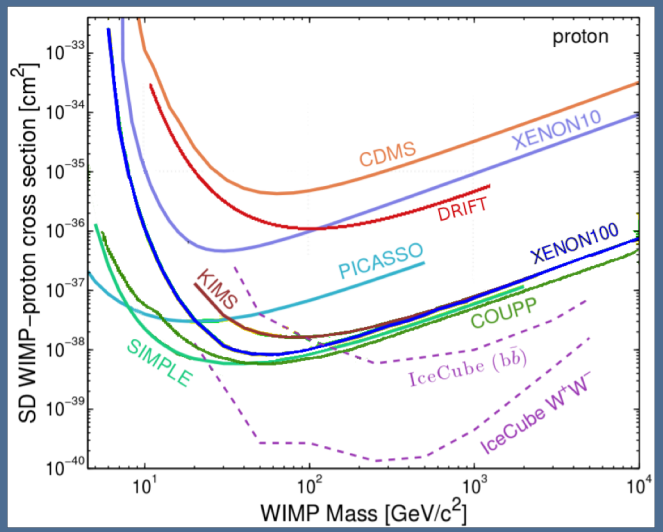


Constraints by Direct Detection

- Constraint for mass - cross section
- Cross section < 10^{-46} cm^2 (SI), $10^{-38}cm^2$ (SD)

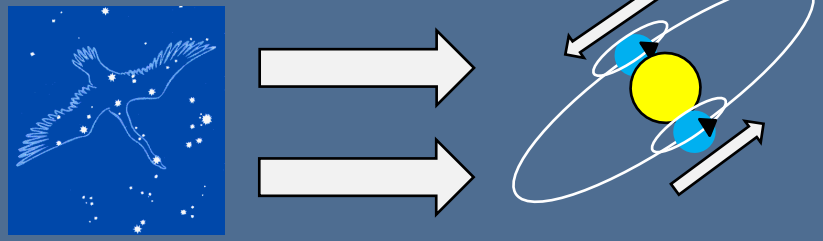


XENON 1T (2018)



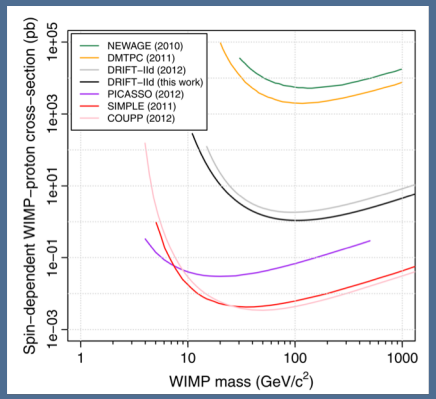
Schumann
arXiv:1501.01200

Directional Direct Detection

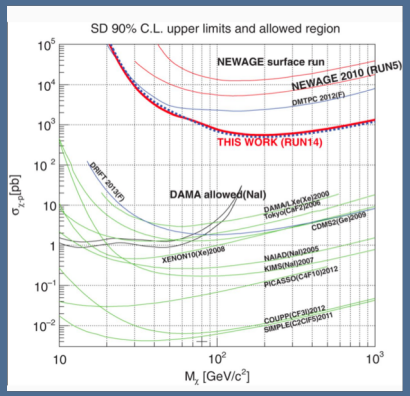


- Ordinally direct detection
  Recoil energy E_R
- Directional detection
  Recoil energy E_R + Direction of nuclear recoil
  (+ time)
- Typical target
  CF_4, CS_2, CHF_3
  (gas detector)

  Ag, Br, C, N, O
  (solid detector)



DRIFT
Phys. of the Dark Universe
9–10 (2015)



NEWAGE
PTEP (2015), 4

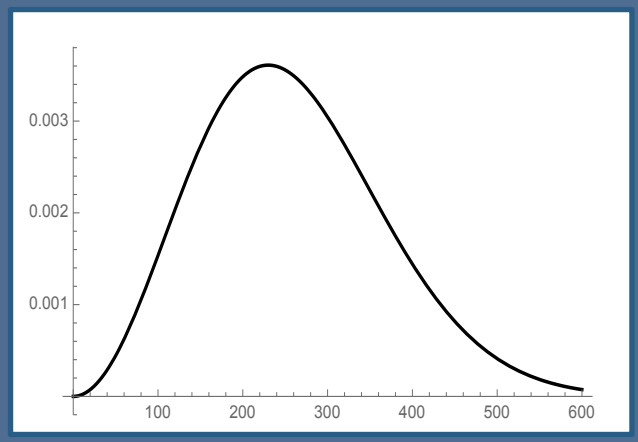
Outline

Velocity distribution 1

- **Maxwell distribution**

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

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

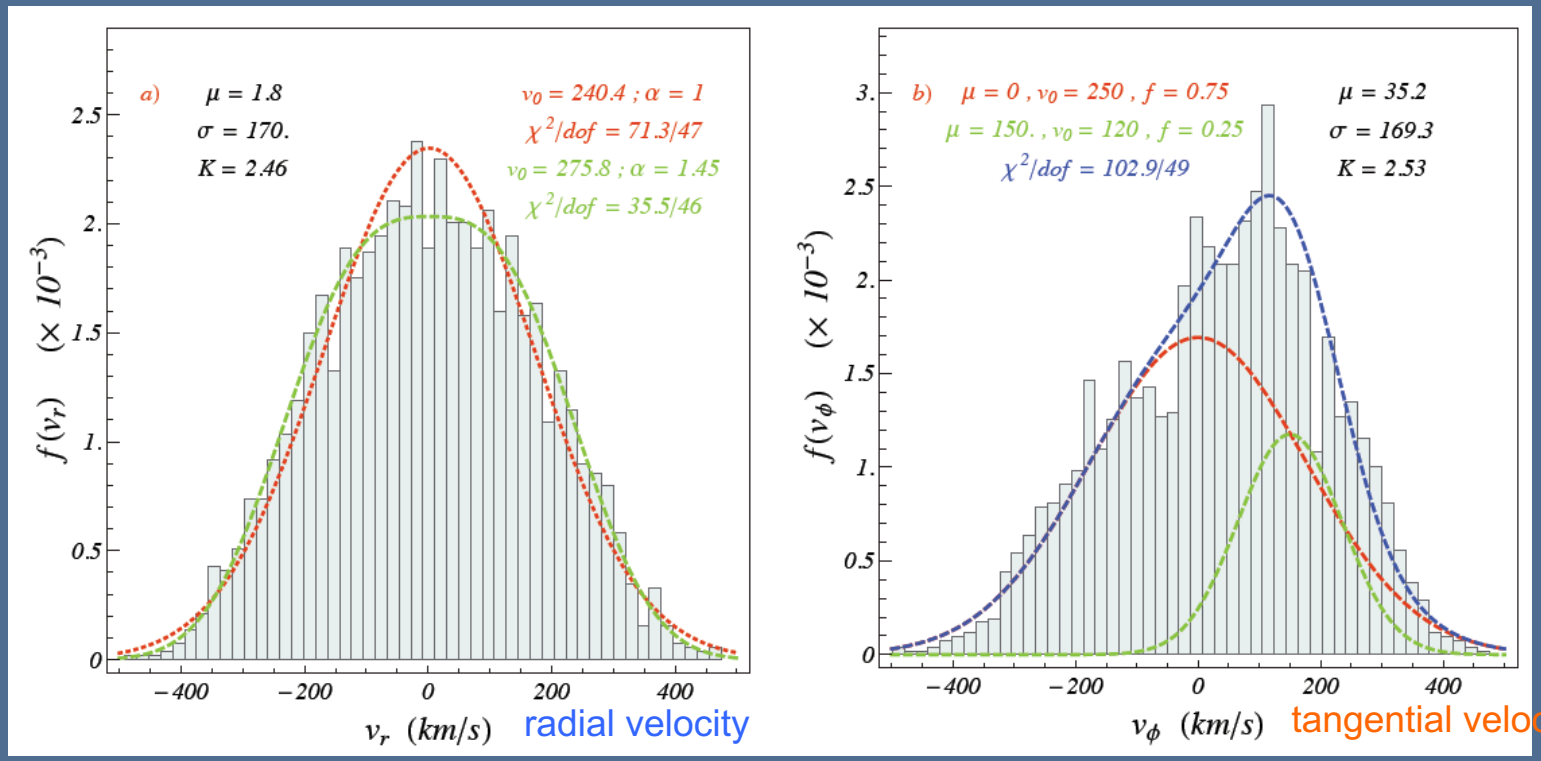


  - ➢ commonly supposed in direct detections
  - ➢ isotropy is also supposed

- **How can we test it?**
  ~~cosmological observations~~
  directional detection

Velocity distribution 2

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



Ling, Nezri, Athanassoula & Teyssier (2009)

cf. Kuhlen et al. (2012), David R. Law (2009) …

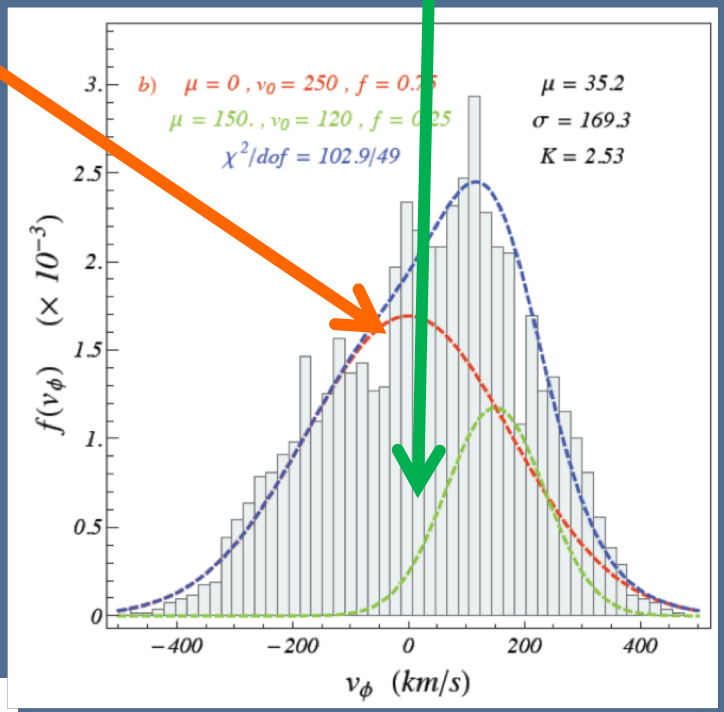
Numerical calculation

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

isotropic

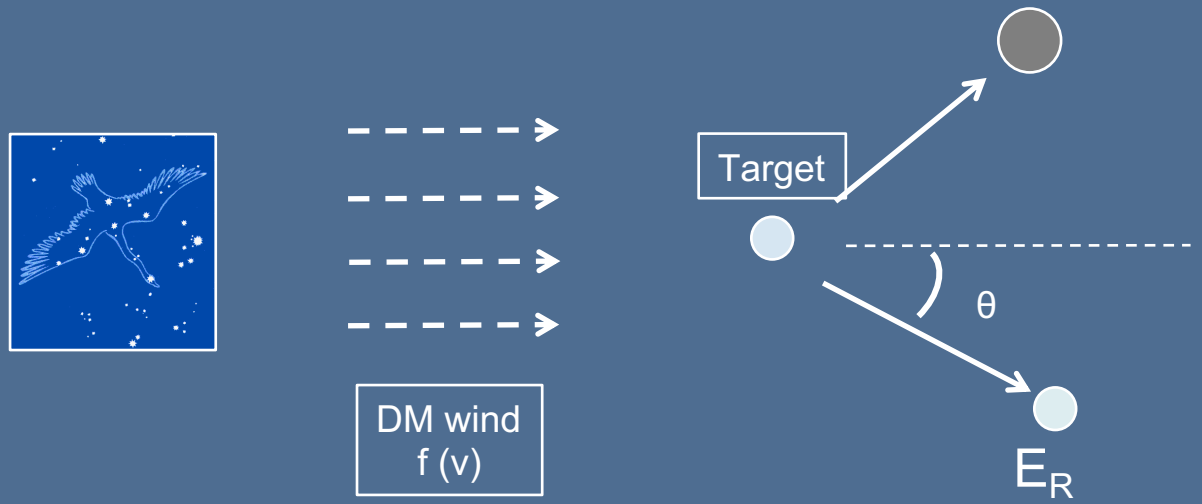
anisotropic

- Tangential velocity
  - anisotropy parameter r
  - r=0.25 is suggested by simulation
- Goal: Discrimination
  - isotropic case (r=0) --- anisotropic case (r=0.3)



Outline

Numerical calculation

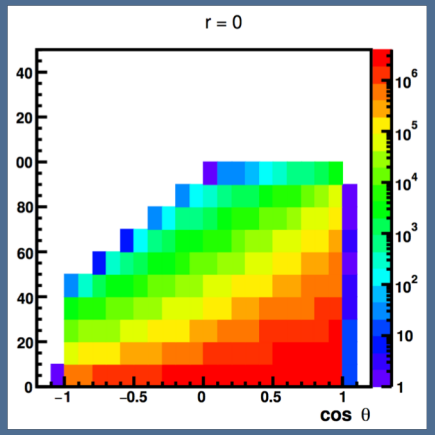


- **Monte Carlo simulation of scattering supposing f(v)**
  Direction (scattering angle) + Recoil energy
  Elastic scattering
  $M_{DM}=3M_N$
  Target : F (light target) /Ag (heavy target)

Analysis

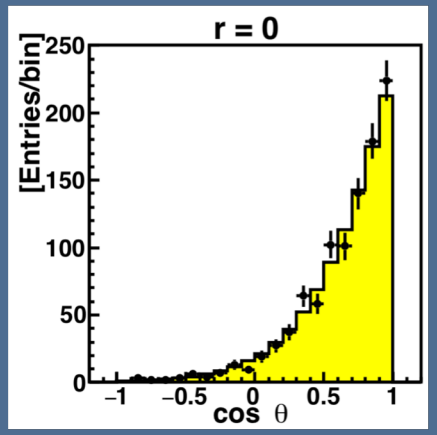
- **depends on resolutions of a detector**

Energy resolution :OK
Angular resolution :OK



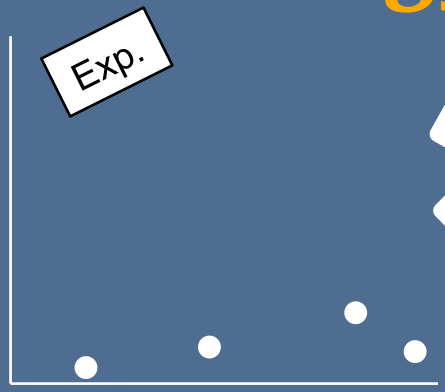
E_R-cosθ
energy-angular distribution

Energy resolution :NG
Angular resolution :OK



cosθ
angular histogram

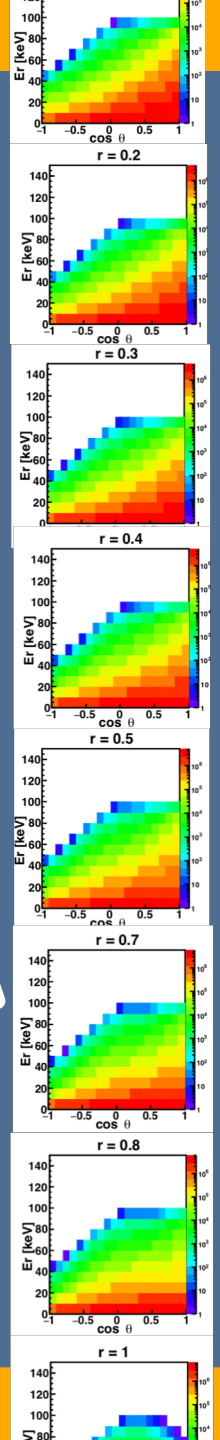
Strategy for discrimination



Isotropic

Which one is the most similar to Exp.?

Anisotropic



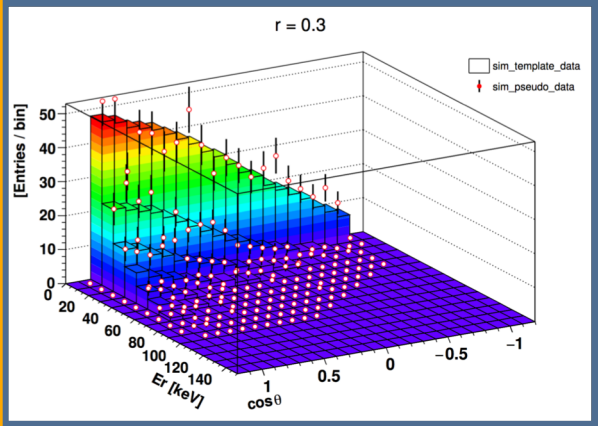
- **Statistical test to examine the similarity of distributions**
  - ✓ Chi-squared test
  - ✓ Likelihood analysis
  - ✓ Kolmogorov–Smirnov test
  - ✓ …

Strategy for discrimination 2

Many Data
(#10^6-10^8)

- ✓ ideal
- ✓ difficult to achieve

ideal "**template**"



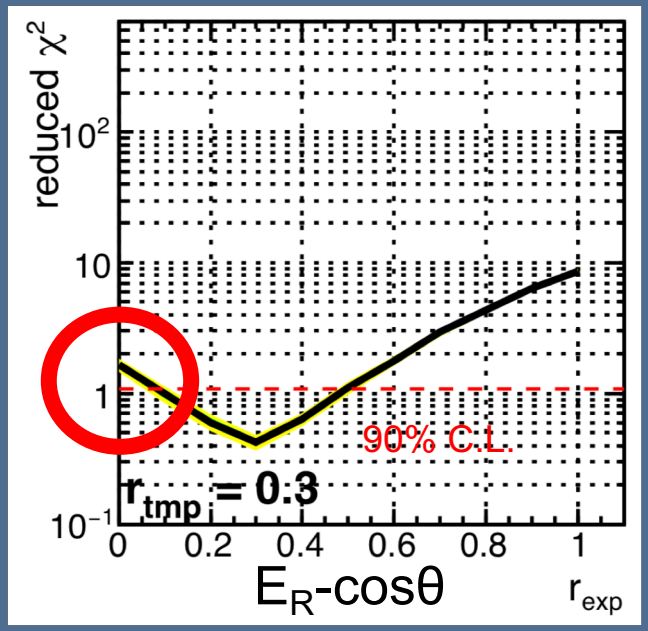
Fewer Data
(#10^3-10^4)

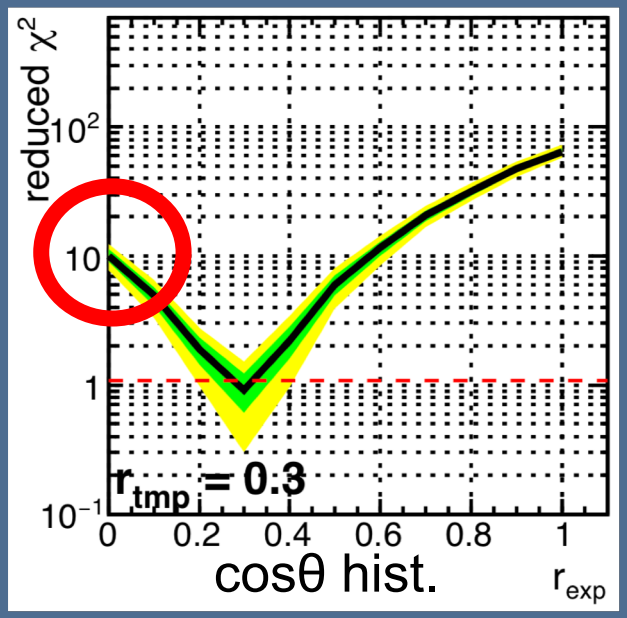
- ✓ realistic (relatively…)

"**pseudo-experimental**" data

Supposing M_{DM} is known...

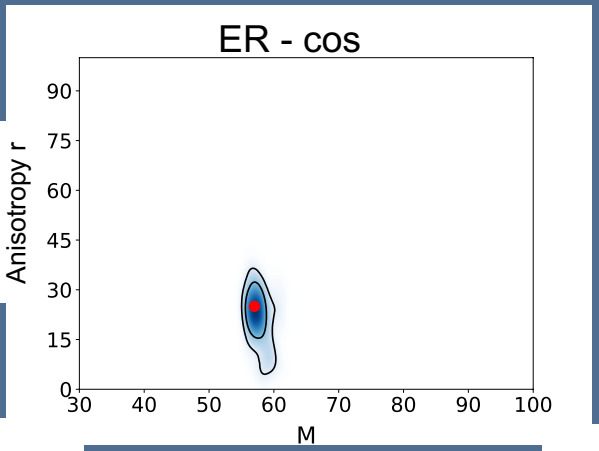
Ethr=50keV (Ag)
M_{dm}=300GeV





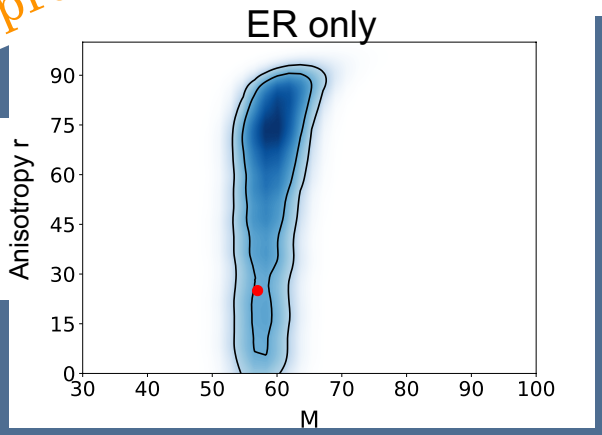
- Required event numbers to exclude isotropic case are
  6×10^3 (ER-cos) / 5×10^3 (cos only) for target F
  6×10^4 (cos only)/ 2×10^4 (cos only) for target Ag.

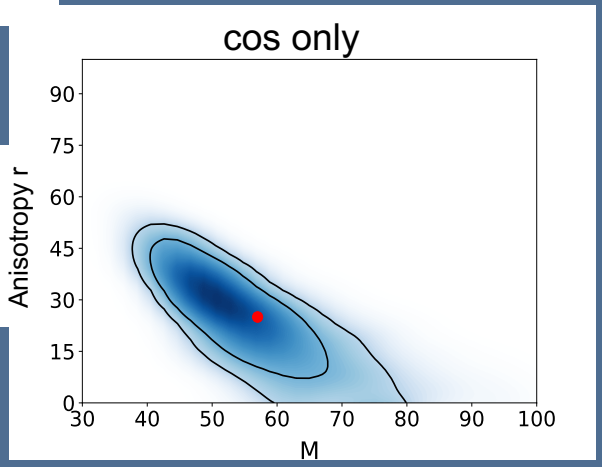
Note: What if M_{DM} is not known?



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

preliminary





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

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.