Can directional detection be a clue to velocity distribution of dark matter?

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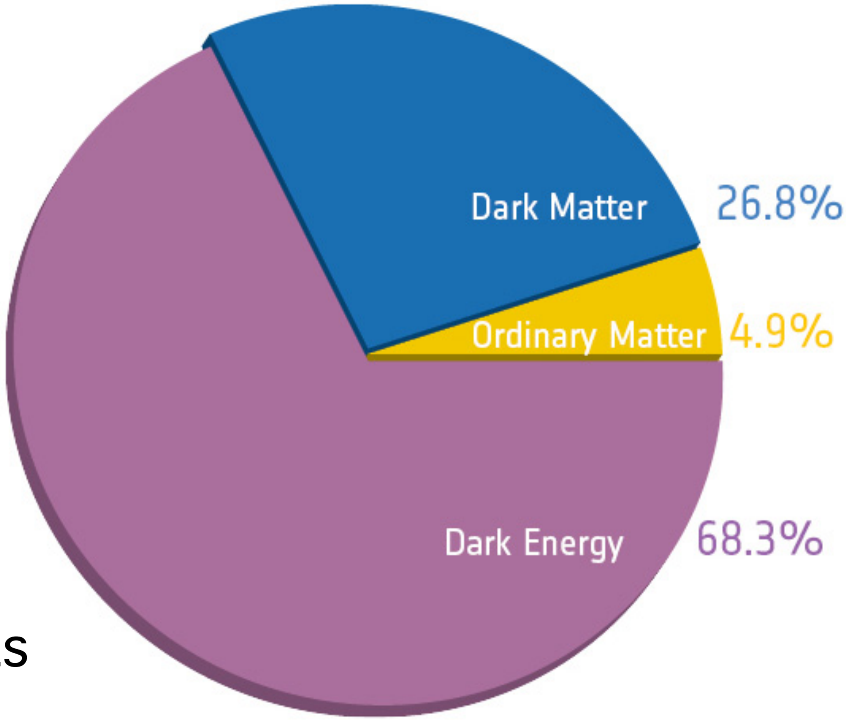
4th workshop on dark matter, dark energy and matter-antimatter asymmetry

Dark Matter

- ✦ No good candidate in SM
  - electrically neutral
  - stable
  - non-relativistic
  - weakly interacting
- ✦ Observations
  - cosmological measurements
  - direct detections
  - indirect detections
  - search at colliders



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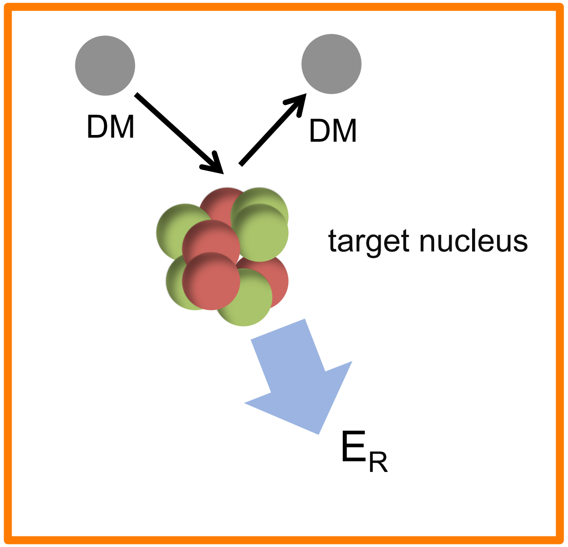
Direct Detection

- ✦ scattering
  - Detecting the recoil energy from scattering of DM and a target nucleon.

- ✦ can calculate

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

  - scattering cross section
  - coupling
  - mass

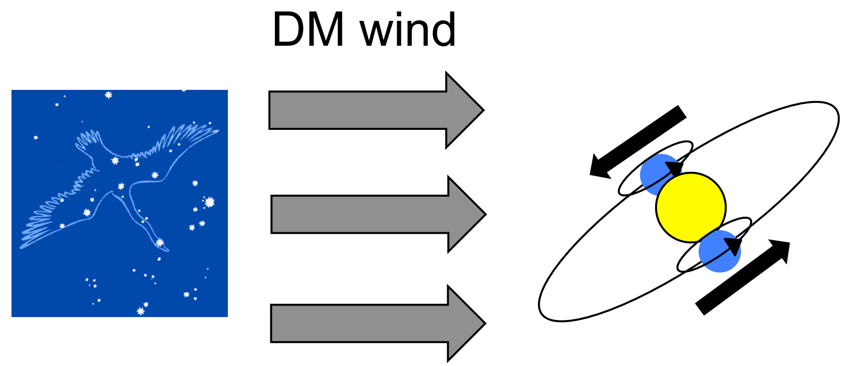


Outline

1. ~~Introduction~~
2. Directional Dark Matter Detection
3. Velocity Distribution of Dark Matter
4. Velocity Distribution Observed in the Directional Detector
5. Summary

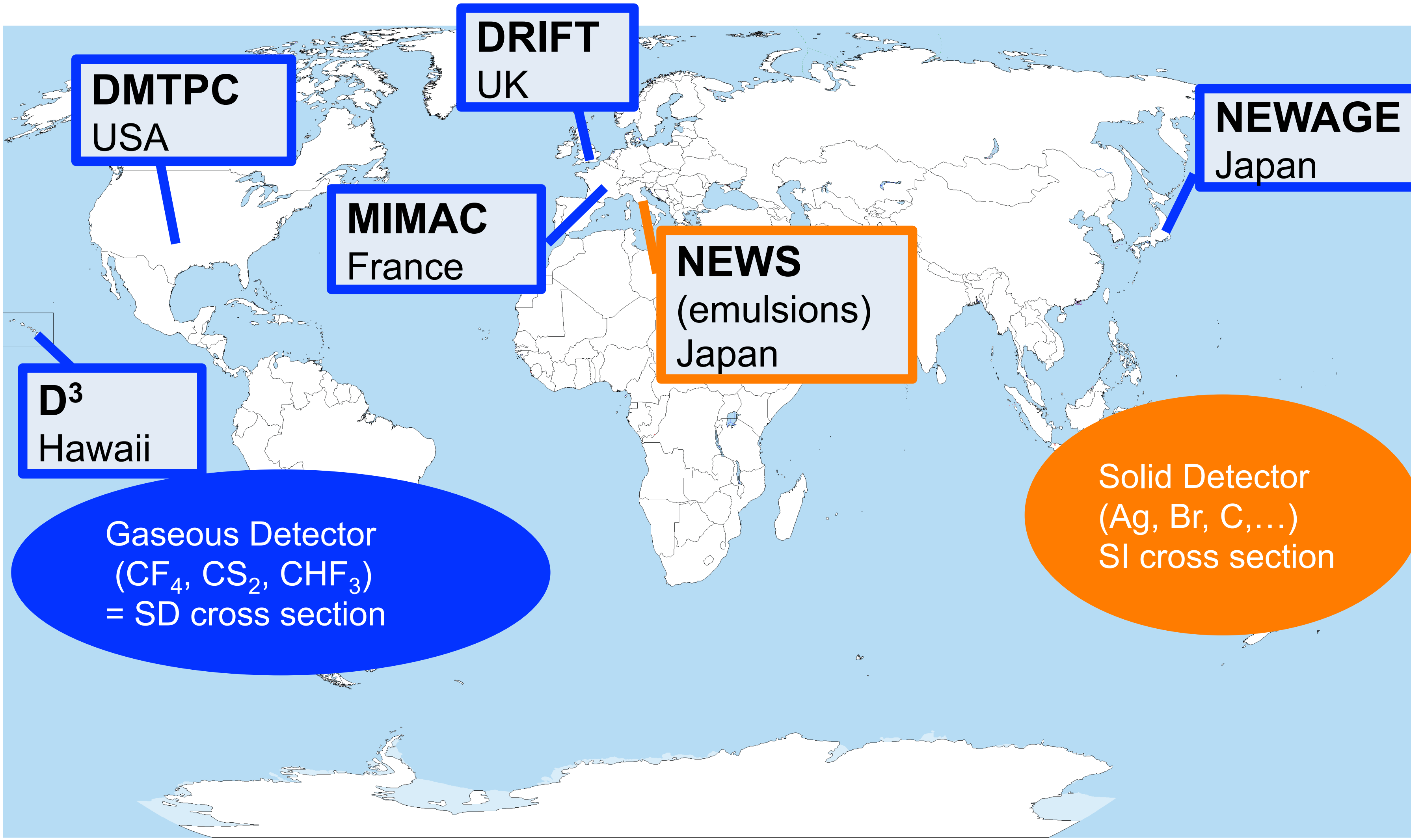
Directional
Dark Matter Detection

To next generation



- ✦ Directional Detection
  - detecting not only the recoil energy but also direction where DM comes from.
- ✦ Advantages
  - Powerful back ground rejection
    Bkg : isotropic
    DM signal : come from the direction of the Cygnus.
  - Detection of annual/daily modulation

Directional Searches



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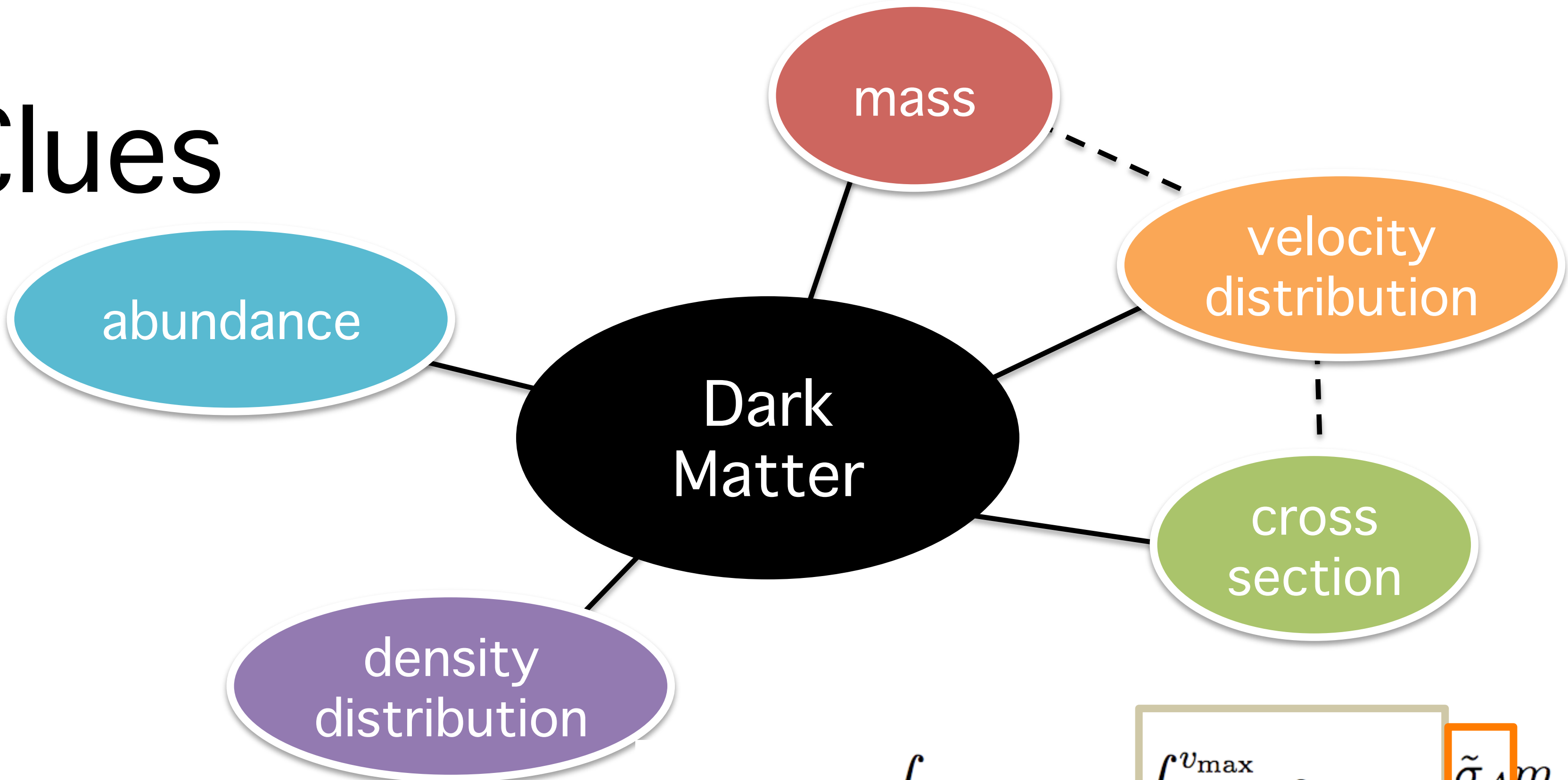
Velocity Distribution of Dark Matter

Clues



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

- In the directional DM search, it can be possible to make a constraint for the velocity distribution.
- Correct distribution is required to derive appropriate constraints for the interaction

Standard Distribution

- Maxwell distribution

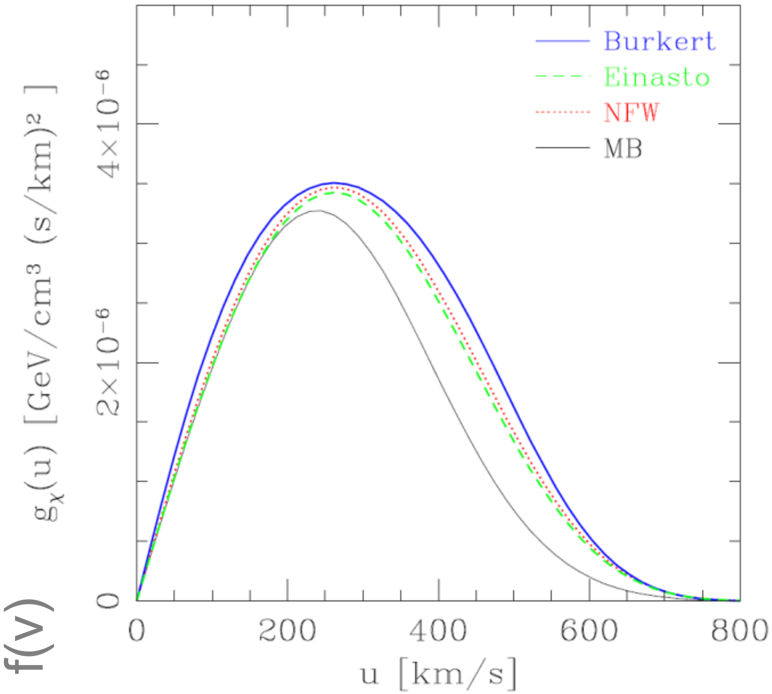
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$

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

- isotropic

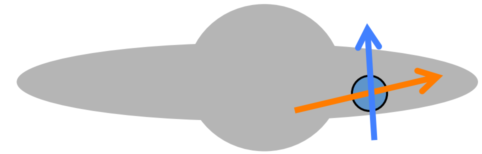
- Is DM distribution surely this shape?

f(v)

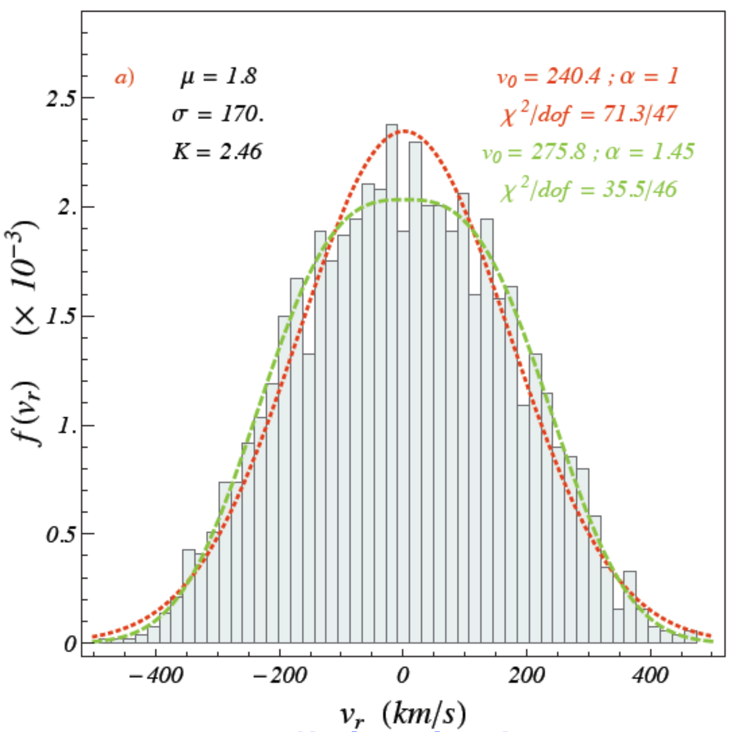


Catena and Ullio (2012)

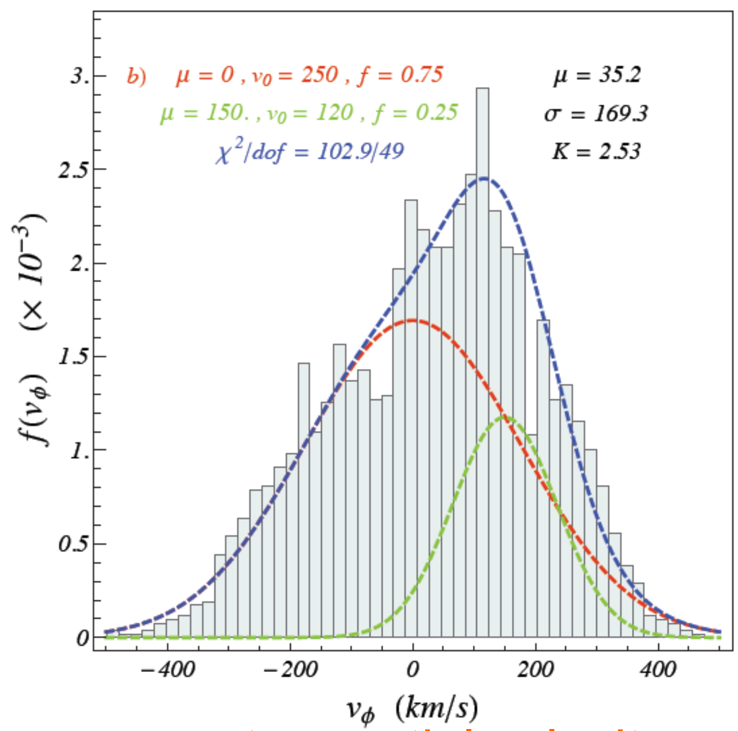
Co-rotating DM



- ✦ N-body simulation including baryons and gas
  - DM co-rotates with baryons in the galaxy.
  - Anisotropic distribution



radial velocity



tangential velocity

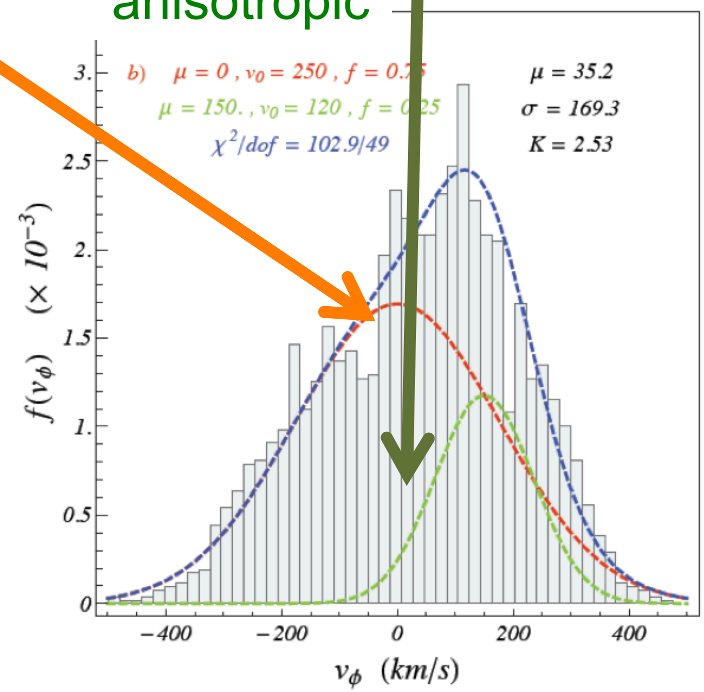
Ling, Nezri, Athanassoula & Teyssier (2009)

Anisotropy parameter “r”

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

isotropic

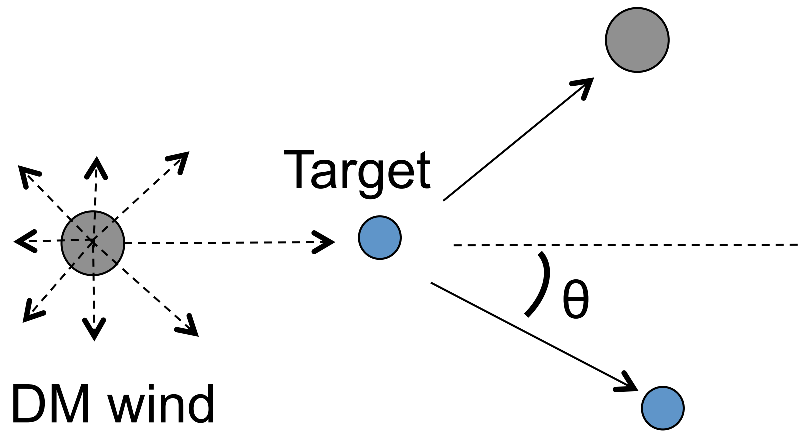
anisotropic



- ✦ Tangential velocity
  - Anisotropy parameter $0 < r < 1$
  - r=0.25 is suggested by N-body simulation

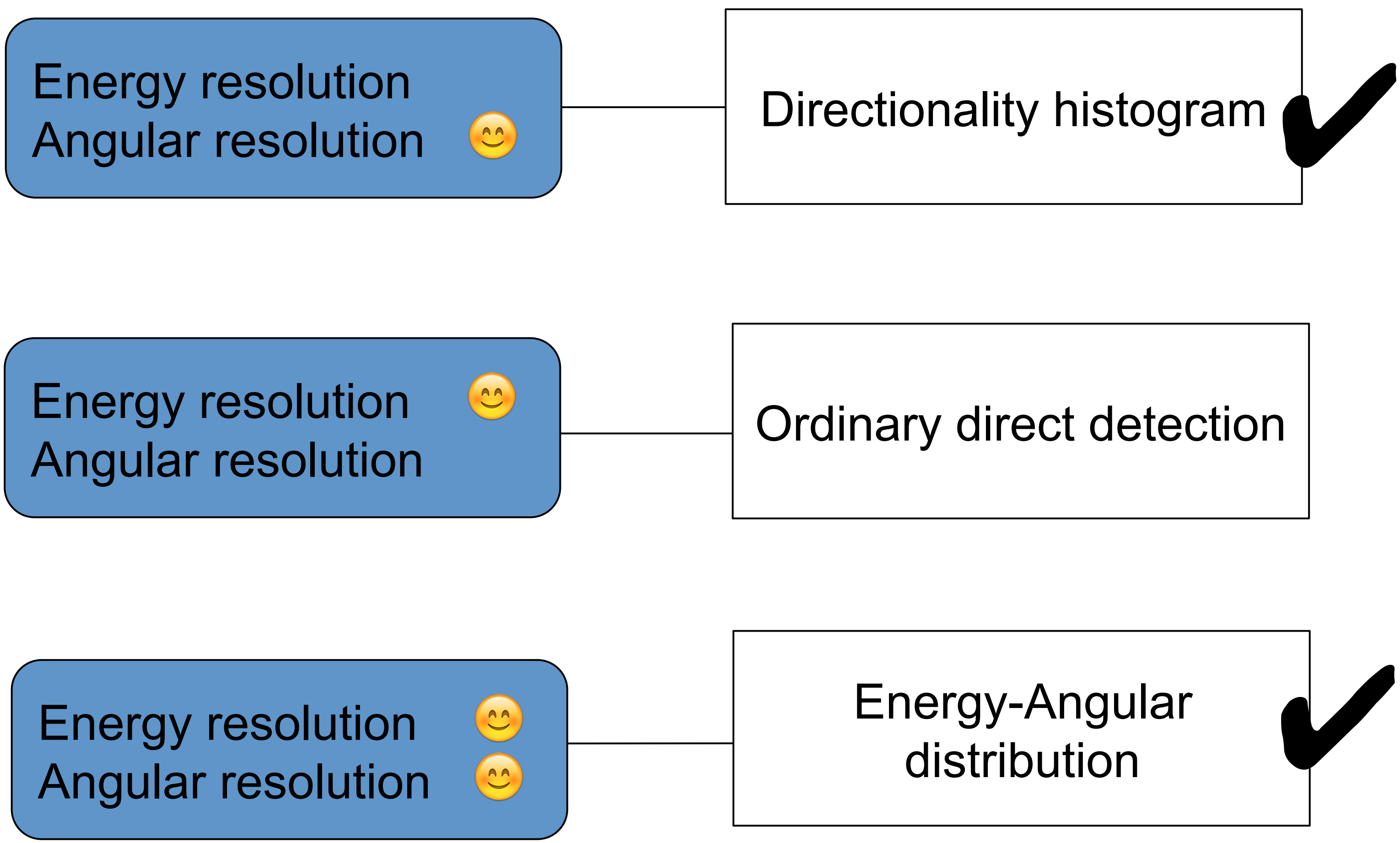
Velocity Distribution observed in Directional Detector

Can we distinguish velocity distributions?



- Monte Carlo simulation
  - Direction (scattering angle)
  - Recoil energy
- Elastic scattering
- mass relation $m_\chi = 3m_N$

Analysis


Energy resolution
Angular resolution
Directionality histogram
Energy resolution
Angular resolution
Ordinary direct detection
Energy resolution
Angular resolution
Energy-Angular distribution

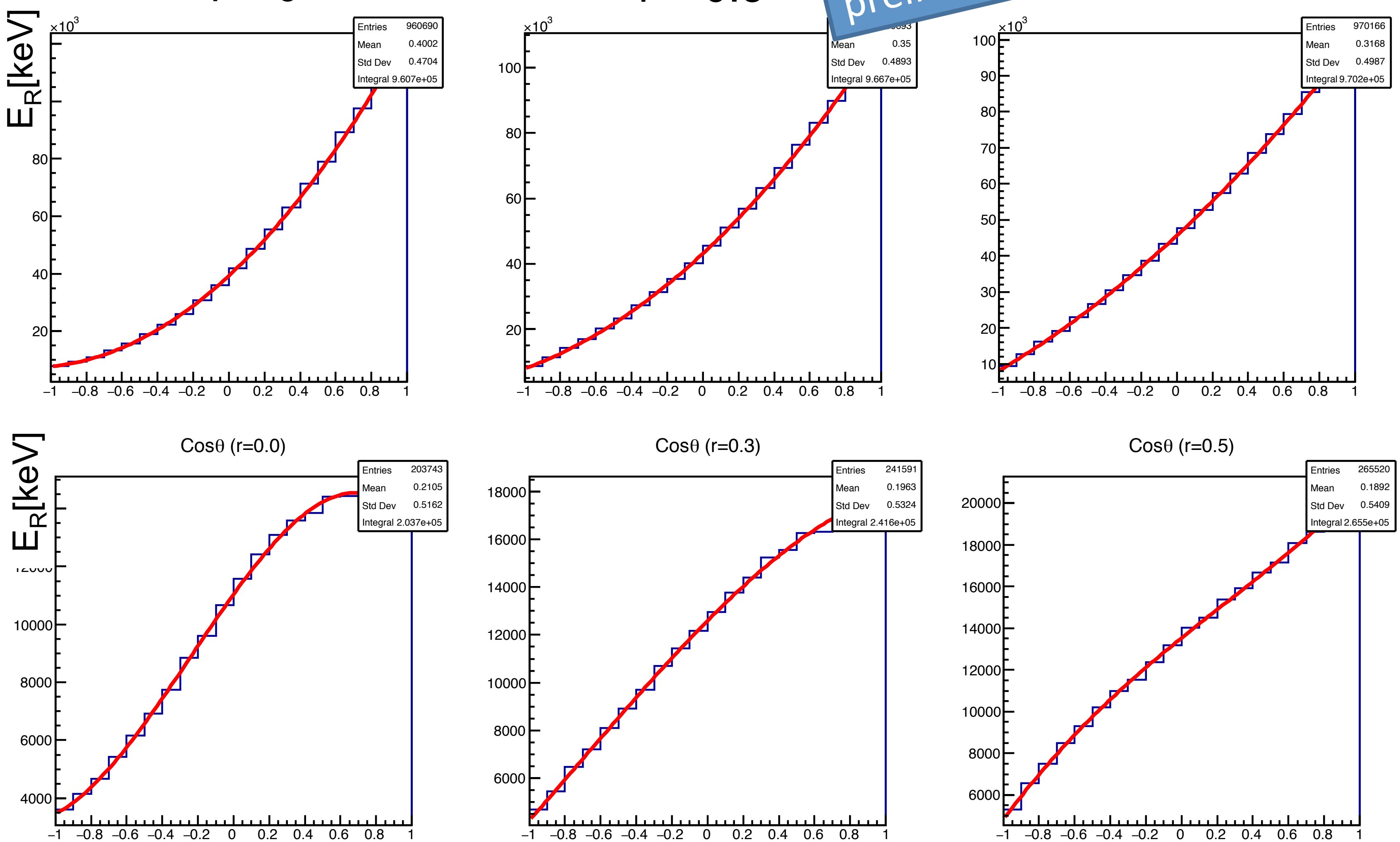
Directionality (1)

r = 0 | r = 0.3 | r = 0.5

preliminary

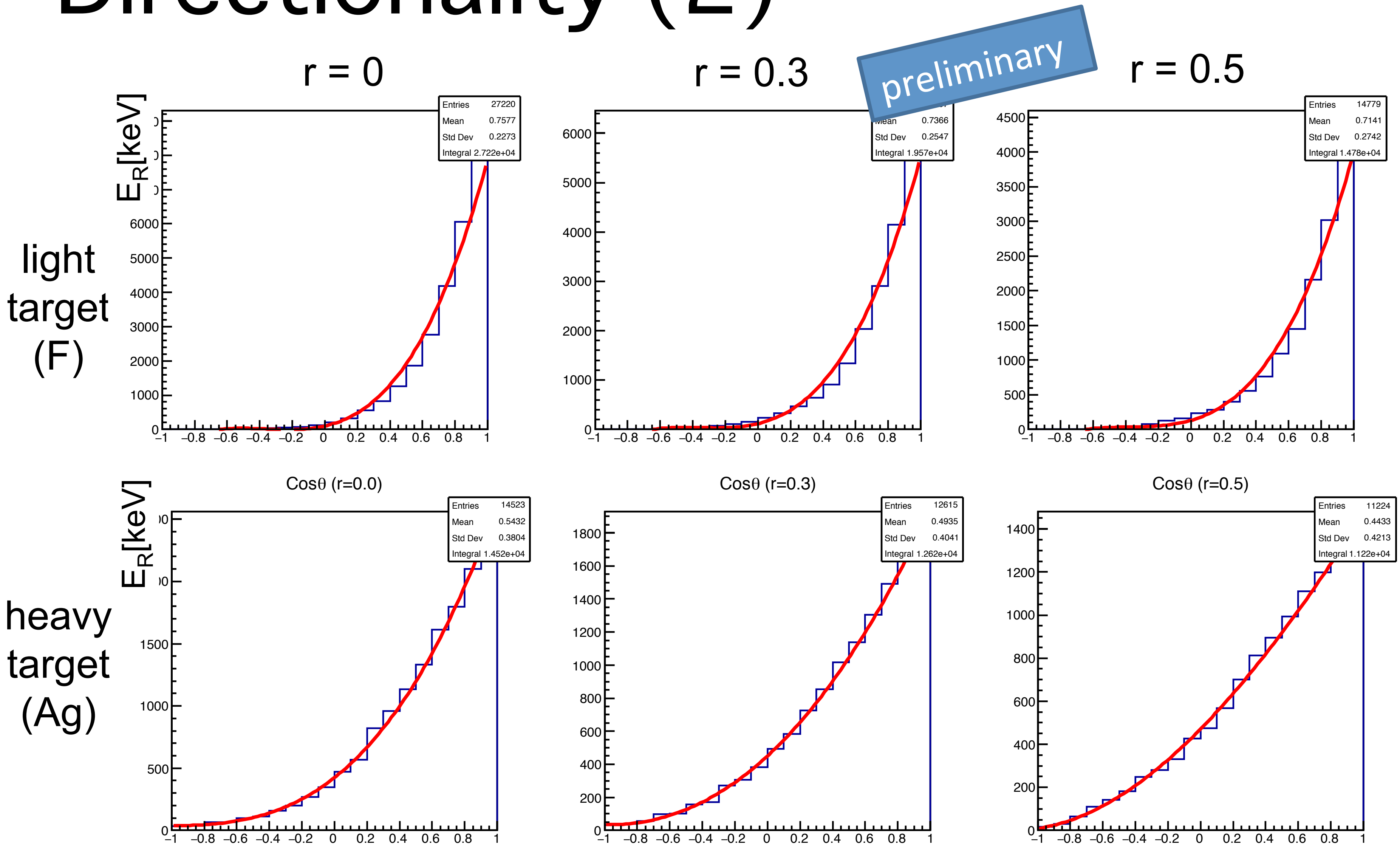
light target (F)

heavy target (Ag)



Ethr = 0keV

Directionality (2)

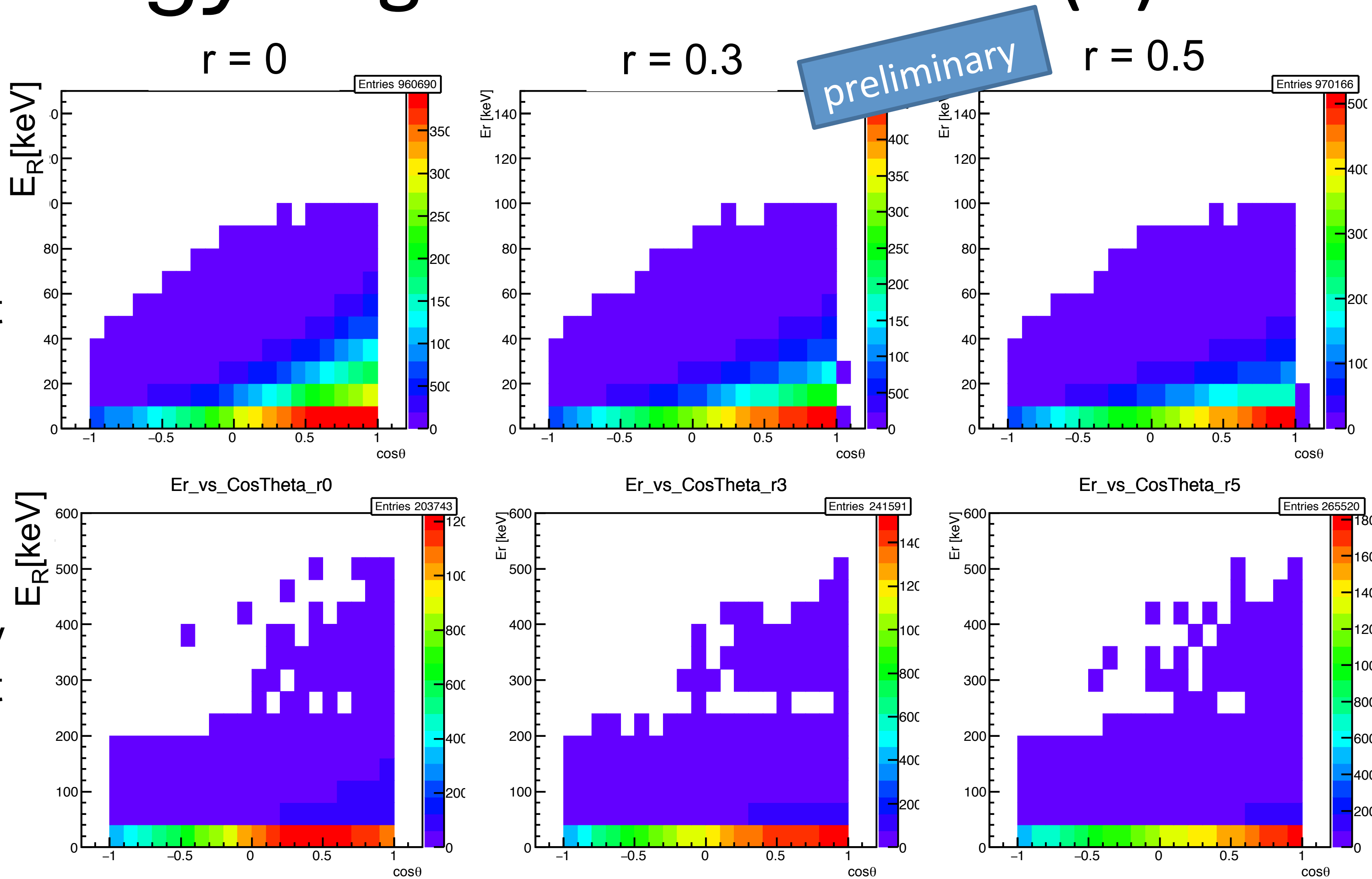


Ethr=50keV (F)
100keV (Ag)

Can directional detection be a clue to velocity distribution of dark matter?

Energy resolution 😊
Angular resolution 😊

Energy-angular distribution (1)



light target (F)

heavy target (Ag)

Ethr = 0keV

Can directional detection be a clue to velocity distribution of dark matter?

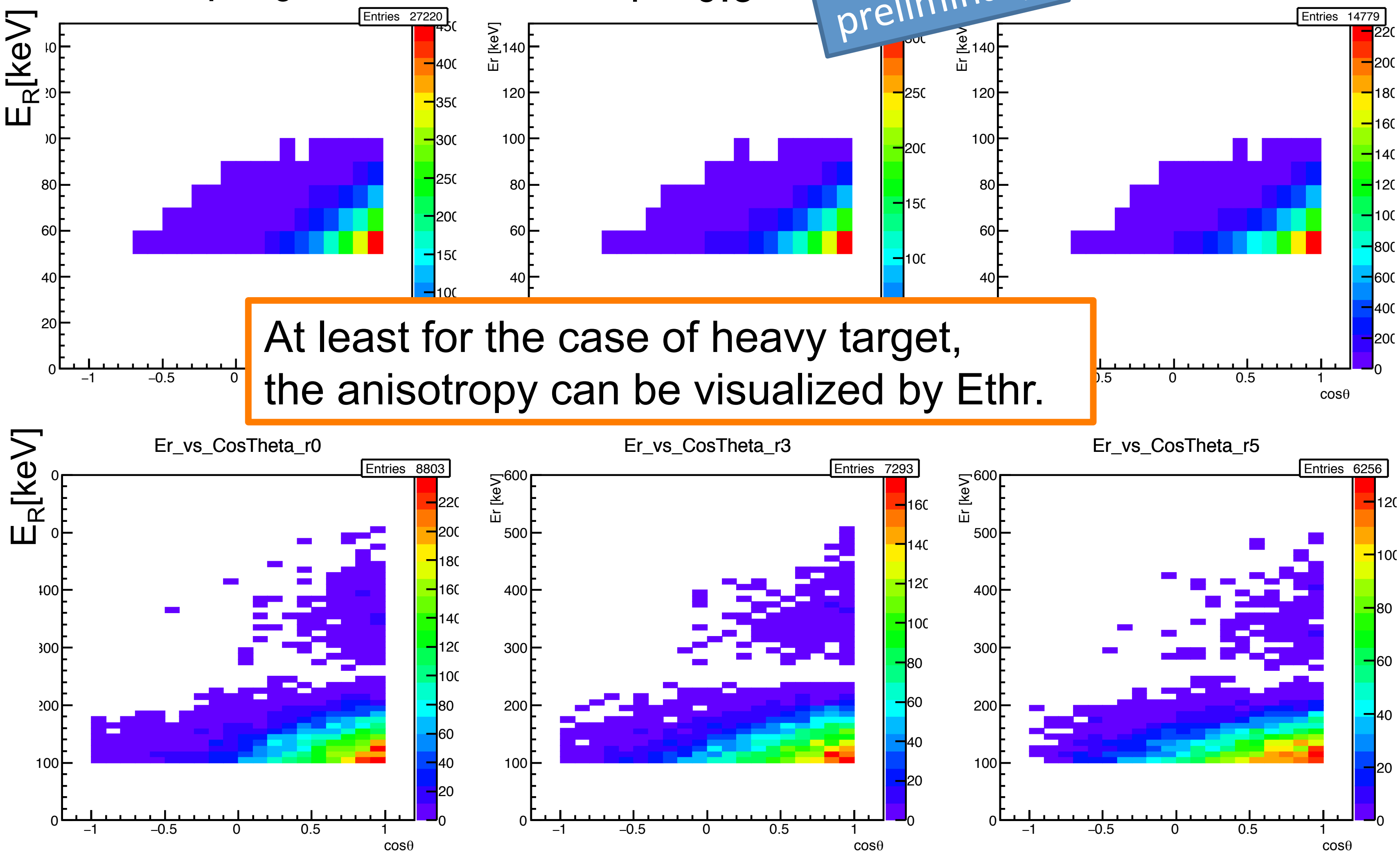
Energy-angular distribution (2)

r = 0 | r = 0.3 | r = 0.5

preliminary

light target (F)

heavy target (Ag)



At least for the case of heavy target,
the anisotropy can be visualized by Ethr.

Ethr=50keV (F)
100keV (Ag)

Realistic Analysis

Many Data (#10^6)

- ✓ ideal
- ✓ difficult to achieve

"expected" template

χ squared test

$$\chi^2 = \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}}$$

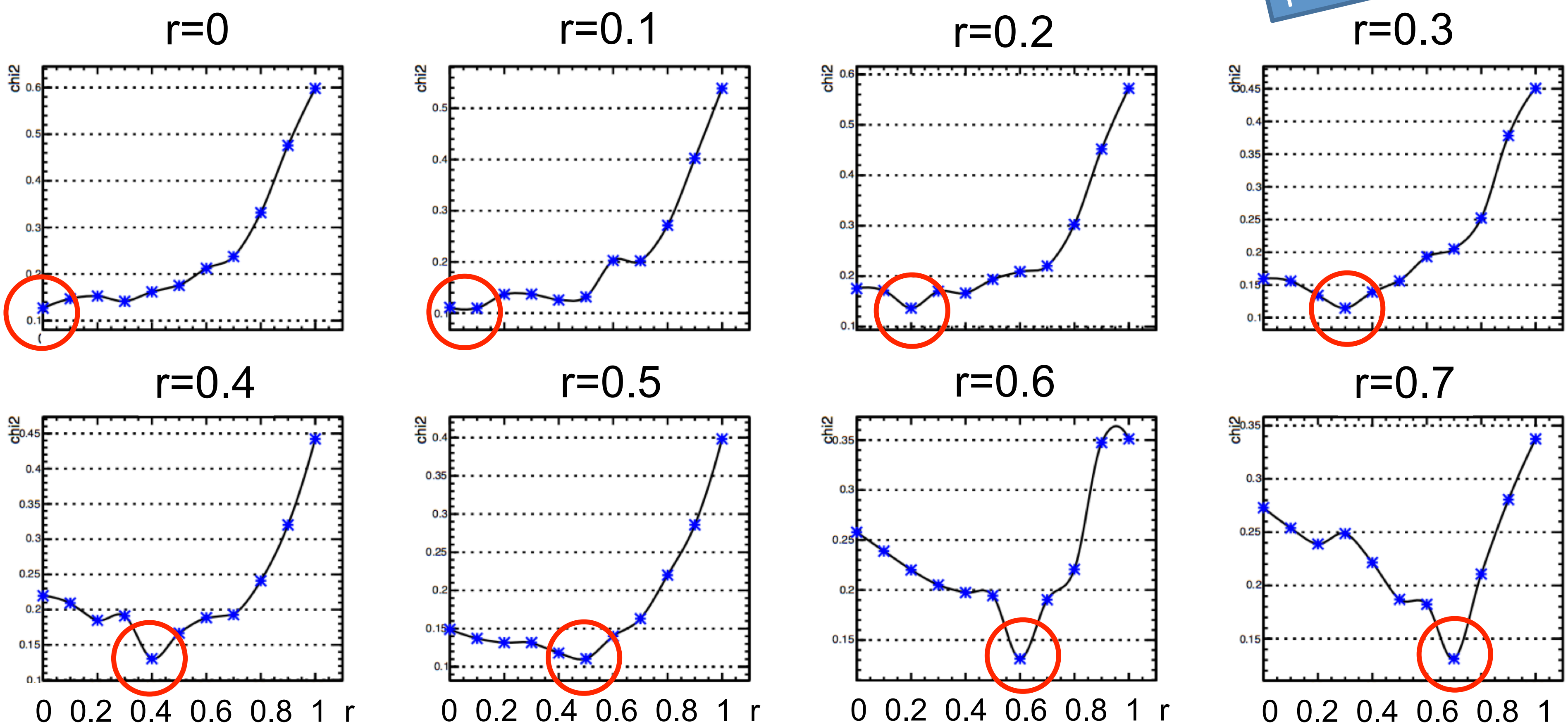
Few Data (#10^3)

- ✓ realistic

"pseudo-experimental" data

Chi squared test for r (#10^3)

preliminary



Chi squared test can point out correct anisotropy parameter.

Ethr=100keV (Ag)

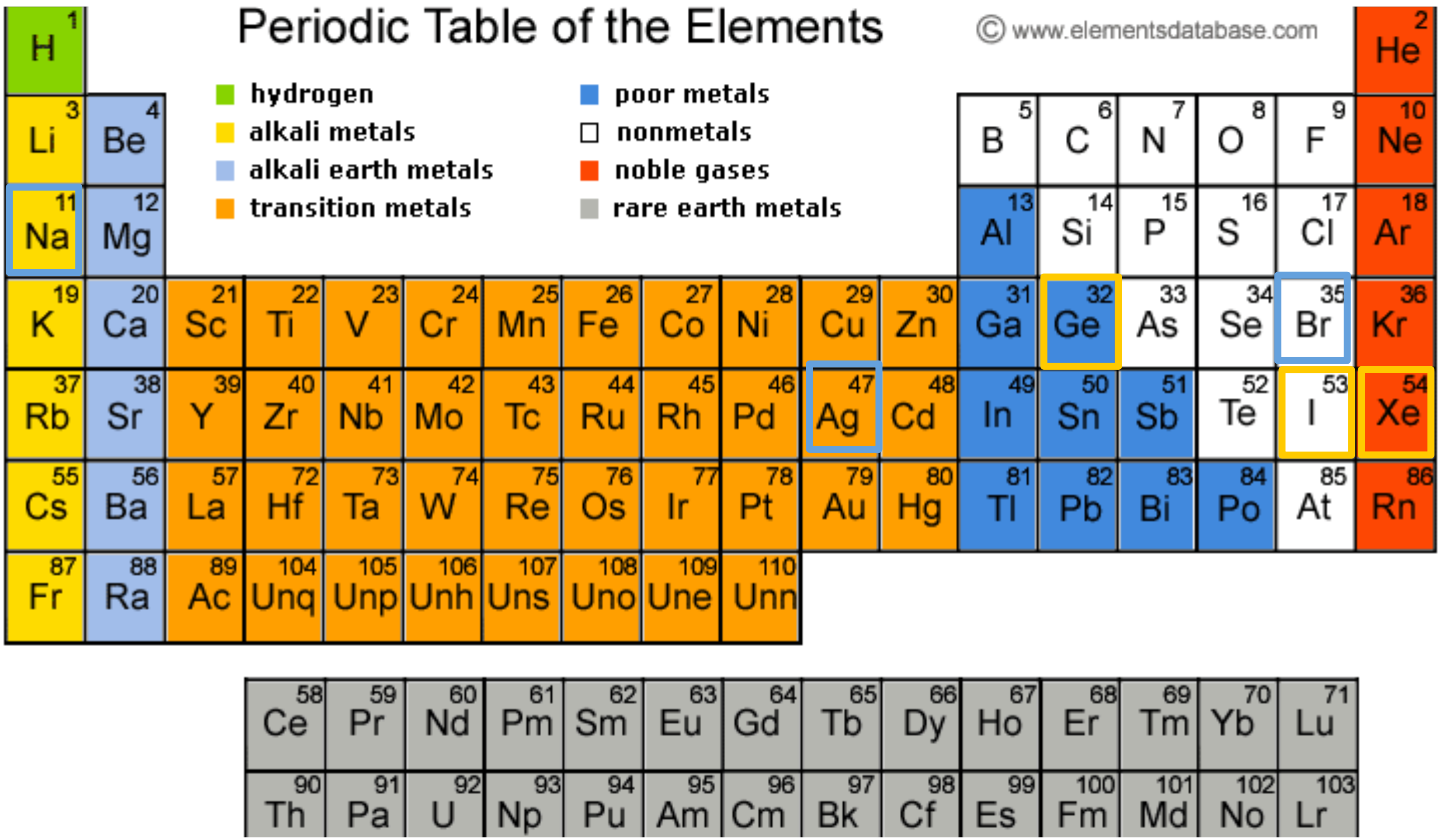
Summary & Discussion

✦ I discussed the possibility to distinguish the distribution models of dark matter in the direct detection.

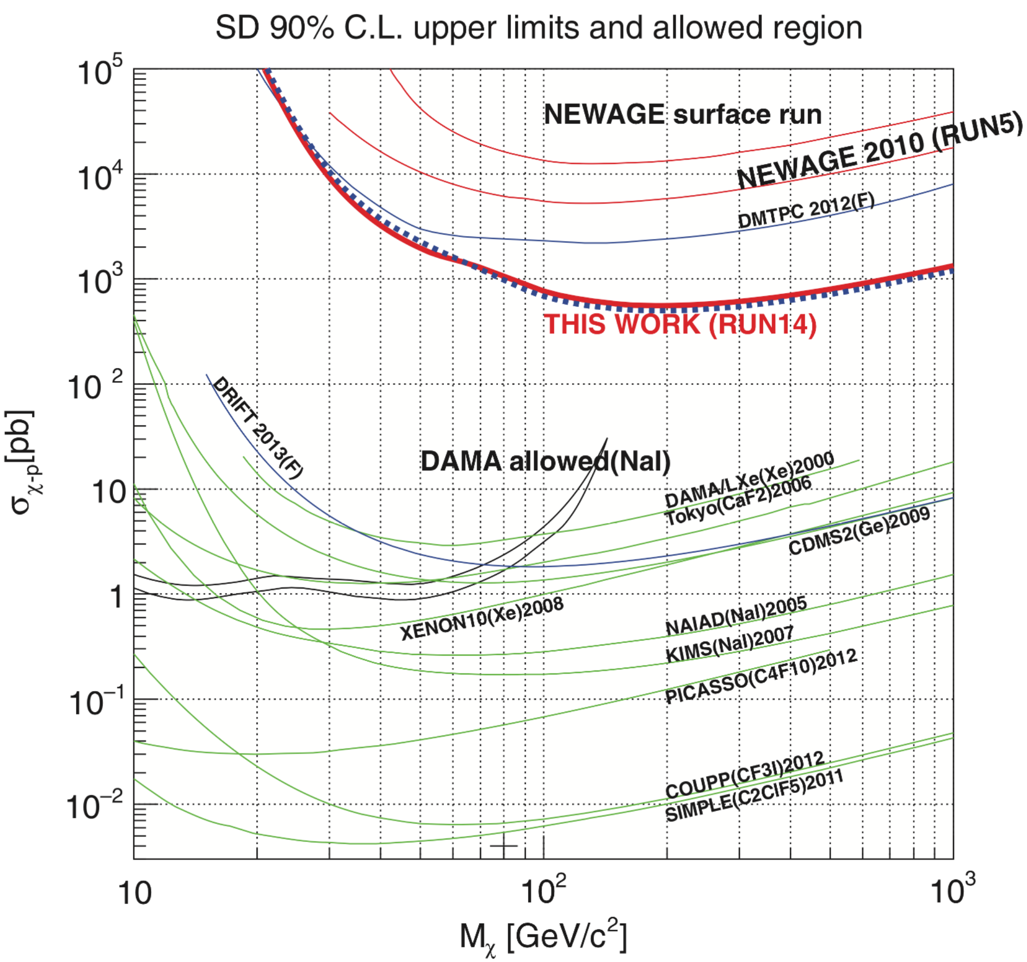
✦ With “template data”, the chi squared test is helpful to figure out anisotropy if O(1000) data is obtained.

Backup Slides

Periodic Table



NEW AGE



SD 90% C.L. upper limits and allowed region
NEWAGE surface run
NEWAGE 2010 (RUN5)
DMTPC 2012(F)
THIS WORK (RUN14)
DRIFT 2013(F)
DAMA allowed(NaI)
DAMA/LXe(Xe)2000
Tokyo(CaF2)2006
CDMS2(Ge)2009
XENON10(Xe)2008
NAIAD(NaI)2005
KIMS(NaI)2007
PICASSO(C4F10)2012
COUPP(CF3I)2012
SIMPLE(C2ClF5)2011
σχ-p[pb]
Mχ [GeV/c2]

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