

Anisotropy of DM velocity distribution measured with directional detection

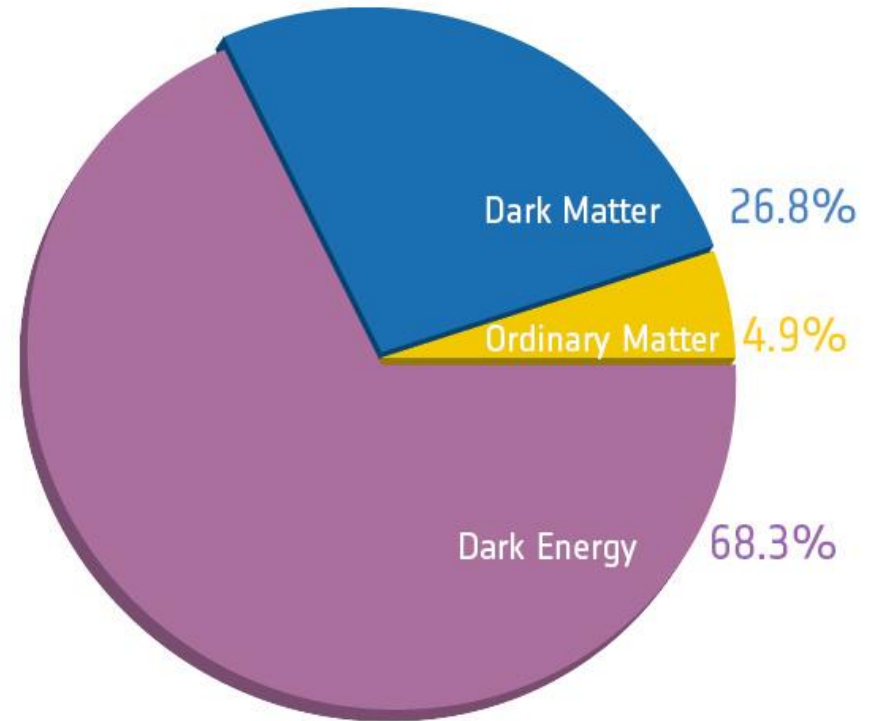
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Collaboration with Ryota Yakabe (Kobe Univ.), Tatsuhiro Naka (Nagoya Univ.) and Kentaro Miuchi (Kobe Univ.)

arXiv:1707.05523

Dark Matter

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



Anisotropy of DM velocity distribution measured with directional detection

Direct Detection



✦ Scattering

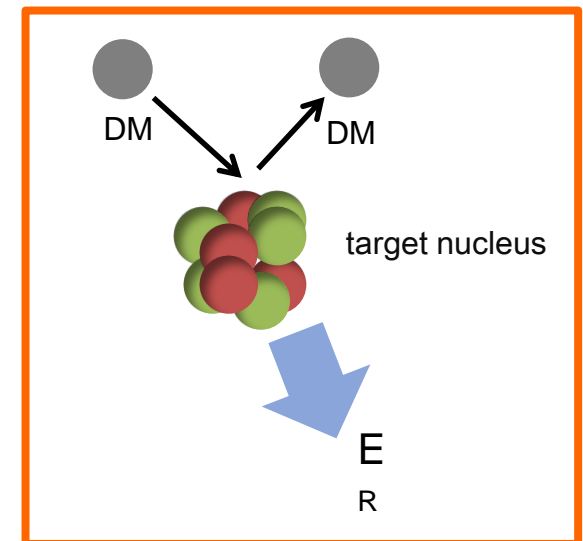
- Detect **recoil energy** of DM-target scattering

✦ Constraint for cross section

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

Event rate

Cross section



Directional detection

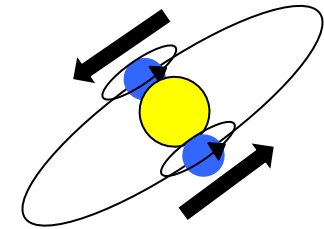
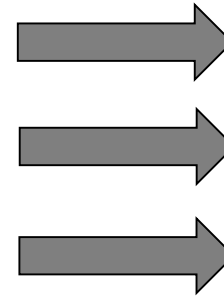
See
Asada's talk on 29th Aug.

✦ Direction

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



DM wind

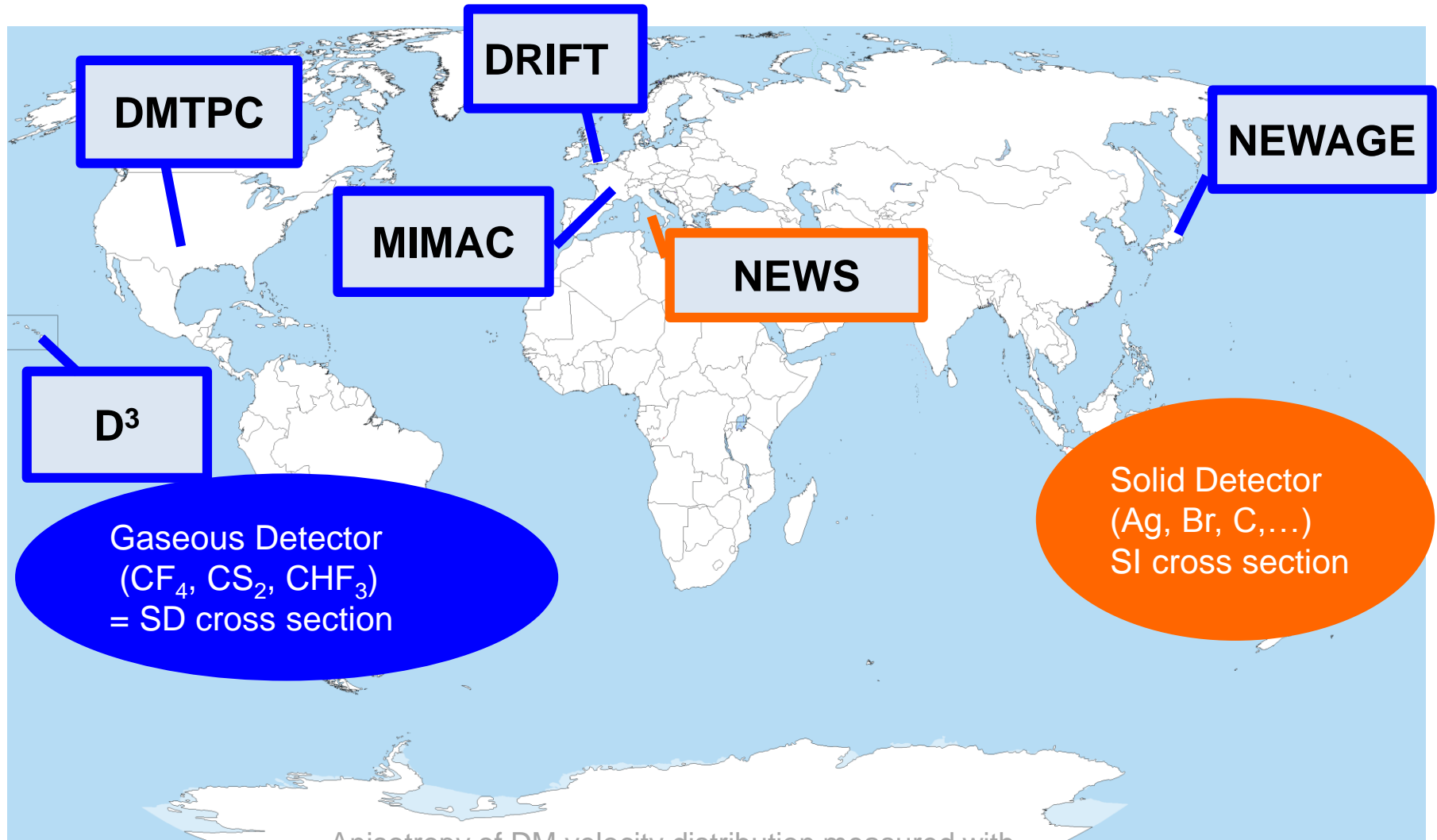


the Solar system

✦ Advantages

- Powerful back ground rejection
Bkg : isotropic
DM signal : come from the direction of the Cygnus

Directional Searches



Anisotropy of DM velocity distribution measured with directional detection



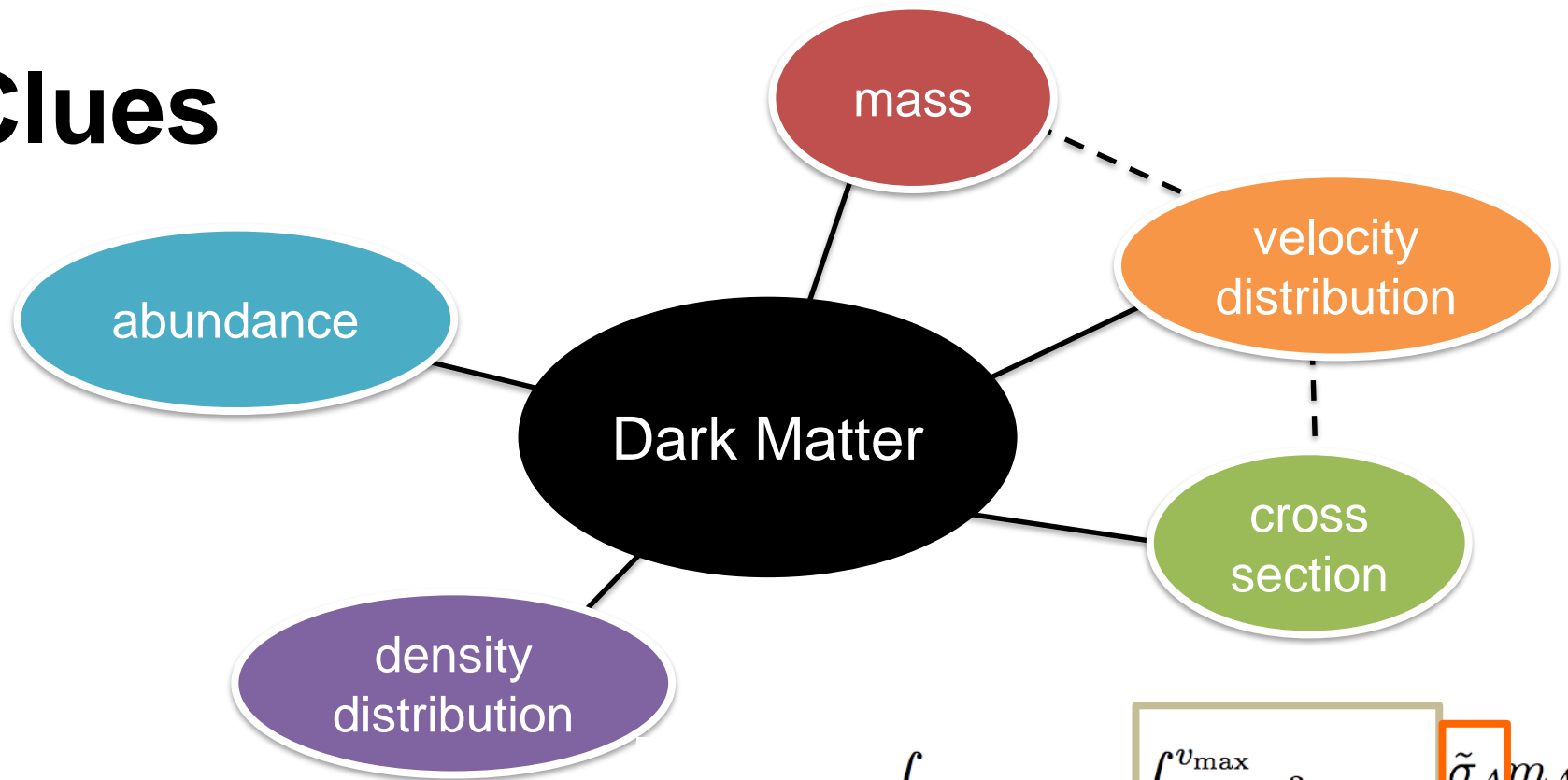
Outline

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



Velocity Distribution of Dark Matter

Clues



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

- ✦ 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

Anisotropy of DM velocity distribution measured with directional detection

Standard Distribution

✦ Maxwell distribution

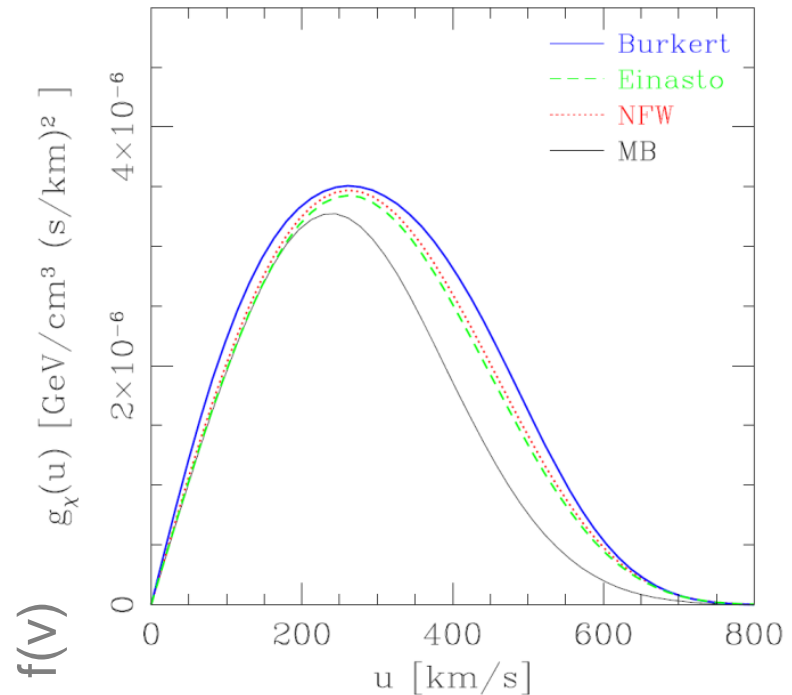
$$f(v) = \frac{1}{(\pi v_0^2)^{3/2}} e^{-(v+v_E)^2/v_0^2}$$

v_0 : velocity of the Solar system

v_E : Earth's velocity relative to DM

✦ isotropic

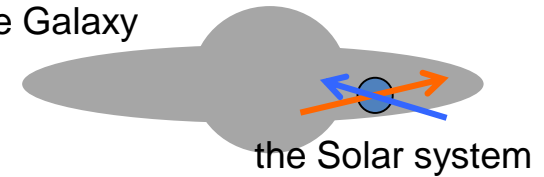
✦ Is DM distribution surely this shape?



Catena and Ullio (2012)

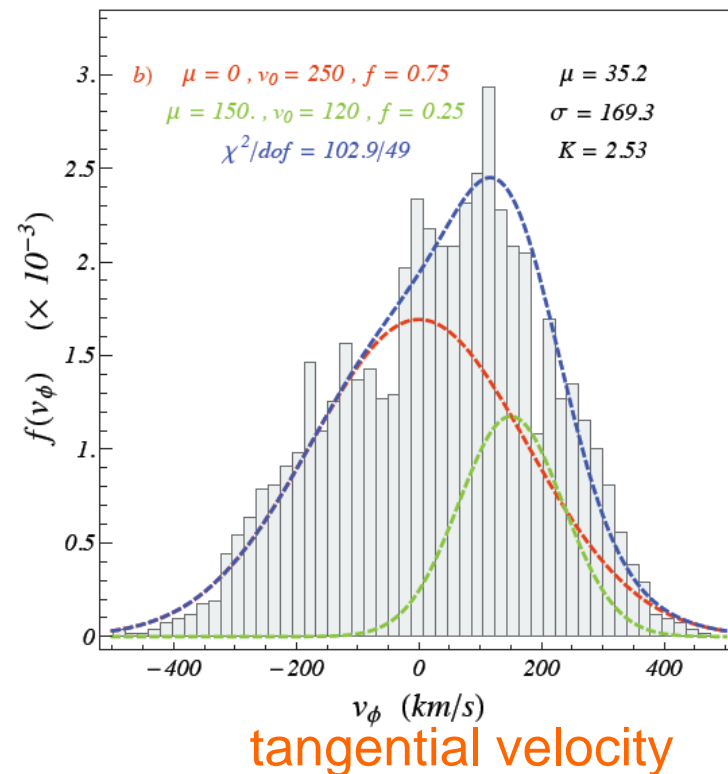
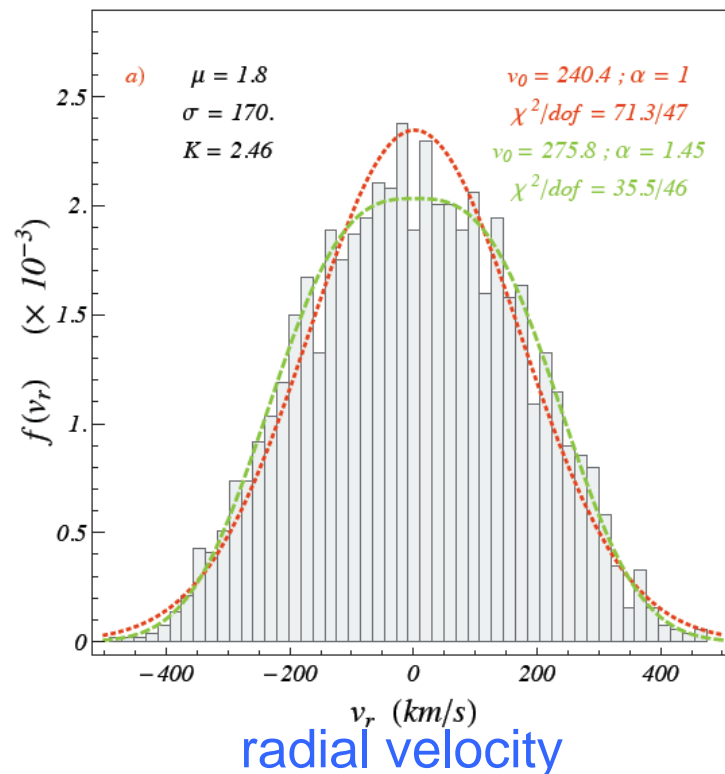
Co-rotating DM

the Galaxy



the Solar system

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



Anisotropy parameter “r”

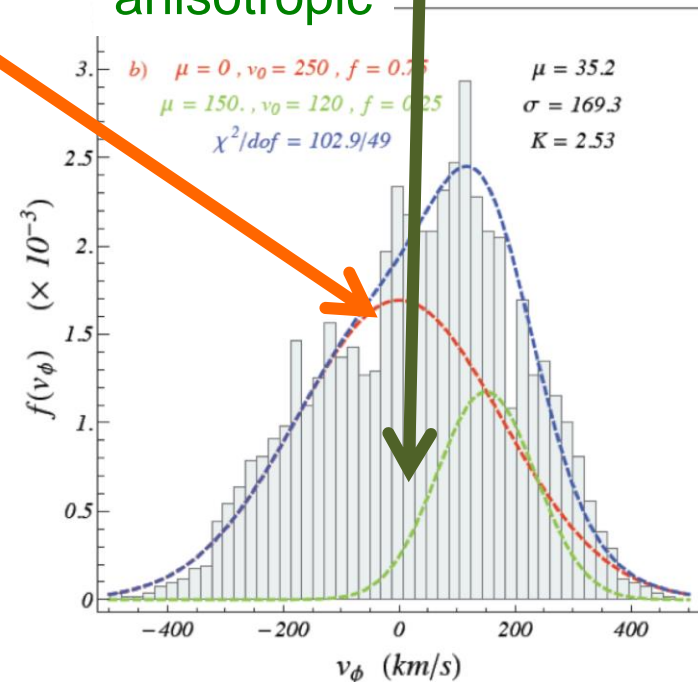
$$f(v_\phi) = \frac{1-r}{N(v_{0,\text{iso.}})} \exp\left[-v^2/v_{0,\text{iso.}}^2\right] + \frac{r}{N(v_{0,\text{ani.}})} \exp\left[-(v-\mu)^2/v_{0,\text{ani.}}^2\right]$$

isotropic

anisotropic

★ Tangential velocity

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





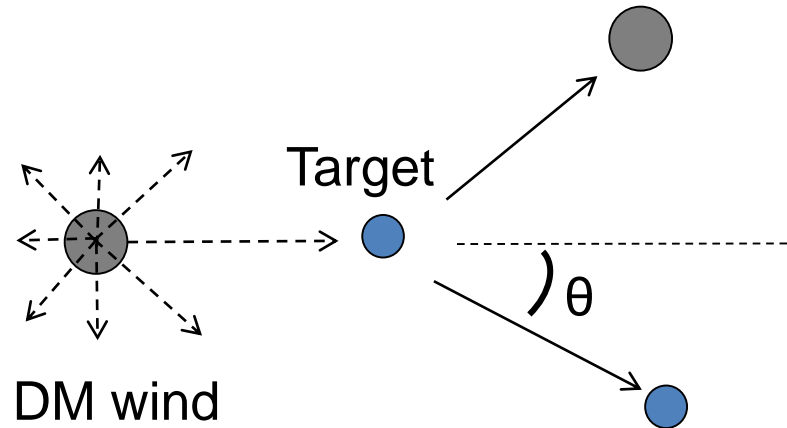
Velocity Distribution observed in Directional Detector

cf.

Ben Morgan, Anne M. Green, Neil J. C. Spooner (2004)

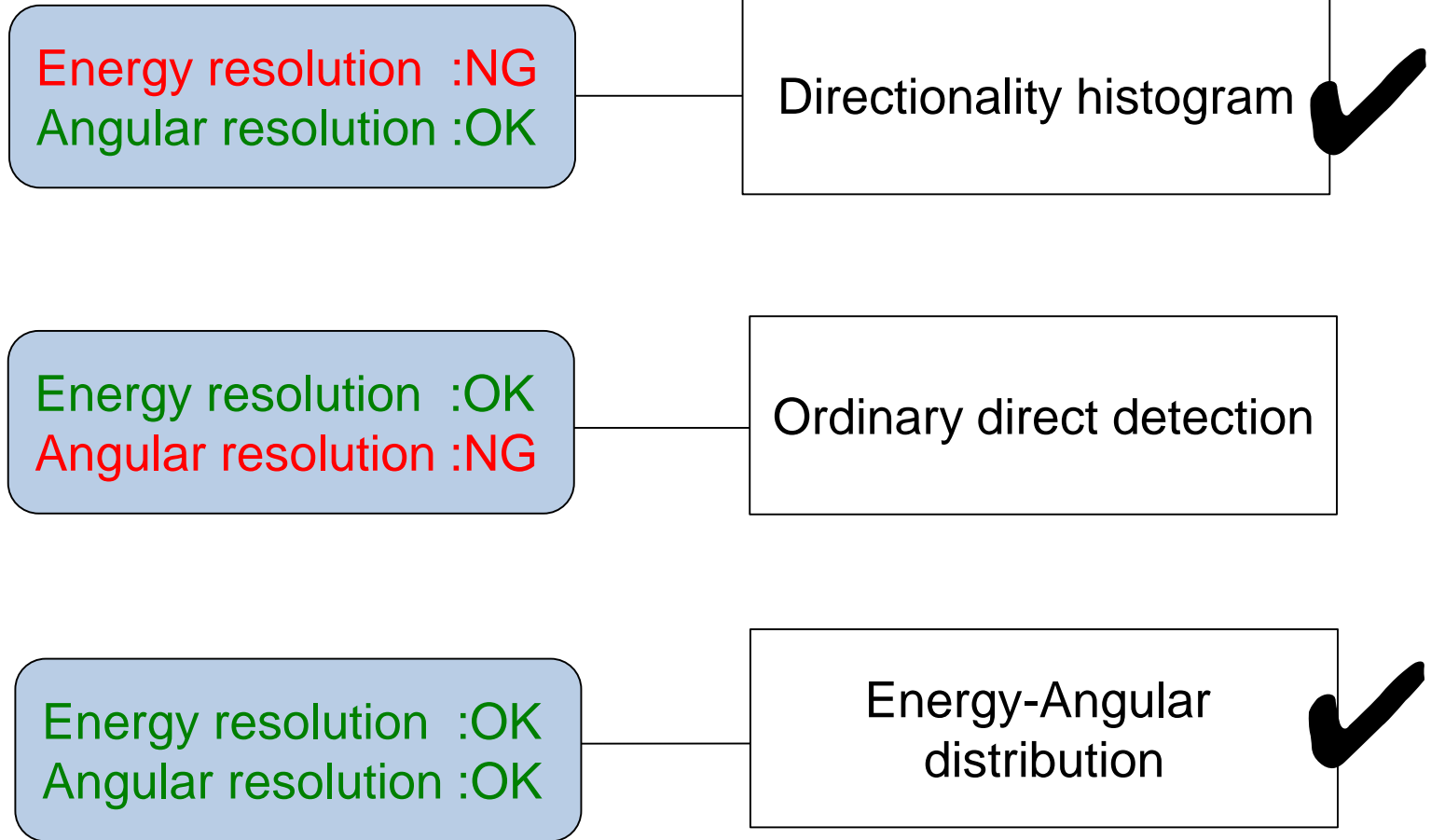
Ole Host, Steen H Hansen (2007)

Set up of simulation



- ◆ Monte Carlo simulation
 - Direction (scattering angle)
 - Recoil energy
- ◆ Elastic scattering
- ◆ mass relation $m_{\text{dm}}=3m_{\text{N}}$

Analysis

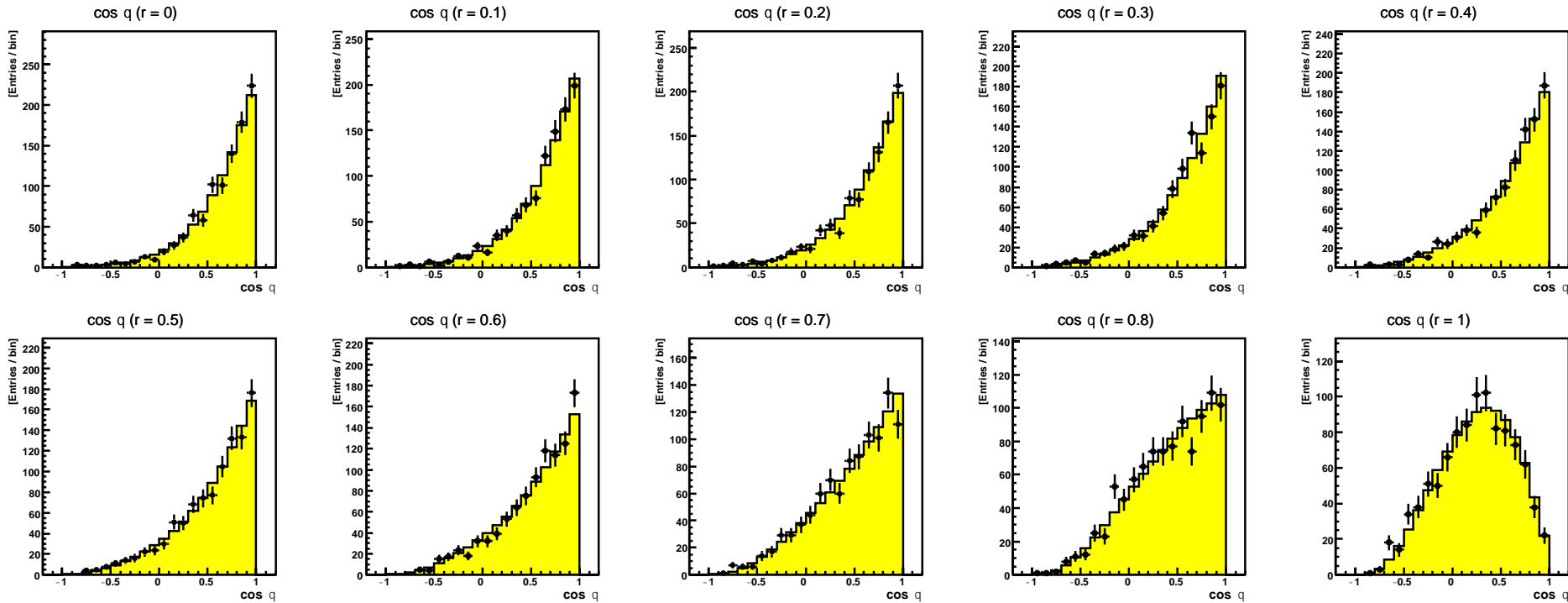


Anisotropy of DM velocity distribution measured with directional detection

Directionality Histogram

(light target)

Ethr=20keV (Light target F)



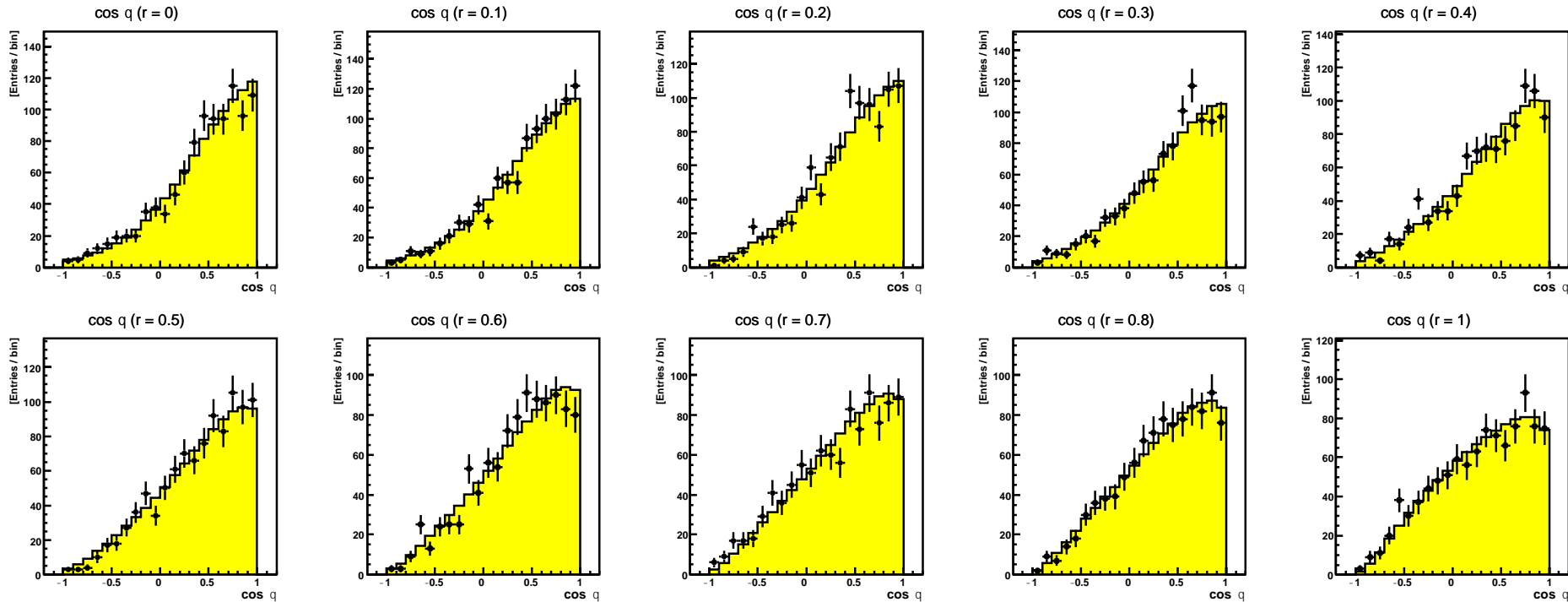
✓ Shape for $r=0.3$ is quite similar to that for $r=1$.

Anisotropy of DM velocity distribution measured with directional detection

Directionality Histogram

(heavy target)

Ethr=50keV (Ag)



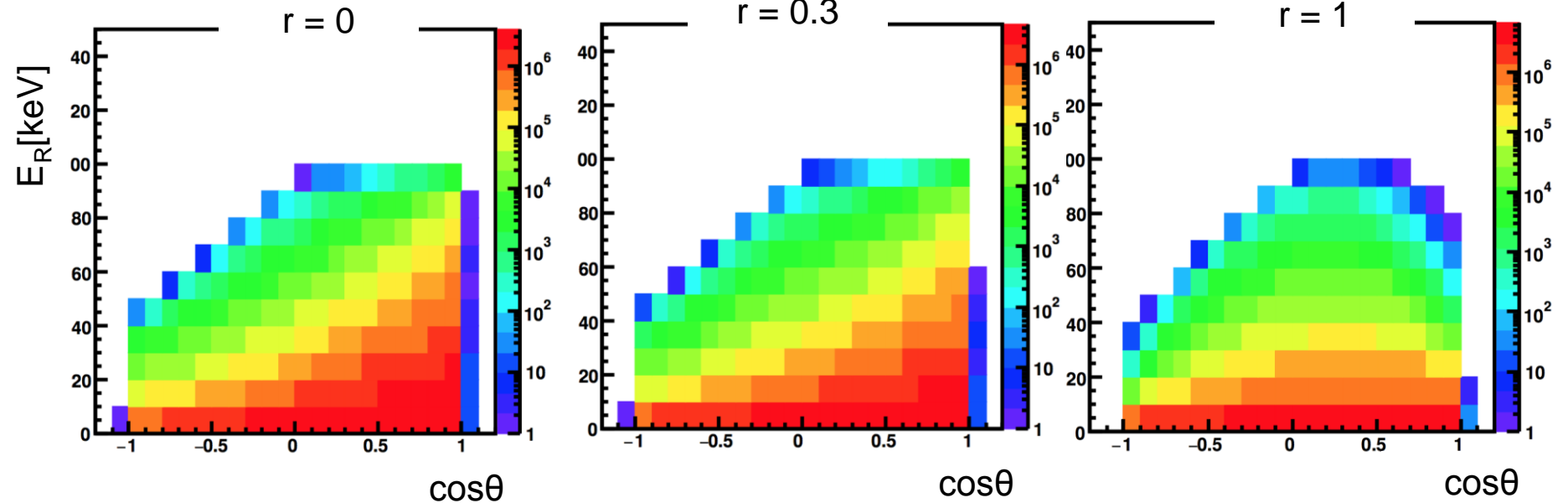
✓ Shape for $r=0.3$ is quite similar to that for $r=1$ in both case target F and Ag.

Anisotropy of DM velocity distribution measured with directional detection

Energy resolution :OK
Angular resolution :OK

Energy-angular distribution

light target (F)



$E_{thr} = 0 \text{ keV}$

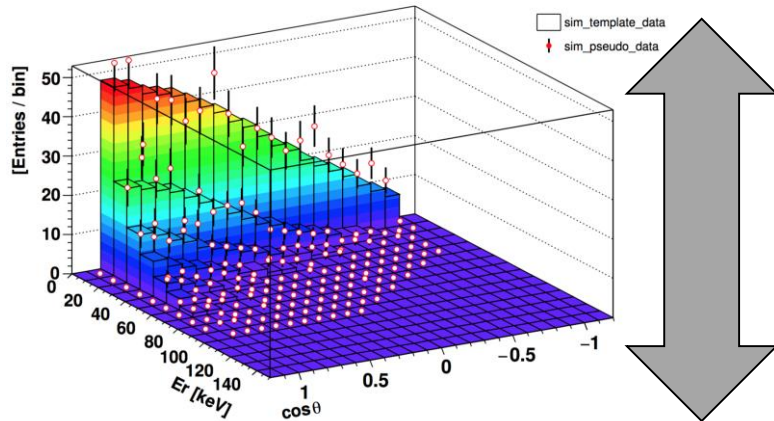
- ✓ Even in energy-angular distribution, shape for $r=0$ and 0.3 is similar.
- ✓ Concrete method to compare the distributions is required.

Chi squared test

Many Data
(#10⁸)

- ✓ ideal
- ✓ difficult to achieve

ideal “**template**”



chi squared test

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

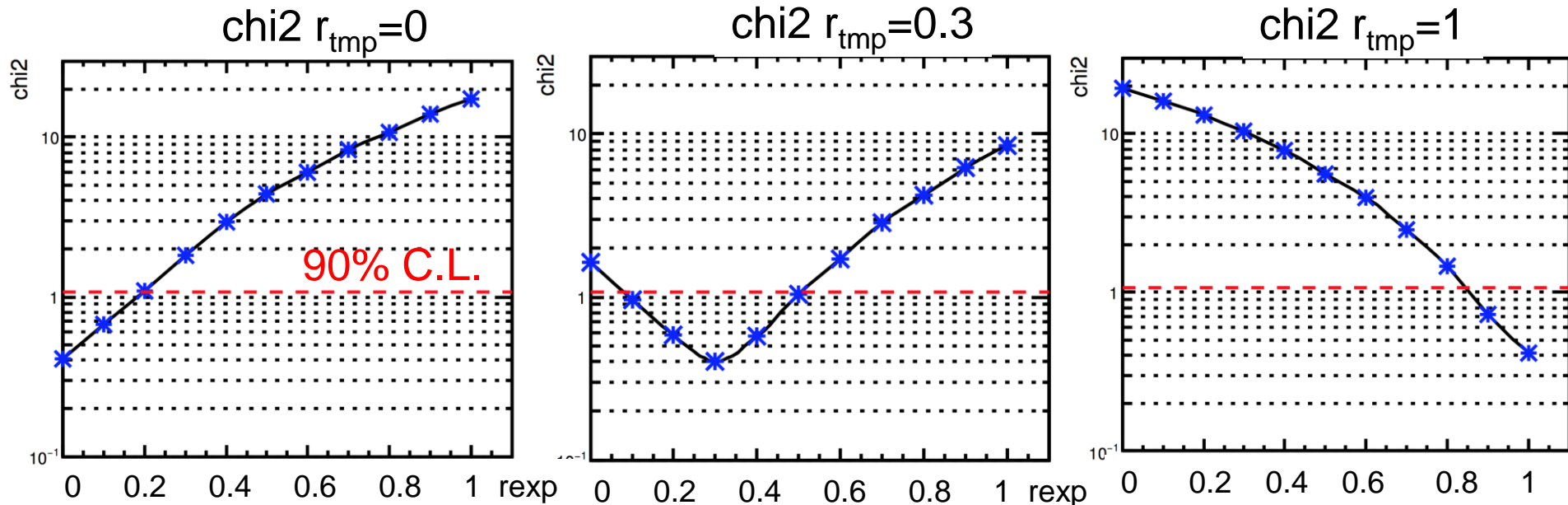
Few Data
(#10⁴)

- ✓ realistic

“**pseudo-experimental**” data

Chi squared test for r (light target)

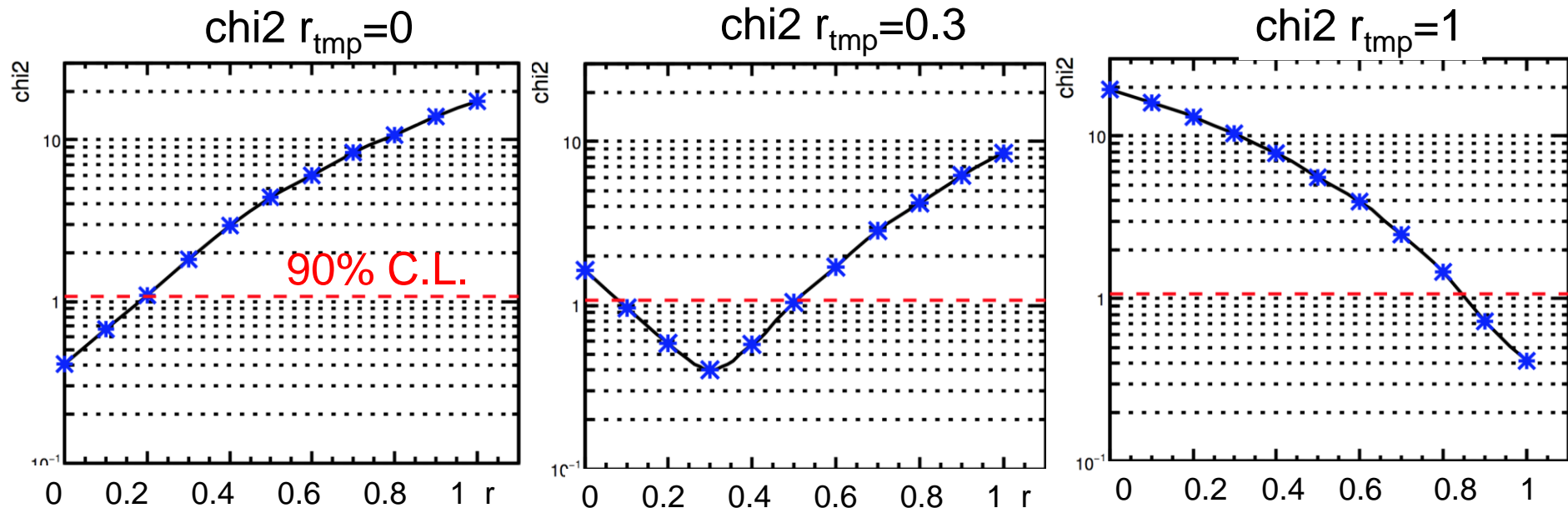
#exp.= $6 \cdot 10^3$
E_{thr}=20keV (F)



- ✓ If $r=0.3$, isotropic case ($r=0$) can be excluded at 90% C.L.
- ✓ Energy threshold is a factor to clearly characterize the difference between $r=0$ and 0.3.

Chi squared test for r (heavy target)

#exp.= $6 \cdot 10^4$
E_{thr}=100keV (Ag)



- ✓ If $r=0.3$, isotropic case ($r=0$) can be excluded at 90% C.L.
- ✓ Energy threshold is a factor to clearly characterize the difference between $r=0$ and 0.3.
- ✓ Due to form factor effect, more signal number is required in heavy target case than light target case.

Anisotropy of DM velocity distribution measured with directional detection

Summary

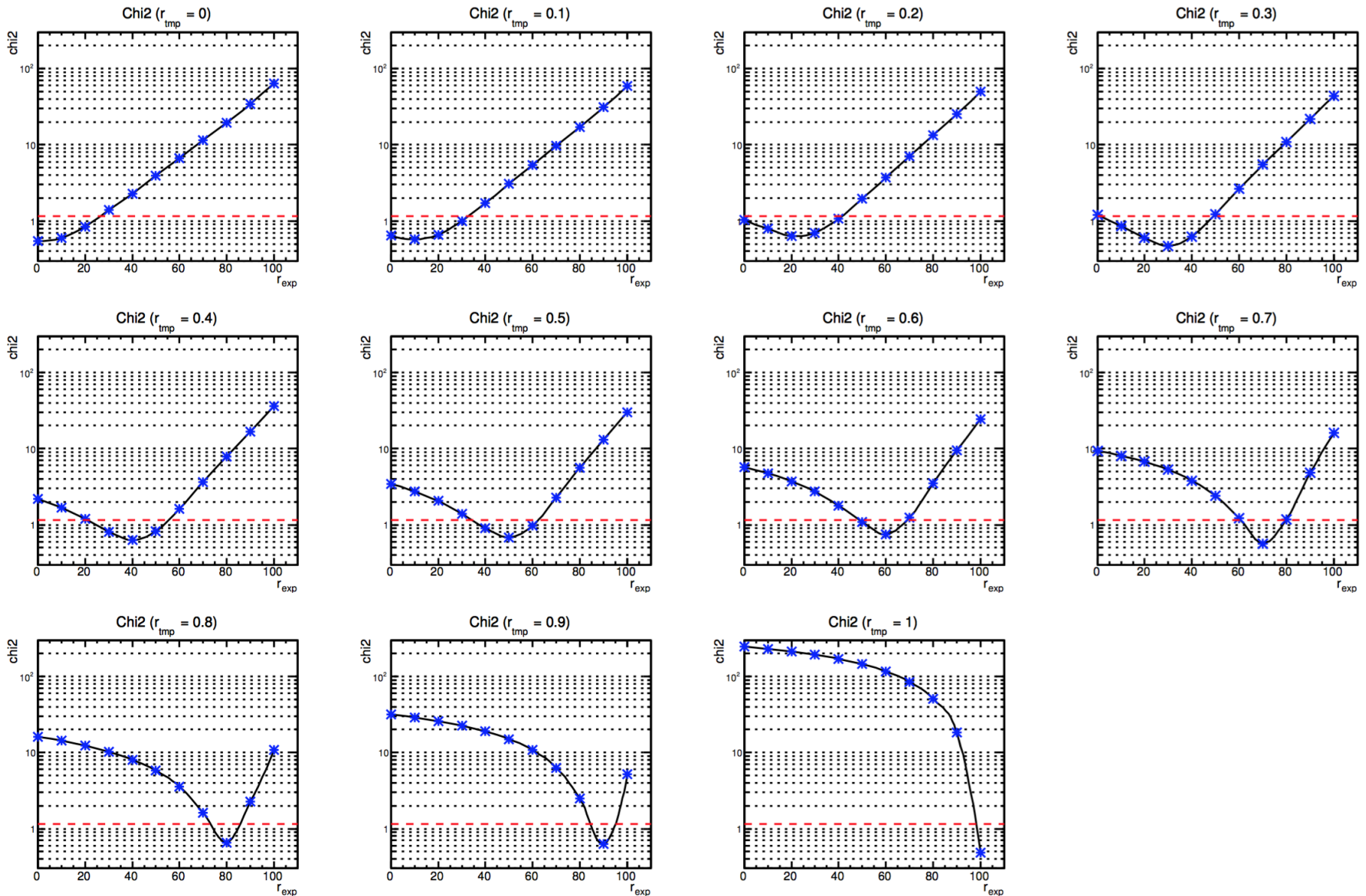
- ✦ Possibility to discriminate the anisotropy in the velocity distribution of DM is discussed.
- ✦ With “template data”, the chi squared test is helpful to figure out anisotropy if $O(10^4)$ data is obtained.

Backup Slides

Anisotropy of DM velocity distribution measured with
directional detection

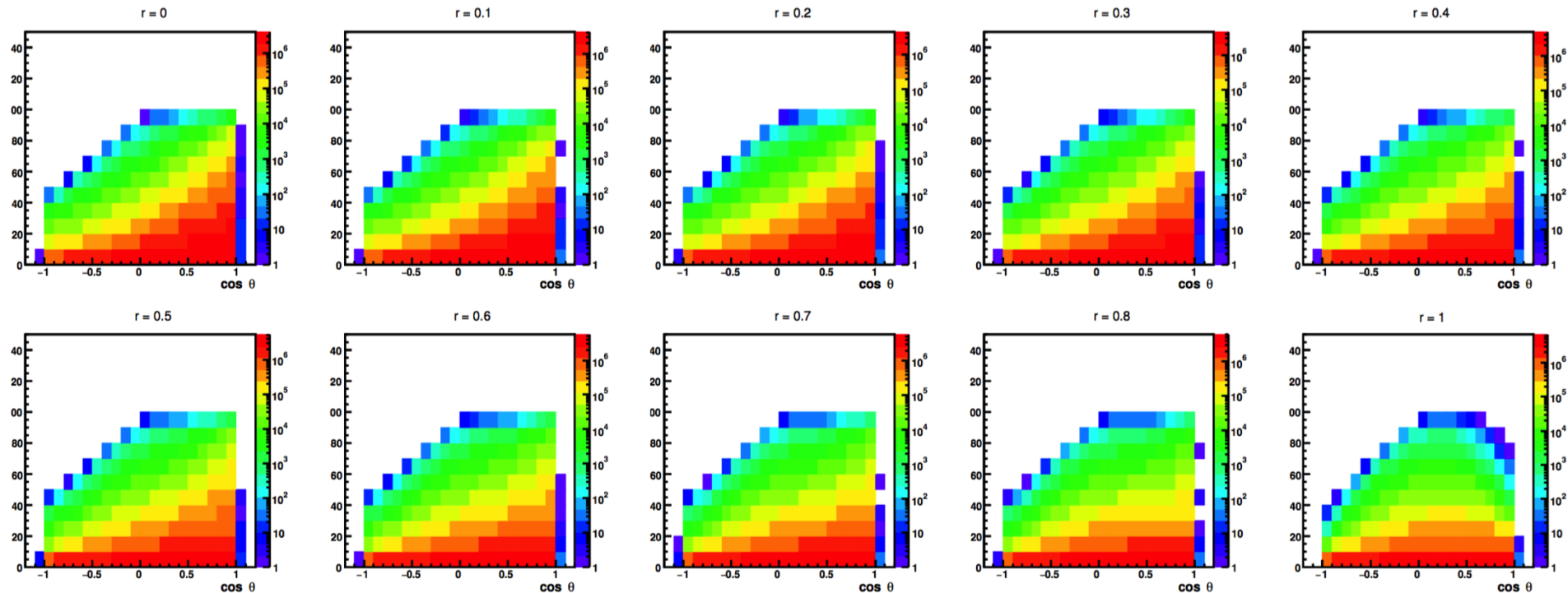
Chi squared test (F)

#exp.= $6 \cdot 10^3$
E_{thr}=20keV (F)



Energy-angular distribution

(light target)

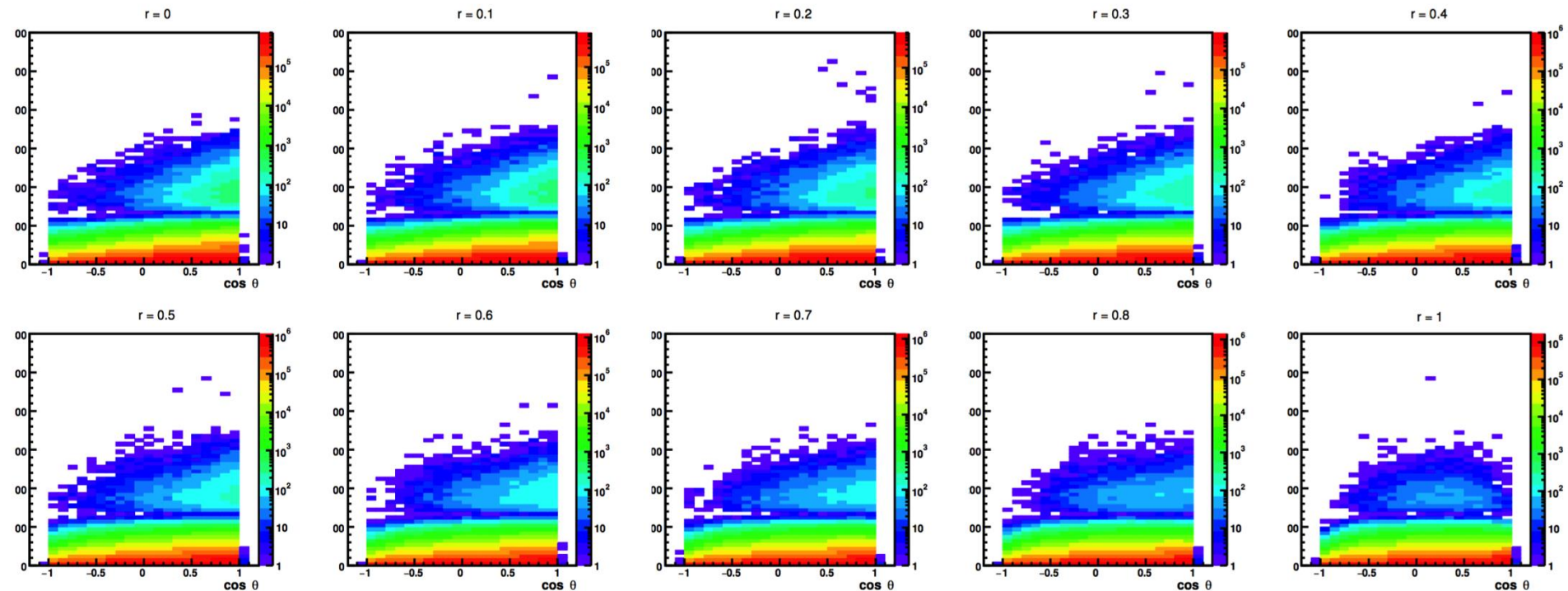


$E_{thr} = 0 \text{ keV}$

Anisotropy of DM velocity distribution measured with directional detection

Energy-angular distribution

(heavy target)



$E_{thr} = 0 \text{ keV}$

Anisotropy of DM velocity distribution measured with directional detection

Periodic Table

Periodic Table of the Elements © www.elementsdatabase.com

- hydrogen
- alkali metals
- alkali earth metals
- transition metals

- poor metals
- nonmetals
- noble gases
- rare earth metals

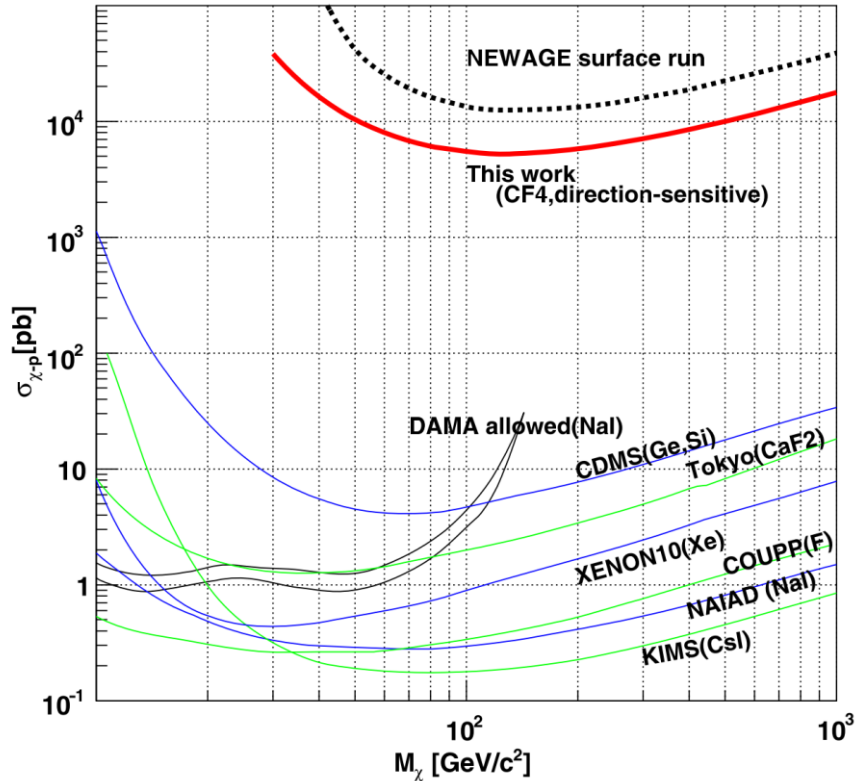
H ¹																	He ²
Li ³	Be ⁴											B ⁵	C ⁶	N ⁷	O ⁸	F ⁹	Ne ¹⁰
Na ¹¹	Mg ¹²											Al ¹³	Si ¹⁴	P ¹⁵	S ¹⁶	Cl ¹⁷	Ar ¹⁸
K ¹⁹	Ca ²⁰	Sc ²¹	Ti ²²	V ²³	Cr ²⁴	Mn ²⁵	Fe ²⁶	Co ²⁷	Ni ²⁸	Cu ²⁹	Zn ³⁰	Ga ³¹	Ge ³²	As ³³	Se ³⁴	Br ³⁵	Kr ³⁶
Rb ³⁷	Sr ³⁸	Y ³⁹	Zr ⁴⁰	Nb ⁴¹	Mo ⁴²	Tc ⁴³	Ru ⁴⁴	Rh ⁴⁵	Pd ⁴⁶	Ag ⁴⁷	Cd ⁴⁸	In ⁴⁹	Sn ⁵⁰	Sb ⁵¹	Te ⁵²	I ⁵³	Xe ⁵⁴
Cs ⁵⁵	Ba ⁵⁶	La ⁵⁷	Hf ⁷²	Ta ⁷³	W ⁷⁴	Re ⁷⁵	Os ⁷⁶	Ir ⁷⁷	Pt ⁷⁸	Au ⁷⁹	Hg ⁸⁰	Tl ⁸¹	Pb ⁸²	Bi ⁸³	Po ⁸⁴	At ⁸⁵	Rn ⁸⁶
Fr ⁸⁷	Ra ⁸⁸	Ac ⁸⁹	Unq ¹⁰⁴	Unp ¹⁰⁵	Unh ¹⁰⁶	Uns ¹⁰⁷	Uno ¹⁰⁸	Une ¹⁰⁹	Unn ¹¹⁰								

⁵⁸ Ce	⁵⁹ Pr	⁶⁰ Nd	⁶¹ Pm	⁶² Sm	⁶³ Eu	⁶⁴ Gd	⁶⁵ Tb	⁶⁶ Dy	⁶⁷ Ho	⁶⁸ Er	⁶⁹ Tm	⁷⁰ Yb	⁷¹ Lu
⁹⁰ Th	⁹¹ Pa	⁹² U	⁹³ Np	⁹⁴ Pu	⁹⁵ Am	⁹⁶ Cm	⁹⁷ Bk	⁹⁸ Cf	⁹⁹ Es	¹⁰⁰ Fm	¹⁰¹ Md	¹⁰² No	¹⁰³ Lr

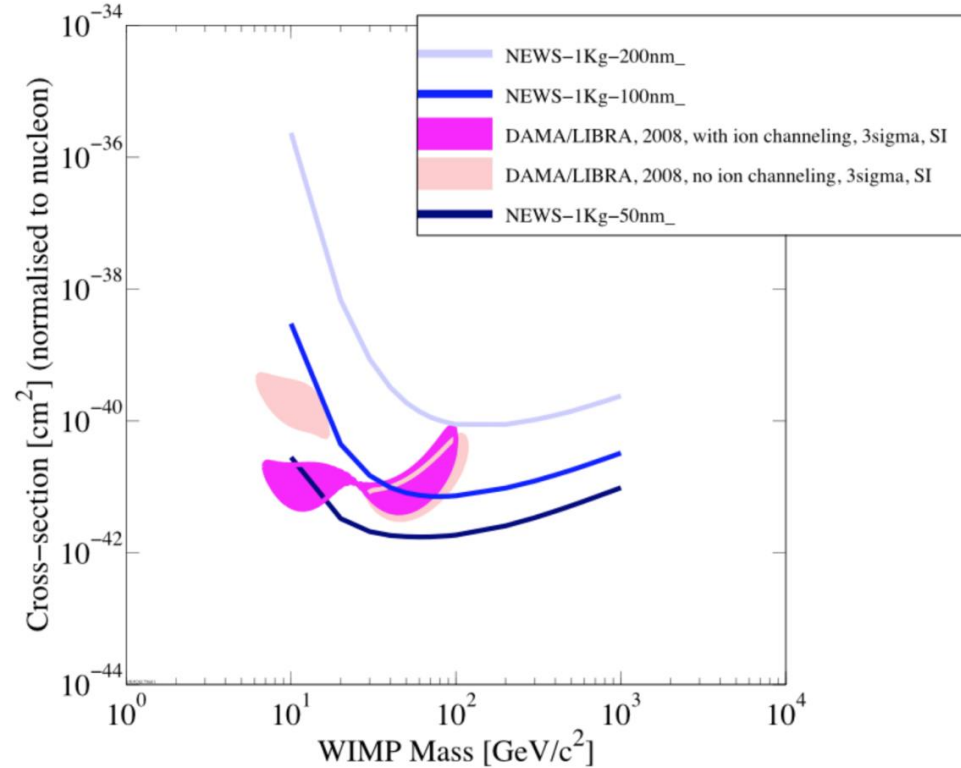
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Sensitivity

SD 90% C.L. upper limits and allowed region



NEWS(2010)



NEWS (expected) ()

Anisotropy of DM velocity distribution measured with directional detection