Dark matter in 3D with directional detection

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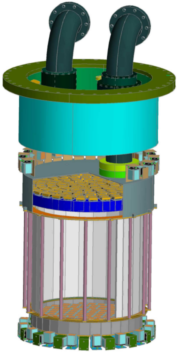
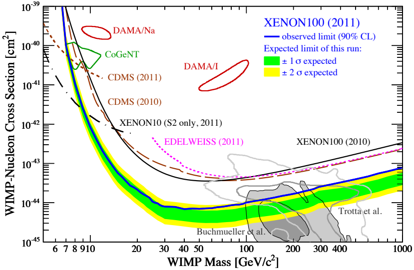
with Daniele Alves and Jay Wacker

Outline

1. Overview
2. Reconstructing the dark matter distribution function
3. Distribution function and statistics
4. Test using N-body simulations

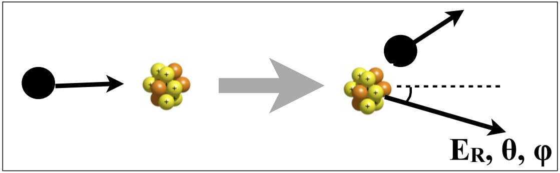
Direct detection experiments

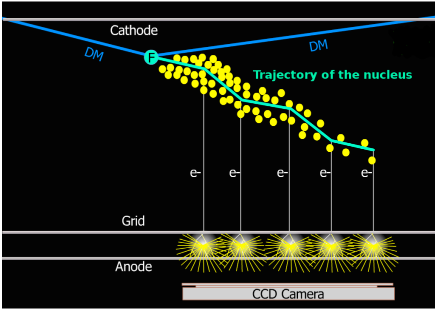




- New limits on scattering cross section
- Information about dark matter mass and escape velocity

Directional detection





Dark matter halo characterized by a distribution function

$$P(\vec{r},\vec{v}) = f(\vec{r},\vec{v})d^3v d^3r$$

A detector on Earth measures

$$f_{Sun}(\vec{v}) = f(\vec{r}_{Earth},\vec{v})$$

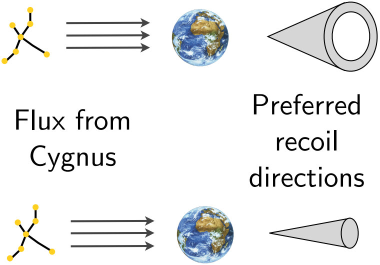
Jeans theorem states

$$f(\vec{r},\vec{v}) = f\left(I_1[\vec{r},\vec{v}], I_2[\vec{r},\vec{v}], I_3[\vec{r},\vec{v}]\right)$$

$$\Rightarrow f_{Sun}(\vec{v}) = f\left(I_1[\vec{r}_0,\vec{v}], I_2[\vec{r}_0,\vec{v}], I_3[\vec{r}_0,\vec{v}]\right)$$

$f_{Sun}(\vec{v})$ allows to reconstruct the global distribution function!

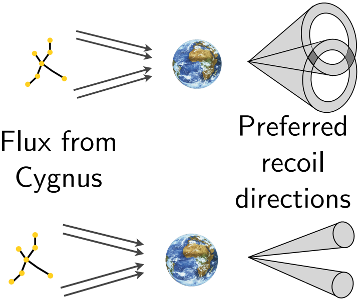
Isotropic $f(v)$



Flux from Cygnus

Preferred recoil directions

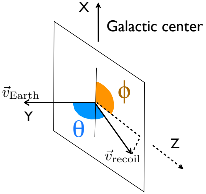
Anisotropic $f(\vec{v})$



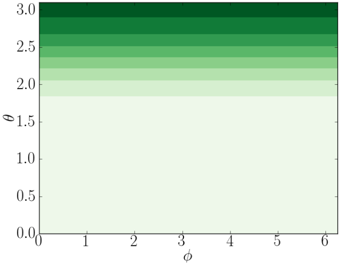
Flux from Cygnus

Preferred recoil directions

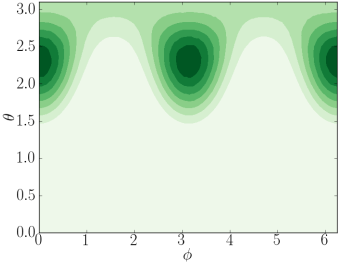
Ring-like features for low E_R and point-like features for high E_R for each of the preferred directions.



$\theta - \phi$ profiles of the detection rate



$$f(v) = e^{-\frac{v^2}{v_0^2}} - 1$$



$$f(\vec{v}) = (e^{-\frac{v^2}{v_0^2}} - 1)e^{-\alpha\frac{v_t^2}{v_0^2}}$$

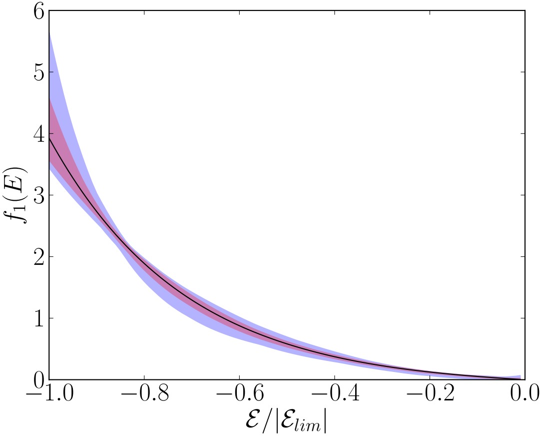
Model independent parameterization of the distribution function

$$f(\vec{r},\vec{v}) = f(\mathcal{E}, L_t, L_z) = f_1(\mathcal{E}) f_2(L_t) f_3(L_z)$$

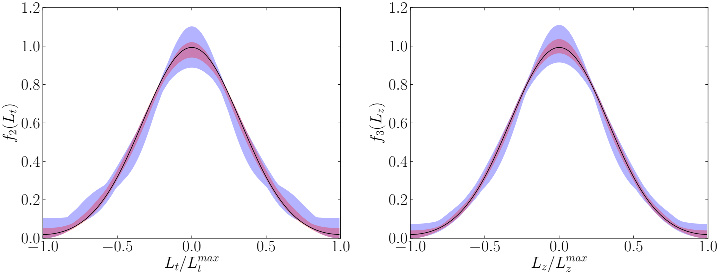
$$L_t = \sqrt{L^2 - L_z^2}$$

$$\boxed{\begin{aligned} f_1(E) &= \sum_i c_i P_L^{(i)}\left(\frac{\mathcal{E}}{\mathcal{E}_{lim}}\right) \\ f_2(L_t) &= \sum_i d_i \cos\left(i\pi \frac{L_t}{L_{max}}\right) \\ f_3(L_z) &= \sum_i f_i \cos\left(i\pi \frac{L_z}{L_{max}}\right) \end{aligned}}$$

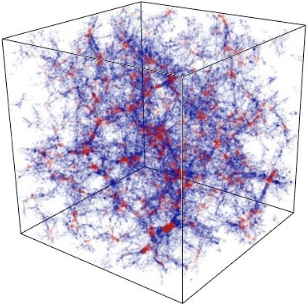
Michie distribution with $m_{DM} = 6$ GeV – Sulphur nuclear target 10^3 and 10^4 signal events

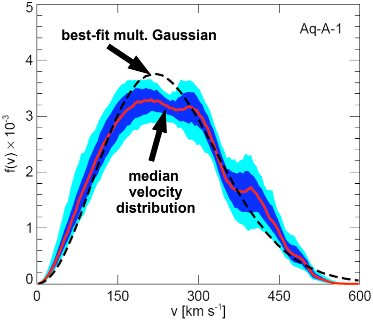


Michie distribution with $m_{DM} = 6$ GeV – Sulphur nuclear target 10^3 and 10^4 signal events

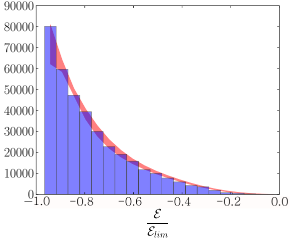


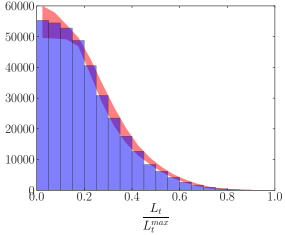
Best current possible estimates of $f(\vec{r}, \vec{v})$
Via Lactea II : 10^9 particles, each of mass $\approx 10^3 M_{Sun}$

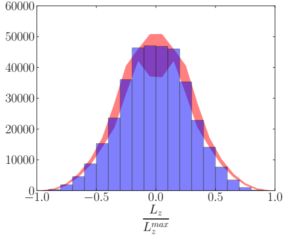




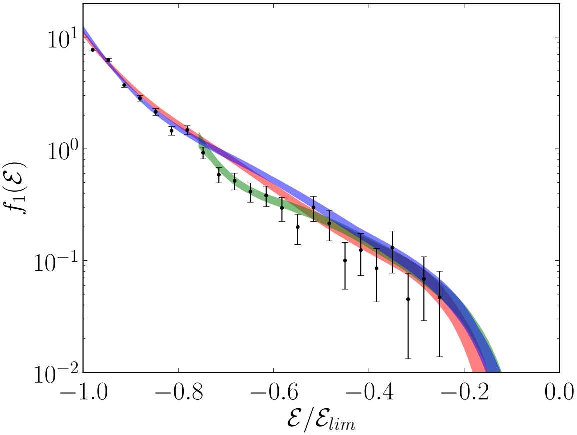
E, L_t, L_z distributions near the Earth



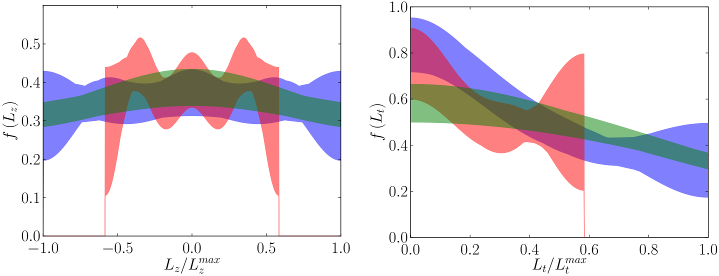




$f_1(E)$ at 4.5, 8 and 30 kpc away from the center of the galaxy



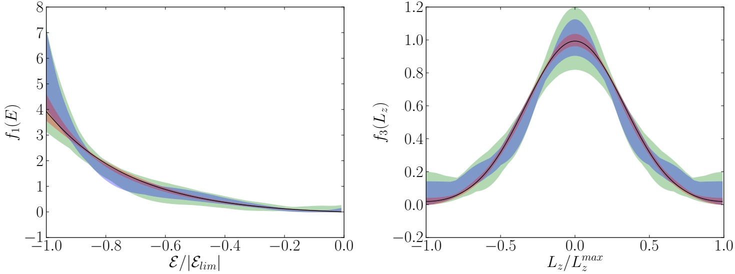
$f_2(L_t)$ and $f_3(L_z)$ at 4.5, 8 and 30 kpc away from the center of the galaxy



Good agreement at 1 σ, small discrepancies at large distances probably due to our choice of integrals of motion

- Directional sensitivity is necessary to understand the kinematic properties of the dark matter halo
- The local velocity distribution near the Earth gives direct access to the galactic dark matter distribution function using Jeans theorem
- Series expansions allow to parameterize the distribution function in a model independent way
- Multidimensional fitting techniques allow to get a reasonable estimate of the shape of the DF with about 1000 events
- Very good fits of the local velocity distribution function from the VLII simulation using our ansatz
- Jeans theorem seems verified near the center of the galaxy for VLII data

Thank you


$f_1(E)$
8
7
6
5
4
3
2
1
0
-1
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
$\mathcal{E}/|\mathcal{E}_{lim}|$
$f_3(L_z)$
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-1.0
-0.5
0.0
0.5
1.0
L_z/L_z^{max}