FITS FOR DARK MATTER DIRECT DETECTION

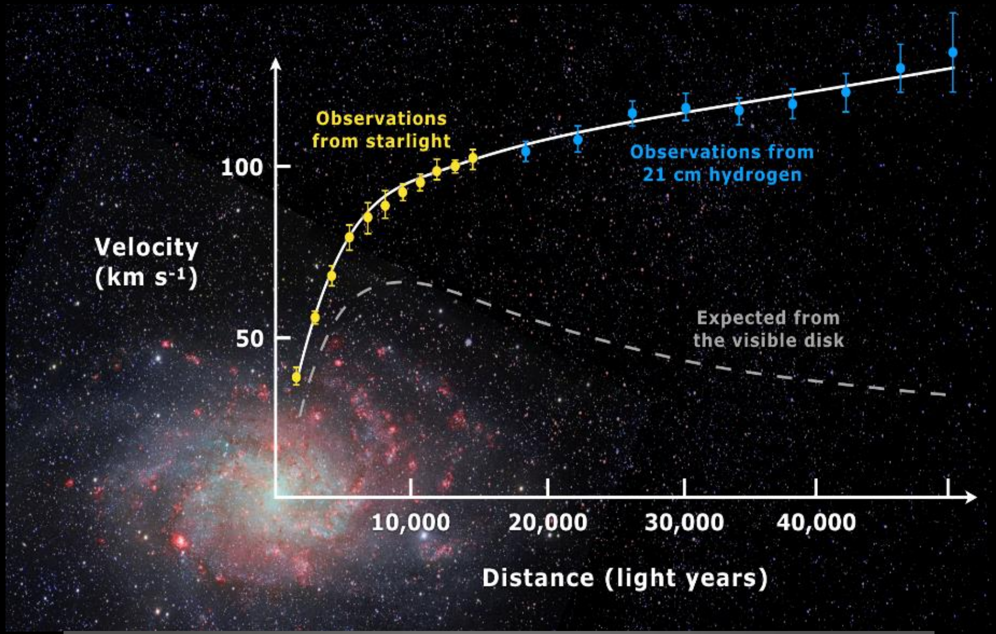
Lauren Street

University of Cincinnati

Motivation

- Dark matter (DM) to explain[1]
  - Flat galactic rotation curves, etc.

- Direct detection
  - DM-nuclei scattering



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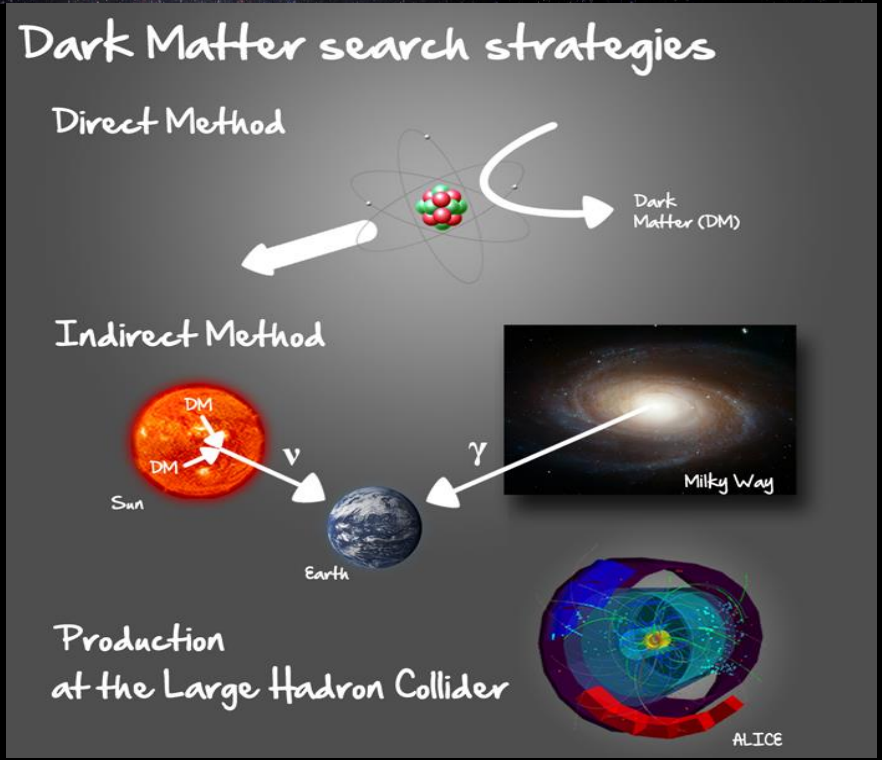


Credit: HAP/A. Chantelauze (http://www.hap-astroparticle.org/186.php)

Xenon100

- Liquid Xe – various isotopes[5]

- Describe process using effective field theory (EFT)
  - Various couplings – Wilson coefficients (WC)

$$\text{DM} + {}^{iso}\text{Xe} \rightarrow \text{DM} + {}^{iso}\text{Xe}$$

Compare EFT to exp. → constrain values for WC's

Plan for comparison

- Xenon100 $\rightarrow$ scattering events in energy bin

- EFT $\rightarrow$ scattering events as function of WC's

- Minimize chi-squared $\rightarrow$ best fit values for WC's
  - Easy example: Lagrangian depends on only one WC - C61u

Procedure

- Mathematica packages DirectDM[3] and DMFormfactor[2],[4] $\rightarrow \frac{d\sigma(v,E_R,\hat{C})}{dE_R}$

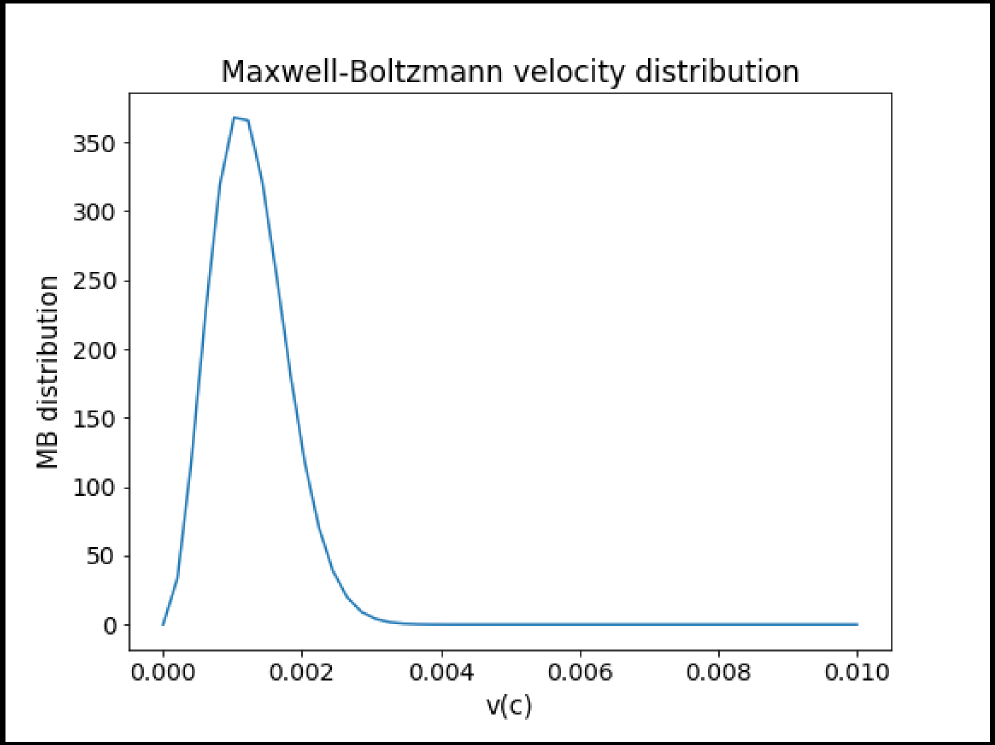
- C61u from two main pipelines:

General code - inputs relevant parameters	Hardcoded for Xenon100 – input recoil energy

Procedure – Differential rate

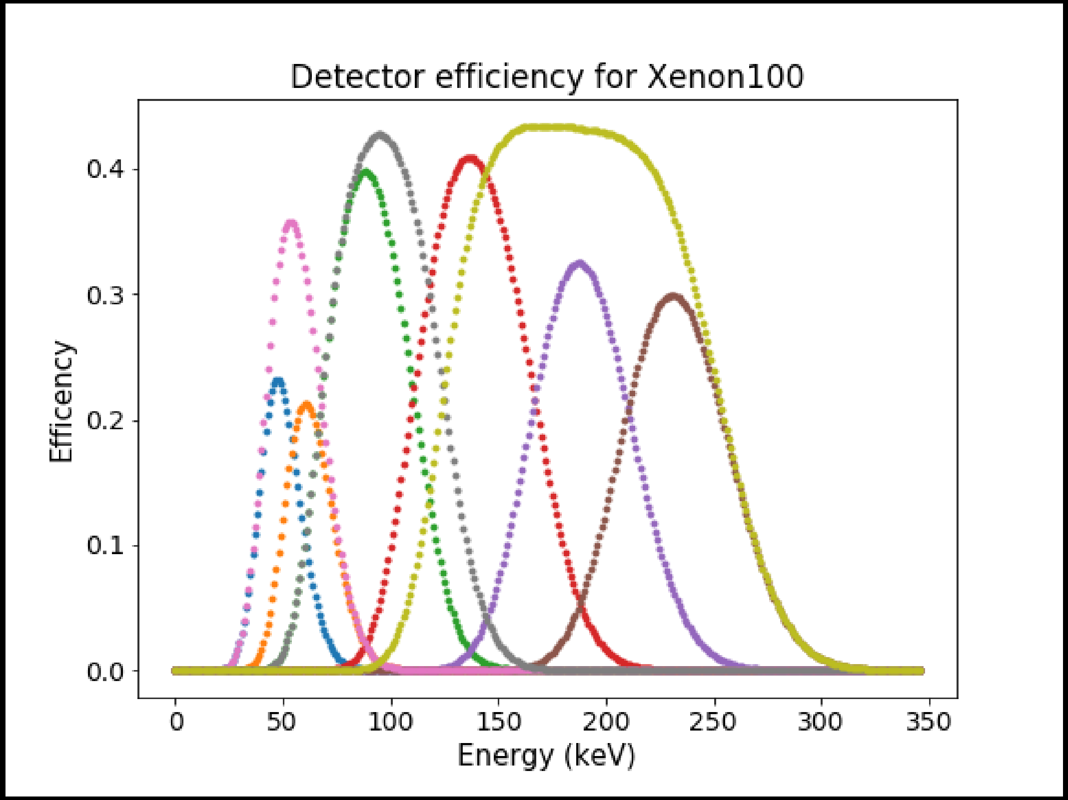
- Integrate $\frac{d\sigma(v,E_R,\hat{C})}{dE_R} v f_E(v)$ over velocity $\rightarrow$ $\frac{dR(\hat{C})}{dE_R}$ [5]
  - Use scipy.integrate.quad

- Assume DM mass and $f_E(v)$ of DM halo



Procedure – Scattering events

- Integrate $\frac{dR}{dE_R} G_j(E_R)$ over recoil energy $\rightarrow R_j(\hat{C})$ [5]
  - Use numpy.trapz
  - Depends on detector efficiency [5]



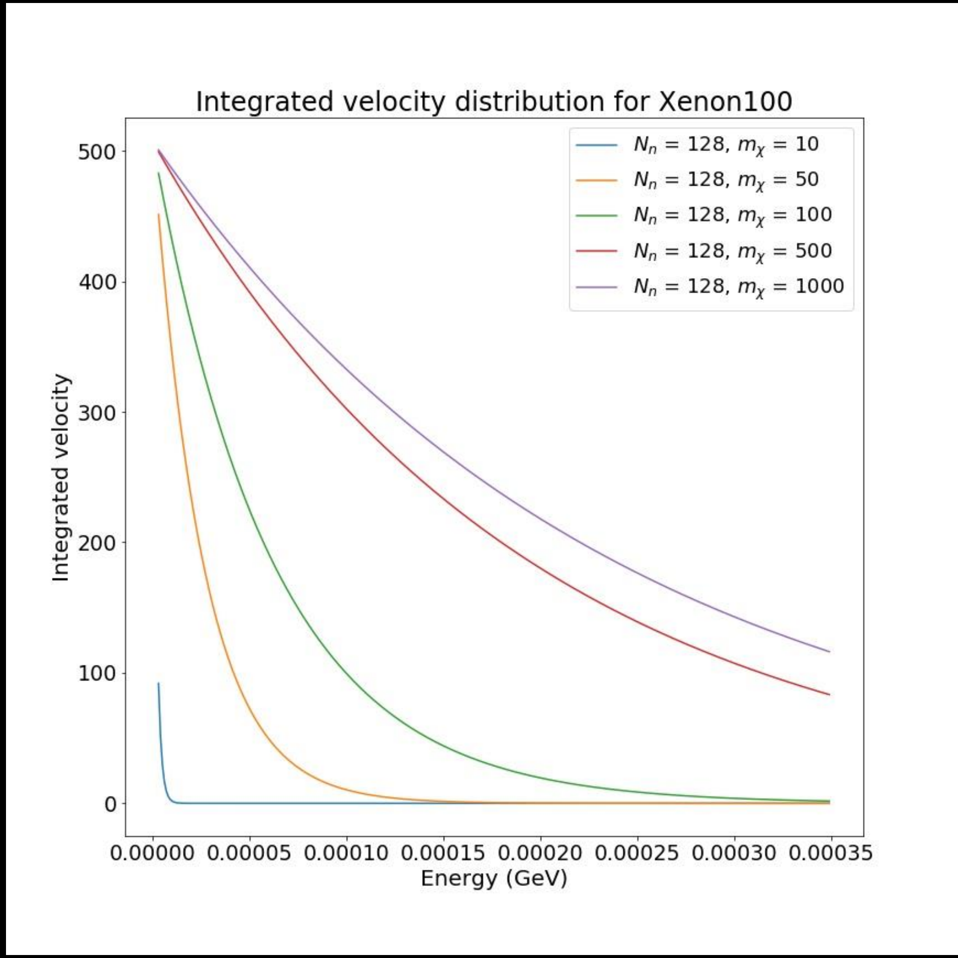
- Multiply $R_j(\hat{C})$ by exposure time $\rightarrow N_j(\hat{C})$

Procedure – Minimize chi-squared

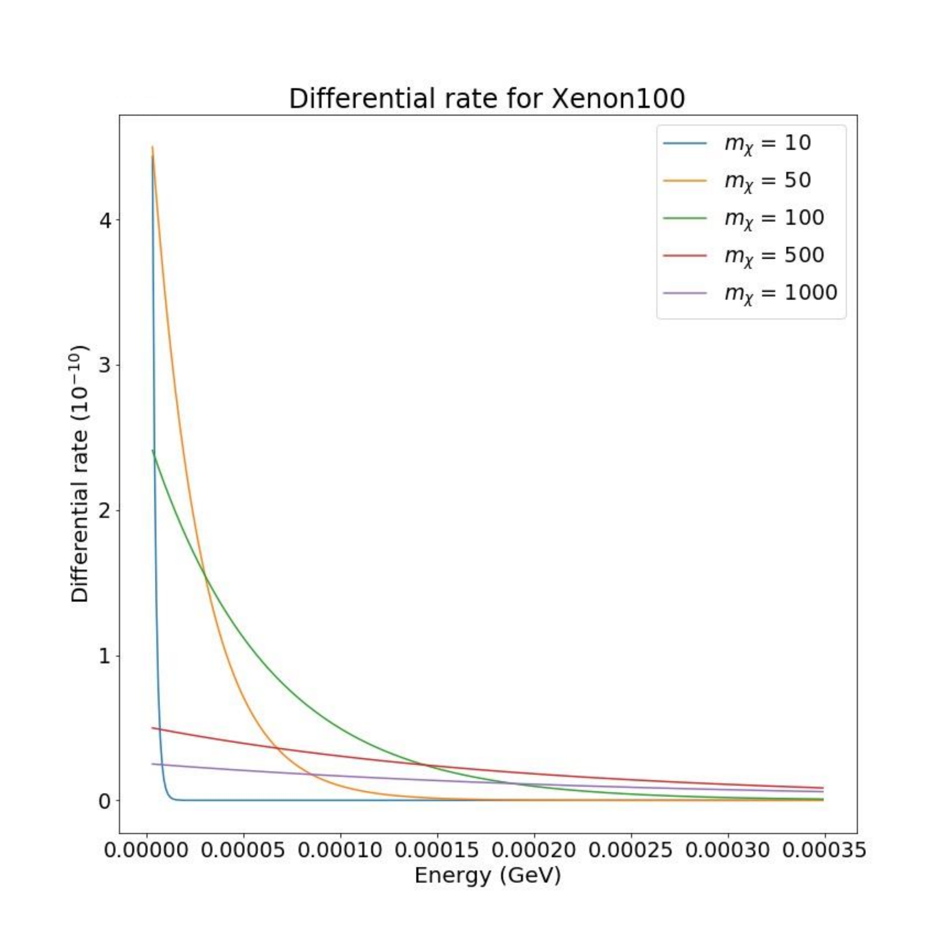
- N_{obs} and $N_{pred} \rightarrow \chi^2$ [6]
  - $\chi^2(\hat{C}) = \sum_{j=1}^{n} \frac{\left[N_{0,j} - \left(N_{b,j} + N_j(\hat{C})\right)\right]^2}{\delta N_{0,j}^2}$
  - $N_{0,j}$, $N_{b,j}$, and $\delta N_{0,j}$ from Xenon100 [5]

  - Use scipy.optimize.minimize $\rightarrow$ C61u that gives best fit to data

Results



Integrated velocity distribution for Xenon100
N_n = 128, m_χ = 10
N_n = 128, m_χ = 50
N_n = 128, m_χ = 100
N_n = 128, m_χ = 500
N_n = 128, m_χ = 1000
Integrated velocity
0
100
200
300
400
500
0.00000 0.00005 0.00010 0.00015 0.00020 0.00025 0.00030 0.00035
Energy (GeV)



Differential rate for Xenon100
m_χ = 10
m_χ = 50
m_χ = 100
m_χ = 500
m_χ = 1000
Differential rate (10^{-10})
0
1
2
3
4
0.00000 0.00005 0.00010 0.00015 0.00020 0.00025 0.00030 0.00035
Energy (GeV)

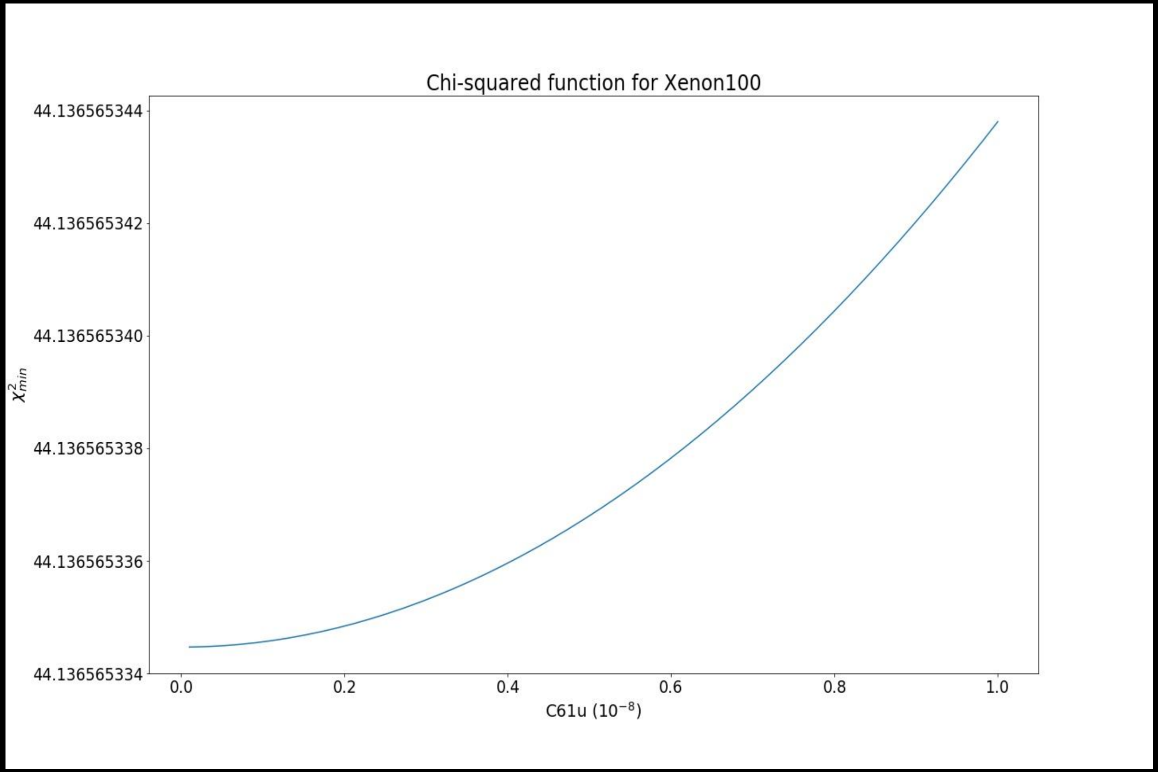
Results (for $m_\chi = 10$ GeV)

- Found C61u that gives best fit to data to be:

$$\text{C61u}|_{best} = 7.9 * 10^{-9}$$

- Chi-squared min per d.o.f.:

$$\frac{\chi^2_{min}}{d.o.f.} = 41.2$$



Future

- Some functions hardcoded for Xenon100 very slow
- General code to depend on variable parameters

- Velocity
  - Distributions from simulations
- WC's
  - Add more WC's to fit

Conclusions

- Found WC that gives best fit to Xenon100 data

- Code in python takes cross-section from Mathematica
  → chi-squared → C61u
  - Two different pipelines

- Many things to fix in future

References

[1] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018).

[2] N. Anand, A.L. Fitzpatrick, and W.C. Haxton (2013) e-print: 1308.6288.

[3] F. Bishara, J. Brod, B. Grinstein, and J. Zupan (2017) e-print: 1708.02678.

[4] A.L. Fitzpatrick, W. Haxton, E. Katz, N. Lubbers, and Y. Xu (2012) e-print: 1203.3542.

[5] XENON collaboration and B. Farmer (2017) e-print: 1705.02614

[6] M. Maltoni and T. Schwetz (2013) e-print: 0304176.

Backup: Formulation

- Experiments measure scattering of dark matter (DM) off of nuclei
- Theoretical rate[5]
  - Differential rate

$$\frac{dR}{dE_R} = N_T n_\chi \sum_i n_i \int_{v_{min}}^{\infty} \left(\frac{d\sigma(v, E_R)}{dE_R}\right)_i v f_E(v) d^3 v$$

  - Total rate

$$R_j(\hat{C}) = \int \frac{dR}{dE_R} G_j(Es_R) dE_R$$

- Chi-squared function[6]

$$\chi^2(\hat{C}) = \sum_{j=1}^{n} \frac{\left[N_{0,j} - \left(N_{b,j} + N_j(\hat{C})\right)\right]^2}{\delta N_{0,j}^2}$$