PLR
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Fall 2018

Structure of the code

- laidbax
- laidbax.egg-info
- notebooks
- old_notebooks
- HISTORY.rst
- laidbax_logo.png
- LICENSE
- MANIFEST.in
- README.rst
- requirements.txt
- setup.py

Laidbax

- data → CSV files
- __init__.py
- base_model.py
- signals.py
- sources.py
- untitled

Notebooks

- pdf_cache
- Basic checks.ipynb
- SR0 limit.ipynb
- Tutorial.ipynb
- WIMP limits.ipynb
- compute_limits.py

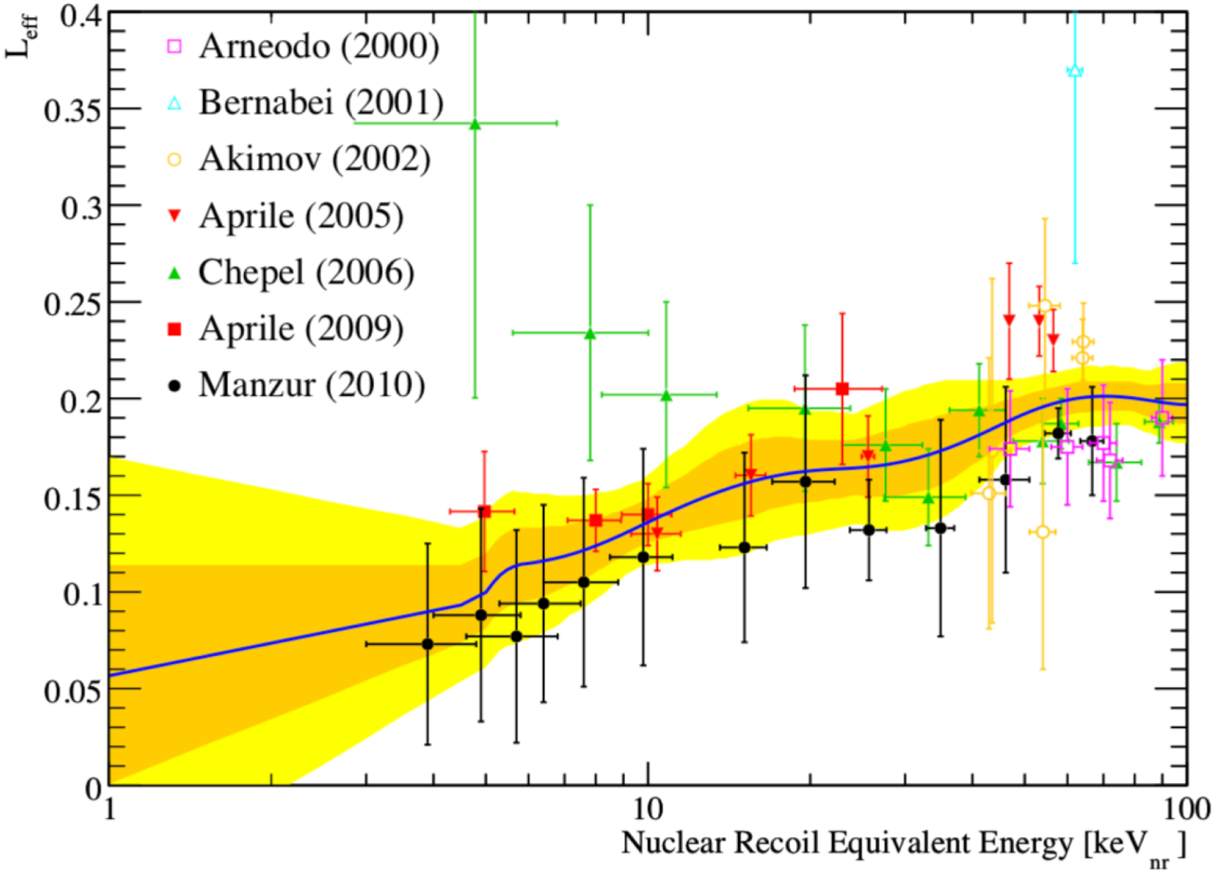
Old_Notebooks

- bologna_nocls_limits
- Basic checks on model.ipynb
- Make data files.ipynb
- Multiple WIMP masses (limit curve).ipynb
- Qy fitting from Nuclear recoil calibration.ipyn
- Simple WIMP analysis.ipynb
- nest_ER_photon_yield.npz
- qyfitexample_spectrum.csv

Understanding of the Code

- Create the likelihood function for different WIMP masses
  - WIMP mass = [7, 10, 20, 50 ,100, 200, 1000] GeV
  - Use the configuration from base_model and remove WIMPs source
  - Add each WIMP mass with cross section = 1e-45cm2 from the list(csv files) to the configuration
  - Add rate parameter(WIMP mass) and shape parameter Leff
    - Leff parametrized with t , t = [-2, -1, 0, 1, 2] --> [-2σ, -1σ, 0, +1σ, +2σ]
  - Create the log likelihood function

Leff: Relative scintillation efficiency



Blue line: Gaussian fit for all measurements of Leff

Orange shade: 1σ

Yellow shade: 2σ

I think (not sure): By taking account of the uncertainties in Leff, we get a band of limits curve instead of just one single curve.

Code

- Simulate background datasets
    - 1000 datasets
- To be continued……

Problems

- For WIMP with mass 7 and 20 GeV, same problem as before. Errors on getting the limit.

PLR in Xenon100

Expected N of background

Distribution of signal and background events

$$\lambda(\sigma) = \frac{\max\limits_{\sigma\ \text{fixed}} \mathscr{L}\left(\sigma; \mathcal{L}_{\text{eff}}, v_{\text{esc}}, N_b, \epsilon_s, \epsilon_b\right)}{\max \mathscr{L}\left(\sigma, \mathcal{L}_{\text{eff}}, v_{\text{esc}}, N_b, \epsilon_s, \epsilon_b\right)} \equiv \frac{\mathscr{L}\left(\sigma, \hat{\hat{\mathcal{L}}}_{\text{eff}}, \hat{\hat{v}}_{\text{esc}}, \hat{\hat{N}}_b, \hat{\hat{\epsilon}}_s, \hat{\hat{\epsilon}}_b\right)}{\mathscr{L}\left(\hat{\sigma}, \hat{\mathcal{L}}_{\text{eff}}, \hat{v}_{\text{esc}}, \hat{N}_b, \hat{\epsilon}_s, \hat{\epsilon}_b\right)}.$$

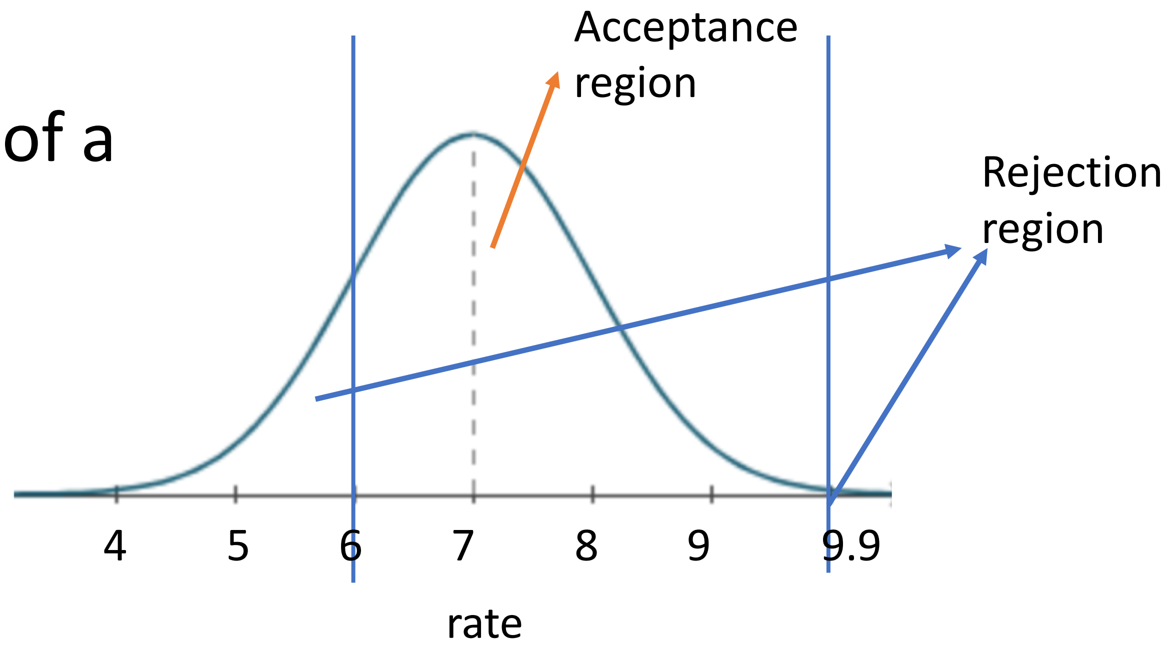
Hypothesis Test(procedure)

- 1. Choose null hypothesis(H0).
- 2. Choose a test statistic -> to determine whether reject H0 or not
- 3. PDF for the null hypothesis (probability vs. test statistic)
- 4. Determine the acceptance and rejection region
- 5. Compare the measurement(test statistic) of the data to the PDF and to see if it is within the acceptance region

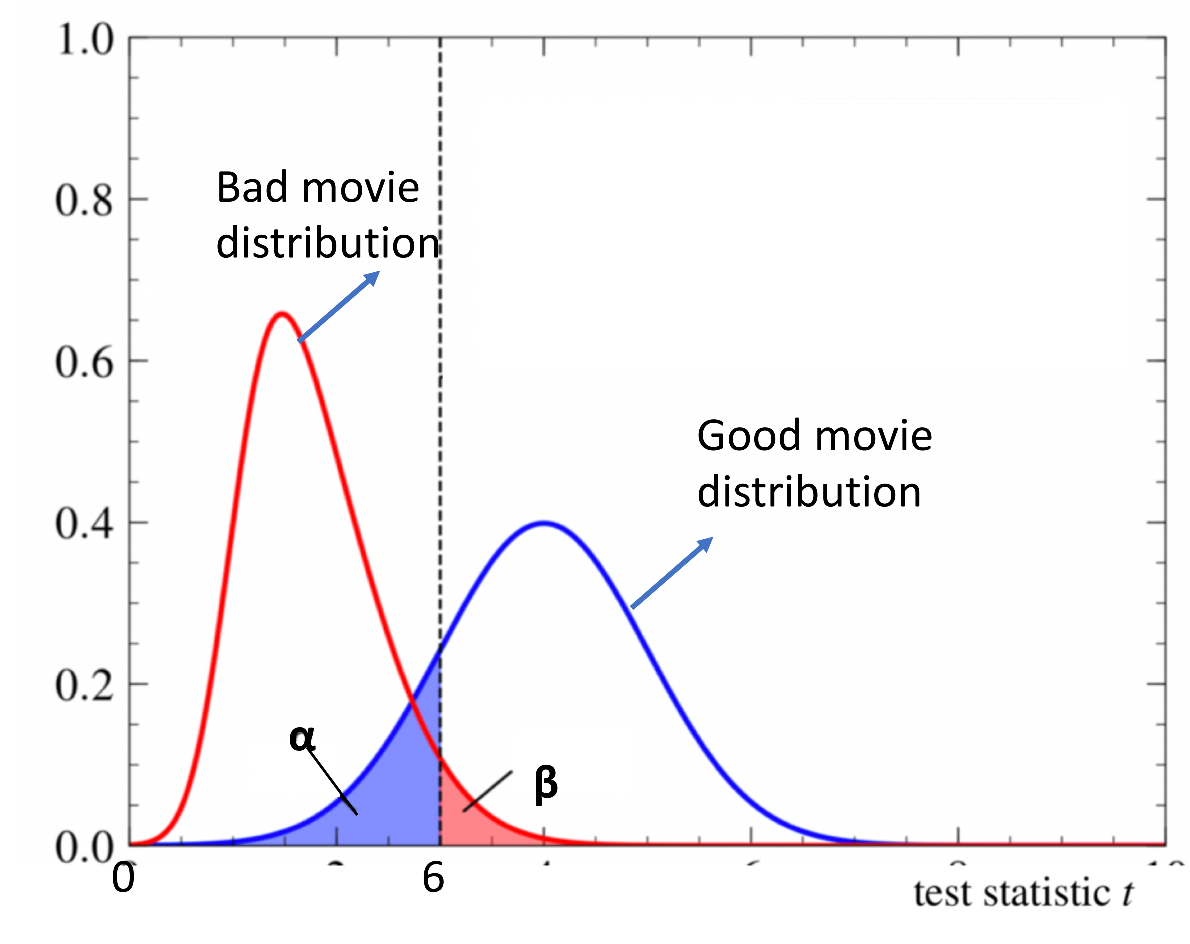
Hypothesis Test(example)

- Null hypothesis: The X is a good movie
- Test statistic: The rate from IMDb

Distribution of a good move



- Adding an alternative hypothesis: H1: The movie X is a bad movie

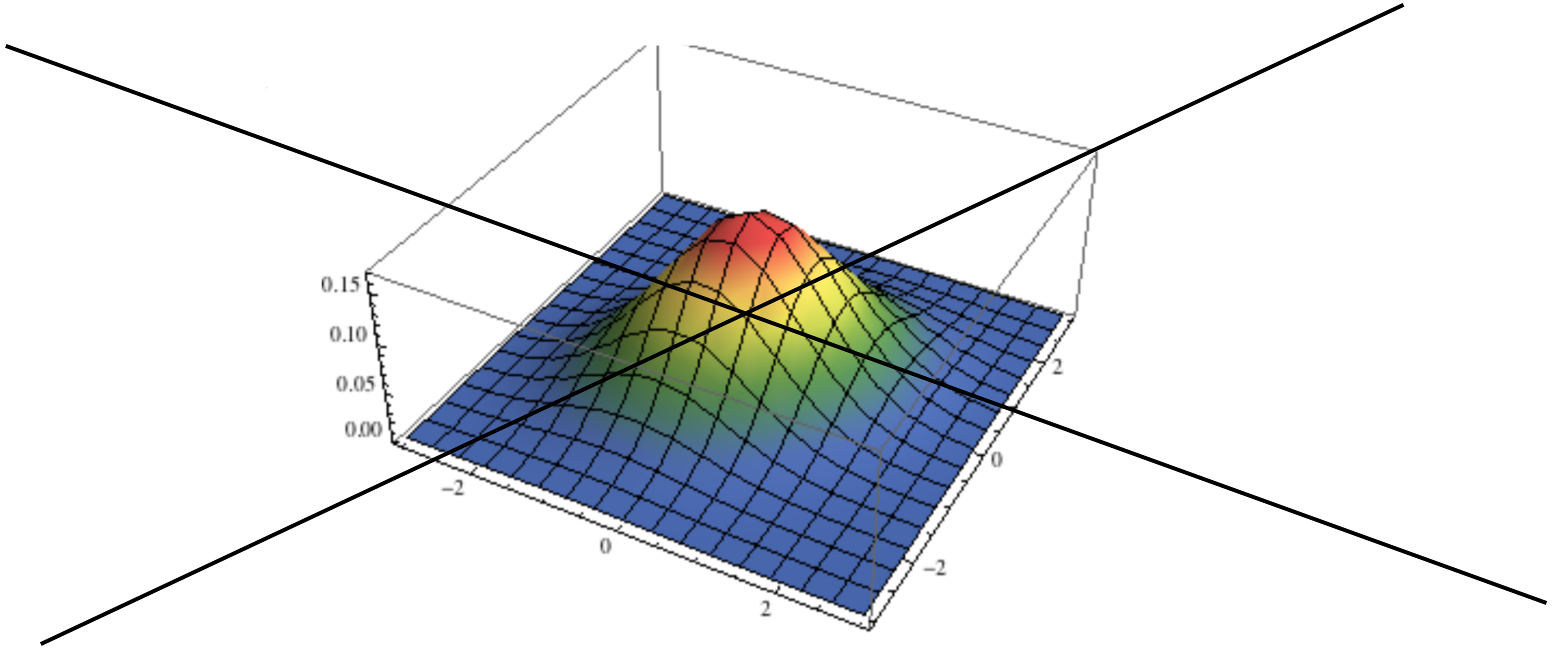


α: Type 1 error: Reject H0, even though it is true

β: Type 2 error: Reject H1, even though it is true

Likelihood

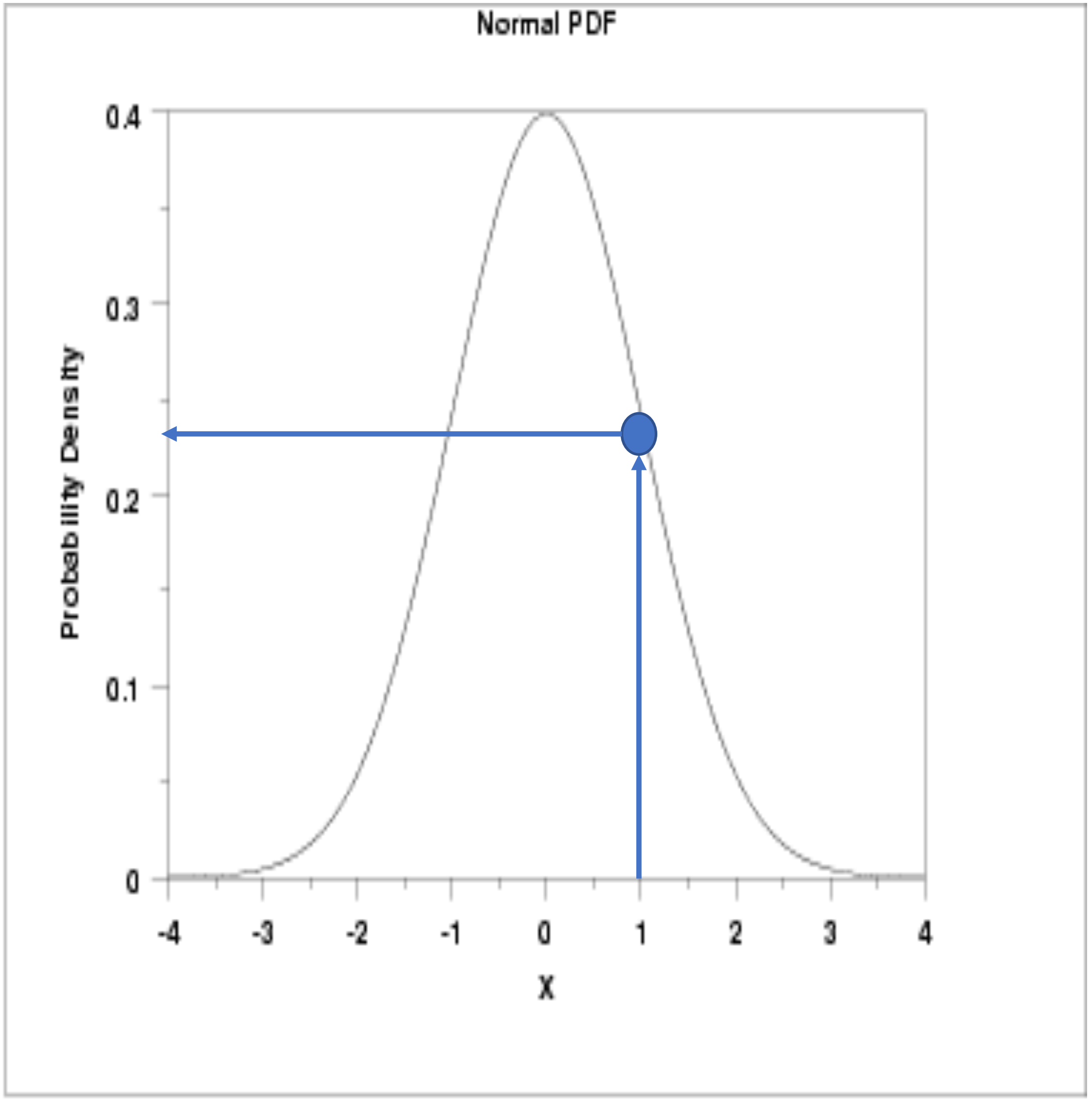
- We want test statistic to be a function of multiple observables
  - Test statistic is a function of rate, box-office grosses…….
- Instead of creating N-D PDF, we use likelihood



Probability vs. Likelihood

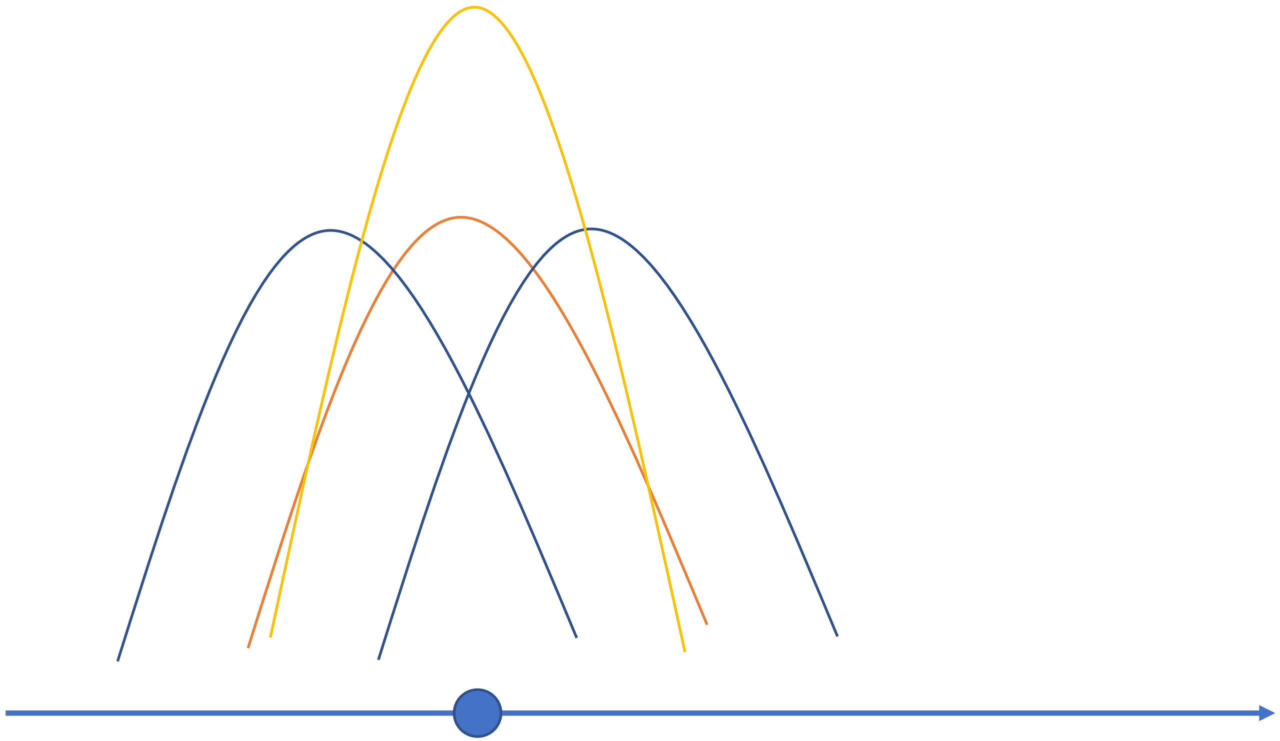
- Probability: given the fixed distribution(PDF), the probability that an event can occur
    - Fixed PDF/model parameter
    - Unfixed observed data

- Likelihood: Given the event is true, the probability that this will happen
    - Unfixed parameters(shape or location of the distribution)
    - Fixed observed data



Maximize the likelihood

- So for likelihood, we can change the location and the shape of the distribution to maximize the likelihood of the event.



PLR

Parameter of Interest
(cross section)

H0

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}})}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})} .$$

H1

Nuisance
parameters

- $L(\hat{u},\theta)$ = P($\hat{u}$, x)*Gaus($\hat{u}$, θ), θ is the nuisance parameter and float to maximize L
  - $\hat{u} = f(\theta)$

PLR for WIMPs

- Test Statistic:

Parameter of Interest
(cross section)

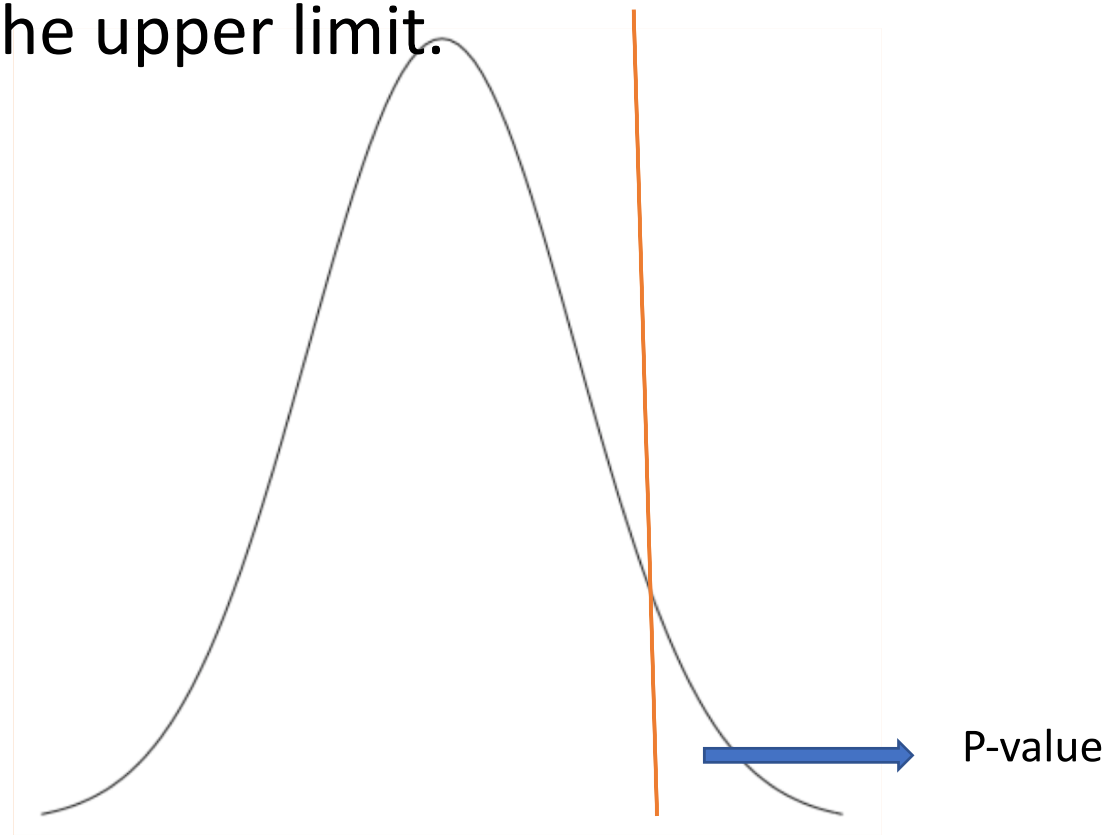
$$\lambda = \frac{\mathcal{L}(\mu{=}0;\, \hat{\hat{\theta}})}{\mathcal{L}(\mu{\neq}0;\hat{\theta})}$$

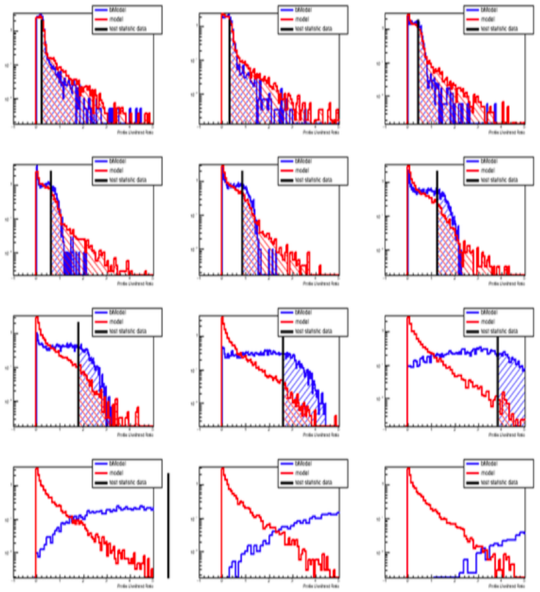
Nuisance
parameters

- Discover WIMP
  - H0: There are no WIMPs, u=0(Background only)
  - H1: There are WIMPs, u≠0
- WIMP limit set
  - H0: WIMPs exist with specific u = u_test (signal+background)
  - H1: WIMPs exist with u ≠ u_test

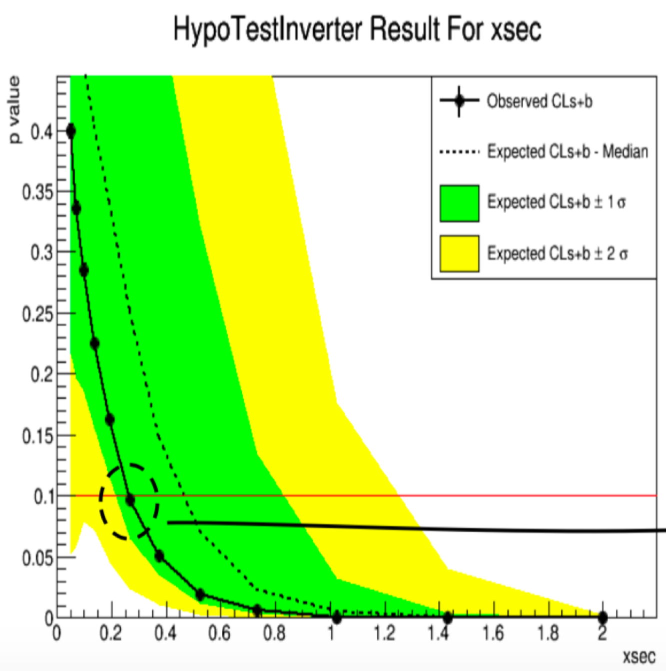
Setting the limit

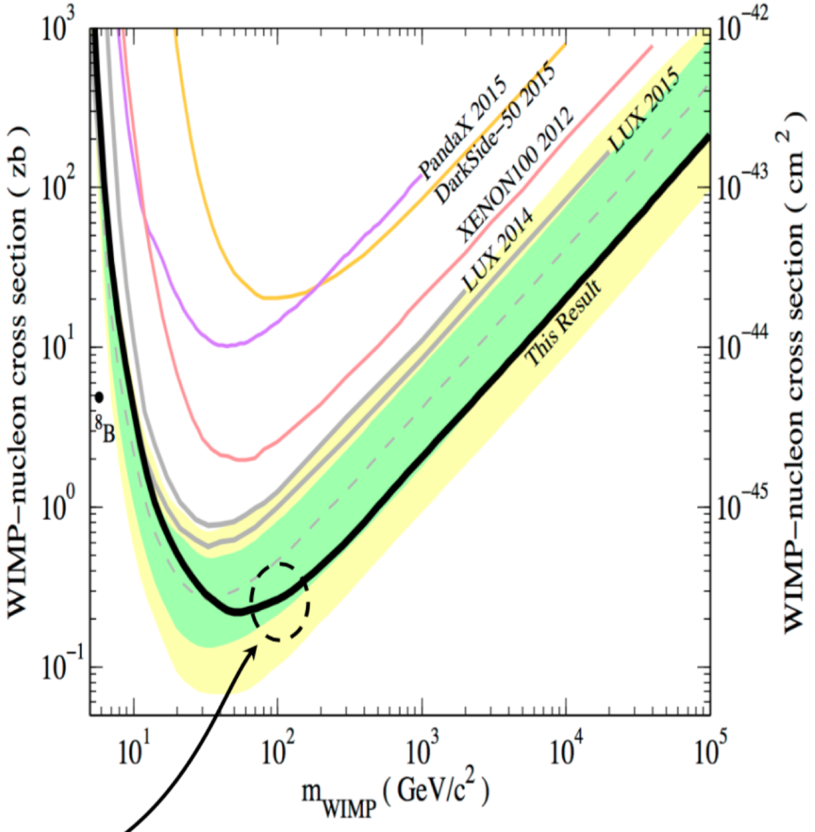
- For WIMP with each mass, varying u_test and when the u_test leads to a p-value=0.1, the u_test is the upper limit.
- Then varying the WIMP mass





Limit Setting for One Mass Illustration





Slide from Shaun

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TO DO

- Structure of the code

This week

Figure out what is going on in the code, WIMP limit

Syntax of blueice

Numerical Analysis

Play with different parameters

General idea of the code

Use blueice to create 1) likelihood function and 2) its interval to find the roots by using Brent's method and the roots will be plotted in the limit graph as the cross-section.

For likelihood function: 1) adds two rate parameters: WIMP recoil, electron recoil 2) adds 1 shape parameter: WIMP mass

(why is the WIMP recoil rate parameter = 0 to make a discovery?)

Problem

- Set cross section = 1e^-45, wimp interaction = SD, got an error.

```
~/Desktop/blueice/blueice/inference.py in one_parameter_interval(lf, target, bound, confidence_level, kind, bestfit_routine, t_ppf, **kwargs)
            return brentq(t, bound, global_best, args=[1 - confidence_level])
        elif kind == 'upper':
-->         return brentq(t, global_best, bound, args=[confidence_level])

/anaconda3/lib/python3.7/site-packages/scipy/optimize/zeros.py in brentq(f, a, b, args, xtol, rtol, maxiter, full_output, disp)
        if rtol < _rtol:
            raise ValueError("rtol too small (%g < %g)" % (rtol, _rtol))
-->     r = _zeros._brentq(f,a,b,xtol,rtol,maxiter,args,full_output,disp)
        return results_c(full_output, r)

ValueError: f(a) and f(b) must have different signs
```

Interpretation of the syntax

- one_parameter_interval(lf, target, bound, confidence_level, kind, bestfit_routine, t_ppf, **kwargs)

- Set a confidence_level(100%) interval of kind(a range of WIMP mass) on the parameter target(WIMP rate multiplier) of likelihood function

lf = likelihood function

target = WIMP rate multiplier

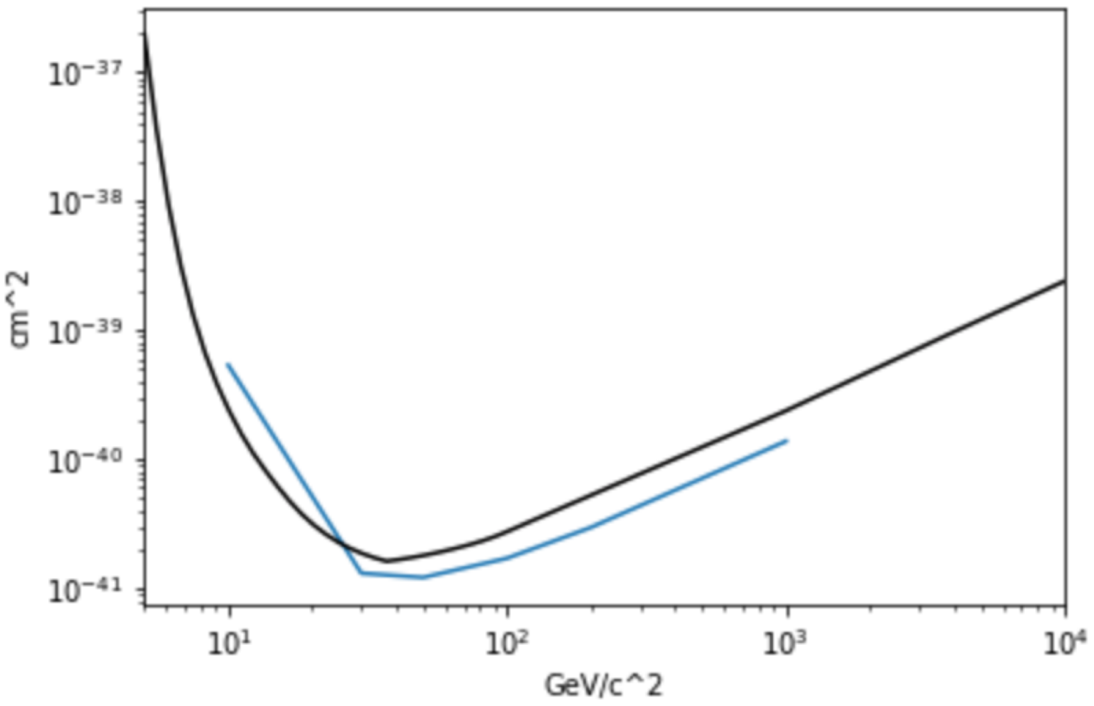
bound = 10

kind = WIMP mass

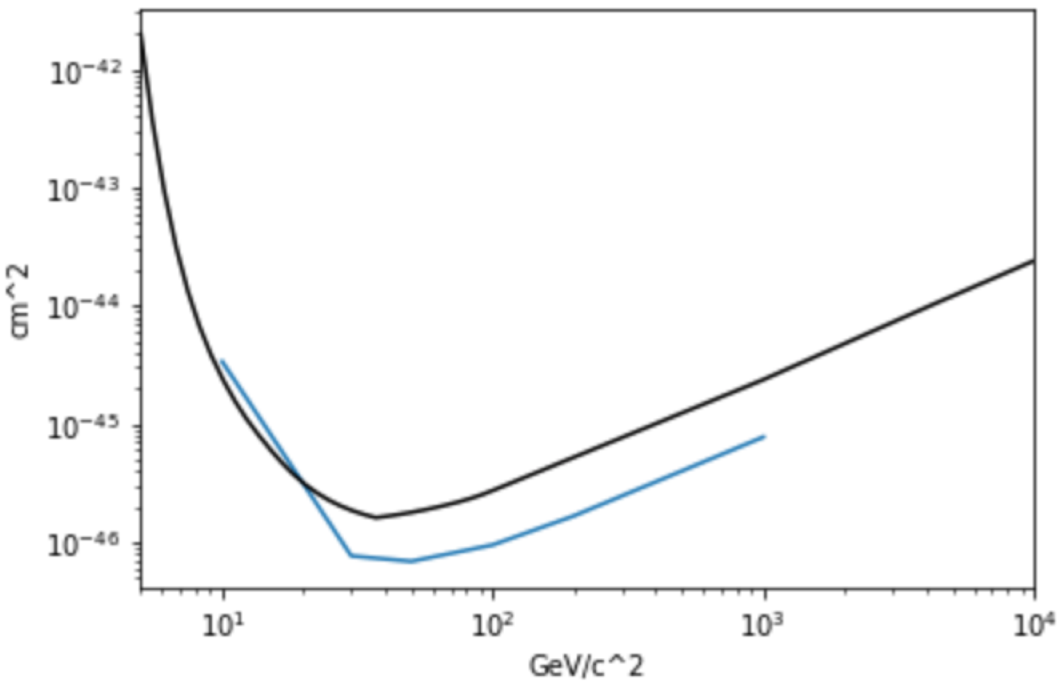
What I think…..

- Using Brent's method to find roots of the function and it requires f(a) and f(b) have different signs.
- Brent's Method: iteration of (bisection method + secant method)(I could make a slide on this method, if anyone is interested…..)
- When set CS to 1e^-45, the likelihood is too small, and the function curve is around zero-axis.
- Solution: increase the likelihood by decreasing the WIMP energy in the macro ---> No Effect
- Does it worth to dig more into it?

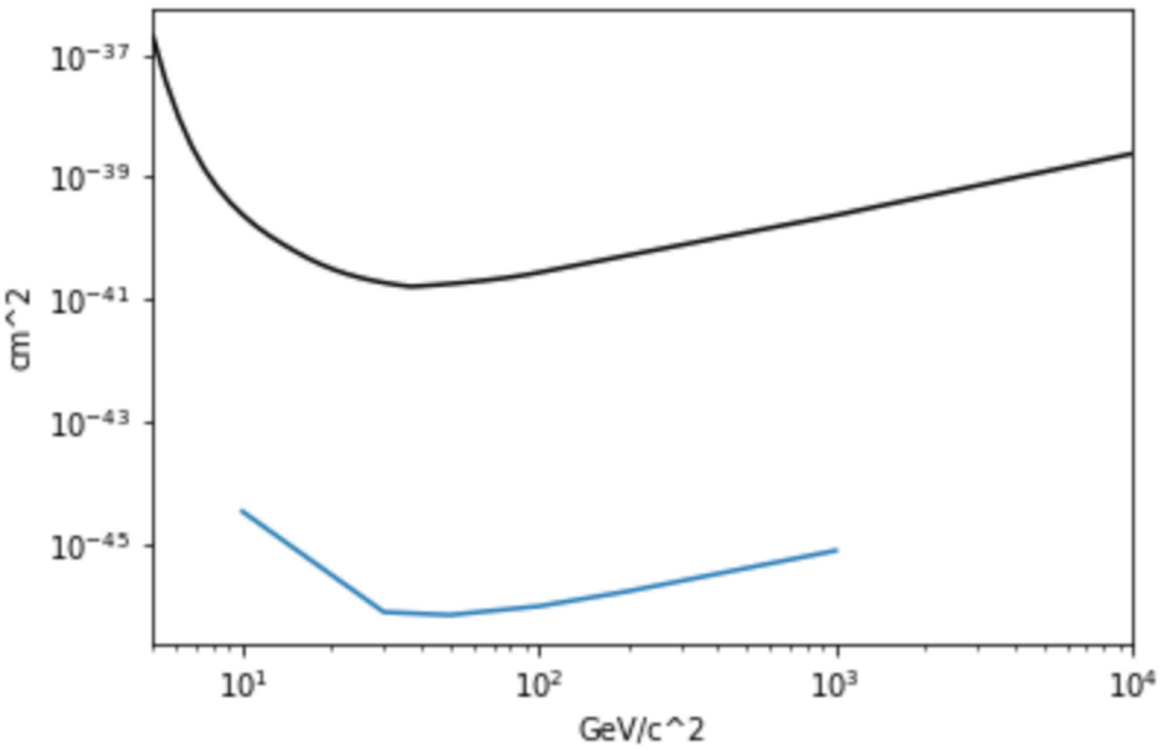
Cross-section: 1e^-40
WIMP Interaction:
SD_n_central (spin dependent)



Cross section: 1e^-45
WIMP Interaction: SI
(spin independent)



Cross-section: 1e^-40
WIMP Interaction: SI

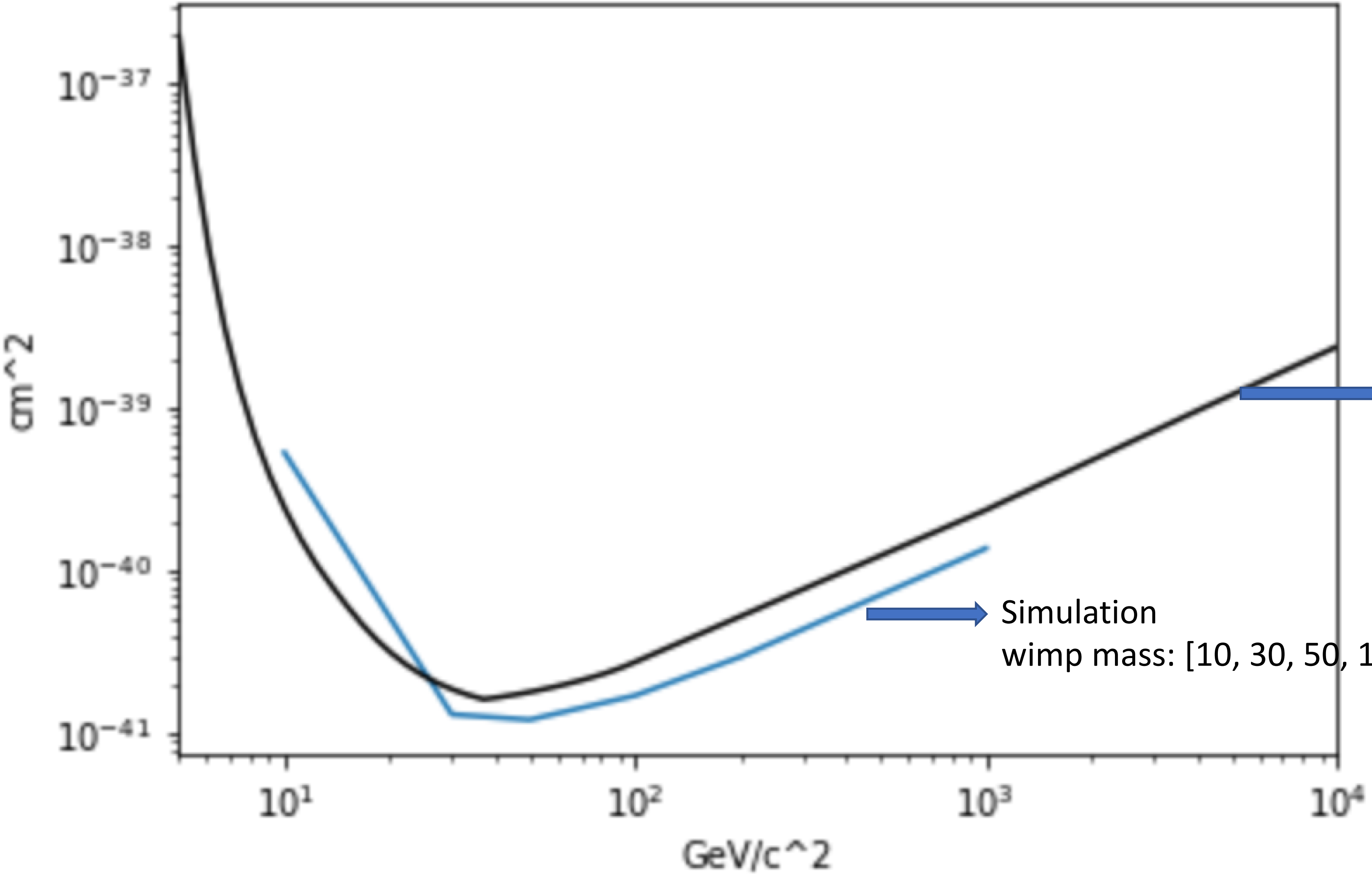


Next Week

- Analyze the simulation Macro
- Any remaining/new problems from this meeting

Macro(Xenon1T)

- Set Sources: energy distribution: er_background + nr_background(cnns and radiogenic neutrons) + 50Gev 10^-45 WIMP(nr)
- Set parameters



Model?

Simulation
wimp mass: [10, 30, 50, 100, 200, 1000] GeV

Info for the black line

5 GeV	**10 GeV**	**10^2 GeV**	**10^3 GeV**	**10^4 GeV**
1.98e^-37 cm^2	2.37e^-40 cm^2	2.75e^-41 cm^2	2.38e^-40 cm^2	2.41e^-39 cm^2

Base model(Xenon 1T)

- WIMP Parameters:

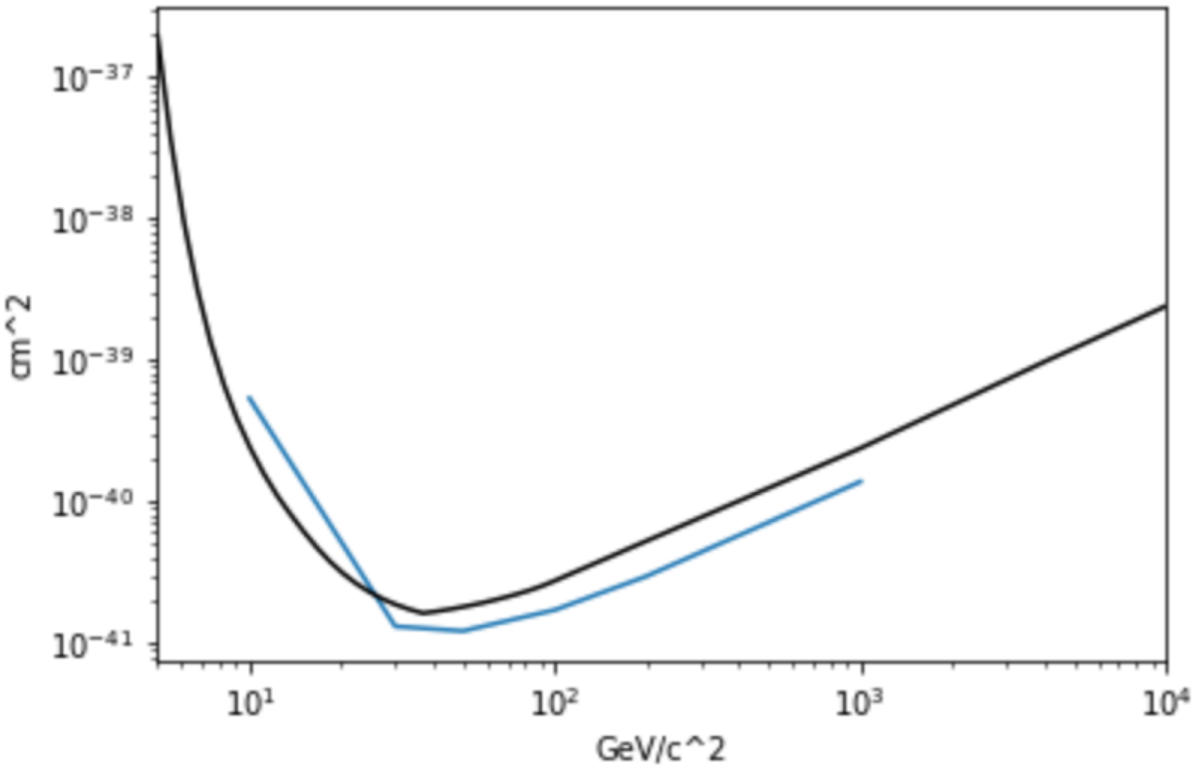
Detection	Sigma_nucleon	Wimp mass	NR cutoff	ER cutoff	WIMP interaction
Elastic NR	1e^-45 cm^2 → 10 e^-40 cm^2	50 Gev/c^2	1 keV	0.18keV	SI → SD_n_central

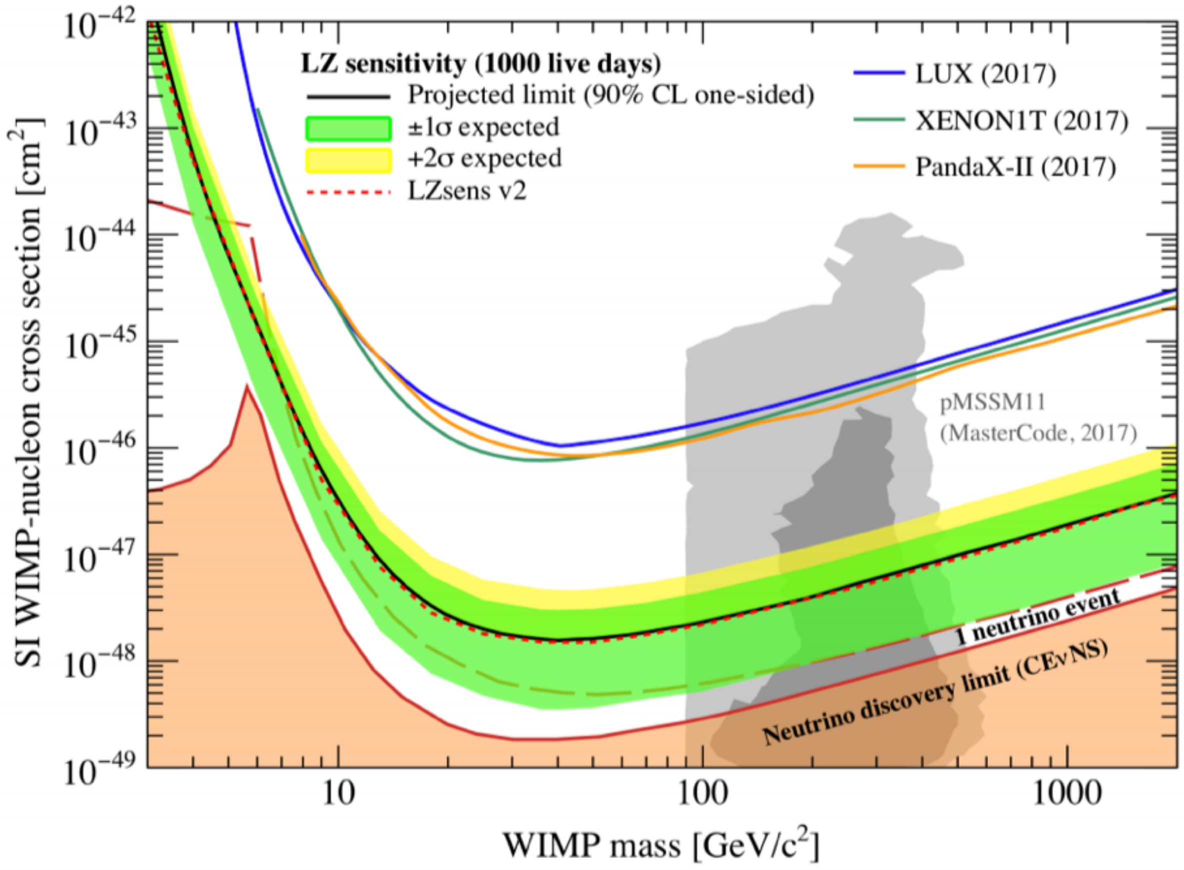
- Detector parameters:

Fiducial mass	Electron lifetime	Drift velocity
1042 kg	452 us	1.44 m/ms

Pdf_sampling_multiplier:1->0.1

Wimp limits curve





Questions?

- What other parameters do I need to know/change?