PLR

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Configuration

- Souces:
    - ER background(1e7)
    - CNNS(coherent neutrino-nucleus scattering, 5e6)
    - radiogenic neutrons(55e6)
    - accidental coincidences
    - wall leakage
    - anomalous flat component
    - 50 GeV WIMP(5e6)

WIMP parameters

	XE1T	LZ
Detection mechanism	elastic nr	
Interaction	SI	
nr_response_cutoff	1 keV	1.1 keV?
Er_response_cutoff	0.18 keV	
WIMP sigma nucleon	1e^-45	1e^-45
Wimp mass	50 GeV	

Detector parameter

	XE1T	LZ
S1_area_threshold (efficiency operates on coincidence)	0	
S2_area_threshold	150	
S1_min_photons_detected (coincidence requirement on S1)	3	S1 coincidence level: 3-fold
S1, S2 bias (primarily due to self-trigger)	csv files	
e_lifetime	452 us	850 us
v_drift	1.44 m/ms	1.88 m/ms
Drift field	117 V/cm	310 V/cm
Photon-detection-efficiency	0.1442/1.15 ~0.125	gi_liquid = 0.119 gi_gas = 0.102
double_pe_emission_probability	0.15	
Electron extraction efficiency	1	0.95
S2 gain	11.52/1.15 ~10.02	79?
Single phe width	0.4181	0.38

For sampling the light and charge yield in space

	XE1T	LZ
Fiducial volume radius	39.85cm	TPC 73cm
Fiducial volume zmax	-83.45 cm	TPC active height 146cm
Fiducial volume zmin	-13.45 cm	
Fiducial_mass	1042 kg	5.6 tonne = 5600kg
N_samples_for_source_positions	Int(1e5)	N_samples_for_source_positions
s1_relative_ly_map	file	

np.pi * rmax**2 * (zmax - zmin) * density

S1/S2 generation parameters

	Xe1T	LZ
NEST's basic quanta yield	73	
Fano factor for smearing the base quanta yield(From the NEST code)	0.03	
S1 peak detection efficiency(number of detected photons)	(0. , 0. , 0. , 0.5135, 0.787 , 0.851 , 0.9165, 0.9255…..1)	

ER

	Xe1T	LZ
Er reference energy	5 KeV	
Er max response energy	12 KeV	
Er polynomial order	3	
Er_qy_0, Er_qy_1, Er_qy_2	0	
the coefficients for the PCA and the normalization before and after applying the PCA		
p_er_electron_fluctuation	0.045	

NR global fit parameters

	Xe1T	LZ
Nr alpha…….nr lambda	….	
Lindhard_k	…..	
p_nr_electron_fluctuation	0.02	

Add wimp source to the configuration (c)

energy distribution: wimp Xgev csv files

color: red

recoil type: nr

name: wimp Xgev

 # events for pdf: the amount of events to simulate to create the PDF.

ignore setting: nr ignore settings

nr_ignore_settings = ['er_reference_energy', 'er_max_response_energy', 'er_poly_order', 'p_er_electron_fluctuation', 'function_of_log_energy']

Ignore these if you're an NR source

PDF from blueice

```
lf = LogLikelihood(c)
```

Which parameters to vary
Which space to analyze in

Model / Source

Configuration

Energy spectra
Yields, LCE maps, ...

Fast MC

PDF estimation

Histogram of events

LogLikelihood

Unbinned and binned
Morphing / interpolation

Statistical tools (external)

Minimizers, MCMC, ...

Simulated data
Real data

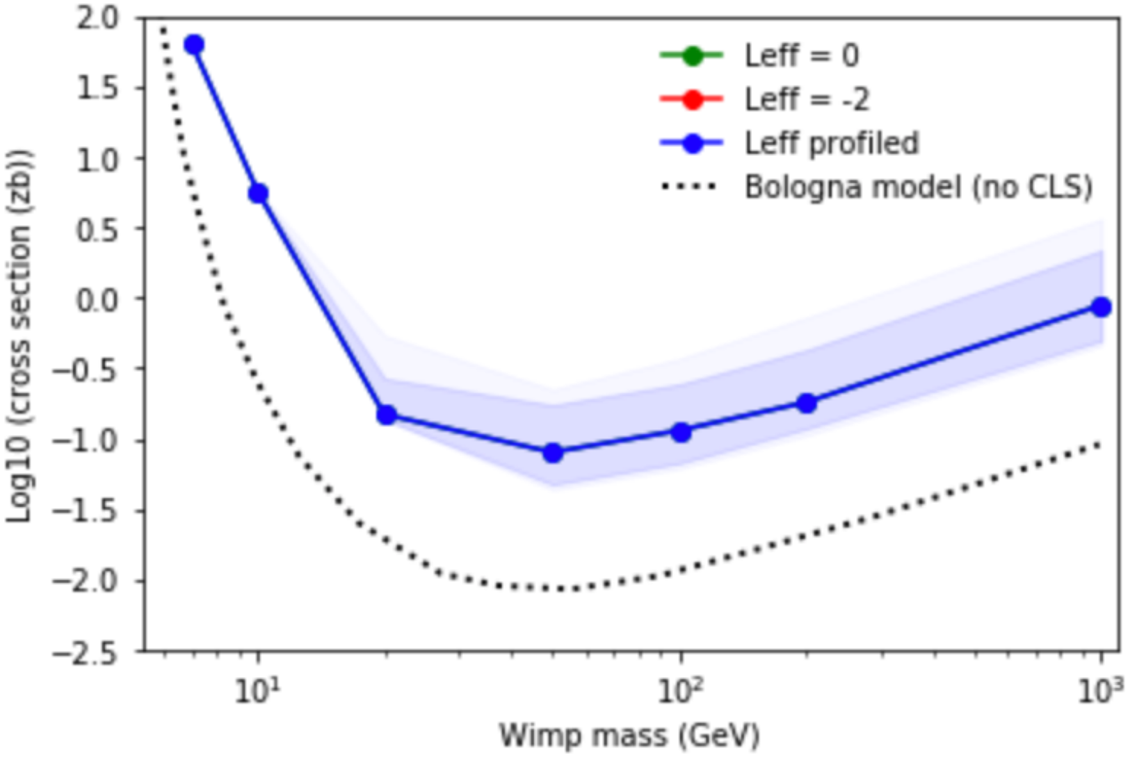
The Monte Carlo's settings become parameters in the analysis(the rate of WIMPs, electron lifetime...) ?
Data dimensions become the space for comparison(cS1 and cS2) ?

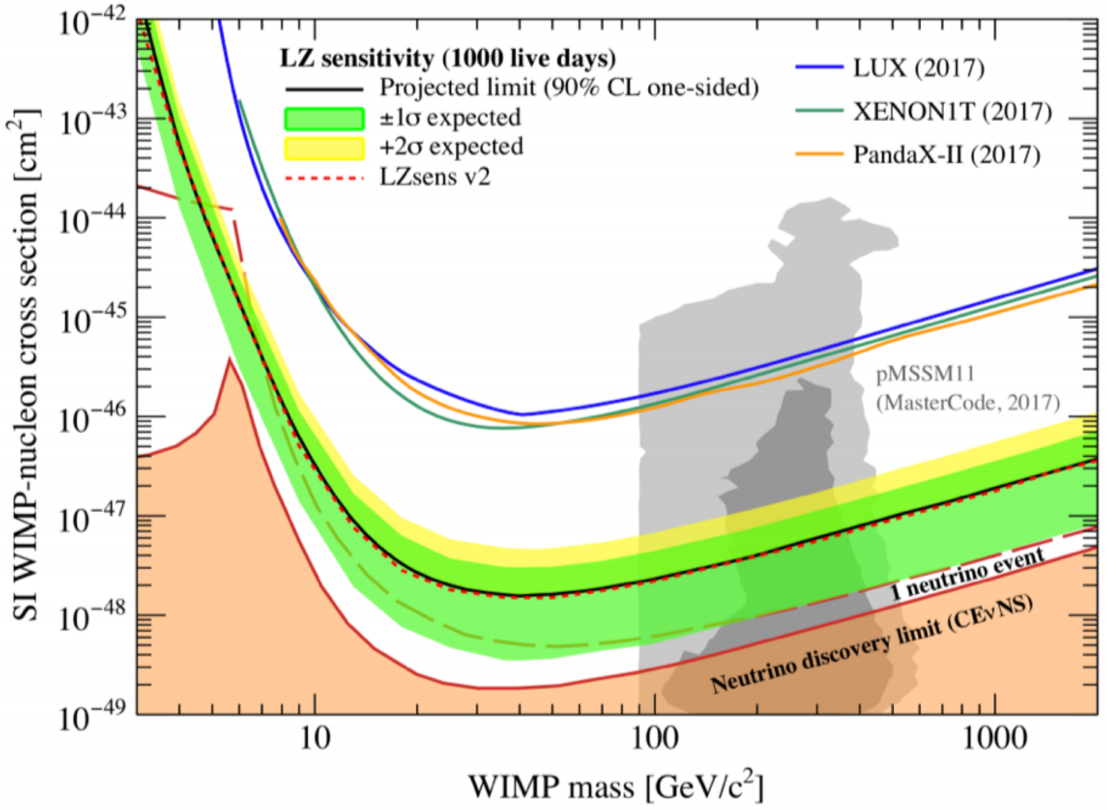
How to solve it?

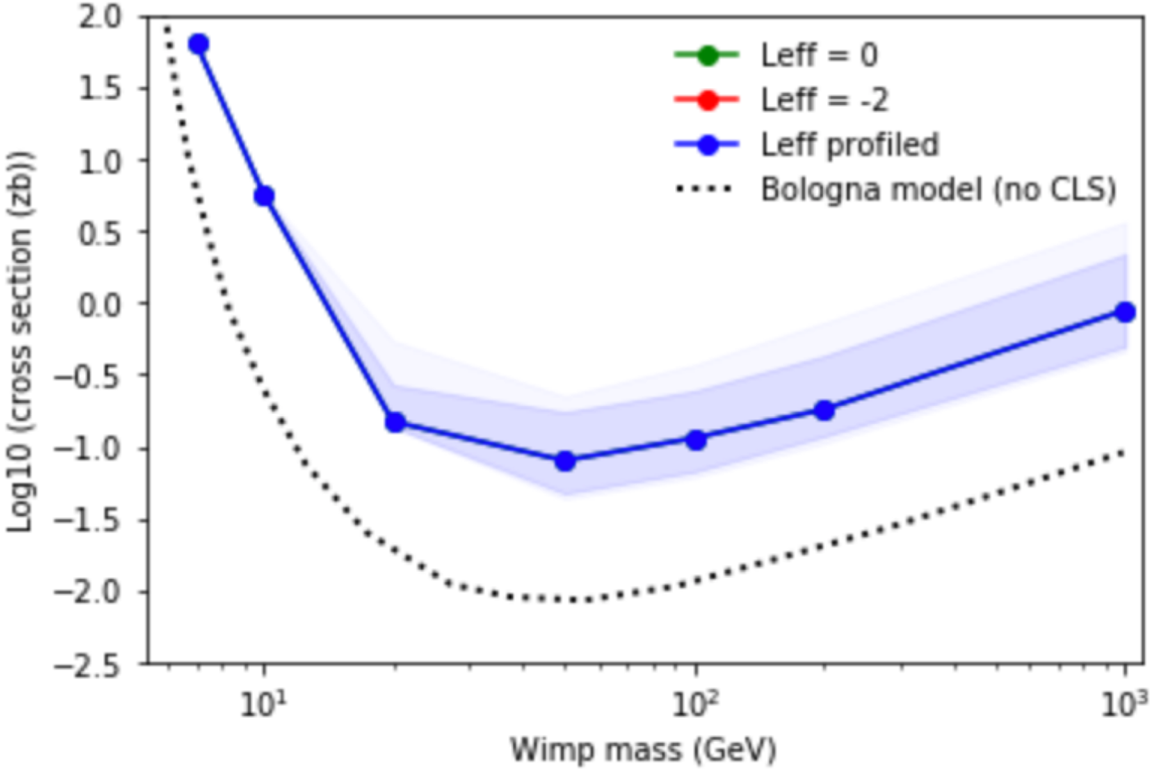
- First, how to create a problem like this?
- Start with the mass of 10 GeV
  - # events for pdf
  - # trials
  - Shape parameter of Leff
- Playing with numbers set # trials = 100, no Leff shape parameter

to have an error or not to have an error									
1 x	8 x	15 x	22 x	29 o	36 o	43 o	50 o	63 o	82 o
2 o	9 x	16 x	23 x	30 o	37 o	44 o	51 o	66 x	84 x
3 x	10 x	17 x	24 o	31 o	38 o	45 x	52 o	67 o	90 o
4 x	11 o	18 x	25 x	32 x	39 o	46 o	53 x	70 o	99 o
5 x	12 x	19 x	26 x	33 o	40 o	47 o	54 o	72 o	100o
6 x	13 o	20 x	27 x	34 o	41 o	48 x	55 o	75 o	107x
7 x	14 x	21 x	28 o	35 x	42 x	49 x	60 o	77 o	135x

- From patterns, it is random not to have an error with small numbers of events, however, from 140~160, they are all error-free, one can conclude that up to a large number, it is not a random anymore, take the average, 150 is the number.
- Back to the csv files, for 10 GeV, 1000 events in total, with 86 events that are not zero, for 7 GeV, 1000 events in total, with 40 events that are not zero, if 150 for 10 GeV, around 322 for 7 GeV
- Try 325


Leff = 0
Leff = -2
Leff profiled
Bologna model (no CLS)
Log10 (cross section (zb))
Wimp mass (GeV)


LZ sensitivity (1000 live days)
Projected limit (90% CL one-sided)
±1σ expected
+2σ expected
LZsens v2
LUX (2017)
XENON1T (2017)
PandaX-II (2017)
pMSSM11
(MasterCode, 2017)
1 neutrino event
Neutrino discovery limit (CEνNS)
SI WIMP-nucleon cross section [cm²]
WIMP mass [GeV/c²]



Leff = 0
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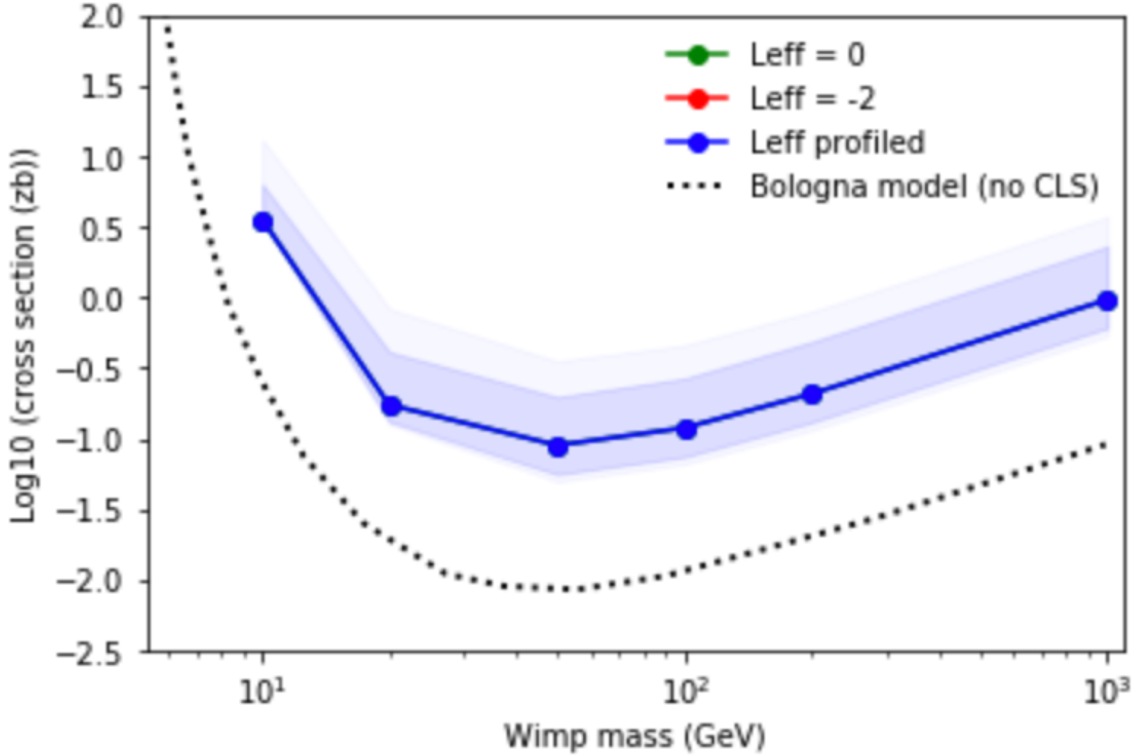


Leff = 0
Leff = -2
Leff profiled
Bologna model (no CLS)
Log10 (cross section (zb))
Wimp mass (GeV)

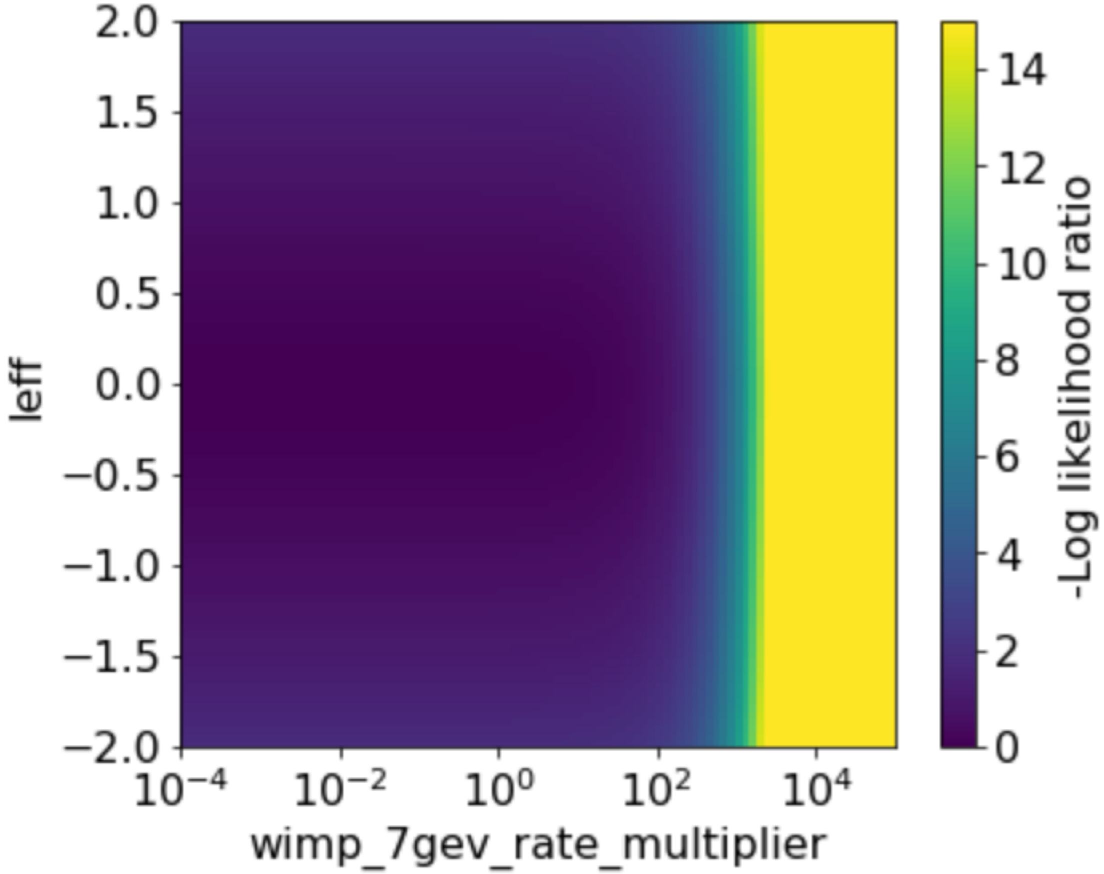
Table of Failures

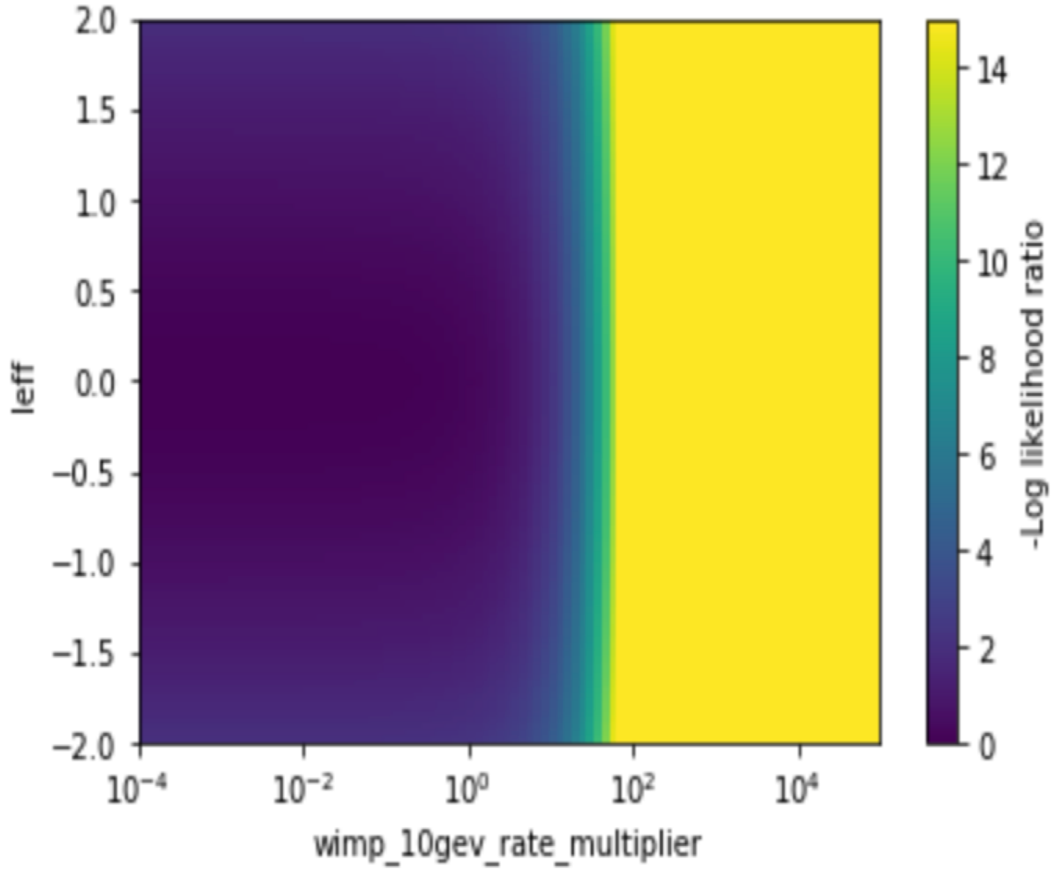
trials

	100		Shape parametes of Leff	100	1000			
Below 150	Randomly							
Above 150	No errors							
			fail					
				Mostly				
					Fails			

Change the scale (-4,1) ->(-4,5)

Thanks, Jonathan !





Test on 50 GeV WIMP

B

1000 trials
Simulate(blueice) the background-only data using the likelihood function of 50 GeV and multiply by the rate of 50 GeV
A list of background data [0….999]

Change the rate of the source　　Source name　　multiplier

```
bg_dsets = [lfs[50].base_model.simulate(rate_multipliers=dict(wimp_50gev=0))
            for _ in tqdm(range(n_trials))] #a list blueice.model
```

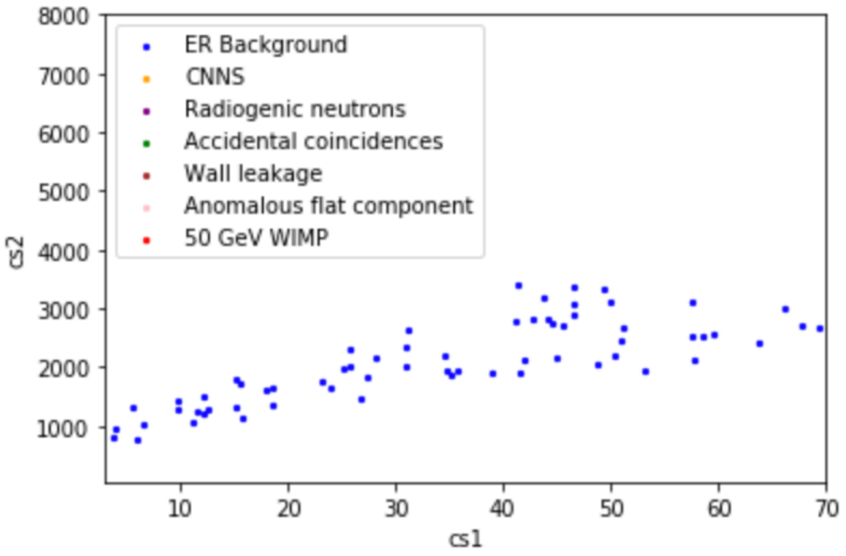
B +S

Choose ONE background dataset from the list
Set the likelihood function(50 GeV in this case) to the background data
Plot ONE set of background+signal data

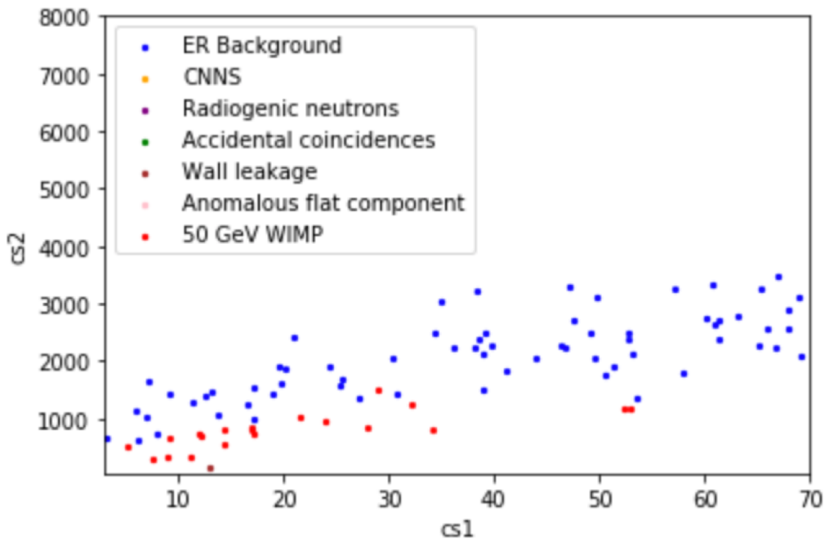
Set the log likelihood function of 50 GeV to the background dataset
Use the syntax from blueice, plot_likelihood_ratio, plots the loglikelihood ratio with two changing parameters, Leff and rate_multipliers.

Rate_multipliers in background

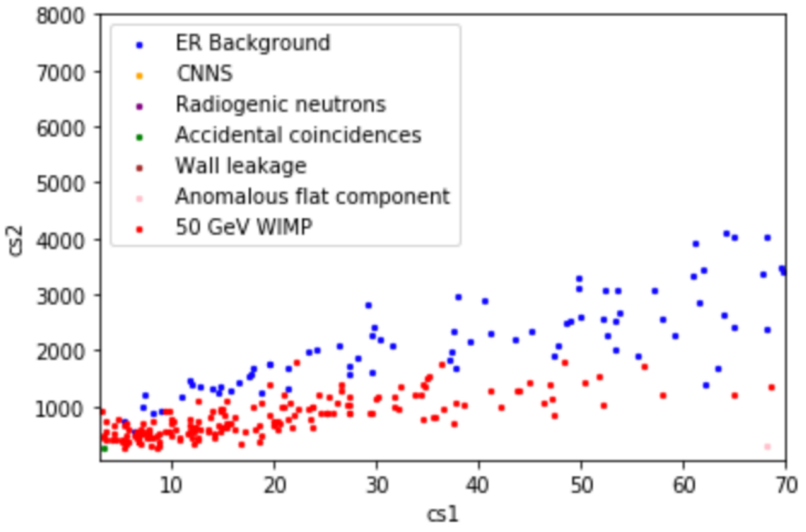
From step 2, 50gev=0



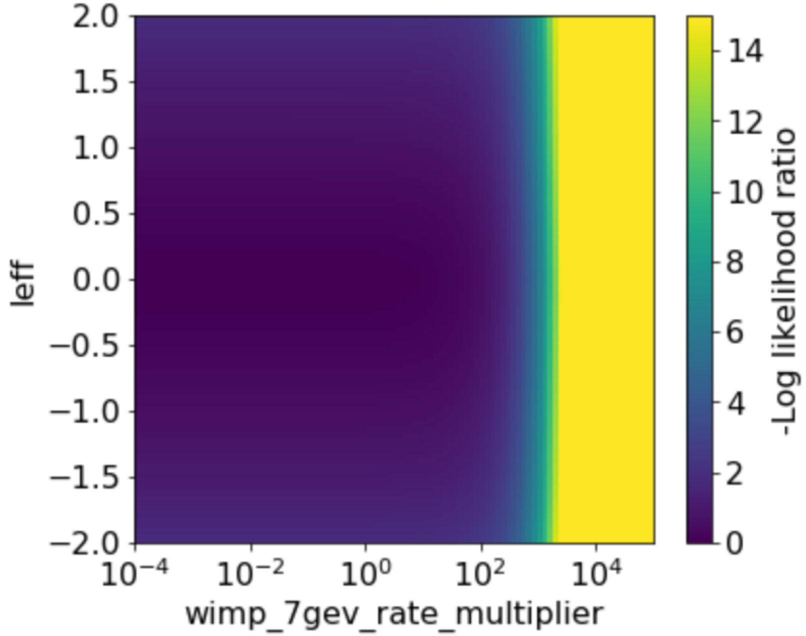
50gev = 1



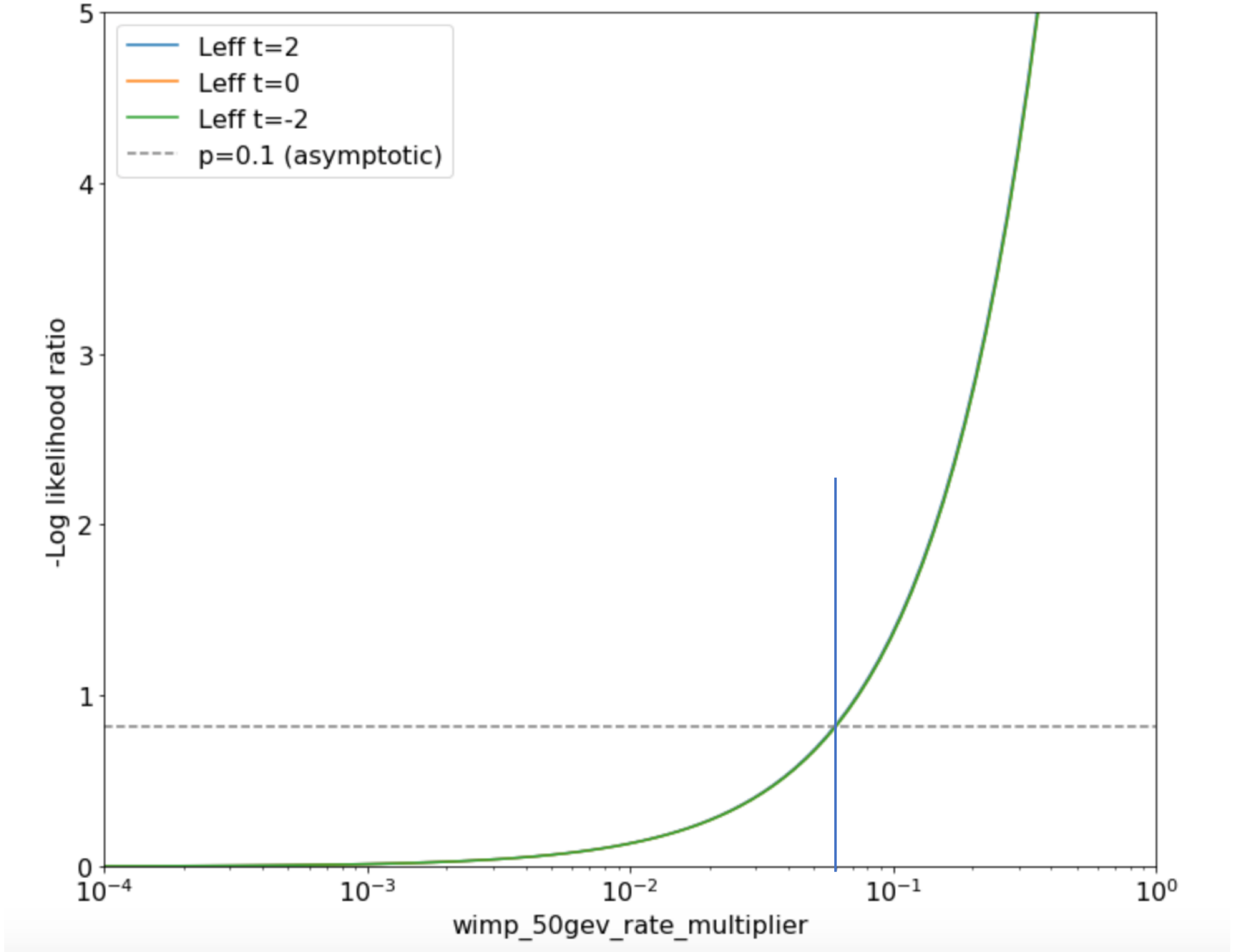
50gev = 10



Plotting in another way:

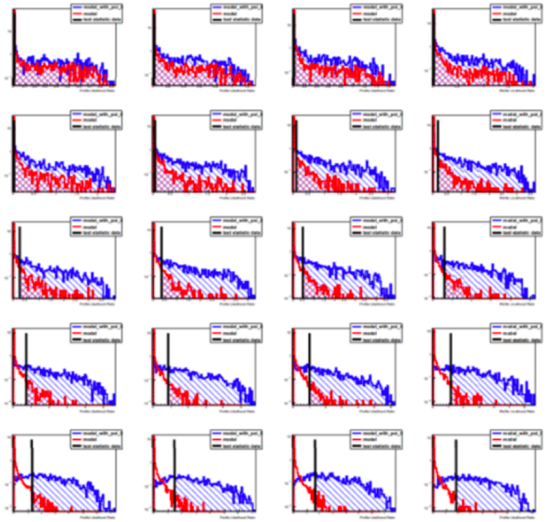


rate_multipliers is a list of rate multipliers for each source in self.source_name_list

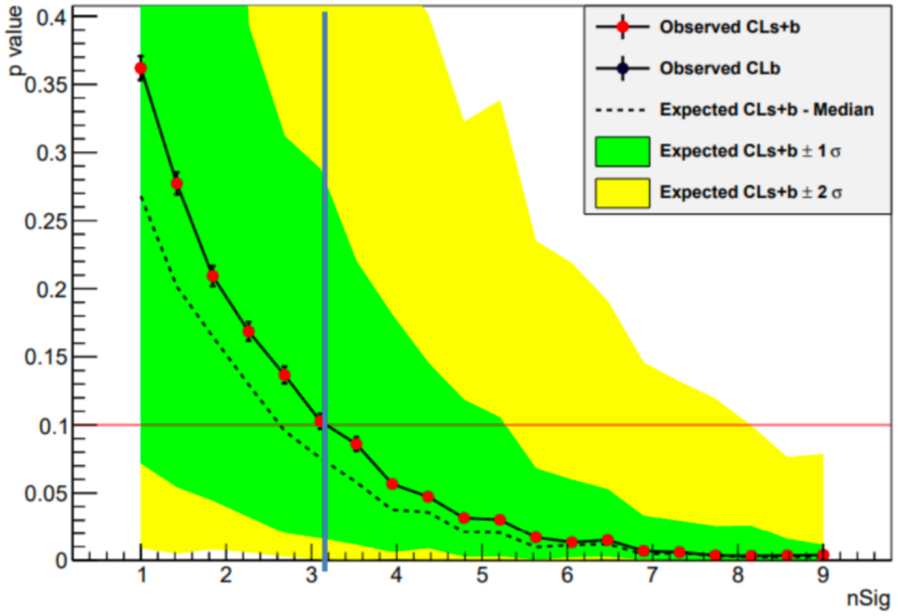


Signal_events = rate_multiplier * number_expected_events

Limit Setting for One Mass Illustration



Different run than before



- $\lambda = \dfrac{L(u{=}u\_test, Leff, \theta)}{L(u{\neq}u\_test\ Leff, \theta)}$

B+S

Only B

Intersects at ~3.2 signal events so our limit is the value of POI that yields an expected 3.2 signal events

Setting the limits

1. create 3 dictionaries: {m: empty N-dimensional arrays(number of trials, in this case, it is 1000)} m is the wimp mass.

- Limits on likelihood ratio
- Limits on profile likelihood ratio
- Limits on likelihood ratio lowleff

2. Two for loops

```
for m in wimp_masses:
    lf = log likelihood function[m]
    for i, d in the background data sets:
        set lf into the backgournd data d
        target = wimp_mgev_rate_multiplier
        using three one_parameter_interval() to get the three limits
```

limits[m][i] = set a 90% confidence level interval of kind(upper)? on the parameter target of lf, with leff=0

limits_lowleff[50][i] = same as limits except that leff = -2

limits_plr = same as limits except no restrictions on leff

```
one_parameter_interval(lf, target, bound=100,confidence_level = 0.499, kind='upper', leff=0) * scale
```

Tests on the three limits: run 10 events, print them out

- Limits: {20: array([.....10 numbers]), 50 array([.....10numbers])......}
- Limits_lowleff: {20:array([0,0,0,....0,]), 50 array([same 10 numbers as in limits]), all zeros for 100, 200,1000}
- Limits_plr {20: array([10 numbers slightly larger than limits])......}

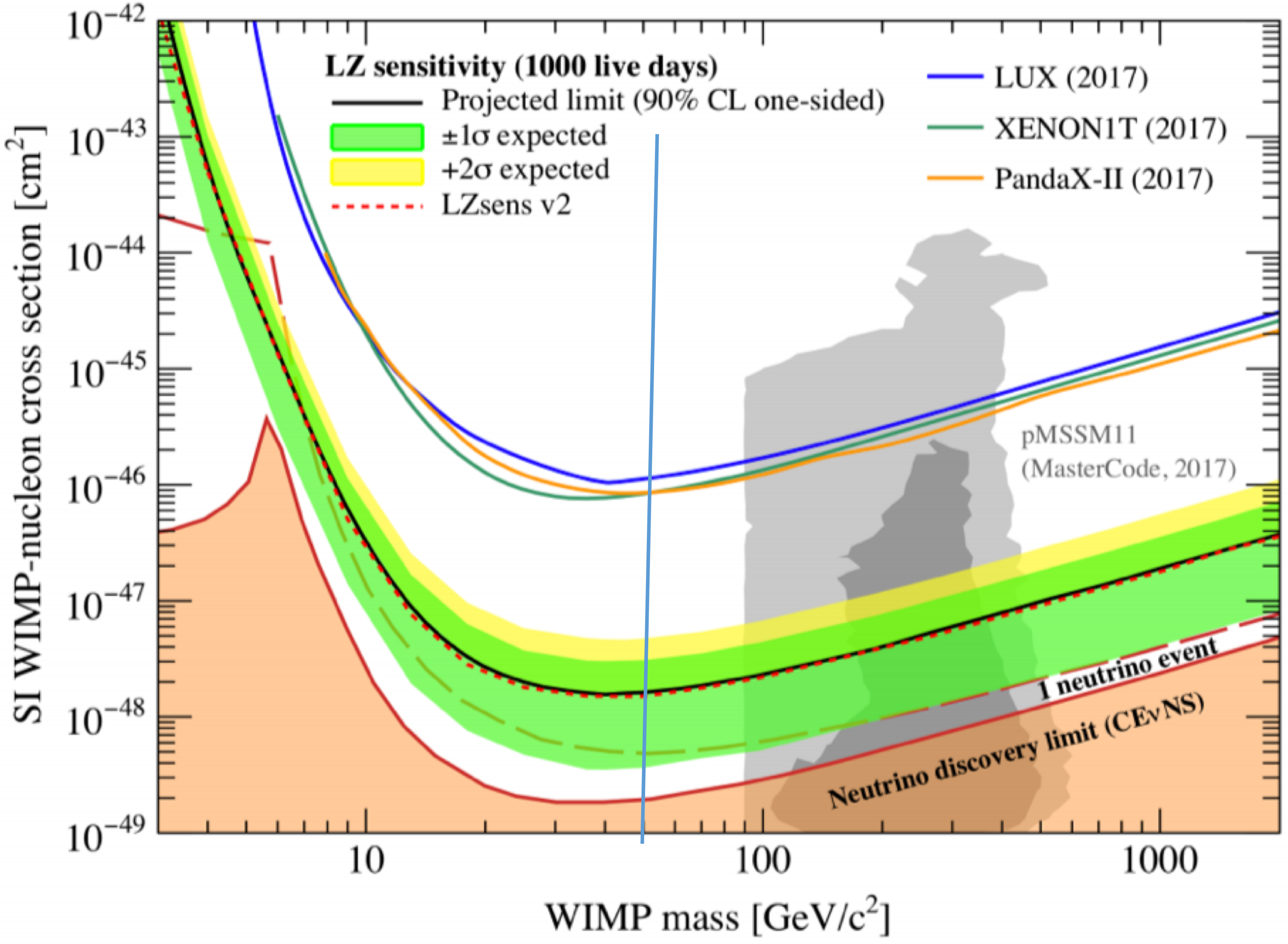
Comparison:

- In my code, in one background +signal data, varying rate_multiplier, get a number at p=0.1, 1000 limits for one mass, then, find the median of 1000 limits, and plot.
- In Shaun’s slide, varying the datasets, get the number at p=0.1, 1 limit for one mass.

Same problems as before

- Errors for 7GeV, cannot run the code since the number is too low.
- Increasing the trails to 100000, it doesn't help.
- For 7GeV, it works when I changed the confidence level from 0.9 to 0.5, and only numbers around 0.5(testing from 10 ~10000 trials) not working below or above 0.5 too much
- Understand more how the confidence level affects the result

Why 50GeV?

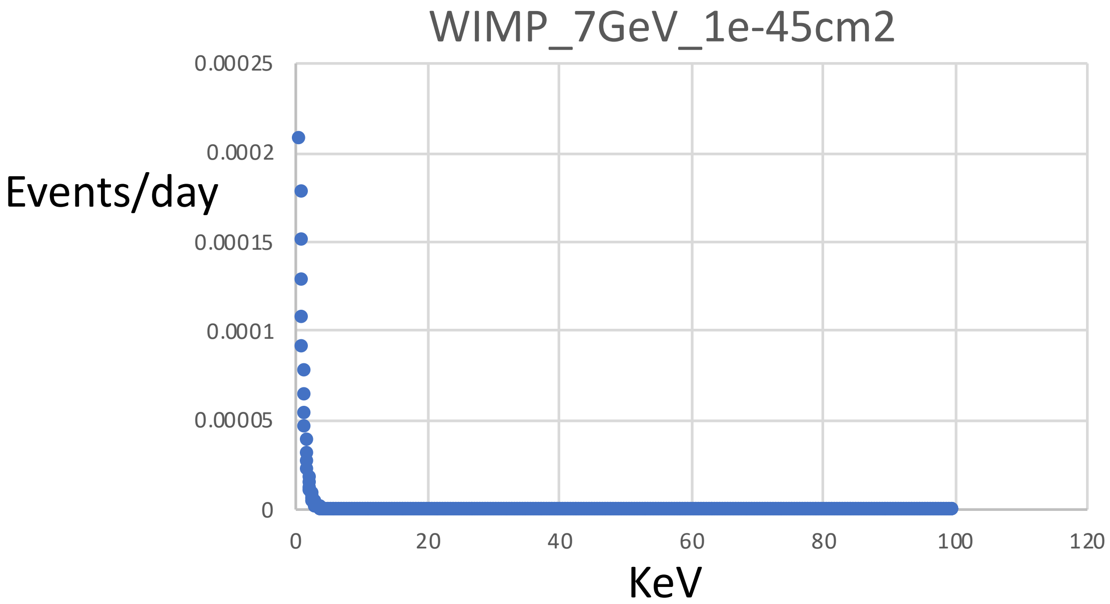


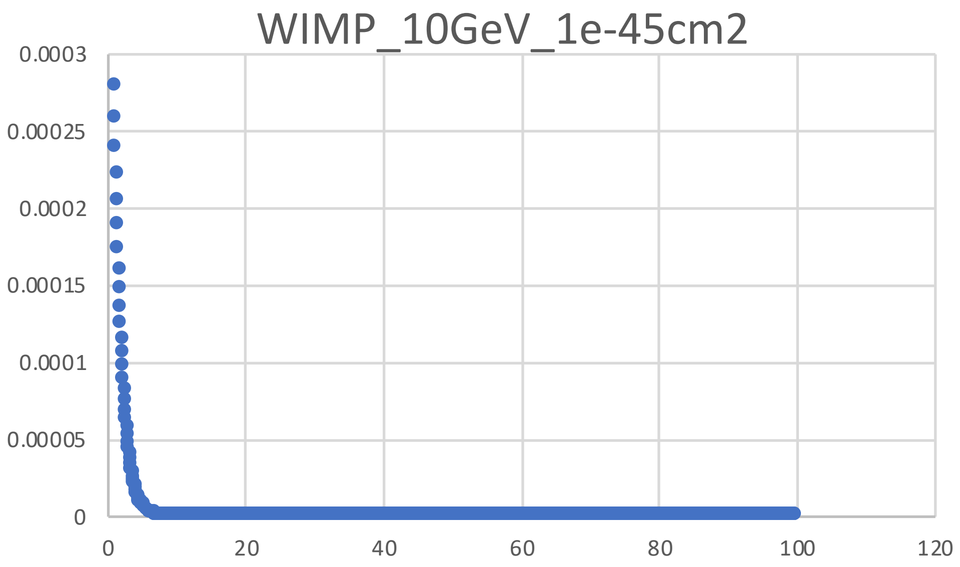
Just testing on 50 GeV? Change it to other values?

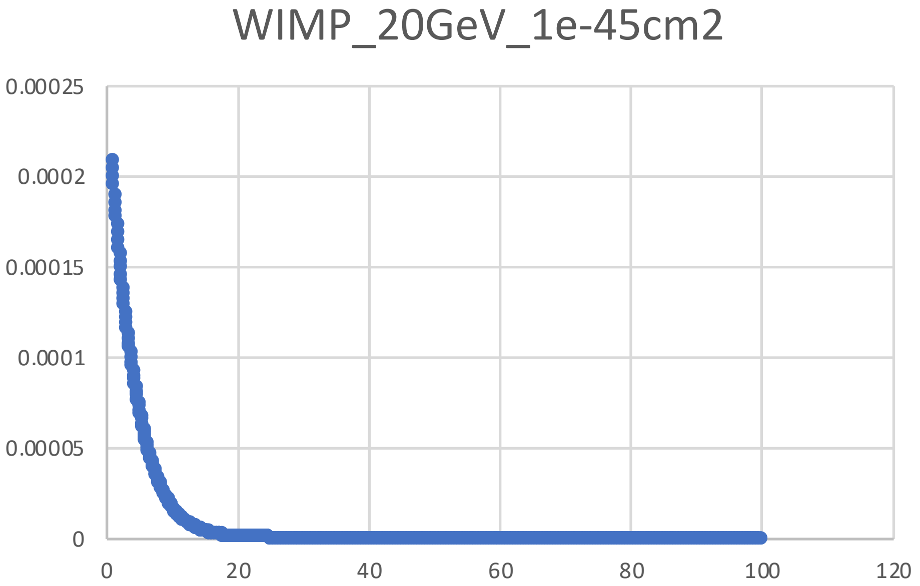
Understanding of the Code

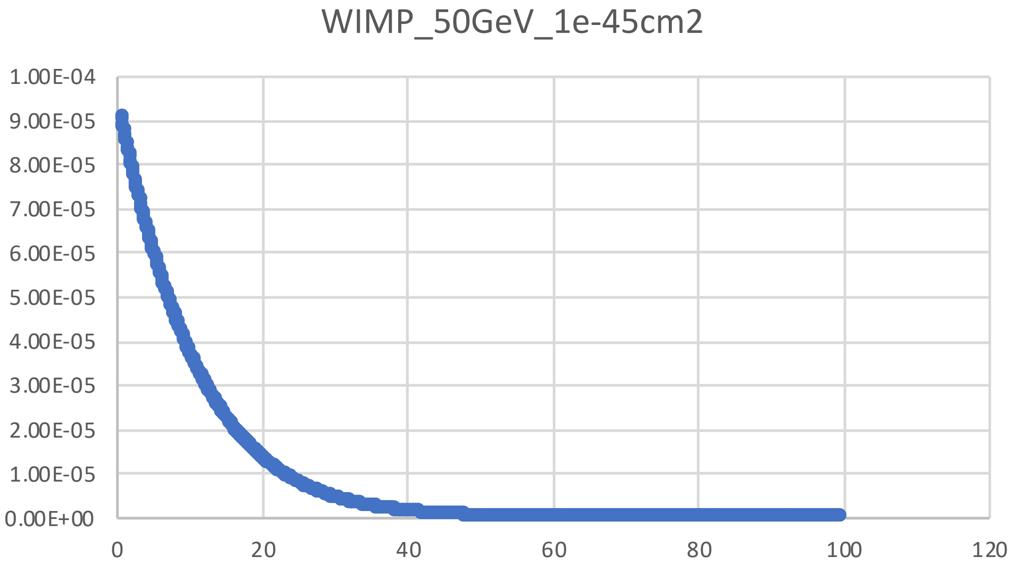
- Create the likelihood function for different WIMP masses
  - Use the configuration from base_model and remove WIMPs source
  - Add each WIMP mass with cross section = 1e-45cm2 from the list(csv files) to the configuration

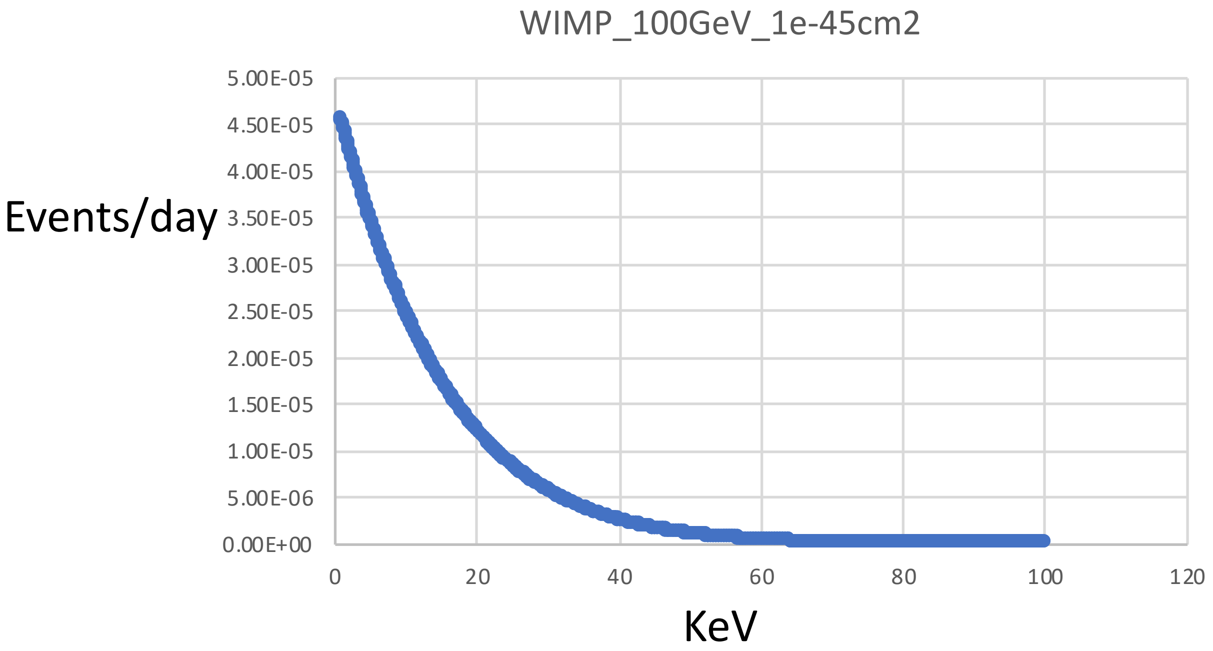
Plotted CSV files used for WIMP:

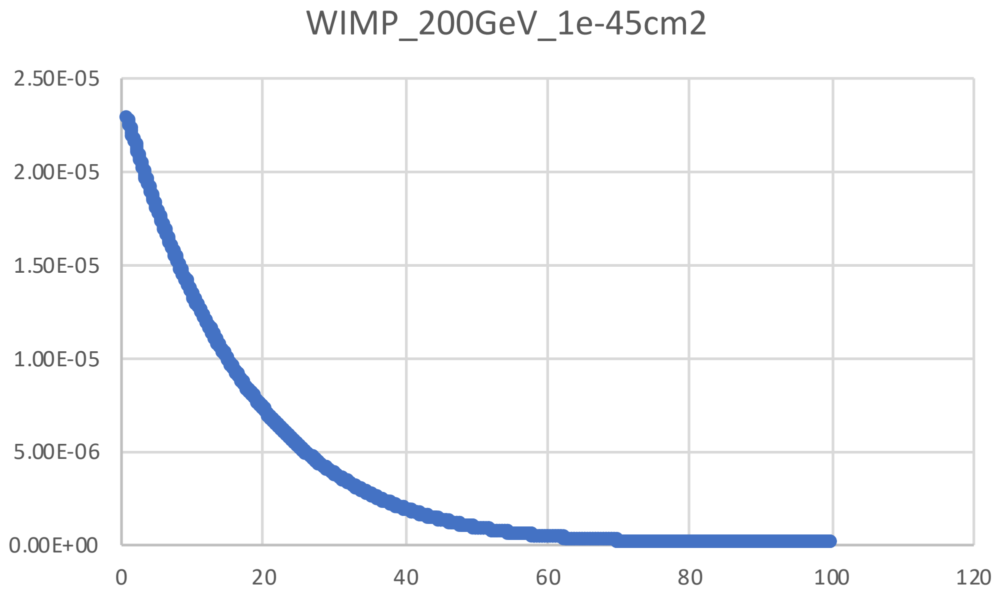


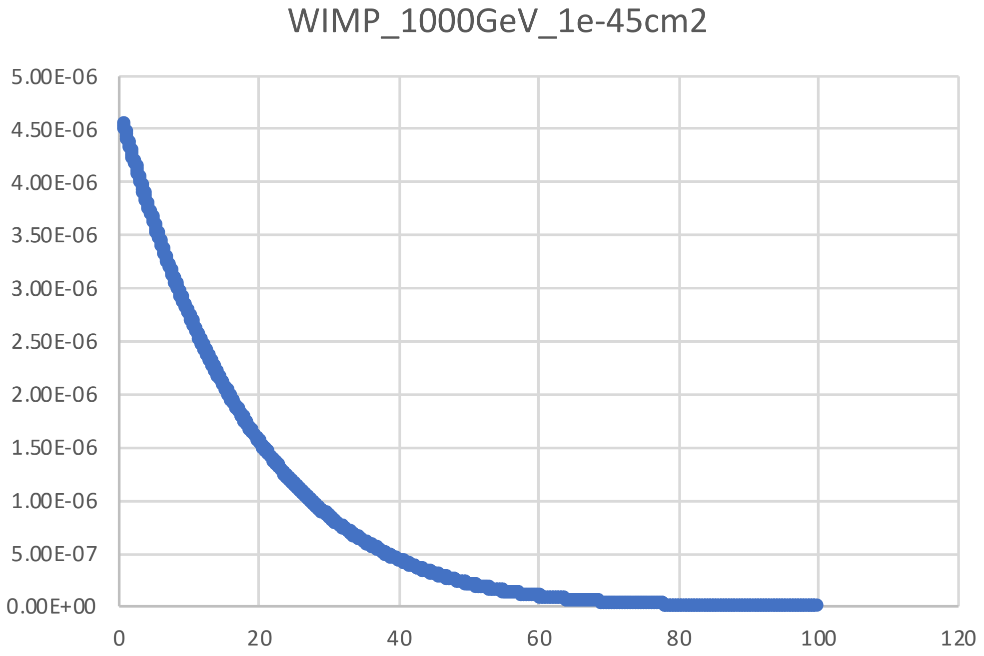







WIMP_100GeV_1e-45cm2
Events/day
5.00E-05
4.50E-05
4.00E-05
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0
20
40
60
80
100
120
KeV


WIMP_200GeV_1e-45cm2
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0
20
40
60
80
100
120


WIMP_1000GeV_1e-45cm2
5.00E-06
4.50E-06
4.00E-06
3.50E-06
3.00E-06
2.50E-06
2.00E-06
1.50E-06
1.00E-06
5.00E-07
0.00E+00
0
20
40
60
80
100
120

Rate multiplier

- rate_multipliers is a list of rate multipliers for each source in self.source_name_list
- The rate parameter to the likelihood function is a multiplier for the *total* rate of WIMPs, (not just the rate of detectable events). This was done so we can easily convert to a cross section: just multiply by the reference cross section (1e-45 cm2) for which the WIMP spectrum was generated.

- $\lambda = \frac{L(u{=}u\_test, Leff, \theta)}{L(u{\neq}u\_test\ Leff, \theta)}$ $\longrightarrow$ B+S; $\longrightarrow$ Only B

- Floating u_test and nuisance parameters to maximize the ratio

Background

LZ

ER background

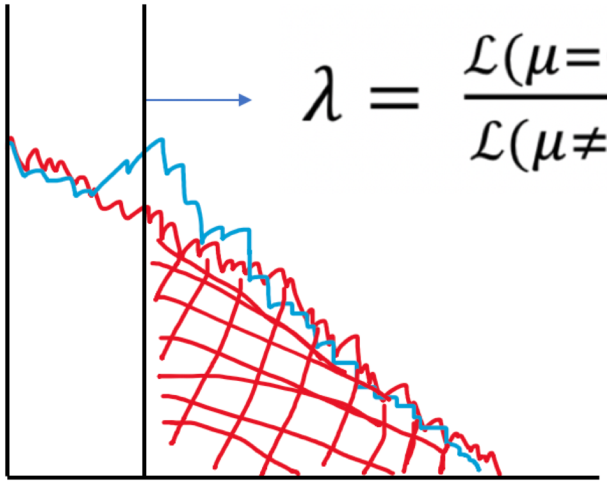
Background	σ/N
^{222}Rn (ER)	10%
pp+^{7}Be+^{14}N ν (ER)	2%
^{220}Rn (ER)	10%
^{136}Xe $2\nu\beta\beta$ (ER)	50%
Det. + Env. (ER)	20%
^{85}Kr (ER)	20%

NR background

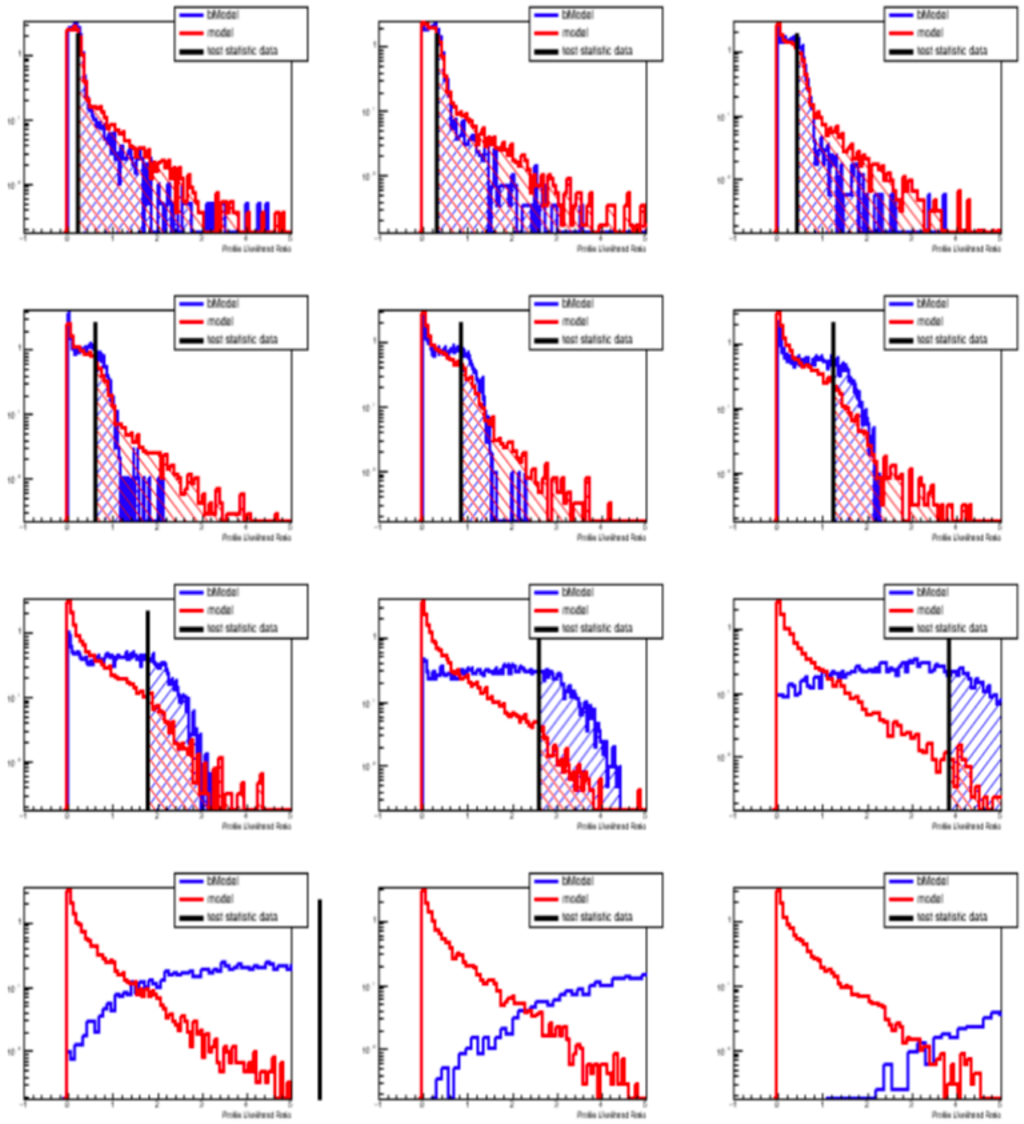
Background	σ/N
^{8}B solar ν (NR)	15%
Det. + Env. (NR)	20%
Atmospheric ν (NR)	25%
hep ν (NR)	15%
DSN ν (NR)	50%

Xe1T

using the likelihood function of 50 GeV and multiply by the rate of 50 GeV



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



Varying POI (cross section in this case?)

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_r
outine, t_ppf, **kwargs)
    376             return brentq(t, bound, global_best, args=[1 - confidence_level])
    377         elif kind == 'upper':
--> 378             return brentq(t, global_best, bound, args=[confidence_level])
    379
    380

/anaconda3/lib/python3.7/site-packages/scipy/optimize/zeros.py in brentq(f, a, b, args, xtol, rtol, maxiter, full_out
put, disp)
    508         if rtol < _rtol:
    509             raise ValueError("rtol too small (%g < %g)" % (rtol, _rtol))
--> 510         r = _zeros._brentq(f,a,b,xtol,rtol,maxiter,args,full_output,disp)
    511         return results_c(full_output, r)
    512

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

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 numbers