LZStats

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Error (limit setting)

```
EvalPLR: POI_test = 30, POI_hat = -4.71328, uncond_ML = -50.3983, cond_ML = -16.
9961, TS = 66.8045, time (create/fit1/2) 0, 2.54, 0.79, status (U/C) 0, 0
[#0] ERROR:Generation -- a_beta::RooRealVar:randomize: fails with unbounded fit
range
----> Trying with Migradimproved
----> Trying with Scan
```

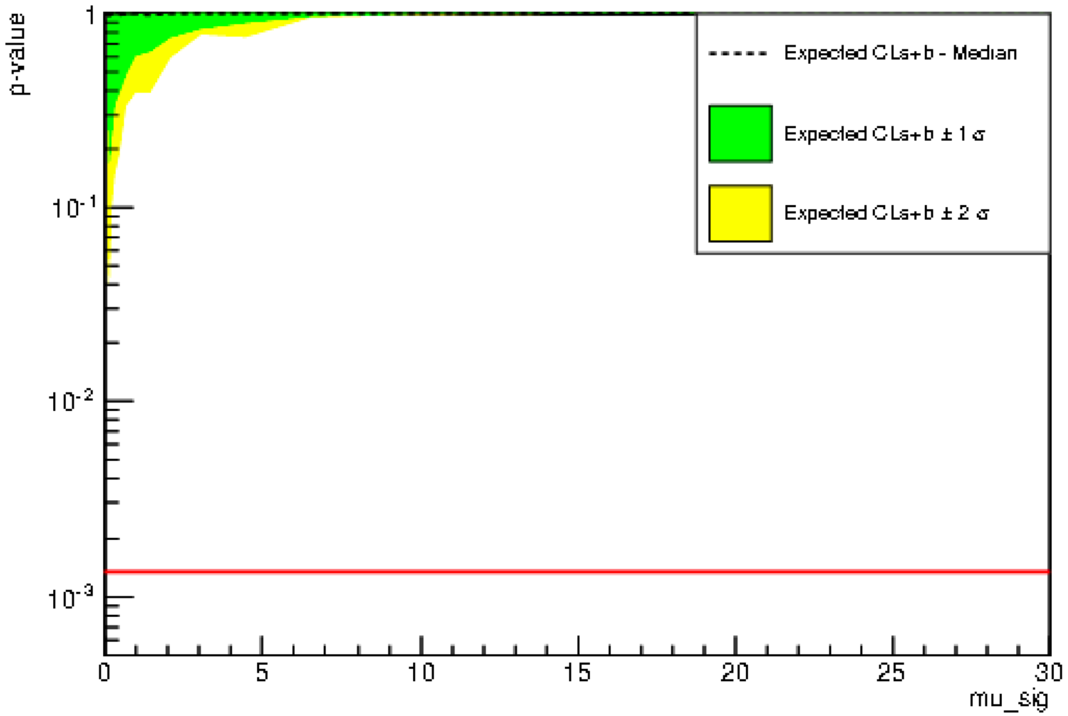
Each toy run has this error, 3 GeV and 40 GeV

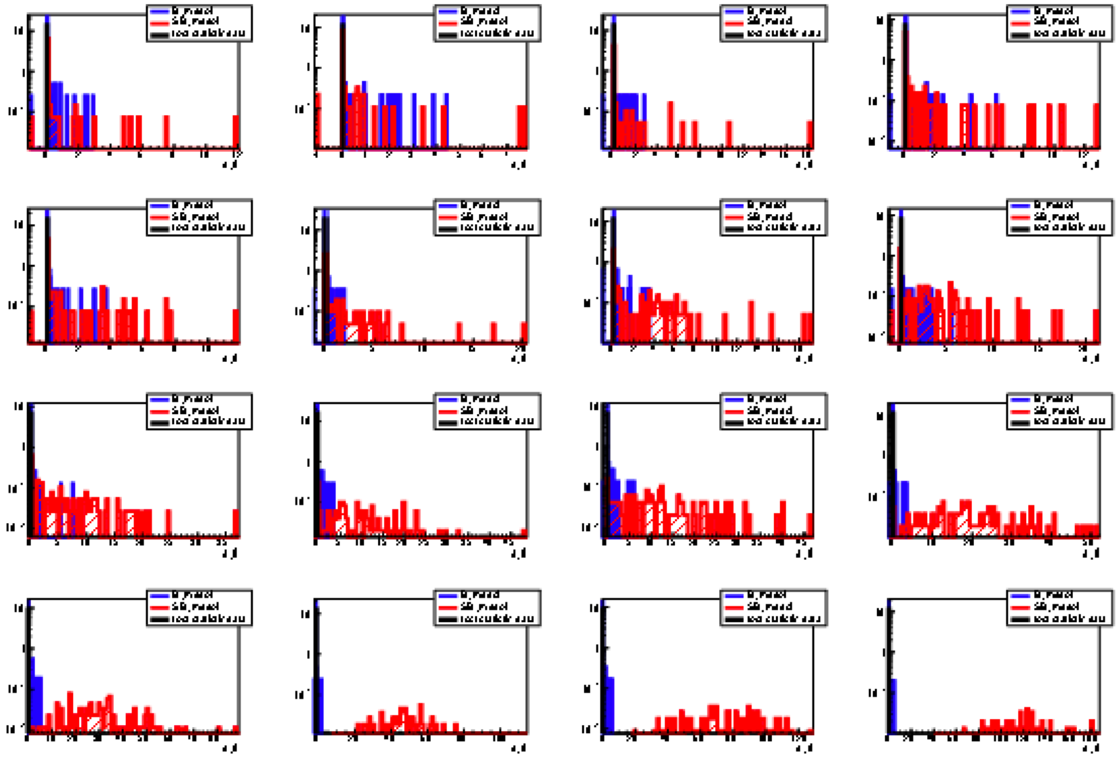
mu_sig = (-100, 100), negative bound setting

46 GeV w, mu_sig (0,100) → No more this error

Error (Discover)

H0: only background, mu_signal = 0
H1: both background and signal

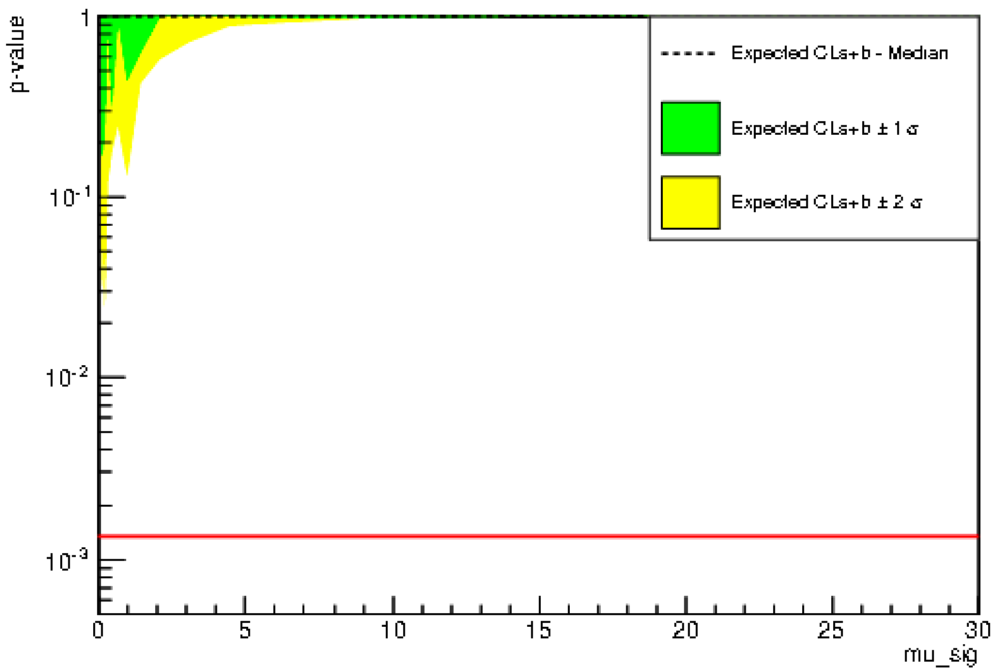




40 GeV, mu_sig: (-100, 100)

Error: generation

New Error (Discovery)



46 GeV, mu_sig (0, 100)

Fraction: 1839 errors out of 3200 total toy run

```
-> test statistic is negative (fit failed) - setting it to -1
EvalPLR: POI_test = 0, POI_hat = 8.32396e-06, uncond_ML = -2.8915, cond_ML = -2.
89173, TS = -1, time (create/fit1/2) 0, 0.3, 0.17, status (U/C) 0, 0
-> test statistic is negative (fit failed) - setting it to -1
```

To do

- Dig into the cause of errors:
  - Start with 3 GeV, change the mu_sig to (0, 100), limiting mu_sig to positive value.

Update+To do

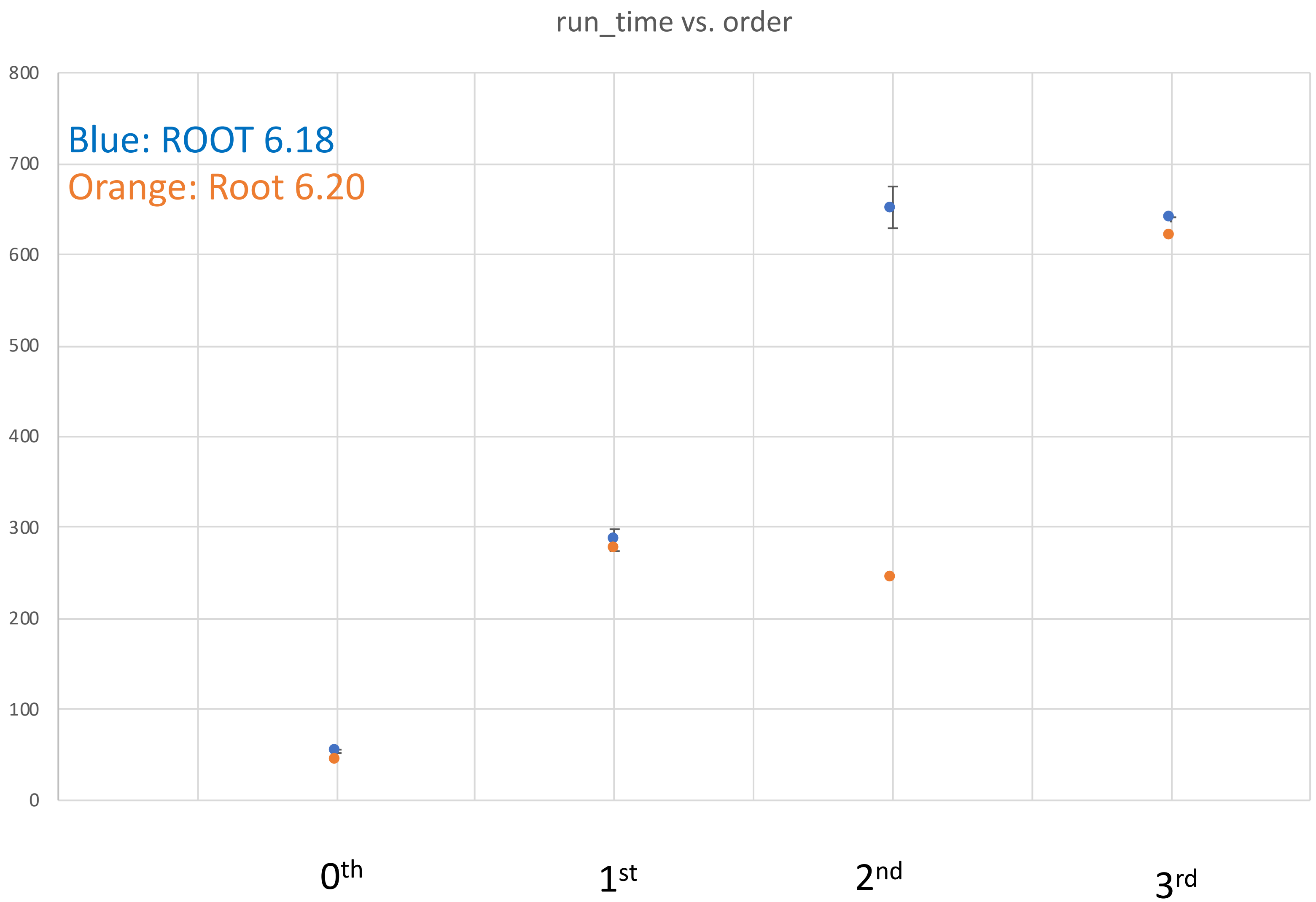
- Fitting errors at the low mass (3GeV) for the new workspace→ write a code to count the total errors →figure out what causes the error
- Also errors for the 40 GeV.
  - Screen, can only see the parts starting from POI=12.5, no errors after that
  - Run 40 GeV again, errors at lower POI
- Have problem with the master branch on LZStats

New update

- PdfMaker: add YAML configuration to WIMP & Background PDF
  - Do not need to change parameters in LZNESTUtils and source setup & build everytime changes a parameter
  - Tested n_sample parameter in YAML config, it works as expected!
- LZStats:
  - When source setup.sh, it changes ROOT to version 6.16
  - Works on Jonathan’s git branch (jn_ROOT6.20.00) to test how ROOT 6.20 affect the run time of different interpolation order

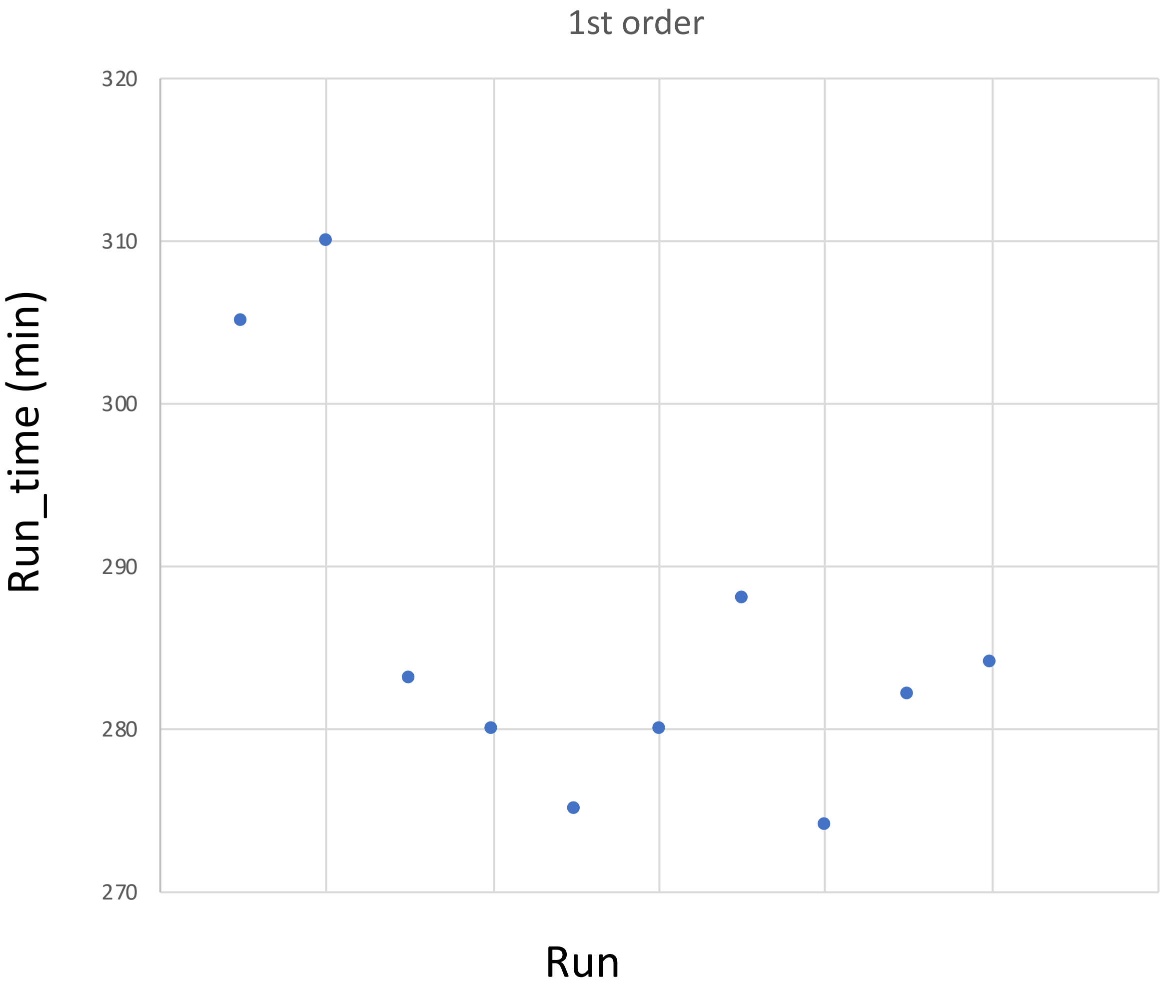
ROOT 6.18 & 6.20

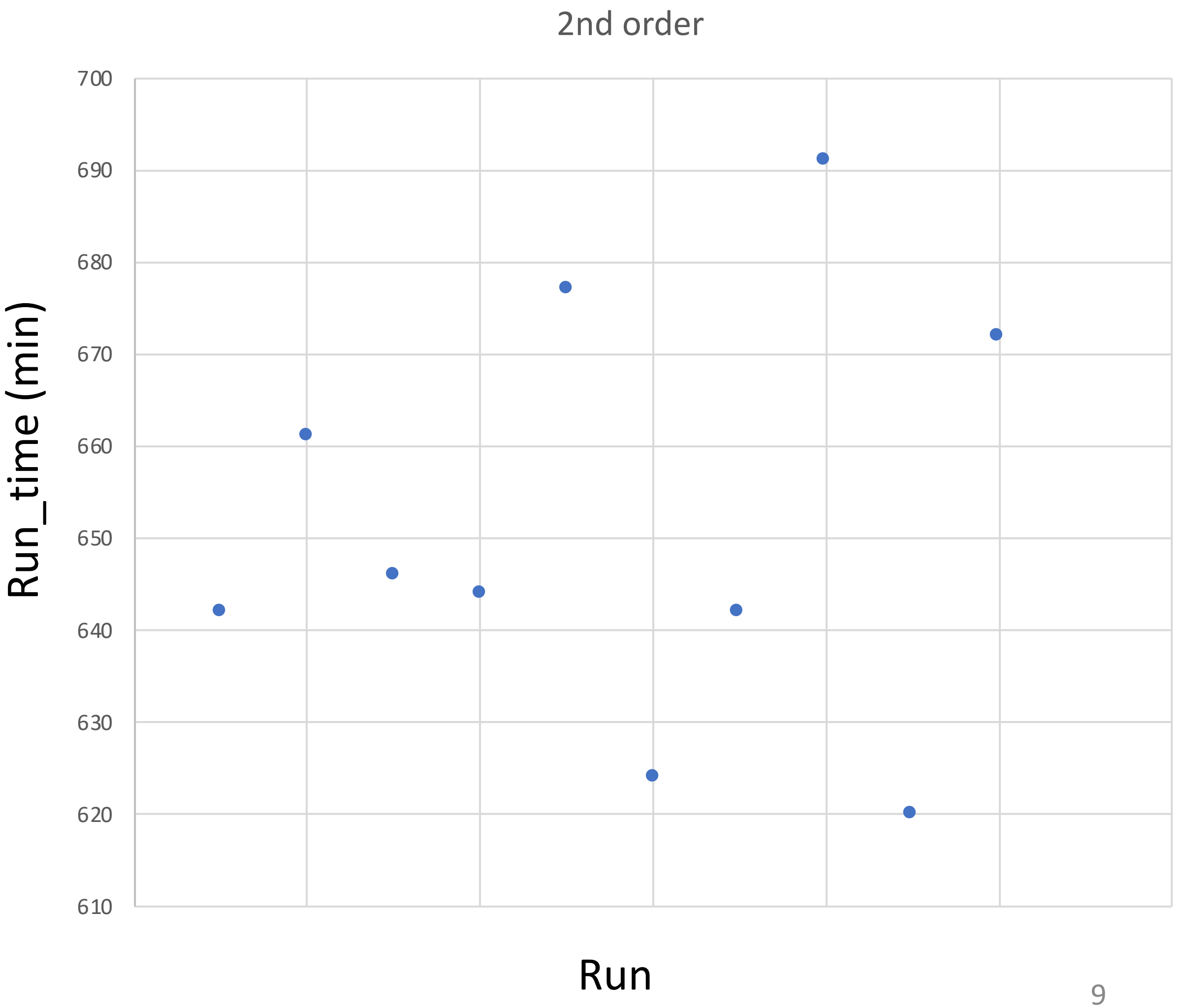
	0th	1st	2nd	3rd
run_time(min)	53.9 (10 runs)	286.1 (10 runs)	651.9 (10 runs)	641
STD	1.9	12.1	22.9	
run_time(min)	44	278.5 (2 runs)	245?	621



1^{st} & 2^{nd} orders

Submit 10 runs at the same time, some runs are not using 100% CPU at the beginning -> higher run time for these specific runs-> higher STD

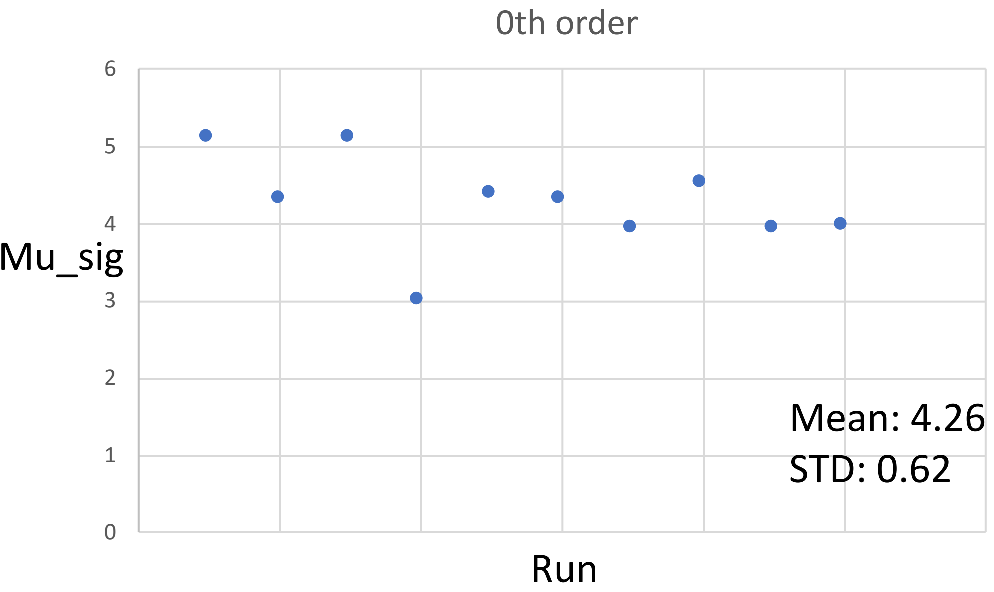


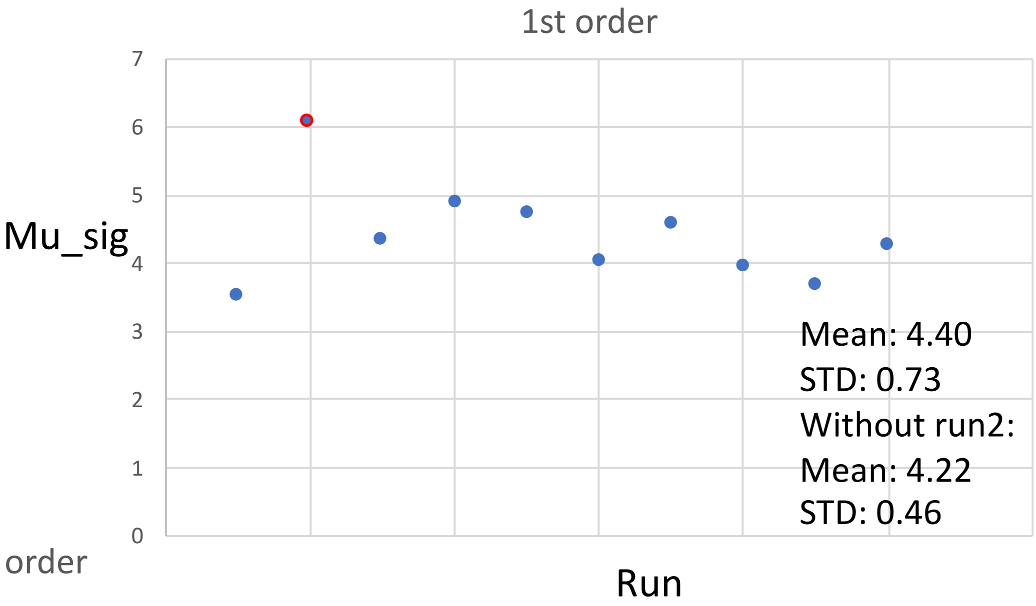


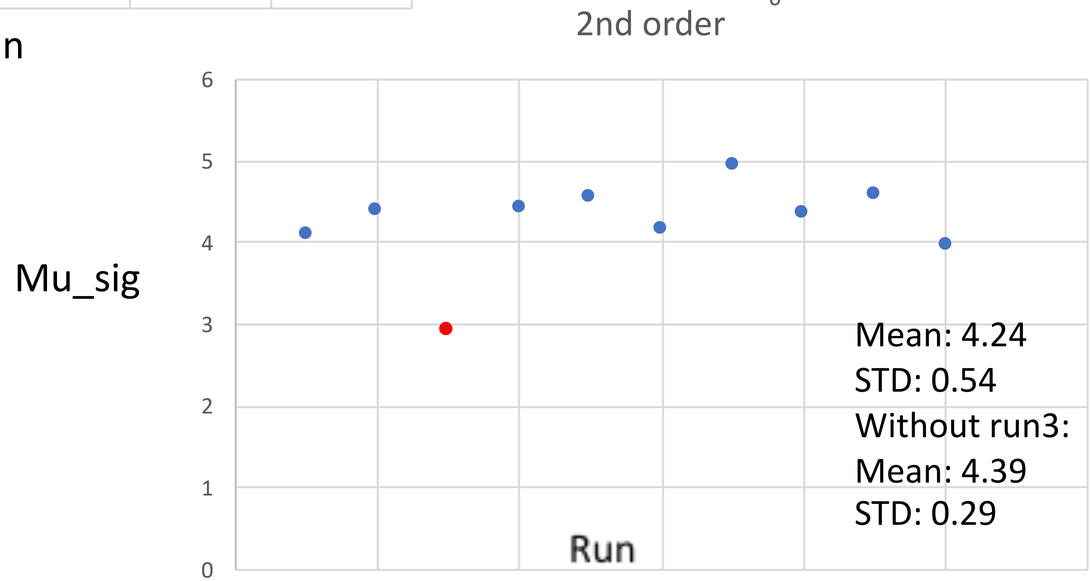
Previous Slides

Interpolation

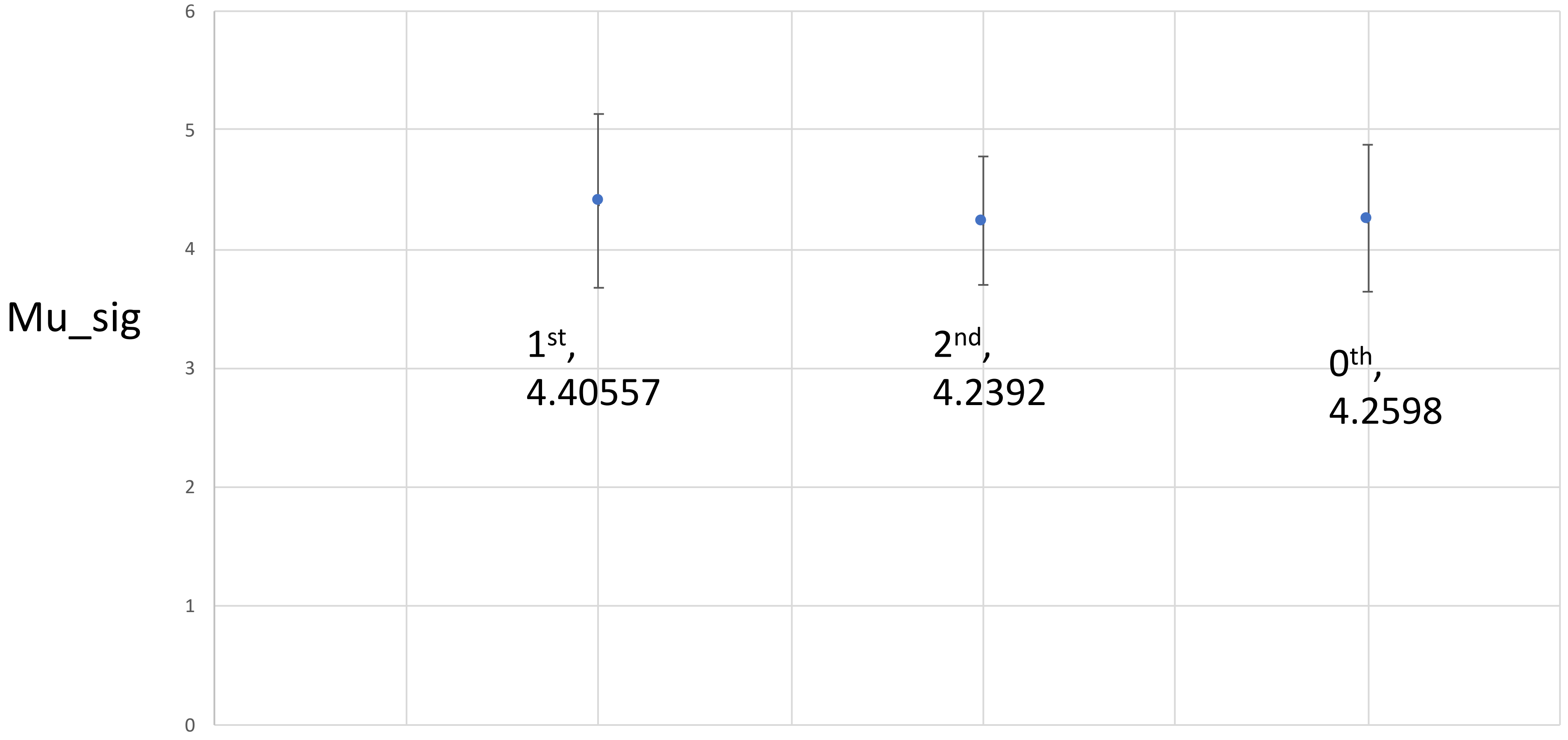
WIMP mass: 10GeV
N_sample: 10 ^6







mu_sig vs. order



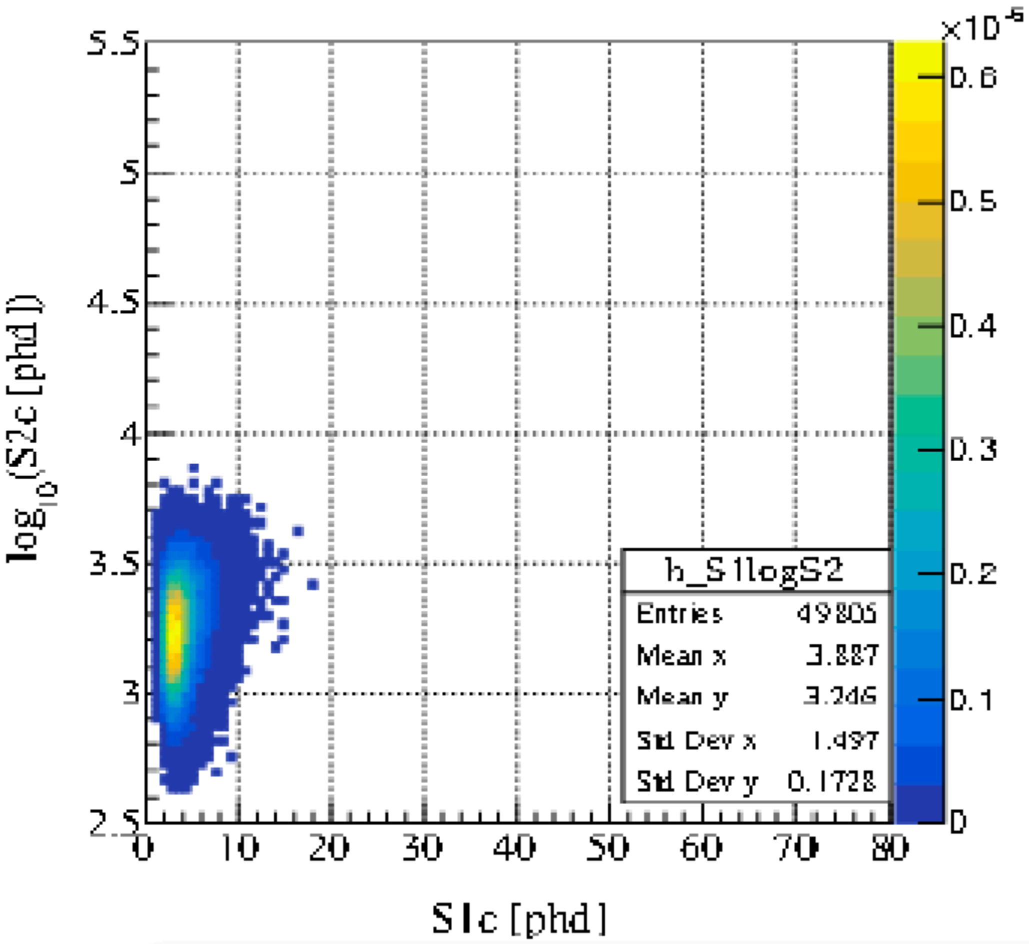
What’s new?

- New update
- Try different interpolation order 0~3
- Organize the output

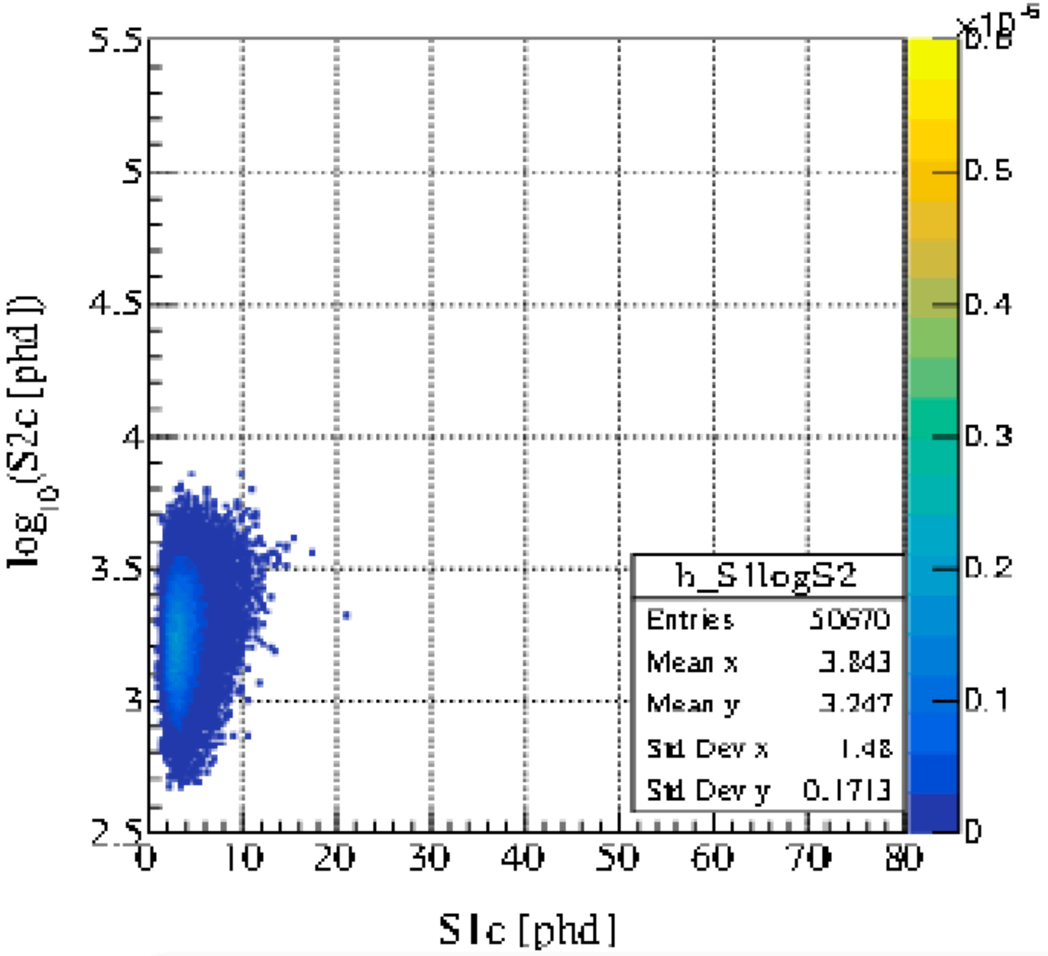
New update (Detector)

Parameter	Before	After
g1	0.118735	0.150
g1_gas	0.1018	0.1186
eLife_us	850	944.56
r_max_fiducial	688 cm	688 mm
z_max_fiducial	1330 cm	1330 mm

WIMP signal PDF



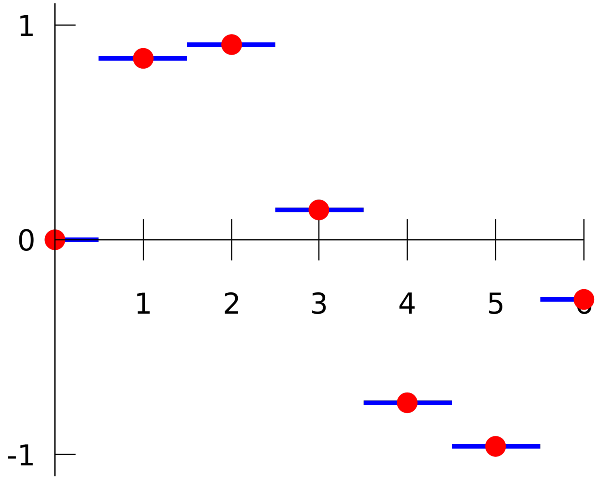
Before



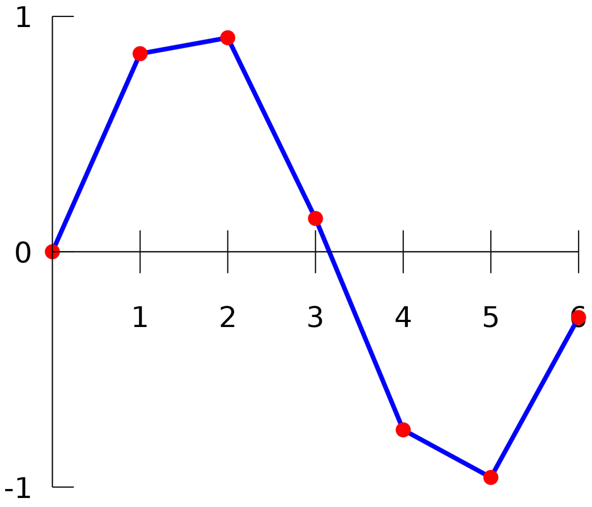
After

Interpolation Method

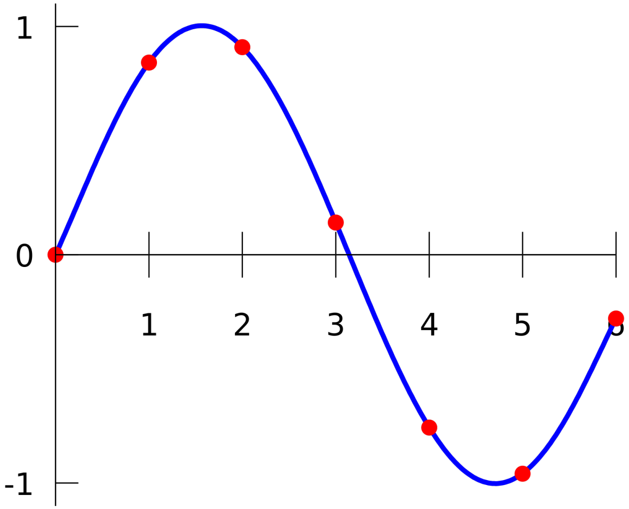
- Construct new data points within the range of know data points (discrete set)→ bring up the bins surrounded by 0 events
- Change interpolation order 0~3(in the code to create workspace)



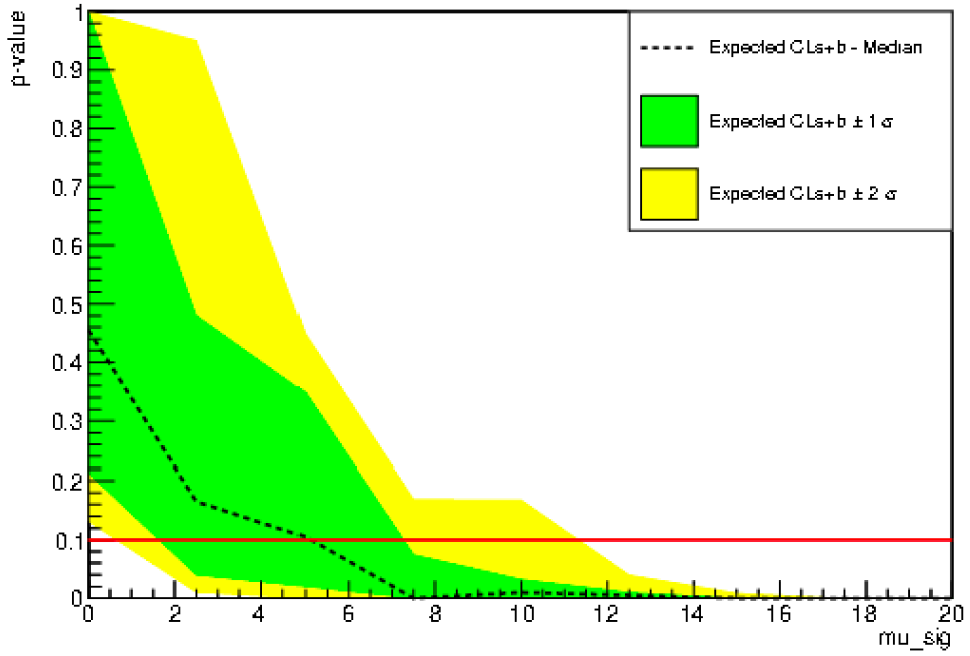
0th



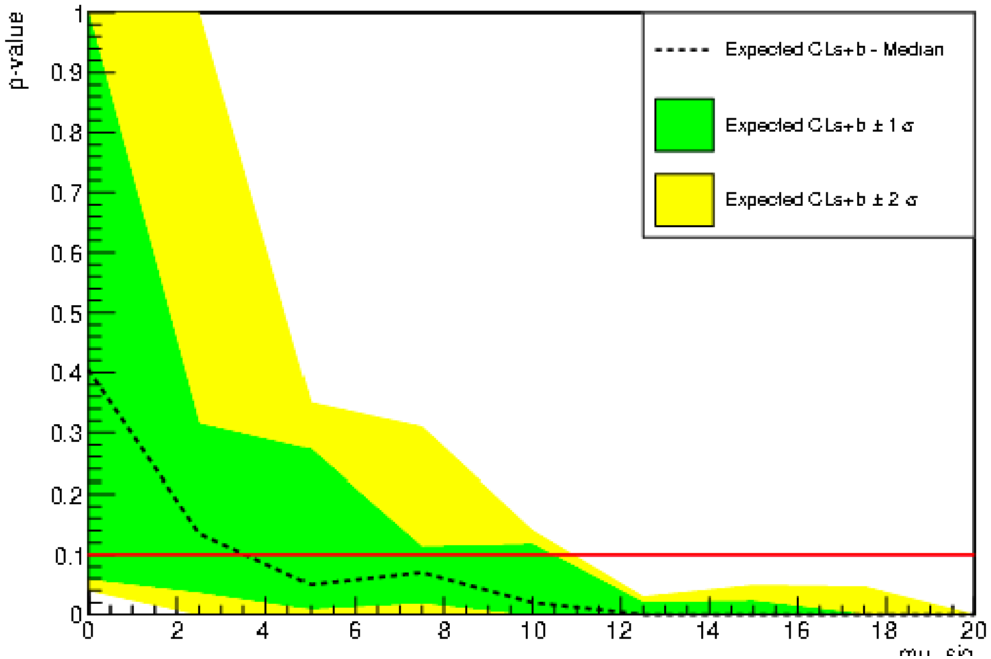
1st



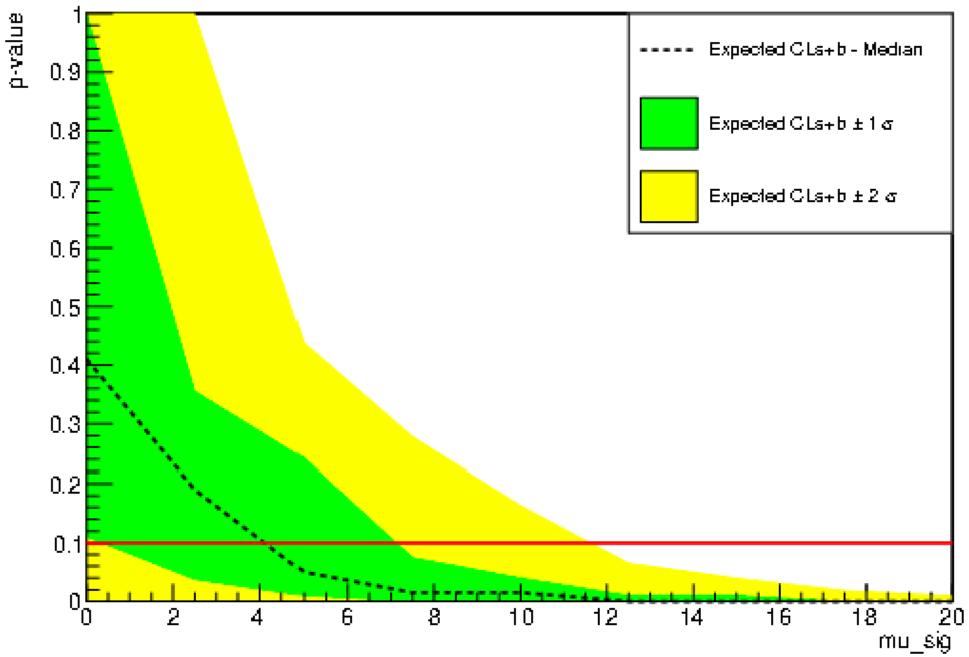
2nd?



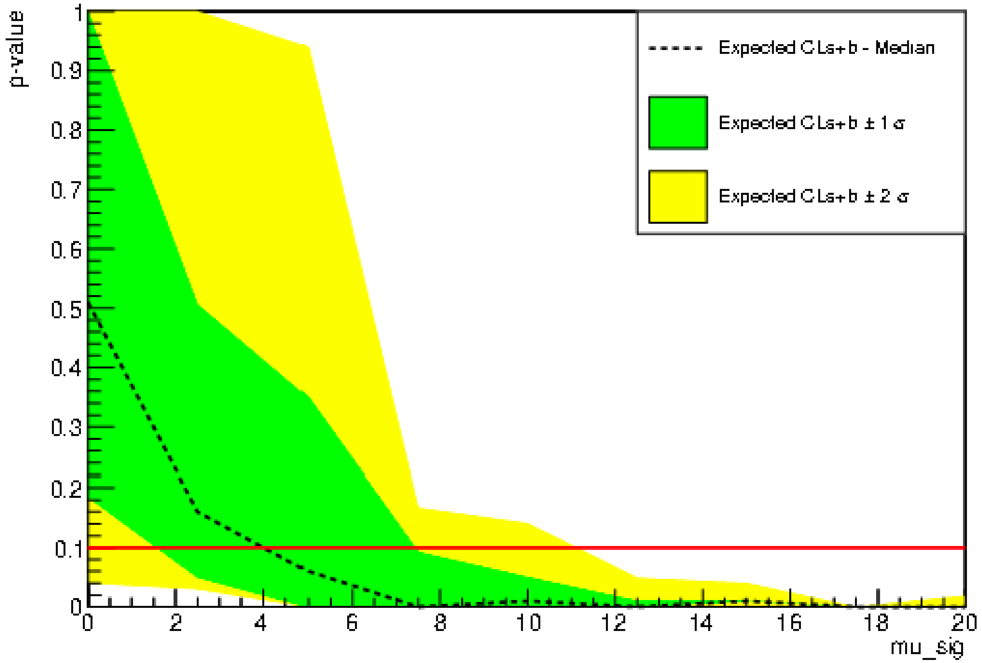
0^{th} order
~1 h



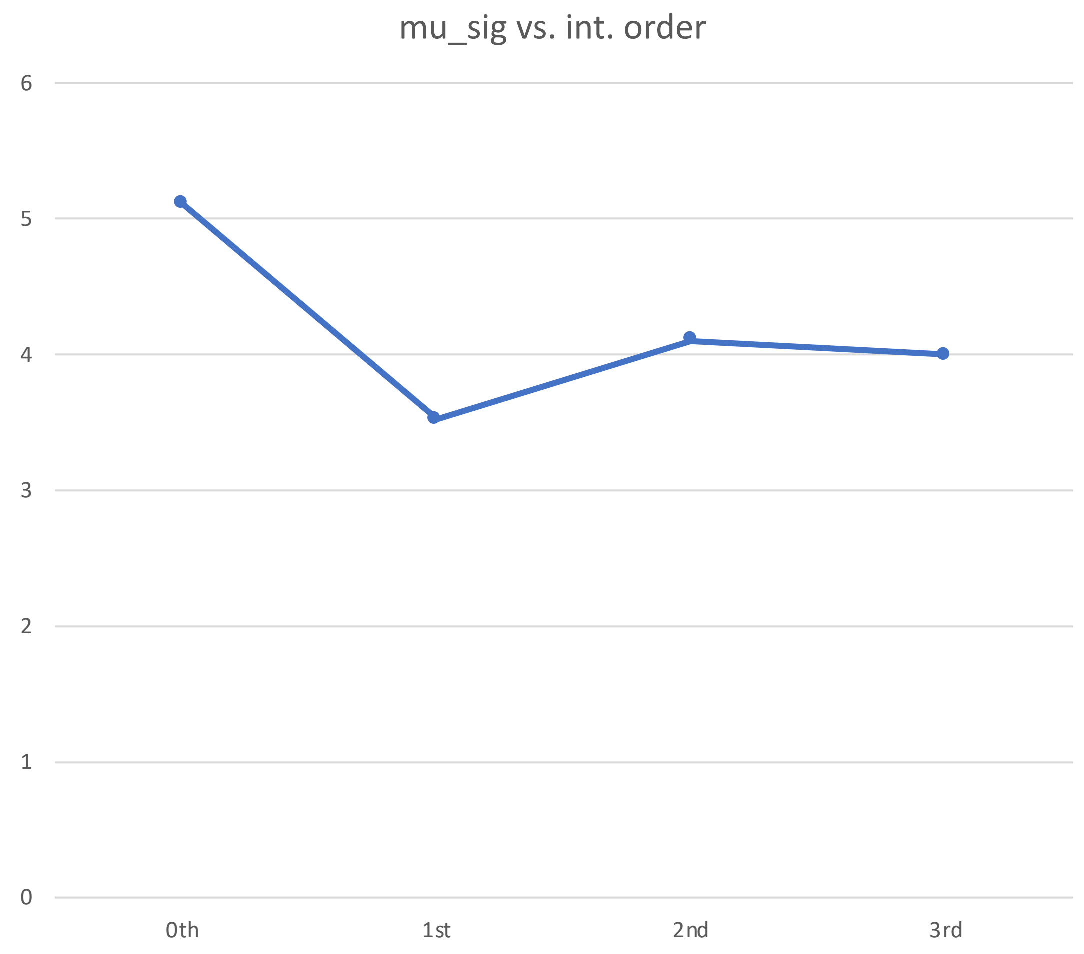
1^{st} order
~5 h

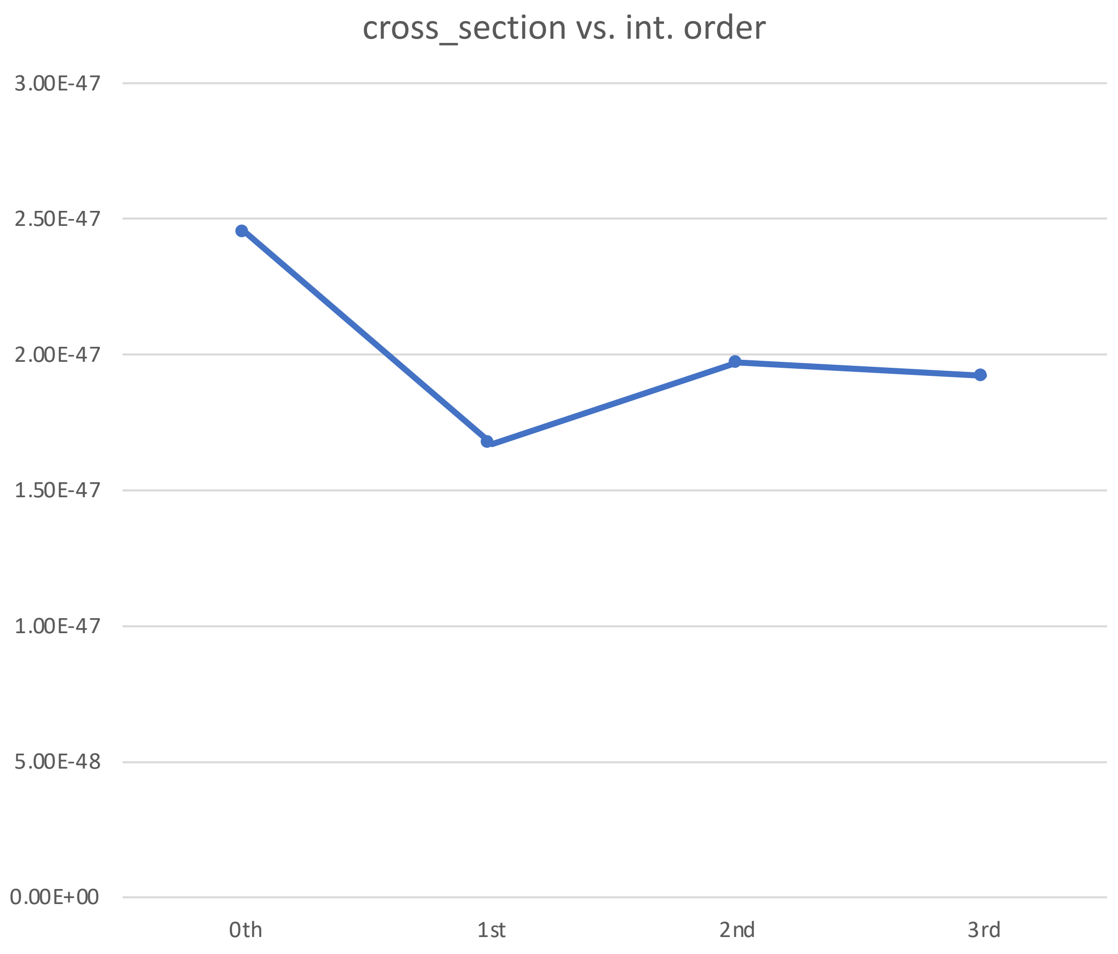


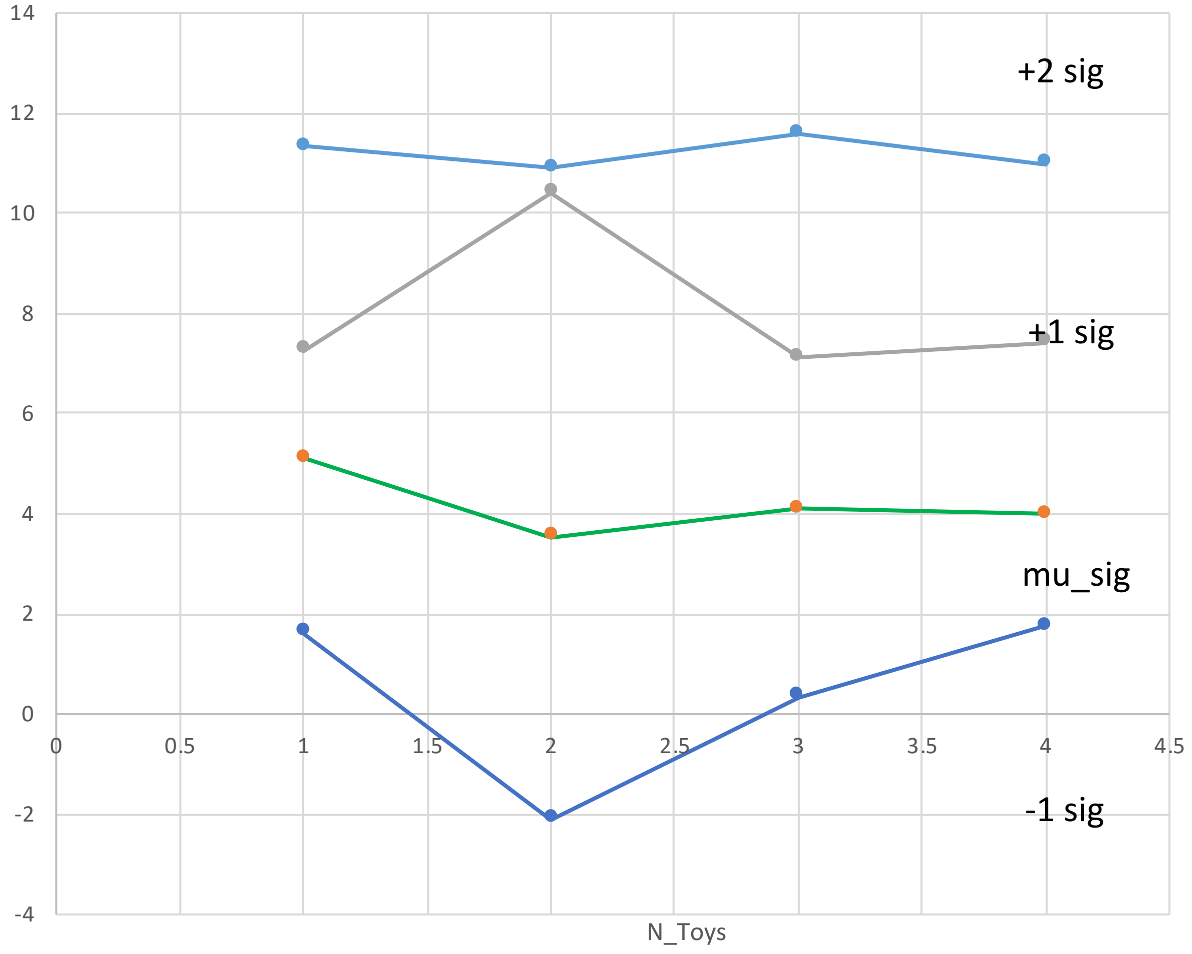
2^{nd} order
~8 h



3^{rd} order
~10.5h


mu_sig vs. int. order
6
5
4
3
2
1
0
0th
1st
2nd
3rd


cross_section vs. int. order
3.00E-47
2.50E-47
2.00E-47
1.50E-47
1.00E-47
5.00E-48
0.00E+00
0th
1st
2nd
3rd

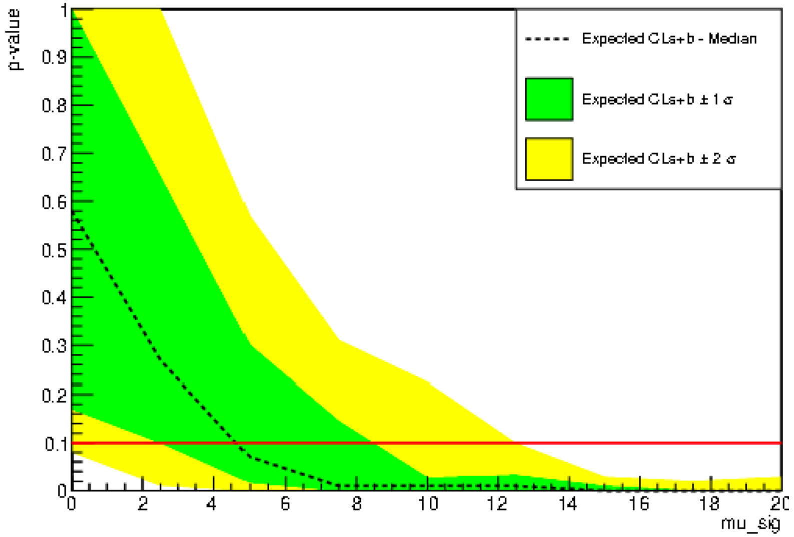

14
12
10
8
6
4
2
0
-2
-4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
N_Toys
+2 sig
+1 sig
mu_sig
-1 sig


-2 sig vs. order
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0th
1st
2nd
3rd

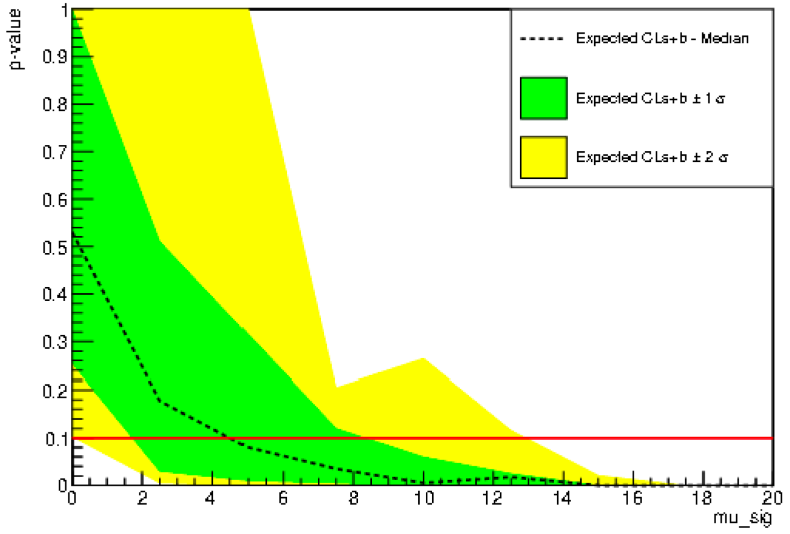
What’s new?

- Try different # of Toys.
- Plot mu_sig, -1 sig, +1 sig, -2 sig, +2sig, cross section vs. NToys

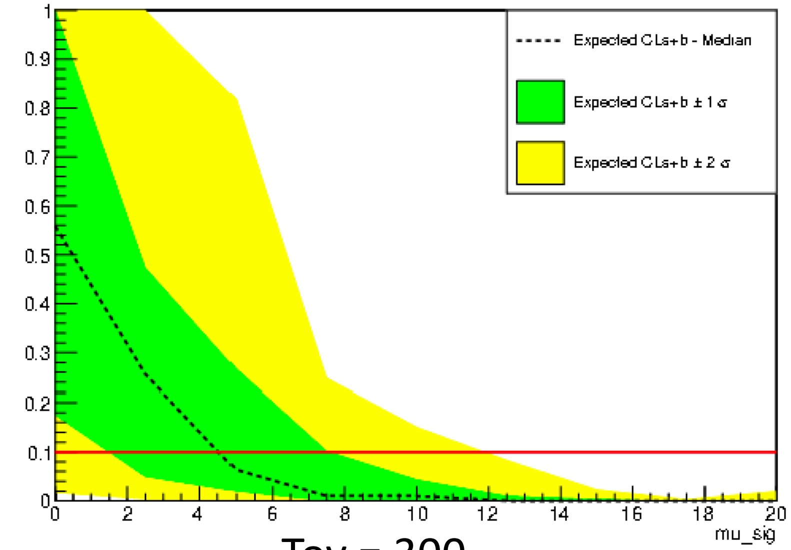
g1 = 0.118, 10^7 sample size



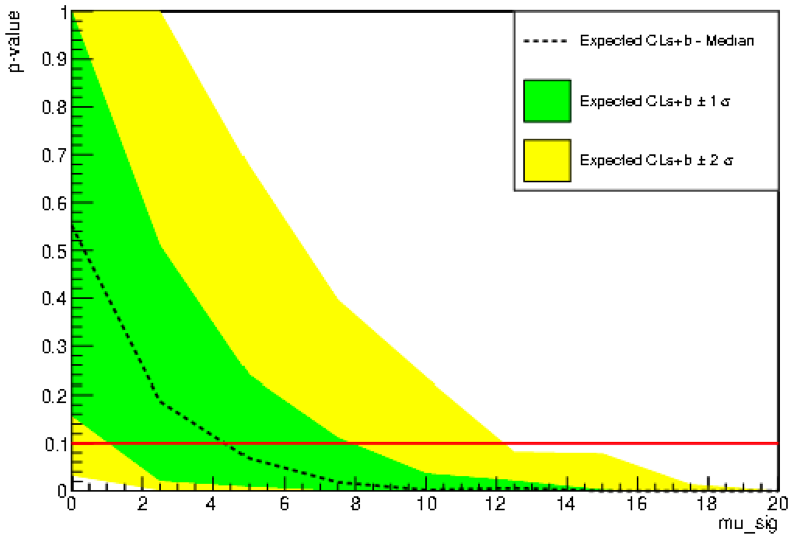
Toy = 100



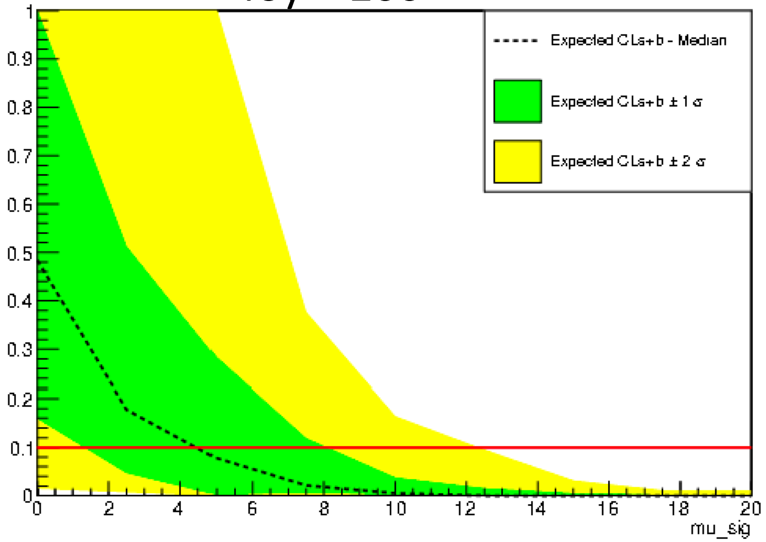
Toy = 200



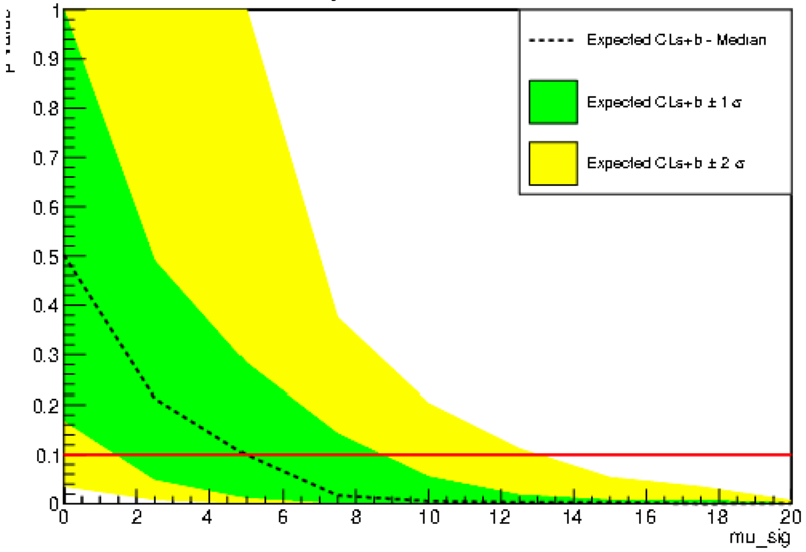
Toy = 300



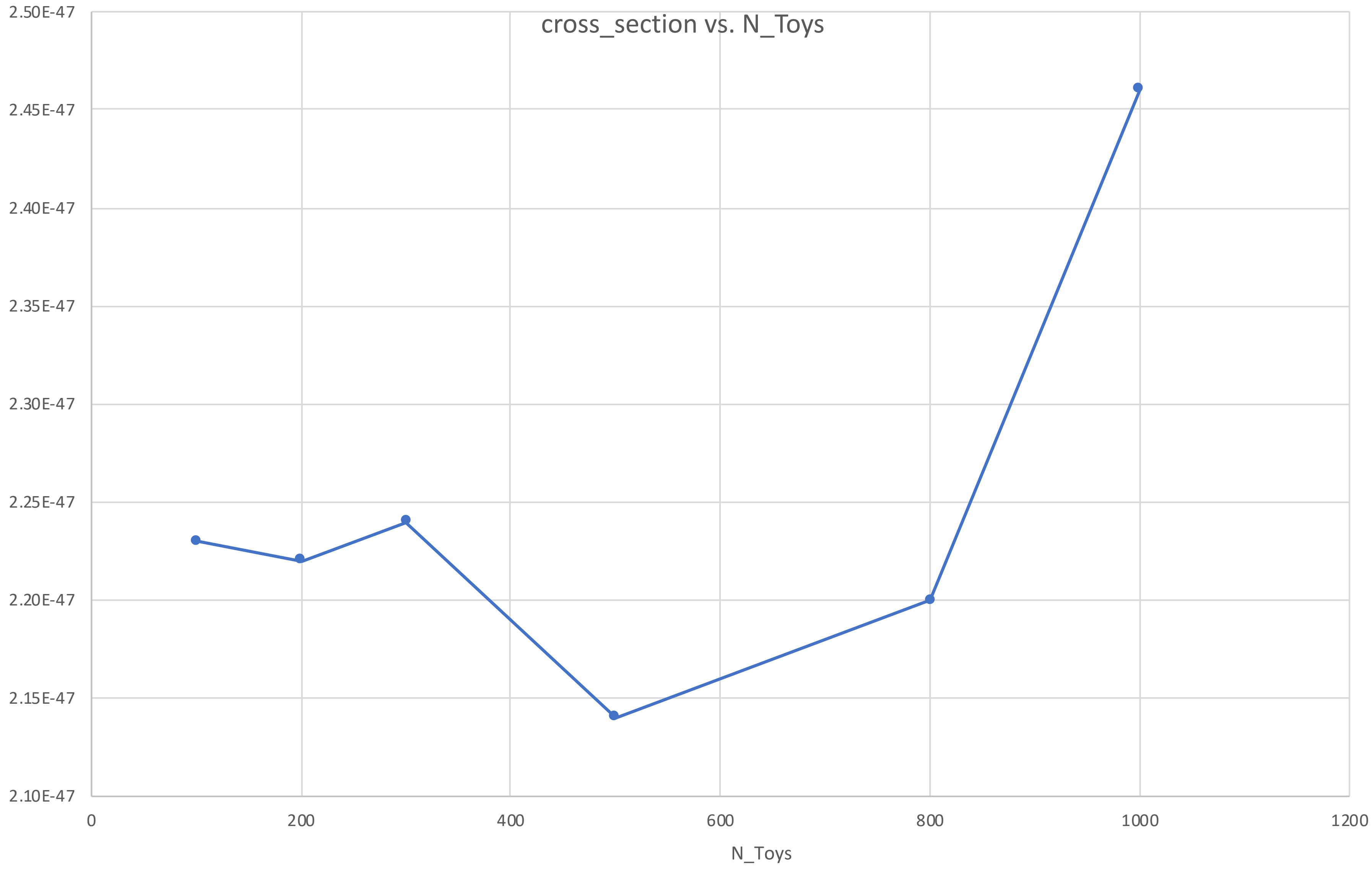
Toy = 500

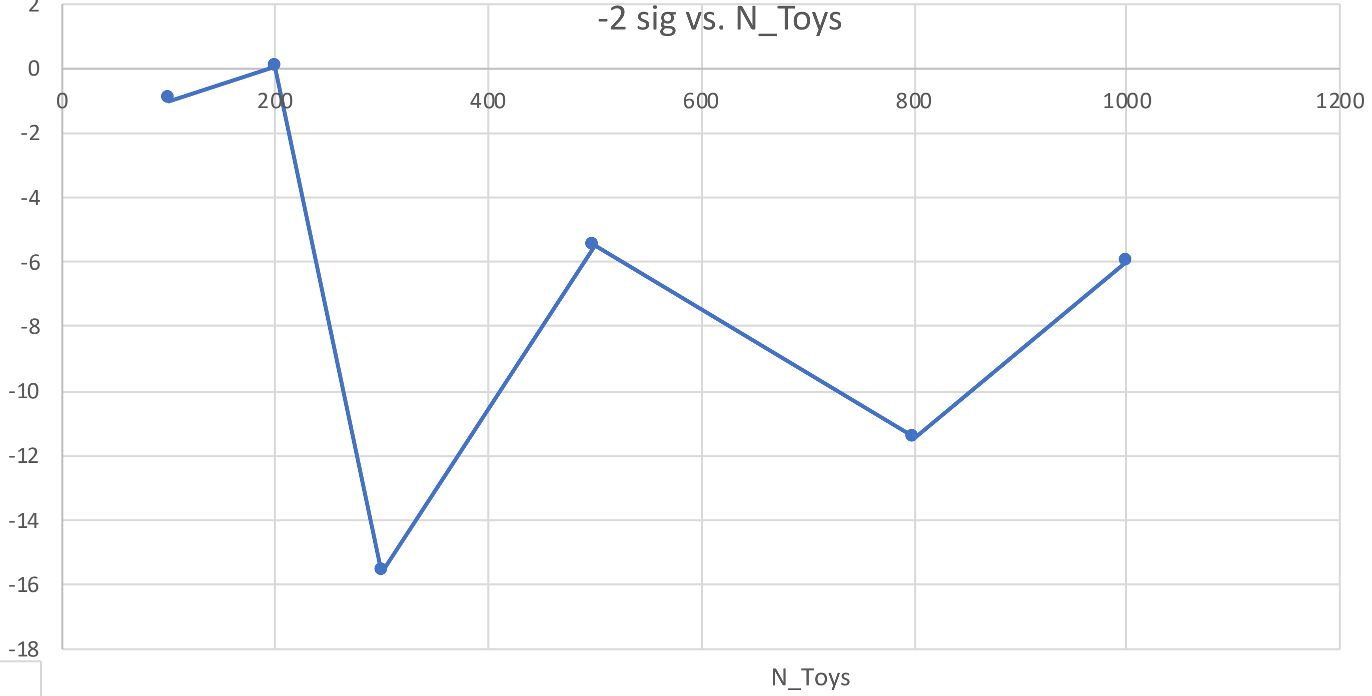


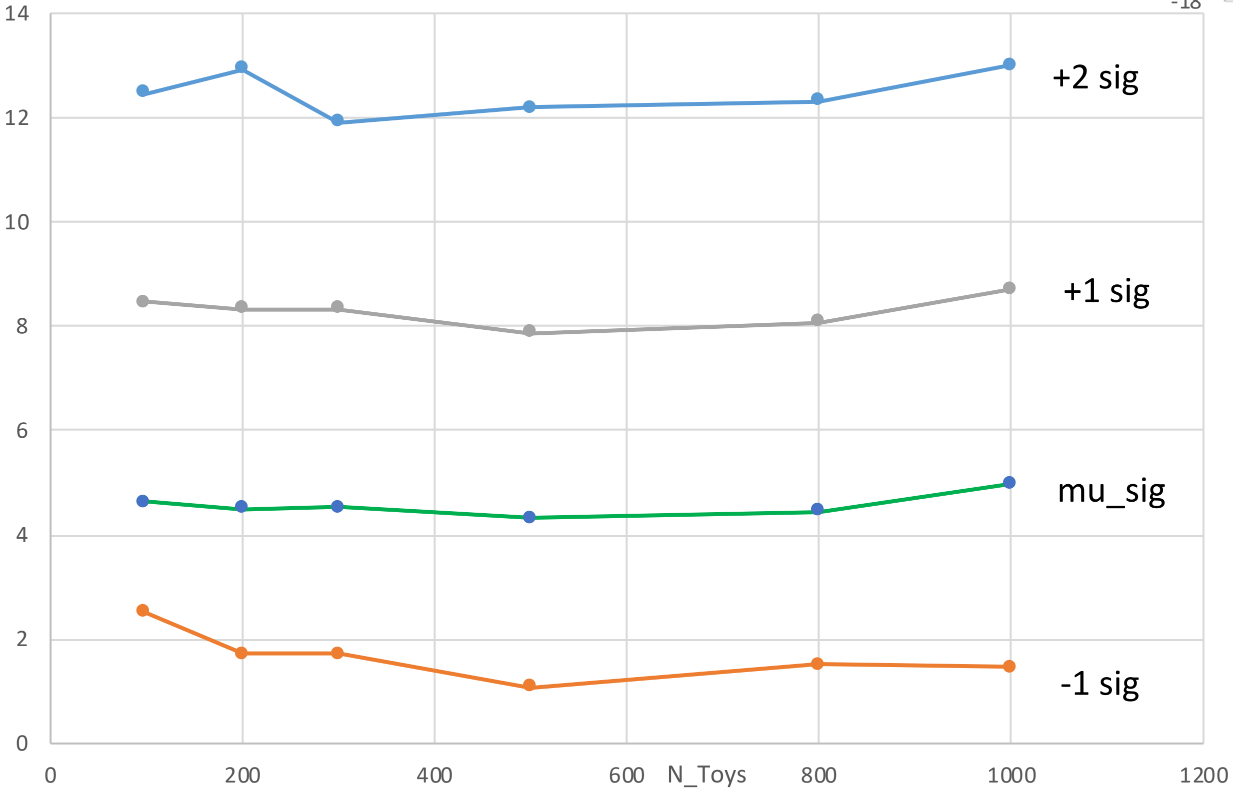
Toy = 800



Toy = 1000


cross_section vs. N_Toys
2.50E-47
2.45E-47
2.40E-47
2.35E-47
2.30E-47
2.25E-47
2.20E-47
2.15E-47
2.10E-47
0
200
400
600
800
1000
1200
N_Toys

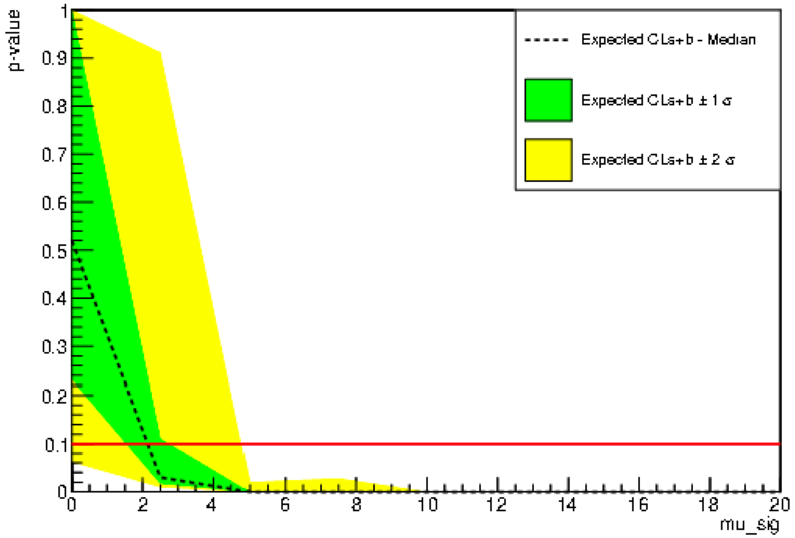

-2 sig vs. N_Toys
N_Toys


+2 sig
+1 sig
mu_sig
-1 sig
N_Toys

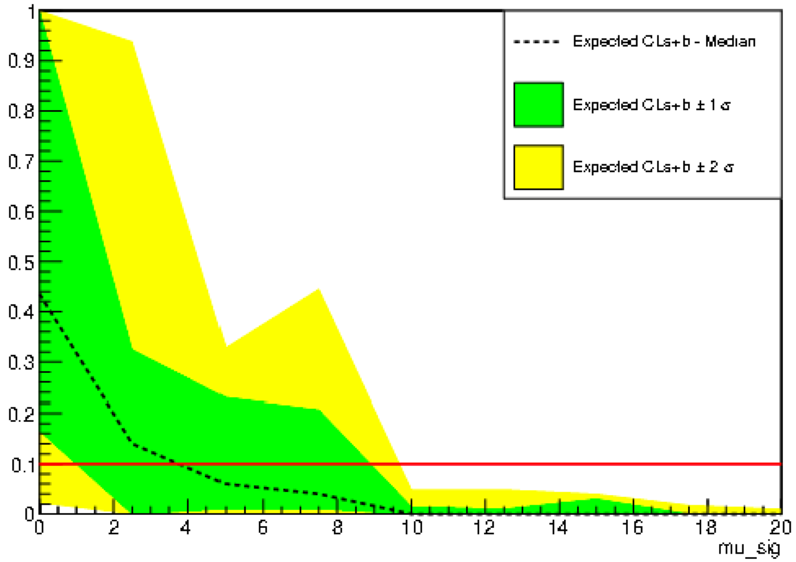
What’s new?

- Run 10 GeV WIMP mass with changing g1 values (0.05, 0.118, 0.13) and changing n_sample values (10^6 & 10^7)

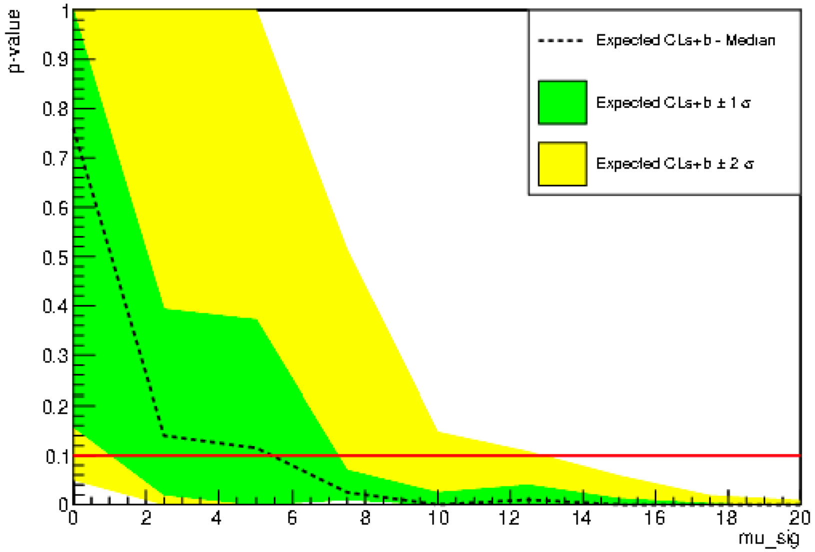
10 GeV
n_sample = 10^6



g1 = 0.05
mu_sig = 2.1429
cross_section = 6.8e-47

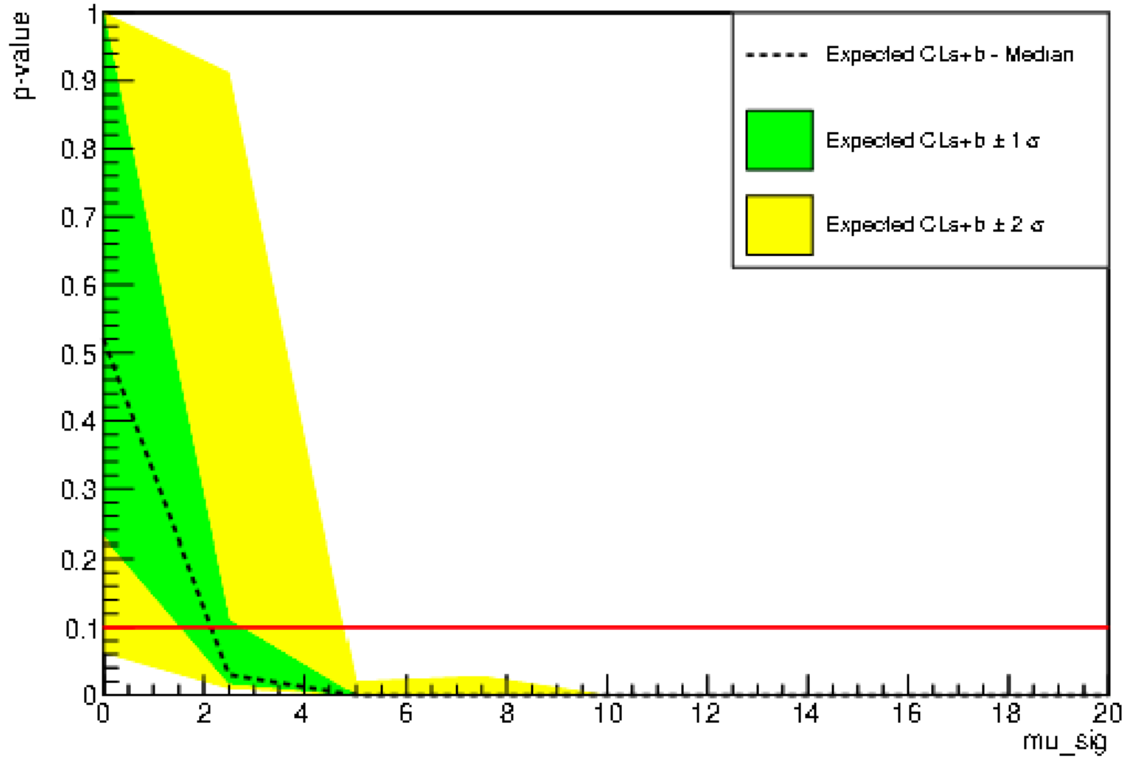


g1 = 0.118
mu_sig = 3.7500
cross_section = 1.84e-47



g1 = 0.13
mu_sig = 5.4167
cross_section = 2.3e^-47

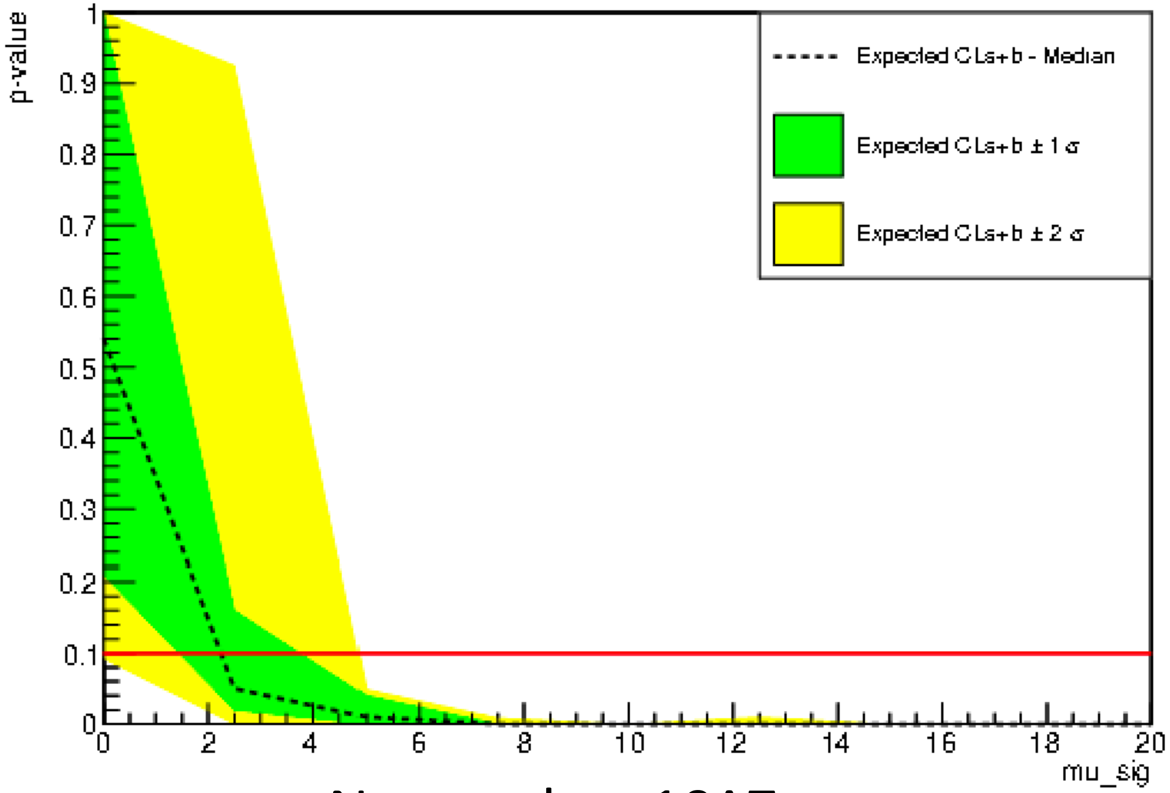
10 GeV, g1 = 0.05



N_sample = 10^6

mu_sig = 2.1429

cross_section = 6.8e-47

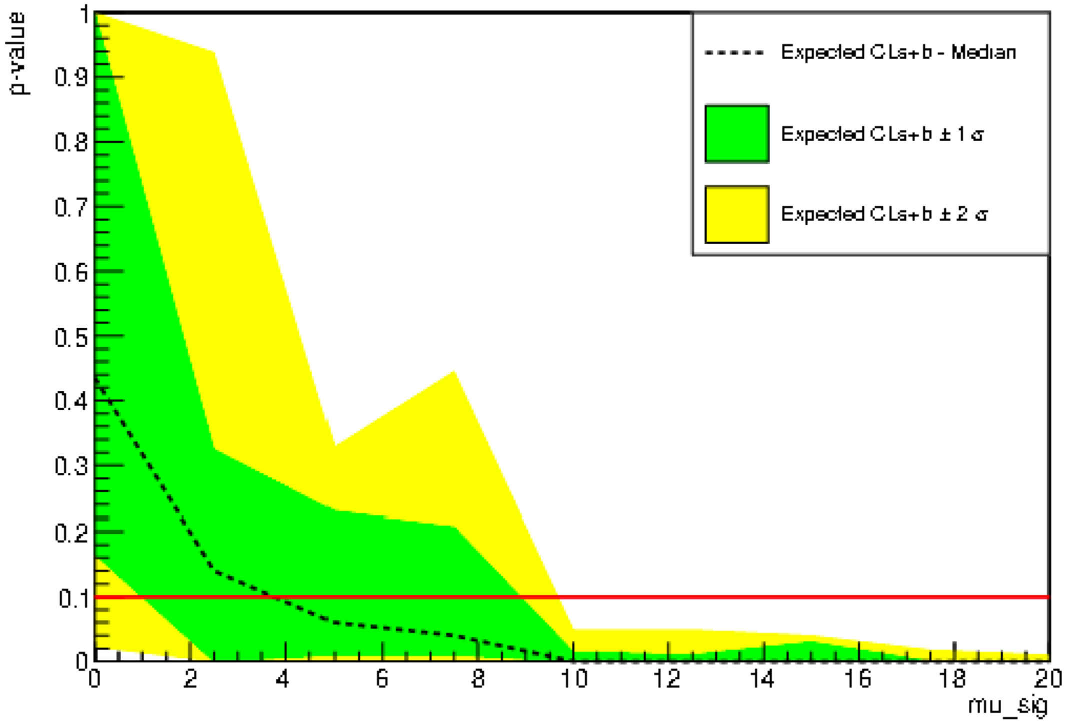


N_sample = 10^7

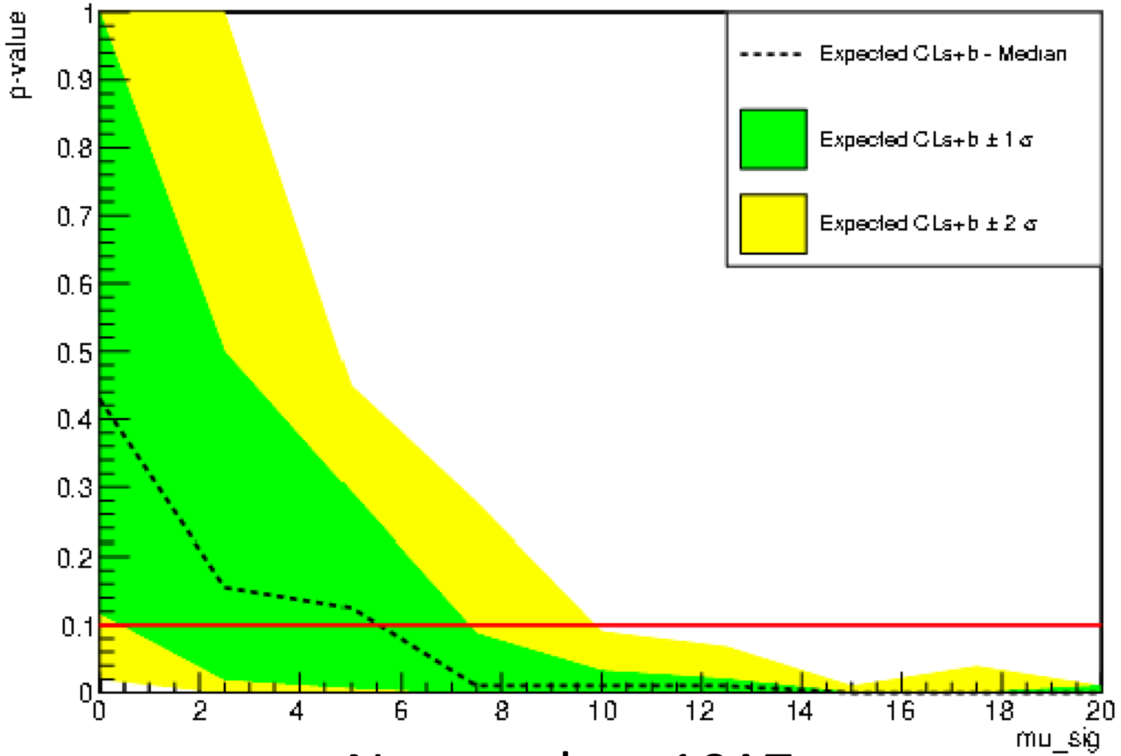
mu_sig = 2.2449

cross_section = 7.2e-47

10 GeV, g1 = 0.118

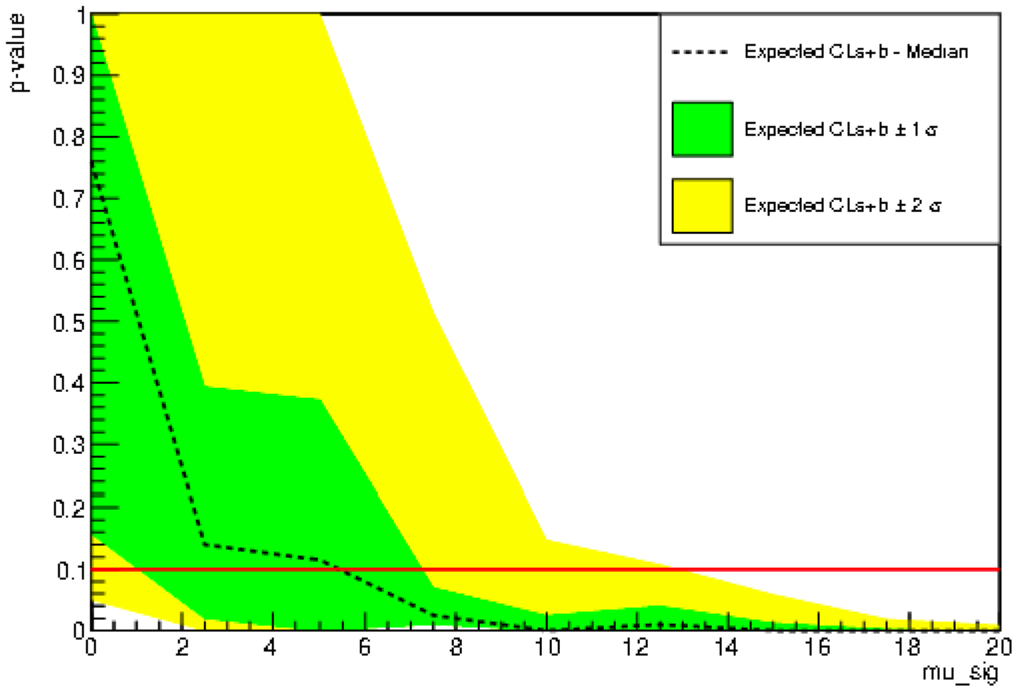


N_sample = 10^6
mu_sig = 3.7500
cross_section = 1.84e-47



N_sample = 10^7
mu_sig = 5.54
cross_section = 2.74e-47

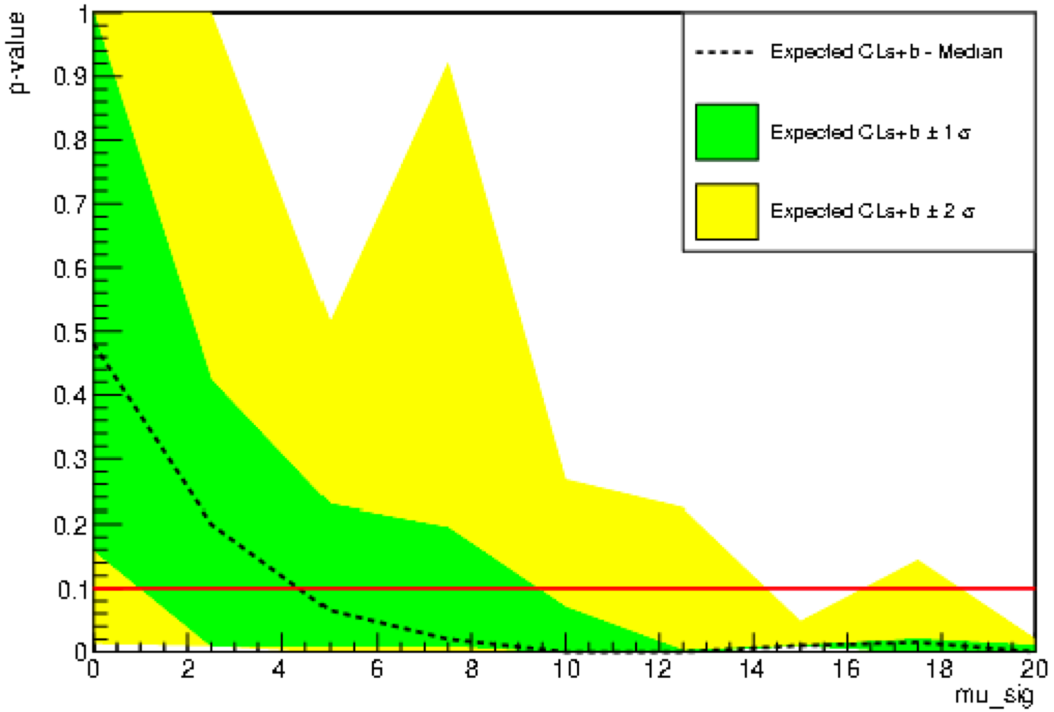
10 GeV, g1 = 0.13



N_sample = 10^6

mu_sig = 5.4167

cross_section = 2.3e-47

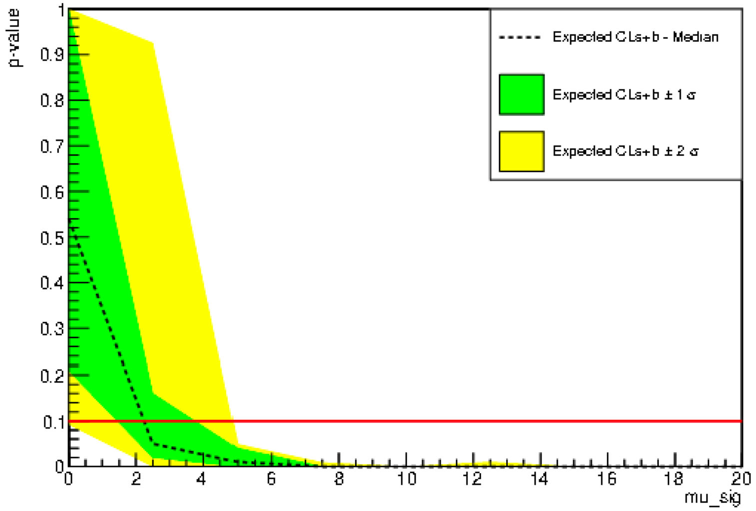


N_sample = 10^7

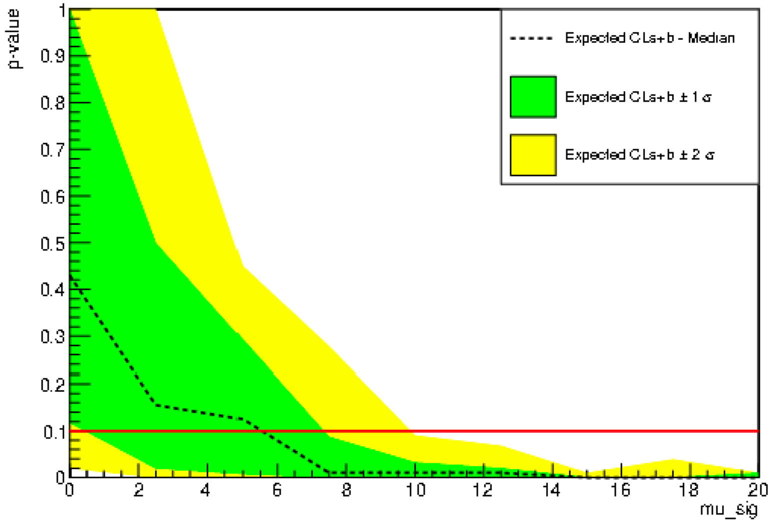
mu_sig = 4.3544

cross_section = 1.8e-47

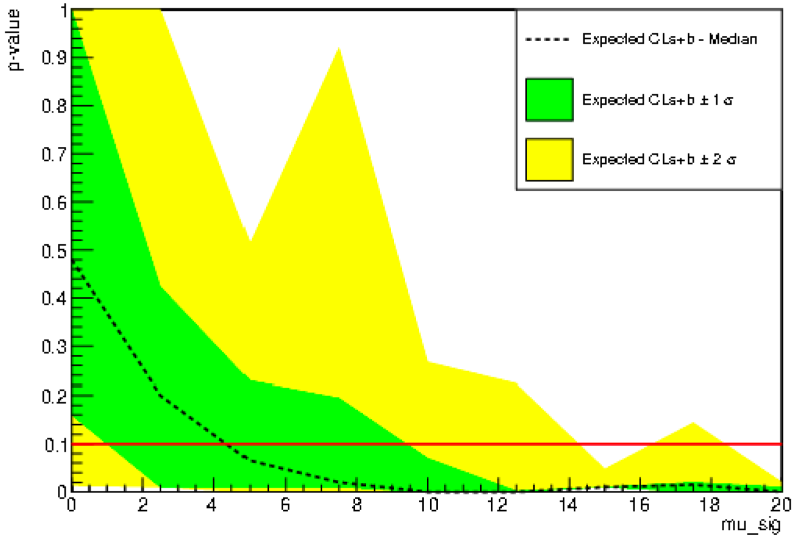
10 Gev
n_sample = 10^7



g1 = 0.05
mu_sig = 2.2449
cross_section = 7.2e-47



g1 = 0.118
mu_sig = 5.54
cross_section = 2.74e-47



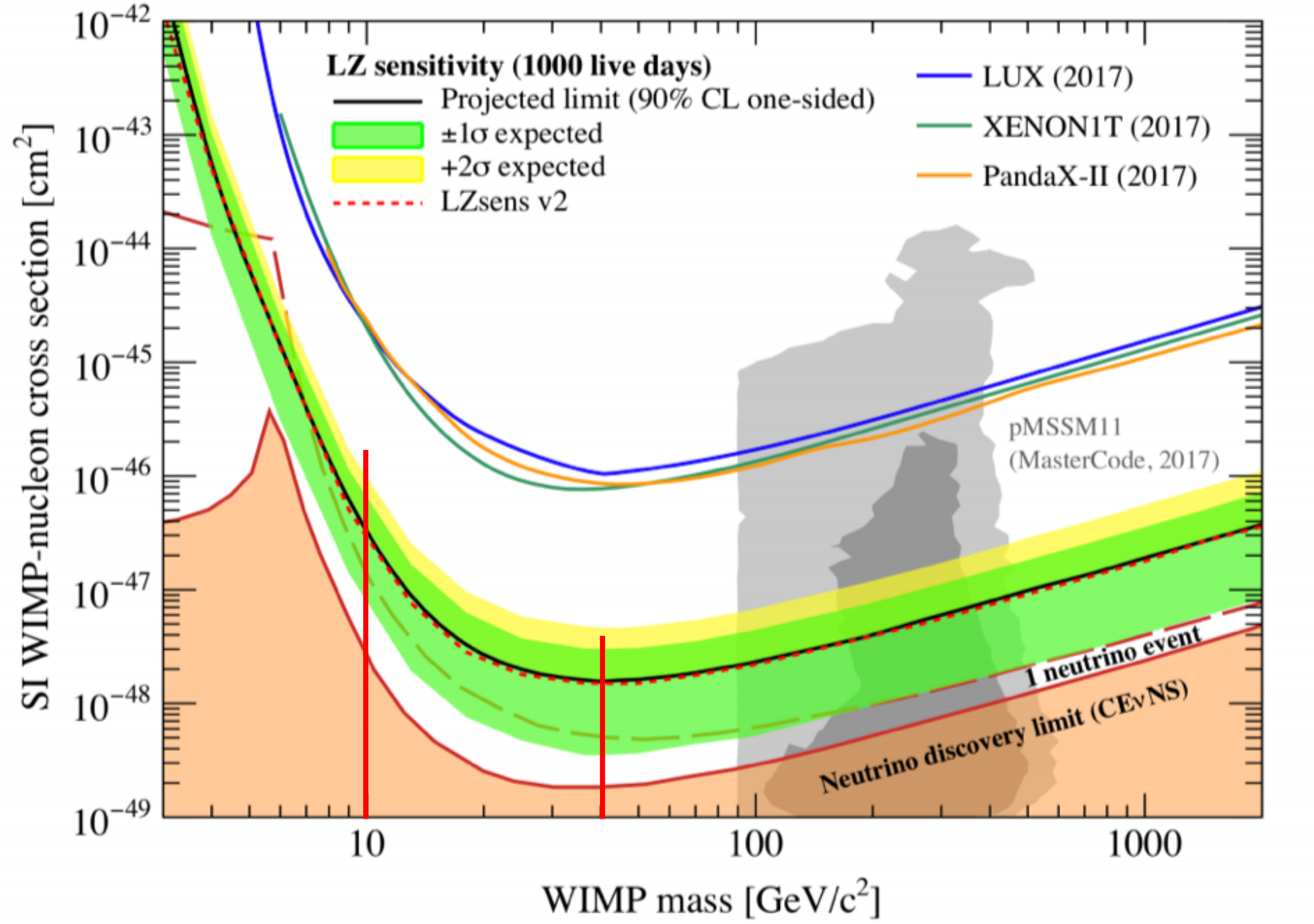
g1 = 0.13
mu_sig = 4.3544
cross_section = 1.8e-47

Comparison (10 GeV vs 40 GeV)

- Change g1 from 0.05 -> 0.13
  - Cross section for 10 GeV changes 75%
  - Cross section for 40 GeV changes 27%
- Why is there a more dramatic change in lower WIMP mass when changing g1 ?

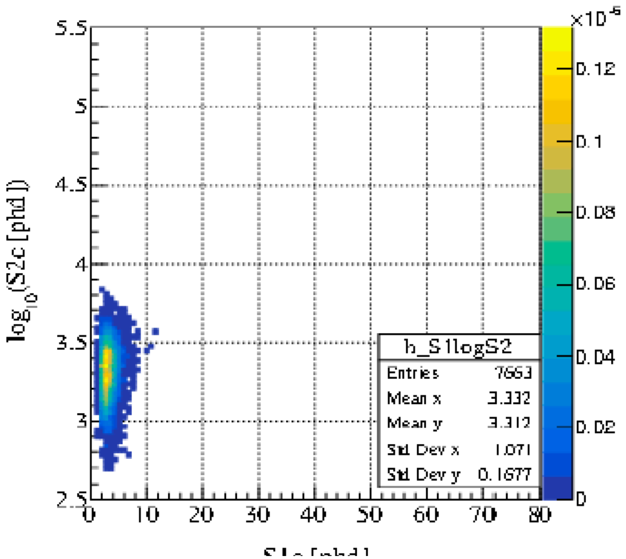
Limit plot

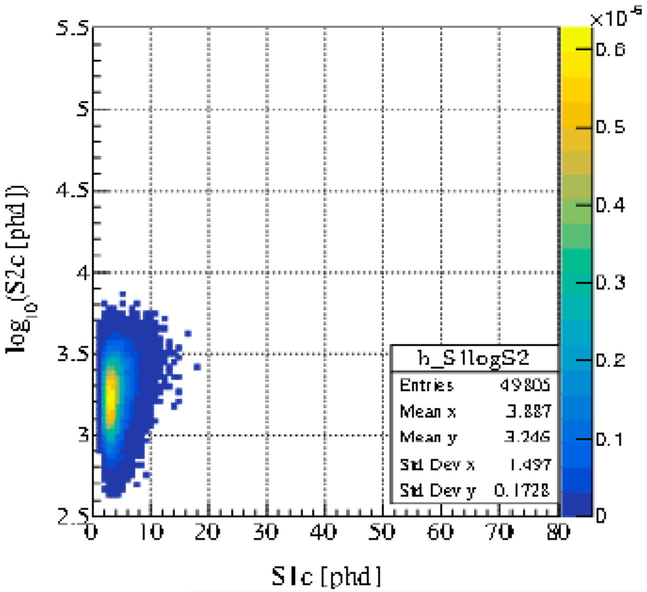
10 GeV ~ 3e^-47

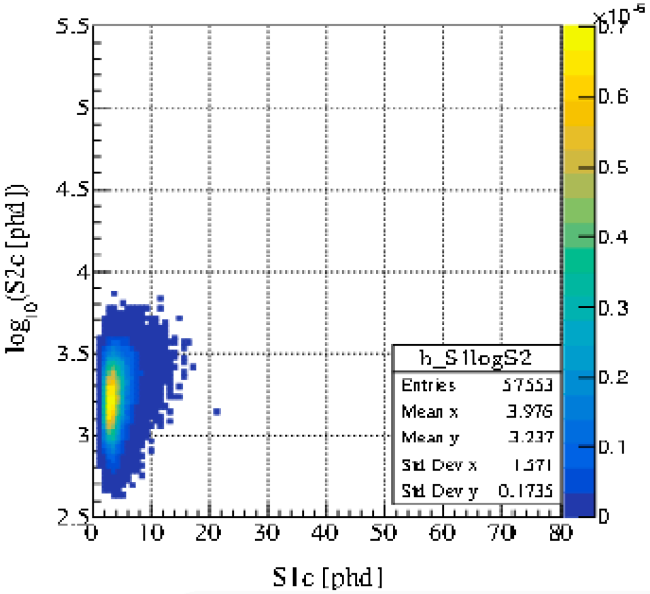


WIMP 10GeV

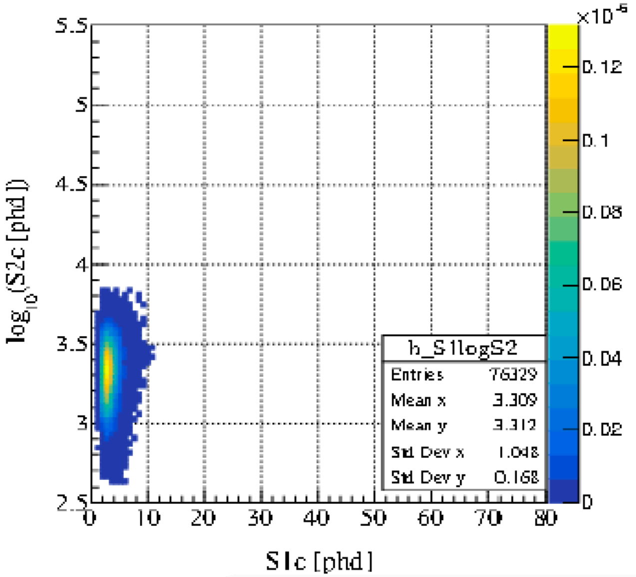
N_sample = 10^6

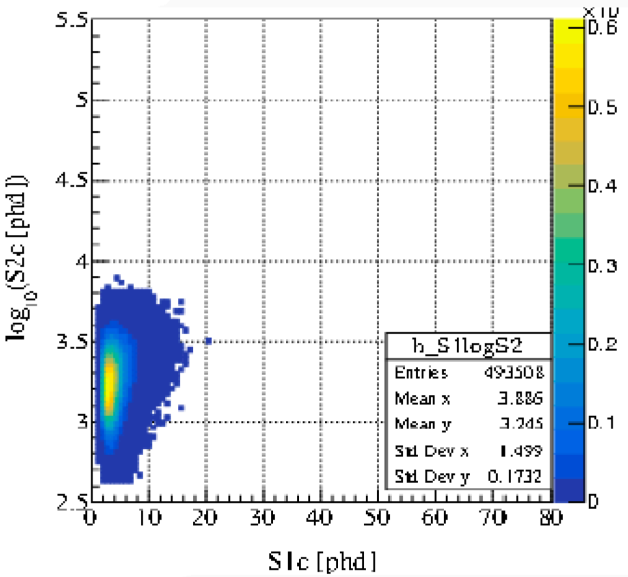


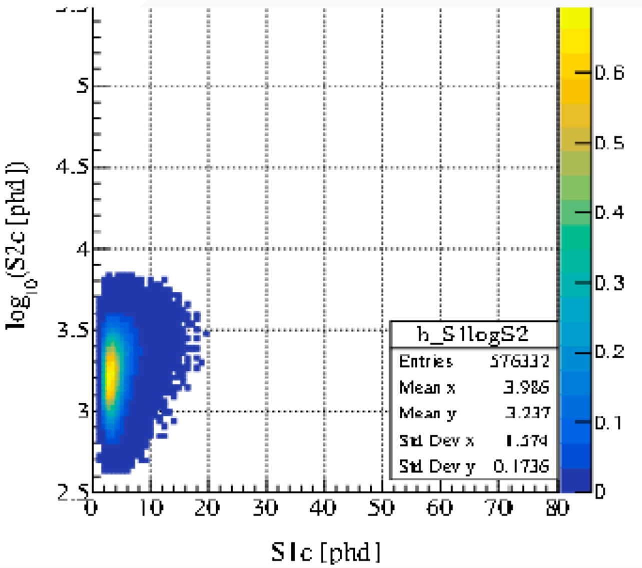




N_sample = 10^7







g1 = 0.05

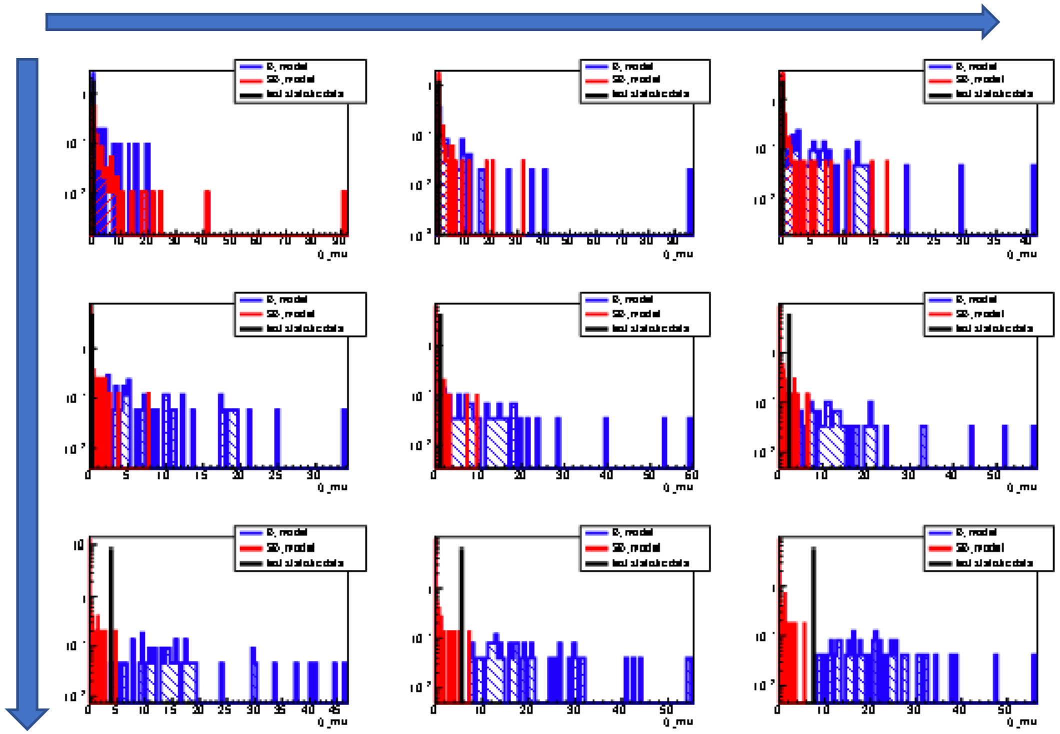
g1 = 0.118

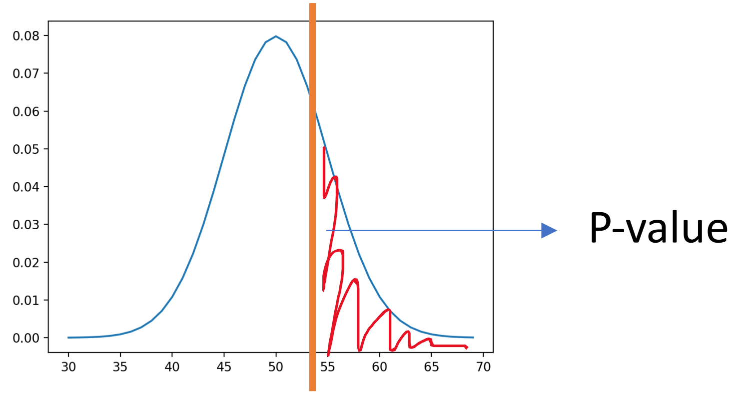
g1 = 0.13

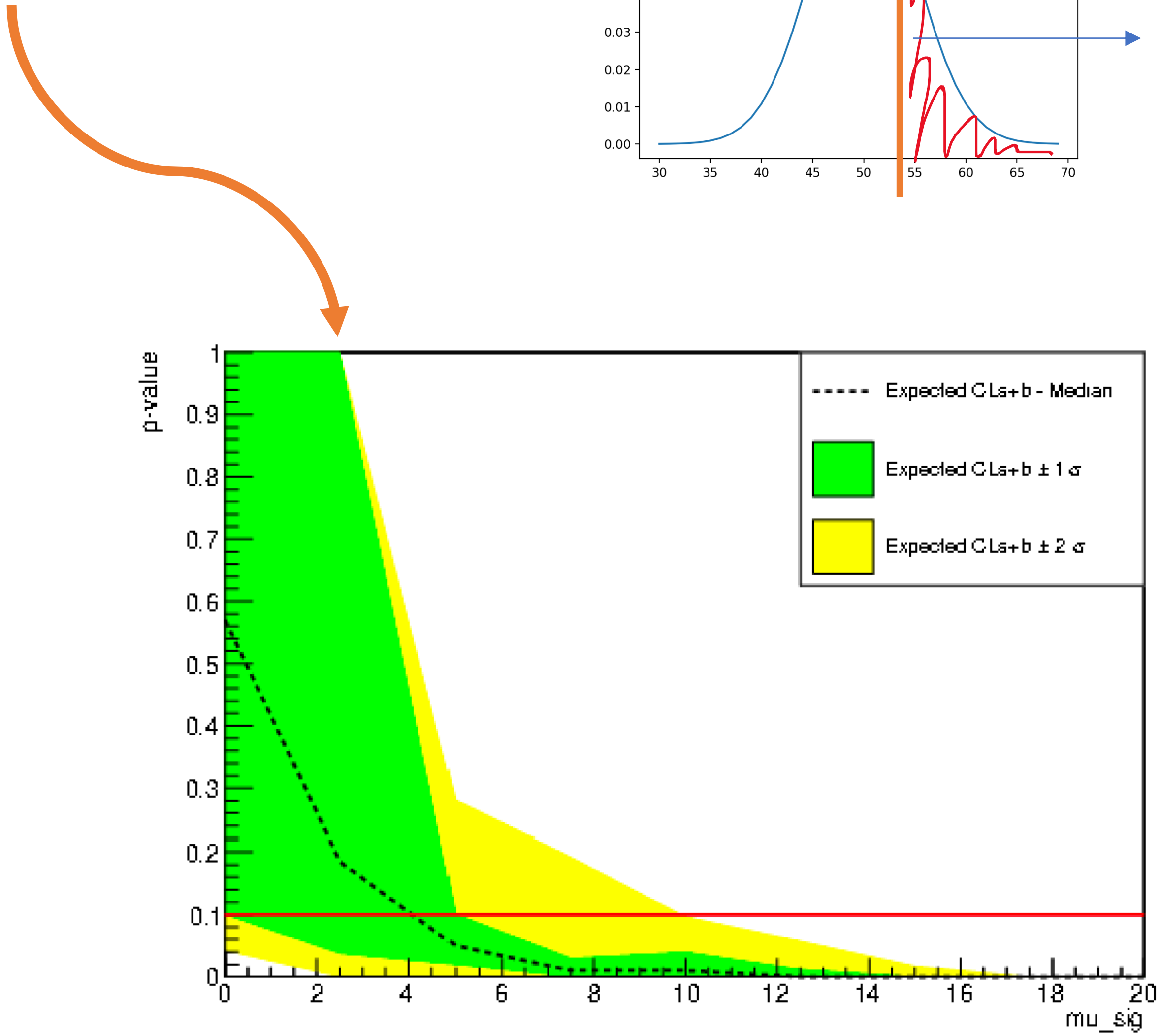
What’s new?

- Analyze the graph
- Change g1 value and compare the limits

POI = 0 ~ 20



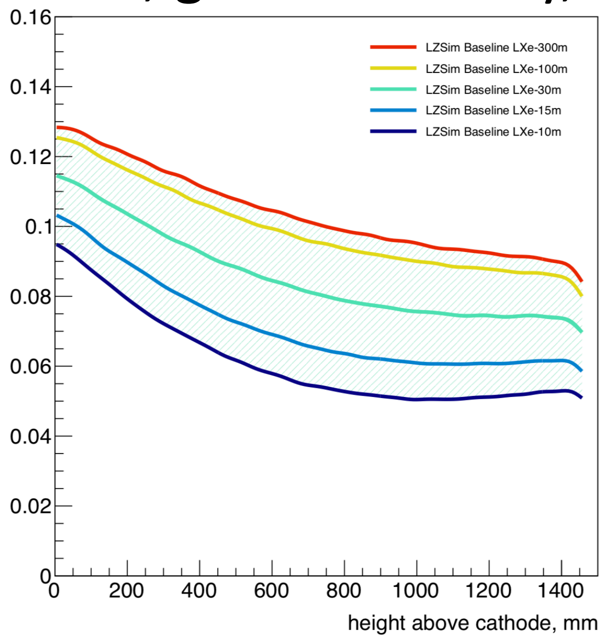

P-value


p-value
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ
mu_sig

g1

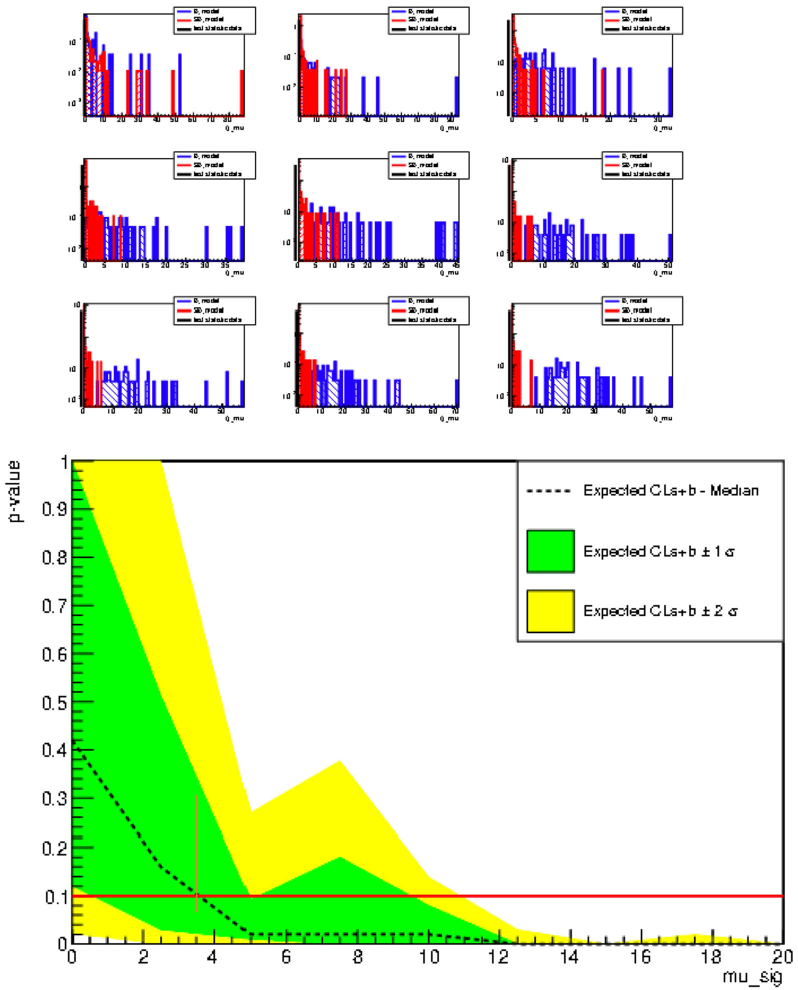
- g1
  - Photon detection efficiency: the average fraction of S1 light that is detected by PMTs.
  - Detected photoelectrons/emitted scintillation photon
  - Property of the combination of PMTs and detector, grid reflectivity, Xe absorption of light…
- LZsim baseline in Liquid Xe

g1_min ~ 0.05
g1_default ~ 0.118
g1_max~0.13



Code

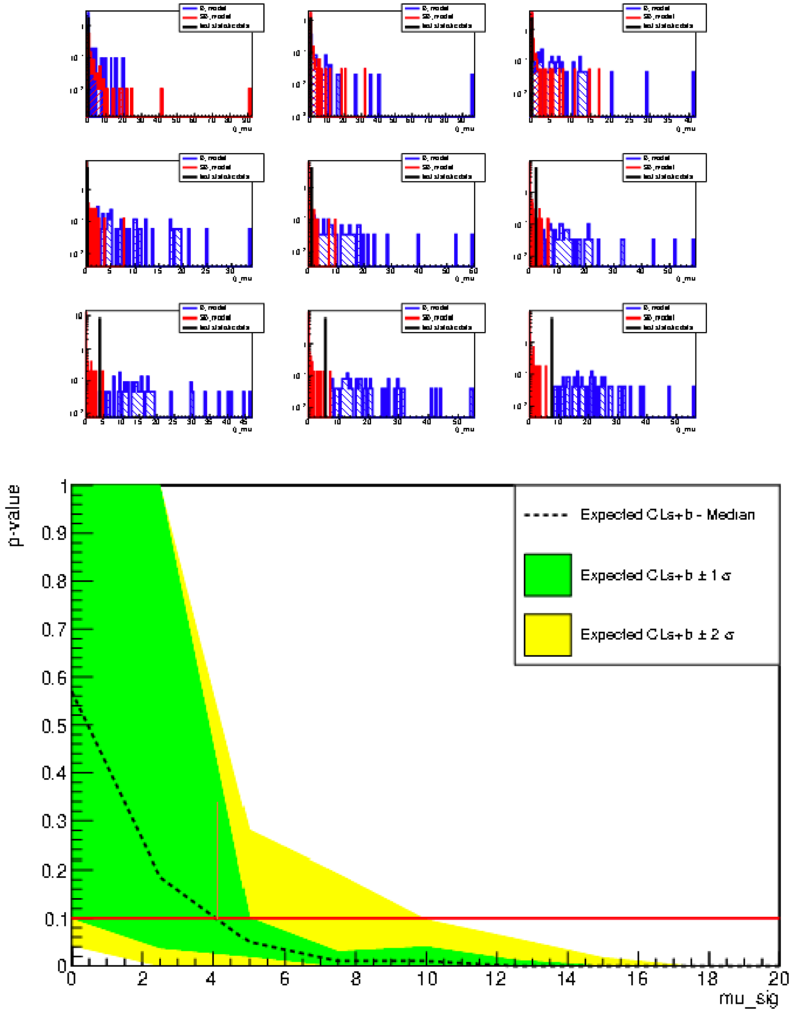
- LZNESTUtils
  - Change Detector parameters
  - Source setup.sh
  - Source .ci/build.sh
  - Get new NESTInterference
- PdfMaker
  - Recompile signal and background codes with the new NESTInterference



g1 = 0.05

mu_sig = 3.5027

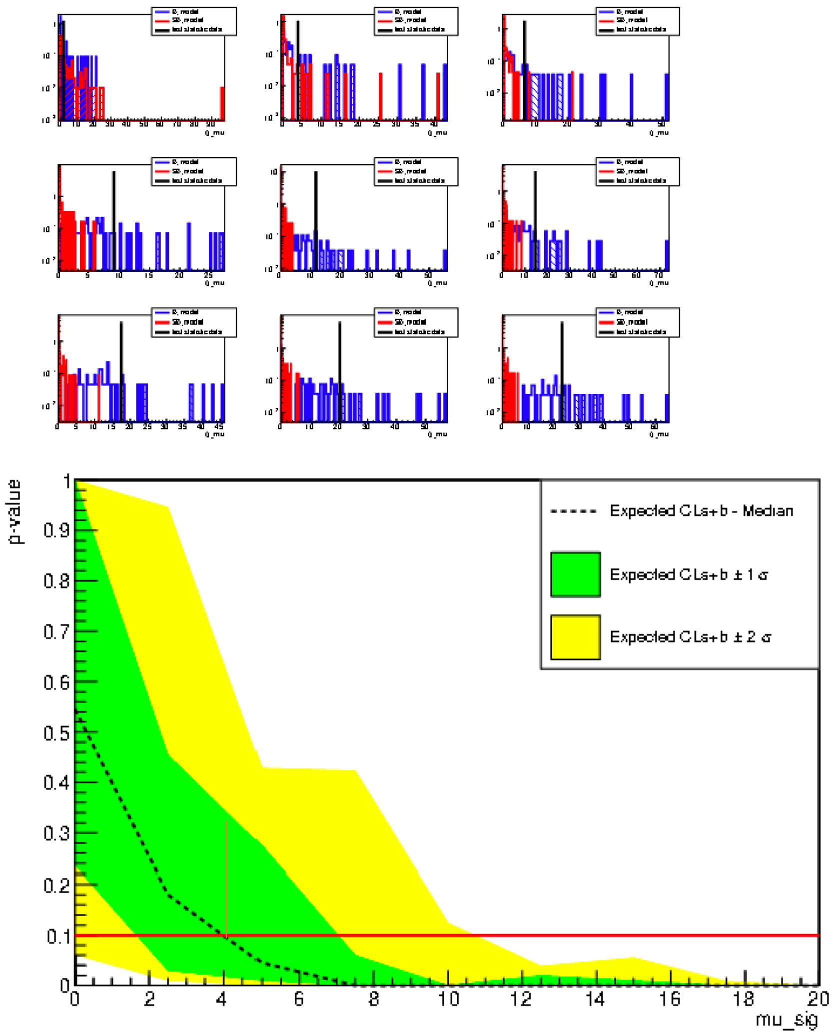
cross_section = 1.44e^-48



g1 = 0.118

mu_sig = 4.0625

cross_section = 1.12e^-48



g1 = 0.13

mu_sig = 3.9835

cross_section = 1.05e^-48

To do

- Try lower WIMP mass (10GeV) and see how the sensitivity changes.

What’s new:

- Figure out what’s causing the error.
  - Constant pp value→ in the code(for HypoTestInversion), remove any constant parameters → number of parameters are not consistent.
- Update the Low_NR_Groups, re-generate the workspace.
  - No more problem running the LZStats.
- Compare the two versions of code and workspaces

Code (pp)

Before	After
a0_tmp = bckg_rate * exposure = bckg_rate*livedays*fiducial_mass = 542.16 a_pp = a0_tmp mu_pp = Range (507, 574) sigma_pp = systematic_uncertainties * a0_tmp = 2% * 542.16 ~10	a0_tmp = bckg_rate * exposure = bckg_rate*livedays*fiducial_mass = 542.16 a_pp = a0_tmp mu_pp = a0_tmp sigma_pp = systematic_uncertainties * a0_tmp = 2% * 542.16 ~10

```
w->factory("Gaussian::constraint_pp(mu_pp,a_pp,sigma_pp)");
```

Workspace (comparison)

- Information printed out from workspace:
  - Constraints changed:

Background	Before	After
B8	0.011109	1
DSN	0.011109	1
DetER	0.011109	1
DetNR	0.011109	1
Kr85	0.011109	1
Rn220	0.011109	1
Rn222	0.572416	1
atm	0.011109	1
hep	0.011109	1
pp	0.000521151	1
vvBB	0.825786	1

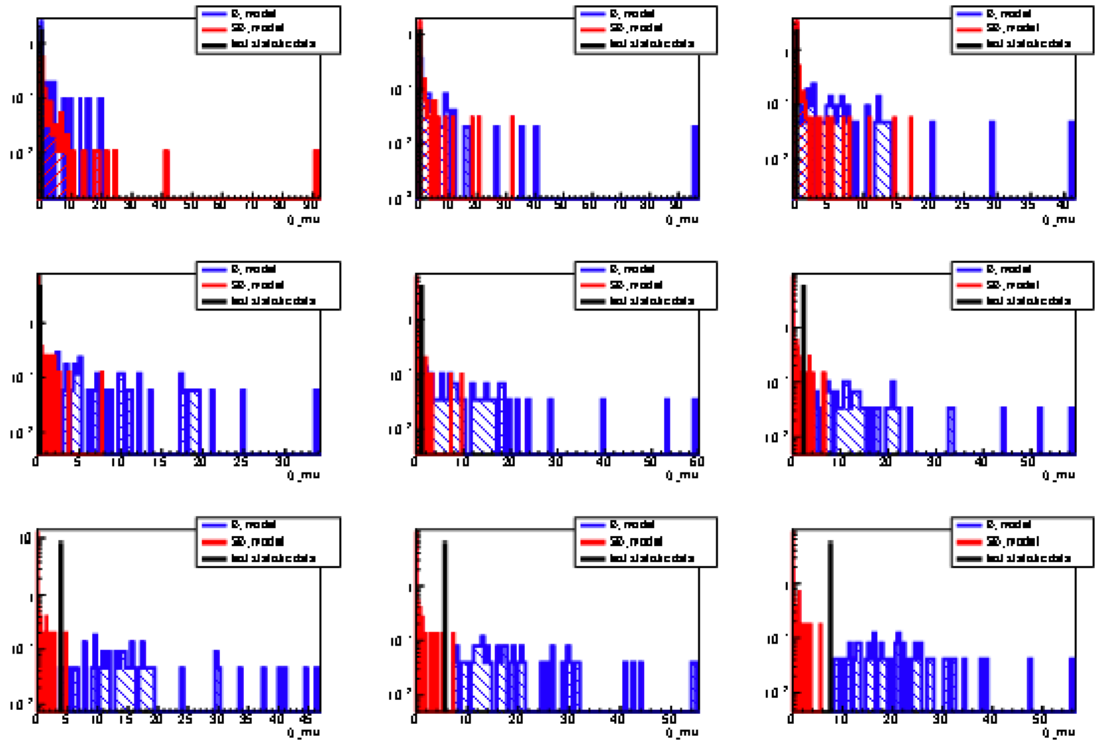
Constraint: Gaussian distribution of (x=mu_pp
mean = a_pp,
Sigma = sigma_pp)

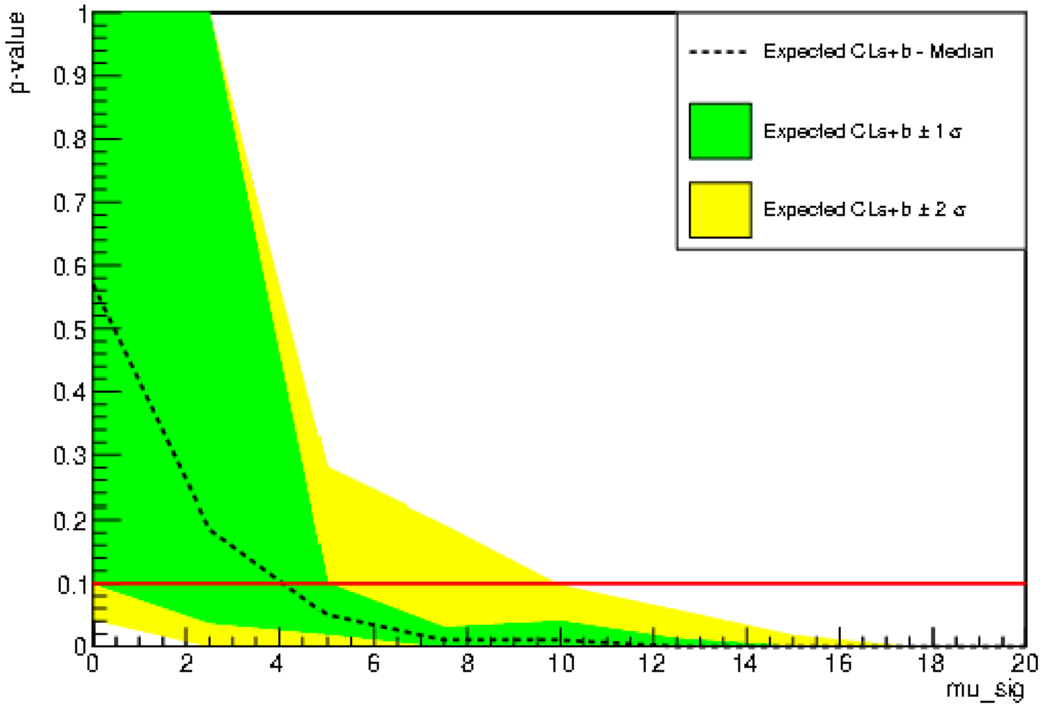
$$\sim \frac{(x-\mu)^2}{\sigma^2}$$

- Total Event Model:
  - Event Model * Total Constraints

	Before	After
Event Model	8.09546e-13	4.80763e-13
Total Event Model	4.62575e-32	4.80763e-13

WIMP (40GeV)





p-value
mu_sig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ

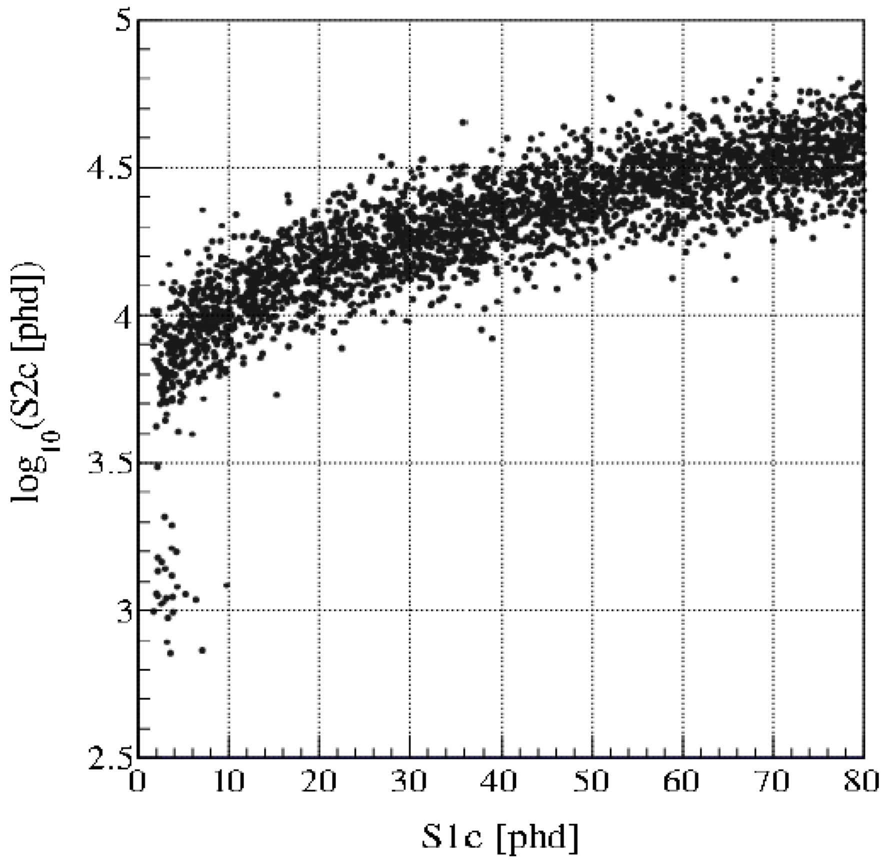
What's done

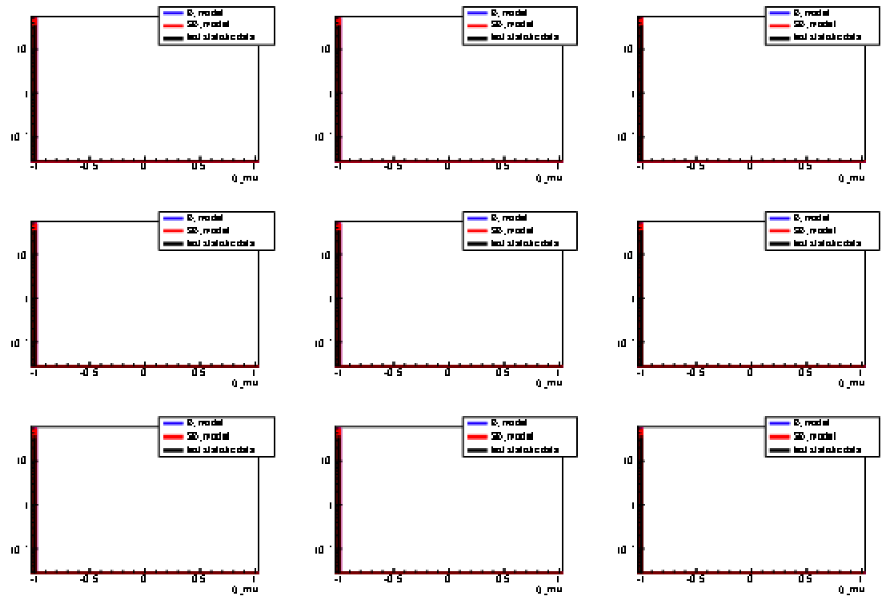
- LZNESTUtils: Change to a new branch
- PdfMakers: compile the background code successfully
- LowR_NR: passed 12 root files (1 signal +11 backgrounds) to make a workspace (1 root file)
- LZStats: run the code locally with the workspace generated from the LowR_NR

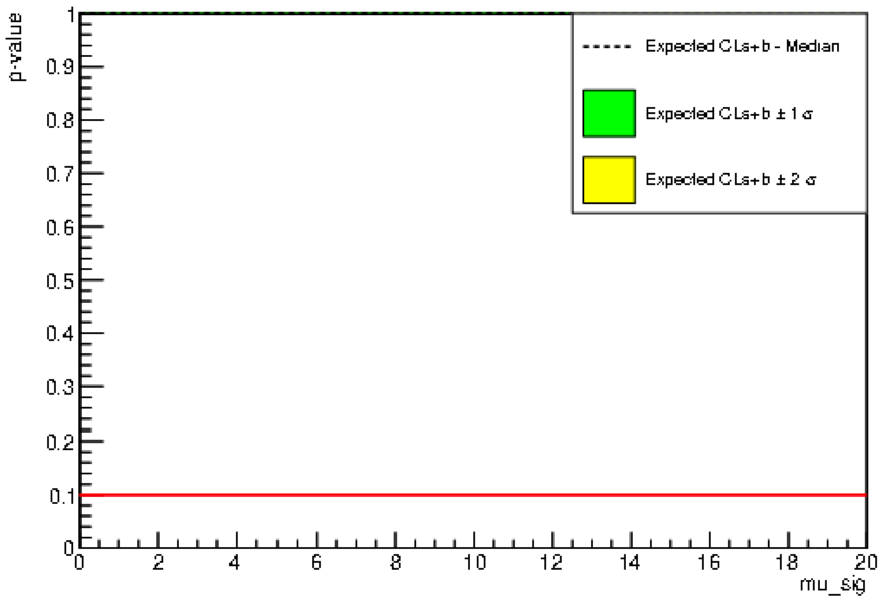
Running LZStats

- Frequentist Analysis (limit setting)
  - Confidence level: 90%
  - Fiducial mass (kg): 5600
  - Livetime(days) : 1000
  - Paritcle mass (GeV): 40
  - MC toys per point : 100
  - Number of Points: 9
  - Min POI: 0
  - Max POI: 20

Problem


log10(S2c [phd])
S1c [phd]

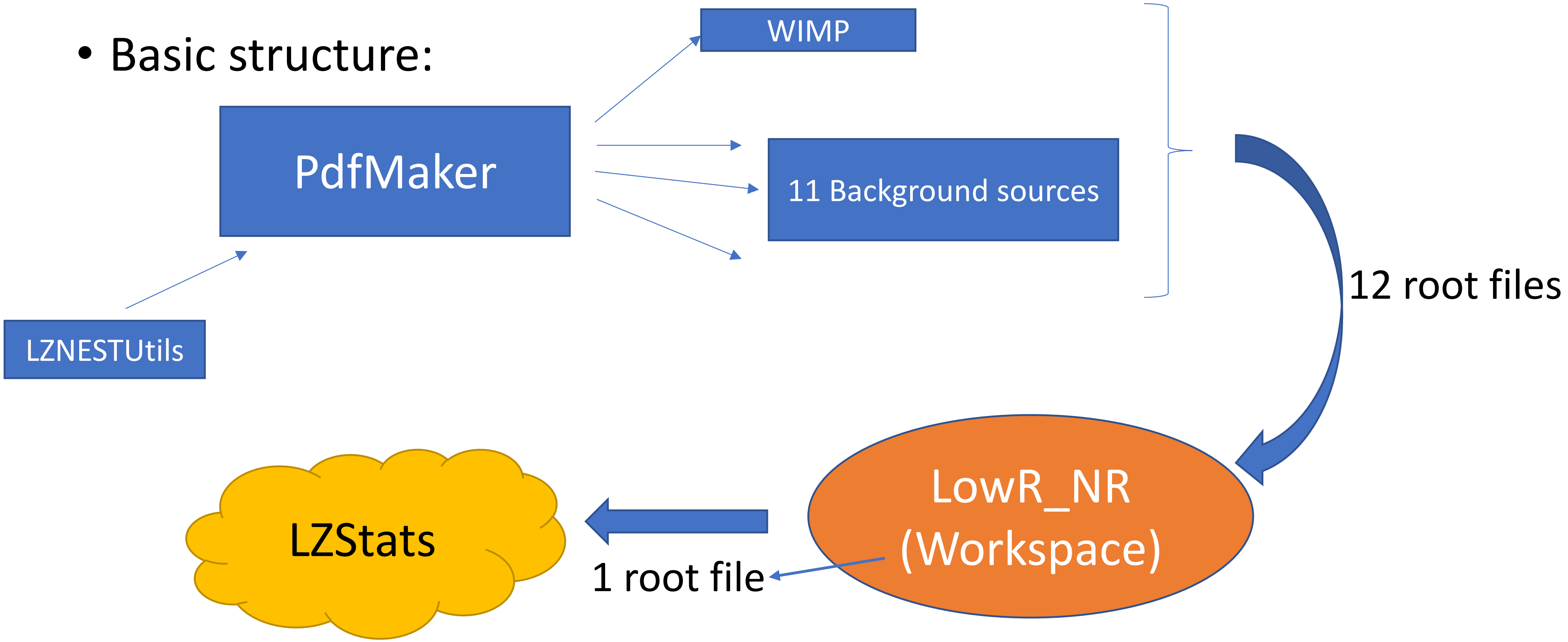



p-value
mu_sig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ

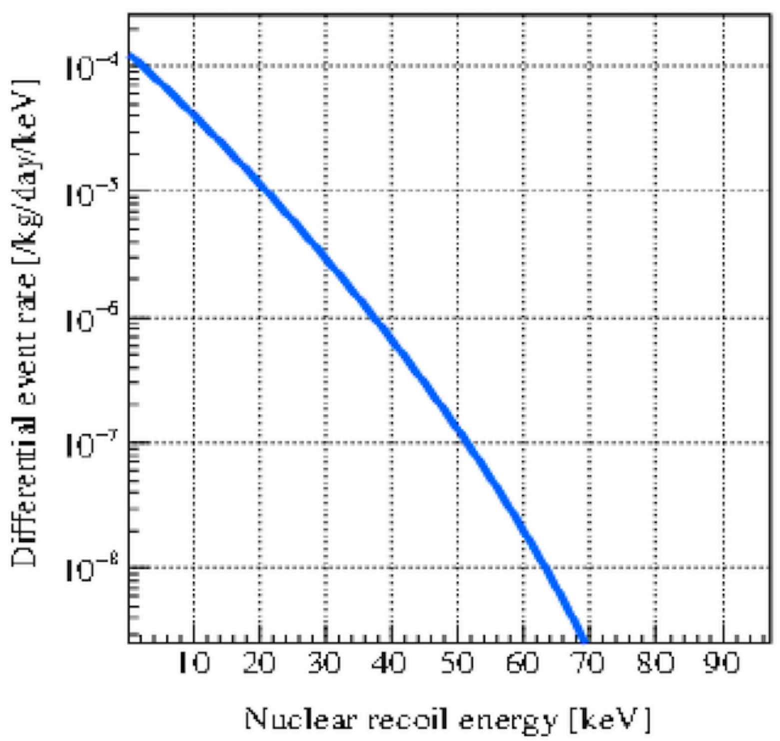
```
Error in <ROOT::Math::FitResult>: FitConfiguration and Minimizer result are not
consistent
Number of free parameters from FitConfig = 12
Number of free parameters from Minimizer = 11
```

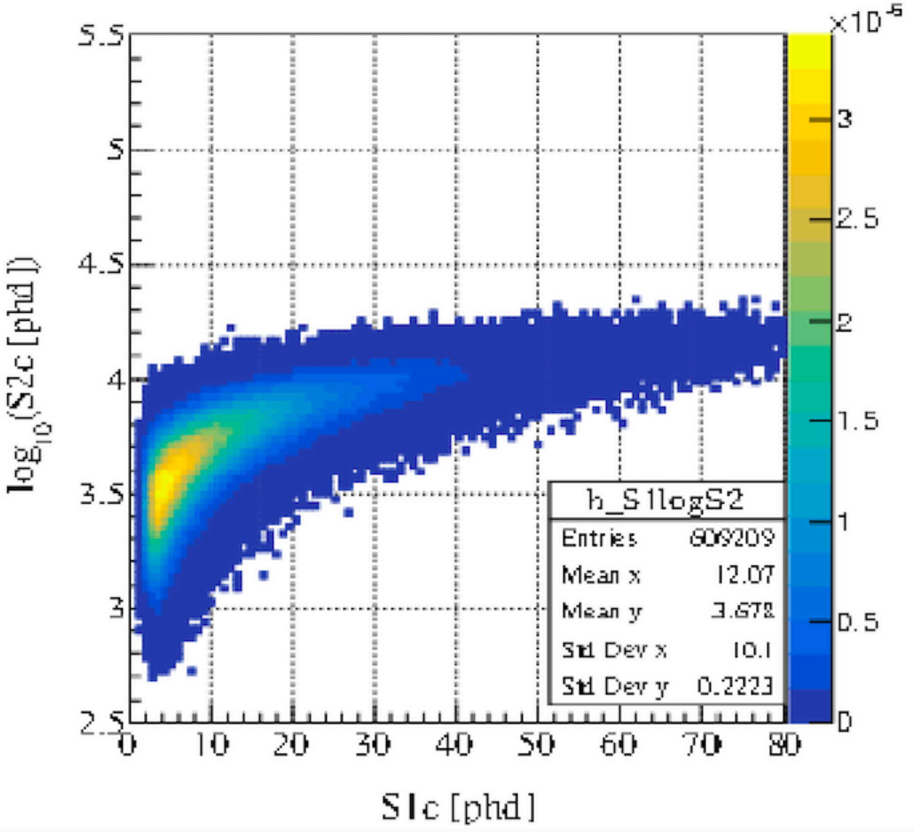
Changed LZStats

- Basic structure:



Output of signal (40GeV WIMP) from PdfMaker





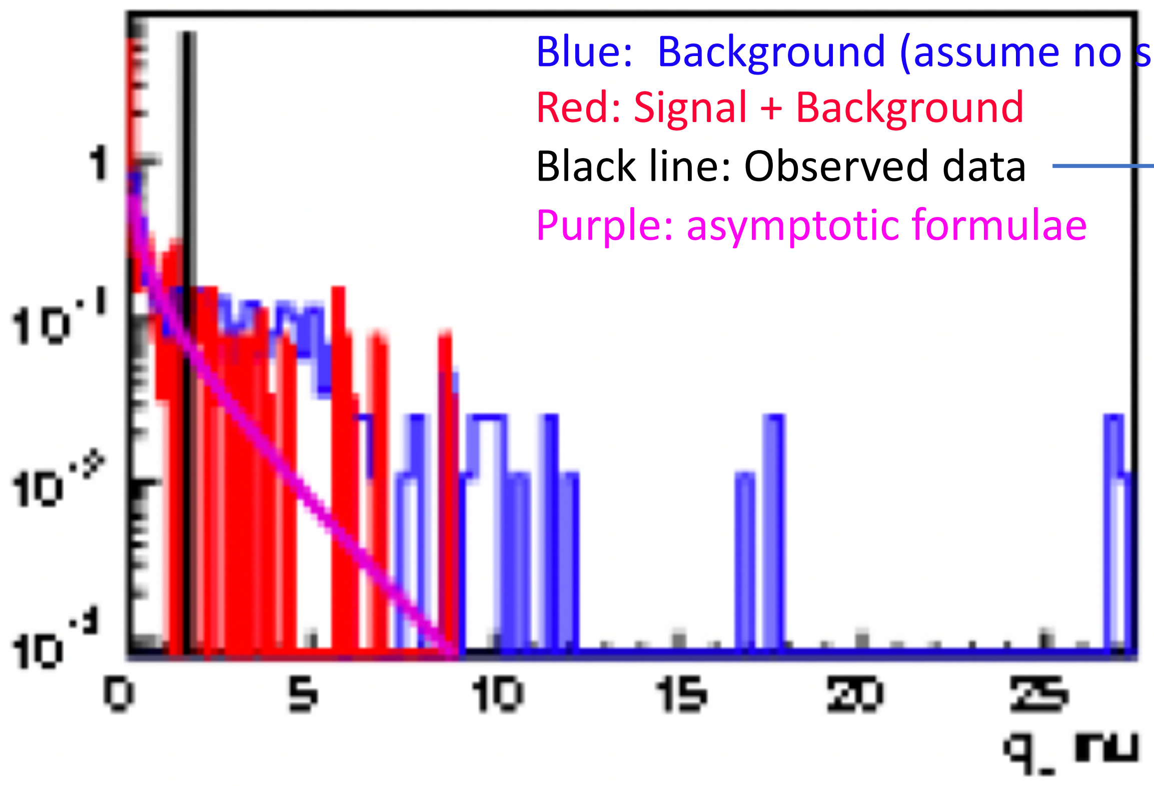
Workspace → RooWorkspace

- Settings
  - WIMP_mass = 40
  - Interaction type = Spin Independent
  - Livedays = 1000
  - Fiducial (kg) = 5600

Problem/To do

- Have trouble compiling the background code, one function in the background code is not defined in the LZNESTUtils → possible solution: change branches in the LZNESTUtils.

Analysis of a single graph



Blue: Background (assume no signal)

Red: Signal + Background

Black line: Observed data → The **median** of the B-distribution

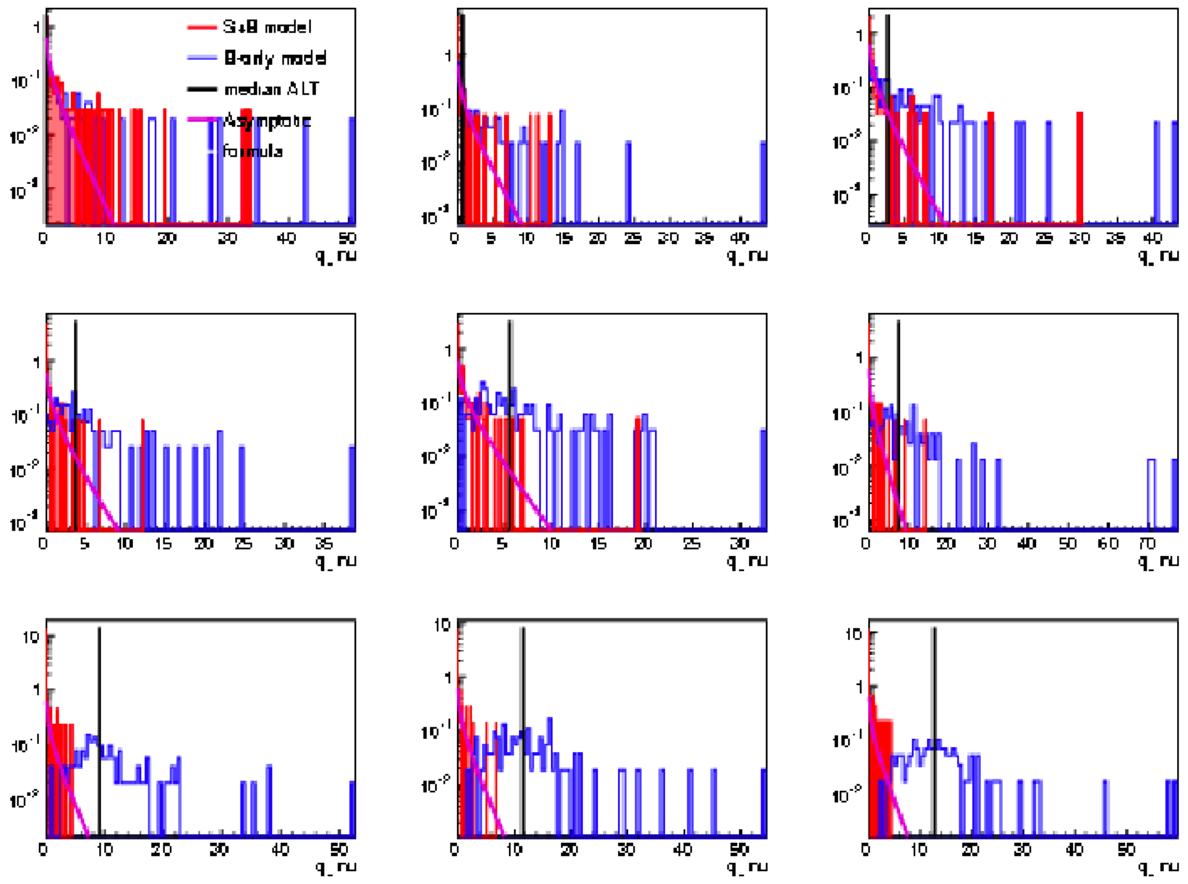
Purple: asymptotic formulae

→ $t = -2ln\frac{\mathrm{L(B+S)}}{\mathrm{L(best\ fit)}}$

Hypothesis:

- **H0**: The data has both background and signal events fixed signal
- **H1**: The data only has background events floating

Increasing POI (0~15)

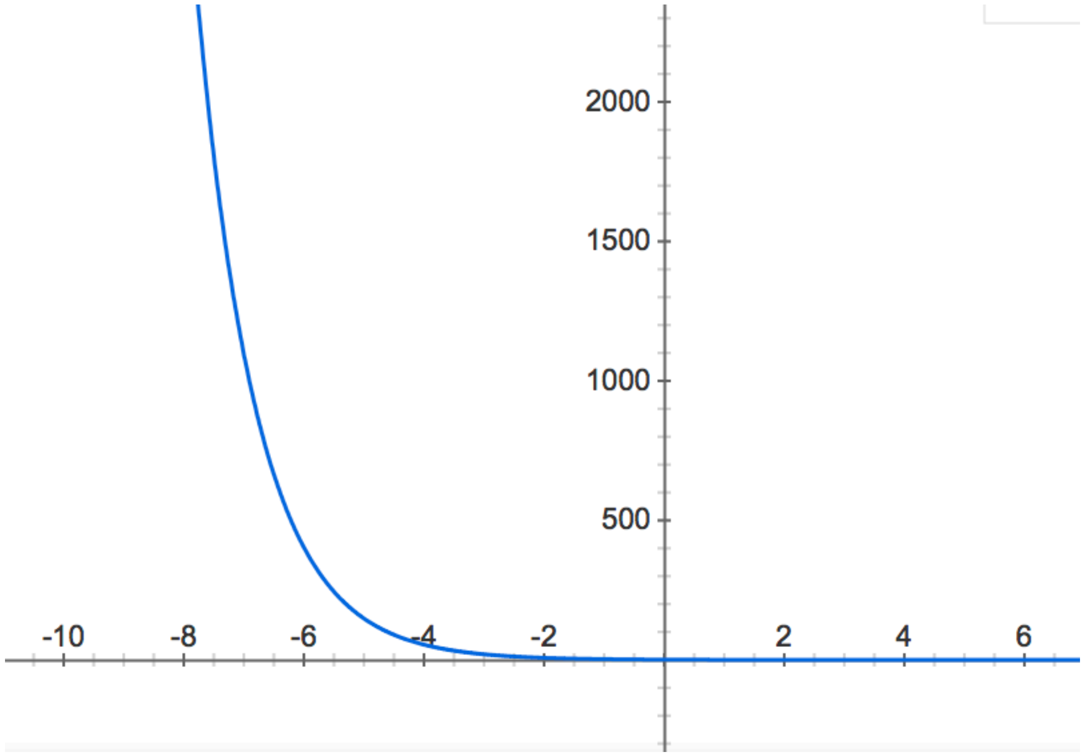


Method

- Background is fixed for different WIMP masses
- For one WIMP mass, increasing values of the parameter of interest (POI)→ the cross section of the WIMP's interaction with Xenon
- Find the upper limit on the POI

$$L(\mu, \boldsymbol{\theta}) = \prod_{j=1}^{N} \frac{(\mu s_j + b_j)^{n_j}}{n_j!} e^{-(\mu s_j + b_j)} \prod_{k=1}^{M} \frac{u_k^{m_k}}{m_k!} e^{-u_k}$$

For high POI → high μsj



Equations & Graphs

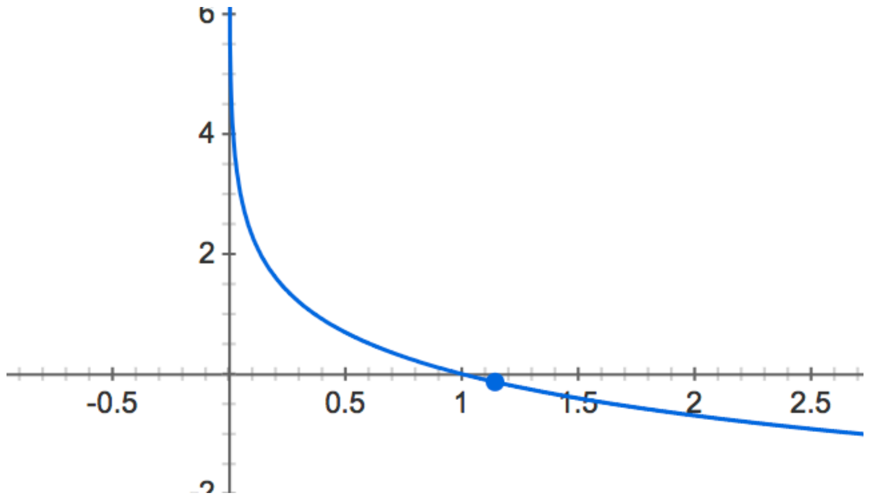
$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}})}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})}$$

μ : fixed

$\hat{\mu}$: floating

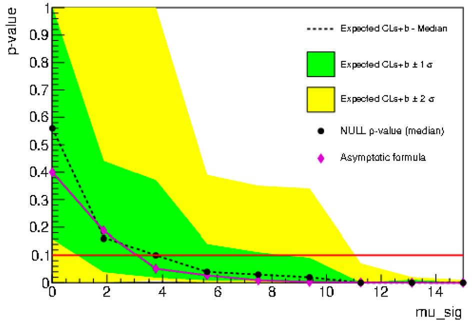
$$t_\mu = -2 \ln \lambda(\mu)$$

$\ln x$ vs x



To do

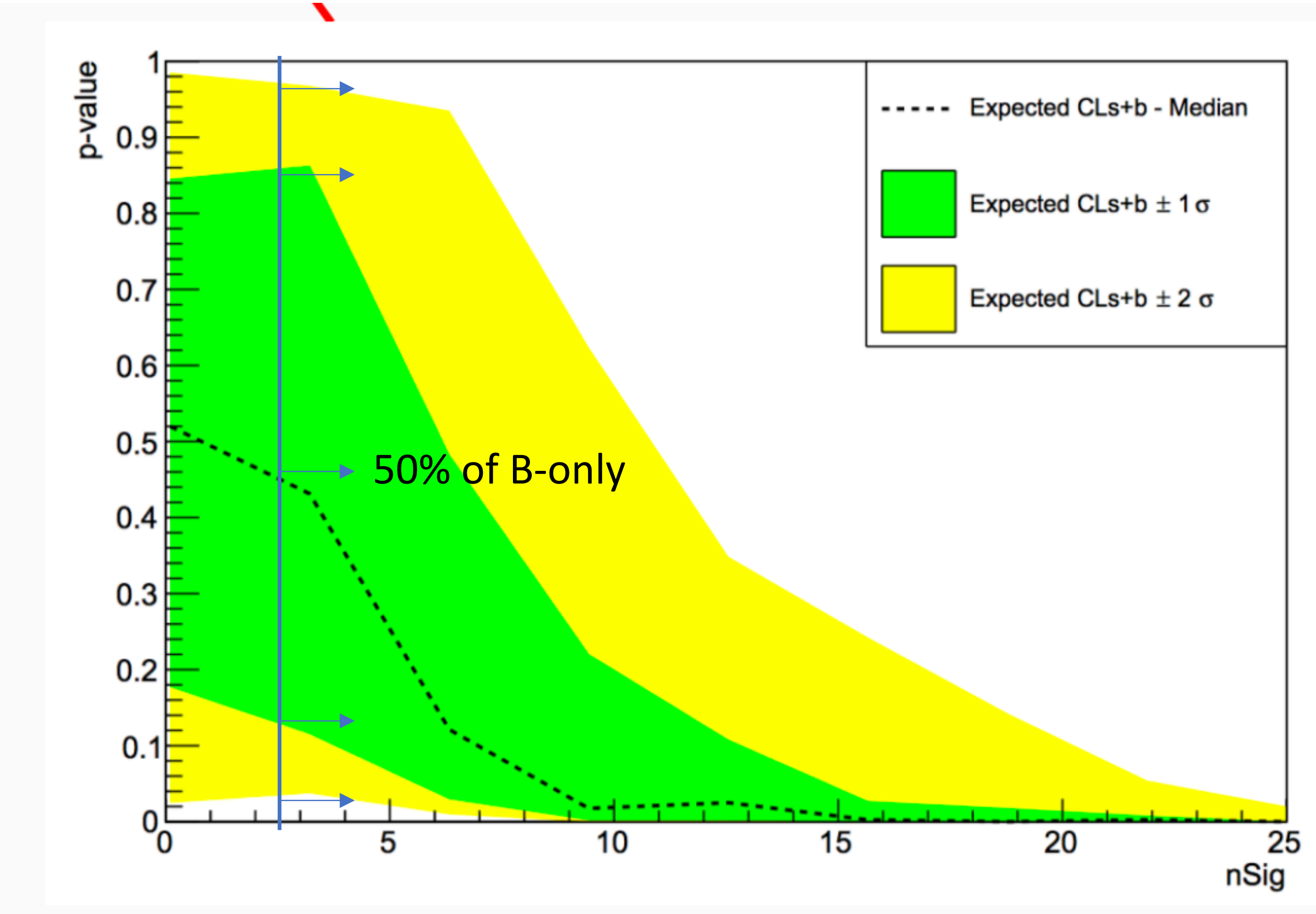
- How to get the upper limit, basically how to get this graph from the nine graphs.
- Analyze the graph



Done:

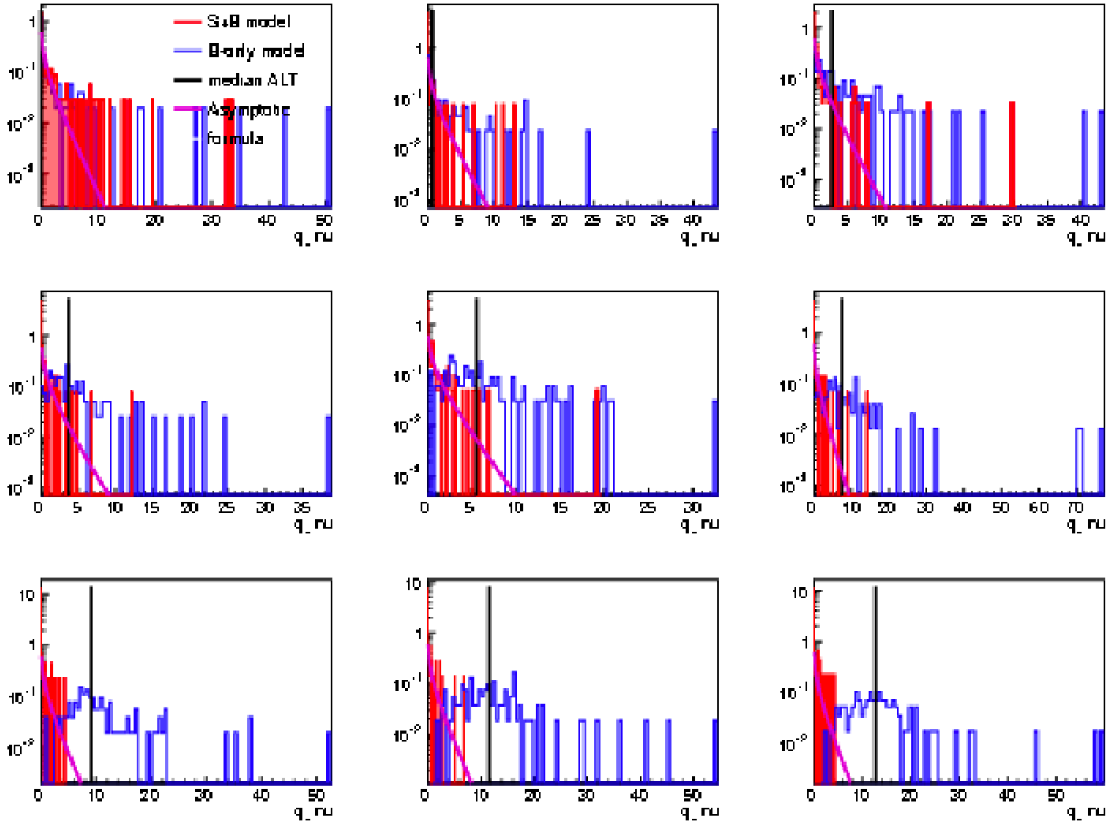
- For mass = 2.0000 GeV
  - ERROR: WIMP histogram is empty for mass 2.0 → Mass 2.0 is too small
- Mass: 10, 16.2222, 27.8256, 46.4159, 66.6667, 100, 200, 1000
- Moved the output from scratch to hdfs.

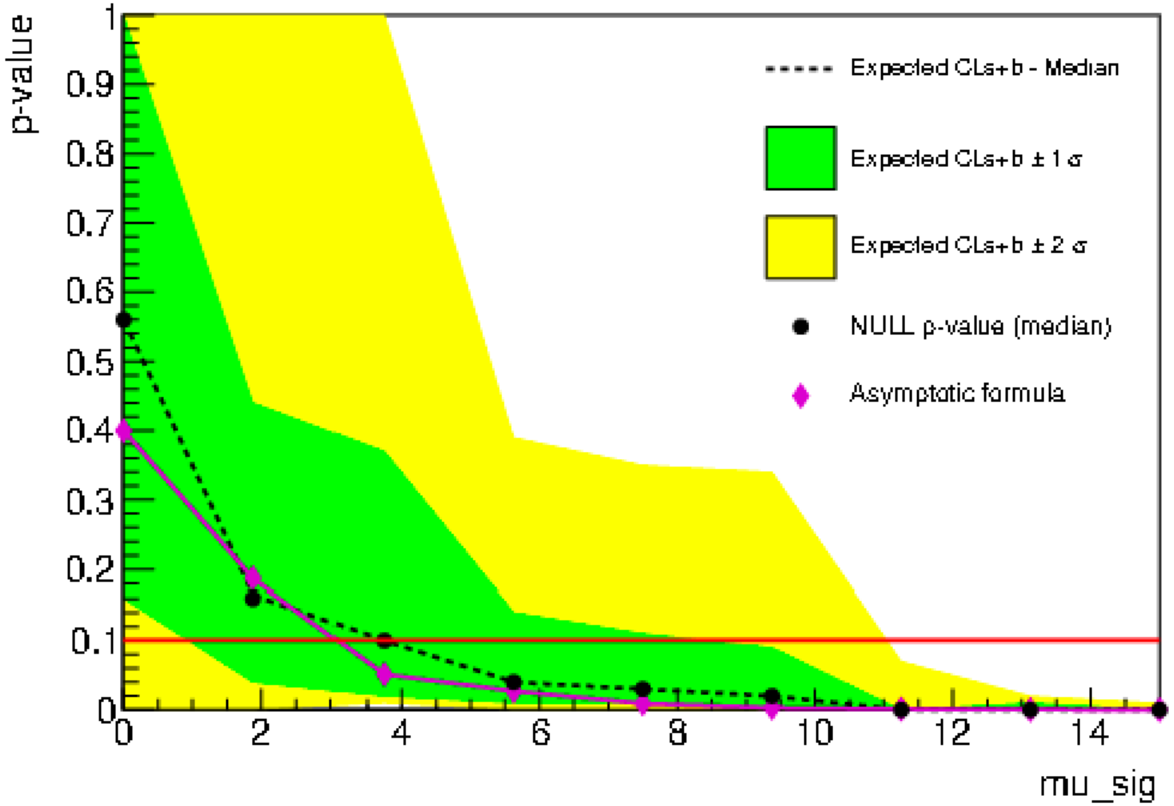
- Settings: 100 Ntoys, 1e7 samples, take 9 POI, 1000 livedays



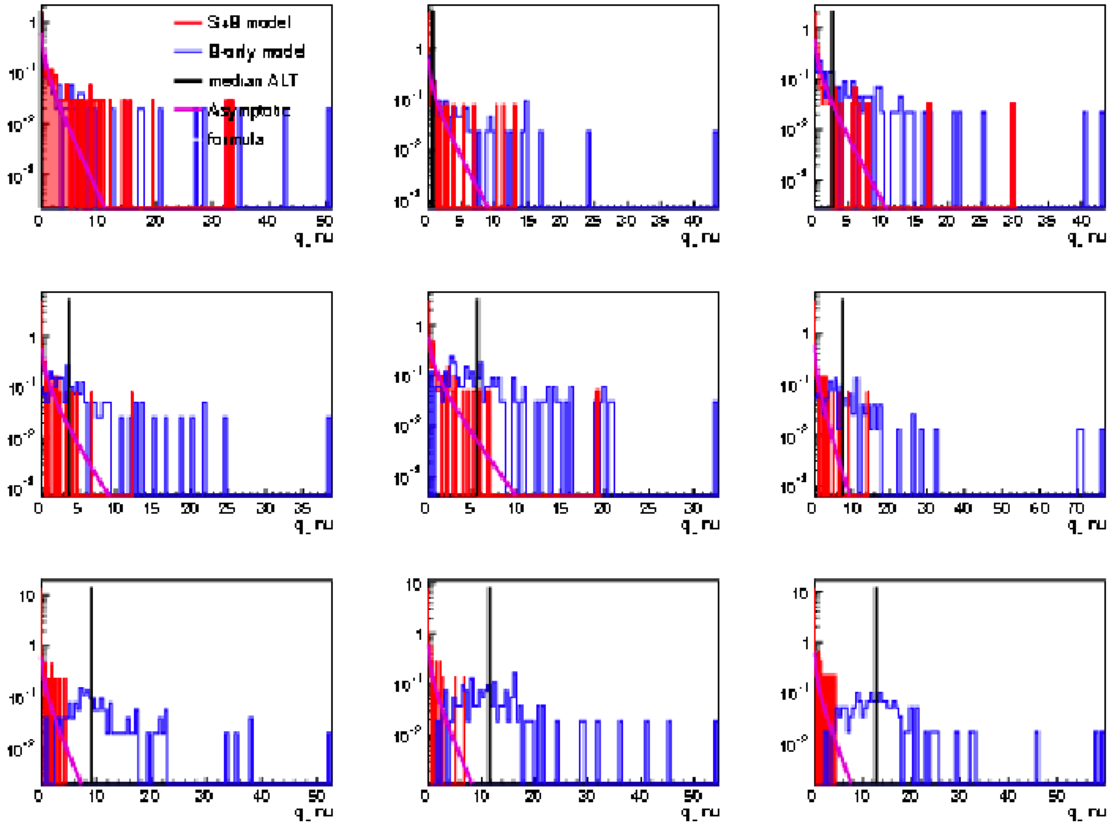
p-value
nSig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ
50% of B-only

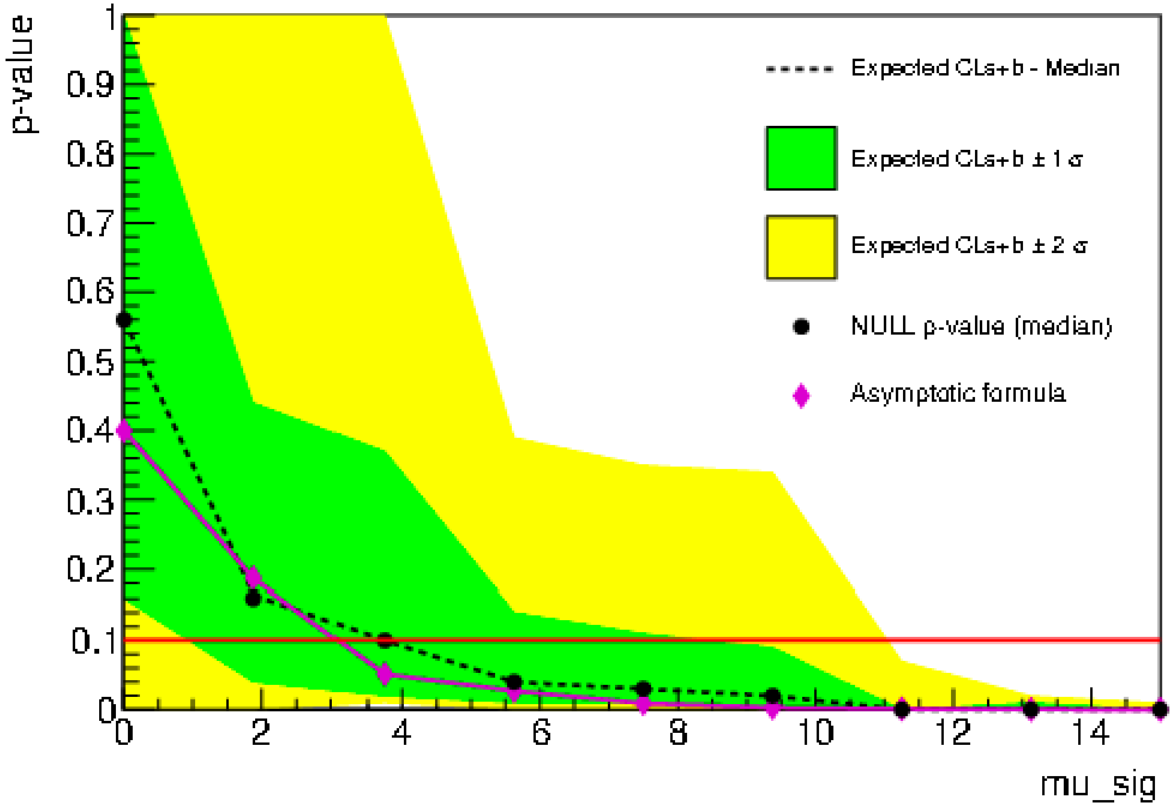
Mass = 16.2222


S+B model
B-only model
median ALT
Asymptotic formula
q_mu

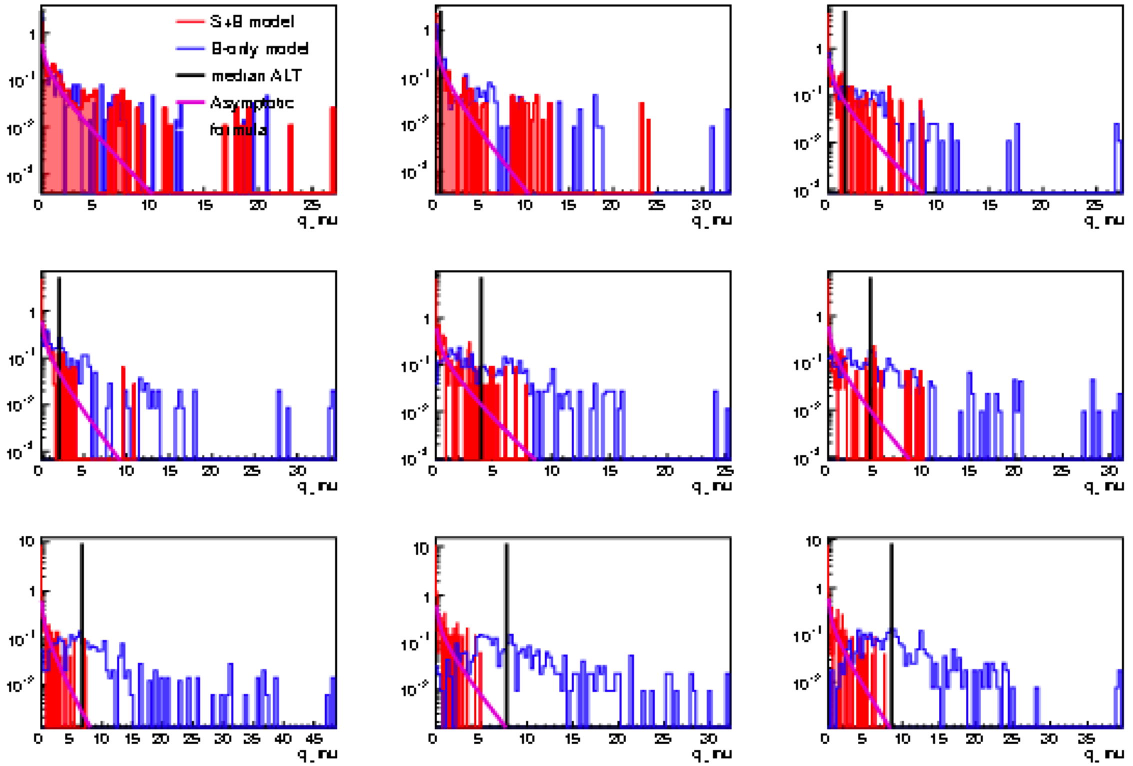

p-value
mu_sig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ
NULL p-value (median)
Asymptotic formula

Mass = 16.2222

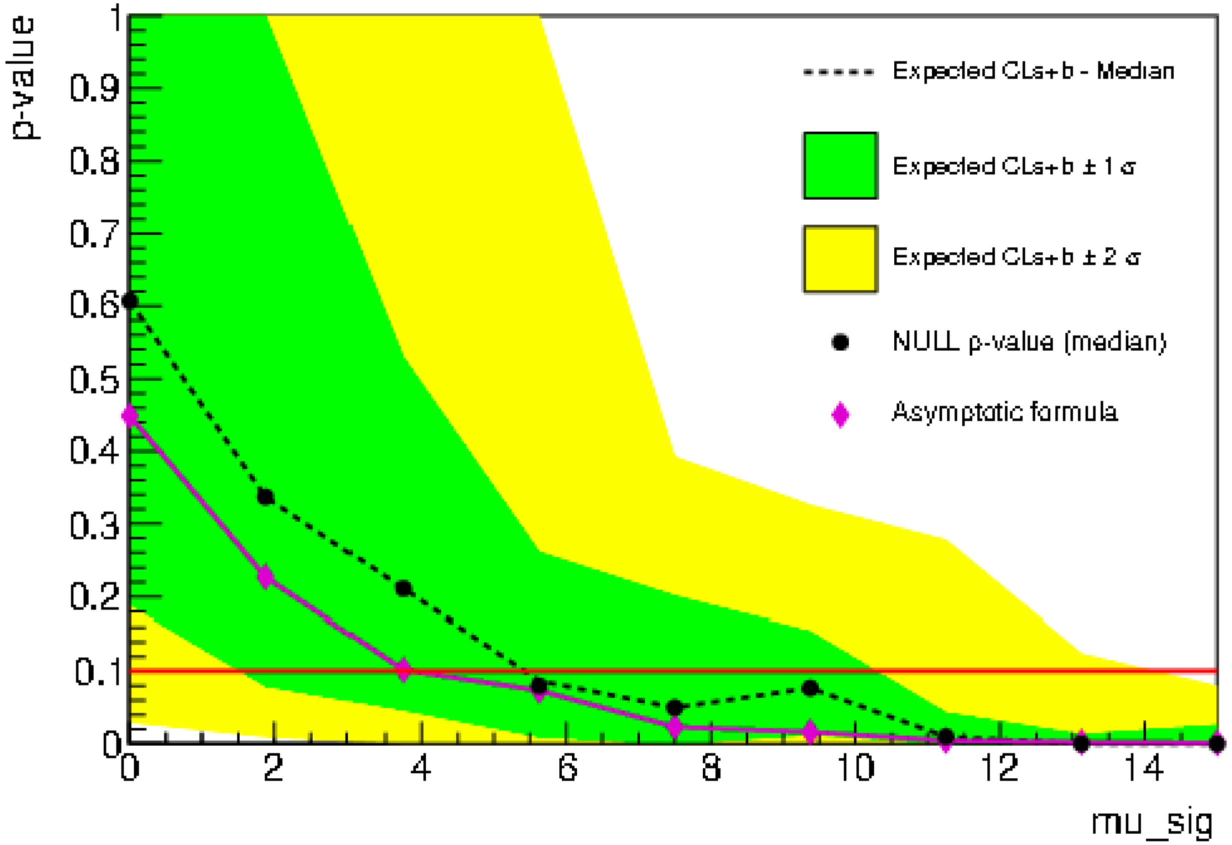

S+B model
B-only model
median ALT
Asymptotic formula
q_mu


p-value
mu_sig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ
NULL p-value (median)
Asymptotic formula

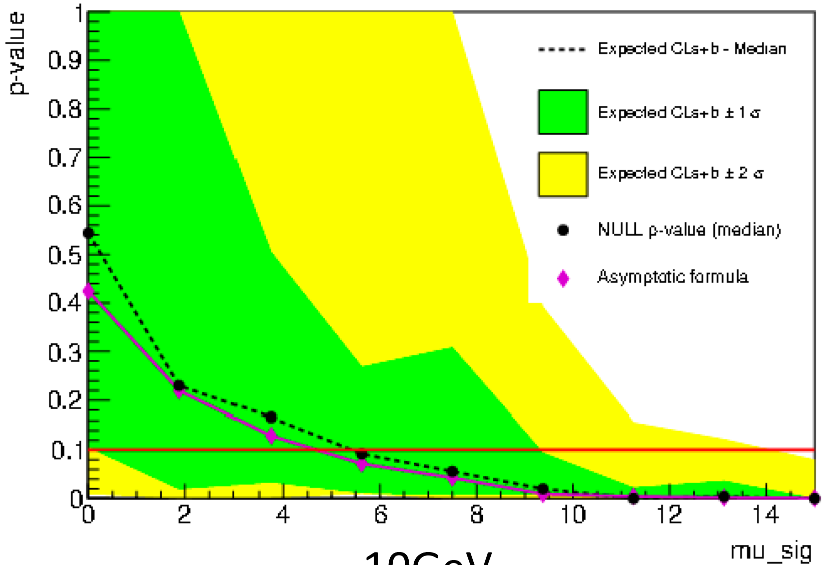
Mass = 66.6667



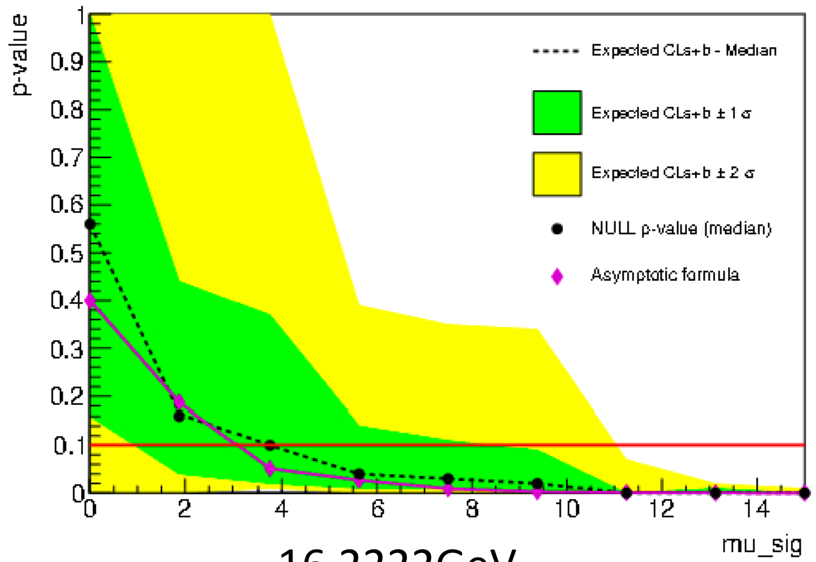
S+B model
B-only model
median ALT
Asymptotic formula
q_mu



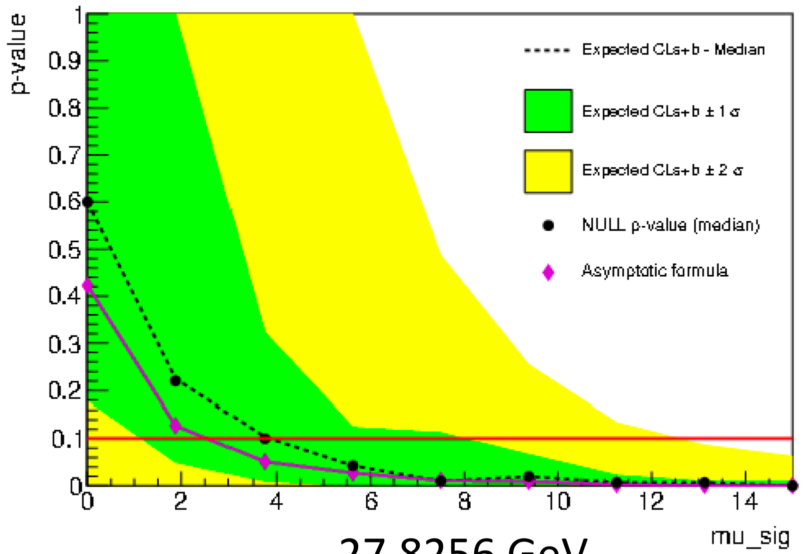
p-value
mu_sig
Expected CLs+b - Median
Expected CLs+b ± 1 σ
Expected CLs+b ± 2 σ
NULL p-value (median)
Asymptotic formula



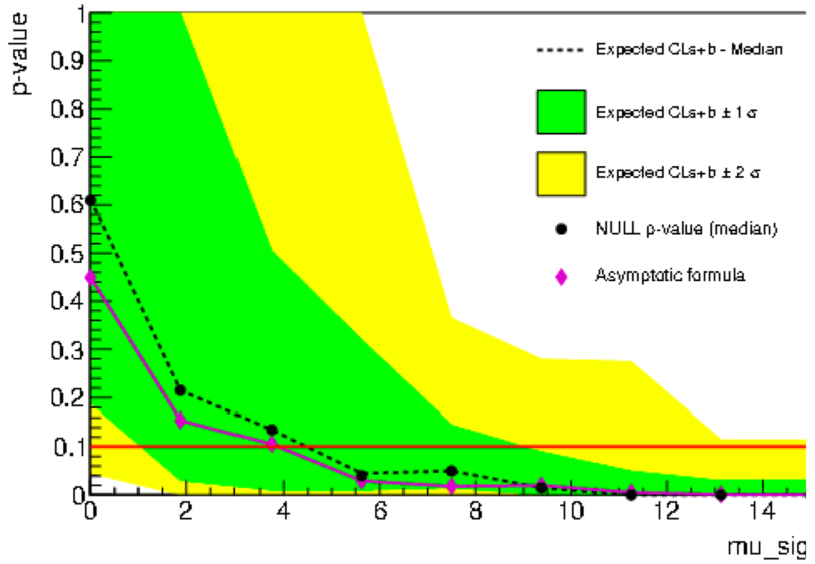
10GeV



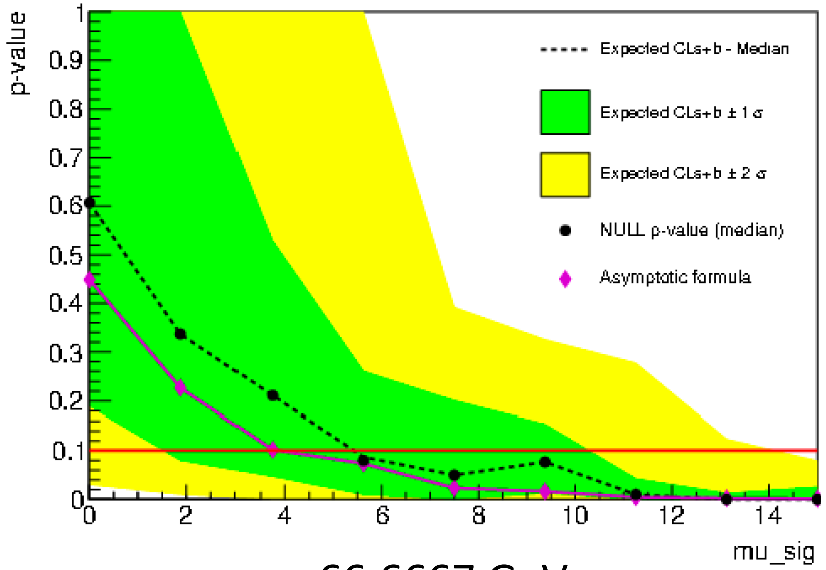
16.2222GeV



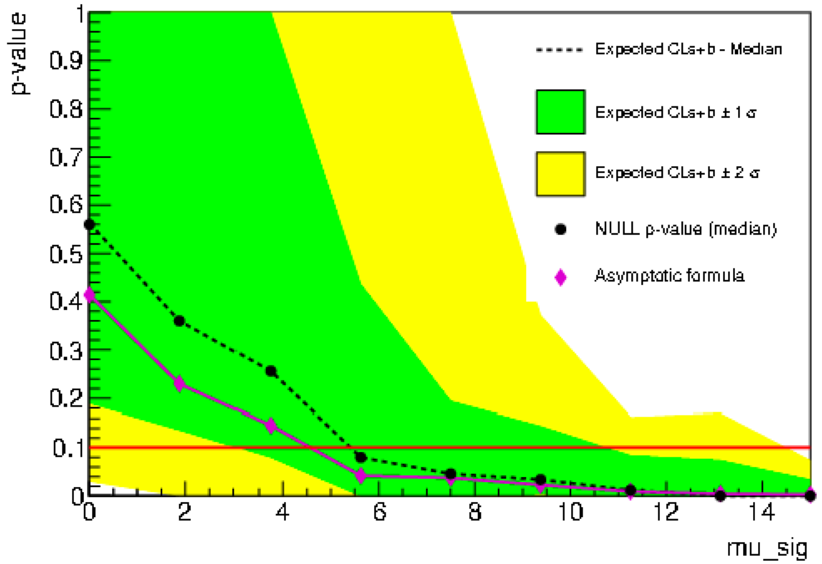
27.8256 GeV



46.4159 GeV

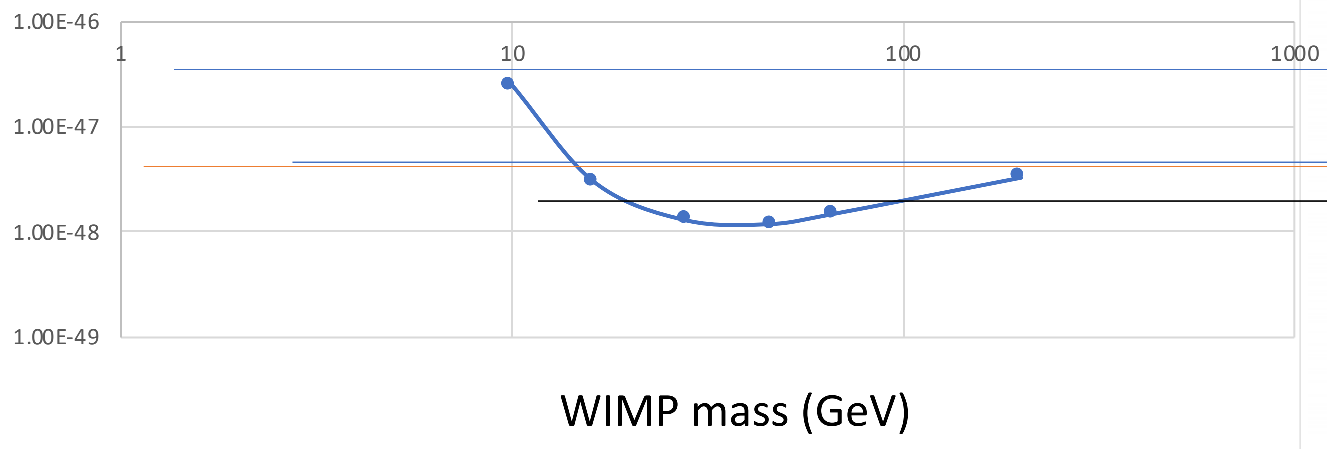


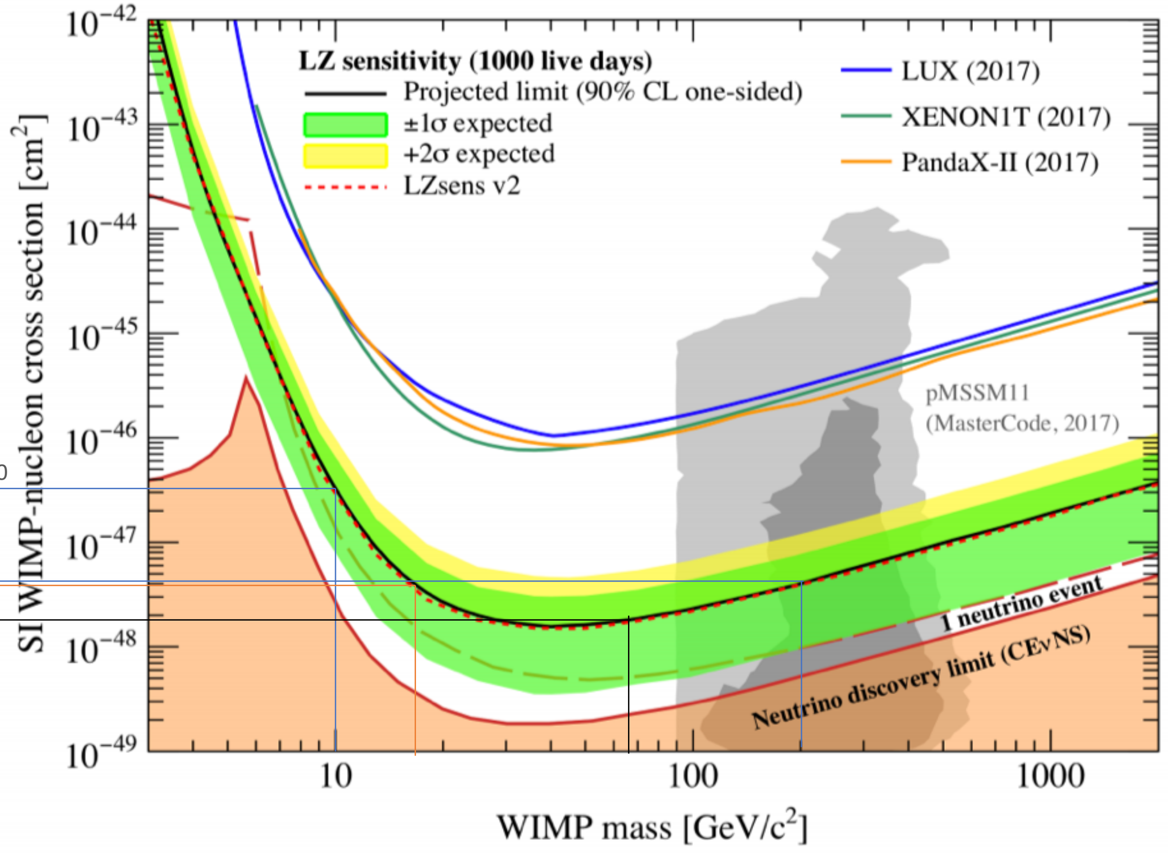
66.6667 GeV



200 GeV

log scale lz sensitivity :





Understanding the structure of LZStats

- **Submit_MassJobs.sh:**
  - calls for the other two scripts, the one that submits jobs to the cluster
  - Kr mass = 2.0000 & 66.6667
  - #jobs for each mass = 10
- **runWiscJobs.py:**
  - Defines variables and parameters for a job running
- **Submit_lzstats.sh:**
  - When run Submit_MassJobs.sh, each job runs this script on the cluster
- **Setup.sh:**
  - set up the environment

Problem

- For one mass, when extracting 10 tar.gz files, only get one result "…run1"
- Check the error text, ImportError

```
ImportError: /cvmfs/lz.opensciencegrid.org/external/Python/2.7.15/x86_64-centos7
-gcc7-opt/lib/python2.7/lib-dynload/array.so: undefined symbol: _PySlice_Unpack
Info in <RooWorkspace::SaveAs>: ROOT file ./output/lzstats-LZ projected 1e7-WIMP
```

- Ask Jonathan:
  - For the Jobs submitted to the cluster, the python cannot load the yaml package → unable to change the run number → all the runs have the same run number, run1
- The yaml package is exported in setup.sh