ISTEP2015 Tutorial

Zprime Searches at 13TeV pp Collider

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1. Introduction

Various extensions of the Standard Models predict the existence of new kinds of heavy gauge bosons [1], either neutral (Z') or charged (W'). Due to their simplicity and clean signature in leptonic decay, searches for Z' and W' serve as the benchmark to examine the potential of future high energy colliders.

In this study, we are particular interested in the Sequential Standard Model (SSM)[2]. The SSM Z' is a carbon copy of SM Z boson with the same couplings, but only with a heavier mass. In SSM, Z' is created through qqbar annihilation and then decays with decay width Gamma(Z')~0.03MZ'.

A search for new high-mass narrow resonances in dimuon and dielectron invariant mass spectra has been obtained at the 7 and 8TeV LHC. With about 20fb-1 of 8TeV data, the 95% CL lower limits on SSM Z' mass are 2.90TeV from ATLAS [3] and 2.90TeV from CMS [4]. The US Snowmass report [5] presented the ability to exclude a Z' at collision energy of 14/33 TeV with 300/3000fb-1 of collected data. The 95% CL lower mass limits for SSM Z' mass is 6.44 TeV given 300fb-1 at sqrt(s)=14TeV.

[1] see e.g. arXiv:0801.1345; *sites.google.com/site/**z**prime**guide***
[2]G. Altarelli et.al., Z. Phys. C45 (1989) 109; V. Barger, W.Y. Keung, Phys.Lett. B94 (1980) 377-380.
[3] arXiv:1405.4123
[4] arXiv:1412.6302
[5] arXiv:1308.5874

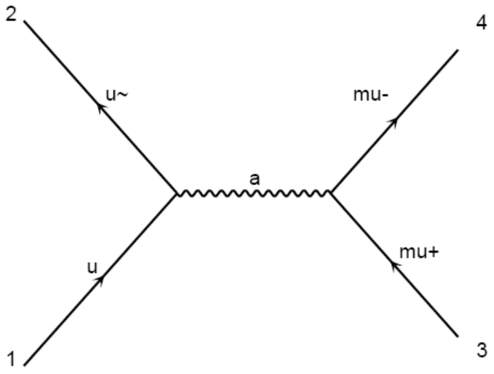


diagram 1 QCD=0, QED=2

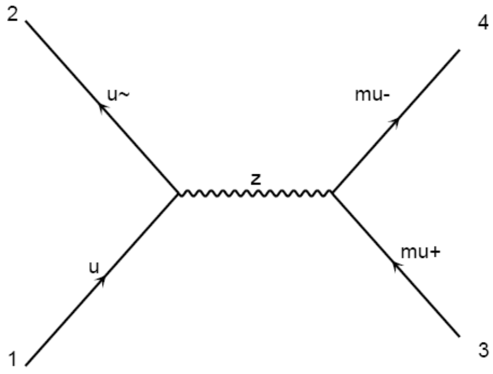


diagram 2 QCD=0, QED=2

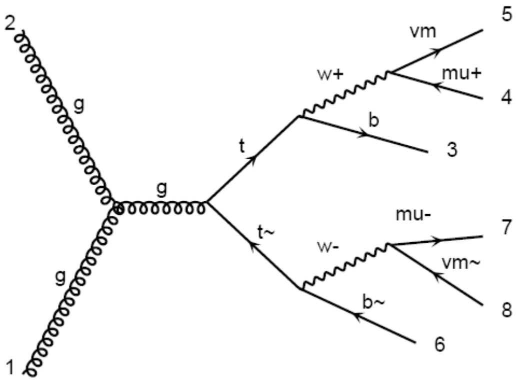


diagram 1 QCD=2, QED=4

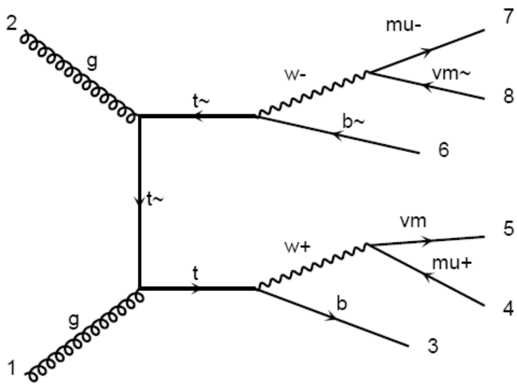


diagram 2 QCD=2, QED=4

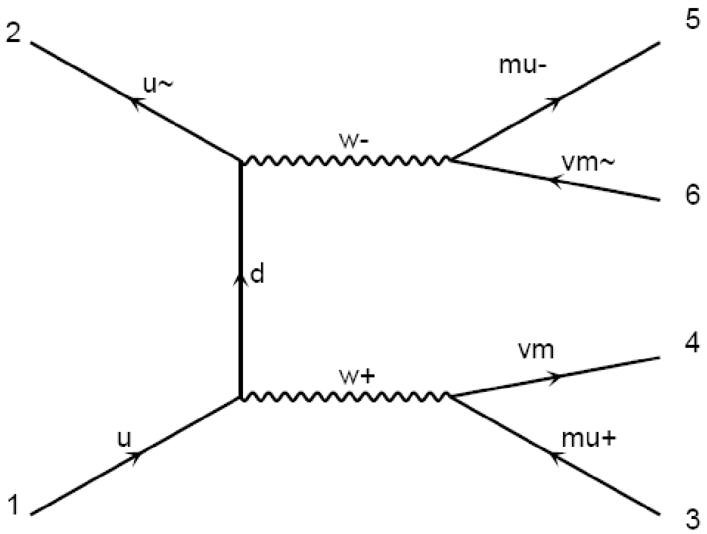


diagram 3 QCD=0, QED=4

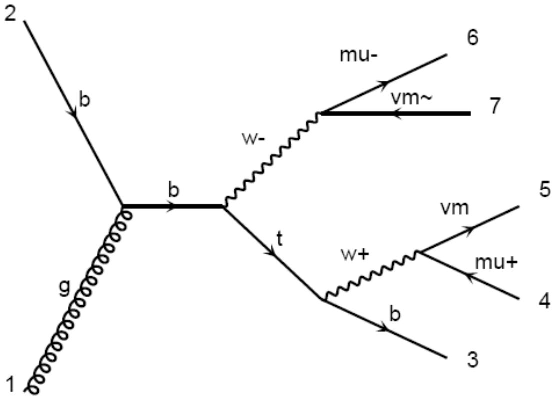


diagram 1 QCD=1, QED=4

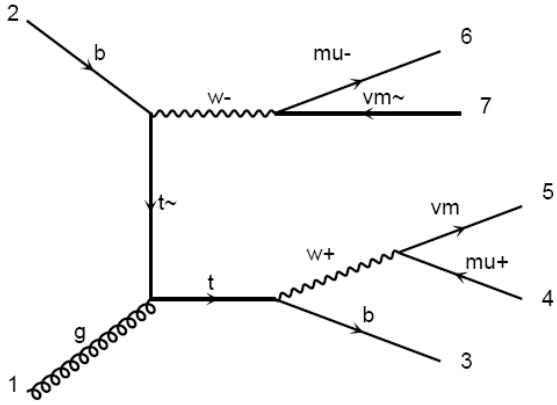


diagram 2 QCD=1, QED=4

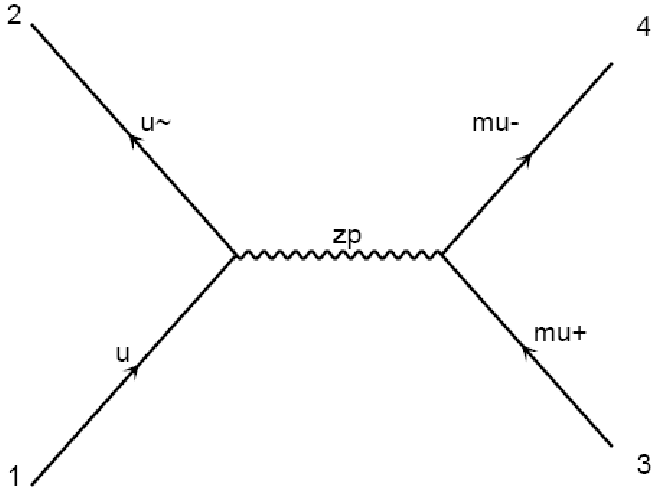
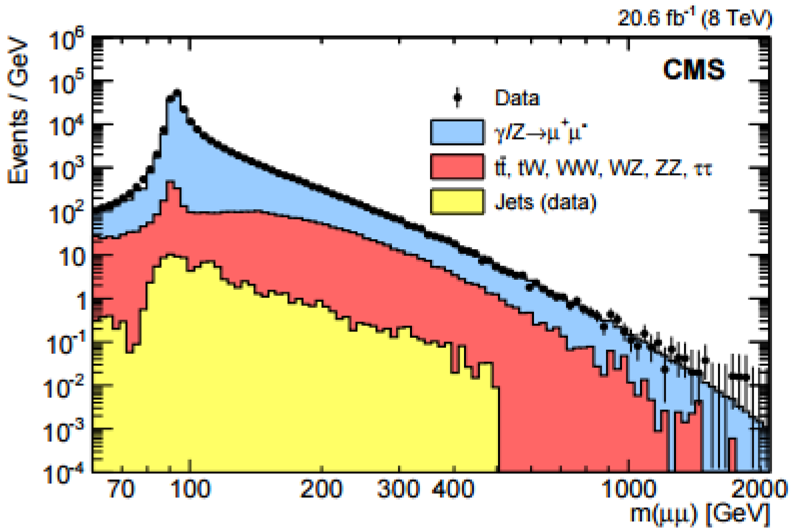
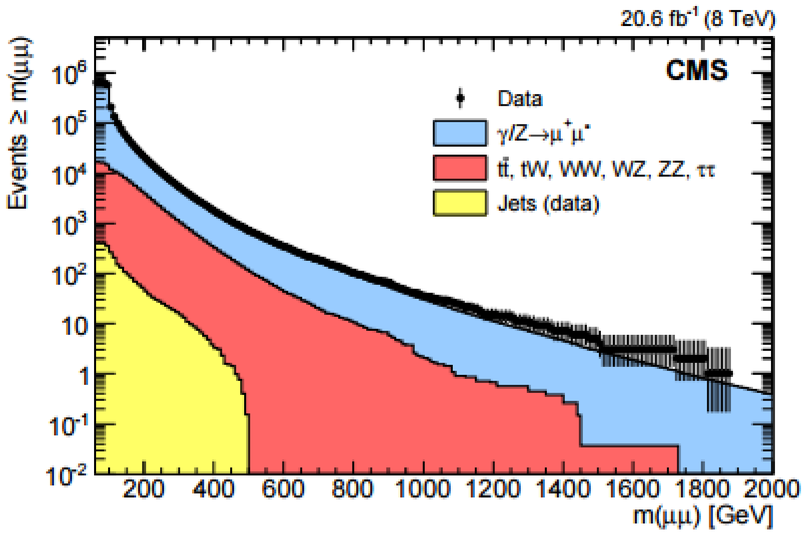


diagram 1 QCD=0, QED=2

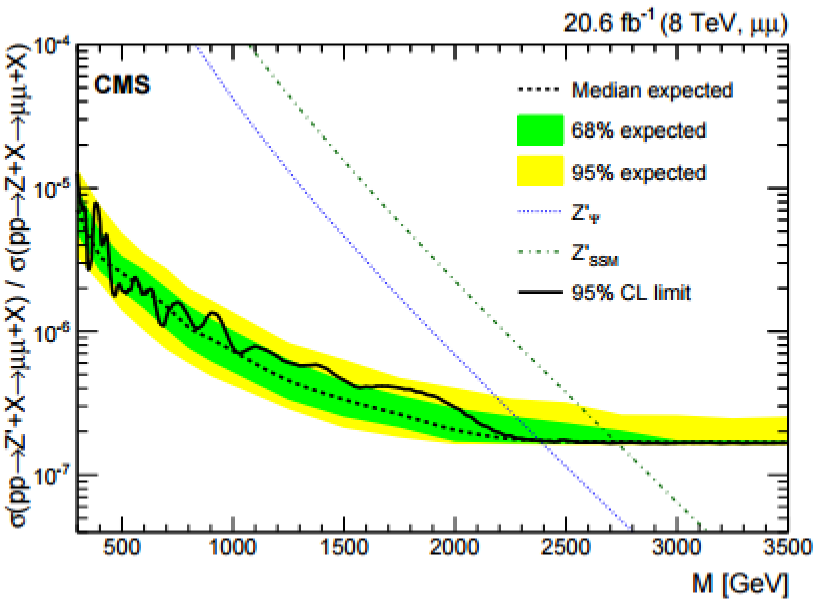
Mll distributions



Cumulative Mll distributions



CMS 8TeV mu-channel Limit plot



2. MG5_aMC@NLO and Zprime

Download MG5_aMC@NLO, “./bin/mg5”, “turorial”, get familiar with it; “install pythia-pgs”, “install ExRootAnalysis”, “install Delphes”
We provide the Z' model directory “sm-ZP”, please put it under “models” in MG package;

2.1 /users/liqiang/istep2015/CEPC-DATA/Analysis/package/ @whale12.hepg.sdu.edu.cn
2.2 goto MG webpage http://madgraph.hep.uiuc.edu/
2.3 ask for USB transfer

generate pp>Zp>mu+mu- with CTEQ6L1, Switch on Pythia, cuts on PTl>10GeV, |etal|<3., Mll>900GeV
For your refs:

MZ'(GeV)	Width(GeV)	Xsec (pb)
2000	59.8	0.01558 +- 2.035e-05 pb
2100	62.8	0.01206 +- 1.673e-05 pb
2200	65.8	0.009381 +- 1.327e-05 pb
2300	68.8	0.007326 +- 1.001e-05 pb
2400	71.8	0.005759 +- 8.379e-06 pb
2500	74.8	0.004547 +- 6.202e-06 pb
2600	77.8	0.003591 +- 5.353e-06 pb
2700	80.8	0.002864 +- 5.067e-06 pb
2800	83.8	0.002286 +- 4.031e-06 pb
2900	86.9	0.001829 +- 3.202e-06 pb
3000	89.9	0.001466 +- 2.782e-06 pb
3100	92.9	0.00118 +- 2.559e-06 pb
3200	95.9	0.0009568 +- 1.963e-06 pb
3300	98.9	0.0007717 +- 1.622e-06 pb
3400	101.9	0.0006258 +- 1.708e-06 pb
3500	104.9	0.0005123 +- 1.173e-06 pb
3800	113.9	0.0002796 +- 3.864e-07 pb
4000	119.9	0.0001894 +- 3.144e-07 pb
4500	134.9	7.523e-05 +- 1.546e-07 pb

3. ISTEP2015 Basic Tutorials

/users/liqiang/istep2015/CEPC-DATA/Analysis/ @whale12.hepg.sdu.edu.cn
Or Ask for USB transfer
ISTEP2015 Zprime search MC samples are stored here
/users/liqiang/istep2015/CEPC-DATA/Analysis/data

DY 80K, 0.007476 +- 6.427e-06 pb
TTbar 40K, 0.0007598 +- 1.198e-06 pb
TW 10K, 8.888e-05 +- 2.135e-07 pb
WW 40K, 0.000338 +- 3.497e-07 pb
Note all these samples are applied with Mll>900GeV, assuming this is a special trigger of 2 muons with invariant mass larger than 900GeV.

We also provide signal samples for Z' mass from 2TeV to 4.5TeV, each with 10K.

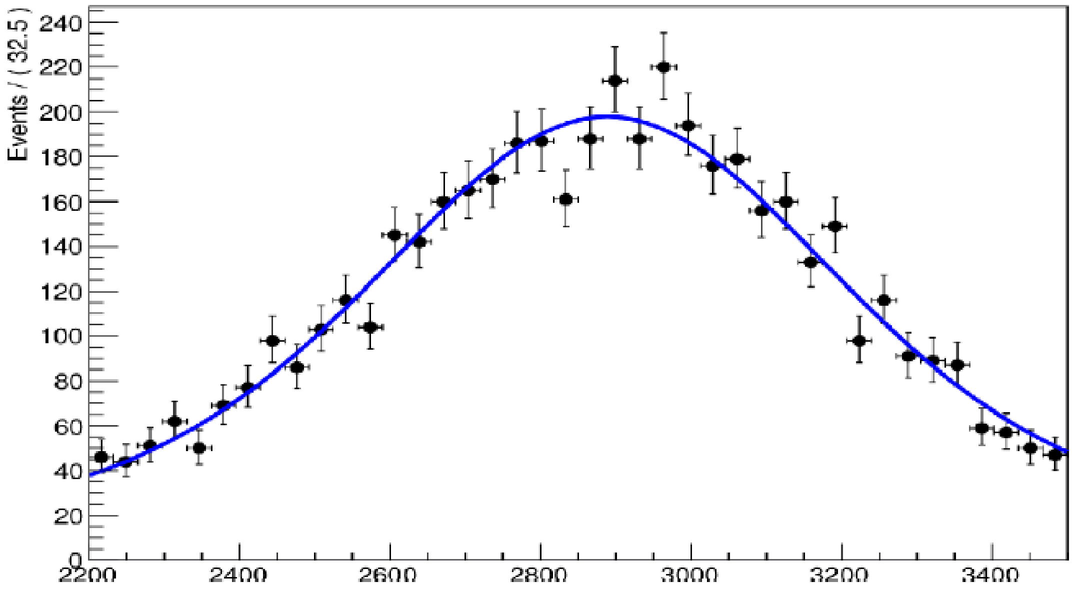
3.0 run "bash runntuple.sh" (which calls ntuple_chain.C), to get Ntuples from above
You need to reset root and Delphes library path in the root macro.
If you don't know how, you can skip this step and go to next step

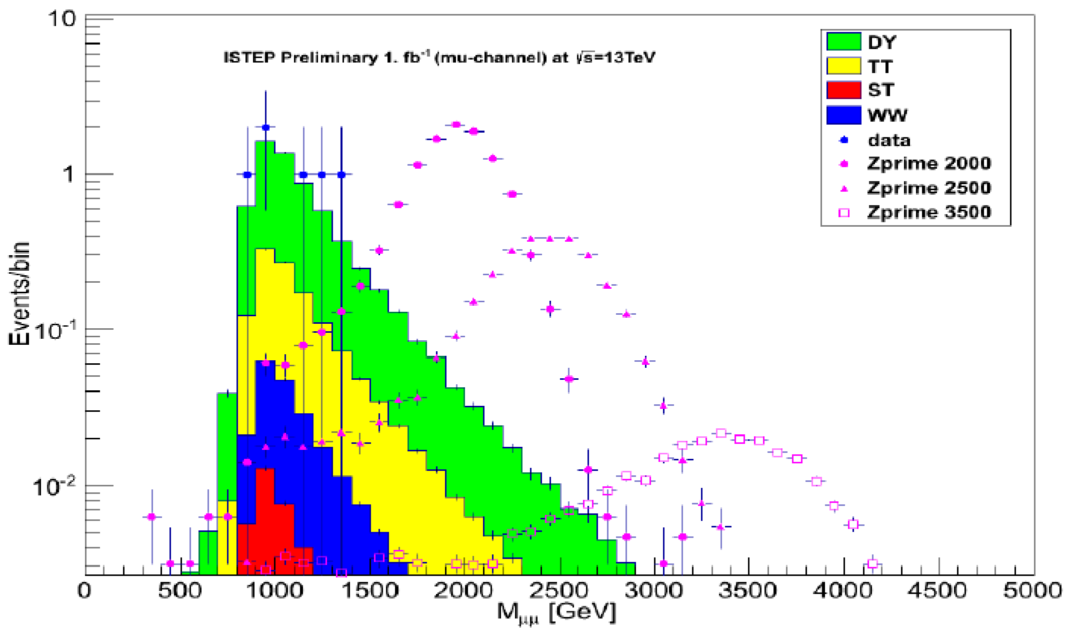
Starting from /users/liqiang/istep2015/CEPC-DATA/Analysis/ntuple
3.1 Run ".x producehiso.C" to get Mll histograms. (Lumi weights are applied inside. You can adjust luminosity and others). You will get the output figure and out.root files.

3.2 We also provide "data" with 1fb-1 and 10fb-1, named as "outdata.root"
Stored here /users/liqiang/istep2015/CEPC-DATA/Analysis/ntuple-data-tree
3.3 Use fit2.C to fit Signal (use Ntuples from (3.1)) , please adjust the fit parameters: root -b -q fit2.C\(\"ZP3000\"\)
3.4 Use out.root and outdata.root from above, draw Data/MC comparisons with plot.C. Please also plot PT_ll and cumulative Mll plots
3.5 Use cutcounting.C to perform simple statistic studies.
3.6 Read ATLAS and CMS Z' papers and prepare your reports

Please refer to Siguang and Glen's lectures

Example Plots:





5. Advanced Projects

5.1 If We know DATA/MC has different Muon Identification Efficiency, and we have already measured the DATA/MC Scale Factors as:

0.99 for Muon PT>60 GeV, |eta|<1.5
0.95 for Muon PT>60 GeV, 2.5>|eta|>1.5
0.97 for Muon PT in [15-60] GeV, |eta|<1.5
0.92 for Muon PT in [15-60] GeV, 2.5>|eta|>1.5

Can you apply these SF on MC samples?

5.2 Muon Selection efficiency? (You can compare Generator Muon and Reconstruction Muon.)

5.3 We only consider WW but not WZ or ZZ for the diboson contributions, can you give an estimate how much WZ or ZZ contribute?

5.4 Shape Analysis instead of Cut/counting?

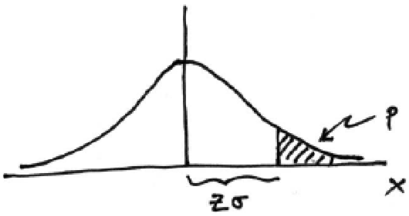
5.5 Signal selection efficiency for every mass points? Compare with ATLAS/CMS papers.

5.6 Bkg fitting?

You can think and test more

Significance from p-value

Often define significance Z as the number of standard deviations that a Gaussian variable would fluctuate in one direction to give the same p-value.



$$p = \int_Z^\infty \frac{1}{\sqrt{2\pi}} e^{-x^2/2}\, dx = 1 - \Phi(Z)$$ **1 - TMath::Freq**

$$Z = \Phi^{-1}(1-p)$$ **TMath::NormQuantile**

E.g. $Z = 5$ (a "5 sigma effect") corresponds to $p = 2.9 \times 10^{-7}$.

Frequentist upper limit on Poisson parameter

Consider again the case of observing $n \sim \text{Poisson}(s + b)$.

Suppose $b = 4.5$, $n_{\text{obs}} = 5$. Find upper limit on s at 95% CL.

Relevant alternative is $s = 0$ (critical region at low n)

p-value of hypothesized s is $P(n \le n_{\text{obs}}; s, b)$

Upper limit s_{up} at CL = $1 - \alpha$ found from

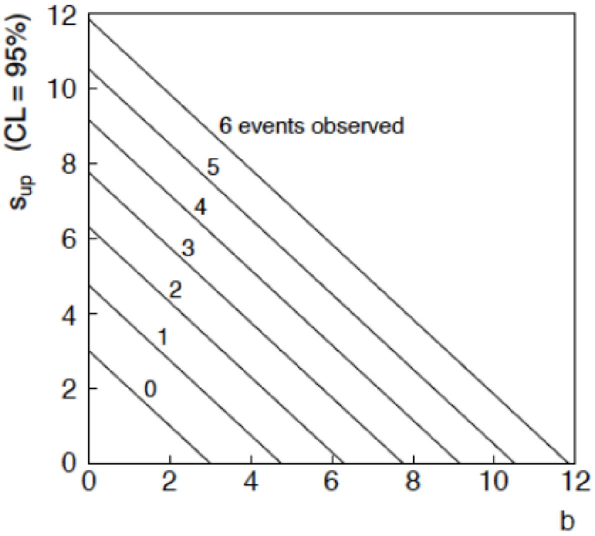
$$\alpha = P(n \le n_{\text{obs}}; s_{\text{up}}, b) = \sum_{n=0}^{n_{\text{obs}}} \frac{(s_{\text{up}} + b)^n}{n!} e^{-(s_{\text{up}}+b)}$$

$$s_{\text{up}} = \frac{1}{2} F^{-1}_{\chi^2}(1 - \alpha; 2(n_{\text{obs}} + 1)) - b$$

$$= \frac{1}{2} F^{-1}_{\chi^2}(0.95; 2(5+1)) - 4.5 = 6.0$$

n ~ Poisson(s+b): frequentist upper limit on s

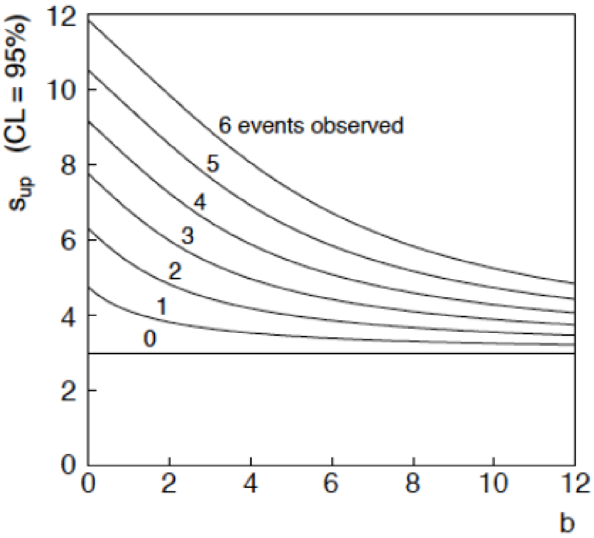
For low fluctuation of n formula can give negative result for s_{up}; i.e. confidence interval is empty.



Bayesian interval with flat prior for s

For $b > 0$ Bayesian limit is everywhere greater than the (one sided) frequentist upper limit.

Never goes negative. Doesn't depend on b if $n = 0$.



$s/\sqrt{b}$ for expected discovery significance

For large $s + b$, $n \rightarrow x \sim$ Gaussian(μ,σ) , $\mu = s + b$, $\sigma = \sqrt{(s + b)}$.

For observed value x_{obs}, p-value of $s = 0$ is Prob($x > x_{obs} \mid s = 0$),:

$$p_0 = 1 - \Phi\left(\frac{x_{\rm obs} - b}{\sqrt{b}}\right)$$

Significance for rejecting $s = 0$ is therefore

$$Z_0 = \Phi^{-1}(1 - p_0) = \frac{x_{\rm obs} - b}{\sqrt{b}}$$

Expected (median) significance assuming signal rate s is

$$\mathrm{median}[Z_0|s + b] = \frac{s}{\sqrt{b}}$$

Better approximation for significance

Poisson likelihood for parameter s is

$$L(s) = \frac{(s+b)^n}{n!} e^{-(s+b)}$$

For now no nuisance params.

To test for discovery use profile likelihood ratio:

$$q_0 = \begin{cases} -2\ln\lambda(0) & \hat{s} \geq 0\,, \\ 0 & \hat{s} < 0\,. \end{cases}$$

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

So the likelihood ratio statistic for testing $s = 0$ is

$$q_0 = -2\ln\frac{L(0)}{L(\hat{s})} = 2\left(n\ln\frac{n}{b} + b - n\right) \quad \text{for } n > b, \ 0 \text{ otherwise}$$