SSM Z' at pp collider

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Z' in Sequential Standard Model

SSM: SM + Z'(carbon copy of Z), with the same couplings constants
Not gauge invariant, thus not realistic, but useful.
$\Gamma_{Z'} \sim 0.03 M_{Z'}$;
$Br(e^+e^-/\mu^+\mu^-) \sim 3.3\%$(same as Z)

95% CL lower limits on Z'_{SSM} mass at 8TeV pp collider[1]:
muon channel: 2770GeV
barrel-barrel electron channel: 2650GeV
combined muon and electron channels: 2960GeV

Background Simulation at 8TeV

Simulation Frame: MadrGraph5 + Pythia8 + Delphes3 (No PileUp)
signal process: $pp \to Z' \to \mu^+\mu^-$; luminosity $L = 20.6/fb$
background and K-factor: Z/γ 1.3[2]; $t\bar{t}$ 1.8[3]; single top 1.6[4]; diboson(WW 1.6,WZ 1.8,ZZ 1.6)[5]; Jets and cosmic ray(ignored)[1].

Table : Number of Events in different region of invariant mass (M_{ll}) when compared with the reference[1]

Process	resource	$120 - 200GeV$	$> 200GeV$	$> 400GeV$
total	Reference	78k	20k	1.7k
	My result	68k	16k	1.4k
Z/γ	Reference	72k	16k	1.5k
	My result	63k	13k	1.2k
$t\bar{t}$	Reference	4.5k	2.6k	0.2k
	My result	4.0k	2.0k	0.1k
diboson+other	Reference	1.7k	1.0k	0.1k
	My result	1.3k	0.9k	0.1k

binned maximum likelihood[6]

Expectation value of n

$$E[n] = \mu s + b \tag{1}$$

likelihood function for μ

$$L(\mu) = \frac{(\mu s + b)^n}{n!} e^{-(\mu s + b)} \tag{2}$$

likelihood ratio

$$\frac{1}{2}\chi^2 = \ln \frac{L(1)}{L(0)} = \ln[\frac{(s+b)^n}{n!} e^{-(s+b)}] - \ln[\frac{b^n}{n!} e^{-b}] = n \ln(1 + \frac{s}{b}) - s \tag{3}$$

significance

$$\chi = \sqrt{2[n \ln(1 + s/b) - s]} \tag{4}$$

where $n = b + s$ for $\mu = 1$.
To simplify, we use only 1 bin.

significance at 8 TeV pp collider

luminosity $L = 20.6/fb$
Limit of Z' mass in reference[1] $M(Z') > 2.77TeV$
formula of significance: $\sqrt{2[(N_s + N_b)\ln(1 + \frac{N_s}{N_b}) - N_s]}$

Table : Events in mass window $M(Z') \pm 10\%$ and significance(No PileUp)

$M(Z')$(TeV)	signal(N_s)	background(N_b)	significance
2.7	2.12884	0.0526865	3.46234
2.8	1.21273	0.0370911	2.52323
2.9	0.915892	0.0265108	2.21329
3.0	0.583065	0.019821	1.718
3.1	0.38848	0.0139417	1.38904

optimizing mass window

luminosity $L = 20.6/fb$

Table : significance in different mass window

$M(Z')$	$\pm 14\%$	$\pm 16\%$	$\pm 18\%$	$\pm 20\%$	$\pm 25\%$
2.7	3.68	3.67	3.66	3.62	3.50
2.8	2.67	2.73	2.71	2.76	2.67
2.9	2.34	2.38	2.37	2.32	2.21
3.0	1.89	1.90	1.92	1.89	1.78
3.1	1.51	1.56	1.57	1.54	1.45

the most sensitive mass window: $M(Z') \pm 18\%$

Z' mass limit: $M(Z') > 3.00TeV$

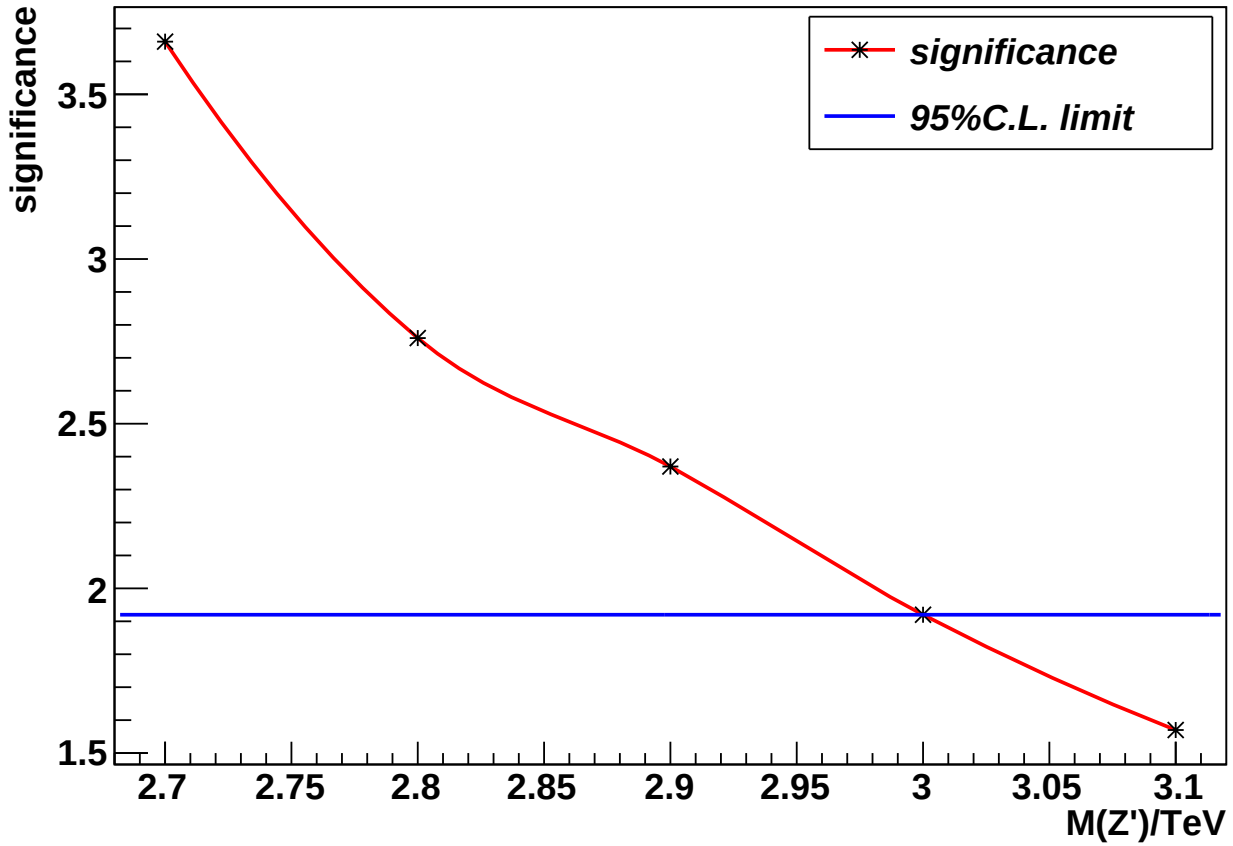

Figure : statistical signifance in mass window $M(Z') \pm 18\%$

pp collision at 14TeV

Luminosity: $L = 300/fb$, Snowmass PileUp=50
reference[7]: mass limit 6.44TeV for process $pp \to Z' \to e^+e^-$
reference[8]: mass limit 3.7TeV for process $pp \to Z' \to t\bar{t}$
My process: $pp \to Z' \to \mu^+\mu^-$

Table : Events and significance in mass window $M(Z') \pm 10\%$

	No PileUp			0PileUp	50 PileUp		
$M_{Z'}(TeV)$	N_s	N_b	signif	N_s	N_s	N_b	signif
5.0	1.93	0.068	3.10	9.43	9.28	0.16	7.64
5.3	0.987	0.045	2.12	4.98			
5.5	0.603	0.032	1.61	3.38	3.34	0.062	4.53
6.0	0.179	0.013	0.824		1.16	0.023	2.64
6.5	0.0626	0.0047	0.484	0.414	0.417	0.0076	1.60

Events when piling up are more than No PileUp

reason :Muon Efficiency when No PileUp(in default Delphes Card) different from Snowmass 50PileUp Card

Table : comparing of muon efficiency in two cards

$\|\eta\|$ range	p_T/GeV range	default(No PU)	50 PileUp
	$p_T < 10$	0	0
$\|\eta\| < 1.5$	$10 < p_T < 1.0e3$	0.95	0.99
	$p_T > 1.0e3$	$0.95\exp(0.5 - \frac{p_T}{2.0e3})$	0.99
$1.5 < \|\eta\| < 2.4$	$10 < p_T < 1.0e3$	0.95	0.97
	$p_T > 1.0e3$	$0.95\exp(0.5 - \frac{p_T}{2.0e3})$	0.97
$\|\eta\| > 2.4$		0	0

e.g. when $p_T = 10TeV$, efficiency=0.11 when No PileUp while 0.97 in snowmass 50PileUp card

Z' mass limit at 14TeV: $M(Z') > 6.30TeV$

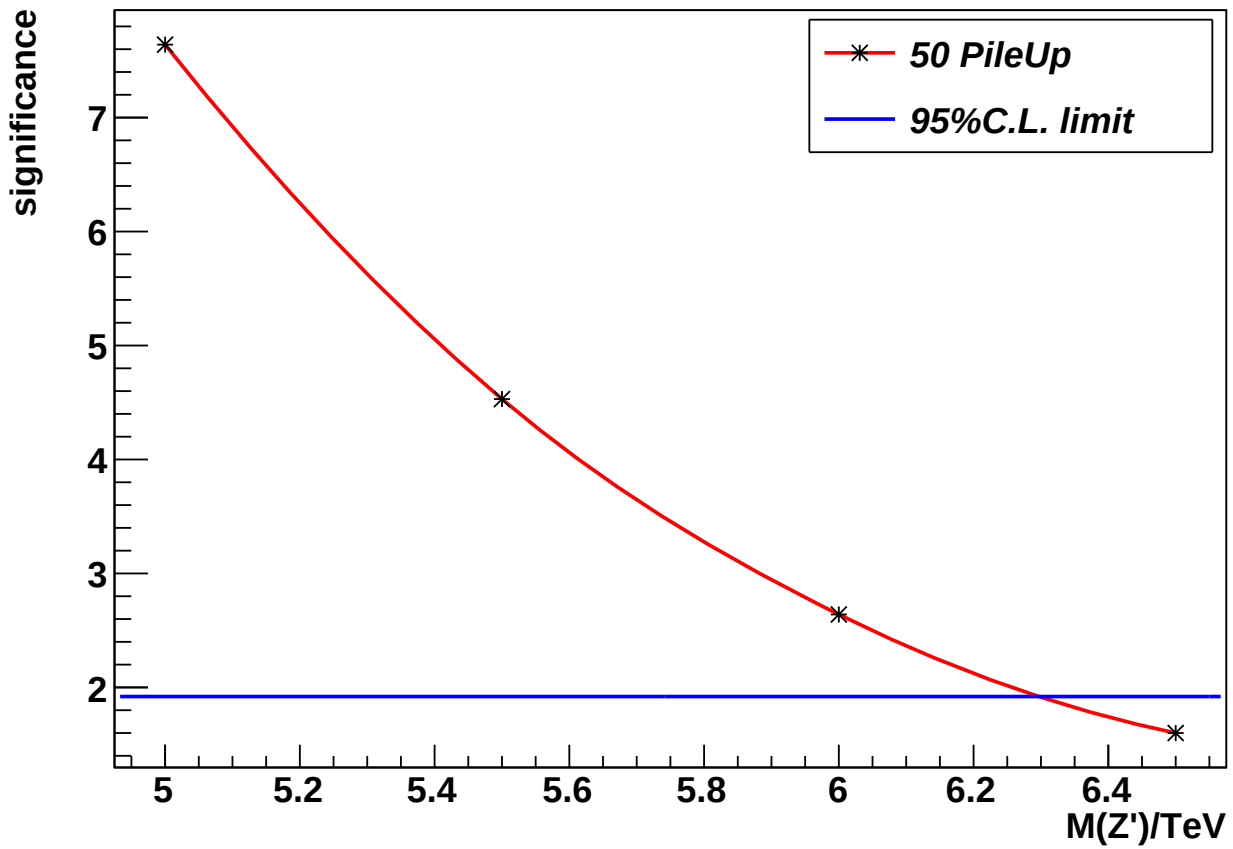

Figure : statistical signifance in mass window $M(Z') \pm 10\%$

100TeV

signal $p + p \to Z' \to \mu^+ + \mu^-$ at 100TeV
Luminosity: $L = 1000 fb^{-1}$
PileUp=140

Table : Events in mass window $M(Z') \pm 10\%$

$M(Z')(TeV)$	N_s	N_b	signif
30	2.09021	0.0333	3.63
32	1.16936	0.02027	3.68
33	0.876628	0.01519	2.32
34	0.662394	0.01172	2.01
35	0.496358	0.00884	1.74

optimizing mass window

Table : significance in different mass window

$M(Z')(TeV)$	$\pm 5\%$	$\pm 8\%$	$\pm 9\%$	$\pm 10\%$	$\pm 11\%$	$\pm 15\%$
32	2.41	2.67	3.68	2.68	2.68	2.61
33	2.12	2.29	2.31	2.32	2.31	2.25
34	1.82	1.99	2.00	2.01	2.01	1.95
35	1.58	1.72	1.74	1.74	1.73	1.67

the best sensitive mass window is $M(Z') \pm 10\%$

Z' mass limit at 100TeV: $M(Z') > 34.2TeV$

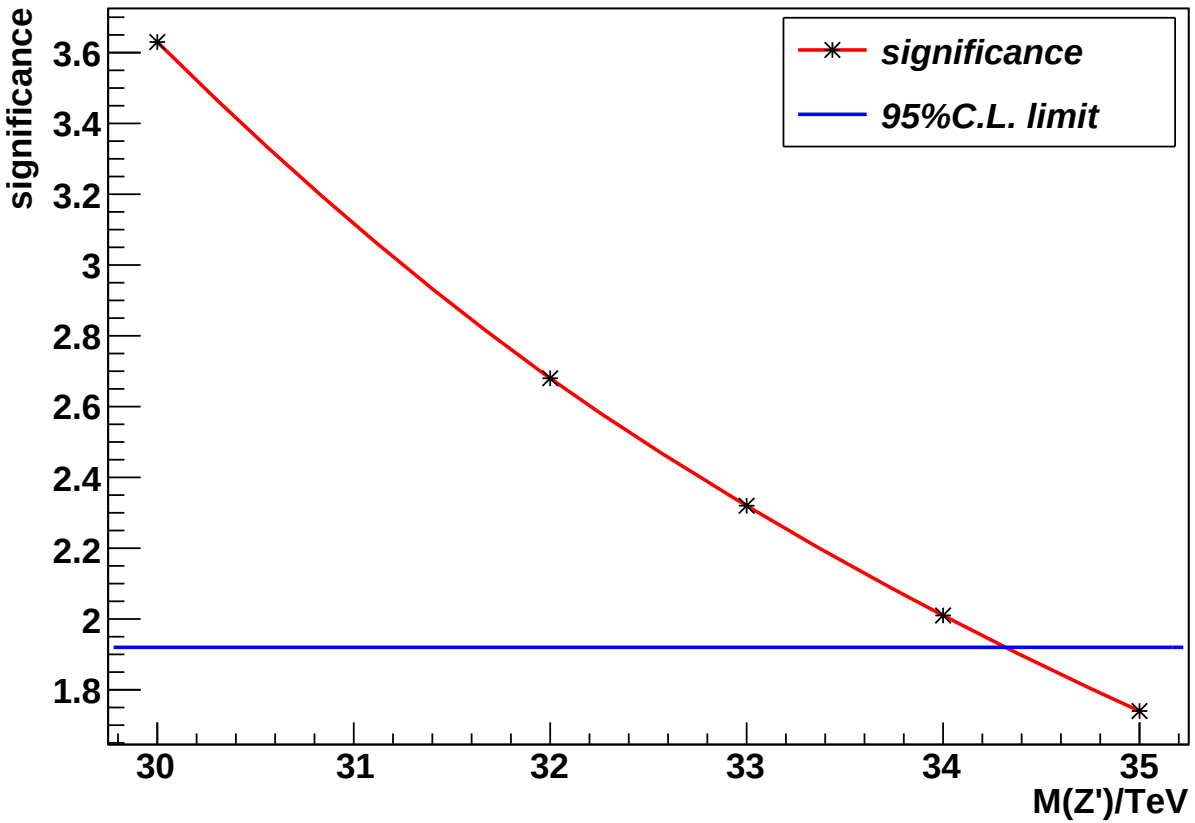

Figure : statistical signifance in mass window $M(Z') \pm 10\%$

Conclusion

$\sqrt{s} = 8TeV, \mathcal{L} = 20.8fb^{-1}$, No PU, 95%CL limit: $M(Z') > 3.0TeV$, Reference[1] Result: 2.77TeV

$\sqrt{s} = 14TeV, \mathcal{L} = 300fb^{-1}$, 50 PU, 95%CL limit: $M(Z') > 6.3TeV$, Reference[7] Result: 6.44TeV

$\sqrt{s} = 100TeV, \mathcal{L} = 1000fb^{-1}$, 140PU, 95%CL limit: $M(Z') > 34.3TeV$

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