Collider Signatures of the SO(5)xU(1) Gauge-Higgs Unification

田中 実

大阪大学

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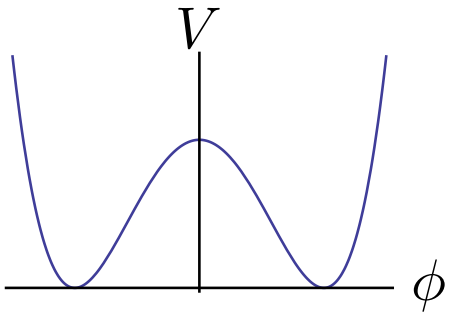
共同研究者　細谷 裕, 植草宣弘

Introduction

Electro-Weak Symmetry Breaking

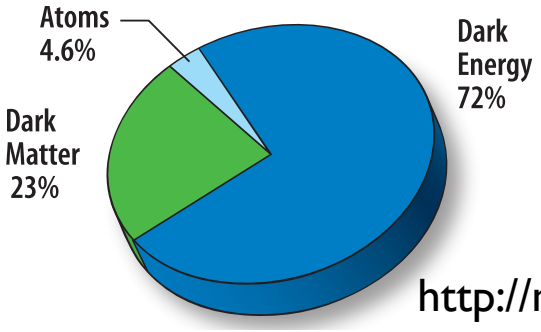


Higgs mechanism: Not seen yet.

Naturalness and hierarchy problem: New physics?

Dark Matter

WIMP?



http://map.gsfc.nasa.gov/

A possible solution: Dark Higgs scenario

Stable Higgs in gauge-Higgs unification

Y. Hosotani, P. Ko, MT(PLB680,179,2009)

How do we confirm it?

Collider phenomenology based on H parity

definite H parity for each 4d particle

Nontrivial signals

Higgs pair production

H-even KK Z production

etc.

Model

Hosotani, Oda, Ohnuma, Sakamura, PRD78,096002(2008).

$SO(5) \times U(1)$ in 5D warped space-time.

EWSB by Hosotani mechanism.

4D Higgs field: Wilson line phase,

$$\hat{\theta}_H(x) = \theta_H + \frac{H(x)}{f_H} \,. \qquad f_H \simeq 246\,\mathrm{GeV}$$

→ A new dynamical parity, H-parity,

$$H(x) \to -H(x) \,.$$

KK modes: H-even towers and H-odd towers

Y. Hosotani, MT, N. Uekusa, PRD82, 115024(2010).

Model parameters

EW parameters: $k,\ g_A,\ g_B,\ z_L = e^{kL}$

EW inputs: $m_Z,\ \alpha,\ \sin^2\theta_W$

$$z_L \longrightarrow m_H$$

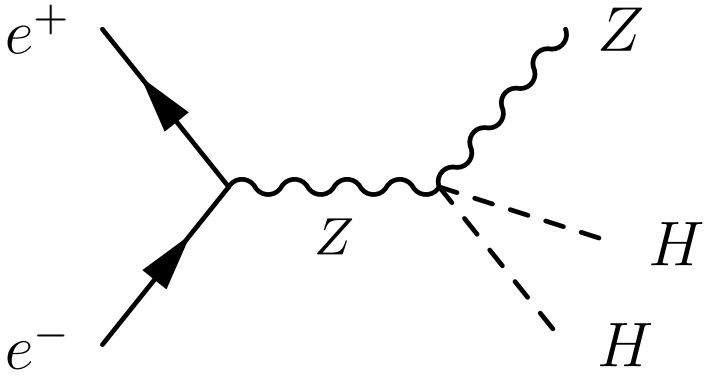
$z_L = e^{kL}$	$\sin^2\theta_W$	$k(\mathrm{GeV})$	$m_{\mathrm{KK}}(\mathrm{GeV})$	c_{top}	$m_H(\mathrm{GeV})$	$m_W^{\mathrm{tree}}(\mathrm{GeV})$
10^{15}	0.2312	4.666×10^{17}	1,466	0.432	135	79.82
10^{10}	0.23	3.799×10^{12}	1,194	0.396	108	79.82
10^{5}	0.2285	2.662×10^{7}	836	0.268	72	79.70

	# data	$z_L = 10^{15}$	10^{10}	10^{5}	SM
$\sin^2\theta_W$		0.2309	0.2303	0.2284	0.2312
χ^2 $[A_{FB}]$	6	6.30441	6.43451	7.12513	10.8335
χ^2 [Z decay]	8	16.5153	37.6908	184.468	13.6264
χ^2 [sum]	14	22.8197	44.1253	191.593	24.4599

Higgs pair production at Linear Collider

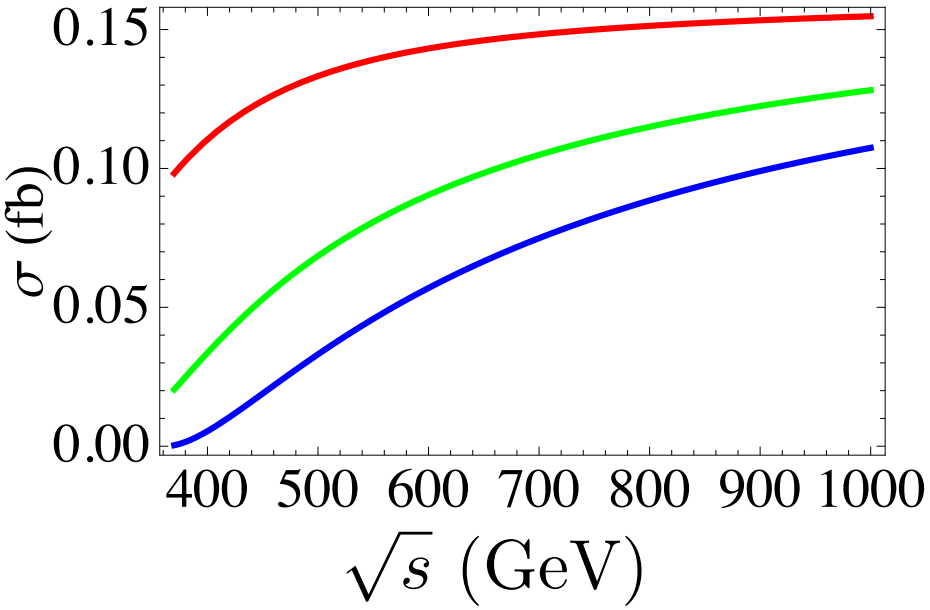
Signal: $e^+e^- \to ZHH$

H's are missing.



total cross section for

$m_H = 72,\ 108,\ 135\,\mathrm{GeV}$



Z_L violates the unitarity

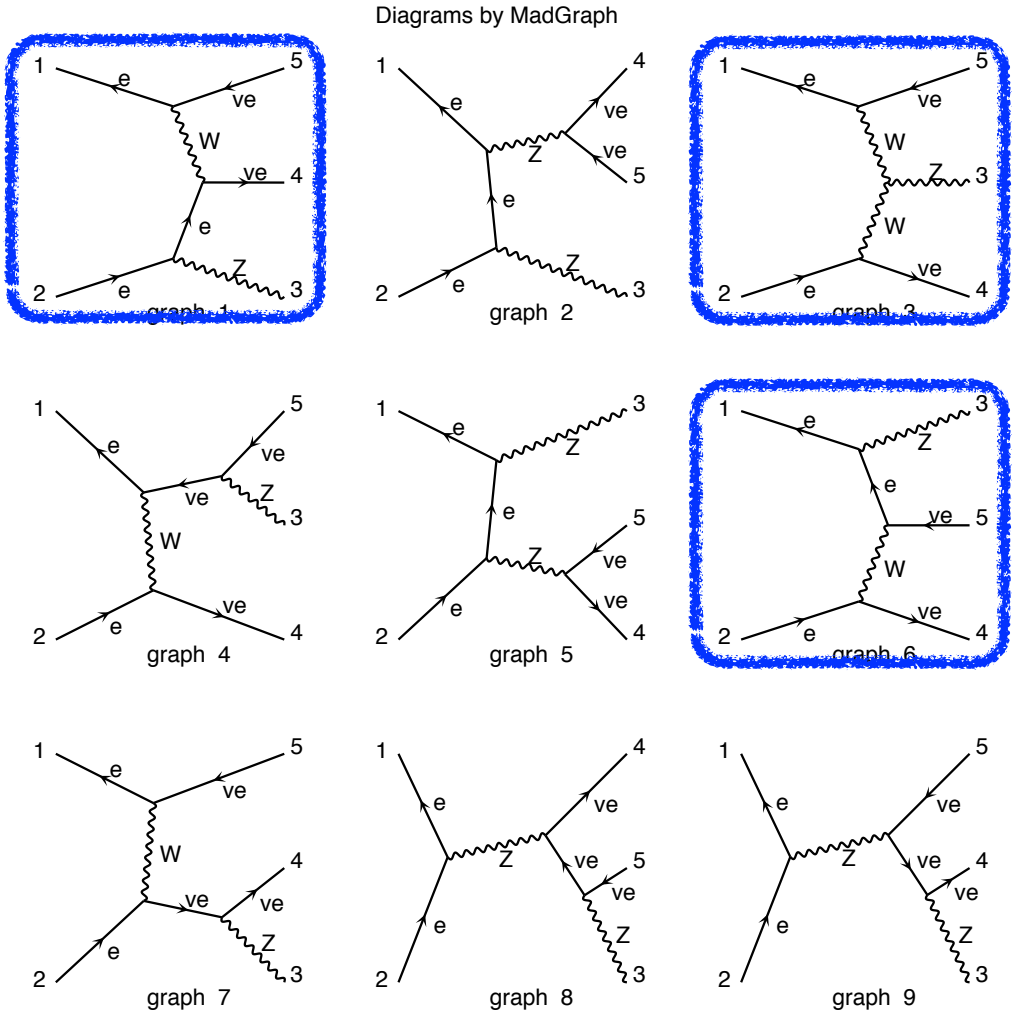
unless $s/m_{\mathrm{KK}}^2 \ll 1$.

$m_{\mathrm{KK}} \sim 1.5\,\mathrm{TeV}$

$\sqrt{s} = 500\,\mathrm{GeV}$

in the following.

LC background $e^+e^- \to Z\nu\bar{\nu}$



BG cross section with

$M_{\rm miss} \geq 120\,{\rm GeV}$

$\sigma_{\rm BG} \simeq 311\,{\rm fb}$

Need polarizations!

beams and Z

LC with polarizations

Ideal case: $e^+_L e^-_R \to Z_L HH\,,\ Z_L \nu\bar{\nu}$

$\sigma_{\rm signal} \simeq 0.12, 0.056,\ 0.024\,{\rm fb}$

$\sigma_{\rm BG} \simeq 0.42,\ 0.39,\ 0.36\,{\rm fb}$ $|\cos\theta| < 0.6$ is applied.

Significance: $\mathcal{S} \equiv \dfrac{N_{\rm signal}}{\sqrt{N_{\rm signal} + N_{\rm BG}}}$

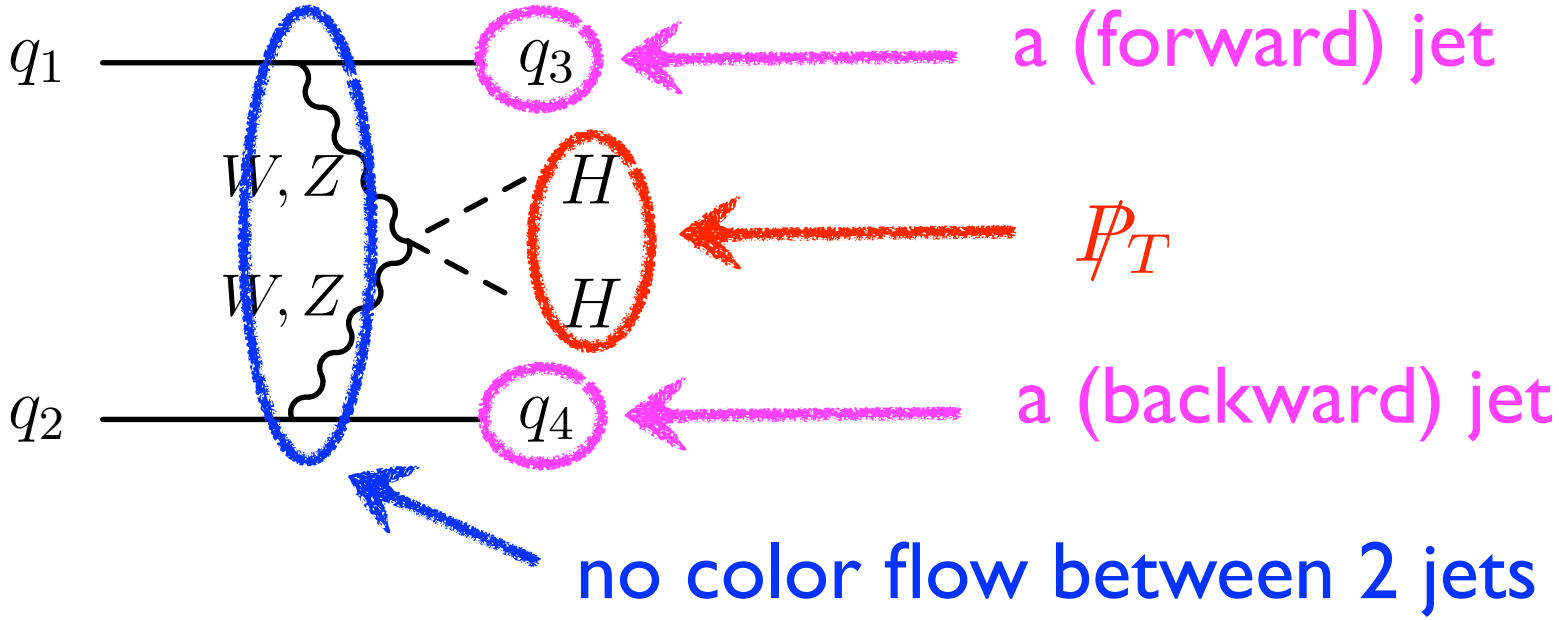
$\mathcal{S} = (1.4,\ 0.73,\ 0.34)\sqrt{L/100\,{\rm fb}^{-1}}$

A few (or more) $\rm ab^{-1}$ is required!

$\mathcal{S} = 1.1\sqrt{L/100\,{\rm fb}^{-1}}$ for $\sqrt{s} = 750\,{\rm GeV},\ m_H = 135\,{\rm GeV}$

Higgs pair production at LHC

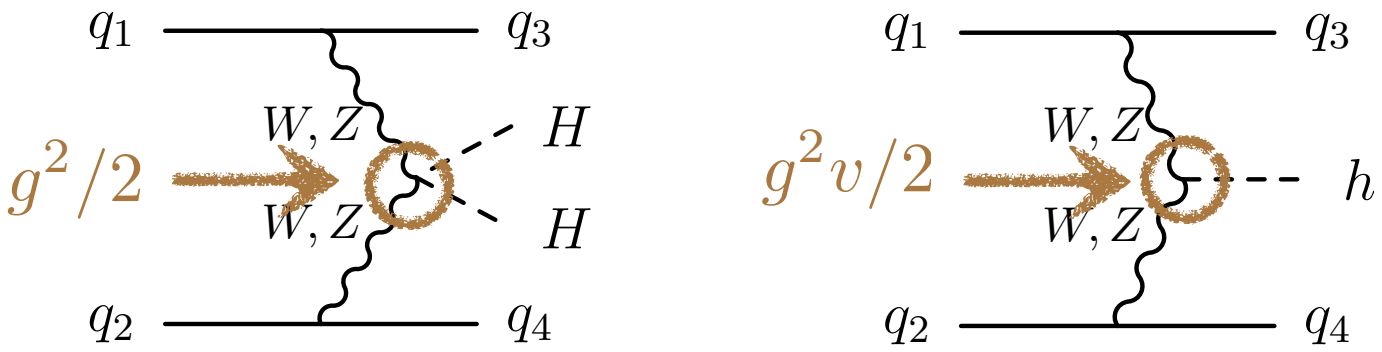
Signal: Weak boson fusion



Background: Wjj, Zjj, jjj

→ Similar as invisible Higgs search

Signal cross section at LHC



$$\frac{d\sigma_{HH}}{dm^2_{HH}} = \frac{\bar{\beta}_f}{32\pi^2 v^2}\sigma_h|_{m_h^2=m^2_{HH}}$$

in the SM

$$\sigma_{HH} \sim 1.5\,\text{fb}$$

$$\sigma_{BG} \simeq 167\,\text{fb}$$

$$\mathcal{S} \sim 1.2\sqrt{L/100\,\text{fb}^{-1}}$$

Éboli, Zeppenfeld

$p_T^j > 40$ GeV, $|\eta_j| < 5.0$,

$|\eta_{j1} - \eta_{j2}| > 4.4$, $\eta_{j1} \cdot \eta_{j2} < 0$,

$\not{p}_T > 100$ GeV.

$M_{jj} > 1200$ GeV, $\phi_{jj} < 1$.

H-even KK Spectra

KK gluon

Table 14: KK gluon masses $m_{G^{(n)}}$ in unit of GeV.

$z_L \setminus n$	1	2	3	4	5
10^{15}	1143.4	2597.79	4060.29	5524.61	6989.61
10^{10}	939.287	2123.35	3313.67	4505.36	5697.54
10^{5}	676.998	1508.23	2342.77	3177.87	4013.1

KK W

Table 15: KK W boson masses $m_{W^{(n)}}$ in unit of GeV.

$z_L \setminus n$	1	2	3	4	5
10^{15}	1132.69	1799.15	2586.69	3284.74	4049.02
10^{10}	926.031	1468.74	2109.46	2677.61	3299.47
10^{5}	657.626	1038.84	1487.22	1885.54	2320.8

KK Z

Table 16: KK Z boson masses $m_{Z^{(n)}}$ in unit of GeV.

$z_L \setminus n$	1	2	3	4	5
10^{15}	1129.49	1802.53	2583.37	3288.13	4045.64
10^{10}	922.087	1472.93	2105.3	2681.86	3295.21
10^{5}	651.946	1045.02	1480.99	1892.00	2314.27

Focus on the first KK Z.

Couplings

Table 25: The couplings of the first KK Z boson with charged leptons, $g_{fI}^{(Z_1)}\sqrt{L}/g_A$.

z_L	eL	μL	τL	eR	μR	τR
10^{15}	0.0310237	0.0310238	0.0310529	2.52033	2.42011	2.35629
10^{10}	0.0382222	0.0382224	0.0382616	2.13663	2.03326	1.96297
10^{5}	0.0549348	0.0549354	0.0550174	1.62351	1.53169	1.45818

Table 26: The couplings of the first KK Z boson with left-handed quarks, $g_{fL}^{(Z_1)}\sqrt{L}/g_A$.

z_L	u	c	t	d	s	b
10^{15}	-0.0399184	-0.0399209	-0.206095	0.0488131	0.048804	-0.558474
10^{10}	-0.0491807	-0.0491842	-0.256412	0.0601393	0.0601274	-0.672188
10^{5}	-0.0706849	-0.0706938	-0.386896	0.0864351	0.0864104	-0.927167

Table 27: The couplings of the first KK Z boson with right-handed quarks, $g_{fR}^{(Z_1)}\sqrt{L}/g_A$.

z_L	u	c	t	d	s	b
10^{15}	-1.65847	-1.58714	-1.4692	0.829233	0.793569	0.723936
10^{10}	-1.40259	-1.32685	-1.1796	0.701297	0.663427	0.579202
10^{5}	-1.06424	-0.991935	-0.754189	0.532119	0.495967	0.376702

Table 24: The couplings of the first KK W boson with leptons, $g_{fL}^{(W_1)}\sqrt{L}/g_A$ and the couplings of the first KK Z boson with neutrinos, $g_{fL}^{(Z_1)}\sqrt{L}/g_A$.

z_L	$e\nu_e$	$\mu\nu_\mu$	$\tau\nu_\tau$	ν_e	ν_μ	ν_τ
10^{15}	-0.138009	-0.138008	-0.137939	-0.0577078	-0.0577075	-0.0576242
10^{10}	-0.170013	-0.170012	-0.169923	-0.0710978	-0.0710974	-0.0709898
10^{5}	-0.244187	-0.244186	-0.24403	-0.102185	-0.102184	-0.101988

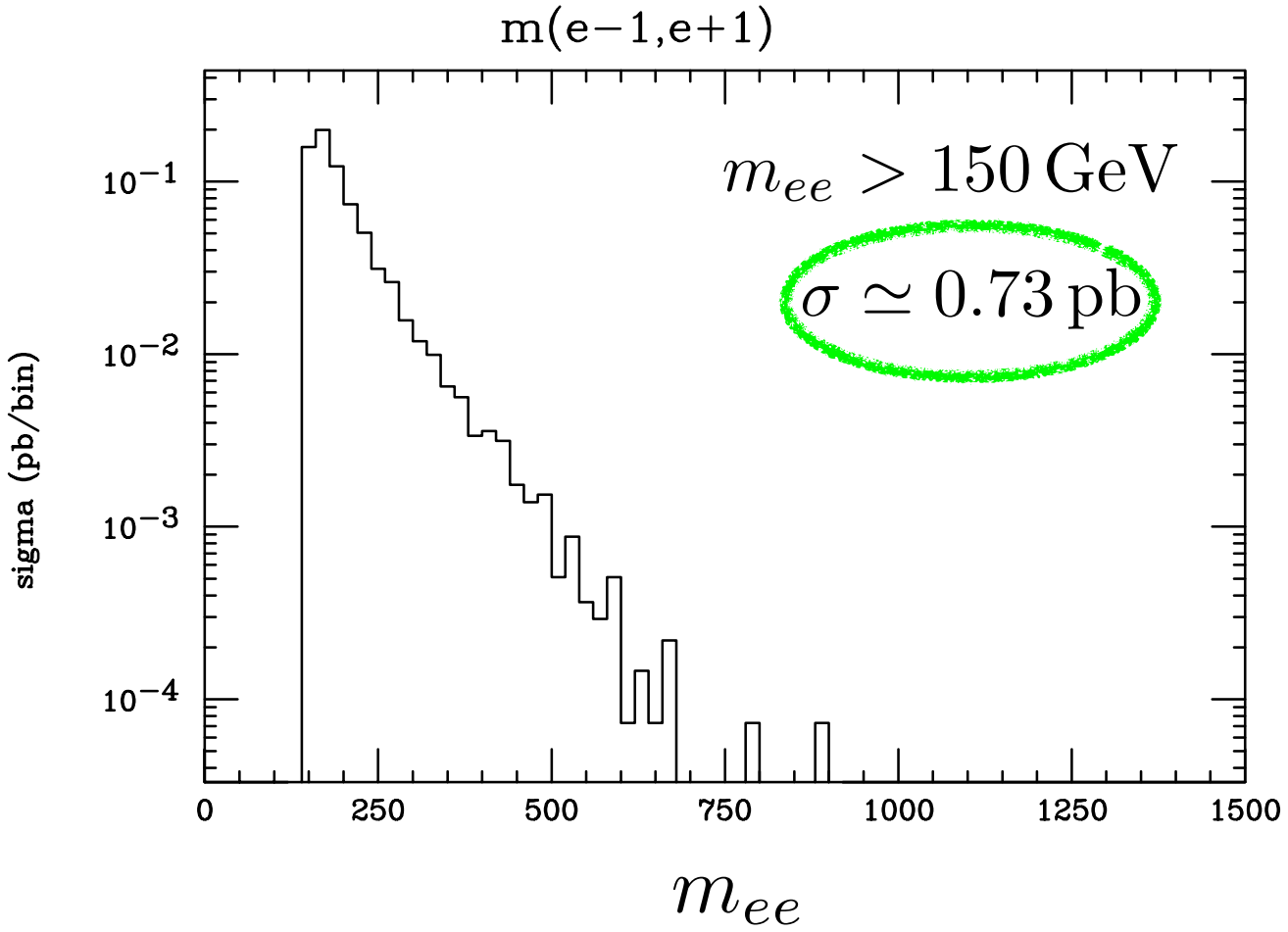
Decay width and BR

Table 28: First KK Z boson decay: the branching fraction and the total width.

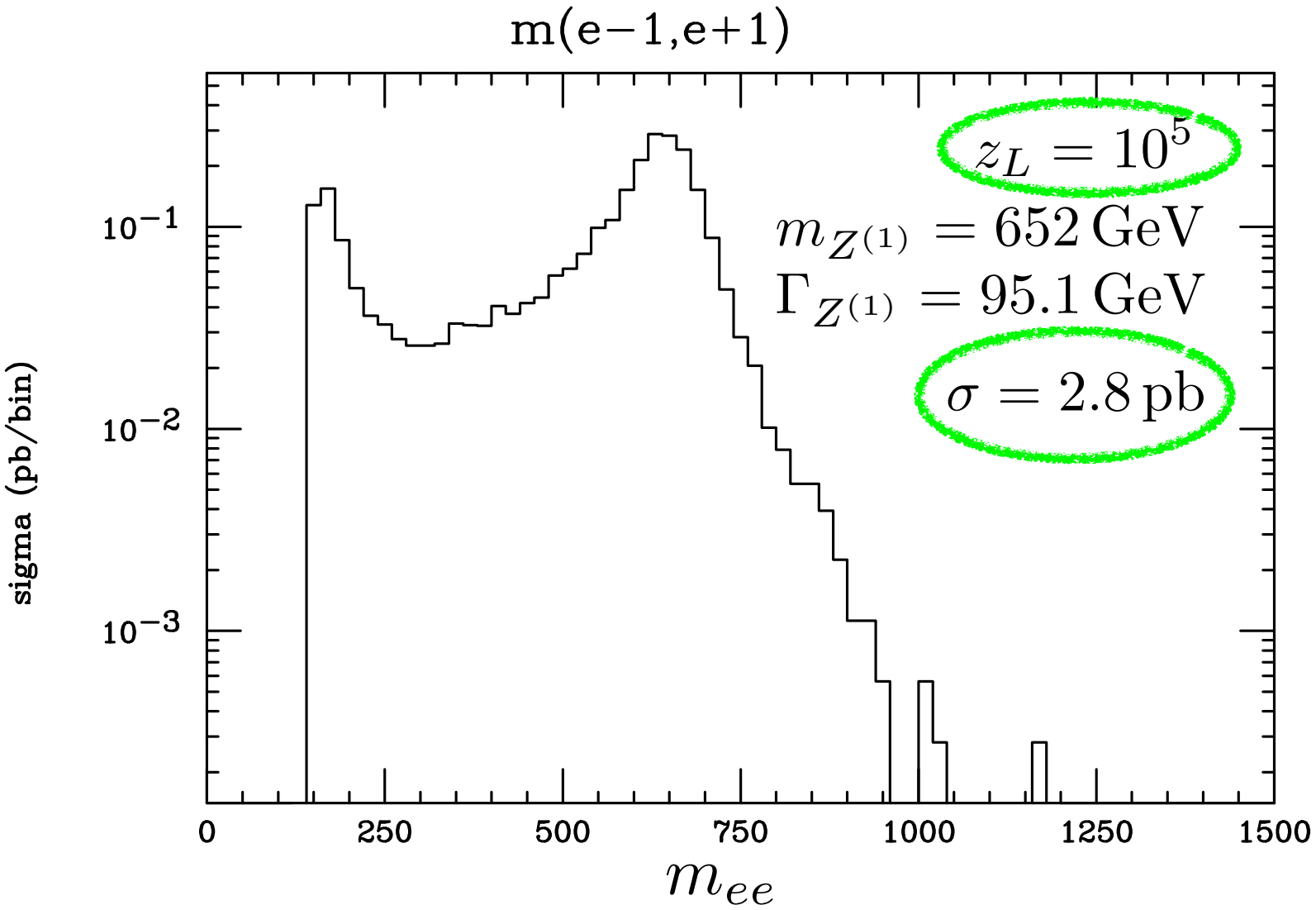
z_L	10^{15}	10^{10}	10^5
e (%)	14.1396	14.18	13.253
μ (%)	13.0376	12.8416	11.798
τ (%)	12.3591	11.9693	10.6941
$\nu_e + \nu_\mu + \nu_\tau$ (%)	0.0222139	0.0470403	0.157124
$(u + c)/2$ (%)	17.6028	17.3854	16.0203
$(d + s + b)/3$ (%)	3.68474	4.40884	7.27081
c (%)	16.8299	16.4225	14.9003
b (%)	5.58161	7.3338	15.0894
t (%)	14.1818	12.9648	10.2446
$u + d + s + c$ (%)	40.6781	40.6636	38.7638
total width (GeV)	371.761	217.536	95.0912

KK Z at Tevatron: $p\bar{p} \to Z^{(1)} X \to e^- e^+ X$

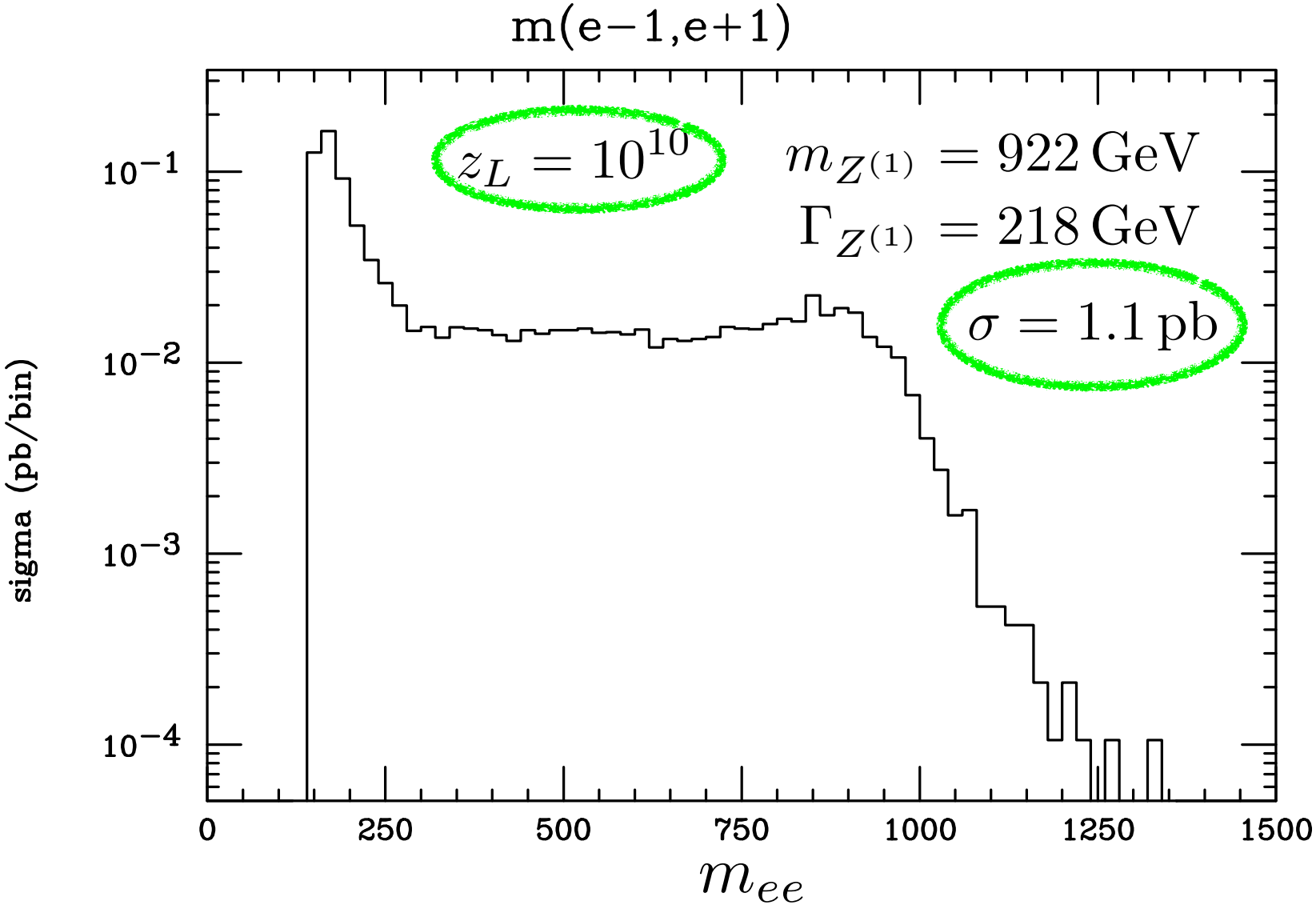
Background: $p\bar{p} \to e^- e^+ X$



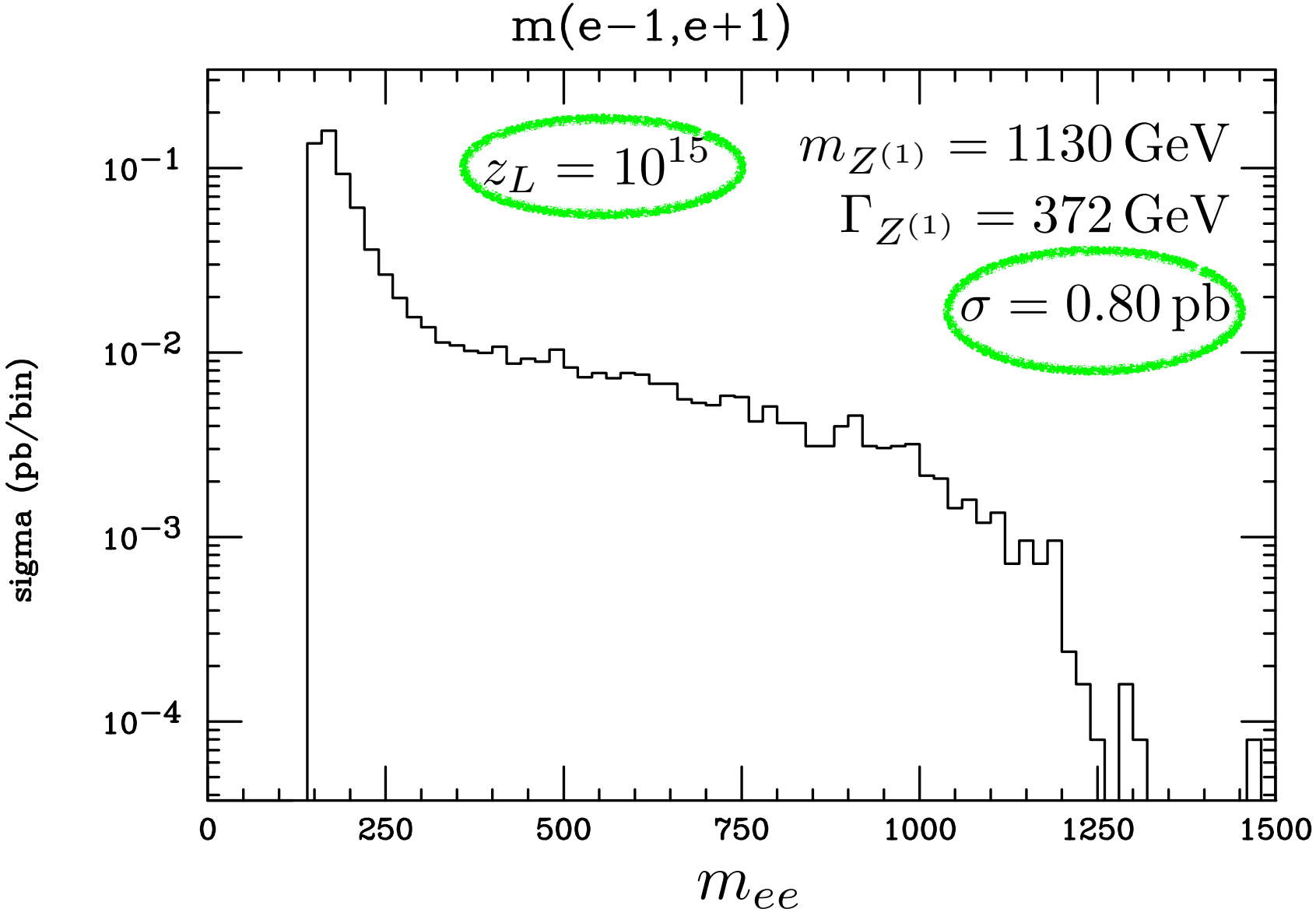
$$p\bar{p} \to Z^{(1)} X \to e^- e^+ X$$



$$p\bar{p} \to Z^{(1)} X \to e^- e^+ X$$



$$p\bar{p} \to Z^{(1)} X \to e^- e^+ X$$



Significance at Tevatron $L = 2.5\,\mathrm{fb}^{-1}$

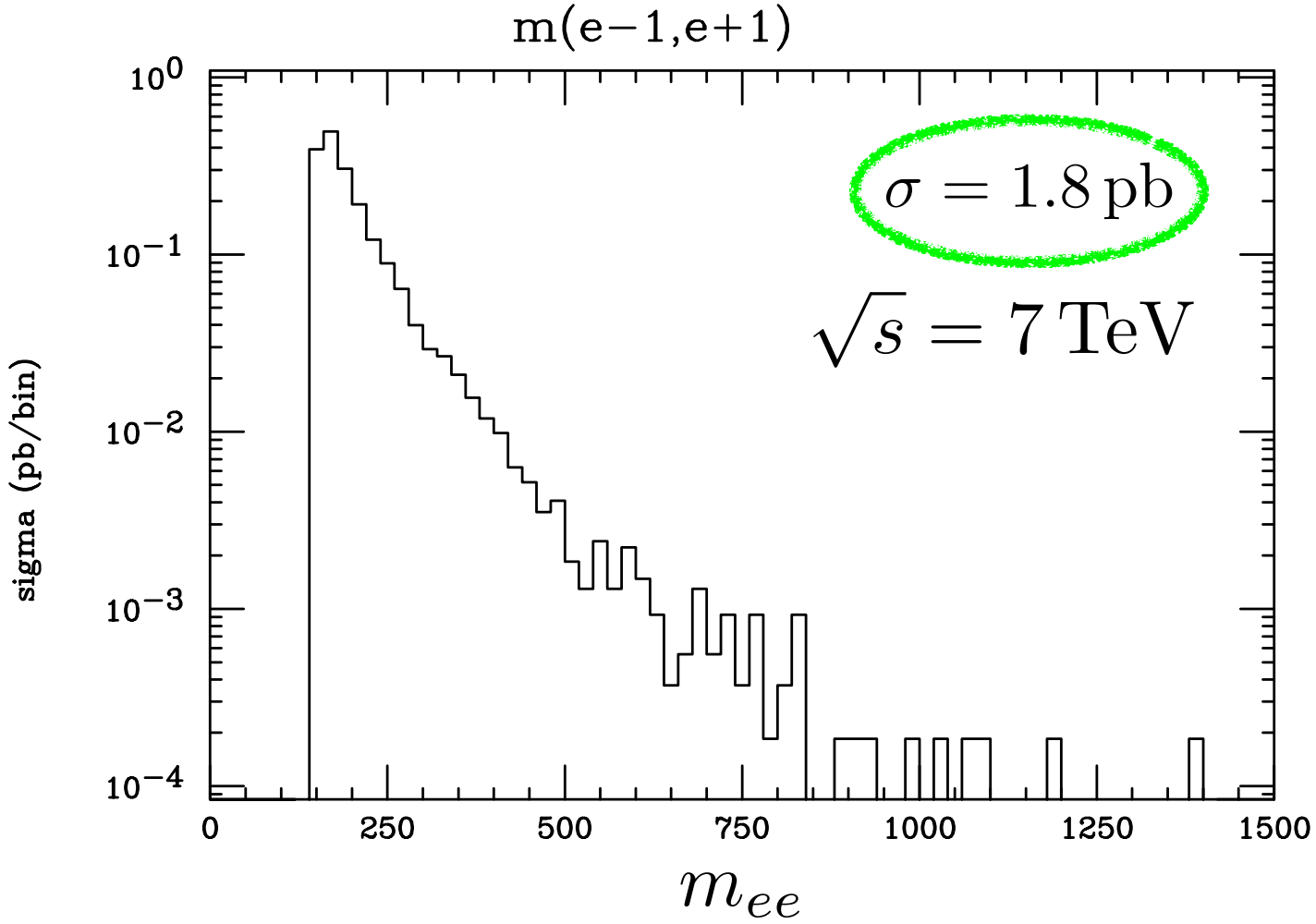
z_L	10^5	10^{10}	10^{15}
$\mathcal{S}$	7.3	3.3	0.85

↑ 10% theoretical uncertainty included.

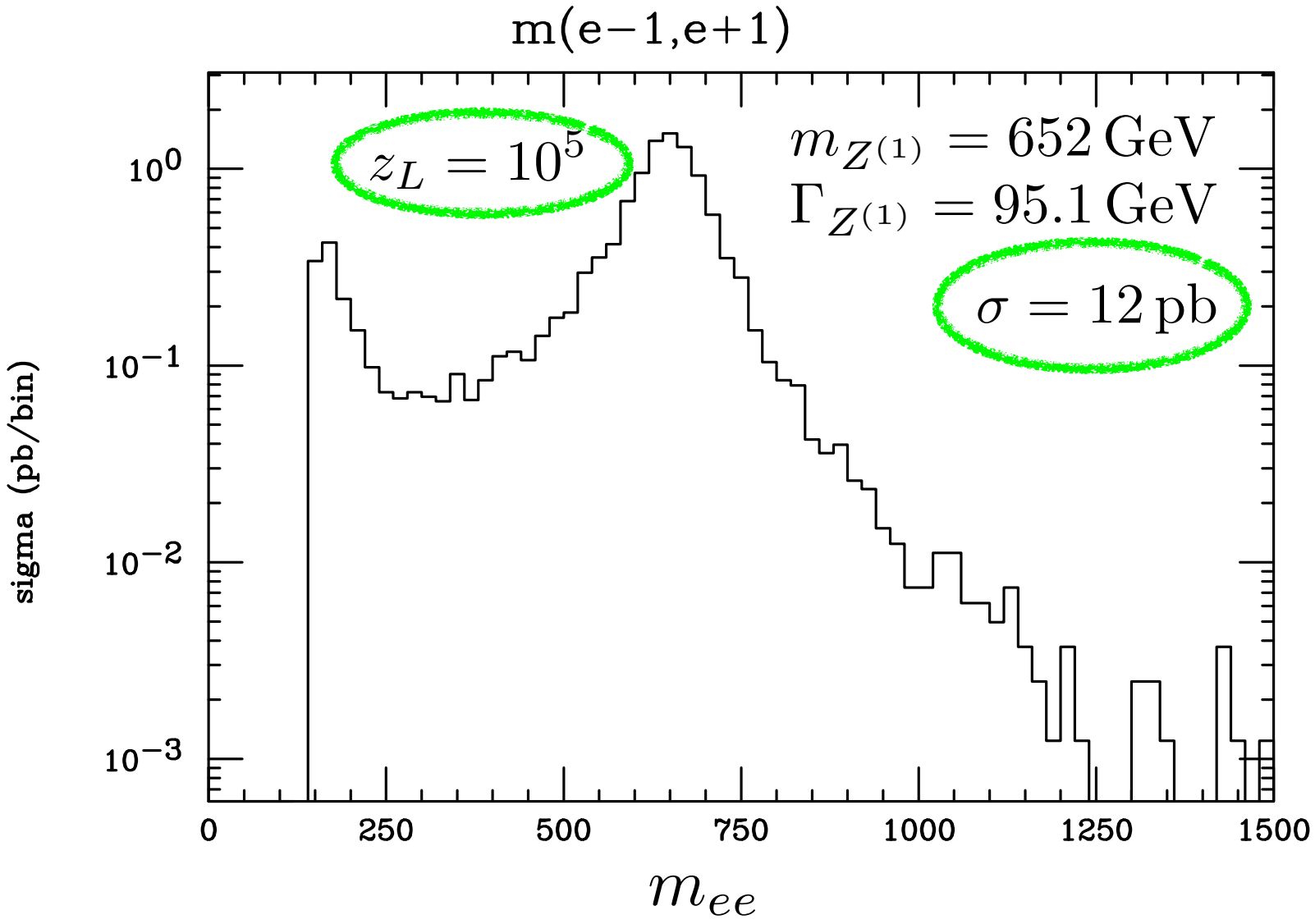
disfavored

KK Z at LHC: $pp \to Z^{(1)} X \to e^- e^+ X$

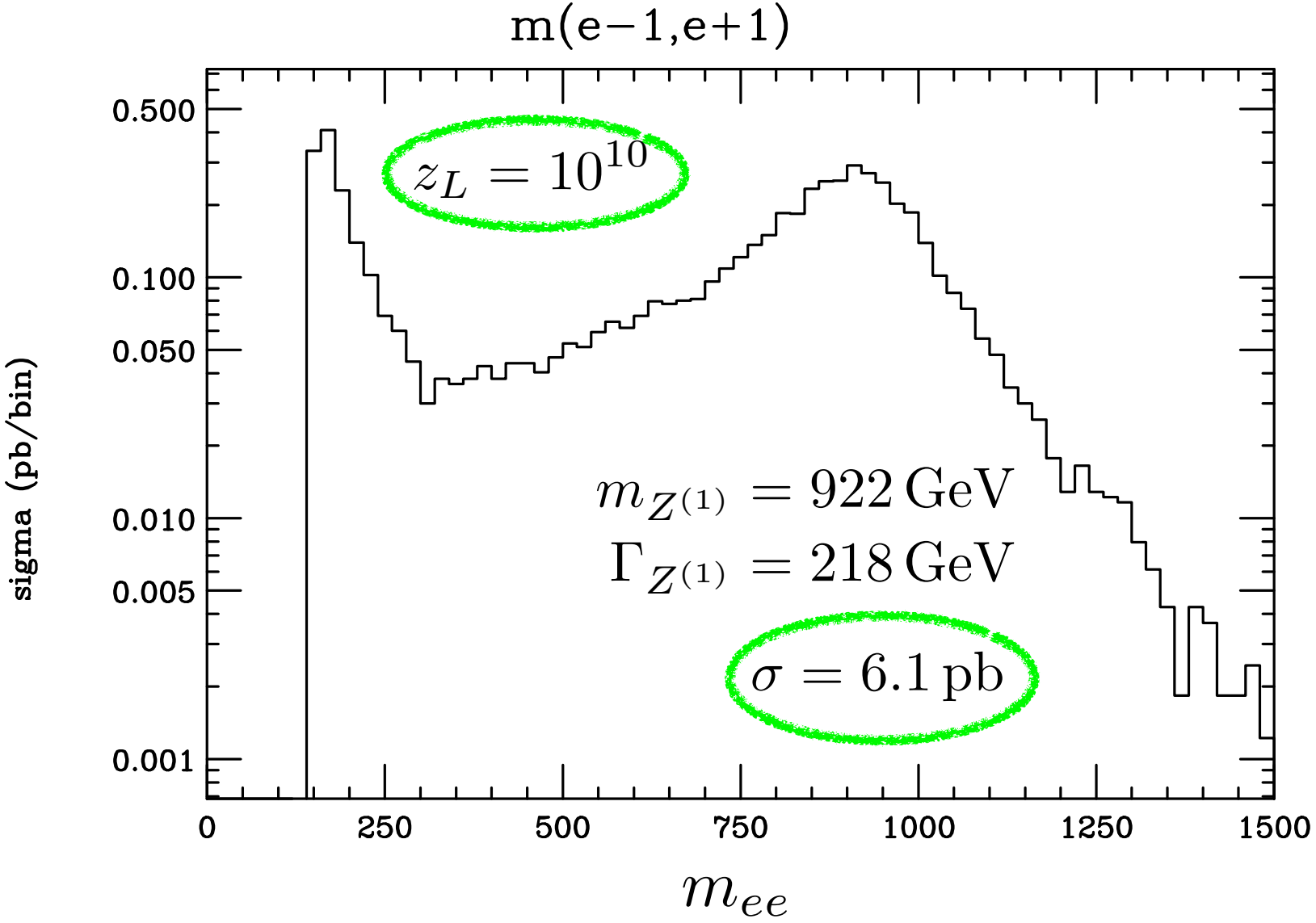
Background: $pp \to e^- e^+ X$



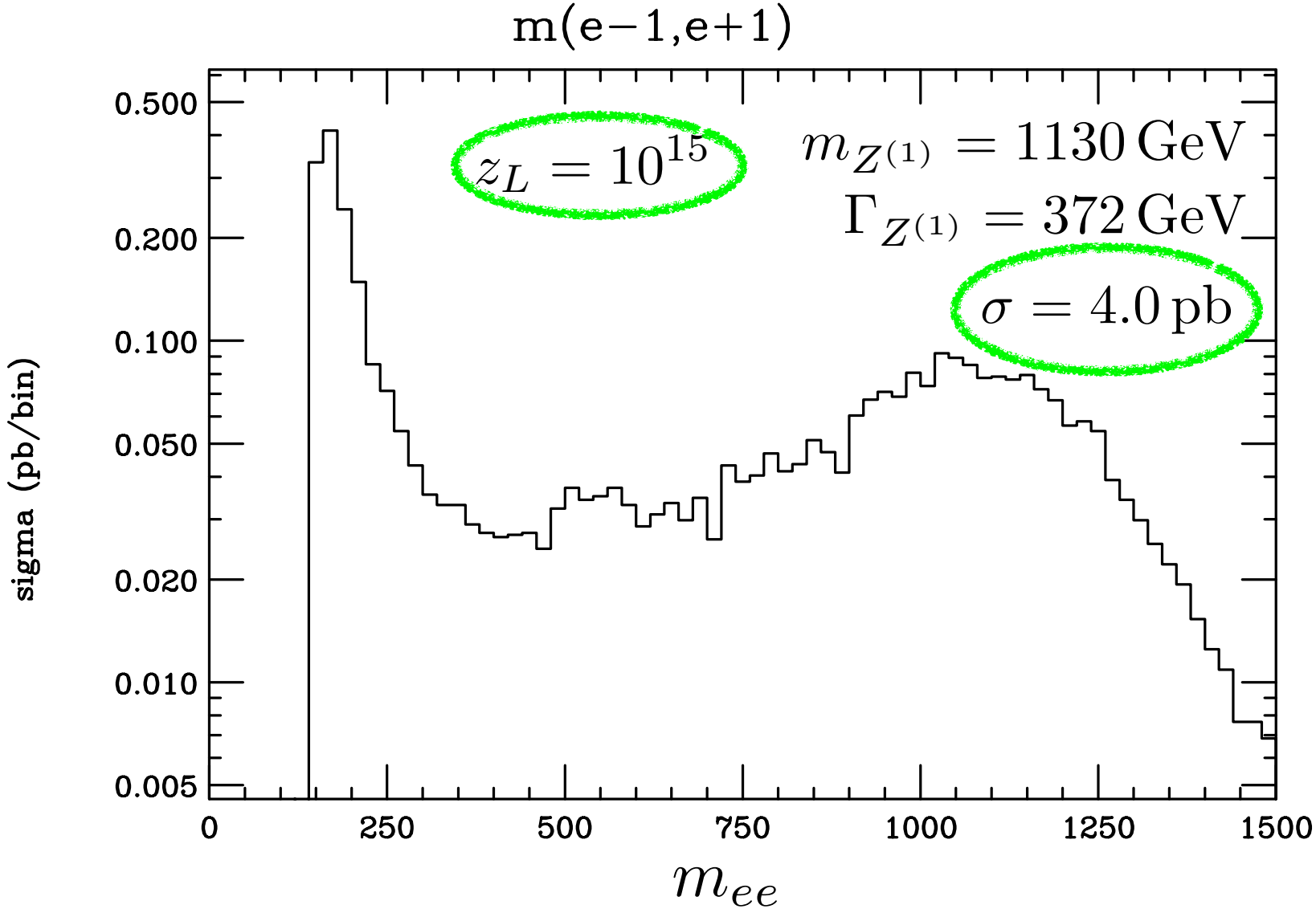
$$pp \to Z^{(1)} X \to e^- e^+ X$$



$$pp \to Z^{(1)} X \to e^- e^+ X$$



$$pp \to Z^{(1)} X \to e^- e^+ X$$



Significance at LHC $\sqrt{s} = 7\,\mathrm{TeV}$

z_L	10^5	10^{10}	10^{15}
$L = 10\,\mathrm{pb}^{-1}$	6.3	4.3	2.9
$L = 100\,\mathrm{pb}^{-1}$	8.2	6.5	4.9
$L = 1000\,\mathrm{pb}^{-1}$	8.5	7.0	5.4

10% theoretical uncertainty included.

Summary

- The first KK Z production at Tevatron suggests a larger warp factor. $z_L = 10^5$ unlikely
- Dark Higgs seems difficult at the present model.

  $m_H = 108(135)\,\mathrm{GeV}$ for $z_L = 10^{10(15)}$
- The first KK Z production may be discovered at LHC with $100\,\mathrm{pb}^{-1}$ even for $z_L = 10^{15}$.