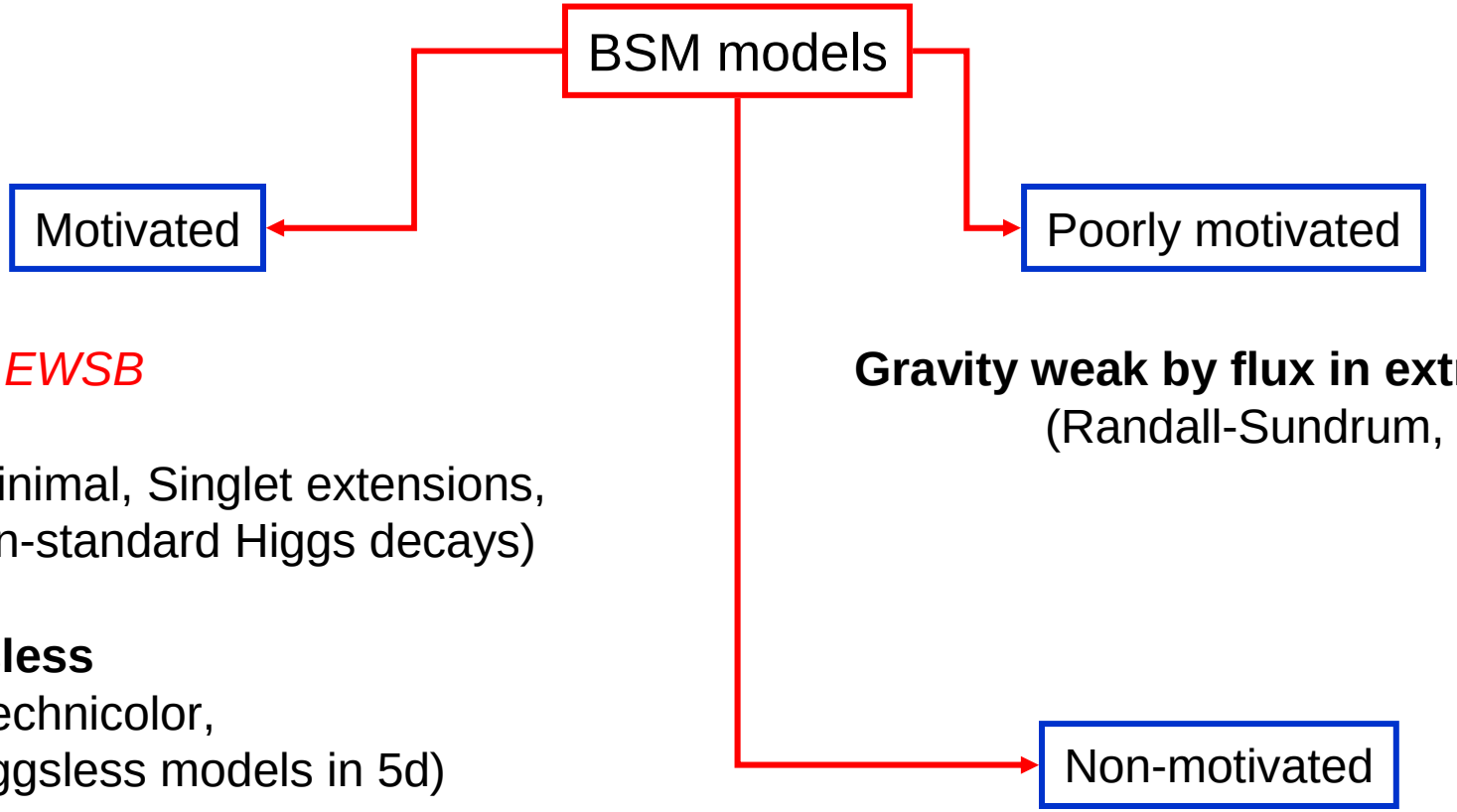
Higgsless models

Slava Rychkov (SNS Pisa)

4th Monte Carlo Workshop, Frascati, 18-20/02/2008



a) by EWSB

SUSY

(Minimal, Singlet extensions,
non-standard Higgs decays)

Higgsless

(Technicolor,
Higgsless models in 5d)

Composite Higgs

(Higgs as a Pseudo-GoldstoneGB,
Little Higgs,
gauge-Higgs unification in 5d)

b) by Dark Matter

many models, minimality?

Gravity weak by flux in extraD

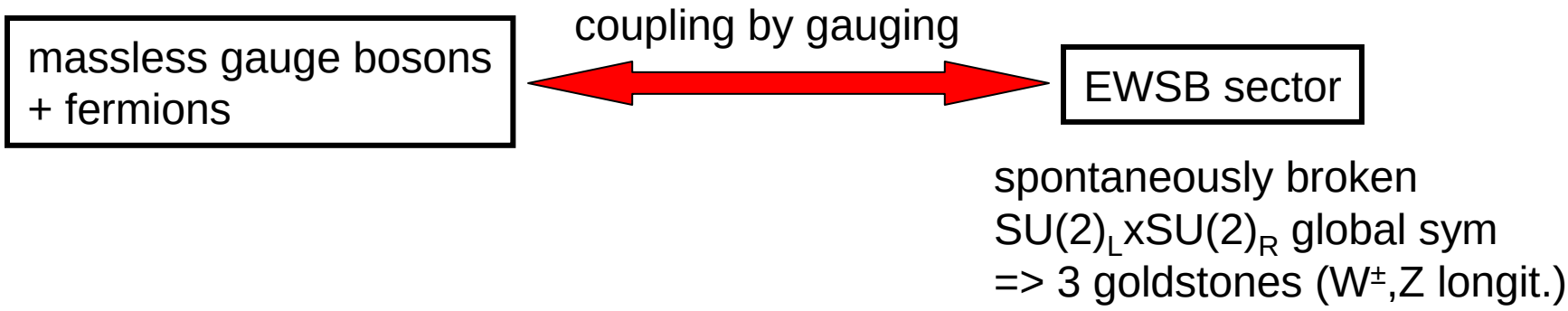
(Randall-Sundrum, ADD)

- generic Z'
- unparticle physics
- hidden sector models
  (hidden valley)

- Higgsless models = models without scalar boson with coupling to WW,ZZ, its role played by new heavy vector bosons
- Technicolor – 1st example
- Recently – Higgsless models in 5d

This talk: low-energy effective description of Higgsless models

- **Key to Higgsless models**: unitarity in longitudinal WW scattering
- Equivalently: Goldstone boson scattering



EWSB example 1: standard Higgs

$$|D_\mu H|^2 + \lambda(|H|^2 - v^2)^2$$

v=174 GeV

EWSB example 2: Goldstones-only

- Cross out Higgs boson from all vertices
- Equivalently: Take $\lambda \longrightarrow \infty$. Higgs absolute value freezes: $|H|^2 = v^2$

$$H = U \begin{pmatrix} 0 \\ v \end{pmatrix}, \quad UU^\dagger = 1, \quad U = \exp\left(i \frac{\sqrt{2}}{v} \pi^a T^a \right)$$

SU(2) generators

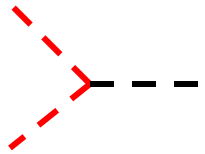
- Elastic 2⟶2 scattering of Goldstones π^a:

$$\frac{1}{v^2} \varepsilon^{abe} \varepsilon^{cde} (\partial_\mu \pi^a \pi^b)(\partial_\mu \pi^c \pi^d)$$

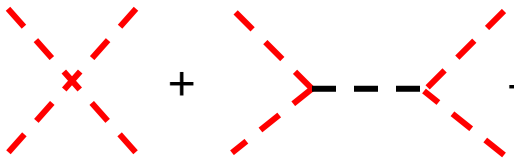
$$A \propto \frac{s}{v^2}$$

=> unitarity exceeded at $\sqrt{s} \sim 1$ TeV

- Putting Higgs boson back in restores unitarity:



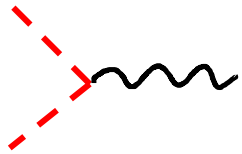
$$\frac{1}{\sqrt{2}v} h (\partial \pi^a)^2$$



+crossings

$$A_{\text{tot}} \propto \frac{M_h^2}{v^2} \frac{s}{M_h^2 - s} \longrightarrow \text{const}$$

Restoring unitarity with vector bosons

vertex: 

$$\frac{g_s}{2}\varepsilon^{abc}(\partial_\mu \pi^a \pi^b)V_\mu^c$$

- 4-Goldstone vertex is `dissolved' into exchanges of new massive vector bosons:

 +crossings;

$$A \propto \frac{g_s^2 s}{M_V^2 - s} \propto \begin{cases} s, & s << M_V^2 \\ \text{const}, & s >> M_V^2 \end{cases}$$

- Electroweak scale: $v = \sqrt{\frac{2}{3}}\frac{M_V}{g_s}$

Important differences between $V^{\pm}$,V^0 and the Higgs boson

- V-bosons are quite narrow:

$$\frac{\Gamma_V}{M_V} = 0.04\left(\frac{M_V}{1\,\text{TeV}}\right)^2$$

0.5 for Higgs boson

- Mass above 1 TeV allowed?
  ρ-meson scaled up from QCD gives V-bosons at 2 TeV!

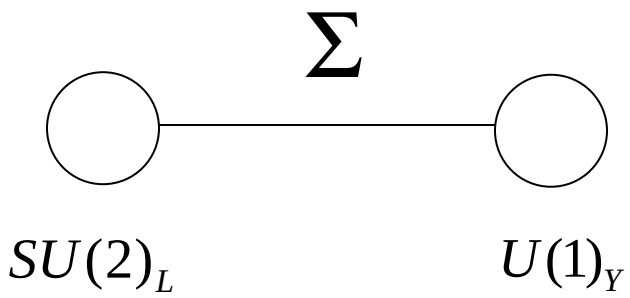
Model building: Goldstones only, once again

- $SU(2)_L \times SU(2)_R \longrightarrow SU(2)_{L+R}$ breaking is realized by 2x2 matrix:

$$\Sigma \to L\Sigma R^\dagger \qquad \langle\Sigma\rangle = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \qquad \mathscr{L}_{\rm EWSB} = \frac{v^2}{2}|\partial_\mu \Sigma|^2, \quad \Sigma\Sigma^\dagger = 1$$

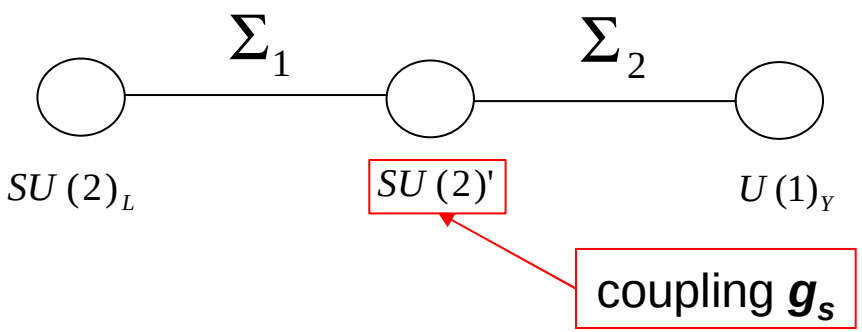
- Coupling of EWSB sector to SM via gauging:

$$\mathscr{L}_{\rm EWSB} \to \frac{v^2}{2}|D_\mu \Sigma|^2 \qquad D_\mu\Sigma = \partial_\mu\Sigma - ig\hat{W}_\mu\Sigma + ig'\Sigma T_3 B_\mu, \quad \hat{W} = W^a T^a$$



Simplest Higgsless model (3-SITE MODEL)

$$\Sigma_{\text{old}} = \Sigma_1 \Sigma_2$$



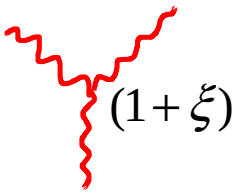
$$\mathscr{L}_{\text{EWSB}} = v^2 \text{Tr}|D_\mu \Sigma_1|^2 + v^2 \text{Tr}|D_\mu \Sigma_2|^2$$

$$D_\mu \Sigma_1 = \partial_\mu \Sigma_1 - i\hat{W}_\mu \Sigma_1 + i\Sigma_1 \hat{V}_\mu$$
$$D_\mu \Sigma_2 = \partial_\mu \Sigma_2 - i\hat{V}_\mu \Sigma_2 + i\Sigma_2 T_3 B_\mu$$

- In this model the gauge bosons are slightly heavier than optimal: $M_V = \sqrt{2} g_s v$

=> Ampl. grows (although only ¼ as fast) for $\sqrt{s} >> M_V$ (unitarity not fully restored)

- Anomalous WWZ coupling:



$$\xi = \frac{M_Z^2}{2M_V^2} < 3\% \quad \text{(LEP2)} \quad \Rightarrow \quad M_V > 400\,\text{GeV}$$

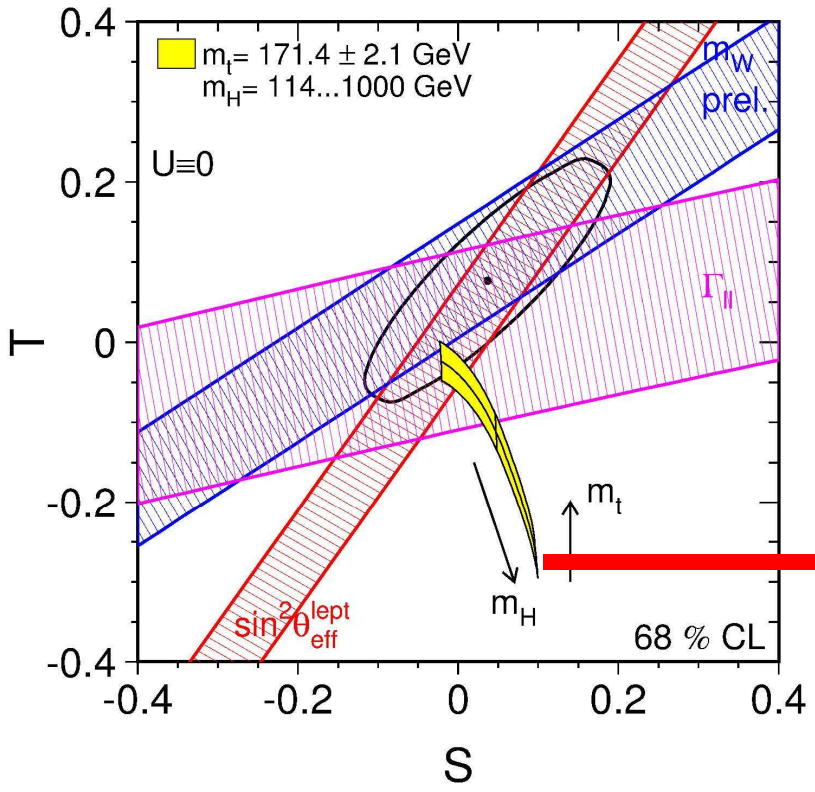
ElectroWeak Precison Tests

$$\Delta T \simeq -0.1\, ln\frac{M_V}{100\mathrm{GeV}}$$

$$\Delta S \simeq 0.05\, ln\frac{M_V}{100\mathrm{GeV}} + 0.6\left(\frac{1\mathrm{TeV}}{M_V}\right)^2$$

Same as for heavy SM Higgs boson

New big ΔS from mixing



can be canceled by other effects => finetuning

(for M_V=1 TeV)

Phenomenology

Expect 2 (W',Z') heavy vector bosons:

- mass M_V = 400 GeV ÷ 2 TeV, most likely around 1 TeV
- neutral slightly heavier than charged ;
- relatively narrow, width $\frac{\Gamma_V}{M_V} = 0.04\left(\frac{M_V}{1\,\mathrm{TeV}}\right)^2$
- strongly coupled to longitudinal W,Z: $g_s \approx \frac{M_V}{v}$
- coupling to light fermions only via mixing $\approx g\frac{M_W}{M_V}$

$\Rightarrow$dominant model-independent production mode: VBF
(DY suppressed; GF uncertain since coupling to top not predicted)

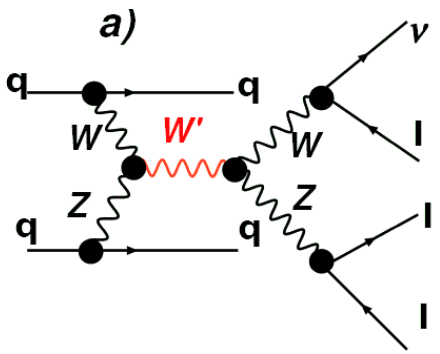
$\Rightarrow$dominant decay mode into two EW bosons: W'$\rightarrow$WZ, Z' $\rightarrow$WW

Since Z' $\rightarrow$ZZ absent, will be easy to distinguish from heavy Higgs

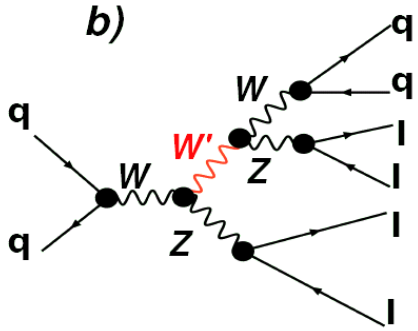
see also Birkedal, Matchev, Perelstein (hep-ph/0412278)
Azuelos, Delsart, Idarraga (hep-ph/0602198, LH-2005, w/detector simulation)

Parton-level study of Belyaev et al (arXiv:0708.2588)

[Look for W' since WZ is easier than WW]

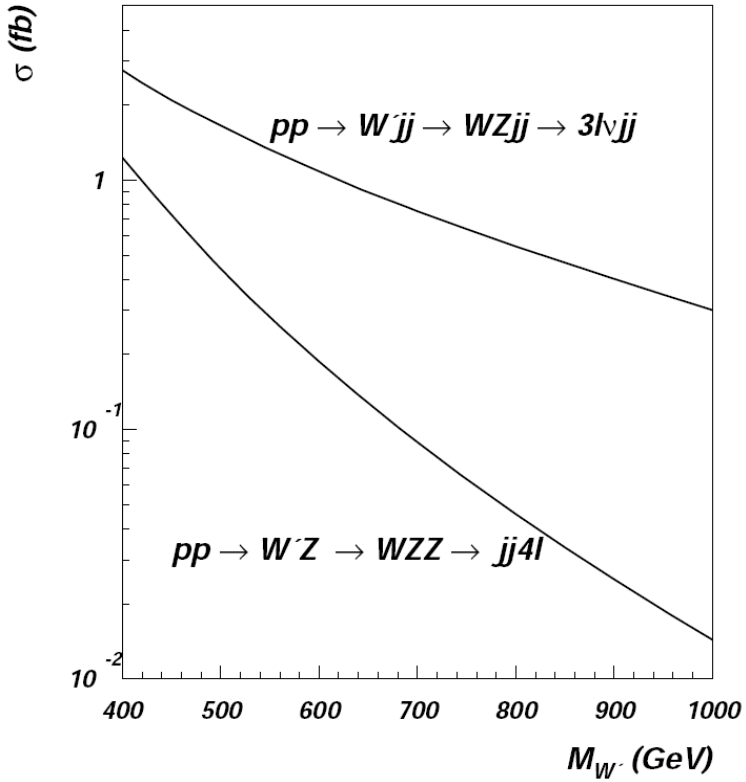


VBF

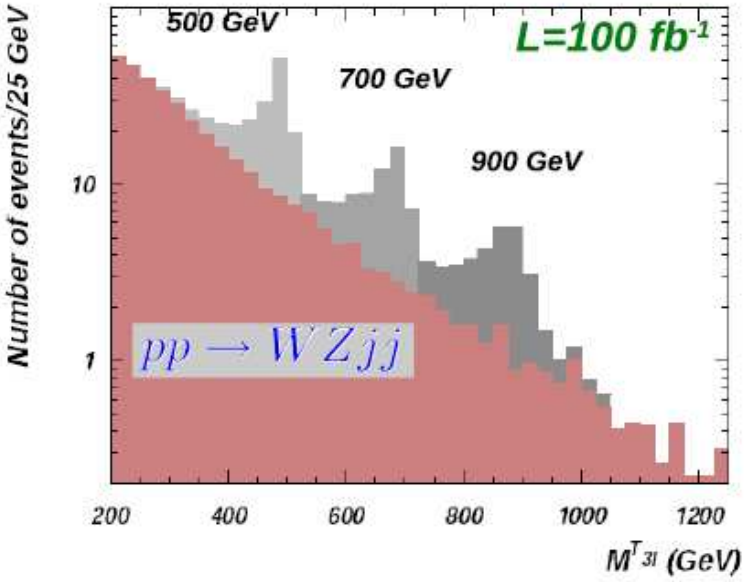


AP

sigma x BR for W' [fb]



$pp \to W'qq \to WZqq \to qq3l\nu$

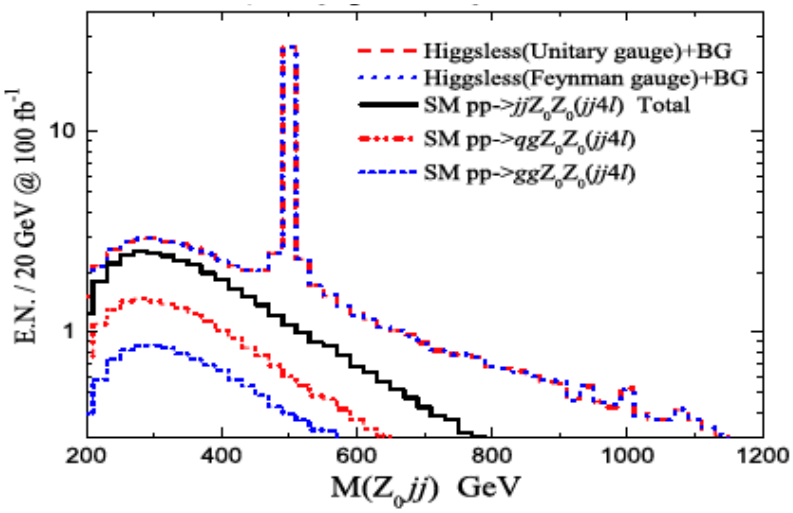


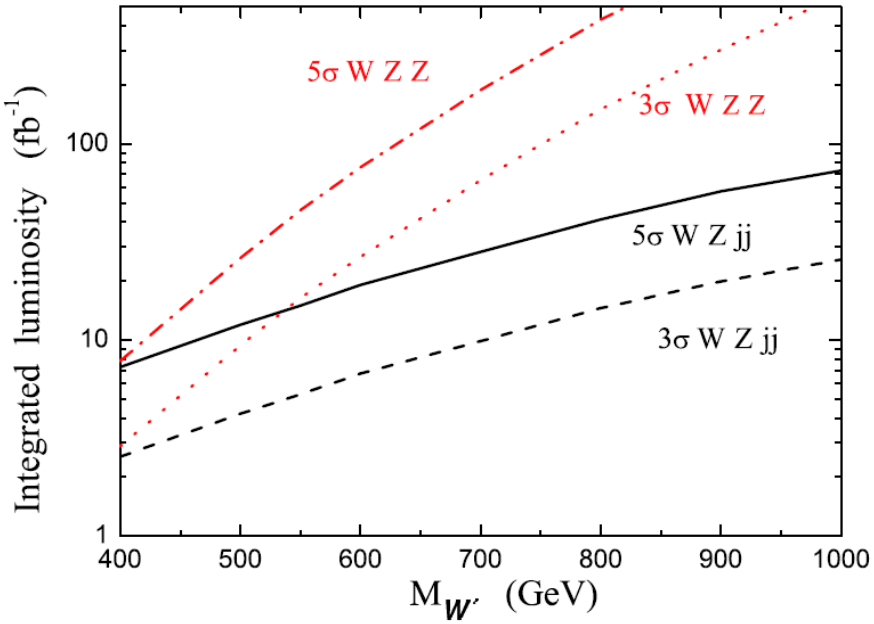
$E_j > 300\,\text{GeV},\ p_{Tj} > 30\,\text{GeV}$

$|\eta_j| < 4.5,\ \ |\delta\eta_{jj}| > 4$

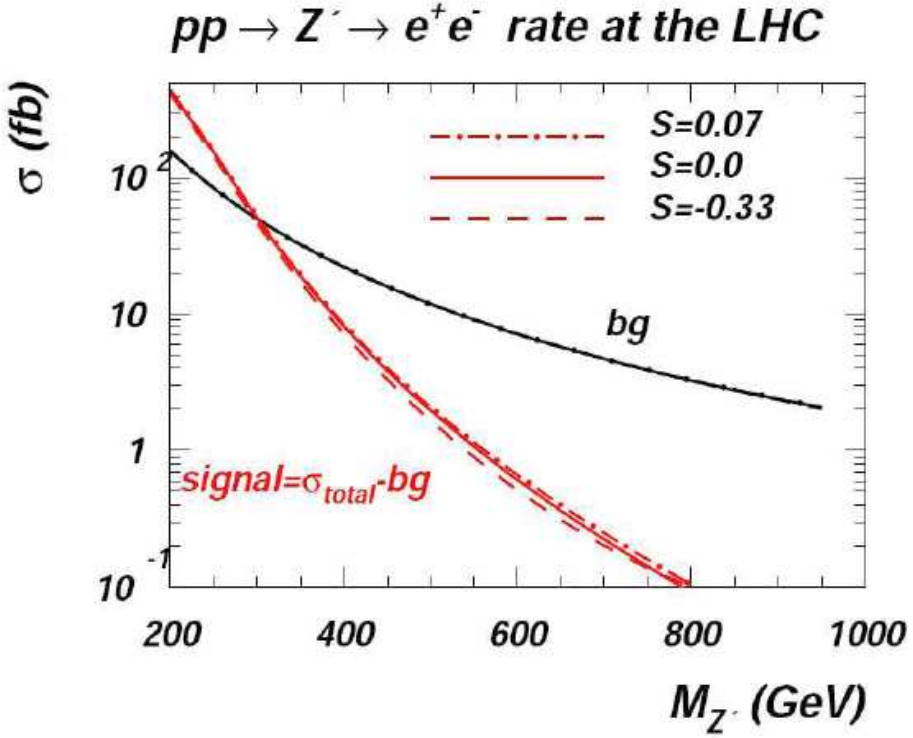
$p_{Tl} > 10\,\text{GeV},\ |\eta_l| < 2.5$

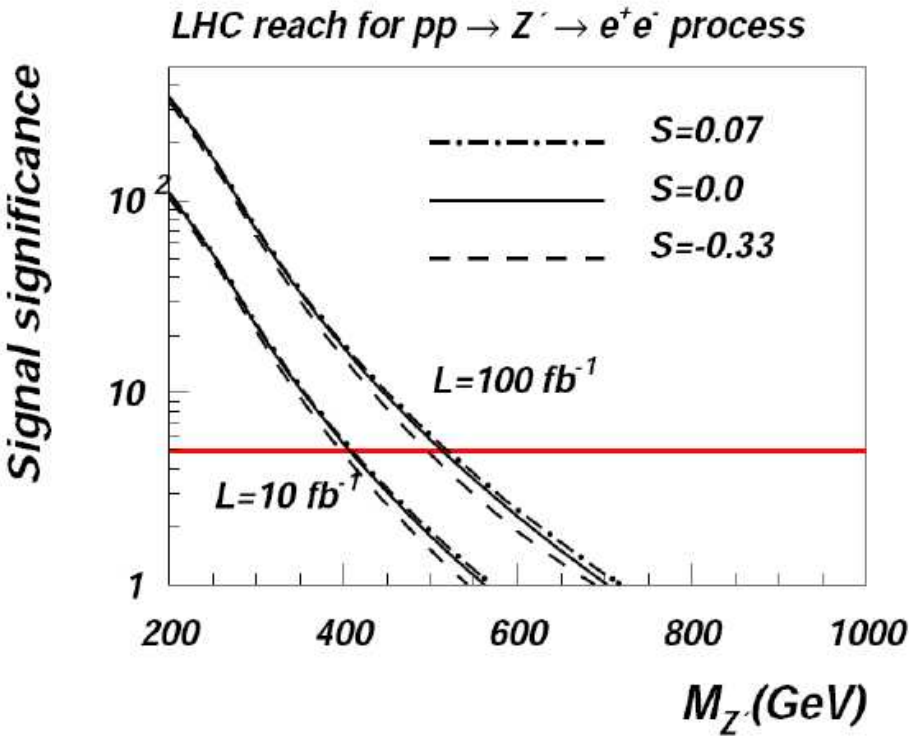
$pp \to W^* \to W'Z \to WZZ \to 2j4l$





LHC reach for DY di-lepton signature





- Decay and production are suppressed by x^4 compared to 'usual' PYTHIA Z' model
- One should be prepared to face with this scenario with very different Z'/W' features
  - Discovery reach for DY process is about 0.5-0.6 TeV (vs 3-5 TeV)
  - fermiophobic Z' required by EW data (vs SM-like Z'-fermions couplings)
  - Z'WW coupling is non-vanishing to provide unitarity (vs vanishing Z'WW vertex)

Conclusions

Searches for charged heavy vector in Higgsless models are comparable to searching for a heavy Higgs in VBF

With 30 (80) 1/fb can cover the mass region <700 GeV (1 TeV)

Searching for neutral vector more challenging due to absence of 'gold-plated decay' $Z' \rightarrow ZZ$