Early LHC potential to test Higgsless models

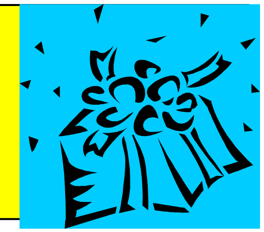
Elena Accomando

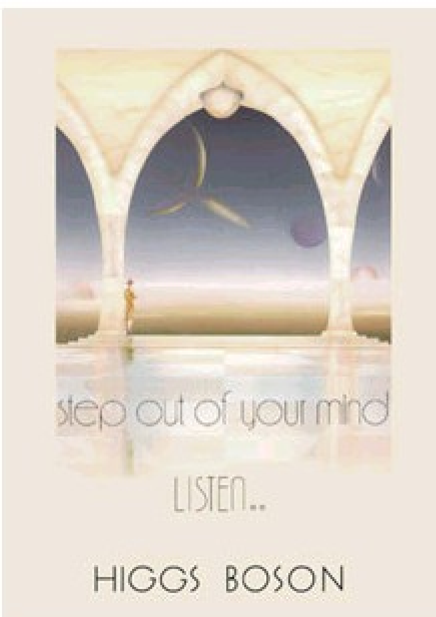
Southampton University and RAL

ElectroWeak Symmetry Breaking physics

2009: 45th birthday of the Higgs

the basic EWSB realization





... But up to now, this shy scalar particle has an *output* only in Britain

Musicians:

Higgs Boson - Piano/Keyboards
Chuck Scirocco - Guitar
Kevin Jeffries - Bass

Nu-jazz Rock Fusion 4 particle physicists, in theory!

EWSB Prospects at the LHC

- Different models are characterized by different EWSB mechanisms.
- How to disantangle different theories?
- What are the most sensitive processes to be looked at?

EWSB physics is expected to bloom at TeV scale

EWSB Prospects at the LHC

We can divide models in 3 main classes

- **Models with at least a light elementary Higgs**

  (SM, SUSY, 2HDM, Left-Right, etc.)

- **Models with a light composite Higgs**

  (SILH)

- **Models with no Higgs**

  (BESS, Extra-dimension, Linear Moose)

  No scalars but NEW vector bosons!

w/wo Higgs models and perturbative unitarity

•Models with at least a light elementary Higgs

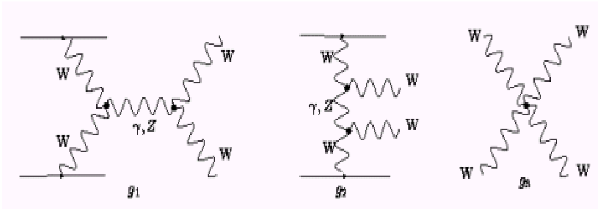
no unitarity violation

•Models with a light composite Higgs

delayed unitarity violation (compared to noH SM)

•Models with no Higgs

delayed unitarity violation via NEW gauge bosons



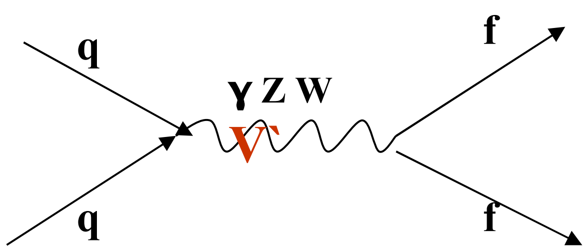
Vector boson scattering (VBS)

Scalar and gauge sector are strictly related
Look at HE: new gauge bosons? weak or strong gauge interactions?

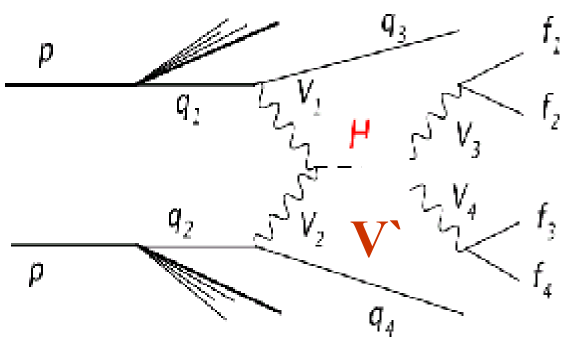
EWSB physics and Gauge Sector

where do we get clues at the LHC?

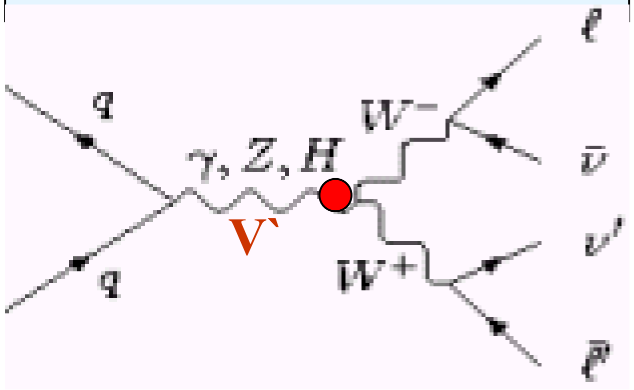
Drell-Yan



Vector boson scattering



Di-boson production



.... triple boson production, and ..... even more complicated processes where (extra) gauge bosons and/or Higgs bosons can be produced.

via on and off-resonance analyses

EWSB Prospects at the LHC

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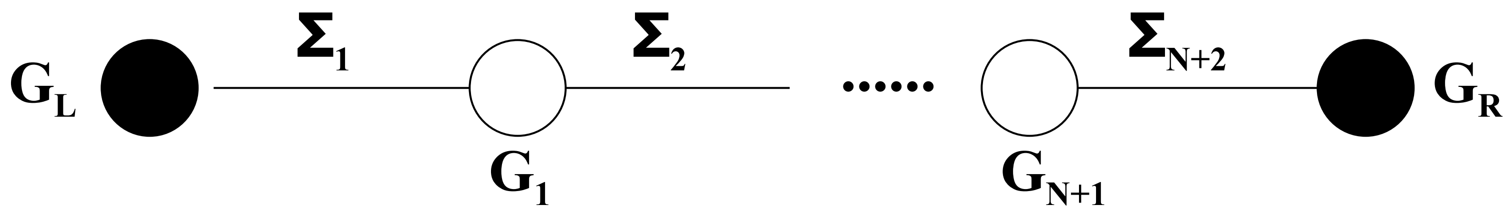
Higgsless Models and New gauge bosons

... a bit of history

- **BESS `85** **[Casalbuoni, De Curtis, Dominici, Gatto]** — **1 extra vector boson**
- **Extra dimension `90** **[Antoniadis, Arkani-Hamed, Dimopoulos, Dvali, ...]** — **A tower of extra bosons**
- **Deconstructed models `00** **[Arkani-Hamed, Cohen, Georgi, Hill, Pokorsky, Wang, ...]** — **1 and more extra bosons**
- **Linear Moose model** **[Foadi et al., Casalbuoni et al., Chivukula et al., ...]** — **1 and more extra bosons**

The Higgsless Linear Moose model

or the most general framework



- **The '85 BESS model can be recast in a 3-site model (N=0), and its extension (N=1) in a**

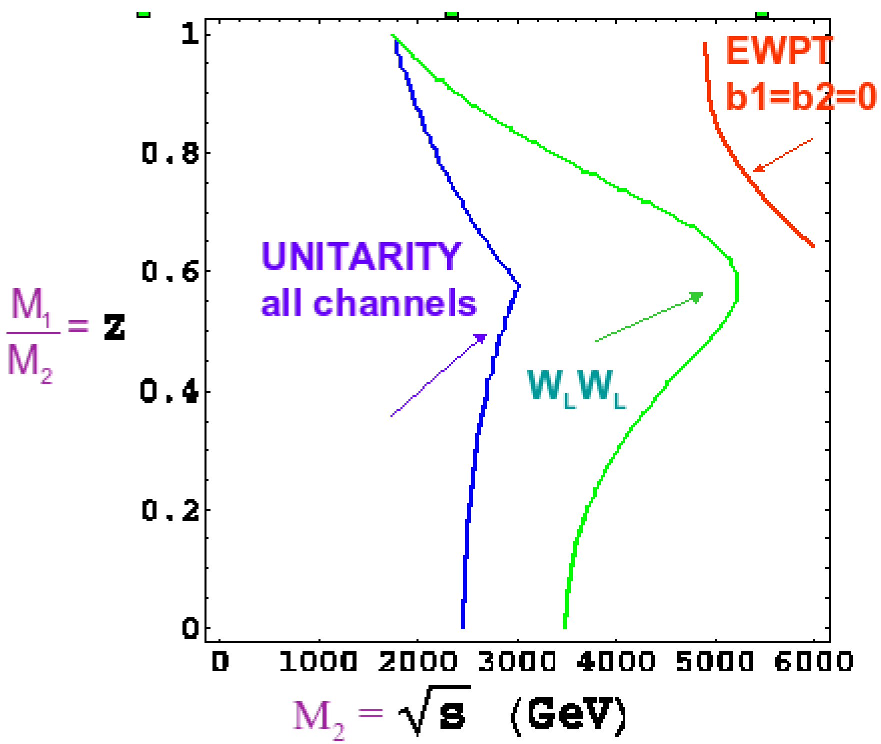
4-site Linear Moose model (N=1)

(Casalbuoni, De Curtis, Dominici, Gatto, Feruglio, '89, see also E.A., '08, Foadi, Frandsen, Ryttov, Sannino, '07)

- **Gauge groups G_i=SU(2) with symmetry $SU(2)_L \ast SU(2)_R$**
- **6 extra gauge bosons $W`_{1,2}$ and $Z`_{1,2}$**
- **5 new parameters $\{M_1, M_2, b_1, b_2, g_1\}$ related to their 2 masses and couplings to bosons and fermions.**

The Higgsless 4-site Linear Moose model

Unitarity versus EW precision tests



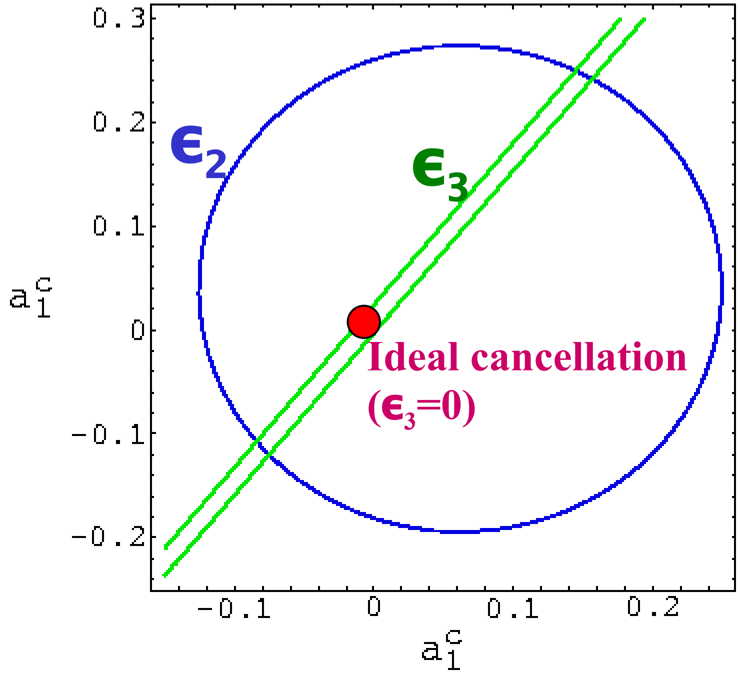
Generally, in Higgsless theories, Unitarity and EWPT are hardly compatible!

A direct coupling between new gauge bosons and ordinary SM matter must be included: $b_{1,2} \neq 0$

The Higgsless 4-site Linear Moose model

and the EW precision tests

De Curtis, Dominici, Fedeli



Bounds on charged couplings (and masses) from low energy precision measurements ϵ_i

$-0.1 < a^c_{1,2}(W`_{1,2}\ ff) < 0.25$

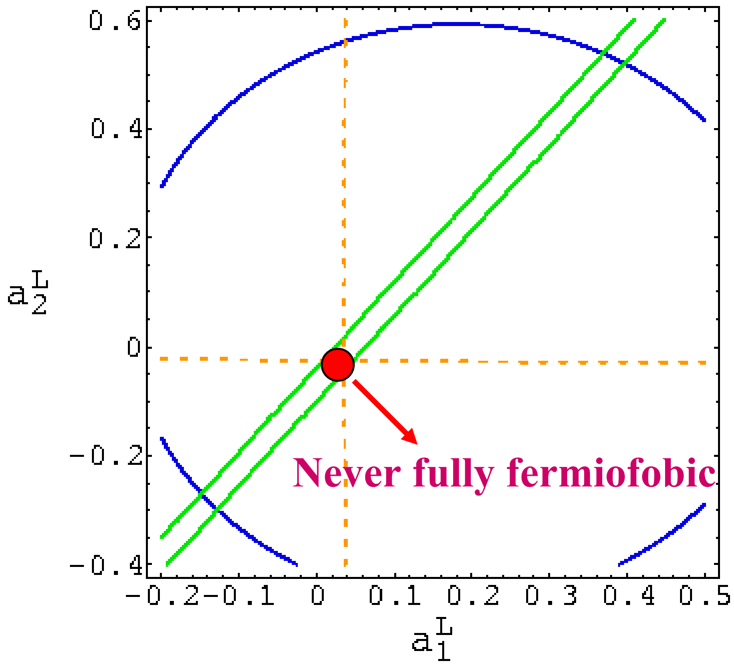
M_1=1000 GeV and M_2=1250 GeV

couplings are SM-size

The Higgsless 4-site Linear Moose model

and the EW precision tests

De Curtis, Dominici, Fedeli



Bounds on neutral couplings (and masses) from low energy precision measurements ϵ_i

$-0.3 < a^L_{1,2}(Z`_{1,2}\ ff) < 0.5$

M_1=1000 GeV and M_2=1250 GeV

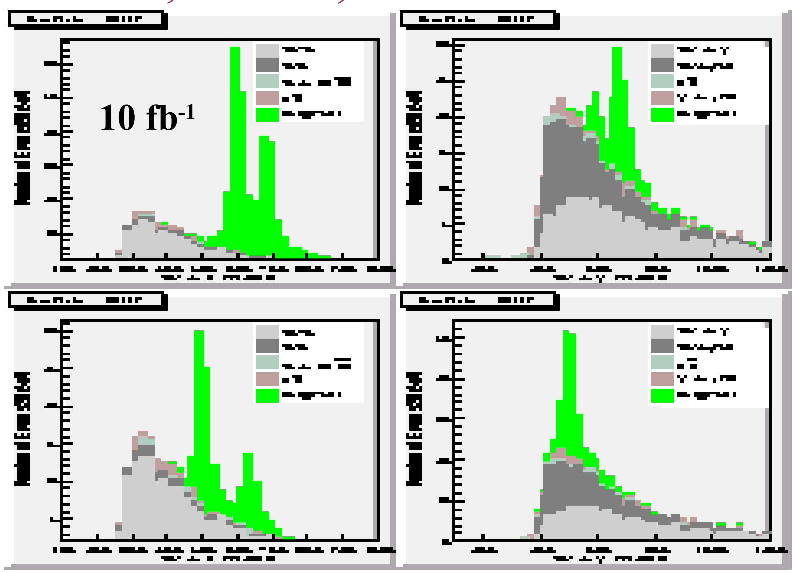
couplings are SM-size

Higgsless Models and new $Z'_{1,2}$ and $W'_{1,2}$ at the LHC

Owing to the usual tension between unitarity and EW precision tests, the extra gauge-boson couplings to SM matter must be small!

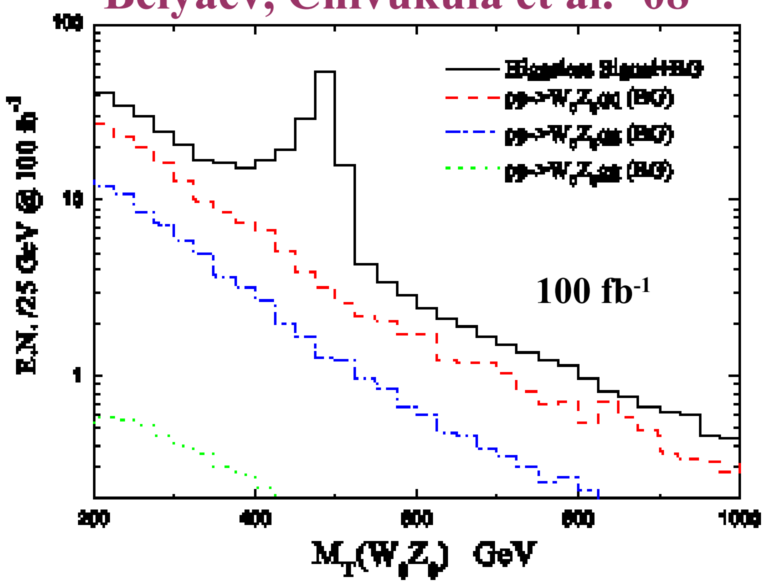
In literature main focus was on complex processes

Hirn, Martin, Sanz `07



di-boson production

Belyaev, Chivukula et al. `08



Vector boson scattering

Higgsless Models and new $Z'_{1,2}$ and $W'_{1,2}$ at the LHC

Drell-Yan processes can be as well

a good EWSB discovery channel

Let`s start from the simple!

Belyaev et al. Phys. Rev. '09
E.A., De Curtis, Dominici, Fedeli, Phys. Rev. '08

Event Generator FAST_2f

(E.A.)

FAST_2f is an upgrade of PHASE [E.A., Ballestrero, Maina], a MCEG for multi-particle processes at the LHC. It is dedicated to Drell-Yan processes at the Leading-Order and it is interfaced with PYTHIA

Processes

We consider charged and neutral Drell-Yan leptonic channels

- **pp -> *ll* with *l*=e,μ**
- **pp -> $l\nu$ with *l*=e,μ and $l\nu = l^- \nu + l^+ \nu$**

Kinematical cuts

Acceptance cuts:

$\eta(l)<2.5$, $P_t(l)>20$ GeV, $P_t^{miss}>20$ GeV

Selection cuts:

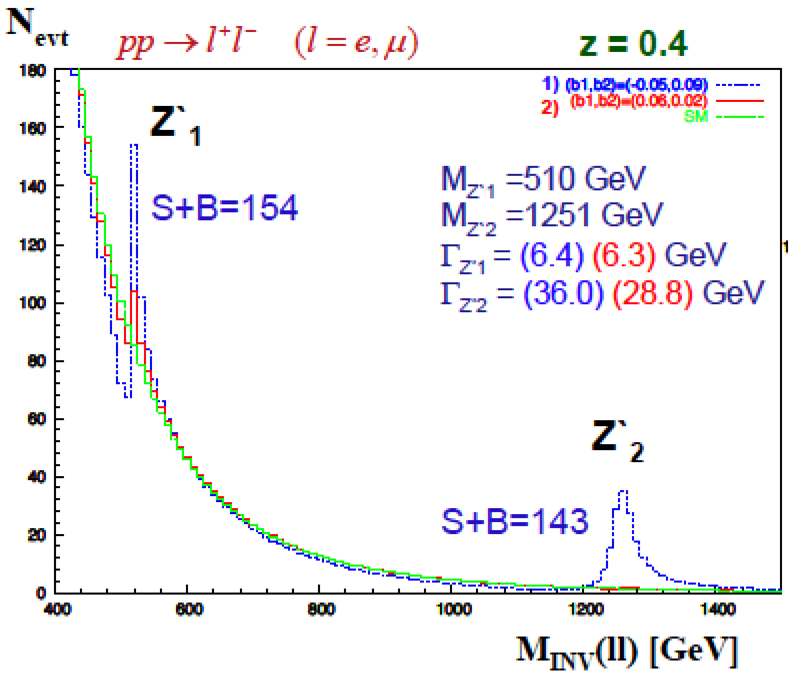
$M_{inv}(ll)>500$ GeV for pp -> *ll*

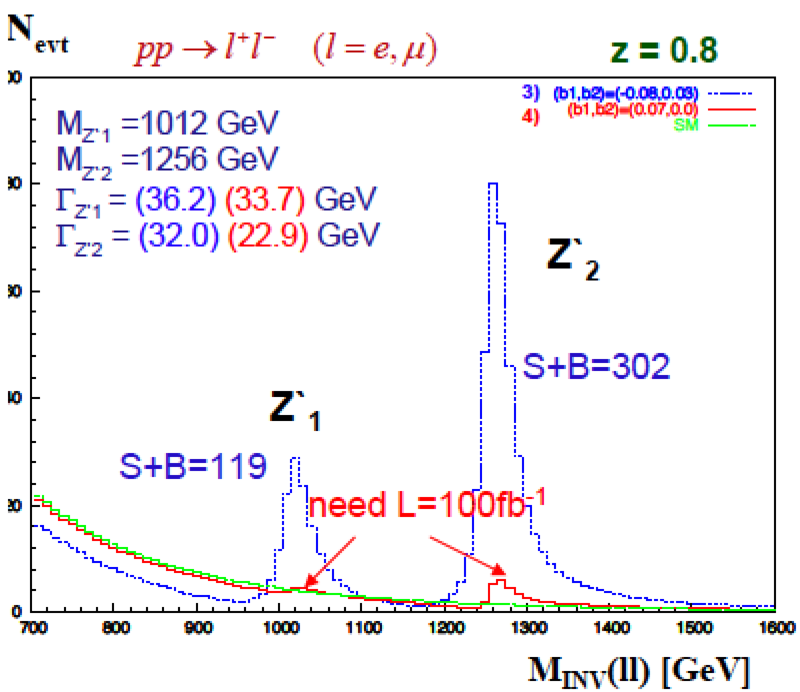
$P_t(l)>250$ GeV for pp -> $l\nu$

no realistic detector simulation is included!

$Z'_{1,2}$ Drell-Yan production at the LHC

E.A., De Curtis, Dominici, Fedeli





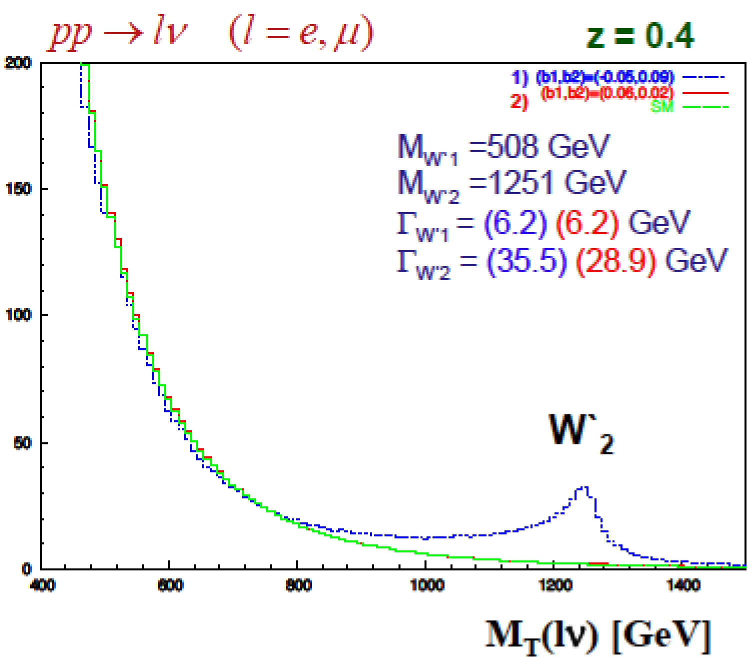
Total # of evts in a 10GeV-bin versus $M_{inv}(l+l-)$ for L=10fb^{-1}. Sum over e,μ

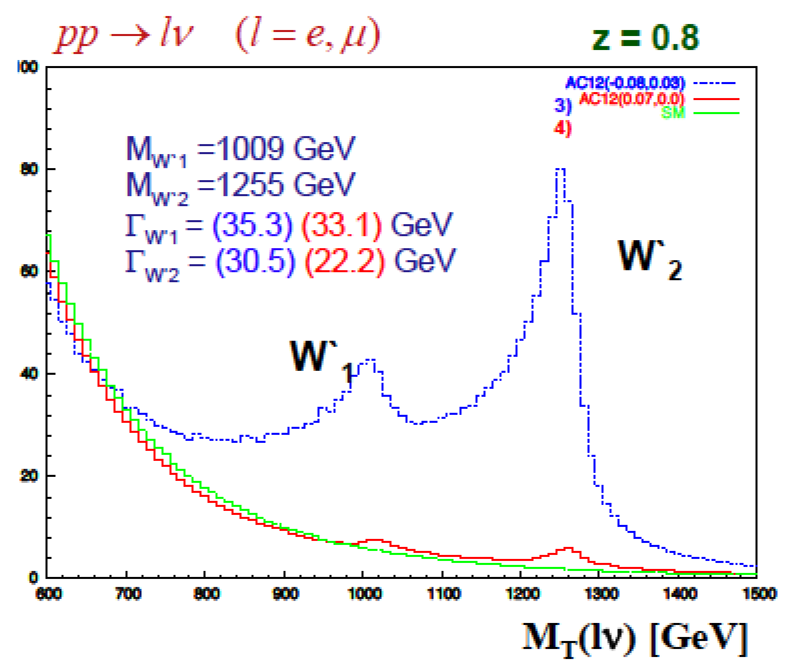
S+B=#evts($M \pm \Gamma$)

$W'_{1,2}$ Drell-Yan production at the LHC

E.A., De Curtis, Dominici, Fedeli

$M_2 = M_1/z$





Total # of evts in a 10GeV-bin versus $M_T(l\nu)$ for $L=10fb^{-1}$. Sum over e,μ

$W'_{1,2}$ Drell-Yan production at the LHC

	$M_{1,2}$(GeV)	$b_{1,2}$	M_t^{cut}(GeV)	$N_{evt}^{sig}(W_1)$	$N_{evt}^{tot}(W_1)$	$\sigma(W_1)$	$N_{evt}^{sig}(W_2)$	$N_{evt}^{tot}(W_2)$	$\sigma(W_2)$
1)	500,1250	-0.05,0.09	400	36	2435	0.7	776	2214	16.5
2)	500,1250	0.06,0.02	400	0	2609	0	1	1807	0
3)	1000,1250	-0.08,0.03	700	808	1230	23.0	1112	1189	32.3
4)	1000,1250	0.07,0.0	700	12	443	0.6	17	88	1.8

# of evts for the W`$_{1,2}$ DY-production for $M_t(l\nu_l) > M_t^{cut}$

$\sigma = N_{evt}^{sig}/\sqrt{N_{evt}^{tot}}$ for an integrated luminosity L=10 fb^{-1}

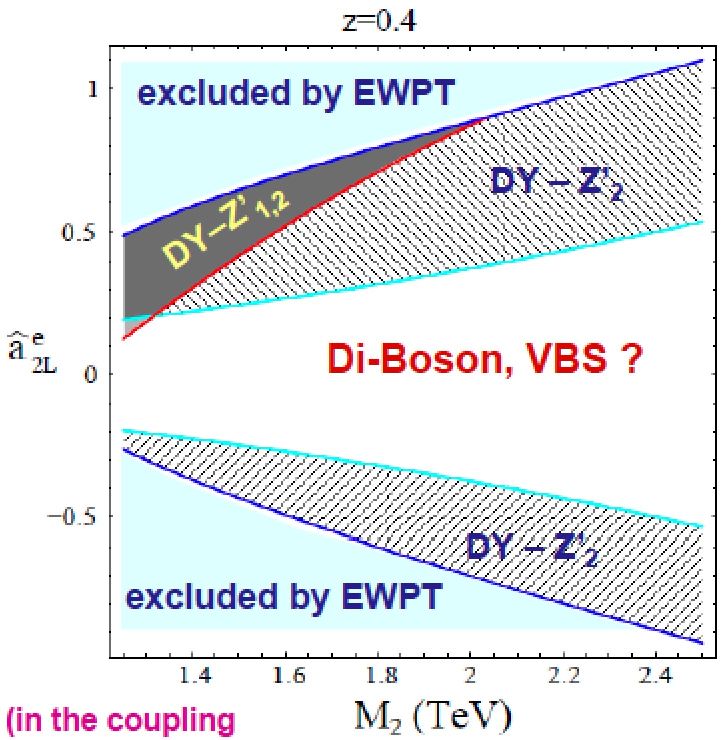
The statistical significance for the W`s production can be a factor 2 bigger than for the Z`s but it is less clean.

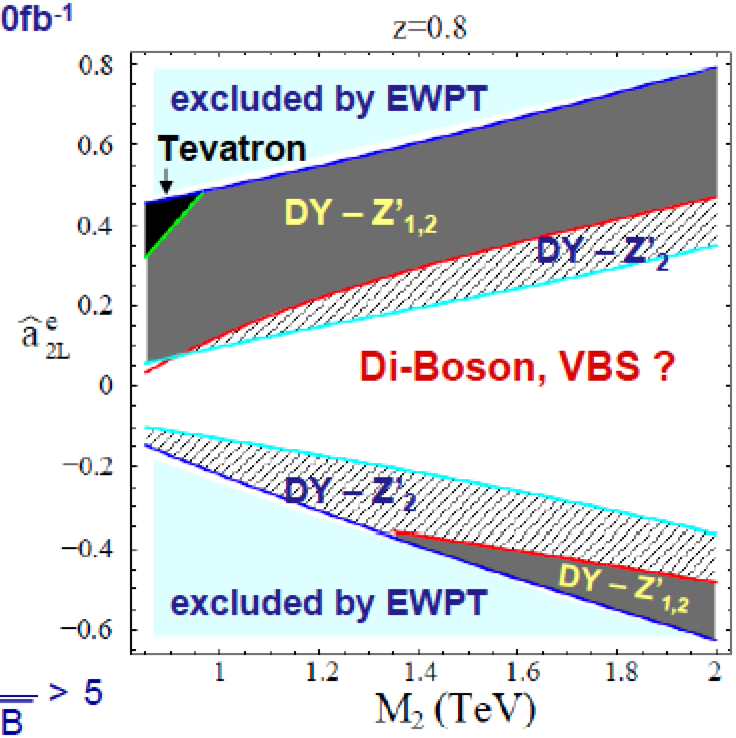
Neutral and charged channel are complementary

All six extra gauge bosons could be investigated at the LHC start-up with L ~ 1-2 fb^{-1} for $M_{1,2}$ < 1TeV

Discovery @ the LHC
DY-processes in the neutral channel, $Z`_1$, $Z`_2$ exchanges

L=100fb^{-1}





(in the coupling the electric charge –e is factorized)

$$\frac{S}{\sqrt{S+B}} > 5$$

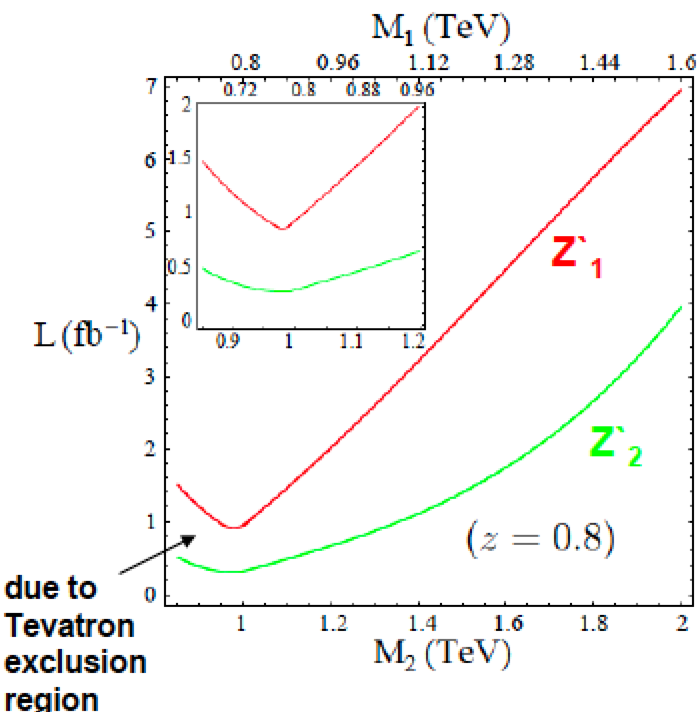
within $|M_{inv}(l^+l^-)-M_i| < \Gamma_i$ (i=1,2)

acceptance cuts:
$\eta(l)<2.5$, $Pt(l)>20$ GeV

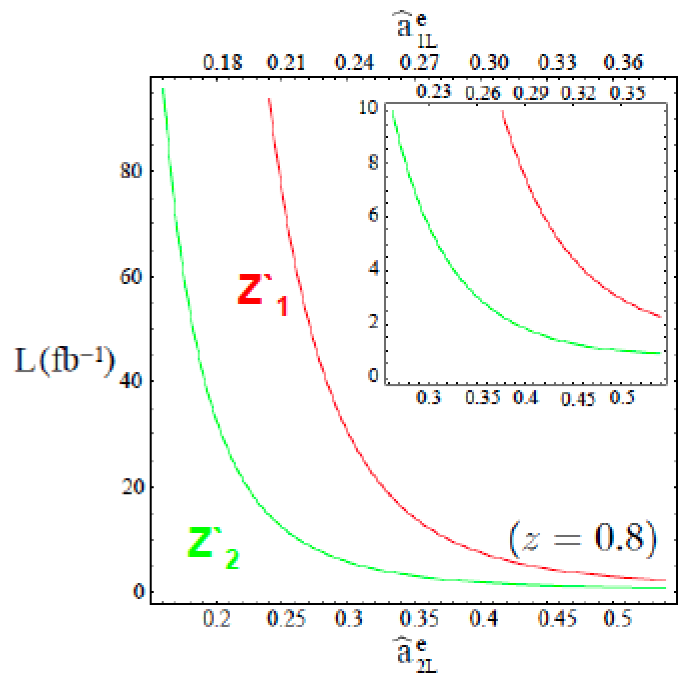
Tevatron: direct limit from neutral DY leptonic channels for L=4fb^{-1} in $p\bar{p} \to l^+l^-$ $(l = e, \mu)$

Bounds from LEP2 not effective

Discovery @ LHC in the early stage low luminosity run



Luminosity needed for a 5σ-discovery for the maximum coupling allowed by EWPT



Luminosity needed for a 5σ-discovery versus the electron-boson left handed coupling (M_1=1TeV, M_2=1.25TeV)

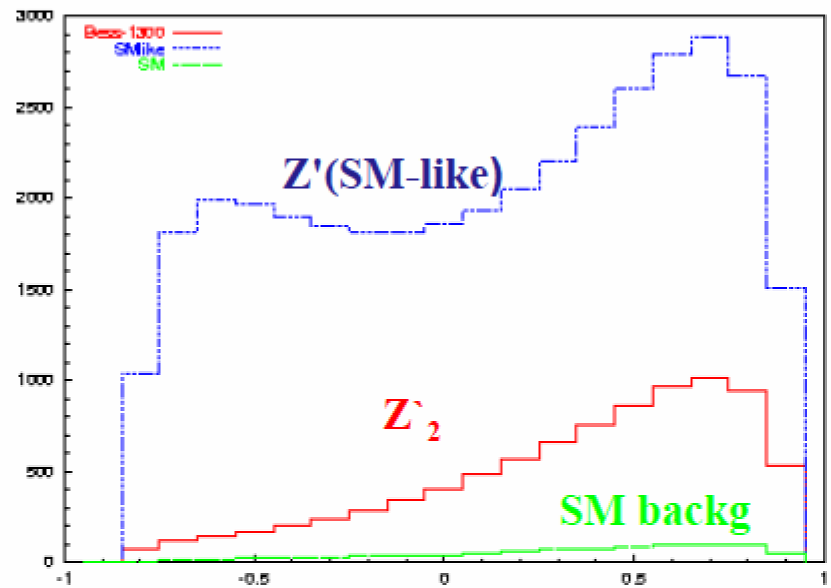
The low-edge of the spectrum detectable with L~1-2 fb^{-1}

How to distinguish the various models? Forward-backward charge asymmetry A_{FB} in pp $\rightarrow l^+ l^-$

$$\frac{d\sigma}{d\cos\theta^*} \propto \frac{3}{8}(1+\cos^2\theta^*) + A^{\ell}_{FB}\cos\theta^*$$

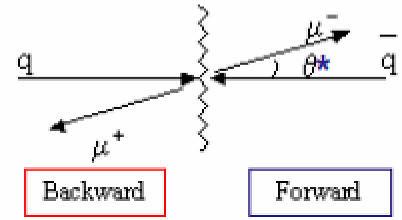
L=100 fb^{-1}

dσ L/dcosθ*(l^-) (l=e,μ)



cosθ*(l^-)

evts for Z`$_2$ ~ 1000



θ* is the angle of the l^- with the incoming quark in the dilepton frame (Collins-Soper)

Approximate the direction of the incoming quark with the boost direction of the leptonic system with respect to the beam axis (Dittmar, 1997)

$M_{Z`2}=M_{Z`(SM\text{-}like)}$=1.3 TeV

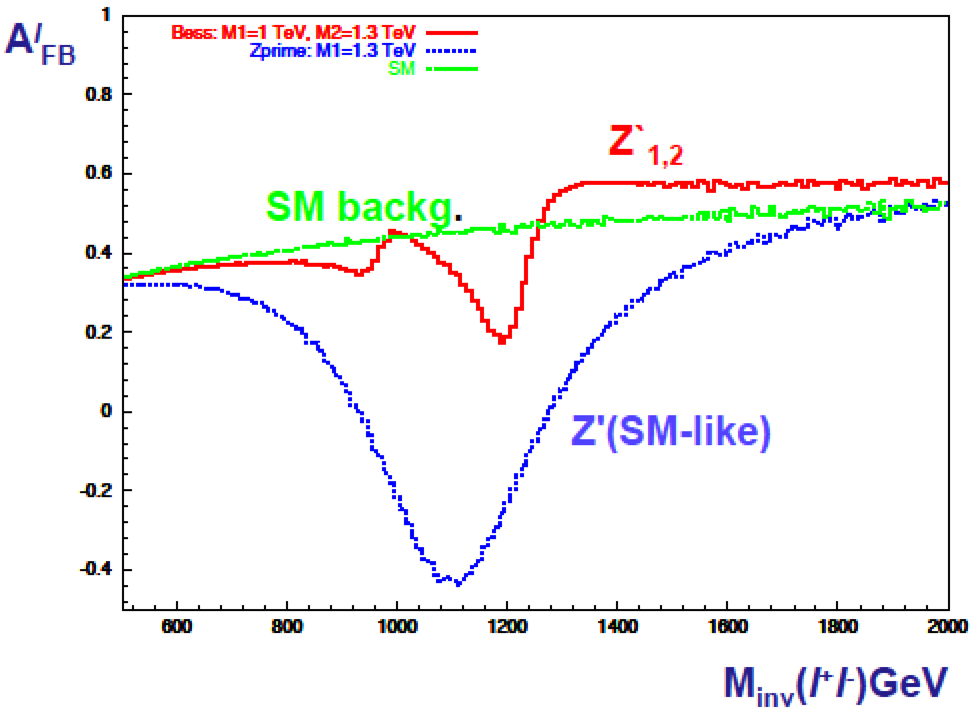
we select the events within

$|M_{inv}(l^+l^-)-M_{Z`}| < 3\Gamma_{Z`}$

Rapidity cut: $|y(l^+l^-)|>1$

Forward-backward asymmetry A_{FB} in pp $\rightarrow l^+ l^-$

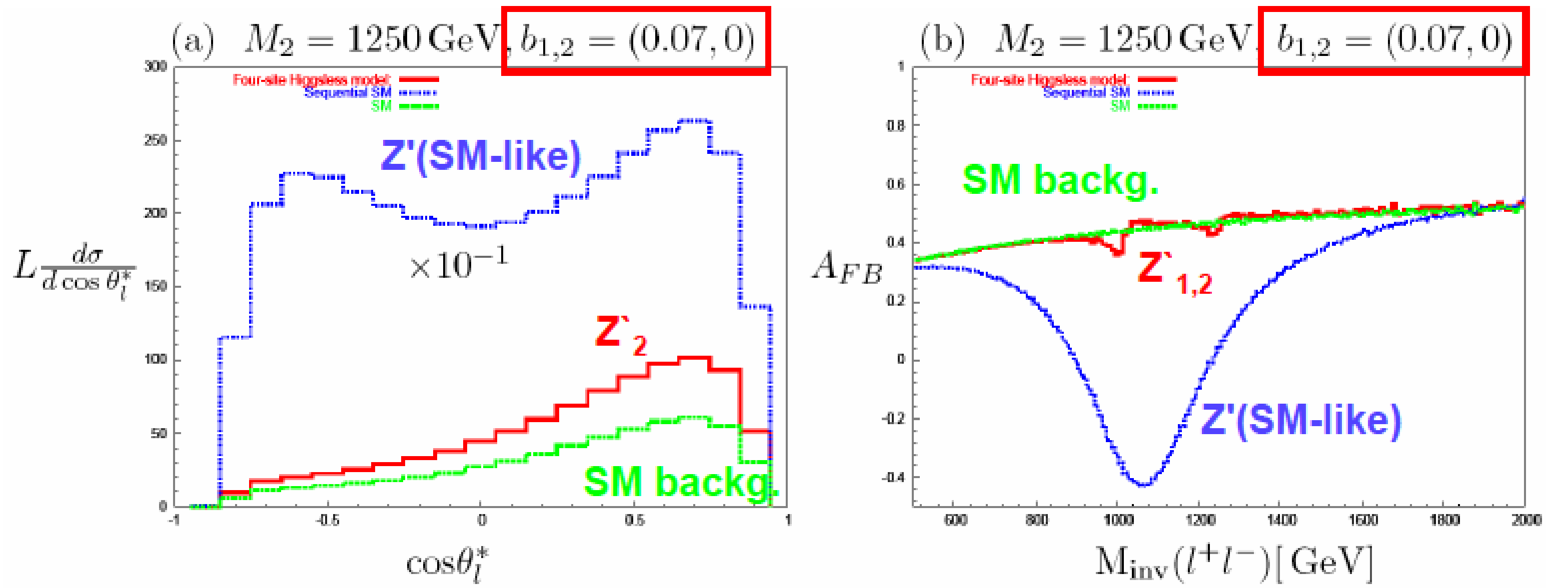
(Dittmar,Nicollerat,Djouadi 03; Petriello,Quackenbush 08)



$M_{Z`1}$ =1.0TeV
$M_{Z`2}$ =1.3TeV
$M_{Z`(SM\text{-}like)}$ =1.3TeV

$$A_{FB} = \left[\frac{d\sigma^F}{dM_{\rm inv}} - \frac{d\sigma^B}{dM_{\rm inv}}\right] \Big/ \left[\frac{d\sigma^F}{dM_{\rm inv}} + \frac{d\sigma^B}{dM_{\rm inv}}\right]$$

On- and off-resonance A_{FB} for a single resonance scenario



- The on-resonance A_{FB} is more pronounced in the 4-site model due to the difference between the left and the right-handed fermion-boson couplings
- The off-resonance A_{FB} could reveal the double-resonant structure not appreciable in the dilepton invariant mass distribution

Conclusions

- Higher dimensional gauge theories naturally suggest the possibility of Higgsless theories
- Linear moose models provide an effective description of Higgsless theories. They are calculable, not excluded by the EW precision measurements and describe new spin-1 gauge bosons which delay the unitarity violation scale
- DY processes are the favoured channel to discover the new $Z'_{1,2}$ and $W'_{1,2}$ even during the early stage LHC data taking!
- A_{FB} for distinguishing among various models with Z`

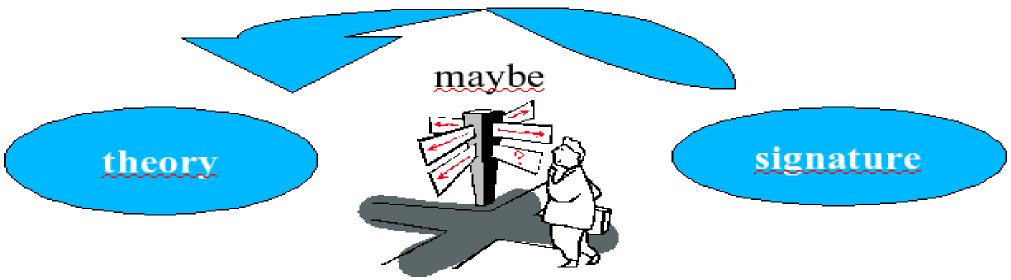
This analysis is part of a wider project developed within NExT

NExT project

A. Belyaev, E.A., S. King, S. Moretti, R. Ribeiro dos Santos,
C. Shepherd-Themistocleous

target is solving the so-called LHC inverse problem:

Which model is it?



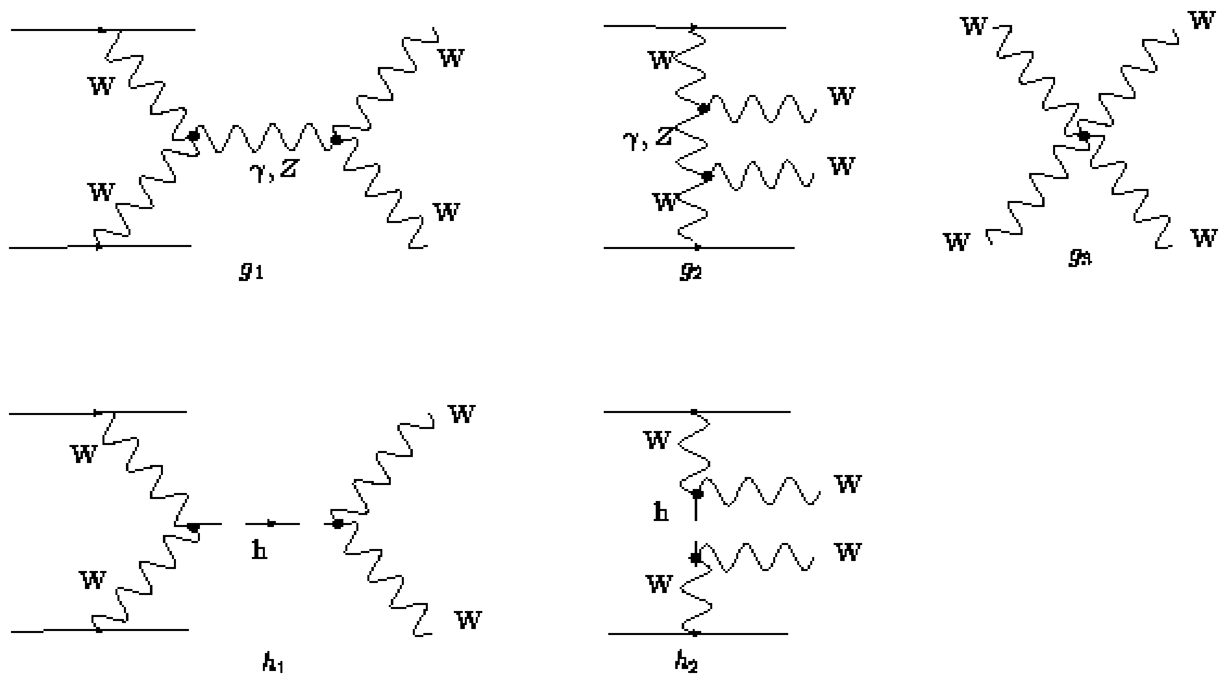
Degeneracies !

By exploring the most promising BSM theories , i.e. SUSY, DEWSB, and LEXD, the basic idea is to create a strategy capable to deconvolute the LHC signals using a comprehensive set of kinematical variables, and to identify the underlying theory.

theory and experiment for the same goal!

w/wo Higgs models and unitarity

e.g. WW scattering:



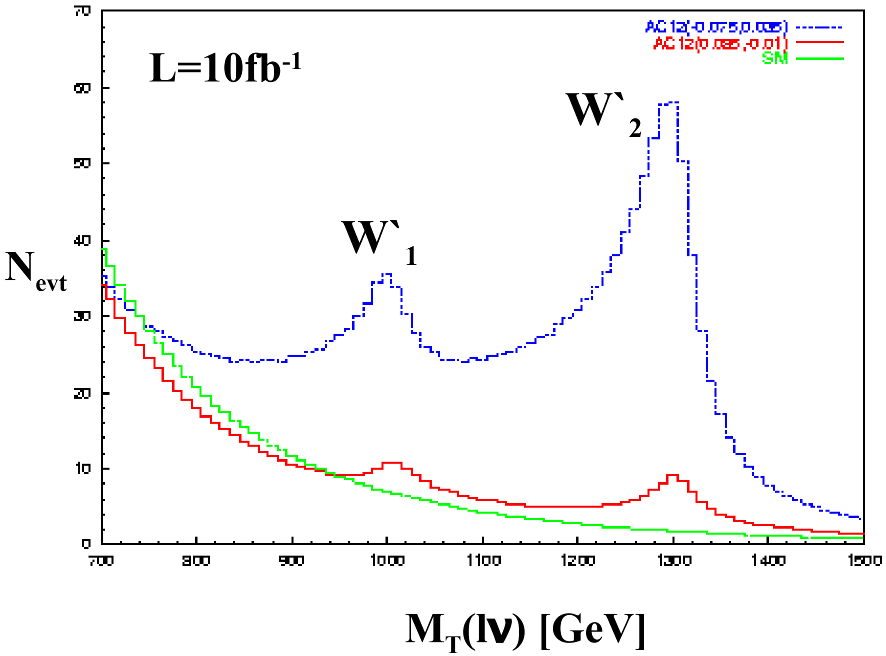
for ON-SHELL incoming W's

$g_i \propto s^2$ $\boxed{\Sigma\, g_i \propto s = M_{WW}^2}$ $\Sigma(g_i + h_i) \to Const.$

The Higgsless Linear Moose model in Drell-Yan processes at the LHC

E.A., De Curtis, Dominici, Fedeli

pp -> l ν (l=e, μ)



pp -> l l (l=e, μ)