Electroweak Symmetry Breaking without Higgs Bosons at LHC

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Introduction

We investigate the alternative scenarii to the EW symmetry breaking by the Higgs mechanism

Several motivations

- No Higgs yet discovered
- Theoretical annoyances : hierarchy, naturalness, triviality
- Higgs potential is ad-hoc (why a fundamental scalar ?), Yukawa couplings are ad-hoc...

Alternatives studied at LHC

- Technicolor (strong dynamic symmetry breaking)

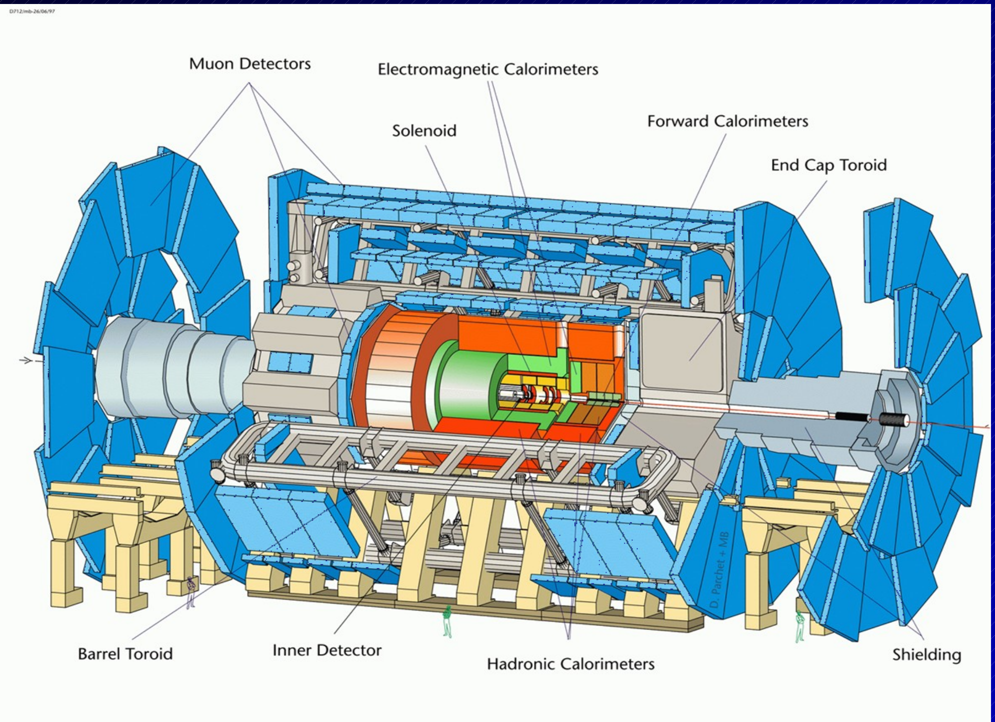
- Chiral Lagrangian (generic parametrization of new physics)
- Warped Extra-dimensions (Symmetry broken by boundary conditions)

The Detectors & the LHC

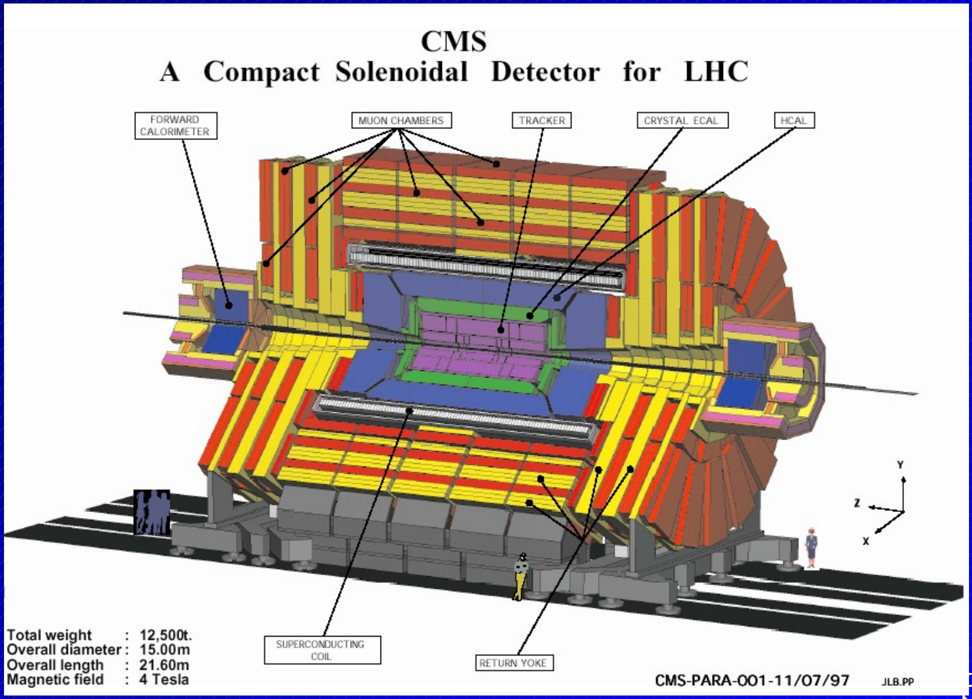
Large Hadron Collider : p-p collision at $\sqrt{s}$=14TeV, high luminosity up-to $10^{34}cm^{-2}s^{-1}$
(10^{13} bb, 10^{10} Ws, 10^{8} tt, 10^{6} Higgs per year)

2 multi-purpose detectors with different concepts:

ATLAS : A Toroidal LHC ApparatuS



CMS : Compact Muon Solenoid



Technicolor models

Technicolor in short

- A new strong interaction, new technifermions, mimicking QCD at higher E
- Dynamic symmetry breaking : 3 Goldstone bosons (or technipions) are “eaten” to give mass to W,Z bosons.
- Advantages : dynamic EW breaking (not ad-hoc), free of naturalness & hierarchy problems

QCD	$\leftrightarrow$	TC
SU(3)	$\leftrightarrow$	SU(N_{TC})
$\langle qq \rangle \sim \Lambda_{QCD}^3$	$\leftrightarrow$	$\langle TT \rangle \sim \Lambda_{TC}^3$

But : Mass of fermion ? Agreement with data (EW precision constraint) ?

Extension of Technicolor

- Extended Technicolor : color & technicolor are subset of higher group. Massive fermions but allow FCNC
- Walking TC : slow running of couplings raises <TT> masses & prevent FCNC
- Topcolor assisted TC : new interaction for 3rd family contributes to top mass

Technicolor in CMS

A "straw-man" model is considered : phenomenology of lowest technihadrons in the color-singlet sector : **π_{TC} (pseudo-scalar) and ρ_{TC}, ω_{TC} (vectors)**

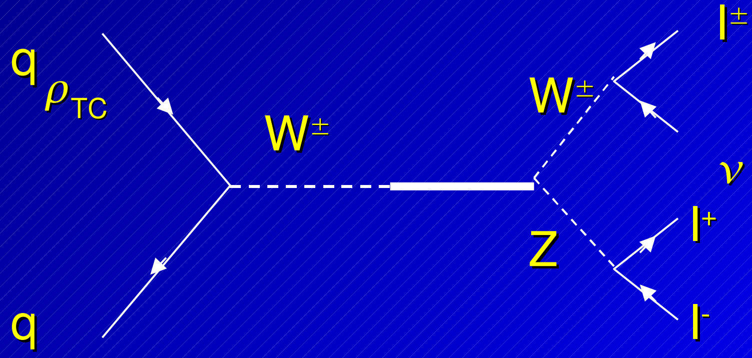
$$\rho_{\rm TC} \rightarrow \cos^2\chi\langle\pi_{\rm TC}\pi_{\rm TC}\rangle + 2\cos\chi\sin\chi\langle\pi_{\rm TC}W_{\rm L}\rangle + \sin^2\chi\langle W_{\rm L}W_{\rm L}\rangle$$

K. Lane hep-ph/9903372

Signal channel : $qq \rightarrow \rho_{TC} \rightarrow WZ \rightarrow 3lept + \nu$ cleanest channel

scan of several masses of ρ_{TC} , π_{TC} .

xsection 1– 300 fb



Main backgrounds

WZ	: 0.38pb
ZZ	: 0.07pb
Zbb	: 330pb
tt	: 490pb

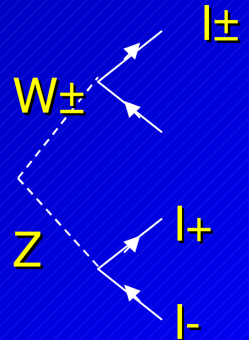
P. Kreuzer
CMS Note 2006/135

The Analysis

Event production

- Signal & backgrounds events generated with Pythia 6.2 (+comphep for Zbb)
- Detector simulation/reconstruction with CMS fast simulation FAMOS
- Pile-up addition according to low luminosity at $2 \times 10^{33} cm^{-2} s^{-1}$
- Fast-sim validated against full-sim for a test point at $m(\rho_{TC})$, $m(\pi_{TC})$=300 GeV

Event reconstruction



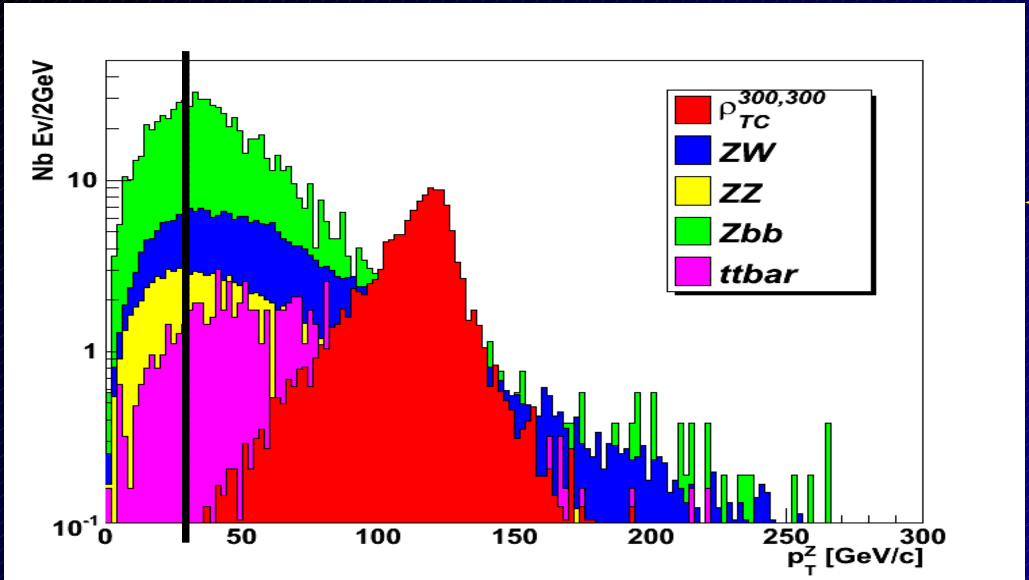
Reconstructed leptons : 3 highest-pt, isolated, $P_T(1,2,3) > 30,10,10$ GeV

Z Reconstruction : same flavor, opp. charge, $|m_{ll} - m_Z| < 7.8$GeV

W Reconstruction : 3rd lepton+Etmiss, choose solution with min $p_z(\nu)$

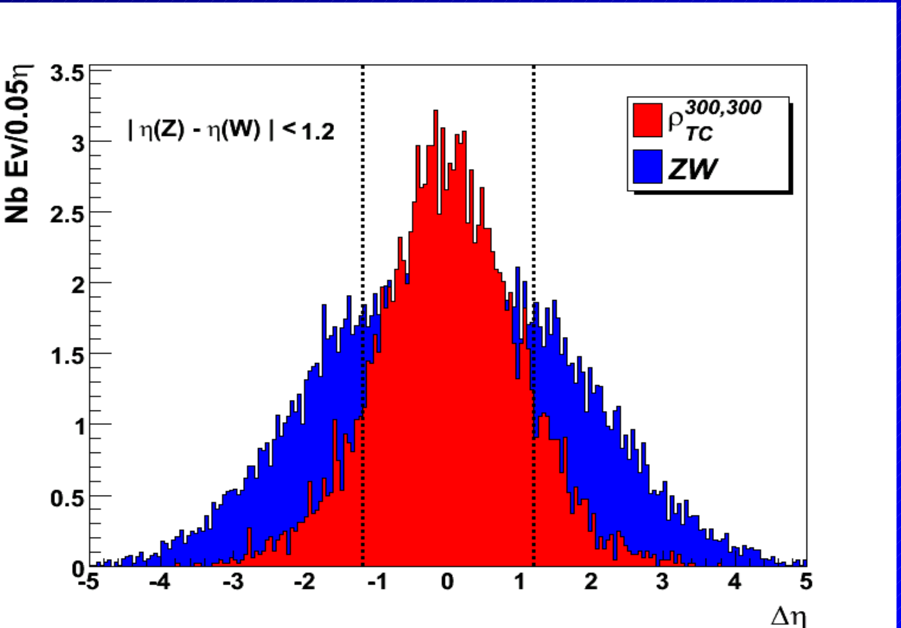
W,Z kinematics : $|\eta(Z) - \eta(W)|<1.2$ $P_T(Z), P_T(W)>30$GeV

Analysis : illustrations



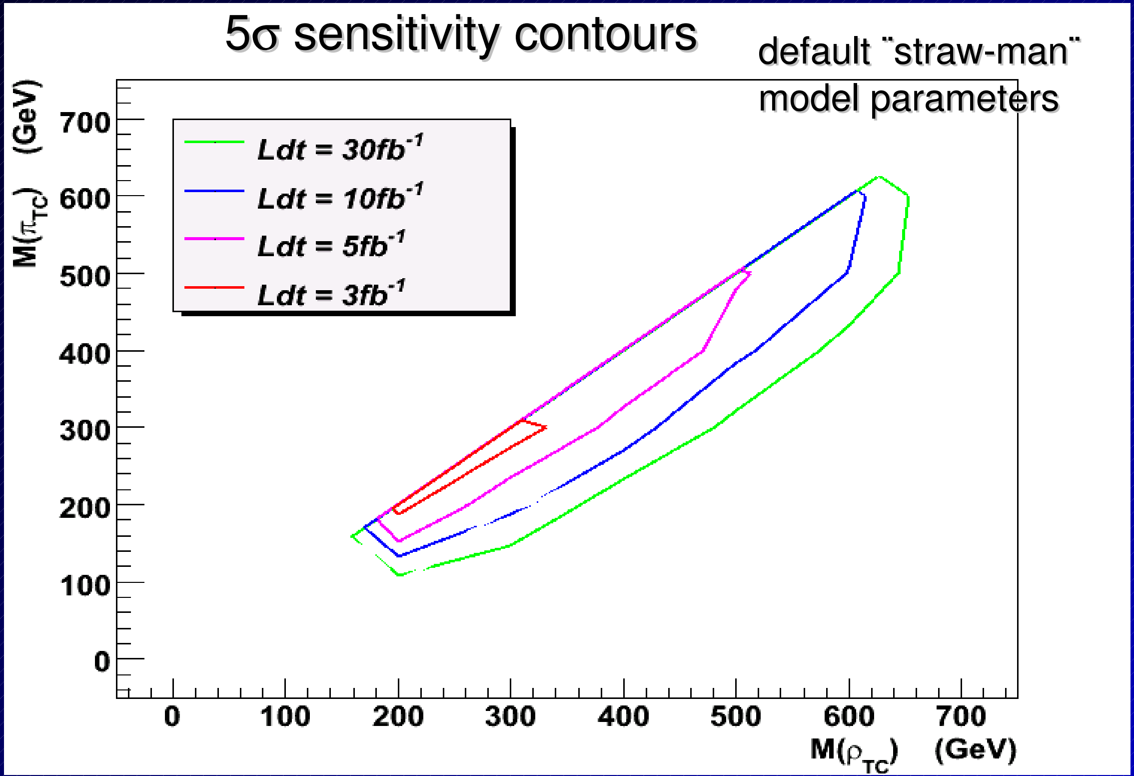
Pt distributions
keep cuts low to preserve exponential shape

$|\eta(Z) - \eta(W)|$ distributions



Analysis results

- Fit performed on final mass distrib (signal: gaussian pdf, bg : expo pdf)
- Sensitivity computed from likelihood : $S = \mathrm{sqrt}(2 \ln (L_{S+B}/L_B))$
- Repeat several 'MC experiments' to get average sensitivity for each point



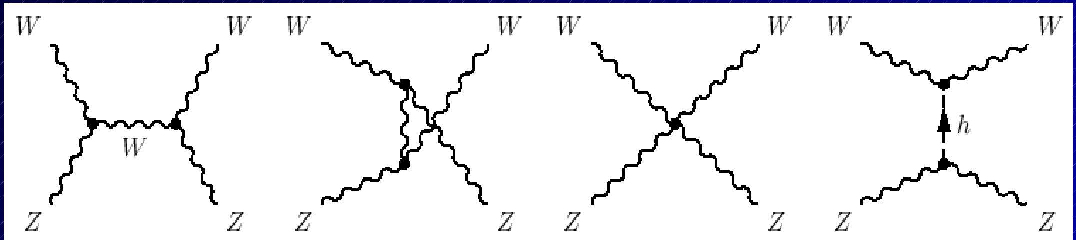
Systematic uncertainties estimated from full sim studies
- missing Et
- fake leptons in Bg
- lepton ID

⇒ Effect on significance ~ -11%

Effect from NLO cross-sections ~ -6%

Vector Boson Scattering

For alternative scenario to Higgs mechanism,
Vector Boson Scatering (VBS) is of crucial importance



$$a_0^0(\omega^+\omega^- \to \omega^+\omega^-) \xrightarrow{s<<M_h^2} -\frac{s}{32\pi v^2}$$

In no higgs scenario when ($\sqrt{s}$>1.7TeV)

$$a_0^0(\omega^+\omega^- \to \omega^+\omega^-) \xrightarrow{s>>M_h^2} -\frac{M_h^2}{8\pi v^2}$$

or even in too heavy Higgs scenario (M_H >870GeV) ...

... VBS processes lead to pertubative unitarity violation

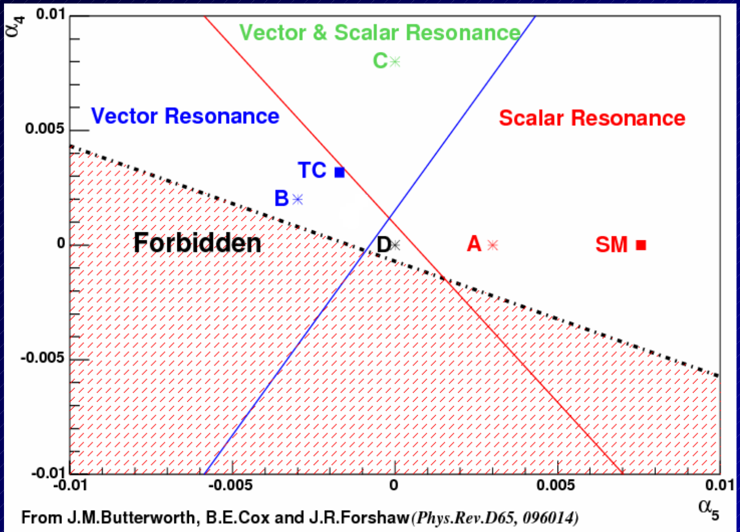
This is non-physical so we MUST see new physics here

Chiral Lagrangian models

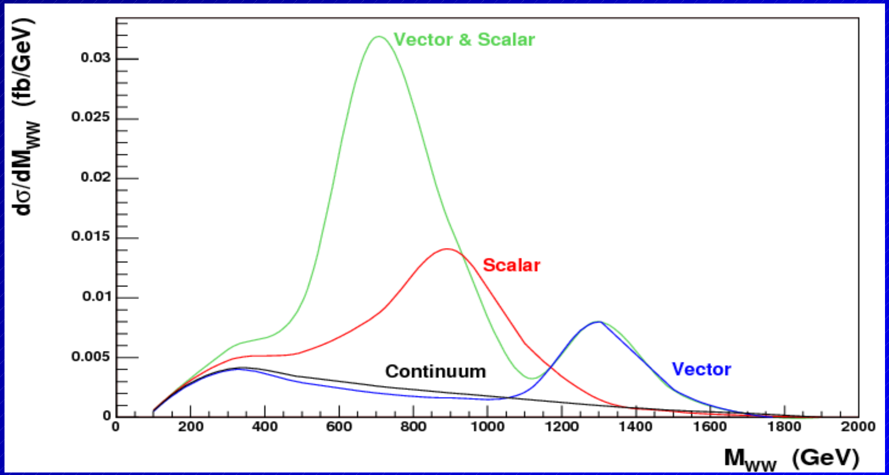
A generic low-energy effective theory

- expanded in terms of EW Goldstone boson fields
- new physics parametrized through coeff. of higher order operators
- lowest dimension (4) operators contribute to VBS with **2** couplings **a_4 & a_5**

Higher order terms suppress unitarity violation. Assume nevertheless a unitarization procedure inspired from QCD pions scattering (Pade procedure)



(a4,a5) parameter space



WW mass distributions

Warped Extra-dimension

Csaki et al.
hep-ph/0308038
Cacciapagila et al
hep-ph/0409126

A more recent model

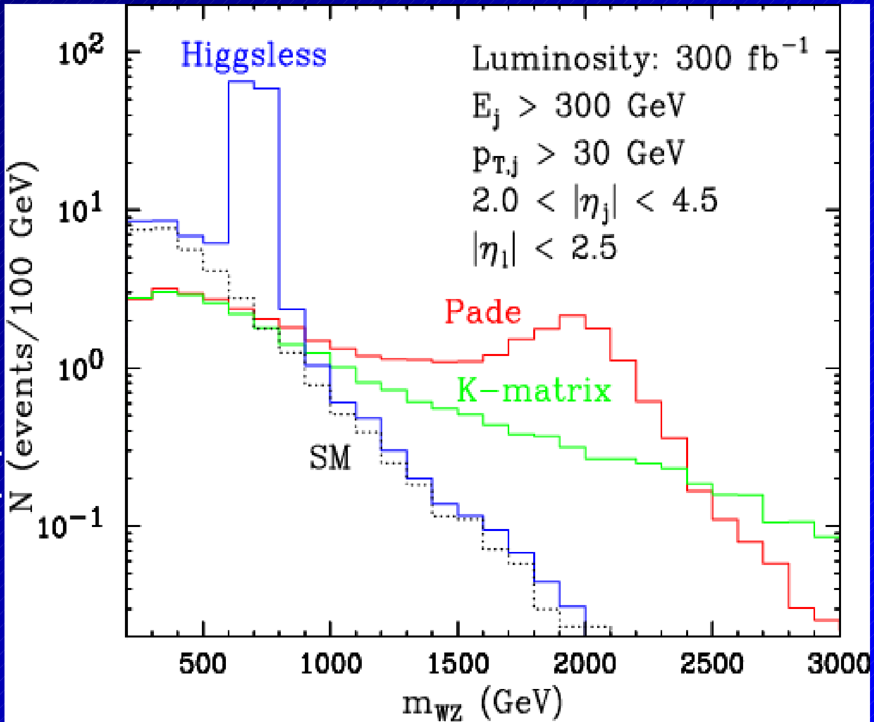
- 2 branes at different energy scale
- Separated by a warped ED on which SM fermions are localized

EW symmetry broken through boundary conditions

... also give mass to fermions according to their position in ED

Resonances through KK excitations of vector bosons

A. Birkedal, et. al.
hep-ph/0412278



Analysis in Atlas

Signal

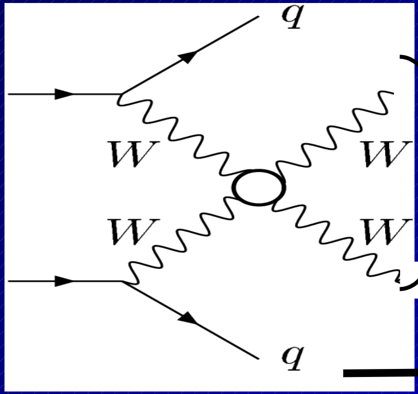
focus on WW, WZ scattering in ChL model

xsection for ~1TeV resonance

WW : 50-100 fb

WZ : 1-10 fb

signal characteristics :



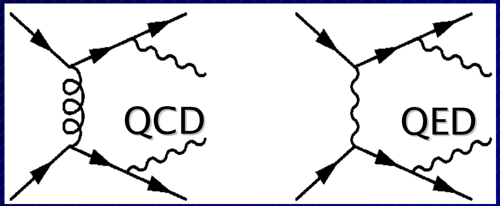
High p_T bosons

Few/no jets in central region (no colour exchange)

Forward tag jets

Main Backgrounds

irreducible	$qq \rightarrow VVqq$	4pb	
reducible	ttbar	700pb	
	W/Z+Njets	60/25 pb and+	



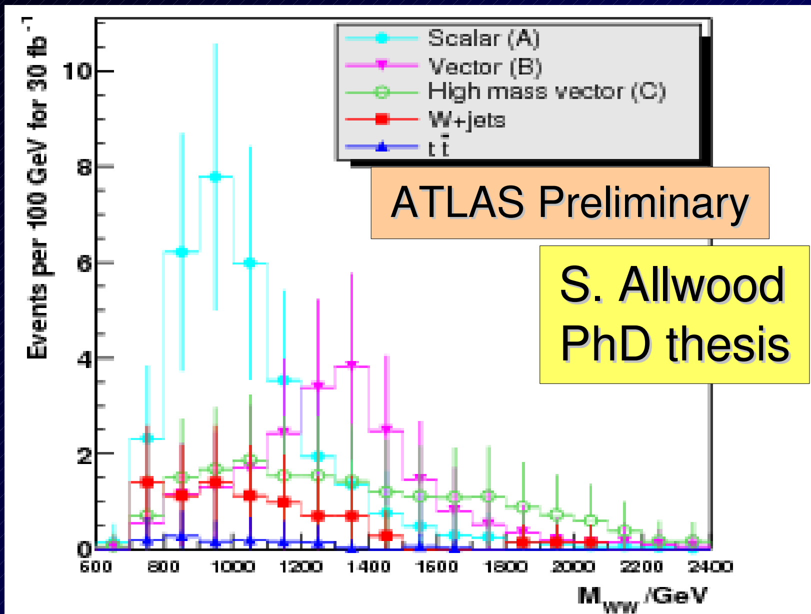
SM irreducible bg

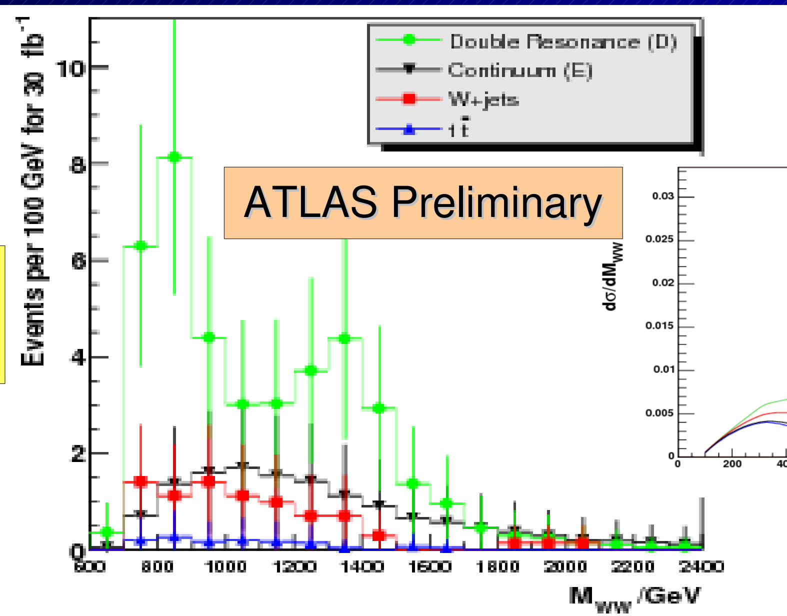
Essential cuts

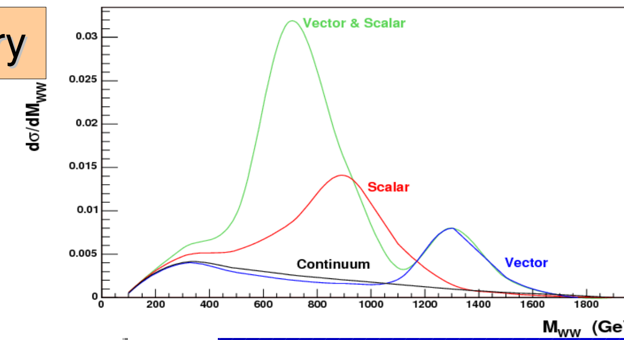
- High Pt, isolated leptons -> V reconstruction
- High Pt jet(s) -> V reconstruction
- Forward Jet tag
- Jet veto
- Mass cuts (V mass, resonance)

WW analysis in Atlas

WW → qqlν fast (ATLFAST) simulation study : signal & w+jets, ttbar generated in Pythia
Work being compared with full simulation, Alpgen







	Total σ after event selection (fb)			
Signal scenario	Signal	ttbar	W+jets	**S/√B for 30 fb^{-1}**
Scalar (A)	1.05	0.04	0.28	**10.17**
Vector (B)	0.70	0.04	0.28	**6.78**
Scalar + Vector (C)	1.33	0.04	0.28	**12.88**
Continuum (D)	0.47	0.04	0.28	**4.26**

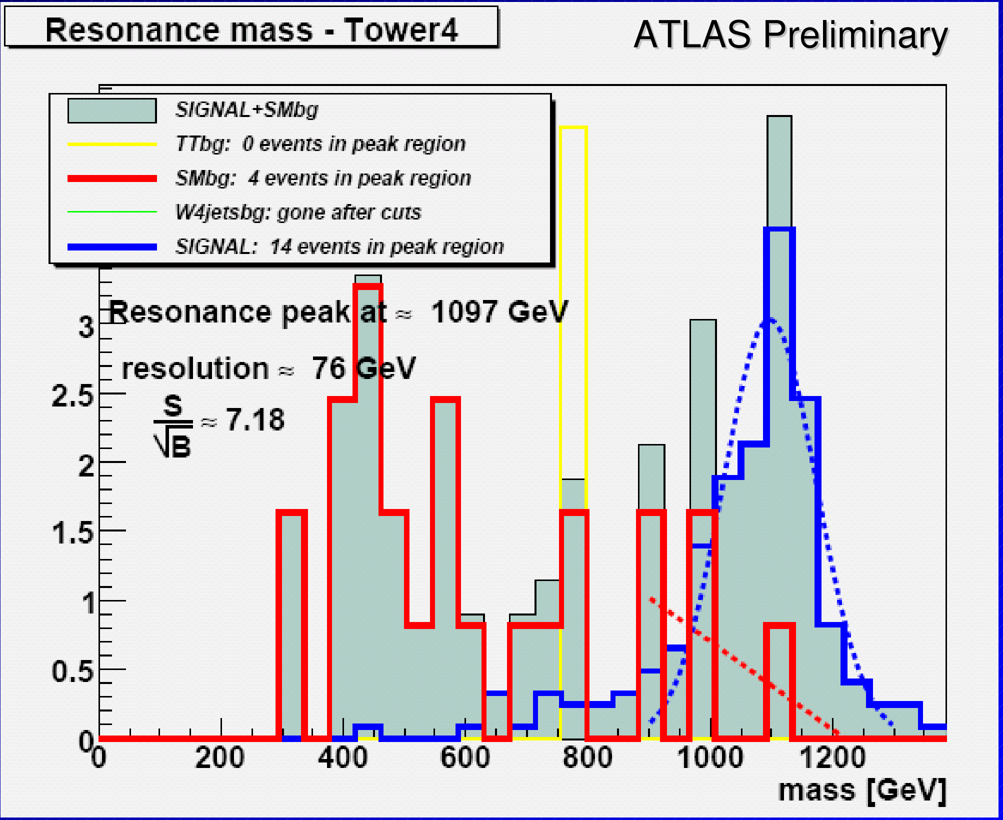
WZ Analysis in Atlas

First fast-sim analysis in WZ→ jjll channel

Atlas Note
com-phys-2006-041

Full-sim in 3 decay channels : jjll , jjlν ,lllν

- Generation : Pythia(signal)
  Madgraph (qqWZ bg)
  MC@NLO (ttbar bg)
  Alpgen (W+4jets)
- Full Atlas simulation/reco



Expected sensitivity :

1.15 TeV resonance
  100fb^{-1} in WZ → jjll, lvjj channels
  300fb^{-1} in WZ → lllv channel

750 GeV resonance
  100fb^{-1} in WZ → jjll channel

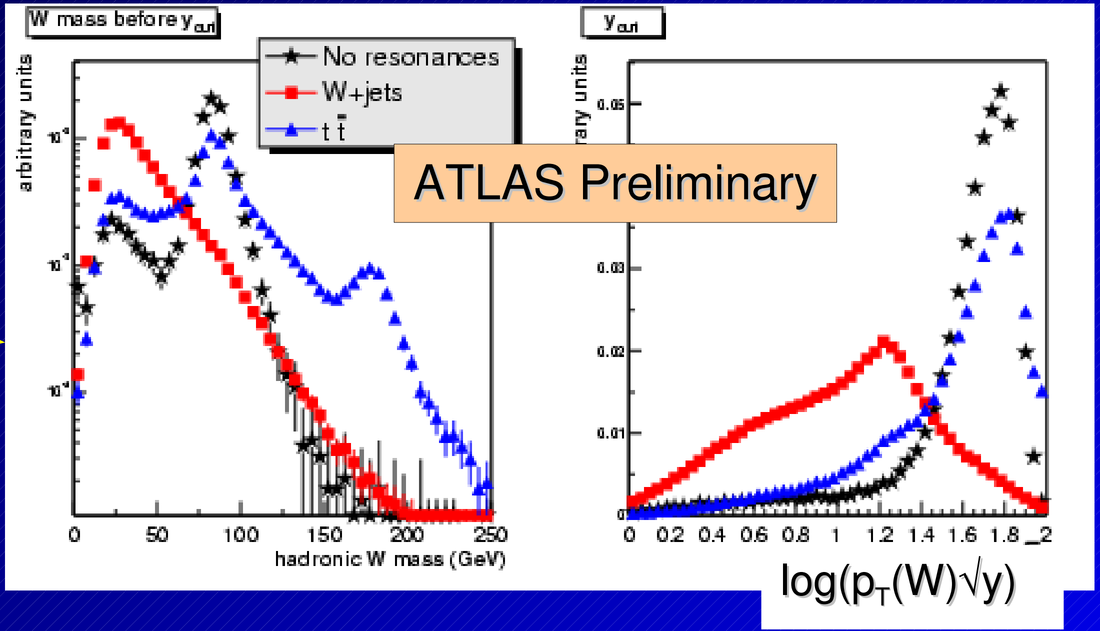
Experimental challenges

Previous/current full-simulation analysis allow to identify experimental challenges related to VBS studies

Jets importance

- High Pt VB produce large jets with sub-structure
  - Reconstruction issues
  - Bg rejection criteria

Tools development such as "Ysplitter"
(Y ~ Kt distance between subjets inside a jet)



- Jet Tagging / veto-ing (important cuts)
  - Pile-up effects

Difficult experimental backgrounds

- W/Z+jets : theoretical uncertainties, mis-identification...
- Next important focus in work plans

Conclusion

Electroweak symmetry breaking is still NOT understood.
Several alternate models are seriously under study at the LHC

Atlas & CMS expect to be sensitive to a wide parameter space

- Starting at a few fb^{-1} in technicolor models

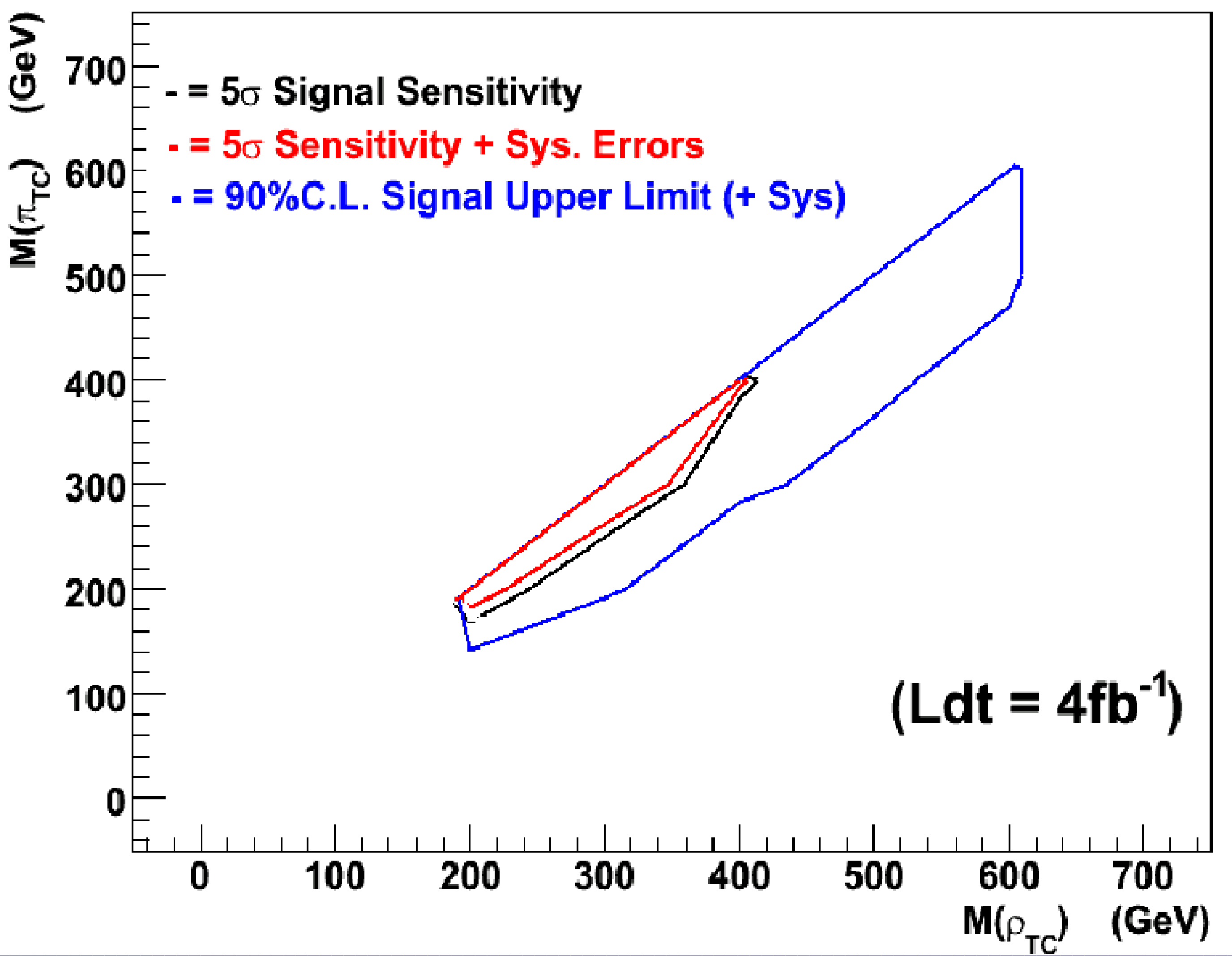
- from 30 fb^{-1} at typical points of the generic Chiral Lagrangian model

- Studies have stressed out key difficulties of the analysis : work is now focusing on these points

We expect very exciting discoveries if no Higgs is found !

Back-up slides

CMS Sensitivity for TC including systematic errors



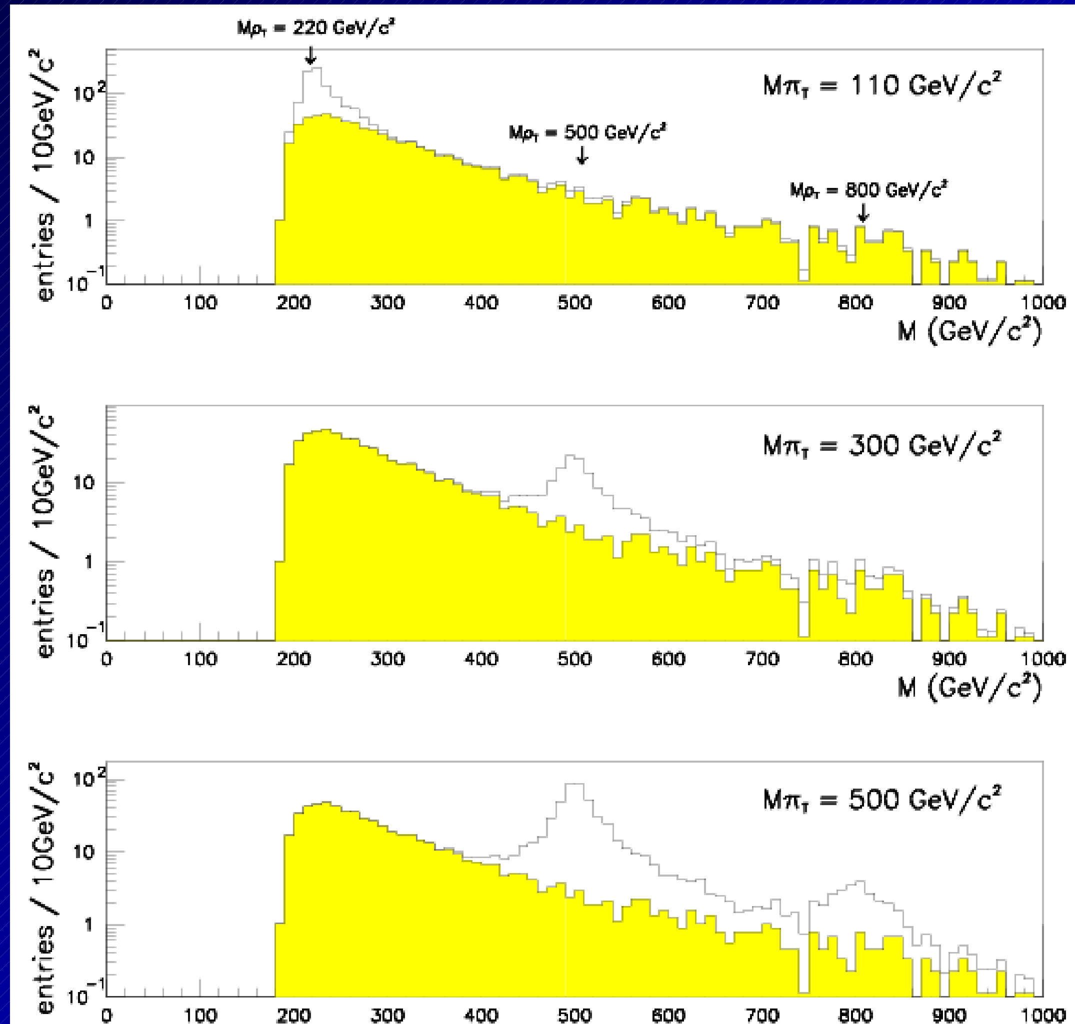
Relative systematic uncertainties on SM BG:

- accuracy of lepton efficiency determination: 2.7%
- accuracy of fake rate determination: 8.5%
- absolute E_T^{miss} energy scale: 6.6%

ATLAS TDR Technicolor study with ZW final state

- Considers only the largest background (ZW).
- Lepton reco. eff. assumed 100% (it is more like 90%).
- Similar selection criteria to CMS study, but without $\Delta\eta_{ZW}$ cut.
- Cut on ρ_{TC} helicity.

Azuelos et al.
Atlas Note phys-99-020



M_{ZW} for 30 fb^{-1}

Detailed cuts WW analysis

- Leptonic W: highest-p_T lepton + E_T^{miss}
- Hadronic W: highest-p_T jet(s)
- top cut: reject events with m(W+jet)~m_{top}
- tag jets: more outward than Ws
- p_T(WW+tag jets) ~0:
- central jet veto:

- Cut at p_T^W>320GeV
- Cut at p_T^W>320GeV, $m_W \pm 2\sigma$
- 140 < m(W+jet) < 270GeV
- E>300GeV, $|\eta|$>2.5
- p_T(WW+tag jet) <50GeV
- ≤1 extra jet, p_T> 20GeV

Detailed cuts WZ analysis

Leptons	Id, isolation, Pt cut (15 GeV)
Vector Boson	Mass cut ($\pm$15GeV), Pt cut (59GeV), $\Delta\Phi$(W,Z)>1.0
Forward Jets	2 required, E>200 GeV, Pt>15 GeV, $\Delta\eta$>4
JetVeto	No extra central Jet, No b-jet
Resonance	Mass cut : $\pm$150GeV