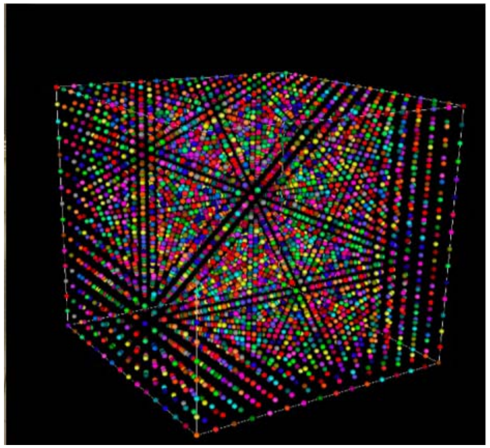
Search for Strong Symmetry Breaking signals at the LHC

Discovery potential

Note:

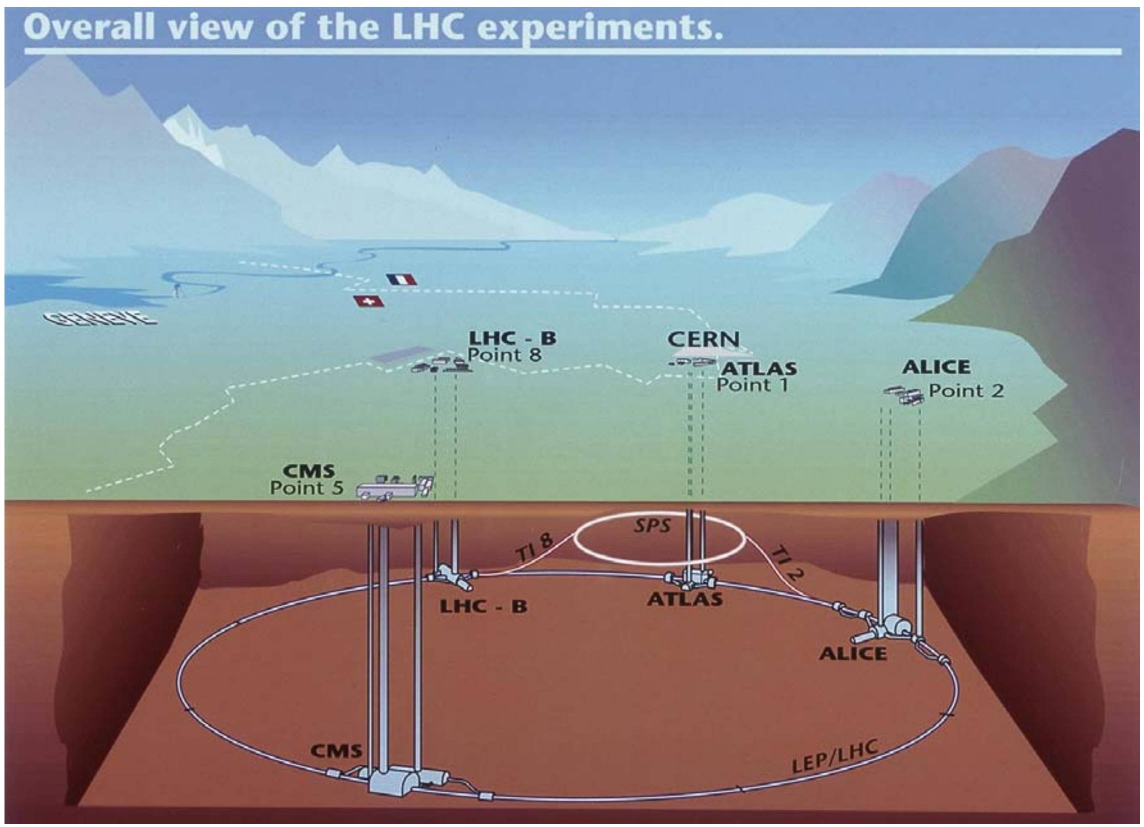
not all potential signal channels shown have been evaluated with LHC detector simulation,
but the study of these generic signals are certainly of high priority



apology:
- bias towards ATLAS
- some analysis results not yet public

LHC running plans

- **Present plans (still good possibility to change) are:**
  - first injections end of June
  - first physics run (typically 2 months) in 2008,
    - most likely at 10 TeV c.m. energy
    - possibly start in August or September



Why Dynamical Symmetry Breaking?

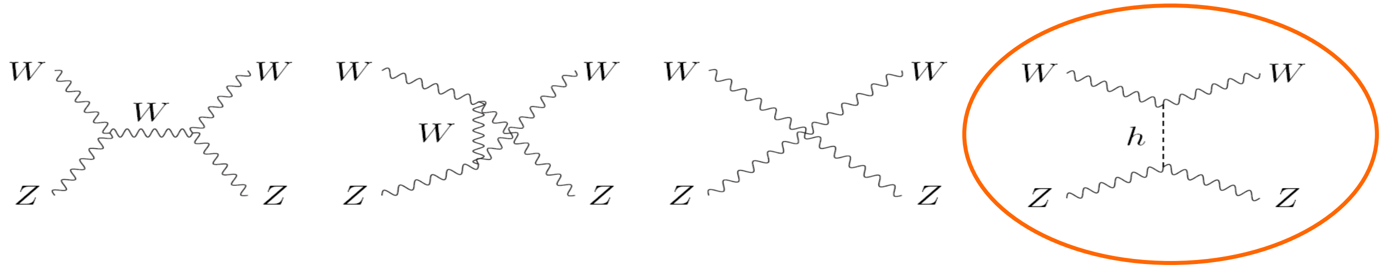
SM Higgs can be found at LHC with 10-20 fb^{-1},
and MSSM Higgs's parameter space well covered
but what if not found??

Fine tuning

For Λ = 10 TeV, $\delta m_h^2 \sim$ →

$-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim (2\ \mathrm{TeV})^2$ | $\frac{1}{16\pi^2}g^2\Lambda^2 \sim (700\ \mathrm{GeV})^2$ | $\frac{1}{16\pi^2}\lambda^2\Lambda^2 \sim (500\ \mathrm{GeV})^2$

Unitarity



Flavour

Dark matter

while satisfying stringent constraints from precision EW measurements

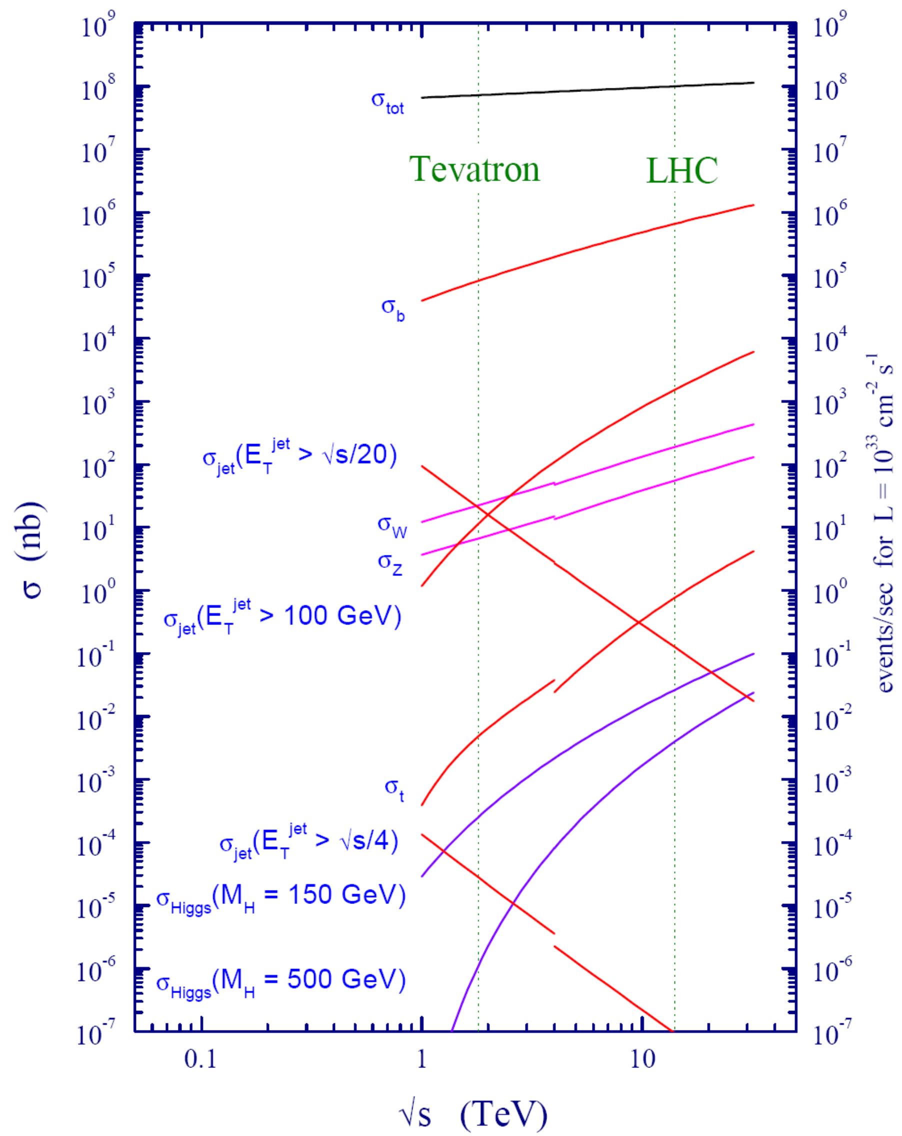
Variety of models of Dynamical EWSB

- **QCD-like**
  - low scale technicolor
  - adjoint representations (Sannino)
  - Degenerate Bess
- **effective: Chiral Lagrangian**
- **extraD, higgsless**
- **top see-saw**
- **little Higgs**
- **fourth family**

experimental challenges: backgrounds

- **Hadronic backgrounds are huge**
  - ➔ (semi)leptonic channels only viable
  - estimates at tree level, using AlpGen (parton shower Matrix-element matching), with loose preselection:
    $W_{e\nu}$ + 2, 3, or 4 partons: ~ 500 pb, 120 pb or 30 pb
  - large uncertainties in these cross sections (K-factors)
- **signals for VB scattering much weaker:**
  - e.g: $W_{l\nu}Z_{jj}$ + 2 j, (m_{WZ} = 800 GeV) ~ 35 fb

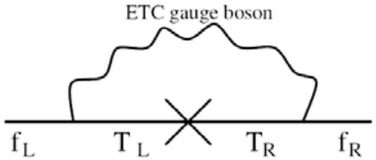
proton - (anti)proton cross sections



Technicolor, a "conservative" approach

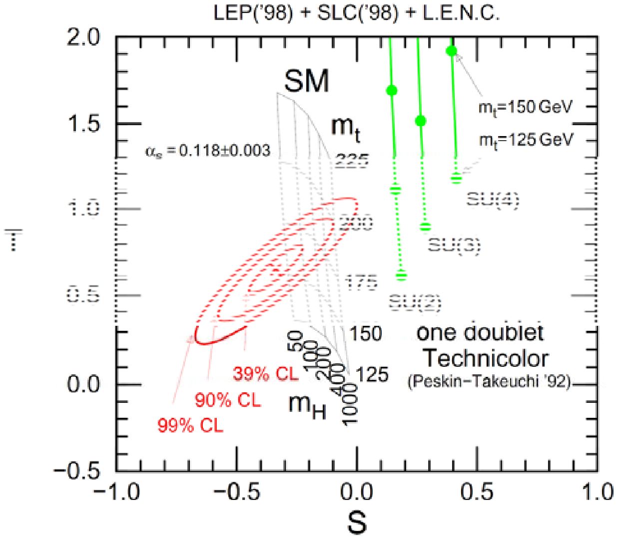
- **QCD-like, prototype theory:**
  - confinement of technifermions, and asymptotic freedom
  - chiral symmetry breaking:
    GB: long. components of gauge bosons ➔ ewsb
  - technimeson resonances
- **Extended TC: embed $SU(3)_C$,$SU(N_{TC})$ and flavor in higher symmetry**
  - to generate masses of fermions

$$m \sim v^3 / M_{ETC}^2$$



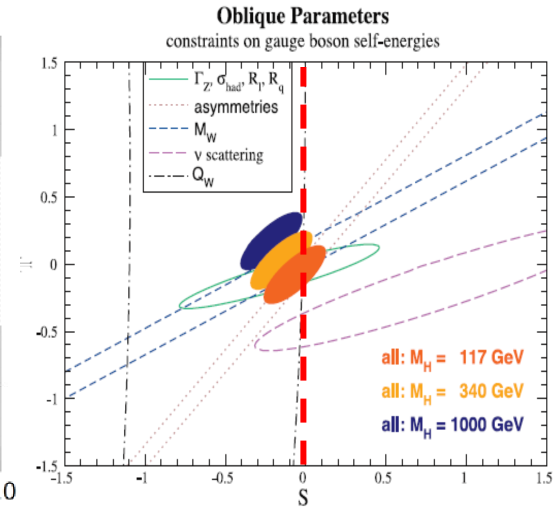
  - but FCNC's
    → ETC scale very high (~ 10^3 TeV) → fermion masses too low
- **walking couplings (conformal)**
  - can be achieved by large N_f, or otherwise, respecting asymptotic freedom and chiral SB
  - allows realistic fermion and technipion masses
  - TC scale relatively low
- **top color**
  - to account (partly) for very large mass of 3rd family

EW constraints



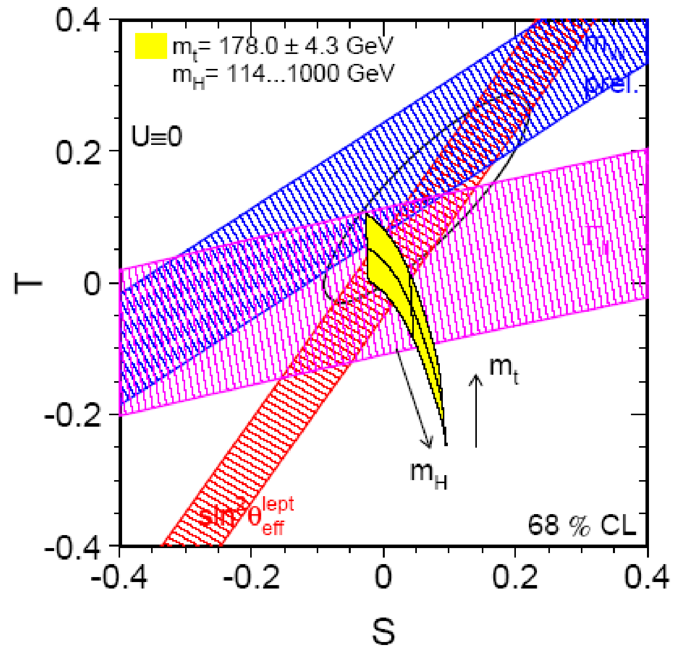
$S = -0.3 \pm 0.2$

LEP+SLC, 1998



$S = -0.03 \pm 0.11$

PDG 2002



$S = +0.07 \pm 0.10$

(LEWWG 2005)

but $S \approx 0.25\, N \left(\frac{N_{TC}}{3} \right)$

$\Rightarrow$ “minimal” technicolor ruled out

Low Scale Technicolor

- **walking:**

K.D. Lane et al, PL B388 (1996) 803
PL B405 (1997) 305

  - large number of technifermion doublets N_D
    ➔ relatively low scale: $\Lambda_{TC} \simeq v / \sqrt{N_D}$
  - or multiscale

- **phenomenology dictated by lower scale:**

Technicolor Strawman Model

K.D. Lane et al., PR D60 (1999) 075007
PR D67 (2003) 115011

  - mixing between V_L and π_T : $\sin\chi \approx 1/\sqrt{N_D} \sim 1/3$

$$|\Pi_T\rangle = \cos\chi |\pi_T\rangle + \sin\chi |V_L\rangle$$

  - narrow resonances: $\Gamma \sim \text{GeV}$

$$\rho_T^{\pm,0} \to V_L V_L, \quad V_L \pi_T \qquad (\rho_T \to \pi_T \pi_T \text{ possibly closed})$$

$$\omega_T \to \gamma Z$$

$$a_T^{\pm} \to \gamma W$$

    - contribute to unitarizing GB scattering at high energy
    - contribute to S parameter

Strawman Model

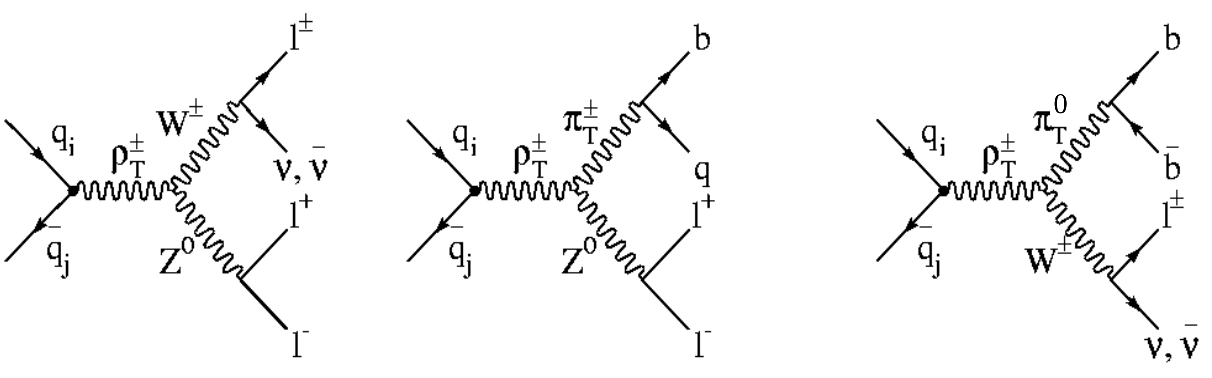
- **present limits:**

$$m_{\pi_T} > 105\ \text{GeV},\ m_{\rho_T} > 200\ \text{GeV}$$

- **implemented in PYTHIA** **S. Mrenna**

- **small S ➔** $m_{a_T} \sim m_{\rho_T}$

(**J. Hirn, V. Sanz, hep-ph/0612239**, disputed: **R. Foadi et al., arXiv:0712.1948**)



...

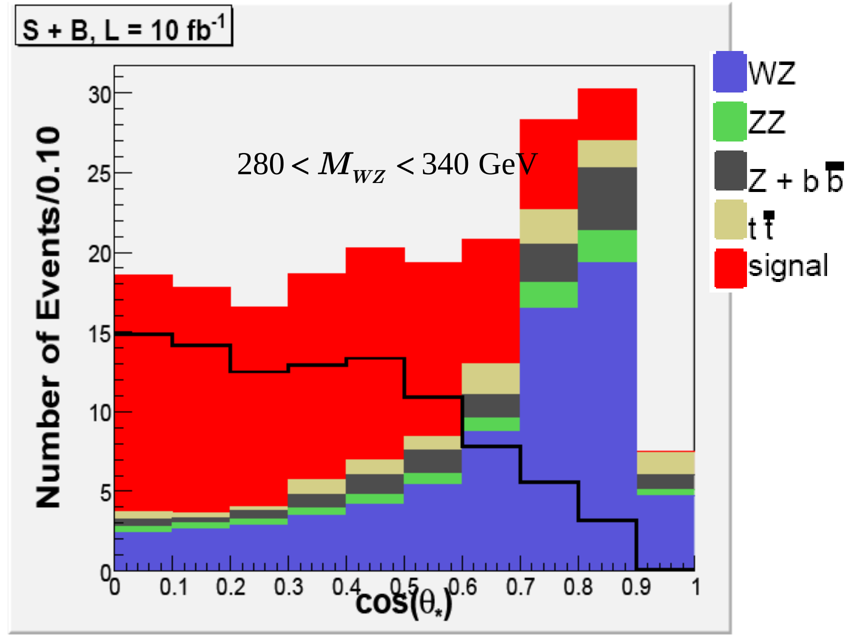
$\rho_T \to W + Z \to 3\ell + \nu$

clean signal, but low BR

Backgrounds:

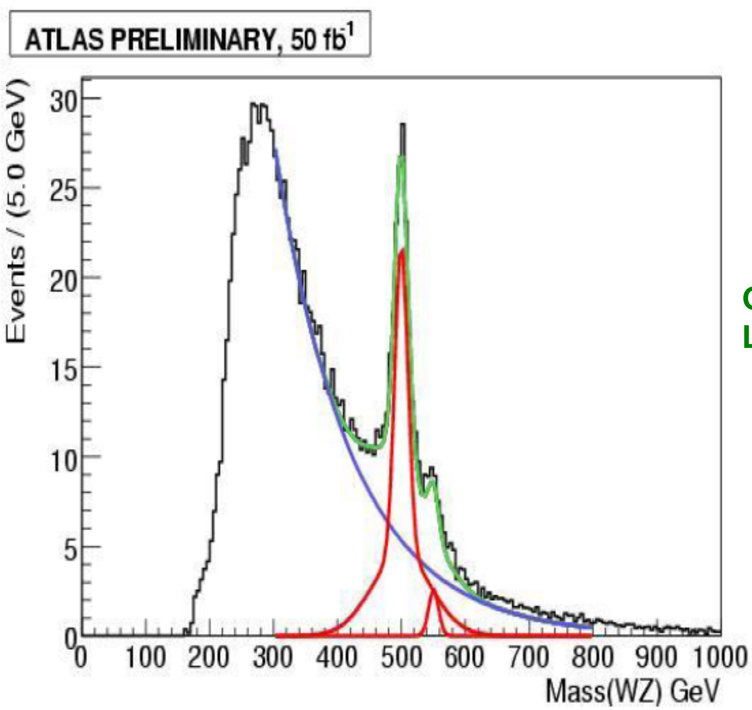
$t\bar{t}, WZ, ZZ, Zb\bar{b}$

- reconstruct $Z \to \ell\ell, W \to \ell\nu$
- $p_T(W), p_T(Z) > 50$ GeV
- $H_T \equiv \sum E_T(jets) < 125$ GeV



$$\frac{d\sigma\left(q\bar{q} \to \rho_T^{\pm} \to W_L^{\pm} Z_L\right)}{d\cos\theta} \propto \sin^2\theta$$

GA, K. Black, T. Bose, J. Ferland, Y. Gershtein, K. Lane and A. Martin, Les Houches report, arXiv:0802.3715



5 σ discovery:

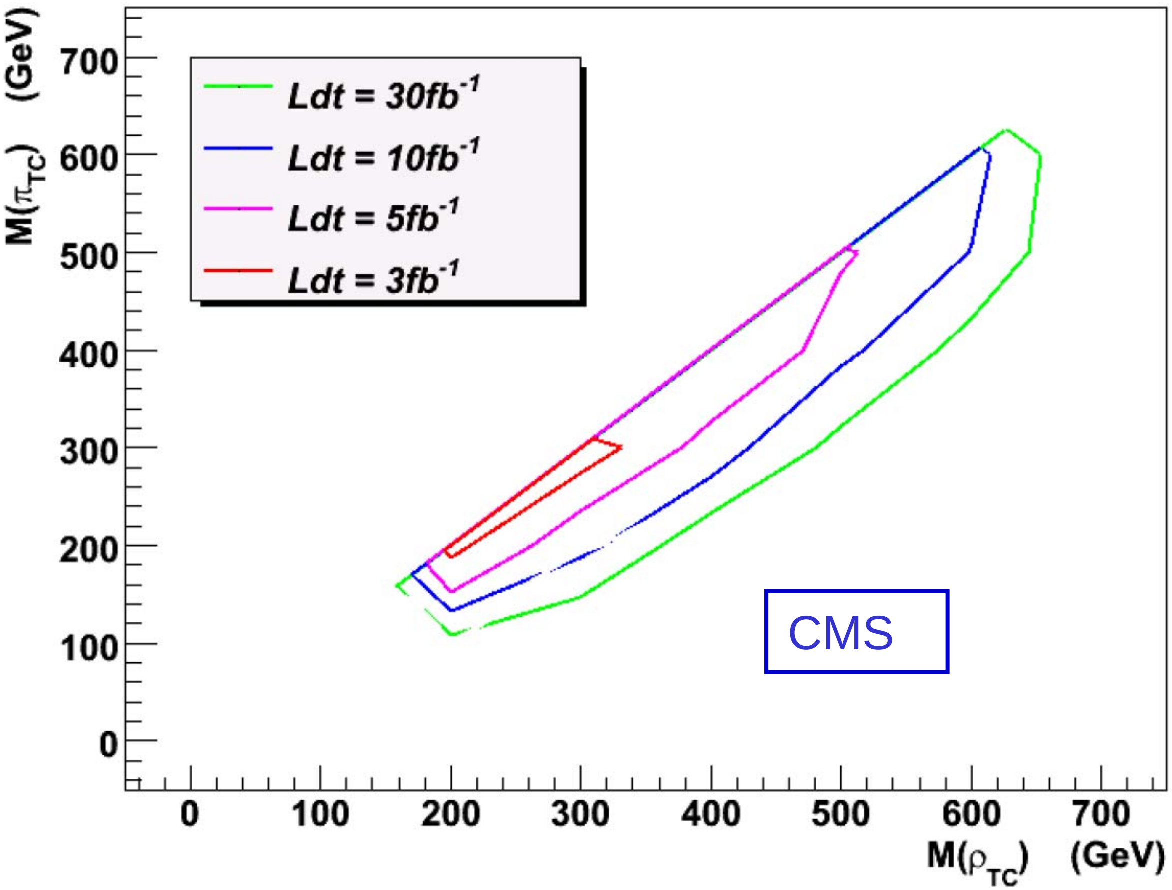
$m_{\rho_T} = 300$ GeV, $m_{a_T} = 330$ GeV, $m_{\pi_T} = 200$ GeV $\Rightarrow 2.4$ fb^{-1}

$m_{\rho_T} = 400$ GeV, $m_{a_T} = 440$ GeV, $m_{\pi_T} = 275$ GeV $\Rightarrow 7.2$ fb^{-1}

$m_{\rho_T} = 500$ GeV, $m_{a_T} = 550$ GeV, $m_{\pi_T} = 350$ GeV $\Rightarrow 15$ fb^{-1}

PGS simulation

$\rho_T \to W + Z \to 3\ell + \nu$



CMS TDR, p. 497, Note 2006/135

- reconstruct $Z \to \ell\ell, W \to \ell\nu$
- $p_T(W), p_T(Z) > 30$ GeV
- $|\Delta[\eta(Z) - \eta(W)]| \leq 1.2$

BR's vary strongly if

$$m_{\rho_T} > m_{\pi_T} + m_W$$

$a_T^{\pm} \to \gamma W_L^{\pm} \to \gamma \ell \nu$

$$\sigma \times BR = 65 \text{ fb}$$

Backgrounds:

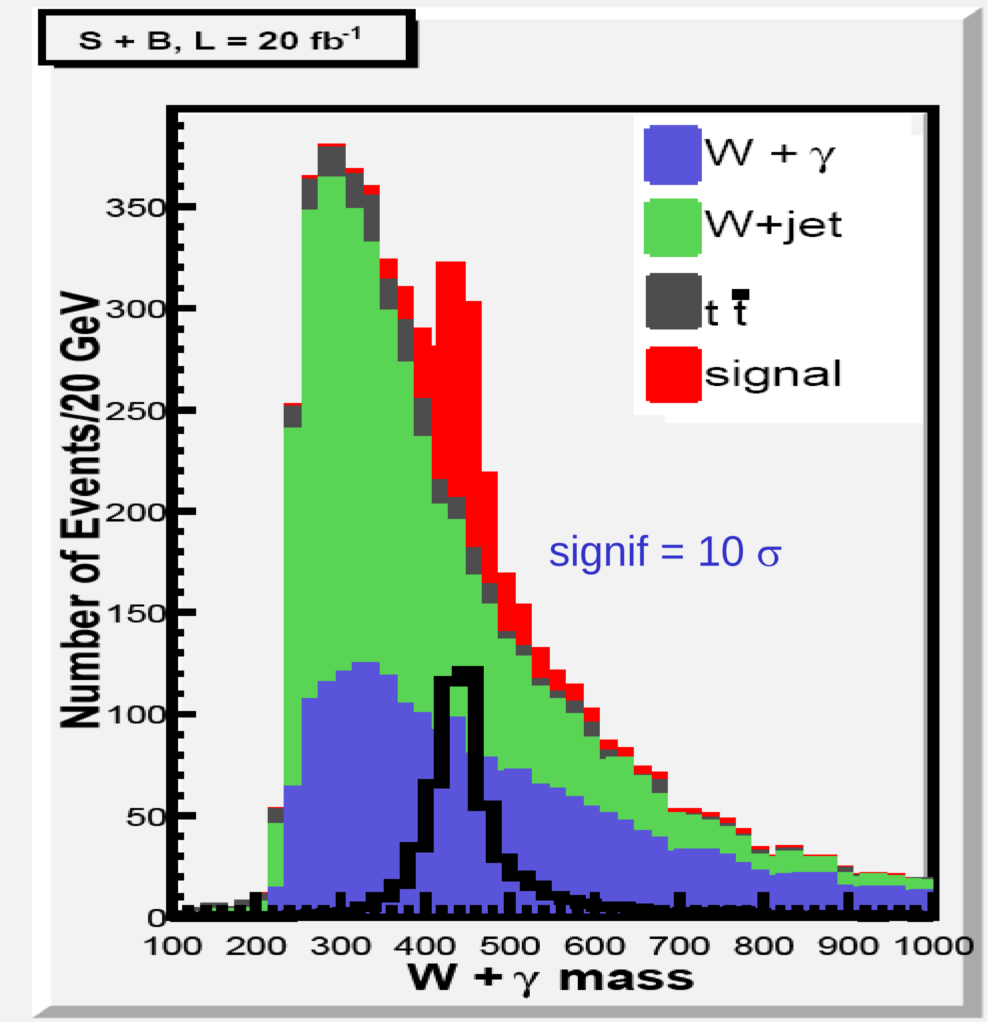
$t\bar{t}, W\gamma, W+j$

- $p_T(\ell) > 10$ GeV, $|\eta| < 2.5$
- $\not{E}_T > 20$ GeV
- reconstruct $W \to \ell \nu$
- $p_T(W), p_T(\gamma) > 100$ GeV

expected angular distribution

$$\frac{d\sigma\left(q\bar{q} \to a_T^{\pm} \to W_L^{\pm}\gamma\right)}{d\cos\theta} \propto 1+\cos^2\theta$$

less obvious



GA, K. Black, T. Bose, J. Ferland, Y. Gershtein, K. Lane and A. Martin, Les Houches report, arXiv:0802.3715

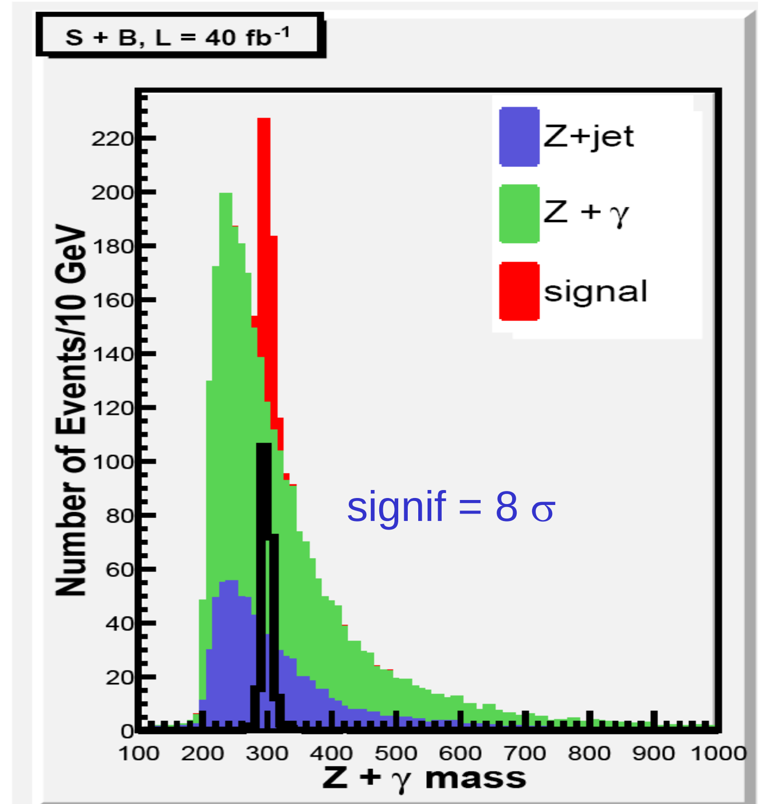
$\omega_T \to \gamma Z \to \gamma \ell\ell$

$\sigma \times BR = 19$ fb (300/330/200)

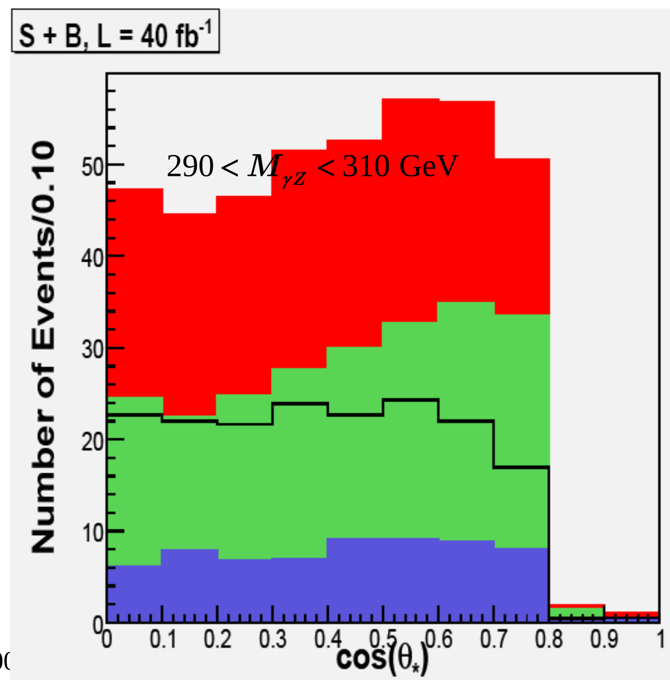
Backgrounds:

$Z\gamma, Z+j$

- $p_T(\ell) > 10$ GeV, $|\eta| < 2.5$
- reconstruct $Z \to \ell\ell$
- $p_T(Z), p_T(\gamma) > 80$ GeV



GA et al, Les Houches report, arXiv:0802.3715



$$\frac{d\sigma\left(q\bar{q} \to \omega_T \to Z\gamma\right)}{d\cos\theta} \propto 1 + \cos^2\theta$$

$\rho_T^\pm, a_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^- bq$

- **discovering a technipion:**
  - **→ clear indication of technicolor nature of new physics**
  - π_T decays principally to heaviest fermion pair possible
    - but top coupling suppressed (Top-color assisted TC)
- $\rho_T^\pm, a_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^- bq$

Backgrounds:

$t\bar{t}, Zjj$ (including $Zbj, Zb\bar{b}$)

100's of pb

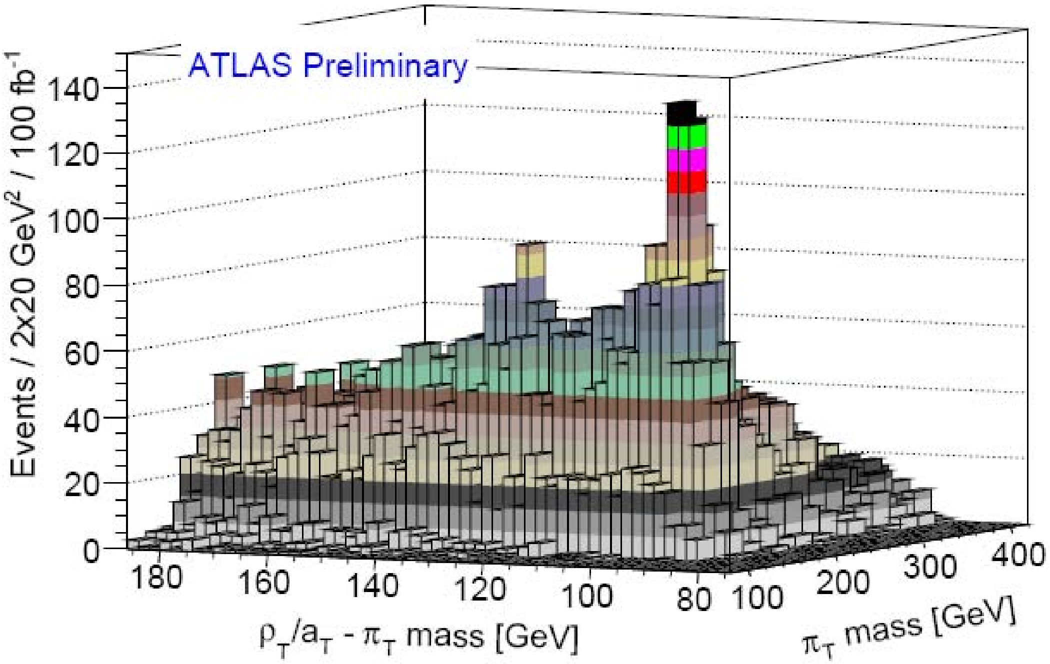
  - high backgrounds, but good Z reconstruction and possibility of seeing 3 resonances !
  - large uncertainties: will need data driven optimization

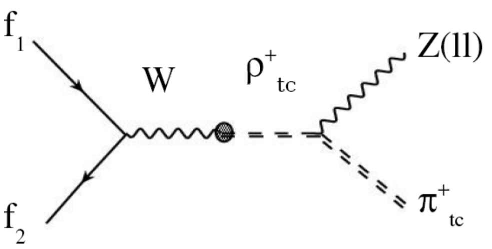
- reconstruct $Z \to \ell\ell$
- 2 jets, (1 b-tagged, 1 non-tagged), $p_T > 65, 80$ GeV
- obtain better resolution in ρ/π_T reconstruction by considering $m_{\rho_T} - m_{\pi_T}$

$\rho_T^\pm, a_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^- bq$

$$m_{\rho_T}, m_{\omega_T} = 300 \text{ GeV},$$
$$m_{a_T} = 330 \text{ GeV},$$
$$m_{\pi_T} = 200 \text{ GeV}$$

for 5s significance, need
~ 8 fb^{-1} for ρ_T
~ 50 fb^{-1} for π_T



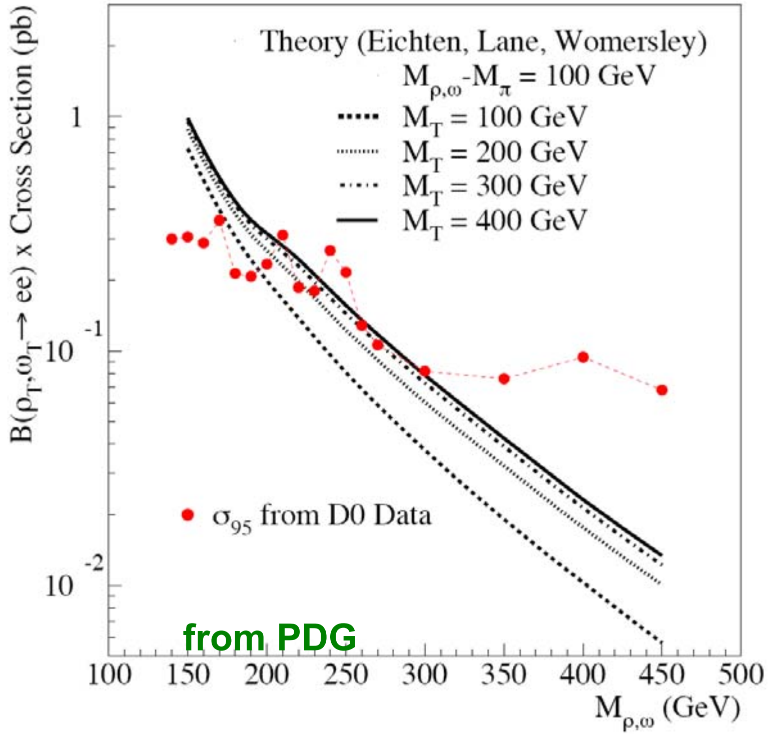


GA et al, Les Houches report, arXiv:0802.3715
ATL-PHYS-CONF-2008-003

$\rho_T^0 \to \ell^+\ell^-$

present Tevatron limits:

$$m_{\omega_T} = m_{\rho_T} < 203 \text{ GeV} \quad \omega_T/\rho_T \to \ell^+\ell^-$$
$$\text{for } m_{\omega_T} < m_{\pi_T} + m_W$$
$$\text{or } M_T > 200 \text{ GeV}$$
$$m_{\omega_T} = m_{\rho_T} < 280 \text{ GeV} \quad \omega_T/\rho_T \to \ell^+\ell^-$$
$$\text{for } m_{\omega_T} < m_{\pi_T} + m_W$$
$$\text{or } M_T > 500 \text{ GeV}$$

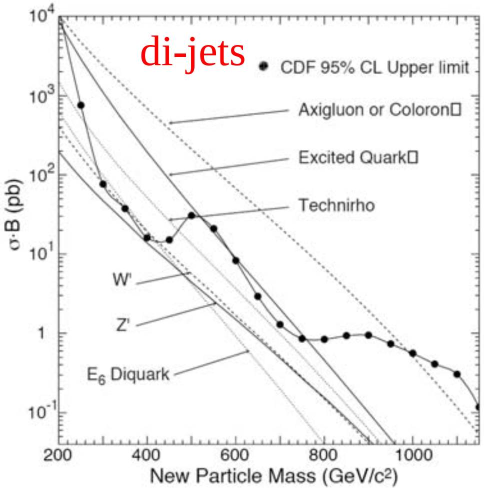


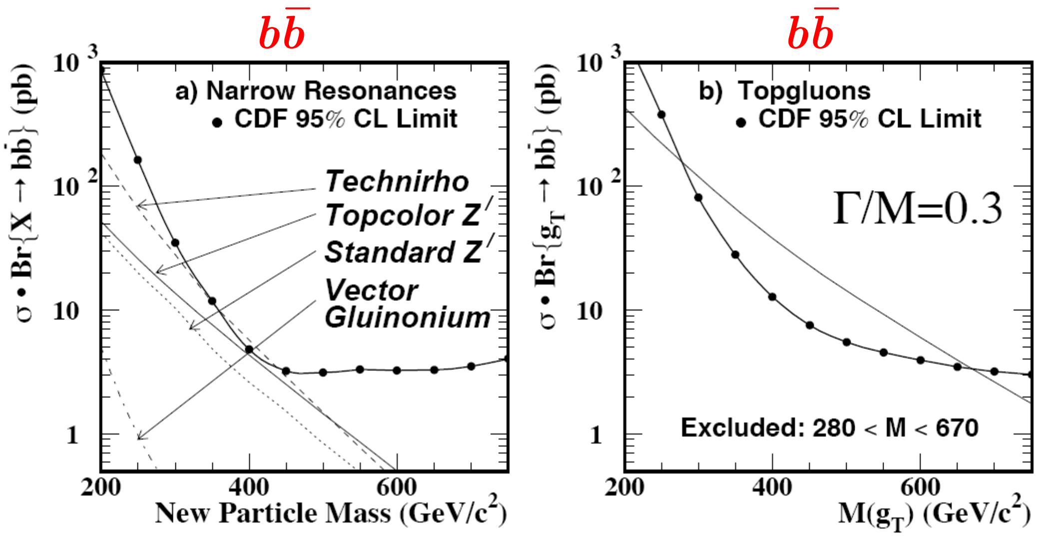
Strawman model:

5σ discovery of $\rho_T/\omega_T \to \mu\mu$, of mass 600 GeV with ~1 fb^{-1} at LHC

- more difficult to determine the nature of new physics:
  - Z' (from E_6, for example: $Z'_\chi, Z'_\psi, Z'_\eta$, or Z'_{LRSM})?
  - G* (KK state of graviton)?
  - possibly use angular, rapidity distributions, eventually spin correlations (in ττ) *(details not yet public)*

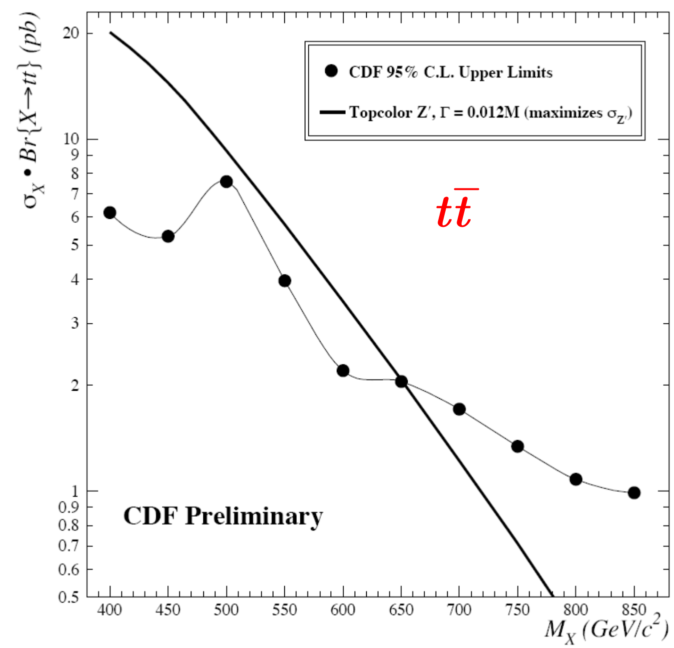
Tevatron searches $\rho_T^0 \to jj$





$$260 < m_{\rho_{T8}} < 480 \text{ GeV} \qquad \rho_{T8} \to q\bar{q},\ gg$$

from PDG



ew-strength Z' resonance would hardly be detectable in $t\bar{t}$ channel

$t\bar{t}$ cross section at LHC ~ 830 pb!

look at polarizations and spin correlations?

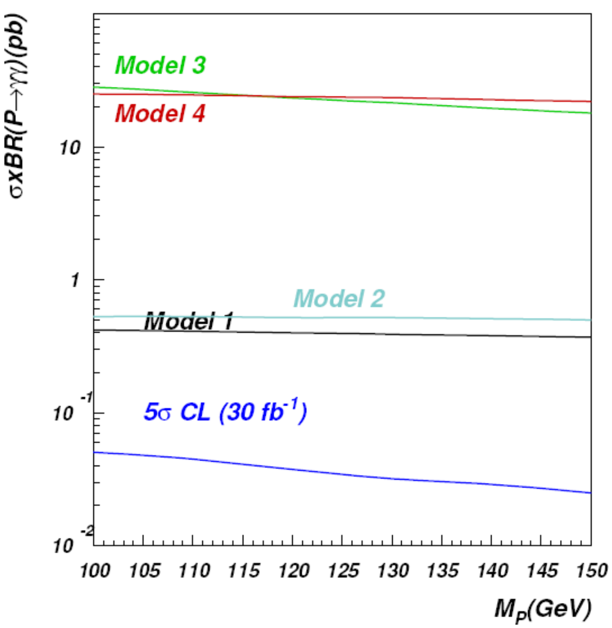
$\pi'_T \to \gamma\gamma$

A. Belyaev, A. Blum, R. S. Chivukula and E. H. Simmons, Phys. Rev. D72, 055022 (2005)

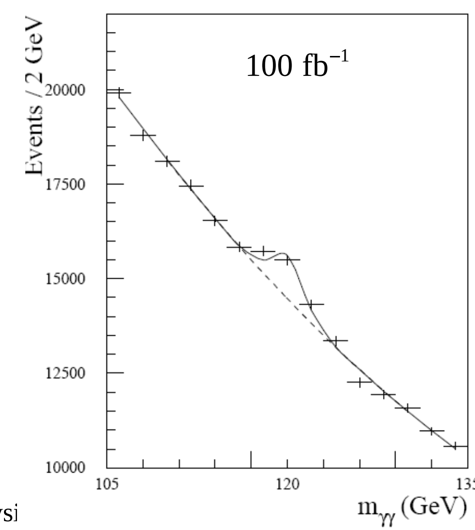
- 2nd lightest π_T has anomalous couplings to gluons
  ➔ large production enhancement relative to SM Higgs

enhancement factors for 130 GeV P' relative to SM Higgs

Model	Decay mode	κ^P_{prod}	κ^P_{dec}	$\kappa^P_{tot/xx}$	σ(pb) Tevatron/LHC
3) multiscale	$b\bar{b}$	1100	0.43	470	130 / 8000
	$\tau^+\tau^-$	1100	0.2	220	6.1 / 380
	$\gamma\gamma$	1100	0.27	300	0.34 /22
4) low scale	$\tau^+\tau^-$	120	0.6	72	2/120
	$\gamma\gamma$	120	2.9	350	0.4/25



cross sections and 5σ-discovery (30 fb^{-1}) at the LHC
→ *same search as for SM Higgs, but can be extended to higher masses*



1: one-family model
2: one family model with light d-type tc-fermions
3: multiscale
4: low-scale

Chiral Lagrangian, a bottom-up approach

- **In absence of light Higgs, ewsb realized non-linearly**
  - low energy: Fermi theory, VB's are not explicit
  - at low energies, interactions of quarks dominated by QED and QCD
    - dimension 3 and 4 operators of the type:

$$\bar{Q}_L M_Q Q_R, \quad \bar{Q}_L \not{D} \bar{Q}_L, \quad \bar{Q}_R \not{D} \bar{Q}_R, \quad \frac{1}{4} A_{\mu\nu} A^{\mu\nu} \quad \text{where} \quad \begin{cases} Q_{L,R} = \begin{pmatrix} U \\ D \end{pmatrix}_{L,R} \\ D_\mu = \partial_\mu + ieqA_\mu \end{cases}$$

    - weak interactions are present in the form of current-current interactions (Fermi interaction) of dimension 6
  - at masses ~ m_W, we introduce the W and Z vector fields with explicit $SU(2)_{L:}$ x $U(1)_Y$ symmetry

ew quark interactions: $\mathcal{L} = i\bar{Q}_L \not{D}_L Q_L + i\bar{Q}_R \not{D}_R Q_R$ where $\begin{cases} D_{L\mu} = \partial_\mu - ig'\left(q + \frac{\tau^3}{2}\right) B_\mu + ig\frac{\tau^\alpha}{2} W_\mu^\alpha \\ D_{R\mu} = \partial_\mu - ig' B_\mu \end{cases}$

kinetic terms: $\mathcal{L}_{4(W)} = -\frac{1}{2} tr[W_{\mu\nu} W^{\mu\nu}] - \frac{1}{2} tr[B_{\mu\nu} B^{\mu\nu}]$

The Chiral Lagrangian

- and terms violating the symmetry:

mass terms: $\mathcal{L}_{2(W)} = M_W^2 W^{+\mu} W_\mu^- + \frac{1}{2} M_Z^2 Z^\mu Z_\mu$ and $\bar{Q}_L M_Q Q_R$

- to solve the problem, introduce a field Σ with appropriate transformations under $SU(2)_L$ x $U(1)_Y$ (non-linear sigma model)
  - field Σ is a unitary 2 x 2 matrix (3 degrees of freedom)

$$\Sigma(x) = e^{-\frac{i}{v}\mathbf{w}(x)} \quad \text{with } \mathbf{w}(x) = w^a(x)\tau^a; \; a = 1,2,3$$

  - fermion mass terms $\bar{Q}_L \Sigma M_Q Q_R$ respect the symmetry
  - VB mass terms arise from k.e. terms of the Σ field

$$\mathcal{L}_{2(W)} = -\frac{v^2}{4} tr[V_\mu V^\mu], \quad \text{with} \quad \begin{cases} V_\mu = \Sigma\left(D_\mu \Sigma\right)^\dagger \\ D_\mu \Sigma = \partial_\mu \Sigma + igW_\mu \Sigma - ig'\Sigma B_\mu \end{cases}$$

    - massive VB's defined from combination:

$$V_\mu = -igW_\mu \Sigma + ig'\Sigma B_\mu$$

ref: W. Kilian, EW Symmetry Breaking, the Bottom-Up approach, Springer tracts #198

anomalous couplings

- **Assuming CP invariance, additional dim-4 operators are possible:**

$$\mathcal{L}_1 = \alpha_1 g g' \,\mathrm{tr}\left[\Sigma \mathbf{B}_{\mu\nu} \Sigma^\dagger \mathbf{W}^{\mu\nu}\right]$$
$$\mathcal{L}_2 = i\alpha_2 g' \,\mathrm{tr}\left[\Sigma \mathbf{B}_{\mu\nu} \Sigma^\dagger [V^\mu, V^\nu]\right]$$
$$\mathcal{L}_3 = i\alpha_3 g \,\mathrm{tr}\left[\mathbf{W}_{\mu\nu} [V^\mu, V^\nu]\right]$$
$$\mathcal{L}_4 = \alpha_4 (\mathrm{tr}\,[V_\mu V_\nu])^2$$
$$\mathcal{L}_5 = \alpha_5 (\mathrm{tr}\,[V_\mu V^\mu])^2$$
$$\mathcal{L}_6 = \alpha_6 \,\mathrm{tr}\,[V_\mu V_\nu]\,\mathrm{tr}\,[T V^\mu]\,\mathrm{tr}\,[T V^\nu]$$
$$\mathcal{L}_7 = \alpha_7 \,\mathrm{tr}\,[V_\mu V^\mu]\,\mathrm{tr}\,[T V_\nu]\,\mathrm{tr}\,[T V^\nu]$$
$$\mathcal{L}_8 = \tfrac{1}{4}\alpha_8 g^2 (\mathrm{tr}\,[T \mathbf{W}_{\mu\nu}])^2$$
$$\mathcal{L}_9 = \tfrac{i}{2}\alpha_9 g \,\mathrm{tr}\,[T \mathbf{W}_{\mu\nu}]\,\mathrm{tr}\,[T [V^\mu, V^\nu]]$$
$$\mathcal{L}_{10} = \tfrac{1}{2}\alpha_{10} (\mathrm{tr}\,[T V_\mu]\,\mathrm{tr}\,[T V_\nu])^2$$
$$\mathcal{L}_{11} = \alpha_{11} g \epsilon^{\mu\nu\rho\lambda} \,\mathrm{tr}\,[T V_\mu]\,\mathrm{tr}\,[V_\nu \mathbf{W}_{\rho\lambda}]$$

- expansion of $\Sigma(x) = e^{-\frac{i}{v}\mathrm{w}(x)}$ leads to infinite order representing a loop expansion by a power series in terms of

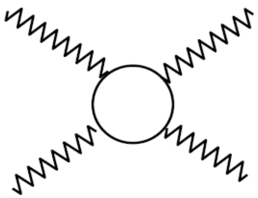
$$\frac{E^2}{\Lambda^2} = \frac{E^2}{4\pi v^2}; \qquad \Rightarrow \text{ scale of effective theory} = \Lambda = 4\pi v \sim 3 \text{ TeV}$$

VB scattering in ChL

❑ Assuming custodial symmetry

(assume global $SU(2)_L$ x $SU(2)_R$ breaking to $SU(2)_C$; VB's singlet under $SU(2)_R$)

- only 2 terms describe VB scattering

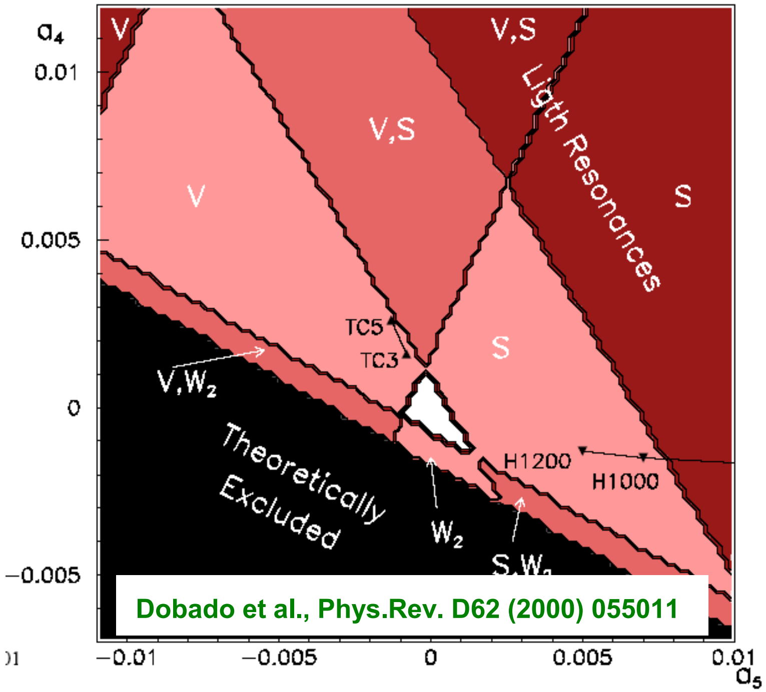


$$\mathcal{L}_4 = \alpha_4 (\mathrm{tr}\,[V_\mu V_\nu])^2$$
$$\mathcal{L}_5 = \alpha_5 (\mathrm{tr}\,[V_\mu V^\mu])^2$$

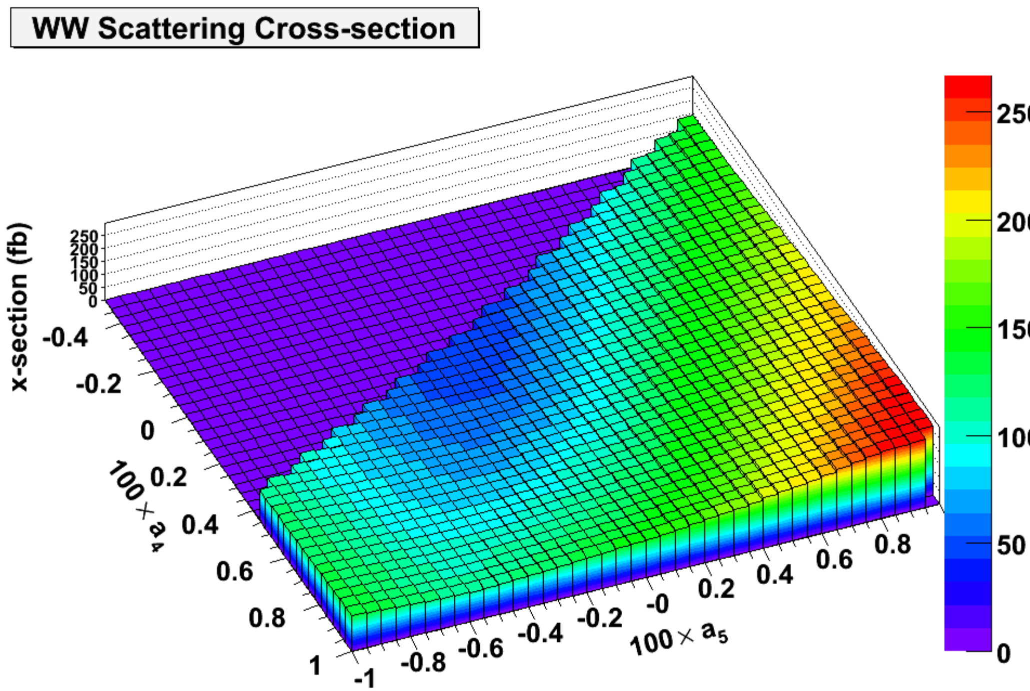
- One can map out the parameter space explorable by LHC
  - in the presence of a Higgs:
    C Ruwiedel, M Schumacher, N Wermes, ATL-COM-PHYS-2006-070
  - and more generally
    S. Belyaev et al., Phys Rev D59 015022 (1998)
    O J P Éboli et al., hep-ph/0606118

❑ Unitarization of ChL

- must assume some unitarization procedure at high mass since we don't have a full expansion
- Padé (or Inverse Amplitude) Method
  - very good description of $\pi\pi$ scattering and resonances
- K-matrix: non-resonant (implemented in Whizard MC)



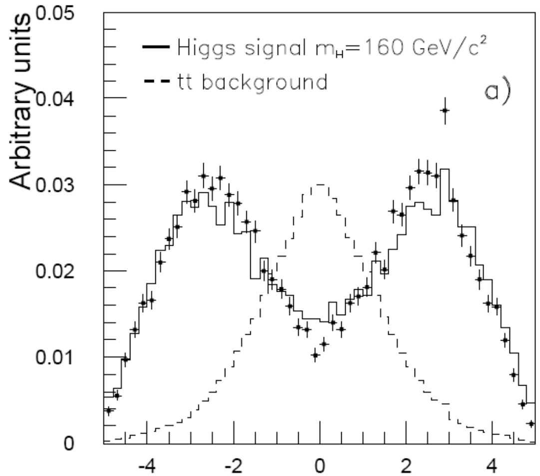
Dobado et al., Phys.Rev. D62 (2000) 055011



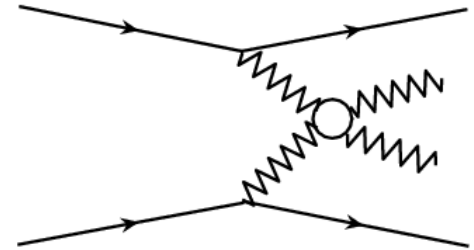
Erkcan Ozcan, UCLondon

Forward Jet tagging and central jet veto

- **fwd jet tagging in VB fusion processes**
  - QCD vs VV scattering



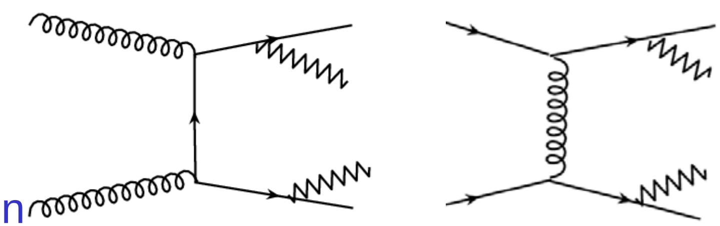
D. Rainwater, hep-ph/0702124 η



VB scattering

  - gg fusion contribution to (H) resonance production has distinctive azimuthal distribution

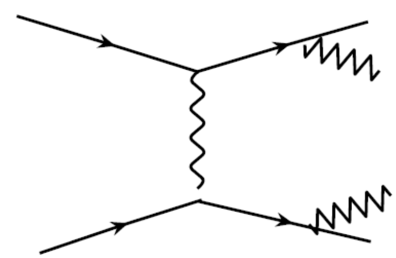
    V. Del Duca et al. / Nuclear Physics B 616 (2001) 367



QCD background

  - pileup effects
    - intense activity in the forward region at high luminosity can fake forward jets

- **jet veto**
  - no color connection between the two VB's → reduced jet activity in the central region
  - efficient at rejecting ttbar, for example



QED background

heavy jet mass

- **Highly boosted W or Z → jj yield single jet**
  - ***W Z j j*** appears as ***W+3j*** or ***Z+3j*** for pT > 250 GeV
  - can select jets with mass close to m_V but would like to be sure that they are made up of two subjets

1. **Ysplitter:**

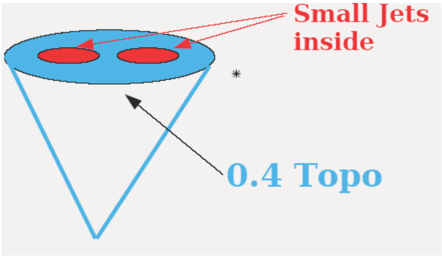
J. M. Butterworth, B. E. Cox and J. R. Forshaw, Phys. Rev. D 65 (2002), [hep-ph/0201098]

   1. use k_T algorithm on jet constituents and get y-value at which one switches from 2 to 1 jet ⇒ measure of subjet structure and mass of decaying boson

$$y_2 = \min\left(E_a^2, E_b^2\right) \bullet \theta_{ab}^2 \Big/ p_{T(jet)}^2$$

$$Y \text{ scale } = \sqrt{p_{T(jet)}^2 \bullet y_2}$$

2. **cone or k_T with smaller radii**
   1. also provide information on subjet structure



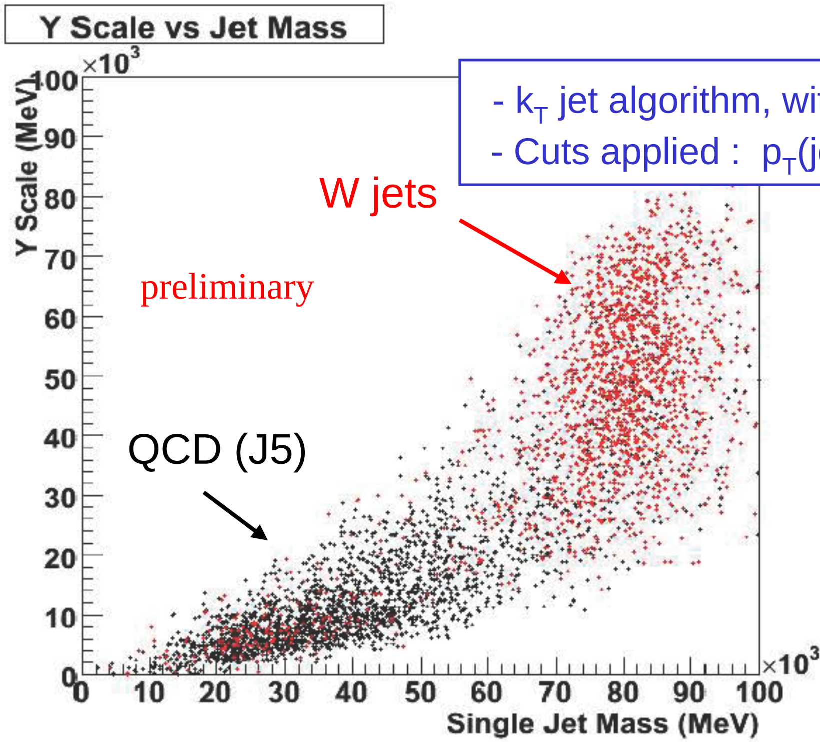
Method also suggested for search of vector quarks

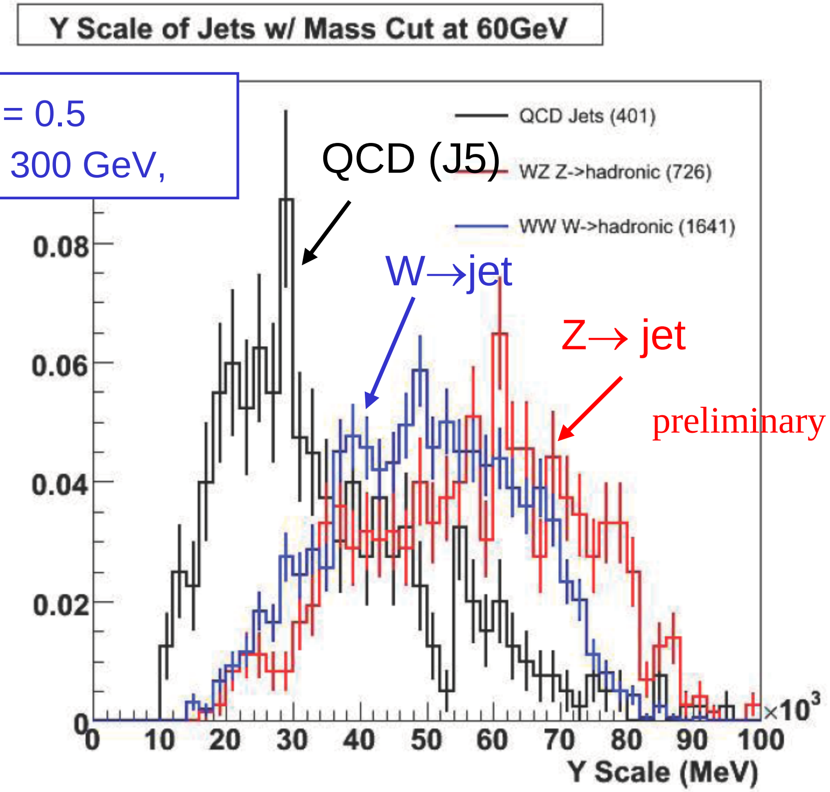
W. Skiba, D. Tucker-Smith, hep-ph/0701247

B. Holdom, hep-ph/0702037

YSplitter

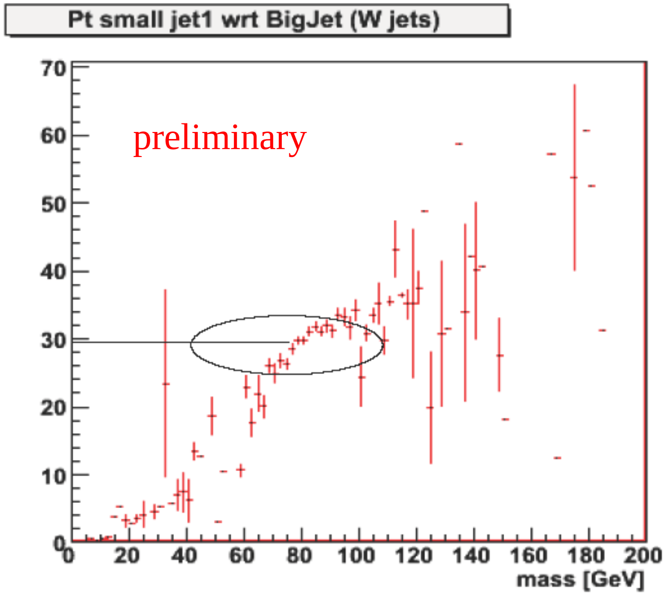
- k_T jet algorithm, with R = 0.5
- Cuts applied : p_T(jet) > 300 GeV,

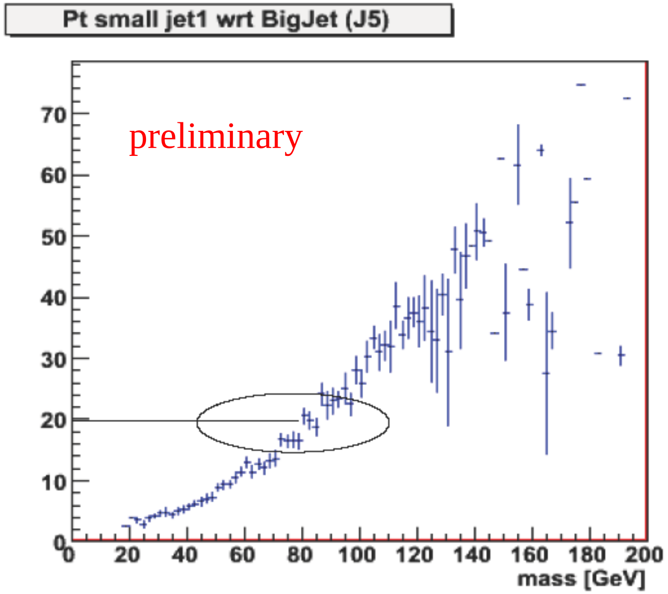




Even after mass cut, y cut rejects ~65% of W+jets bg with signal efficiency of ~80%

subjets with cone algorithm

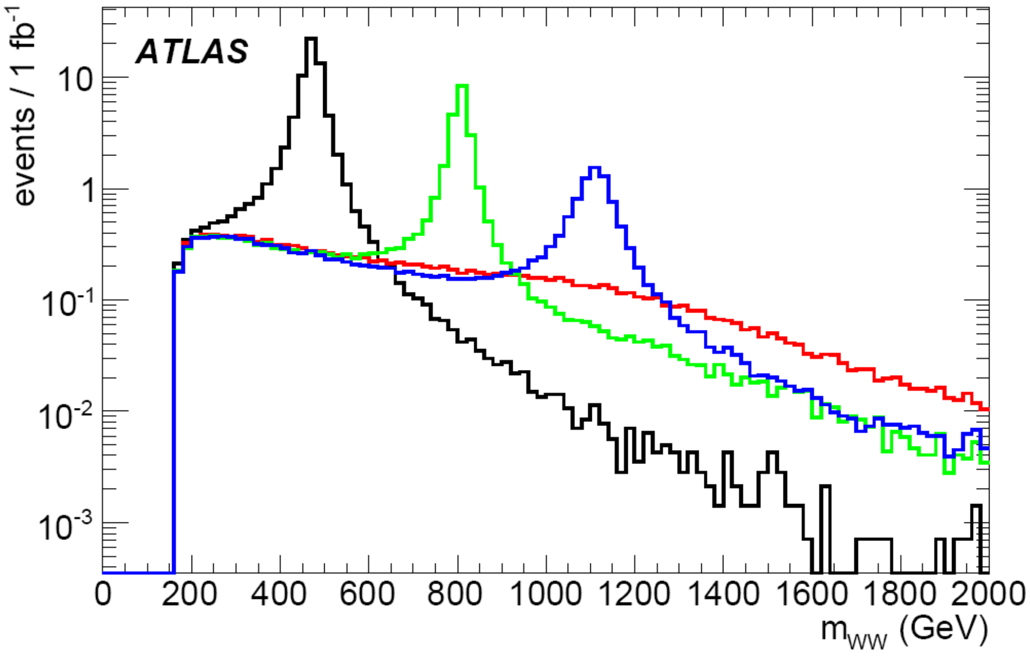




2 jets of R = 0.2
inside jet of R = 0.7

Other observables also considered:
- jet moments
- dipole moment

Search at the LHC



Sorry,
preliminary results not ready to be shown, yet.

typically:
a few 10's to 100 fb^{-1} required for discovery of resonances of mass 500 GeV to 1 TeV

eventually, distinguish scalar from vector resonance in WW channel

nonresonant channel very difficult

variety of channels:

$$WW \text{ (Vector of Scalar)} \rightarrow \ell\nu\, jj$$

$$WZ \text{ (Vector)} \rightarrow \ell\nu\, jj, \quad (jj)\ell\ell, \quad \ell\nu\,\ell\ell$$

$$ZZ \text{ (Scalar)} \rightarrow \ell\ell\,(jj), \quad \ell\ell\,\nu\nu$$

Minimal Walking TC

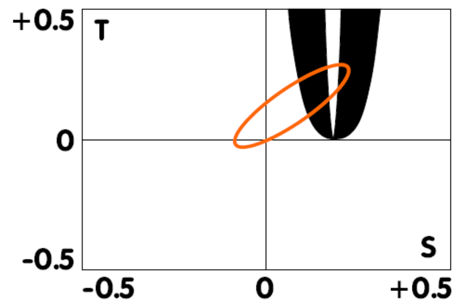
R. Foadi et al., arXiv:0706.1696, 07121948
F. Sannino, arXiv:0804.0182 *and ref. therein*
T. Appelquist et al., hep-ph/9906555

- doublet of technifermions in adjoint representation of SU(2)

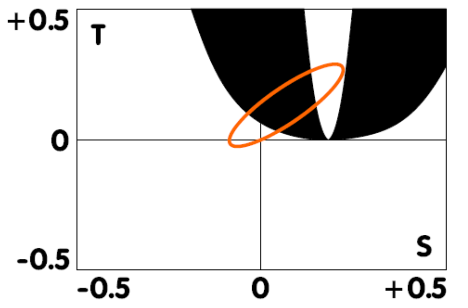
$$T_L^a = \begin{pmatrix} U^a \\ D^a \end{pmatrix}_L, \quad U_R^a, \quad D_R^a, \quad a = 1,2,3 = \text{ adjoint Tc index of SU(2)}$$

Interesting features:

- nearly conformal (walking), with only 2 techniflavours
- satisfies ew constraints
- dark matter candidate possible
- new heavy lepton
- light Higgs ~ 150 GeV
- possibility of unification of couplings



(a) Standard-model-like charge assignment (I)



(b) Integerly charged leptons (III)

Fig. 12.11: Including nonperturbative corrections. The black area represents the accessible range for the oblique parameters S and T for the masses of the fourth family leptons $m_E, m_N \in [m_Z; 10m_Z]$ and with degenerate techniquarks, which corresponds to a contribution of $0.8/2\pi$ to S from the latter. The ellipse is the 68% confidence level contour for a global fit to electroweak precision data [39] with the third oblique parameter U put to zero and for a Higgs mass of $m_H = 150$ GeV, as expected for the S(2,2) model. Putting U to zero is also consistent with the S(2,2) model, where it lies typically between 0 and 0.05.

model is being implemented in MC generator (CalcHep, Sherpa)

Other models

❑ Higgsless model

- KK states of γ , W
  A. Birkedal et al, hep-ph/0412278
  R. Malhotra, hep-ph/0611380
- s-channel of
  $$WZ \rightarrow Z_1 \rightarrow WZ$$
  gives rise to resonance
- regularization of VV cross section by tower of KK states

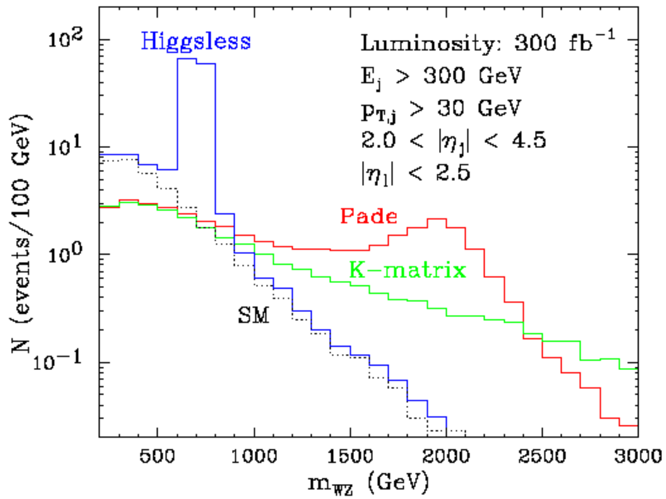
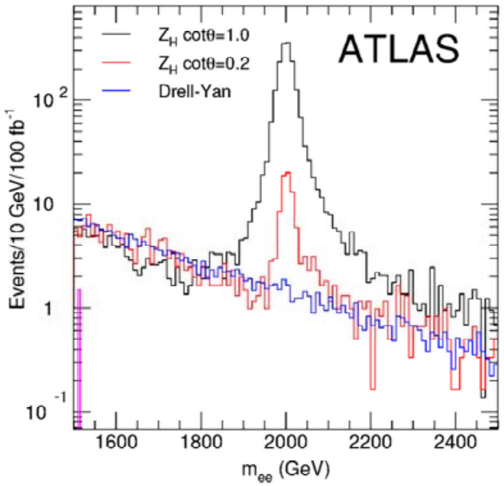
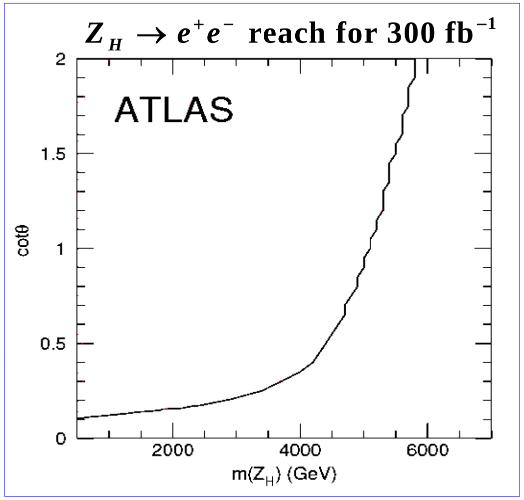


FIG. 4. The number of events per 100 GeV bin in the $2j + 3\ell + \nu$ channel at the LHC with an integrated luminosity of 300 fb^{-1} and cuts as indicated in the figure. The model assumptions and parameter choices are the same as in Fig. 2.

❑ Little Higgs

- (not strong dynamics)
- higgs as a pseudo GB of larger global symmetry breaking
- rich phenomenology: heavy isosinglet u-type quark, W', Z', triplet Higgs…





heavy quarks

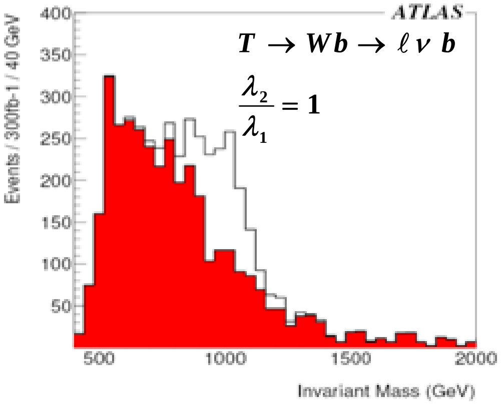
- **isosinglet heavy top**
  - in top see-saw model:

B. Dobrescu, C. Hill, PRL 81 (19998) 2634
R.S. Chivukula, PRD 59 (1999) 075003

condensate with top to produce heavy Higgs ~ 600 GeV will be consistent with v ~ 250 GeV

$$\mathcal{L} = -(\bar{t}_L, \bar{\chi}_L)\begin{pmatrix} m_{tt} & m_{t\chi} \\ m_{\chi t} & m_{\chi\chi} \end{pmatrix}\begin{pmatrix} t_R \\ \chi_R \end{pmatrix}$$

  - also found in little Higgs models



3 parameters: m_t, m_T, and Yukawa coupling ratio λ_1/λ_2

$$\Gamma(T \to th) = \Gamma(T \to tZ) = \frac{1}{2}\Gamma(T \to bW) = \frac{\kappa^2}{32\pi} M_T$$

$$\kappa = \frac{\lambda_1^2}{\sqrt{\lambda_1^2 + \lambda_2^2}}$$

- **isosinglet D-type quarks, in E_6**
- **4^{th} family**

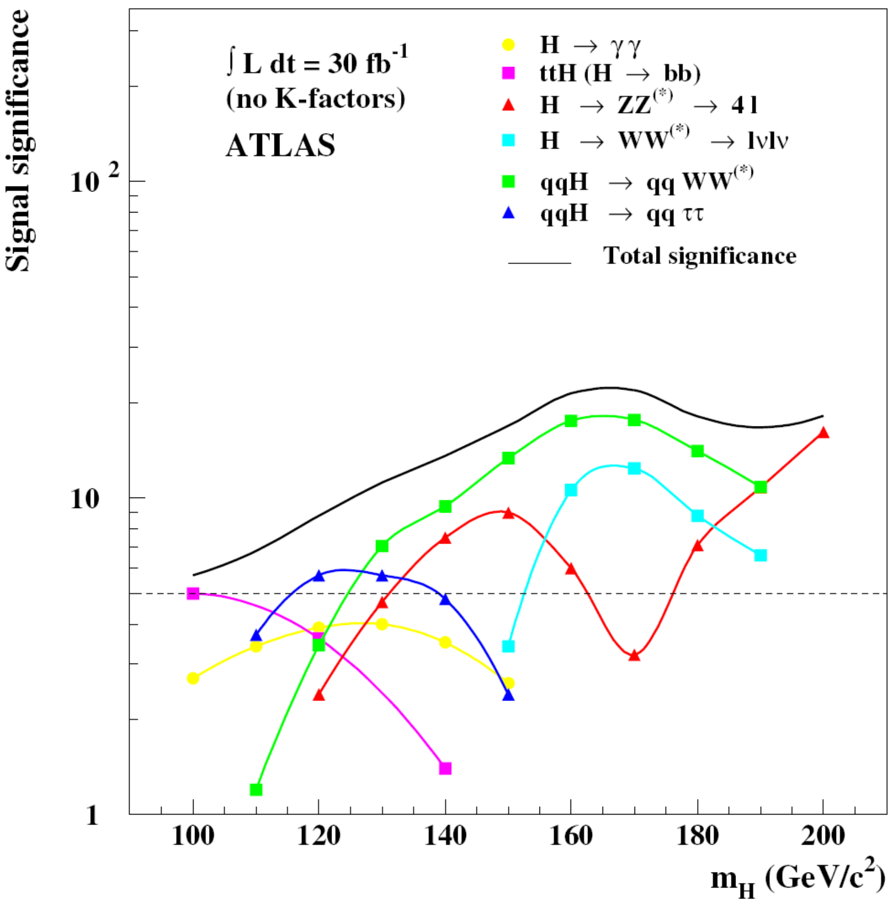
B. Holdom, hep-ph/0702037, arXiv:0705.1736

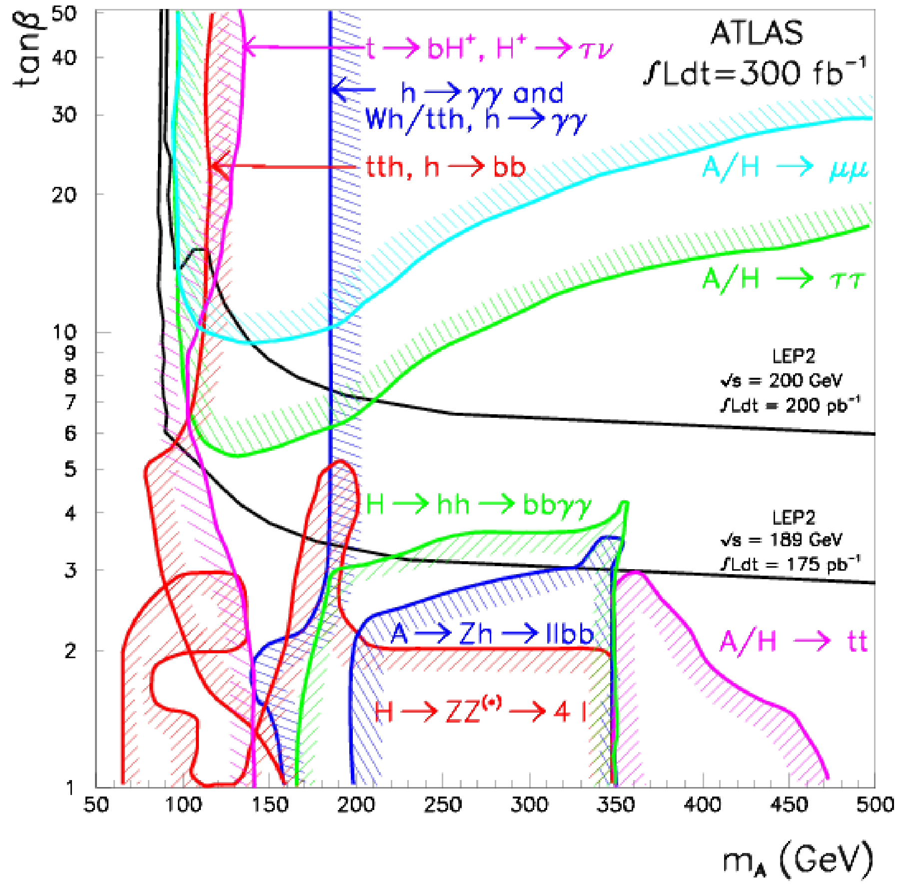
Conclusion

- **Dynamical SB scenarios have received less attention than they deserve, relative to SM or SUSY**
  - because of S-parameter ? “death of Technicolor”
  - too contrived?
- **Some interesting scenarios suggested**
  - ew constraints generally satisfied
  - some generic features and predictions:
    - VB resonance, also in VB scattering
    - rho-like resonances, possibly wide spectrum, even light Higgs
    - technipions
    - extra families: leptons, heavy quarks
- **With few fb^{-1}, some simple channels, if we’re lucky, could be discovered**
  combination of channels will be needed to understand the tru nature of new physics behing the DSB

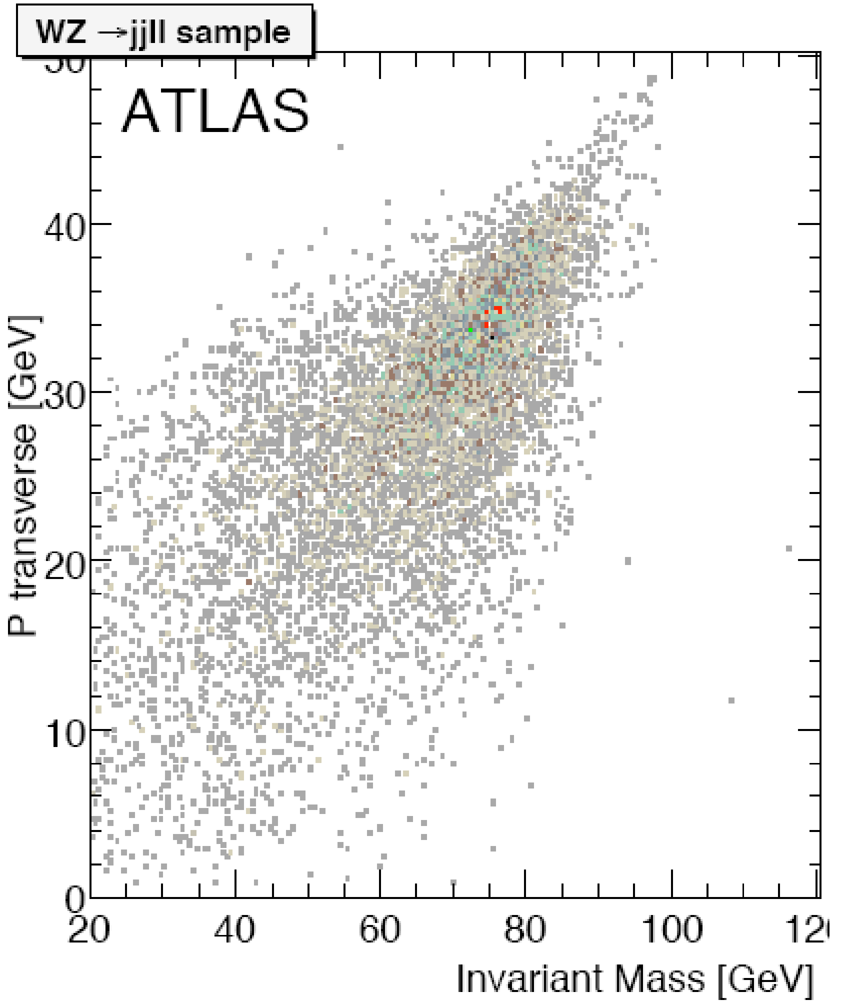
backup

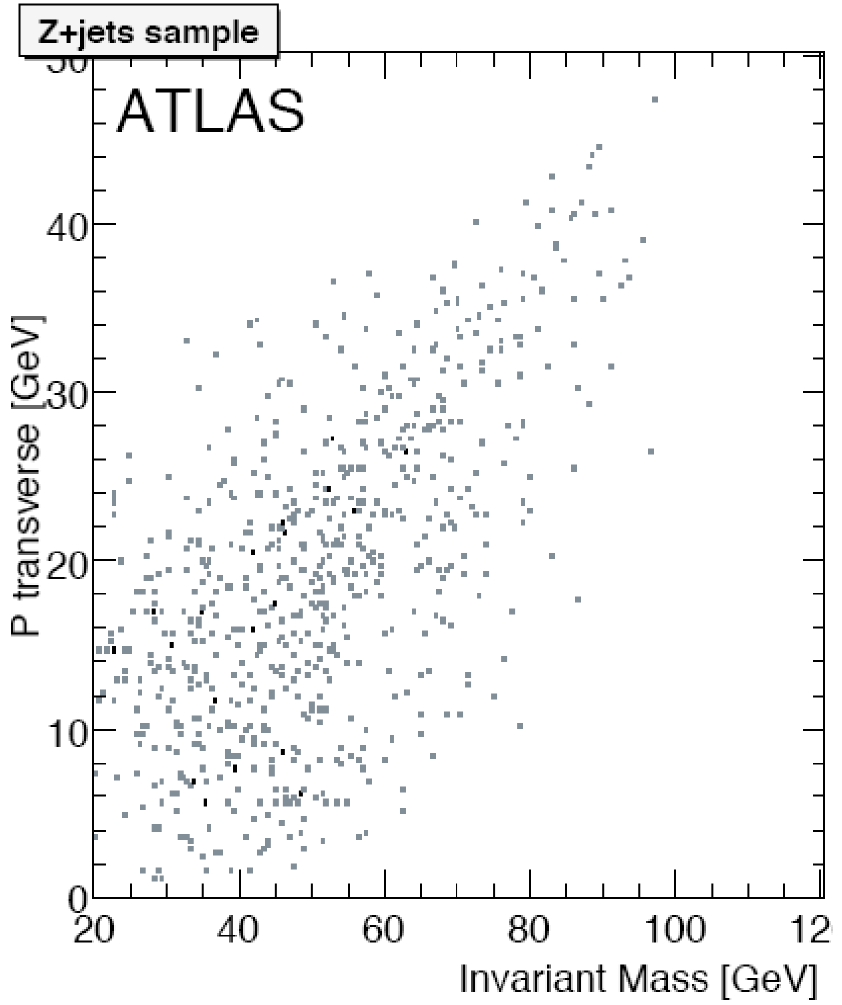
Higgs search – a reminder

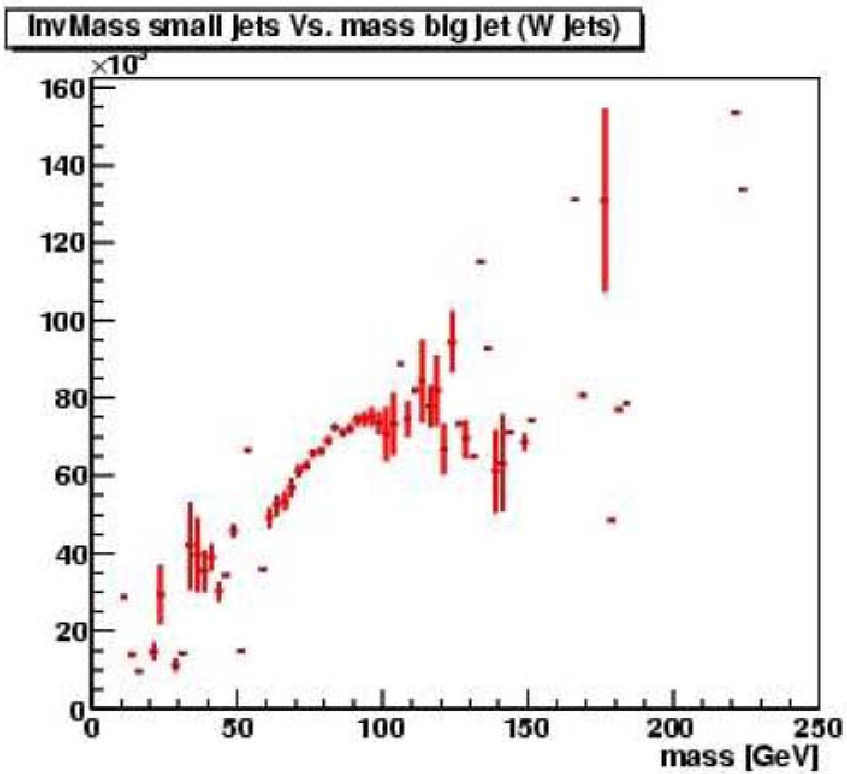


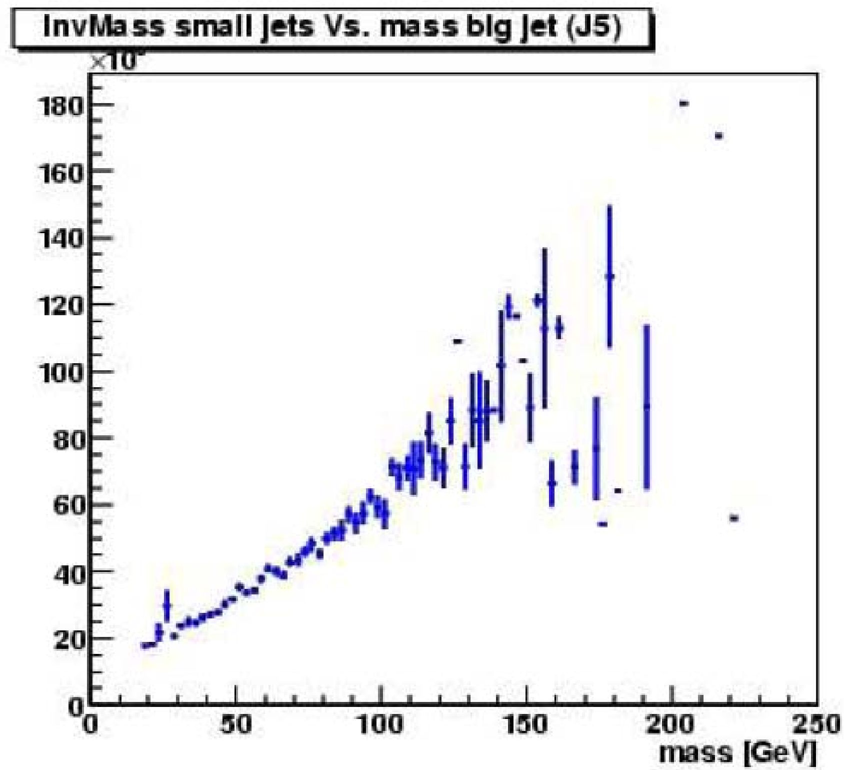


hep-ph/0702124


WZ →jjll sample
ATLAS
P transverse [GeV]
Invariant Mass [GeV]
0
10
20
30
40
20
40
60
80
100


Z+jets sample
ATLAS
P transverse [GeV]
Invariant Mass [GeV]
0
10
20
30
40
20
40
60
80
100


InvMass small jets Vs. mass big jet (W jets)
×10³
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
mass [GeV]


InvMass small jets Vs. mass big jet (J5)
×10³
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
mass [GeV]