Phenomenology of Technicolor
with a
light TC Higgs

Mads Toudal Frandsen

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DIAS   DANISH INSTITUTE FOR ADVANCED STUDY

Higgs Center, Edinburgh April 2013

Phenomenology of Technicolor
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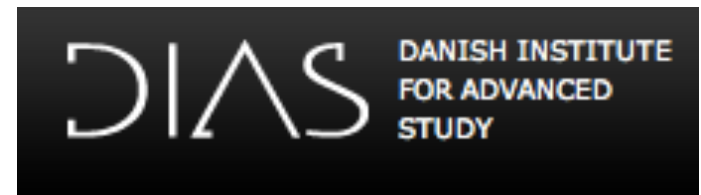
arXiv:1211.1083
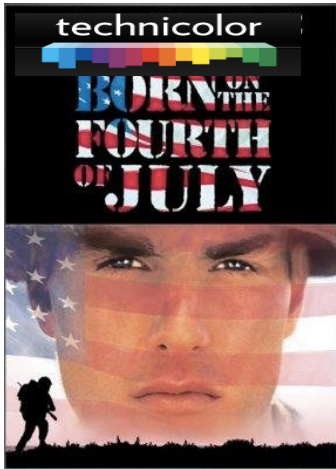**w/ R. Foadi and F. Sannino**

arXiv:1212.0015
w/ R. Foadi

Work in progress with
A. Belyaev, M. Brown and R. Foadi.

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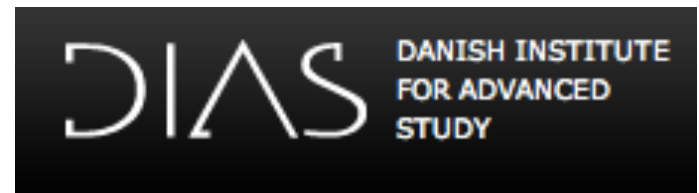Mads Toudal Frandsen

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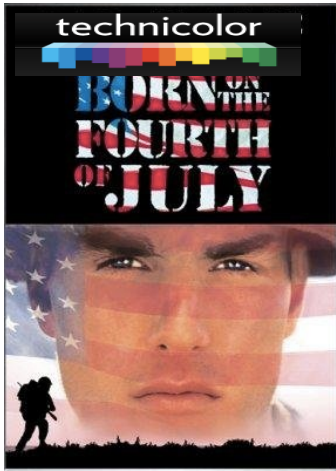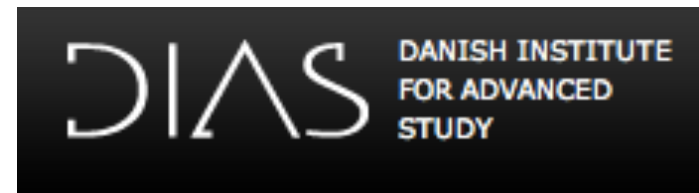**w/ R. Foadi and F. Sannino**

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TC

➢ Not just BSM of choice for the rich and famous

TC

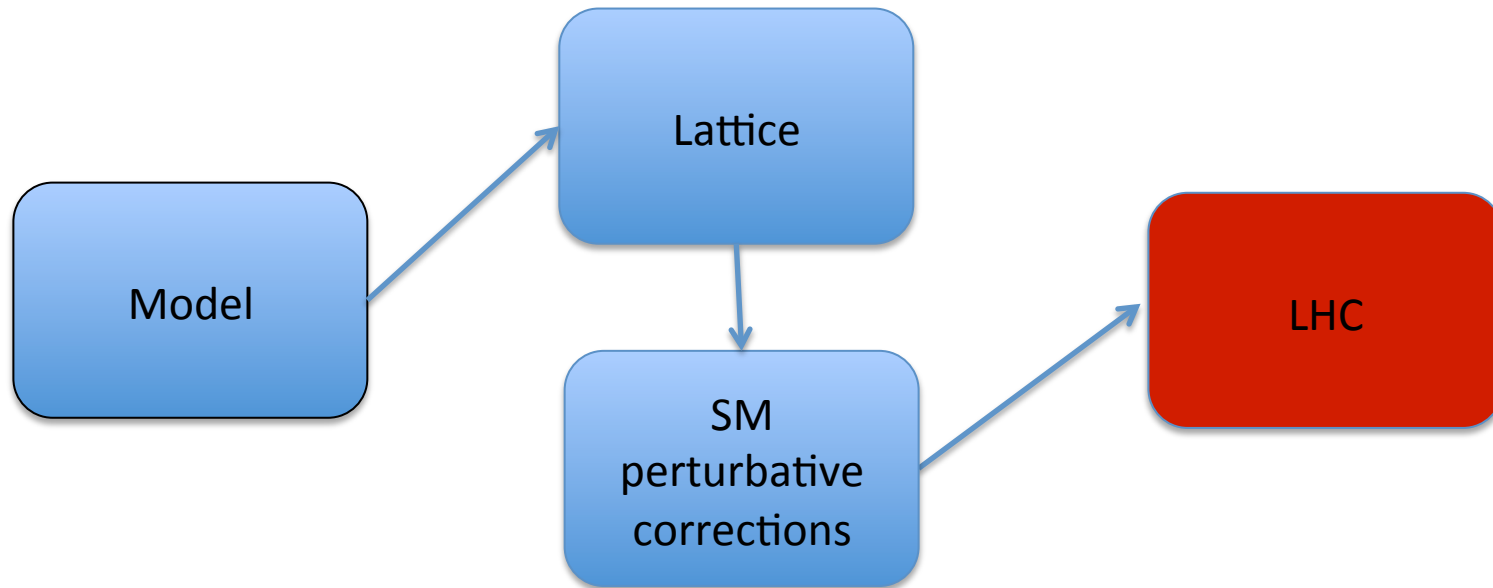- Predictive:

CP³ - Origins
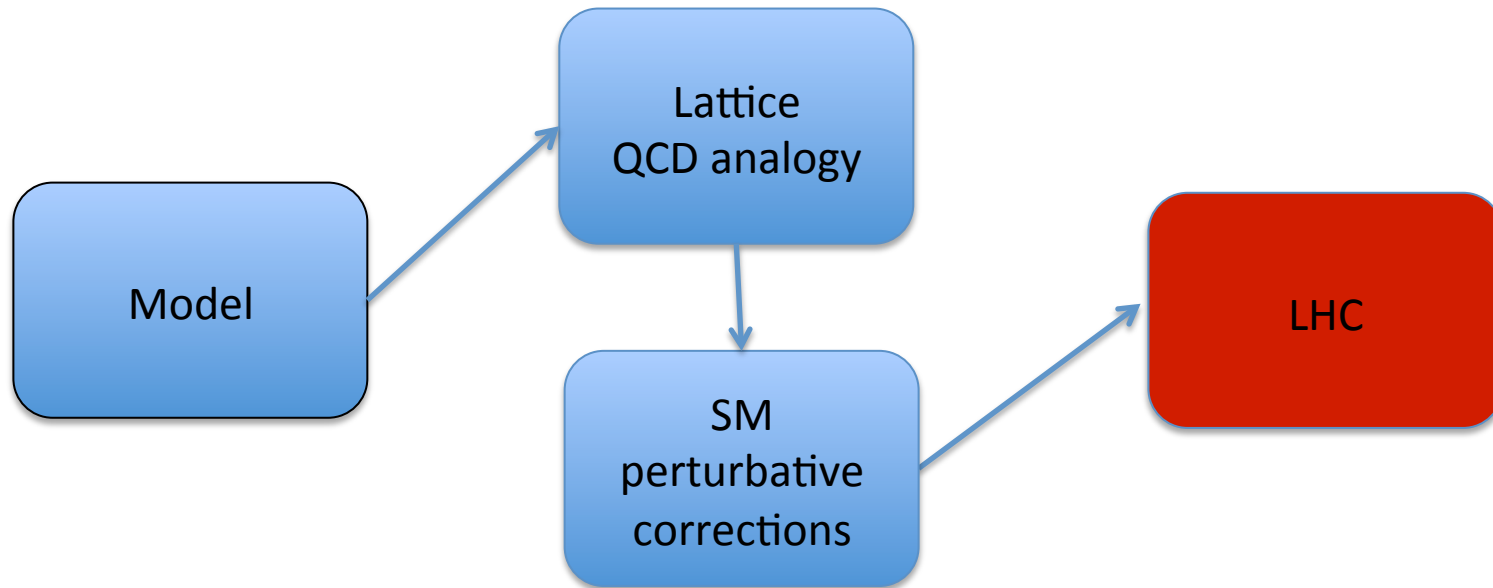Particle Physics & Cosmology

TC

- Predictive:

TC

- ## Predictive:

No new parameters in TC+SM sector! Of course not the full story

TC

- Predictive:
- We have data!

| QCD | Lattice | LHC |

Outline

➢ **Scalars in QCD**

• Light and SM Higgs-like scalar in QCD
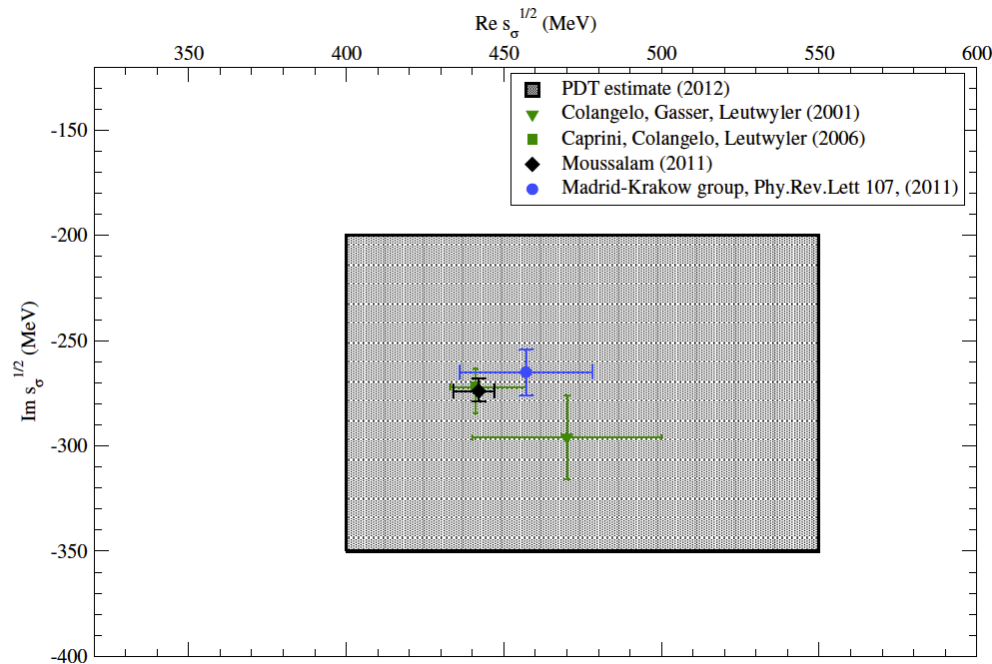
➢ TC Higgs

• Light and SM Higgs-like (?)

➢ Phenomenology

Mass of the QCD σ

$f_0(500)$ the lightest resonance in QCD (non GB)

PDG 2012: m_σ=400-550 MeV, Γ_σ=400-700 MeV $\sqrt{s_\sigma} = m_\sigma - i\Gamma_\sigma/2$

(Pelaez '13)

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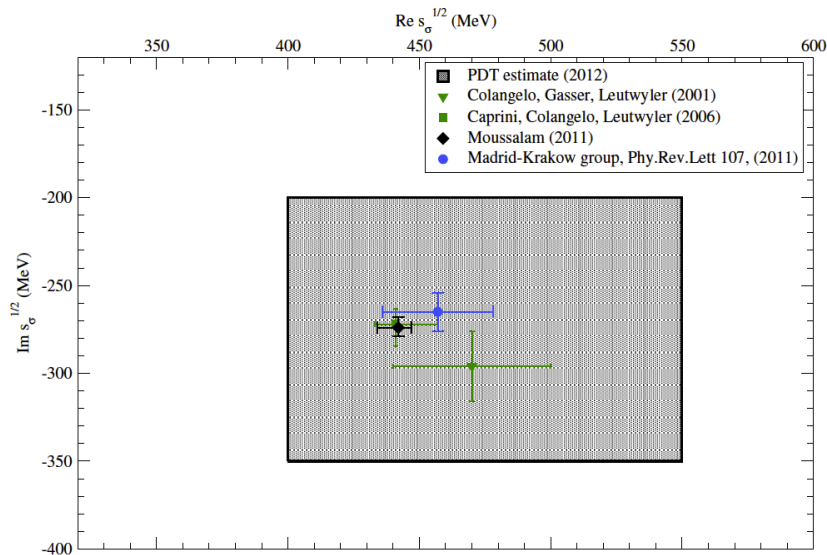

(Pelaez '13)

- QCD is a Higgs-full theory

- Expect that TC is Higgs-full

- Light TC Higgs
- from dynamics (TC-dilaton?)
- Scaling (gauge geometry)
- Scalar mixing
- top corrections
- …

(See talk by F. Sannino)

Couplings of the TC - Higgs

Parameterising the deviations of TC Higgs couplings from the SM Higgs

$$\mathcal{L}_H = \frac{2M_W^2 \, c_W}{v} H W_\mu^- W^{+\mu} + \frac{2M_Z^2 \, c_Z}{v} H Z_\mu Z^\mu - \sum_f \frac{M_f \, c_f}{v} H \bar{f} f + \frac{g_{H\gamma\gamma}}{v} H F_{\mu\nu} F^{\mu\nu} + \frac{g_{Hgg}}{v} H G_{\mu\nu}^a G^{a\mu\nu}$$

In the SM we have $\quad c_W^{\text{SM}} = c_Z^{\text{SM}} = 1$

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In the SM we have
$$c_W^{SM} = c_Z^{SM} = 1$$

In TC by custodial symmetry have
$$c_W^{TC} = c_Z^{TC} = c_\Pi^{TC}$$

$$\mathcal{L} = \frac{c_\Pi^{TC}}{v} H \partial_\mu \Pi^a \partial^\mu \Pi^a$$

Π^a the eaten technipions (SM GB's)

Couplings of the QCD σ

Similarly in QCD: $\mathcal{L} = \dfrac{c_\pi^{\text{QCD}}}{f_\pi} \sigma \partial_\mu \pi^a \partial^\mu \pi^a$

m_σ (MeV)	$\left|g_{\sigma\pi\pi}\right|$ (GeV)	$\left|c_\pi^{\text{QCD}}\right|$
$441^{+16}_{-8} - i(272^{+9}_{-12.5})$	$3.31^{+0.35}_{-0.15}$	1.0035 ± 0.12
$474 \pm 6 - i(254 \pm 4)$	3.58 ± 0.03	1.0264 ± 0.024
$443 \pm 2 - i(216 \pm 4)$	2.97 ± 0.04	1.0479 ± 0.020
$452 \pm 12 - i(260 \pm 15)$	2.65 ± 0.01	0.8026 ± 0.053
$457^{+14}_{-13} - i(279^{+11}_{-7})$	$3.59^{+0.11}_{-0.13}$	1.0169 ± 0.06
$445 \pm 25 - i(278^{+22}_{-18})$	3.4 ± 0.5	1.0013 ± 0.17
$453 - i271$	3.5	1.0255

In terms of pi-pi scattering partial wave amplitude:

$$g^2_{\sigma\pi\pi} \equiv - \lim_{s \to m_\sigma^2} 16\pi \, (s - m_\sigma^2) \, a_{00}(\pi\pi \to \pi\pi)$$

Couplings of the QCD σ

$$\mathcal{L} = \frac{c_\pi^{\text{QCD}}}{f_\pi} \sigma \partial_\mu \pi^a \partial^\mu \pi^a \qquad \left(\mathcal{L} = \frac{c_\Pi^{\text{TC}}}{v} H \partial_\mu \Pi^a \partial^\mu \Pi^a \quad c_W^{\text{TC}} = c_Z^{\text{TC}} = c_\Pi^{\text{TC}} \right)$$

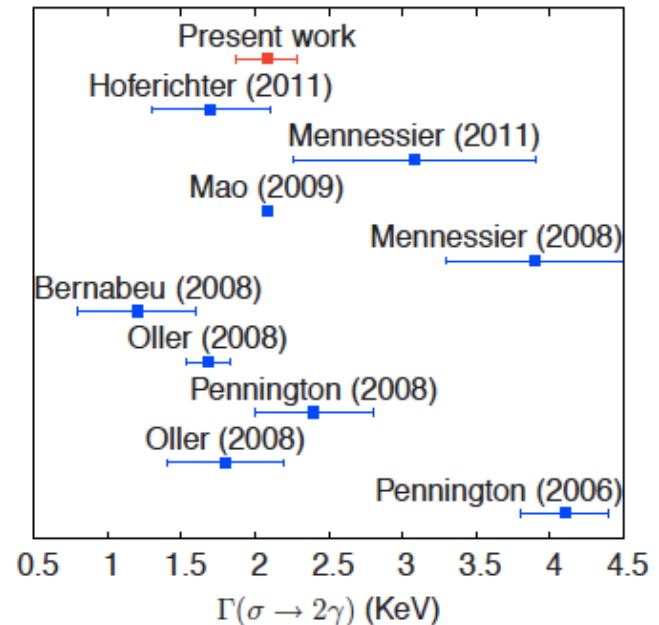| m_σ (MeV)	$\left\|g_{\sigma\pi\pi}\right\|$ (GeV)	$\left\|c_\pi^{\text{QCD}}\right\|$
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σ-GB couplings are SM-Higgs like!

Couplings of the σ

$$\mathcal{L} = \frac{c_\pi^{QCD}}{f_\pi}\sigma\partial_\mu\pi^a\partial^\mu\pi^a$$

$$\Gamma(S \to \gamma\gamma) = \frac{1}{64\pi}|g_{S\gamma\gamma}^{(2)}|^2\frac{m_S^3}{\Lambda^2}$$

m_σ (MeV)	$|g_{\sigma\pi\pi}|$ (GeV)	$|c_\pi^{QCD}|$
$441_{-8}^{+16} - i(272_{-12.5}^{+9})$	$3.31_{-0.15}^{+0.35}$	1.0035 ± 0.12
$474 \pm 6 - i(254 \pm 4)$	3.58 ± 0.03	1.0264 ± 0.024
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σ-GB couplings are SM-Higgs like!

Couplings of the σ

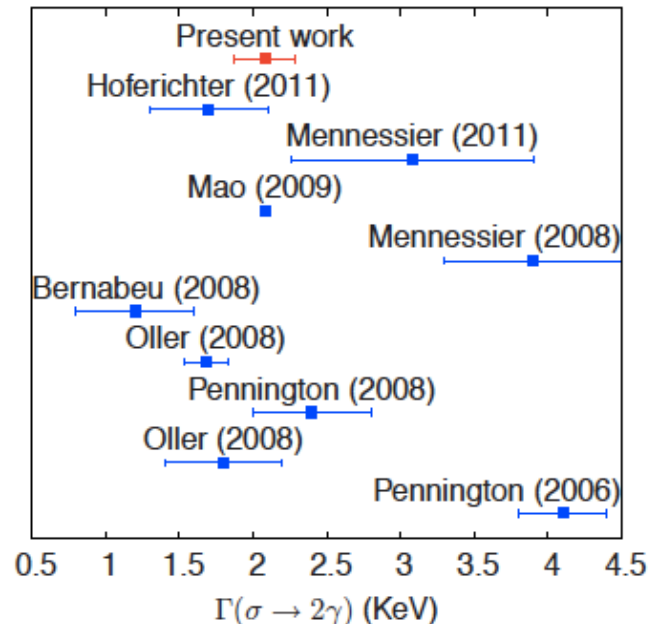$$\mathcal{L} = \frac{c_\pi^{\text{QCD}}}{f_\pi} \sigma \partial_\mu \pi^a \partial^\mu \pi^a$$

(1 keV → [QCD Scale up] → 3 x 10⁻⁶ GeV   SM Higgs 10⁻⁵ GeV)

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Present work
Hoferichter (2011)
Mennessier (2011)
Mao (2009)
Mennessier (2008)
Bernabeu (2008)
Oller (2008)
Pennington (2008)
Oller (2008)
Pennington (2006)

0.5 1 1.5 2 2.5 3 3.5 4 4.5

$\Gamma(\sigma \to 2\gamma)$ (KeV)

σ-GB couplings are SM Higgs-like!

σ-γγ couplings SM Higgs-like (?)

Couplings of the σ

- QCD σ light (wrt to vector resonances)
- SM Higgs-like (GB and photon couplings)

...but not *really* light
$$\frac{m_\sigma}{f_\pi} \gg \frac{m_H}{v}$$

Couplings of the σ

- QCD σ light (wrt to vector resonances)
- SM Higgs-like (GB and photon couplings)
  ...but not *really* light

$$\frac{m_\sigma}{f_\pi} \gg \frac{m_H}{v}$$

If TC-Higgs couplings arises from 'QCD-like' dynamics
And it is driven light because of EW-corrections

Then expect a narrow SM-Higgs like TC Higgs:
(compare $f_0(980)$...)

$$c_W^{TC} = c_Z^{TC} = c_\Pi^{TC} \quad \sim 1$$

One candidate the SU(3) MWT model (NMWT/sextet)

Techni-Higgs fermion couplings

Typical scenario: couplings to SM fermions from ETC four fermion interations:

$$g_{ETC}^2 \frac{\bar{Q}Qff}{\Lambda_{ETC}^2} \rightarrow g_{ETC}^2 \frac{\langle \bar{Q}Q \rangle_{TC}(r_t H + v)\bar{f}f}{\Lambda_{ETC}^2 v} = \frac{m_f}{v}(v\bar{f}f + r_t H\bar{f}f)$$

If all SM top mass generated by ETC *and* r_t ~1 then SM like Yukawa

For a techni-dilaton, using Ward-identities and TD pole-dominance:
Where γ_m is the anomalous dim. of TC mass operator and F_{TD} the
dilaton decay constant

$$r_t = (3 - \gamma_m)\frac{v}{F_{TD}}$$

(Bando, Matumoto & Yamawaki '86
Yamawaki, Matsuzaki '12;
Choi, Hong & Matsuzaki)

TC-Higgs vs SM Higgs

➤ Some deviation in Higgs couplings – could be small
  work in progress…

➤ Presence of additional resonances – coupled to TC Higgs

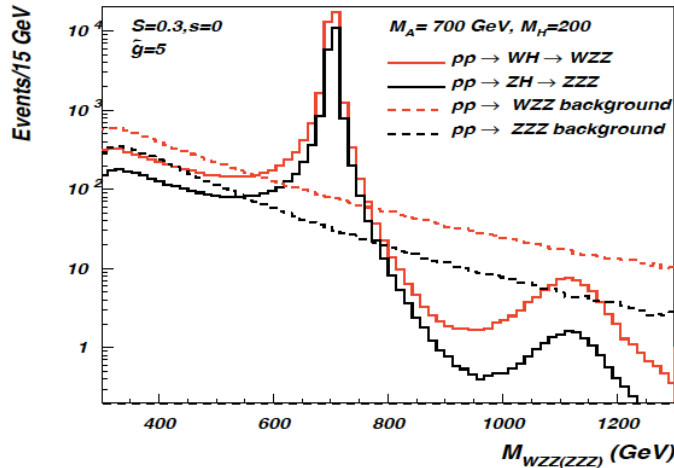# Phenomenology of a light TC Higgs

(e.g. A. Belyaev, MTF et al '08,
Hapola & Sannino '11;
Andersen et al '11;
MTF & Sannino '12)

- Massive vector and fermion couplings can be SM like

- Di-photon decay sensitive to new technifermions
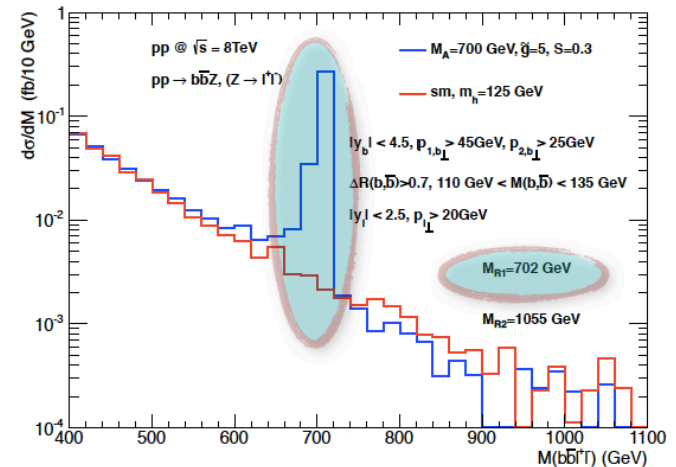
- Resonances coupled to the TC-Higgs
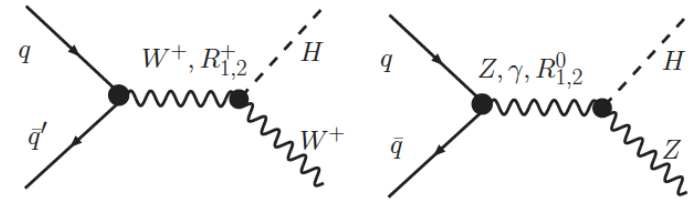
$$pp \rightarrow HV \rightarrow VVV$$

$$pp \rightarrow HZ \rightarrow b\bar{b}ll$$

(Belyaev, Foadi, MTF, Jarvinen, Pukhov & Sannino '08)

(T. Hapola preliminary)

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Phenomenology of a light TC Higgs
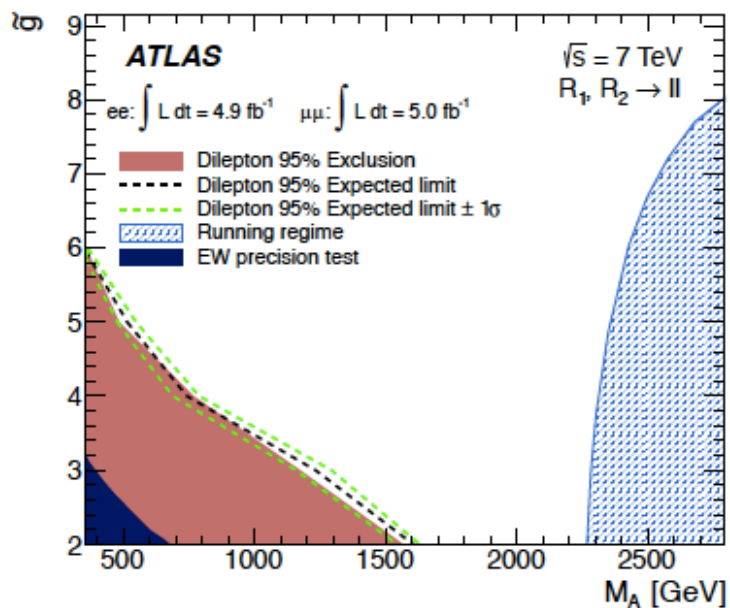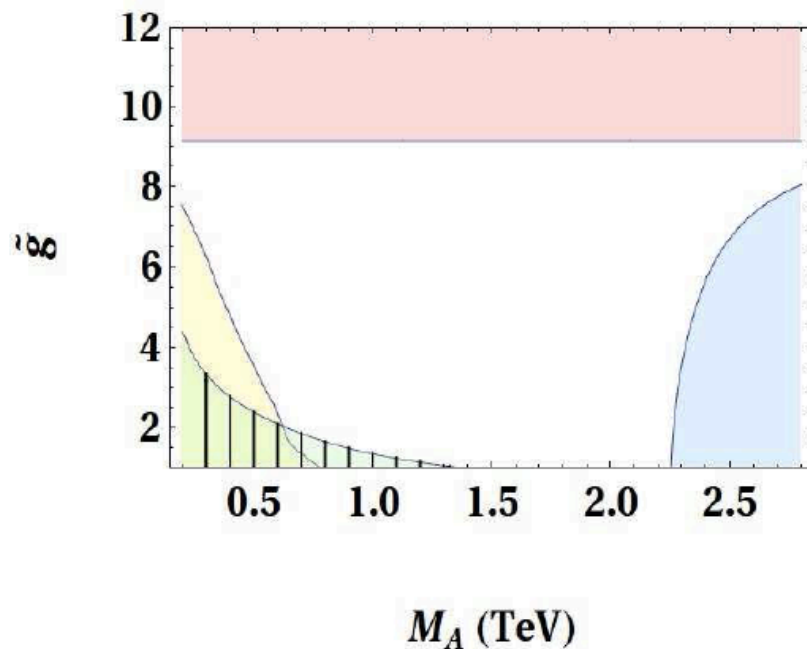
Dilepton limits on vector resonances
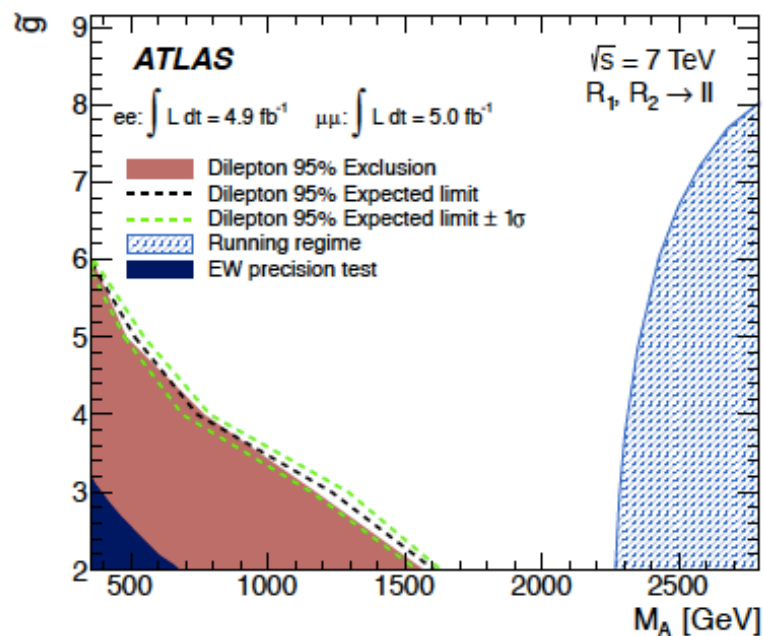
Figure 8. Bounds in the $(M_A, \tilde{g})$ plane of the MWT parameter space: (i) The electroweak precision measurements exclude the dark area in the bottom left corner. (ii) The requirement to stay in the walking regime excludes the hatched area in the right corner. (iii) The red area (black dashed line) shows the observed (expected) exclusion at 95% CL in the dilepton channel. The green dashed lines show the $\pm 1\sigma$ bands of the expected exclusion limit.

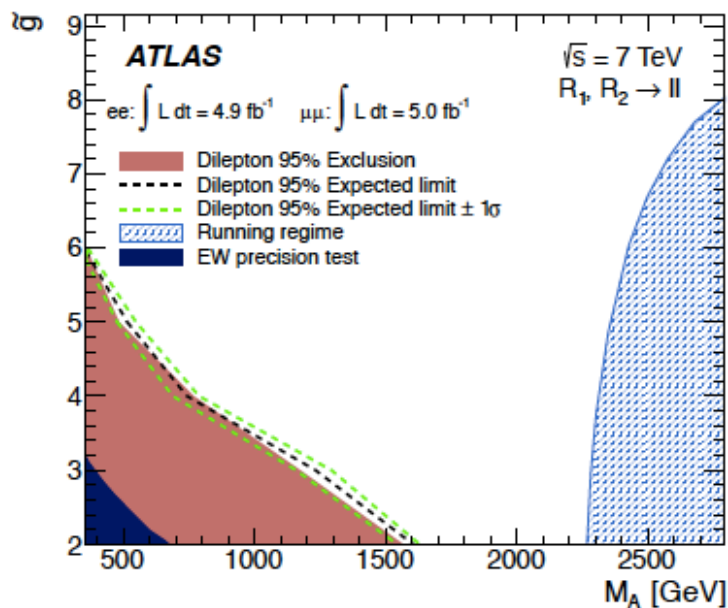# Phenomenology of a light TC Higgs

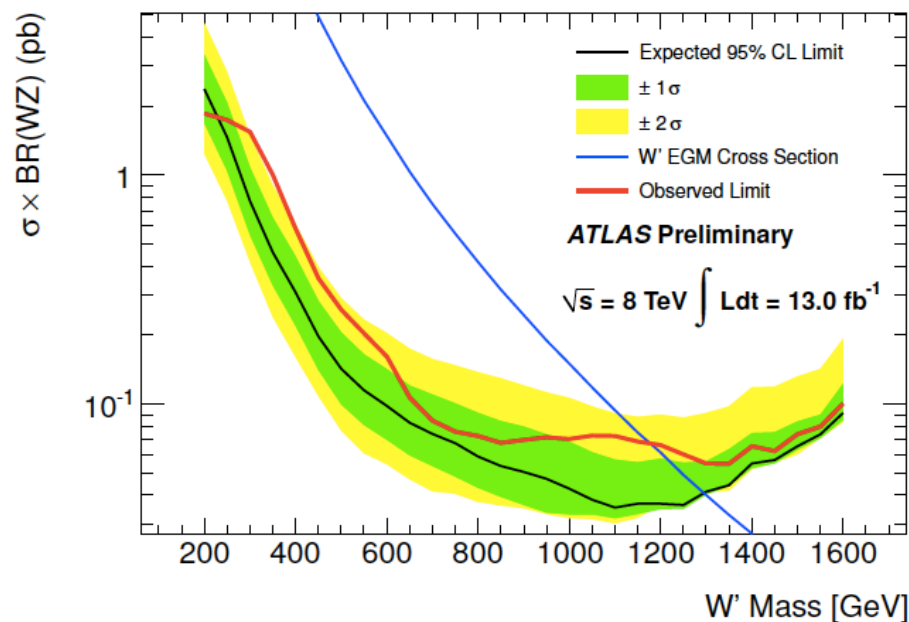Dilepton limits on vector resonances

(ATLAS '12)

(A. Belyaev, MTF et al '08)

Phenomenology of a light TC Higgs

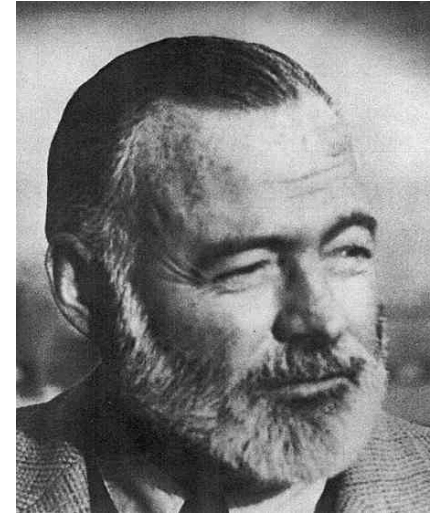Dilepton & diboson limits on vector resonances

(ATLAS '12)

(ATLAS '13)

Summary

- **TC natural theory of EWSB**
- Rumours of its death exaggerated

know what ya' mean!

Summary

- **TC natural theory of EWSB**
  - Rumours of its death exaggerated
  - Predictive!

- **TC *can* feature a light Techni-Higgs:**
  - Dynamics (Techni-Dilaton),
  - Radiative corrections (top),
  - Mass Mixing (e.g. low-scale TC, Ultra Miminal TC)

- **Light TC-Higgs *expected* have SM Higgs-like couplings**
  - fermion couplings, depend on ETC

- **Signatures: Self-coupling, Resonances!**