Towards an asymptotically safe model of electroweak interactions

Federica Bazzocchi,
Sissa & INFN Trieste

APPS 2011, Amsterdam

Based on: Fabbrichesi, Percacci,Tonero, Zanusso PRD83,2011; Fabbrichesi, Percacci,Tonero, Vecchi PRL107,2011; FB,Fabbrichesi, Percacci,Tonero, Vecchi PLB705,2011; FB,Fabbrichesi, Percacci,Tonero, Vecchi to appear.

Weinberg (1976)

- A quantum field theory that has a fixed point with a finite number of UV-attractive directions is said to be asymptotically safe
- The demanding that a theory is asymptotically free imposes constraints along the directions UV-repulsive and leave free parameters in the UV-attractive direction: highly predictive
- asymptotic safety may provide a rationale for picking accetable quantum field theory more than demanding to a theory to be renormalizable

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Example...

$$\tilde{f} = k f$$

$$\frac{d\tilde{f}}{dt} = \tilde{f} - \frac{N}{64\pi^2}\tilde{f}^3$$

$$\tilde{f}^* = \pm\frac{8\pi}{\sqrt{N}}$$ UV-attractive

$$\tilde{f}^* = 0$$ UV-repulsive

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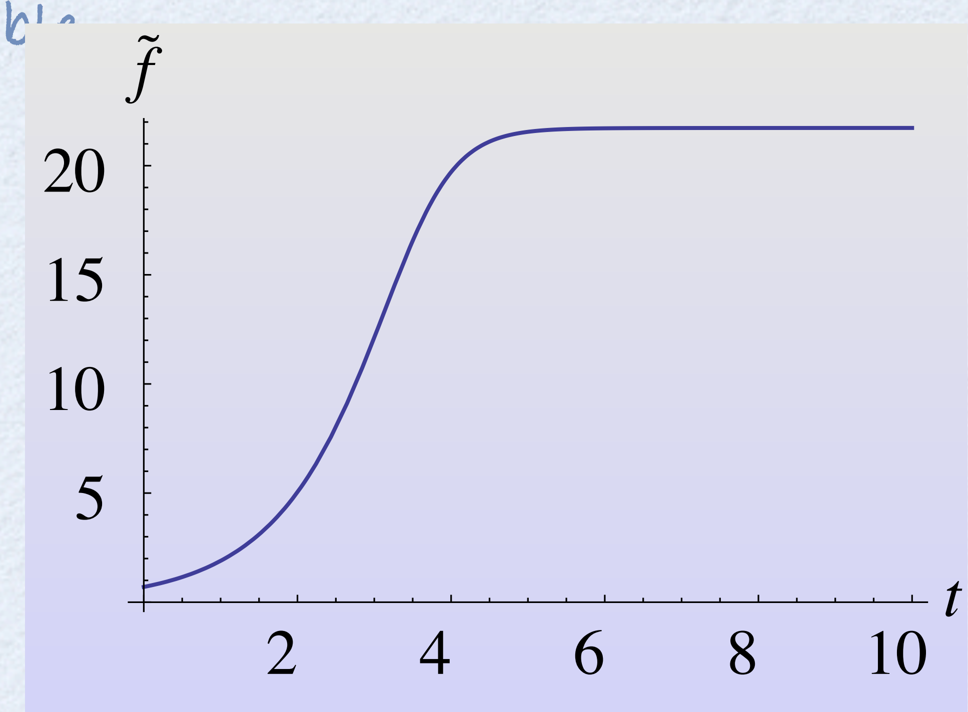

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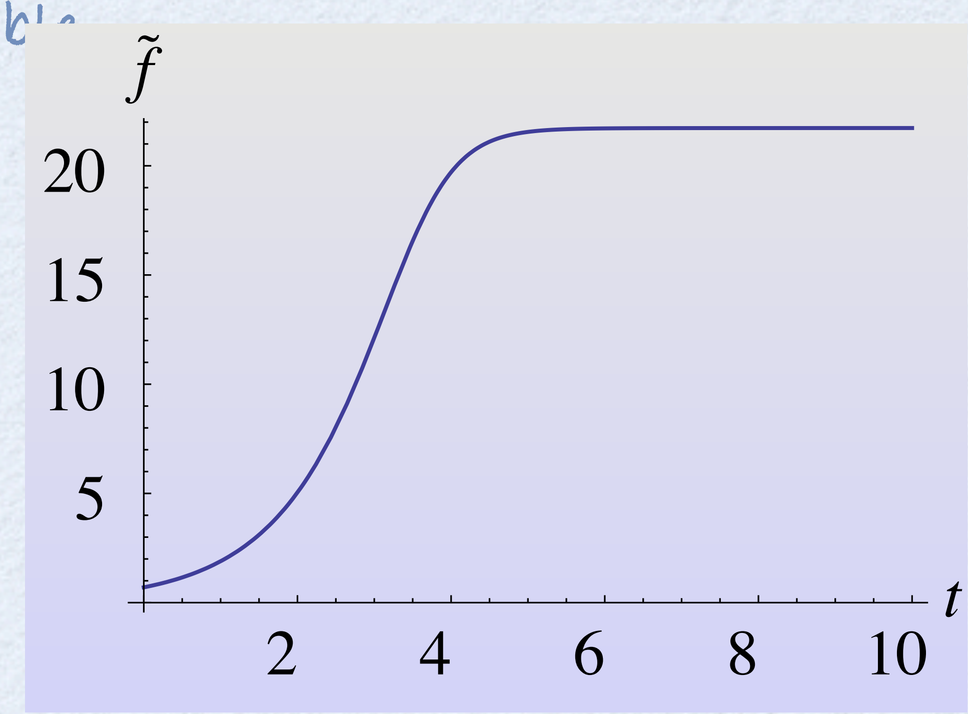

drawback...

in the RGE evolution the theory may become strongly interacting thus non perturbatively. Perturbation theory maybe only a rough guide for a phenomenological approach

EW Non Linear Sigma Model

- Minimal realization of the SM: only particles already discovered (NO HIGGS BOSON)
- Fermions and gauge bosons couple to the Nambu-Goldstone bosons associated to the EW symmetry breaking
- It corresponds to take the limit of infinite mass of the higgs boson: NLSM (so far no gauge)

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Real World...

- Gauge interactions
- EWPT ?
- pf >1 we should include higher order derivative terms O(p ^ 4)...
- Unitarity?
- Fermions

Assumptions:

- we use perturbation theory only as a rough guide
- one loop computations and analysis of the presence/consequenece of UV-attractive FPs
- one loop results are assumed to hold at least qualitative in the non-perturbative solution
- when studying O(p^4) operators and fermions we may "freeze" the gauge coupling and neglect them (they flow very slowly)

Gauging the NLSM

$$\frac{1}{f^2}\partial_\mu U^\dagger \partial^\mu U$$ it has a SU(2)L x SU(2)R global symmetry $$U \to LUR^\dagger$$

$$\frac{1}{f^2}(D_\mu U)^\dagger D^\mu U$$ we gauge SU(2)Lx U(1)y=T3R $$U \to LUR_3^\dagger$$

$$D_\mu U = \partial_\mu U + igt^k W_\mu^k - ig' U t^3 B_\mu$$

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$$T = U(2t^3)U^\dagger$$

$$W_{\mu\nu} = t^k W_{\mu\nu}^k = \partial_\mu W_\nu - \partial_\nu W_\mu + ig[W_\mu, W_\nu]$$

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$$a_0 g^2 \frac{1}{f^2}[Tr(TV_\mu)]^2 + \frac{1}{2}a_1 g g' B_{\mu\nu} Tr(TW^{\mu\nu}) + \frac{1}{2} i a_2 g' B_{\mu\nu} Tr(T[V^\mu, V^\nu]) + i a_3 g Tr(W_{\mu\nu}[V^\mu, V^\nu])$$

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controls T

controls S

oblique parameters

$$T \propto [\Pi_{33}(0) - \Pi_{11}(0)]$$
$$S \propto [\Pi'_{33}(0) - \Pi'_{3B}(0)]$$

Gauging the NLSM

$$g^2, {g'}^2 << \tilde{f}^2$$

$$\frac{dg^2}{dt} = -\frac{29}{2}\frac{g^4}{(4\pi)^2}$$

$$\frac{d{g'}^2}{dt} = \frac{1}{6}\frac{{g'}^4}{(4\pi)^2}$$

$$\frac{d\tilde{f}^2}{dt} = 2\tilde{f}^2 - \frac{1}{2}\frac{\tilde{f}^2}{(4\pi)^2}(\tilde{f}^2 a_0(1+2a_0) + 6g^2 + 3{g'}^2)$$

$$\frac{da_0}{dt} = \frac{1}{2}\frac{1}{(4\pi)^2}(\tilde{f}^2 a_0(1-2a_0) + \frac{3}{2}{g'}^2)$$

$$\frac{da_1}{dt} = \frac{1}{(4\pi)^2}(\tilde{f}^2 a_1 + \frac{1}{6})$$

FP	eigenvalue	eigenvector components		
		$\tilde{f}$	a_0	a_1
I	−1.99	1.00	11.6×10^{-6}	14.1×10^{-6}
I	1.99	−0.997	0.0795	-42.2×10^{-6}
I	3.98	0	0	1
II	−1.99	1.00	66.0×10^{-6}	29.9×10^{-6}
II	−0.996	−0.998	0.0563	-40×10^{-6}
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UV repulsive, we have to fix it at the FP

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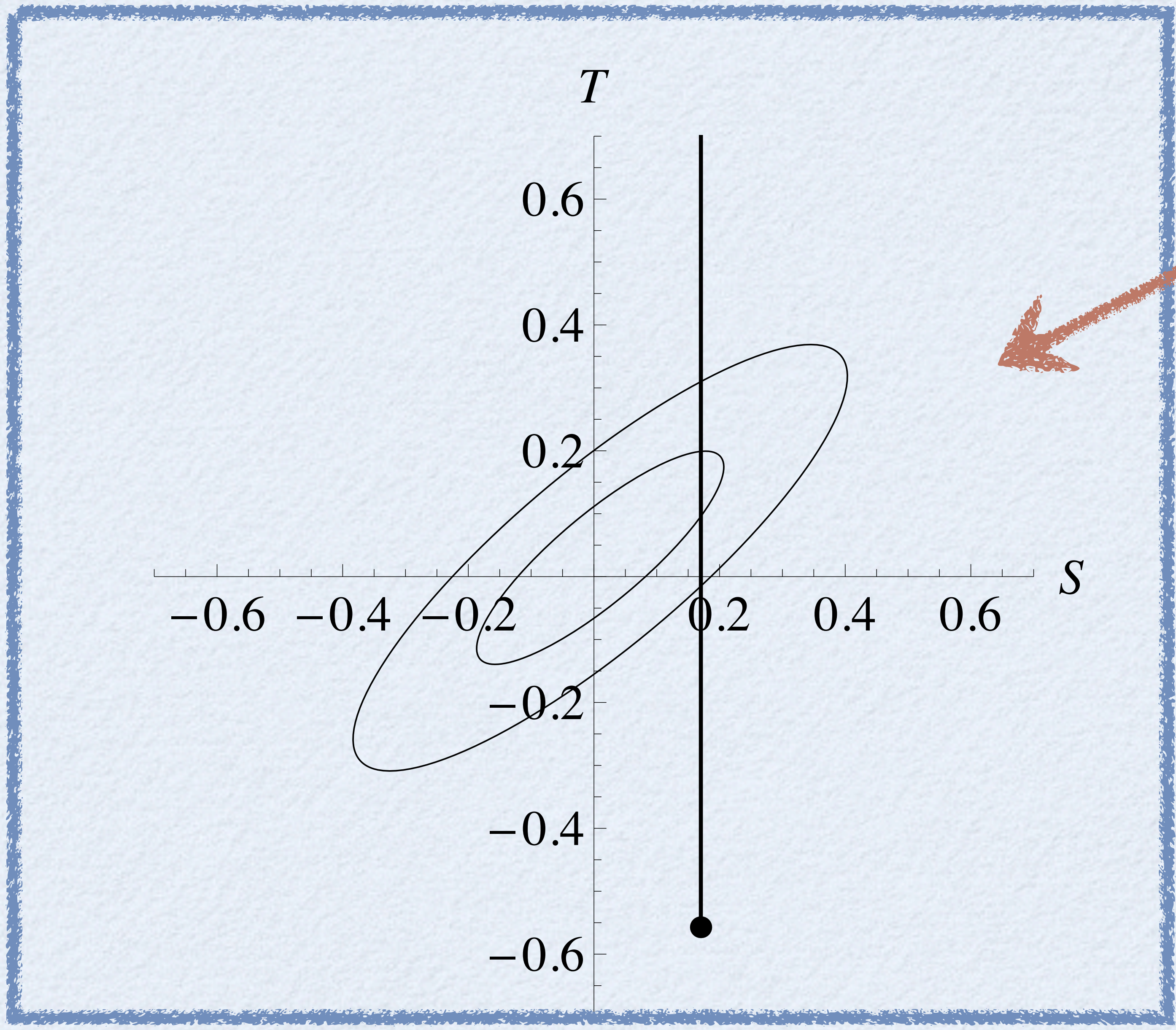
Gauging the NLSM

$$S = -16\pi a_1(m_Z) + \frac{1}{6\pi}\left[\frac{5}{12} - \log\left(\frac{m_H}{m_Z}\right)\right]$$

$$T = \frac{2}{\alpha_{em}} a_0(m_Z) - \frac{3}{8\pi\cos^2\theta_W}\left[\frac{5}{12} - \log\left(\frac{m_H}{m_Z}\right)\right]$$



agreement with the experimental bounds

Scattering amplitude and unitarity

$$A(\pi^i\pi^j \to \pi^k\pi^l) = A(s,t,u)\delta^{ij}\delta^{kl} + A(t,s,u)\delta^{ik}\delta^{jl} + A(u,s,t)\delta^{il}\delta^{jk}$$

isospin amplitudes
I=0,1,2

$$\begin{cases} A_0(s,t,u) = 3A(s,t,u) + A(t,s,u) + A(u,s,t) \\ A_1(s,t,u) = A(t,s,u) - A(u,s,t) \\ A_2(s,t,u) = A(t,s,u) + A(u,s,t) \end{cases}$$

$$A(s,t,u) = s\frac{f^2}{4}$$

$$t_{IJ} = \frac{1}{64\pi}\int_{-1}^{1} d\cos\theta P_J(cos\theta)A_I(s,t,u)$$

partial waves decomposition

$$t_{00} = \frac{sf^2}{64\pi} = \frac{\tilde{f}^2}{64\pi} < \frac{1}{2} \longrightarrow N > 2\pi$$

$$\tilde{f}^* = \pm\frac{8\pi}{\sqrt{N}}$$

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for large N the NLSM does not violate unitarity, unfortunately EW symmetry has N=2, so...

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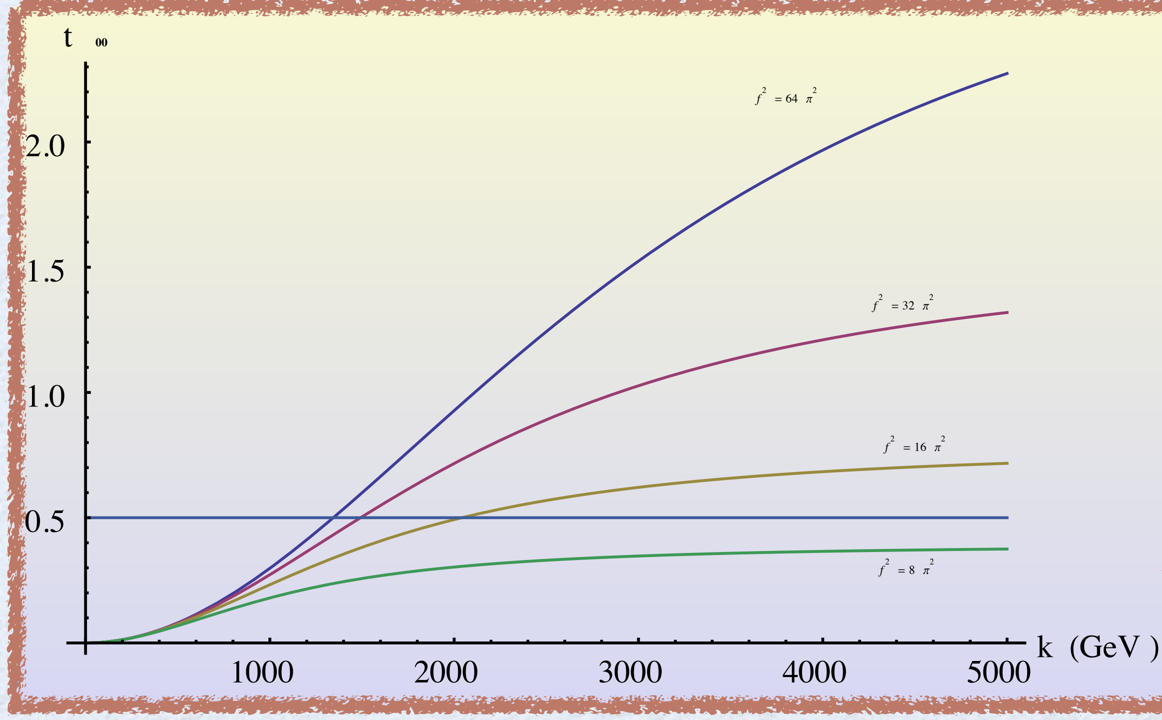

O(p^4) & Resonances

$$a_4[Tr(V_\mu V_\nu)]^2 + a_5[Tr(V_\mu V^\mu)]^2$$

control the resonances

$$\frac{d\tilde{f}}{dt} = \tilde{f} - \frac{1}{4}\frac{\tilde{f}^3}{(4\pi)^2} - \frac{1}{6}\frac{\tilde{f}^5}{(4\pi)^2}(4a_4 + 7a_5)$$

$$\frac{da_4}{dt} = \frac{1}{12}\frac{1}{(4\pi)^2}\tilde{f}^2(19a_4 + 10a_5) - \frac{1}{6}\frac{1}{(4\pi)^2} + \mathcal{O}(a_{4,5}^2\tilde{f}^4)$$

$$\frac{da_5}{dt} = -\frac{1}{24}\frac{1}{(4\pi)^2}\tilde{f}^2(22a_4 + 28a_5) - \frac{1}{12}\frac{1}{(4\pi)^2} + \mathcal{O}(a_{4,5}^2\tilde{f}^4)$$

FP $\quad \tilde{f}^* = 38.6, \quad a_4^* = 0.00016, \quad a_5^* = -0.00018$

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comparable to O(p^6)

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O(p^4) & Resonances

IAM prescription

$$t_{00}^{(2)} = \frac{s f^2}{64\pi} = \frac{\tilde{f}^2}{64\pi} < \frac{1}{2}$$

$$t_{00}^{(4)} = \frac{s^2 f^4}{1024\pi}\left[\frac{16(11a_5 + 7a_4)}{3} + \frac{101/9 - 50\log(s/\mu^2)/9 + 4i\pi}{16\pi^2}\right]$$

unitarized amplitude

$$t_{00}(s) = \frac{t_{00}^{(2)}}{1 - t_{00}^{(4)}/t_{00}^{(2)}} + \mathcal{O}(s^3)$$

the poles of the amplitude are interpreted as resonances →

$$m_S^2 = \frac{12\,v^2}{16\,[11a_5(\mu) + 7a_4(\mu)] + \frac{1}{16\pi^2}\frac{101}{3}}$$

Preliminary!

$m_S \sim 600$ GeV

Including the fermions

$$\mathcal{L}_\psi = \bar{\psi}_L i\gamma^\mu \partial_\mu \psi_L + \bar{\psi}_R i\gamma^\mu \partial_\mu \psi_R - \frac{2h}{f}(\bar{\psi}_L^a U \psi_R^a + H.c.)$$

$$m = \frac{2h}{f} = hv$$

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Real World...

- Splitting up and down, 3 families
- gauge interactions (no SU(2)R)

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for the moment...

$$\frac{d\tilde{f}}{dt} = \tilde{f} - \frac{N}{64\pi^2}\tilde{f}^3 + \frac{N_c}{4\pi^2}h^2\tilde{f}$$

$$\frac{dh}{dt} = \frac{1}{16\pi^2}\left(4N_c - 2\frac{N^2-1}{N}\right)h^3 + \frac{1}{64\pi^2}\frac{N^2-2}{N}h\tilde{f}^2$$

UV repulsive, FP no phenomenologically accetable

Including fermions

$$\mathcal{L}_{\psi^4} = \lambda_1 \left(\bar\psi_L^{ia}\psi_R^{ja}\bar\psi_R^{jb}\psi_L^{ib}\right) + \lambda_2 \left(\bar\psi_L^{ia}\psi_R^{jb}\bar\psi_R^{jb}\psi_L^{ia}\right)$$
$$+ \lambda_3 \left(\bar\psi_L^{ia}\gamma_\mu\psi_L^{ia}\bar\psi_L^{jb}\gamma^\mu\psi_L^{jb} + \bar\psi_R^{ia}\gamma_\mu\psi_R^{ia}\bar\psi_R^{jb}\gamma^\mu\psi_R^{jb}\right)$$
$$+ \lambda_4 \left(\bar\psi_L^{ia}\gamma_\mu\psi_L^{ib}\bar\psi_L^{jb}\gamma^\mu\psi_L^{ja} + \bar\psi_R^{ia}\gamma_\mu\psi_R^{ib}\bar\psi_R^{jb}\gamma^\mu\psi_R^{ja}\right)$$

dimensional parameters

$$\frac{d\tilde f}{dt} = \tilde f - \frac{1}{32\pi^2}\tilde f^3 + \frac{N_c}{4\pi^2}h^2\tilde f$$
$$\frac{dh}{dt} = \frac{1}{16\pi^2}\left[4N_c - 3 + \frac{16}{\tilde f^2}(N_c\tilde\lambda_1 + \tilde\lambda_2)\right]h^3 + \frac{1}{64\pi^2}\left[\tilde f^2 - 16(N_c\tilde\lambda_1 + \tilde\lambda_2)\right]h$$
$$\frac{d\tilde\lambda_1}{dt} = 2\tilde\lambda_1 - \frac{1}{4\pi^2}\left[N_c\tilde\lambda_1^2 + \frac{3}{2}\tilde\lambda_1\tilde\lambda_2 - 2\tilde\lambda_1\tilde\lambda_3 - 4\tilde\lambda_1\tilde\lambda_4\right]$$
$$\frac{d\tilde\lambda_2}{dt} = 2\tilde\lambda_2 + \frac{1}{4\pi^2}\left[\frac{1}{4}\tilde\lambda_1^2 + 4\tilde\lambda_1\tilde\lambda_3 + 2\tilde\lambda_1\tilde\lambda_4 - \frac{3}{4}\tilde\lambda_2^2 + 2(2N_c+1)\tilde\lambda_2\tilde\lambda_3 + 2(N_c+2)\tilde\lambda_2\tilde\lambda_4\right]$$
$$\frac{d\tilde\lambda_3}{dt} = 2\tilde\lambda_3 + \frac{1}{4\pi^2}\left[\frac{1}{4}\tilde\lambda_1\tilde\lambda_2 + \frac{N_c}{8}\tilde\lambda_2^2 + (2N_c-1)\tilde\lambda_3^2 + 2(N_c+2)\tilde\lambda_3\tilde\lambda_4 - 2\tilde\lambda_4^2\right]$$
$$\frac{d\tilde\lambda_4}{dt} = 2\tilde\lambda_4 + \frac{1}{4\pi^2}\left[\frac{1}{8}\tilde\lambda_1^2 - 4\tilde\lambda_3\tilde\lambda_4 + (N_c+2)\tilde\lambda_4^2\right].$$

Including fermions

	$\tilde{\lambda}_1$	$\tilde{\lambda}_2$	$\tilde{\lambda}_3$	$\tilde{\lambda}_4$	ϵ_h
fp0	0	0	0	0	0.5
fp1a	0	-28.71	-7.18	0	1.22
fp1b	0	0	7.85	-9.51	0.5
fp1c	0	25.61	-4.27	0	-0.15
fp1d	25.80	-1.77	0.19	-1.15	-1.42
fp2a	13.41	20.10	-3.80	-0.24	-1.03
fp2b	20.86	-3.56	7.04	-8.94	-1.00
fp2c	0	-36.55	2.34	-13.92	1.43
fp2d	0	0	-15.79	0	0.5
fp2e	37.17	-37.36	-8.43	-1.65	-1.38
fp2f	-2.92	32.59	4.67	-12.04	-0.10
fp3a	$0.$	31.67	4.67	-12.06	-0.30
fp3b	19.95	-8.59	-15.27	-0.36	-0.80
fp3c	31.22	-44.52	0.73	-13.38	-0.74
fp3d	-4.87	1.54	-5.42	-20.10	0.83
fp4	0	0	-5.42	-20.13	0.5

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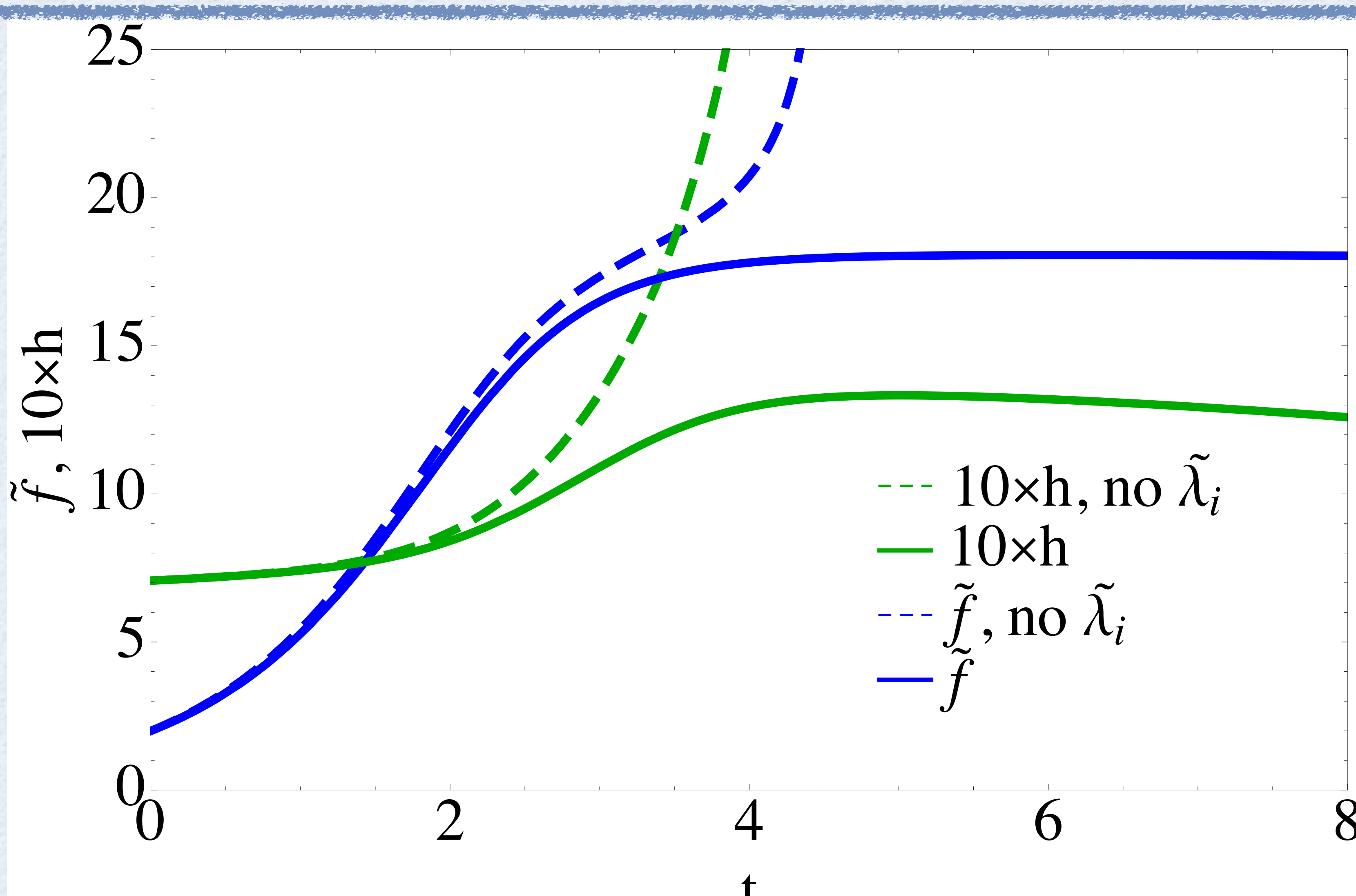
fp2c	0	−36.55	2.34	−13.92	1.43
fp2d	0	0	−15.79	0	0.5
fp2e	37.17	−37.36	−8.43	−1.65	−1.38
fp2f	−2.92	32.59	4.67	−12.04	−0.10
fp3a	0.	31.67	4.67	−12.06	−0.30
fp3b	19.95	−8.59	−15.27	−0.36	−0.80
fp3c	31.22	−44.52	0.73	−13.38	−0.74
fp3d	−4.87	1.54	−5.42	−20.10	0.83
fp4	0	0	−5.42	−20.13	0.5



$t = \log k/v$

Including fermions

	$\tilde{\lambda}_1$	$\tilde{\lambda}_2$	$\tilde{\lambda}_3$	$\tilde{\lambda}_4$	ϵ_h
fp0	0	0	0	0	0.5
fp1a	0	−28.71	−7.18	0	1.22
fp1b	0	0	7.85	−9.51	0.5
fp1c	0	25.61	−4.27	0	−0.15
fp1d	25.80	−1.77	0.19	−1.15	−1.42
fp2a	13.41	20.10	−3.80	−0.24	−1.03
fp2b	20.86	−3.56	7.04	−8.94	−1.00
fp2c	0	−36.55	2.34	−13.92	1.43
fp2d	0	0	−15.79	0	0.5
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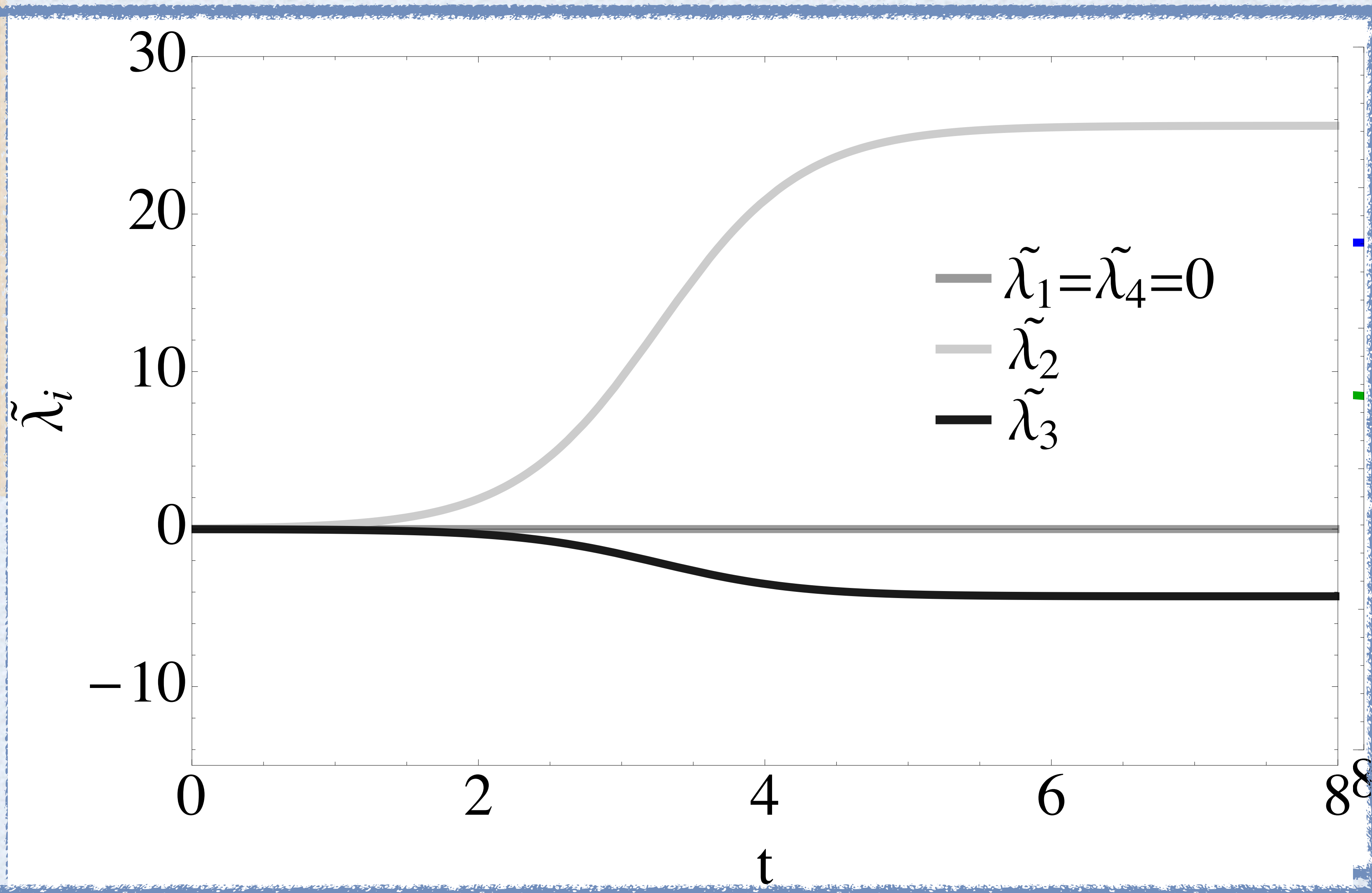

Phenomenological constraints

$$\mathcal{L}_{qqqq} = \frac{2\pi A}{\Lambda^2} \bar{\psi}_L^{ia} \gamma_\mu \psi_L^{ia} \bar{\psi}_L^{jb} \gamma^\mu \psi_L^{jb}$$

E. Eichten, K. D. Lane, M. E. Peskin, PRL 50 (1983) 811

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$$\Lambda_{bound} > 9.5$$
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TeV

New J. Phys. 13 (2011) 053044

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$$\tilde{\lambda}_3(k) = \frac{2\pi}{\Lambda^2_{bound}} k^2$$

(B, De Sanctis,
Fabbrichesi and Tonero
1111.5936[hep-ph])

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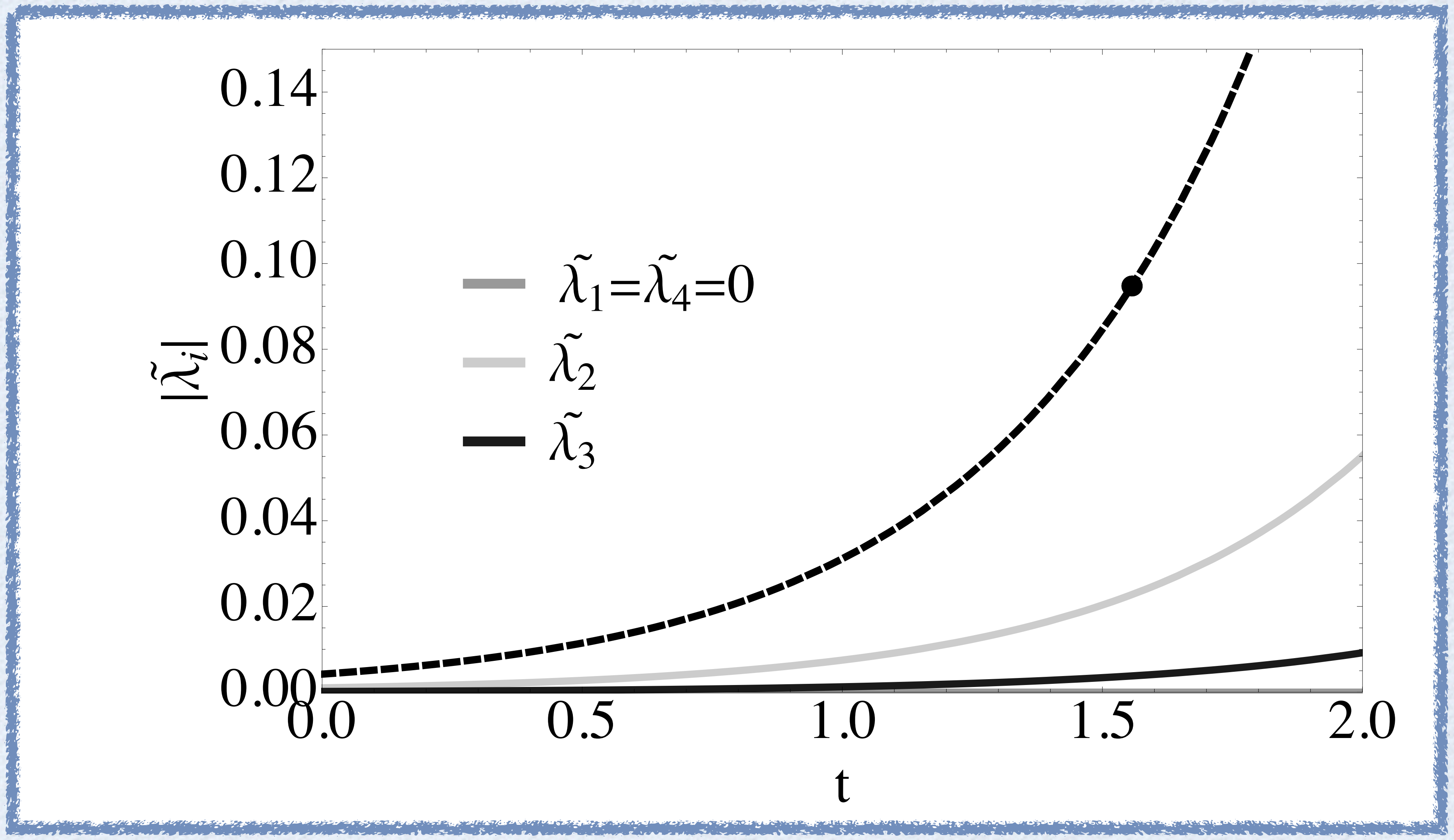
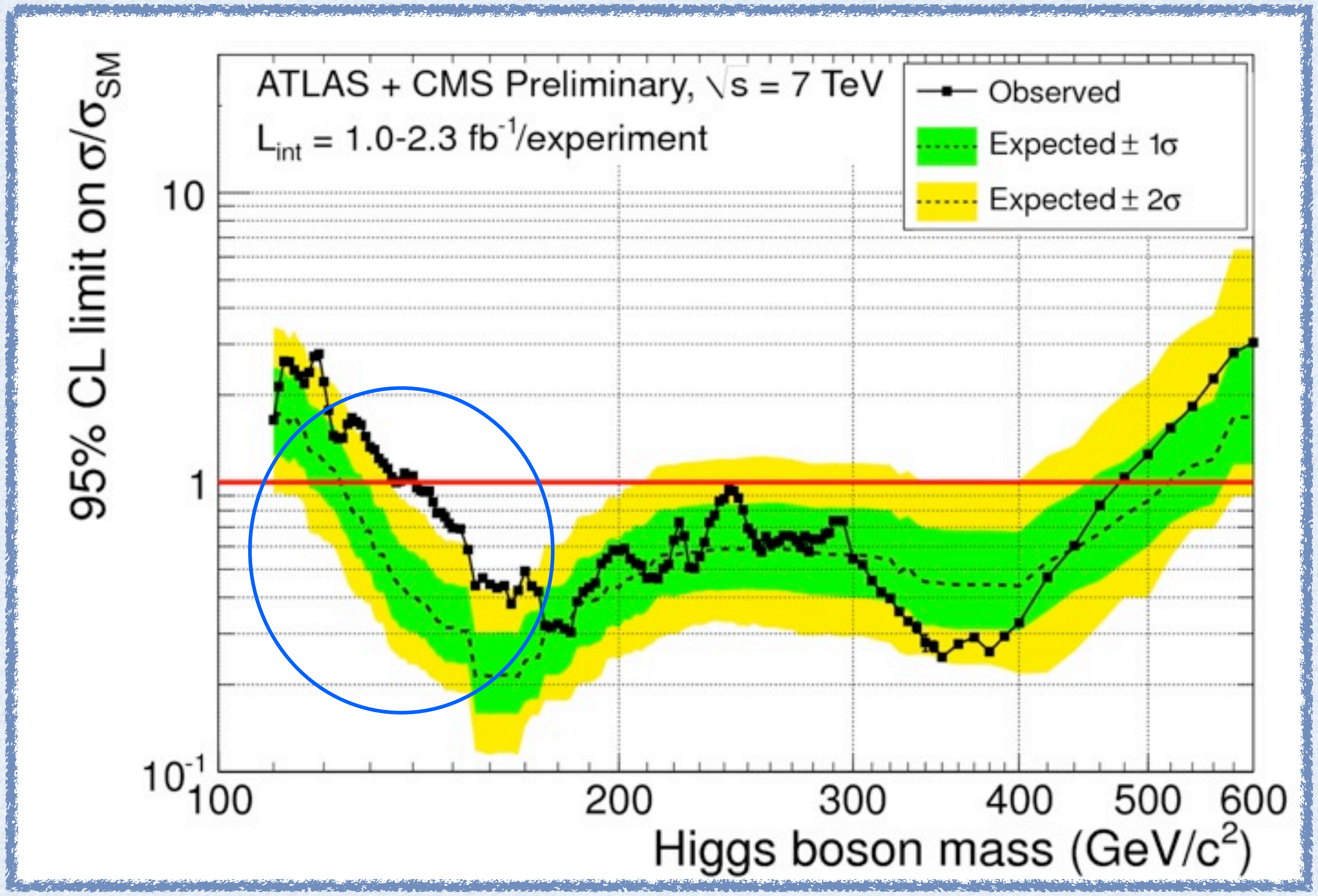
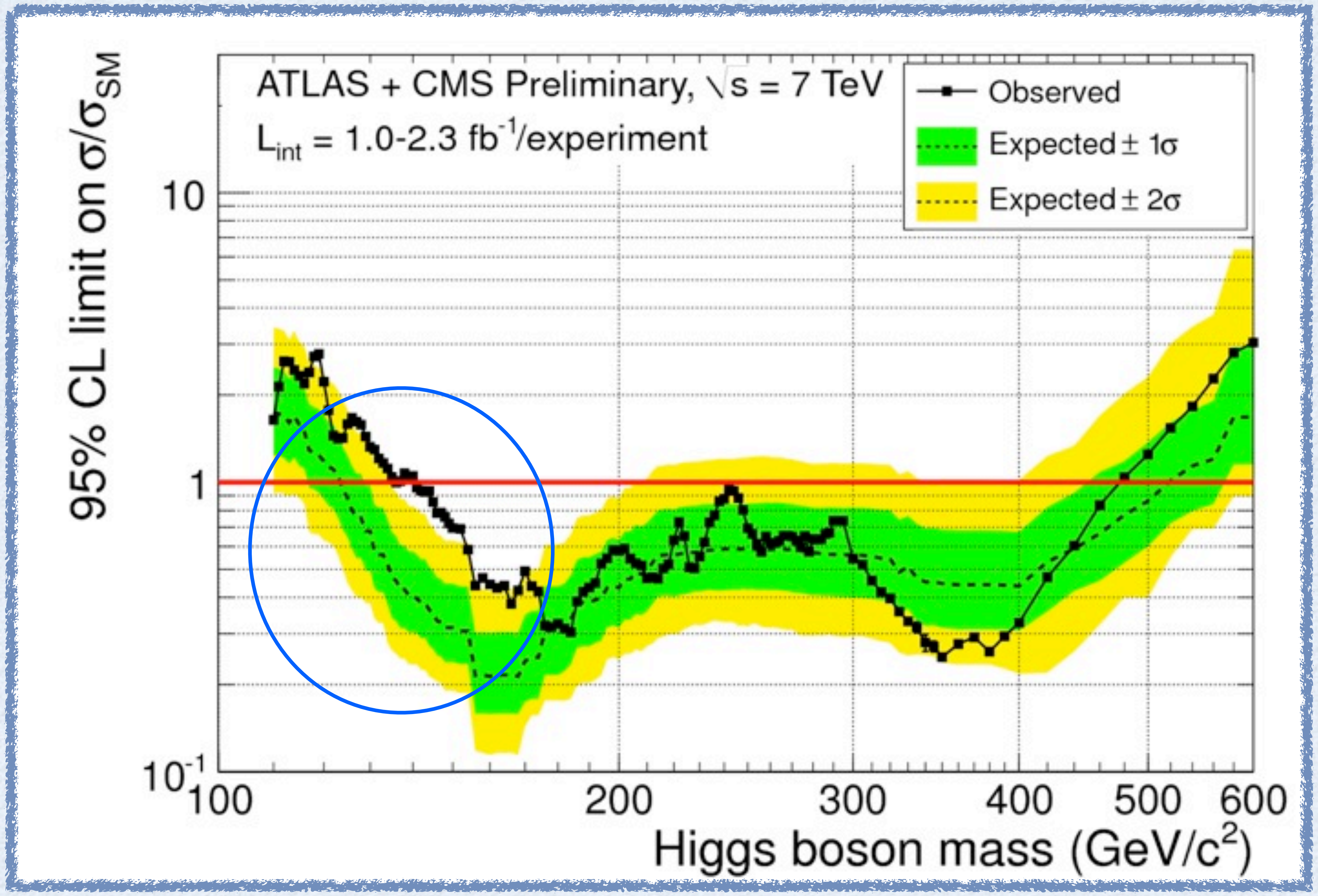


Conclusions



Conclusions



many efforts would spend into Higgs reduced production, invisible decays, non standard scenarios...

Conclusions

- a scenario with no Higgs boson is a real possibility
- asymptotic safe description of EW interactions is competitive with other higgsless or composite framework
- drawback: we lack of satisfactory mathematical tools, perturbative computations are only a rough guide
- a complete description is deeply challenging but difficult
- is it possible to distinguish it from other higgsless scenarios?

Conclusions

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Thanks!