Dynamical electroweak symmetry breaking by modern walking technicolour

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CP^3-Origins

Motivation

- Higgs mass unstable against radiative corrections (hierarchy problem, fine tuning)
- Higgs has not been detected
- not a single elementary scalar is known
- some guidance: superconductivity: Higgs dof composite
- most of the mass is of dynamical origin
- Higgs potential: only mass scale on Lagrangian level

More guidance

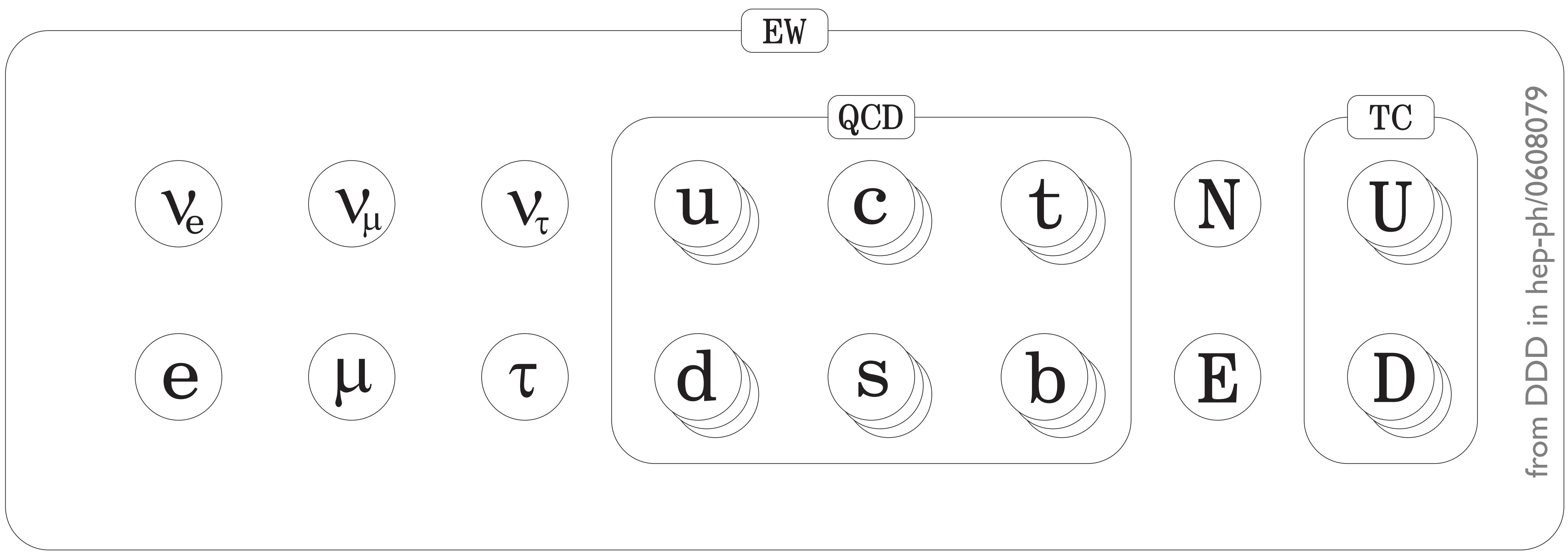
Gedankenexperiment:

Standard model
without Higgs sector

Technicolour

Weinberg PRD13(1973),
Weinberg PRD19(1979)
Susskind PRD20(1979)

$$\mathcal{G} = \mathcal{G}_{TC} \times SU(3)_{QCD} \times SU(2)_Y \times U(1)_Y$$



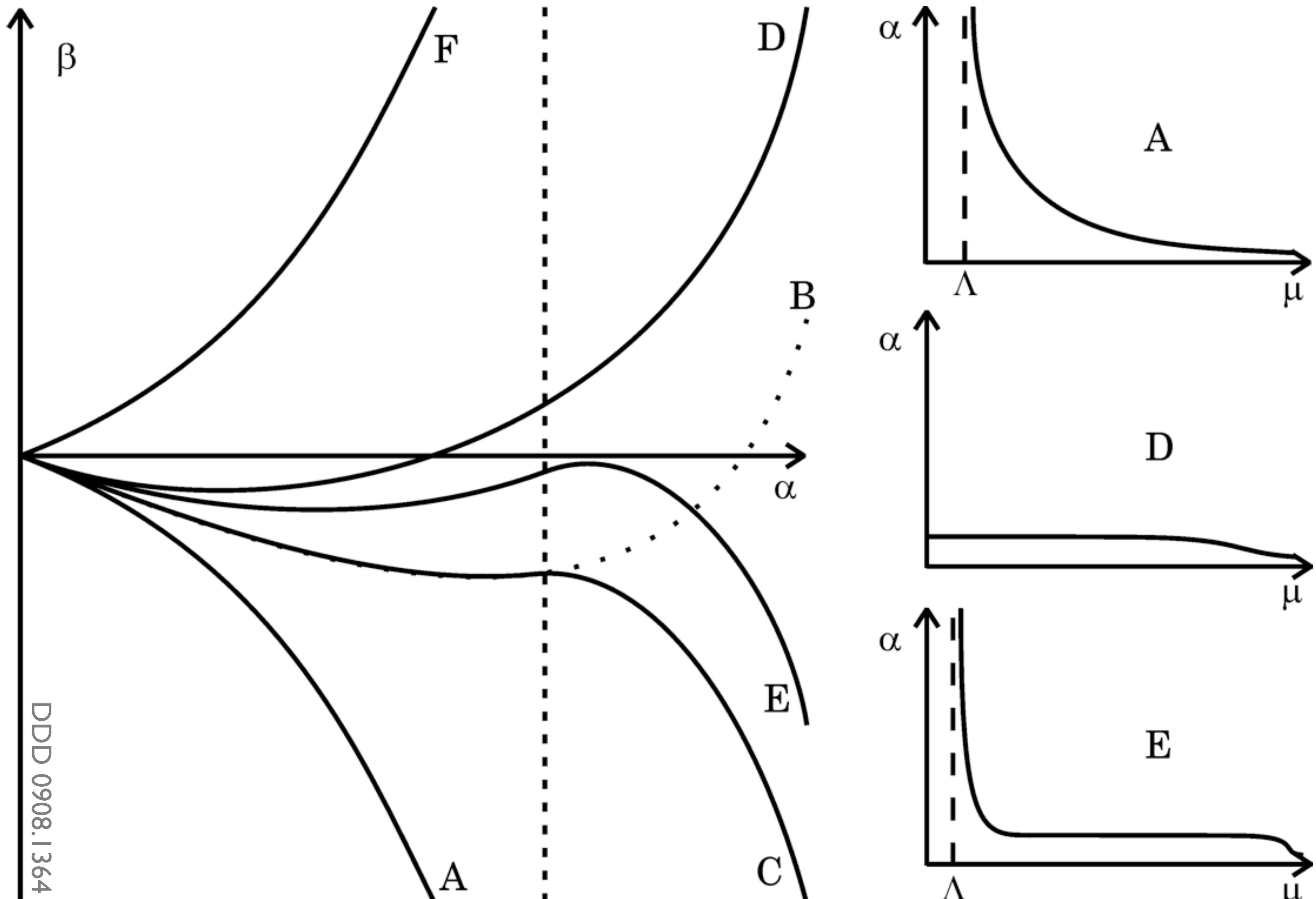
$$\underbrace{f_\pi}_{O(10^2\,\mathrm{MeV})} \mapsto \underbrace{\Lambda_{\mathrm{ew}}}_{O(10^2\,\mathrm{GeV})}$$

$$\pi^\pm \mapsto W_L^\pm$$

$$\pi^0 \mapsto Z_L^0$$

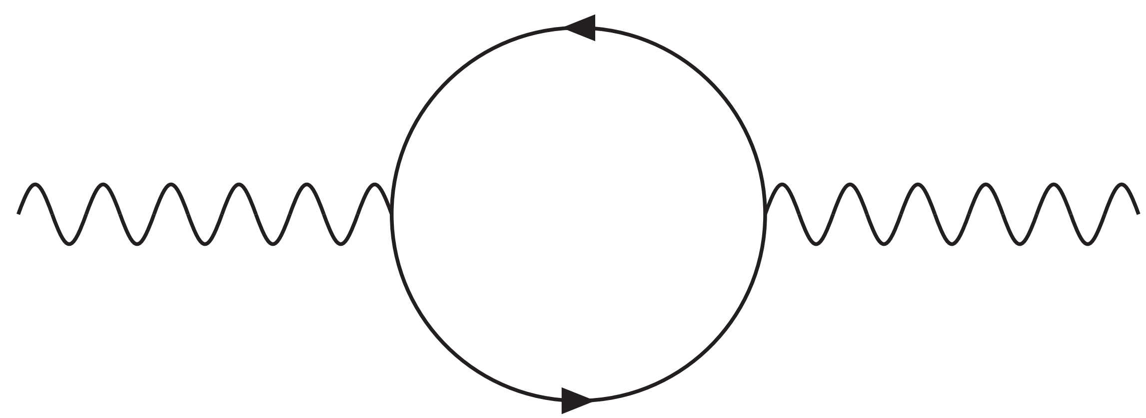
Phases: Walking

Holdom PRD24(1981)
PLB150(1985)
...



DDD 0908.1364

S parameter



$$S \overset{\text{walking}}{<} S_{\text{naive}} = \frac{d(R)N_f}{12\pi}$$

Peskin & Takeuchi PRL65(1990)

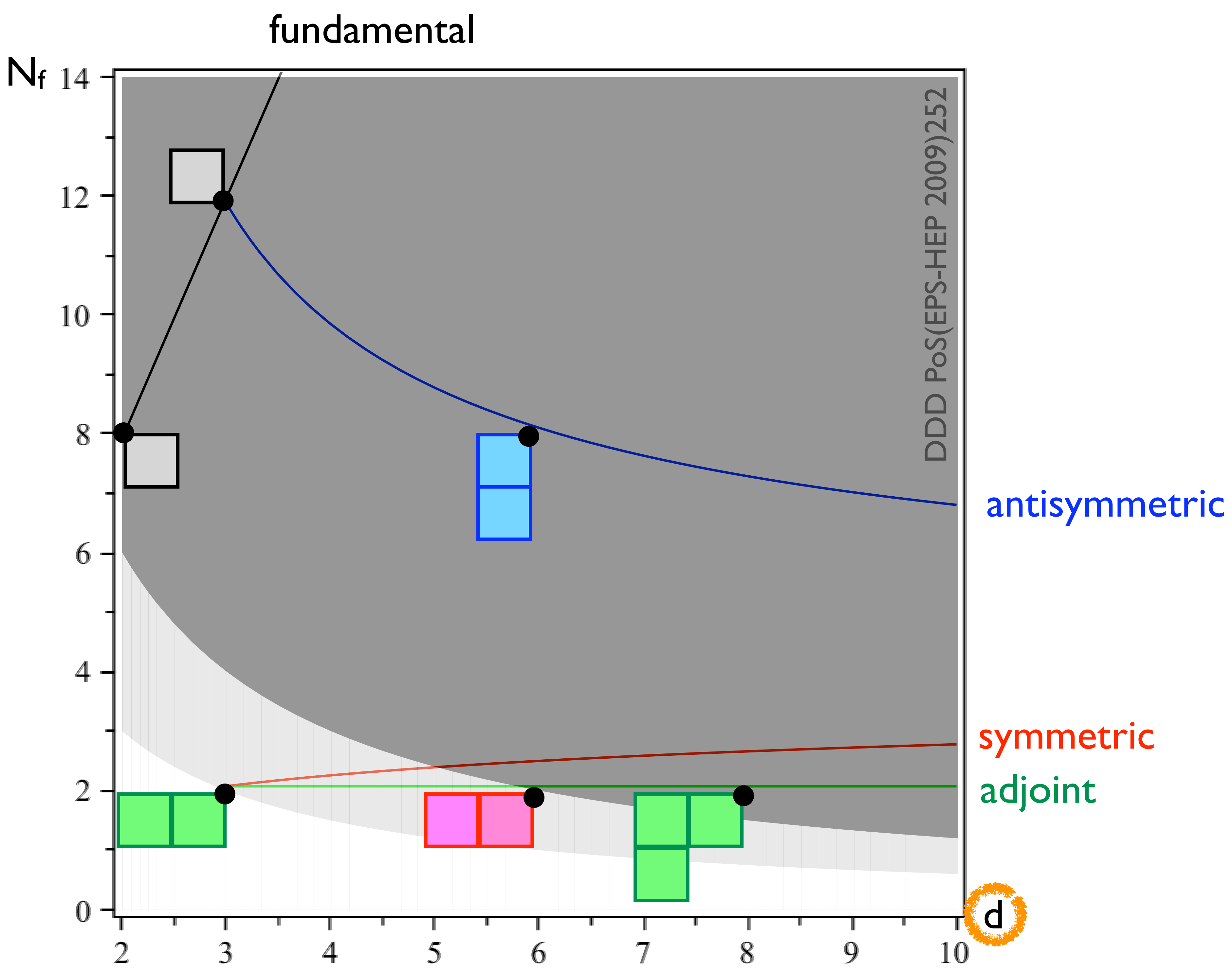
if Extended technicolour

$$\# \frac{Q\bar{Q}Q'\bar{Q}'}{\Lambda^2_{\rm ETC}} \qquad \underbrace{\# \frac{Q\bar{Q}q\bar{q}}{\Lambda^2_{\rm ETC}}}_{\sim \frac{\Lambda^3_{\rm TC}}{\Lambda^2_{\rm ETC}}} \qquad \# \frac{q\bar{q}q'\bar{q}'}{\Lambda^2_{\rm ETC}}$$

FCNCs

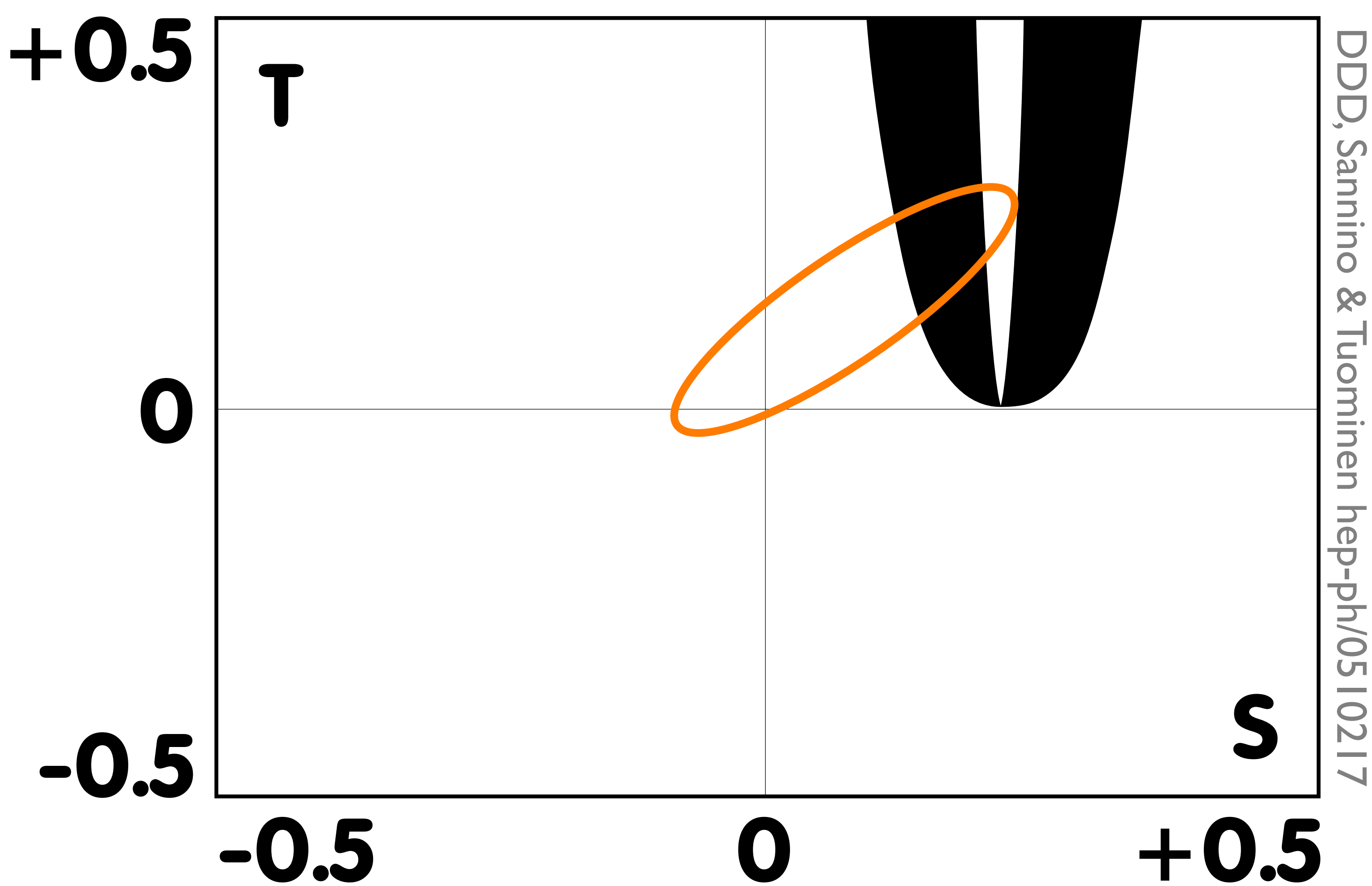
$$\begin{aligned} \langle \bar{Q}Q \rangle_{\rm ETC} &= \exp\left[\int_{\Lambda_{\rm TC}}^{\Lambda_{\rm ETC}} \frac{d\mu}{\mu}\gamma(\mu)\right] \langle \bar{Q}Q \rangle_{\rm TC} = \\ &= \exp\left[\int_{g_{\rm TC}}^{g_{\rm ETC}} dg \frac{\gamma(g)}{\beta(g)}\right] \langle \bar{Q}Q \rangle_{\rm TC} \end{aligned}$$

Phasediagram

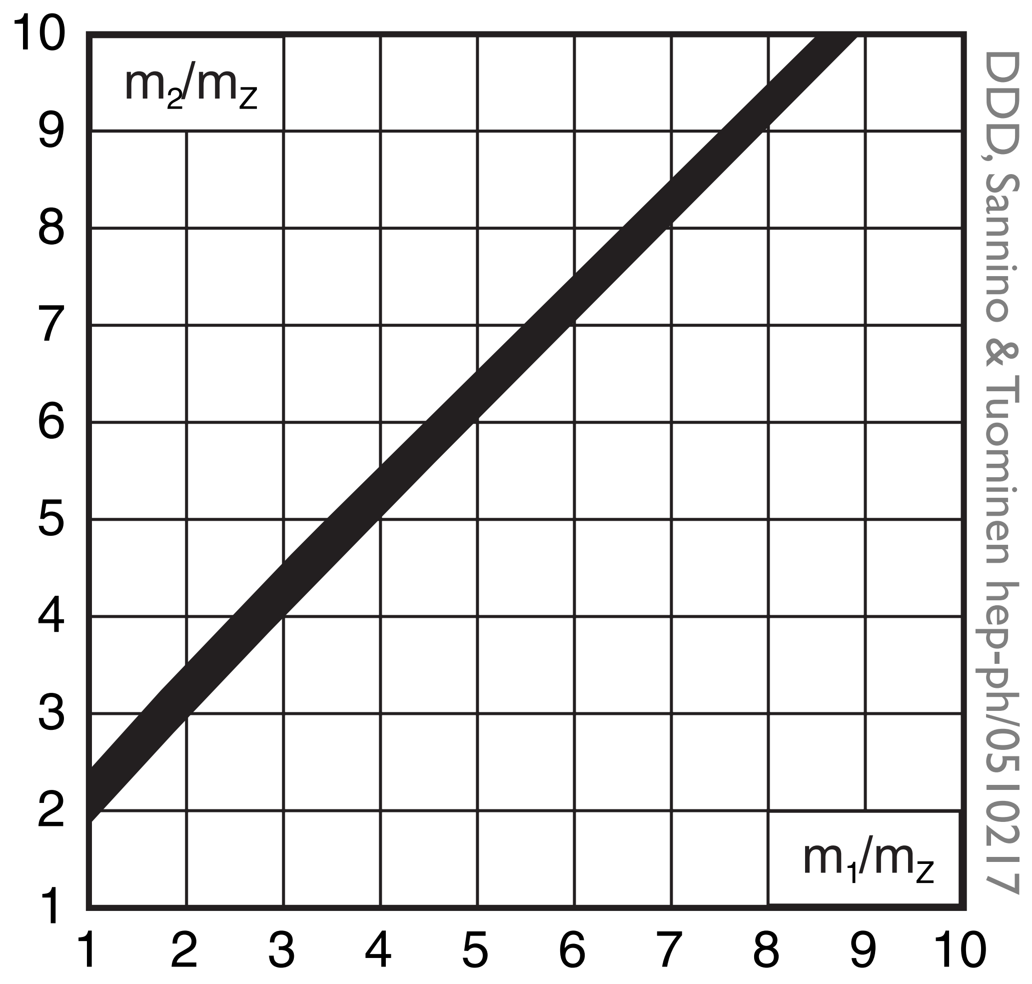


Minimal walking technicolour

SM-like hypercharge assignment



data from: ALEPH, DELPHI, L3, OPAL, SLD Collaborations and LEP Electroweak Working Group and SLD Electroweak Group and SLD Heavy Flavour Group, Phys.Rept.427:257,2006



Minimal walking technicolour

Nambu-Goldstone modes

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$ NMWT

$$\{U\bar{D}, D\bar{U}, (U\bar{U} - D\bar{D})/\sqrt{2}\} \mapsto \{\pi^+, \pi^-, \pi^0\} \mapsto \{W_L^+, W_L^-, Z_L^0\}$$

$$SU(4) \to SO(4)$$ MWT

additionally

UU, DD, UD
$\bar{U}\bar{U}, \bar{D}\bar{D}, \bar{U}\bar{D}$ & $UG, DG, \bar{U}G, \bar{D}G$ → Dark matter

$$m_\pi^2 = O(m_Z^2)$$

DDD & M. Järvinen 0901.3528

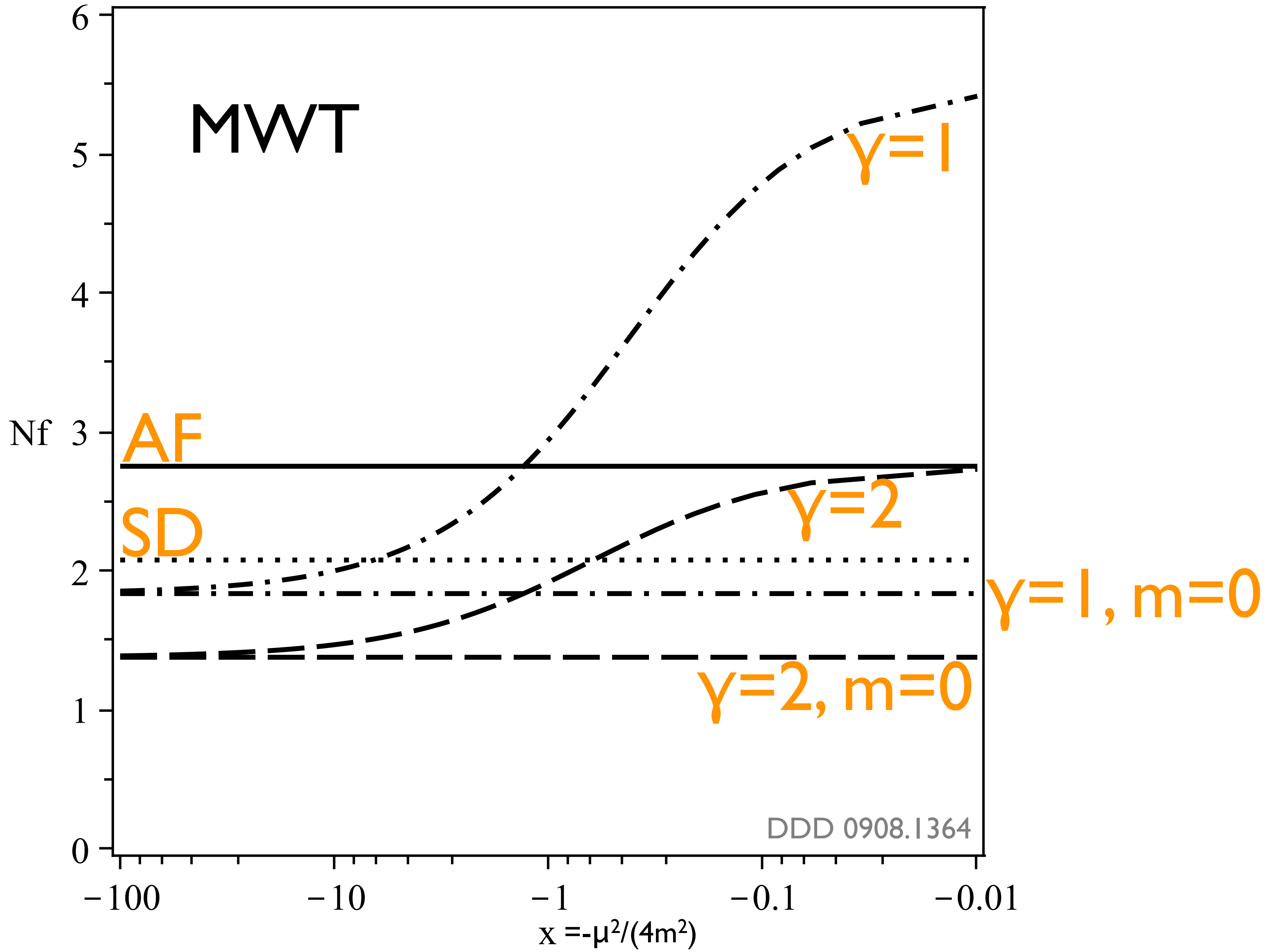
Real-life technicolour

- Coupling to electroweak gauge group
- Standard model fermion masses
- Vacuum alignment
- Technipion masses
- Mass of dark matter candidates

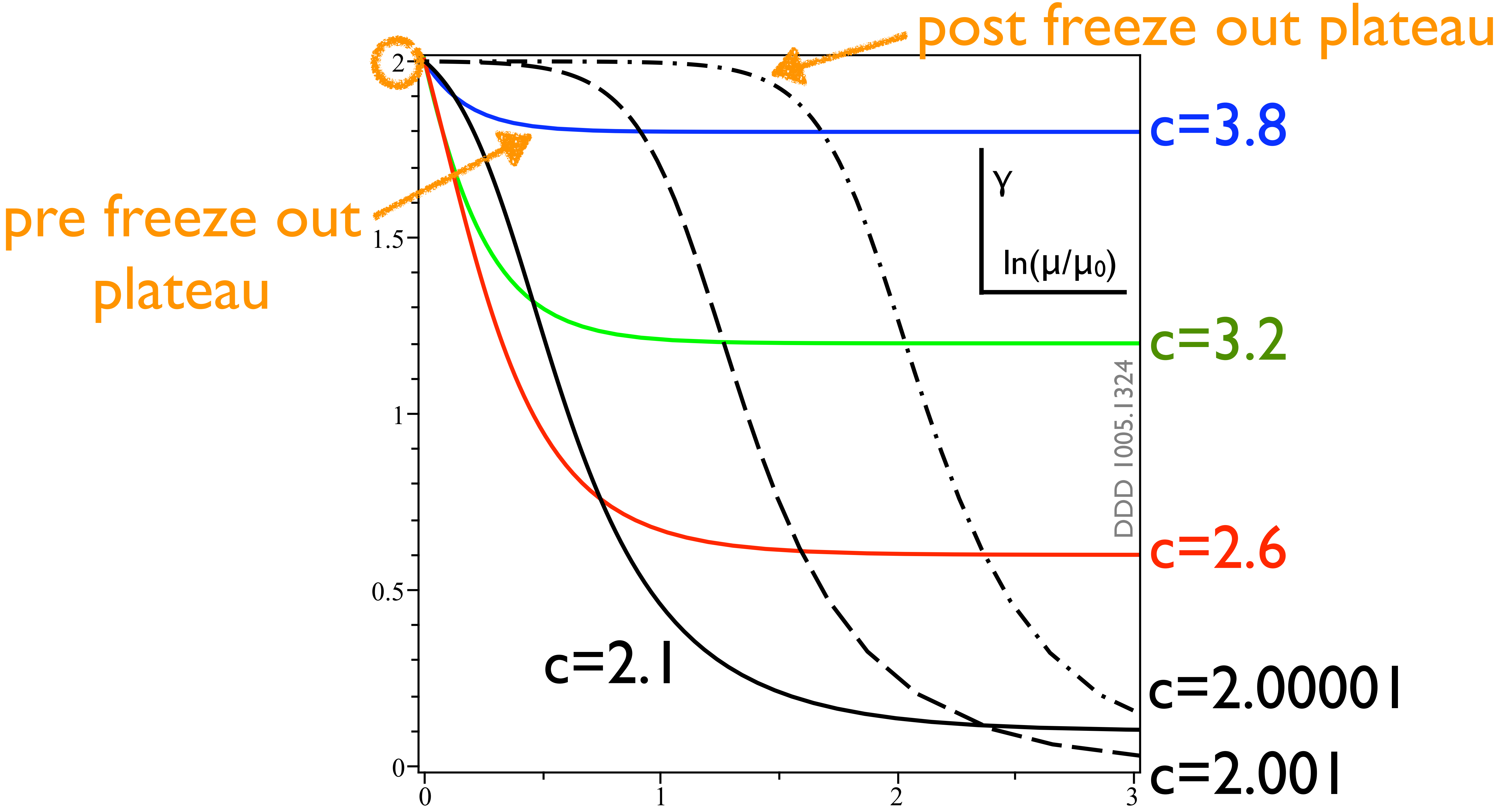
Take into account:

- Techniquark masses — DDD 0908.1364 & 1005.1324
- Four-fermion interactions — Fukano & Sannino 1005.3340

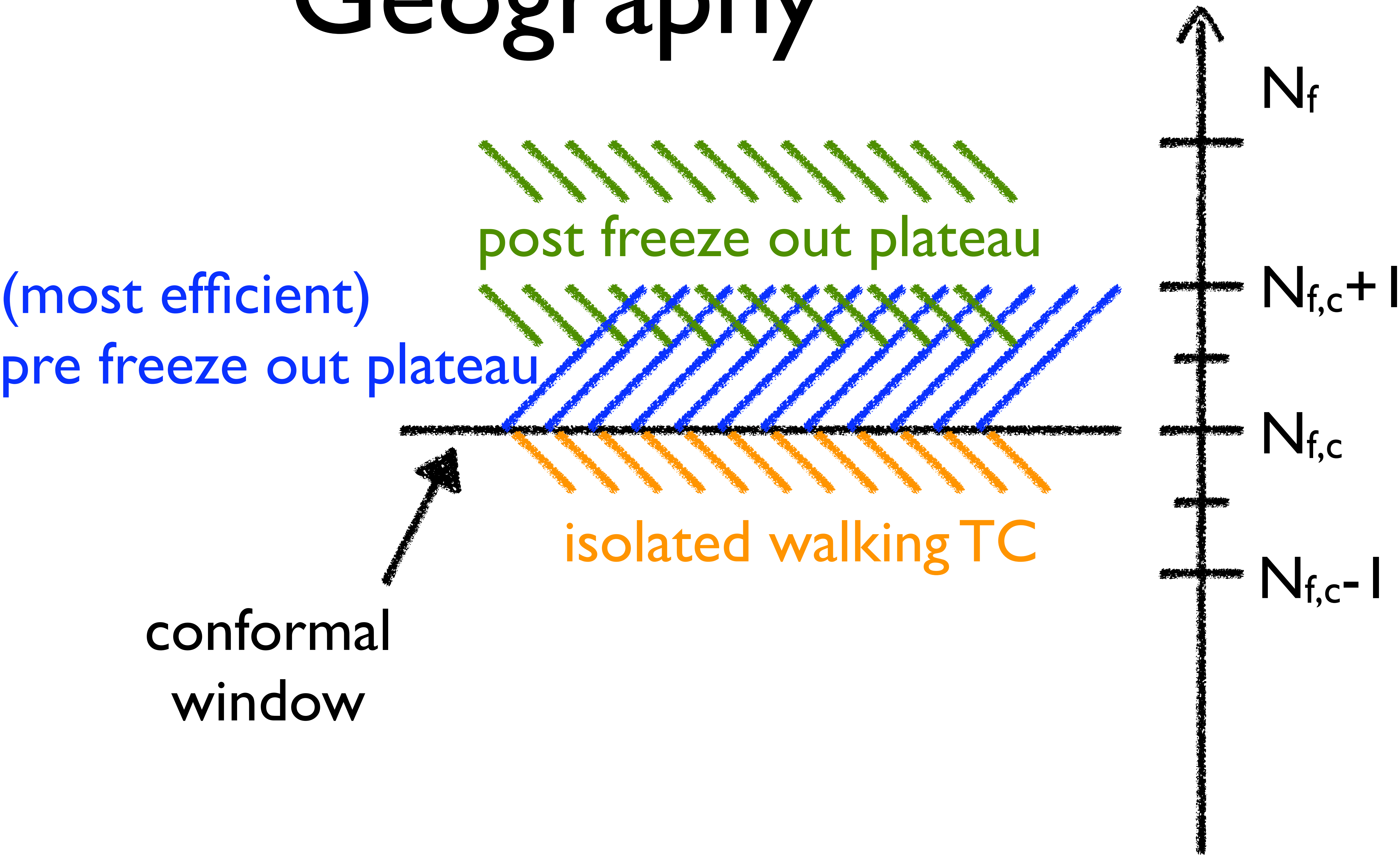
Quasiconformal window



Different types of walking



Geography



N$_f$
post freeze out plateau
(most efficient)
pre freeze out plateau
N$_{f,c}$+1
N$_{f,c}$
isolated walking TC
N$_{f,c}$-1
conformal
window

Conclusion

- quasiconformal dynamics (walking) ✓
- oblique parameters $\Rightarrow$ small matter content ✓
- high masses for Nambu-Goldstone modes ✓
- stability of the vacuum alignment ✓

$$\Rightarrow$$

Dynamical electroweak symmetry breaking by quasiconformal technicolor models is feasible.

Outlook

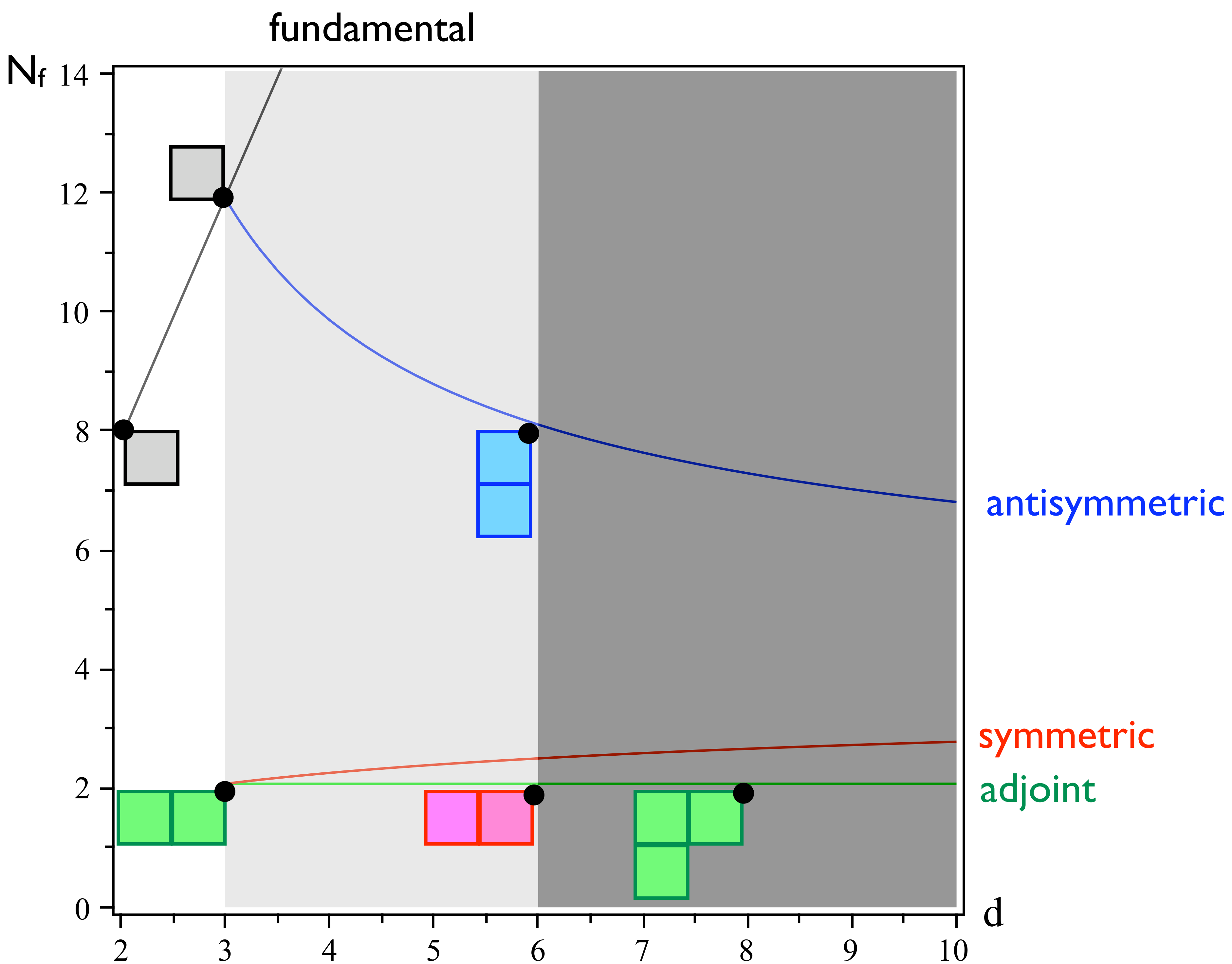
- Collider phenomenology
  Matti Järvinen
  Walking technicolour at colliders

- Mass generation mechanism
  Stefano Di Chiara
  Minimal super conformal technicolour

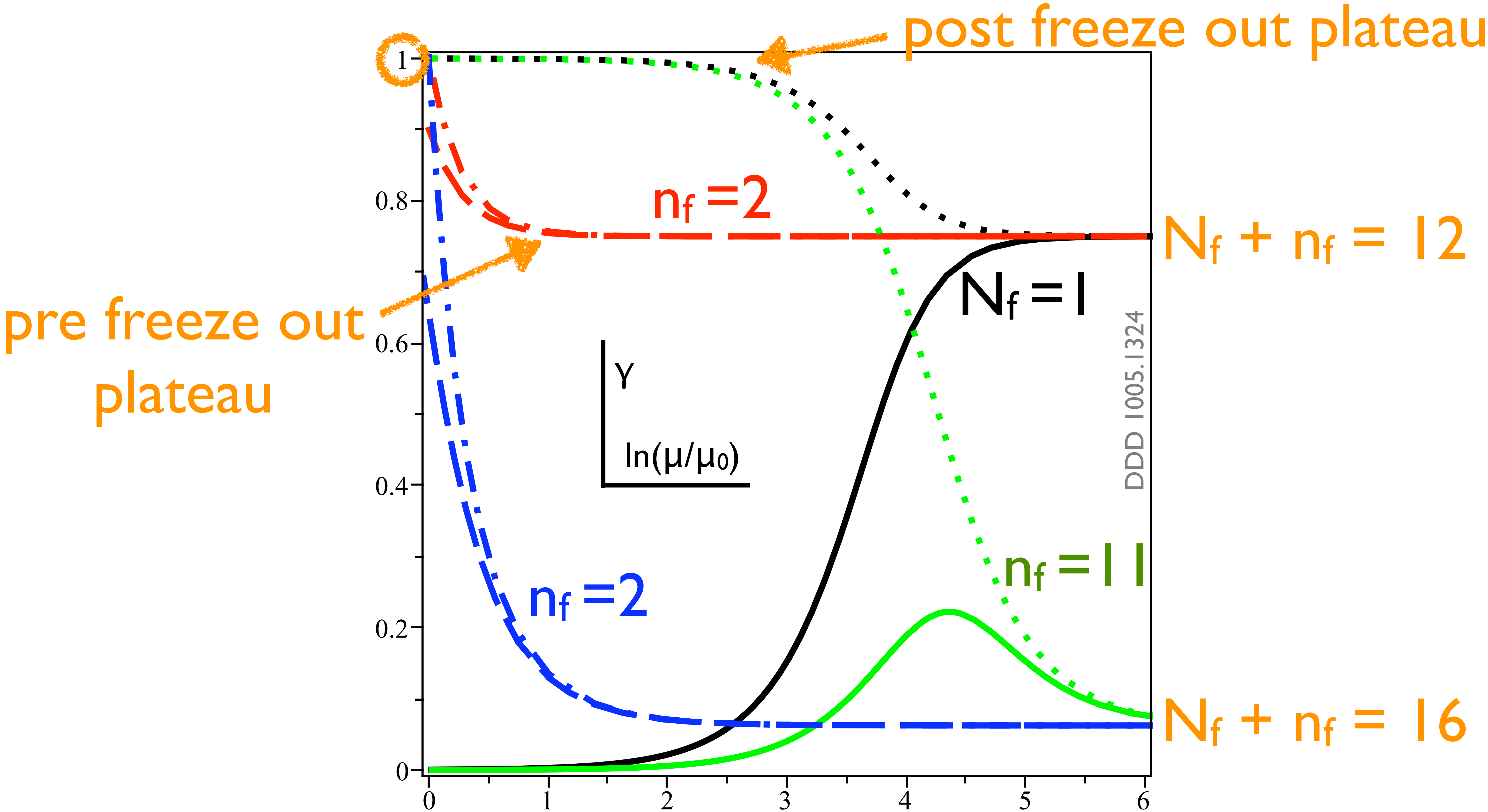
Thank you for your attention!

Partially gauged technicolour

DDD, Sannino & Tuominen hep-ph/0505059



Different types of walking



SU(3) fundamental

Light composite Higgs

The composite Higgs can be much lighter, i.e., O(100GeV), than expected from scaling up QCD.

DDD, Sannino & Tuominen hep-ph/0505059
DDD & Sannino hep-ph/0611341
Doff, Natale & Rodrigues da Silva 0802.1898
Doff & Natale 0902.2379,
0905.2981,
0912.1003

Minimal Walking Technicolour

$$Q = \begin{pmatrix} U_L \\ D_L \\ -i\sigma^2 U_R^* \\ -i\sigma^2 D_R^* \end{pmatrix}$$

$$\langle Q_i^\alpha Q_j^\beta \epsilon_{\alpha\beta} E^{ij} \rangle = -2\langle \bar{U}_R U_L + \bar{D}_R D_L \rangle$$

$$M_{ij} \sim Q_i^\alpha Q_j^\beta \varepsilon_{\alpha\beta} \qquad \text{with } i, j = 1, \ldots, 4.$$

$$\langle M \rangle = \frac{v}{2} E$$

$$M \to u M u^T, \qquad \text{with } u \in \text{SU}(4)$$

$$u E u^T = E, \text{ for } u \in \text{SO}(4)$$

$$S^a E + E S^{aT} = 0,$$

$$M = \left[\frac{\sigma + i\Theta}{2} + \sqrt{2}(i\Pi^a + \tilde{\Pi}^a) X^a \right] E,$$

$$L^a \equiv \frac{S^a + X^a}{\sqrt{2}} = \begin{pmatrix} \frac{\tau^a}{2} & 0 \\ 0 & 0 \end{pmatrix},$$

$$-R^{aT} \equiv \frac{S^a - X^a}{\sqrt{2}} = \begin{pmatrix} 0 & 0 \\ 0 & -\frac{\tau^{aT}}{2} \end{pmatrix},$$

$$Y = -R^{3^T} + \sqrt{2} Y_V S^4,$$

Foadi, Frandsen, Ryttov & Sannino 0706.1696

Minimal Walking Technicolour

$$\mathcal{V}(M) = -\frac{m^2}{2}\,\mathrm{Tr}[MM^\dagger] + \frac{\lambda}{4}\,\mathrm{Tr}[MM^\dagger]^2 + \lambda'\,\mathrm{Tr}[MM^\dagger MM^\dagger] - 2\lambda''[\det(M) + \det(M^\dagger)],$$

$$\mathcal{L}_{\mathrm{ETC}} = \frac{m_{\mathrm{ETC}}^2}{4}\,\mathrm{Tr}[MBM^\dagger B + MM^\dagger]$$

Foadi, Frandsen, Ryttov & Sannino 0706.1696

Unnatural origin of fermion masses for technicolor

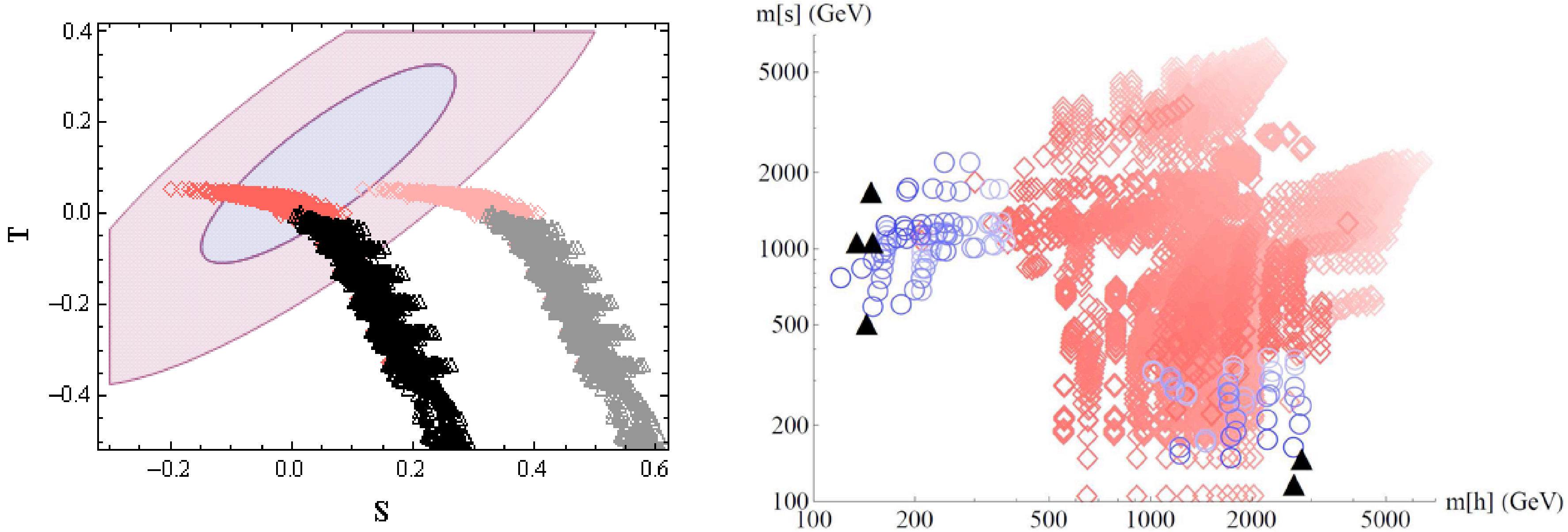


Figure 4. Left: The results of the model and the 90% confidence limit contour allowed by all electroweak data for $m_{\rm ref} = 115\,\mathrm{GeV}$. The light red diamonds are excluded by direct observatons while the black triangles are not. Right: Black triangles show the points consistent with the 90% S-T confidence limit, blue circles correspond to triangles in the left panel that are within the larger ellipse and the red diamonds to triangles even farther out. Lighter points are also farther out.

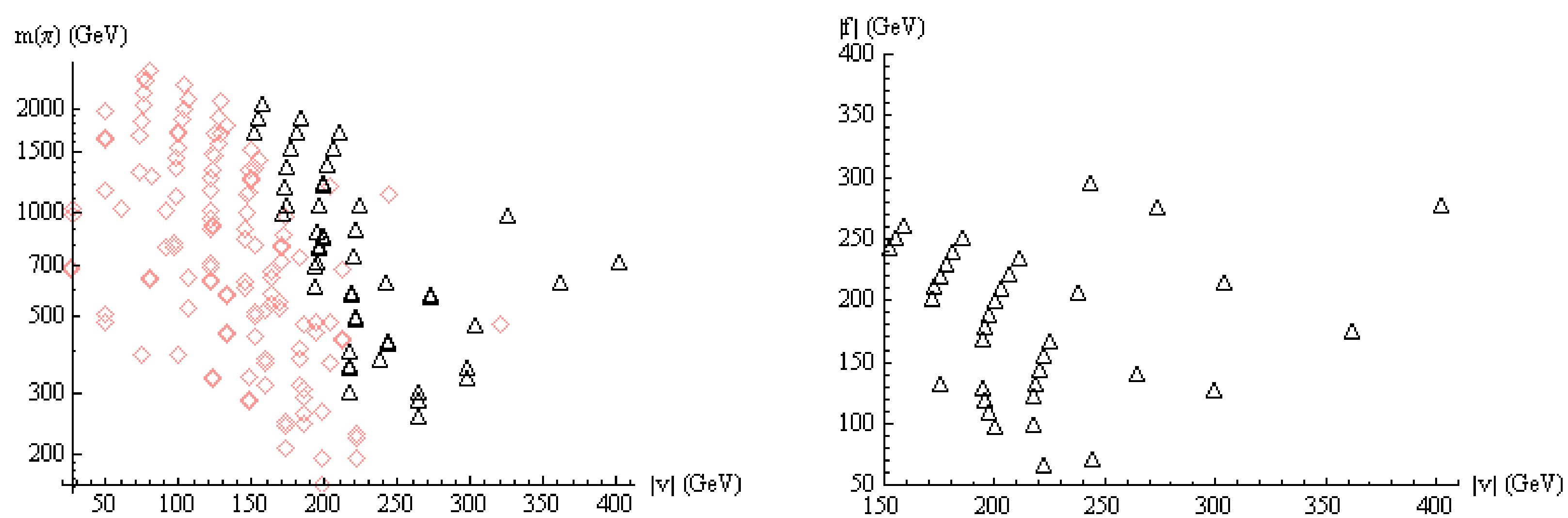


Figure 5. Left: The FCNC constraints on parameters m_π and v on points satisfying direct search and S-T 90% confidence limit. Light red diamonds are unallowed, while black triangles are allowed. Right: The allowed values of the condensates f and v after taking all constraints into account.

Antola, Heikinheimo, Sannino & Tuominen 0910.3681