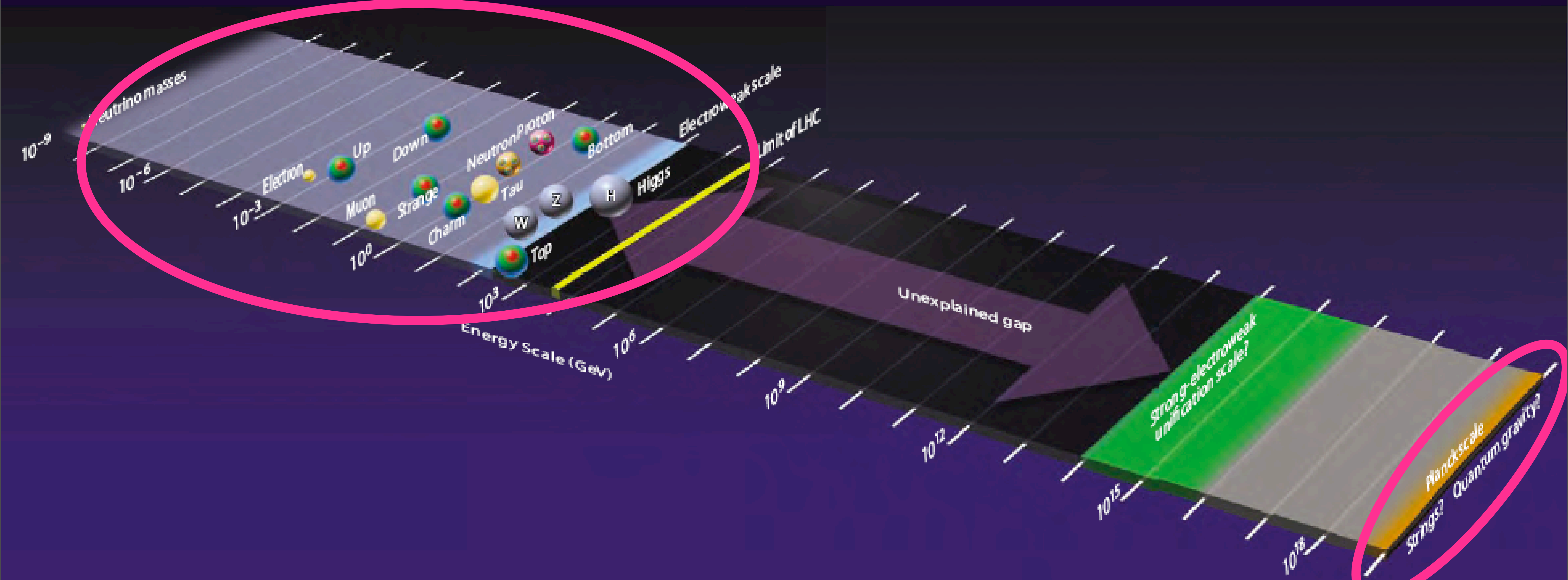
Dynamical Stabilization of the Fermi Scale

Francesco Sannino

LNF 2008


Neutrino masses
10^{-9}
10^{-6}
10^{-3}
10^{0}
10^{3}
10^{6}
10^{9}
10^{12}
10^{15}
10^{18}
Electron
Up
Down
Muon
Strange
Charm
Tau
Neutron/Proton
Bottom
W
Z
H
Higgs
Top
Electroweak scale
Limit of LHC
Energy Scale (GeV)
Unexplained gap
Strong-electroweak unification scale?
Planck scale
Strings?
Quantum gravity?

Part A

Introducing Technicolor

Precision Data

Flavor versus Heavy Quark Masses

Walking Dynamics

Natural Dark Matter candidates

Part B

Phase Diagrams of 4-Dimensional Gauge Theories

All orders (non)supersymmetric beta function

Ladder approximation

Lattice results

From Walking to Unparticle Physics

Part C

Minimal Walking Technicolor (MWT)

The MWT Lagrangian

“A Primer: LHC Phenomenology”

Playing with Unification

Part A

Dynamical EW Breaking

$$L(H) \to -\frac{1}{4} F^{a\mu\nu} F^{a}_{\mu\nu} + i\,\bar{Q}\gamma^{\mu} D_{\mu} Q + \cdots$$

Dots are partially fixed by Anomalies as well as other principles

$$\ldots \quad \to \quad L(\text{New SM Fermions})$$

Technicolor

New Strong Interactions at ~ 250 GeV
[Weinberg, Susskind]

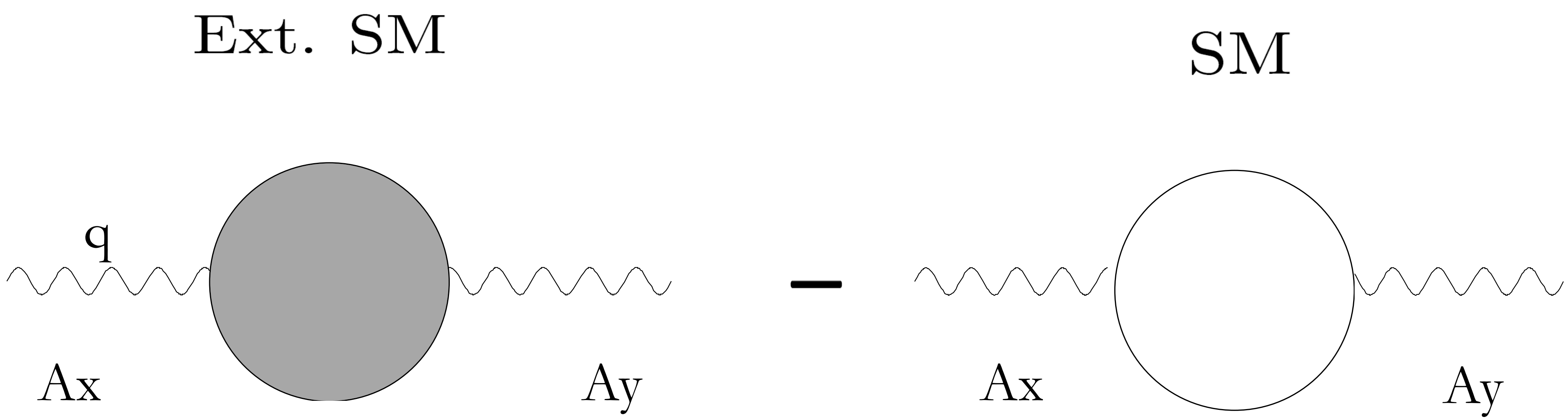
Natural to use QCD-like dynamics.

$$SU(N)_{TC} \times SU(3)_C \times SU_L(2) \times U_Y(1)$$

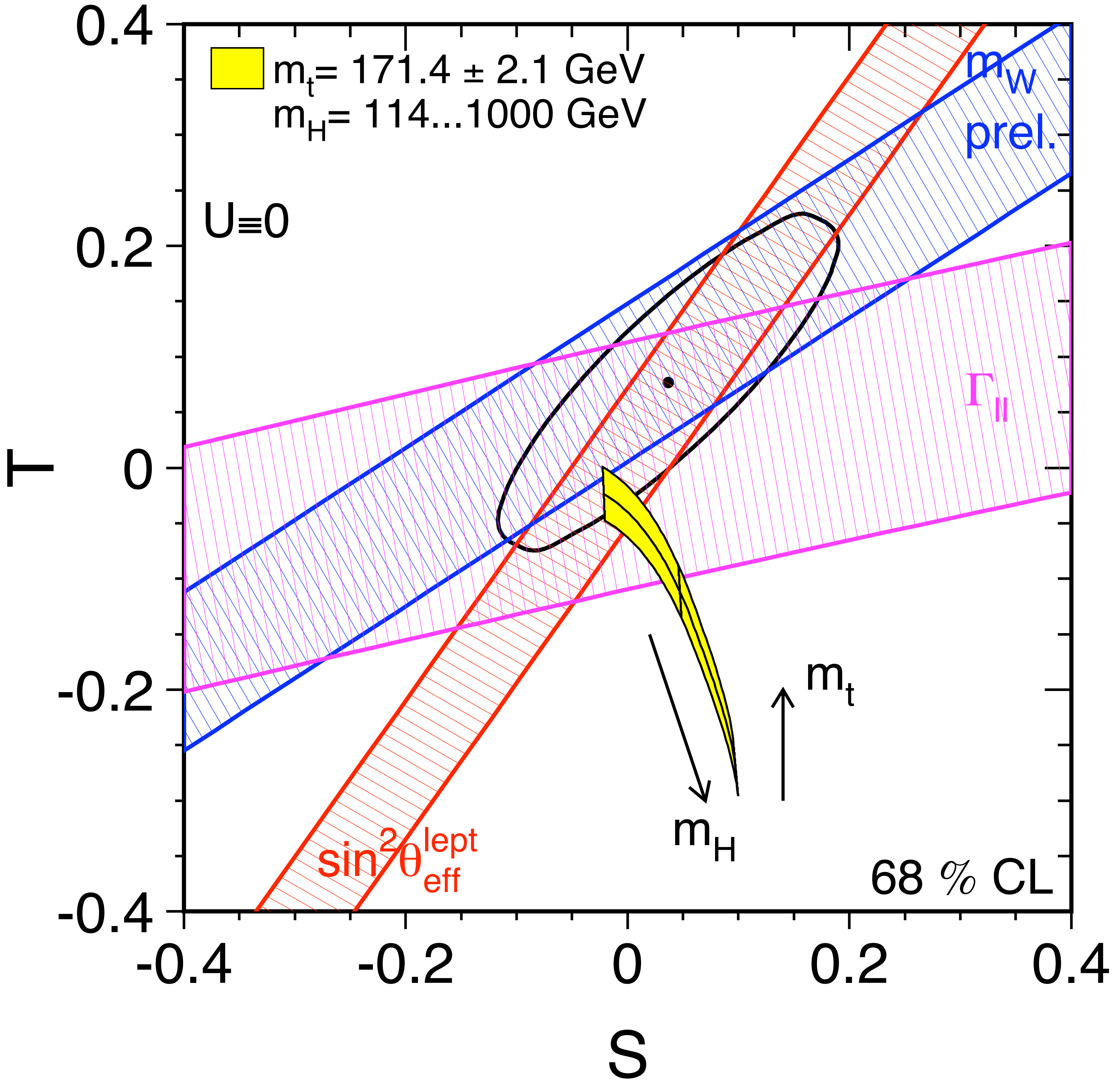
$$\langle Q^f \widetilde{Q}_{f'} \rangle = \Lambda_{TC}^3 \qquad\qquad \Lambda_{TC} \simeq 250 \; GeV$$

Electroweak Precision Measurements

Kennedy-Lynn, Peskin-Takeuchi, Altarelli-Barbieri, Bertolini- Sirlin, Marciano-Rosner



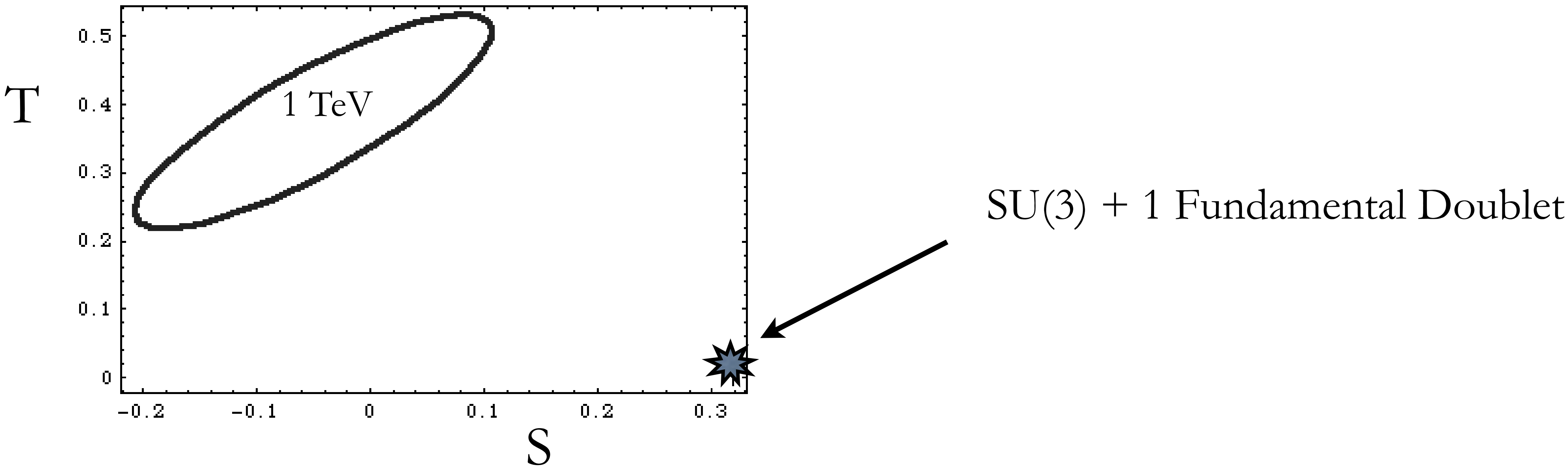
$$\Pi^{\mu\nu}_{XY}(q^2) = \Pi_{XY}(q^2) g^{\mu\nu} + \cdots$$



LEP EWG Summer 2006

Large & Positive S from QCD-like TC

Peskin and Takeuchi, 90



Masses to SM Fermions

The need to Extend Technicolor

$$\bar{L} \cdot H e_R \qquad \rightarrow \qquad \bar{L} \frac{\bar{Q} Q}{\Lambda_{ETC}^2} e_R$$

Different Approaches

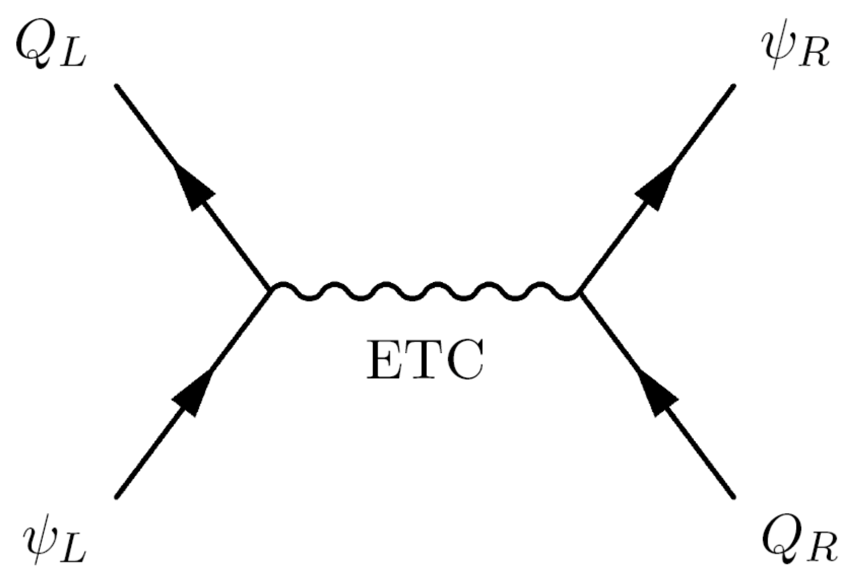
Scalar-less New Gauge Interactions (Extended TC)

Marry SUSY and Technicolor

Add New Scalars in the Flavor Sector

.....

Extended Technicolor



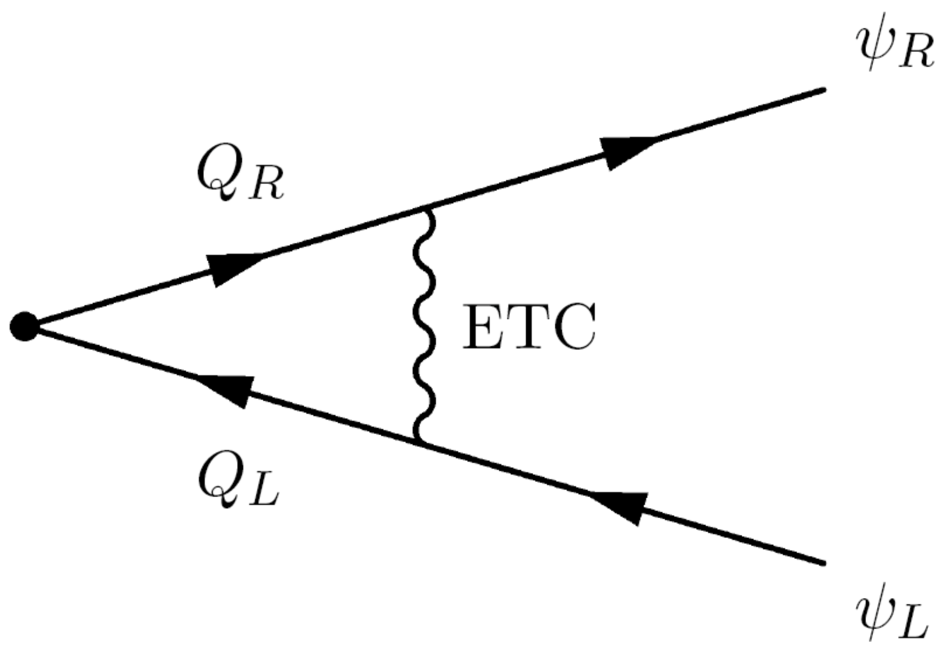
$$\alpha_{ab}\frac{\bar{Q}T^aQ\bar{Q}T^bQ}{\Lambda^2_{ETC}} + \beta_{ab}\frac{\bar{Q}_LT^aQ_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}} + \gamma_{ab}\frac{\bar{\psi}_LT^a\psi_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}} + \ldots$$

PNG Masses

SM-Fermion Masses

FCNC Operators

Beta - Terms



$$m_{\rm f} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC}$$

Gamma - Terms

$$\frac{1}{\Lambda_{ETC}^2}(\bar{s}\gamma^5 d)(\bar{s}\gamma^5 d) + \frac{1}{\Lambda_{ETC}^2}(\bar{\mu}\gamma^5 e)(\bar{e}\gamma^5 e) + \dots$$

$$\downarrow$$

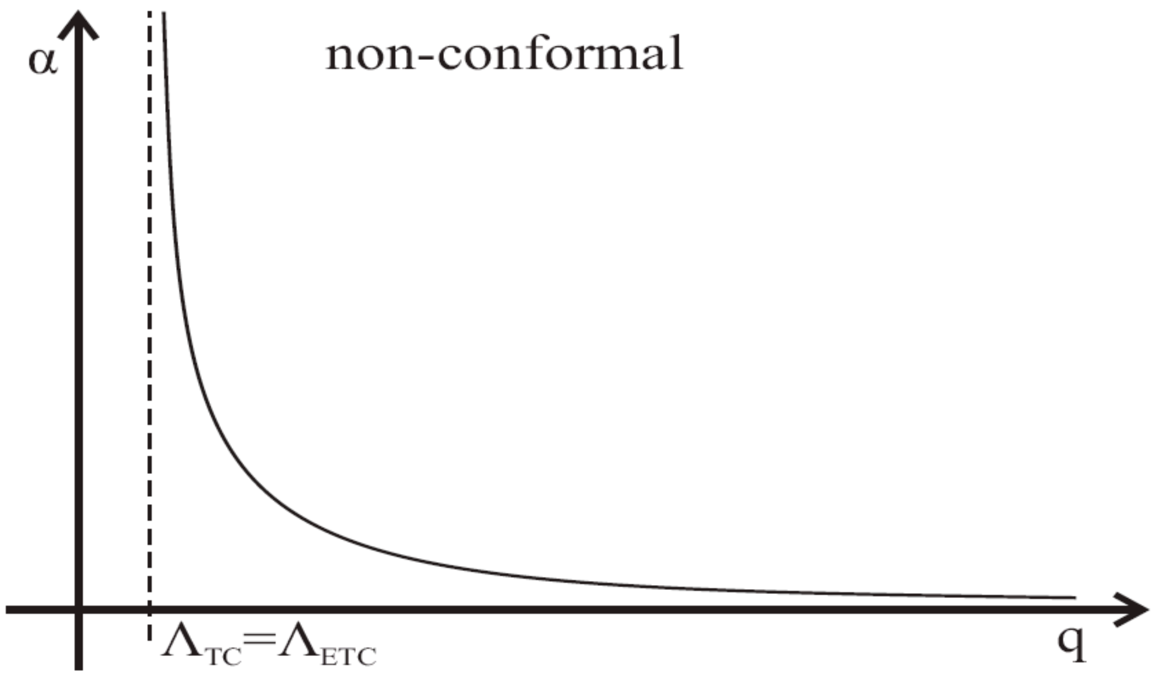
$$\Lambda_{ETC} \geq 10^3 \Lambda_{TC}$$

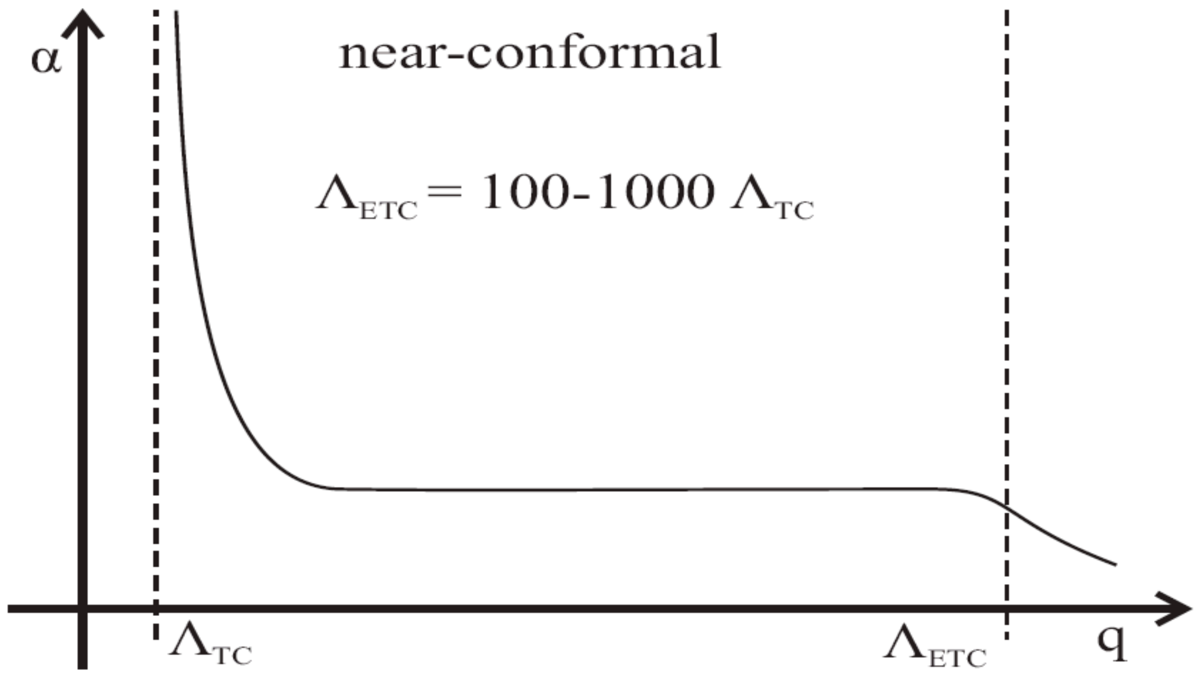
Too small Top mass if

$$< \bar{Q}Q >_{ETC} \approx < \bar{Q}Q >_{TC} \sim \Lambda_{TC}^3$$

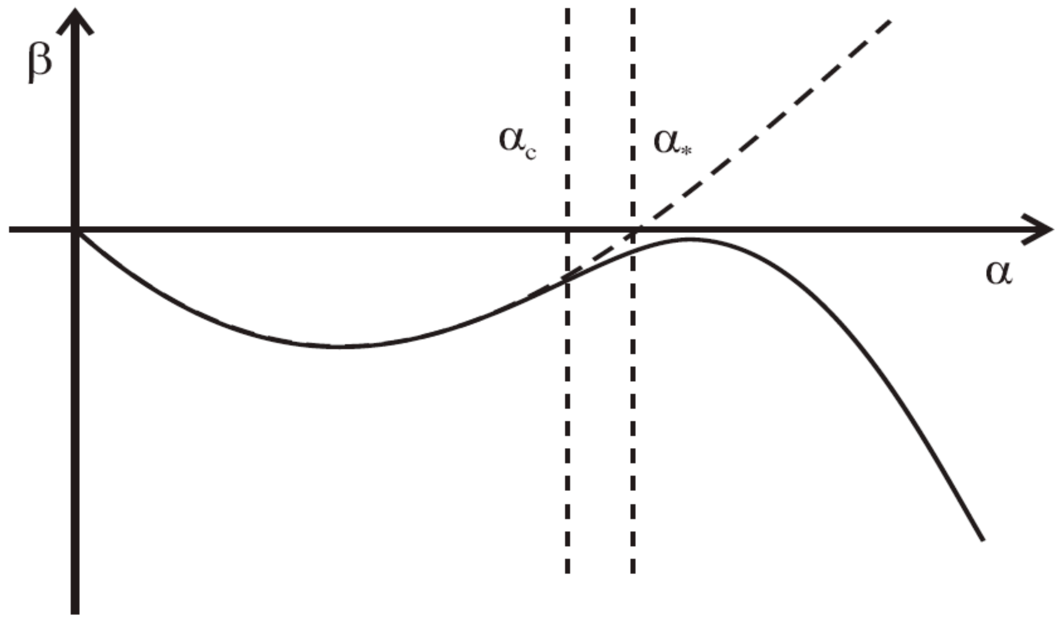
Walking versus Running

Near Conformal Properties





Holdom
Eichten and Lane



Why the walking can help ?

$$\left\langle \bar{Q}Q_{ETC} \right\rangle = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\ \gamma_m(\alpha(\mu))\right) \left\langle \bar{Q}Q_{TC} \right\rangle$$

<u>QCD-Like</u>

$$\exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\ \gamma_m(\alpha(\mu))\right) \quad \sim \quad \left(\ln(\Lambda_{ETC}/\Lambda_{TC})\right)^{\gamma_m}$$

<u>Near the conformal window</u>

$$\exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\ \gamma_m(\alpha(\mu))\right) \quad \sim \quad (\Lambda_{ETC}/\Lambda_{TC})^{\gamma_m(\alpha^\star)}$$

Fermion Mass Enhancement

$$m_{\mathrm{f}} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC} = \frac{g_{ETC}^2}{\Lambda_{ETC}^2} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma_m(\alpha^*)} < \bar{Q}Q >_{TC}$$

S in Walking Technicolor

$$S_{\mathrm{pert}} = \frac{1}{6\pi}\frac{N_f}{2}d(R)$$

$$S_{WTC} < S_{TC}$$

Appelquist, F.S.

However we will take:

$$S_{WTC} \approx S_{\mathrm{pert}}$$

Besides

$$S = S_{(W)TC} + S_{NS}$$

Offset the first term

S from extra Leptons

$$\text{Fermions :} \qquad \psi_L = \begin{pmatrix} \psi_{1L} \\ \psi_{2L} \end{pmatrix}, \qquad \psi_{1R}\,, \qquad \psi_{2R}$$

$$\text{Hypercharge :} \qquad Y\,, \qquad Y + \frac{1}{2}, \qquad Y - \frac{1}{2}$$

$$S_{\text{Leptons}} = \frac{1}{6\pi}\left[1 - 2Y\ln\left(\frac{M_1}{M_2}\right)^2 + \frac{1+8Y}{20}\left(\frac{m_Z}{M_1}\right)^2 + \frac{1-8Y}{20}\left(\frac{m_Z}{M_2}\right)^2 + O\left(\frac{m_Z^4}{M_i^4}\right)\right]$$

$$M_{1,2}^2 \gg m_Z^2$$

Rule:

Find Walking Theories with EW embedding minimizing S

Identified Many EW Viable Walking and Custodial TC Models

Minimal Walking Technicolor (MWT)

Higher Dimensional Representations

F.S. - Tuominen 04
Dietrich - F.S. - Tuominen 05
Dietrich - F.S. 06

Beyond Minimal Walking Technicolor

Partially EW Gauged Technicolor

Split Technicolor

Additional Fermions in SM

Ryttov, F.S. 06

Custodial TC

Similar to BESS models of
Casalbuoni et al.

Appelquist, F.S. 98
Foadi, Frandsen, F.S. 07

Dark Matter

$$\frac{\Omega_{DM}}{\Omega_B} \sim 5$$

What if DM is due to an asymmetry?

A particle similar to the nucleon

But electrically neutral

At most EW-type cross sections

Great if connected to the Electroweak Symmetry Breaking sector of the SM

Technicolor is a natural example

Technibarion is similar to the nucleon

TB number like the B number

At most EW-type cross sections

EW scale and interactions built in

Nussinov, 86
Barr - Chivukula - Farhi 90
Gudnason - Kouvaris - F.S. 06

Naive estimates

$$\frac{m_{TB}}{m_p} \approx \frac{1 \text{ TeV}}{1 \text{ GeV}} = 10^3$$

$$\frac{TB}{B} \propto \exp\left[-\frac{m_{TB}(T^*)}{T^*}\right] \sim 10^{-3} \qquad T^* \sim 200 \text{ GeV}$$

$$\frac{\Omega_{TB}}{\Omega_B} = \frac{TB}{B}\frac{m_{TB}}{m_p} \sim \mathcal{O}(1)$$

Part B

Progress in Strong Interactions

Phase Diagram of Gauge Theories

New Limits for Strongly Interacting Theories

All order beta function for nonsupersymmetric theories

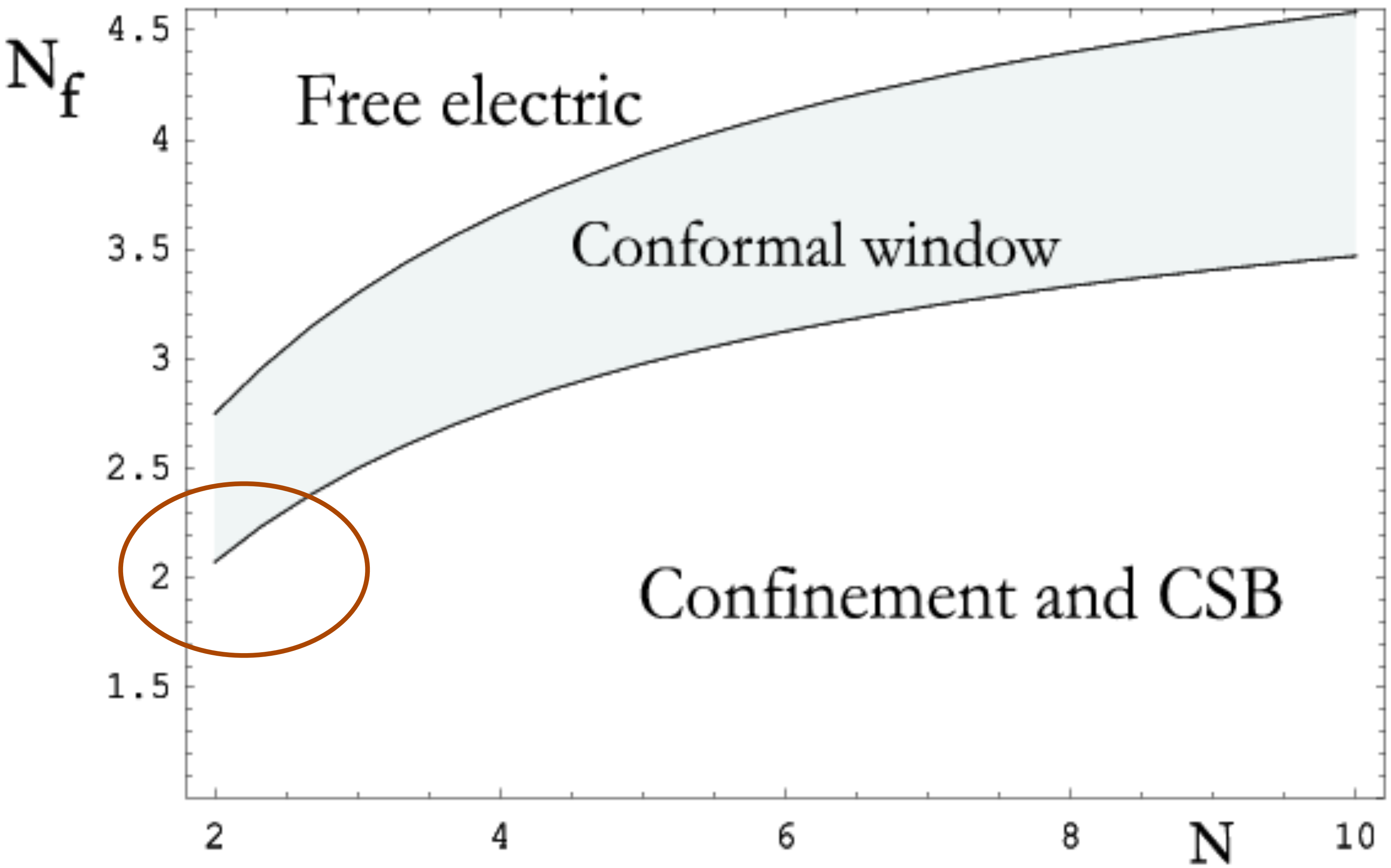
The 2 index Symmetric-Theory

	$SU(N)$	$SU_L(N_f)$	$SU_R(N_f)$	$U_V(1)$	$U_A(1)$
$Q_{\{ij\}}$	$\square\square$	$\square$	1	1	1
$\widetilde{Q}^{\{ij\}}$	$\overline{\square\square}$	1	$\overline{\square}$	-1	1
G_μ	Adj	0	0	0	0

Here Q and $\widetilde{Q}$ are Weyl fermions.

The A-type is obtained by substituting $\square\square$ with $\begin{smallmatrix}\square\\ \square\end{smallmatrix}$.

Phase Diagram for the Symmetric Theory

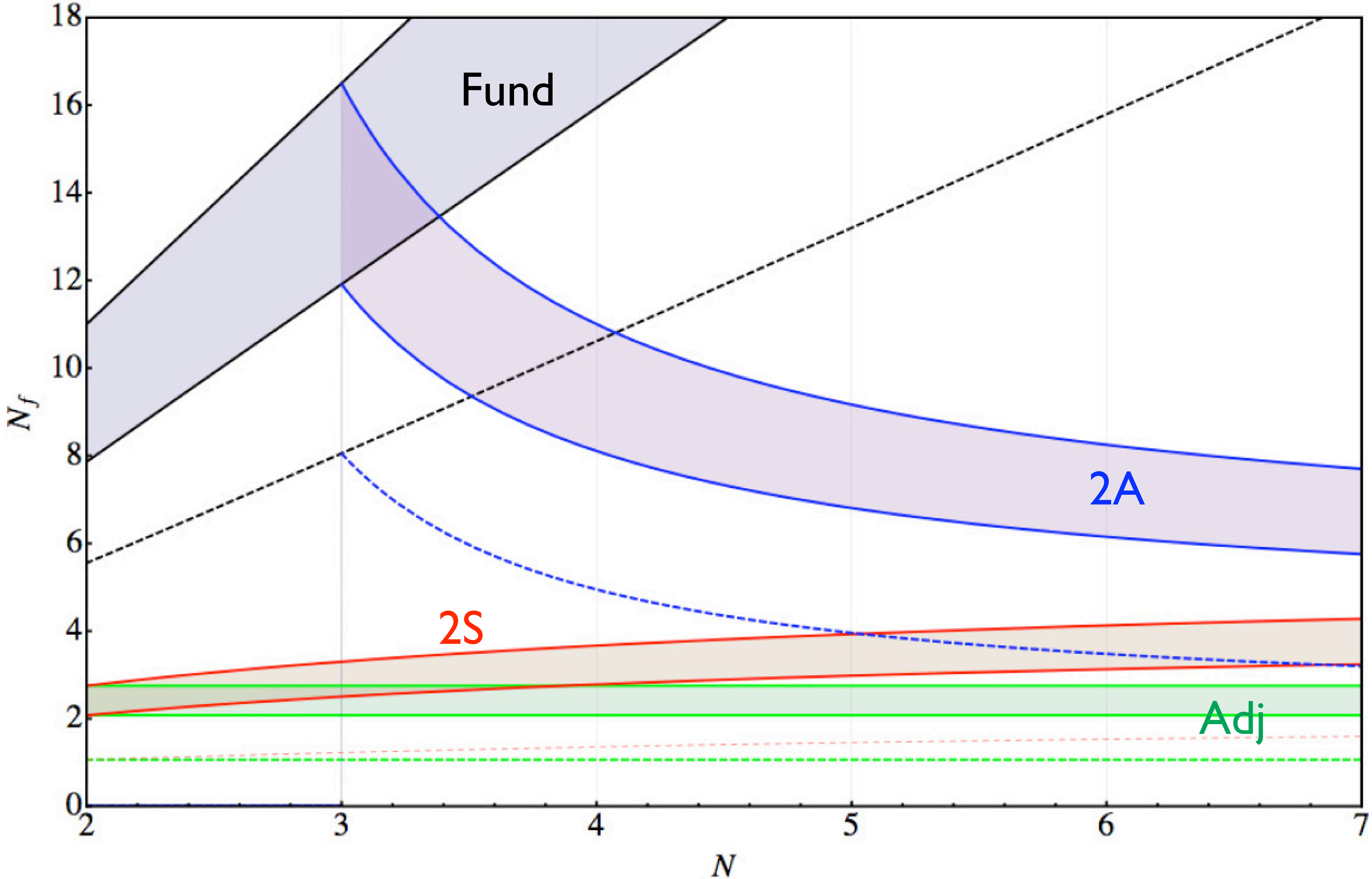


F.S. - Tuominen 04

Using Ladder Approximation

Is this the minimal walking theory?

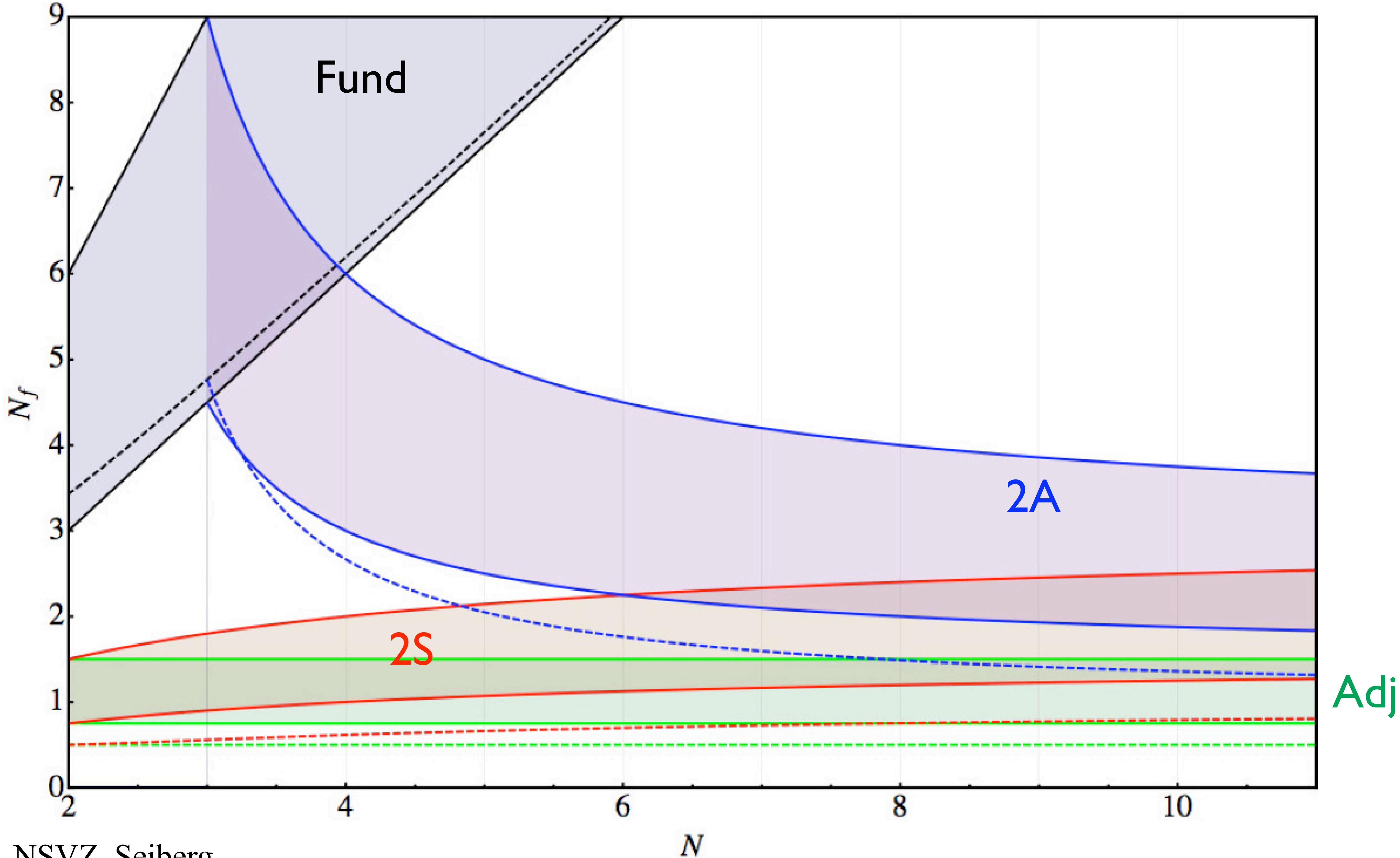
Non-SUSY Phase Diagram for HDRs



Ladder approximation

Dietrich and F.S. 06

SUSY Phase Diagram for HDRs



NSVZ, Seiberg
Intriligator-Seiberg

Ryttov and F.S. 07

All orders beta function

$$\beta(g) = -\frac{g^3}{(4\pi)^2}\frac{\beta_0 - \frac{2}{3}\,T(r)\,N_f\,\gamma(g^2)}{1-\frac{g^2}{8\pi^2}C_2(G)\left(1+\frac{2\beta_0'}{\beta_0}\right)}$$

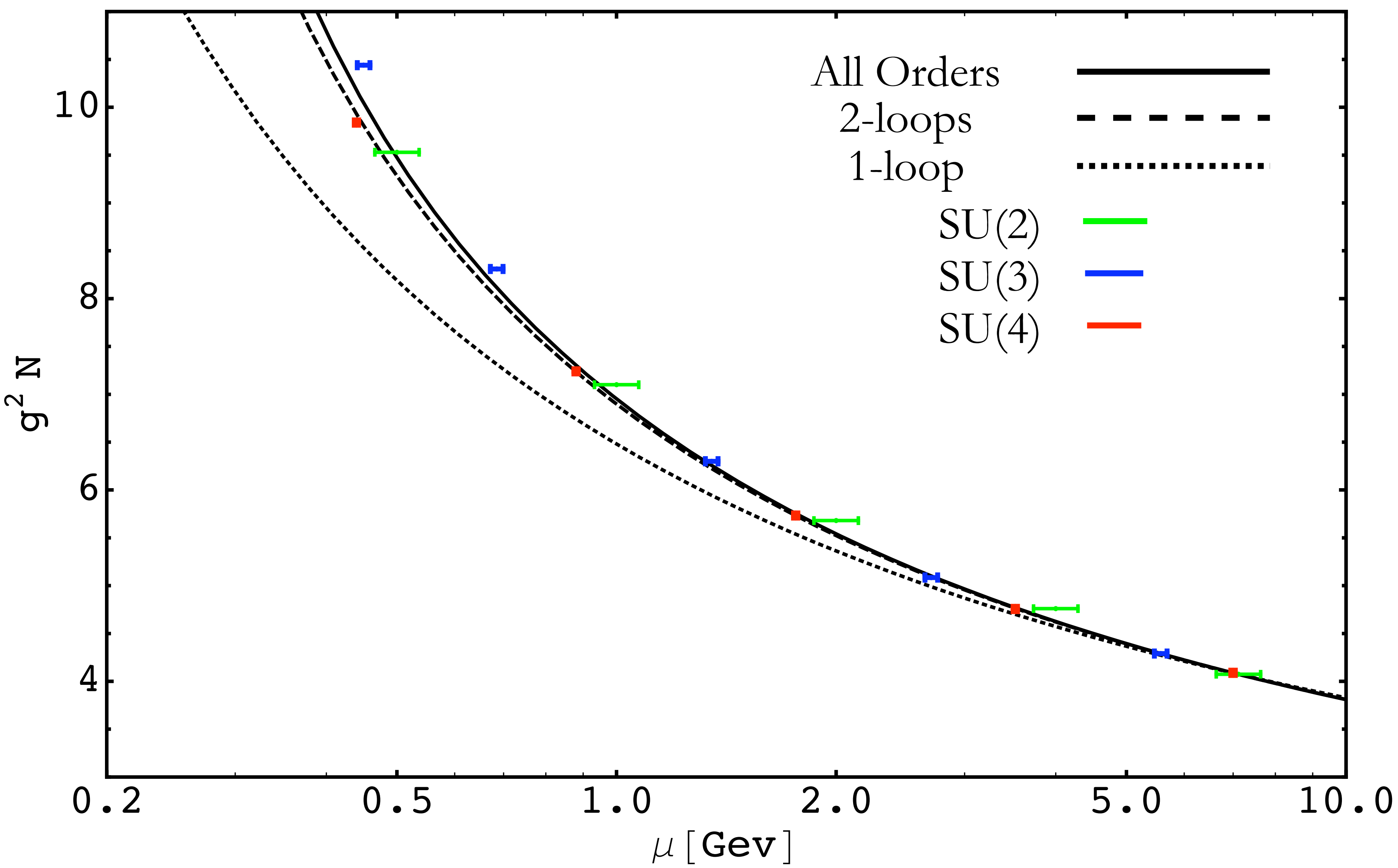
$$\gamma = -d\ln m/d\ln\mu$$

$$\beta_0 = \frac{11}{3}C_2(G) - \frac{4}{3}T(r)N_f$$

$$\beta_0' = C_2(G) - T(r)N_f$$

Ryttov and F.S. 07

Running in Yang - Mills for different N



Luscher, Sommer, Wolff, Weisz, 92	SU(2)
Luscher, Sommer, Weisz, Wolff 94	SU(3)
Lucini and Moraitis 07	SU(4)

Bounds on the Conformal Window

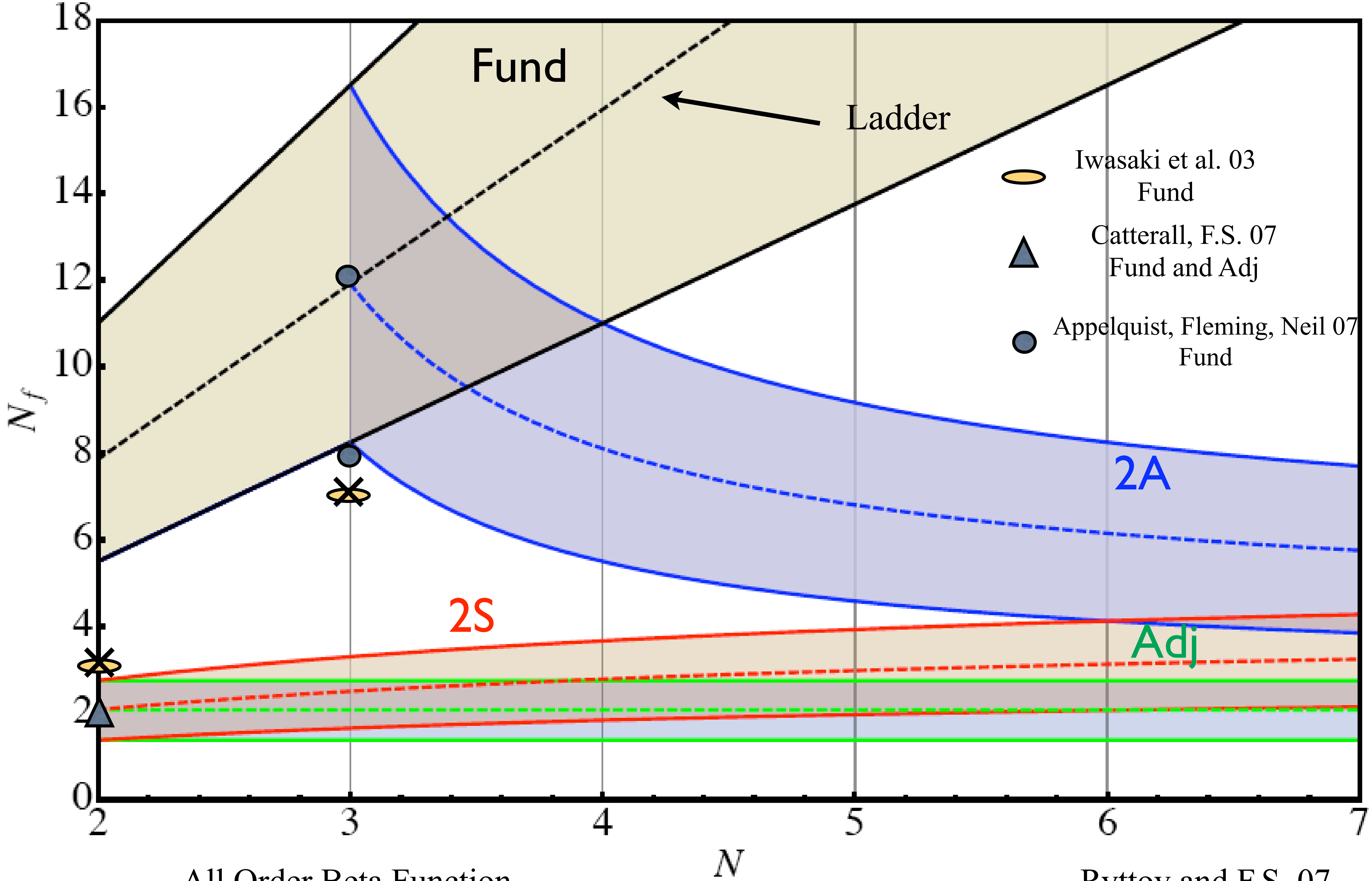
$$\beta = 0 \longrightarrow \gamma = \frac{11C_2(G) - 4T(r)N_f}{2T(r)N_f}$$

Unitarity of the Conformal Operators demands:

$$\gamma \leq 2$$

Ryttov and F.S. 07

Non-SUSY Phase Diagram Bound

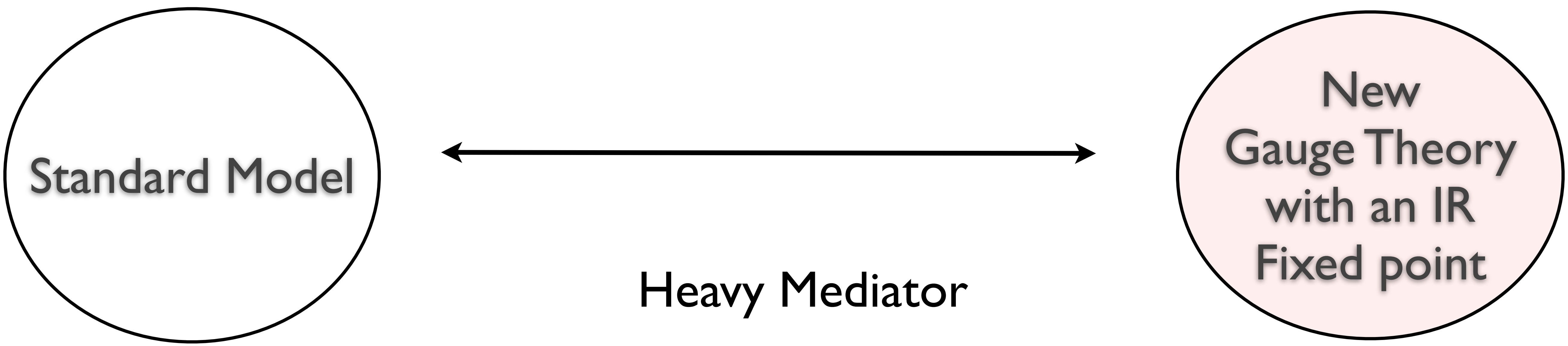


All Order Beta Function

Ryttov and F.S. 07

Landscape of the Unparticle World

Cartoon of the Unparticle World



Georgi 07

Information on nonperturbative aspects of HDRs

Part C

The Minimal Walking Theory

2 Adj. Dirac Flavors of SU(2)

$$Q_L^a = \begin{pmatrix} U^a \\ D^a \end{pmatrix}_L , \qquad U_R^a, \qquad D_R^a \qquad a = 1, 2, 3$$

$$Y(Q_L) = \frac{y}{2} \qquad Y(U_R, D_R) = \left(\frac{y+1}{2}, \frac{y-1}{2}\right)$$

$$\mathcal{L}_L = \begin{pmatrix} N \\ E \end{pmatrix}_L \qquad N_R \qquad E_R$$

$$Y(\mathcal{L}_L) = -3\frac{y}{2} \qquad Y(N_R, E_R) = \left(\frac{-3y+1}{2}, \frac{-3y-1}{2}\right)$$

$\mathcal{N} = 4$ super Yang-Mills

The MWT Lagrangian

$$\mathcal{L}_H \;\rightarrow\; \boxed{-\frac{1}{4}\mathcal{F}^a_{\mu\nu}\mathcal{F}^{a\mu\nu} + i\bar{Q}_L\gamma^\mu D_\mu Q_L + i\bar{U}_R\gamma^\mu D_\mu U_R + i\bar{D}_R\gamma^\mu D_\mu D_R}$$
$$+i\bar{L}_L\gamma^\mu D_\mu L_L + i\bar{N}_R\gamma^\mu D_\mu N_R + i\bar{E}_R\gamma^\mu D_\mu E_R$$

$$\mathcal{F}^a_{\mu\nu} \;=\; \partial_\mu\mathcal{A}^a_\nu - \partial_\nu\mathcal{A}^a_\mu + g_{TC}\epsilon^{abc}\mathcal{A}^b_\mu\mathcal{A}^c_\nu \qquad\qquad a,b,c \;=\; 1,\ldots,3$$

$$D_\mu Q^a_L \;=\; \left(\delta^{ac}\partial_\mu + g_{TC}\mathcal{A}^b_\mu\epsilon^{abc} - i\frac{g}{2}\vec{W}_\mu\cdot\vec{\tau}\delta^{ac} - ig'\frac{y}{2}B_\mu\delta^{ac}\right)Q^c_L$$

What you see is "not" what LHC will see

LHC effective theory

$$\boxed{\mathcal{L}(\text{Composites}) + \mathcal{L}(\text{Mixing with SM})} + \mathcal{L}(\text{New Leptons}) + \mathcal{L}(\text{SM} - \text{Higgs})$$

Low Energy Scalar Sector

$$M_{ij} \sim Q_i^\alpha Q_j^\beta \varepsilon_{\alpha\beta}$$

$$M = \begin{pmatrix} i\Pi_{UU} + \widetilde{\Pi}_{UU} & \frac{i\Pi_{UD} + \widetilde{\Pi}_{UD}}{\sqrt{2}} & \frac{\sigma + i\Theta + i\Pi^0 + A^0}{2} & \frac{i\Pi^+ + A^+}{\sqrt{2}} \\ \frac{i\Pi_{UD} + \widetilde{\Pi}_{UD}}{\sqrt{2}} & i\Pi_{DD} + \widetilde{\Pi}_{DD} & \frac{i\Pi^- + A^-}{\sqrt{2}} & \frac{\sigma + i\Theta - i\Pi^0 - A^0}{2} \\ \frac{\sigma + i\Theta + i\Pi^0 + A^0}{2} & \frac{i\Pi^- + A^-}{\sqrt{2}} & i\Pi_{\overline{UU}} + \widetilde{\Pi}_{\overline{UU}} & \frac{i\Pi_{\overline{UD}} + \widetilde{\Pi}_{\overline{UD}}}{\sqrt{2}} \\ \frac{i\Pi^+ + A^+}{\sqrt{2}} & \frac{\sigma + i\Theta - i\Pi^0 - A^0}{2} & \frac{i\Pi_{\overline{UD}} + \widetilde{\Pi}_{\overline{UD}}}{\sqrt{2}} & i\Pi_{\overline{DD}} + \widetilde{\Pi}_{\overline{DD}} \end{pmatrix}$$

Low Energy Vector Sector

$$A_i^{\mu,j} \sim \ Q_i^\alpha \sigma^\mu_{\alpha\dot\beta} \bar{Q}^{\dot\beta,j} - \frac{1}{4}\delta_i^j Q_k^\alpha \sigma^\mu_{\alpha\dot\beta} \bar{Q}^{\dot\beta,k}$$

$$A^\mu = \begin{pmatrix} \frac{a^{0\mu}+v^{0\mu}+v^{4\mu}}{2\sqrt{2}} & \frac{a^{+\mu}+v^{+\mu}}{2} & \frac{x^\mu_{UU}}{\sqrt{2}} & \frac{x^\mu_{UD}+s^\mu_{UD}}{2} \\ \frac{a^{-\mu}+v^{-\mu}}{2} & \frac{-a^{0\mu}-v^{0\mu}+v^{4\mu}}{2\sqrt{2}} & \frac{x^\mu_{UD}-s^\mu_{UD}}{2} & \frac{x^\mu_{DD}}{\sqrt{2}} \\ \frac{x^\mu_{\overline{UU}}}{\sqrt{2}} & \frac{x^\mu_{\overline{UD}}-s^\mu_{\overline{UD}}}{2} & \frac{a^{0\mu}-v^{0\mu}-v^{4\mu}}{2\sqrt{2}} & \frac{a^{-\mu}-v^{-\mu}}{2} \\ \frac{x^\mu_{\overline{UD}}+s^\mu_{\overline{UD}}}{2} & \frac{x^\mu_{\overline{DD}}}{\sqrt{2}} & \frac{a^{+\mu}-v^{+\mu}}{2} & \frac{-a^{0\mu}+v^{0\mu}-v^{4\mu}}{2\sqrt{2}} \end{pmatrix}$$

Comprehensive Effective Technicolor Lagrangian

Vector Mesons

Yukawas

** Link to MWT via Modified Weinberg Sum Rules **

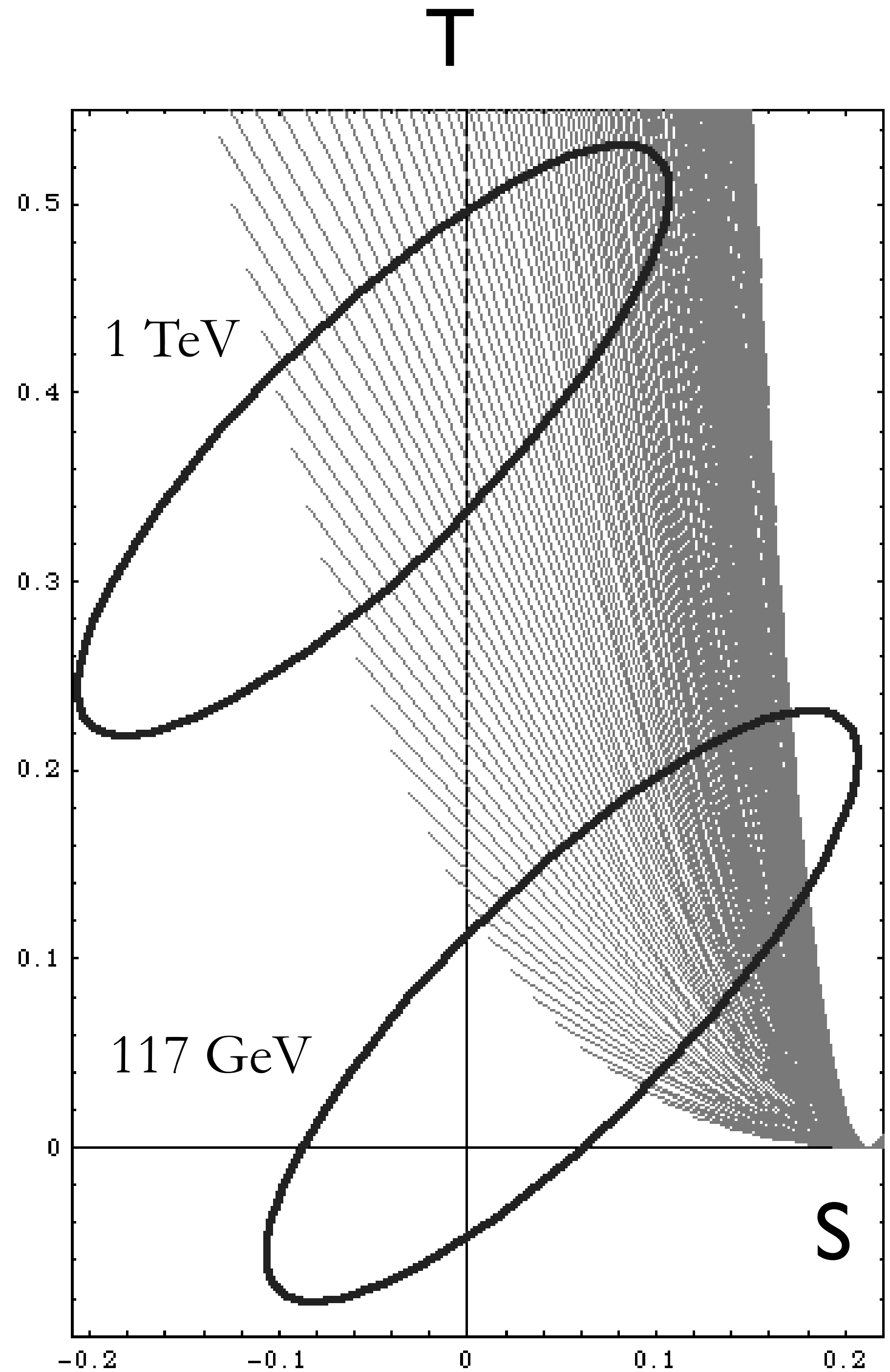
Written in a renormalizable form

With imposed constraints from Precision Data

<u>A working technicolor benchmark</u>

Foadi, Frandsen, Ryttov & F.S. 07

MWT versus EWPD



LEP EWG Summer 2006

$$100 \text{ Gev} < M_1 < 800 \text{ Gev}$$

Y=-3/2 for Leptons

$$100 \text{ Gev} < M_2 < 1000 \text{ Gev}$$

$$S_{\text{Leptons}} = \frac{1}{6\pi}\left[1 - 2Y\ln\left(\frac{M_1}{M_2}\right)^2 + \frac{1+8Y}{20}\left(\frac{m_Z}{M_1}\right)^2 + \frac{1-8Y}{20}\left(\frac{m_Z}{M_2}\right)^2 + O\left(\frac{m_Z^4}{M_i^4}\right)\right]$$

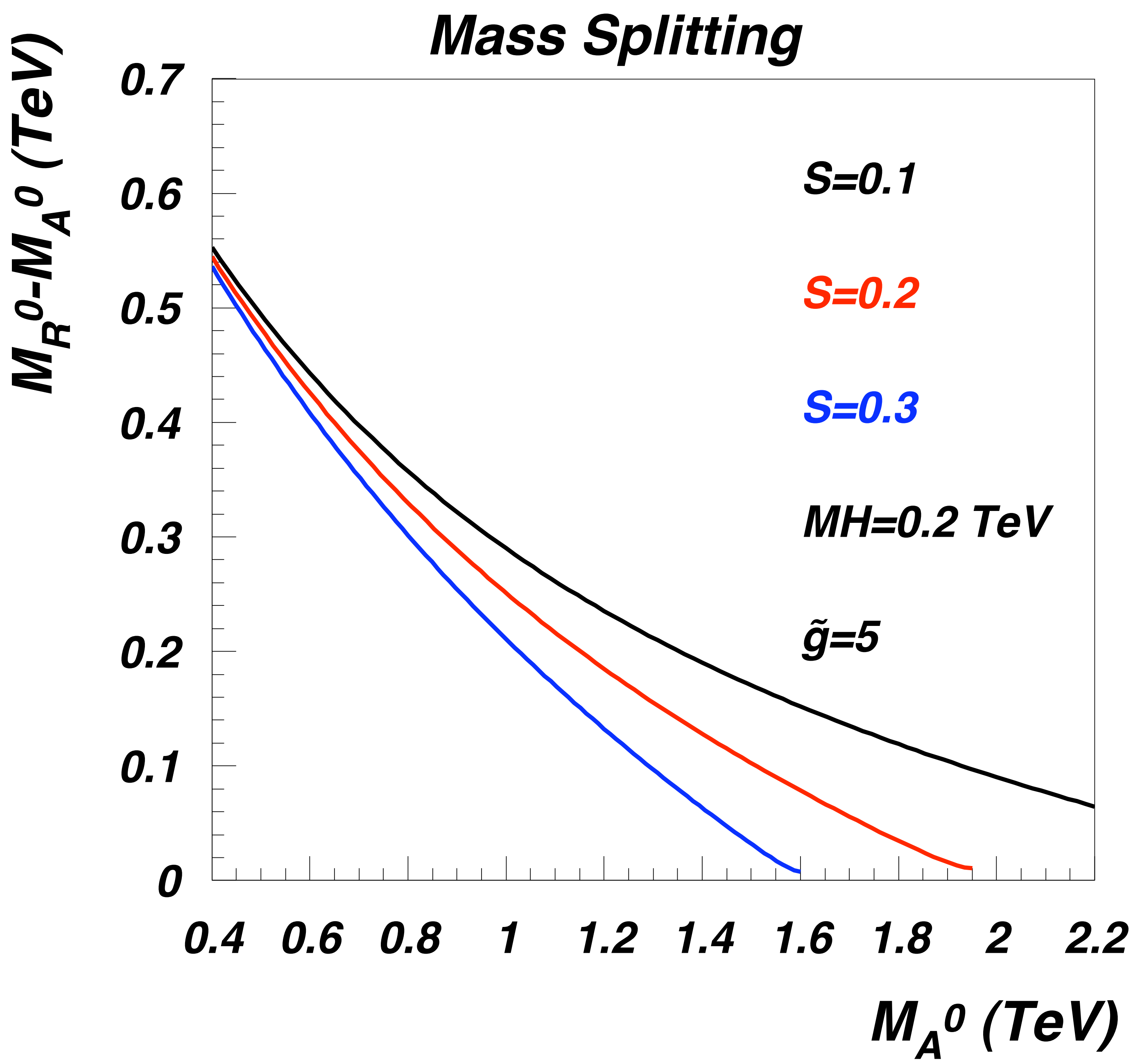
LHC Phenomenology

In collaboration with

A. Belyaev
R. Foadi
M. T. Frandsen
M. O. Jarvinen

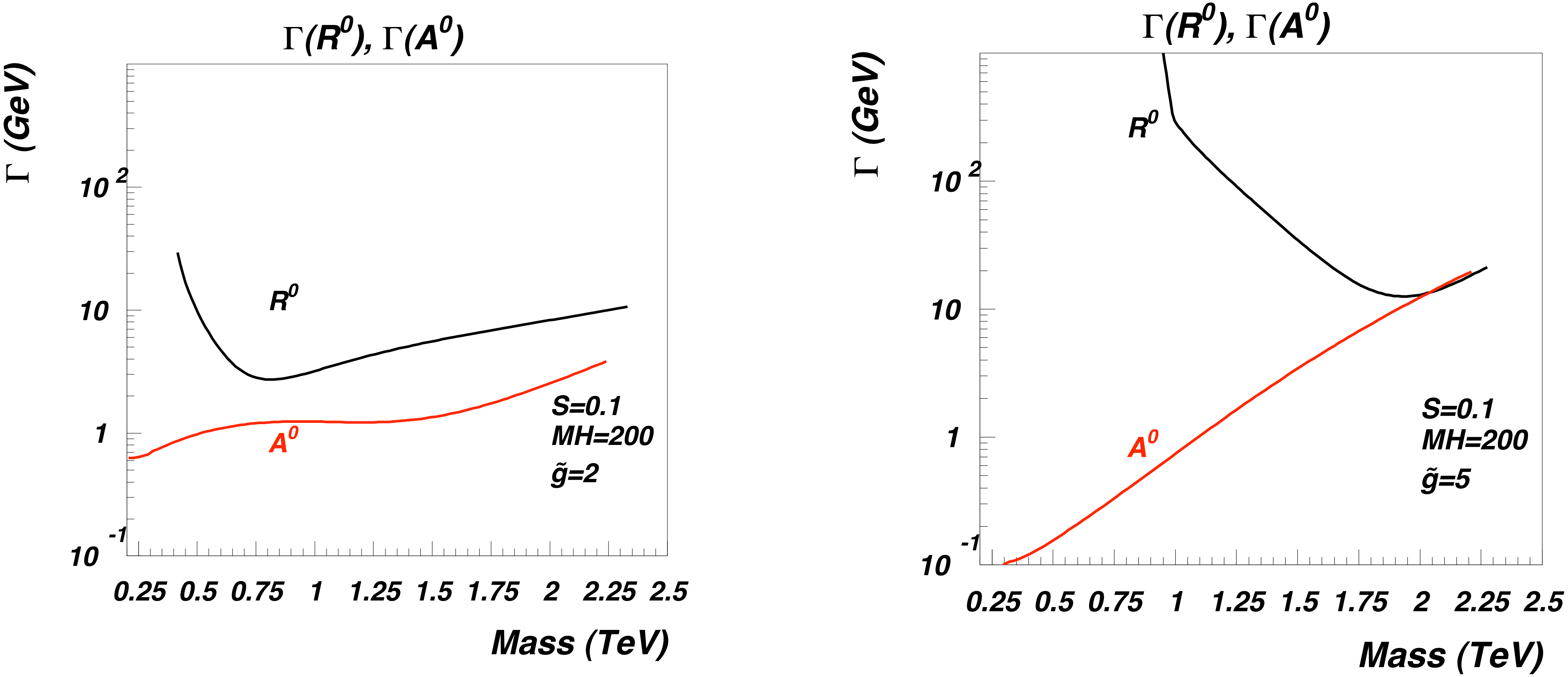
A primer/work in progress

Vector-Axial Mass Splitting



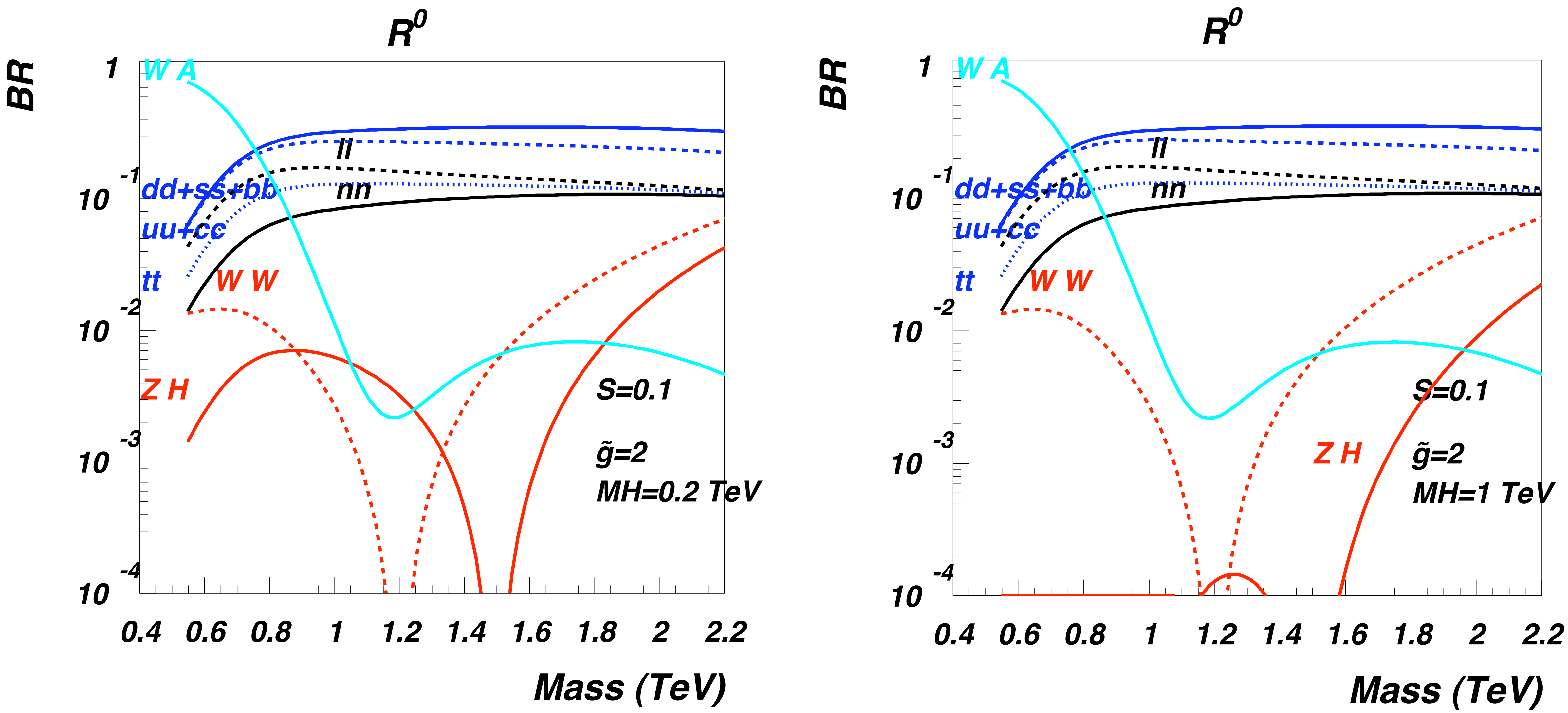
Within the LHC reach for small values of S if $M_{\mathrm{V}} > M_{\mathrm{A}}$

Vector-Axial Decay Widths



Vector wider than the axial 'cause of the decay V->2A

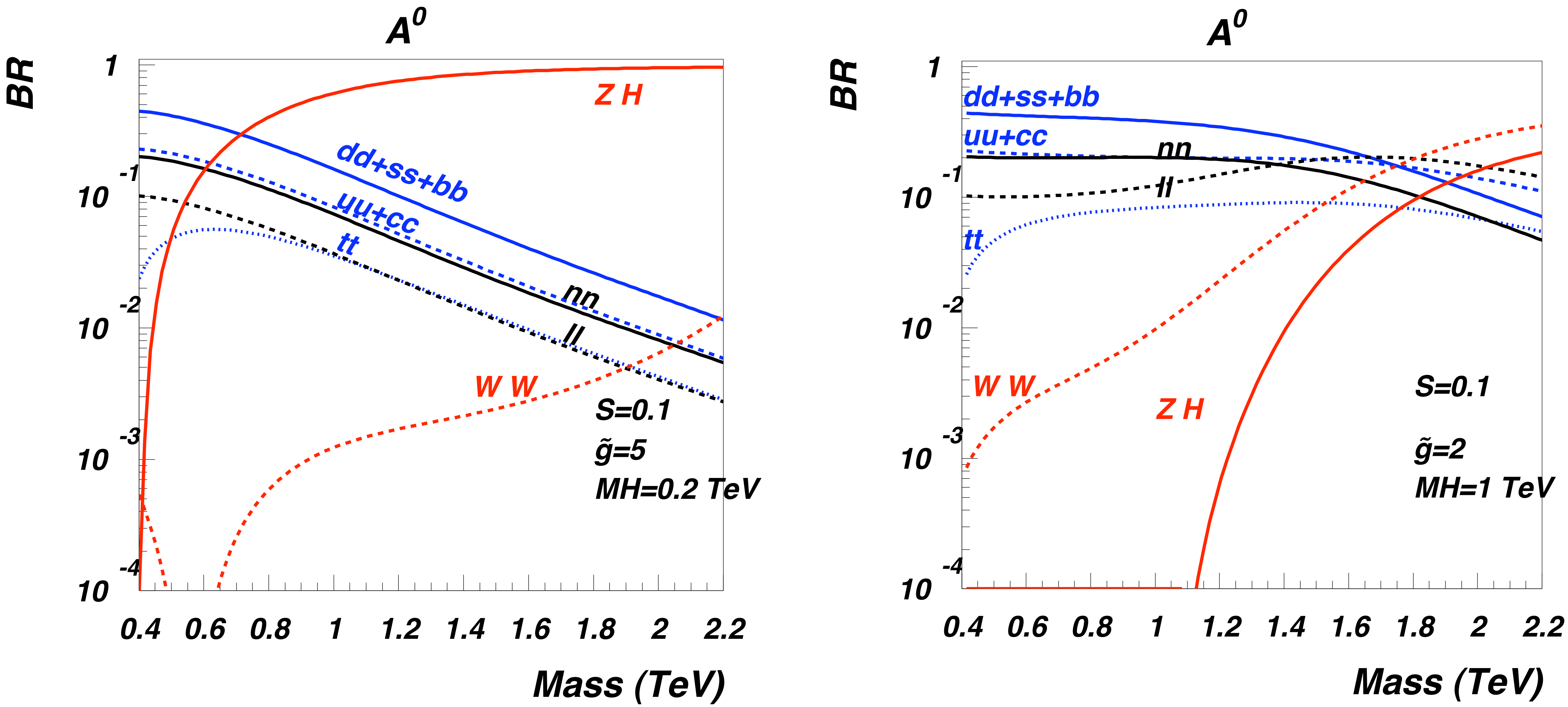
Vector Resonances Branching Ratios



BRs for different Composite Higgs Masses

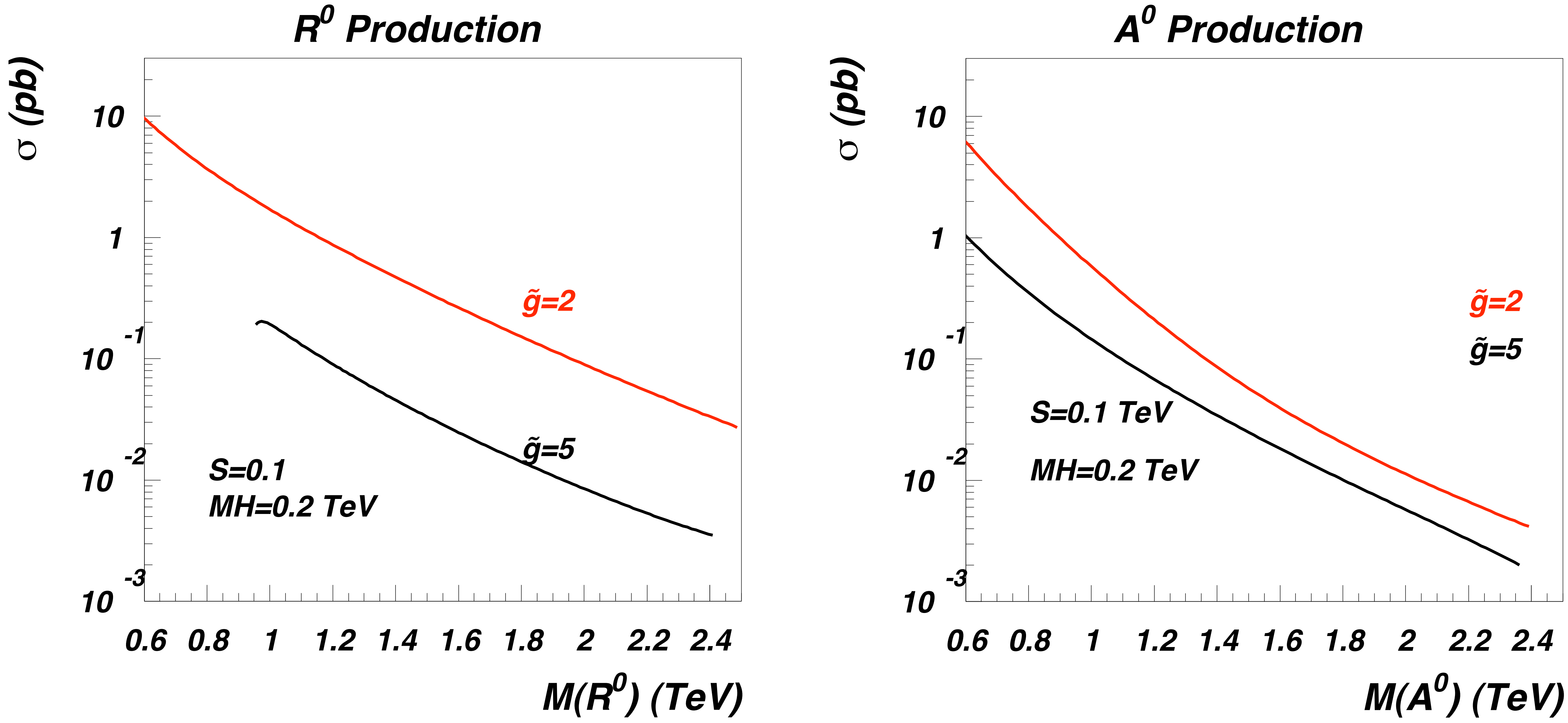
BR in WW drops and rises (small S)

Axial Resonances Branching Ratios

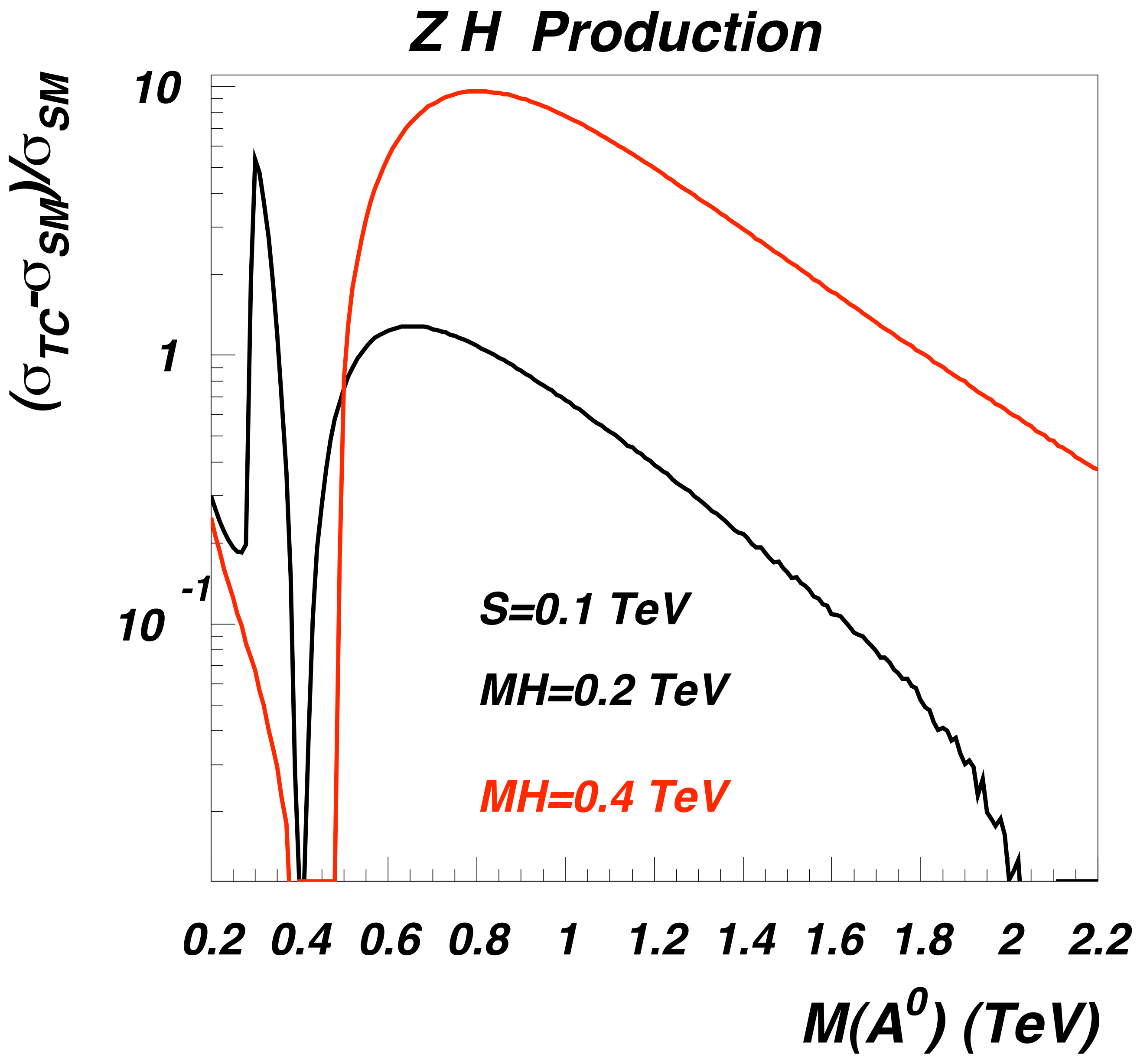


BRs for different Composite Higgs Masses

Vector & Axial Direct production



Associate Higgs Production



Vanishing for finite values of the axial mass: small S

Playing with Unification

Farhi-Susskind, 79

Gudnason-Ryttov-F.S. 06

1 - loop running for SU(n)

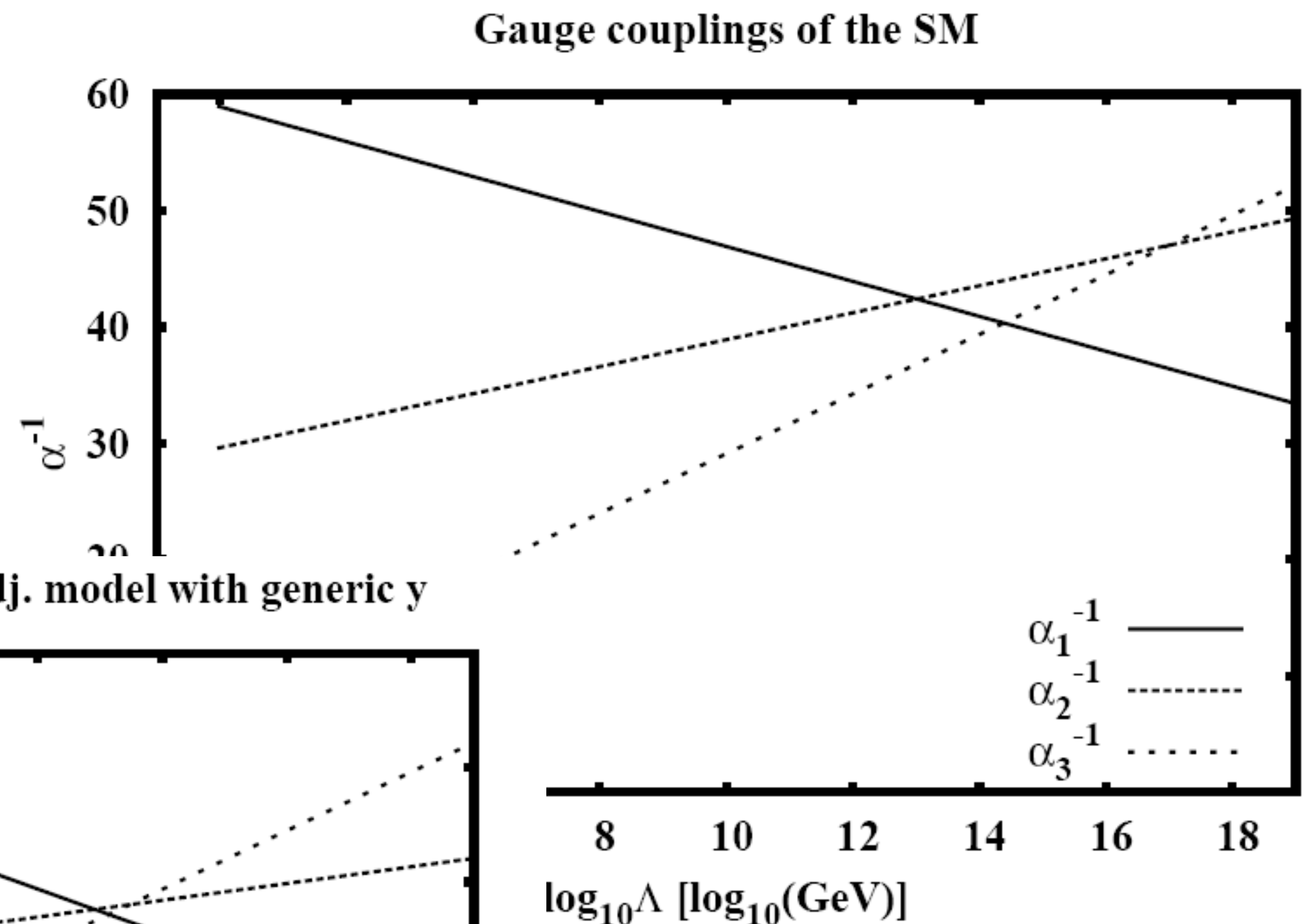
$$\alpha_n^{-1}(\mu) = \alpha_n^{-1}(M_Z) - \frac{b_n}{2\pi} \ln\left(\frac{\mu}{M_Z}\right)$$

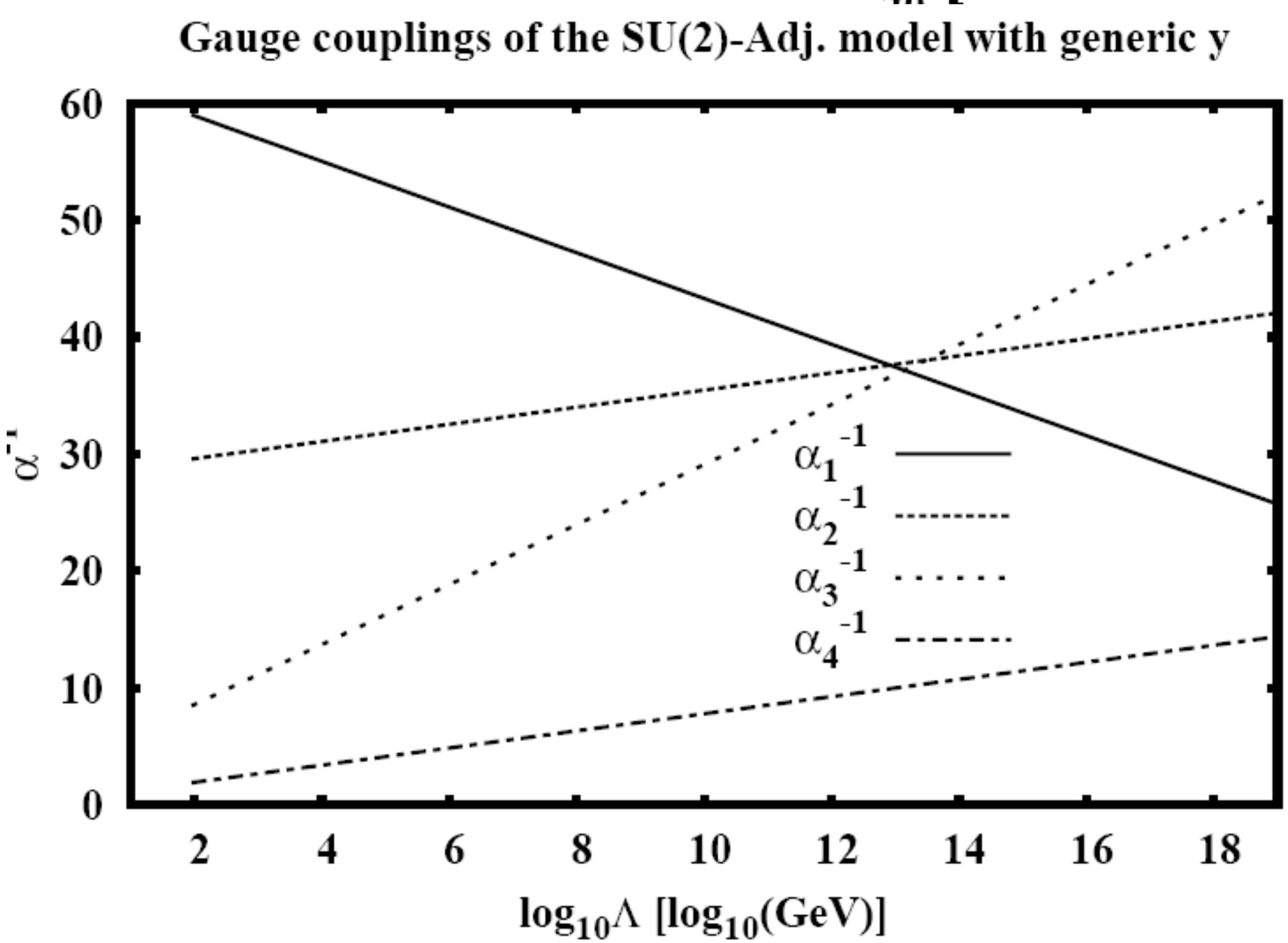
Degree of SU(3)xSU(2)xU(1) Unification

$$B_{Th} \leftarrow \frac{b_3 - b_2}{b_2 - b_1} \quad = \quad \frac{\alpha_3^{-1} - \alpha^{-1}\sin^2\theta_w}{(1+c^2)\alpha^{-1}\sin^2\theta_w - c^2\alpha^{-1}} \rightarrow B_{Exp}$$

Unification Scale

$$M_{GUT} = M_Z \exp\left[2\pi \frac{\alpha_2^{-1}(M_Z) - \alpha_1^{-1}(M_Z)}{b_2 - b_1}\right]$$


Gauge couplings of the SM
60
50
40
30
20
α^{-1}
α_1^{-1}
α_2^{-1}
α_3^{-1}
8
10
12
14
16
18
$\log_{10}\Lambda$ [$\log_{10}$(GeV)]


Gauge couplings of the SU(2)-Adj. model with generic y
60
50
40
30
20
10
0
α^{-1}
α_1^{-1}
α_2^{-1}
α_3^{-1}
α_4^{-1}
2
4
6
8
10
12
14
16
18
$\log_{10}\Lambda$ [$\log_{10}$(GeV)]

Adding Adjoint SM Matter

Minimal Walking Technicolor + SM Adjoint Matter

Colored Octet of Majorana Particles

Weak Triplet of Majorana Fermions

Extra SM Weyl Singlet

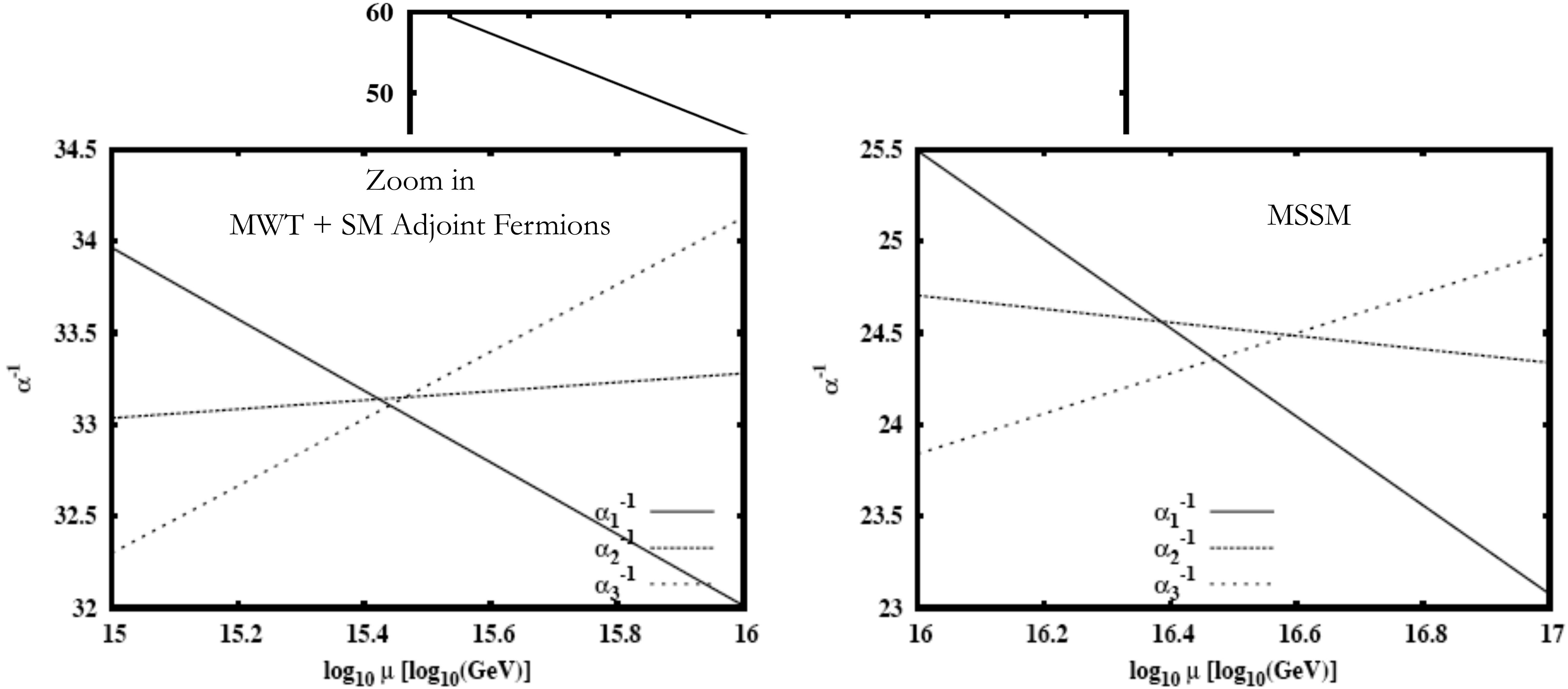
$$\begin{aligned} b_3 &= \frac{4}{3}N_g - 11 + 2 \\ b_2 &= \frac{4}{3}\left(N_g + 1\right) - \frac{22}{3} + \frac{4}{3} \\ b_1 &= \frac{4}{3}\left(N_g + 1\right) \end{aligned}$$

Gudnason-Ryttov-F.S. ph/0612230

Bajc-Senjanovic ph/0612029

$$B_{\mathrm{Th}} = 13/18 = 0.72(2) \quad \text{versus} \quad B_{\mathrm{Exp}} \simeq 0.72$$

MWT + SM Adjoint Fermions



What LHC can see and how may it deceive you

- Composite States: Technirho, composite (light) Higgs
- Detect Light Higgs: “Elementary or Composite ?”
- Study: pp -> HW,   pp -> HZ.   pp->HW (enhanced)
- 4th Family of Leptons no Quarks

What LHC can see and how may it deceive you

- wino/bino/gluino-like produced. Have you seen SUSY, WTC or ... ?
- Study their couplings to SM fermions

Unpleasant scenario:

- WW scatttering is unitarized at the tree level up to 4 TeV with new vectors states of about 1.5 TeV. LHC and ILC will not dicover! (Foadi and FS 08)

Summary

- Introduced different types of viable technicolor theories

- Phase diagram of Higher Dimensional Representations

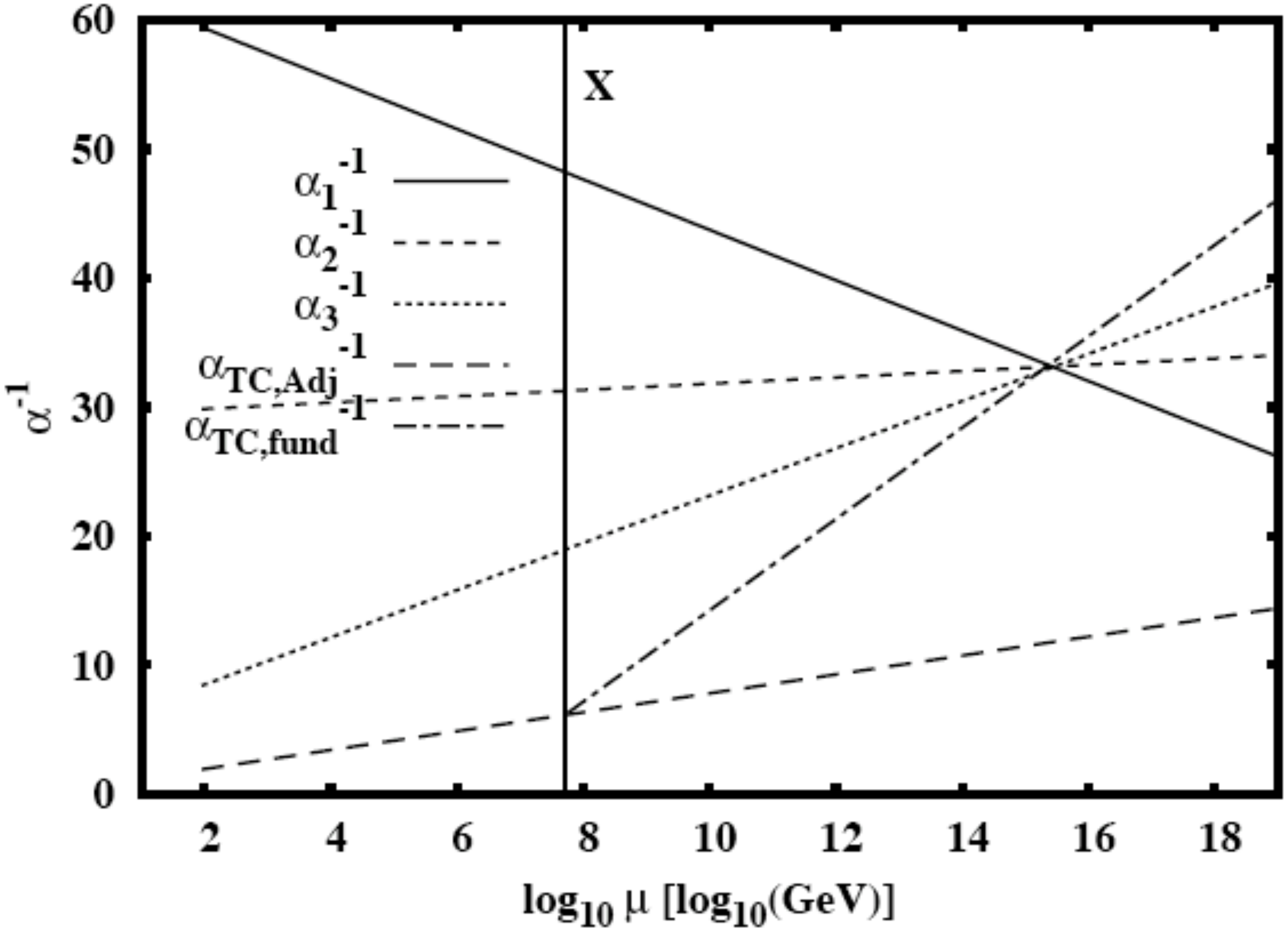
- Presented Minimal Walking Technicolor

- Benchmark for “any” serious model breaking dynamically the electroweak symmetry and passing LEP I & II precision tests.

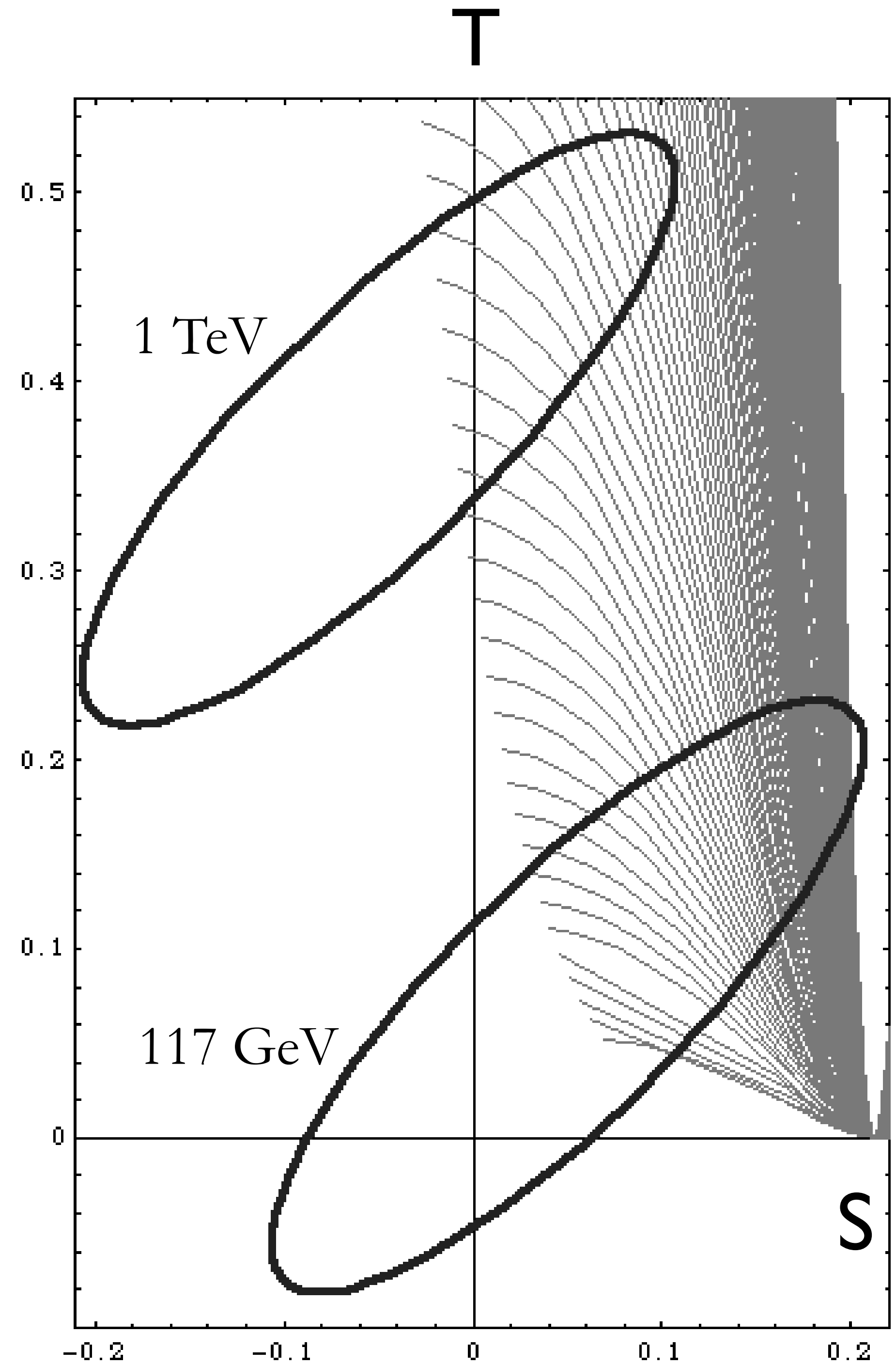
- Dark Matter as a technibaryon

- Unification

Unifying also TC
Cartoon!



MWT versus EWPD



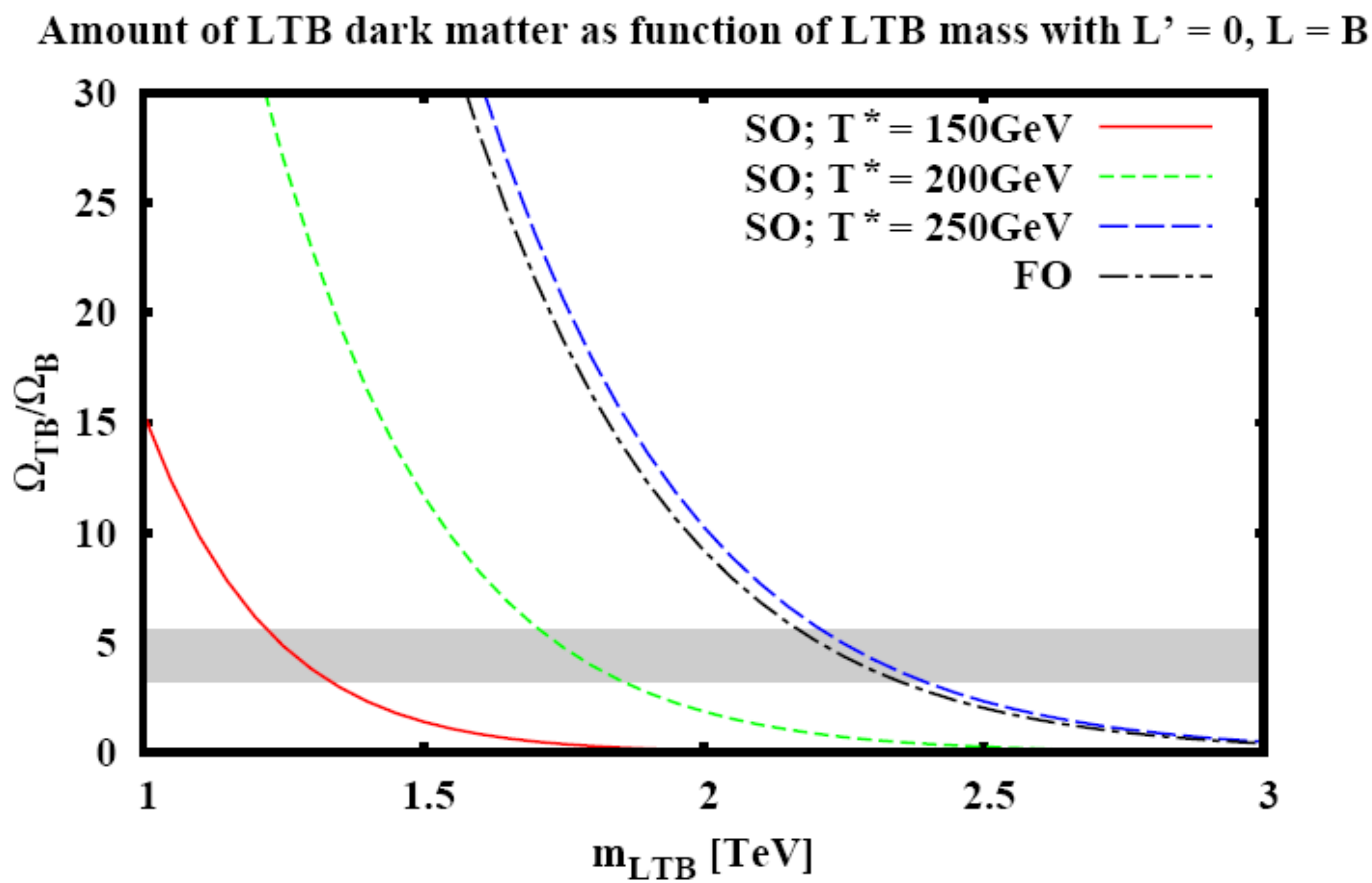
LEP EWG Summer 2006

$46 \text{ Gev} < M_1 < 800 \text{ Gev}$

Y=-1/2 for Leptons

$100 \text{ Gev} < M_2 < 1000 \text{ Gev}$

DD - Technibaryon as DM



Gudnason, Kouvaris and F.S. 06

Constrained by CDMS to be at most only a 40-60% fraction of DM

Cosmological Constant Problem

- Why is empty space so nearly empty?

$$\rho_{vac} < 10^{-46}\,\mathrm{GeV}^{4} \approx 10^{-29}\ \mathrm{g\ cm}^{-3}$$

- Standard Model sets the scale to:

$$\rho_{sm} > 10^{8}\,\mathrm{GeV}^{4}$$

- Mismatch by 54 order of magnitude!!

$$\Lambda = \frac{8\pi G_{\text{Newton}}}{c^4}\varrho_{\text{vac}}$$

Dark Matter in MWT

a) Heavy Neutrino for y=1/3.

Kainulainen, Tuominen, Virkajärvi. 06

b) Dark Majorana

Kouvaris 07

TB Dark Matter Beyond MWT

SU(4), 8 flavors, only 2-flavors EW gauged

$$\epsilon_{t_1 t_2 t_3 t_4} Q_L^{t_1 t_2, f} Q_L^{t_3 t_4, f'} \epsilon_{f f'}$$

Dietrich-F.S. 06

Cannot be easily constrained by CDMS

Higgsless versus Higgsfull

Higgsless:

$$\frac{M_H}{M_V} > 1$$

Higgsfull:

$$\frac{M_H}{M_V} \leq 1$$

Spectrum of Hadronic/Technihadronic States

Using 't Hooft Large N and Unitarity in Pion-Pion Scattering in QCD

Vector Meson is a quark-antiquark state: $\rho(770)$

Broad Sigma of multiquark nature $f_0(600)$

F.S. & Schechter, 95
Harada, F.S. and Schechter, 03
Caprini, Colangelo,Leutwyler 05
Maiani,Piccinini, Polosa, Riquer 04
F.S. and Schechter, 07

Higgsless: 't Hooft Extension

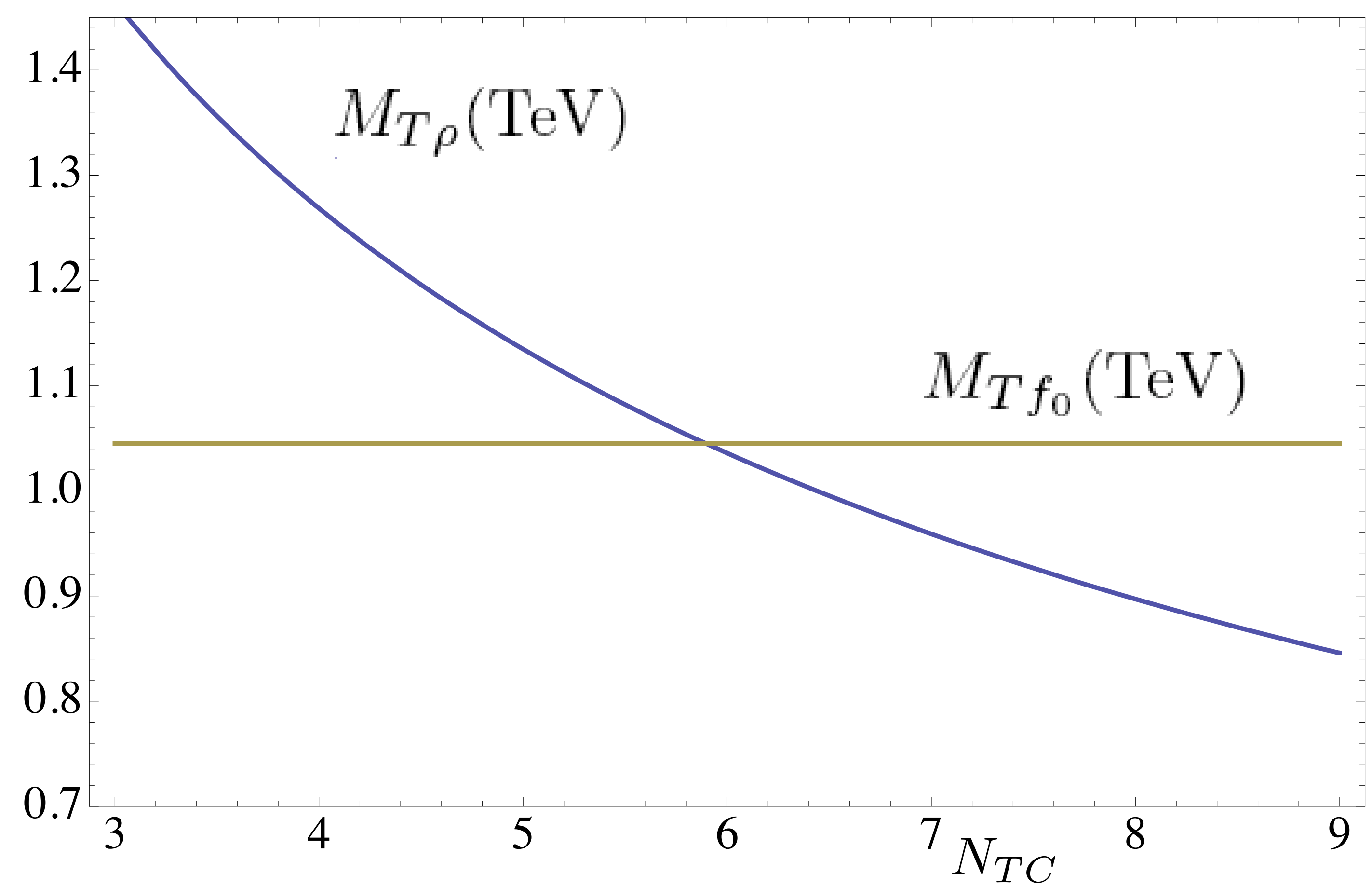
$$M_{T\rho} \quad = \quad \frac{\sqrt{2}v_0}{F_\pi}\frac{\sqrt{3}}{\sqrt{N_D\,N_{TC}}}m_\rho \qquad v_0 \sim 250\mathrm{GeV}$$

$$M_{Tf_0} \quad = \quad \frac{\sqrt{2}v_0}{F_\pi\sqrt{N_D}}\left(\frac{N_{TC}}{\sqrt{3}}\right)^{\frac{p-1}{2}} m_{f_0} \qquad p \geq 1$$

F.S. 07

$$N_D = \frac{N_{TF}}{2}$$

$$N_D = 2$$



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S - T

S-measures the left - right type current correlator

$$S = -16\pi \frac{\Pi_{3Y}(m_Z^2) - \Pi_{3Y}(0)}{m_Z^2}$$

T-measures deviations from

$$m_{\mathrm{W}}^2 = \cos^2\theta_{\mathrm{W}}\, m_{\mathrm{Z}}^2$$

$$T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 m_Z^2}$$

Conditions

Universe Electric Neutrality

Chemical Equilibrium

EW Sphaleron Processes, Kuzmin-Rubakov-Shaposhnikov

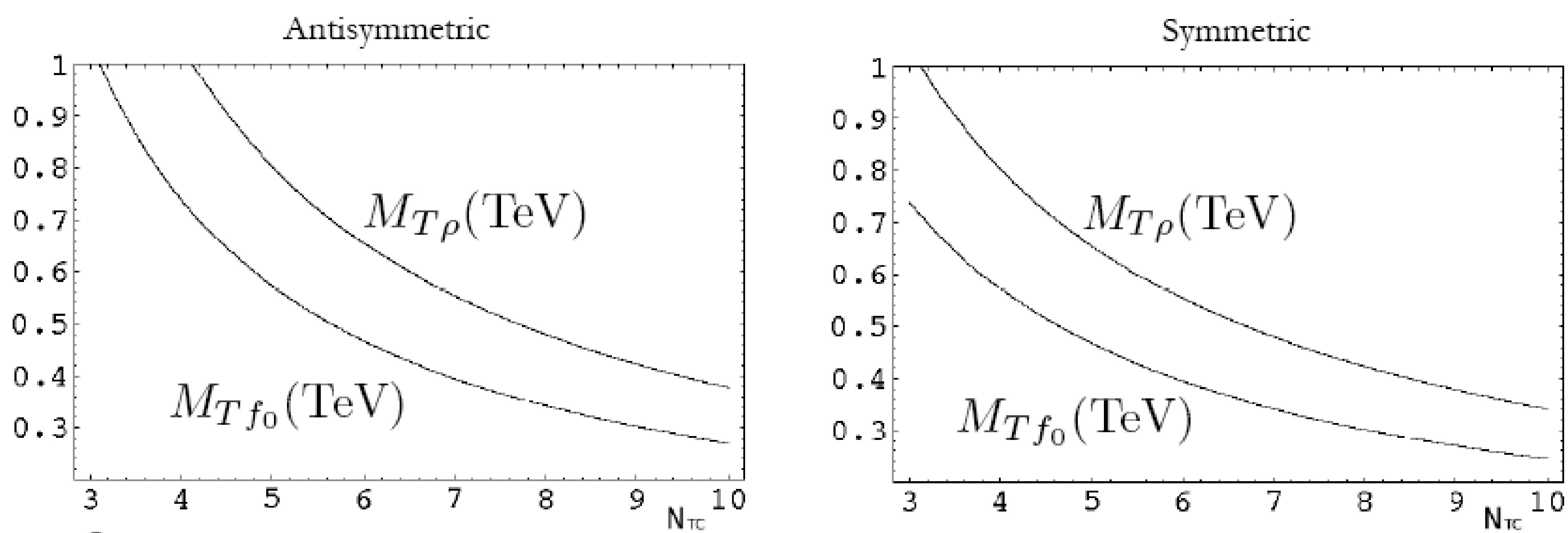
TB - B violated at High Energies & approx. conserved at EW

M_H/M_V < 1 in MWT theories

$$M_{T\rho} = \frac{\sqrt{2}v_0}{F_\pi}\frac{\sqrt{3}\sqrt{2}}{\sqrt{N_D\,N_{TC}(N_{TC}\mp 1)}}m_\rho$$

$$M_{Tf_0} = \frac{\sqrt{2}v_0}{F_\pi}\frac{\sqrt{3}\sqrt{2}}{\sqrt{N_D\,N_{TC}(N_{TC}\mp 1)}}m_{f_0}$$

F.S. 07



$N_D = 2$