Danish Institute for Advanced Study

University of Southern Denmark

Composite Dynamics vs LHC

Francesco Sannino

CP^3 - Origins

Particle Physics & Cosmology

Nordita June 2012

Riddles

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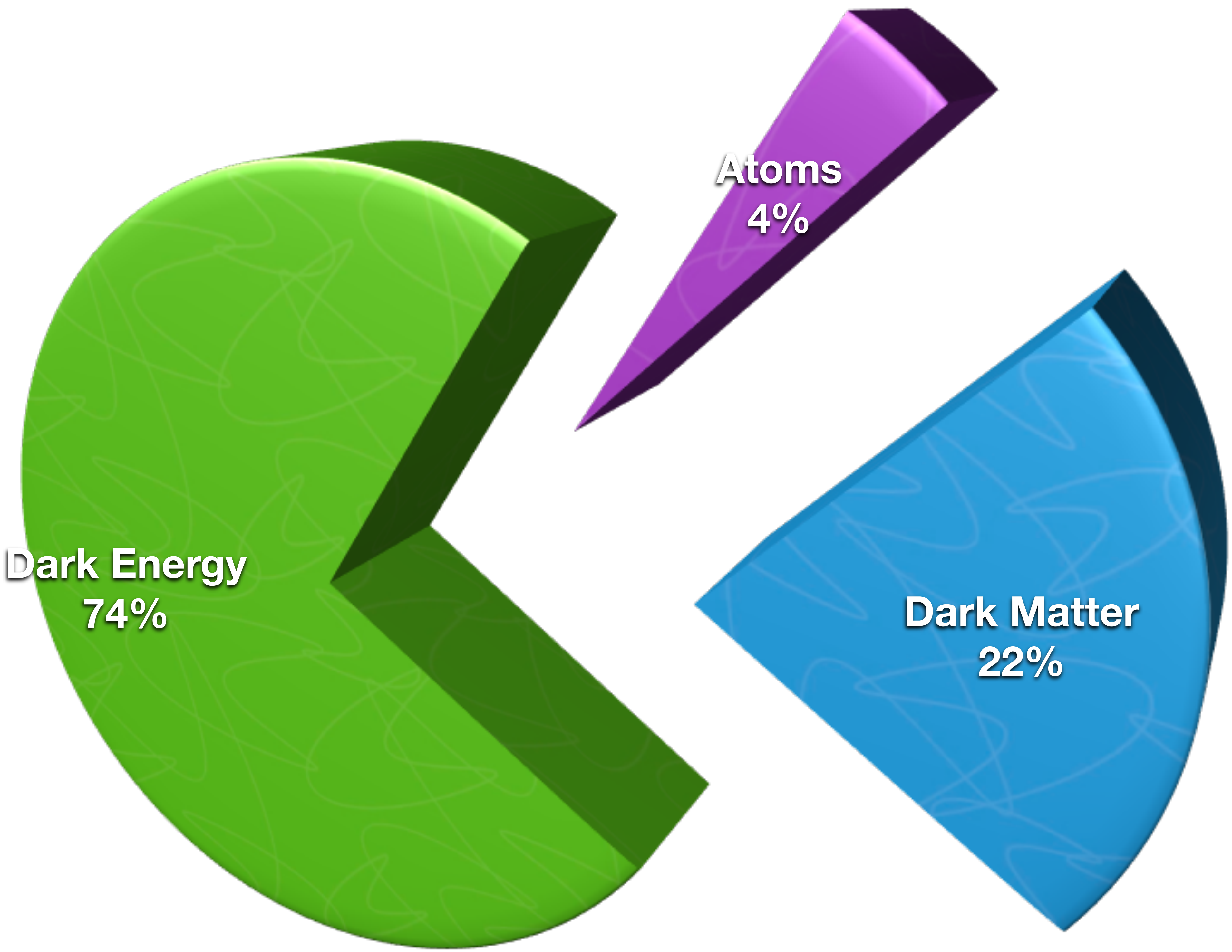

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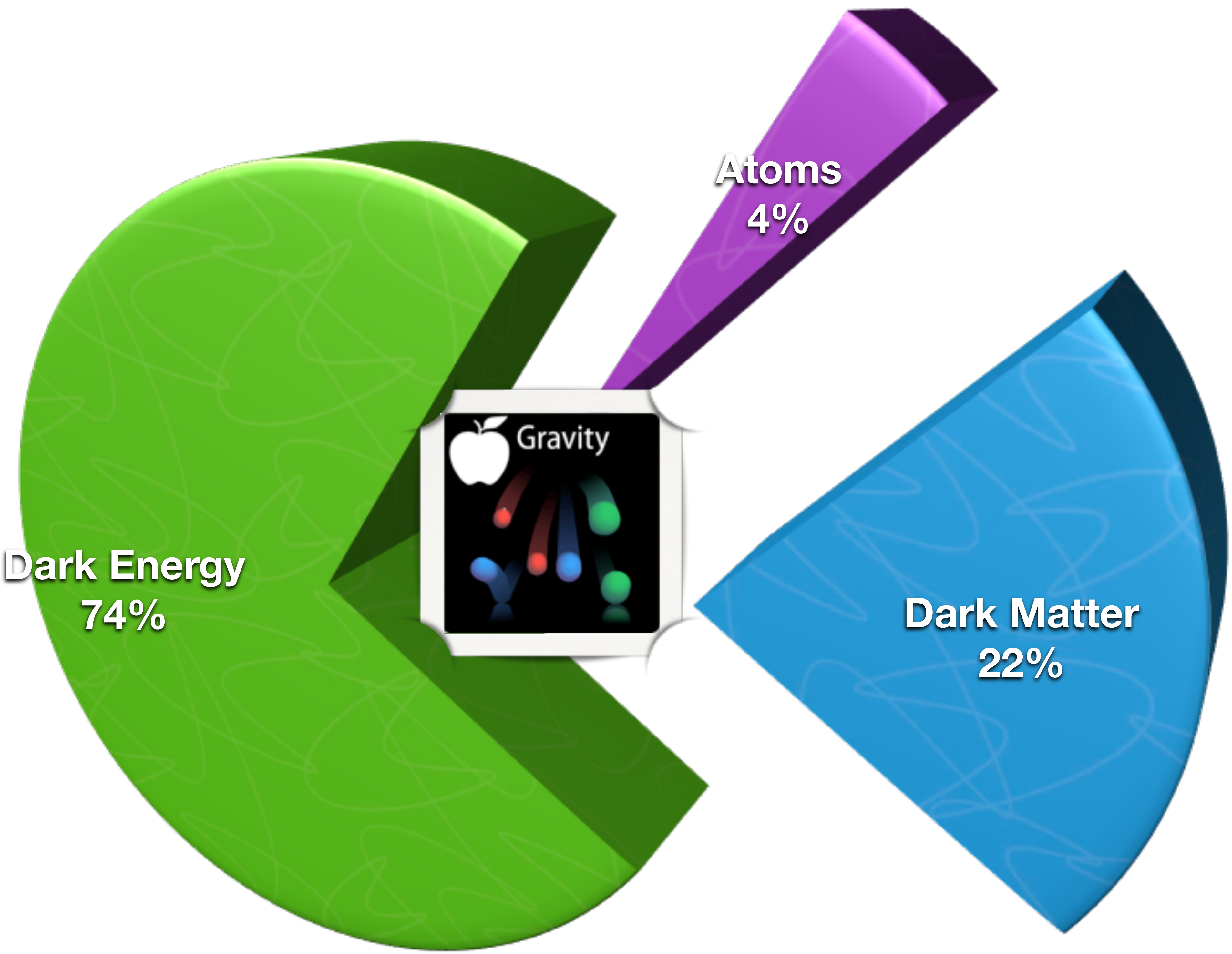

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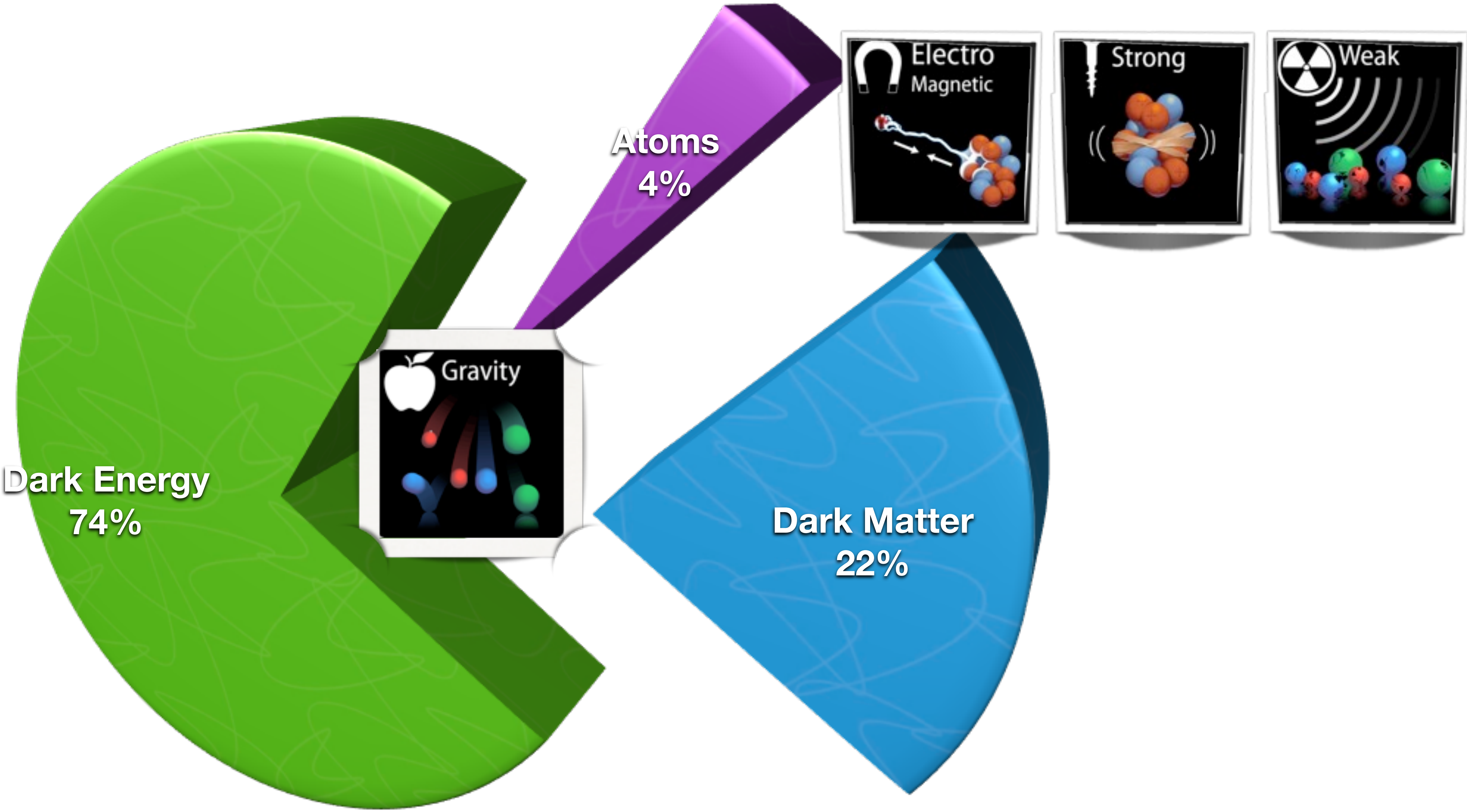

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4%
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Fermi Scale

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$$M_H^2 = 2\lambda\, v^2$$

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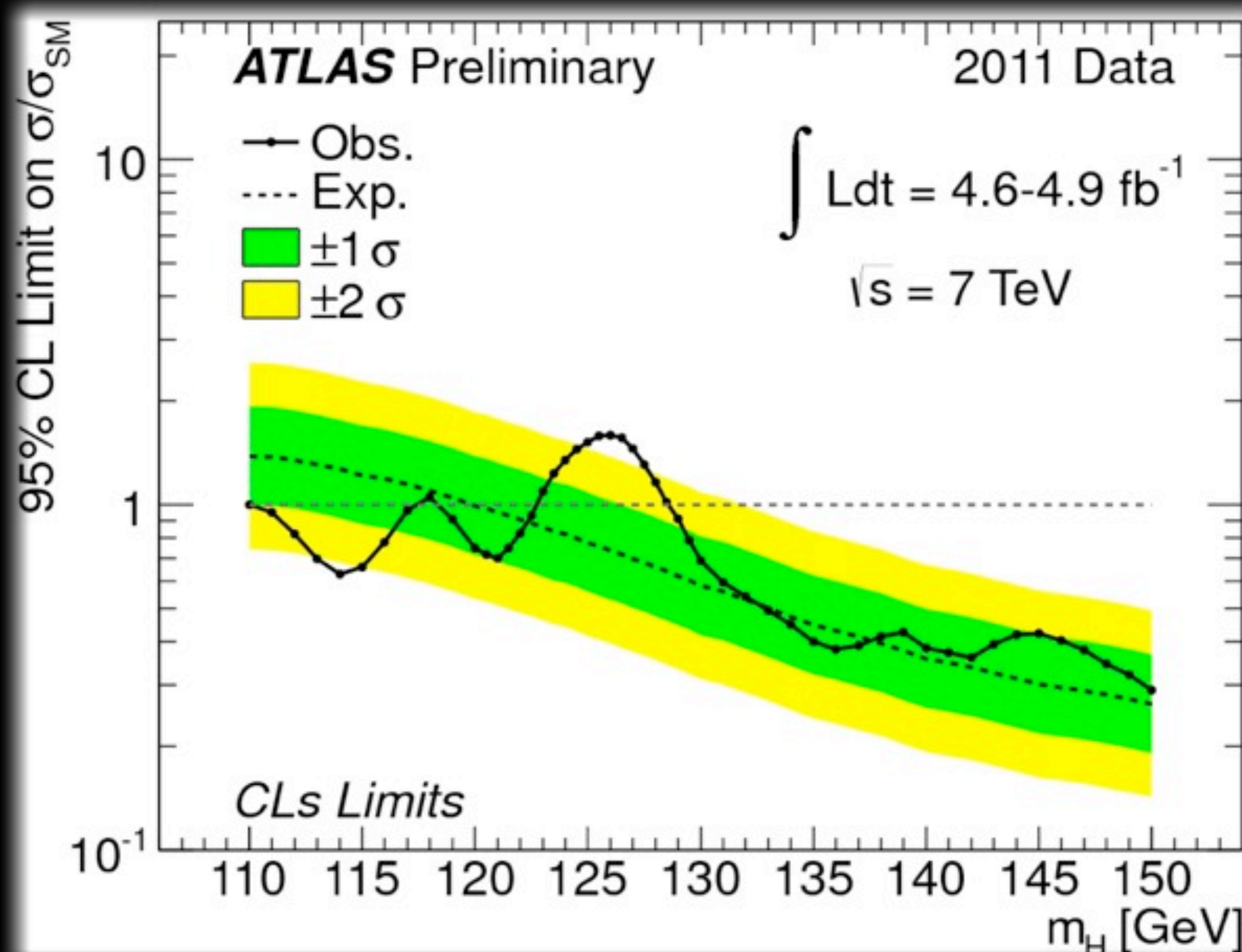
Top has the right energy scale!

Light quarks and leptons are also natural!

O' Higgs, where art thou!



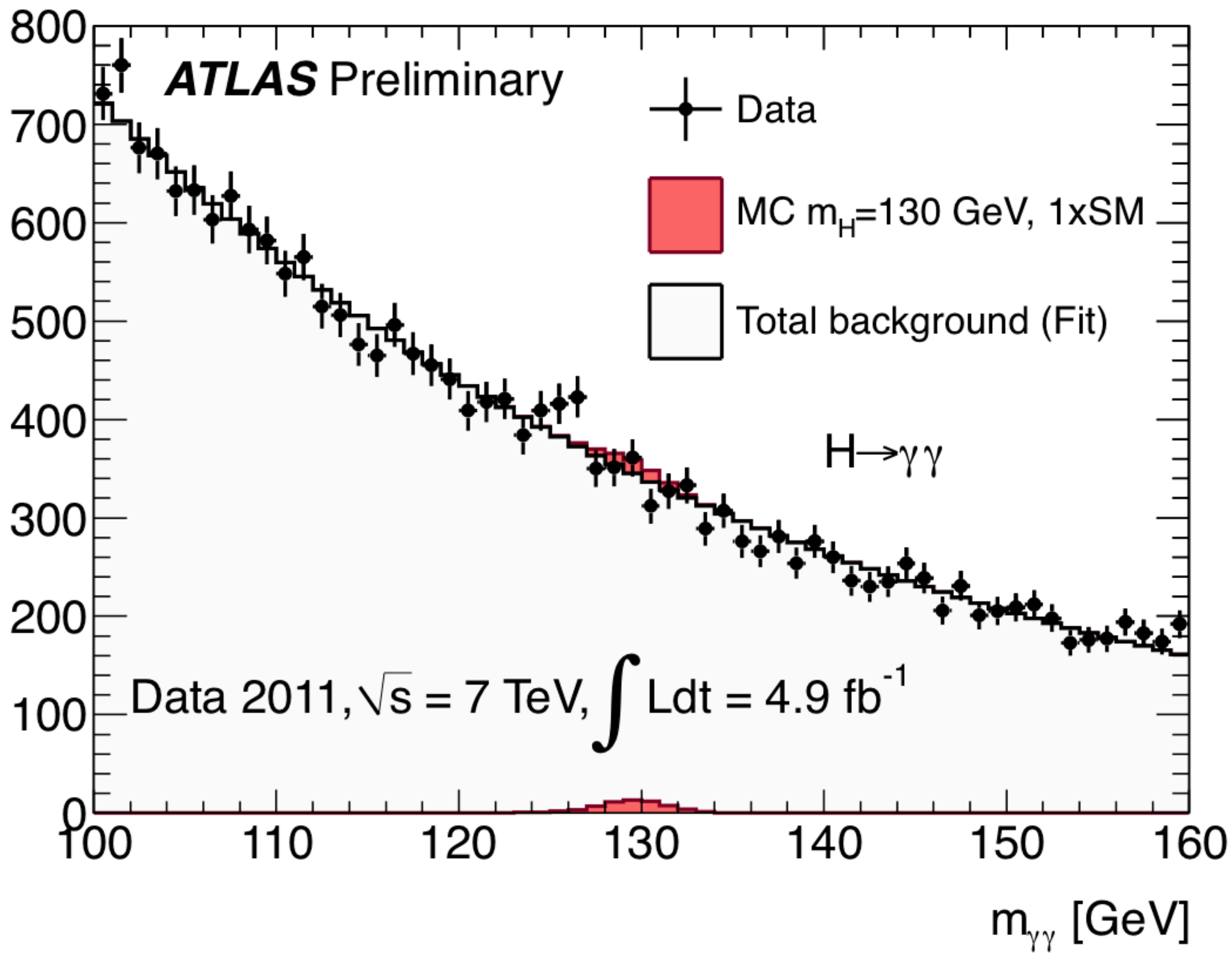
Excluded @ 95% CL

$$112.7 < M_H < 115.5 \text{ GeV}$$

$131 < M_H < 453$ GeV except $237 - 251$ GeV

Does it look like the Higgs?

Does it look like the Higgs?



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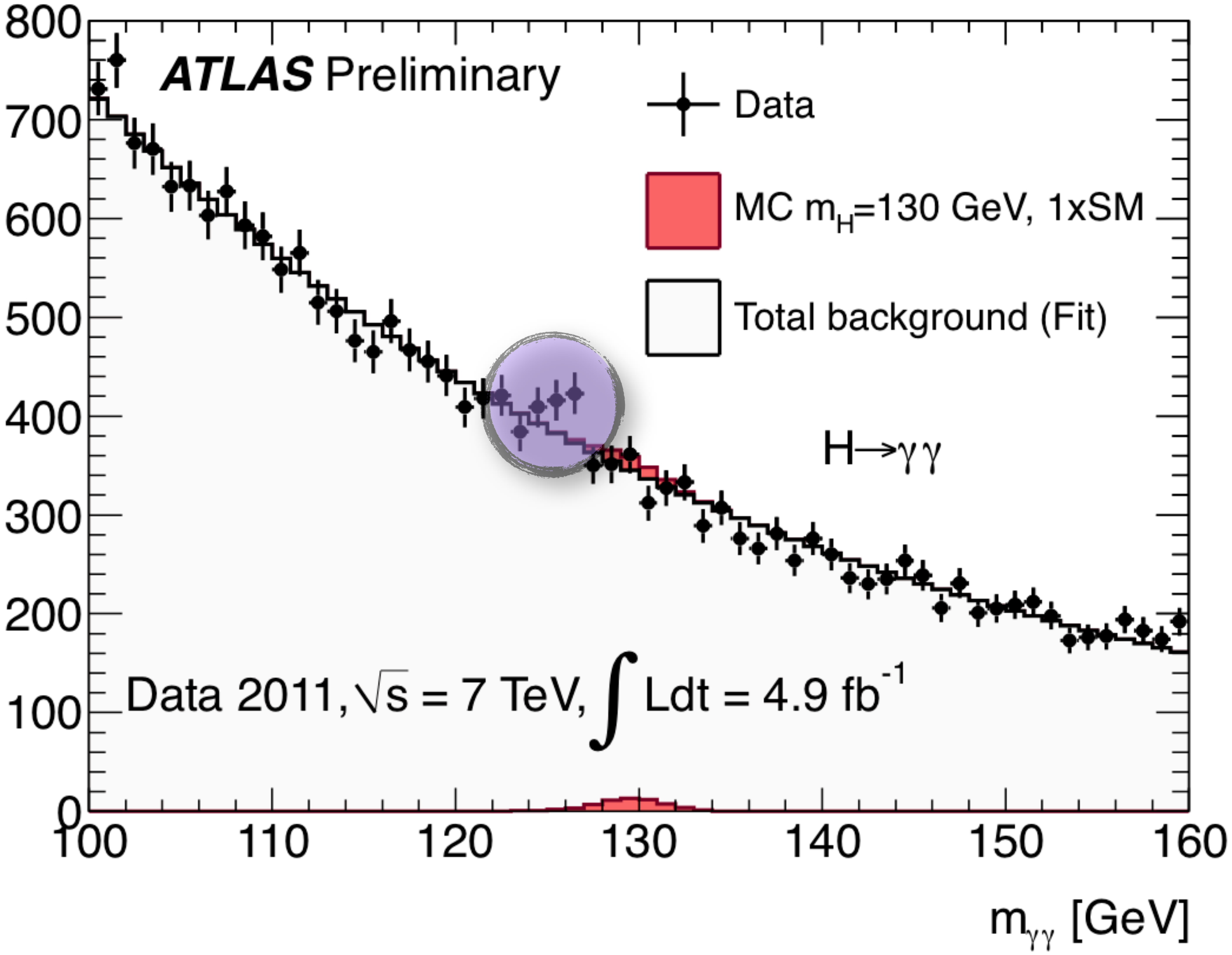

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$$pp \to \gamma\gamma \quad 4.9\mathrm{fb}^{-1} \quad m_H = 126.5 \pm 0.7 \text{ GeV} \quad R = 2^{+0.9}_{-0.7}$$

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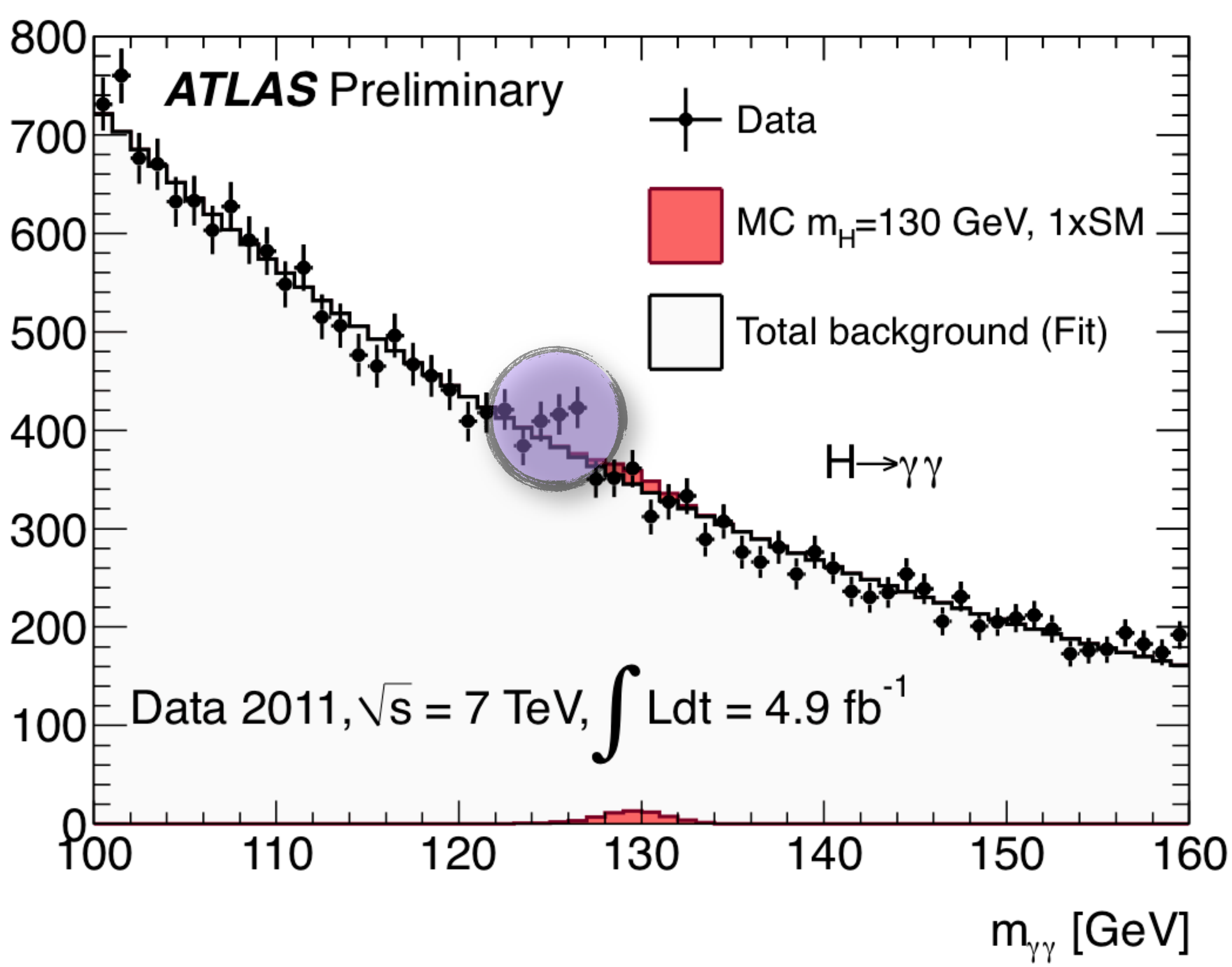

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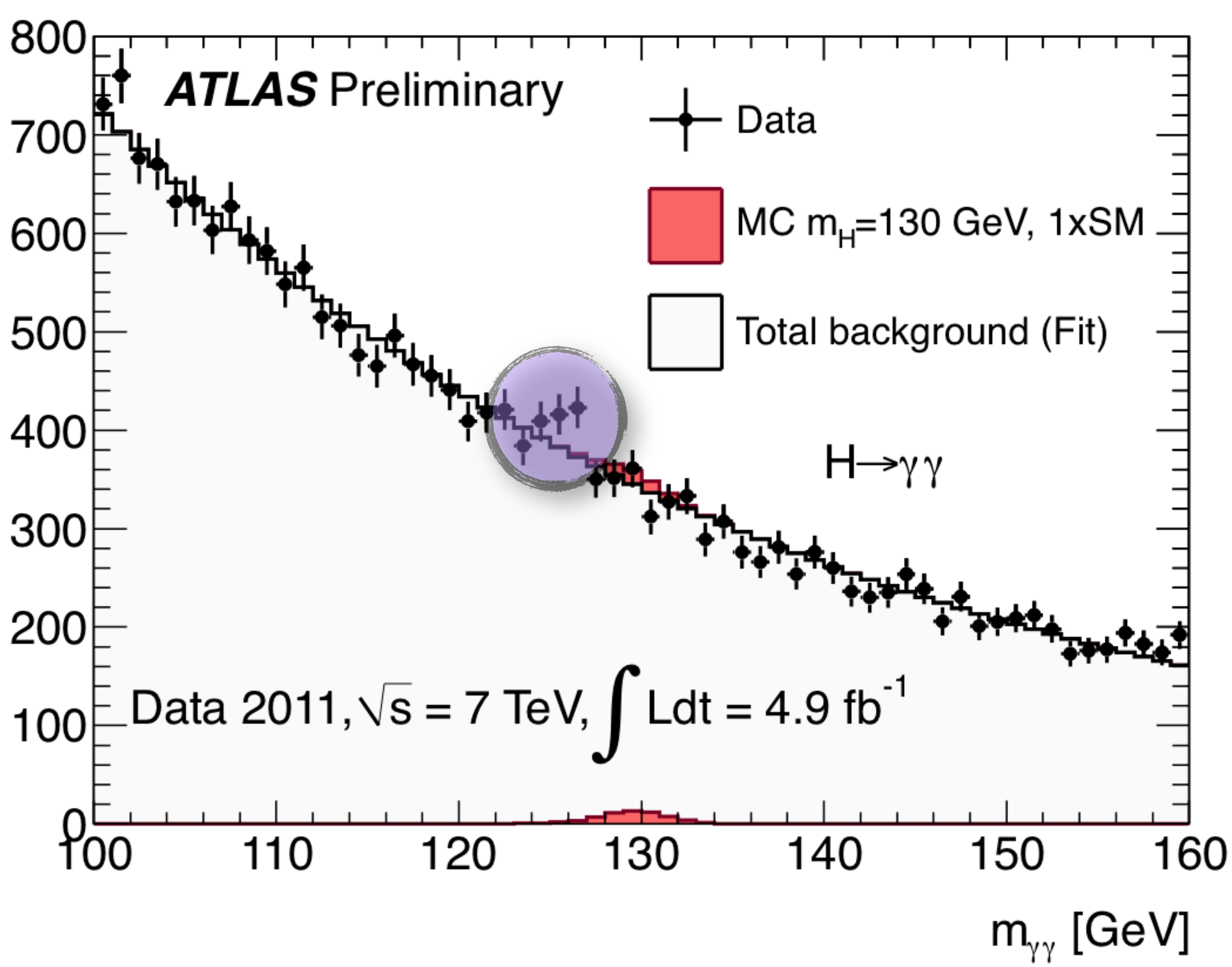

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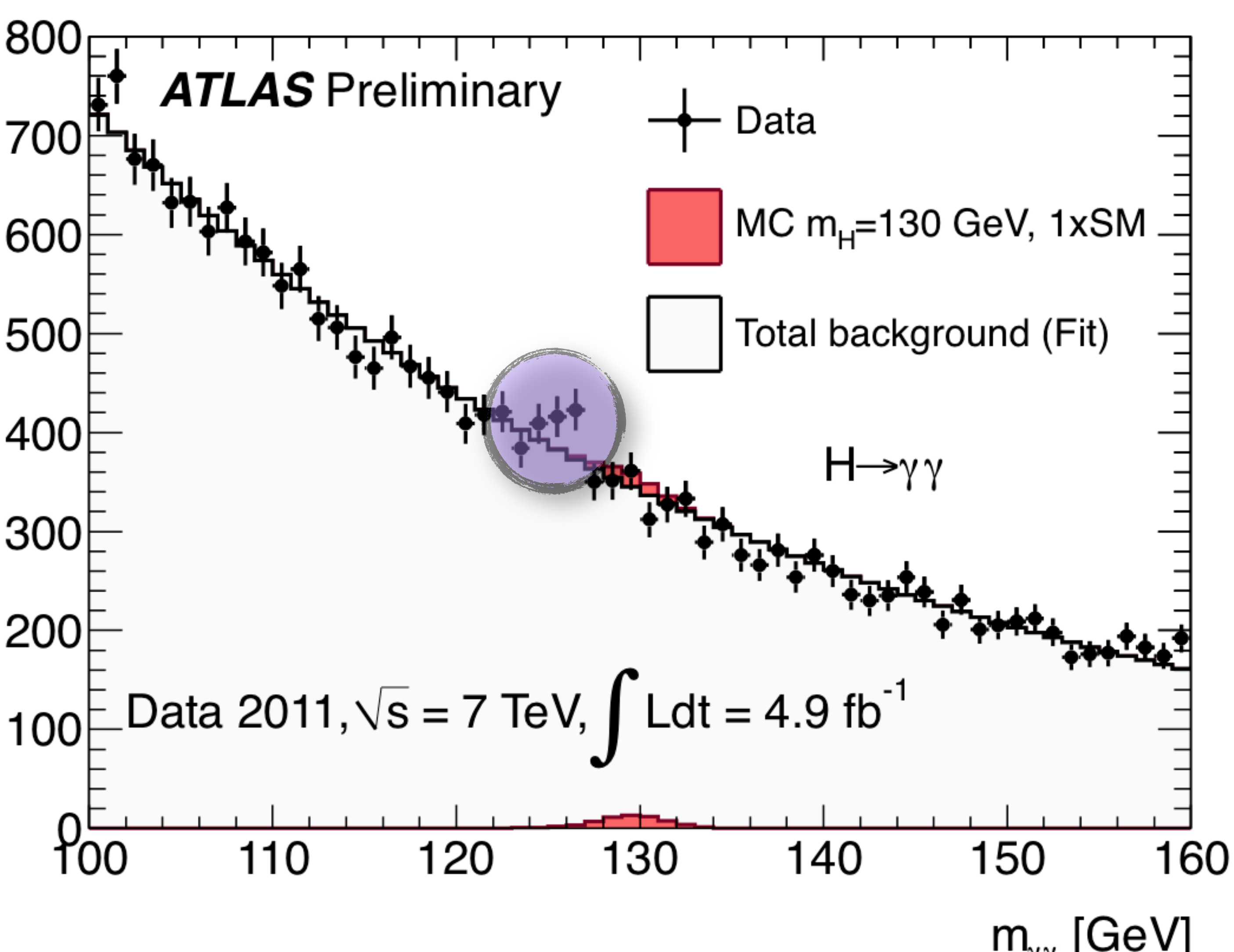

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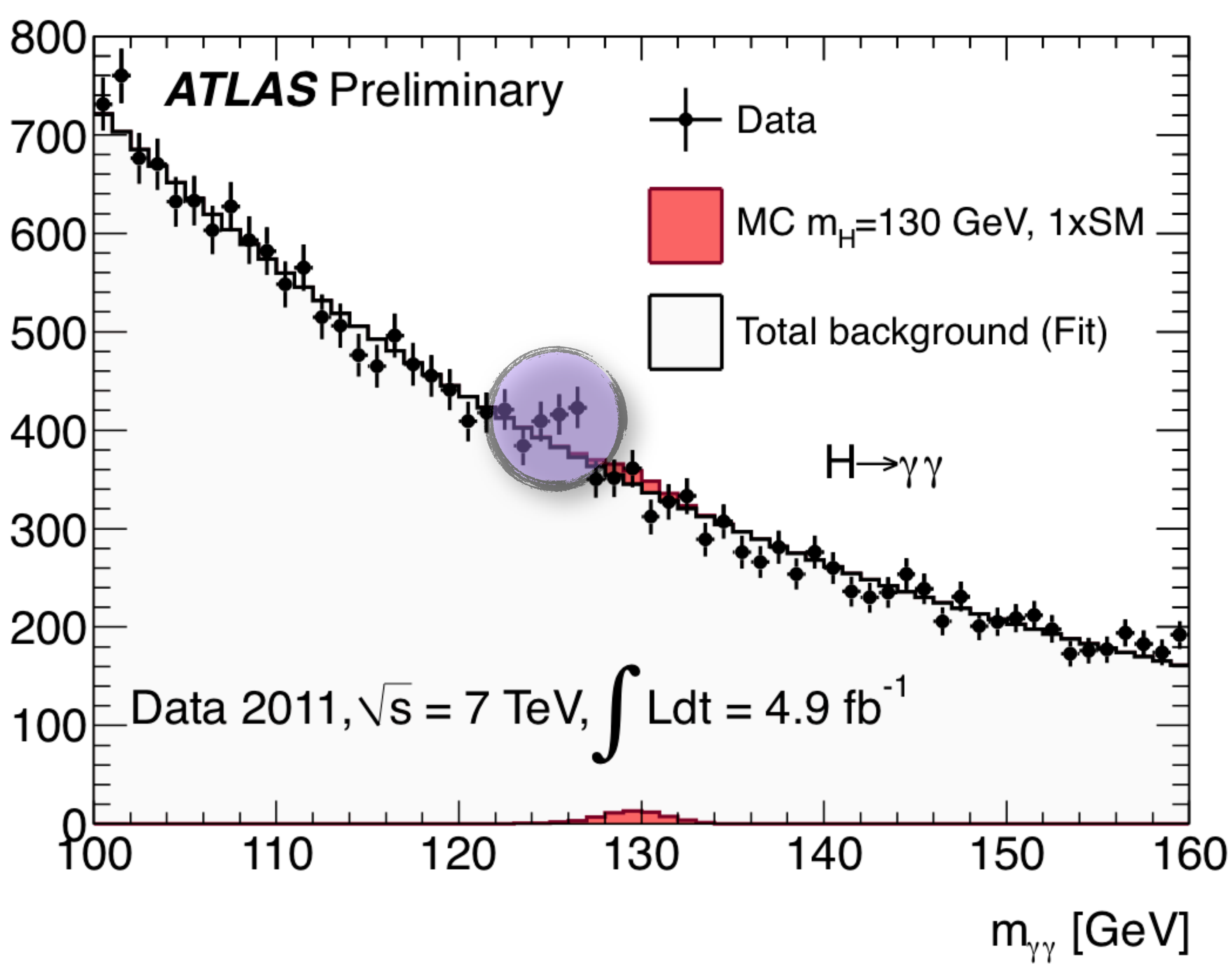

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  - Low scale SUSY ?
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Di Vecchia, like the eta pirme

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- What kind of models can do this?

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Dietrich, Sannino, Tuominen hep-ph/0510217

Dietrich, Sannino hep-ph/0611341

ν critical exponent

N_f^c critical number of techniflavors for conformality

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Calculable perturbative examples

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Calculable perturbative examples

Grinstein, Uttayarat 1105.2370

Antipin, Mojaza, Sannino 1107.2932

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X Compositeness

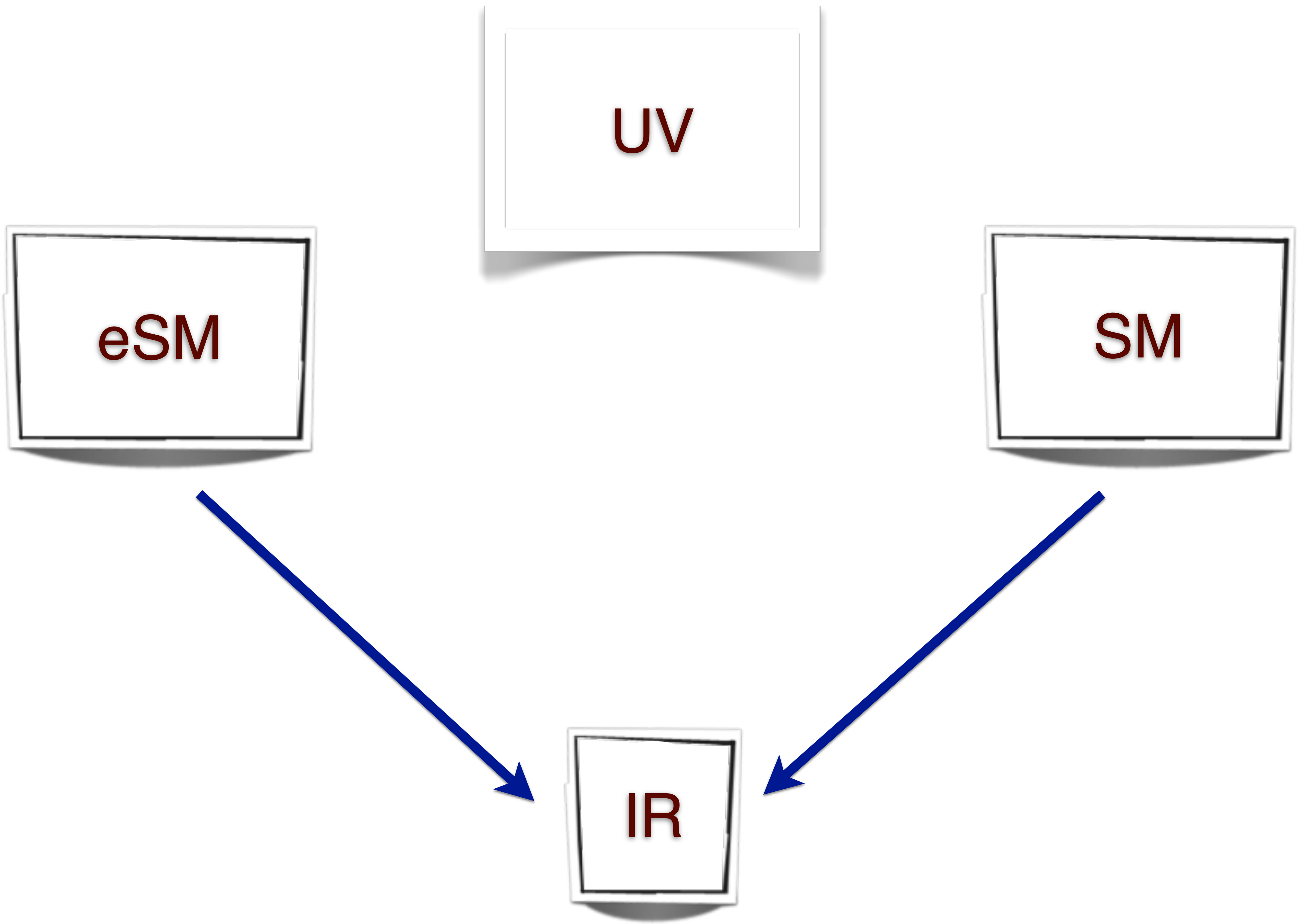
SM goes magnetic

UV

eSM

SM

SM goes magnetic



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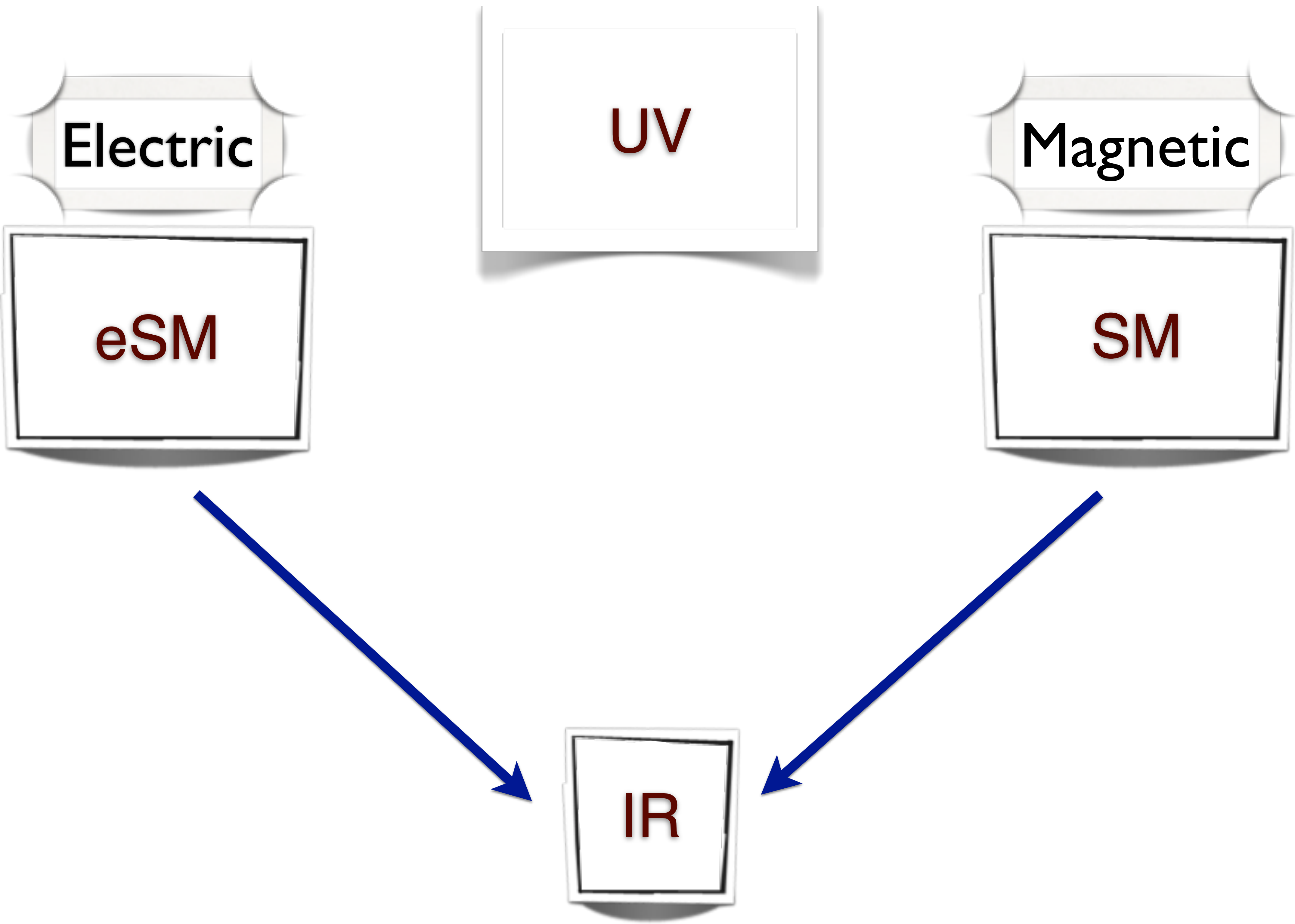

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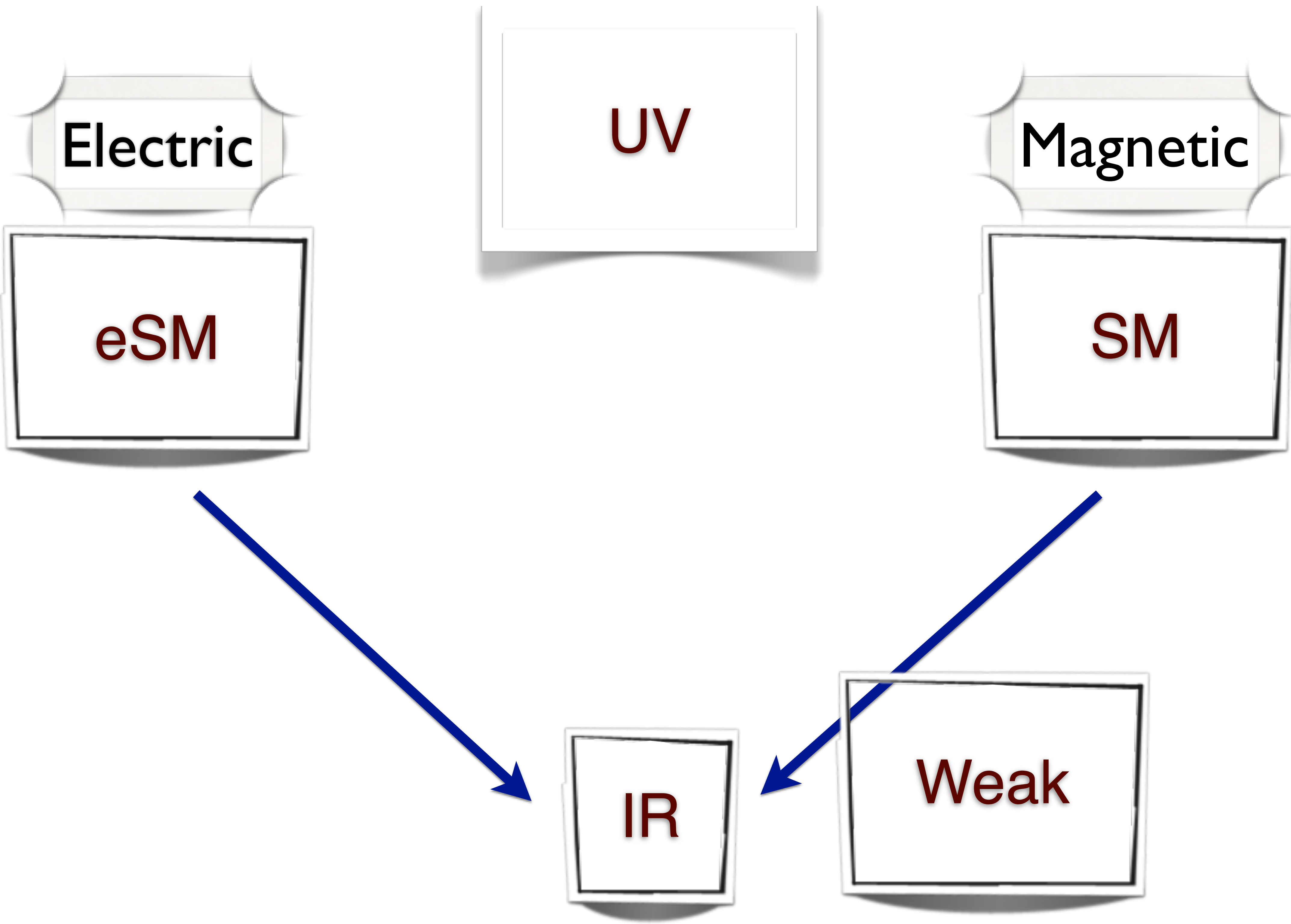

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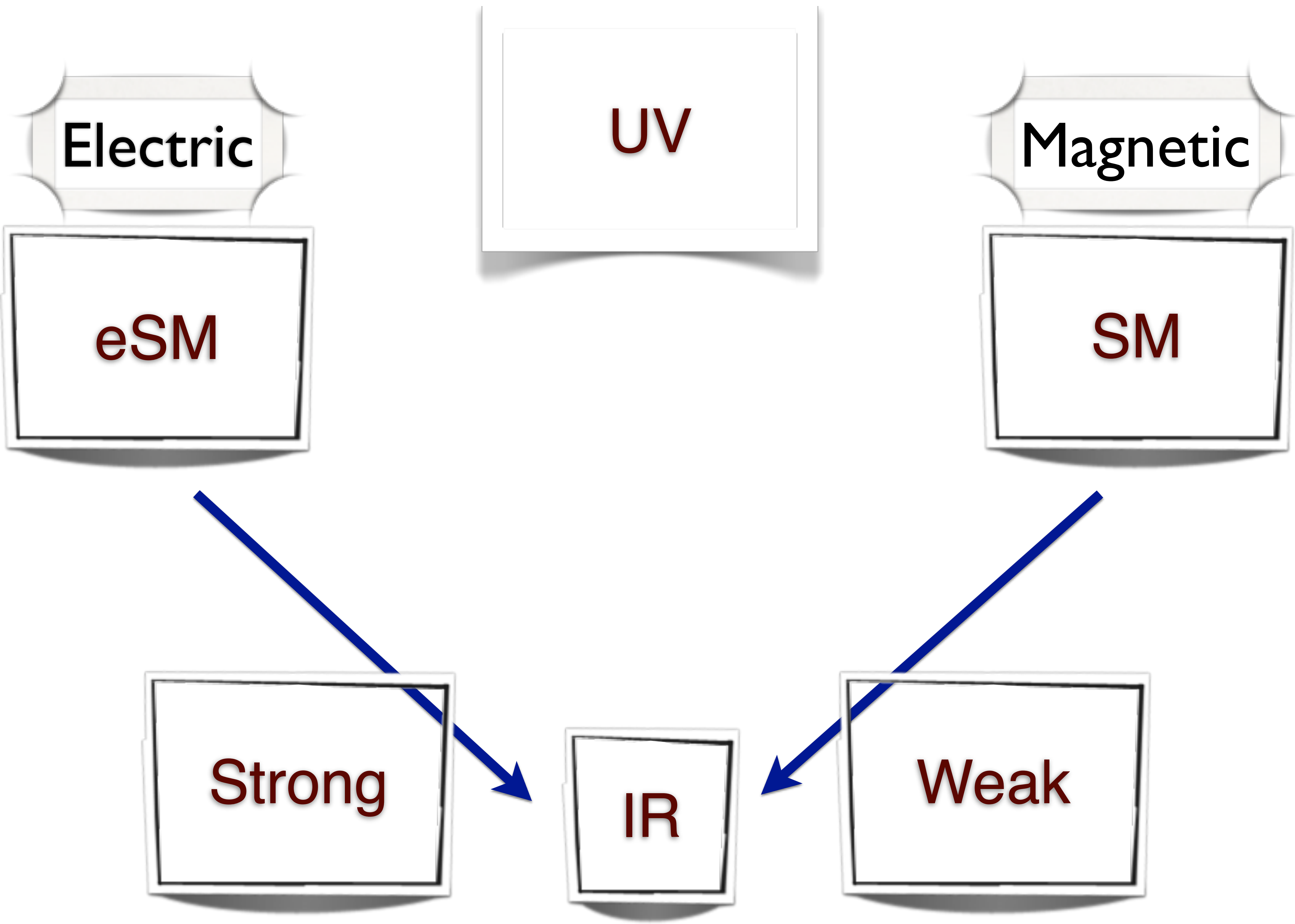
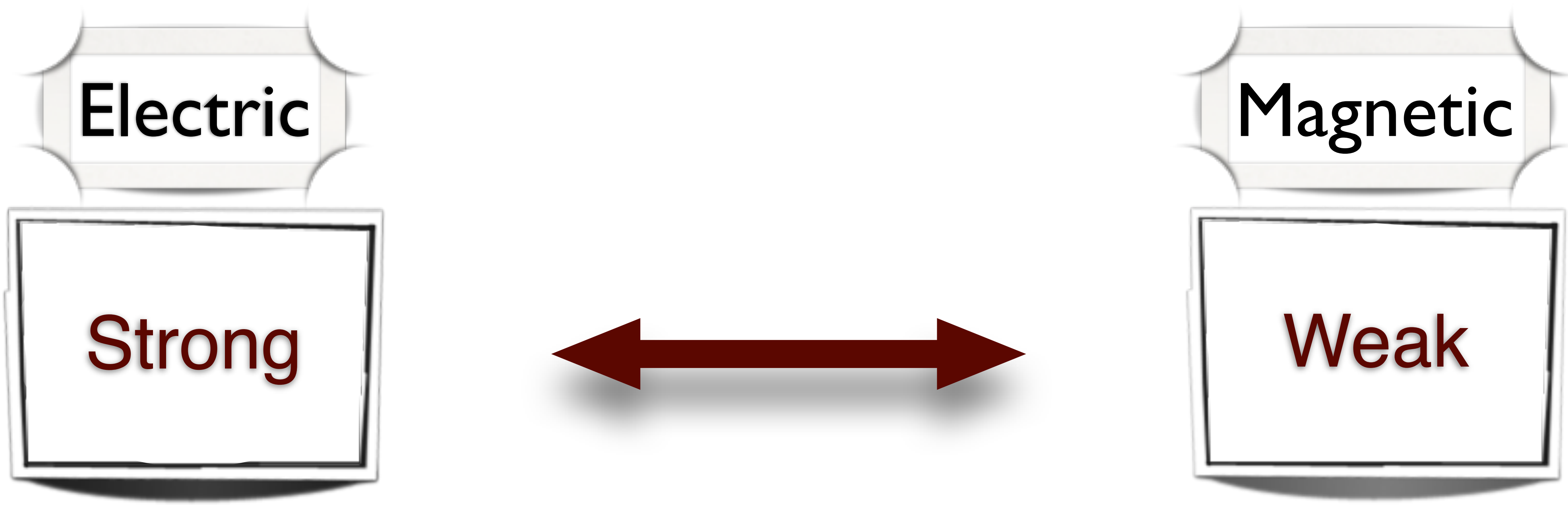


Electro - Magnetic



Electro - Magnetic

Electric

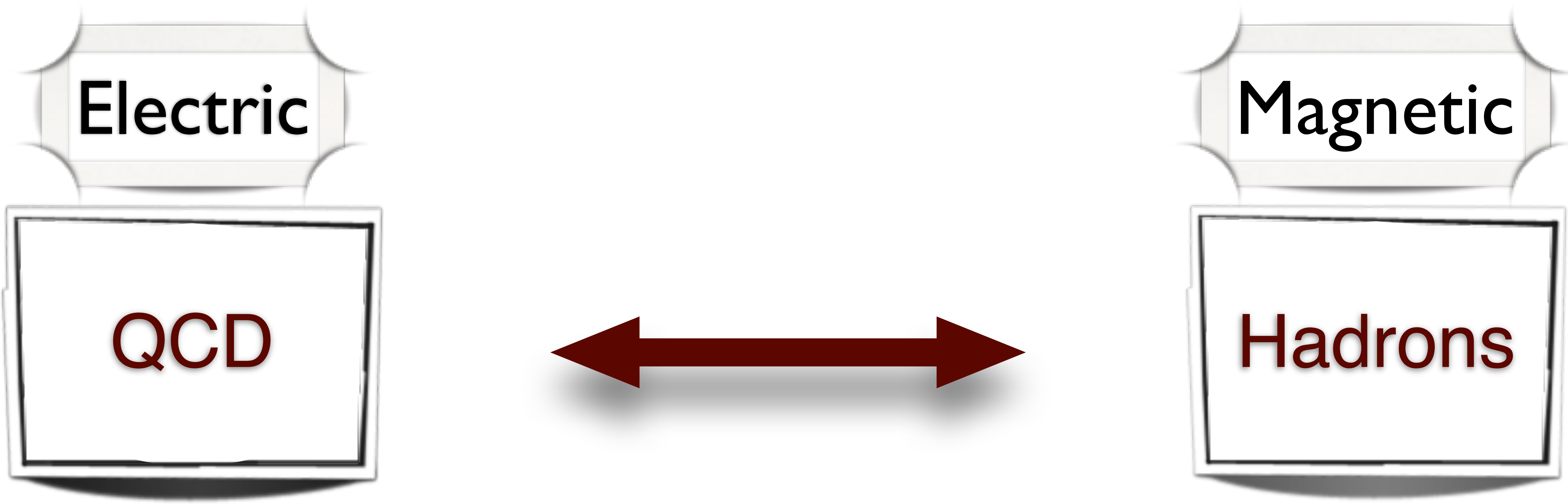
Strong

Magnetic

Weak

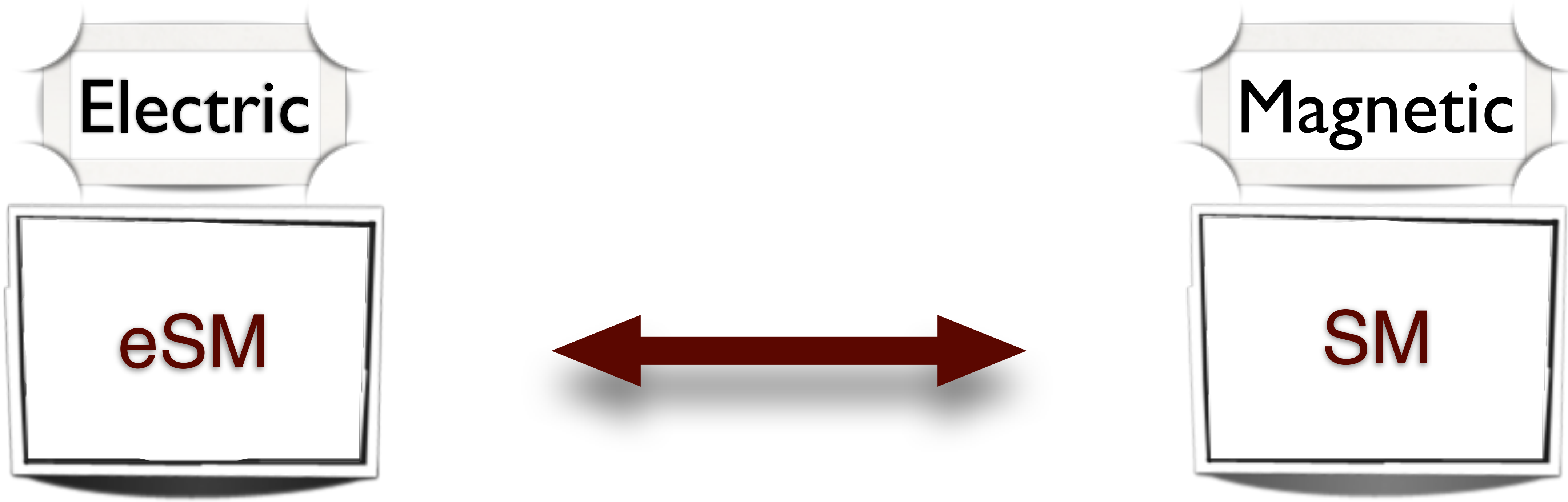
$e\,g = 2\,\pi\,n$

Large N QCD is an example



No fundamental scalars in the electric description

eSM contains only fermions



Could one explain why we have at least 3 families?

A SM-like example

Fields	$[SU(3)]$	$SU(N_f)_L$	$SU(N_f)_R$
q	$\square$	$\overline{\square}$	1
$\widetilde{q}$	$\overline{\square}$	1	$\square$
l	1	$\overline{\square}$	1
$\widetilde{l}$	1	1	$\square$
H	1	$\square$	$\overline{\square}$

$$N_f = 2n_g$$

Pati-Salam Lepton - Quark Unification

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Pati-Salam Lepton - Quark Unification

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p	$\square$	$\overline{\square}$	1
$\widetilde{p}$	$\overline{\square}$	1	$\square$
H	1	$\square$	$\overline{\square}$

A SM-like example

Fields	$[SU(3)]$	$SU(N_f)_L$	$SU(N_f)_R$
q	$\square$	$\overline{\square}$	1
$\widetilde{q}$	$\overline{\square}$	1	$\square$
l	1	$\overline{\square}$	1
$\widetilde{l}$	1	1	$\square$
H	1	$\square$	$\overline{\square}$

$$N_f = 2n_g$$

Pati-Salam Lepton - Quark Unification

Fields	$[SU(4)]$	$SU(N_f)_L$	$SU(N_f)_R$
p	$\square$	$\overline{\square}$	1
$\widetilde{p}$	$\overline{\square}$	1	$\square$
H	1	$\square$	$\overline{\square}$

Adding stuff..

Fields	$[SU(4)]$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_p$	$U(1)_{AF}$
λ_m	Adj	1	1	0	1
p	$\square$	$\overline{\square}$	1	$\frac{2n_g-4}{4}$	$-\frac{4}{2n_g}$
$\widetilde{p}$	$\overline{\square}$	1	$\square$	$-\frac{2n_g-4}{4}$	$-\frac{4}{2n_g}$
Φ_p	$\square$	$\overline{\square}$	1	$\frac{2n_g-4}{4}$	$-\frac{2n_g-4}{2n_g}$
$\widetilde{\Phi}_{\widetilde{p}}$	$\overline{\square}$	1	$\square$	$-\frac{2n_g-4}{4}$	$-\frac{2n_g-4}{2n_g}$
M	1	$\square$	$\overline{\square}$	0	$-1+\frac{8}{2n_g}$
H	1	$\square$	$\overline{\square}$	0	$\frac{8}{2n_g}$

Adding stuff..

Fields	$[SU(4)]$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_p$	$U(1)_{AF}$
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Φ_p	$\square$	$\overline{\square}$	1	$\frac{2n_g-4}{4}$	$-\frac{2n_g-4}{2n_g}$
$\widetilde{\Phi}_{\widetilde{p}}$	$\overline{\square}$	1	$\square$	$-\frac{2n_g-4}{4}$	$-\frac{2n_g-4}{2n_g}$
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- ‘t Hooft AMC
- Flavor Decoupling

Nardecchia, Mojaza, Pica, Sannino 1101.1522

eDual with no scalars!

Fields	$[SU(2n_g - 4)]$	$SU(2n_g)_L$	$SU(2n_g)_R$	$U(1)_p$	$U(1)_{AF}$
λ	Adj	1	1	0	1
p	$\square$	$\square$	1	1	$-\frac{2n_g-4}{2n_g}$
$\widetilde{p}$	$\overline{\square}$	1	$\overline{\square}$	-1	$-\frac{2n_g-4}{2n_g}$

Sannino 1102.5100

eDual with no scalars!

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λ	Adj	1	1	0	1
P	$\square$	$\square$	1	1	$-\frac{2n_g-4}{2n_g}$
$\widetilde{P}$	$\overline{\square}$	1	$\overline{\square}$	-1	$-\frac{2n_g-4}{2n_g}$

- The Higgs in electric variable is:

$$H = P\lambda\lambda\widetilde{P}$$

Sannino 1102.5100

eDual with no scalars!

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$$3 \leq n_g \leq 6$$

Sannino 1102.5100

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Sannino 1102.5100

- Much needs to be tested...

LHC can test X Compositeness

- eSM bound states at the TeV scale

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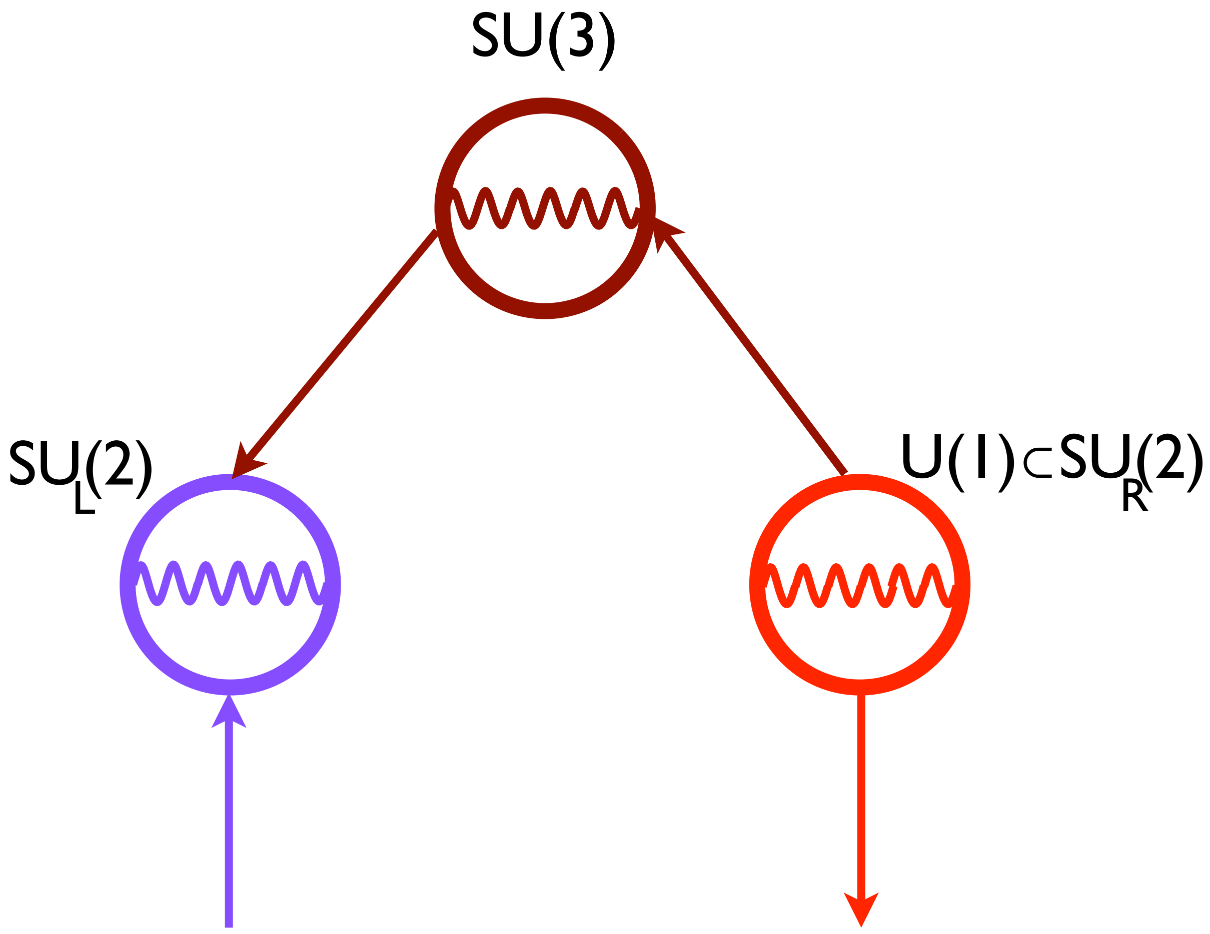
LHC can test X Compositeness

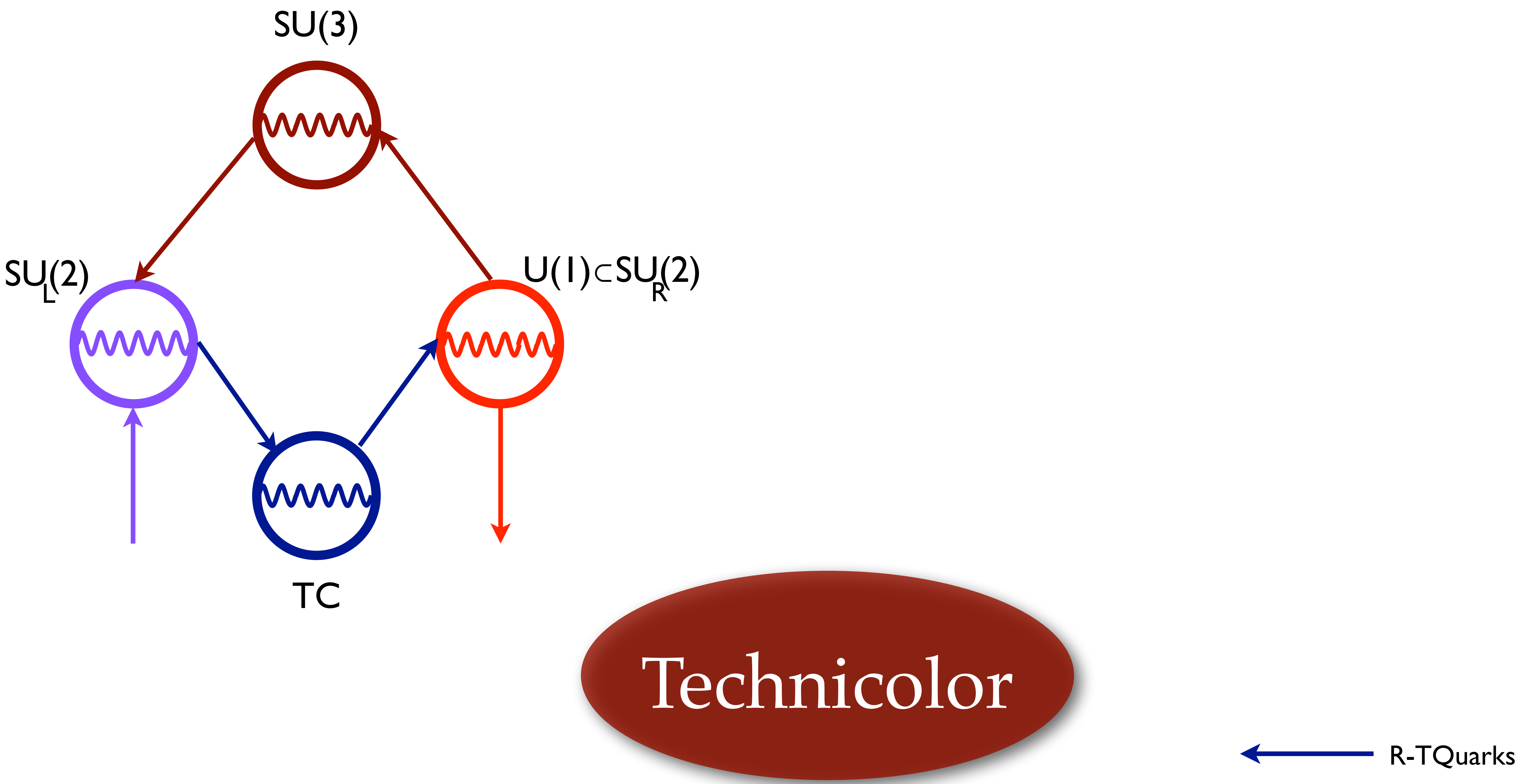
- eSM bound states at the TeV scale
- Vector like top particles
- Ordinary Higgs + excitations
- Non Higgs composite scalars

Back to Technicolor

Technicolor



Technicolor



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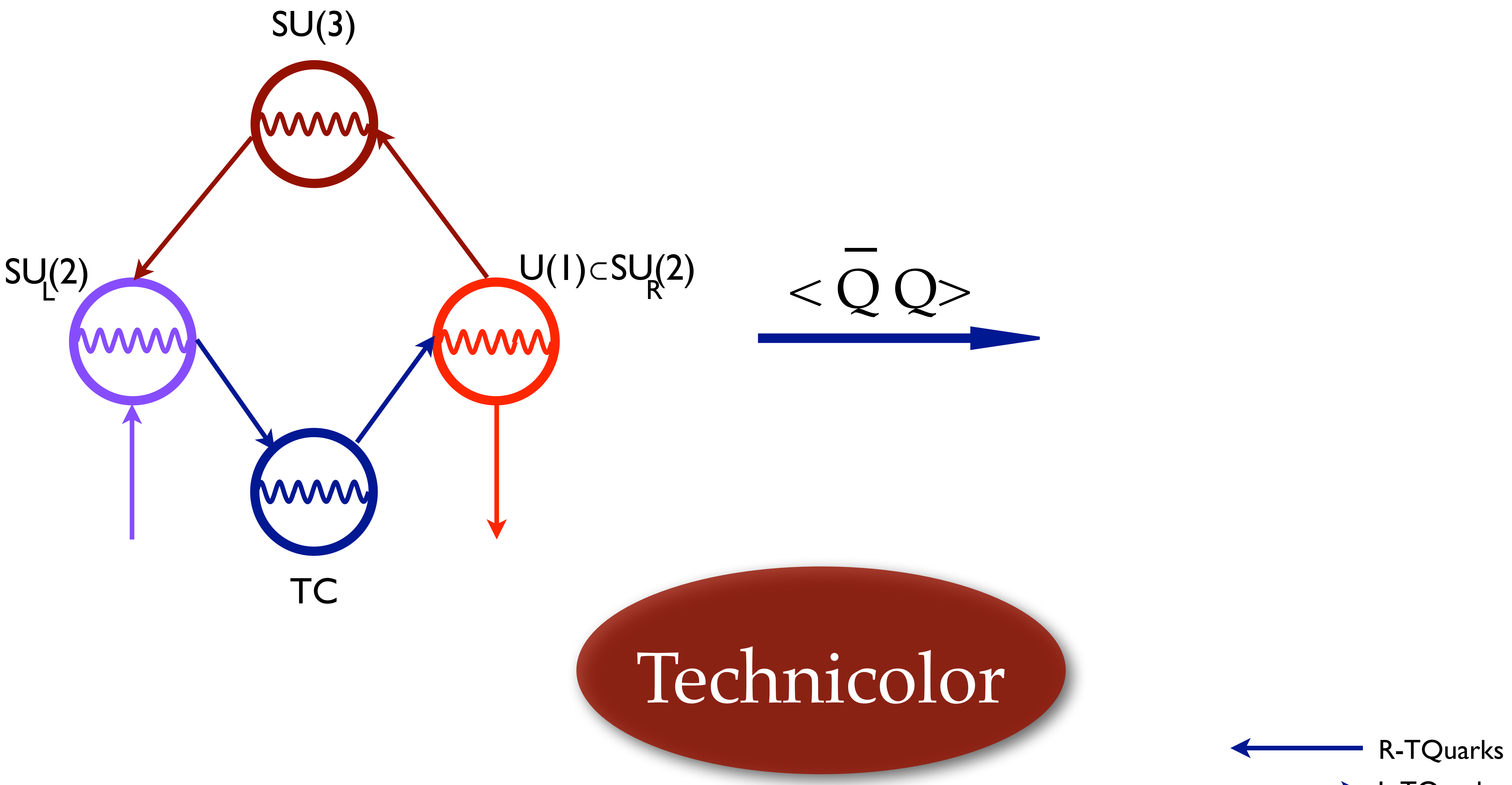

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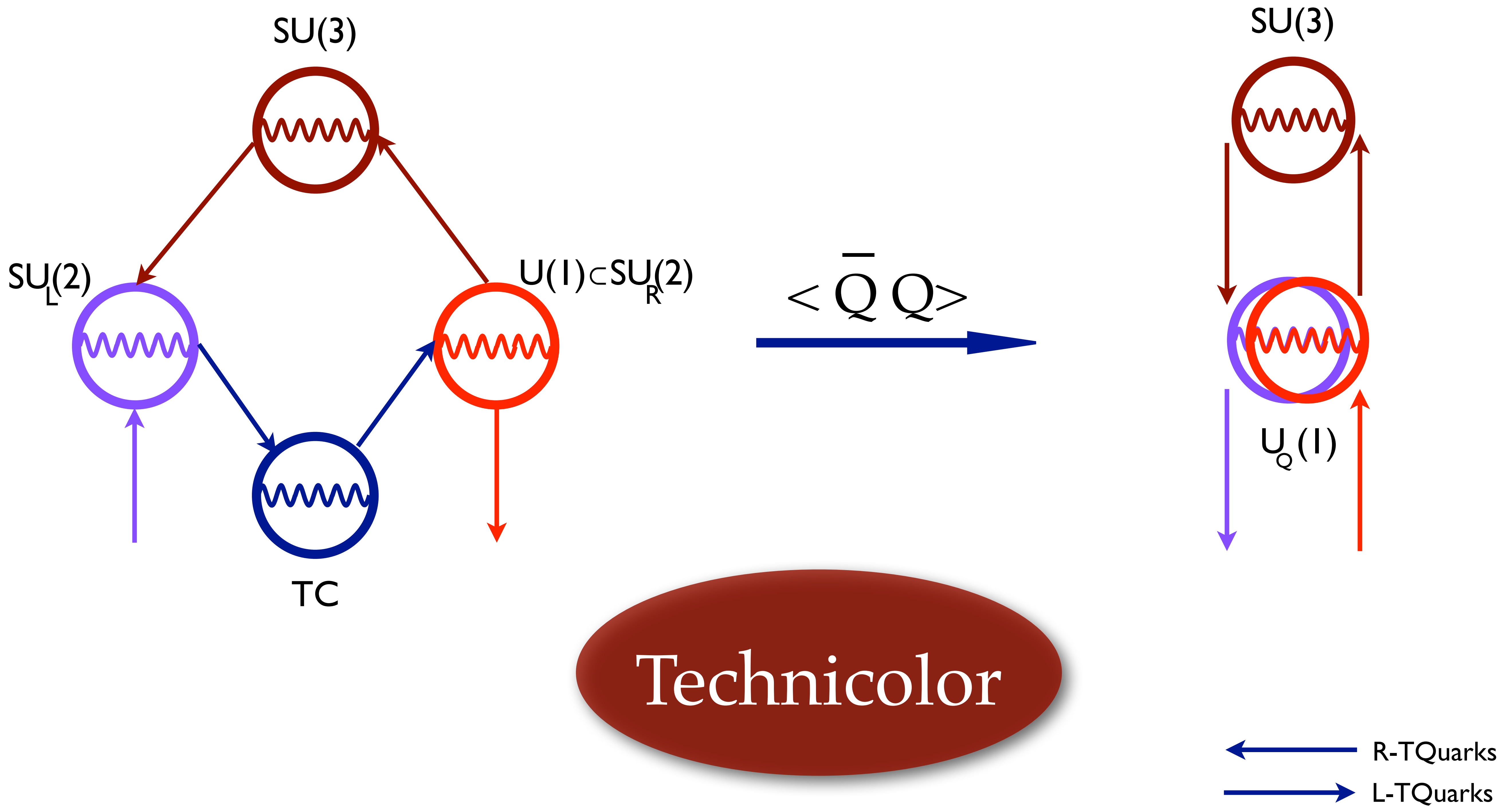

Dynamical EW Breaking

Dynamical EW Breaking

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

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Dots are partially fixed by Anomalies as well as other principles

Dynamical EW Breaking

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$$\cdots \qquad \longrightarrow \qquad L(\text{New SM Fermions})$$

QCD-like TC

New Strong Interactions at ~ 250 GeV

[Weinberg, Susskind]

QCD-like TC

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Natural to use QCD-like dynamics.

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

QCD-like TC

New Strong Interactions at ~ 250 GeV
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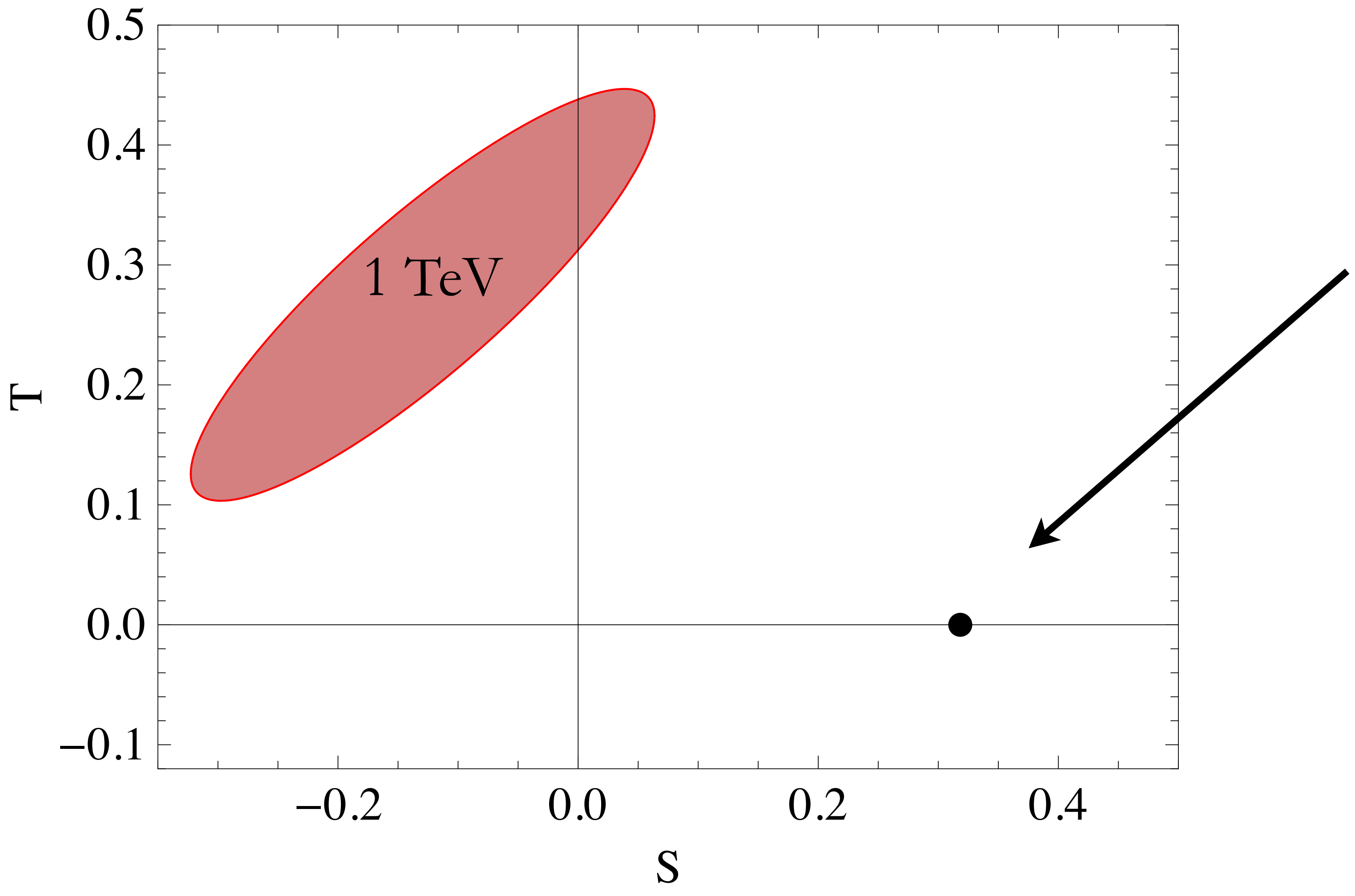
Natural to use QCD-like dynamics.

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

$$\langle Q^f \widetilde{Q}_{f'} \rangle = \Lambda_{TC}^3 \qquad\qquad \Lambda_{TC} \simeq 1 \text{ TeV}$$

Need novel dynamics

Large & Positive S from QCD-like Technicolor



SU(3) + 1 Fund. Doublet

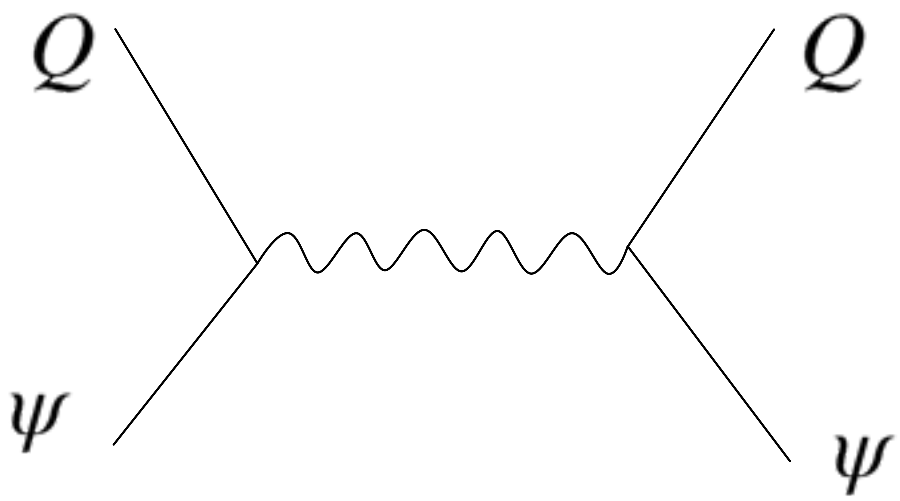
Weinberg, Susskind

SM Fermion Masses

Extending Technicolor

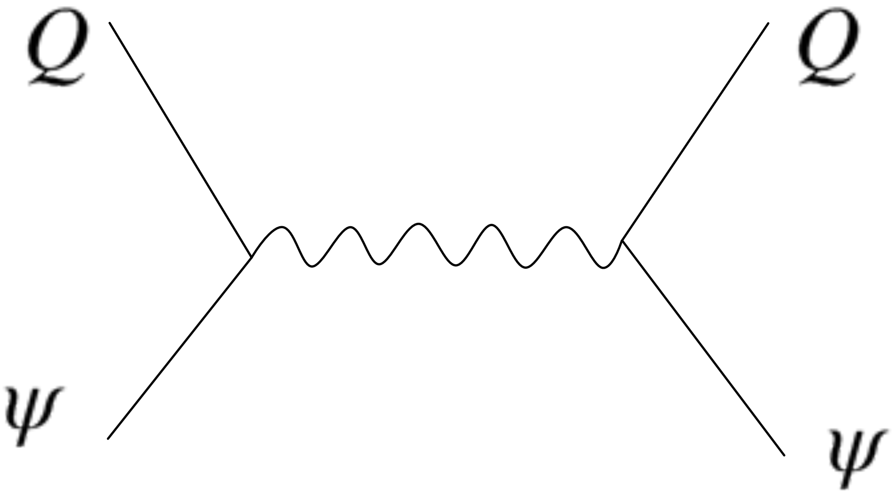
$$\bar{L} \cdot H e_R \qquad \rightarrow \qquad \bar{L} \frac{\bar{Q} Q}{\Lambda_{ETC}^2} e_R$$

Extended Technicolor



Eichten & Lane 80

Extended Technicolor

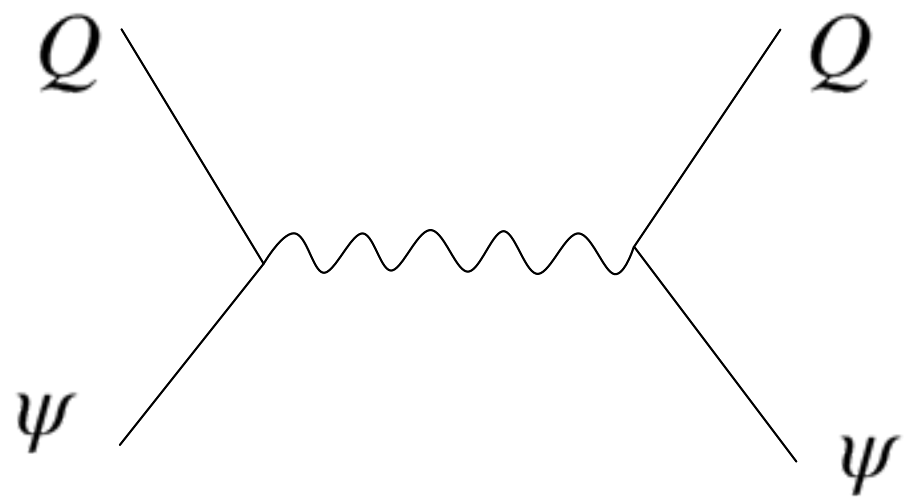


Eichten & Lane 80

Recent investigations

Ryttov & Shrock 10

Extended Technicolor



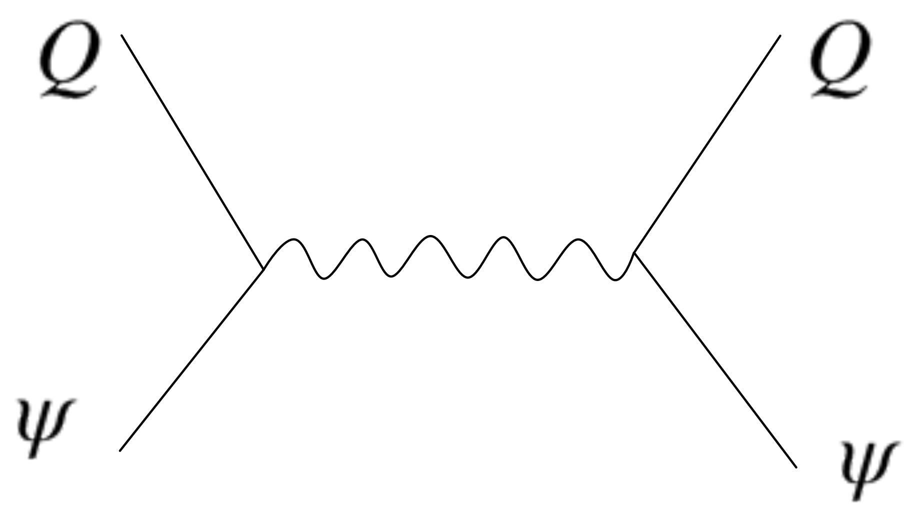
Eichten & Lane 80

Recent investigations

Ryttov & Shrock 10

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

Extended Technicolor



Eichten & Lane 80

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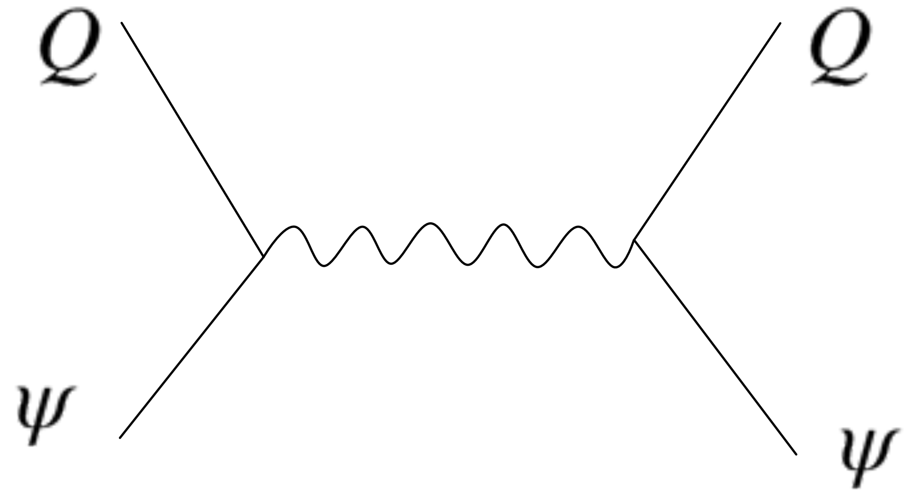
PNG
Masses

Extended Technicolor



Eichten & Lane 80

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Ryttov & Shrock 10

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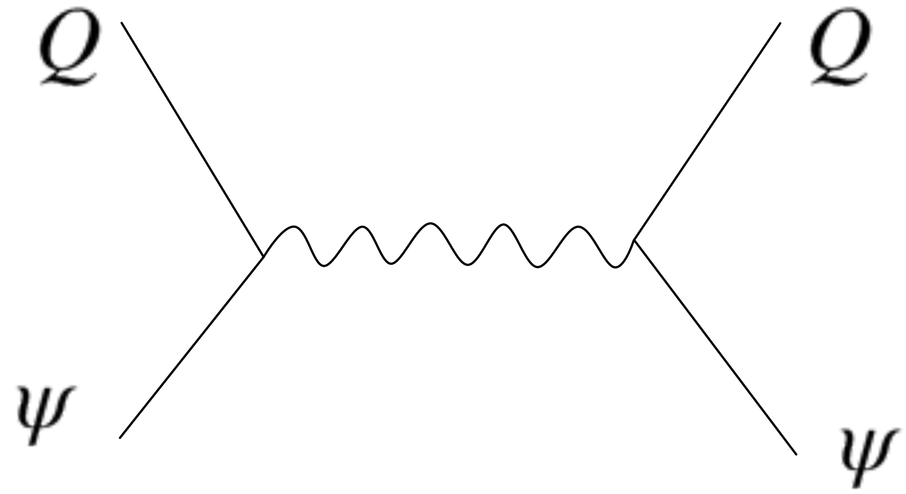
PNG
Masses

SM-Fermion
Masses

Extended Technicolor



Eichten & Lane 80

Recent investigations
Ryttov & Shrock 10

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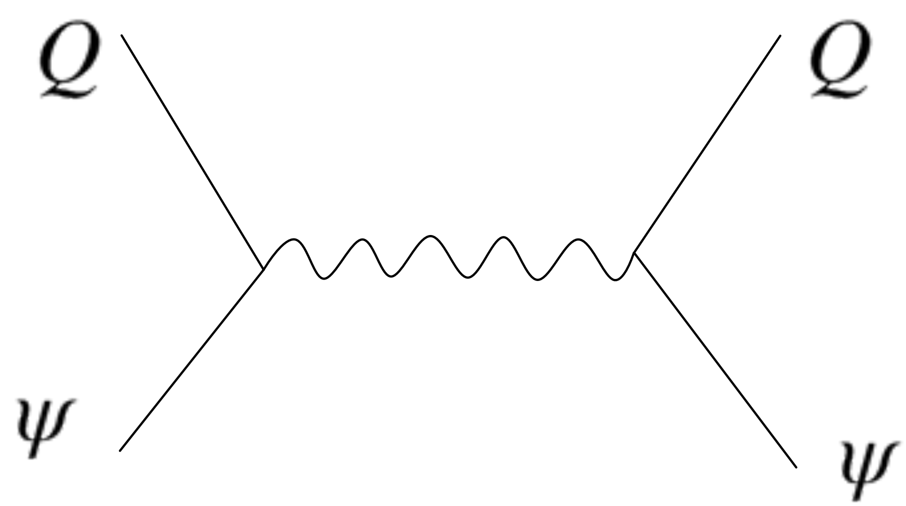
PNG
Masses

SM-Fermion
Masses

FCNC
Operators

Extended Technicolor



Eichten & Lane 80

Recent investigations

Ryttov & Shrock 10

Fukano, Sannino 10

Modifies TC dynamics

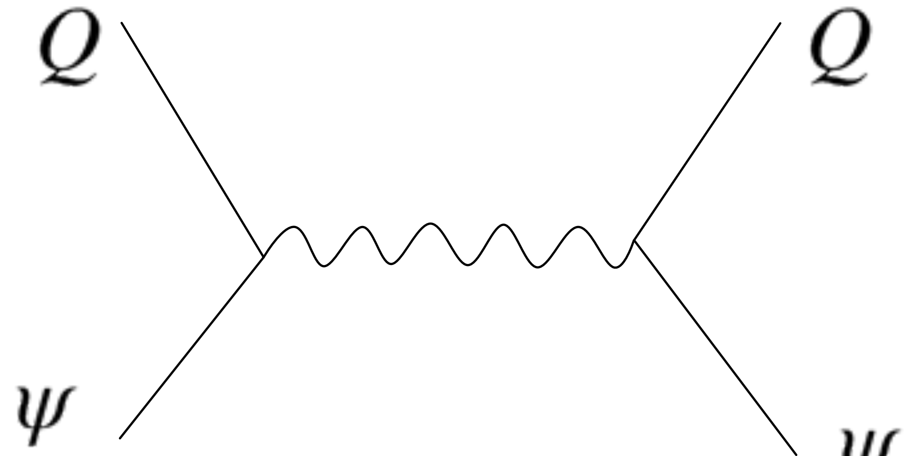
$$\alpha_{ab}\frac{\bar{Q}T^aQ\bar{Q}T^bQ}{\Lambda^2_{ETC}} + \beta_{ab}\frac{\bar{Q}_LT^aQ_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}} + \gamma_{ab}\frac{\bar{\psi}_LT^a\psi_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}} + \dots$$

PNG Masses

SM-Fermion Masses

FCNC Operators

Extended Technicolor



Eichten & Lane 80

Recent investigations

Ryttov & Shrock 10

Fukano, Sannino 10

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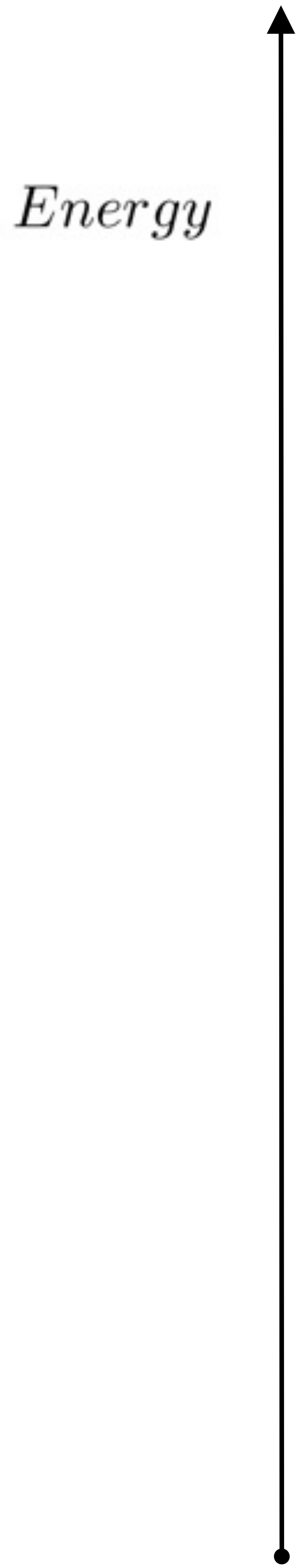
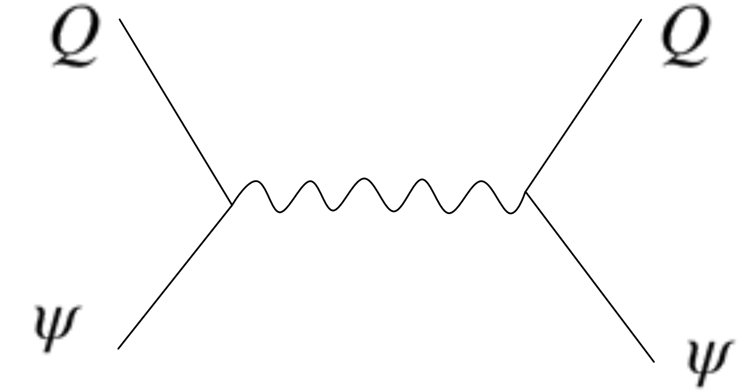
PNG Masses

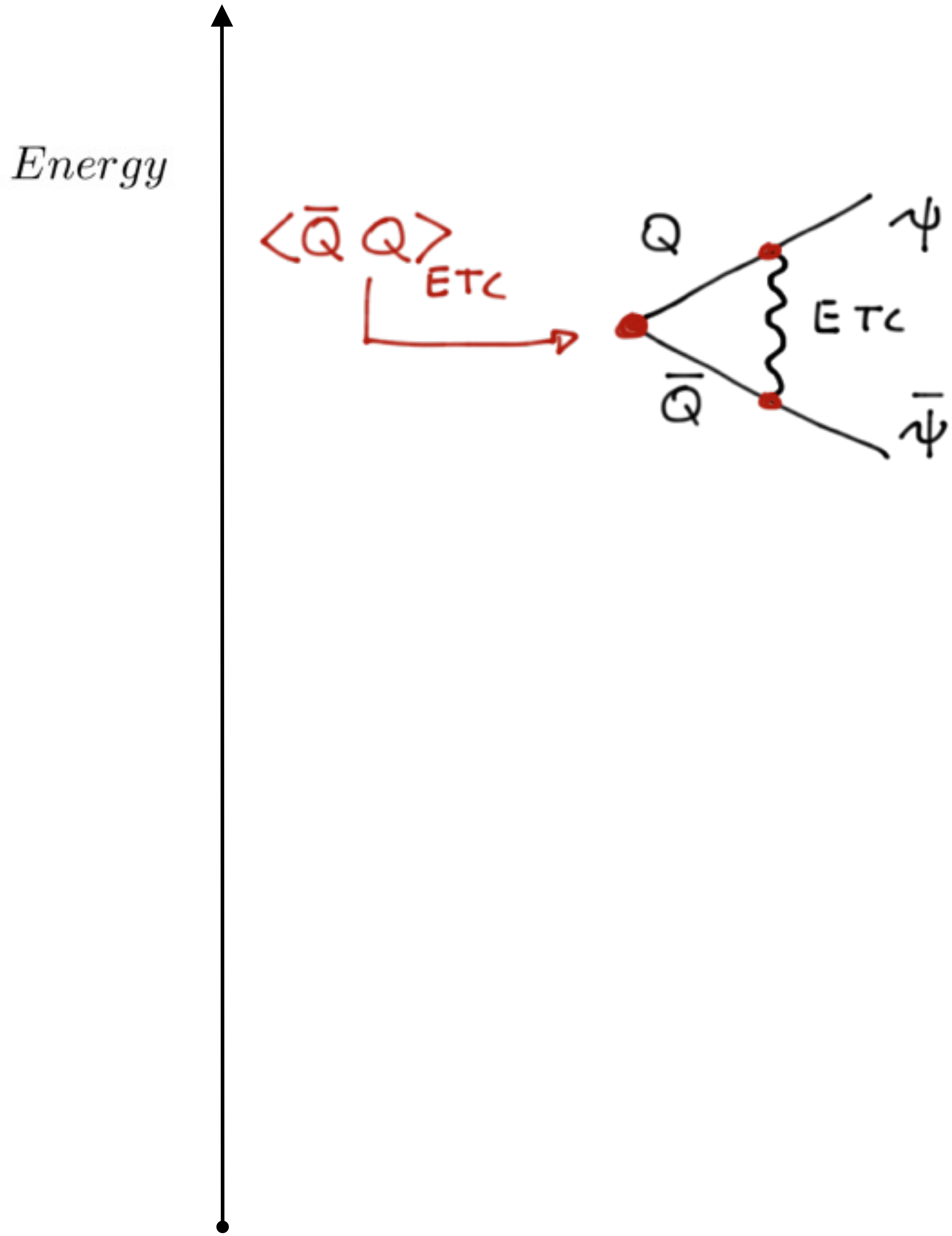
SM-Fermion Masses

FCNC Operators

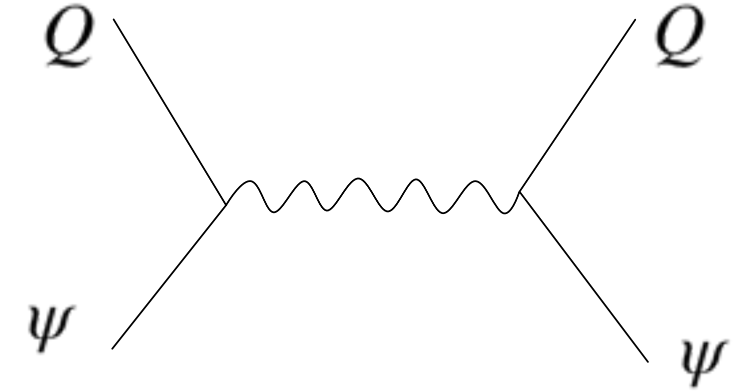
Antola, Di Chira, Sannino, Tuominen 10,11


$Energy$

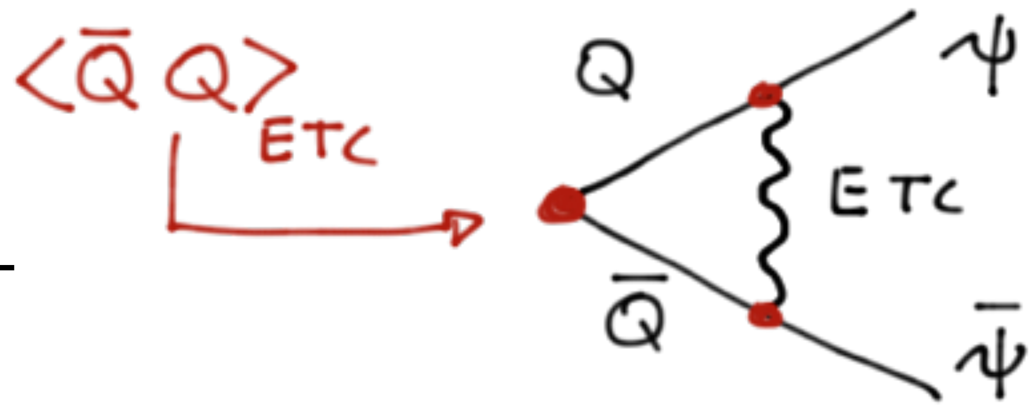

Q
Q
ψ
ψ

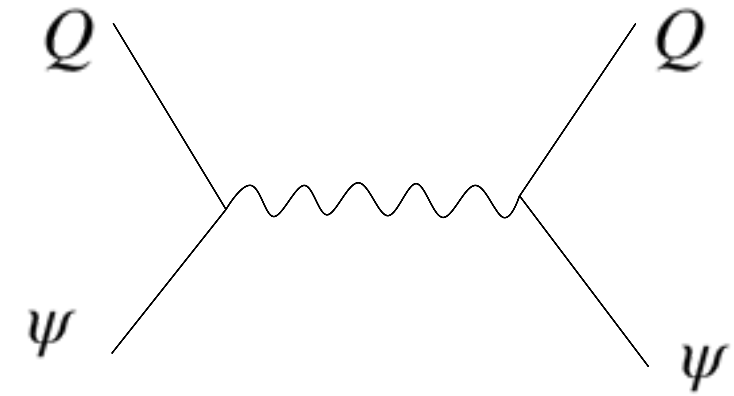


$Energy$
$\langle \bar{Q} Q \rangle_{ETC}$
Q
ETC
$\bar{Q}$
ψ
$\bar{\psi}$

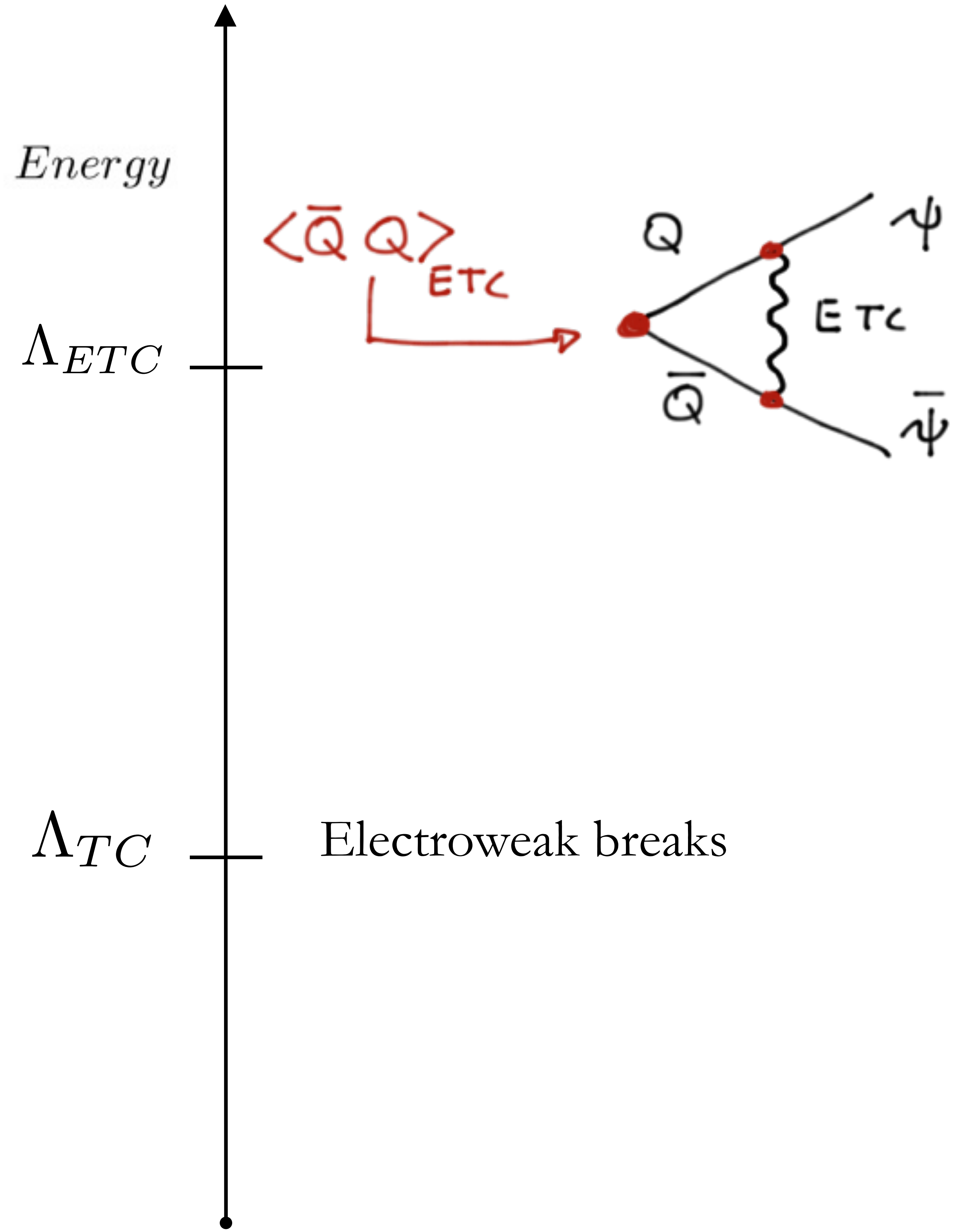


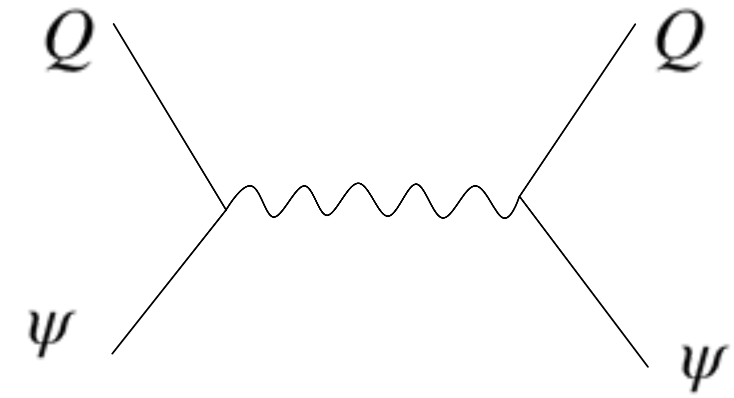
Q
Q
ψ
ψ





$$m_{\mathrm{f}} \approx \frac{g^2_{ETC}}{\Lambda^2_{ETC}} < \bar{Q}Q >_{ETC}$$





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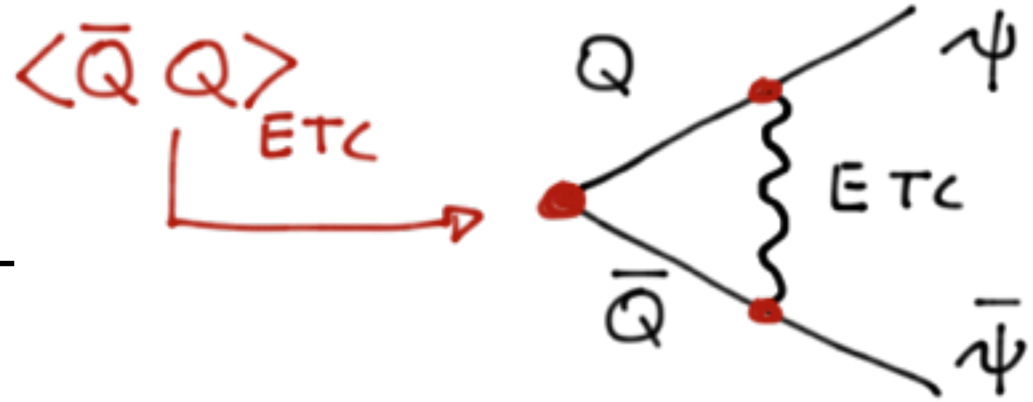
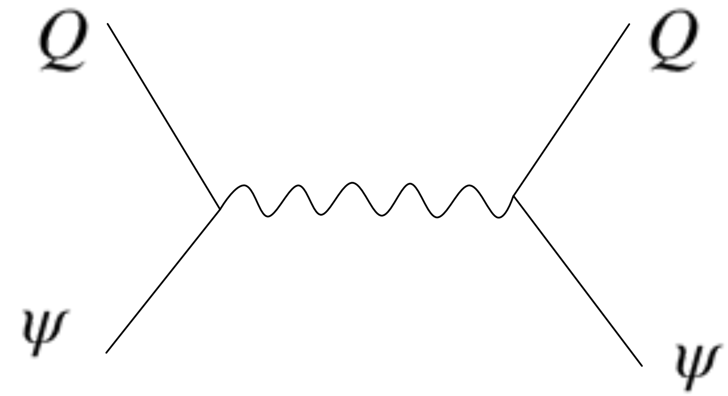


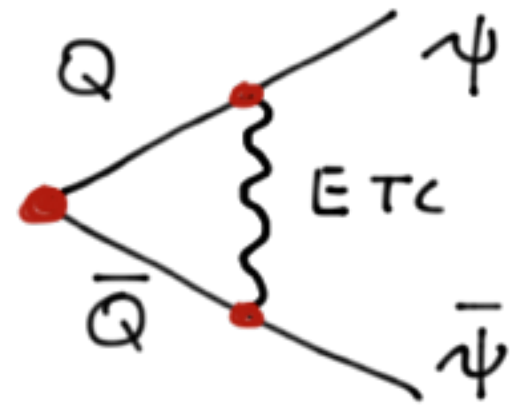


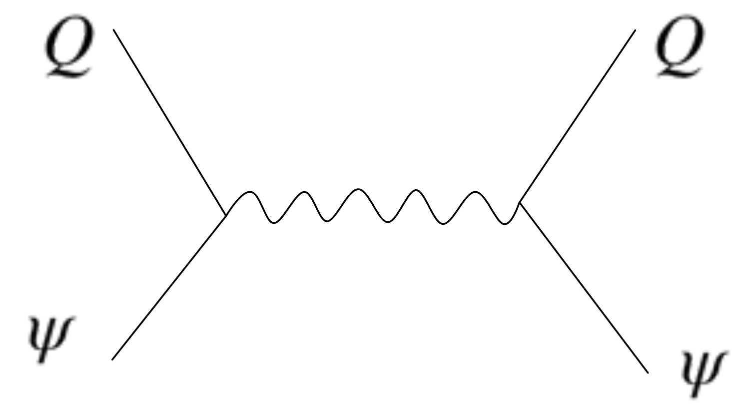
$$m_{\rm f} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC}$$

Electroweak breaks

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

$\langle \bar{Q} Q \rangle_{ETC}$





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$$\boxed{m_{\mathrm{f}} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC} \quad \ll \quad m_{\mathrm{Top}}}$$

Need to go beyond QCD

Walking

$$\delta = n_f - n_f^c$$

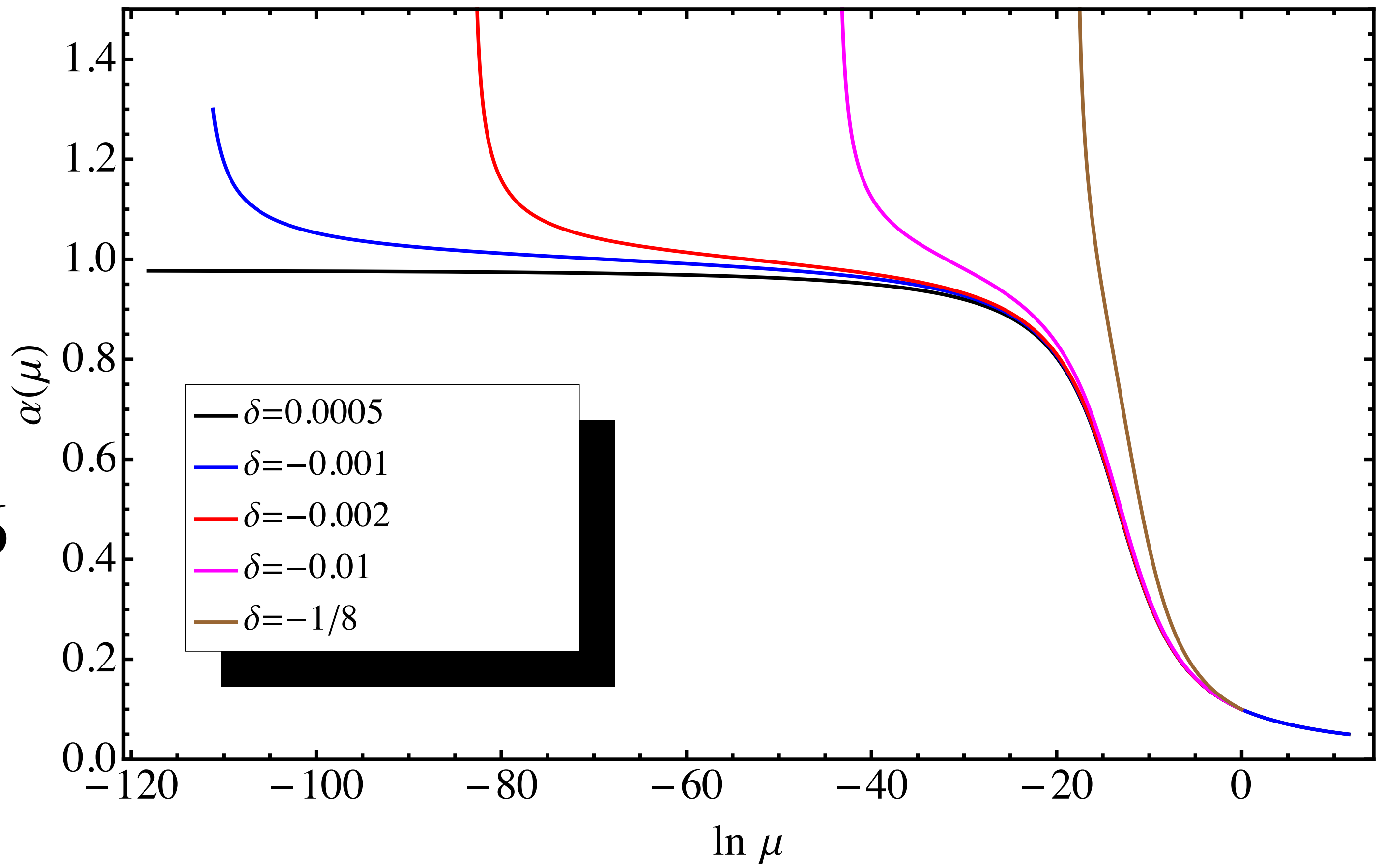
Miransky 85

Miransky & Yamawaki 89

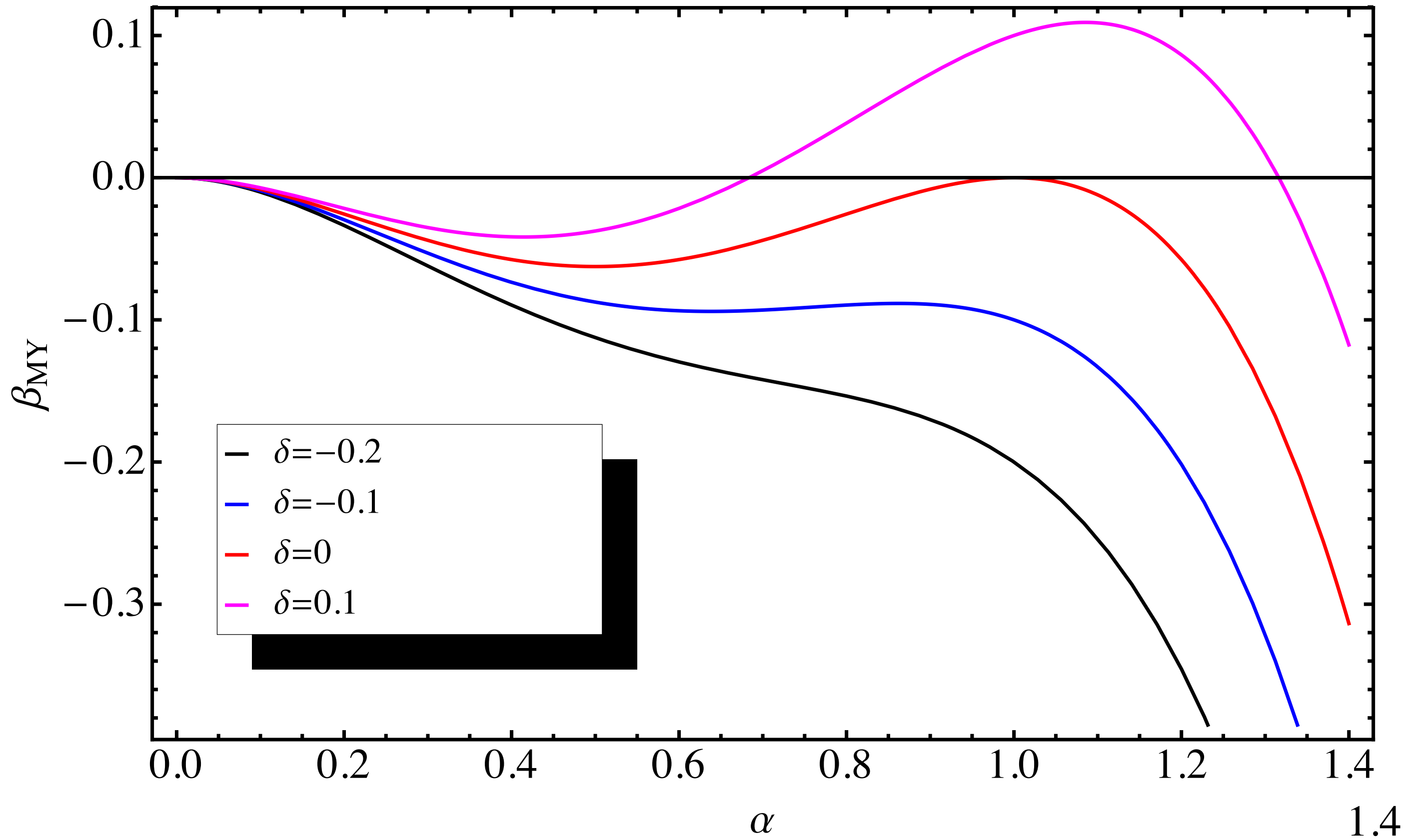
Miransky & Yamawaki 97

Yamawaki, Bando, Matumoto 86

Appelquist, Karabali, Wijewardhana 86



Walking



$$\beta_{MY} = -\alpha^2\left((\alpha-1)^2-\delta\right)$$

$$\delta = n_f - n_f^c$$

Sannino 2012

Miransky 85

Miransky & Yamawaki 89

Miransky & Yamawaki 97

Yamawaki, Bando, Matumoto 86

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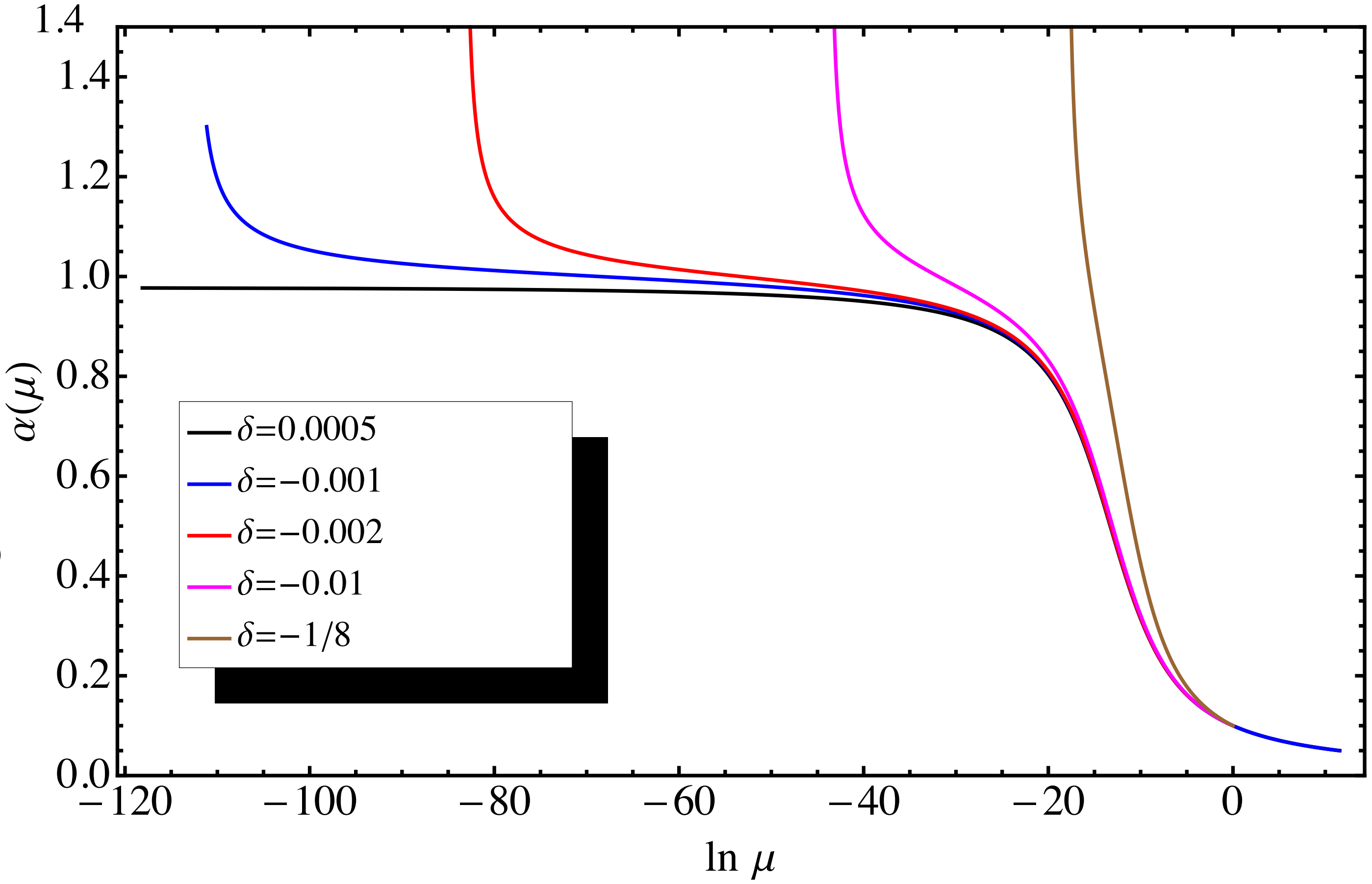

Condensate Enhancement

$$\langle \bar{Q}Q \rangle_\mu = \exp\left(\int_{\alpha(\Lambda)}^{\alpha(\mu)} \mathrm{d}\alpha \frac{\gamma(\alpha)}{-\alpha^2((\alpha-1)^2+|\delta|)} \right) \langle \bar{Q}Q \rangle_\Lambda$$

$$\simeq \exp\left(\gamma(1) \int_{\alpha(\Lambda)}^{\alpha(\mu)} \mathrm{d}\alpha \frac{1}{\beta_{MY}} \right) \langle \bar{Q}Q \rangle_\Lambda \;\; = \left(\frac{\mu}{\Lambda} \right)^{\gamma(1)} \langle \bar{Q}Q \rangle_\Lambda$$

$$m_{\rm f} \approx \frac{g^2_{ETC}}{\Lambda^2_{ETC}} < \bar{Q}Q >_{ETC} = \frac{g^2_{ETC}}{\Lambda^2_{ETC}} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma(\alpha^*)} < \bar{Q}Q >_{TC}$$

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

If large anomalous dimension, around $\gamma(\alpha^*) \sim 1.7$

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

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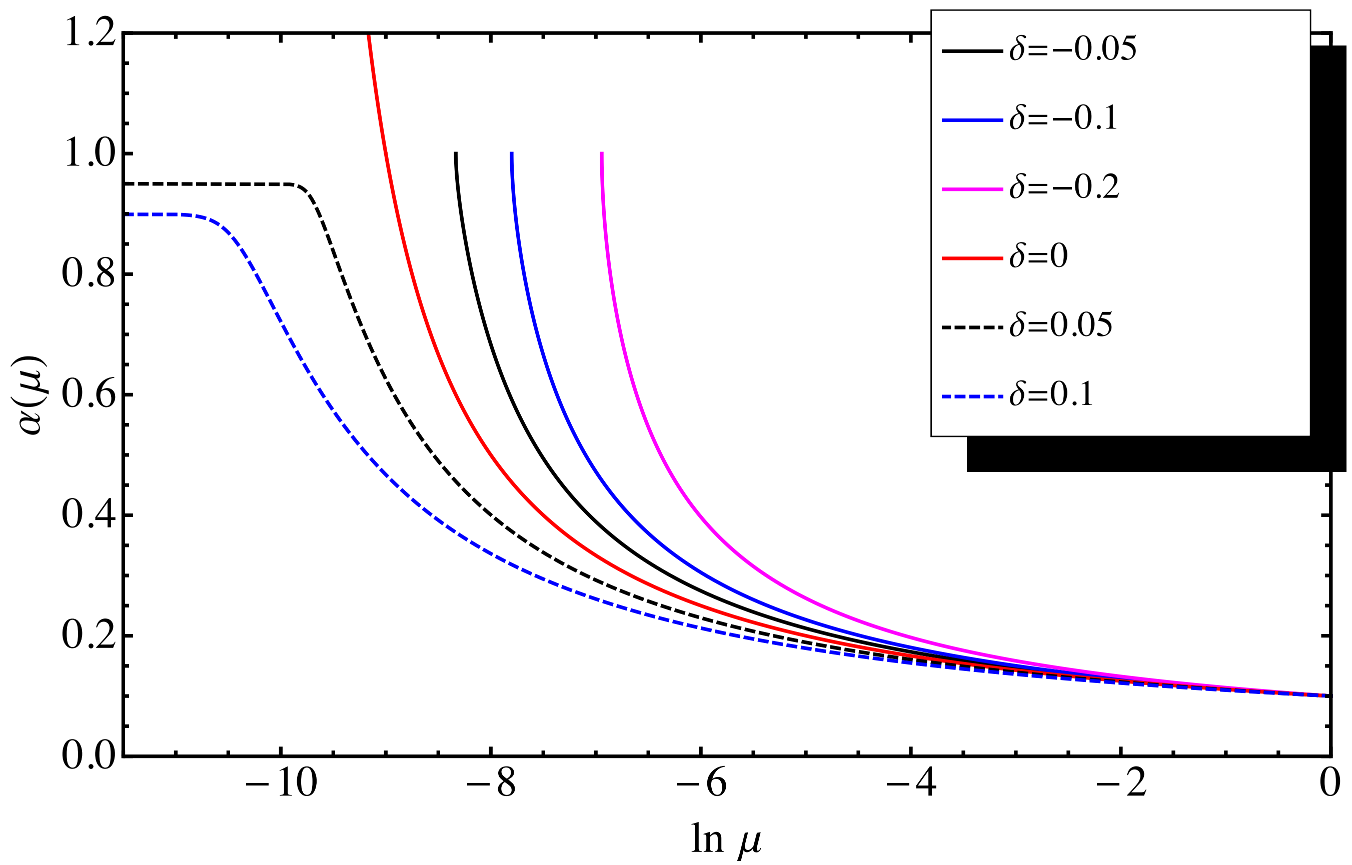
If large anomalous dimension, around $\gamma(\alpha^*) \sim 1.7$

$$\downarrow$$

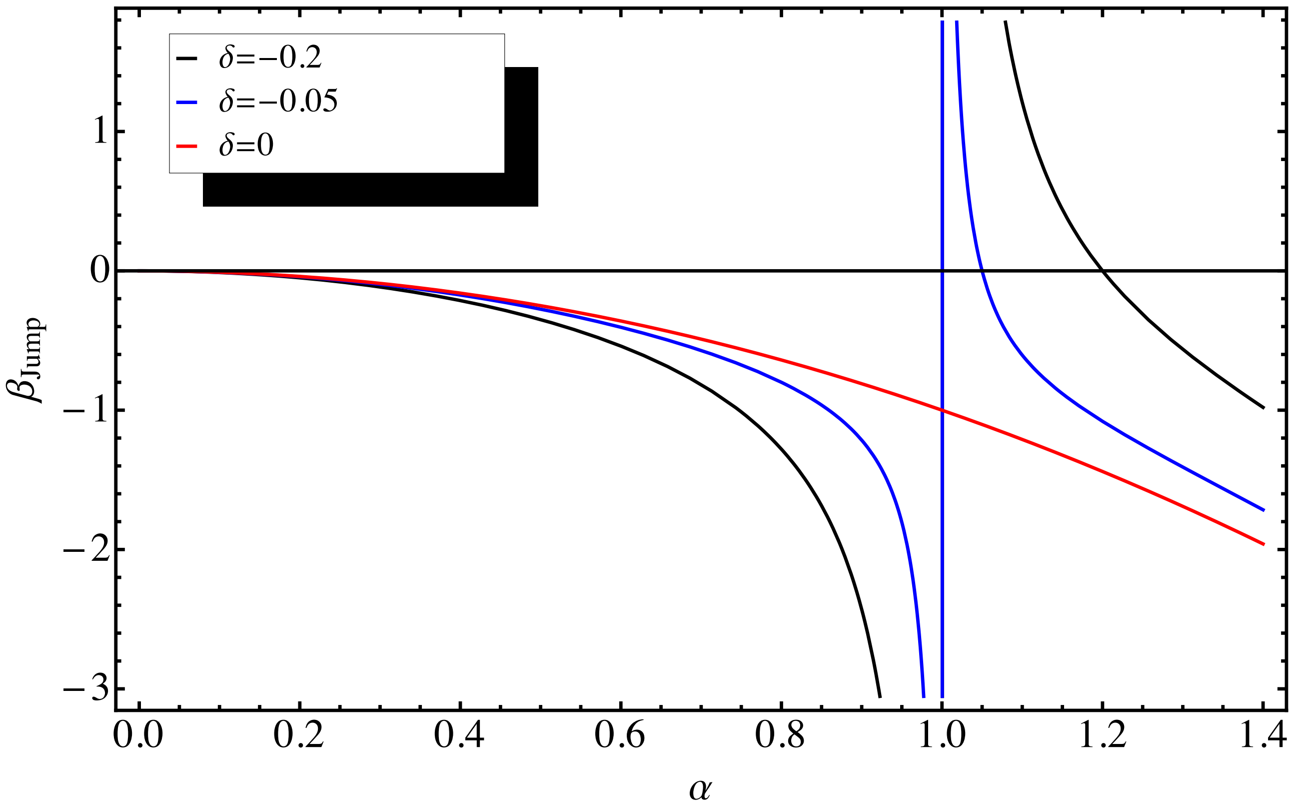
Fermion Mass Enhancement & FCNC decoupling

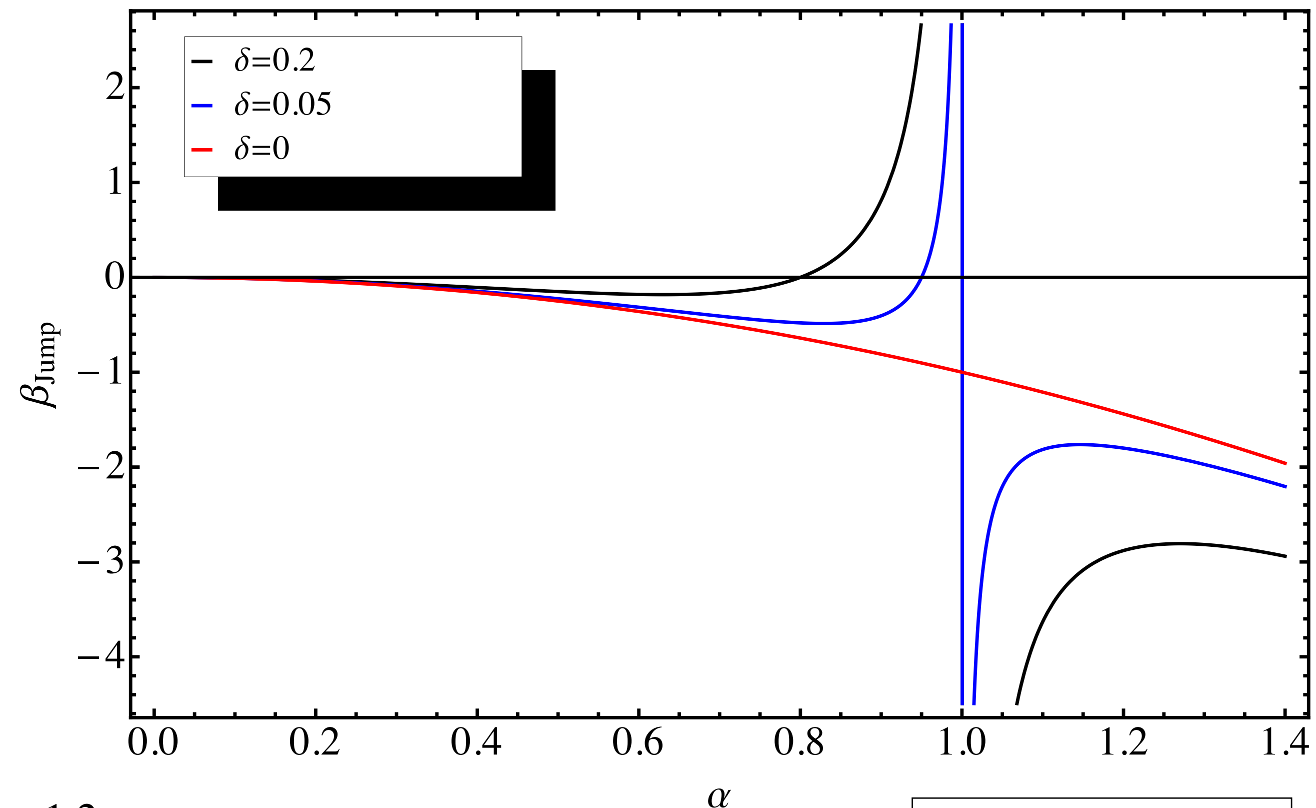
Jumping



Sannino 2012

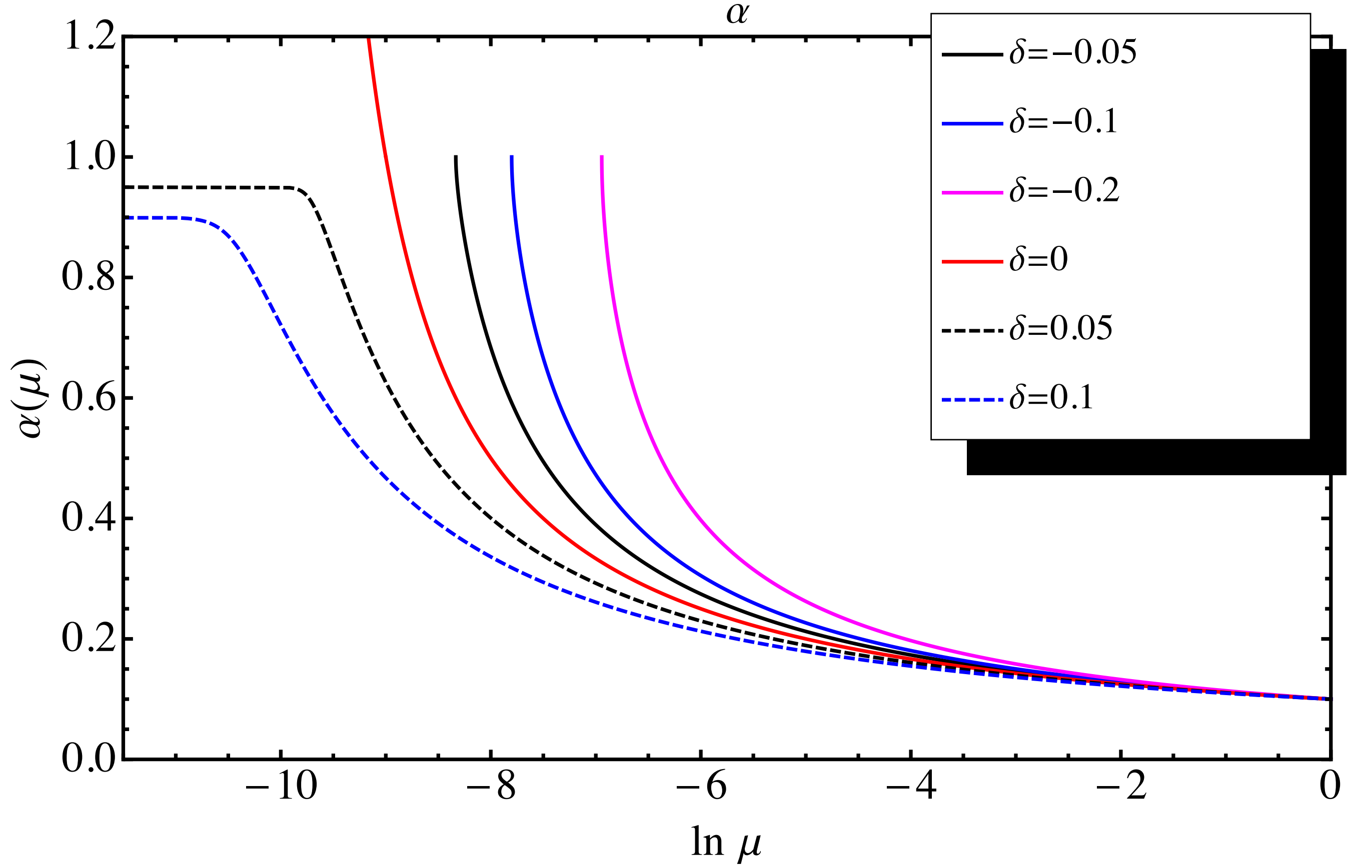
Jumping





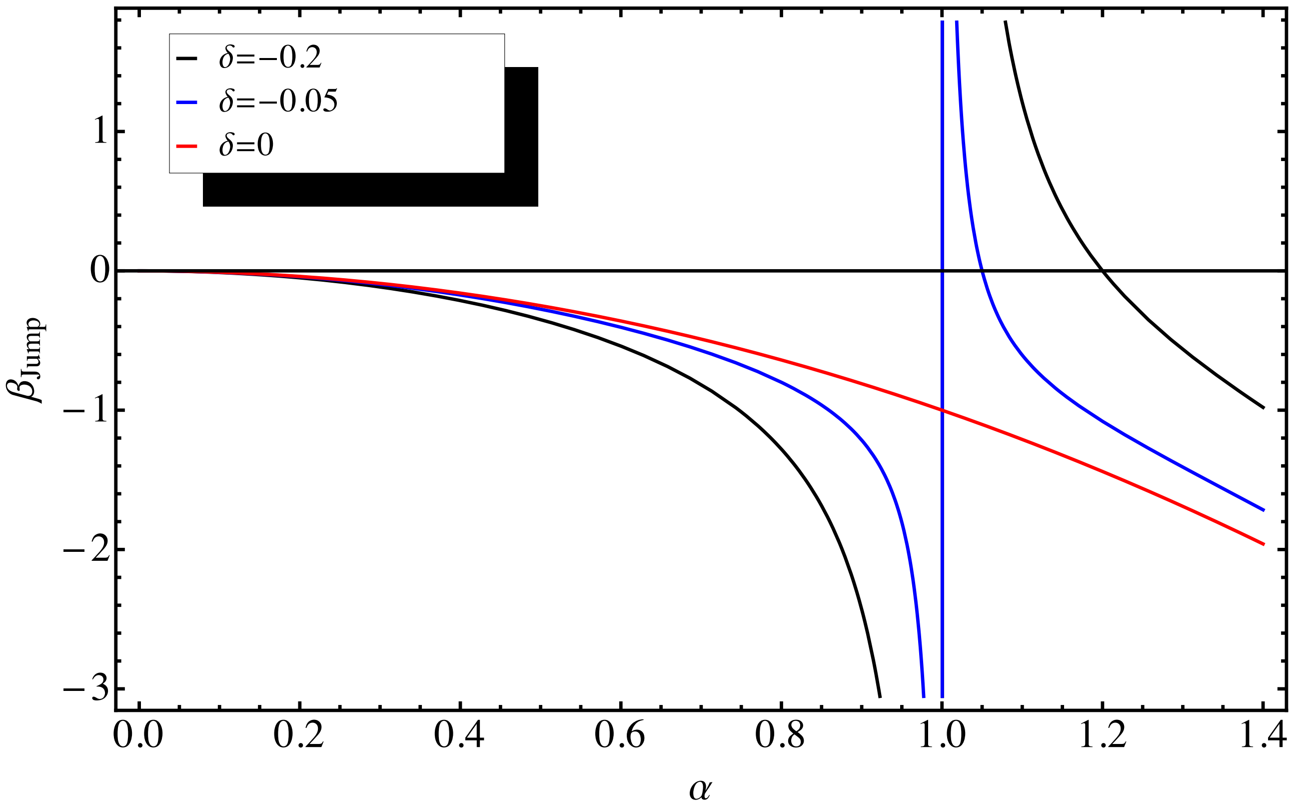
$$\beta_{Jump} = -\alpha^2 \frac{1-\delta-\alpha}{1-\alpha}$$

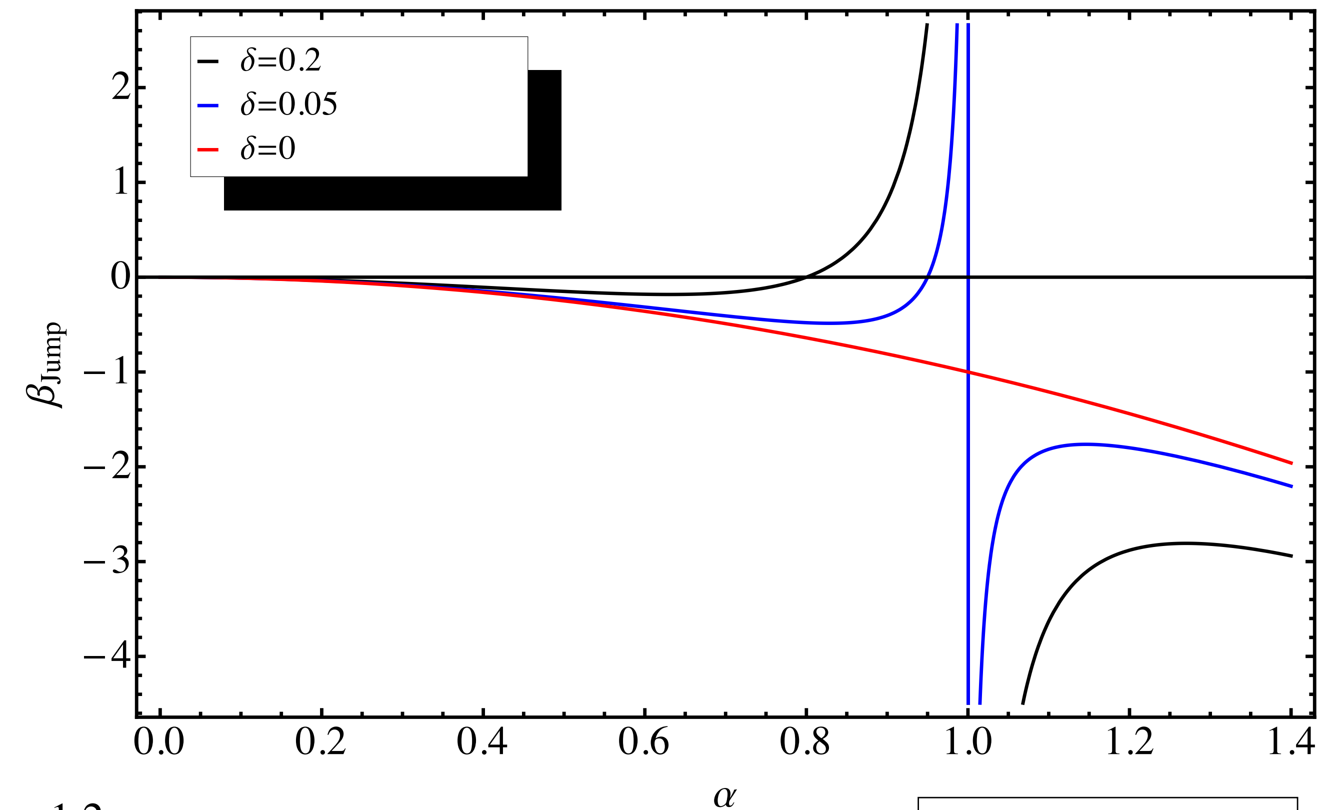
$$\delta = n_f - n_f^c$$



Sannino 2012

Jumping

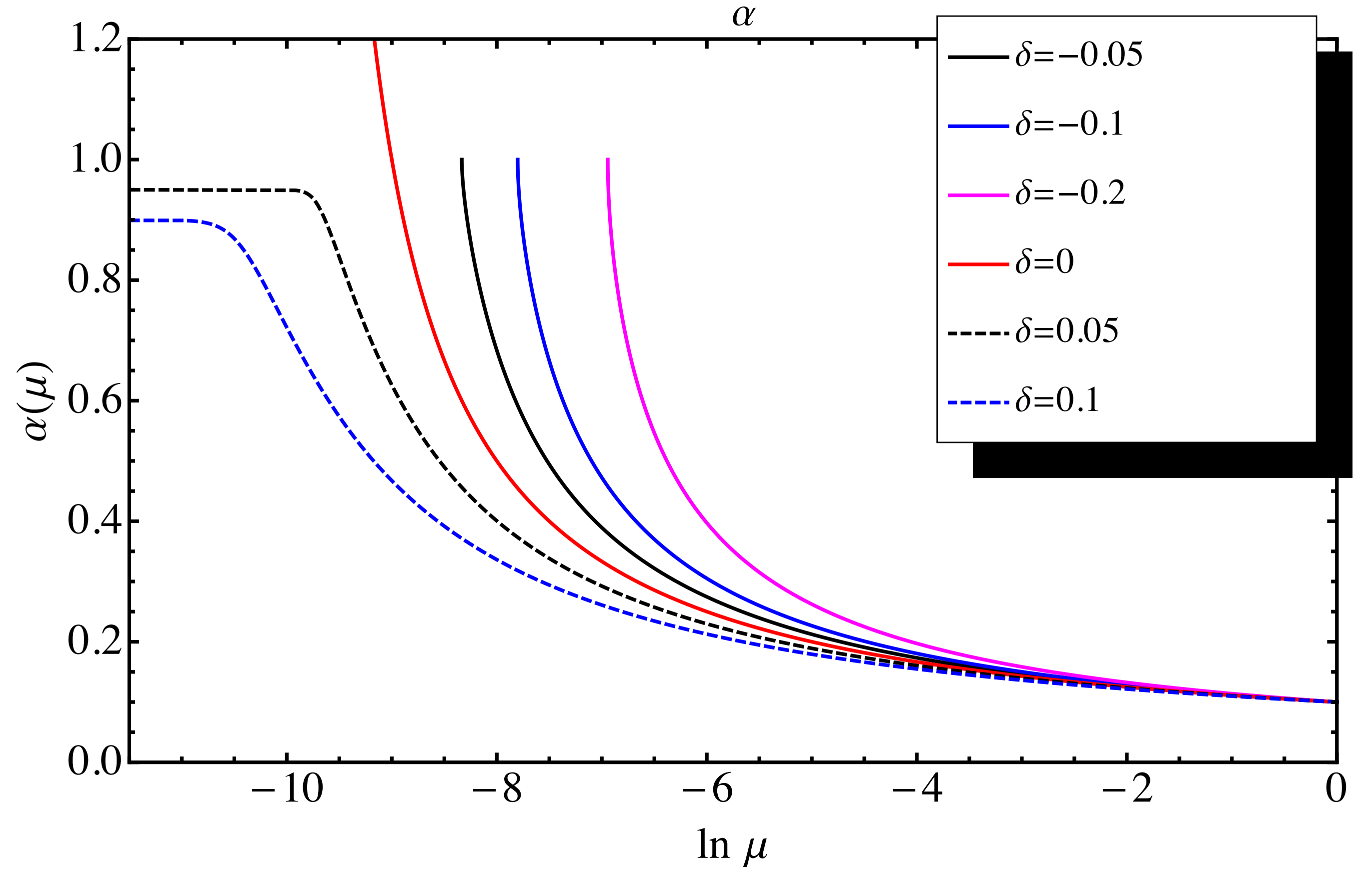




$$\beta_{Jump} = -\alpha^2 \frac{1-\delta-\alpha}{1-\alpha}$$

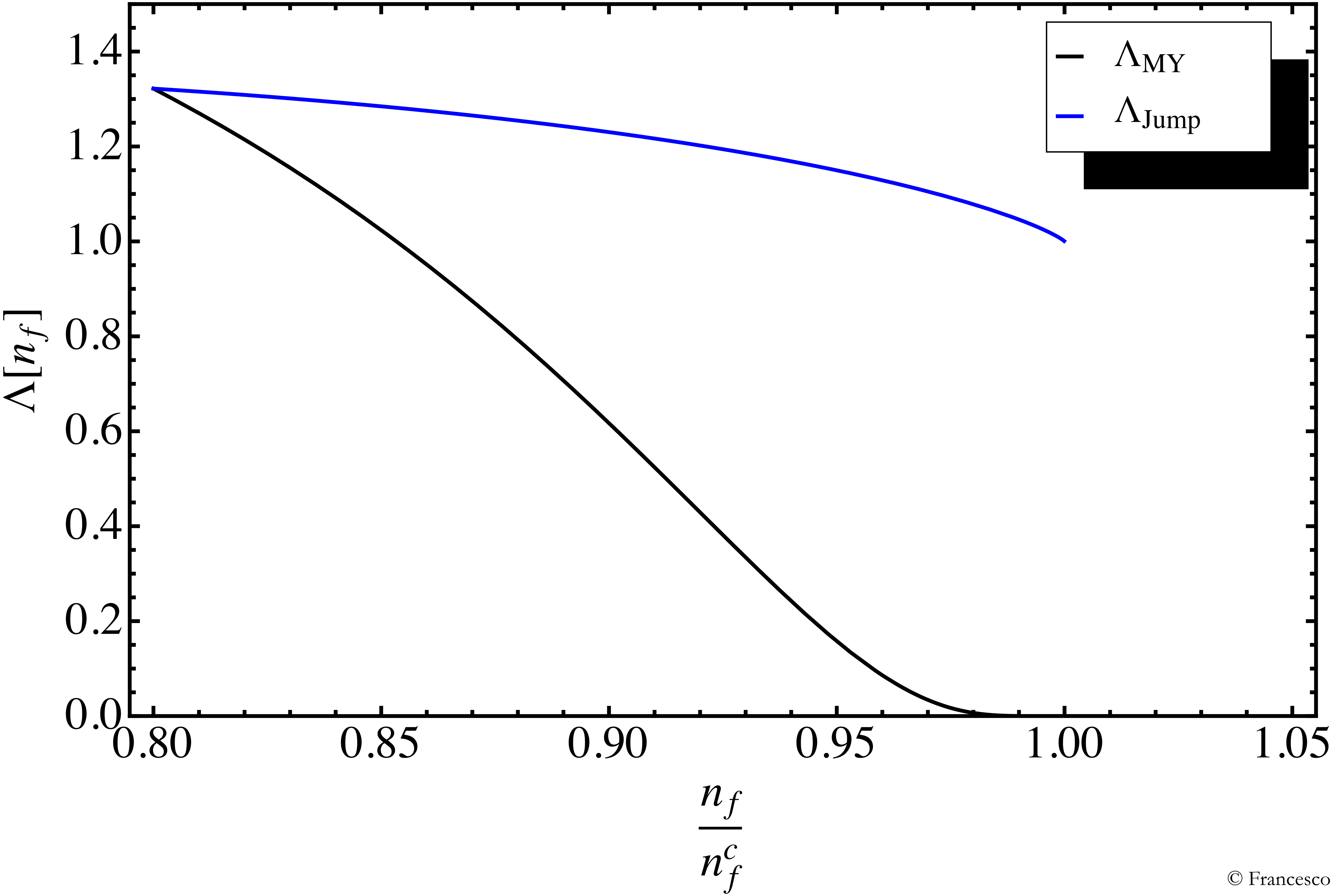
$$\delta = n_f - n_f^c$$

$$\langle \bar{Q}Q \rangle_\mu \simeq \gamma(1) \;\ln\left(\frac{\mu}{\Lambda}\right) \langle\, \bar{Q}Q \rangle_\Lambda$$

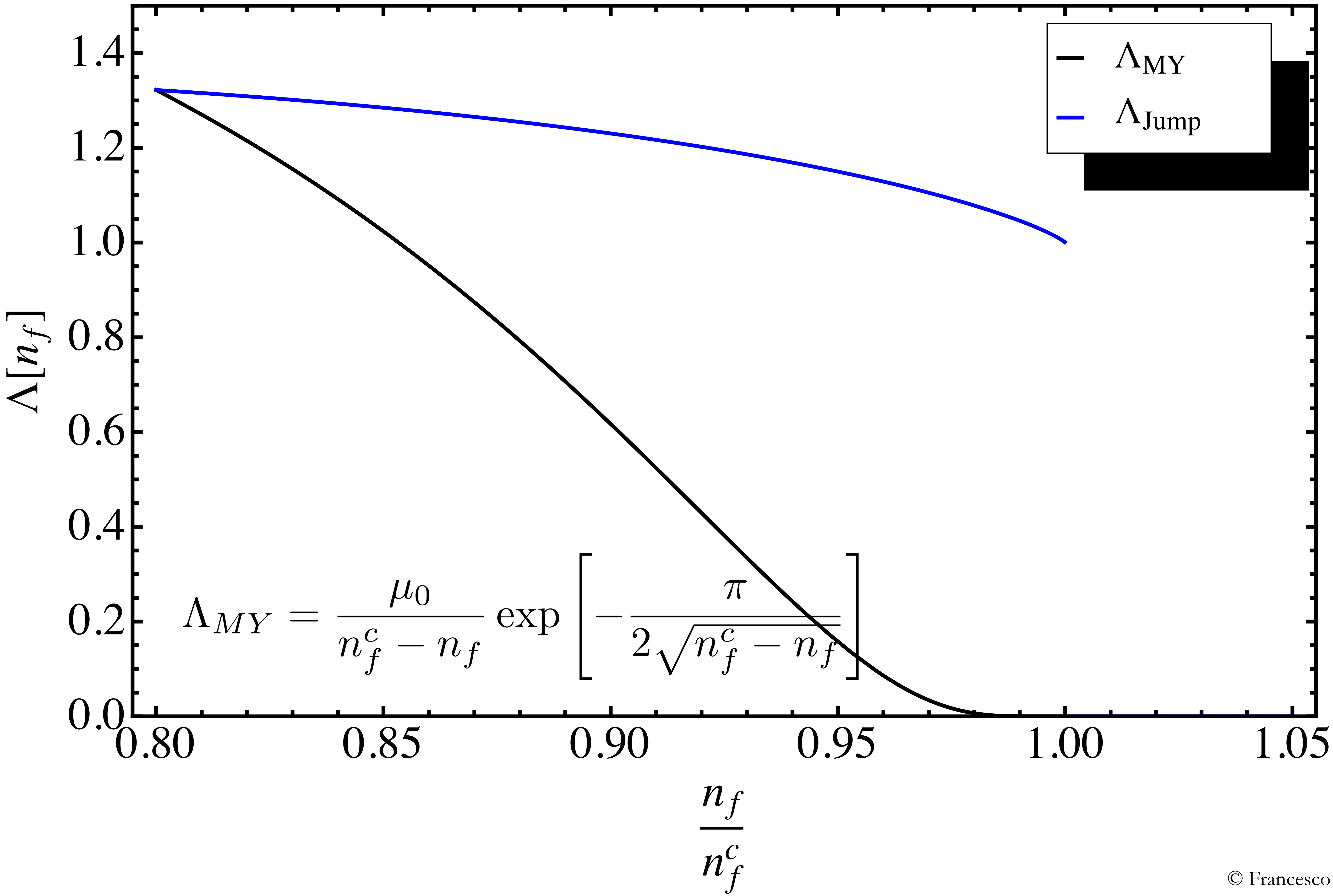


Sannino 2012

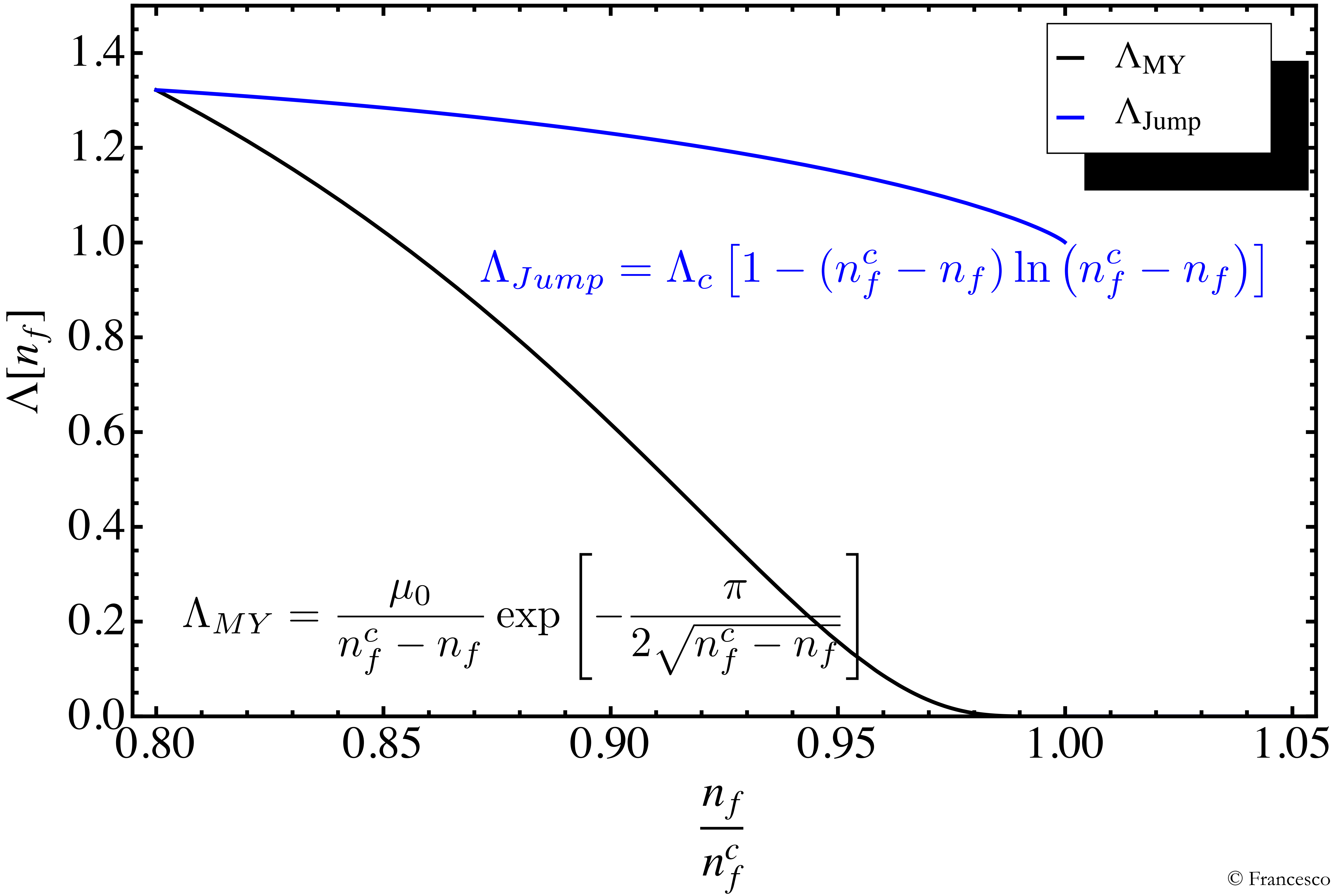
Walking or Jumping?



Walking or Jumping?



Walking or Jumping?



Wanted!

Wanted!

- Minimal Technicolor passing precision tests

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- Minimal Technicolor passing precision tests
- ETC for Fermion masses generation

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- Non QCD dynamics/Walking not Jumping

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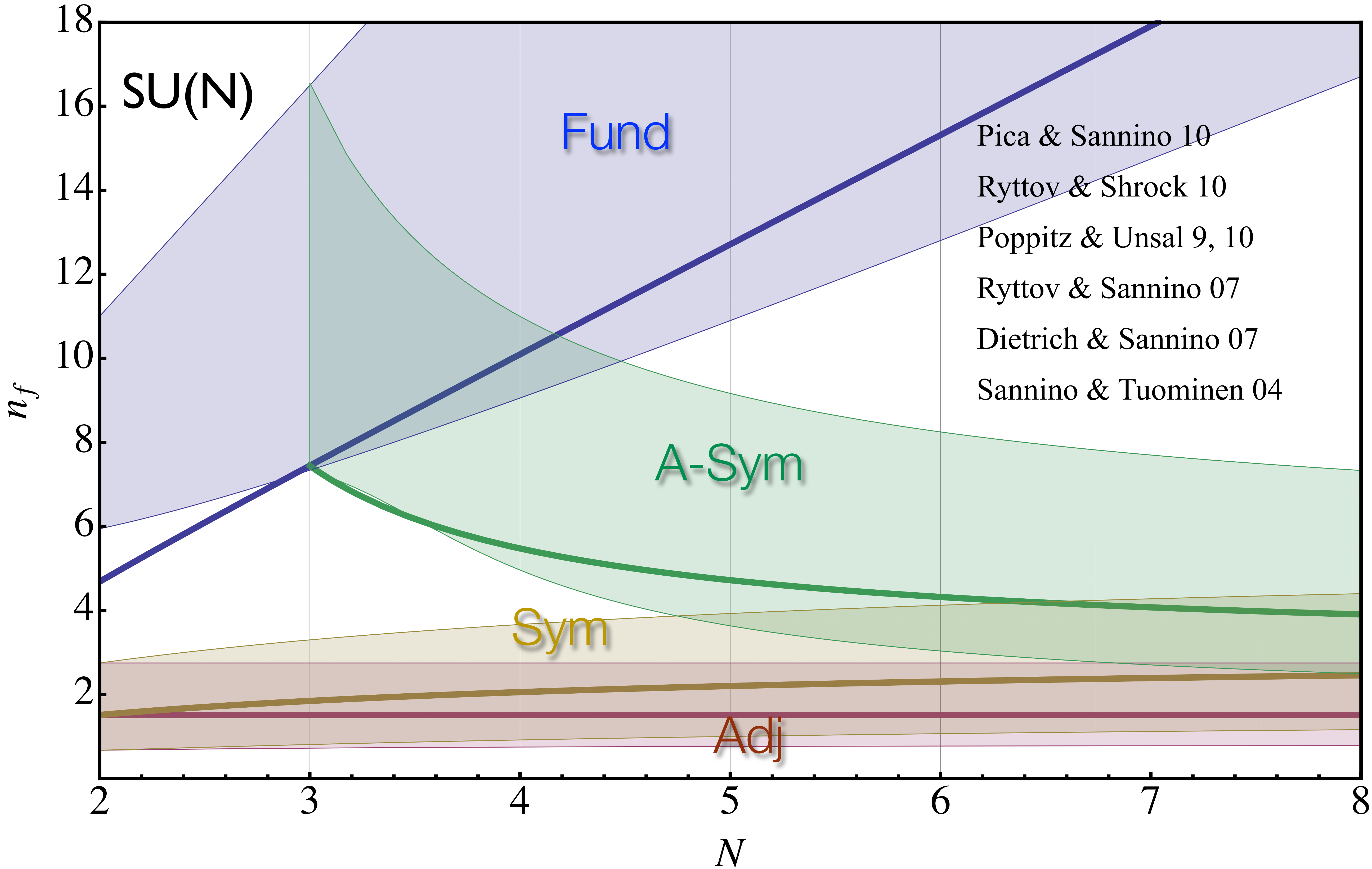
- Non QCD dynamics/Walking not Jumping
- Large mass anomalous dimensions

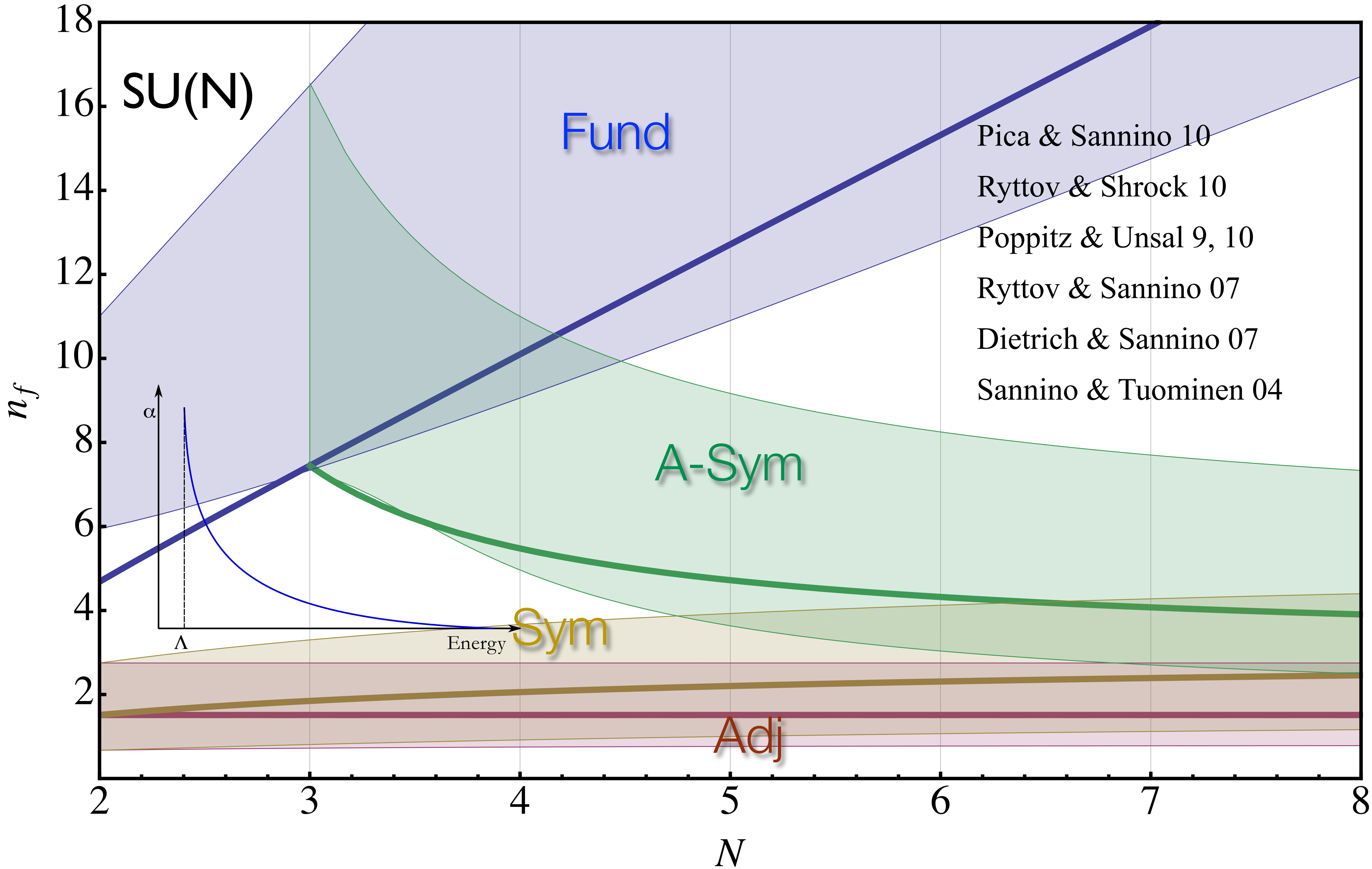
Wanted!

- Minimal Technicolor passing precision tests
- ETC for Fermion masses generation
- Non QCD dynamics / Walking not Jumping
- Large mass anomalous dimensions
- Dark matter candidates

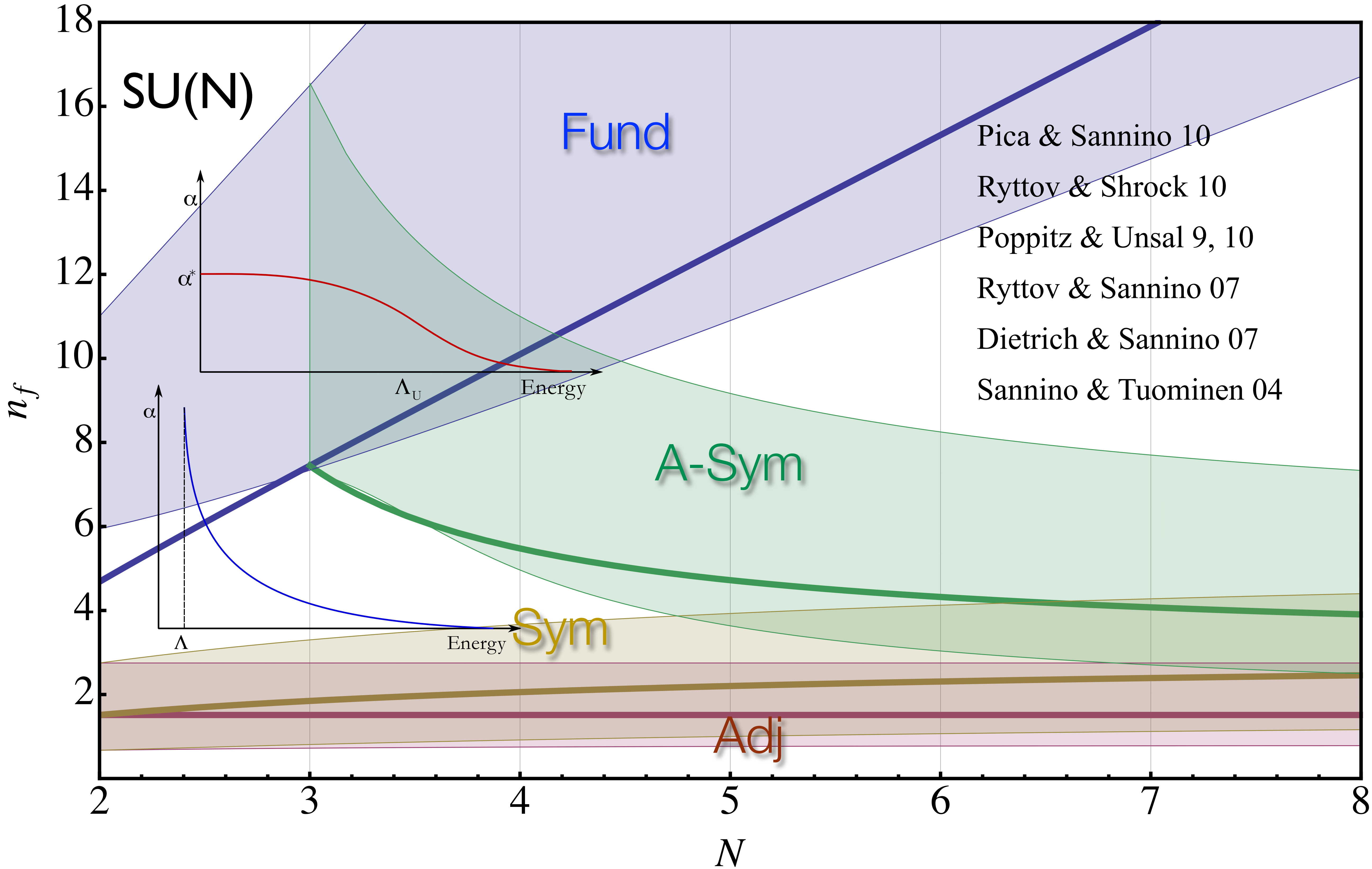
SU(N) Phase Diagram



SU(N) Phase Diagram



SU(N) Phase Diagram



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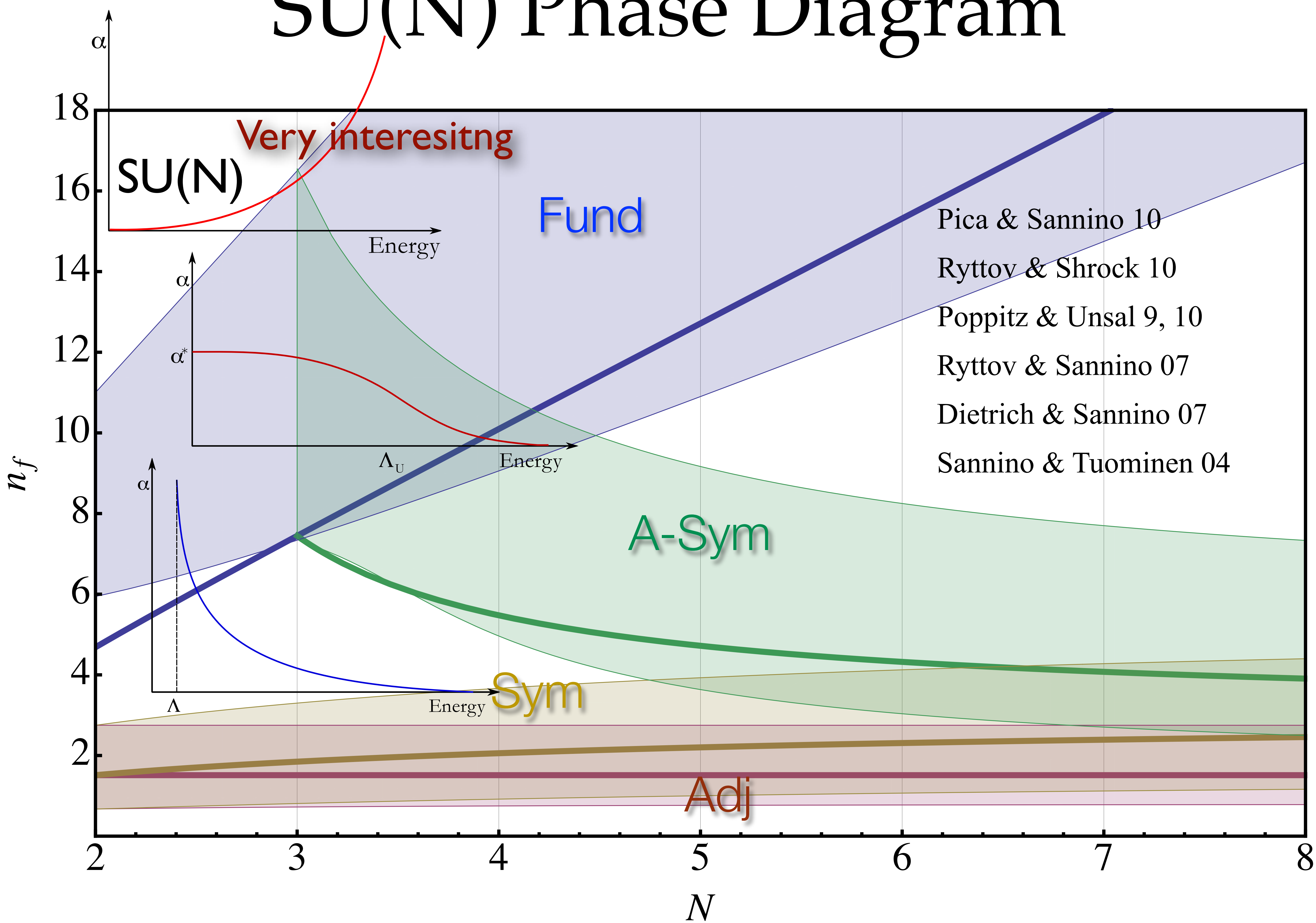
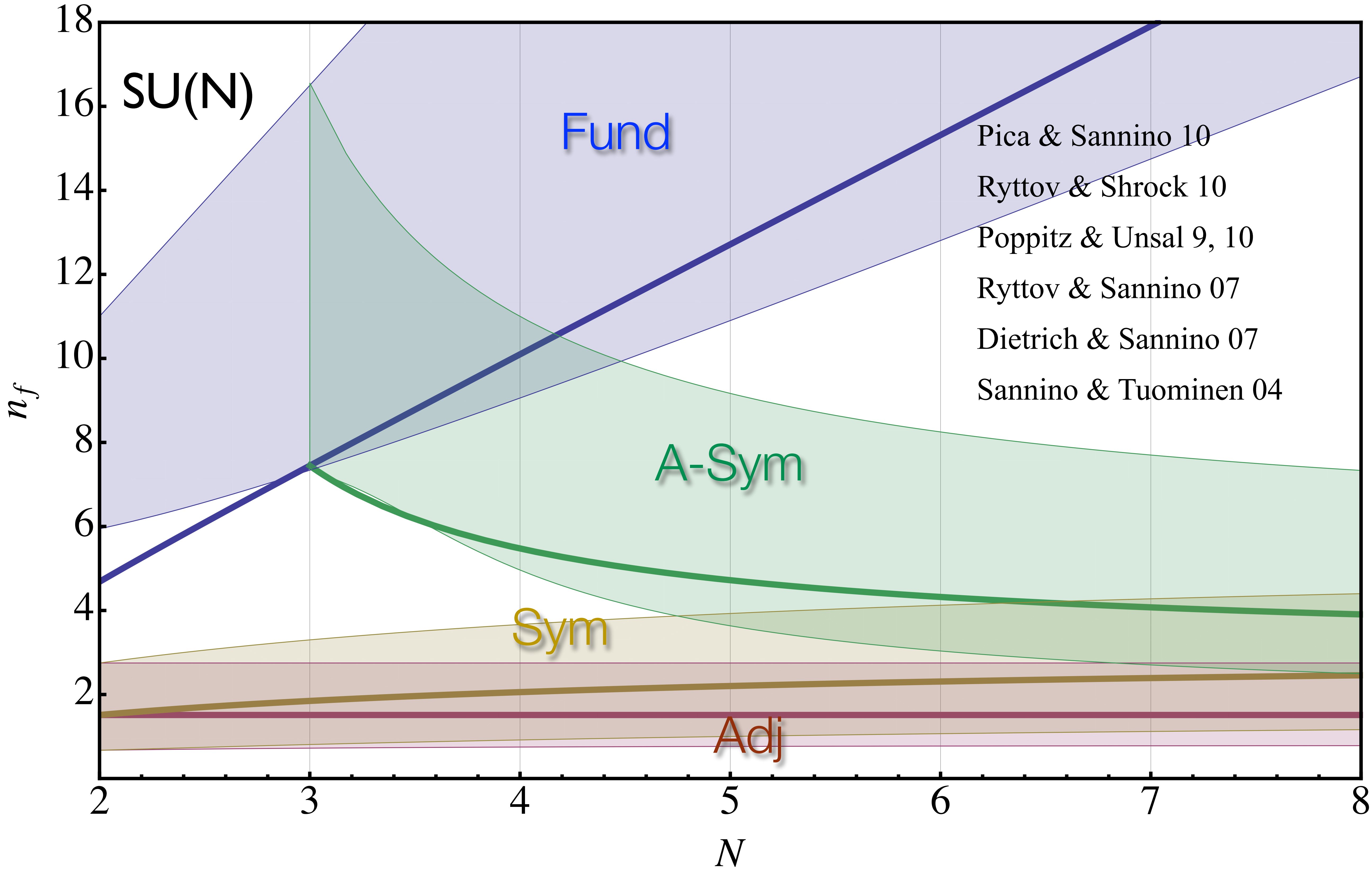


SU(N) Phase Diagram



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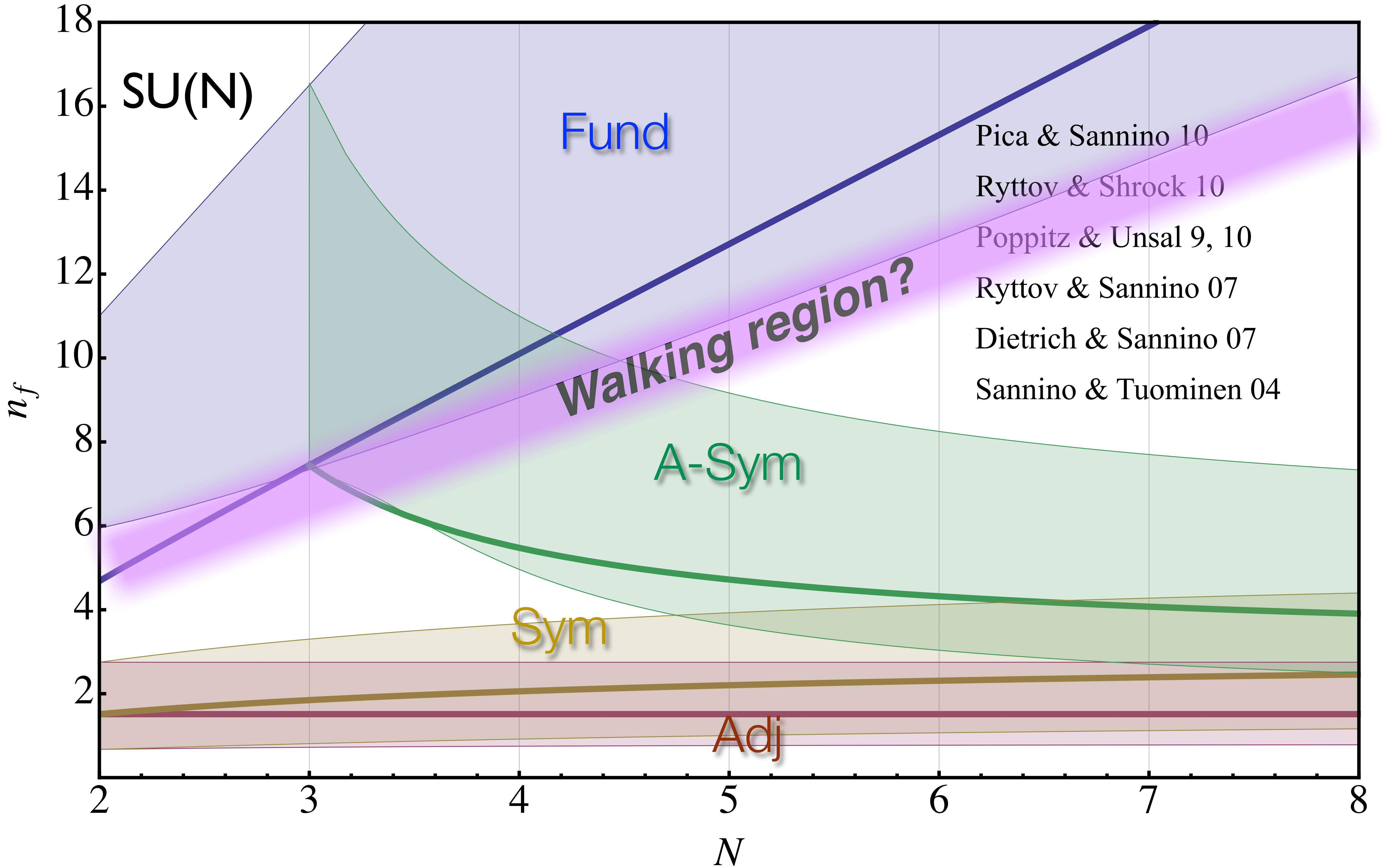
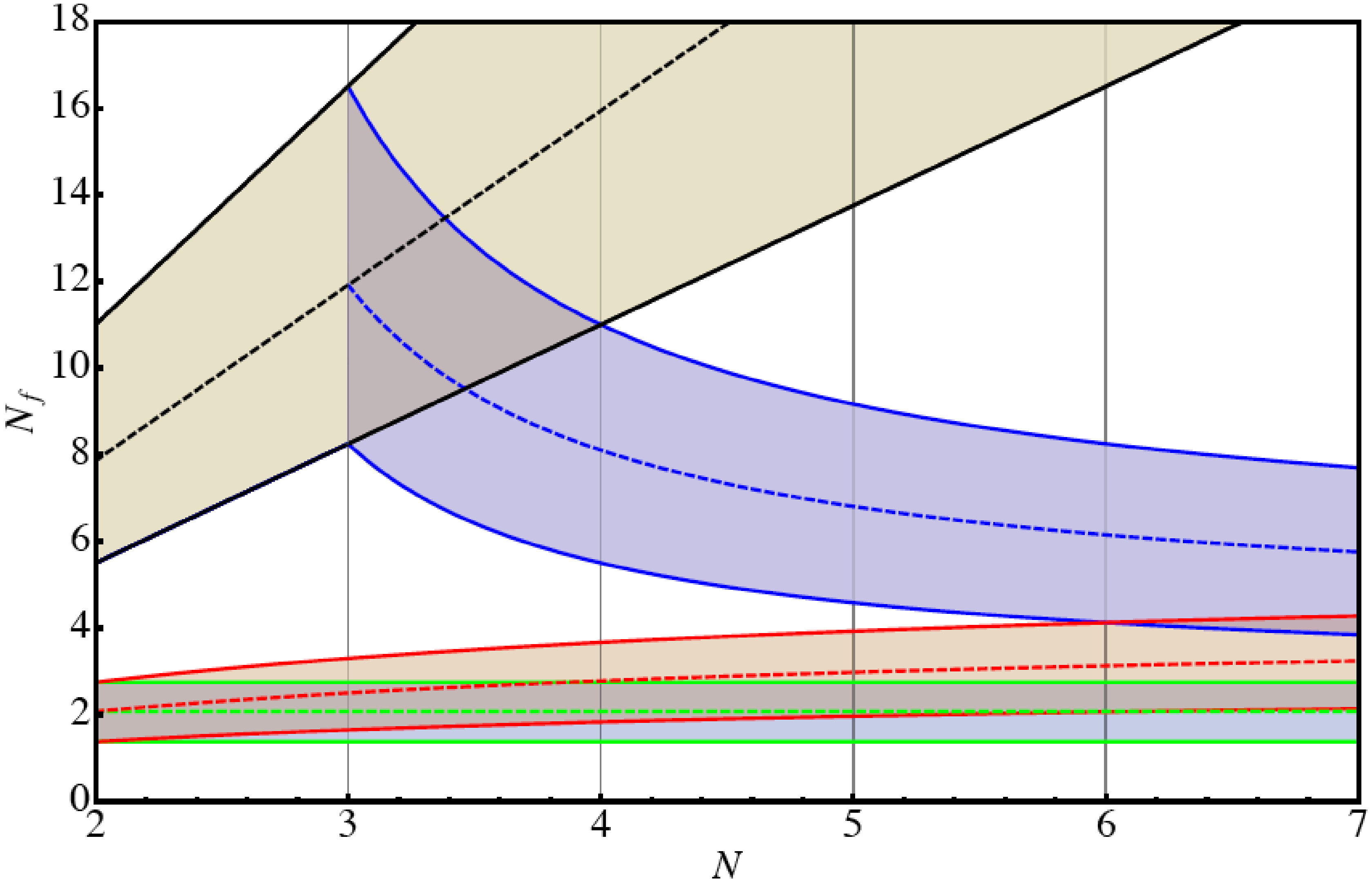


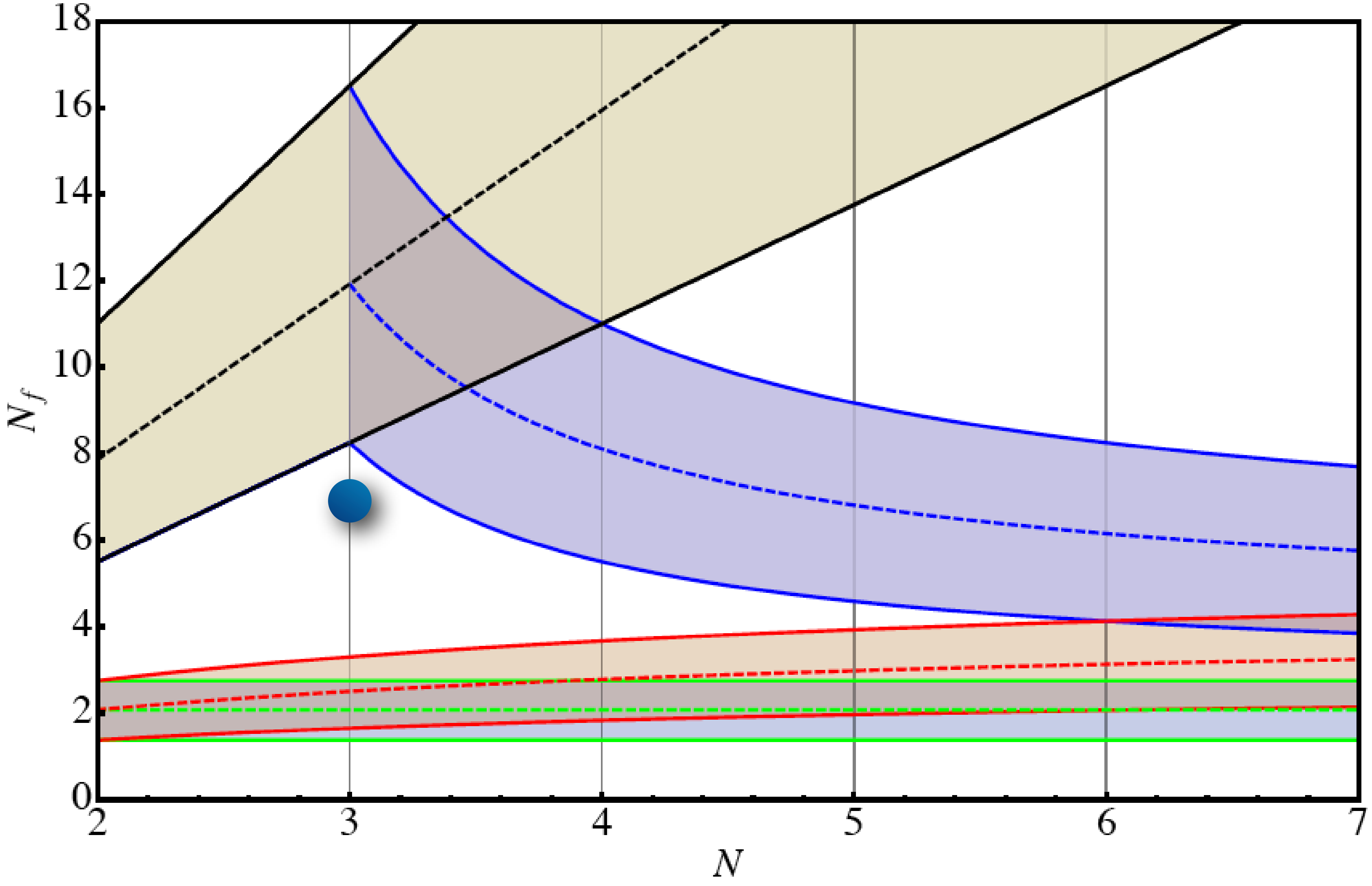
No seriously, Walking?



Dietrich Sannino 06

Fukano & Sannino 10

No seriously, Walking?

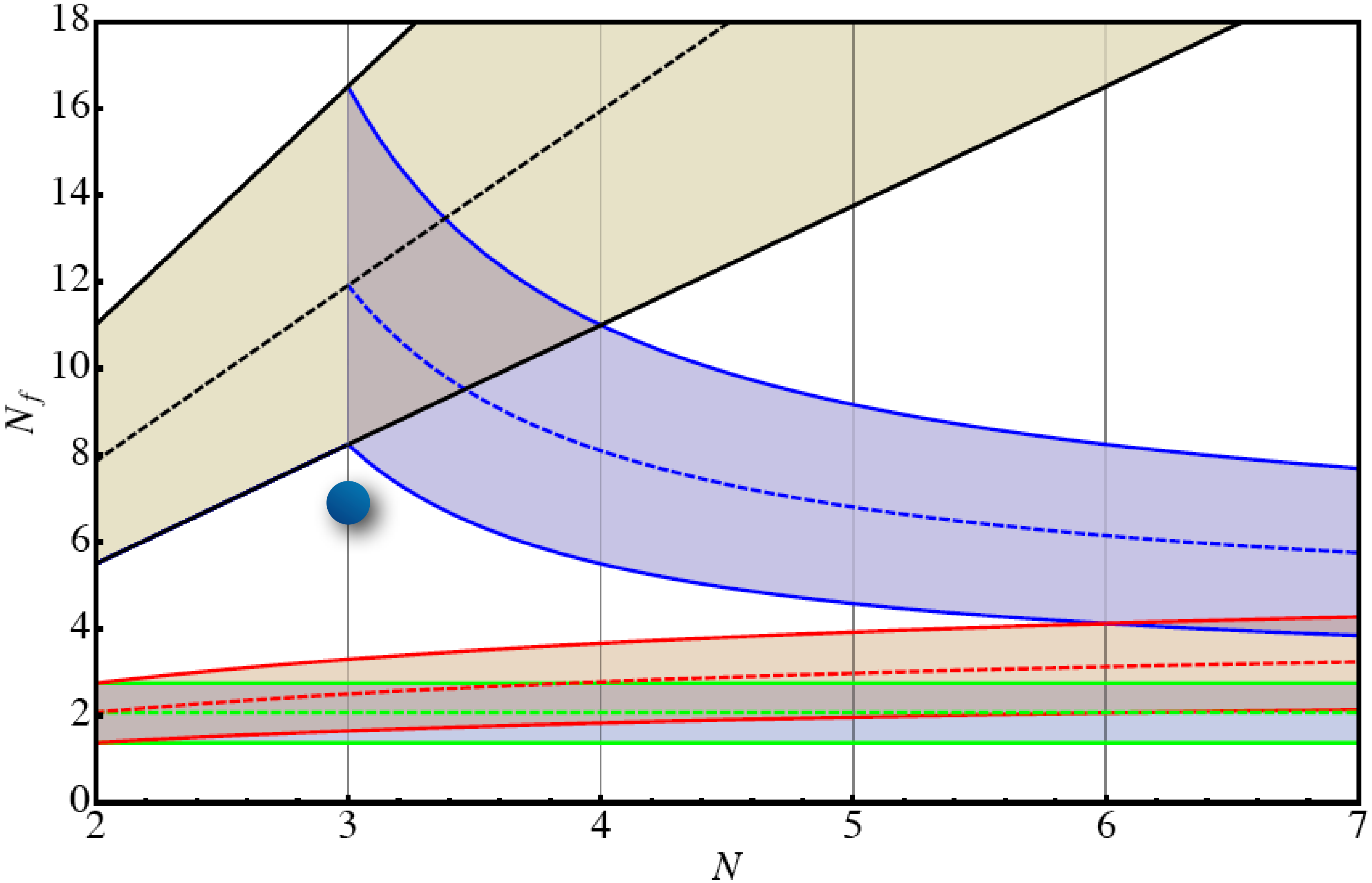


Dietrich Sannino 06

Fukano & Sannino 10

How can one tune an integer number?

No seriously, Walking?



Dietrich Sannino 06

Fukano & Sannino 10

How can one tune an integer number?

Anomalous dimensions may be small

ideal Walking = iWalk

Fukano & Sannino 10

ideal Walking = iWalk

Fukano & Sannino 10

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

ideal Walking = iWalk

Fukano & Sannino 10

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

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

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Fukano & Sannino 10

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Fukano & Sannino 10

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

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Appelquist, Soldate, Takeuchi and Wijewardhana, 88

Miranky and Yamawaki 88

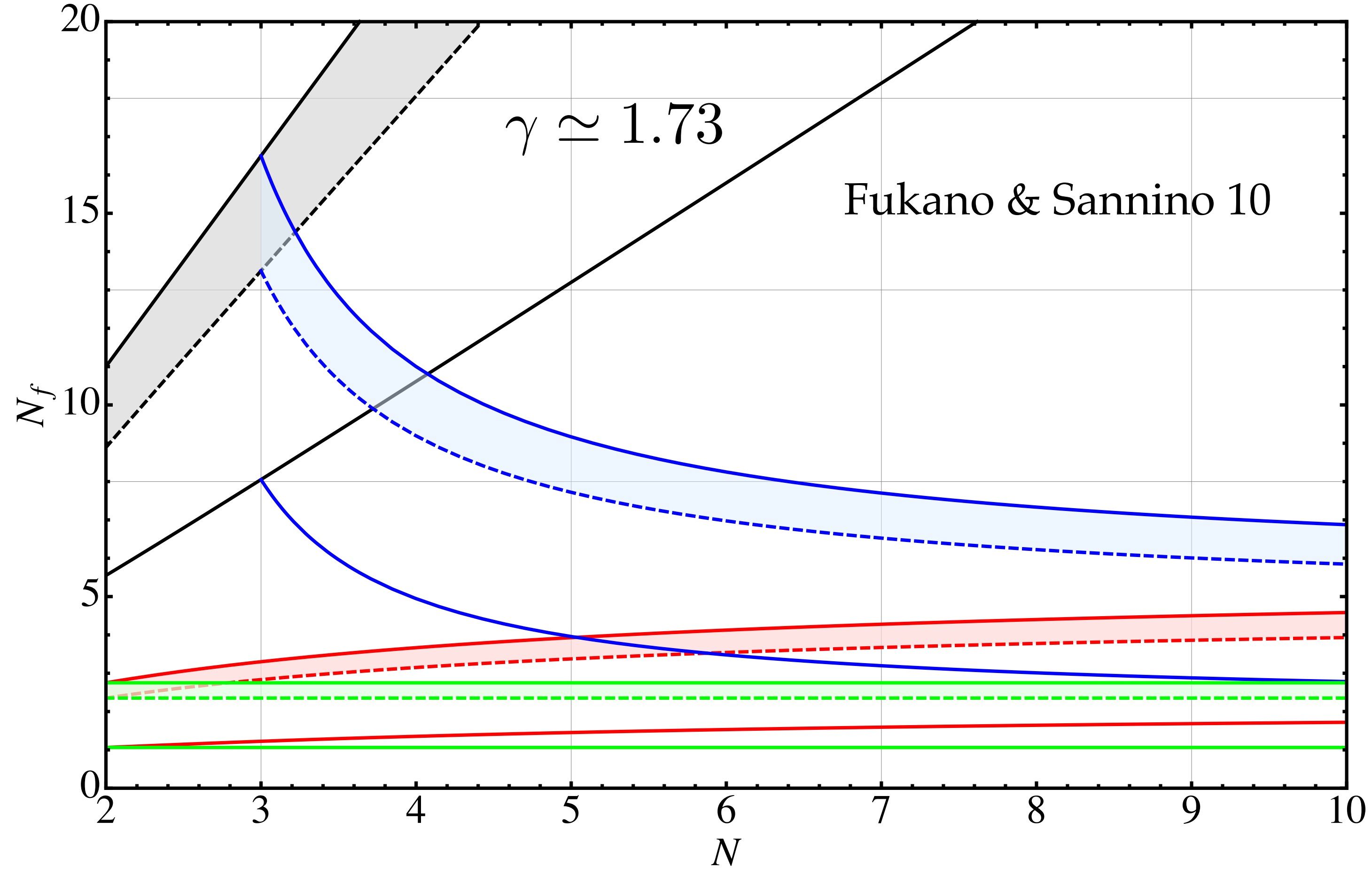
Kondo, Mino, Yamawaki 89

Takeuchi 96

Yamawaki, Kurachi and Shrock 08

Gauged Nambu Jona-Lasinio

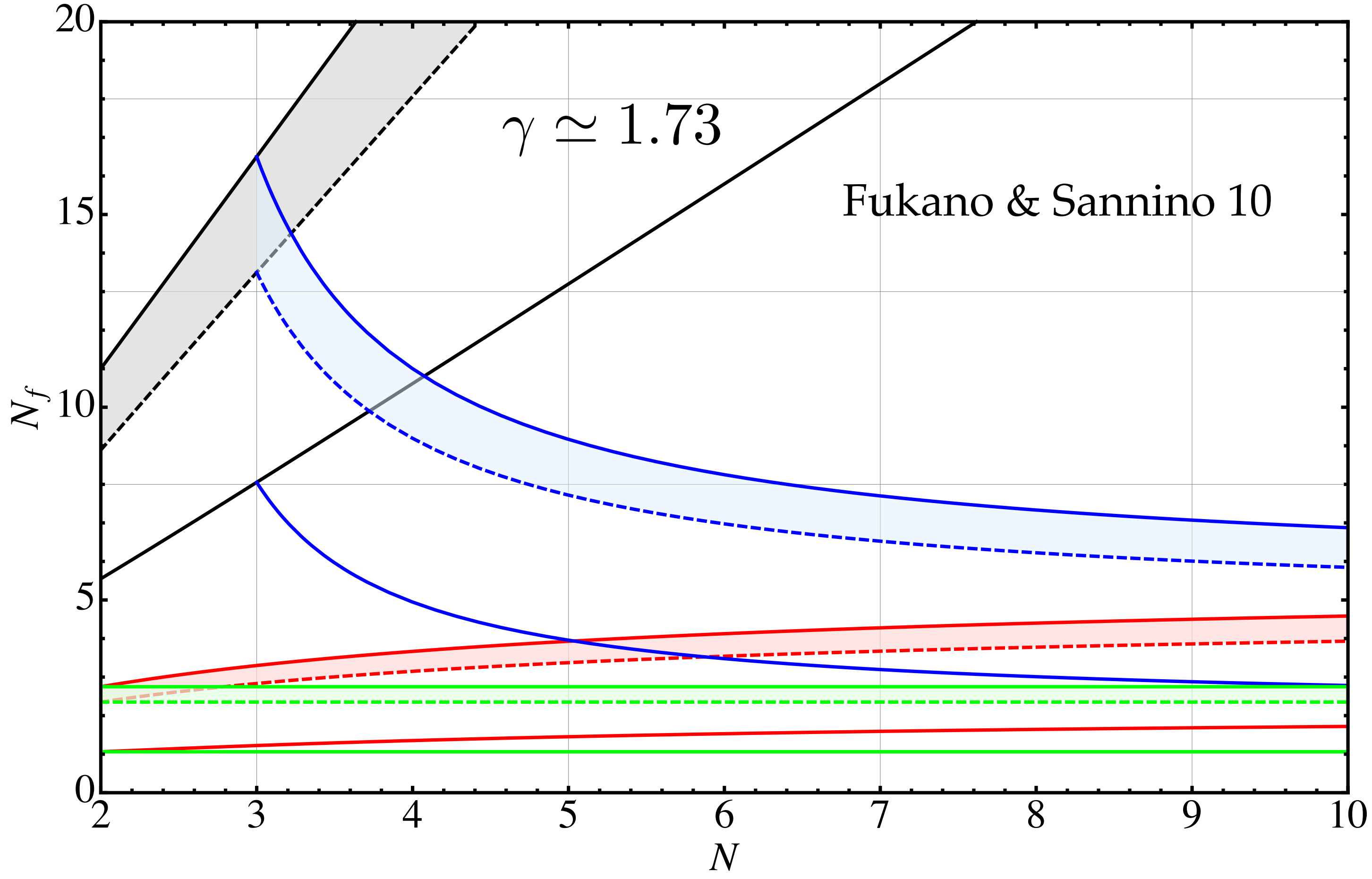
Fukano & Sannino 10



Gauged Nambu Jona-Lasinio

Fukano & Sannino 10

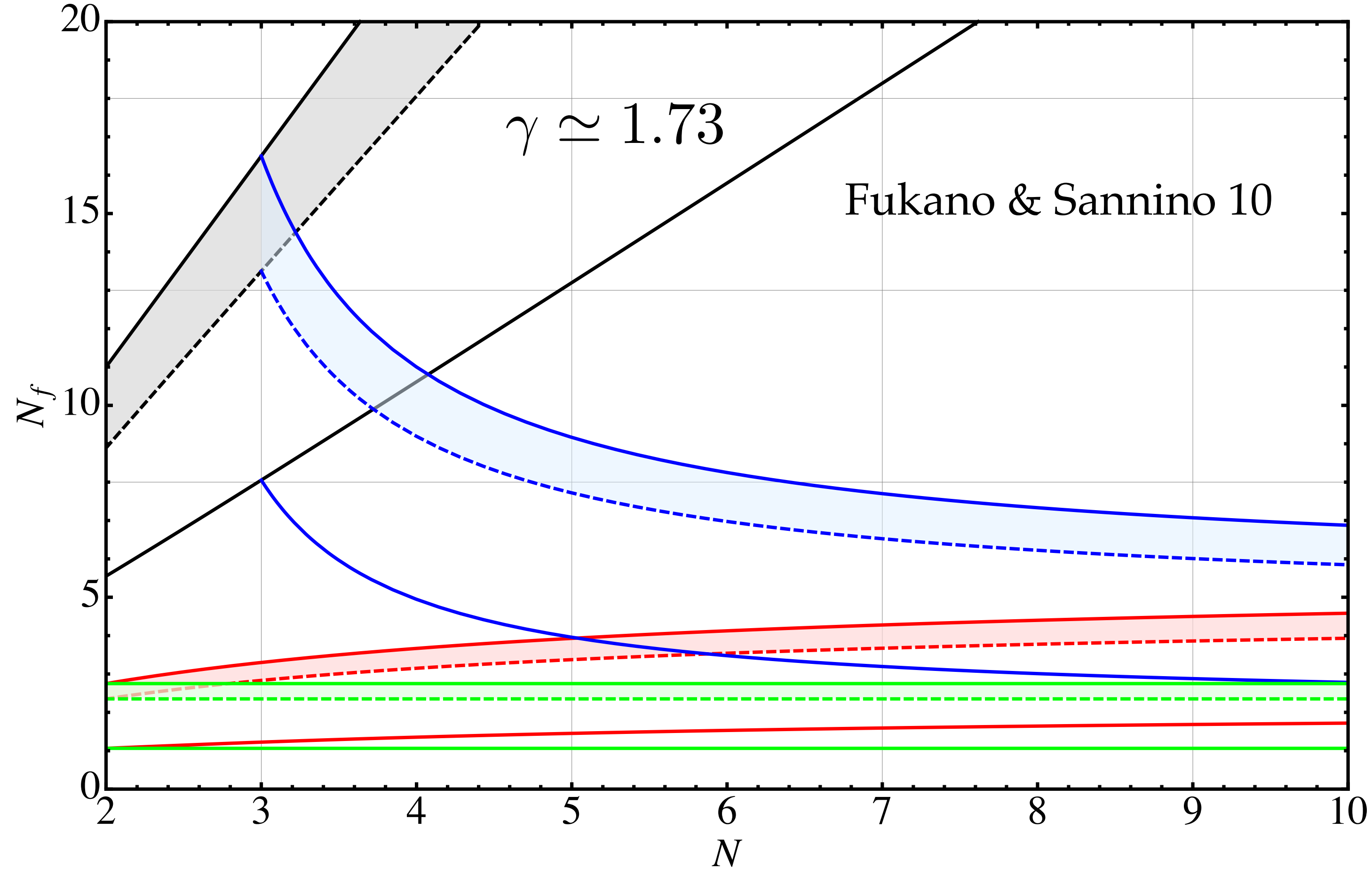
- As if the number of flavors is continuous



Gauged Nambu Jona-Lasinio

Fukano & Sannino 10

- As if the number of flavors is continuous
- Anomalous dimensions increase



Gauged Nambu Jona-Lasinio

Fukano & Sannino 10

- As if the number of flavors is continuous
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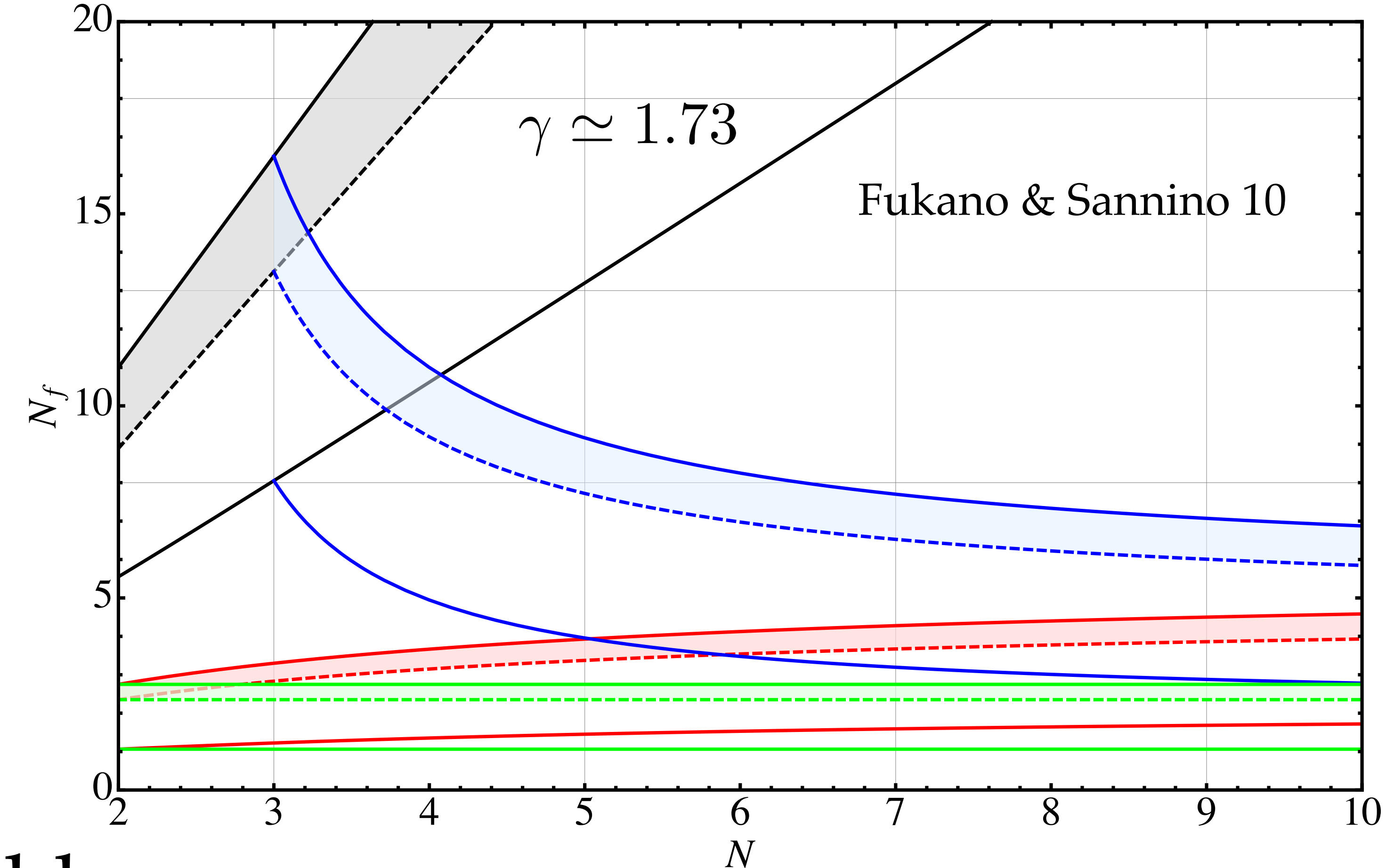
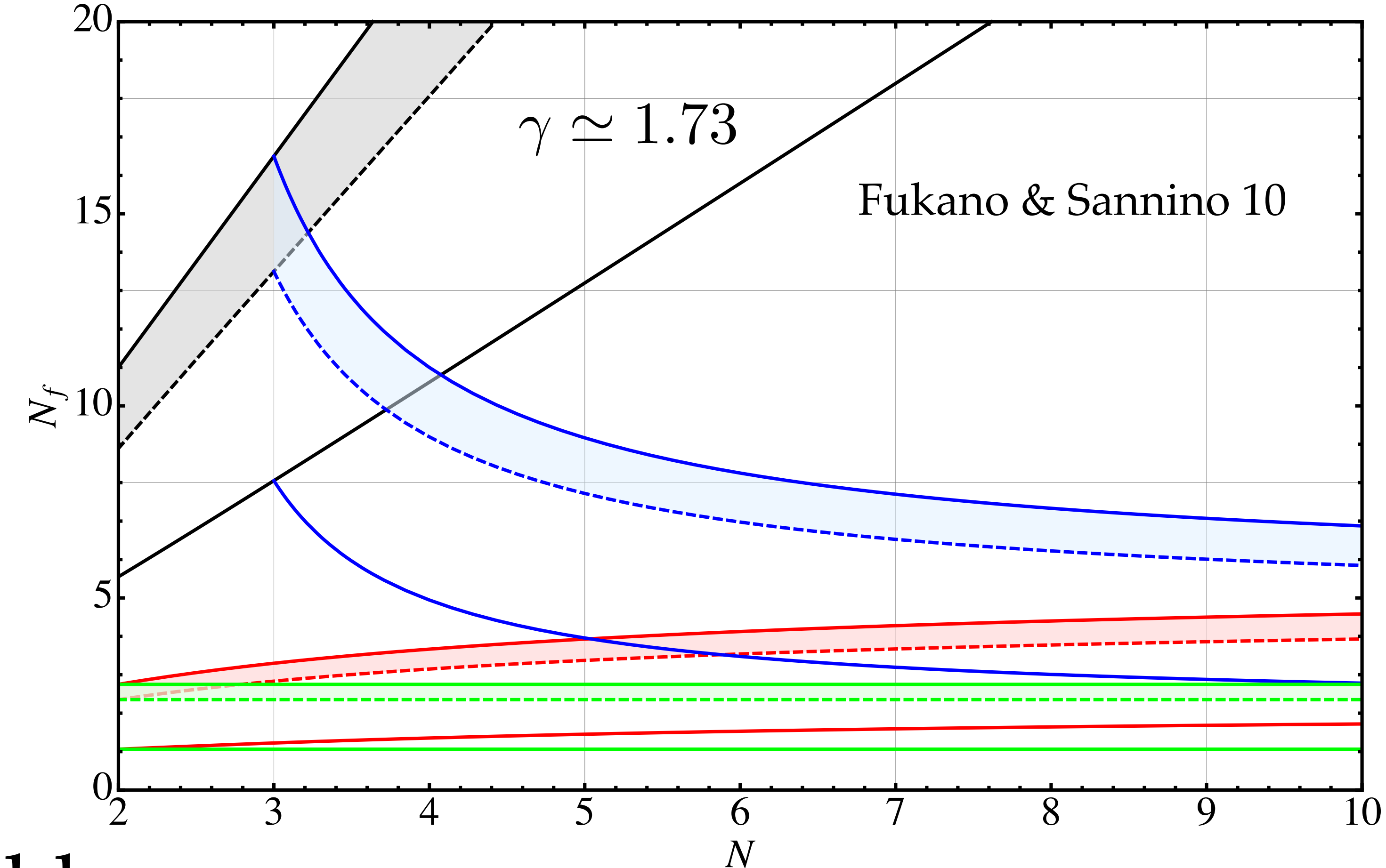


- Phenomenologically viable

Gauged Nambu Jona-Lasinio

Fukano & Sannino 10

- As if the number of flavors is continuous
- Anomalous dimensions increase

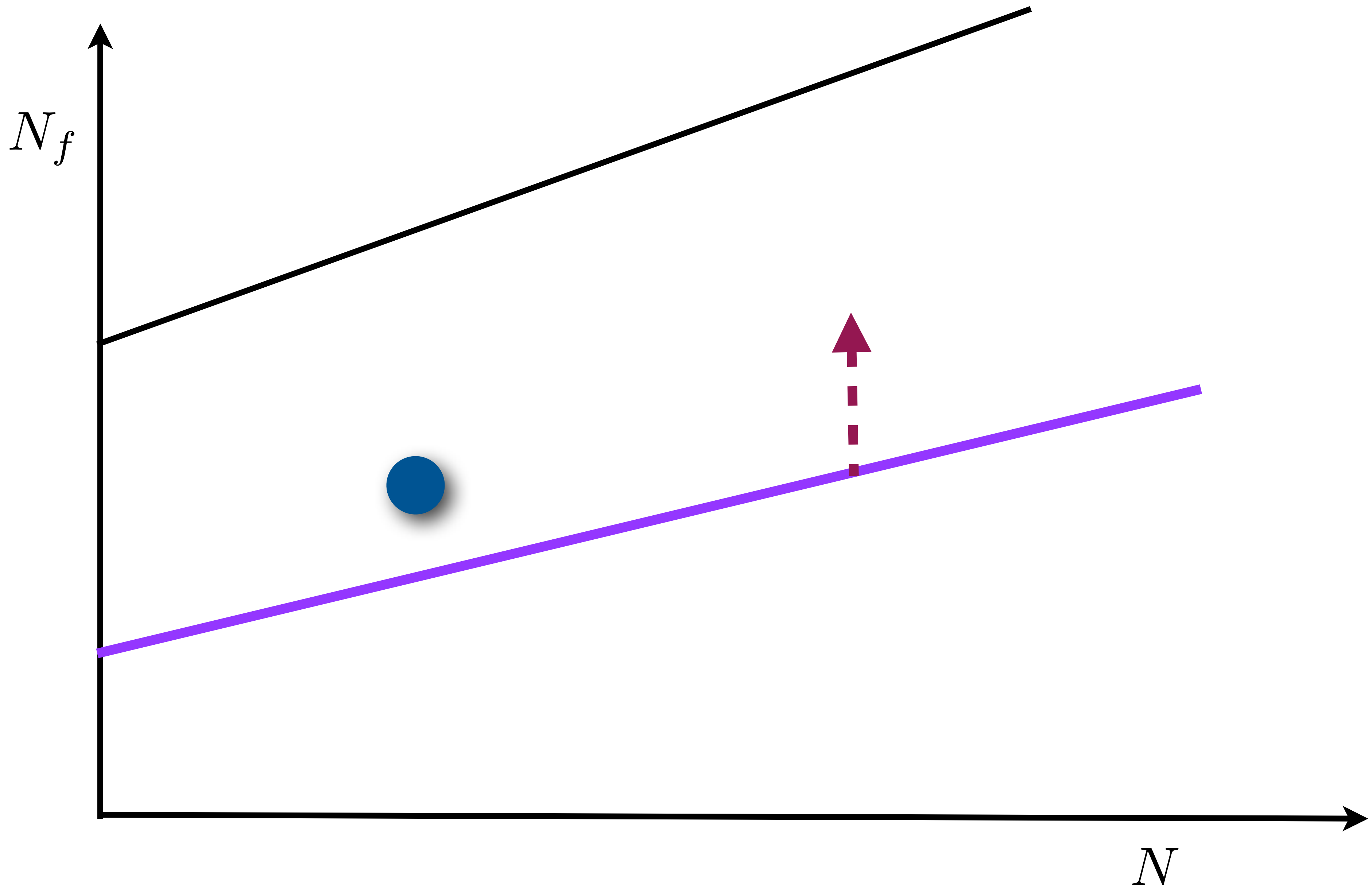


- Phenomenologically viable
- Being tested!

iWalk recipe

Fukano & Sannino 10

- TC in isolation is in the CW
- Strong four fermion brings theory out of CW



Minimal TC

U

D

Minimal TC

- Minimal WT

$SU(2)_{TC}$ $\square\!\square$ **U** **N** **D** **E**

Sannino & Tuominen 04

Dietrich, Sannino, Tuominen 05

Frandsen, Masina, Sannino 09

Minimal TC

- Minimal WT

$SU(2)_{TC}$ $\square\square$ **U** **N** **D** **E**

Sannino & Tuominen 04

Dietrich, Sannino, Tuominen 05

Frandsen, Masina, Sannino 09

- Next to MWT

$SU(3)_{TC}$ $\square\square$ **U** **D**

Sannino, Tuominen 04

Dietrich, Sannino, Tuominen 05

Minimal TC

- Minimal WT

$SU(2)_{TC}$ $\square\square$ **U** **D** **N** **E**

Sannino & Tuominen 04
Dietrich, Sannino, Tuominen 05
Frandsen, Masina, Sannino 09

- Next to MWT

$SU(3)_{TC}$ $\square\square$ **U** **D**

Sannino, Tuominen 04
Dietrich, Sannino, Tuominen 05

- Orthogonal

$SO(4)_{TC}$ $\square$ **U** **D**

Frandsen, Sannino 09

Minimal TC

- Minimal WT

$SU(2)_{TC}$ $\square\!\square$ **U** **D** **N** **E**

Sannino & Tuominen 04
Dietrich, Sannino, Tuominen 05
Frandsen, Masina, Sannino 09

- Next to MWT

$SU(3)_{TC}$ $\square\!\square$ **U** **D**

Sannino, Tuominen 04
Dietrich, Sannino, Tuominen 05

- Orthogonal

Vanilla TC

$SO(4)_{TC}$ $\square$ **U** **D**

Frandsen, Sannino 09

- Ultra MT

$SU(2)_{TC}$ $\square$ **U** **D**

Ryttov & Sannino 08

(Next) Minimal Walking Technicolor

(Next) Minimal Walking Technicolor

- Next to minimal is just outside the conformal window

  Fodor, Holland, Kuti, Nogradi, Schroeder, Wong

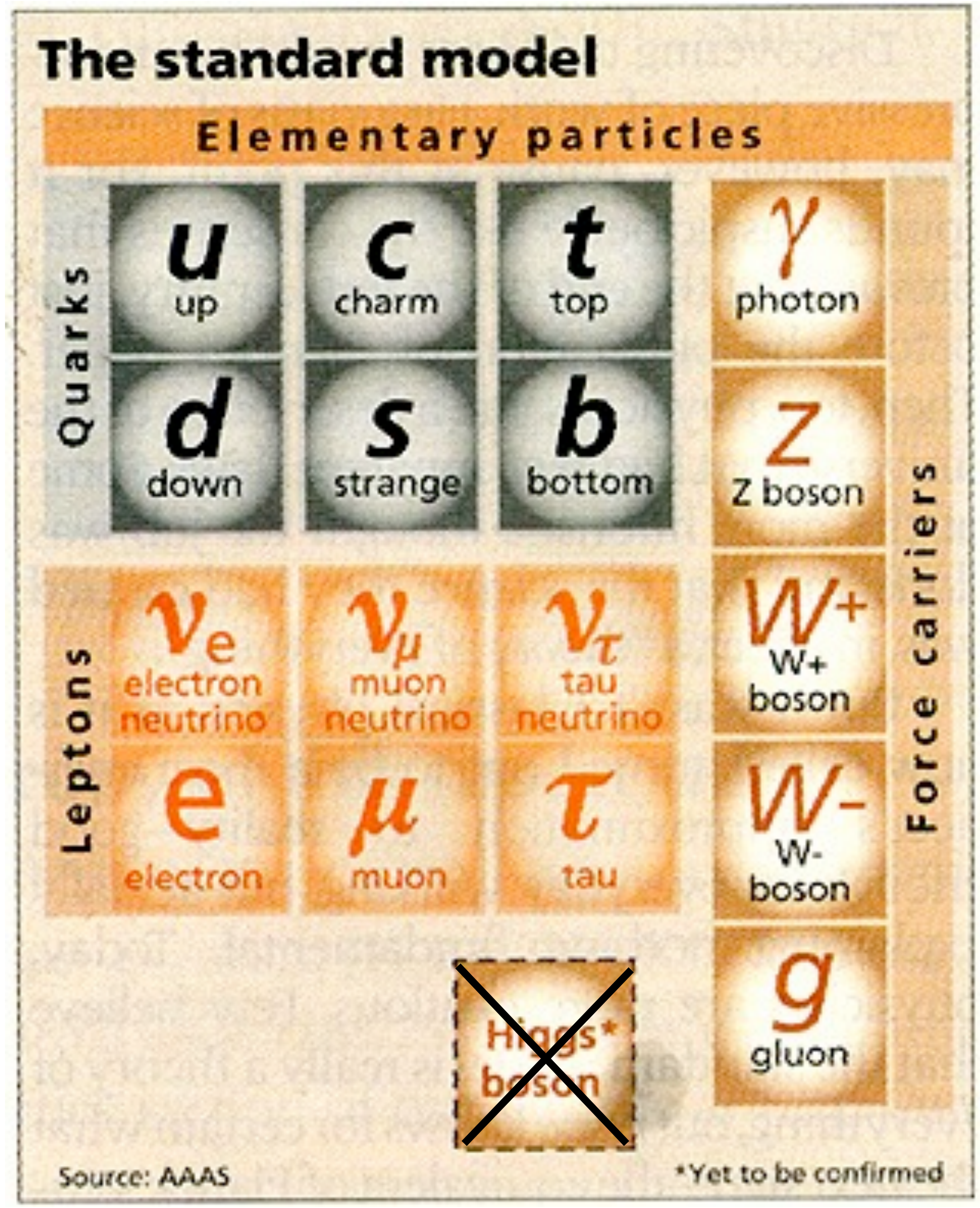
(Next) Minimal Walking Technicolor

- Minimal Walking TC is ideal for iWalk

  Catterall & Sannino;
  Del Debbio, Lucini Patella, Pica, Rago
  Hietanen, Rummukainen, Tuominen
  Catterall, Giedt, Sannino

- Next to minimal is just outside the conformal window

  Fodor, Holland, Kuti, Nogradi, Schroeder, Wong



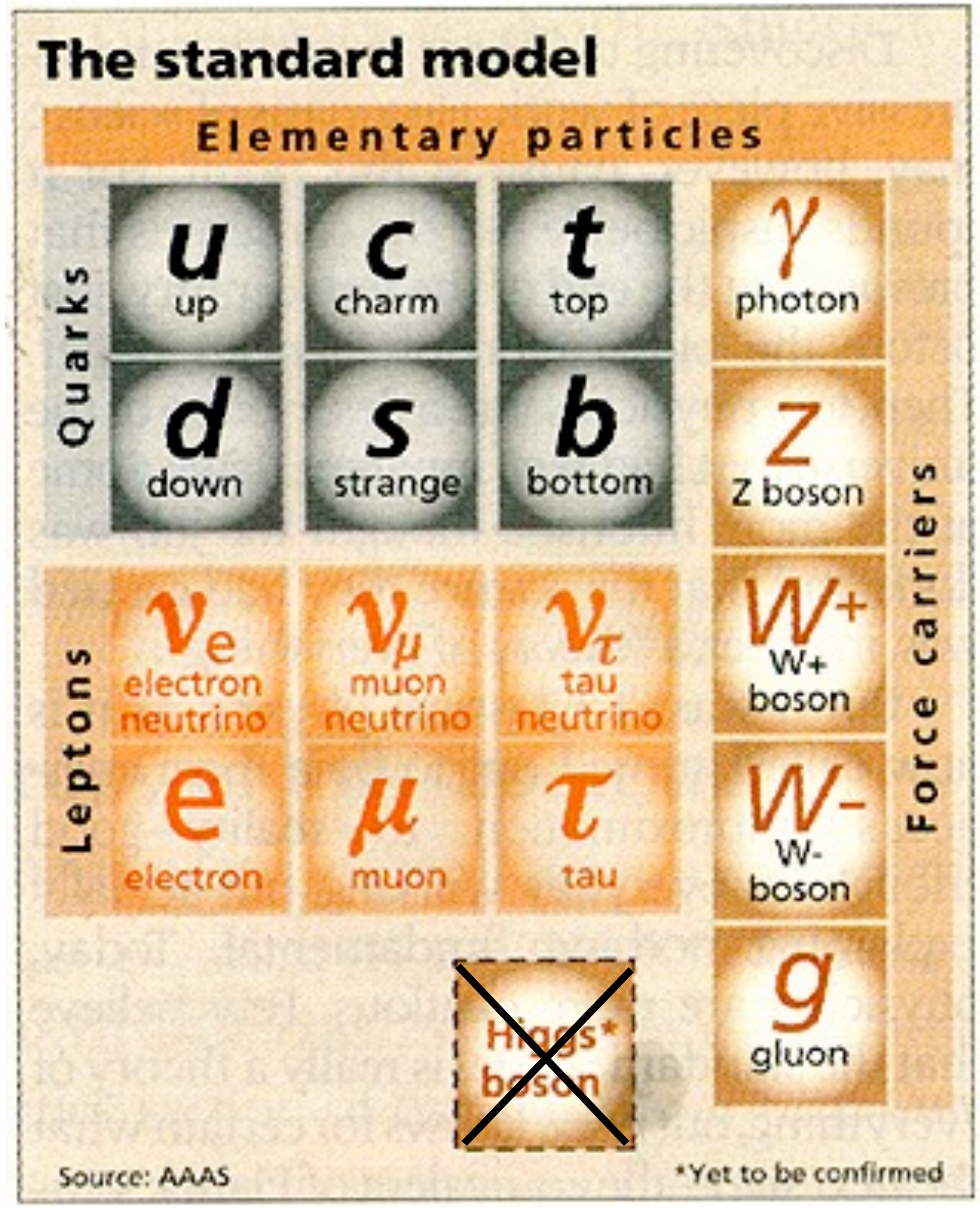
U(1)

SU(2)

SU(3)

F.S. + Tuominen 04

Dietrich, F.S., Tuominen 05



U(1)

SU(2)

SU(3)

N Extra Neutrino

ζ Extra Electron

U t-up

G t-glue

D t-down

SU(2)

F.S. + Tuominen 04

Dietrich, F.S., Tuominen 05

U and D: Adj of SU(2)

S beyond TC...

S beyond TC...

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

S beyond TC...

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

S beyond TC...

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

Offset the first term

New Leptons

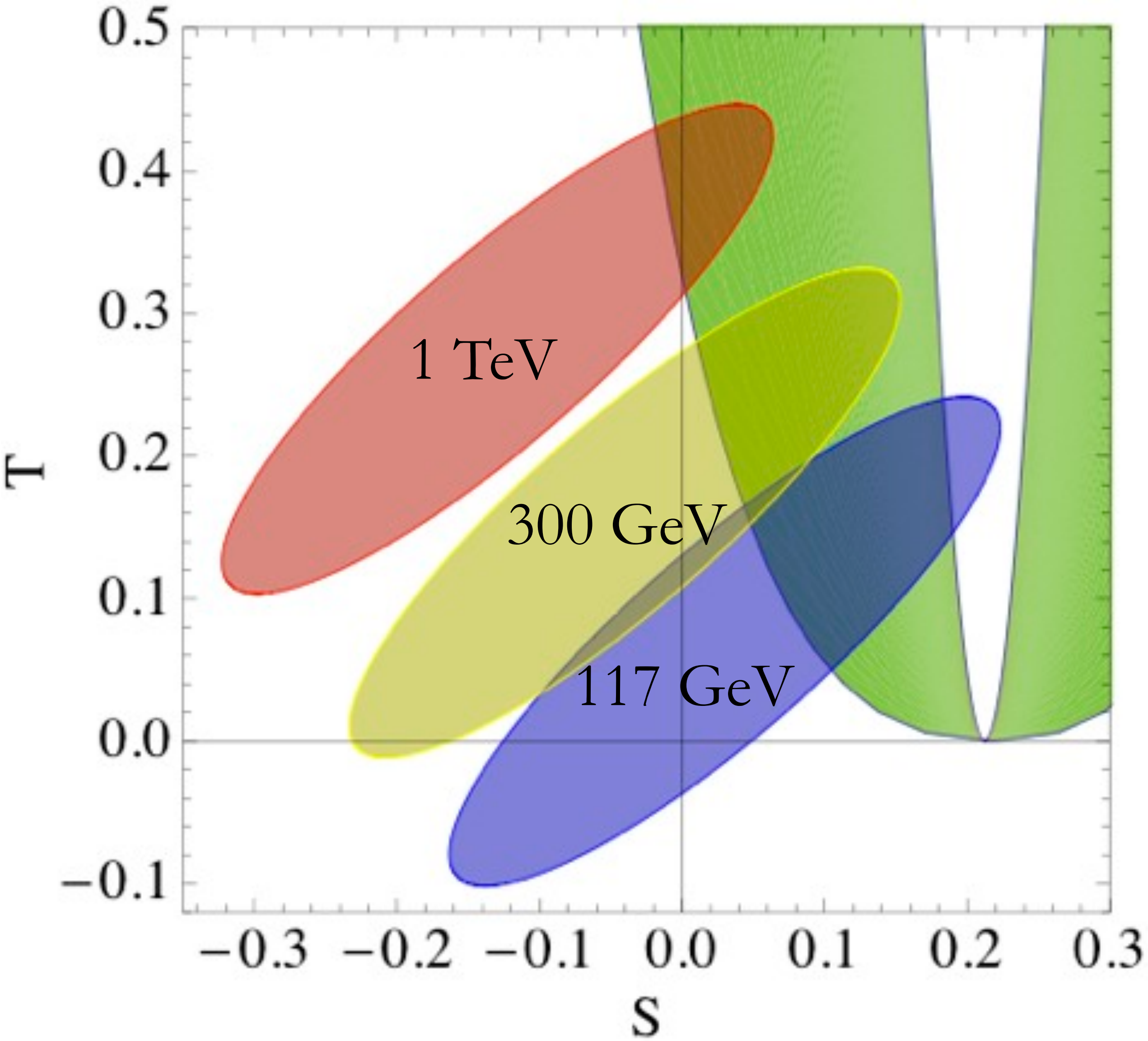
$$\text{Fermions}: \qquad \psi_L = \begin{pmatrix} \psi_{1L} \\ \psi_{2L} \end{pmatrix}, \qquad \psi_{1R}, \qquad \psi_{2R}$$

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

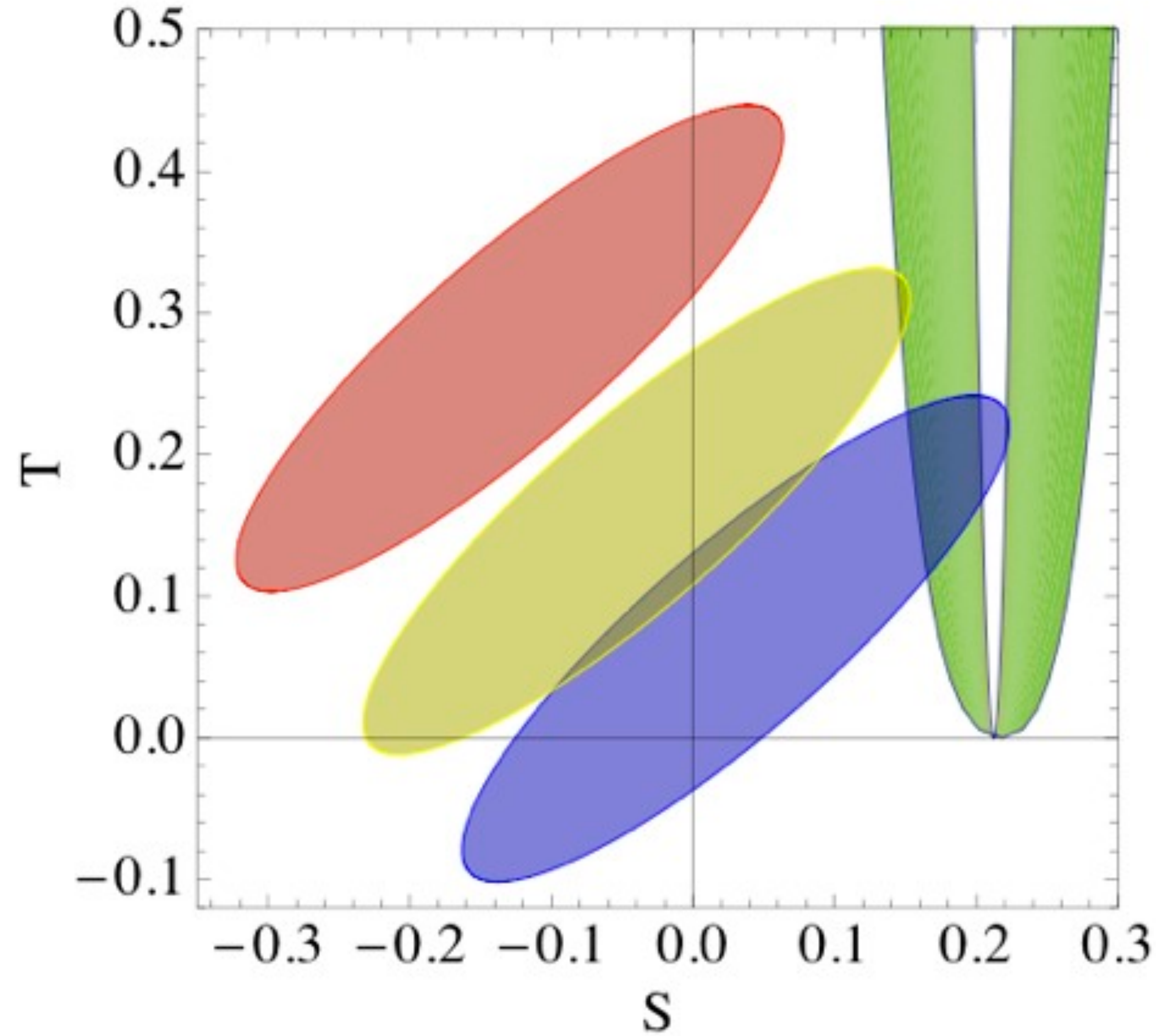
$$S_{\text{Leptons}} = \frac{1}{6\pi}\left[1 - 2Y \ln\left(\frac{M_1}{M_2}\right)^2 + \frac{1+8Y}{20}\left(\frac{m_Z}{M_1}\right)^2 + \frac{1-8Y}{20}\left(\frac{m_Z}{M_2}\right)^2 + O\left(\frac{m_Z^4}{M_i^4}\right)\right]$$

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

New Leptons & Precision Data



Exotic Leptonic hypercharge Y=-3/2



Standard Model Leptonic hypercharge

MWT Lagrangian

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

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

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

MWT Lagrangian

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

$$+i\bar{L}_L\gamma^\mu D_\mu L_L + i\bar{N}_R\gamma^\mu D_\mu N_R + i\bar{E}_R\gamma^\mu D_\mu E_R$$

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

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What you see is “not” what LHC will see

MWT Effective Lagrangian

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

Foadi, Frandsen, Ryttov & F.S. 07

MWT Effective Lagrangian

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

Composite Higgs	H
Composite Axial - Vector States	$R_{1,2}$

Foadi, Frandsen, Ryttov & F.S. 07

MWT Effective Lagrangian

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

Composite Higgs $\quad$ H

Composite Axial - Vector States $\quad$ $R_{1,2}$

Heavy Electron $\quad$ ζ

2 Heavy Majoranas $\quad$ $N_1 \quad N_2$

Frandsen, Masina, Sannino 09

Hapola, Masina, Sannino 11

Foadi, Frandsen, Ryttov & F.S. 07

Effective Theory for LHC

Vector Mesons

Yukawas

Link to MWT via 2nd modified Weinberg Sum Rule
[Appelquist - Sannino]

Written in a renormalizable form

With imposed constraints from Precision Data

Foadi, Frandsen, Ryttov & F.S. 07

Effective Theory for LHC

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[Appelquist - Sannino]

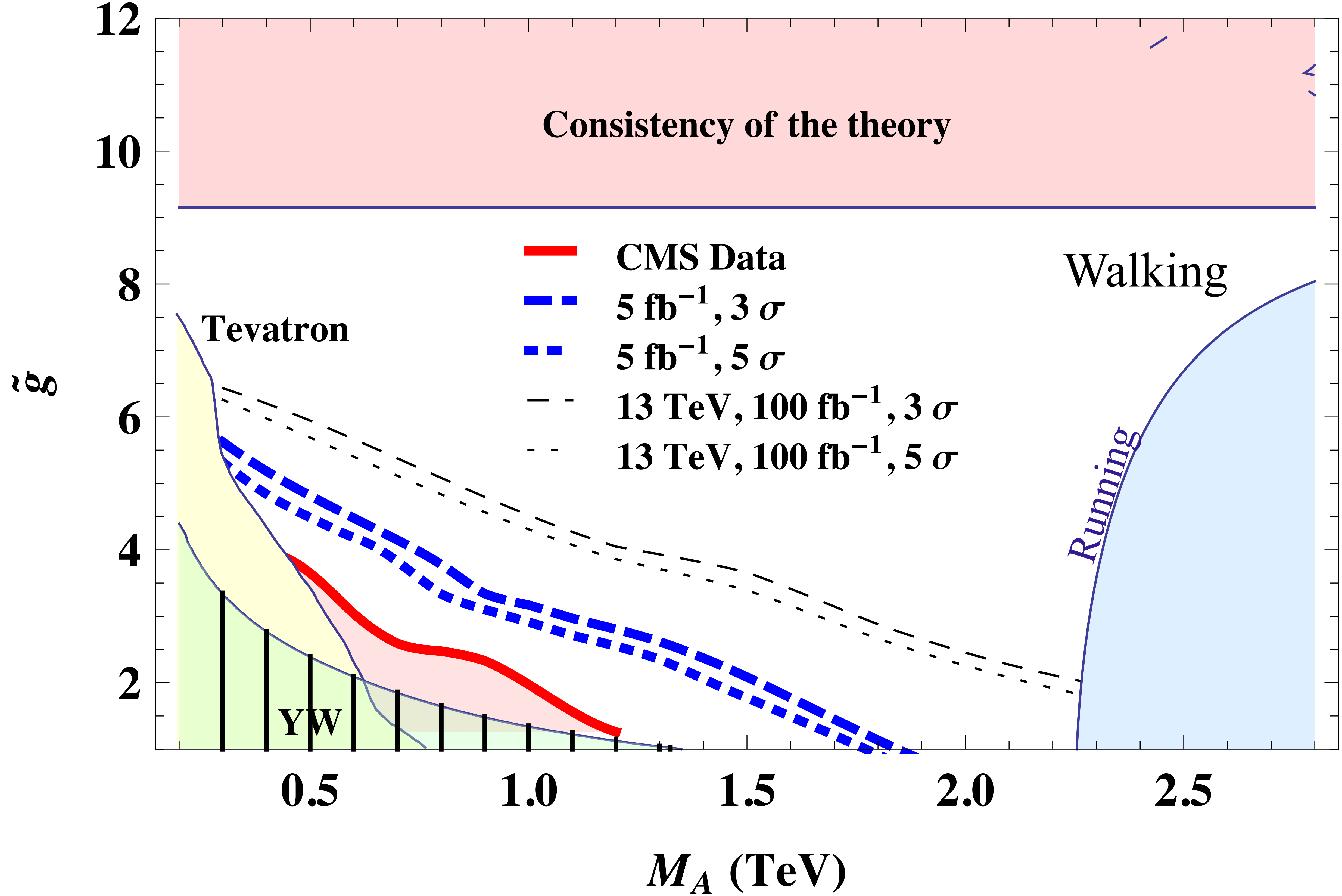
Written in a renormalizable form

With imposed constraints from Precision Data

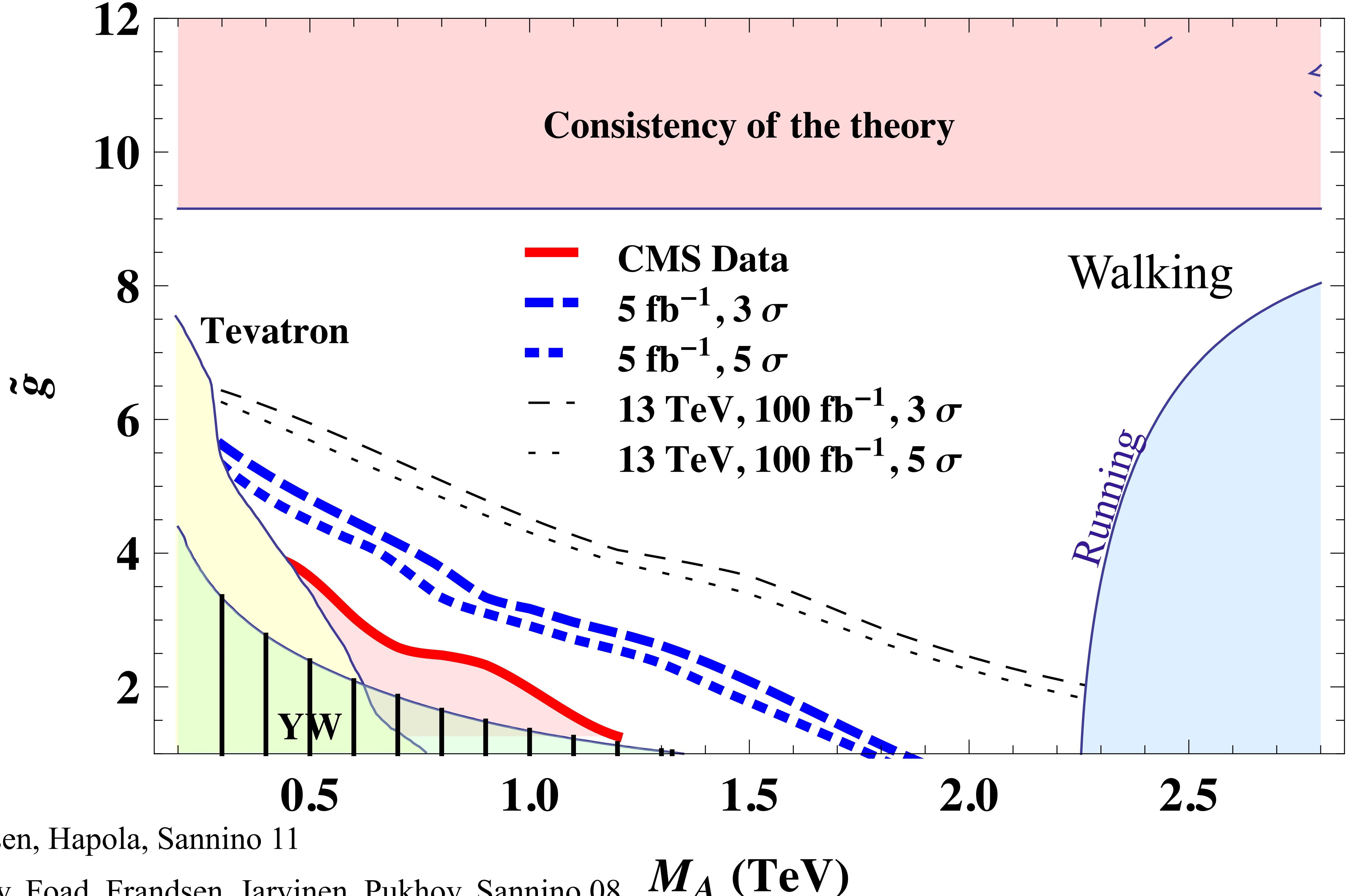
A working technicolor benchmark

Foadi, Frandsen, Ryttov & F.S. 07

Constraining MWT



Constraining MWT



Andersen, Hapola, Sannino 11

Belyaev, Foad, Frandsen, Jarvinen, Pukhov, Sannino 08

Non - walking template

Non - walking template

- TC theories with smallest naive S-parameter

Non - walking template

- TC theories with smallest naive S-parameter

- Non-traditional ETC

Non - walking template

- TC theories with smallest naive S-parameter

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- Simplest theory with dark matter candidate

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- TC theories with smallest naive S-parameter

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SU(2) with two Dirac fundamental flavors

Ryttov, Sannino 08
Appelquist, Sannino 98
Lewis, Pica, Sannino 2011

Non - walking template

- TC theories with smallest naive S-parameter

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SU(2) with two Dirac fundamental flavors

Ryttov, Sannino 08
Appelquist, Sannino 98
Lewis, Pica, Sannino 2011

- Could be made walking by adding EW singlets techniquarks

Conclusions

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- X compositeness

Conclusions

- X compositeness
- Walking & jumping

Conclusions

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- Minimal walking models are S-safer

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Conclusions

- X compositeness
- Walking & jumping
- Minimal walking models are S-safer
- Ready templates for LHC
- Minimal TC signals at the LHC by Järvinen