DYNAMICAL FERMION MASS GENERATION BY STRONG YUKAWA INTERACTIONS

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Flavour in the Era of the LHC

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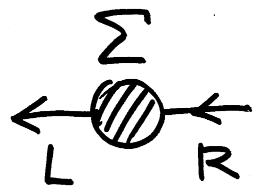
Use of the general principle of spontaneous breakdown of continuous symmetry for realistic $SU(2)_L \times U(1)_Y$ gauge and chirally invariant effective field theory description of electroweak phenomena is a necessity: Hard fermion and gauge boson symmetry breaking mass terms ruin decent behavior of scattering amplitudes

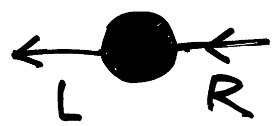
SPONTANEOUS FERMION MASS GENERATION

- masslessness of the field protected by CHIRAL SYMMETRY

- fermion mass emerges as a pole in full propagator due to CHIRALLY INVARIANT INTERACTION

$$S(p) = \frac{1}{\not{p} - \Sigma(p)} = \boxed{\frac{\not{p} + \Sigma(p)}{p^2 - \Sigma^2(p)}}$$





$$m^2 = \Sigma^2(p^2 = m^2)$$

- by definition : non-perturbative

GENUINELY DISTINCT (KNOWN TO ME) REALIZATIONS

1. Complex scalars : $\mathcal{L}_{int} = y\bar{\Psi}_L \Psi_R \phi$ + H.c.

arrange for condensation ($\phi_0 = (-M^2/\lambda)^{1/2}$)

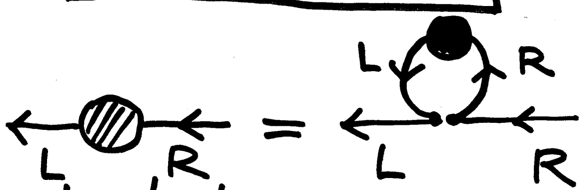
"non-pert."

$\mathcal{L}_{int} \to \bar{\Psi}_L \boxed{y\phi_0} \Psi_R$ + H.c.

this is what happens in S.M.

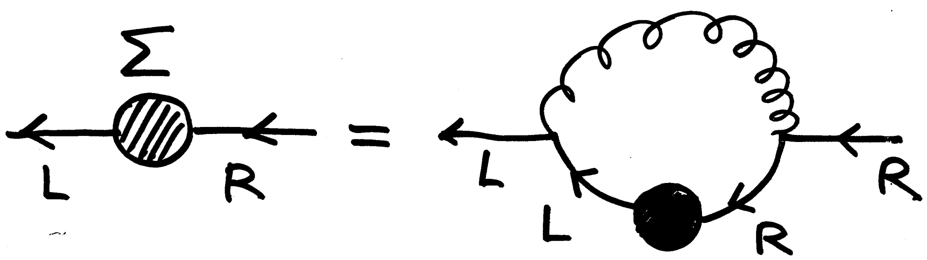
2. Fermions : $\mathcal{L}_{int} = G\bar{\Psi}_L \gamma_\mu \Psi_L \cdot \bar{\Psi}_R \gamma^\mu \Psi_R$

$\mathcal{L}_{int} \to \bar{\Psi}_L \boxed{G\gamma_\mu \underbrace{\Psi_L \bar{\Psi}_R}\gamma^\mu} \Psi_R$



this is what happens in NJL & replicas

3. Vectors : $\mathcal{L}_{int} = [g_L\bar{\Psi}_L\gamma_\mu\Psi_L + g_R\bar{\Psi}_R\gamma_\mu\Psi_R]B^\mu$

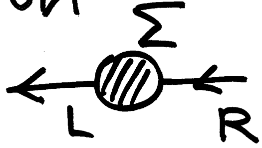


this is what happens in remaining models

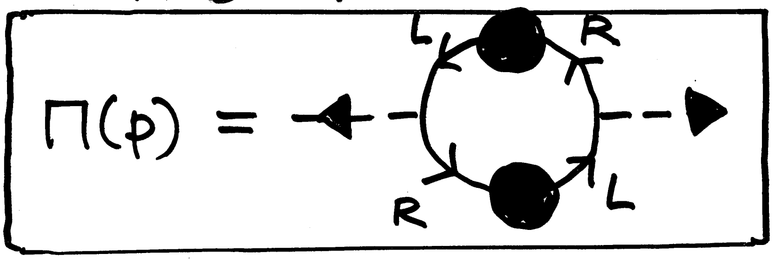
OUR SUGGESTION

- employ complex scalars

$$\mathcal{L}_{int} = y\bar{\Psi}_L \Psi_R \phi + y\bar{\Psi}_R \Psi_L \phi^*$$

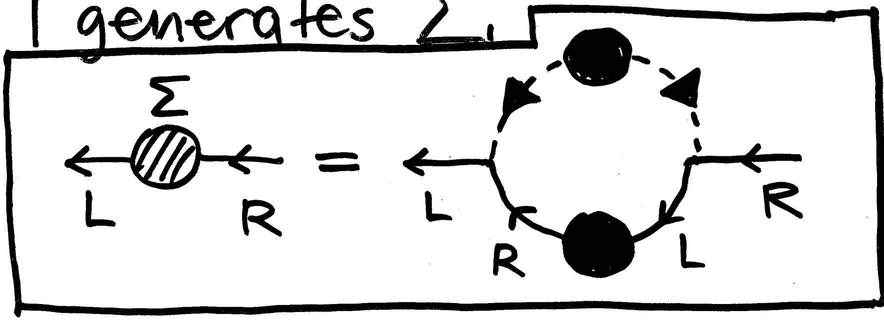
- consider $M^2 > 0$: ϕ is a heavy scalar
  no condensation
- assume $\Sigma(p)$ is generated : 

- Σ generates Π



$$\mathcal{L}^{(0)}_{eff}(\phi) = \partial_\mu \phi^* \partial^\mu \phi - M^2 \phi^* \phi - \tfrac{1}{2}\phi^* \Pi \phi^* - \tfrac{1}{2}\phi \Pi^* \phi$$

- Π generates Σ

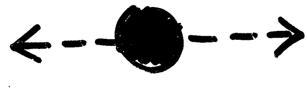


 is the DIFFERENCE OF SCALAR PROP.

ϕ describes two spin-0 particles with different M_i

$$D^{-1}(p) = \begin{pmatrix} p^2 - M^2, & -\Pi(p) \\ -\Pi^*(p), & p^2 - M^2 \end{pmatrix}$$

$$D(p) = \frac{1}{(p^2 - M^2 - |\Pi|)(p^2 - M^2 + |\Pi|)} \begin{pmatrix} p^2 - M^2 & \Pi(p) \\ \Pi(p) & p^2 - M^2 \end{pmatrix}$$

symmetry breaking 

THE MODEL

Tomáš Brauner and Jiří Hošek,
Phys. Rev. D72, 045007 (2005)
(hep-ph/0505231)
(+ Petr Beneš, to be published)

- $$\mathcal{L} = \bar{\Psi}_1 i\partial\!\!\!/ \Psi_1 + \bar{\Psi}_2 i\partial\!\!\!/ \Psi_2 +$$
$$\partial_\mu \phi^* \partial^\mu \phi - M^2 \phi^* \phi - \frac{1}{2}\lambda(\phi^*\phi)^2$$
$$+ y_1 \left[\bar{\Psi}_{1L} \Psi_{1R} \phi + \text{H.c.}\right] + y_2 \left[\bar{\Psi}_{2R} \Psi_{2L} \phi + \text{H.c.}\right]$$

- symmetry : $U(1)_{V_1} \times U(1)_{V_2} \times U(1)_A$
$$\Psi_1 \to \exp[+i\theta\gamma_5]\Psi_1, \quad \Psi_2 \to \exp[-i\theta\gamma_5]\Psi_2$$
$$\phi \to \exp[-2i\theta]\phi$$

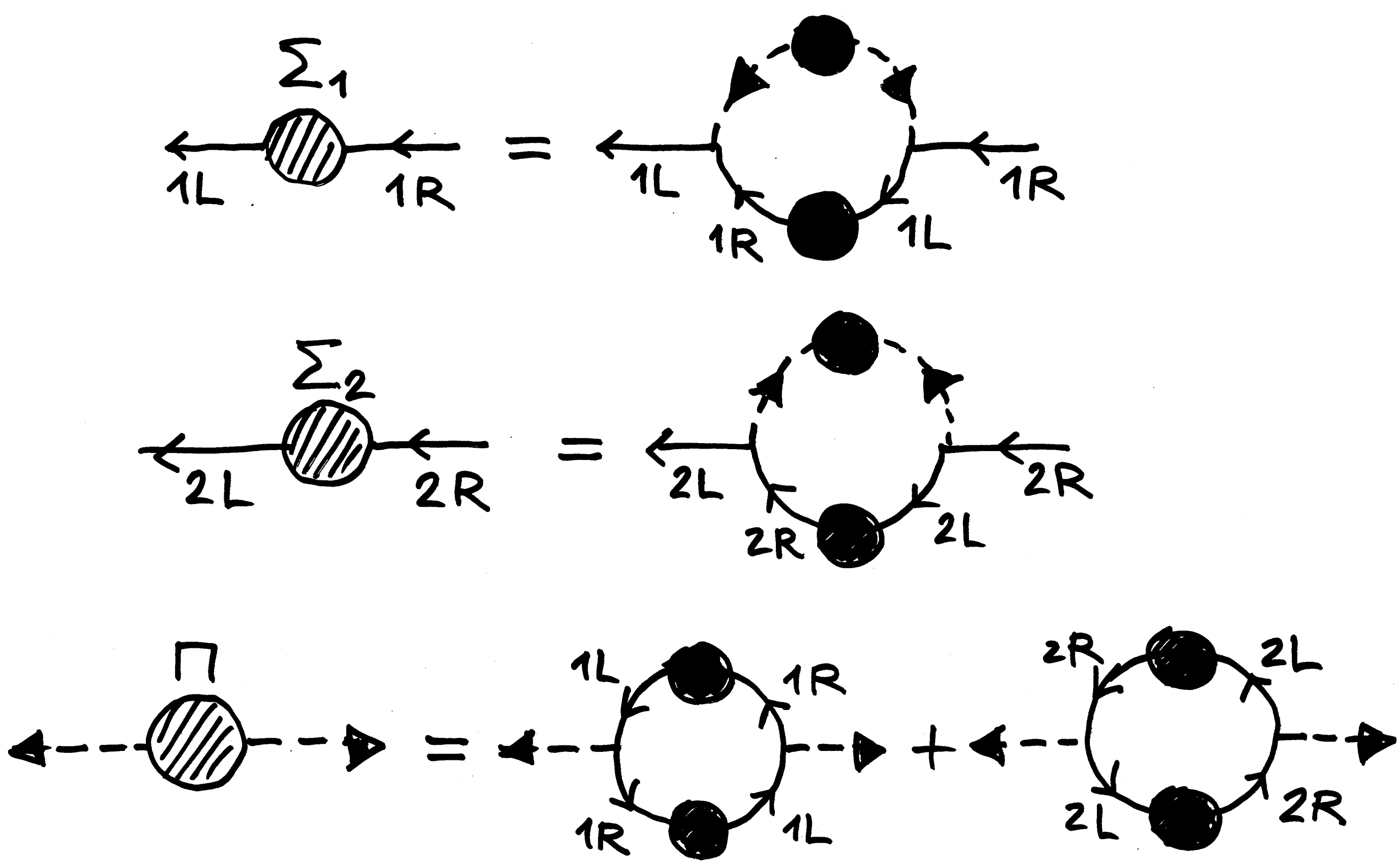
- why two fermion species ?

  model amenable to gauging $U(1)_A$

  axial anomaly has to be absent

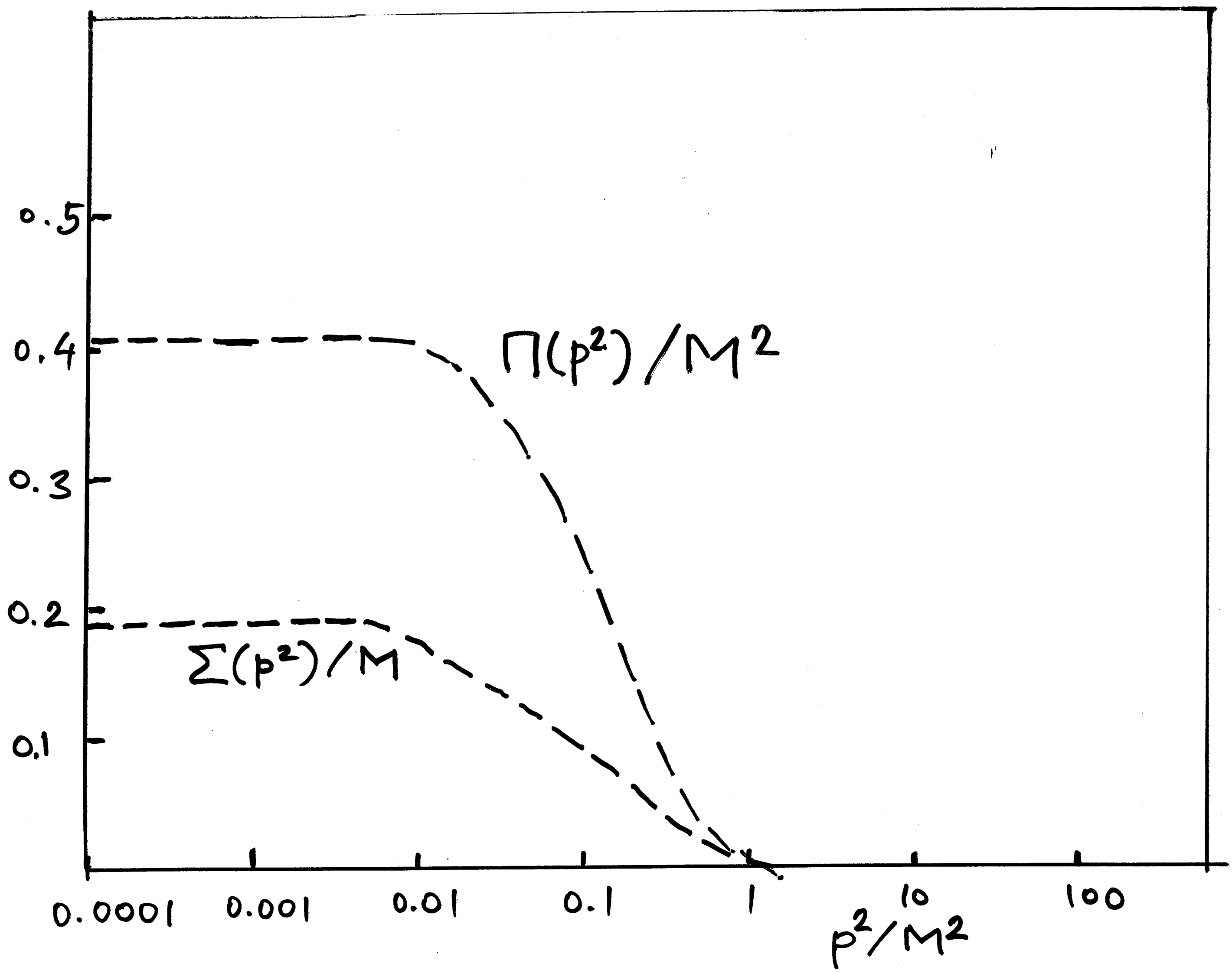
- $\lambda(\phi^*\phi)^2$ irrelevant for non-perturbative low-momentum driven mass generation

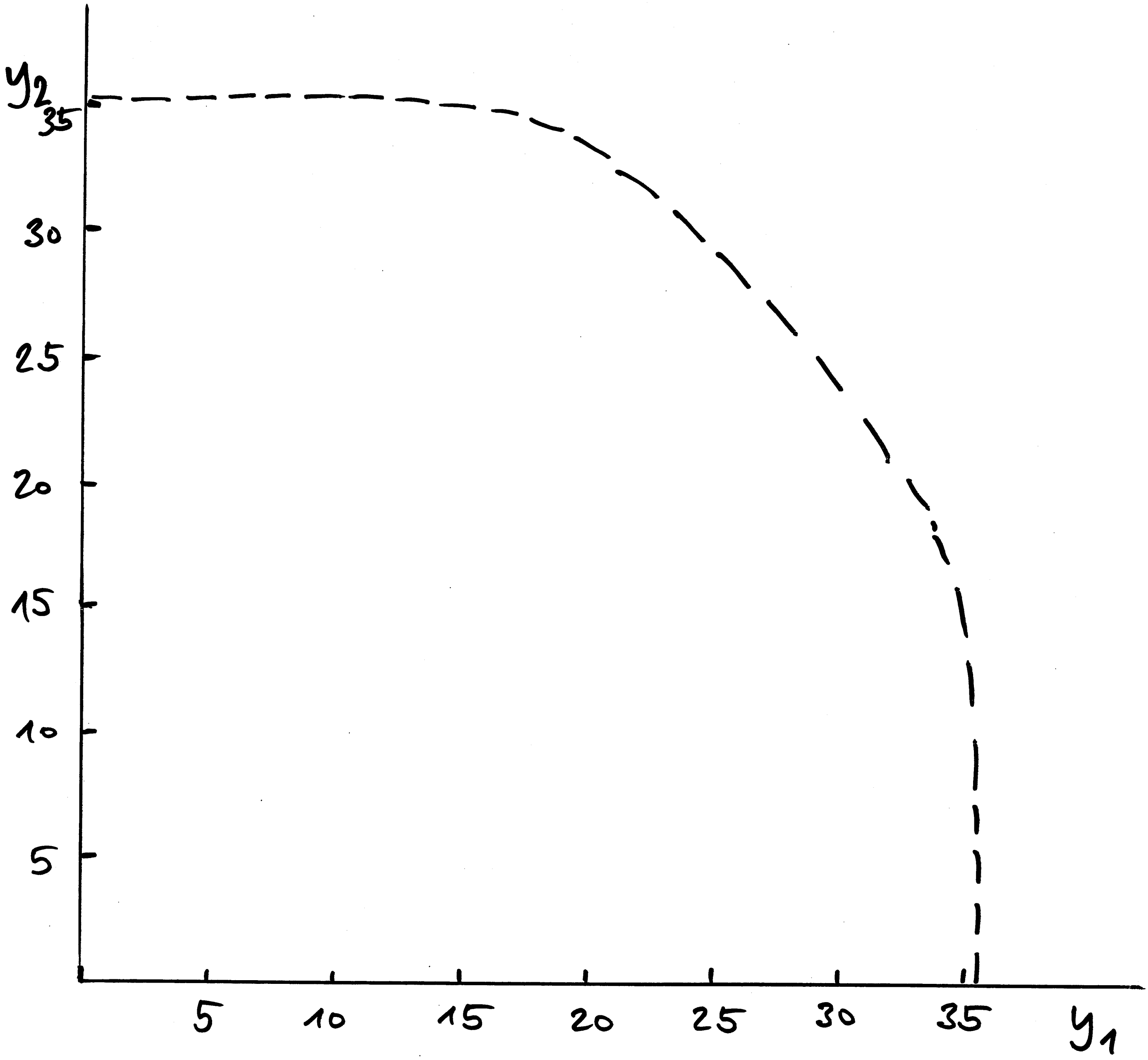
SCHWINGER-DYSON EQUATIONS FOR Σ AND Π



- If the solutions Σ_i, Π exist they should come out UV-finite : corresponding counter-terms prohibited by symmetry
- robust, no tinkering

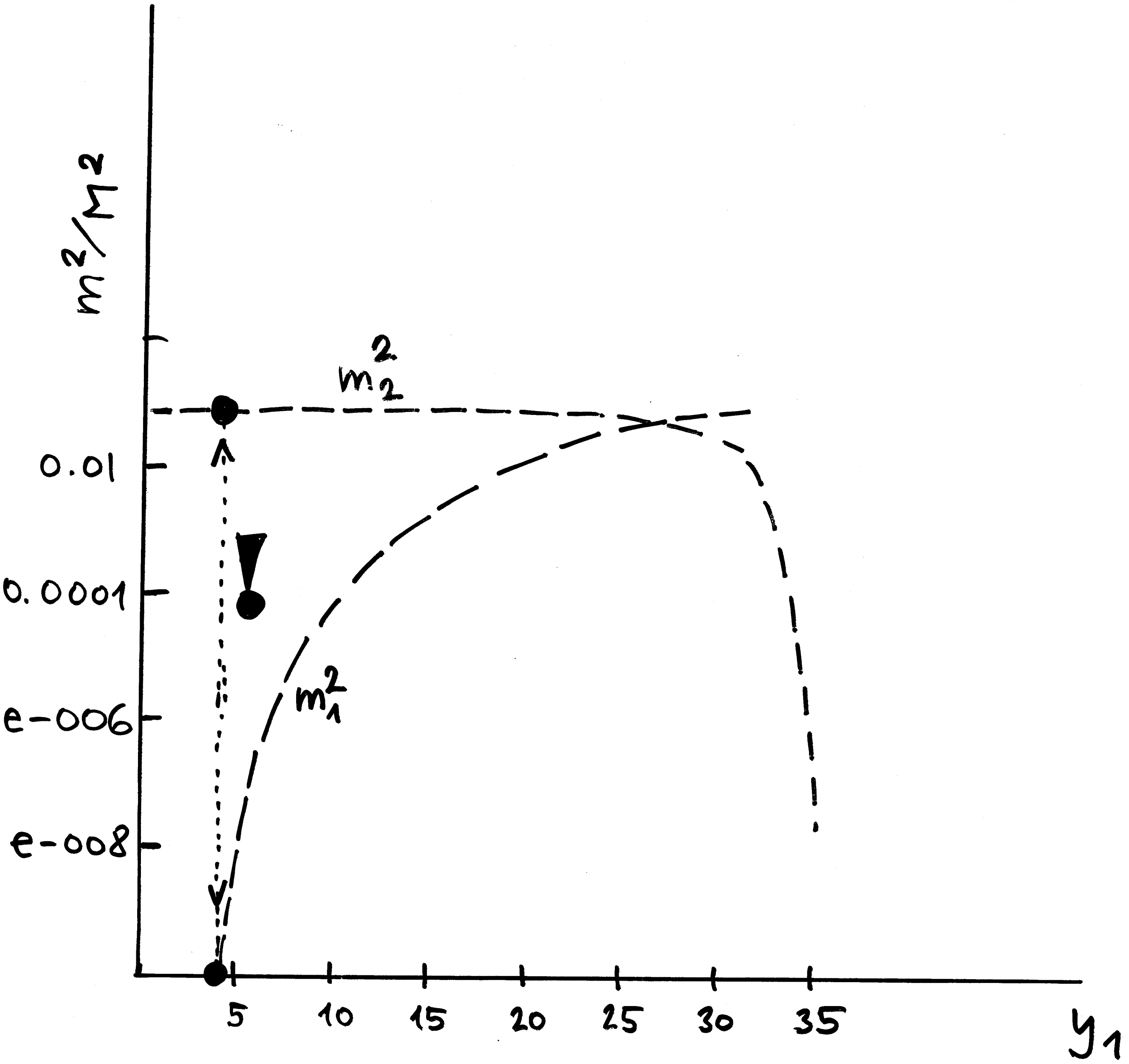
in paper





Critical coupling constants

PRELIMINARY



Fermion masses

PRELIMINARY

- by dimensional argument $m_{1,2} = M f_{1,2}(y_1, y_2)$
- SM approach $m_{1,2} = (-M^2/\lambda)^{1/2} y_{1,2}$
- if verified this should NOT be called FINE TUNING

WHERE IS THE NAMBU – GOLDSTONE BOSON?

- $$j^\mu_A = \bar\psi_1 \gamma^\mu \gamma_5 \psi_1 - \bar\psi_2 \gamma^\mu \gamma_5 \psi_2 + 2i\left[(\partial^\mu \phi)^* \phi - \phi^* \partial^\mu \phi\right]$$

- fermion masses $m_i \sim \Sigma_i$
  boson mass splitting M_1, M_2

naively:

- $$\partial_\mu j^\mu_A = 2im_1 \bar\psi_1 \gamma_5 \psi_1 - 2im_2 \bar\psi_2 \gamma_5 \psi_2 + 2i(M_1^2 - M_2^2)\varphi_1 \varphi_2$$

something is missing: NG excitation

axial-vector Ward identities:

$$q_\mu \Gamma^\mu_{A\psi_1}(p+q, p) = S_1^{-1}(p+q)\gamma_5 + \gamma_5 S_1^{-1}(p)$$

$$q_\mu \Gamma^\mu_{A\psi_2}(p+q, p) = -S_2^{-1}(p+q)\gamma_5 - \gamma_5 S_2^{-1}(p)$$

$$q_\mu \Gamma^\mu_{A\phi}(p+q, p) = -2D^{-1}(p+q)\Xi + 2\Xi D^{-1}(p)$$

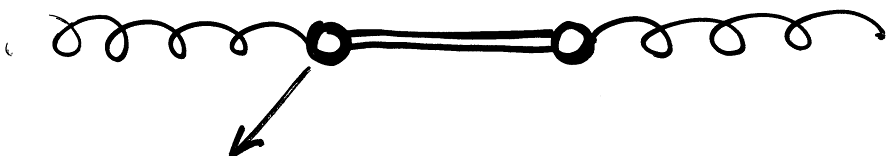
$\Xi = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$: operates in $\phi - \phi^*$ (analog of γ_5)

massless pole in Γ^μ_A : NG boson

- its couplings to ψ_1, ψ_2 and ϕ are calculated
- it is a composite of ψ_i and ϕ

$\boxed{\text{GAUGE BOSON MASS}^2}$

is the residue at the massless pole of the gauge field polarization tensor; here the massless pole is due to the 'would-be' NG boson



UV finite loops containing Σ_i, Π

gauge boson mass is generated only if fermion masses are generated (in contrast with S.M)

- gauging : $\partial \to D + (-\frac{1}{4}F^2)$
- obviously, for $y_1, y_2 = 0$ $(M^2 > 0)$ the gauge boson stays massless

OUTLOOK

- "practical": We know how to generalize the Abelian prototype to electroweak $SU(2)_L \times U(1)_Y$:
  Tomáš Brauner and Jiří Hošek, hep-ph/0407339

- "theoretical": We believe that finding non-perturbatively the full propagators in the strongly coupled Yukawa model should allow the reconstruction of beta functions at large values of the couplings