Light scalars:
From lattice to the LHC via holography

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in collaboration with G.Panico, O.Pujolas & L.Salas

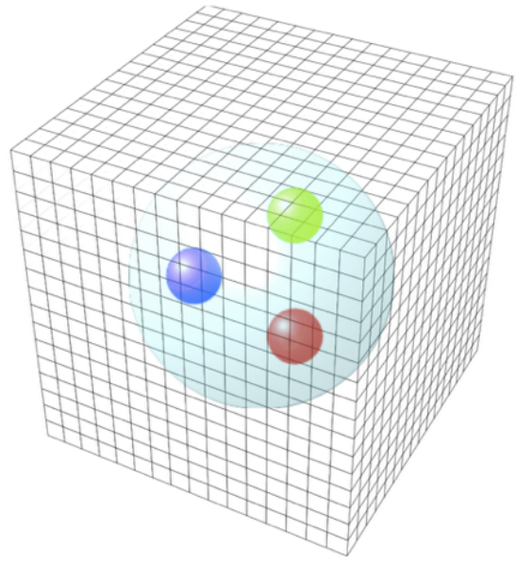
PRELIMINARY

Corfu 2017

While waiting for new physics at the LHC…

we can turn to **lattice new interesting results**:

Light scalar found in gauge theories with large number of fermions around the conformal transition



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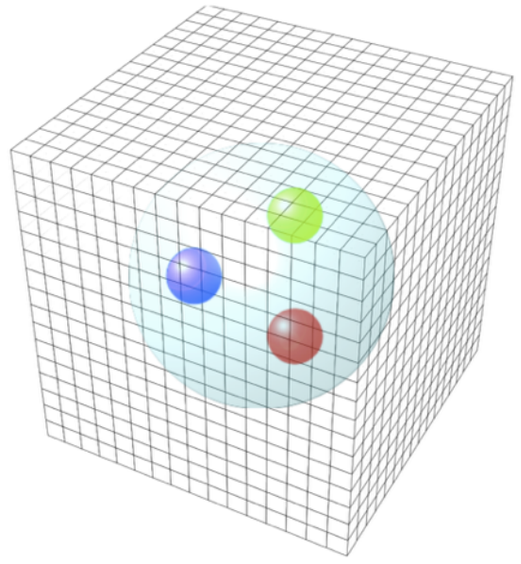
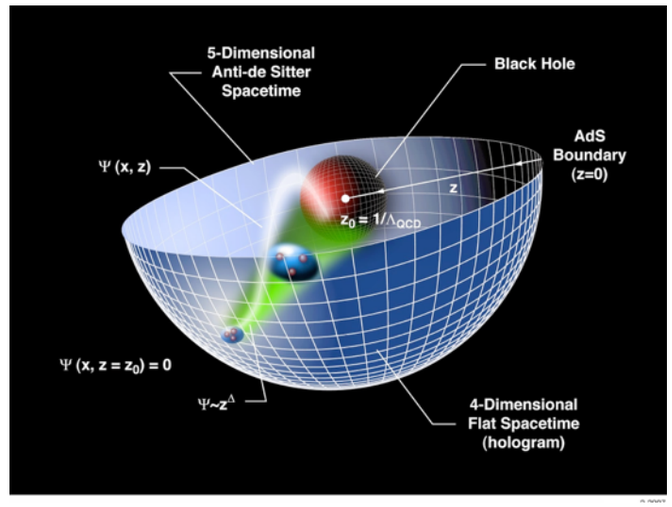


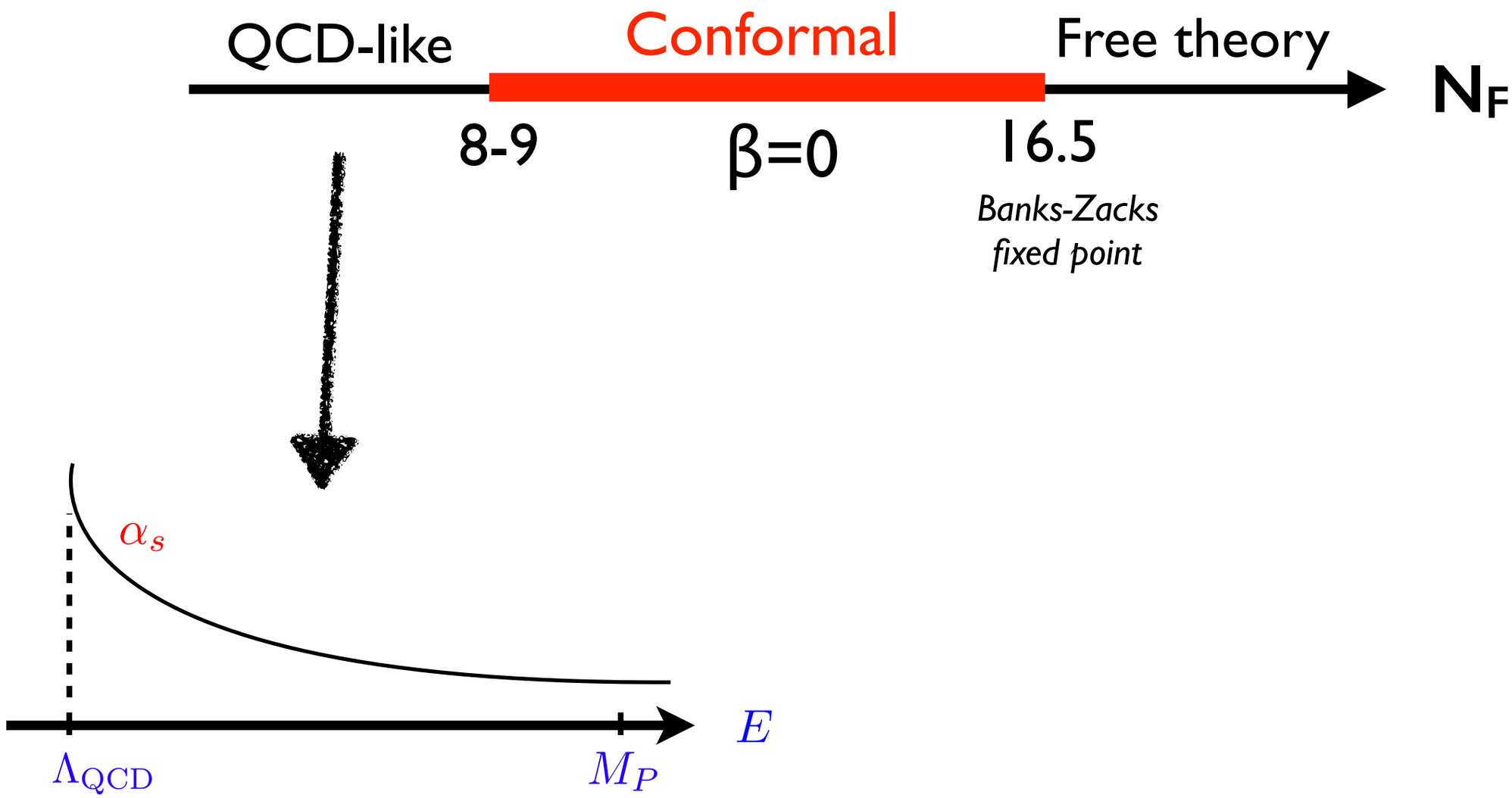
✦ Can this be understood via holography?

(AdS/CFT correspondence)



✦ What are the implications for solutions to the hierarchy problem via strong dynamics (composite Higgs)?

Conformal window in SU(3) with large number of fermions (N_F)



Mass gap ~ Λ_{QCD}

Chiral-symmetry breaking

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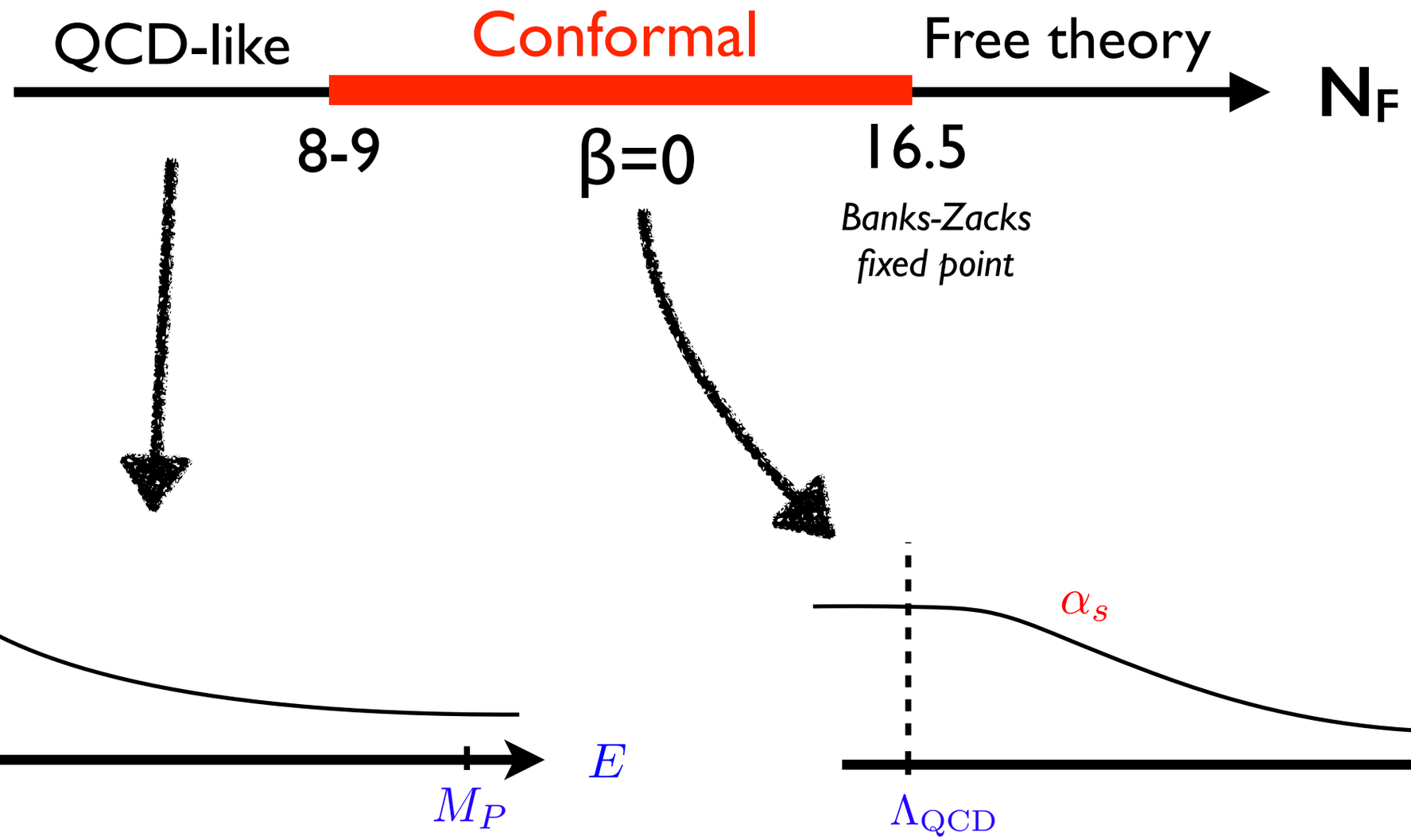

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No mass gap ~ Λ_{QCD}

No chiral-symmetry breaking

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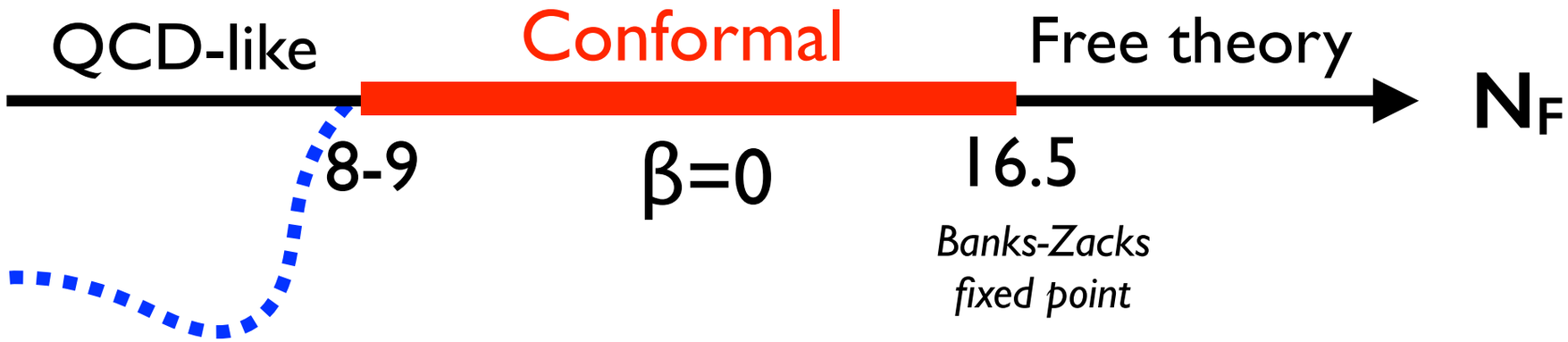
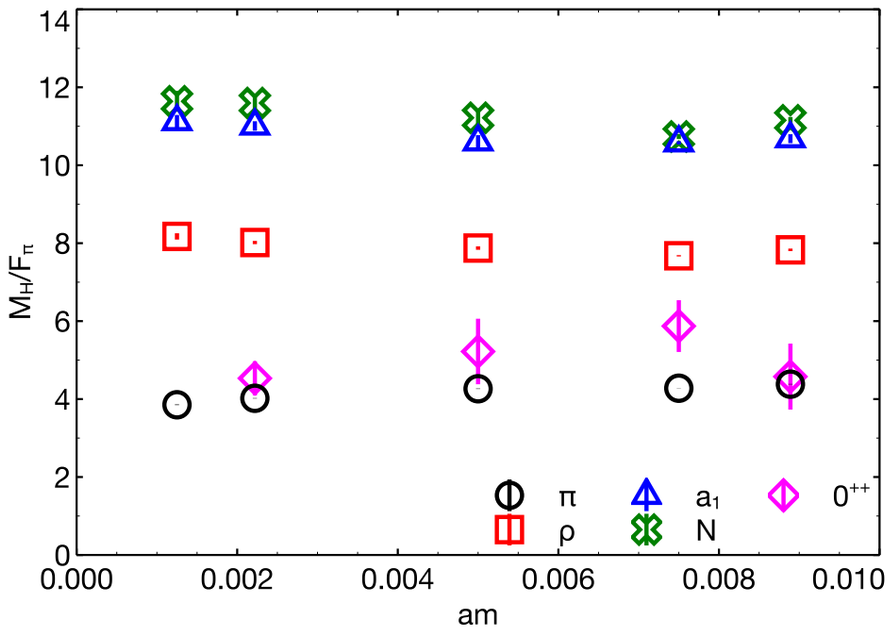
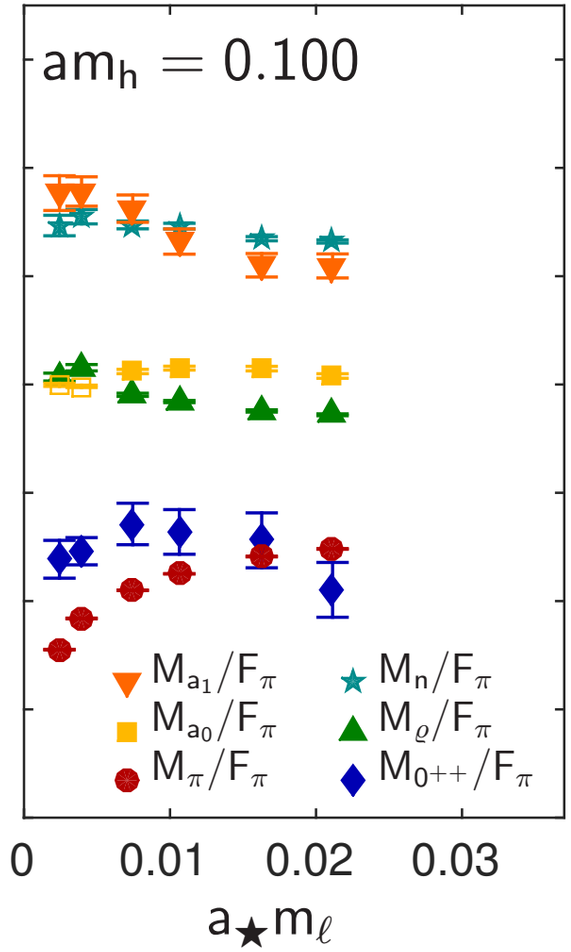


Lattice results:

N_F=8





arXiv:1601.04027

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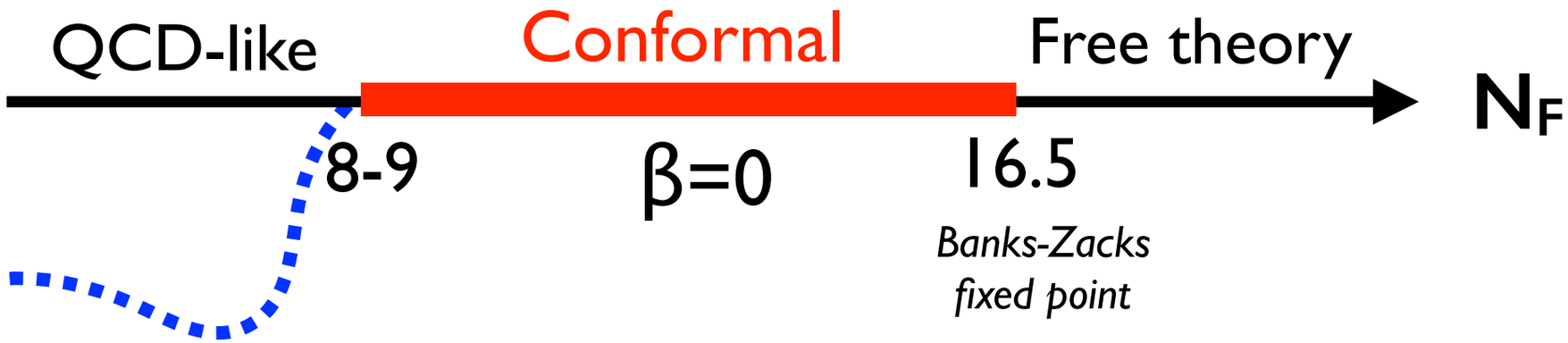

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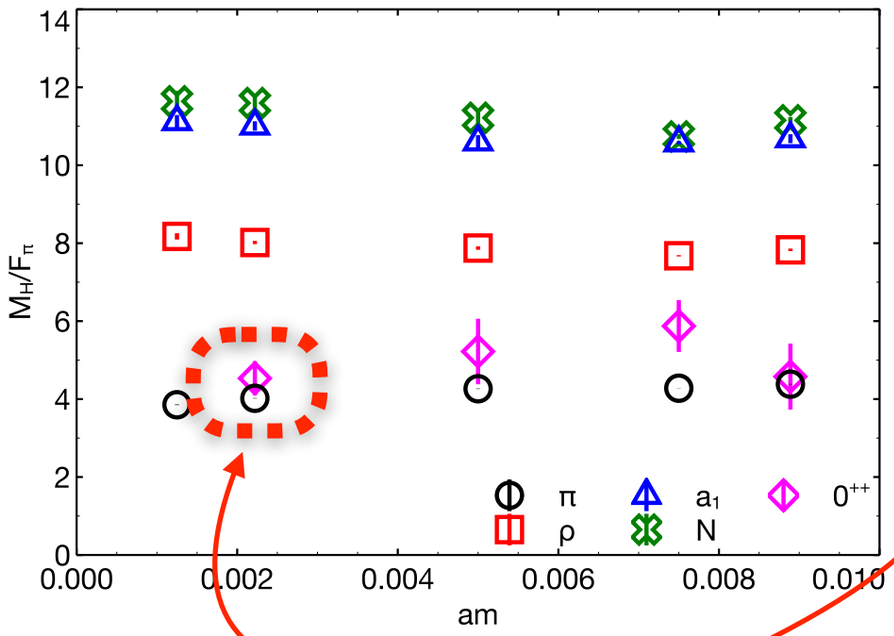

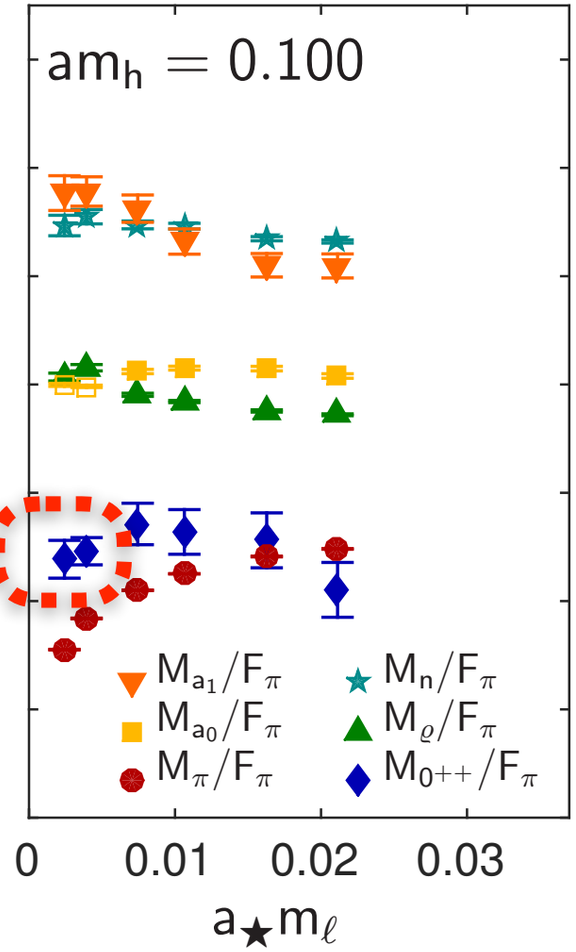

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The scalar, the lightest
(apart form the pion)

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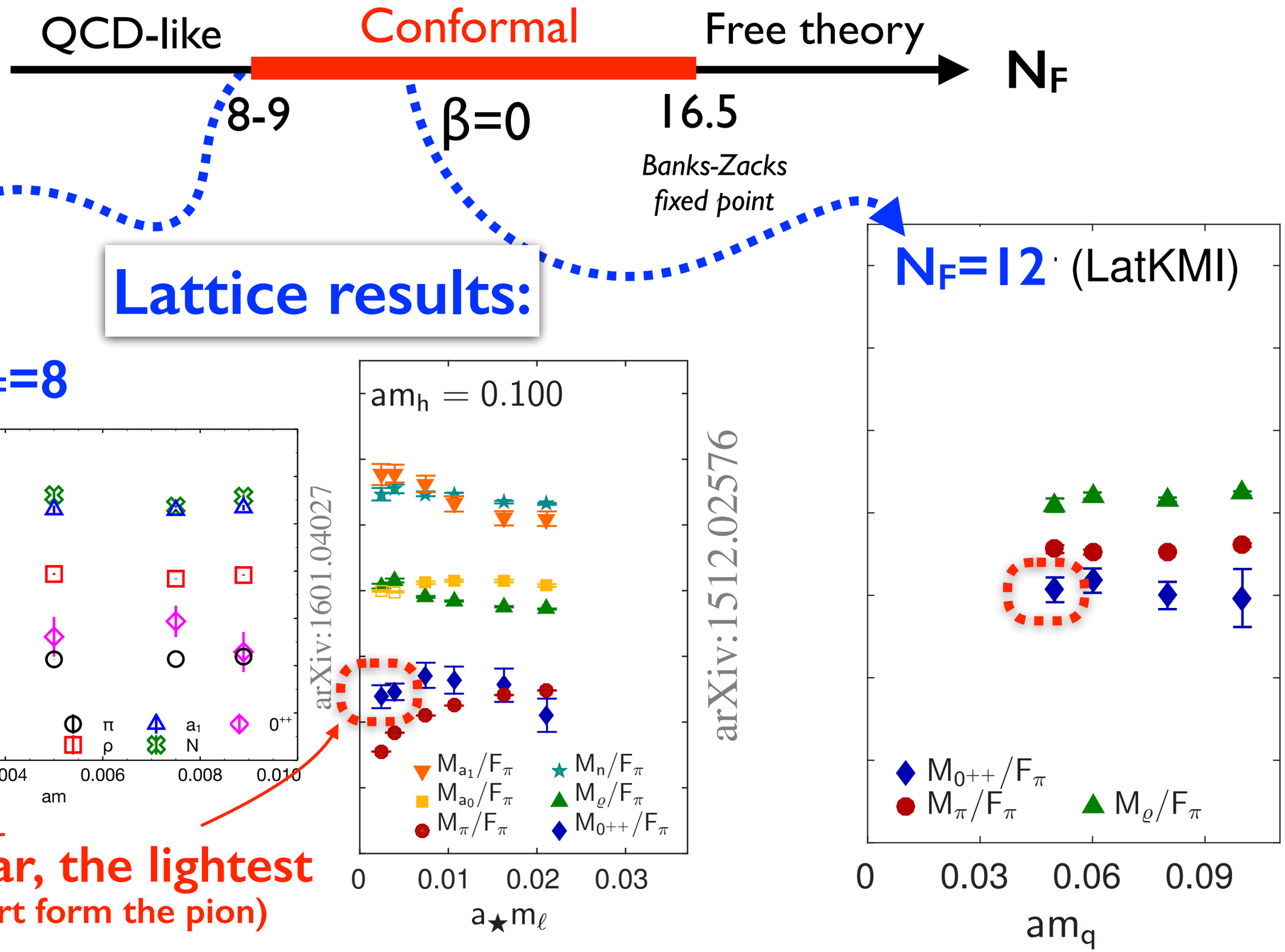

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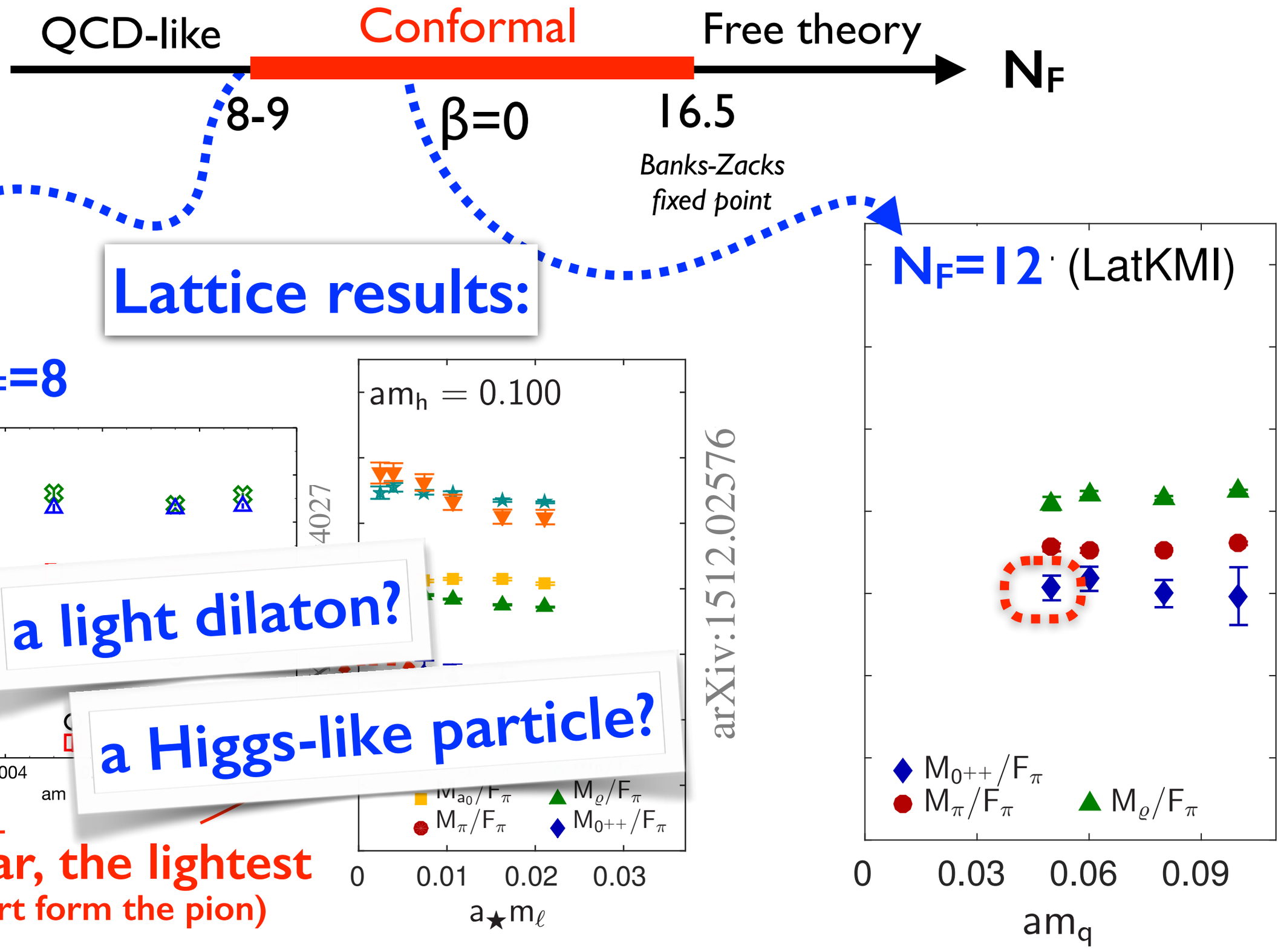
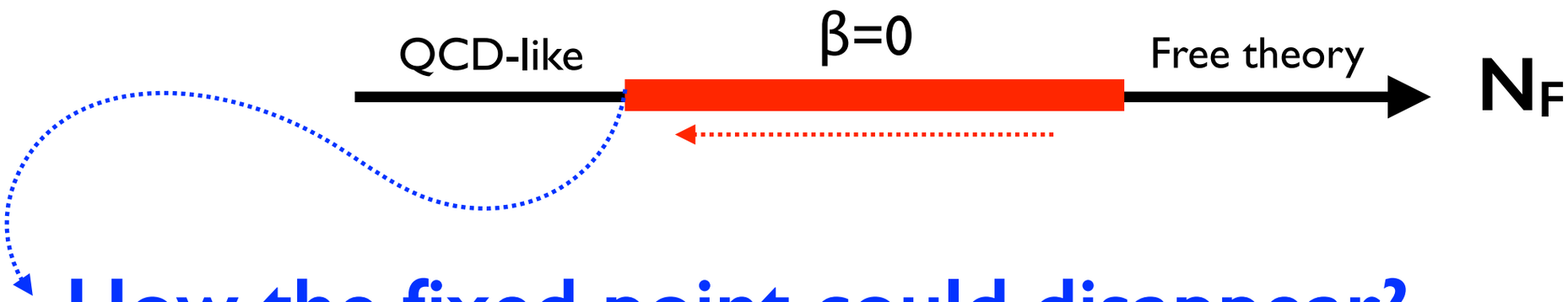


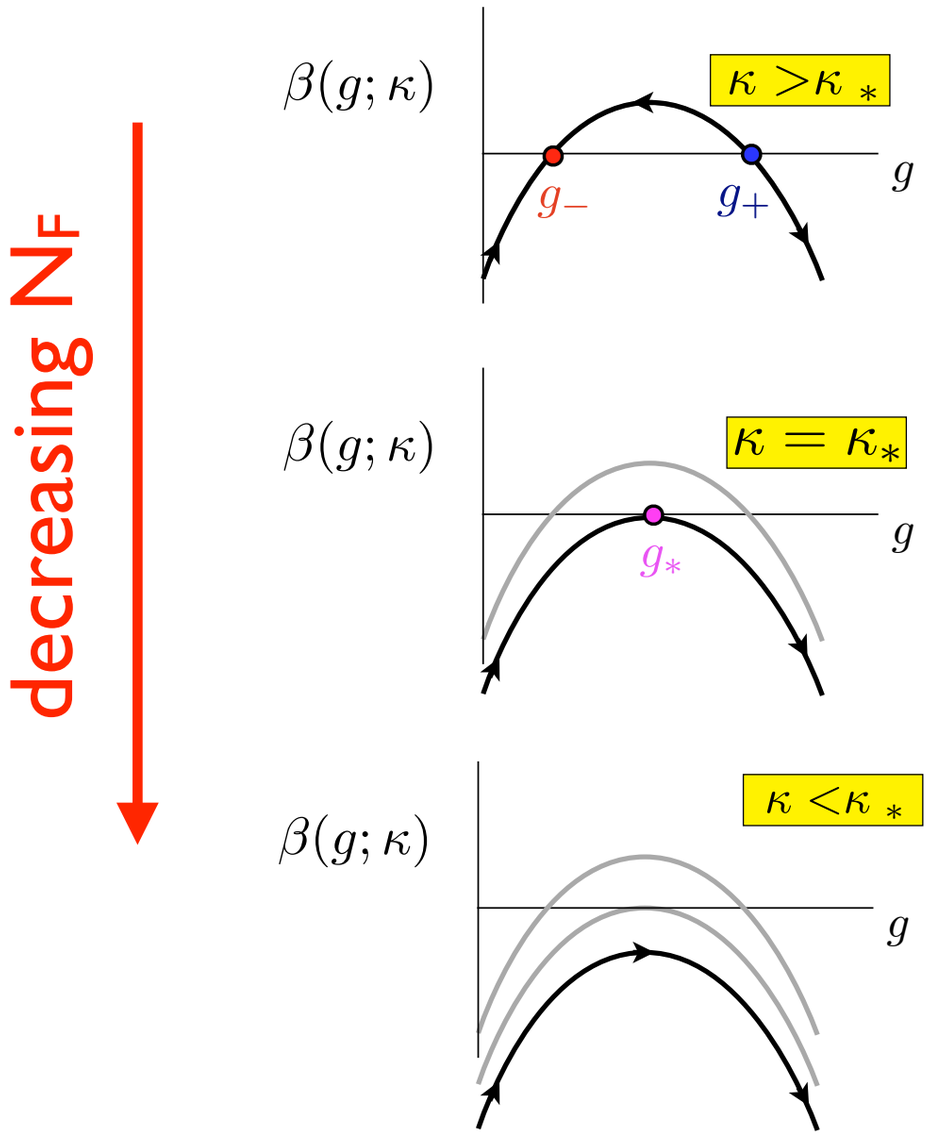
What could we say from holography?

Conformal breaking as N_F decreases



How the fixed point could disappear?

Lee,Son,Stephanov,Kaplan
arXiv:0905.4752
using a truncation of the Schwinger-Dyson eqs.



IR & UV fixed-point annihilation

D.B.Kaplan

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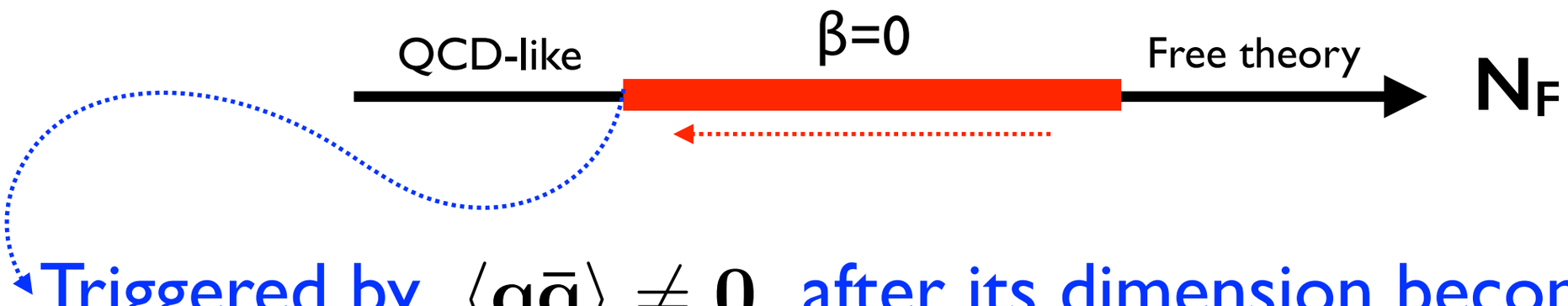

Triggered by $\langle q\bar{q}\rangle \neq 0$ after its dimension becomes imaginary

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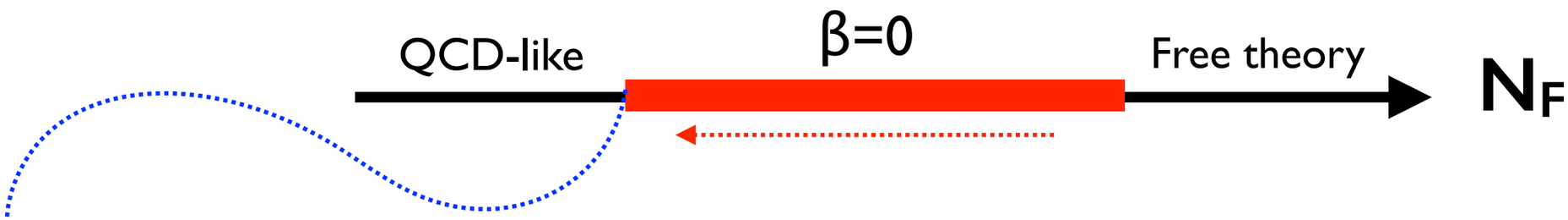

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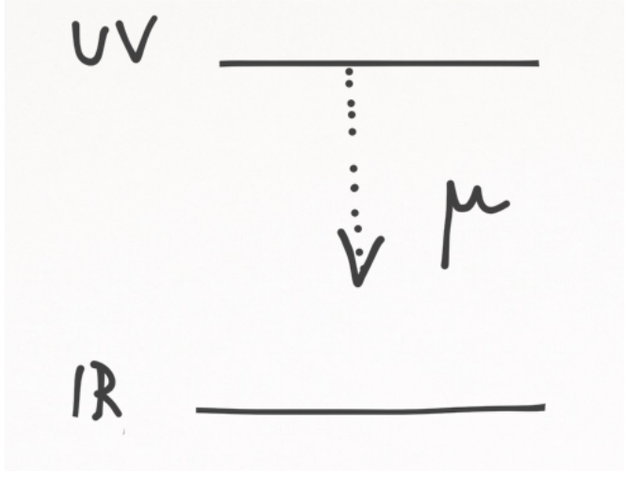
Using AdS/CFT:

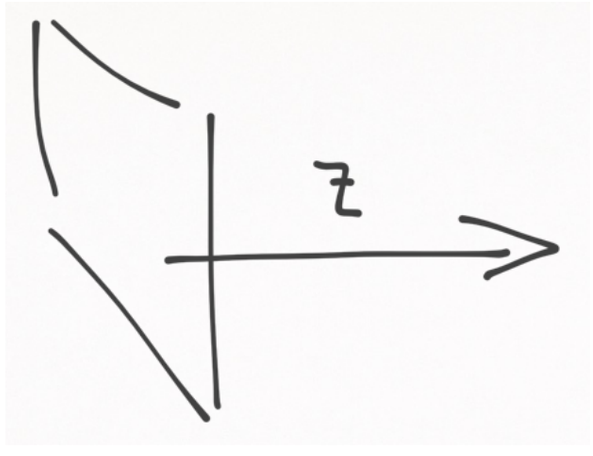
DICTIONARY

$CFT_4 \longleftrightarrow AdS_5$

$\mathbf{RG-scale}\ (\mu) \longleftrightarrow \mathbf{extra\ dim}\ (z)$



Strongly-coupled



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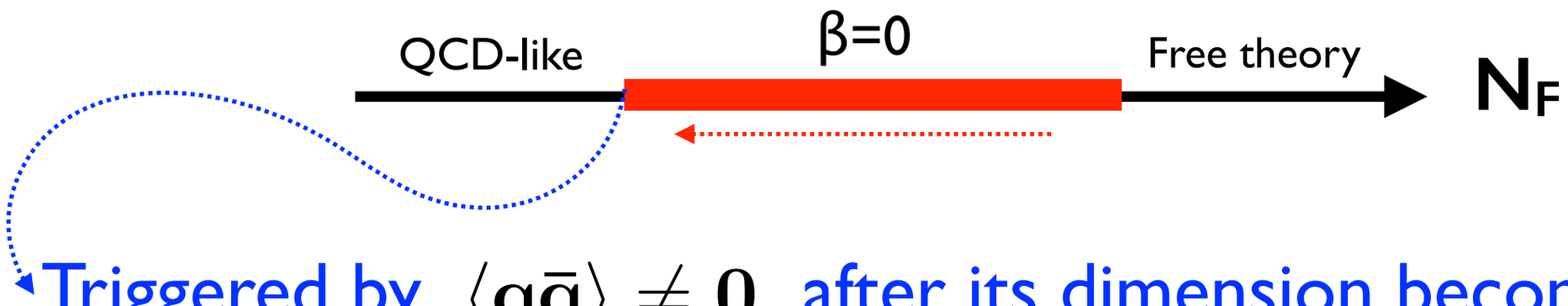

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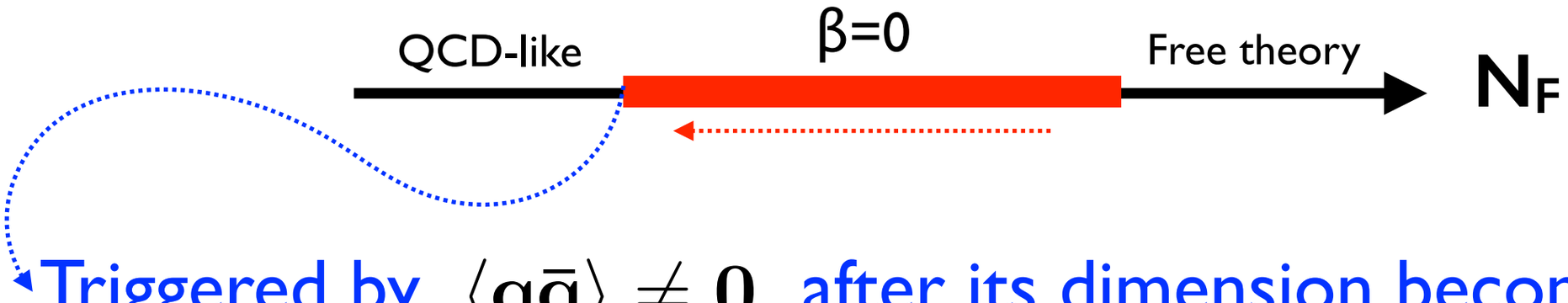

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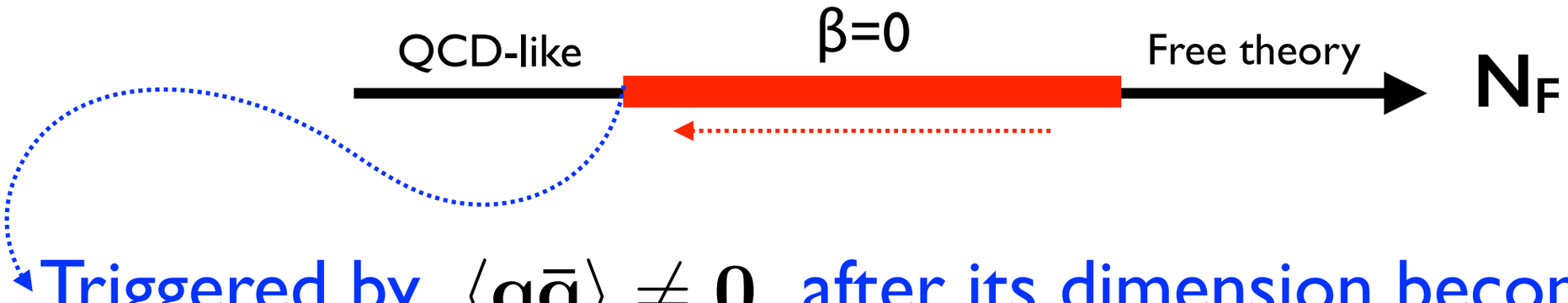

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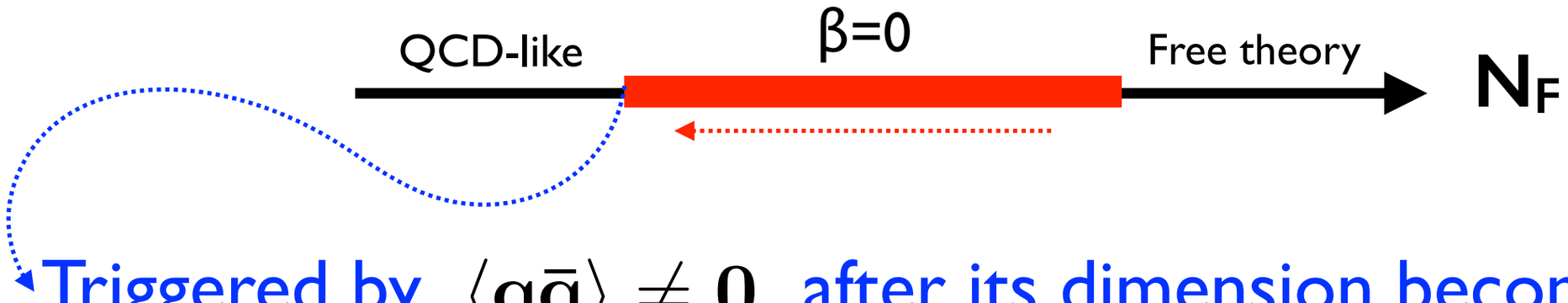

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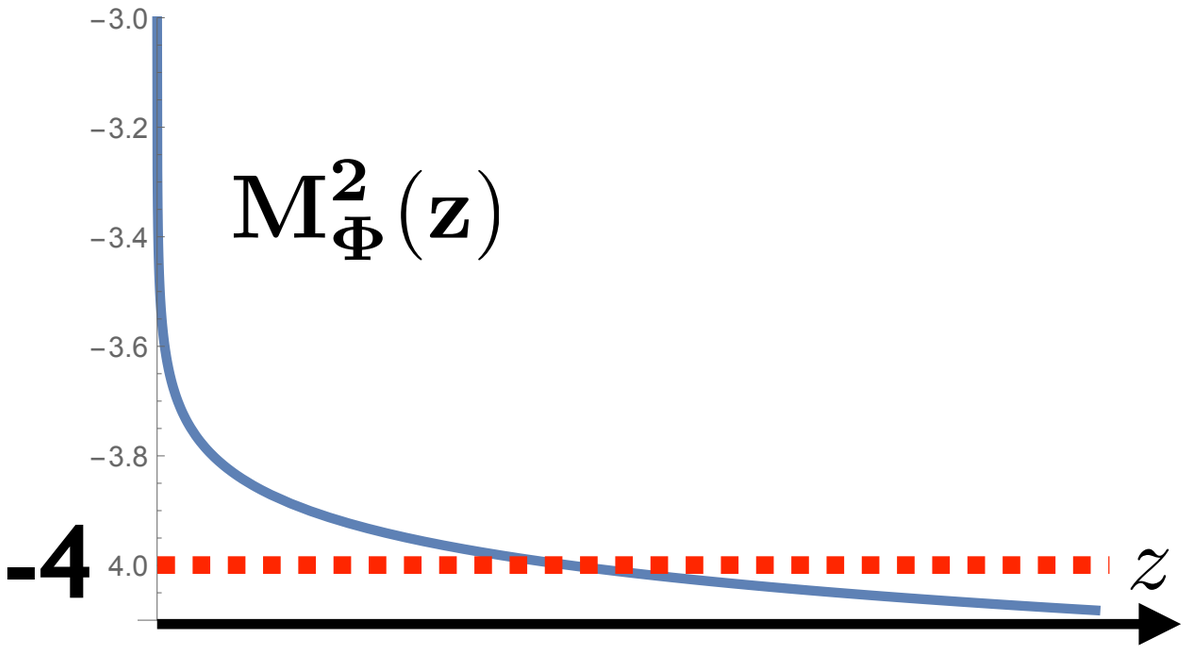
Imaginary when M_Φ goes below the BF bound ($M_\Phi^2 = -4/L^2$)

☛AdS tachyon!

Conformal breaking in AdS_5 due to mass running below the BF bound



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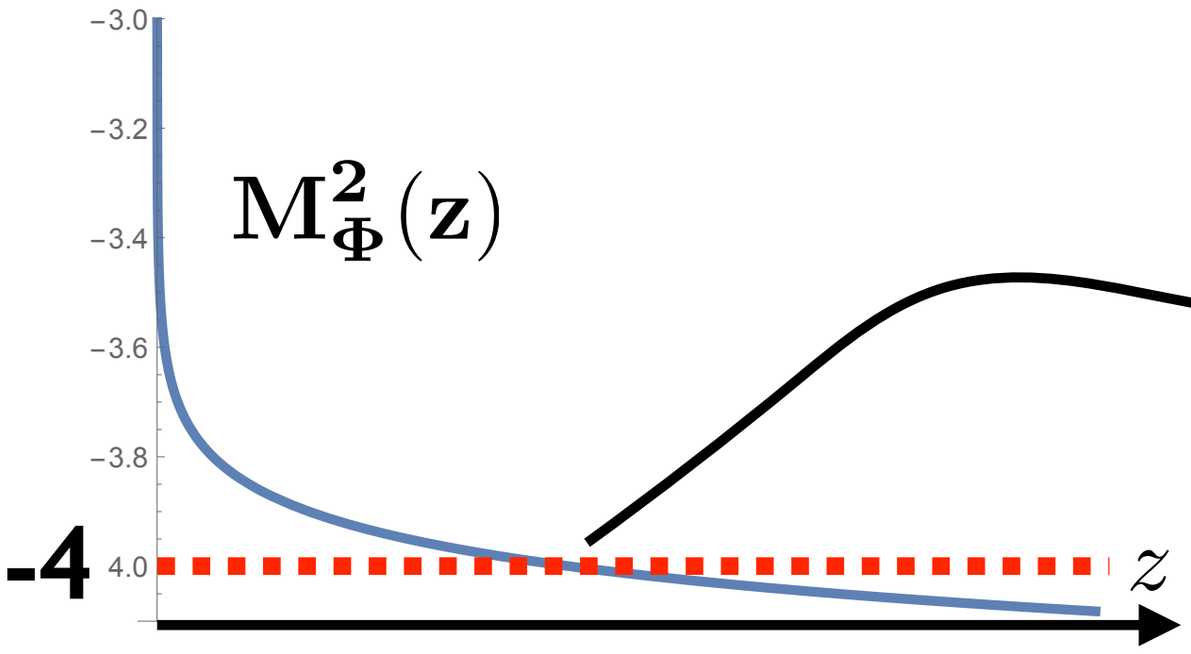

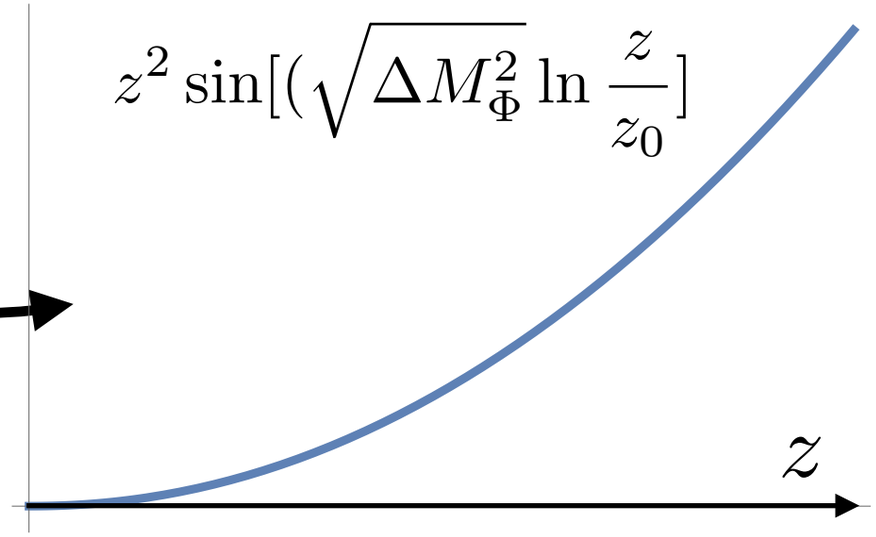

AdS tachyon

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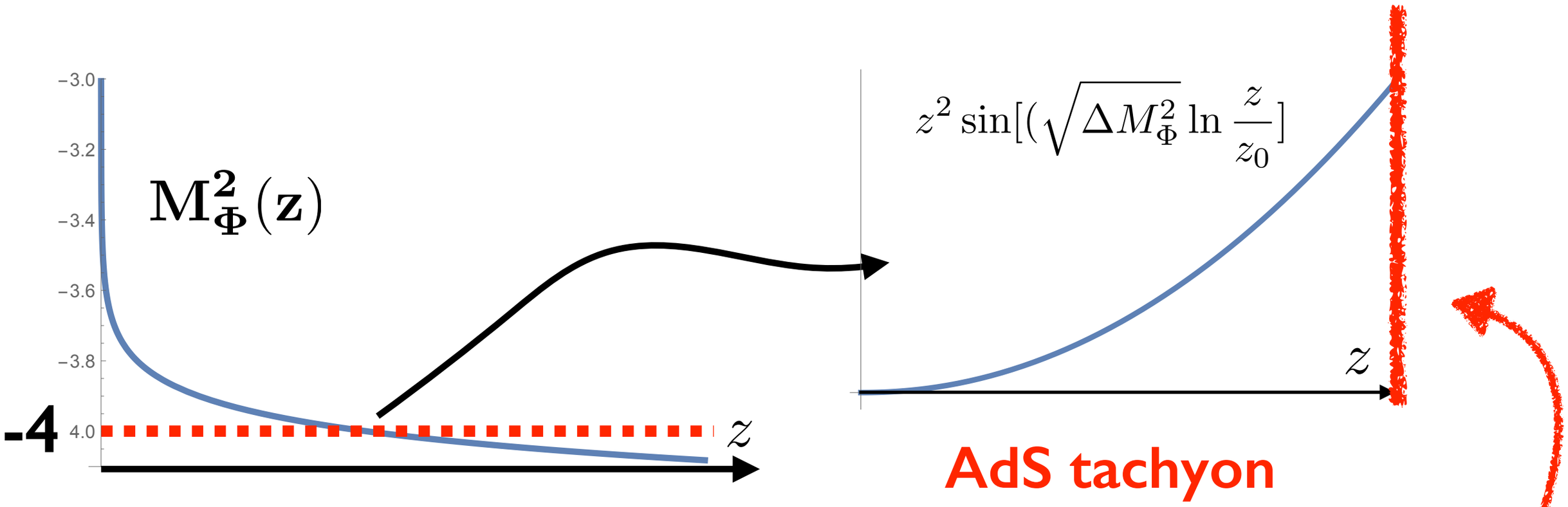

- The <u>metric back-reacts</u> where the tachyon blows up
- For simplification, we can regularize the IR with a brane
  (it will characterize the back-reaction)
- Position of the brane where tachyon becomes order one

$$\mathbf{\Phi}\big|_{\rm IR} = \mathbf{\Phi}_*$$

Light dilaton?

Spontaneous breaking of global-symmetry ☛ Massless Goldstone

Spontaneous breaking of scale invariance ☛ Massless dilaton?

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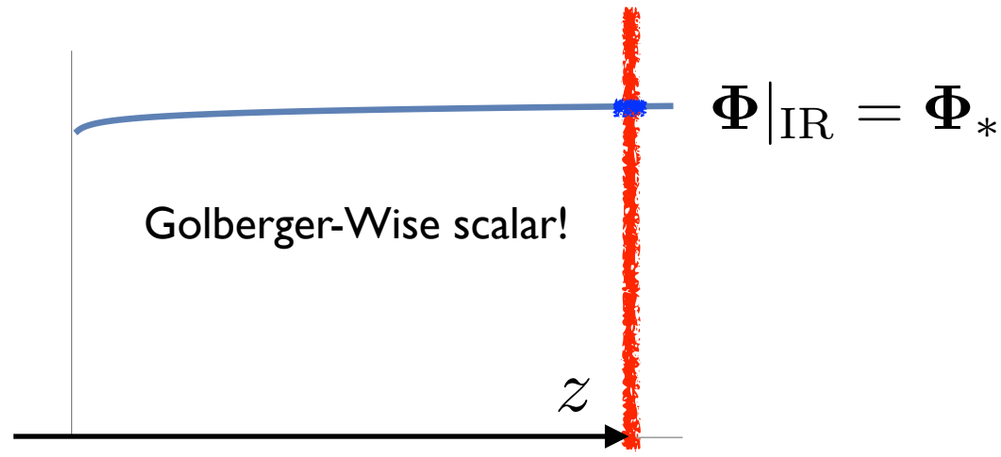
In AdS_5:

Light dilaton expected if the IR brane is almost free to move

(almost flat potential for the (radion) brane position)

Profile of the **tachyon** should be almost flat to lead to a light dilaton *(as brane would be almost free to move)*



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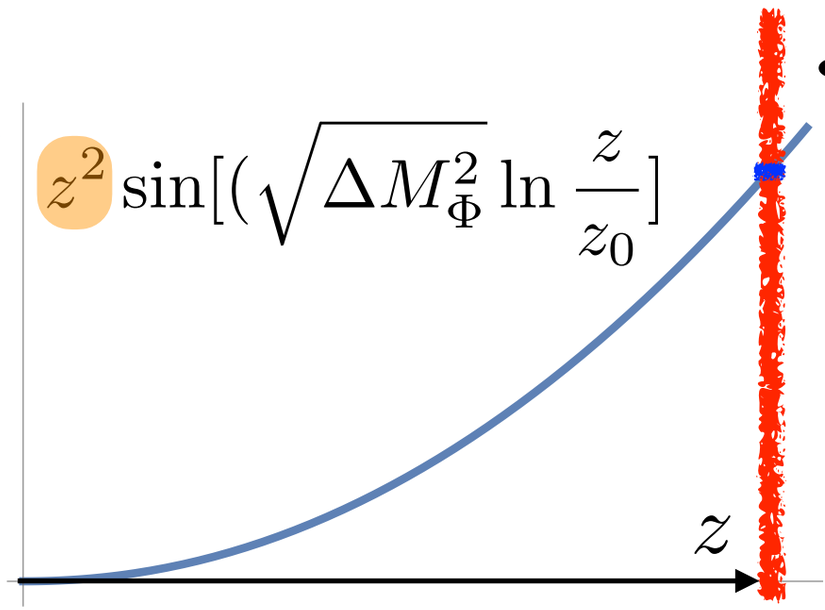
Not the case
for the AdS tachyon:



AdS tachyon grows as ~ z^2
☛ sizable cost of energy to move the brane

No light dilaton expected!

Nevertheless…

as N_F decreases, $q\bar{q}$ approaches the free scalar limit

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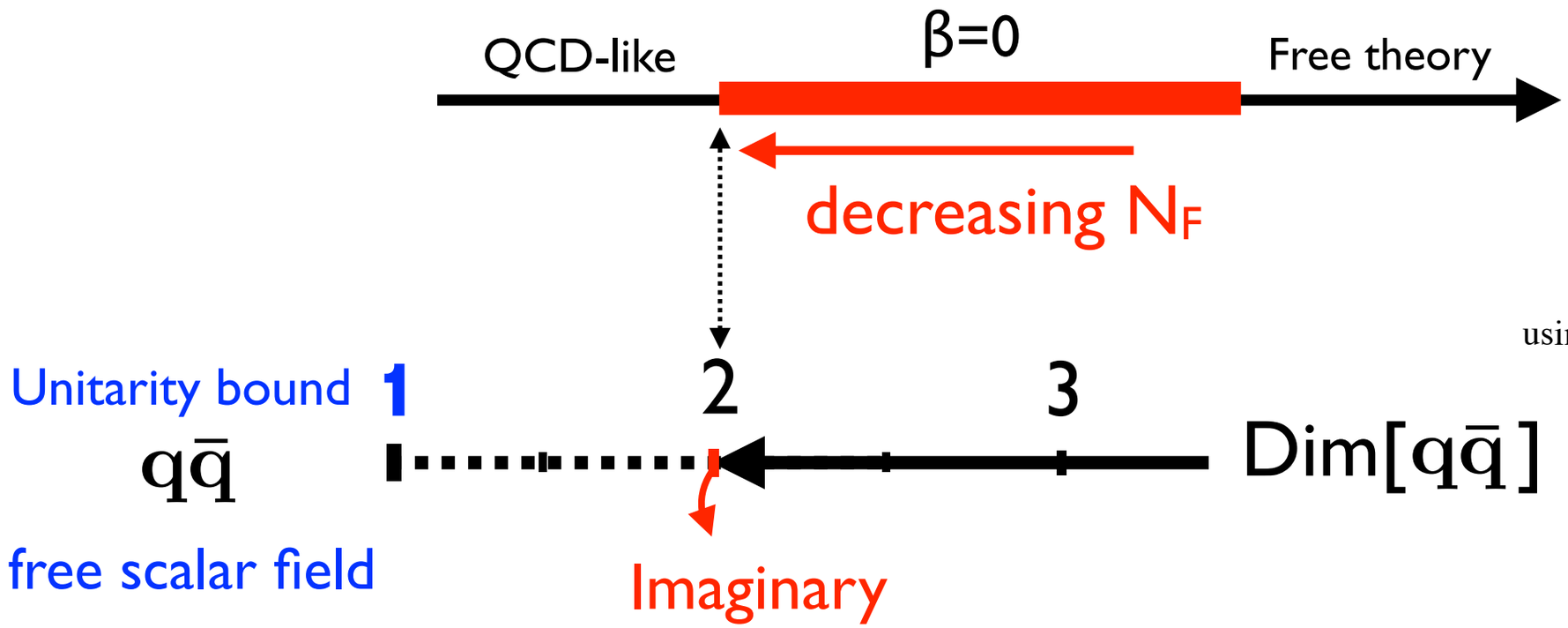

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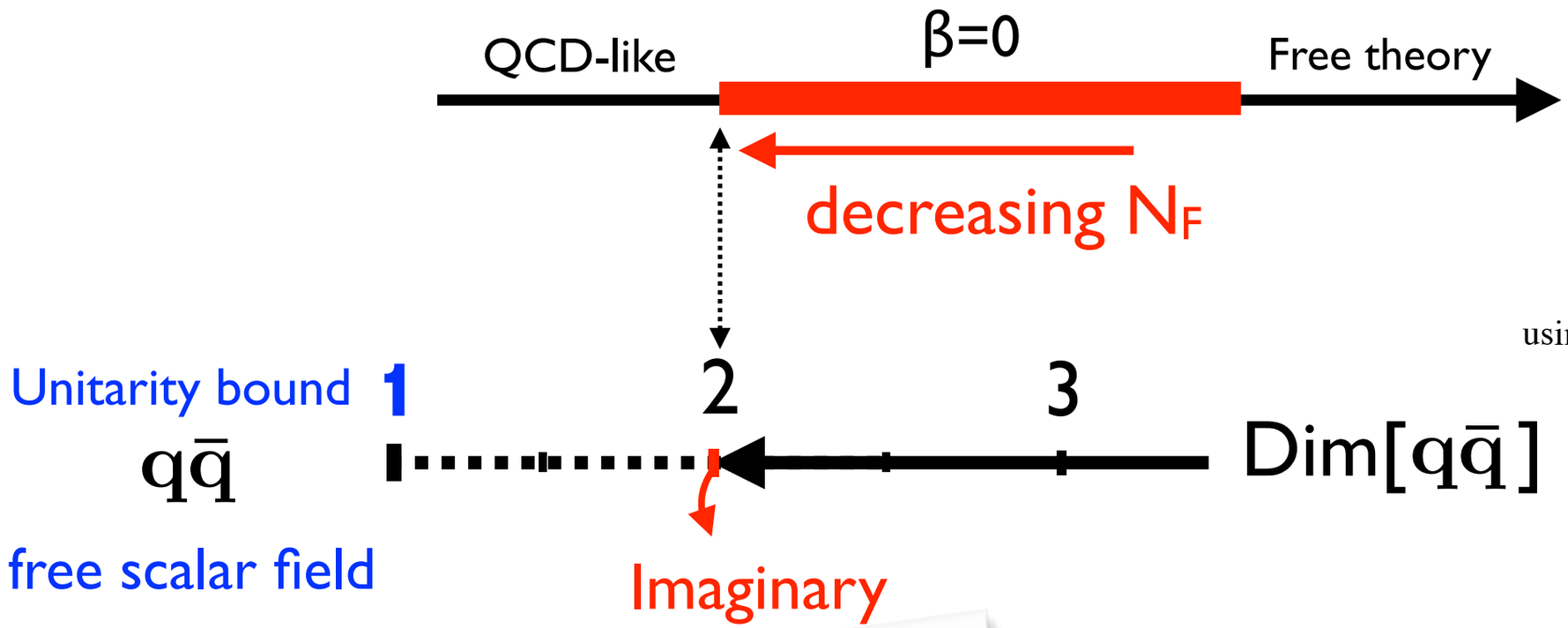

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Limit, of course, not reached!

But… how 2 is close to 1?

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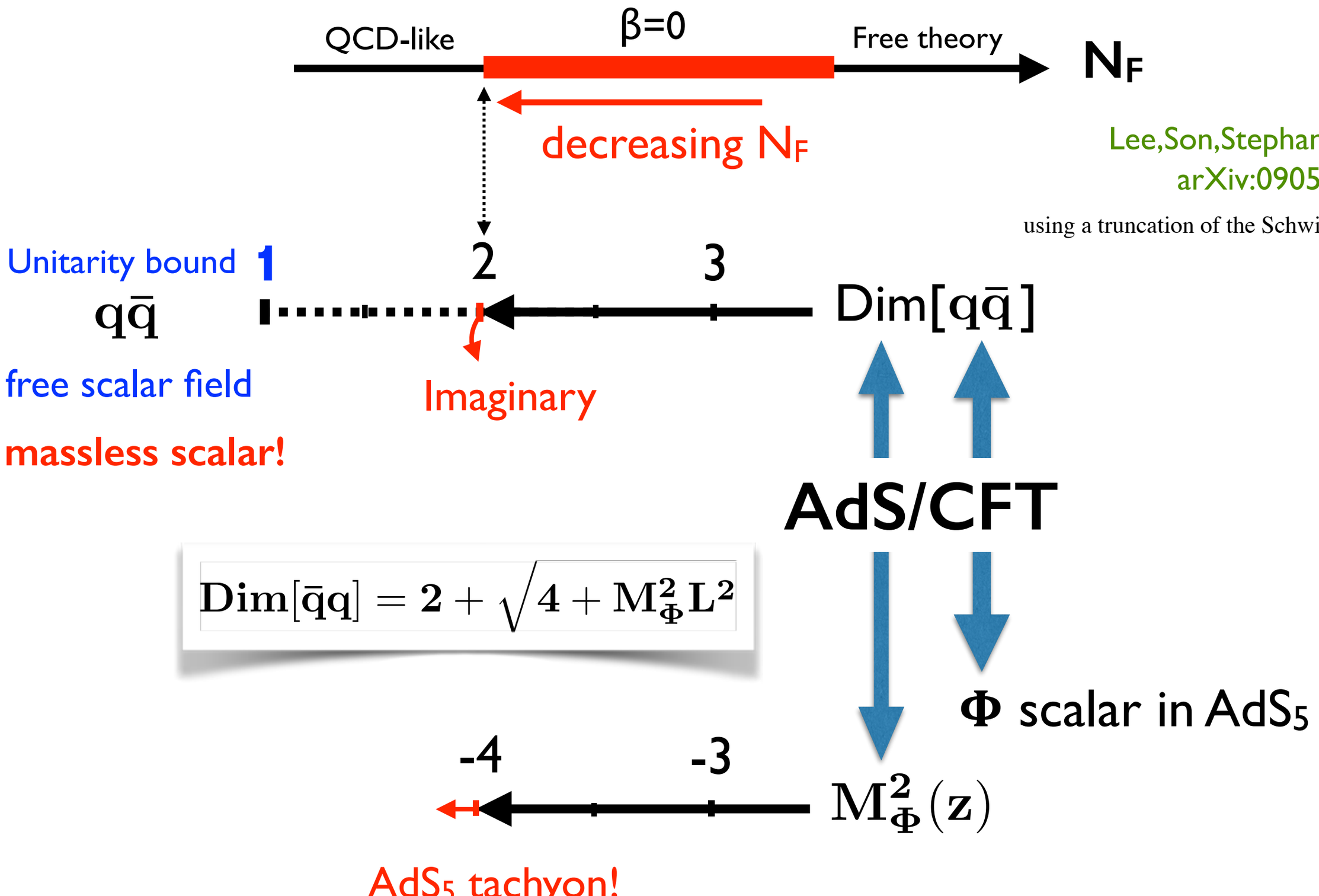
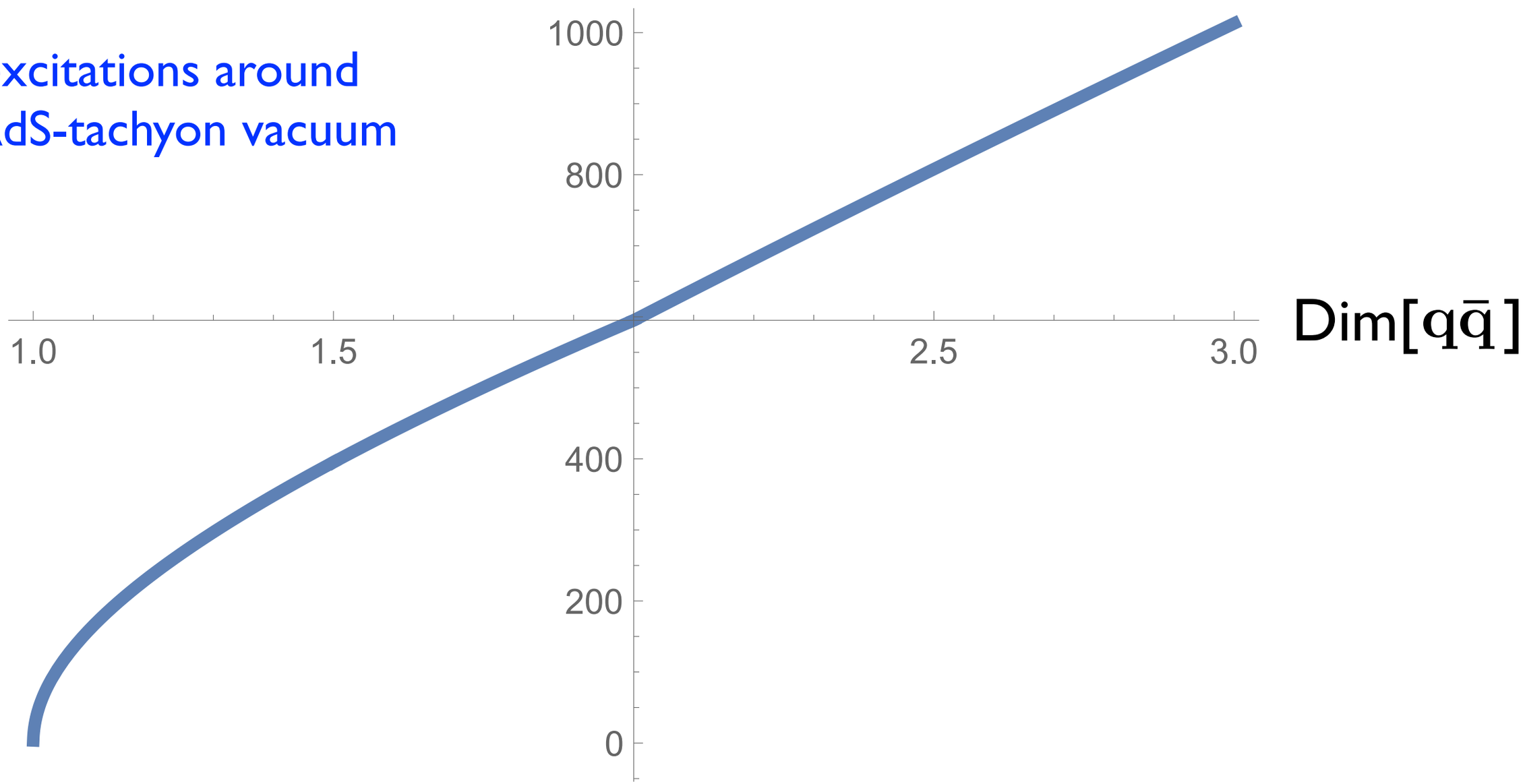


$$\mathbf{Dim}[\bar{q}q] = 2 + \sqrt{4 + M_\Phi^2 L^2}$$

AdS predictions

Scalar
in a AdS box

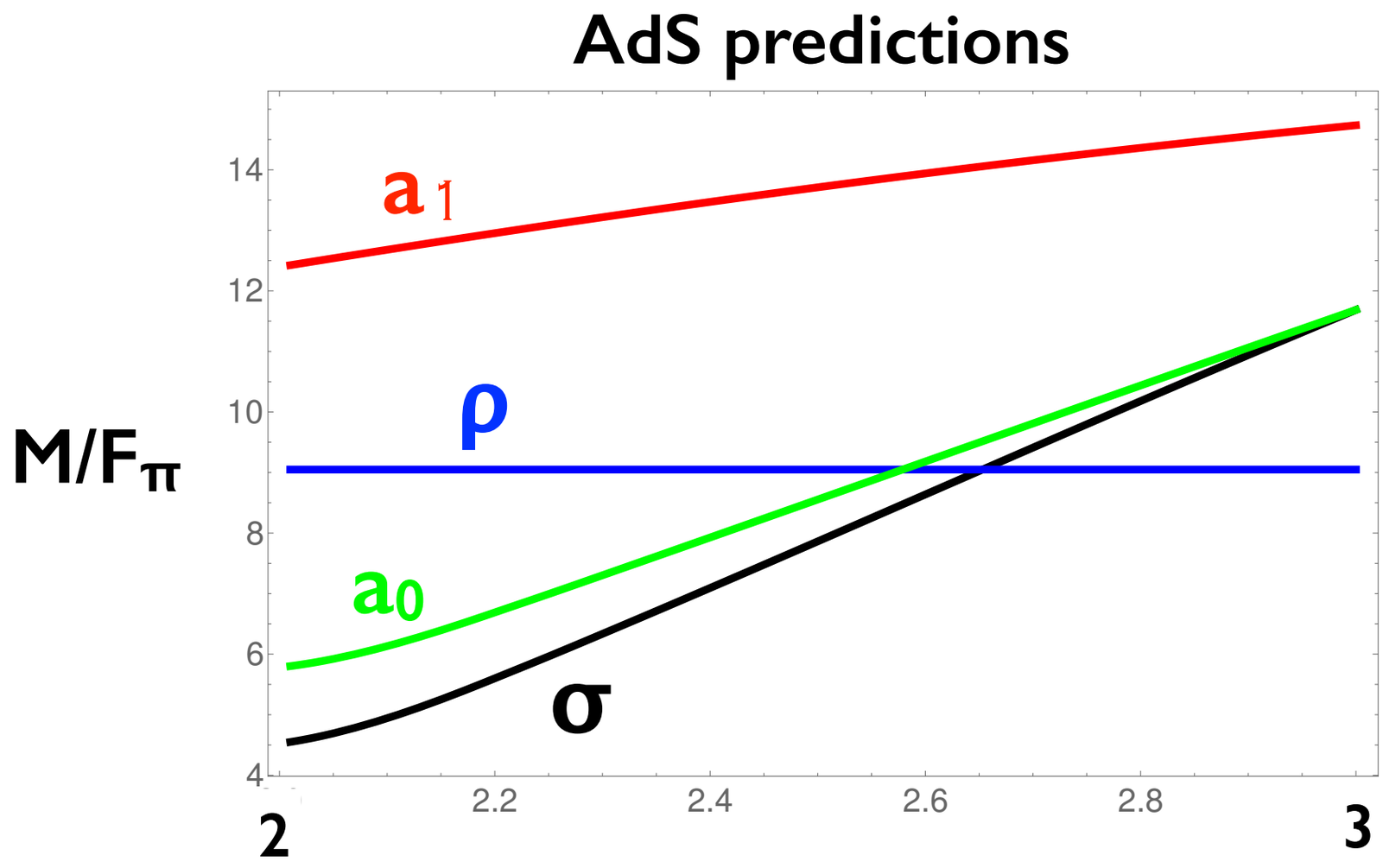
~ excitations around
the AdS-tachyon vacuum



the scalar becomes a factor ~1/2 lighter at dim[qq]=2

$$SU(2) \times \underbrace{SU(2) \to SU(2)}$$

QCD-like theories approaching the conformal transition



The scalars become the lightest resonance!

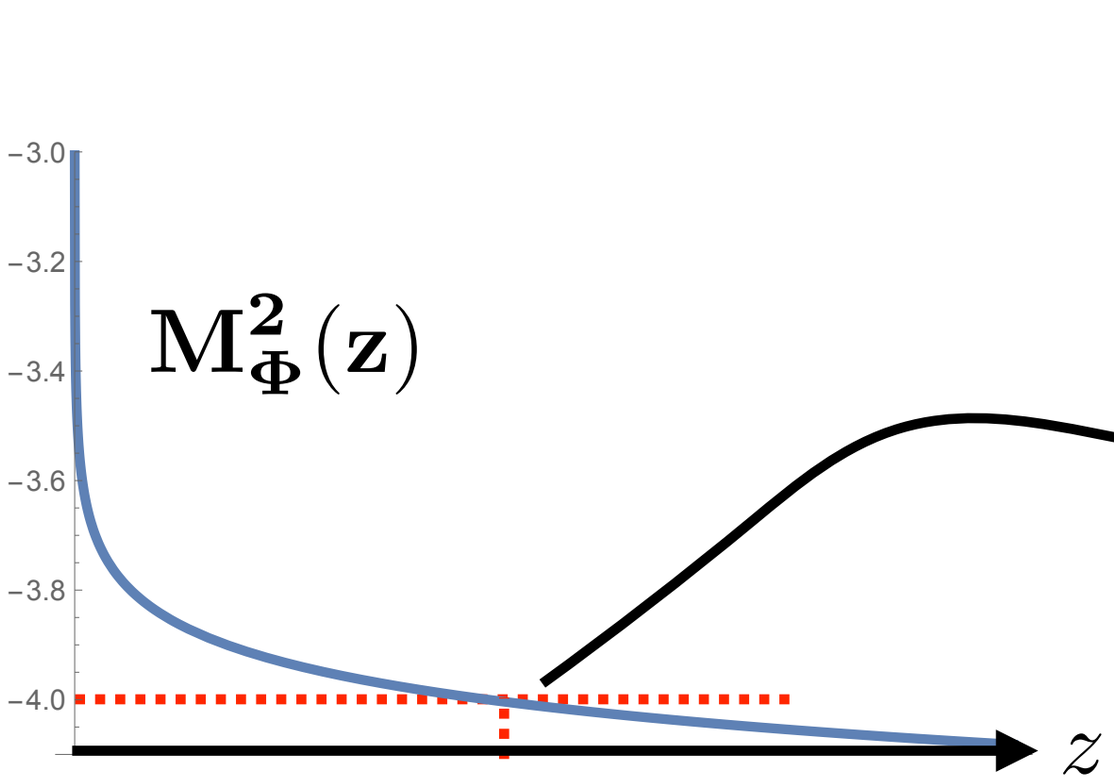
Also the mass splitting ρ-a_1 reduces

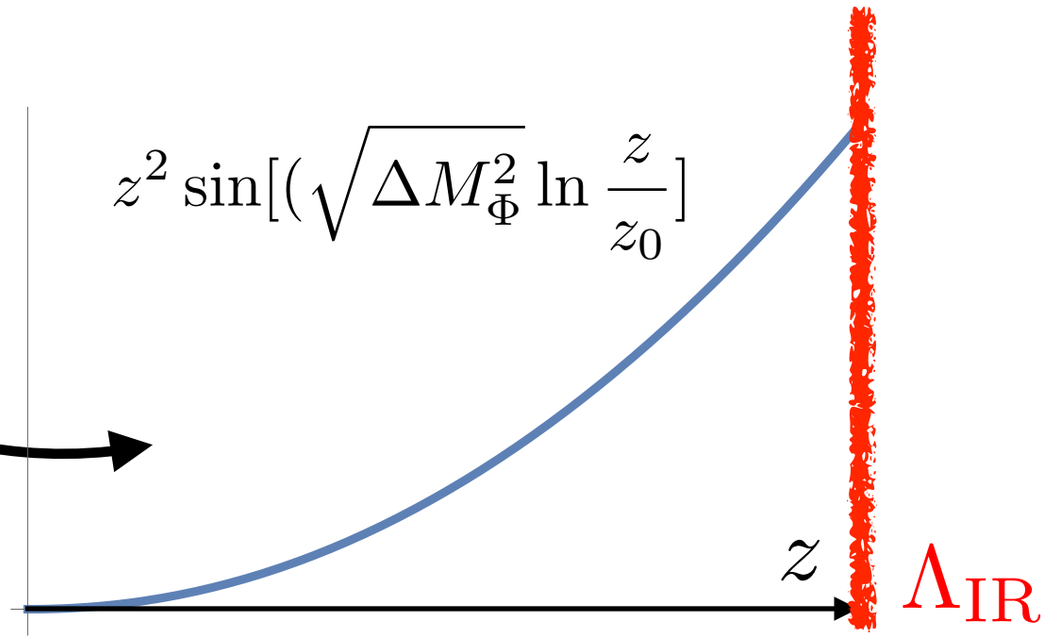
Implications for the LHC

(in strong dynamics to solve the hierarchy problem)

Nice scenarios to solve the hierarchy problem:

Tachyon in AdS puts you out from a CFT





Hierarchy controlled
by the "slow-rolling" of $\mathbf{M_\Phi}$

(stable under radiative corrections)

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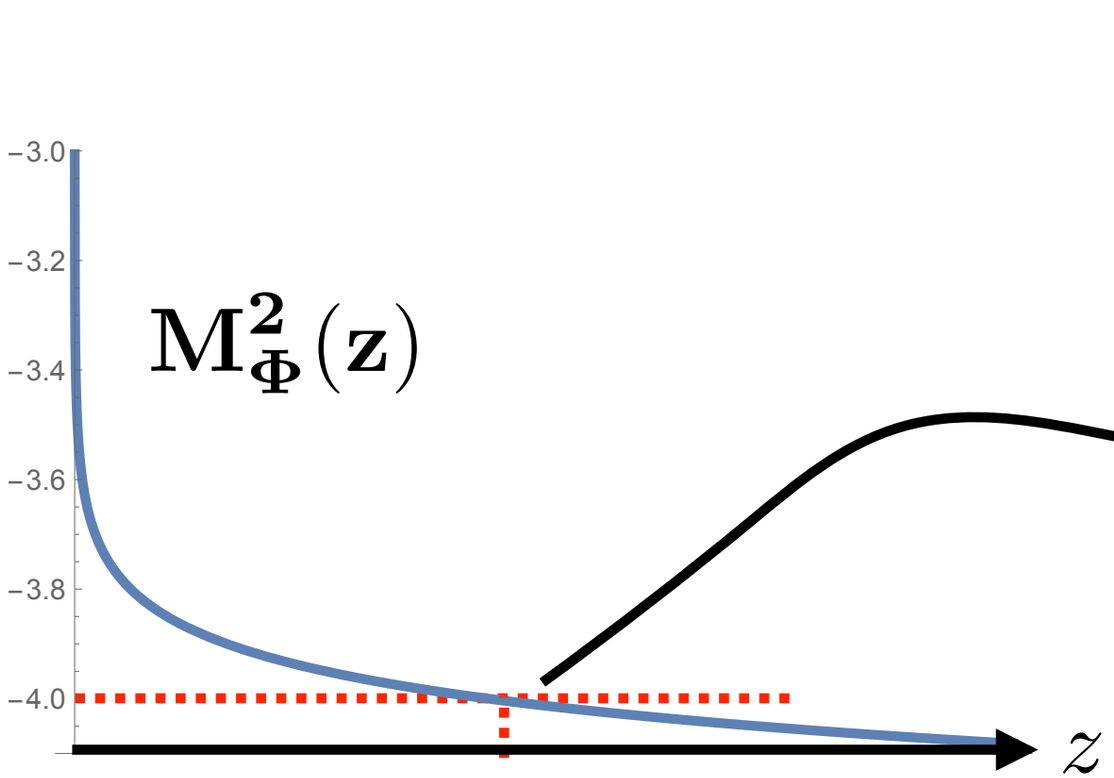

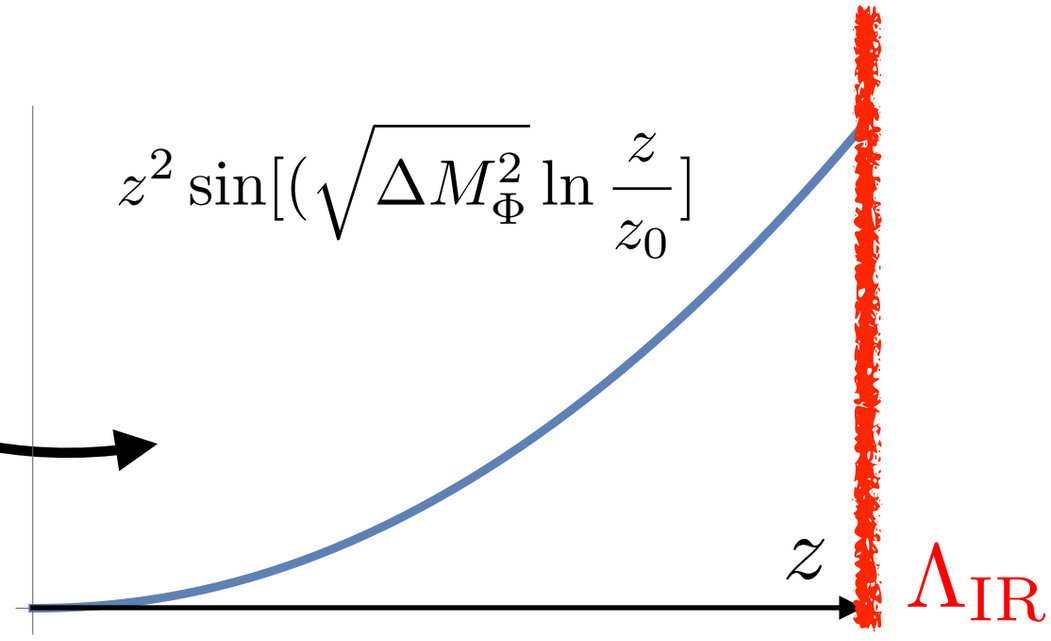

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$$\mathbf{\Phi}|_{\rm IR} \sim \mathcal{O}(\mathbf{1})$$

$$\Delta M_\phi^2 \equiv -4 - M_\phi^2$$

$$\mathbf{\Lambda_{IR} \sim \Lambda_{UV}\, e^{-\pi/\sqrt{\Delta M_\phi^2}}}$$

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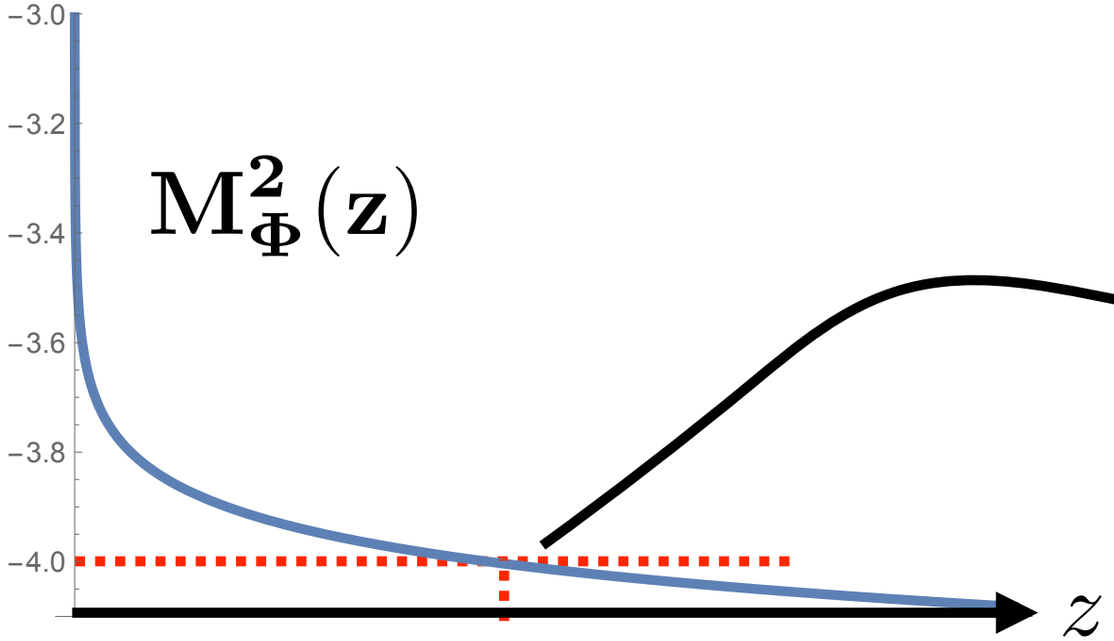

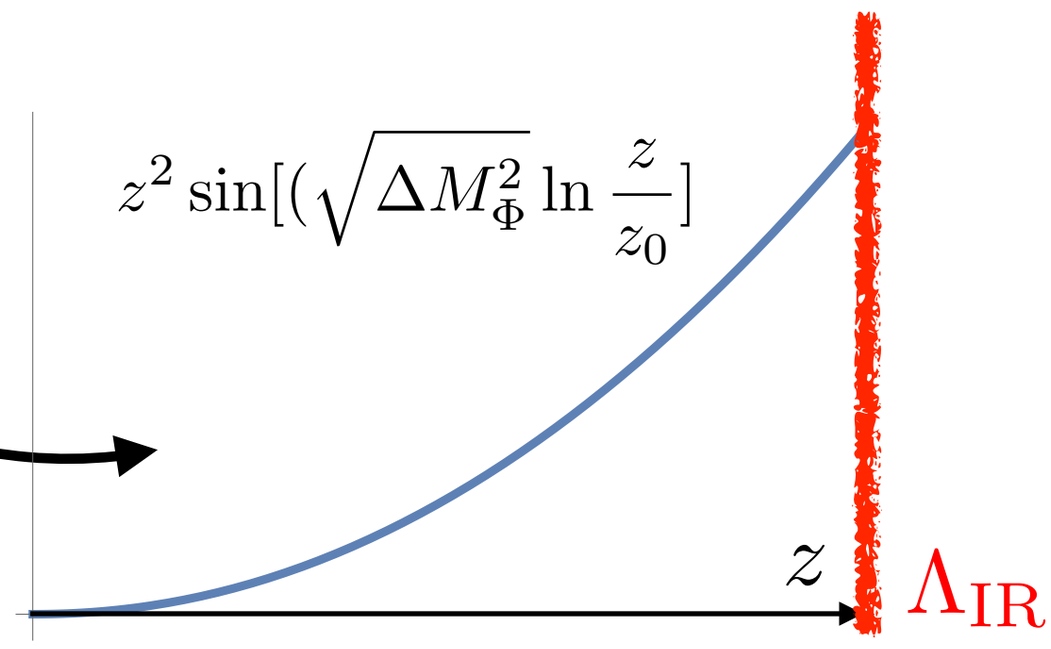

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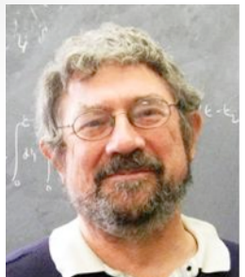
BKT transition



Excitations around the AdS-tachyon expected to be lighter

Could this scalar be the Higgs? Resurrecting Technicolor?

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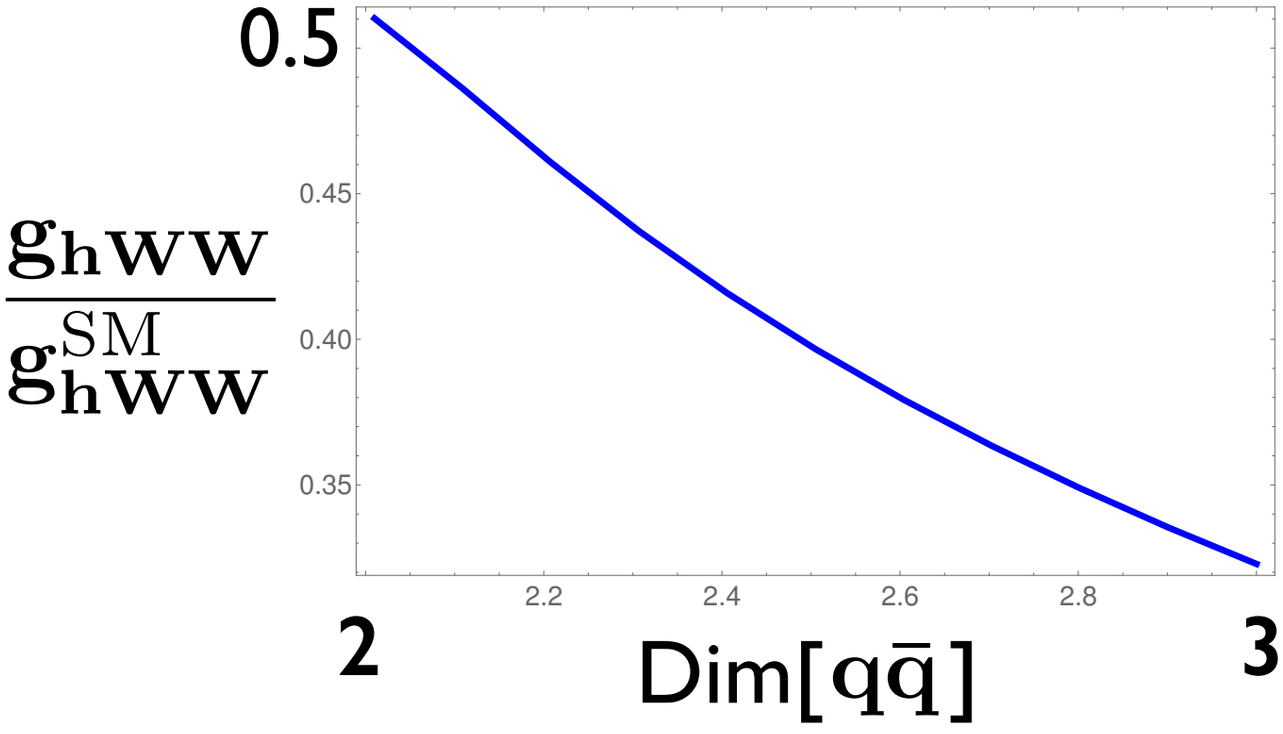
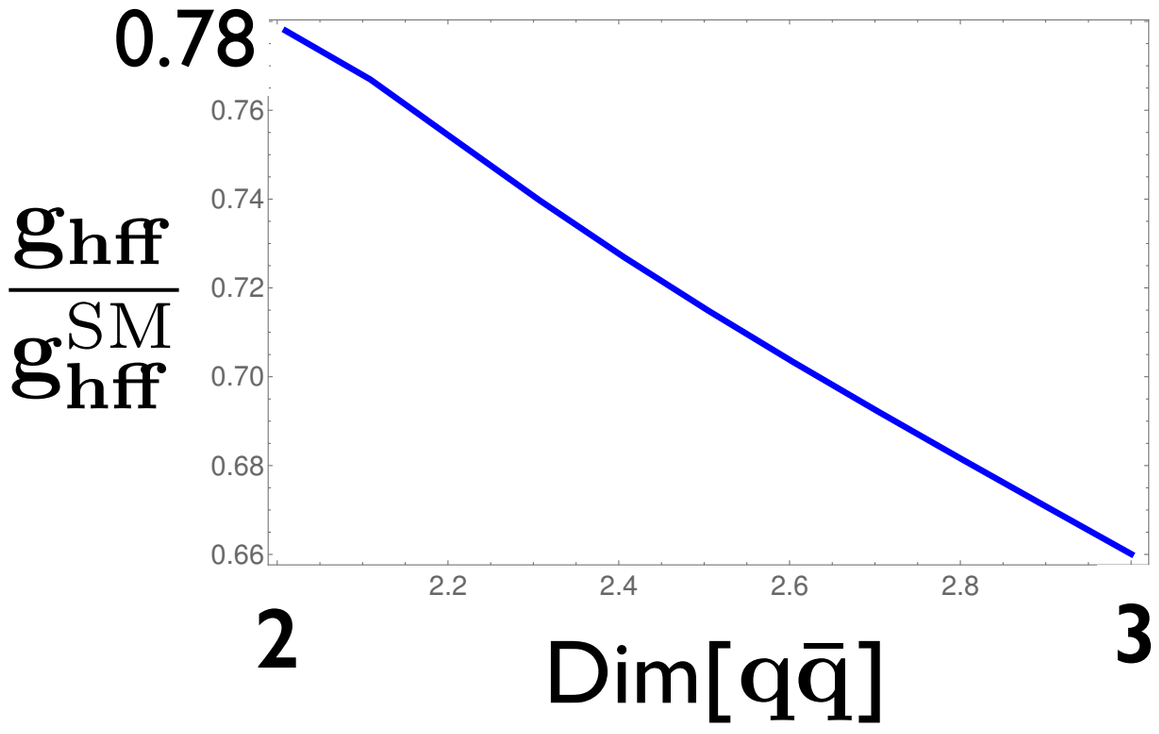
Mass? Not light enough

For $M_{TC\text{-}\rho} \sim$ 2-3 TeV we have $M_H \sim M_{TC\text{-}\rho}/2 \sim$ TeV

Higgs-like coupling? Approaching free scalar limit = SM Higgs





Excitations around the AdS-tachyon expected to be lighter

Could this scalar be the Higgs? Resurrecting Technicolor?

Mass? Not light enough

For $M_{TC\text{-}\rho} \sim$ 2-3 TeV we have $M_H \sim M_{TC\text{-}\rho}/2 \sim$ TeV

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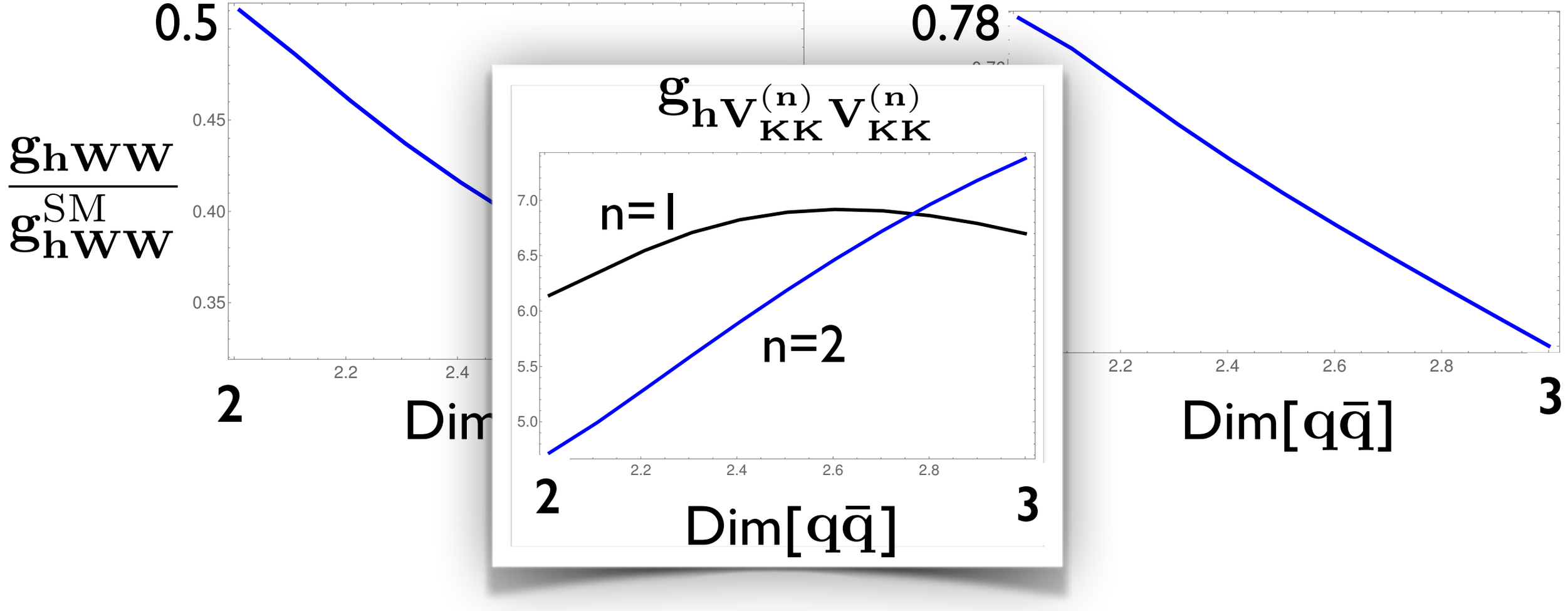
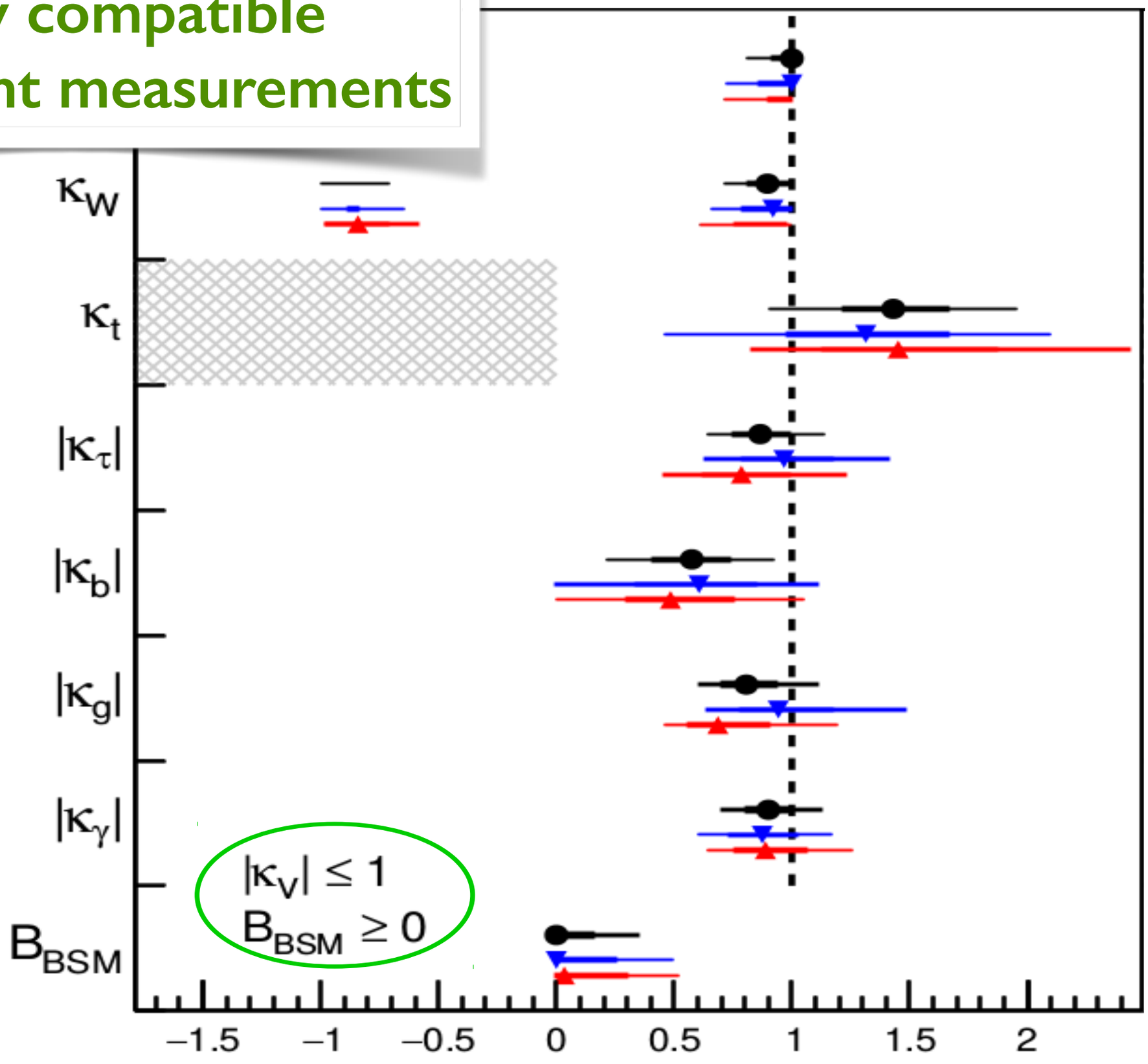


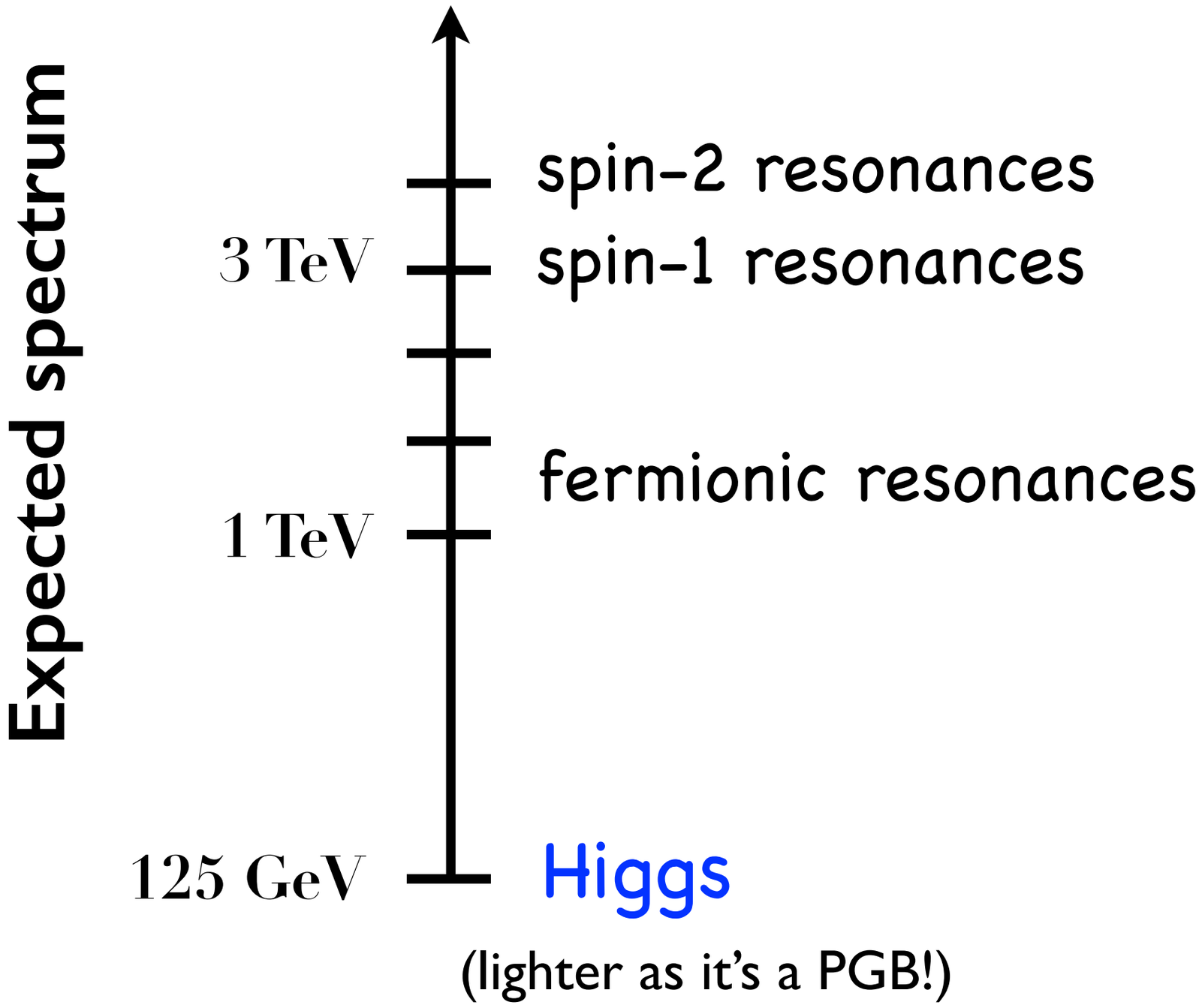
Hardly compatible with present measurements

$$\kappa_i = \frac{g_{Hii}}{g_{Hii}^{\mathrm{SM}}}$$



Composite PGB Higgs

Goldstone from a
G→H breaking
in the strong sector



(lighter as it's a PGB!)

Composite PGB Higgs

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Expected spectrum

3 TeV — spin-2 resonances
spin-1 resonances

1 TeV — fermionic resonances
scalar resonances

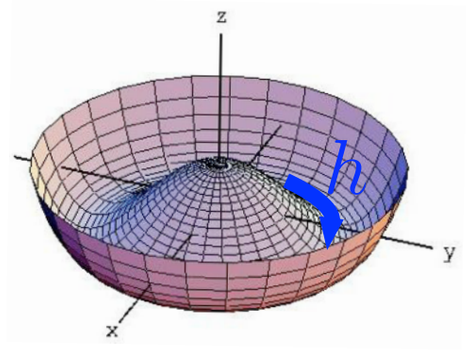
125 GeV — Higgs

(lighter as it's a PGB!)

If due to an AdS tachyon

radial components

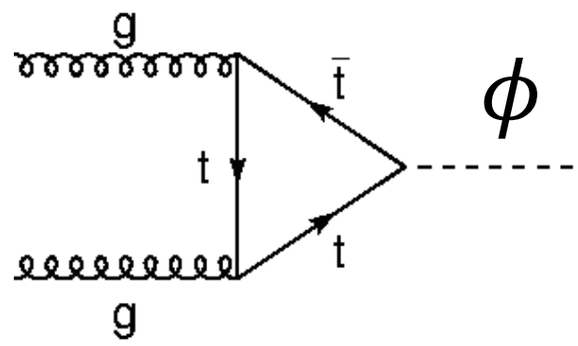
angular components



Singlet ϕ:

$$\sim \frac{\phi}{f}|D_\mu H|^2 - \frac{m_t}{f}\phi \bar{t}_L t_R$$

Main production-mechanism: gluon-fusion



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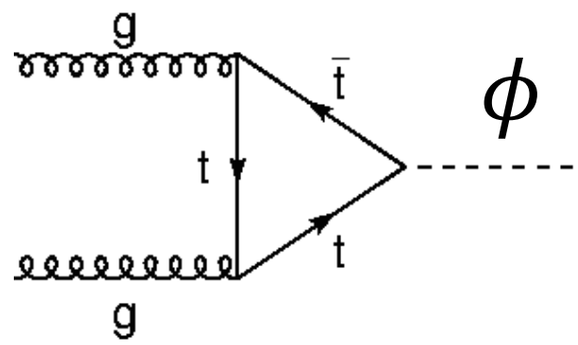
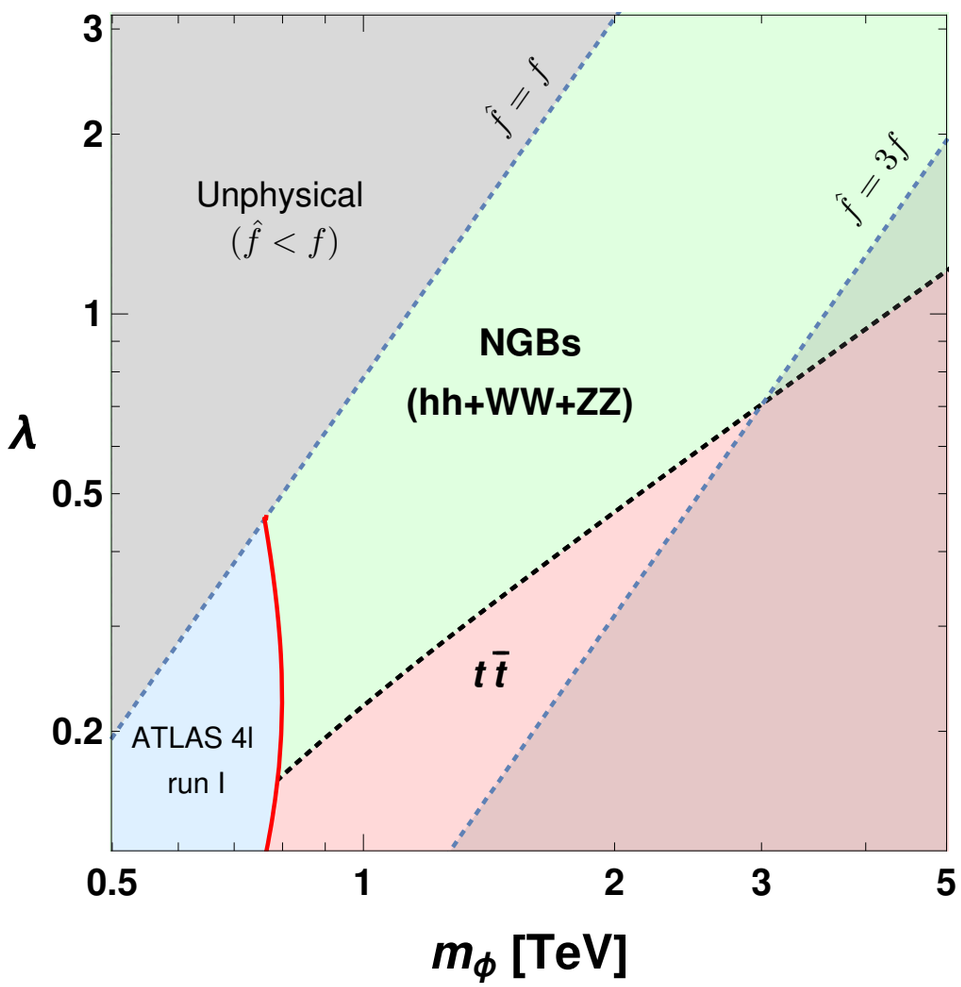
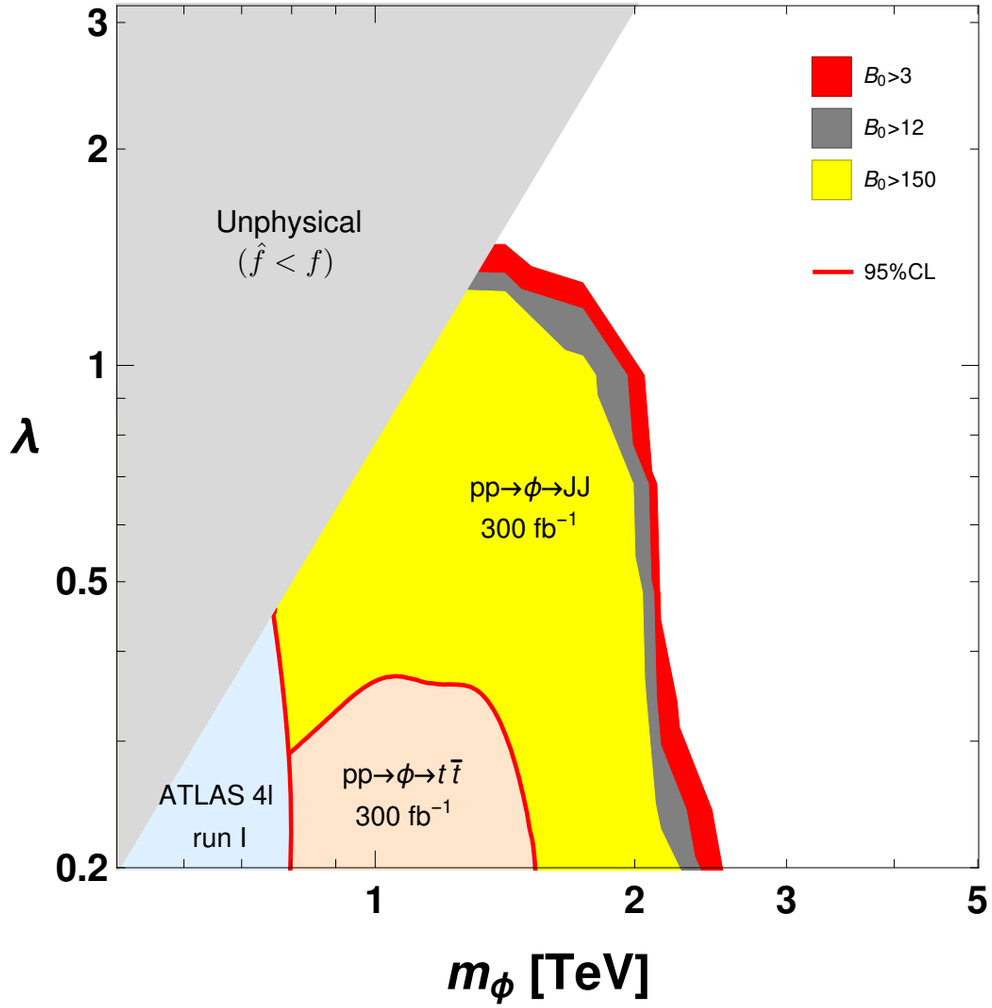


arXiv:1608.01995 (see also 1603.05668)





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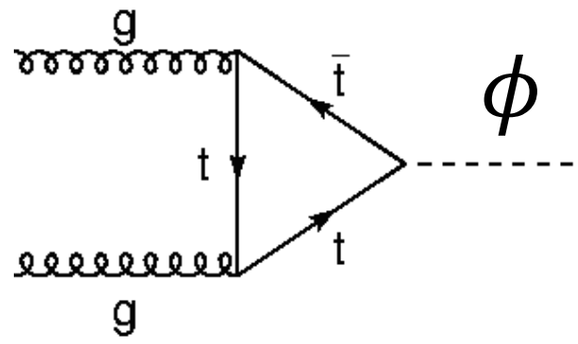

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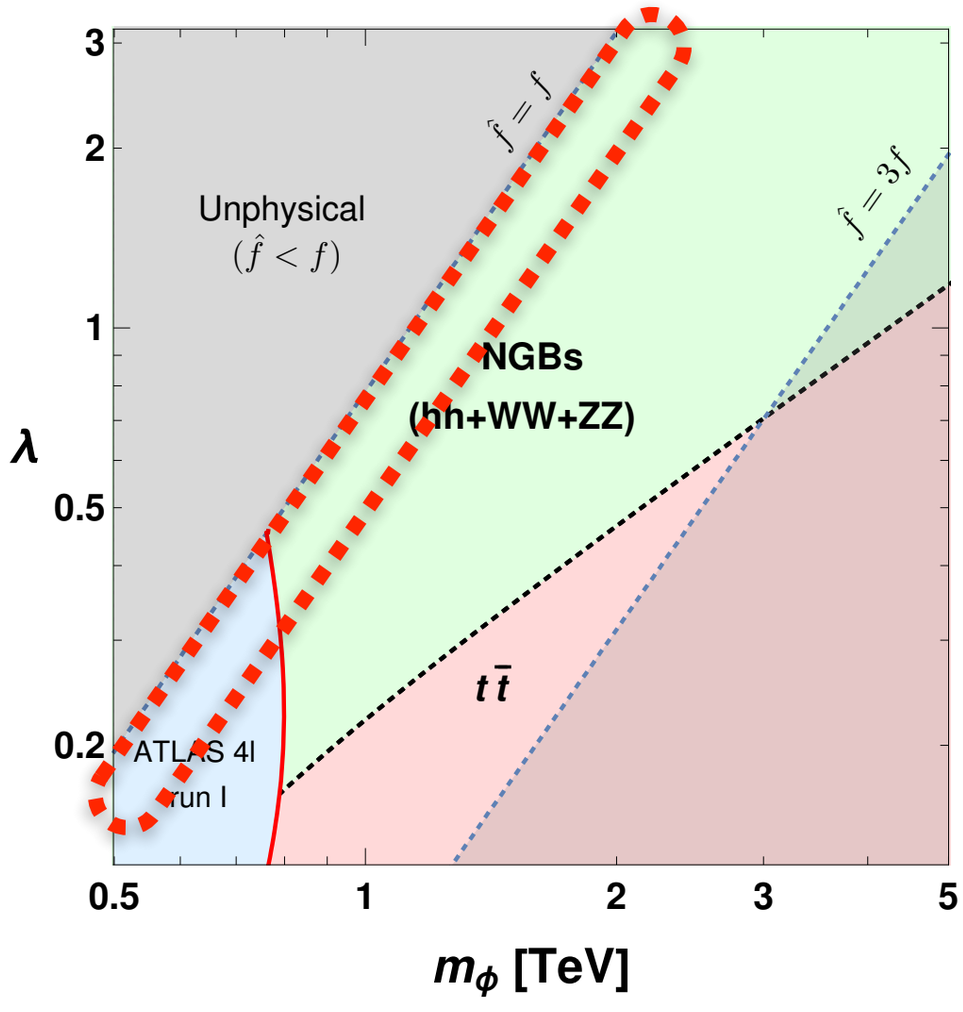

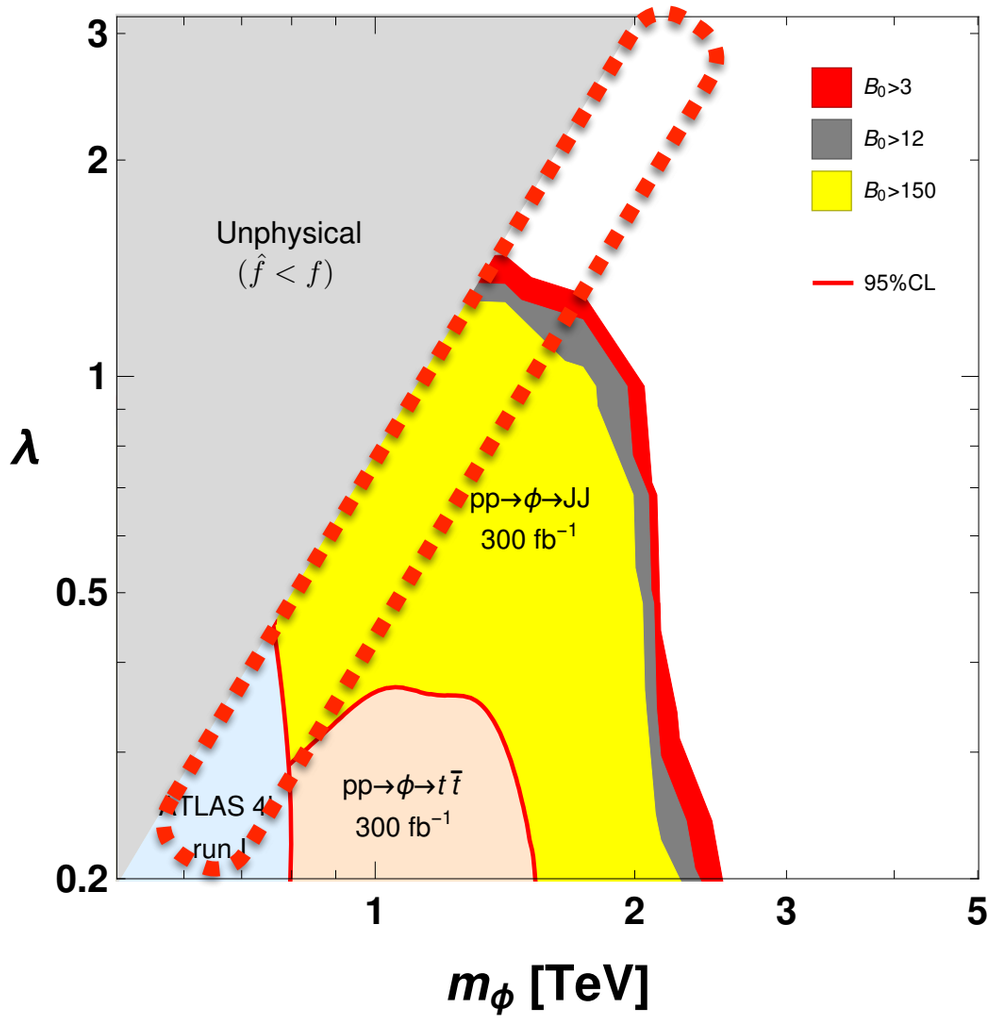

Extra doublet H´ (radial component of the Higgs-phase):

work in progress!

$$y_{ij}(H + iH' + \cdots)\bar{Q}^i_L u^j_R + \cdots$$

leading term safe from FCNC

According to wikipedia: 2HDM Type-III

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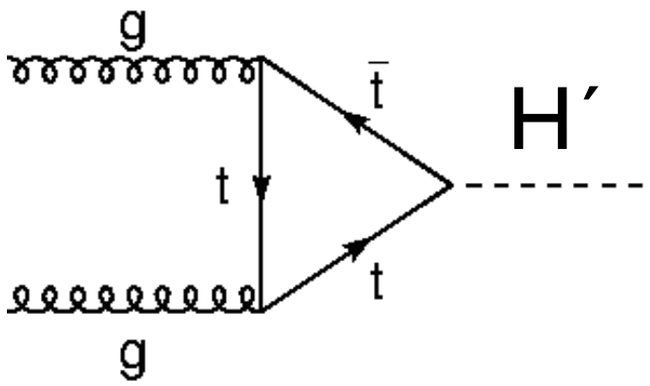
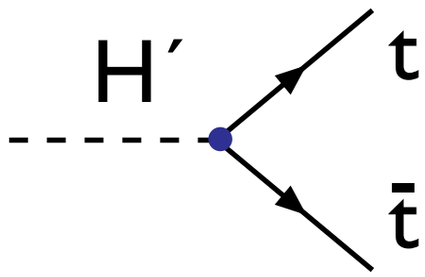
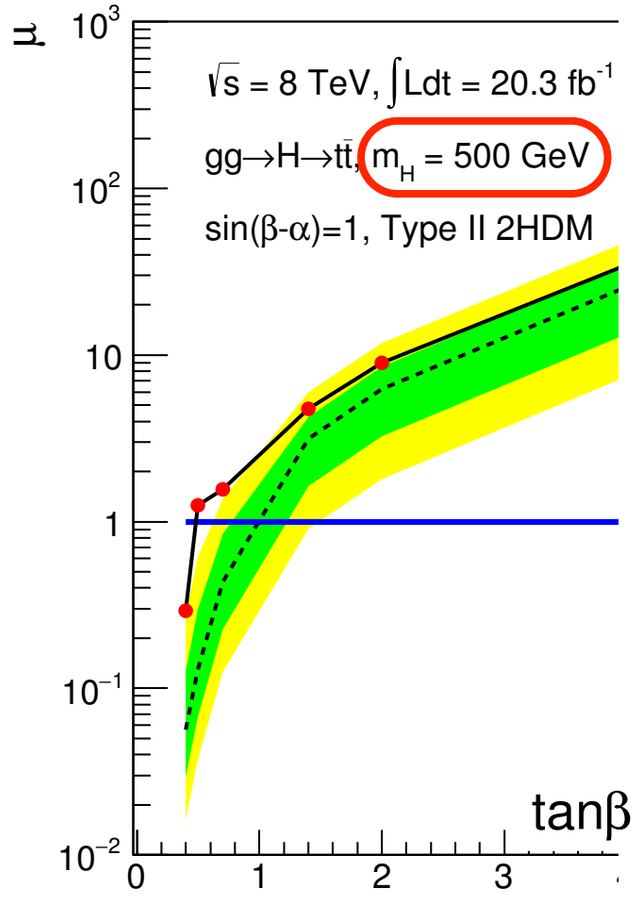
LHC pheno:







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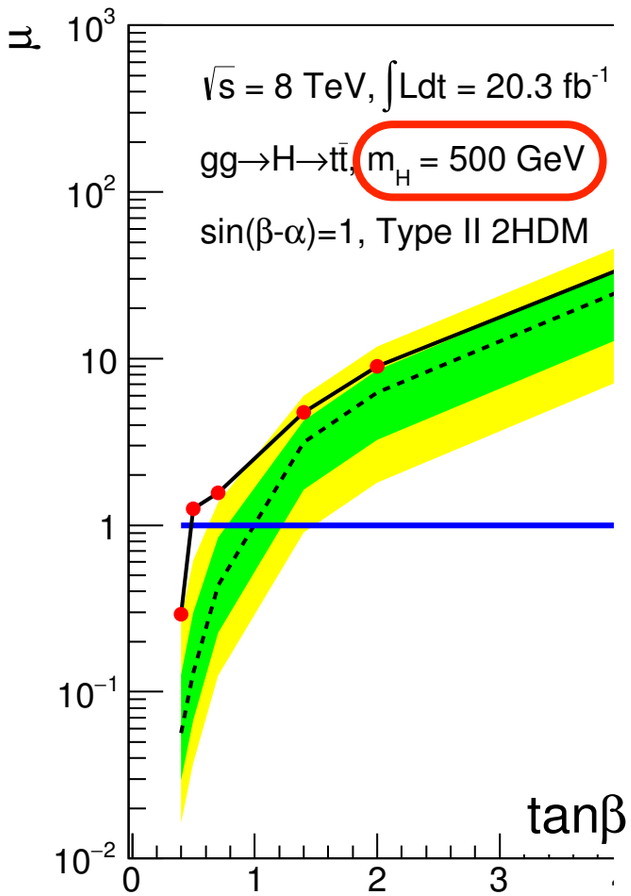

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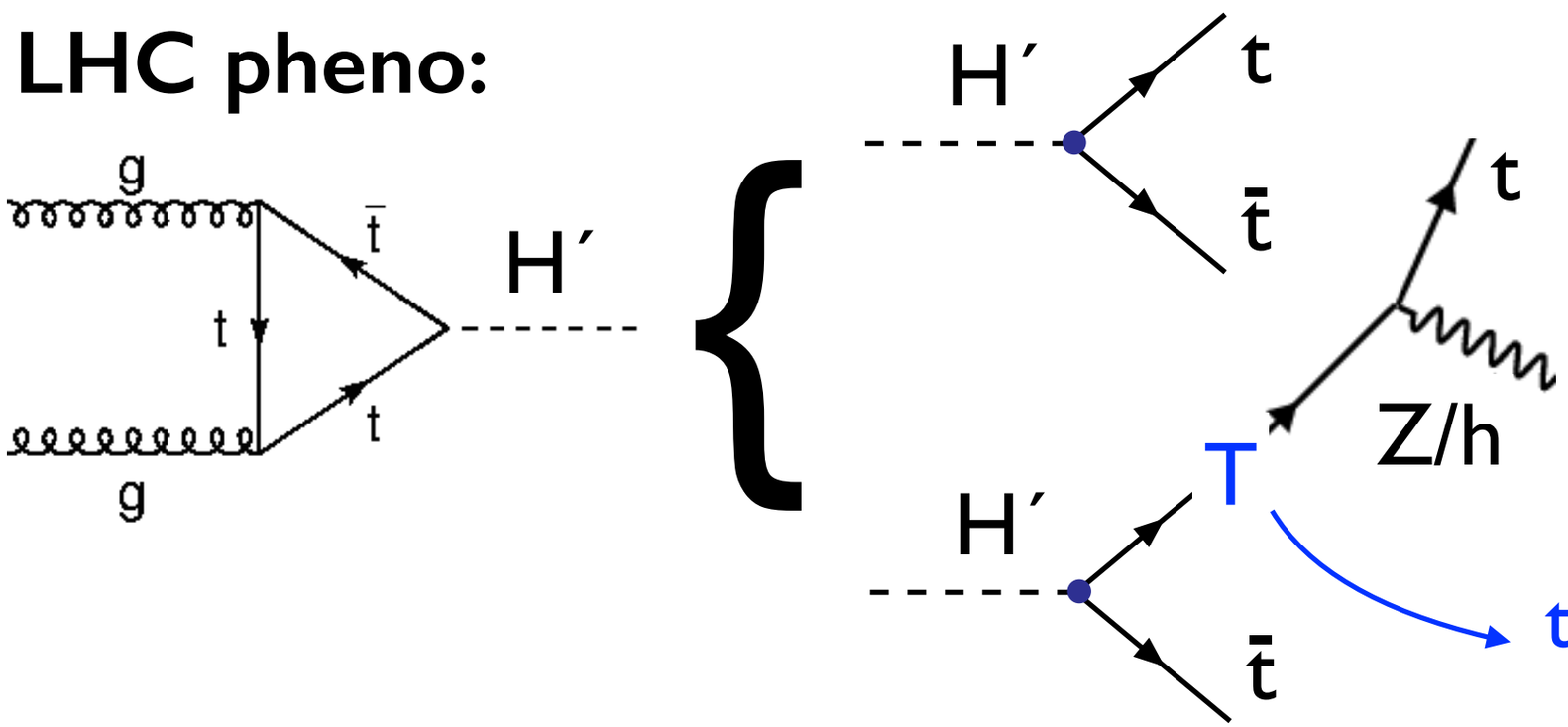

For H´ lighter than T, change in the searches for top partners:

T→H´t̄→tt̄t̄

Conclusions

- Lattice "sees" a **light scalar** close to the **QCD conformal transition**

- From **holography** we could understand this transition as an AdS tachyon turning on (going below the BF bound):

  No light dilaton expected!

- **Lighter scalar** due to **dim[$\bar{q}q$]→2**, close to one (unitarity bound) where the **scalar-operator $q\bar{q}$ decouples**

- BSM implications:

  ☛ in **TC-like scenarios:** a scalar with couplings similar to the Higgs (but heavier than 125 GeV)

  ☛ in **Composite PGB Higgs models:** Higgs partners (radial components) become the lightest resonances, accessible at the LHC

  (extra singlet & doublet with large couplings to the top)

- **Future**: AdS-tachyon phase transition (BKT-type), Efimov states, …