Der Wissenschaftsfonds.

String gravi/dark photons, holography and the hypercharge portal

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with P. Betzios, M. Bianchi, D. Consoli, E. Kiritsis, Y. Mambrini, E. Niederweiser, S. Oribe

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Plan of the talk

- Motivation
- Framework
- Emergent gravitons
- Gravi- / dark- photons
- Emergent axions
- Emergent neutrinos
- Conclusions

Motivation

- Standard Model (SM) is an effective field theory.
- In the IR, we keep terms like

$$S_{SM} = \int d^4x \; g_i(x) O_i(x)$$

low-dimensional operators of SM fields

couplings

Motivation

- Standard Model (SM) is an effective field theory.
- In the IR, we keep terms like

$$S_{SM} = \int d^4x \; g_i(x) O_i(x)$$

low-dimensional operators of SM fields ($O_i(x)$)

couplings ($g_i(x)$)

- These couplings $g_i(x)$ could be dynamical.
  - The coupling of the stress-energy tensor is the metric $g_{\mu\nu}(x)$: dynamical (gravity).
  - The QCD θ-angle is believed to be dynamical (axion).
  - In string theory, Yukawa couplings are also dynamical scalars (quasi)-moduli.
- In this talk we will explore these couplings in a generic holography-inspired framework.

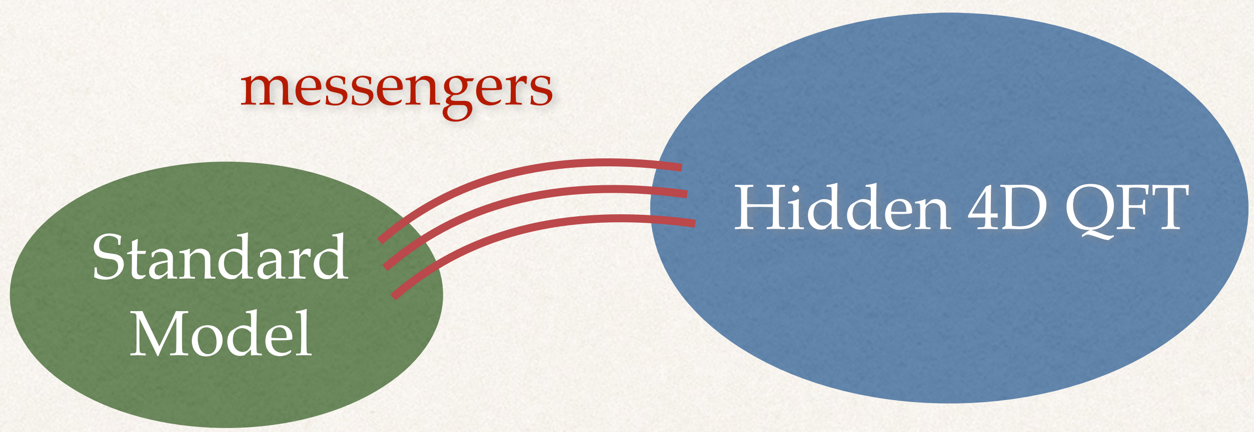
Motivation

- In this holography-inspired scenario, and we will *assume* that

all interaction in nature are described by 4D Quantum Field Theories

Kiritsis

- In this framework, the Fundamental Theory consists of three parts



  - The Standard Model (SM) is just a small sector of the Fundamental Theory.

Nielsen

  - A Hidden Sector (HS) is a (arbitrary) 4D QFT, hidden from the SM in the IR.
  - Messengers which couples the two sectors (SM and HS).

Motivation

- From the SM point of view, operators of the HS will appear as "fields".
- Some of these operators/fields will be protected by symmetries and will remain light.

HS point of view		SM point of view
$\hat{T}_{\mu\nu}$ of the HS	$\longrightarrow$	$g_{\mu\nu}$ graviton Betzios, Kiritsis, Niarchos
$Tr[\hat{F} \wedge \hat{F}]$ of the HS	$\longrightarrow$	a axion PA Betzios Bianchi Consoli Kiritsis
global conserved currents of the HS	$\longrightarrow$	abelian gauge fields Betzios Kiritsis Niarchos Papadoulaki PA Bianchi Consoli Kiritsis

- Occasionally, heavy operators/fields could provide interesting phenomenology.

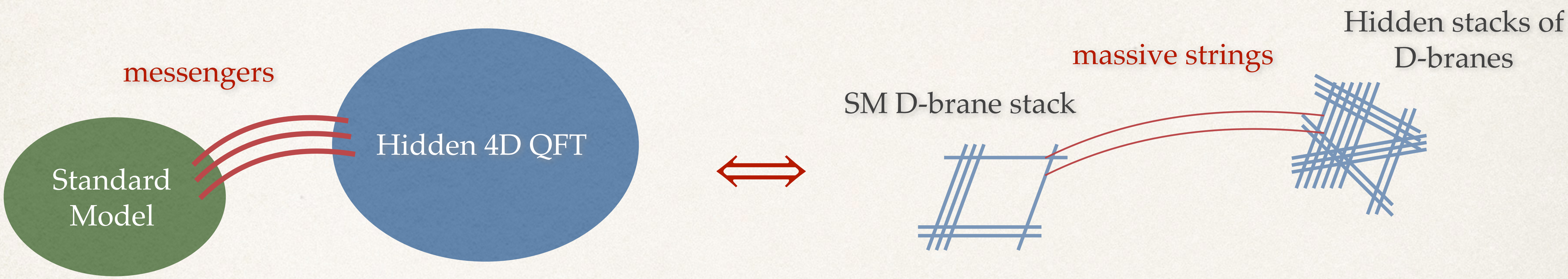
Fermionic operators of the HS/MS	$\longrightarrow$	RH-Neutrinos PA Kiritsis Niederweiser

Motivation

- Our goal is:
  - To build the effective action for these emergent fields.
  - To investigate the phenomenological implications.
- In various cases, we assume a holographic hidden sector.
- Emergent fields (graviton, axions, gauge fields, neutrinos) in this framework are composites, and they are distinct qualitatively from what has been considered so far.
- In this talk, we will flash the origin of emergent gravitons, axions and neutrinos…
- …and we will focus on gravi/dark photons.

Motivation

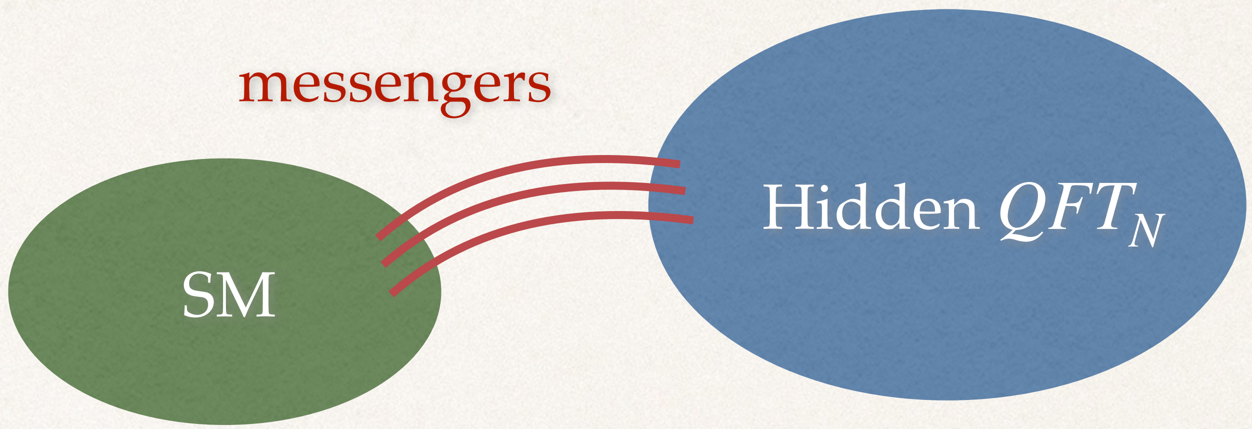
- This picture is quite generic in string theory.



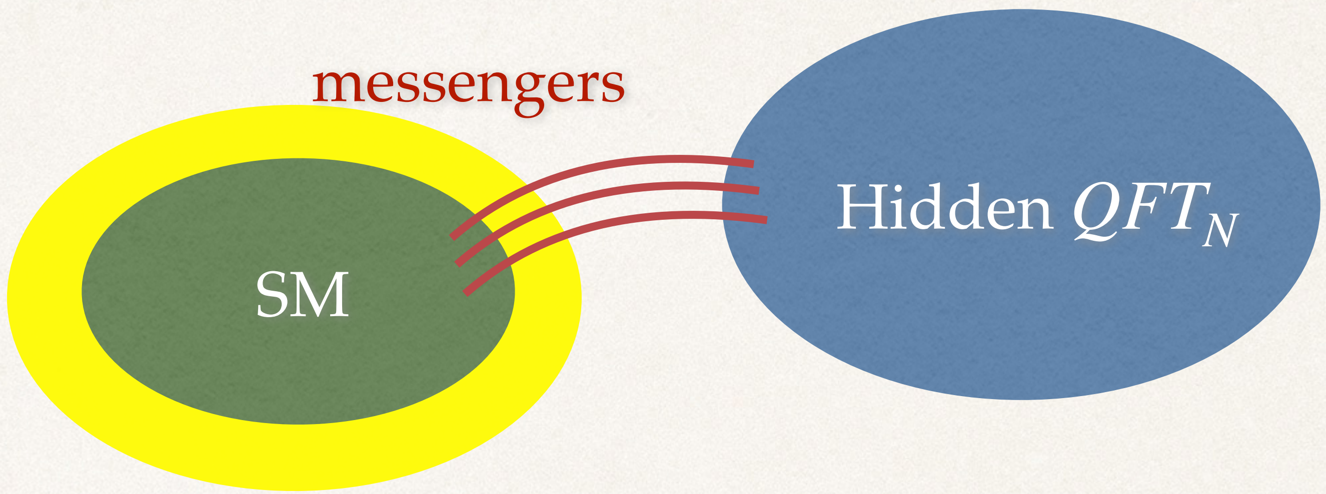
- Consider D-brane realisations of the SM.
    - Standard Model is localized on a collection of stacks of D-branes,
    - Hidden D-branes are at some distance to ensure the stability of the construction (tadpole cancelation). Strings living on these D-branes consist a Hidden sector to the SM at the IR.
    - The closed string sector naturally provides the graviton, gravi-photons, (RR) axions and other moduli.

Framework

Framework

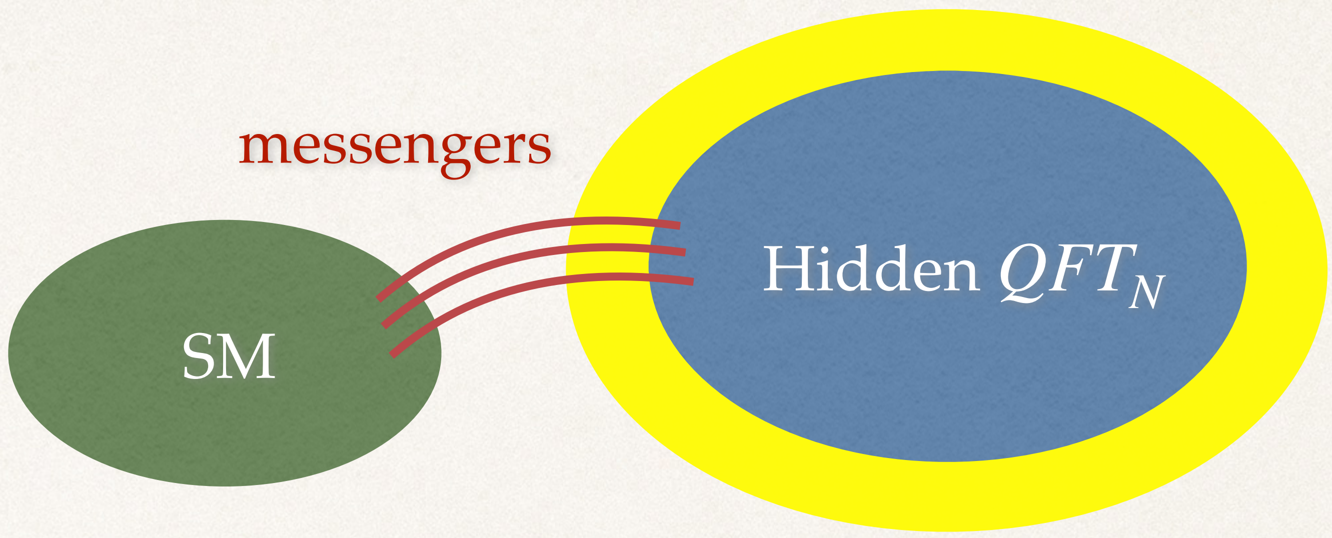


Framework



- The Standard Model (SM):
  - Contains all known/standard fields (quarks, leptons, gauge fields, Higgs).
  - Later, we will loosen this standard definition by investigating extensions.

Framework

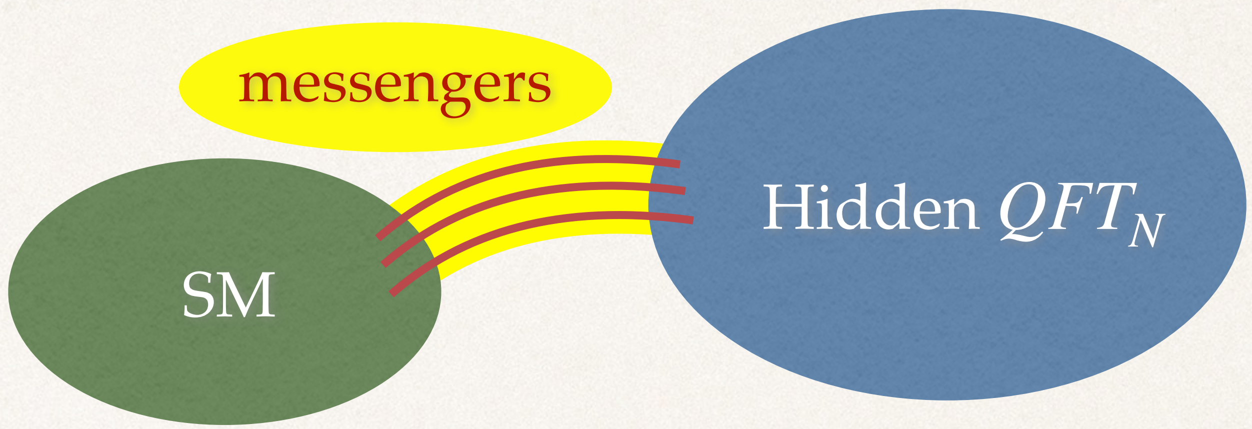


- The Hidden QFT_N :
  - It is UV-complete: At the UV it is either asymptotically free or conformal.
  - Size is enormous and its structure is random.
  - However, we will assume SU(N) with N - large (even astronomical) values.
  - At weak coupling (IR) the hidden theory contains the simplest QFTs:

$$\text{vectors } \hat{A}^{\mu}, \quad \text{scalars } \hat{\phi} \text{ and spin-1/2 particles } \hat{\psi}$$

Nielsen

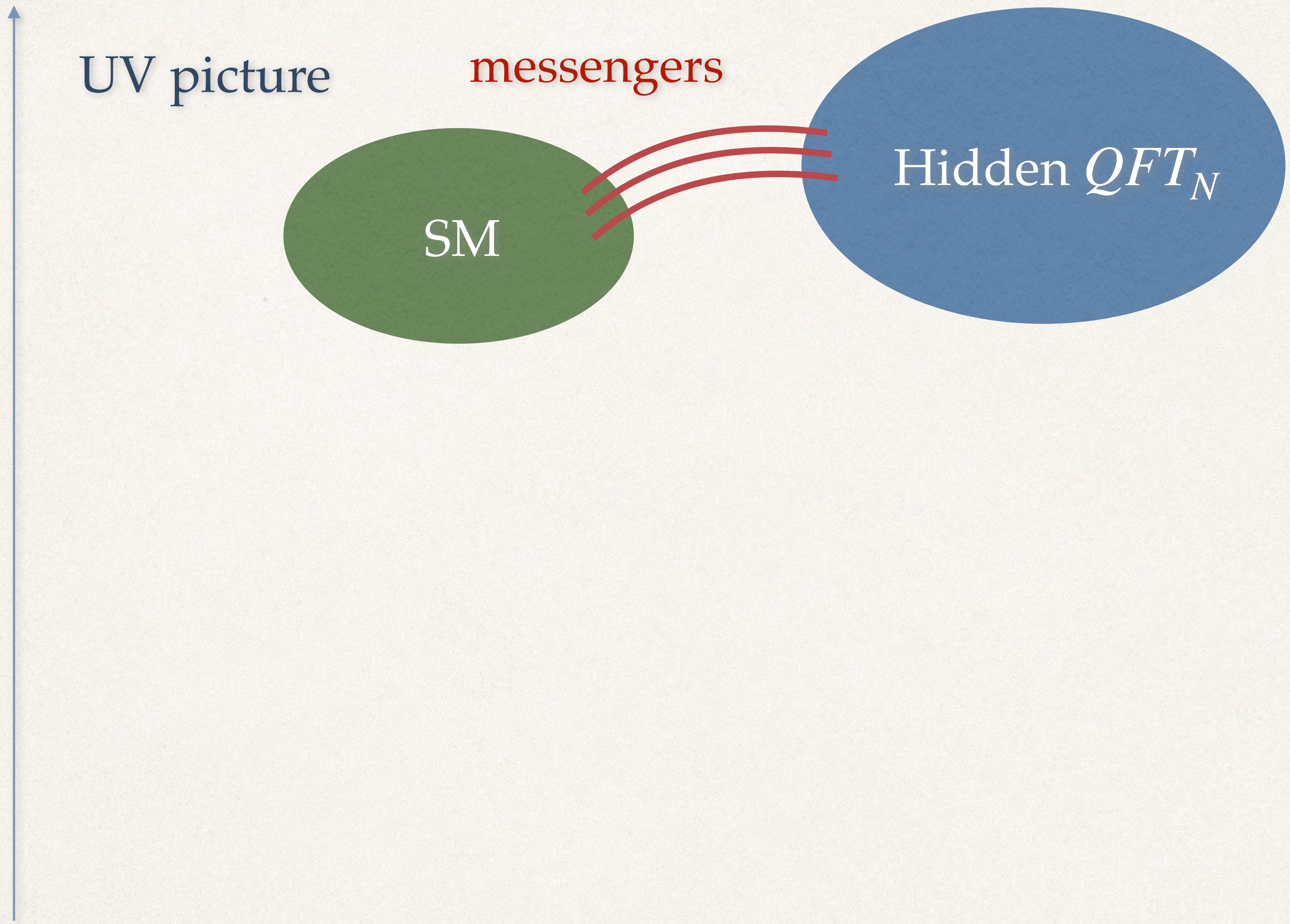
Framework



- Messengers
  - They are charged under both the SM and the HS.
  - They are massive and they can be heavy/light (depending on the HS).
  - In our case we assume to be heavy, with scale $M_{messenger}$.
  - This scale is the largest of all other scales in this framework.

Kiritsis

Framework



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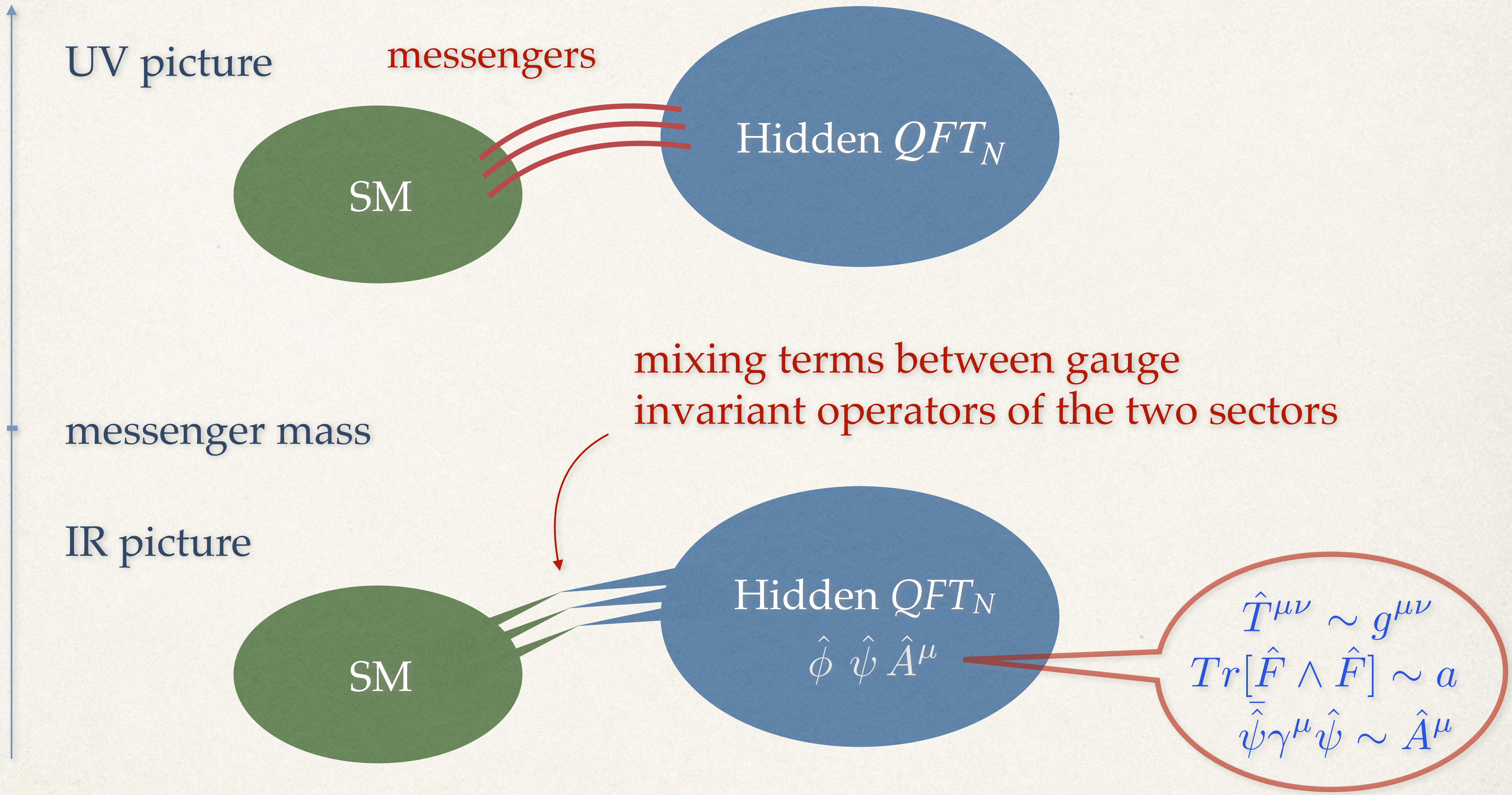
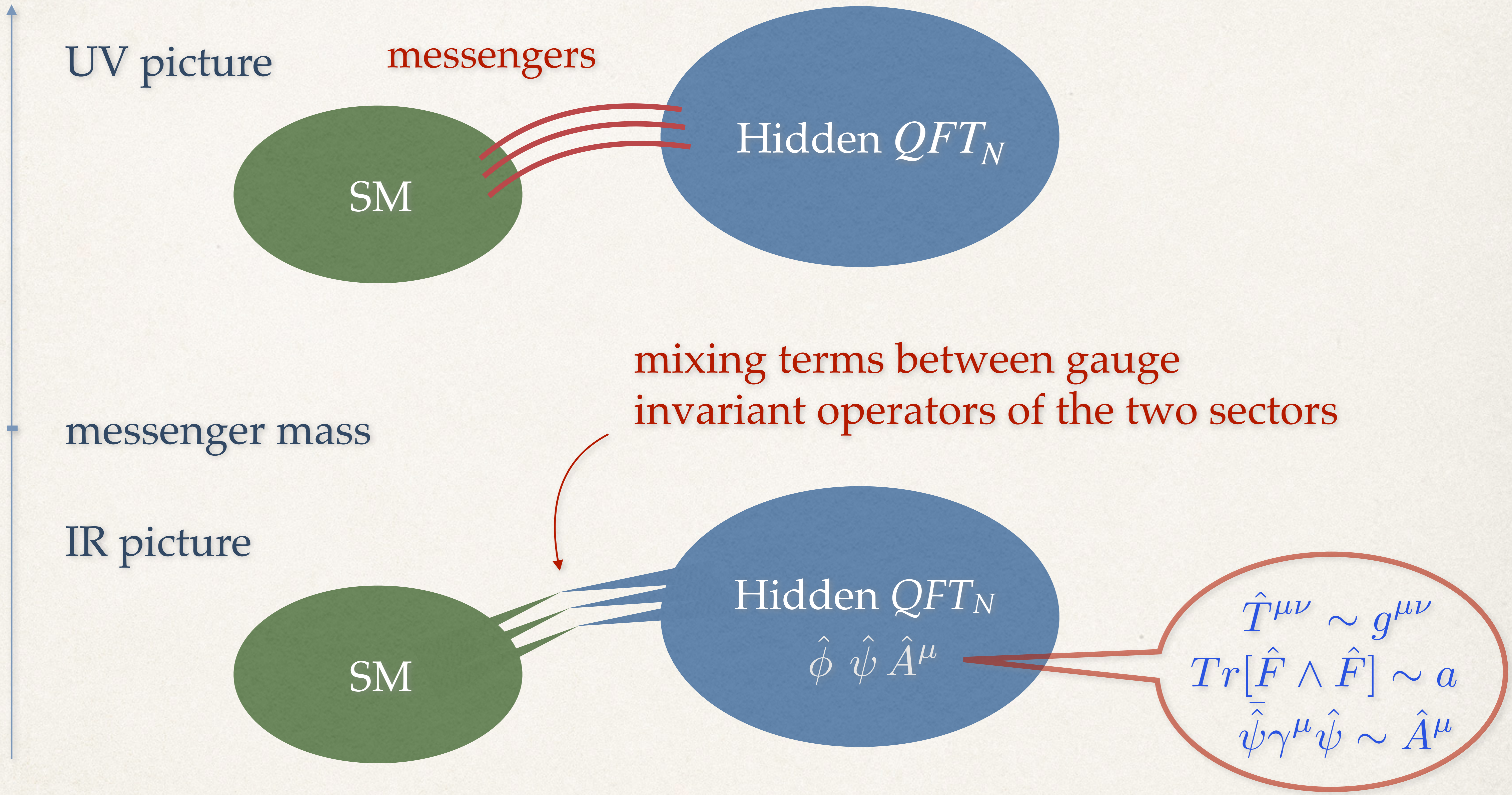


UV picture
messengers
SM
Hidden QFT_N
mixing terms between gauge
invariant operators of the two sectors
messenger mass
IR picture
SM
Hidden QFT_N
$\hat{\phi}\ \hat{\psi}\ \hat{A}^{\mu}$
$\hat{T}^{\mu\nu} \sim g^{\mu\nu}$
$Tr[\hat{F} \wedge \hat{F}] \sim a$
$\bar{\hat{\psi}}\gamma^{\mu}\hat{\psi} \sim \hat{A}^{\mu}$

Framework



operators in Hidden Sector ⟶ weakly coupled fields for the SM

operators protected by symmetries ⟶ light particles

Emergent Gravity

Emergent Gravity

- In this framework, gravity is an avatar of the Hidden QFT.

Kiritsis

$$S_{int} = \lambda \int d^4x \Big(T_{\mu\nu}(x)\hat{T}^{\mu\nu}(x) + c\, T(x)\hat{T}(x) \Big) \longrightarrow h_{\mu\nu} \sim \frac{\hat{T}_{\mu\nu}}{M^4}$$

- In the far IR, the graviton is massless and realise the action

$$S_{eff} = S_{vis} + \int d^4x\; h_{\mu\nu} \Big(T^{\mu\nu} + (2\pi)^4 \lambda^{-1} \Big(1 + \frac{1}{2}\lambda^{-1}\Lambda^{-1} \Big) \eta^{\mu\nu} \Big) + \int d^4x \sqrt{g} \Big(\Lambda + \frac{1}{16\pi G} R \Big) \Big|_{g_{\mu\nu} + \eta_{\mu\nu} + h_{\mu\nu}}$$

- The cosmological constant is given by $\Lambda = -\dfrac{(2\pi)^8}{\lambda^2 \langle \hat{T} \rangle}$.

- The Weinberg-Witten theorem is inapplicable: the final gravitational theory has a non-trivial cosmological constant.

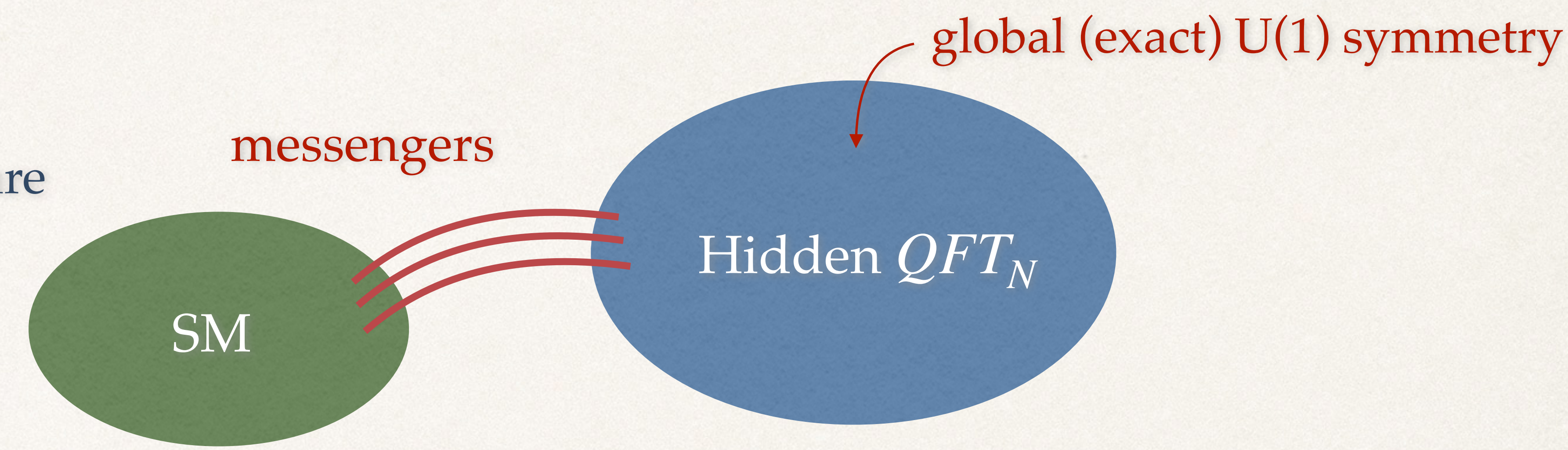
Betzios Kiritsis Niarchos

Graviphotons/Dark-photons

Gravi/Dark-photons

- Back to our setup

UV picture



HS point of view

SM point of view

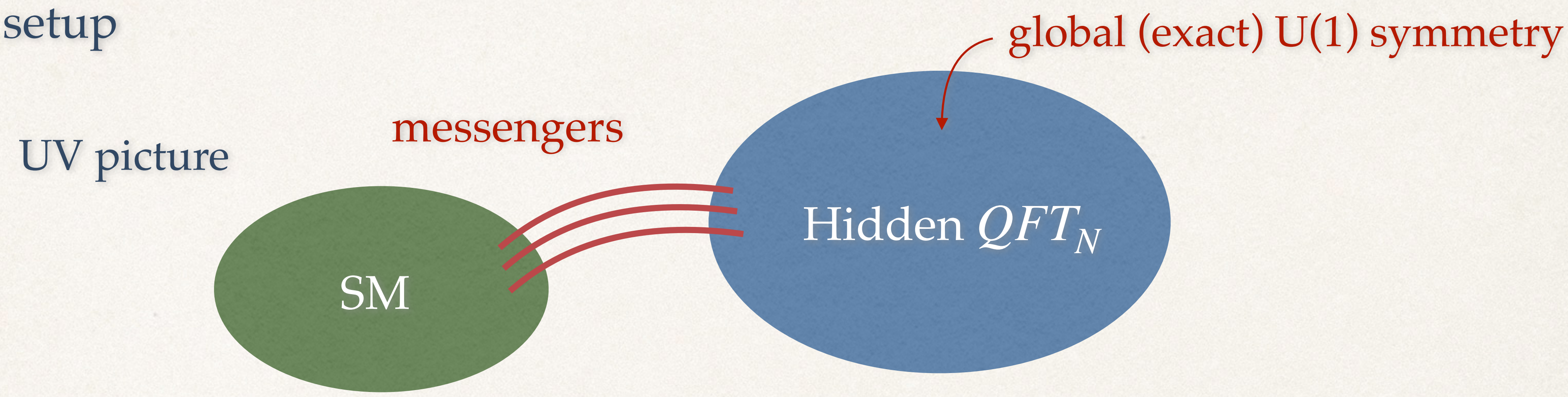
global conserved currents ($\hat{J}^\mu = \bar{\hat{\psi}}\gamma^\mu\hat{\psi}$) ⟶ abelian gauge fields $\hat{A}^\mu$

- Such emergent / composite vectors have
  - (very) light masses
  - a compositeness scale
    - above, it has non-local kinetic term
    - bellow, it behaves like point-like / standard field

Betzios Kiritsis Niarchos Papadoulaki

Graviphotons

- Back to our setup

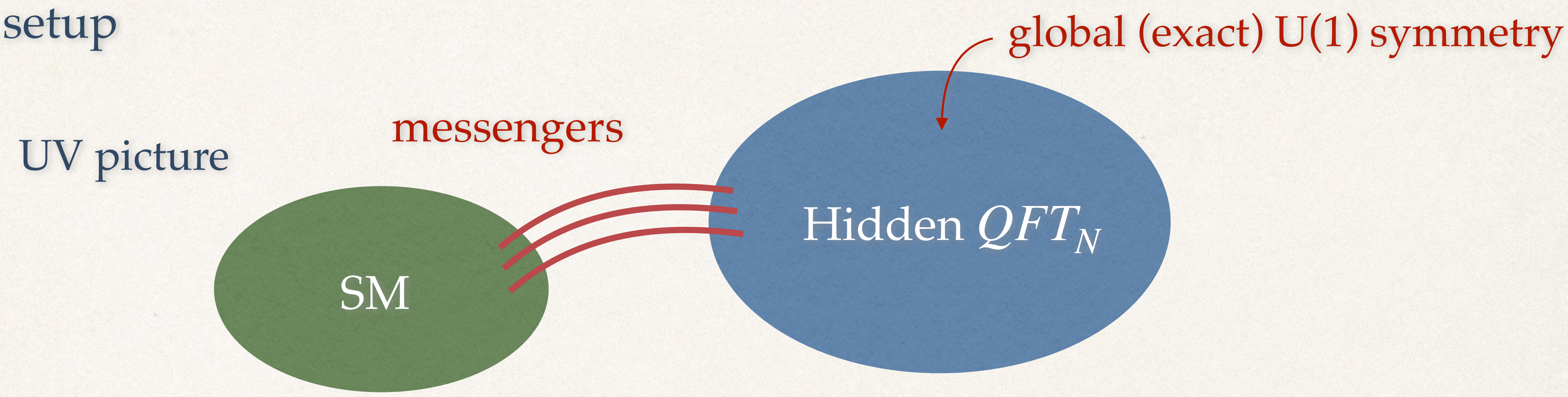


- SM symmetries
  - U(1) non-anomalous gauge symmetries
  - U(1) anomalous gauge symmetries
  - Non-abelian symmetries

- Global symmetries of Hidden sector
  - only messengers are charged
  - R-like symmetry: affects messengers and hidden fields.
  - Flavour symmetries of the Large-N QFT. No messengers are charged.

Graviphotons

- Back to our setup



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Gravi/Dark-photons

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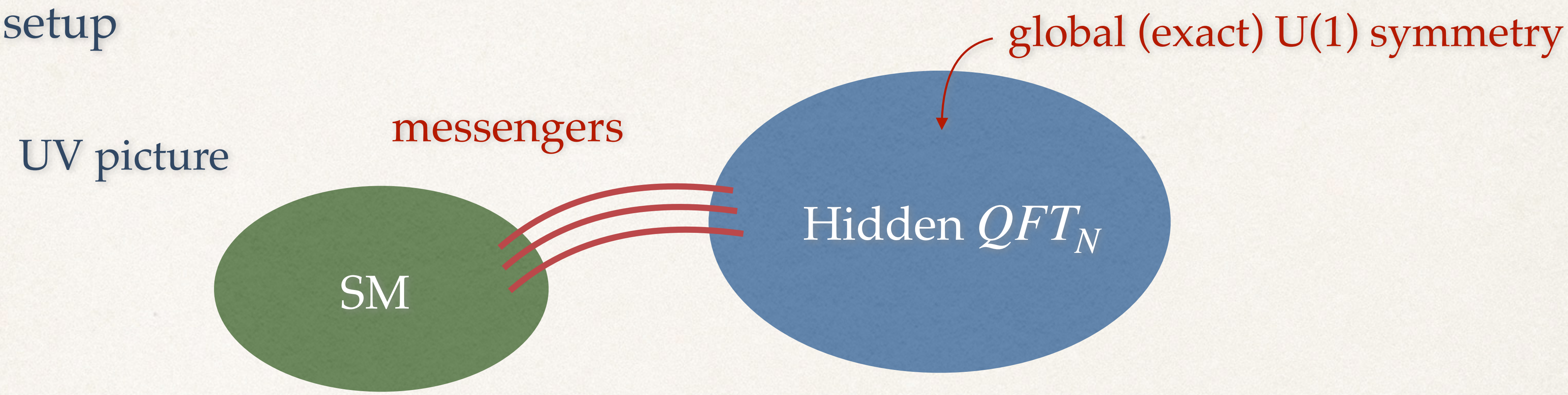

- Emergent gauge fields couple to all gauge invariant antisymmetric tensors of the SM.

$$W_6 \sim \frac{1}{NM^2} Tr[D_\mu H D_\nu H^\dagger] F^{\mu\nu}_{\hat{A}} + \frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu}_{\hat{A}} [\bar{\psi}\gamma_{\mu\nu} H \psi + c.c.]$$
$$+ \frac{1}{N^{\frac{3}{2}} M^2} F^{\hat{A}}_{\mu\nu} F^{Y,\mu\nu} H H^\dagger + \frac{1}{N^2 M^4} F^{\hat{A}}_{\mu\nu} F^{Y,\mu\nu} [\bar{\psi} H \psi + c.c.] + \cdots$$

emergent gauge fields — SM fields

- Couplings are taken after using EFT principles and large-*N* expansions.

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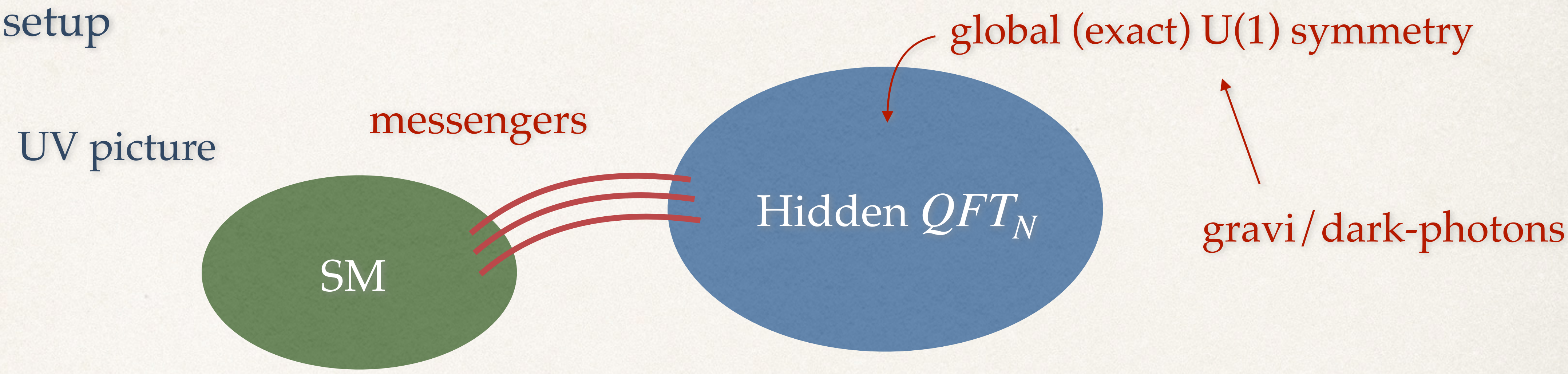
Gravi/Dark-photons

- Back to our setup



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emergent gauge fields ↗ SM fields

- Couplings are taken after using EFT principles and large-N expansions.

- These emergent vectors can play the role of gravi-/dark-photons.

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Mixings

- With the effective action of couplings between gravi/dark-photons and SM fields we can evaluate mixing with SM abelian fields (hypercharge or anomalous U(1)'s).

$$W_6 \sim \frac{1}{NM^2} Tr[D_\mu H D_\nu H^\dagger] F^{\mu\nu}_{\hat{A}} + \frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu}_{\hat{A}} [\bar{\psi}\gamma_{\mu\nu} H \psi + c.c.]$$
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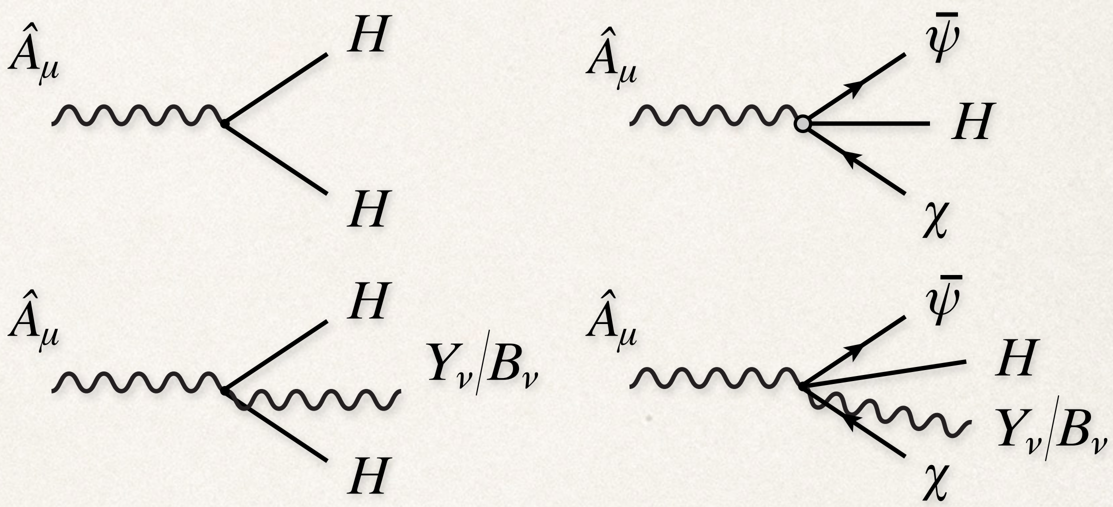
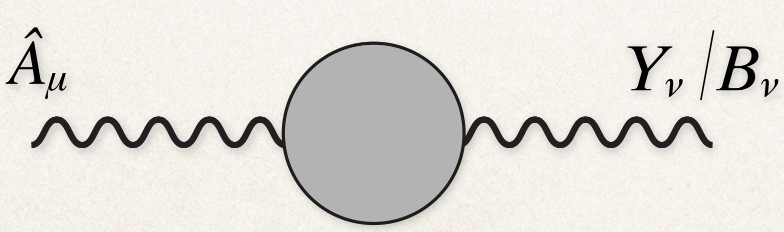




Y^μ hypercharge

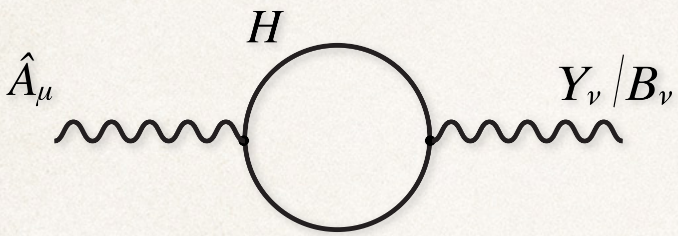
B^μ anomalous U(1)

- We explore two different cases: the unbroken and the broken phase.

Unbroken phase

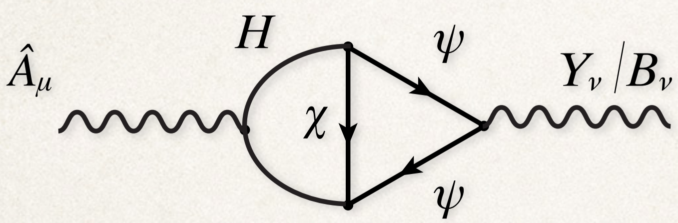
$$W_6 \sim \frac{1}{NM^2} Tr[D_\mu H D_\nu H^\dagger] F^{\mu\nu}_{\hat{A}} + \frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu}_{\hat{A}} [\bar{\psi}\gamma_{\mu\nu} H \psi + c.c.] + \frac{1}{N^{\frac{3}{2}} M^2} F^{\hat{A}}_{\mu\nu} F^{Y,\mu\nu} H H^\dagger + \frac{1}{N^2 M^4} F^{\hat{A}}_{\mu\nu} F^{Y,\mu\nu} [\bar{\psi} H \psi + c.c.] + \cdots$$

- At leading order, we have the 1-loop Higgs diagram

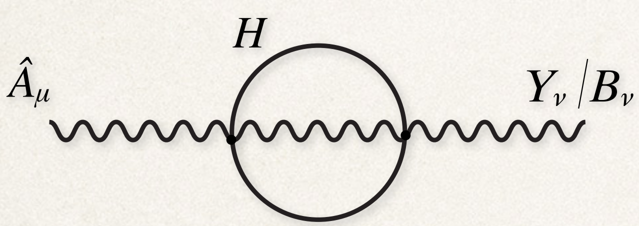


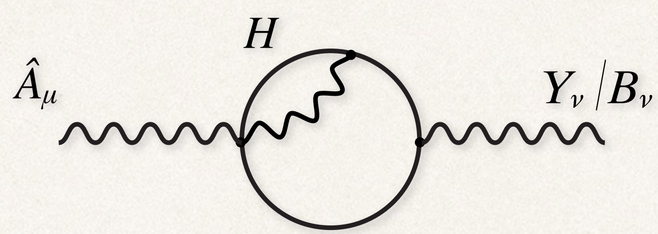
$$\sim \frac{\Omega_3}{8} \frac{Q_Y^H}{N} \frac{\Lambda^2}{M^2} \int d^4p \, F^{\hat{A}}_{\mu\nu}(p) F^{\mu\nu}_Y(-p) + \cdots$$

- At next order, we have 2-loop diagrams (where SM fermions can contribute)

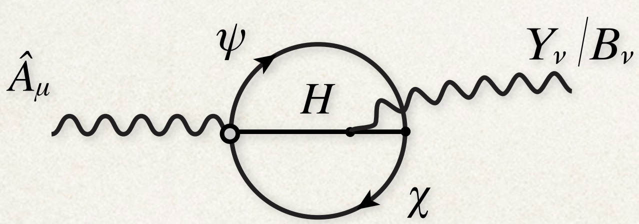


$$\sim Q_Y^\psi |g_{H\psi\chi}|^2 \frac{\Lambda^2}{NM^2}$$

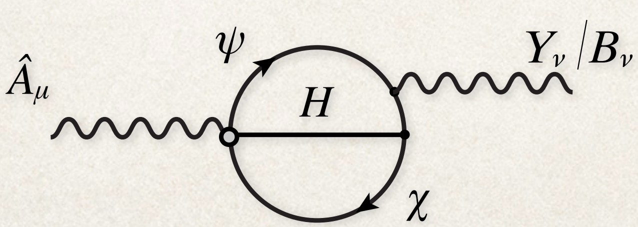




$$\sim \frac{(Q_Y^H)^2}{N}$$



$$\sim \frac{g_{H\psi\chi} m^2}{M^2 N^{\frac{3}{2}}} \log \frac{\Lambda^2}{m^2}$$



$$\sim \frac{Q_Y^H g_{H\psi\chi}}{N^{\frac{3}{2}}}$$

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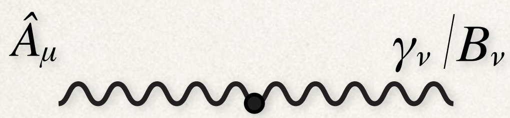
Broken phase

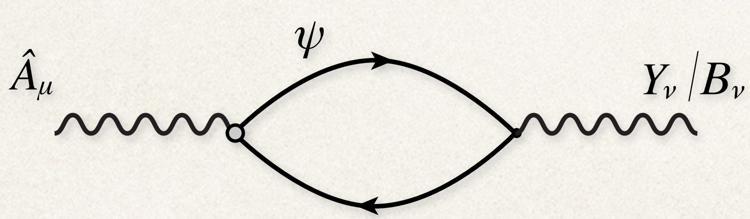
- The action in the broken phase becomes

$$
\begin{aligned}
W_{BROKEN} \sim\ & \frac{4g_w^2}{NM^2}(h+v)^2\, F^{\hat{A}}_{\mu\nu} W_+^{\mu} W_-^{\nu} + \frac{4ie}{NM^2}\,(h+v) F^{\hat{A}}_{\mu\nu} A^{\mu}_{\gamma} \partial^{\nu} h \\
& + \frac{4e}{NM^2}\sqrt{g_w^2 + g_Y^2}\,(h+v)^2 F^{\hat{A}}_{\mu\nu} A^{\mu}_{\gamma} Z^{\nu} + \frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu}_{\hat{A}} \left[(h+v)\bar{\psi}\gamma_{\mu\nu}\psi + c.c.\right] \\
& + \frac{1}{NM^2} F^{\hat{A}}_{\mu\nu}(\cos\theta_w F^{\gamma,\mu\nu} - \sin\theta_w F^{Z,\mu\nu})(h+v)^2 \\
& + \frac{1}{N^2 M^4} F^{\hat{A}}_{\mu\nu}(\cos\theta_w F^{\gamma,\mu\nu} - \sin\theta_w F^{Z,\mu\nu}) \left[\bar{\psi}\psi(h+v) + c.c.\right]
\end{aligned}
$$

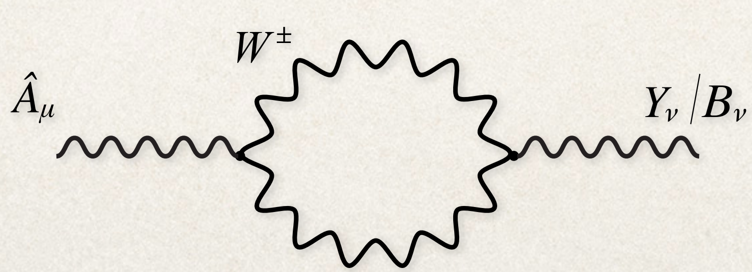
- The mixing is coming at tree- and 1-loop level from the diagrams



$$\sim \frac{v^2}{NM^2}\int d^4p\, F^{\hat{A}}_{\mu\nu}(p)\Big(\cos\theta_w F^{\gamma,\mu\nu} - \sin\theta_w F^{Z,\mu\nu}\Big)(-p)$$



$$\sim 4\Omega_3 Tr_Y \left[\frac{Q_Y m_\psi v}{N^{\frac{3}{2}} M^2}\right] \log\frac{\Lambda^2}{m_\psi^2}$$



$$\sim -e\frac{\Lambda^2}{NM^2}\frac{8i\Omega_3}{(2\pi)^4}$$

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Comments

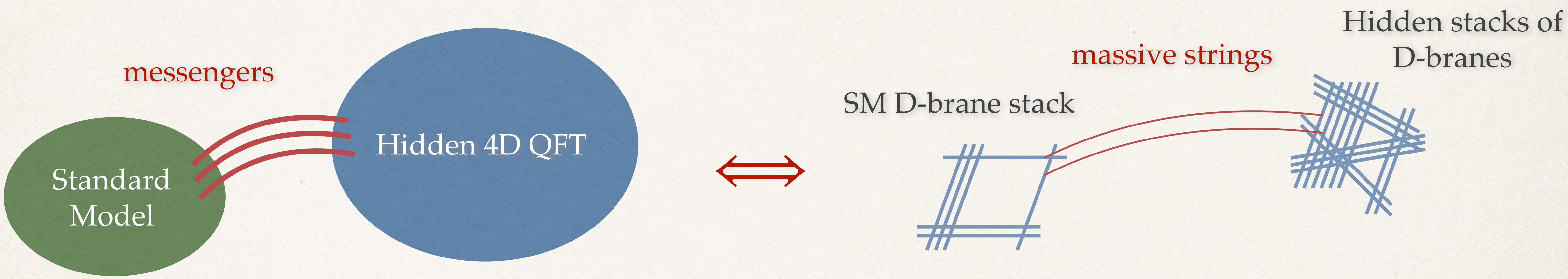
- All contributions are due to the Higgs field: direct or via Higgs-Englert-Brout mech.
- The emergent vector is expected to be light.
- It will mediate a fifth force even though none of the SM particles are directly charged under it. They will acquire an effective charge because of the mixing.
- Standard model quantum effects also correct the coupling of the emergent vector,

$$\frac{\delta g_{hidden}^2}{g_{hidden}^2} \sim \frac{1}{N^2} \frac{m_{SM}^2}{M^2}$$

- Therefore, the correction has an extra suppression since $m_{SM}^2 \ll M^2$.

String theory vs QFT pictures

- The holographic-inspired scenario is similar to string theory picture.



- AdS/CFT correspondence indicates

strongly-coupled, large-N QFTs ⟺ weakly-coupled string theories

and vice versa

- In this framework

emergent vectors ⟺ gravi-/dark-photons in string theory

- Our goal is to compare couplings between U(1)'s and SM fields in the two scenarios.

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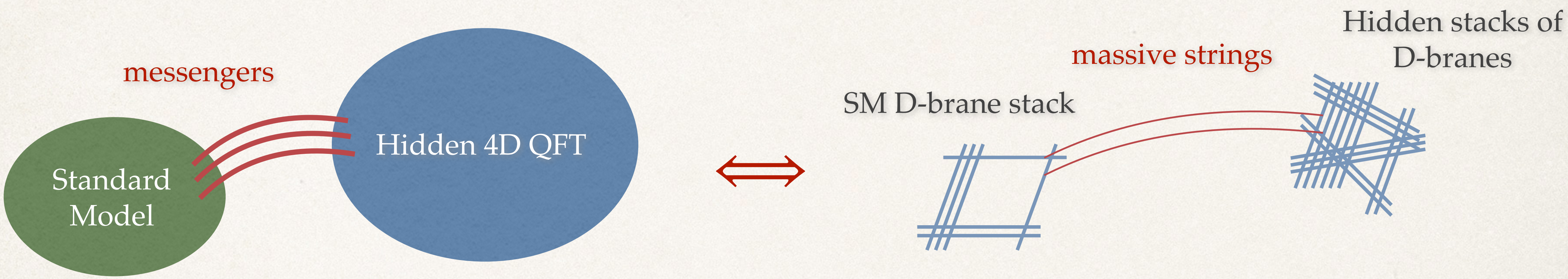

- In string theory, we have two classes of abelian gauge fields

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  - Closed sector (NSNS and RR sectors)

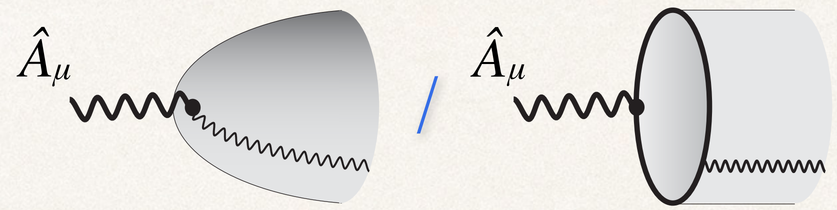
$$G_{MN} \to G_{\mu\nu} + G_{\mu i} + G_{ij} \quad \& \quad C_{MN} \to C_{\mu\nu} + C_{\mu i} + C_{ij} \quad \Longrightarrow \quad \text{gravi-photons}$$

  - Open sector (strings living on D-branes)

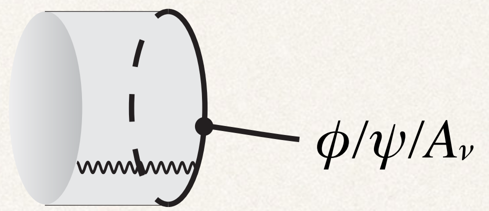
$$A_M \to A_\mu + A_i \quad \Longrightarrow \quad \text{dark-brane-photons}$$

String theory vs QFT pictures

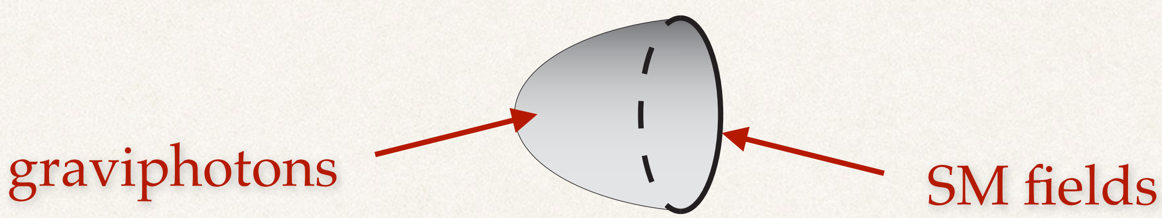
- The relevant stringy amplitudes will include
  - Closed / Open VOs :



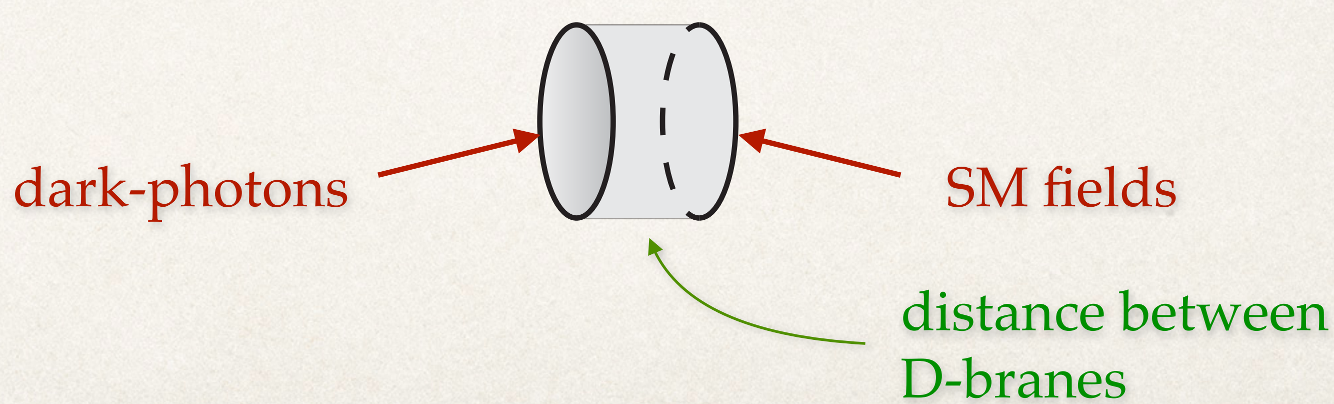
  - Open VOs (SM fields) :



- The lowest order surfaces which can accommodate these computations are
  - Disk :



  - Cylinder :



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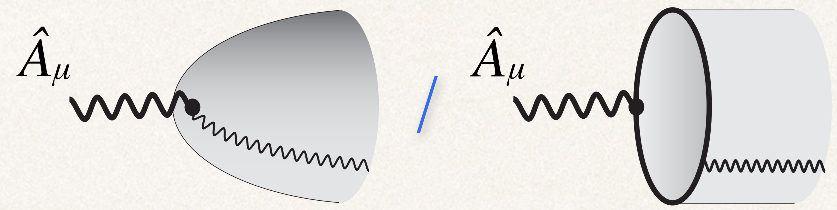

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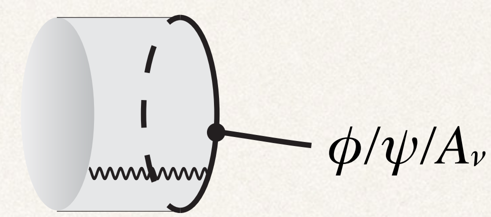

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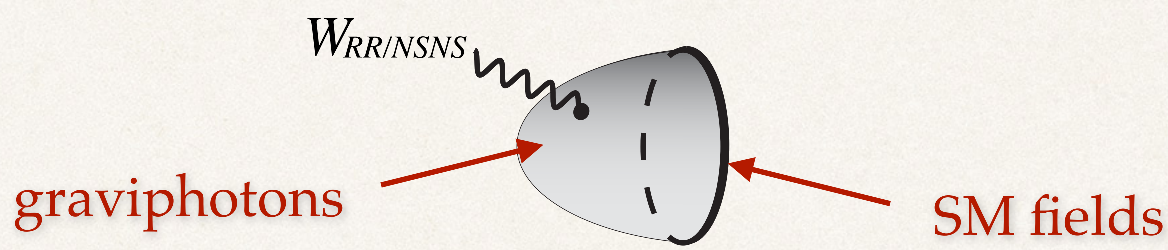

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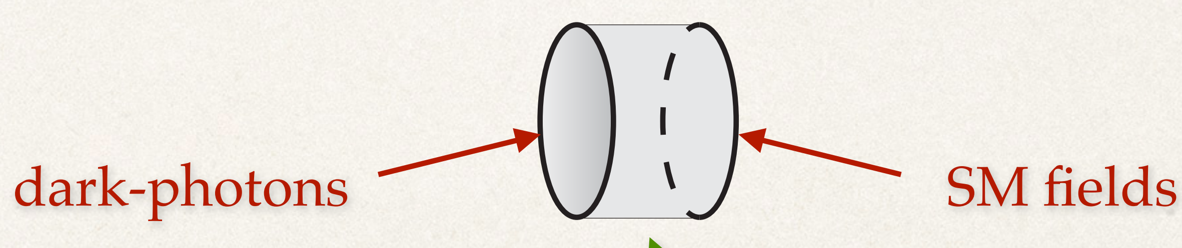


- We will also consider the presence of RR and NSNS fluxes.

Normalization and flatness

- We normalise the VO's by taking the worldsheet fields to have length dimensions.

$$[X],\ [\Psi] \sim \sqrt{\alpha'} = \ell_s$$

- We use correlation function in flat space.
    - The string dual of the QFT described before is expected in a non-trivial asymptotically AdS gravitational background.
    - However, at leading order, flat space is a good approximation.
- In addition, we consider the presence of RR-/NSNS-background fields.

EFT couplings from ST amplitudes

- Couplings from the EFT picture and the corresponding string amplitudes.

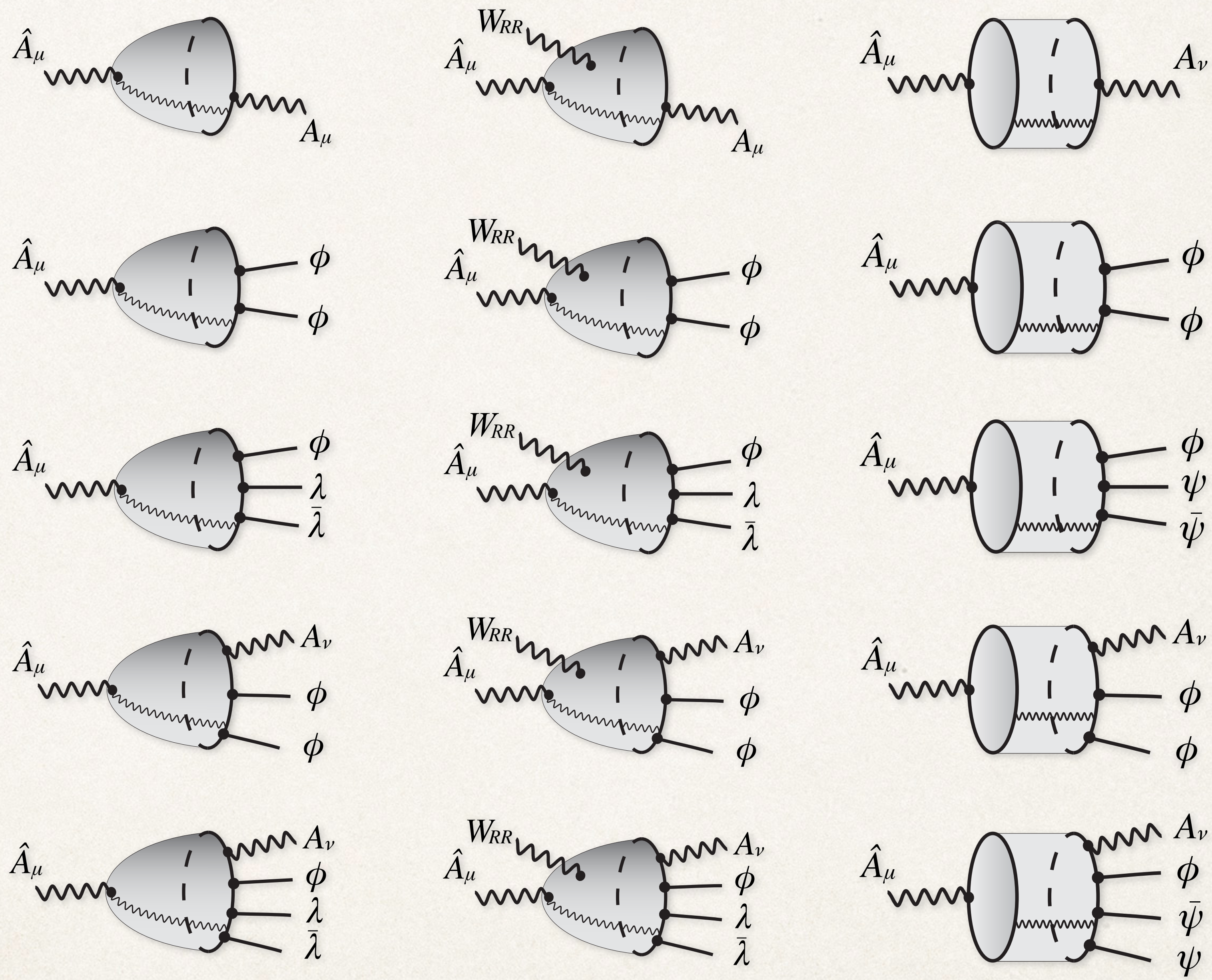
$$\frac{\Lambda^2}{NM^2} F^{\mu\nu} \hat{F}^{\mu\nu}$$

$$\frac{1}{NM^2} D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$$

$$\frac{1}{N^{\frac{3}{2}} M^2} \bar{\psi} \gamma_{\mu\nu} H \psi \hat{F}^{\mu\nu}$$

$$\frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu} \hat{F}_{\mu\nu} H^\dagger H$$

$$\frac{1}{N^2 M^4} F^{\mu\nu} \hat{F}_{\mu\nu} \bar{\psi} H \psi$$



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EFT couplings from ST amplitudes

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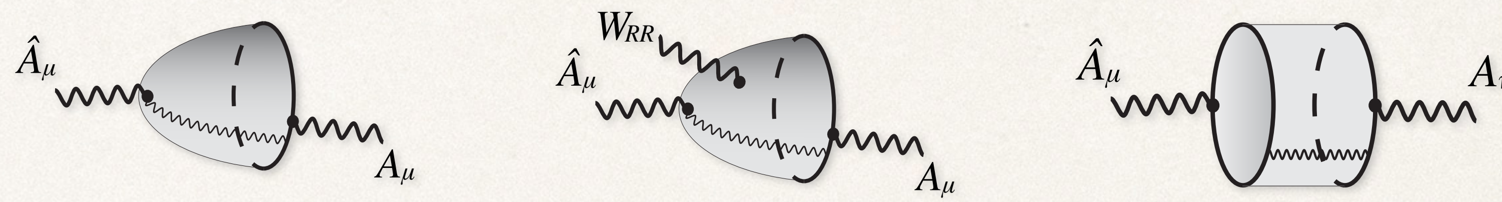
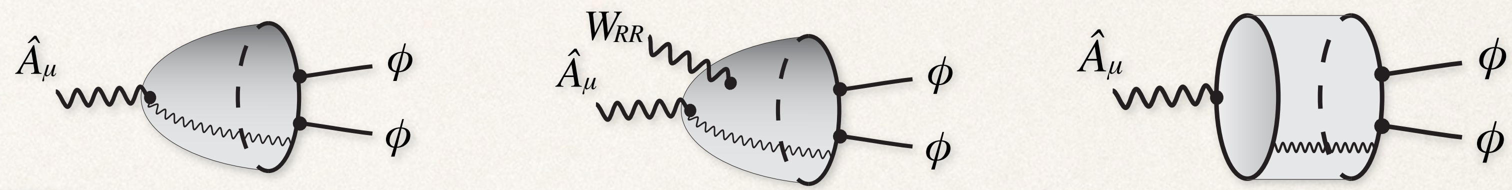
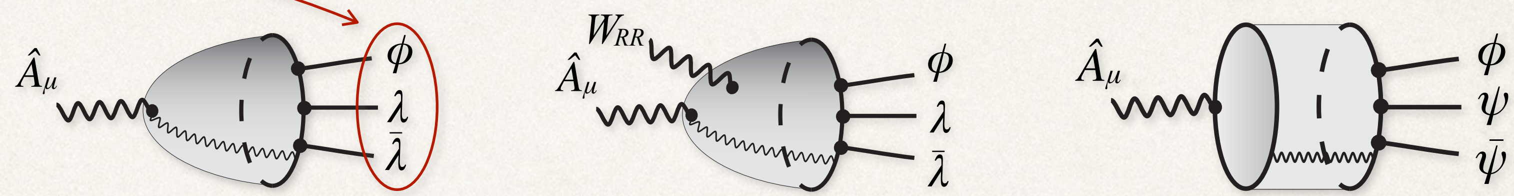
$$\frac{\Lambda^2}{N M^2} F^{\mu\nu} \hat{F}^{\mu\nu}$$



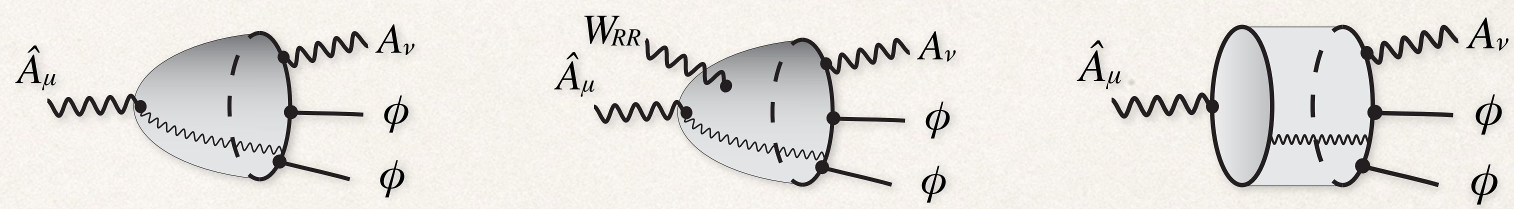
$$\frac{1}{N M^2} D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$$



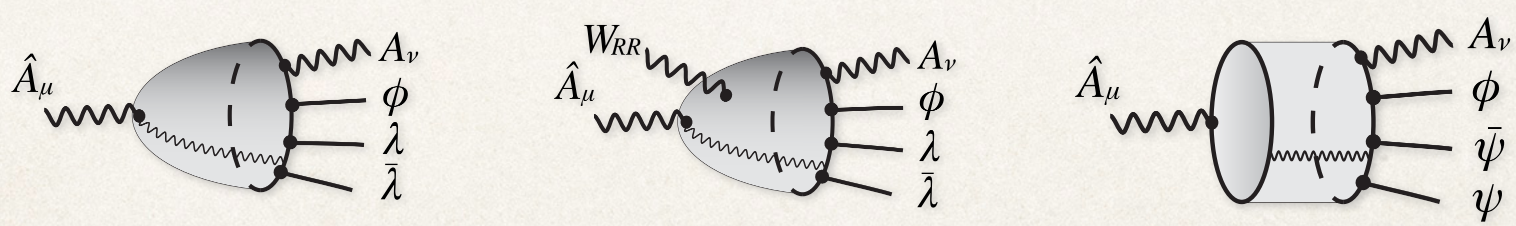
$$\frac{1}{N^{\frac{3}{2}} M^2} \bar{\psi} \gamma_{\mu\nu} H \psi \hat{F}^{\mu\nu}$$



$$\frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu} \hat{F}_{\mu\nu} H^\dagger H$$



$$\frac{1}{N^2 M^4} F^{\mu\nu} \hat{F}_{\mu\nu} \bar{\psi} H \psi$$



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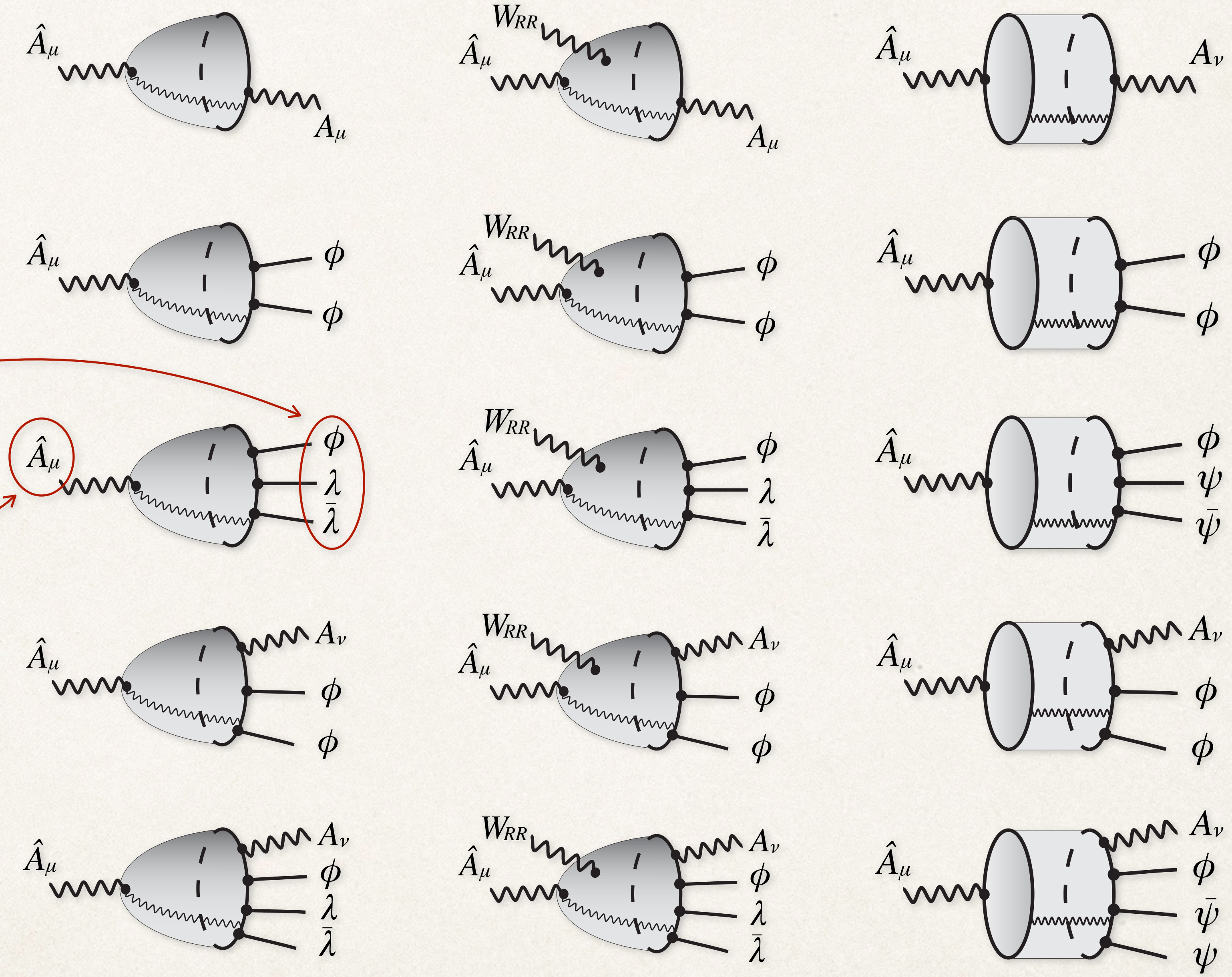
$$\frac{1}{N^{\frac{3}{2}}M^2} F^{\mu\nu}\hat{F}_{\mu\nu} H^\dagger H$$

$$\frac{1}{N^2 M^4} F^{\mu\nu}\hat{F}_{\mu\nu} \bar{\psi} H \psi$$



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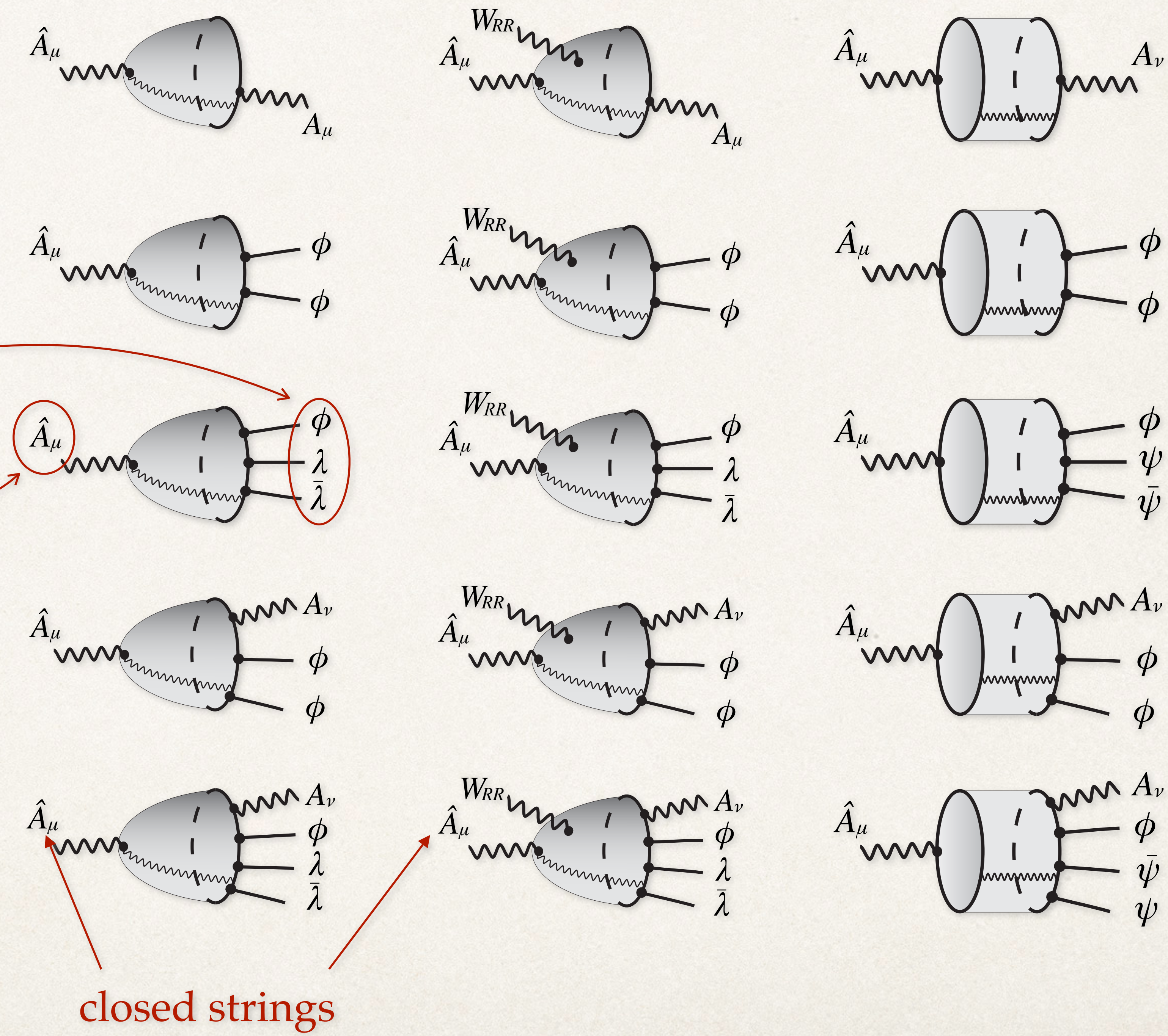
$$\frac{1}{N^2 M^4} F^{\mu\nu}\hat{F}_{\mu\nu}\bar{\psi} H \psi$$



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EFT couplings from ST amplitudes

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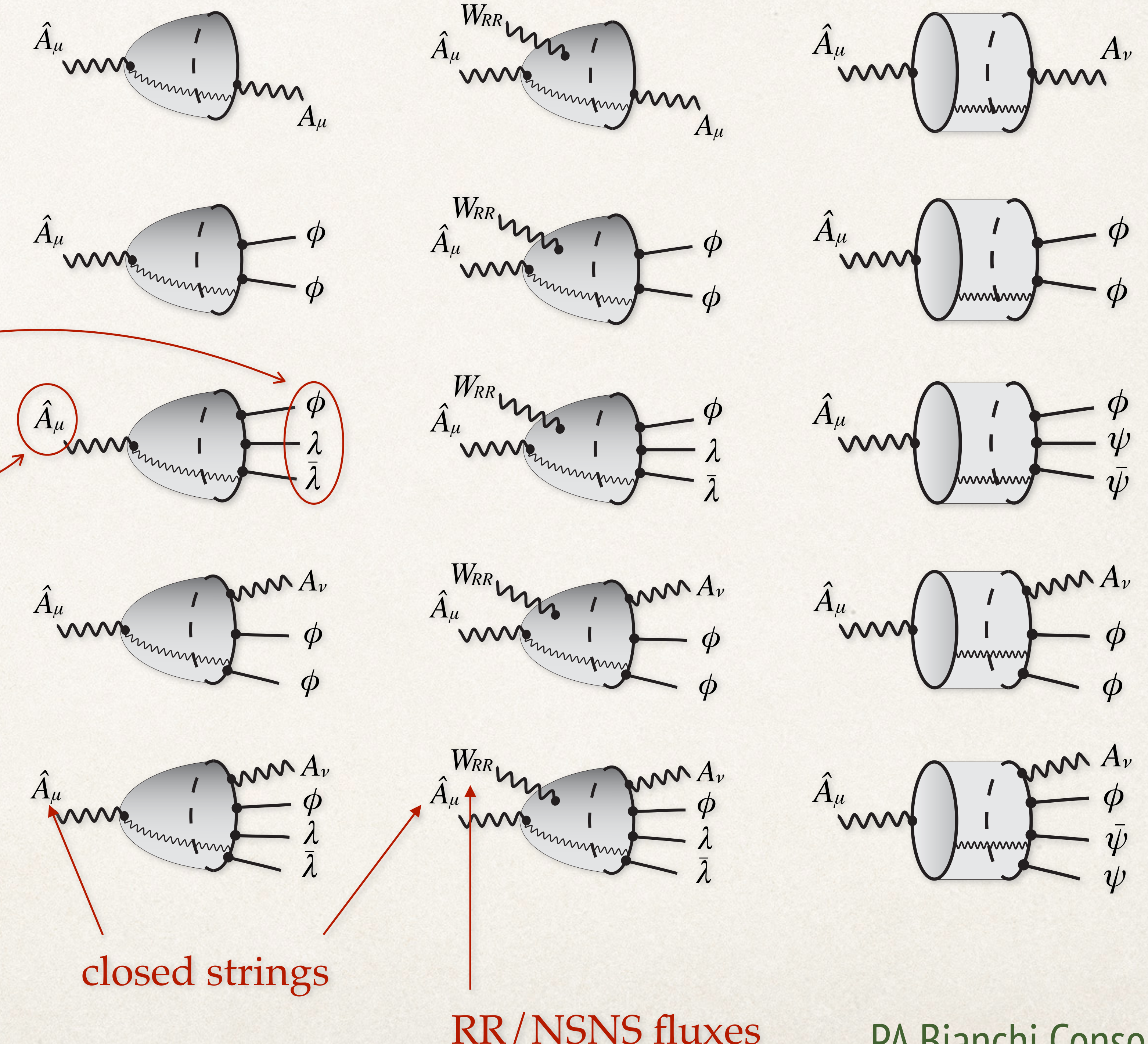

PA Bianchi Consoli Kiritsis

EFT couplings from ST amplitudes

- Couplings from the EFT picture and the corresponding string amplitudes.

$$\frac{\Lambda^2}{NM^2} F^{\mu\nu}\hat{F}^{\mu\nu}$$

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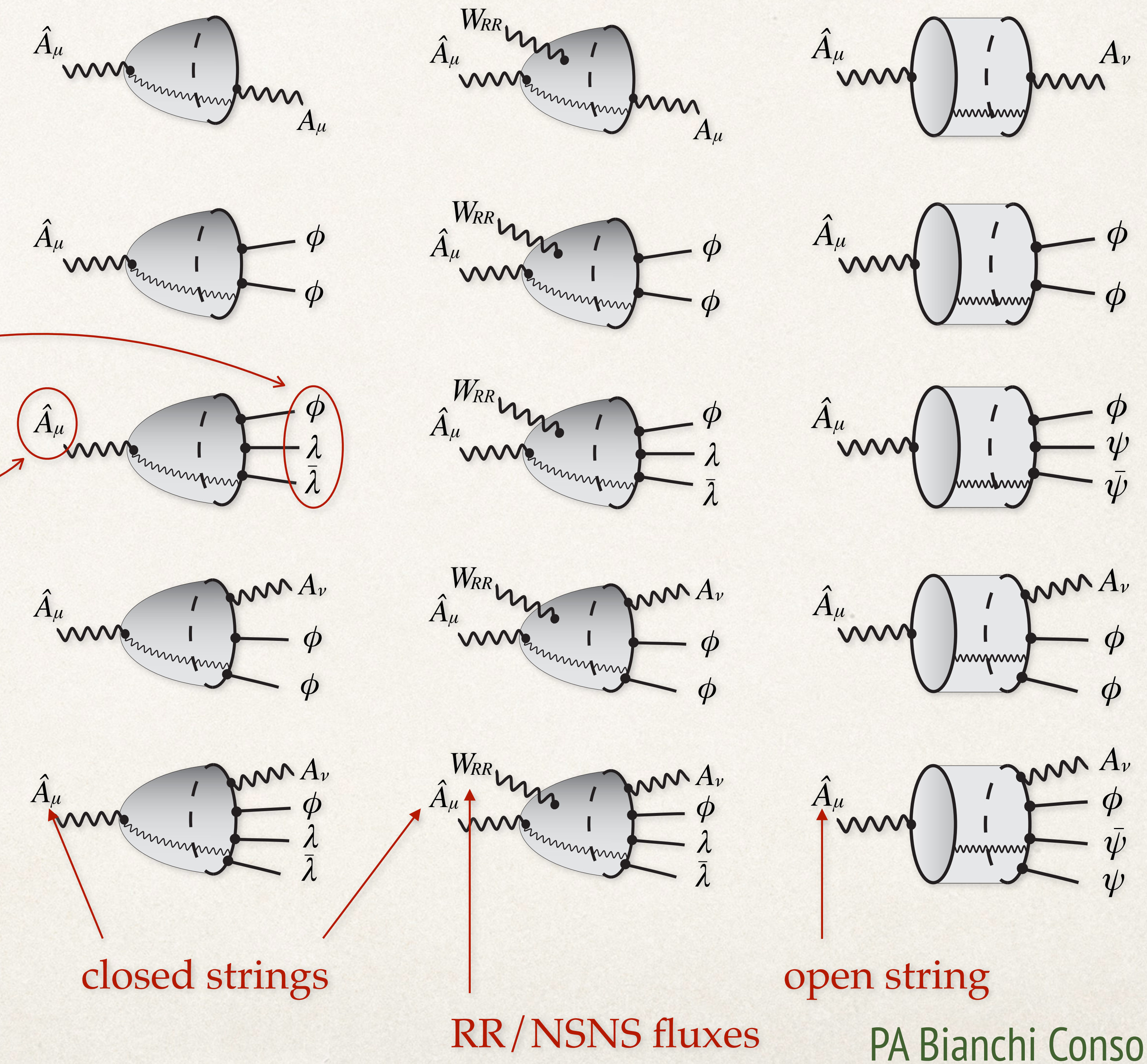
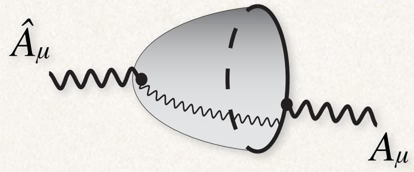
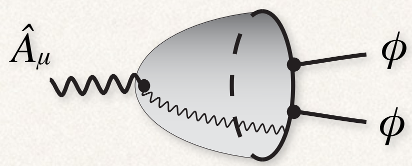
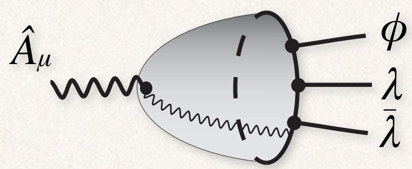
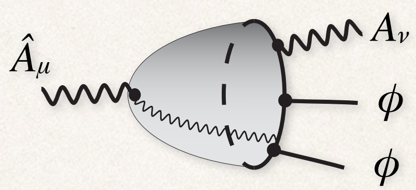
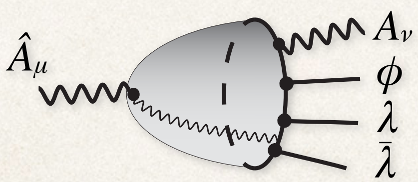


PA Bianchi Consoli Kiritsis

Closed sector (no flux)

- We **fix** two scales: $M_s = \ell_s^{-1}, M_{KK} = \mathcal{V}_6^{1/6}\ell_s^{-1}$. We also **take** $M_s \sim M_{KK} \sim M$.

$\frac{\Lambda^2}{NM^2}F^{\mu\nu}\hat{F}^{\mu\nu}$		$0 \cdot g_s + \mathcal{O}(g_s^2)$
$\frac{1}{NM^2}D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$		$0 \cdot g_s + \mathcal{O}(g_s^2)$
$\frac{1}{N^{\frac{3}{2}}M^2}\bar{\psi}\gamma_{\mu\nu}H\psi\hat{F}^{\mu\nu}$		$g_s^{\frac{3}{2}}\frac{\ell_s^2}{\sqrt{\mathscr{V}_6}}v_\alpha\varphi^i\hat{F}^{\alpha\beta}v_\beta$
$\frac{1}{N^{\frac{3}{2}}M^2}F^{\mu\nu}\hat{F}_{\mu\nu}H^\dagger H$		$0 \cdot g_s^{\frac{3}{2}} + \mathcal{O}(g_s^{\frac{5}{2}})$
$\frac{1}{N^2M^4}F^{\mu\nu}\hat{F}_{\mu\nu}\bar{\psi}H\psi$		$g_s^2\frac{\ell_s^4}{\sqrt{\mathscr{V}_6}}u^\alpha v^\alpha\varphi^i F^{\mu\nu}\hat{F}_{\mu\nu}$

Closed sector (no flux)

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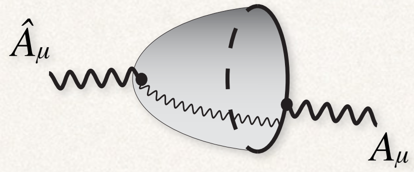
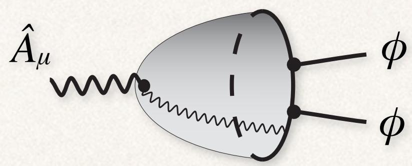
$\frac{\Lambda^2}{NM^2} F^{\mu\nu}\hat{F}^{\mu\nu}$



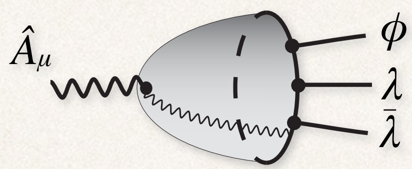
$0 \cdot g_s + \mathcal{O}(g_s^2)$

$\frac{1}{NM^2} D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$



$0 \cdot g_s + \mathcal{O}(g_s^2)$

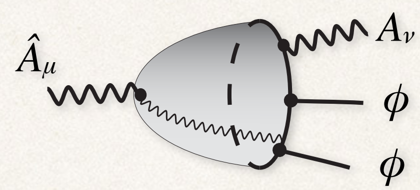
$\frac{1}{N^{\frac{3}{2}}M^2} \bar{\psi}\gamma_{\mu\nu} H \psi \hat{F}^{\mu\nu}$



$g_s^{\frac{3}{2}} \frac{\ell_s^2}{\sqrt{\mathcal{V}_6}} v_\alpha \varphi^i \hat{F}^{\alpha\beta} v_\beta$

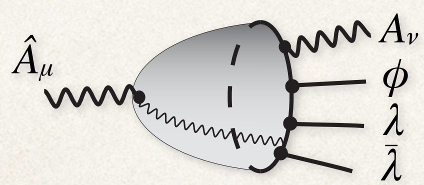
$g_s = \frac{1}{N}$

$\frac{1}{N^{\frac{3}{2}}M^2} F^{\mu\nu}\hat{F}_{\mu\nu} H^\dagger H$



$0 \cdot g_s^{\frac{3}{2}} + \mathcal{O}(g_s^{\frac{5}{2}})$

$\frac{1}{N^2M^4} F^{\mu\nu}\hat{F}_{\mu\nu}\bar{\psi} H \psi$

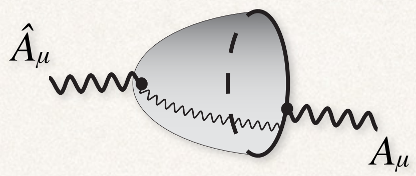


$g_s^2 \frac{\ell_s^4}{\sqrt{\mathcal{V}_6}} u^\alpha v^\alpha \varphi^i F^{\mu\nu}\hat{F}_{\mu\nu}$

Closed sector (no flux)

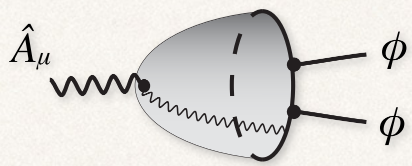
- We **fix** two scales: $M_s = \ell_s^{-1}, M_{KK} = \mathcal{V}_6^{1/6}\ell_s^{-1}$. We also **take** $M_s \sim M_{KK} \sim M$.

$$\frac{\Lambda^2}{NM^2}F^{\mu\nu}\hat{F}^{\mu\nu}$$



$$0 \cdot g_s + \mathcal{O}(g_s^2)$$

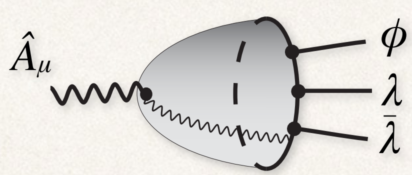
$$\frac{1}{NM^2}D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$$



$$0 \cdot g_s + \mathcal{O}(g_s^2)$$

$M_s \sim M_{KK} \sim M$

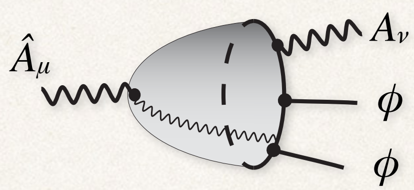
$$\frac{1}{N^{\frac{3}{2}}M^2}\bar{\psi}\gamma_{\mu\nu}H\psi\hat{F}^{\mu\nu}$$



$$g_s^{\frac{3}{2}}\frac{\ell_s^2}{\sqrt{\mathcal{V}_6}}v_\alpha \varphi^i \hat{F}^{\alpha\beta}v_\beta$$

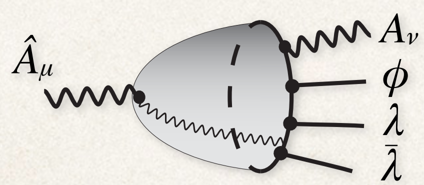
$$g_s = \frac{1}{N}$$

$$\frac{1}{N^{\frac{3}{2}}M^2}F^{\mu\nu}\hat{F}_{\mu\nu}H^\dagger H$$



$$0 \cdot g_s^{\frac{3}{2}} + \mathcal{O}(g_s^{\frac{5}{2}})$$

$$\frac{1}{N^2M^4}F^{\mu\nu}\hat{F}_{\mu\nu}\bar{\psi}H\psi$$



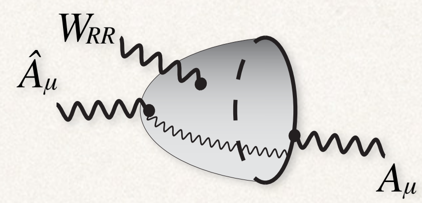
$$g_s^2\frac{\ell_s^4}{\sqrt{\mathcal{V}_6}}u^\alpha v^\alpha \varphi^i F^{\mu\nu}\hat{F}_{\mu\nu}$$

Closed sector (with flux)

- The results are given bellow

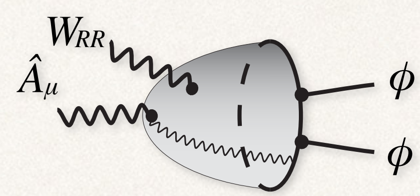
$$\frac{\mathscr{F}_{(ab)}}{M_s^2}$$

$$\frac{\Lambda^2}{NM^2}F^{\mu\nu}\hat{F}^{\mu\nu}$$



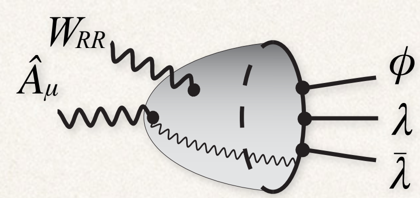
$$g_s^{\frac{3}{2}}\frac{\ell_s^2}{\mathscr{V}_6}\mathscr{F}_{(ab)}F^{\mu\nu}\hat{F}^{(ab)}_{\mu\nu}$$

$$\frac{1}{NM^2}D_\mu H^\dagger D_\nu H\hat{F}^{\mu\nu}$$



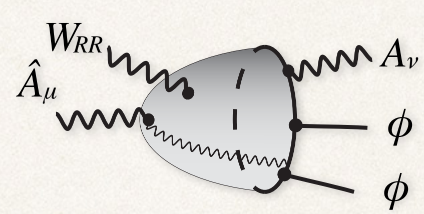
$$g_s^{\frac{3}{2}}\frac{\ell_s^4}{\mathscr{V}_6}\mathscr{F}_{(ab)}k^\mu_\phi\hat{F}_{\mu\nu}k^\nu_{\bar{\phi}}\phi\bar{\phi}$$

$$\frac{1}{N^{\frac{3}{2}}M^2}\bar{\psi}\gamma_{\mu\nu}H\psi\hat{F}^{\mu\nu}$$



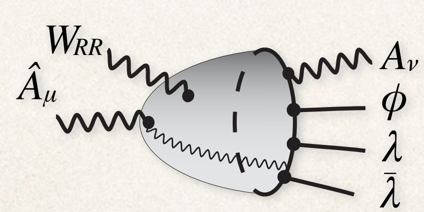
$0\cdot g_s^{\frac{3}{2}}+\mathscr{O}(g_s^{\frac{5}{2}})$(subl. in ∂)

$$\frac{1}{N^{\frac{3}{2}}M^2}F^{\mu\nu}\hat{F}_{\mu\nu}H^\dagger H$$



$$g_s^{\frac{5}{2}}\frac{\ell_s^6}{\mathscr{V}_6}\mathscr{F}_{(ab)}F^{\mu\nu}\hat{F}_{\mu\nu}k^\phi\cdot k_{\bar{\phi}}\phi\bar{\phi}$$

$$\frac{1}{N^2M^4}F^{\mu\nu}\hat{F}_{\mu\nu}\bar{\psi}H\psi$$



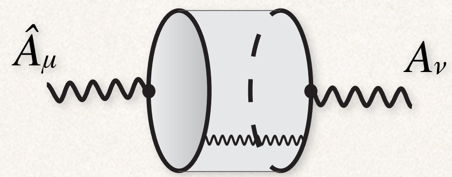
$0\cdot g_s^2+\mathscr{O}(g_s^3)$(subl. in ∂)

- Results are sub-leading in comparison with those without the fluxes.
  That comes from the normalization of the flux $\mathscr{F}_{(ab)}/M_s^2$.

Open sector

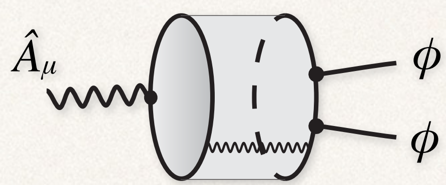
- In this case, $M = \dfrac{\Delta x}{\alpha'}$. From the distance between the branes.

$$\frac{\Lambda^2}{NM^2} F^{\mu\nu} \hat{F}^{\mu\nu}$$



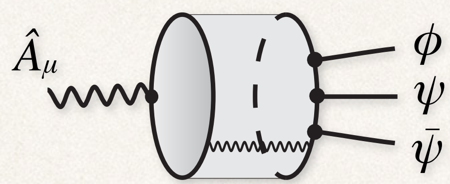
$$g_s F^{\mu\nu} \hat{F}_{\mu\nu} \log \frac{\Lambda^2}{M^2}$$

$$\frac{1}{NM^2} D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$$



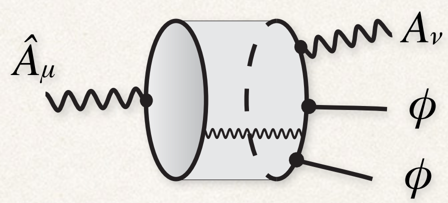
$$\frac{g_s^{\frac{3}{2}}}{M^2} k_\phi^\mu \hat{F}_{\mu\nu} k_{\bar{\phi}}^\nu \phi \bar{\phi}$$

$$\frac{1}{N^{\frac{3}{2}} M^2} \bar{\psi} \gamma_{\mu\nu} H \psi \hat{F}^{\mu\nu}$$



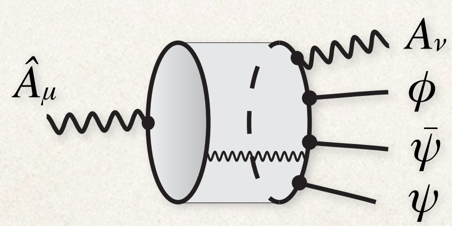
$$0 \cdot g_s + \mathcal{O}(g_s^2)(\text{subl. in } \partial)$$

$$\frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu} \hat{F}_{\mu\nu} H^\dagger H$$



$$\frac{g_s^2}{M^4} F^{\mu\nu} \hat{F}_{\mu\nu} k^\phi \cdot k_{\bar{\phi}} \phi \bar{\phi}$$

$$\frac{1}{N^2 M^4} F^{\mu\nu} \hat{F}_{\mu\nu} \bar{\psi} H \psi$$



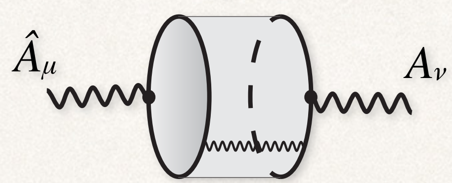
$$\mathcal{O}(g_s^{\frac{5}{2}})(\text{subl. in } \partial)$$

- Results are sub-leading in powers of g_s.

Open sector

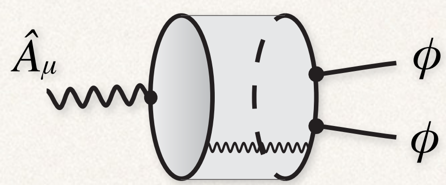
- In this case, $M = \dfrac{\Delta x}{\alpha'}$. From the distance between the branes.

$$\frac{\Lambda^2}{NM^2} F^{\mu\nu} \hat{F}^{\mu\nu}$$



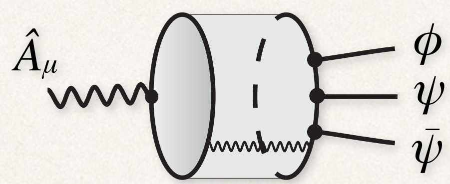
$$g_s F^{\mu\nu} \hat{F}_{\mu\nu} \log \frac{\Lambda^2}{M^2}$$

$$\frac{1}{NM^2} D_\mu H^\dagger D_\nu H \hat{F}^{\mu\nu}$$



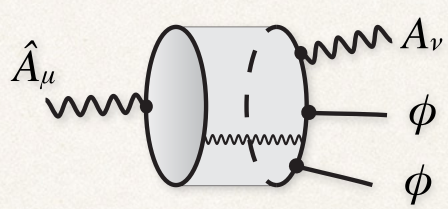
$$\frac{g_s^{\frac{3}{2}}}{M^2} k_\phi^\mu \hat{F}_{\mu\nu} k_{\bar{\phi}}^\nu \phi \bar{\phi}$$

$$\frac{1}{N^{\frac{3}{2}} M^2} \bar{\psi} \gamma_{\mu\nu} H \psi \hat{F}^{\mu\nu}$$



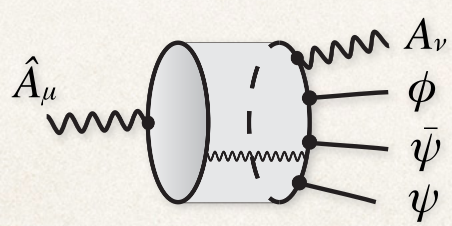
$$0 \cdot g_s + \mathcal{O}(g_s^2)(\text{subl. in } \partial)$$

$$\frac{1}{N^{\frac{3}{2}} M^2} F^{\mu\nu} \hat{F}_{\mu\nu} H^\dagger H$$



$$\frac{g_s^2}{M^4} F^{\mu\nu} \hat{F}_{\mu\nu} k^\phi \cdot k_{\bar{\phi}} \phi \bar{\phi}$$

$$\frac{1}{N^2 M^4} F^{\mu\nu} \hat{F}_{\mu\nu} \bar{\psi} H \psi$$



$$\mathcal{O}(g_s^{\frac{5}{2}})(\text{subl. in } \partial)$$

- Results are sub-leading in powers of g_s .

Comparison with results

- Our results, regarding the couplings $g_s = \dfrac{1}{N}$ in String Theory and the Large-N

EFT coupling	EFT estimate	graviphoton	graviphoton +bulk fluxes	dark photon
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agrement in circles

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agrement in circles

zero at leading order

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agrement in circles

zero at leading order

sub-leading

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agrement in circles

zero at leading order

sub-leading

- Same couplings are expected if we substitute the hypercharge with some anomalous U(1) accompanying the SM (a usual case in semi-realistic D-brane configurations).

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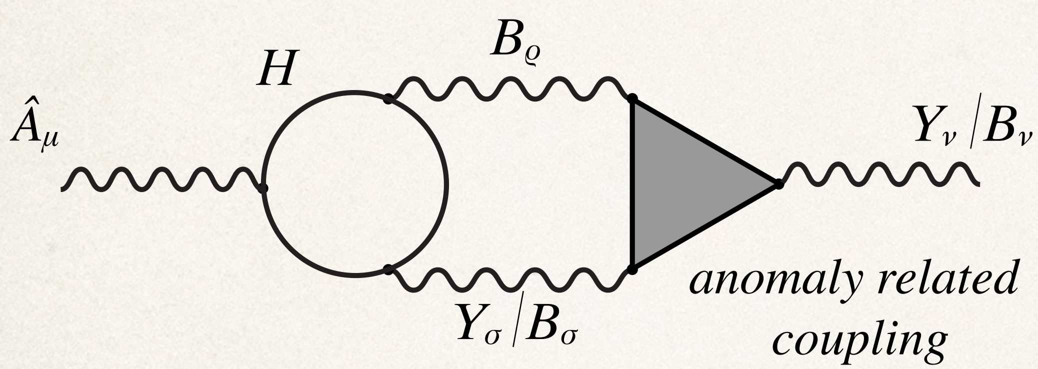
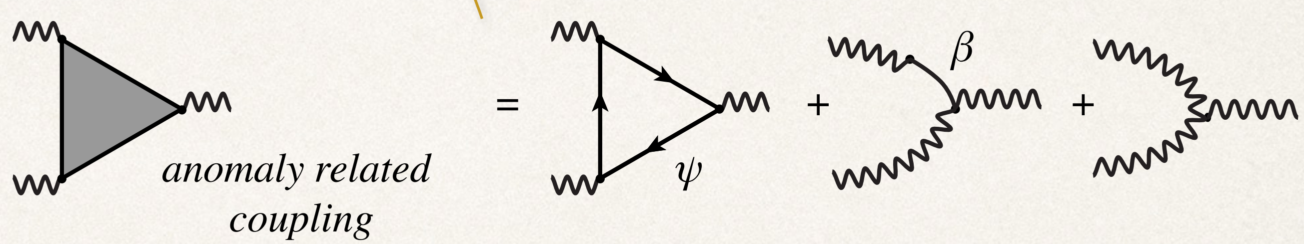
Anomalous U(1)'s

- Assume that there is an anomalous U(1) coupled to the SM.





- The lowest diagram that includes the fermionic loop (and the axion diagram and the GCS coupling that cancel the anomaly) appears at 3-loops and it is highly suppressed.

- Therefore, anomalous U(1)'s (Z′s) have same type of couplings to the dark photons.

Comments and future directions

- Emergent U(1)'s weakly couple to the SM fields and they can play the role of graviphotons/dark-photons.

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- Non-local kinetic terms appear at energies bellow the compactification scale.

  - Effective action will be rebuilt.

  - Spread-out of the wavefunction provides different couplings (weaker) from the point-like case.

  - New limits on graviphoton/dark-photon couplings to the SM fields.

- Emergent U(1)'s could acquire non-vanishing vevs. A very interesting option.

  Kraus Tomboulis

- Emergent U(1)'s option is not very much studied.

  Björken

Emergent Axions

Emergent Axions

- Instanton density $Tr[\hat{F} \wedge \hat{F}] \sim a \implies$ is an ALP (axion-like-particle).
  - protected by symmetries $\longrightarrow$ remains light
  - couples linearly to SM's instanton densities
  - associated U(1) symmetry which is broken by instantons.
- Such emergent/composite axions have
  - (very) light masses
  - a compositeness scale → above, it has non-local kinetic term; → bellow, it behaves like point-like ALP
- Phenomenological studies for both cases are in progress.

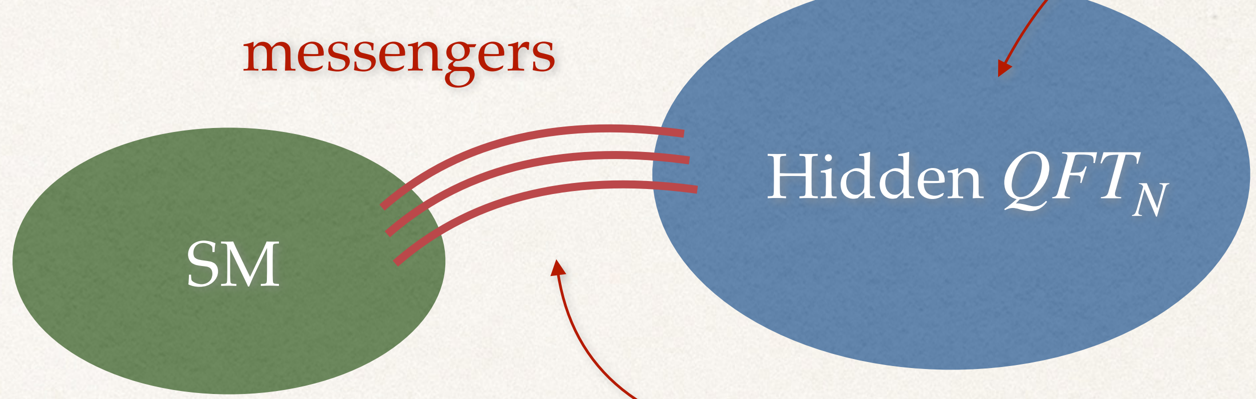
Composite Neutrinos

Neutrinos

- RH-neutrinos can also emerge in this framework.

$\psi \longrightarrow N_R \sim \psi^N$

baryonic type



$\psi,\ \phi \longrightarrow N_R \sim \underbrace{\psi\phi}_{\text{neutral}}$ mesonic type

- They can have two different realizations

  - bound state (baryonic) of N (odd number) fermions from the hidden sector.

    Arkani-Hamed Grossman Robinson, Okui, …

  - bound state (mesonic) of messengers.

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- The effective action of these composite fermions triggers the seesaw mechanism

$$S \sim \int d^4x \left(\bar{L}_L H N_R + \bar{N}_R N_R \right)$$

SM neutrino

sterile neutrino

messenger scale

RH-neutrinos as mesonic messengers

- We assume that mesonic scalars get vevs (of order of the messenger scale).
- Playing with the various parameters, we get (via type I seesaw mechanism)
  - Models with heavy sterile neutrinos
  - Models with light/ultra-light sterile neutrinos.

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- Study cases where type II/III (inverse/radiative) seesaw mechanisms can apply.
- Phenomenological implications (leptonic mixing matrix, leptogenesis).
- Additionally, we can span over semi realistic D-brane configurations for patters that fall in one of the heavy/light categories.

Conclusions

Conclusions

- We consider a holography-inspired scenario of the SM and a hidden 4D QFT which communicate via massive messengers.
- In this framework operators of the HS appear as weakly coupled particles to the SM.
- Special interest: operators protected by symmetries $\Longrightarrow$ light particles.
- We focus on gravitons, axions, graviphotons / dark-photons and neutrinos.
- Phenomenological implications are on the go.
- Emergent fields in this framework are composites, and they are distinct qualitatively from what has been considered so far.