Bonn
May 2013

Scattering in General Gauge Mediation

+ work on Quivers in SARAH & SPheno with
Aoife Bharucha & Andreas Goudelis

General Gauge Mediation in 5D
GGM and Deconstruction
Warped General Gauge Mediation
Hybrid Gauge Mediation
General Resonance Mediation
Holography for General Gauge Mediation

1207.4484   1210.4935   and   1303.4534

Moritz McGarrie

AvH fellow
Host: Andreas Weiler

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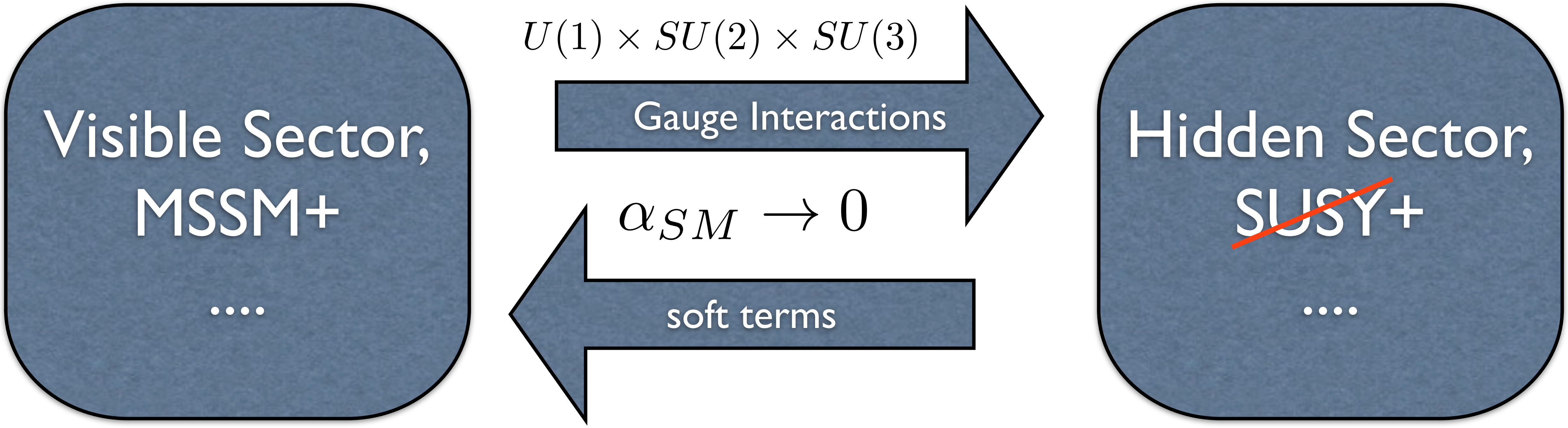
DESY

Alexander von Humboldt
Stiftung / Foundation

Gauge Mediated Supersymmetry Breaking



It can be model independent (GGM) to address
<u>strong coupling</u>

$$\mathcal{L}_{int} = g_{SM}\left(JD + J_\mu A^\mu - j_\alpha \lambda^\alpha - \bar{j}^{\dot{\alpha}} \bar{\lambda}_{\dot{\alpha}}\right)$$

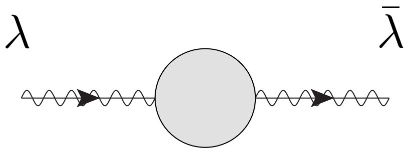
See also:
Gouvea, Moroi, Murayama
9701244
Meade, Seiberg, Shih
0801.3278
... etc

The key point of GGM: we want to understand and encode <u>strongly coupled</u> hidden sectors that break supersymmetry dynamically

The building blocks

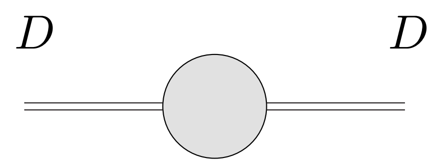
current current correlators

$F.T.\ \langle j_\alpha(x)\bar{j}_{\dot\alpha}(y)\rangle$



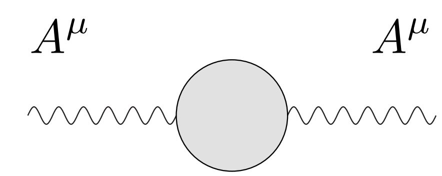
$= \tilde{C}_{1/2}(s)$

$F.T.\ \langle J(x)J(y)\rangle$



$= \tilde{C}_0(s)$

$F.T.\ \langle J_\mu(x)J_\nu(y)\rangle$

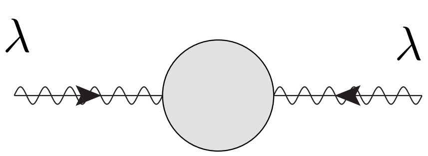


$= \tilde{C}_1(s)$

A "model" makes an assumption about the "blobs"

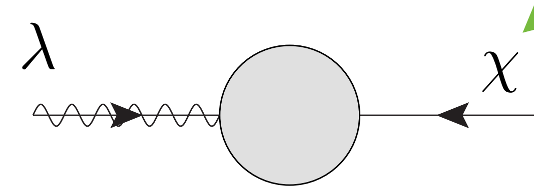
gaugino

Majorana gaugino soft mass

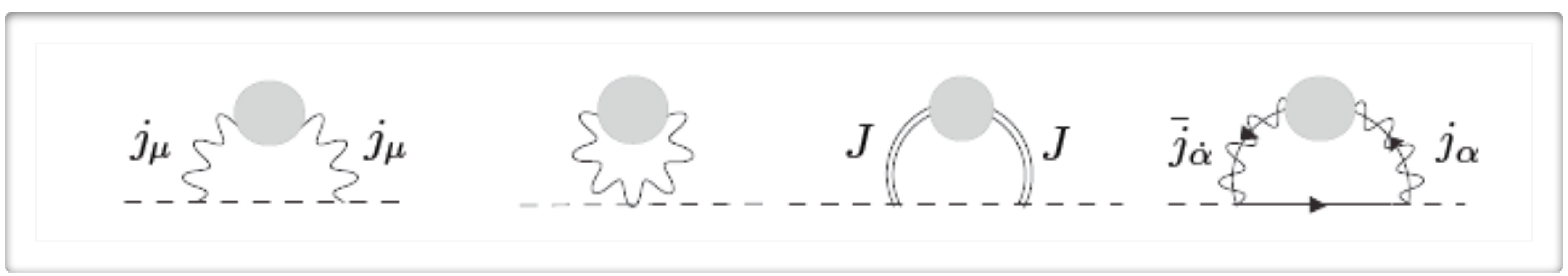


$F.T.\ \langle j_\alpha(x)j_\beta(y)\rangle$

new fermion d.o.f.



Dirac soft mass possible
(Benakli & Goodsell)



is an sfermion soft mass

perturbative in α_{SM}, all orders in the "electric" hidden sector couplings α_{hidden}

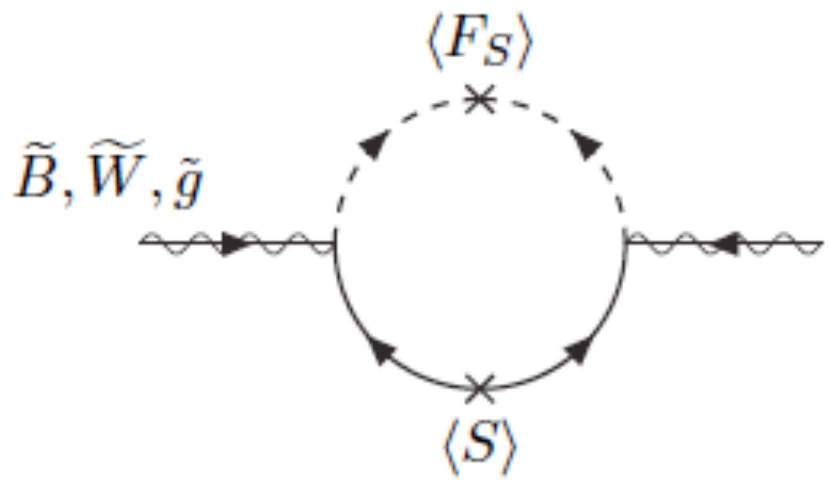
If the model is a just a messenger model then the GGM programme achieves little... Just use the reviews (in most cases)

Giudice & Rattazzi 9801271

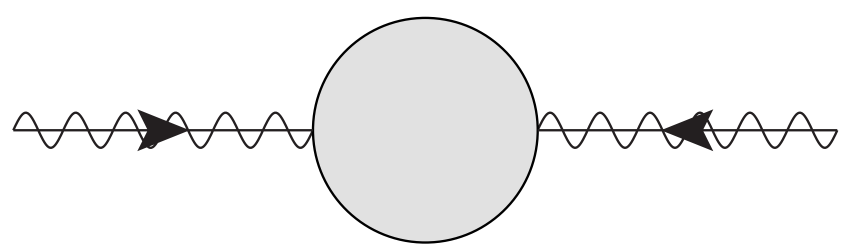
S.Martin 9608224

What is a blob?

In a perturbative model, (like a messenger model) a blob
is just a simple one loop diagram



At strong coupling it is (unfortunately) very complicated

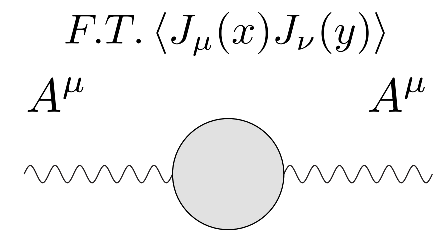


I'm sorry
(its not my fault, I'm just the messenger)

A 10-100 PeV collider?

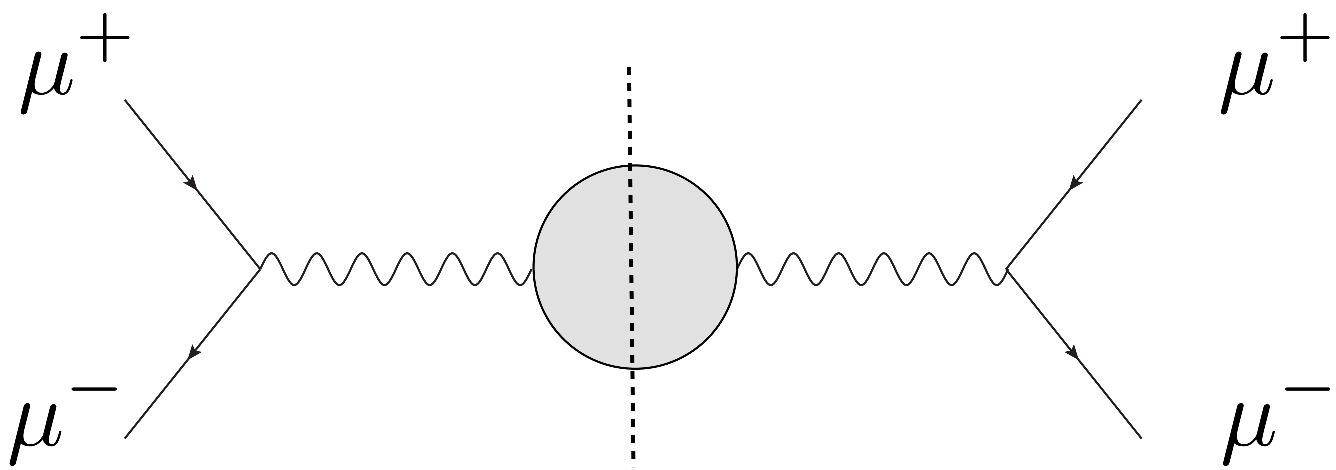
A thought experiment

cross sections of visible to hidden matter for perturbative messenger models.



$$= \tilde{C}_1(s)$$

Visible sector:
leptons
sleptons
quarks
squarks
....



Hidden sector:
messenger fields
+ spurion

$$W = X \Phi \tilde{\Phi}$$

$$X = M + \theta^2 F$$

$$\phi_\pm \text{ with } m_\pm^2 = M^2 \pm F$$

$$\psi, \tilde{\psi} \quad \text{with} \quad M$$

optical theorem

$$\sigma(\text{visible} \to \text{hidden}, s) = \frac{(4\pi\alpha)^2}{2s} \text{Disc } \Pi(s)$$

Examples

~~$SUSY$~~

$$\text{Disc}\tilde{C}_0(s) = \frac{1}{4\pi s} \sqrt{s^2 - 4|X|^2 + 4|F|^2}$$

$SUSY$

$$\text{Disc}\tilde{C}_0(s) = \frac{1}{4\pi s} \left(1 - \frac{4M^2}{s}\right)^{1/2}$$

"In principle" determine GGM correlators from experimental cross sections

$$i(16\pi^2\alpha)^2 \left[\tilde{C}_a(s) - \tilde{C}_a(0)\right] = \sum_{cuts} \frac{s}{\pi} \int_{s_0'}^{\infty} ds' \frac{\sigma_a(s')}{s' - s}$$

soft masses and cross sections are related

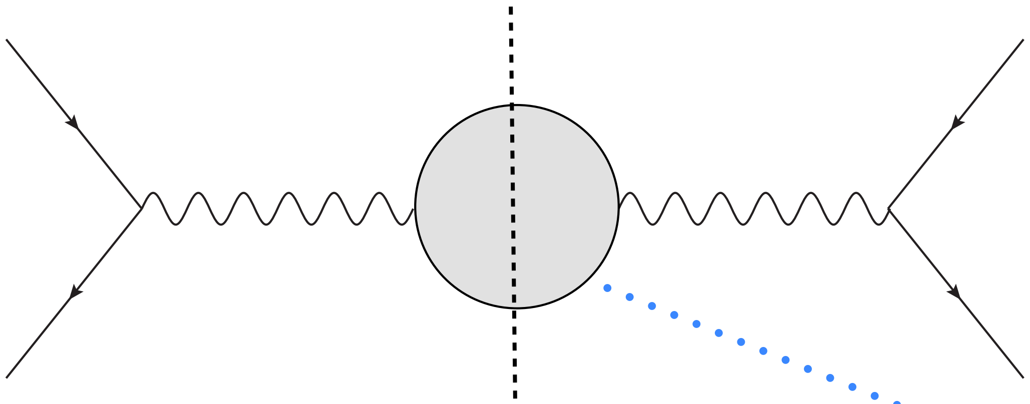
But we want to get away from perturbative messenger models

Example: The quiver models

Can we develop intuition with QCD?

Can QCD tell us something about the “blobs” and therefore something about the soft masses?

QCD



$$i\mathcal{M}(e^+, e^- \to e^+, e^-)$$

gives $\sigma(e^+, e^- \to hadrons)$

quark current $\mathcal{O}^\mu = \bar{q}\gamma^\mu q$

perturbative in α_{em}

all orders in α_s

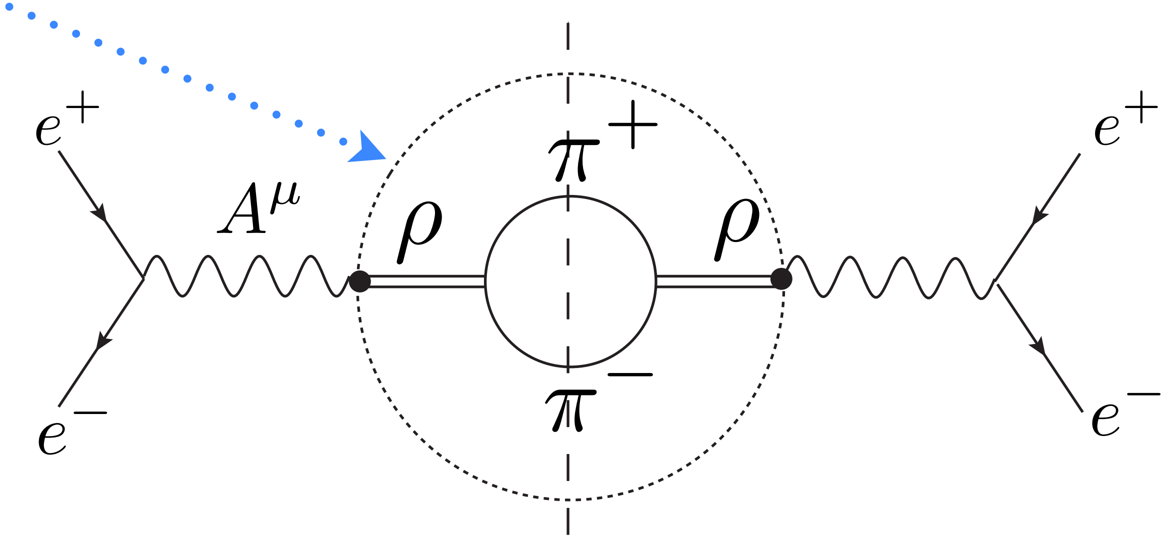
$=$

Hadronic picture

“look under the hood”

Sum of many parts

one such piece: $\sigma(e^+e^- \to \pi^+, \pi^-)$



$$F(s) = \frac{m_\rho^2}{s + m_\rho^2}$$

perturbative in α_{em}

perturbative in α_{mag}

Summary

The key idea is to build models around scattering

ALL old GMSB models are of this type

RED $$\sigma_a(visible \to hidden) = \frac{(4\pi\alpha)^2}{2s}\ Disc\ \tilde{C}_a(s)$$

OR

$$F(s) = \frac{m_\rho^2}{s + m_\rho^2}$$

form factor or no form factor?

BLACK? $$\sigma_a(visible \to hidden) = \frac{(4\pi\alpha)^2}{2s}|F(s)|^2\ Disc\ \tilde{C}_a(s)$$

Similar to the hadronic world: perhaps we should take it more seriously?

$$\text{Duality in } e^+, e^- \to \text{hidden?}$$

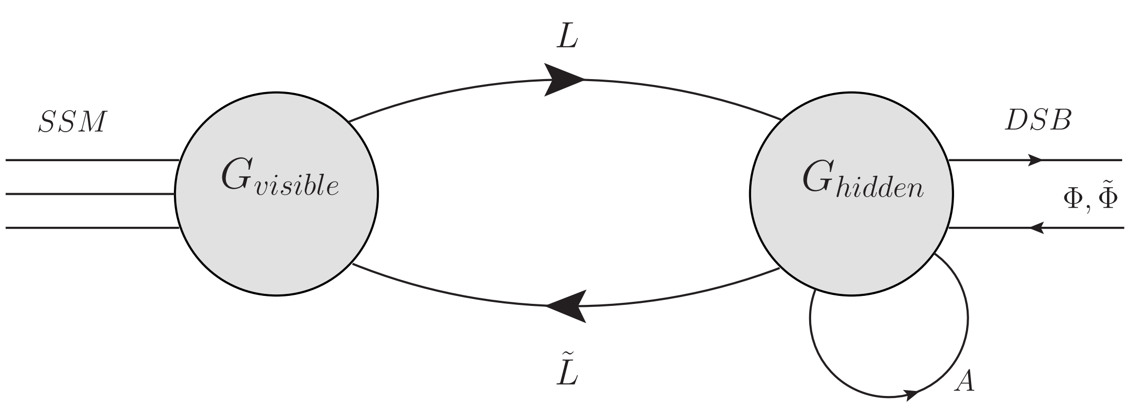
Ideally, determine this form factor from experiment	impossible
or from computer simulations	hard
or from toy models and effective field theory	possible

What does this tell us about SUSY breaking?

SF	Spin 0	Spin $\frac{1}{2}$	Generations	$(U(1)_A, \mathrm{SU}(2)_B, \mathrm{SU}(3)_c, U(1)_B, \mathrm{SU}(2)_A)$	R-Parity
$\hat{q}$	$\tilde{q}$	q	3	$(\frac{1}{6}, \mathbf{1}, \mathbf{3}, 0, \mathbf{2})$	-1
$\hat{l}$	$\tilde{l}$	l	3	$(-\frac{1}{2}, \mathbf{1}, \mathbf{1}, 0, \mathbf{2})$	-1
$\hat{H}_d$	H_d	$\tilde{H}_d$	1	$(-\frac{1}{2}, \mathbf{1}, \mathbf{1}, 0, \mathbf{2})$	$+1$
$\hat{H}_u$	H_u	$\tilde{H}_u$	1	$(\frac{1}{2}, \mathbf{1}, \mathbf{1}, 0, \mathbf{2})$	$+1$
$\hat{d}$	$\tilde{d}_R^*$	d_R^*	3	$(\frac{1}{3}, \mathbf{1}, \overline{\mathbf{3}}, 0, \mathbf{1})$	-1
$\hat{u}$	$\tilde{u}_R^*$	u_R^*	3	$(-\frac{2}{3}, \mathbf{1}, \overline{\mathbf{3}}, 0, \mathbf{1})$	-1
$\hat{e}$	$\tilde{e}_R^*$	e_R^*	3	$(1, \mathbf{1}, \mathbf{1}, 0, \mathbf{1})$	-1
$\hat{L}$	L	ψ_L	1	$(-\frac{1}{2}, \overline{\mathbf{2}}, \mathbf{1}, \frac{1}{2}, \mathbf{2})$	$+1$
$\hat{\tilde{L}}$	$\tilde{L}$	$\psi_{\tilde{L}}$	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1}, -\frac{1}{2}, \overline{\mathbf{2}})$	$+1$
$\hat{K}$	K	ψ_K	1	$(0, \mathbf{1}, \mathbf{1}, 0, \mathbf{1})$	$+1$
$\hat{A}$	A	ψ_A	1	$(0, \mathbf{3}, \mathbf{1}, 0, \mathbf{1})$	$+1$

Table 2. Matter fields of the model.

$$W_{\mathrm{SSM}} = Y_u\, \hat{u}\, \hat{q}\, \hat{H}_u - Y_d\, \hat{d}\, \hat{q}\, \hat{H}_d - Y_e\, \hat{e}\, \hat{l}\, \hat{H}_d + \mu\, \hat{H}_u\, \hat{H}_d$$



$$W_{\mathrm{Quiver}} = \frac{Y_K}{2} \hat{K}(\hat{L}\, \hat{\tilde{L}} - V^2) + Y_A\, \hat{L}\, \hat{A}\, \hat{\tilde{L}}$$

$$W_{\mathrm{Messenger}} = X \Phi \tilde{\Phi},$$

Form factor

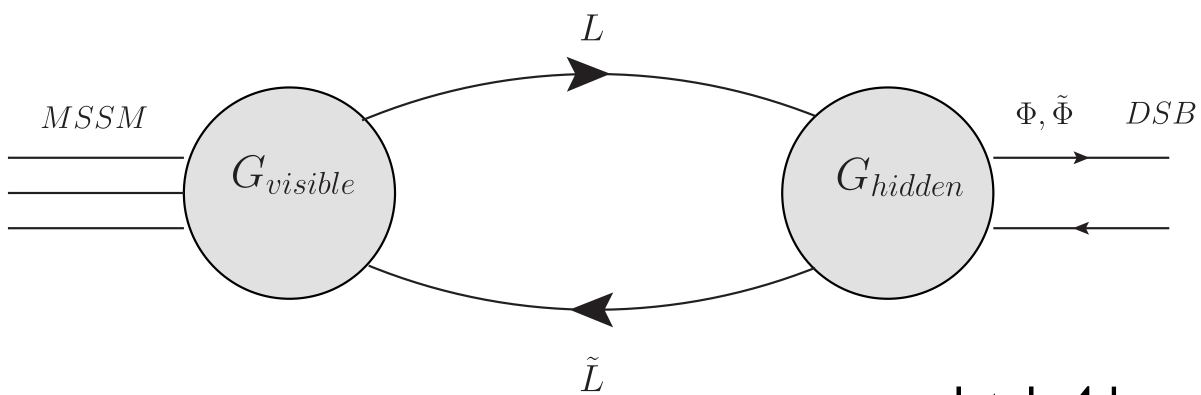
$$F(s) = \frac{m_\rho^2}{s + m_\rho^2}$$

SARAH: Florian Staub
1207.0906

See also Andreas Goudelis' talk on Wednesday

What does this tell us about SUSY breaking?

Simplest case
corresponds to a 2 site quiver model



completely 4d

Form factor

$$F(s) = \frac{m_\rho^2}{s + m_\rho^2}$$

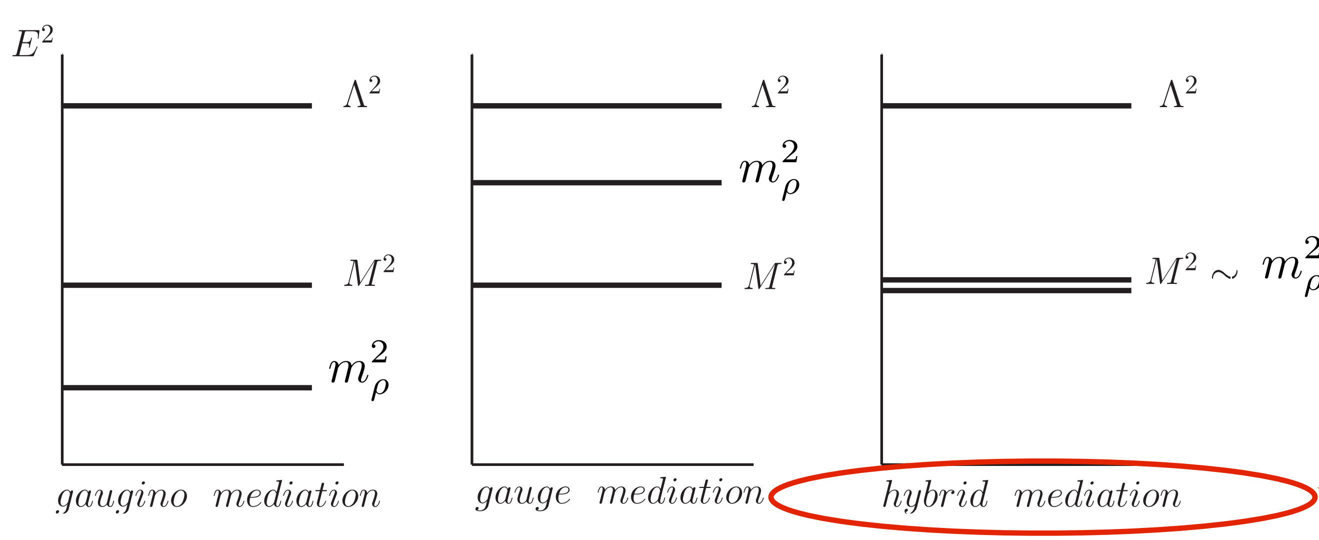
"GGM and Deconstruction"
McGarrie 1009.0012 and 1101.5158

Extensions in Auzzi & Giveon 1009.1714 1011.1664 + ...
easyDiracgauginos Abel & Goodsell 1102.0014

Bharucha, Goudelis M.M.
To appear

A hidden local symmetry,
exhibits vector meson dominance

3 Regimes depends on ratio $y = \frac{m_\rho}{M}$



most likely?

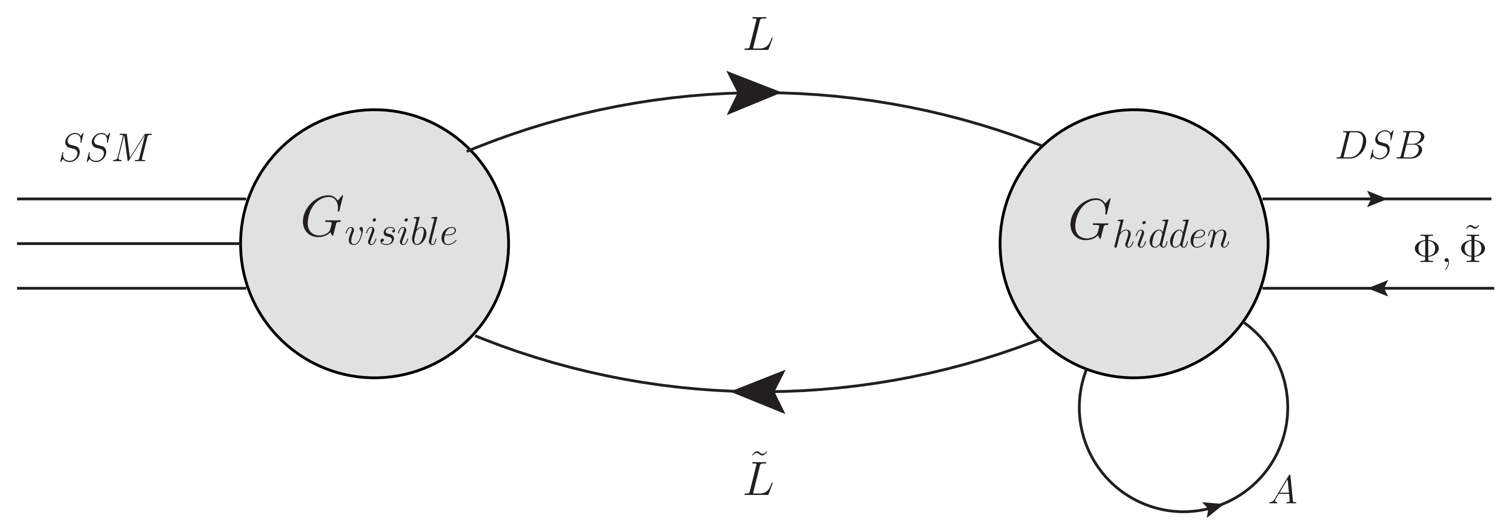
We have a new hybrid regime where

$$@M_{SUSY} : m_\lambda^2 > m_{\tilde{f}}^2$$

soft masses are analytically calculable at 2 loops!
and cross sections are now known.

A quiver model: GMSB+

- non decoupled D-terms: lifts the Higgs (sometimes substantially)
- extra adjoints of SU(2),SU(3): lifts the Higgs
- More natural than NMSSM?



$$m_h^2 \simeq m_z^2 \cos 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v_{ew}^2}\left[\log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2})\right]$$

$$\Delta = (\frac{g_A^2}{g_B^2})\frac{2m_L^2}{m_v^2 + 2m_L^2}$$

$$m_z^2 \to m_z^2 + \left(\frac{g_1^2\Delta_1 + g_2^2\Delta_2}{2}\right) v_{ew}^2$$

$$\delta\mathcal{L} = -g_1^2\Delta_1(H_u^\dagger H_u - H_d^\dagger H_d)^2 - g_2^2\Delta_2 \sum_a (H_u^\dagger\sigma^a H_u + H_d^\dagger \sigma^a H_d)^2$$

A quiver model is an example of an effective description of strong coupling

Under explored compared to NMSSM

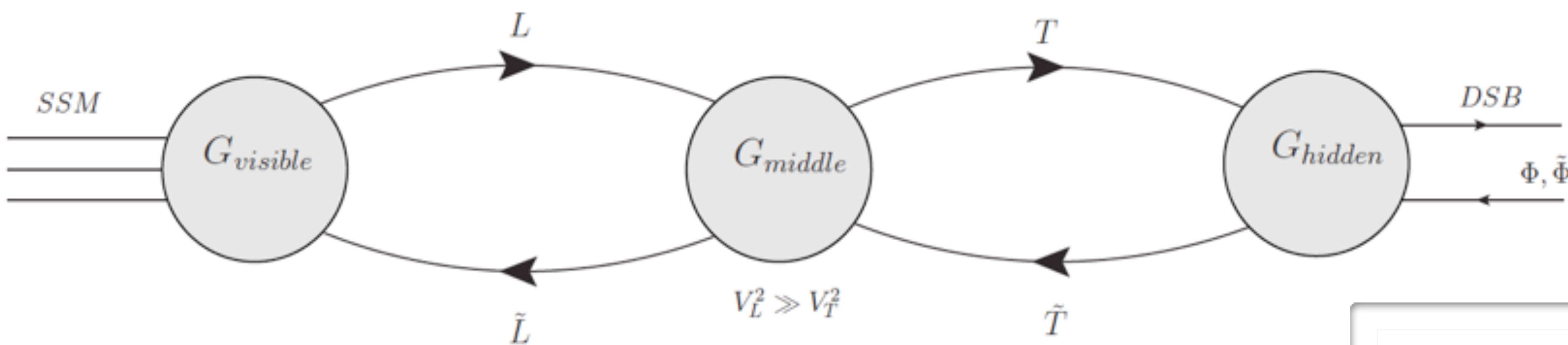
"Holography for General Gauge Mediation"

A holographic quiver

M.M. Rodolfo Russo 1004.3305
M.M. Daniel C.Thompson 1009.4696
M.M. 1210.4935

currently putting this into SARAH!
Aoife Bharucha & AndreasGoudelis

- non decoupled D-terms
- extra adjoints of SU(2),SU(3)
- Interesting RGE's



An AdS/SQCD proposal

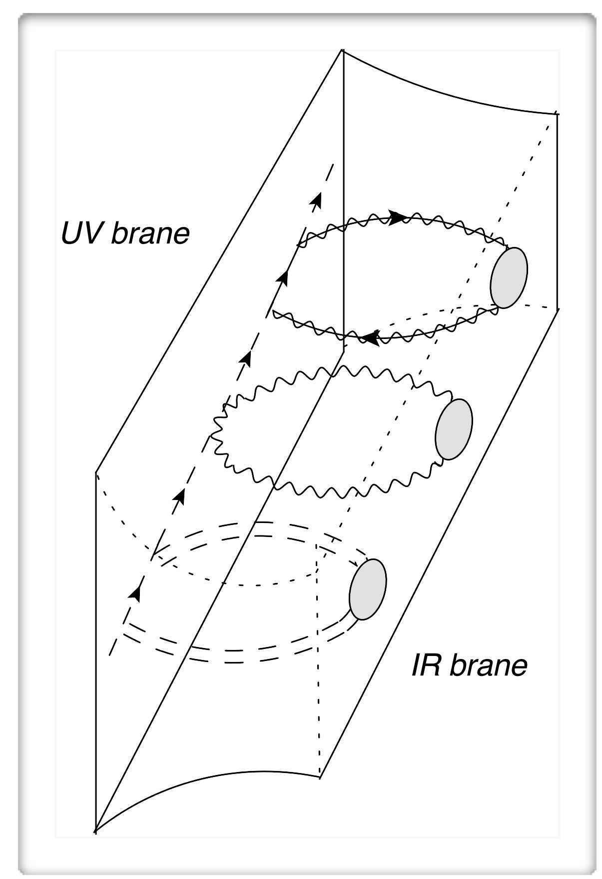
4D: operator		Field	Δ	m^2
$\mathcal{O}(x)$	$\rightarrow$	$D(z,x)$	2	-4
$\mathcal{O}_\alpha(x)$	$\rightarrow$	$\lambda_\alpha(z,x)$	5/2	1/2
$\mathcal{O}_\mu(x)$	$\rightarrow$	$A_\mu(z,x)$	3	0

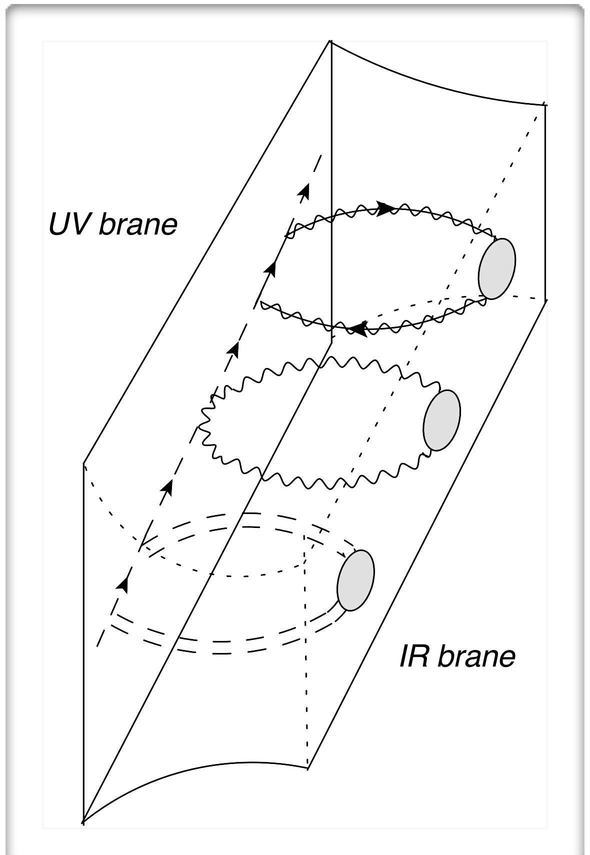
The UV operators that correspond to bulk fields

$$\mathcal{O}_{L,R} = \phi^\dagger \phi_{L,R}$$

$$\mathcal{O}^\alpha_{L,R} = -i\sqrt{2}\phi^\dagger q^\alpha_{L,R}$$

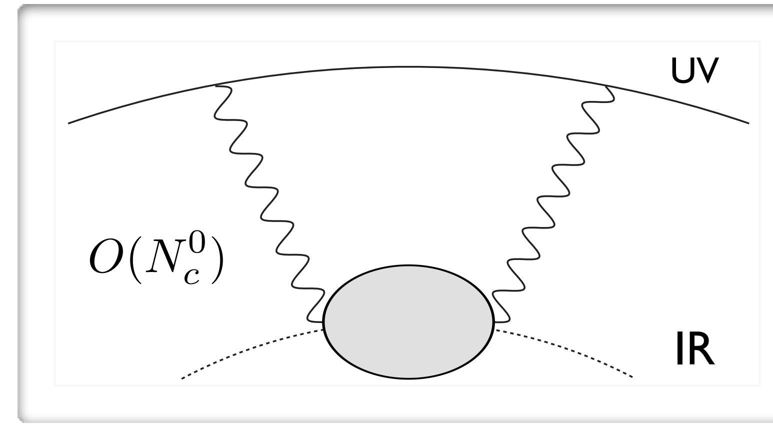
$$\mathcal{O}^\mu_{L,R} = \bar{q}\sigma^\mu q_{L,R} - i\left(\phi^\dagger \partial^\mu \phi - \partial^\mu \phi^\dagger \phi\right)_{L,R}$$





Holographic Scattering

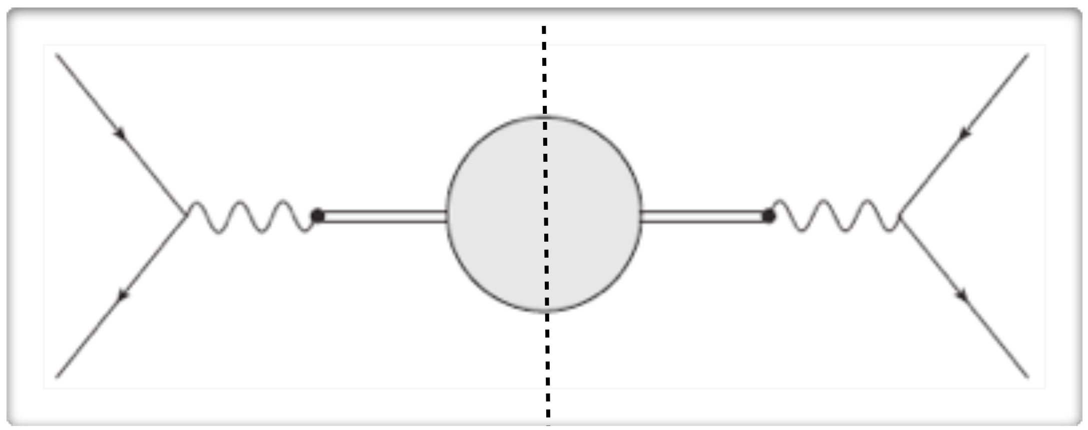
$$g_n = g_5 g_{IR} \int dz \psi_n(z) \varphi(z) \tilde{\varphi}(z) \delta(z - L_1)$$



The form factor encodes a sum of monopole contributions
of an infinite tower of vector mesons with decay constants for each meson

$$F_n \epsilon_\mu = \langle 0 | \mathcal{O}_\mu | \rho_n \rangle$$

meson decay constant



Final states can be taken to be messenger fields

$$\sigma_a(vis \to hid) = \frac{(4\pi\alpha_{SM})^2}{2s} (g_{IR}^2 g_5^2) \sum_{n=1} \frac{F_n \psi_n(z)}{s + m_n^2} \sum_{\hat{n}=1} \frac{F_{\hat{n}} \psi_{\hat{n}}(z)}{s + m_{\hat{n}}^2} \text{Disc } \tilde{C}_a(s/\hat{M})$$

$$\text{Duality in } e^+, e^- \to \text{hidden?}$$

What next?

Pheno

implement more of these models (including Dirac gauginos) into SARAH with Aoife Bharucha & Andreas Goudelis

Theory

There are plenty of ways this instructive toy model may be extended!

Back up slides

soft terms

- everything completely calculable

$$\Lambda = \frac{F}{M}$$

$$N = n_{5plets} + 3n_{10plets}$$

$$x = \frac{F}{M^2}$$

$$y = \frac{m_v}{M}$$

$$m_{\lambda,r} = N\Lambda\left(\frac{g_r^2}{16\pi^2}\right)g(x)$$

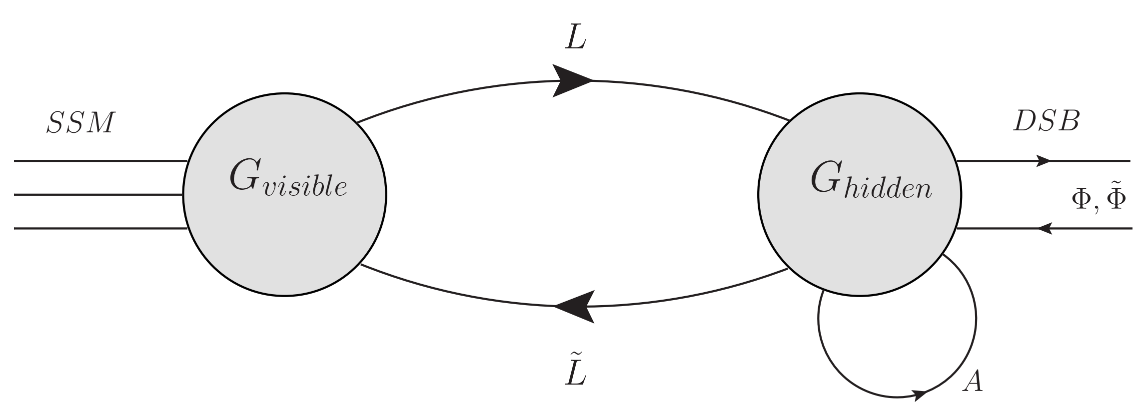
$$\mathcal{L}_{soft} \supset \frac{1}{2}\left(m_{\tilde{G}}\tilde{G}\tilde{G} + m_{B_B}\tilde{B}_B\tilde{B}_B + m_{W_B}\tilde{W}_B\tilde{W}_B\right) + h.c.$$

$$m_\lambda^{A=1,2} \equiv 0.$$

$$m_L^2 = m_{\tilde{L}}^2 = N\Lambda^2 \sum_{i=1,2} 2C_L^{B,i}\left(\frac{g_{Bi}^2}{16\pi^2}\right)^2 f(x),$$

$$m_{SM}^2 = N\Lambda^2 \sum_{i=1,2} 2C_{SM}^{B,i}\left(\frac{g_i^2}{16\pi^2}\right)^2 S(x, y_i),$$

A-terms are vanishing at the messenger scale



"Holography for General Gauge Mediation"

M.M.: 1210.4935

IR hardwall/
slice of AdS

also $AdS/\cancel{SUSY}$

"Warped General Gauge Mediation"
M.M. Daniel C. Thompson 1009.4696

Abel & Gherghetta 1010.5655

"General Gauge Mediation in 5D"
M.M. Rodolfo Russo 1004.3305

Check list

1. Metric: slice of AdS $\quad ds^2 = \left(\frac{R}{z}\right)^2 (\eta^{\mu\nu} dx_\mu dx_\nu + dz^2)$
2. Interval $\quad L_0 < z < L_1$
3. Flavour symmetries $\quad SU(N_f)_L \times SU(N_f)_R \to SU(N_f)_V$
4. Scale matching $\quad \frac{R}{g^2_{5d(YM)}} = \frac{N_c}{12\pi^2}$
5. Sources $\quad A^0_\mu(x), \lambda^0_\alpha(x), D^0(x)$
6. Operators $\quad \mathcal{O}_\mu(x), \mathcal{O}_\alpha(x), \mathcal{O}(x)$
7. Bulk field $\quad A^\mu(q,z) = A^\mu_0(q) K(q,z)$
8. Bulk to boundary propagator $\quad K(q,z) = \frac{V(q,z)}{V(q,L_0)}$

$$V(q,z) = zq\left[Y_0(qL_1)J_1(qz) - J_0(qL_1)Y_1(qz)\right]$$

N=1 5d super Yang-Mills
action in the bulk

compute...

“Holography for General Gauge Mediation”

IR hardwall/
slice of AdS

N=1 5d super Yang-Mills action in the bulk

$$SU(N_f)_L \times SUN(N_f)_R$$

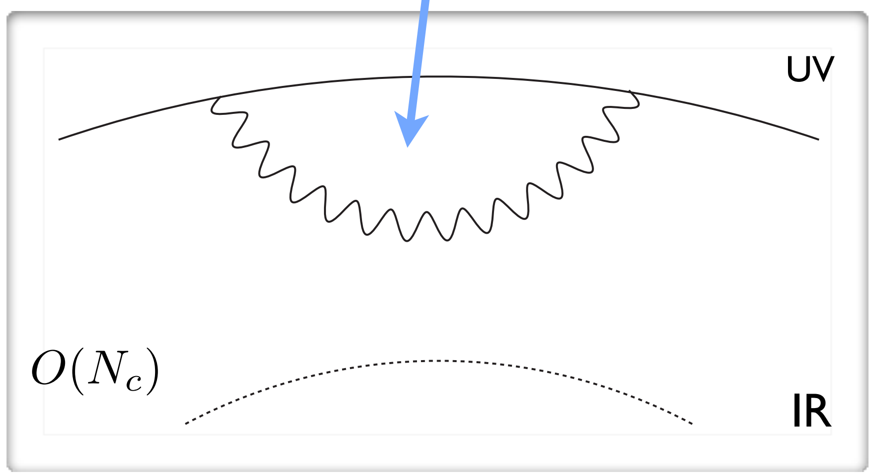
$$ds^2 = \left(\frac{R}{z}\right)^2 (\eta^{\mu\nu} dx_\mu dx_\nu + dz^2) \qquad L_0 < z < L_1 \qquad \frac{R}{g^2_{5d(YM)}} = \frac{N_c}{12\pi^2}$$

$$A^\mu(q,z) = A_0^\mu(q)\frac{V(q,z)}{V(q,L_0)}$$

$$\int d^4x e^{ip.x} \langle \mathcal{O}_\mu(x)\mathcal{O}_\nu(0)\rangle = \Pi(p^2)P^{\mu\nu}$$

$$\Pi(q^2) = \frac{1}{q}\left(\frac{R}{z}\frac{\partial_z V(q,z)}{V(q,L_0)}\right)_{z=L_0}$$

gives a log running piece



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$$\mathcal{O}^\mu_{L,R} = \bar{q}\sigma^\mu q_{L,R} - i\left(\phi^\dagger\partial^\mu\phi - \partial^\mu\phi^\dagger\phi\right)_{L,R}$$

UV boundary correlators give a supersymmetric effective action

$$\left[3\Pi_1(q^2) - 4\Pi_{1/2}(q^2) + \Pi_0(q^2)\right] \equiv 0 \qquad \langle \mathcal{O}_\alpha(x)\mathcal{O}_\beta(0)\rangle \equiv 0$$

Related to the Gibbons-Hawking boundary terms of SYM

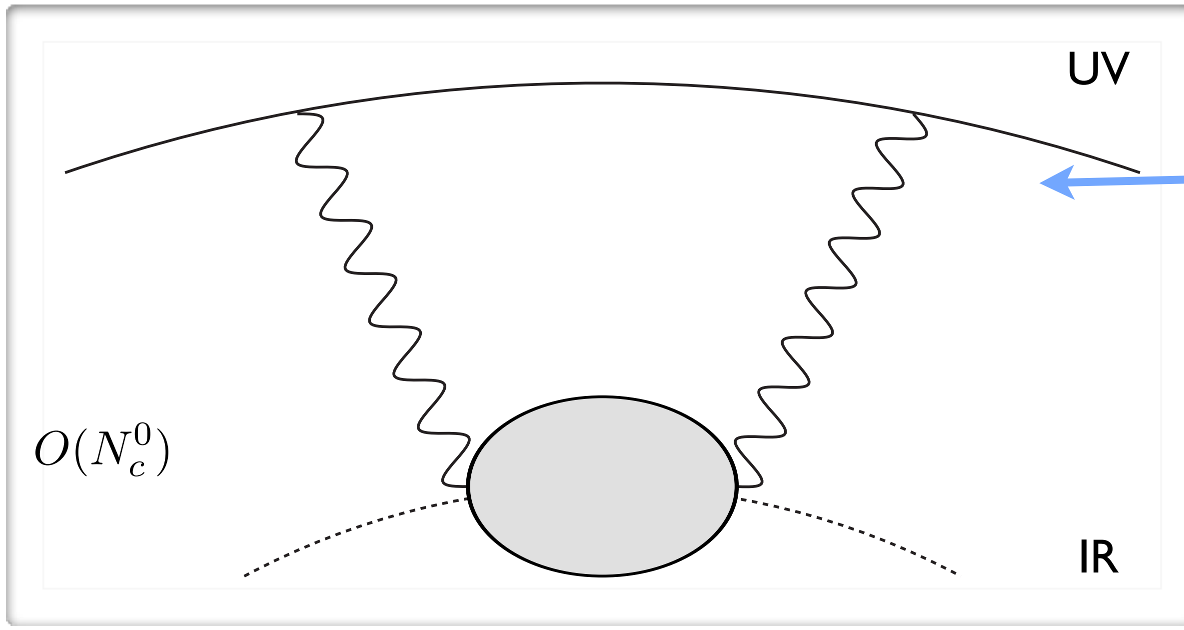
Introduce IR localised correlators that encode supersymmetry breaking

SUSY breaking currents located on an IR brane or live in the bulk

$$A_\mu J^\mu = \int dz K(p,z) A^0_\mu J^\mu = A^0_\mu J^\mu \Lambda(p)$$

An effective vertex function generated by a bulk to boundary propagator

Ignore $O(1/N_c)$ corrections



$A^0_\mu \Lambda(p) \tilde{C}(p^2/M^2) P^{\mu\nu} \Lambda(p)\ A^0_\nu$

$$\delta L^{\not{SUSY}}_{eff}|_{UV} = \frac{g^2_{SM}}{2}\tilde{C}_0(0) D_0^2 - i g^2_{SM}\tilde{C}_{1/2}(0)\lambda_0\sigma_\mu\partial^\mu\bar{\lambda}_0 - \frac{g^2_{SM}}{4}\tilde{C}_1(0) F_{\mu\nu,0}F_0^{\mu\nu}$$

may be written as a boundary effective action too

If you also assume a messenger sector then*

* this part is not necessary. It is a further additional assumption

$$m_\lambda = \left(\frac{\alpha_{IR}}{4\pi}\right)\left(\frac{R}{z}\right)\left[\frac{2Fg(x)}{M}\right]$$

soft masses are calculable!

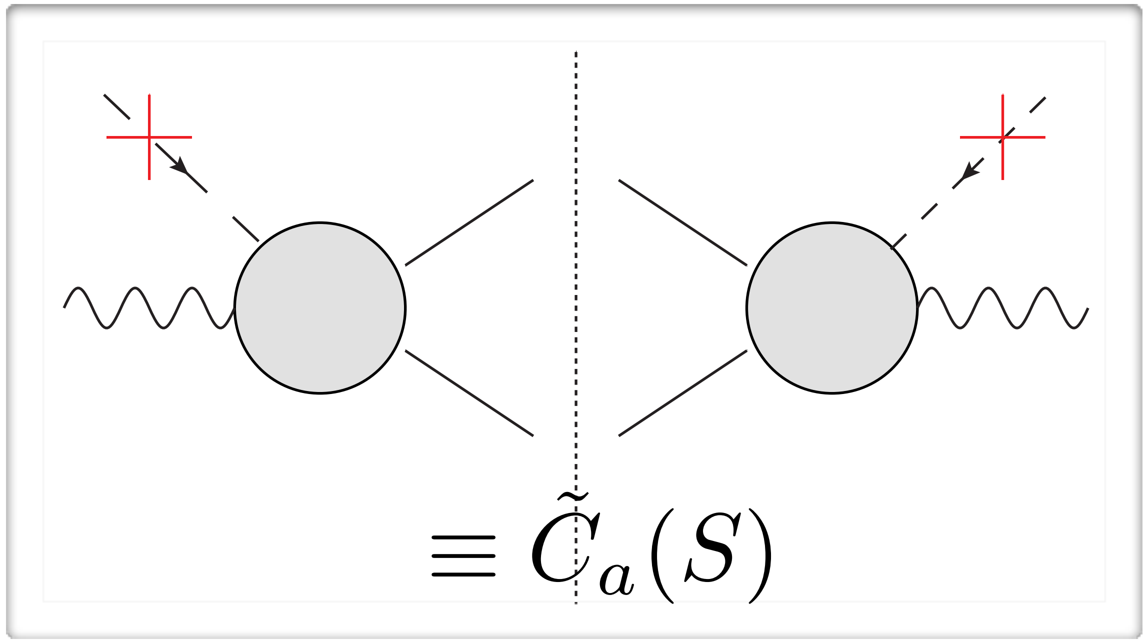
$$m^2_\phi = \left(\frac{\alpha_{IR}}{4\pi}\right)^2\left(\frac{R}{z}\right)^2\left[\frac{F}{M}\right]^2\left|\frac{1}{\hat{M}}\right|^2\int dp\ p\ \Lambda^2(p)$$

Speculative

A Veneziano-like amplitude for GGM?

D.Vecchia and Drago (1969)
Chua, Hama & Kiang (1970)
Frampton (1970)
Many others...

$$F(s) \sim \frac{\Gamma(1-\alpha(s)\Gamma(\lambda - \frac{1}{2})}{\Gamma(\lambda-\alpha(s))\Gamma(\frac{1}{2})}$$



$A(1 \to 2)$

A fit to the pion data

$$\lambda \sim 2$$

$$\lim_{s\to\infty} F(s) \simeq 1/s^{\lambda-1}$$

$$\alpha(s) = 1/2 + s/2m_\rho^2$$

Infinitely rising linear Regge trajectories

Forward scattering amplitude

Higher spin states contribute too!

The point is that holographic models are toy models with a separation of scales between the spin 0,1/2,3/2,2 and the higher spin states.