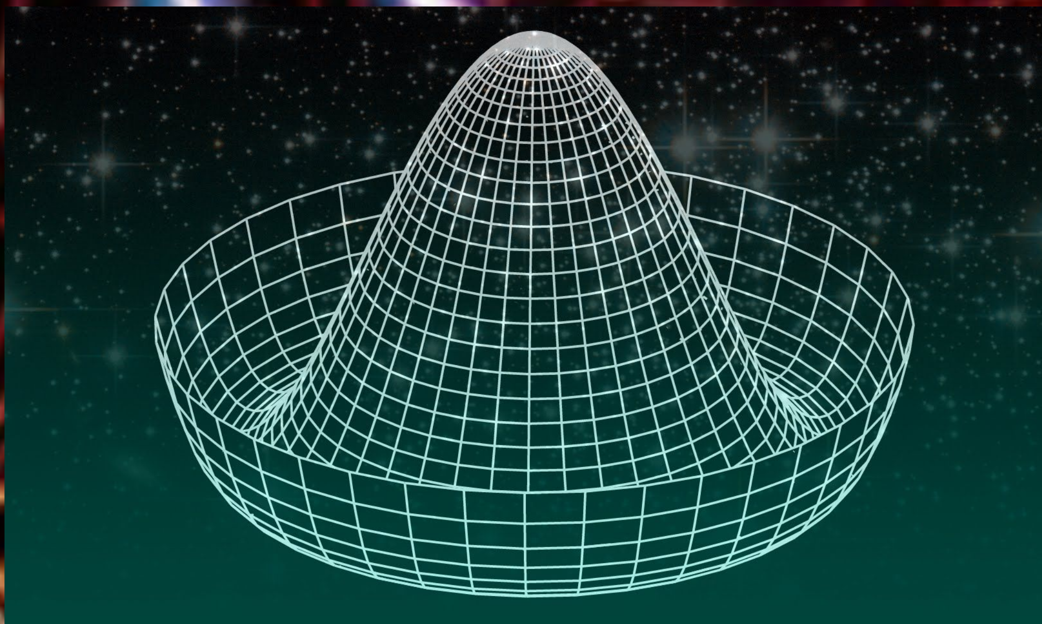
Any Room Left For Technicolour? :Holographic modelling



We found the higgs...

But nothing else out to 1 TeV...

So all BSM is now fine tuned at 1 in 100..

Still worth ruling out ideas...

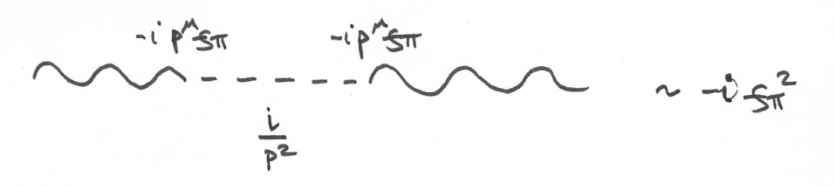
Nick Evans University of Southampton

Electroweak Scale – Technicolour

The base idea is to repeat QCD

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

The scale is set by v = fπ…

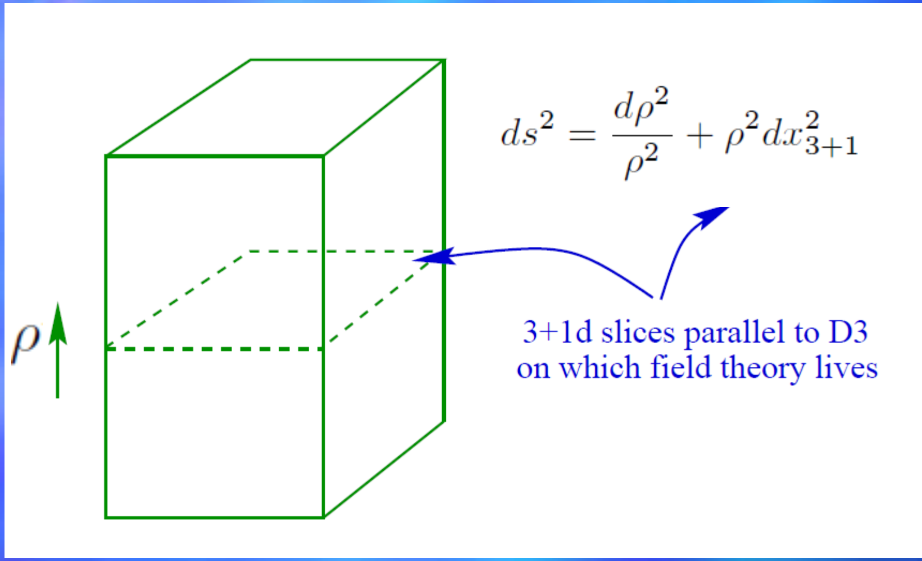


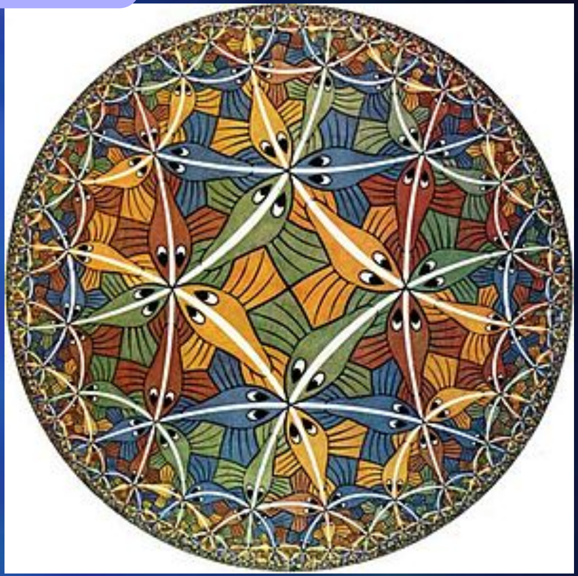
There is no scalar below this scale in QCD… dead?

Adding extra electroweak singlet quarks changes the running of the technicolour gauge group…

But how do we compute in non-QCD like strong coupling?

How Does AdS/CFT Work 1





Dilatations

$$\int d^4x\ \partial^\mu\phi\partial_\mu\phi, \qquad x \to e^{-\alpha}x, \qquad \phi \to e^{\alpha}\phi$$

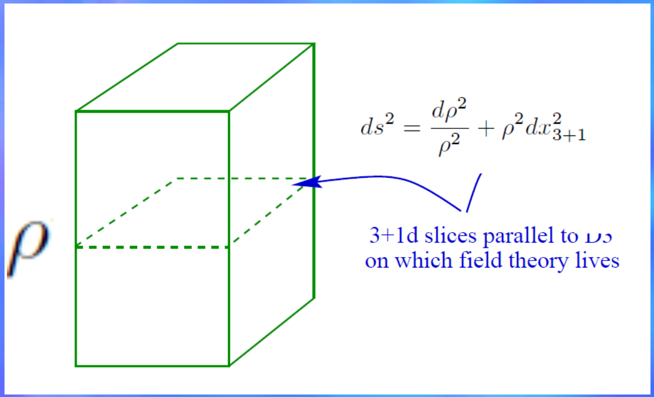
Become spacetime symmetry of AdS

$$\rho \to e^{\alpha}\rho$$

is a continuous mass dimension

$\rho \to$ RG Scale

How Does AdS/CFT Work2



$$\sqrt{-Detg} = Det\left[-\begin{pmatrix} -\rho^2 & 0 & 0 & 0 & 0 \\ 0 & \rho^2 & 0 & 0 & 0 \\ 0 & 0 & \rho^2 & 0 & 0 \\ 0 & 0 & 0 & \rho^2 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\rho^2} \end{pmatrix}\right]^{1/2} = \rho^3$$

Operators and sources appear as fields in the bulk

Eg

$$\int d^4x \; m \; \bar{\psi}\psi$$

m is the quark mass
c is the quark condensate

A field for the mass,

$$S = \int d^4x \int d\rho \, \frac{1}{2}\rho^3 (\partial_\rho L)^2$$

$$\partial_\rho \left[\rho^3 \partial_\rho L\right] = 0$$

$$L = m + \frac{c}{\rho^2}$$

Running Dimensions in Holography

Raul Alvares, NE, Keun-Young arXiv:1204.2474 [hep-ph]; Matti Jarvinen, Elias Kiritsis arXiv:1112.1261 [hep-ph]

Holographically we can change the dimension of our operator by adding a mass term

$$\partial_\rho[\rho^3 \partial_\rho L] - \rho \Delta m^2 L = 0$$

$$L = \frac{m_{FP}}{\rho^\gamma} + \frac{c_{FP}}{\rho^{2-\gamma}}, \qquad \gamma(\gamma - 2) = \Delta m^2$$

$\Delta m^2 = -1$ corresponds to $\gamma = 1$ and is special – the Breitenlohner Freedman bound instability…

DUALITY between strong dynamics condensation and a 5th dimensional higgs mechanism

So we can include a running coupling by a running mass squared for the scalar.

$$\Delta m^2 = -2\gamma = -\frac{3(N_c^2 - 1)}{2N_c \pi}\alpha$$

The only free parameters are Nc, Nf, m, Λ

Formation of the Chiral Condensate

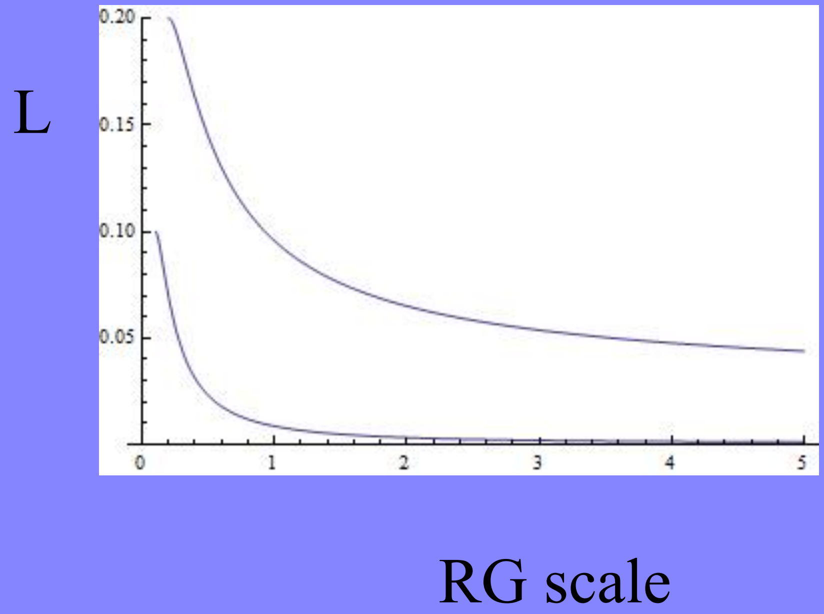
We solve for the vacuum configuration of L

$$\partial_\rho[\rho^3 \partial_\rho L] - \rho \Delta m^2 L = 0\,.$$

Shoot out with

L'(ρ=L) = 0

This is a string theory inspired on-shell IR boundary condition



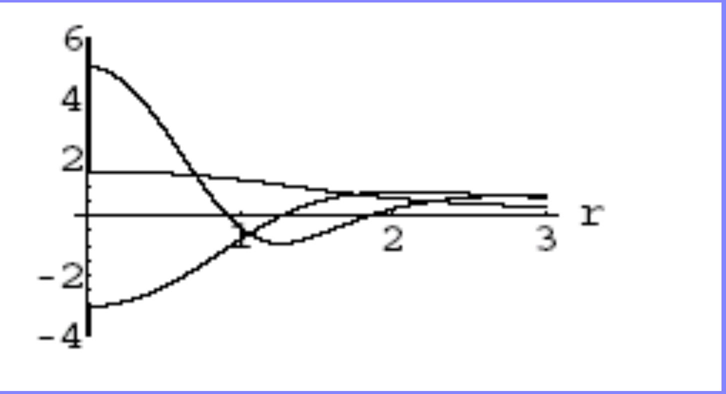
Read off m and qq in the UV…

Meson Fluctuations

$$S = \int d^4x \, d\rho \, \mathrm{Tr}\, \rho^3 \left[\frac{1}{\rho^2 + |X|^2} |DX|^2 + \frac{\Delta m^2}{\rho^2} |X|^2 + \frac{1}{2\kappa^2} (F_V^2 + F_A^2) \right]$$

$$L = L_0 + \delta(\rho) e^{ikx} \qquad k^2 = -M^2$$

$$\partial_\rho(\rho^3 \delta') - \Delta m^2 \rho \delta - \rho L_0 \delta \left. \frac{\partial \Delta m^2}{\partial L} \right|_{L_0} + M^2 R^4 \frac{\rho^3}{(L_0^2 + \rho^2)^2} \delta = 0 \, .$$



The normalizable solutions pick out particular mass states… the σ and its radial excited states…

The gauge fields let us also study the operators and states

$$\bar{q} \gamma^\mu q \to \rho \ \text{meson}$$

$$\bar{q} \gamma^\mu \gamma^5 q \to \text{a meson}$$

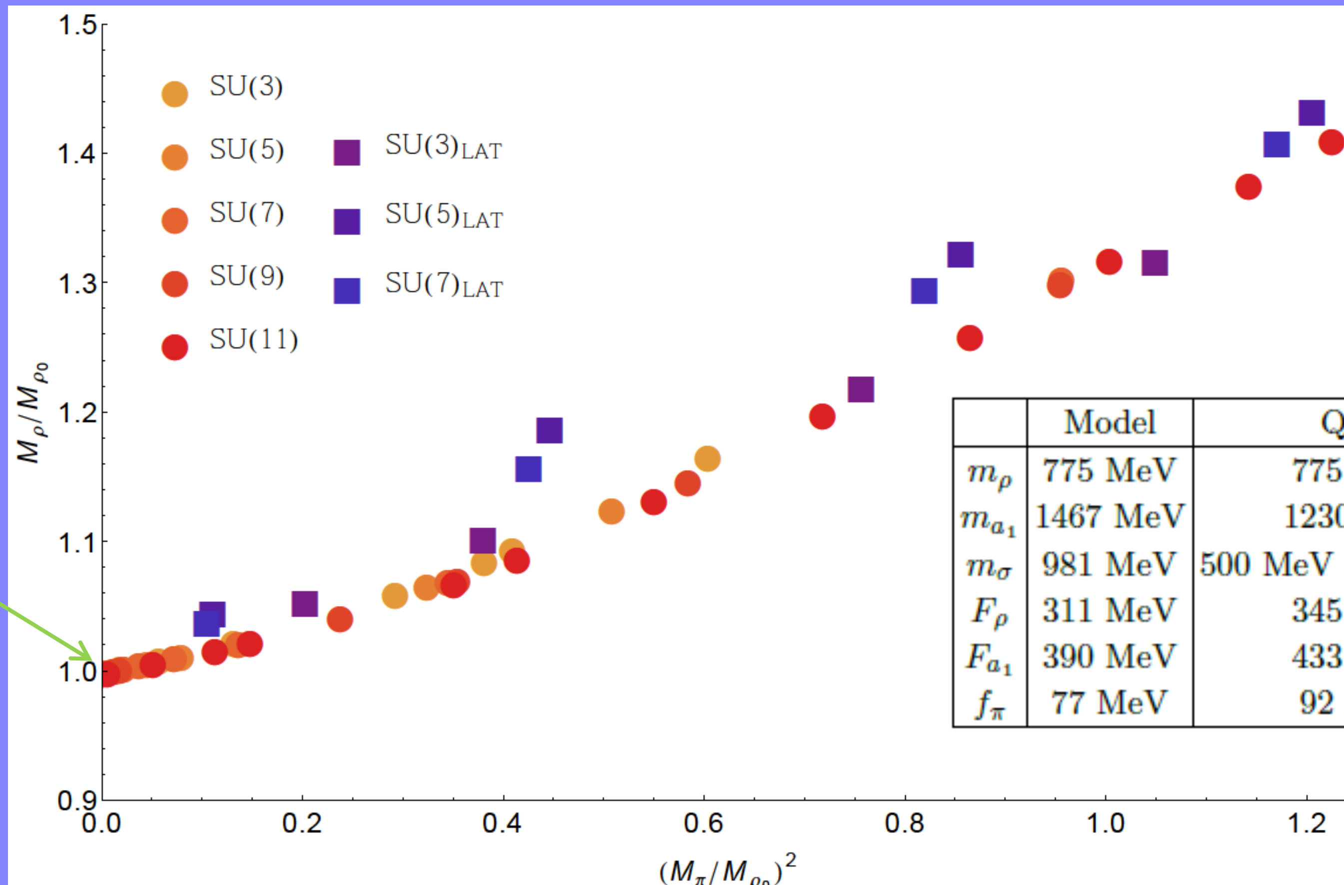
SU(Nc) gauge + 3 quarks

NE, Erdmenger & Mark Scott

arXiv:1412.3165 [hep-ph]

M_rho = 1 defines Λ

Real QCD lies here



	Model	QCD
m_ρ	775 MeV	775 MeV
m_{a_1}	1467 MeV	1230 MeV
m_σ	981 MeV	500 MeV & 980 MeV
F_ρ	311 MeV	345 MeV
F_{a_1}	390 MeV	433 MeV
f_π	77 MeV	92 MeV

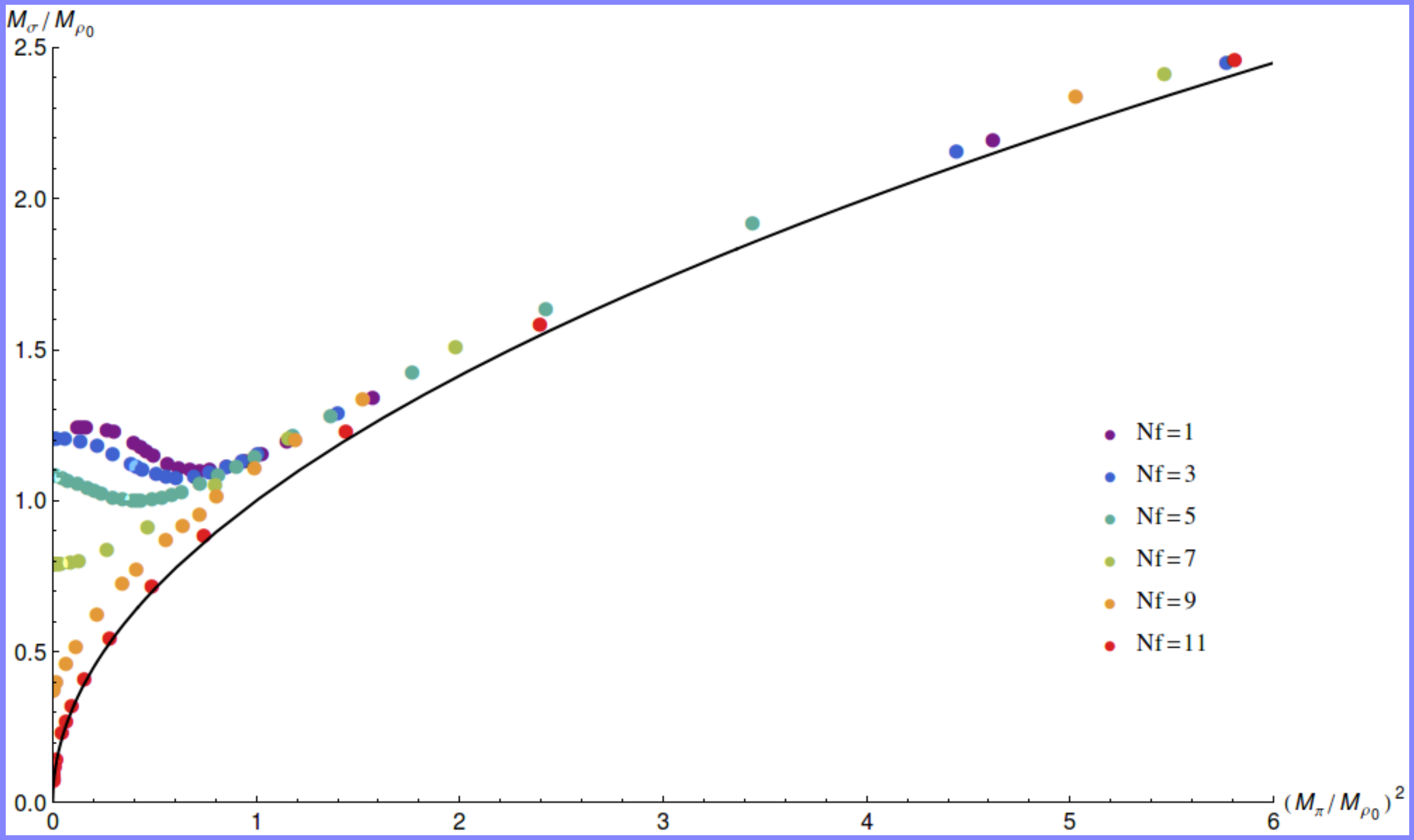
There is very little Nc dependence – basically quenched…

Hence comparison to quenched lattice data (Bali et al… arXiv1304.4437)

All of these models lie within 10-15% on any point....

SU(3) gauge theory + Nf quarks

The QCD point is not right for the f0(500) but about right for the f0(980) – is the f0(500) odd eg a molecule ???



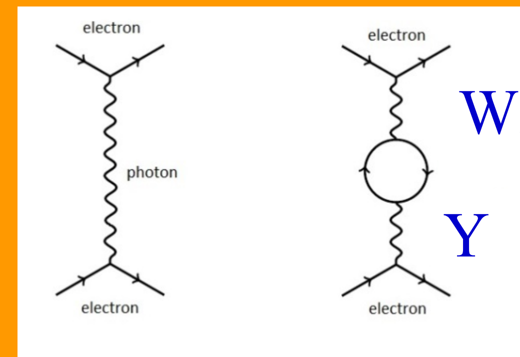
We indeed see a light sigma relative to the rho… cf higgs

Technicolour Exclusions

S broken gauge theories have non-decoupling effects

$$\left.\frac{d\Pi_{3Y}}{dq^2}\right|_{q^2=0}$$

Counts the number of electroweak doublets



Low energy computation:

$$S = 4\pi\left[\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2}\right]$$

$S_{QCD} = 0.3$

It has been suggested that as one approaches the critical Nf at the edge of the conformal window V-A symmetry is restored and S-> 0

$$S = \int d^4x\, d\rho\, \mathrm{Tr}\, \rho^3 \left[\frac{1}{\rho^2 + |X|^2}|DX|^2 + \frac{\Delta m^2}{\rho^2}|X|^2 + \frac{1}{2\kappa^2}(F_V^2 + F_A^2)\right]$$

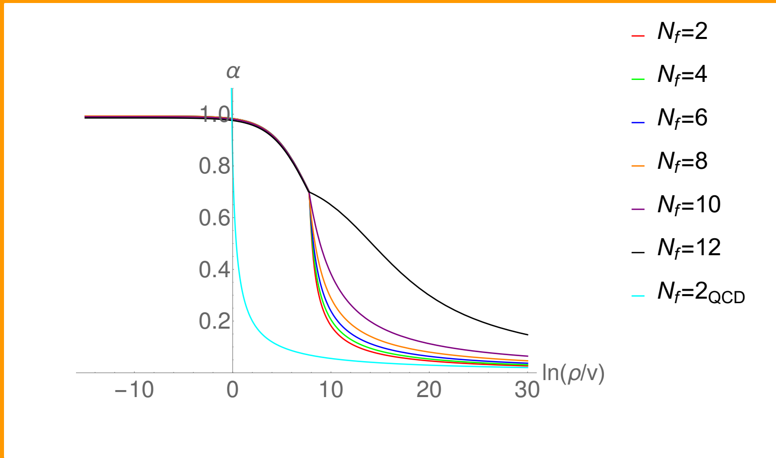
V-A symmetry is restored holographically by $\kappa \to 0$
(no Nf prediction)

Giving TC a last chance…

Most likely there is no choice of Nc Nf that will realize the physical mh…

But let's imagine we get lucky… because we don't know the IR running of the gauge coupling we don't know which Nc Nf combination to pick…

So lets holographically describe all Nc Nf pairs:



tune κ to give S=0.1…

Change the IR running (NfIR) to give mh = fp/2

Most likely the spectrum is in every case wrong! BUT if there is one theory that works we hope to have captured it… lets rule it out!

Pheno Exculsions Dilepton channel

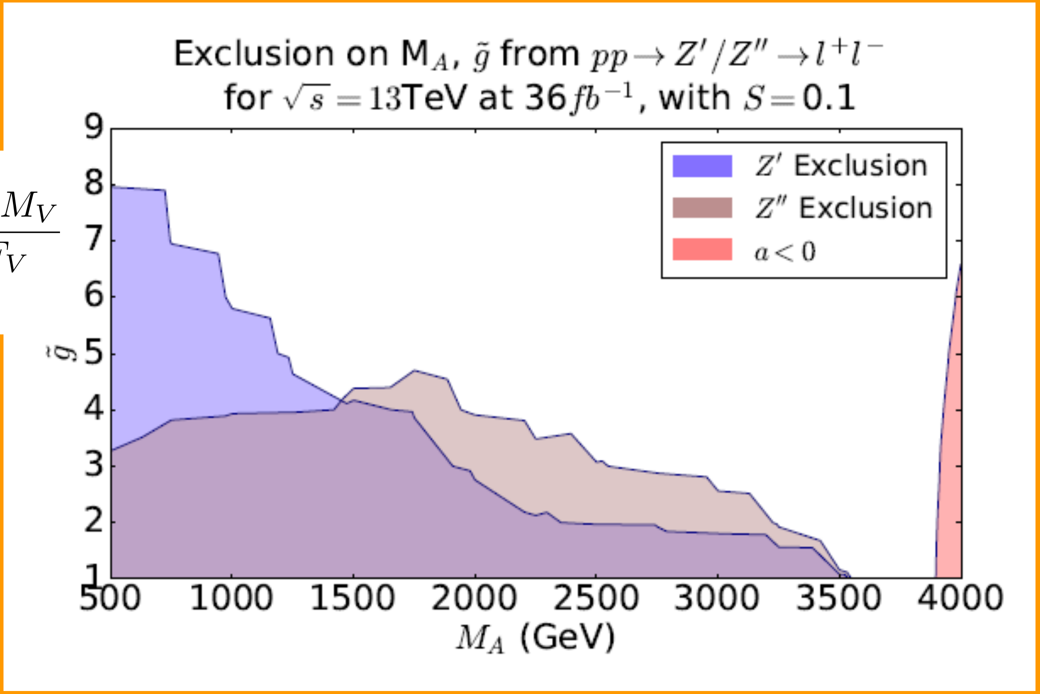
Walking Technicolor in the light of Z' searches at the LHC

Alexander Belyaev[a,c] , Azaria Coupe[a] , Mads Frandsen[b] , Emmanuel Olaiya[c] , Claire Shepherd-Themistocleous[c]

$$\begin{aligned}\mathcal{L}_{boson} = &-\frac{1}{2}\mathrm{Tr}[\tilde{W}_{\mu\nu}\tilde{W}^{\mu\nu}] - \frac{1}{4}\tilde{B}_{\mu\nu}\tilde{B}^{\mu\nu} - \frac{1}{2}\mathrm{Tr}[F_{L\mu\nu}F_L^{\mu\nu}+F_{R\mu\nu}F_R^{\mu\nu}]\\ &+ m^2\mathrm{Tr}[C_{L\mu}^2+C_{R\mu}^2] + \frac{1}{2}\mathrm{Tr}[D_\mu M D^\mu M^\dagger] - \tilde{g}^2 r_2 \mathrm{Tr}[C_{L\mu} M C_R^\mu M^\dagger]\\ &- \frac{i\tilde{g}r_3}{4}\mathrm{Tr}[C_{L\mu}(M D^\mu M^\dagger - D^\mu M M^\dagger) + C_{R\mu}(M^\dagger D^\mu M - D^\mu M^\dagger M)]\\ &+ \frac{\tilde{g}^2 s}{4}\mathrm{Tr}[C_{L\mu}^2 + C_{R\mu}^2]\mathrm{Tr}[M M^\dagger] + \frac{\mu^2}{2}\mathrm{Tr}[M M^\dagger] - \frac{\lambda}{4}\mathrm{Tr}[M M^\dagger]^2,\end{aligned}$$

They generically model SM + higgs + rho and a mesons

$$\tilde{g} = \frac{\sqrt{2}M_V}{F_V}$$

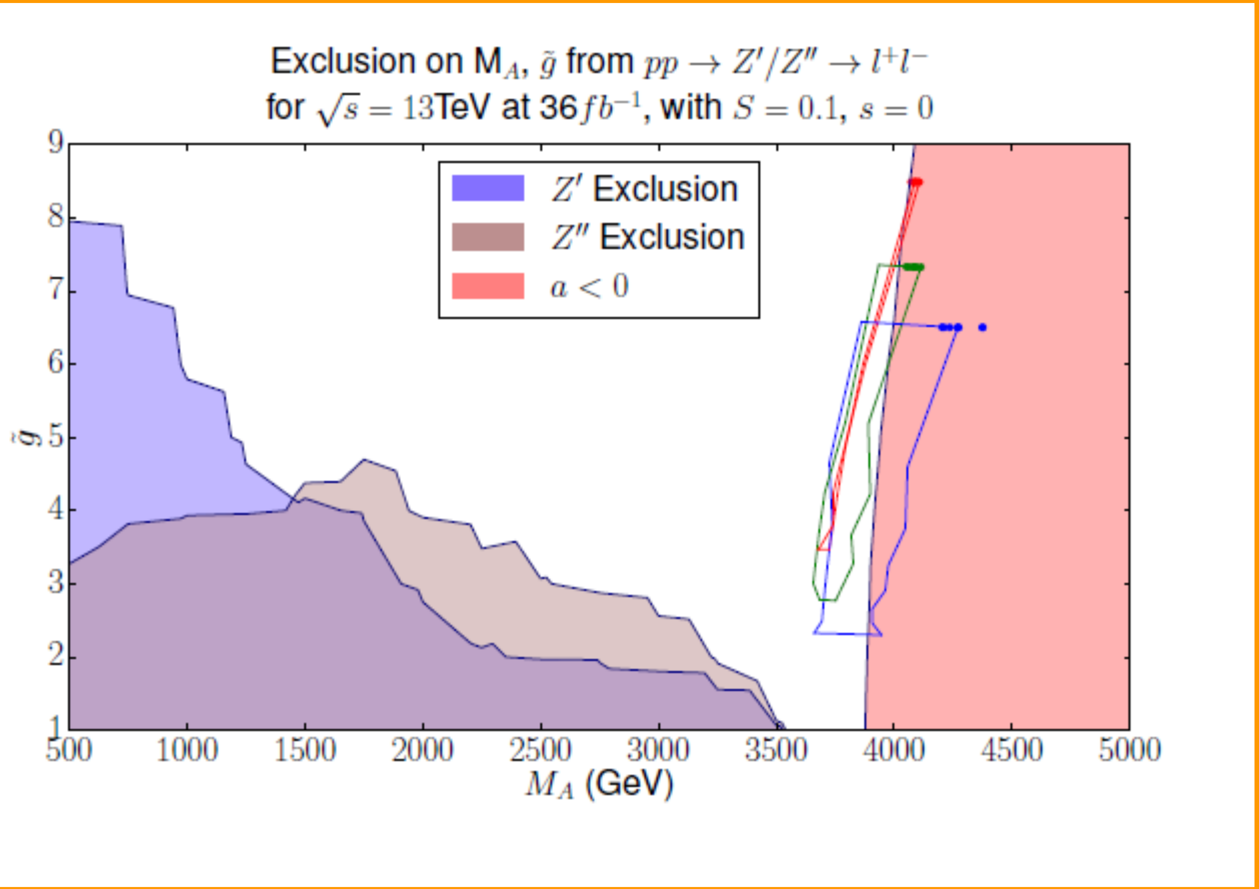


from Z' and Z'' DY processes

Looks like pretty good reach and exclusion

But where do real models lie in the space?

With Belyaev, Coupe, Locke, Scott. 1812.09052



Red is Nc = 3

Green Nc = 4

Blue Nc = 5

Moving downwards is adding electroweak doublets

The a=0 line is where the rho and a become degenerate in mass and decay constant – elsewhere conspiracies balance S= 0.1

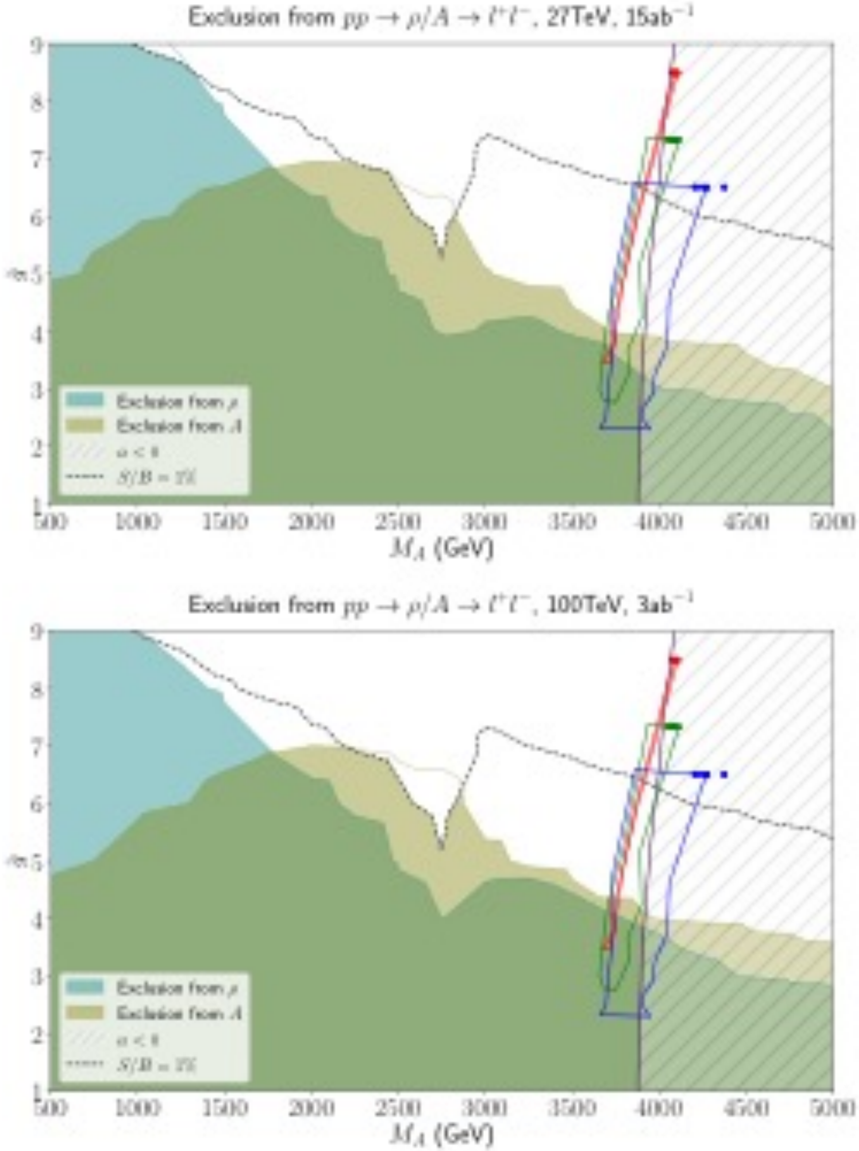


FIG. 3: Shaded areas present 95% CL projected exclusion on the $M_A - \tilde{g}$ plane for 27(15 ab^{-1}) (top) and 100 TeV (3 ab^{-1})(bottom) pp collider from dilepton DY resonance searches. The notations are the same as in Figure 2.

Motivates need to look at additional channels...

Eg Vector Boson Fusion

EG diboson and boson higgs final staes

Conclusions

- The origin of mass remains a key element of the SM
- Can we do a better job of computing at strong coupling; is the higgs potential dynamical in origin?
- Holography can be brought, at least in toy form, all the way to the theories in question
- We can mimic QCD
- We can explore simply technicolour like models
- Low doublet models still escape direct detection bounds (if you believe in tuning for a light dynamical higgs)

- TO DO: Ideal walking theories
- TO DO: new signals that try to exclude all theory space
- TO DO: composite higgs model and composite top partners