Spin-two mediators for Dark Matter

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LHC DM meeting
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A new spin-two resonance?

We know of elementary particles

spin zero, one and half

$$\phi \qquad A_\mu \qquad \Psi_\alpha$$

spin-two would be the first of its kind*

described as a field with two space-time indices

$$G_{\mu\nu}$$

and quite special because its interactions
necessarily indicate a new scale

e.g. $$-\frac{1}{\Lambda} G_{\mu\nu}\, \partial^\mu h \partial^\nu h$$

* f2 in QCD

Origin of a spin-two resonance

Glueball

new strong force
cofinement, bound states

KK-graviton

new extra-dimensions
Kaluza-Klein excitation
of the graviton

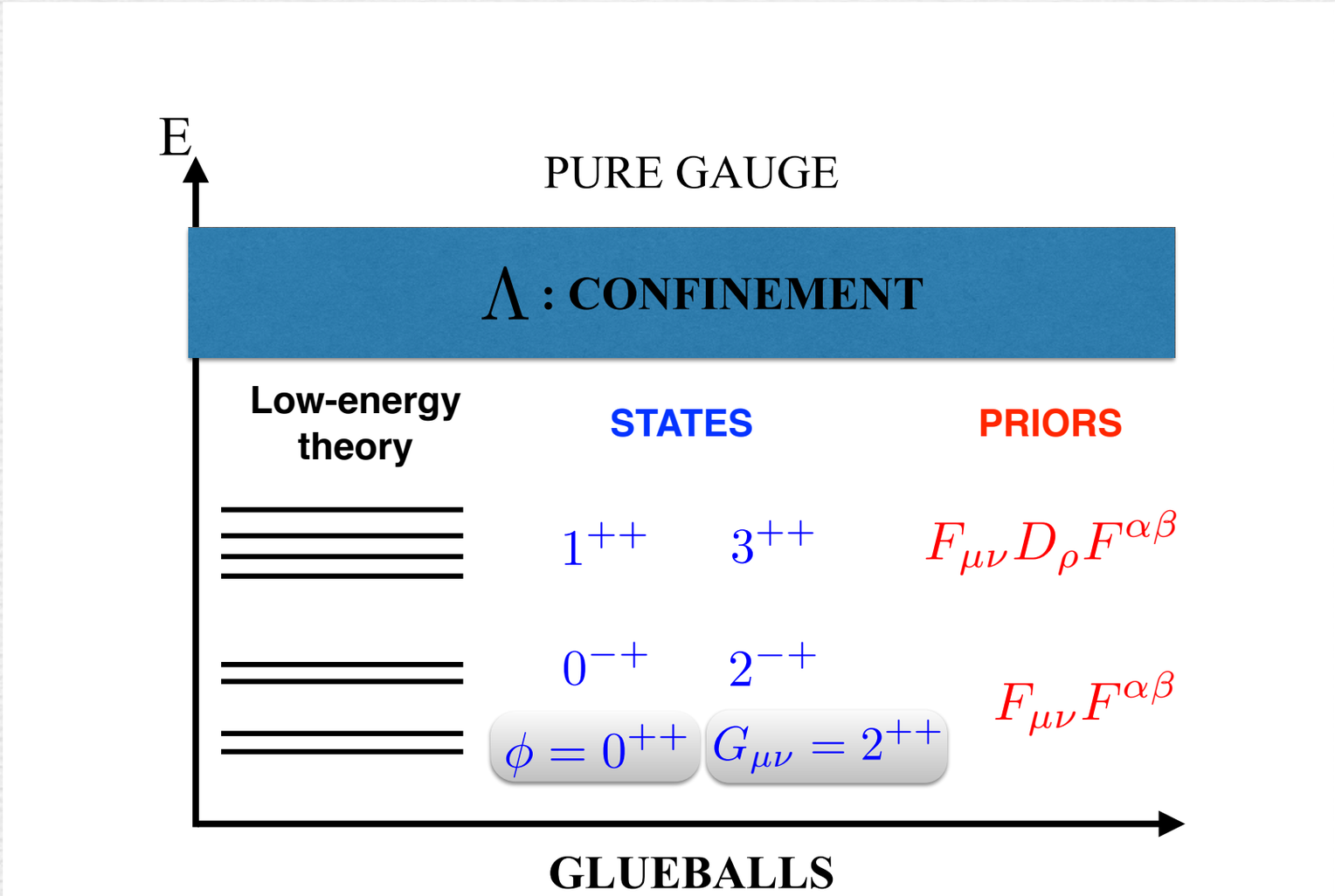
two possible interpretations
scale of interactions

e.g. $$-\frac{1}{\Lambda} G_{\mu\nu}\, \partial^\mu h \partial^\nu h$$

scale of confinement **compactification scale**

Example 1. Pure Yang-Mills

In pure-YM the lightest states are scalars and spin-two

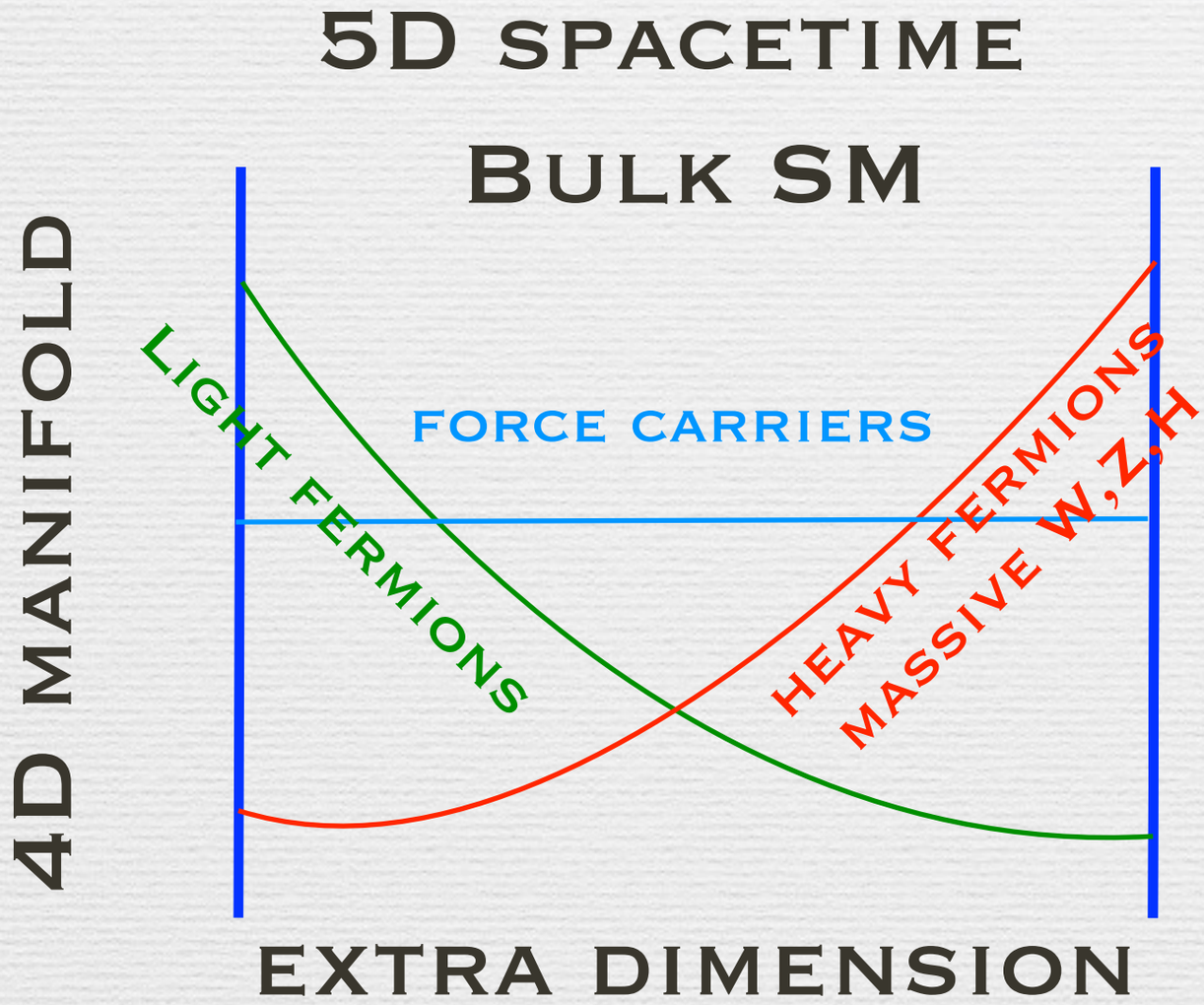


VS.

composite DM could interact with the SM via these bound states: spin-two mediator

Example 2. Extra-dimensions

Warped extra-dimensions
TeV gravity, also dual description of strong force



KK-graviton overlaps more with massive W,Z and H, heavy fermions and force mediators (gluons, photons) than light quarks and leptons

Dark Matter could be an extra-dimensional field with a large overlap with KK-graviton

s=2 and the Higgs

common origin of s=2 and the Higgs particle

Composite Higgs

Higgs as a
pseudo-Goldstone boson
from new strong sector
like a pion

Holographic Higgs
Gauge-Higgs

Higgs as an
extra-dimensional
component of a new force

descriptions are dual
but extra-dimensional models allow us to
obtain quantitative results

s=2 and the Higgs

common origin of s=2 and the Higgs particle

Composite Higgs

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Higgs as an
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**In Dillon, VS.
1603.09550**

Scenario where the Higgs and a s=2 are linked,
and avoid the issue of s=1
Benchmark values for couplings of s=2 to SM,
predictions for BRs to Zgamma, ZZ, etc

Couplings: symmetry arguments

Fok, Guimaraes, Lewis and VS. 1203.2917

	KK-graviton	Glueball
propagation	Pauli-Fierz	Pauli-Fierz
interactions	gravity stress-tensor $-\frac{c_i}{\Lambda} G_{\mu\nu}\, T_i^{\mu\nu}$	exactly the same 1->2 due to Lorentz/CP $-\frac{c_i}{\Lambda} G_{\mu\nu}\, T_i^{\mu\nu}$

KK-graviton vs glueballs:
indistinguishable in 1->2 processes

MC implementation

Mawatari et al.
1603.03421, 1601.05729,
and 1306.6464 (Higgs characterisation)

the following interactions are implemented

$$\mathcal{L}_2 = -\frac{1}{\Lambda}\left[\kappa_g\, T^g_{\mu\nu} + \kappa_q\, T^q_{\mu\nu} + \kappa_\gamma\, T^\gamma_{\mu\nu}\right] X_2^{\mu\nu} \,,$$

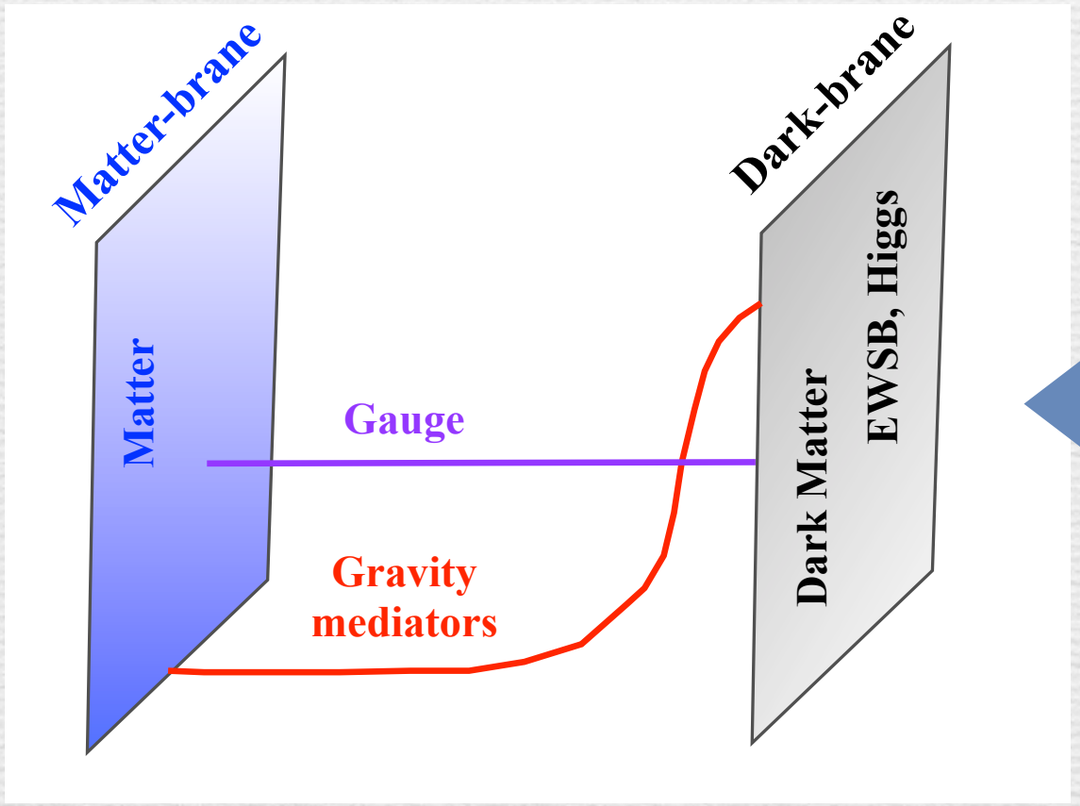
gluon light quarks photon

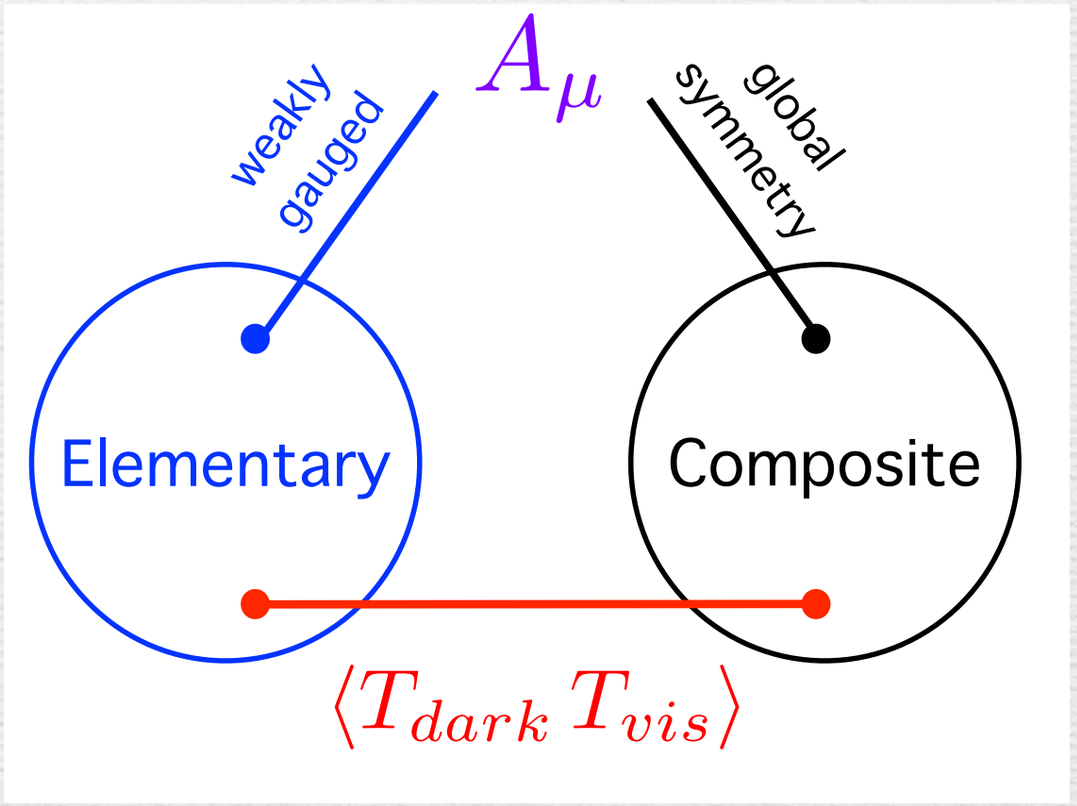
Other relevant interactions
can be adapted from the RS model in FR
(basis for bulk RS searches at LHC)

A set-up for DM

In 1306.4107 and 1401.5301 (w/ Lee and Park)
we proposed DM models with spin-two mediators and benchmarks with and without a connection to the Higgs

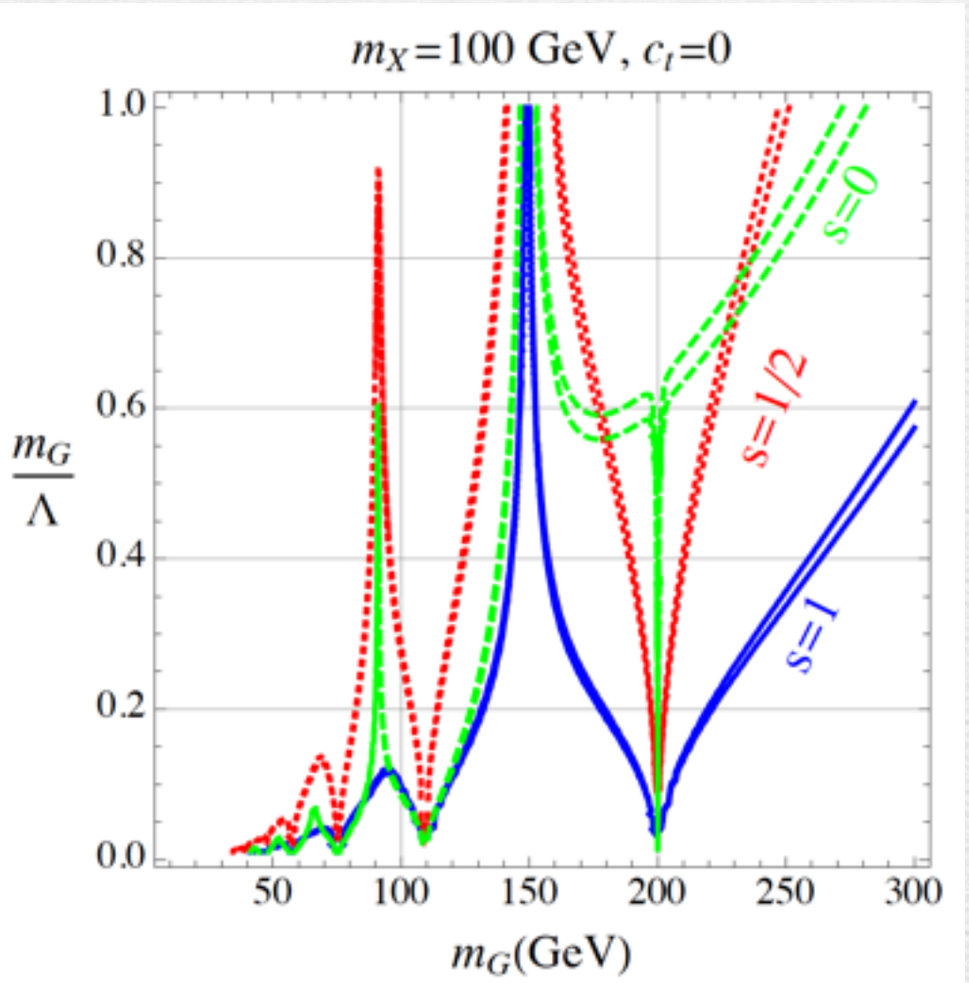
in the papers: relevant cross sections and widths
study DM/mediator phenomenology (colliders/Astro/Cosmo)
not an exhaustive study, more work to be done



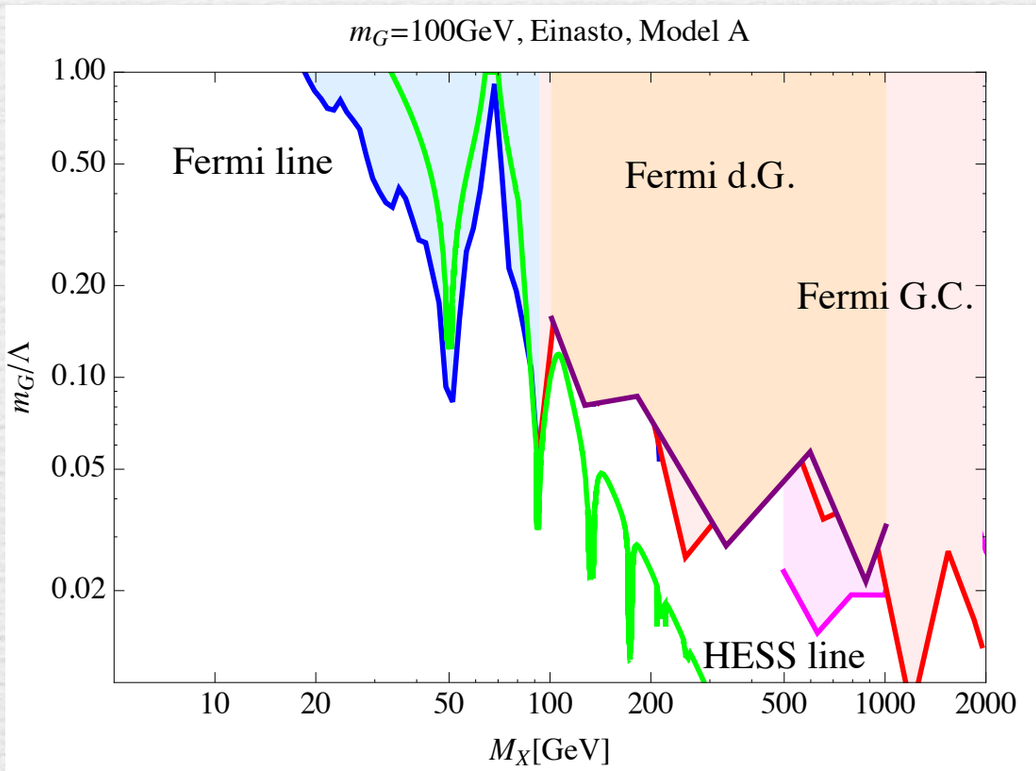


Features spin-2 mediators

channels	DM mass	X (s=0)	X (s=1/2)	X (s=1)
s-channel	$m_{\rm DM} < m_W$	d-wave	p-wave	s-wave
s-channel	$m_{\rm DM} > m_W$	s-wave	p-wave	s-wave
t-channel	$m_{\rm DM} > m_G$	s-wave	s-wave	s-wave



for low masses, the effect of multiple (tower) of spin-two resonances included also ID mostly affects the region of DM mass

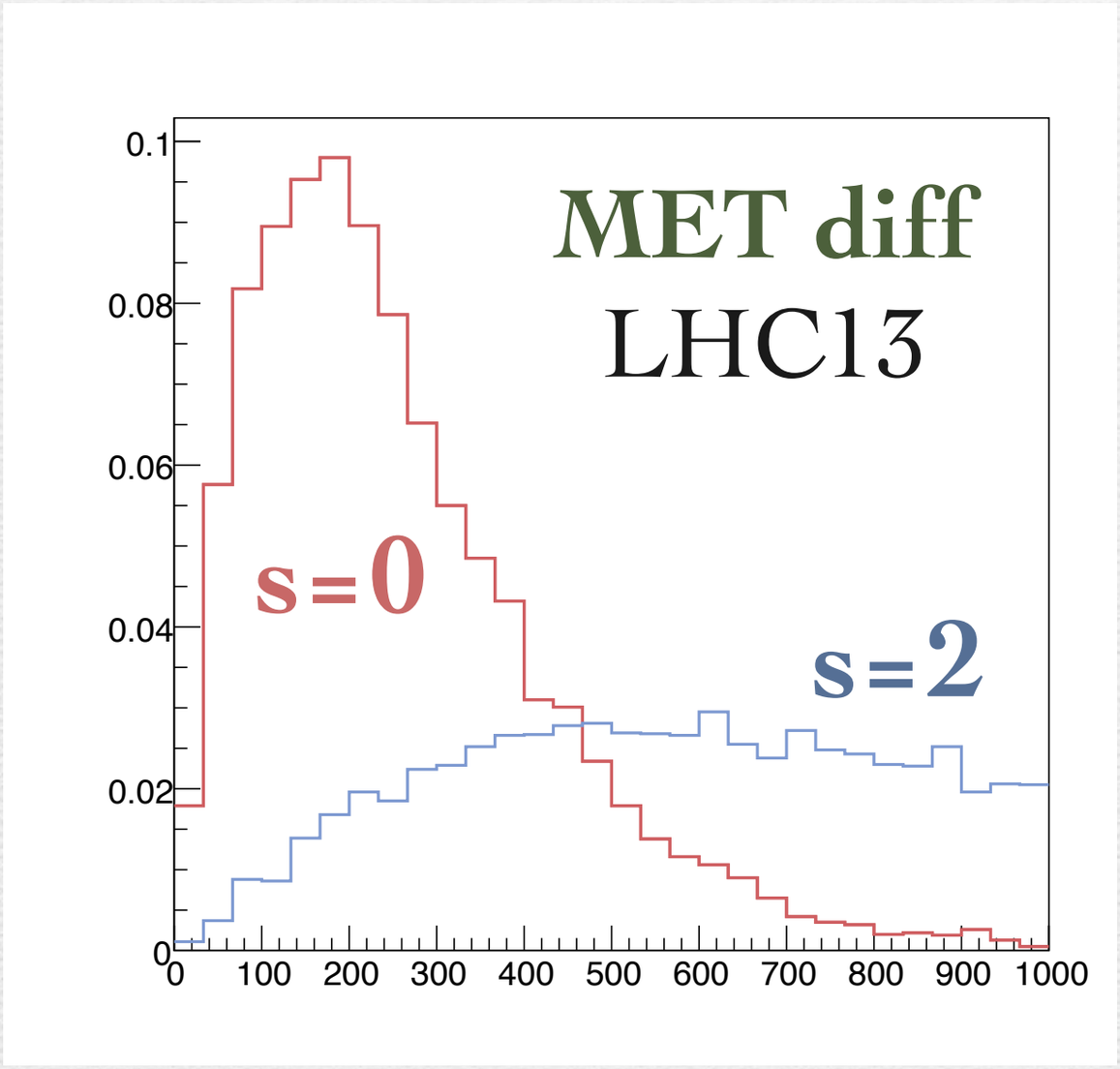


Features spin-2 mediators

LHC limits

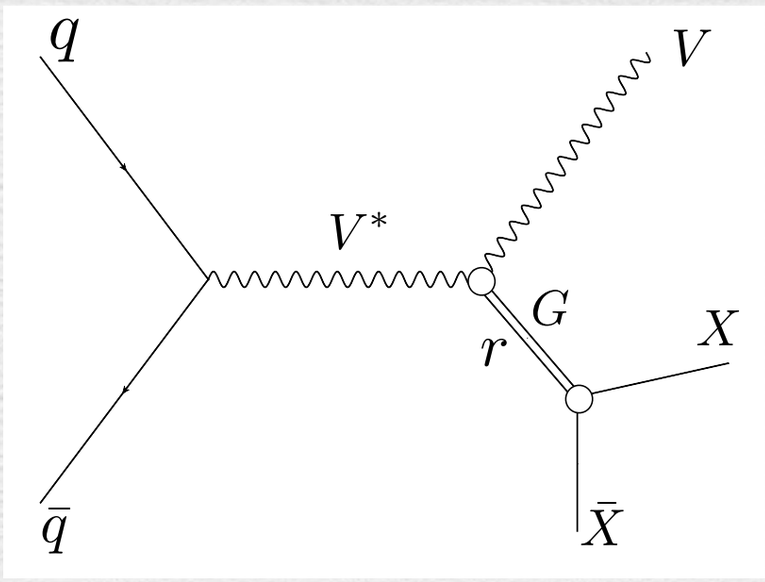
coupling to massive particles and gluons/photons via loops

production ggF, ttG, VG and VBF



MET features depend on the spin of the mediator

spin-two leads to harder final states



Features spin-2 mediators

Two more comments:

apart from mono-W,Z,h and VBF
an interesting final state t-tbar-MET
reinterpretation from stop searches
(but harder final states)

LHC limits general

simplified models with direct coupling to light quarks and leptons can be defined
but need to study current bounds in this case

Conclusions

- Spin-two resonances appear in theories of extra-dimensions (KK-graviton) and strong interactions (bound states called glueballs). We use extra-dimensional models to obtain quantitative results

- Due to symmetries, leading interactions in both cases are the same, indistinguishable. The origin of the Higgs and a s=2 resonance could be linked, providing a benchmark for studies

- Some of the relevant interactions (gluons, light quarks and photons) are included in the MC, but Zgamma, ZZ, WW should be added with specific relations.
  Higgses and third generation quarks are also important, as they are typically predicted in models

- LHC signatures of spin-two mediators in mono-X characterized by interesting kinematics: harder MET, different angular corrs in VBF and ttH… compared to scalar/axion/Z' mediators

Couplings of the s=2 to gauge bosons

A heavy resonance in two bosons?
it couples to SM gauge interactions we expect
WW, ZZ and Zgamma (and hh)

couplings of resonance to
ZZ, Zgamma and di-gamma are related

$$g_{z\gamma} = (c_1\alpha_1 - c_2\alpha_2)s_{2W}$$
$$g_{\gamma\gamma} = c_1\alpha_1 c_W^2 + c_2\alpha_2 s_W^2$$
$$g_{zz} = c_1\alpha_1 s_W^2 + c_2\alpha_2 c_W^2$$

non-zero Zgamma means non-zero ZZ or digamma

$c_1\alpha_1$: coupling to hypercharge
$c_2\alpha_2$: coupling to SU(2)L