EFT for Strongly Coupled Scenarios of 750GeV Resonance

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Motivation

Goal:

- test a possibility to describe the 750GeV excess as a composite resonance of some new strong confining (above 750GeV) dynamics

- capture a broad range of models within a single EFT framework and test their structural features

Motivation

<u>Assumptions</u>:

- new resonance S has a spin 0
- S is an EW singlet
- S is produced directly
- S decays to SM states only
- S is a part of a new strong sector which
  - produces PNGB Higgs
  - Goldstone sym breaking and top mass from partial compositeness

Framework

- EFT for SM + S, characterised by two unknown parameters

$m_\rho \sim g_\rho f$	cutoff, typical mass of composite states (>1TeV)
$g_\rho \sim 1 - 4\pi$	typical coupling of composite states
$\xi = v^2/f^2$	EW tuning $\xi \lesssim 0.2$

- Power Counting

$$m_\rho^2 f^2 \left[\frac{S}{f}\right]^{\#_S} \left[\frac{H}{f}\right]^{\#_H} \left[\frac{y_q\, \bar{q}q}{m_\rho^2 f}\right]^{\#_{\bar{q}q}} \left[\frac{gA}{m_\rho}\right]^{\#_A} \left[\frac{p}{m_\rho}\right]^{\#_p}$$

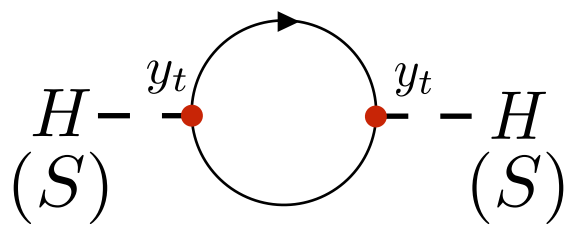
generic composite states

SM coupling to the strong sector controlled by Yukawas and gauge couplings

Framework

- Selection Rules
  - CP, e.g. forbids SHH for pseudoscalar S
  - Goldstone symmetry can require a presence of symmetry breaking sources

$$\frac{y_t^2}{(4\pi)^2}$$



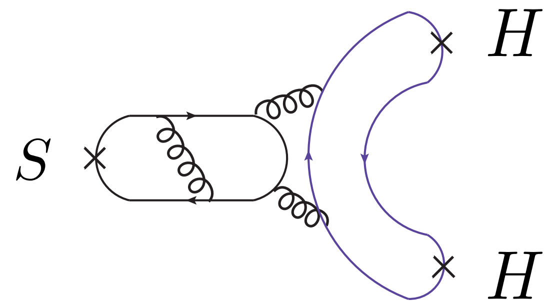
Higgs mass in CH

Pion mass splitting in QCD

Framework

- "loop" suppression

$$\frac{g_\rho^2}{(4\pi)^2}$$



1/N in large N

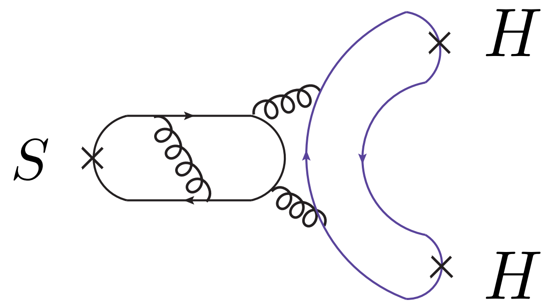
$g_\rho \simeq 4\pi/\sqrt{N}$

Zweig rule
in QCD, e.g.
for
$\phi \to \pi\pi\pi$

Framework

▸"loop" suppression

$$\frac{g_\rho^2}{(4\pi)^2}$$

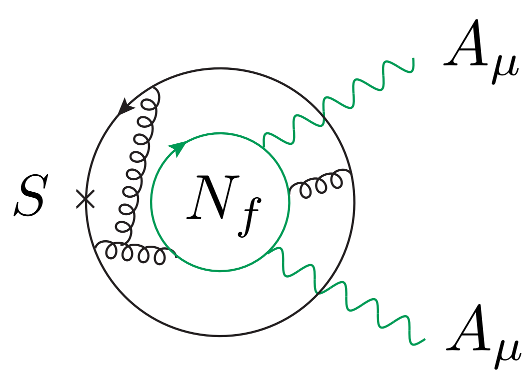


1/N in large N

$g_\rho \simeq 4\pi/\sqrt{N}$

Zweig rule
in QCD, e.g.
for
$\phi \to \pi\pi\pi$

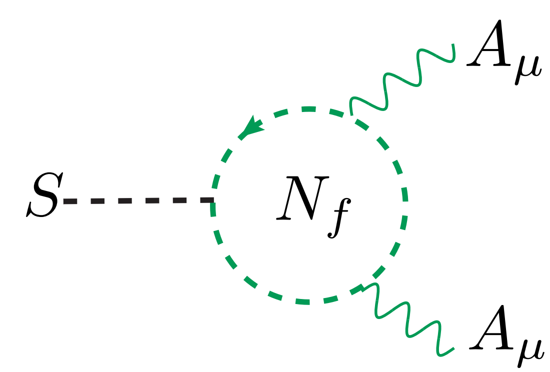
$$N_f \frac{g_\rho^2}{(4\pi)^2}$$



Nf/N in large N

not relevant in
QCD because

$N_f \sim N_c$



1 loop in 5DCH

* Same parametric form of the coupling is obtained for a NGB S with a Goldstone symmetry broken by anomaly

Scenarios

- S
  - scalar
    - generic
    - NGB(p.c.)
  - pseudoscalar
    - generic
    - NGB
      - p.c.
      - anom.

SX^2
$S\bar{q}Hq$
$S\|D_\mu H\|^2$
$S\|H\|^2$
S^2

Scenarios

- S
  - scalar
    - generic
    - NGB(p.c.)
  - pseudoscalar
    - generic
    - NGB
      - p.c.
      - anom.

	generic	NGB(p.c.)	generic	p.c.	anom.
SX^2	$k_X \frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$k_X \frac{3y_t^2}{(4\pi)^2}\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$k_X \frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$k_X \frac{3y_t^2}{(4\pi)^2}\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$\frac{N_f^{(X)} g_X^2}{(4\pi)^2}\frac{1}{f}$
$S\bar{q}Hq$	$k_q y_q \frac{1}{f}$	$k_q y_q \frac{1}{f}$	$ik_q y_q \frac{1}{f}$	$ik_q y_q \frac{1}{f}$	—
$S\lvert D_\mu H\rvert^2$	$k_H \frac{1}{f}$	$k_H \frac{3y_t^2}{(4\pi)^2}\frac{1}{f}$	—	—	—
$S\lvert H\rvert^2$	$\tilde{k}_H \frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f}$	$\tilde{k}_H \frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f}$	—	—	—
S^2	$k_S m_\rho^2$	$k_S \frac{3y_t^2}{(4\pi)^2} m_\rho^2$	$k_S m_\rho^2$	$k_S \frac{3y_t^2}{(4\pi)^2} m_\rho^2$	$k_S \frac{N_f g_\rho^2}{(4\pi)^2} m_\rho^2$

- “Generic” cases allow for additional “loop” suppression

Scenarios

- S
  - scalar
    - generic
    - NGB(p.c.)
  - pseudoscalar
    - generic
    - NGB
      - p.c.
      - anom.

	generic	NGB(p.c.)	generic	p.c.	anom.
SX^2	1	$y_t^2/16\pi^2$	1	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$S\bar{q}Hq$	y_q	y_q	y_q	y_q	0
$S\lvert D_\mu H\rvert^2$	1	$y_t^2/16\pi^2$	0	0	0
$S\lvert H\rvert^2$	$y_t^2/16\pi^2$	$y_t^2/16\pi^2$	0	0	0
S^2	1	$y_t^2/16\pi^2$	1	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$

- "Generic" cases allow for additional "loop" suppression

Higgs Physics

- Generic CH effects lead to $\xi \lesssim 0.2$

- Higgs-scalar S mixing affects Higgs phenomenology. We concentrate on the effects which can be dominated by S.

	effect of scalar S		compositeness
	generic	PNGB	effects [+MC]
$\frac{2g'^2}{v^2}\lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu},\ \frac{g_S^2}{v^2}\lvert H\rvert^2 G_{\mu\nu}G^{\mu\nu}$	$k_{g,\gamma}\tilde{k}_H\,\frac{3y_t^2}{(4\pi)^2}\,\frac{1}{g_\rho^2}\boxed{\frac{m_\rho^2}{M_S^2}}\xi$	$k_{g,\gamma}\tilde{k}_H\,\frac{9y_t^4}{(4\pi)^4}\,\frac{1}{g_\rho^2}\,\frac{m_\rho^2}{M_S^2}\xi$	$\frac{3y_t^2}{(4\pi)^2}\,\frac{1}{g_\rho^2}\xi$
$\frac{g}{v^2}(H^\dagger\sigma^i\overleftrightarrow{D}_\mu H)(D_\nu W^{\mu\nu})^i,\ \frac{g'}{v^2}(H^\dagger\overleftrightarrow{D}_\mu H)(\partial_\nu B^{\mu\nu})$			$\frac{1}{g_\rho^2}\xi$
$\frac{g}{v^2}(D_\mu H)^\dagger\sigma^i(D_\nu H)W^{i\mu\nu},\ \frac{g'}{v^2}(D_\mu H)^\dagger(D_\nu H)B^{\mu\nu}$			$\frac{1}{g_\rho^2}\xi\left[\frac{N_f g_\rho^2}{(4\pi)^2}\right]$
$\frac{1}{v^2}\bar{q}Hq\lvert H^2\rvert$	$y_q(k_q-\frac{1}{2}k_H\tilde{k}_H)\,\frac{3y_t^2}{(4\pi)^2}\,\frac{m_\rho^2}{M^2}\xi$	$y_q k_q\,\frac{3y_t^2}{(4\pi)^2}\,\frac{m_\rho^2}{M^2}\xi$	$\boxed{y_q\xi}$
$\frac{1}{v^2}\partial_\mu\lvert H\rvert^2\partial^\mu\lvert H\rvert^2$	$\frac{1}{2}k_H\tilde{k}_H\,\frac{3y_t^2}{(4\pi)^2}\,\frac{m_\rho^2}{M^2}\xi$	$\frac{1}{2}\left(\tilde{k}_H^2\frac{m_\rho^2}{M^2}-k_H\tilde{k}_H\right)\frac{9y_t^4}{(4\pi)^4}\,\frac{m_\rho^2}{M^2}\xi$	$\boxed{\xi}$

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$\frac{g}{v^2}(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H)(D_\nu W^{\mu\nu})^i,\ \frac{g'}{v^2}(H^\dagger \overleftrightarrow{D}_\mu H)(\partial_\nu B^{\mu\nu})$	$k_{g,\gamma}\tilde{k}_H\,\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\boxed{\frac{m_\rho^2}{M_S^2}}\xi$	$k_{g,\gamma}\tilde{k}_H\,\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M_S^2}\xi$	$\frac{1}{g_\rho^2}\xi$
$\frac{g}{v^2}(D_\mu H)^\dagger\sigma^i(D_\nu H)W^{i\mu\nu},\ \frac{g'}{v^2}(D_\mu H)^\dagger(D_\nu H)B^{\mu\nu}$			$\frac{1}{g_\rho^2}\xi\left[\frac{N_f g_\rho^2}{(4\pi)^2}\right]$
$\frac{1}{v^2}\bar{q}Hq\vert H^2\vert$	$y_q(k_q - \frac{1}{2}k_H\tilde{k}_H)\,\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$y_q k_q\,\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$\boxed{y_q\xi}$
$\frac{1}{v^2}\partial_\mu\vert H\vert^2\partial^\mu\vert H\vert^2$	$\frac{1}{2}k_H\tilde{k}_H\,\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$\frac{1}{2}\left(\tilde{k}_H^2\frac{m_\rho^2}{M^2} - k_H\tilde{k}_H\right)\frac{9y_t^4}{(4\pi)^4}\frac{m_\rho^2}{M^2}\xi$	$\boxed{\xi}$

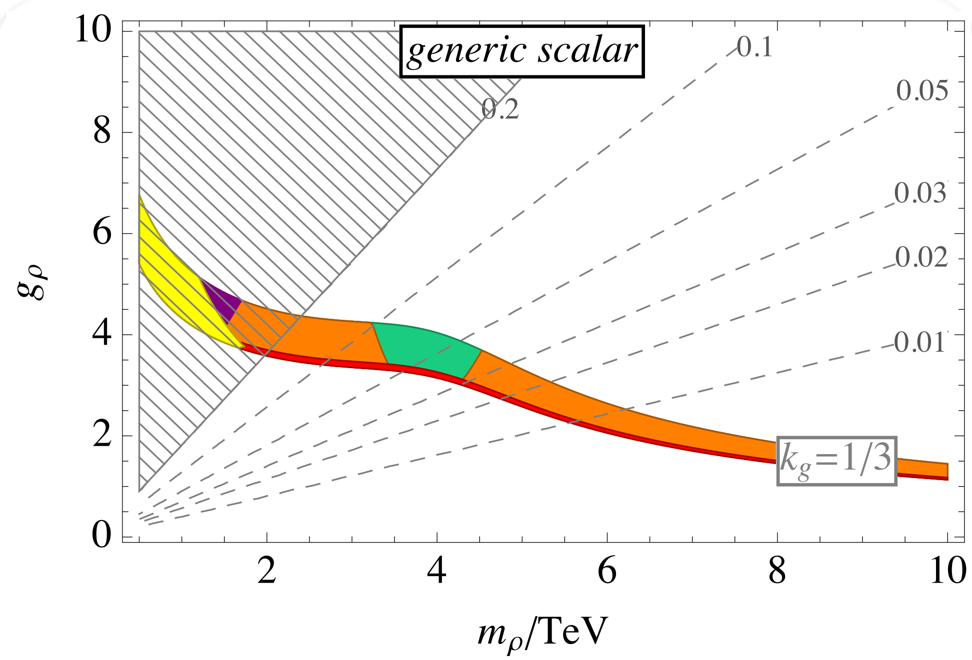
- $h \to gg/\gamma\gamma$ can show the effect of S for $m_\rho/M_S \gtrsim g_\rho/y_t$

	effect of generic scalar S	generic CH distortion
$\delta\Gamma_{h\to gg}/\Gamma^{\rm SM}_{h\to gg}$	$-\xi\frac{12y_t^2 k_g\tilde{k}_H}{g_\rho^2 I_g}\frac{m_\rho^2}{M_S^2}$	$\sim 2\xi$
$\delta\Gamma_{h\to\gamma\gamma}/\Gamma^{\rm SM}_{h\to\gamma\gamma}$	$-\xi\frac{24y_t^2 k_\gamma\tilde{k}_H}{g_\rho^2(I_\gamma+J_\gamma)}\frac{m_\rho^2}{M_S^2}$	$\sim \xi$

Parametric Analysis

Scalar

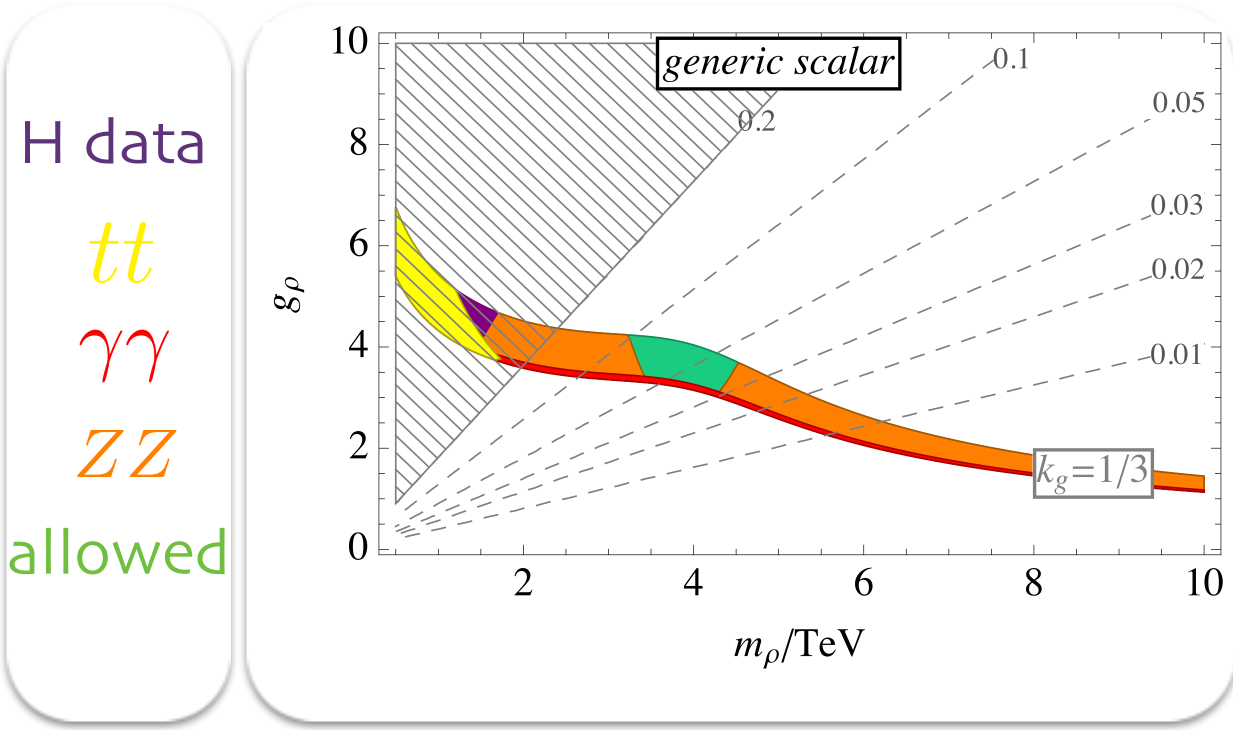
H data
tt
$\gamma\gamma$
ZZ
allowed



- generic case has strong tension with SVV (can be tuned) and with a Higgs data, in addition $M_S^2/m_\rho^2 \ll 1$

Parametric Analysis

Scalar



- generic case has strong tension with SVV (can be tuned) and with a Higgs data, in addition $M_S^2/m_\rho^2 \ll 1$

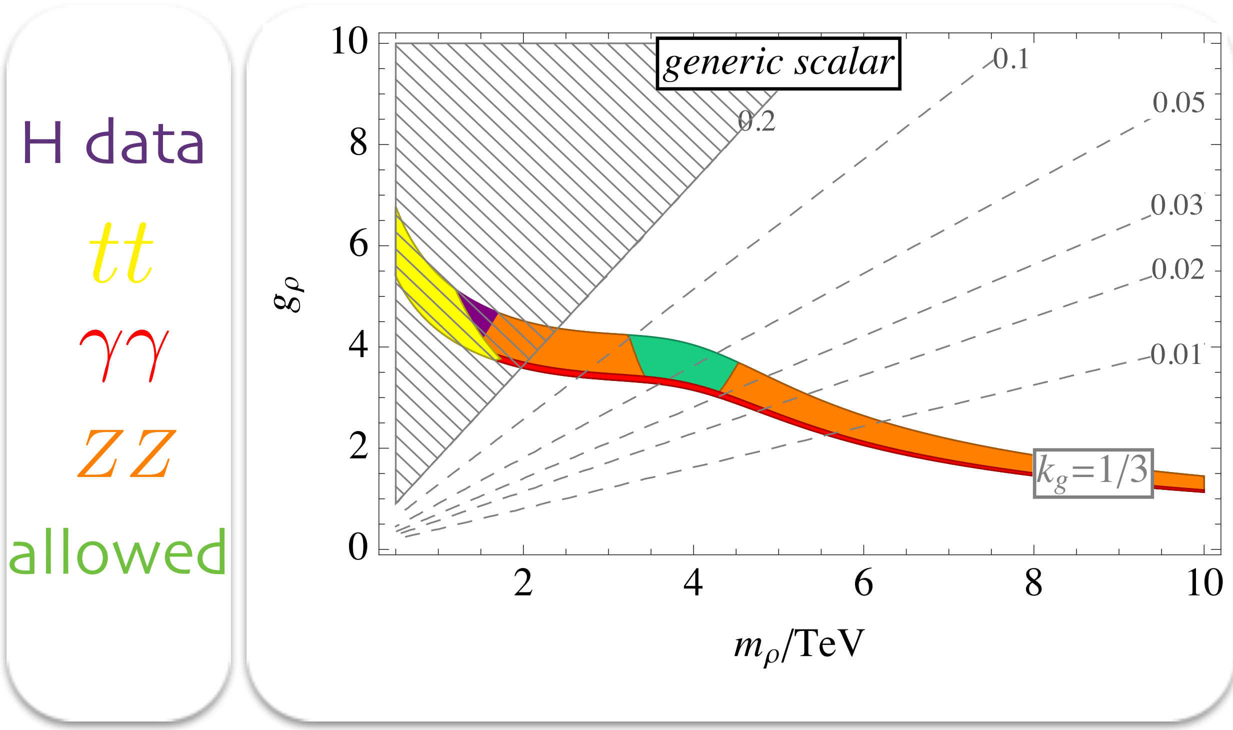
- need to maximize the x-sections ratio

$$\sigma^{13}_{\gamma\gamma}/\sigma^{8}_{VV} \sim \frac{k_\gamma^2}{k_H^2}\frac{1}{g_\rho^4}$$

$k_\gamma \;\; k_H$ - dim-less coeffs of order-1

Parametric Analysis

Scalar



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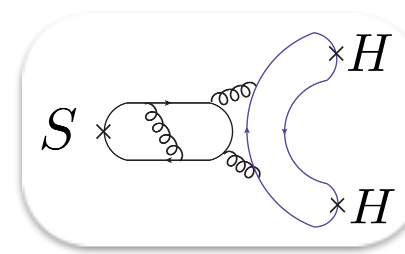
k_γ

k_H

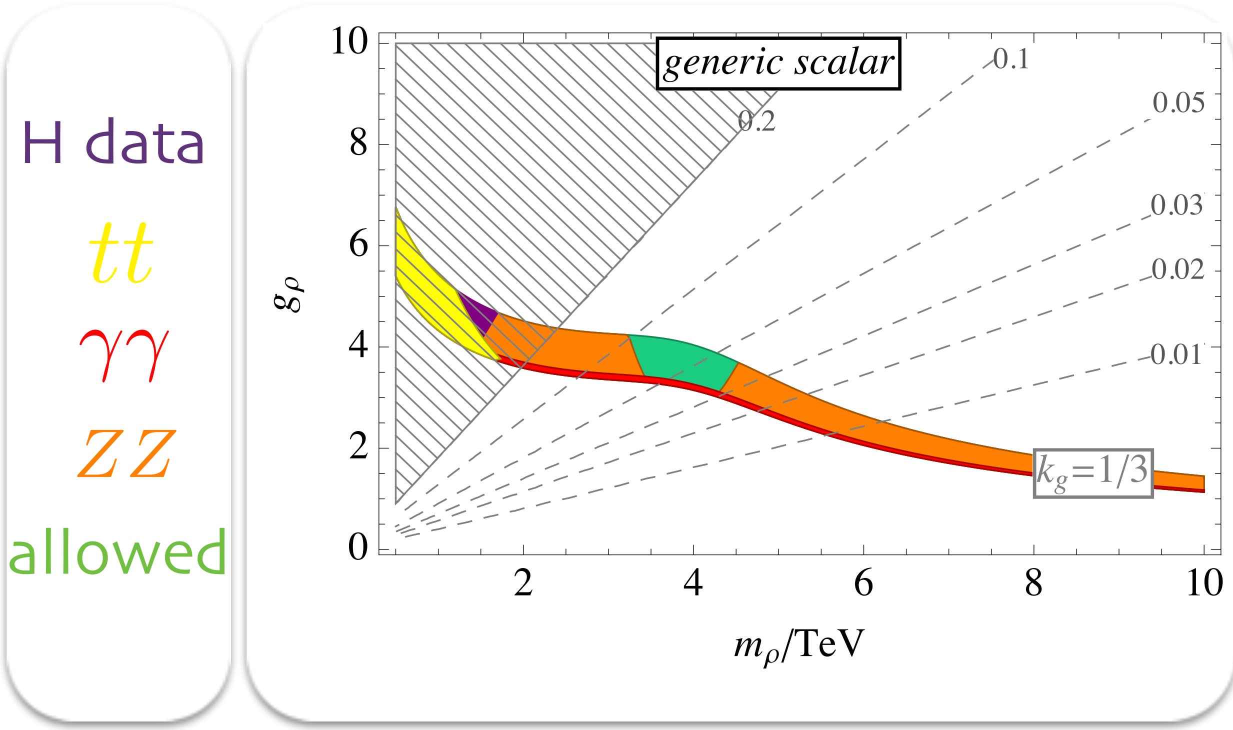


$M_S^2/m_\rho^2 \ll 1$

g_ρ

Parametric Analysis

- Scalar



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$$\sigma^{13}_{\gamma\gamma}/\sigma^{8}_{VV} \sim \frac{k_\gamma^2}{k_H^2}\frac{1}{g_\rho^4}$$

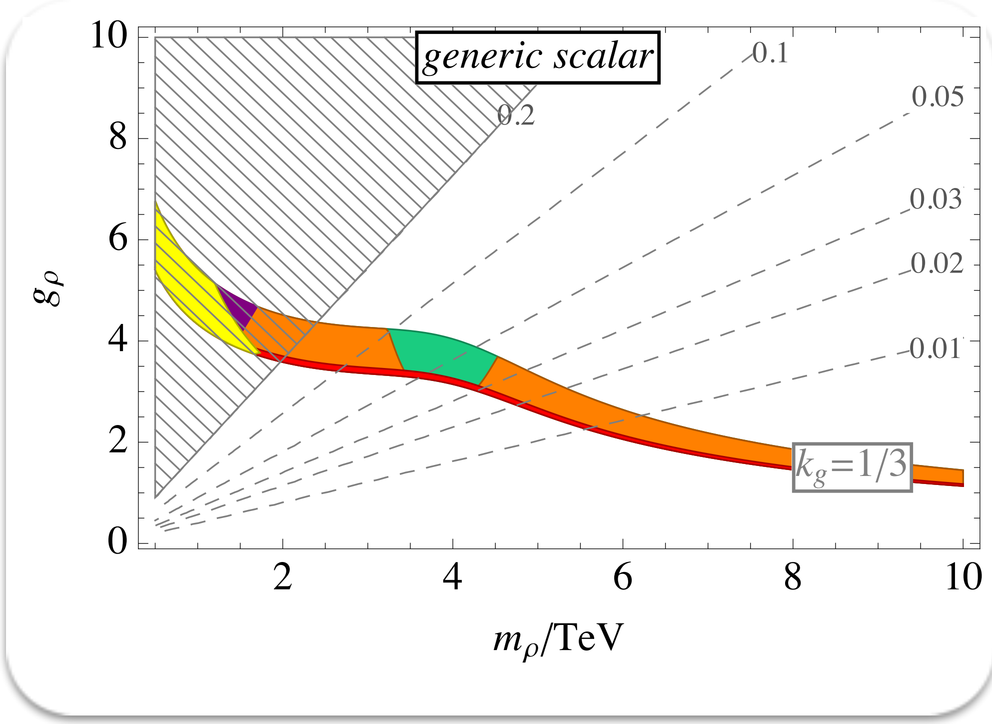
- a necessary and sufficient condition is a g_ρ reduction achieved by lowering S-gluons coupling

$$\sigma^{13}_{\gamma\gamma} \sim \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma_{HH}+\Gamma_{tt}} \sim \frac{k_g^2}{(k_H^2+k_t^2)}\frac{1}{g_\rho^4 f^2}\frac{k_\gamma^2}{g_\rho^4}$$

Parametric Analysis

Scalar

H data
tt
$\gamma\gamma$
ZZ
allowed



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- need to maximize the x-sections ratio

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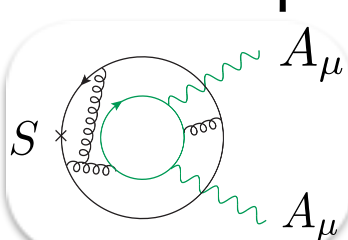
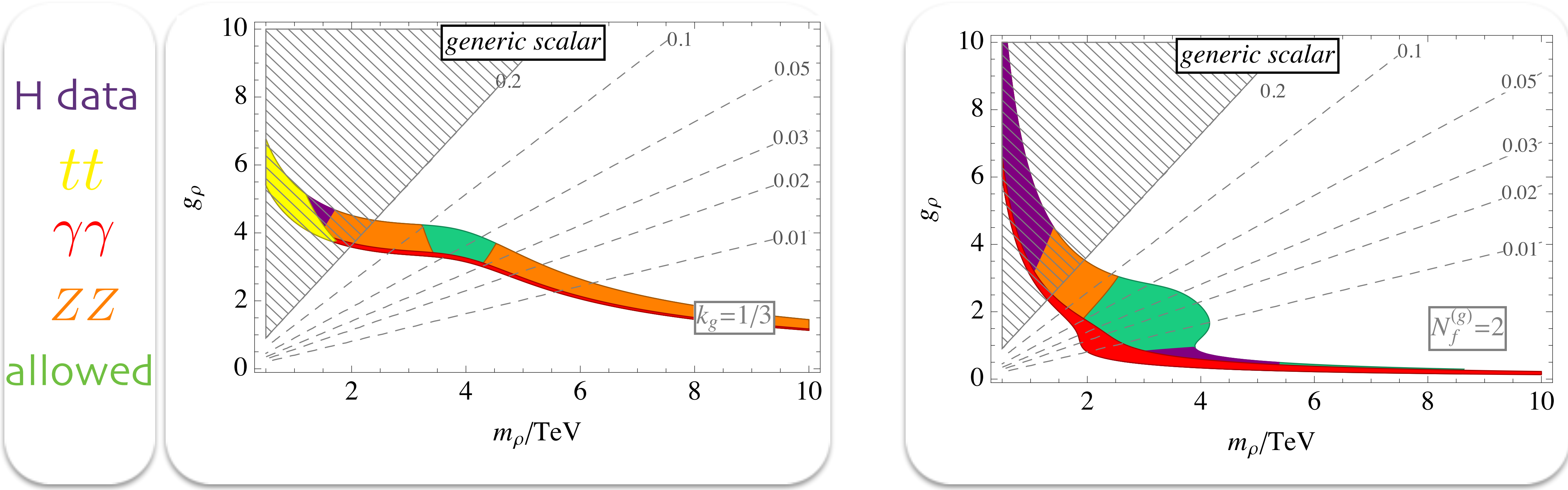
- realized in a loop suppression scenario



$$k_g \to k_g N_f^{(g)} \frac{g_\rho^2}{(4\pi)^2}$$

Parametric Analysis

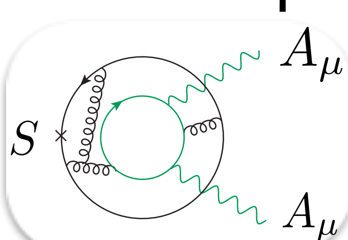
Scalar



- a necessary and sufficient condition is a g_ρ reduction achieved by lowering S-gluons coupling

$$\sigma_{\gamma\gamma}^{13} \sim \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma_{HH}+\Gamma_{tt}} \sim \frac{k_g^2}{(k_H^2+k_t^2)}\frac{1}{g_\rho^4 f^2}\frac{k_\gamma^2}{g_\rho^4}$$

- realized in a loop suppression scenario



$$k_g \to k_g N_f^{(g)} \frac{g_\rho^2}{(4\pi)^2}$$

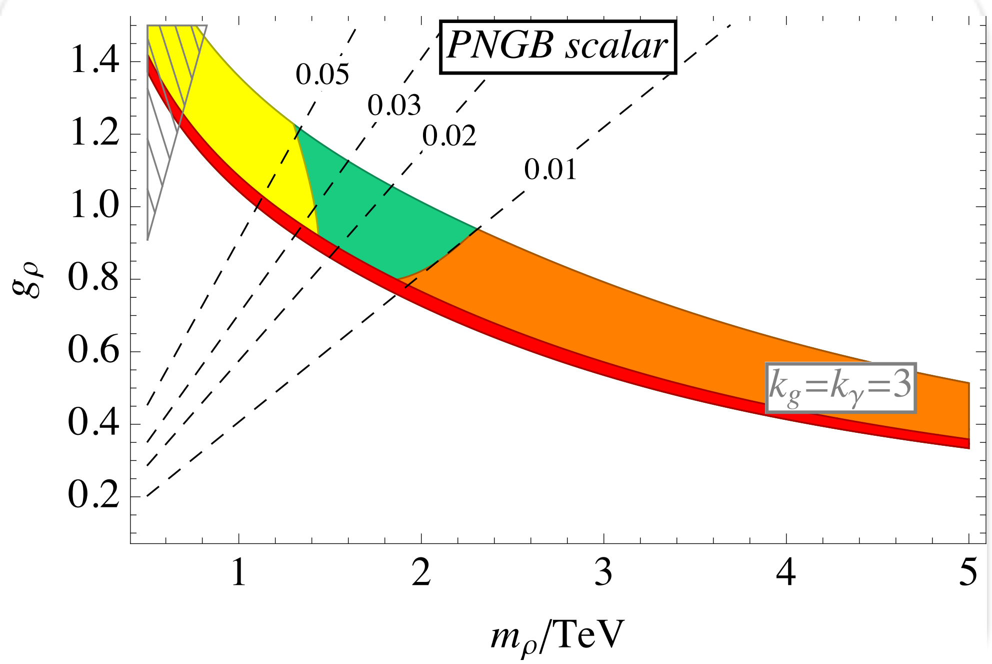
Nf~1-2 points at scenarios with the top partners only

- S width ~20GeV

Parametric Analysis

- NG (pseudo) Scalar with a breaking by partial compositeness

tt
$\gamma\gamma$
ZZ
allowed



- can provide $M_S \ll m_\rho$

- couplings to gluons and gammas are overly suppressed

$$\frac{3y_t^2}{(4\pi)^2}\frac{g_X^2}{g_\rho^2}\frac{1}{f}\ SF_{\mu\nu}F^{\mu\nu}$$

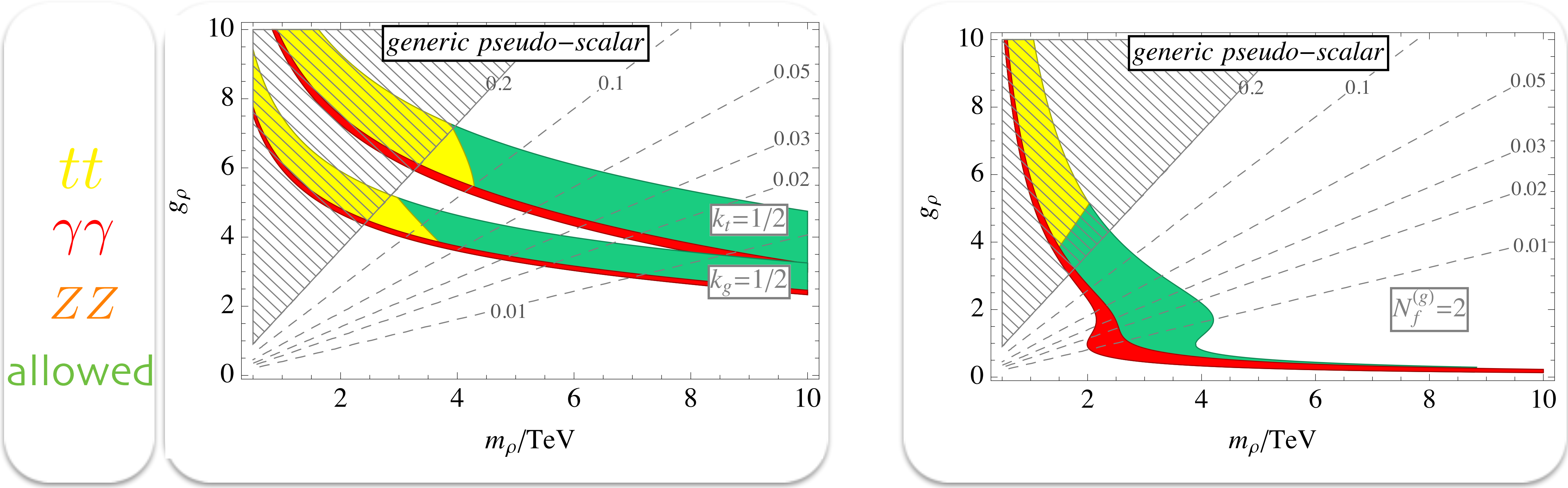
while Stt is large,

$$y_t\frac{v}{f}S\bar{t}t$$

leading together to $g_\rho \lesssim 1 \quad \xi < 0.05$

Parametric Analysis

Pseudo-scalar



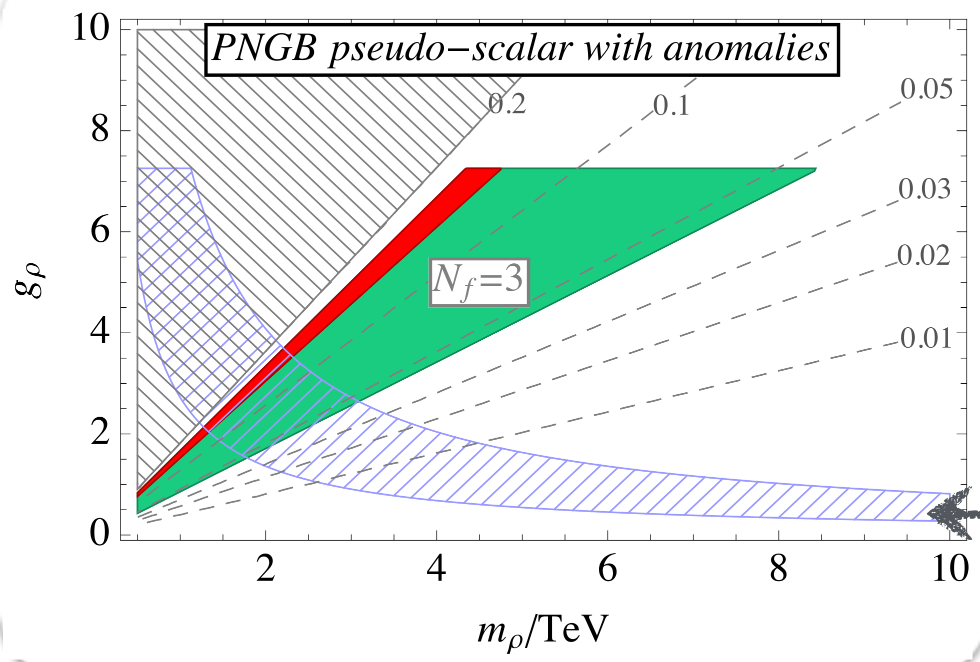
- mild tension with tt in the generic case, requires ~50% tuning
- significant gap between MS and a NP scale
- all the bounds (besides γγ @8TeV) get weaker for a loop suppressed Sgg, and NP scale moves down
- S width ~20GeV

Parametric Analysis

- PNGB Pseudo-scalar with anomalies

$\gamma\gamma$

allowed



QCD η' mass rescaled

$M_S \sim N_f^{1/2}(g_\rho/4\pi)m_\rho$

- requires $N_f^{(\gamma)}$~3, and weakly sensitive to $N_f^{(g)}$
- M_S=750GeV prefers m_ρ<3 TeV
- S width less than 1 GeV

Numerical Scan

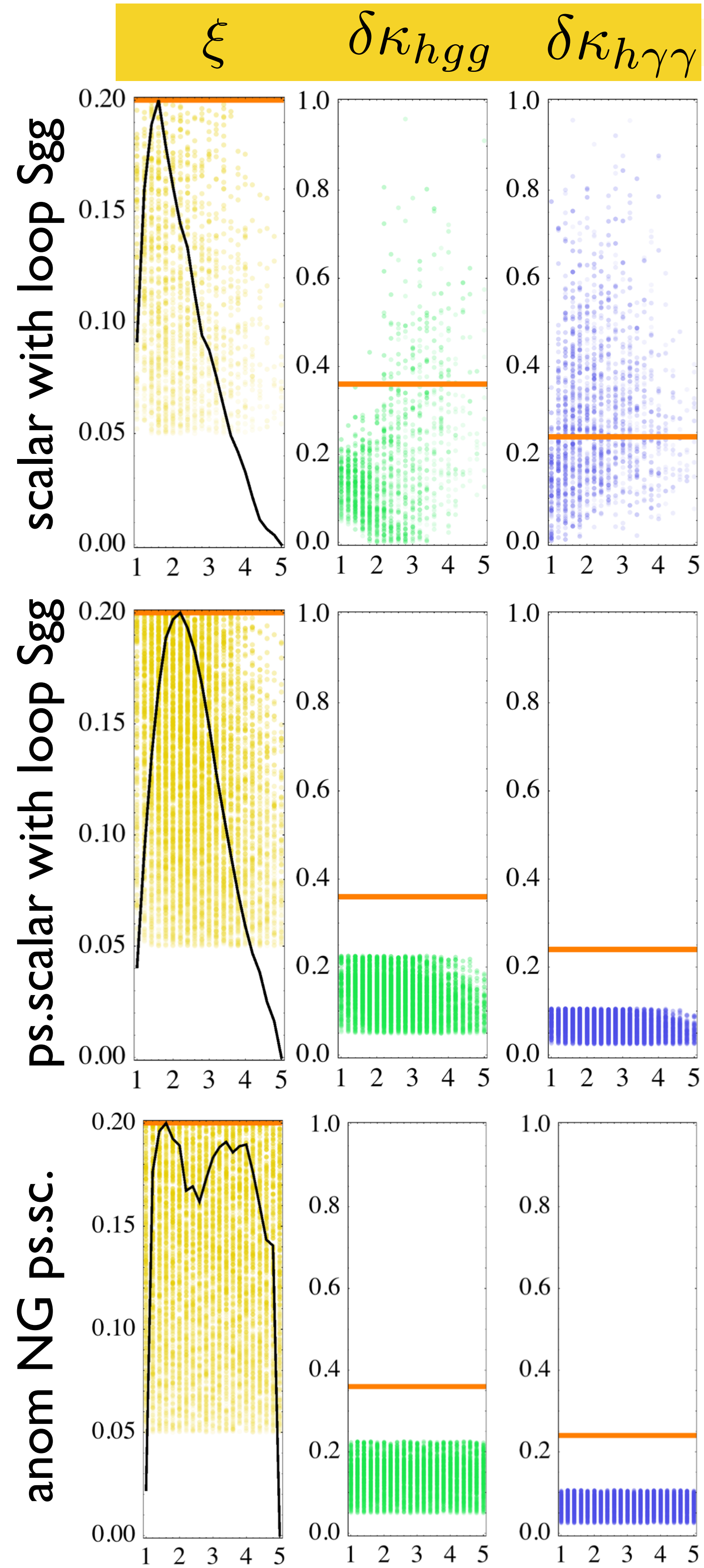
- all the order-1 coefficients are varied between 0.5 and 2, such that P(k=0.5…1)=P(k=1…2)

- $\xi = 0.05 - 0.2$

- “likelihood” for NP responsible for the excess to reside at a particular value of m_ρ:

$$\mathcal{L}(m_\rho) = \sum_i \xi_i(m_\rho)$$

Numerical Scan



$m_\rho \sim 1.5TeV$

(th estimate $m_\rho \lesssim 1TeV$)

$\Gamma_S = 10 - 20GeV$

deviations in $H\gamma\gamma$

$m_\rho \sim 2.5TeV$

(th estimate $m_\rho \lesssim 1TeV$)

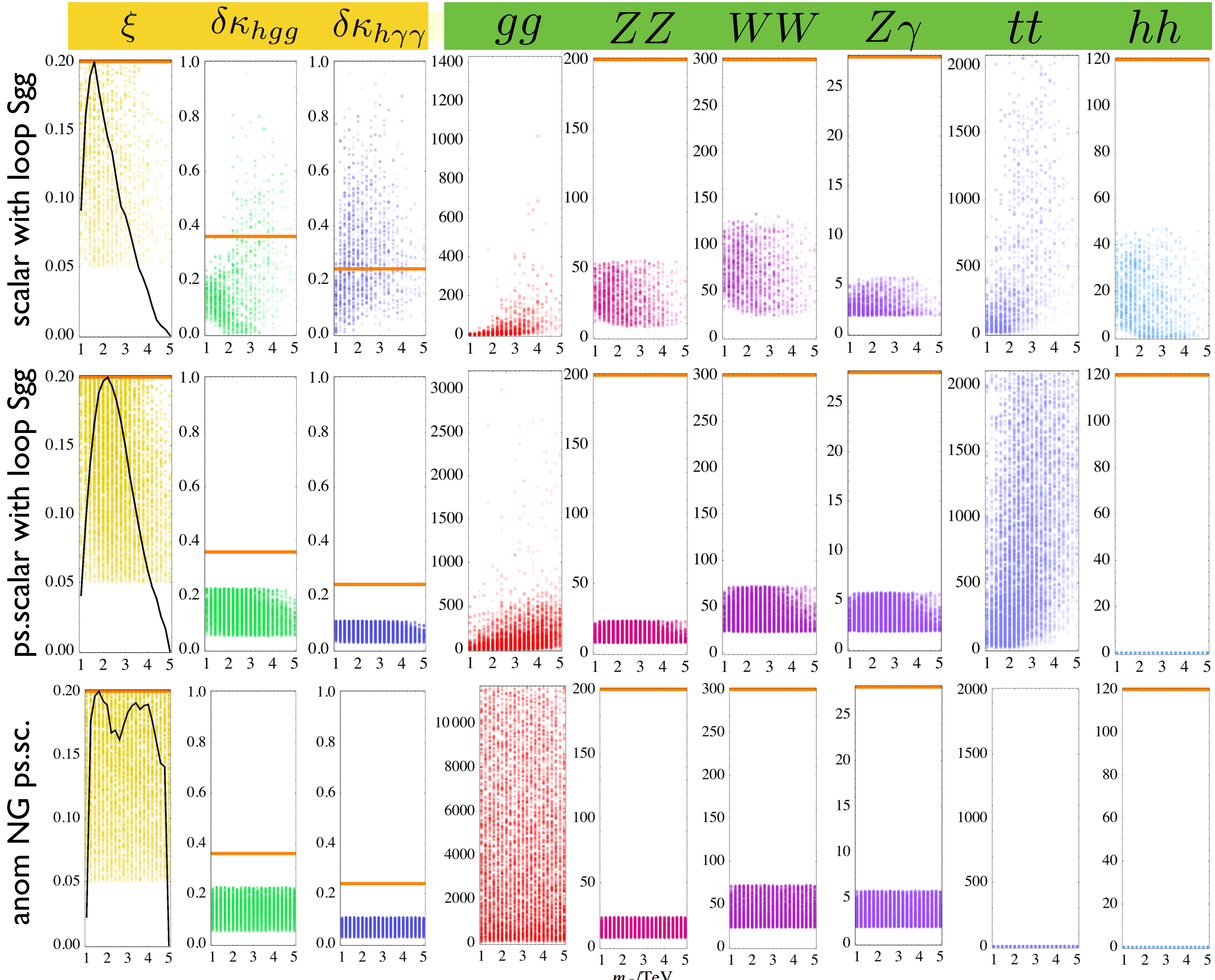
$\Gamma_S = 10 - 20GeV$

no preference for m_ρ

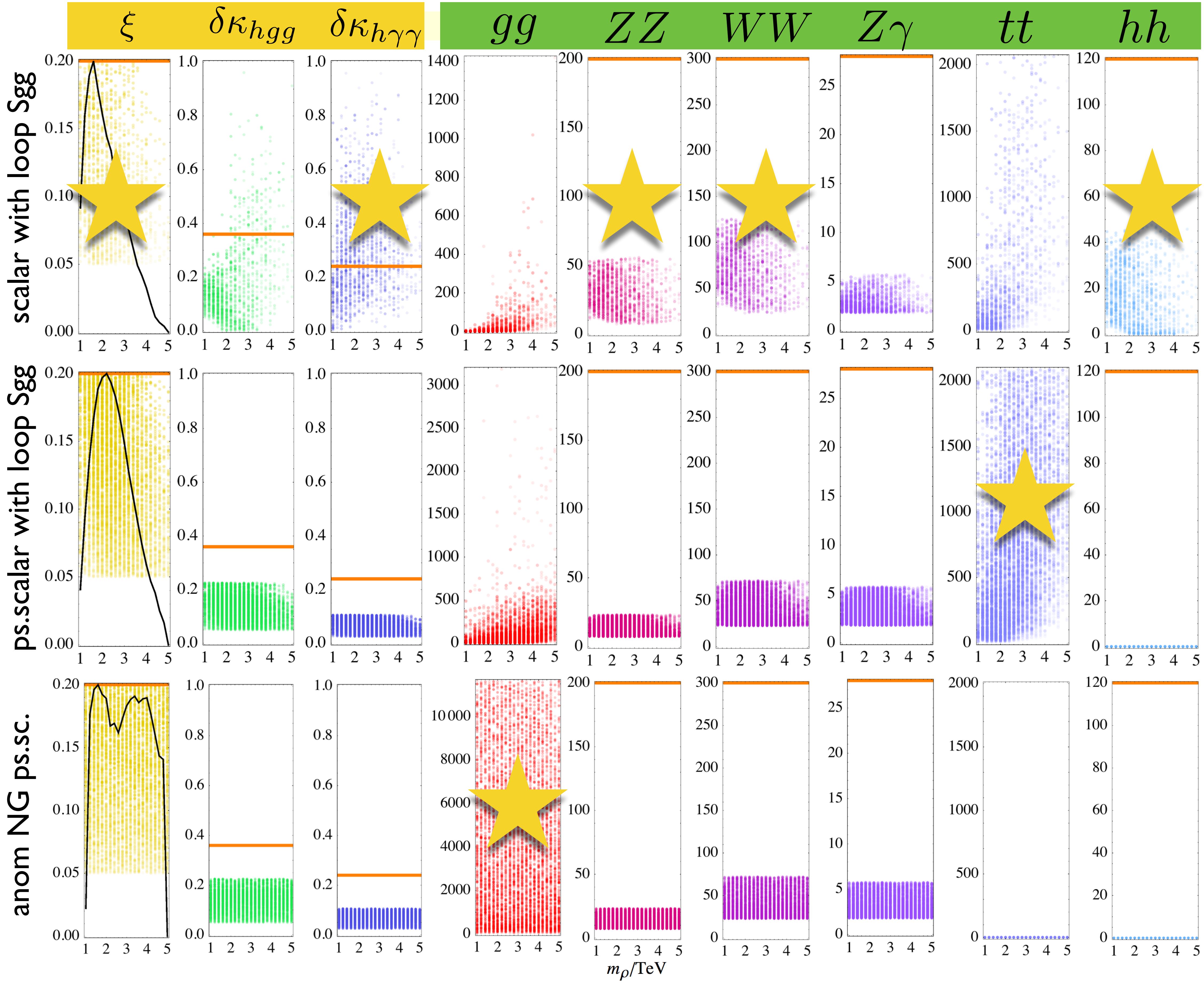
(th estimate $m_\rho \lesssim 3TeV$)

$\Gamma_S < 1GeV$

Numerical Scan



Numerical Scan

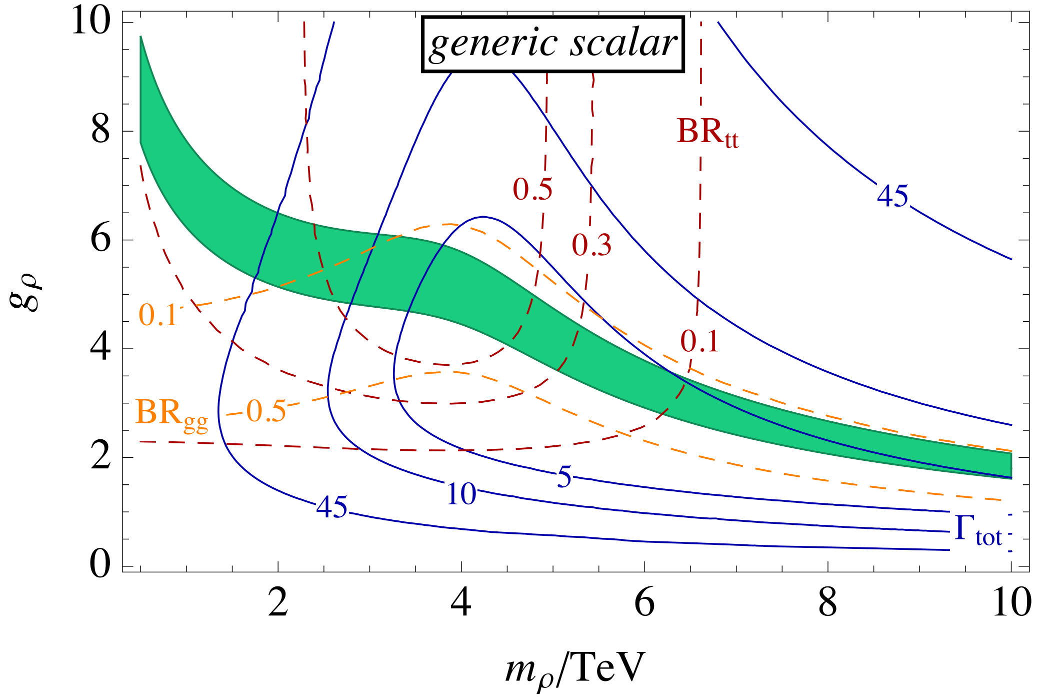


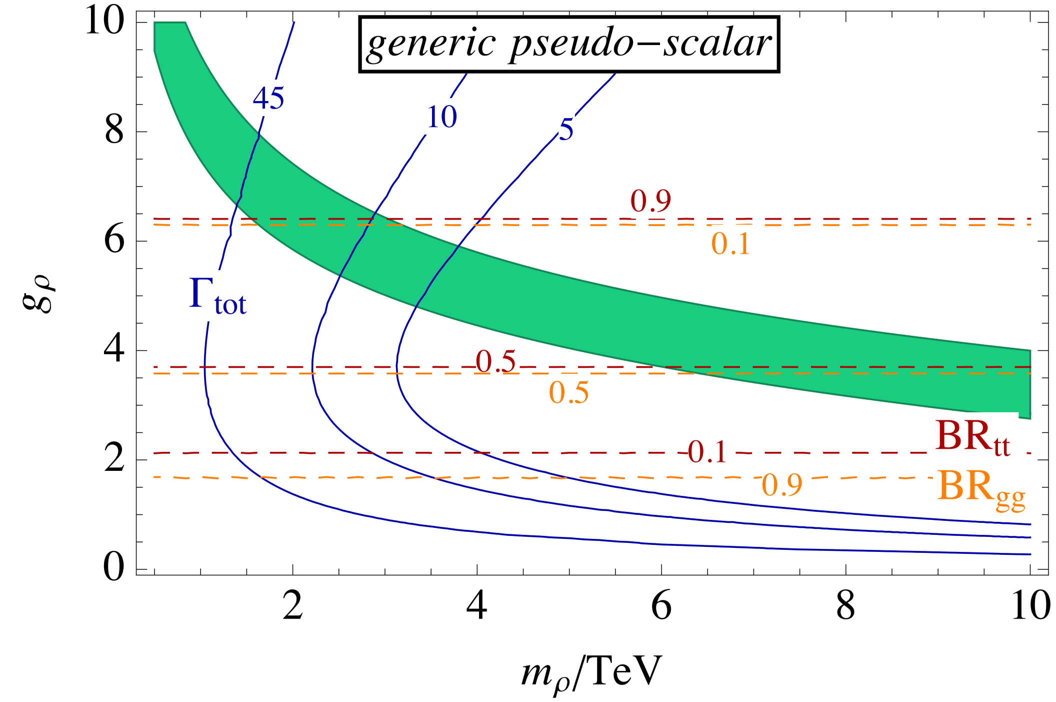
Conclusions

- we tested several composite S+H scenarios within a common EFT framework and identified the most viable ones
- the features necessary to reproduce the “S-data” give useful guidelines for building UV completions
- derived patterns of possible future signals in different channels can allow to distinguish between different scenarios

Thank you!

BR's


generic scalar
g_ρ
m_ρ/TeV
BR_{tt}
BR_{gg}
Γ_{tot}
45
10
5
0.5
0.3
0.1


generic pseudo−scalar
g_ρ
m_ρ/TeV
Γ_{tot}
BR_{tt}
BR_{gg}
45
10
5
0.9
0.1
0.5

bounds

parameter	8TeV	13TeV
$\sigma_{\gamma\gamma}$	< 1.5 fb	
σ_{ZZ}	< 12 fb	< 200 fb
σ_{WW}	< 40 fb	< 300 fb
$\sigma_{Z\gamma}$	< 11 fb	< 28 fb
σ_{hh}	< 39 fb	< 120 fb
σ_{tt}	< 450 fb	
σ_{jj}	< 2.5 pb	
$\kappa_{h\gamma\gamma}$	1.0 ± 0.24	
κ_{hgg}	1.12 ± 0.24	