# Wide Composite Vector Resonances at the LHC

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Rencontre de Physique des Particules
LAPTh Annecy

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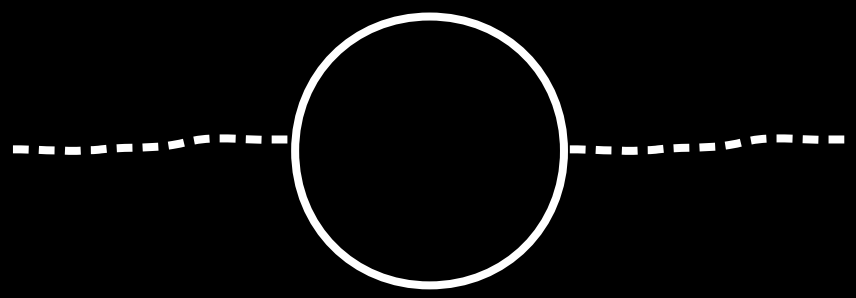
# Outline

- Naturalness and the Composite Higgs paradigm
- Composite Higgs at the LHC
- Bounding elusive partners: status and prospects
- Conclusions

# Naturalness and Composite Higgs



$\sim \Lambda^2$

- Naturalness considerations are still on of the main guidance for the search of BSM Physics at the LHC
- In the SM no symmetries are protecting the 125 GeV scalar from quadrative divergent radiative corrections
- NP contributions are required to stabilise the EW scale
- A moderate level of fine tuning requires NP to lie at the TeV scale
- The Goldstone symmetry guarantees lightness of scalars

# Naturalness and Composite Higgs

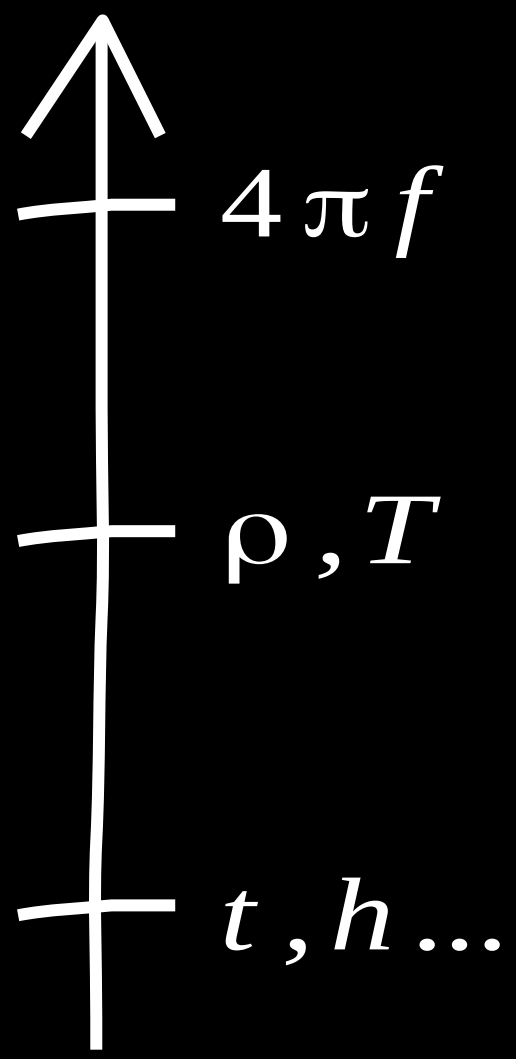
General idea

- The Higgs is a bound state of a new strongly interacting sector at a scale f >> v with a cut-off scale ~10 TeV [Georgi and Kaplan '84]
- The lightness of the Higgs is ensured by its pseudo GB nature
- Strong sector resonances stabilise the Higgs mass at the EW scale

Concrete realisations

- SO(5)/SO(4) coset ensures 4 Gbs and a custodial symmetry: MCHM [Agashe et al. '05]
- Two sets of composite resonances below the theory cut off:
  - Spin one states, $\rho^0, \rho^\pm$
  - Spin one half states, vector like top partners
- Non minimal cosets can provide extra scalars and DM candidate

# Naturalness and Composite Higgs



# A minimal Lagrangian for a Composite Higgs

[For a comprehensive review see Panico and Wulzer '15]

$$L \supset \frac{f^2}{4} d_\mu^2 - \frac{1}{4} \rho_{\mu\nu}^2 + \frac{M_\rho^2}{2} \left(\rho_\mu - \hat{e}_\mu / g_\rho\right)^2 + \bar{\Psi}\left(i \hat{D} - M\right)\Psi + \bar{t}_R \hat{D} t_R$$

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  [Kaplan '91]

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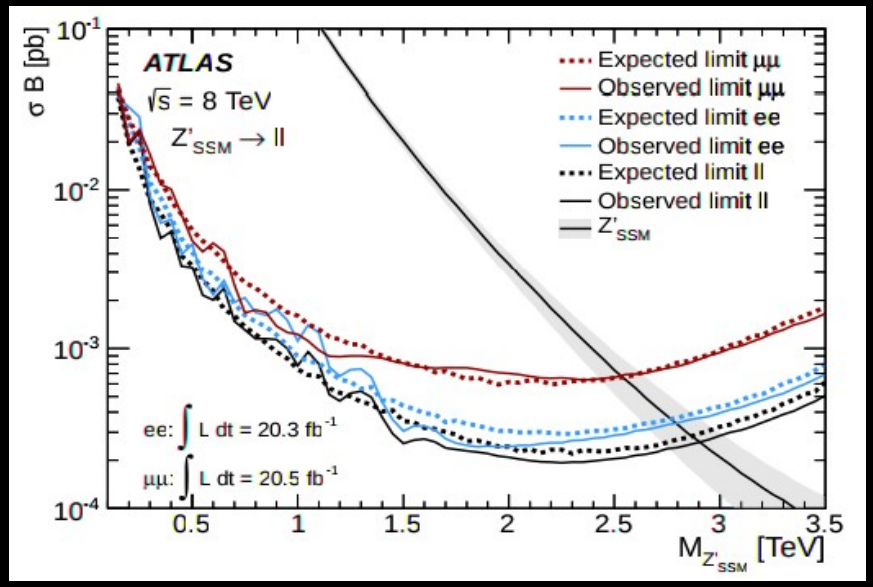
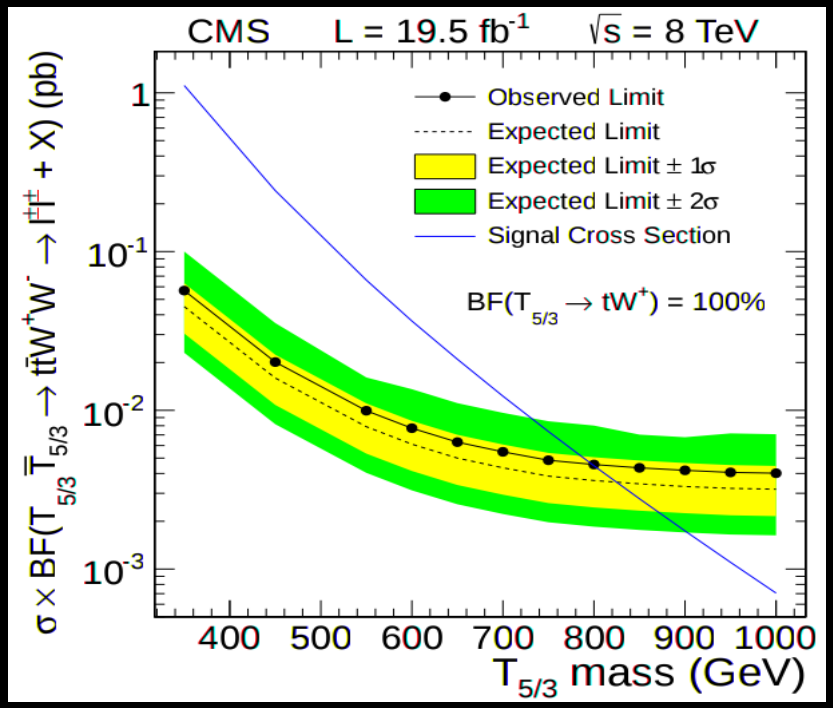
Rich phenomenology to be explored at the LHC

# Composite Higgs at the LHC

[For a comprehensive review see Panico and Wulzer '15]

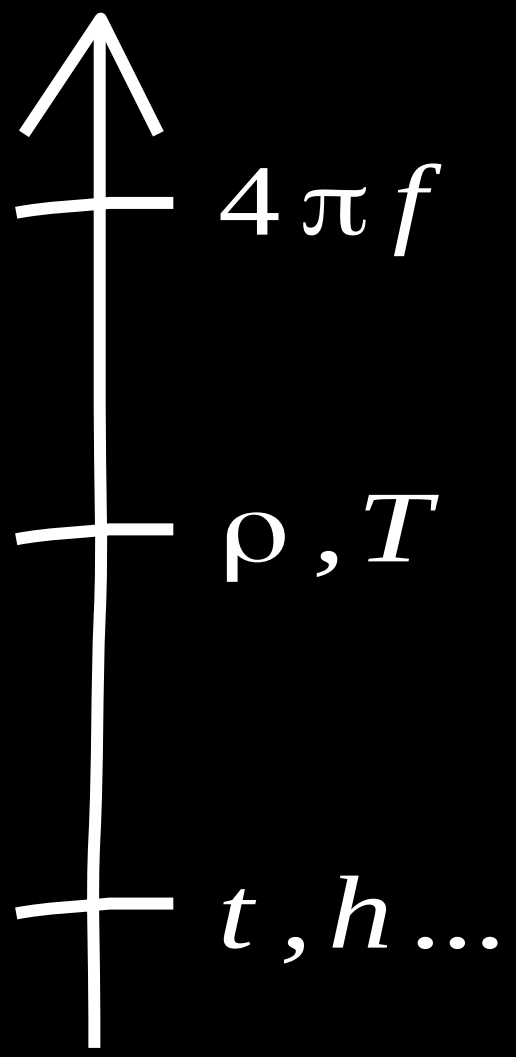
- Modifications of the Higgs signal rates, controlled by $\xi \equiv v^2/f^2$
- DY and diboson production of $\rho$ resonances: (semi)leptonic final states
- Pair and single production of VLQs




- Limits on $\rho$ resonances ~ 2 TeV, essentially from dilepton
- Limits on VLQs ~ 800 GeV, essentially from pair production

# Naturalness and Composite Higgs



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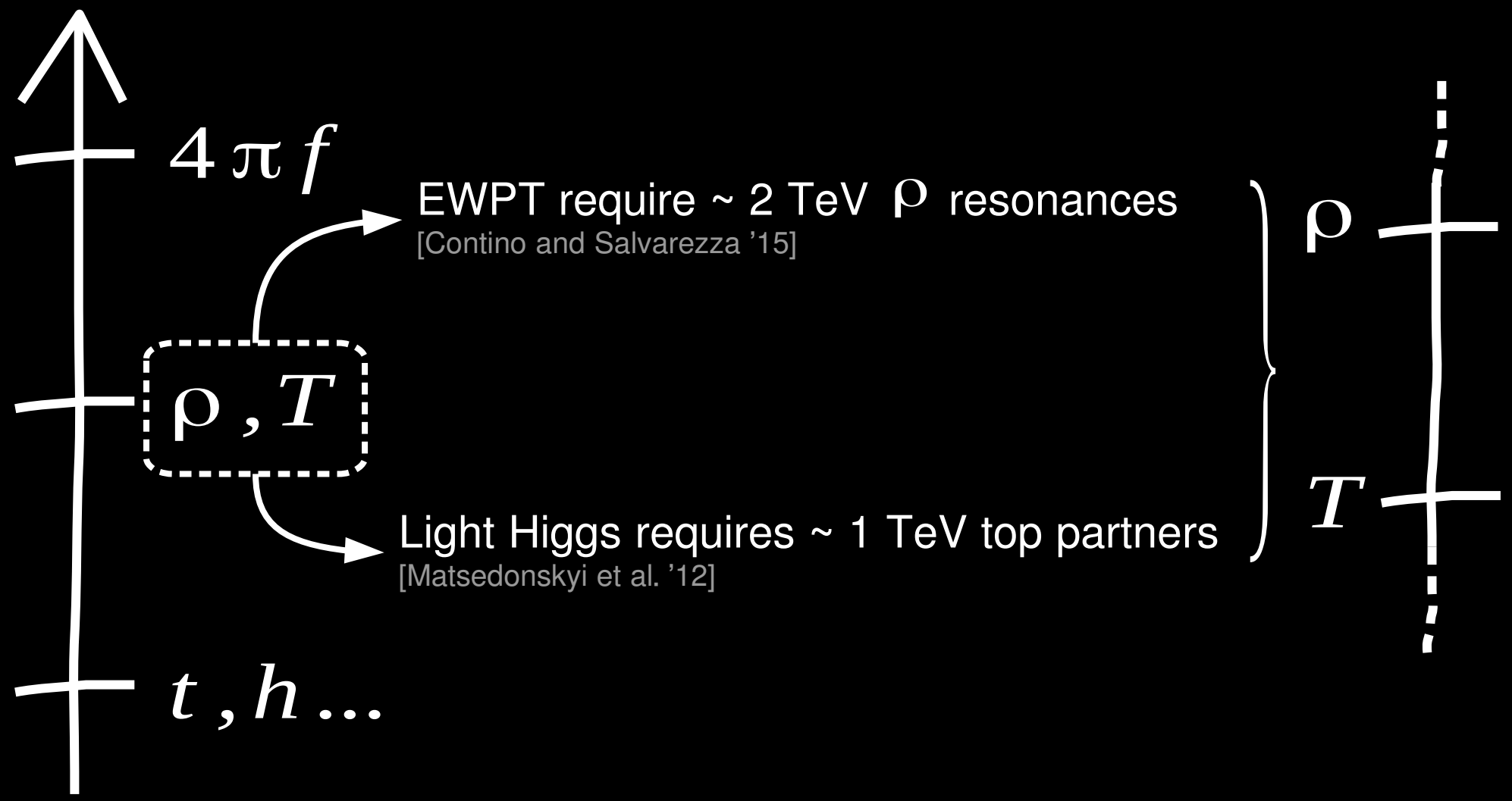
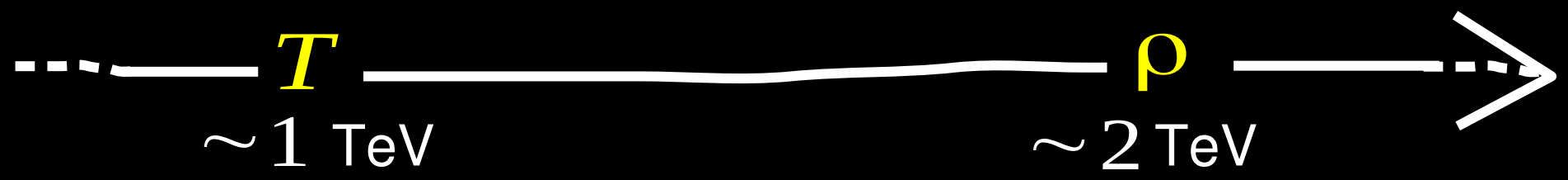
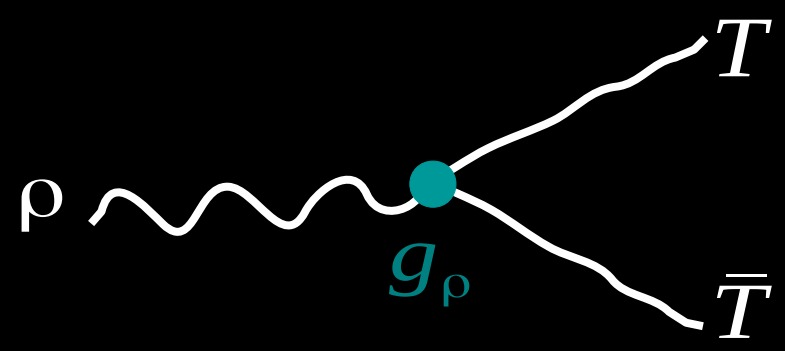


# Wide ρ at the LHC

- Naturalness, a light Higgs and the LEP/LHC data point to a particular spectrum configuration



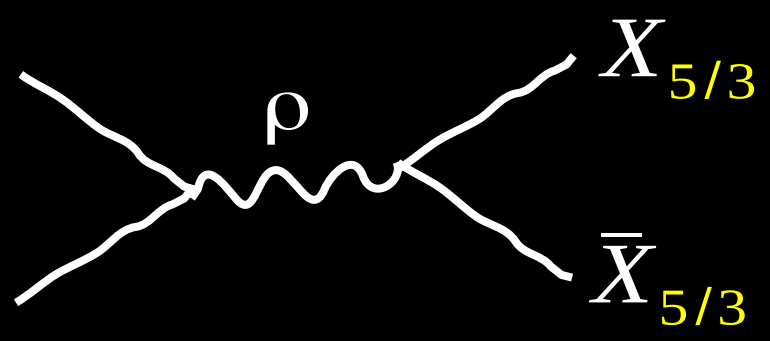



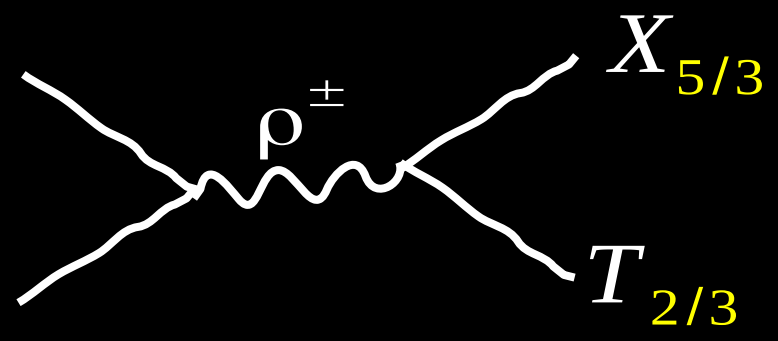

$BR \sim 1$

- If kinematically allowed $\rho$ will mainly decay into VLQs, since $g_\rho \gg g_{ew}$
- This relax LHC limits on $\rho$ masses. Stronger limit set by the S-parameter
  [DB et al. '12, Greco and Liu '15]
- It allows a different pair production mode for VLQs

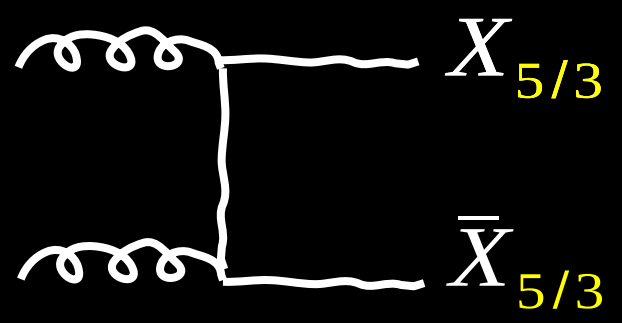
# Wide $\rho$ at the LHC

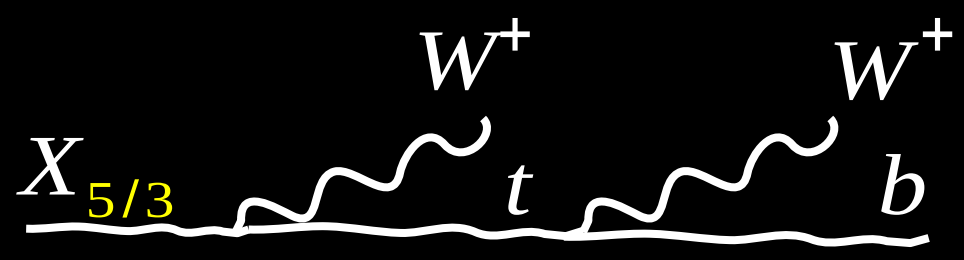
- Typically, $\rho$ mainly decay in the $(X,T)_{7/6}$ doublet




- $X_{5/3}$ decays through charged current and give rise to a SS2L final stat
- The SS2L search use to bound $X_{5/3}$ can be exploited to constrain $\rho$

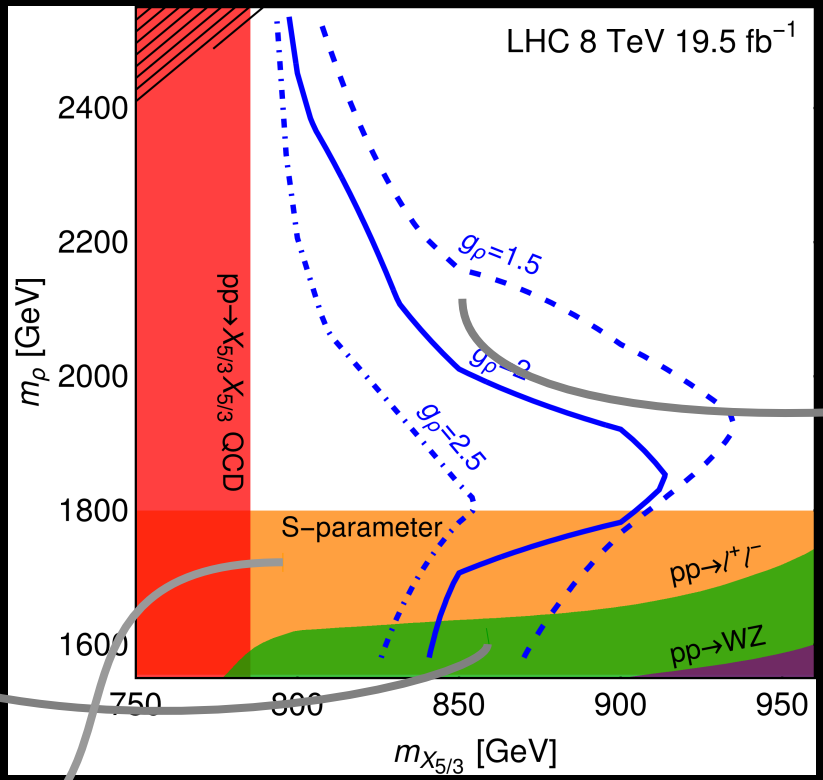


# Wide ρ at the LHC

- We recast the CMS SS2L analyses targeting QCD pair produced $X_{5/3}$

Direct searches not effective if $m_\rho > 2 m_{X_{5/3}}$



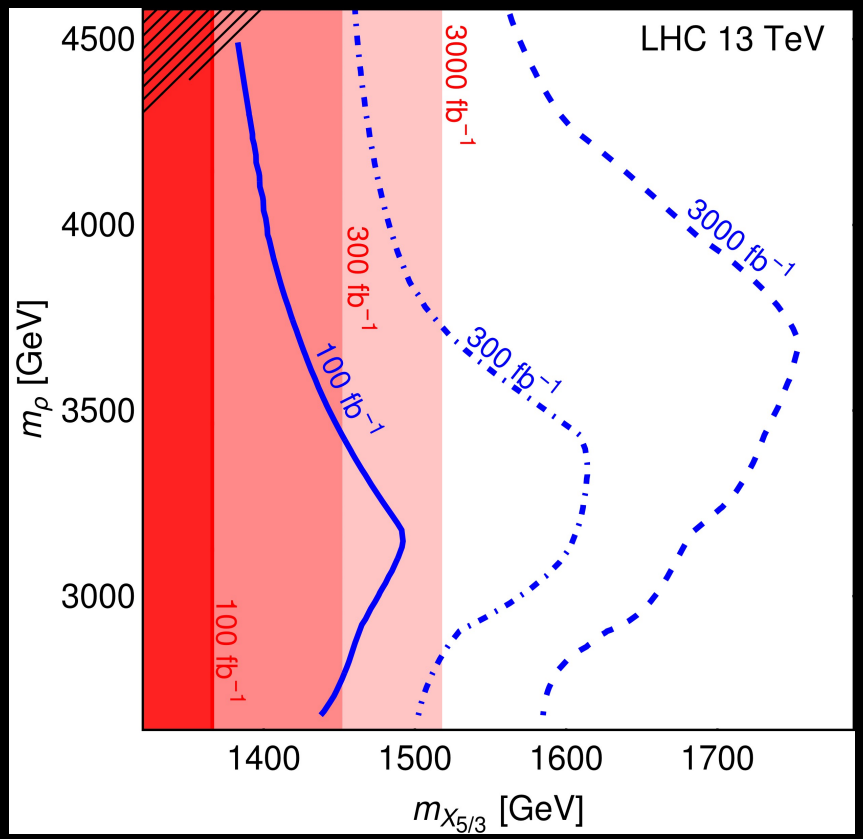

LHC8 already set bounds on this naturalness favoured regime

S-parameter sets the stronger bound

[CMS SS2L search available at the MadAnalysis5 Public Analysis database wepage]

# Wide $\rho$ at the LHC

- Testing the 13 TeV LHC sensitivity on this scenario




- Sensitivity with 100/fb comparable with 3000/fb and just QCD production
- Up to 3500 GeV $\rho$ with 1700 GeV $X_{5/3}$ can be excluded
- CMS already released SS2L analysis with ~3/fb at 13 TeV. Not included here
- Significant increase of the fine tuning associated with top partners in CHMs

- If SS2L signals are detected, possible to investigate the underlying model structure. High luminosity is required.

# Conclusions

- Composite Higgs models are a compelling alternative to SUSY theories
- Naturalness, a light Higgs and present collider data point to a scenario where $\rho$ can decay into a pair of light top partners
- These wide $\rho$ excape the limits from direct searches, due to their reduced rates into SM final states
- Providing an alternative mode for pair producing top partners they can be bounded using VLQs designed analyses already with 8 TeV data
- LHC 13 will greatly improve on this naturalness favoured scenario
- Reconstruction of (possible) SS2L excess will shed light on the underlying physics structure

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Thank you!