A Light Composite Higgs and its Heavy Vector Partners

Kenneth Lane, with Lukas Pritchett
Boston University

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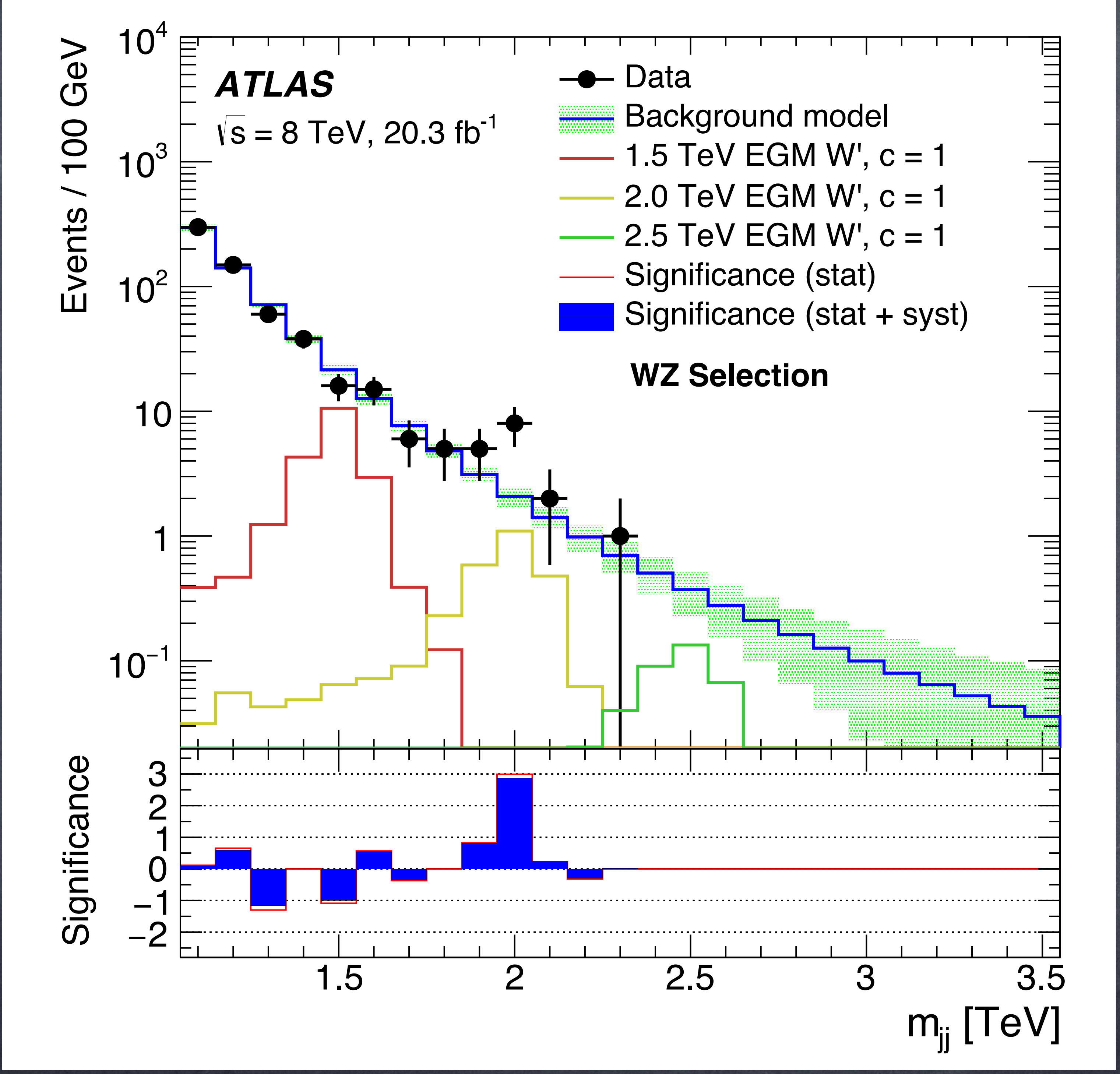
- The data
- The light composite Higgs model
- $\rho_H, a_H \to VV, VH$ decays
- $\rho_H,\, a_H \to VV,\, VH$ cross sections
- Tests for Run 2

ATLAS "WZ" nonleptonic



Run 1

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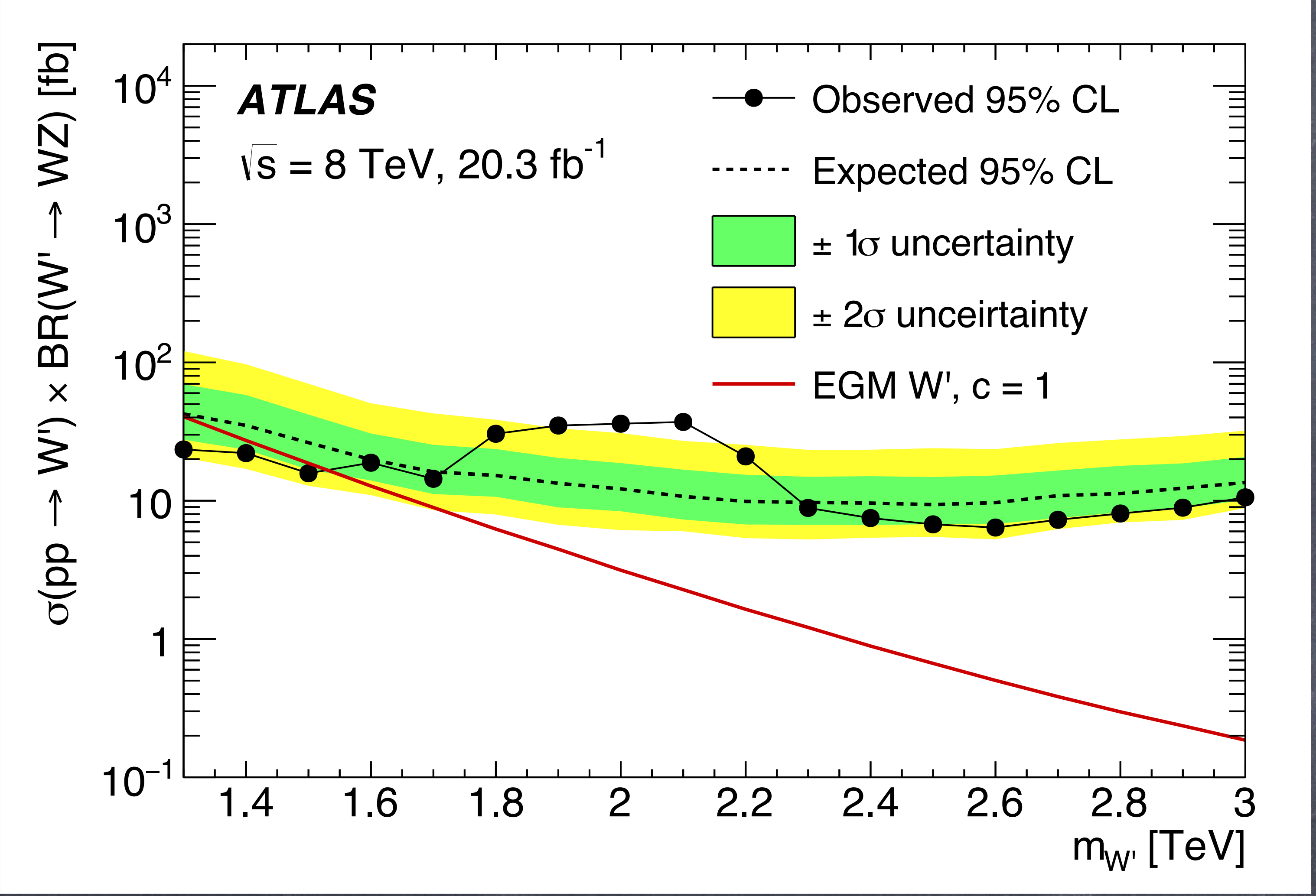
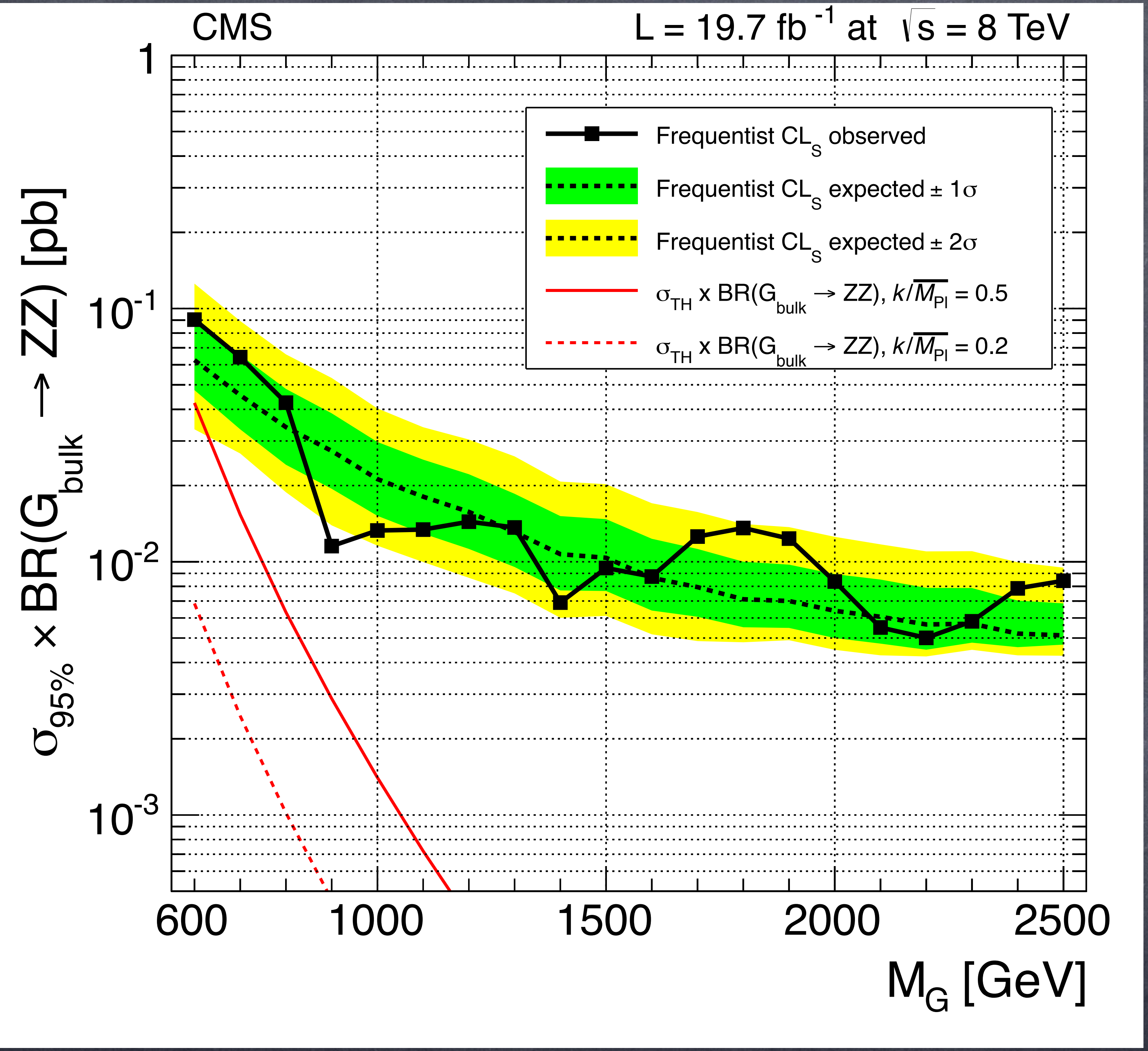


Run 1

CMS "ZZ" semileptonic



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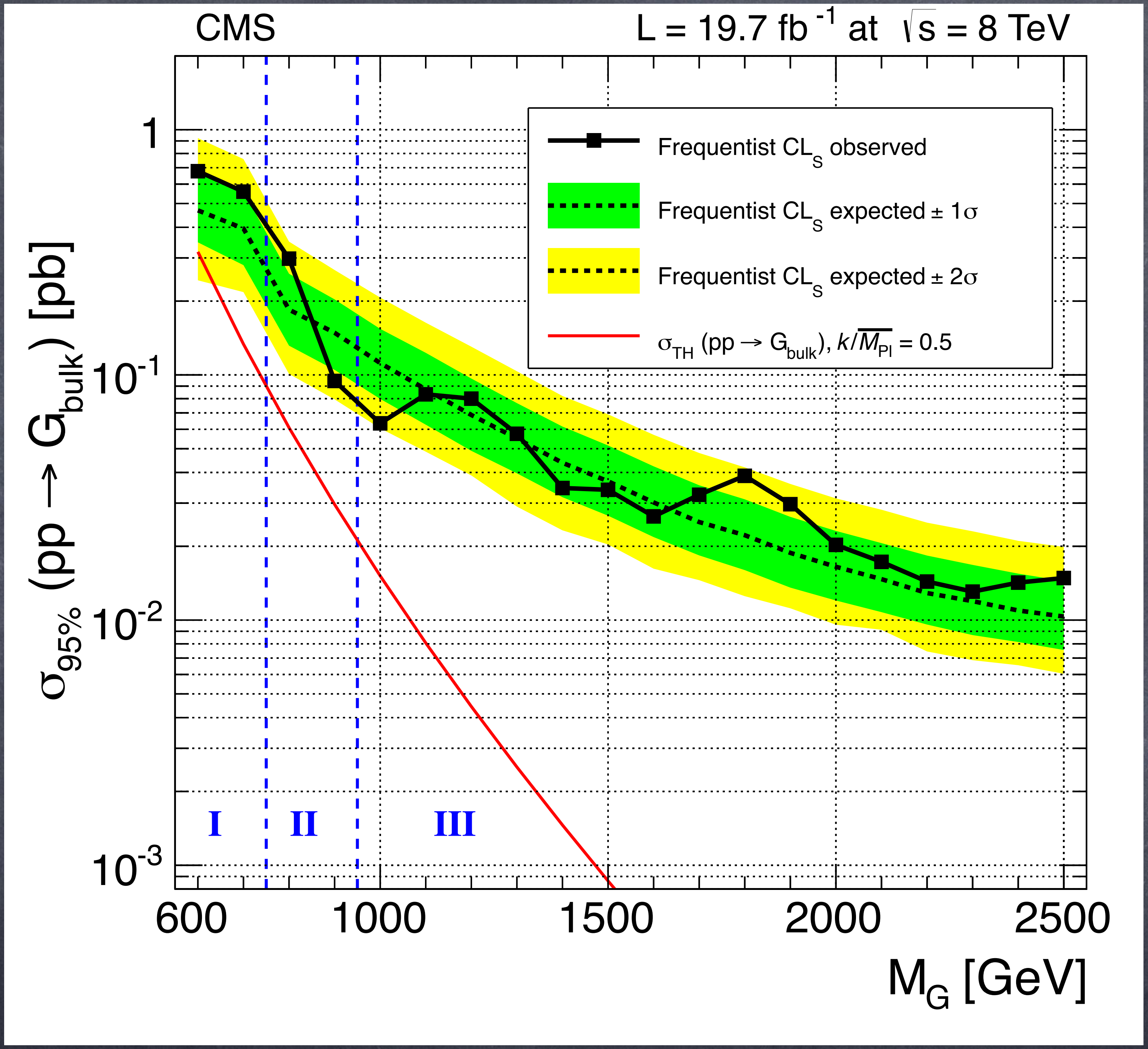

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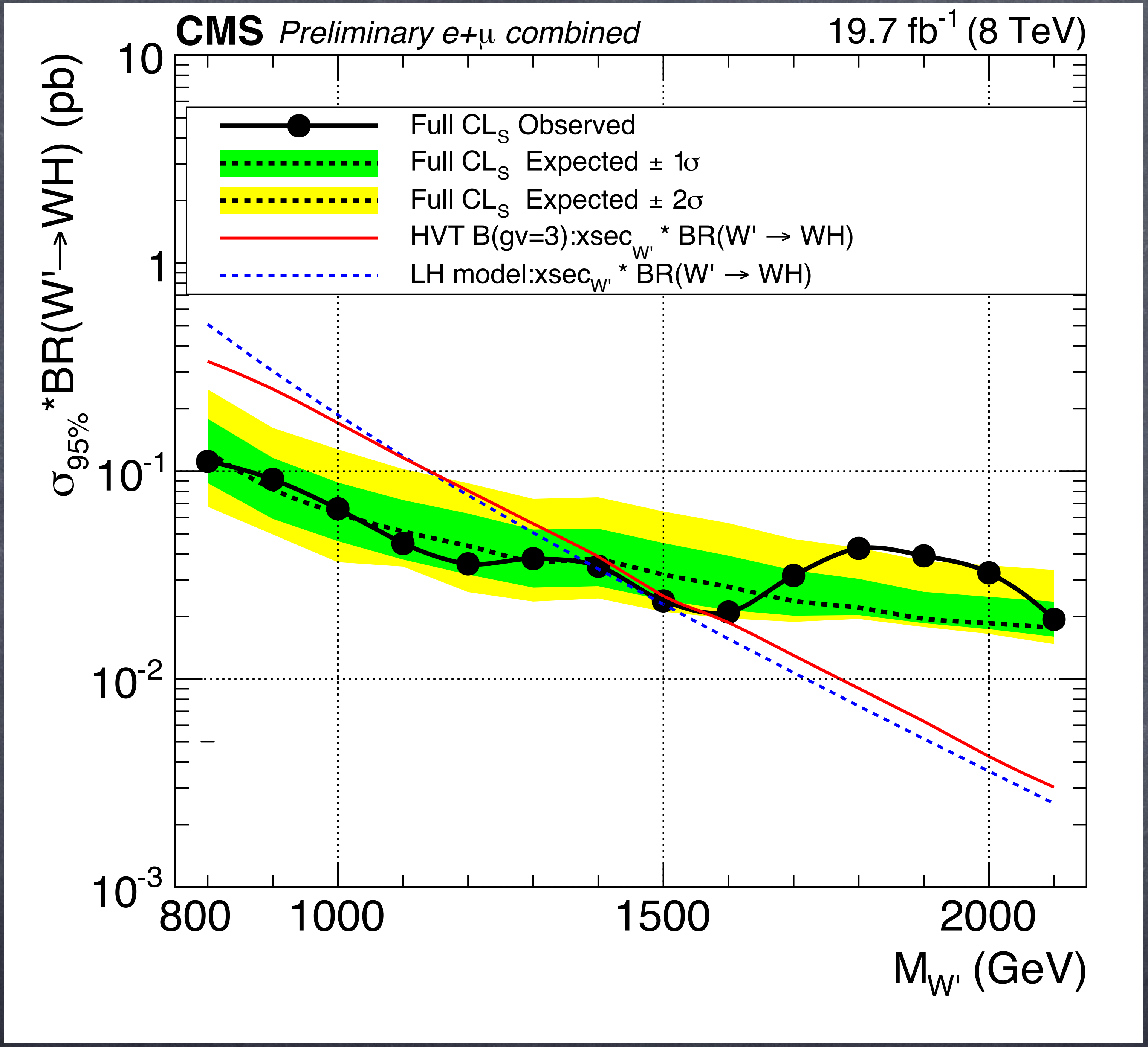

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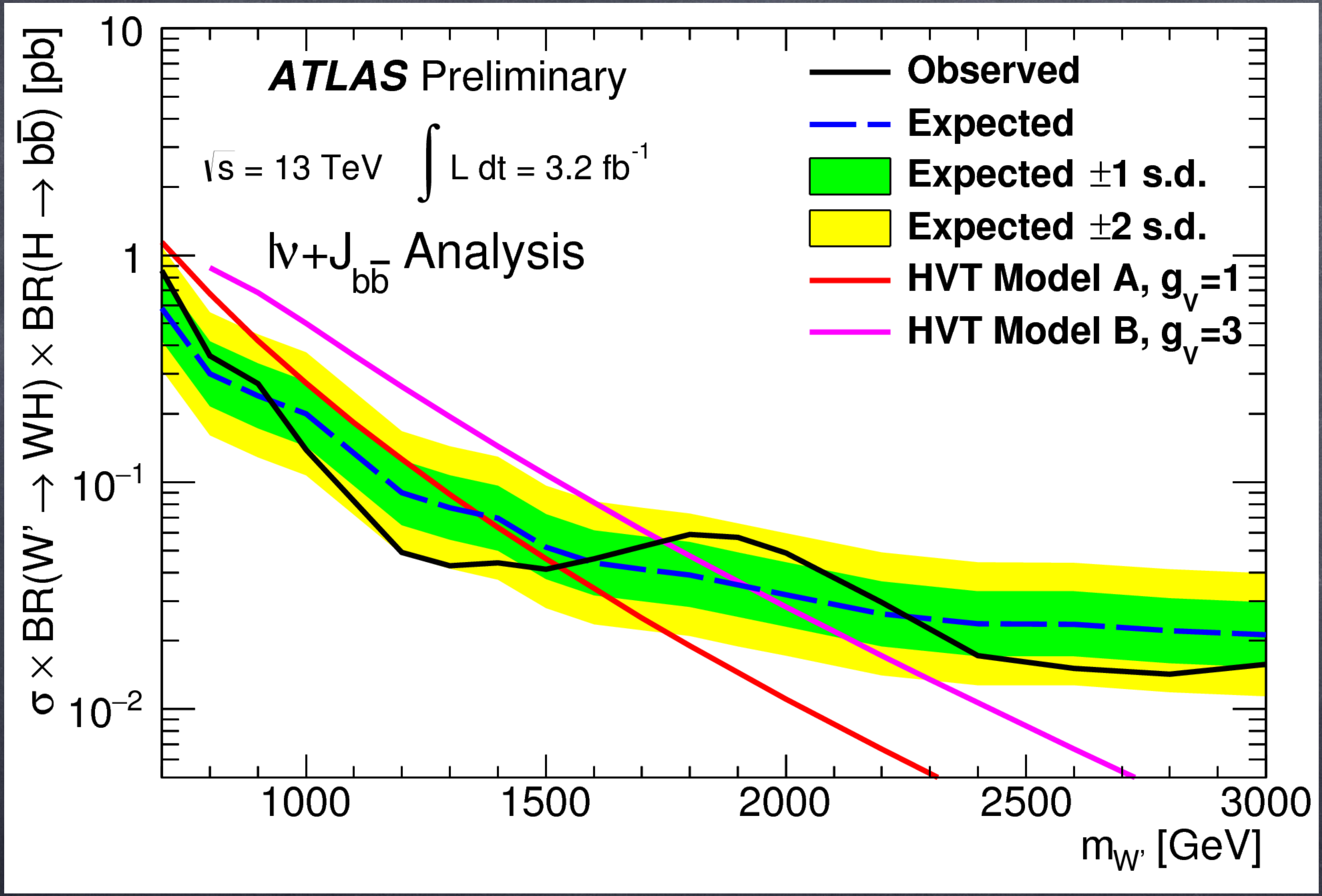
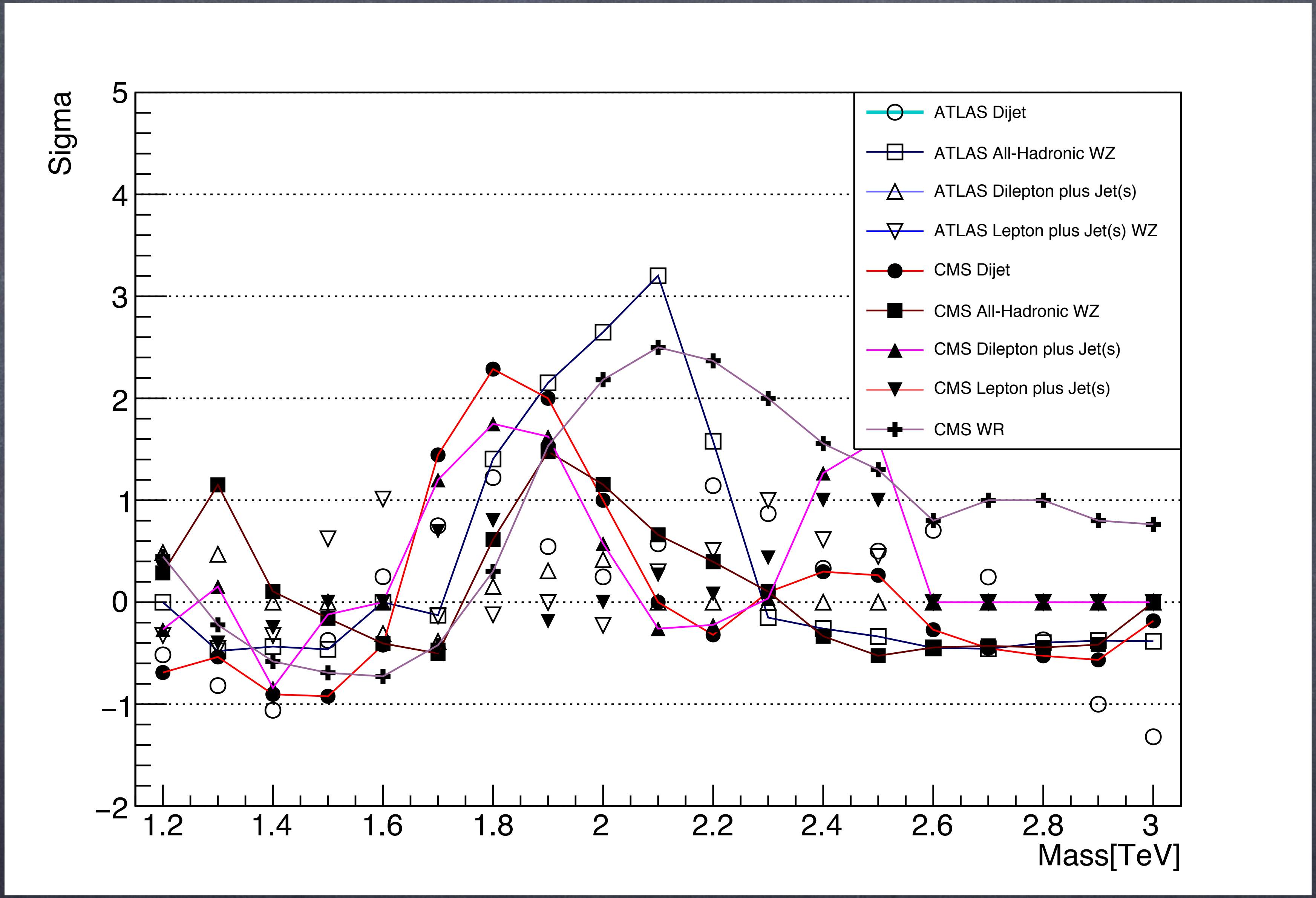


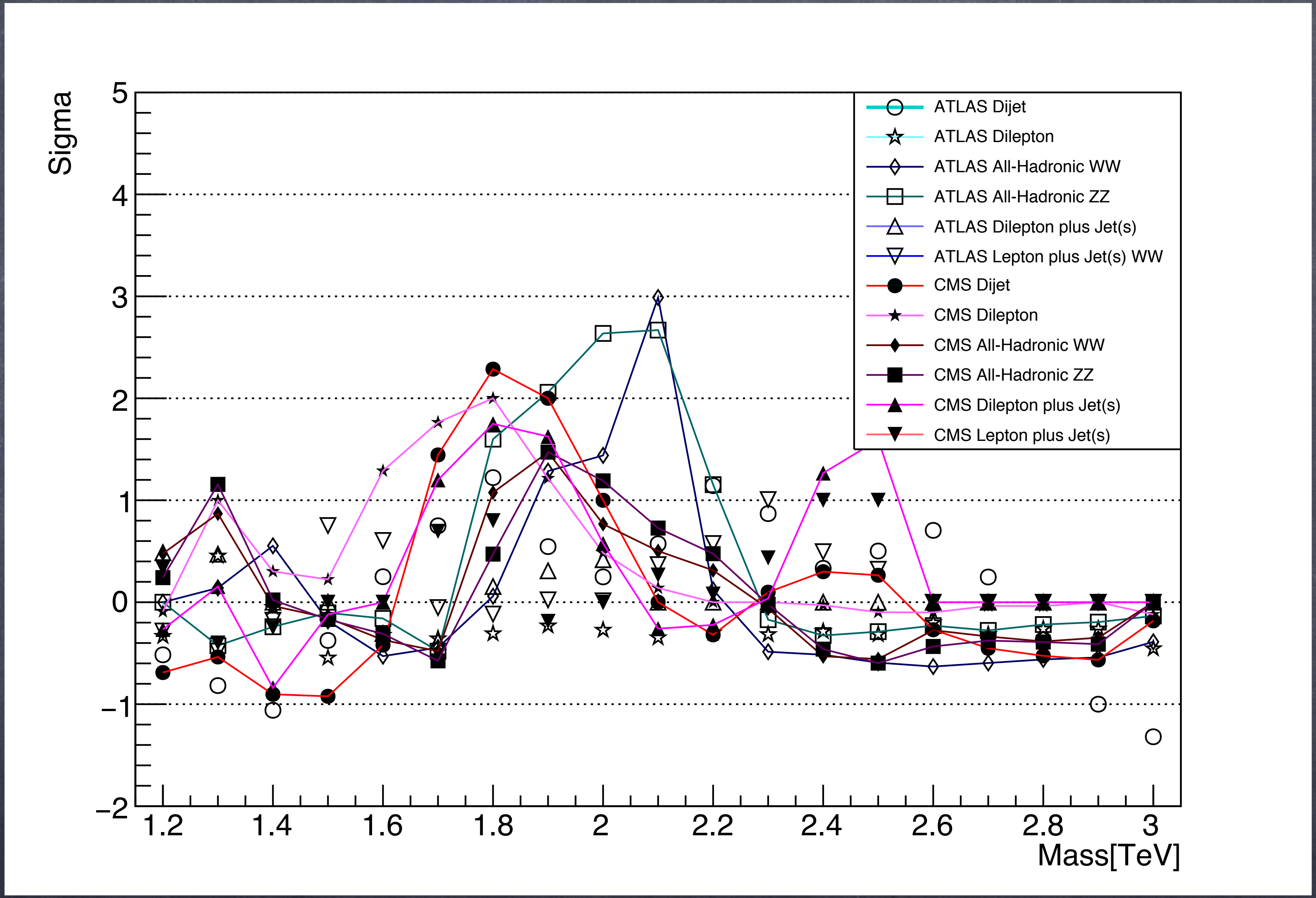
Run 2

“WZ” resonance significances



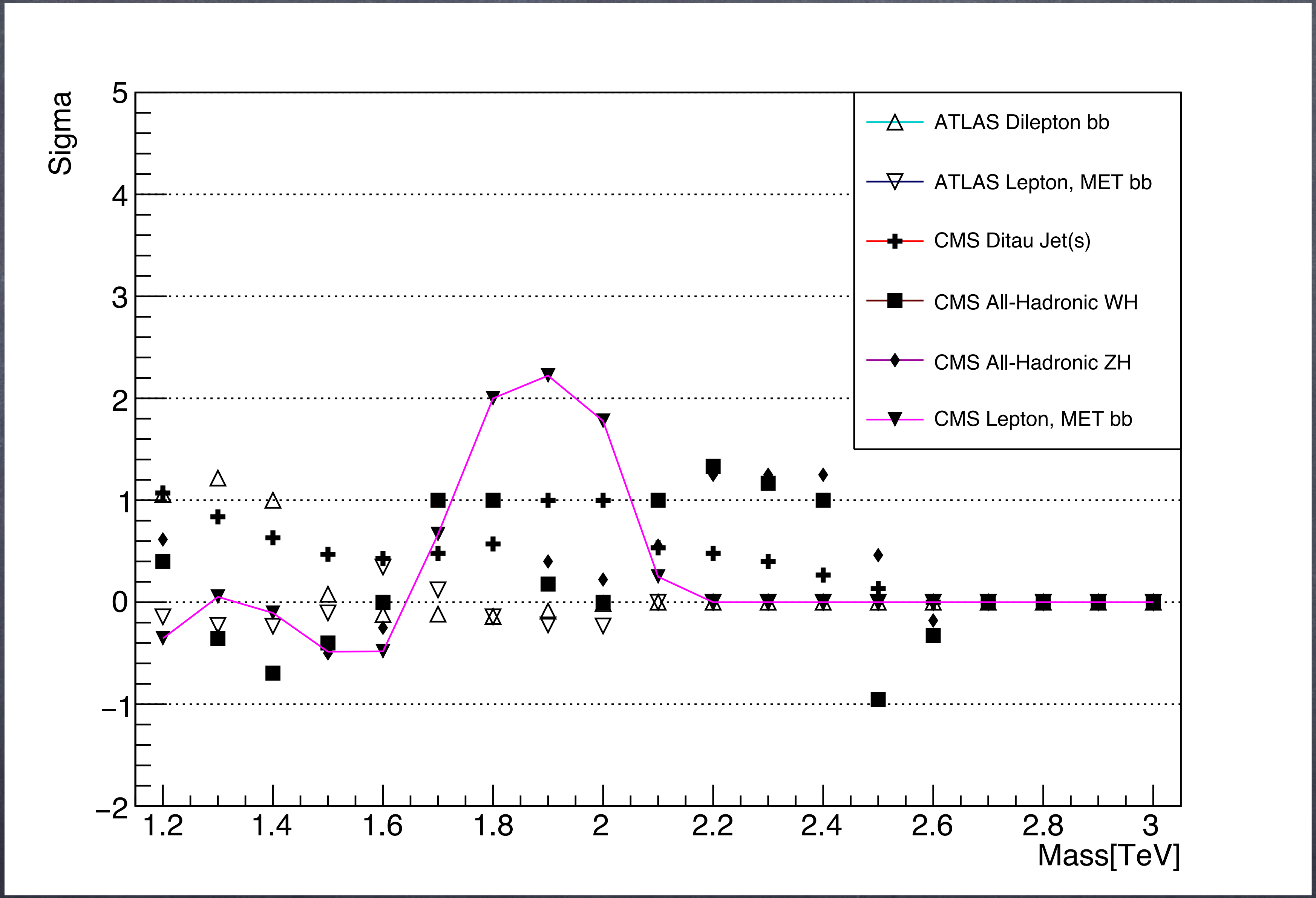
Run 1

“WW,ZZ” resonance significances



Run 1

WH resonance significances



Run 1

A new composite Higgs model

- ALL models for H(125) are finely-tuned:

-> The SM (of course)

-> SUSY

-> even composite Higgs models!

They require top, W-partners — none have been found.

(see, e.g., Guidice 1307.7879

Bellazzini, Csaki, Serra 1401.2457,

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Do we need top, W partners?

A new composite Higgs model

TC models (Yamawaki, et al., Sannino, et al.)

- No plausible explanation why H(125) is so light (dilaton??)

- No plausible explanation why H(125) is so much lighter than other technihadrons — where is ρ_T??

A new composite Higgs model

(KL, PRD 90, (2014) 9, 09525; arXiv:1407:2270;
KL + Luke Pritchett, in preparation;
see also Chivukula, Cohen, KL NPB 343 (1990) 554)

A fine-tuned solution (inspired by BHL PRD41, 1647 (1989))

NJL applied to strong ETC:

- Strong ETC, not TC, drives EWSB!

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- Strong ETC, not TC, drives EWSB!
- ETC coupling is fine-tuned to be near the critical value for EWSB.

The fine tuning: in the large-N approximation,

$$m_f, M_H \simeq 2m_f \ll \Lambda_{ETC} = \Lambda$$ (a physical cut-off)

A new composite Higgs model

- WEAK TC binds T-fermions to make technihadrons $\rho_H, a_H, \ldots$ with

$$M_{\rho_H}, M_{a_H}, \cdots = \mathcal{O}(\Lambda_{TC}) = 1 - 2\,\mathrm{TeV} \gg M_H,\ \text{but} \ll \Lambda$$

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(this slide is too small to hold the argument)

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$$M_{\rho_H}, M_{a_H}, \cdots = \mathcal{O}(\Lambda_{TC}) = 1 - 2\,\mathrm{TeV} \gg M_H, \text{ but } \ll \Lambda$$

- The Higgs is much lighter than $\rho_H, a_H, \ldots$

- and there are no top, W-partners!

a simplest TC-ETC model:

$$\mathcal{L}_{ETC} = G_1\, \bar{q}_L^{ia}\, t_{Ra}\ \bar{t}_R^{b}\, q_{Lib} + G_3\, \bar{T}_L^{i\alpha}\, U_{R\alpha}\ \bar{U}_R^{\beta}\, T_{Li\beta} + G_2\ \left(\bar{q}_L^{ia}\, t_{Ra}\ \bar{U}_R^{\alpha}\, T_{Li\alpha} + \text{h.c.}\right)$$

$q_L = (t, b)_L \in (2, \frac{1}{6}, 3_C, 1_{TC})$, $t_R \in (1, \frac{2}{3}, 3_C, 1_{TC})$, $b_R \in (1, -\frac{1}{3}, 3_C, 1_{TC})$

$T_L = (U, D)_L \in (2, 0, 1_C, d_{TC})$, $U_R \in (1, \frac{1}{2}, 1_C, d_{TC})$, $D_R \in (1, -\frac{1}{2}, 1_C, d_{TC})$

consider this model in the limit of

large-N and weak-TC

In the limit of **large N and weak TC:**

$$m_t = \frac{G_1 N_C m_t}{8\pi^2}\left(\Lambda^2 - m_t^2 \ln\frac{\Lambda^2}{m_t^2}\right) + \frac{G_2 d_{TC} m_U}{8\pi^2}\left(\Lambda^2 - m_U^2 \ln\frac{\Lambda^2}{m_U^2}\right)$$

$$m_U = \frac{G_2 N_C m_t}{8\pi^2}\left(\Lambda^2 - m_t^2 \ln\frac{\Lambda^2}{m_t^2}\right) + \frac{G_3 d_{TC} m_U}{8\pi^2}\left(\Lambda^2 - m_U^2 \ln\frac{\Lambda^2}{m_U^2}\right)$$

Independence of N_C and $d_{TC} = \dim(d_{TC})$

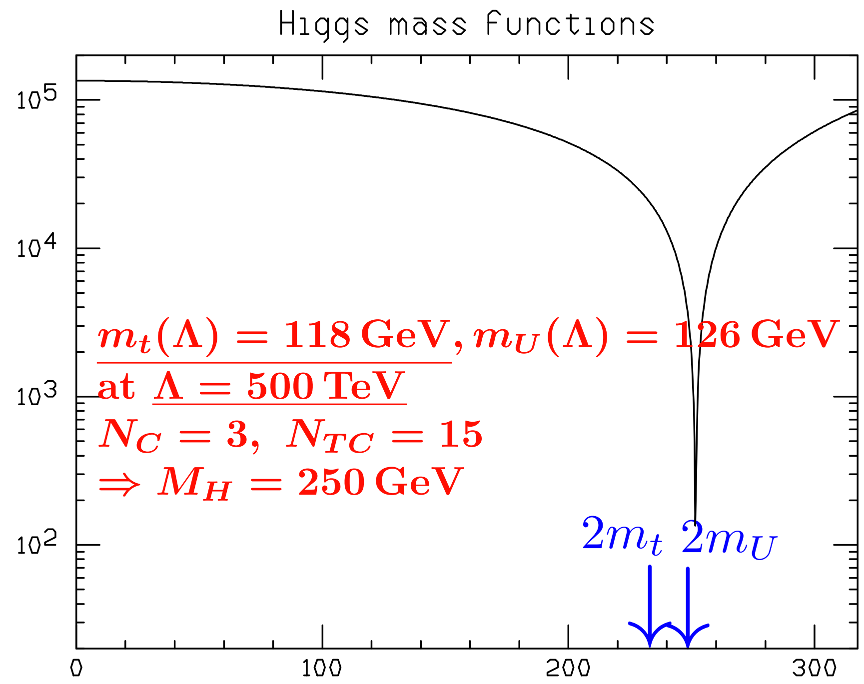
$\Rightarrow G_2 = (m_U/m_t) G_1 = (m_t/m_U) G_3$

A **magic** relation that makes everything else work—
including disappearance of Λ^2-divergence!

$$\Gamma_{0^+}^{\bar{t}t\to\bar{t}t}(p) = m_t^2\left[\frac{m_t^2 N_C(p^2-4m_t^2)}{8\pi^2}\int_0^1 dx\,\ln\left(\frac{\Lambda^2}{m_t^2-p^2x(1-x)}\right)\right.$$

$$\left.+\frac{m_U^2 N_{TC}(p^2-4m_U^2)}{8\pi^2}\int_0^1 dx\,\ln\left(\frac{\Lambda^2}{m_U^2-p^2x(1-x)}\right)\right]^{-1}$$

This has a pole at $p = M_H(\Lambda) = 250\,\mathrm{GeV}$



$$M_H \cong 2\sqrt{\frac{N_C m_t^4 + d_{TC} M_U^4}{N_C m_t^2 + d_{TC} M_U^2}}$$

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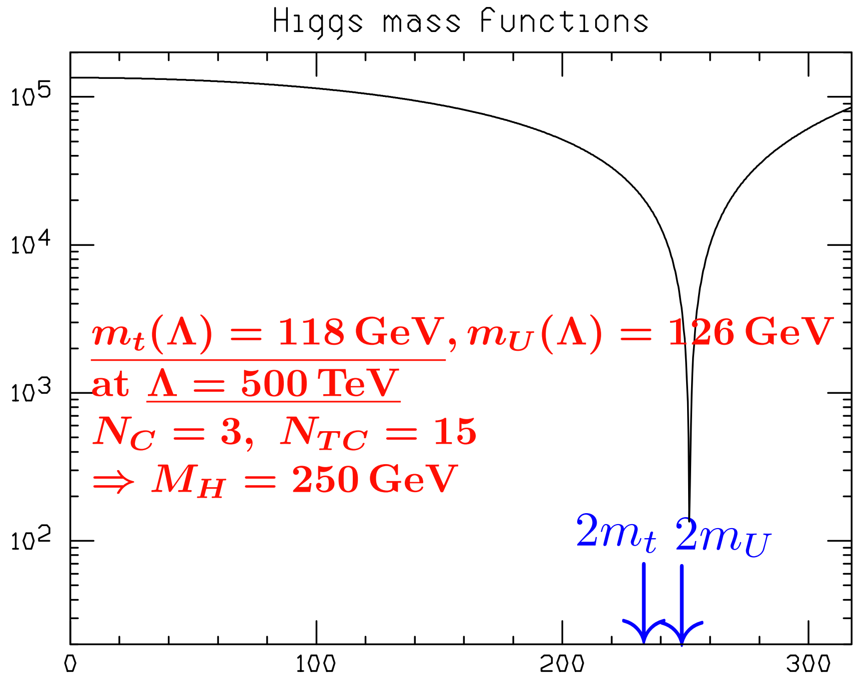

$$M_H \cong 2\sqrt{\frac{N_C m_t^4 + d_{TC} M_U^4}{N_C m_t^2 + d_{TC} M_U^2}}$$

N.B.: These are masses at scale Λ — to be renormalized to Λ_{EW}

The Higgs' heavy vector partners — ρ_H and a_H

KL & Luke Pritchett, PLB 753, 211-214; 1507.07102

- ρ_H and a_H are the most accessible technihadron partners of $H(125)$

- Describe them via Hidden Local Symmetry as the gauge bosons of an $SU(2)_L \otimes SU(2)_R$ flavor symmetry.

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- ρ_H and a_H are the most accessible technihadron partners of $H(125)$
- Describe them via Hidden Local Symmetry as the gauge bosons of an $SU(2)_L \otimes SU(2)_R$ flavor symmetry.
- TC interactions are vectorial, isospin and parity-invariant:

$\rightarrow\ g_L = g_R \equiv g_{\rho_H} = 3-5$ (minimizes S from ρ_H and a_H too!)

$\rightarrow\ \rho^0_H \rightarrow W^+_L W^-_L,\ \rho^\pm_H \rightarrow W^\pm_L Z_L$

$\rightarrow\ a^0_H \rightarrow Z_L H,\ a^\pm_H \rightarrow W^\pm_L H$

(the Goldstone bosons of EWSB)

Decay rates and Cross sections

- ρ_H and a_H are parity-doubled isotriplets $\Rightarrow M_{\rho_H} \cong M_{a_H}$
- Near the EW phase transition $H, W_L^{\pm}, Z_L$ are a degenerate (2,2) quartet => equal decay rates!

$$\Gamma(\rho_H^0 \to W^+W^-) \cong \Gamma(\rho_H^{\pm} \to W^{\pm}Z) \cong \frac{g_{\rho_H}^2 M_{\rho_H}}{48\pi}$$

$$\Gamma(a^0 \to ZH) \cong \Gamma(a^{\pm} \to W^{\pm}H) \cong \frac{g_{\rho_H}^2 M_{a_H}}{48\pi}$$

$$\Gamma(a_H^0 \to W^+W^-) \cong \Gamma(a_H^{\pm} \to W^{\pm}Z) \cong \frac{g_{\rho_H}^2 M_W^2 M_{a_H}^3}{24\pi M_{\rho_H}^4}$$

M_{ρ_H} $(M_{a_H} = 1.05 M_{\rho_H})$	$\boldsymbol{\Gamma(\rho_H \to VV)}$ (GeV)	$\boldsymbol{\Gamma(a_H \to VH)}$ (GeV)	$\boldsymbol{\Gamma(a_H \to VV)}$ (GeV)
1800	178	184	0.82
1900	188	196	0.78
2000	198	208	0.74

for $g_{\rho_H} = 3.86$

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N.B.: These widths may be significantly depleted $(\sim 1/4?)$ by the $\bar{t}t$, $\bar{t}b$ content of H, W_L, Z_L

$\rho_H, a_H \to VV, VH$ cross sections

- ρ_H, a_H are mainly produced at LHC via Drell-Yan.
- Large VV coupling of ρ_H => appreciable VBF too.
- Small VV coupling of a_H => NO appreciable VBF.

$\sqrt{s}$ (TeV)	M_{ρ_H} (GeV)	$\sigma(\rho^{\pm}_H)$ (fb) $(DY+VBF)$	$\sigma(\rho^0_H)$ (fb) $(DY+VBF)$	$\sigma(a^{\pm}_H)$ (fb)	$\sigma(a^0_H)$ (fb)
8	1800	1.53+0.36	0.74+0.18	0.71	0.37
8	1900	1.05+0.24	0.50+0.12	0.51	0.27
8	2000	0.73+0.15	0.36+0.08	0.36	0.17
13	1800	7.61+3.67	3.74+1.93	4.65	2.23
13	1900	5.74+2.62	2.81+1.37	3.16	1.69
13	2000	4.37+1.90	2.16+0.99	2.39	1.27

for $g_{\rho_H} = 3.86,\ M_{a_H} = 1.05 M_{\rho_H},\ Y_{T_L} = 0, Y_{U_R} = -Y_{D_R} = \frac{1}{2}$

$\rho_H,\ a_H \to VV,\ VH$ cross sections

- $\rho_H,\ a_H$ are mainly produced at LHC via Drell-Yan.
- Large VV coupling of ρ_H => appreciable VBF too.
- Small VV coupling of a_H => NO appreciable VBF.
- $\sigma_{DY}(a_H) \simeq 0.5\,\sigma_{DY}(\rho_H)$
- $\sigma_{DY}(13\,\mathrm{TeV}) = 5 - 7\,\sigma_{DY}(8\,\mathrm{TeV})$!!
- $\sigma_{VBF}(a_H) < 0.01\ \sigma_{VBF}(\rho_H)$
- $\sigma_{VBF}(\rho_H) \simeq \frac{1}{4}\sigma_{DY}(\rho_H)$ at $\sqrt{s} = 8\,\mathrm{TeV}$, rising to about $\frac{1}{2}\sigma_{DY}(\rho_H)$ at $13\,\mathrm{TeV}$
- proton pdf's $\Rightarrow\ \sigma(\rho_H^{\pm}) \simeq \sigma(\rho_H^{+}) \simeq 2\sigma(\rho_H^{0})$ uniformly
  ditto for a_H
  $\Rightarrow W^+Z \gg W^-Z,\ W^+H \gg W^-H$

Predictions & recommendations for Run 2- $\mathbf{300\,fb^{-1}}$!

- VV production from ρ_H only: $W^\pm Z, W^+W^-$ but NO ZZ !

  => Distinguish W from Z — using leptonic decays.

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- Difficult to explain DY+VBF > few fb at 8 TeV.
  Therefore, Run 1 was an up-fluctuation — like H(125)!
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- There will be NO top & W partners.
  Our model doesn't need them!

That's all, Folks!