W' Searches at the LHC

– Signal & Interferences

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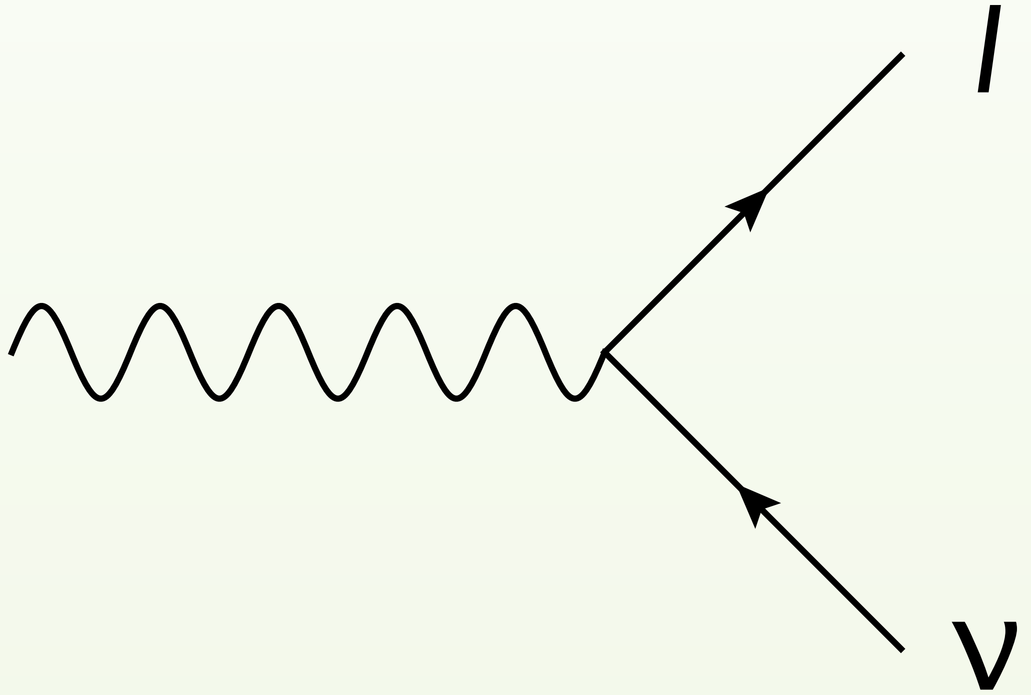
W' Searches at the LHC – Signal & Interferences

- Overview of 4-site model (Higgsless, Breaking EWS Strongly)
- Parameters of the model and constraints
- What could be seen at LHC
- Importance of interference term for W' exclusion limits (i.e. correct definition of "signal")

What is a W'?

- Heavy twin to Standard Model $W^{\pm}$ (i.e. charged vector boson with couplings analogous to W)



- Theory expectations: *L-R* symmetric, Extra-dimensions, Technicolour, Higgsless

CMS search for W'

CMS-EXO-10-014

CERN-PH-EP/2010-074
2011/01/04

Search for a heavy gauge boson W′ in the final state with an electron and large missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

Abstract

A search for a heavy gauge boson W′ has been conducted by the CMS experiment at the LHC in the decay channel with an electron and large transverse energy imbalance E_T^{miss}, using proton-proton collision data corresponding to an integrated luminosity of 36 pb^{-1}. No excess above standard model expectations is seen in the transverse mass distribution of the electron-E_T^{miss} system. Assuming standard-model-like couplings and decay branching fractions, a W′ boson with a mass less than 1.36 TeV/c^2 is excluded at 95% confidence level.

Submitted to Physics Letters B

- 36 pb^{-1} data
- SM-like W' (1989): *Altarelli* et al. → large coupling, small width

The Higgs sector – from fancy rewriting to strong dynamics

$$\mathcal{L}_H = |D_\mu \Phi|^2 - \frac{m_H^2}{2v^2}\left(|\Phi|^2 - \frac{v^2}{2}\right)^2$$

$$= \frac{1}{4}\mathrm{Tr}\Big((D_\mu\Sigma)(D_\mu\Sigma)^\dagger\Big) - \frac{m_H^2}{8v^2}\left(\frac{1}{2}\mathrm{Tr}\left(\Sigma\Sigma^\dagger\right) - v^2\right)^2$$

with

$$\Sigma = \sqrt{2}\begin{pmatrix} \phi_0 & -\phi_-^* \\ \phi_- & \phi_0^* \end{pmatrix}$$

The Higgs sector – pion Σ-model

$$\mathcal{L}_H = \frac{1}{4}\mathrm{Tr}\Big((D_\mu\Sigma)(D_\mu\Sigma)^\dagger\Big) - \frac{m_H^2}{8v^2}\left(\frac{1}{2}\mathrm{Tr}\left(\Sigma\Sigma^\dagger\right) - v^2\right)^2$$

- *SU(2)$_L$* x *SU(2)$_R$* symmetry: $\Sigma \longrightarrow g_L \Sigma g_R^\dagger$

  (SM: gauging *SU(2)$_L$* and τ^3 of *SU(2)$_R$*)
- Σ unitary in limit $m_H \to \infty$ $(\Sigma\Sigma^\dagger = 2\,|\Phi|^2\,\mathbb{1})$
- Higgs VEV plays role of f_π

Effective description of strong sector?

- Technicolour (1979): *Susskind*, *Weinberg*, ...
- Recent developments (past decade):

  Sannino, *Chivukula*, *Csáki*, *Grojean*, ...
- W' in the picture?

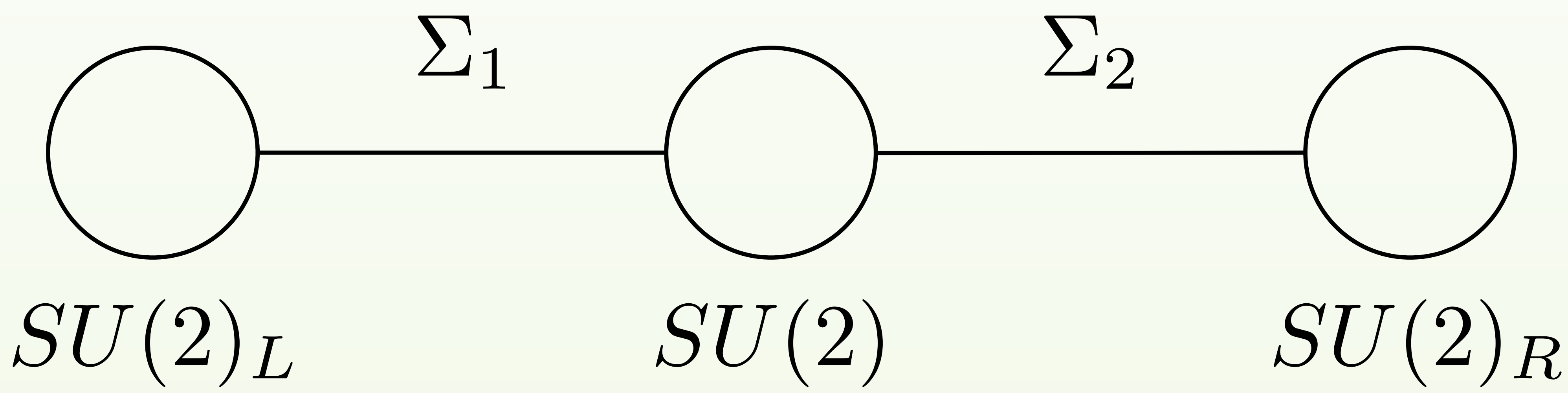
  → Hidden Local Symmetry (~1985):

  Bando, *Kugo*, *Yamawaki*, ... (ρ-meson)

  Casalbuoni, *De Curtis*, *Dominici*, ... (BESS-model)

Hidden Local Symmetry as Moose diagram

$$\Sigma = \Sigma_1 \cdot \Sigma_2$$

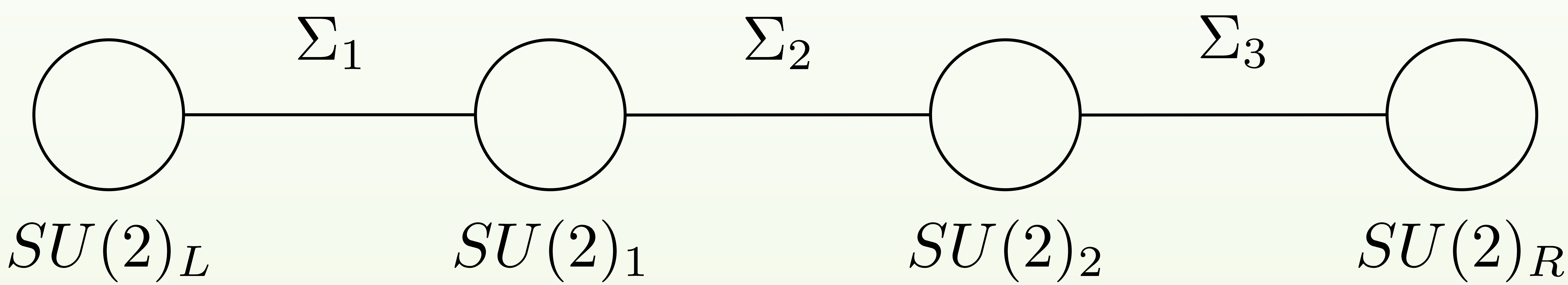


- Extra heavy vector resonance

  (ρ, or degenerate $W^{\pm}$-Z)
- Minimal BESS: excluded unless fermiophobic
- Studied by *Belyaev*, *Eboli*, *He*, *Matchev*, *Perelstein*, ...

4-site model (Higgsless)

$$\Sigma = \Sigma_1 \cdot \Sigma_2 \cdot \Sigma_3$$



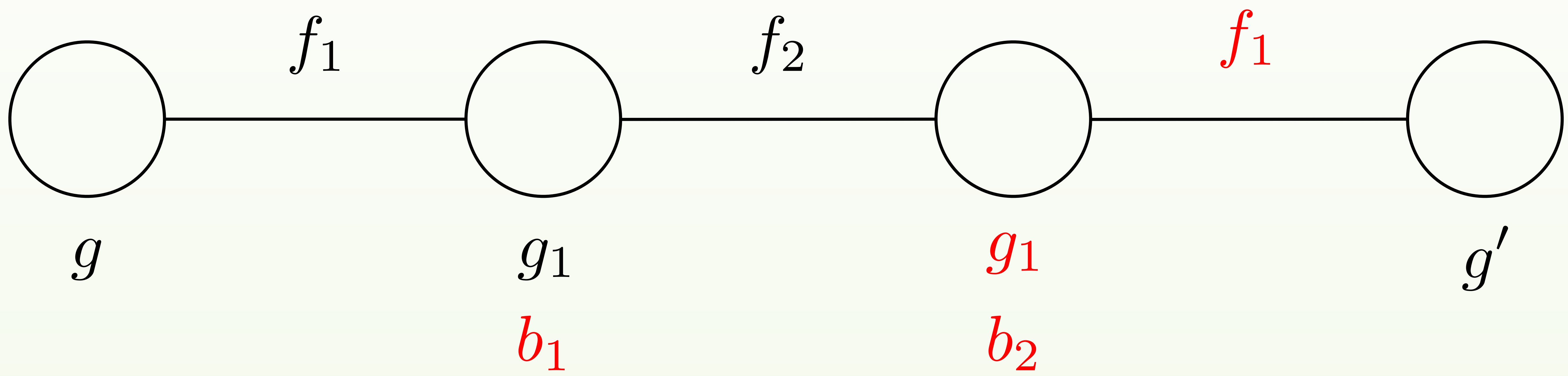
- Infinite number of "sites"

  → Reconstruct extra-dimension (2001):

  Arkani-Hamed, Georgi, ...

- Capture essential features even with few sites

Parameters



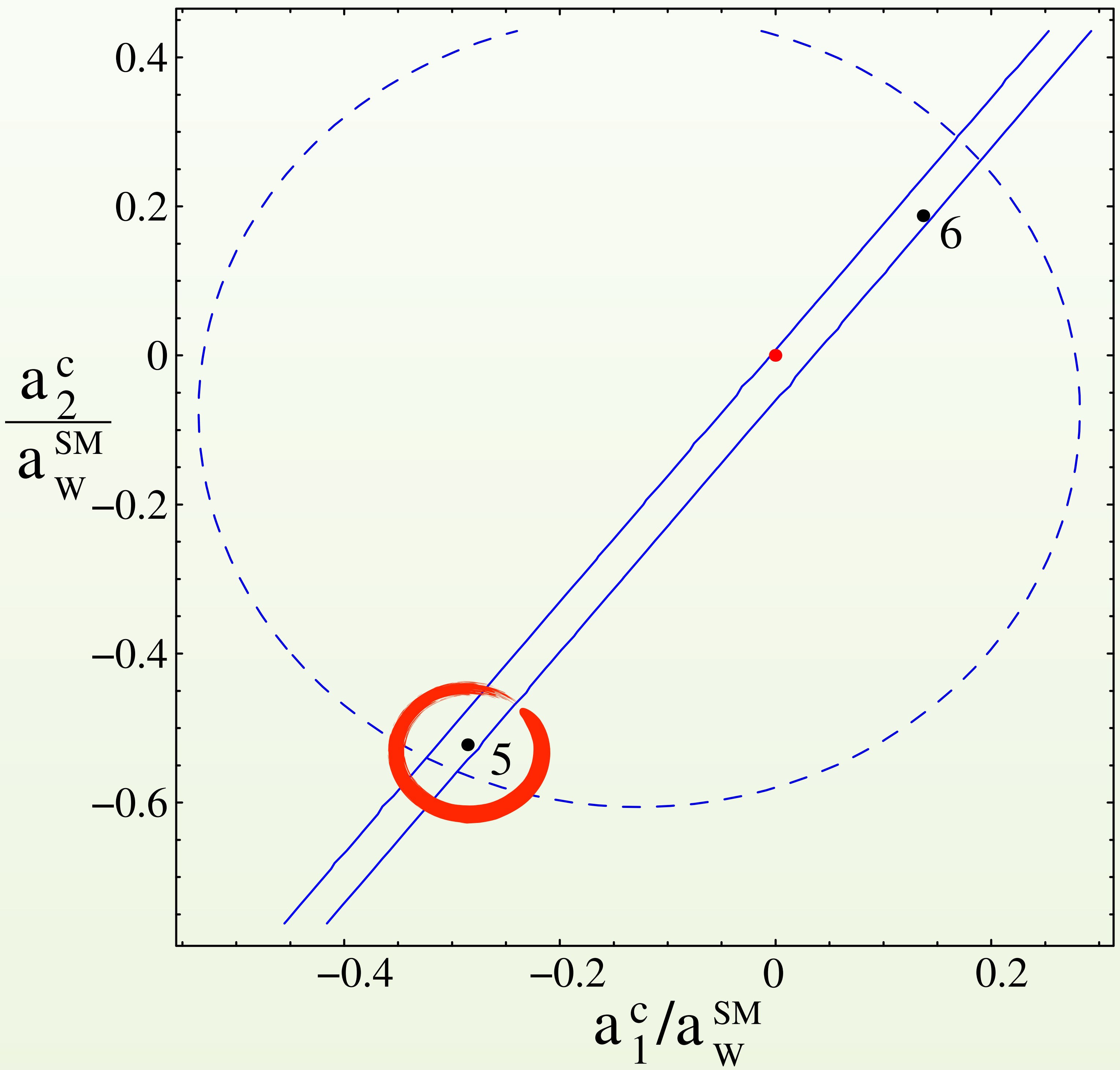
- *L* ↔ *R* symmetry for simplicity
- Direct (*L*-handed) fermion couplings
- 7 parameters (4 more than SM)

  → Fix 3 with e, G_F and m_Z
- 4 independent parameters (masses, couplings)

Electroweak precision tests

- Z-physics at LEP (mass, width, asymmetry)
- From 4 to 3 free parameters (2 masses, 1 coupling)
- Two independent b_i → evade "fermiophobia"

$m_1 \simeq 1000$ GeV, $m_2 \simeq 1250$ GeV

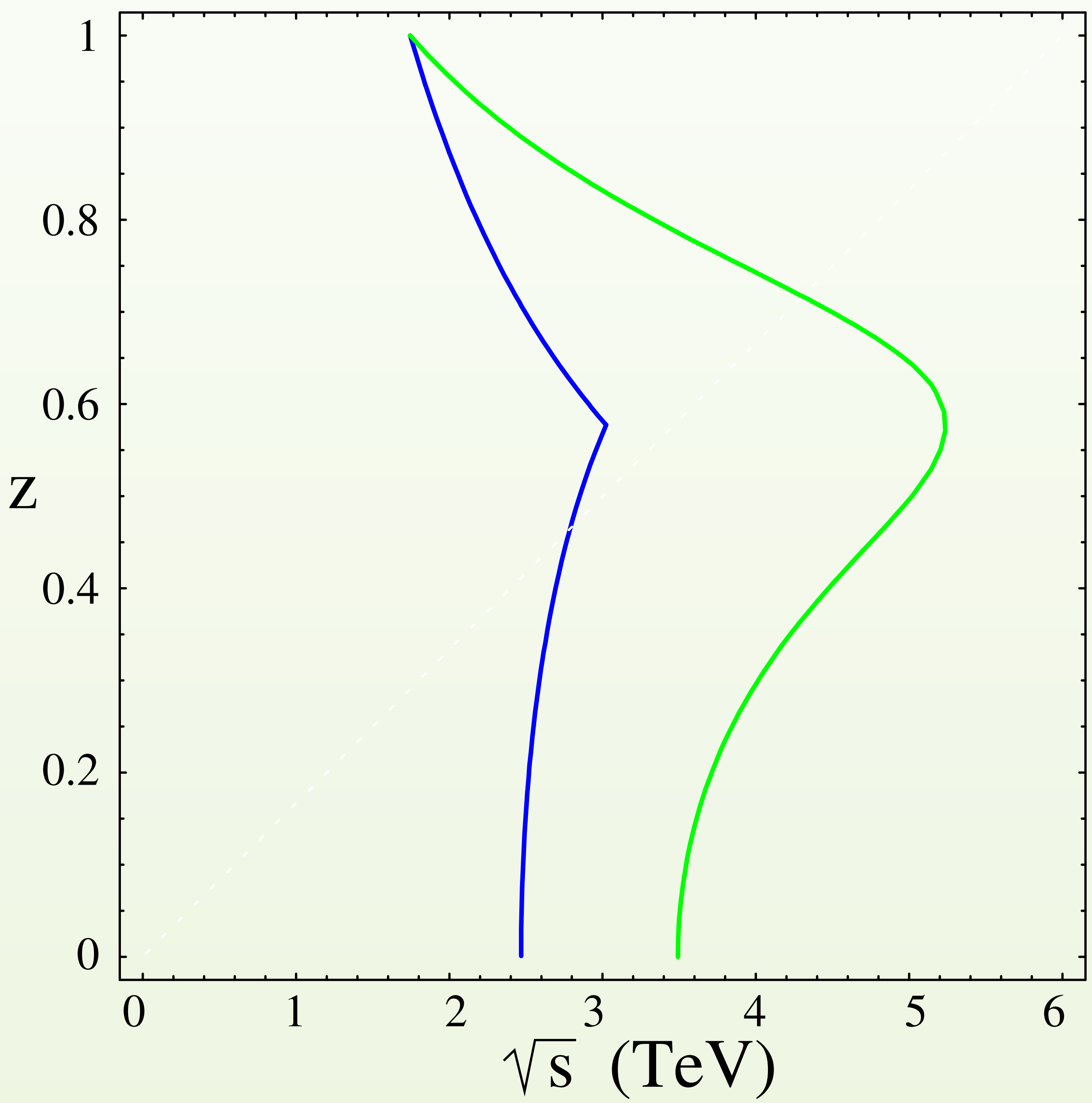


arXiv:0807.5051 – *Accomando* et al.

Perturbative unitarity bound

- Validity of effective description
  → limit on mass range:
  $m_1 < m_2 < \Lambda$
- (≃ Validity of Σ-models)

$z = m_1 / m_2$



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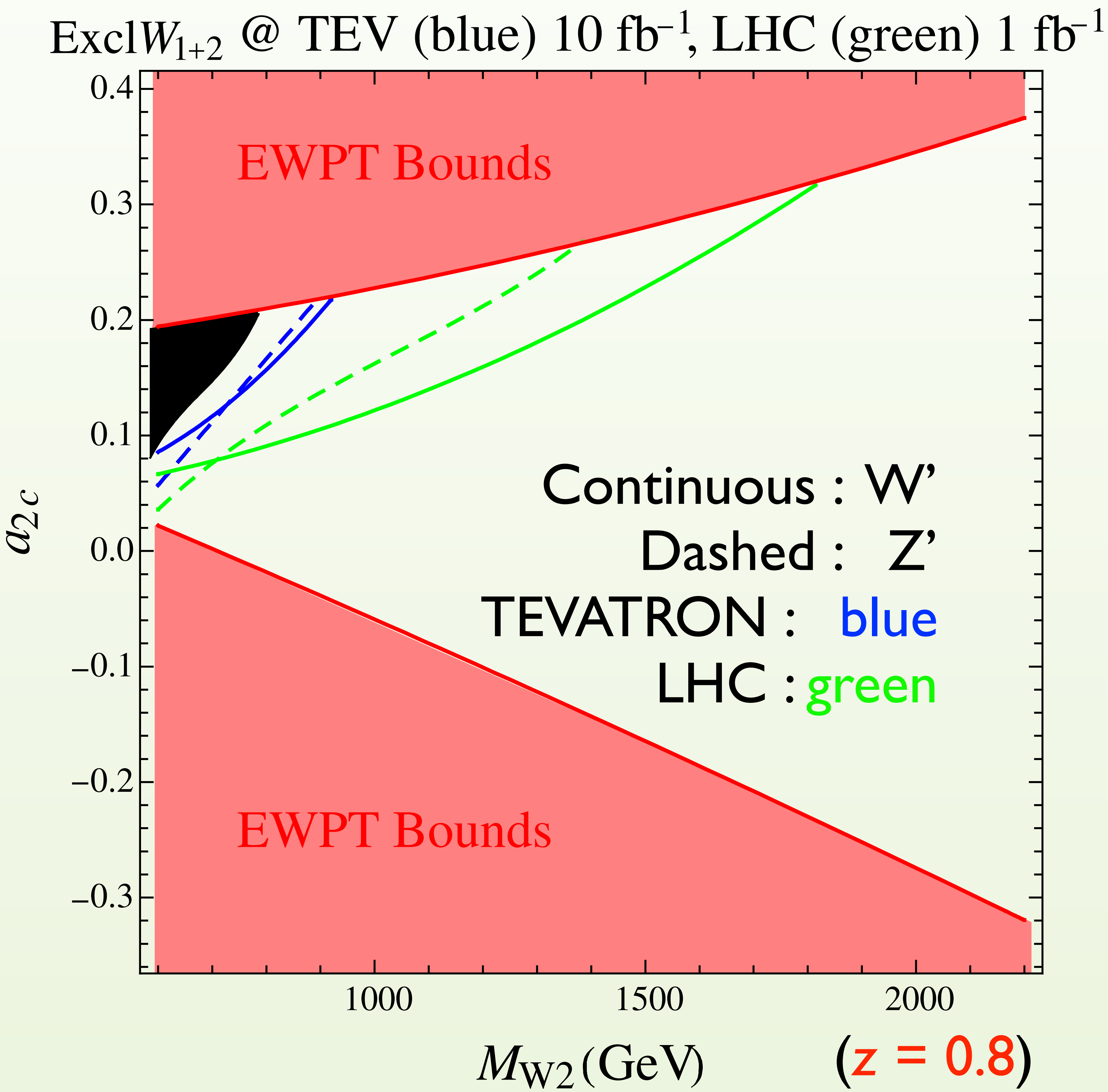
Exclusion limits on parameter space Z' vs. W' searches

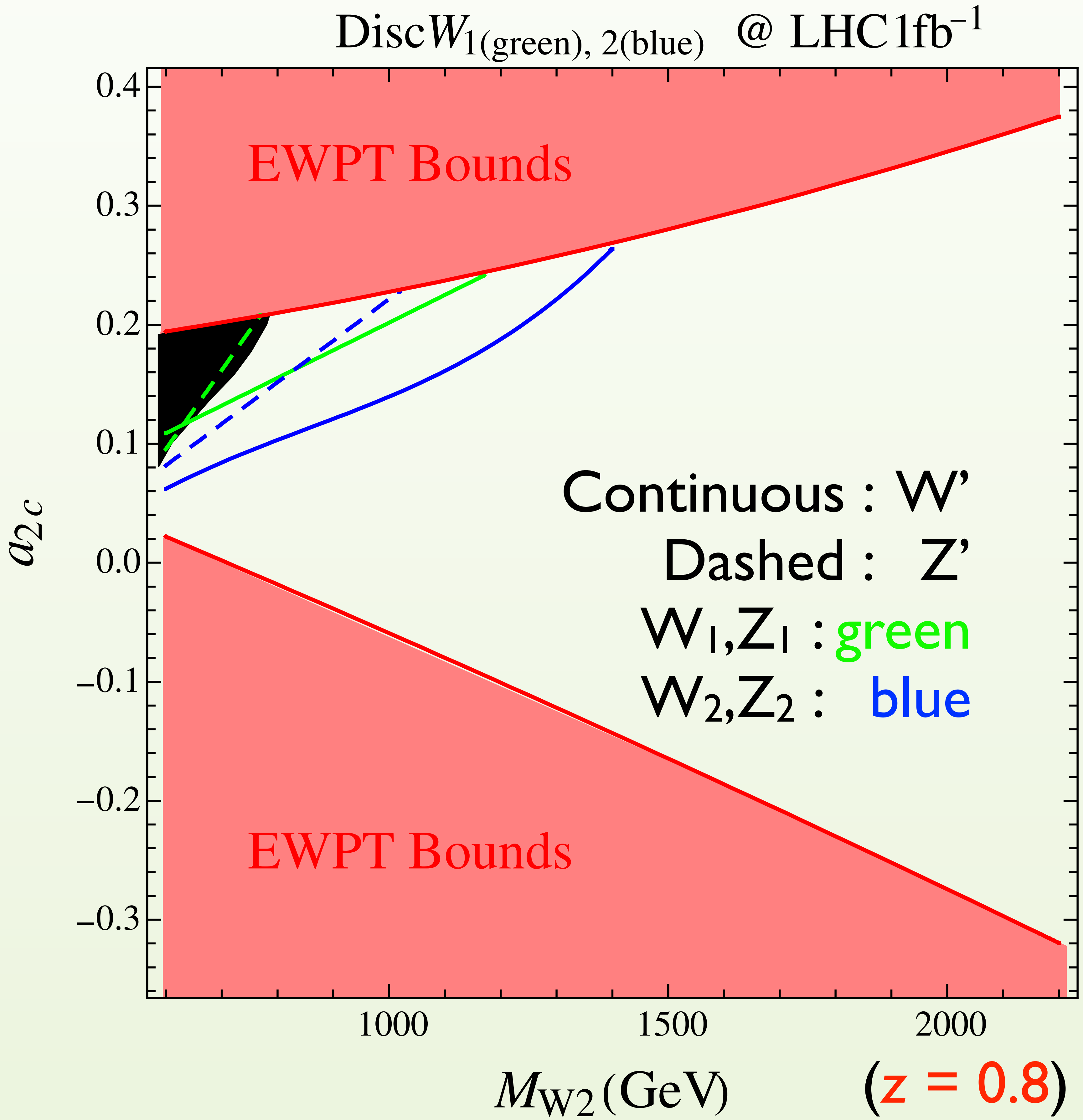


(z = 0.8)

- Significant portion of parameter space will be probed
- W' more potential than Z' at LHC (larger production) but more difficult analysis...

Discovery potential
Z' vs. W' searches

- Can one separate the two resonances?
- Distinguish the lighter resonance: only in the charged channel



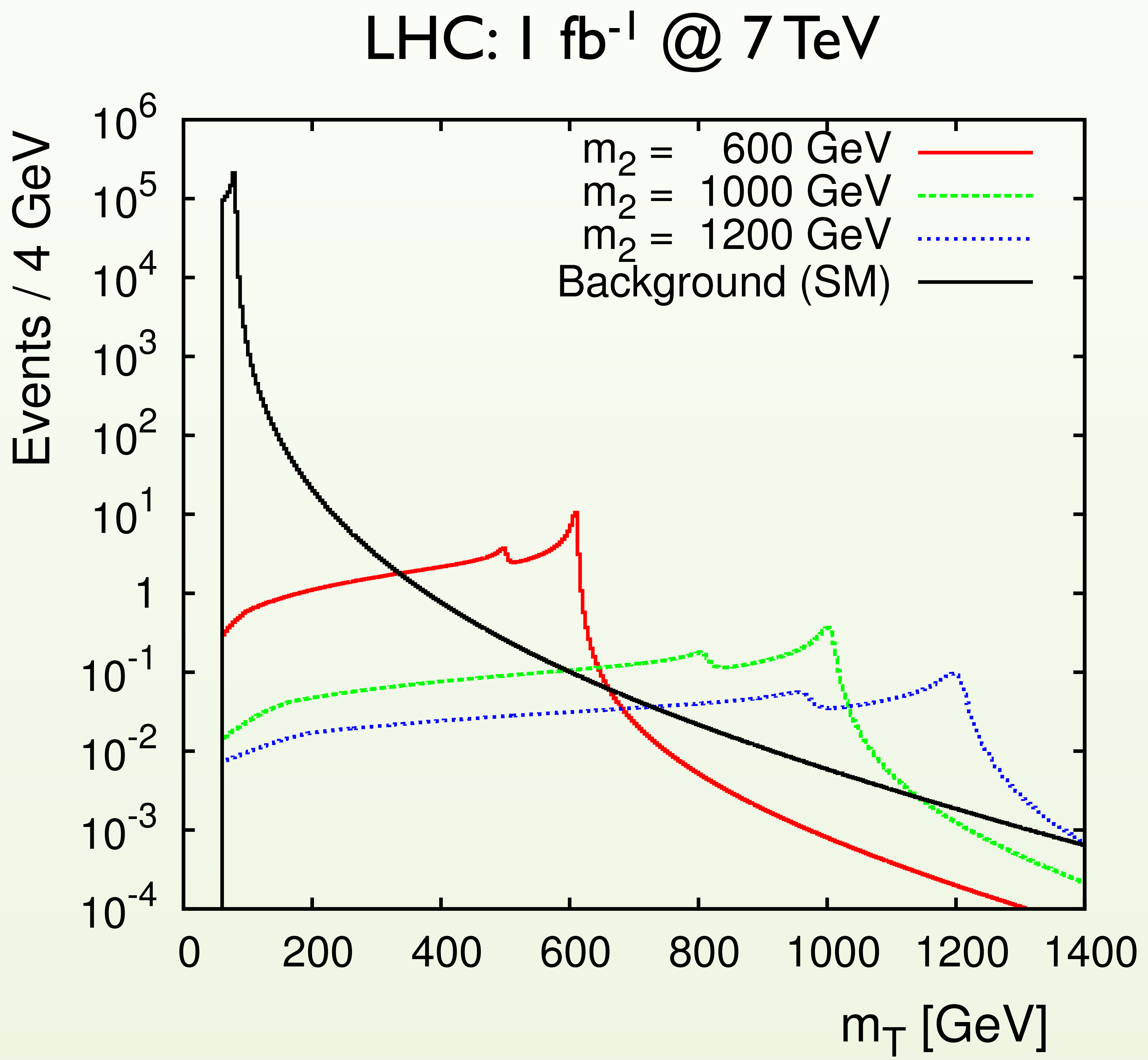
LHC Phenomenology – charged channel

- Benchmark: fixed mass ratio ($z = 0.8$)

  & maximal allowed coupling to fermions
- Di-lepton production: 1 charged + 1 neutrino
- LHC: 1 fb^{-1} @ 7 TeV
- $E_T > 30$ GeV & $|\eta| < 2.5$
- Look at transverse mass:

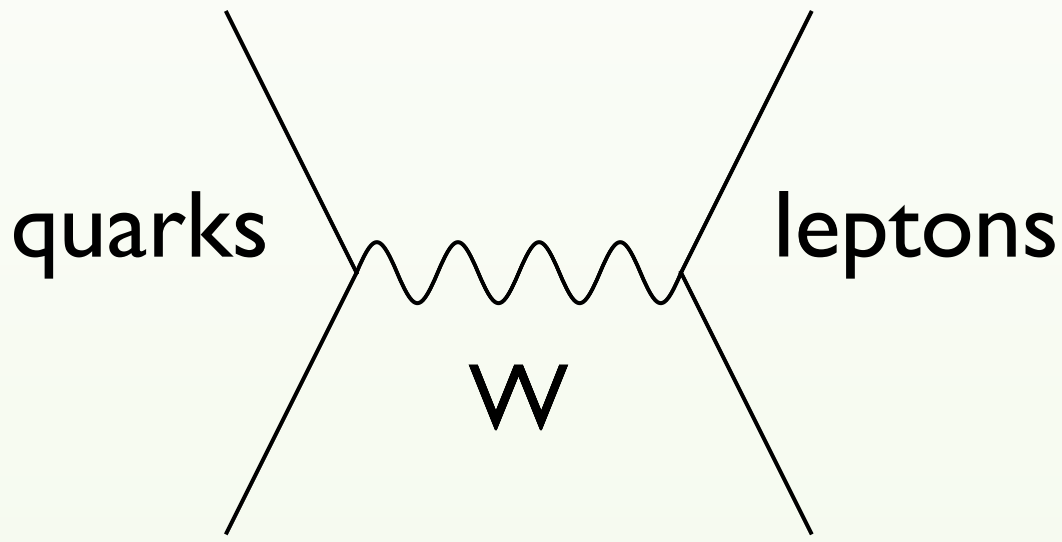
$$m_T = \sqrt{2\, E_T^e E_T^{\text{miss}}\,(1 - \cos\Delta\phi_{e,\text{miss}})}\ \left(= 2\, E_T\right)$$

m_T distributions – background and "signal"



What is the "signal"?

Signal and interference



$$\longrightarrow \quad \frac{1}{s-m^2}$$

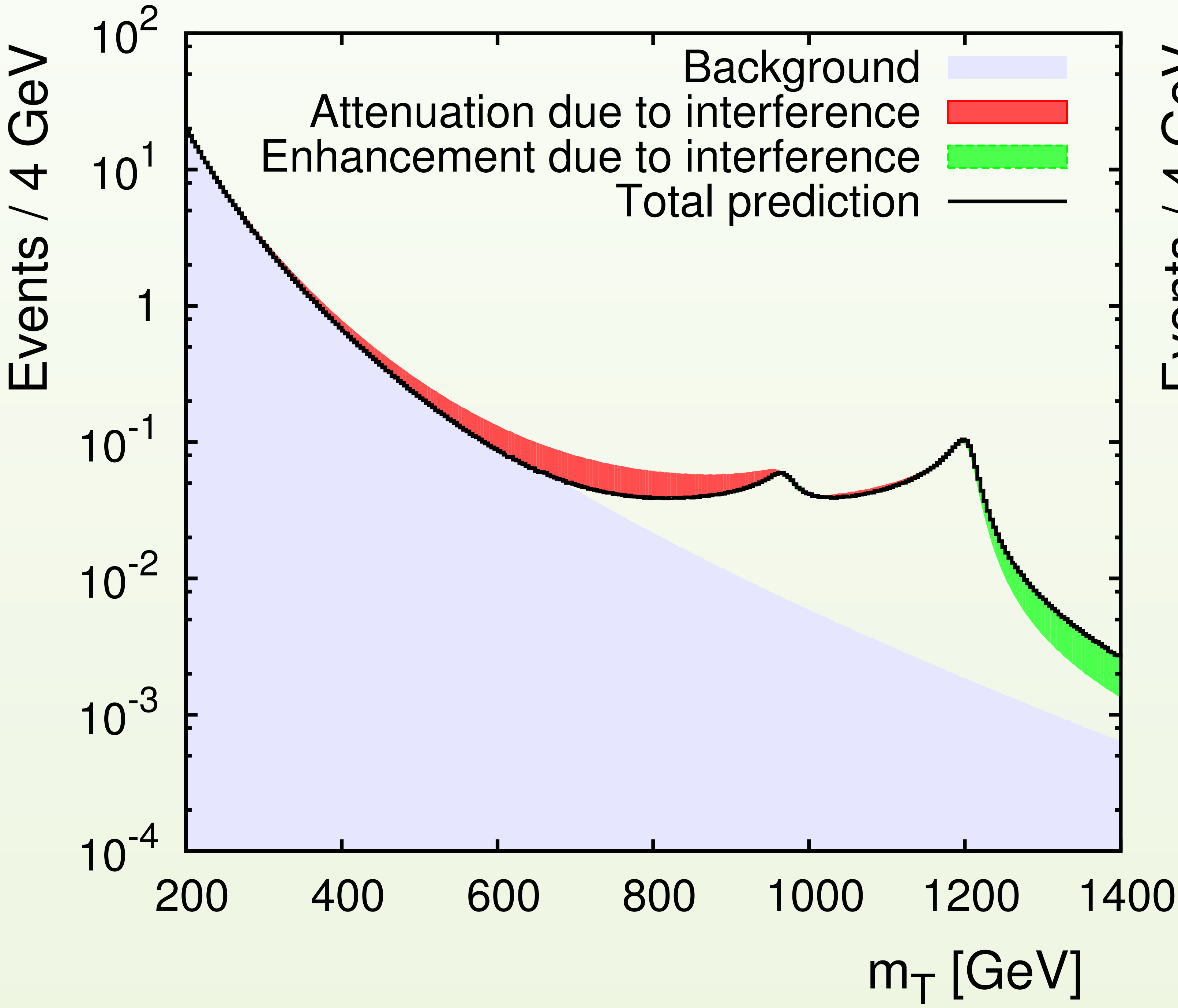
Total prediction for cross-section:

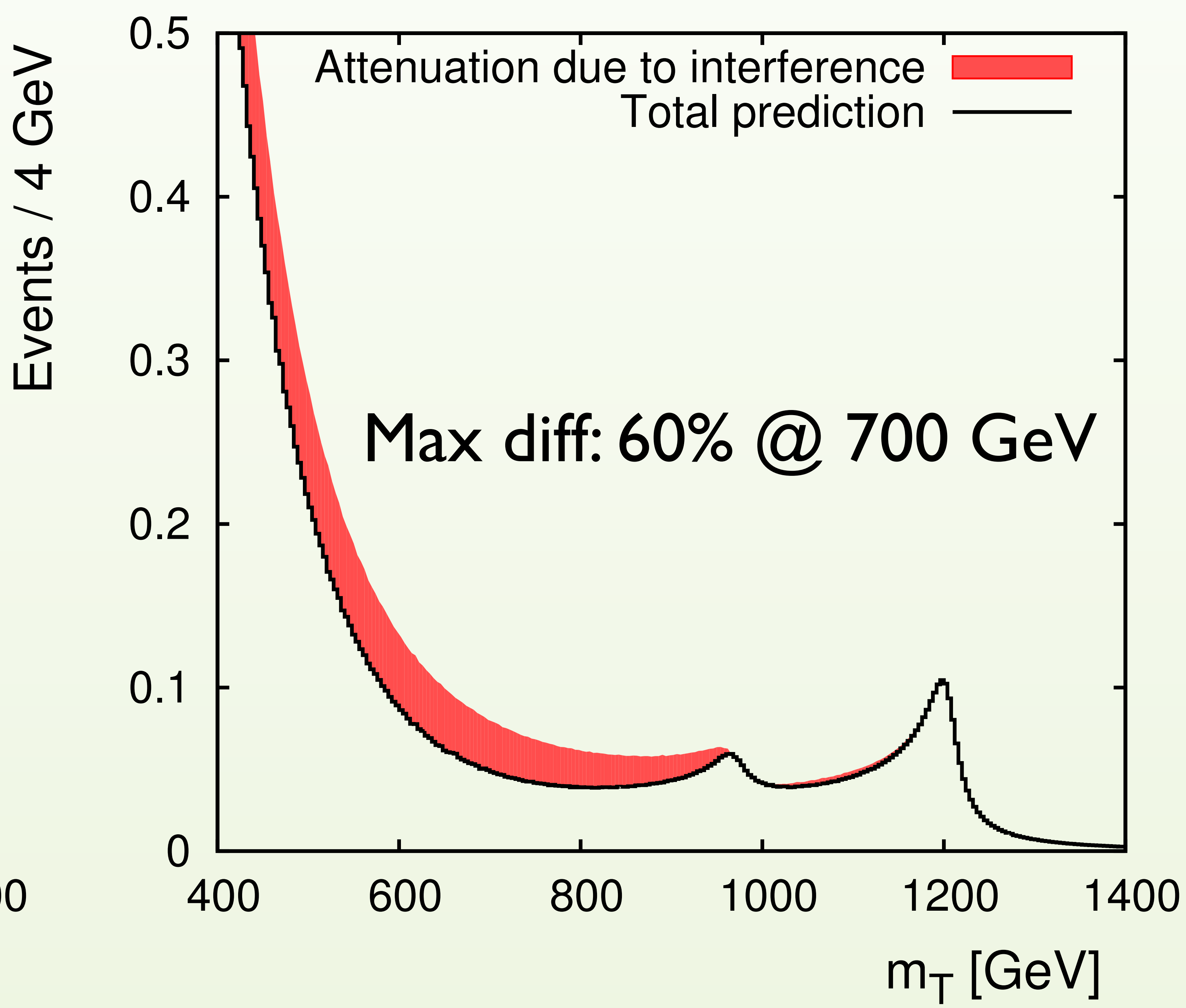
$$\left(\frac{1}{s-m_W^2}\right)^2 + \left(\frac{1}{s-m_{W_i}^2}\right)^2 + \left(\frac{1}{s-m_W^2}\frac{1}{s-m_{W_i}^2}\right)$$

Background Signal Interference

m_T distribution including interference

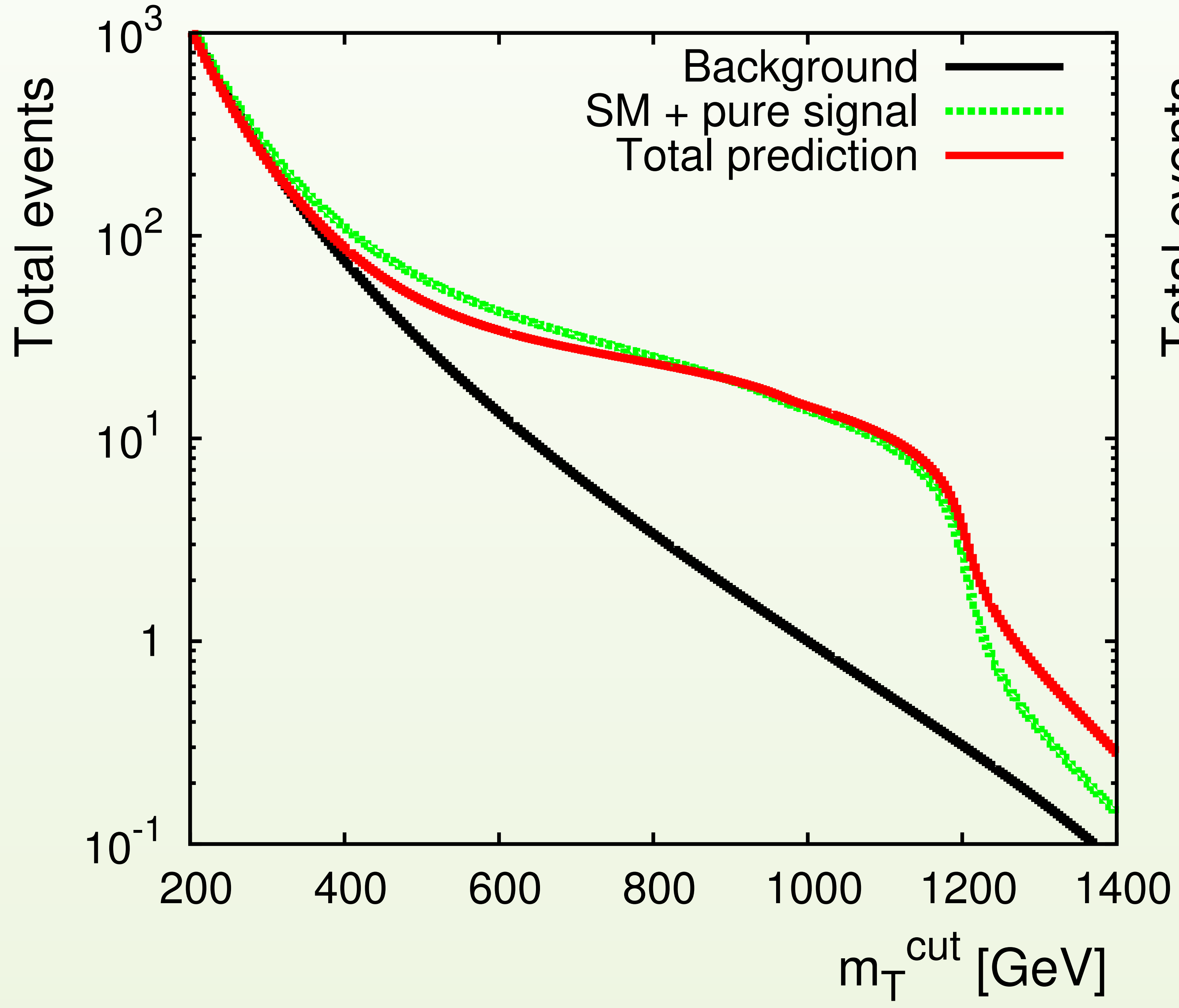
$m_1 \simeq 960$ GeV, $m_2 \simeq 1200$ GeV

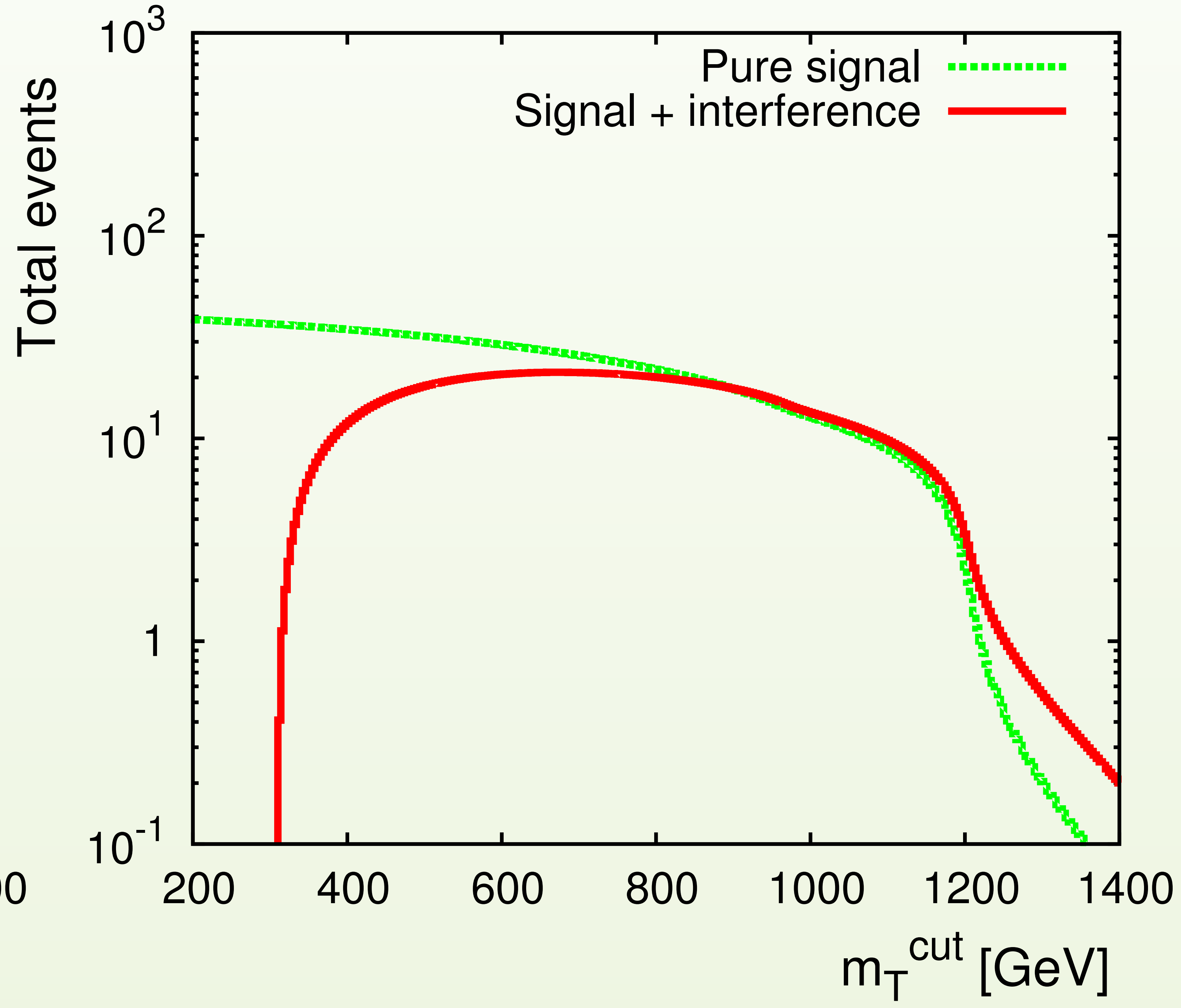




Counting strategy – total number of events

$m_1 \simeq 960$ GeV, $m_2 \simeq 1200$ GeV



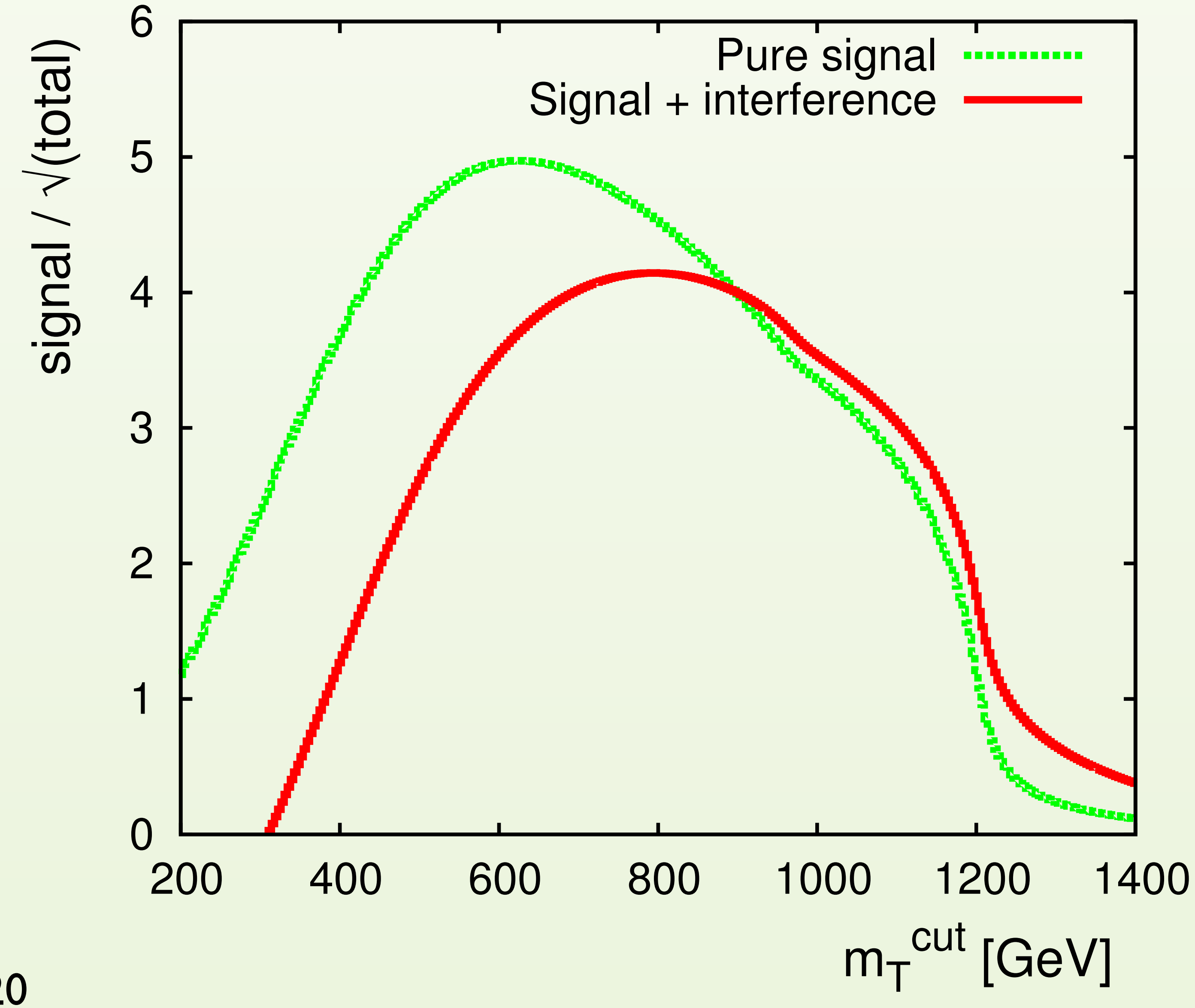


Statistical significance

$m_1 \simeq 960$ GeV, $m_2 \simeq 1200$ GeV

m_T^{cut} [GeV]	Background	Pure signal	Signal + interf.
500	30	32 (4.6σ)	18 (2.6σ)
600	13	29 (5.0σ)	21 (3.5σ)
900	2	18 (4.0σ)	18 (4.0σ)

- Pure signal → overestimation!
- Shift in "optimal" cut



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$m_1 \simeq 800$ GeV, $m_2 \simeq 1000$ GeV

m_T^{cut} [GeV]	Background	Pure signal	Signal + interf.
300	236	91 (5.5σ)	41 (2.5σ)
400	76	84 (7.3σ)	56 (4.9σ)
700	7	55 (7.1σ)	53 (6.9σ)

Conclusions

- If there is something to see, LHC will probably see it
- If nothing is seen $\rightarrow$ careful in placing exclusion limits (need correct definition of signal? possibly significant!)

Future work

- Follow-up on this hint in collaboration with RAL for more realistic analysis of interference effect
- 4-lepton final state...

Thank you!

Backup slides

Expressions for masses

$$m_Z \simeq \frac{g}{c_{\tilde{\theta}}} \cdot \frac{f_1 f_2}{\sqrt{f_1^2 + 2 f_2^2}} \left(1 + \mathcal{O}\left(\frac{g^2}{g_1^2}\right)\right), \qquad \tan\tilde{\theta} = \frac{g'}{g}$$

$$m_1 = g_1\, f_1$$

$$m_2 = g_1 \sqrt{f_1^2 + 2 f_2^2}$$

$$g_1 \simeq \frac{e}{s_{2\theta}} \frac{m_1}{m_Z} \sqrt{2(1 - z^2)}, \qquad z = \frac{m_1}{m_2}$$

EWPT parameters from experiment

- ε_i parametrise deviation from tree-level SM + QED corrections (~1990) *Altarelli* et al.
- Experimental data from LEP (Z-peak)

$$\frac{m_W^2}{m_Z^2} = \left.\frac{m_W^2}{m_Z^2}\right|_B \quad (1 + 1.43\,\epsilon_1 - 1.00\,\epsilon_2 - 0.86\,\epsilon_3)$$

$$\Gamma_l = \Gamma_l\big|_B \quad (1 + 1.20\,\epsilon_1 - 0.26\,\epsilon_3)$$

$$A_{FB}^{\mu} = A_{FB}^{\mu}\big|_B \; (1 + 34.72\,\epsilon_1 - 45.15\,\epsilon_3)$$

EWPT detail – *Altarelli* et al.

- "Fundamental" parameters: e, G_F and m_Z
- Define

$$s_\theta^2 c_\theta^2 = \frac{\sqrt{2}\, e^2}{8\, m_Z^2\, G_F}, \qquad \frac{m_W^2}{m_Z^2} = c_\theta^2 \left(1 - \frac{s_\theta^2}{c_{2\theta}} \Delta r_W\right)$$

$$\mathcal{L}_Z = -\frac{e}{s_\theta c_\theta}\left(1 + \frac{\Delta\rho}{2}\right) Z_\mu \, \bar{\psi}\left[\gamma^\mu g_V + \gamma^\mu \gamma_5 g_A\right]\psi$$

$$g_V = \frac{\mathbf{T^3}}{2} - (1 + \Delta k)\, s_\theta^2 \; \mathbf{Q}, \qquad g_A = -\frac{\mathbf{T^3}}{2}$$

EWPT detail – *Altarelli* et al.

$$\epsilon_1 = \Delta\rho \qquad \left(= (5.0 \pm 1.1) \cdot 10^{-3}\right)$$

$$\epsilon_2 = c_\theta^2 \Delta\rho + \frac{s_\theta^2}{c_{2\theta}} \Delta r_W - 2 s_\theta^2 \Delta k \qquad \left(= (-8.8 \pm 1.2) \cdot 10^{-3}\right)$$

$$\epsilon_3 = c_\theta^2 \Delta\rho + c_{2\theta} \Delta k \qquad \left(= (4.8 \pm 1.0) \cdot 10^{-3}\right)$$

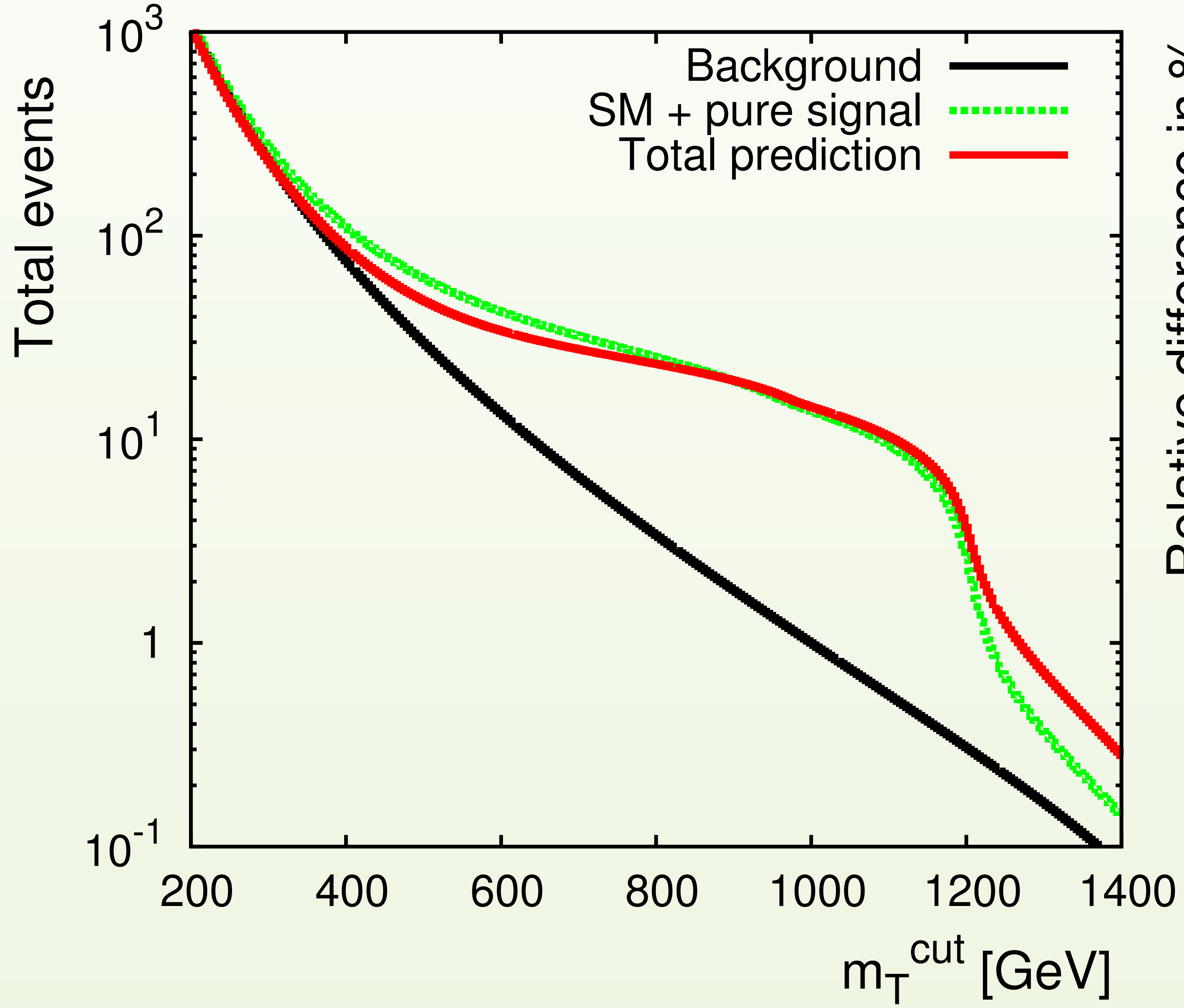
In 4-site model:

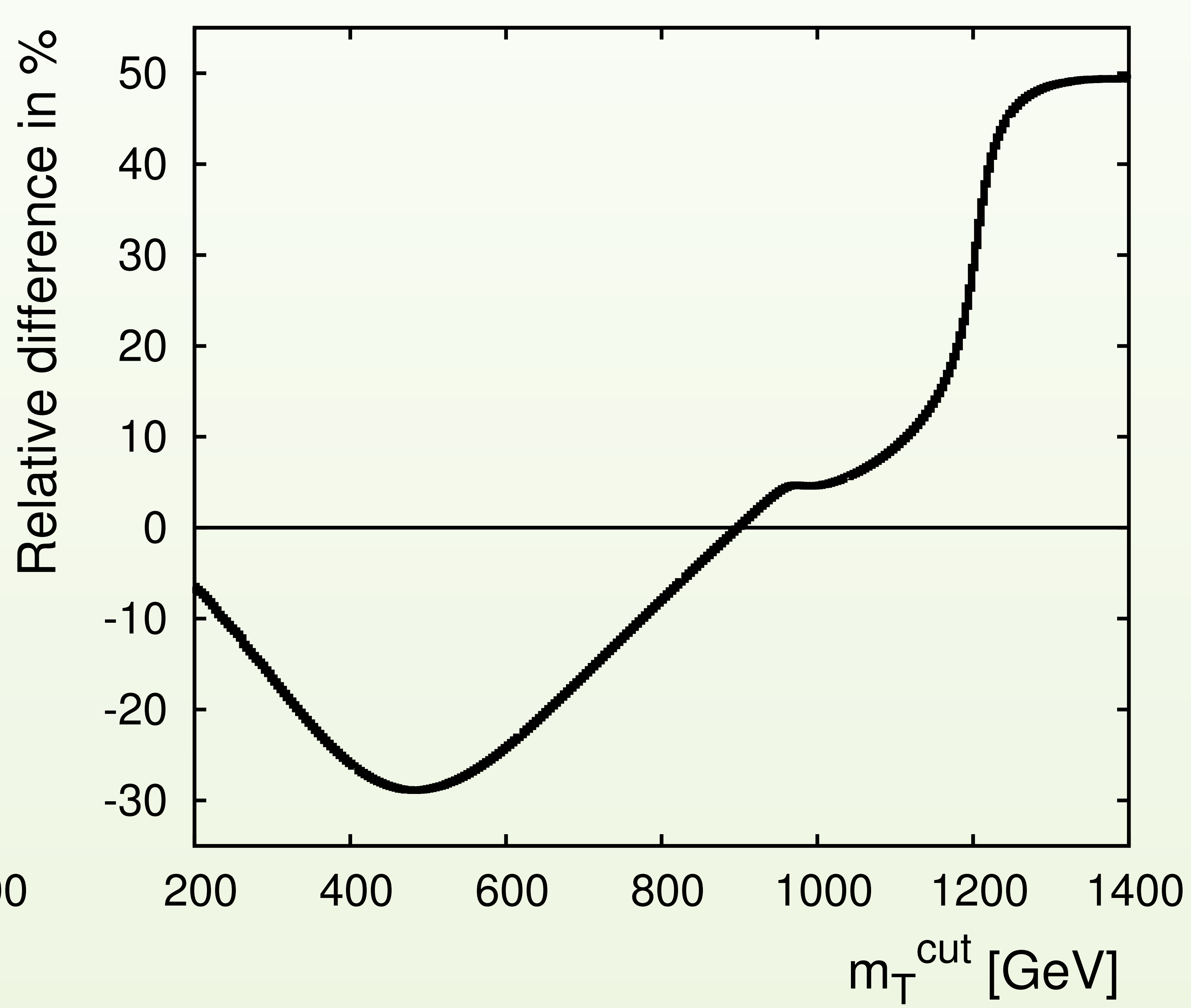
$$\epsilon_{1,2} \simeq -\frac{(1-z^2)(b_+^2 + z^2 b_-^2)}{4}$$

$$\epsilon_3 \simeq \frac{g^2}{2 g_1^2}(1 - z^4) - \frac{b_+ - z^2 b_-}{2(1 + b_+)}$$

Total number of events – relative difference

$m_1 \simeq 960$ GeV, $m_2 \simeq 1200$ GeV





Significance compared to background

$m_1 \simeq 960$ GeV, $m_2 \simeq 1200$ GeV