Saloniki, Sep. 2007, Artemis meeting

A Natural NIGHTMARE for the LHC

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D. G. Cerdeño, A. Dedes, T. E. J. Underwood, JHEP0609:067 (2006)

Also in progress with T. Figy, F. Krauss and T. Underwood

"...Thus the experiments must see either the SM Higgs, or other new physics or both. ..."

J. Butterworth, on behalf of the ATLAS and CMS collaborations, arXiv:0709.2547, 17 Sep 2007.

Might the LHC see nothing ?

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YES !

The "Phantom Sector"

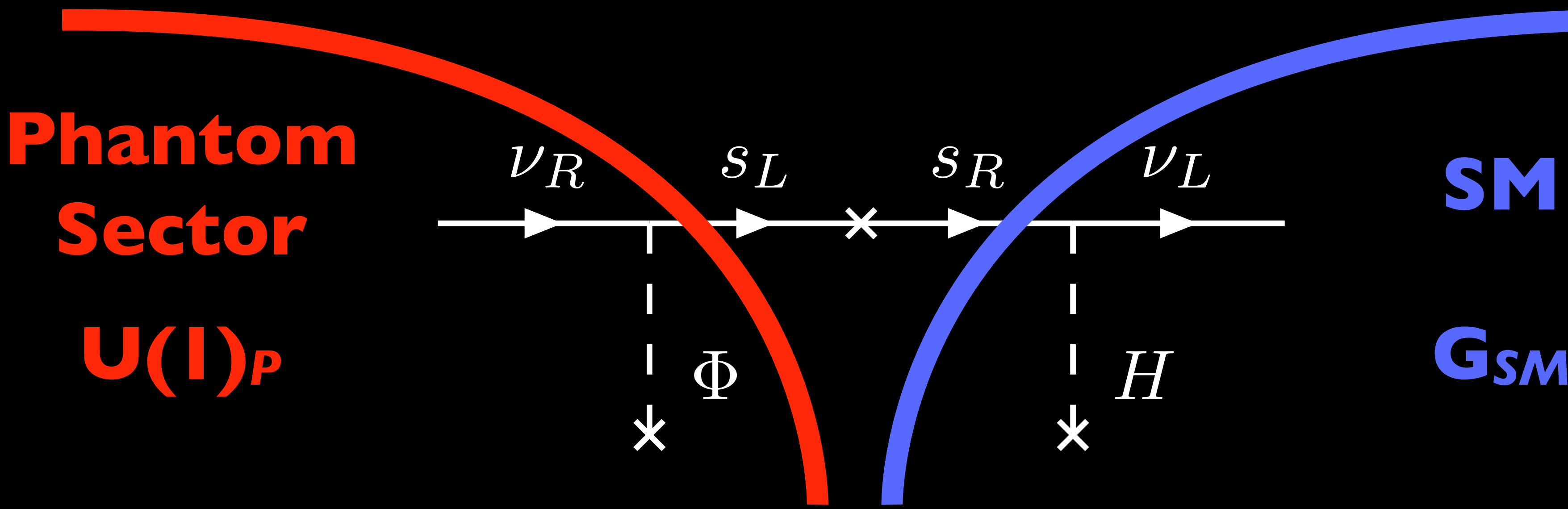
- Just 2 openings in the SM for renormalisable operators coupling $SU(3)_C \times SU(2)_L \times U(1)_Y$ singlet fields to SM fields

B.Patt, F.Wilczek, hep-ph/0605188

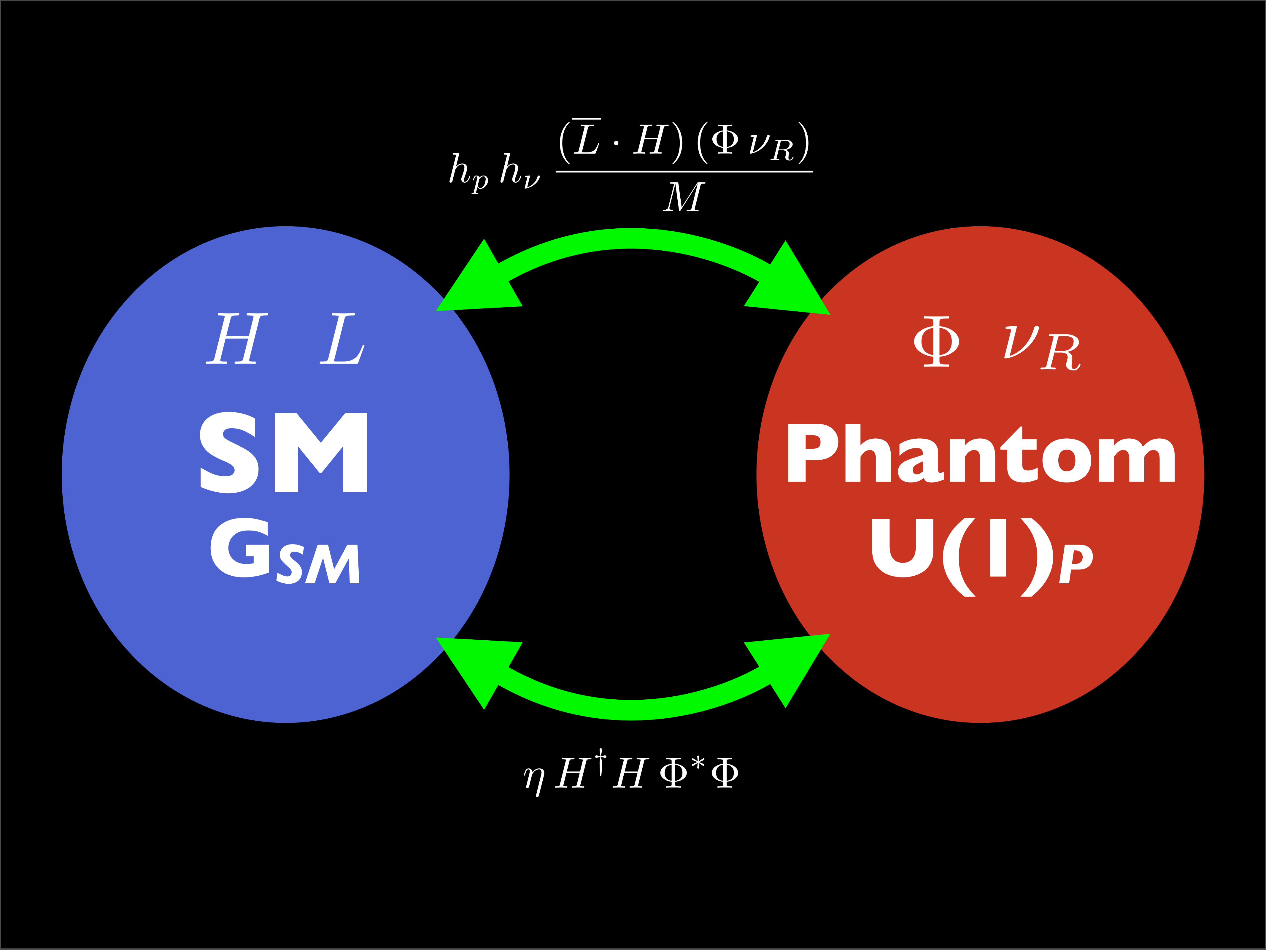
$$\mathcal{L}_{\rm link} \;=\; H^\dagger H \; ?^* ? \;+\; \widetilde{H}\,\overline{L}\,?'_R$$

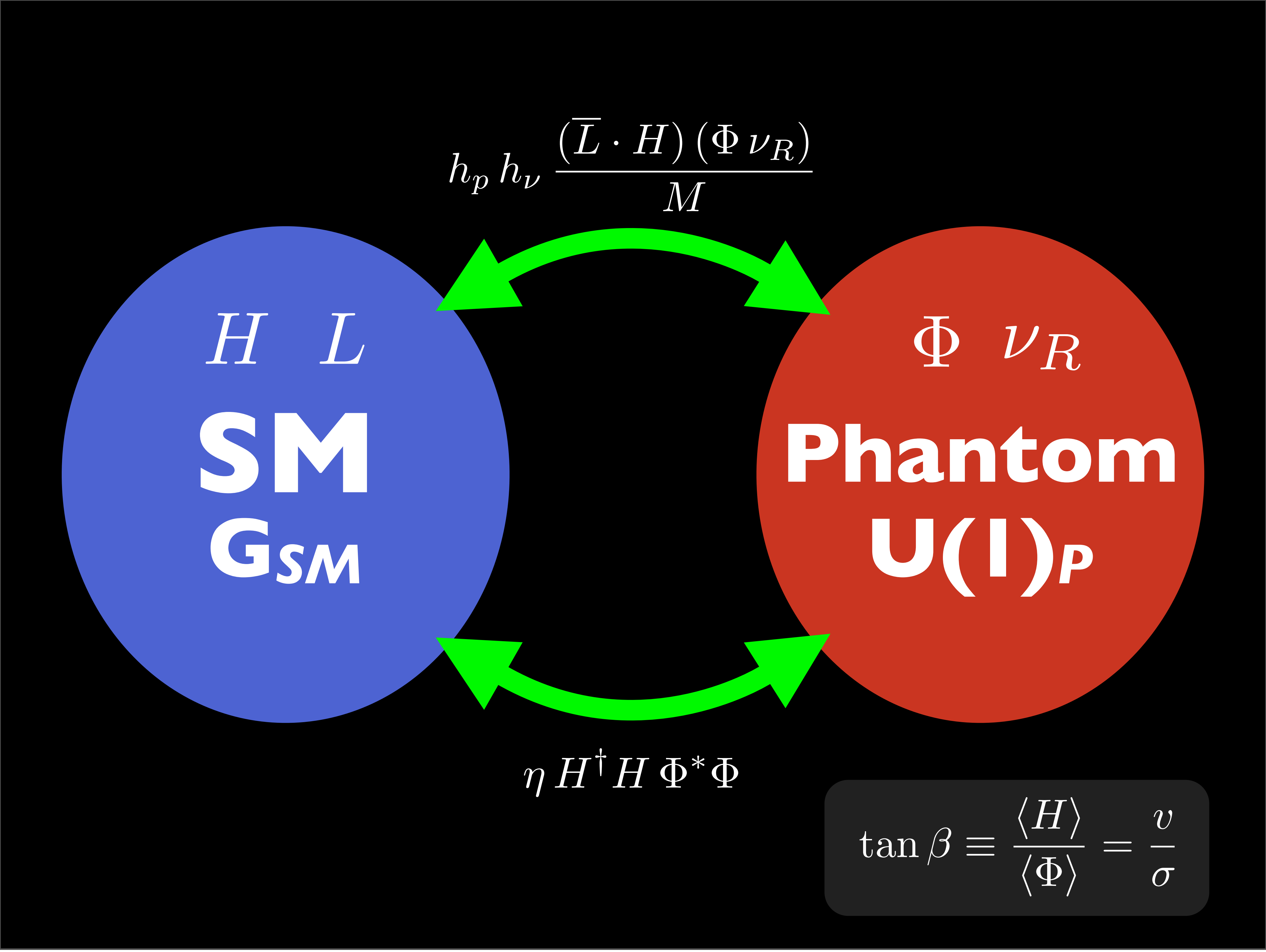
- Fill in the gaps!
  - but do it so that *B - L* is conserved

A Dirac See-Saw



$$\mathcal{L} = h_p\, h_\nu\, \frac{(\overline{L} \cdot H)\,(\Phi\, \nu_R)}{M}$$


$h_p\, h_\nu\, \frac{(\overline{L} \cdot H)\,(\Phi\, \nu_R)}{M}$
$H \quad L$
SM
G_{SM}
$\Phi \quad \nu_R$
Phantom
$U(1)_P$
$\eta\, H^\dagger H\, \Phi^* \Phi$


$h_p\, h_\nu\, \frac{(\overline{L} \cdot H)\, (\Phi\, \nu_R)}{M}$
$H \quad L$
SM
G_{SM}
$\Phi \quad \nu_R$
Phantom
$U(1)_P$
$\eta\, H^\dagger H\, \Phi^* \Phi$
$\tan\beta \equiv \frac{\langle H \rangle}{\langle \Phi \rangle} = \frac{v}{\sigma}$

Succesful baryogenesis in this model requires :

$$0.1\ \mathrm{GeV}\ \lesssim\ \sigma\ \lesssim\ 2\ \mathrm{TeV}\left(\frac{T_{RH}}{10^{16}\,\mathrm{GeV}}\right)$$

D. G. Cerdeño, A. Dedes, T. E. J. Underwood, JHEP0609:067 (2006)

Higgs sector

$$V = \mu_H^2 H^* H + \mu_\Phi^2 \Phi^* \Phi + \lambda_H (H^* H)^2 + \lambda_\Phi (\Phi^* \Phi)^2 - \eta H^* H \Phi^* \Phi$$

- Two massive Higgs bosons mix:

$$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix} = O \begin{pmatrix} h \\ \phi \end{pmatrix} \quad \text{and} \quad O = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

- SSB in the Phantom Sector would trigger electroweak symmetry breaking

Spontaneous Symmetry Breaking of a global, continuous symmetry results in one (or more) physical massless particle(s), called Nambu - Goldstone Boson(s), denoted as

$$\mathcal{J}$$

It has a peculiar property ....

$$\mathcal{L} = \frac{1}{2\,\sigma}\,\mathcal{J}\cdot\partial_\mu\, j^\mu \;\rightarrow\; -\frac{m^2_{H_i}}{\sigma}\,O_{i2}\;H_i\,\mathcal{J}\,\mathcal{J}$$

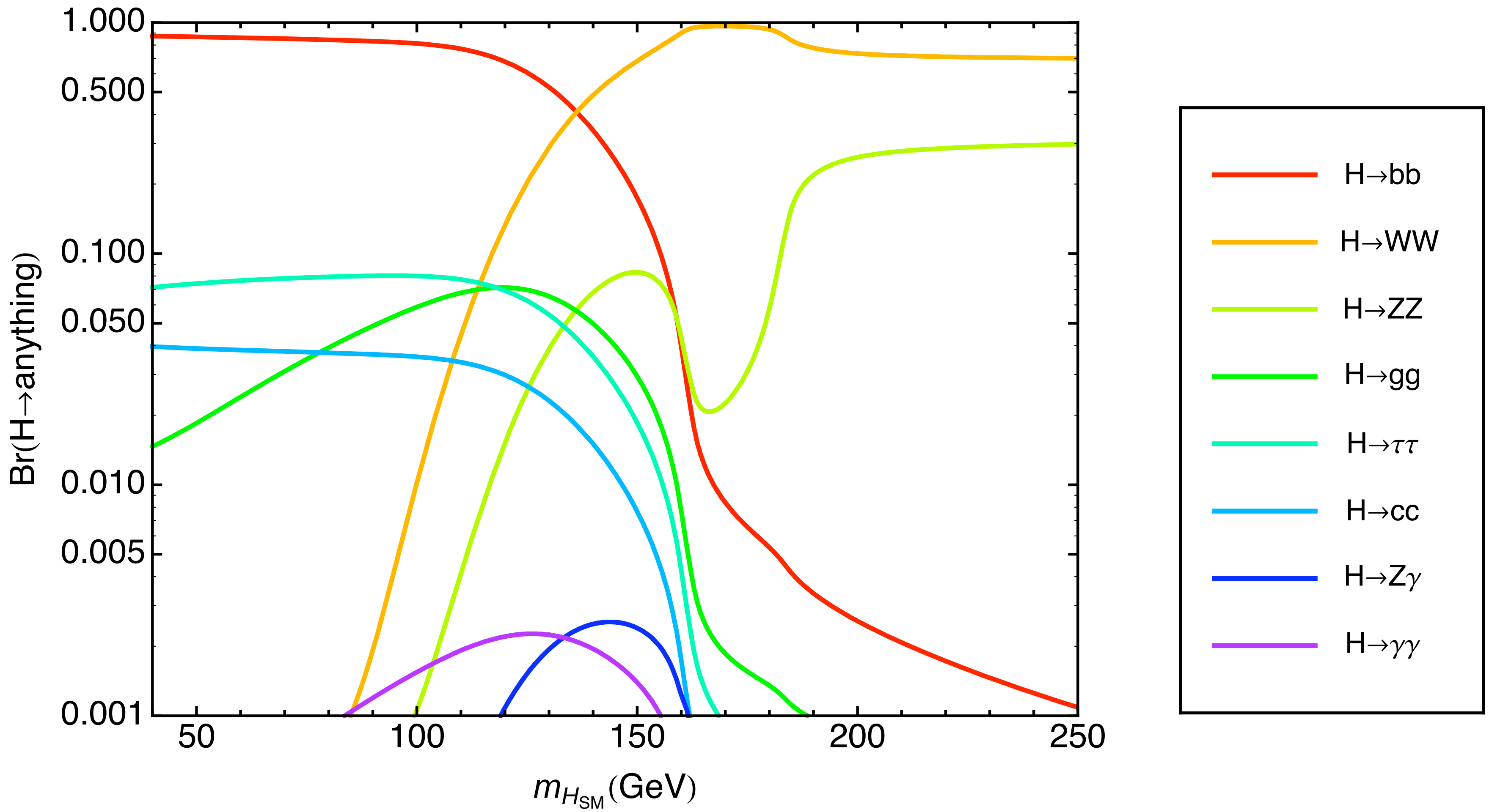
R. Shrock, M.Suzuki, PLB110:250 (1982)

- Higgs decays to $\mathcal{J}\,\mathcal{J}$ (invisible) possible!

$$\frac{\Gamma(H_1 \rightarrow JJ)}{\Gamma(H_1 \rightarrow b\bar{b})} = \frac{1}{12}\left(\frac{m_{H1}}{m_b}\right)^2 \tan^2\beta\;\tan^2\theta$$

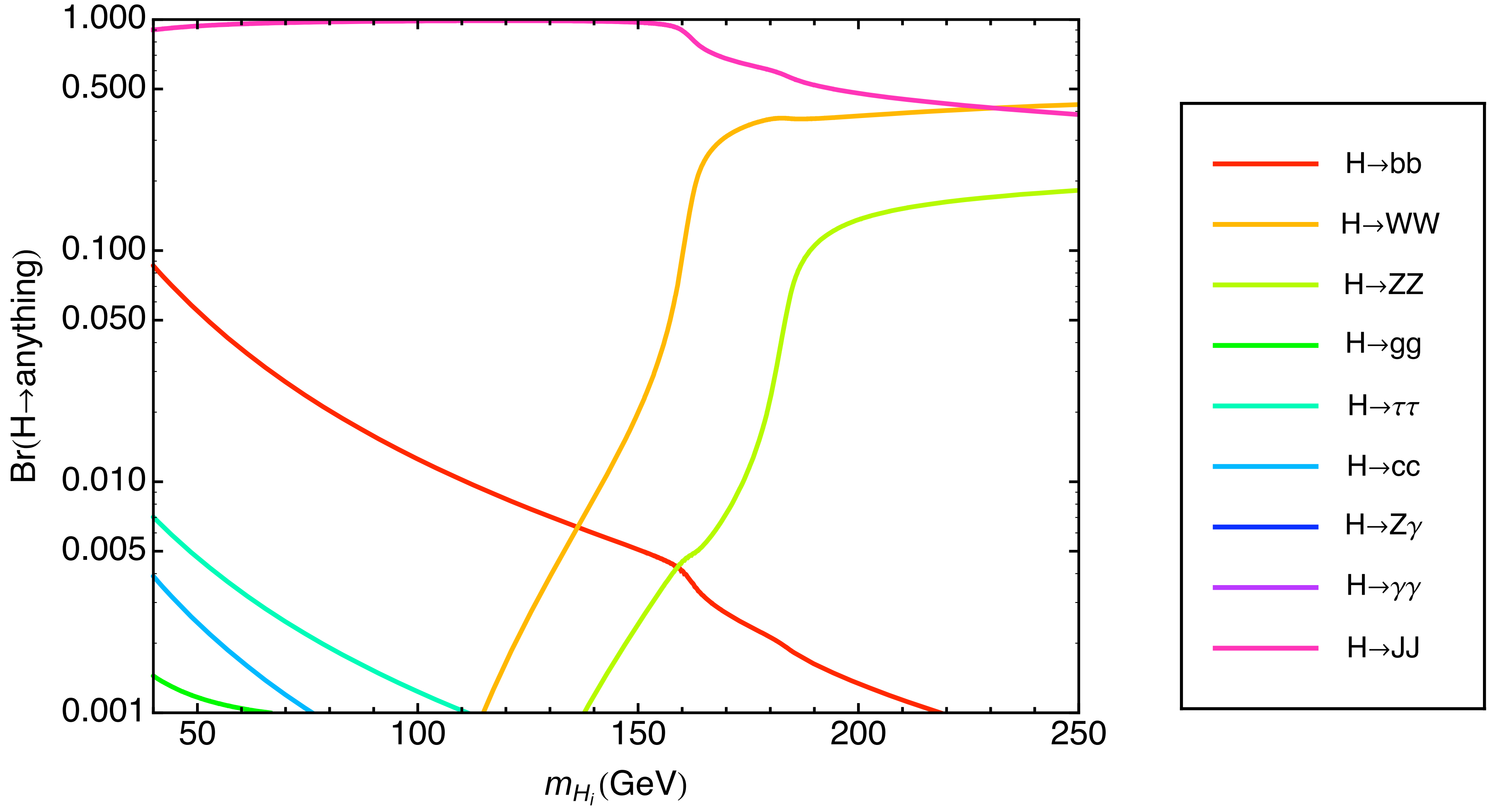
A.Joshipura, S.Rindani PRL69:3269 (1992)

Higgs branching ratios in the Standard Model

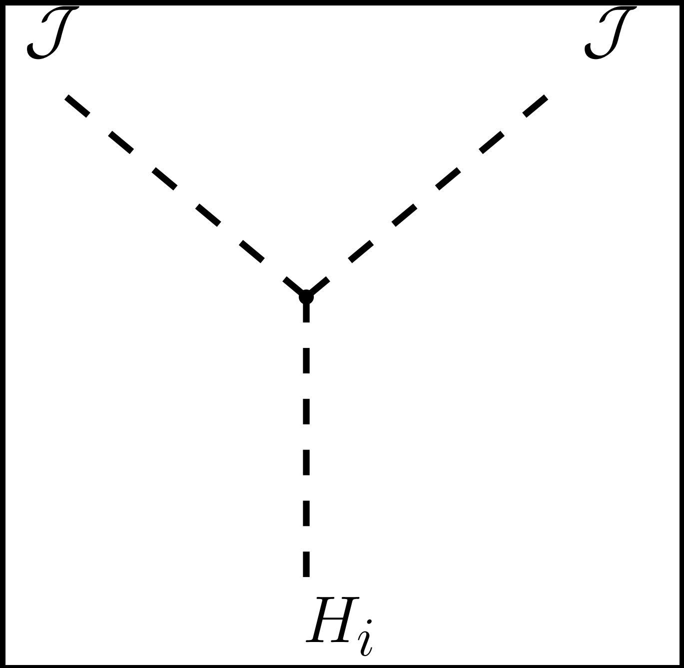


SM rates taken from HDECAY: A.Djouadi, J.Kalinowski, M.Spira, hep-ph/9704448

Higgs branching ratios for $\tan\theta = 1\,,\ \tan\beta = 1$



Higgs signal : INVISIBLE DECAY, DIVISION AND DILUTION !



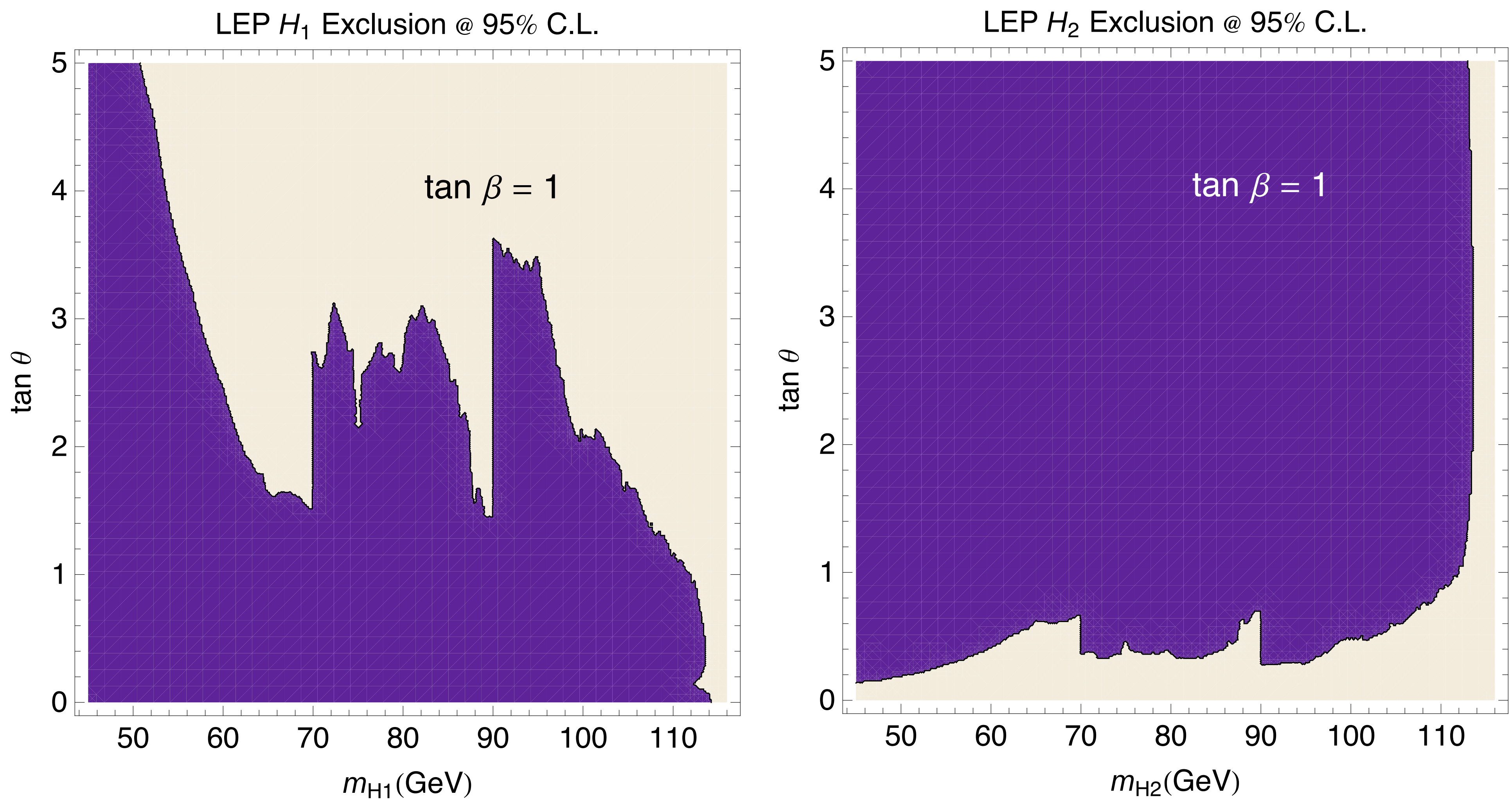
LEP/LHC Phenomenology

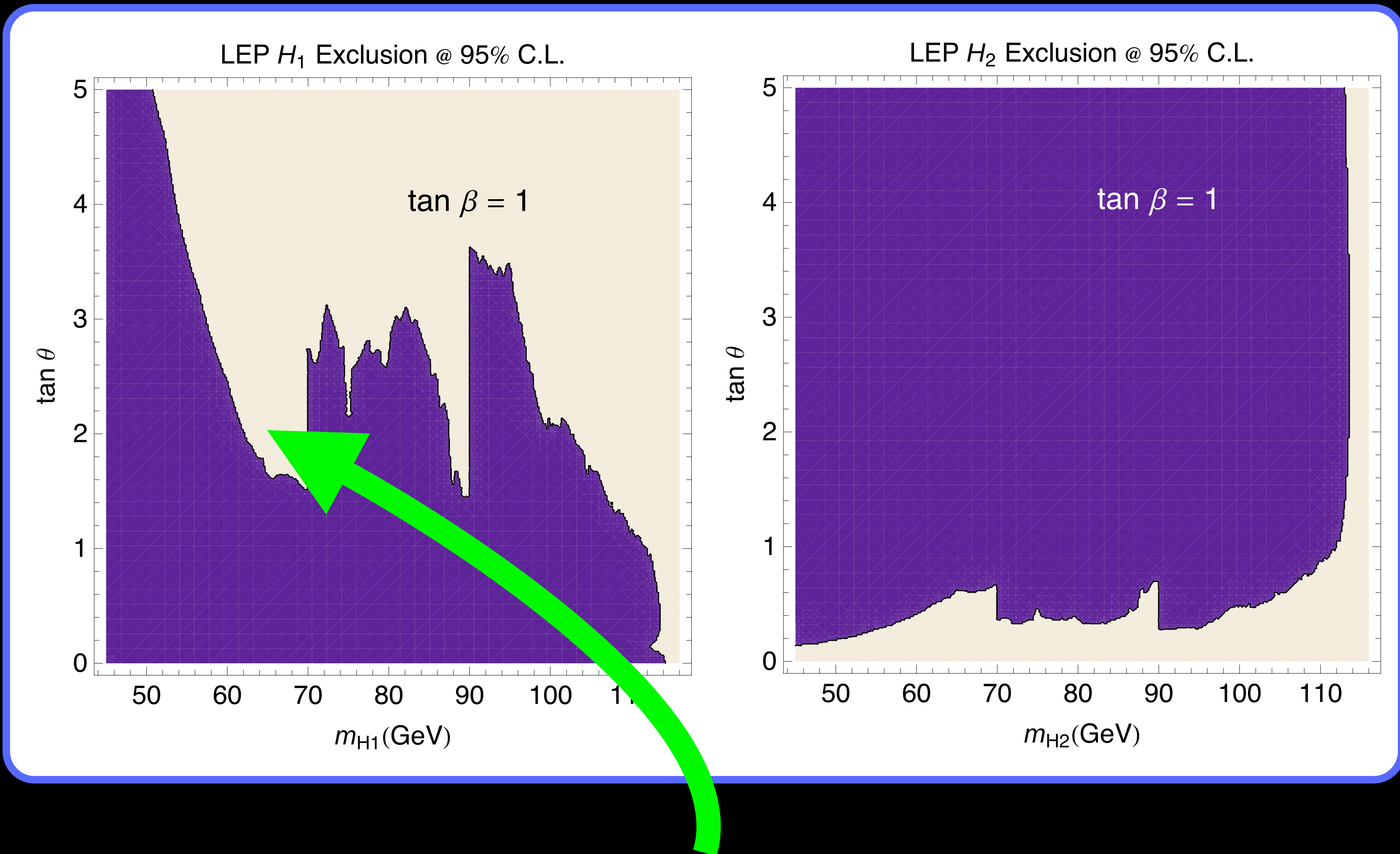
Look at the number of visible events ($H \to YY$) compared to the number expected in the SM

$$\mathcal{R}_i^2 \equiv \frac{\sigma(e^+e^- \to H_i\, X)\,\mathrm{Br}(H_i \to YY)}{\sigma(e^+e^- \to h\, X)\,\mathrm{Br}(h \to YY)}$$

Define a similar parameter for invisible events

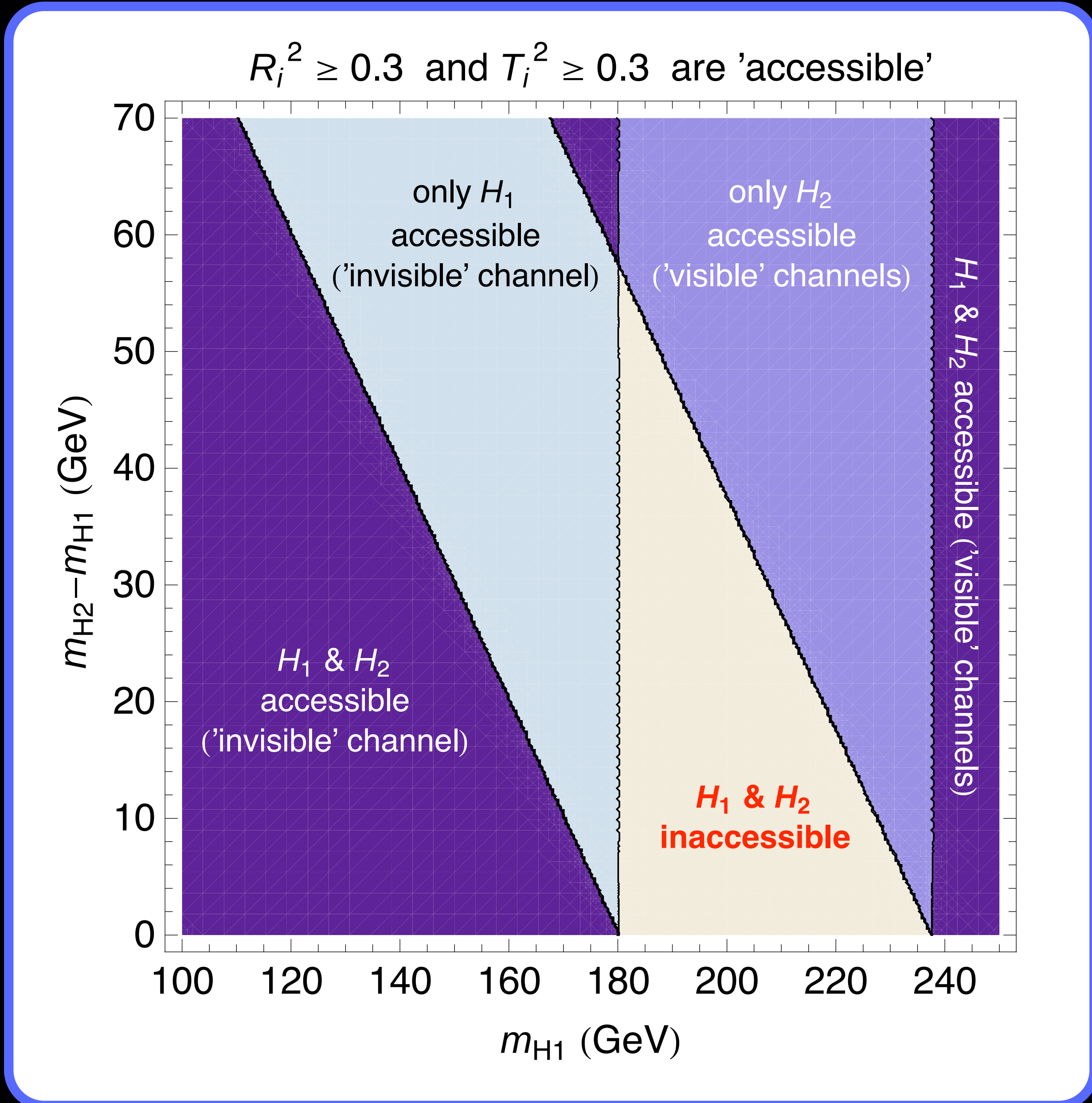
$$\mathcal{T}_i^2 \equiv \frac{\sigma(e^+e^- \to H_i\, X)}{\sigma(e^+e^- \to h\, X)}\,\mathrm{Br}(H_i \to \mathcal{J}\mathcal{J})$$


LEP H_1 Exclusion @ 95% C.L.
tan β = 1
tan θ
m_{H1}(GeV)
LEP H_2 Exclusion @ 95% C.L.
tan β = 1
tan θ
m_{H2}(GeV)



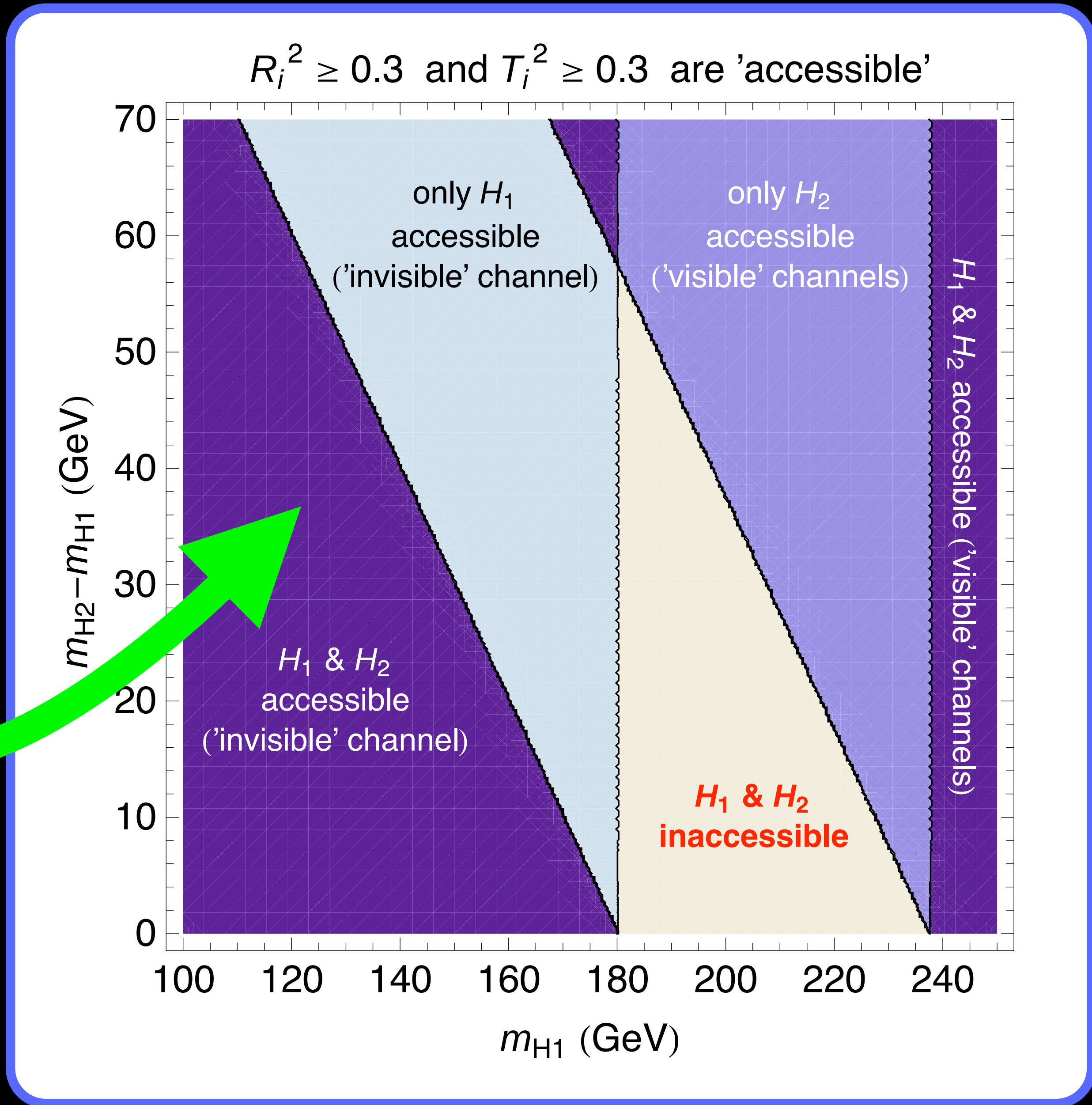
LEP could have missed a partially invisible Higgs

At higher masses, relevant for the Tevatron and LHC



At higher masses, relevant for the Tevatron and LHC

Both Higgs bosons invisible



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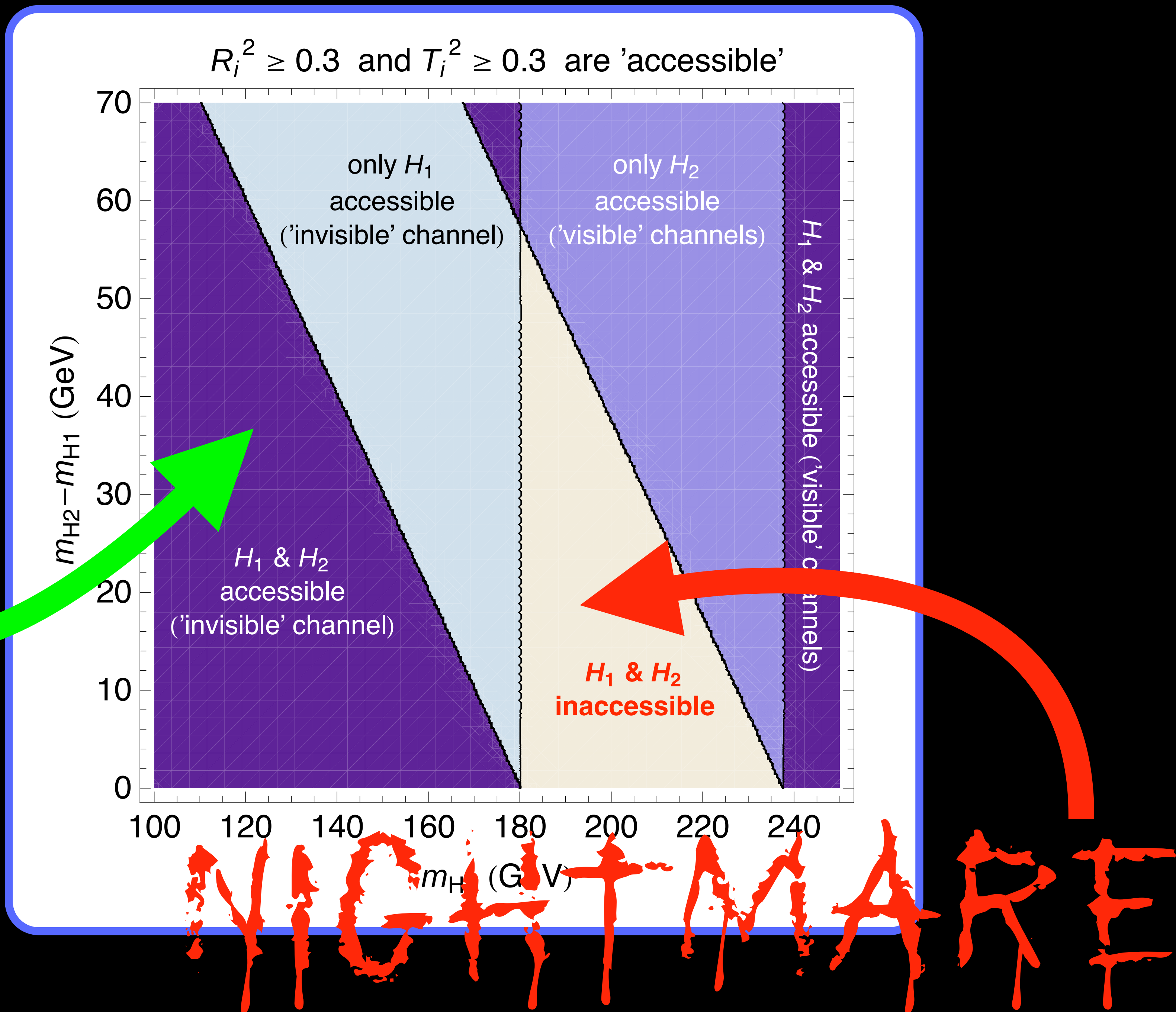
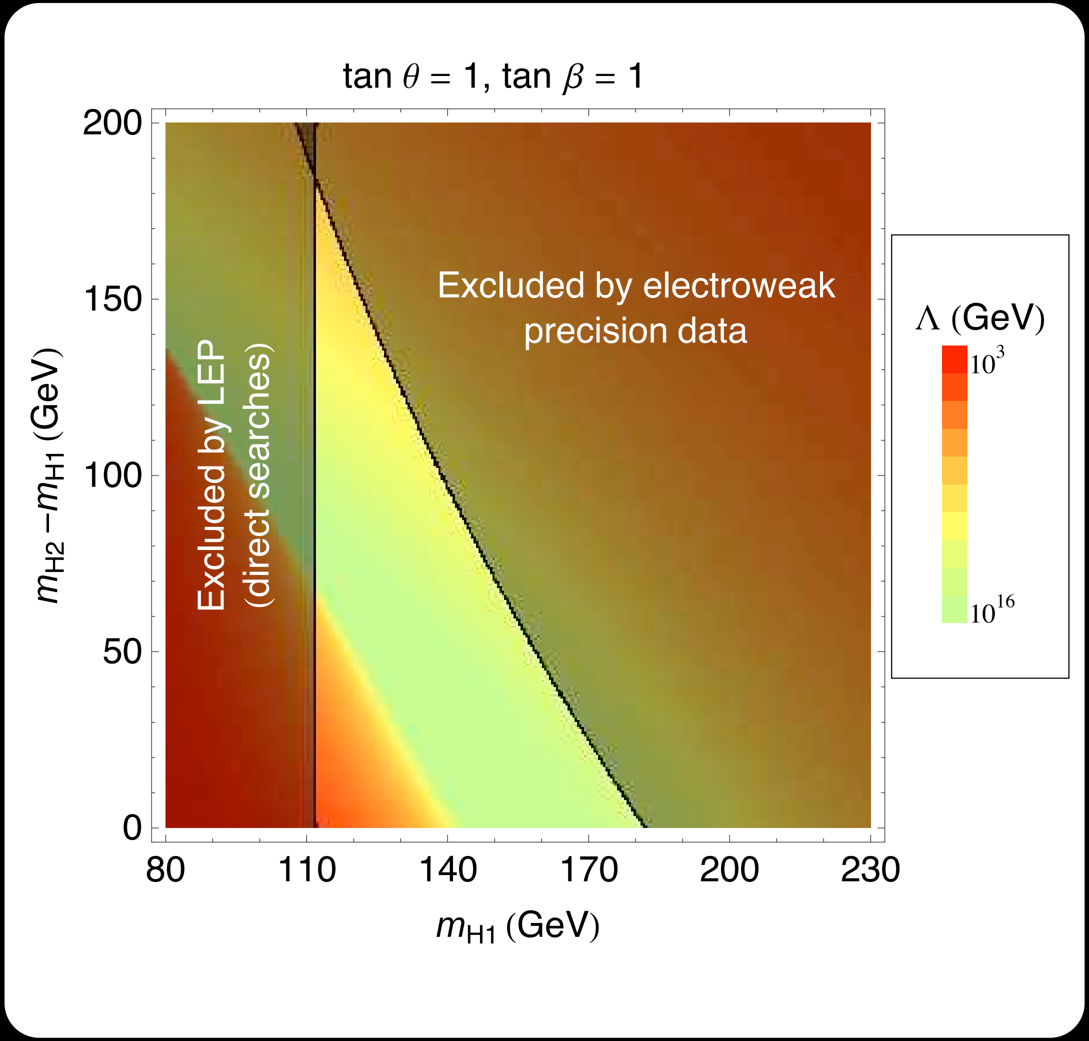


Vacuum stability & triviality



Require that λ_Φ , λ_H , η don't encounter Landau poles and the potential is positive, at least up to a scale Λ

Invisible Higgs strategies

- Z + H
- Vector boson fusion
- Central exclusive diffractive production

F. de Campos, O.Eboli, J.Rosiek, J.Valle, PRD55(1997)1316
S.Martin, J.Wells, PRD60(1999)035006
S.G.Frederiksen, N.Johnson, G.L.Kane, J.Reid, PRD50(1994)4244
J.P.Eboli, D.Zeppenfeld, PLB495(2000)147
R.M.Godbole, M.Guchait, K.Mazumdar, S.Moretti,D.P.Roy, PLB571(2003)184
K.Belotsky, V.A.Khoze, A.D.Martin, M.G.Ryskin, EPJC36(2004)503
H.Davoudiasl, T.Han, H.E.Logan, PRD71(2005)11500

Naïve estimates show m_{H_i}> 120 GeV with $\tan\theta = 1$, $\tan\beta = 1$ are difficult to discover at the LHC

SHERPA results

$m_{H_1} = 65\,\mathrm{GeV},$

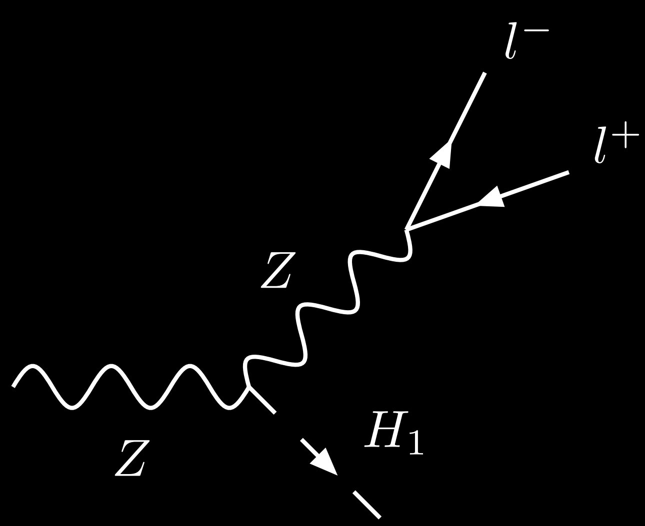
$m_{H_2} = 110\,\mathrm{GeV},$

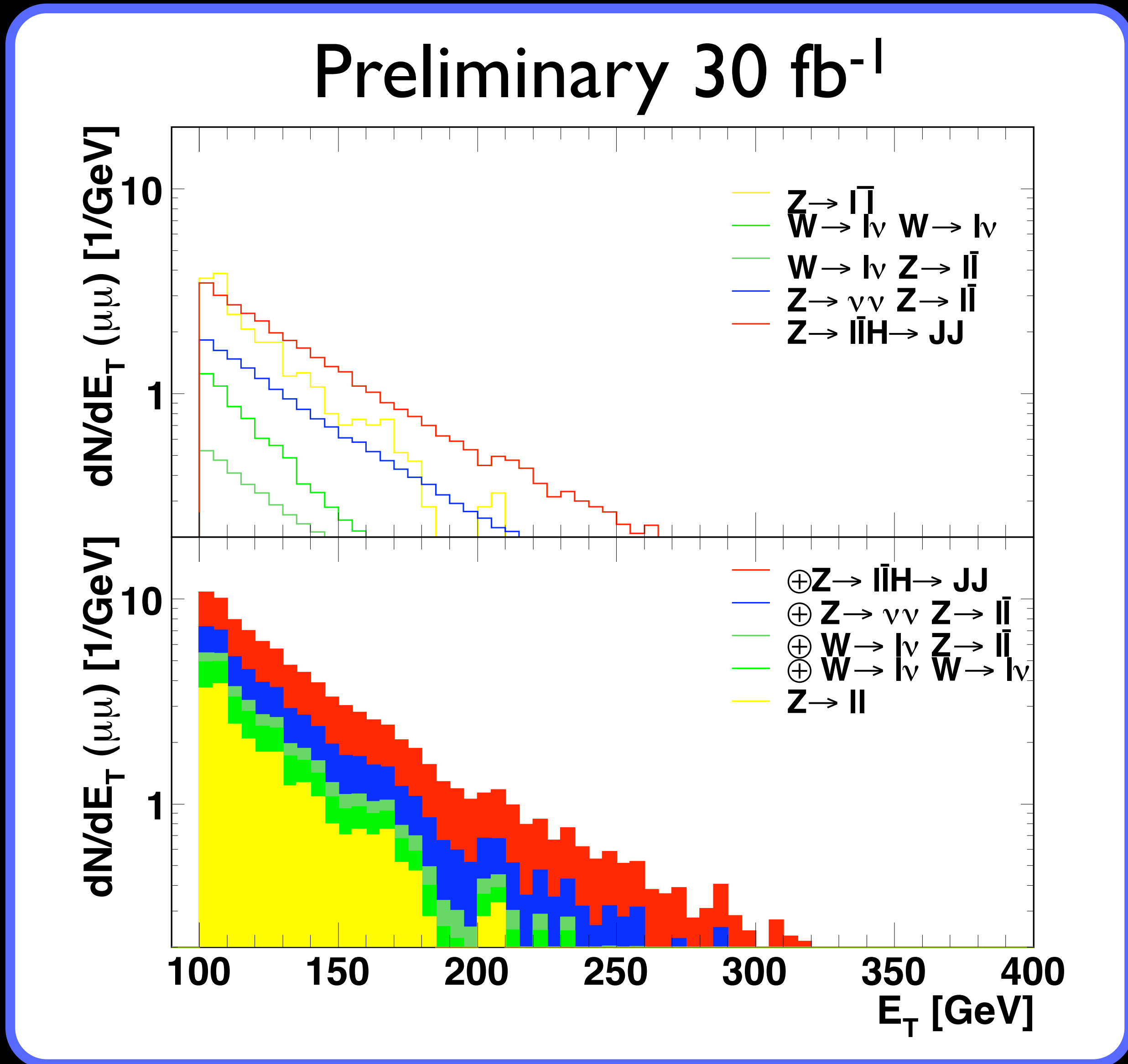
$\tan\beta = 1,\ \tan\theta = 1,$

$p_T^l > 15\,\mathrm{GeV},$

$|\eta^l| < 2.5,$

jets: simple cone, $R = 0.4$





Conclusions

- A very simple "Phantom Sector" with a spontaneously broken global symmetry can provide
  - small Dirac neutrino masses
  - successful baryogenesis
- Higgs bosons naturally vanish (into invisible Goldstone bosons) in this model
- LHC Higgs phenomenology becomes very challenging in this case
- Advancing our Higgs→invisible strategies is vital.